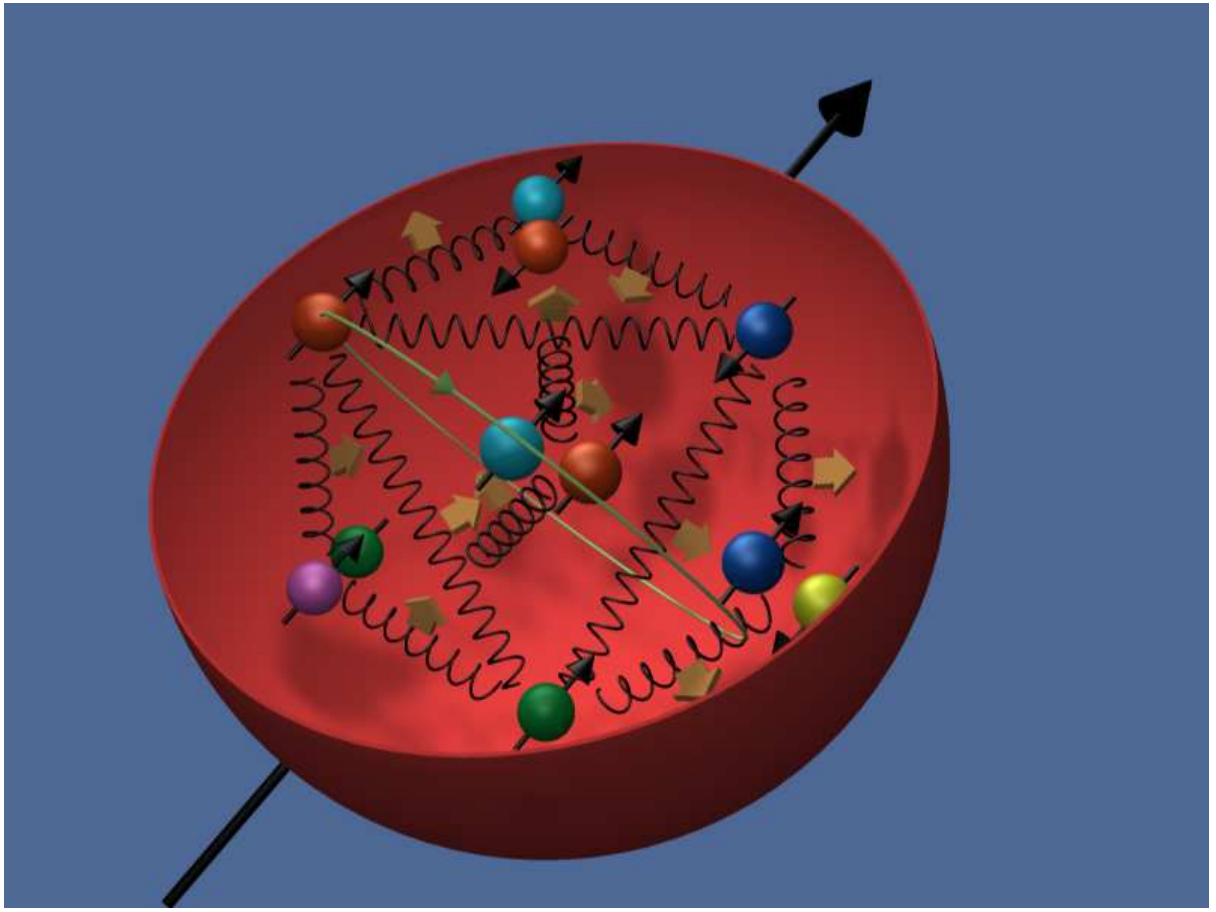
The HERMES Recoil Detector

R. Kaiser
University of Glasgow

21. March 2005

- HERMES and the Spin of the Nucleon
- Generalised Parton Distributions
- Recoil Detector Design and Performance
- Projected Physics Results

The Spin of the Nucleon



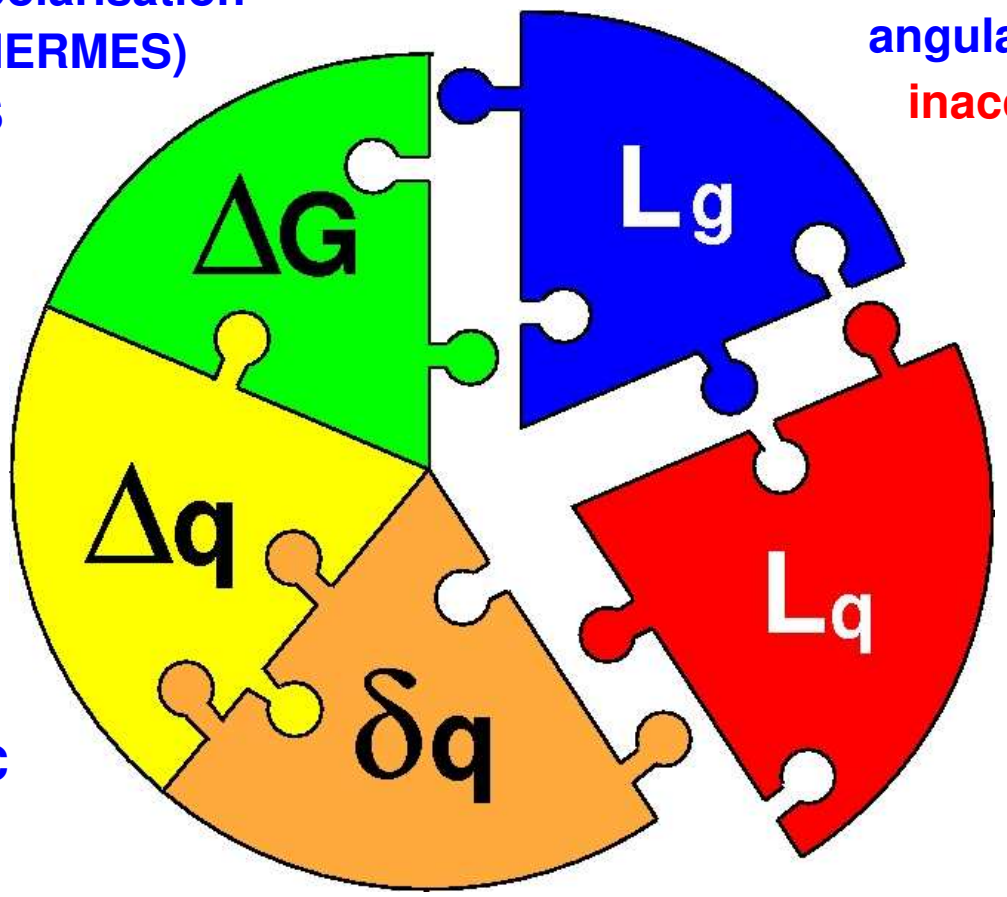
$$S_z = \frac{1}{2} = J_q + J_g = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

