Spin Physics Results from COMPASS

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for the COMPASS collaboration

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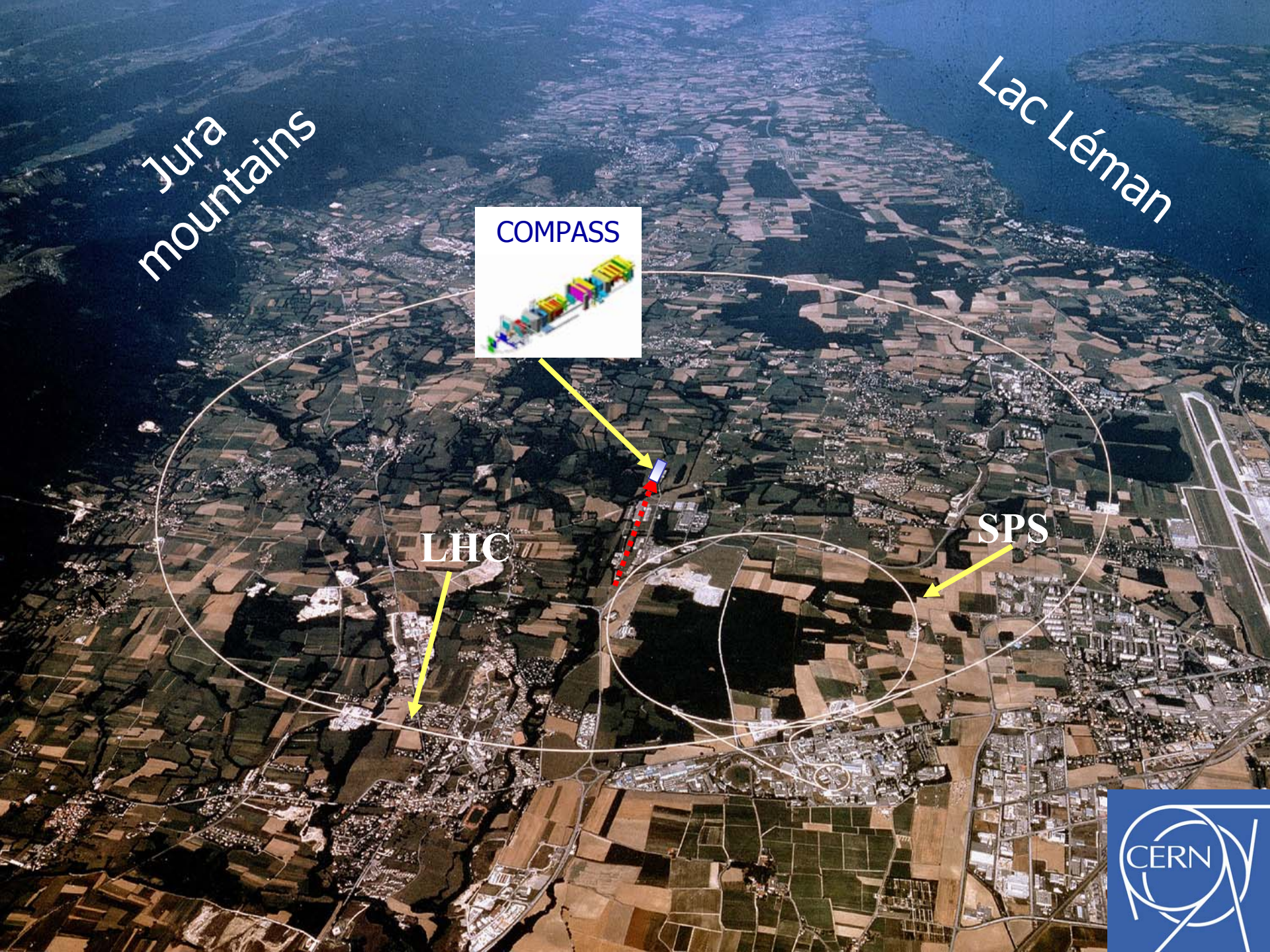
bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung
06FR9069

COMPASS: Nucleon spin studies

- Selection of Results
  - DIS and Polarized Distribution Functions
  - Polarization of the strange quark sea
  - Asymmetry of the polarized sea
  - Direct measurements of $\Delta g/g$
  - Transversity measurements

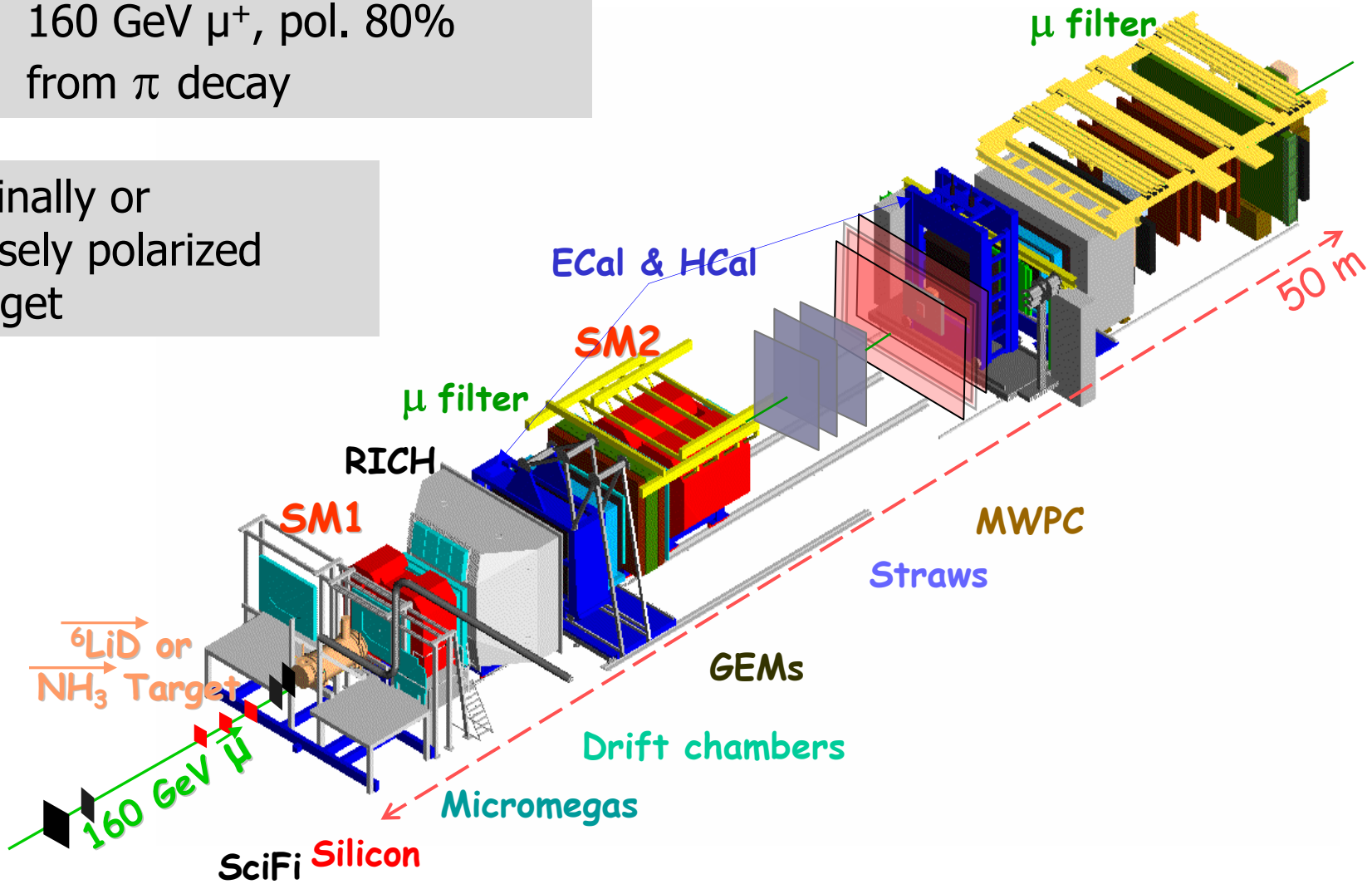
- Future plans
  - Near future: transverse and longitudinal data
  - Study of GPD using DVCS and HEMP
  - Drell-Yan


Jura mountains
Lac Léman
COMPASS
LHC
SPS
CERN

COMPASS

Beam: 160 GeV μ^+, pol. 80%
from π decay

longitudinally or
transversely polarized
fixed target

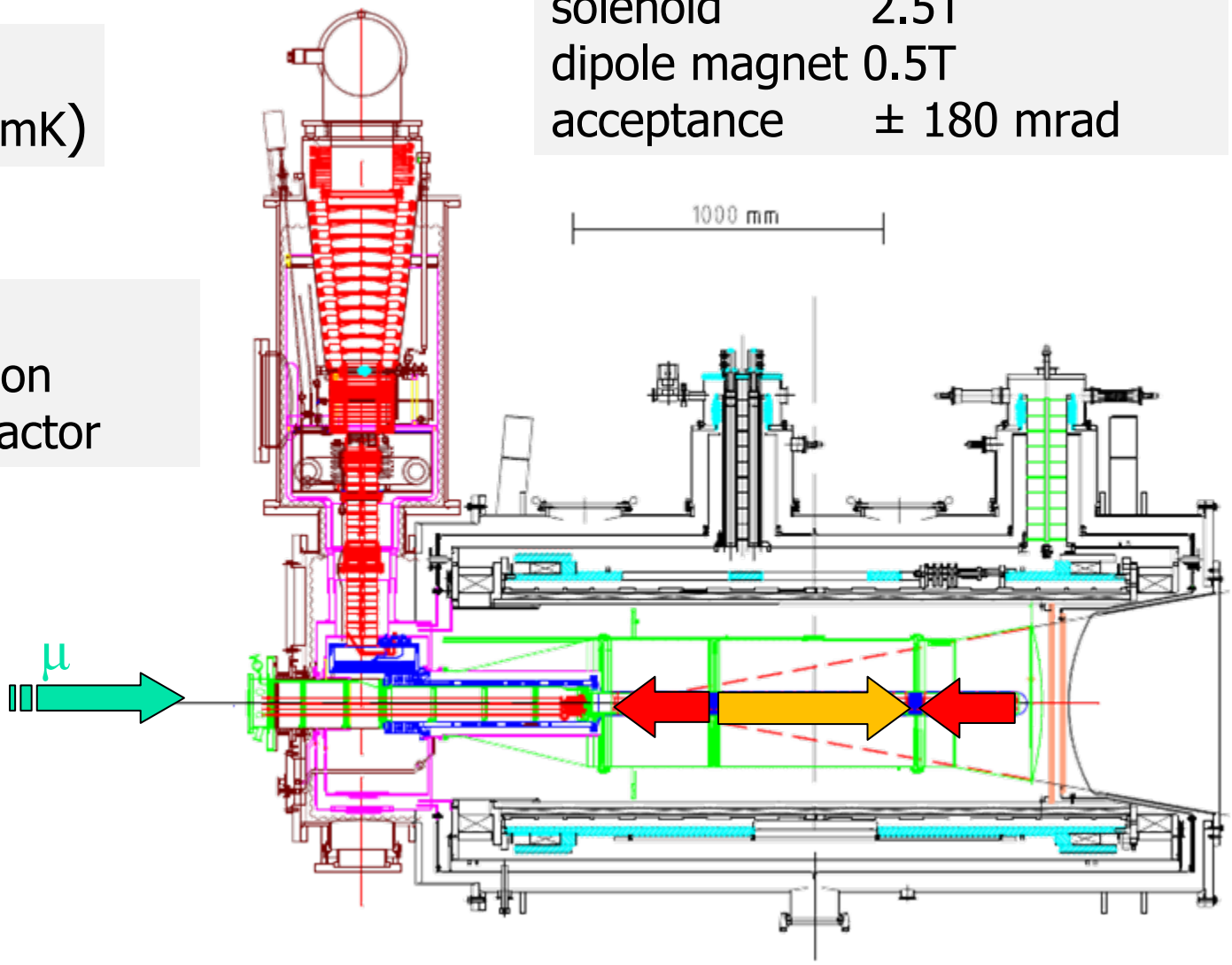


COMPASS target system

^{3}He – ^{4}He dilution refrigerator (T~50mK)

^{6}LiD or NH_3
50/90% polarization
40/16% dilution factor

solenoid 2.5T
dipole magnet 0.5T
acceptance ± 180 mrad



Longitudinal spin effects

Longitudinal asymmetries

Inclusive scattering

$$A_1 = \frac{\sum_q e_q^2 \Delta q(x,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

with

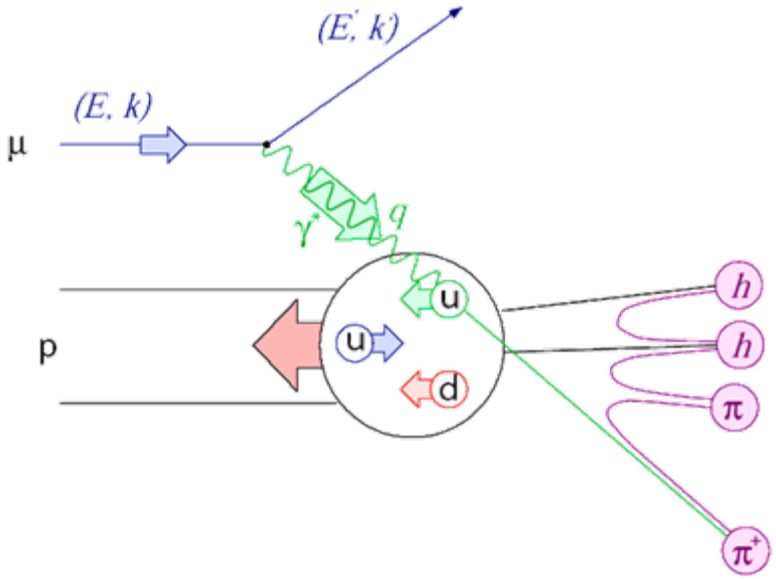
$\Delta q = q^+ - q^-$

$A_1 = g_1/F_1$

Semi-inclusive scattering

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

with $z = E_h/(E - E')$

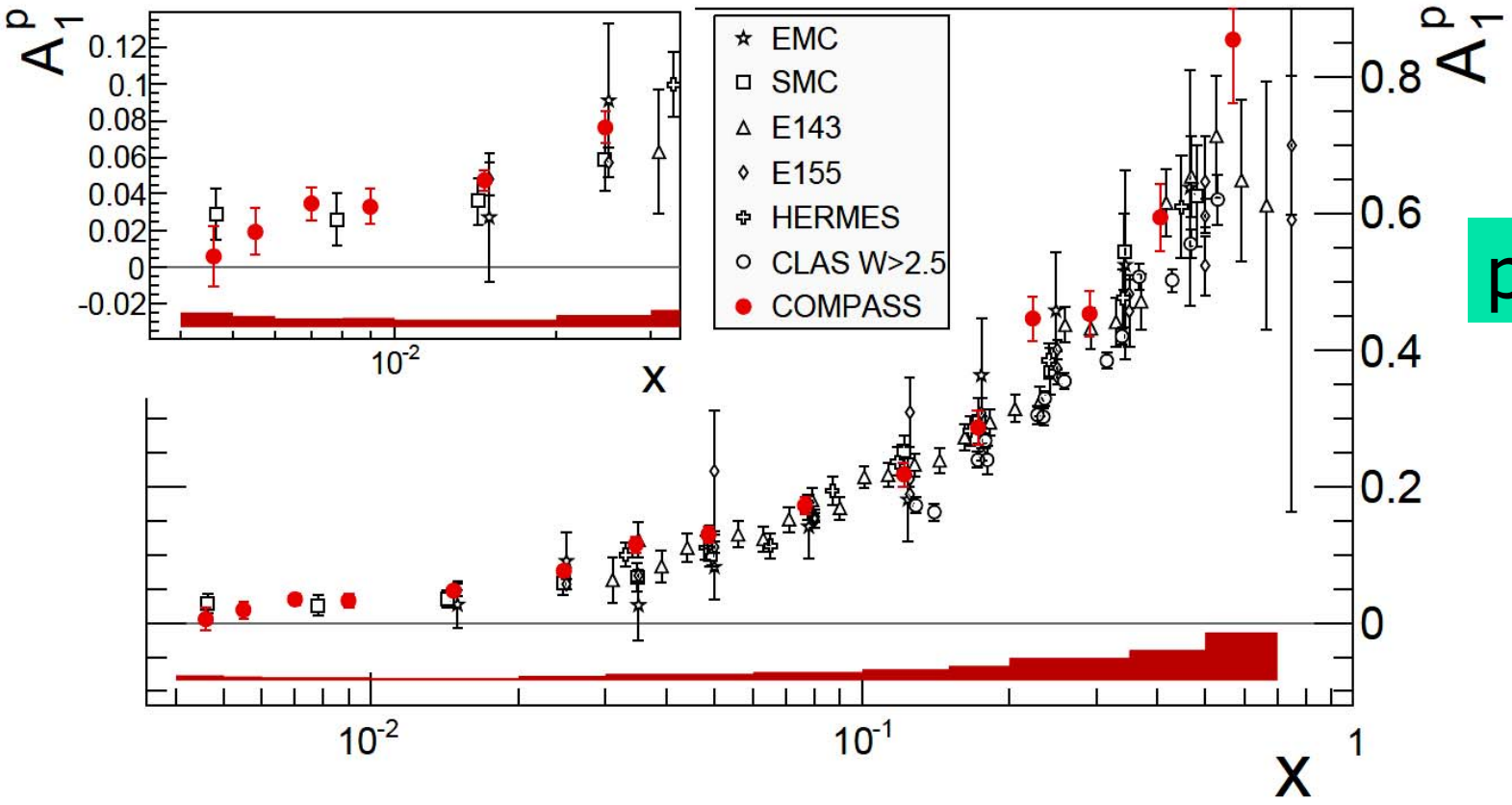


Inclusive asymmetries

- Double-spin asymmetries

$$A^{\mu} = \frac{1}{P_b P_T f}\frac{N^+ - N^-}{N^+ + N^-}; A^{\mu} = D(A_1 + \eta A_2)$$

