Summary of “Spin” session
DIS 2011, Newport News

Hall A   Hall B   Hall C

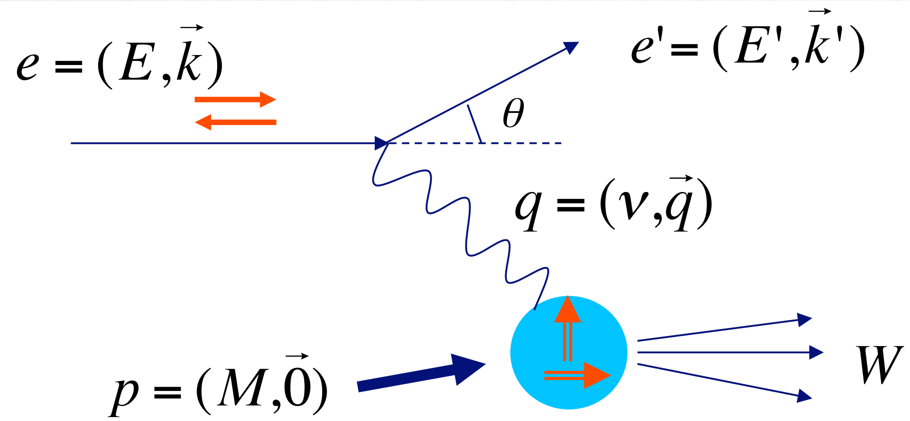
- pdfs and the longitudinal spin structure
- TMDs and the transverse spin structure

  3D picture in the $(x, \vec{k}_T)$ space

- GPDs and the spin sum rule

  3D picture in the $(x, \vec{b}_T)$ space

inclusive scattering - g1, g2



$$Q^2 = -q^2 = 4EE'\sin^2\tfrac{\theta}{2}$$

$$x = \frac{Q^2}{2M\nu}$$

$$A_1 = \frac{\sigma^T_{1/2} - \sigma^T_{3/2}}{\sigma^T_{1/2} + \sigma^T_{3/2}} = \frac{g_1 - \gamma^2 g_2}{F_1}$$

$$A_2 = \frac{2\sigma^{LT}}{\sigma^T_{1/2} + \sigma^T_{3/2}} = \gamma\,\frac{g_1 + g_2}{F_1}\,.$$

Unpolarized case

$$\frac{d^2\sigma}{d\Omega dE'} = \sigma_{Mott}\left[\frac{1}{\nu}F_2(x,Q^2) + \frac{2}{M}F_1(x,Q^2)\tan^2\tfrac{\theta}{2}\right]$$

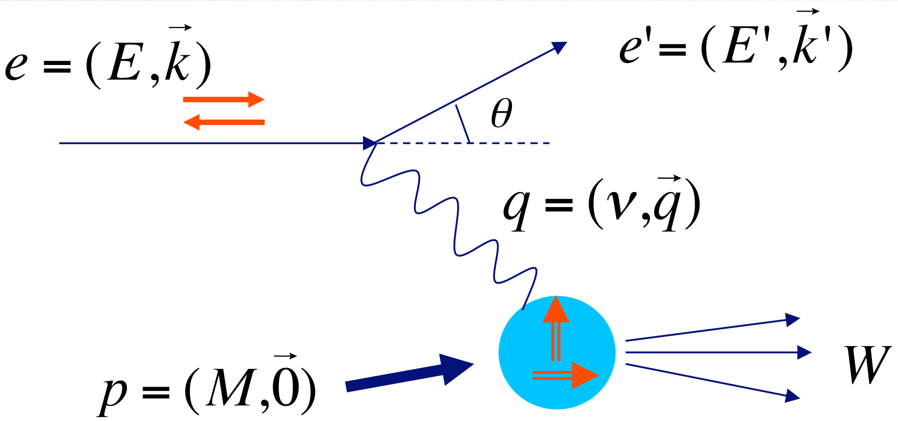
Polarized case

$$\frac{\mathrm{d}^2\sigma_{LL}(x,Q^2)}{\mathrm{d}x\,\mathrm{d}Q^2} = \frac{8\pi\alpha^2 y}{Q^4} \times \left[\left(1 - \frac{y}{2} - \frac{y^2}{4}\gamma^2\right) g_1(x,Q^2) - \frac{y}{2}\gamma^2 g_2(x,Q^2)\right]$$

$$\frac{d^3\sigma_{LT}}{dx\,dy\,d\phi} = -h_l \cdot \cos\phi \cdot \frac{4\alpha^2}{Q^2} \cdot \gamma \cdot \sqrt{1 - y - \frac{\gamma^2 y^2}{4}} \times \left(\frac{y}{2} g_1(x,Q^2) + g_2(x,Q^2)\right).$$

$$g_1(x,Q^2) = \frac{1}{2}\sum_q e_q^2 \Delta q(x,Q^2).$$

inclusive scattering - g_1, g_2



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Polarized case

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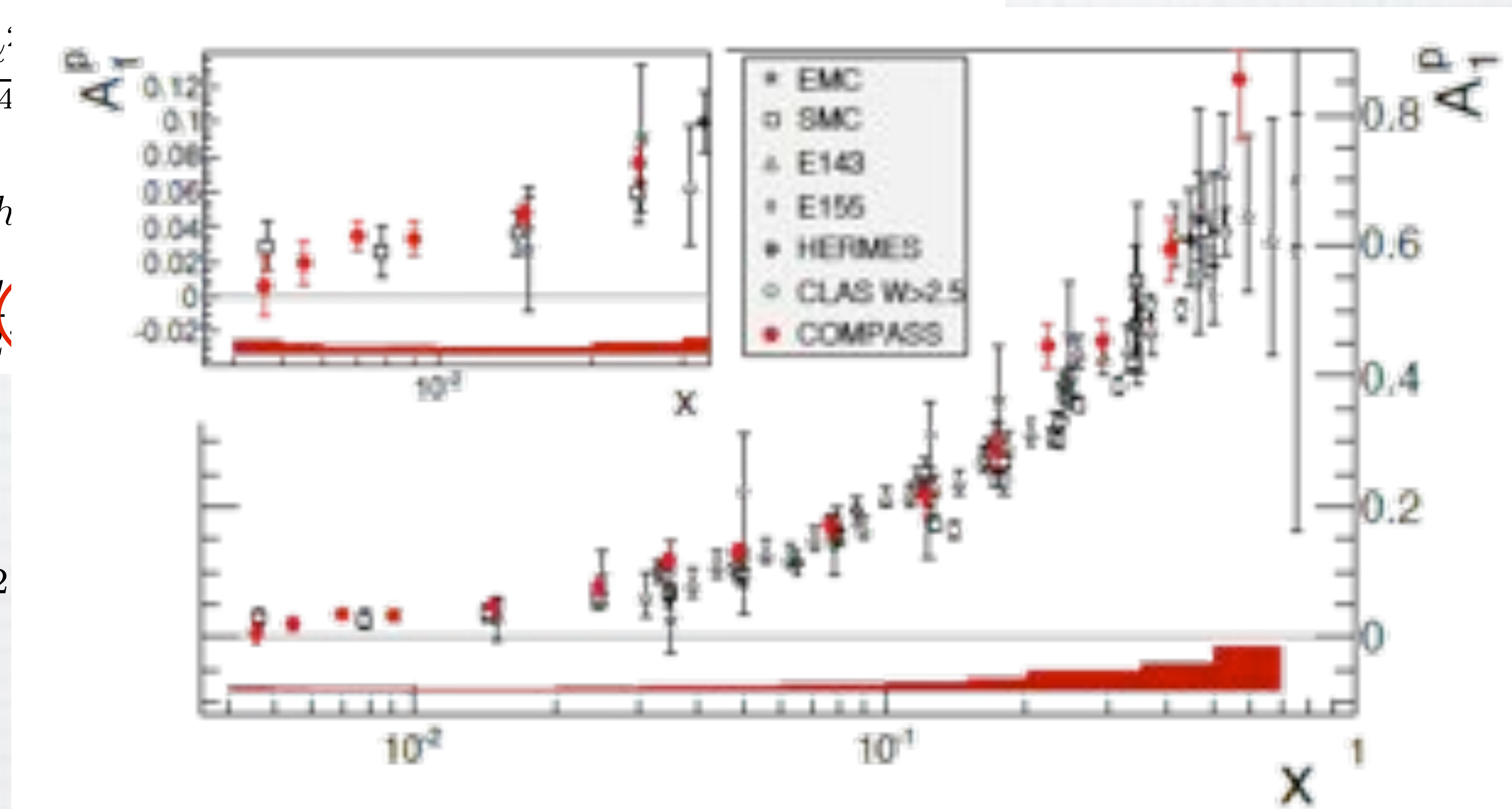
$$\frac{d^3\sigma_{LT}}{dxdyd\phi} = -h \ldots$$

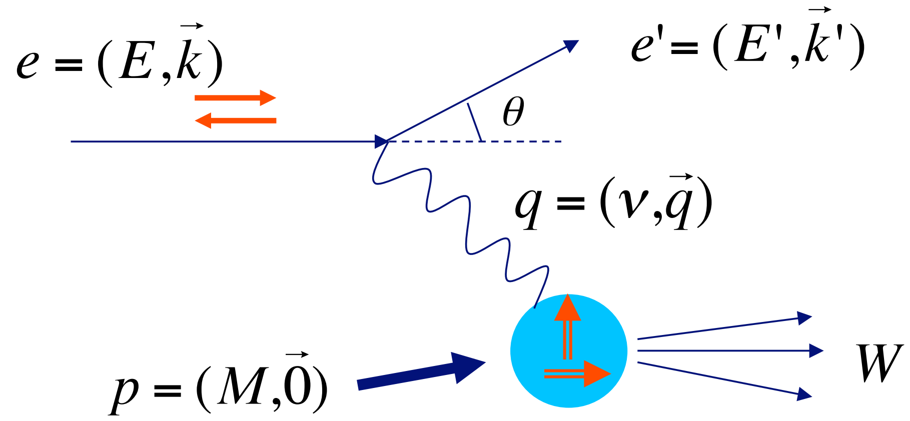
$$\times\left(\frac{y}{2} \ldots\right.$$

$$g_1(x,Q^2) = \frac{1}{2}\sum_q e_q^2 \Delta q(x,Q^2) \ldots$$

DIS



inclusive scattering - g_1, g_2



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$$g_1(x,Q^2) = \frac{1}{2}\sum_q e_q^2 \Delta q(x,Q^2).$$

twist-2

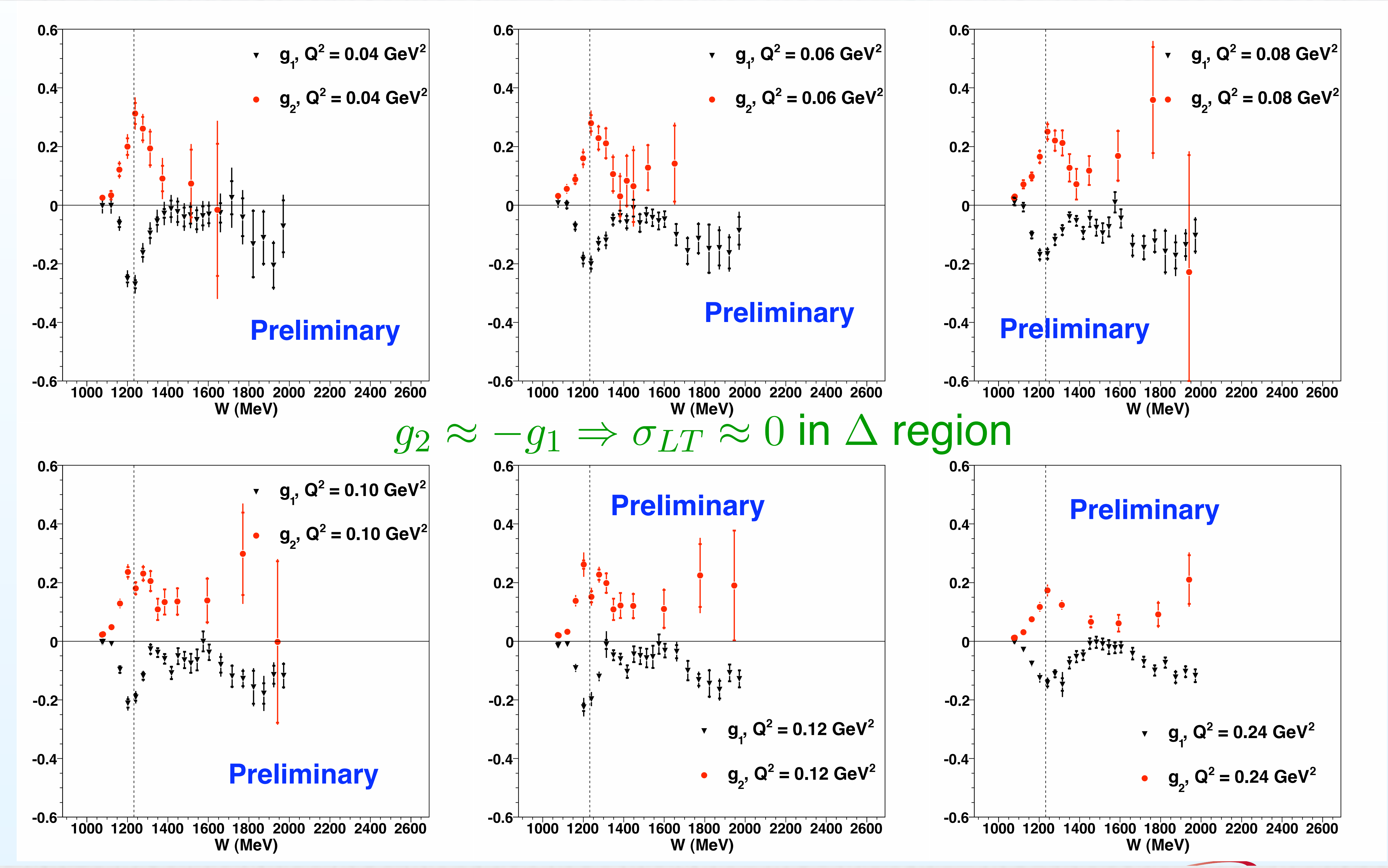
higher twist

$$g_2(x,Q^2) = g_2^{\mathrm{WW}}(x,Q^2) + \bar{g}_2(x,Q^2)$$

$$g_2^{\mathrm{WW}}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 g_1(y,Q^2)\frac{dy}{y}$$

inclusive scattering - g1, g2

- *Vincent Sulkovsky (Hall A)*-



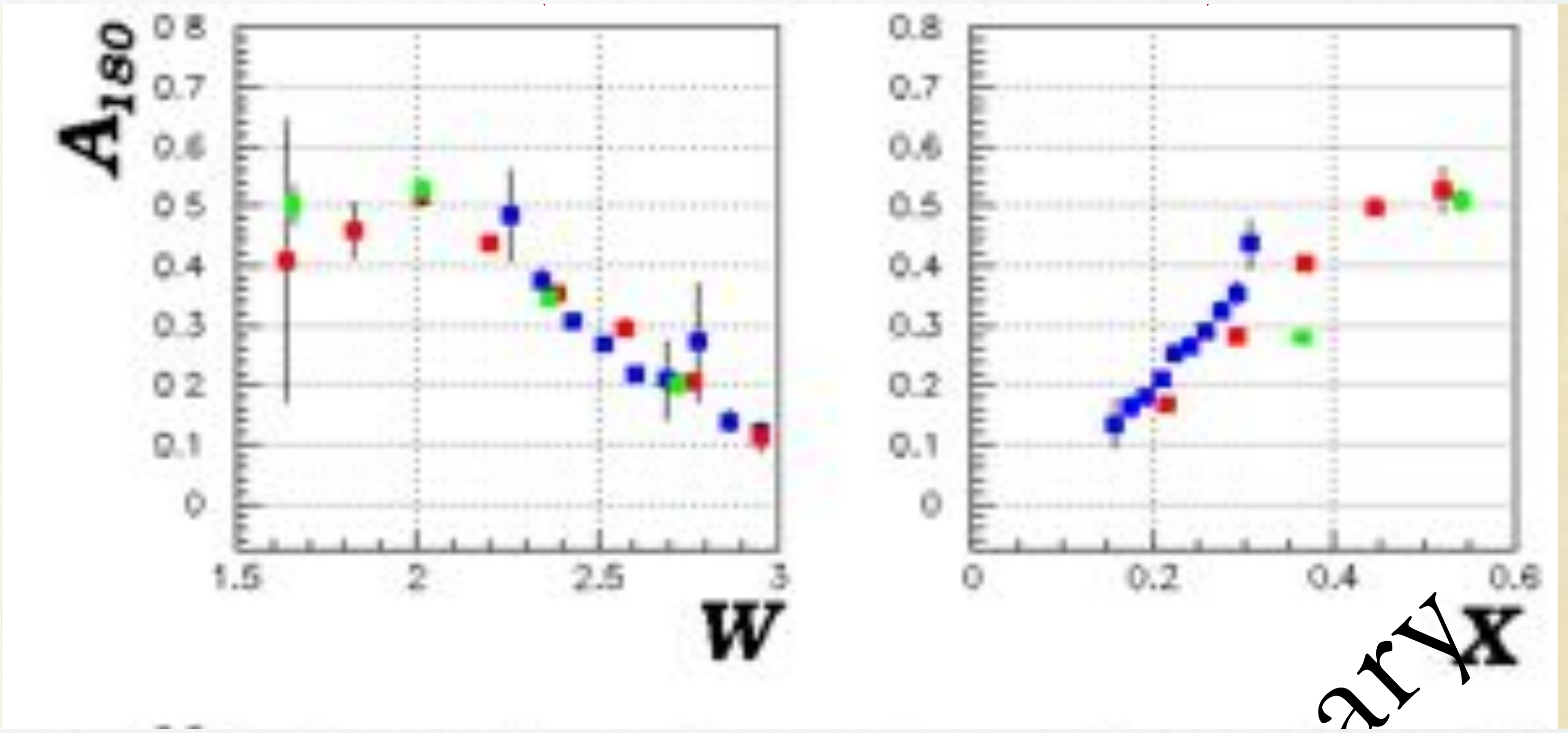
$g_2 \approx -g_1 \Rightarrow \sigma_{LT} \approx 0$ in Δ region

inclusive scattering - g1, g2

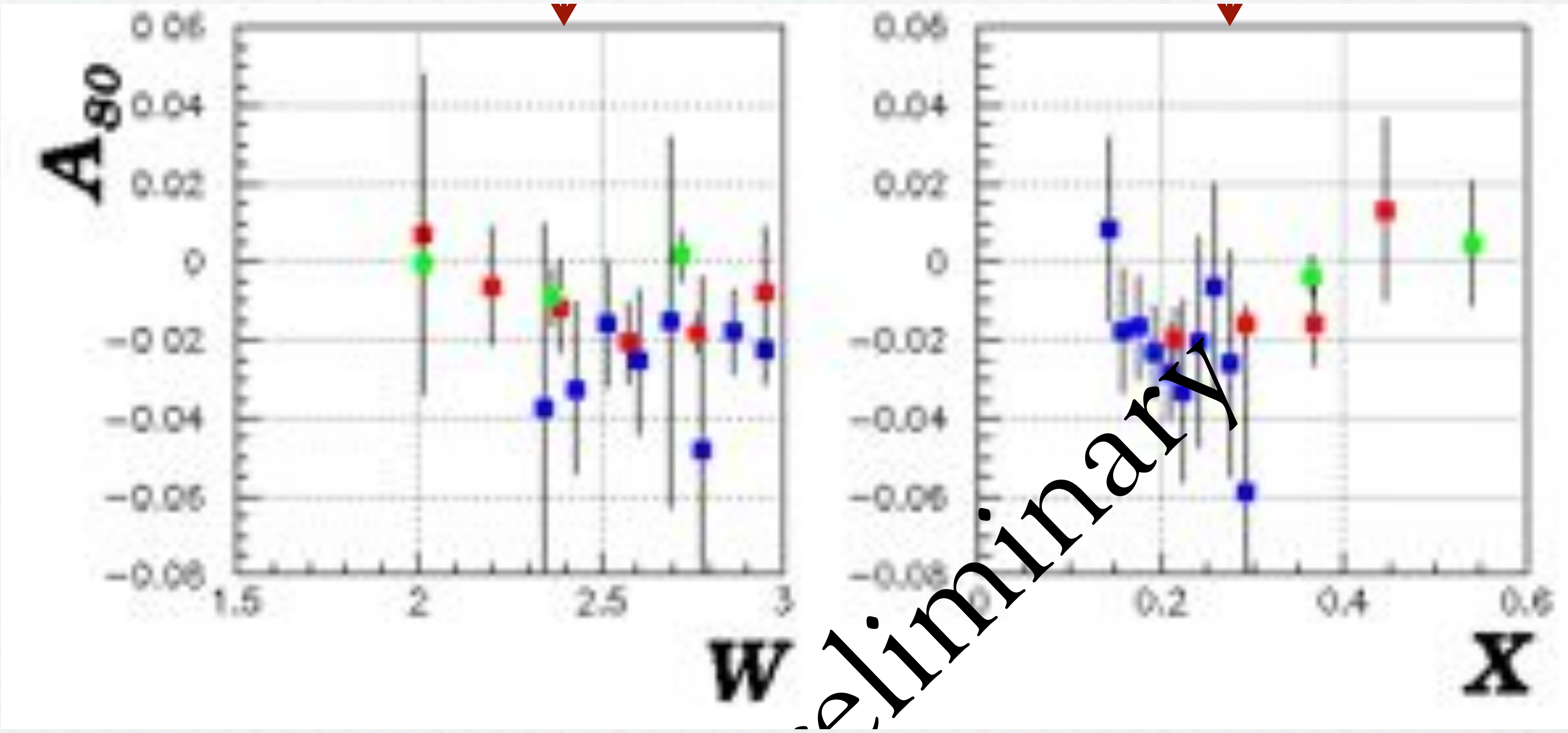
- Hovhannes Baghdasaryan (Hall C) -

➤ Q^2 1.7 GeV^2
➤ Q^2 2.5 GeV^2
➤ Q^2 3.5 GeV^2

➤ Small Q^2 dependence



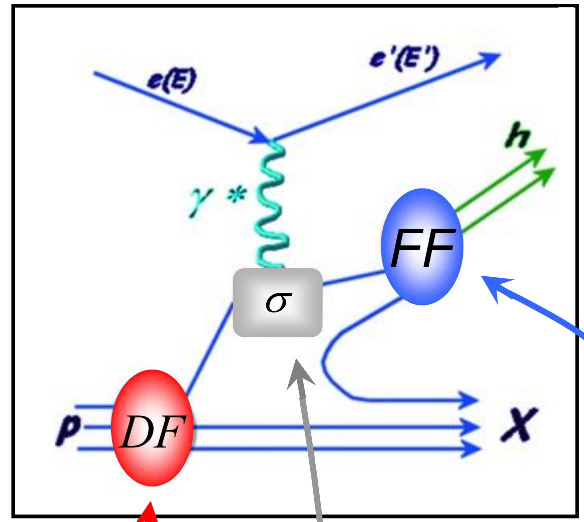
➤ Non-zero Asymmetry (2%)
➤ In some kinematics ranges A_{80} is about 20% of A_{180}



semi-inclusive deep inelastic scattering

nucleon polarisation / quark polarisation

N/q	U	L	T
U	f_1 number density		
L		g_1 - helicity	
T			h_1 - transversity



$$\sigma^{ep\to ehX} = \sum_q DF \otimes \sigma^{eq\to eq} \otimes FF$$

Intrinsic k_T quark distribution

Distribution Functions (DF)

nucleon polarisation / quark polarisation

N/q	U	L	T
U	f_1 number density		$h_1^\perp$ - Boer-Mulders
L		g_1 - helicity	$h_{1L}^\perp$ -
T	$f_{1T}^\perp$ - Sivers	g_{1T} -	h_1 - transversity; $h_{1T}^\perp$ -

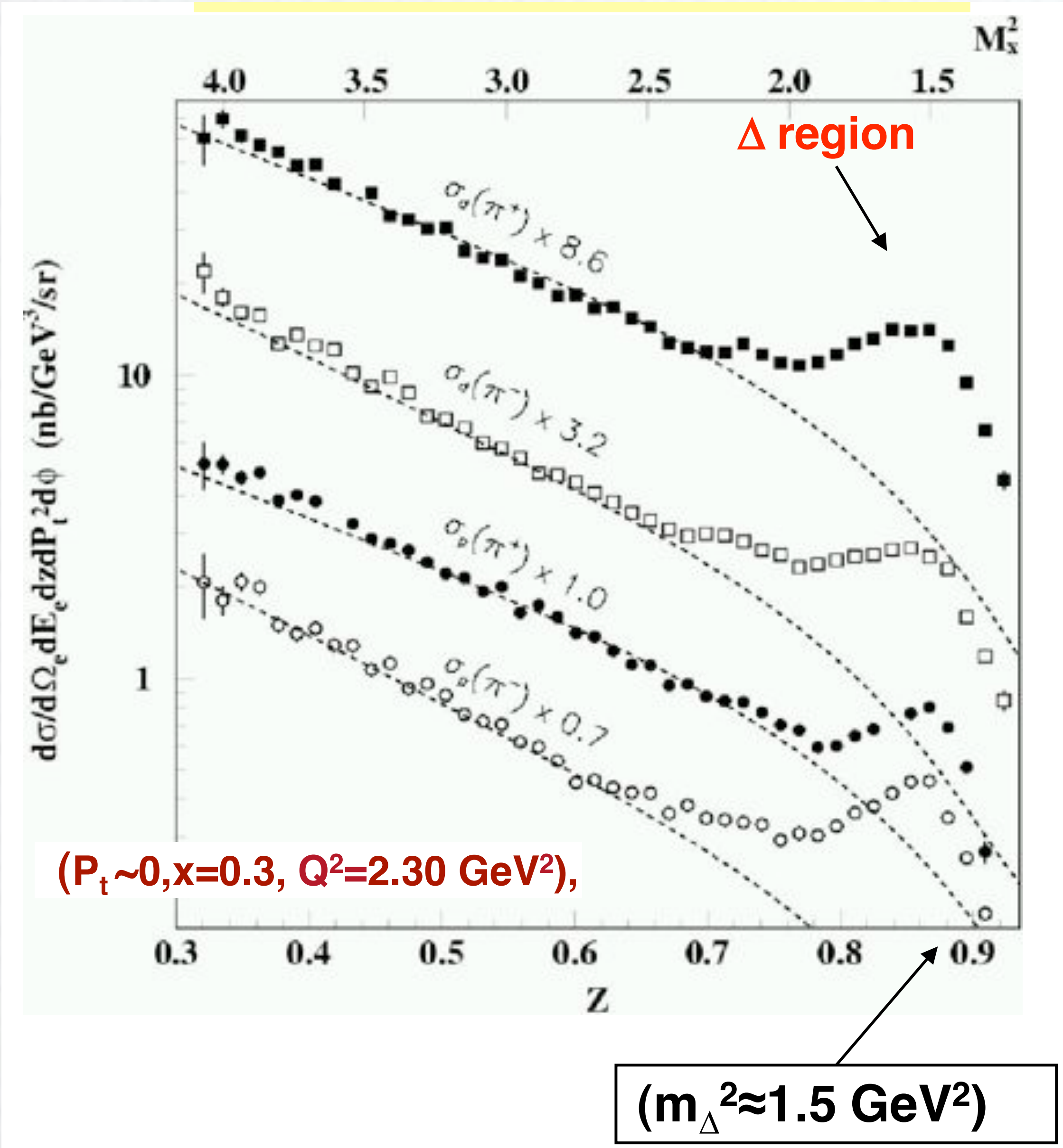
- Marco Contalbrigo -

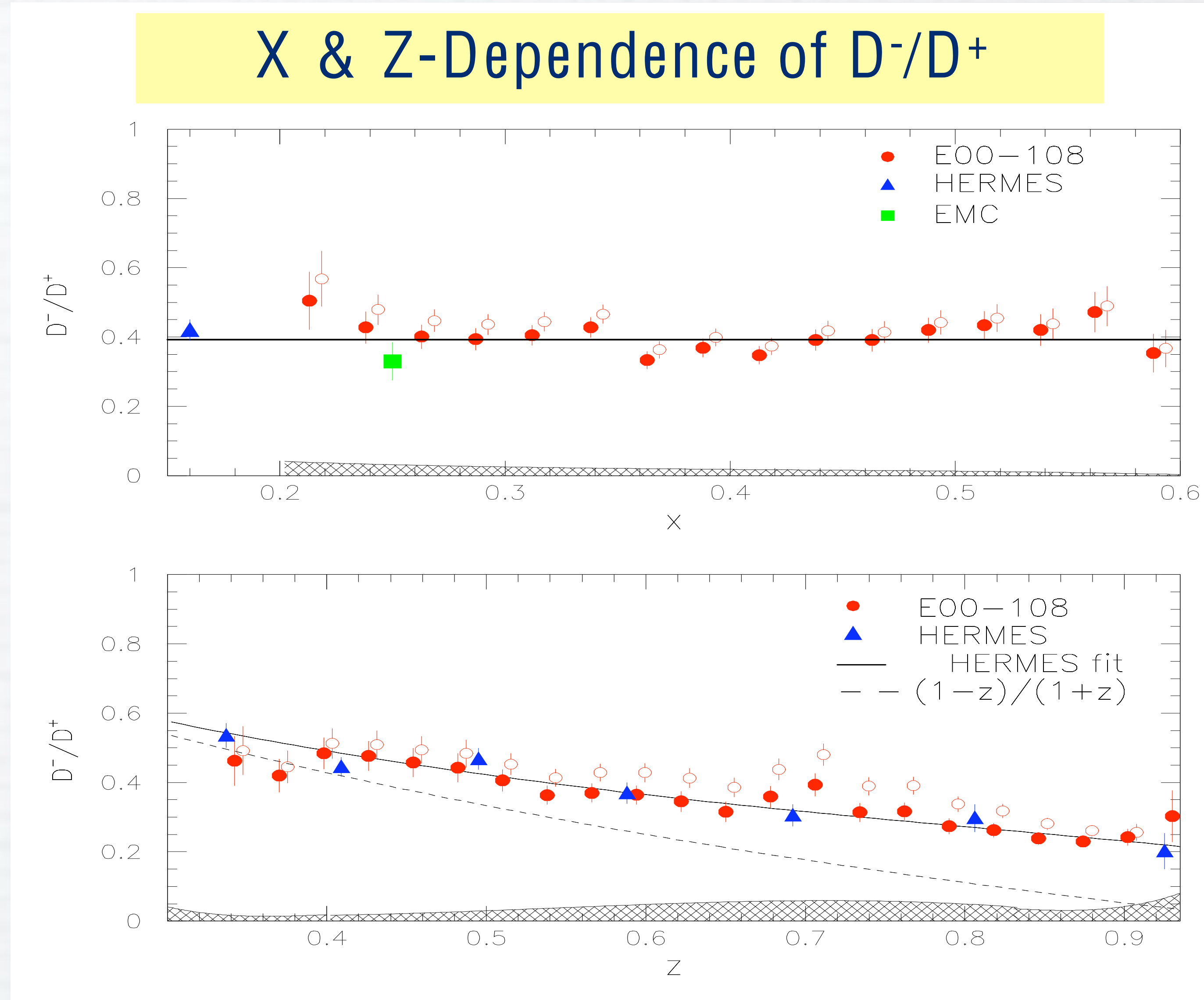
Fragmentation Functions (FF)

N/q	U	L	T
U	D_1 unpolarized		$H_1^\perp$ - Collins

test of the factorization

- Hamlet Mkrtchyan -





$$\sigma \sim \Sigma e_q^2 q(x)\, D_q^{\pi}(z)$$

factorization

Good agreement between our data and simple quark-parton model for z< 0.65 (assuming factorization)

- D^-/D^+ ration evaluated from pion cross section ratio
- fragmentation functions do not depend on x (as expected)
- depend on z, in agreement with HERMES and EMC results

quark helicities

- Josh Rubin -

Assuming:

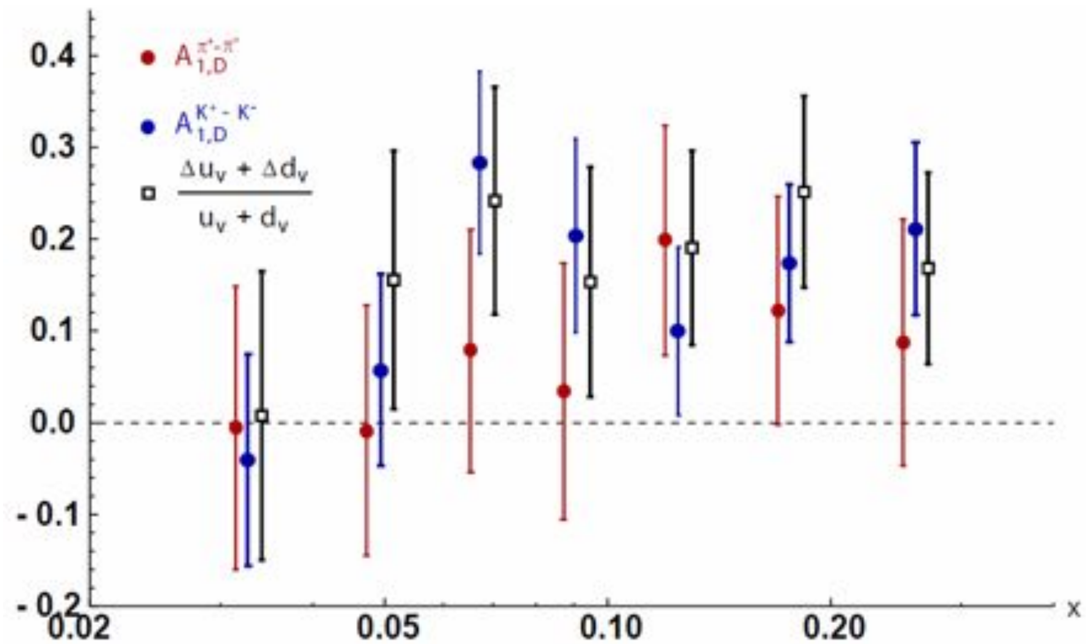
Charge conjugation symmetry of fragmentation functions:

$$D_q^{h^+} = D_{\bar{q}}^{h^-}$$

On the Deuteron:

$$A_{1d}^{h^+-h^-}(x) = \frac{\Delta u_v + \Delta d_v}{u_v + d_v}(x)$$

(Under leading order, leading twist, current fragmentation assumptions)



Different models with different assumptions. Good agreement.

