Selected Recent Results from HERMES

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For the hermes Collaboration

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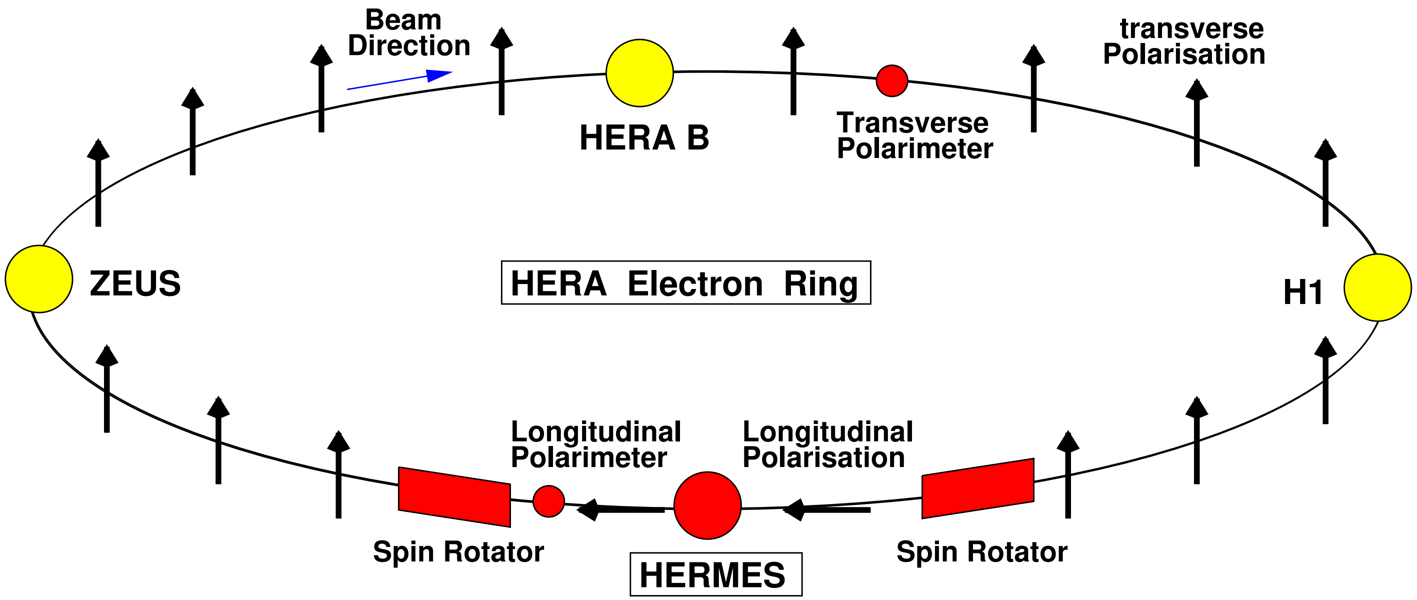
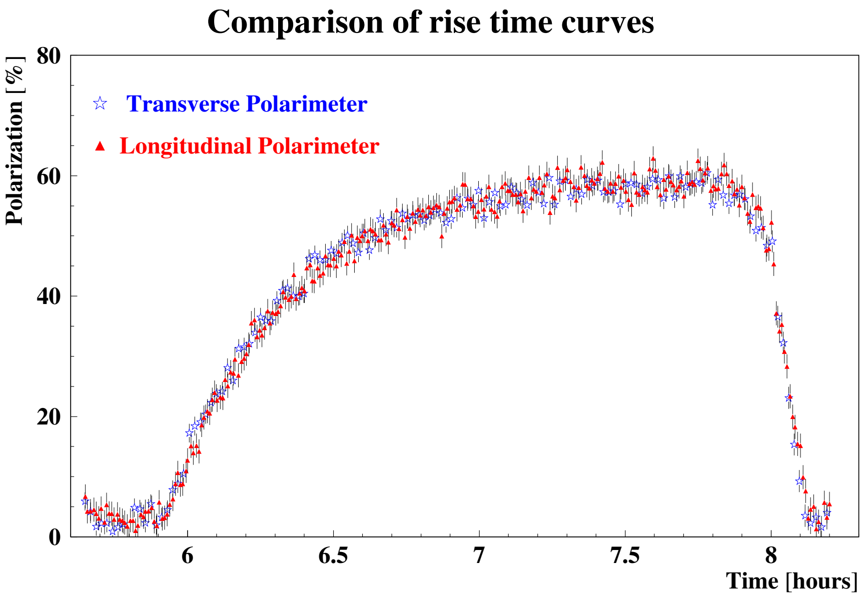
- HERA polarized $\mathbf{e^{\pm}}$ beam,
  HERMES forward spectrometer & polarized internal target
- First measurement of the tensor structure function $\mathbf{b_1}$
- Deeply Virtual Compton Scattering on nuclei (D, Ne, Kr)
- Observation of $\mathbf{f_0(980)}$ scalar meson in electroproduction

Most other HERMES physics topics covered in parallel talks
$\Rightarrow$ list will be given at the end of this talk

