Overview of Exclusive Physics at hermes

Eduard Avetisyan

DESY

Prague, July 10, 2007

Why? How? What?

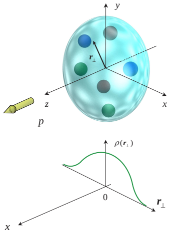
eXclusive

Why? How? What?

From Flat to 3D

Form factors

$ep \longrightarrow e'p'$



transverse charge

From Flat to 3D

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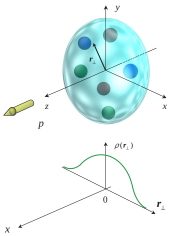
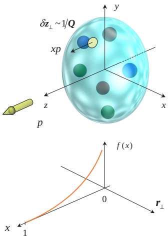


transverse charge

Parton density

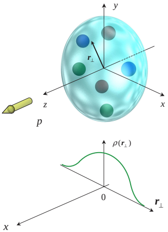
$ep \longrightarrow e'X$

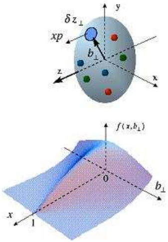


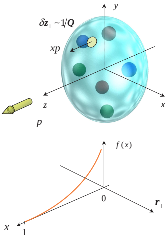
longitudinal momentum and helicity

From Flat to 3D

Form factors	GPDs	Parton density
$ep \longrightarrow e'p'$	$ep \longrightarrow e'Xp'$	$ep \longrightarrow e'X$





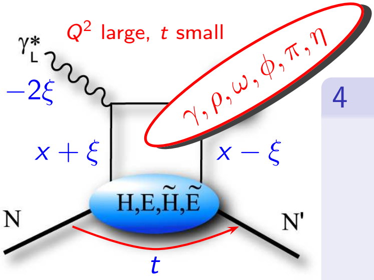


transverse charge

correlated momentum,
helicity distribution
in transverse space

longitudinal momentum
and helicity

Exclusive = GPDs !



-Collins, Frankfurt, Strikman (1997)-

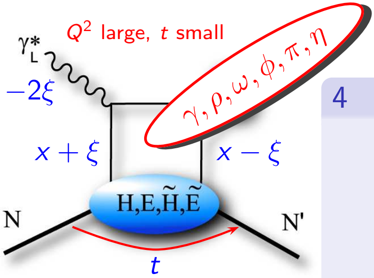
4 Generalized Parton Distributions

H	$\widetilde{H}$
E	$\widetilde{E}$
↓	↓
unpolarized	polarized

- GPDs depend on

$x+\xi$	longitudinal momentum fraction of the quark
-2ξ	exchanged longitudinal momentum fraction
t	4-momentum transfer squared

Exclusive = GPDs !



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4 Generalized Parton Distributions

H	$\widetilde{H}$	
E	$\widetilde{E}$	⇒ nucleon helicity flip
↓ unpolarized	↓ polarized	

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$x+\xi$	longitudinal momentum fraction of the quark
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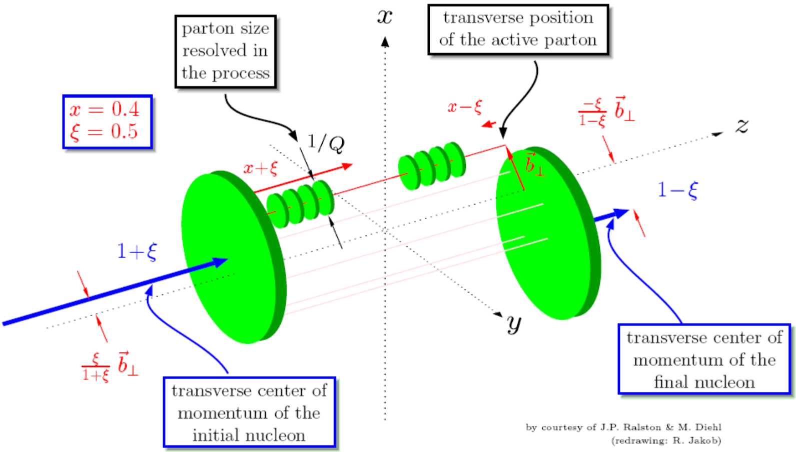
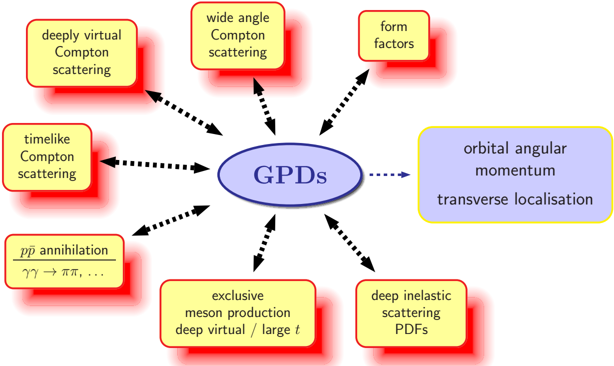
Geometrical Interpetation of GPDs



Processes Involving GPDs



- Quantum numbers of final state selects different GPDs
  - DVCS (γ): all GPDs H, E, $\widetilde{H}$, $\widetilde{E}$
  - vector mesons (ρ, ω, ϕ): unpolarized GPDs H, E
  - pseudoscalar mesons (π, η): polarized GPDs $\widetilde{H}$, $\widetilde{E}$

Close Relatives of GPDs

Forward limits (link to PDFs): $(t \to 0, \xi \to 0)$

for quarks:	$H^q(x,0,0) = q(x)$	$\widetilde{H}^q(x,0,0) = \Delta q(x)$
for antiquarks:	$H^q(x,0,0) = -\bar{q}(-x)$	$\widetilde{H}^q(x,0,0) = \Delta \bar{q}(-x)$
for gluons:	$H^g(x,0,0) = xg(x)$	$\widetilde{H}^g(x,0,0) = x\Delta g(x)$

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No corresponding relation for polarised $(E, \widetilde{E})$ GPDs $\Rightarrow$ accessible ONLY in exclusive processes!

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Sum rules (link to Form Factors):

$$\int_{-1}^{+1} H^q(x,\xi,t)dx = F_1^q(t) \qquad \int_{-1}^{+1} E^q(x,\xi,t)dx = F_2^q(t)$$

$$\int_{-1}^{+1} \widetilde{H}^q(x,\xi,t)dx = g_A^q(t) \qquad \int_{-1}^{+1} \widetilde{E}^q(x,\xi,t)dx = h_2^q(t)$$

Close Relatives of GPDs

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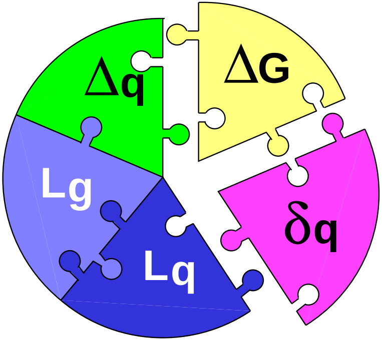
Ji sum rule - relation to total angular momentum! *- Ji,PRL 78 (1997) 610 -*

$$\frac{1}{2}\int_{-1}^{1} dx\; x\,[H^q(x,\xi,t) + E^q(x,\xi,t)] \stackrel{t\to 0}{=} J_q = \frac{1}{2}\Delta\Sigma + L_q$$

What can we learn from GPDs?



Proton Spin

(HERMES, Phys. Rev. D 75 (2007) 012007)

$$\frac{1}{2} = \underbrace{\frac{1}{2}(\overbrace{\Delta u + \Delta d + \Delta s}^{\sim 33\%} + L_q}_{J_q} + \underbrace{\Delta G + L_g}_{J_g}$$

Δq: well known from DIS & SIDIS

ΔG: first indications from DIS

L_q, L_g: unknown!

