Exclusive ρ^0 production measured with the HERMES Recoil Detector

Inaugural-Disertation
zur Erlangung des Doktorgrades der Naturwissenschaften
der Justus-Liebig-Universität Gießen
des Fachbereich 07
(Mathematik und Informatik, Physik, Geographie)

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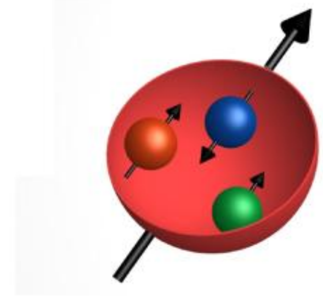
15. Juli 2010

Outline

- Motivation
  - The Spin Structure of the Nucleon
  - Generalized Parton Distributions (GPDs)
  - DVCS process
  - Hard meson electroproduction
- Hermes Experiment
  - Recoil Detector
- Exclusive ρ^0 production at Hermes with the Recoil Detector at Hermes
  - b Slope with Recoil Detector
- Outlook

The Spin Structure of the Nucleon

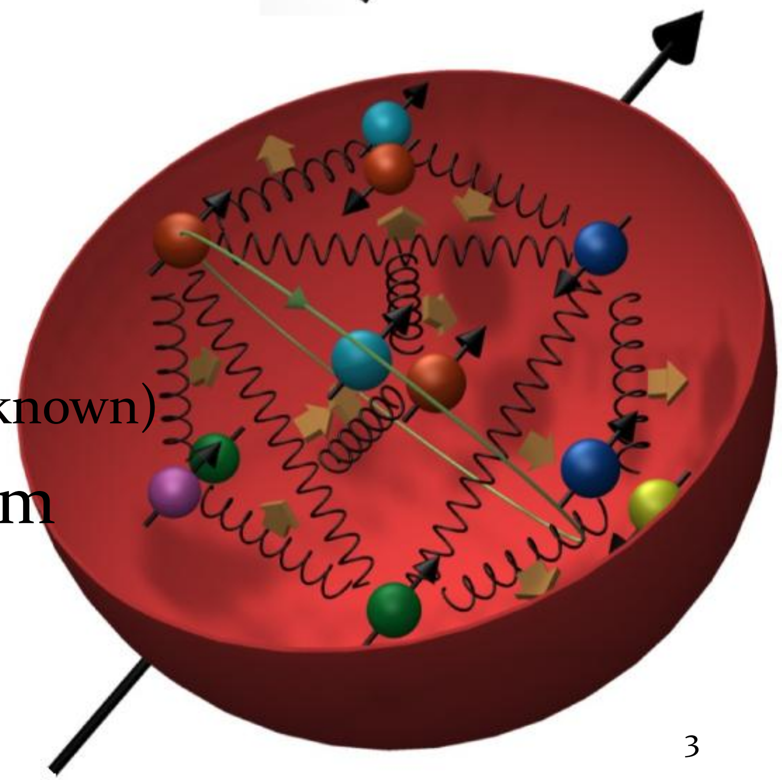
$$S_z = \frac{1}{2} = J_q + J_g = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$



- $\Delta\Sigma$ Spin of quarks
  - $\Delta\Sigma$= 0.330±0.011(theo.)±0.025(exp.)±0.028(evol.).

    Airapetian et al. [HERMES Collaboration]
    Phys. Rev. D 75, 012007 (2007)
  - $\Delta\Sigma$= 0.33±0.03(stat)±0.05(syst).

    E.M.Kabuss [COMPASS Collaboration]
    PoS Confinement 8(2008)080
- ΔG Spin of gluon (expected to be small)
- $L_{q,g}$ Orbital angular momentum (unknown)
- $J_{q,g}$ Total orbital angular momentum



How to access L_q?

Generalized Parton Distributions

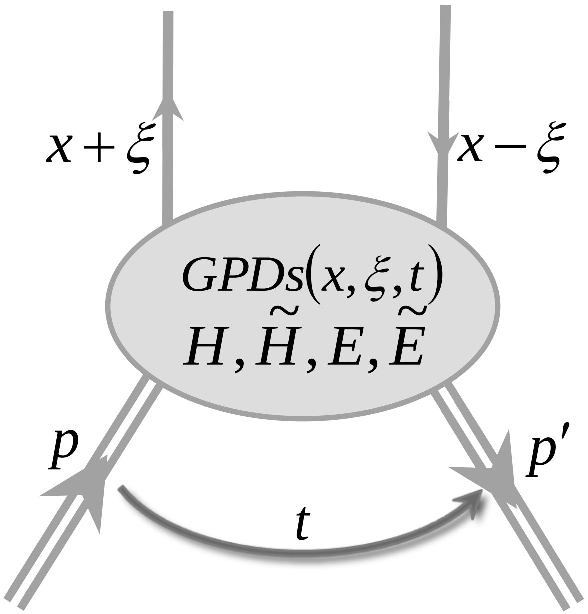
Study of hard exclusive processes
leads to a new class of PDF's

Generalized **P**arton **D**istribution

At leading twist and for a proton target
there are 4 quark GPDs:

$$H^q, E^q, \widetilde{H}^q, \widetilde{E}^q$$

possible access to
orbital angular momentum



GPDs can be accessed in **D**eeply **V**irtual **C**ompton **S**cattering (DVCS)

Generalized Parton Distributions

Nucleon Structure: GPDs $H^q, E^q, \tilde{H}^q, \tilde{E}^q$

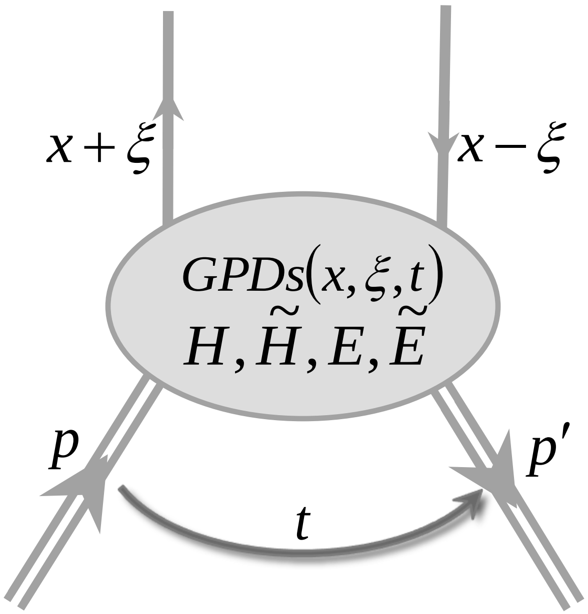
GPDs $\rightarrow$ **PDFs** (GPDs in the limit $t \rightarrow 0$)

$$H_q(x,0,0) = q(x)$$

$$\tilde{H}_q(x,0,0) = \Delta q(x)$$

PDFs characterize longitudinal momentum distributions

Longitudinal momentum fraction → **DIS**



GPDs $\rightarrow$ **FFs** (First moments of GPDs)

$$\int_{-1}^{1} dx H_q(x,\xi,t) = F_1^q(t)$$

$$\int_{-1}^{1} dx E_q(x,\xi,t) = F_2^q(t)$$

FFs characterize charge and magnetization distributions in the impact parameter space.

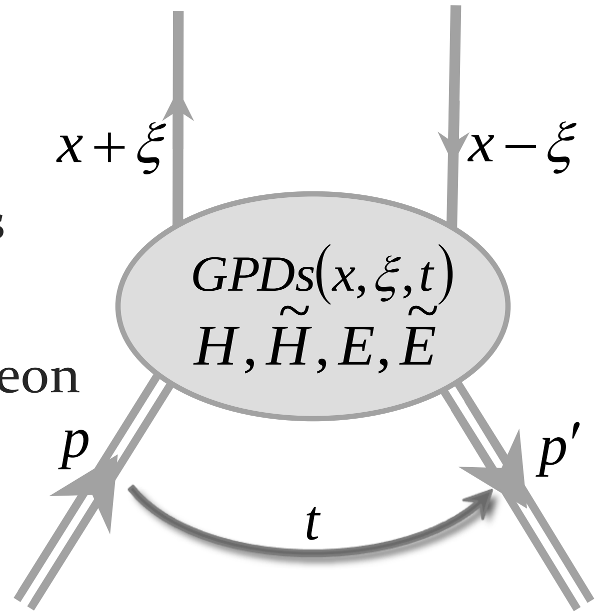
Transverse position → **Elastic Scattering**

Ji Relation

Ji, Phys. Rev. Lett. 78, 610 - 613 (1997)

$$J_q = \lim_{t \to 0} \int_{-1}^{1} x dx \left\{ H_q(x, \xi, t) + E_q(x, \xi, t) \right\}$$

$$J_g = \lim_{t \to 0} \int_{0}^{1} dx \left\{ H_g(x, \xi, t) + E_g(x, \xi, t) \right\}$$



$x \pm \xi$ parton longitudinal momentum fractions

ξ fraction of the momentum transfer

t invariant momentum transfer to the nucleon

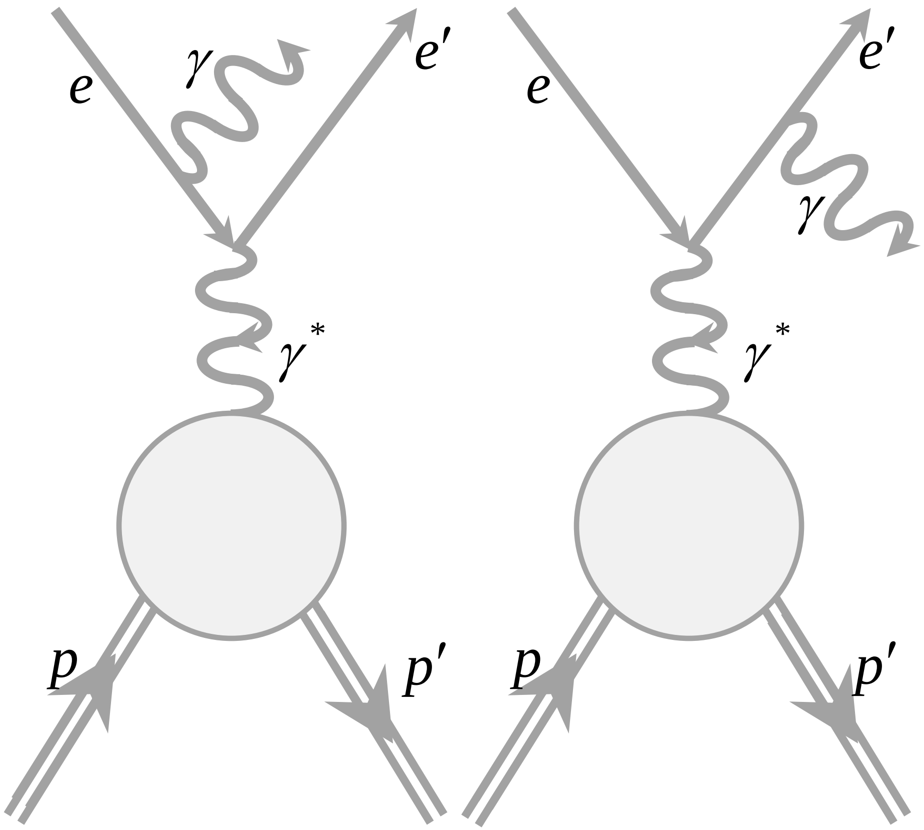
$H_q, \tilde{H}_q$ conserve nucleon helicity

$E_q, \tilde{E}_q$ flip nucleon helicity

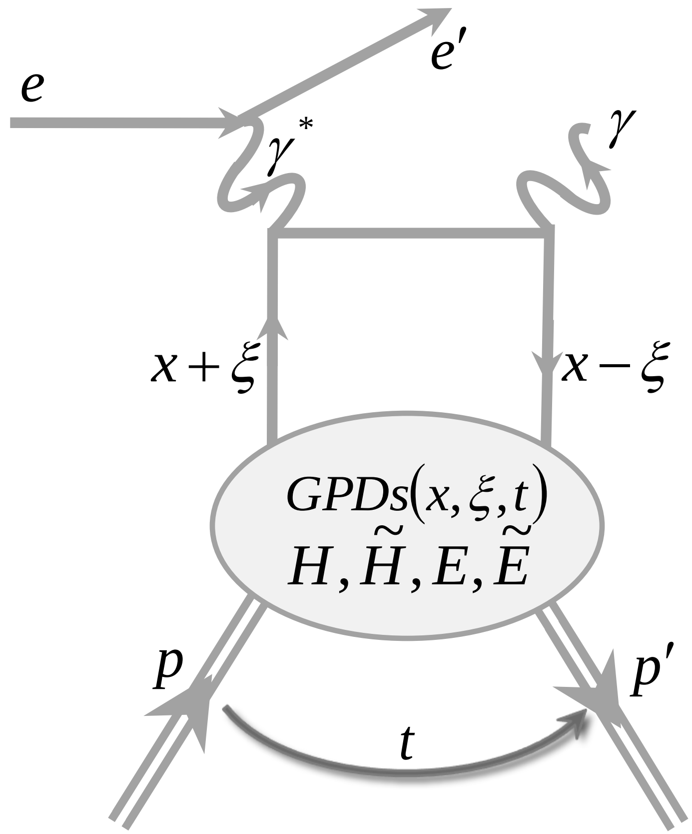
GPDs and the DVCS process

two experimentally undistinguishable processes: Same initial and final state

$$d\sigma \propto |\tau_{\mathrm{DVCS}} + \tau_{\mathrm{BH}}|^2 = |\tau_{\mathrm{DVCS}}|^2 + |\tau_{\mathrm{BH}}|^2 + \underbrace{(\tau^*_{\mathrm{DVCS}}\tau_{\mathrm{BH}} + \tau^*_{\mathrm{BH}}\tau_{\mathrm{DVCS}})}_{\text{Interference Term}}$$



Bethe-Heitler



DVCS

GPDs and the DVCS process

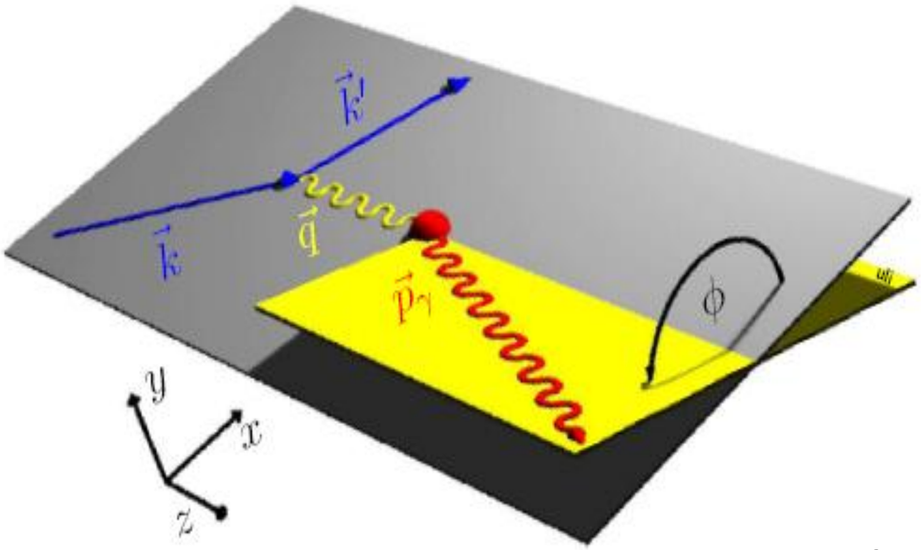
$$d\sigma \propto |\tau_{\rm BH}|^2 + \underbrace{(\tau^*_{\rm DVCS}\tau_{\rm BH} + \tau^*_{\rm BH}\tau_{\rm DVCS})}_{I} + |\tau_{\rm DVCS}|^2$$