Subm. Phys. Lett. B (hep-ex/1001.4654)

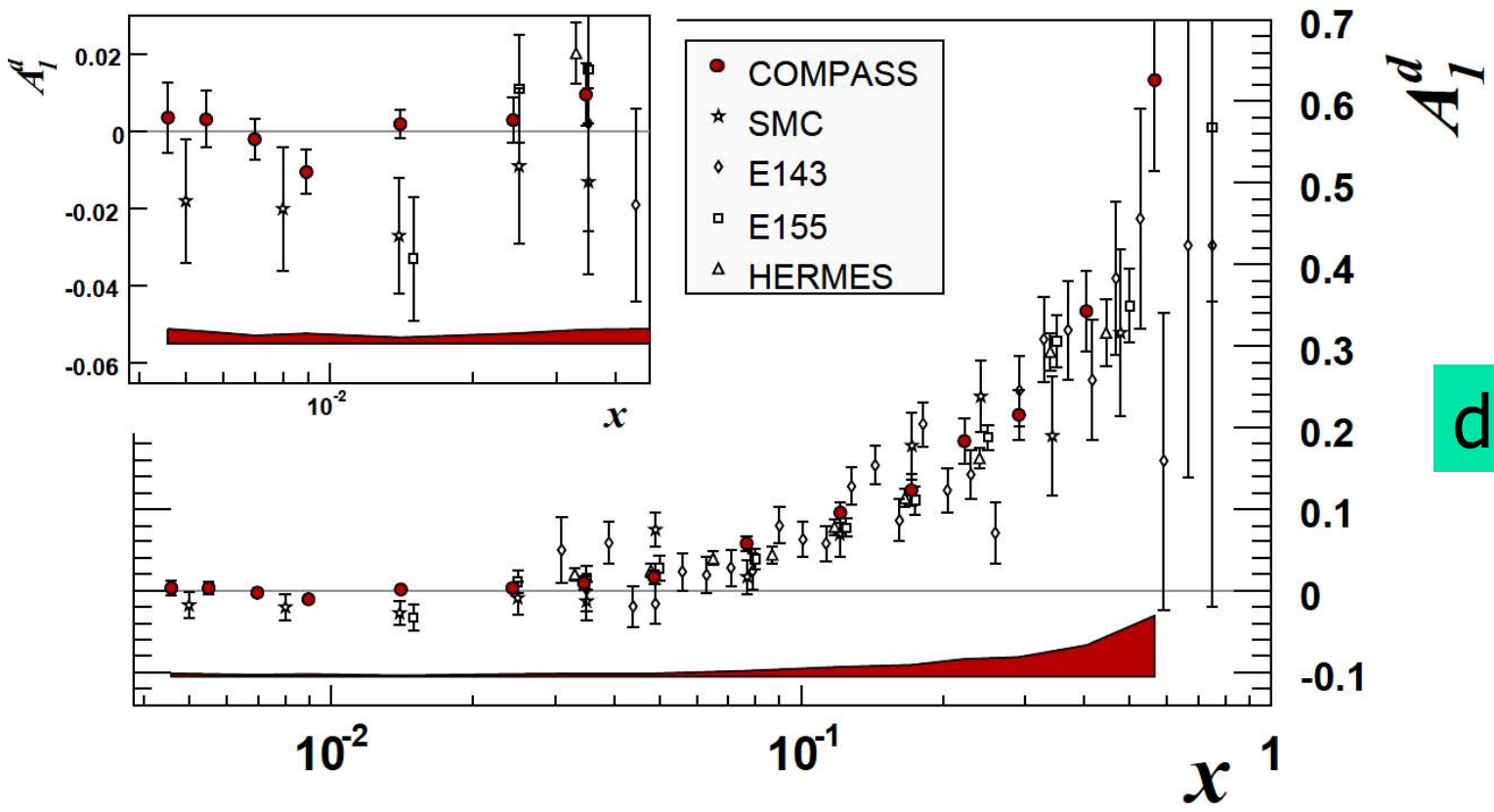


proton

Main advantages of COMPASS: high energy, high Q2, low x

Inclusive asymmetries

Phys. Lett. B 647 (2007) 330-340

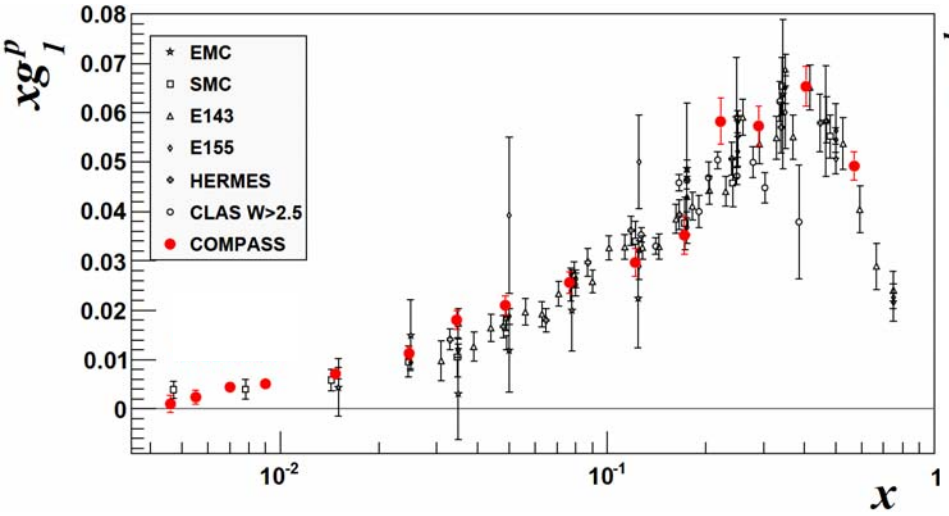


deuteron

Proton & Deuteron $g_1(x)$ world data

Proton data - world

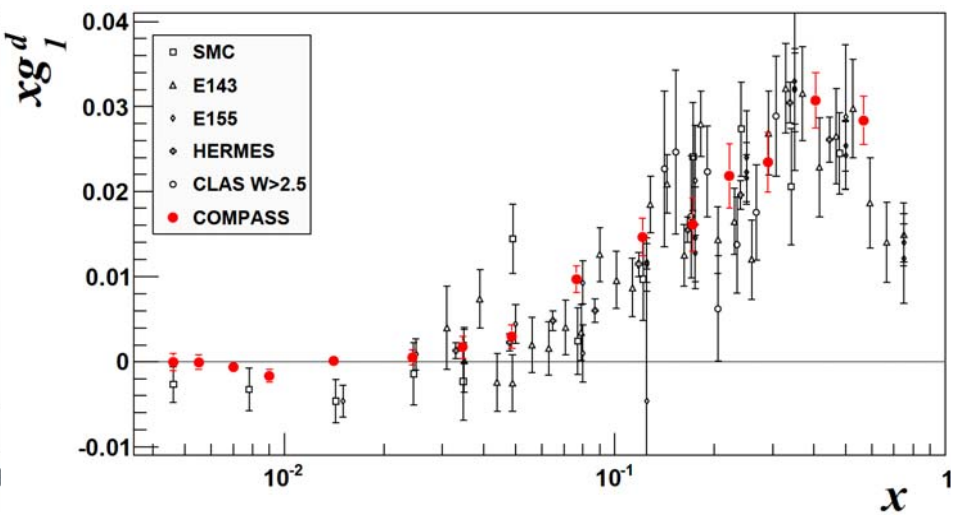
Subm. Phys. Lett. B (hep-ex/1001.4654)



COMPASS data: 2007

Deuteron data - world

Phys. Lett. B 647 (2007) 8



COMPASS data: 2002 – 2006

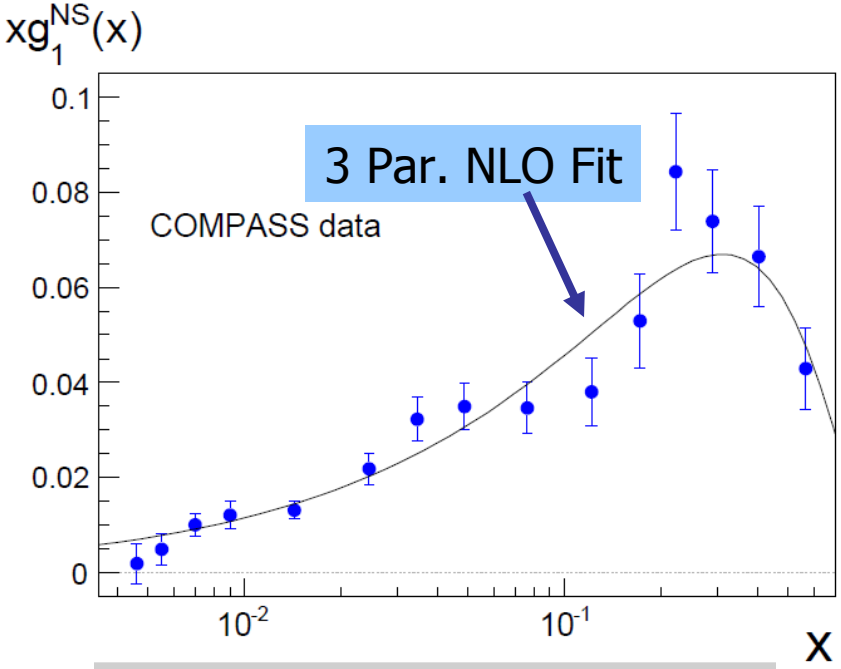
From first moment of g_1^d:

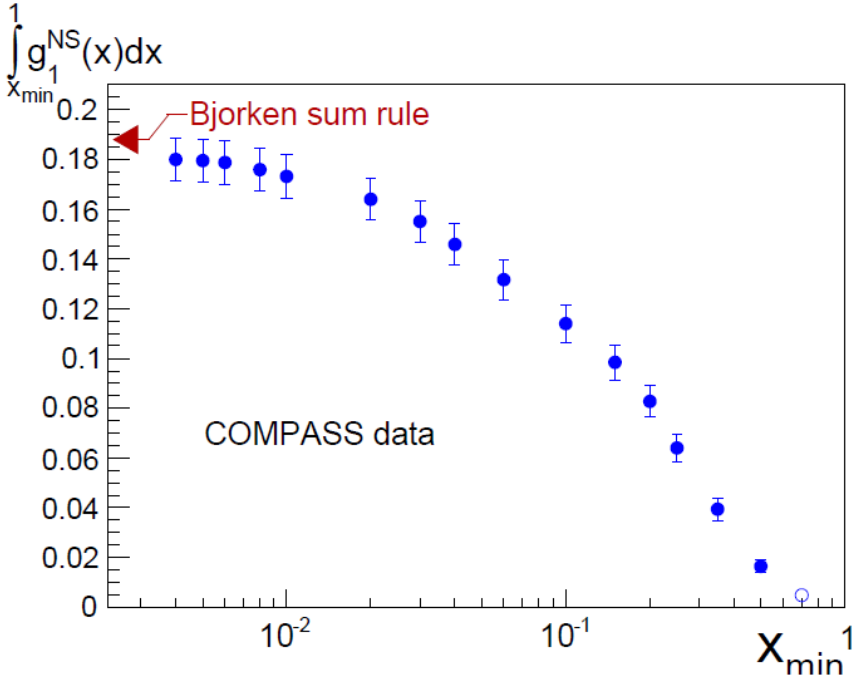
$\Delta\Sigma = a_0 = 0.33 \pm 0.03 \pm 0.05$ (evol. to $Q^2 = \infty$)

$(\Delta s + \Delta s) = 1/3(a_0 - a_8) = -0.08 \pm 0.01 \pm 0.02$

Test of the Bjorken sum rule

$$\Gamma_1^{NS} = \Gamma_1^p - \Gamma_1^n = \frac{1}{6}\left|\frac{g_A}{g_V}\right| C_1^{NS}(Q^2)$$