The Spin Puzzle

Gluon polarisation is positive (HERMES)
COMPASS
RHIC

$\Delta\Sigma = \Sigma\Delta q = 0.2...0.3$

EMC (1988)
SMC
HERMES
SLAC

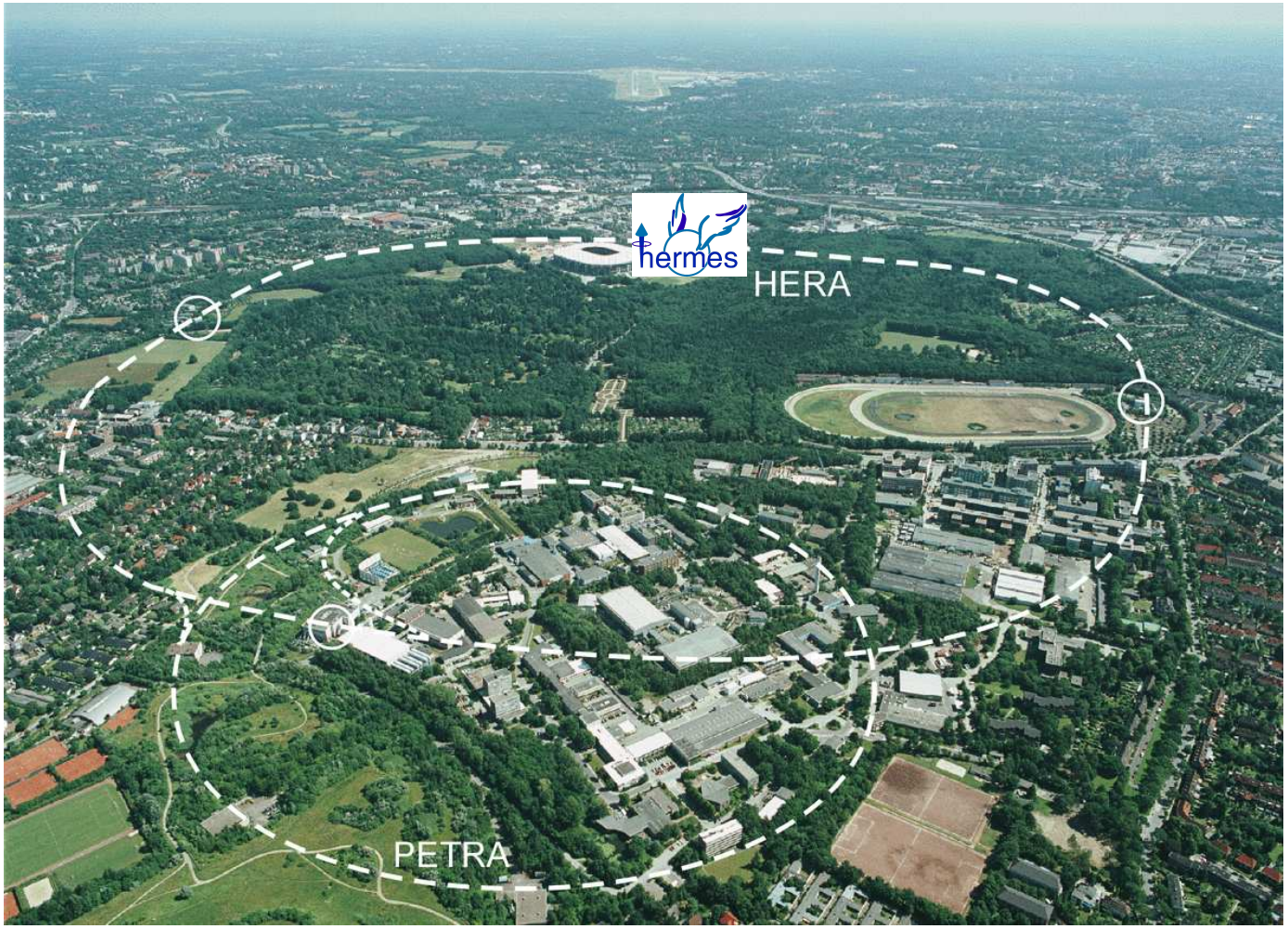


Gluon orbital angular momentum
inaccessible

Quark orbital angular momentum
accessible through GPDs

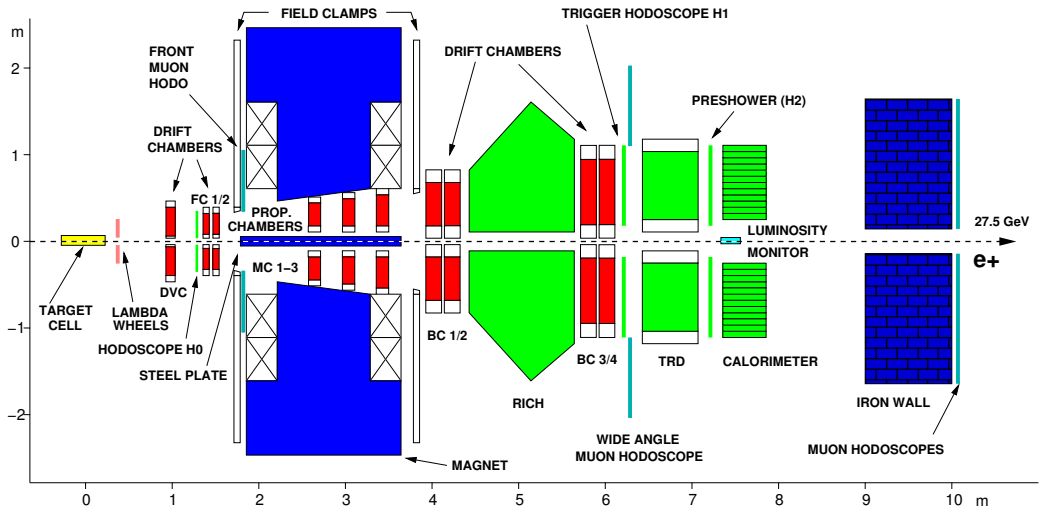
Transversity

HERMES - HEra MEsurement with Spin



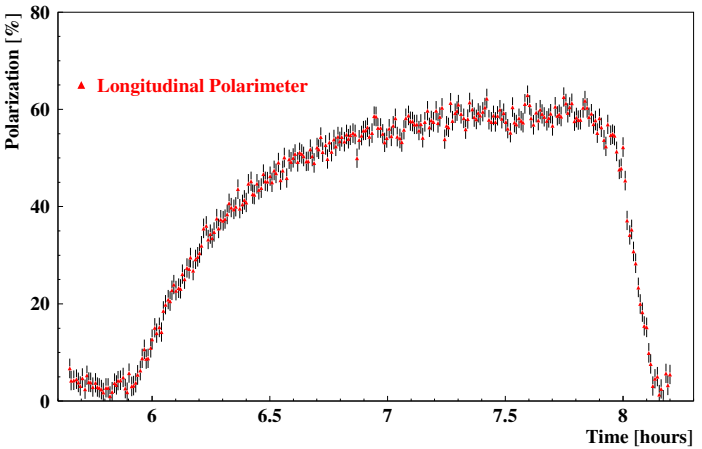
UNIVERSITY of GLASGOW

The HERMES Experiment

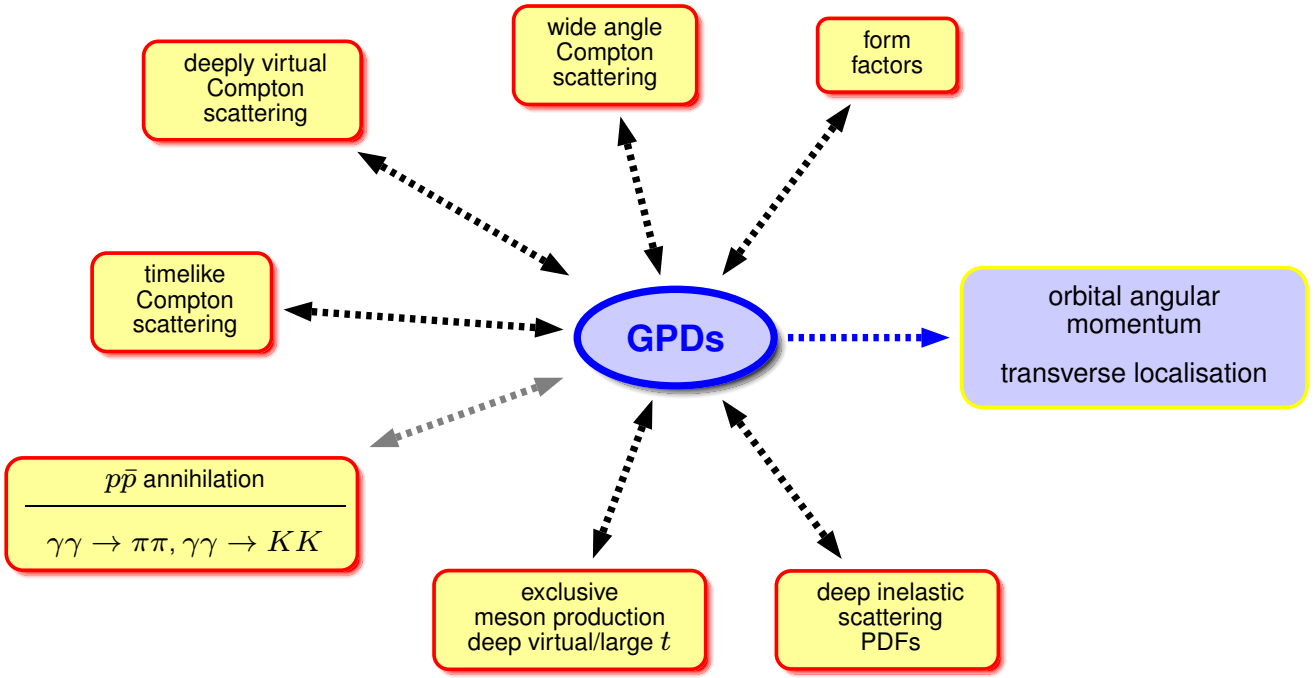


- E_b = 27.6 GeV
- I_b = 10-30 mA
- $P_b \sim 50\%$

- target density 10^{13} - 10^{15}/cm^2
- p, d , He, N, Ne, Kr, Xe targets
- polarised $e^{\pm}$ beams
- Sokolov-Ternov effect

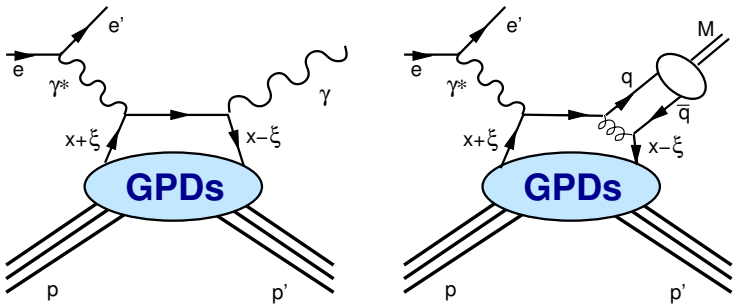


Generalised Parton Distributions



- link form factors and parton distribution functions
- provide access to transverse localisation of quarks and to their orbital angular momentum

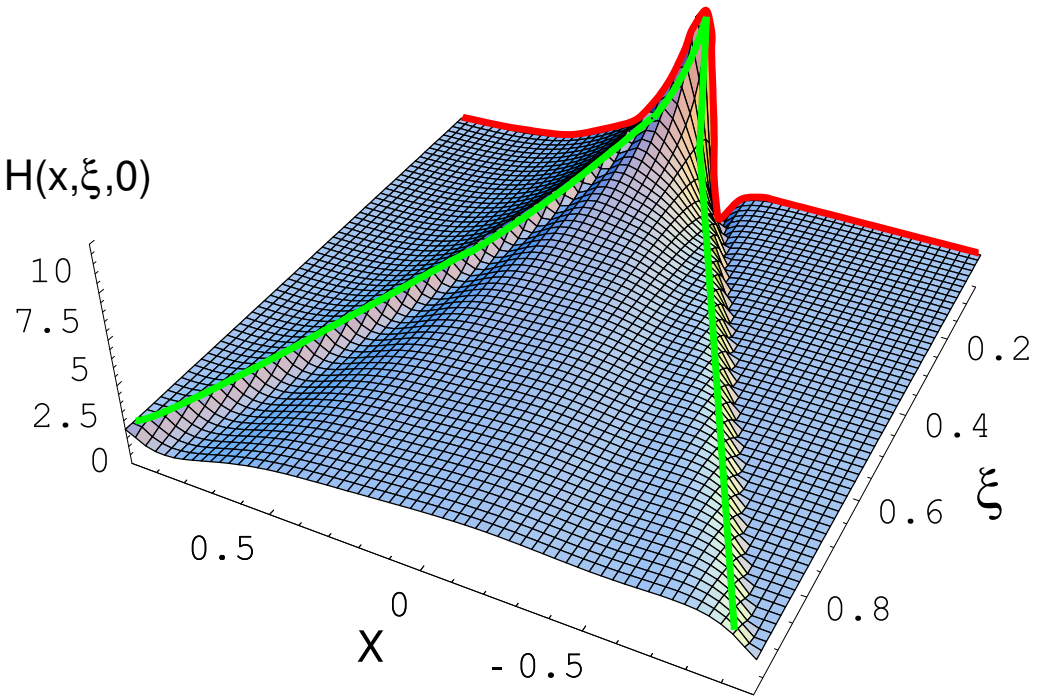
Generalised Parton Distributions

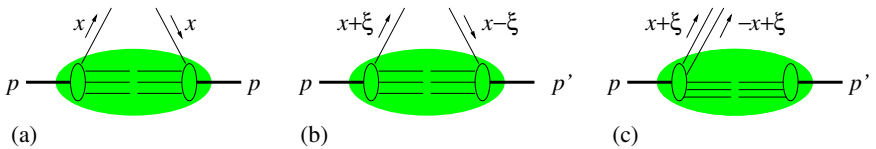


- functions of three variables: x, ξ, t
- H_q: nucleon spin preserved, E_q: nucleon spin flipped
- H_q: unpolarised $\tilde{H}_q$: polarised
- 4 (chirality conserving) quark GPDs: $H_q(x,\xi,t)$, $\tilde{H}_q(x,\xi,t)$, $E_q(x,\xi,t)$, $\tilde{E}_q(x,\xi,t)$

- parton distribution functions
  $q(x) = H_q(x,0,0)$
  $\Delta q(x) = \tilde{H}_q(x,0,0)$
- $q(-x) = -\bar{q}(x)$
  $\Delta q(-x) = \Delta\bar{q}(x)$
- form factors
  $F_1^q(t) = \int_{-1}^{1} dx H^q(x,\xi,t)$
  $F_2^q(t) = \int_{-1}^{1} dx E^q(x,\xi,t)$
  $g_a^q(t) = \int_{-1}^{1} dx \tilde{H}^q(x,\xi,t)$
  $h_a^q(t) = \int_{-1}^{1} dx \tilde{E}^q(x,\xi,t)$
- quark orbital angular momentum
  $J_q = \frac{1}{2}\int_{-1}^{1} x\, dx[H_q + E_q]$
  $= \frac{1}{2}\Delta\Sigma + L_q$ [X.Ji 1997]

Generalised Parton Distributions





(a) Usual pdf, representing the probability to find a parton with momentum fraction x in the nucleon (red line).

(b) GPD in the region where it represents the emission of a parton with momentum fraction $x + \xi$ and its re-absorption with momentum fraction $x - \xi$ (outside green lines).

(c) GPD in the region where it represents the emission of a parton pair. Here $x + \xi > 0$ and $x - \xi < 0$ (inside green lines).

(GPD model plot by M.Vanderhaeghen)

Hadron Tomography

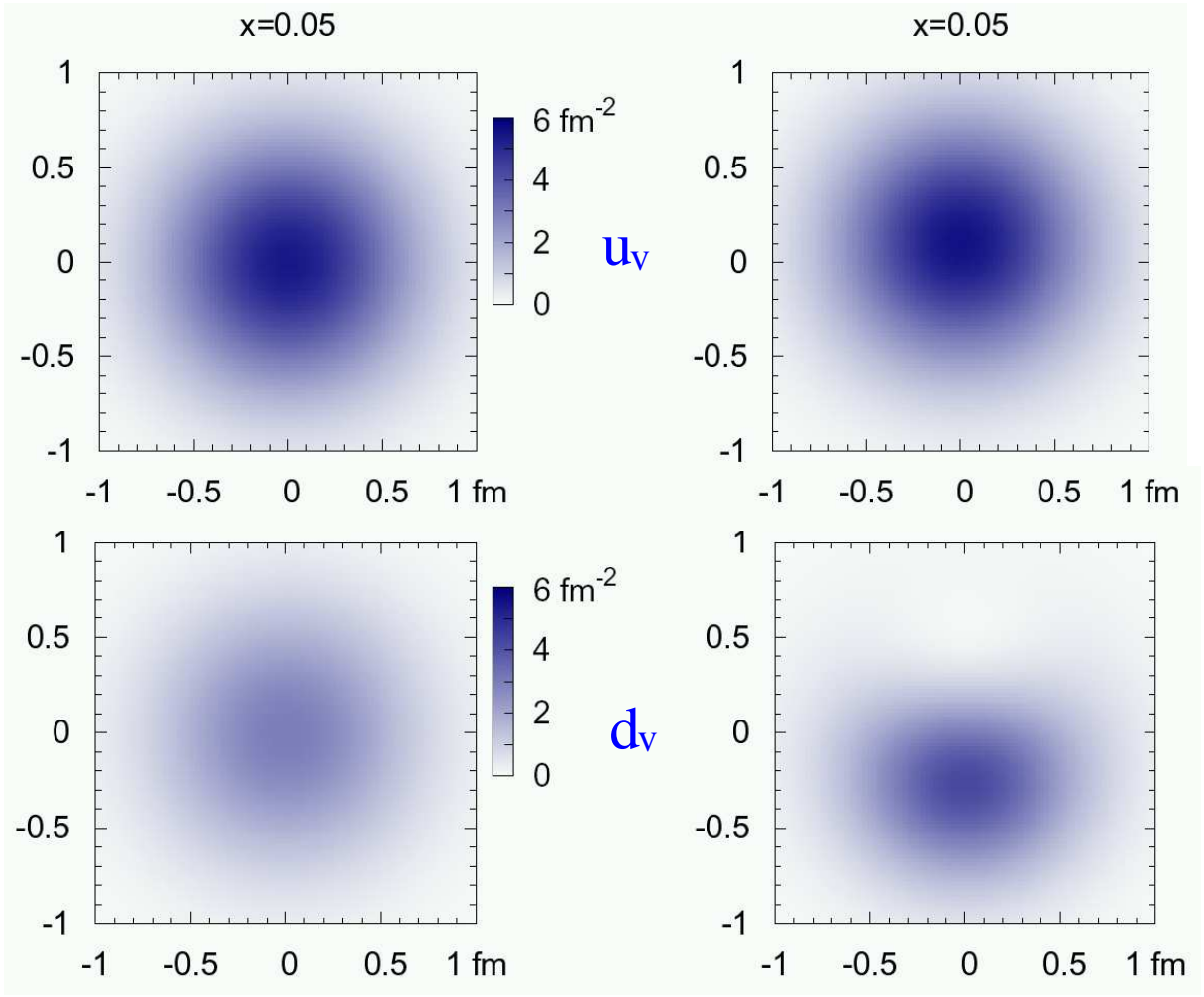
- GPDs at $\xi = 0$ can be used to obtain quark densities in the mixed representation of longitudinal momentum and transverse position in the infinite momentum frame.

$$q_v(x, \mathbf{b}) = \int \frac{d^2\mathbf{\Delta}}{(2\pi)^2} e^{-\mathbf{b}\mathbf{\Delta}} H_v^q(x, t = -\mathbf{\Delta}^2)$$

  where $\mathbf{b}$ is the 2-dim. impact parameter.

