Overview of the nucleon spin studies at COMPASS

Nucleon:
almost all visible matter

Spin:
fundamental quantum number

ICNFP 2013 - Crete, Greece

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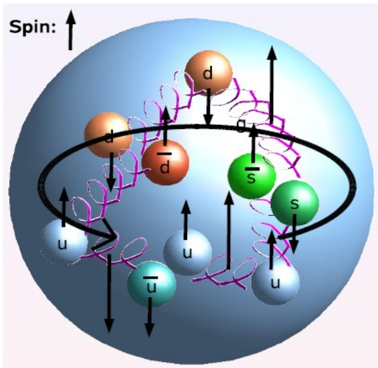
on behalf of the COMPASS collaboration

Motivation

- **Motivation I:** Nucleon spin structure



Where does the proton spin (complex structure in QCD) come from?

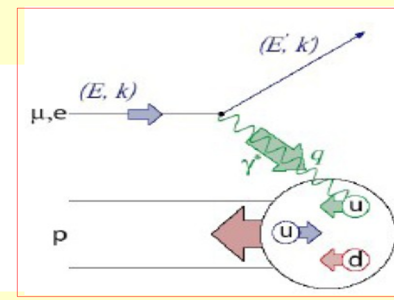
$$\left(\frac{S_z^N}{\hbar}\right) = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_z^q + \Delta G + L_z^g \longrightarrow \textbf{Ji sum rule}$$

$$= \lim_{t\to 0}\int_{-1}^{+1} dx\, x\,[\underbrace{H(x,\xi,t)+E(x,\xi,t)}_{\text{GPDs}}] + J^g$$

Mostly studied in polarised Deep Inelastic Scattering (DIS)

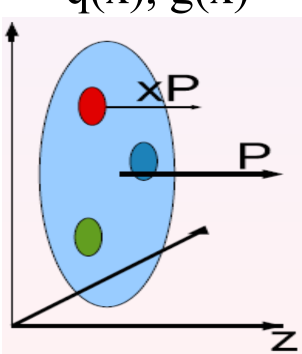
- $\Delta\Sigma = \int_0^1 \Delta u(x)+\Delta\bar{u}(x)+\Delta d(x)+\Delta\bar{d}(x) + \Delta s(x)+\Delta\bar{s}(x)\,dx$
- $\Delta G = \int_0^1 \Delta g(x)\,dx$
- L^q related to TMDs
- $\Delta\Sigma + L^q$ related to GPDs

$Q^2 = -q^2$
$\nu = E - E'$
$x = Q^2 / 2M\nu$
$y = \nu / E$

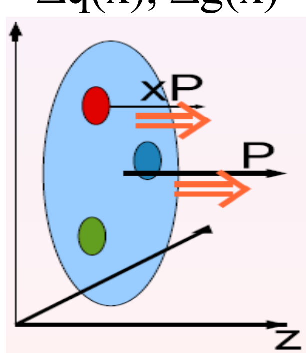


- **Motivation II:** Parton Distribution Functions (PDFs), TMDs and GPDs

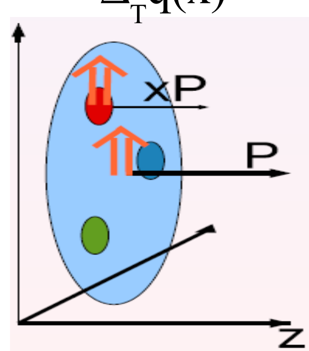
Unpolarised
q(x), g(x)



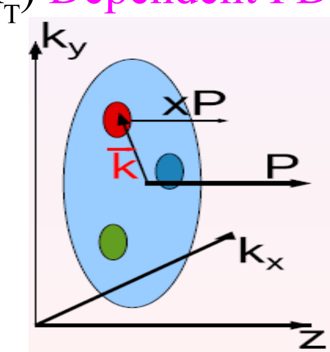
Helicity
Δq(x), Δg(x)



