Final Report

EUROTeV

European Design Study Towards a Global TeV Linear Collider

Design Study

implemented as

Specific Support Action

Contract number: *011899*

Project coordinator: *Dr. Eckhard Elsen, DESY*

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ACTIVITY REPORT

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2 PROJECT WEB-PAGE

The project web-page is hosted at www.eurotev.org.

3 LIST OF CONTRACTORS

Partici-pant Number	Participant Name (organisation, city, country)	Participant short name
1	Deutsches Elektronen-Synchrotron, Hamburg and Zeuthen, D	DESY
2	The Science & Technology Facilities Council, Swindon, UK	STFC
3	Commisariat à l'Energie Atomique, Paris, F	CEA
4	European Organization for Nuclear Research, Geneva, CH	CERN

Partici-pant Number	Participant Name (organisation, city, country)	Participant short name
5	Centre National de la Recherche Scientifique/Institut National de Physique Nucléaire et de Physique des Particules, Paris, F	CNRS/IN2P3
	Laboratoire de l'Accélérateur Linéaire, Orsay, F	CNRS/IN2P3-LAL
	Laboratoire d'Annecy-le-vieux de Physique des Particules, Annecy, F	CNRS/IN2P3-LAPP
	UMR8607: Université Paris Sud, Orsay, France	CNRS/IN2P3 Paris Sud
	UMR5814: Université de Savoie, Chambéry, France	CNRS/IN2P3 Savoie
6	Sincrotrone Trieste Societa Consortile per Azioni, Trieste, I	ELETTRA
7	Fraunhofer Gesellschaft zur Förderung der Forschung e.V., Institut für graphische Datenverarbeitung, Darmstadt, D	FHG
8	Gesellschaft für Schwerionenforschung mbH, Darmstadt, D	GSI
9	Istituto Nazionale di Fisica Nucleare, Frascati, I	INFN
	INFN Laboratori Nazionali di Frascati, Frascati, I	INFN-LNF
	INFN Sezione di Milano, Milano, I	INFN-Mi
	INFN Sezione di Roma 2, Roma, I	INFN-Ro2
10	Paul Scherrer Institut, Villigen, CH	PSI
11	Royal Holloway and Bedford New College, Egham, UK	RHUL
12	Technische Universität Darmstadt, Darmstadt, D	TUD
13	Humboldt-Universität zu Berlin, Berlin, D	UBER
14	The Chancellor, Masters and Scholars of the University of Cambridge, Cambridge, UK	UCAM-DPHYS
15	University College London, London, UK	UCL
16	Lancaster University, Lancaster, UK	ULANC
17	The University of Liverpool, Liverpool, UK	ULIV
18	University of Manchester, Manchester, UK	UMA
19	Universität Mannheim, Mannheim, D	UMH
20	Università degli Studi di Udine, Udine, I	UNIUD
21	The Chancellor, Masters and Scholars of the University of Oxford, Oxford, UK	UOXF.DL
22	Uppsala Universitet, Uppsala, S	UU

4 ACTIVITIES

The activities of EUROTeV have shaped the research landscape for the Linear Collider in Europe over the past four years. EUROTeV encompassed the efforts of the two large communities ILC and CLIC that advance this access path to high-energy physics using colliding e^+e^--beams. The establishment of a design study enabled the relevant work to be completed in an environment that was amenable to the complexity of the studies and of the international structures of the programmes.

4.1 OVERVIEW

The design study EUROTeV embraced the intellectual European expertise for the development of the International Linear Collider (ILC) and provided the synergies to advance the beam dynamics, diagnostics and stabilisation concepts for CLIC. EUROTeV has provided the core of the European contribution to the Reference Design Report of the ILC except for the superconducting acceleration technology which purposely was excluded from the activities of the studies.

The results of the studies entered the Reference Design Report and the studies continued where adequate.

Following the completion of the Reference Design Report the activities continued into the Technical Design Phase of the ILC. CLIC studies continued and were geared towards the completion of the conceptual design report of the machine which is currently planned for 2010.

It proved to be a tremendous advantage that EUROTeV was able to adapt to the changing needs of the Global Design Effort that coordinated the worldwide effort for the ILC. An example can be seen in the layout of the beam delivery system for the ILC: starting from two interaction regions with 2 mrad and 20 mrad crossing angles the design evolved to a single 14 mrad crossing angle. While these numbers seem small the impact on the beam extraction is considerable. The respective working group was able to adapt to these changing requirements. There are other examples of this kind.

In summary EUROTeV enabled the European partners interested in advancing the design of the Linear Collider to explore the options for the design of such a machine in the worldwide effort. Given the constraints of research budgets worldwide and the demands in High Energy Physics related to the swift commissioning of the LHC the resources of the European Commission united the European effort and made a significant and shaping role for the worldwide effort towards a Linear Collider.

4.2 PROJECT OBJECTIVES AND PARTNERS INVOLVED IN THE WORK PACKAGES

The partners involved in the work packages are indicated in the table below. The selection of partners followed their expertise and prior engagement in the scientific topics at the time of proposal writing.

It was the aim of the EUROTeV to cover the salient research topics of the ILC except for the acceleration technique. The acceleration technique using L-band super-conducting cavities was selected in an international selection process which was completed only after EUROTeV proposal submission. Nonetheless, to quote the referee for the EUROTeV proposal "the study will address some of the most critical items of research as they have been identified by an International Review Committee (ILC-TRC) in the beginning of 2003. The studies are well in line with the current scope and roadmap towards a world wide Design Effort - the Global Design Organisation (GDO). It is recognised that the studies can be naturally integrated into and complemented by additional studies inside the GDO.

The urgent need to increase (and even bootstrap) funding for the Linear Collider in Europe is competently addressed."

This main objective was competently addressed and is well documented in the Reference Design Report of the Global Design Effort (GDE).

Participant		**Work Package**							
Number	**Short Name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	DESY	■		■	■	■	■	■	■
2	STFC	■	■	■	■				
3	CEA		■						
4	CERN	■	■	■		■	■		
5	CNRS/IN2P3	■				■	■	■	
6	ELETTRA								■
7	FHG								■
8	GSI								■
9	INFN	■		■					■
10	PSI						■		
11	RHUL	■				■	■		
12	TUD		■						
13	UBER				■				
14	UCAM-DPHYS					■			
15	UCL					■			
16	ULANC		■						
17	ULIV				■				
18	UMA		■				■		
19	UMH								■
20	UNIUD								■
21	UOXF.DL					■		■	
22	UU					■	■		

Table: Engagement of the participants in the various work packages

Consequently the primary objectives of the EUROTeV Design Study were focused on critical R&D in the following collider subsystems:

- Beam Delivery System (BDS)
- Damping Rings (DR)
- Polarised Positron Sources (PPS)

In addition, four (more general) critical areas have been identified for study:

- Critical Beam Diagnostics
- Integrated Luminosity Performance Studies
- Metrology and Stabilisation
- Global Accelerator Network (remote operations)

These topics form the basis of the Work Packages implemented for EUROTeV. The detailed objectives are presented and assessed in the following chapters.

4.3 WORK PERFORMED AND END RESULTS

4.3.1 BEAM DELIVERY SYSTEM

The goals of the Work Package WP2 were:

- Optimised design of BDS magnetic lattice for two interaction regions, including magnetic tolerance specifications.
- Prototype development of a crab cavity RF system.
- Development, testing and evaluation of intra-train feedback systems.
- Design of mechanical spoilers for the collimation system, including prototype tests of wakefield performance and materials testing for beam damage assessment.
- Demonstration of the performance of high-field superconducting quadrupoles in a strong solenoid field (as required for the strong final doublet at the interaction point).

BDSLD: Beam Delivery System Lattice Design

The main goal of this task was to develop the beam delivery system lattice designs for both the International Linear Collider (ILC) and Compact Linear Collider (CLIC). The BDS lattice designs need to satisfy several constraints which include: design of a final focus system to achieve nanometre-level vertical beam sizes at the collision point, design of a collimation system to remove halo particles which ensures that the background in the detector is tolerable, provision of emittance measurement and coupling correction as well as measurements of the important physics parameters such as polarisation and energy, and finally to extract the highly degraded beam after the collision.

The design of the final focus system adopted for both ILC and CLIC is based on local chromaticity correction and needs careful cancellations of geometric and chromatic aberrations due to the interleaved nature of the sextupoles in this scheme. Automatic procedures which realise simultaneously the demagnification, the chromatic correction and the aberration minimisation of the final focus beam line have been independently developed for both ILC and CLIC. The procedures developed are now used routinely to optimise the ILC and CLIC beam delivery systems. The ATF2 proposal at the Accelerator Test Facility (ATF) at KEK, Japan uses a scaled down version of local chromaticity correction final focus scheme. The beam tests at this facility in the next few years will not only demonstrate the experimental verification of the local chromaticity correction principle but will also allow to test different tuning algorithms developed for the ILC and CLIC.

The collimation system lattice design is based on providing the two-stage collimation approach based on the spoiler, absorber scheme. The amount of collimation required known as collimation depths is decided by the apertures near the interaction region and by beam parameters. These collimation depths decide the required spoiler openings which allow the synchrotron radiation fan generated in the final doublet to cleanly pass through the interaction region without generating any background in the detector. The required vertical spoiler openings of less than 1 mm are a major source of wakefields and dilute the luminosity. The collimation depths estimations provided a useful tool to compare different crossing angle configurations in case of the ILC for different beam parameters and various detector concepts. The tracking of the beam halo through the beam delivery system for ILC optimised lattices showed a clear improvement in the collimation efficiencies.

The large bunch spacing for the cold linac technology chosen for the ILC allows the possibility of head-on or small crossing angle configurations at the collision point. Such configuration does not need a so called crab-crossing scheme, avoids complexity in the incoming beam and is favoured by the experimental physics programme. This scheme, however, does not allow separate beam channels for the extraction as feasible in the large crossing angle scheme. Both the small crossing angle and the large crossing angle demand special magnet design developments. Due to the pros and cons of both large and small crossing angle schemes, initially two interaction regions, one with 2 mrad and one with 20 mrad crossing angles were chosen for the ILC. The detailed designs of these schemes were evaluated for both cost and performance and finally only one interaction region configuration with an intermediate crossing angle of 14 mrad with two complementary detectors in a push-pull configuration was chosen for the ILC Reference Design Report.

CRABRF: Crab cavity RF system Design

The development of a crab cavity and its RF system is a critical requirement for the ILC large crossing angle scheme. The luminosity loss without the crab cavities is ~75% for a 14 mrad crossing angle configuration. Crab cavities rotate bunches longitudinally to provide a head-on collision at the interaction point in spite of the nonzero crossing angle of the beams. An analysis of system requirements and issues related to the choice of cavity frequency are important to meet the required specifications. A recommendation based on a 3.9 GHz superconducting RF cavity has been adapted from the deflecting cavity developed at Fermi National Laboratory for other application. The 3.9 GHz cavity offers a compact solution compared to 1.3 or 2.6 GHz and allows the cavities to be located very close to the interaction point. A key issue for the crab cavities is the relative phase synchronisation between the cavities on either side of the interaction point. The relative jitter can cause horizontal offset at the interaction point reducing the luminosity.

A major challenge presented by 3.9 GHz cavity is its higher susceptibility to wakefields generated by off-axis bunches. A detailed computer simulations and analysis was carried out to address this. The wakefield calculations require accurate knowledge of the R/Q values, frequencies and impedances of all the unwanted harmful modes. An experimental set-up was established at Daresbury Laboratory to measure mode impedances with a stretched wire technique and R/Qs with a bead pull technique. A multi-cell prototype cavity has been manufactured for this purpose. To minimise wakefields, the number of cells must be optimised against overall length. The lower-order modes (LOM) have to be extracted from the crab cavity to avoid unwanted energy spread: same-order modes (SOM, as the dipole mode has two polarisations; one at which the cavity is driven and the other is the unwanted mode) and higher-order modes (HOM), c.f. figure.

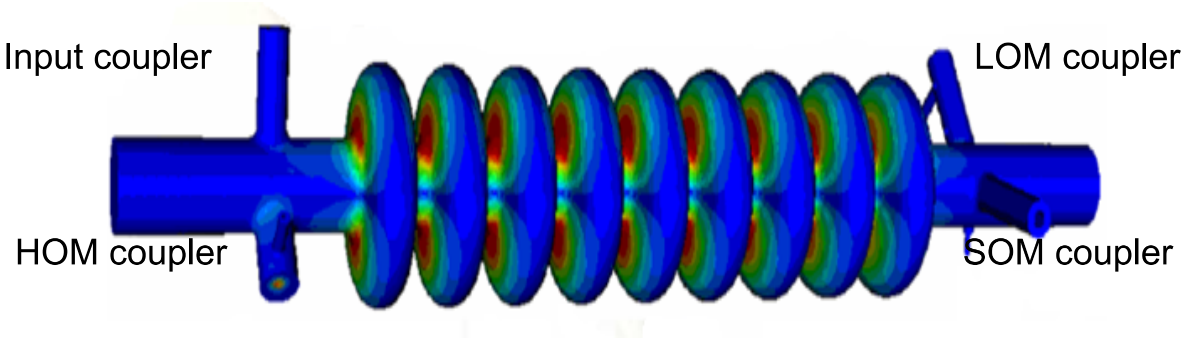

Figure: ILC Crab cavity based on the FNAL CKM cavity

The key issue for the crab cavities is phase synchronisation. The phasing accuracy for the ILC crab cavities with respect to each other is 0.125° r.m.s. at 3.9 GHz which corresponds to a timing accuracy of 90 fs. A scheme of synchronisation has been investigated and tested at Daresbury Laboratory. As a preliminary proof of principle experiment for the phase control and synchronisation system, two low-power single cell superconducting RF cavities were mounted in a vertical cryostat. This operation required use of a new clean room and ultra clean water rinse facility at Daresbury. The phase of the field in each cavity is sampled, compared to the timing reference and the error is sent to a digital signal processor to determine how the input signal must be varied to eliminate the error. An RF interferometer is provided between each crab cavity so that the same clock signal is available at both systems. The validation of the control system involved a test where two superconducting cavities are mounted in the same vertical cryostat were stabilised using two digital control systems and the digital control systems were synchronised using the interferometer. These tests have demonstrated a performance very close to the required ILC specifications of phase stability.