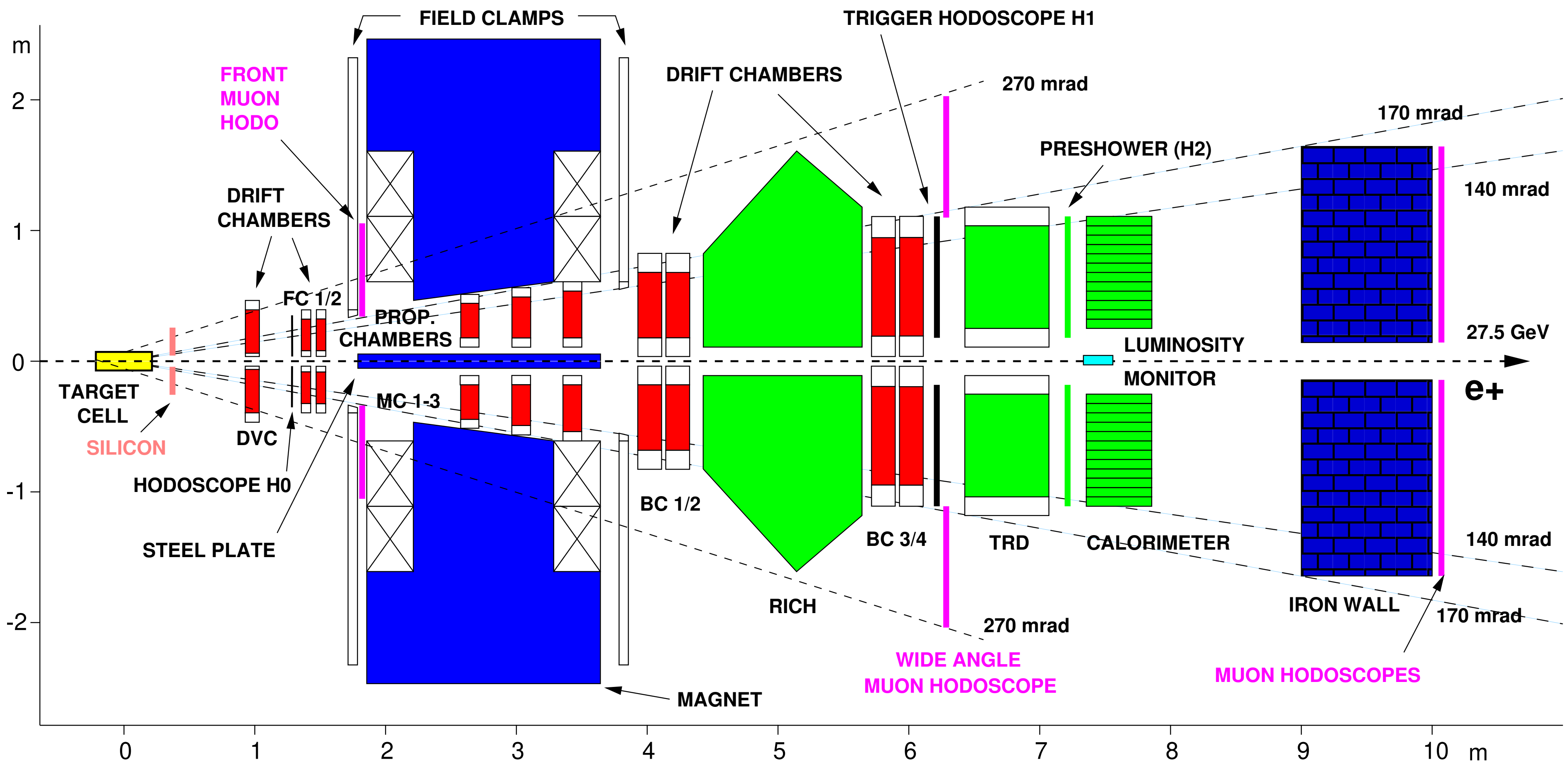
Polarized Beam at HERA





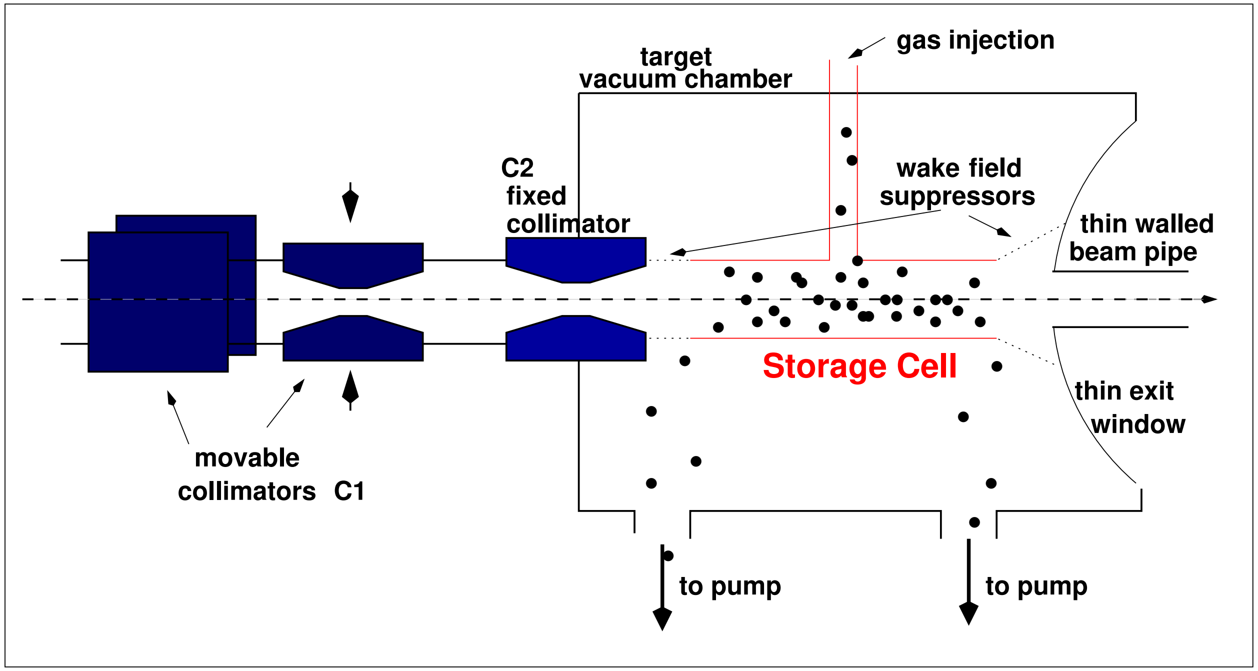
- 27.5 GeV e^+/e^- beam
- Self-polarizing through Sokolov-Ternov-Effect
- Average beam polarization of about 55%

The HERMES Experiment



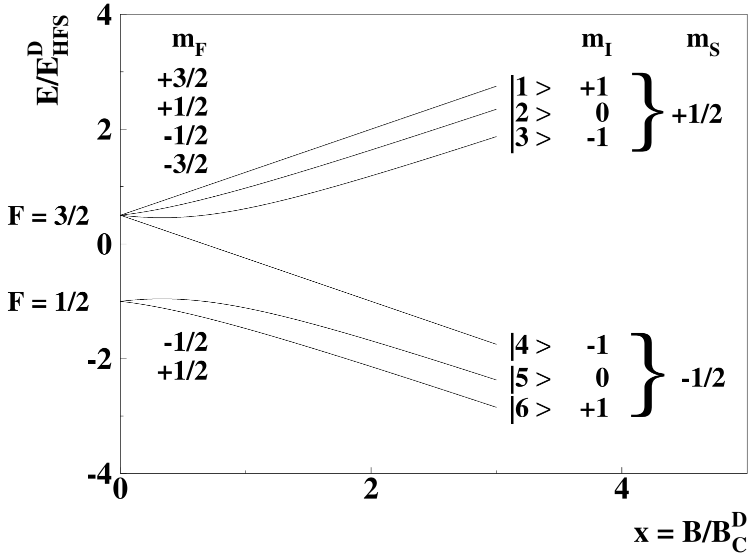
- Forward spectrometer: 40 mrad $\leq \Theta \leq$ 220 mrad
- Tracking: $\mathcal{O}(50)$ tracking planes per half spectrometer:
  $\delta p/p \sim 1\%$ (2%), $\delta\Theta \leq 0.6$ (1) mrad
- PID: $e^{\pm}, \pi^{\pm}, K^{\pm}, p$ by Cherenkov (RICH $\geq$ 1998), TRD, Preshower, Calorimeter

HERMES Internal Gas Target



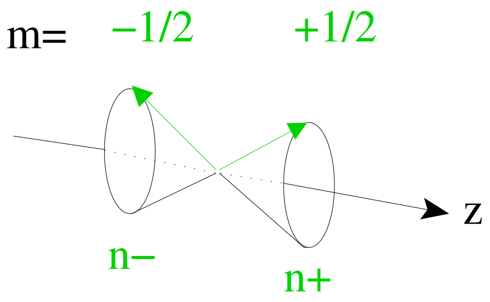
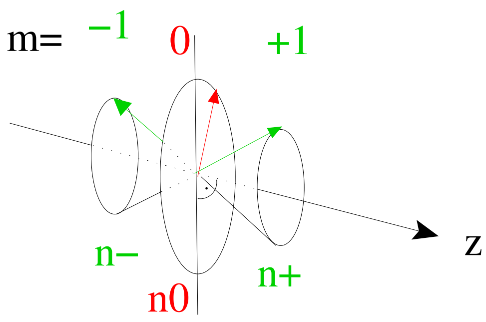
Polarized deuterium hyper-fine splittings