$|\tau_{\rm BH}|^2$ calculable in QED with the knowledge of the Form Factors

$|\tau_{\rm DVCS}|^2$ is parameterized in terms of Compton Form Factors $\mathcal{H}_q, \widetilde{\mathcal{H}}_q, \mathcal{E}_q, \widetilde{\mathcal{E}}_q$
(convolutions of GPDs $H_q, \widetilde{H}_q, E_q, \widetilde{E}_q$)

At HERMES kinematics: $|\mathcal{T}_{DVCS}|^2 \ll |\mathcal{T}_{BH}|^2$

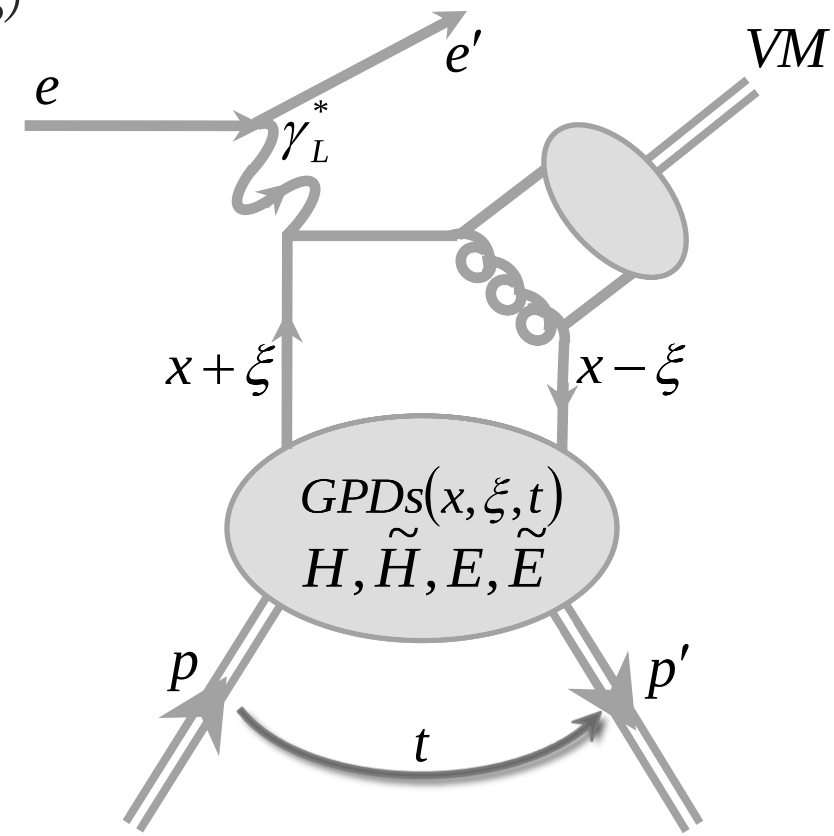
GPDs accessible through *cross-section differences* and *azimuthal asymmetries* via interference term I
(GPDs enter in linear combinations)



Exclusive ρ^o production

- the only process where the gluon contribution enters in LO
- exclusive ρ^o sensitive to $H_{q,g}$ and $E_{q,g}$ at the same order in α_s

M. Diehl, A.V. Vinnikov, Phys.Lett.B609,286-290,(2005)



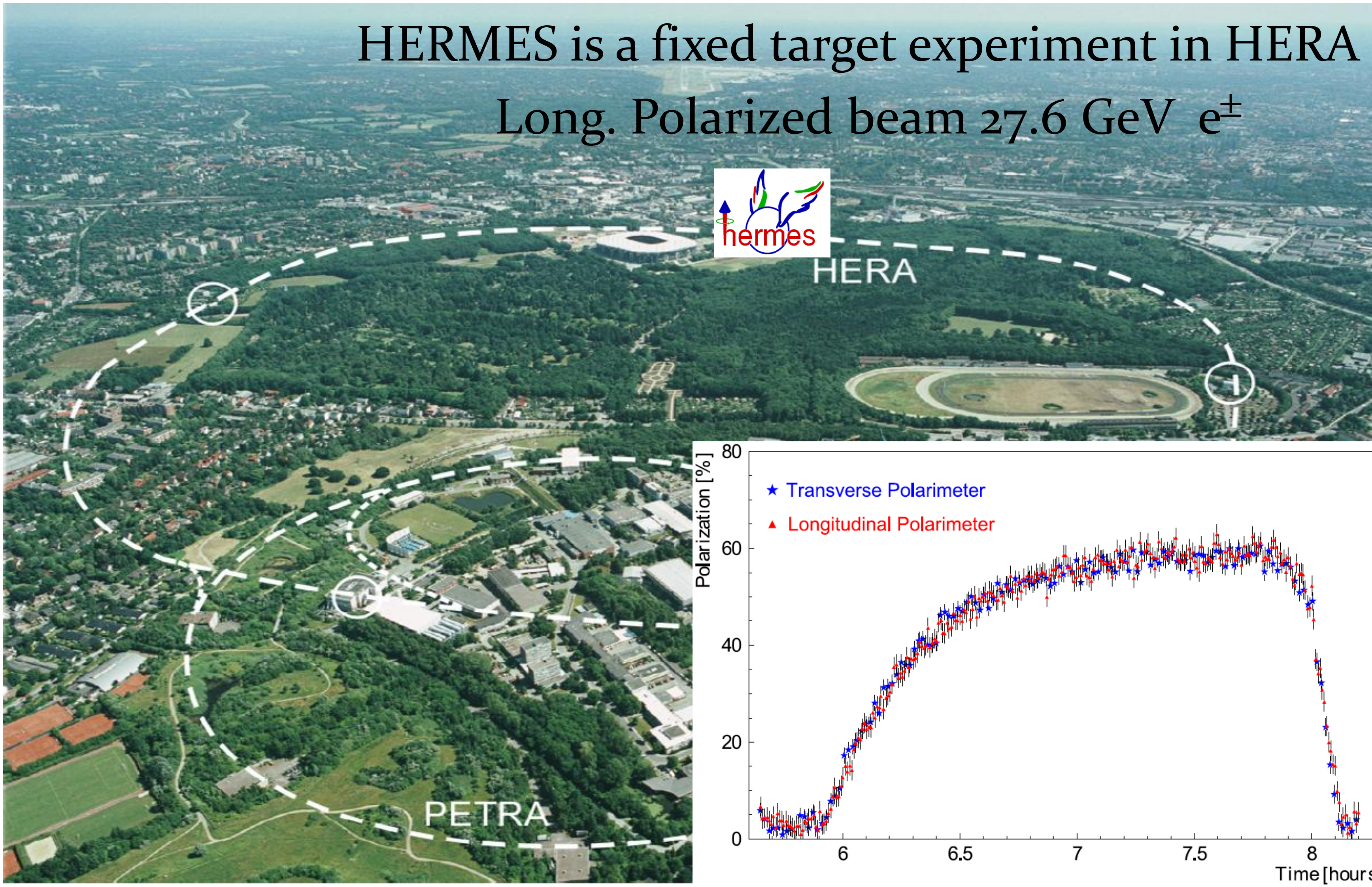
- The quark helicity is conserved in hard scattering process
- The meson acts as a helicity selector:
  - The longitudinally polarized vector meson channels are sensitive only to the unpolarized GPDs (H and E)
  - The pseudo-scalar channels are sensitive only to the polarized GPDs ($\tilde{H}$ and $\tilde{E}$)
- DVCS depends on both, the unpolarized and polarized GPDs.
- Hard meson electroproduction reactions are complementary to the DVCS process, as they provide an additional tool to disentangle the different GPDs.

K. Goeke, M V. Polyakov, M. Vanderhaeghen, Prog.Part.Nucl.Phys.47,401-515(2001)

Hermes in Hamburg - Germany

HERMES is a fixed target experiment in HERA

Long. Polarized beam 27.6 GeV $e^{\pm}$

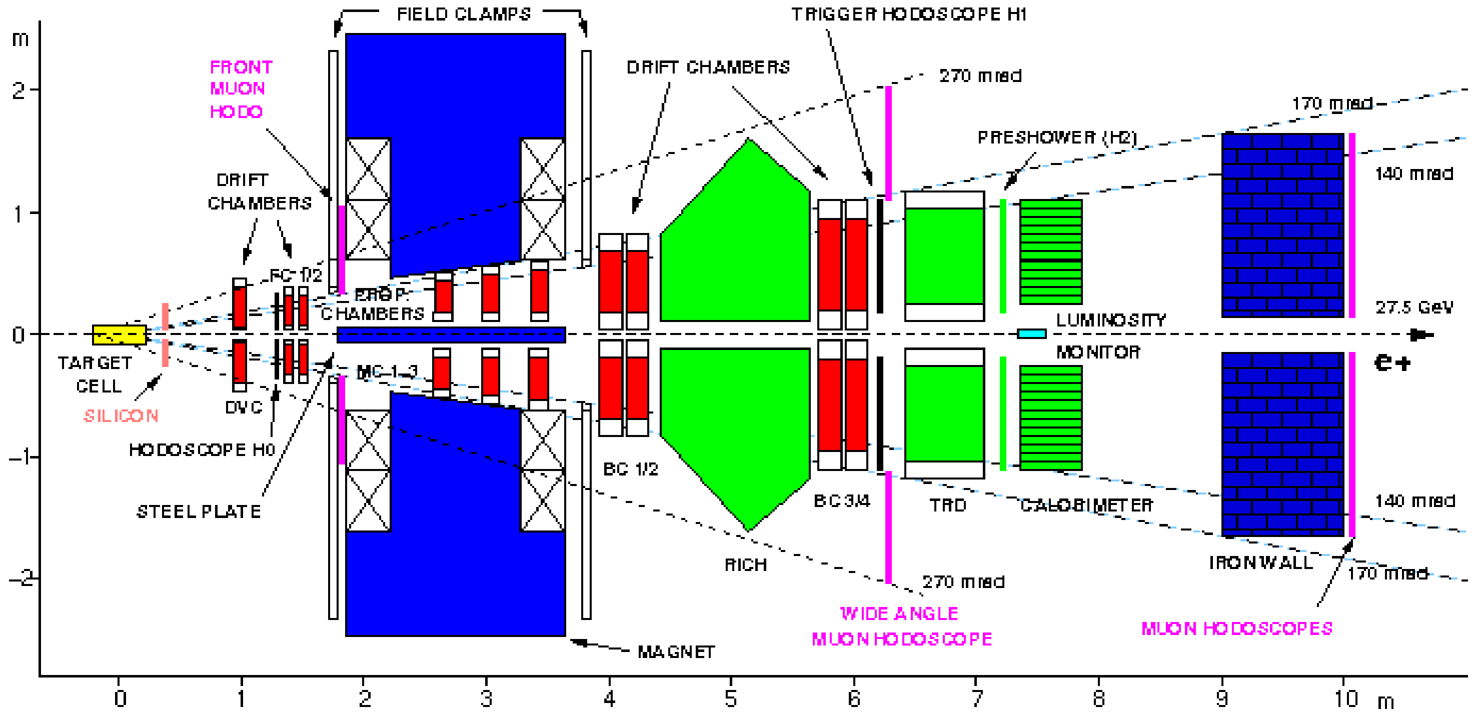


Hermes Spectrometer

HERA Beam: 27.6GeV, $e^{\pm}$, $\langle P \rangle \approx 35-55\%$

Polarized gas targets: H, D, He.

Unpolarized gas targets: H, D, N, He, Ne, Xe, Kr.



- Exactly one DIS lepton and one photon detected in the Calorimeter.
- Recoil Proton undetected

Exclusivity via Missing Mass $M_x^2 = (q + p + q')^2$

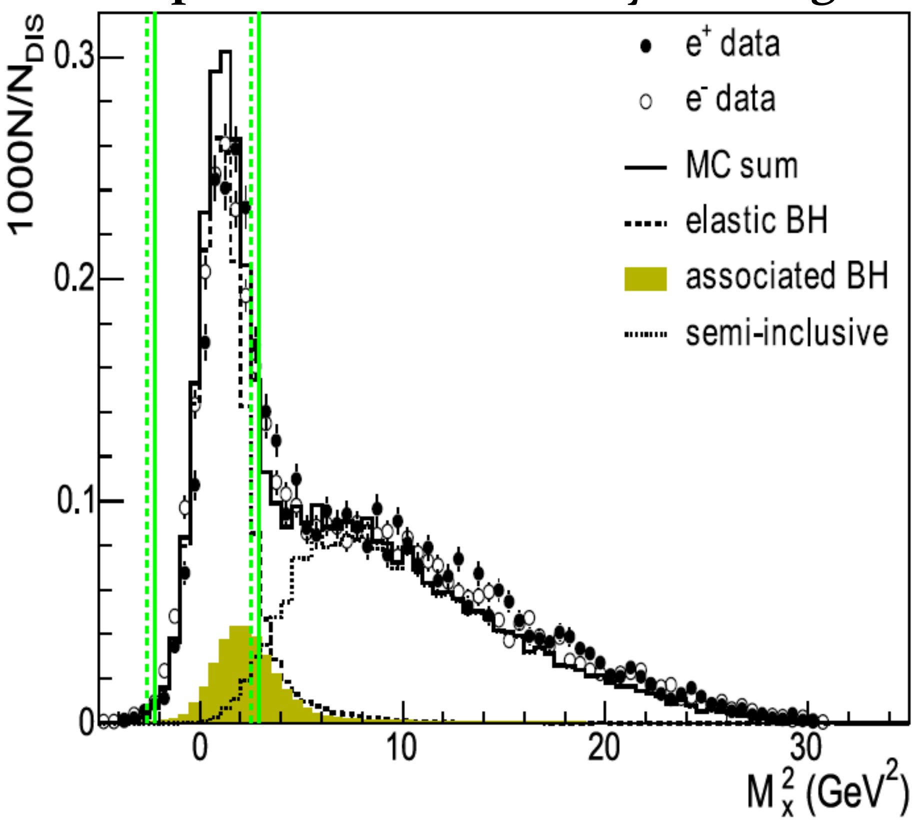
$-(1.5)^2 < M_x^2 < (1.7)^2 GeV^2$ exclusive region

Overall background contribution $\approx 15\%$ in exclusive region

DVCS at Hermes without Recoil Detector

Recoil protons identified by missing mass

$$M_x^2 = \left(P_e + P_p - \left(P_{e'} + P_\gamma\right)\right)^2$$



15% overall background

12% from associated BH production

Impossible to separate associated from elastic production **without the Recoil Detector.**

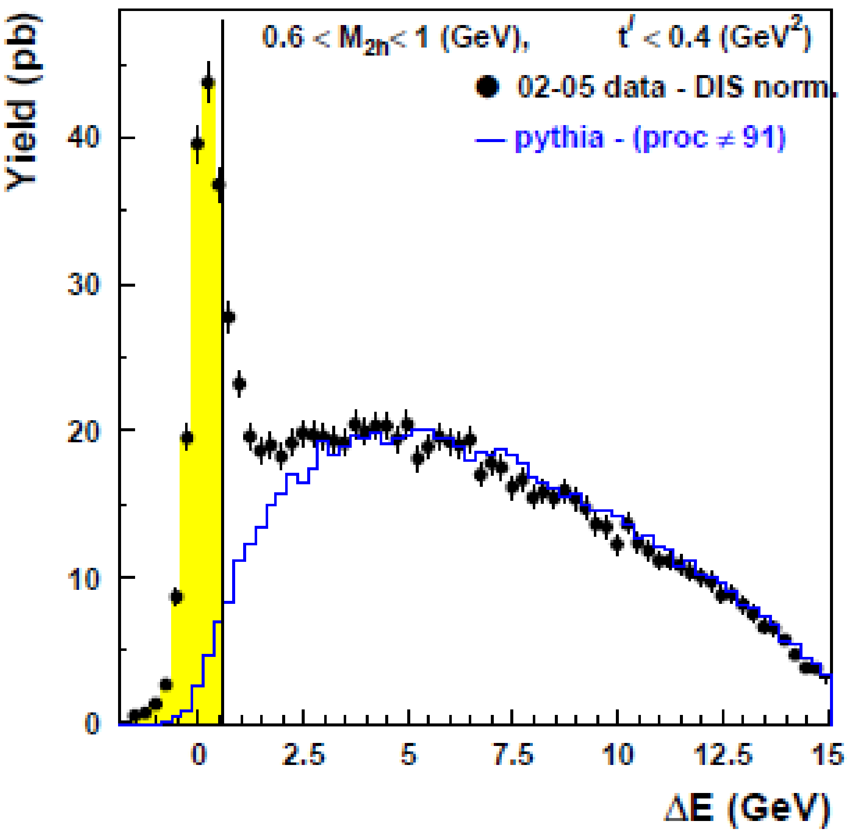
Semi-inclusive π° background corrected for the results