- Based on GPD models first fits to existing data are already being carried out.
- M.Burkardt, Phys.Rev.D62, 071503 (2000)
  J.R.Ralston, B.Pire, Phys.Rev.D66,111501 (2002)

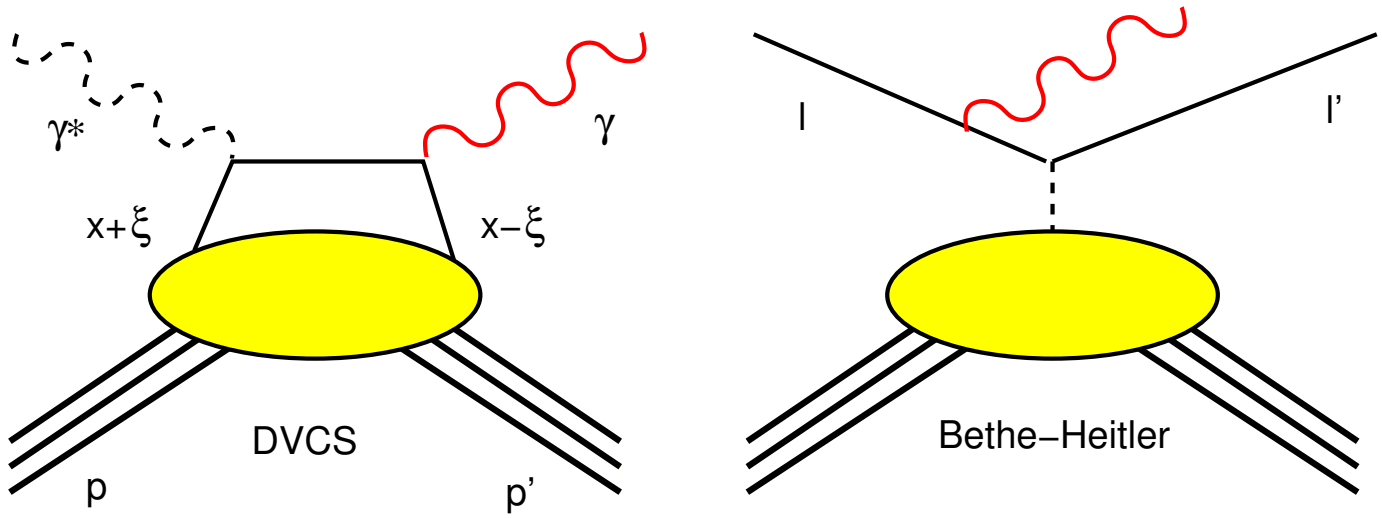
Hadron Tomography



unpolarised polarised

- $u_v(x, \mathbf{b})$ and $d_v(x, \mathbf{b})$
- left: unpolarised right: polarised
- GPD fit to form factor data
- M.Diehl et al. hep-ph/0408173

Deeply Virtual Compton Scattering



- simplest hard exclusive process: DVCS, main background: Bethe-Heitler (BH). $ep \rightarrow e'p'\gamma$
- DVCS amplitude can be expressed in terms of GPDs
- at HERMES energies the interference of DVCS- and BH-amplitude allows the separate measurement of the real and the imaginary part of DVCS amplitude
- need to measure beam charge and beam spin azimuthal asymmetries
- requires polarised $e^{\pm}$ beam, unpolarised hydrogen target

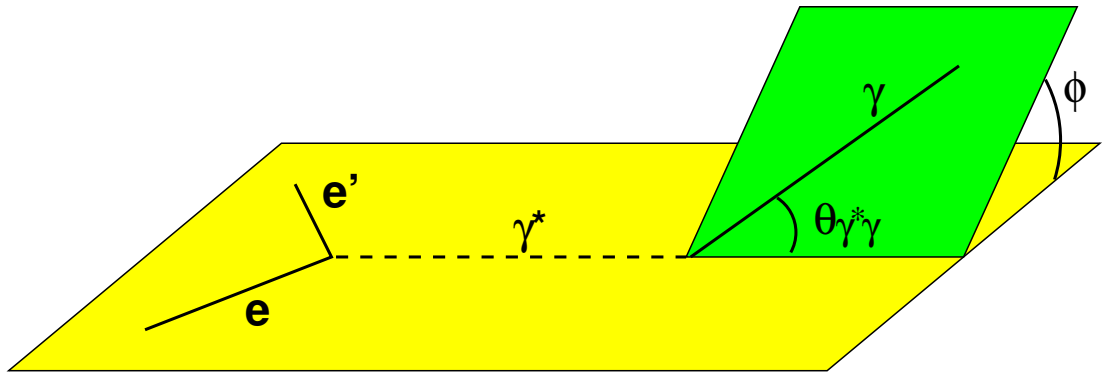
UNIVERSITY of GLASGOW

DVCS Asymmetries and GPDs

Beam Spin $$A_{LU}(\phi) = \frac{d\sigma^{\uparrow}(\phi) - d\sigma^{\downarrow}(\phi)}{d\sigma^{\uparrow}(\phi) + d\sigma^{\downarrow}(\phi)} \propto \sin\phi \Rightarrow \mathfrak{Im}(H)$$

Beam Charge $$A_{C}(\phi) = \frac{d\sigma^{+}(\phi) - d\sigma^{-}(\phi)}{d\sigma^{+}(\phi) + d\sigma^{-}(\phi)} \propto \cos\phi \Rightarrow \mathfrak{Re}(H)$$

Target Spin $$A_{UL}(\phi) = \frac{d\sigma^{\Uparrow}(\phi) - d\sigma^{\Downarrow}(\phi)}{d\sigma^{\Uparrow}(\phi) + d\sigma^{\Downarrow}(\phi)} \propto \sin\phi \Rightarrow \mathfrak{Im}(\tilde{H})$$

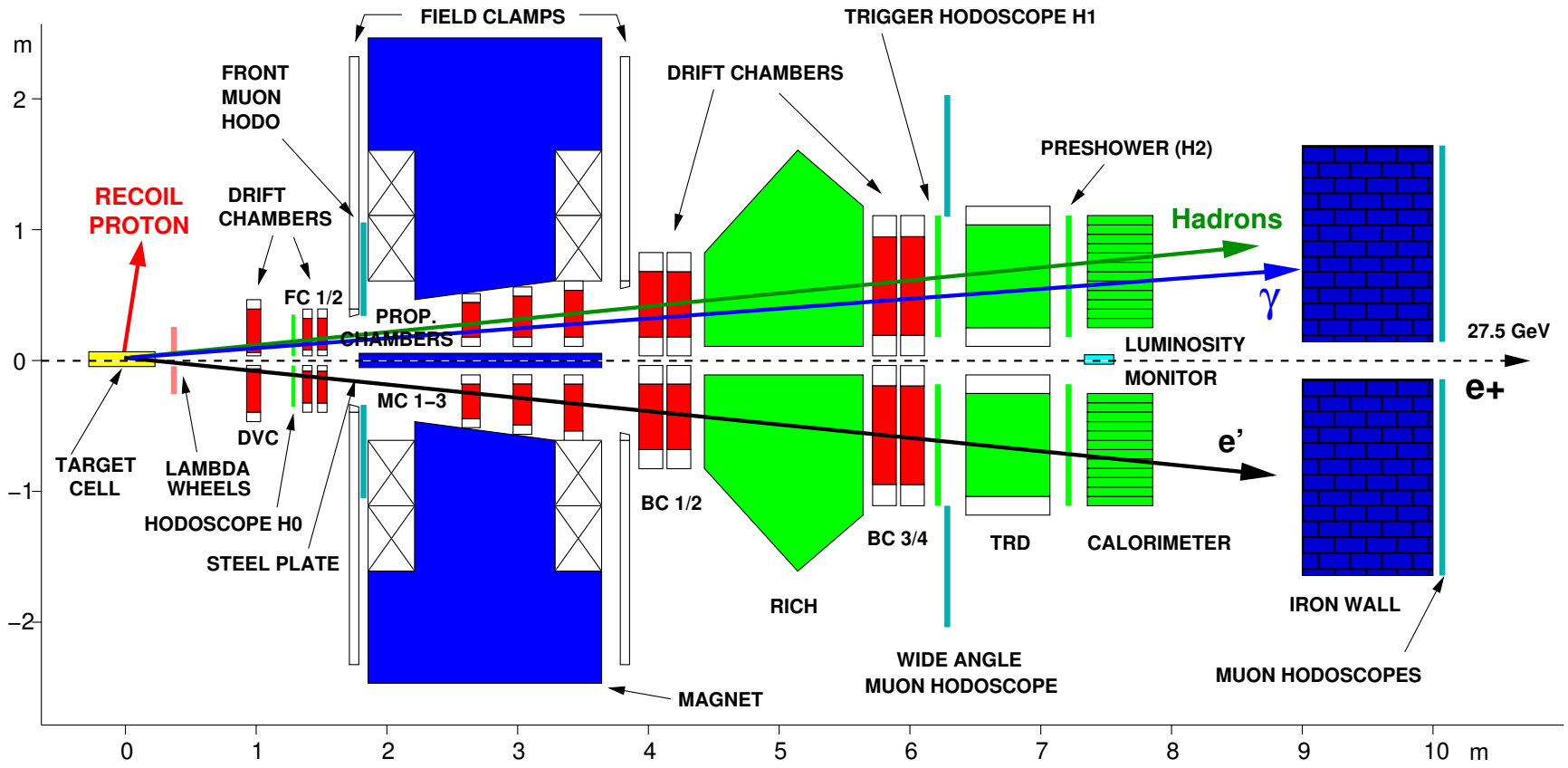


Requirements on DVCS Measurements

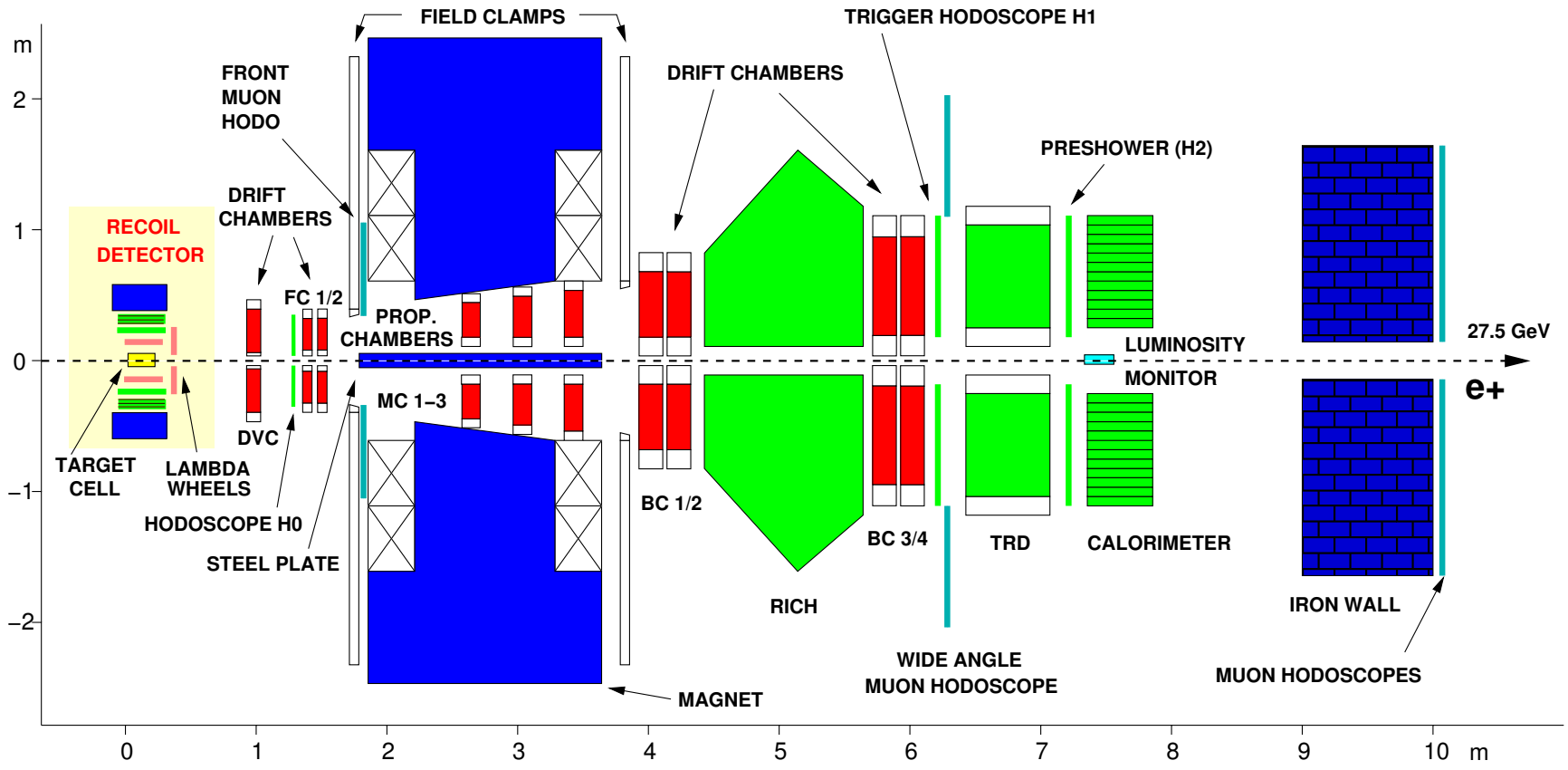
- Exclusivity - measure all reaction products, scattered electron, photon and recoil protons.
- Measurable effect - DVCS cross section dominates BH at high energies (ZEUS, H1). At medium energies BH dominates the cross section but interference between DVCS and BH leads to large asymmetries.
- Polarised $e^{\pm}$ beam - to measure beam spin and beam charge asymmetry.
- t-resolution - must be sufficient for extrapolation to $t \rightarrow 0$ for Ji sum rule.
- High statistics - high target density, beam current, polarisation