GPDs allow access to J_q, J_g through Ji's sum rule:

$$J_{q,g} = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} dx \cdot x \cdot [H_{q,g}(x, \xi, t) + E_{q,g}(x, \xi, t)]$$

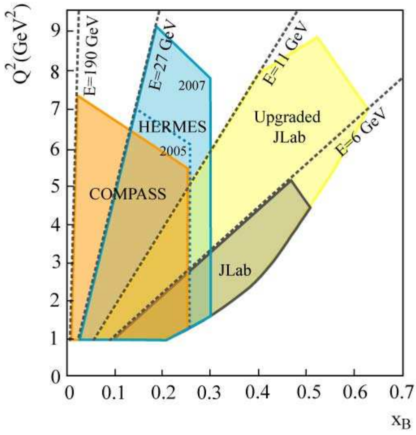
Kinamatical Coverage of Experimental Data

collider experiments:

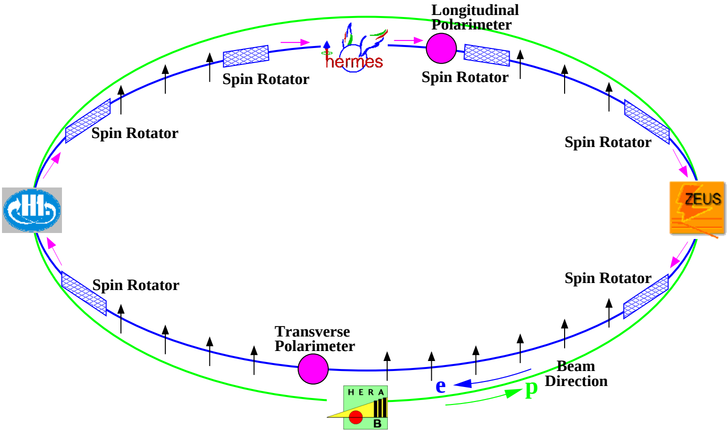
$10^{-}4 < x_B < 0.021$: probing gluons

fixed target experiments:

- Compass $0.006 < x_B < 0.3$: gluons and quarks $(q_v + q_s)$
- HERMES $0.02 < x_B < 0.3$: gluons and quarks $(q_v + q_s)$
- JLAB (@6GeV)$0.13 < x_B < 0.6$: quarks (valence)



The HERA Accelerator

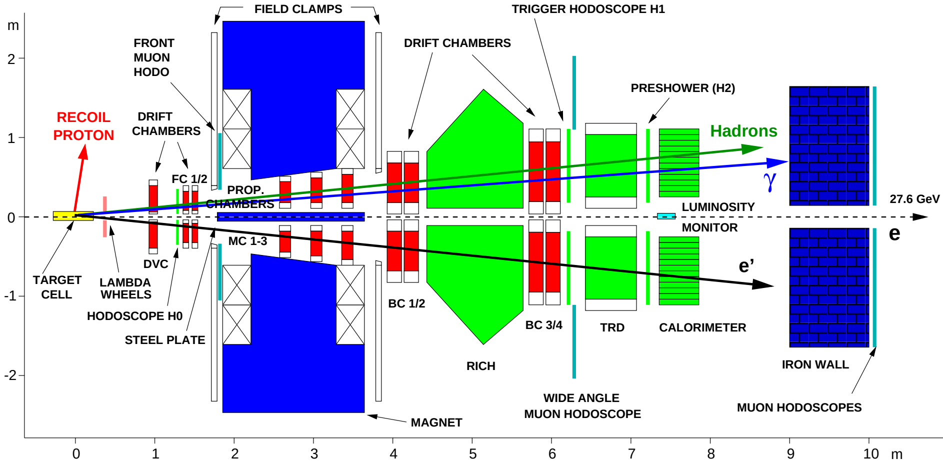


Possibility of e^{+} and e^{-} beams with $E_{beam} = 27.5 GeV$

Naturally polarised! $\langle P_{beam} \rangle \approx 30 - 60\%$

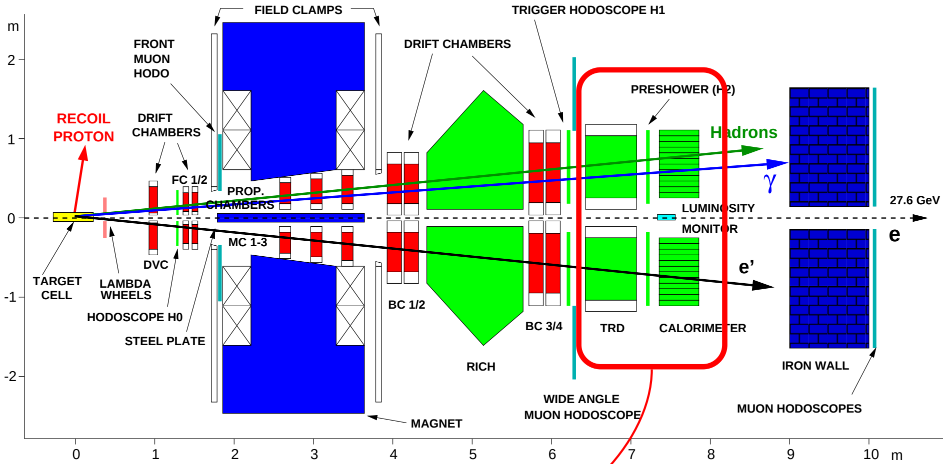
Spin rotators used to obtain longitudinal polarisation

Spectrometer



Fixed target (**H,D**,N,Ne,Kr,Xe), high longitudinal/transverse polarisation!

Spectrometer



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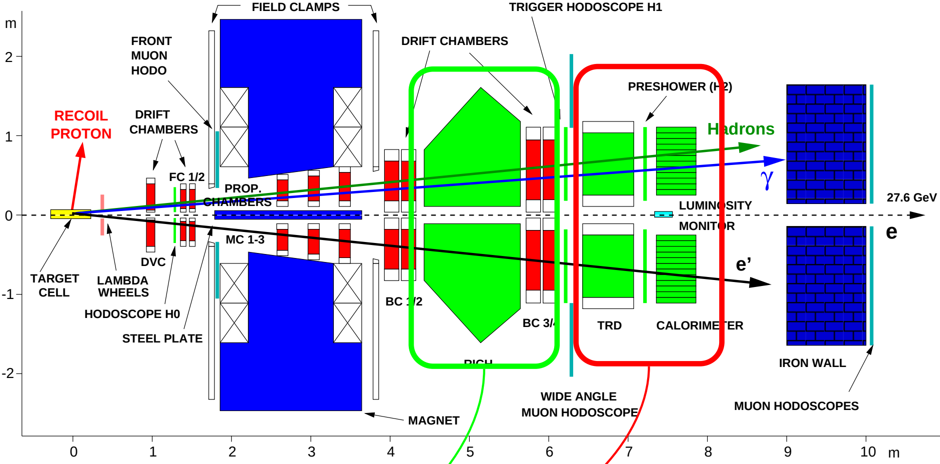
$e^{\pm}$: EM-Calorimeter, TRD, Preshower

Spectrometer



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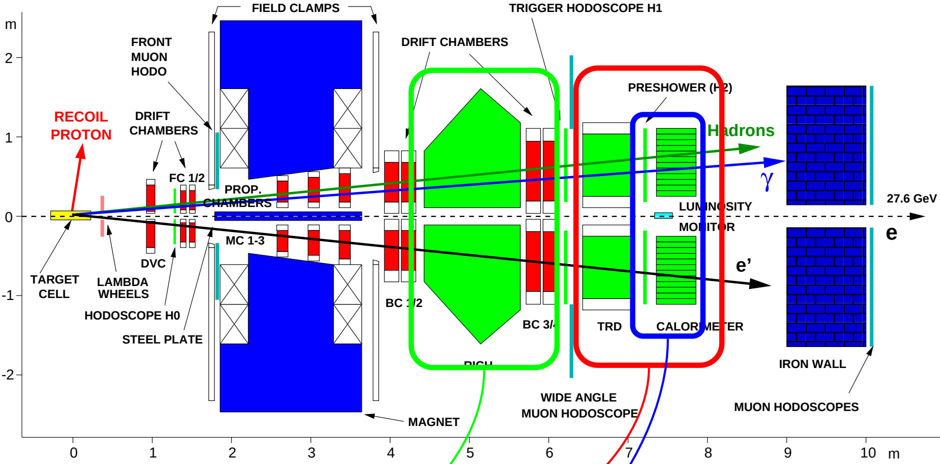
hadron PID: RICH

Spectrometer



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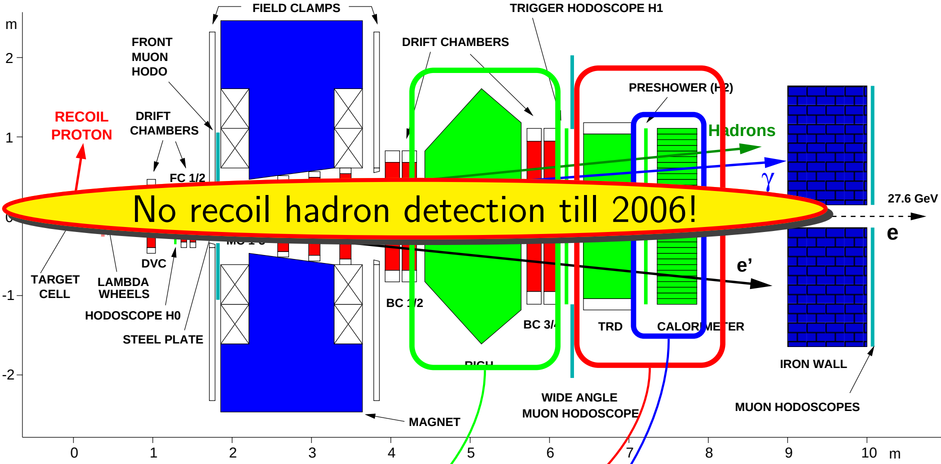

No recoil hadron detection till 2006!