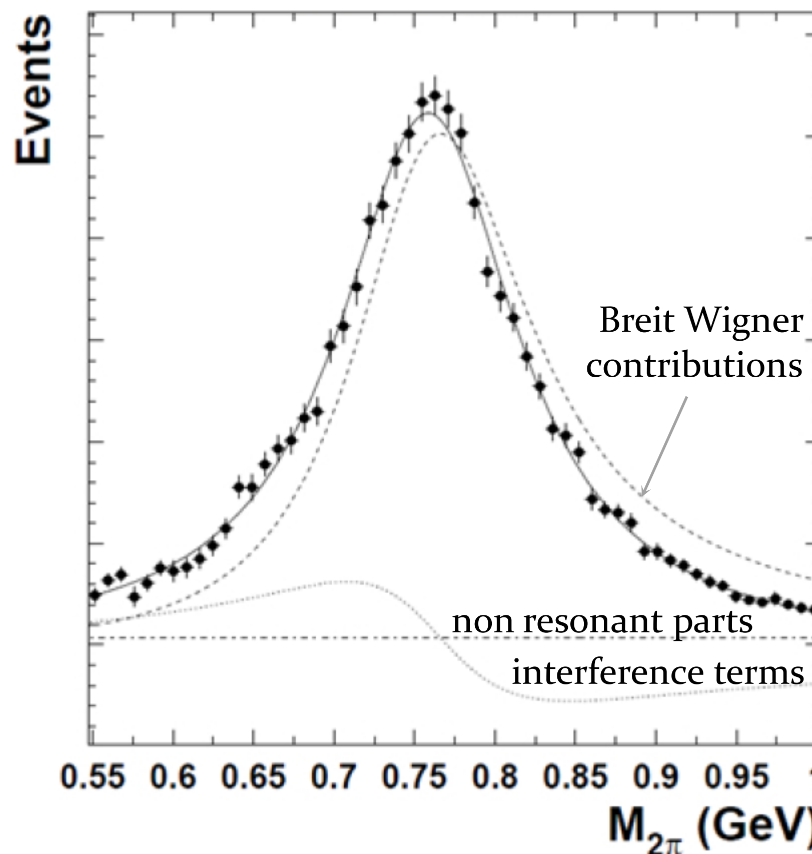
$ep \rightarrow e'p\gamma$	Elastic BH
$ep \rightarrow e'\Delta^+\gamma$	Associated BH
$ep \rightarrow e'\pi^0 X$	Semi-Inclusive BH

MC study used to estimate the uncertainties from the effect of the acceptance, bin-width, smearing and misalignments

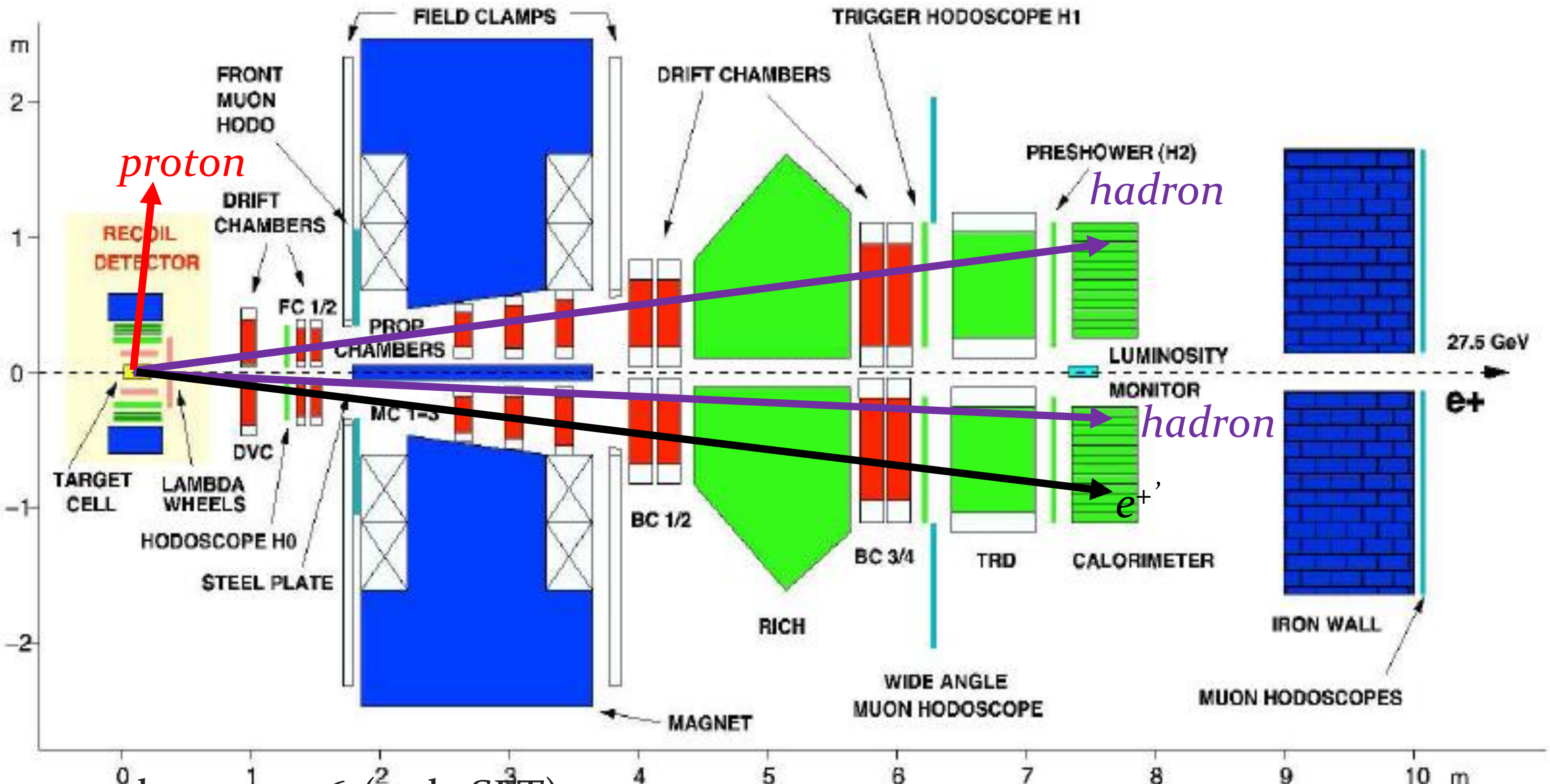
Exclusive ρ° production at Hermes without Recoil Detector. $ep \to e'p\rho^0, \rho^0 \to \pi^+\pi^-$

- exclusive events: main contribution at small values of
  $\Delta E = E_e + E_p - E_{e'} - E_\rho - E_{p'}$ and $t' = t - t_0$
- non-exclusive events ($\Delta E > \mathbf{0}$) contribute due to the experimental resolution and restricted acceptance
- Event produced in non-exclusive processes as an estimate of background size: **11%**





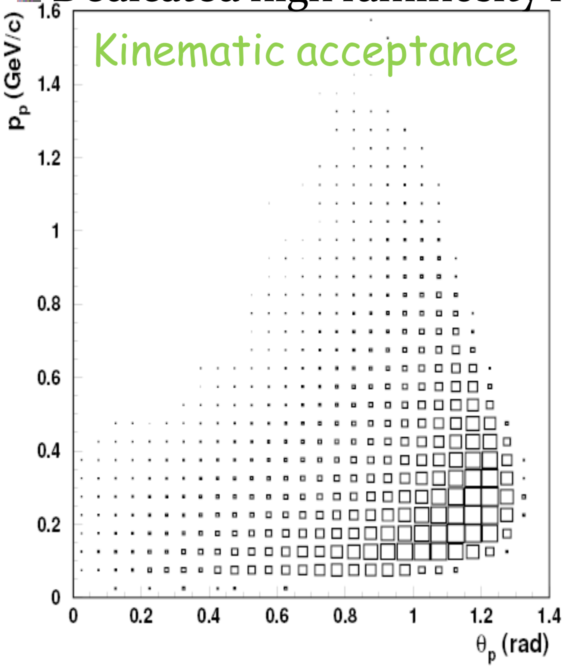
Hermes Spectrometer with Recoil Detector

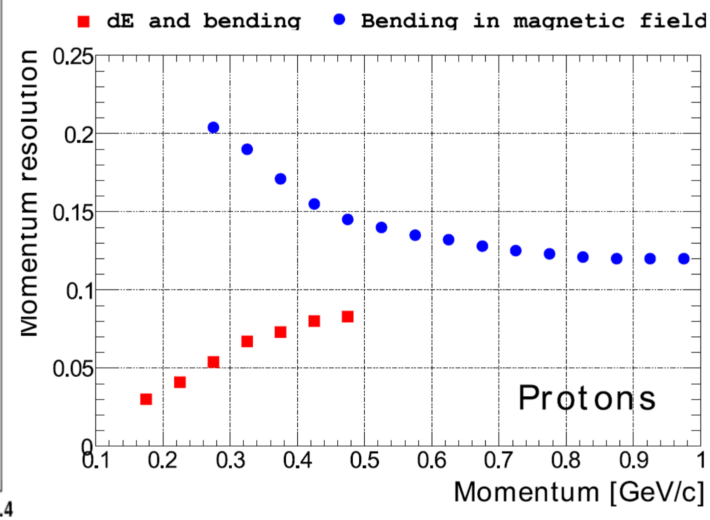


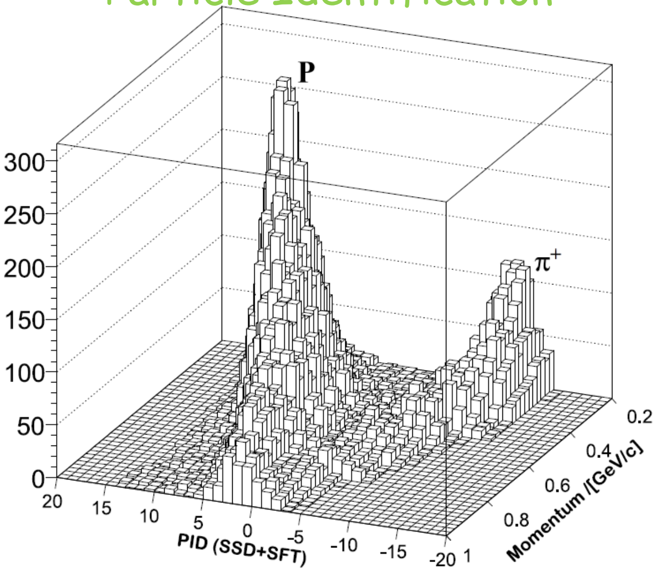
- Electron beam 2006 (only SFT)
  - Unpolarized hydrogen/deuterium target: 9.6 Mil. DIS
- Positron beam 2006/2007 (all sub-detectors)
  - Unpolarized hydrogen target: **37.9** Mil. DIS
  - Unpolarized deuterium target: 9.8 Mil. DIS
- Two beam helicities, electron and positron beam

Recoil Detector – Design Requirements

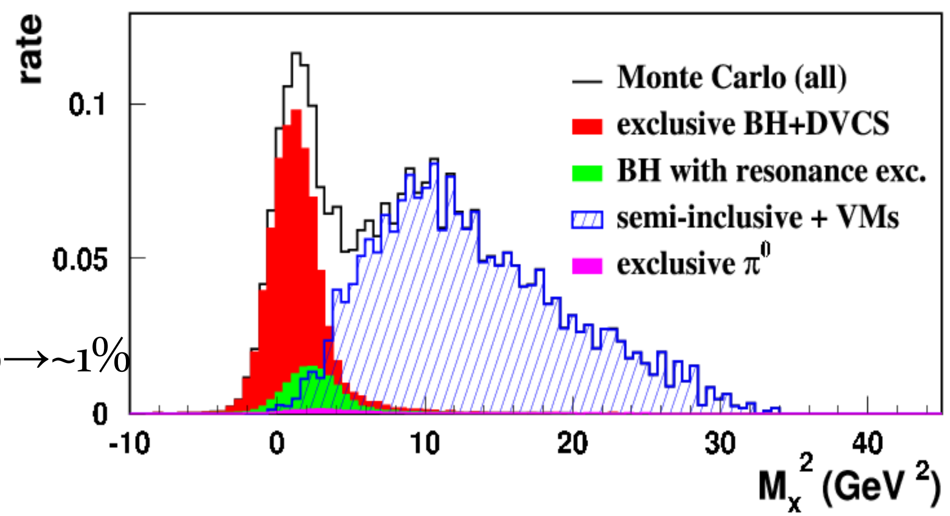
- Recoil Detector installed to identify the recoiling proton
- Dedicated high luminosity run in 2006~2007 with unpolarized hydrogen and deuterium target.