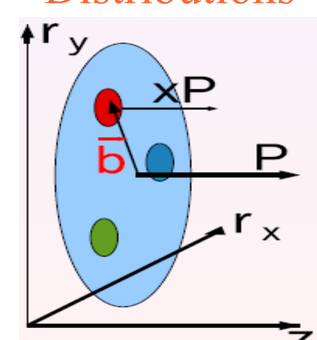
Transversity
$\Delta_T q(x)$



Transverse Momentum (k_T) Dependent PDFs

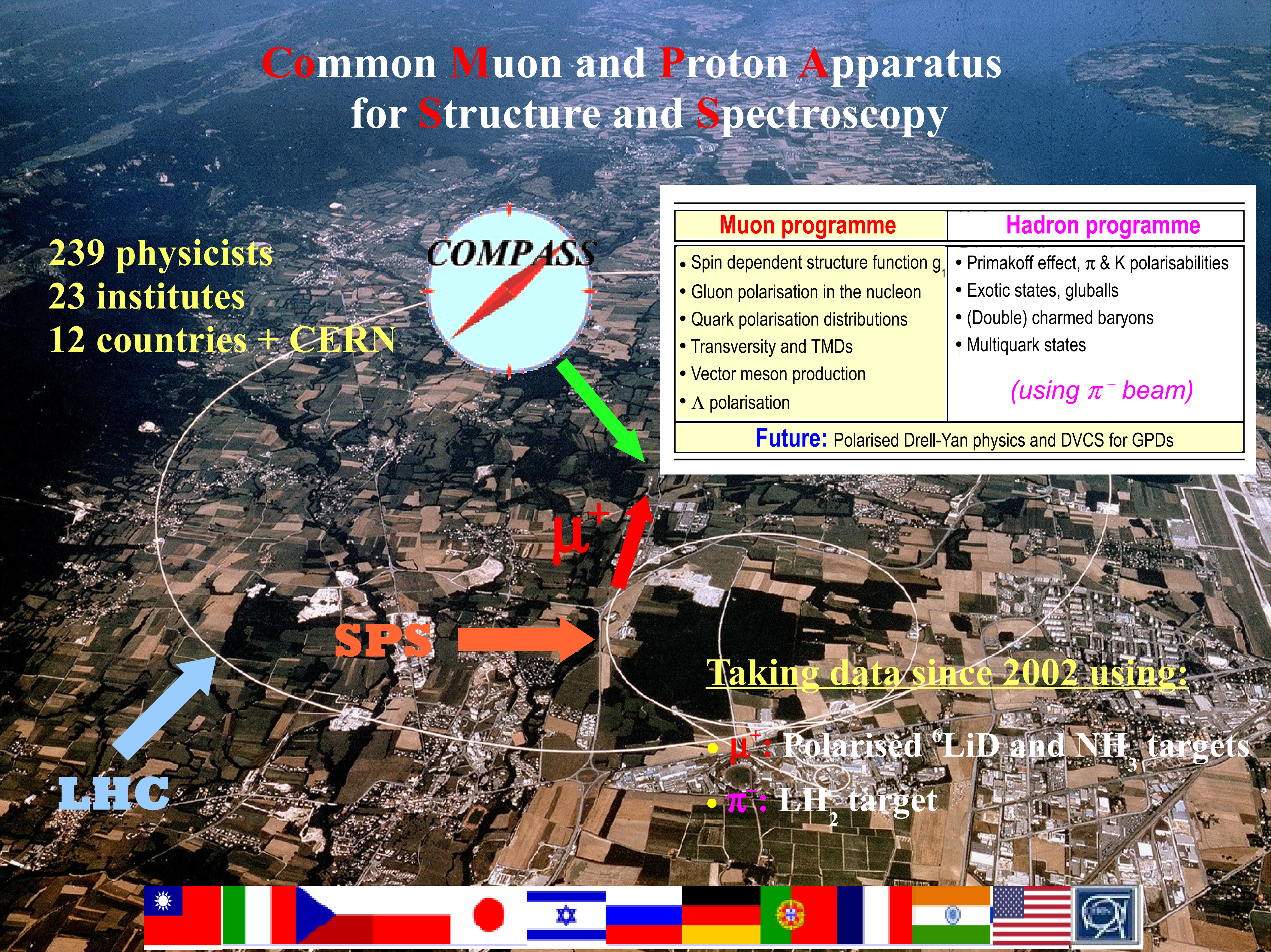


Generalized Parton Distributions



Common Muon and Proton Apparatus for Structure and Spectroscopy

239 physicists
23 institutes
12 countries + CERN

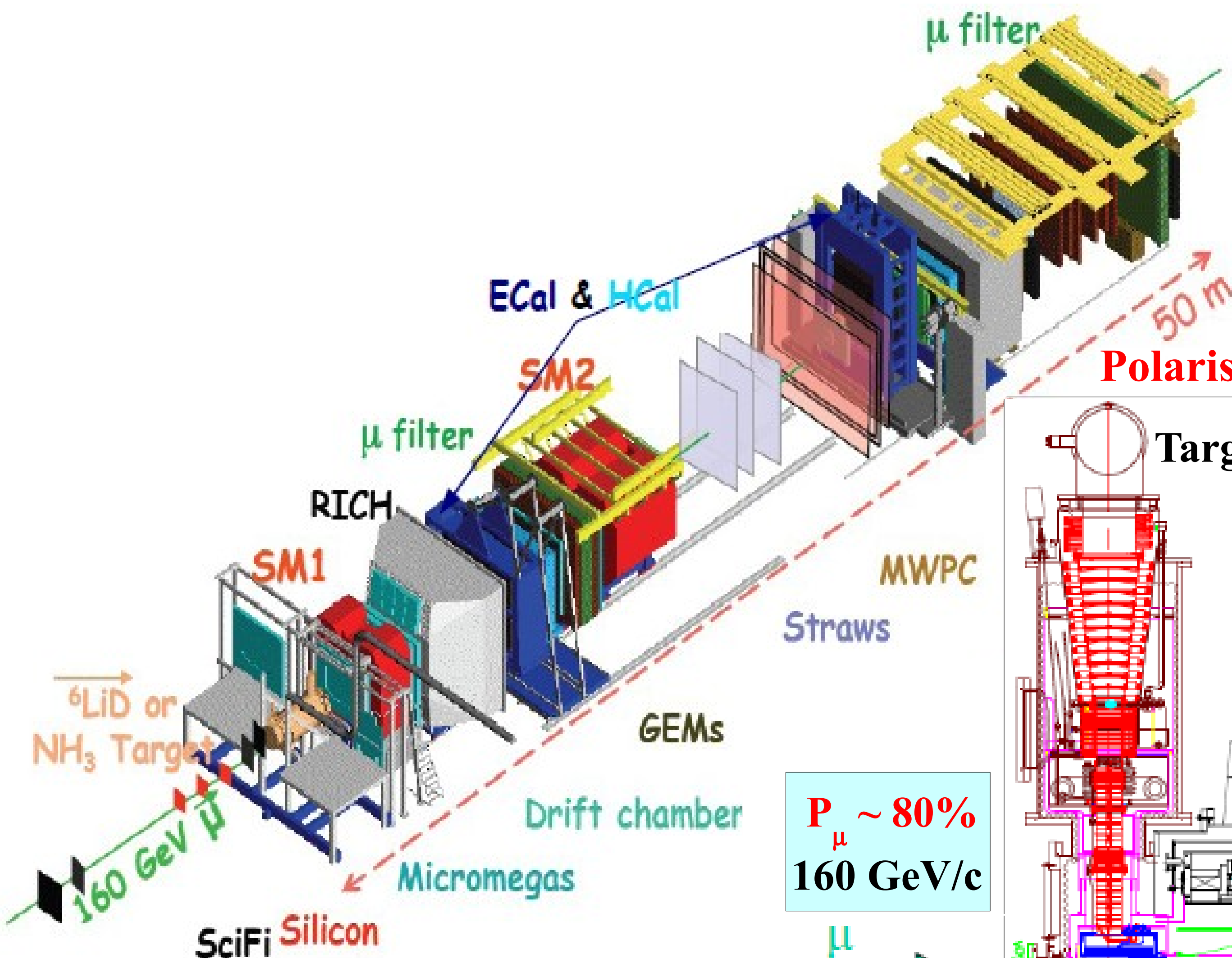


Muon programme	Hadron programme
