DVCS and Exclusive Processes at Hermes

Caroline Riedl

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Outline

- Motivation
- GPDs and DVCS Azimuthal Asymmetries
- DVCS Measurements at Hermes
- The Hermes Recoil Detector
- Summarizing Overview

The Composition of the Nucleon's Spin

$$\frac{1}{2} = \underbrace{\frac{1}{2}\Delta\Sigma + L_{\rm q}}_{J_{\rm q}} + \underbrace{\Delta G + L_{\rm g}}_{J_{\rm g}}$$

- $\Delta\Sigma = 1/3$ from DIS and SIDIS

  Hermes: Phys. Rev. **D75** (2007) 012007

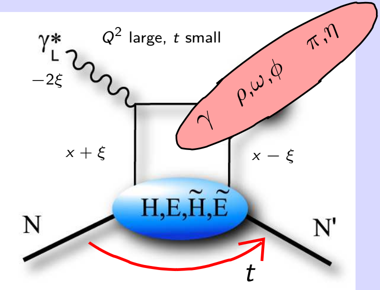
  $\Delta\Sigma = 0.330 \pm 0.011\ (\text{theo}) \pm 0.025\ (\text{exp}) \pm 0.028\ (\text{evol})$
- ΔG: first indication from DIS and pp $\rightarrow$ small
- $L_{\rm q} \rightarrow\ ?\ \rightarrow$ Ji's sum-rule! $\leftarrow$ Generalized Parton Distributions

  Ji's sum rule: Ji, PRL **78** (1997) 610

$$J_{\rm q,g} = \frac{1}{2} \lim_{t\rightarrow 0} \int_{-1}^{1} {\rm d}x\, x \left[H_{\rm q,g}(x,\xi,t) + E_{\rm q,g}(x,\xi,t)\right]$$

- $L_{\rm g} \rightarrow$? might be accessible at higher energies than Hermes via GPDs

GPDs: the clever parameterization of the nucleon



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

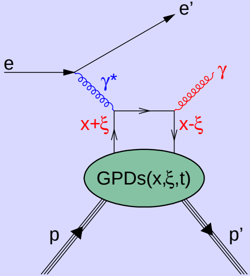
- PDFs: $H^{\mathrm{q}}(x,0,0) = q(x)$, $\widetilde{H}^{\mathrm{q}}(x,0,0) = \Delta q(x)$ forward limit
  Form Factors: $\int \mathrm{d}x\ [\mathrm{GPD}] = f(t)$, independent of ξ
  $\Rightarrow$ GPDs: simultaneous description of transverse position (FF) and momentum distribution (PDF): "Nucleon Tomography"
- Sum rule for J of quarks/gluons! Need H and E for $t \to 0$

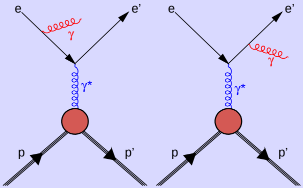
Recent theoretical reviews:

PPNP **47** (2001) 401; Phys. Rept. **388** (2003) 41; Phys. Rept. **418** (2005) 1

DVCS: the prime process to access GPDs

$\mathrm{eN} \rightarrow \mathrm{eN}\gamma$





- $\mathrm{d}\sigma \propto |\mathcal{T}|^2 = |\mathcal{T}_{\mathrm{DVCS}}|^2 + |\mathcal{T}_{\mathrm{BH}}|^2 + \mathcal{I}$
- Interference: $\mathcal{I} = \mathcal{T}_{\mathrm{DVCS}}\mathcal{T}^*_{\mathrm{BH}} + \mathcal{T}^*_{\mathrm{DVCS}}\mathcal{T}_{\mathrm{BH}}$
- Hermes kinematics: $|\mathcal{T}_{\mathrm{DVCS}}|^2 < |\mathcal{T}_{\mathrm{BH}}|^2$
- $\mathcal{I} \propto \pm(c_0 + \sum_n [c_n \cos(n\phi) + s_n \sin(n\phi)])$
  - c_n = Lin. Comb. (UU), (UT), (LL), (LT)
  - s_n = Lin. Comb. (LU), (UL), (UT), (LT)