UNIVERSITY of GLASGOW

The HERMES Spectrometer

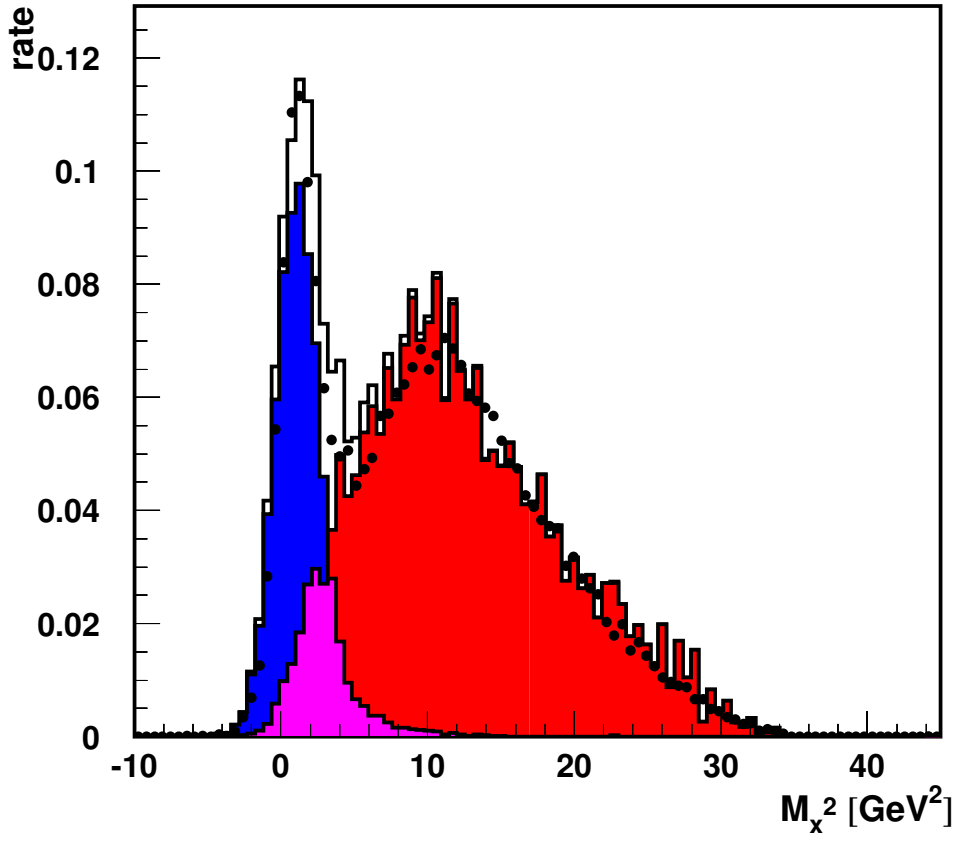


The HERMES Spectrometer



Recoil Detector - Motivation

- Spectrometer resolution not sufficient to ensure exclusivity for a given event.



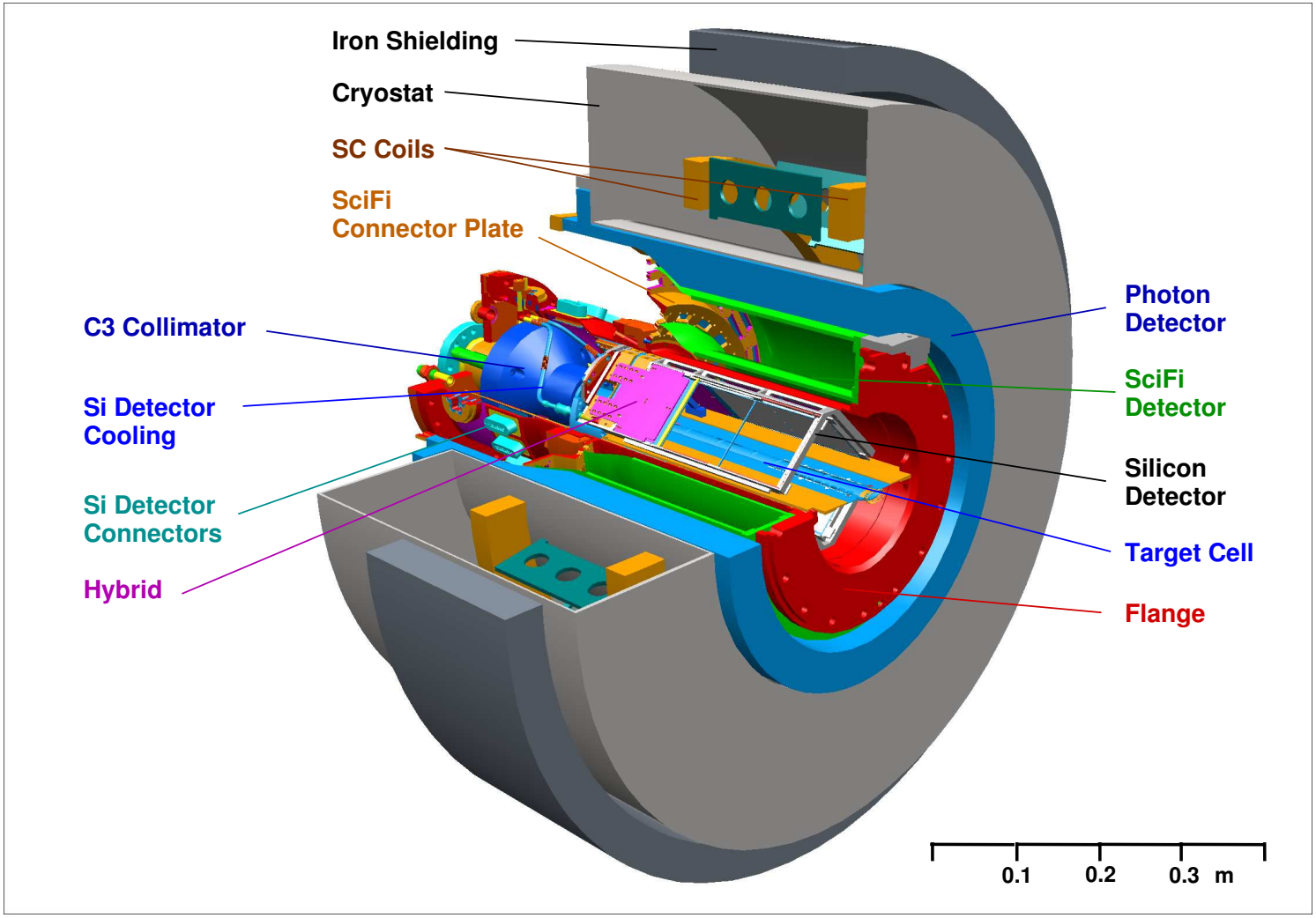
Recoil Detector - Motivation

- Spectrometer resolution not sufficient to ensure exclusivity for a given event.
- Suppress background from soft pions and intermediate Δ^+ production. With increased statistics the resulting systematic error would otherwise become dominant.

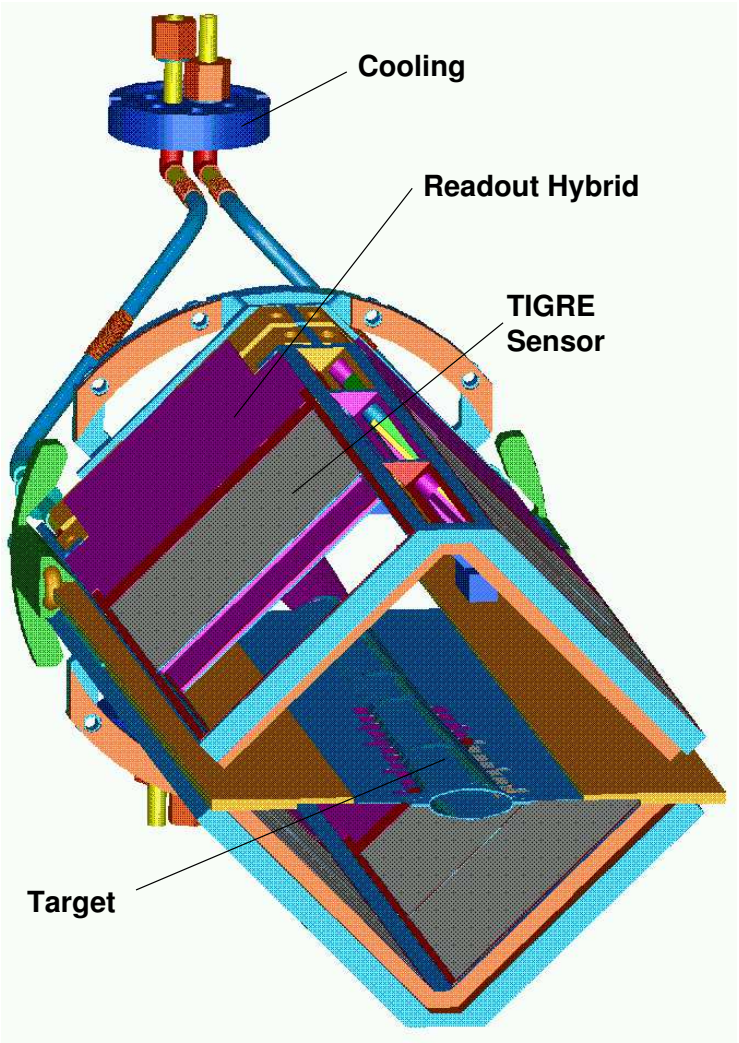
Recoil Detector - Motivation

- Spectrometer resolution not sufficient to ensure exclusivity for a given event.
- Suppress background from soft pions and intermediate Δ^+ production. With increased statistics the resulting systematic error would otherwise become dominant.
- t-resolution of the spectrometer does not allow binning in t; important for extrapolation $t \longrightarrow 0$.

