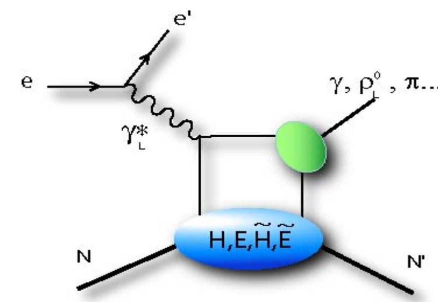
Latest hermes results

on

Hard-Exclusive Processes

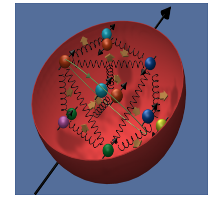


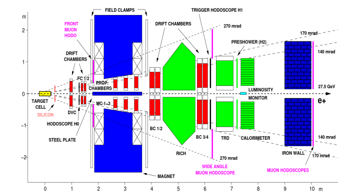
Tibor Keri

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

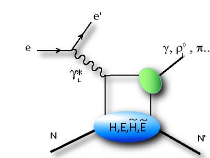
on behalf of the HERMES collaboration

Outline

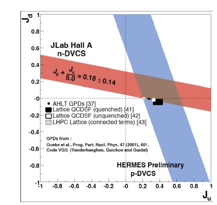




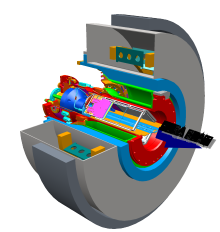
- Motivation
- HERMES
- GPD



  - hard exclusive processes
  - recent results

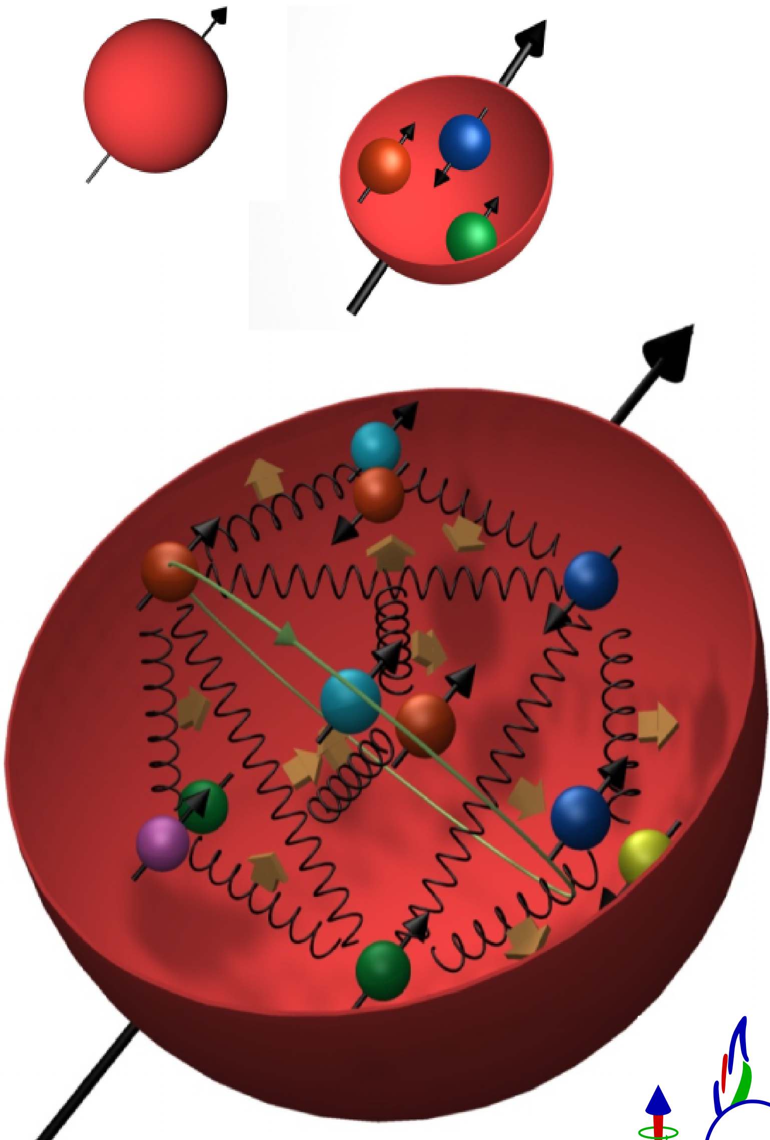


- Recoil Detector



- Summary and Outlook

The Nucleon Spin



$$\tfrac{1}{2} = \tfrac{1}{2}\,\Delta\Sigma + L_q + \Delta G + L_g$$

ΔΣ := spin of quarks
≈ 1/3 via DIS and SIDIS

ΔG := spin of gluon
≈ O(0.1) from COMPASS and HERMES

Lq := orbital angular momentum of quarks
yet unknown

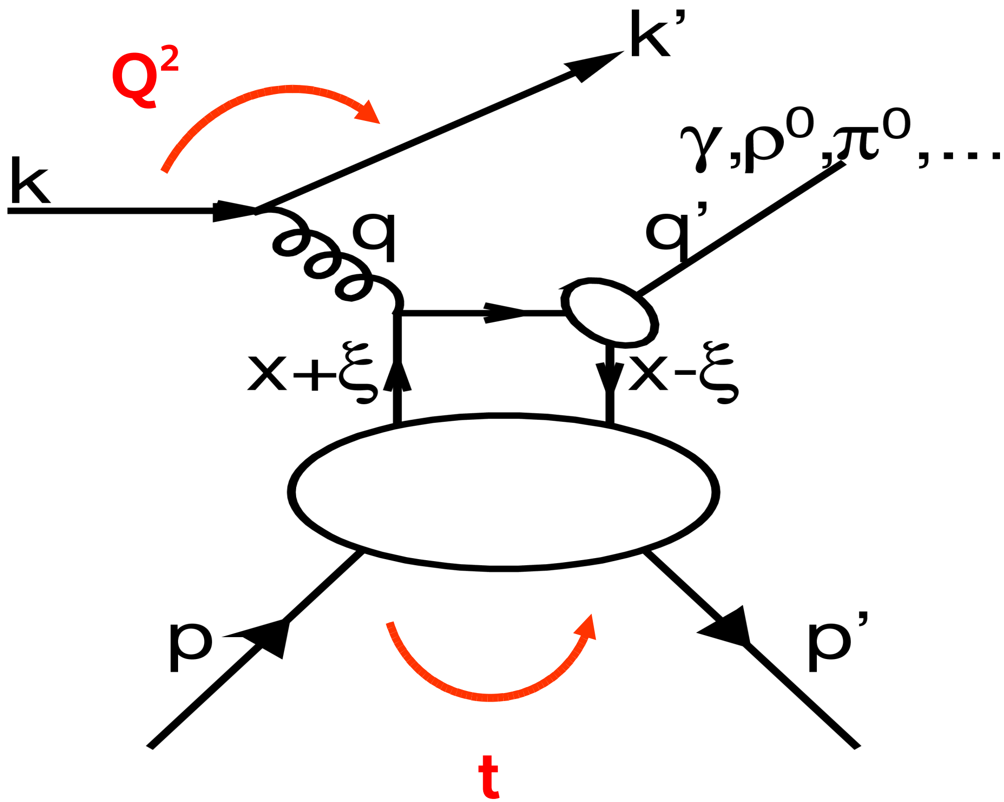
Lg := orbital angular momentum of gluon
yet unknown

Jq := total angular momentum of quark
:= ½ ΔΣ +Lq
Jg := total angular momentum of gluon
:= ΔG + Lg

hermes

motivation for the
HERa **ME**asurements of **S**pin
experiment

Hard Exclusive Processes



some useful kinematic variables

Q^2 := -q := -(k-k')^2
squared four momentum transfer

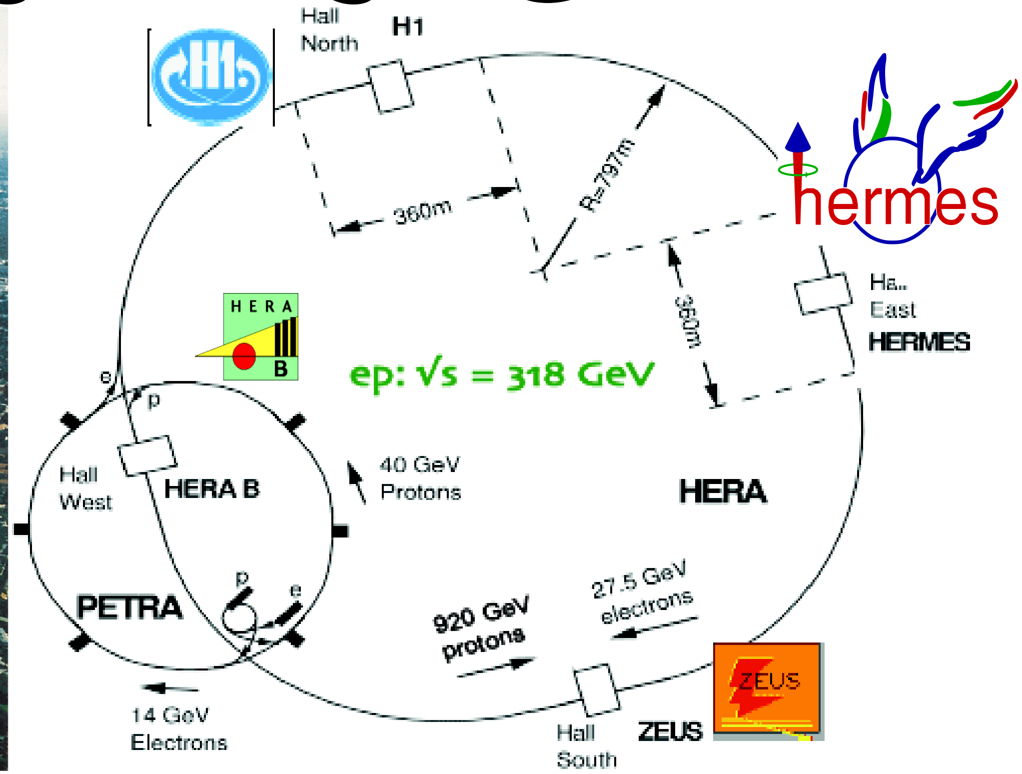
x := Q^2/(2pq)
longitudinal momentum fraction

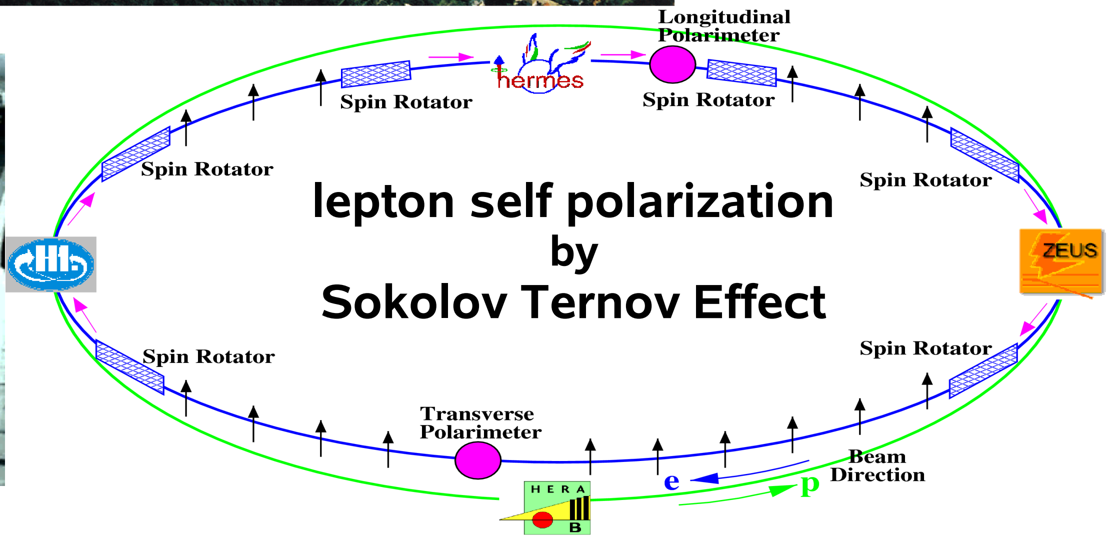
ξ :=x_B/(2-x_B)
skewedness

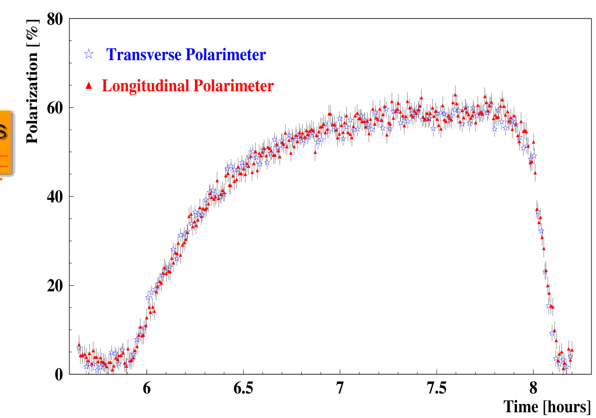
t := (p-p')^2
squared four momentum transfer

