Review of COMPASS Spin Physics
- A Personal Selection -

Diffraction 2010

Otranto , September 2010

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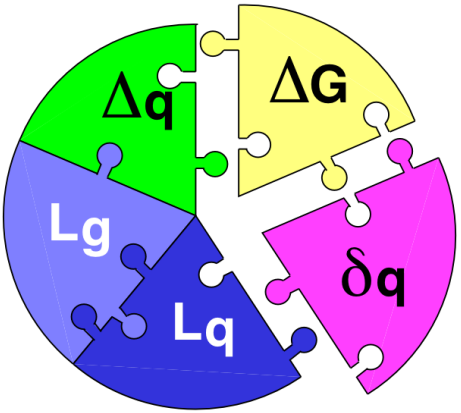
* on behalf of the COMPASS collaboration

bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung

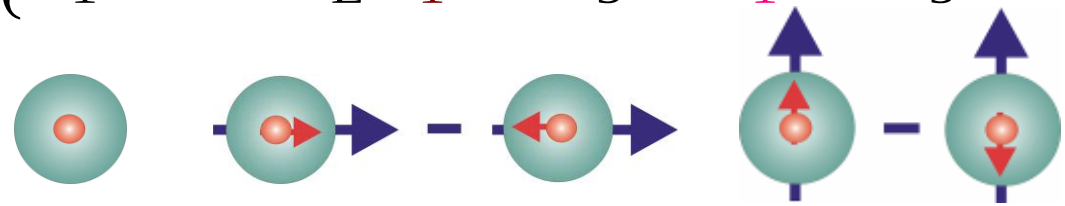
The Spin of the Nucleon



$$\frac{s_z^N}{\hbar} = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_z^q + \Delta G + L_z^g$$

All started with EMC (88):
$\Delta\Sigma = 0.12 \pm 0.17$

$$\Phi^{Tw2}_{Corr}(x) = \frac{1}{2}\left\{ f_1(x) + S_L\, g_1(x)\gamma_5 + h_1(x)\gamma_5\gamma^1 S_T \right\} n^+$$



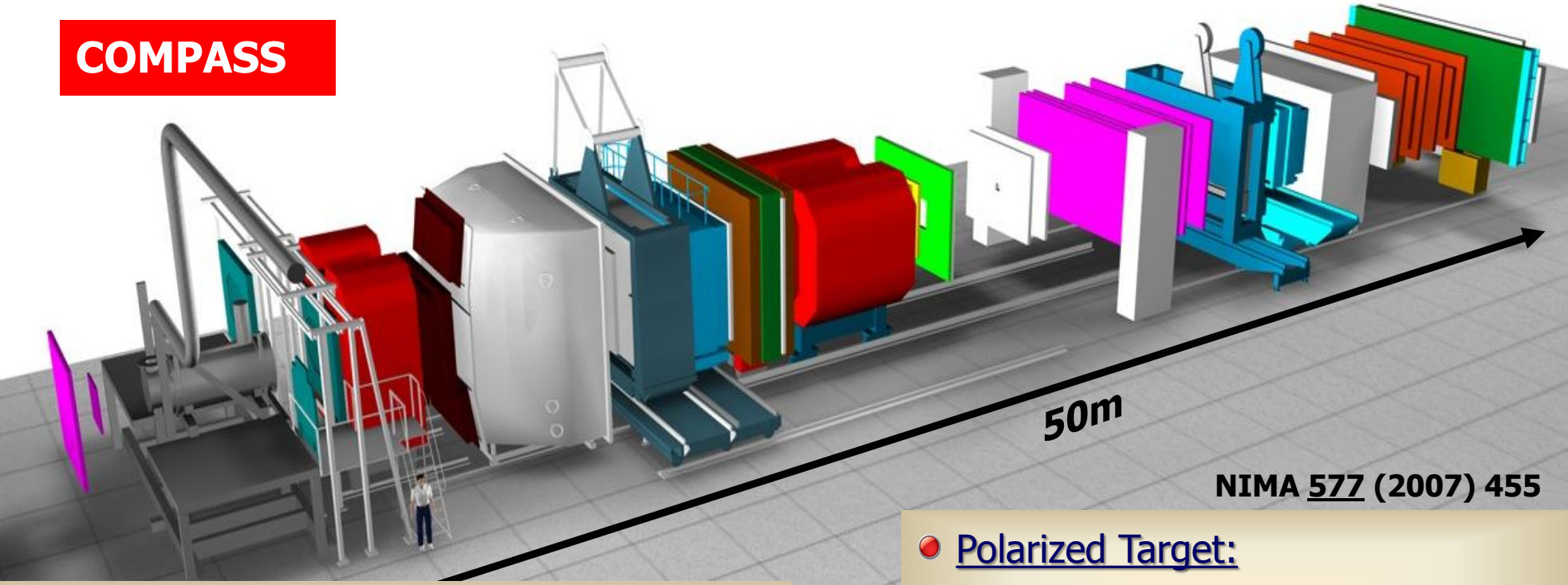
OUTLINE:

- **Helicity distribution of quarks** $\Delta\Sigma = \Delta u_v + \Delta d_v + \Delta q_s$
- **… and gluons** ΔG
- **Transverse spin phenomena** $h_1,\ f_{1T}^{\perp},\ldots$
- **Outlook - COMPASS-II**

Polarized DIS & SIDIS Experiments @ CERN

	1980	1990	2000	2010	2020
EMC	g_1, EJ				
SMC		g_1, EJ, Bj			
COMPASS			ΔG, g_1, Δf, TSD, TMD		
COMPASS-II				GPD, TSD, TMD	

COMPASS



NIMA 577 (2007) 455

- Polarized μ^+ Beam: 160 GeV/c P_B= -0.8
  - with choice of μ^+,μ^- 100…200 GeV/c

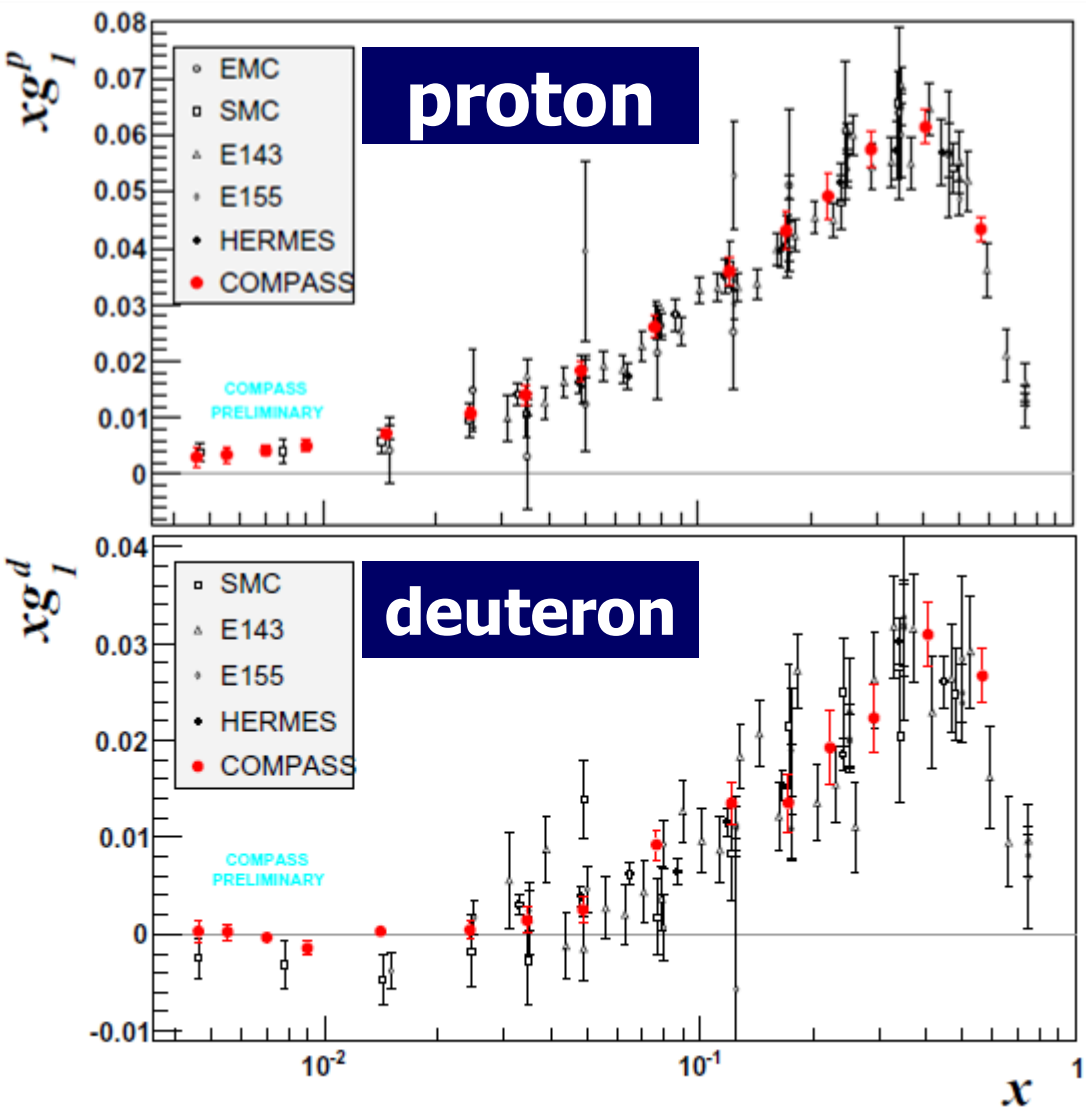
- Polarized Target:
  - 2002 – 2006: ^{6}LiD P_T= 0.5
  - 2007, 2010: NH_3 P_T= 0.8

Longitudinal Spin Structure

Spin Structure Function $g_1(x,Q^2)$

$$\sigma_{DIS}^{\text{inclusive}} \propto g_1(x) \propto \frac{1}{2}\sum_q e_q^2 \left\{\Delta q(x) + \Delta\bar{q}(x)\right\}$$

- Very precise data
- Good agreement among Experiments



Deuteron data:

From Γ^1 @ $Q^2 \to \infty$

COMPASS:

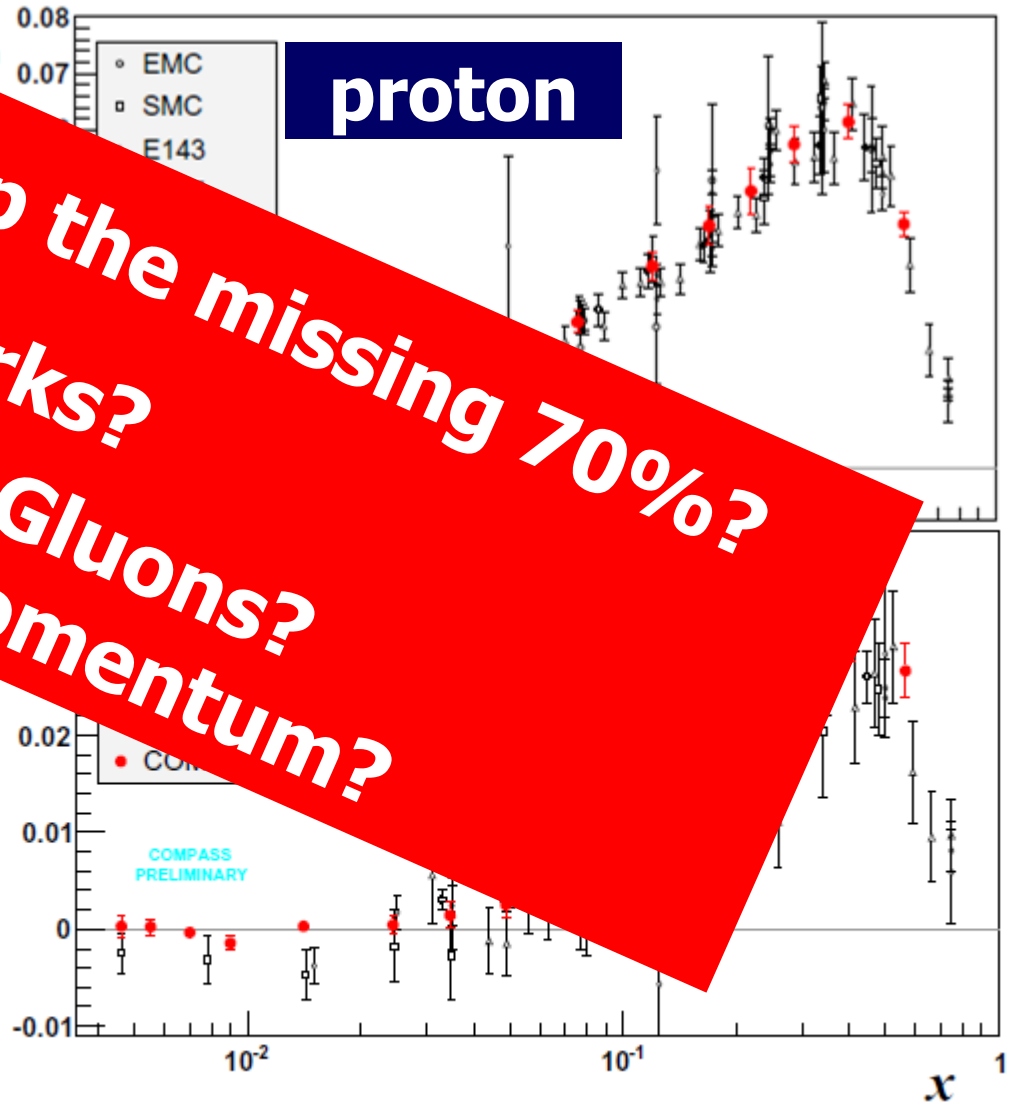
- $a_0 = 0.33 \pm 0.03 \pm 0.05$
- $\Delta s + \Delta\bar{s} = 1/3(a_0 - a_8)$
  $= -0.08 \pm 0.01 \pm 0.02$

Spin Structure Function $g_1(x,Q^2)$

$$\sigma_{DIS}^{inclusive} \propto \frac{1}{2}\sum e_q^2 \left\{\Delta q(x) + \Delta\bar{q}(x)\right\}$$

- Ve
- G
- Large

What makes up the missing 70%?
- Sea Quarks?
- Polarized Gluons?
- Angular Momentum?



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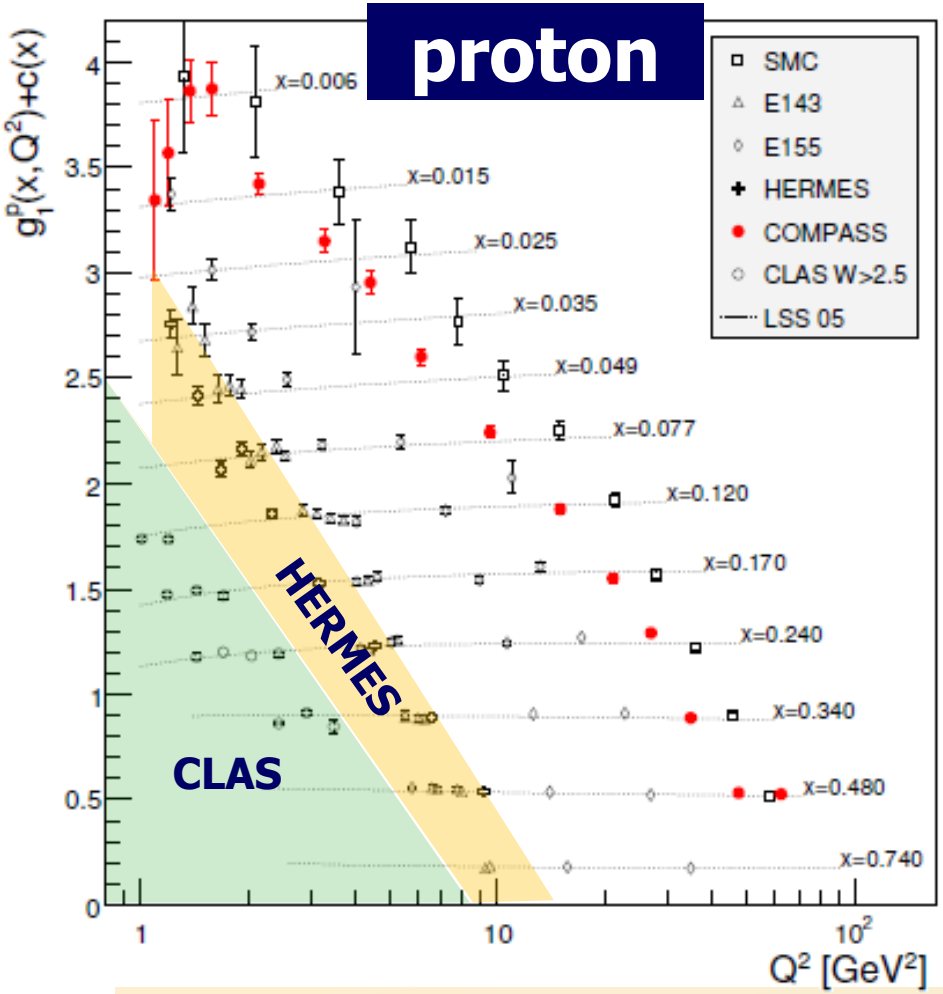
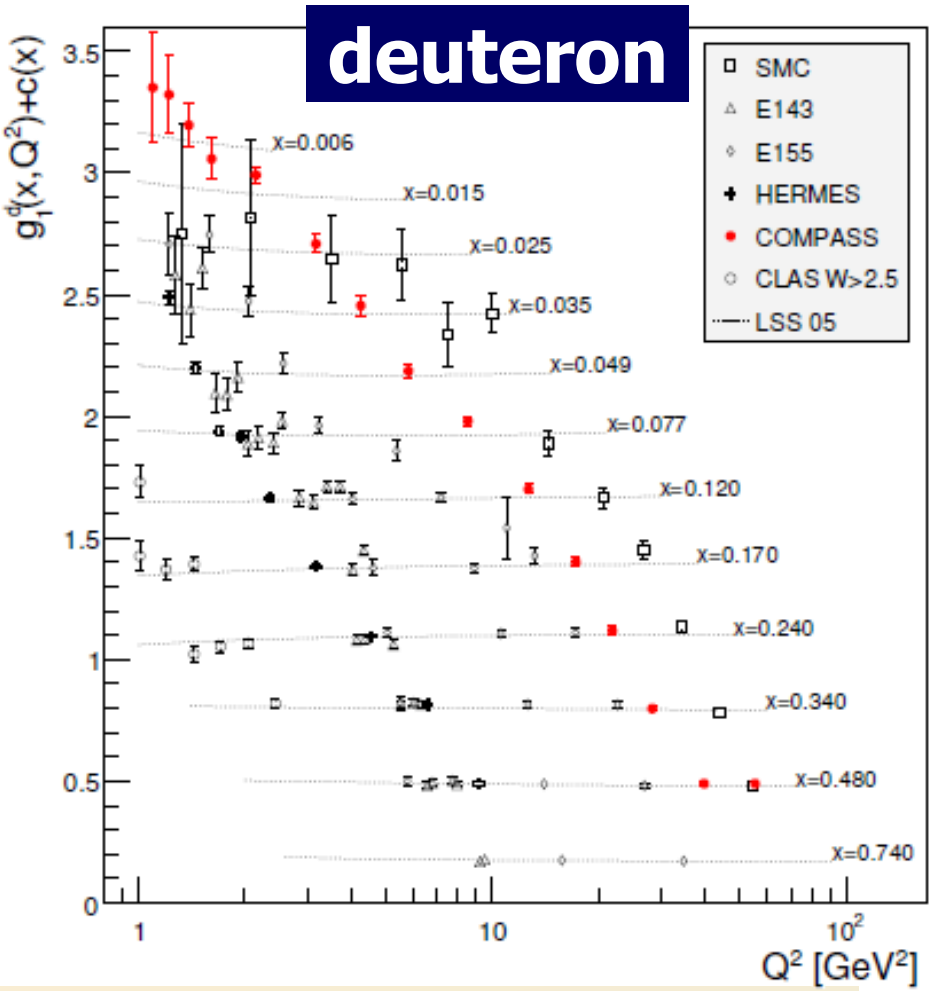
Global NLO QCD Analysis

