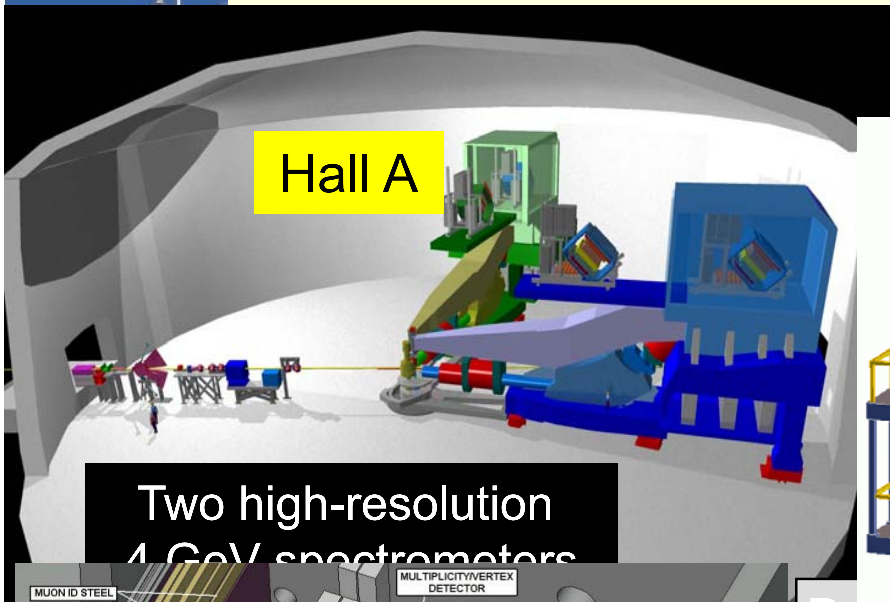
SUMMARY OF THE SPIN SESSION

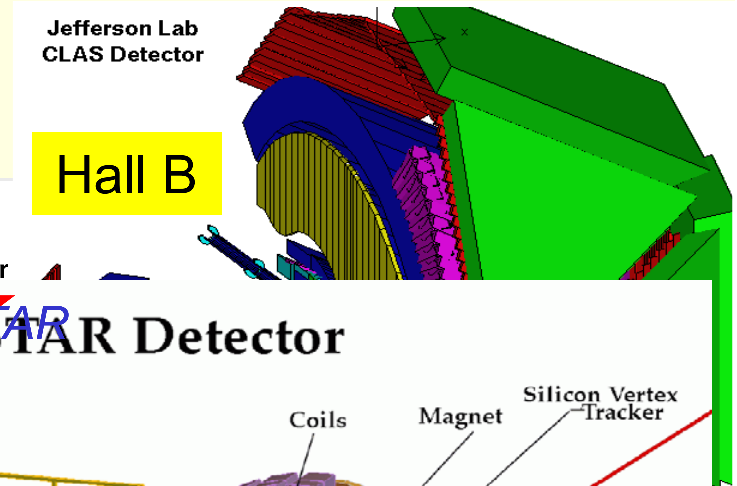
EXPERIMENT PART

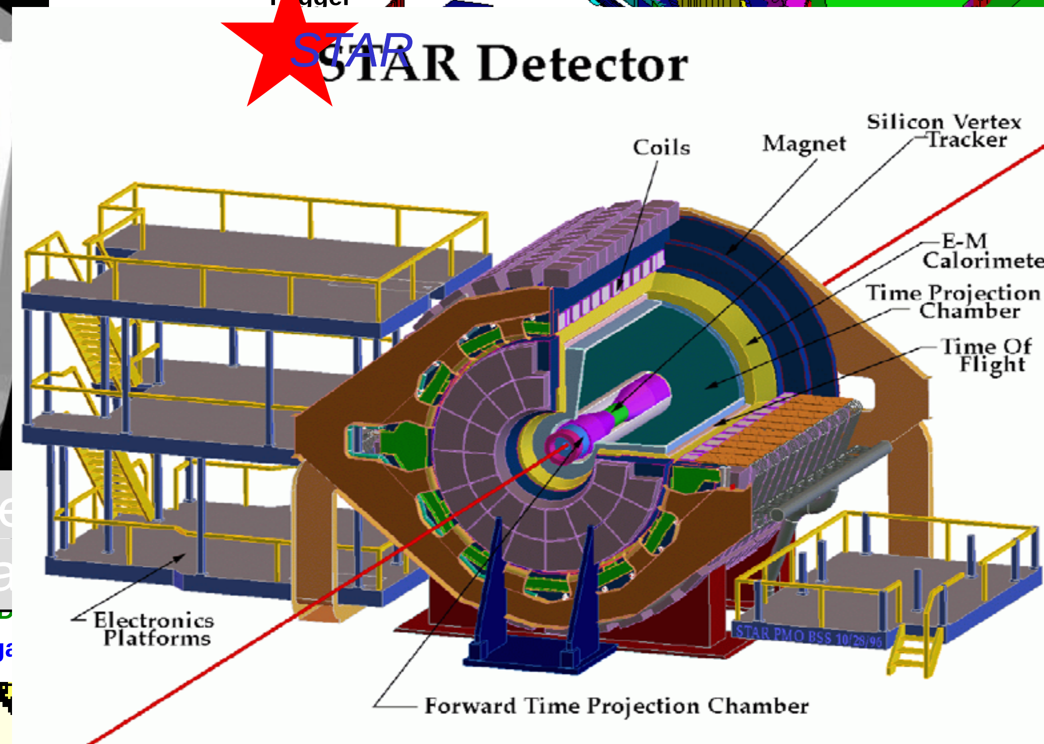
Andrea Bressan

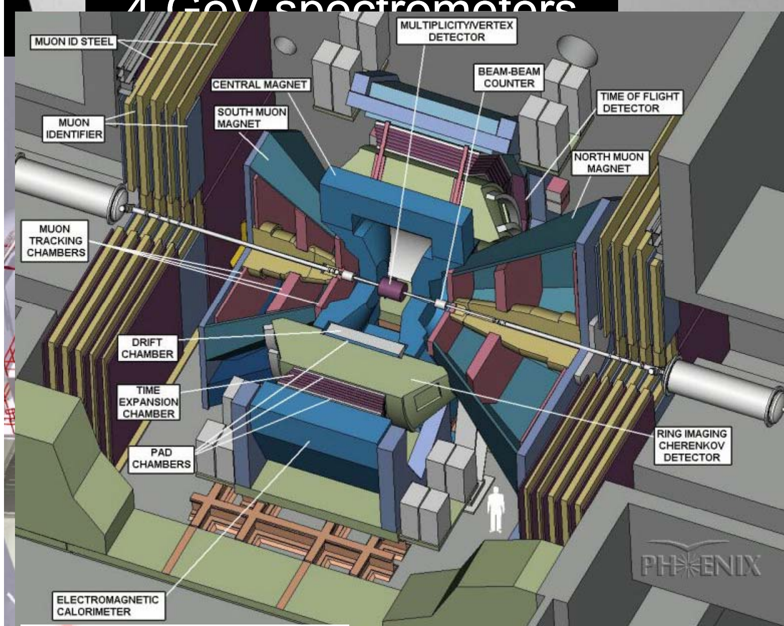
University of Trieste

Who is who?



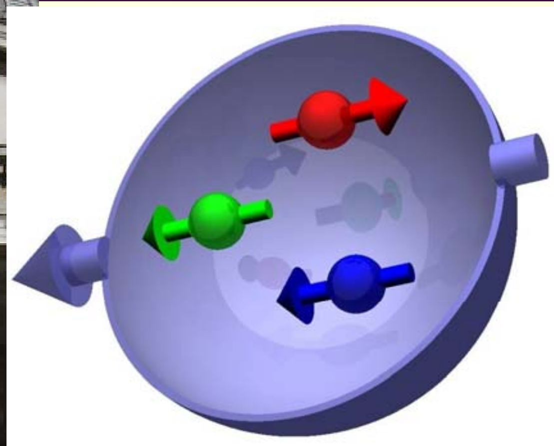






Beams: 250 GeV pp; <60>% polarization
Lumi: 1.2 $10^{31} cm^{-2}s^{-1}$

What we are after?



Naïve parton model

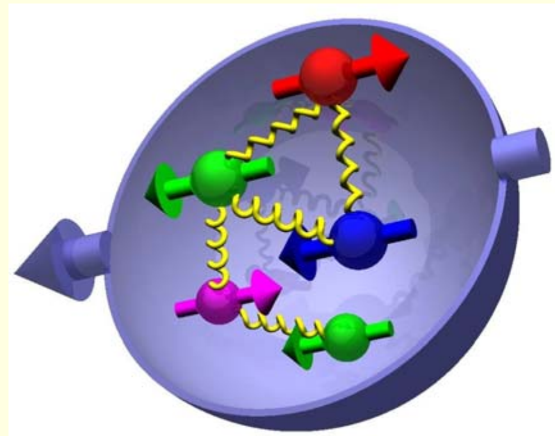
$$\Delta u_v = \tfrac{4}{3} \qquad \Delta d_v = -\tfrac{1}{3}$$

BUT

1989 EMC measured

$\Sigma = 0.120 \pm 0.094 \pm 0.138$

⟹ Spin Puzzle

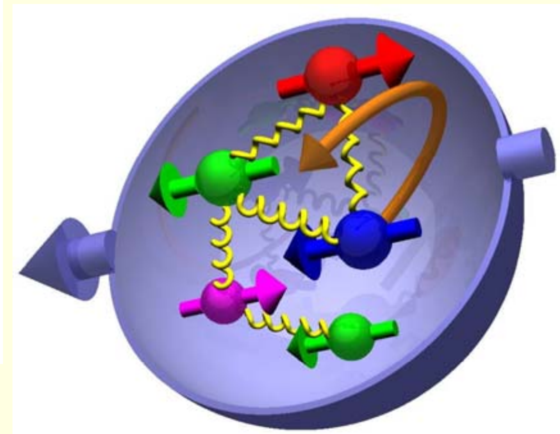


Unpolarised structure fct.

Gluons are important !

⟹ ΔG

⟹ Sea quarks Δq_s



Full description of J_q and J_g needs orbital angular momentum

$$\frac{1}{2} = \frac{1}{2}\left(\Delta u_v + \Delta d_v + \Delta q_s\right) + L_q + \Delta G + L_g$$

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

$$\Delta q_s = (\Delta u_s + \Delta d_s + \Delta \bar{u} + \Delta \bar{d} + \Delta s + \Delta \bar{s})$$

COMPASS: Valence PDFs

$$A^{+/-} = \frac{(\sigma^{\rightleftarrows}_{h^+} - \sigma^{\rightleftarrows}_{h^-}) - (\sigma^{\rightrightarrows}_{h^+} - \sigma^{\rightrightarrows}_{h^-})}{(\sigma^{\rightleftarrows}_{h^+} - \sigma^{\rightleftarrows}_{h^-}) + (\sigma^{\rightrightarrows}_{h^+} - \sigma^{\rightrightarrows}_{h^-})}$$

- For LO:

$$A_d^{\pi^+-\pi^-}(x) = A_d^{K^+-K^-} = \frac{\Delta u_v(x) + \Delta d_v(x)}{u_v(x) + d_v(x)}$$

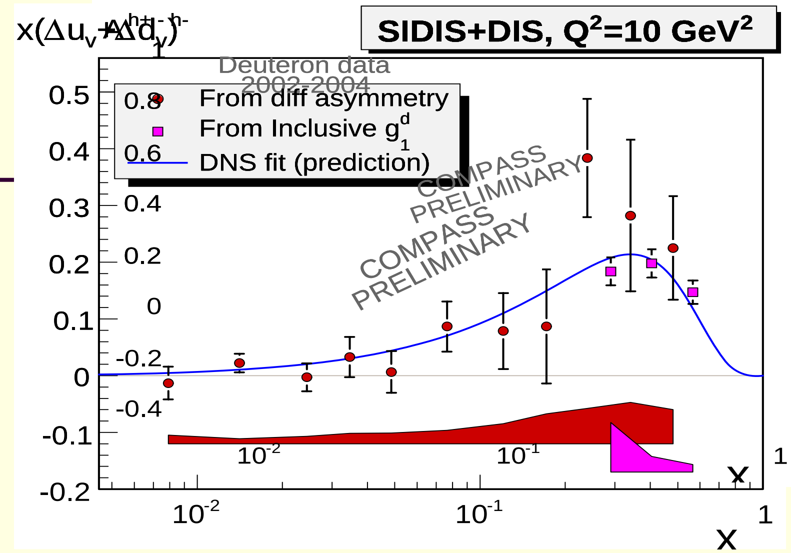
- Assuming:

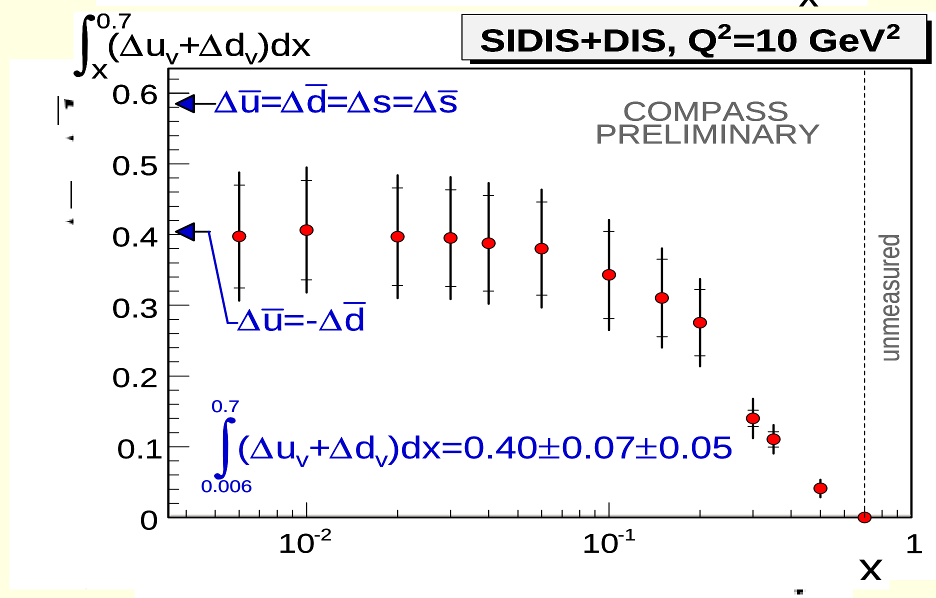
$$\Gamma_1^N = \frac{1}{9}(a_0 + \frac{1}{4}a_8)$$

$$\Gamma_v = \int_0^1 (\Delta u_v(x) + \Delta d_v(x))dx$$

$$\Delta\bar{u} + \Delta\bar{d} = 3\Gamma_1^N - \frac{1}{2}\Gamma_v + \frac{1}{12}a_8$$

$$= (\Delta s + \Delta\bar{s}) + \frac{1}{2}(a_8 - \Gamma_v)$$

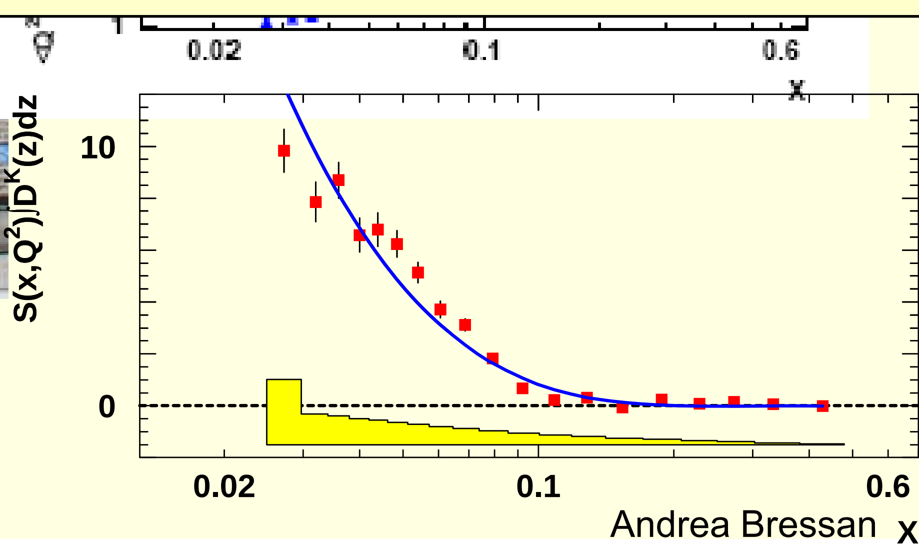




- Γ_v is $2.5\sigma_{stat}$ away from flavour symmetric sea scenario

HERMES: polarized and unpolarized s-PDF

- Need longitudinal polarized deuterium target
  - ⟹ strange quark sea in proton and neutron identical
  - ⟹ fragmentation simplifies
- All needed information can be extracted from HERMES data alone
  - ⟹ inclusive $A_{1,d}(x,Q^2)$and kaon $A^K_{1,d}$ (x,Q^2) double spin asym.
  - ⟹ Kaon multiplicities → D_Q^K and D_S^K
- Only assumptions used:
  - ⟹ isospin symmetry between proton and neutron
  - ⟹ charge-conjugation invariance in fragmentation



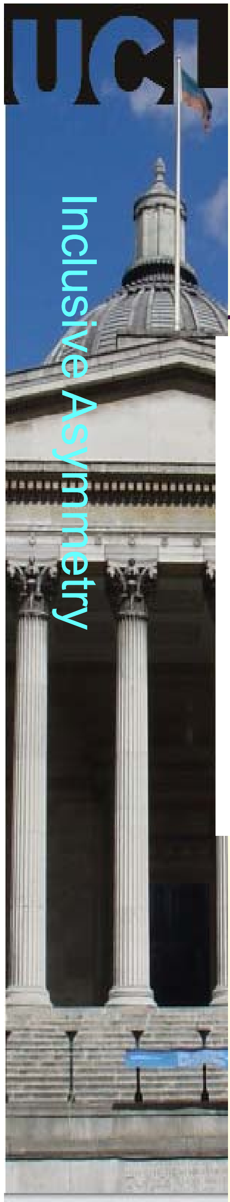
Q(x): CTEQ-6L & DSS

$$S(x) \neq k(\bar{u}+\bar{d})/2$$

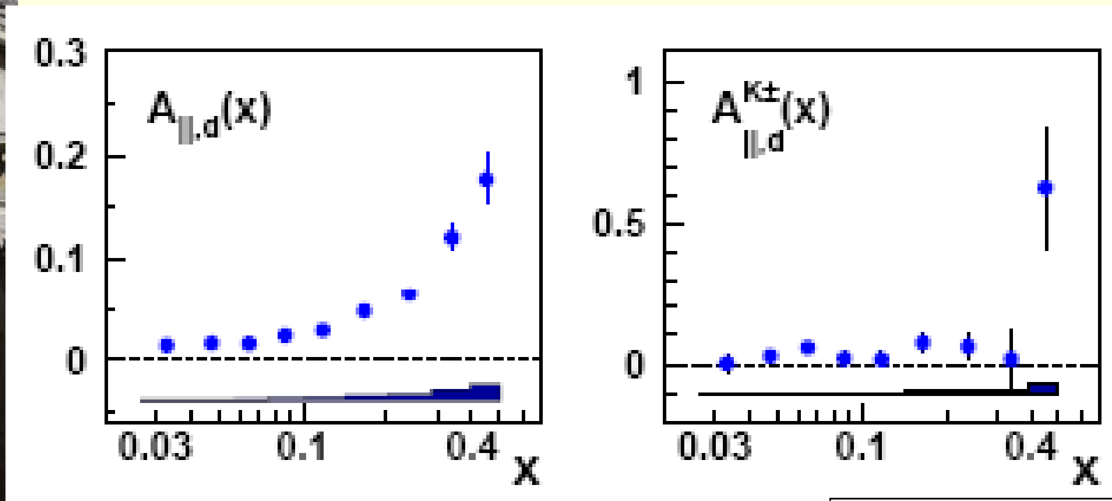
s(x) + sbar(x)

$$\frac{dN^{K^\pm}(x)}{dN^{DIS}} = \frac{Q(x)\int D_Q^K(z)dz + S(x)\int D_S^K(z)dz}{5Q(x)+2S(x)}$$

HERMES: polarized and unpolarized s-PDF



Inclusive Asymmetry

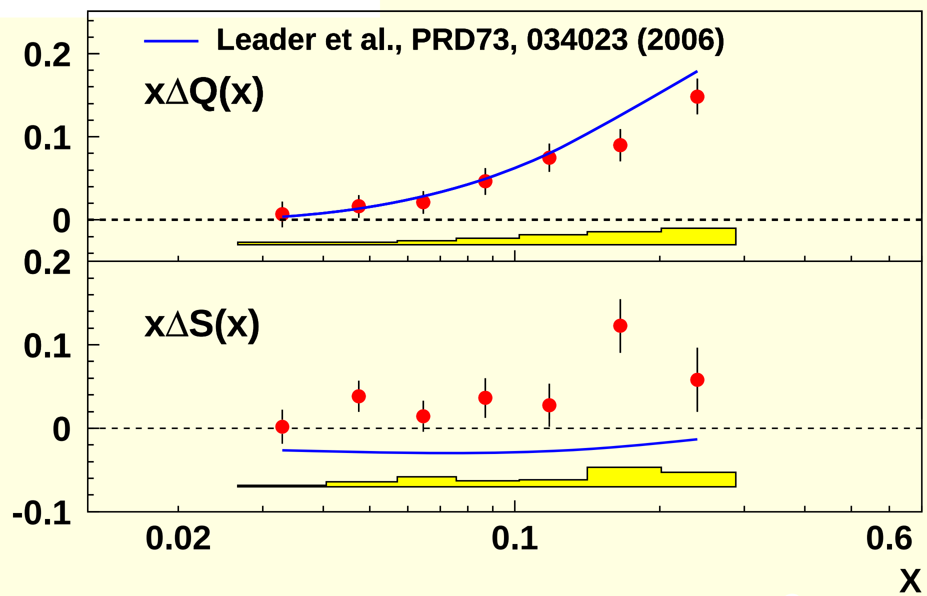


Kaon Asymmetry

$$\vec{e}+\vec{d}\rightarrow e'K^{\pm}X$$

$$\int_{0.02}^{0.6}\Delta Q = 0.359 \pm 0.026 \pm 0.018$$

$$\int_{0.02}^{0.6}\Delta S = 0.037 \pm 0.019 \pm 0.027$$



GLOBAL FIT

deFlorian, Sassot, Stratmann, Vogelsang

This paper presents the first "global" NLO analysis of the data from DIS, SIDIS, and RHIC in terms of the helicity PDFs. While there have been quite a few NLO

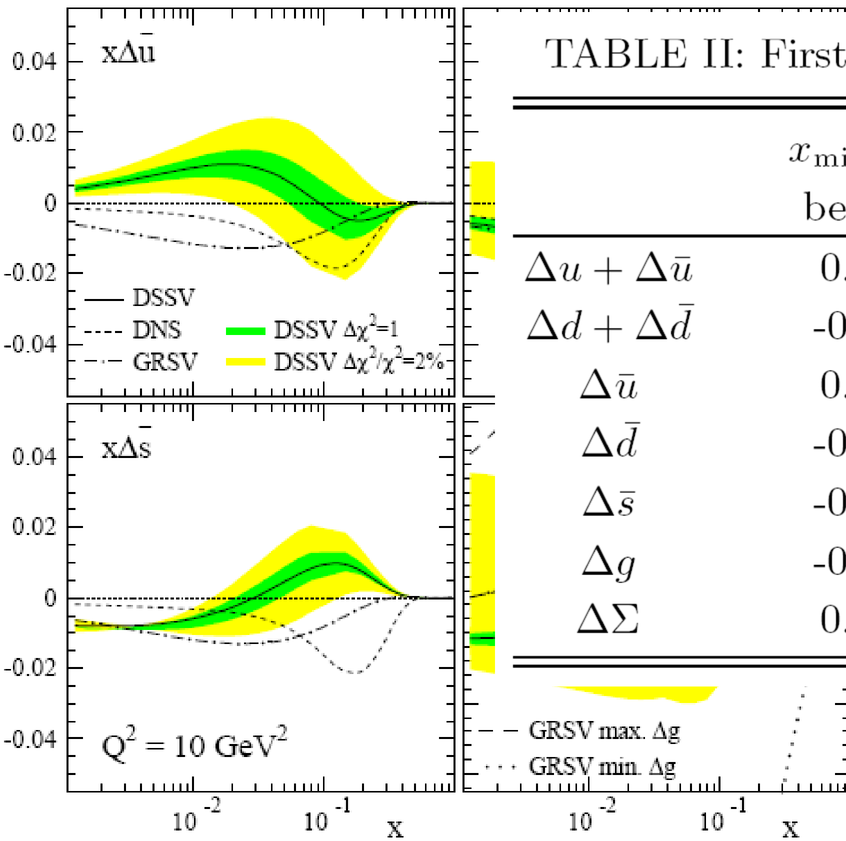


TABLE II: First moments $\Delta f_j^{1,[x_{\min}-1]}$ at $Q^2 = 10\,\mathrm{GeV}^2$.

	$x_{\min} = 0$	$x_{\min} = 0.001$	
	best fit	$\Delta\chi^2 = 1$	$\Delta\chi^2/\chi^2 = 2\%$
$\Delta u + \Delta\bar{u}$	0.813	$0.793\ ^{+0.011}_{-0.012}$	$0.793\ ^{+0.028}_{-0.034}$
$\Delta d + \Delta\bar{d}$	-0.458	$-0.416\ ^{+0.011}_{-0.009}$	$-0.416\ ^{+0.035}_{-0.025}$
$\Delta\bar{u}$	0.036	$0.028\ ^{+0.021}_{-0.020}$	$0.028\ ^{+0.059}_{-0.059}$
$\Delta\bar{d}$	-0.115	$-0.089\ ^{+0.029}_{-0.029}$	$-0.089\ ^{+0.090}_{-0.080}$
$\Delta\bar{s}$	-0.057	$-0.006\ ^{+0.010}_{-0.012}$	$-0.006\ ^{+0.028}_{-0.031}$
Δg	-0.084	$0.013\ ^{+0.106}_{-0.120}$	$0.013\ ^{+0.702}_{-0.314}$
$\Delta\Sigma$	0.242	$0.366\ ^{+0.015}_{-0.018}$	$0.366\ ^{+0.042}_{-0.062}$

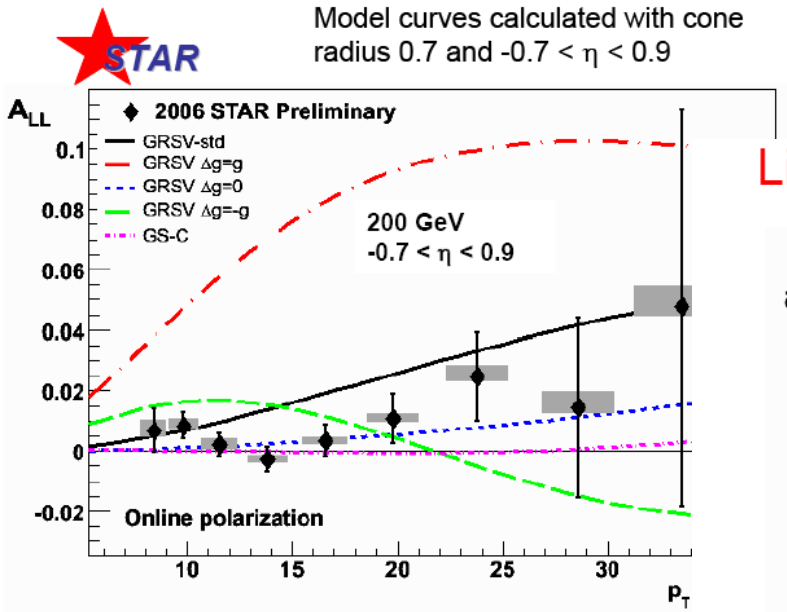
FIG. 2: Our polarized sea and gluon densities compared to previous fits [6, 8]. The shaded bands correspond to alternative fits with $\Delta\chi^2 = 1$ and $\Delta\chi^2/\chi^2 = 2\%$ (see text).