HERMES Recoil Detector - 3D CAD



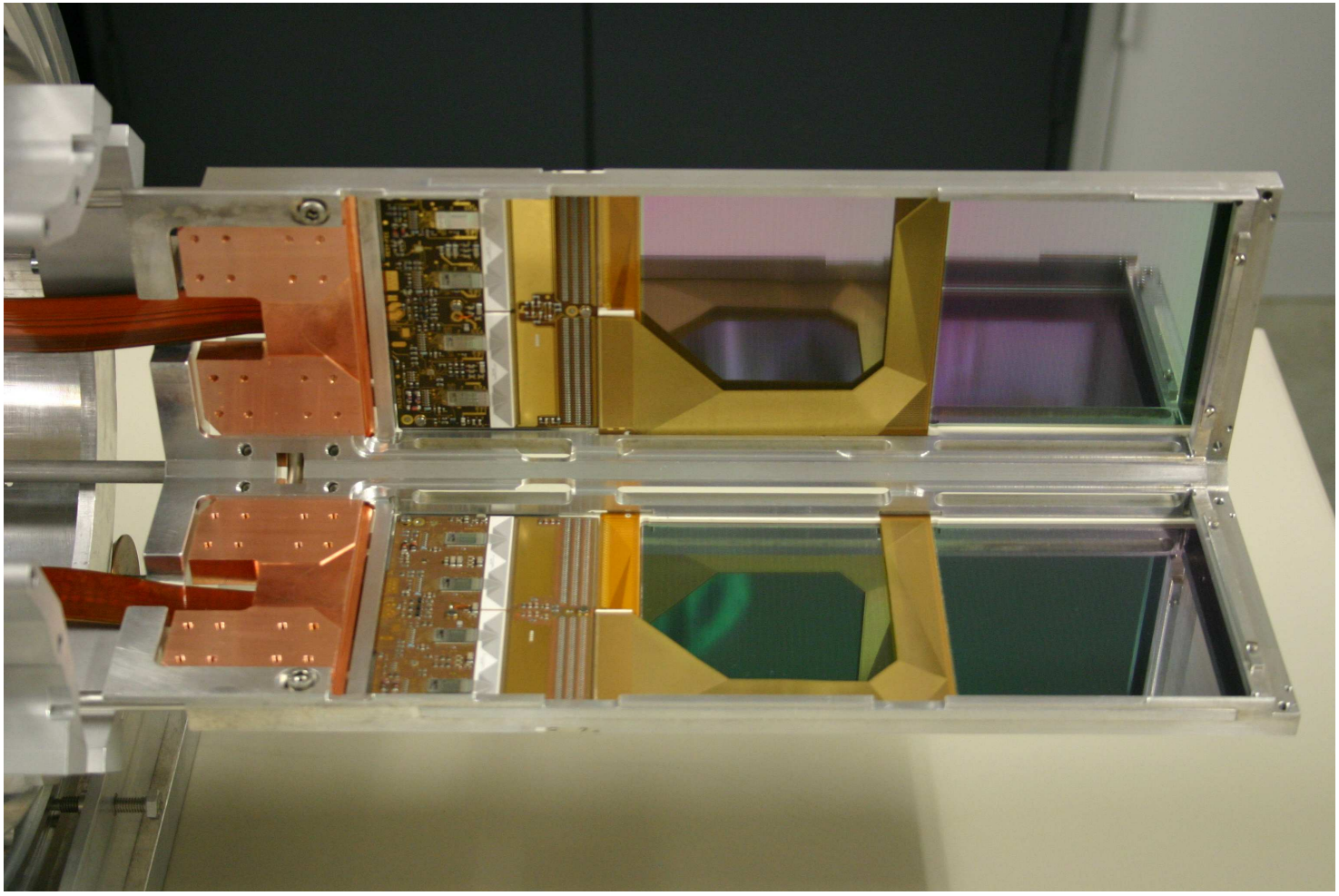
Silicon Detector



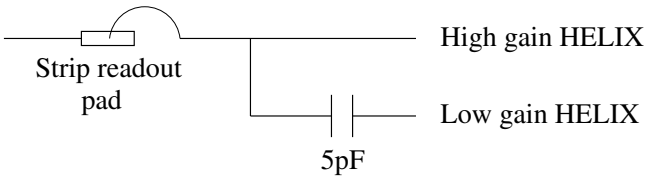
- 16 TIGRE sensors inside beam vacuum
- 300 μm double sided, 4096 channels total
- 76 % ϕ-acceptance
- p-measurement from dE/dx 135-500 MeV/c
- space points for tracking $p > 135$ MeV/c
- π/p PID from dE/dx $p < 250$ MeV/c

UNIVERSITY of GLASGOW

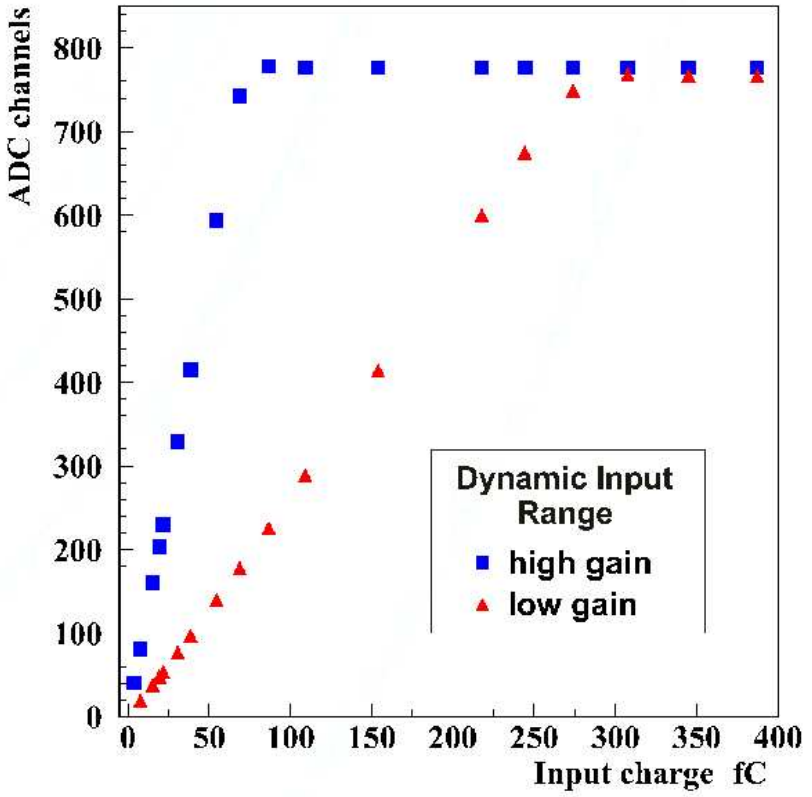
Silicon Detector



Silicon Detector Readout



- split signal into high and low gain channel
- 2 Helix 3.0 chips per silicon strip
- adjust dynamic range through capacitor to ± 70 MIPs
- S/N (MIP) 6.5

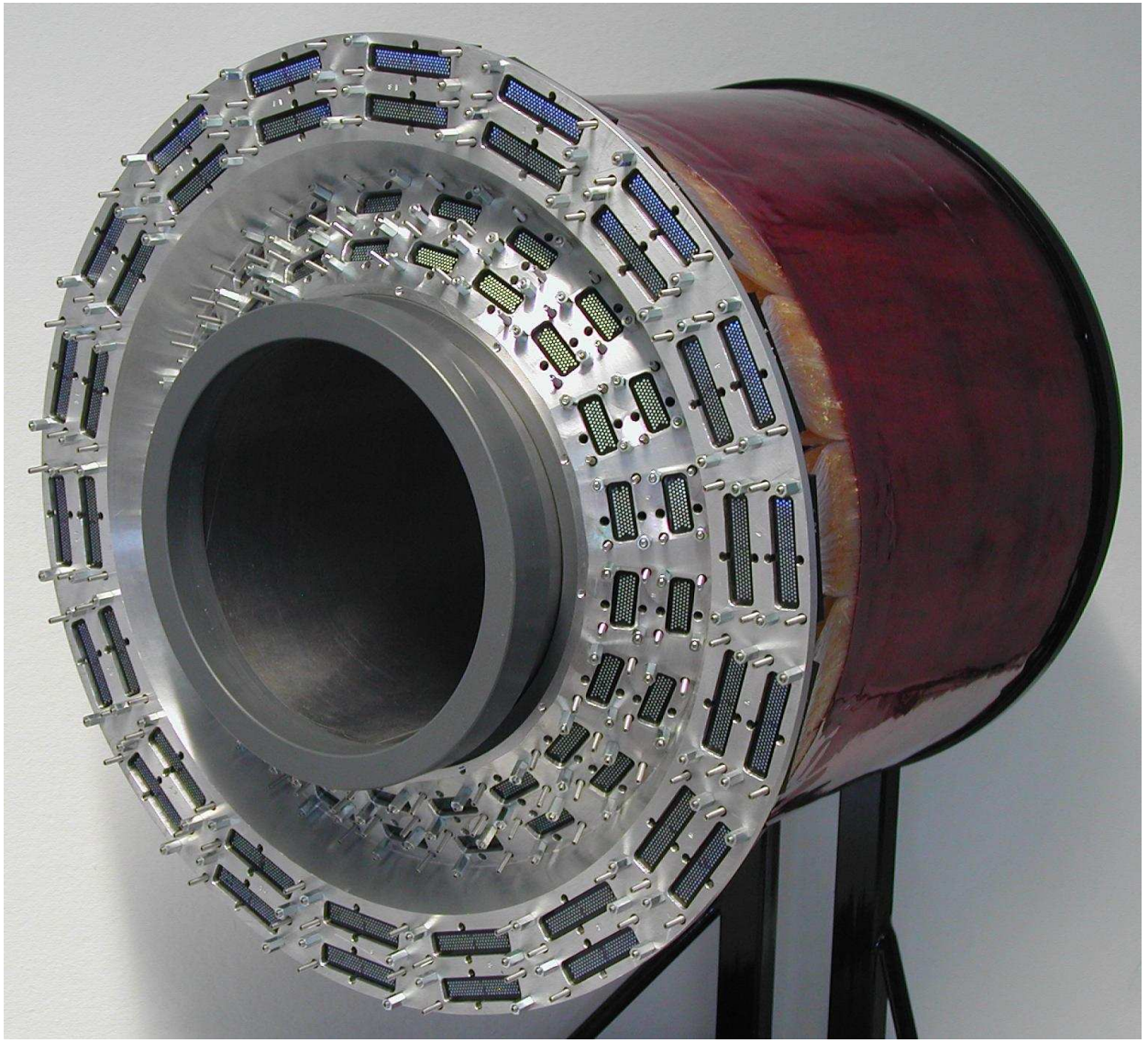


Scintillating Fibre Tracker

- 2 cylinders of 2×2 layers, 10° stereo angle
- 1 mm Kuraray fibres, mirrored ends
- 4992 channels total
- Kuraray lightguides, 64 channel Hamamatsu PMTs
- p-measurement 300-1200 MeV/c
- π/p PID from dE/dx $250 < p < 450$ MeV/c