Fixed target (**H,D**,N,Ne,Kr,Xe), high longitudinal/transverse polarisation!

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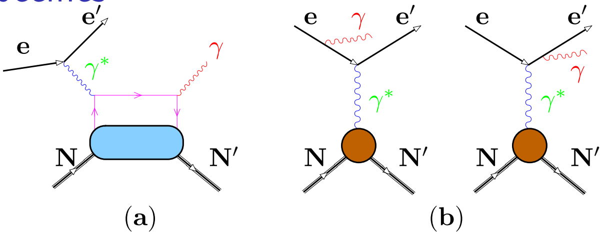
DVCS - Specifics



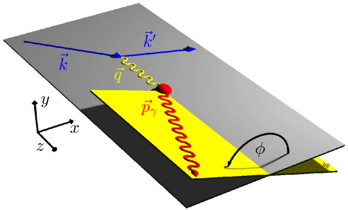
$$e + N \rightarrow e' + \gamma + N'$$

- The simplest probe of GPDs (no gluons in the leading order)
- Same final state in DVCS and Bethe-Heitler ⇒ Interference!
- $d\sigma(\mathrm{eN} \rightarrow \mathrm{eN}\gamma) \propto |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \underbrace{\mathcal{T}_{BH}\mathcal{T}^*_{DVCS} + \mathcal{T}^*_{BH}\mathcal{T}_{DVCS}}_{\mathcal{I}}$
- $|\mathcal{T}_{BH}|^2 >> |\mathcal{T}_{DVCS}|^2$ at HERMES → no direct X-section measurement
- Good news: $\mathcal{I}$ interference term allows access to (certain) GPD combinations through asymmetries!

All the glory of the asymmetries!

Interference term $\mathcal{I}$ induces azimuthal asymmetries in cross-section:

- Beam-charge asymmetry $A_C(\phi)$:
  $d\sigma(e^+,\phi) - d\sigma(e^-,\phi) \propto \mathrm{Re}[F_1\mathcal{H}] \cdot \cos\phi$
- Beam-spin asymmetry $A_{LU}(\phi)$:
  $d\sigma(\overrightarrow{e},\phi) - d\sigma(\overleftarrow{e},\phi) \propto \mathrm{Im}[F_1\mathcal{H}] \cdot \sin\phi$
- Long. target-spin asymmetry $A_{UL}(\phi)$:
  $d\sigma(\overset{\Leftarrow}{P},\phi) - d\sigma(\overset{\Rightarrow}{P},\phi) \propto \mathrm{Im}[F_1\widetilde{\mathcal{H}}] \cdot \sin\phi$
- Transverse target-spin asymmetry $A_{UT}(\phi,\phi_s)$



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

$\Rightarrow$ TTSA is the only DVCS asymmetry where $\mathcal{E}$ enters in leading order
As models for $\mathcal{E}$ depend on $J_q \Longrightarrow \mathrm{A}_{\mathrm{UT}}^{\sin(\phi-\phi_S)\cos\phi}$ is sensitive to J_q !

(F_1, F_2 are the Dirac and Pauli form factors, calculable in QED)
($\mathcal{H}, \mathcal{E}, \widetilde{\mathcal{H}}, \widetilde{\mathcal{E}}$ are the Compton form factors, moments of corresponding GPDs)

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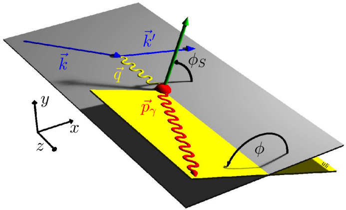

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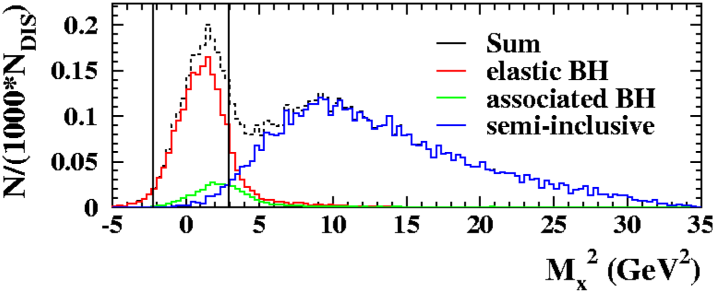
Measurement of DVCS

- No recoil proton detection (1996-2005) $\Rightarrow$ missing mass technique used
- $M_x^2 = (P_e + P_p - P_{e'} - P_\gamma)^2$
- SIDIS (π^0) Background contribution $\sim$ 5% estimated from MC



A_C Beam Charge Asymmetry

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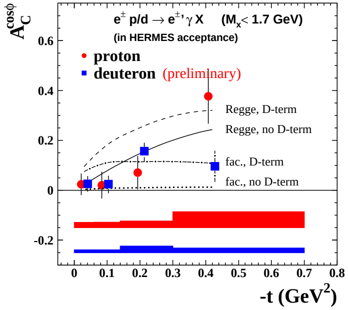

- model for proton from M.Vanderhaeghen et al (PRD 60 (1999) 094017)
- Contributions to $e + d \to e + X + \gamma$:

$ed \to ed\gamma$	coherent production	$\sim 20\%$
$ed \to epn\gamma$	incoherent production	$\sim 60\%$
$ed \to e\Delta\gamma$	associated production	$\sim 15\%$

- coherent contribution enhanced at small $-t$ (up to $\sim 40\%$)
- neutron contribution ONLY at large $-t$

HERMES, Phys. Rev. **D75** (2007) 011103(R)

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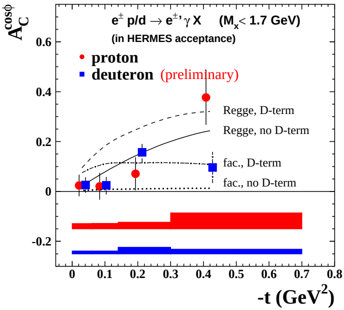

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Regge model with D-term disfavoured by the $-t$-dependence of the BCA

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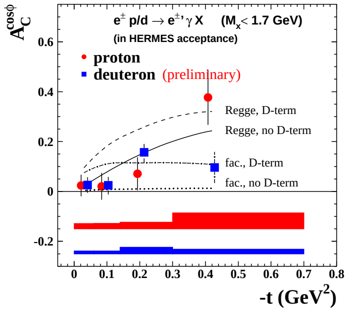

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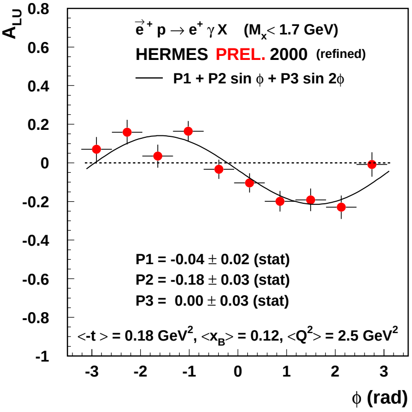
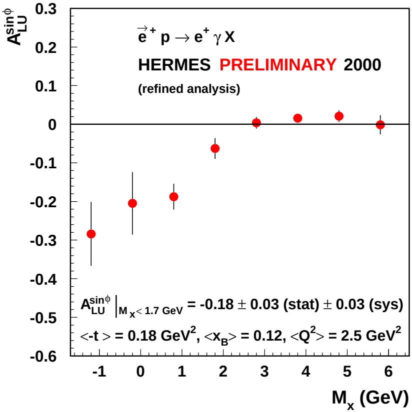
HERMES, Phys. Rev. **D75** (2007) 011103(R)

~ 20 **times more data on tape! Updates coming soon!**

A_{LU} Beam Spin Asymmetry

$$A_{LU}(\phi) = \frac{1}{P_B} \cdot \frac{d\sigma(\overrightarrow{e},\phi) - d\sigma(\overleftarrow{e},\phi)}{d\sigma(\overrightarrow{e},\phi) + d\sigma(\overleftarrow{e},\phi)} \propto \mathrm{Im}[F_1\mathcal{H}] \cdot \sin\phi$$