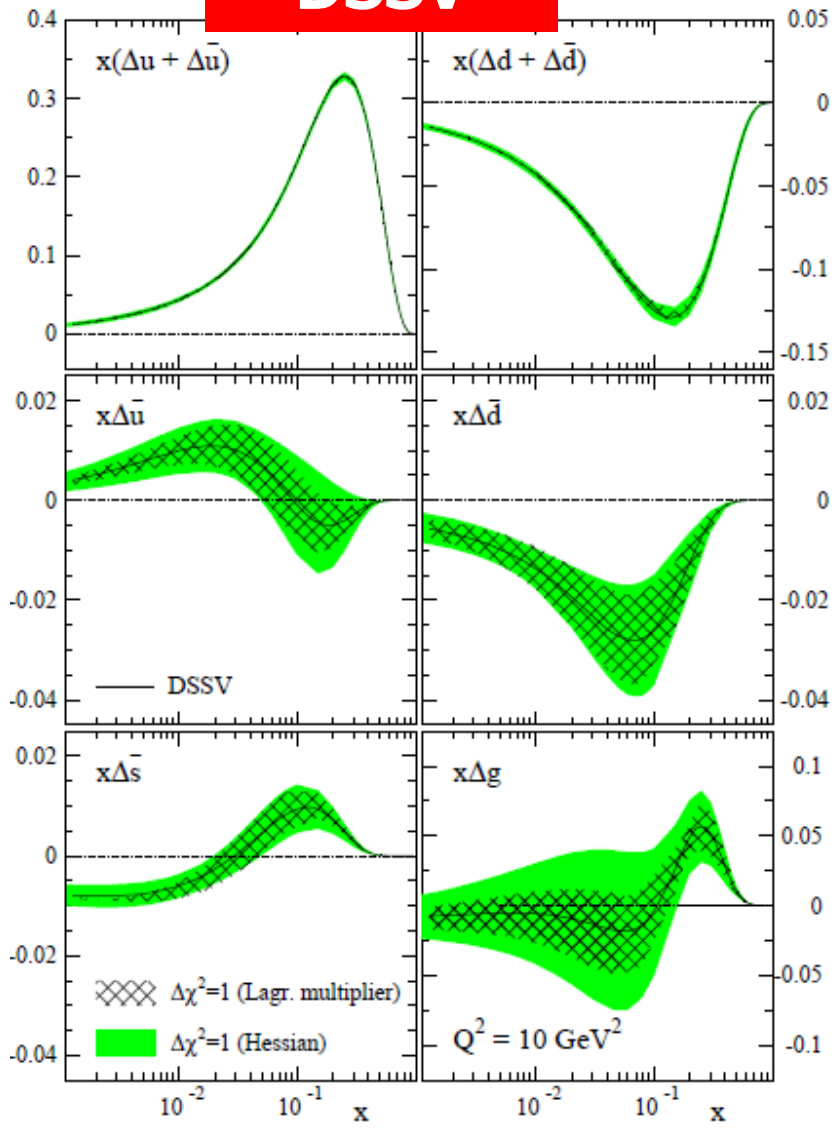




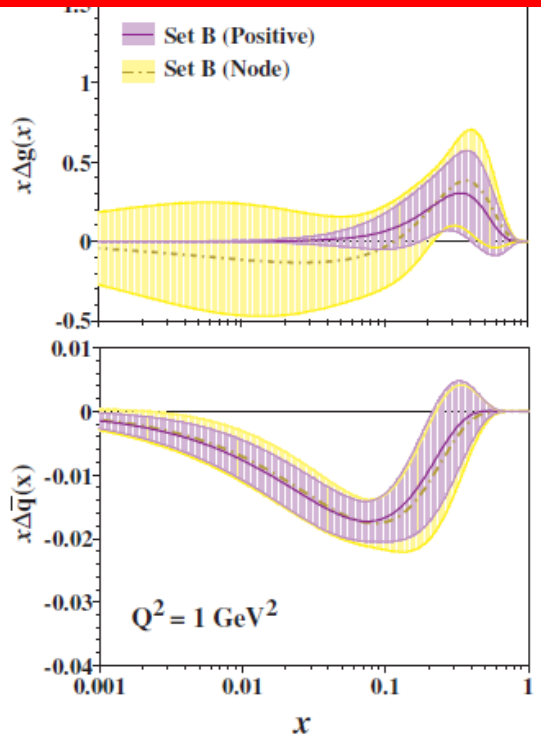
- extract Quark & Gluon PDFs through Q^2 evolution
- $\Delta\Sigma = 0.30 \pm 0.01(\text{stat.}) \pm 0.02(\text{evol.})$ -all data

Selected Results from two Global Fits

DSSV

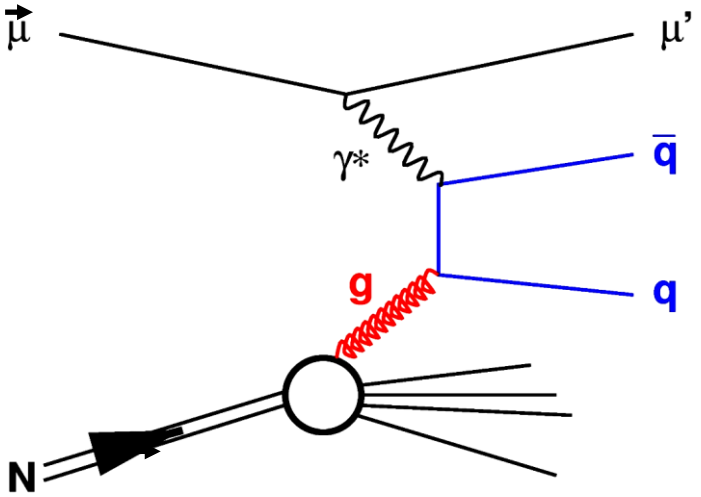


Hirai, Kumano, Saito



- Quark distributions well determined
- Possibility of a node @ x=0.1 in Δg(x)
- SIDIS prefer Δs>0 (x>0.01)
  - Incl. data require Δs<0 (SU3)
  - Fits give indication for a node

Direct Access to the Gluon Polarization (SIDIS)



Strategies to suppress background:

- **q = c**

  charm fragmentation:

  - **D^0, D^* (60%)**
  - **D^+ (20%)**
  - **D^+_S, Λ^+_C (10% each)**

- **Hadrons with large p_T**

  q = u, d, s

- Direct measurement of $\Delta G/G$ in **Photon-Gluon-Fusion**

$$A_{\parallel} = R_{pgf} \langle \hat{a}_{pdf} \rangle \left\langle \frac{\Delta g}{g} \right\rangle$$

- single charmed meson
  - quasi-real photons
  - MC: AROMA,RAPGAP
- high-p_T hadron pairs (no ID of π, K)
  - $Q^2 > 1$ GeV^2 (MC: LEPTO)
  - $Q^2 < 1$ GeV^2 (MC: PYTHIA)
- high-p_T single hadron
  - small Q^2 (MC: PYTHIA)

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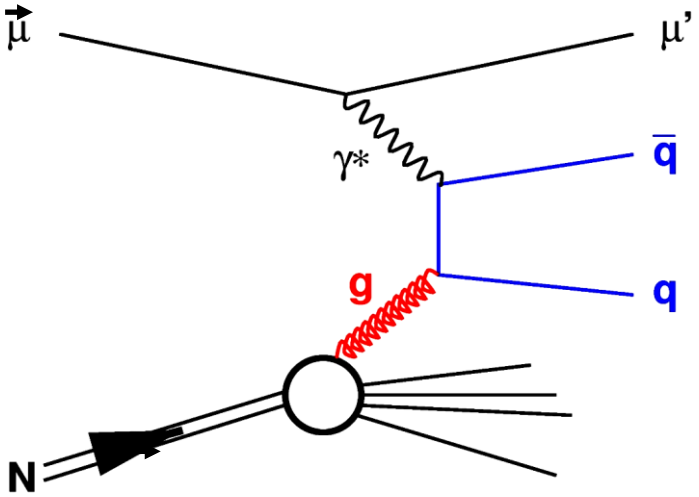

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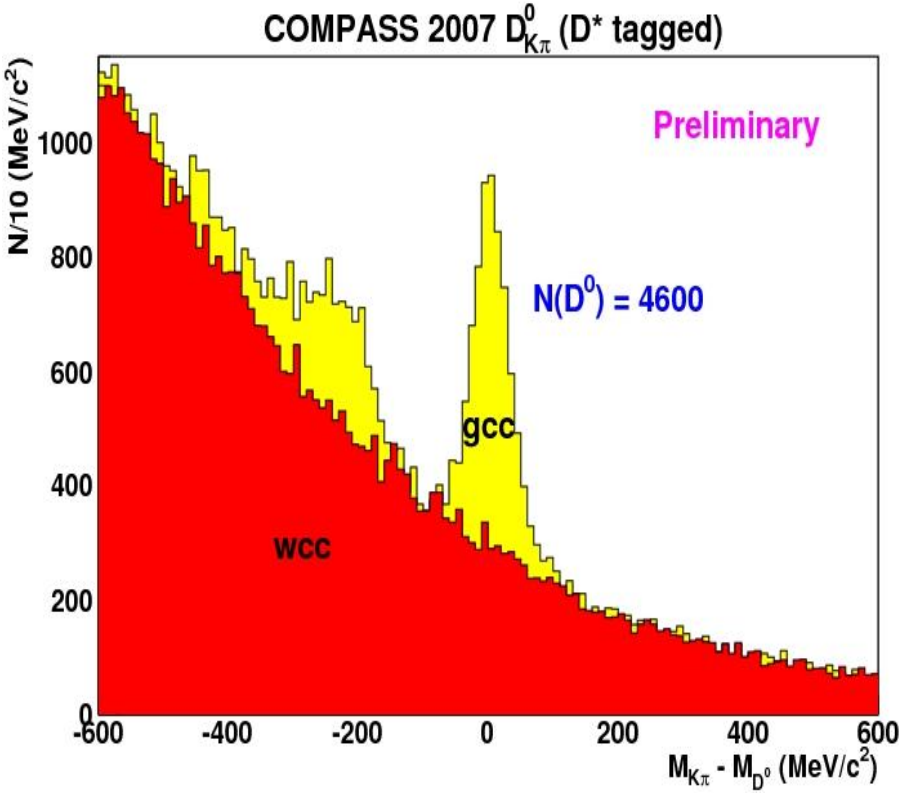
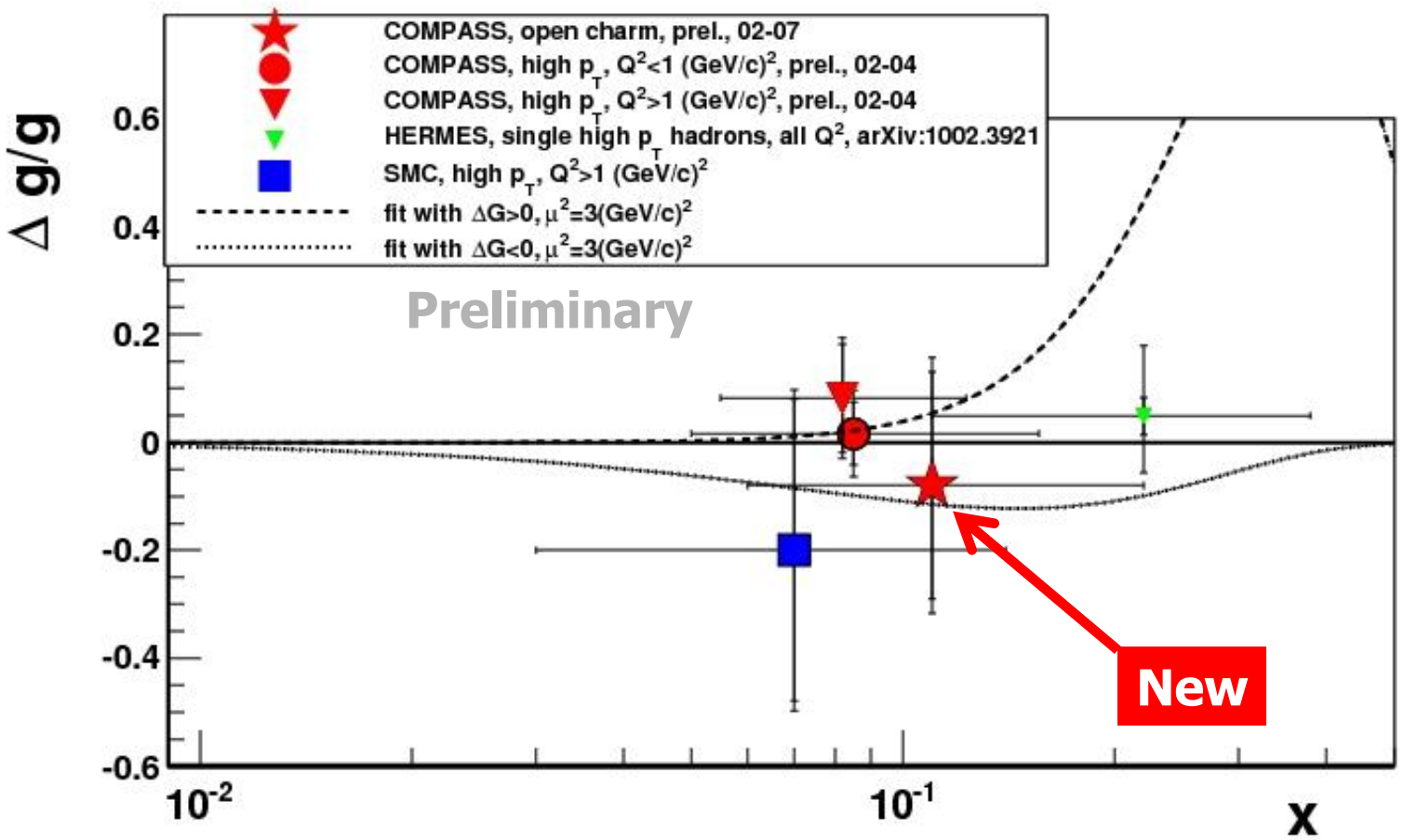