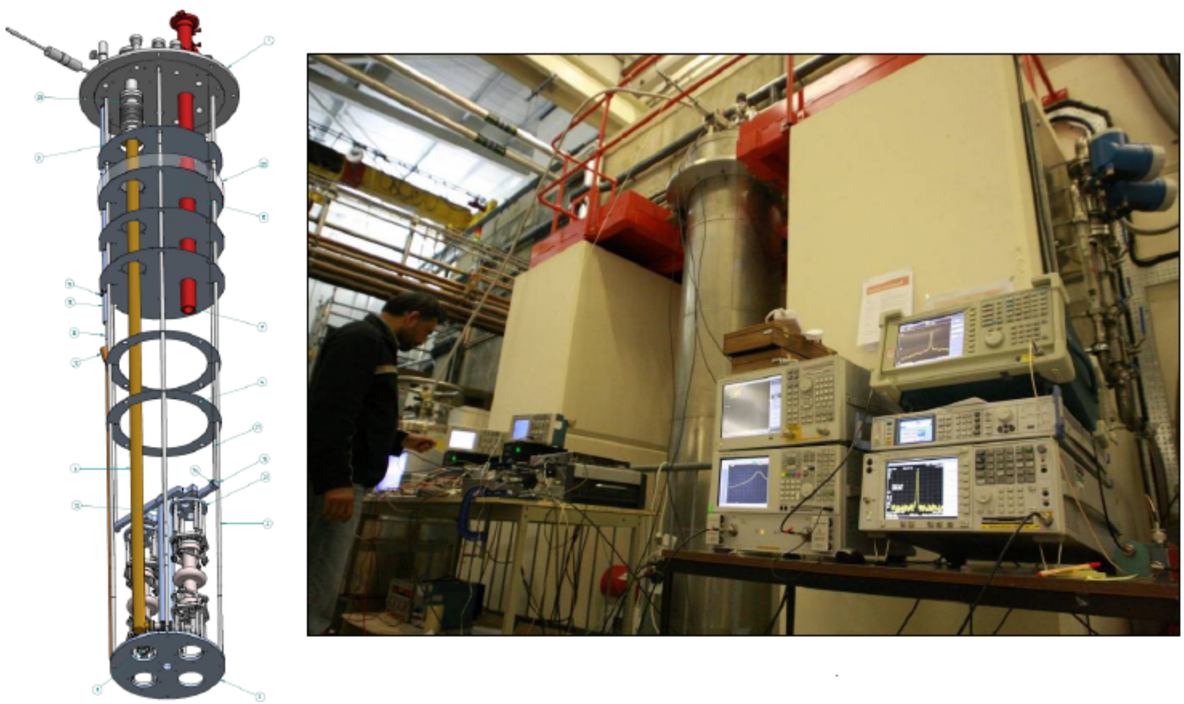

Figure: ILC crab cavity RF system validation tests for the two cavities

FFBK: Fast Beam based Feedback

A number of fast beam-based feedback systems are required at the ILC. At the interaction point a very fast system, operating on nanosecond timescales within each bunch train, is required to compensate for residual vibration-induced jitter on the final focus magnets by steering the electrons and positrons into collision. A pulse-to-pulse feedback system is envisaged for optimising the luminosity on intra-train timescales of 200 ms. The key components of the system are beam position monitors for registering the design orbit; fast signal processors to translate the raw BPM pick-up signals into a position output; feedback circuits, including delay loops, for applying gain and taking account of system latency; amplifiers to provide the required output drive signals; and kickers for applying the position or angle correction to the beam.

Critical issues for the intra-train feedback performance include the latency of the system, as this affects the number of corrections that can be made within the duration of the bunch train and the feedback algorithm. All analogue feedback system is required for room temperature linear collider designs with very short bunch trains. The lowest latency of 23 ns has been achieved using FONT3 (Feedback on Nanosecond Time scale).

For the ILC a prototype digital system has been built (FONT4) which incorporates a digital feedback processor based on a state-of-the-art Field Programmable Gate Array. The use of digital processor allows to implementing more sophisticated algorithms which can be optimised for possible jitter scenarios at ILC. However, a penalty is paid in terms of a longer signal processing latency. This is tolerable in case of ILC with long multi-bunch trains.

The prototype of this feedback has been tested at ATF, KEK. The system has been designed with a latency goal of less than 140 ns. This meets the ILC minimum specification of 150 ns bunch spacing. This latency goal allows the measurement of the first bunch position and correction of both the second and the third ATF bunches. The beam tests carried out shows perfect correction of the third bunch as expected.

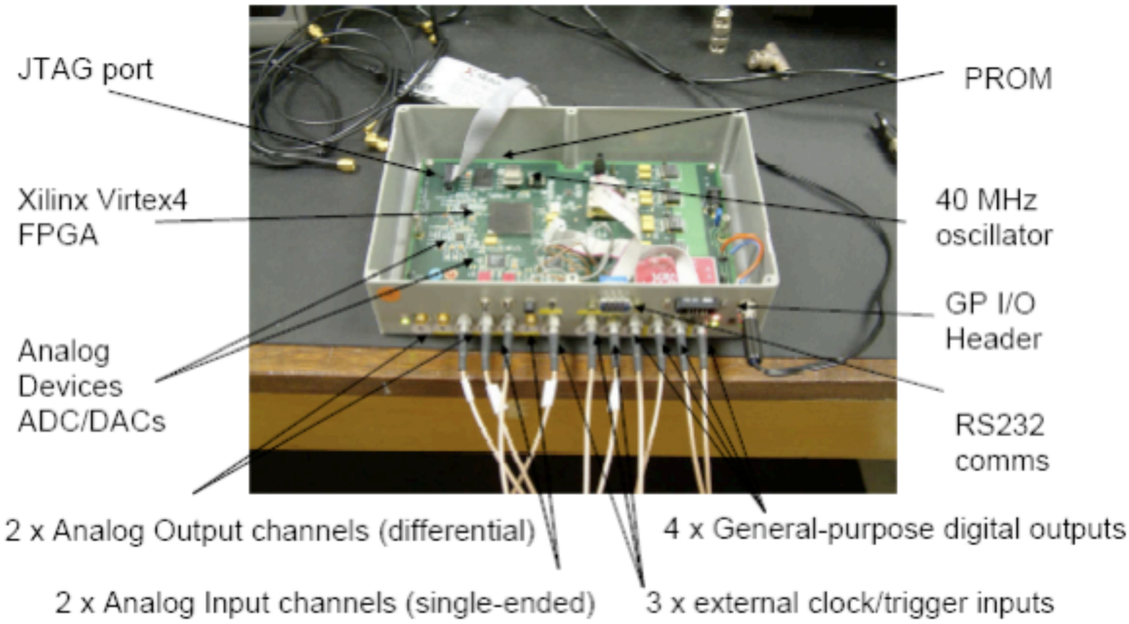

Figure: FONT4 Digital Feedback Board

SWMD: Spoiler Wakefields and Mechanical Design

The aim of this task was to deliver the collimator design for the ILC to minimise the background in the detector. The two stage collimation approach needs a spoiler, which is less than one radiation length long followed by an absorber which is ~20-30 radiation length long. A short bunch (300 µm in case of ILC) passes through this long structure. In order to validate the wakefield simulations in this regime, experimental tests were carried out. The design criterion is based on the wake field simulations and experimental agreement as well as the machine protection issues.

Several spoiler jaws with different geometries and materials were fabricated and installed in the wake field test box at SLAC End Station A beam line. This facility provided 28 GeV beam with bunch charge and length close to the ILC parameters. The wakefields of these spoilers were simulated to compare with the experimental tests. For most of the spoilers a good agreement (within 10%) was found between the simulations and the experimental results.

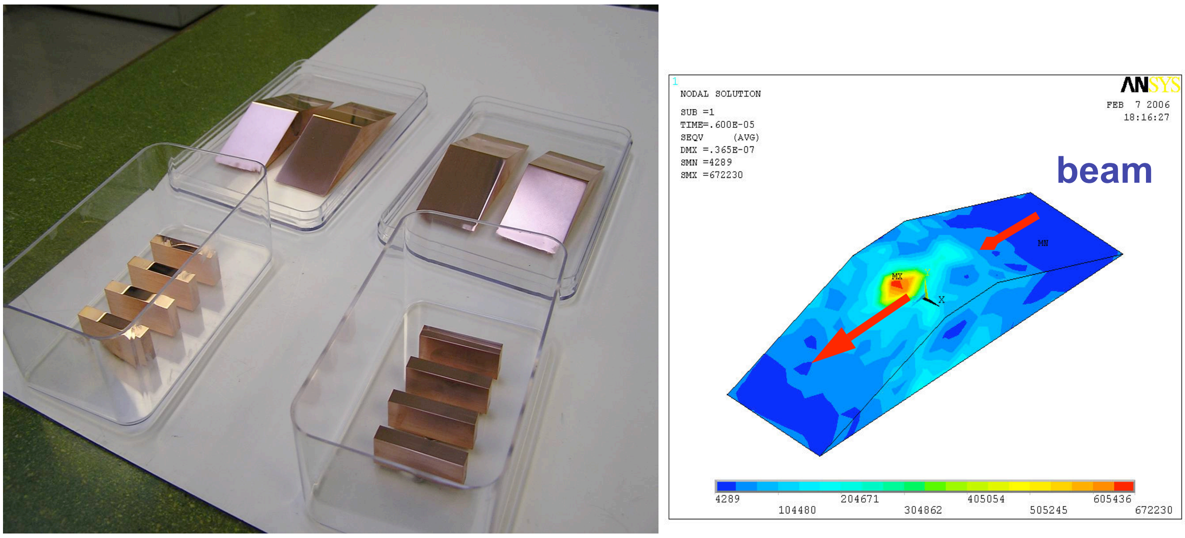

Figure: Spoiler jaws for experimental wake fields tests & spoiler jaw beam damage simulations

Another important criterion is the survival of the spoiler in case of errant beam. To understand the bunch survival, different spoiler materials were simulated for beam damage. The criterion was to select a material which survives two bunches at 250 GeV and one bunch at 500 GeV energy. The simulations showed that Titanium (or Beryllium) with graphite provide such a material. To test these simulations, beam damage studies have been organised at ATF, KEK. First phase of these tests have been completed and no beam damage was observed as the required beam conditions were not met. The second phase of beam damage studies are being planned now, which are based on measuring the shock waves using Visor.

A preliminary, conceptual design for the adjustable jaw spoilers for the ILC BDS has been worked out. The design is based on the optimisation of the geometry and material of collimators in the ILC to mitigate the effects of both short range transverse wakefields and errant beam impacts. This design will serve as a starting point towards a complete engineering design when design of jaws will be finalised.

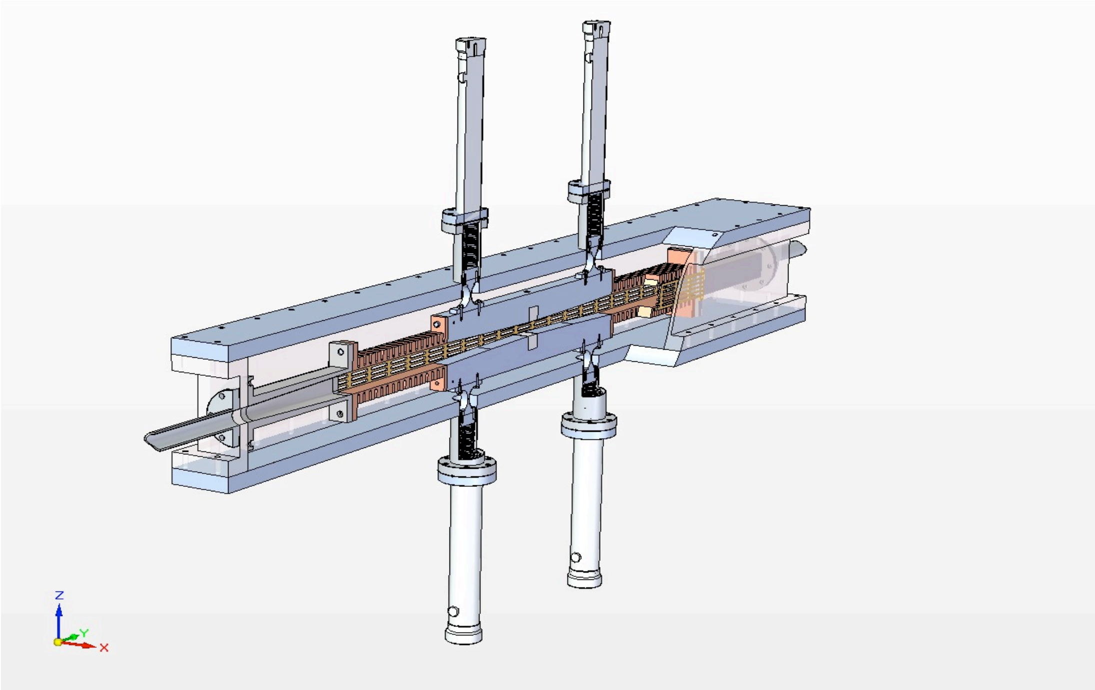

Figure: Engineering design of conceptual baseline spoiler design

SCFD: Super Conducting Final Doublet technology R&D

The magnetic feasibility of the ILC head-on or small crossing angle region is based on a large-aperture, large-gradient superconducting quadrupole magnet embedded in the field of a detector solenoid. As a feasibility test a large aperture Nb_3Sn superconducting magnet has been fabricated at CEA, Saclay (this part is an independent R&D project), which was foreseen to undergo the high-field test. The magnet has length of 1 m, aperture diameter of 56 mm and a gradient of 211 T/m. The cross-section of the quadrupole cold mass is based on the LHC arc quadrupoles. The prototype will be tested at high gradient in April 2009 at both 4.2 K and 1.8 K temperatures in dedicated cryostat in the horizontal test cryogenic station.

The test of the high gradient performance and mechanical stability of Nb_3Sn quadrupole in an external field of 2 T parallel to its axis was originally foreseen in the warm bore of a 2 T solenoid. However, this coil was destroyed by a major electrical breakdown in 2006. It was then foreseen to make this test with an 8 T facility assembled at CEA for the NeuroSpin project. The 1 m long quadrupole would have been inserted vertically halfway along the 1 m long solenoid operated from 2 T to 4 T to allow a complete study of the superposition of the quadrupole transverse and end fields with the solenoid field, which is representative of the ILC final doublet conditions for different final doublet distances from the interaction point. This needed a detailed magnetic field modelling of the solenoid-quadrupole configuration.

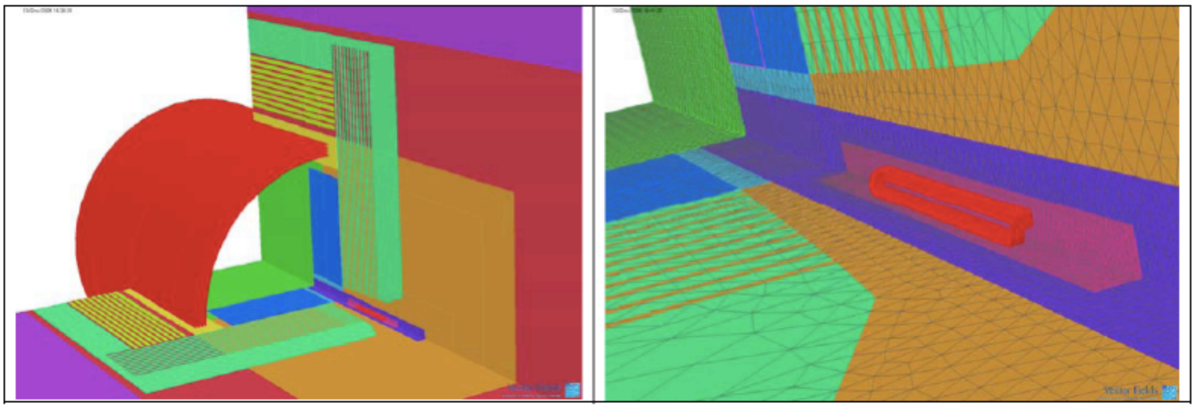

Figure: Magnetic 3D modelling of the ILC-LDC superconducting solenoid with the final quadrupole

Although the quadrupole tests in external magnetic field could not be completed within the EUROTeV duration, the 3D magnetic and mechanical modelling efforts initiated by this task, both for the quadrupole and for the solenoid magnets, lead the way to a successful investigation of the ILC interaction region properties. It was shown that the final focus doublets fabricated from NbTi conductor technology would be able to sustain the external magnetic field of a 4 T solenoid field foreseen in the Large Detector Concept (LDC) for the ILC detector with 20% operational margin. The detailed design optimisation of the solenoid has allowed the European LDC collaboration to propose a solid conceptual design to one of the ILC detectors.