Required tools
to
access spin

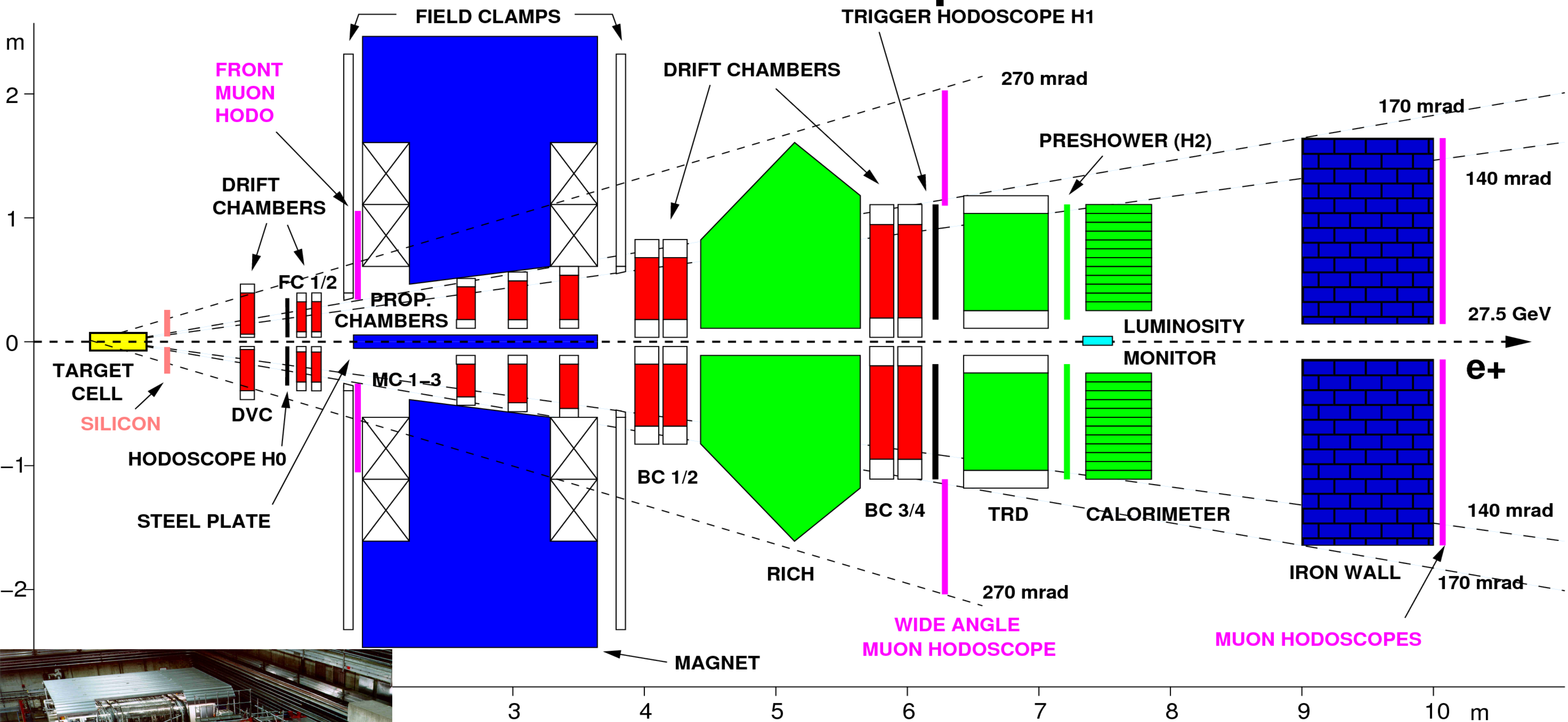
Hadron-Elektron-Ring-Anlage @ DESY

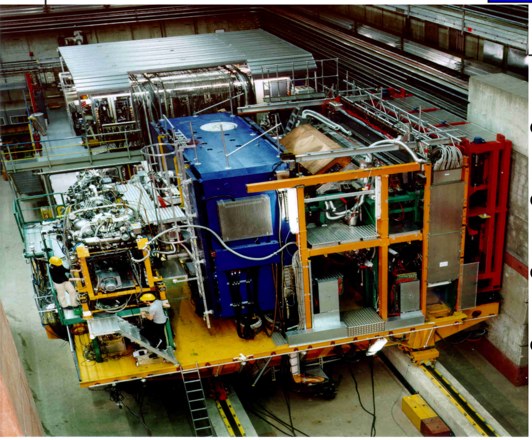






The HERMES forward spectrometer



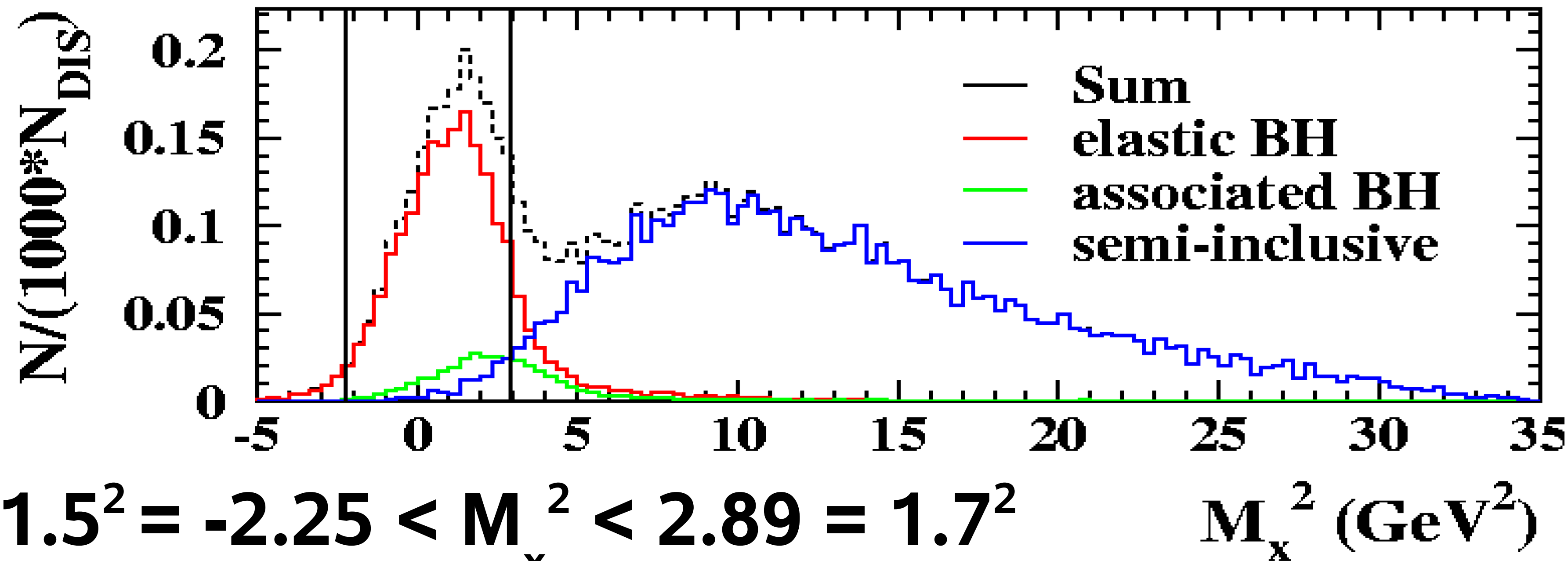


- •fixed gas target (H,D,N,Ne,Kr,Xe) very high long./trans. polarization
- •very high efficient PID by RICH
- •lepton/gamma detection by Preshower and by EM-Calorimeter
- •access to recoiling proton properties via missing mass method

Short story about missing mass method

MC on ep -> e'γX'

$M_x^2 = (p_e + p_p - p_{e'} - p_\gamma)^2$ **squared invariant missing mass**



X' = p

X' = Δ+

others

$-1.5^2 = -2.25 < M_x^2 < 2.89 = 1.7^2$

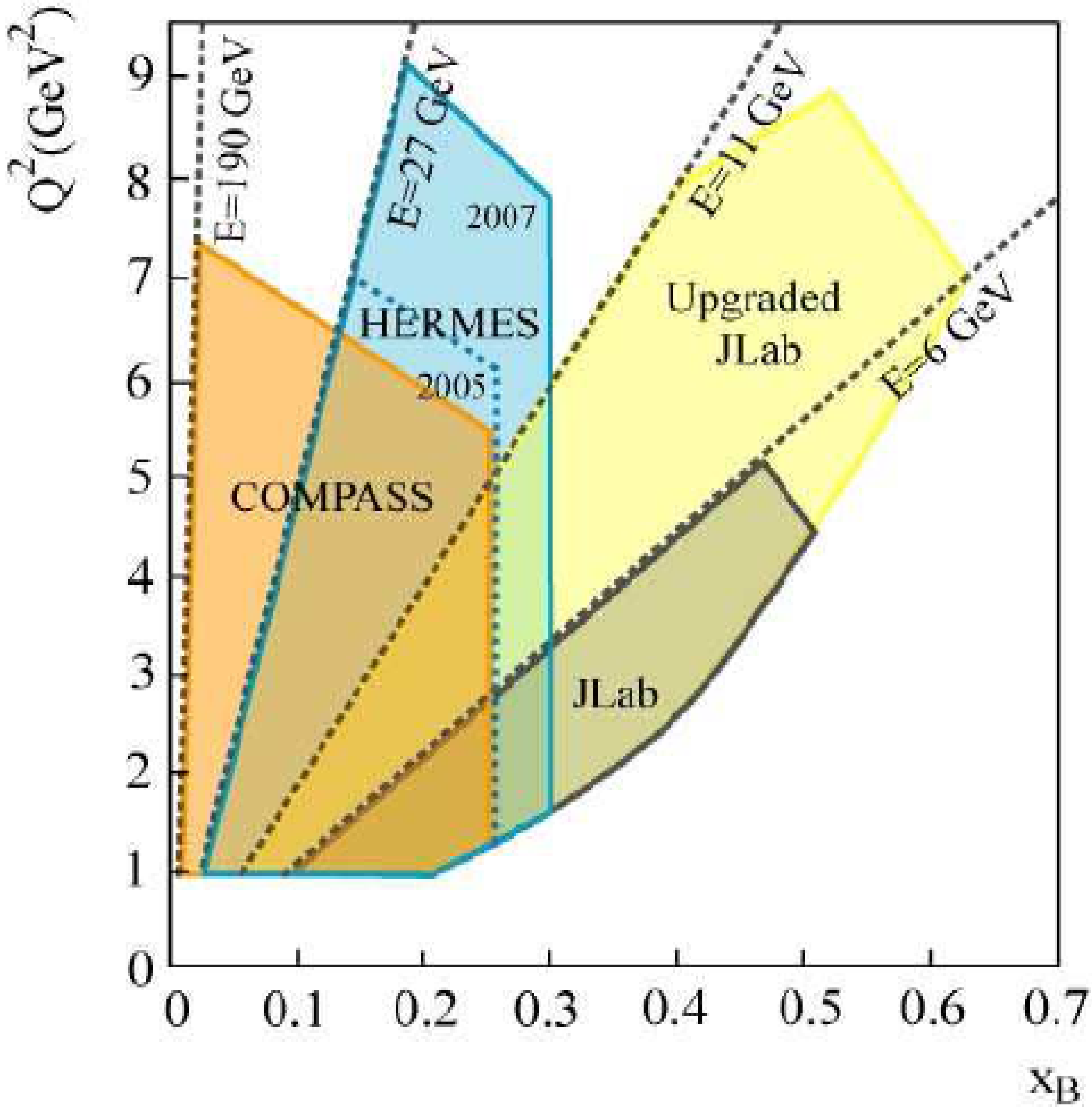
event selection for exclusivity → **background contamination**

5% semi-inclusive

11% associated BH

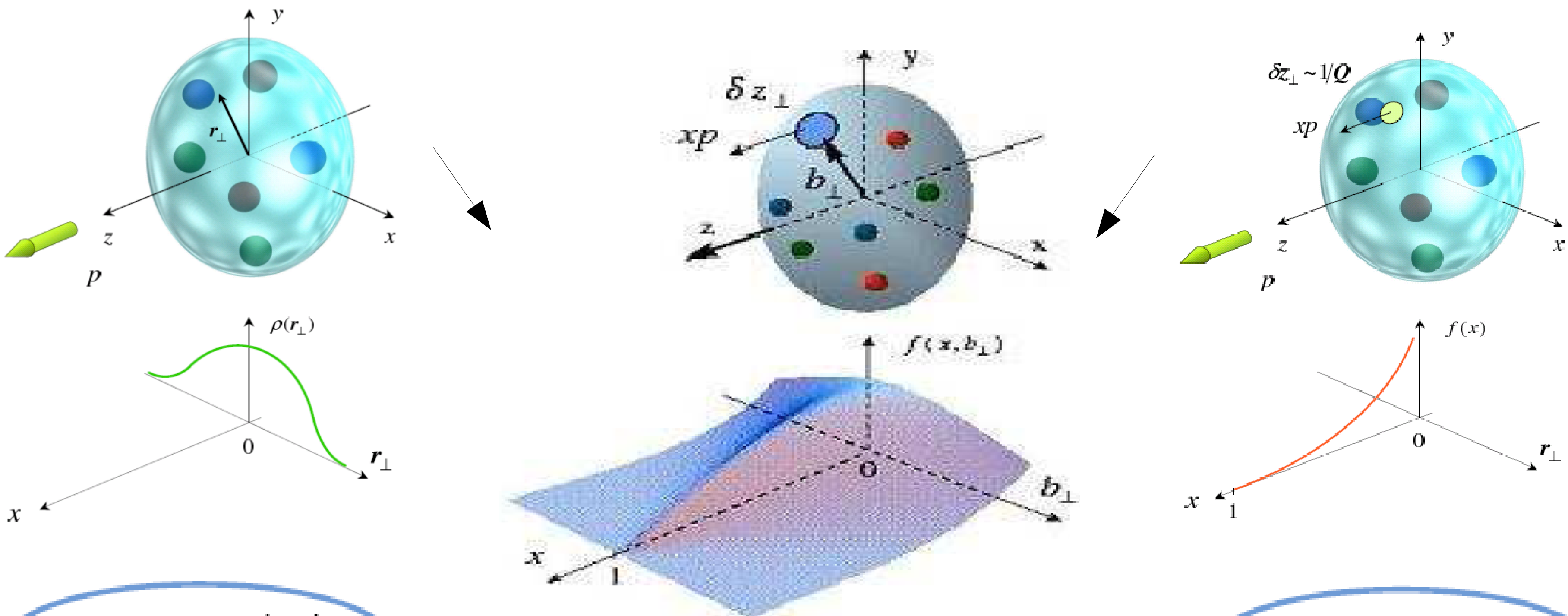
Kinematic Coverage

- **collider experiments H1 and Zeus**
  - 10-4 < x_B < 0.01
  - 5 < $(Q/GeV)^2$ < 100
- **fixed target experiments**
  - **Compass**
    - 0.006 < x_B < 0.25
    - 1 < $(Q/GeV)^2$ < 7.5
  - **HERMES**
    - 0.02 < x_B < 0.3
    - 1 < $(Q/GeV)^2$ < 9
  - **JLAB(@6GeV)**
    - 0.1 < x_B < 0.5
    - 1 < $(Q/GeV)^2$ < 5
  - **JLAB(@12GeV)**
    - 0.1< x_B < 0.65
    - 1 < $(Q/GeV)^2$ < 9



Let's switch to physics

Generalised **P**arton **D**istribution (GPD)



GPD

$ep \rightarrow e'p'$

Form Factors

Transverse
Position

Elastic Scattering

$F^q_1(t)$, $F^q_2(t)$

$ep \rightarrow e'Xp'$

GPD -> 3D view

Trans. Pos. & Long. Mom. Dis.

Hard Exclusive Processes

$ep \rightarrow e'X$

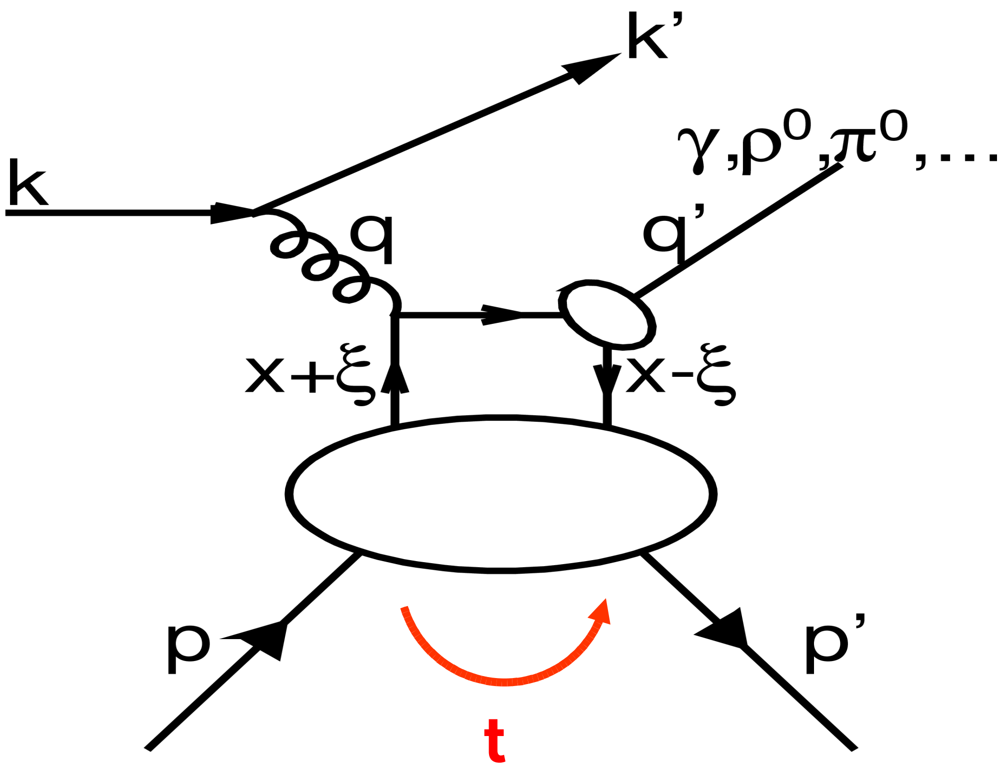
Parton Distribution Functions

Longitudinal
Momentum Distribution

Deep Inelastic Scattering

q(x),Δq(x)

GPD formalism



unpolarized	polarized	nucleon helicity
$H(x,\xi,t)$	$\widetilde{H}(x,\xi,t)$	conserved
$E(x,\xi,t)$	$\widetilde{E}(x,\xi,t)$	flipped

GPDs → FFs (First moments of GPDs)

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

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

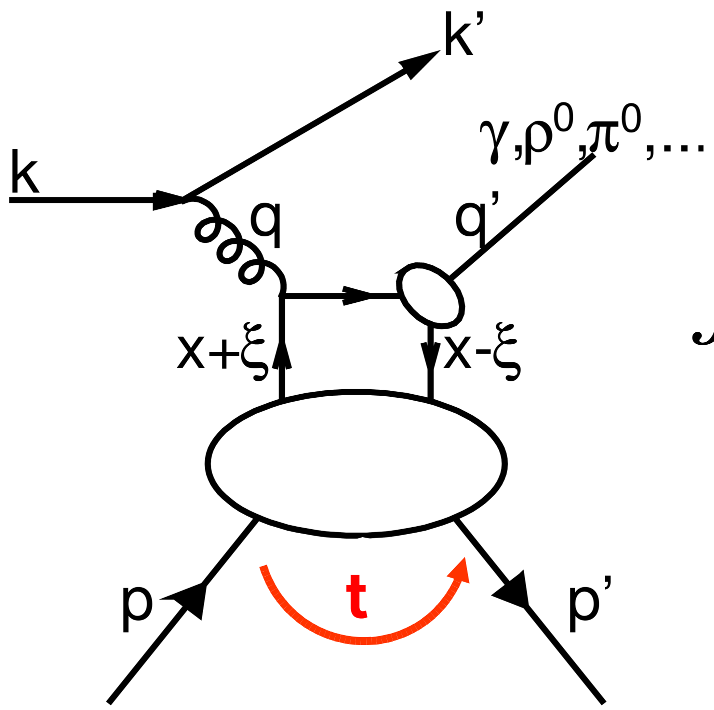
GPDs → PDFs (GPDs in the limit t → 0)

