Spin Sessions Summary
-Experimental Part-
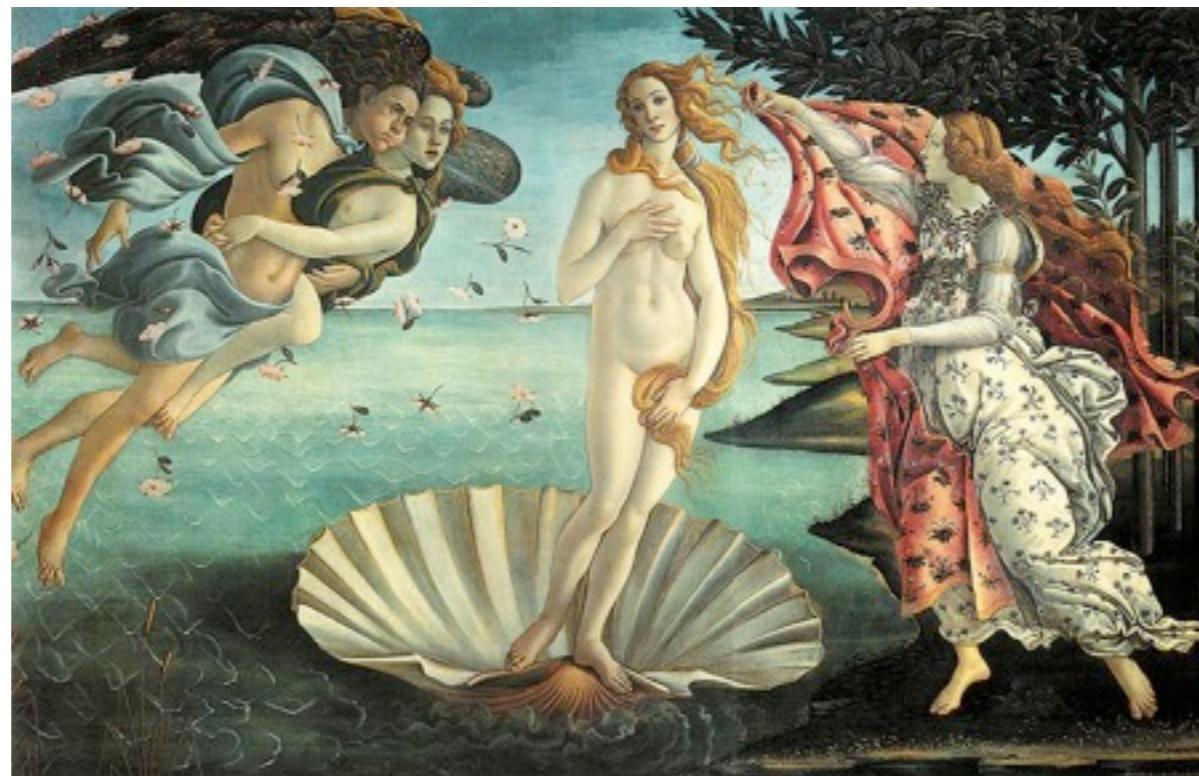
Caroline Riedl
DIS10 @ Florence
April 23, 2010

Volcano Statistics

Eyjafjallajökull and the spin sessions

- Talks given in person: 19

- Talks given via EVO: 11

- Talks given "on behalf of": 5

- Talks canceled: 9

2010: Spin in DIS and pp

- ## Spin Puzzle $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \mathcal{L}$
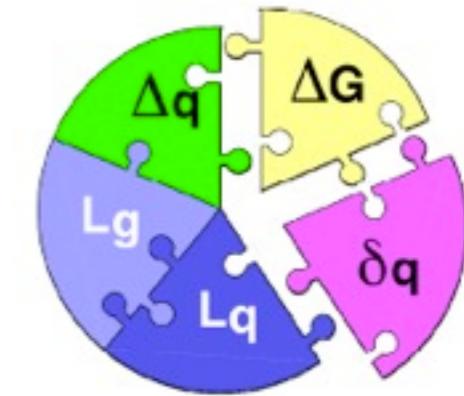
  - Quark helicity distributions: input to improved global fits

  - Gluon polarization ΔG: better constraints

  - Orbital angular momentum of partons $\mathcal{L}$: GPDs, TMDs

- ## Dynamic Hologram of the Nucleon
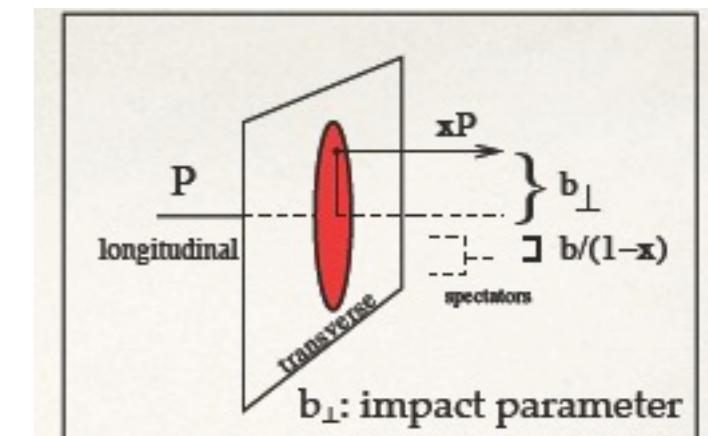
  - Nucleon tomography: Generalized Parton Distributions

 - Correlations between spin & transverse parton momentum

Overview: Experimental Spin Talks @ DIS10

$A_1, g_1, \Delta q, \Delta\overline{u}-\Delta\overline{d}$ → COMPASS

W production $A_L: \Delta\overline{u}/\overline{u}, \Delta\overline{d}/\overline{d}$ → STAR, PHENIX

ΔG → STAR, PHENIX, COMPASS

A_2, g_2 → HERMES

Helicity

HERMES ← DVCS

HERMES ← DVCS $\vec{H}$

HERMES ← A_{UT} ω, ϕ

CLAS ← Generalized Parton Distributions

Exclusive

Transverse Effects

CLAS, PHENIX, STAR, COMPASS, HERMES, BELLE ← Transverse **spin** and TMDs

Transverse momentum dependent FFs → BELLE

SSA in inclusive hadrons on H↑ → HERMES

$\Lambda\uparrow, \vec{\Lambda}$ → COMPASS, HERMES

n SSA in SIDIS → Hall A

SIDIS asy on $\vec{D}$ → COMPASS

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DIS10: Experimental **Spin Sessions Summary** - Caroline Riedl - Florence, April 23, 2010

COMPASS: polarized PDFs

Elena Zemlyanickina

- All d 2002-2006 and p 2007 data (new data 2011)

- Extracted from SIDIS double-spin asymmetries of identified hadrons

✓ Good agreement on non-strange PDFs with results of previous QCD fits
✓ Shape of $\Delta s(x)$ disagrees significantly with previous fits
✓ Flavour asymmetry of the light sea quarks have been observed
 $\Delta\bar{u} \gtrsim \Delta\bar{d}$

5
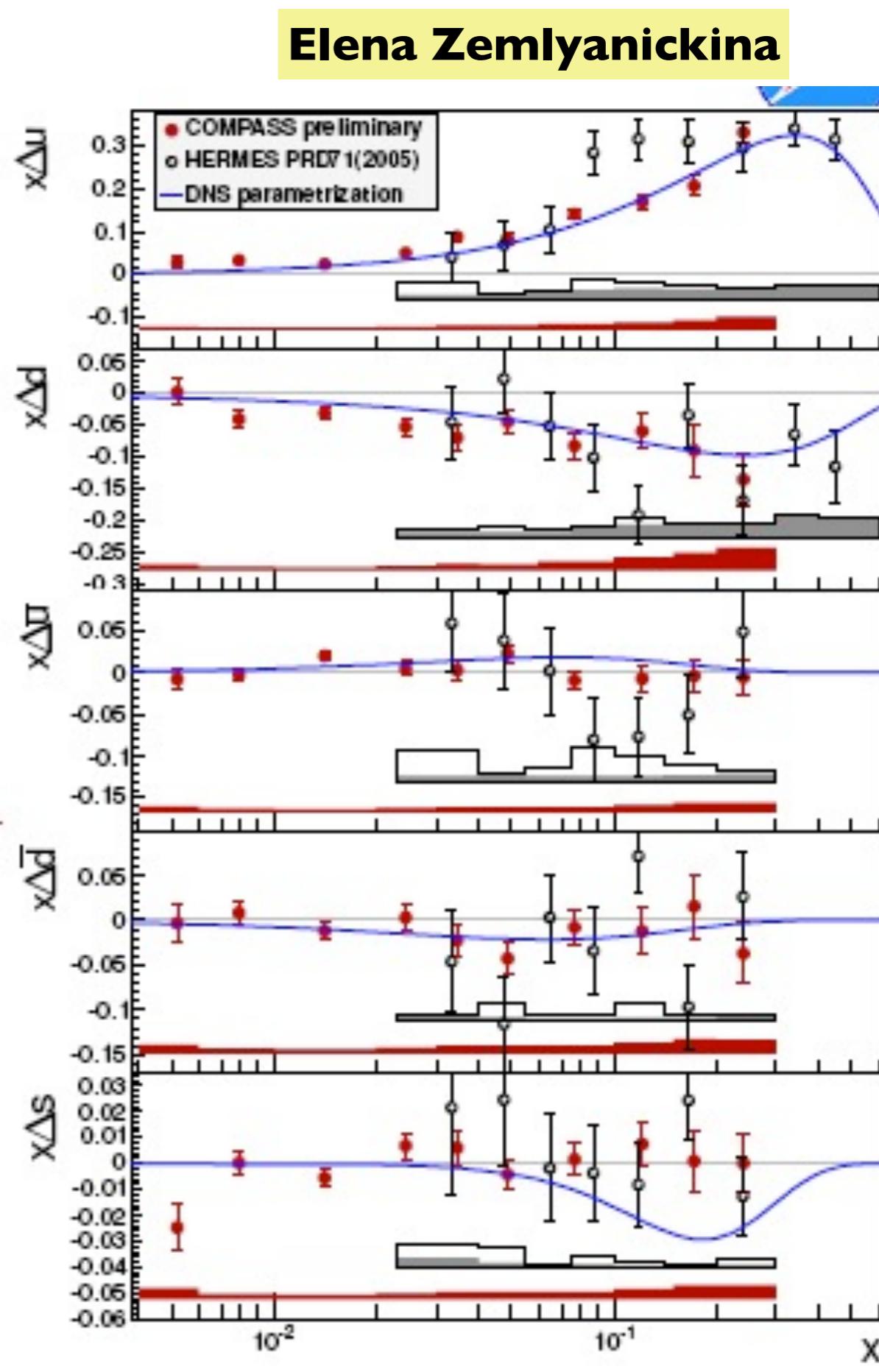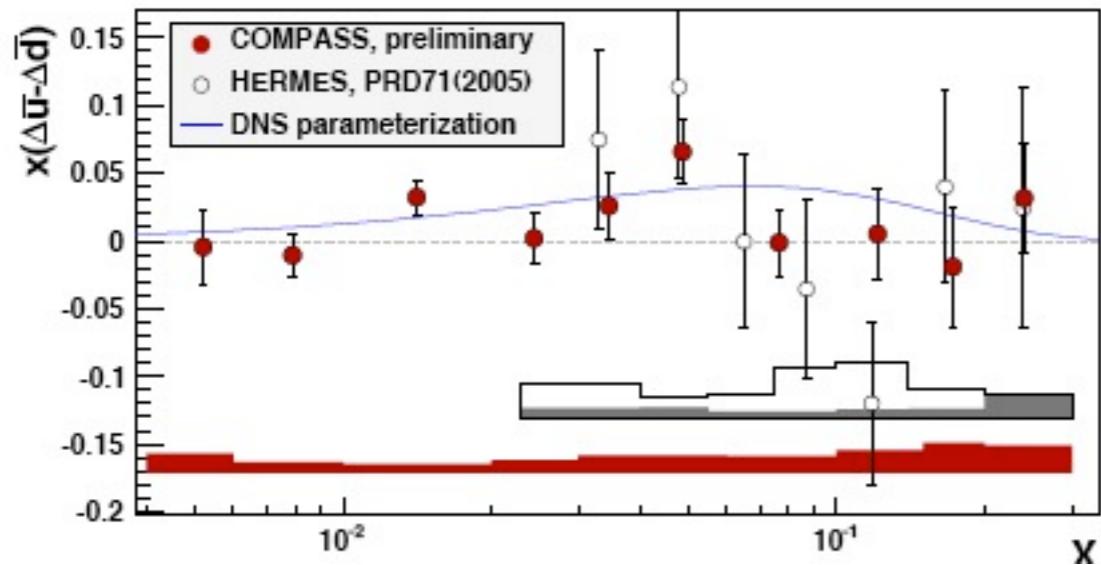
PHENIX: W production in pol. pp

- Ideal probe for polarized PDFs: hard scale, no FF uncertainties

- First 500 GeV run spring 2009

- Parity violating beam-spin asymmetry A_L
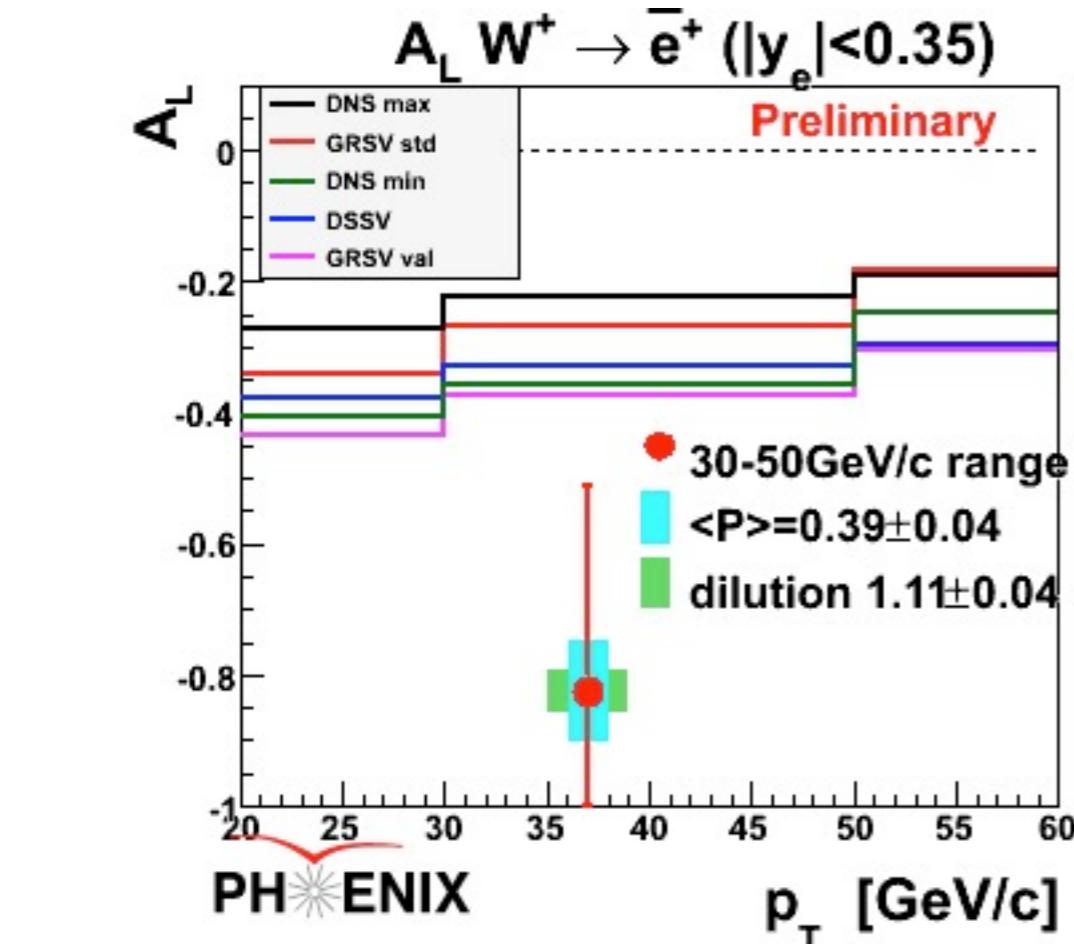
Ken Barish for Mickey Chiu

Proton helicity ="+"

$u_+(x_1)$ ν

W^+

$\bar{d}(x_2)$ l^+

	Background	Signal
p_T Range (GeV/c)	12-20	30-50
Raw Asymmetry	0.035 ± 0.047	-0.29 ± 0.11

Positive charge

EMCal cluster associated with track
Isolation cut ($E_{cone} < 2$GeV)

PH✹ENIX

Preliminary

A_L $W^+ \to \bar{e}^+$ ($|y_e| < 0.35$)