4.3.2 DAMPING RINGS

The goals of the Work Package WP3 were to study the crucial issues for the Linear Collider Damping Rings (DR) and in particular:

- Quantitative understanding of the electron-cloud effect, and its relevance and mitigation in the ILC damping ring.
- Produce a correct and experimentally benchmarked model for the fields of wiggler magnet systems suitable for use in dynamic aperture optimisation simulations.
- Investigate the applicability of RF separator technologies for injection and extraction, allowing strong compression of the bunch distance.
- Development and evaluation of beam-based tuning algorithms for obtaining the required ultra-low emittance in the ring.

ECLOUD: Studies of electron cloud and other instabilities

An electron cloud in the positron damping rings of ILC and CLIC could drive multi-bunch, single-bunch, and incoherent single-particle instabilities, as well as degrade the vacuum contributing to a pressure instability. Each of these phenomena can lead to unacceptable emittance growth and beam loss.

The impact of the electron cloud (e-cloud) issue on the positron damping ring was important in the choice of the Baseline Configuration (BC), used for the reference design and cost estimate. The ILC Baseline Configuration was the first milestone of the Global Design Effort (GDE). For the DR this involved the choice of layout and circumference comparing eight different lattice designs ranging between 3 and 17 km. A simulation campaign to evaluate the impact of the electron cloud for the eight different lattice designs was carried on by an international collaborative study with a strong participation of the WP3 ECLOUD task force. The recommendation, discussed at the CERN DR meeting November 2005 with an active contribution of WP3 participants, is to choose a 6 km lattice for the DR and intensify the R&D on e-cloud simulation codes and mitigation techniques. The objective of the e-cloud R&D is to be ready for the design phase to evaluate the mitigation techniques that are needed to guarantee the DR performance with minimum impact on costs.

The WP3 ECLOUD activity has been dedicated to developing and benchmarking of simulation codes and study of mitigation techniques to enable recommendations for controlling the e-cloud effects.

Faktor2, a new simulation code modelling electron cloud build-up and ion generation, has been developed to extend the capabilities of the existing ECLOUD code. It allows electron cloud simulations both for 3D wiggler structures with or without antechambers, and for more complex surface profiles for the inner wall of the vacuum chamber. In the years 2007-2008 Faktor2 has been successfully benchmarked against the ECLOUD code for the MBB dipole chambers of the CERN SPS. The ECLOUD code had previously been benchmarked against SPS beam experiments. Simulations with the ECLOUD code have also shown good agreement with experimental observations at DAΦNE. Faktor2 is the first Deliverable of the WP3 task described in EUROTeV Report-2008-082.

Studies of vacuum system requirements in the presence of electron cloud have been performed and the distributed pumping speed per unit length required to avoid pressure instability has been evaluated. Recommendations for the vacuum system design include a NEG-coated beam pipe, pumping through an antechamber, strong local pumping near the photon absorbers.

To suppress the electron cloud build-up, both the photoelectron yield and the “effective” secondary emission yield (SEY) must be, and must stay, below certain tight threshold values. The technical mitigation options include low SEY coatings, mechanically or magnetically rough surfaces, grooves, and clearing electrodes. Novel types of coatings based on amorphous carbon, ideally on a black-metal substrate, which have been developed at CERN in 2007-08, combine a low maximum secondary emission yield around 1, with UHV compatibility, and low resistivity. Beam tests at the SPS indeed demonstrated the complete suppression of electron cloud formation in regions with these coatings. Carbon-coated samples were also tested for photon-induced desorption in a dedicated beam line at the ESRF, showing a desorption yield lower than that for stainless steel. One remaining uncertainty for applications in ILC or CLIC is the yet unknown photo-emission yield. To qualify the effectiveness of the carbon coatings for a positron beam it is planned to install a carbon-coated test chamber in the CESR-TA facility at Cornell University during 2009.

Electron-driven multi-bunch instabilities in the positron damping rings can be combated with a strong bunch-by-bunch feedback. It was shown at DAΦNE that the damping rates of several independent feedbacks add up linearly, pointing to a practical way for lowering the damping times. Specifically, for a bunch distance of 3 ns (the same as foreseen for the ILC damping ring) DAΦNE has demonstrated a damping in 15 revolution periods (~5 μs) with 2 feedbacks.

In the electron damping rings of CLIC and ILC, ions created during the beam passage by residual-gas ionization can be trapped along the length of a bunch train. These transient ions can give rise to substantial linear and non-linear transverse tune shifts, which increase along the length of the train, as well as to the “fast beam-ion instability”. The impact of ion effects in the electron damping ring has been studied both by analytical and simulation methods. A dedicated simulation code has been developed to evaluate these effects. Recommendations include vacuum pressure below 1 ntorr, bunch by bunch feedback systems and mini-trains separated by gaps in the bunch filling pattern.

The results of the work done by the ECLOUD task are described in the second Deliverable “Report on Impact of e-Cloud and Fast Ion Instabilities on DR Performance, Including Recommendations for Controlling the Effects”, EUROTeV Report-2008-083.

WGLRDYN: Wiggler Field Modelling and Impact on Dynamic Aperture

The WGLRDYN activity was focused on the optimisation and modelling of permanent magnet wigglers (TESLA type) and normal-conducting electromagnetic (DAFNE wiggler). A collaboration with the Yerevan Physics Institute has been initiated to study the possibility to achieve a larger aperture and a better field quality with respect to the TESLA permanent-magnet wiggler design. The YerPhI Institute has provided different sets of wiggler field maps optimising the field quality for permanent magnet wigglers with different values of the magnet gap. These field maps have been analysed to calculate the trajectory and the nonlinear terms that affect the beam dynamics. The aperture of this magnet is still small for the ILC positron damping ring but it would be sufficient for the electron damping ring and it could be considered as an alternative solution for the electron ring.

Before the start-up of EUROTeV the poles of the electromagnetic wigglers of the DAΦNE main rings were shimmed in order to reduce the non-linearities that affect the beam dynamics. The EUROTeV activity started with a comparison of wiggler models with beam measurements at DAΦNE (tune shift with amplitude, beam decoherence) for the modified wigglers.

A more efficient method to reduce the integrated odd multipoles (the even ones tend to vanish for the periodicity of the magnet) on the beam trajectory has been proposed. The magnetic axis of the poles is alternatively displaced to compensate the integrated odd multipoles in each half-period of the wiggler. In order to check the effectiveness of this approach, tracking studies have been performed and used to tune the model of the wiggler. This work has been delayed due to the priorities of the DAΦNE collider: one wiggler has been modified on February 2009, the magnetic measurements are in good agreement with calculations. The wiggler will be installed in the ring for beam tests before summer 2009: an improvement of the dynamic aperture and beam lifetime is expected.

RFSEP: Application of RF separators to DR

Because of the high priority assigned by the GDE in the Baseline Configuration recommendation the activity of the RFSEP task has been concentrated on strip-line kickers driven by fast pulsers. The goals of the RFSEP tasks are:

- Design and tests of a strip line kicker for beam injection in DAΦNE storage rings
- Study of a strip line kicker for ILC damping ring

The kicker performances, in terms of efficiency and field uniformity, have been evaluated for different strip line geometries. The pulser requirements in terms of output voltage and pulse length have been determined as well. A dedicated feedthrough which assures better performances with respect to the commercial ones in terms of reliability and impedance matching has been designed and tested. The strip line kickers for beam injection in DAΦNE storage rings have been realised, tested and installed in both the machine rings in

November ’07. Since then they are working for DAΦNE injection in a reliable way with the old pulse generators. The final version of the FID fast pulse generators has shown poor reliability, they failed after one month of continuous injection in DAΦNE. The interactions with the manufacturers are continuing to understand the failure cause and to improve the reliability. Nevertheless, due to the high flexibility of the stripline design, different “hybrid” configurations using a combination of the new and old pulsers were successfully tested. The betatron oscillations excited on the stored beam by the stripline connected to the fast pulser were measured for each bunch and showed the proper temporal shape: the total pulse duration was less than 11 ns with a residual tail below 2% of the peak amplitude.

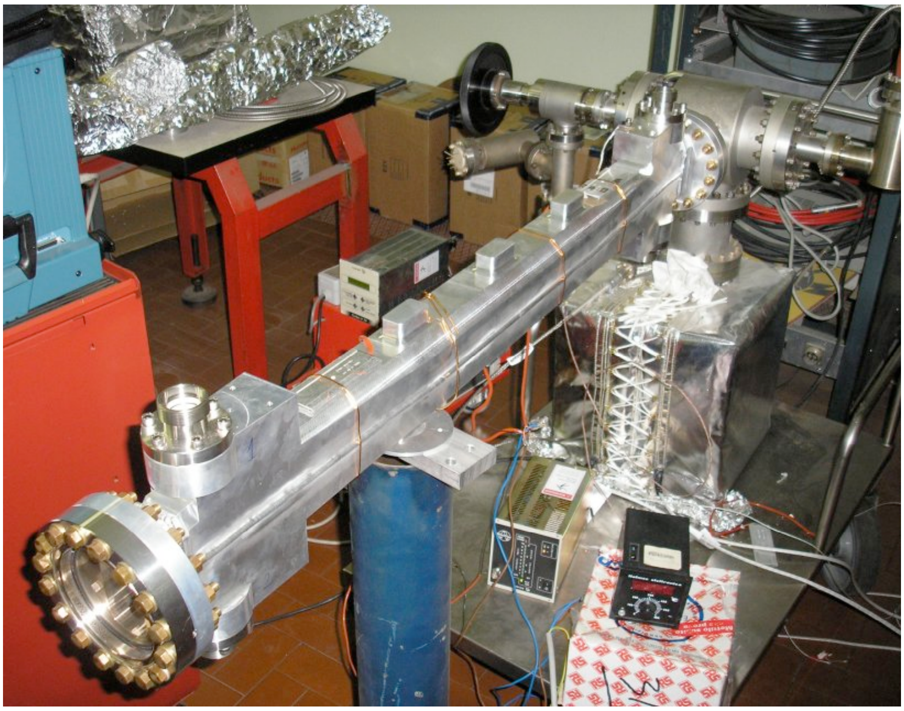

Figure: The DAΦNE stripline kicker during high voltage tests

The design of a stripline kicker for the ILC damping ring, with a total pulse duration below 6 ns, has been completed in 2008 following the same criteria adopted for the DAΦNE kicker. The adoption of a tapered stripline allows to minimise the impedance of the device and to obtain uniform deflecting fields in a wide area in the transverse plane. The beam emittance growth is therefore minimised. A prototype of this kicker is under construction, it will be ready by end of April 2009 to be tested in the ATF facility at KEK.

LETS: Low Emittance Tuning Simulations

The damping rings determine the smallest emittances achievable at the interaction point of the linear collider, and so the emittance achievable from the damping rings has a direct consequence on the luminosity of the machine. The low emittance tuning task concentrates on minimising the extracted emittance from the DR in the presence of mechanical and magnetic errors in the lattice to less than the design value of 20 pm-rad. During the 4 years of the EUROTeV project there have been many different lattices proposed for the ILC damping rings. Studies in both analytical and simulation have been performed for all of these lattices, and presented to the wider community. This work has helped in choosing the final configuration.

An initial assessment of the possible tuning algorithms showed that the use of a response-matrix based method, using skew-quadrupoles for both vertical dispersion correction and coupling correction was optimal. The correction algorithm designed for the DR designs has been shown to produce extracted emittances at the required level for the linear collider luminosity goals, under realistic error conditions in the machine. The algorithm performance has also been studied under the influence of long term ground motion in the DR. The simulation is used to understand the long term evolution of the extracted emittance over time, and gives details on the required correction timetable. Studies were performed to find the minimum number of beam diagnostics and correctors needed to achieve the required extracted emittances and to optimise their location. An optimisation was also performed on the required number of skew-quadrupoles used in the tuning algorithm.

4.3.3 POLARISED POSITRON SOURCE

The goals of the Work Package WP4 were:

- Evaluate possible technologies for the helical undulator, and produce a final engineering design.
- Complete evaluation (computer modelling) of spin performance including relevant hardware specifications.
- Feasibility study of a spin flip transport system, including estimation of systematic errors.
- Specification and engineering design of the photon target and collimator.
- Development of a low-energy polarimeter (including prototype beam testing) suitable for use with the source.

HURD: Helical undulator R & D

An evaluation was made of the possible technologies available for generating the required helical undulator field. A permanent magnet and a superconducting magnet design was developed and a prototype of each was constructed and tested. This assessment clearly showed that the superconducting solution was the best choice for the ILC. Following this selection process the superconducting design was further developed through several stages and four more short prototypes were constructed and tested. Each of these was successful and this helped to develop the parameters for the undulator (period, field, magnet bore) that were adopted by the RDR for the ILC and are still in place today.

In parallel to the magnetic studies of the undulator was an intensive study of the vacuum performance. As the undulator consists of a very long thin tube it is very difficult to pump down due to conductance limitations. Two solutions were investigated, Non-Evaporable Getter (NEG) coating and cryo-pumping. The application of a NEG coating to accelerator vacuum chambers is now a relatively mature technique. However, no one has so far been able to coat tubes as narrow as those required by the ILC undulator. A plan was put in place for how coating of such narrow tubes might be achieved but this was stopped when it was decided to use a superconducting device as this is a cold bore magnet which will act as a cryo-pump naturally. In this case the main issues were estimating how far apart the necessary discrete ion pumps could be and furthermore ensuring that no synchrotron radiation could strike the inner surface of the undulators to liberate gas molecules.

Following the intensive R&D period on the superconducting magnet an engineering design was developed for a full scale cryomodule. It was decided that the longest feasible length of individual undulators was about 1.75 m and so a design was adopted that put two of these undulators into a single cryomodule. The engineering design was completed and construction initiated. Two undulators were successfully built and tested and they both exceeded the design field level by about 30%. They have now both been incorporated into a 4 m long cryomodule and this is currently undergoing cryogenic commissioning.