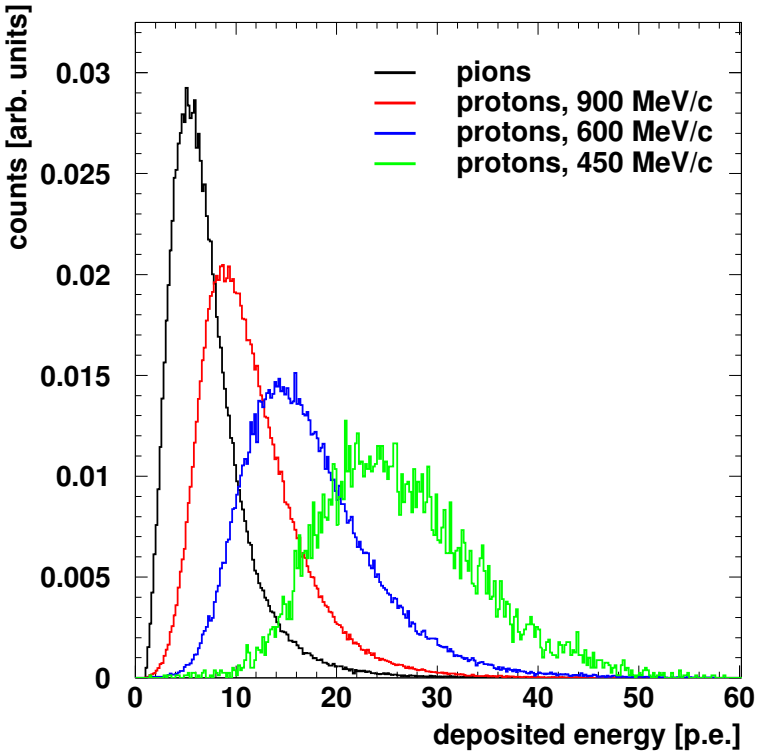
UNIVERSITY of GLASGOW

Scintillating Fibre Tracker

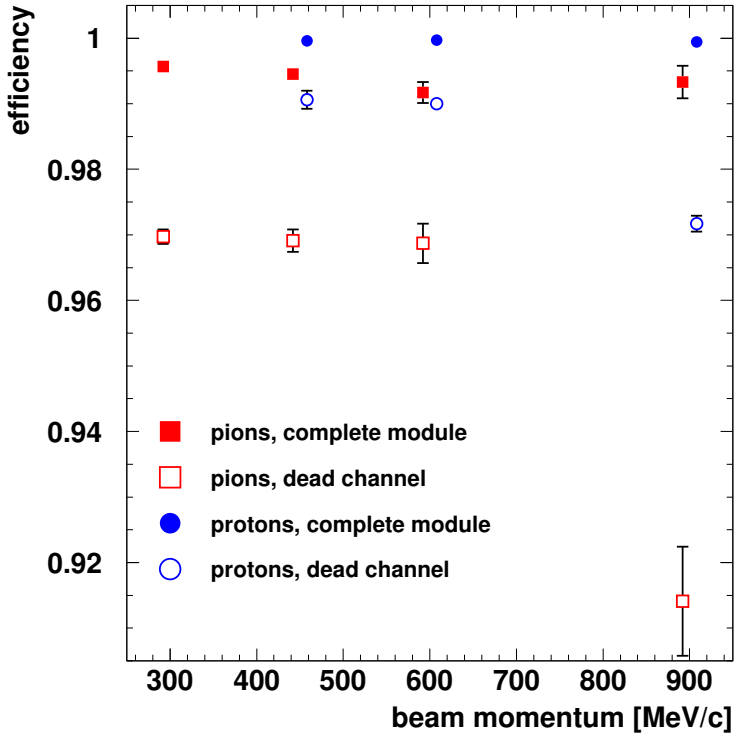


UNIVERSITY of GLASGOW

SciFi Testbeam Results



SciFi response for different proton momenta

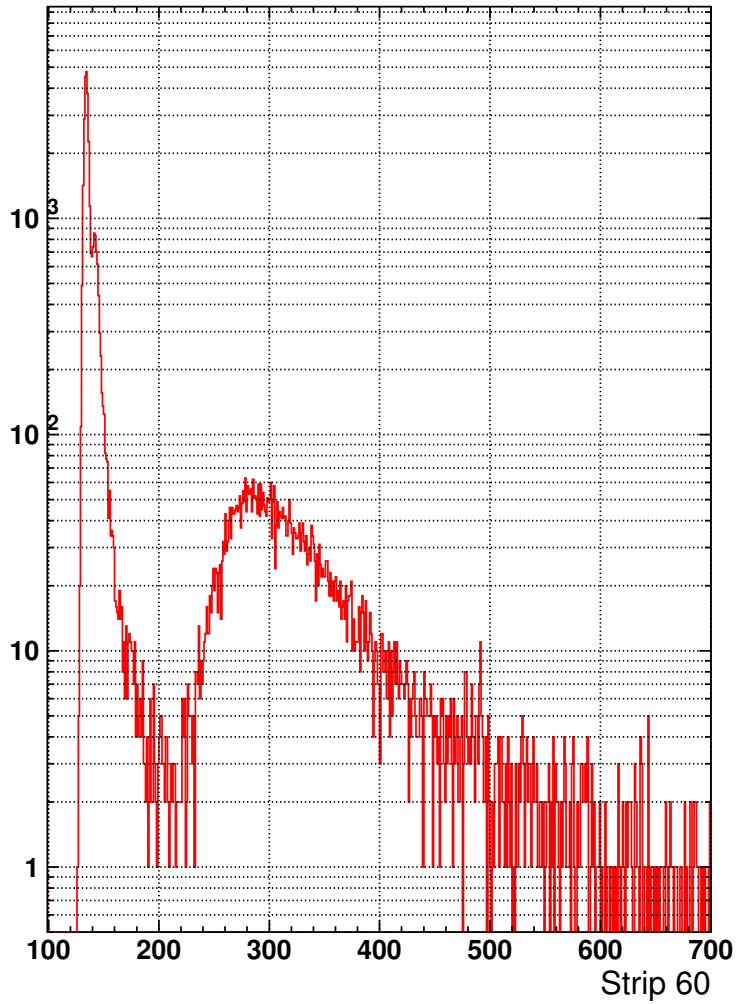


SciFi module efficiencies (module = double layer of fibres; two modules to get one space point)

Photon Detector

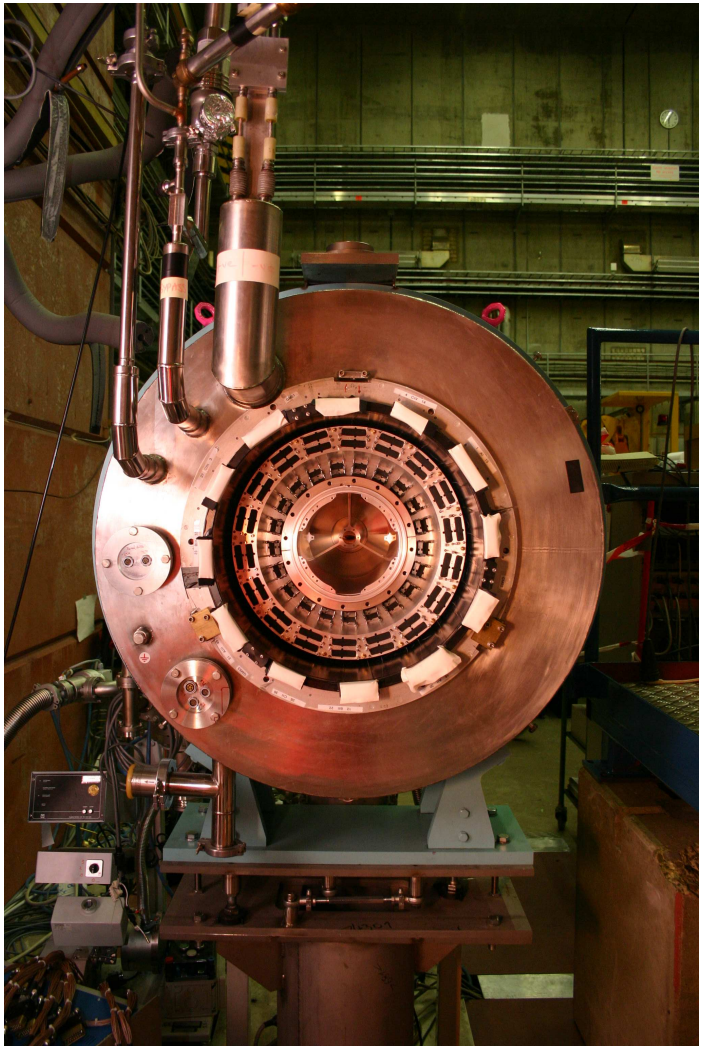
- detect photons from intermediate Δ-resonances
  $\Delta^+ \rightarrow p\pi^0 \rightarrow p\gamma\gamma$
- reconstruct π^0 if both photons are detected
- contribute to pion/proton separation (together with SciFi)
- provide Cosmics Trigger

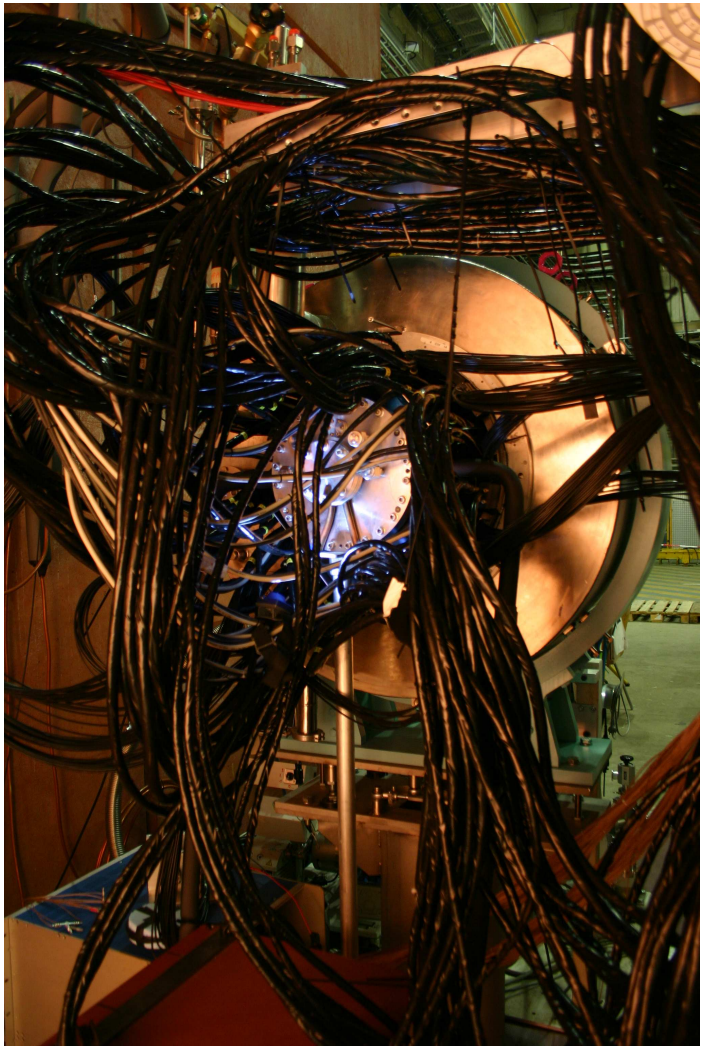
Photon Detector Cosmics Spectrum



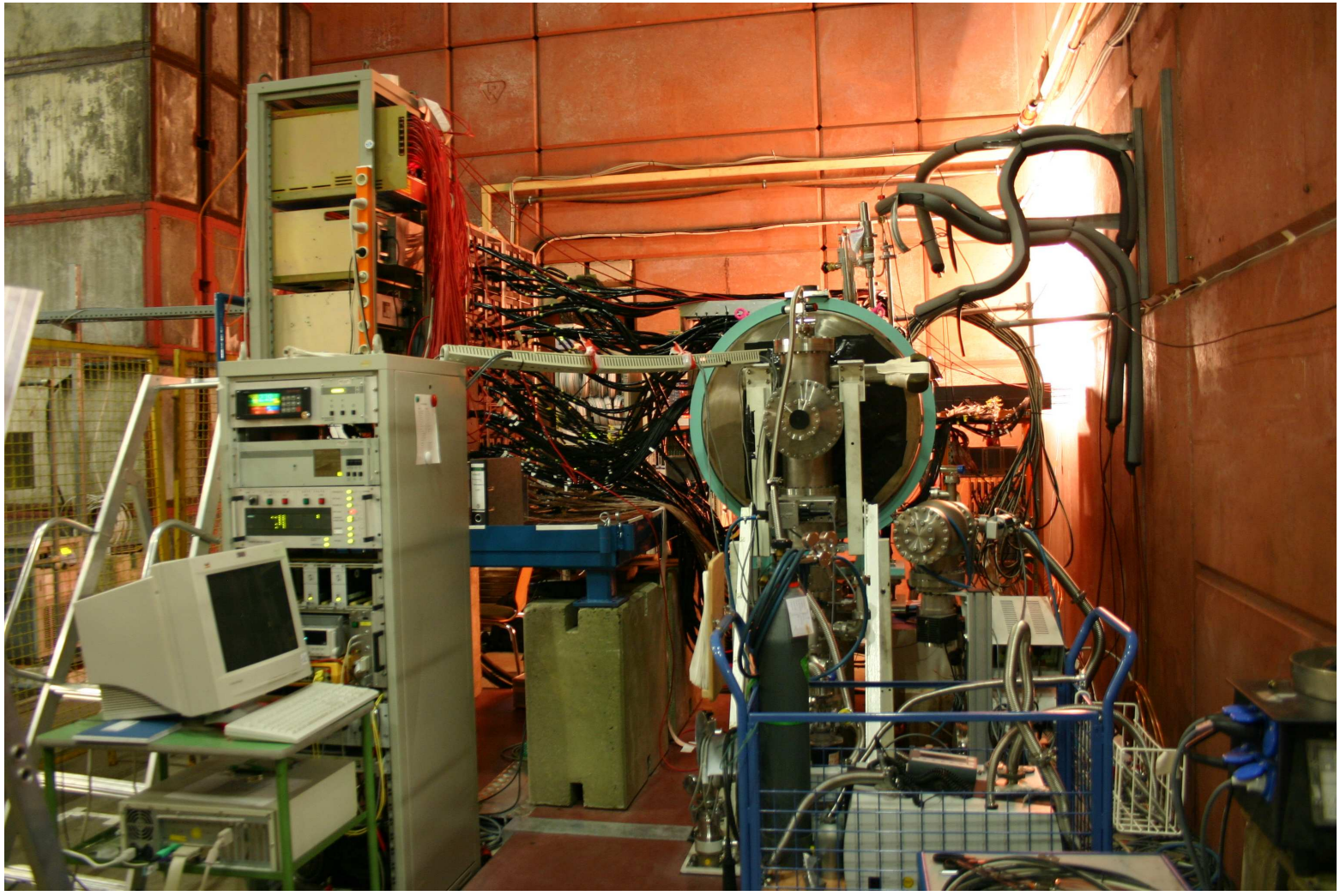
- Cosmics Trigger: OR of lower half of inner layer
- Rate: $\sim$ 20 Hz
- MIP - pedestal separation: $\sim$ 170 channels (data from stand-alone cosmics test)