quark helicities

- Josh Rubin -

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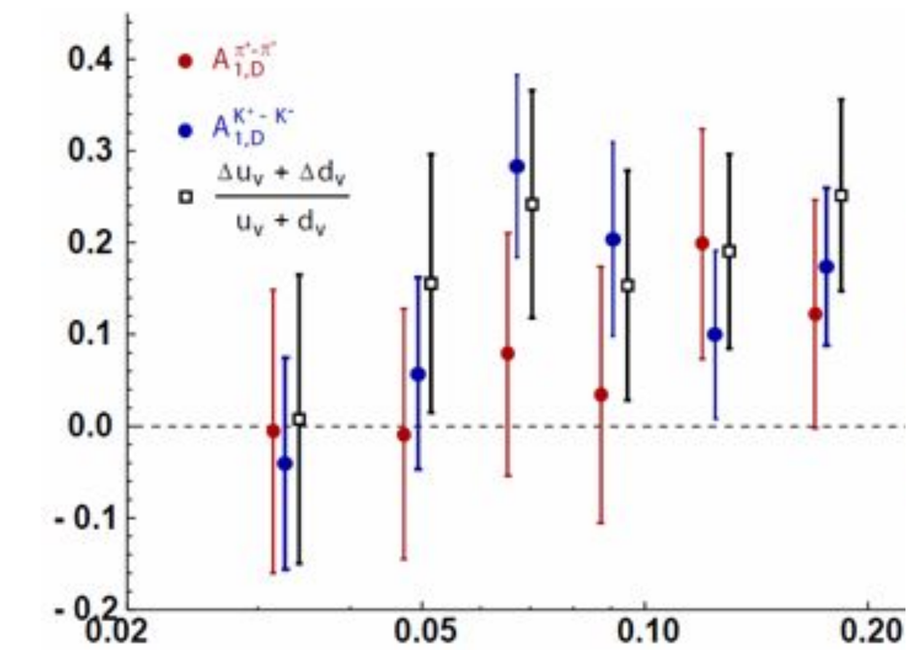
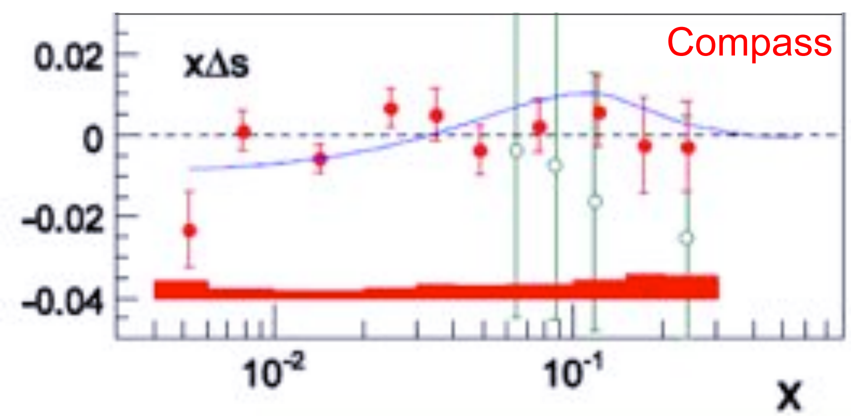


Different models with different assumpti

- Claude Marchand-

$$A_1^{h\,(p/d)}(x,z,Q^2) \approx \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}$$



Unpolarized PDF: MRST04
F.F: DSS parametrization, $\Delta s = \Delta\bar{s}$

PLB 693(2010)227

$$\Delta s(\mathrm{SIDIS}) = -0.01 \pm 0.01(\mathrm{stat}) \pm 0.01(\mathrm{syst}) \quad @ \; 0.003 < x < 0.3$$

- Tentative extraction of $R_{SF} = D_s^K / D_u^K$ from K multiplicities
  → better constrain Δs obtained from SIDIS

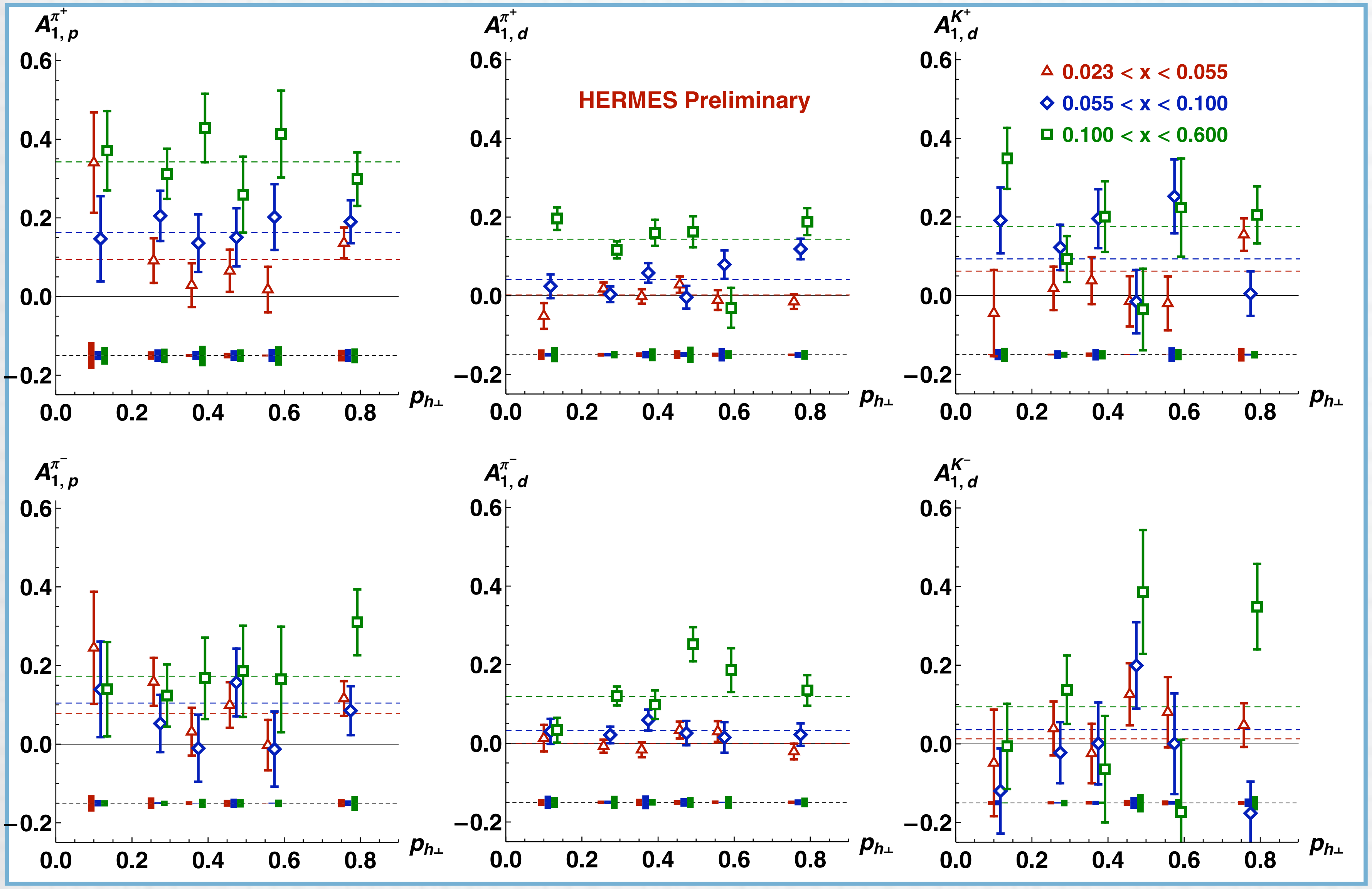
semi-inclusive double spin asymmetries

- Josh Rubin -

$$A_1^h = \frac{\sigma_{1/2}^h - \sigma_{3/2}^h}{\sigma_{1/2}^h + \sigma_{3/2}^h} \overset{LO}{=} \frac{\sum_q e_q D_q^h(z, p_{h\perp}) \Delta q(x)}{\sum_{q'} e_{q'} D_{q'}^h(z, p_{h\perp}) q'(x)}$$

Each *x*-bin	0.2<z<0.35	0.35<z<0.5	0.5<z<0.9
$0<p_{h\perp}<0.3$			leading
$0.3<p_{h\perp}<0.5$			
$0.5<p_{h\perp}<1.0$	mid-rapidity		

Highest energy hadron & influenced by fewest $q\bar{q}$ pairs



No significant $p_{h\perp}$ dependence observed

semi-inclusive double spin asymmetries

- Josh Rubin -

- Sucheta Jawalkar-

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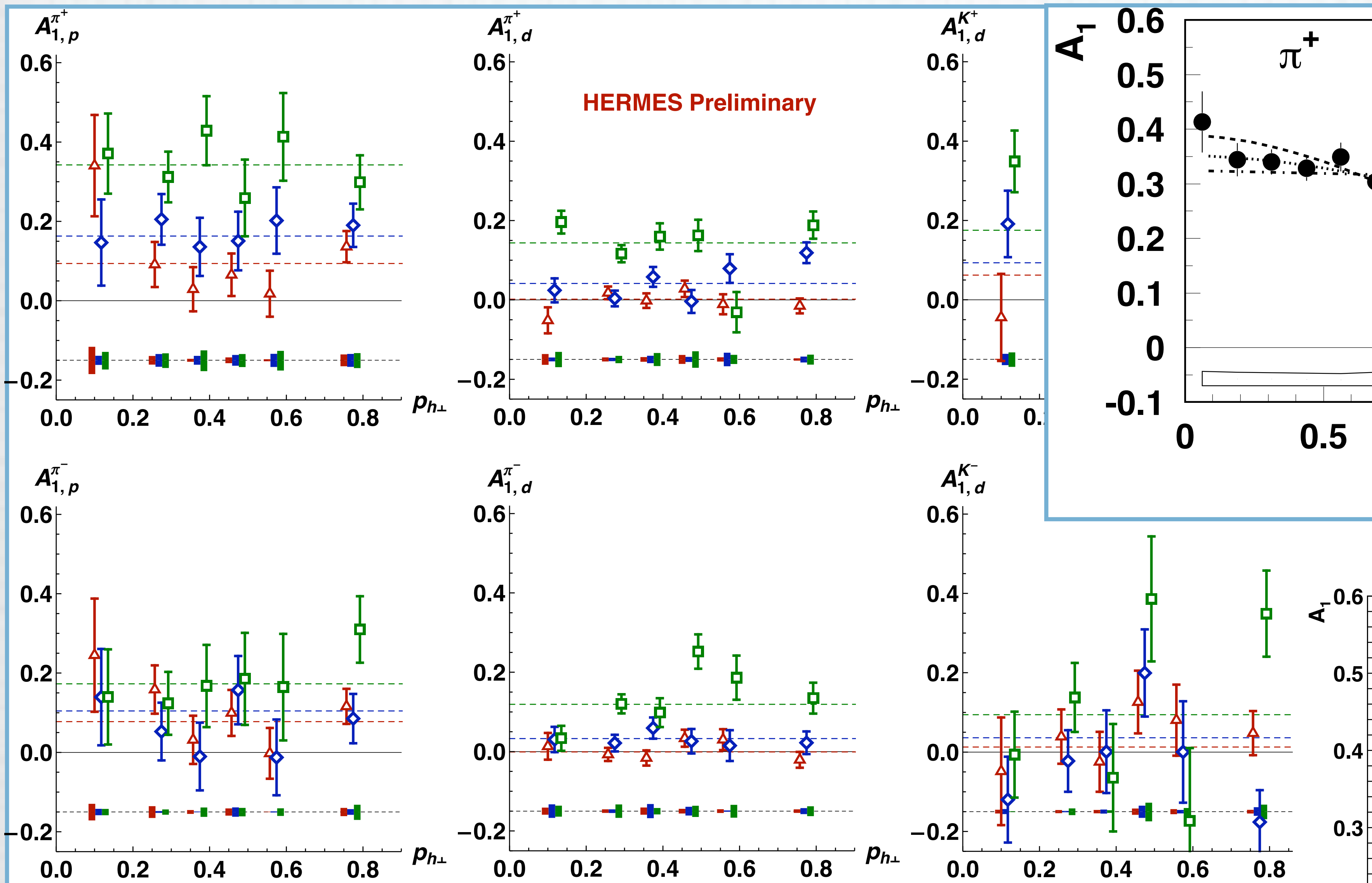
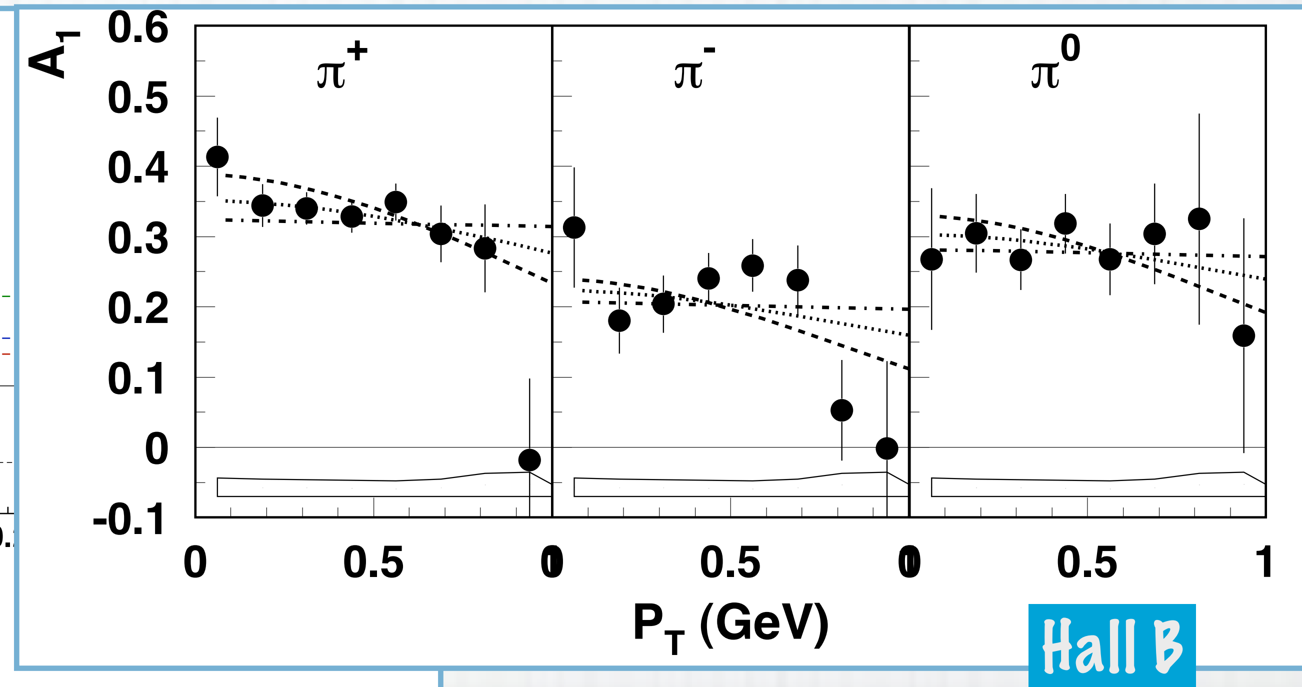
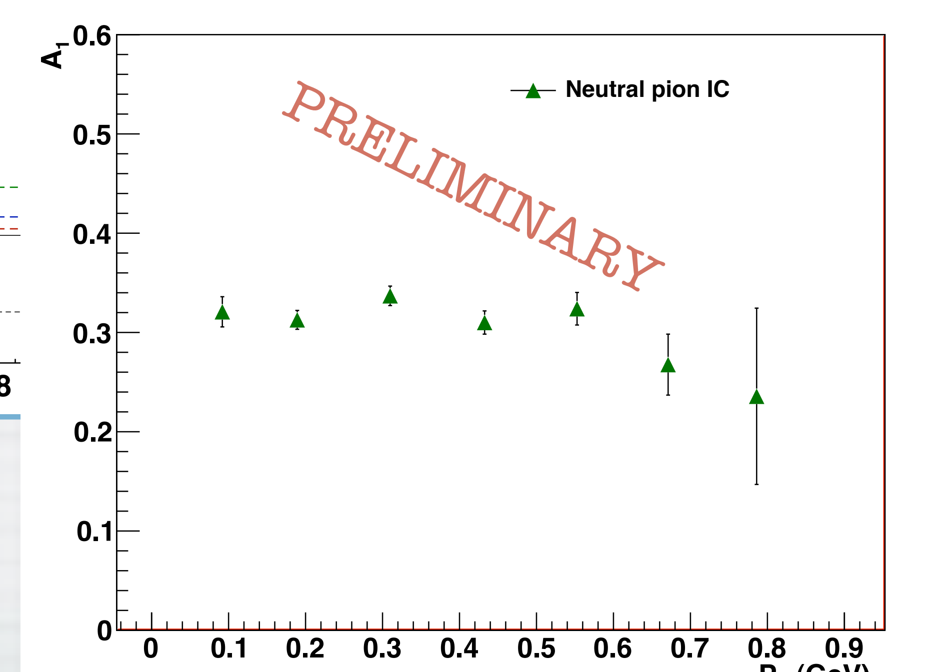


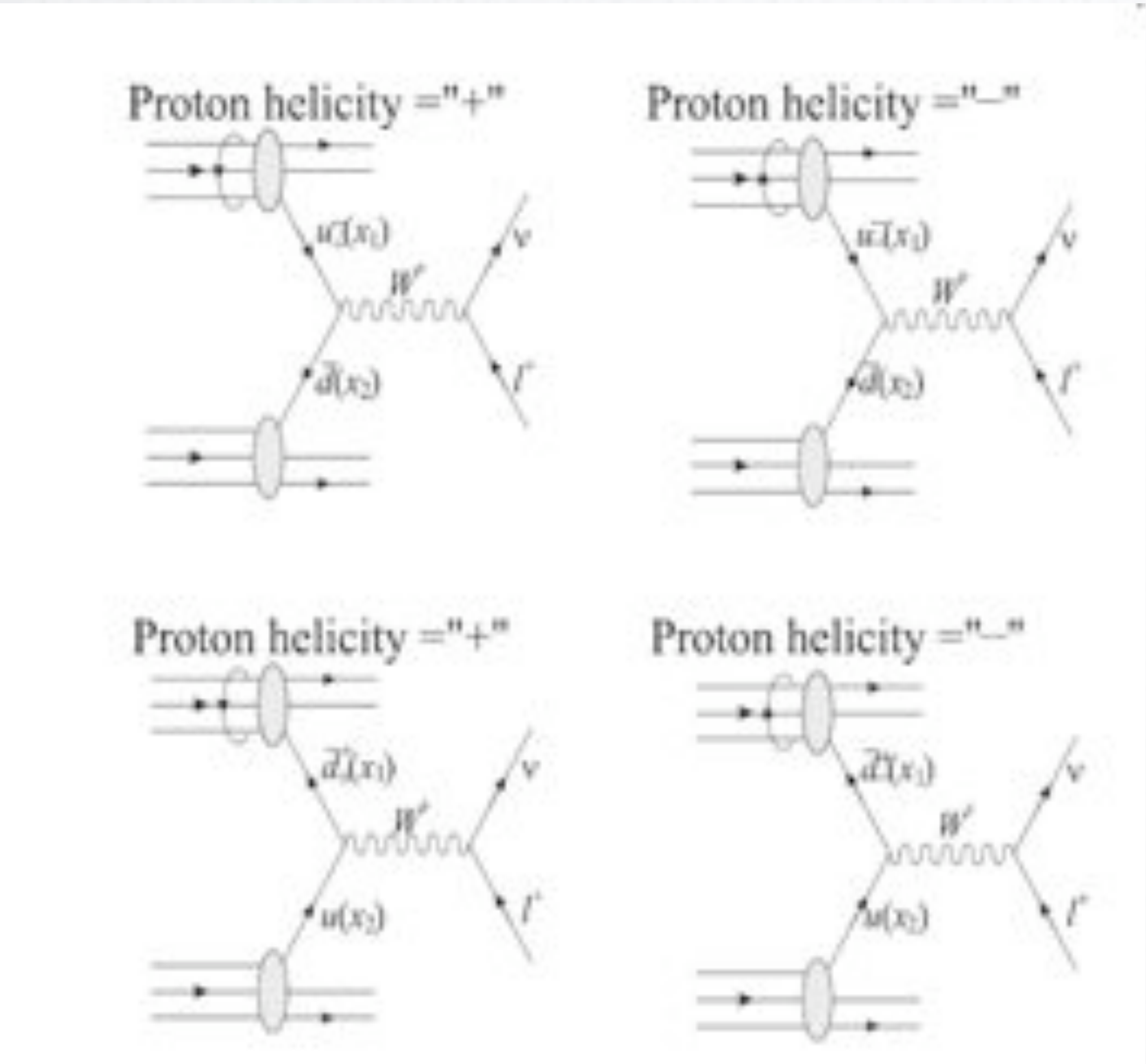




No significant $p_{h\perp}$ dependence observed

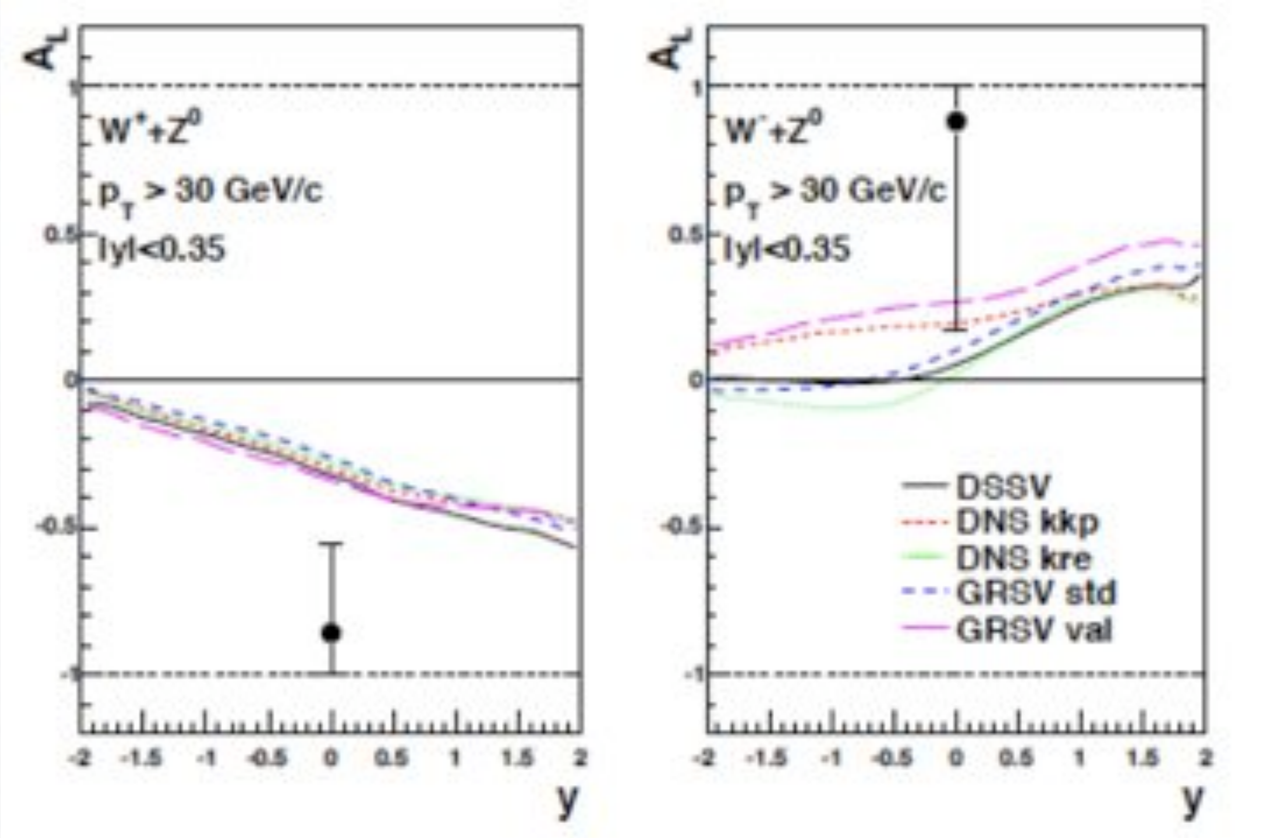
quark helicities from W production in pp

- Rusty Towell -



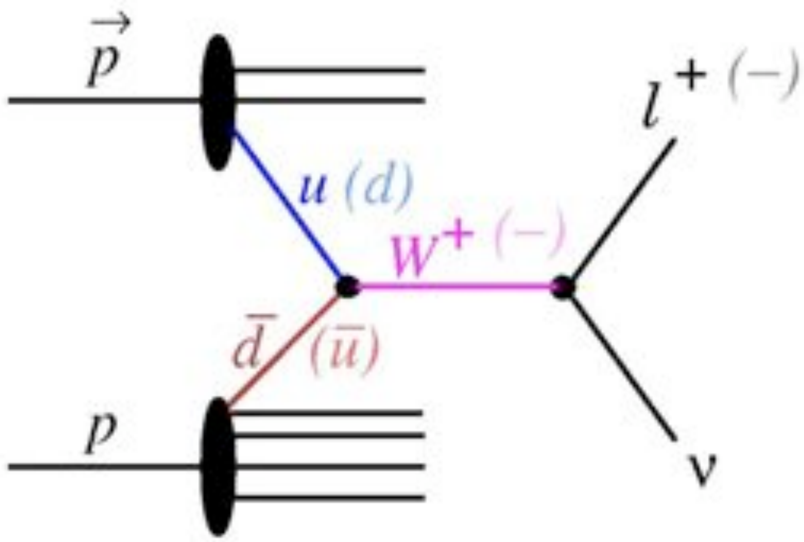
- W probes sea and valence quark spin
- W couple only left-handed quarks with right-handed anti-quarks
- W program is underway

$$A_L^{W^+} = -\frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$



probing the sea through W production

- Joe Seele -



$u + \bar{d} \to W^+ \to e^+ + \nu$

$\bar{u} + d \to W^- \to e^- + \bar{\nu}$

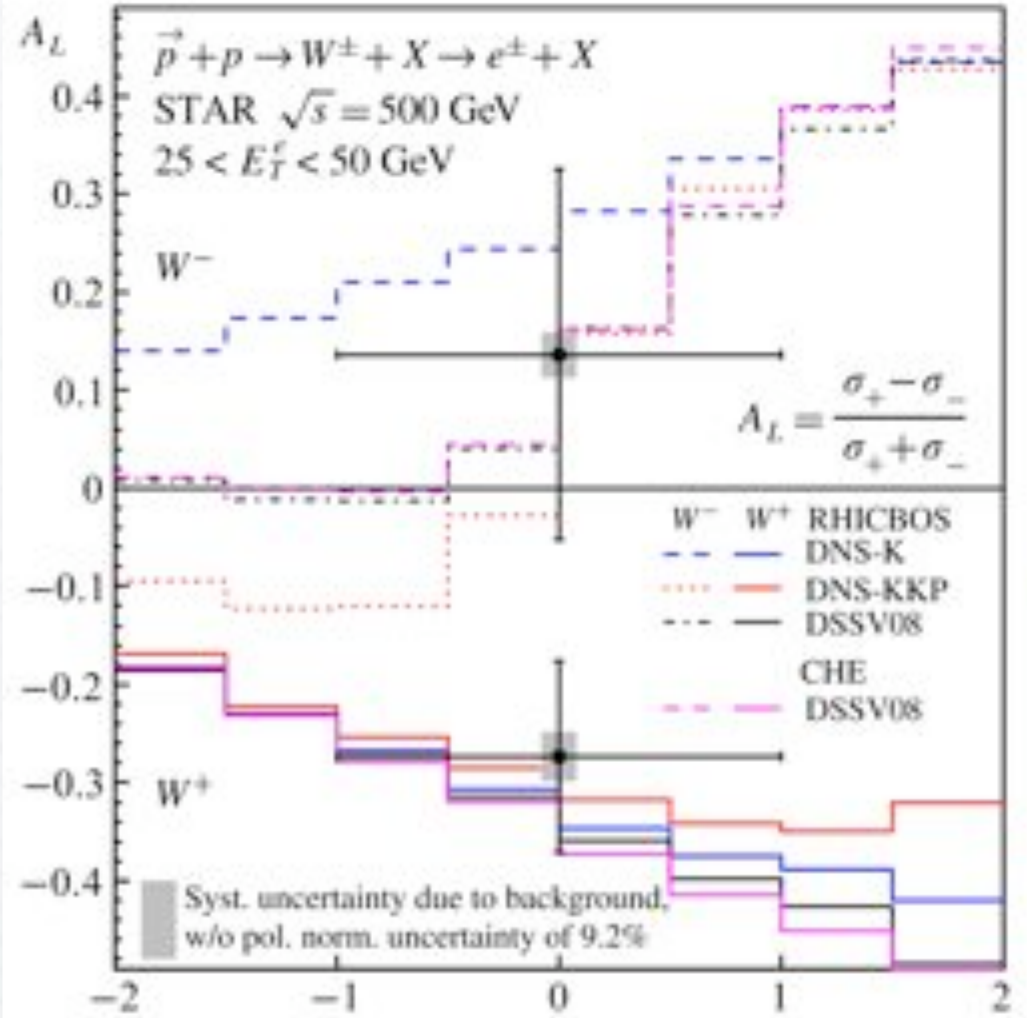
- Detect Ws through e^+ and e^- decay channels
- V-A coupling leads to perfect spin separation
- Neutrino helicity gives preferred direction in decay

Measure parity violating single helicity asymmetry A_L

(Helicity flip in one beam while averaging over the other)

$A_L^{W^-} \propto -\Delta d(x_1)\bar{u}(x_2) + \Delta\bar{u}(x_1)d(x_2)$ $\quad A_L^{W^+} \propto -\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)$

J. Seele (MIT) for the STAR Collaboration - DIS 2011



STAR Run 9 Result

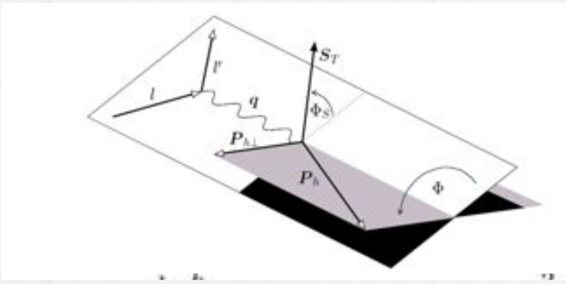
$A_L(W^+) = -0.27 \pm 0.10(stat) \pm 0.02(syst)$

$A_L(W^-) = 0.14 \pm 0.19(stat) \pm 0.02(syst)$

arXiv:1009.0326

- with expected 300 pb^{-1} program STAR will provide strong constrains on the polarized sea pdf

TMDs and the 3D image of the nucleon: $(x, \vec{k}_T)$



$$\frac{d\sigma^h}{dx\,dy\,d\phi_S\,dz\,d\phi\,d\mathbf{P}_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$

$$\Big\{ \Big[F_{\mathrm{UU,T}} + \epsilon F_{\mathrm{UU,L}} + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi) F_{\mathrm{UU}}^{\cos(\phi)} + \epsilon\cos(2\phi) F_{\mathrm{UU}}^{\cos(2\phi)}\Big]$$

$$+ \lambda_l \Big[\sqrt{2\epsilon(1-\epsilon)}\sin(\phi) F_{\mathrm{LU}}^{\sin(\phi)}\Big]$$

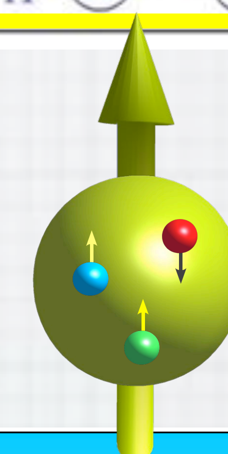
$$+ S_L \Big[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi) F_{\mathrm{UL}}^{\sin(\phi)} + \epsilon\sin(2\phi) F_{\mathrm{UL}}^{\sin(2\phi)}\Big]$$

$$+ S_L\lambda_l \Big[\sqrt{1-\epsilon^2} F_{\mathrm{LL}} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi) F_{\mathrm{LL}}^{\cos(\phi)}\Big]$$

$$+ S_T \Big[\sin(\phi-\phi_S)\left(F_{\mathrm{UT,T}}^{\sin(\phi-\phi_S)} + \epsilon F_{\mathrm{UT,L}}^{\sin(\phi-\phi_S)}\right) + \epsilon\sin(\phi+\phi_S) F_{\mathrm{UT}}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S) F_{\mathrm{UT}}^{\sin(3\phi-\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S) F_{\mathrm{UT}}^{\sin(\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi-\phi_S) F_{\mathrm{UT}}^{\sin(2\phi-\phi_S)}\Big]$$

$$+ S_T\lambda_l \Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S) F_{\mathrm{LT}}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S) F_{\mathrm{LT}}^{\cos(\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S) F_{\mathrm{LT}}^{\cos(2\phi-\phi_S)}\Big]\Big\}$$

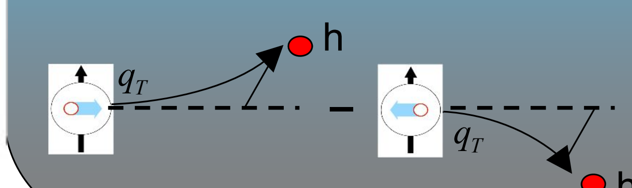
nucleon \ quark	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	$g_{1T}^\perp$	h_1 $h_{1T}^\perp$



Sivers effect

$\propto f_{1T}^\perp(x, p_T^2) \otimes D_1(z, k_T^2)$

- correlation between parton transverse momentum and nucleon transverse polarization
- requires orbital angular momentum



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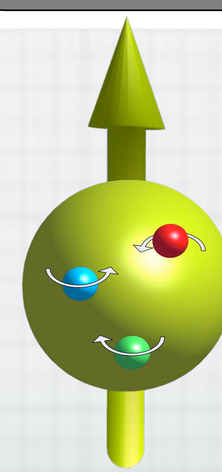
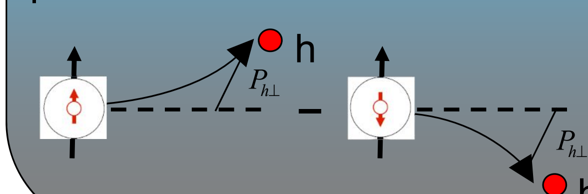


Collins effect

- $\propto h_1(x, p_T^2) \otimes H_1^\perp(z, k_T^2)$
- correlation between parton transverse polarization in a transversely polarized nucleon and transverse momentum of the produced hadron