$\Downarrow$



- Pure gas target $\Rightarrow$ no dilution
- 90 s cycling time $\Rightarrow$ low systematics
- Polarized gases: H,D (Storage cell fed by Atomic Beam Source)
- Unpolarized: H, D, He, N, Ne, Kr

Vector and Tensor Polarization

	Spin-$\frac{1}{2}$ Nucleon	Spin-1 Deuteron
		
Vector polarisation	$\boxed{P_z = \frac{n^+ - n^-}{n^+ + n^-}}$ $\lvert P_z \rvert \leqq 1$	$\boxed{P_z = \frac{n^+ - n^-}{n^+ + n^- + n^0}}$ $\lvert P_z \rvert \leqq 1$
Tensor polarisation		$\boxed{P_{zz} = \frac{(n^+ + n^-) - 2n^0}{n^+ + n^- + n^0}}$ $-2 \leqq P_{zz} < 1$

Polarized Atomic Deuterium Target

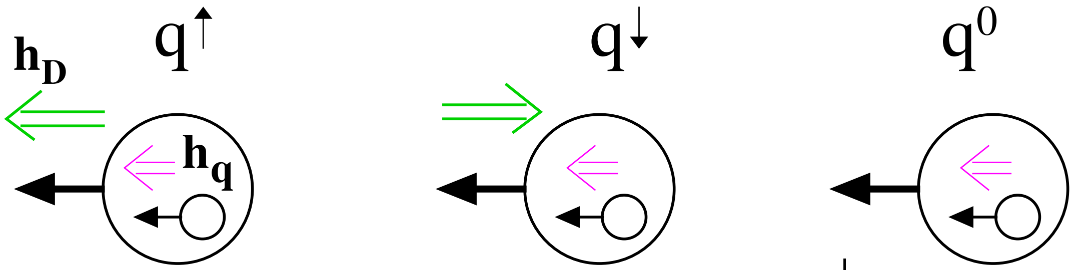
- Spin states can be separately chosen
- Target ‘mode’: combine 2 spin states

target mode	hyperfine states injected by ABS	injected no. of particles	P_z	P_{zz}
vector +	$\|1> + \|6>$	n^+	$+1$	$+1$
vector –	$\|3> + \|4>$	n^-	-1	$+1$
tensor $\pm$	$\|3> + \|6>$	$n^+ + n^-$	0	$+1$
tensor 0	$\|2> + \|5>$	n^0	0	-2
			(ideal values)	

$\Rightarrow$ $\boxed{\text{Large } P_{zz} \approx 1.665 \text{ (at tiny } P_z \approx -0.01\text{) accomplished}}$

- 6 weeks of special data taking in ‘tensor operation’
- 2.4 Mio. DIS events recorded for the extraction of b_1^d

DIS Structure Functions in the QPM



$\boxed{\text{Spin-}\frac{1}{2}}$ Nucleon | $\boxed{\text{Spin-1}}$ Deuteron

$$F_1^{p,n} = \frac{1}{2}\sum_q e_q^2\left(q^{\uparrow} + q^{\downarrow}\right) \qquad F_1^d = \frac{1}{3}\sum_q e_q^2\left(q^{\uparrow} + q^{\downarrow} + q^0\right)$$

$$g_1^{p,n} = \frac{1}{2}\sum_q e_q^2\left(q^{\uparrow} - q^{\downarrow}\right) \qquad g_1^d = \frac{1}{2}\sum_q e_q^2\left(q^{\uparrow} - q^{\downarrow}\right)$$

$$b_1^d = \frac{1}{2}\sum_q e_q^2\left(2q^0 - (q^{\uparrow} + q^{\downarrow})\right)$$

b_1^d measures nuclear effects that make the deuteron look different from just the most simple proton-neutron system

Extraction of Tensor Asymmetry

$$\frac{d^2\sigma_{\rm meas}}{dx\,dQ^2} = \frac{d^2\sigma_{\rm unpol}}{dx\,dQ^2}\left[1 - P_z P_B D A_1 + \frac{1}{2} P_{zz} A_{zz}\right]$$

- $\sigma_{\rm unpol} = \sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow} + \sigma^0$
- $P_{zz} = \frac{n^+ + n^- - 2n^0}{n^+ + n^- + n^0}$

$$A_{zz} = \frac{(\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow}) - 2\sigma^0}{3\sigma_{\rm unpol} P^0_{zz}}$$

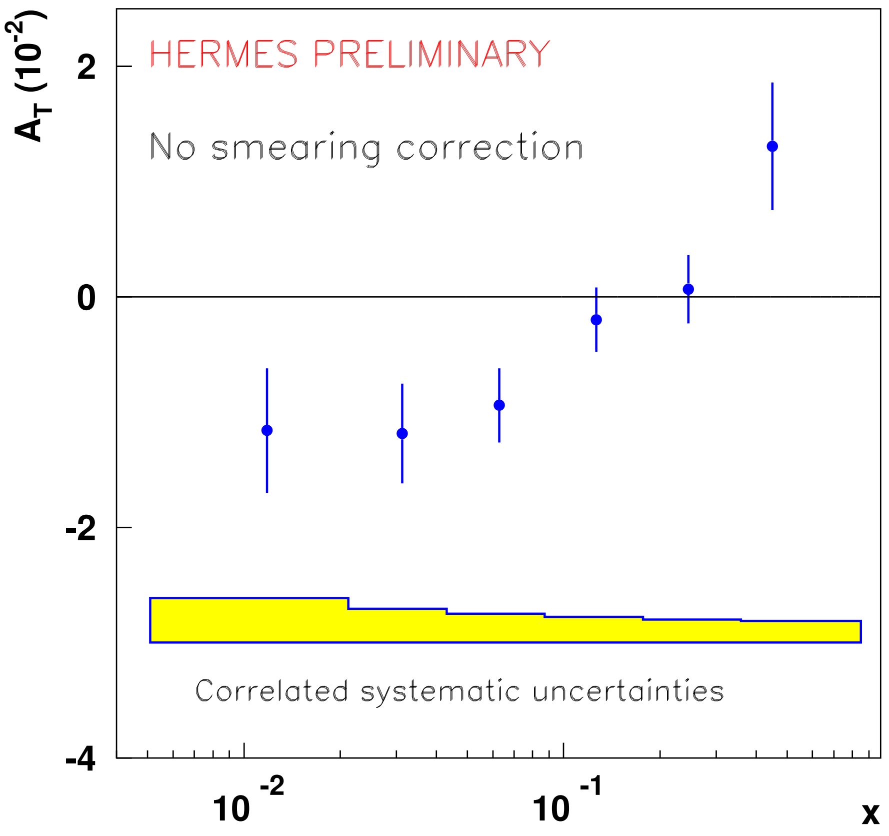
	vector term	tensor term
$\sigma^{\uparrow\uparrow}$	$+\lvert P_z \cdot P_B\rvert$	$+P^0_{zz}$
$\sigma^{\uparrow\downarrow}$	$-\lvert P_z \cdot P_B\rvert$	$+P^0_{zz}$
σ_0	< 0.01	$-2P^0_{zz}$