[HERMES, PRL 87 (2001) 182001]

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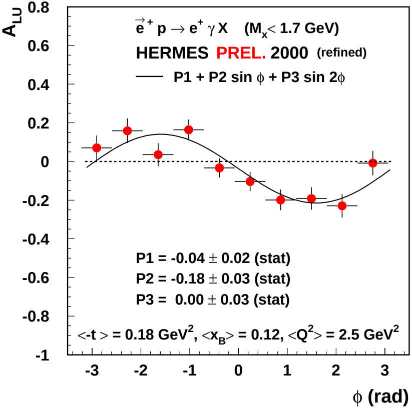

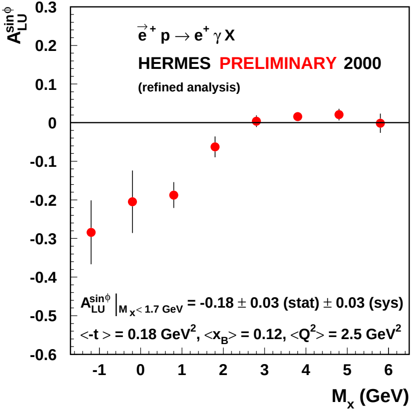

[HERMES, PRL 87 (2001) 182001]

The $A_{LU}^{\sin\phi}$ moment of the asymmetry is large and negative in the exclusive region, small and positive in the SIDIS

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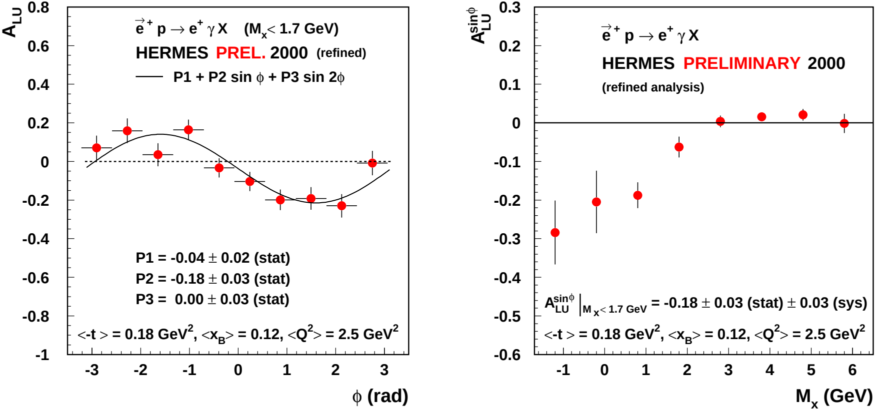
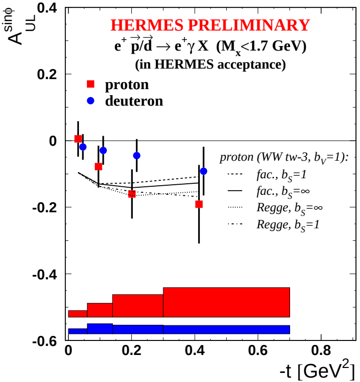


[HERMES, PRL 87 (2001) 182001]

More data on tape! Updates coming soon!

Longitudinal Target Spin Asymmetry A_{UL}

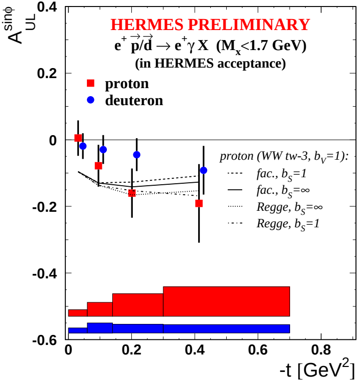
$$A_{UL}(\phi) = \frac{1}{P_T} \cdot \frac{d\sigma(\overleftarrow{P},\phi) - d\sigma(\overrightarrow{P},\phi)}{d\sigma(\overleftarrow{P},\phi) + d\sigma(\overrightarrow{P},\phi)} \propto \mathrm{Im}[F_1 \widetilde{\mathcal{H}}] \cdot \sin\phi$$

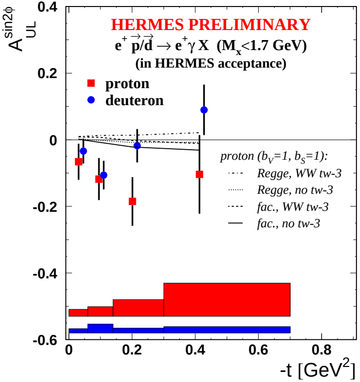


the sin ϕ moment in agreement with GPD models

Longitudinal Target Spin Asymmetry A_{UL}

$$A_{UL}(\phi) = \frac{1}{P_T} \cdot \frac{d\sigma(\overleftarrow{P},\phi) - d\sigma(\overrightarrow{P},\phi)}{d\sigma(\overleftarrow{P},\phi) + d\sigma(\overrightarrow{P},\phi)} \propto \mathrm{Im}[F_1 \widetilde{\mathcal{H}}] \cdot \sin\phi$$





the sin ϕ moment in agreement with GPD models

unexpectedly large sin 2ϕ moment! twist-3 GPDs?

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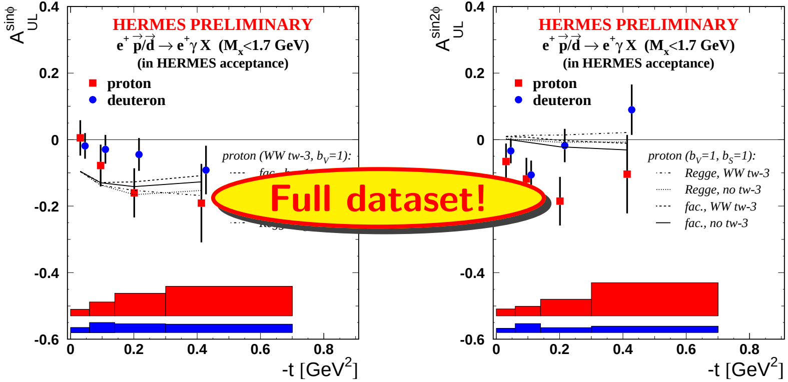


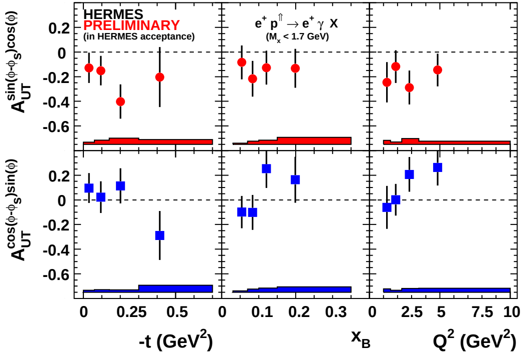
the $\sin\phi$ moment in agreement with GPD models

unexpectedly large $\sin 2\phi$ moment! twist-3 GPDs?

Transverse Target Spin Asymmetry A_{UT}

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

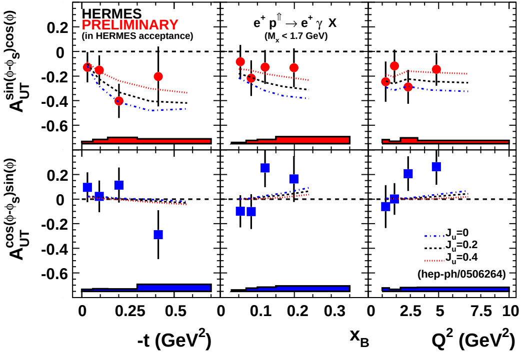
$$\propto \mathrm{Im}[F_2\mathcal{H}-F_1\mathcal{E}]\sin(\phi-\phi_S)\cos\phi+\mathrm{Im}[F_2\widetilde{\mathcal{H}}-F_1\xi\widetilde{\mathcal{E}}]\cos(\phi-\phi_S)\sin\phi$$