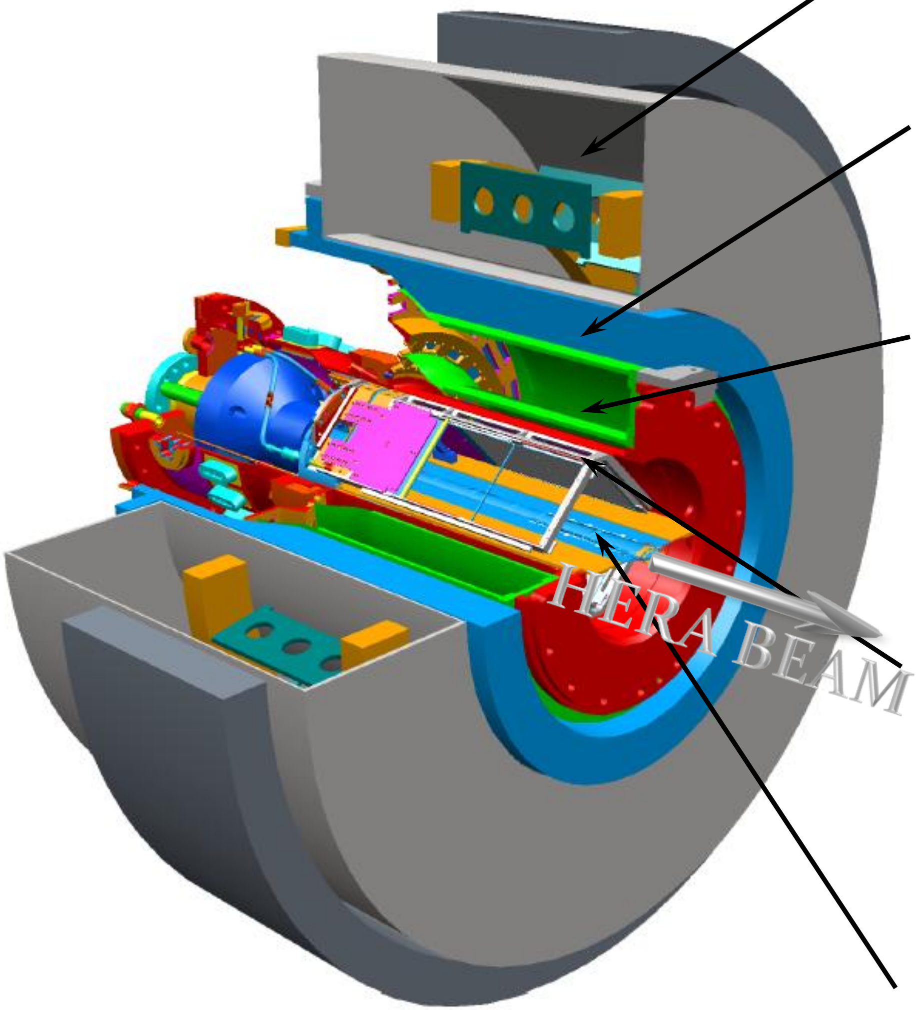




- Improve Exclusivity
  - Detect recoiling proton
  - Background suppression
    - semi-incl. BH : 5%→<< 1%
    - BH with resonance excitation: 11%→~1%



Recoil Detector at Hermes



1 Tesla Superconducting Solenoid

Photon Detector(PD)

- 3 layer of tungsten-scintillator
- detect gammas, p/π PID

Scintillating Fiber Tracker (SFT)

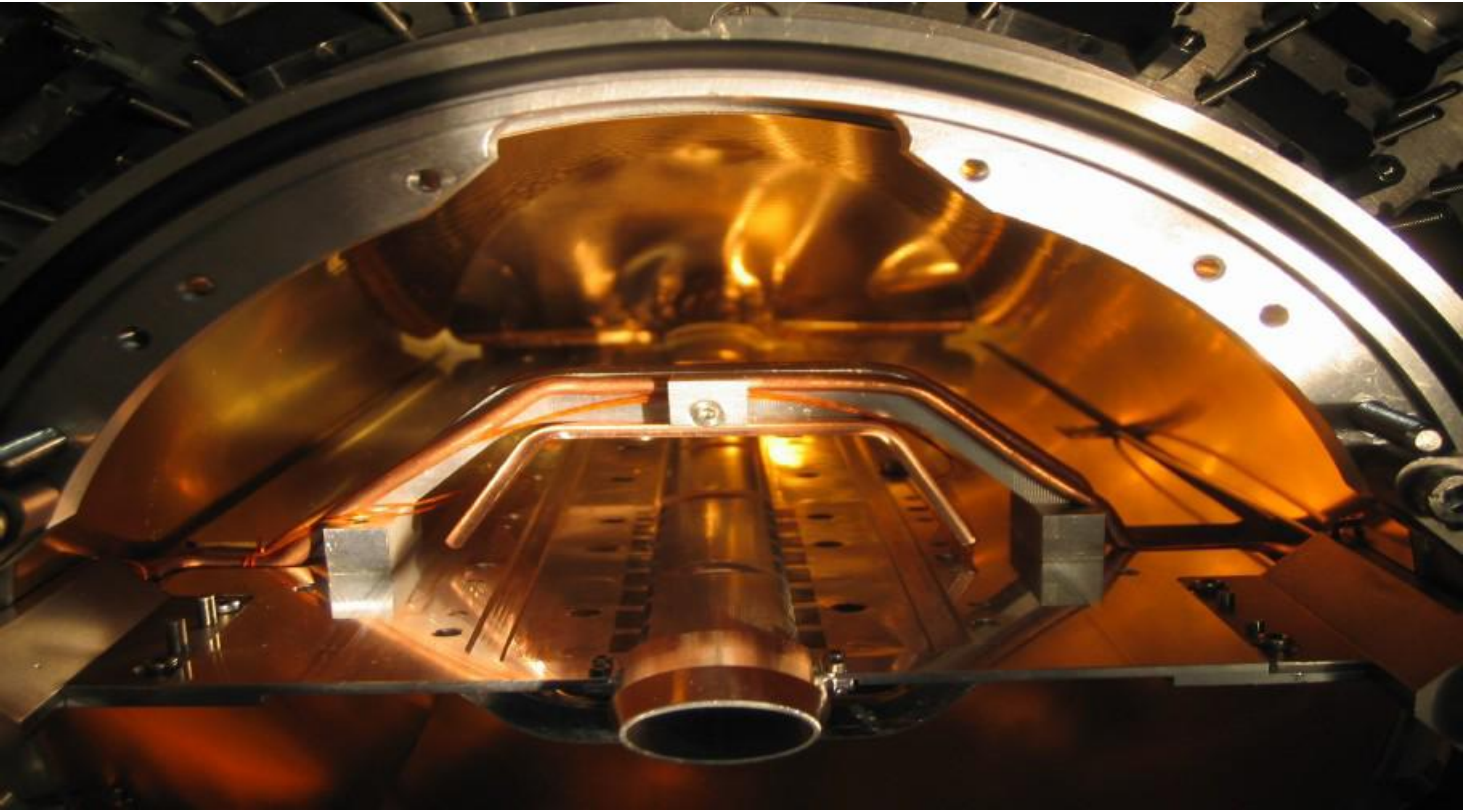
- 2 barrels of scintillation fibers with 2 parallel and 2 stereo layers
- Momentum reconstruction by bending in magnetic field

Silicon Strip Detector (SSD)

- Momentum reconstruction by energy deposit for low-momentum protons and deuterons
- Inside the HERA vacuum

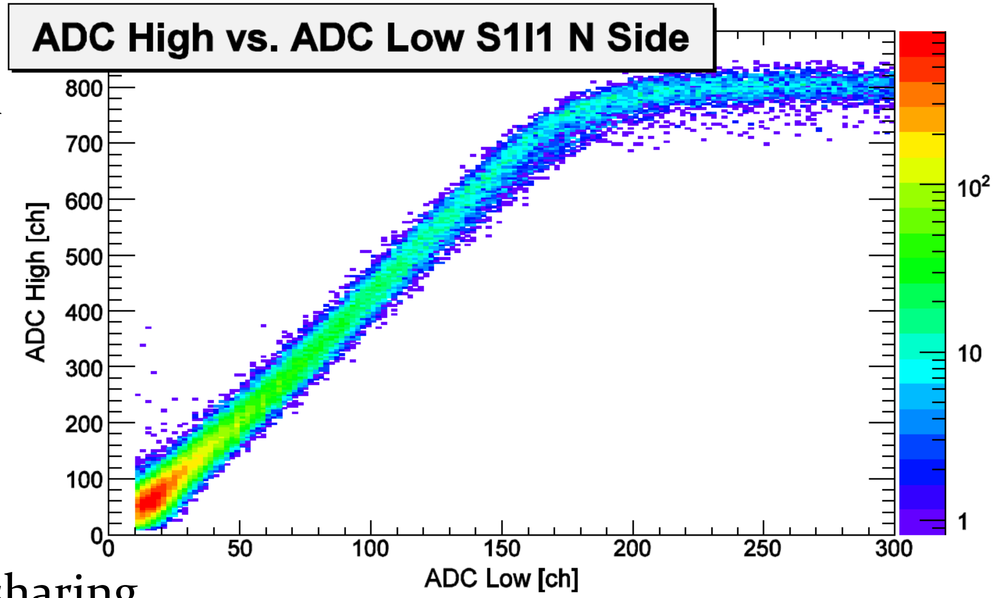
Target Cell of Unpolarized Target

Target cell inside beam pipe

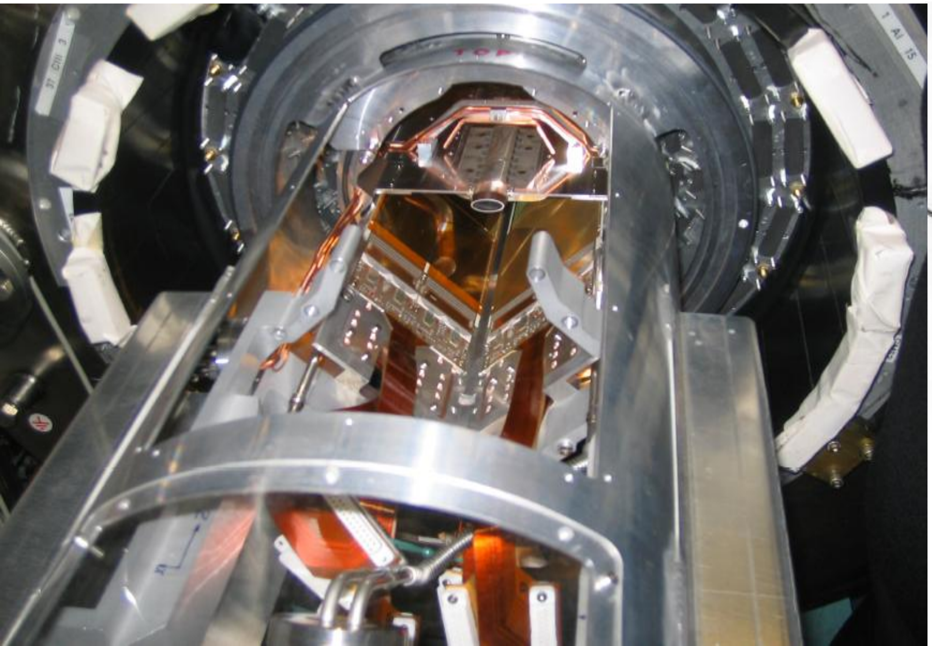


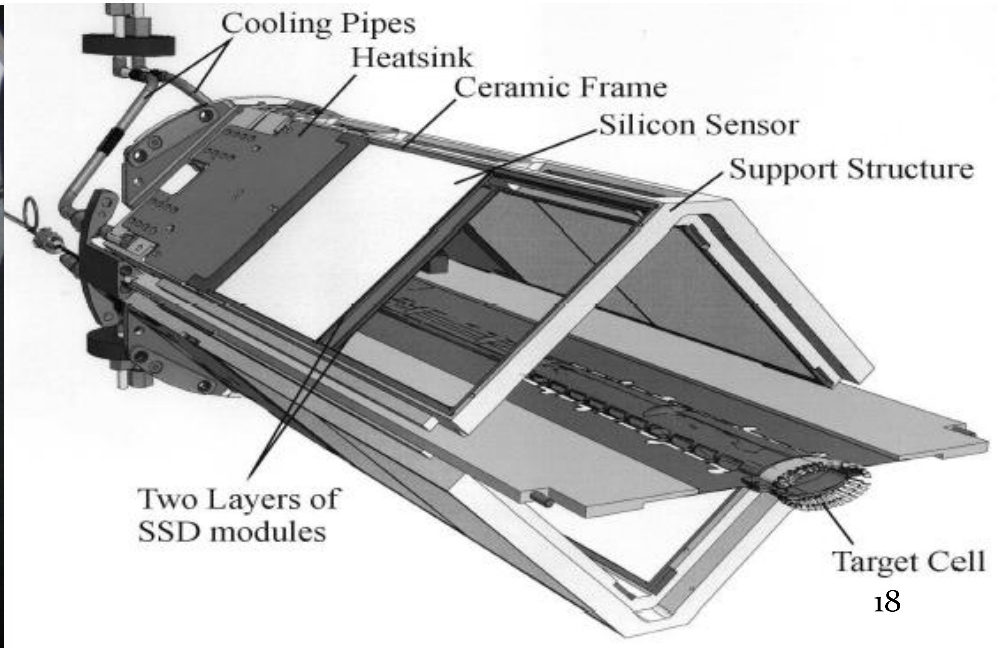
Silicon Strip Detector (SSD)

- 2 layers of double sided TIGRE sensors
- 16 TIGRE sensors operate in beam vacuum few cm close to the beam
- Size 97mmX97mm, thickness=300μm
- 128 strips per side, perpendicular w.r.t. each other, pitch=758μm
- 8192 channels in total
- Proton momentum : 135-500 MeV/c

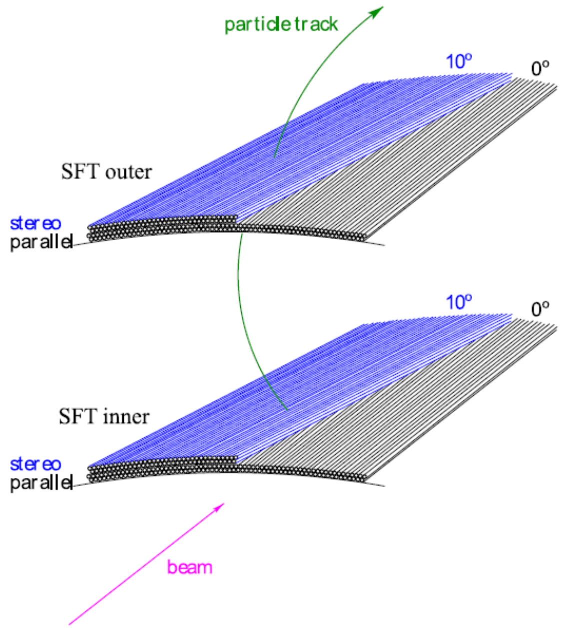


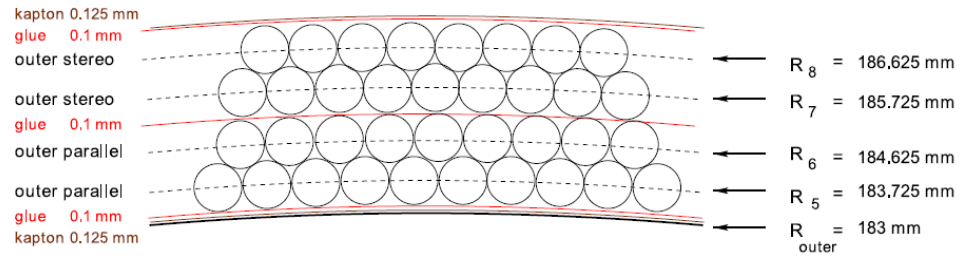
- The high and low gain yields from charge sharing

