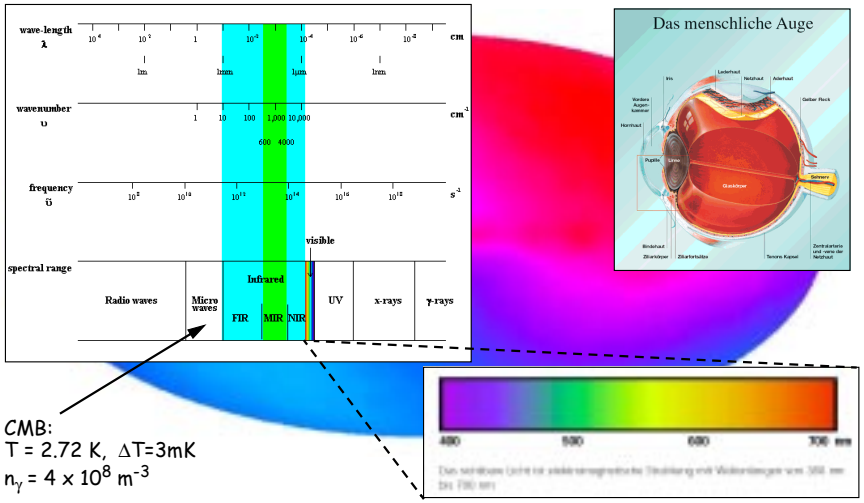
Detectors for Particle Physics

DESY Summer Student Lectures

2006

Carsten Niebuhr

Introduction



Literature

Textbooks:

K.Kleinknecht: *Detectors for Particle Radiation*
Cambridge University Press, 1998

W.R. Leo: *Techniques for Nuclear and Particle Physics Experiments*
Springer 1994

G.F.Knoll: *Radiation Detection and Measurement*
Wiley, 3rd edition

D.Green: *The Physics of Particle Detectors*
Cambridge University Press, 2000

C.Grupen: *Particle Detectors*
Cambridge University Press, 1996

W.Blum, L.Rolandi: *Particle Detection with Driftchambers*
Springer, 1994

Overview articles:

T.Ferbel: *Experimental Techniques in High Energy Physics*
Addison-Wesley 1987

Other sources:

Particle Data Group: *Review of Particle Physics*
Eur. Phys. J. C15, 1-878 (2000)

R.K.Bock, A.Vasilescu: *The Particle Detector BriefBook*
Springer, 1998 and //physics.web.cern.ch/Physics/ParticleDetector/BriefBook/

Further Sources on the Web

DETECTOR PHYSICS and APPLICATIONS CENTER - DePAC

http://besch2.physik.uni-siegen.de/~depac/DePAC/DePAC_main/DePAC_main_tutorials.html

CERN Summer Student Lecture Programme 2005

http://ph-dep-dt2.web.cern.ch/ph-dep-dt2/lectures_PD_2005.htm

Lecture Notes by Helmuth Spieler

http://www-physics.lbl.gov/~spieler/

Vorlesungsskripte D.Wegener Dortmund (in german)

http://www.physik.uni-dortmund.de/e5/

Transperancies of Detector Lecture C.N. (in german)

http://www.desy.de/~niebuhr/Vorlesung/Detektor/vorlesung.html

Transperancies of Detector Lecture Robert Klanner / Ralf Röhlsberger

http://adweb.desy.de/~klanner/Lehre/DetektorVorlesung/Overview.html

Topics of the Lecture

Part I

- Introduction
- Examples
- General Concepts
- Interaction of Charged Particles with Matter
  - Energy Loss: Bethe Bloch Formula
  - Multiple Scattering

Part II

- Use of Track Detectors for Momentum Measure-ment
- Gas Detectors
  - Proportional Chamber
  - Drift Chamber
  - TPC
  - MSGC, GEM
- Silicon Detectors
  - Strip Detectors
  - Pixel Detectors