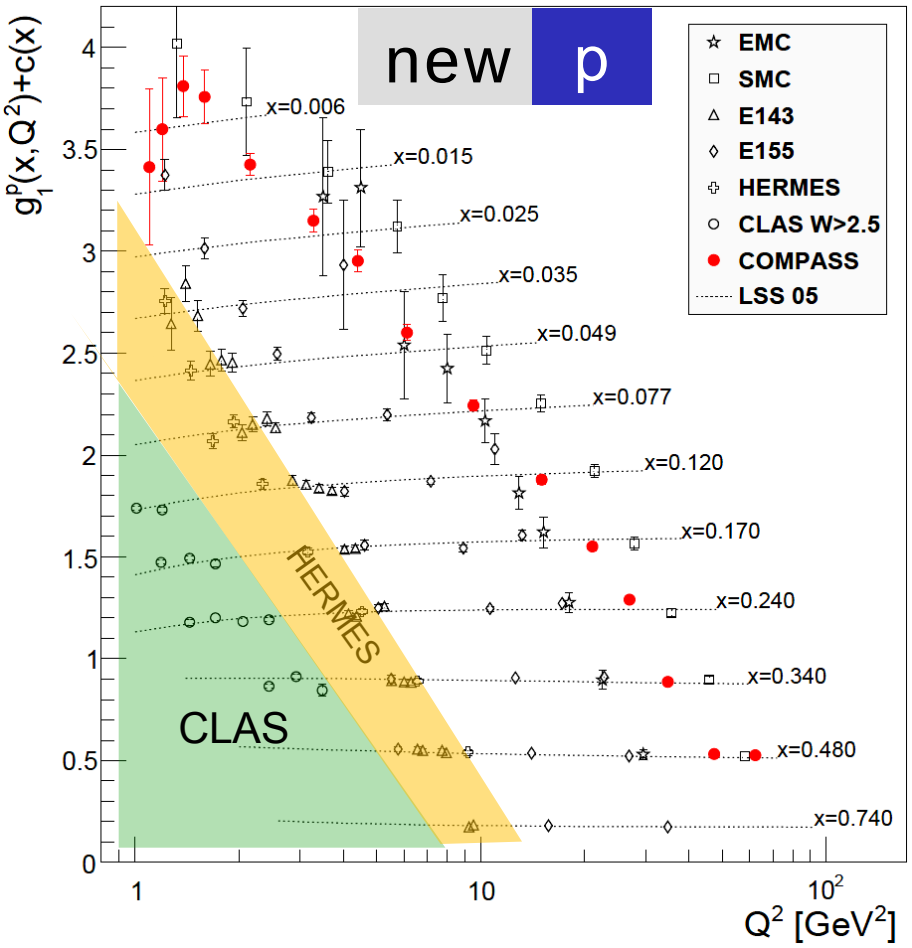


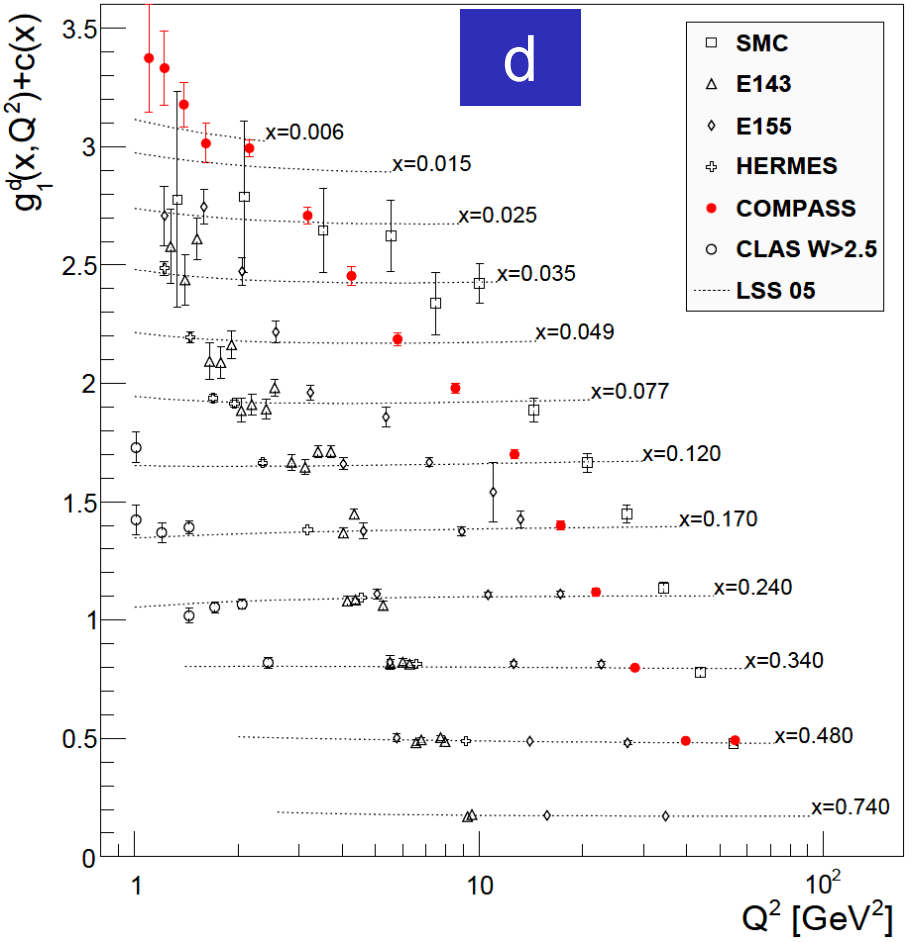
$$g_1^{NS}(x,Q^2) = 2\left[g_1^p(x,Q^2) - \frac{g_1^d(x,Q^2)}{1-1.5\omega_D}\right]$$

$|g_A/g_V|$ = 1.2694 ± 0.0028 from neutron beta decay (PDG)

Proton & deuteron $g_1(x,Q^2)$

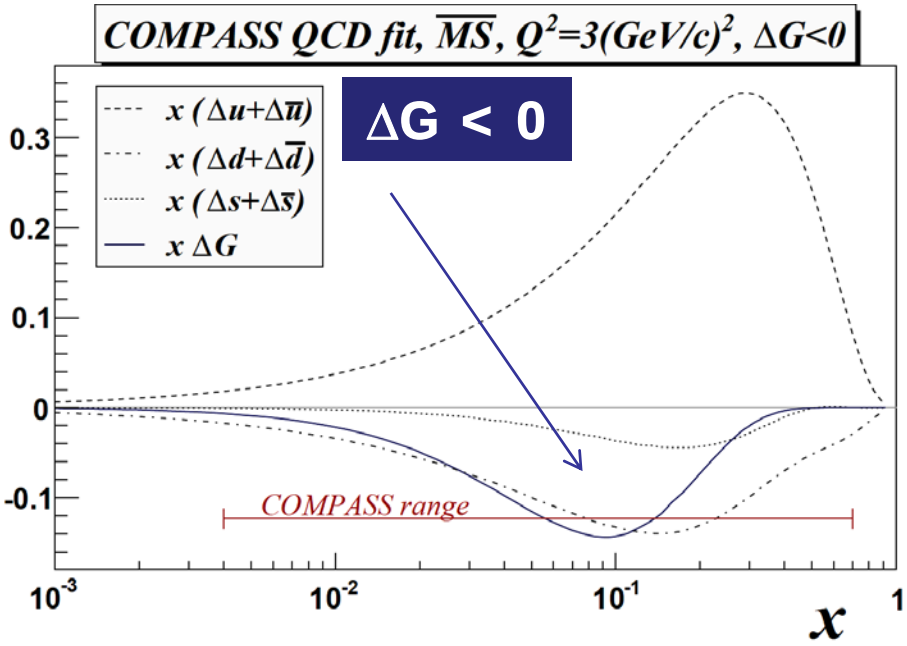
- unique kinematical domain
- important for global QCD analyses

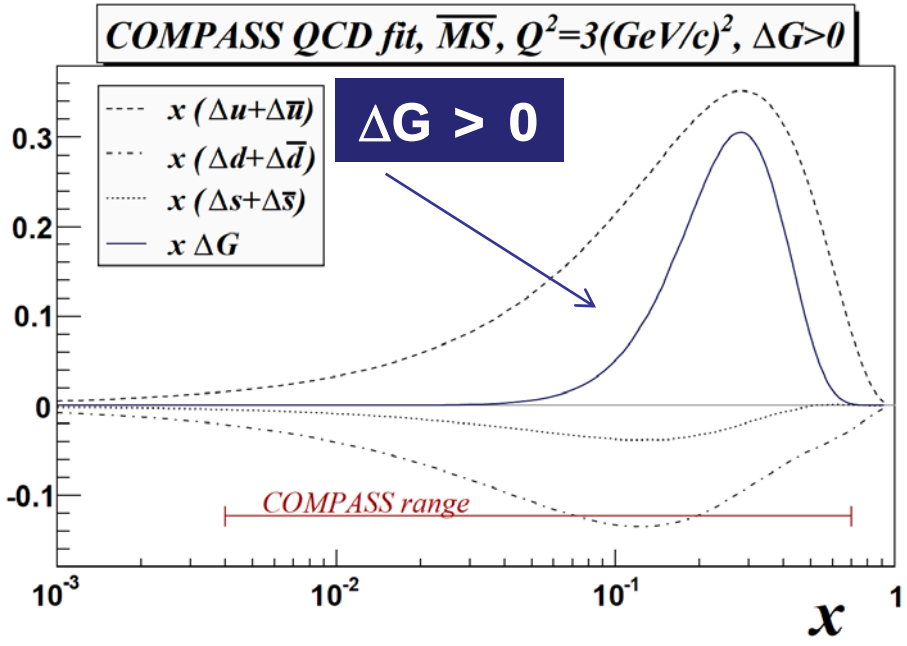




QCD fit results – gluon polarization

- Compass deuteron + world data (proton 2007 not included)



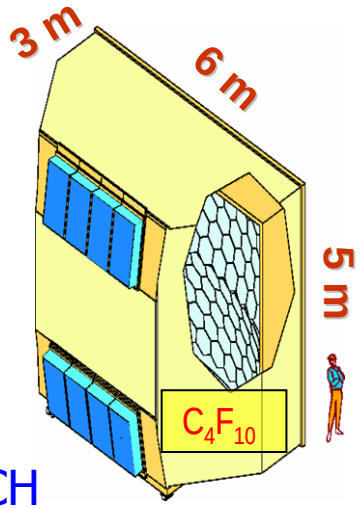


- COMPASS analysis (2007) : positive and negative solution for ΔG(x)
- First moment in both cases small: $|\eta_G|$ = 0.2-0.3
- Is ΔG positive or negative?
- Direct measurements of ΔG(x) needed

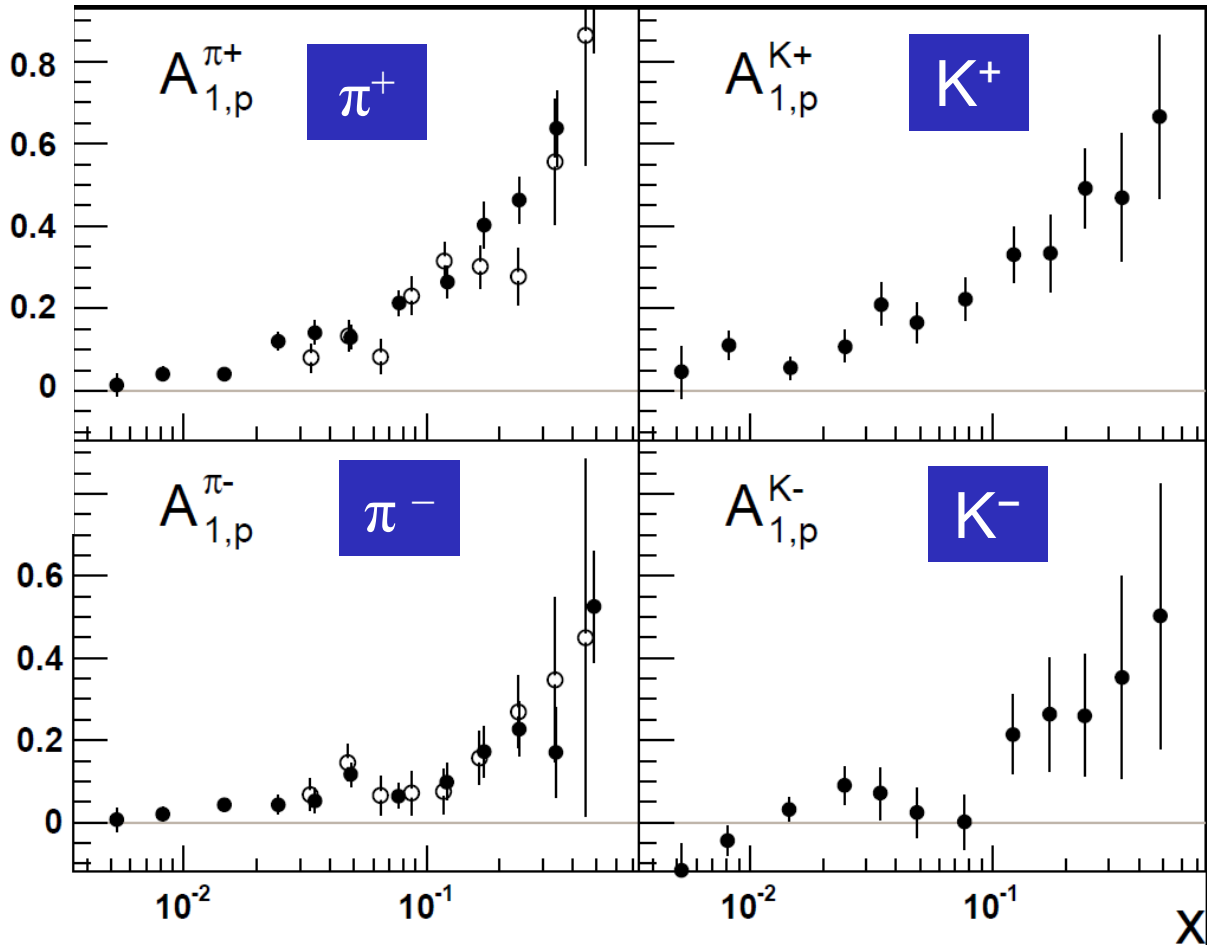
Semi-inclusive results

- First measurement of A^K

Proton



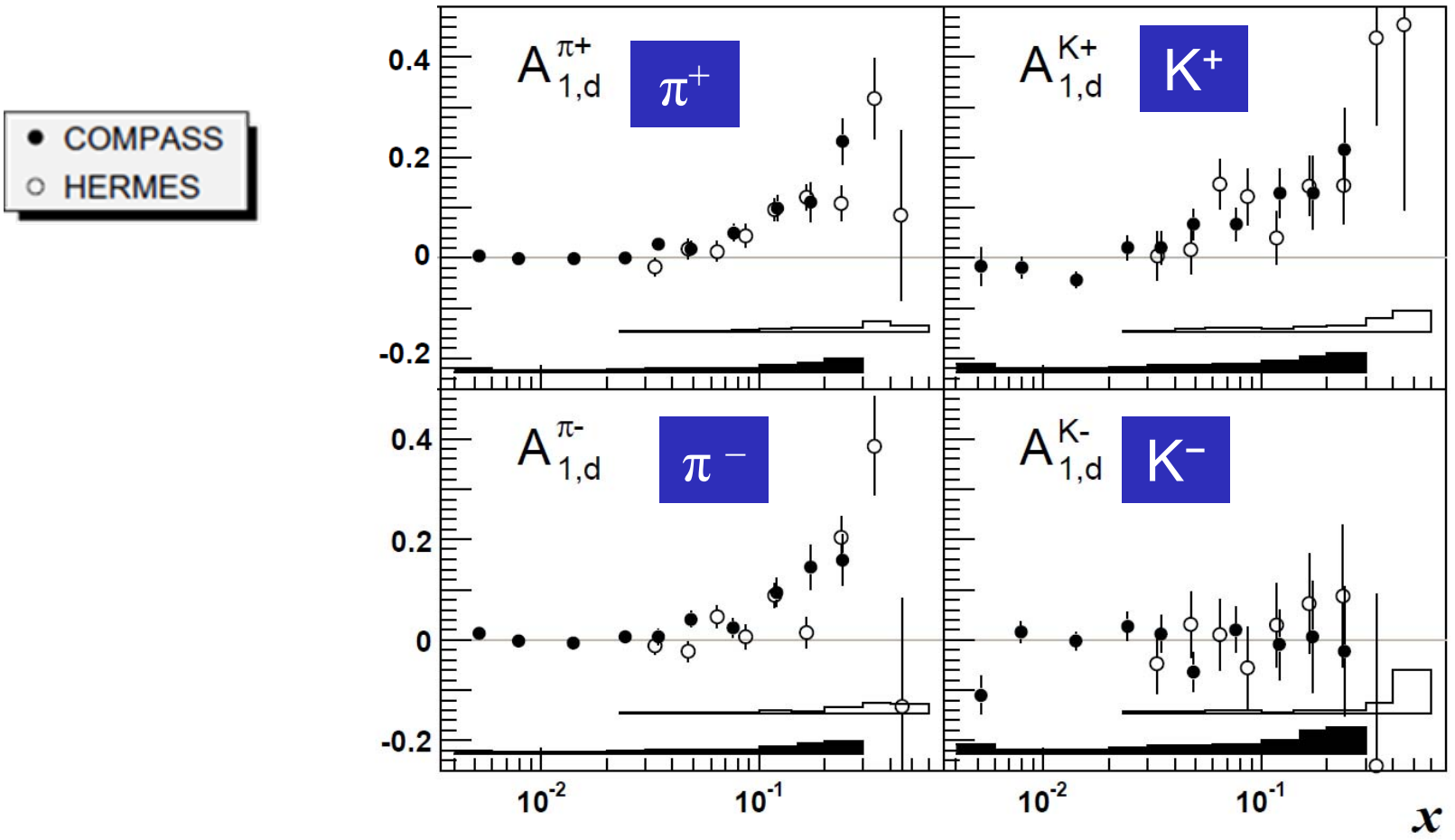
RICH



- COMPASS preliminary, proton data 2007
- HERMES PRD71(2005)