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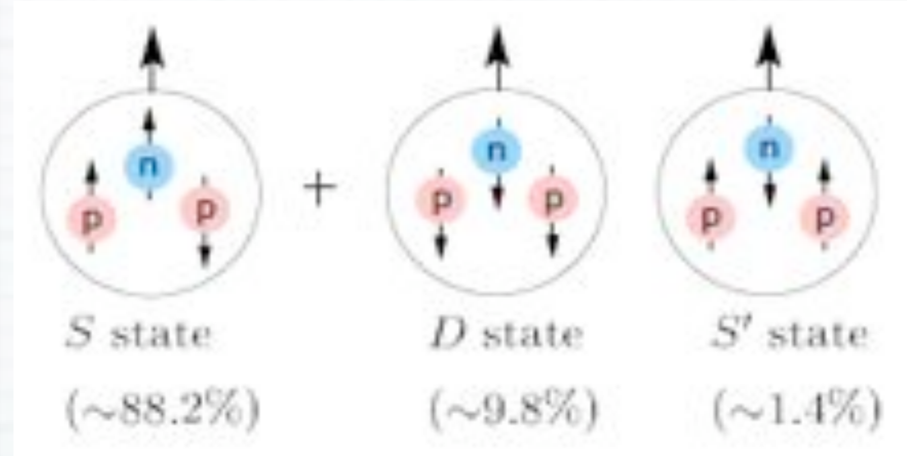
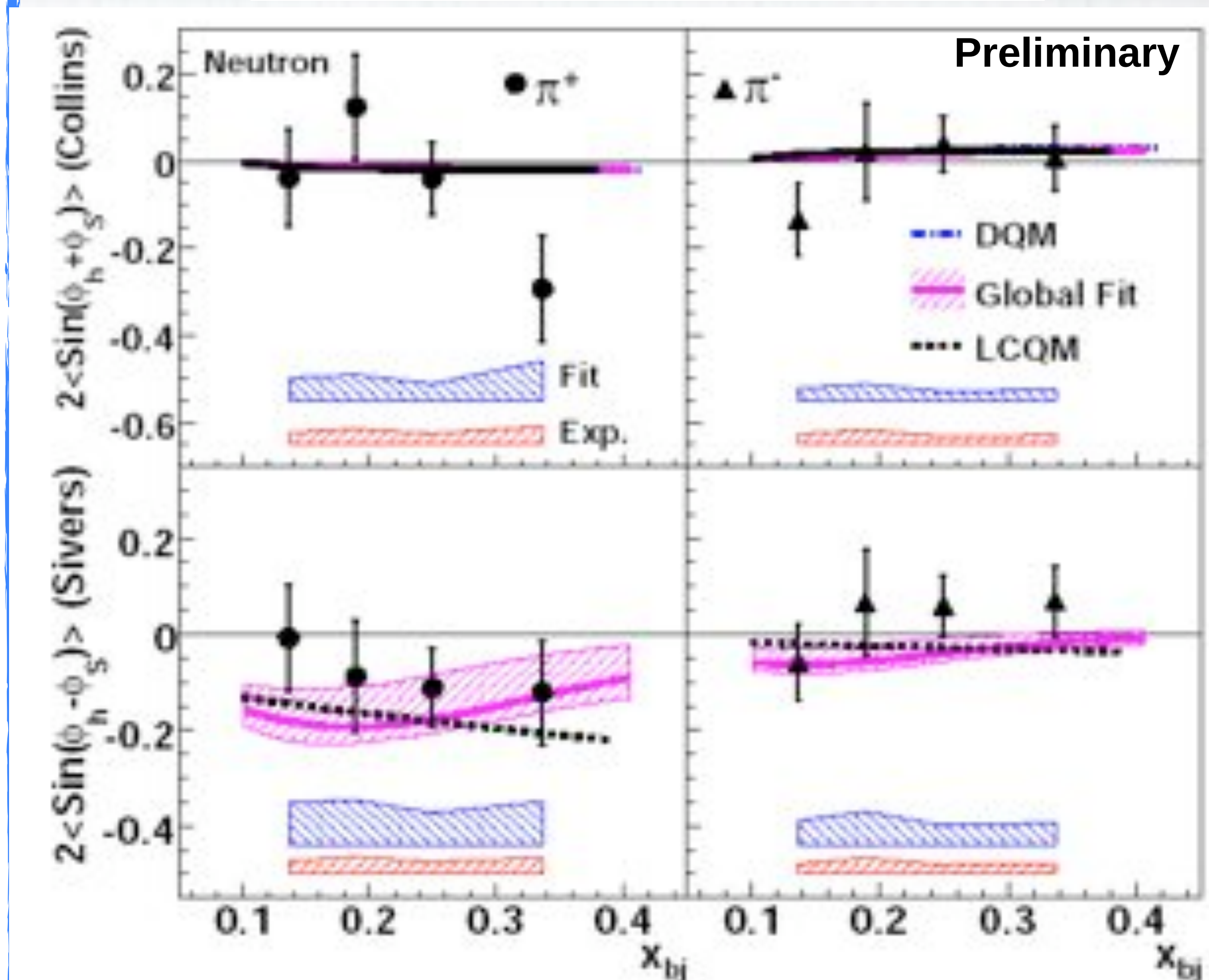
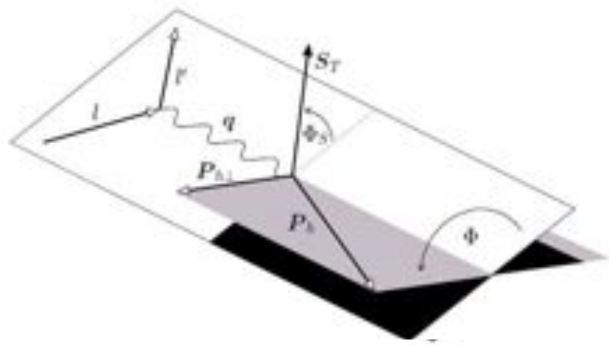
Sivers and Collins effects

* previous measurements for pions and kaons from hermes COMPASS
  * Collins and Sivers effects observed
* new results from Hall A
* consistent with zero collins amplitude
  * kinematical suppressed at JLAB kinematics
* hint for non-zero Sivers effect for π^+
  * along with proton and deuteron data will help to constrain the d-quark Sivers DF





Cahn and Boer-Mulders effects



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$$+ S_T \Big[\sin(\phi-\phi_S)\left(F_{\mathrm{UT,T}}^{\sin(\phi-\phi_S)} + \epsilon F_{\mathrm{UT,L}}^{\sin(\phi-\phi_S)}\right) + \epsilon\sin(\phi+\phi_S) F_{\mathrm{UT}}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S) F_{\mathrm{UT}}^{\sin(3\phi-\phi_S)}$$
$$+ \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S) F_{\mathrm{UT}}^{\sin(\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi-\phi_S) F_{\mathrm{UT}}^{\sin(2\phi-\phi_S)}\Big]$$

$$+ S_T\,\lambda_l \Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S) F_{\mathrm{LT}}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S) F_{\mathrm{LT}}^{\cos(\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S) F_{\mathrm{LT}}^{\cos(2\phi-\phi_S)}\Big]\Big\}$$

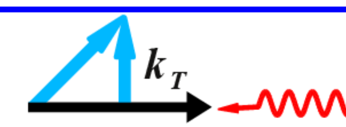
nucleon \ quark	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

$$\sigma_{UU}^{\cos(\phi)} \propto \left[f_1 \otimes D_1 + h_1^\perp \otimes H_1^\perp + \ldots\right]/Q$$

$$\sigma_{UU}^{\cos(2\phi)} \propto h_1^\perp \otimes H_1^\perp + \left[f_1 \otimes D_1 + \ldots\right]/Q^2$$

- Cahn effect:

Cahn Effect



kinematical effect due to transv. momentum of partons in the nucleon

- Boer-Mulders effect: Boer-Mulders TMD

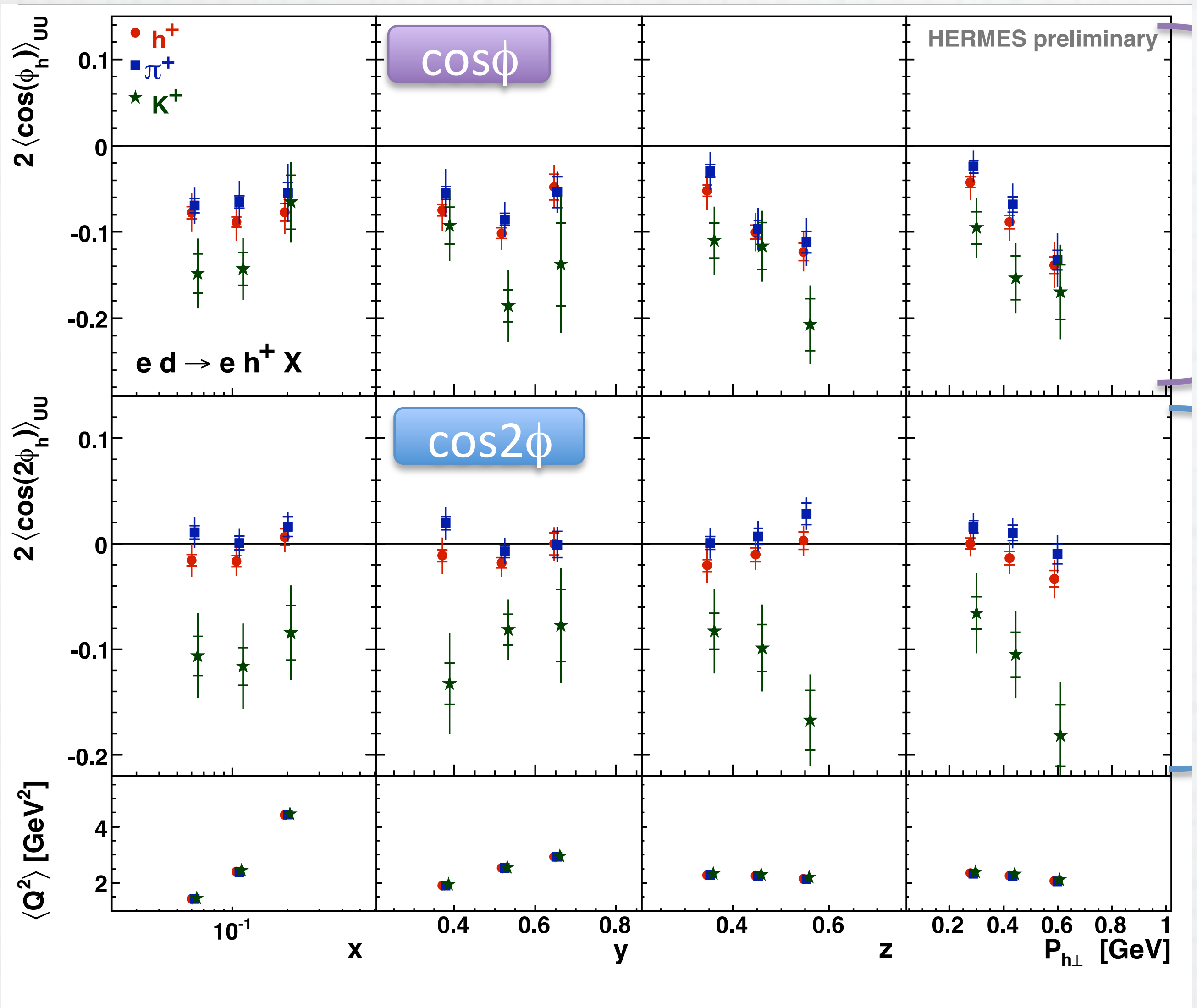
Boer-Mulders $h_1^\perp$:

correlation of parton transv. momentum and transv. polarization in an unpolarized nucleon

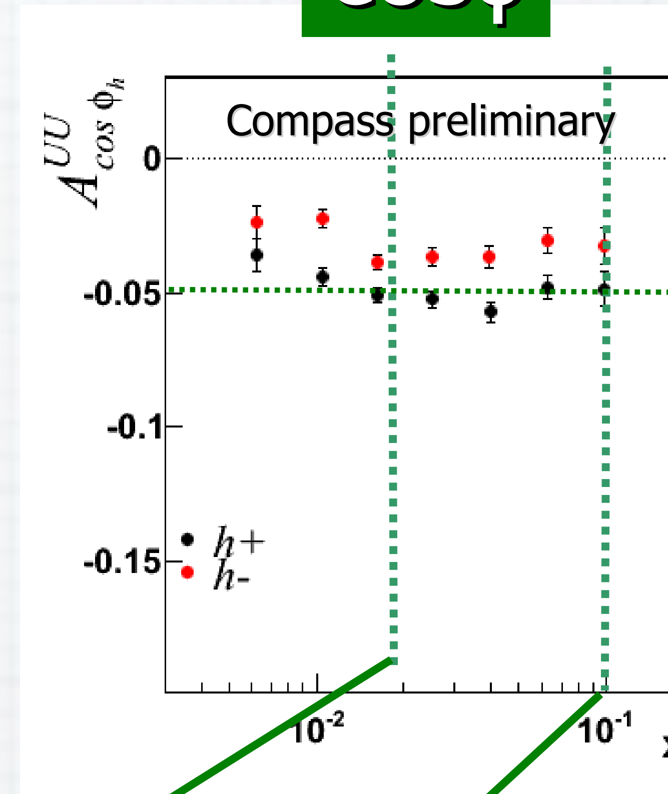
Cahn and Boer-Mulders effects

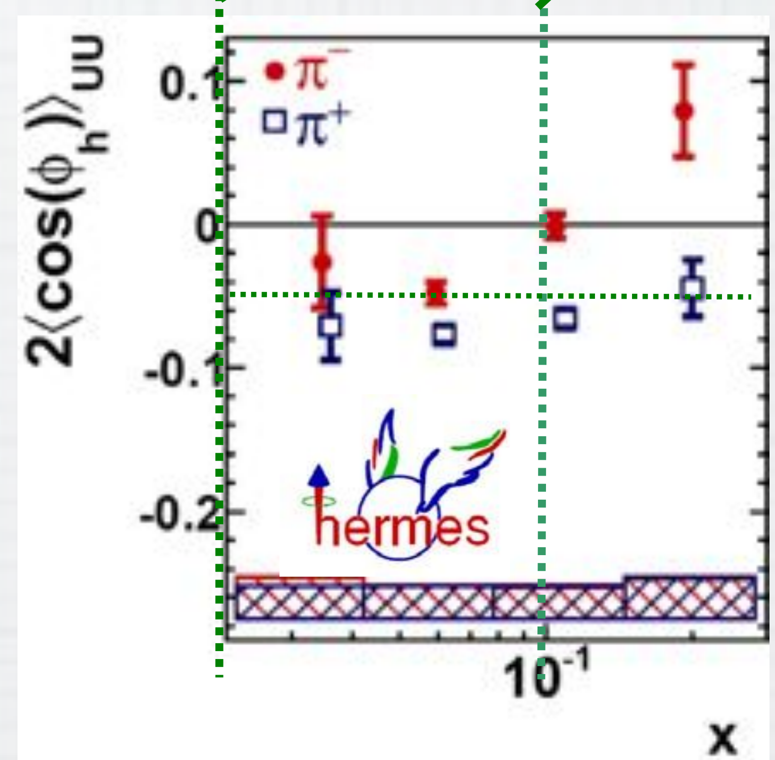
- Marco Contalbrigo -

- Christian Schill -



cosϕ





$$\sigma_{UU}^{\cos(\phi)} \propto \left[f_1 \otimes D_1 + h_1^\perp \otimes H_1^\perp + \ldots \right] / Q$$

$$\sigma_{UU}^{\cos(2\phi)} \propto h_1^\perp \otimes H_1^\perp + \left[f_1 \otimes D_1 + \ldots \right] / Q^2$$

- role of sea quarks
- strange Collins FF
- higher-twist effects

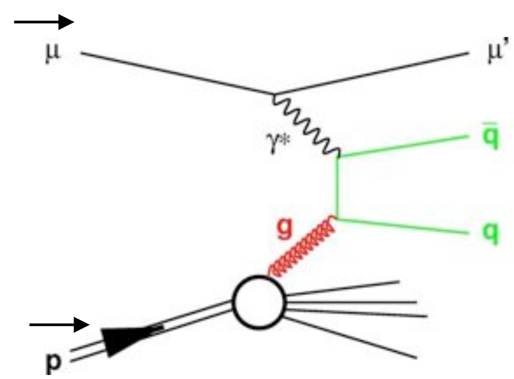
gluon polarization

$$S_N = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

- Fabienne. Kunne -

1. Lepton Nucleon ($\vec{\text{Lepton}}$ $\vec{\text{Nucleon}}$)

Photon Gluon Fusion



$\Delta G/G(x)$

SMC, HERMES, COMPASS

2. Proton Proton collisions ($\vec{\text{Proton}}$ $\vec{\text{Proton}}$)

Gluon-Quark + Gluon-Gluon +…

$$\frac{\Delta G}{G} \times \frac{\Delta q}{q} + \frac{\Delta G}{G} \times \frac{\Delta G}{G} + \ldots$$

$A_{LL}(p_T)$

RHIC : PHENIX & STAR

- open charm production
  - $\gamma^* g \to c\bar{c}$ ⇒ reconstruct D^0 mesons
- high p_T hadron production
  - $\gamma^* g \to q\bar{q}$ ⇒ reconstruct 2 jets or h^+h^-

More abundant channels

$p\,p \to \pi^0 X$ **PHENIX**

$p\,p \to$ jet X **STAR**

3 processes contribute:
- $\Delta G(x_1) . \Delta G(x_2)$
- $\Delta G(x_1) . \Delta q(x_2)$
- $\Delta q(x_1) . \Delta q(x_2)$

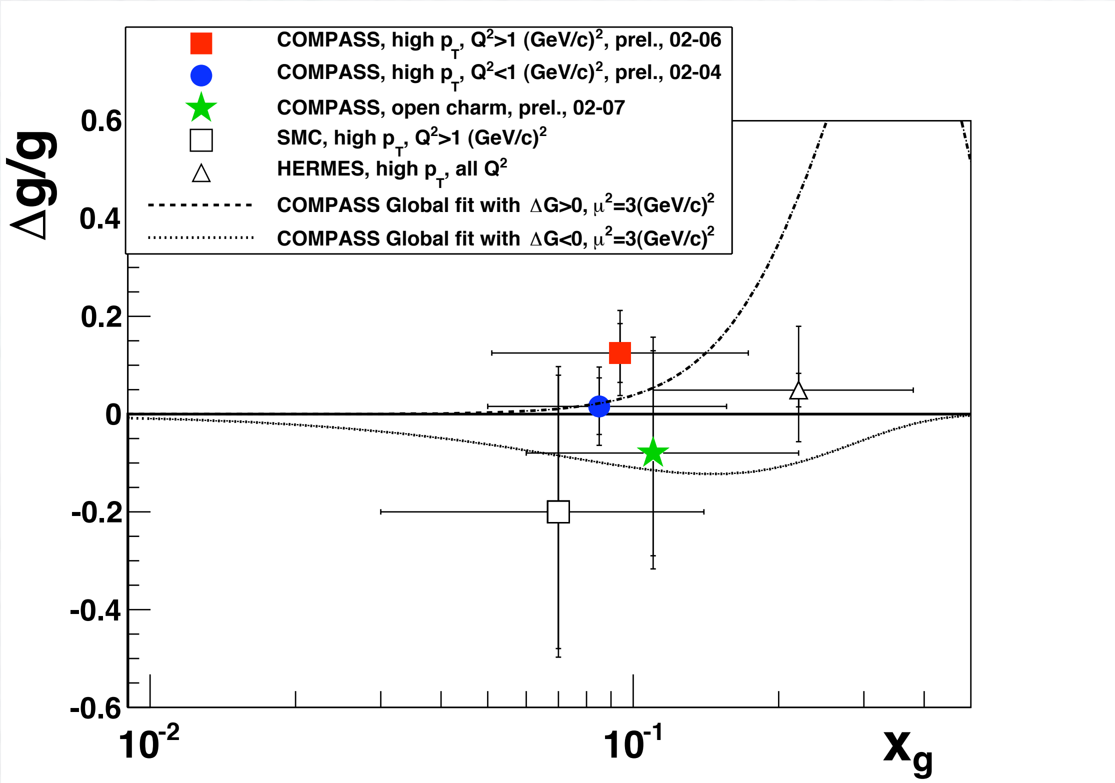
Other channels

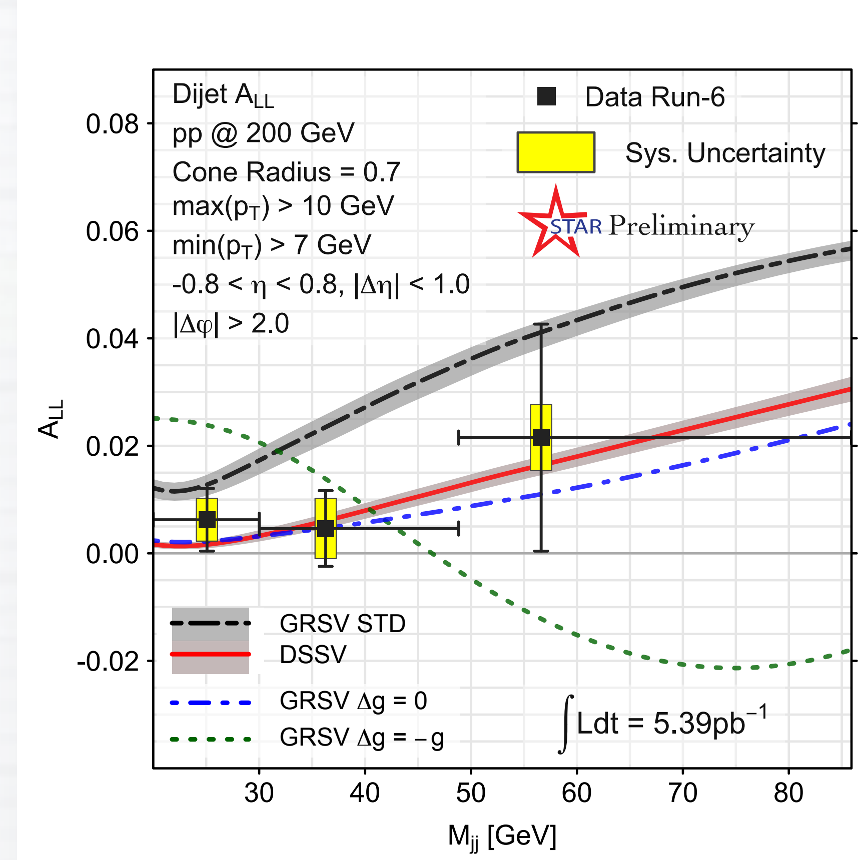
$p\,p \to$ jet jet   proj. STAR 500 GeV, low x

gluon polarization

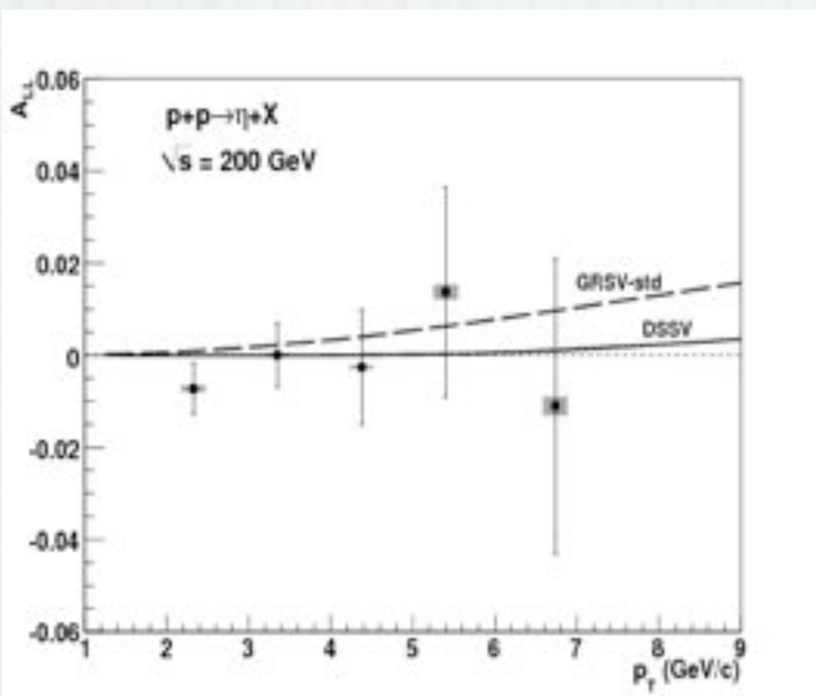
- Claude Marchand - - Krzysztof Kurek -

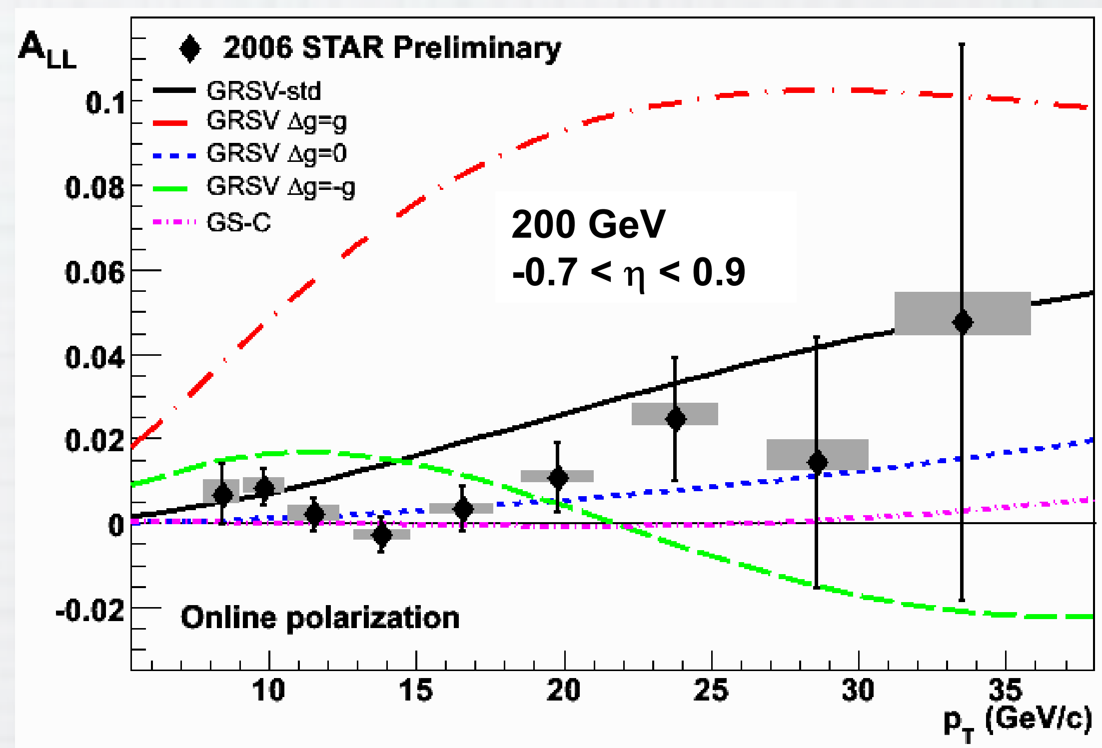
- Matt Walker-





- Amaresh Datta - - Pibero Djawotho-

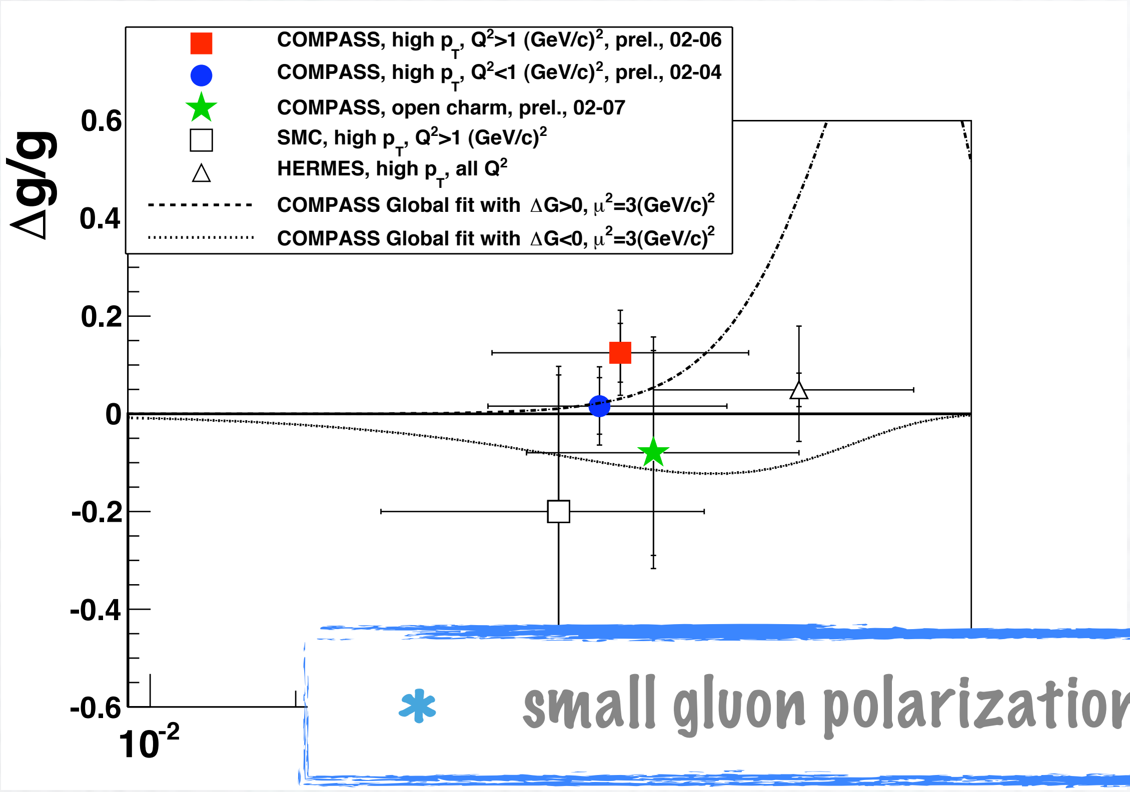


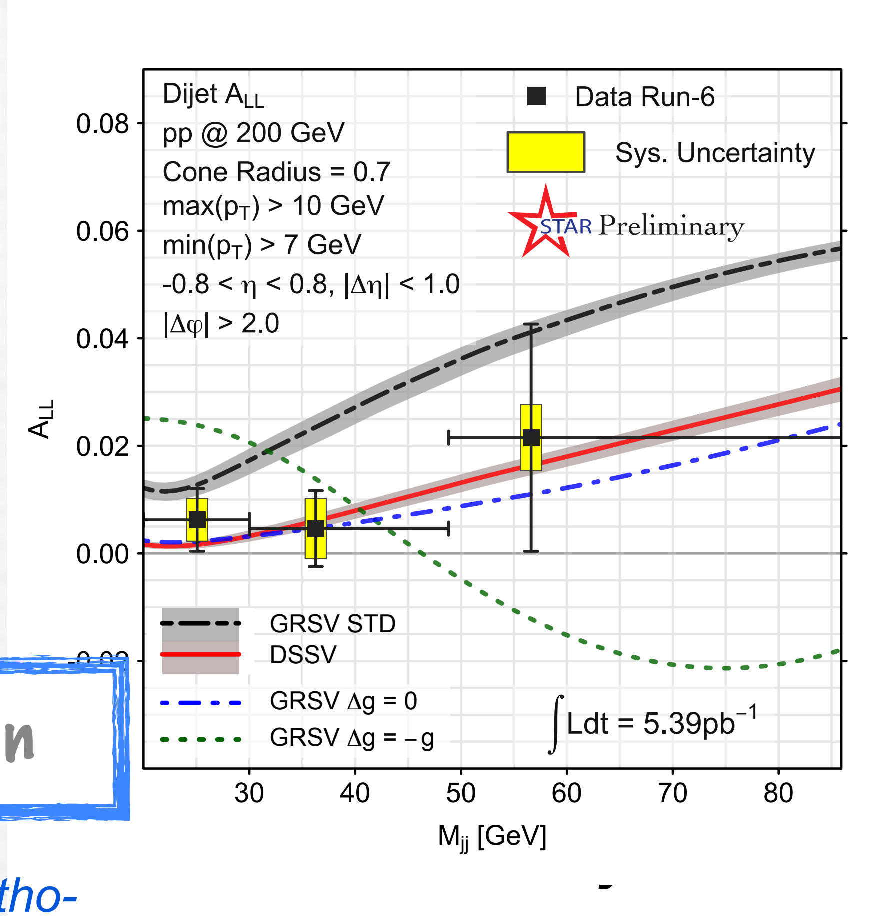


gluon polarization

- Claude Marchand - - Krzysztof Kurek -

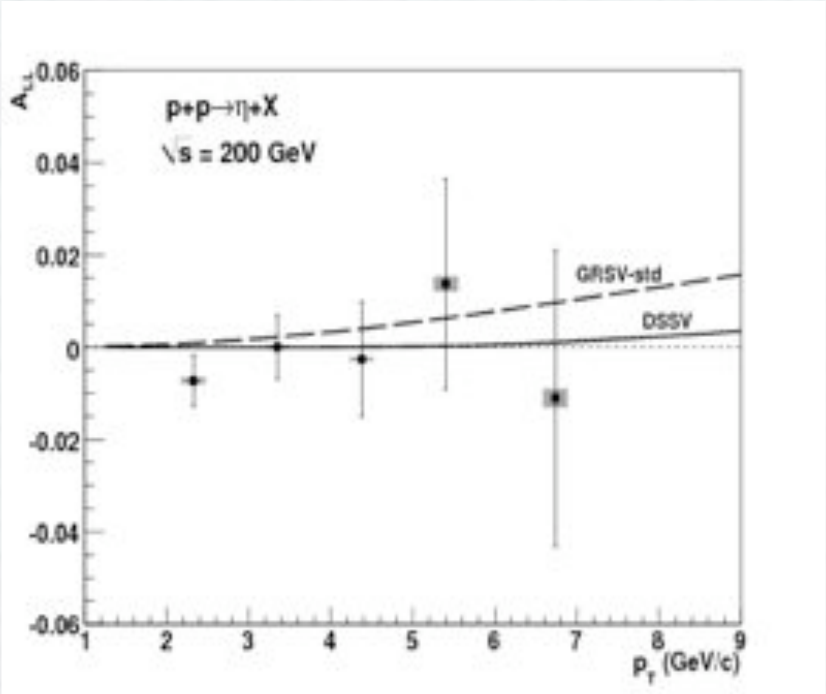
- Matt Walker-

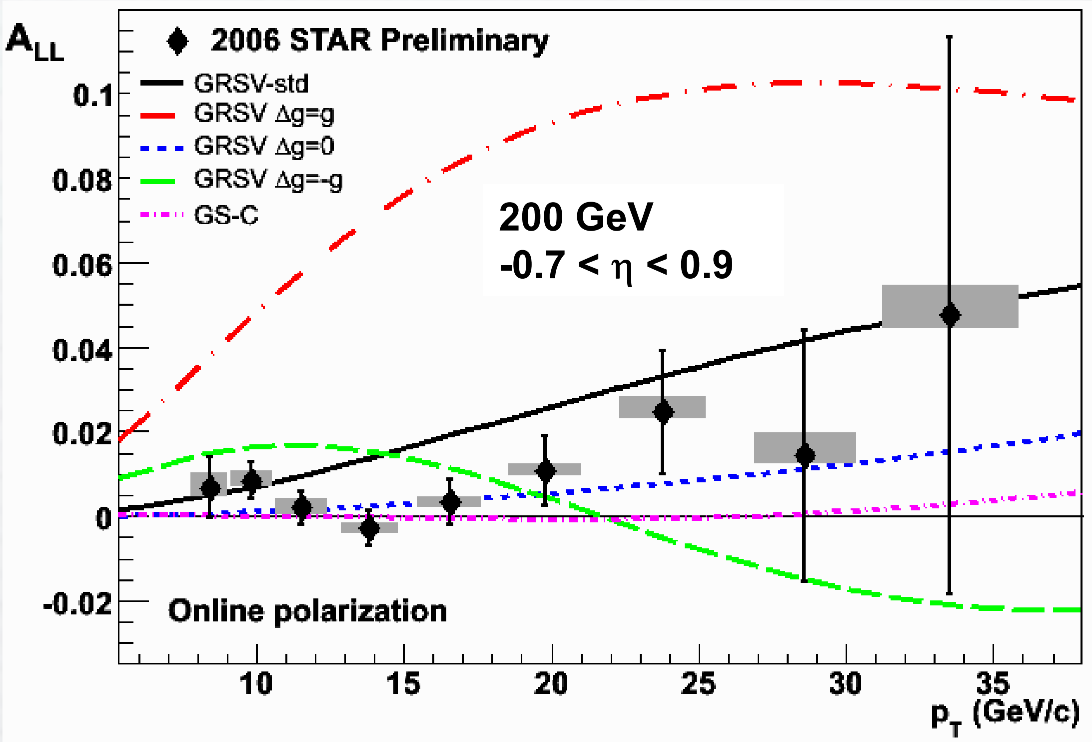




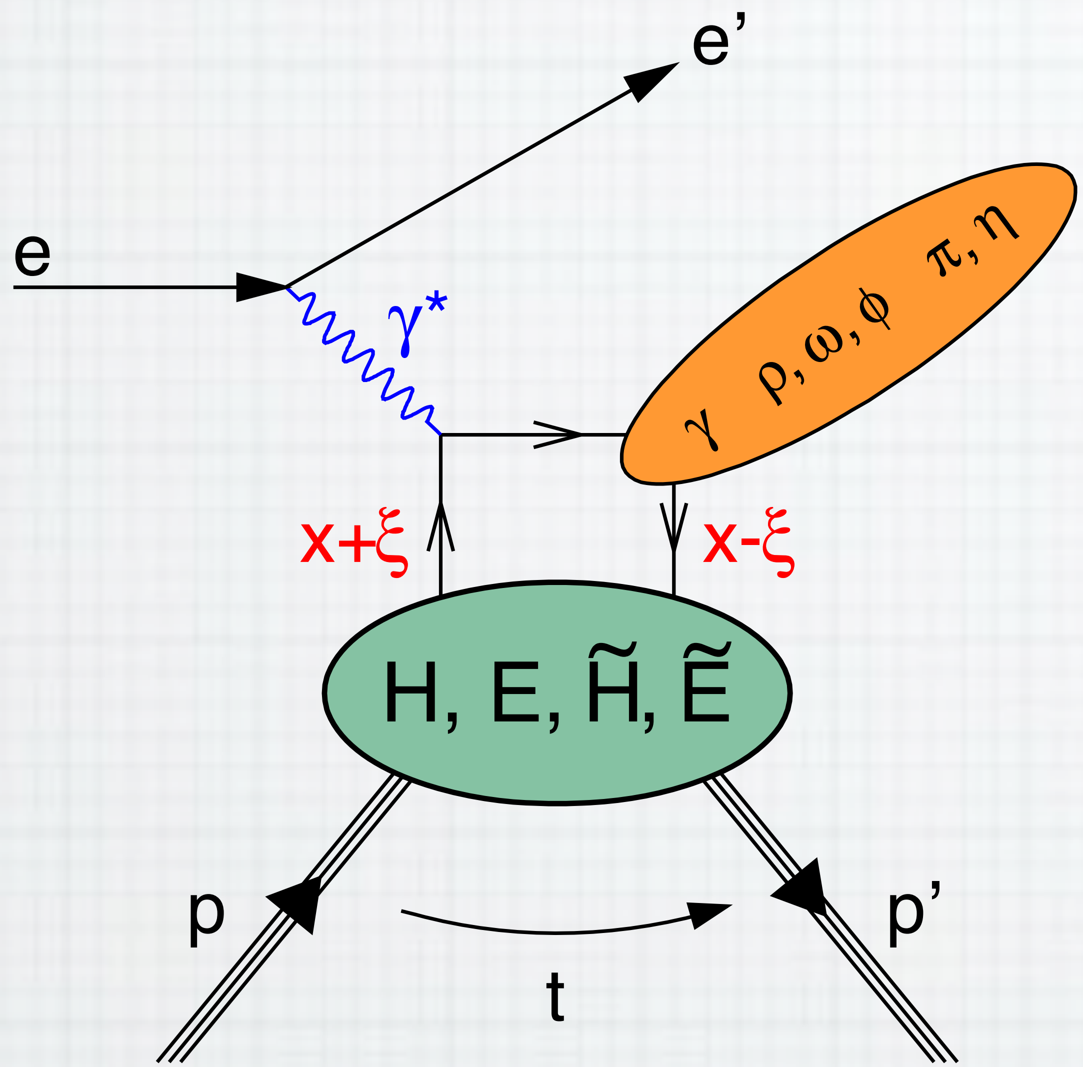
* small gluon polarization in the measured x region