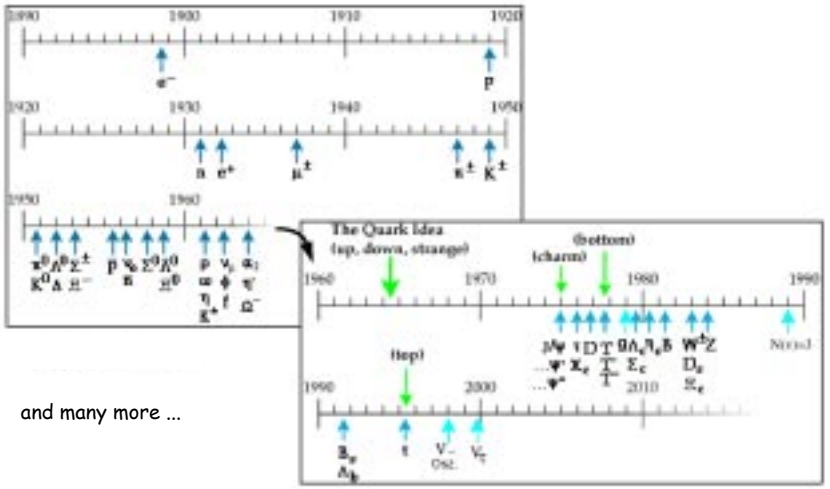
Part III

- Scintillation Counters
- Photodetectors
- Cherenkov Counters
- Transition Radiation
- Calorimeters
  - Shower Development
  - electromagnetic
  - hadronic

Common Lecture by Robert Klanner
Friday, Aug 11th, Sem 4

- not covered
  - Trigger
  - DAQ

What are the Objects ?

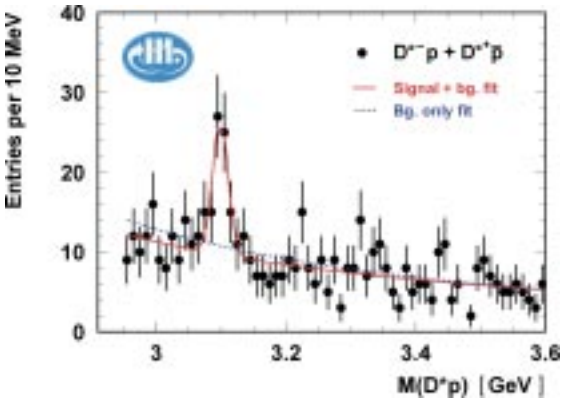


and many more ...

Fundamental Interactions

	Strong force	Electro-weak force		Gravity
Forces	Strong force	Electro-magnetic force	Weak force	Gravity
Exchanged particles	Gluon	Photon	W,Z bosons	Graviton
Magnitude	1	0.01	10^{-5}	10^{-40}
	Nuclei Hadron Nuclear fusion Solar energy	Molecule, Atom Electronics Synchrotron rad. Aurora	Neutron decay Nuclei decay Neutrino Geothermy	Gravitation Galaxy Black Hole Stellar Pinwheel
Example	$\rho^0 \to \pi^+\pi^-$	$\pi^0 \to \gamma\gamma$	$K^0 \to \pi^+\pi^-$	
Lifetime [s]	$\approx 10^{-24}$	$\approx 10^{-16}$	$\approx 10^{-10}$	
$c\tau$ [mm]	$\approx 3\times10^{-13}$	$\approx 3\times10^{-5}$	≈ 30	

Example for a Resonance observed at HERA



Pentaquark Candidate:

$\theta^0_c \to D^{*-} p \to K^- \pi^+ \pi^- p$

minimal quark content: $uudd\bar{c}$

sofar only seen by H1 ...