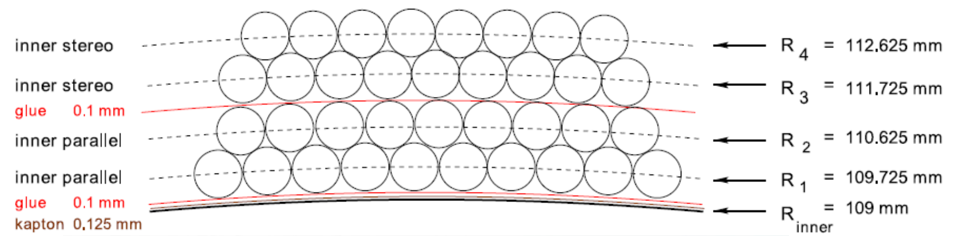




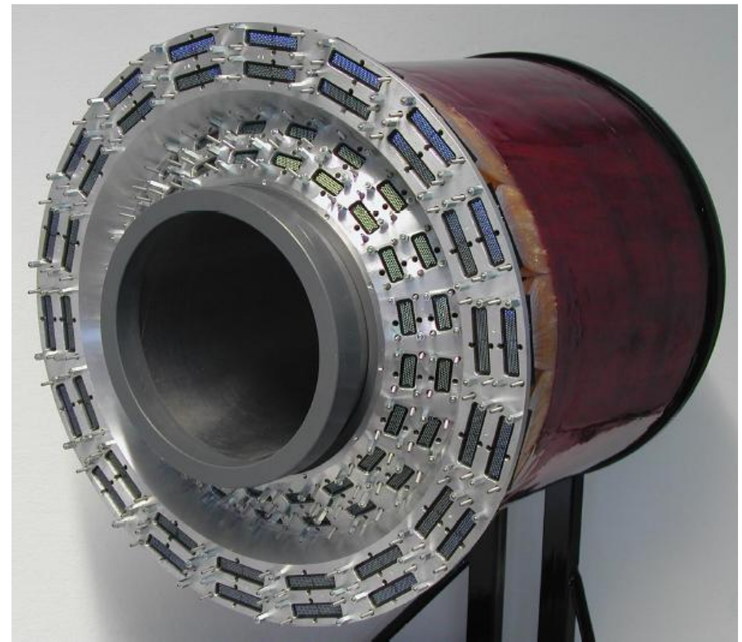
Scintillating Fiber Tracker





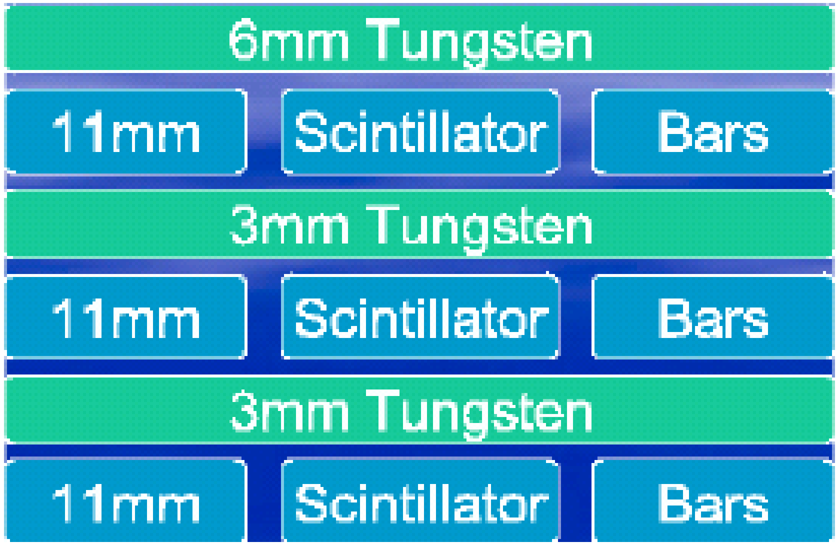


- 2 cylinders of 2X2 layers,
    - parallel and 10° stereo angle
- 1mm Kuraray fibers, mirrored ends and double cladding
    - 7010 fibers
- PMT Hamamatsu 64 channels
    - 5822 Read Out Channel
- Proton momentum 250-1200 MeV/c

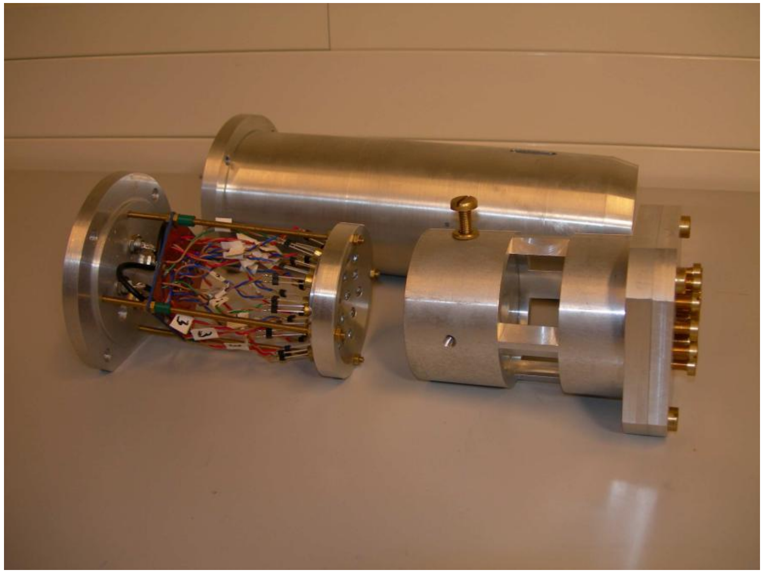


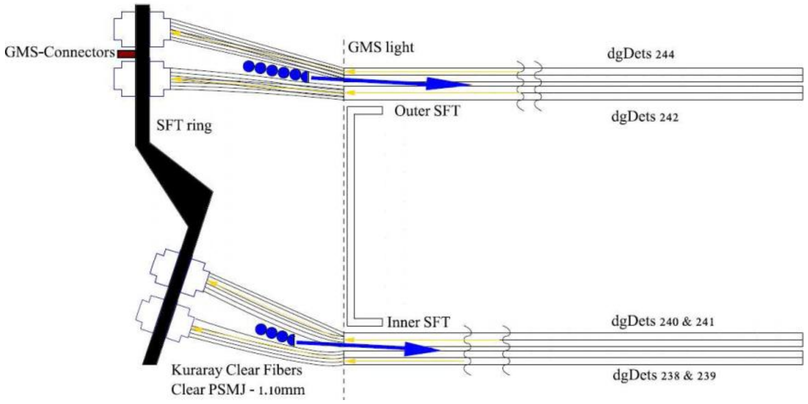
Photon Detector

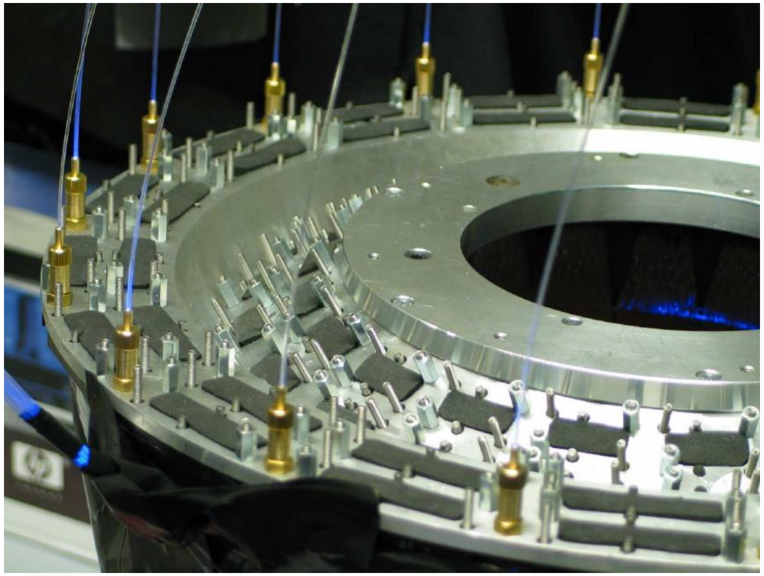
- 3 layers of Tungsten/Scintillator
  - A layer parallel to beam line,
    B and C layer stereo under +45°/-45°
- Strips: 2X1X28cm³
- same PMTs as for SFT are used
- Main purpose
  - 1γ from π° decay
  - Reconstruct π° if 2 γ's detected



Gain Monitoring System

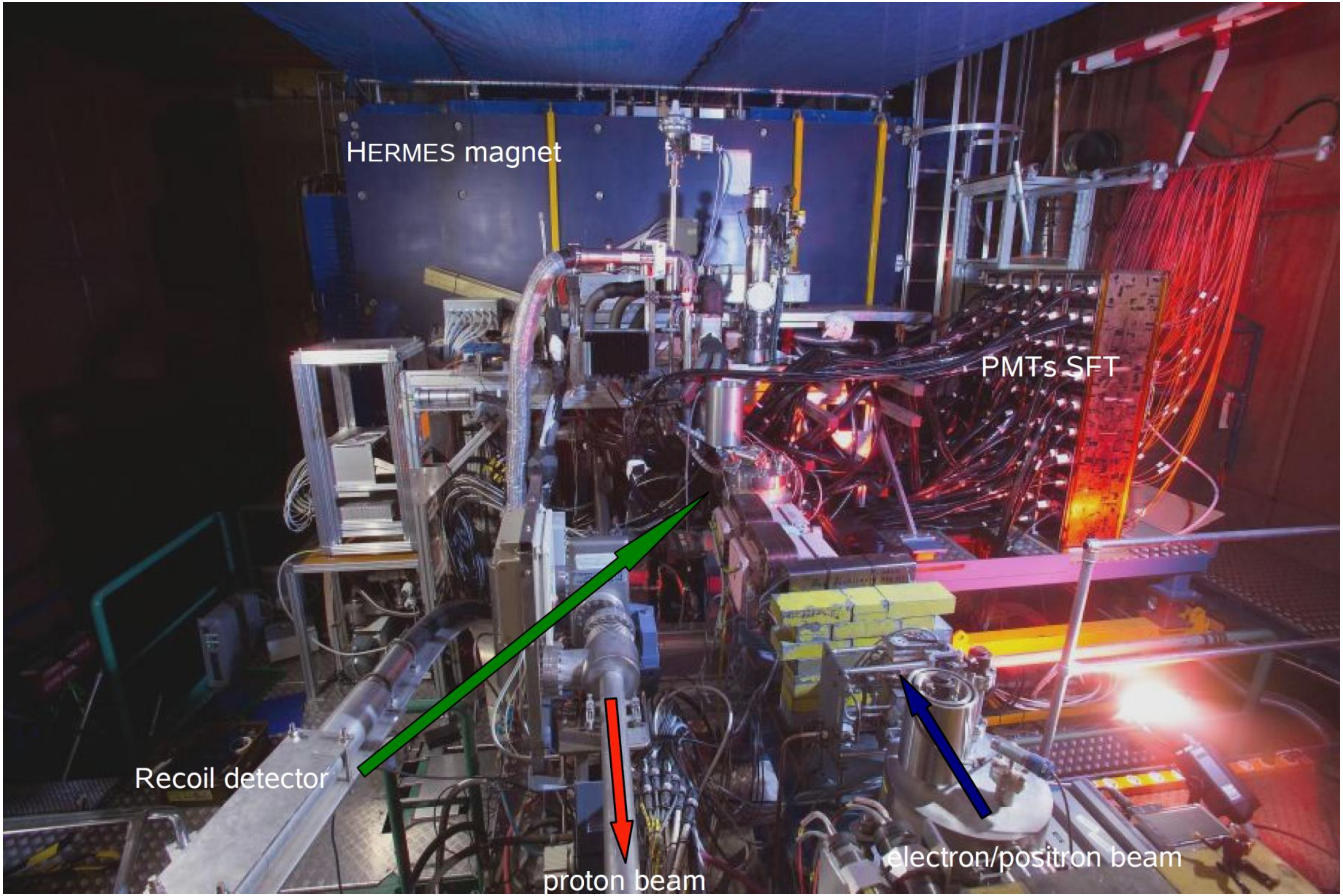






- Light source containing 19 blue LEDs
- CAEN C529 LED driver module
- The stability monitored by:
  - Philips Photonics 1911 reference PMT
  - α-source surrounded by a Yap scintillator crystal

Recoil Detector area



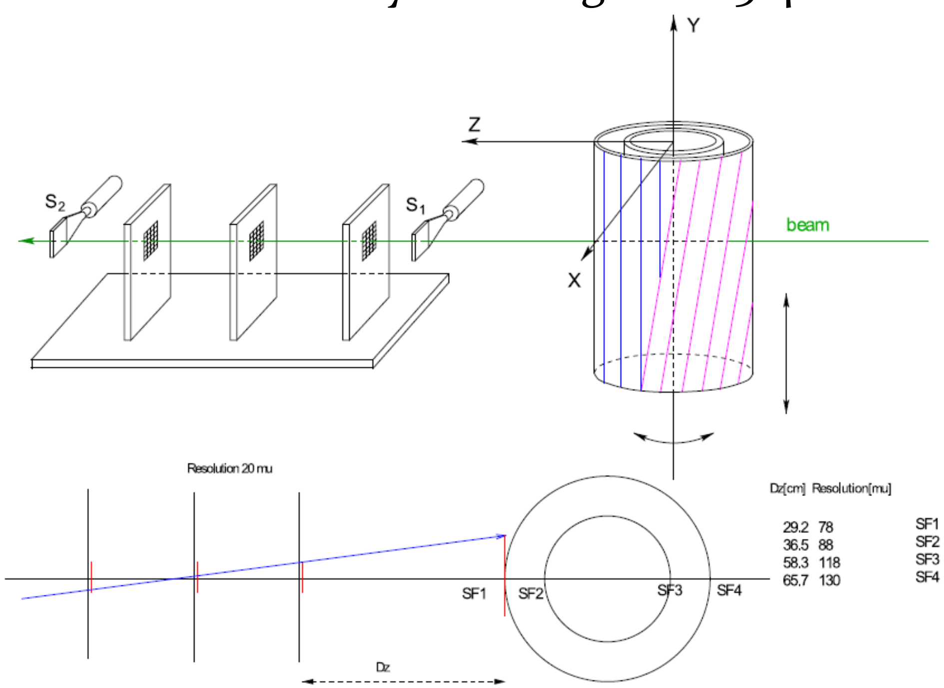
Scintillating Fiber Tracker performance

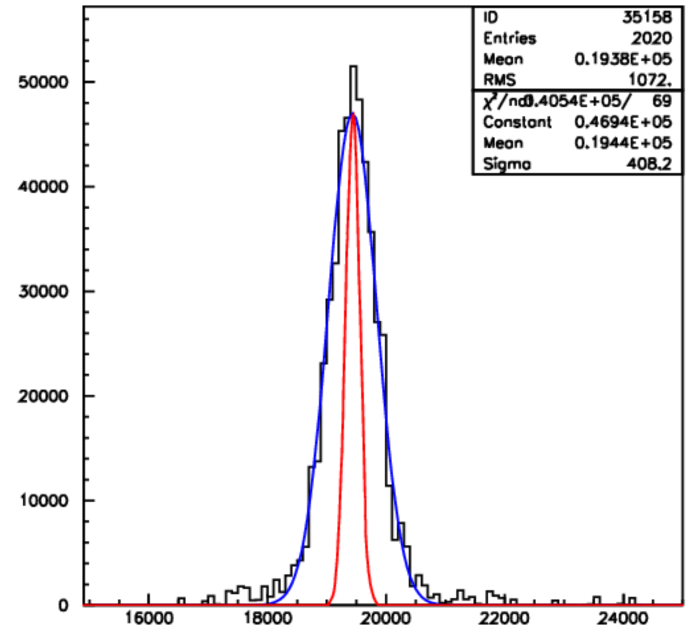
Alignment at Desy22 electron

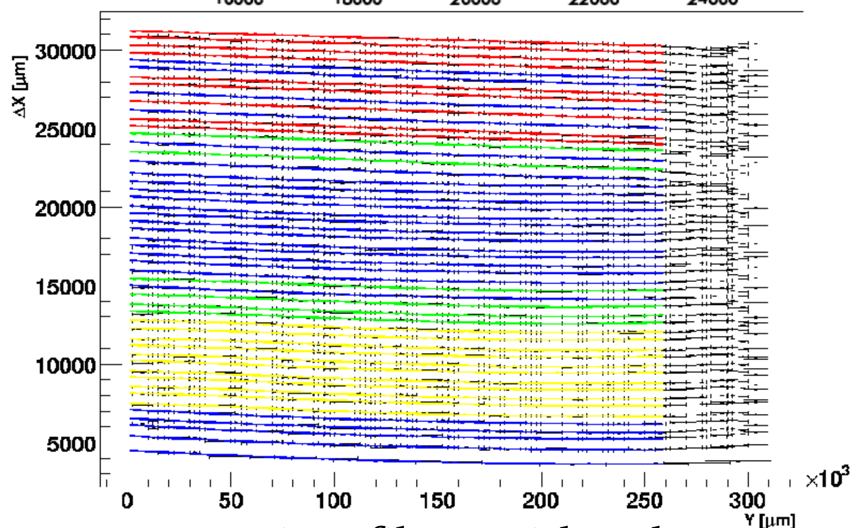
- 5.5 GeV e+/e-test beam

ZEUS Telescope System resolution of 100μm

  - Three silicon detector of 32×32mm²
  - Two plastic scintillators 40×40mm²
- Data taking setup
  - 15 runs at different y positions
  - 30 angular positions of 6° difference
    - total number of runs: 15x30=450runs
  - 150 runs for the calibration and the pedestal
- Residual distribution yields a sigma of 50μm