- Amaresh Datta - - Pibero Djawotho-



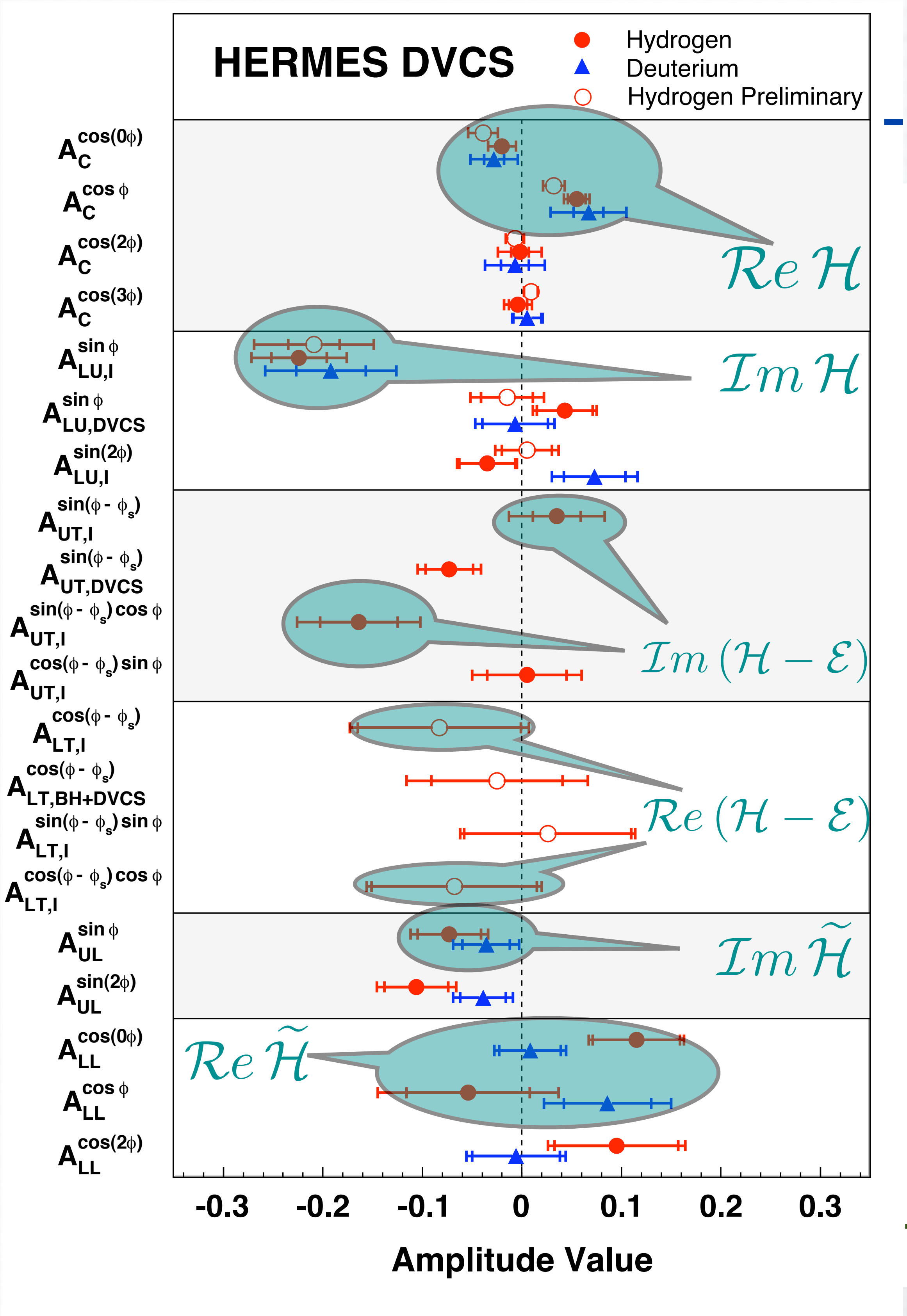


GPDs and the 3D image of the nucleon: $(x, \vec{b}_T)$



- Sensitivity of different final states to different GPDs
- For spin-1/2 target 4 chiral-even leading-twist quark GPDs: $H, E, \widetilde{H}, \widetilde{E}$
- $H, \widetilde{H}$ conserve nucleon helicity, $E, \widetilde{E}$ involve nucleon helicity flip
- DVCS (γ) → $H, E, \widetilde{H}, \widetilde{E}$
- Vector mesons (ρ, ω, ϕ) → H, E
- Pseudoscalar mesons (π, η) → $\widetilde{H}, \widetilde{E}$

deeply virtual Compton scattering



Beam-Charge Asymmetry

Beam-Spin Asymmetry

Transverse Target-Spin Asymmetry

Transverse Double-Spin Asymmetry

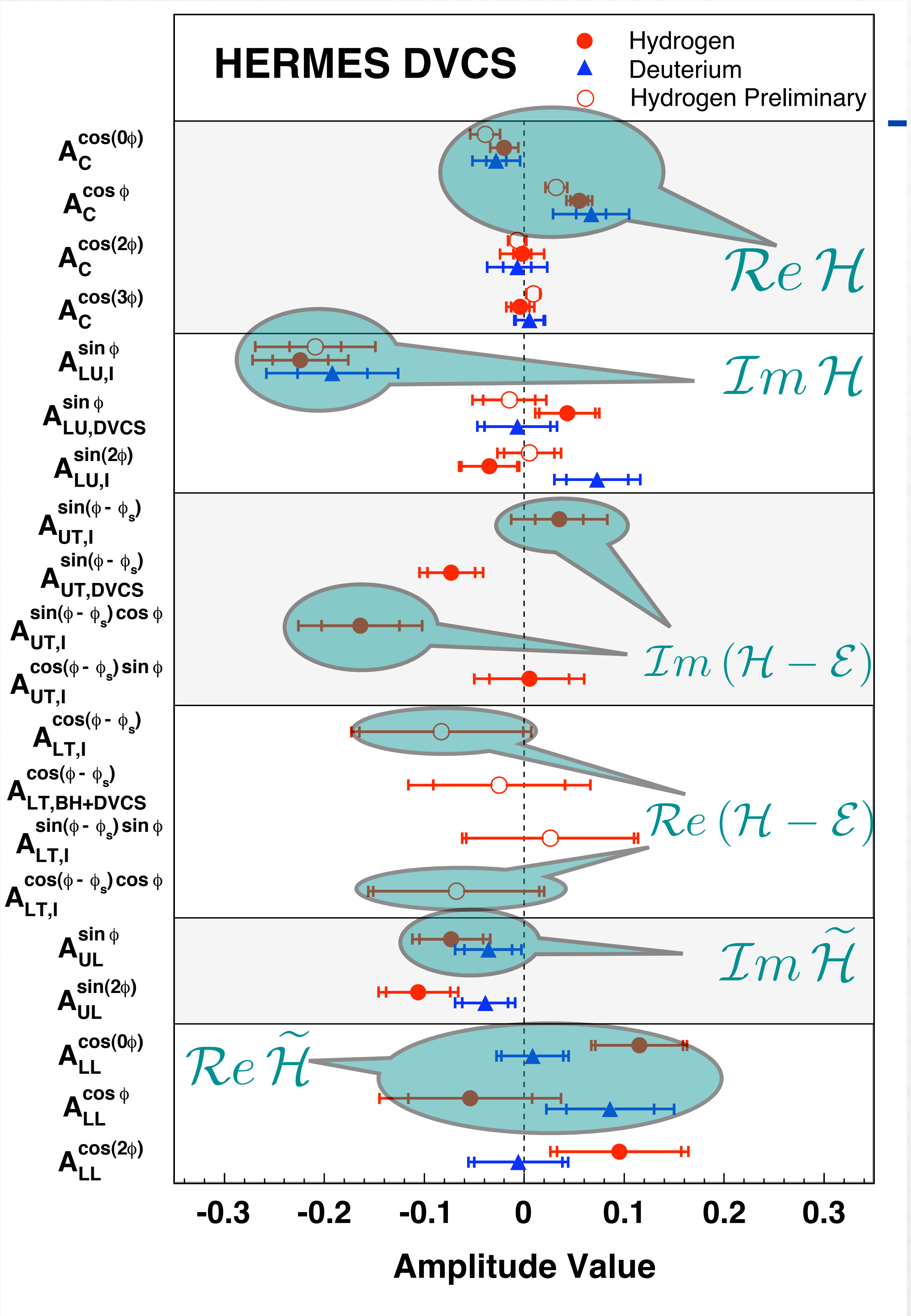
Longitudinal Target-Spin Asymmetry

Longitudinal Double-Spin Asymmetry

+ BCA and BSA on nuclear targets

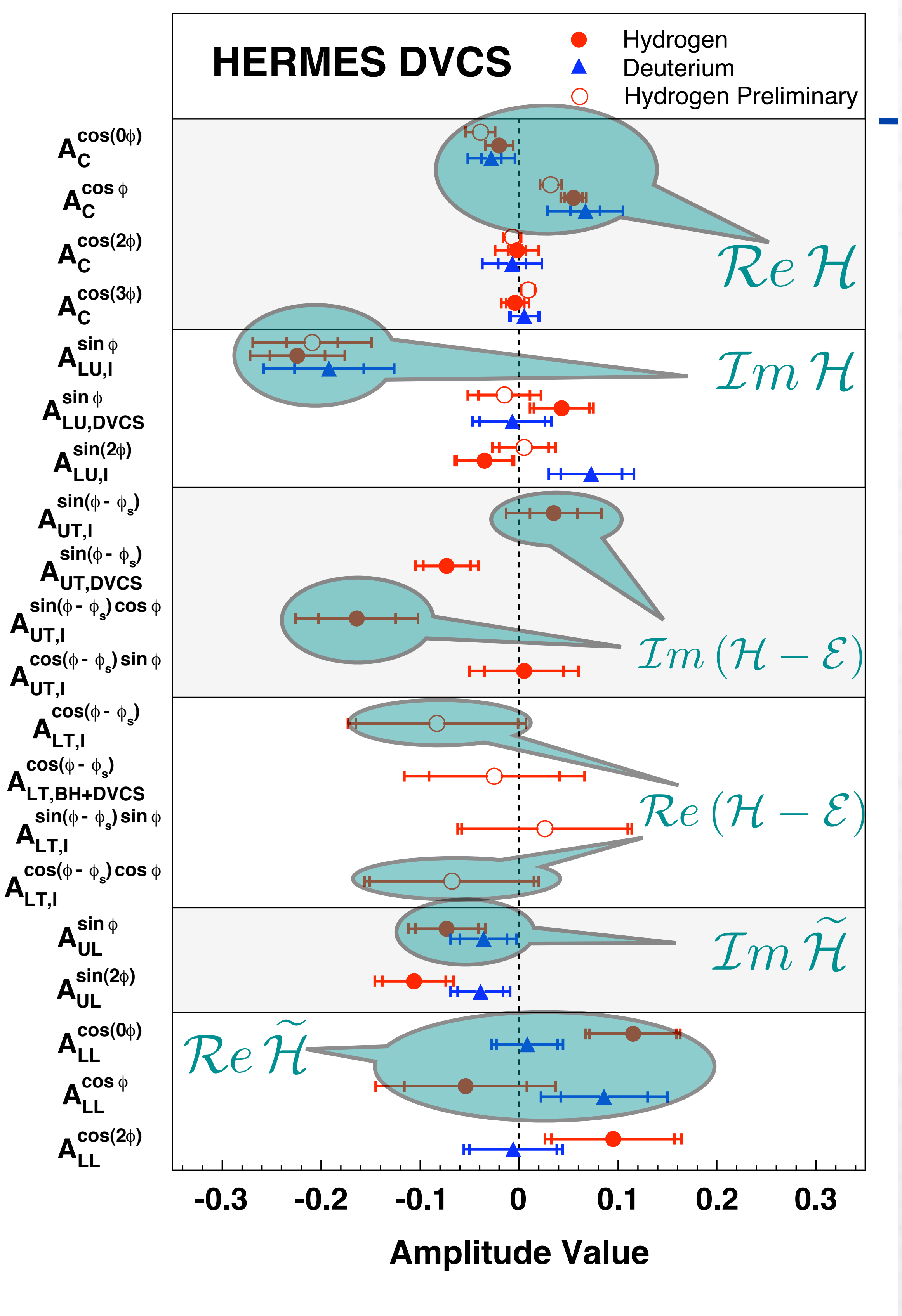
deeply virtual Compton scattering

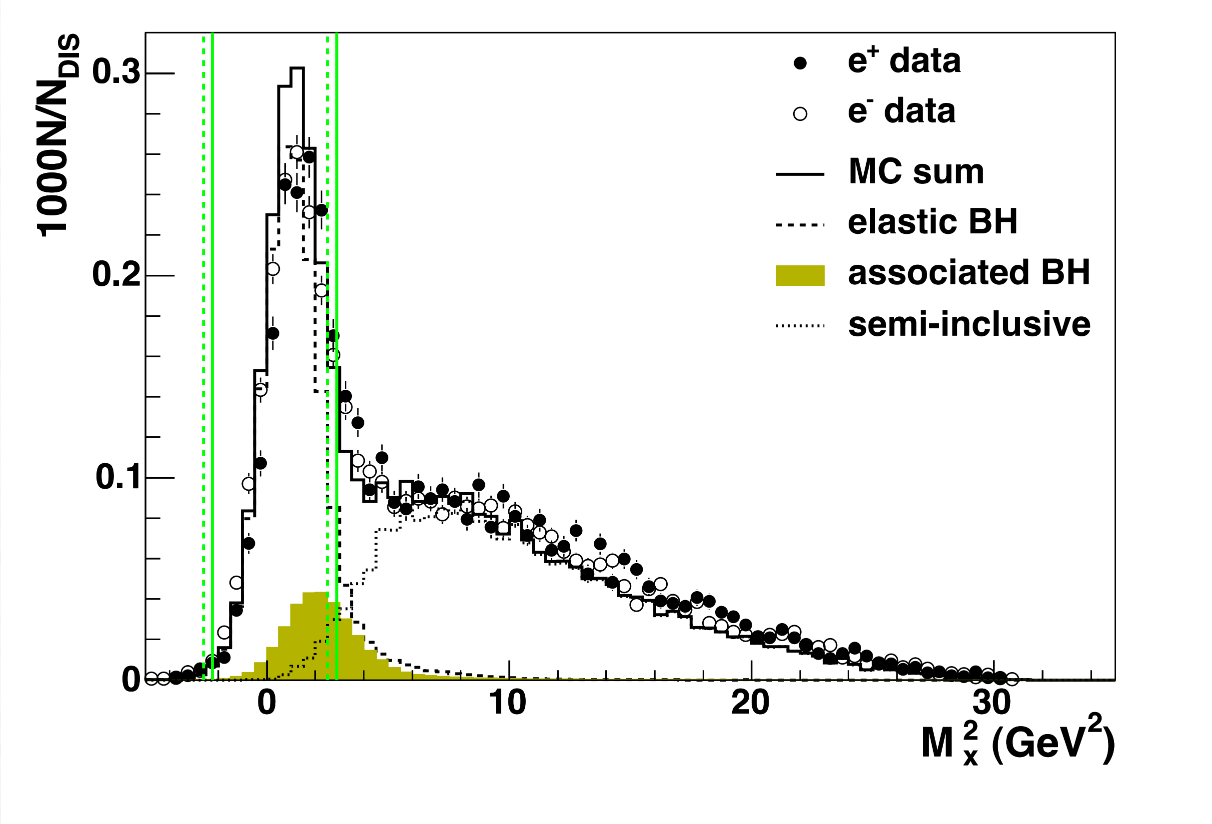
- Aram Movsisyan-



deeply virtual Compton scattering

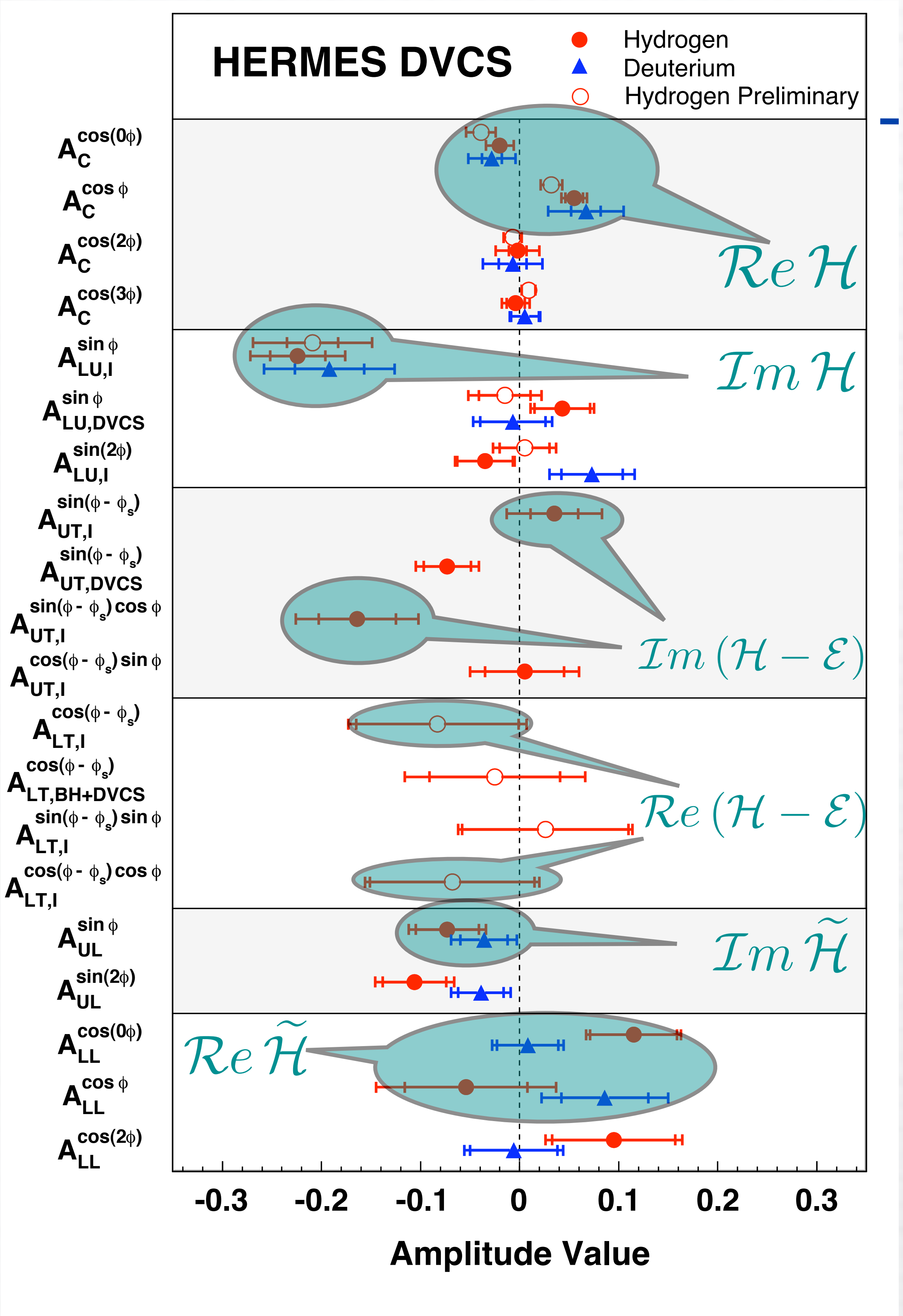
- Aram Movsisyan-

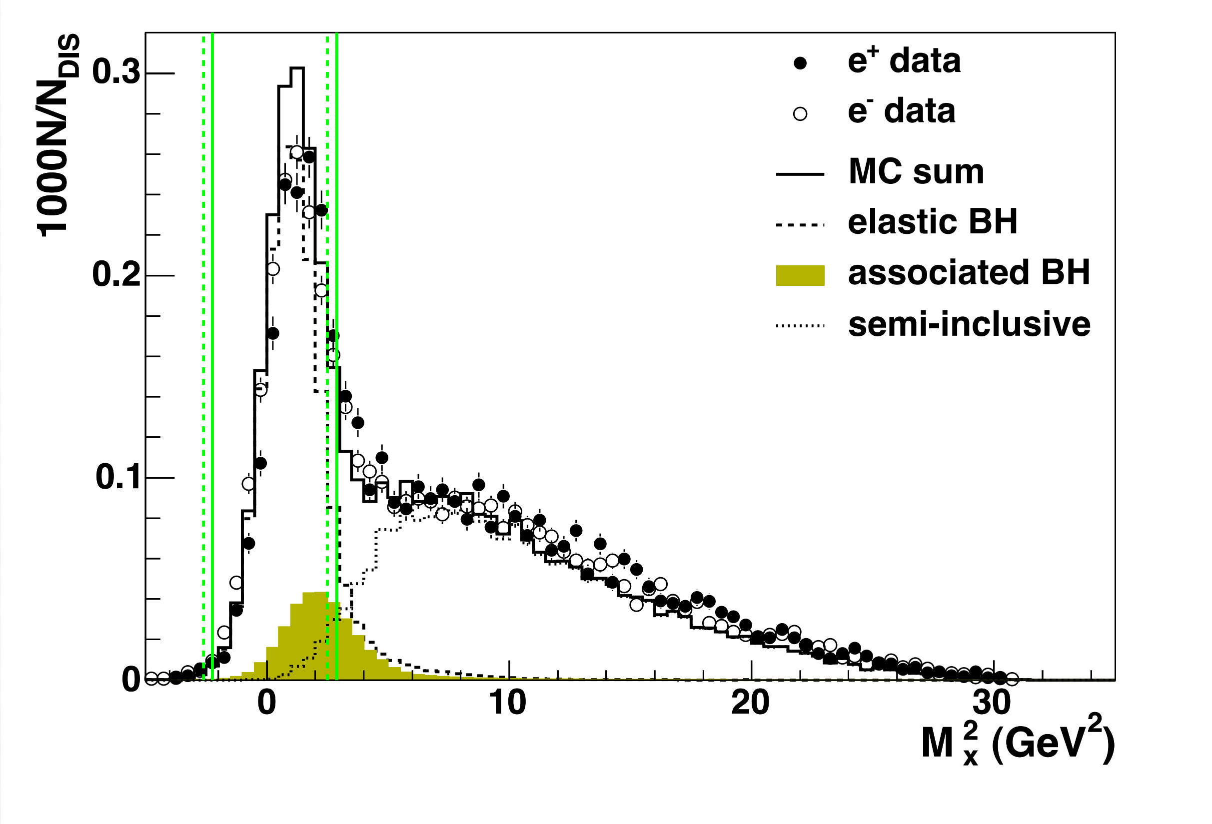




- Aram Movsisyan-

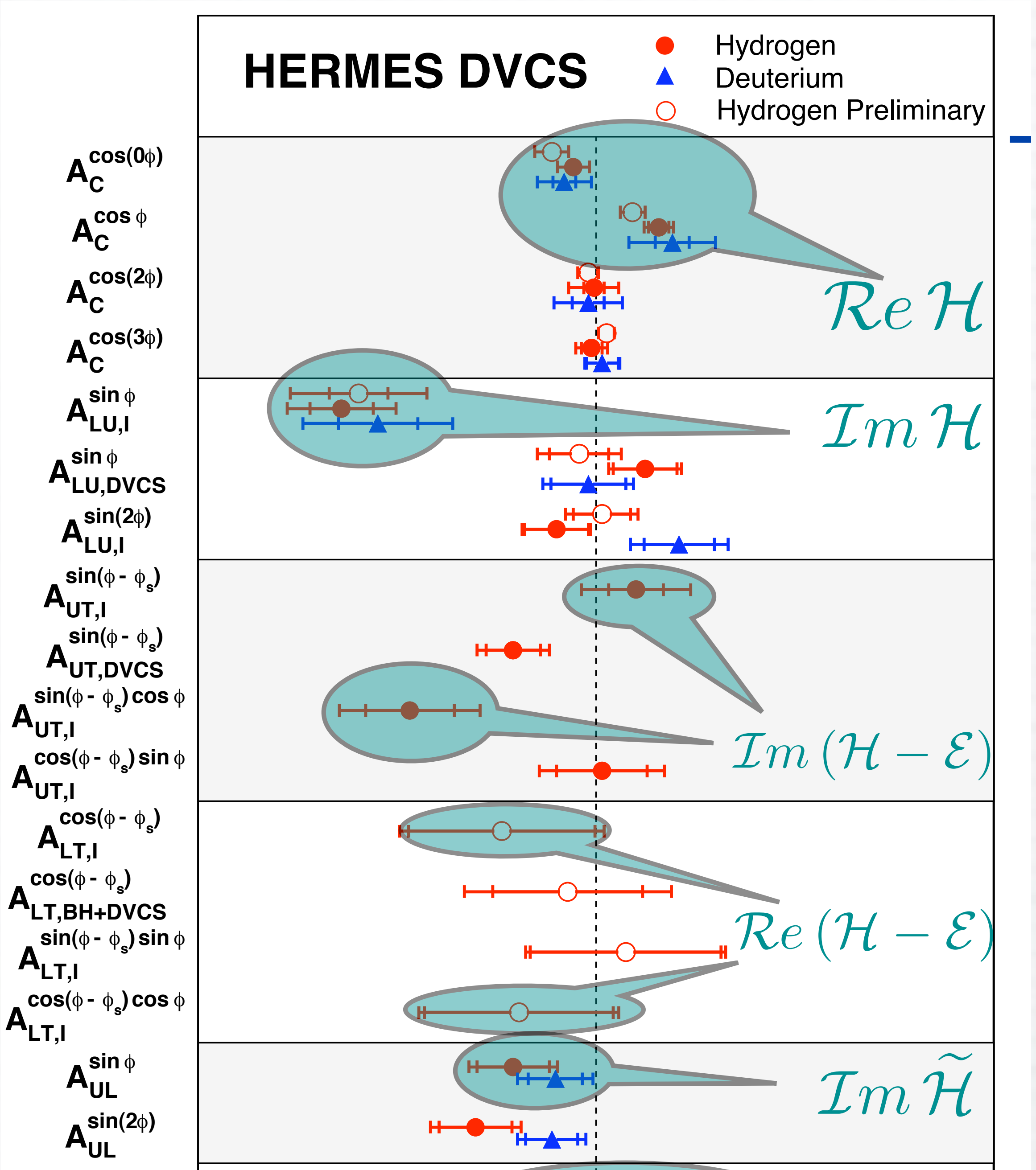
deeply virtual Compton scattering

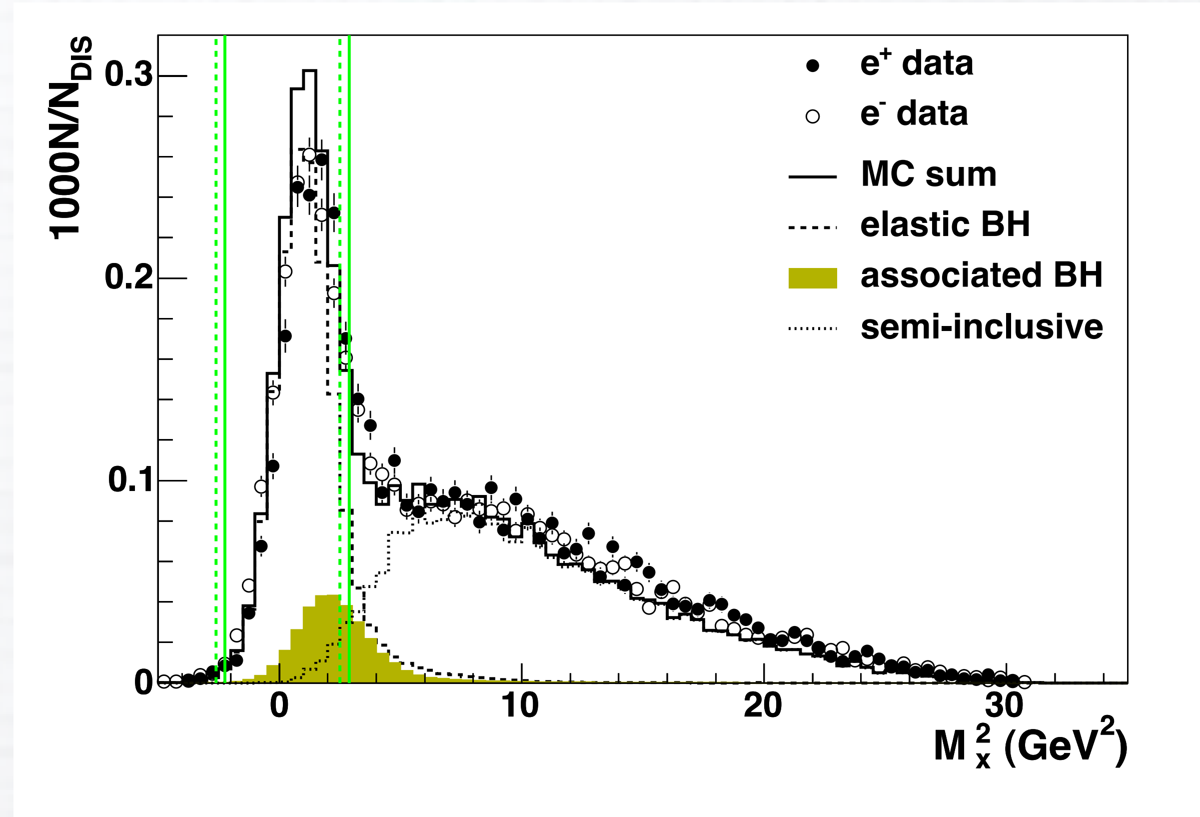




- associated cannot be resolved
- associated is part of the signal

deeply virtual Compton scattering





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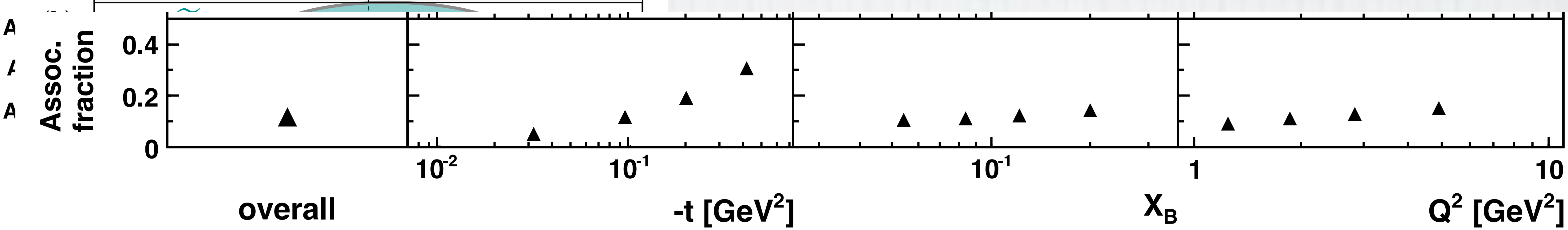
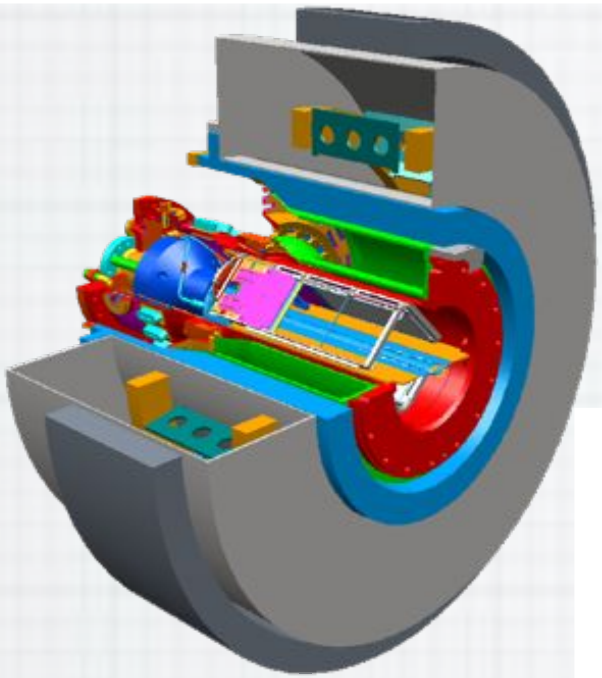
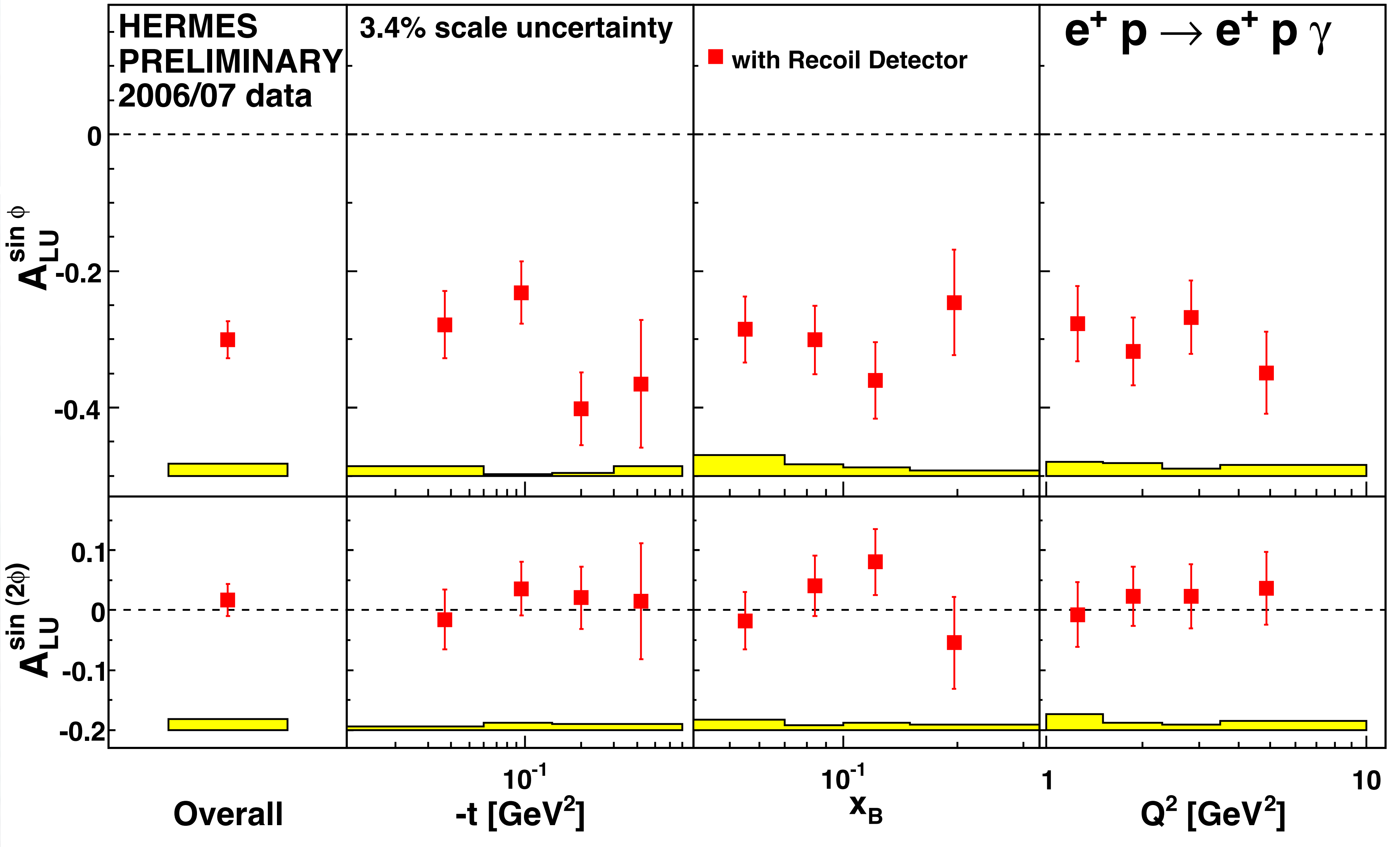