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

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

x : parton momentum fraction
ξ : skewedness
t : parton momentum transfer

GPDs and Exclusive Processes



access to (total) orbital angular momentum via

Ji Sum Rule Ji, PRL 78(1997)610

$$J_{q,g} = \lim_{t\to 0} \int_{-1}^{+1} dx\, x \left(H_{q,g} + E_{q,g} \right)$$

access to different GPDs
by
different final state

Vector mesons (ρ,ω,Φ,..) : H, E

Pseudoscalar mesons (π,η,..) : $\tilde{H}, \tilde{E}$

Deeply **V**irtual **C**ompton **S**cattering (γ) : $H, E, \tilde{H}, \tilde{E}$

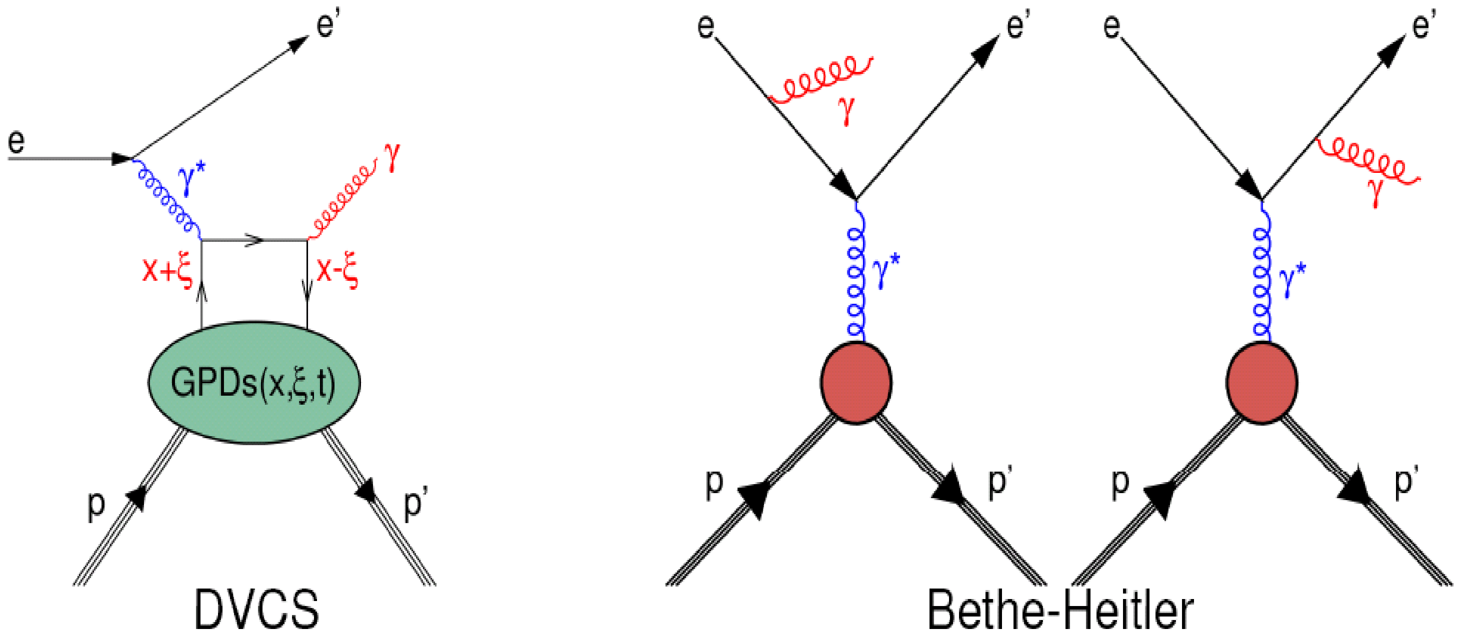
Azimuthal Asymmetries
with
DVCS

Deeply Virtual Compton Scattering

Simplest/Cleanest Hard Exclusive Processes
Deeply-Virtual Compton Scattering (DVCS)

ep -> e'γp'

DVCS final state is indistinguishable from the Bethe Heitler Process (BH)
Amplitudes add coherently



photon production cross section $\mathbf{d\sigma \propto |\tau_{DVCS} + \tau_{BH}|^2}$

Let's use this flaw as stirrup

Access to GPD via DVCS

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

I := interference term

$|\tau_{BH}|^2$ calculable in QED in terms of Dirac and Pauli Form Factors F_1, F_2

$|\tau_{DVCS}|^2$ 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 $H_q, \widetilde{H}_q, E_q, \widetilde{E}_q$)

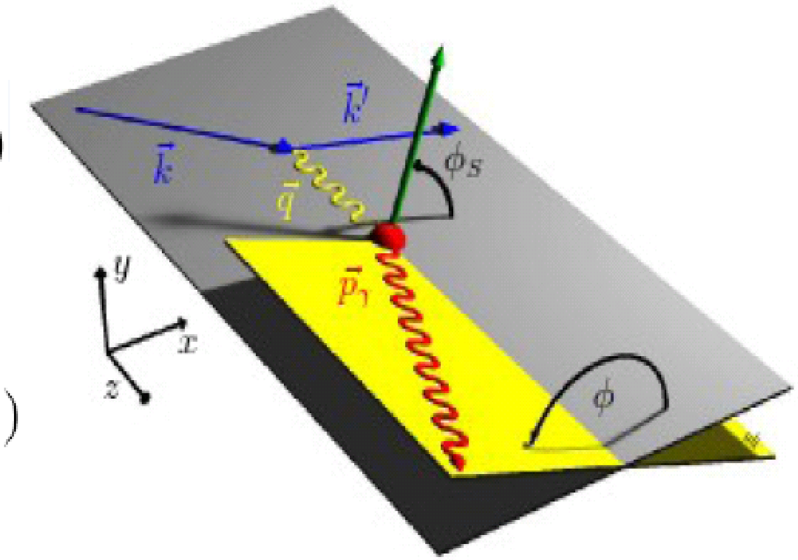
$$I \propto \pm \left(c_0 + \Sigma_n \left(c_n \cos(n\phi) + \lambda s_n \sin(n\phi) \right) \right)$$

GPDs accessible via
- cross-section differences at Zeus and H1 (collider)
- azimuthal asymmetries via interference term at HERMES and JLAB (fixed target)

At HERMES kinematic $|\tau_{DVCS}|^2 \ll |\tau_{BH}|^2$

feature of interference term
- DVCS amplitude directly accessible (Magnitude and Phase)
- GPDs enter in linear combinations

Azimuthal Asymmetries



- Beam-Spin Asymmetry (BSA)

$$A_{LU} = \frac{d\sigma(e^{\rightarrow},\phi) - d\sigma(e^{\leftarrow},\phi)}{d\sigma(e^{\rightarrow},\phi) + d\sigma(e^{\leftarrow},\phi)} \propto \Im m(\mathcal{H})\,\sin(\phi)$$

- Beam-Charge Asymmetry (BCA)

$$A_{C} = \frac{d\sigma(e^{+},\phi) - d\sigma(e^{-},\phi)}{d\sigma(e^{+},\phi) + d\sigma(e^{-},\phi)} \propto \Re e(\mathcal{H})\,\cos(\phi)$$

- Longitudinal Target Spin Asymmetry (LTSA)

$$A_{UL} = \frac{d\sigma(p^{\rightarrow},\phi) - d\sigma(p^{\leftarrow},\phi)}{d\sigma(p^{\rightarrow},\phi) + d\sigma(p^{\leftarrow},\phi)} \propto \Im m(\widetilde{\mathcal{H}})\,\sin(\phi)$$

- Transverse Target Spin Asymmetry (TTSA)

$$A_{UT} = \frac{d\sigma(p^{\uparrow},\phi) - d\sigma(p^{\downarrow},\phi)}{d\sigma(p^{\uparrow},\phi) + d\sigma(p^{\downarrow},\phi)} \propto f(\mathcal{H},\mathcal{E},\widetilde{\mathcal{H}},\widetilde{\mathcal{E}},\phi,\phi_S)$$

TTSA is only asymmetry where GPD E is not suppressed
Models for E depend on Jq
TTSA is sensitive to Jq

Beam Spin Asymmetry

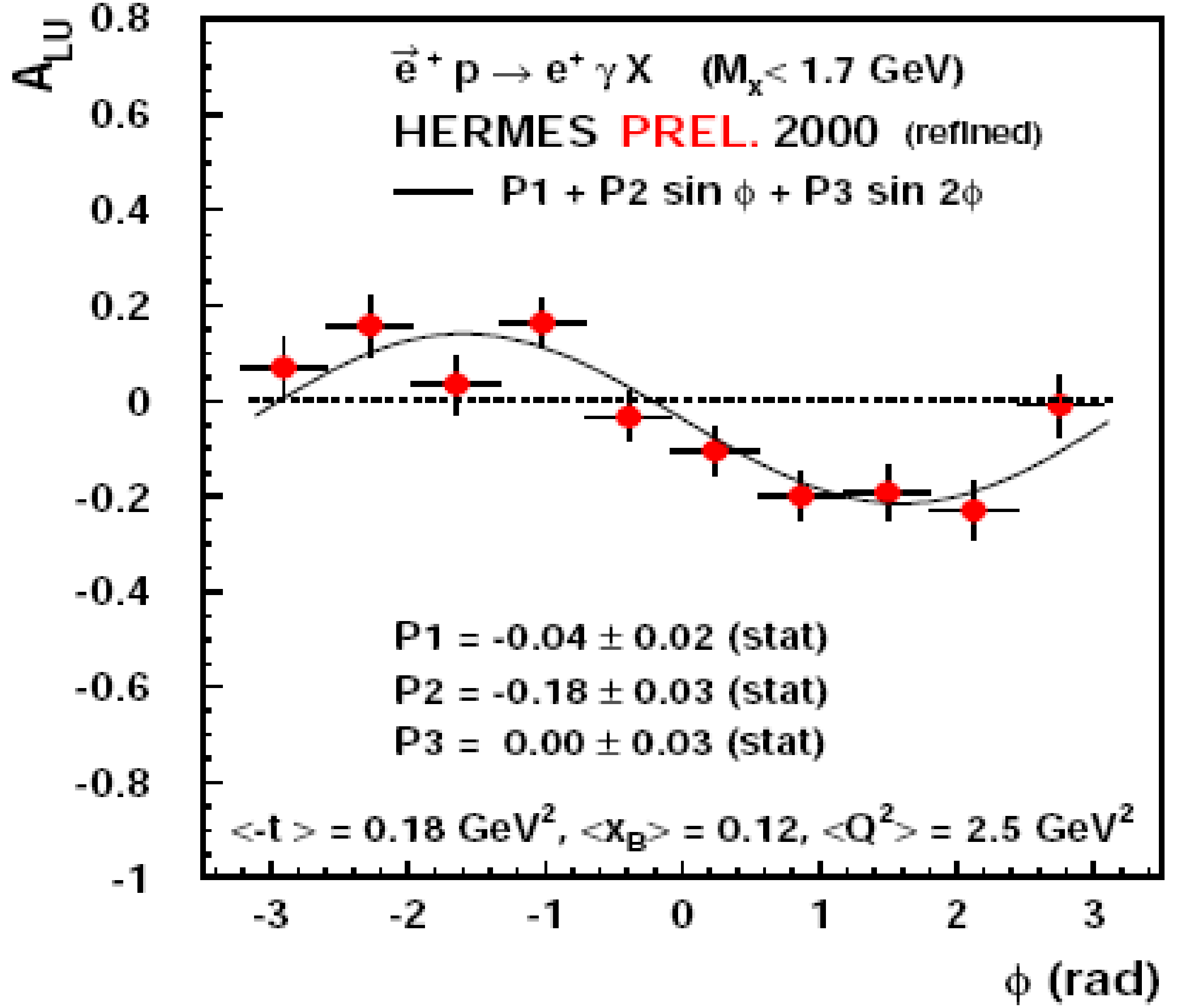
$$A_{LU} = \frac{d\sigma(e^{\rightarrow},\phi) - d\sigma(e^{\leftarrow},\phi)}{d\sigma(e^{\rightarrow},\phi) + d\sigma(e^{\leftarrow},\phi)} \propto \Im m(\mathcal{H}) \sin(\phi)$$

First measurements of DVCS asymmetrys

$$A_{LU}^{\sin(\Phi)} = -0.18 \pm 0.03 \text{ (stat.)} \pm 0.03 \text{ (sys.)}$$

refined analysis gives consistent result

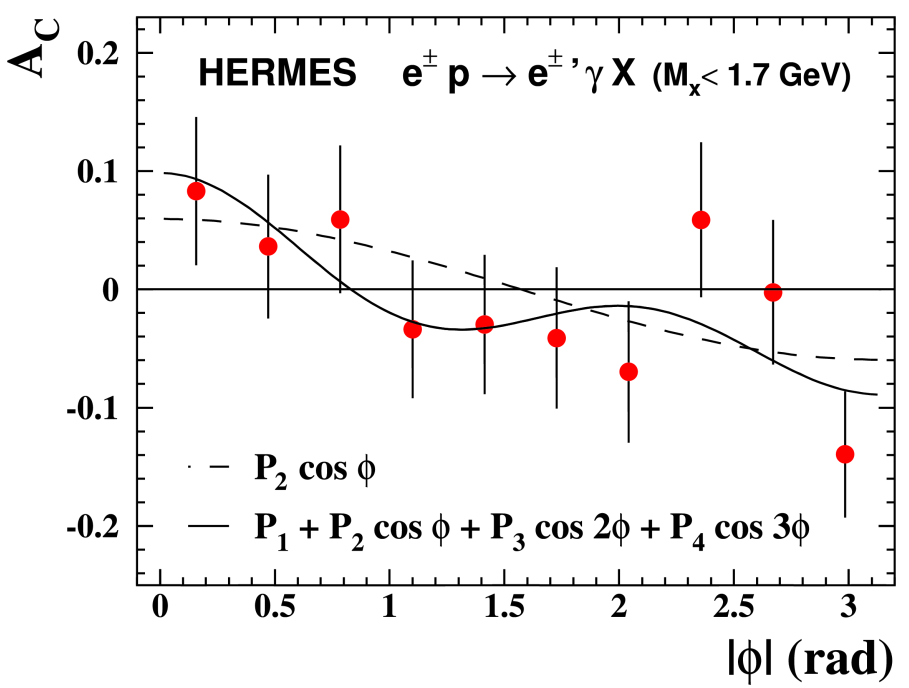
Phys, Rev. Let. **87**(2001)182001



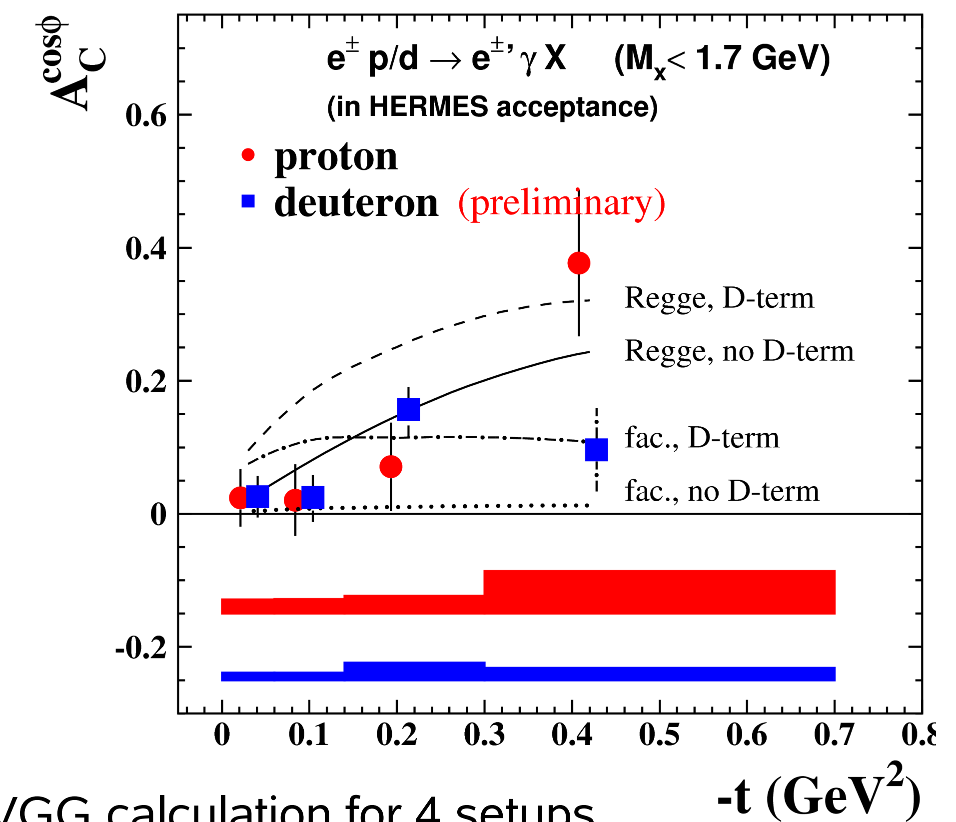
one order more HERMES HERA-II data available; refinement in progress

Beam Charge Asymmetry

$$A_C = \frac{d\sigma(e^+,\phi) - d\sigma(e^-,\phi)}{d\sigma(e^+,\phi) + d\sigma(e^-,\phi)} \propto \Re e(\mathcal{H}) \cos(\phi)$$



$A_c^{\cos(\Phi)}$ = 0.063 ± 0.029(stat.) ± 0,026(sys.)