Measuring ΔG

A_{LL} from STARS jets

2006 inclusive jets A_{LL}

Model curves calculated with cone radius 0.7 and $-0.7 < \eta < 0.9$

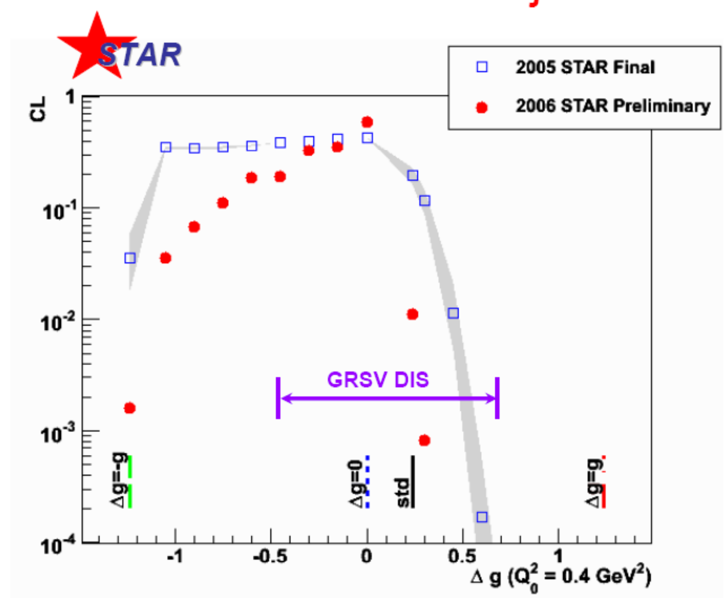


A_{LL} systematics (x 10^{-3})

- Statistical uncertainties are 3-4 ti
for $p_T > 13$ GeV/c

Carl Gagliardi – DIS2008 – Jets in pp at RHIC

Limits on ΔG from 2006 jet results



- Within the GRSV framework:
  - GRSV-std excluded with 99% CL
  - $\Delta G < -0.7$ excluded with 90% CL

ALL from $\pi^0,\pi^\pm,\eta$ at phenix

π^0 A_{LL} at 200GeV – RUN6 improvement

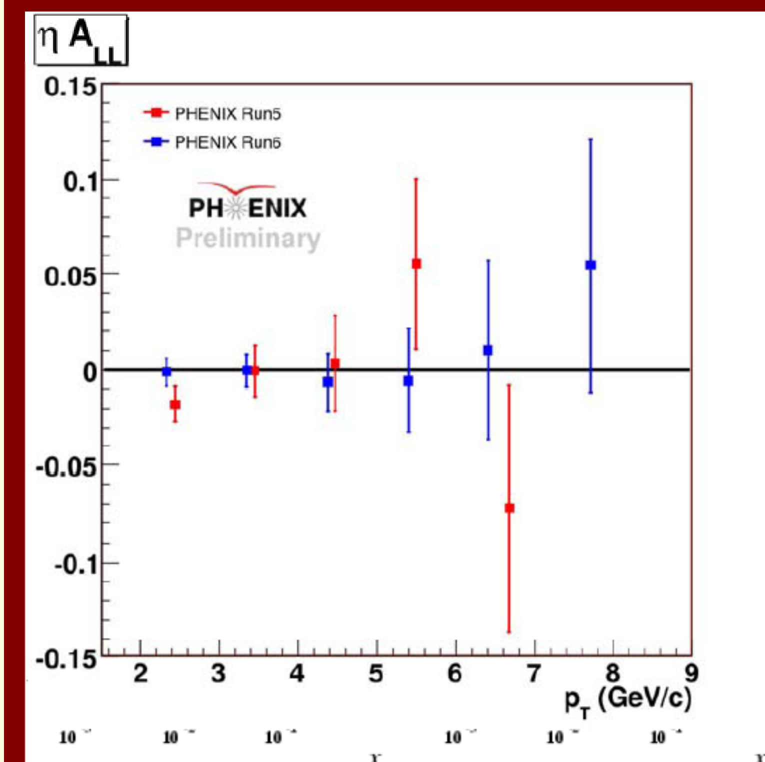
200GeV RUN5 2.5pl

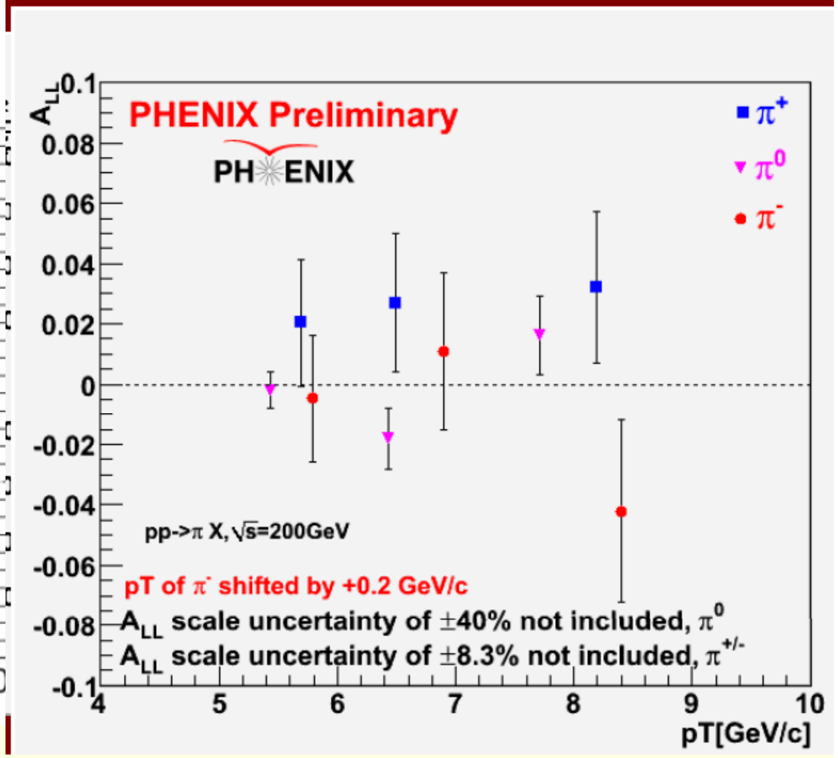
200GeV RUN6 6 p

- Significant statistic

$$\Delta G \geq 0 \Rightarrow A_{LL}^{\pi^+} > A_{LL}^{\pi^0} > A_{LL}^{\pi^-}$$

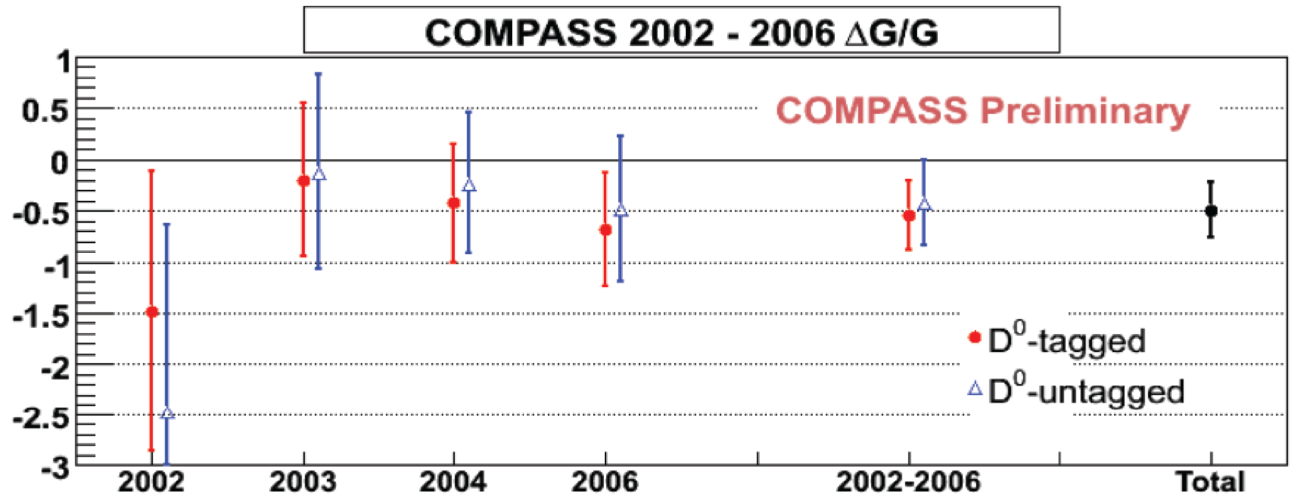
$$\Delta G << 0 \Rightarrow A_{LL}^{\pi^+} < A_{LL}^{\pi^0} < A_{LL}^{\pi^-}$$





COMPASS OPEN CHARM

Photon-Gluon Fusion Process (PGF)



$$\Delta G/G = -0.49 \pm 0.27\ (\text{stat}) \pm 0.11\ (\text{syst})$$

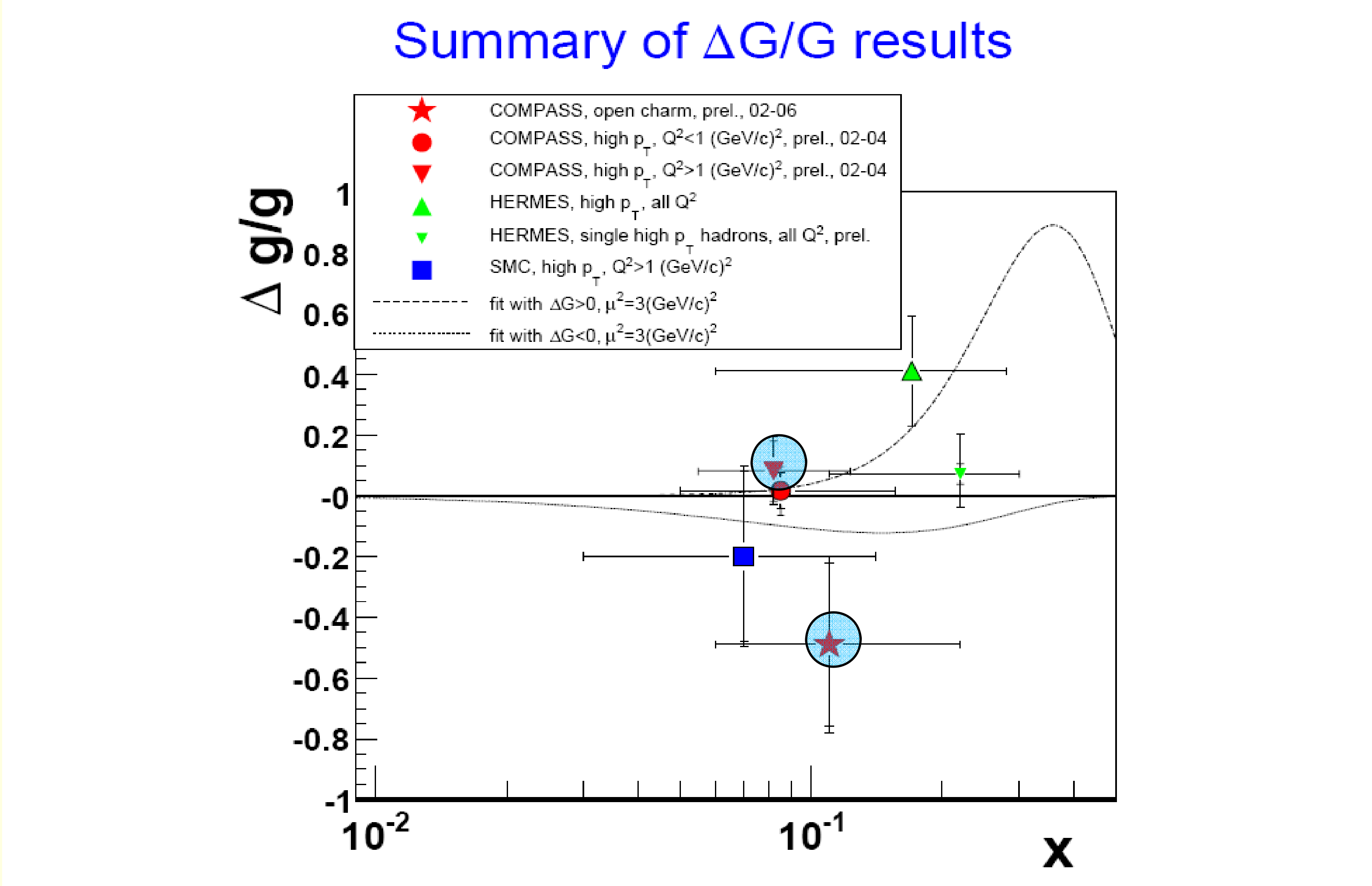
Systematics :

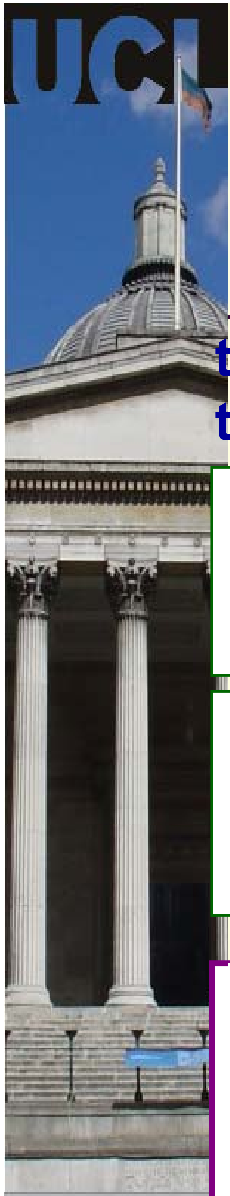
Source	D⁰	D*
Beam polar	0.025	0.025
Target polar	0.025	0.025
Dil. Fact.	0.025	0.025
False asymmetry	0.05	0.05
Signal extraction (Σ)	0.07	0.01
a_{LL} (charm mass)	0.05	0.03
TOTAL	**0.11**	**0.07**

$$\langle x_g \rangle = 0.11^{+0.11}_{-0.05}$$

$$\langle \mu^2 \rangle = 13\, GeV^2$$

COMPASS HIGH-p_T





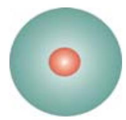
The 3rd Twist-2 structure function

three quark distribution functions (DF) are necessary to describe the structure of the nucleon at LO

q(x)

$f_1^q(x)$

→ vector charge



unpolarised DF

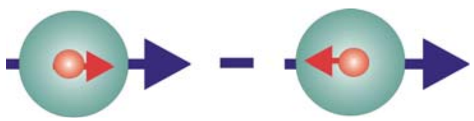
quark with momentum *xP* in a nucleon

well known – unpolarised DIS

Δq(x)