Semi-inclusive results

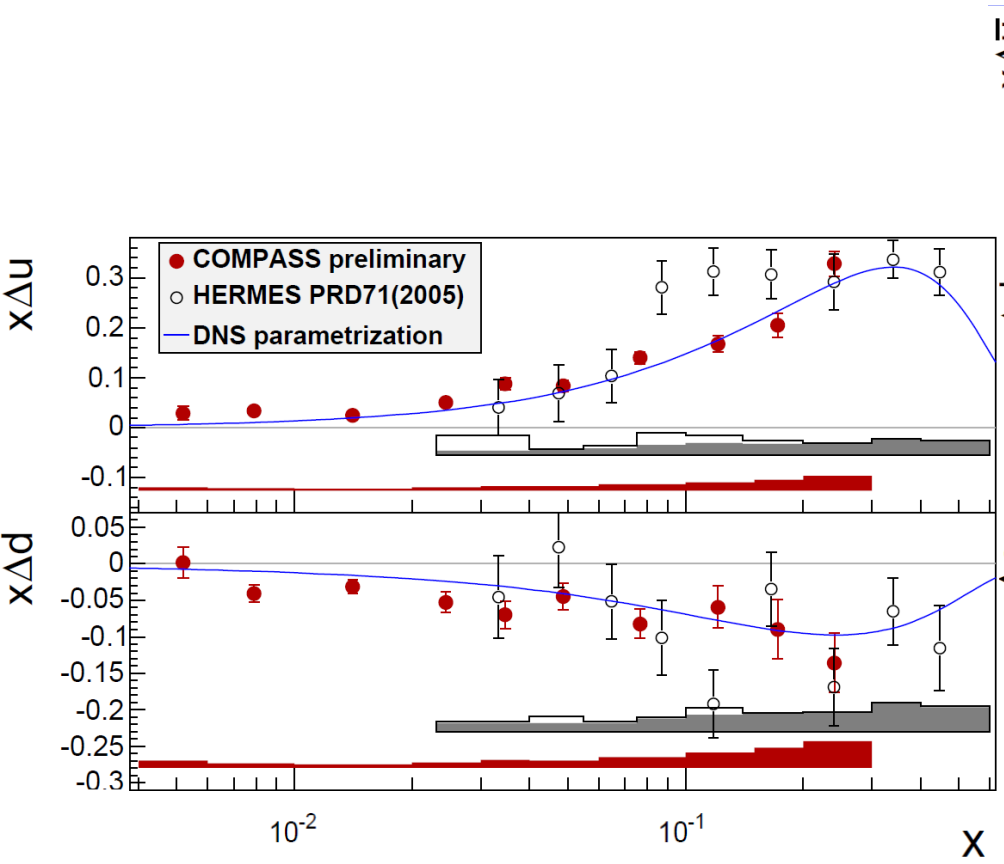
Deuteron

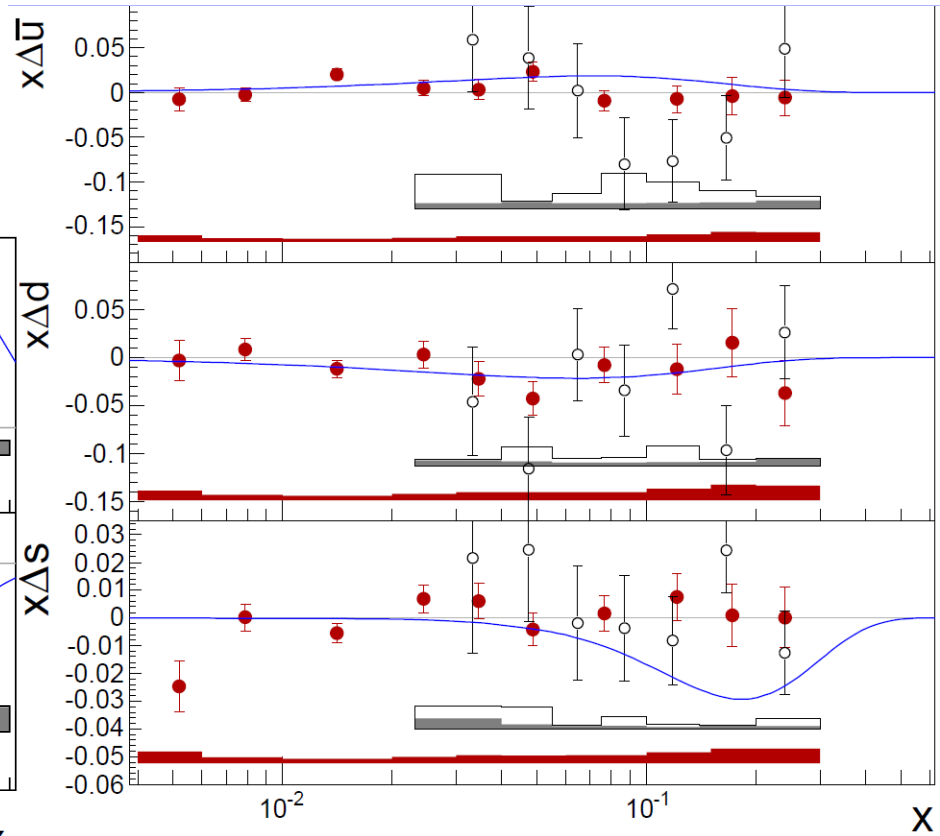


Compass results for Δu(x), Δd(x), and Δs(x)

- LO semi-inclusive data analysis of COMPASS proton and deuteron data

DNS: De Florian, Navarro, Sassot, Phys. Rev. D71, 2005

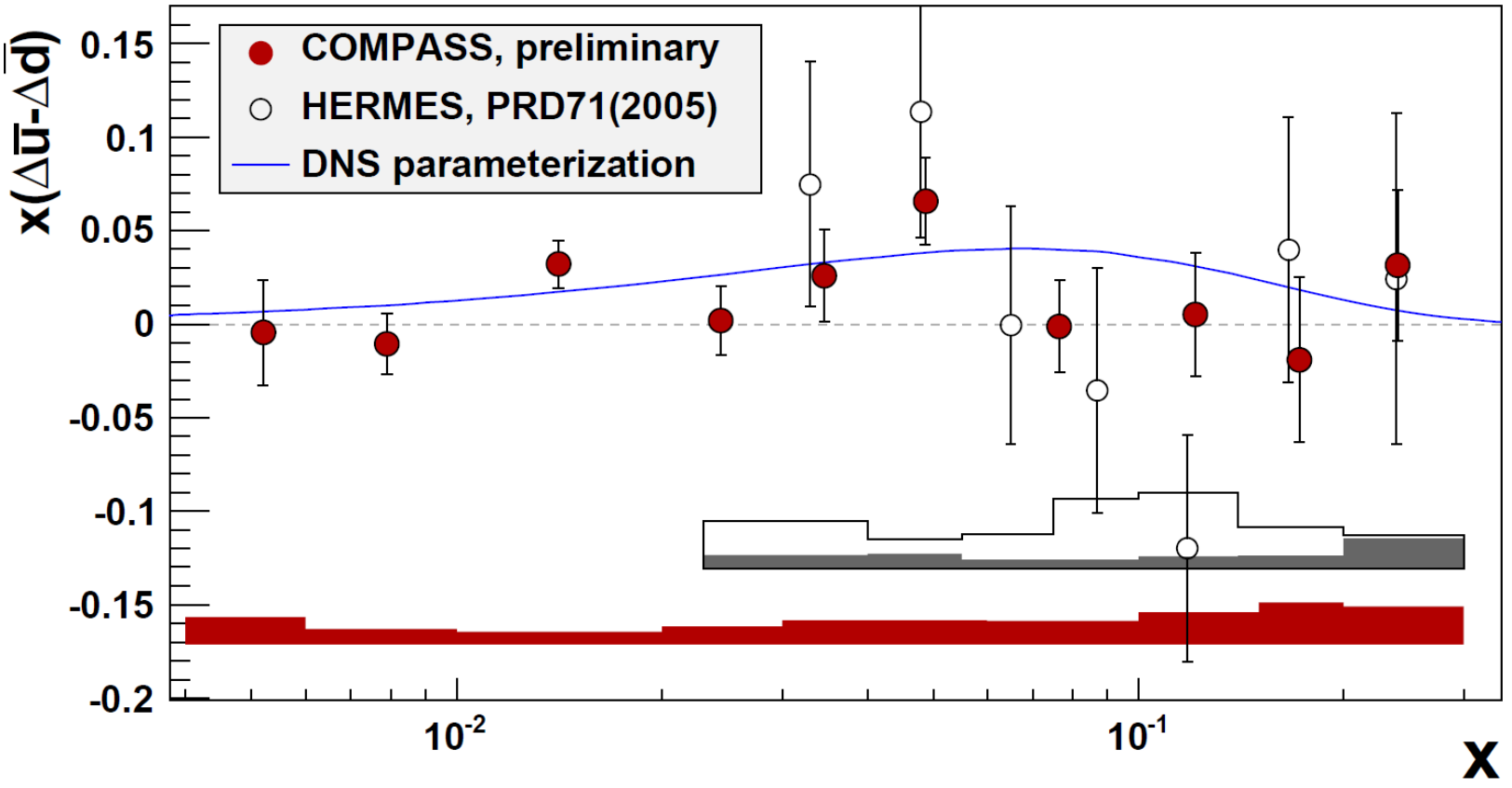




Δs Integral: $\int_{0.004}^{0.3} \Delta s(x)dx = -0.01 \pm 0.01 \pm 0.01$

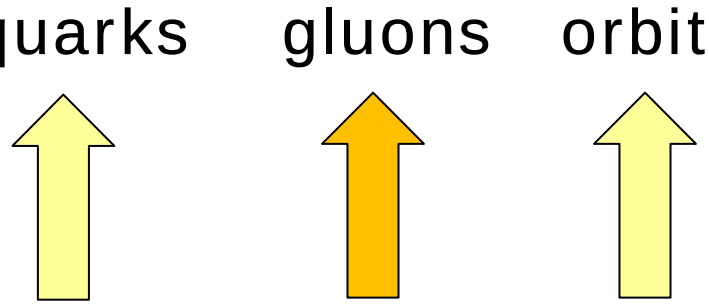
Flavour asymmetry? $\Delta\bar{u} - \Delta\bar{d}$

- considerable asymmetry in the unpolarised case
- models naturally predict asymmetry for polarized case
- Rather small effect, $\Delta\bar{u} > \Delta\bar{d}$



Gluon polarization

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



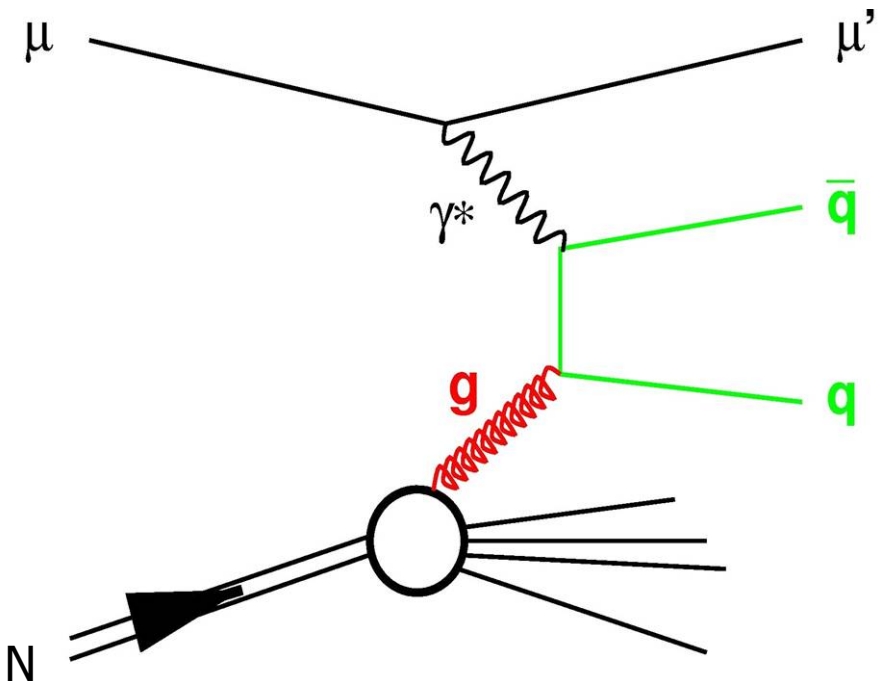
small ~0.15

unknown

poorly known

Hadron production in DIS via PGF

Principle: Gluon polarization enters via photon-gluon fusion (PGF)



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

- Measure $A_{||}$
- calculate R_{pgf}, $\left\langle \hat{a}_{pgf} \right\rangle$ and background by Monte Carlo

Δg/g from open charm

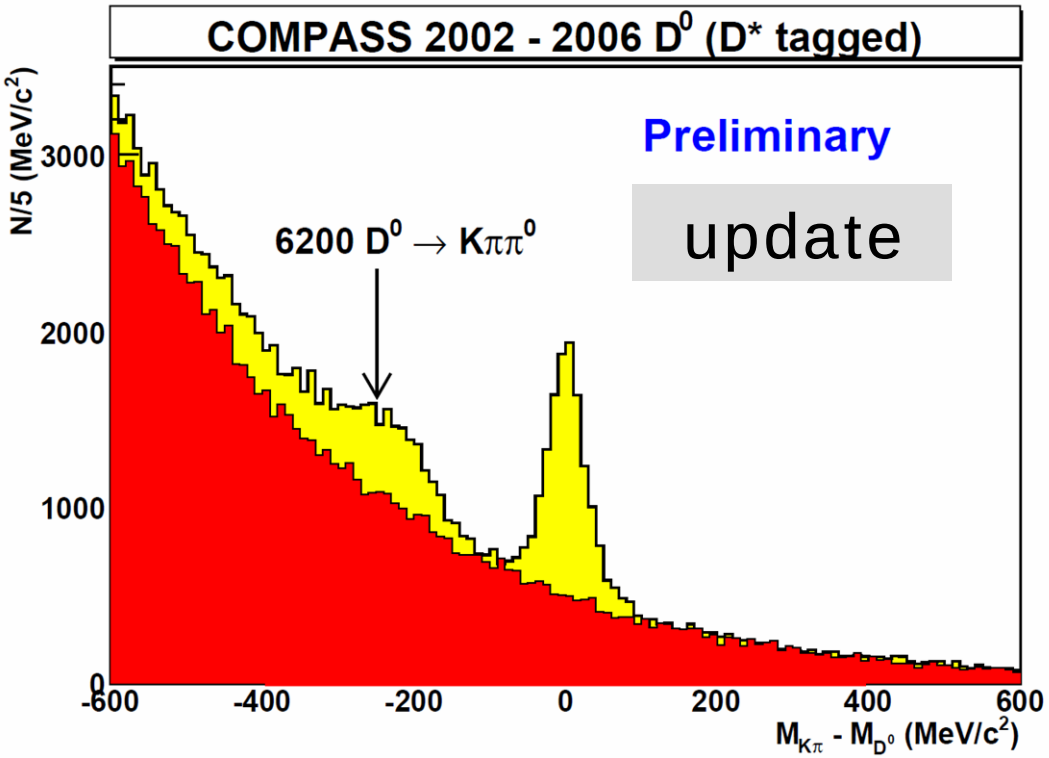
- cleanest process
  - little physics background

- observe asymmetry in D meson production
  - only one D meson via $D \to \pi K$ (BR ~ 4%)
  - background drastically reduced when looking to D^* decay in coincidence with slow pion

$$D^* \to D^0 + \pi_S \to K + \pi + \pi_S$$

Update on open charm

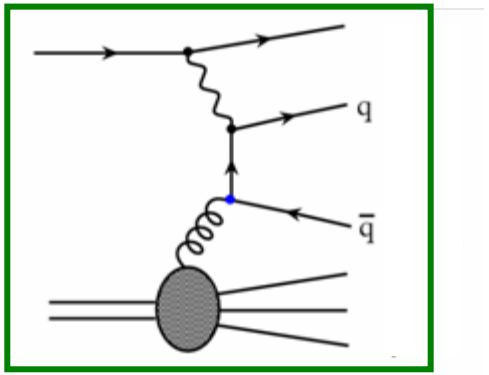
- 2002–2006 deuteron data
- new channels in D* sample
  - sub-threshold kaons
  - 3-body decay with non-observed π^0



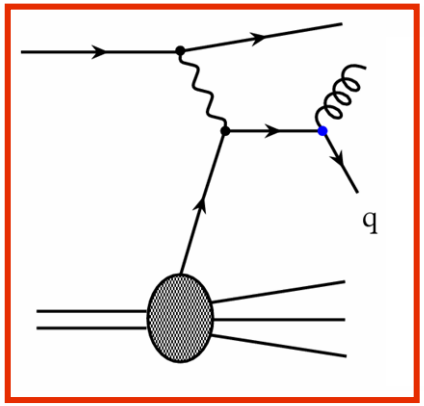
- old $\langle \Delta g/g \rangle_x$ = -0.49 ± 0.27 (stat.) ± 0.11 (syst.)
- new $\langle \Delta g/g \rangle_x$ = -0.39 ± 0.24 (stat.)