• Spin dependent structure function g_1 • Gluon polarisation in the nucleon • Quark polarisation distributions • Transversity and TMDs • Vector meson production • Λ polarisation	• Primakoff effect, π & K polarisabilities • Exotic states, glueballs • (Double) charmed baryons • Multiquark states *(using π^- beam)*
Future: Polarised Drell-Yan physics and DVCS for GPDs	

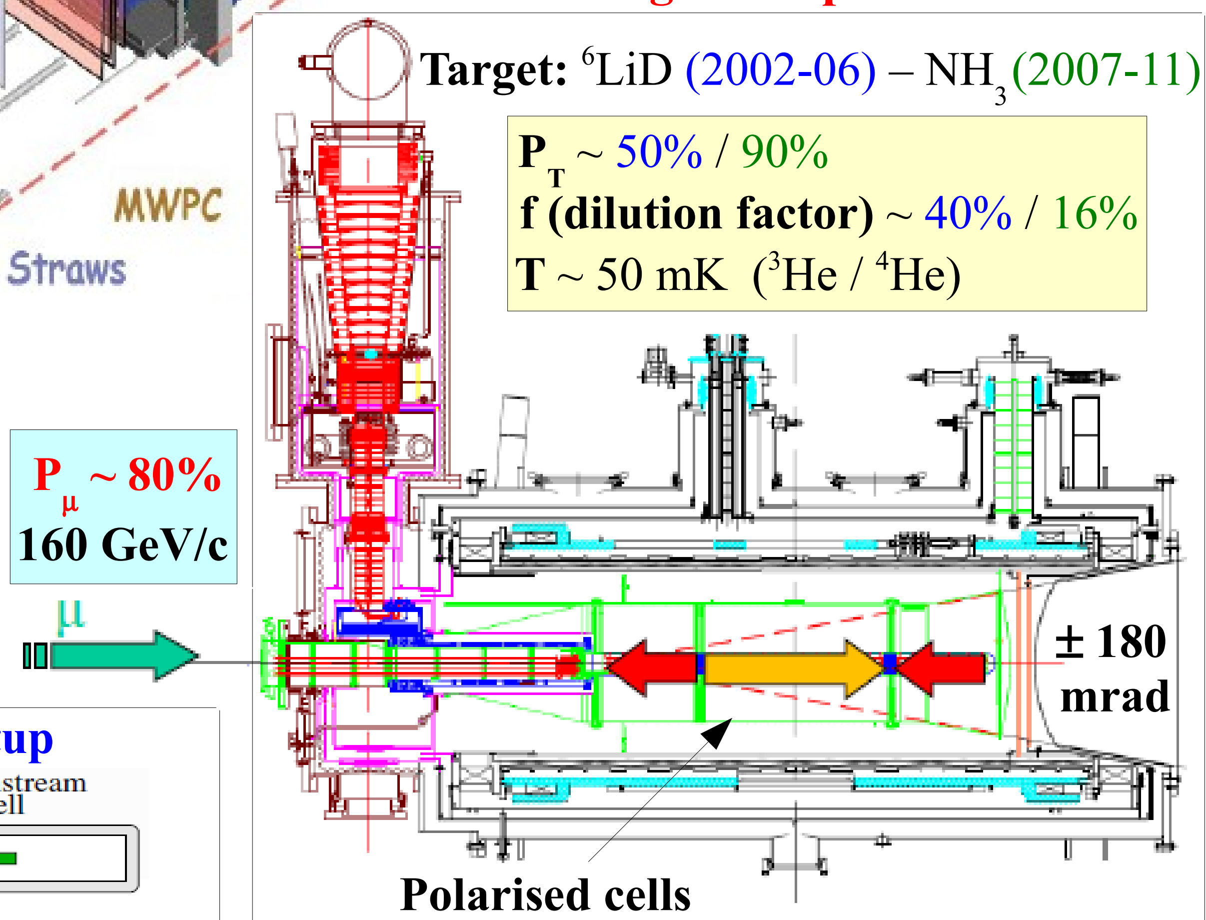
Taking data since 2002 using:

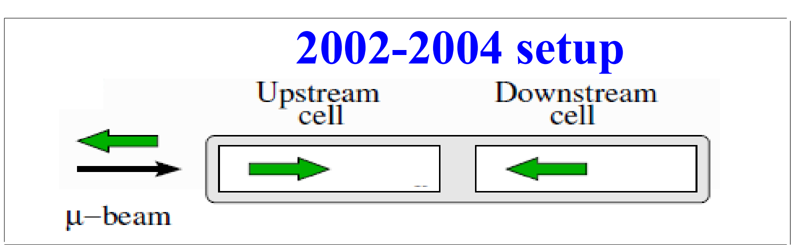
- μ^+: Polarised ^{6}LiD and NH_3 targets
- π^-: LH_2 target

The spectrometer and polarised (longitudinal example) target



Polarised Target Setup: 2006 onwards





Leading Order (LO) description of the nucleon structure

(when the intrinsic transverse momentum of quarks, k_T, is also taken into account)

<u>8 TMD PDFs</u> are required:

Nucleon \ Quark	Unpolarised	Longitudinal Polarisation	Transverse Polarisation
Unpolarised	f_1 *(Number density)*		$h_1^{\perp}$ *(Boer Mulders)*
Longitudinal Polarisation		g_1 *(Helicity)*	$h_{1L}^{\perp}$ *(Worm Gear)*
Transverse Polarisation	$f_{1T}^{\perp}$ *(Sivers)*	g_{1T} *(Worm Gear)*	h_1 / $h_{1T}^{\perp}$ *(Pretzelosity)*

Study q(x, Q^2) and g(x, Q^2)

Study Δq(x, Q^2) and Δg(x, Q^2)

(Transversity)

Study Δ_Tq(x, Q^2)

Surviving k_T integration

$$\Phi^{Tw-2}_{Coll}(x) = \frac{1}{2}\left\{q(x) + S_L\gamma_5\Delta q(x) + S_L\gamma_5\gamma^1\Delta_T q(x)\right\}$$

Contain information about the Orbital Angular Momentum (OAM) of quarks

Investigated at COMPASS <u>via measurement of spin asymmetries</u>

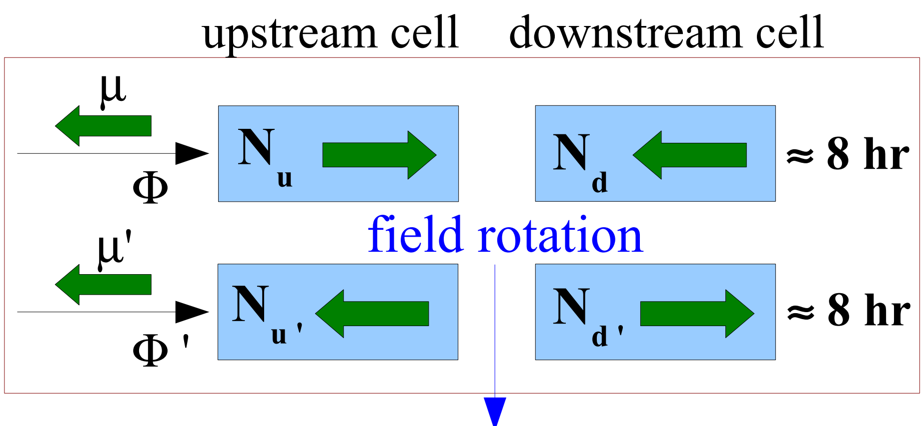
COMPASS results with a longitudinally polarised target

Asymmetry measurement (example): $A_1^N := \frac{\Delta\sigma_{\gamma^*N}}{\sigma_{\gamma^*N}} = \frac{\left(\sigma^{\rightleftarrows}_{\gamma^*N} - \sigma^{\leftleftarrows}_{\gamma^*N}\right)}{\sigma^{\text{unpol}}_{\gamma^*N}}$

- **The number of reconstructed events inside each spin configuration of the target,** N_t (t = u, d, u', d'), **can be used to extract the inclusive A_1^d / A_1^p asymmetries:**

$$A^{\exp} = \frac{1}{2}\left(\frac{N_u - N_d}{N_u + N_d} + \frac{N_{d'} - N_{u'}}{N_{d'} + N_{u'}}\right) = f \cdot P_\mu \cdot P_T \cdot D \cdot A_1 \longrightarrow A^{\mu N}$$