$g_1^q(x)$

→ axial charge



helicity DF

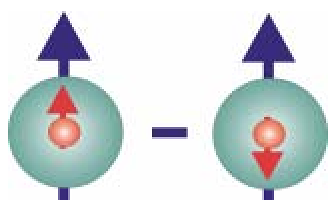
quark with spin parallel to the nucleon spin in a longitudinally polarised nucleon

known – polarised DIS

$\Delta_T q(x) = q^{\uparrow\uparrow}(x) - q^{\uparrow\downarrow}(x)$

$h_1^q(x)$,

→ tensor charge



transversity DF

quark with spin parallel to the nucleon spin in a transversely polarised nucleon

largely unknown

ALL 3 OF EQUAL IMPORTANCE

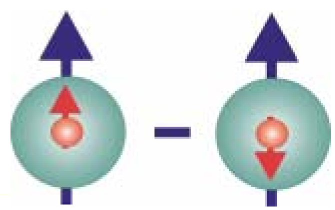
Transversity DF

$\Delta_T q(x) = q^{\uparrow\uparrow}(x) - q^{\uparrow\downarrow}(x)$

$h_1^q(x)$,

$\delta q(x)$,

$\delta_T q(x)$



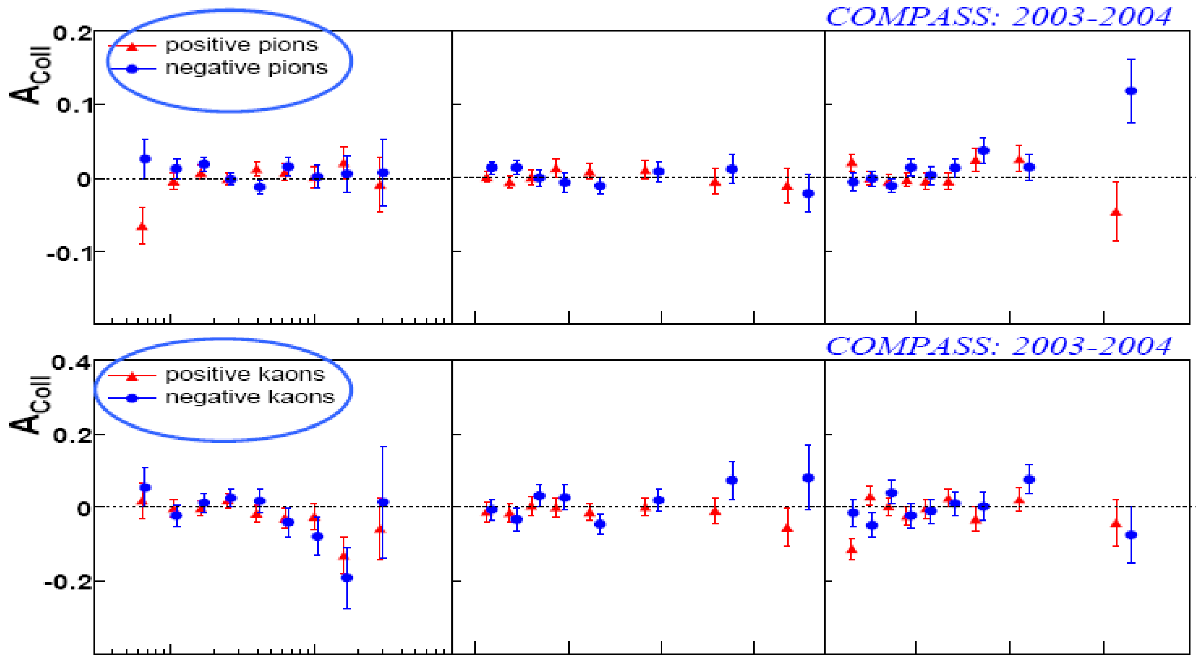
$q = u_v, d_v, q_{sea}$

quark with **spin** parallel to the nucleon spin in a transversely polarised nucleon

Properties:

- probes the relativistic nature of quark dynamics
- no contribution from the gluons → simple Q^2 evolution
- Positivity: Soffer bound……………..$2|\Delta_T q| \leq q + \Delta q$ *Soffer, PRL 74 (1995)*
- first moments: tensor charge………$\Delta_T q \equiv \int dx\ \Delta_T q(x)$
- sum rule for transverse spin in Parton Model framework…………$\frac{1}{2} = \frac{1}{2}\sum \Delta_T q + L_q + L_g$ *Bakker, Leader, Trueman, PRD 70 (04)*
- it is related to GPD's
- is chiral-odd: decouples from inclusive DIS

Collins Final on Deteron - COMPASS

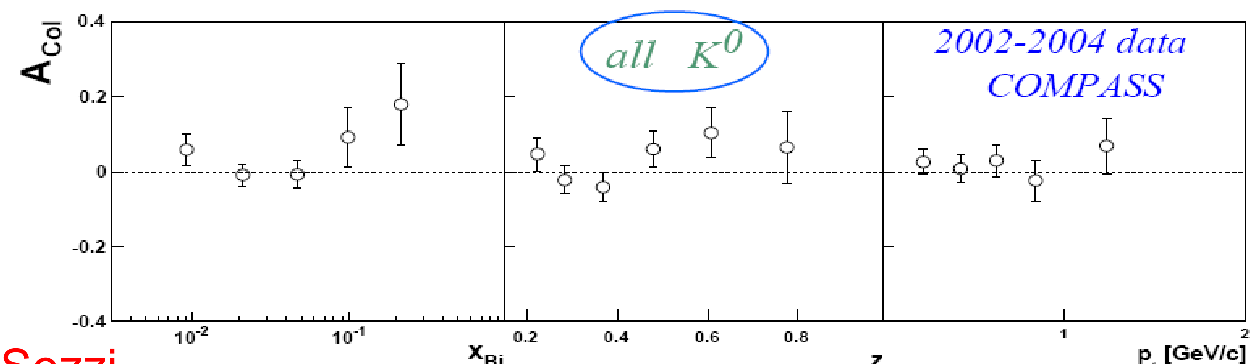


Final Results

all deuteron data

hep-ex/0802.2160

(subm. PLB)



Final Results

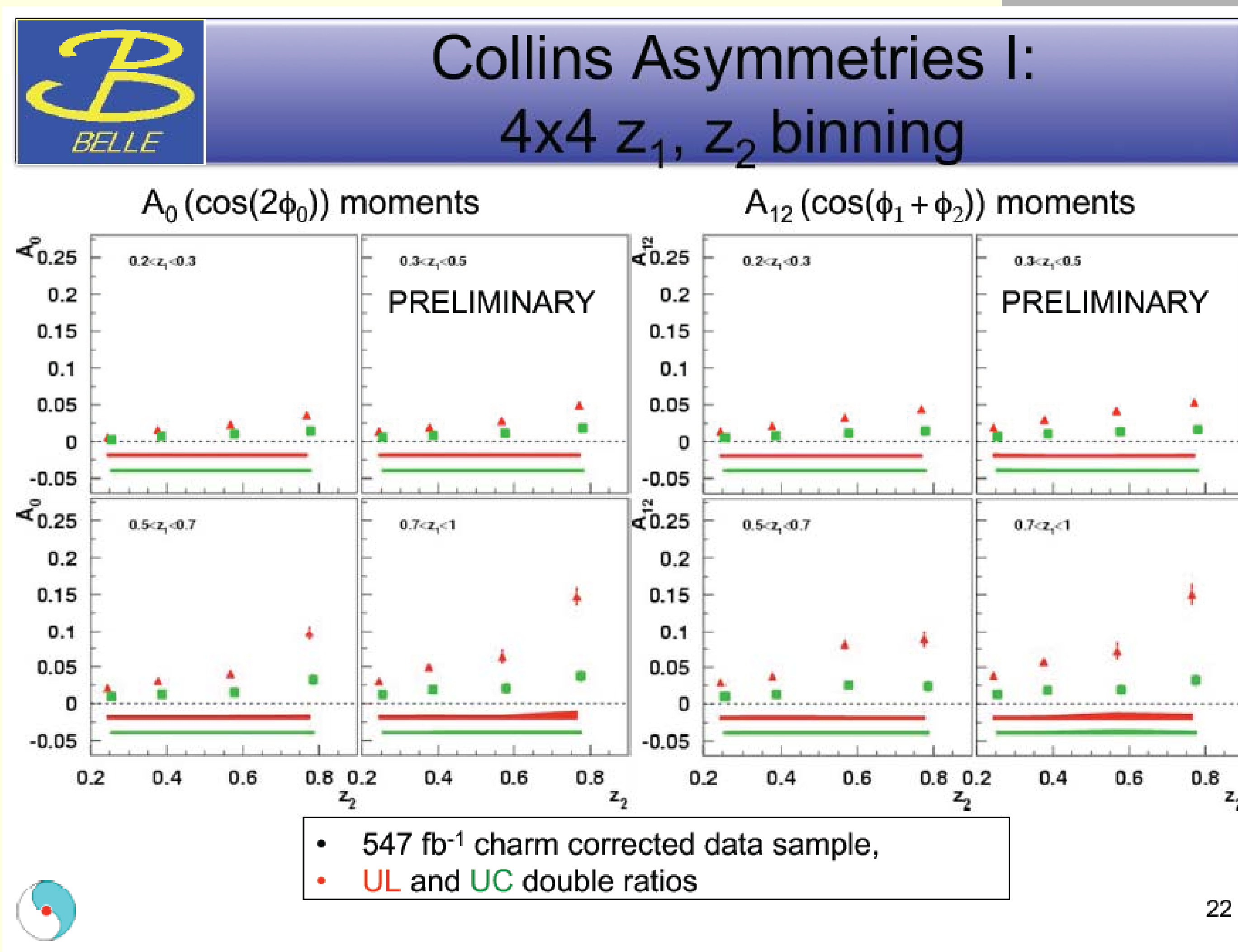
all deuteron data

hep-ex/0802.2160

(subm. PLB)

Federica Sozzi

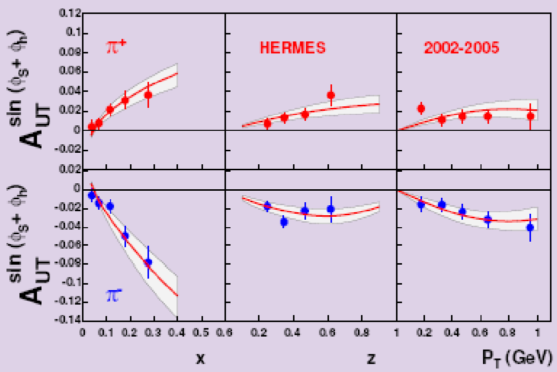
Collins FF from Belle



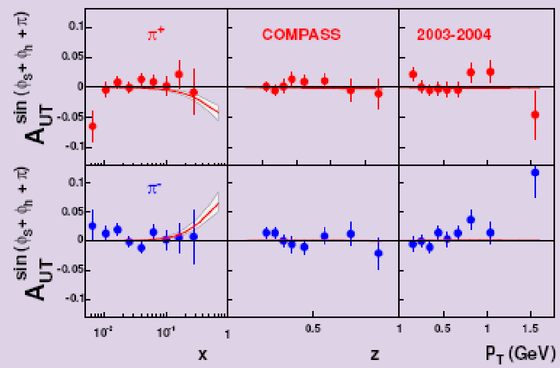
Global Fit

Preliminary results

HERMES $A_{UT}^{sin(\phi_h+\phi_S)}$



COMPASS $A_{UT}^{sin(\phi_h+\phi_S+\pi)}$

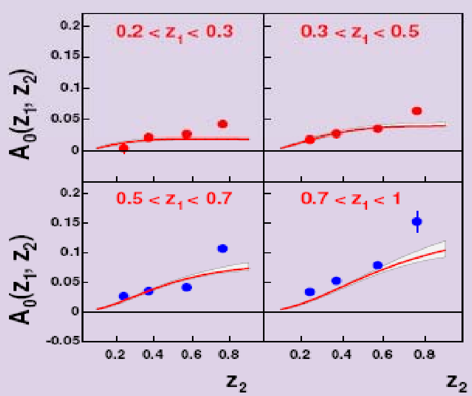


Global Fit

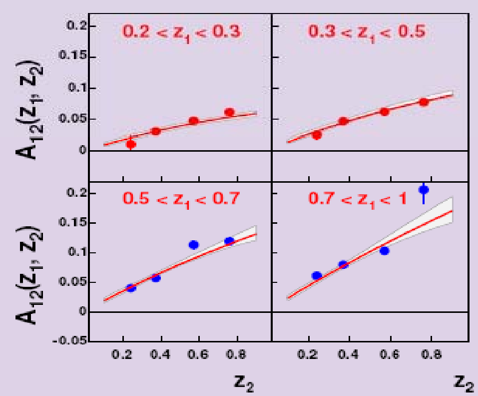
Introduction | Collins effect in SIDIS and e^+e^- annihilation | C | Description of the data & Predictions

Preliminary results

BELLE $\cos(2\varphi_0)$



BELLE $\cos(\varphi_1 + \varphi_2)$

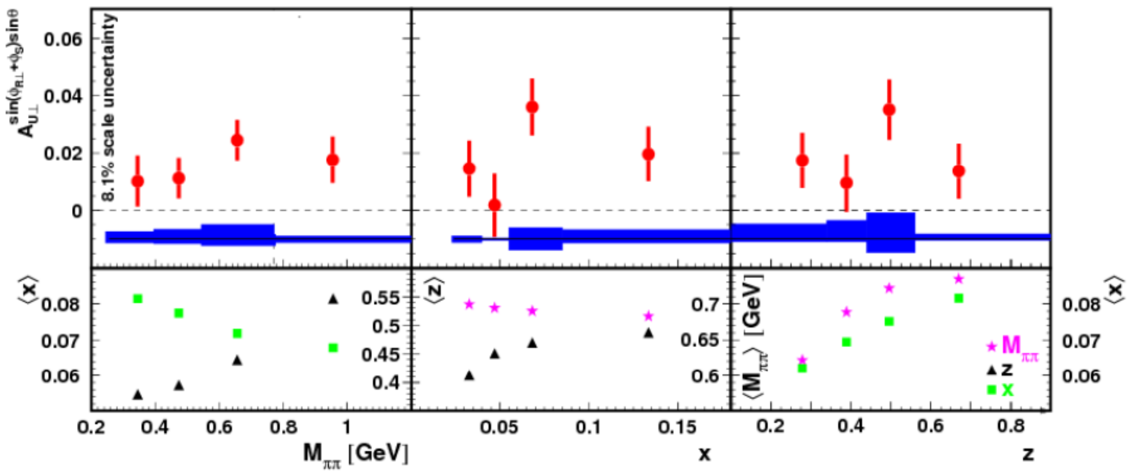


Alexei Prokudin | London, 7-11 April 2008 | Effects of intrinsic parton motion in SIDIS | 21

For Collins FF and Transversity → Andreas Metz

Final 2-hadron from Hermes

Extracted Asymmetry Amplitudes



✓average amplitude positive :

$$A_{U\perp}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta} = 0.018\pm0.005_{\mathrm{stat}}\pm0.002_{\mathrm{b-scan}}+0.004_{\mathrm{acc}}$$

✓8.1% scale systematic uncertainty contribution from target polarization

✓ the asymmetric error band combines ***b-scan*** effect and acceptance effect

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- ✓Non-zero asymmetry amplitudes
- ✓World first evidence of the Dihadron FF $H_1^{\sphericalangle}$
- ✓Positive amplitudes in the whole range of the invariant mass
  - rule out the sign change predicted by Jaffe
  - shape consistent with later model by Radici & Bacchetta
- ✓Big contribution from *s*-*p* wave interference around $\rho^0(770)$
- ✓Asymmetry results sensitive to transversity

Xiaorui Lu

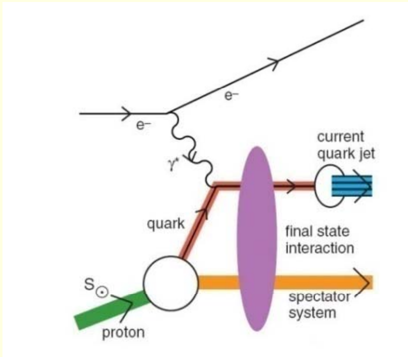
Also Measurements from COMPASS on Deuteron… F. Sozzi