- real signal ??
- statistically fluctuation ??
- detector effect ??
- need very good under-standing of detector response
  - significance of signal S/B
  - resolution
  - efficiency / acceptance

Detection of Particles and Radiation

The goal of experimental particle physics: measurement of

- particle properties
- reaction probabilities (→ cross sections)

This requires determination of:

- particle type (mass, charge, spin etc)
- momentum / energy of particle
- emission angles

Elements contributing to such measurements :

- position sensitive detectors → position, direction
- deflection in magnetic field → $|\vec{p}|$
- calorimetry: total energy absorption and measurement → E_{tot}
- mass determination → m
- Cherenkov radiation or time of flight → β
- transition radiation → γ

Criteria for Ideal Detector

Because in general there can be very complex event topologies one often aims at

reconstruction of full event kinematics (background rejection)

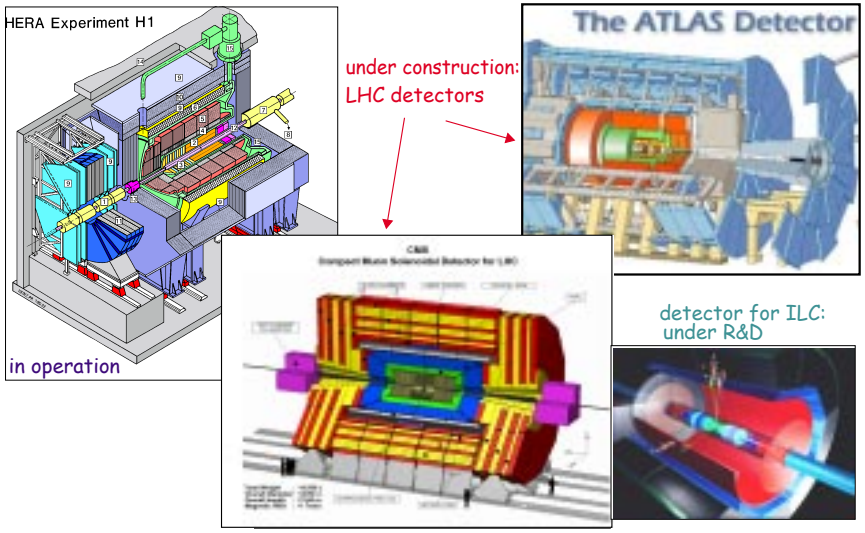
Most important:

- high efficiency
- high resolution
- high acceptance → try to cover full solid angle (4π)

also very important (partly conflicting demands):

- particle identification capability
- fast response
- high rate capability
- small dead time
- hermeticity
- longevity of detector components
- high reliability
- good accessibility (for repairs)
- low cost

Modern Collider Detectors



Some Particle Physics Experiments

Besides the large collider detectors there are many other expts: www.hep.net/experiments/all_sites.html

Bates Linear Accelerator (MIT)
BLAST , OOPS , SAMPLE

Beijing IHEP
ARGO-YBJ , BES , Tibet ASgamma

Brookhaven
BRAHMS , Crystal Ball (E913/914) , E787 , E821/muon g-2 , E850 , E852 , E863/ EMU01 , E864 , E865 , E869 , E877 , E881 , E885 , E890 , E891 , E895 , E905 , E906 , E907 , E909 , E910 , E913/914 (Crystal Ball) , E917 , E923 , E926 , E927 , E949, E953 , EIC , EMU01/E863 , High Gain Harmonic Generation FEL , ICAE , IFEL , IMB , LEGS , MECO , Microundulator FEL , NuMass/E952 , PHENIX , PHOBOS , pp2pp , Smith-Purcell , STAR , Zero Degree Calorimeter

CERN
ALEPH , ALICE , AMS , ANTARES , ASACUSA , ATHENA , Atlas (European) , ATRAP , CDHS neutrino experiment/WA1 , CERES/NA45 , CHORUS , CMS , CosmoLEP , CPLEAR/PS195 , Crystal Barrel/PS 197 , Crystal Clear/RD18 , DELPHI , EMU01 , FELIX , HARP , ICANOE , ISOLDE , L3 , LHC-B , MISTRAL , NTOF1, NTOF2, NTOF3 , NA45.2/IONS/EL.PAR , NA47/SMC , NA48, NA48.1, NA48.2 , NA49 , NA50 , NA51 , NA52/ Newmass , NA56/SPY , NA57 , NA58/COMPASS , NA59 , NA60 , NOMAD , OBELIX/PS201 , OPAL , OPERA , PAMELA , PS185 , PS205/HELIUMTRAP , PS210 , PS212/DIRAC , PS214/HARP , RD8 , RD11 , RD12/TTC , RD13 , RD27 , RD39/SMSD , RD41/ MOOSE , RD42 , RD44/Geant 4 , RD45 , RD46 , RD48/ ROSE , RD49/RADTOL , TOSCA , TOTEM , WA85 , WA92 (Beatrice) , WA94 , WA97 , WA98 , WA102