Preliminary

- DNS max
- GRSV std
- DNS min
- DSSV
- GRSV val

- ● 30-50GeV/c range
- ■ $<P> = 0.39 \pm 0.04$
- ■ dilution 1.11 ± 0.04

PH✹ENIX

p_T [GeV/c]
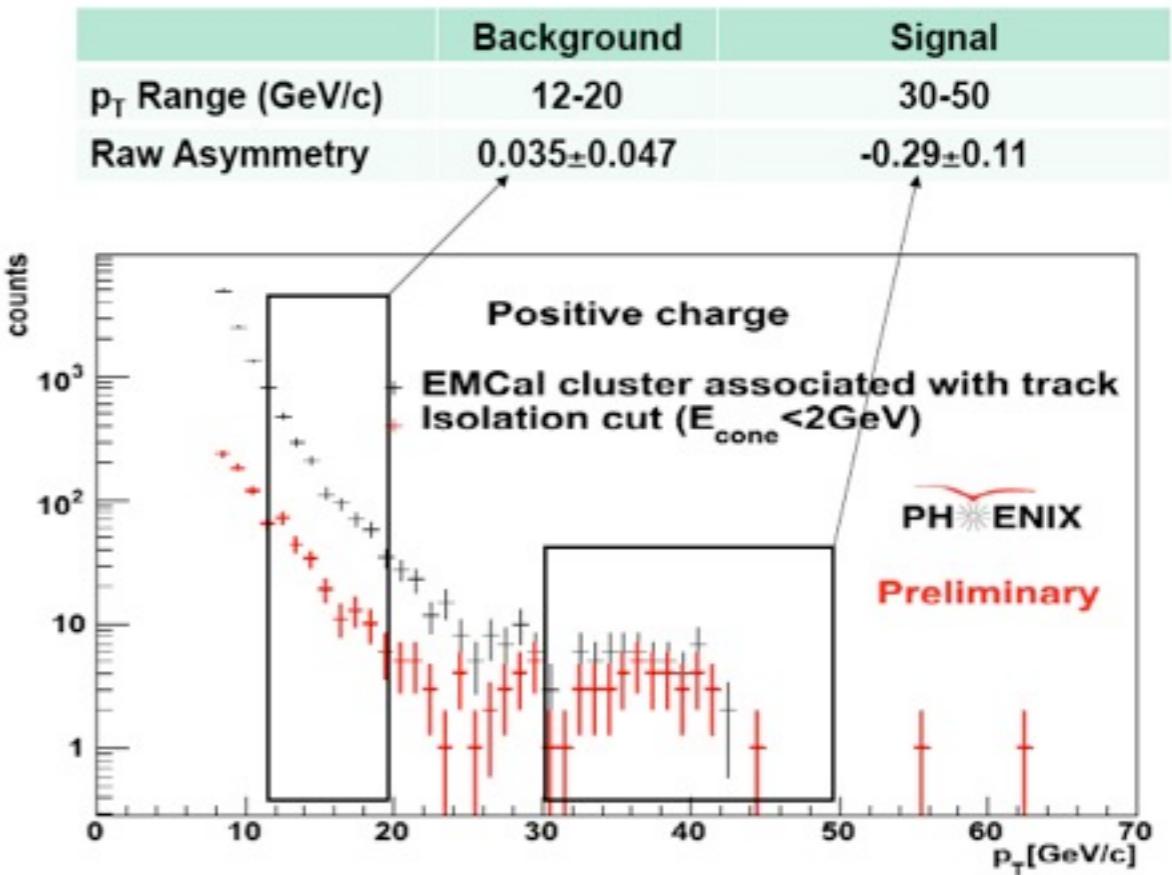
PHENIX prelim

$$A_L^{W^+} = -0.83 \pm 0.31$$

Phenix Muon Arm Upgrade 2011 $\Rightarrow$

improved W measurement

STAR: W production in pol. pp

STAR Preliminary Run9 $\sqrt{s}=500$ GeV

$\vec{p}+p \rightarrow W^{\pm} \rightarrow e^{\pm} + \nu$

$E_T^e > 25$ GeV

W⁻

$A_L = \dfrac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$

W⁺

	W⁻	W⁺	RHICBOS
			DNS-K
			DNS-KKP
			DSSV08
		deFlorian & Vogelsang	
			DSSV08

Syst. uncertainty due to abs. polarization and background

lepton η
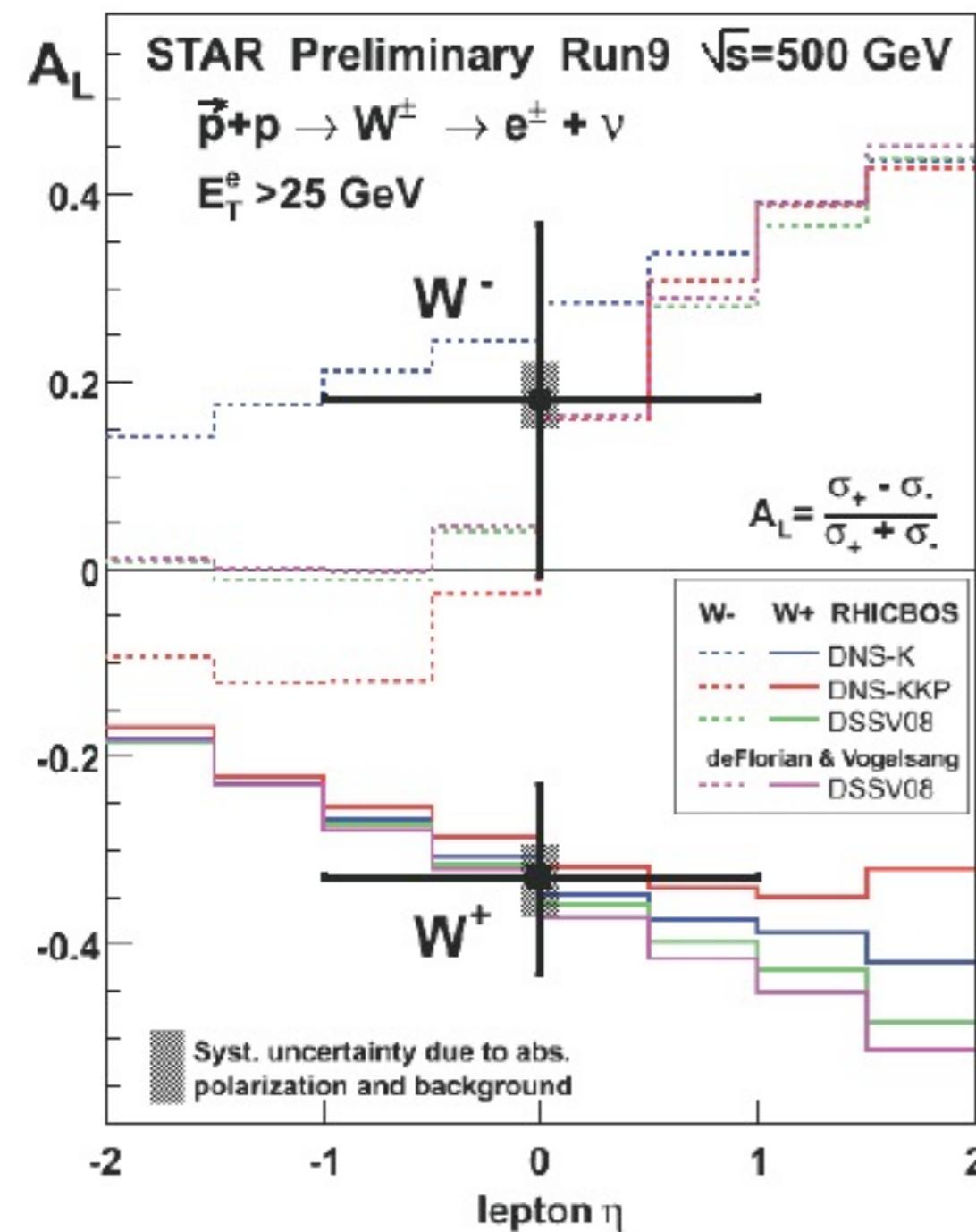
Global analysis predicts positive net helicity difference

$x(\Delta\bar{u} - \Delta\bar{d})$

$$A_L^{W^-} = \frac{1}{2}\left(\frac{\Delta\bar{u}}{\bar{u}} - \frac{\Delta d}{d}\right)$$
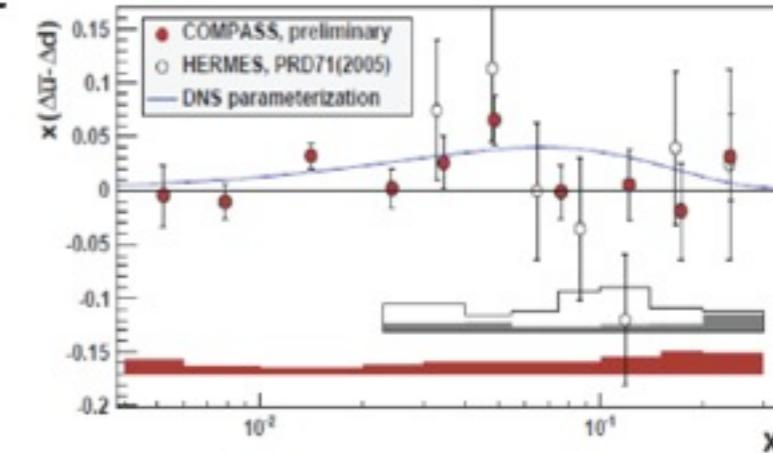
STAR Preliminary Run 9

$$A_L(W^+) = -0.33 \pm 0.10(\text{stat.}) \pm 0.04(\text{syst.})$$

$$A_L(W^-) = 0.18 \pm 0.19(\text{stat.}) {}^{+0.04}_{-0.03}(\text{syst.})$$

$$A_L^{W^+} = \frac{1}{2}\left(\frac{\Delta\bar{d}}{\bar{d}} - \frac{\Delta u}{u}\right)$$

Access to sea quark polarization

- W x-section: reasonable agreement between measured and expected

- STAR forward tracking upgrade (FGT) 2011

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ΔG @ STAR

- Inclusive and correlation measurements

- 1st global analysis including RHIC Spin data

- Strong constrain on size of Δg for 0.05<x<0.2: indication of small value
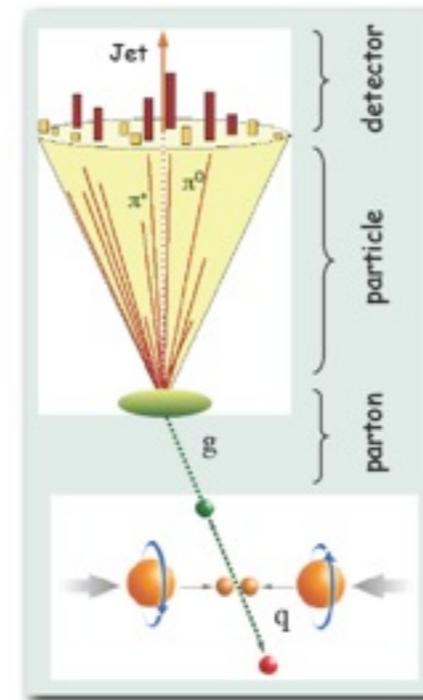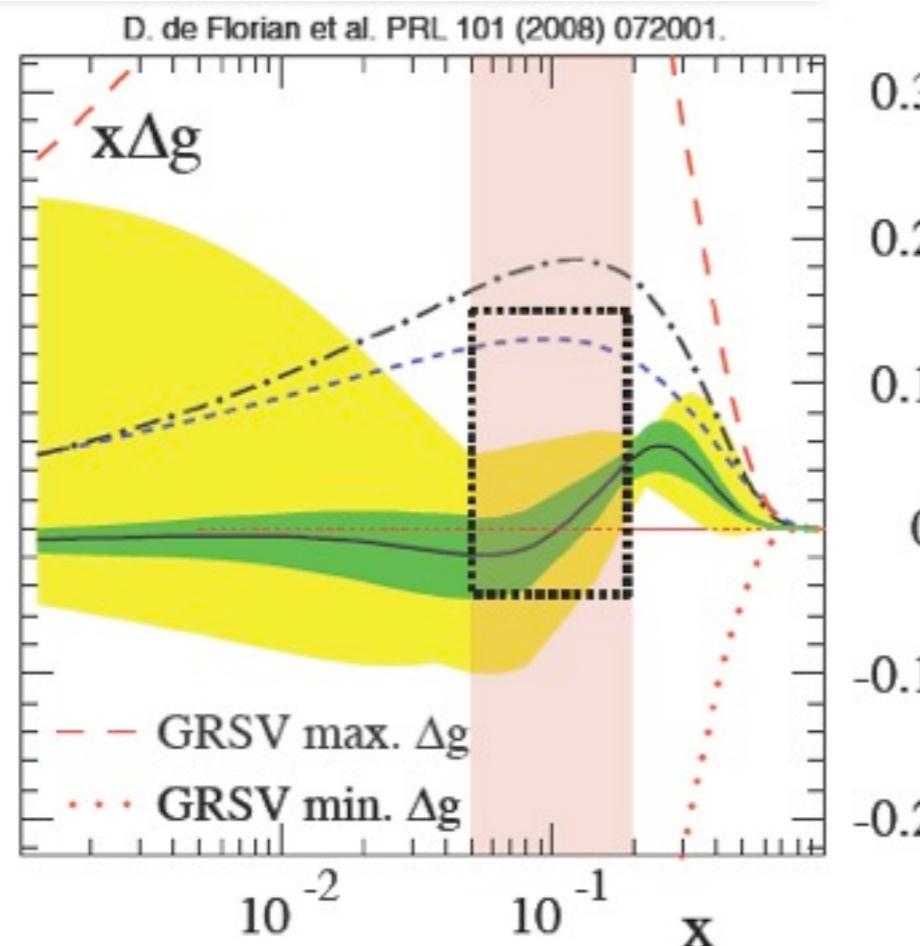
- Run 6 data analyzed; rules out GRSV-MAX

- Run 5 ⇒ 5+6 higher stat precision

  + greater p_T reach

$\vec{p}+\vec{p} \rightarrow \pi^0 + X, \sqrt{s} = 200$ GeV, $-.95 < \eta < .95$

- GRSV standard
- GRSV Δg = 0
- GRSV Δg = -g
- GRSV Δg = g
- GS-C
- DSSV

ΔG≈1.8

ΔG≈0.4

ΔG≈1.0

STAR preliminary

p_T [GeV/c]

D. de Florian et al. PRL 101 (2008) 072001.

$x\Delta g$

— GRSV max. Δg
··· GRSV min. Δg
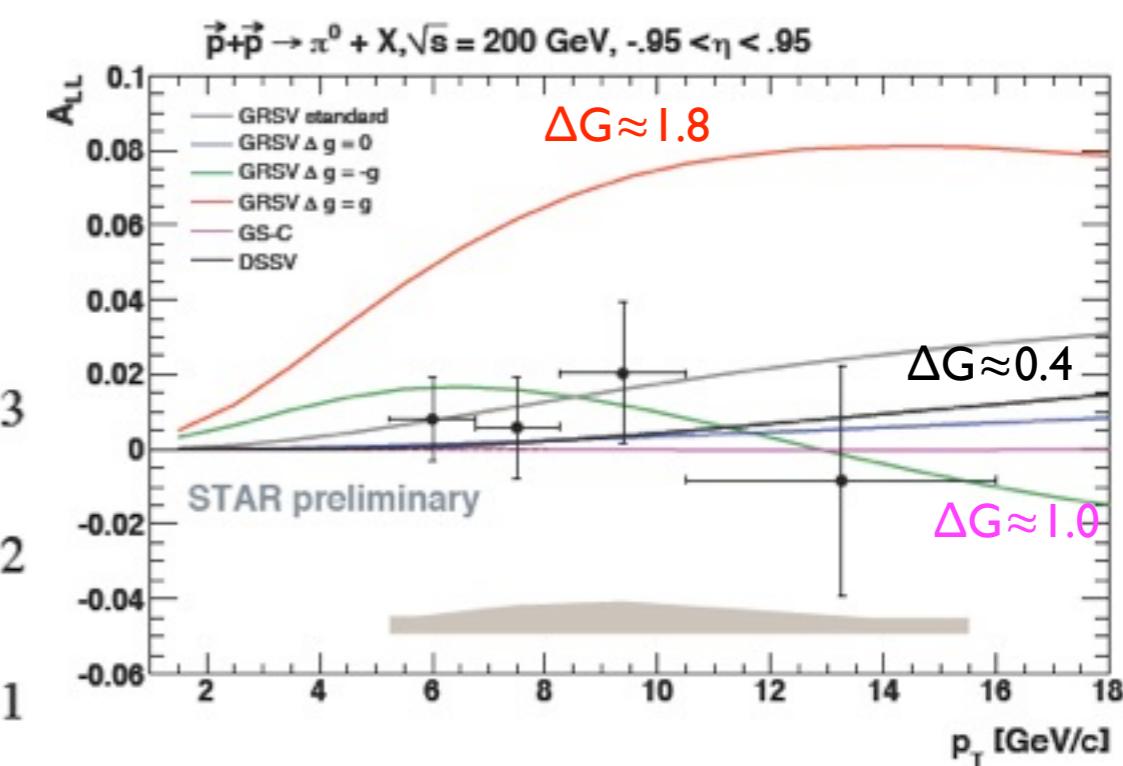
$$A_{LL} \quad \vec{p}+\vec{p} \rightarrow \pi^0 + X$$

- 500 GeV program: extend to small-x ≈ 0.001

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ΔG @ COMPASS

- D^0 double-spin asymmetries in photon-gluon fusion (open charm)

- 2002-2006 data and first time 2007

- Neural network used with signal and background model

$$\frac{\Delta G}{G} = -0.08 \pm 0.21 \ (\pm 0.11)$$

$$@ <x_g> = 0.11, \ <\mu^2> = 13 \ (GeV/c)^2$$

COMPASS 2007 $D^0_{K\pi}$ (D* tagged)