VGG calculation for 4 setups

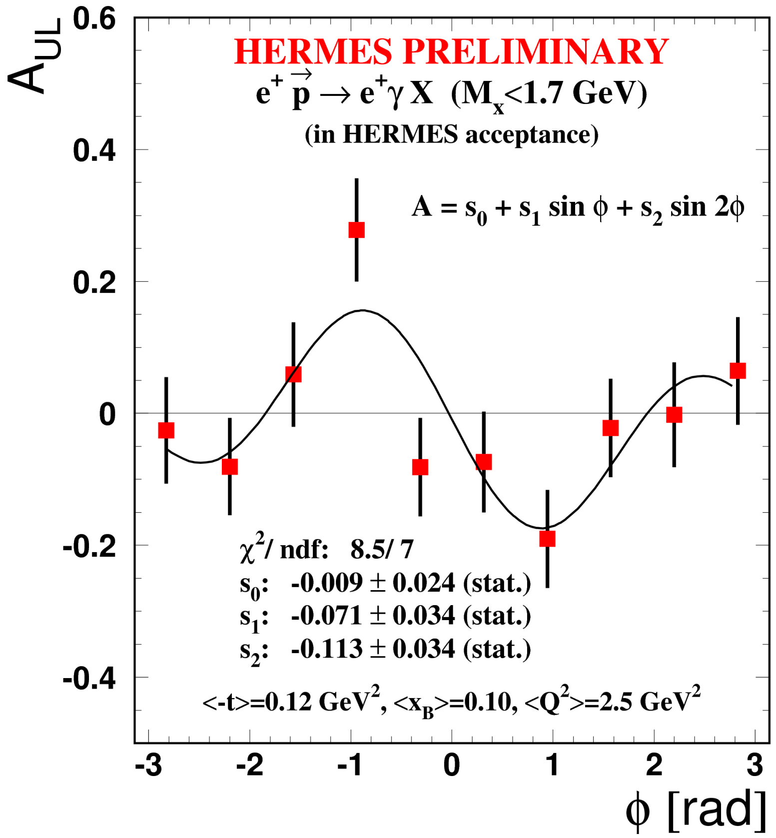
HERMES HERA-I data disflavor Regge/D

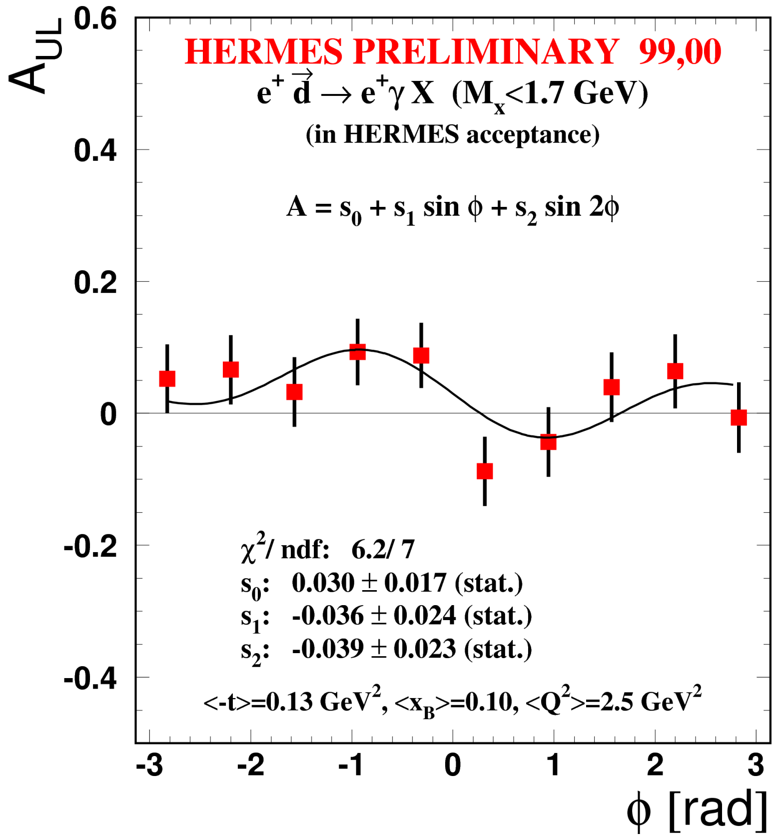
Phys. Rev. **D**75(2007) 011103(R)

more than 10 times more HERMES HERA-II data on tape; currently in progress; coming soon

Longitudinal Target Spin Asymmetry

$$A_{UL} = \frac{d\sigma(p^{\rightarrow},\phi) - d\sigma(p^{\leftarrow},\phi)}{d\sigma(p^{\rightarrow},\phi) + d\sigma(p^{\leftarrow},\phi)} \propto \Im m(\widetilde{\mathcal{H}})\ \sin(\phi)$$





Expected sin(Φ) dependence -> GPD H
Unexpected sin(2Φ) dependence
-> possible π^0 background contamination

consistent with zero for d

All data included

Tranverse Target Spin Asymmetry

$$A_{UT}(\phi,\phi_s) = \frac{1}{|P_T|}\cdot\frac{d\sigma^{\Uparrow}(\phi,\phi_s)-d\sigma^{\Downarrow}(\phi,\phi_s')}{d\sigma^{\Uparrow}(\phi,\phi_s)+d\sigma^{\Downarrow}(\phi,\phi_s')}$$

$$\propto \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}]\cdot\sin(\phi-\phi_S)\cos\phi + \mathrm{Im}[F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}]\cdot\cos(\phi-\phi_S)\sin\phi$$

yet half of data included

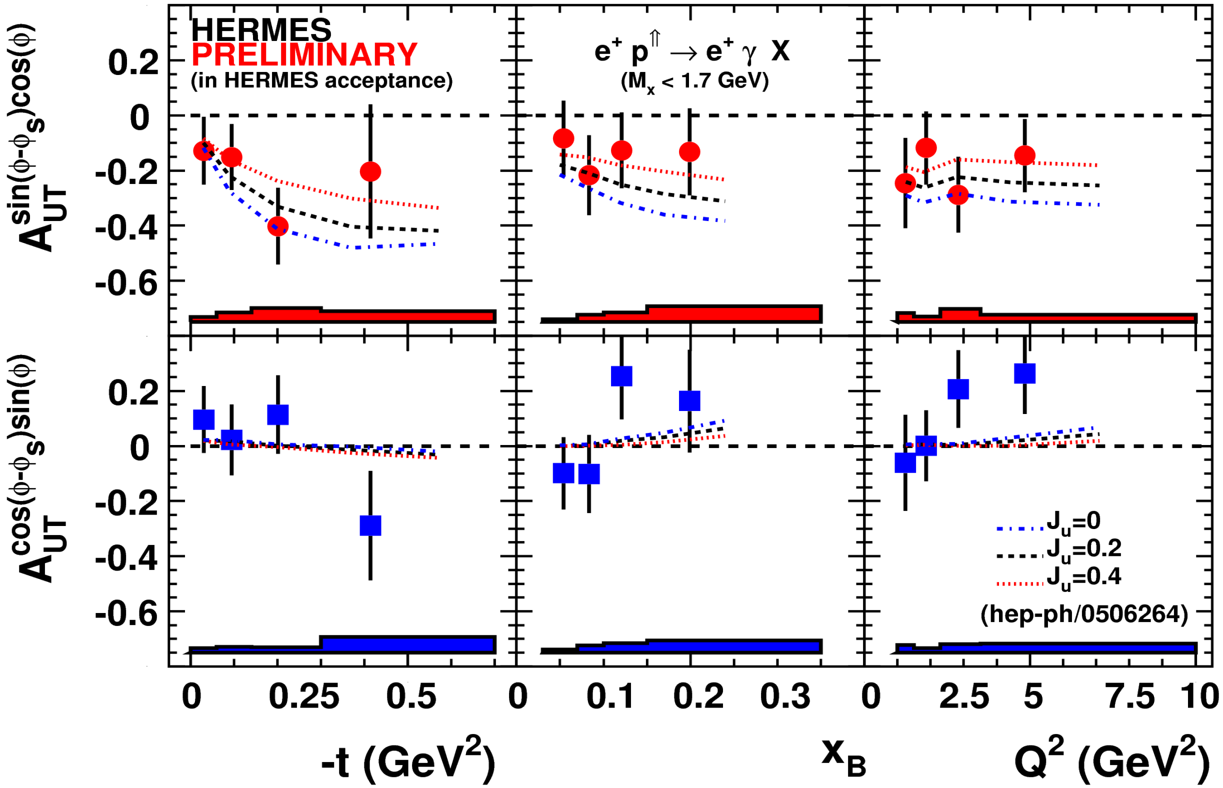
Dependence on Ju with Jd=0
(hep-pj/0506264 and
EPJ C46 (2006))

strong for

$A_{UT}^{\sin(\phi-\phi_S)\cos(\phi)}$

very weak for

$A_{UT}^{\cos(\phi-\phi_S)\sin(\phi)}$



Access to GPD H,E

$$J_{q,g} = \lim_{t\to 0}\int_{-1}^{+1} dx\, x\,(H_{q,g}+E_{q,g})$$

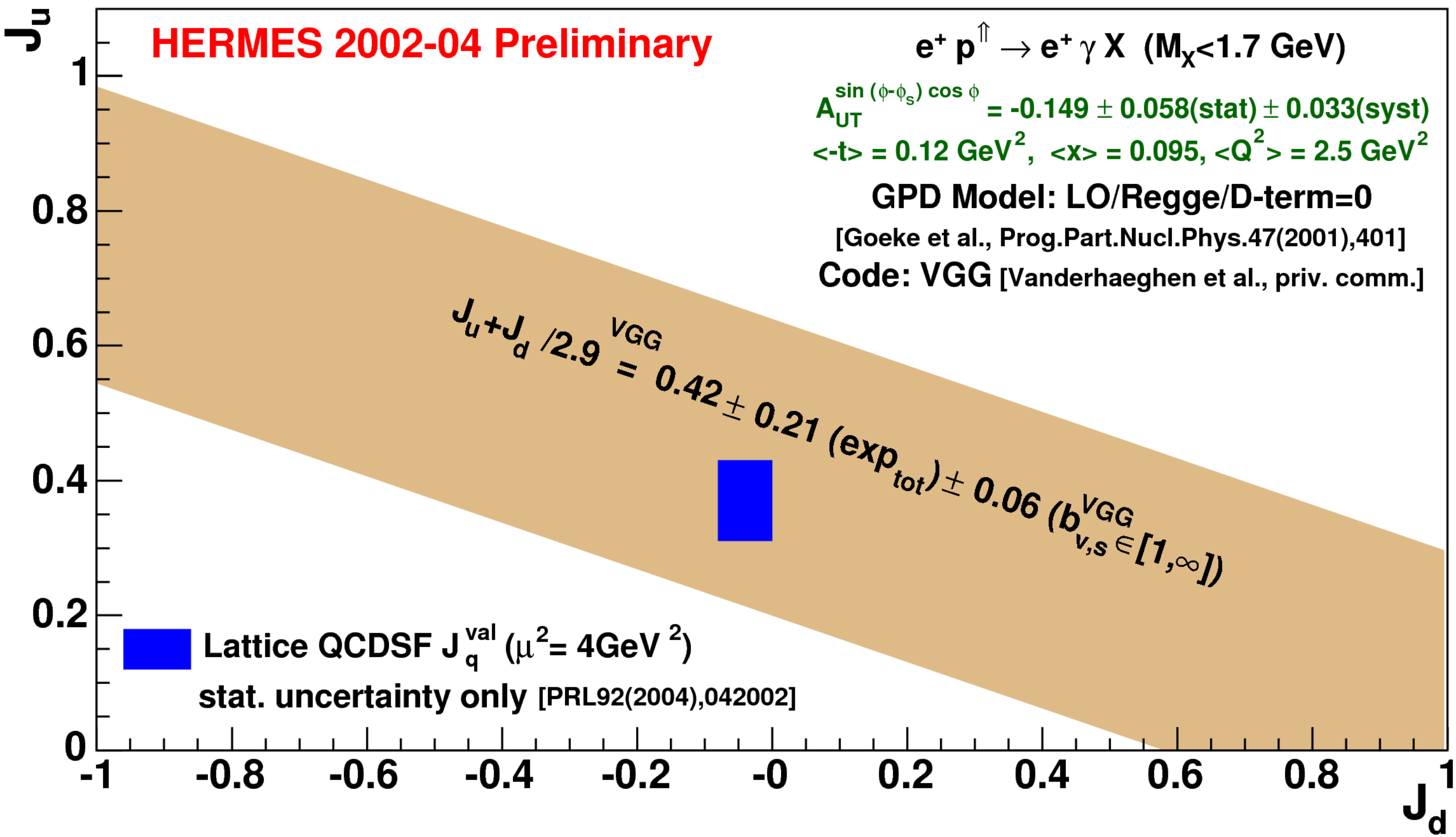
Access to Jq via Ji Sum Rule **Ji, Phys. Rev. Let. 78(1997)610**

first model dependent constraints of Ju possible

Model dependent constraint on Ju, Jd

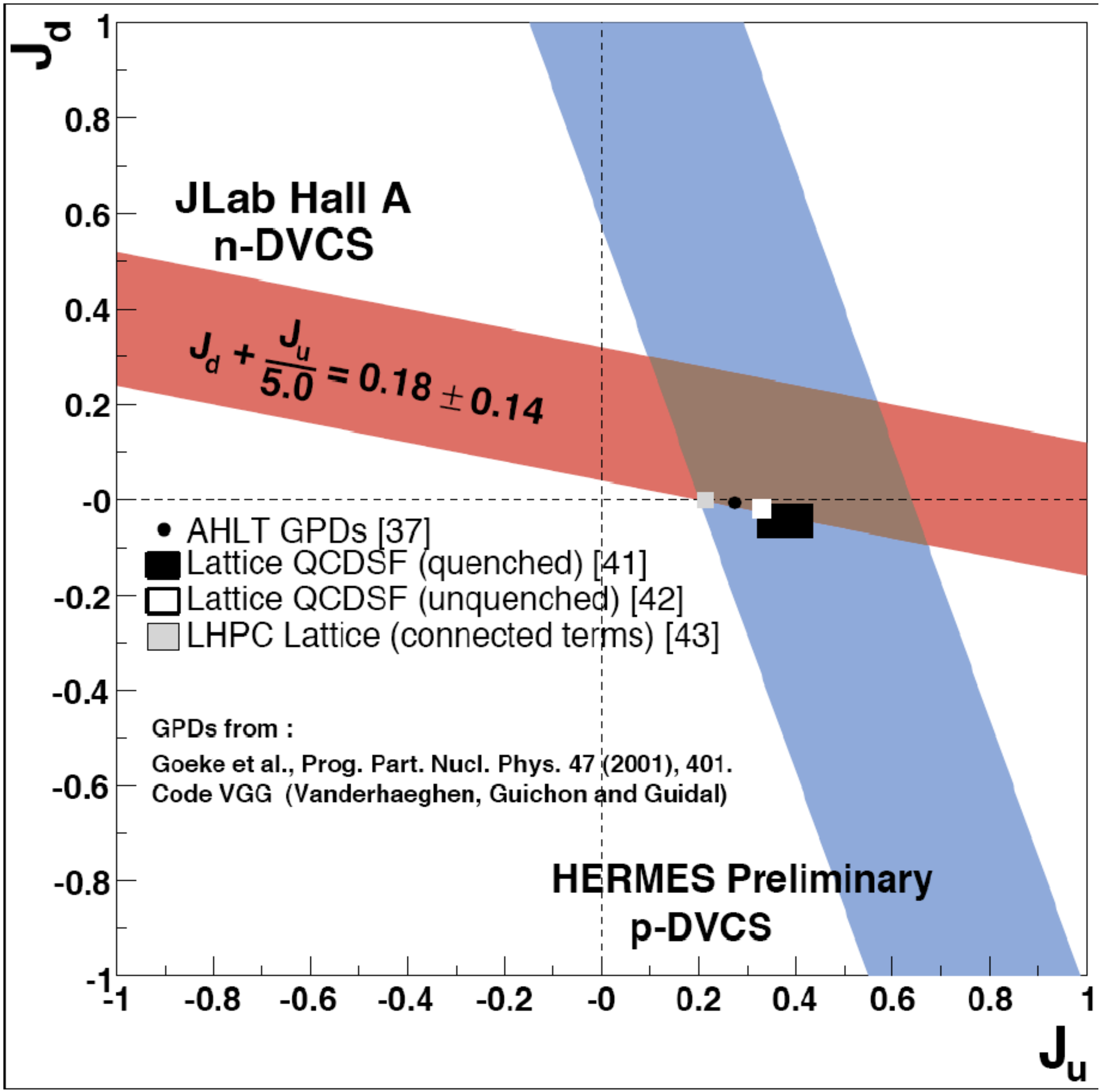
Ju, Jd free parameter in GPD (VGG-code)

model dependent 1-σ constraint on Ju, Jd



Model dependent constraint on Ju, Jd update

mandatory
complementary
of
p-DVCS to n-DVCS
as
p-DVCS sensitive to Ju
n-DVCS sensitive to Jd
so
synergy effect