DESY
H1 , HERA-B , Hermes , TESLA , ZEUS

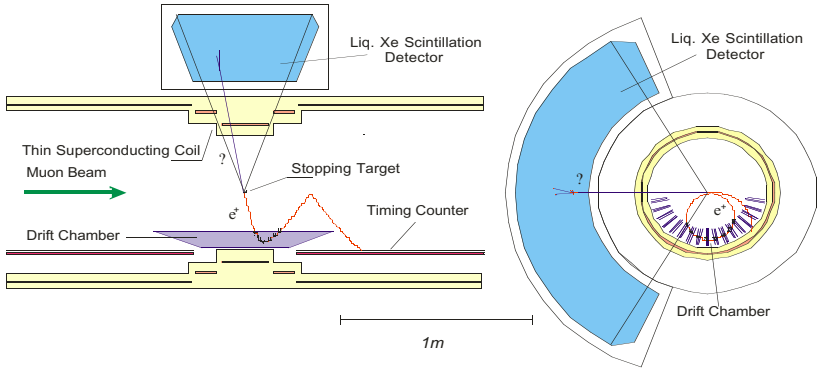
Fermilab
Antihydrogen/E862 , APEX/E868 , Auger Project , BooNE/E898 , BTEV/C0 , CDF/E830 , CDMS/E981 , CEX/E853 , Charmonium/E835 , CMS (US Server) , COSMOS/E803 , D0 (DZero)/E823 , Donut/E872 , E665 , E771 , E789 , Fermi III Project , FOCUS/E831 , HyperCP/E871 , KTEV/E799/E832 , MINOS/E875 , NuMI , NUSEA/E866 , NuTeV/E815 , SDSS , SELEX/ E781 , Zero Degrees/C0

Gran Sasso
BOREXino , CRESST , CUORICINO , DAMA , EASTOP, GALLEX(finished) , GENIUS , GNO , Heidelberg Dark Matter Search (HDMS) , Heidelberg-Moscow Experiment , ICARUS , LUNA , LVD , MACRO , MONOLITH , NOE , OPERA , USA

Search for Rare/Forbidden Decays

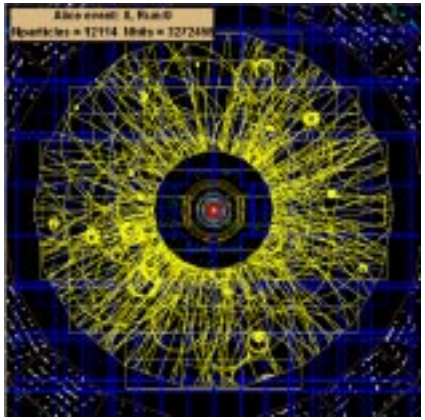
Experiment in preparation at Paul Scherrer Institut (PSI, Switzerland):

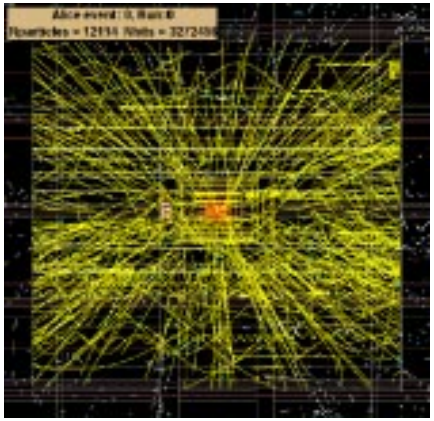
- search for lepton-number violating process: $\mu \rightarrow e\,\gamma$ sensitivity goal: 10^{-13} !
- needs excellent energy resolution, high event rate, but small track multiplicity per event
- start full data taking in 2007