$\propto \mathrm{Im}[F_2\mathcal{H}-F_1\mathcal{E}]$

$\propto \mathrm{Im}[F_2\widetilde{\mathcal{H}}-F_1\xi\widetilde{\mathcal{E}}]$

Transverse Target Spin Asymmetry A_{UT}

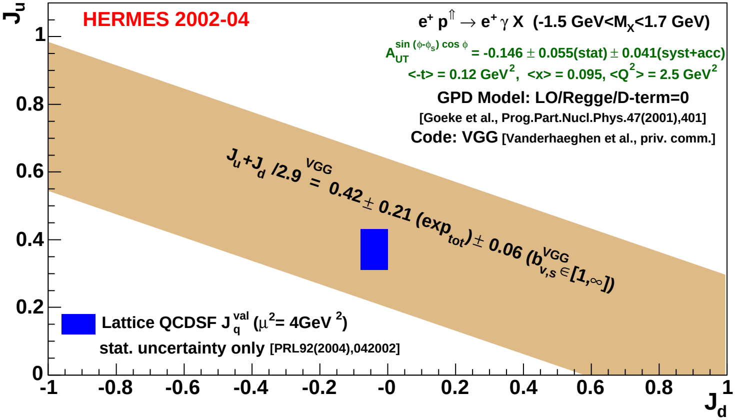


$\propto \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}]$

$\propto \mathrm{Im}[F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}]$

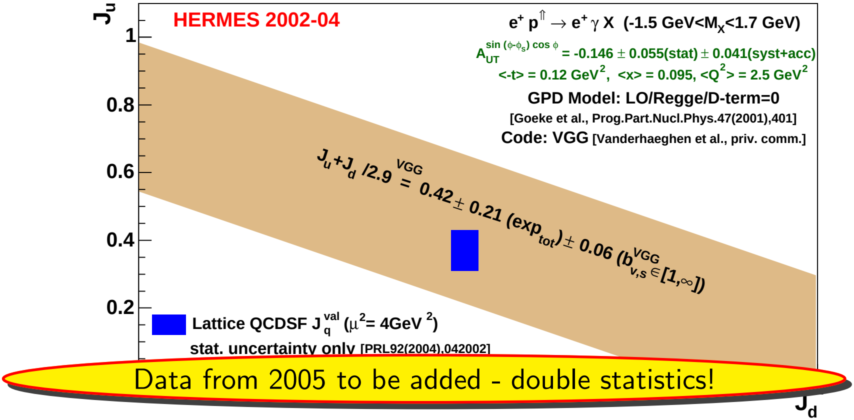
- $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ found much more sensitive to J_u then others
- insensitive to J_d, assumed $J_d = 0$ (supported by lattice QCD)
- allows a model-dependent constrain

Total Angular Momentum - Ji sum rule



- data fitted against the model
- J_u and J_d as free parameters
- First model-dependent constrain on linear comnbination of J_u and J_d!

Total Angular Momentum - Ji sum rule



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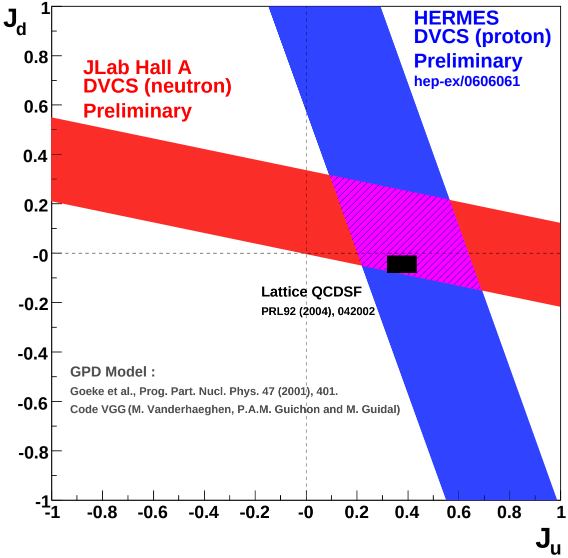
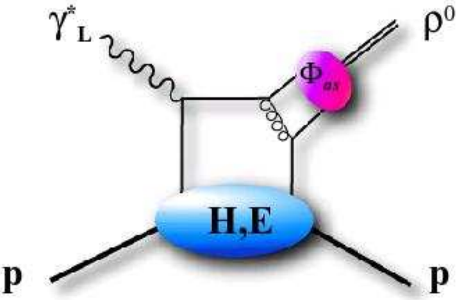
- J_u and J_d as free parameters
- First model-dependent constrain on linear comnbination of J_u and J_d!

Total Angular Momentum - JLAB neutron data

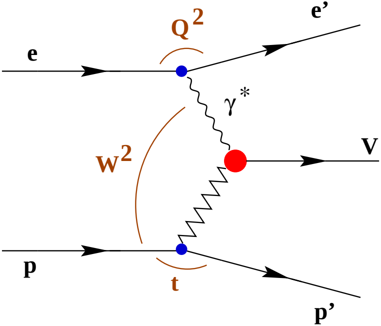


Exclusive Vector Meson (ρ,ω,ϕ) Production

GPD model



VMD model



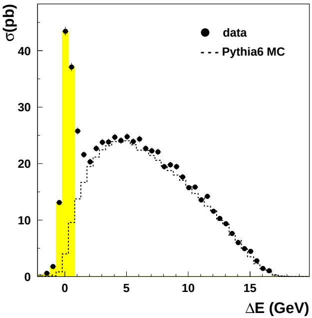
- ρ^0 - probe quark and gluon contents of the nucleon
- ϕ - probe gluonic contents of the nucleon

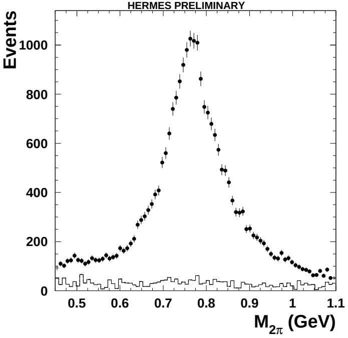
- Describes the production and decay of Vector Mesons (no information on nucleon structure)

Exclusive production: $(ep \rightarrow e'p\rho^0)$, $\rho^0 \rightarrow \pi^+ \pi^-$

- no recoil detection in the analyzed sample
- exclusive ρ^0 sample through the energy and momentum transfer:

$$\Delta E = \frac{M_x^2 - M_p^2}{2M_p} \qquad t' = t - t_0$$





Advantage of TTSA in ρ^0 production

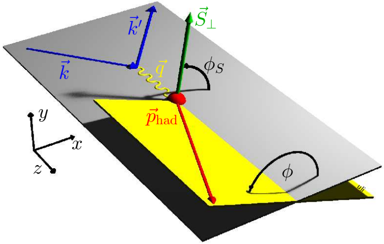
- E is kinematically not suppressed
- access to gluon GPDs
- linear dependence on GPDs:

$$A_{UT}^{\sin(\phi-\phi_s)} \sim \frac{E}{H} \sim \frac{E_q + E_g}{H_q + H_g}$$

- all the calculations:

$$E_q = E_u + E_d \qquad E_g = 0$$

- TTSA allows access to E



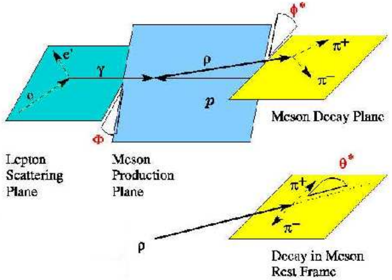
L/T separation of the $\gamma^* p$ X-section

Factorisation proven for γ_L longitudinal photons only!

$$d\sigma(\phi, \phi_s) = \sigma_0 + \sigma_1 |\vec{S}_\perp| \sin(\phi - \phi_s) + \sigma_2 |\vec{S}_\perp| \frac{\epsilon}{2} \sin(\phi + \phi_s)...$$

σ_i: different dependences on $\cos\theta$

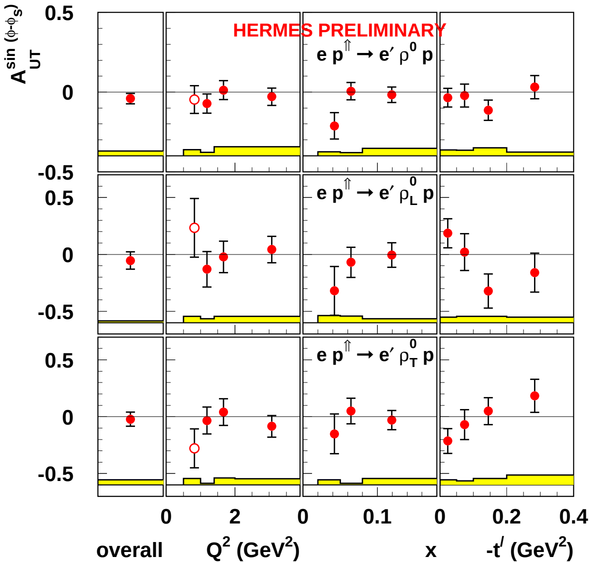
$$\frac{d\sigma_i(\gamma^* p \to \pi^+\pi^- p)}{d(\cos\theta)} = \frac{3\cos^2\theta}{2}\sigma_i(\gamma^* p \to \rho^0_L p) + \frac{3\sin^2\theta}{4}\sigma_i(\gamma^* p \to \rho^0_T p)$$