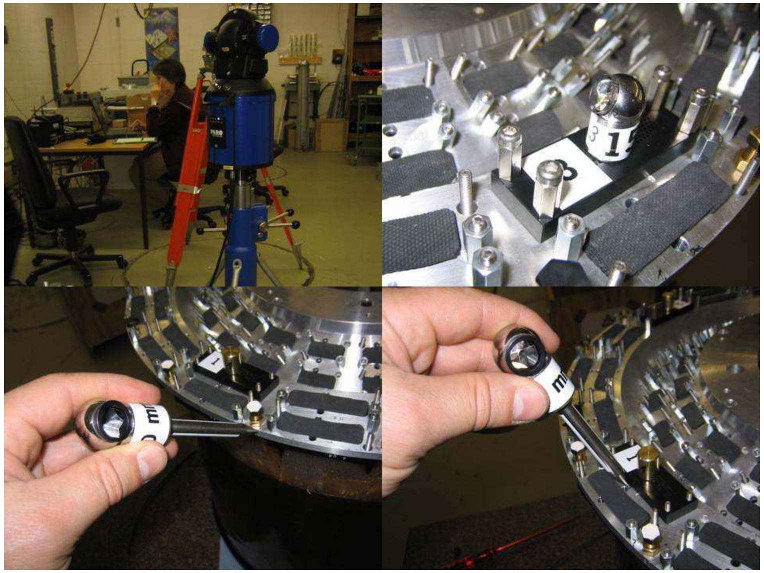




parameterizes fibers with polynoms

Scintillating Fiber Tracker performance

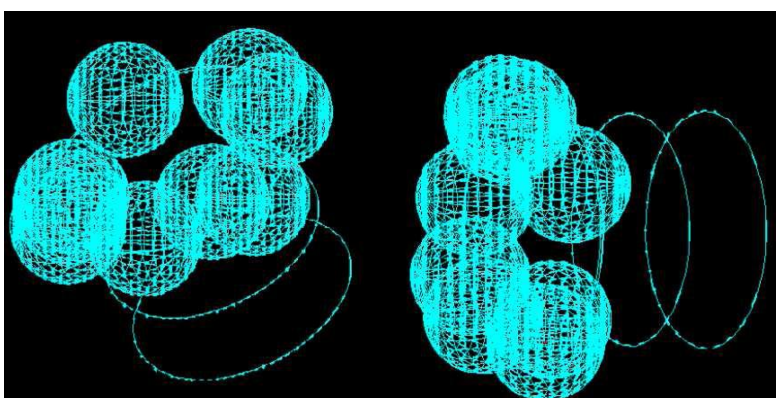
Reference Marks and measurements

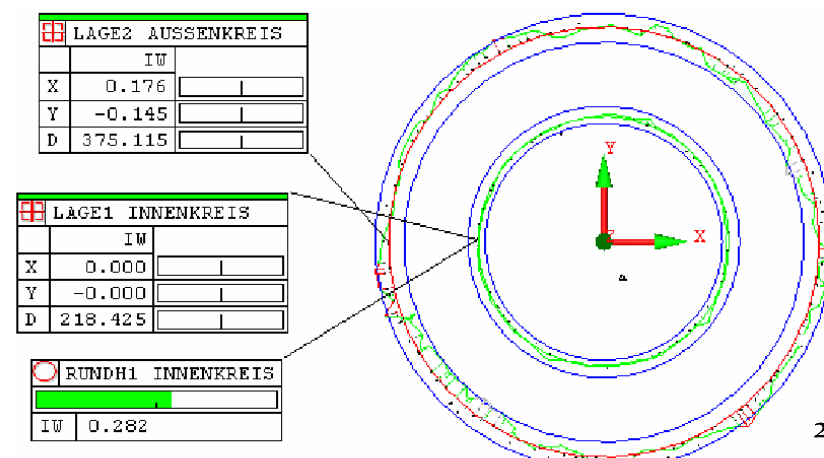


FARO-Laser tracker

Mechanical measurement

- Concentricity: x+0.176mm and y–0.145mm
- Eccentricity ε=0.282

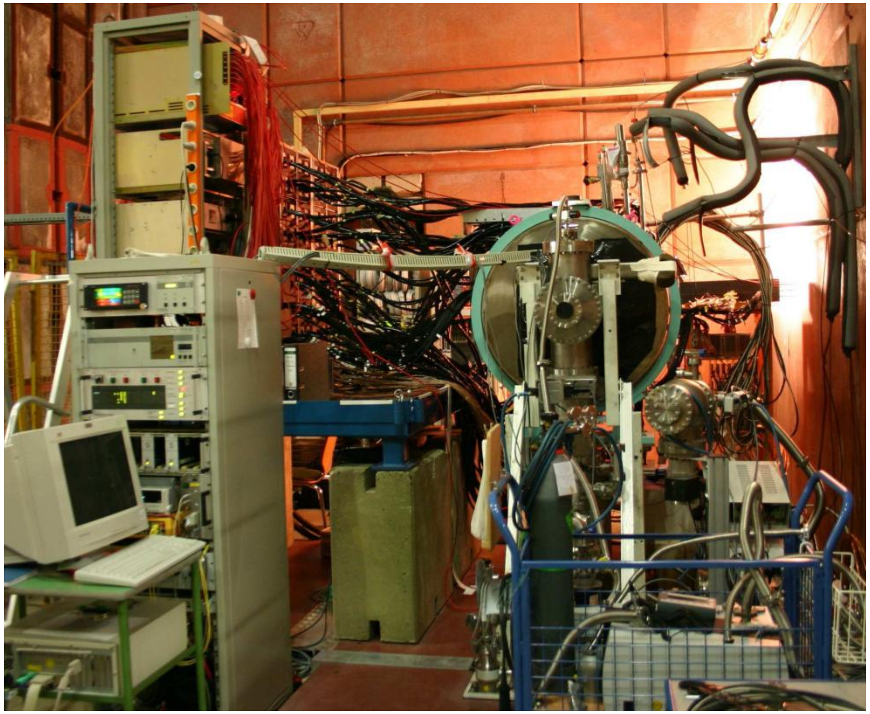


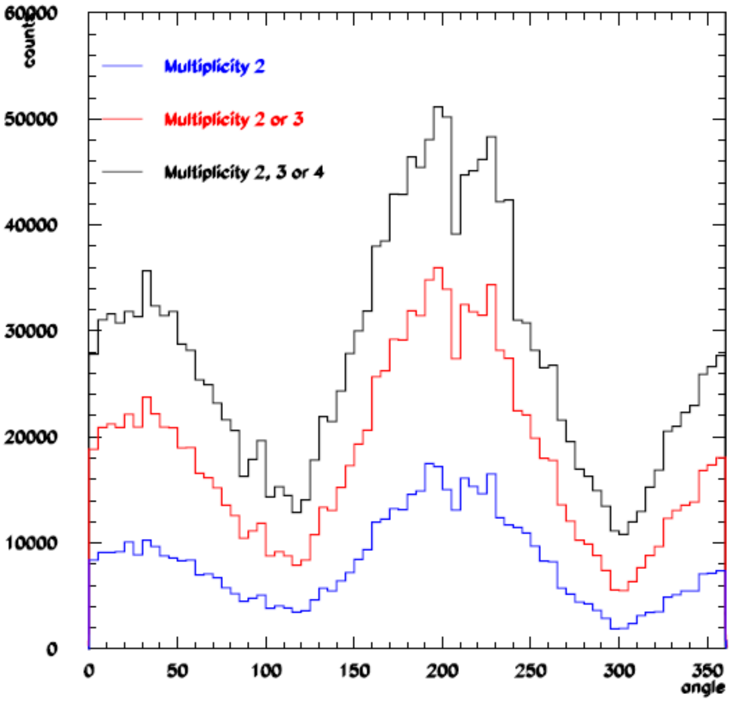


Scintillating Fiber Tracker performance

Cosmic test run

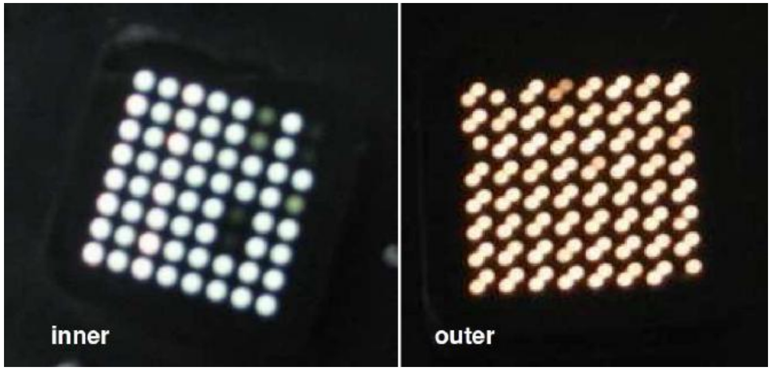
- Study the calibration of sub detector
  - MIP / First PE peak
- Alignment optimized by using cosmic rays
- Cross check of the internal SFT alignment.
- Verification of the mapping.

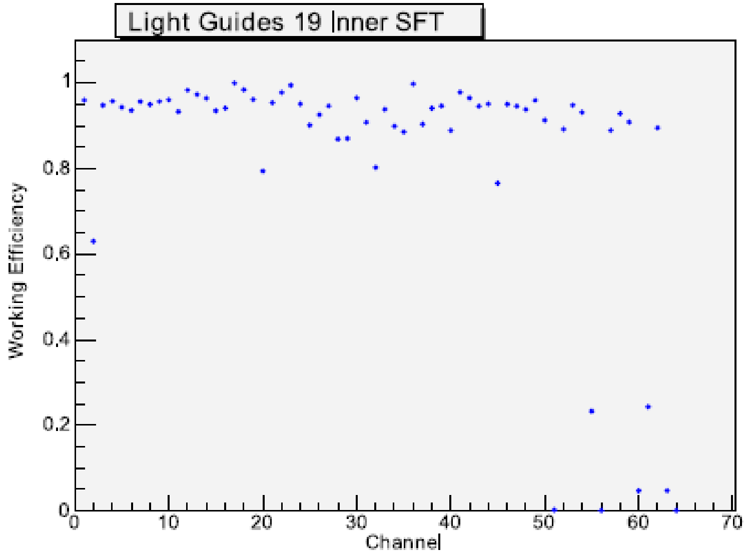


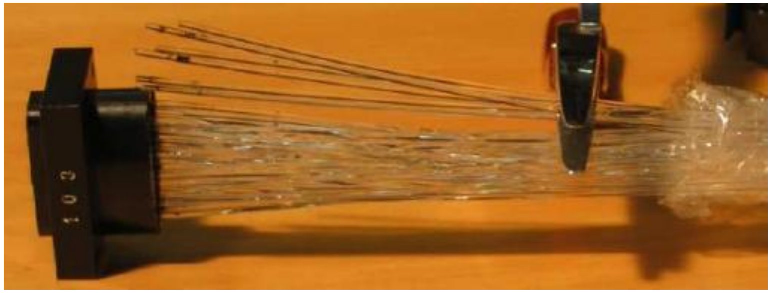


Scintillating Fiber Tracker performance

Test and repair of the Light Guides



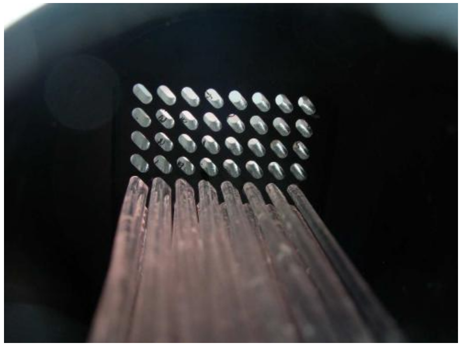


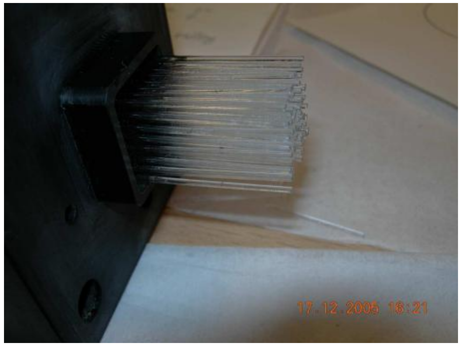


- The light guides were installed and reinstalled
- The relative transmission efficiency

$$\varepsilon_{rel} = \frac{Signal_{Channel}}{Signal_{Maximun}}$$

- The number of affected channels
  - 167 (or 6.3%) for the inner SFT
  - 80 (or up to 3.7%) for the outer SFT