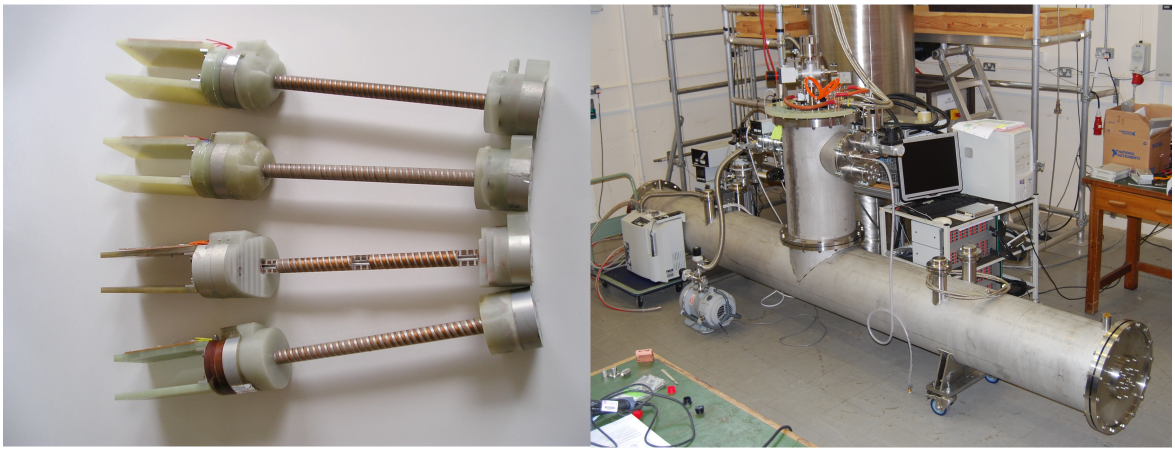

Figure: Undulator winding and the cryostat of the undulator

PTCD: Photon conversion target and collimator design

The photon conversion target is a critical element in any undulator-based positron source for a future high-energy collider. The intense photon beam from the undulator and the interaction between the target and the adjacent magnetic capture system present an extremely challenging environment from the point of view of heat load, shockwaves, radiation damage, eddy currents and activation-related issues such as remote-handling. The target can be partially protected by a reliable photon collimator which can absorb and dissipate the energy from the outer regions of the photon beam prior to the beam hitting the target. Exploiting the angular distribution of photons emitted from a helical undulator, the collimator can also increase the average polarisation of positrons emitted from the target, potentially giving access to a strongly enhanced range of particle physics measurements at the interaction point of the collider.

The role of this task was to explore the physics and engineering challenges presented by the target and collimator and to develop designs that could be used in future colliders. The target design work has taken place in the context of a strong international collaboration both within and beyond EUROTeV. PTCD has contributed substantially to the international effort in this area including leading the design and development of a target prototype based at Daresbury Laboratory.

Rather than risking replicating work needlessly, it was decided at the outset that PTCD should be aligned with an ongoing related study being carried out in the US where experience at operating positron sources of lower intensity at SLAC was being used to develop a target wheel design extrapolating from existing technologies. By contributing to the development of engineering studies and computer simulations of the target wheel with particular emphasis on the target station and remote-handling, PTCD had a significant impact on the design adopted for the International Linear Collider reference design report despite being hampered by a lack of suitable candidates to fill a position originally intended for the University of Liverpool.

Significant concerns about the survival of the target and differing predictions from computer simulations led the collaboration and the broader community to quickly conclude that construction of a prototype was necessary and PTCD adapted rapidly to focus its effort on filling this need. The highest priority was given to an experimental programme to understand how a target based on a rotating metal wheel would interact with the intense magnetic field used to capture positrons. The prototype equipment and much of the engineering effort was funded through UK funding sources with much of the physics staff effort funded through EUROTeV. Manufacture of the titanium wheel itself was carried out by UK industry. Analysis of the data from the prototype is ongoing and, alongside the experience gained by staff working on the project, forms a valuable part of EUROTeV's legacy to ongoing and future linear collider projects.

In parallel with the development of the target design, a smaller but world-leading effort was maintained on studying the role and realisation of the photon collimator. EUROTeV effort was used to supplement and direct a PhD student at the University of Liverpool who developed computer simulations and evaluated alternative designs for the collimator. This work built on work carried out in the PPMODL task discussed elsewhere. These studies will inform the final engineering design of the collimator which will follow at a later time.

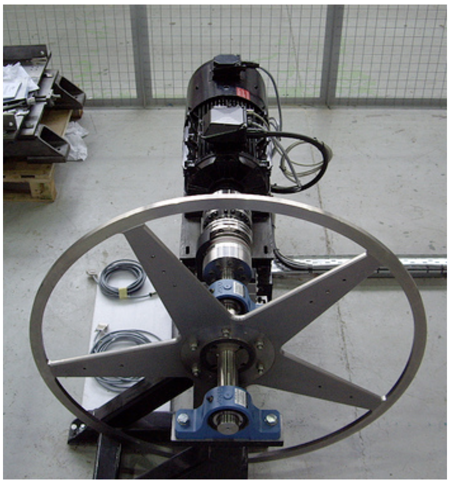

Figure: Target wheel

PPMODL: Source performance modelling

Polarisation has now been fully implemented into the benchmark code Geant4. With the release of Geant4 version 8.2 the newly developed polarisation extension became an integral part of this toolkit. This release already included 5 polarised processes, which address the question of polarisation transport and depolarisation in the target of the polarised positron source.

Geant4 was used in positron source modelling, i.e. for the calculation of positron yield, capture efficiency and beam polarisation for different undulator parameters for baseline source configuration with and without photon collimator. It was the main tool for the data analysis of the E166 experiment, and is also being applied to the design of a low-energy Bhabha polarimeter.

In 2008 this project was continued, and two updated versions were released: 9.2-Beta (June 2008) and the official version 9.2 in December 2008. Version 9.2 includes a new relativistic bremsstrahlung model class which provides an advanced description of the LPM effect. This new class can be applied for electrons and positrons with energies above 1 GeV; the resulting gamma spectra agree well with data taken in experiments with thin targets. The density suppression effect in the old G4eBremsstrahlungModel has been reviewed and improved.

A new Monte Carlo Tool for quick evaluation of yield and degree of positron polarisation of undulator based source was developed based on Geant4. The undulator photon spectrum is generated from analytic formula. The photons are tracked through a conversion target (thickness and material adjustable). The optical matching device capture optics and solenoid are simulated with variable field strength. The first accelerator structure is included with both electromagnetic fields and material; the damping ring acceptance is applied as a phase space cut.

Positron yield, capture efficiency and beam polarisation were calculated for different undulator parameters for the baseline source configuration and for a conventional source scheme (auxiliary source); the impact of different target material was taken into account. The efficiency of different schemes of positron collection optics downstream the target was determined, in particular a pulsed flux concentrator and Lithium lense were considered. The energy deposition and temperature increase in target and optical matching device were calculated.

With the baseline design given in the RDR the positrons will be polarised; with bunch compression the capture efficiency can be increased by a factor of two and the positron polarisation could reach 45%.

The expected activation of source parts for an undulator-based and conventional source has been determined and the required shielding was estimated.

SPINF: Spin rotation & flip system design

A spin rotator for the ILC has been designed which preserves the overall optic axis. The suggested system is fully flexible; longitudinal spin orientation at the IP will be achieved also for non-zero crossing angles. Further, it will be possible to adjust the spin vector in any direction desired. The spin rotator set-up for a main linac following the surface of the earth has been determined. The emittance dilution due to geometric and chromatic aberrations can be kept small. The rotator system is stable, quite short and a suitable candidate meeting all the requirements of the ILC.

A polarised positron beam will be delivered already with the baseline design of the ILC. Spin flip with the same frequency as for the electron beam is essential to allow unbiased physics measurements. A design for a fast spin flip at positron energies of 5 GeV exists (K. Moffeit et al., SLAC-TN-05-045). An alternative scheme has now been suggested (K. Moffeit et al., ILC-NOTE-2008-040) with spin rotation and reversion at 400 MeV which should be much more cost effective.

LEPOL: Low-energy polarimeter R & D

Low-energy polarimetry near the creation point of positrons is necessary to monitor the polarisation, optimise the machine and to trace back failure of systems. The precision requirements for low-energy polarisation measurement are much less than at the interaction point: uncertainties of 5%-10% are sufficient. Choice and design of the low-energy polarimeter are defined by the energy of positrons, the high beam intensity and the requirement that the polarimeter must not reduce the positron yield or disturb the beam. Further, the positron beam at the source has a large transverse size of the order centimetres.

Three options for a low-energy positron polarimeter have been studied in detail: Compton transmission polarimetry, Bhabha polarimetry as polarimeters at the positron source, and Compton polarimetry after the damping ring.

Compton transmission polarimetry is used to measure circular polarisation of photons. Hence, polarised positrons are converted to polarised photons in a Bremsstrahlung target. The photons pass magnetised iron and undergo Compton scattering with the two electrons in the 3d-shell of the iron atoms. The transmission of the photons through magnetised iron depends on both, the polarisation of photons as well as the polarisation of iron electrons. Reversing the polarity of the magnetised iron, an asymmetry in the transmission signal is obtained; it corresponds to the positron polarisation.

The method has been tested at the E-166 experiment at the Final Focus Test Beam area at SLAC. With a Compton transmission polarimeter the polarisation of MeV-positrons has been measured with a precision of about 10%. For the measurement at an undulator source it is essential to extract the polarisation from the measured asymmetries using the analysing power determined with a Monte Carlo simulation. For this purpose Geant4 has been extended with polarised processes.

A Compton transmission polarimeter can be installed after the capture and first acceleration section of the source, where the positron energy has reached 125 MeV. The method is destructive and only a few bunches per pulse can be used for polarimetry. Due to the high beam intensity the measurement is fast. The advantage of this method is robustness and simple set-up which can deal with very poor beam qualities.

A Bhabha polarimeter should be positioned downstream of the positron pre-accelerator, at 400MeV. In a thin magnetised iron foil the polarised positrons undergo Bhabha scattering with the polarised iron electrons. Detailed performance simulations show that a 20 μm-thick iron foil will stand the intense positron beam of large radial extension and yield only marginal emittance increase. Due to the intense ILC beam the measuring time is short and depends only on the time needed to reverse the magnetic field in the iron foil. The method is almost non-destructive and therefore preferable.

Compton polarimetry requires a small radial positron beam size of few μm to achieve sufficient signal rates. Therefore it can only be applied downstream of the damping ring. Simulation studies have been performed for the Compton polarimeter operated at 5 GeV; within a few minutes the required precision can be reached.

Simulation tools

The interaction of polarised particles with matter is treated in dedicated simulation programs, a major program is Geant4. To achieve a complete simulation of polarised processes as obtained, all relevant processes have to be available with polarisation. At the ILC positron source, these processes are essential for modelling the performance of the target and the low-energy polarimeter, in particular, the analysing power cannot be determined without dedicated simulations. A new extension in the Geant4 library of electromagnetic physics was created and is dedicated to polarisation effects in beam applications. It belongs now to the official Geant4 version (http://geant4.cern.ch).

4.3.4 DIAGNOSTICS

The goals of the Work Package WP5 were:

- Prototyping and evaluation of novel beam position monitor (BPM) technologies:
  - Confocal resonator monitor;
  - Transformer monitor.
- Development and prototyping of a robust and reproducible laser-based beam profile monitor.
- Construction and evaluation of a prototype time and phase monitor.
- Construction and evaluation of a prototype wide-band current monitor.
- Design and prototyping of a precision energy spectrometer based on a magnetic chicane.
- Development a cavity-based high-energy polarimeter

CFBPM: A Precision BPM Based on a Nearly Confocal Resonator Cavity

Diagnostic devices aimed at measuring beam position, intensity or time profiles in high intensity accelerators are often perturbed by microwave fields that are generated by the beam itself upstream of the detection device and that propagate in the vacuum pipe, in the wake of the bunches. These parasitic waveguide modes can significantly reduce the signal-to-noise ratio and thereby the sensitivity of the device. The electromagnetic field carried by a bunch is a quasi-TEM mode, while the parasitic waveguide modes travelling inside the vacuum pipe are TE or TM fields. A resonator pickup with spherical mirrors situated transversely to the direction of propagation of the beam can have a high quality factor for the diffraction losses. As a result, reciprocity suggests that it only couples weakly to external TE or TM fields. A Nearly Confocal Resonator (NCR) prototype was designed for maximal parasitic field rejection at multi-GHz frequencies, and it was successfully tested.

Following the change of the RF frequency for CLIC, it was decided to operate the Combiner Ring of CTF3 at the new frequency of 12 GHz and so a new NCR design study was performed. A mirror distance of 6.78 cm and a curvature radius of 8.69 cm was used (this ensures that there is one eigen-mode only at 12 GHz). The vertical dimension of the CTF3 beam pipe remained 3.7 cm, so the elevation of the zenith of the mirror domes above their edges and the mirror radius were then 1.54 cm and 4.94 cm, respectively. As for the previous design at 15 GHz, the geometry was chosen in order to have a large quality factor for the diffraction losses, and thereby a weak coupling to external parasitic TE and TM modes. A complete numerical and experimental investigation of this new NCR pickup was performed, with special emphasis on the coupling between external parasitic modes and the field in the resonator. A dramatic reduction of the coupling to external sources and modes by the resonator was clearly achieved. A good agreement was obtained between the simulations and experimental tests of the NCR prototype; these results were published in IEEE.

A numerical study of the coupling between a bunched electron beam and the NCR pickup was also performed using GdfidL. The simulated shunt impedance showed the presence of undesired resonances at low frequencies, which can however be significantly damped, by placing bricks of absorbing material along the side walls of the beam pipe. The power spectrum induced by a single electron bunch in an extraction waveguide connected to the upper mirror of the NCR pickup was computed. Another simulation was performed, this time without the NCR cavity on the beam pipe. Then, a comparison of the power induced by a bunch train at 12 GHz in these two cases showed that the presence of the NCR cavity reduces the available signal by at least three orders of magnitude, which is about the same reduction as for the parasitic modes propagating in the wake of the bunches, leaving thereby the signal-to-noise ratio practically unchanged. This study was published as a EUROTeV report.

ESPEC: High Energy Spectrometry

This task involved in three distinct experimental systems: the NanoBPM, project to test the best achievable resolution of a cavity BPM system; tests at SLAC T474 which was a full spectrometer test beam system based on a 4 magnet chicane system; the construction of a large (approximately 40) cavity BPM system with studies of long term performance stability and applicability of cavity systems at the ATF. In order to achieve the physics goals of the ILC a fractional energy resolution of better than 10^{-4} is required, which implies that a BPM resolution of better than 100n m is needed, accompanied by corresponding stability.