Summary Gluon Polarization

Presently all Analysis in LO only, NLO coming soon

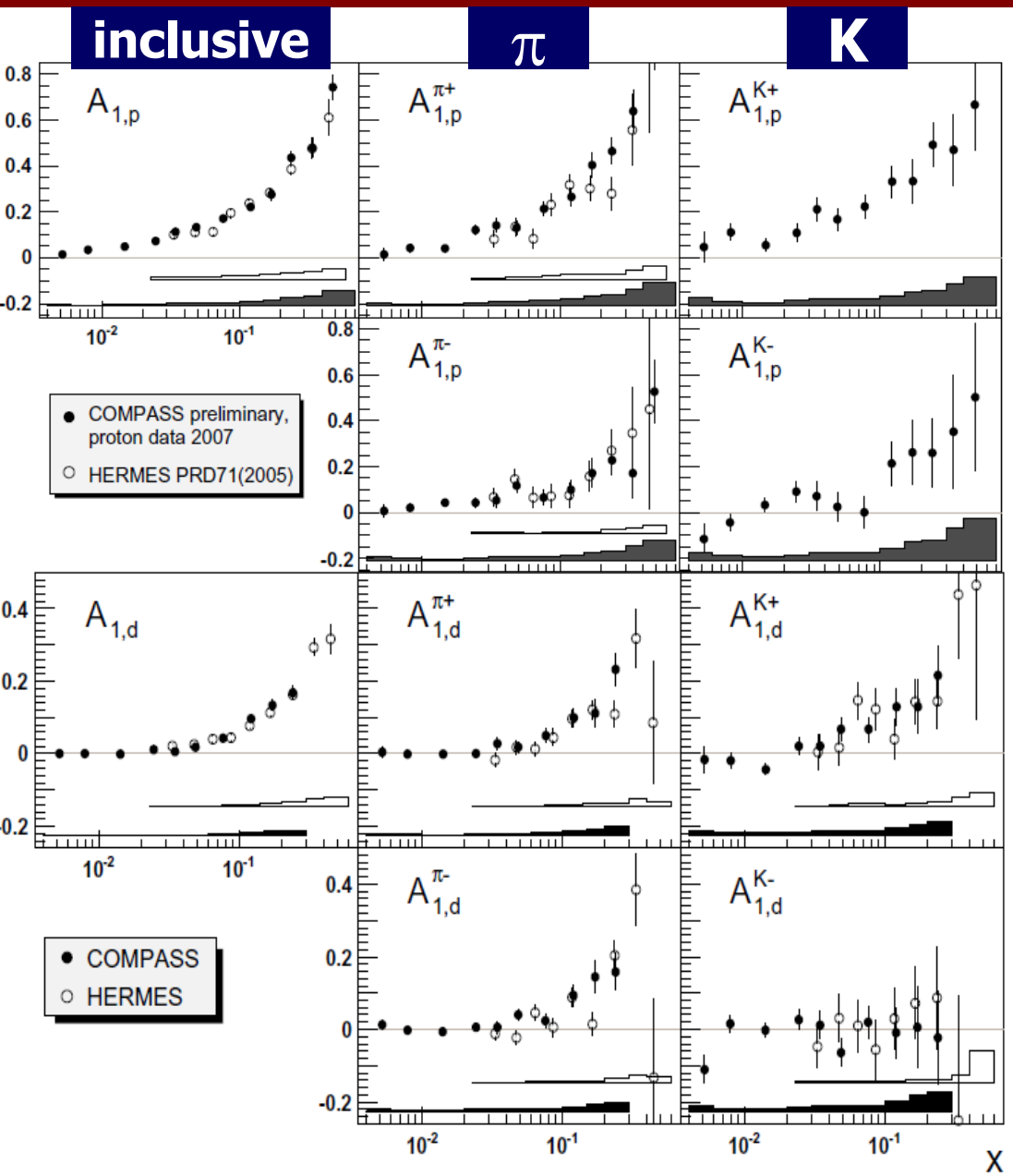


COMPASS Open Charm:

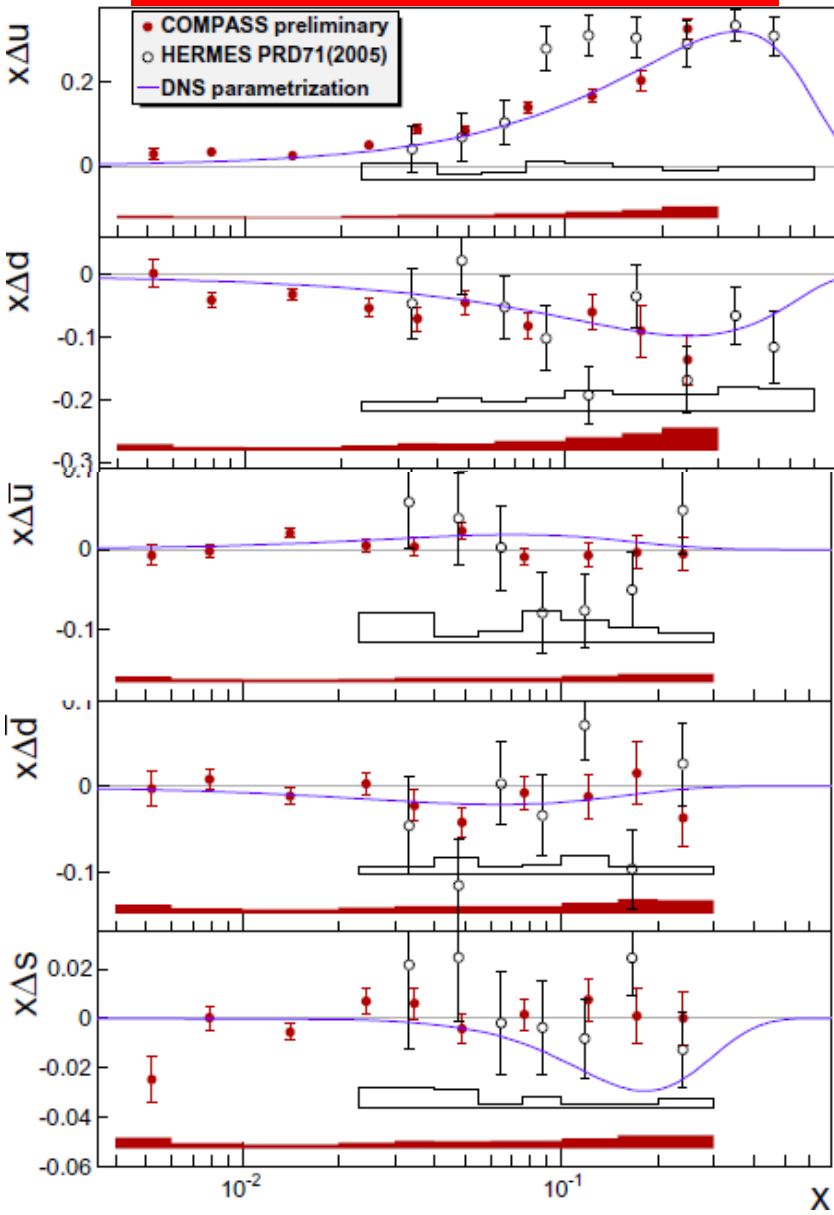
ΔG/G=-0.08+- 0.21(stat) +- 0.11(sys.)
(Systematic error still under investigations)

(Value supersedes previous publication)