Preliminary

N(D^0) = 4600
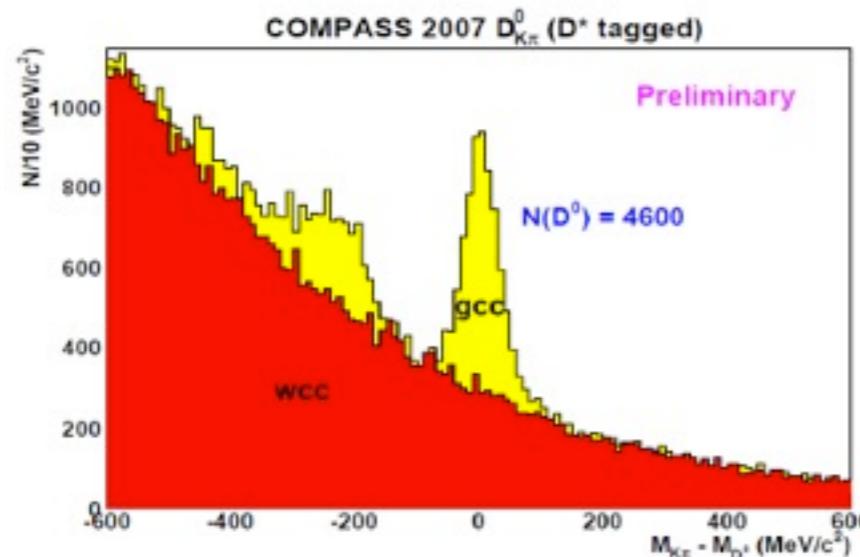
- LO extraction from data

- NLO under study

Legend:
- COMPASS, open charm, prel., 02-07
- COMPASS, high p$_T$, Q^2<1 (GeV/c)^2, prel., 02-04
- COMPASS, high p$_T$, Q^2>1 (GeV/c)^2, prel., 02-04
- HERMES, single high p$_T$ hadrons, all Q^2, arXiv:1002.3921
- SMC, high p$_T$, Q^2>1 (GeV/c)^2
- fit with ΔG>0, μ^2=3(GeV/c)^2
- fit with ΔG<0, μ^2=3(GeV/c)^2

9
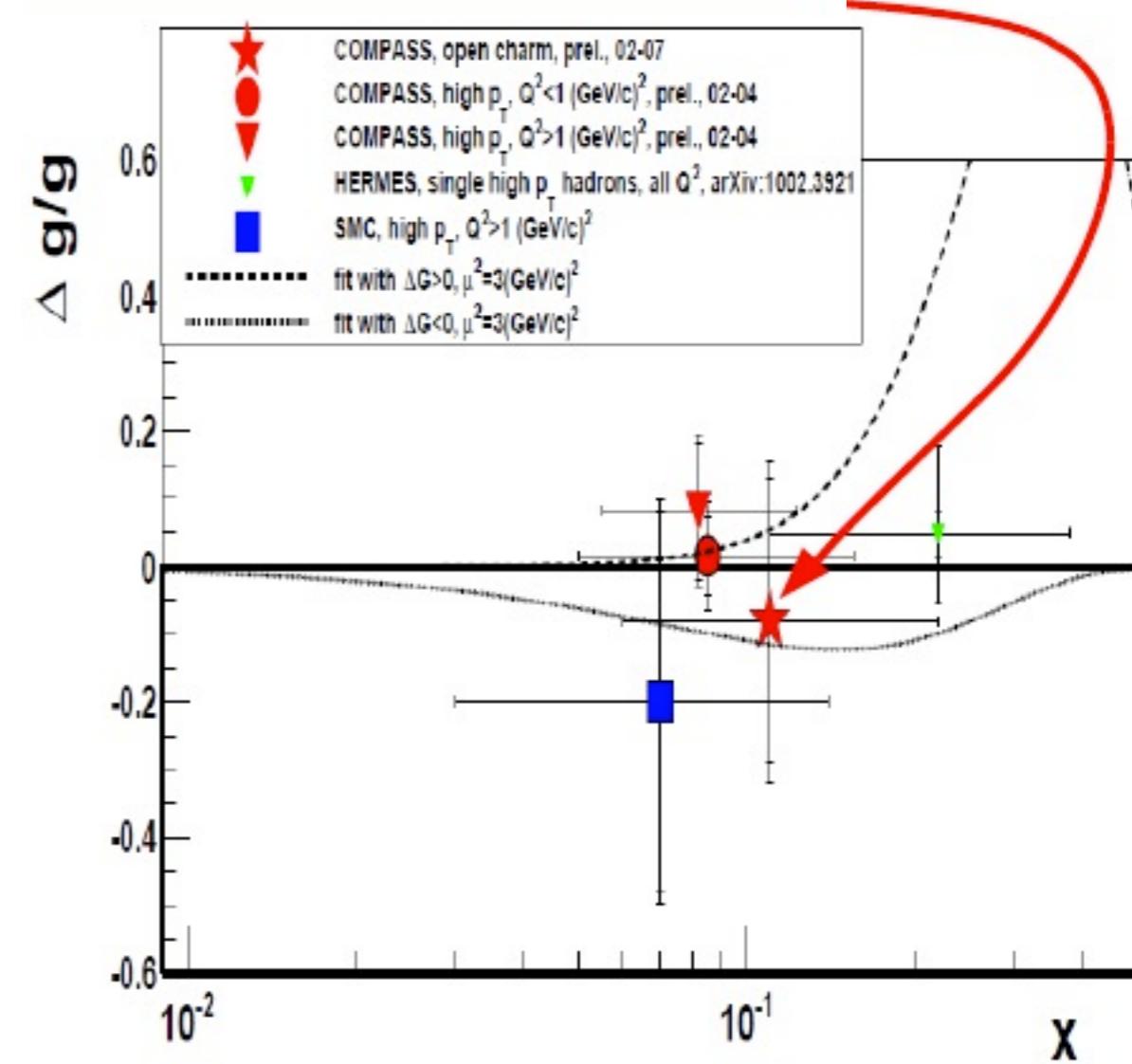
HERMES: A_2 and g_2

- QPM: $g_2 = 0$

- OPE:

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

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

- Sensitivity to g2 is highest if $\alpha = 90°$

Spin Plane

$\vec{S}_N$

α

$\vec{k}, \vec{S}_I$

ϕ

θ

$\vec{k}'$

Scattering Plane

- Complete transversely polarized data set 2002-2005

- QED radiative + detector smearing unfolding
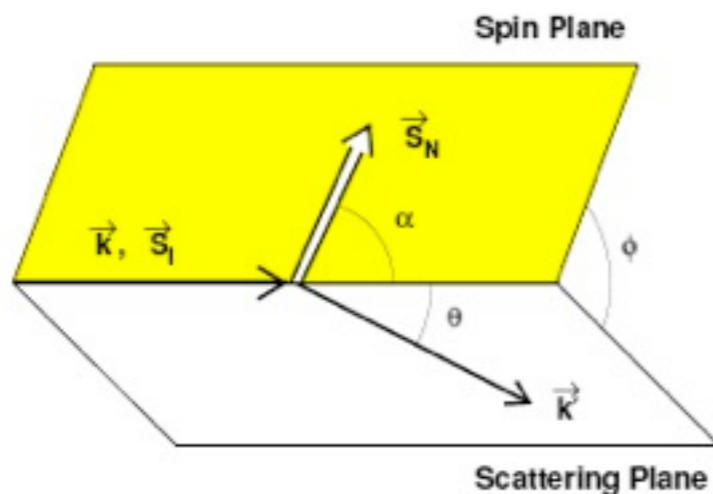
Sucessful test of Wandzura-Wilczek relation

and good transition to Transversity & Sivers!
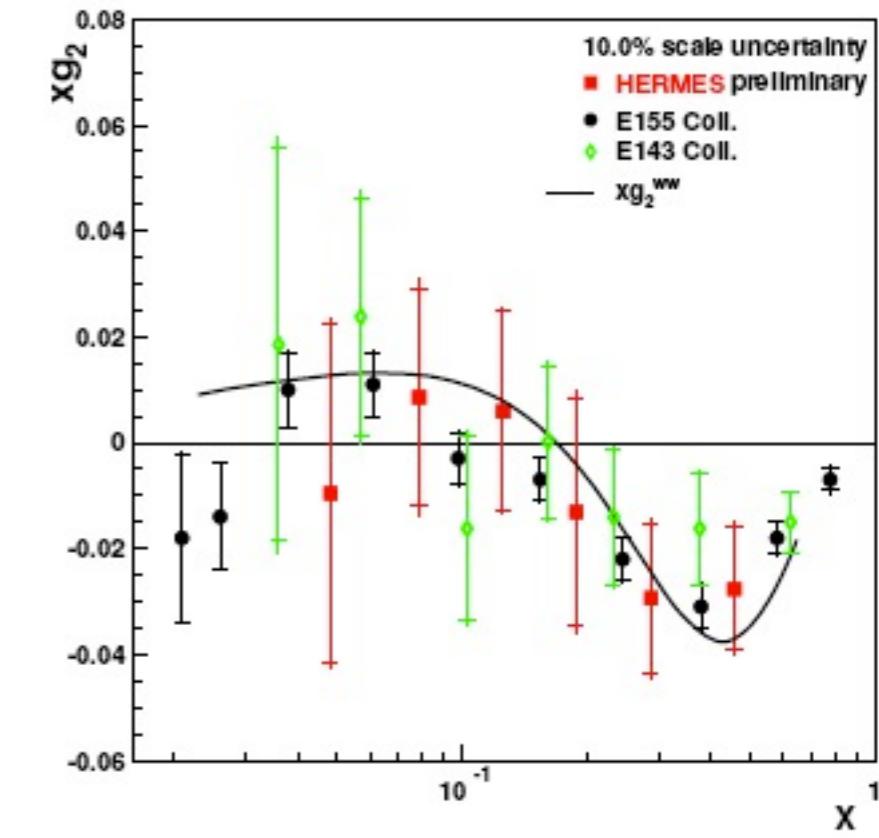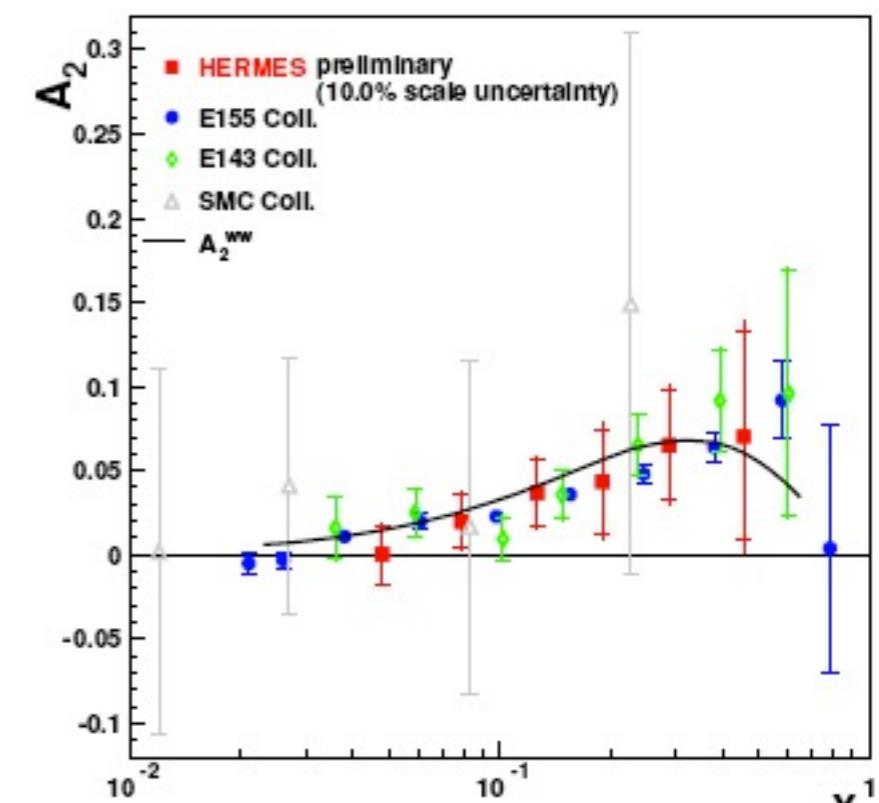
Transverse Spin & TMDs

Spin-momentum structure of the nucleon

TMDs = transverse momentum dependent PDFs

- Quarks can have **intrinsic transverse momentum** relative to infinite momentum of hadron
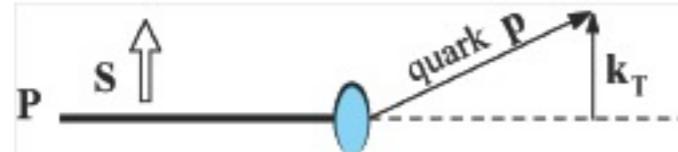
- **TMDs**: give correlation between spin and transverse momentum

- Only **f₁, g₁L, h₁** 'survive' integration over trans.mom

- Except for f_1 and g_{1L}: need SIDIS (or Drell-Yan)

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

chiral odd

Boer-Mulders

Twist-2 TMDs

pretzelosity

Transversity

worm-gear

Sivers

$$f_{1T}^{\perp} =$$

$\Rightarrow \sin(\Phi - \Phi_S)$ modulation

TMDs @ HERMES

Gunar Schnell

Sivers pions

7.3% scale uncertainty

u-quark Sivers DF < 0

$2 \langle \sin(\phi - \phi_S) \rangle_{UT}$

π^+

π^0

π^-

x   z $P_{h\perp}$ [GeV]