SIVERS Mechanism

- The Sivers DF $\Delta_0^T q$ is probably the most famous between TMDs…
- gives a measure of the correlation between the transverse momentum and the transverse spin
- Requires final/initial state interactions of the struck quark with the spectator system and the interference between different helicity Fock states to survive time-reversal invariance
- Time-reversal invariance implies:

$$\Delta_0^T q(x,k_T^2)_{SIDIS} = -\Delta_0^T q(x,k_T^2)_{DY}$$

…to be checked

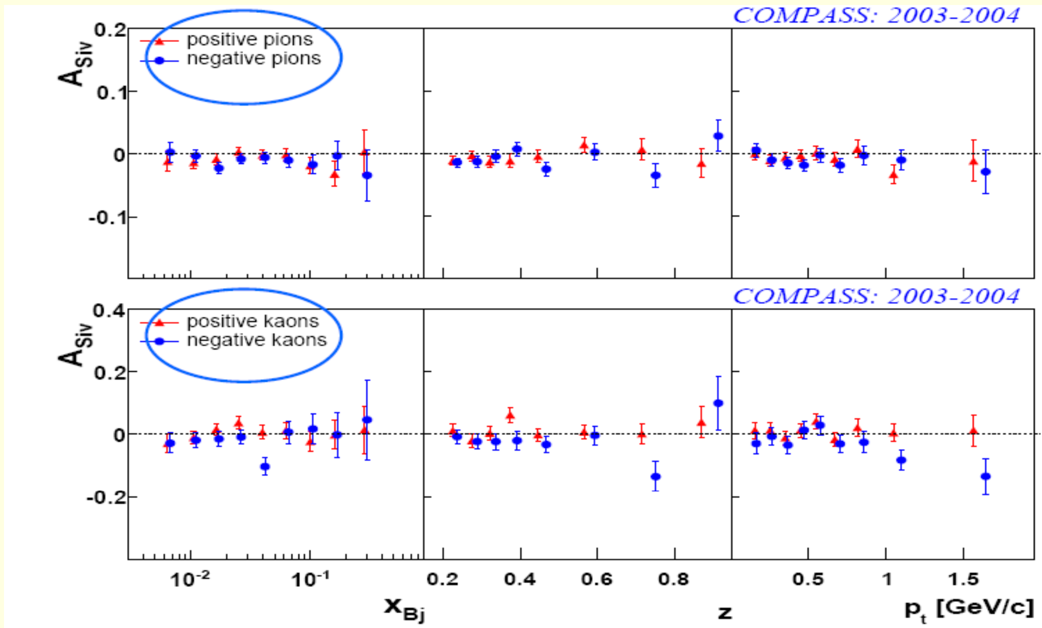


- In SIDIS:

$$N_h^{\pm}(\Phi_S) = N_h^0 \cdot \left\{1 \pm A_S^h \cdot \sin\Phi_S\right\}$$

$$A_{Siv} = \frac{A_S^h}{f \cdot P_T} = \frac{\sum_q e_q^2 \, \Delta_0^T q \cdot D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h}$$

Sivers Final on Deuteron from COMPASS

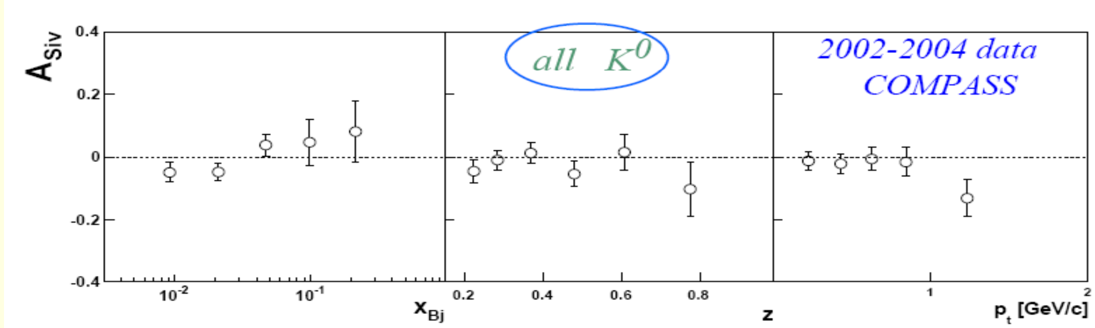


Final Results

all deuteron data

hep-ex/0802.2160

(subm. PLB)



Final Results

all deuteron data

hep-ex/0802.2160

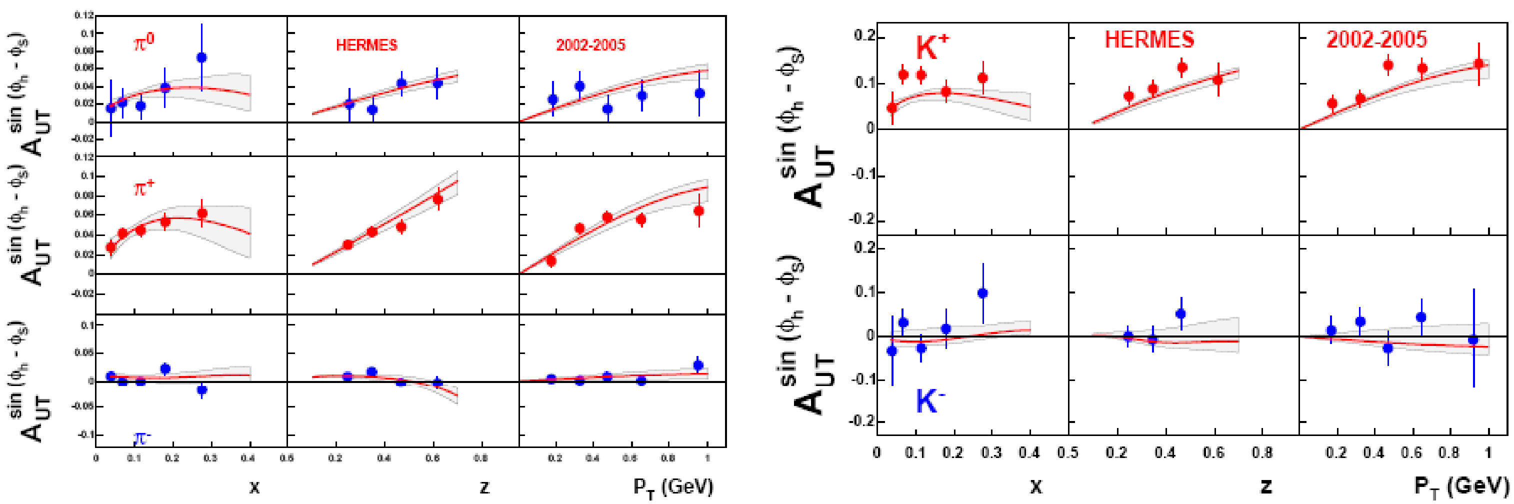
(subm. PLB)

Global Analysis

Stefano Melis

- HERMES data$^{\diamond}$ fit

$ep \rightarrow e\pi X$ $\quad p_{lab} = 27.57$ GeV/c $\quad ep \rightarrow eKX$

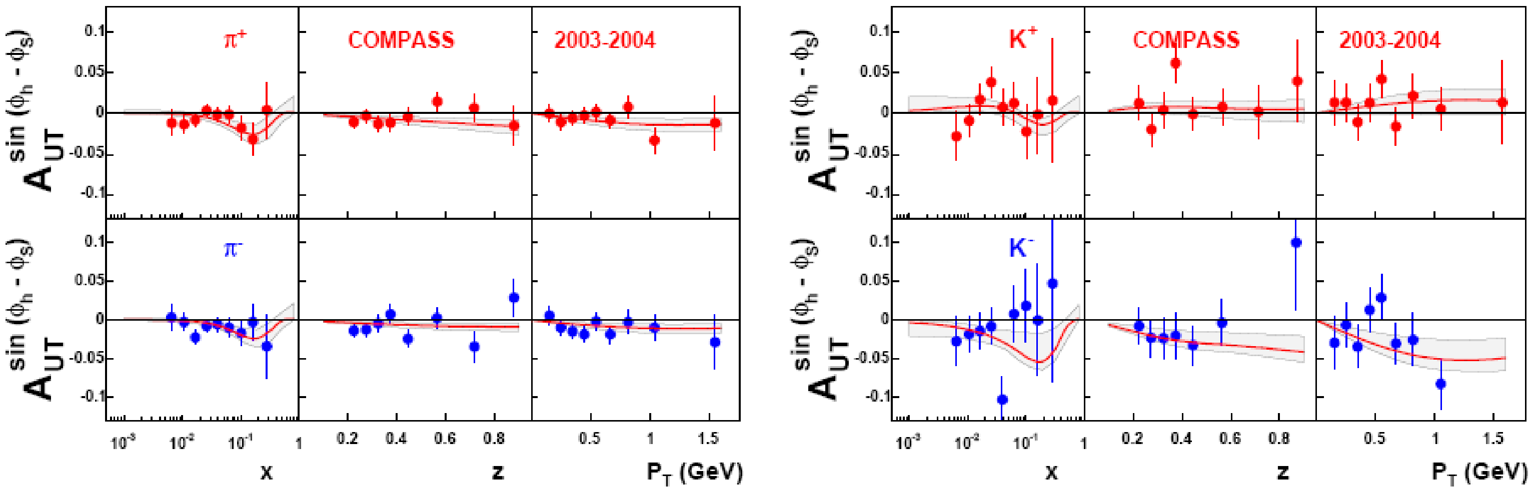


For Sivers DF → Andreas Metz

Global Analysis II

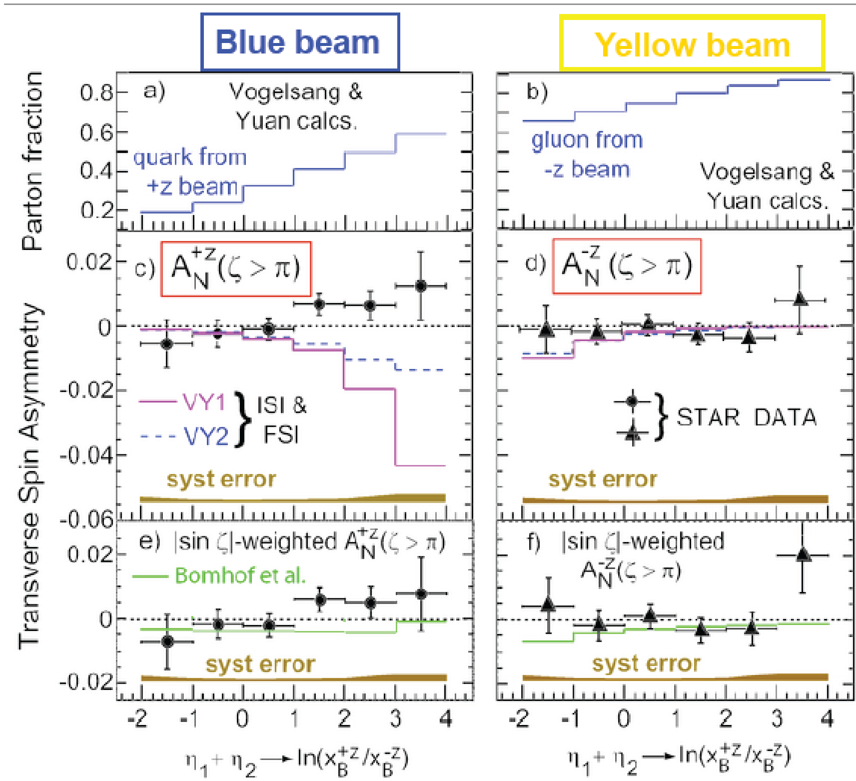
- COMPASS data◇ fit

$eD \rightarrow e\pi X$ $\quad p_{lab} = 160$ GeV/c $\quad eD \rightarrow eKX$



Stefano Melis

STAR Di-jet Sivers Asymmetry vs jet pseudorapidity sum



PRL.99:142003,2007

C.J. Bomhof, P.J. Mulders, W. Vogelsang and F. Yuan, Phys. Rev. D 75, 074019 (2007)

Reverse calc. A_N signs for Madison convention

Scale Bomhof calcs by 1/⟨|sin ζ|⟩ ≈ 3.0 to get A_N of unit max. magnitude

u-d and ISI-FSI Cancellations?

Test with jet charge sign selection?

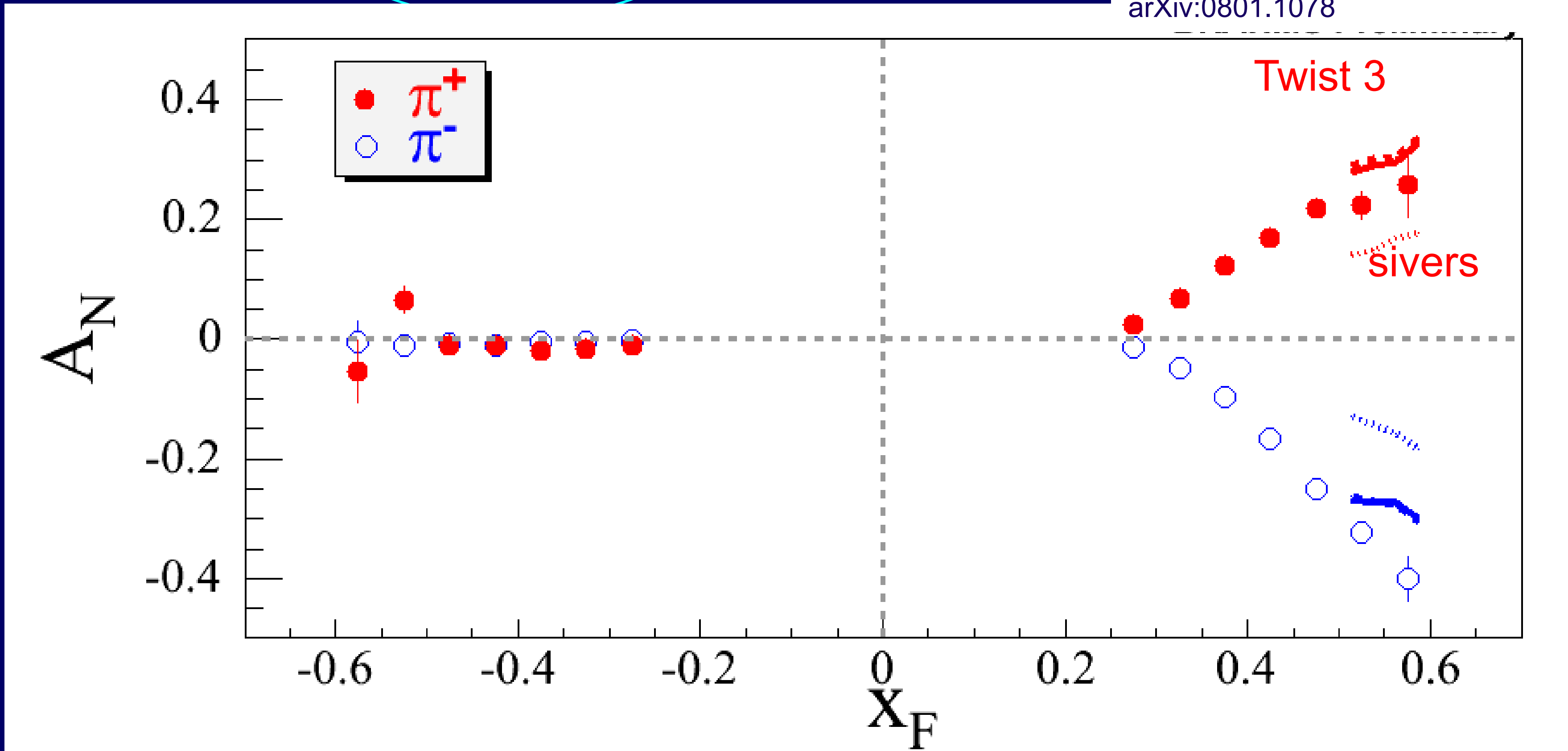
Factorization? Universality?