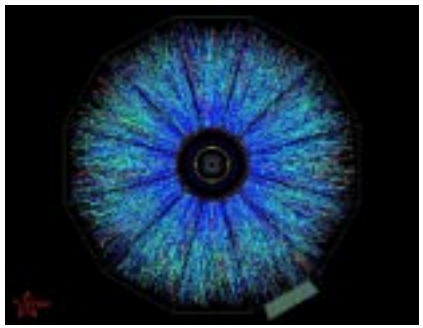
ALICE at LHC

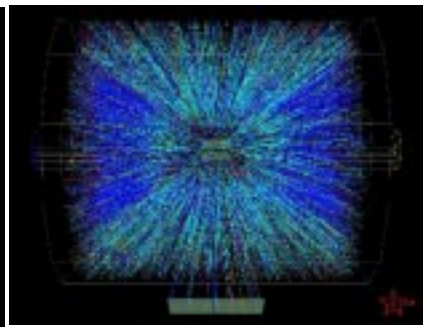
Heavy Ion Physics: this simulation shows 1/10 of all 10000-20000 expected tracks in a typical event. The separation of all these tracks puts very high demands on the position resolution and double hit seperation of the device.





Real Event in STAR at RHIC



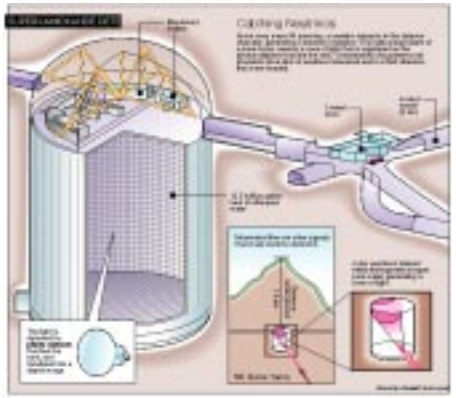


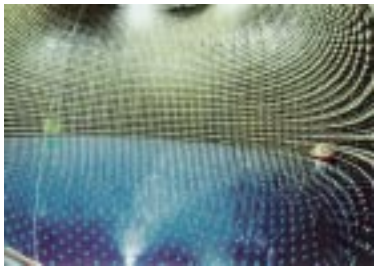
≈ 2000 tracks per event

Super-Kamiokande (Japan)

Search for proton-decay and for neutrino oscillations

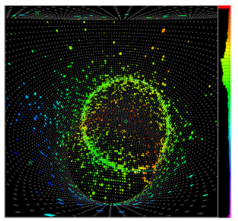
- 50000 tons of water
- 12000 photo tubes





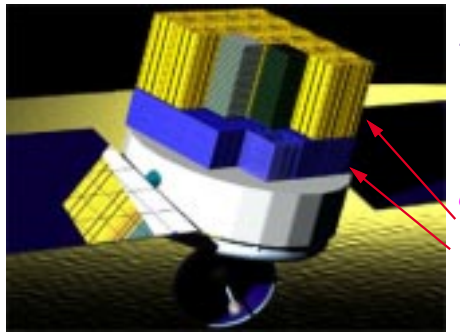
Reactions :

- $\nu_\mu N \rightarrow \mu N$ → Cherenkov
- $\nu_e N \rightarrow eN$ → shower



Satellite based Detectors

Liftoff scheduled for August 2007



GLAST Gamma-Ray observatory for high energy photons in the range 20MeV to >300 GeV

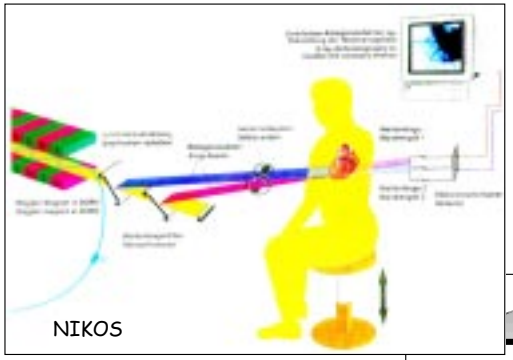
Astro particle physics

- history of star formation
- acceleration mechanism of AGN's
- sources of gamma ray bursts
- nature of dark matter

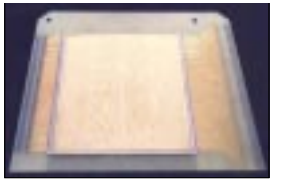
Components (need highest reliability !)