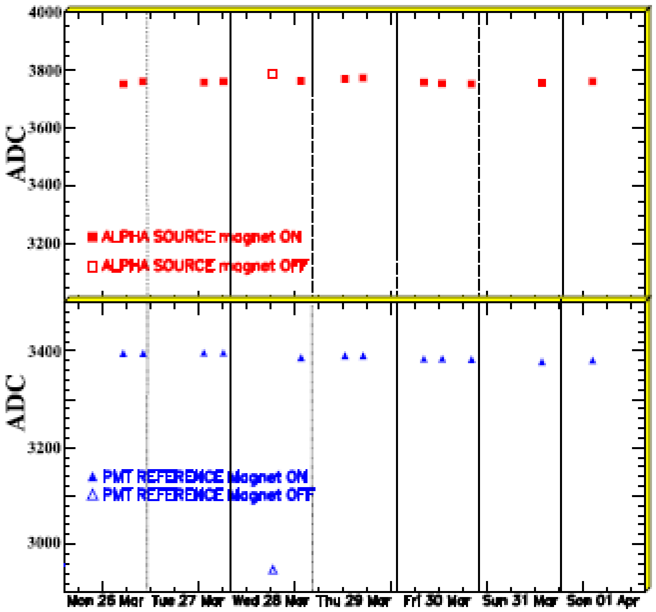


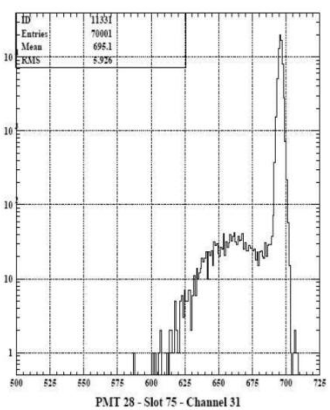


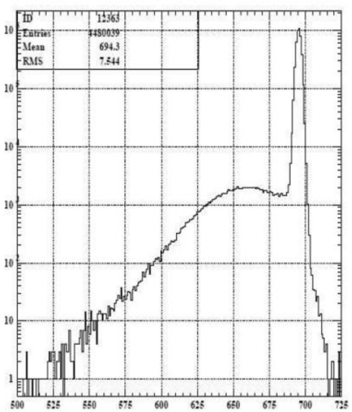
Scintillating Fiber Tracker performance

Servicing measurements

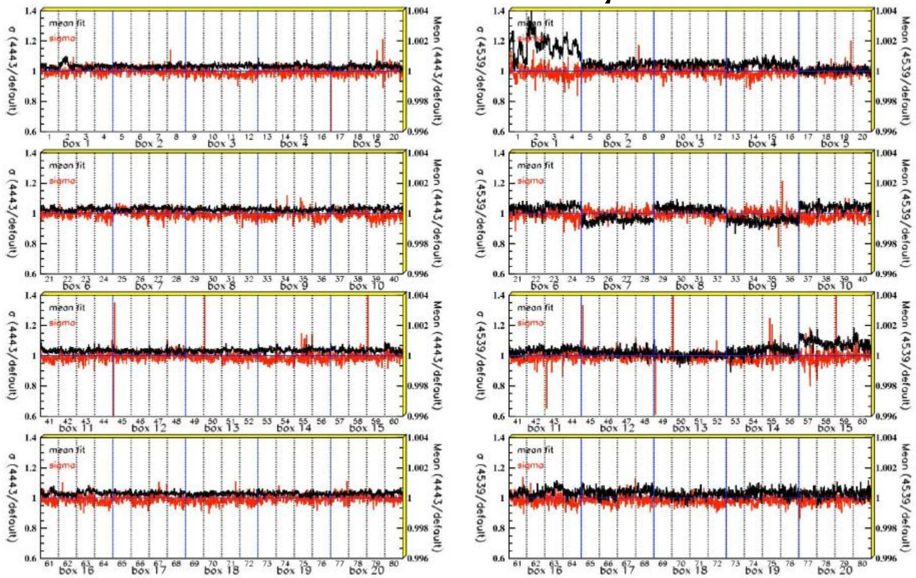
GMS system & PMT reference

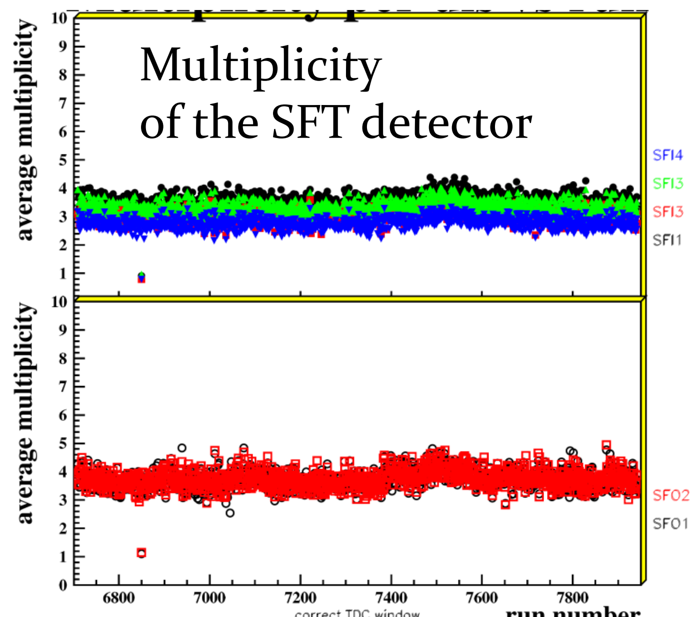






Pedestal stability

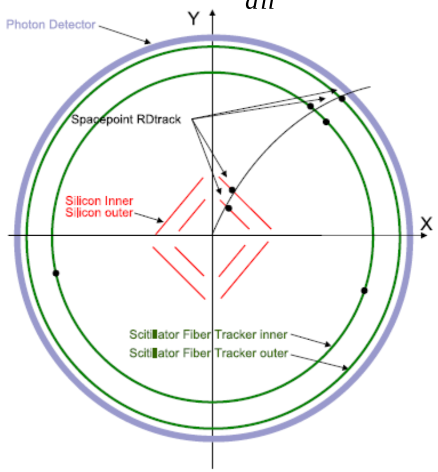


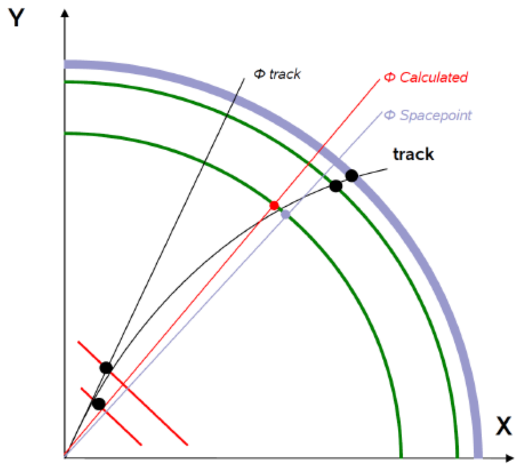


Scintillating Fiber Tracker Efficiency

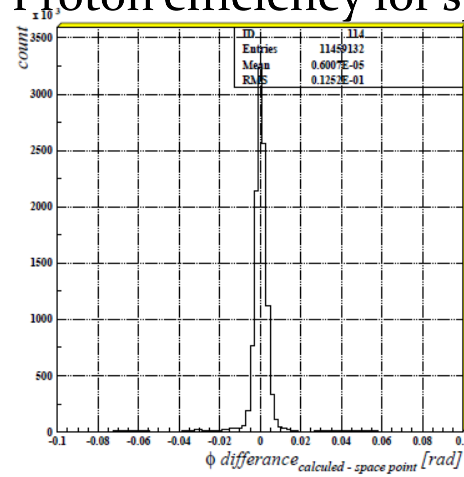
$$Efficiency\ : \varepsilon = \frac{N_{\det}}{N_{all}}, N_{all} = N_{\det} + N_{no\_\det}$$

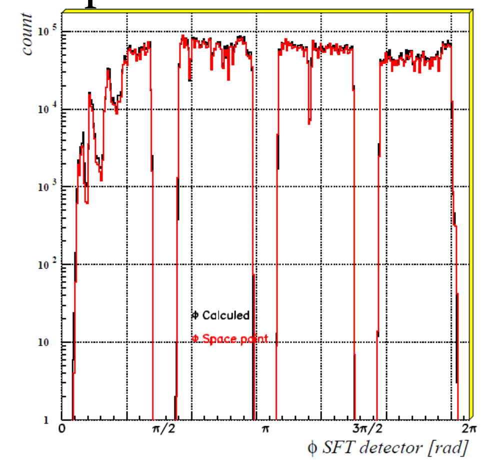
$$\Delta\varepsilon = \frac{\sqrt{N_{all}/(N_{all}-1)}}{N_{all}^2} \cdot \sqrt{\left(N_{no\_\det}^2 . N_{\det}\right) + \left(N_{no\_\det} . N_{\det}^2\right)}$$





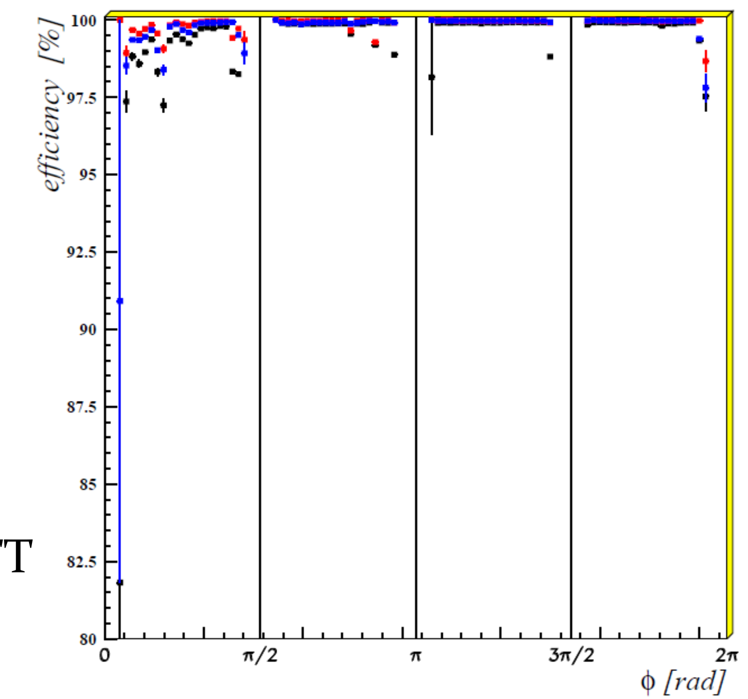
Proton efficiency for space point in inner SFT





- Proton efficiency in inner SFT
  - higher than 99.5% for all quadrants
- Efficiency stability inner SFT, the fluctuation less than 1% in 2007
- Less efficiency for positive pions

- Efficiency problem in first quadrant of the outer SFT
  - Huge n° Ghost hits



Selection of exclusive ρ° events

Kinematical cuts

$p_{\pi^+} + p_{\pi^-} < 0$ Selects hadrons with opposite charge.

$|p_e| > 3.5 GeV/c$ Momentum of lepton

$W^2 < 7.0 GeV^2$ Energy of vector meson

$y < 0.85$

$m_{kk} > 1.04 GeV$

$0.6 GeV < m_{\pi\pi} < 1.0 GeV$

$-t' < 0.4 GeV^2$

$0.5 GeV^2 < q^2 < 7.0 GeV^2$

Geometrical cuts

$|x_{calo}| < 175 cm$, $30 cm < y_{calo} < 108 cm$ } Position in the Calorimeter

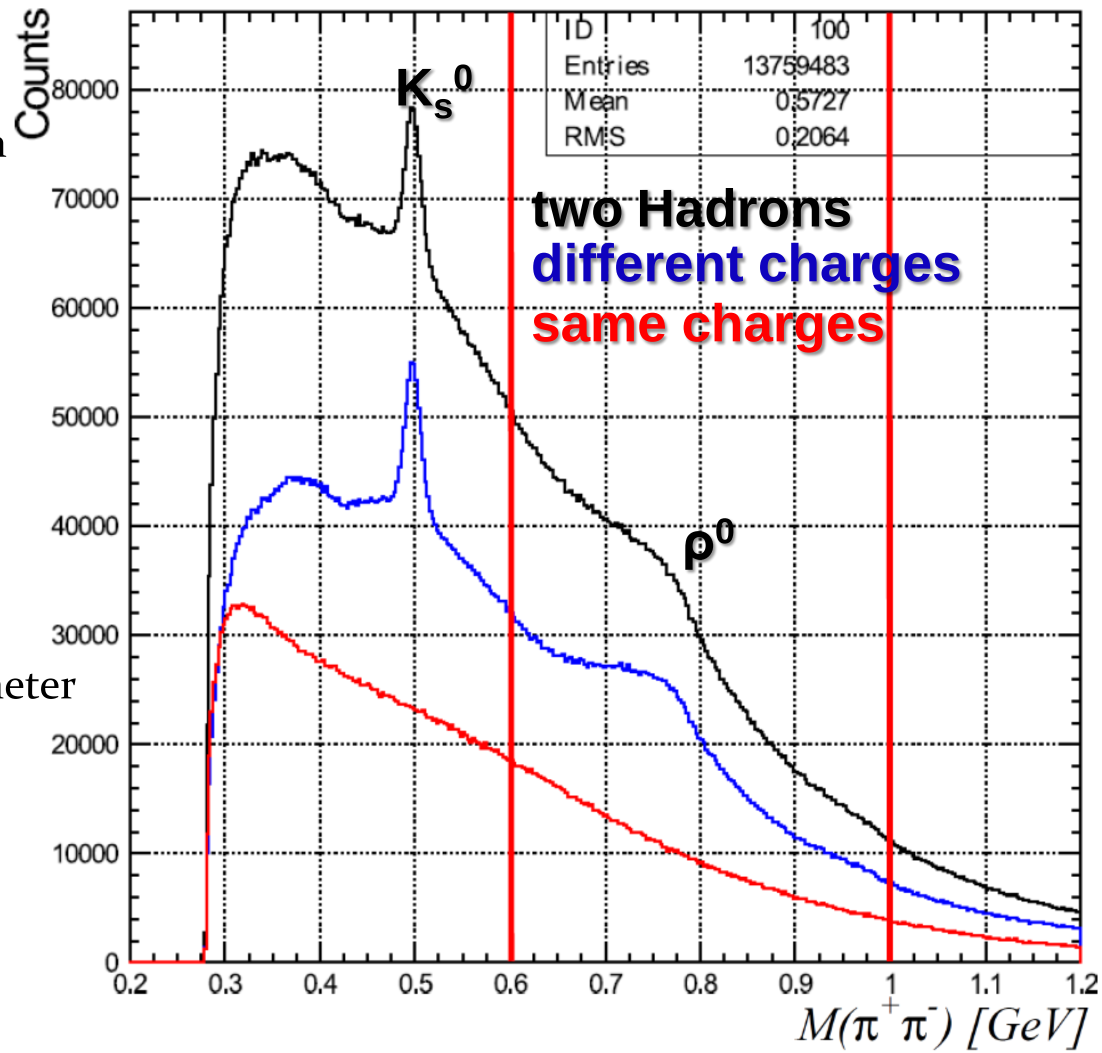
$|x| < 100 cm$, $|y| < 54 cm$ } Rear Field clamp

Target Region cuts

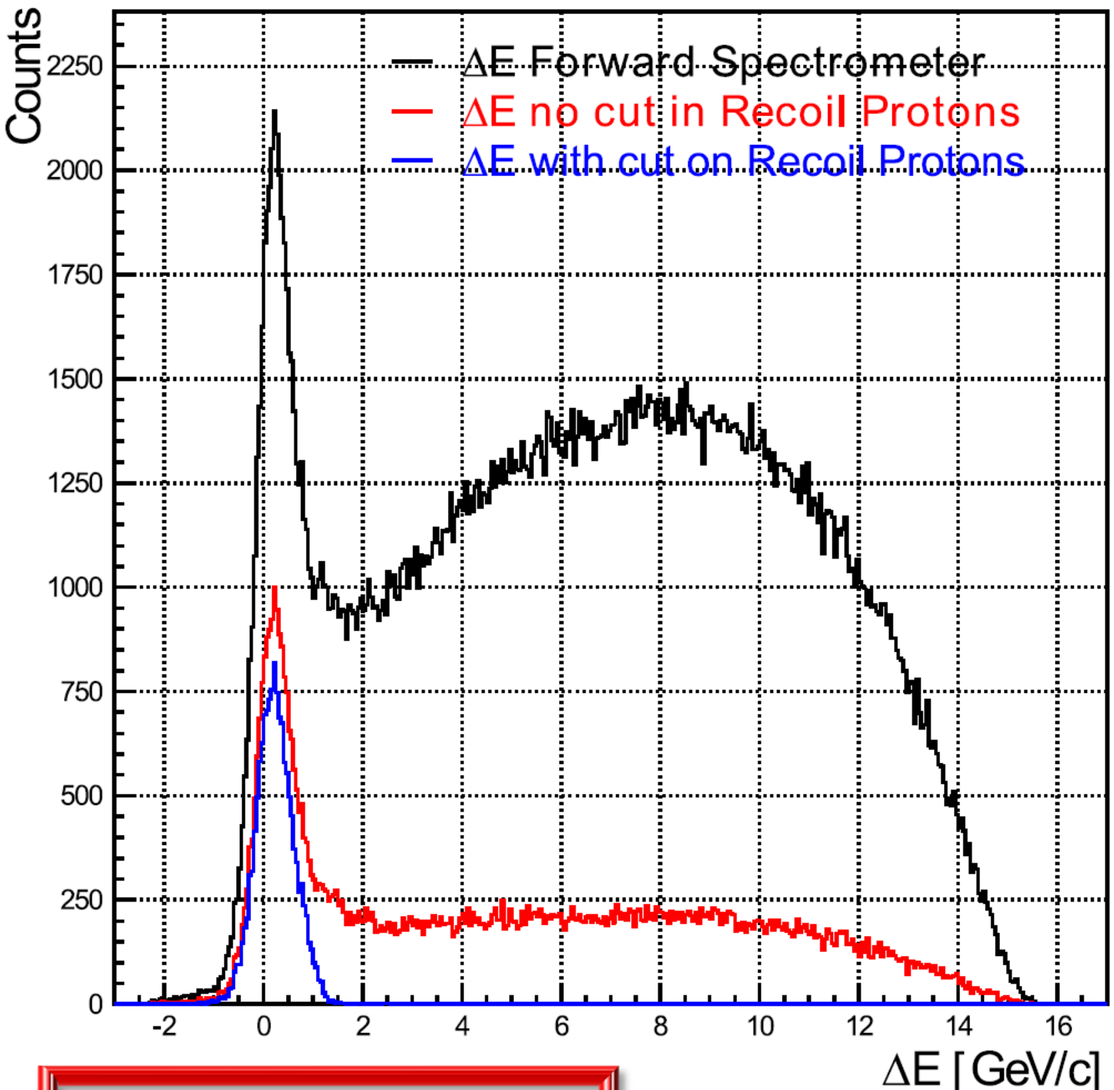
$5cm < Z_{Vertex\_Forward\_Spectrometer} < 20cm$