D = Depolarisation factor



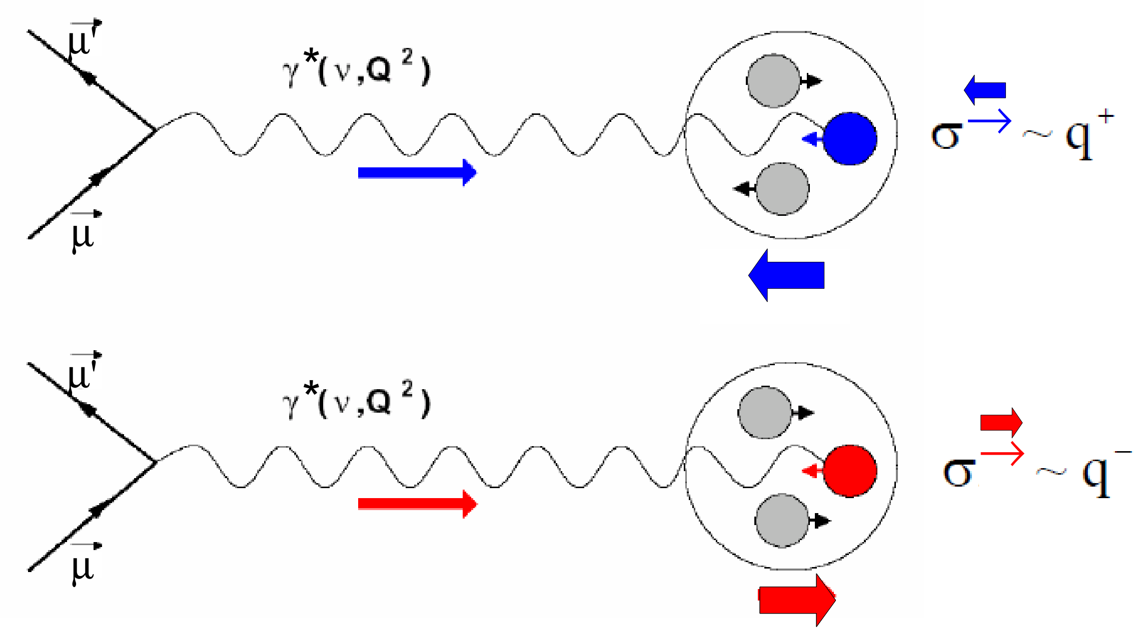
equal acceptance for both cells

- **Weighting each event with $\omega = (fP_\mu D)$:**

$$A_1 = \frac{1}{2P_T}\left(\frac{\sum_{i=0}^{N_u}\omega_i - \sum_{i=0}^{N_d}\omega_i}{\sum_{i=0}^{N_u}\omega_i^2 + \sum_{i=0}^{N_d}\omega_i^2} + \frac{\sum_{i=0}^{N_{u'}}\omega_i - \sum_{i=0}^{N_{d'}}\omega_i}{\sum_{i=0}^{N_{u'}}\omega_i^2 + \sum_{i=0}^{N_{d'}}\omega_i^2}\right)$$

statistical gain: $\frac{\left\langle \sum_{i=0}^{N_{tot}} \omega_i^2 \right\rangle}{\left\langle \sum_{i=0}^{N_{tot}} \omega_i \right\rangle^2}$