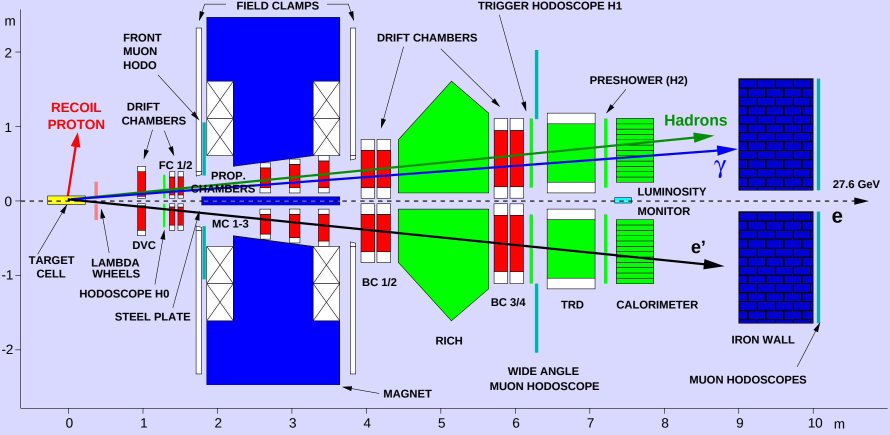
(beam state, target state) **U**n-, **L**ong.-, **T**rans.-pol

- Project out sin- and cos-moments by different:
  - beam charges
  - beam helicities
  - target polarizations (long. and trans.)

⇒ Azimuthal asymmetries

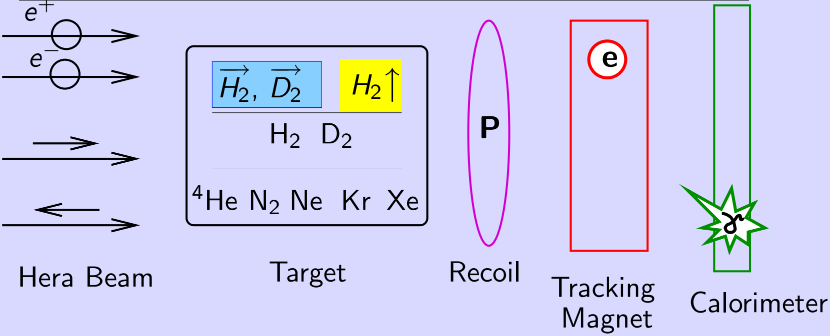
⇒ Linear combinations of GPDs

The Hermes forward spectrometer



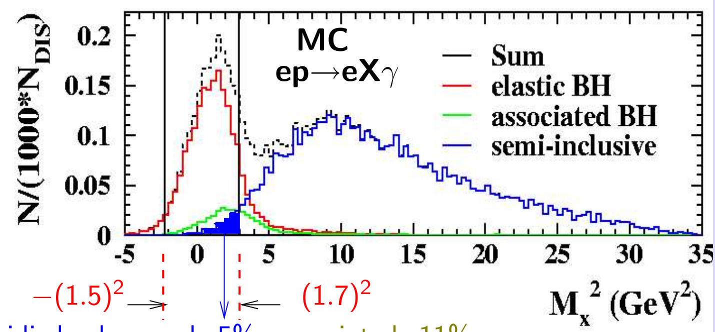
The powerful DVCS data pool of Hermes

Hermes (1): 1996-2000, (2): 2002-2005, (3): 2006-2007



- 2 beam charges (1,2,3), 2 beam helicities (1,2,3)
- longitudinally (1) and transversely (2) polarized target
- unpolarized nuclear targets (1,2)
- Recoil Detector (3)

Finding exclusive events



X=p

$X=\Delta^+ \rightarrow {p\pi^0 \atop n\pi^+}$

$X=\pi^0+..$

sidis background: 5%, associated: 11%

- Classic technique at Hermes: access to exclusivity via missing mass

$$M_{\rm x}^2 = (P_{\rm e} + P_{\rm P} - (P_{\rm e'} + P_\gamma))^2$$

- 2006/07: recoiling proton detected ⇒ all reaction partners measured!