The programme at the SLAC End Station A (ESA) enabled detailed analysis and characterisation of the SLAC BPMs and full tests of a spectrometer system. A suitable BPM was designed, fabricated and tested. The spectrometer system and beam-line was simulated using Geant4 and BDSIM. Sub-micron resolution and micron level stability over 20 hours was demonstrated for a 1 m long BPM triplet and micron-level stability over 1 hour for three BPM stations distributed over a 30 m long baseline. The resolution of existing ESA BPM was improved to around 300 nm. The ILC spectrometer cavity design has been used as a template to develop the S- and C-band systems deployed at ATF2 and hence more widely the beam delivery BPMs for the whole ILC.

At the ATF2 the ESPEC group has utilised its experience and hardware from ESA to deliver:

- 9 channels of S-Band mixer electronics (four were reused from ESA).
- Complete RF processing code and online analysis for all ATF2 BPM systems.
- RF tone calibration system.
- Complete RF simulations of the BPM and electronics performance.

The objectives at the ATF were to test monopole suppressing RF cavity BPMs and to assess their performance. Two triplets of BPMs were used in the beam, and by comparing the apparent position of the beam from one BPM of a triplet with the position predicted from the other two, it was possible to assess the resolution and stability of these devices. Resolutions of order 20 nm were obtained, with stability at the level of 40 nm over a period of two hours, verifying the overall performance characteristics of cavity BPM systems for use in the ILC spectrometer.

The related work on the energy spectrum extraction and its implication for precision physics has resulted in a Ph.D thesis on the luminosity spectrum and the impact on the top threshold.

FLUM: Fast Luminosity Monitoring Based on Low Angle Calorimeters

At the ILC beamstrahlung will be created during the collision of the high intensity beams. A fraction of the beamstrahlung photons create low energy e^+e^- pairs, which hit the forward calorimeters of the detector. The FLUM task investigated the possibility of using two low-angle calorimeters, BeamCal and GamCal, to perform a fast analysis of the beamstrahlung photon and pair distributions to obtain as much information as possible about the beam parameters. The feedback system of the accelerator can process this information in real time and with low latency and finally increase the luminosity of the ILC.

A full standalone Geant4 simulation of the forward region of the Large Detector Concept was used to simulate the energy deposition from beamstrahlung pairs in the BeamCal sensor layers. It was shown that a subset of the information of the full detector data is sufficient to reach good precision in the beam parameter reconstruction. In the design of the frontend electronics for BeamCal a very fast readout link is proposed. Each frontend electronics chip will operate 32 channels and will be able to send the information of the sum of the signals of all channels in real time and with a low latency to a dedicated system. The effect of this clustering on the performance of the beam parameter reconstruction was investigated and found to be acceptable. The necessary 8-bit digitisation of the signal information was also found to have negligible influence on the performance of the reconstruction.

The GamCal system was then evolved to a realistic design and the effect of including the information about the total energy of the beamstrahlung photons into the algorithm for beam parameter reconstruction was investigated. The reconstruction of the beam sizes was found to be affected the most. The precision improved by a factor of 2-3 when the energy information of the beamstrahlung gammas was included. The simultaneous reconstruction of all beam parameters at the same time was found to not lead to a stable result when using the BeamCal information alone. A full multi-parameter reconstruction including other systems of the beam diagnostics system and restricting variations of beam parameters was also investigated.

HEPOL: High Energy Polarimetry.

The work concentrated on three main areas: a high-finesse stable two-mirror cavity in the pulsed regime, laser beam waist reduction using a non-planar four-mirror cavity, and polarimetry studies. At LAL a Ti:Sa pulsed laser beam of 1 ps pulse width and 76 MHz repetition rate was locked to a Fabry-Perot cavity of Finesse 30000. This is possibly the highest finesse ever yet achieved in laser pulsed regime. It was possible to reach such high finesse because of the LAL group's contributions to the design and construction of high mechanical stability and flexibility optical mounting systems, very low noise level analogue electronic devices, high flexibility and high precision digital feedback, and new expertise in mode-locked laser dynamics. This experimental result demonstrates the capability of passive Fabry-Perot optical resonators to stack laser pulses with a power enhancement factor of 10000.

An experimental study of four-mirror bow-tie cavities was completed in order to provide a very small laser waist inside the cavity. Two geometrical configurations were studied: planar (2D) and non-planar (3D). Although the mode characteristics were successfully characterised and the theoretical model used to describe the non standard 3D resonator, some optical aberrations were observed when the cavity geometry was pushed toward the instability limit (i.e. the very small mode waist limit). In order to investigate these aberrations, a new 3D cavity was rebuilt using 2" mirror diameters (instead of standard 1" inch mirrors that were used before). The observation of aberrations in the very divergent limit was confirmed: the fundamental mode is elliptic (more precisely generalised astigmatism) with an S shape in the plane transverse to the propagation axis. This phenomenon may have some effects on the geometrical factor of the laser-electron Compton luminosity and so a major effort in modelling was initiated to quantify this effect.

A detailed experimental study was performed of the systematic uncertainty on the HERA electron beam measurement related to the laser polarisation uncertainty. The experimental data recorded by the cavity polarimeter of HERA was used to demonstrate that a few per-mille level of systematic uncertainty on the measurement of the electron beam polarisation can be reached already with a Fabry-Perot cavity. A few improvements were revealed that could enable a per-mille level of accuracy to be attained.

LBPM: Laser-wire Beam Profile Monitor

A design of the diagnostics section of the BDS was developed to include laser-wires (LWs) and a paper was published in PRST-AB. The simulation of the LW signal and the influence of the layout of the LW detectors in the vicinity of the ILC upstream polarimeter showed that operation of the LW is likely to cause unwanted backgrounds to the polarimeter and indicates that it would be advisable to design separate, well separated, stations for each system.

A laser for the PETRA LW system was specified and purchased in order to complete the construction and commissioning of a 2-dimensional LW scanner at the PETRA accelerator. Many tests were performed and data taken using this system and the results were published in NIM A. This LW system was then dismantled in 2007 to make way for the decommissioning of the PETRA II machine. An upgraded LW system was tested at RHUL before being transported to a new location for future use at PETRA III.

A fast scanning system based on electro-optic techniques was designed and constructed. For this, an HV driver system was set up and commissioned at RHUL and a new scanning system was developed using lithium niobate crystals. First results were very promising and indicated that a workable solution is possible using this technology; results were presented at accelerator conferences. More recent results have shown that the device works to specification and does not degrade significantly the quality of the laser beam; a paper has just been submitted for publication in Applied Physics Letters.

The requirements of a mode-locked laser-system for a LW with ILC specifications were specified and a first prototype fibre-laser was constructed. An industrially built driver laser was set up at Oxford for this purpose and a commercial (Amplitude Systèmes) seed laser for a LW laser system was successfully set up and commissioned. The first prototype of an ILC-specification fibre laser amplifier was designed, built and commissioned using the commercial laser system as a seeder. The results were very encouraging and indicate that photonic crystal fibre technology may be suitable for ILC-specification LW systems.

A µm-scale LW system was constructed and commissioned at the ATF extraction line. For this, a new custom-designed lens was installed and tested. Beam tests runs using initially a commercial lens were completed and compared to results with the custom-designed optic; the custom system showed markedly improved performance with laser spot-sizes of order 3 µm being achieved. Detailed investigations of systematic effects, including residual lens aberrations have been studied and have opened the route to even smaller spot-sizes.

PBPM: Precision Beam Position Monitor

The design and construction of the new Precision Beam Position Monitor (PBPM) was completed and a dedicated test bench was designed and manufactured. It includes micro movers having a resolution of 100 nm, and a vibration damped table. Several beam tests were carried out on the high resolution triplet installed in CTF3. The beam tests gave very poor transmission efficiencies, and it was understood that the lack of metallisation on the inside of the ceramic vacuum tubes, on the second and third PBPM, was the cause of this. The high frequency components were no longer bypassed by the titanium coating and saturated the current transformers.

Three new vacuum assemblies were manufactured and installed and a 40 mm diameter BPM was added downstream of the set-up, to provide independent measurement of transmission efficiencies. A new attempt with beam gave much better results where transmissions of ~90%

of the beam were achieved, and an equivalent CLIC beam (1.5 A, 200 ns) resolution of 2 μm was measured in the horizontal plane. The vertical plane was perturbed by the beam losses, and a resolution measurement was not possible. Further beam tests were performed, where the beam energy was two times higher (200 MeV), with an emphasis on optimizing the steering and size of the beam. The transmission through the set-up was not improved significantly (~90%), but the measured resolution (single sample) was measured to be 2μm in the horizontal plane for a 600 mA beam, which corresponds to 650 nm for a CLIC nominal beam. In the vertical plane 1.9 μm was measured for a CLIC type beam. It is believed that the beam losses are still limiting the measured resolution especially in the vertical plane, and it is foreseen to continue the test in order to obtain loss free transmission in the three PBPM's. Also the gain of the acquisition system will be optimized for the future tests, since in order to cover a bigger dynamic position range in this test, the LSB of the ADC was 1.7 μm. The complete results of the beam test are published as a EUROTeV report.

TPMON: Time and Phase Monitor

This task concentrated on the development of a prototype for the phase detection electronics. For a successful high luminosity CLIC machine phase errors between the two beams need to be kept below 0.1° at the point of energy transfer. The measurement and correction of errors must be accurate up to the bandwidth of the structures, expected to be in the 50-100 MHz range. By making a local comparison between the outgoing main beam and, 140 μs later, the drive beam before the turnaround, the need for a high stability global reference was removed. Rather, a local oscillator keeps time between the passing of the two beams. For long term stability, phase locking to a global low frequency timing signal or GPS is foreseen.

The selection of devices for the Intermediary Frequency (IF) phase detection was crucial, in particular mixers and active multipliers were investigated; the important criteria being amplitude to phase conversion at baseband and noise performance. The multiplier performed better on the amplitude dependence, but worse on the noise performance. The signal to noise ratio could be improved by utilising multiple detectors and the analogue summation of their outputs. The system consists of a 30 GHz local oscillator generation scheme from a lower frequency signal, and a down-mixing stage to the IF of 750 MHz. For the up-conversion from the CTF3 timing signal at 3 GHz to 30 GHz a couple of edge compressors and comb generators were investigated.

Tests with beam were performed in CTF3. In order to demonstrate the extraordinary resolution of the system, two systems were built to perform simultaneous measurements of the beam, and the results compared to each other. This was required since the jitter of the CTF3 beam vastly exceeds the specifications of the system. These tests demonstrated the very low noise performance required for the task, the results coming in well below the 10 fs required at 30 GHz. The 3 GHz timing reference signal and the RF pickup were common to both systems, whereas the other parts: LO generation, down-conversion, and IF detection were duplicated. This allowed the resolution of the detector to be established with simultaneous duplicate measurements of one beam, which was required because no sufficiently accurate system exists that can act as a reference to establish sufficient resolution. The set-up closely mimics the final application where a measurement of two beams would occur with a 140 μs delay, thus ensuring de-correlation of the parts that would be common (LO generation) in the final application.

WBCM: Wide-Band Current Monitor

Wall current monitors are commonly used to observe the time profile and spectra of a particle beam by detecting its image current. Within the framework of the EUROTeV program a Wide Band Current Monitor (WBCM) for CLIC and ILC, having a very large bandwidth (100 kHz - 20 GHz) was required. Allowing for these very high frequencies, lumped circuit models are no longer valid and a thorough study of the field configurations for the device was necessary. Several structures have been studied over last four years as described in EUROTeV reports. A structure presenting small mechanical changes with respect to classical designs returned interesting results, even if it did not completely fulfil the specifications. Another three possible geometrical configurations were identified from which two required a reduction of the geometrical aperture and were therefore rejected. The third one, representing a modified version of the structure, was chosen as the best WBCM candidate. Furthermore an analysis of the signals from the structures showed that the initial bandwidth specifications were too stringent and had to be reviewed.

A prototype of a WBCM was completed. The first measurement showed an agreement with the expected average signal level and required bandwidth of 20 GHz. The suppression of the gap resonances, which should appear at about 13 GHz on the test bench, was also demonstrated. A resonance at 6 GHz, which inhibits a correct functioning of the WBCM, is not yet understood but it is believed that this resonance is related to the feed-through and not the WBCM structure. The final assembly of the WBCM revealed some unforeseen problems which require a modification of the WBCM design and a small change in the test bench. Furthermore a full understanding of the keystones of this kind of device has been reached and several options have been found and presented in EUROTeV Reports. Also a review of the original requirements has been performed, showing much fewer constraints for future devices, especially after the lowering of the CLIC working frequency. The new WBCM requires a bandwidth $\geq$ 6 GHz with a high frequency cut-off of 12 GHz, while for the former CLIC frequency of 30 GHz, the bandwidth requirement was $\geq$ 15 GHz with a high frequency cut-off of 30 GHz.

4.3.5 INTEGRATED LUMINOSITY PERFORMANCE STUDIES

The goals of the Work Package WP6 were:

- Conceptual design of a bunch compressor system, and a chicane system for tuning the beam path length, compatible with multi-TeV operation.
- Inclusion of spin in the simulation code GUINEA-PIG, and benchmarking of physics processes.
- Evaluate (model) the performance of various post-LINAC collimation systems for given halo models, and evaluate the impact on the detector. Investigate the impact of luminosity tuning and errors on background performance.
- Identification of key failure modes, and evaluation of their impact on the machine design.
- Develop and optimise beam-based alignment algorithms and feedback systems to optimise the luminosity performance in the bunch compressor, main linac and beam delivery systems.
- Conceptual design of a post-collision extraction lines; studies on the feasibility of post-collision diagnostics.

COLSIM

This task has been focused on the nonlinear collimation concept for CLIC based on skew-sextupoles, which can be adapted more generally to both linear and circular colliders. The optics of the CLIC nonlinear collimation system was further optimised by local correction of high order aberrations (2nd, 3rd, and 4th order) using two additional non-linear elements: a skew octupole and a normal sextupole. In this way, the simulation results gave a luminosity and energy bandwidth comparable to those for the conventional linear optics. An alternative nonlinear system for the Phase-II betatronic cleaning in the LHC was presented. Its performance and cleaning efficiency were studied by tracking using the code Sixtrack. By adjusting optics and collimator settings, a considerable improvement of the cleaning efficiency was obtained, up to the level of the linear system for the vertical direction. It was shown how the module of the horizontal effective impedance is reduced by about a factor 2 and the vertical one by about a factor 3 compared to the LHC Phase-I IR7 insertion. Consequently, using the nonlinear collimation system, the coherent tune shift for the most critical coupled bunch mode has been reduced by about a factor 2 with respect to the Phase-I IR7 insertion. According to the results obtained for CLIC and LHC, it was concluded that a nonlinear collimation system using skew sextupoles for the case of linear and circular colliders appears to be competitive with the corresponding linear systems.

BDSIM is a Geant4 based accelerator tracker code that enables fast tracking of beam particles combined with full simulation of secondary particles and their subsequent propagation. It was developed extensively and implemented within EUROTeV; during this time upgrades have included an extension to the gmad interface in order to define new materials. BDSIM was used extensively for the ILC BDS simulations. The implementation of the ILC 20 mrad and 2 mrad interaction region designs within BDSIM was completed and the energy deposition due to pairs and radiative Bhabhas on beam-line elements in the extraction line of these IRs was determined. The results for the ILC collimation system and extraction lines were checked against MARS and STRUCT simulations. More recently, the major developmental work has been the inclusion of an interface to Placet in order to allow the application of transverse wake-field kicks in collimator elements and to simulate the halo repopulation by secondary particles generated from halo interaction with the collimation system.