d-quark Sivers DF > 0
(cancelation for π^-)
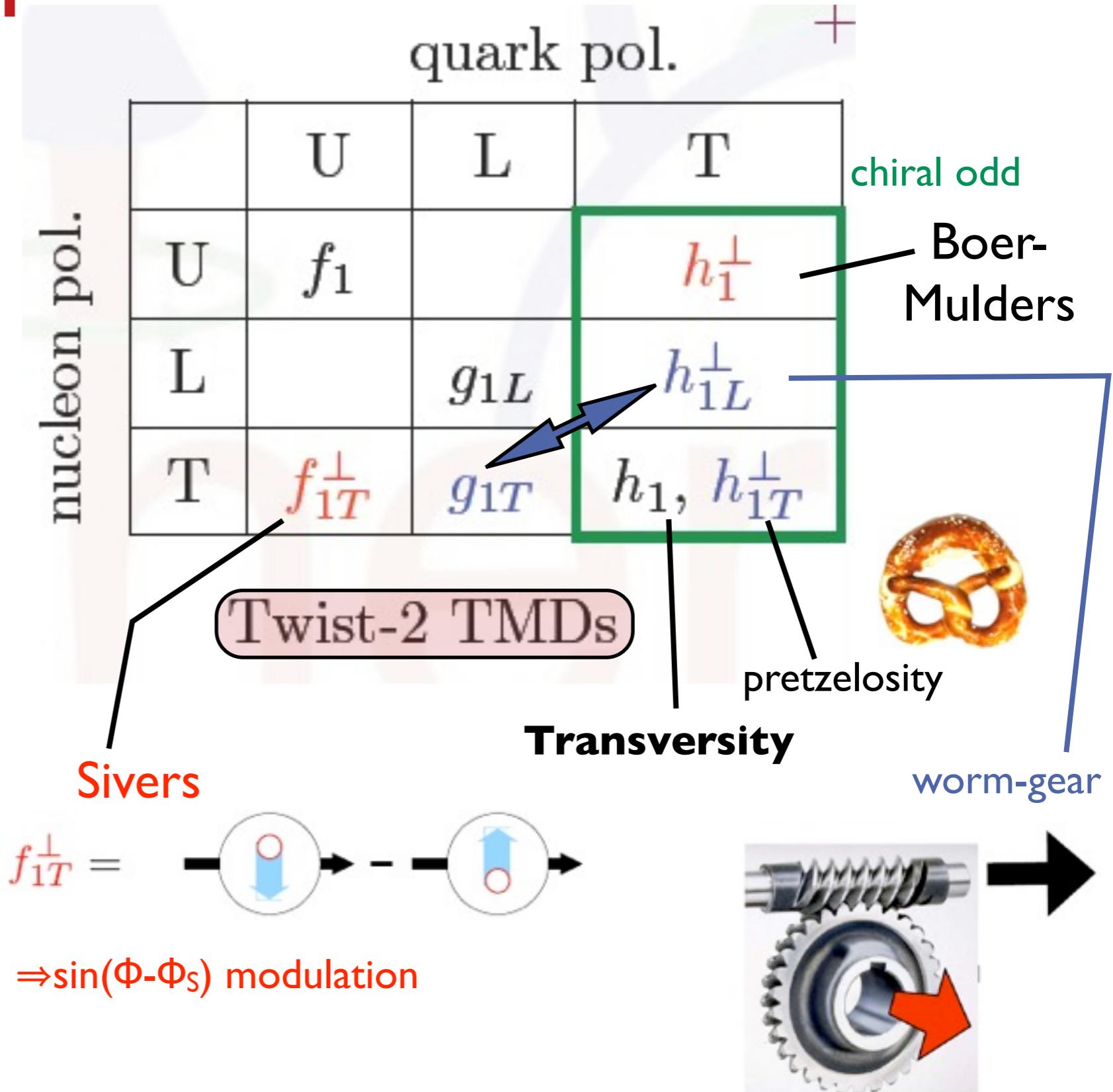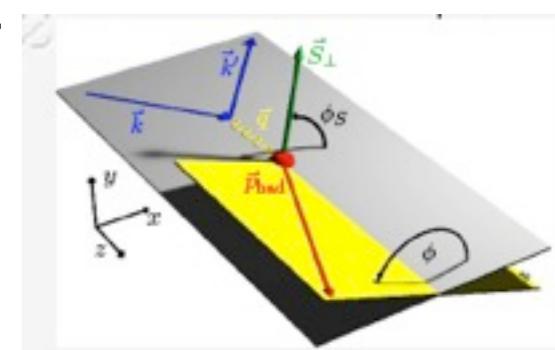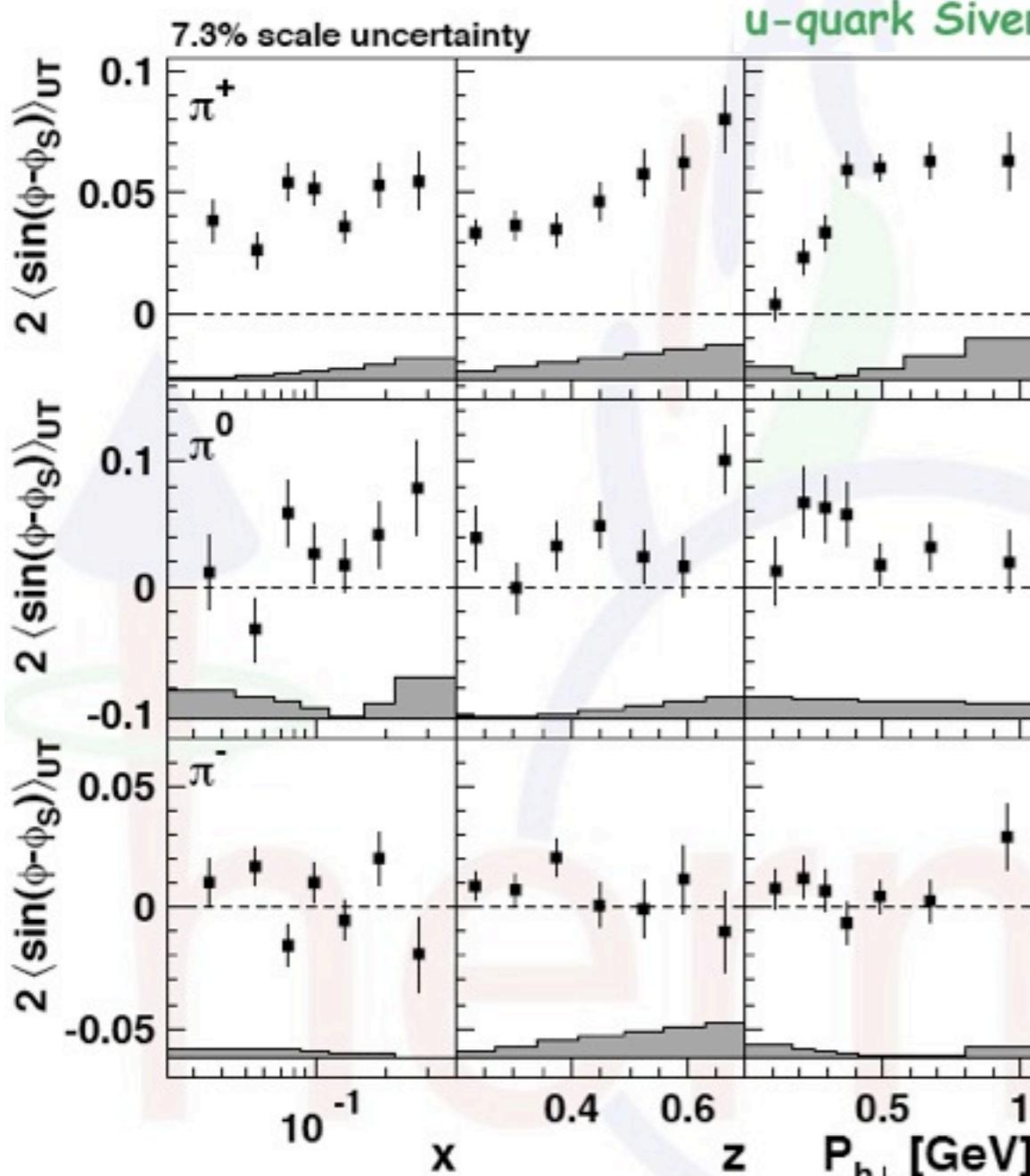
## Evidence for orbital momentum of quarks

$L_z^u > 0$

FSI

π^+

[*M. Burkardt*, Phys. Rev. D66 (2002) 014005]

• Pion difference asymmetry: access to Sivers u-valence DF
• $\sin(\Phi_S)$: large signal found
• $\sin(2\Phi - \Phi_S)$: no signif. signal
• Both related to worm-gear, pretzelosity, Sivers

$K^+ - \pi^+$ "Kaon Challenge"

$2 \langle \sin(\phi - \phi_S) \rangle_{UT}^{K^+} - 2 \langle \sin(\phi - \phi_S) \rangle_{UT}^{\pi^+}$
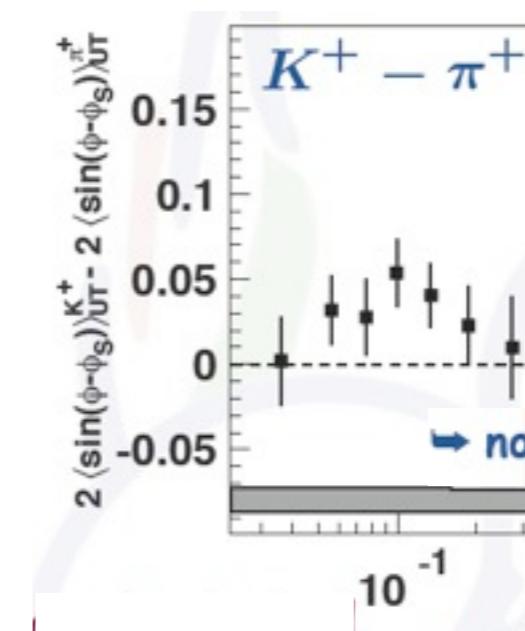
$K^+ = |u\bar{s}\rangle$ & $\pi^+ = |u\bar{d}\rangle$

➡ non-trivial role of sea quarks?

x

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TMDs @ COMPASS

Anna Martin

- Entended kinematic domain wrt HERMES

- **Collins FFs**: correlation between transverse polarization of quark and trans. momentum of produced hadron


Sivers hadrons

COMPASS 2007 proton data
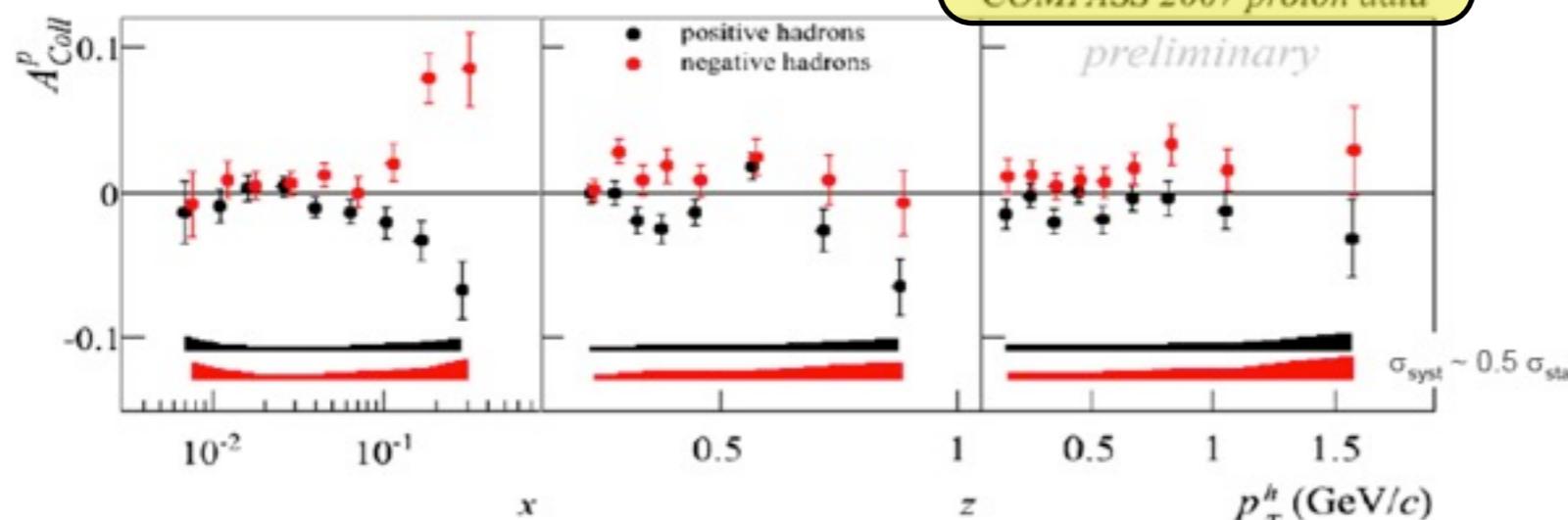
- Clear positive signal in valence region

- Compares well to fit to previous world data
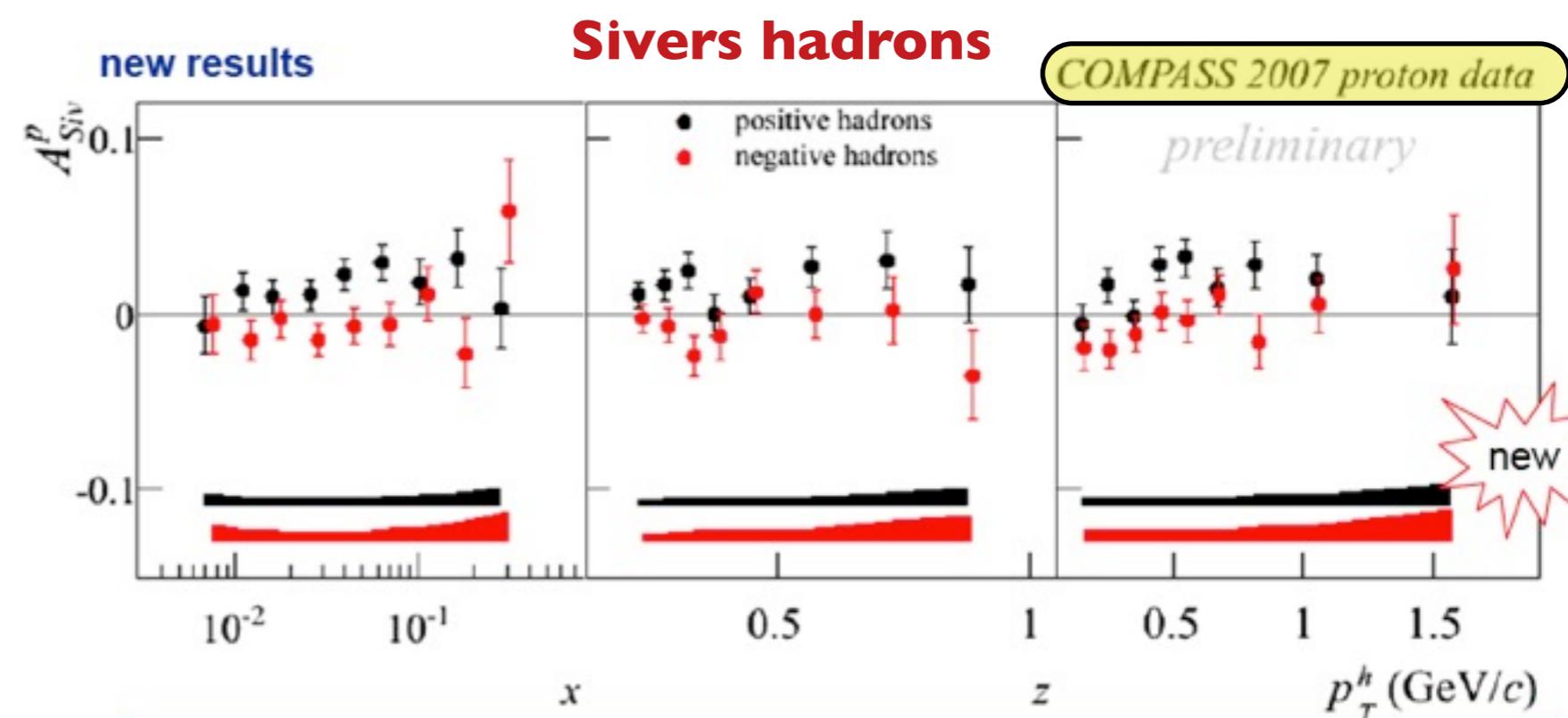
- Now evidence for a positive signal for h+, smaller than HERMES (factor of 2)

- Reason: W-dependence?

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TMDs @ CLAS

Patrizia Rossi

SIDIS pions on longpol target "worm-gear"