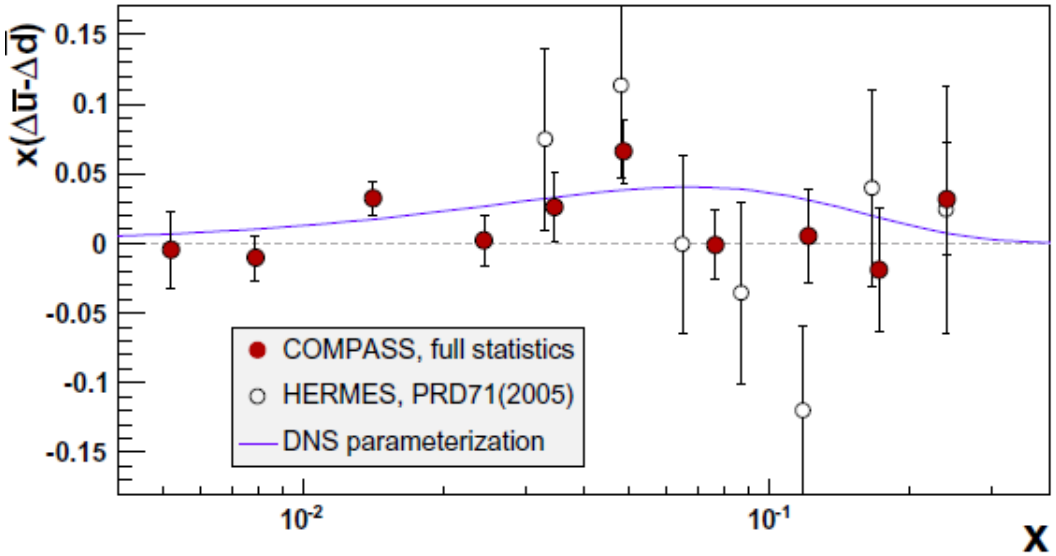
SIDIS Photon-Nucleon Asymmetries



Leading order analysis



Flavor symmetry breaking $\Delta\bar{u} - \Delta\bar{d}$



COMPASS @Q^2=3(GeV/c)^2 : $\int_{0.004}^{0.3}(\Delta\bar{u} - \Delta\bar{d})\mathrm{d}x = 0.052 \pm 0.035(\mathrm{stat}) \pm 0.013(\mathrm{syst})$

HERMES @ Q^2=2.5(GeV/c)^2: $\int_{0.023}^{0.6}(\Delta\bar{u} - \Delta\bar{d})\mathrm{d}x = 0.048 \pm 0.057(\mathrm{stat}) \pm 0.028(\mathrm{syst})$

- Presently only accessible in SIDIS
- Considerable asymmetry in the unpolarized case

$$\int(\bar{u} - \bar{d})\mathrm{d}x = -0.118 \pm 0.012$$

- Model predicts naturally symmetry breaking for polarized case

Transverse Spin Structure

Single Hadron Production Cross Section

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\varepsilon F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h}$$

$$+\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+P_{beam}\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

$$+P_L\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right]$$

$$+P_L P_{beam}\left[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]$$

$$+|\boldsymbol{P}_T|\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)$$

$$+\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big]$$

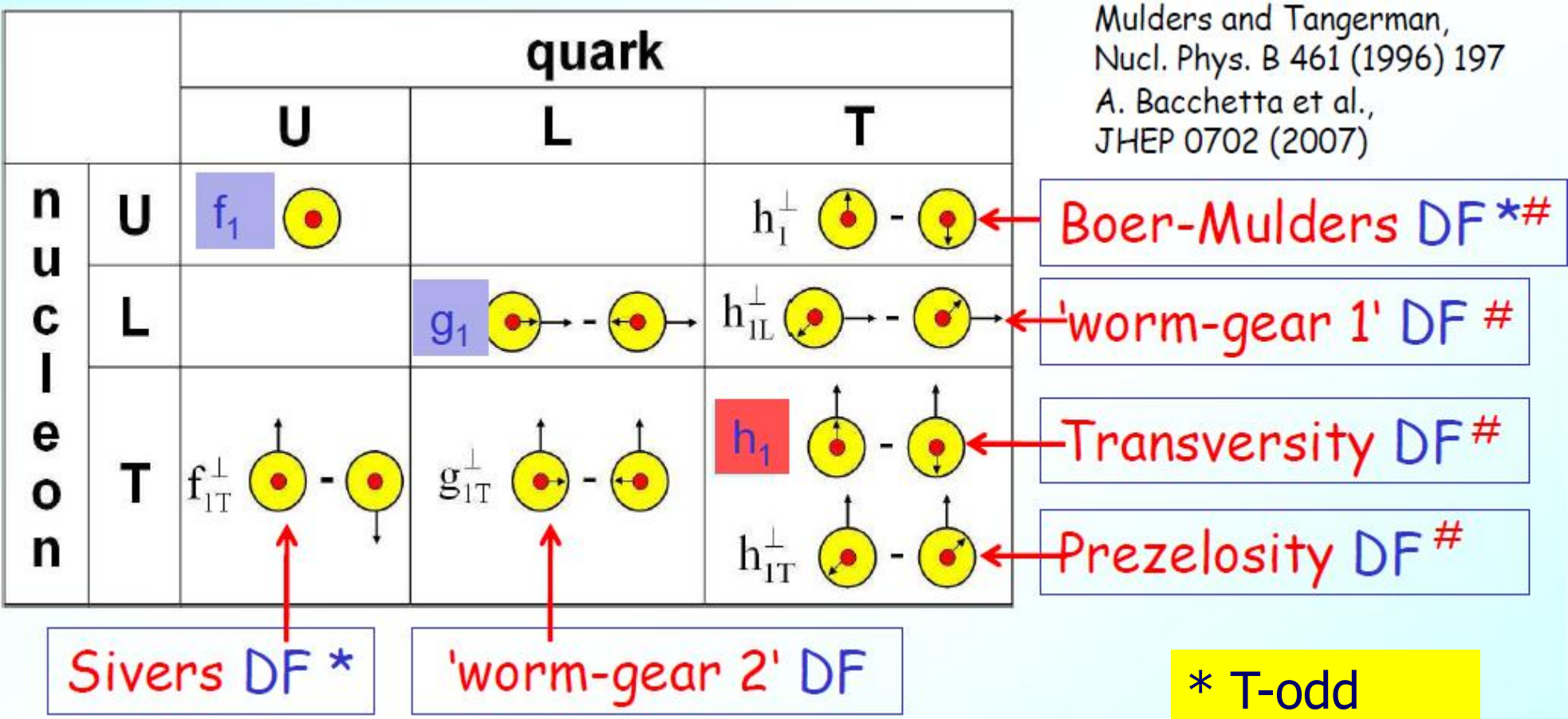
$$+|\boldsymbol{P}_T|P_{beam}\Big[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}$$

$$+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\},$$

- **General expression**
- **Valid for**
  - ☑ **SIDIS**
  - ☑ **exclusive reactions**
- **for entire phase space (TFR, CFR)**

A.Kotzinian NPB 441 (1995) 234
Bacchetta et al, JHEP 0702:093,2007

Transverse Momentum Dependent PDFs



Mulders and Tangerman, Nucl. Phys. B 461 (1996) 197
A. Bacchetta et al., JHEP 0702 (2007)

* T-odd
\# chiral-odd

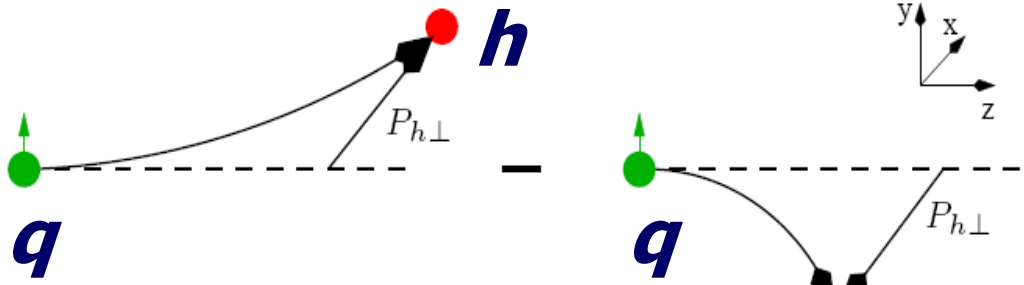
- Only f_1 and g_1 measurable in inclusive DIS, all others in SIDIS

K.Rith

TSD: Transversity DF & Collins FF

- The Collins FF $H_1^{\perp q}(z, p_T)$ correlates the transverse spin of the fragmenting quark and the transverse momentum $P_{h\perp}$ of the produced hadron h

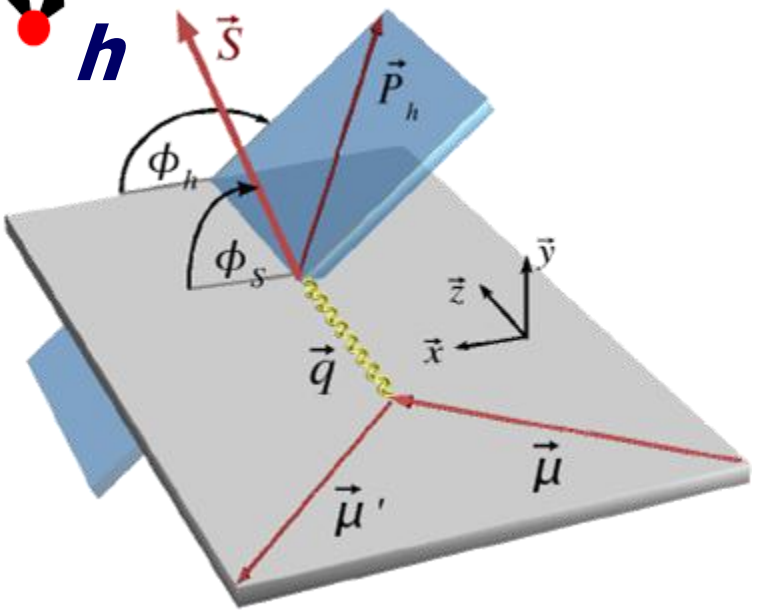
N/q	U	L	T	
U	f_1		$h_1^\perp$	
L		g_1	$h_{1L}^\perp$	
T	$f_{1T}^\perp$	g_{1T}	h_1	$h_{1T}^\perp$