A detailed study of the possible regimes for the intra-bunch wake fields excited in a collimator was performed. Using a semi-analytical approach and having developed a new formula for the resistive wall wake field in the intermediate range regime, the self-induced kick felt a bunch going through a collimator was calculated. The relative routine, tested first as standalone for the several different cases, was then successfully implemented in the PLACET code, where bunches could be tracked through the CLIC-BDS including the effects of the wake fields of the collimators, and the luminosity loss due to collimator misalignments and/or jitters of the incoming beams was estimated. More elaborate nonlinear expressions were implemented in PLACET to take account of near-wall effects in a more correct way. The effect of higher order modes were introduced into the Merlin code in a computationally efficient way. Collimator wakefield tests were performed at SLAC End Station A. Measurements were taken of the deflection of bunches by a wide range of different collimator shapes, materials and apertures. Energy deposition when particles impinge on the collimator was simulated with Geant4 and by FLUKA and EGS. These give temperature rises such that the collimator can survive the direct impact of several bunches undamaged, which actually exceeds the requirements imposed; similar energy depositions in the positron source were also studied.

BCDES

The aim of this task has been to design and evaluate the second CLIC bunch compressor and to design a system to correct the drive beam phase.

The bunch compressors are required to reduce the bunch lengths to fit specifications at the interaction point and in the decelarator, respectively. To facilitate the compression chicanes build of dipole magnets are utilised as displayed in the figure. Particles with higher energy will pass such chicanes on a shorter paths than particles with lower energy. Hence, prior to entering the chicane the longitudinal phase space distribution must be shaped in RF cavities that trailing particles get higher energy than particles at the bunch head. The major issue in the design of such systems are strong radiative effects in the bends of the bunch compressor chicanes which can lead to an increase of transverse emittances. Consequently, the bunch compressor performance had been identified as a critical item for the feasibility of CLIC. The BCDS split in two parts: bunch compressors for the CLIC main beam and bunch compressors for the CLIC drive beam. Systematic studies on the influence of various geometric chicane parameters as well as on electron beam parameters have been performed.

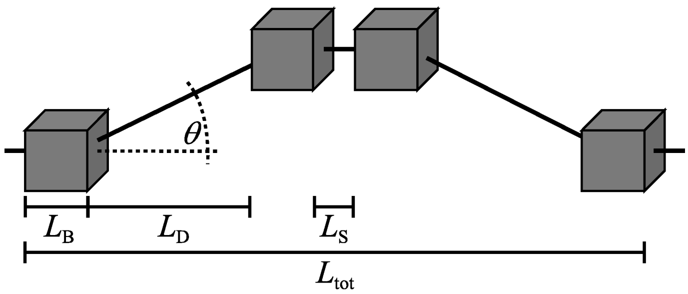

Figure: Sketch of a bunch compressor chicane

Two bunch compressors (MBBC1 and MBBC2) are required for the CLIC main beam to ensure proper beam transport. One at the exit of the damping rings and one in front of the main linac. They must compress the bunches from an initial length of 1.3 mm to 0.044 mm, i.e. by a factor of 30. The intermediate bunch length has to be adjusted to the beam transport in between the chicanes. It was chosen to be 0.175 mm mainly to reduce coherent synchrotron radiation (CSR) in the turn around loop. By using small bending angles and long drift lengths the emittance growth in the chicanes could be reduced to below 30 nm rad in MBBC1 and 20 nm rad in MBBC2. Taking into account the shielding effect of a 20 mm high vacuum chamber both values drop below 10 nm rad; their performance stays within the specifications.

Also for the drive beam two bunch compressors (DBBC1 and DBBC2) are needed. They are located in front of and behind the turn around loop which directs the drive beam into the decelerator as shown in the figure. Besides being used for a moderate compression from 2 mm to 1 mm, they serve for a feed-forward system to correct the bunch phase. Phase and energy errors are measured around the first chicane and the phase correction is applied in the second chicane by changing its path length. Due to the huge emittance the influence of CSR in the chicanes is no major design issue, whereas the requirements of the feed-forward system put some constrains on DBBC1 and DBBC2. For example, their momentum-compaction factors (R56) should not be too small. A high R56 of DBBC1 improves the quality of the energy jitter measurement and a high R56 of DBBC2 limits the relative bunch length jitter, which is induced when correcting the phase.

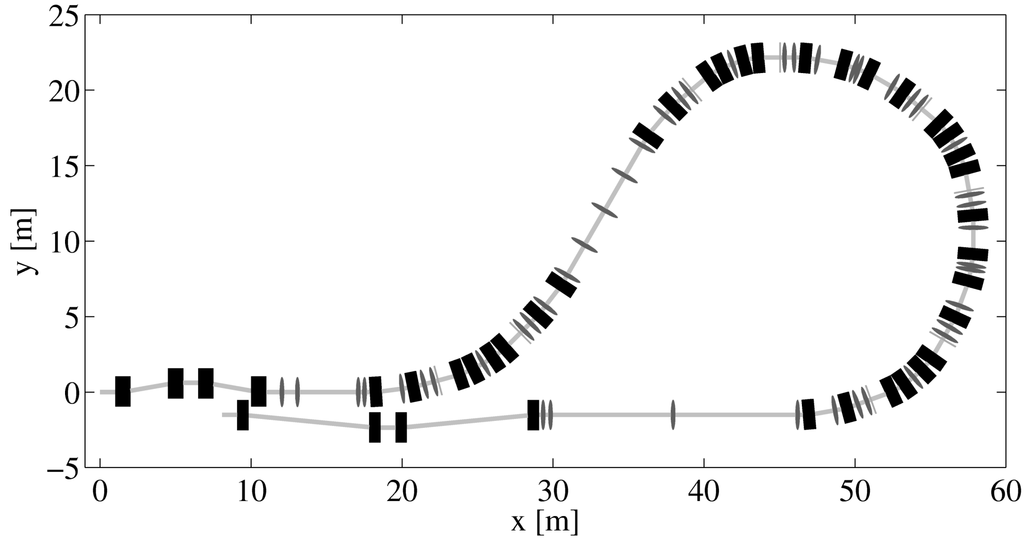

Figure: Drive beam bunch compressors and turn around loop.

FMSIM

Accidental beam loss is an important machine protection issue in future linear colliders. The main aim of the task has been to identify and study the most important failures that can lead to beam loss.

ILC and CLIC share potential failure modes for the main beam. A list of most important failures has been assembled and tools developed to simulate failures in the main linac and the resulting losses. With two supporting studies, it has been shown that significant loss in the ILC main linac is very unlikely. For the beam delivery system the emphasis has been to assess the potential impact (damage) to BDS components (specifically collimators and spoilers) for various failure modes (RF phase and amplitude errors, magnet power supply failures etc.). The simulations confirm the potential for single-bunch damage of critical spoilers, but no failure mode studied resulted in damage to the physics detector. Inclusion of scattering in the spoilers was also studied, and showed that no particles are lost in the detector (to the given statistics of the number of particles tracked).

For CLIC, the failure mode studies focused on the most critical component that is different from the ILC. The CLIC Drive Beam decelerator is responsible for producing the RF power for the main linacs, using Power Extraction and Transfer Structures (PETS). To provide uniform power production, the beam must be transported with very small losses. The failure modes for the operation of the decelerator were investigated, and the impact on beam stability and loss levels were presented. Quadrupole failure, PETS inhibition and PETS RF break down scenarios were being considered.

It was found that a properly steered machine behaves better than an uncorrected one also with respect to failure modes. For a steered machine we conclude: more than two simultaneous quadrupole failures leads to unacceptable loss levels. Quadrupole power supply jitter is acceptable up to 10^{-3}. Inhibiting up to 1/3 of the PETS is not severe for beam stability (up to 2/3 for a dispersion-free steered machine). PETS break down voltage up to 50-200 kV is acceptable for beam stability, depending on the PETS relative position along the lattice.

LAST

The task had two main aims. First, to produce a package that allows to study the preservation of the small beam emittance during the beam transport in future linear colliders. Second, to study the emittance preservation and to develop and improve beam-based methods to improve it.

Two main code packages have been developed in this task. MERLIN, is a library that allows to simulate the beam transport and beam-based alignment. PLACET is a program with similar capabilities that uses an interface language. PLACET has been used to simulate beam transport in CLIC from the exit of the damping ring up to the interaction point and beyond in the post collision line. In addition a dedicated code, FASTION, has been developed to study the beam-breakup that can be generated by rest gas in the beam pipe. Also a code has been developed that allows to optimise complex beam lines. All the codes have been made publicly available and they were used to study the emittance preservation and luminosity in ILC and CLIC.

The preservation of the beam emittance in future linear colliders is of critical importance. The machine will be equipped with beam position monitors (BPMs) and laser wires to measure the beam size. Simple algorithms that centre the beam trajectory in the BPMs cannot achieve the required performance, more complex methods of beam-based alignment are needed. We studied such algorithms, in particular dispersion free steering. In this method the nominal beam and at least one test beam, which is accelerated with a different gradient, are used. The nominal beam is centred in the BPMs and simultaneously the difference between the trajectories of the different beams are minimised. We found that this method can achieve the required performance in ILC and CLIC. A particular problem has been the performance of the alignment method at the beginning of the main linac, where the acceleration with different gradients yields only very small energy difference between the beams and hence not sufficient correction. We found a solution by using the bunch compressor that is located upstream of the main linac to generate beams with different energies at the entrance of the main linac, this solved the problem.

Dynamic machine imperfection during the application of the beam-based alignment procedure could reduce the performance of the methods applied. However, detailed studies showed that the additional emittance growth due to these dynamics imperfections is acceptable.

An additional tool to improve the beam quality are the use of emittance tuning knobs. In case of CLIC they consist of a set of accelerating structures that can be moved transversely thus adding a wakefield kick to the beam in order to compensate the wakefield kicks of the other accelerating structures. We developed a method to find an optimum set of such tuning knobs, which leads to a most rapid correction. We also proposed an efficient method to monitor the beam emittance. Conventionally the beam size is measured at the end of the linac, e.g. using laser wires. We suggest to let the beam collide with a laser beam that has the target size of the main beam. By optimising the beam overlap with the laser the optimum setting of the tuning knobs can be found. Simulation studies performed with this emittance measurement technique showed very good performance.

In the ILC the couplers of the main linac cavities can kick the beam. The impact of these kicks have been investigated and it could be shown that their impact on the beam emittance is small.

In CLIC each accelerating structure is equipped with a wake field monitor that allows to measure the beam offset. The structures are mounted on girders that can be moved to minimise the beam offset and hence the wakefield kicks. This alignment procedure has been shown in simulations to yield very good emittance control. Detailed studies have been performed to establish the tolerances for the CLIC structures. Additional studies allowed to translate these tolerances into tolerances for the structures details.

In order to evaluate the developed algorithms beam tests have been performed in the CLIC test facility CTF3. In this machine one does not expect a significant improvement of the performance as simulations show, since the machine is relatively small. However, it has been demonstrated that the algorithms can be made to run in an automatised fashion and that simulations and measurements agree.

An important decision for the ILC has been the choice between a tunnel that follows the earth curvature and a laser straight tunnel. The cryogenic system is simpler if the tunnel follows the earth curvature as in this case the level of helium is constant along the machine, from the beam dynamics point of view a laser-straight machine is to be preferred. In LAST it has been possible to show that the emittance growth can be kept under control in a curved tunnel.

Initially work on the ILC beam delivery system alignment has been performed in LAST; this activity has later been continued at SLAC. However, beam based alignment have been carried out for CLIC and the final focus test facility ATF2. Algorithms have been established to align the full beam delivery system. They achieve more than 80% of the maximum luminosity in 80% of the random sets of misalignments studied. The algorithms can be tested in the international final focus test facility ATF2 in 2009.

Integrated simulations of the main linac, beam delivery system and beam-beam interaction have been performed. They concentrated on the impact of ground motion and the orbit feedback systems. A baseline feedback system has been developed for ILC. It has been found that ILC and CLIC will lose significant luminosity in a noisy environment if the beam line elements are not stabilised. A particularly important feedback is the one at the interaction point, which keeps the beams in collision. It uses a BPM to monitor deflection angle that the beams receive due to offsets in the beam-beam collisions. The beam offsets are then corrected using kickers. The BPM and kicker need to be located close to the interaction point. Potentially, background could render the BPM signal useless. We carried out studies that show that the expected background level is harmless in ILC and CLIC. In ILC not only the beam offset but also errors of the incoming beam angles can be performed and one can optimise the luminosity with in a bunch train. Detailed studies demonstrated the performance of these methods.

The fast beam-ion instability is severe a concern for CLIC. In this process molecules from rest gas in the beam pipe are ionised by the beam and then trapped inside the beams. The accumulated ions can lead to a multi-bunch instability. Analytically one can predict that a vacuum level of 0.1 nTorr is safe in the main linac. This level of vacuum can however only be achieved using specific techniques, like bake-out, that are difficult if not impossible in the main linac. We developed a new code (FASTION) in order to more accurately quantify the vacuum needs in the main linac. Detailed studies based on this code showed that a vacuum level of 10 ntorr appears acceptable. This level is within reach of conventional techniques that are compatible with the very stringent accuracy requirements of the main linac elements. The code has been made publicly available via the savannah server.

For CLIC a complete parameter optimisation has been performed to reduce the cost to the minimum. The achievable luminosity has been calculated for a large set of structures of different RF frequency, different gradient and different apertures. This required a verification of previously derived approximations of the wakefields induced by the structures, which had a limited region of validity. It has been shown that the model is a good approximation also outside of this region. Based on these results and on RF constraints as well as a cost model the parameter set leading to the minimum cost has been chosen. As a result, the gradient has been reduced from 150MV/m to 100MV/m and the accelerating frequency has been changed from 30 GHz to 12 GHz.

PCDL

The original charge was to bring forth a conceptual design of the beam line between the interaction point (IP) and the beam dump for the multi-TeV Compact LInear Collider (CLIC) for the International Linear Collider (ILC) and discuss suitable instrumentation options in order measure relevant beam dynamical quantities and especially luminosity-related signals. We start by discussing the CLIC part of the project and address ILC in a later section.

We started by investigating the suitability of the ILC beam line optics for the post-collision line for CLIC, which proved not to be the case, because the momentum spread of the beam after colliding is extremely high due to the abundant emission of beamstrahlung photons. If there are quadrupoles in the post-collision line adapted for the main beam the low-energy tail of the beam is over-focused and lost downstream. This triggered an investigation into a very simple beam line design without any beam focusing elements. The design has to ensure safe propagation of the colliding beam with large momentum and angular spread to the beam dump, but also permit the beam to be disposed off in the case the beam are not colliding. To satisfy the constraint in the former case the beam line should be as short as possible. In the latter case the angular spread of the beam is small and the energy density on the dump window can become prohibitively high. This configuration favours a long post collision line to maximise the beam spot size on the dump window. A further difficulty stems from the fact that coherent electron-positron pairs are generated with energies peaking at about 10 % of the beam energy. Also these particles need to be disposed off in a coordinated way in order to prevent the generation of a background in the detector at the IP.