HERMES via p-DVCS
hep-ex/0606061

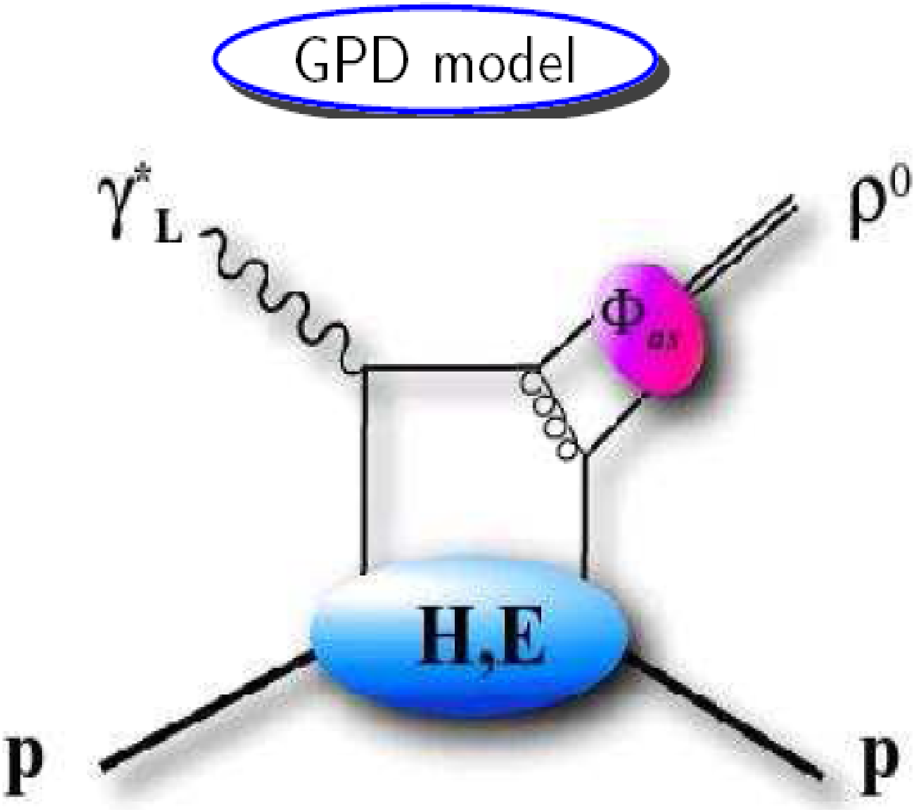
Jlab Hall A via n-DVCS
arXiv:0709.0450[nucl-ex]

LHPC via calculation
arXiv:0705.4295[hep-lat]
Ju=0.214(16)
Jd=0.001(16)

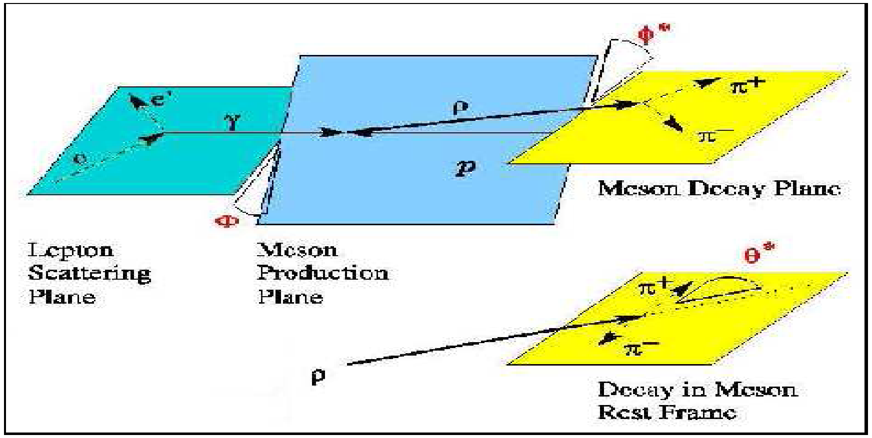
hard-exclusive ρ^0 production

Exclusive ρ^0 production

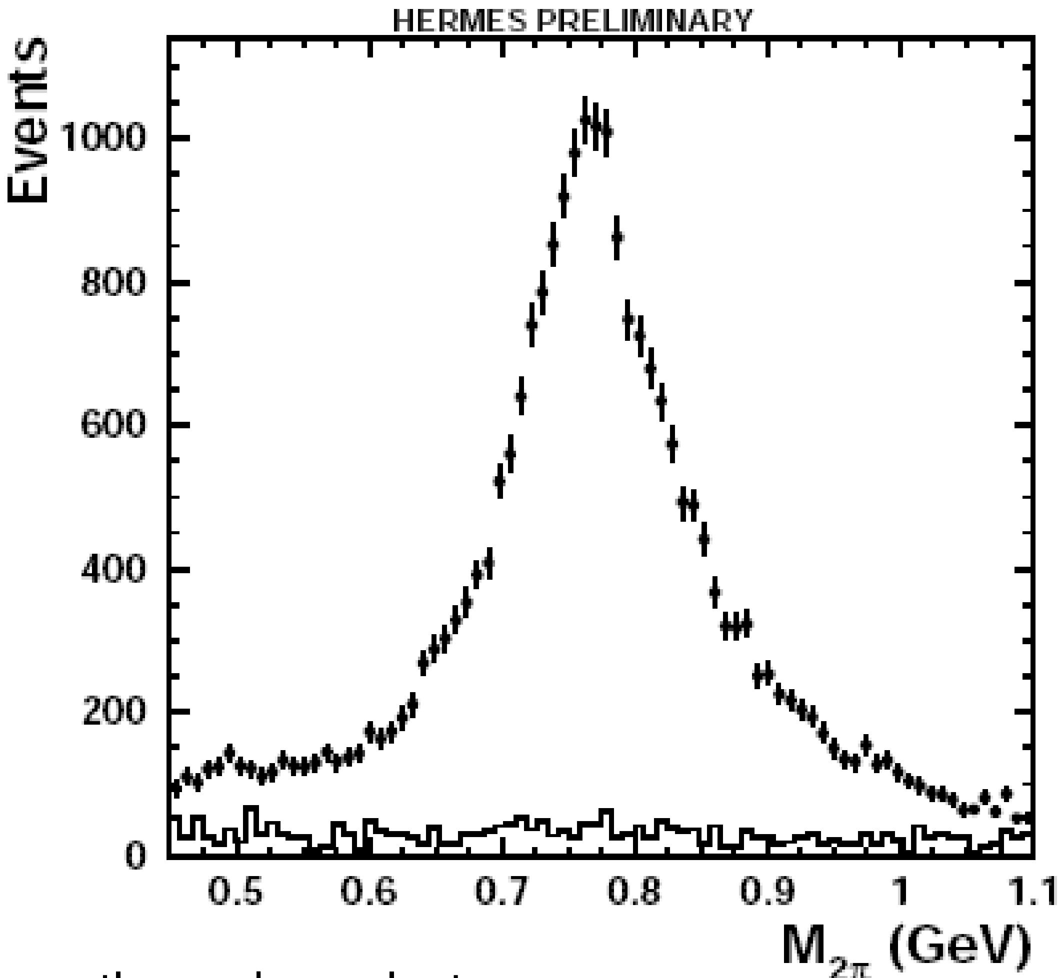
- Advantages
  - probe quark and gluon contents of the nucleon
  - quarks and gluons enter same order of α_S
  - linear dependence on GPDs
  - GPD E is kinematically not suppressed
  - GPD H,E accessible in TTSA

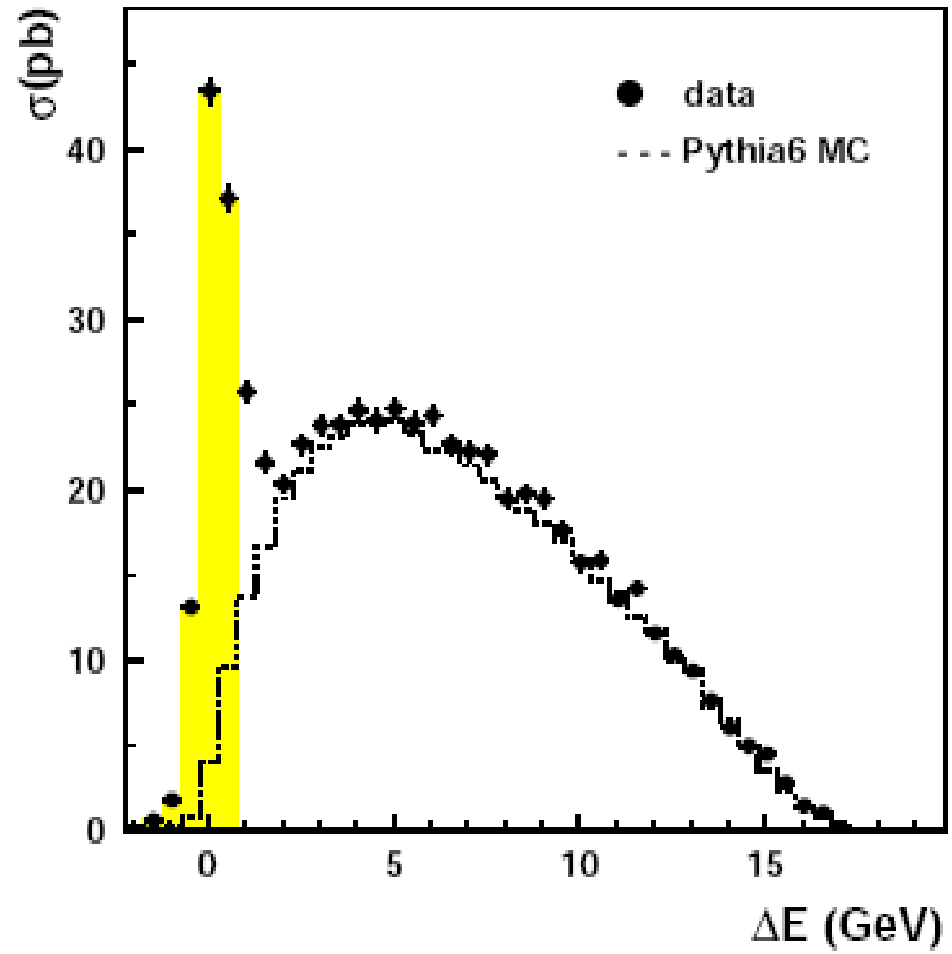


- Challenges
  - factorization proved only for longitudinal photon
  - suppression of transverse component of cross section $\sigma_T/\sigma_L \sim 1/Q^2$
  - for HERMES kinematic ($\langle Q^2 \rangle = 2GeV^2$) yields $R = \sigma_T/\sigma_L \approx 1$
  - under s-channel helicity conservation L/T-separation of ρ^0 equivalent to L/T-separation of γ^*
  - σ_T,σ_L following different θ^*-dependency Diehl, Sapeta (2005)



Event selection for ρ^0-production

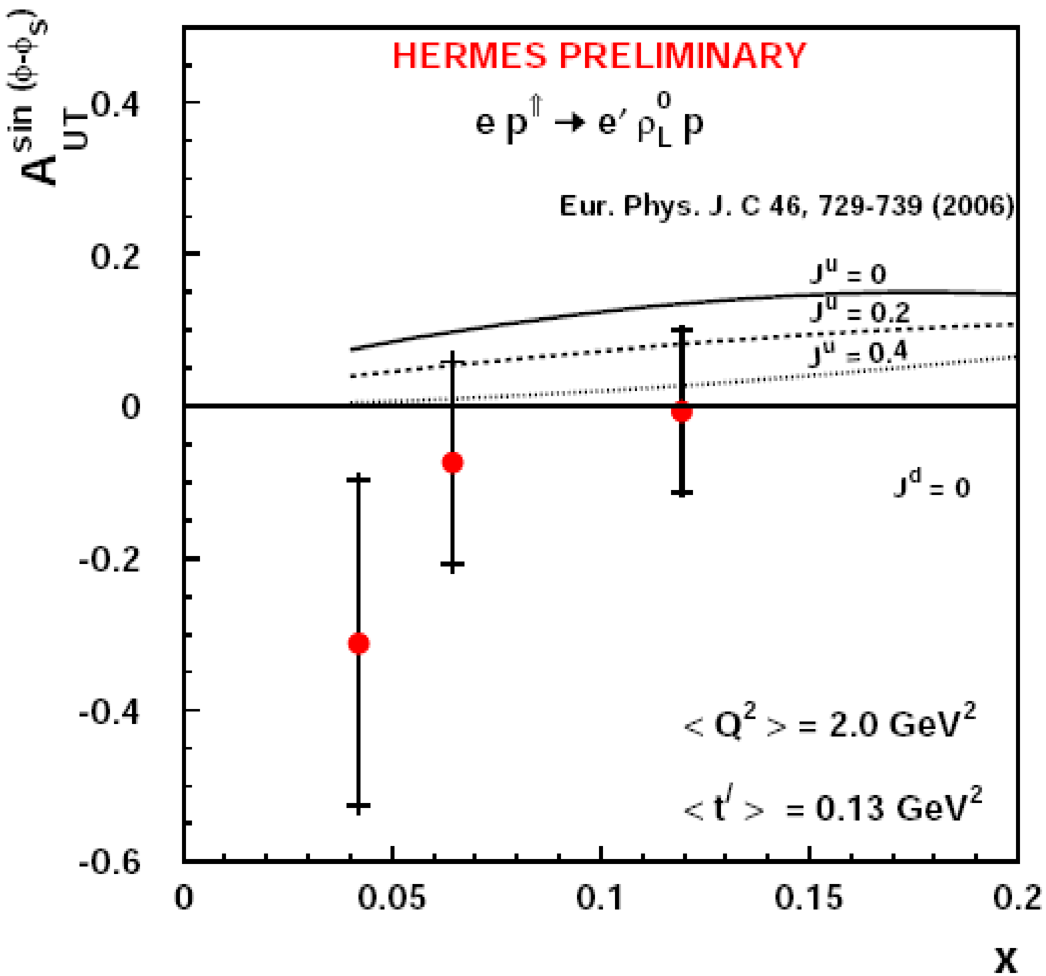


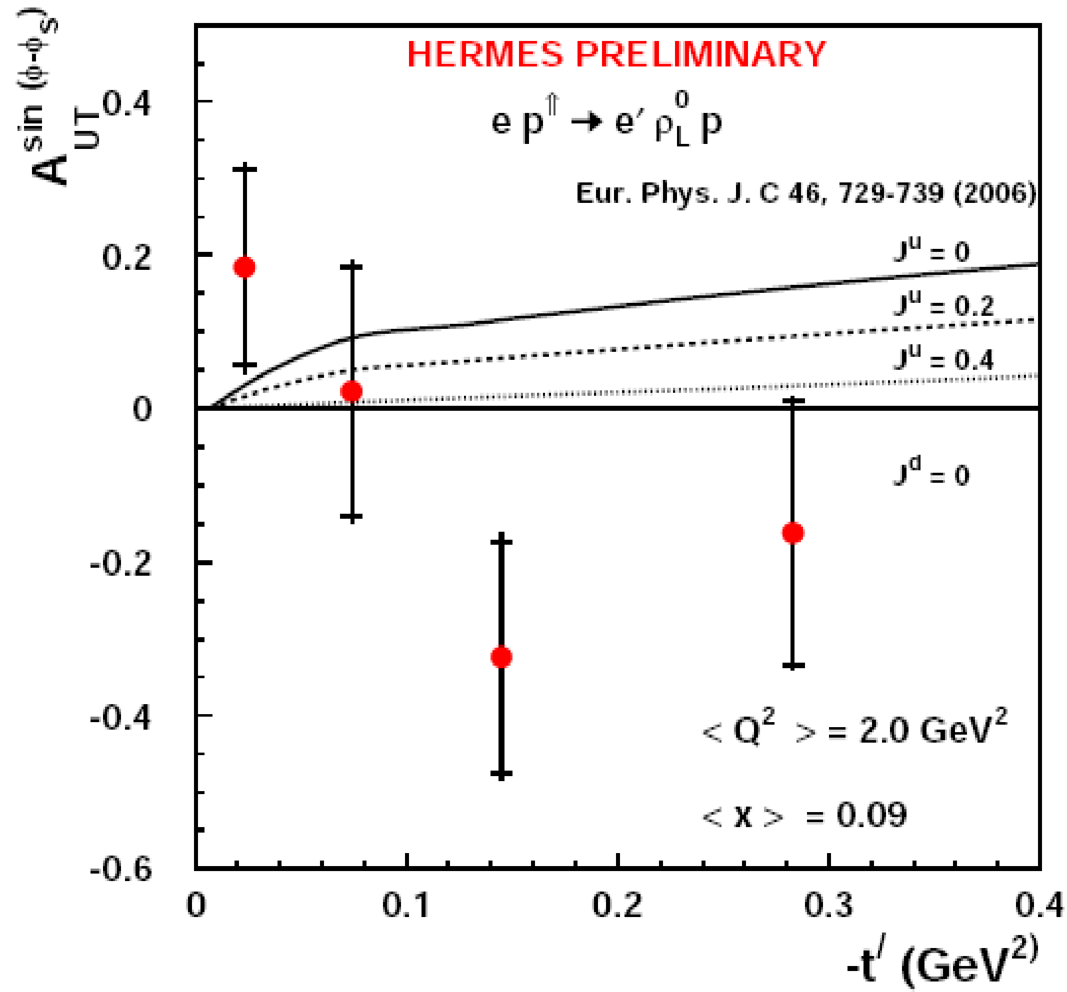


- exactly one beam lepton
- request two oppositely charged pions
- Mρ ≈770MeV
- Γρ ≈150MeV