STAR A_N consistent with zero in both at high-*x* parton and low-*x* gluon region

And smaller than expected from SDIS measurements!

$A_N(\pi)$ at $\sqrt{s}$ = 62 GeV

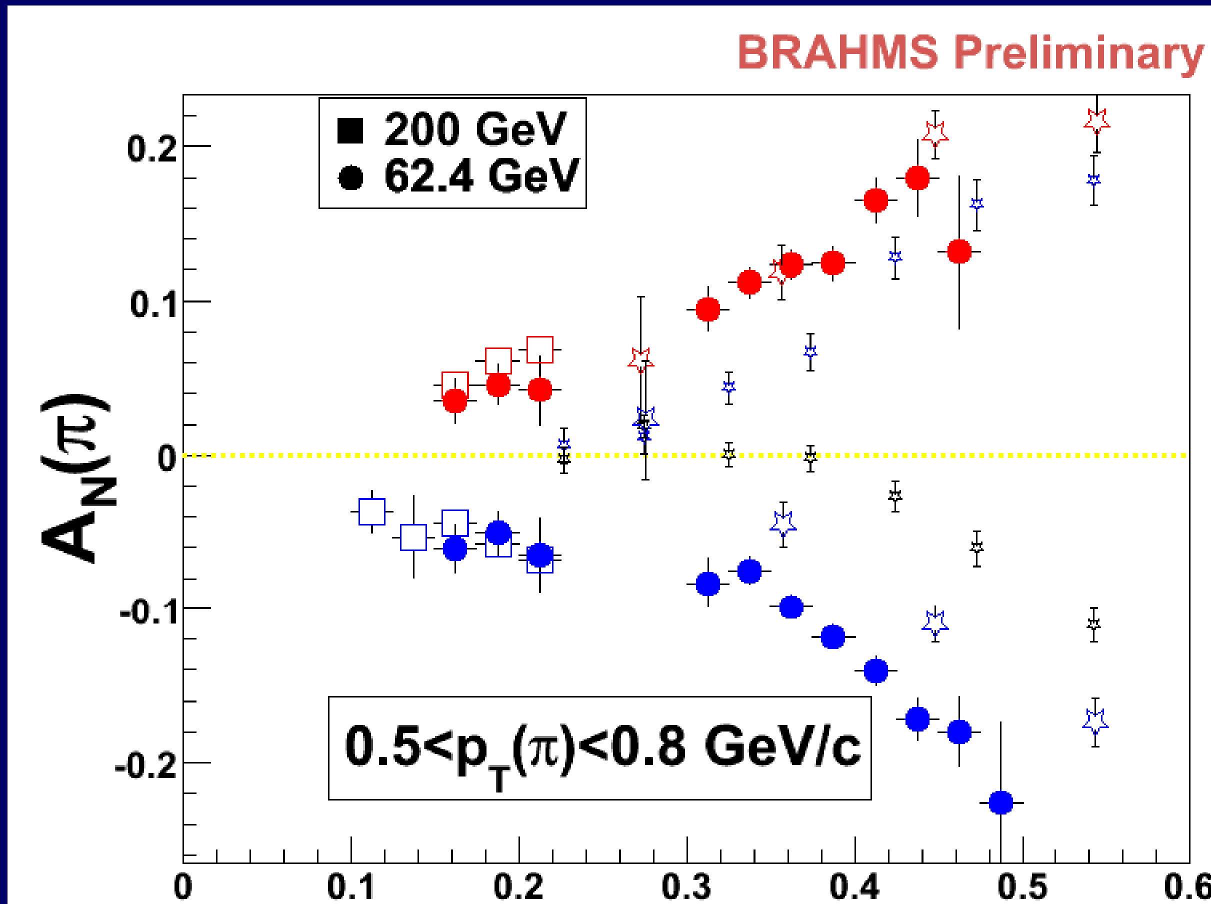
Submitted to Physical Review Letters
arXiv:0801.1078



- Large $A_N(\pi)$: 0.3-0.4 at x_F~0.6 p_T~1.3 GeV
- Strong x_F -p_T dependence. Though $|A_N(\pi^+)|$ ~ !$A_N(\pi^-)|$ $|A_N(\pi^+)/A_N(\pi^-)|$ decreases with x_F-p_T

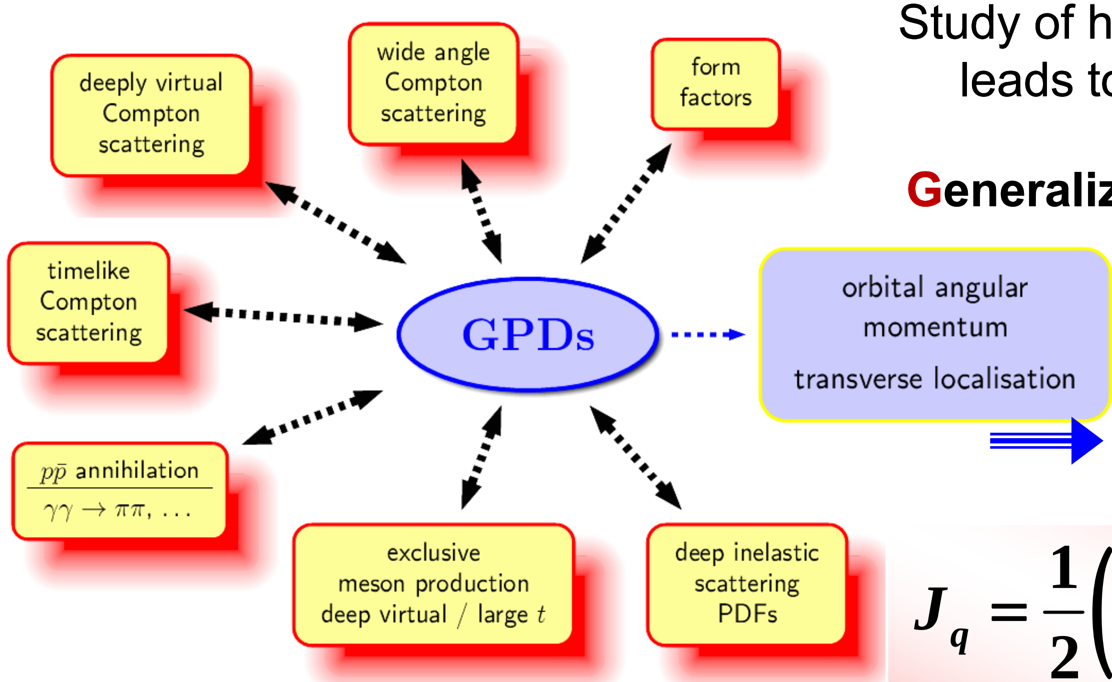
BRAHMS

Unifying 62 and 200 GeV
BRAHMS + E704



E704 data – all pt (small star) pt>0.7 red star.

The Hunt for L_q



Study of hard exclusive processes leads toa new class of PDFs

Generalized Parton Distributions

$$H^q, E^q, \tilde{H}^q, \tilde{E}^q$$

⇒ possible access to orbital angular momentum

$$J_q = \frac{1}{2}\left(\int_{-1}^{1} x dx \left(H^q + E^q\right)\right)_{t \to 0}$$

$$J_q = \frac{1}{2}\Delta\Sigma + L_q$$

from DIS: ~0.3

exclusive: all products of the reaction are detected

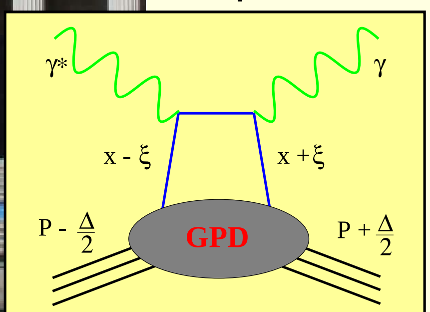
⇒ missing energy (ΔE) and missing Mass (M_x) = 0

GPDs Introduction

What does GPDs charaterize?

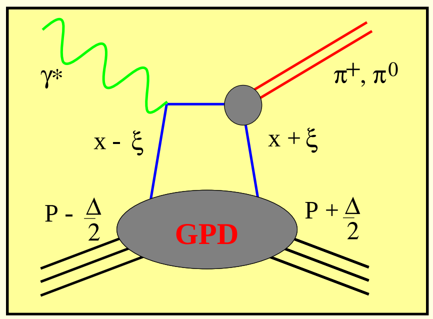
	unpolarized	polarized	
	$H^q(x,\xi,t)$	$\tilde{H}^q(x,\xi,t)$	conserve nucleon helicity $H^q(x,0,0)=q, \tilde{H}^q(x,0,0)=\Delta q$
	$E^q(x,\xi,t)$	$\tilde{E}^q(x,\xi,t)$	flip nucleon helicity not accessible in DIS

quantum numbers of final state ⟹ select different GPD



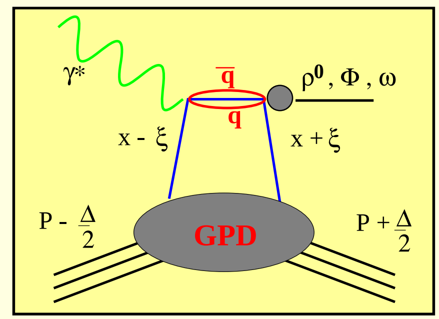
DVCS

$\underbrace{H^q}_{A_C, A_{LU},}$ $\underbrace{E^q}_{A_{UT},}$ $\underbrace{\tilde{H}^q}_{A_{UL}}$ $\tilde{E}^q$



pseudo-scaler mesons

$\underbrace{\tilde{H}^q, \tilde{E}^q}_{A_{UT}, \sigma_{\pi+}}$

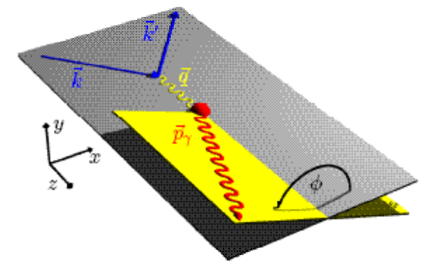


vector mesons

$\underbrace{H^q, E^q}_{A_{UT}, \sigma_{\rho,\Phi,\omega}}$

DVCS ASYMMETRIES

$$d\sigma \sim \left(\tau^*_{BH}\tau_{DVCS} + \tau^*_{DVCS}\tau_{BH}\right) + |\tau_{BH}|^2 + |\tau_{DVCS}|^2$$



→ different charges: e^+ e^- *(only @HERA!)*:

$\Delta\sigma_C \sim \cos\phi \; \mathrm{Re}\{ H + \cancel{\xi \tilde{H}} + \ldots \}$ ⇒ H

→polarization observables:

$\Delta\sigma_{LU} \sim \sin\phi \; \mathrm{Im}\{H + \cancel{\xi \tilde{H}} + \cancel{kE}\}$ ⇒ H