Interpretation of A_1 in terms of structure functions



$$\Delta q(x) = q(x)^+ - q(x)^-$$

$$q(x) = q(x)^+ + q(x)^-$$

+ quark ↑⬆ nucleon

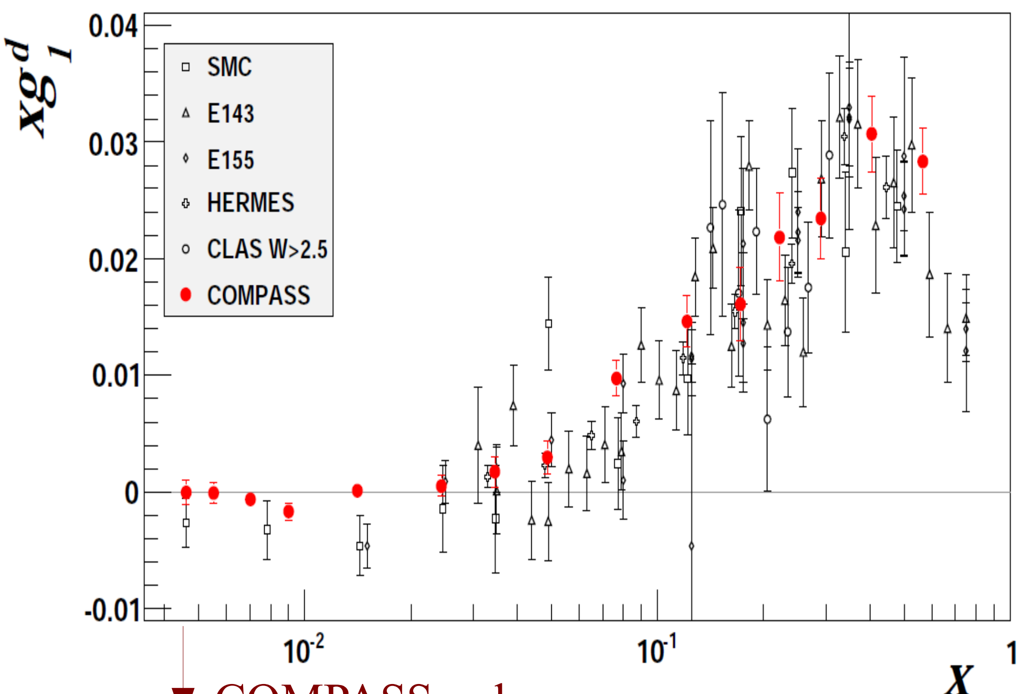
– quark ↑⬇ nucleon

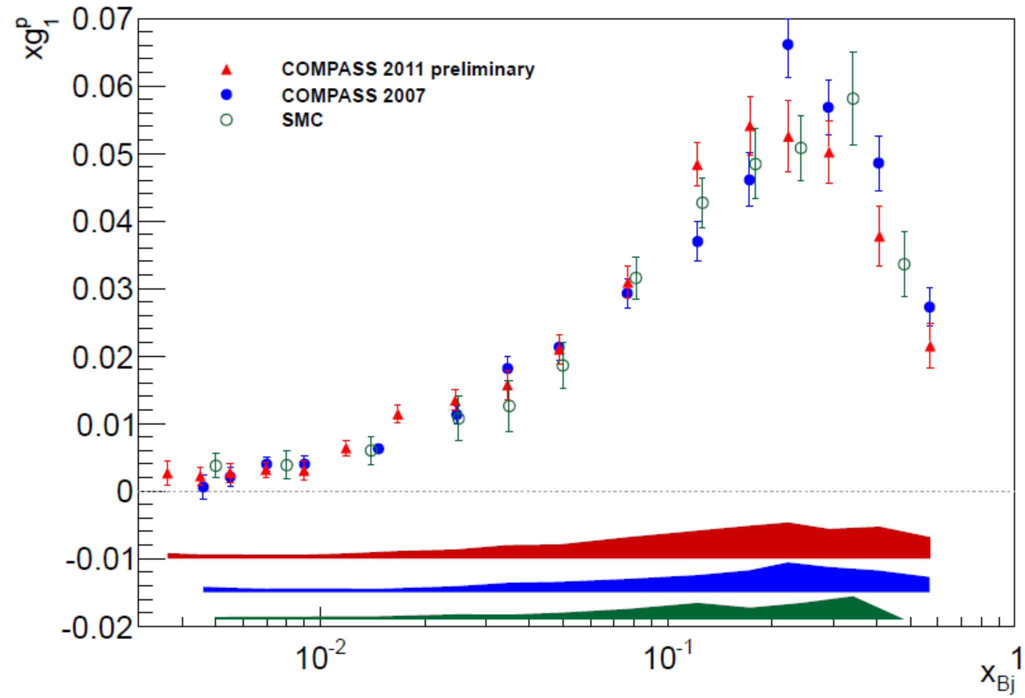
$$A_1(x,Q^2) = \frac{\sigma_{\gamma^* N}^{\overleftarrow{\rightarrow}} - \sigma_{\gamma^* N}^{\overrightarrow{\rightarrow}}}{\sigma_{\gamma^* N}} \approx \frac{\sum_q e_q^2 \Delta q(x,Q^2)}{\sum_q e_q^2 q(x,Q^2)} = \frac{g_1(x,Q^2)}{F_1(x,Q^2)} = \frac{g_1(x,Q^2)\, 2x(1+R)}{F_2(x,Q^2)}$$

- g_1 (polarised structure function) **is obtained from the measured A_1 using:**

$F_2 \rightarrow$ SMC parameterisation and $R = \sigma^L/\sigma^T \rightarrow$ SLAC parameterisation

COMPASS results for $g_1^{d/p}$ and first moments of g_1^d





COMPASS only

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

$$= \frac{1}{9}\left(1 - \frac{\alpha_s(Q^2)}{\pi} + O(\alpha_s^2)\right)\left(a_0(Q^2) + \frac{1}{4}a_8\right) \quad \Rightarrow \quad a_0 = 0.35 \pm 0.03(\mathbf{stat}) \pm 0.05(\mathbf{syst})$$

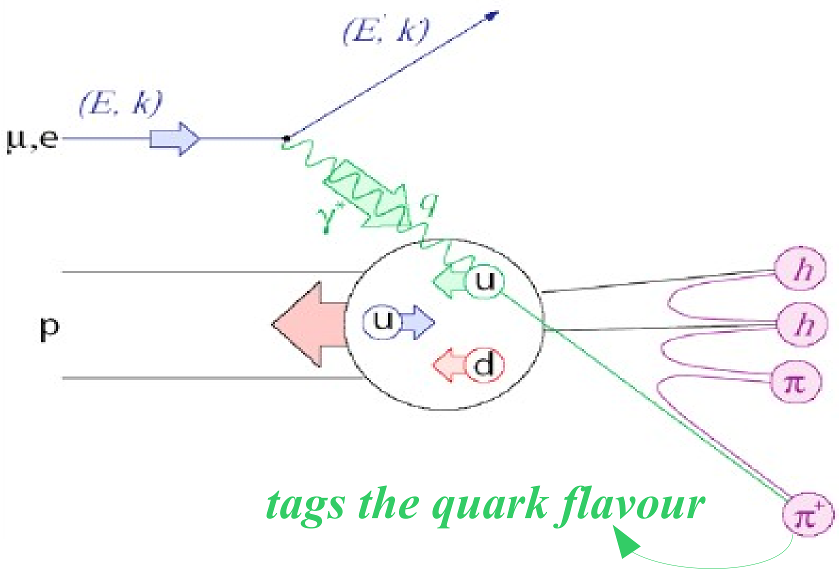
$$\Delta\Sigma^{\overline{MS}} = 0.33 \pm 0.03(\mathbf{stat}) \pm 0.05(\mathbf{syst}) \qquad (\Delta\Sigma^{\overline{MS}} = a_0 \ @Q^2 \to \infty)$$

$$= 0.30 \pm 0.01(\mathbf{stat}) \pm 0.02(\mathbf{syst})$$

(using world data on p, n, d)

$$(\Delta s + \Delta\bar{s}) = \frac{1}{3}(\Delta\Sigma^{\overline{MS}} - a_8) = -0.08 \pm 0.01(\mathbf{stat}) \pm 0.02(\mathbf{syst})$$