deeply virtual Compton scattering



- detection of recoil proton
- suppression of the background to < 1% level



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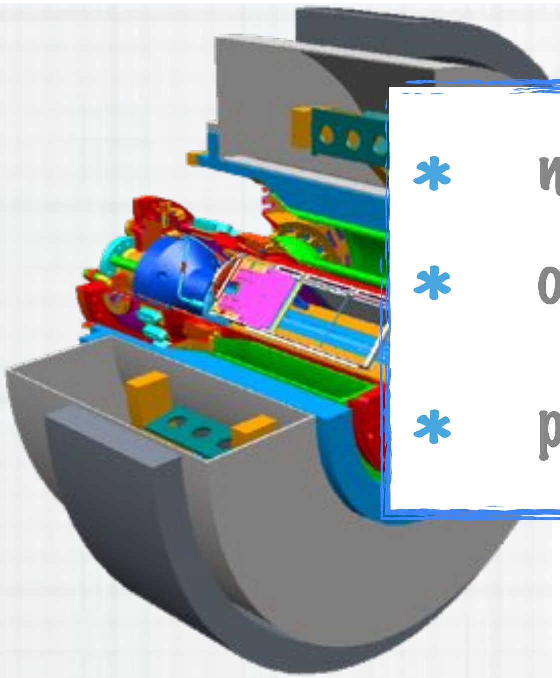
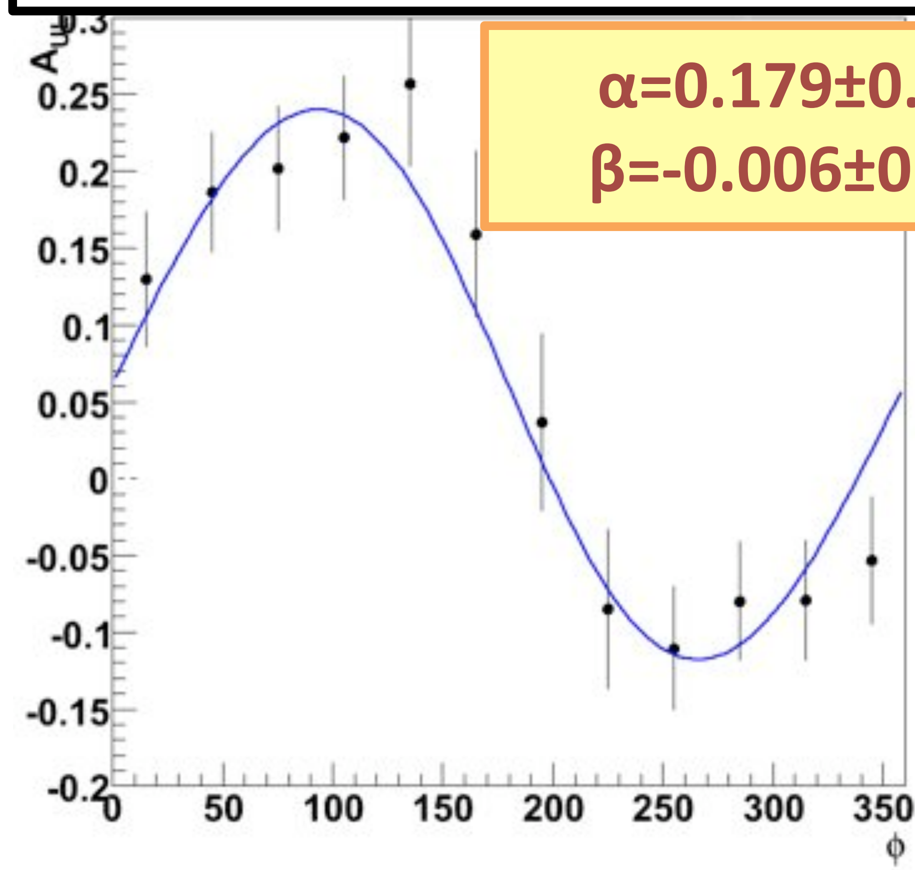
deeply virtual Compton scattering

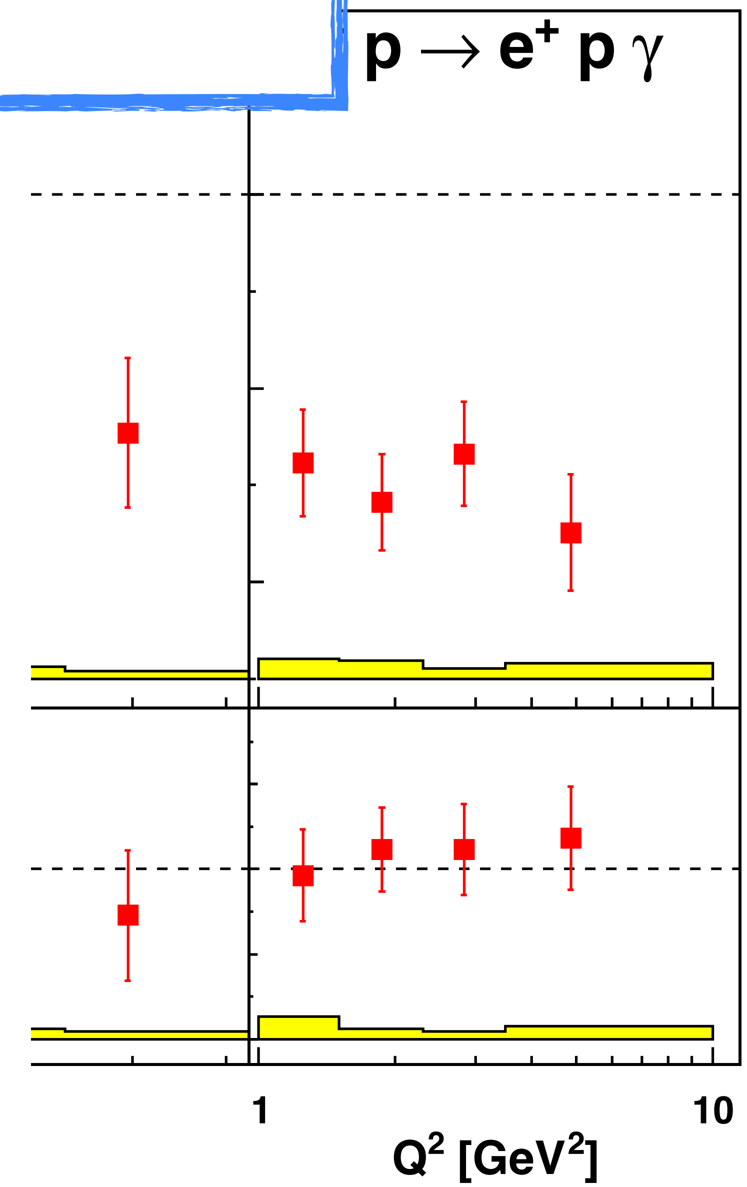


- more DVCS data from HERMES with recoil data
- ongoing analysis on DVCS on He^4 in Hall B
- preliminary results from Hall B on NH^3

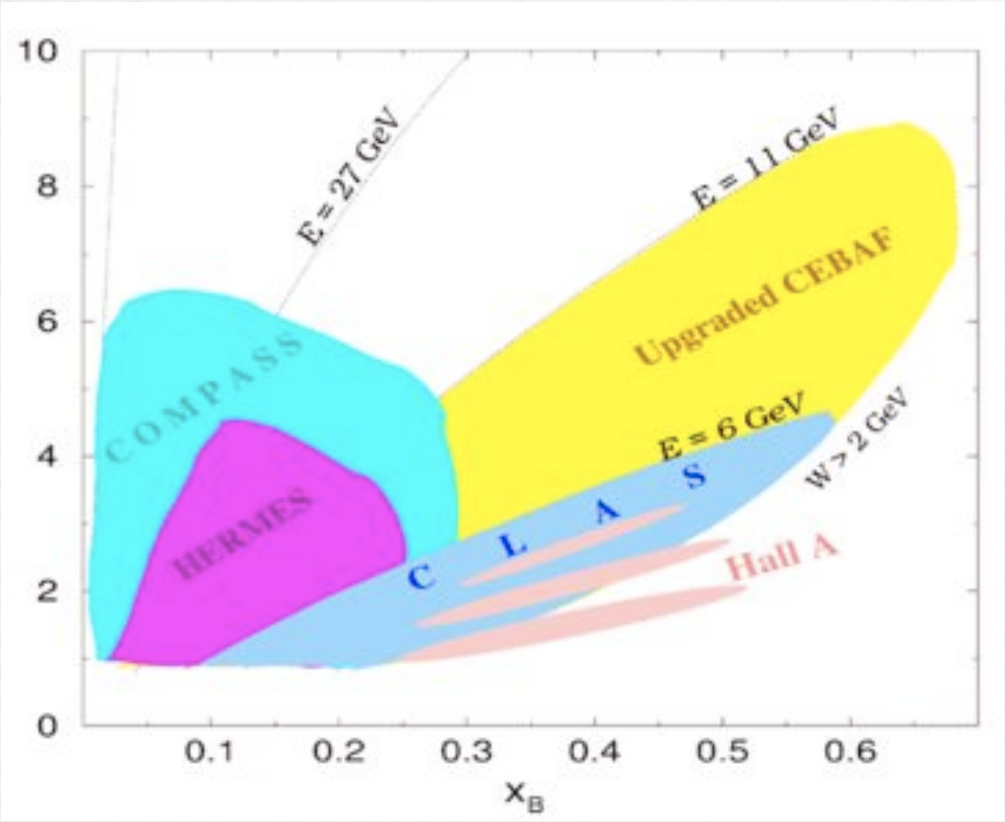
✓ $\langle x_B \rangle \approx 0.21$, $\langle Q^2 \rangle \approx 2.15 GeV^2$

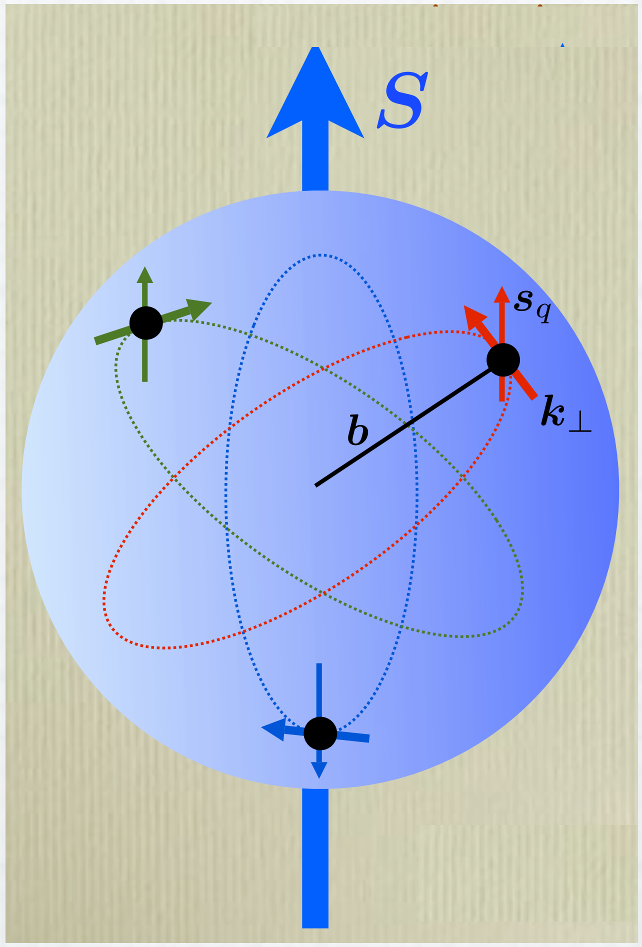
$\alpha = 0.179 \pm 0.017$
$\beta = -0.006 \pm 0.018$





summary



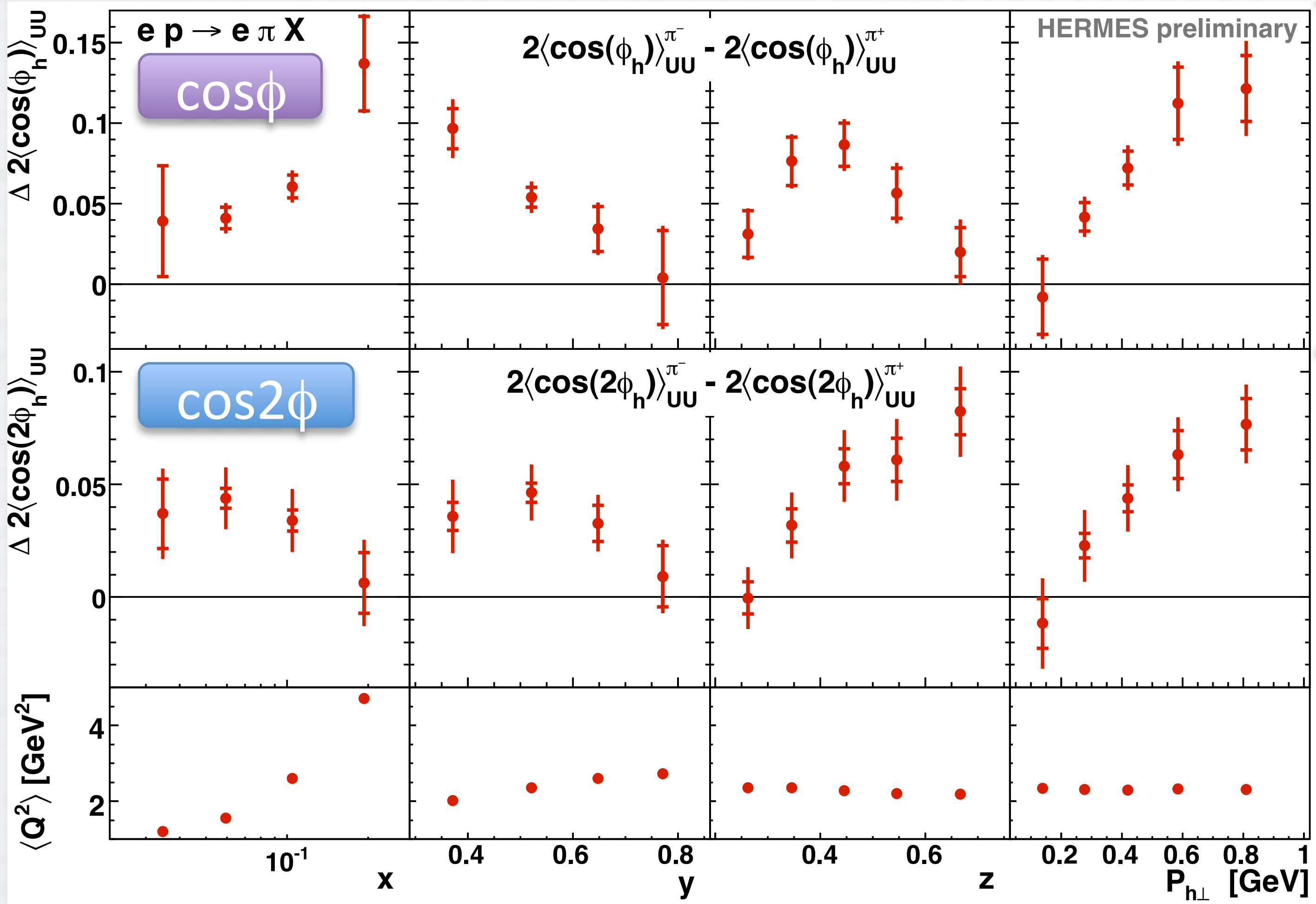


Thanks to the organizers and all the 60 speakers

back up

pion charge asymmetry difference

- Marco Contalbrigo -



$$\sigma_{UU}^{\cos(\phi)} \propto \left[f_1 \otimes D_1 + h_1^{\perp} \otimes H_1^{\perp} + \ldots \right] / Q$$

$$\sigma_{UU}^{\cos(2\phi)} \propto h_1^{\perp} \otimes H_1^{\perp} + \left[f_1 \otimes D_1 + \ldots \right] / Q^2$$

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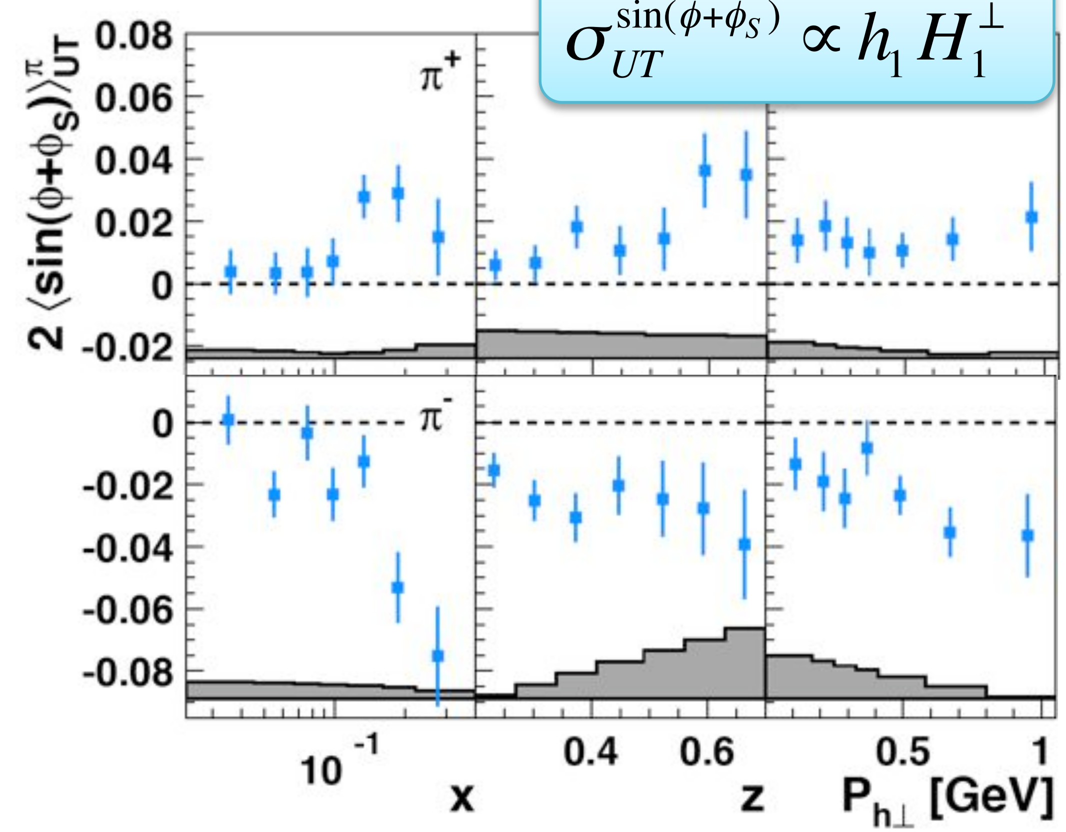
$$\sigma_{UT}^{\sin(\phi+\phi_S)} \propto h_1 H_1^{\perp}$$



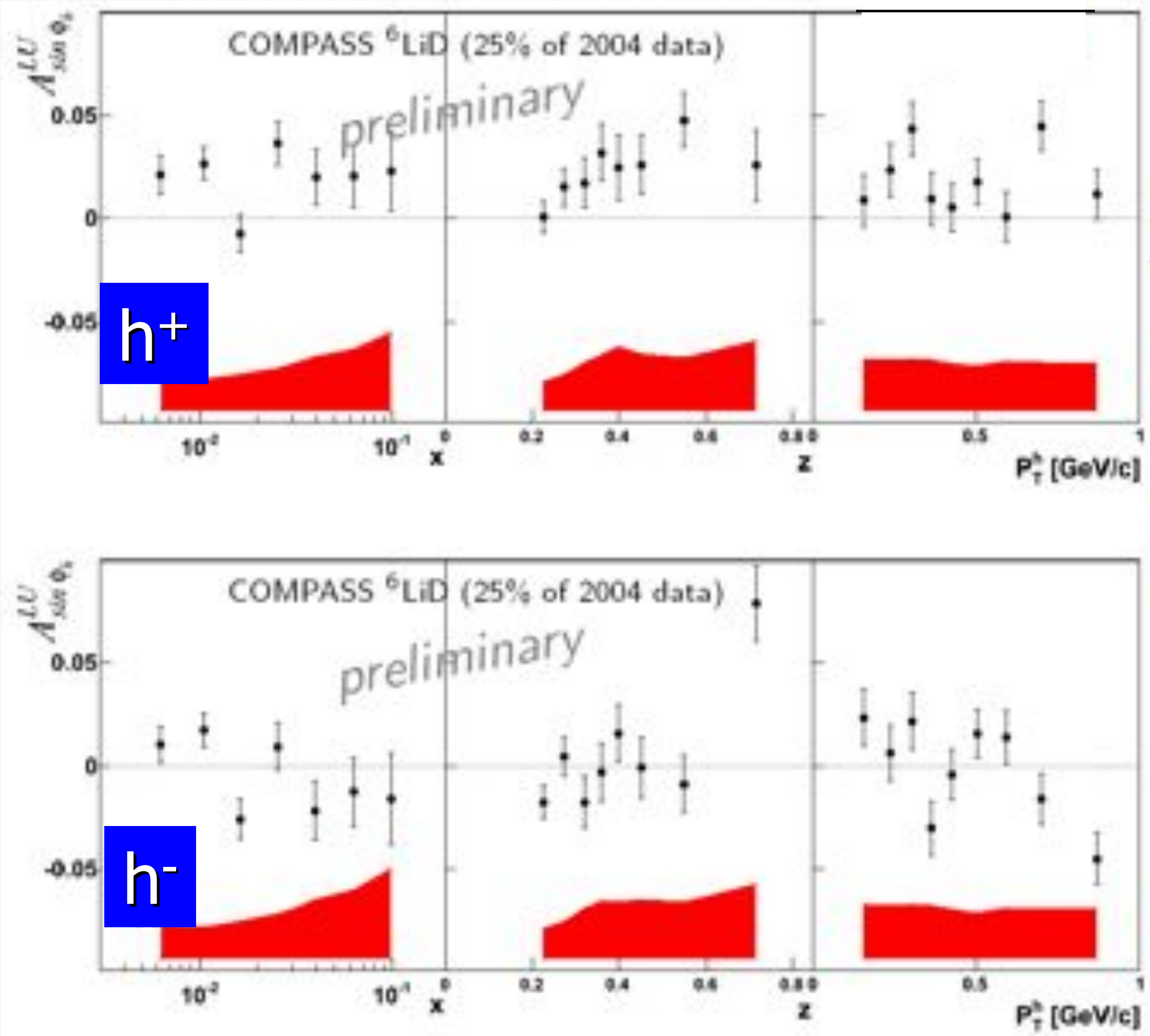
Mild flavor dependendence of k_T expected

From A_{UT}: Collins favored ($u \rightarrow \pi+$) and unfavored ($u \rightarrow \pi-$) fragmentation opposite in sign

With u-dominance
Collins makes the difference !
Hint of non-zero Boer-Mulders

- Christian Schill -

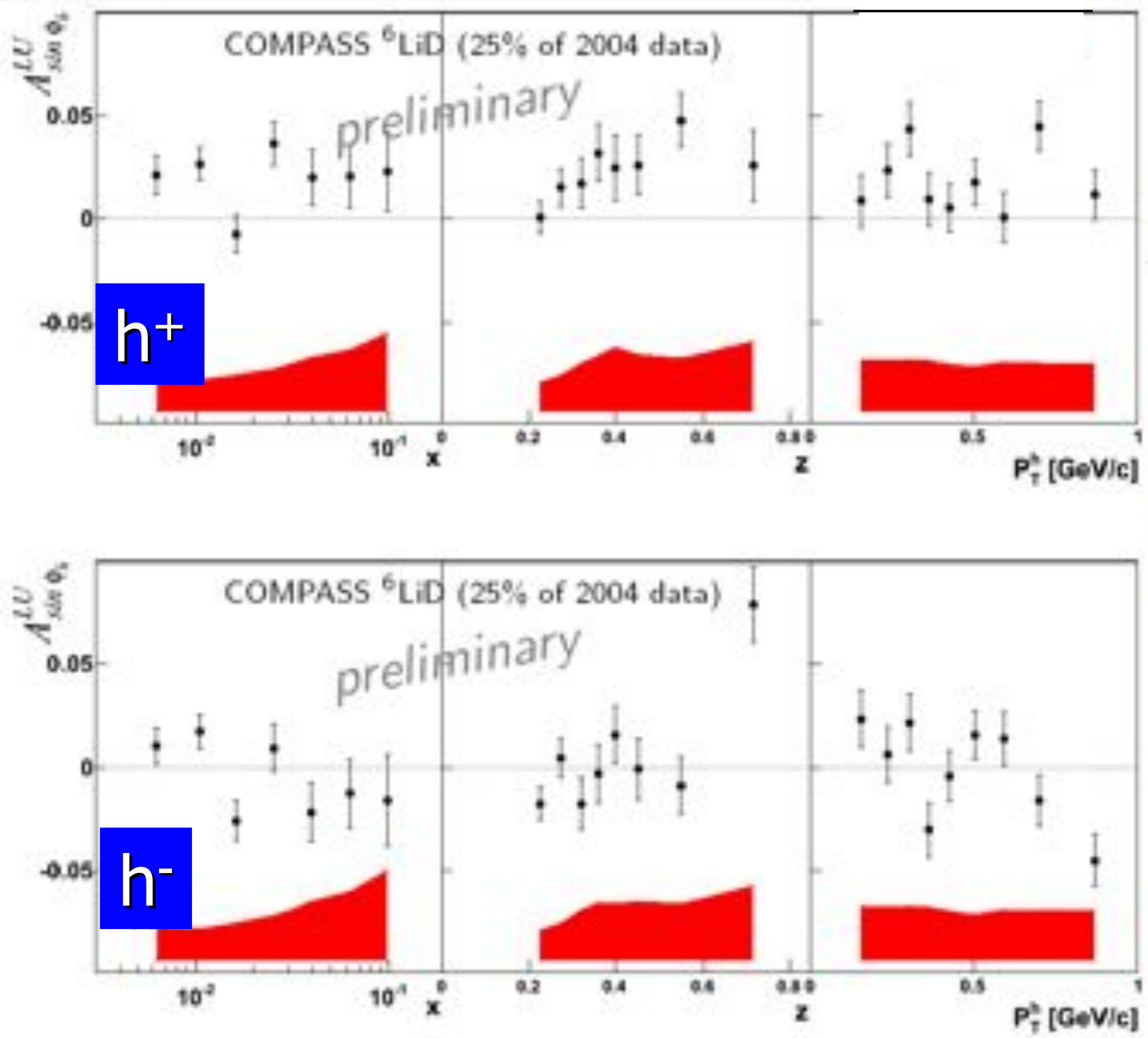
beam spin asymmetries



$A^{LU}_{\sin\phi}$: twist-3 effect due to beam polarization

- h^+ positive asymmetry
- h^- small asymmetry, compatible with zero

beam spin asymmetries



$A^{LU}_{\sin\phi}$: twist-3 effect due to beam polarization

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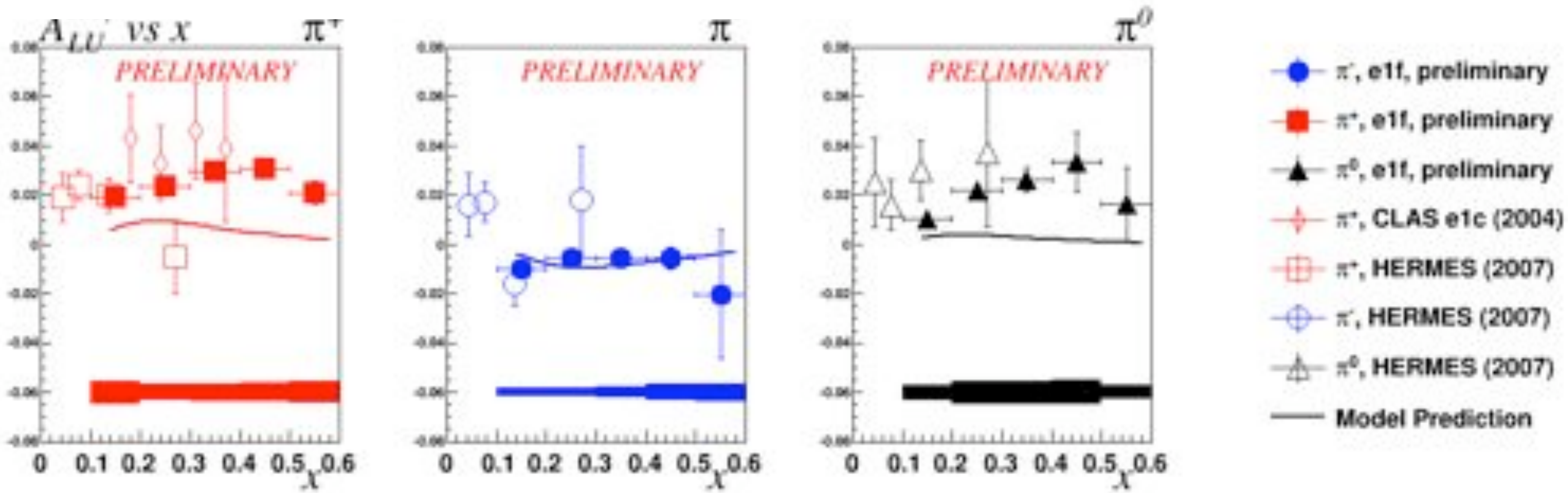
Jefferson Lab