BSA for SIDIS π^0
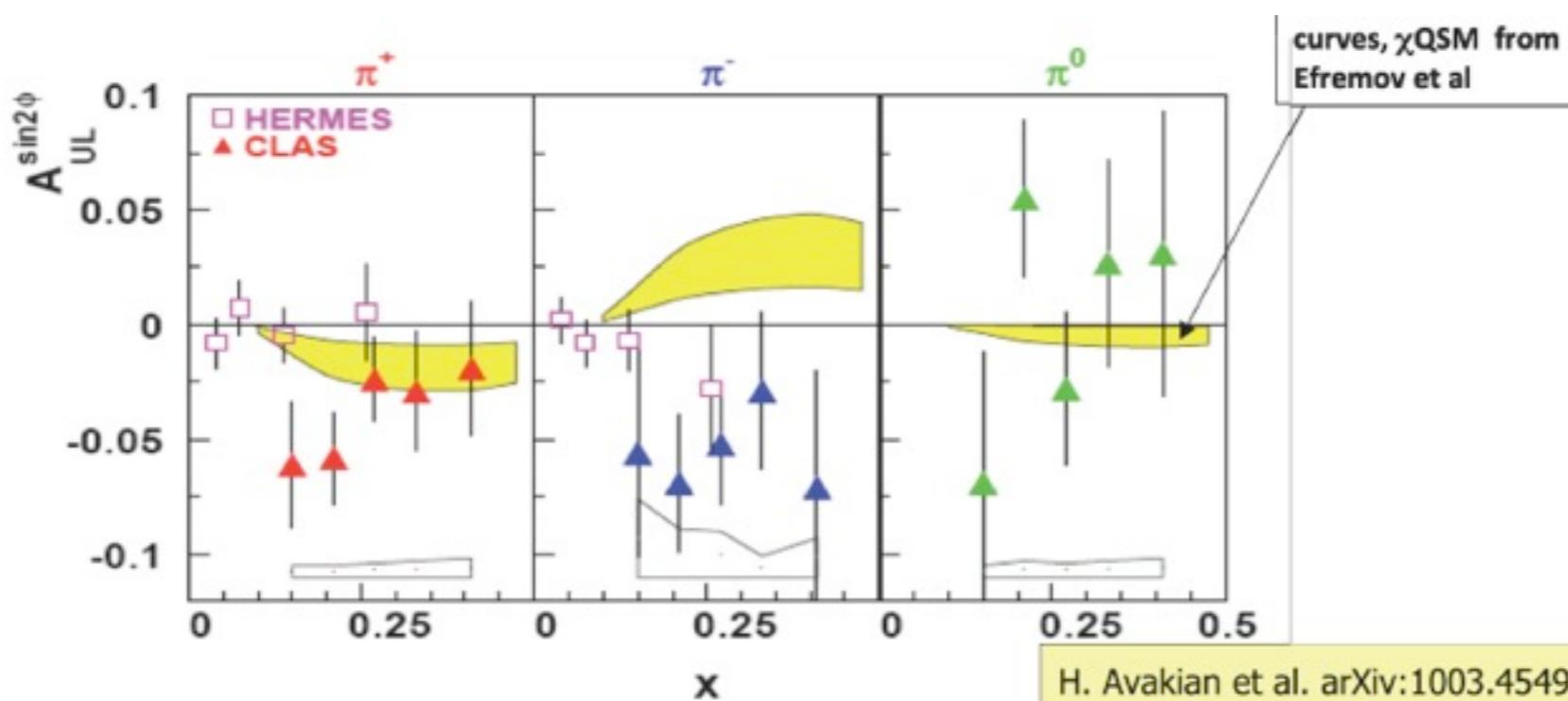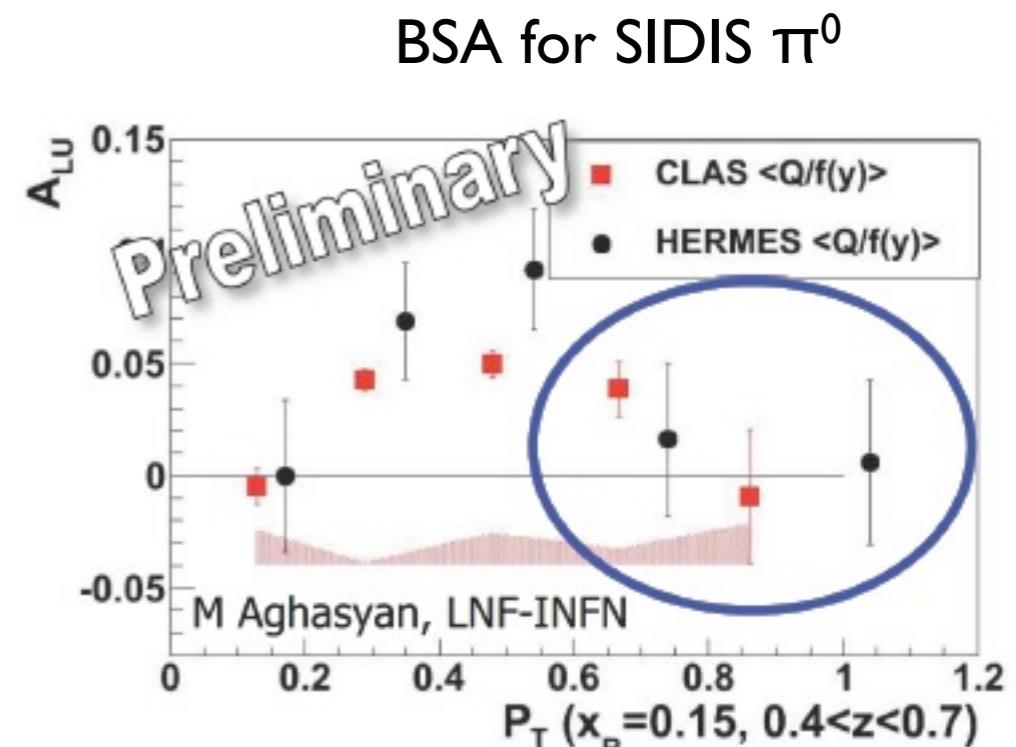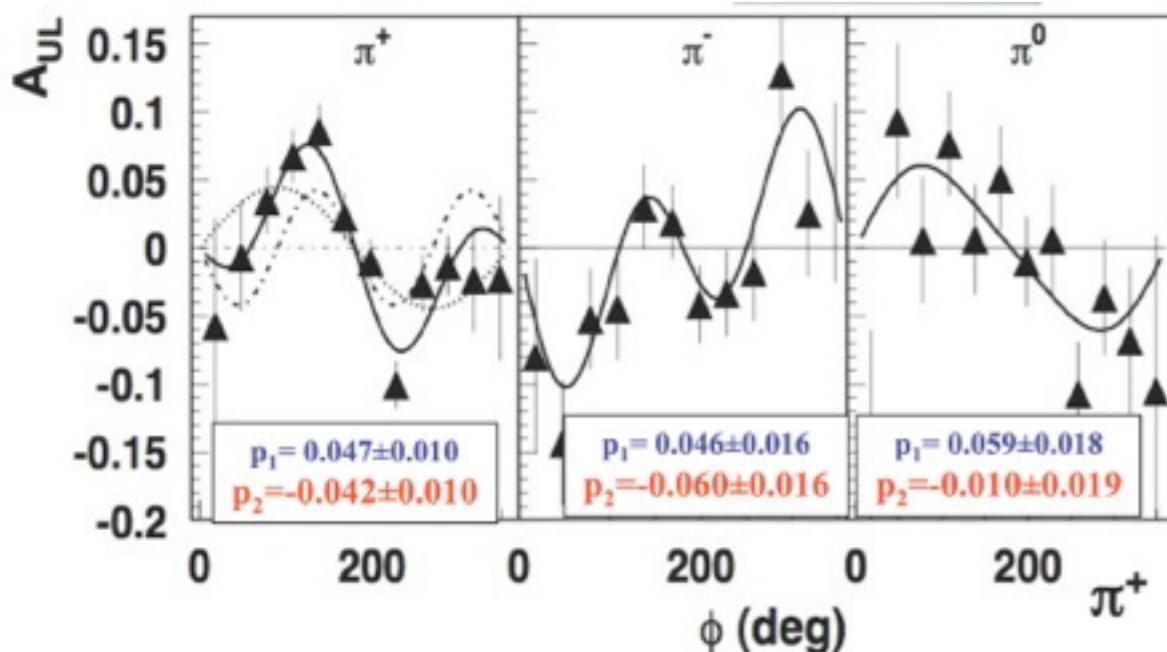
- BSA for π^+ similar $\Rightarrow$ small Collins type contributions for π^+?

- Future: transpol HD-ice target

- JLab12: wider kinematic coverage; high lumi; high polarization

curves, χQSM from Efremov et al

H. Avakian et al. arXiv:1003.4549

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Transverse IFFs @ BELLE

Anselm Vossen

- First Measurement of **Interference Fragmentation Function**

- Measured: azimuthal asymmetries in di-hadron correlations

Interference Fragmentation Function:
Fragmentation of a transversely polarized quark q into two spin-less hadron h1, h2 carries an azimuthal dependence:

$$\propto \left(\vec{k} \times \vec{R}_T \right) \cdot \vec{s}_q$$

$$\propto \sin \phi$$

- Systematics to be finalized
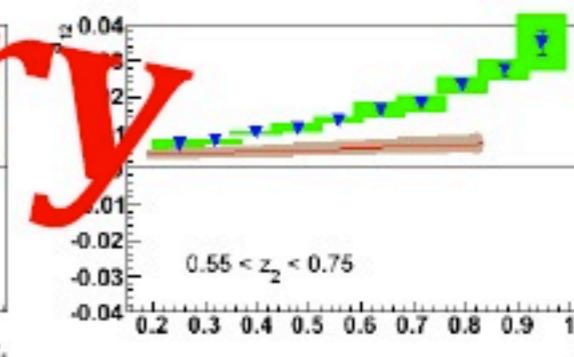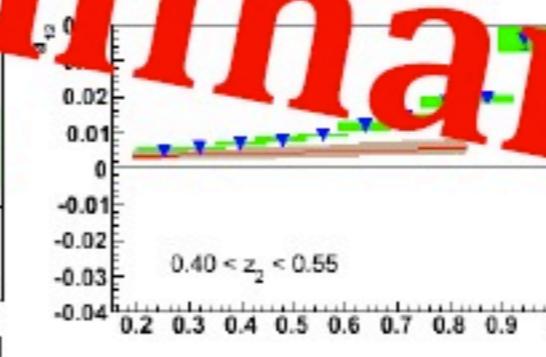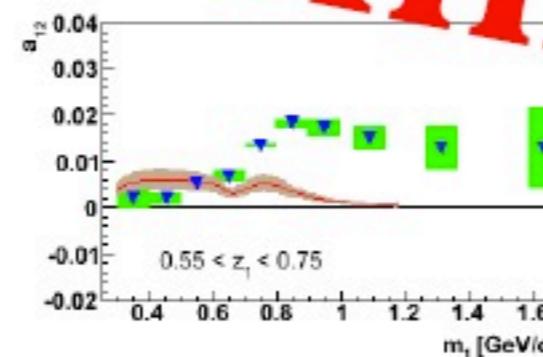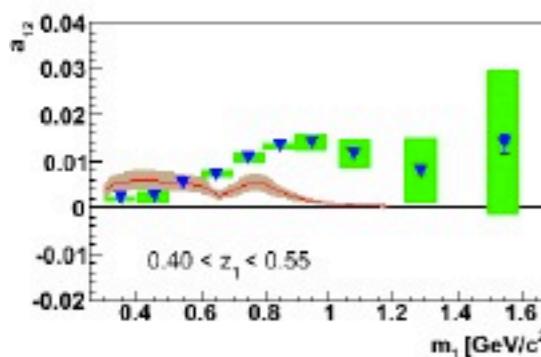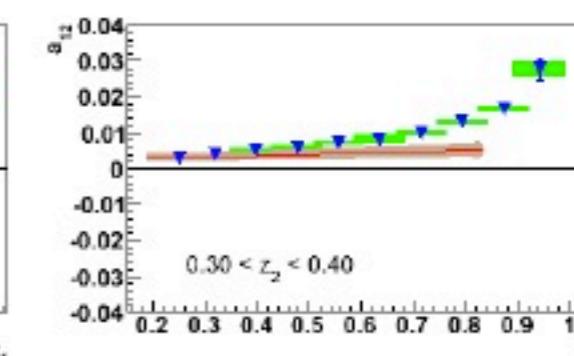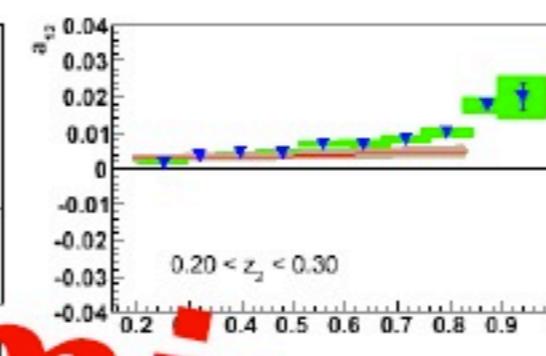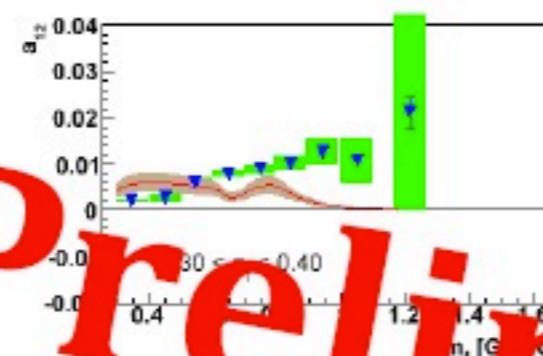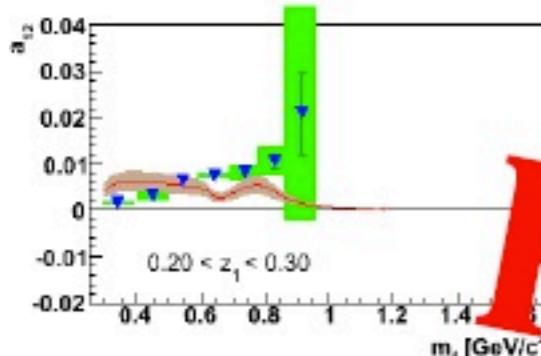
- Future goal: combined analysis of SIDIS, pp, e+e-

    - Extract transversity

    - Disentangle contributions to A_N

TMDs @ RHIC

Andrew Gordon

Long History of transverse SSA in pp

STAR

1976   2002   1991   2008
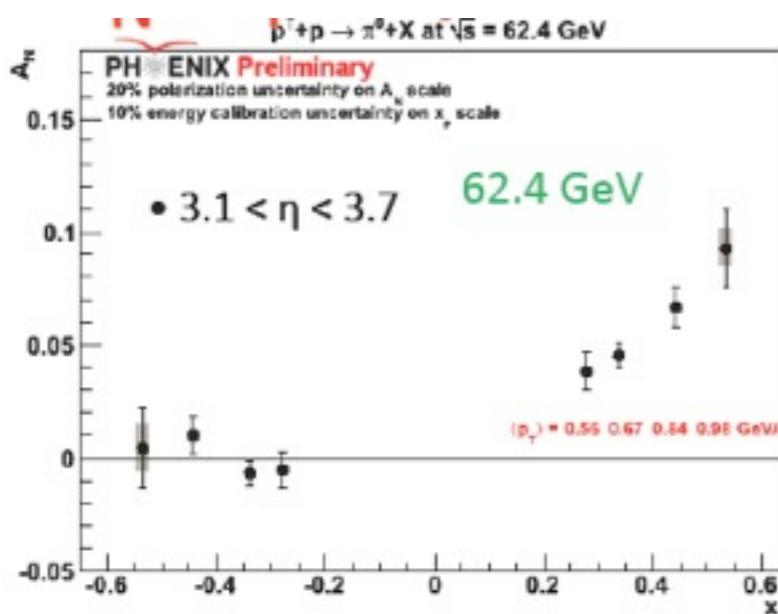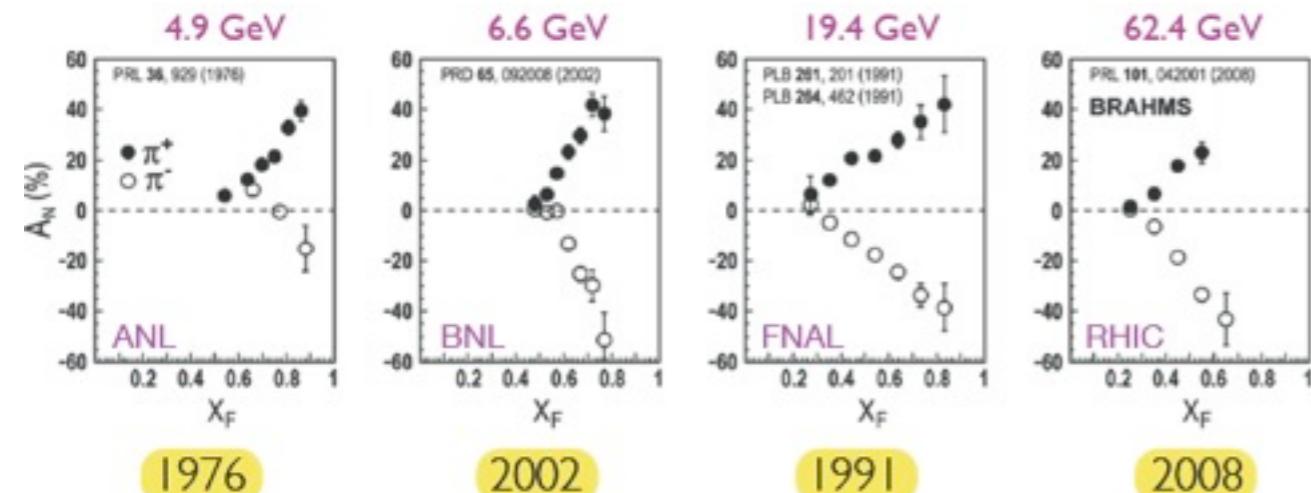
Anselm Vossen for Vipuli Dharmawardane

PHENIX

$PP\uparrow \to \pi X$: largest contributions to A_N come from Sivers mechanism

- Large asymmetry in forward region

- Ongoing analysis: central jet Collins asymmetry

- Asymmetry for ω for understanding of Collins effect

- Rising p_T dependence @ fixed x_F bins not explained

- Extraction of gluon Sivers by $pp\uparrow \to DX$

- Measurement of transverse asymmetry A_{UT}: extraction of transversity needs IFF ($\to$ BELLE)

HERMES: SSA in inclusive hadrons

Alejandro Lopez Ruiz
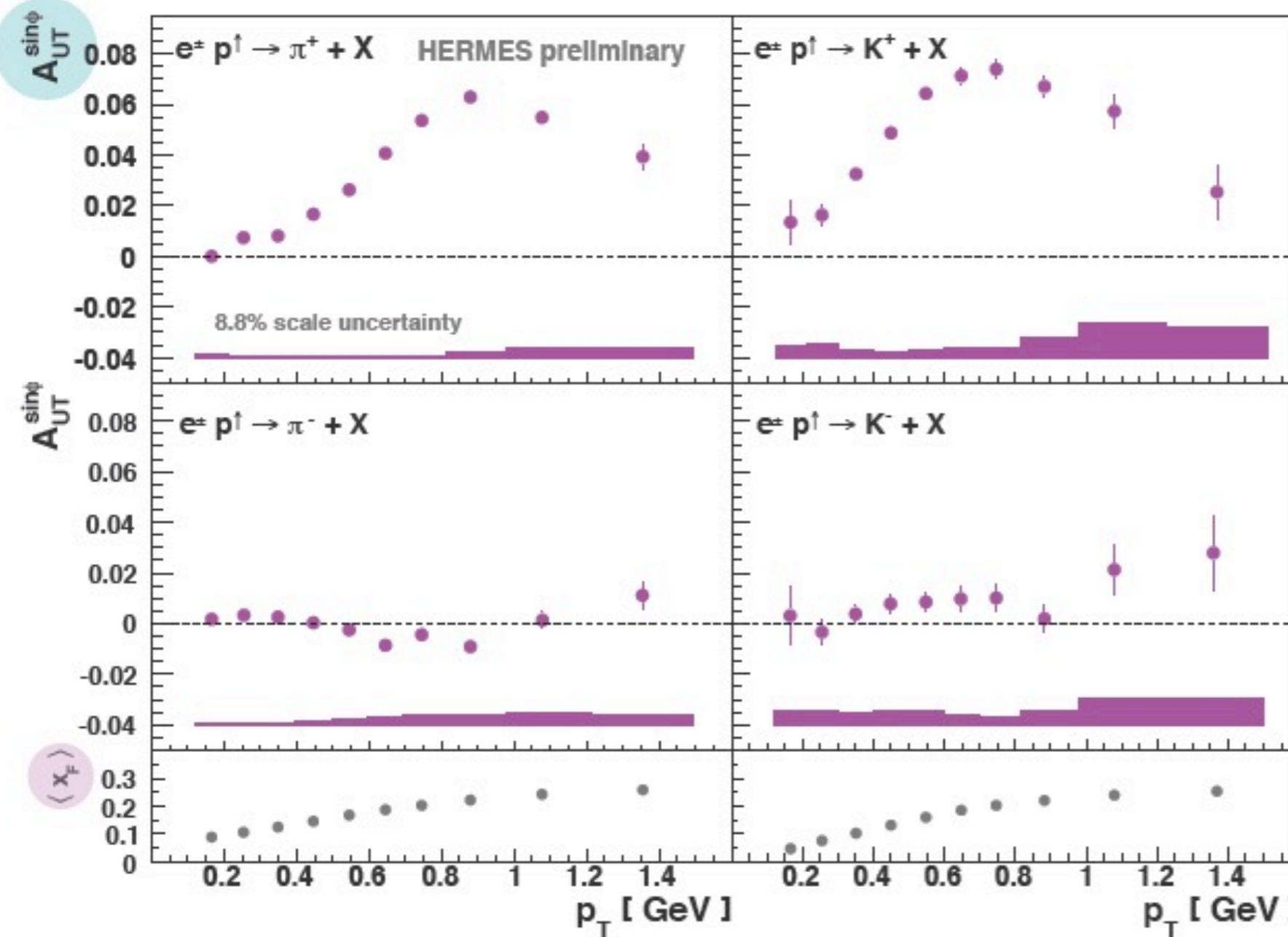
- $ep\uparrow \rightarrow hX$