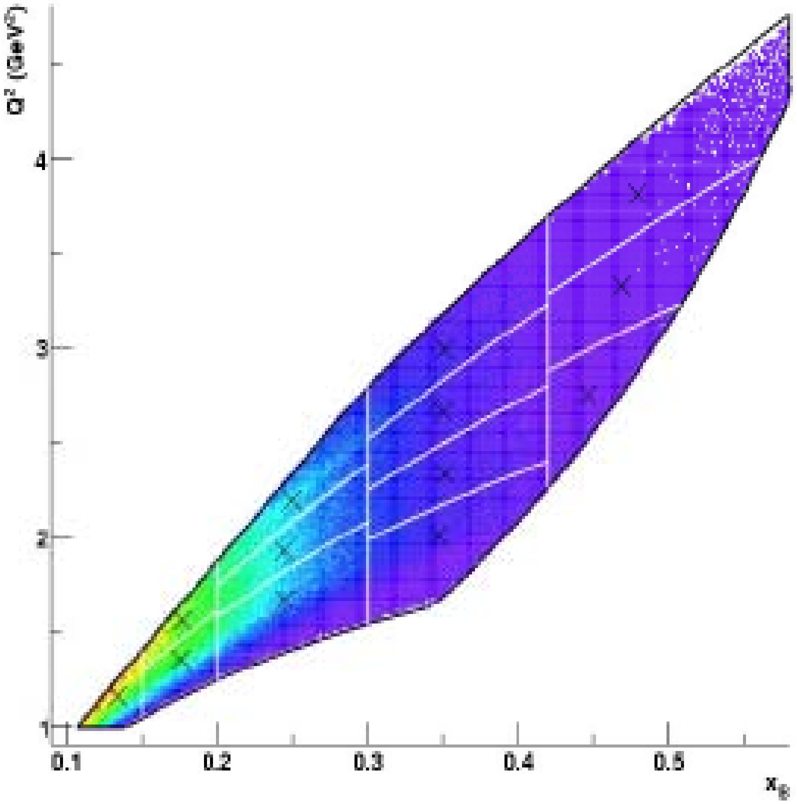
$\Delta\sigma_{UT}$ ↙ beam ↘ target

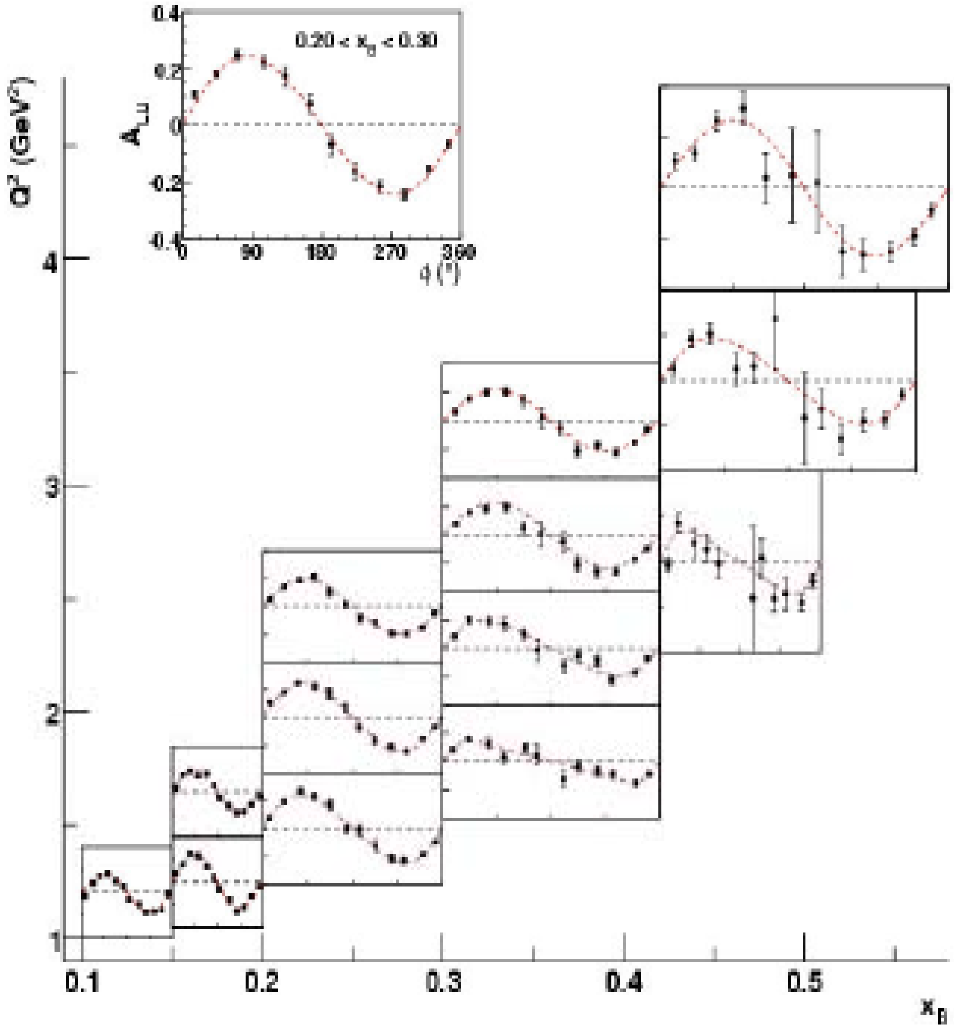
$\Delta\sigma_{UL} \sim \sin\phi \; \mathrm{Im}\{\tilde{H} + \cancel{\xi H} + \ldots\}$ ⇒ $\tilde{H}$

$\Delta\sigma_{UT} \sim \sin\phi \; \mathrm{Im}\{k(H - E \; \cancel{} \ldots \}$ ⇒ H, E

$\xi = x_B/(2-x_B)$, $k = t/4M^2$ kinematically suppressed

CLAS: BSA: coverage and f distributions



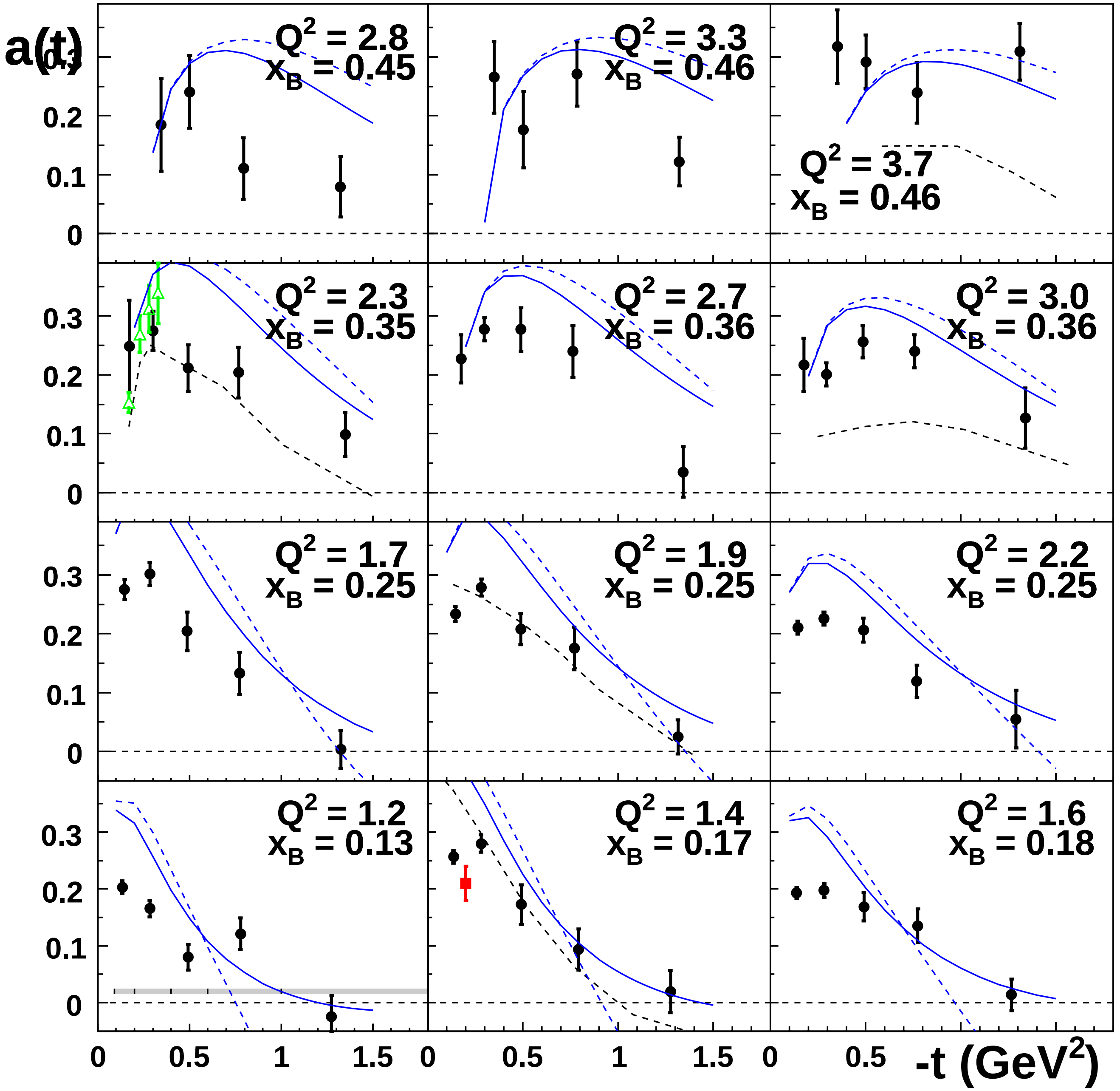


- 13 Q^2, x_B bins
- 5 t bins
- 12 ϕ bins

Fit = $\alpha \sin\phi/(1+\beta\cos\phi)$

Ph.D. Thesis of F.X. Girod

CLAS: BSA: a vs. t



(*) Guidal, Polyakov, Radyushkin, Vanderhaegen, PRD 72 (2005)

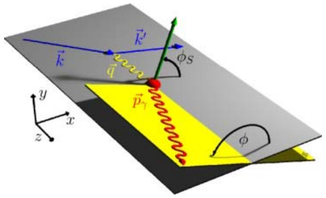
(**) Cano and Laget, PL B551 (2003)

GPD model overestimates the data

arXiv: 0711.4805 [hep-ex]
Submitted to PRL

Ph.D. Thesis of F.X. Girod

Hermes: Transverse Target Spin Asymmetry



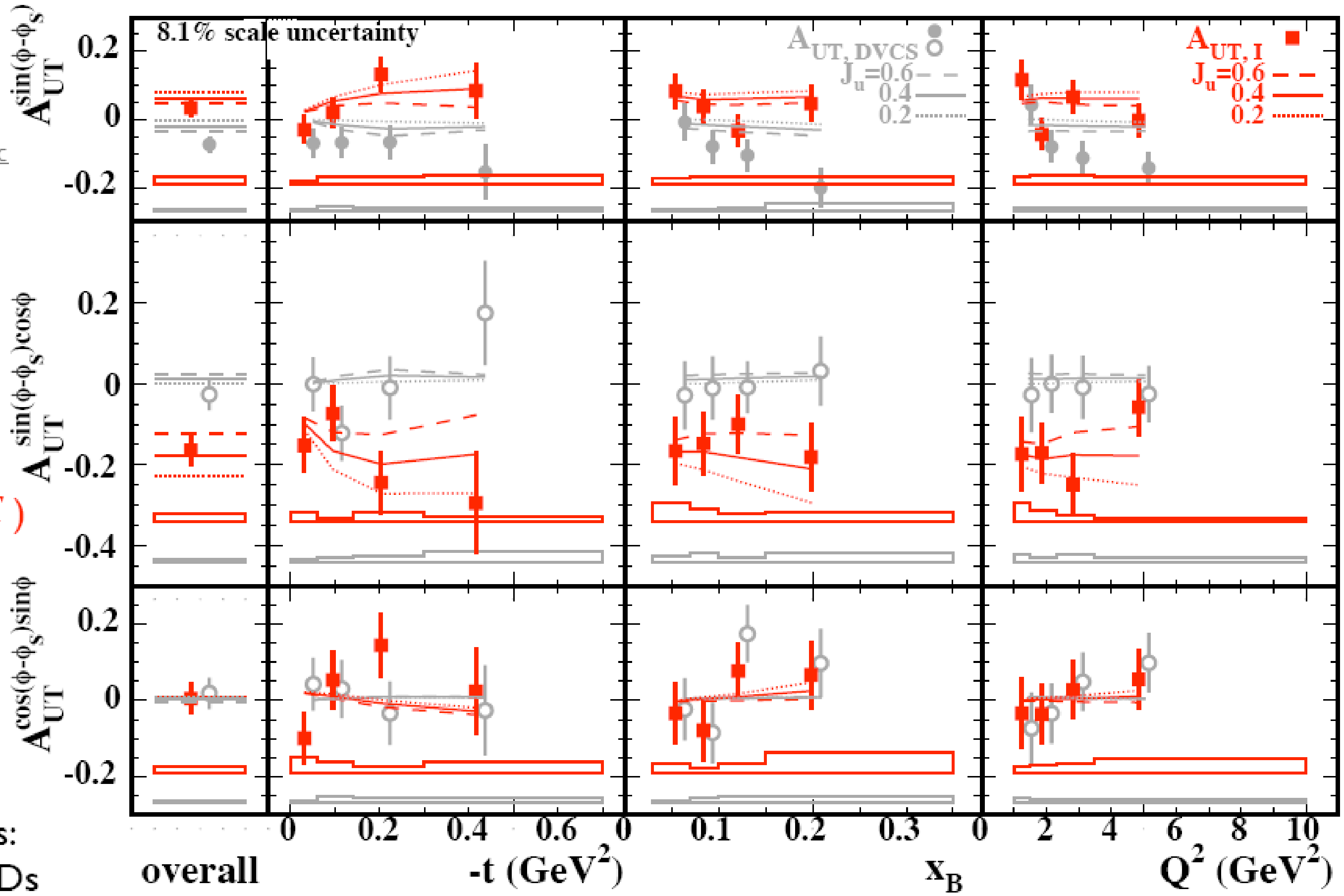
$\propto$ Im($F_1\mathcal{E}$)

$\mathcal{H}$ - $\mathcal{E}$ int^{fnc}

$\propto$ −Im($F_1\mathcal{E}$)

nucleon helicity flip

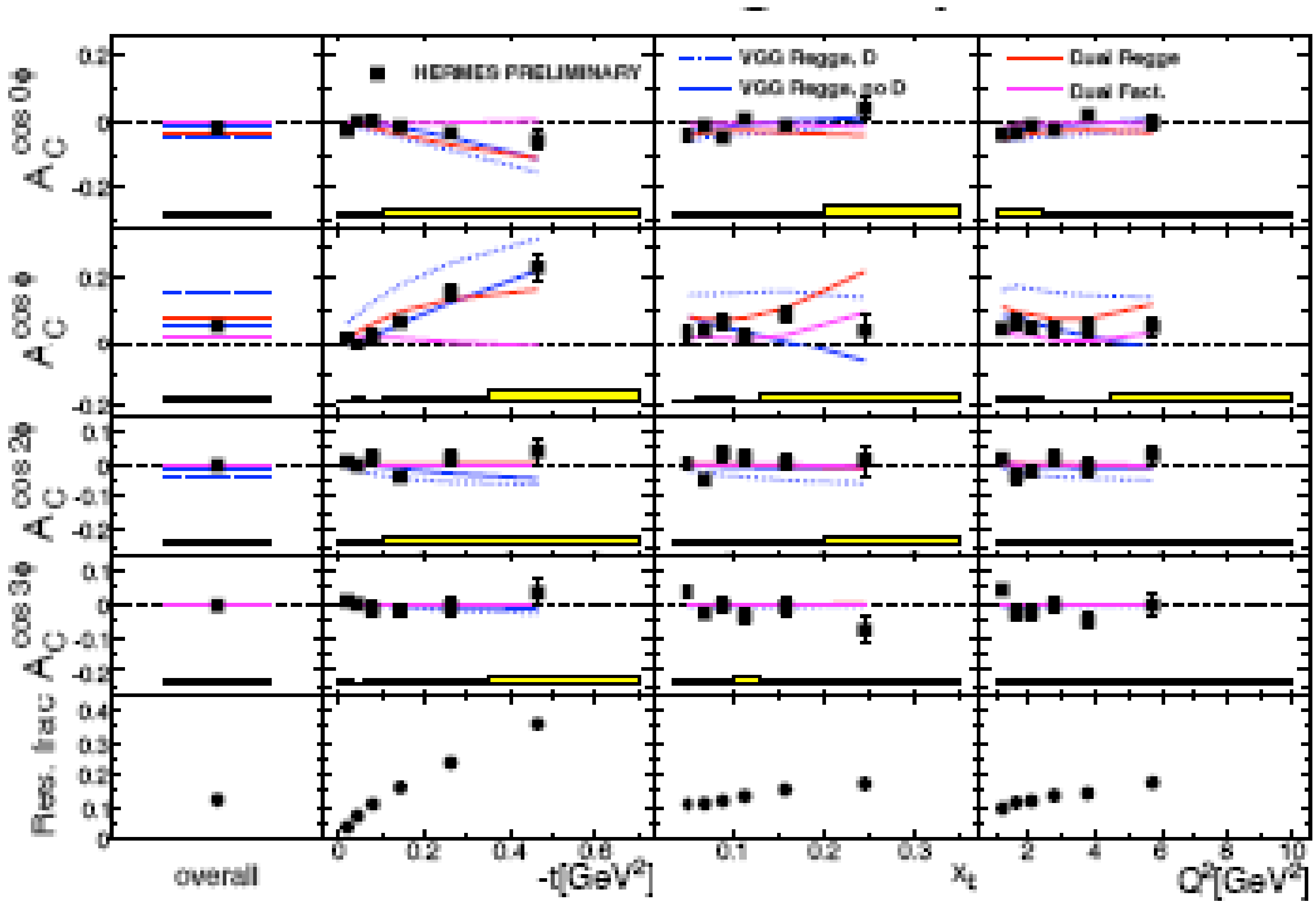
All others: twist-3 GPDs

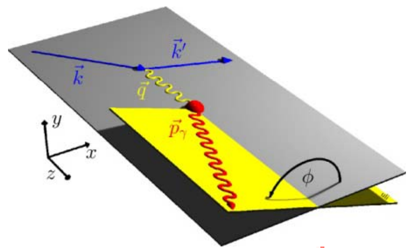


Sensitivity to J_q

Hermes: Charge and Beam Spin Asymmetry

Beam Charge Asymmetry





$\propto -A_C^{\cos\phi}$

$\propto \mathrm{Re}[F_1\mathcal{H}]$

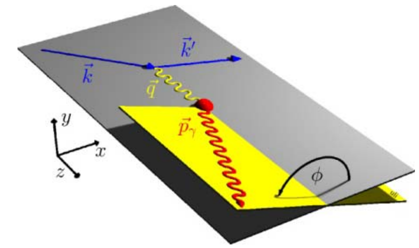
(higher twist)

(higher twist)

Bin-wise fractions of associated production.