Δg/g from high p_t hadron pairs

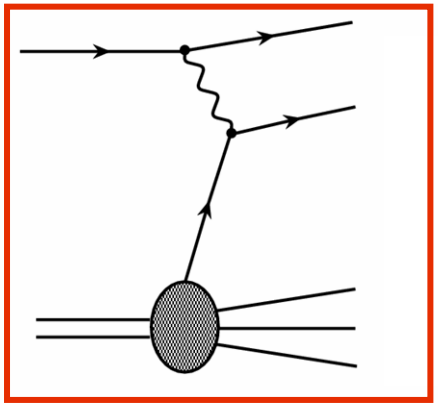
$$A_{LL}^{\mu N \to hh} \approx \hat{a}_{LL}^{PGF} \frac{\Delta g}{g} \frac{\sigma^{PGF}}{\sigma^{tot}} + \hat{a}_{LL}^{QCD-C} A_1 \frac{\sigma^{QCD-C}}{\sigma^{tot}} + \hat{a}_{LL}^{LO} A_1 \frac{\sigma^{LO}}{\sigma^{tot}}$$



Photon-Gluon-Fusion



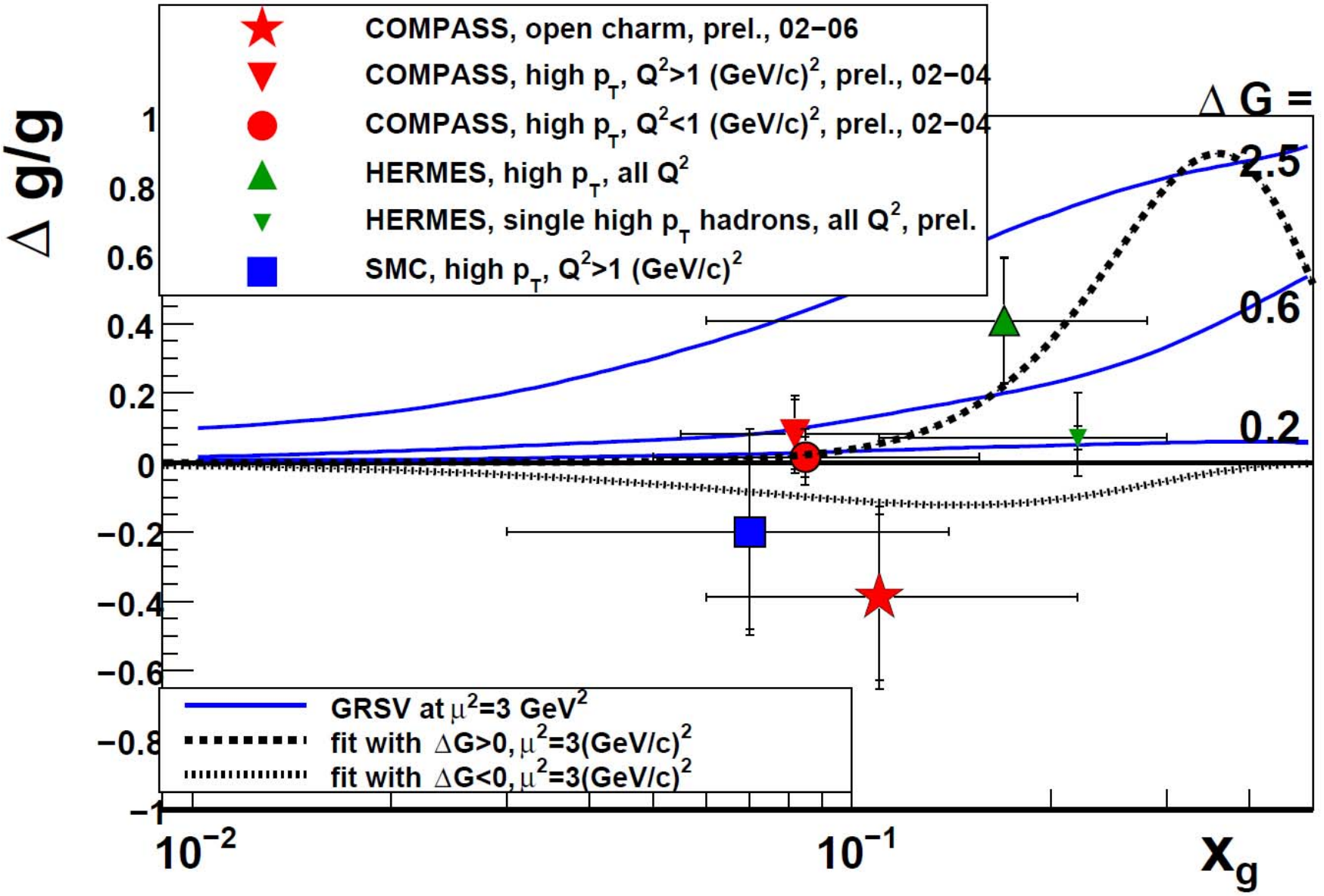
QCD-Compton



Leading Order DIS

+ resolved photon for low Q^2

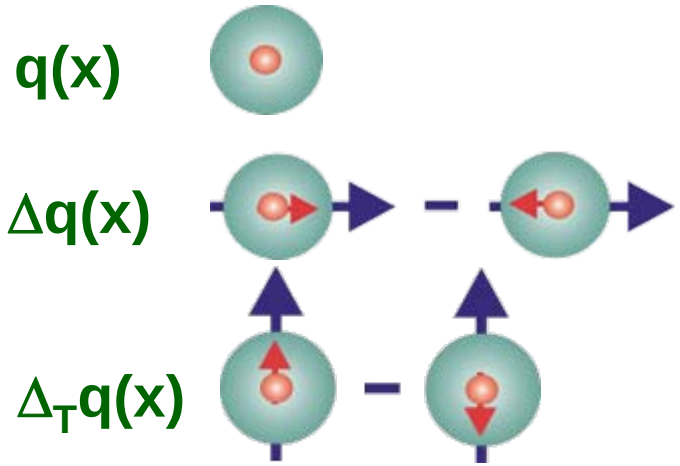
Results on direct measurements of Δg/g



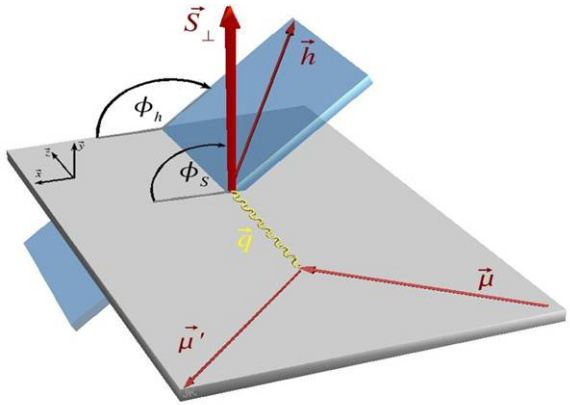
Transverse spin effects

Transversity PDFs

- Transversity
  - Third distribution function (twist-2): $\Delta_T q(x)$
    - Transverse quark spin distribution in transversely polarized nucleon
- Measurement
  - Semi-inclusive DIS
  - transversely polarized target
  - azimuthal asymmetry

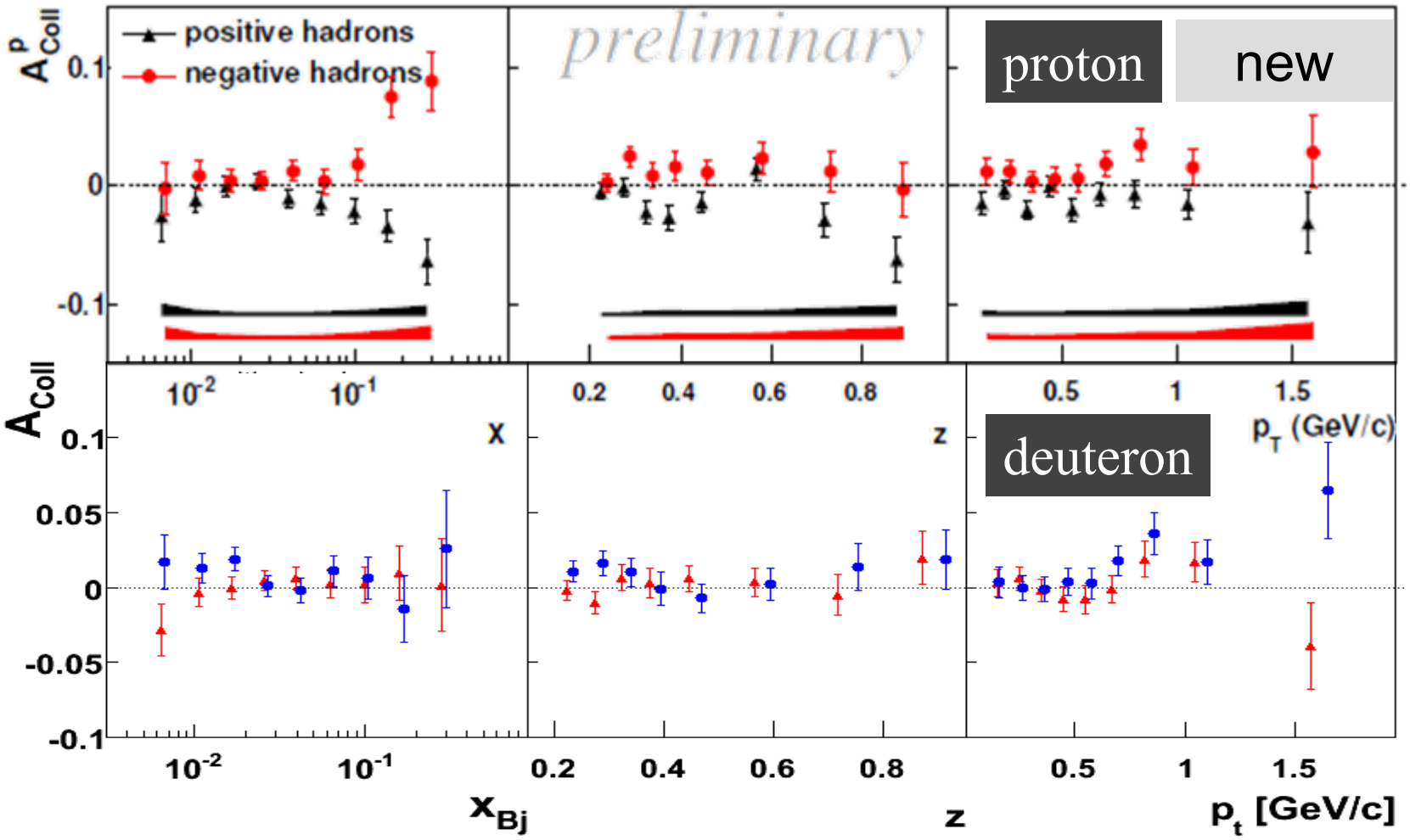


$$A_{Coll} = \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_T^0 D_q^h(z, p_T^h)}{\sum_q e_q^2 q(x) D_q^h(z, p_T^h)}$$



Collins Asymmetries

New: full 2007 proton data set (statistics tripled)