- precision tracker (Si-strips)
- calorimeter (CsI(Tl))
- data acquisition system
- anticoincidence detector

Applications in Medicine

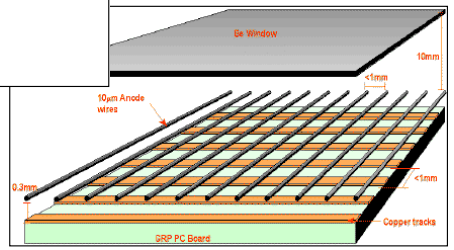


Non-invasive Koronary Angiography using synchrotron radiation



Imaging microgap detector:

Photon rates ≈ 10^6 mm^{-2} s^{-1}



Interplay between Physics and Technology

Almost all effects used in particle detectors are based on the electromagnetic interaction only. Most modern detectors convert the absorbed energy into an electrical signal.

The detection sensitivity and detector performance depends on

- statistical processes in the detector
- fluctuations in the electronics

To maximize detection sensitivity and resolution one must consider and optimize

- signal formation in the detector
- coupling of the detector to the readout electronics
- noise generated in the electronics

Understanding of e.g. a modern tracking detector in high-energy physics or a medical imaging system thus requires knowledge of

- solid state physics
- semiconductor device physics
- semiconductor fabrication technology
- low-noise electronics techniques
- analog and digital microelectronics
- high-speed data transmission
- computer-based data acquisition systems

Interaction of Radiation with Matter

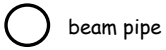
Charged Particles	Neutral Particles
heavy charged particles	neutrons
electrons	gamma radiation
	neutrinos

Coulomb-Interaction with electrons of medium → electrical signal in detector

Mainly "singular" interactions, resulting in energy transfer to charged particles

Cross Section of Typical Collider Detector

Particle type:
- neutrinos (missing energy)
- muons μ
- hadrons: p, π, K ...
  [quarks, gluons → jets]
- electrons, photons
- charged particles



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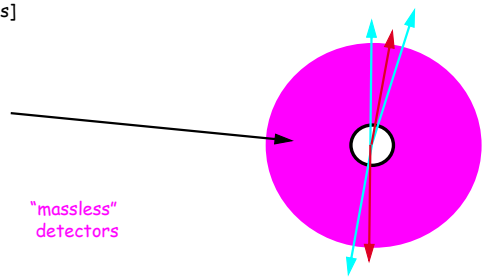
Rough classification
- track detectors for charged particles:
  - gas detectors
  - solid state detectors

"massless" detectors



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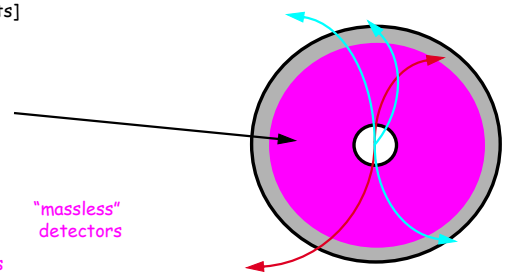

magnet coil
(solenoid, field || beam axis)

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- electrons, photons
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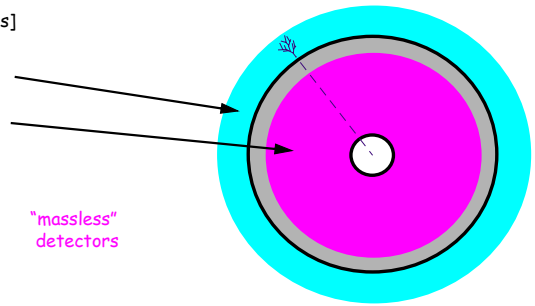
Rough classification
- track detectors for charged particles:
  - gas detectors
  - solid state detectors
- calorimeter for energy measurement
  - electromagnetic
  - hadronic

"massless" detectors



magnet coil
(solenoid, field || beam axis)

high Z material (Pb)