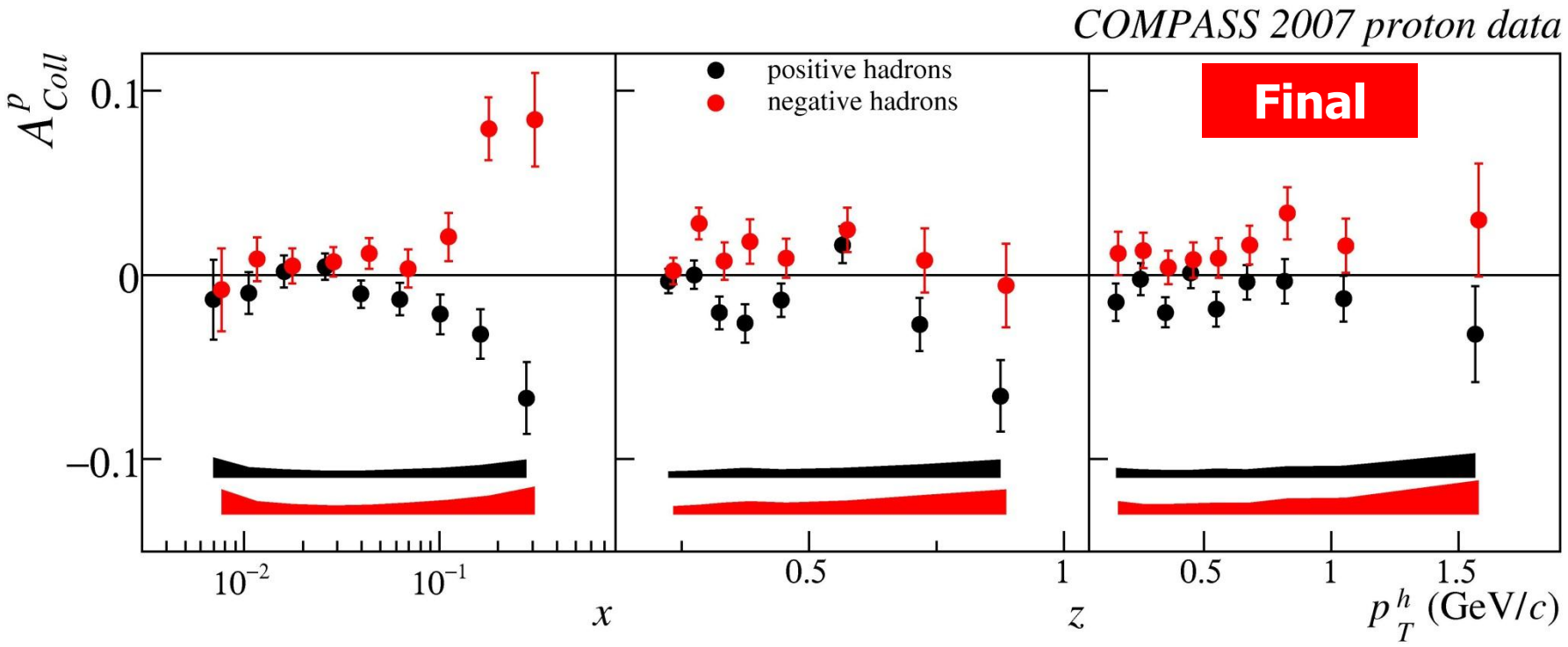
$$A_{\text{Coll}} \propto \frac{\sum_q e_q^2 \; h_1^q(x) \cdot H_1^{\perp q}(z, p_T)}{\sum_q e_q^2 \; f^q(x) \cdot D_q^h(z)}$$

$$A_{Coll} = \frac{A_{UT}^{\sin\phi}}{D_{NN} \cdot f \cdot P}$$

$$\Phi_C = \phi_h - \phi_s - \pi$$



Transversity



- **Collins FF and Transversity distribution function are sizeable**
- **π^- asymmetries unexpectedly large**

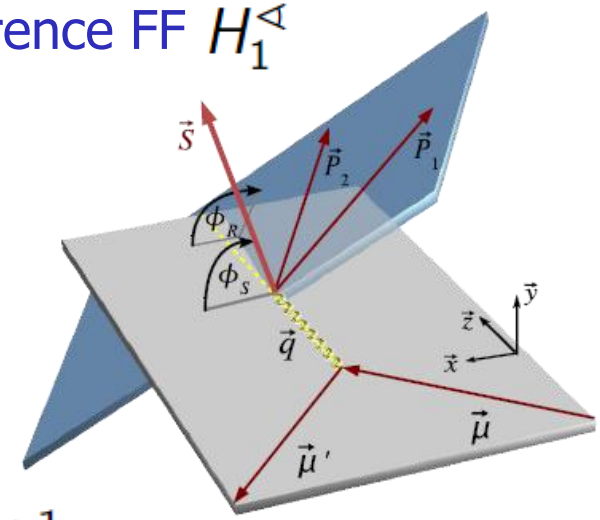
- **Large contribution from unfavoured FF**

$$H_1^{\perp q}{}_{unf} \simeq -H_1^{\perp q}{}_{fav}$$

Two Hadron Interference FF

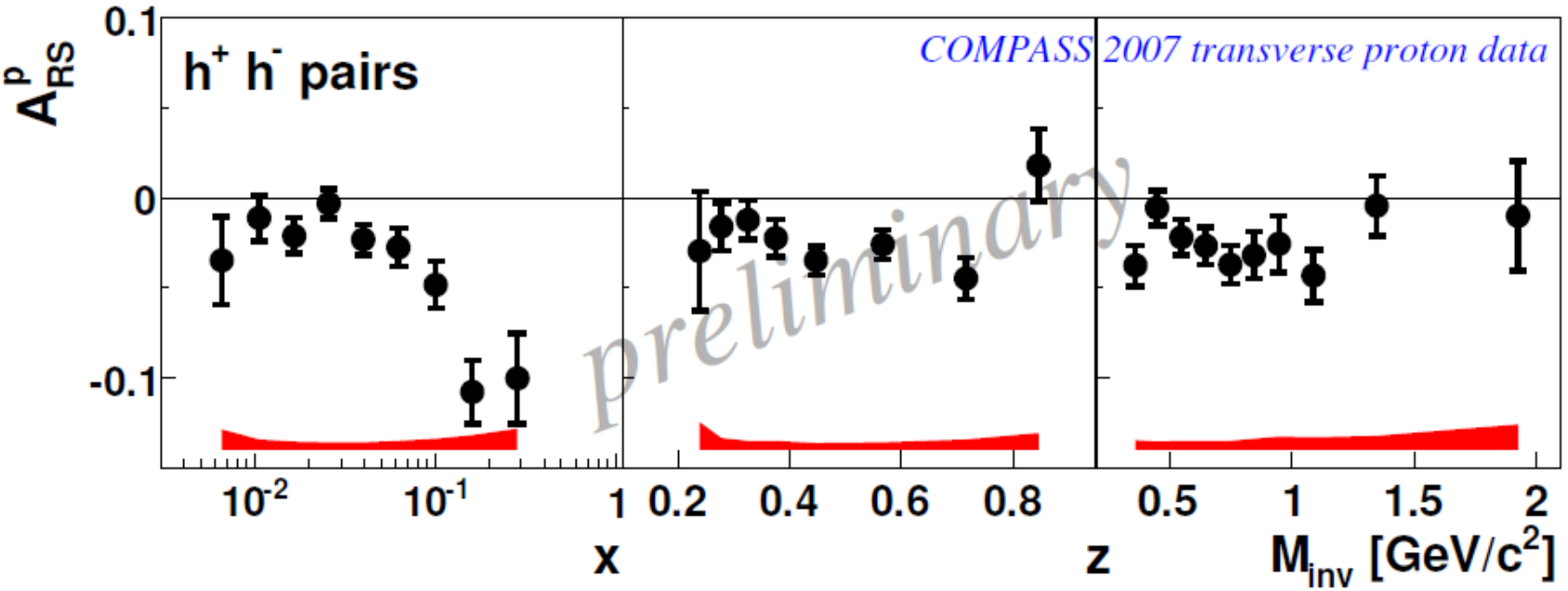
Alternative: couple $h_1^q(x)$ to chiral odd 2-hadron interference FF $H_1^{\sphericalangle}$

$$A_{\text{Coll}} \propto \frac{\sum_q e_q^2 \; h_1^q(x) \cdot H_1^{\sphericalangle q}(z, M_T^2)}{\sum_q e_q^2 \; f^q(x) \cdot D_q^h(z, M_T^2)}$$

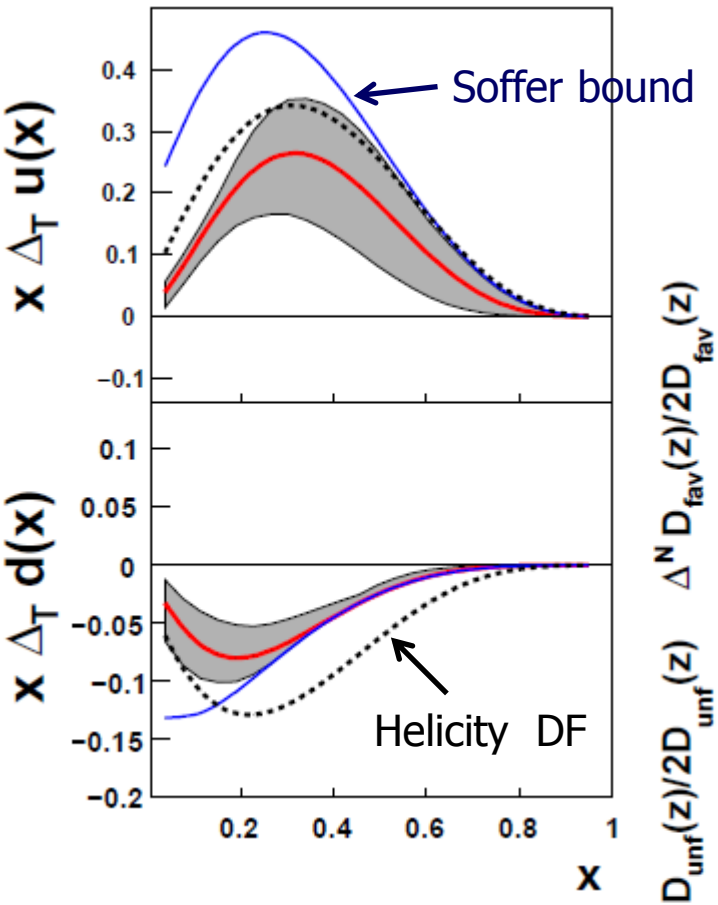


cross-section asymmetry: $\dfrac{\Delta\sigma}{\sigma} \propto A_{RS} \sin\phi_{RS} \sin\theta$