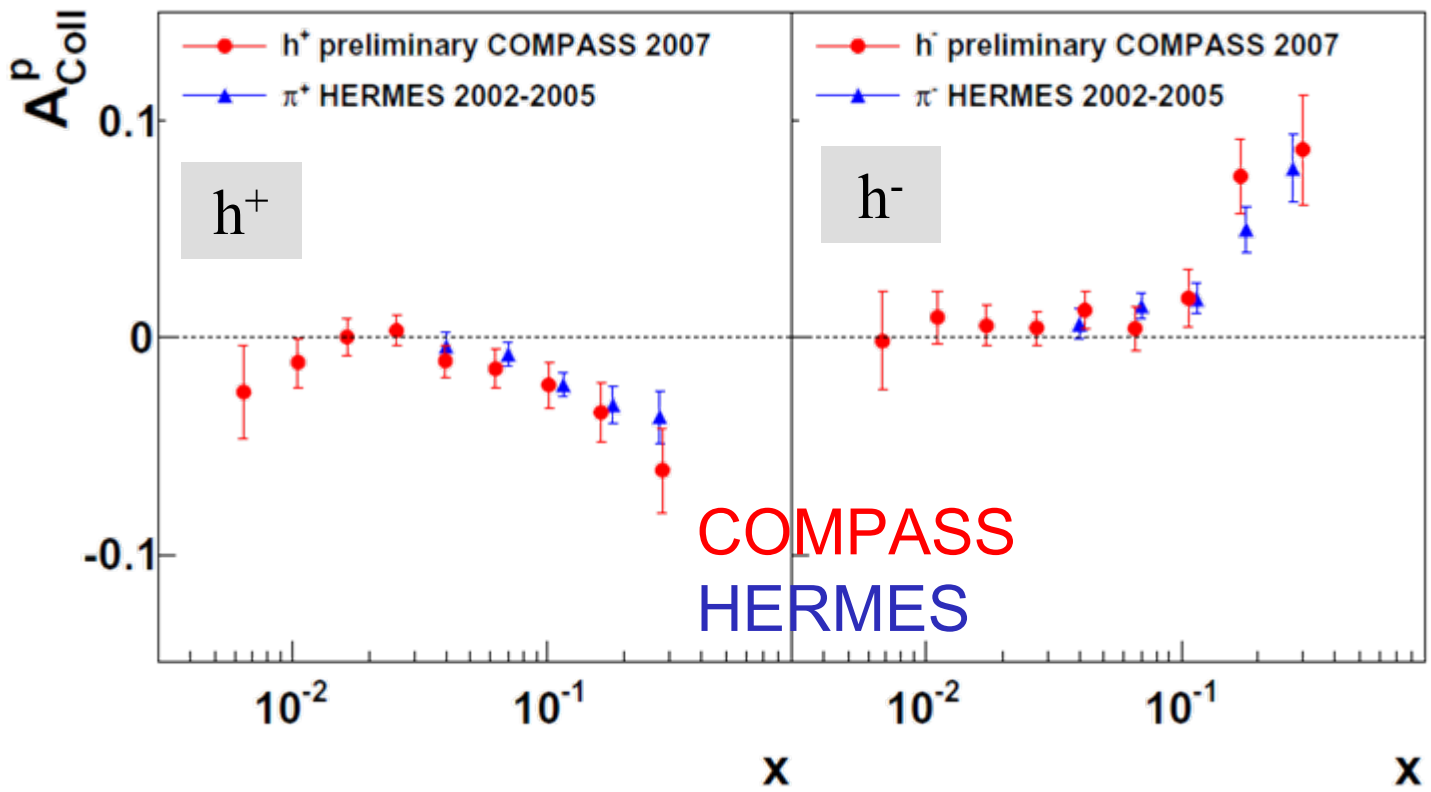
h^+

h^-

h^+

h^-

Comparison



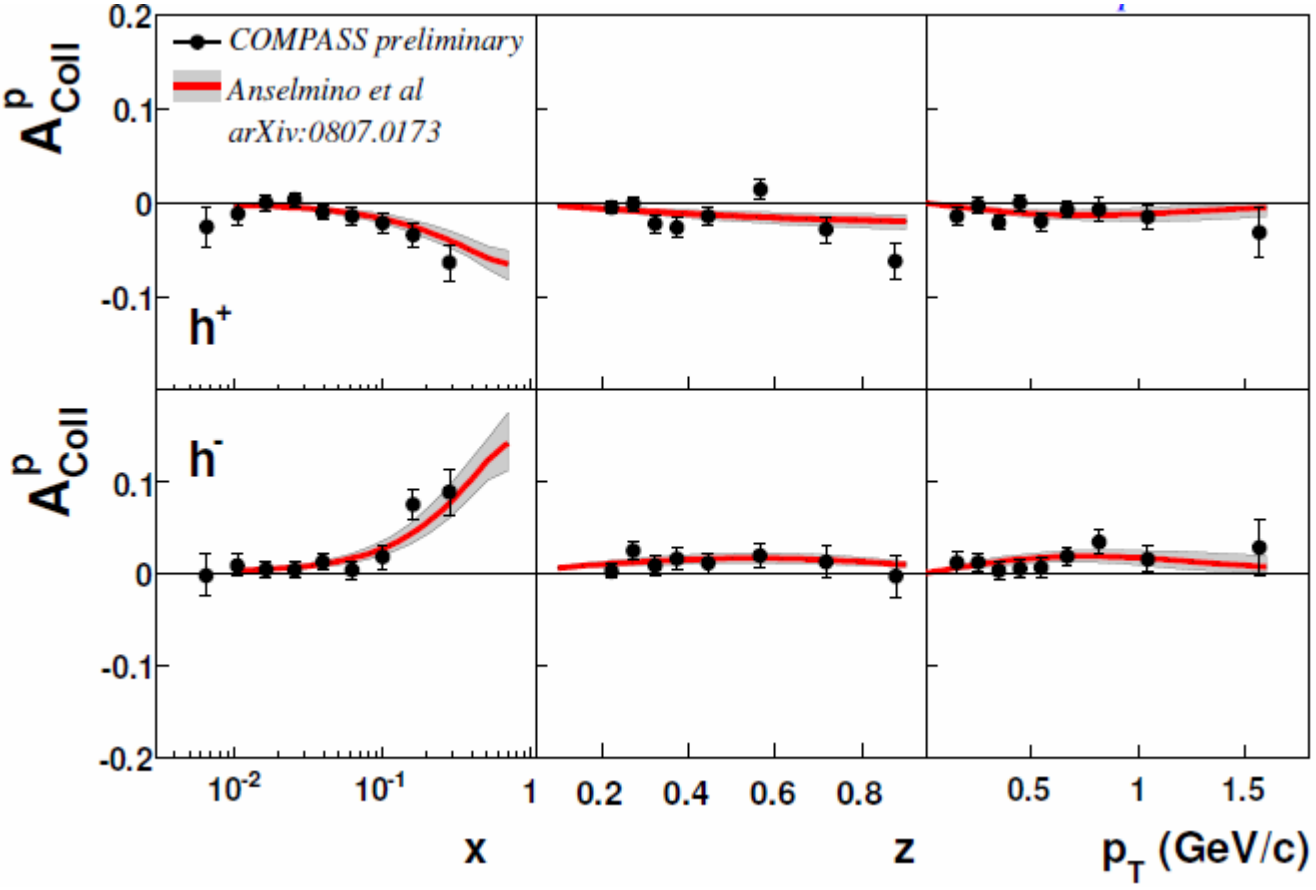
proton

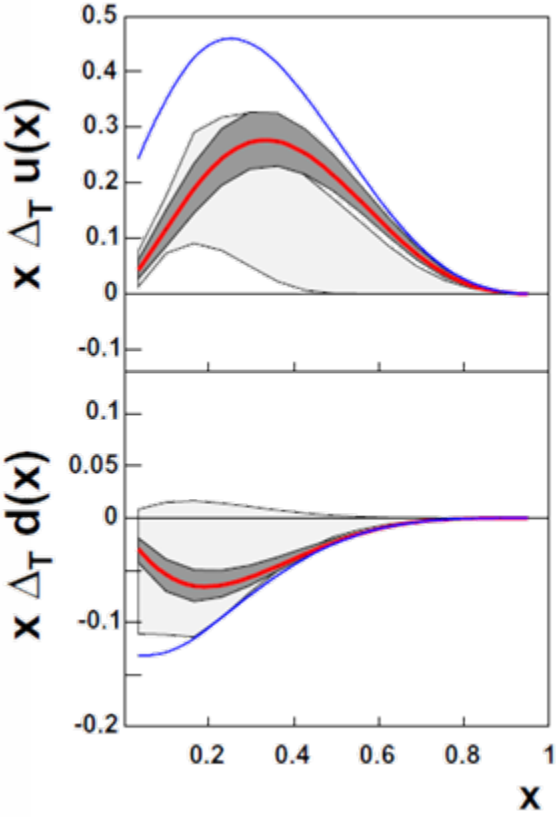
sign change and $D_{nn} \cong y$ applied for HERMES data

- large asymmetry ~10%
- good agreement in common x range
- zero deuteron result important ⇒ opposite sign of u and d quark transversity distribution

Global Fit

- Fit to COMPASS *d*, HERMES, BELLE (FF, e^+e^-)
- in good agreement with new proton data





Transversity $\Delta_T q(x)$ from hadron pairs

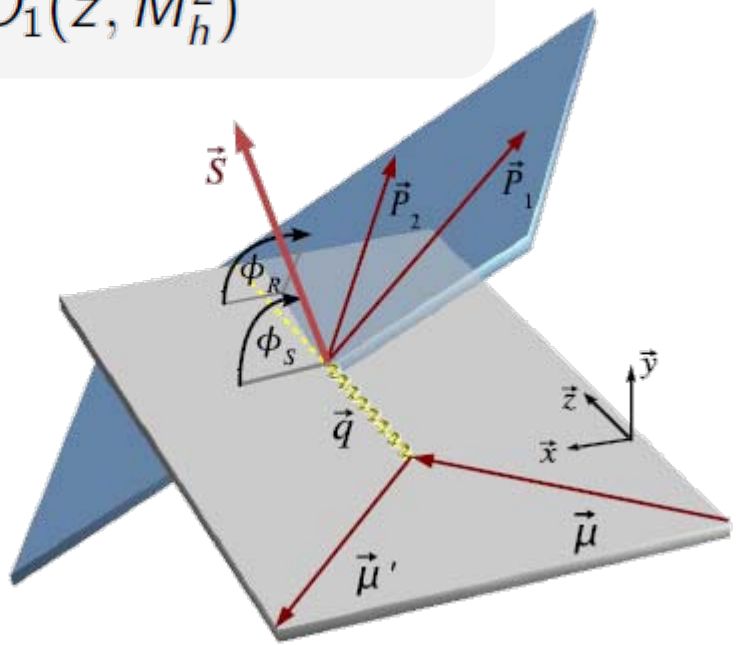
- Alternative: couple $\Delta_T q(x)$ to chiral odd 2-hadron interference FF $H_1^{\sphericalangle}$

$$A_{RS} \propto \frac{\sum_q e_q^2 \Delta_T q(x) H_1^{\sphericalangle}(z, M_h^2)}{\sum_q e_q^2 q(x) D_1(z, M_h^2)}$$

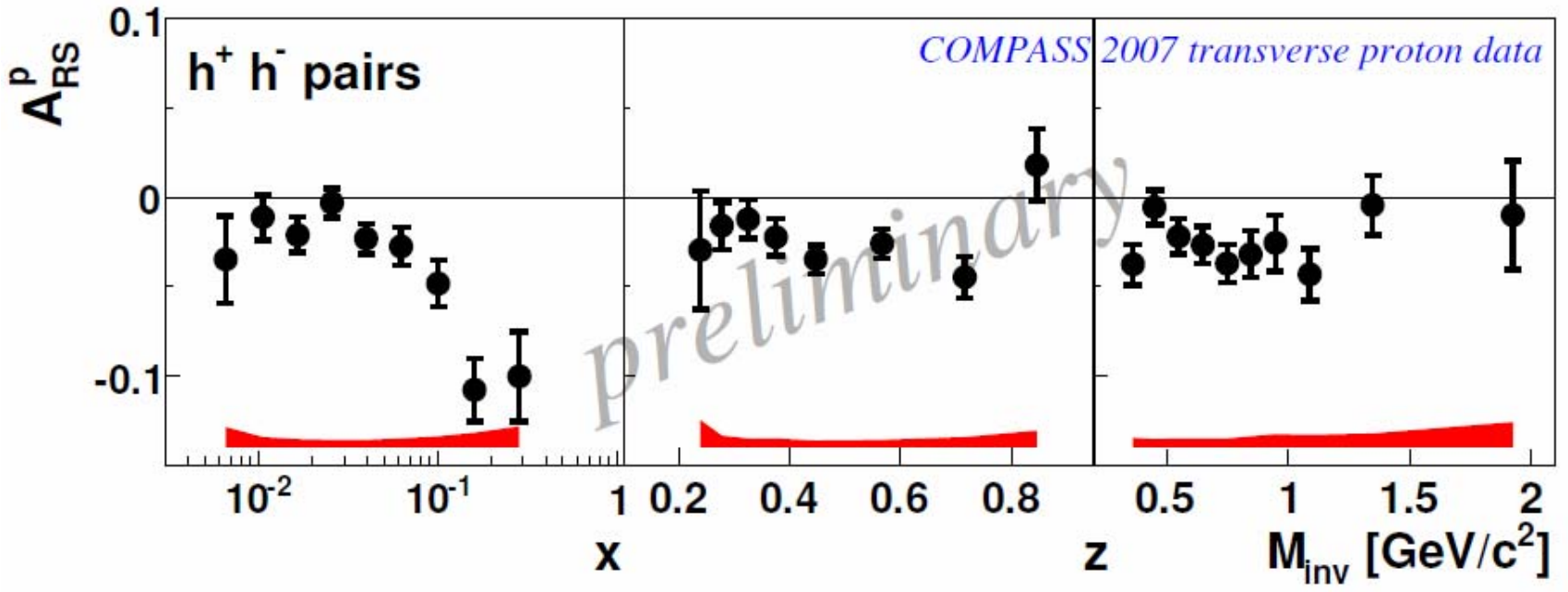
cross-section asymmetry:

$$\frac{\Delta\sigma}{\sigma} \propto A_{RS} \sin\phi_{RS} \sin\theta$$

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



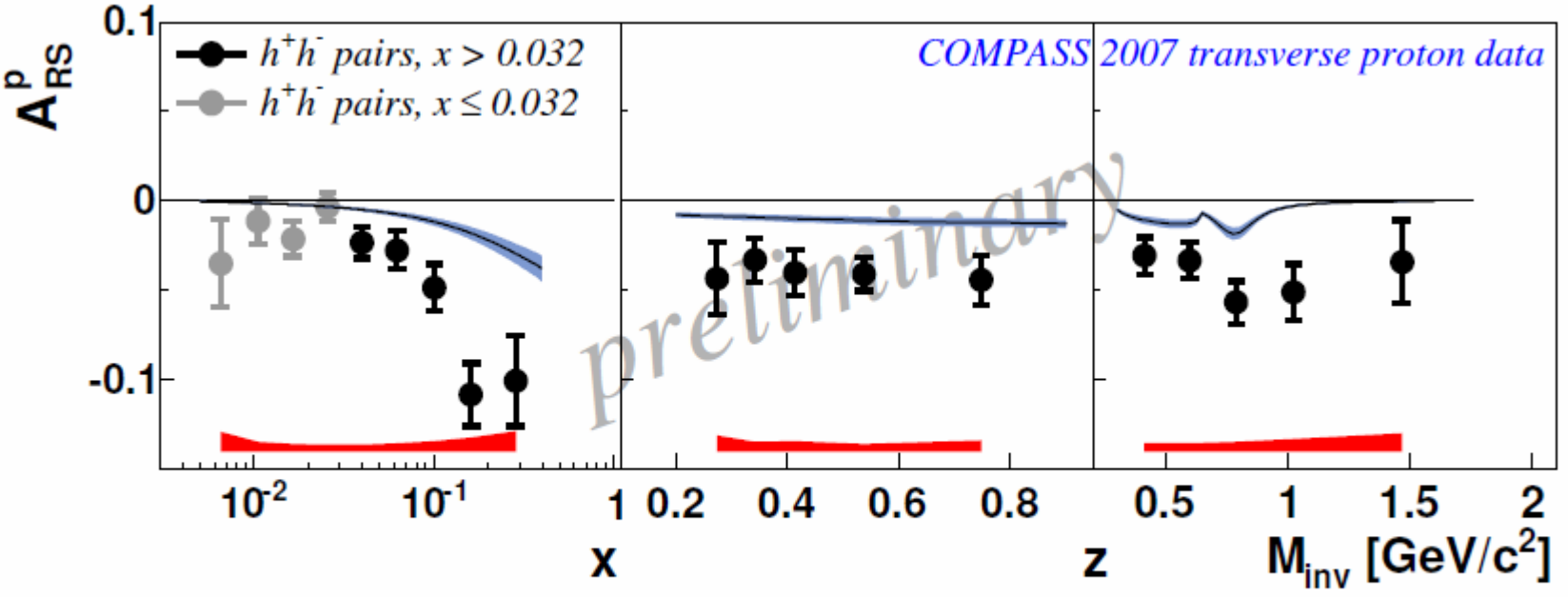
Two-hadron asymmetry



- large asymmetries
- interference FF and transversity sizable

Comparison to a recent Fit

- Recent fit (dominated by HERMES, COMPASS *p* not yet in)



Very recent prediction (Bacchetta, Radici Phys.Rev.D79:034029,2009)

Sivers function $\Delta_0^T q$

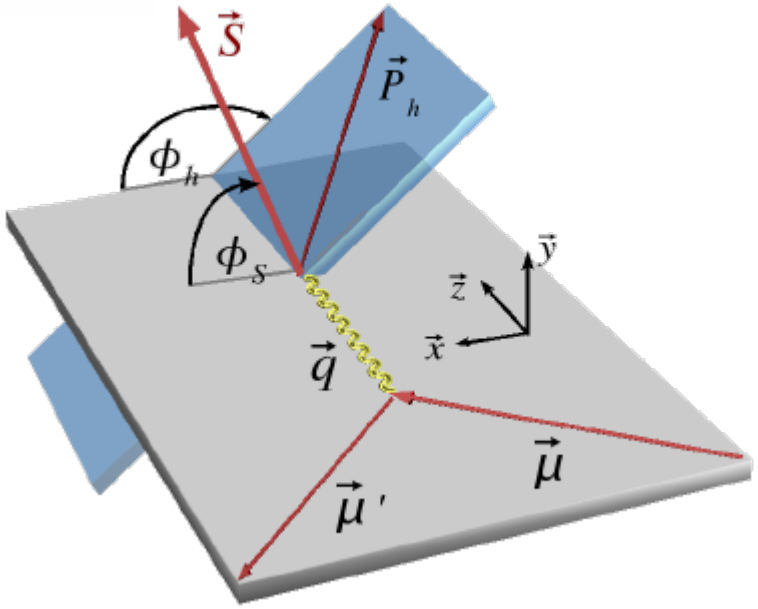
- Sivers Asymmetry:

$$A_{Siv} = \frac{\sum_q e_q^2 \Delta_0^T q(x, p_T^h/z) D_q^h(z)}{\sum_q e_q^2 q(x, p_T^h/z) D_q^h(z)}$$

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

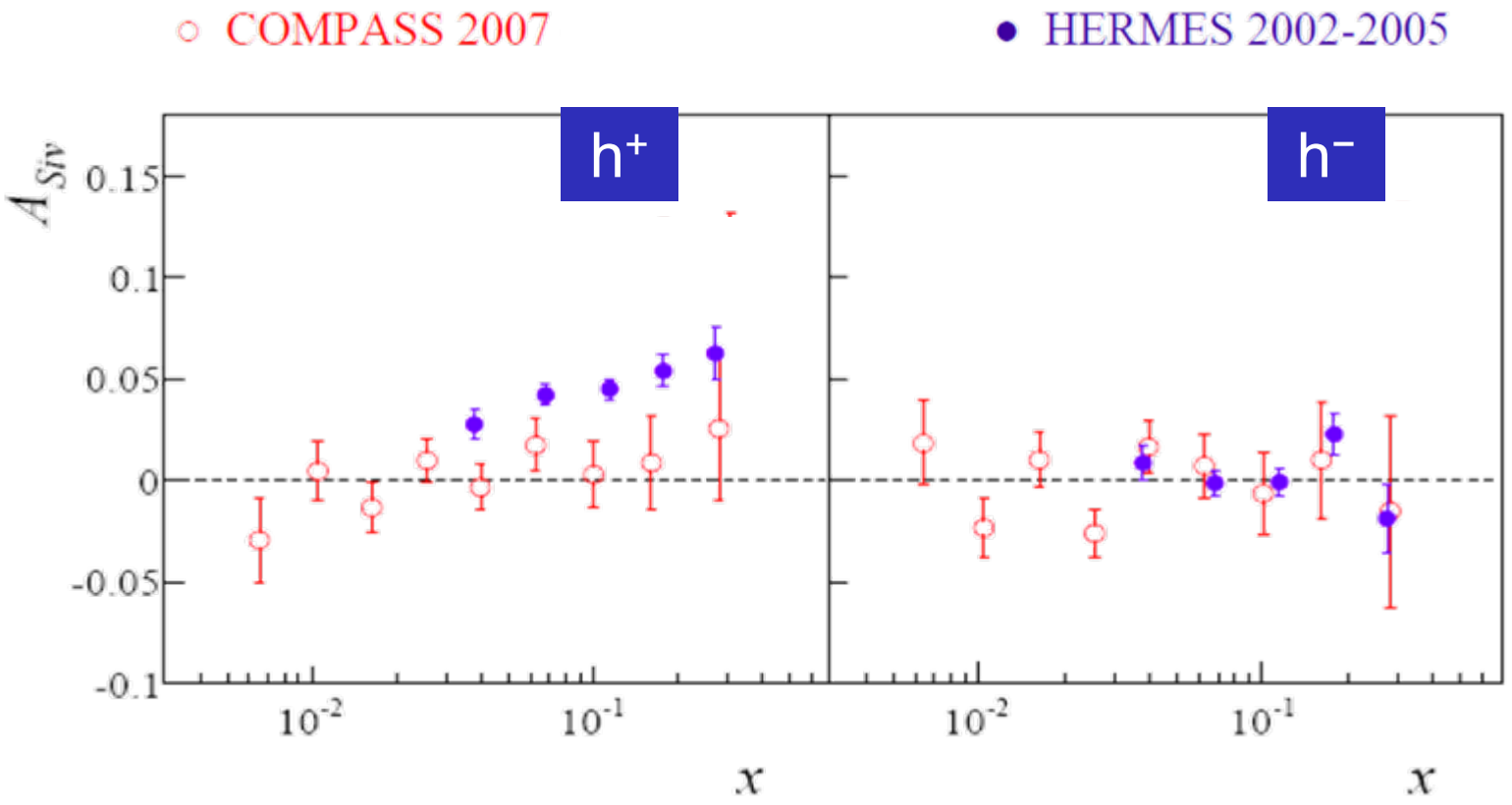
$$\Phi_S = \phi_h - \phi_S$$

- proposed (1990, Sivers)
- thought to vanish (1993, Collins)
- resurrected (2002, Brodsky, Hwang, Schmitt)
- different sign in DY and SIDIS