- Exclusivity via missing mass method
- 10% background by semi-inclusive pions production, limited acceptance and experimental resolution

Comparison with theory





data favors positive Ju in good agreement with DVCS results

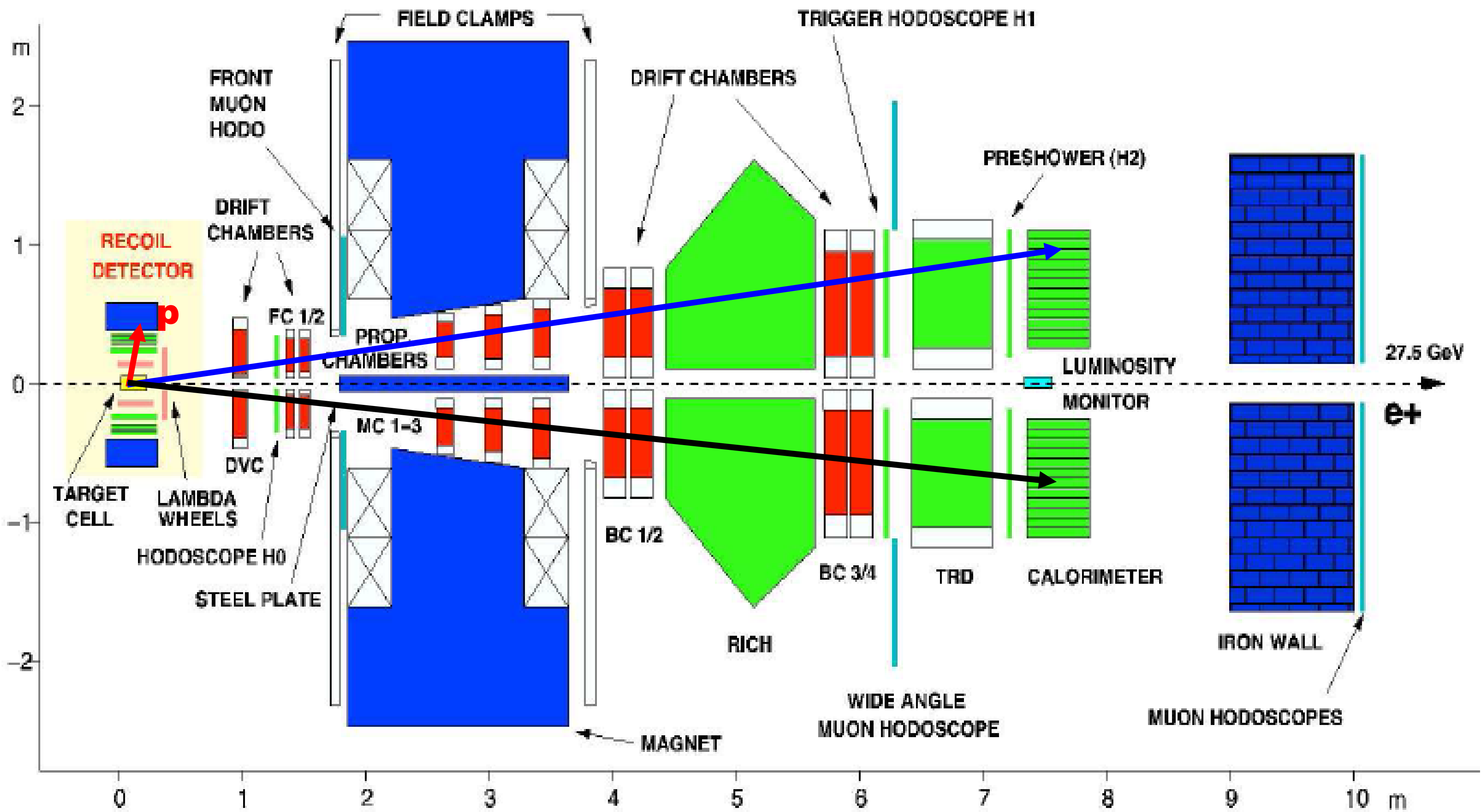
more effort for quantize Ju required

currently fast development in theory

soon new results about constraint on Ju, Jd

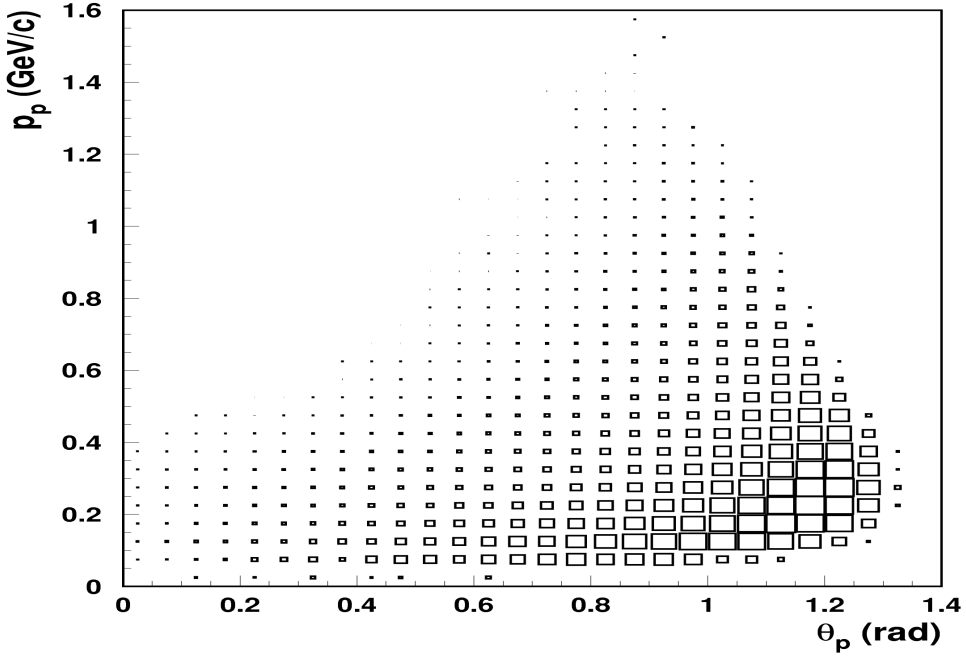
Latest HERMES upgrade
with
Recoil Detector

HERMES Spectrometer Upgrade

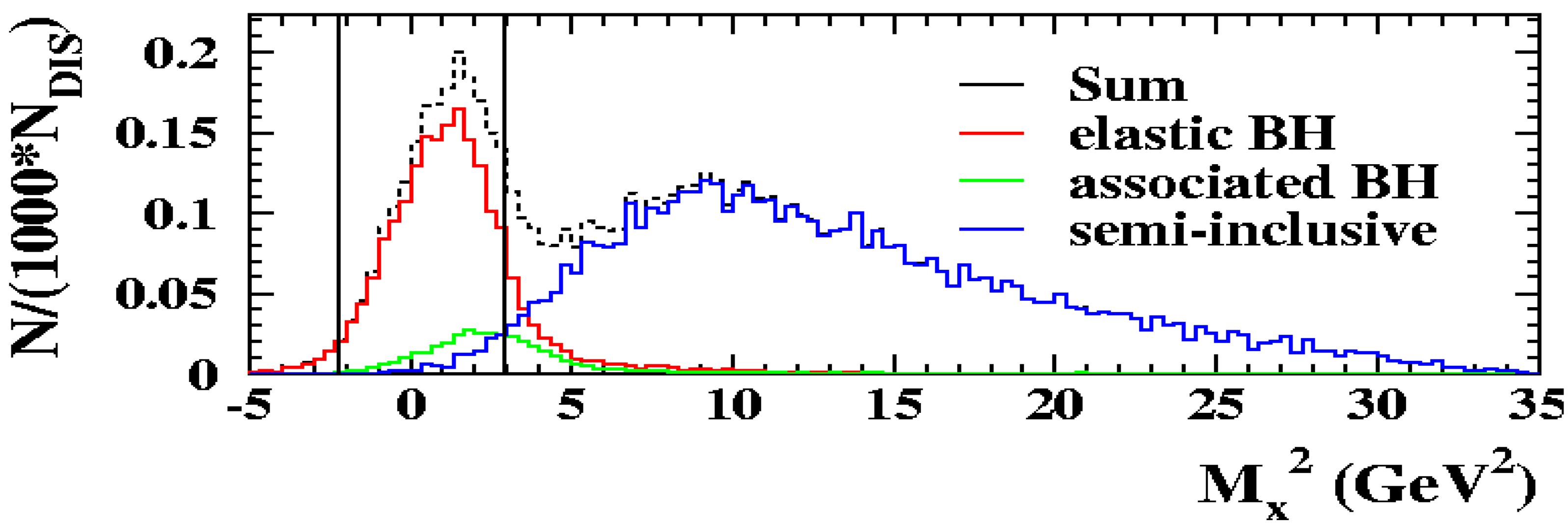


need **R**ecoil **D**etector (RD) to improve exclusivity

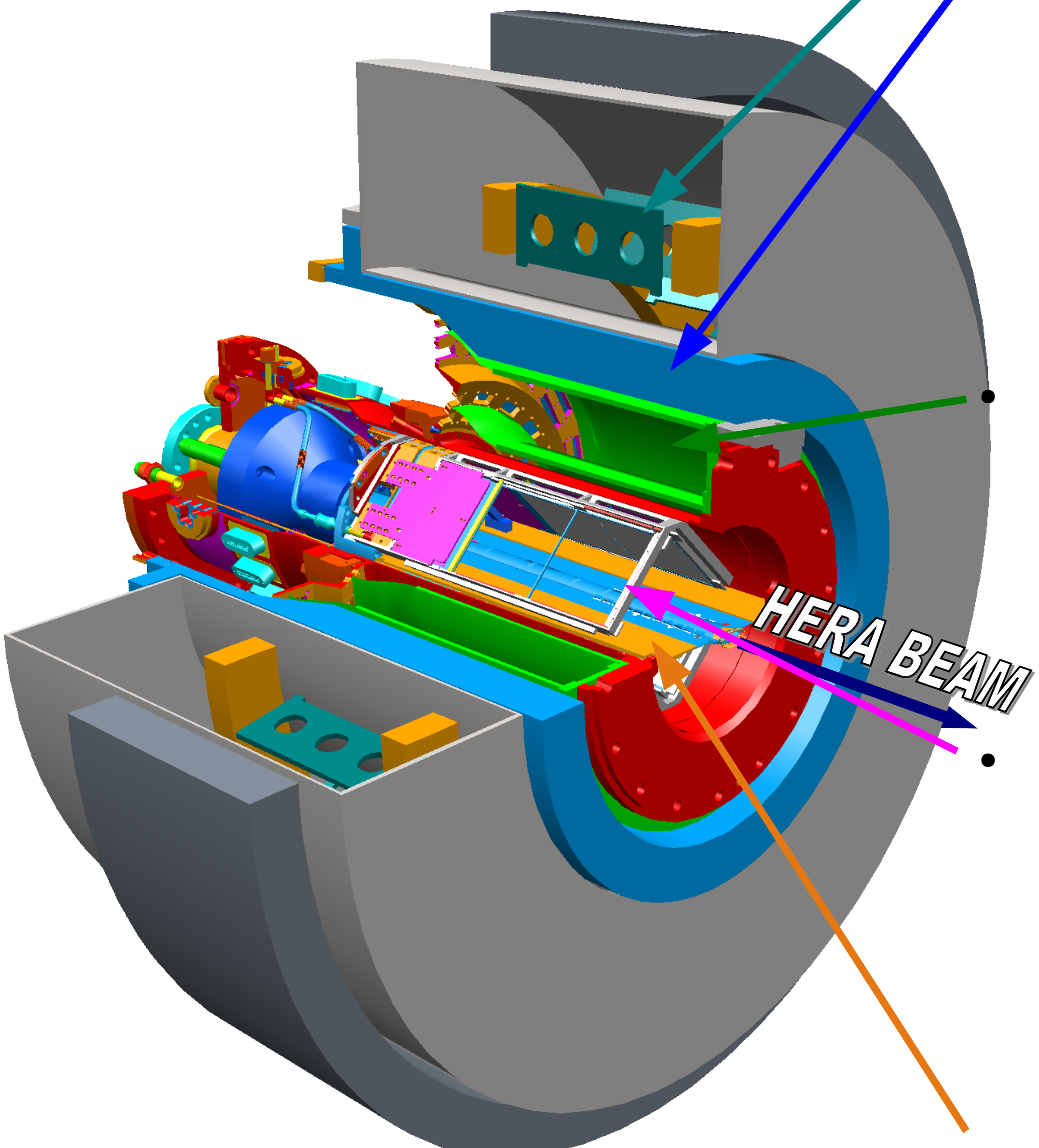
RD – design requirements



- Detect recoiling proton
- improved t resolution
- Suppress background
  - semi-incl. : 5% -> <<1%
  - BH and resonances : 11% -> 1%
- running with unpolarized gas target