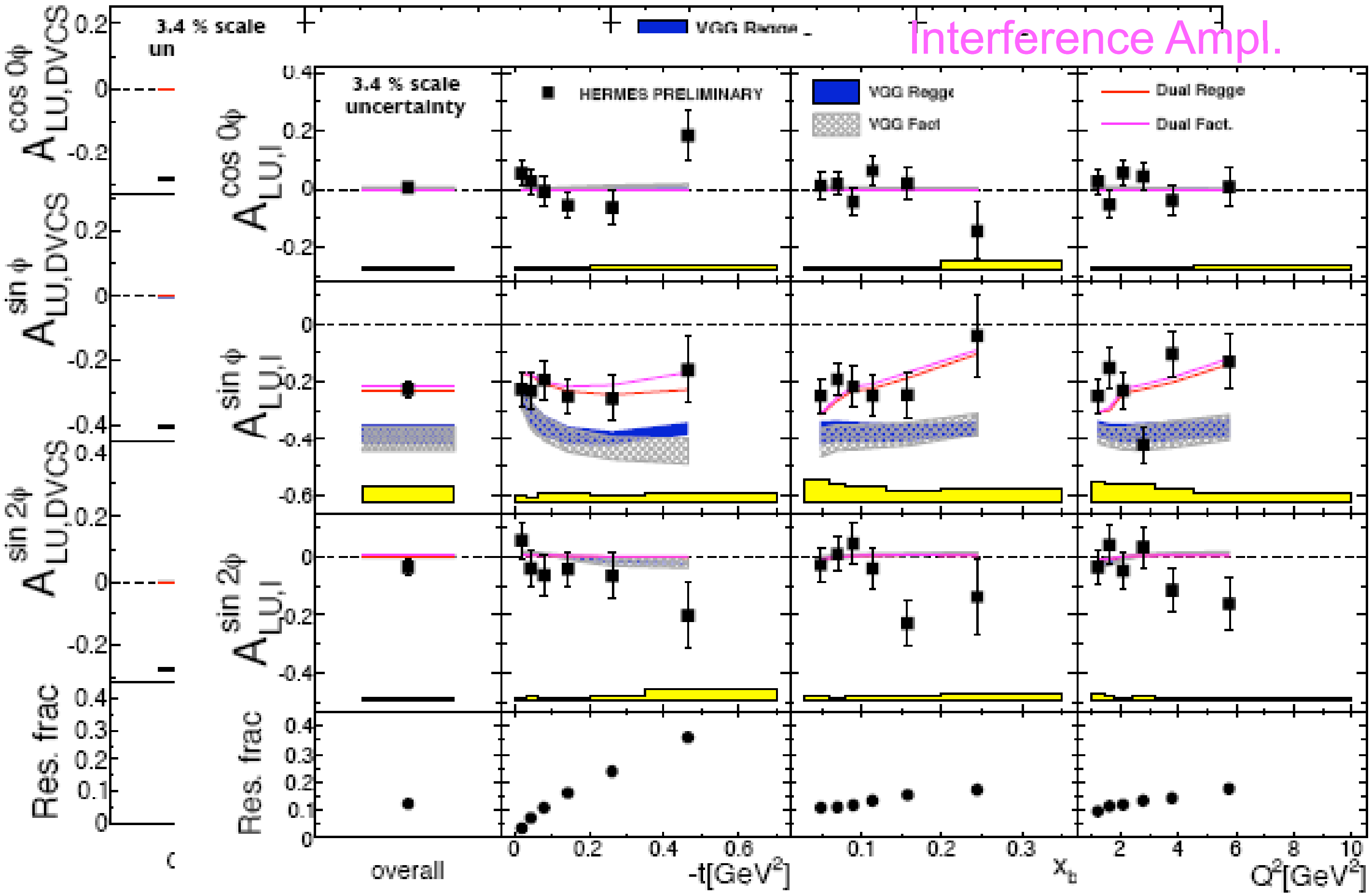
Hermes: Charge and Beam Spin Asymmetry

Beam Spin Asymmetry



DVCS Ampl.

Interference Ampl.

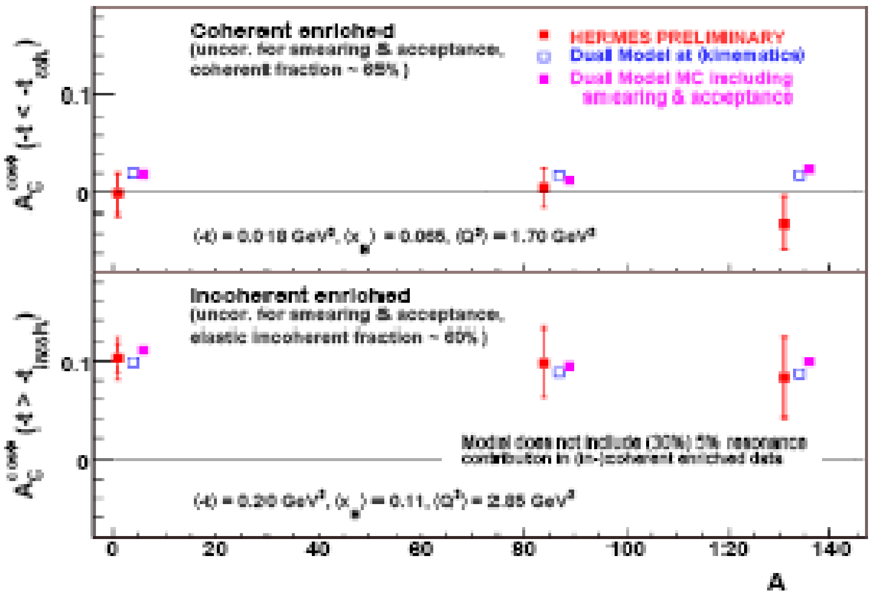


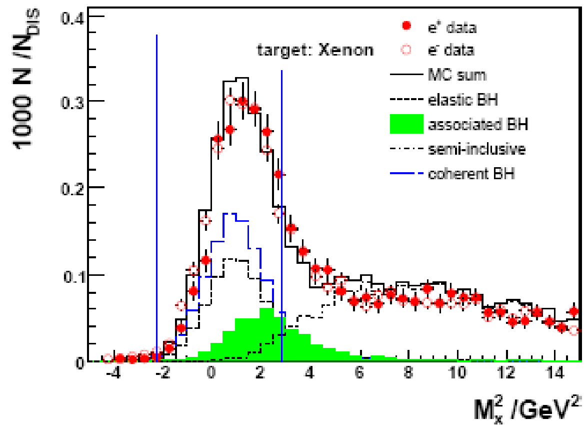
$\propto Im[F_1 \mathcal{H}]$

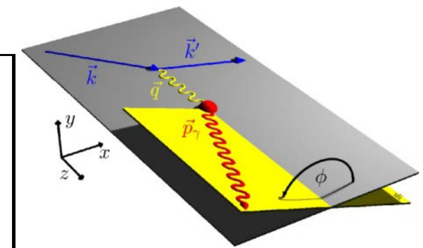
(higher twist)

Hermes: Charge and Beam Spin Asymmetry Heavy Targets

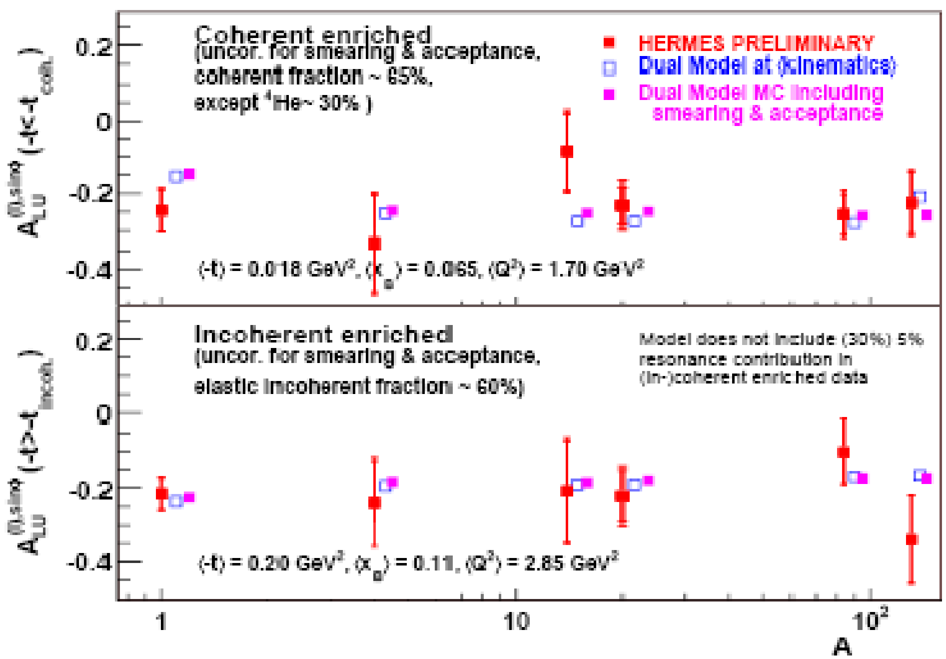
Beam Charge Asymmetry







Beam Spin Asymmetry



Why nuclear DVCS:

- constrain nuclear GPDs
- constrain models attempting to describe nuclear matter
  - ➡ neutron and proton matter distribution in nuclei

What next?

- More data
  Hermes/Compass/RHIC/Jlab
- New Data
  Compass/RHIC…
- New Experiments
  Jlab@12/CompassII

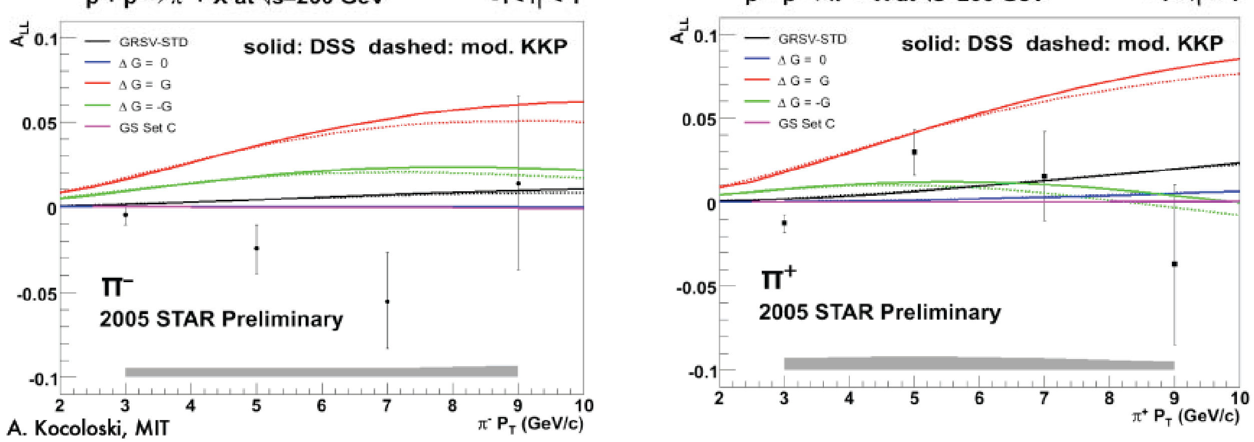
Thanks to all the participants of the Spin Session

[apologies to all speakers not covered in this summary]

… and pions

A_{LL} for Run 6 Neutral Pions

Charged Pion Preliminary A_{LL}



- Maximum gluon polarization scenario disfavored
- Improved precision with Run 6 data
  - Increased polarization: 45% to 55%
  - Increased Luminosity

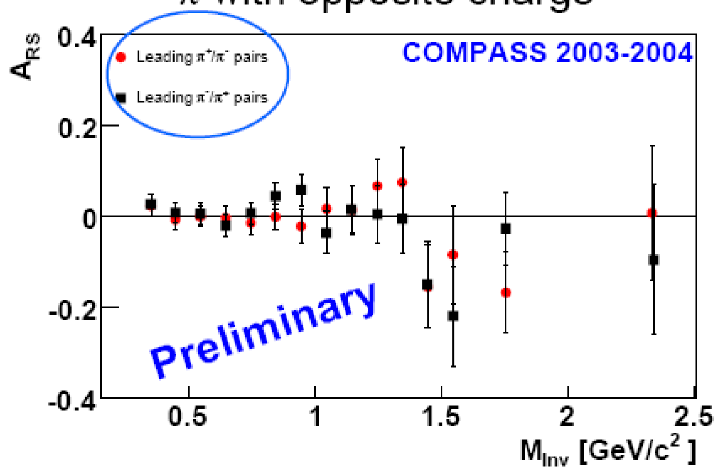
COMPASS 2-hadrons, leading z-hadrons

2) **z-ordered pairs**: select in the event the two hadrons with the highest relative energy z:

for leading hadron pairs the signal enhancement is predicted,
hadrons with higher energy carry more information
about the fragmenting quark polarization

16 combinations, 4 particle combinations times 4 charge combinations

π with opposite charge



π with same charge