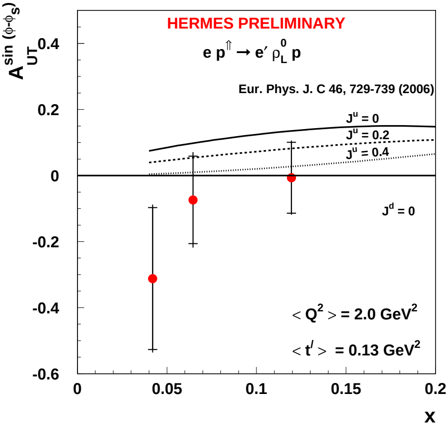
- Diehl, Sapeta (hep-ph/0503023) -

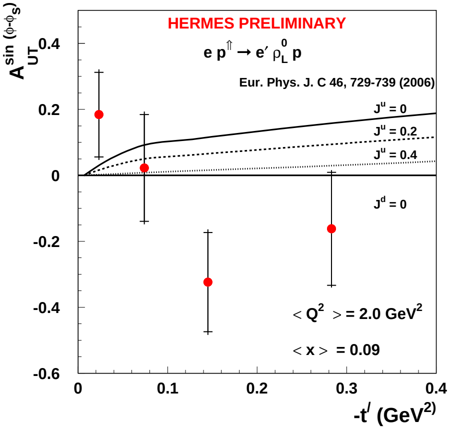
Under the assumption of SCHC a ρ^0_L, ρ^0_T is equivalent γ^*_L, γ^*_T separation

ρ^0 TTSA with L/T separation



Comparison with model





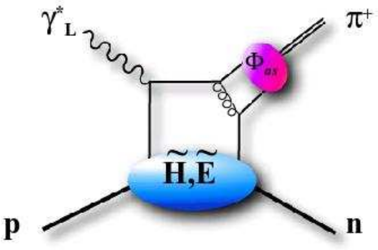
- data favours positive J_u, assuming $J_d = 0$
- work in progress for a J_u constraint

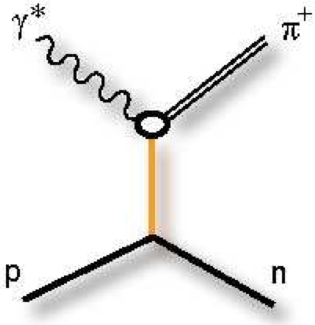
Exclusive π^+ Production

$ep \rightarrow e\pi^+ n$

GPD model

Regge model





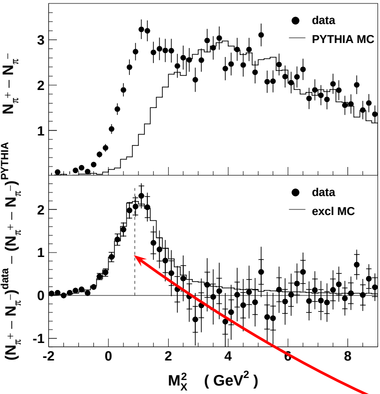
- information about partonic structure of the nucleon

Exclusivity for $ep \to e'\pi^+(n)$

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

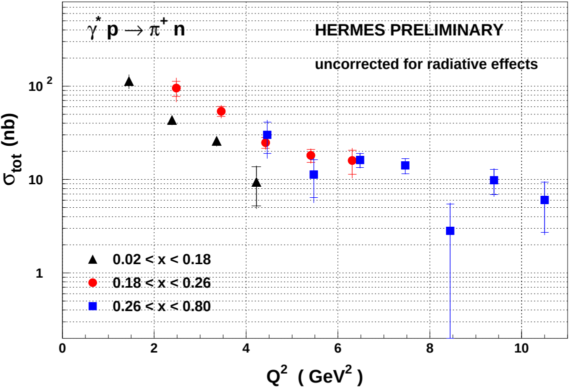
π^+	exclusive π^+	VM_{π^+}	SIDIS
π^-		VM_{π^-}	SIDIS

$$N^{excl} = (\pi^+ - \pi^-)^{data} - (\pi^+ - \pi^-)^{MC}$$



- $\pi^+ - \pi^-$ yield difference was used to subtract the non exclusive background
- exclusive peak centered at the nucleon mass
- exclusive MC based on GPD model

Exclusive π^+ Production Cross Section



$\sigma_{tot} = \sigma_T + \epsilon\sigma_L$

- L/T separation not possible
- HERMES kinematics: $0.80 < \epsilon < 0.96$
- σ_T suppressed by $1/Q^2$

σ_L dominates at large Q^2

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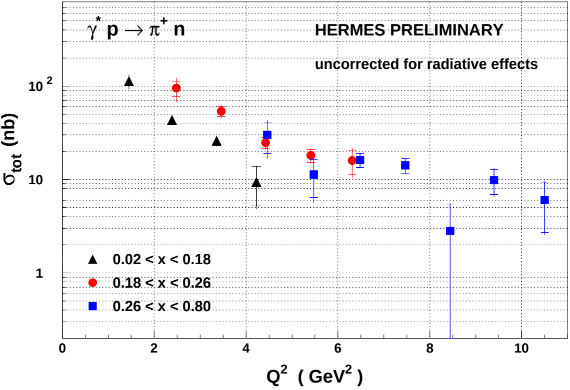

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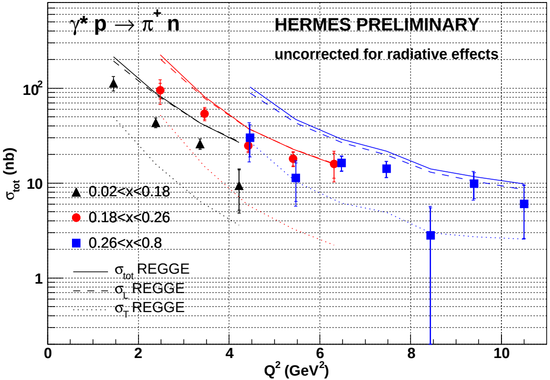
Regge Model



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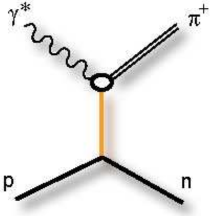
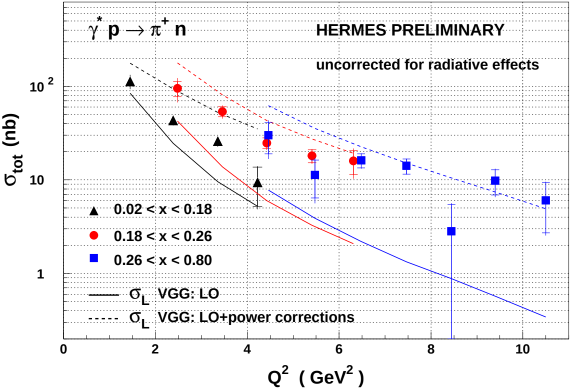


-J.M. Laget (2004)-

Model predicts

- small contribution from σ_T
- $\sigma_L \approx \sigma_{tot}$

GPD model

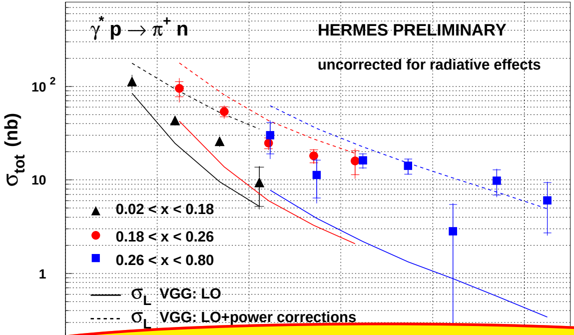


access to $\tilde{H}$ and $\tilde{E}$

-Vanderhaeghen,Guichon,Guidal (1999)-

- LO calculations underestimate the data
- Evaluation of the power correction ($k_\perp$ and soft overlap) appears too large

GPD model



access to $\tilde{H}$ and $\tilde{E}$

Paper arXiv:0707.0222 submitted to PLB!