The gallery of DVCS azimuthal asymmetries

1. Beam Charge Asymmetry $A_{\mathrm{C}}(\phi)$

$$\mathrm{d}\sigma(e^+,\phi) - \mathrm{d}\sigma(e^-,\phi) \propto \mathrm{Re}(F_1\mathcal{H})\cos\phi$$

2. Beam Spin Asymmetry $A_{\mathrm{LU}}(\phi)$

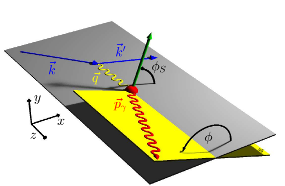
$$\mathrm{d}\sigma(\overrightarrow{e},\phi) - \mathrm{d}\sigma(\overleftarrow{e},\phi) \propto \mathrm{Im}(F_1\mathcal{H})\sin\phi$$

3. Longitudinal Target Spin Asymmetry $A_{\mathrm{UL}}(\phi)$

$$\mathrm{d}\sigma(\overset{\Leftarrow}{P},\phi) - \mathrm{d}\sigma(\overset{\Rightarrow}{P},\phi) \propto \mathrm{Im}(F_1\widetilde{\mathcal{H}})\sin\phi$$

4. Transverse Target Spin Asymmetry $A_{\mathrm{UT}}(\phi,\phi_s)$

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

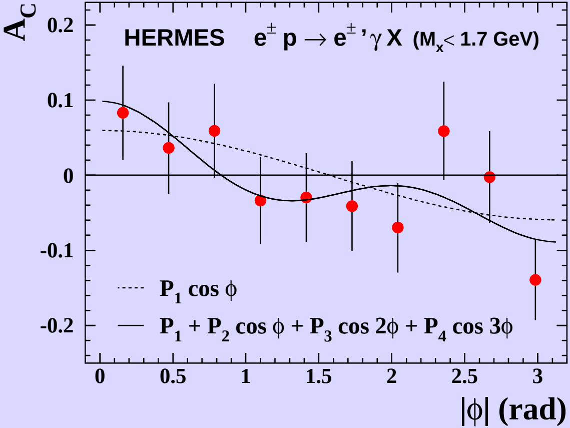


DVCS–BH interference term $\mathcal{I}$ induces azimuthal asymmetries $\Rightarrow$ GPDs

F_1, F_2: Pauli, Dirac Form Factors; $\mathcal{H}$, $\widetilde{\mathcal{H}}$, $\mathcal{E}$, $\widetilde{\mathcal{E}}$: Compton Form Factors (convolutions of hard scattering amplitude and corresponding twist-2 GPD)

1. Beam Charge Asymmetry (BCA) versus ϕ

$$A_C(\phi) = \frac{d\sigma(e^+,\phi) - d\sigma(e^-,\phi)}{d\sigma(e^+,\phi) + d\sigma(e^-,\phi)} \propto \mathrm{Re}(F_1\mathcal{H})\cos\phi$$



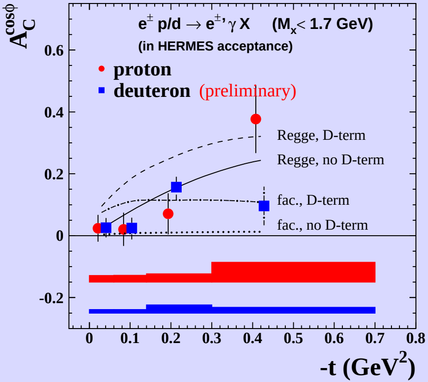
$P_1 = -0.011 \pm 0.019$

$P_2 = 0.060 \pm 0.027$

$P_3 = 0.016 \pm 0.026$

$P_4 = 0.034 \pm 0.027$

BCA $\cos\phi$ amplitude



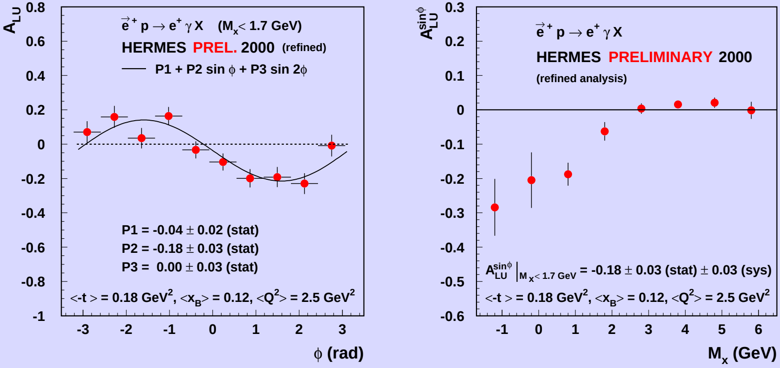
- Model (proton data only): PR**D**60 (1999) 094017 and PPNP**47** (2001) 401 ⇒ Regge-inspired with D-term disfavored
- Contributions for ed → e$X\gamma$: coherent (X=d): 20% incoherent (X=pn): 60% associated (X=Δ): 15%

Hermes publication: Phys. Rev. **D**75 (2007) 011103(R)

Factor of ≈ 20 more e^- and factor of ≈ 7 more e^+ data on tape!