- Wes Gohn (Hall B)-



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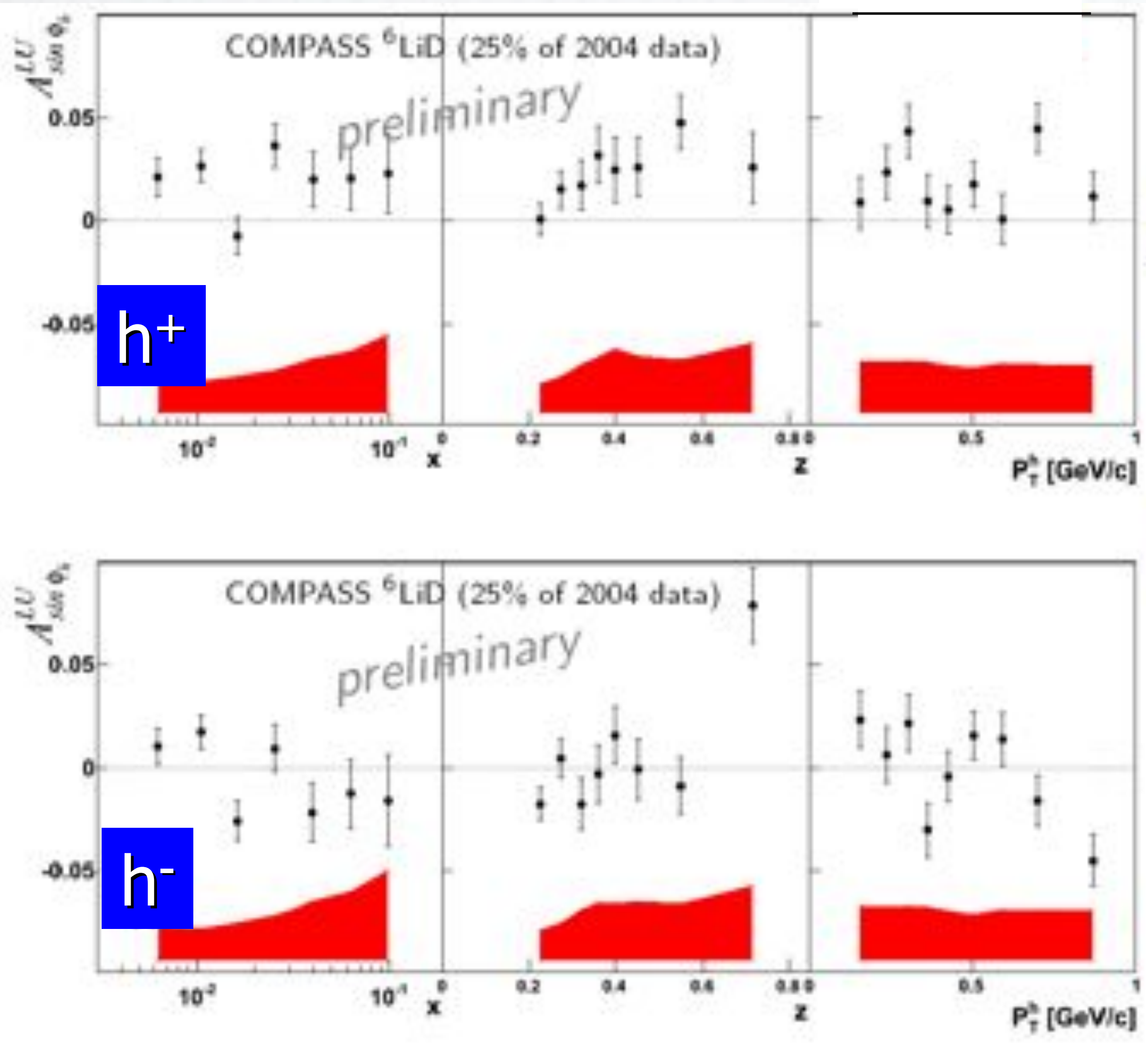
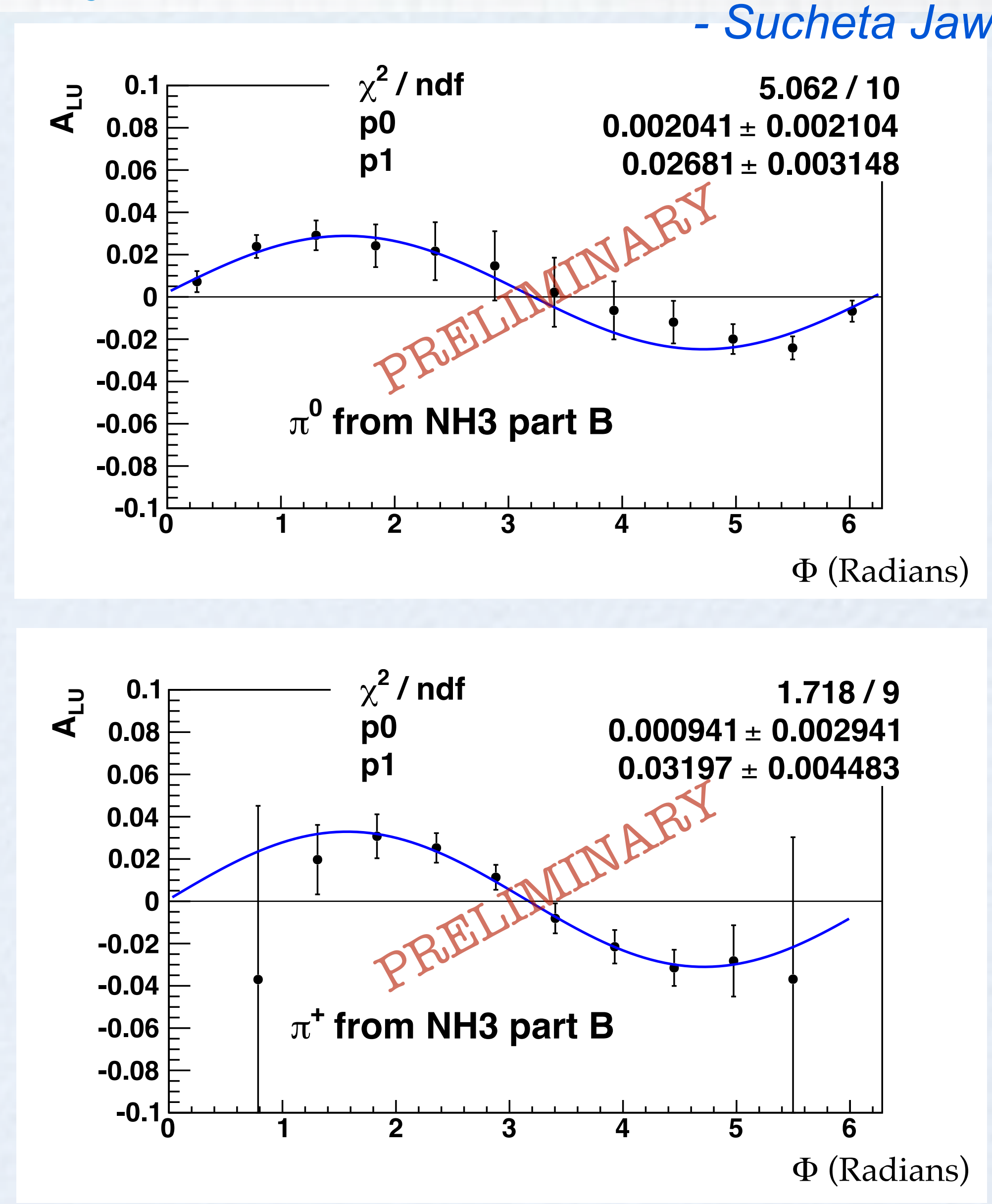
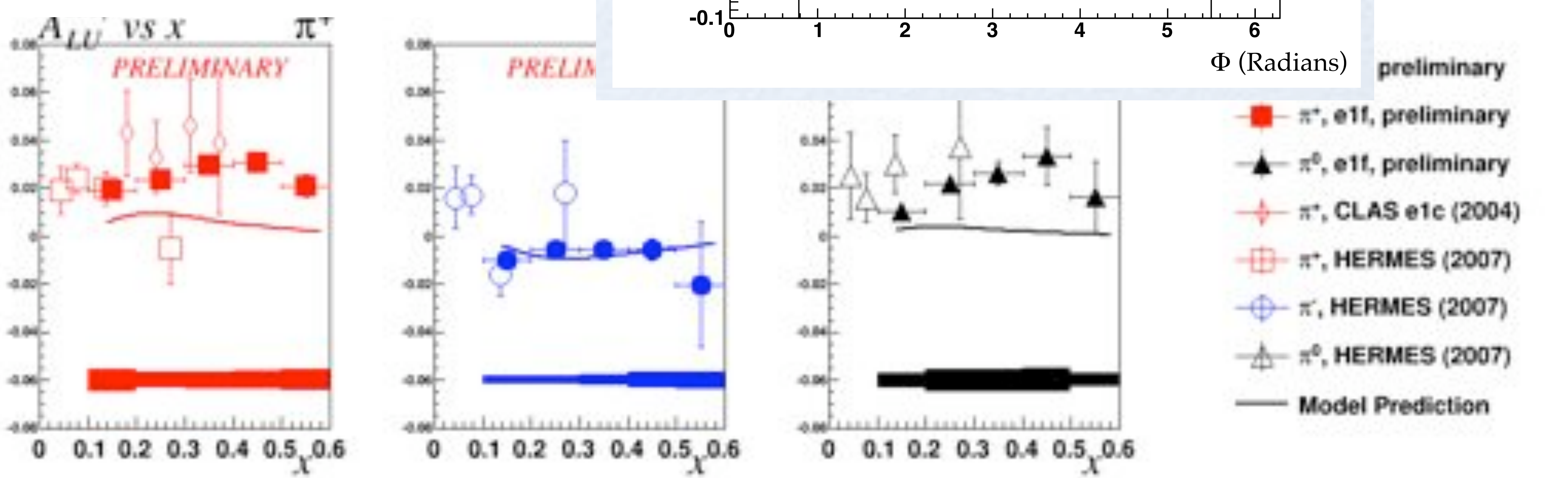
beam spin asymmetries

- Christian Schill -

- Sucheta Jawalkar (Hall B)-



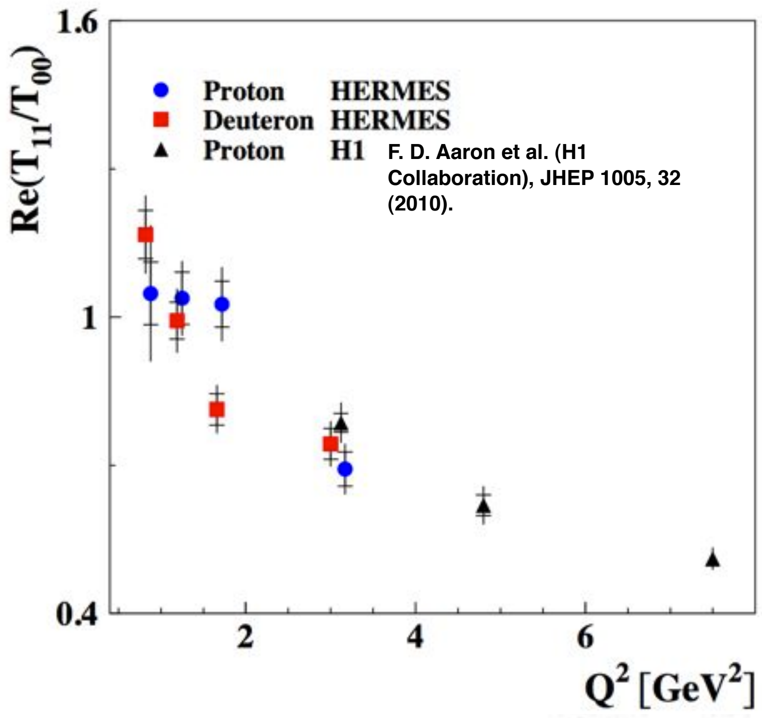


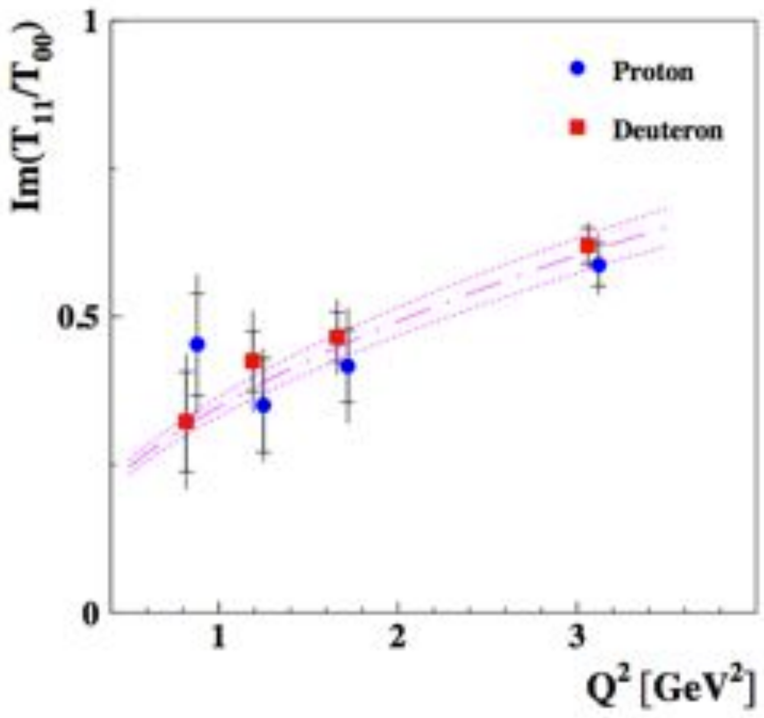


- Wes Gohn (Hall B)-

helicity amplitude ratios of exclusive ρ^0 production

- Morgan Murray-





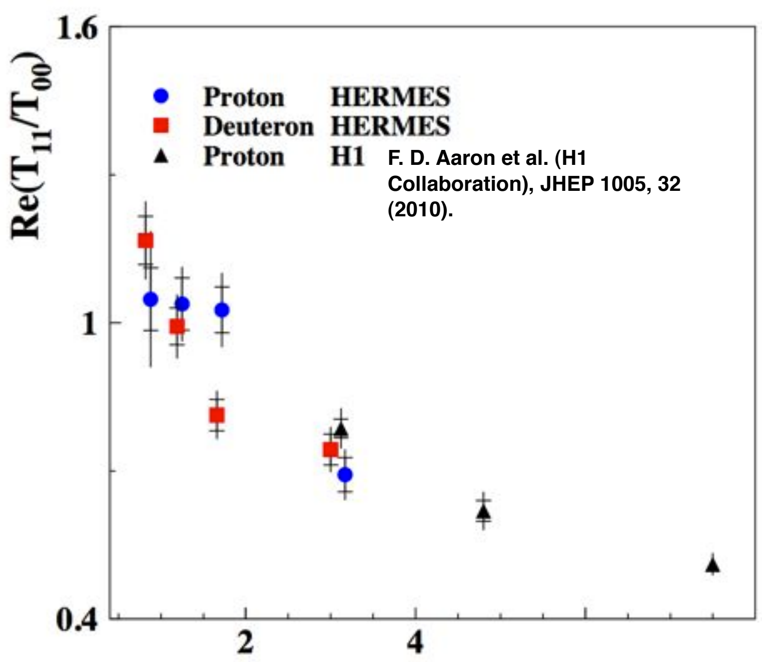
Real Part follows a/Q
with a=1.11±0.03GeV
as expected!

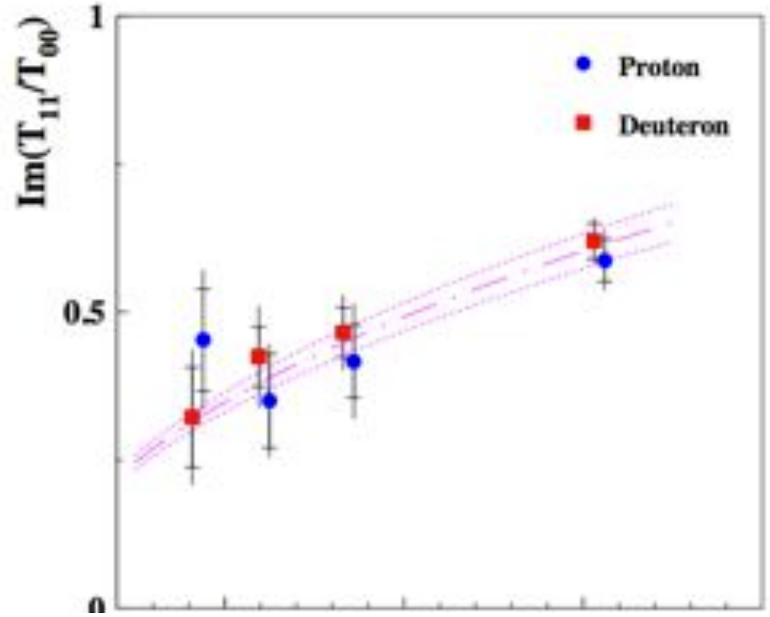
Imaginary Part follows bQ
with b=0.34±0.02GeV^{-1}
(fit has no basis in theory)

Monday, August 22, 2011

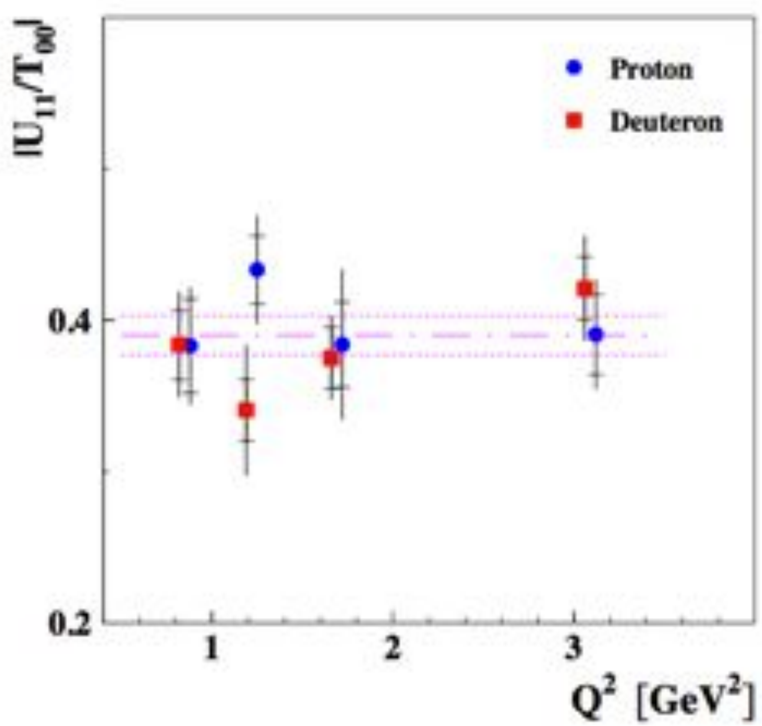
helicity amplitude ratios of exclusive ρ^0 production

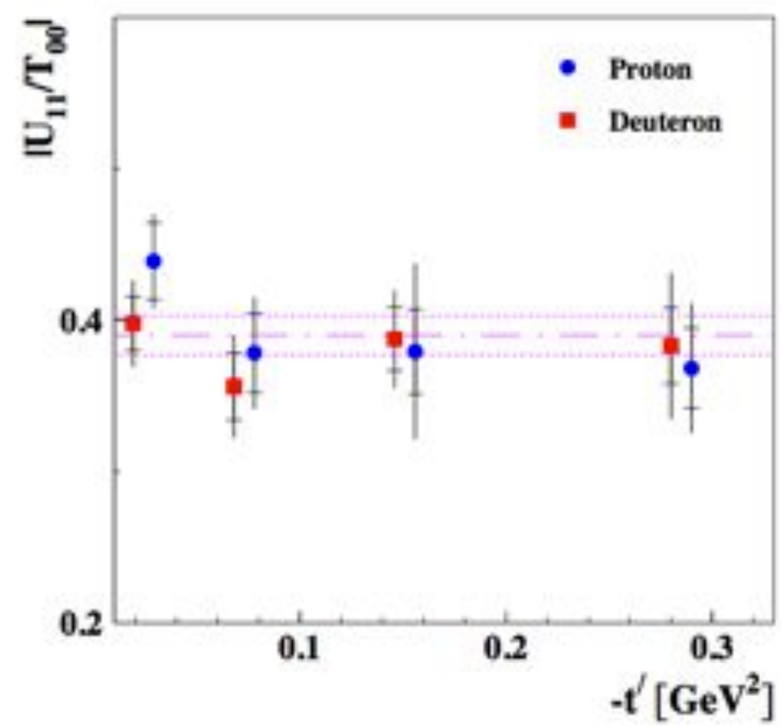
- Morgan Murray-





Real Part follows with a=1.11±0.03 as expected!

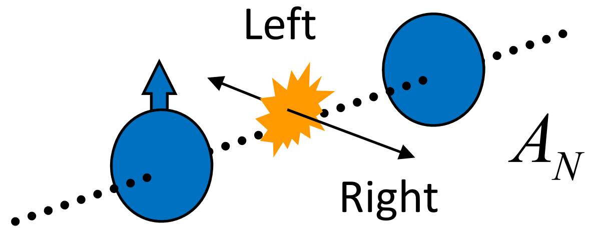




Existence established to 20σ (integrated extraction)

Magnitude of U_{11} is 2.5x smaller than T_{00}

inclusive hadron asymmetries



$$A_N = \frac{1}{P}\frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

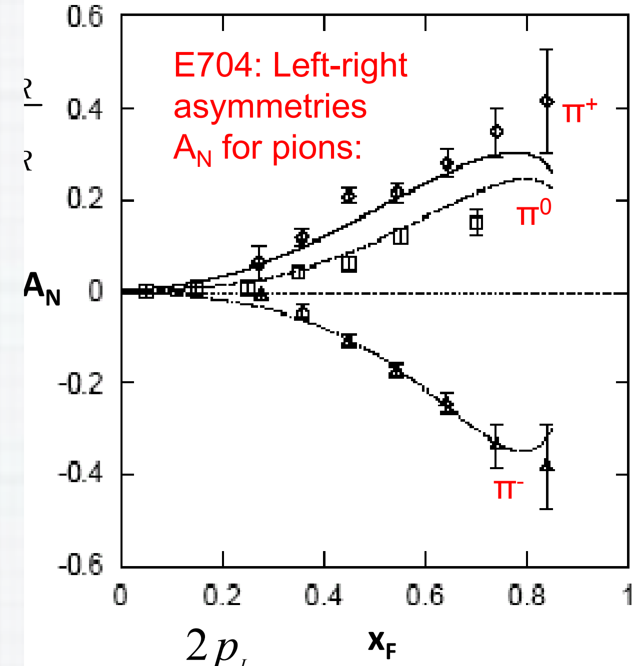
Possible Expansion:

$$A_N = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow} \propto f_{1T}^\perp \otimes D_1 + \delta q \otimes H_1^\perp + \ldots$$

Sivers Function (angular momentum) → Sivers Effect

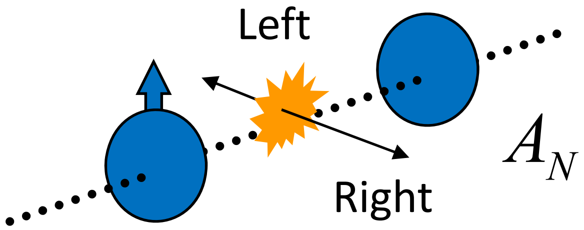
Transversity (structure)

Collins Function (Fragmentation) → Collins Effect



$$x_F = \frac{2p_L}{\sqrt{s}}$$

inclusive hadron asymmetries



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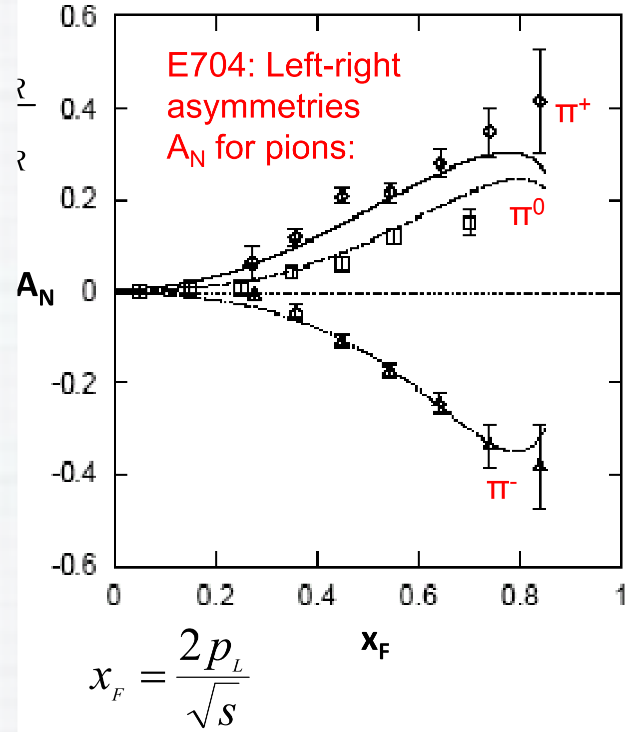
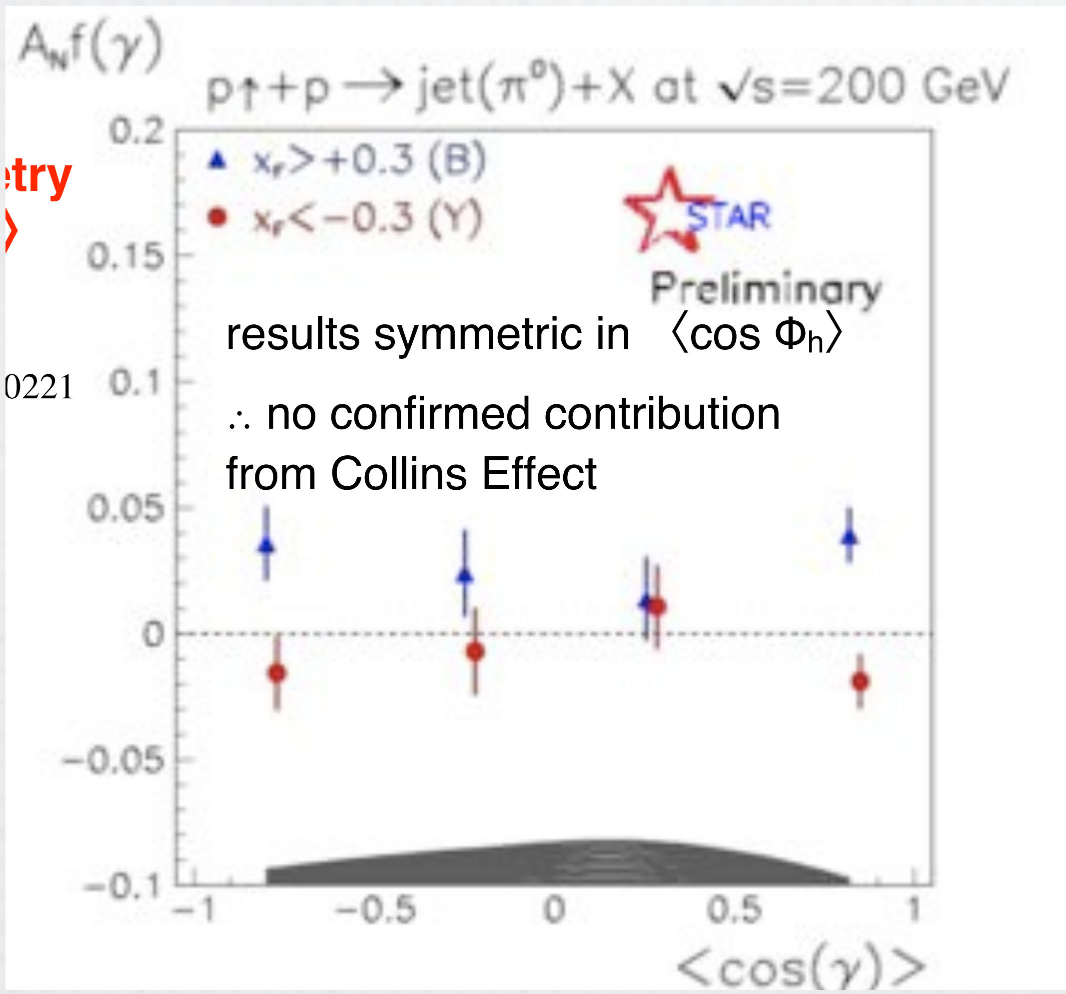
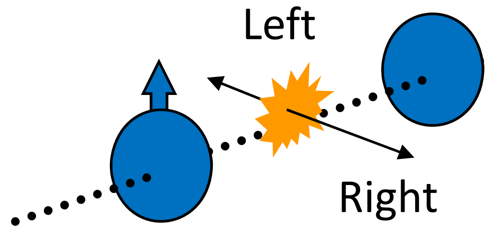




inclusive hadron asymmetries



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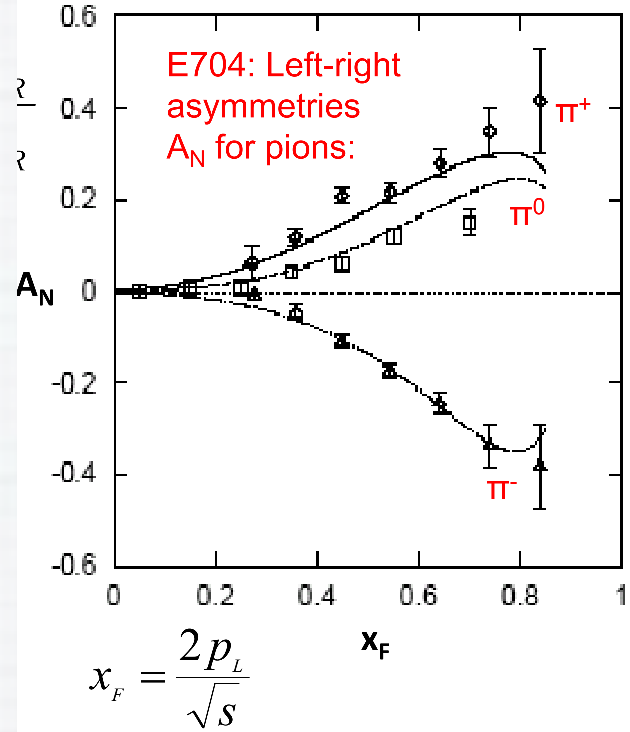
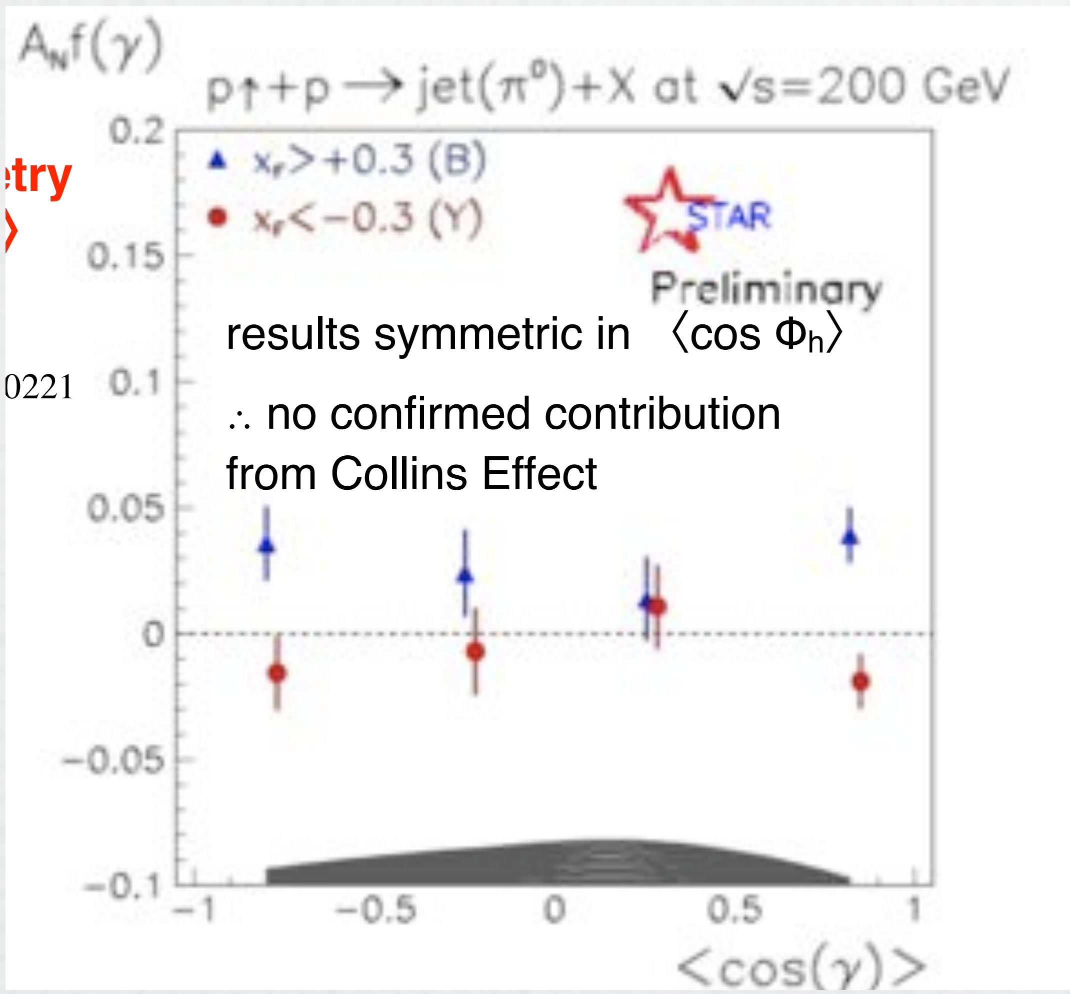
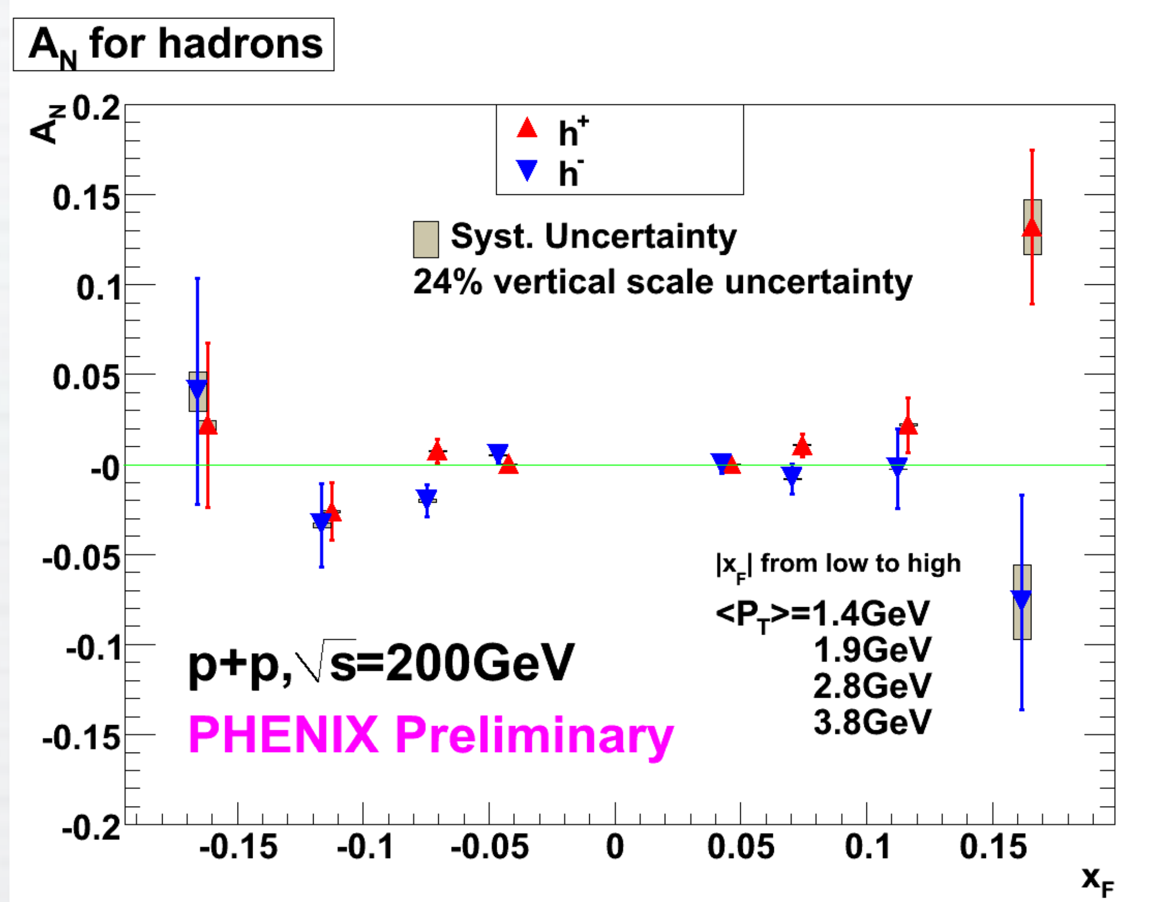