- No lepton detection required

- A_N in ep is smaller in size than for pp

- A_N resembles Sivers effect

- Also available: 2dim binning in (x_F, p_T)

COMPASS: SIDIS h on longitudinally polarized D

sinΦ moment
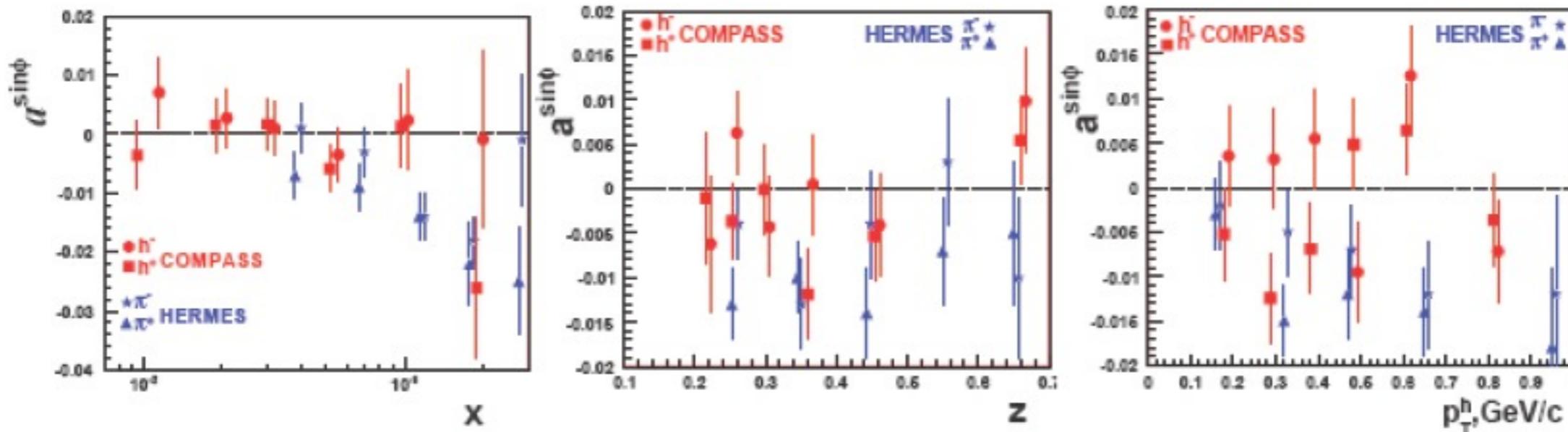
- SSA may provide information on transversity

- All harmonic moments for n>0 compatible with 0

Hall A: SSA in SIDIS on transpol target

- Polarized neutron target (He3) via fast spin exchange

- Data taking Nov.08-Feb09

- Projected statistics on pion asymmetry. Exp. summer 2010

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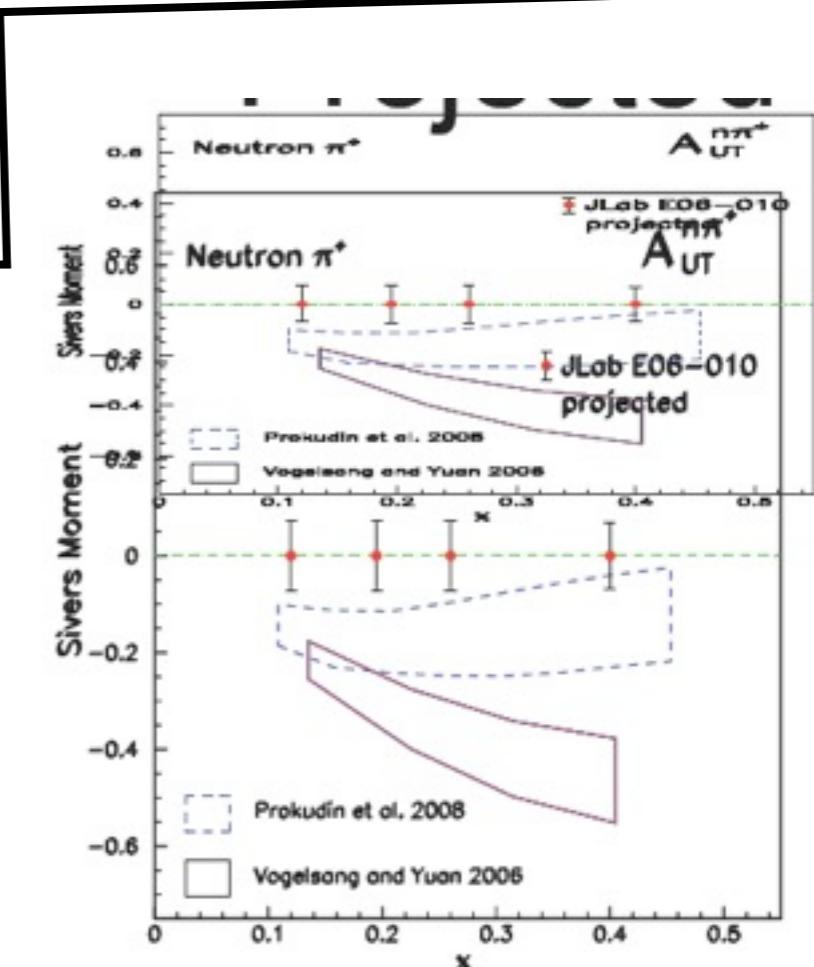
COMPASS: Lambda Polarization

Ideal probe to study spin effect

- Self analyzing weak decay $\Lambda \to p\pi^-$

**Transverse Λ polarization $\rightarrow$**

- Access to transversity

Preliminary COMPASS 2007 transverse proton data Λ

Preliminary COMPASS 2007 transverse proton data $\overline{\Lambda}$
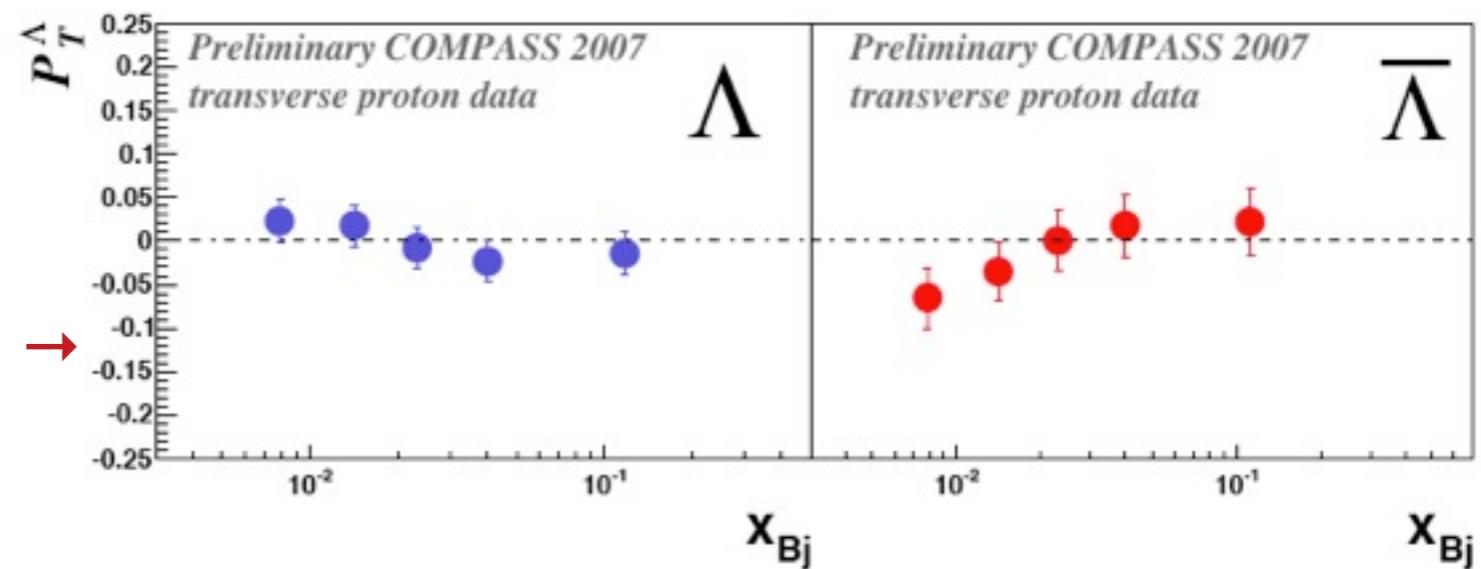
Longitudinal spin transfer of quark to baryon

New HERMES result

NOMAD ($\nu_\mu N \to \mu\Lambda X$)
E665 ($\mu N \to \mu'\Lambda X$)
COMPASS ($\mu N \to \mu'\Lambda X$)
HERMES Preliminary ($eN \to e'\Lambda X$)

COMPASS (2003-2004) Λ $\overline{\Lambda}$

$D_{LL}^\Lambda \neq D_{LL}^{\overline{\Lambda}}$

COMPASS (2003-2004) Λ $\overline{\Lambda}$
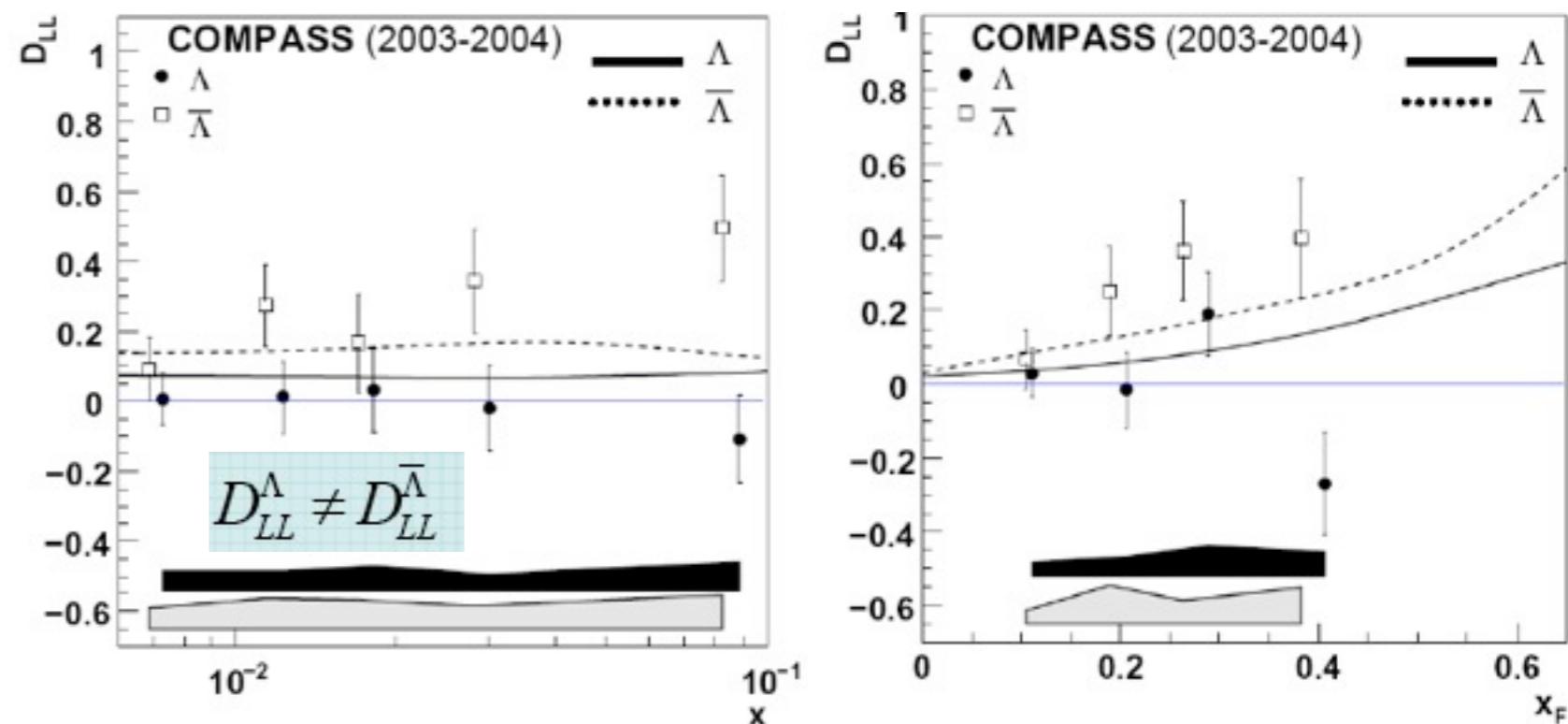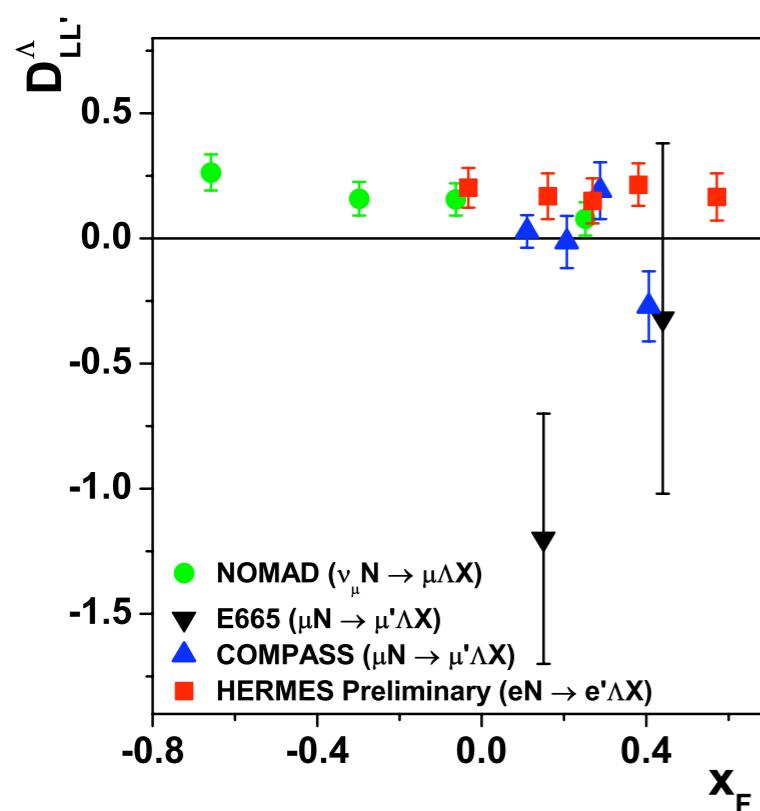
Test of the strangeness quark and antiquark symmetry

$$s(x) \neq \overline{s}(x), \Delta s(x) \neq \Delta\overline{s}(x)$$

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Hard Exclusive Reactions and GPDs

- **Generalized Parton Distributions** provide multi-dimensional picture of the nucleon