Extraction of the quark helicity distributions from Semi-Inclusive DIS (SIDIS)



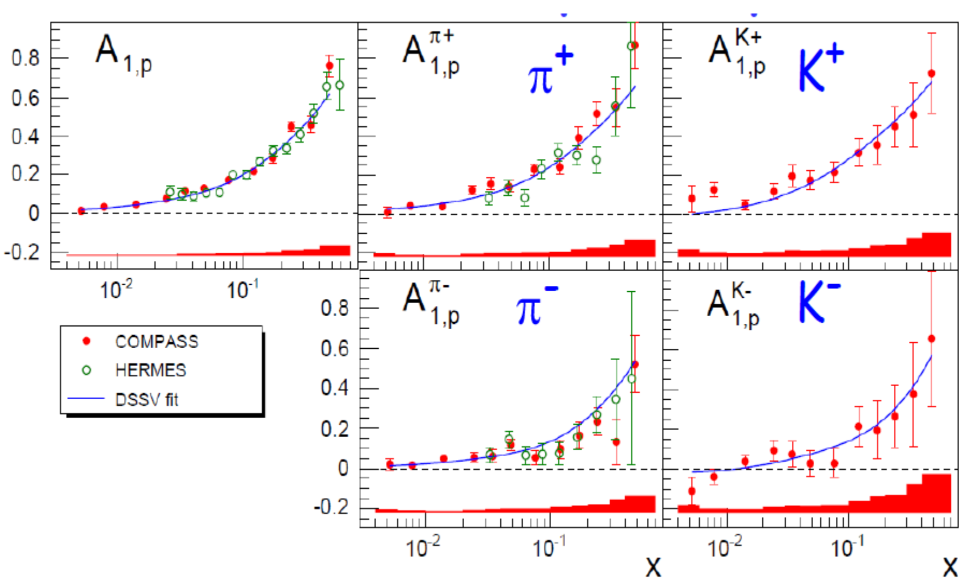
- **We have at Leading Order *(LO)* in QCD :**

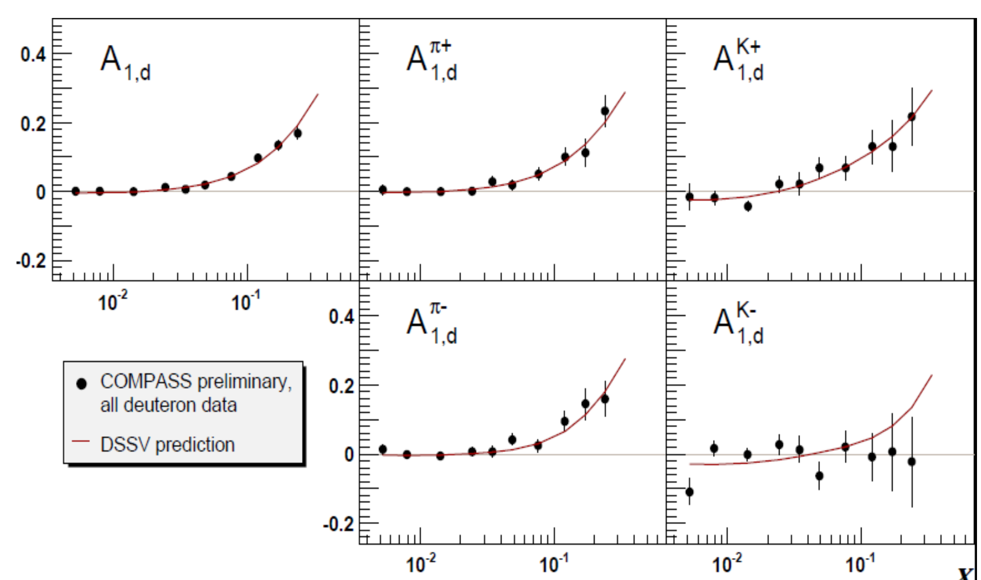
$$A^{h}_{1,(p/d)}(x,z,Q^2) \approx \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}$$

– Unpolarised PDFs ($q(x, Q^2)$) → MRST04

– Fragmentation function of a quark to a hadron ($D_q^h(z, Q^2)$) → DSS parameterisation