2. Beam Spin Asymmetry (BSA)

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

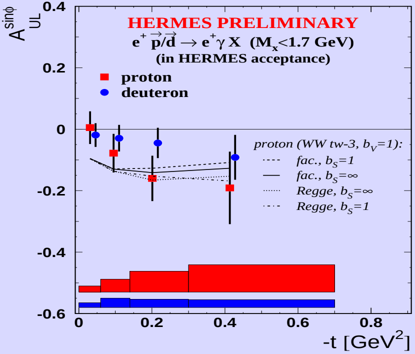


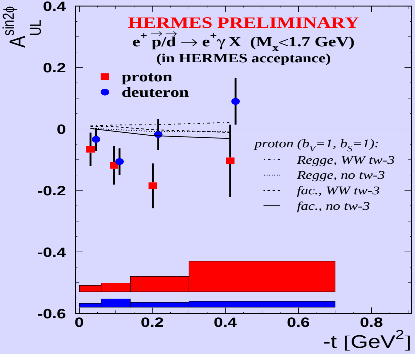
Hermes publication: PRL **87** (2001) 182001

Factor of ≈ 9 more data on tape

3. Longitudinal Target Spin Asymmetry (LTSA)

$$A_{\rm UL}(\phi) = \frac{1}{\langle | P_{\rm T} | \rangle} \cdot \frac{d\sigma(\overleftarrow{P},\phi) - d\sigma(\overrightarrow{P},\phi)}{d\sigma(\overleftarrow{P},\phi) + d\sigma(\overrightarrow{P},\phi)} \propto \mathrm{Im}(F_1 \widetilde{\mathcal{H}}) \sin\phi$$



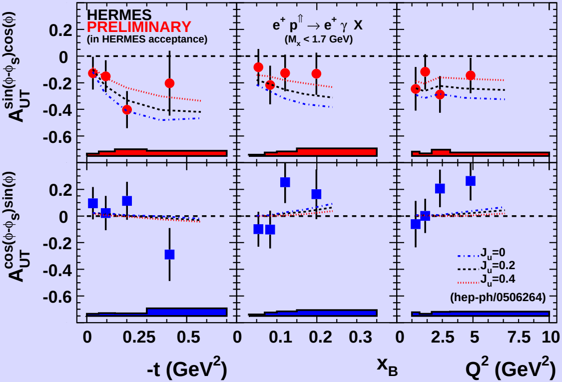


GPD model: see reference @ BCA

Plots: Full statistics

4. Transverse Target Spin Asymmetry (TTSA)

$$A_{\mathrm{UT}}(\phi,\phi_s) = \frac{1}{\langle |P_{\mathrm{T}}| \rangle} \cdot \frac{d\sigma(\phi,\phi_s) - d\sigma(\phi,\phi_s+\pi)}{d\sigma(\phi,\phi_s) + d\sigma(\phi,\phi_s+\pi)} \propto$$



sensitive to J_{u}:

$\mathrm{Im}(F_2\mathcal{H} - F_1\mathcal{E}) \cdot$

$\sin(\phi - \phi_s)\cos\phi +$

NOT sensitive to J_{u}:

$\mathrm{Im}(F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}) \cdot$

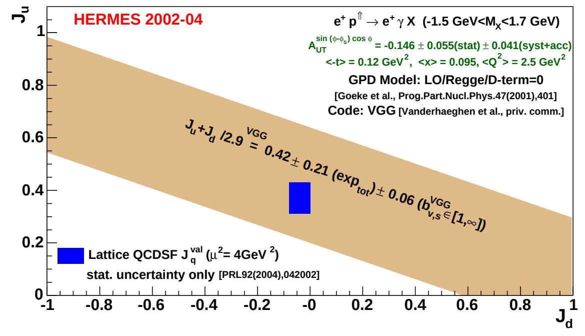
$\cos(\phi - \phi_s)\sin\phi$

Sensitivity on J_{u}: hep-ph/0506264, assuming $J_{\mathrm{d}} = 0$

Factor of 1 more data

First (Model-Dependent) Contraint on $J_u + k \cdot J_d$

$$\chi^2(J_u, J_d) = \frac{\left(A_{UT}^{\sin(\phi-\phi_s)\cos\phi}|_{exp} - A_{UT}^{\sin(\phi-\phi_s)\cos\phi}|_{VGG(J_u, J_d)}\right)^2}{\delta A_{stat}^2 + \delta A_{sys}^2}$$