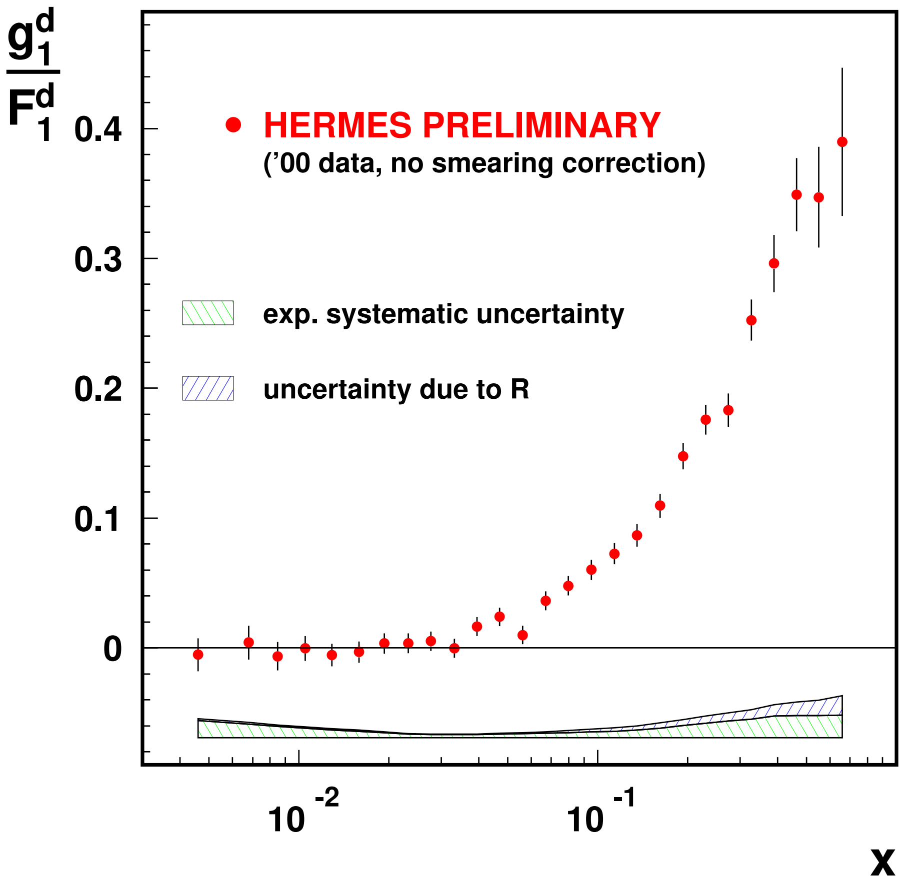
$$\lvert P_z \cdot P_B\rvert = 0.45 \pm 0.04$$
$$P^0_{zz} = 0.83 \pm 0.03$$

Use vector+, vector– and tensor0 modes to calculate A_{zz} for 6 bins in x_{Bj} (tensor$\pm$ mode only for cross check):

$$A_{zz} = \frac{1}{P^0_{zz}} \cdot \left[\frac{N^{\uparrow\uparrow} + N^{\uparrow\downarrow} - 2\cdot N^0}{N^{\uparrow\uparrow} + N^{\uparrow\downarrow} + N^0}\right]$$

Result: Tensor Asymmetry A_{zz}





- $|A_{zz}|$ of $\mathcal{O}(1\%)$ over measured range

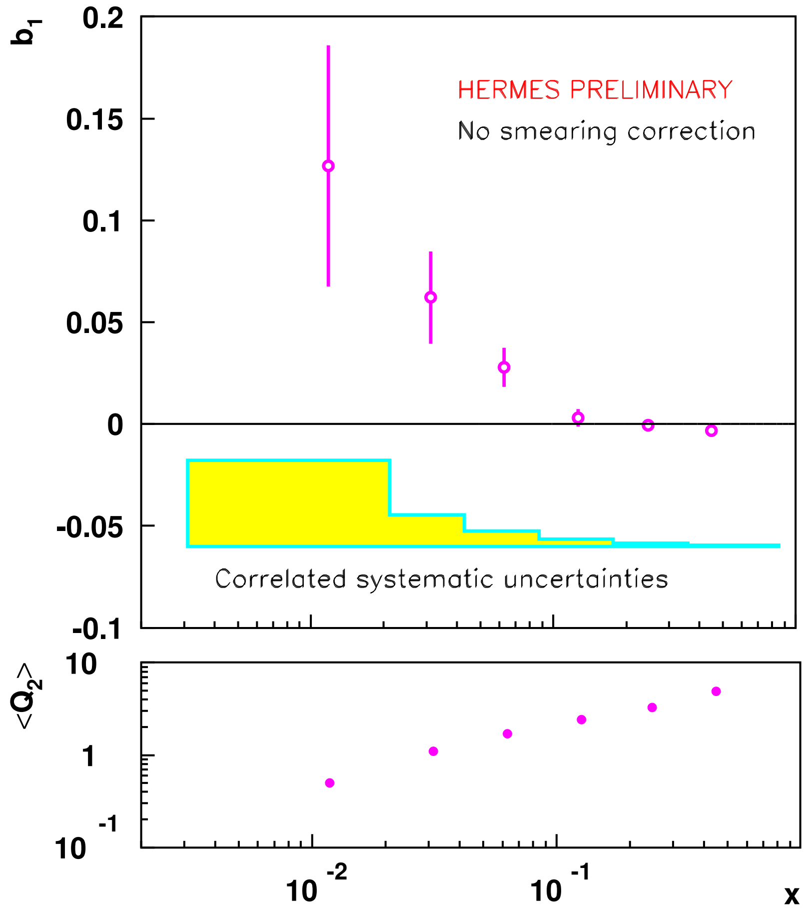
Note: $A_{zz} \equiv A_T$

- At small x_{Bj}: $|A_{zz}| \approx |A_1|$

$\frac{g_1}{F_1} \approx A_1$

- At larger x_{Bj}: little impact on g_1^d determination

Model Calculations for b_1



Theory work $<$ 1997:

- binding & Fermi motion effects at $\mathbf{x \geq 0.2}$

Theory $\geq$ 1997: Double scattering

- diffr. nucl. shadowing + pion excess mech.
  Nikolaev et al., PLB 398, 245 (1997)
- coherent double scattering
  Edelmann et al., PRC 57, 3392 (1998)
- double scattering through VMD
  Bora & Jaffe, PRD 57, 6906 (1998)

$\hookrightarrow$ observe significant enhancement of $\mathbf{b_1}$ at small $\mathbf{x_B}$:

$\triangleright$ Close-Kumano sum rule $\int \mathbf{dx\, b_1(x, Q^2) = 0}$ violated ??

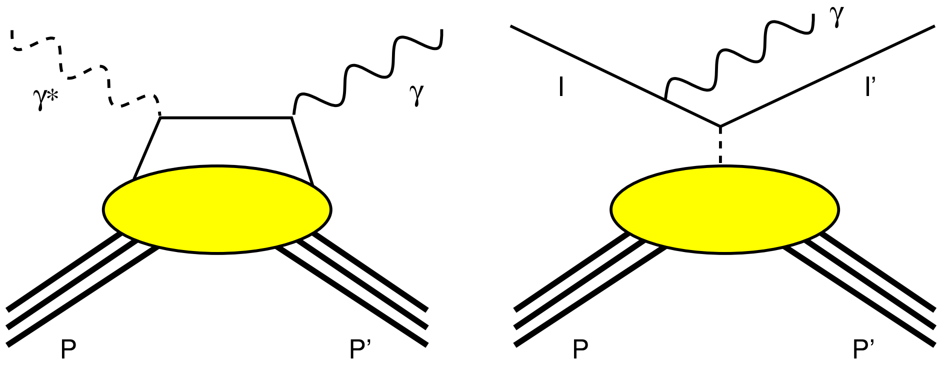
$\triangleright$ interpretable as tensor polarization of the quark sea ?