- Access via **DVCS or DVMP**

  At leading twist and for a proton target there are 4 quark GPDs:

  $$H, E, \widetilde{H}, \widetilde{E}$$
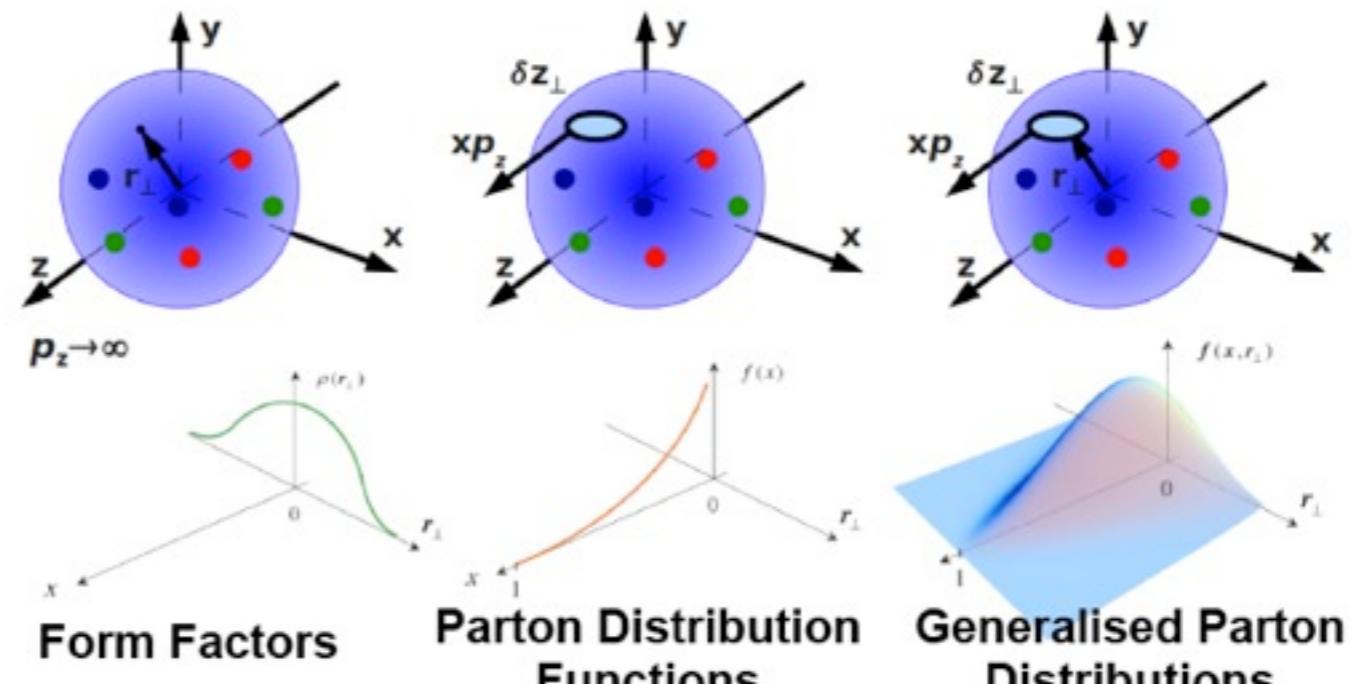
- Ji sum rule for **total angular momentum of quarks**:

$$\int dx\, x \left[H_q(x, \zeta, t=0) + E_q(x, \zeta, t=0) \right] = 2J_q$$

Form Factors

Parton Distribution Functions

Generalised Parton Distributions

20
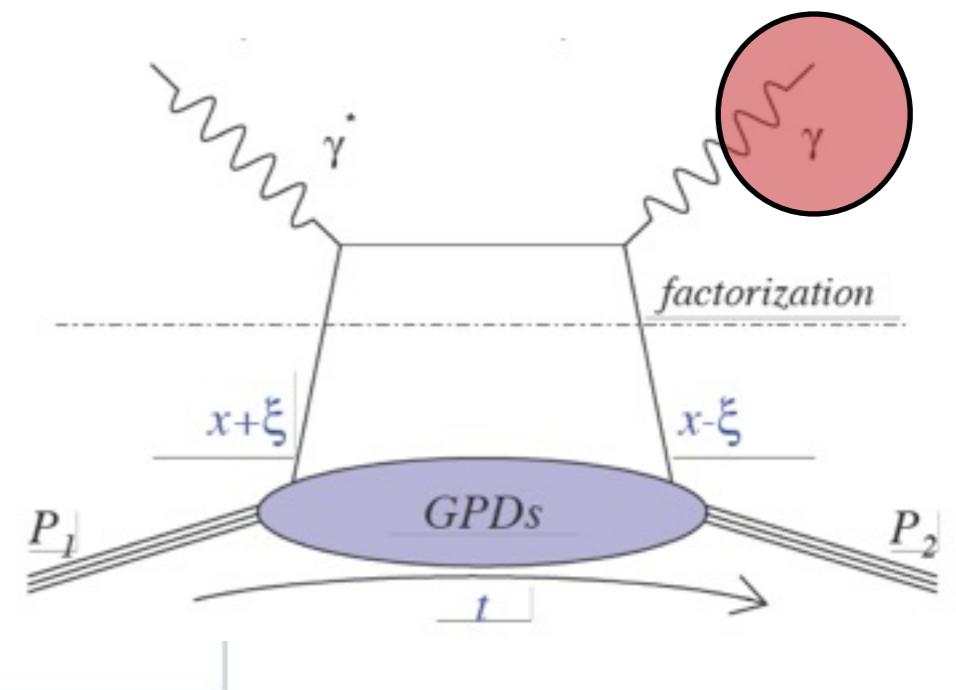
HERMES: DVCS on $\vec{H}$

Deeply Virtual Compton Scattering ep→epγ

VGG Regge

Bethe Heitler
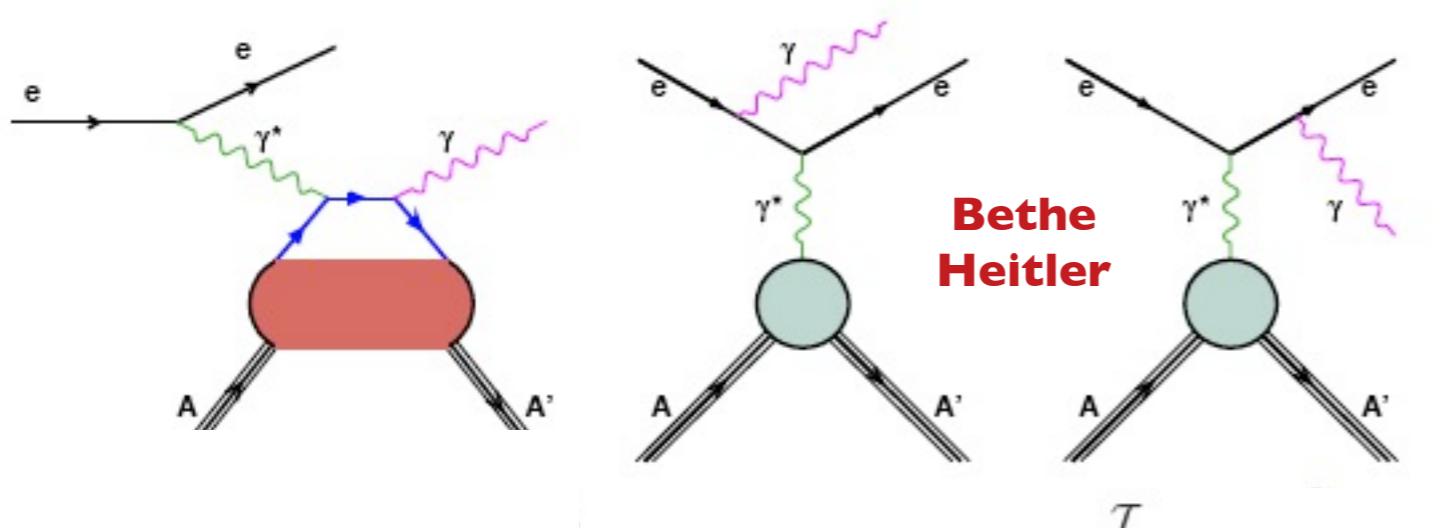
$$|\tau|^2 = |\tau_{\mathrm{BH}}|^2 + |\tau_{\mathrm{DVCS}}|^2 + \overbrace{\tau_{\mathrm{BH}}\tau_{\mathrm{DVCS}}^* + \tau_{\mathrm{BH}}^*\tau_{\mathrm{DVCS}}}^{\mathcal{I}}$$

$$\mathcal{I} = \frac{-e_\ell K_{\mathcal{I}}}{\mathcal{P}(\phi)}\left(P_\ell\, P_{\mathrm{L}} \sum_{n=0}^{2} c_{n,\mathrm{LP}}^{\mathcal{I}} \cos(n\phi) + P_{\mathrm{L}} \sum_{n=1}^{3} s_{n,\mathrm{LP}}^{\mathcal{I}} \sin(n\phi) \right)$$

Beam Polarisation   Target Polarisation

+ terms associated with an unpolarised target

Target spin asymmetry

Double spin asymmetry
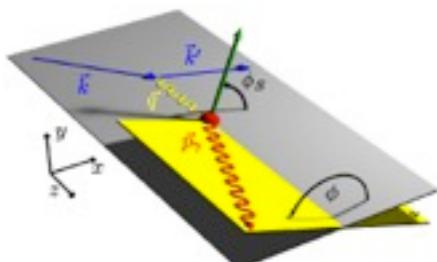
Sensitive to Imaginary / Real part of **Compton Form Factor** $\widetilde{H}$
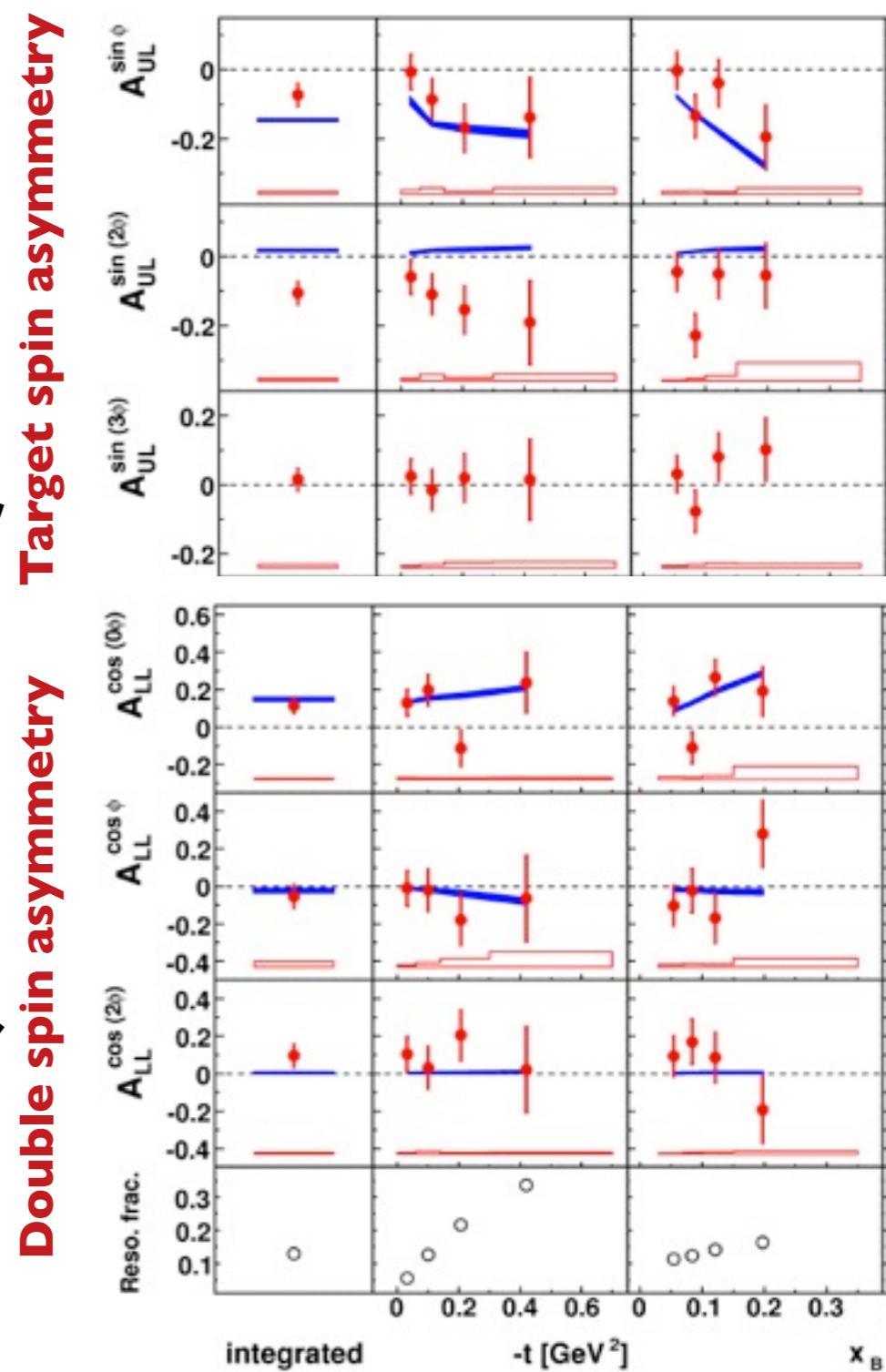
Hrachya Marukyan
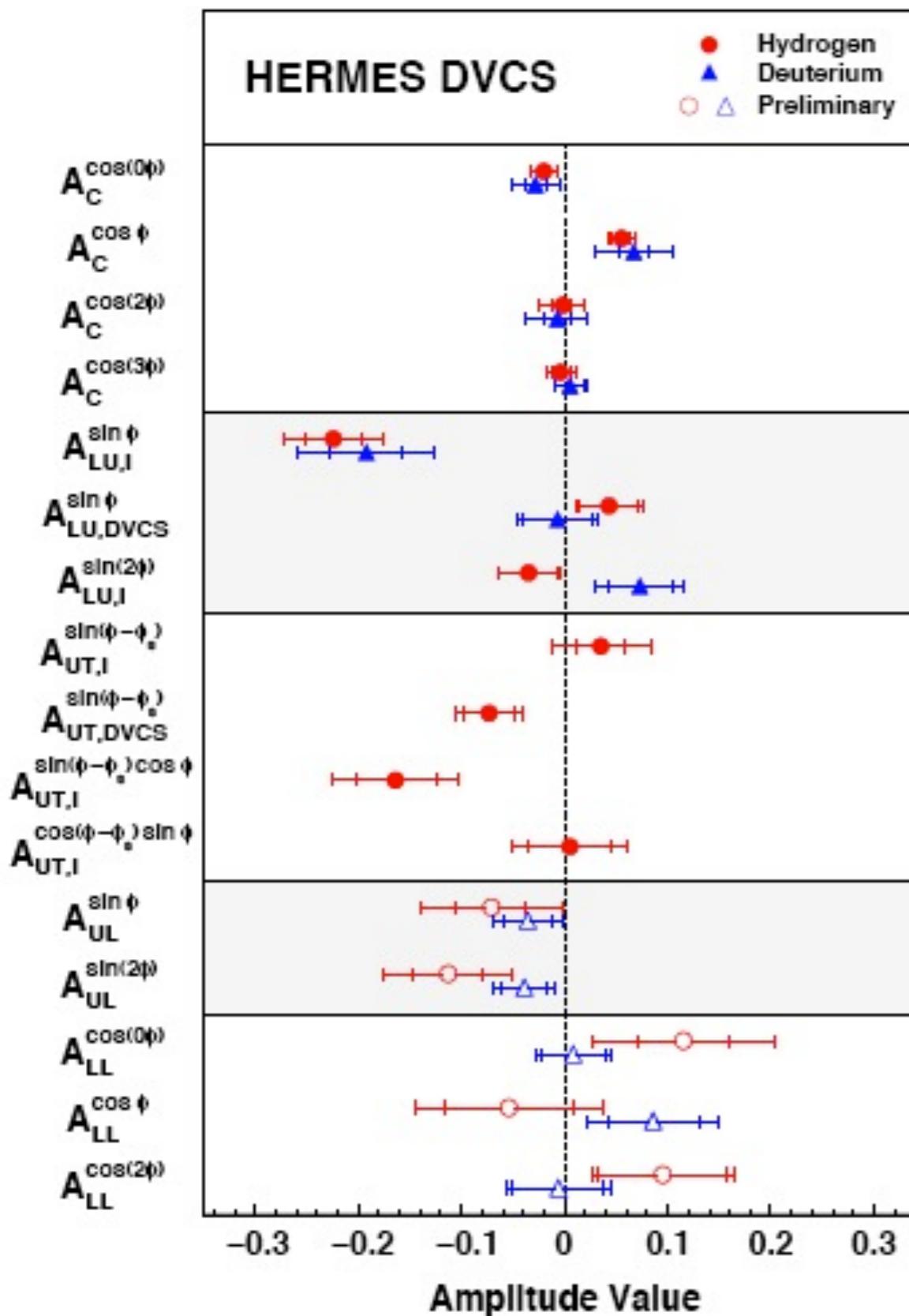
- Spin-1 target: 9 GPDs