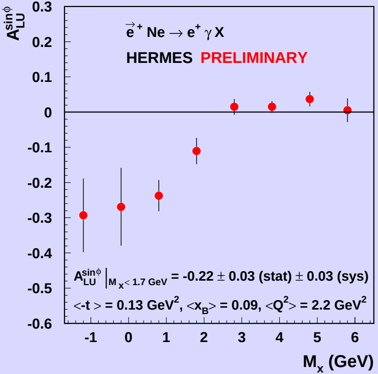
- J_u and J_d free params in GPD model (VGG)
- 1–sigma constraint on J_u vs. J_d: $\chi^2(J_u, J_d) \leq \chi^2_{min} + 1$ (brown band)

2b. DVCS on nuclear targets

- How does the nuclear environment modify parton-parton correlations?
- Hermes nuclear targets: ^{2}H, ^{4}He, ^{14}N, ^{20}Ne, $^{82-86}$Kr, $^{129-134}$Xe

2b. DVCS on nuclear targets

- How does the nuclear environment modify parton-parton correlations?
- Hermes nuclear targets: ^{2}H, ^{4}He, ^{14}N, ^{20}Ne, $^{82-86}$Kr, $^{129-134}$Xe
- Nuclear BSA: clear $\sin\phi$ amplitude in the exclusive region



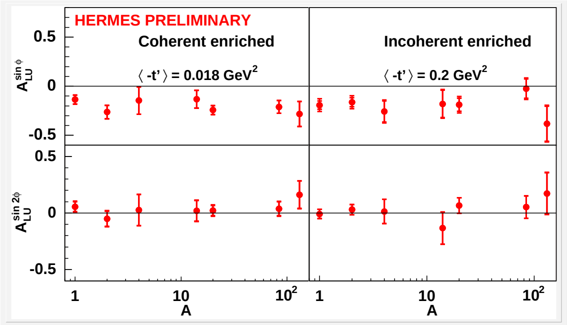
Integrated kinematics:

Neon: $-0.22 \pm 0.03 \pm 0.03$

proton: $-0.18 \pm 0.03 \pm 0.03$

2b. DVCS on nuclear targets

- How does the nuclear environment modify parton-parton correlations?
- Hermes nuclear targets: ^{2}H, ^{4}He, ^{14}N, ^{20}Ne, $^{82-86}$Kr, $^{129-134}$Xe



Nuclear-to-hydrogen ratio of BSA $\sin\phi$ amplitudes:

(A/H)=1.58±0.26 (coherent)

incoherent:

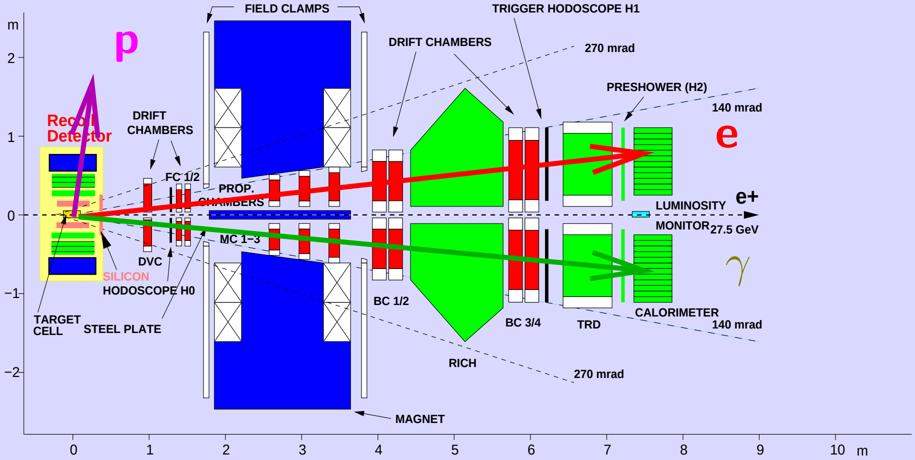
(A/H) consistent with 1

√ GPD model prediction

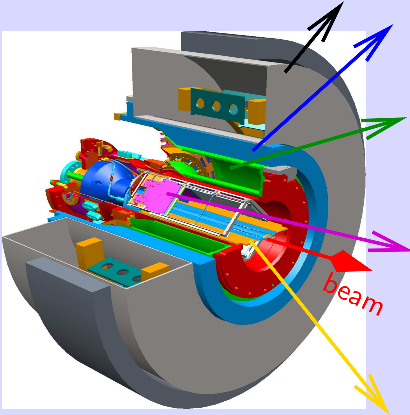
PR**C68** (2003) 015204

Factor of ≈ 2/1 more data on tape for Xenon/Krypton

Recoil Detector installation: December 2005

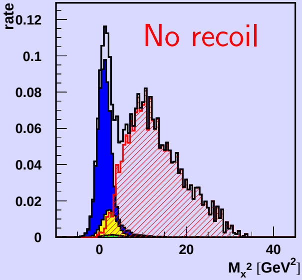


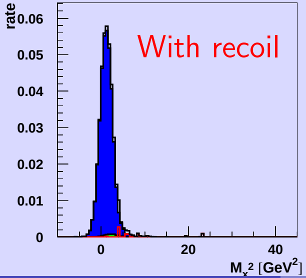
The Hermes Recoil Detector



- Superconducting Solenoid (1 Tesla)
- Photon Detector
  - 3 layers of Tungsten/Scintillator
  - π^0 **background supression**
- Scintillating Fiber Tracker
  - 2 Barrels
  - Each 2 parallel- & 2 stereo-layers
  - Stereo angle: 10°
  - **Momentum reconstruction** & **PID**
- Silicon Strip Detector
  - 2 Layers
  - 16 double-sided sensors
  - (10cm×10cm) active area
  - Inside accelerator vacuum
  - **Momentum reconstruction** & **PID**
- Target Cell with unpol. H_2 or D_2

The Recoil Road to genuine exclusivity at Hermes



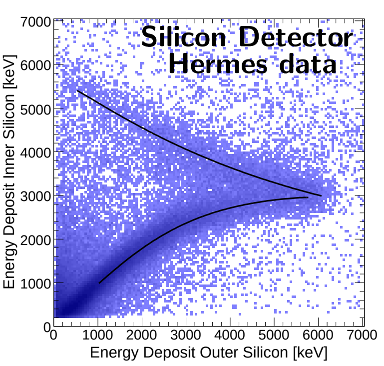


Silicon & Fiber Tracker:
$p_\mathrm{p} \in [135, 1200]$MeV/c
p/π **PID** for $p < 700$MeV/c
Photon Detector:
p/π **PID** for $p > 650$MeV/c

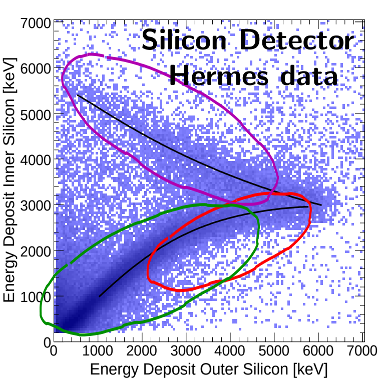
- Recoiling protons
  - Enhance **signal fraction**
  - Improve t-resolution
- Background pions and protons
- Photons from $\pi^0 \to \gamma\gamma$

$\Rightarrow$ Reduce **background contributions**:
- **sidis**: 5% $\searrow \ll$ 1%
- associated production: 11% $\searrow$ 1%

Recoil: First physics signatures



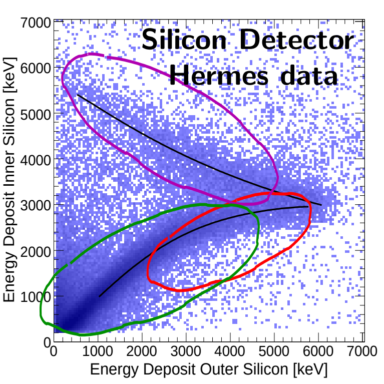
Recoil: First physics signatures



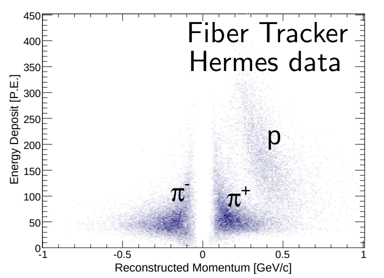
Momentum (p) reconstruction:

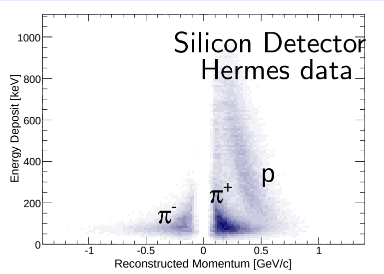
1. Low momentum protons:
   $\Rightarrow$ p by Σ(energy deposits)
2. Higher momentum protons:
   $\Rightarrow$ p by Bethe-Bloch (dE/dx)
3. High momentum particles:
   $\Rightarrow$ p by bending in B-field,
   $\Rightarrow$ tracks formed by spacepoints in (up to) 2 subdetectors

Recoil: First physics signatures



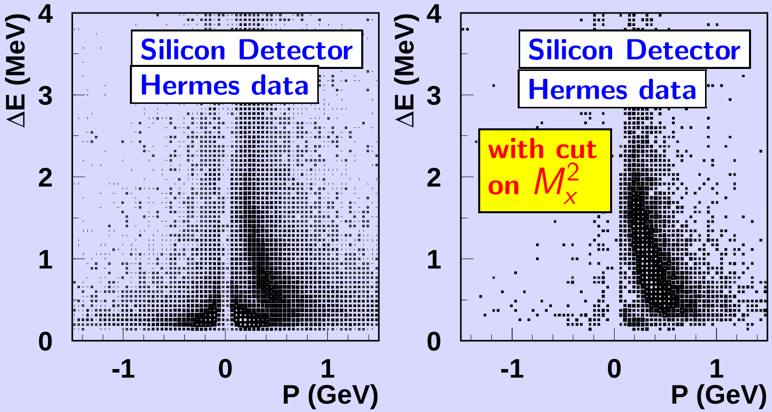
$\Rightarrow p/\pi$ PID:





Recoil: Proof of Principle

Response of Recoil Silicon Detector for "traditional DVCS candidates" (events with 1 lepton and 1 photon in front spectrometer):

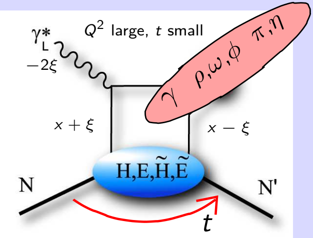


The Recoil Adventure goes on!

- Hera stopped its operation 4 weeks ago, Hermes took last data
- Collected statistics (*preliminary*) with operational recoil detector:
  - Electron beam 2006 (only Fiber Tracker operational):
    H_2: 5k DVCS (3 Mio DIS), D_2: 1k DVCS (0.8 Mio DIS)
  - Positron beam 2006/07 (all subdetectors fully operational):
    H_2: 42k DVCS (28 Mio DIS), D_2: 10k DVCS (7 Mio DIS)
- Analysis of BCA and BSA with recoil data
- Detector understanding in progress
  - Calibration
  - Alignment
  - Noise
  - Tracking
  - ...

$\Rightarrow$ Watch out for first results!

Summary: Hermes and Exclusive Processes



unpolarized	polarized	
H: BCA, BSA, TTSA E: TTSA	$\widetilde{H}$: LTSA (TTSA) $\widetilde{E}$: (TTSA)	
$J^{\mathcal{P}} = 1^-$ mesons	x-section $J^{\mathcal{P}} = 0^-$ mesons	see talk J. Dreschler
photon: $J^{\mathcal{P}} = 1^-$ (DVCS)		

- GPD models agree in general with measurements
- First model-dependent extraction of $J_\mathrm{u} + k \cdot J_\mathrm{d}$ possible
- Most published DVCS results await a significant statistics upgrade: BCA (factor 20 / 7 more), BSA (factor 9), TTSA (factor 1)
- Recoil-data is being prepared for physics analysis
  $\Rightarrow$ exploit direct exclusivity: no mass is missing anymore!
- Once background contribution is measured: refined analysis of pre-recoil DVCS and DVMP data