Deeply Virtual Compton Scattering

Generalized Parton Distributions: Unified theoretical description of inclusive and (hard) exclusive processes

DVCS: $\mathbf{ep} \rightarrow \mathbf{ep}\gamma$ $\quad (\gamma^* p \rightarrow \gamma p)$ in Bjorken limit

dominant subprocess for DVCS in pQCD: 'hand-bag' diagram



Bethe-Heitler (BH) process has identical final state

$$d\sigma \sim |\tau_{BH} + \tau_{DVCS}|^2 = |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \mathcal{I}$$
$$\mathcal{I} = \tau_{BH}^* \tau_{DVCS} + \tau_{BH} \tau_{DVCS}^*$$

DVCS dominated by BH in most of HERMES kin. region

Interference term: access to DVCS amplitudes

$\Rightarrow$ Use BH as an 'amplifier' to study DVCS

ϕ-dependence of Asymmetries

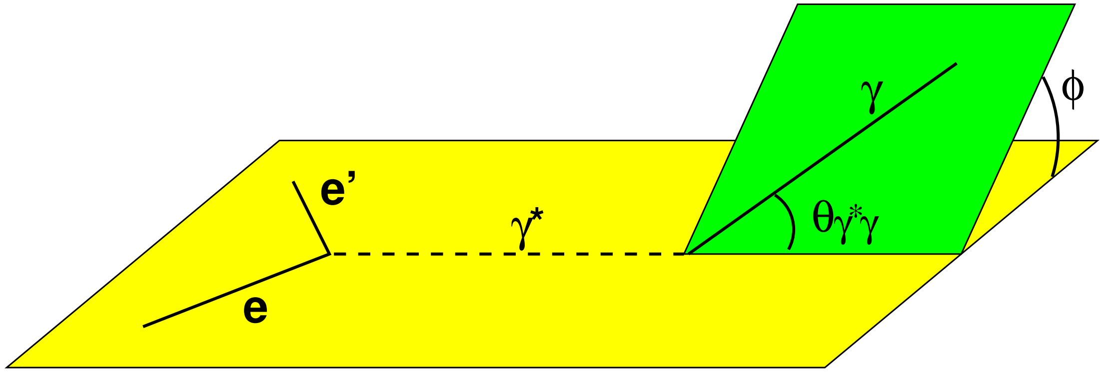
Beam Spin Asymmetry
(Long. pol. beam, unpol. target)

$$A_{LU}(\phi) = \frac{d\sigma^{\uparrow}(\phi) - d\sigma^{\downarrow}(\phi)}{d\sigma^{\uparrow}(\phi) + d\sigma^{\downarrow}(\phi)} \propto \sin\phi \cdot Im(\mathcal{I})$$

Beam Charge Asymmetry
(Unpol. beam, unpol. target)

$$A_C(\phi) = \frac{d\sigma^{+}(\phi) - d\sigma^{-}(\phi)}{d\sigma^{+}(\phi) + d\sigma^{-}(\phi)} \propto \cos\phi \cdot Re(\mathcal{I})$$

$\Rightarrow$ Real and imaginary part of a linear combination of DVCS amplitudes separately accessible through A_{LU} and A_C



NOTE: Measuring A_{LU} and A_C probes predominantly GPD H.

DVCS on Nuclear Targets

Proton Target	Probe nucleon GPDs	H^q, $\tilde{H}^q$ E^q, $\tilde{E}^q$	for $t \to 0$: ordinary PDFs do not exist in DIS

Nuclear Targets — Probe convolution of nucleon GPDs with nucleon momentum spectra inside nucleus

- at large -t: Incoherent scattering $\Rightarrow$ again nucleon GPDs
- at small -t: Coherent scattering, overlap with incoherent (incoherent sample causes dilution of nuclear effect !)

$\Rightarrow$ Problem: Need a model to relate nuclear to nucleon GPDs

$\Rightarrow$ Question: What do we learn about the nucleus' structure ?

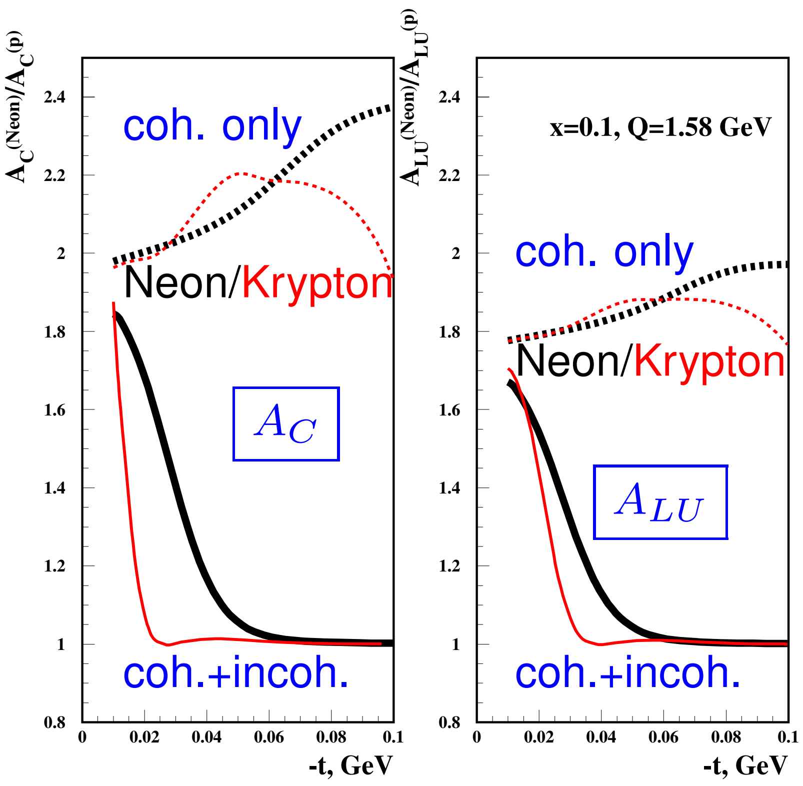
Polyakov, PL B555 (2003), 57: Large idealized nucleus with 'skin'

$\Rightarrow$ may probe deviations of the distributions of energy, 'pressure' and 'shear forces' (on quarks w.r.t. nucleus) from that of electric charge

Nucleus vs. Proton Asymmetry Ratios

$$\frac{A_C^{nucleus}(\phi)}{A_C^{proton}(\phi)} \propto \frac{\int dx\, I_{PV(x\pm\xi)}\, [H^p(x,\xi,0)+(A/Z-1)H^n(x,\xi,0)]}{\int dx\, I_{PV(x\pm\xi)}\, H^p(x,\xi,0)} \propto \frac{A}{Z} > 1\ !$$

$$\frac{A_{LU}^{nucleus}(\phi)}{A_{LU}^{proton}(\phi)} \propto \frac{H^p(\xi,\xi,0)-H^p(-\xi,\xi,0)+(A/Z-1)[H^n(\xi,\xi,0)-H^n(-\xi,\xi,0)]}{H^p(\xi,\xi,0)-H^p(-\xi,\xi,0)} \propto \frac{A}{Z} > 1\ !$$