We have reconciled these conflicting constraints with a post-collision beam line design that is about 150 m long and consists mainly of a vertical dog-leg chicane which starts 20 m downstream of the IP and displaces the beam downwards by 11 cm. The chicane consists of a wide-aperture normal-conducting magnets of approximately 4 m length with a field of approximately 1 T. The chicane has the added benefit to separate the primary beam from the beamstrahlung photons by the 11 cm mentioned above. This permits using the beamstrahlung photons for diagnostic purposes in a beamstrahlung detector behind the beam dump that is sensitive to muon-pairs generated in the beam dump. Furthermore, the part of the coherent pairs with the opposite charge of the primary beam is deflected upwards in the first magnets of the chicane allowing them to be disposed of in a secondary beam dump and also being used for diagnostic means in a position sensitive detector which is possible due to the finite dispersion on the secondary beam dump. A fraction of the primary beam will be lost near the collimators that are interspersed with the chicane magnets. Instrumenting these collimators with e.g. embedded pin-diodes or scintillation counters will permit to detect whether the beams are in collision. Finally we have investigated the window at the end of the post-collision line which has to sustain the full load of the 14 MW beam power on top of being rather large. We found that a design similar to that of the LHC beam dump windows made of a sandwich of carbon composite and aluminium coating will be adequate.

We investigated the ILC extraction line with IP configurations with different crossing angles, emphasising aspects both of the beam line design and of detector and physics capabilities. The baseline configuration chosen for the ILC consists of a single IP with a crossing angle of 14 mrad. While this layout allows more convenient spent beam extraction and makes post-IP polarimetry and spectrometry easier, but adds complexity to the incoming beam dynamics and a dependence on an effective crab-crossing scheme to deliver the full luminosity. Two alternative designs with either head-on collisions or a very small crossing-angle of 2 mrad have been studied to mitigate these disadvantages. These designs trade off simpler pre-collision dynamics for increased extraction difficulty. Moreover, they allow better calorimetric coverage in the forward region of the detector and easier calibration procedures to monitor field distortions in its tracking volume.

Within the PCDL task we focused on establishing a credible and economical minimal design for the 2 mrad alternative scheme. After an initial attempt to mimic the baseline 14 mrad layout we developed an improved version which minimises the number of magnets and incorporates added flexibility. It does not include the energy and polarisation diagnostics without, however, precluding future upgrades with novel techniques. Using tracking studies of beam losses with high statistics evaluated under realistic conditions it was shown that acceptable power losses and magnet parameters could be obtained for the full range of specified ILC beam parameters. High-statistics tracking studies explored possibilities to infer transverse beam sizes and offsets at the IP for tuning purposes by measuring the spent beam tail profiles at well-chosen protection collimators using the detection of secondary emission currents from tungsten wires or titanium strips built in to the collimator. Furthermore, the higher-order chromatically-corrected final focus optics was successfully re-fitted to integrate the 2 mrad extraction line, including the effects of fringe field from a few closely located extraction line magnets.

In addition, we evaluated the rate of backscattered photons into the ILC detectors coming from beam losses along the extraction line and their contribution to background in the vertex detector. We performed benchmarking studies of different beam tracking codes and comparisons of beam losses in the earlier designs of the different extraction lines, contributed to the alternative head-on design in order to estimate power losses in the sensitive electrostatic separators and to evaluate the luminosity reduction from parasitic collisions, and studied a dedicated beam parameter and performance optimisation for the e^-e^- mode of operation.

HTGEN

Halo particles in linear colliders can result in significant losses, radiation and serious background which may reduce the overall performance of future linear colliders.

We studied halo sources and describe analytical estimates and detailed simulations. We assembled a comprehensive list of potential halo production processes. The list was presented and discussed at several conferences including the major accelerator conferences EPAC'06, PAC'07 and various EUROTeV meetings. The list and the analytical estimates can be considered now as a rather solid agreed basis for any further linear collider design studies. As a main deliverable of this EUROTeV task, we developed simulation codes for the dominant halo production processes and provide interfaces for tracking processes. The code is made available as the program package HTGEN on the web (http://hbu.home.cern.ch/hbu/HTGEN.html), together with detailed installation instructions and a user manual.

Together with the code, we also provide ready to use examples for halo and tail generation for the ILC and CLIC. Results of the ILC and CLIC simulations were presented at conferences and are described in our reports. Even under relative optimistic assumptions, we typically find that 10^{-4} to 10^{-5} of the beam particles will become halo particles and impact on the spoilers and collimators in the beam delivery system. At high energy, this will result in a non-negligible flux of secondary muons, many of which will reach the detectors and be visible as machine induced detector background.

The simulations have also shown, that a good vacuum quality, particularly at the lower energy end of linear accelerators, will be important to minimise the halo production.

An overview of the work with the a description of the main scientific results and detailed references has been presented as EUROTeV-Report-2008-076.

BBSIM

The aim of the task has been to benchmark the beam-beam simulation code GUINEA-PIG and to improve it by adding polarisation. GUINEA-PIG is a dedicated code to simulate the beam-beam interaction at the collision point of linear colliders. Due to the very high density of each beam at collision they produce a very strong electro-magnetic field. The field of each beam exerts a force on the incoming beam that is strong enough to modify the particle trajectory significantly during the collision. The resulting bending of the particle trajectories leads to the emission of beamstrahlung, a radiation similar to synchrotron radiation produced in a magnetic field. As a consequence the colliding particles loose energy, which leads to the development of a luminosity spectrum. The beamstrahlung also leads to the generation of electron-positron pairs and hadrons, both of which contribute to the detector background. All of these processes are included in GUINEA-PIG.

The code has been compared to CAIN, the other widely used beam-beam simulation code. Good agreement has been found in the results, with the exception of the number of pairs with large angles produced in the collision for which a substantial difference has been discovered. These pairs are an important source of background in the vertex detector and give a lower limit to the radius of its innermost layer. For one of the pair production processes the beam-beam simulations have been compared to BFKL, a physics code that simulates pair production. Good agreement has been found with GUINEA-PIG confirming the model implemented in this code.

The energy loss of the beam particles during collision leads to the development of a luminosity spectrum. For the physics experiments it is of critical importance to correctly reconstruct this spectrum. A proposed method reconstructs the spectrum by measuring the angles of Bhabha events. However, these angles are impacted by the strong beam fields. GUINEA-PIG has been extended to simulate this effect. It has been shown that this leads to very important correction of the luminosity spectrum and that further study is required.

Finally, GUINEA-PIG has been translated from C into C++ and renamed GUINEA-PIG++. The code has been extended to include polarisation of the beam particles and to track the evolution of the spin during the collision.

4.3.6 METROLOGOGY AND STABILITY

The goals of the Work Package WP7 were:

- Develop and build a prototype of a laser-based system capable of rapidly and accurately surveying 10-20 km of accelerator (LICAS).
- Evaluation of mechanical stabilisation technologies for use in critical areas of the ILC; address specifically commercially available inertial devices, and laser-based feedback systems.
- Measure, catalogue and characterise ground motion spectra at various test facilities and potential collider sites around the world; implementation of a public central database server for storing the results.

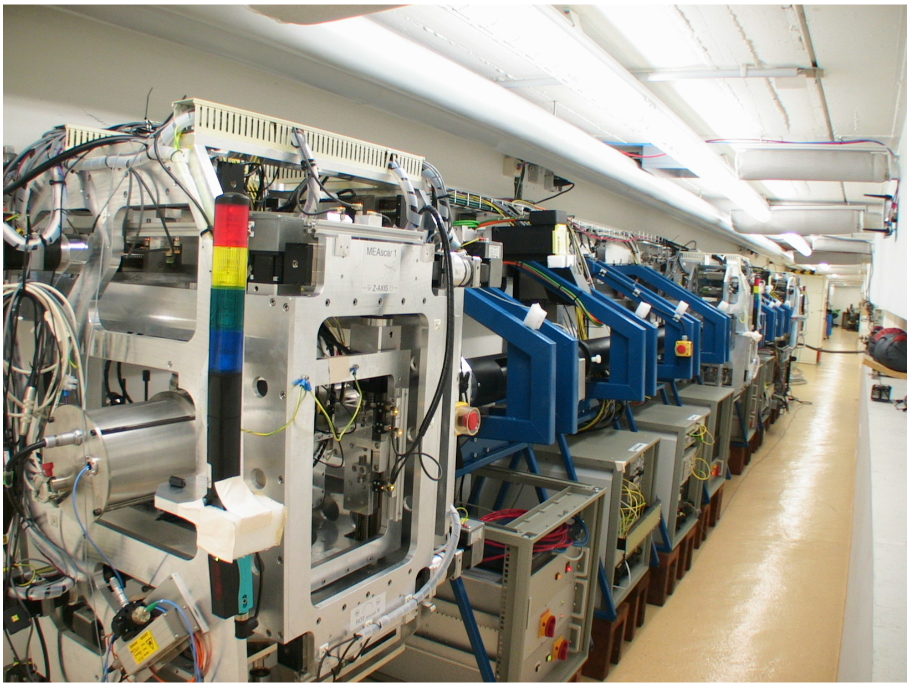

Figure: The RTRS prototype

RTRS: Rapid Tunnel Reference Surveyor

The primary aim of this task was to develop a method for surveying a network of reference markers in the tunnel of the ILC main linac. This method should be accurate enough to allow beam-based alignment to proceed successfully with the goal to reduce emittance growth in the main linac to below 10 nm rad. The method should provide in-situ calibration with sufficient resolution to verify, on-line the status of calibrations. The implicit goal was to carry out the survey faster than conventional techniques so as to reduce downtime and its associated costs. It should also be less labour intensive and thus more cost effective than conventional techniques. Moreover it should not rely on a fixed installation throughout the entire tunnel. A secondary aim was to simulate the increase of emittance in the ILC main linac due to realistic machine misalignments.

In the course of the studies it turned out that the largest problems for the accuracy of the RTRS are the systematic errors resulting from miscalibration. Such systematic errors show up as a residual curvature in a network that has been measured as straight. The ability to accurately calibrate the RTRS is therefore crucial. The accuracy of the calibration, given a correct and complete numerical model of the measurement processes, is limited by either the resolution or stability of the sensing elements, whichever is worse. The stability and resolution of the existing RTRS sensors is sufficient.

Simulations indicate that the systematic errors can be reduced by increasing the inter-car separation. At an inter-car separation of 25 m, a 4-car RTRS with calibration accuracy of 5 µm (5 µrad) results in systematic errors better than the specification of 200 µm over a 600 m segment. The analysis of calibration data and simulations indicate that this level of accuracy is achievable. A final comparison of the tunnel surveys performed with the fully calibrated RTRS prototype with a conventional survey is still outstanding. It is expected to be completed in 2009. In its current form the RTRS survey process is approximately two to three times faster than a conventional survey with a team of two surveyors. It is also largely automated and can be remotely controlled.

It was important to improve the method by which the survey accuracy is specified beyond the simple statement of a tolerance over a fixed distance. A beam dynamics simulation helped to understand the emittance growth in a linac following the survey process. It could be shown that the conventional open air survey methods in conjunction with highly accurate GPS measurements led to unacceptable emittance growth in the main linac, even when optimistic assumptions for accuracy were made and systematic errors from temperature gradient driven refraction in air were ignored. Using similar simulations it could be shown that the RTRS can achieve the desired accuracy. These tools have been made available to the beam dynamics simulation community. Work on the reconstruction of full RTRS style surveys through the entire ILC tunnel and in the presence of GPS information is computationally very challenging and still under development.

It thus became clear that the RTRS is a useful instrument for ILC survey. As a result of the studies it is also clear that several improvements can be suggested and should be incorporated. The inter-car spacing should be increased to 25 m to reduce systematic errors. For measurement redundancy there should be preferably 5 cars. The position of the sensing element (CCD and FSI position and angles) on each car should avoid symmetries that lead to ambiguous results. The 6 D motion system should be replaced by hexapods to simplify the mechanical system and improve access. In addition several improvements on the optical system and the CCD should be envisaged.

MSTBT: Mechanical Stabilisation Technology

Future linear colliders with high luminosity will have vertical beam sizes in the nm range. The relative motion between the last two focusing magnets, the final doublets, should not exceed a third of the beam size above 4 Hz. Unfortunately, major vibration sources like ground motion and acoustic noise can induce displacements of a few nanometres above 4 Hz. Thus, an active stabilisation of the final doublets must be carried out, particularly at their resonance frequencies. To operate such a system, one needs to assess the possibility of measuring in the nanometre range, find suitable actuators, analyse the vibration behaviour of the final doublet, and use numerical simulations to develop the active feedback. The derived active feedback system has been tested on a realistic prototype of a final doublet. Analysis tools for the optimisation of the signal have been tested and parameters have resulted (frequency resolution, windowing, spectral density, root mean square, transfer function, relative motion). The sensor requirements have been studied: resolution, small weight and size, in the frequency range 0.01 Hz to 2 kHz and magnetic and radiation environment. Sensors used in the seismic domain fulfil the specifications adequately. Accelerometers and geophones have been thoroughly tested and assessed. PMD molecular sensors developed especially for the harsh environment of accelerators seem a robust choice. Actuators have also been studied (CEDRAT APA). Acquisition systems have been tested for the feedback loop and for precision vibration measurements. Instrumental noise definition has been assessed (spectral difference, corrected difference). The requirements for adequate instrumentation and acquisition systems for the nanometre level measurements are thus well understood.

To test the different developments in terms of active stabilisation, several prototypes were built: The prototype used for this experiment is a 2.5 m long steel beam in cantilever mode, respecting the elementary parameters planned for the final doublet. Furthermore, the eigenfrequencies of this linear structure are included in the desired range. The prototype allowed for a modal analysis and e.g. an assessment of the acoustic noise at high frequencies. It turns out that acoustic noise at high frequency (above 300 Hz) can have non-negligible effects and induce vibrations on the structure. The accelerator environment has to be designed to minimise acoustic perturbations. It could also be shown that with a commercial isolation system and the feedback developed within EUROTeV, the r.m.s. -vibration was reduced to 0.13 nm at 4 Hz from an initial rms of 5 nm.