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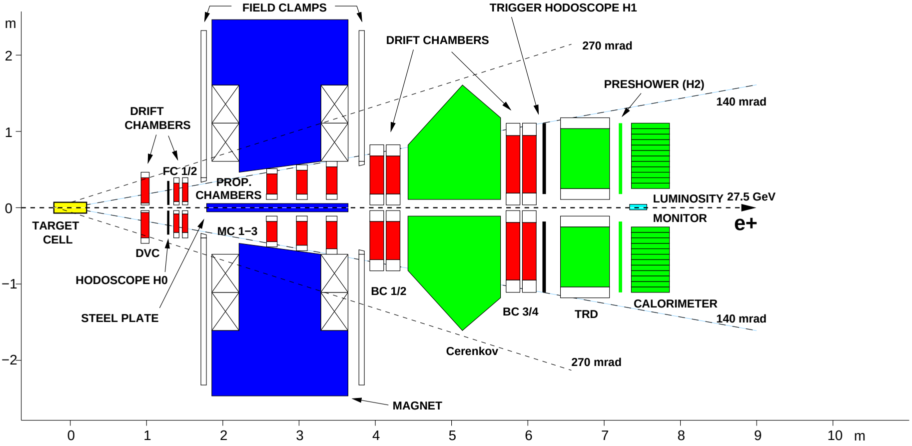
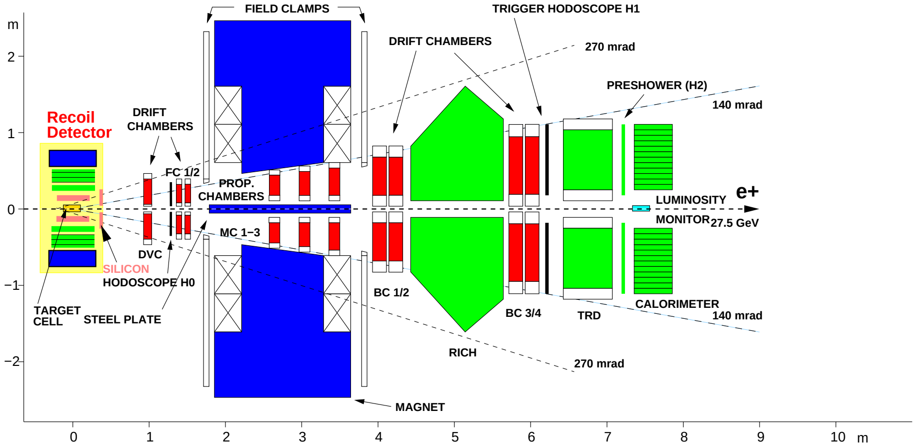
The Recoil Detector Upgrade!

1996-2005 - no recoil nucleon detection



The Recoil Detector Upgrade!

2006-2007 - RECOIL detector!



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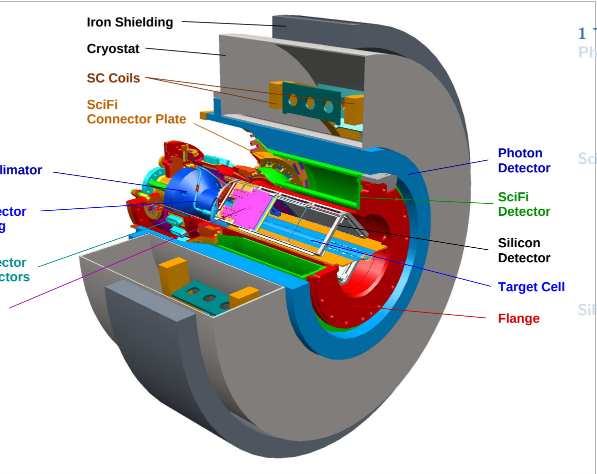


1 Tesla Superconducting Solenoid

Photon Detector

- 3 Layers of Tungsten/Scintillator
- PID for higher momenta
- detects $\Delta \longrightarrow p\pi^0$

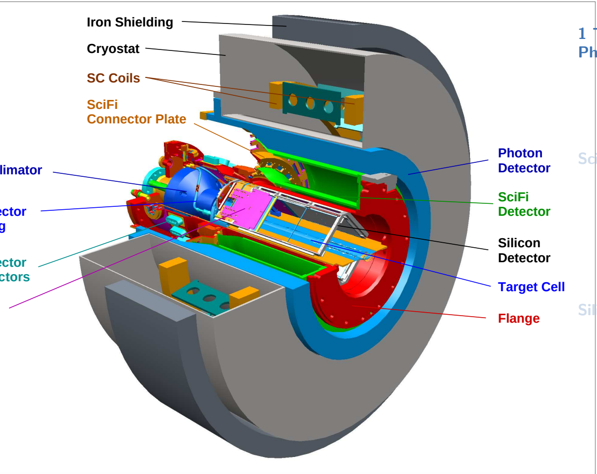
Scintillating Fiber Detector

- 2 Barrels
- 2 Parallel and 2 Stereo Layers in each barrel
- 10^o Stereo Angle
- Momentum reconstruction & PID

Silicon Detector

- 16 doublesided sensors
- 10 x 10 cm active area
- 2 layers
- Inside beam vacuum
- Momentum reconstruction & PID

The Recoil Detector Upgrade!



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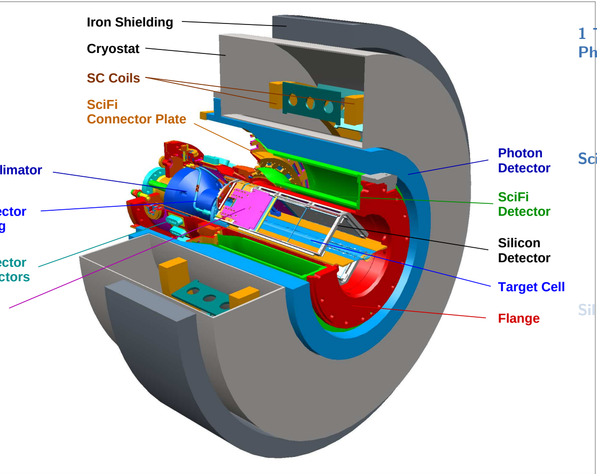

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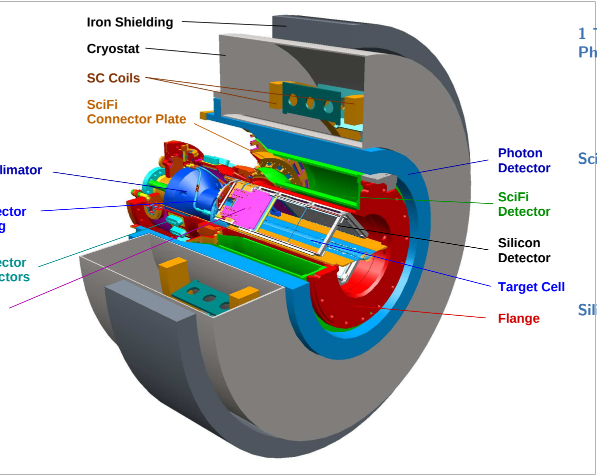

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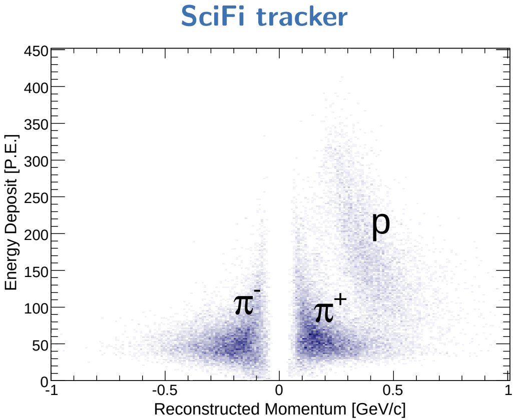
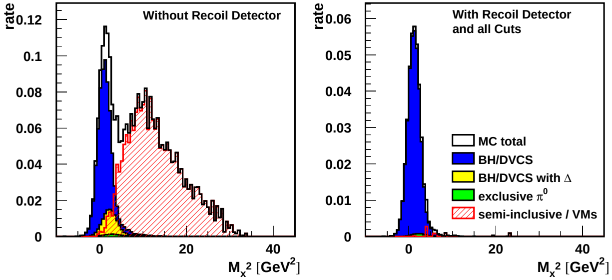
Recoil PID



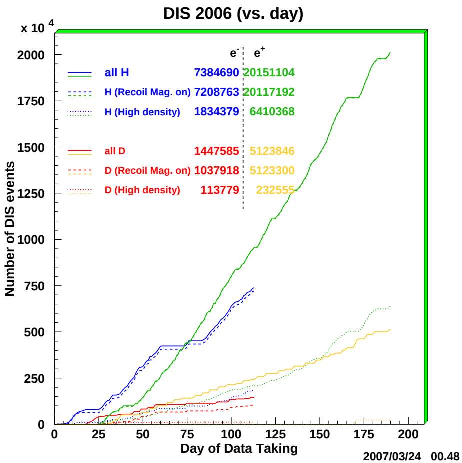
Energy deposition in individual layers allow p, π^+ identification!