Recoil Detector Test-Experiment



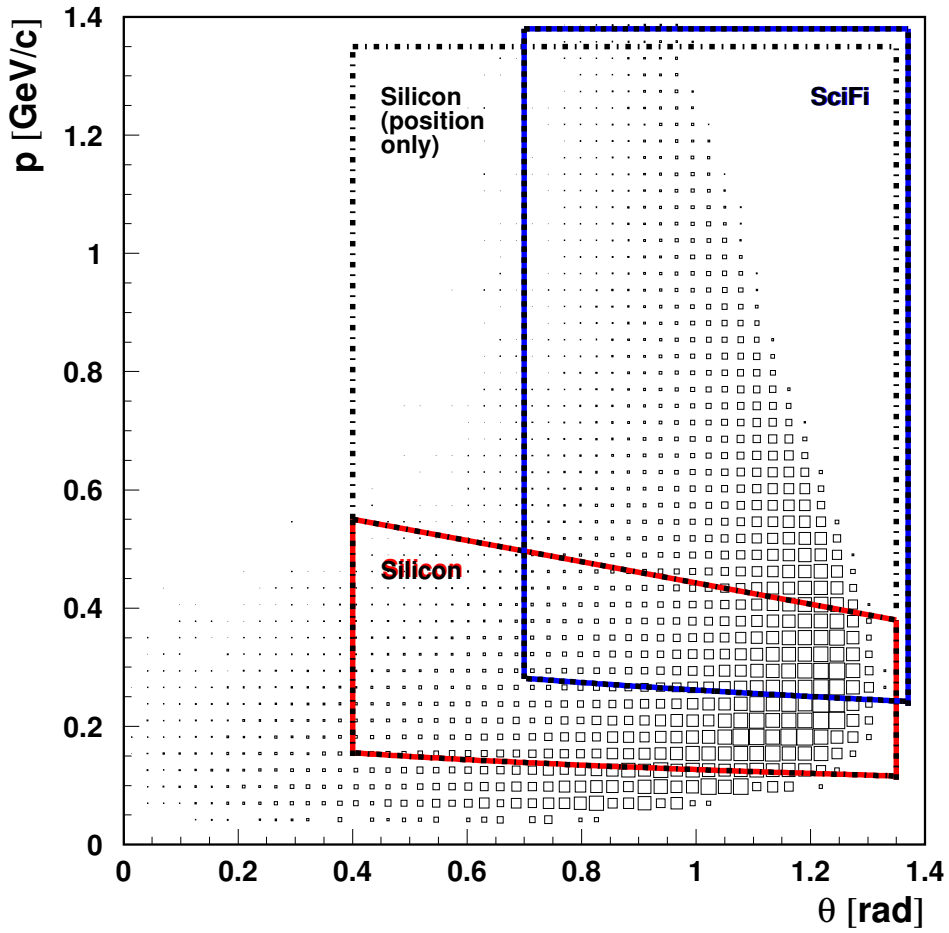


Recoil Test-Experiment Overview



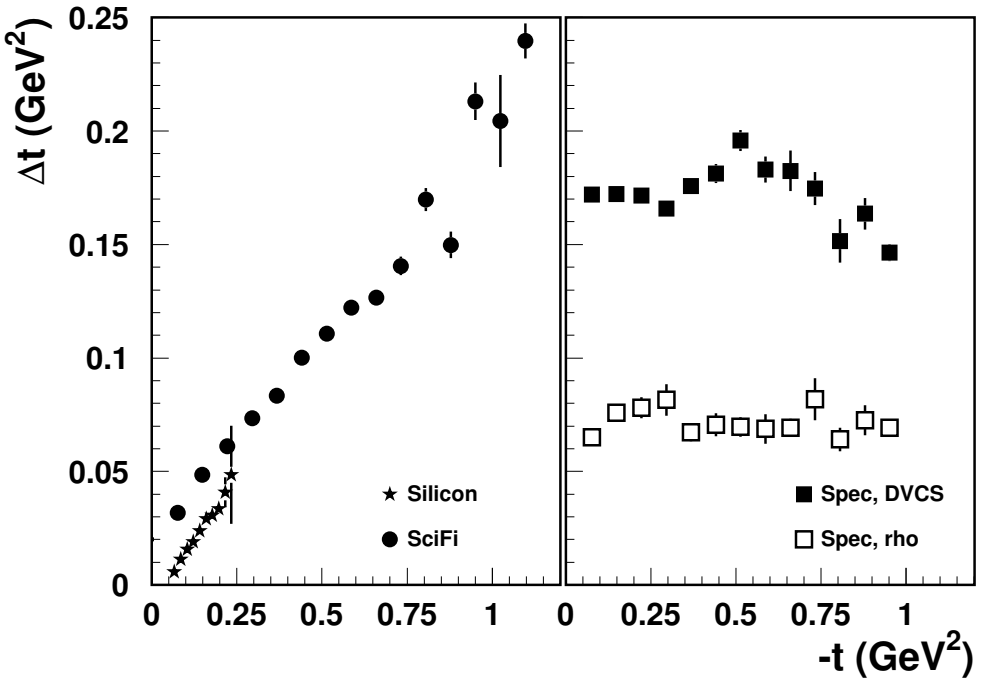
UNIVERSITY of GLASGOW

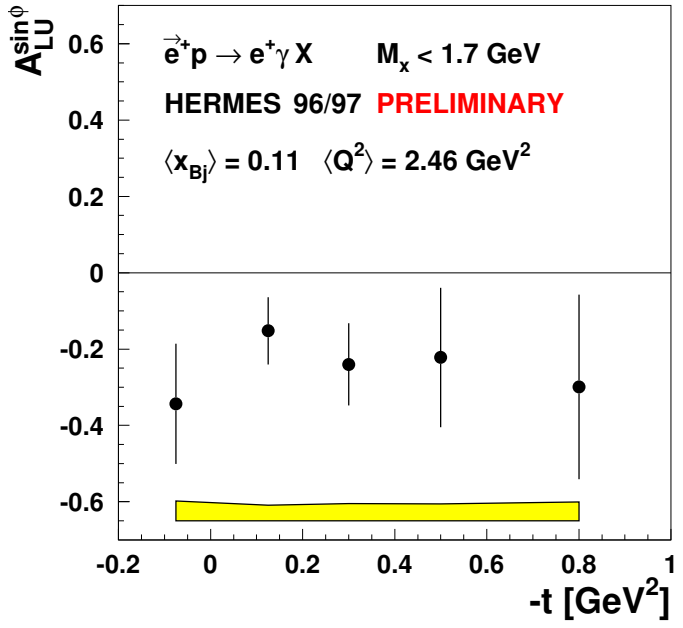
Recoil Detector Kinematic Coverage



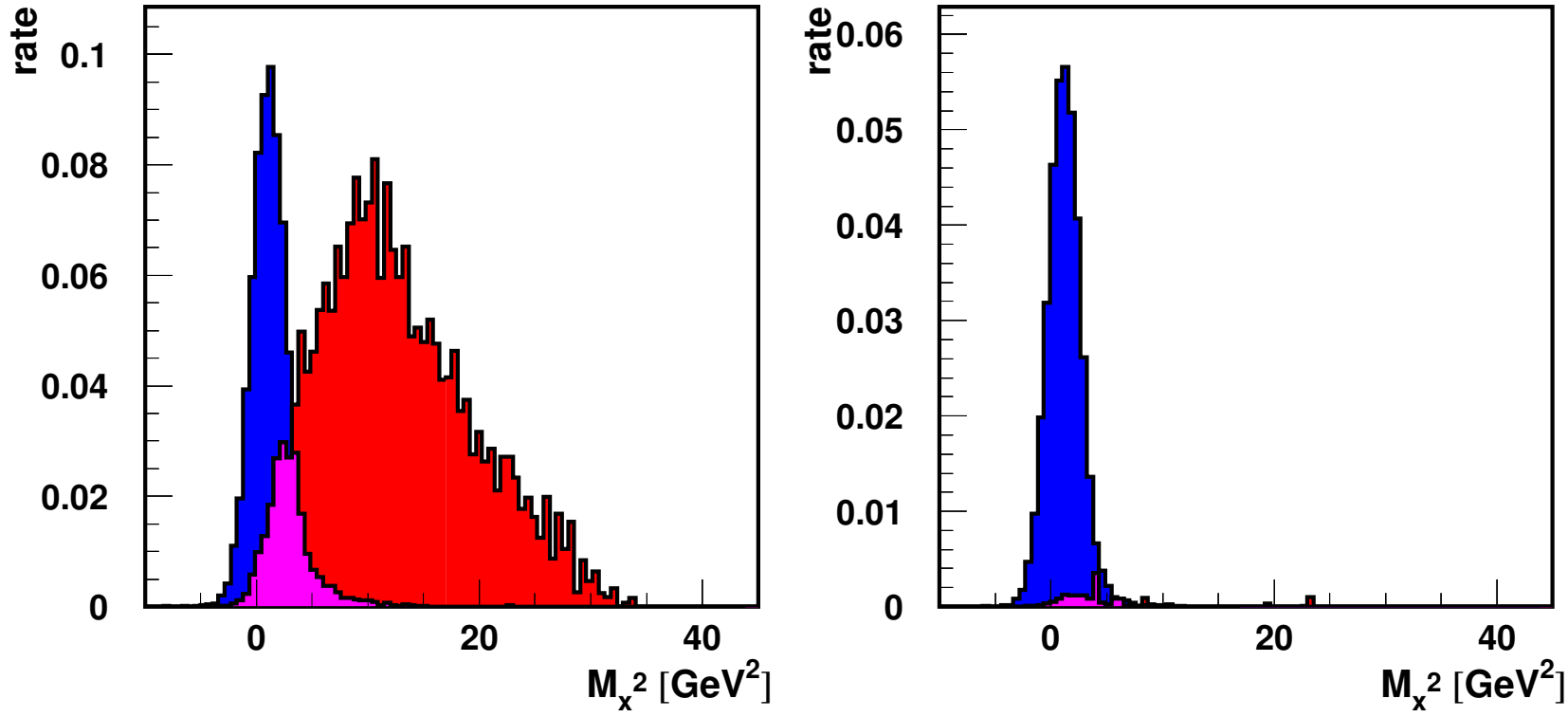
- Si low momentum cut-off 135 MeV/c (10 MeV), require signal in both layers
- Scifi low momentum cut-off 250 MeV/c
- Si dE/dx measurement up to 500 MeV/c (3 MIPs)