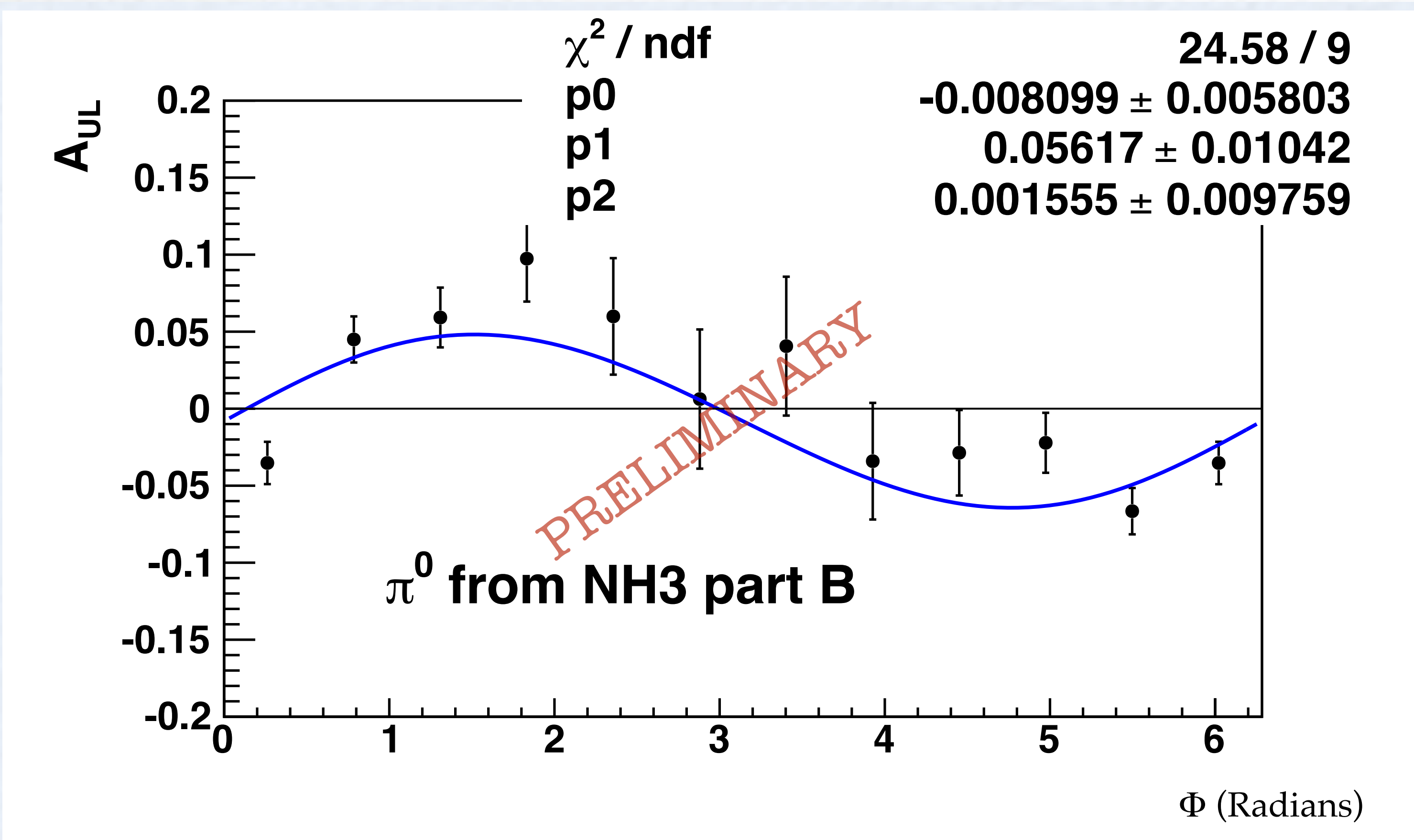


new results on worm-gear DF Hall B

- Sucheta Jawalkar -

$$+ S_L \left[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi)F_{UL}^{\sin(\phi)} + \epsilon\sin(2\phi)F_{UL}^{\sin(2\phi)}\right]$$

- $\propto h_{1L}^{\perp}(x, p_T^2) \otimes H_1^{\perp}(z, k_T^2)$

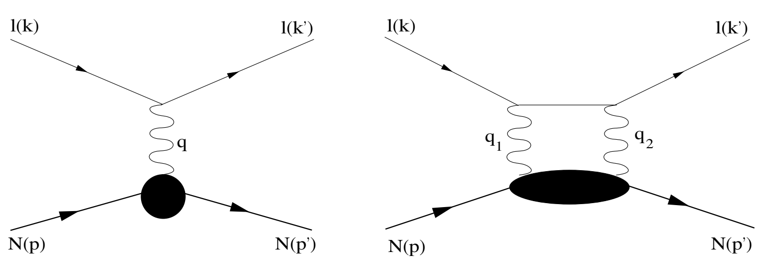


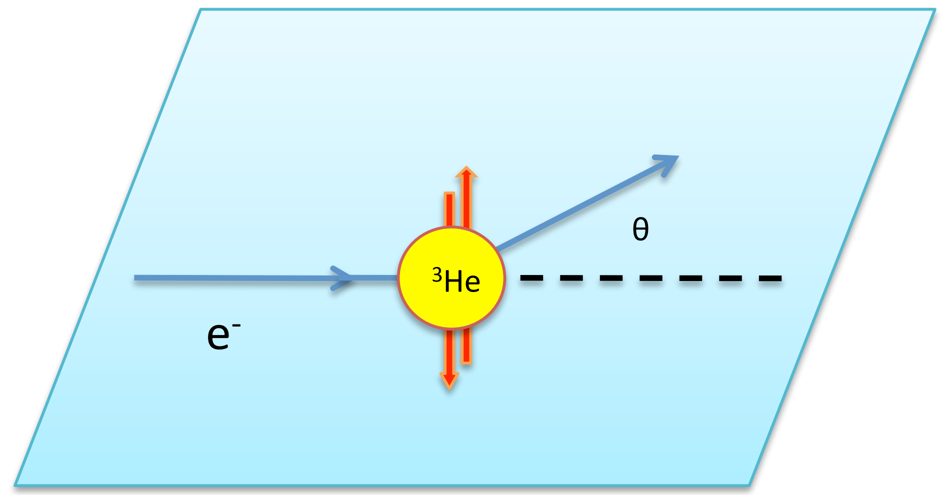
- significant sin(phi)
- negligible sin(2phi)
  - consistent with HERMES results

$$H_1^{\perp,\text{unfav}}(z) \approx -H_1^{\perp,\text{fav}}(z)$$

two photon exchange

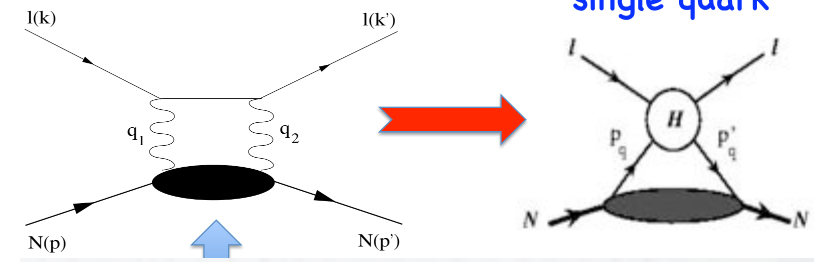
$$A_y(Q^2) = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$





At low Q^2, entire nucleon is involved

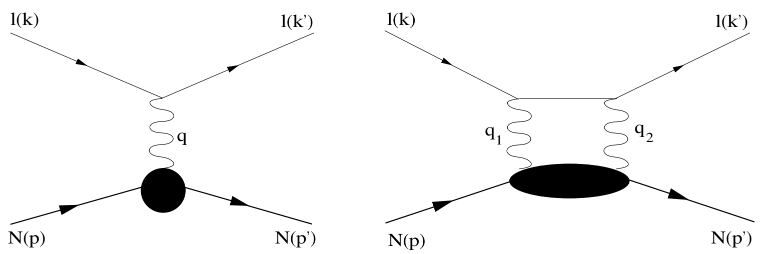
At large Q^2, assume interaction with a single quark

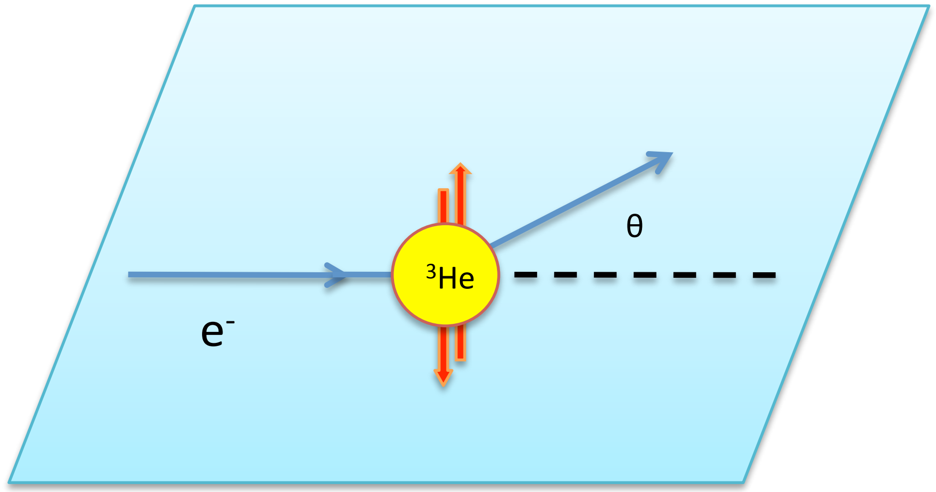


Monday, August 22, 2011

two photon exchange

$$A_y(Q^2) = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$





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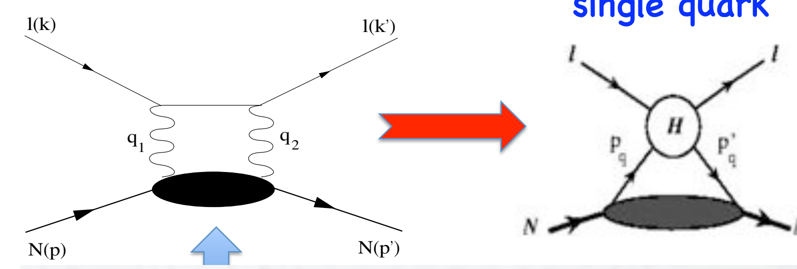
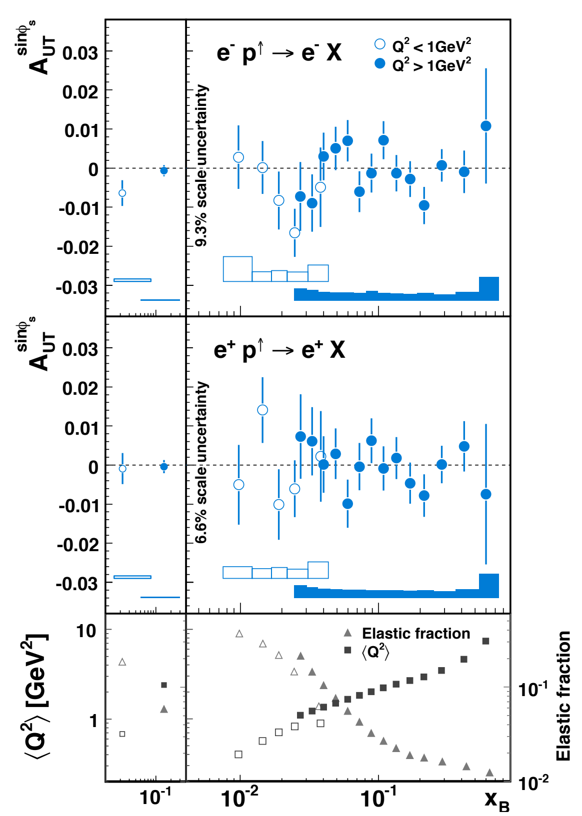


HERMES Proton

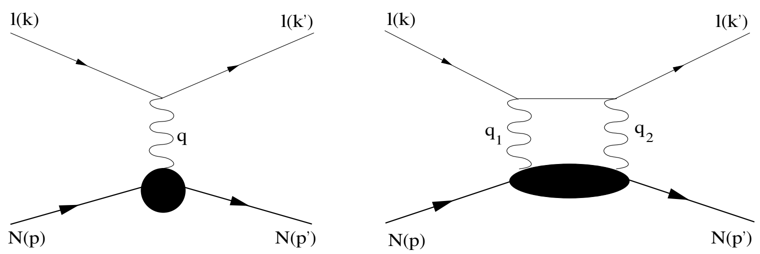


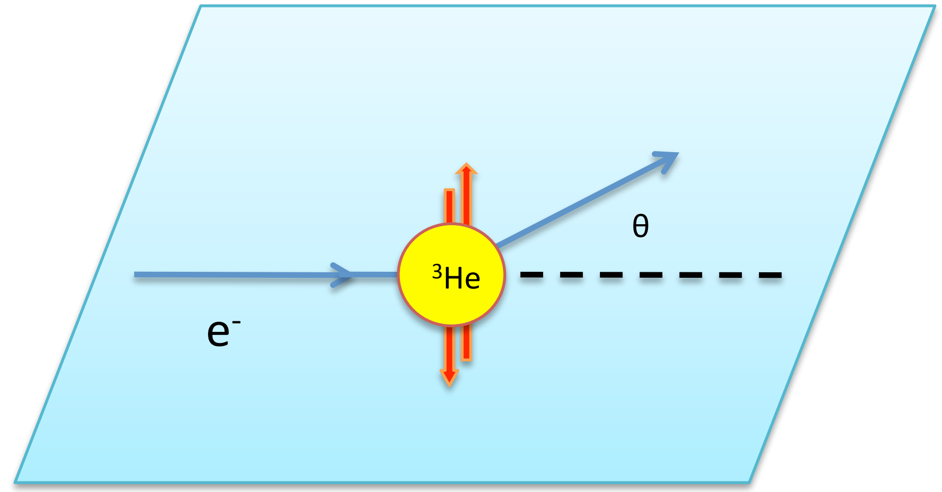
Jefferson Lab

- Todd Averett (Hall A) -

two photon exchange

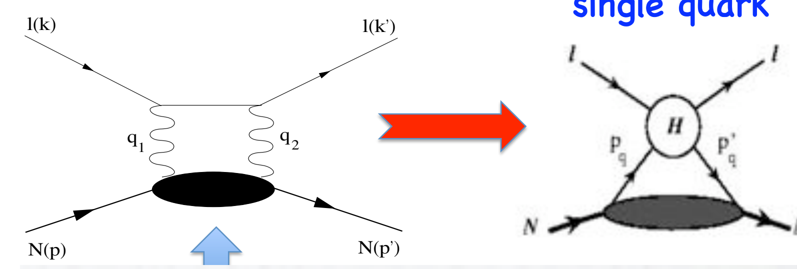
$$A_y(Q^2) = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$





At low Q^2, entire nucleon is involved

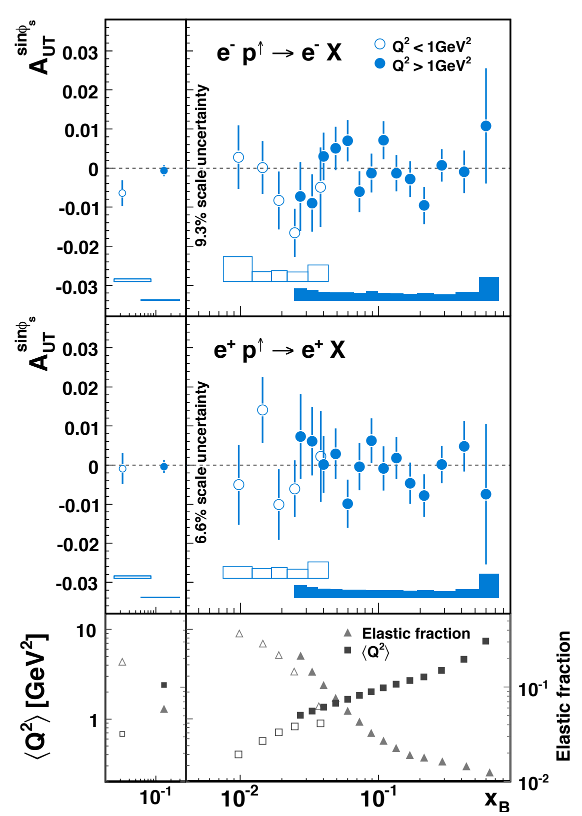
At large Q^2, assume interaction with a single quark

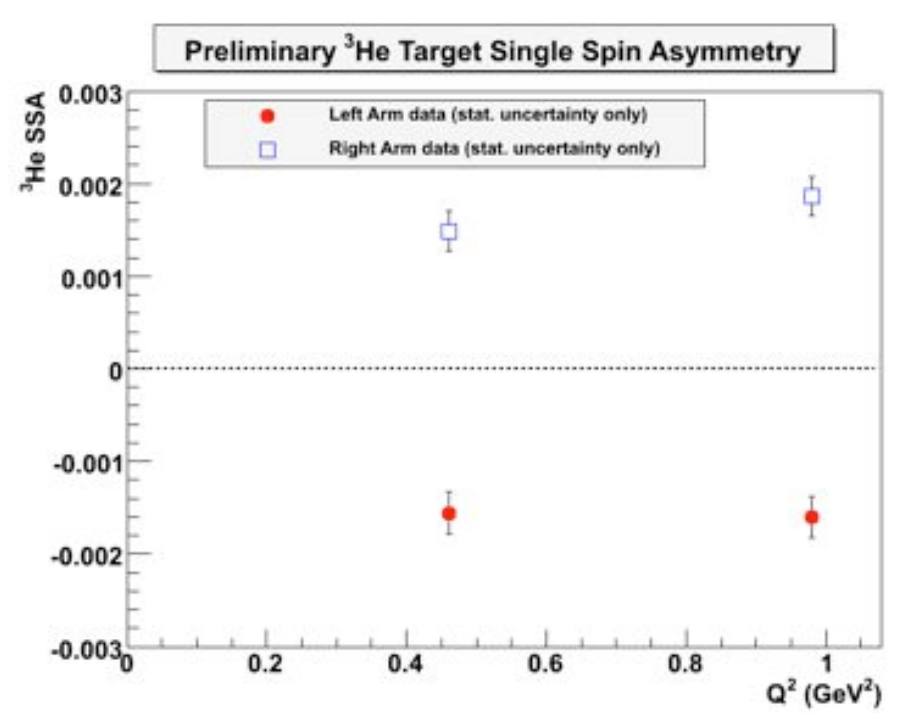


quasi elastic

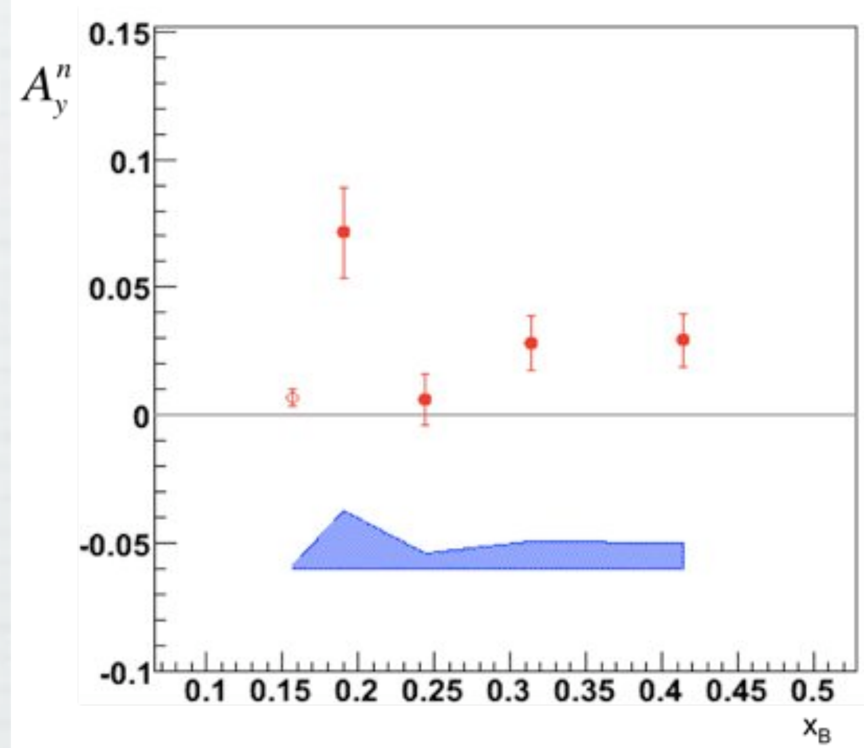
DIS

HERMES Proton





Preliminary Results Neutron



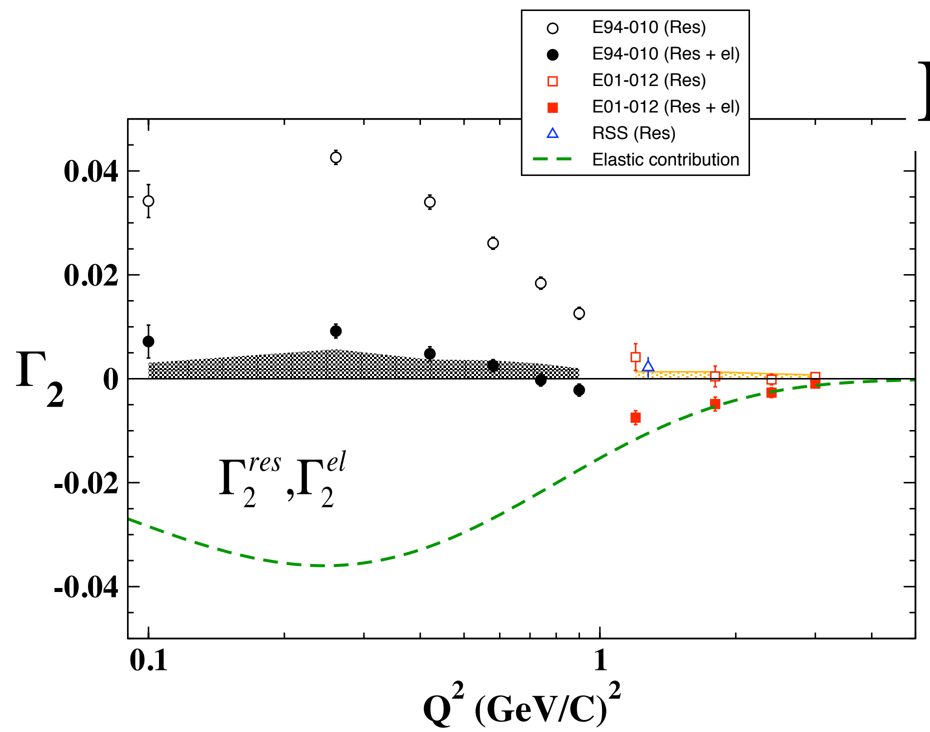
inclusive scattering - g_1, g_2

- Nilanga Liyanage (Hall A)-

$$\Gamma_2(Q^2) = \int_0^1 dx\; g_2(x,Q^2) = 0$$

H.Burkhardt and W.N. Cottingham
Annals Phys. **56** (1970) 453.

- Sum-rule satisfied for the leading twist part (g_2^{WW}) be definition; so if there is any violation, it is all due to higher-twist



Γ_2^n from E01-012

$$\Gamma_2 = \Gamma_2^{res} + \Gamma_2^{el} + \Gamma_2^{DIS}$$
$$= \Gamma_2^{res} + \Gamma_2^{el} + \Gamma_2^{WW,DIS} + \overline{\Gamma}_2^{DIS}$$

Known part

unknown part

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inclusive scattering - g_1, g_2

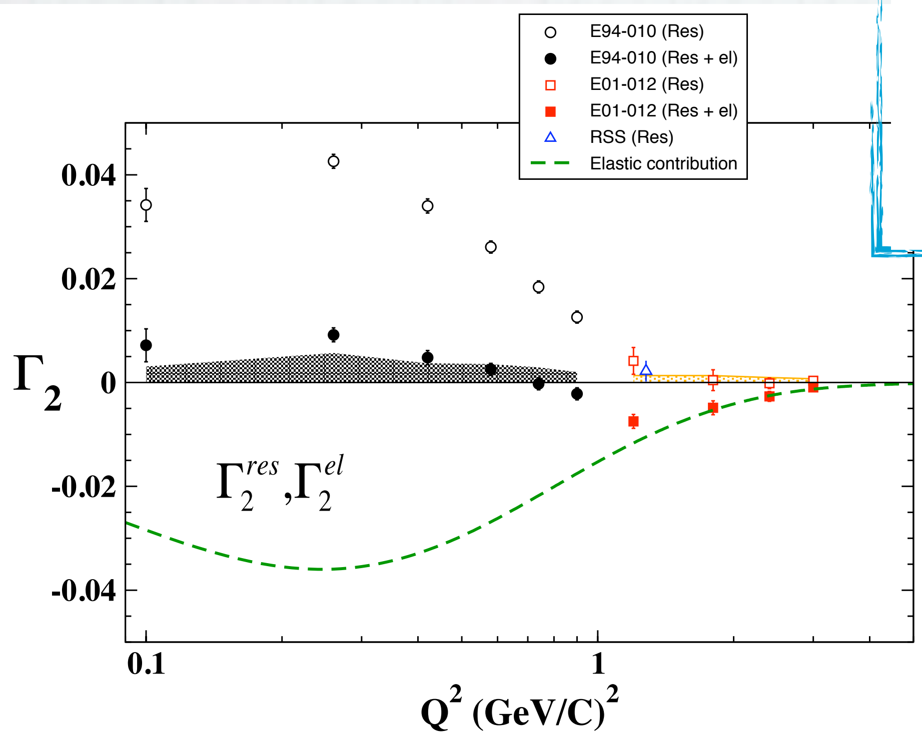
- Nilanga Liyanage (Hall A)-

$$\Gamma_2(Q^2) = \int_0^1 dx\, g_2(x,Q^2) = 0$$

H.Burkhardt and W.N. Cottingham Annals Phys. **56** (1970) 453.

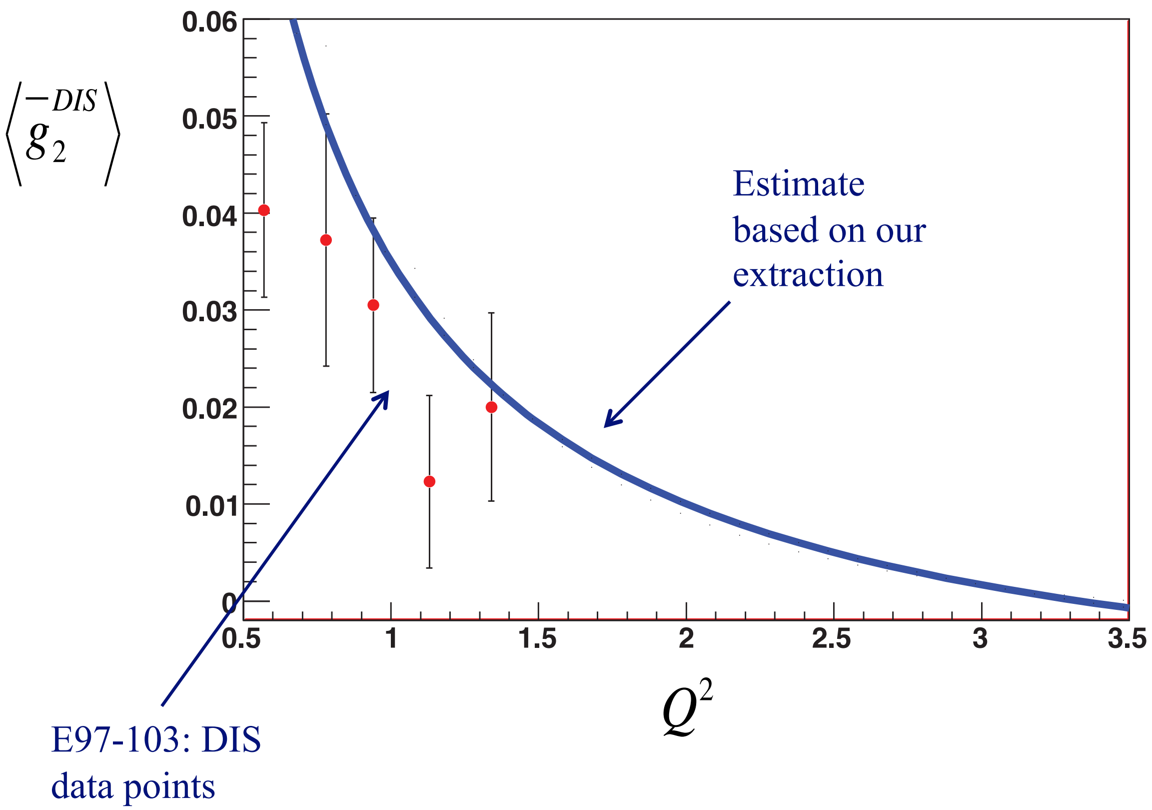
- Sum-rule satisfied for the leading twist part (g_2^{WW}) be definition; so if there is any violation, it is all due to higher-twist

- Γ_2^n, evaluated without the higher-twist part from DIS is clearly not zero below $Q^2 \sim 2.5$ GeV^2.
- If we assume BC sum-rule as valid, can extract the higher twist part of Γ_2: positive and large, may be as large as Γ_2^{WW}.



$$\Gamma_2 = \Gamma_2^{res} + \Gamma_2^{el} + \Gamma_2^{DIS}$$
$$= \Gamma_2^{res} + \Gamma_2^{el} + \Gamma_2^{WW,DIS} + \overline{\Gamma}_2^{DIS}$$

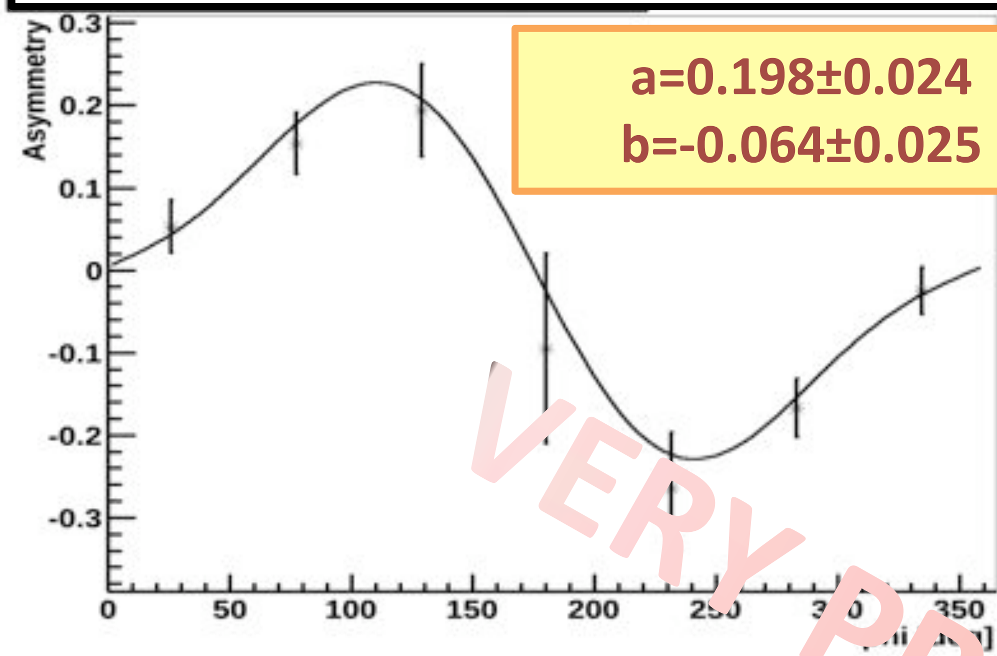
Known part — unknown part



exclusive π^0 production

✓Both photons in IC:

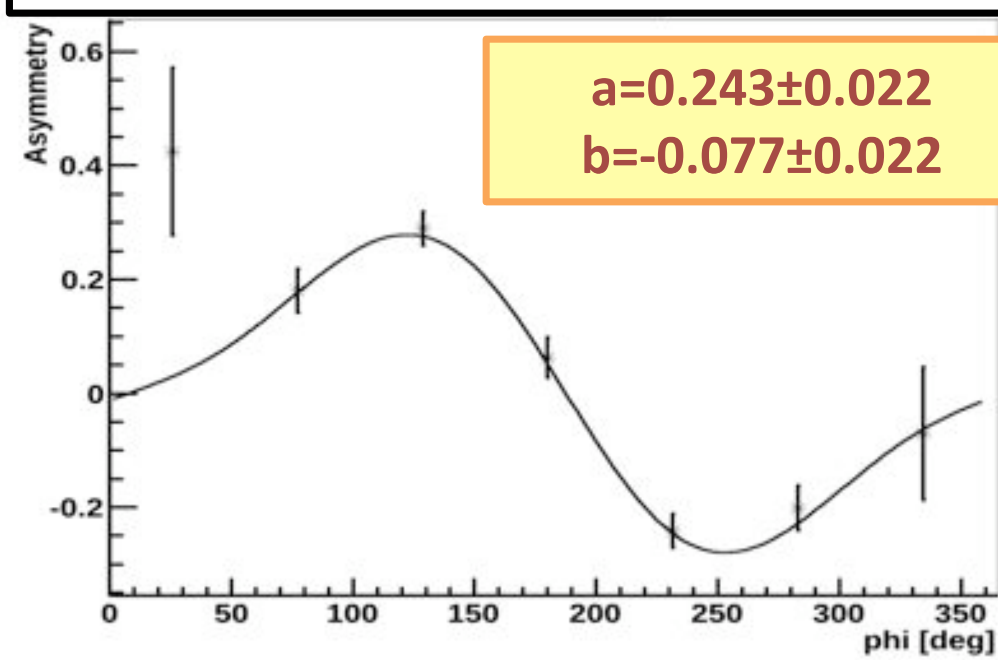
a=0.198±0.024
b=-0.064±0.025



$$A = a \cdot \sin\phi + b \cdot \sin 2\phi$$

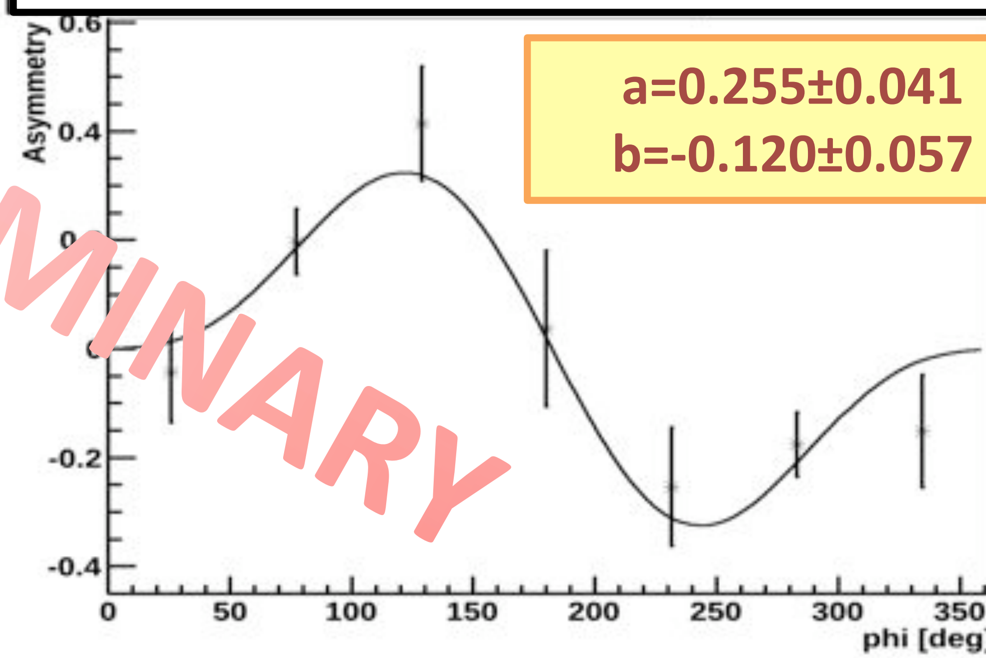
✓Both photons in EC:

a=0.243±0.022
b=-0.077±0.022



✓One photon in EC, second in IC:

a=0.255±0.041
b=-0.120±0.057



VERY PRELIMINARY

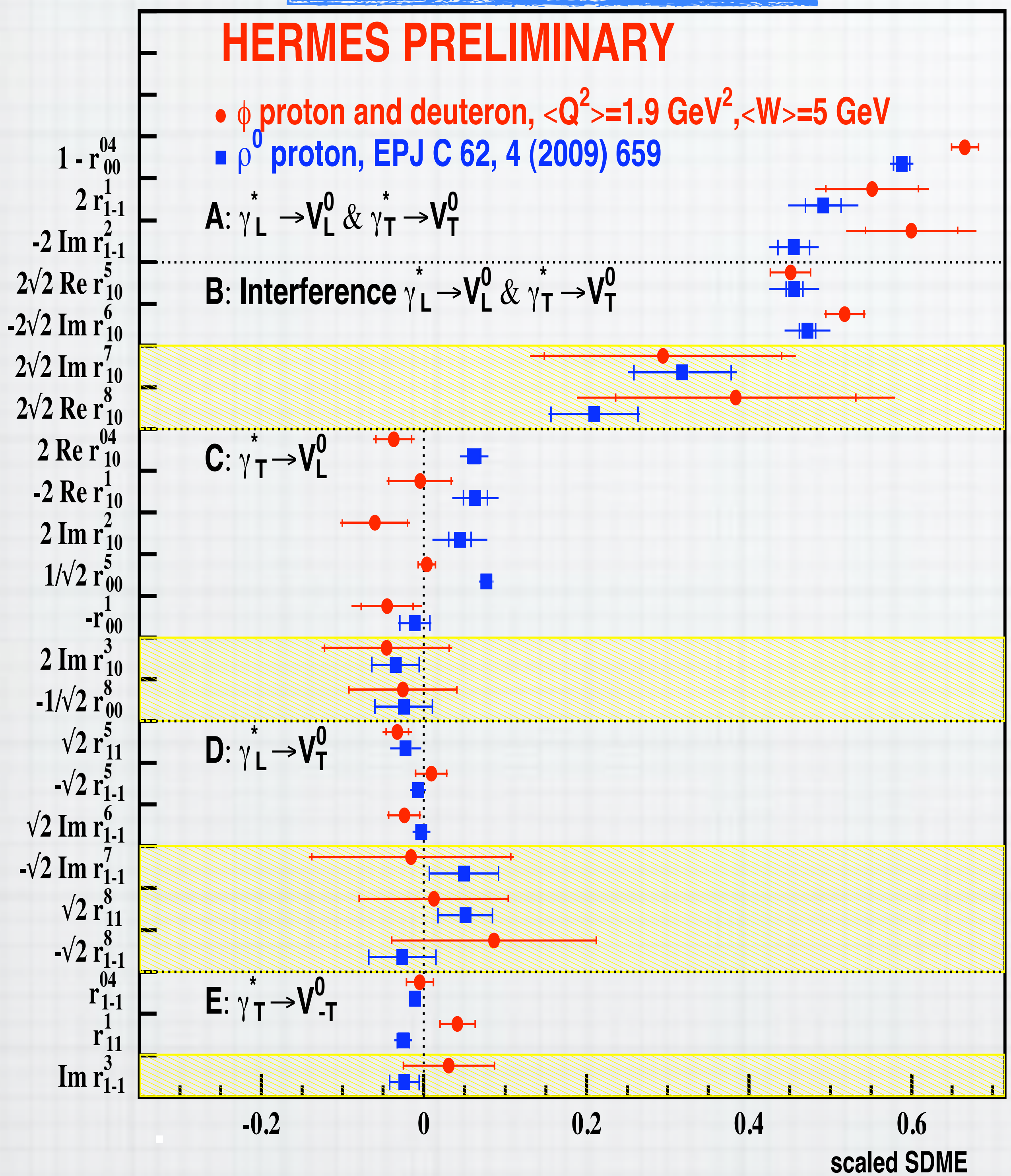
- Bohdan Marianski -

exclusive vector meson production

- Morgan Murray-

$$|T_{00}| \sim |T_{11}| \gg |T_{01}| > |T_{10}| \gtrsim |T_{1-1}|,$$

* SDME method



exclusive vector meson production

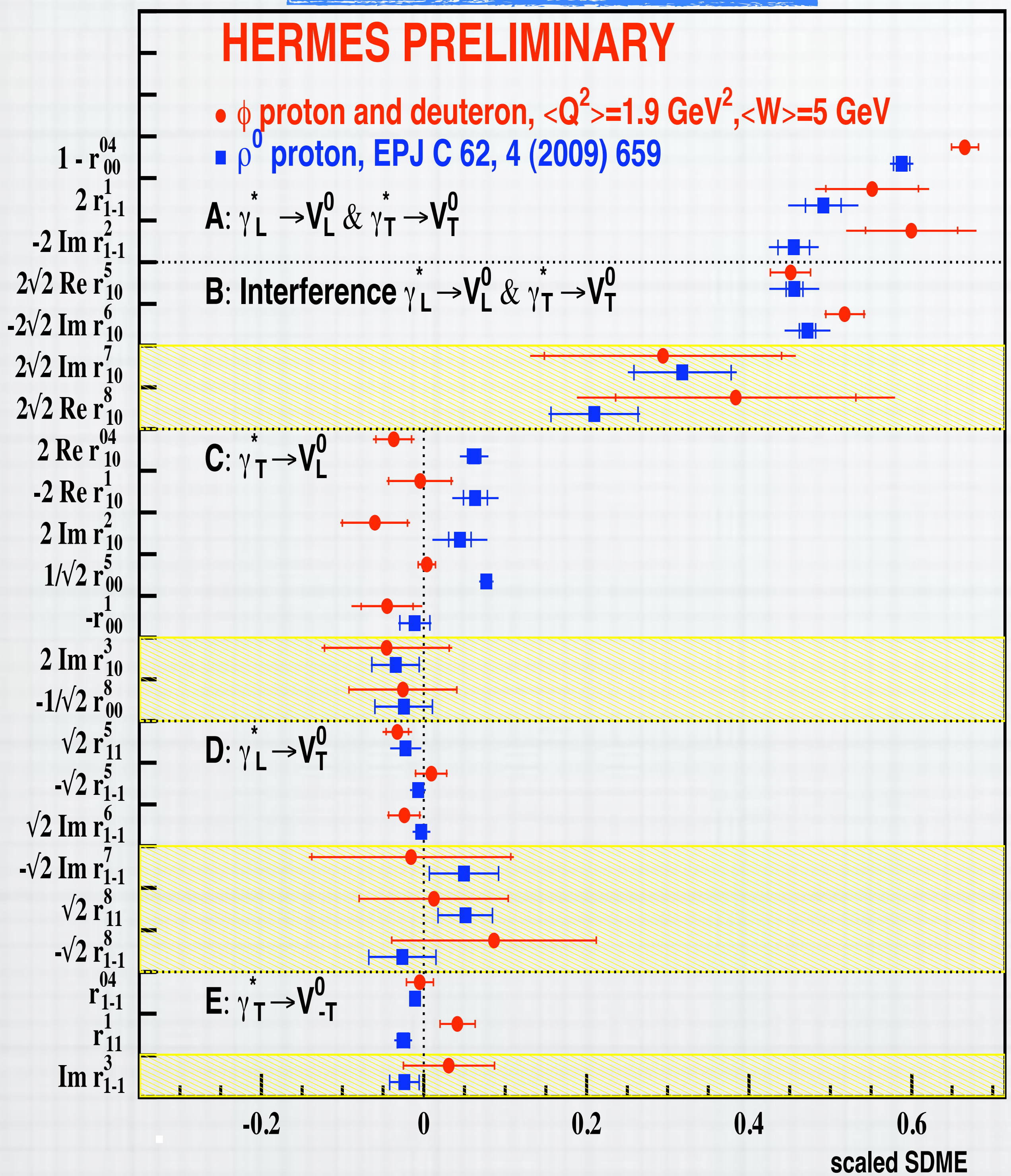
- Bohdan Marianski -

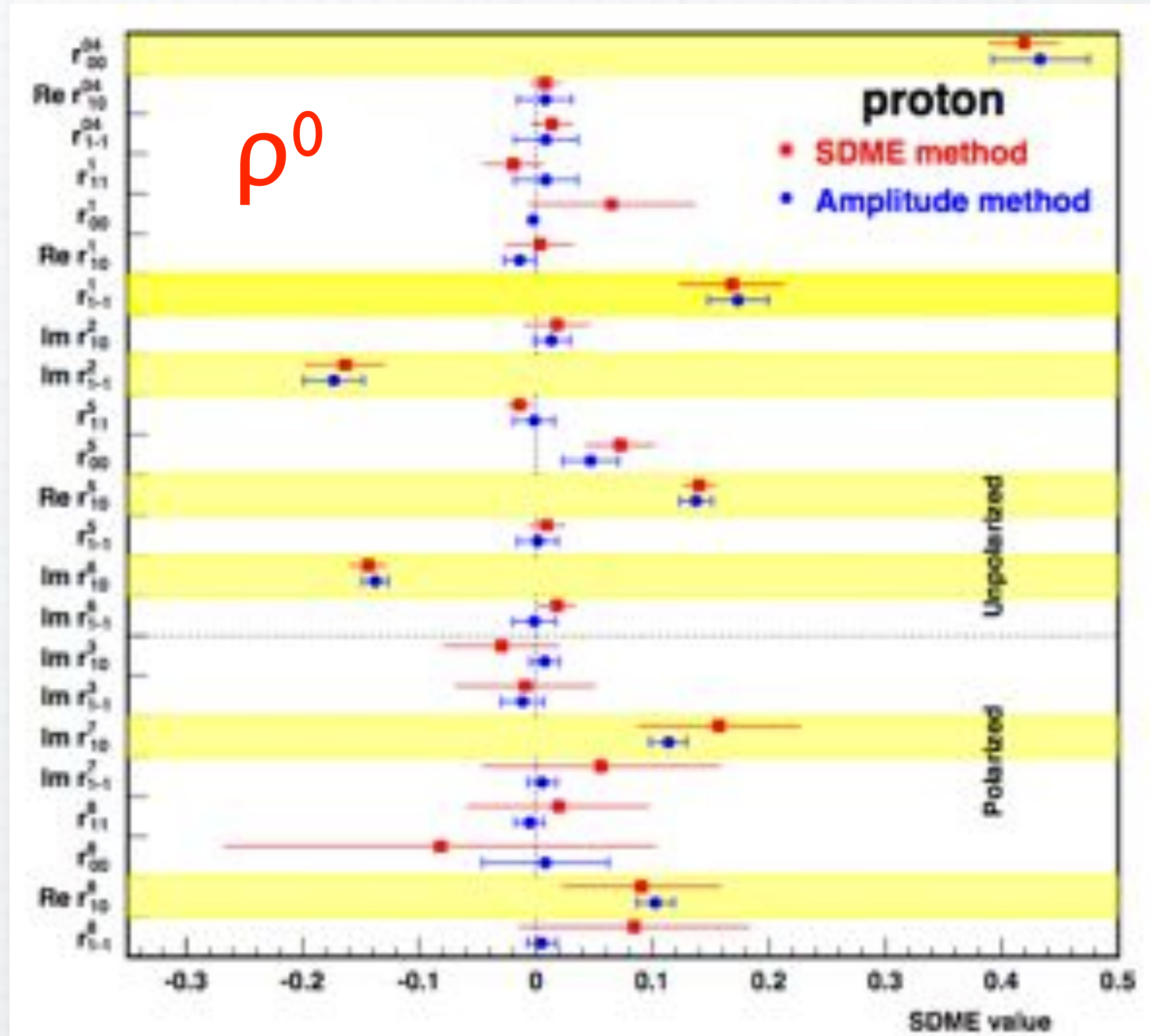
- Morgan Murray-

$$|T_{00}| \sim |T_{11}| \gg |T_{01}| > |T_{10}| \gtrsim |T_{1-1}|,$$

* SDME method

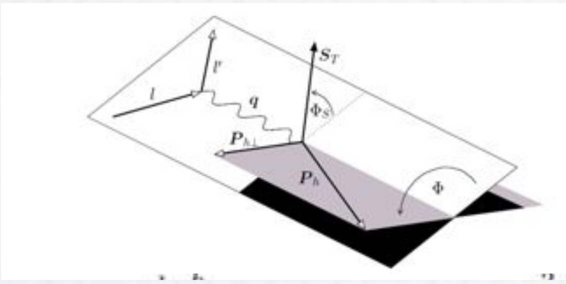
* helicity amplitude ratio method





- Ami Rostomyan & Oleg Eyser -

TMDs and the 3D image of the nucleon: $(x, \vec{k}_T)$



$$\frac{d\sigma^h}{dx\,dy\,d\phi_S\,dz\,d\phi\,d\mathbf{P}_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$

$$\Big\{ \Big[F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi)F_{UU}^{\cos(\phi)} + \epsilon\cos(2\phi)F_{UU}^{\cos(2\phi)}\Big]$$

$$+ \lambda_l \Big[\sqrt{2\epsilon(1-\epsilon)}\sin(\phi)F_{LU}^{\sin(\phi)}\Big]$$

$$+ S_L \Big[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi)F_{UL}^{\sin(\phi)} + \epsilon\sin(2\phi)F_{UL}^{\sin(2\phi)}\Big]$$

$$+ S_L\lambda_l \Big[\sqrt{1-\epsilon^2}F_{LL} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi)F_{LL}^{\cos(\phi)}\Big]$$

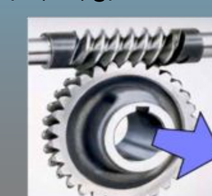
$$+ S_T \Big[\sin(\phi-\phi_S)\Big(F_{UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\Big) + \epsilon\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)} + \sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S)F_{UT}^{\sin(\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi-\phi_S)F_{UT}^{\sin(2\phi-\phi_S)}\Big]$$

$$+ S_T\lambda_l \Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S)F_{LT}^{\cos(\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S)F_{LT}^{\cos(2\phi-\phi_S)}\Big]\Big\}$$

nucleon \ quark	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	$g_{1T}^\perp$	h_1, $h_{1T}^\perp$

Worm-gear (UL)
(Kotzinian-Mulders)

- $\propto h_{1L}^\perp(x, p_T^2) \otimes H_1^\perp(z, k_T^2)$
- describes the probability to find transversely polarized quarks in a longitudinally polarized nucleon
- accessible in UT measurements through $\sin(2\phi+\phi_S)$ Fourier component



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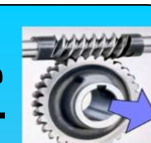
Worm-gear



$\propto g_{1T}^\perp(x, p_T^2) \otimes D_1(z, k_T^2)$

- describes the probability to find longitudinally polarized quarks in a transversely polarized nucleon (→ "**trans-helicity**")
- accessible in LT DSAs through the leading-twist $\cos(\phi-\phi_S)$ Fourier component

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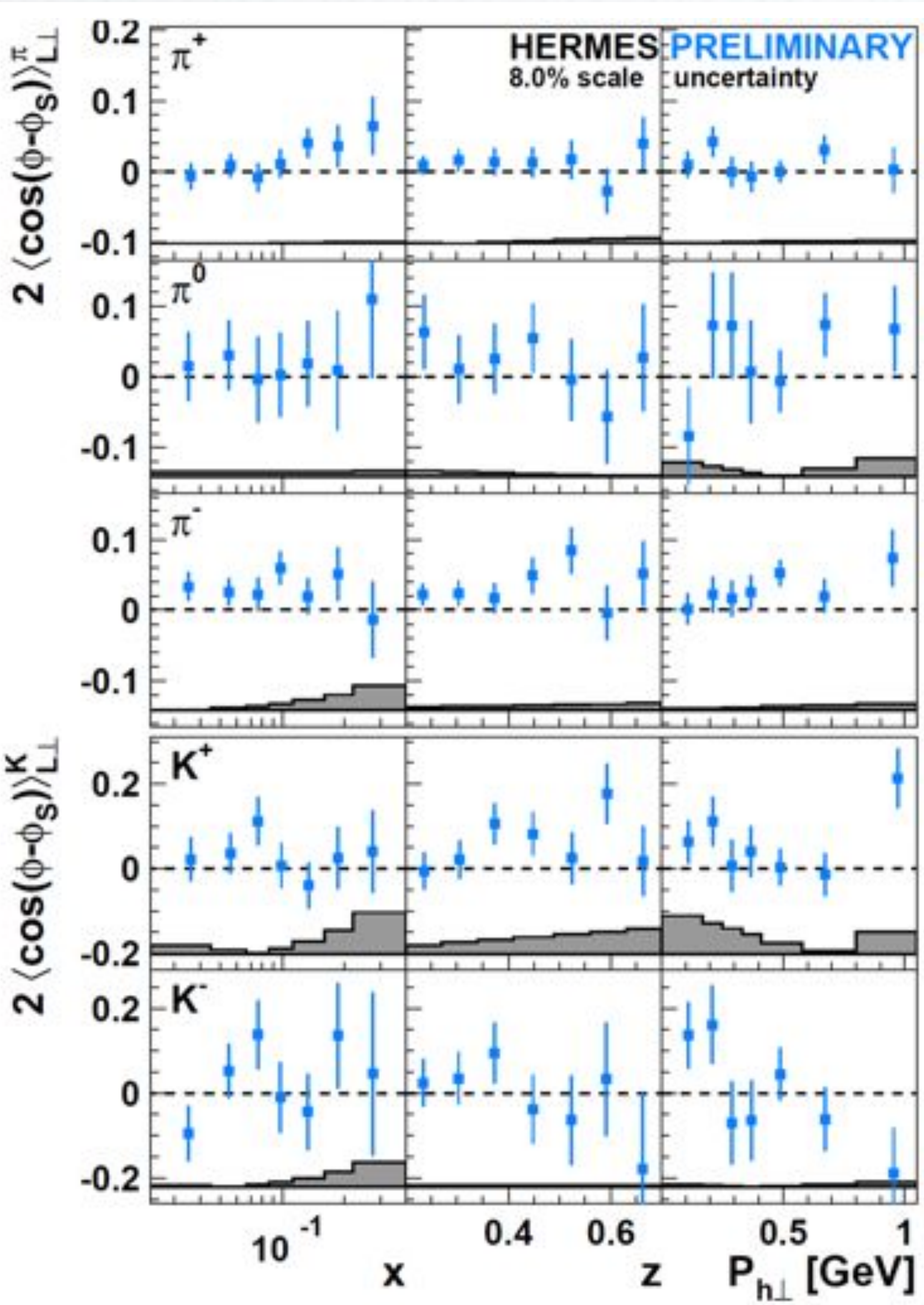
- Luciano Pappalardo-

results on worm-gear DF from HERMES, COMPASS, Hall A



proton

slightly positive ?

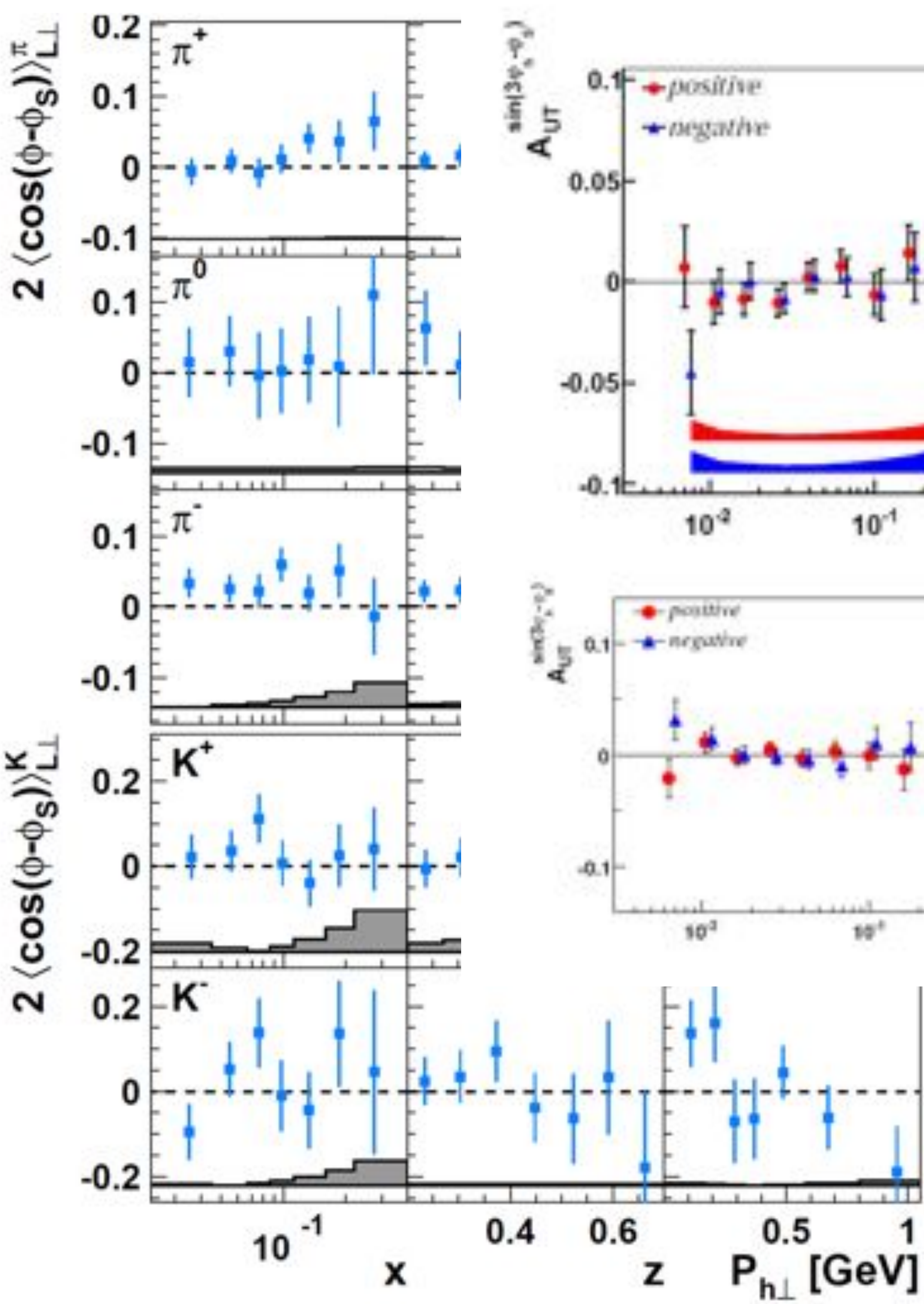
≈ 0

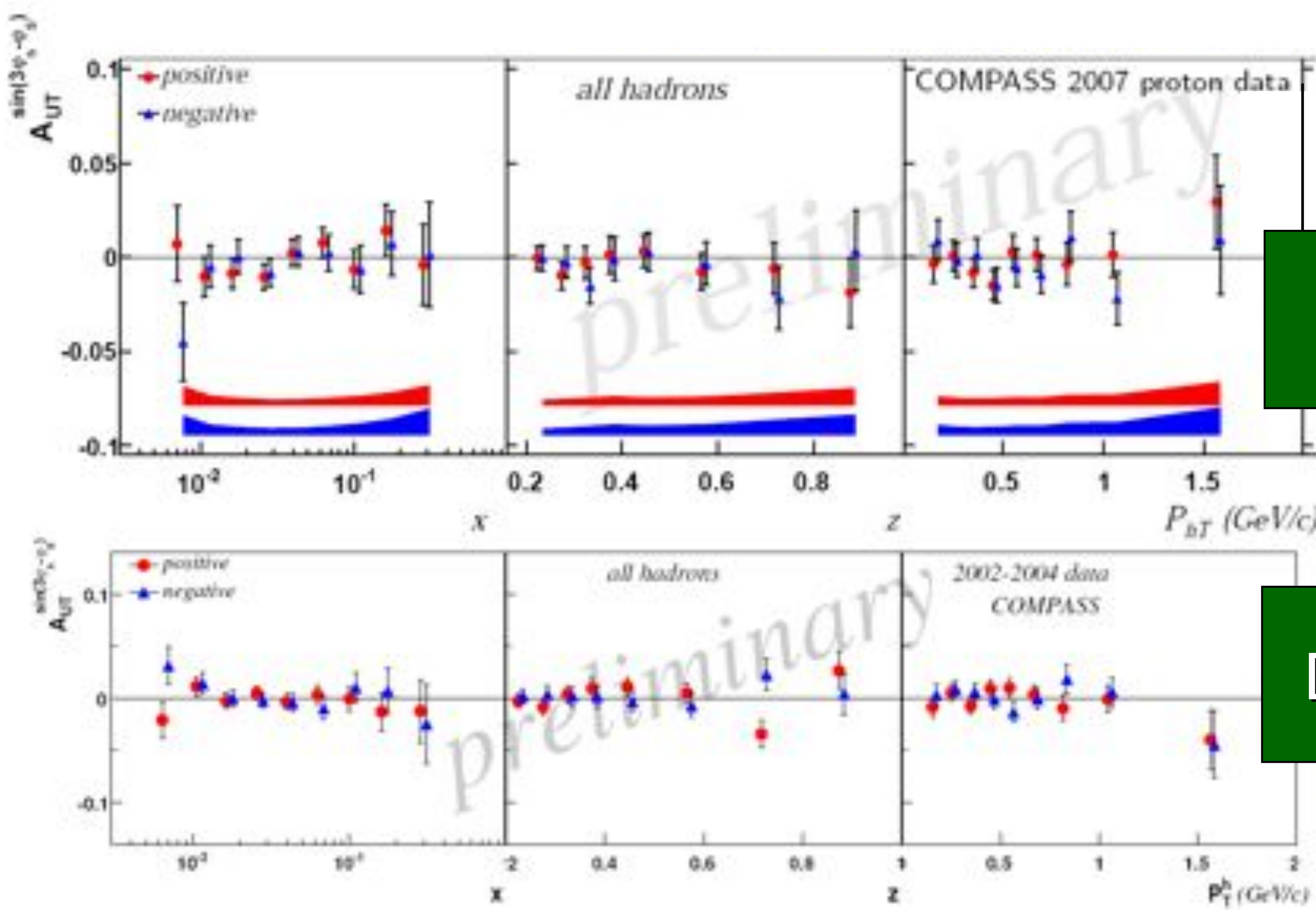
positive!

slightly positive ?

≈ 0

results on worm-gear DF from HERMES, COMPASS, Hall A



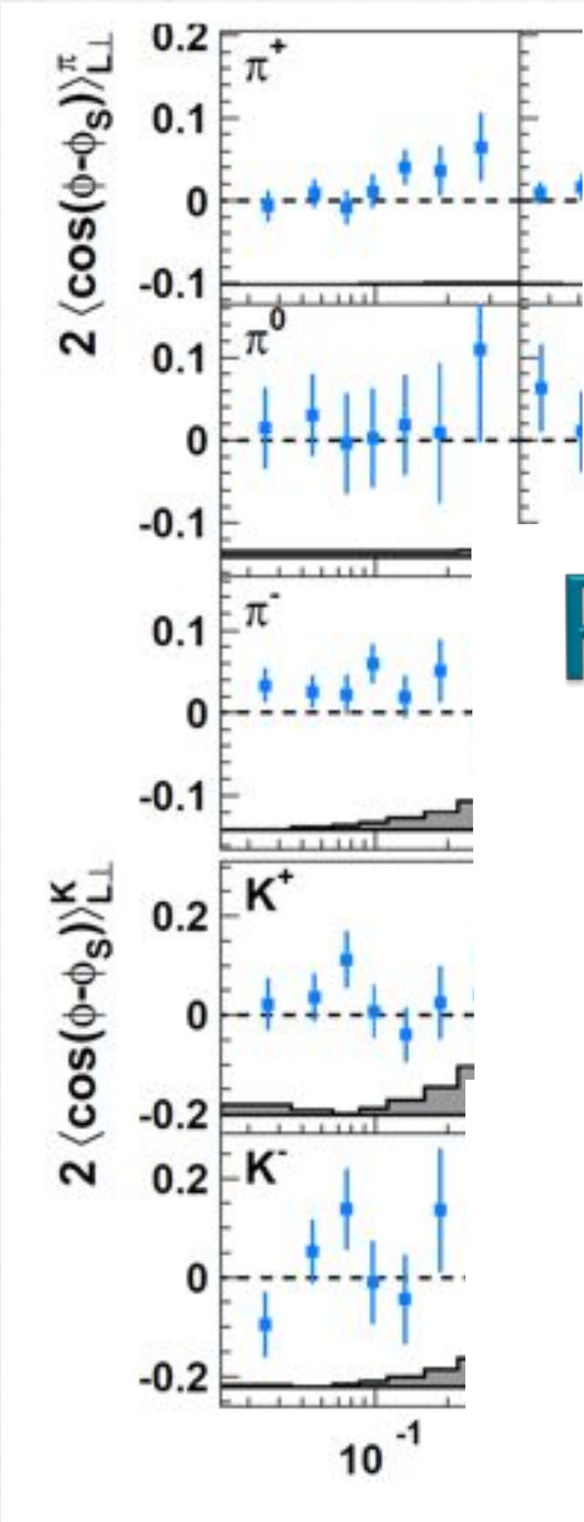


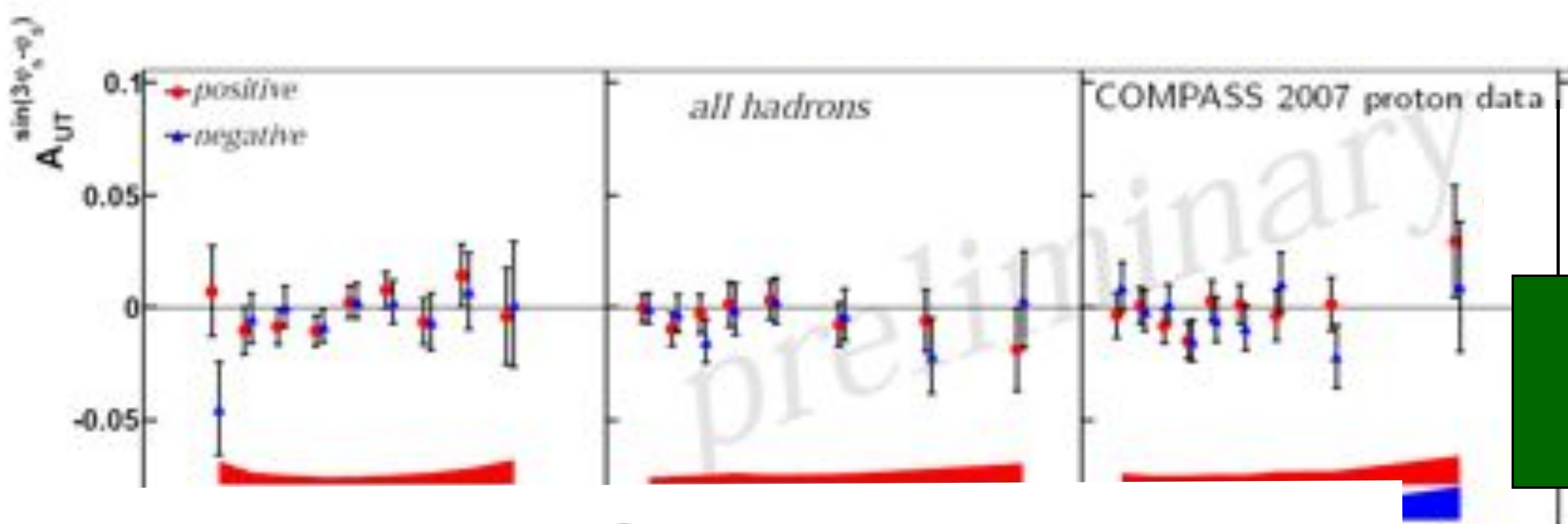
Proton

Deuteron

≈ 0

results on worm-gear DF from HERMES, COMPASS, Hall A

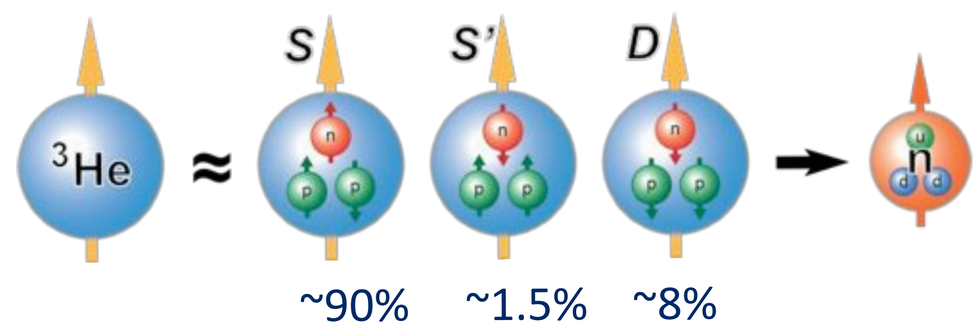


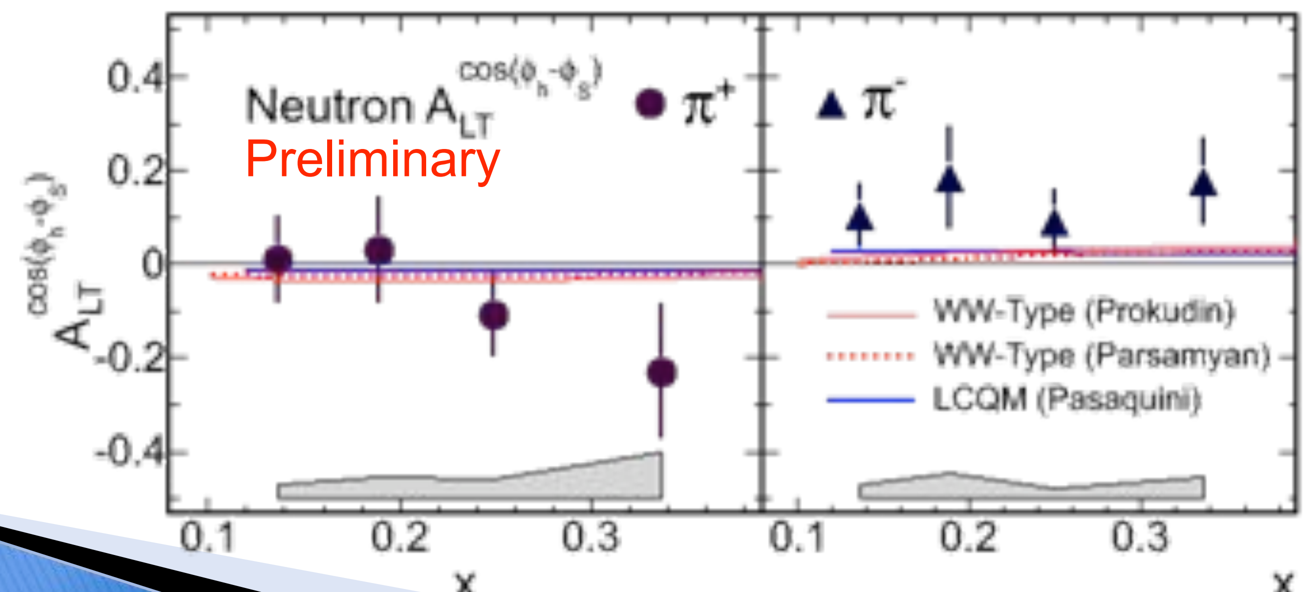


Proton

Deuteron

Polarized ^{3}He Target





Jefferson Lab

Jin Huang <jinhuang@mit.edu>