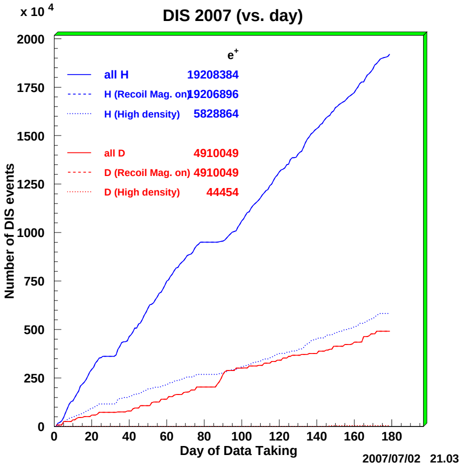
DVCS with Recoil



- **Direct measurement of the recoil proton momentum**
- **Reduction of semi-inclusive background**
- **Suppress background from associated BH $\Delta \rightarrow p\pi^0$**
- **Will re-evaluate pre-recoil data background contribution (currently MC-based)**

Recoil Data



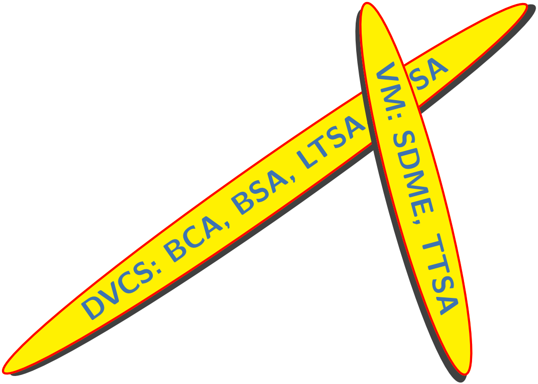


$>$ 60M DIS events collected with Recoil detector on Hydrogen!

Exclusivity @ HERMES

DVCS: BCA, BSA, LTSA, TTSA

Exclusivity @ HERMES



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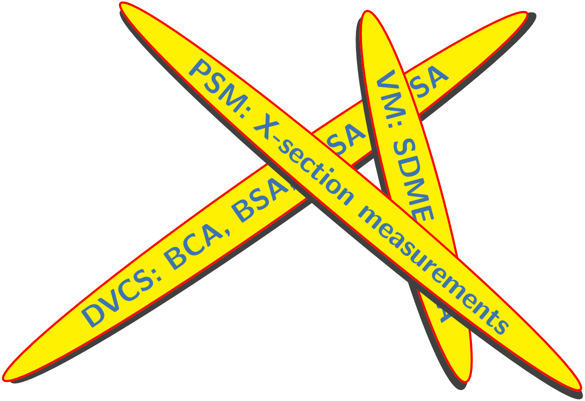

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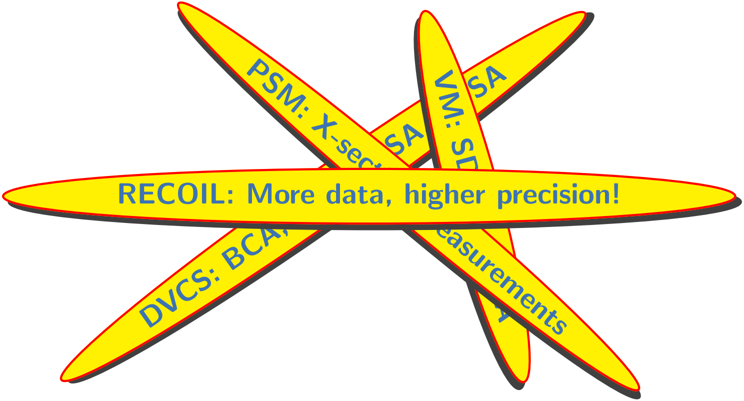

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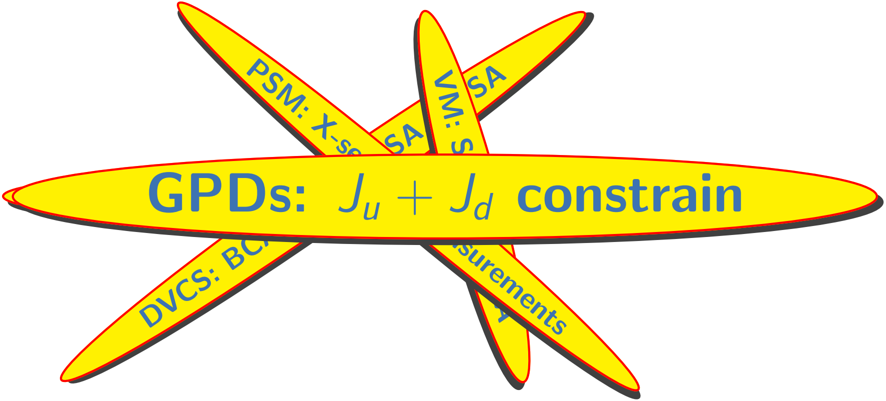

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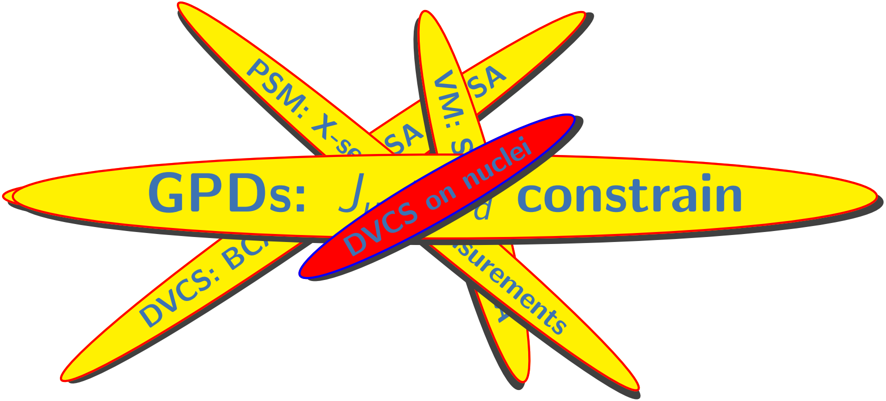

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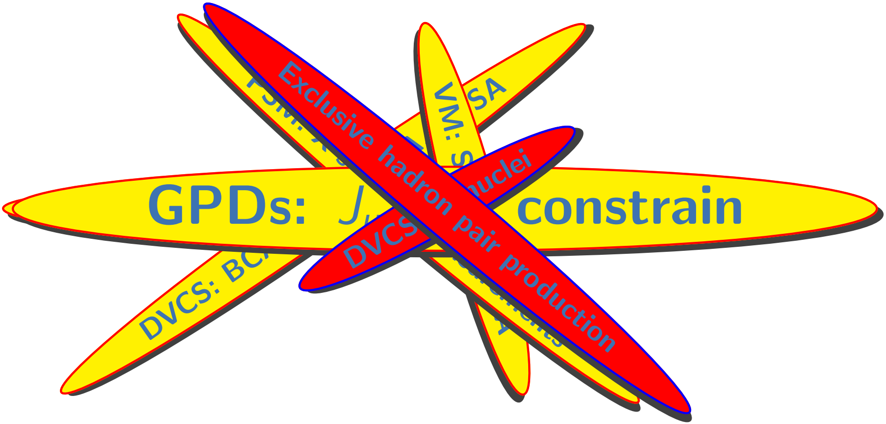

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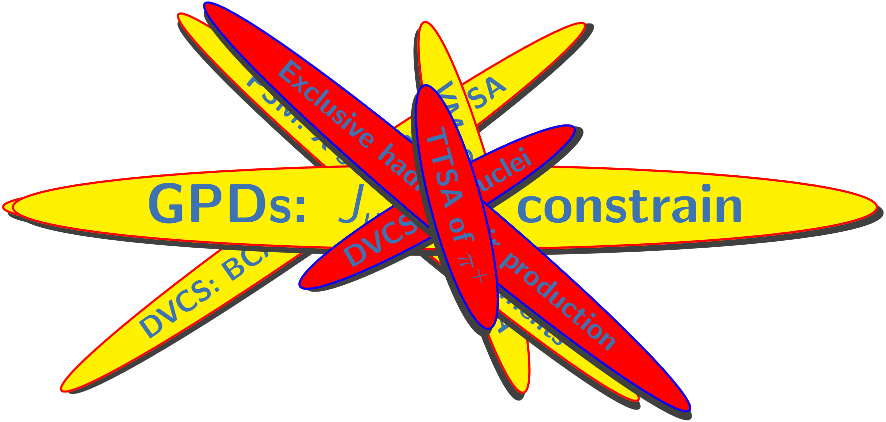

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