Recoil Detector t-Resolution



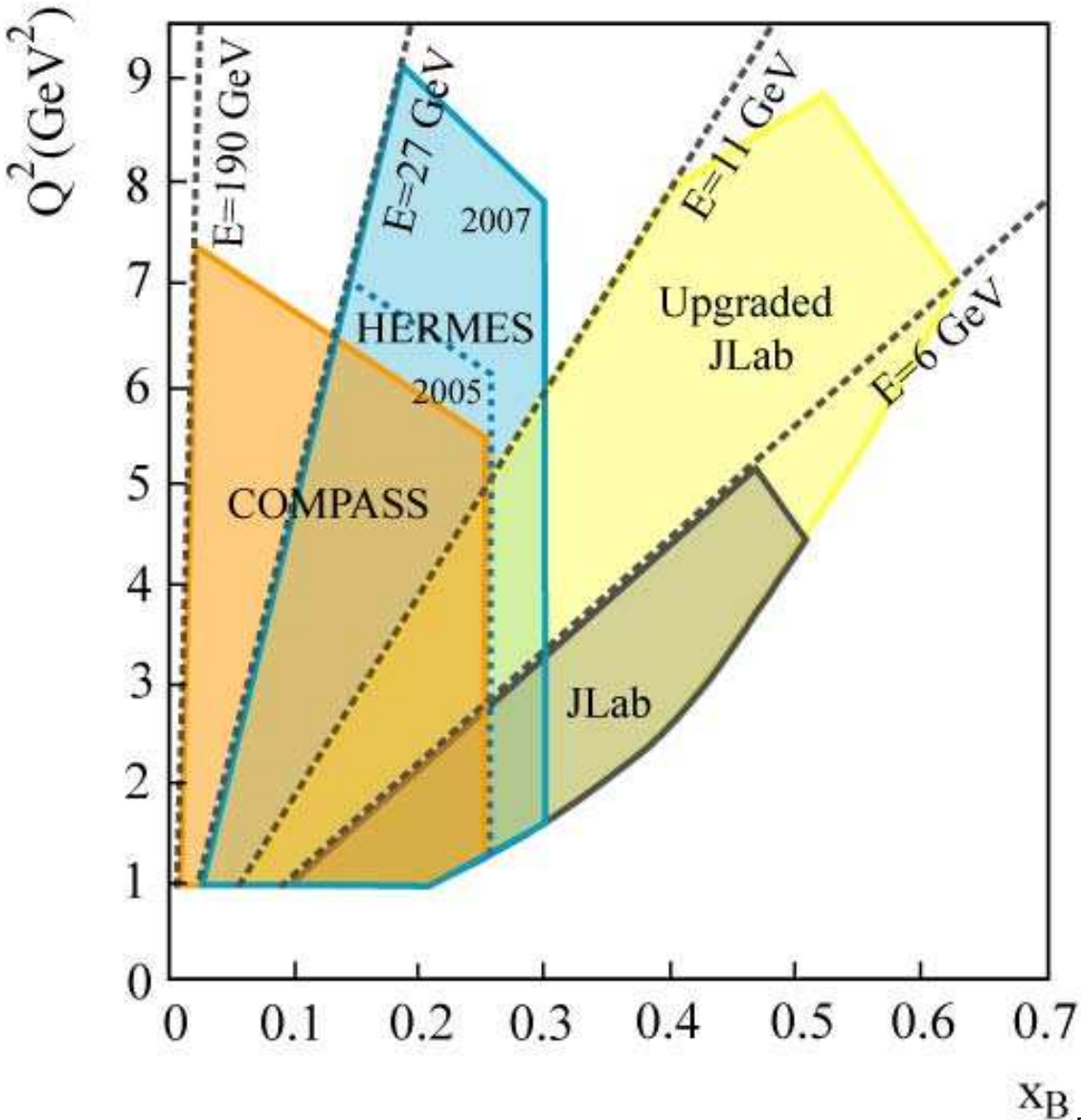


Exclusivity

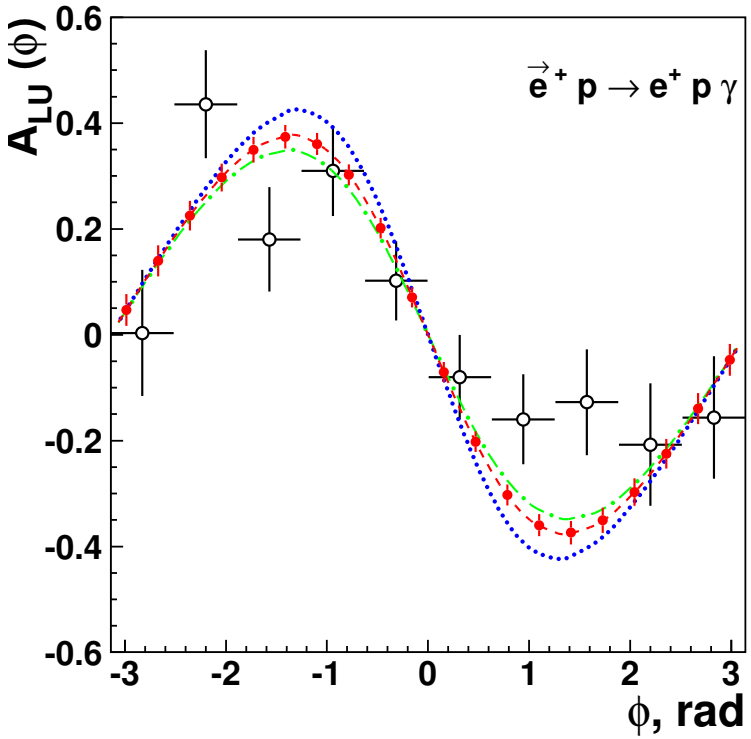


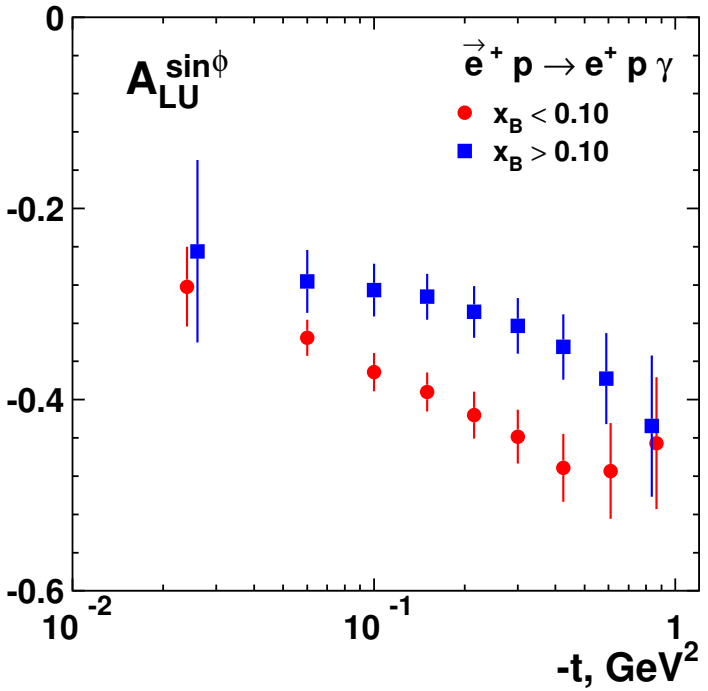
- Combination of coplanarity cuts, single proton requirement, pion rejection, photon cluster from π^0 (MC simulation)

Current and Future DVCS Experiments



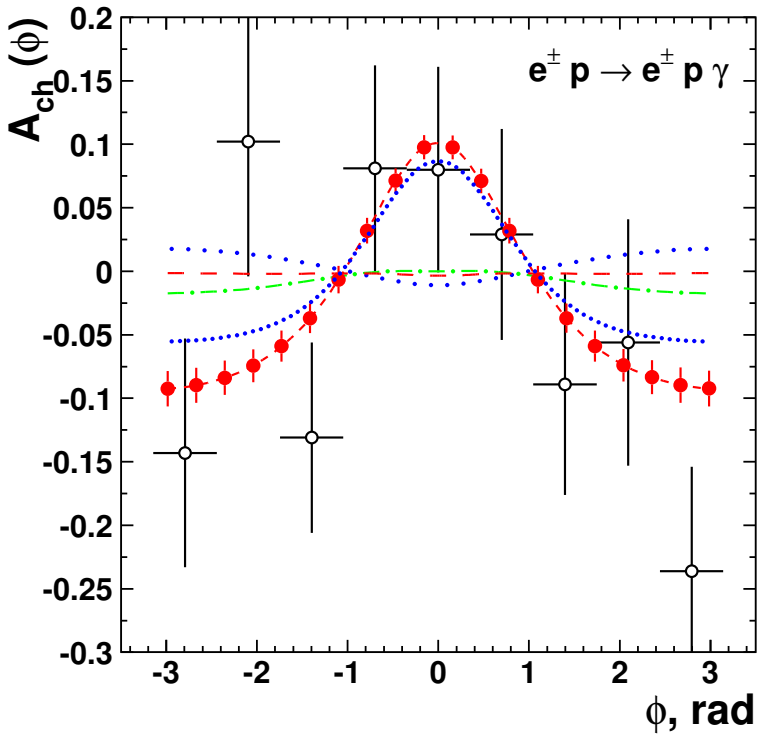
Proton Beam Spin Asymmetry

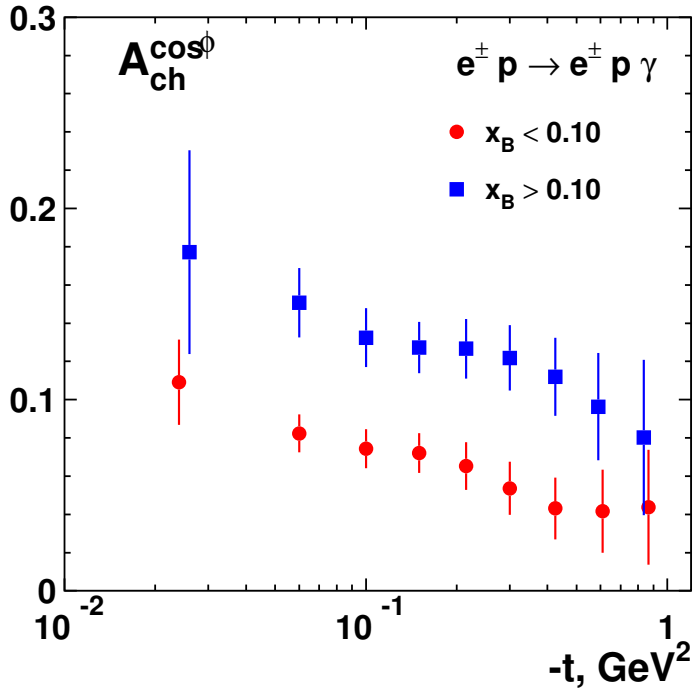




Projection based on 2 fb^{-1}.

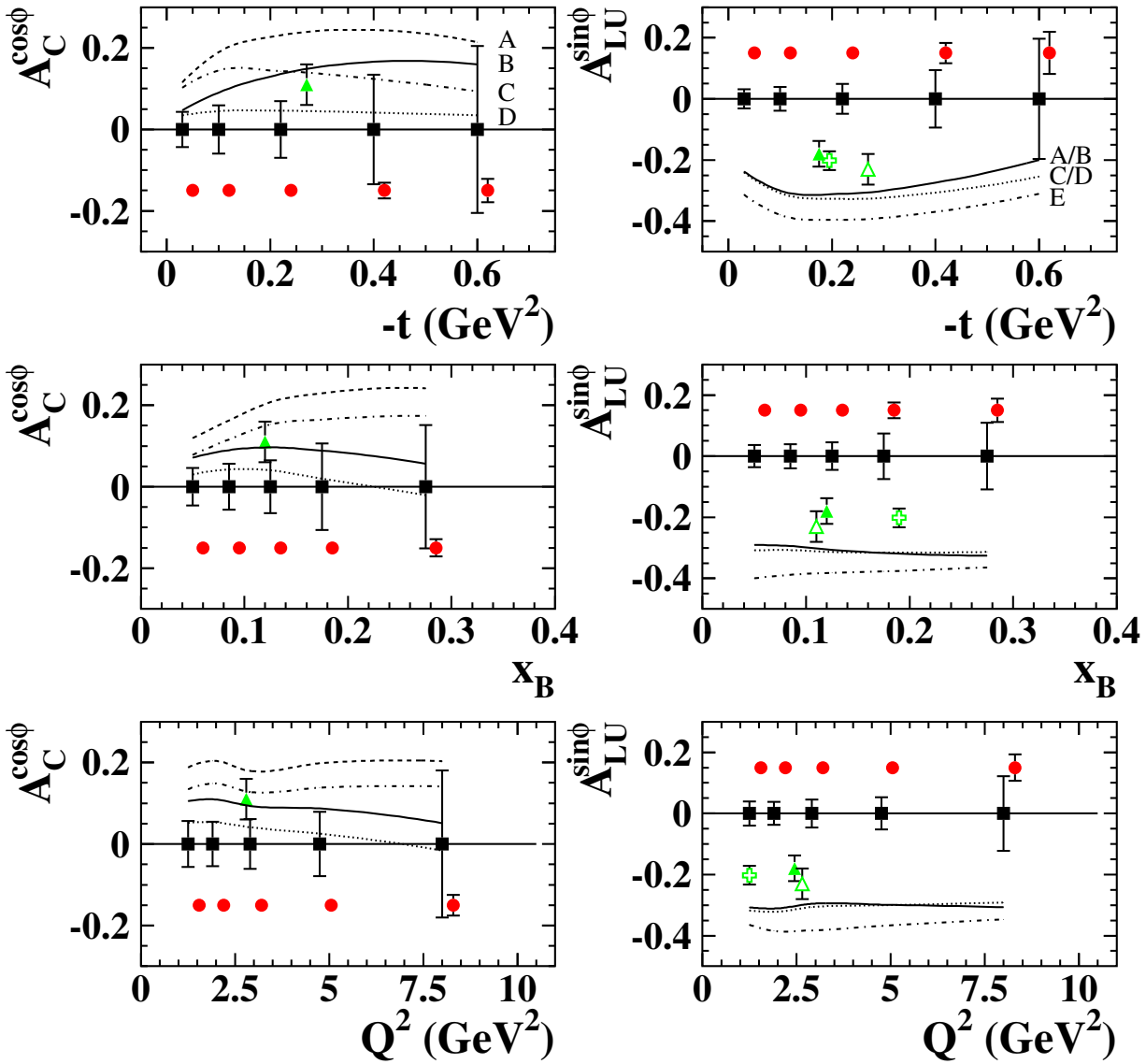
Proton Beam Charge Asymmetry





Projection based on 2 fb^{-1}.

HERMES DVCS Projections Overview



- green triangles: HERMES published
- green crosses: CLAS published
- black squares: HERMES 1996-2000
- red circles: HERMES 2005-2007 Recoil Detector 1 fb^{-1}

Summary and Outlook

- Generalised Parton Distributions offer exciting new insights into the structure of hadrons, especially spin structure and transverse location.
- The HERMES Recoil Detector
  - combines Si-detector inside beam vacuum, SciFi tracker in solenoidal magnetic field of 1 T and photon detector
  - order of magnitude more statistics
  - non-exclusive background $\sim 1\%$ and improved t-resolution
- High statistics measurements of DVCS beam spin and beam charge asymmetry incl. t-dependence.
- Currently being tested with cosmics.
- Installation in the summer of 2005; data taking will begin in the fall.

UNIVERSITY of GLASGOW