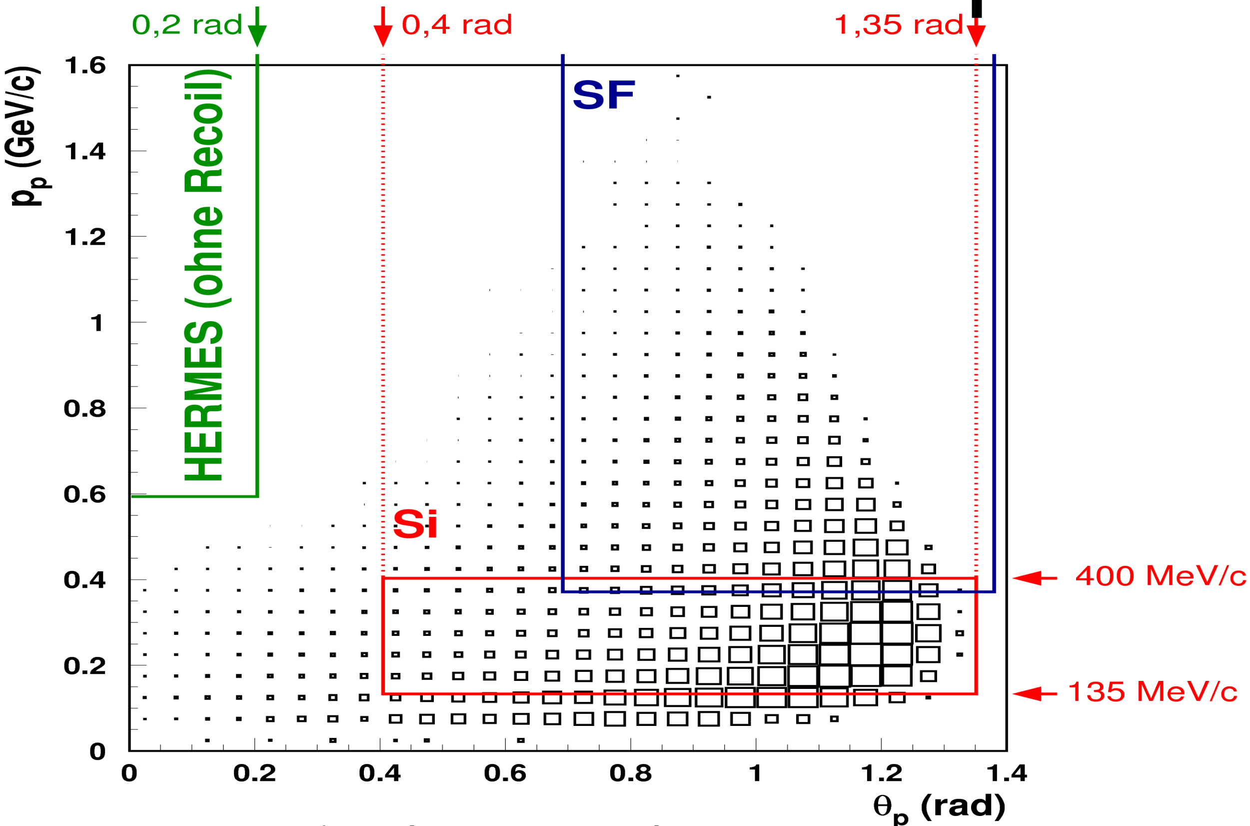
RD – realization

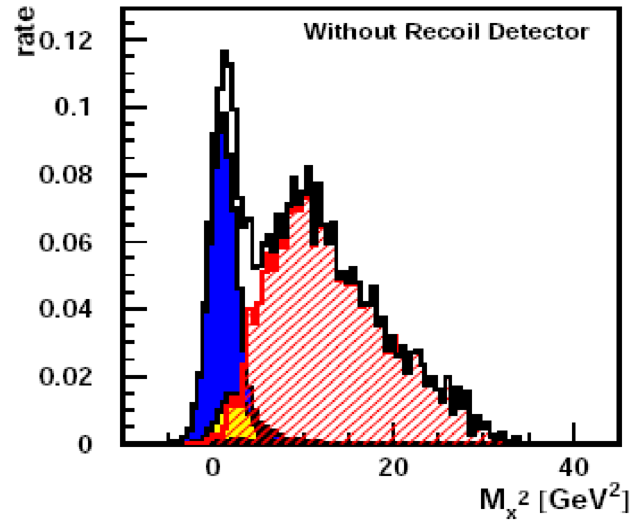


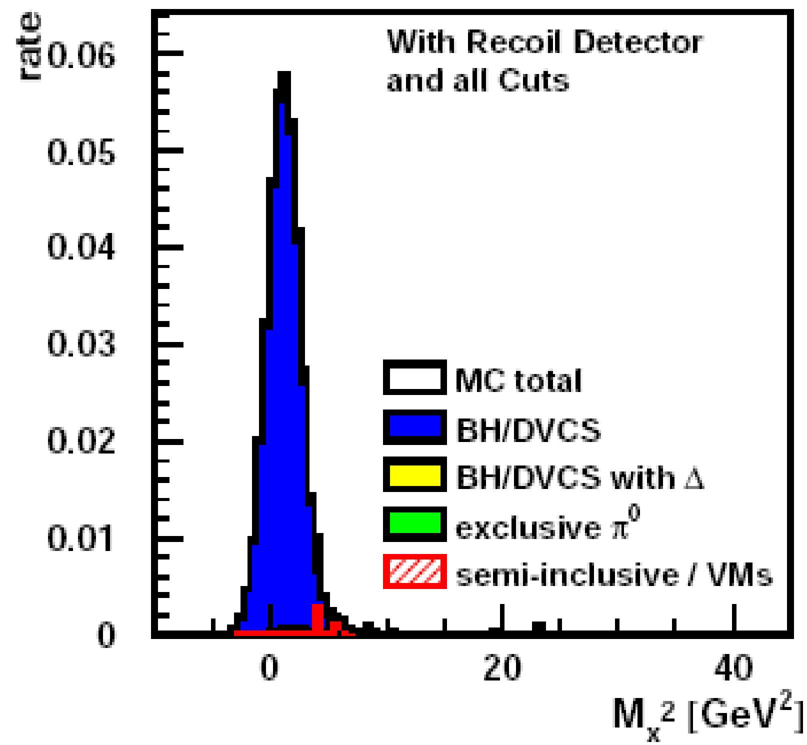
- **1T superconducting solenid**
- **Photon Detector (PD)**
  - 3 Layers of Thungsten and Scintillators (0°/+45°/-45°) as EM-calorimeter
  - PID for higher momentum
  - detects π^0 -> ´Y´Y for Δ^+ -> $p\pi^0$ identification
  - cosmic trigger for alignment, calibration ...
- **Scintillating Fiber Tracker (SFT)**
  - 2 Barrels
  - 2 Parallel- and 2 Stereo-Layers in each barrel
  - 10° stereo angle
  - momentum reconstruction & PID
- **Silicon Strip Detector (SSD)**
  - inside beam vacuum
  - 2 layers with total 16 double sided Tigre-sensors
  - 100x100mm2 active area
  - momentum reconstruction & PID
- **Target cell with unpolarized H/D gas**

installed 2005

RD – features and performance



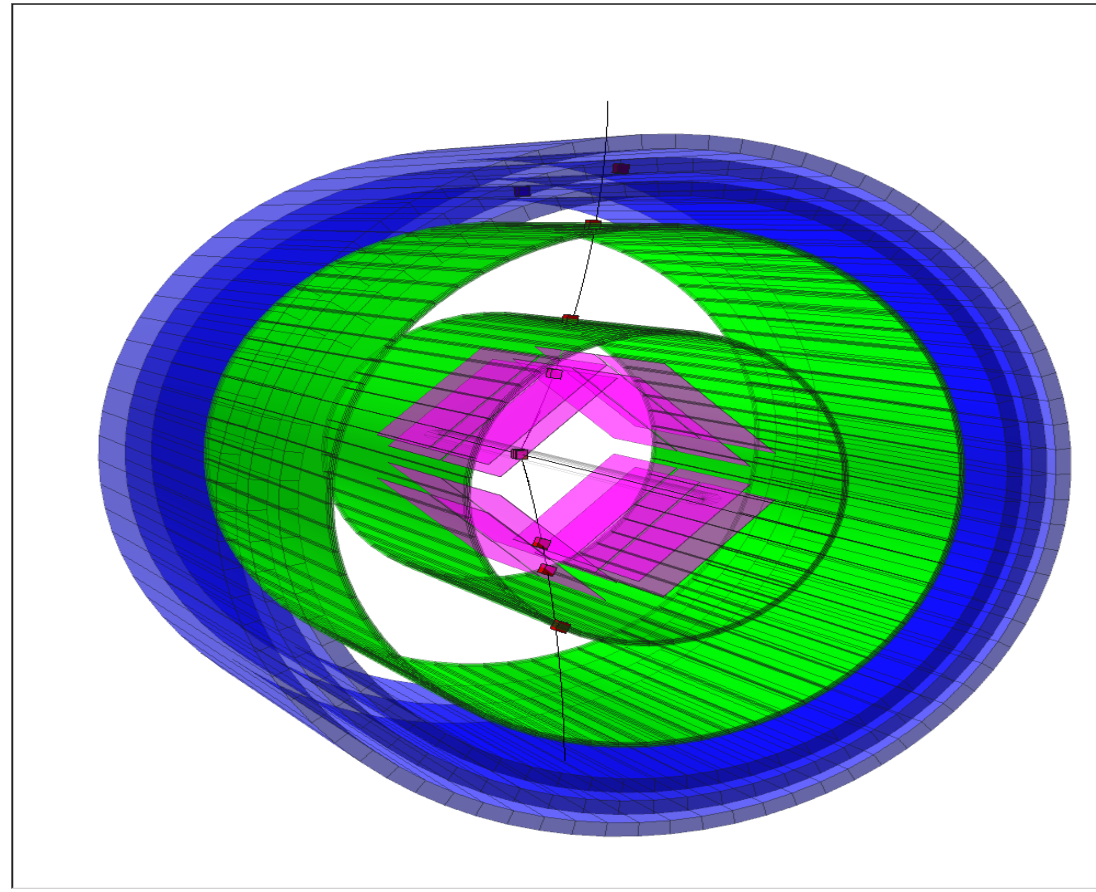


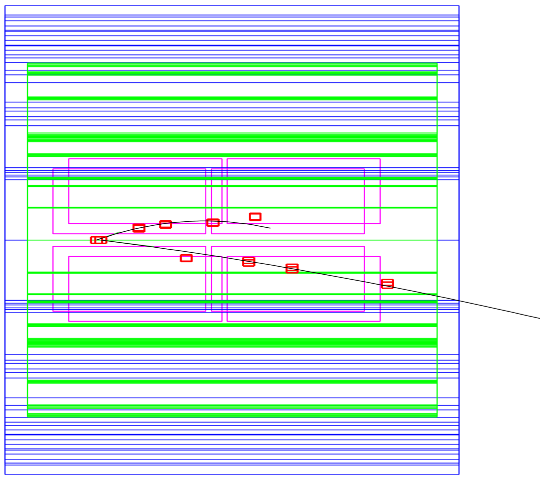


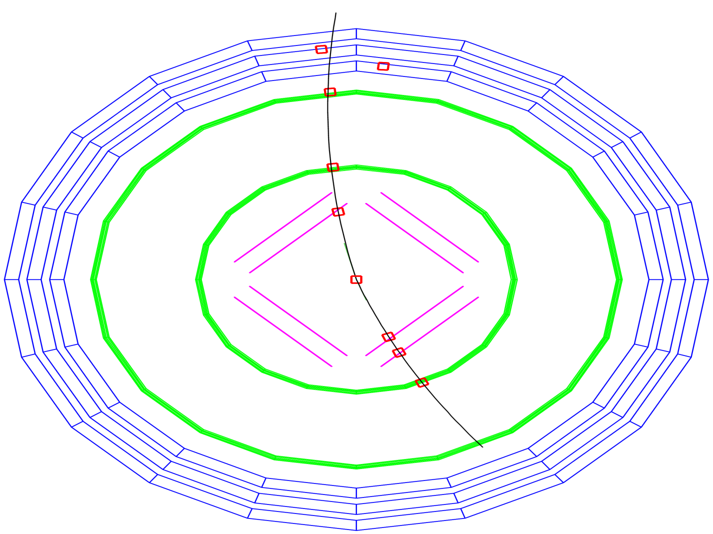
- 4 spacepoints by SSD and SFT for precise momentum measurement to improvement t resolution
- suppression of Δ^+ resonances by PD
- PID for background suppression by all
  - semi-inclusive 5% -> <<1%
  - associated BH 11% -> 1%