$\phi_{RS} = \phi_R + \phi_S - \pi; \quad \sin\theta \simeq 1$

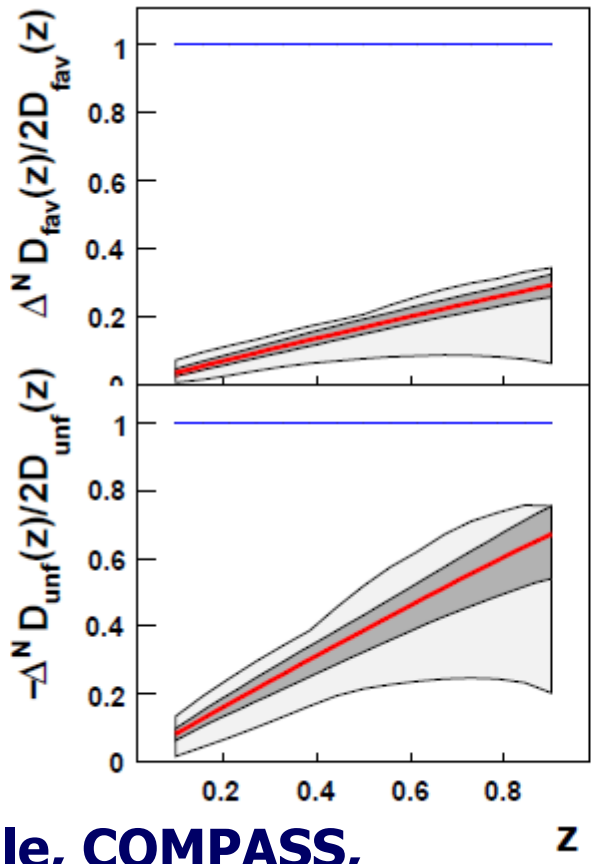


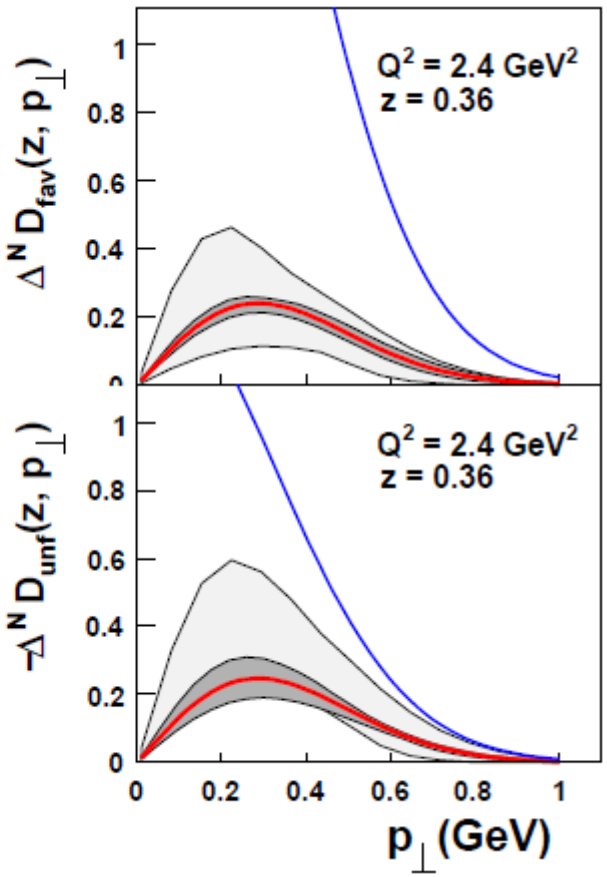
Transversity DF and Collins FF from a Global Fit



- **Indication for large contribution from unfavoured FF**

$$H_1^{\perp q}{}_{unf} \simeq -H_1^{\perp q}{}_{fav}$$





- **Extraction based on Belle, COMPASS, HERMES data @ Q²=2.4 (GeV/c)²**

Anselmino et al.

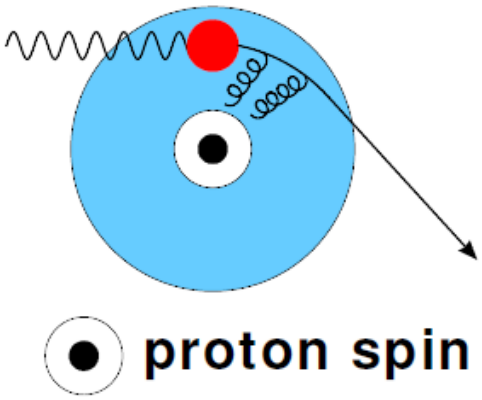
TMD: Sivers Asymmetry

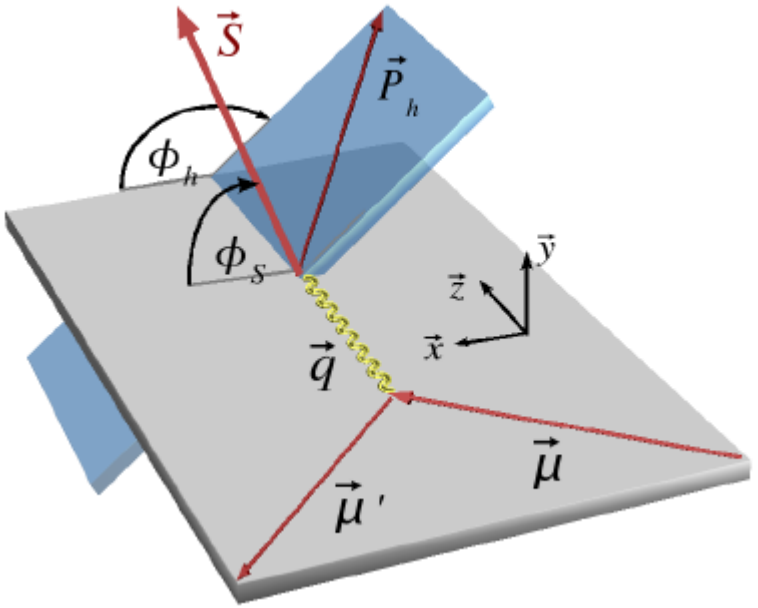
$$A_{Siv} \propto \frac{\sum_q e_q^2 \, f_{1T}^{\perp q}(x, p_T^h/z) \cdot D_q^h(z)}{\sum_q e_q^2 \, f^q(x, p_T^h/z) \cdot D_q^h(z)}$$

N/q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

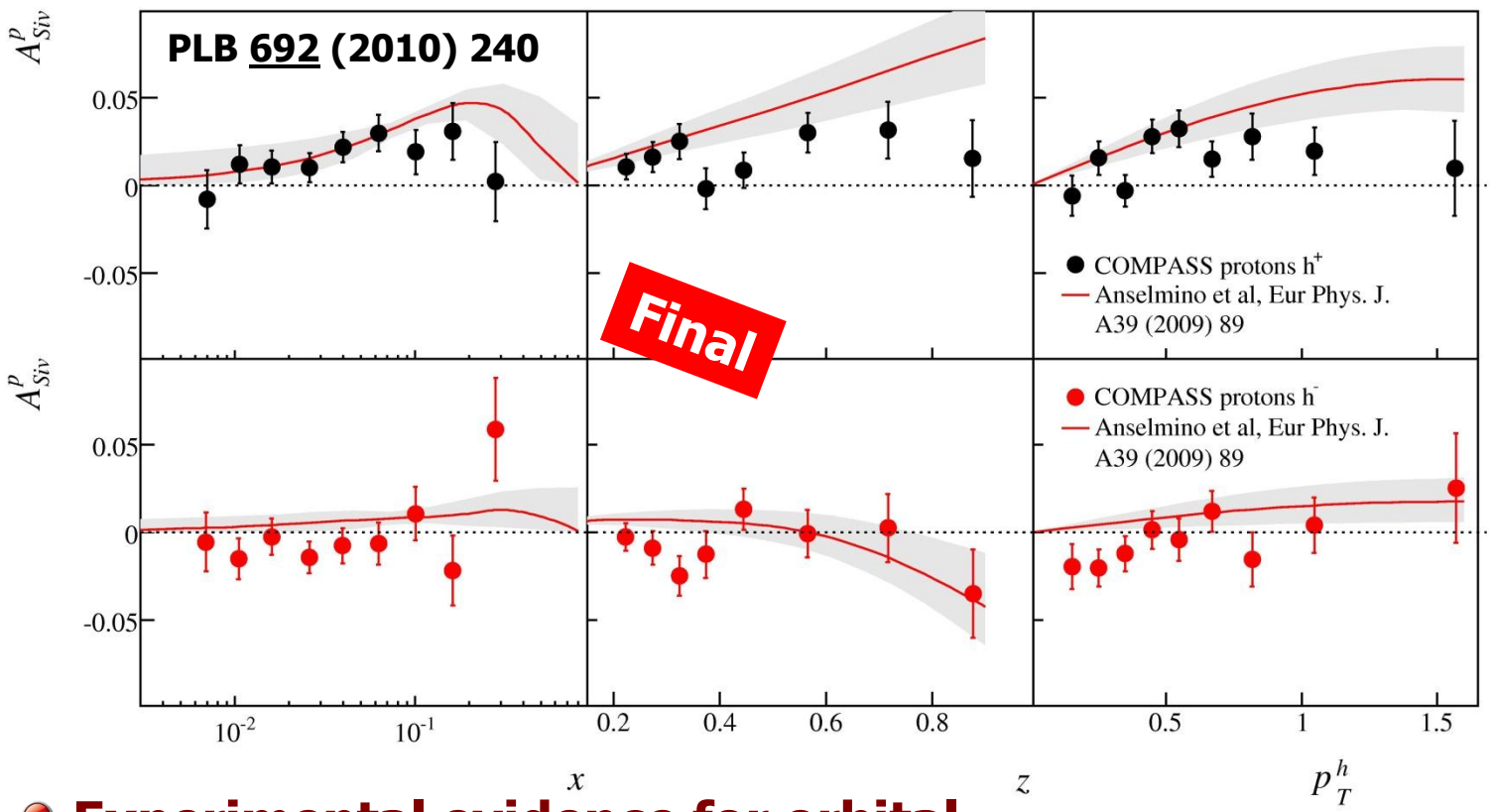
$$\frac{\Delta\sigma}{\sigma} \propto A_{Siv} \sin\Phi_S$$