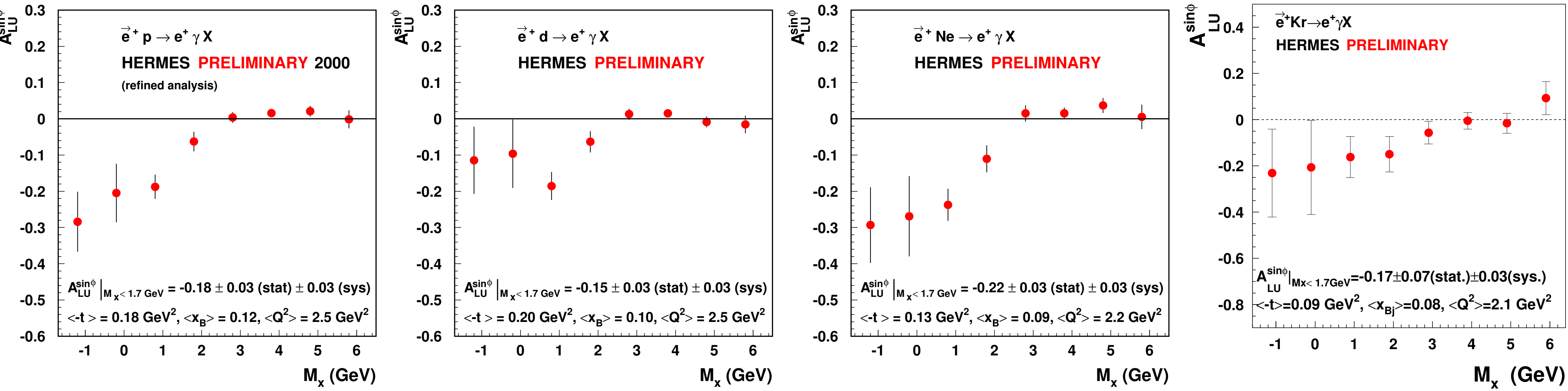


- Impulse approximation ($x_{Bj} \geq 0.05$)
  Guzey/Strikman, hep-ph/0301216

$\Rightarrow$ Nucl. effect only at $-t < 0.05$
(diluted by incoh. contrib.)

- better t-resolution crucial
- Now: use average kinematics

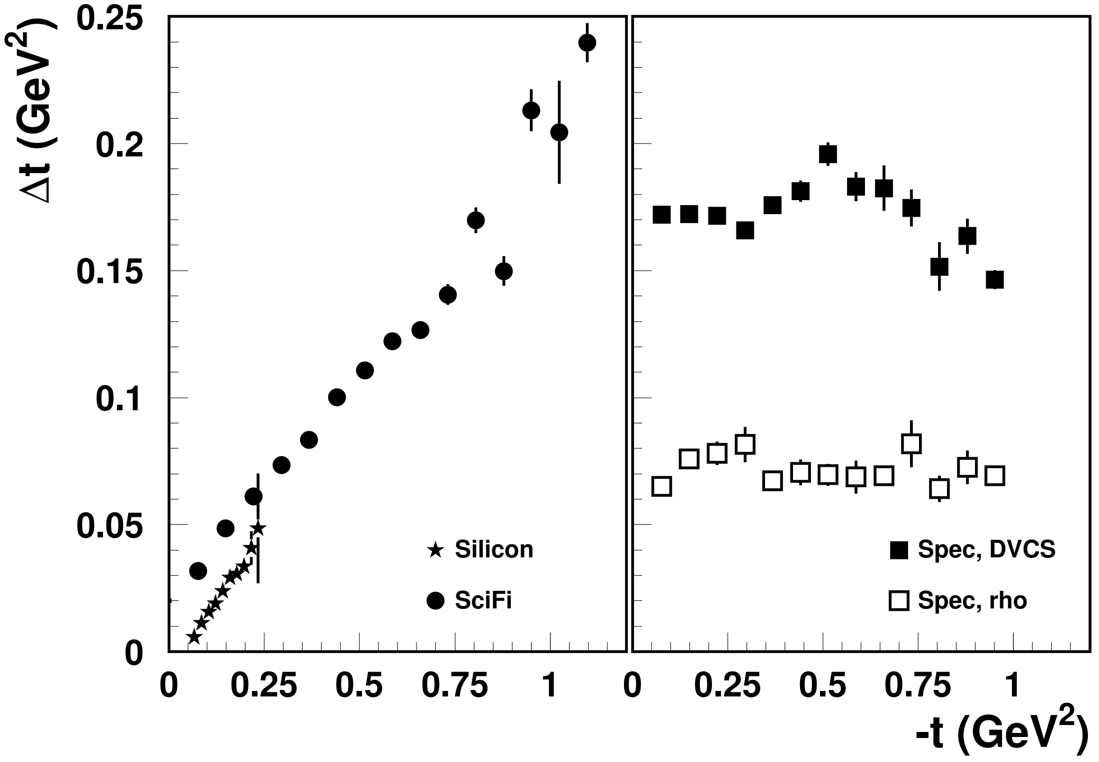
Nuclear Targets - Beam Spin Aymmetry



$\frac{A_{LU}^{nucleus}}{A_{LU}^{proton}}$	Guzey/Strikman hep-ph/0301216	Kirchner/Müller hep-ph/0302007	HERMES result for $\sin\phi$ moment
Deuteron	—	1.15	0.83 ± 0.29
Neon	1.05 ± 0.01	1.31	1.22 ± 0.32
Krypton	1.18 ± 0.01	—	0.94 ± 0.44

$\Rightarrow$ Present statistical accuracy not sufficient

Future DVCS Measurements at HERMES



- Construct & install RECOIL DETECTOR ($\simeq$ 2004/05)
- Reduce non-exclusive background to below 1%

$\Leftarrow$ Significant improvement of t-resolution at low -t

- Measure t-dependence of A_C and A_{LU} precisely

- Measurements on nuclear targets possible in 2005/06
- Statistics on nuclear target will concentrate on low -t

$\Rightarrow$ Good chance to challenge model builders

(need predictions at exact kinematics of measurements !)

Meson Nonets in Const. Quark Model

$\mathbf{SU(3)_c}$ $\mathbf{q\bar{q}}$ representations:

- Vector ($J^{PC} = 1^{--}, L = 0$): ρ^0, ω, ϕ,J/ψ; $\rho^\pm, K^*$
- Pseudo-scalar ($J^{PC} = 0^{-+}, L = 0$): $\pi^0, \eta, \eta_c, \eta'; \pi^\pm, K$
- Scalar ($J^{PC} = 0^{++}, L = 1$) with masses below 2 GeV:
  - I=0 candidates: $\sigma(400-1200)$, $f_0(980)$, $f_0(1370)$, ...
  - I=1 candidates: $a_0(980)$, $a_0(1450)$

$\Rightarrow$ light scalars problematic: may not be $\mathbf{q\bar{q}}$ states, but

- $K\bar{K}$ bound states (molecules: $(qq)(\bar{q}\bar{q})$)
- multiquark ($q\bar{q}g$) hybrid states
- mixed glueball state - vacuum scalar state

Decay modes: $f_0(980)$ dominant $\pi\pi$; $a_0(980)$ dominant $\eta\pi$

$\Rightarrow$ field of controversy for almost 40 years

Scalar Mesons at HERMES ?