Proton Sivers Asymmetry

- compatible with zero for the deuteron
- large effect seen by HERMES, not confirmed by COMPASS
- clarification needed



Outlook

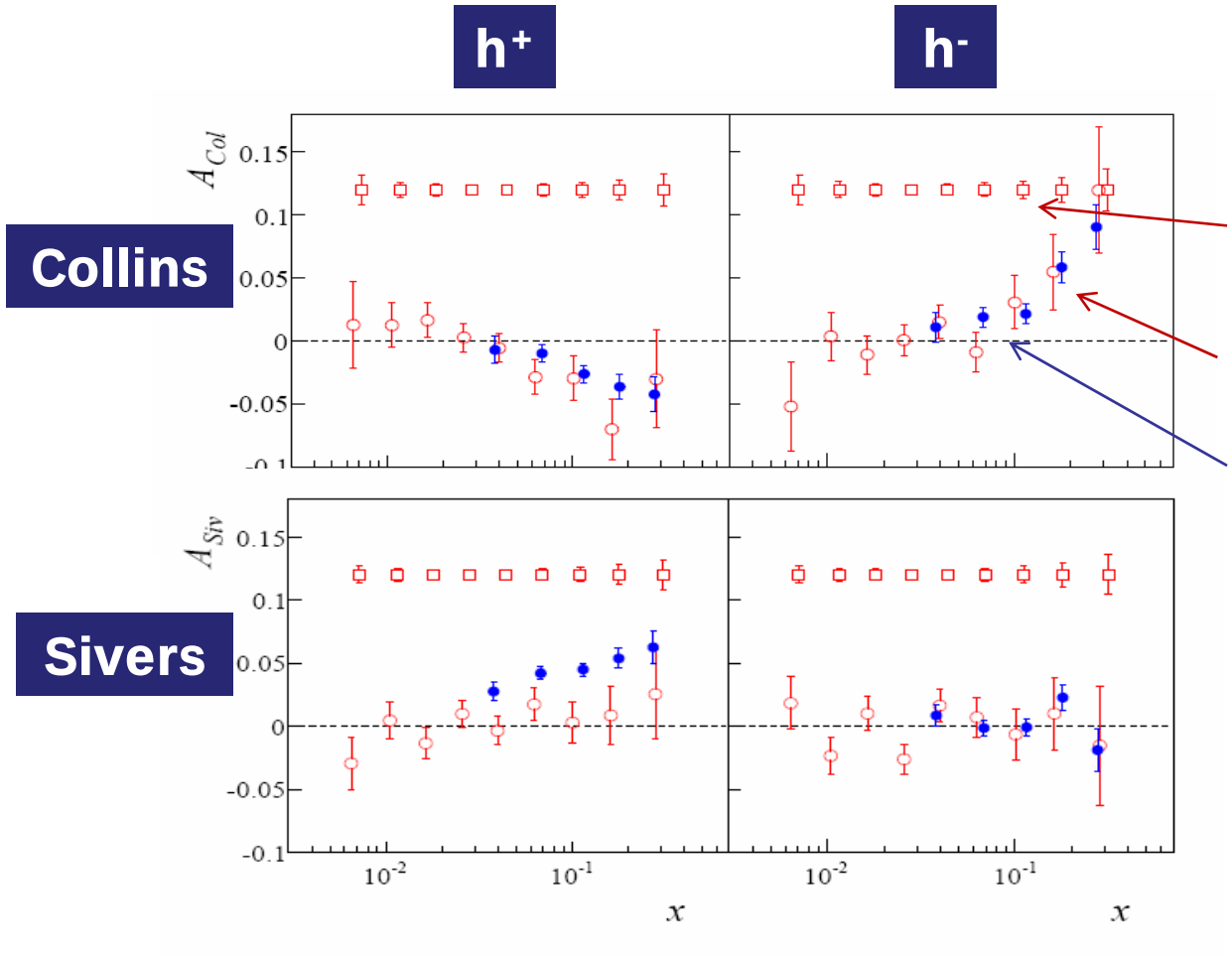
COMPASS future

- Short term plans: 2010, 2011
- Mid term proposal: 2012 and beyond

2010: Transversity, one year on a NH_3 target

- Goal: improve statistics on the proton

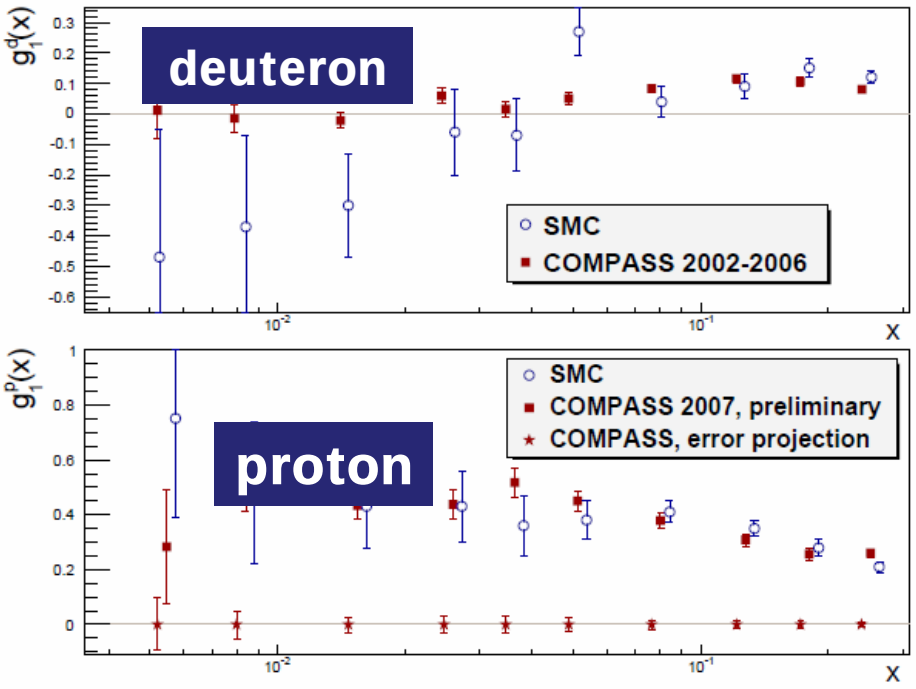
E = 160 GeV
I = 2×10^8 μ/spill

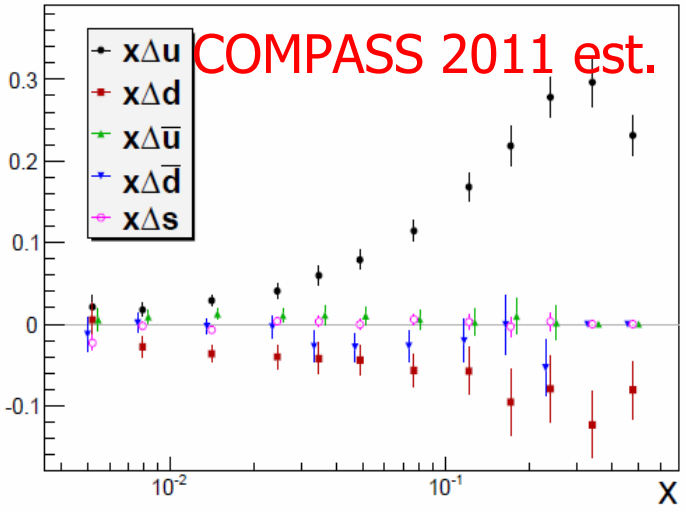


2011: Longitudinal, one year on a NH_3 target

- Goal: improve statistics on proton

E = 200 GeV
I = 2×10^8 μ/spill





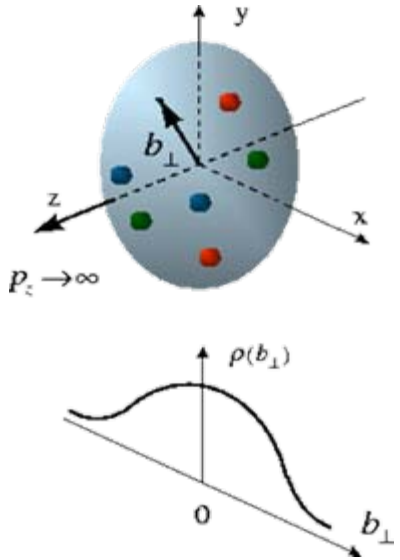
► Proton and deuteron data with similar accuracy

Proposal for 2012 and beyond

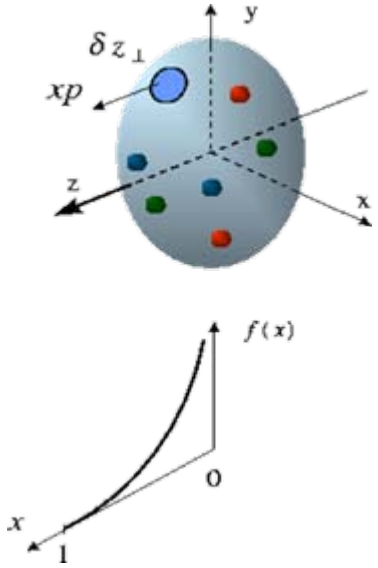
- Study of the Generalized Parton Distributions (GPDs)

  - Natural extension of:

Form factors
(spatial distributions)



PDFs
(momentum distributions)

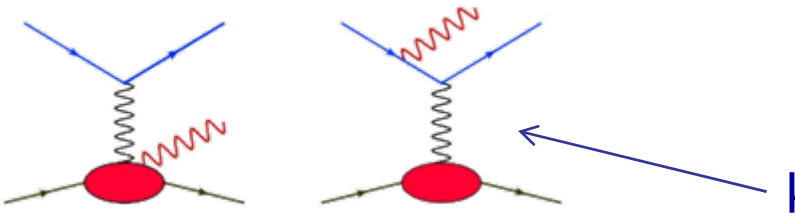


Access through:- Deeply Virtual Compton Scattering (DVCS)

- Hard Exclusive Meson Production (HEMP): ρ, ω, ϕ, π, η

Generalized Parton Distributions and DVCS

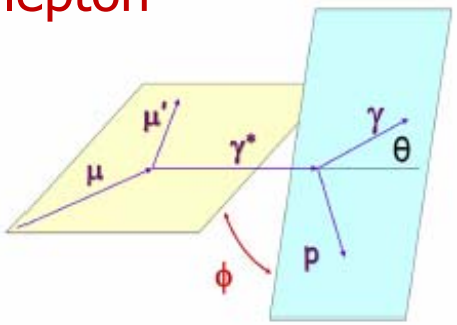
- Cross section

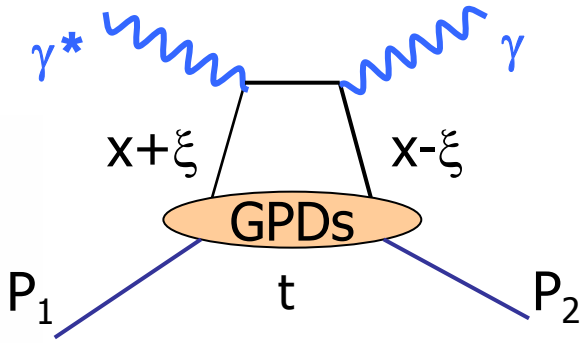


$$d\sigma \propto \left| \text{Deep VCS} + \text{Bethe-Heitler} \right|^2$$

$$d\sigma = d\sigma^{BH} + \left[d\sigma^{DVCS}_{unpol} + P_\mu d\sigma^{DVCS}_{pol} \right] + e_\mu a^{BH} \left[\mathrm{Re}(T^{DVCS}) + P_\mu \, \mathrm{Im}(T^{DVCS}) \right]$$

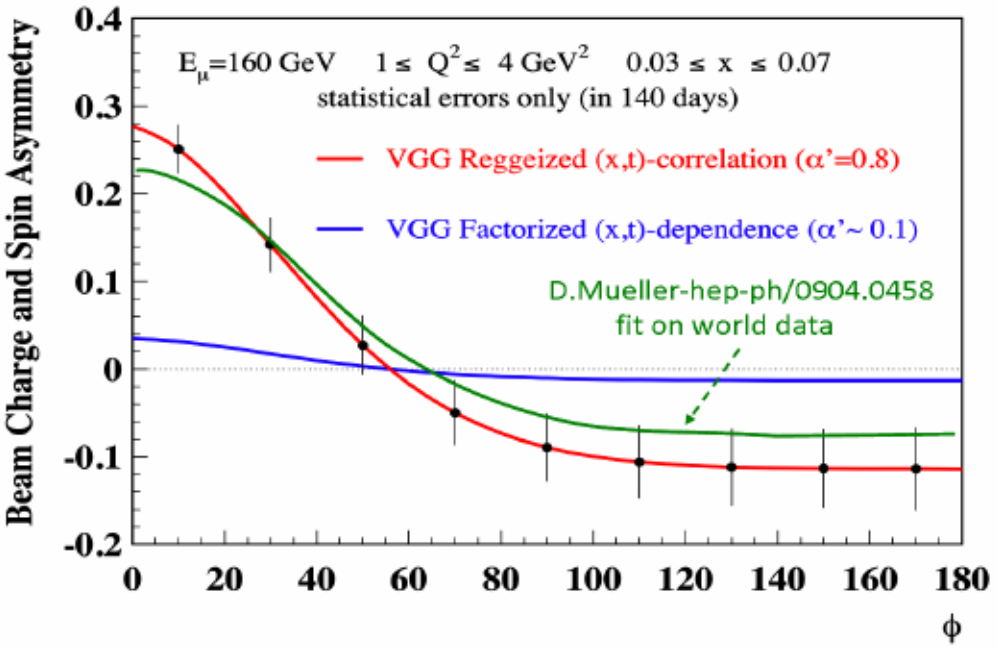
- Experimental apparatus must detect
  - Incident and scattered lepton
  - Outgoing real photon
  - Recoiling soft proton