- No coherent signature found for deuterium w/in uncerts. Unique measurement

- Nuclear data published

- **2006/2007 unpolarized proton data released** - huge data set

- Analysis including **Recoil detector information 2006/2007** in progress

Hrachya Marukyan
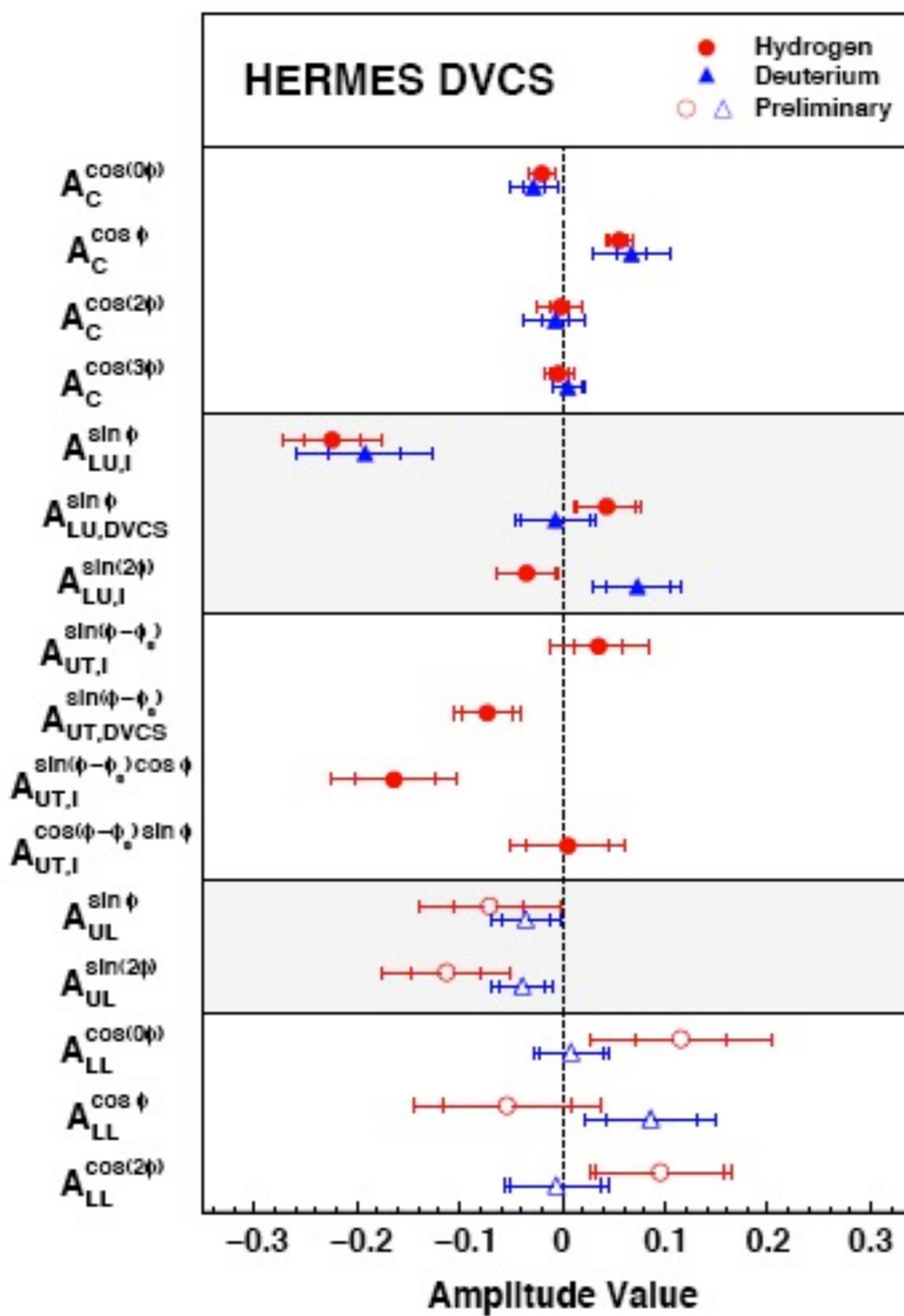
Hrachya Marukyan
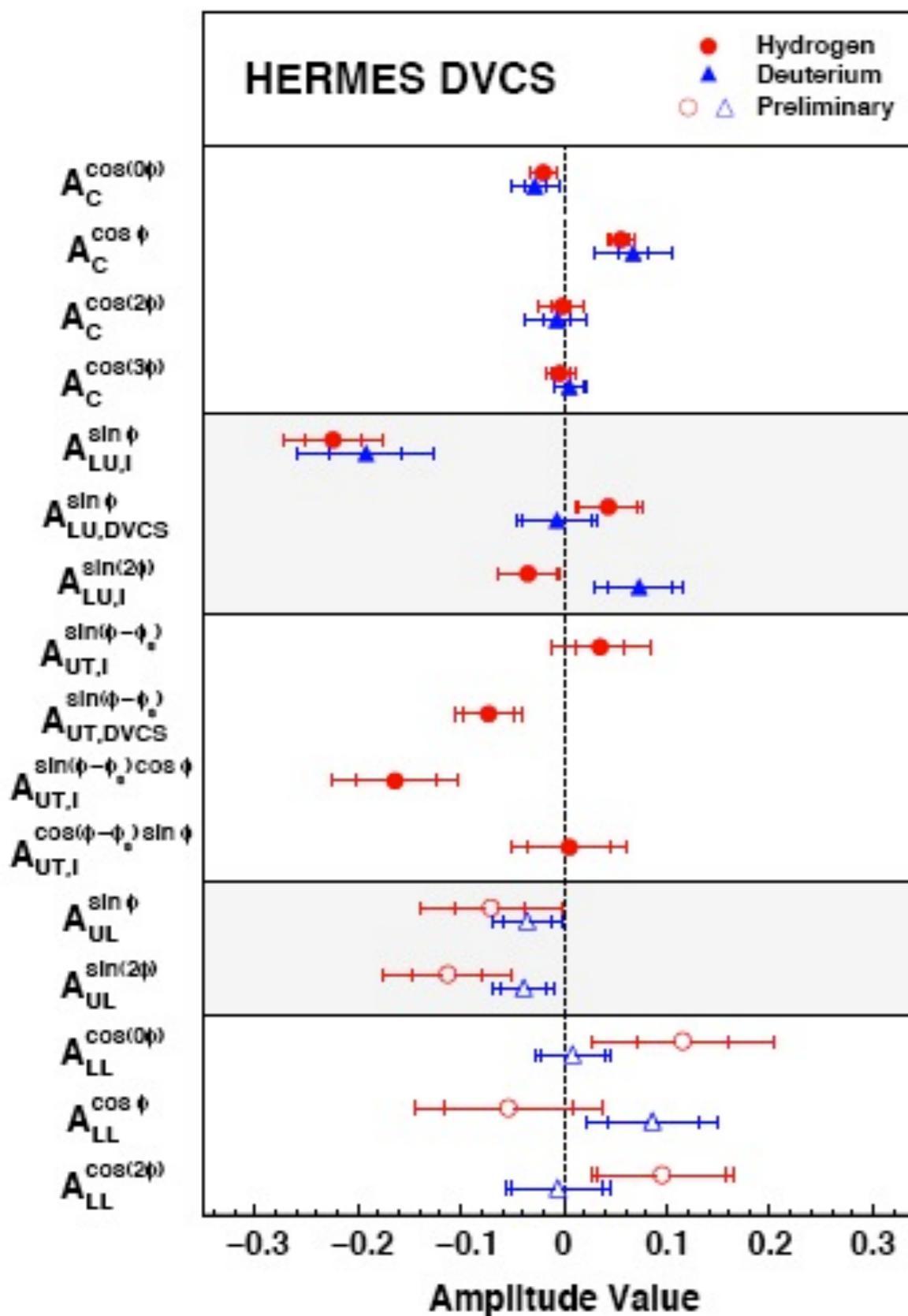
- JHEP 06 (2008) 066, JHEP 11 (2009) 083
- Nucl. Phys. B 829 (2010
- Arxiv:1004.0177(hep-ex)
- Hermes preliminary

$\Leftarrow$ **Beam-charge asymmetry:** $\cos(0\phi), \cos\phi$
$$\propto \Re e(\mathcal{H}), \Re e(\mathcal{H}_1)$$

$\Leftarrow$ **Beam-helicity asymmetry:** $\sin\phi$
$$\propto \Im m(\mathcal{H}), \Im m(\mathcal{H}_1)$$

$\Leftarrow$ **Transverse Target-spin asymmetry:**
$$\sin(\phi - \phi_s)\cos(n\phi) \propto \Im m(\mathcal{H} - \mathcal{E})$$

$\Leftarrow$ **longitudinal Target-spin asymmetry:** $\sin\phi$
$$\propto \Im m(\tilde{\mathcal{H}}), \Im m(\tilde{\mathcal{H}}_1)$$

$\Leftarrow$ **Double spin asymmetry:** $\cos(0\phi), \cos\phi$
$$\propto \Re e(\tilde{\mathcal{H}}), \Re e(\tilde{\mathcal{H}}_1)$$

GPDs @ CLAS

Francois Girod

DVCS A_{LU}

DVCS A_{UL}
20% of stat shown

- Dedicated run 2009 with inner calo for target and double spin asymmetry

- Results to be released

- Cross section measurements: Re(H)

- Future: transverse target run with HD-Ice target: GPD E
  $\Rightarrow$ **constrain on $J_u + J_d$**

- Flavor separation with **exclusive meson production**

Model independent extraction
Using only A_{LU} and A_{UL} with sensitivity to $\mathcal{H}$ and $\tilde{\mathcal{H}}$

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M. Guidal, arXiv:1003.0307

HERMES: ω and Φ A_UT

$J^P = 1^-$

**Φ A_UT**

ω A_UT
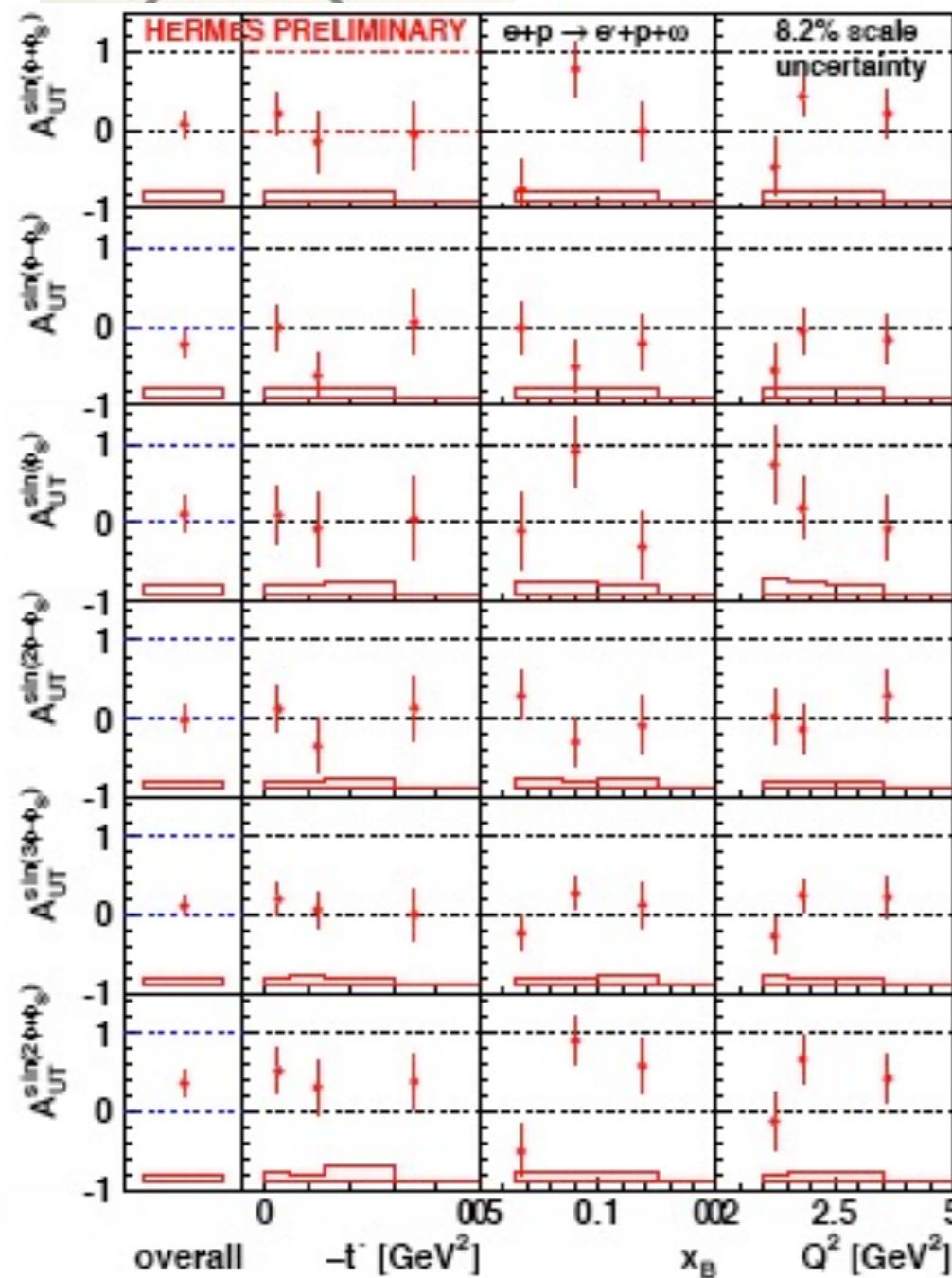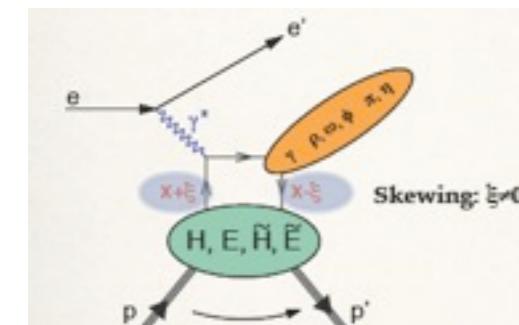
- A_UT for light vector mesons:
  $\propto$ interference(H*E)

- Φ compatible with 0
  $\Rightarrow$ E(sea) and E(gluon)
  negligible

- ω < 0 as expected
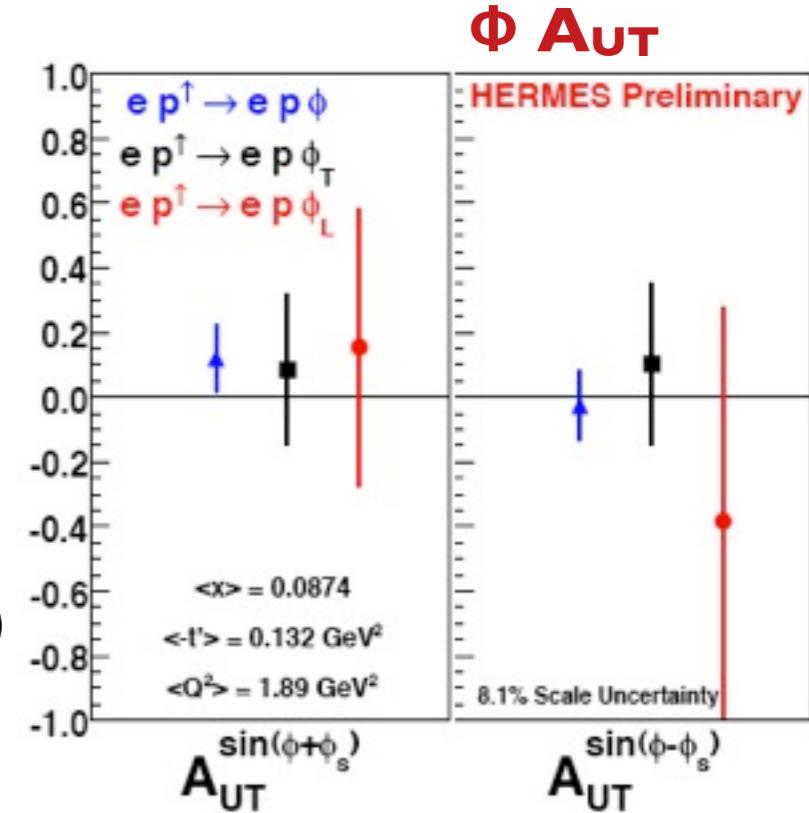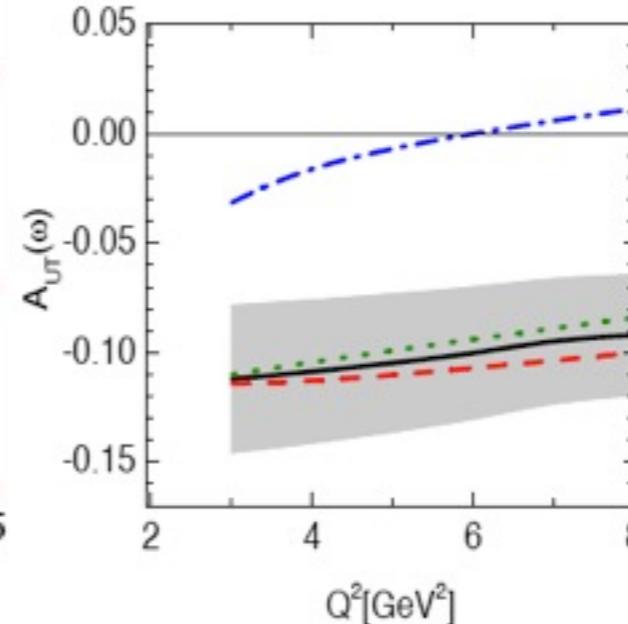
u- and d-quarks in GPD E do not cancel:

$$A_{UT} \propto \mathcal{I}m\left[(2E^u - E^d) / (2H^u - H^d)\right]$$

(≈ -0.10 expected)

Overview: Experimental Spin Talks @ DIS10

$A_1, g_1, \Delta q, \Delta\bar{u}-\Delta\bar{d}$ → COMPASS

W production A_L: $\Delta\bar{u}/\bar{u}, \Delta\bar{d}/\bar{d}$ → STAR, PHENIX

ΔG → STAR, PHENIX, COMPASS

A_2, g_2 → HERMES

Helicity

DVCS → HERMES

DVCS $\vec{H}$ → HERMES

A_{UT} ω, ϕ → HERMES

Generalized Parton Distributions → CLAS

Exclusive

Transverse Effects

Transverse spin and TMDs → COMPASS, HERMES, CLAS, PHENIX, STAR

Transverse momentum dependent FFs → BELLE

$\Lambda\uparrow, \vec{\Lambda}$ → COMPASS, HERMES

n SSA in SIDIS → Hall A

SSA in inclusive hadrons on H↑ → HERMES

SIDIS asy on $\vec{D}$ → COMPASS