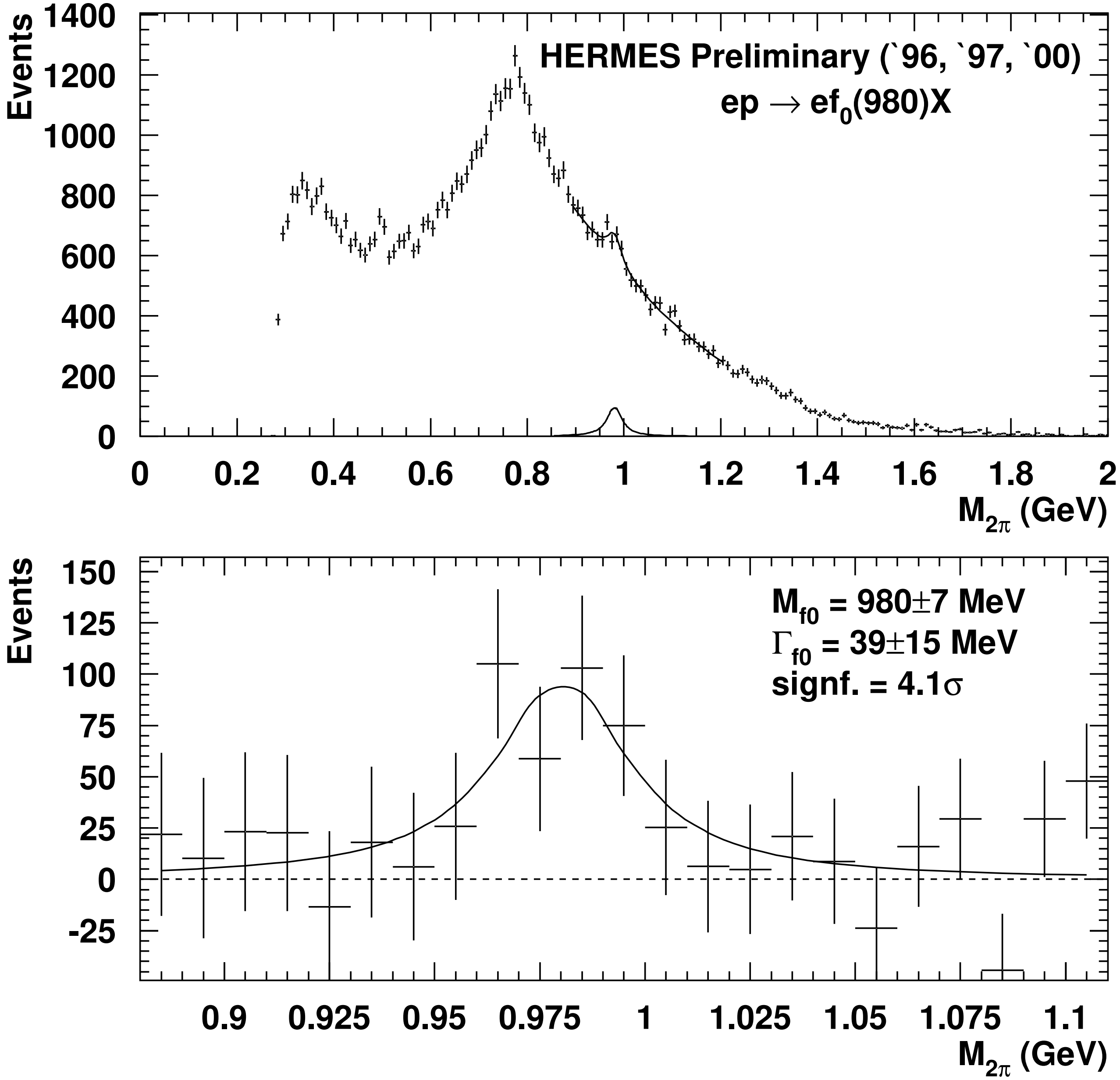
HERMES (non-)capabilities to look for scalar mesons:

- difficult to separate from background, as in other scattering exp's
- can not do phase shift analysis, but Breit-Wigner fit
- can study kinematic ($\mathbf{Q^2, x_{Bj}, p_t^2, t}$) dependences
- different targets available: H, ^{2}H, ^{20}Ne, ^{84}Kr

HERMES data analysis to extract $\mathbf{f_0(980)}$:

- data: 1996-2000; unpolarized hydrogen
- DIS cuts: $\mathbf{W^2 > 4}$ GeV^2, $\mathbf{y < 0.85}$
- reaction: $\mathbf{e\ A \rightarrow e'\ \pi^+\ \pi^-\ h\ X}$ (non-exclusive !)
- 2.5 < $\mathbf{p_\pi}$ > 15 GeV (dual RICH: C_4F_{10}/Aerogel)