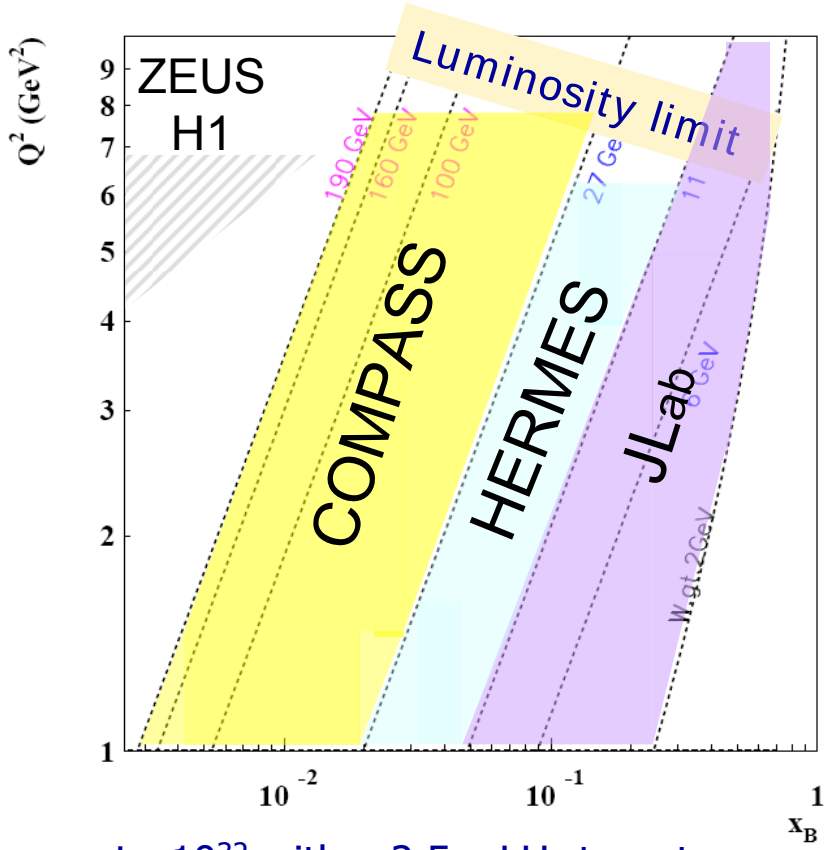


GPDs at COMPASS – kinematical coverage

- Unique features
  - Both μ^+ and μ^- polarized beams
  - Apparatus: upgrades
  - First tests done in 2008



Prediction for 1 year of data taking

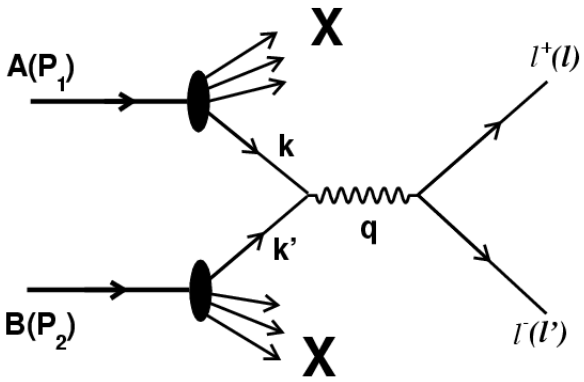


L=10^{32} with a 2.5m LH_2 target

Complementary to HERA and HERMES/JLAB

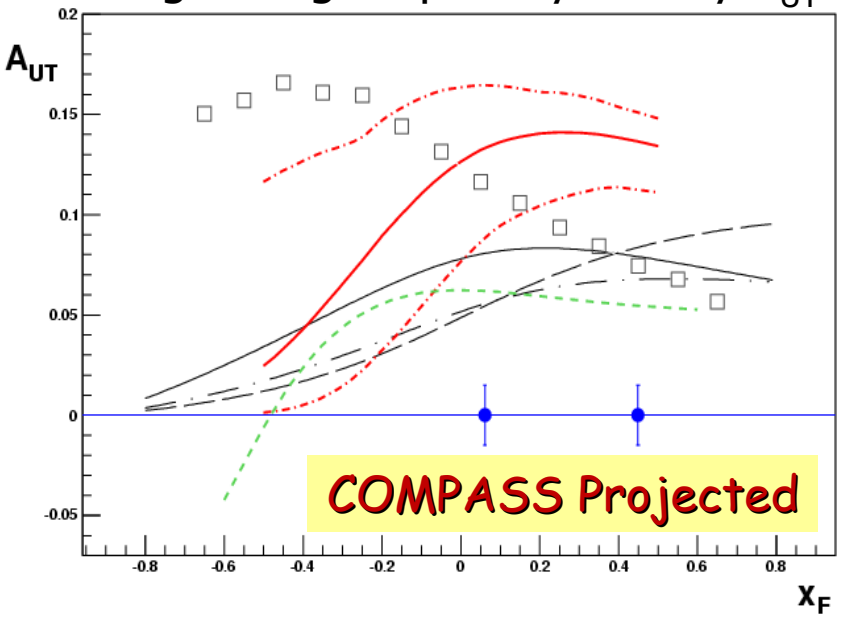
Measurements of TMDs using Drell-Yan

$$\pi + p^{\uparrow} \rightarrow l\bar{l} + X$$



Drell-Yan (pp) gives direct access to chiral odd PDFs like the Sivers function

Single Target Spin Asymmetry A_{UT}

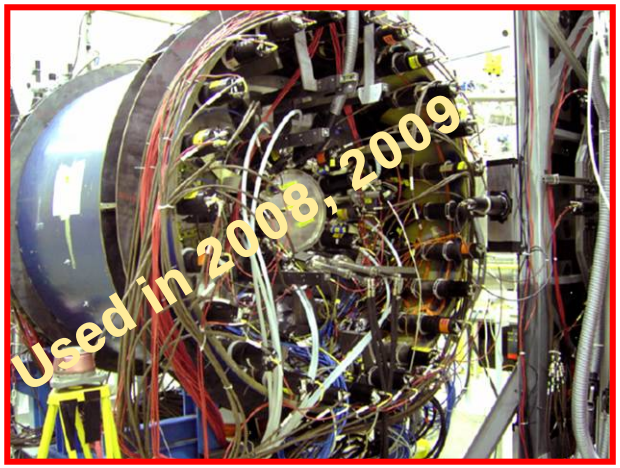


Models for Sivers function

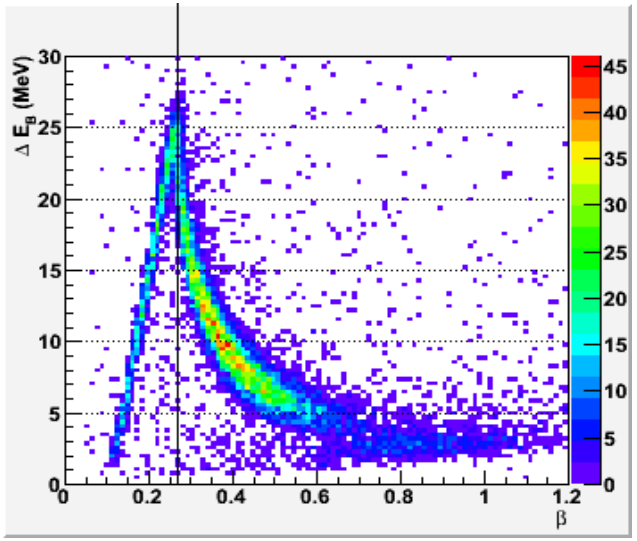
Spectrometer upgrades

- New equipments (Phase I)
  - Large Recoil Proton Detector

Prototype: 1.2 m long; target: 40 cm



  - 2.5 m long LH_2 target
  - Large angle ECAL calorimeter/project



- R&D (Phase II)
  - New polarized target/superconducting magnet (Transverse field)

Summary

- COMPASS is a major player in the nucleon spin physics
  - PRESENT
    - Many important results with μ^+ beam
    - Lots of data are being analyzed, additional results to come
  - NEAR FUTURE (2010 and 2011)
    - Improved statistics on the proton (T and L)
  - MID-TERM (>2012)
    1. GPD measurements (μ^+ and μ^- beams)
    2. DRELL-YAN measurements

Spares

First moment of g_1

singlet axial current: $a_0 = \Delta u + \Delta d + \Delta s$ $= \Delta\Sigma$ (quark contribution to nucleon spin)

non-singlet axial current: $a_8 = \Delta u + \Delta d - 2\Delta s$ (from hyperon beta decay)

$$\Gamma_1^N(Q_0^2 = 3(\mathrm{GeV}/c)^2) = \int_0^1 g_1^N(x)\,dx = 0.0502 \pm 0.0028(\mathrm{stat}) \pm 0.0020(\mathrm{evol}) \pm 0.0051(\mathrm{syst})$$

- in literature (S.A. Larin *et al.*, PLB404 (1997) 153):

$$\Gamma_1^N(Q^2) = \frac{1}{9}\left(1 - \frac{\alpha_s(Q^2)}{\pi} + O(\alpha_s^2)\right)\left(a_0(Q^2) + \frac{1}{4}a_8\right)$$

(from Y. Goto *et al.*, PRD62 (2000) 034017: $a_8 = 0.585 \pm 0.025$)

$$a_0(Q_0^2 = 3(\mathrm{GeV}/c)^2) = 0.35 \pm 0.03(\mathrm{stat}) \pm 0.05(\mathrm{syst})$$

extrapolating to $Q^2 \to \infty$

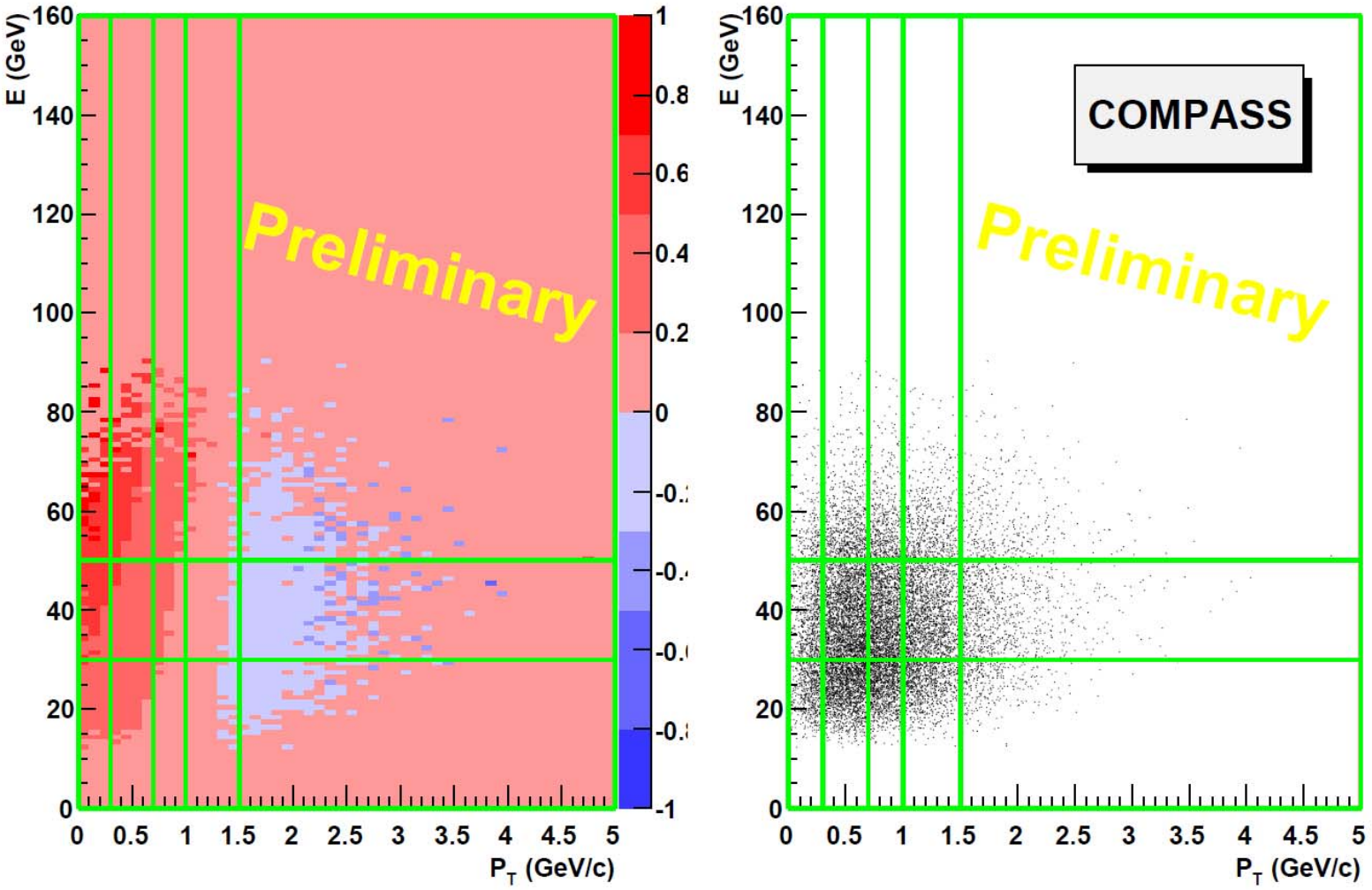
$$\hat{a}_{0\left(Q^2 \to \infty\right)} = 0.33 \pm 0.03(\mathrm{stat}) \pm 0.05(\mathrm{syst})$$

$$(\Delta s + \Delta\bar{s}) = \frac{1}{3}(\hat{a}_0 - a_8) = -0.08 \pm 0.01(\mathrm{stat}) \pm 0.02(\mathrm{syst})$$

Analyzed channels

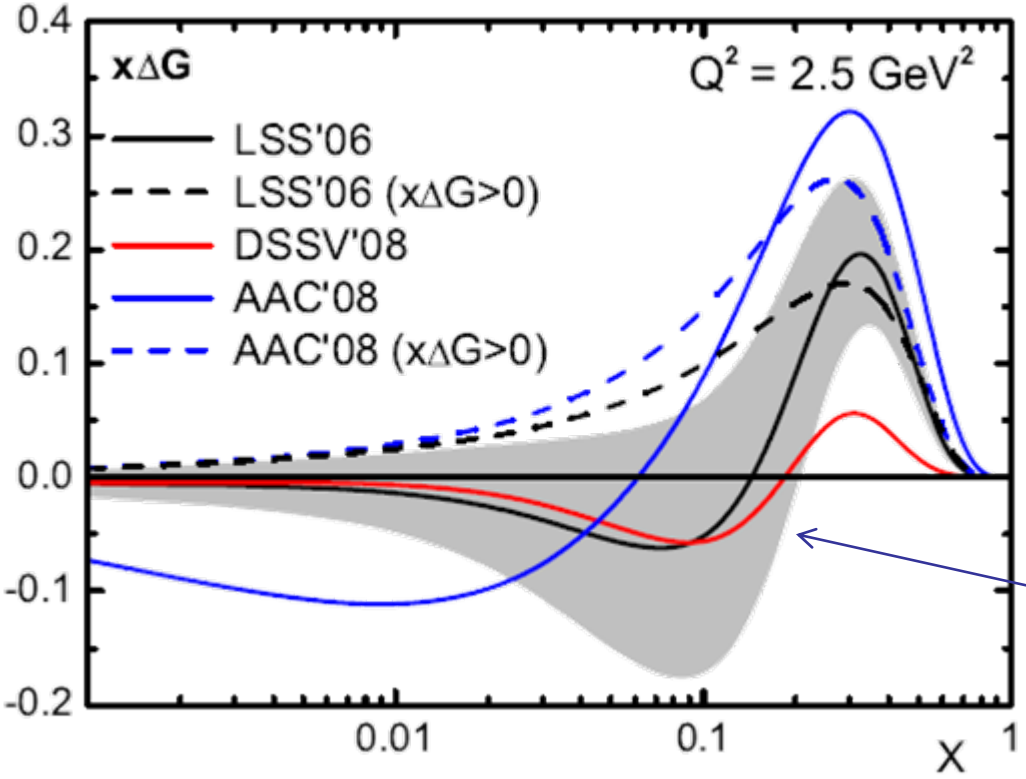
- analyzed data sets:
  - single charmed meson
    - quasi-real photons — AROMA
  - high-p_T hadron pairs (no ID, pions/kaons)
    - $Q^2 > 1$ GeV^2 — LEPTO
    - $Q^2 < 1$ GeV^2 — PYTHIA
- All analyses in LO till now (plus parton showers)

Open charm analyzing power a_{LL}



ΔG is calculated by many other groups…

From E. Leader, Spin-2008



LSS-06 :
Leader, Sidorov, Stamenov,
Phys. Rev. D73, 2006

AAC'06 :
Hirai, Kumano, Saito,
Phys. Rev. D74, 2006

DSSV-08:
De Florian, Sassot, Stratmann, Vogelsang,
Phys. Rev. Lett. 101, 2008
+
HERMES, Blumlein, Bottcher

ΔG(x) can also change sign!

- The shape of ΔG(x) is still unknown
- Dedicated measurements of ΔG(x) needed