The design of the active stabilisation feedback loop within EUROTeV included numerical simulations to obtain a state-space model of the structure to control. Matlab/Simulink was used to derive the dynamic response of this structure under predefined loads. Finite element modelling is of prime importance to show that the results are indeed representative. Experimental vibration measurements are required to measure the different eigenfrequencies and their corresponding mode shapes, and to understand the level of damping. Several feedback algorithms were developed. The originality of the first approach is to consider only the measurable behaviour of the system instead of considering a fine model representative of the system. This algorithm is based on a state space representation and is dedicated to lumped perturbation. One can state that this algorithm is able to reject narrow peaks at a nanometre scale. However, for the eigenfrequencies, this method is quite limited, because working at a given frequency does not allow treating a bandwidth. Considering these remarks, a second algorithm was developed. The dynamic response was studied together with Simulink for feedback development. By correctly initialising the different matrices of the State-Space model in Simulink it is possible to describe the dynamic response of the structure under prescribed acceleration. To verify this approach the Final Focus FF (QD0 and other magnets) support (although rigid) for the Accelerator Test Facility in Japan was examined and included ATF2 noise measurement, simulation, floor attachment, relative motion. A second prototype for the study of vibration isolation was begun and the feedback studies for active compensation with multi-actuator/multi-sensor system were continued.

StaFF: Stabilisation of Final Focus

The stabilisation requirements for the Final Focus system of the ILC require sensors to monitor the motion of these components with respect to each other. Networks of multiple laser interferometers were used. Such a system is able to monitor over a large variety of time scales covering ranges of micro-seconds to hours. It provides nanometre-level resolutions over metre distances. It scales favourably in price for large number of measurements. It allows for absolute distance measurements, albeit with a slightly reduced resolution.

The StaFF group produced a prototype that has demonstrated these features and the details are well documented.

Simulations have shown that, if it is possible to achieve nanometre-level resolutions in the relevant single interferometers it will be possible to use a multi-lateration-network of multiple interferometers to determine the position of two objects with respect to each other. A small, cheap interferometer system for demonstration was thus constructed. The StaFF prototype comprised a compact interferometer launch head which was to be mechanically stable, but still adjustable for focus, pointing and coupling efficiency. The amplifier and ADC systems developed by LiCAS to suit fixed frequency interferometry (FFI) had to be adapted. The custom-built electronics guaranties optimal cost scalability for large systems.

The simulations and prototype set up in 2D allow to study how to combine single interferometers into a multilateration network. Detailed studies have been done to prepare a set-up at ATF2 to measure the relative motion between the QD0 and the Shintake monitor, which measures the beam spot size of ATF2. The system will be implemented in 2009 and will allow corrections for relative motions, for up to several minutes.

A simulation to monitor the QD0s on both sides of the IP in case of the ILC has been developed. We developed a simulation to establish possible resolutions and established conceptually how to implement such a network into the ILC detectors.

PGMS: Precision Ground Motion Spectra

The ground vibrations measurement database of DESY is unique and first of its kind as it contains data of 20 sites around the world including both, high energy laboratory sites and synchrotron radiation facilities. The measurements for this database were performed from 2003 to 2006 and are therefore, recent. The superconducting modules (cryomodules) vibration data have been collected since 2006 and currently comprise of data on mechanical stability of Type II and III cryomodules, at room temperature. As the data volume increased to a few TB, it was decided to make this data accessible to the worldwide scientific community via the internet.

The version of the homepage described here has been redesigned using ZMS which is an open source ZOPE-based Content Management System for science, technology and engineering, using the DESY design templates to comply with corporate identity policies. ZOPE stands for “Z Object Publishing Environment”. This homepage uses the Andrew File System (AFS) to store the entire database. In this way, it acts as a data backup tool. In addition, it assures ease of navigation and data retrieval through its tree structure since by utilising the homepage http://vibration.desy.de users do not need to login to the DESY AFS network.

This distribution is done by grouping files and folders into volumes (in this case ~ 8 GB per volume). These volumes are objects containing folders, files and mount points (links to other volumes), to create another layer between the visible path and the physical position of the data on the servers. The advantage of this system is that volumes can be moved to other machines and discs, while they are being used. Administrators and Information Technology (IT) personnel can work in the background to maintain the machines at peek efficiency and exchange faulty hard disc drives without any performance loss.

The *Sites Measured* section displays the names of all the sites measured in alphabetical order. Cryomodule vibration data are included as one of the items in this menu. In the case of ground vibration measurements for a site, a short description of the *cultural noise* situation of a site is followed by a detailed description of the sensor position for each measurement. Moreover, maximum and minimum levels of ‘cultural noise’ for each given site are selected from the data set and can also be downloaded. For the cryomodule vibration data, a detailed description of the sensor positions, dates of the measurements and photographs of the sensor positions are provided.

Change of emphasis following the changes of International Context

- PGMS: In the original UK LC-ABD simulation task, it was proposed to do ground motion modelling for the linear collider, which was shown as contribution to the EUROTeV WP7 and no EU resources were requested for this task. The LC-ABD project started in April 2004 before the linac technology decision was announced (August 2004). The discussion to form an International collaboration on ATF2 project at KEK started during the first international linear collider workshop at KEK, November 2004. The ground motion modelling task was not continued due to the request to study tolerances and to develop tuning procedures for ATF2, which was thought to be more urgent by the international collaboration developing the ATF2 proposal. STFC is continuing on developing different tuning procedures to address the challenging tuning requirements to achieve around 35 nm beam spot size at the ATF2, which has started commissioning early 2009.
- RTRS: The 5-car prototype of the RTRS (Rapid Tunnel Reference Surveyor) was intended to be used for long distance survey in the tunnels of the European XFEL project. Its design and construction would only be possible and useful if the UK program for ILC survey had continued into the period where the XFEL tunnels were complete. Due to circumstances beyond our control the UK program was terminated prematurely and the LiCAS program had to ramp down rapidly. This was announced in December 2007. The group has adapted to the new circumstances and the reduced resources by focussing the efforts on a more complete program of work with the 3-car prototype and more simulations of the performance of other RTRS configurations. The studies have shown that a 4-car RTRS with 25 m car separation would be sufficient as the sole instrument for the survey of the ILC reference network. With the use of a high precision surface network monitored by GPS one can expect to relax the specifications even further.

4.3.7 GLOBAL ACCELERATOR NETWORK – MOBILE VIRTUAL LABORATORY

The goals of Work Package WP8 were

- Evaluation of human needs to support the concept of remote operation.
- Produce a "collaboration tool" (Multipurpose-Virtual-Laboratory, MVL) as test bed for in-field evaluation of remote operation.

ODI: Overall Design and Integration

The task ‘Overall Design and Integration’ coordinated the work of all tasks aiming for an overall design of the tools to fulfil the needs of the community. At the first place a user survey had been performed and analysed. As a result a requirements document and the overall design of the mobile virtual laboratory has been worked out and a work plan had been produced.

An example the ranking of possible users for the activities ‘commissioning of equipment’ and ‘trouble shooting on accelerator components’ to be supported by the mobile virtual laboratory is shown in the figure.

Figure: User ranking of remote activities

The work in the different tasks were monitored and coordinated by regular phone meetings and annual workshops organised. At these workshops integration tests and design evaluations had been performed and as a result the work plan had been adapted.

SC: System Components

The task 'System Components' provided and integrated the software components of the GANMVL tool. In particular the GANMVL lab server and the client components were implemented using secure tunnelling based on the grisphere environment. Laboratory servers have been installed at DESY, at Elettra and Milano. At Elettra the GANMVL version 2.2 is used as production release for the machine operation since 2007.

The client components include audio and video tools for the communication of the remote users with the local operators. For this purpose EVO as well as Skype were integrated. For low resolution (MPEG3) and high resolution (MPEG4) video streaming various open source codecs were integrated into GANVML.

To allow remote operation remote desktops based on VNC, NX, a http wizard as well as generic virtual instruments based on the IVI standards were implemented.

The figure shows the GANMVL software at work with the portal connected to the laboratory server at Elettra on the left and the video streaming window on the right bottom.

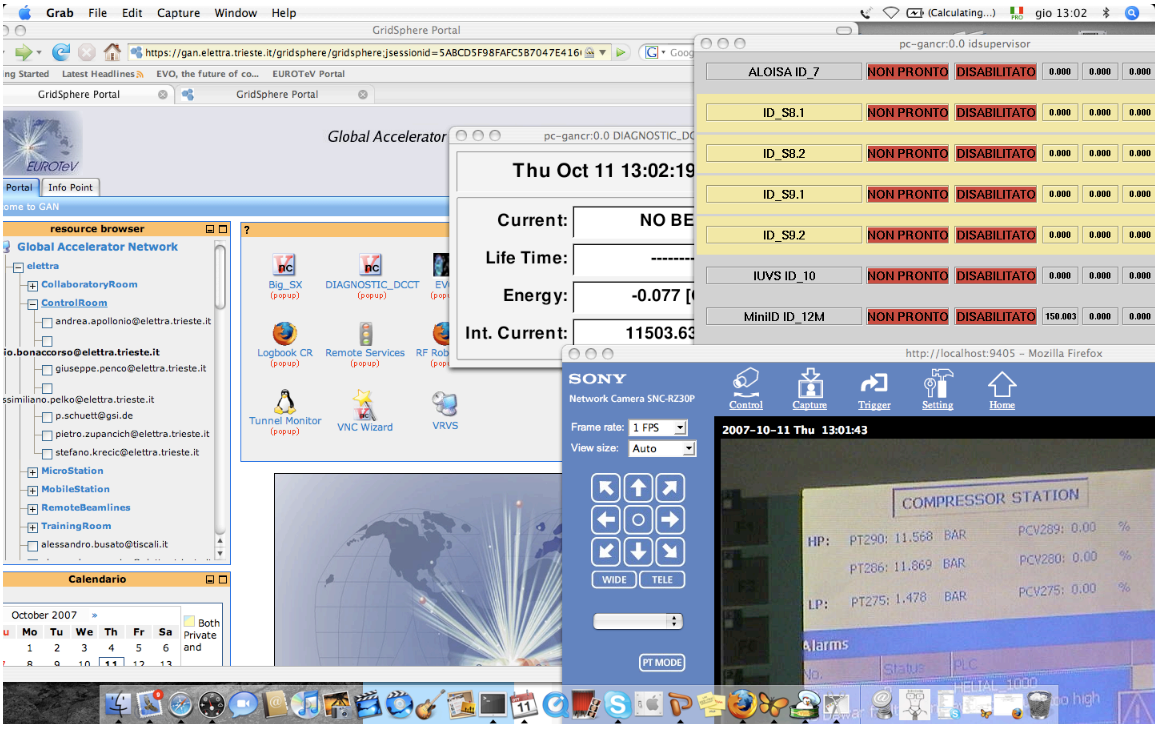

Figure: GANMVL at work

A Help System for the GANMVL has been designed to be both an effective support for users of the distributed and collaborative environment and a complete reference and documentation repository for GANMVL administrators and developers. The Help System is available on the public section of the GANMVL website. The wiki-like interface allows registered GANMVL users to easily complete and extend the Help System by editing and/or adding new pages or topics.

Network monitoring tools based on MonALISA were implemented and tested in the GANMVL framework. Servers have been installed in Trieste and Milano and the LISA client has been tested. A MonALISA repository specific for GANMVL was set up.

A Hi-Res video transmission was tested but could not be implemented in a stable version until the end of this project.

ME: Mechanical and Electrical Design

This task consisted of integrating the functionality of the mobile virtual laboratory in a compact and transportable hardware set up and proving special hardware for capturing audio and video from a location of the accelerator systems, supporting video conferences between local and remote experts, supporting the connection of apparatus and devices for virtual instruments services and transmitting data from optical systems.

Three hardware set-ups of the mobile and semi-mobile stations have been followed and the final set-ups have been tested at DESY. For the semi-mobile station the hardware assembly and the implementation of the virtual instrument server package has been successfully tested at DESY. The figure shows the fully equipped semi-mobile station. The devices are ready for field tests in other laboratories.

Figure: Hardware of the semi-mobile station

DGF: Demonstration of GAN and far remote operating

In addition to the evaluation of specific parts of GANMVL in various workshops the two main prototype versions of the GANMVL server client software were implemented on the participating laboratories and an evaluation with specific test scenarios were done.

For the evaluation test and training scenarios were designed specific to the activities in the laboratories and laboratory studies were carried out. Common evaluation questionnaires were developed and used to retrieve the feedback from the evaluation. In addition the test sessions were analysed by an experimenter to identify additional problems and to ensure successful completion of the tasks. Finally a report has been written on the outcome of the usability review regarding the GANMVL.

The figure shows the user rating on general aspects for the final version 2.2 of the GANMVL.

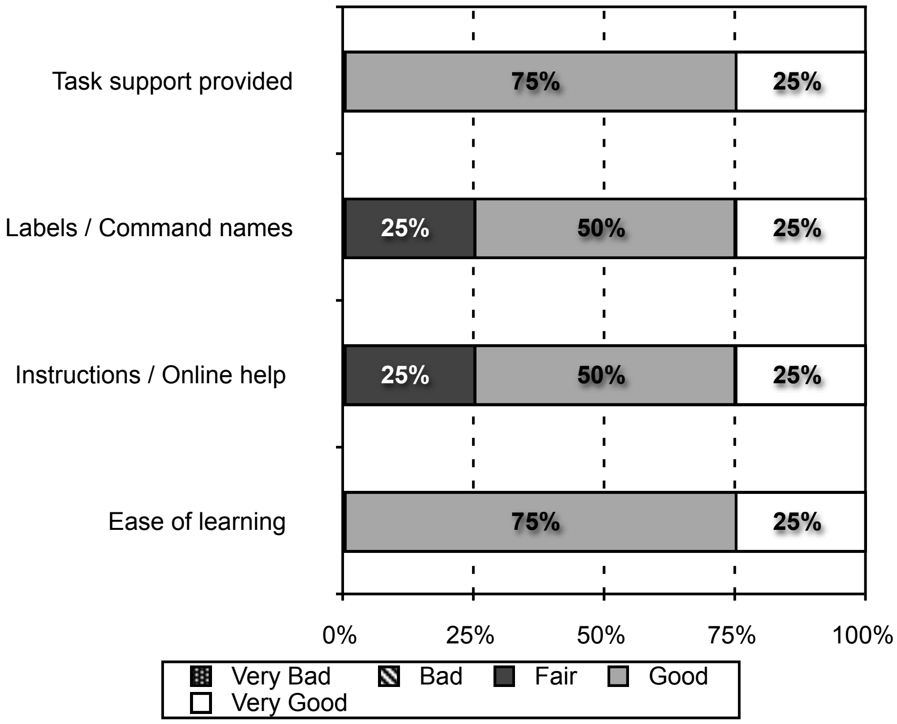

Figure: User ranking of the GANMVL aspects

5 DISSEMINATION AND USE

All results of EUROTeV are publicly available from the web-page www.eurotev.org.

The most relevant achievement is the European Contribution to the Reference Design Report for the ILC available from http://www.linearcollider.org/cms/?pid=1000437. This report is the basis for further design specification of the Linear e^+e^- Collider based on superconducting technology.

At the same time EUROTeV enabled significant progress in the studies for the CLIC, the two-beam acceleration proposal based on X-band technology. The CLIC collaboration aims to produce a conceptual design report for the machine by 2010. Many of the studies of EUROTeV will contribute to that report.

The ILC will be built by an international collaboration. It will be hosted in one of the regions Asia, Europe or Americas. The other regions will contribute to its design, construction and operation.