Identification of $f_0(980)$ at HERMES



top: after cuts

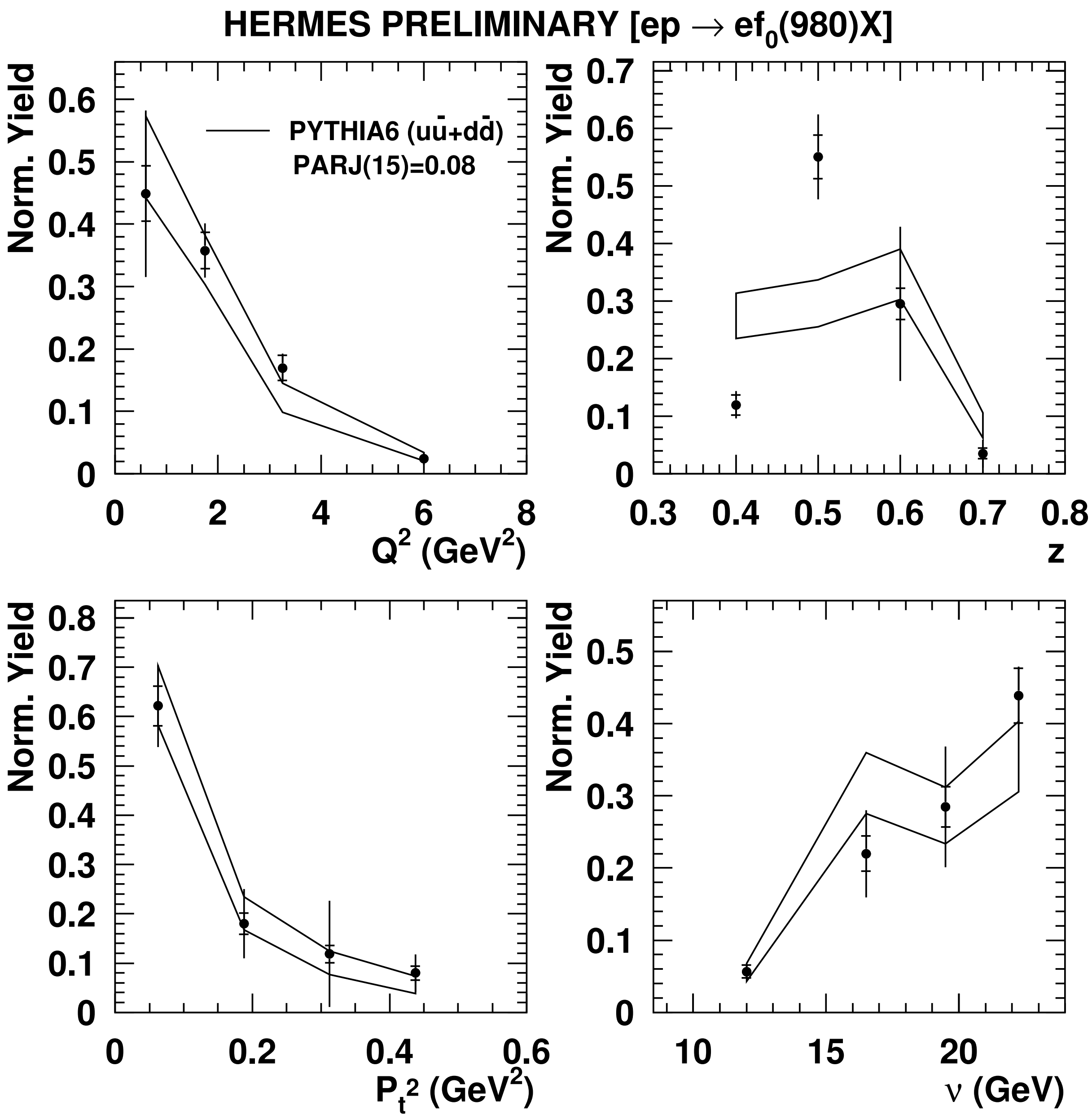
bot: after background subtraction

- fit using 3^{rd}order polynomial + Breit-Wigner shape
- only in the region 0.9 - 1.1 GeV to exclude ρ-region

$\Rightarrow$ peak seen at book mass 980 MeV

$\Rightarrow$ narrow width favored (39 ± 15 MeV)

Kinematic dependences for $f_0(980)$



points: data (in acceptance)

bands: PYTHIA6: $u\bar{u} + d\bar{d}$
+ full HERMES chain

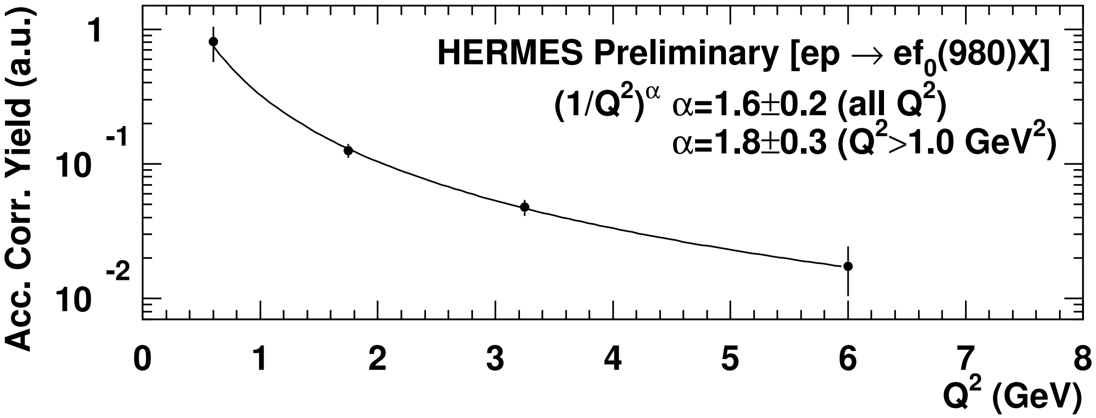
MC- data comparison:

⇒ supports $q\bar{q}$ hypothesis

(no other MC exists yet)

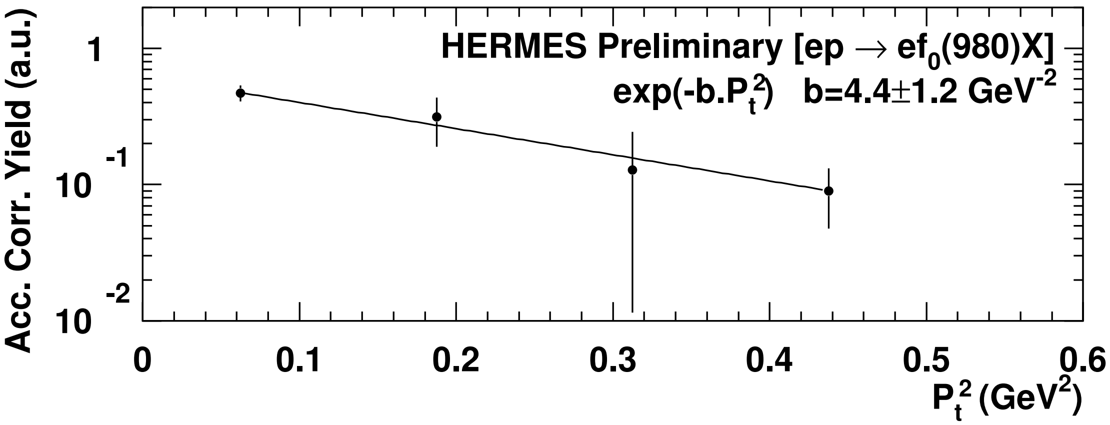
- Q^2, P_t^2, ν: ok
- peak at $z = 0.5$ stronger in data

Acceptance-corrected data on Hydrogen



- DIS: $\alpha = 2$

$\Rightarrow$ not inconsistent with $f_0(980)$ produced by DIS fragmentation



- P_t^2-slope consistent with NOMAD result (b=5.3 $\pm$ 0.2)

Summary & Conclusions

- First measurement of tensor structure function $\mathbf{b_1}$:
  - significant enhancement of $\mathbf{b_1}$ with decreasing $\mathbf{x_{Bj}}$
  - suggests significant tensor polarization of the quark sea
  - qualitative agreement with coherent double scattering models
- Deeply Virtual Compton Scattering on Nuclei (D, Ne, Kr)
  - beam-charge (1^{st} time) & single beam-spin asymmetry measured
  - Exp^{ly}: separation of coherent sample not easy; more data needed
  - Theor^{ly}: more work on interpretation highly appreciated
- Observation of $\mathbf{f_0(980)}$ in electroproduction (1^{st} time)
  - kinematics consistent with $\mathbf{f_0(980)}$ being a $\mathbf{q\bar{q}}$ state produced in DIS fragmentation

Parallel Talks on HERMES Results

- Monday, August 4, 16:30-16:50 (Room A114)
  P. Liebing:
  Double Spin Asymmetries in 1- and 2-Pion Production at HERMES
- Monday, August 4, 14:55-15:20 (Room C520)
  R. Kaiser:
  Exclusive Measurements at HERMES
- Tuesday, August 5, 14:50-15:15 (Room A114)
  T.-A. Shibata:
  Experimental Results on Polarized Quark Distributions from HERMES
- Thursday, Aug. 7, 11:25-11:50 (Room A114)
  G. Schnell:
  Transversity measurements at HERMES