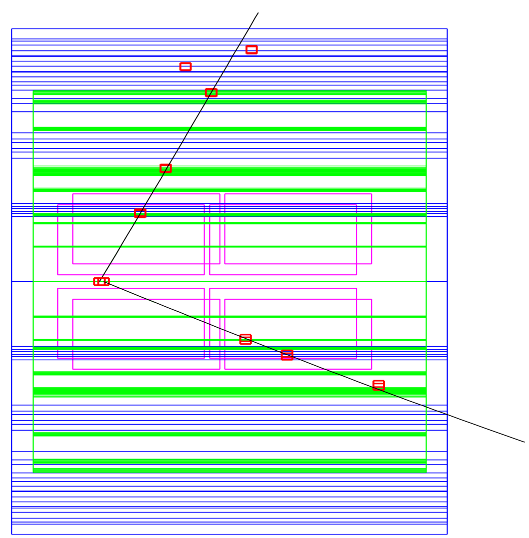
RD – event display

for pathology; for example
run 20000 event 98629798



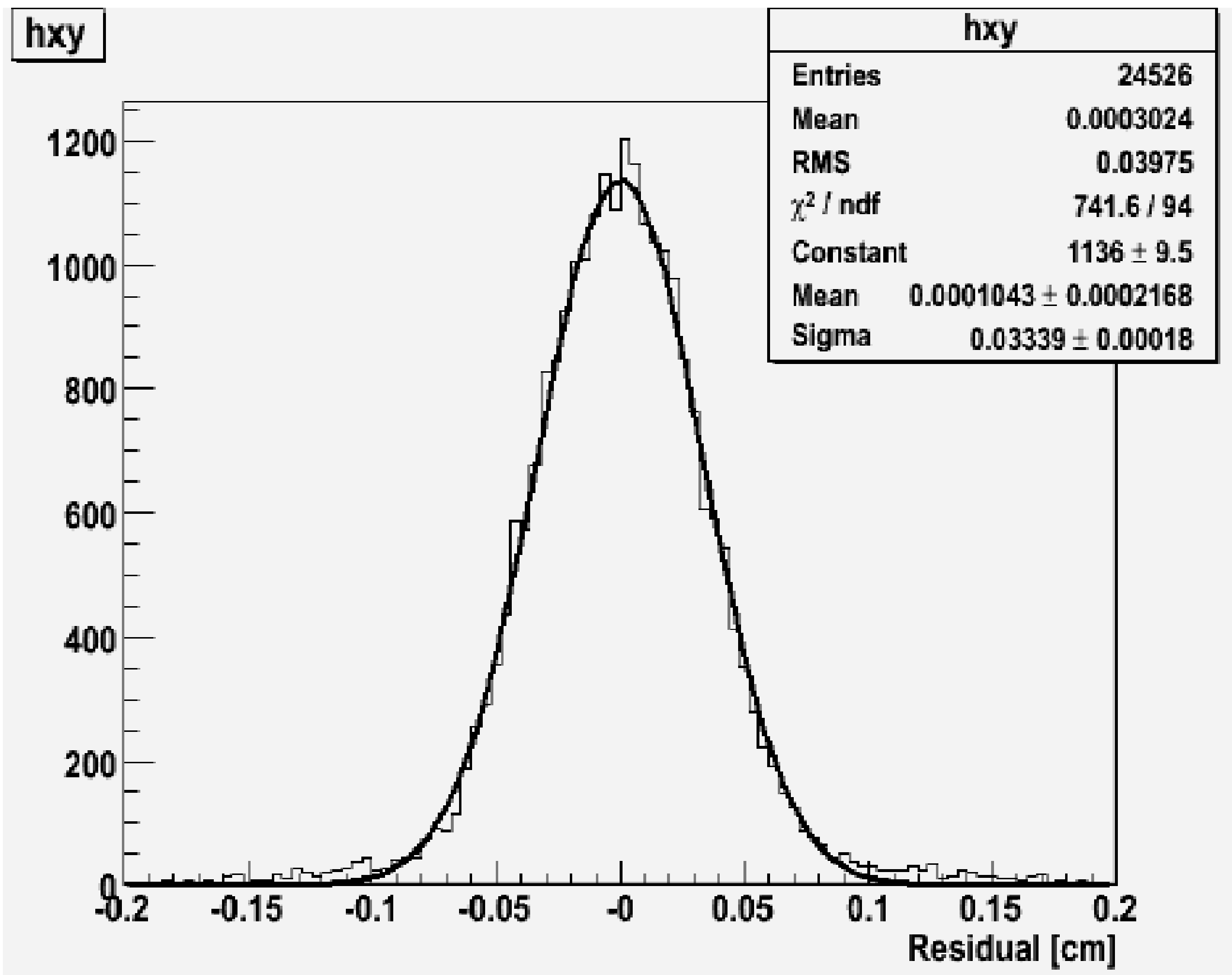




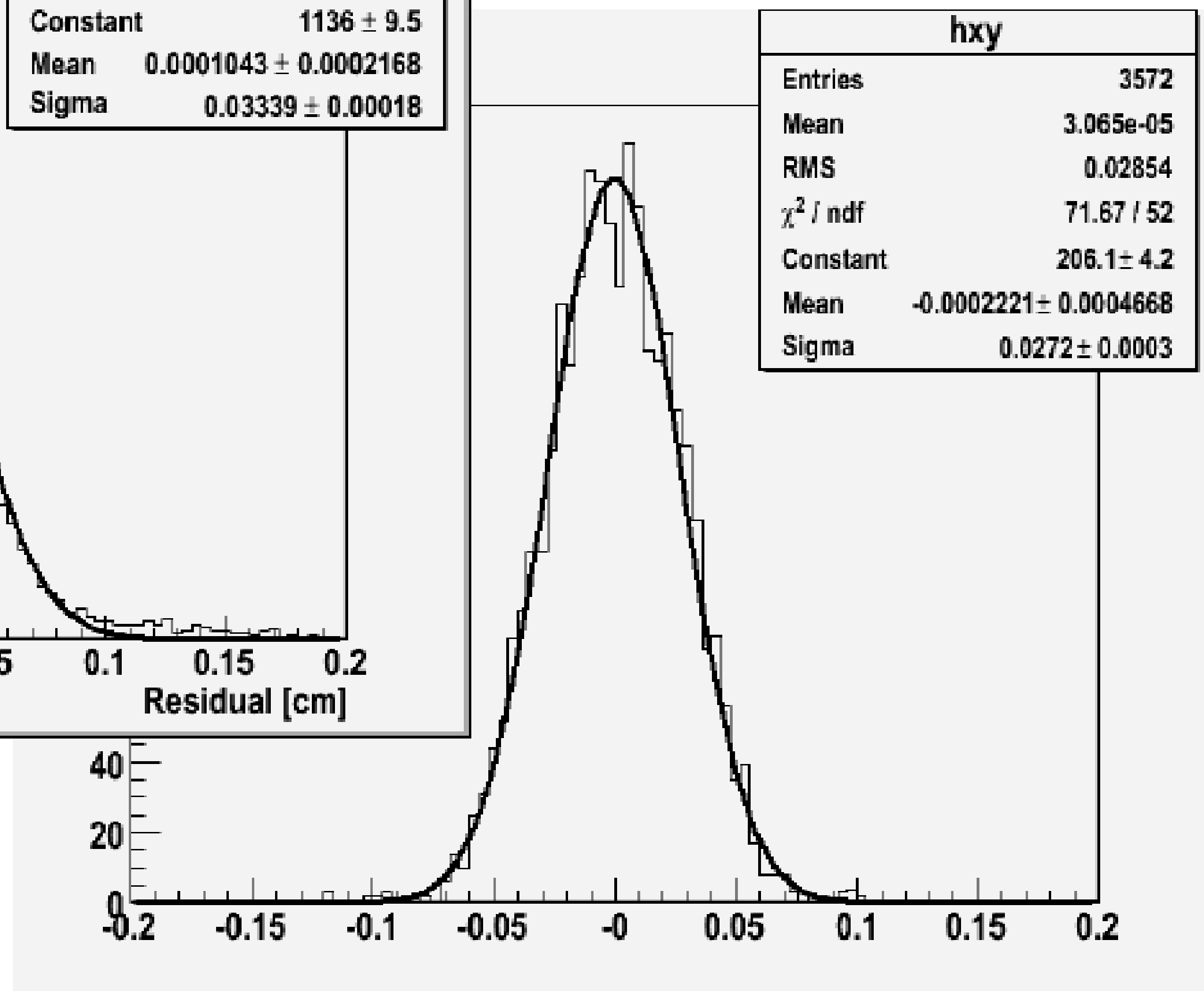


RD - residuals

track reconstruction in x,y-position

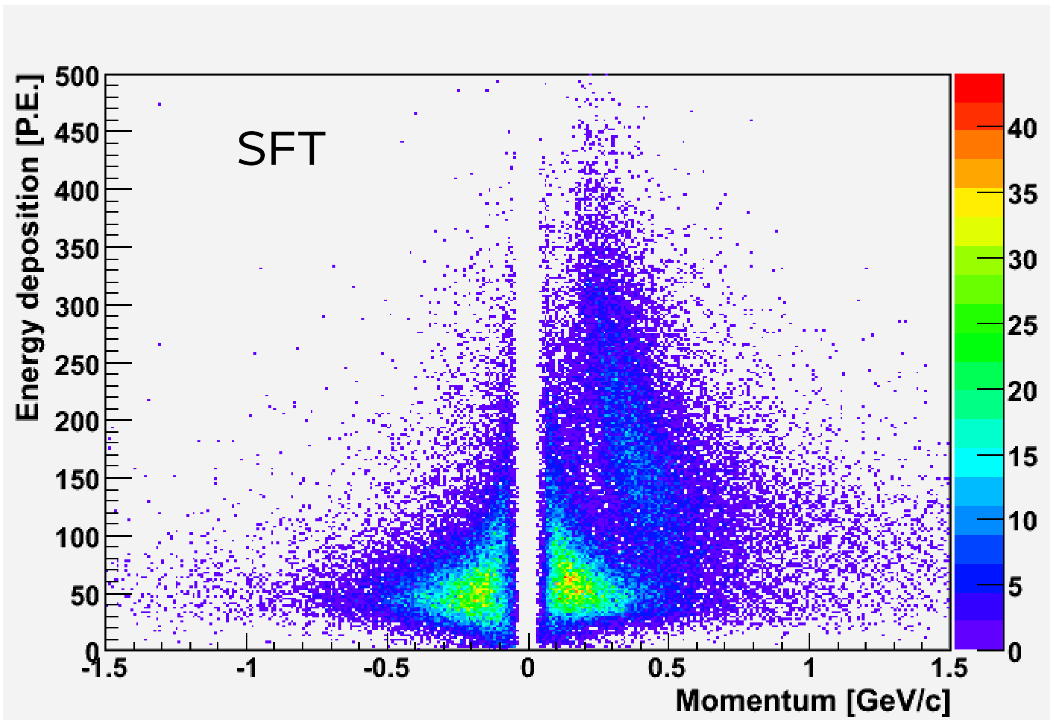


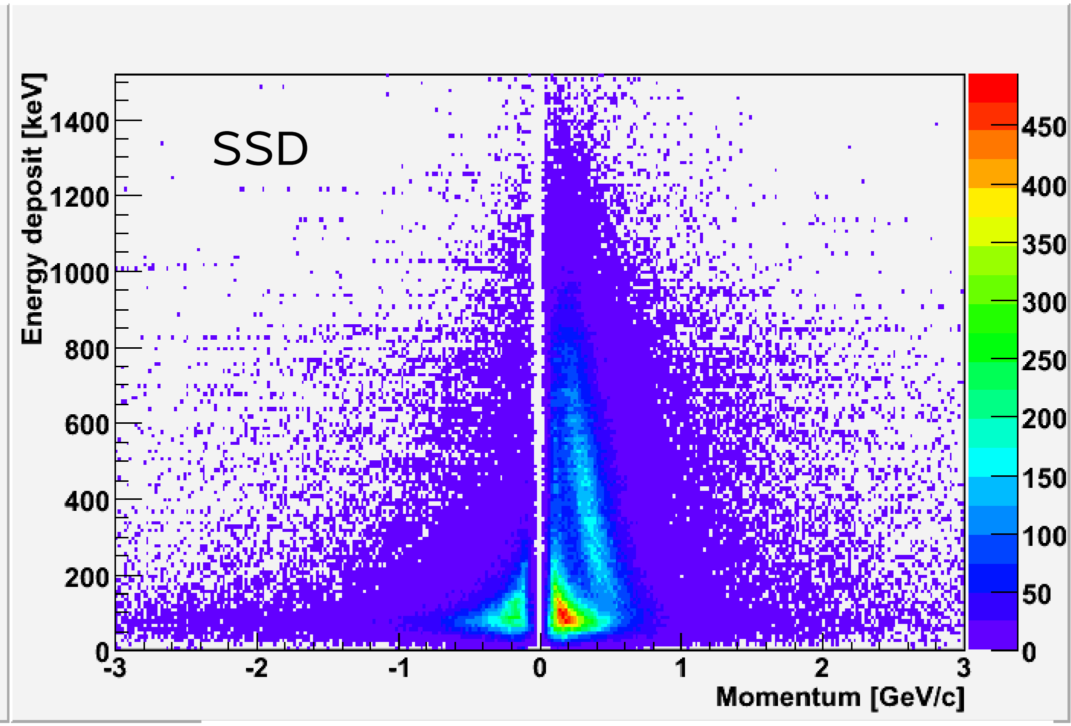
Data



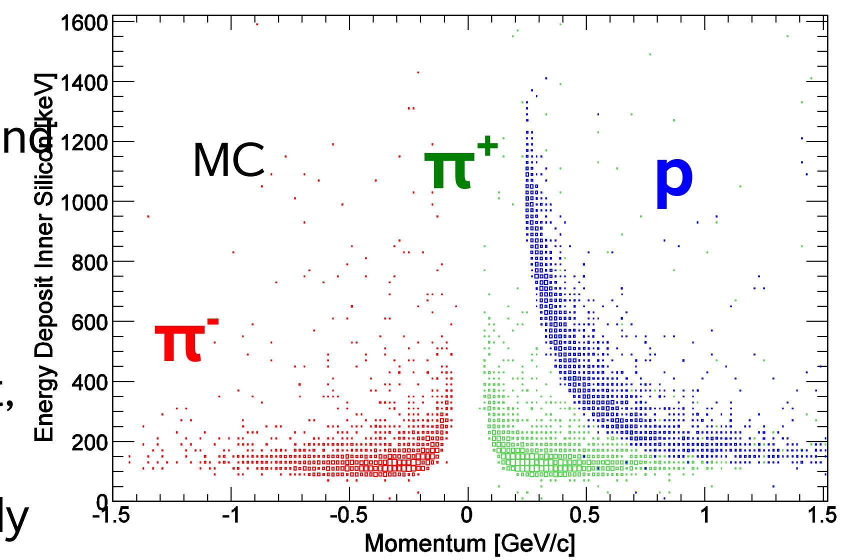
MC

PID with RD for real data and MC

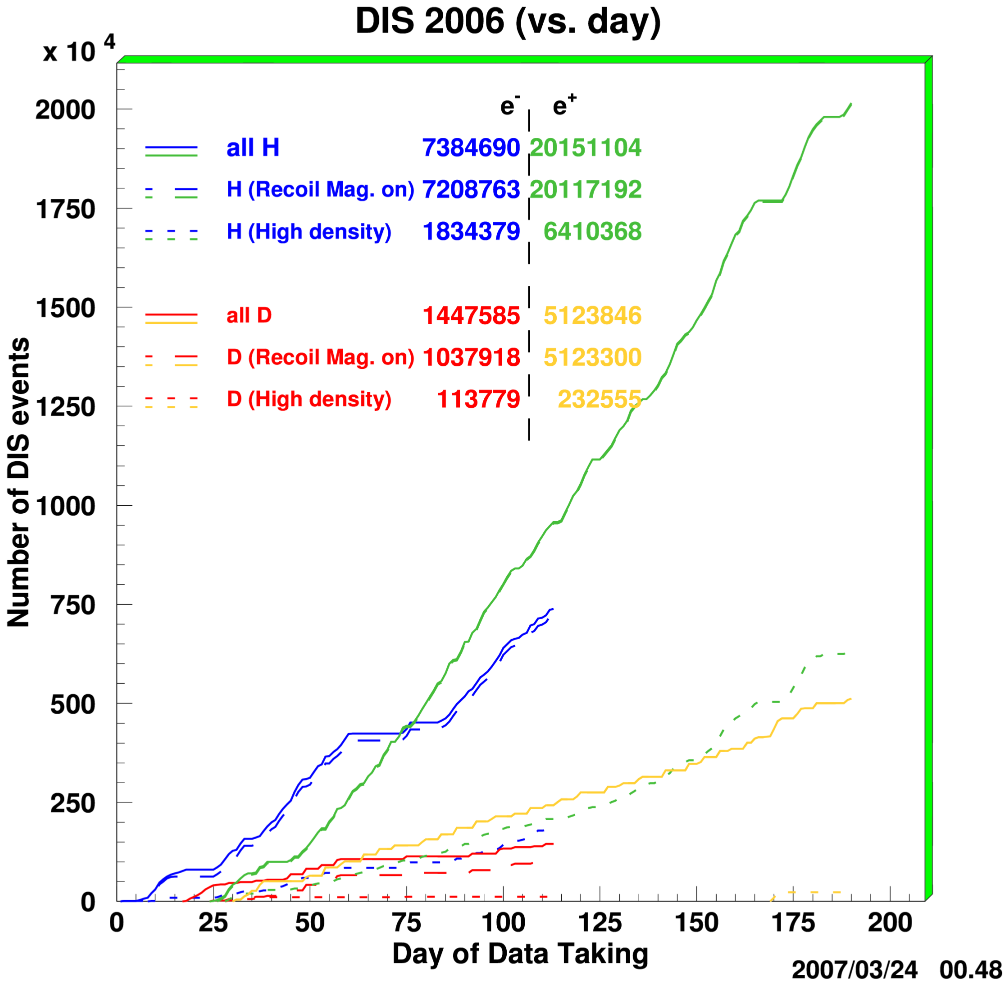


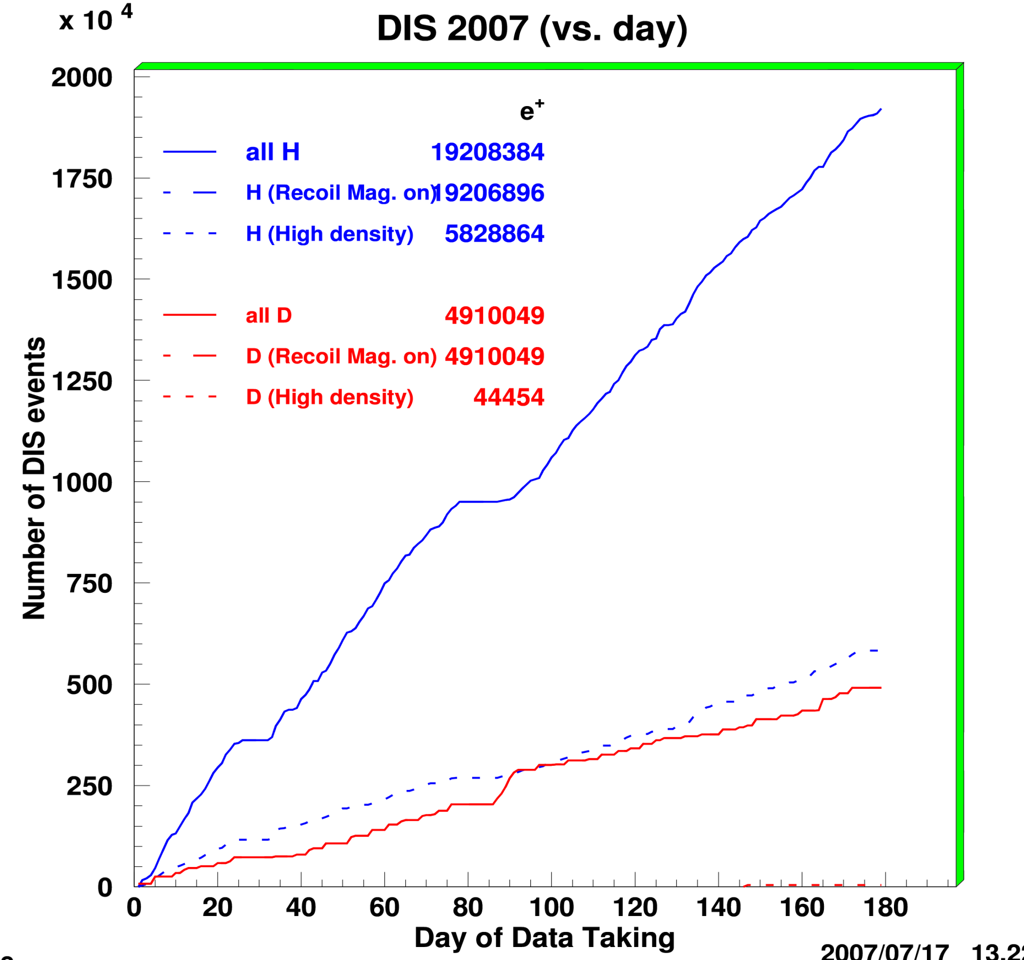


- full tracking routines including alignment already
- Efficiency of the tracking algorithm studied on MC and found to be above 98%
- study of efficiencies, residuals, ghost tracks in progress
- settle down time deviations of calibration, alignment, noise, ...
- elative company improving understanding RD rapidly



RD - available data

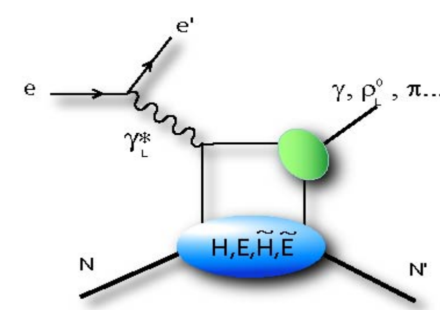




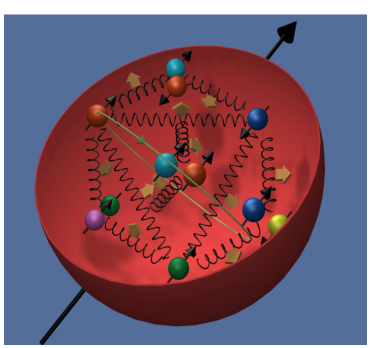
- e- beam 2006 (with SFT only)
  - H: 13k DVCS candidates / 7,4M DIS
  - D: 2k DVCS candidates / 1,5M DIS
- e+ beam 2006/2007 (full RD)
  - H: 60k DVCS candidates / 40M DIS
  - D: 15k DVCS candidates / 10M DIS

Summary and Outlook

- HERMES successful pathfinder work
  - on interpretation of GPDs
  - measuring Beam Charge/Spin Asymmetries
  - measuring L/T-Target Spin Asymmetry
  - first time ρ^0_L, ρ^0_T cross section separation
  - model dependent constraints on Ju, Jd



- 2007/06/30 23:29:59 End of HERA
  - successful data taking with Recoil Detector
  - a lot more HERMES data available



- soon new results with Recoil Detector (RD)
- re-analyzing previous data with RD informations
- improving understanding of GPDs
- improving constraints of nucleon spin budget
- collaboration meeting next week; releases in pipeline
- watch out the next weeks for new results