$$\Phi_S = \phi_h - \phi_S$$



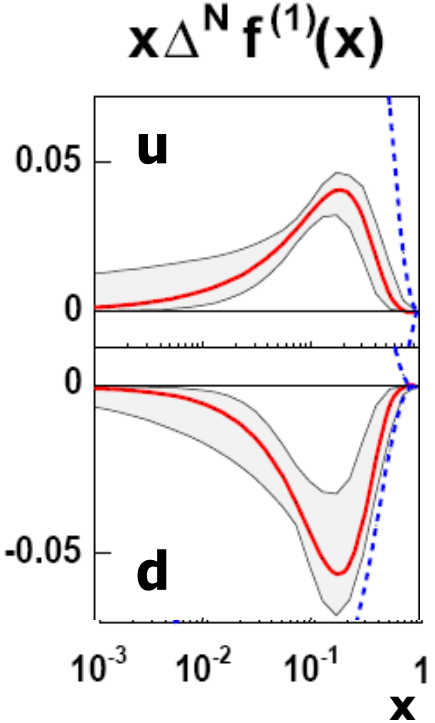


Sivers Asymmetries



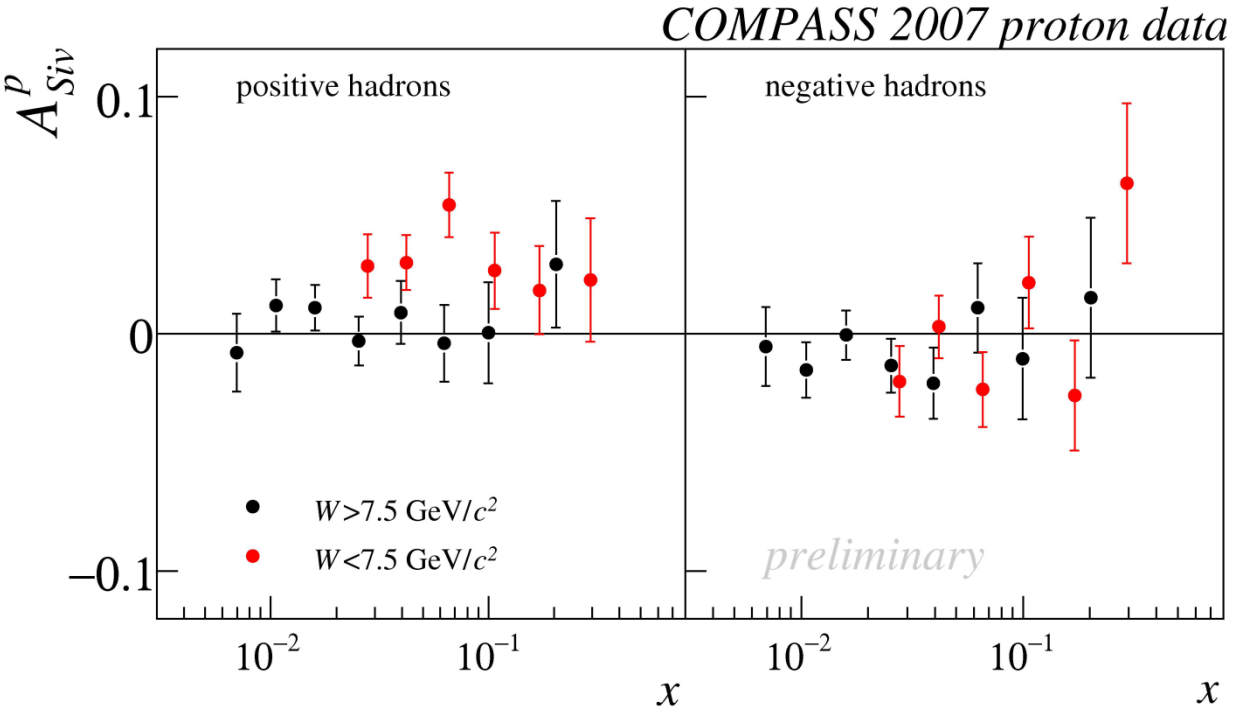
- **Experimental evidence for orbital momentum of the quarks**

- **COMPASS π and K /deuteron and HERMES /proton used to extract Sivers function**

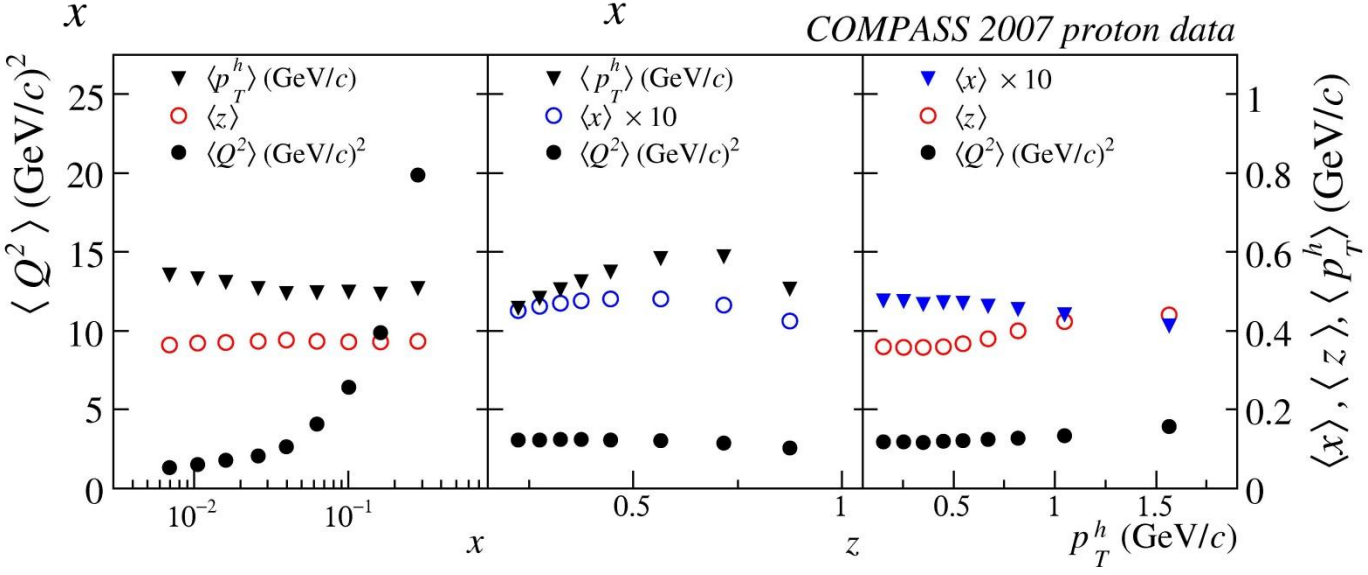


Anselmino et al.

Kinematic Effects

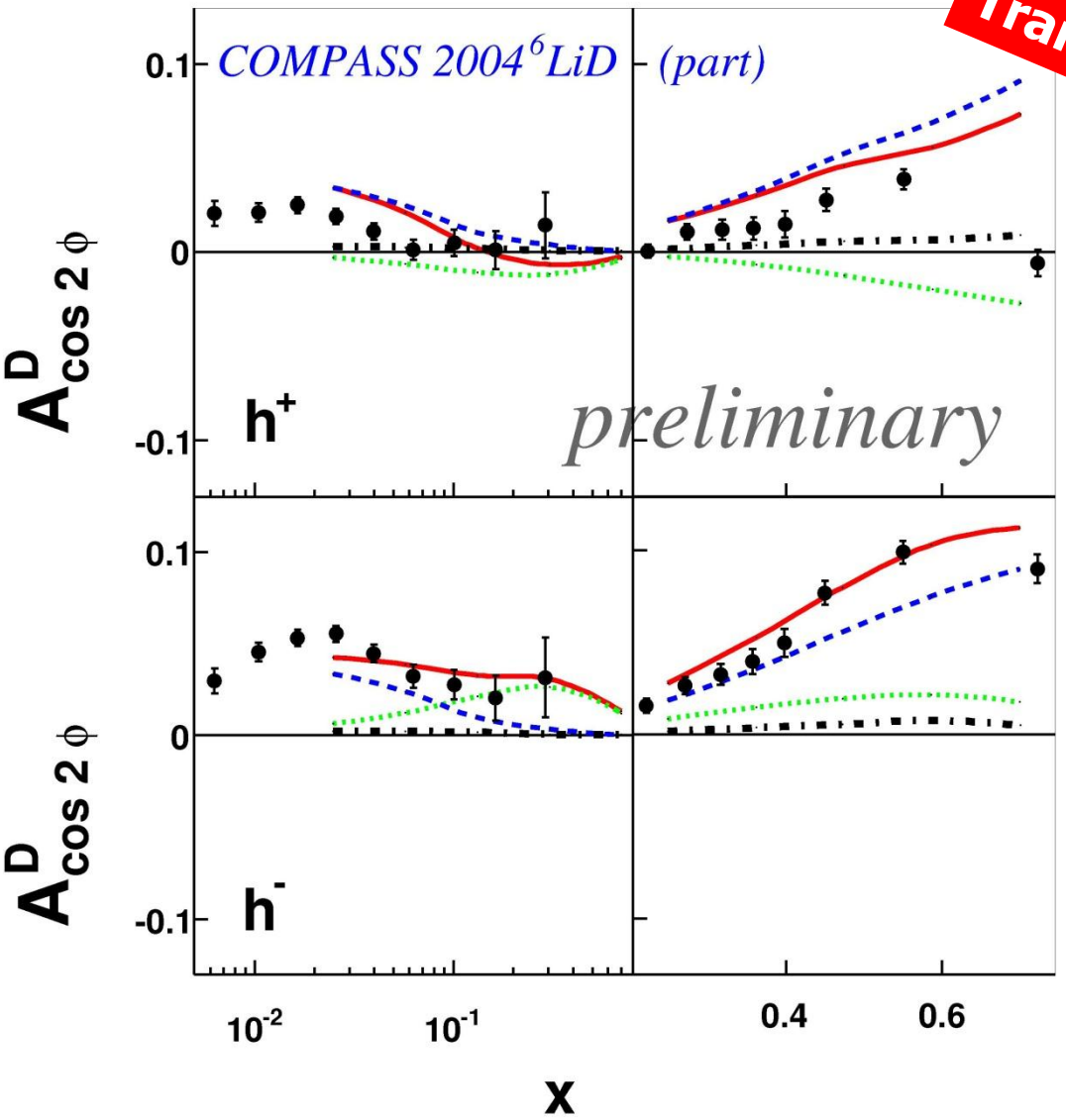


Dependance on hadronic mass?



TMD: Cahn & Boer-Mulders Asymmetries

- **Unpolarized target**



Sensitive to Transverse Momentum Distributions

Barone, Prokudin, Ma
arXiv:0804.3024 [hep-ph]

- *Sum of all contributions*
- *Cahn effect*
- *Boer-Mulders*
- *QCD (first order)*

Outlook – COMPASS II

DVCS & DVMP Measurements
Transverse Imaging
Beam Charge & Spin asymmetry
GPD H
later GPD E

Drell-Yan Measurements
Sivers PDF
Boer Mulders PDF
Test of factorization approach

PDFs and Fragmentation
s(x)
Kaon FF

Chiral Perturbation Theory
→ Jan Friedrich's presentation

Upgrade existing

COMPASS Spectrometer

@ CERN/SPS

Proposal submitted to CERN (2010-05-17)

Presently under discussion at SPSC

Data taking can start 2012

CERN-SPSC-2010-014/SPSC-P-340

… later you may practice during lunch break