$5cm < Z_{Vertex\_Recoil\_Detector} < 20cm$

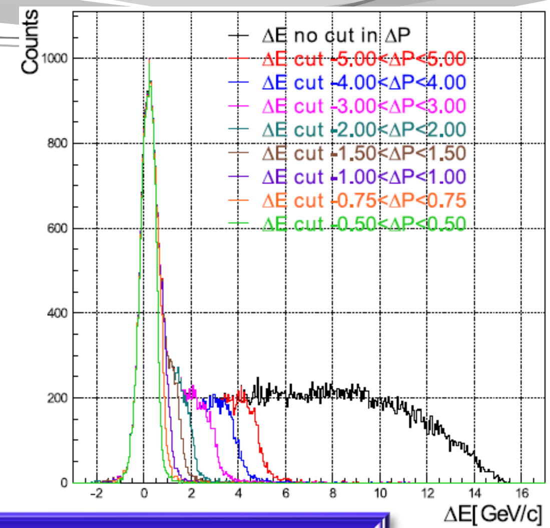
$-2cm < \Delta Z < 2cm$



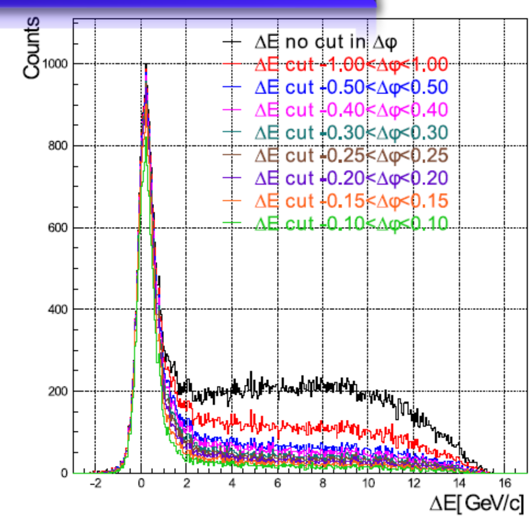
ΔE distributions comparison without and with Recoil Detector



$$-1.0GeV < \Delta E < 0.6GeV$$



$$|\Delta\phi| < 0.1rad$$

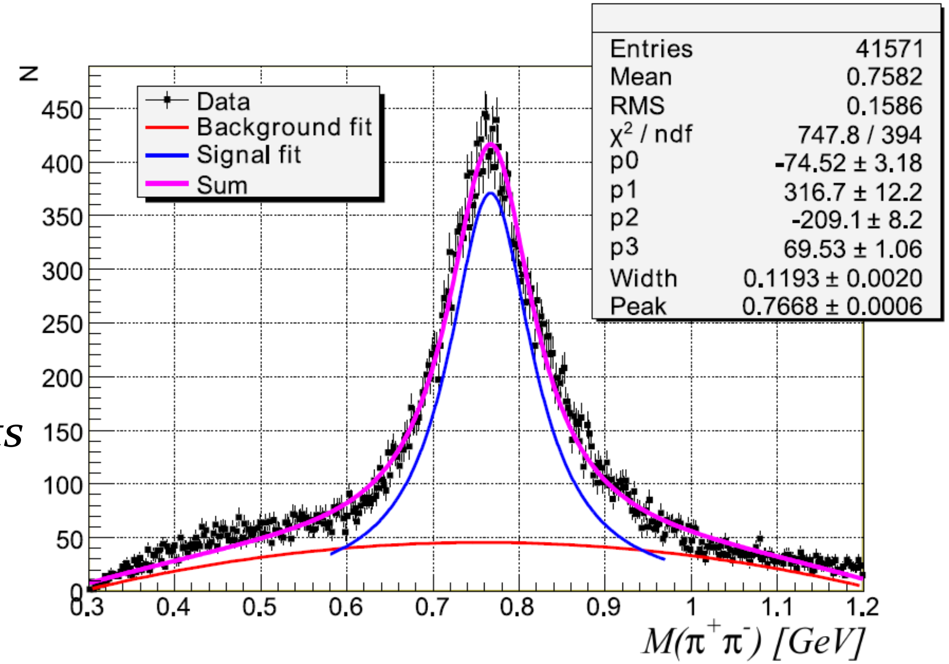


$$|\Delta P| < 1.00GeV / c$$

ρ° mass distributions with/without Recoil Detector

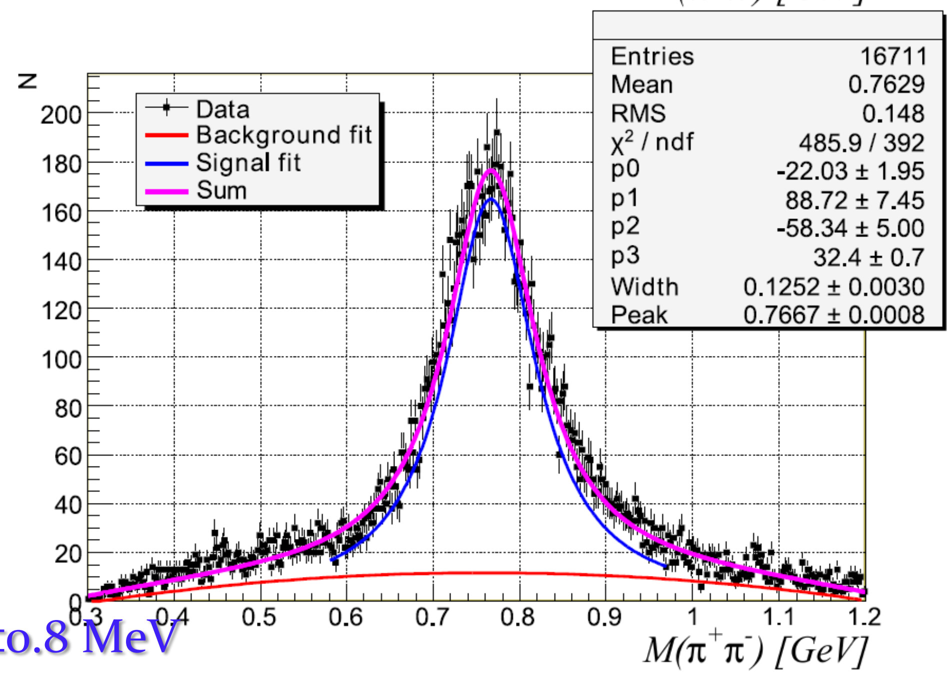
Integral of the background fit 7510.66
Signal fit at the same interval 25061.1.

The background is without the recoil detector playing an important role on the *Sum of the fits*



Integral of the background fit 1924.63
Signal fit at the same interval 11550.8.

The background is clearly suppressed in the analysis with the Recoil Detector

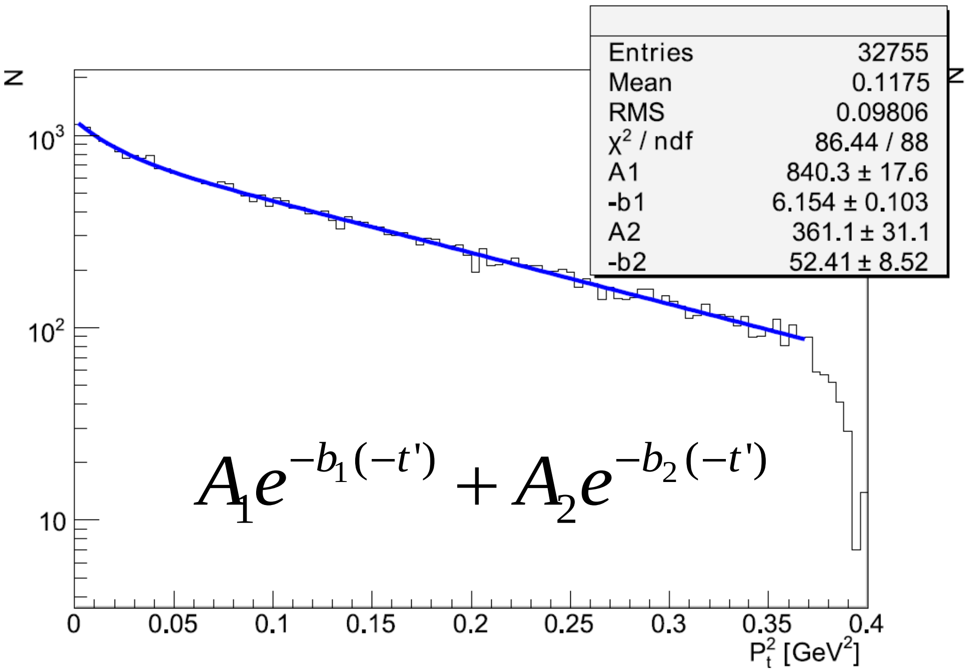


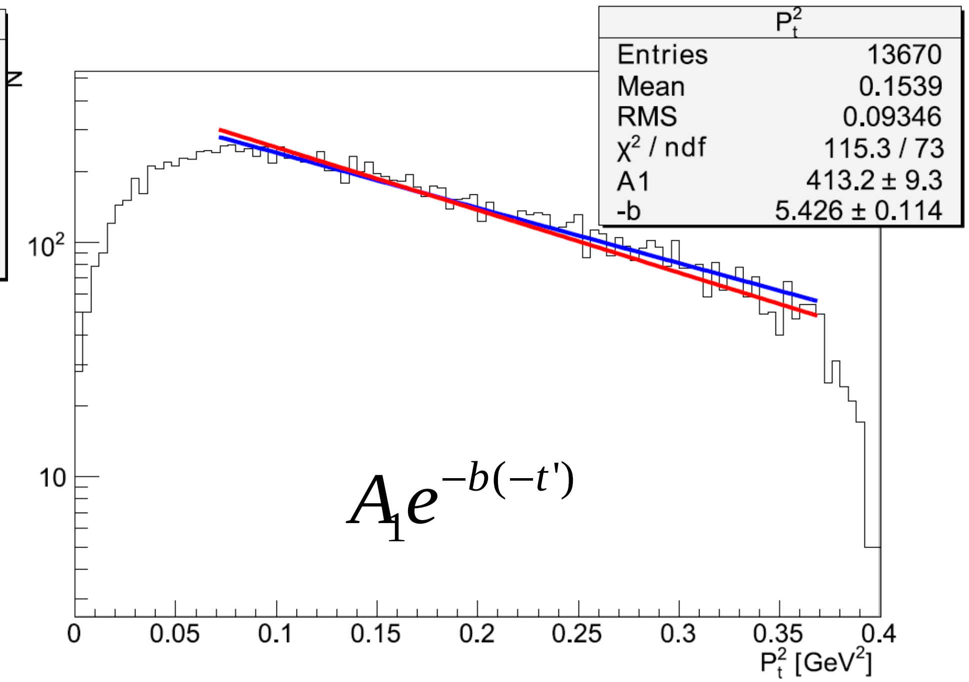
mass ρ(770) = 775.49±0.34 MeV

C. Amsler *et al.* (Particle Data Group), PL **B667**, 1 (2008)

mass ρ° extracted with recoil detector =766.7±0.8 MeV

Diffractive Slope parameter b extraction from data





Fit of the two exponential function:

- The signal
- The gas contamination.

- Negligible contribution of background from non exclusive ρo production.

Fit function used is the one exponential

- The signal

- Negligible amount of non exclusive background
- Data are different at low –t' due to the big acceptance effect of the Recoil detector

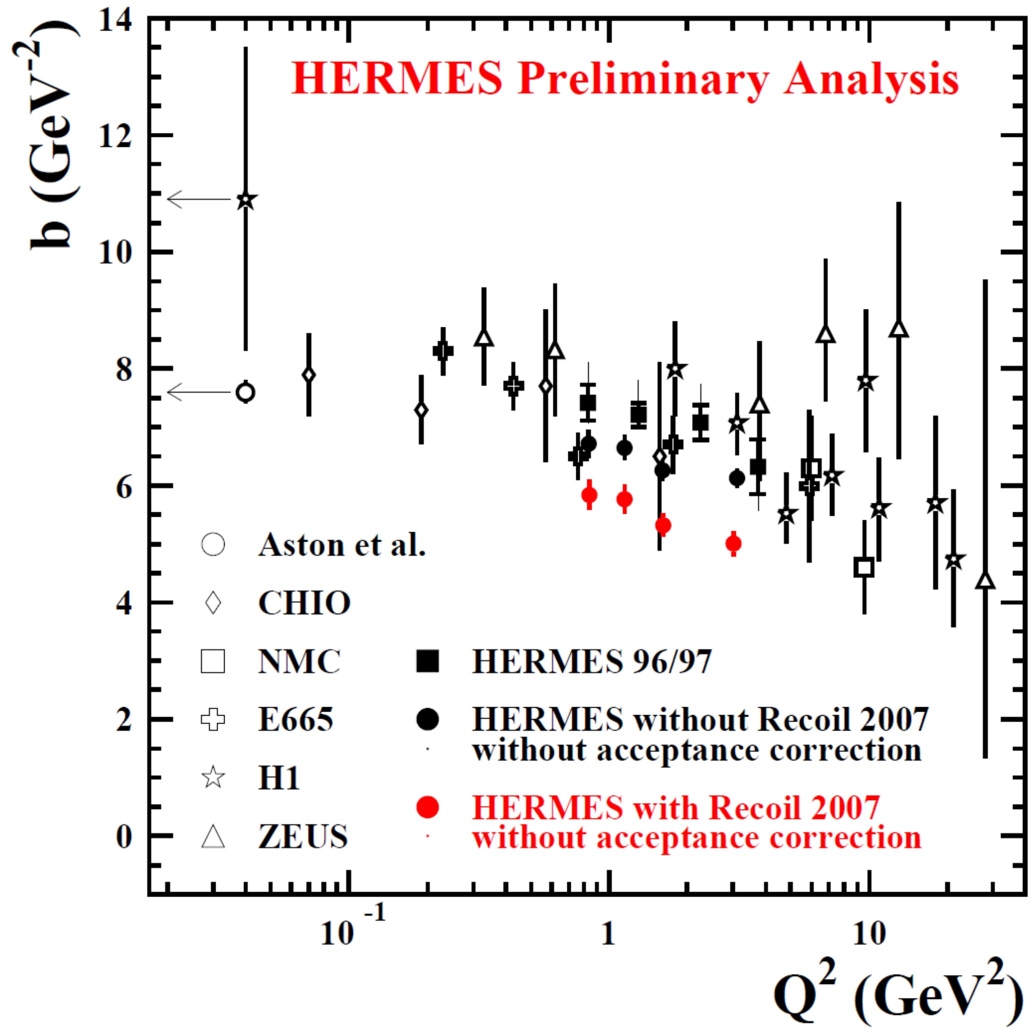
b Slope with and without Recoil Detector

The slope parameter b is a measure of the transverse size of the ρ° vector meson ($b = 1/3\,(\langle r_{\rho^\circ}^2\rangle + \langle r_p^2\rangle)$), where $\langle r_p^2\rangle$ is a measure of the transverse size of the proton.

B.Povh and J.Hufner,
Phys. Rev. Lett. 58(1987) 1612

In certain theoretical models, $b(Q^2)$ is needed to check the –t' dependence of GPDs Slope

K. Goeke, M V. Polyakov and M. Vanderhaeghen,
Prog.Part.Nucl.Phys.47(2001) 401



Summary and Outlook

- Data from Hermes using the Recoil Detector are ready for physics analysis.
- Exclusive ρ^0 production with the Recoil Detector can be selected in principle without background.
- The analysis of the diffractive-exclusive production of ρ^0 mesons is described.
  - unpolarized Hydrogen target data from 2007
- The final measurement of the $b(Q^2)$ dependence will require additional *Monte Carlo studies of the Hermes Collaboration and can finally be used to tune GPD models.*