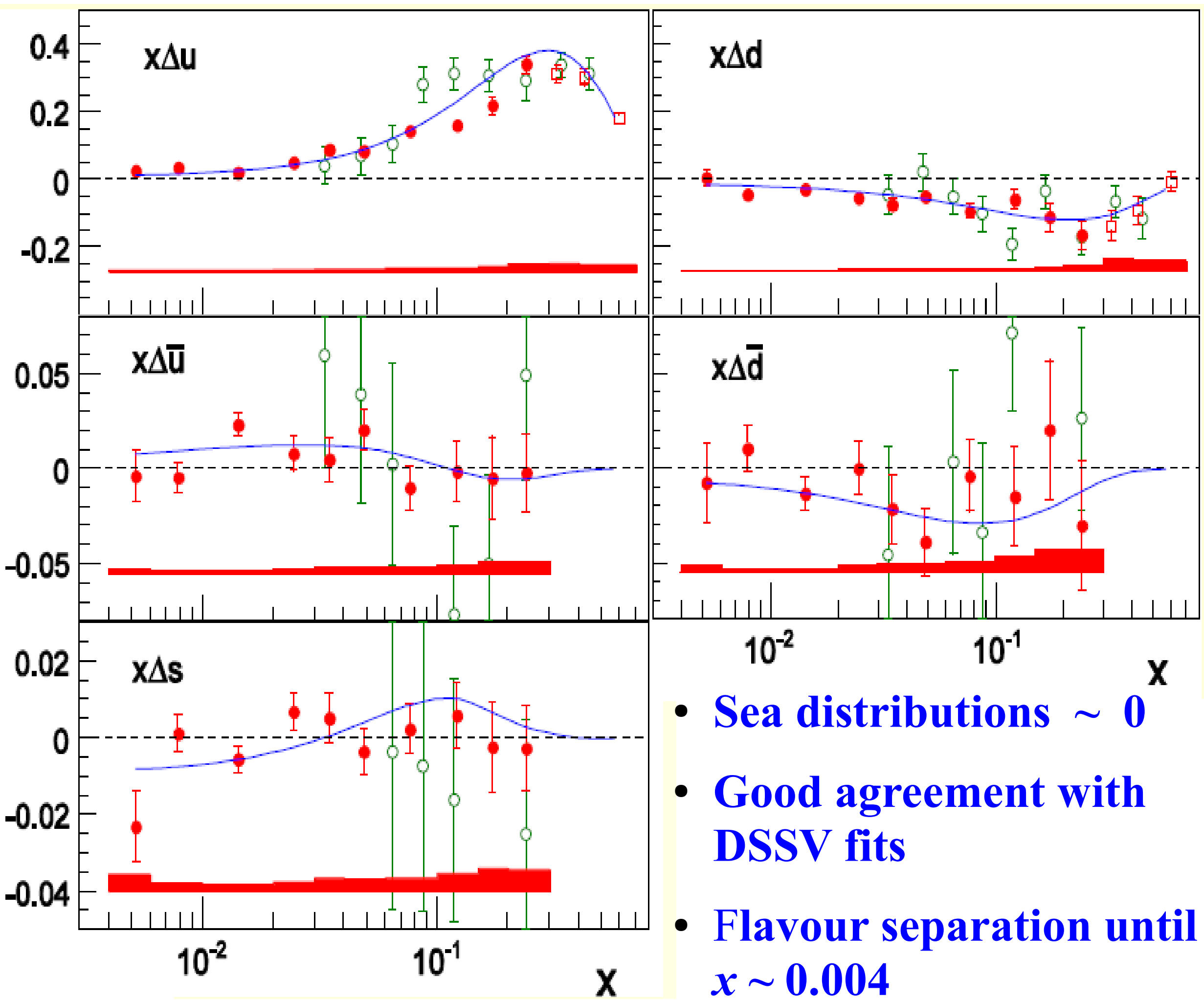
- **Results for $A^{h}_{1,(p/d)}$** (allows the separate extraction of Δu, Δd, $\Delta \bar{u}$, $\Delta \bar{d}$, Δs and $\Delta \bar{s}$):





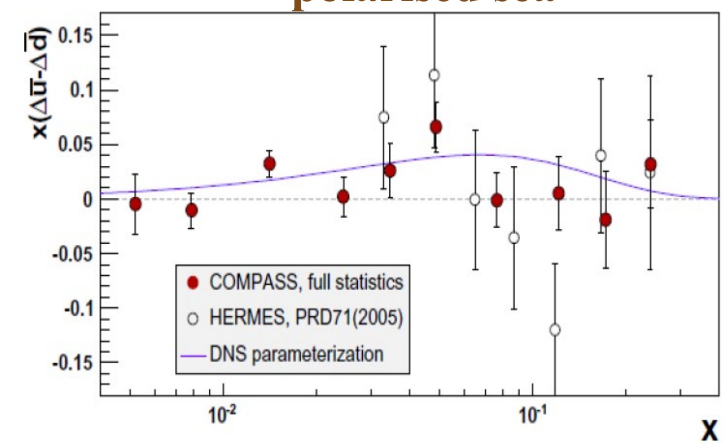
Quark helicities from SIDIS: $Q^2 = 3\ (\mathrm{GeV}/c)^2$ and $x < 0.3$

● COMPASS PLB693(2010)227, ○ HERMES, — DSSV

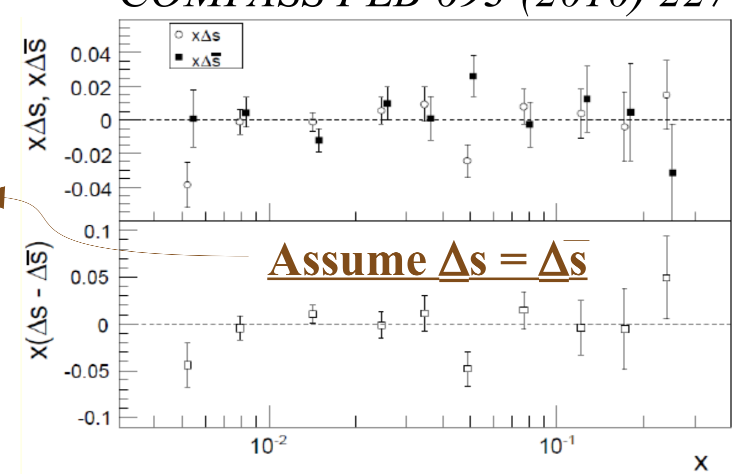


- Sea distributions ~ 0
- Good agreement with DSSV fits
- Flavour separation until $x \sim 0.004$

No flavor asymmetry in the polarised sea



COMPASS PLB 693 (2010) 227



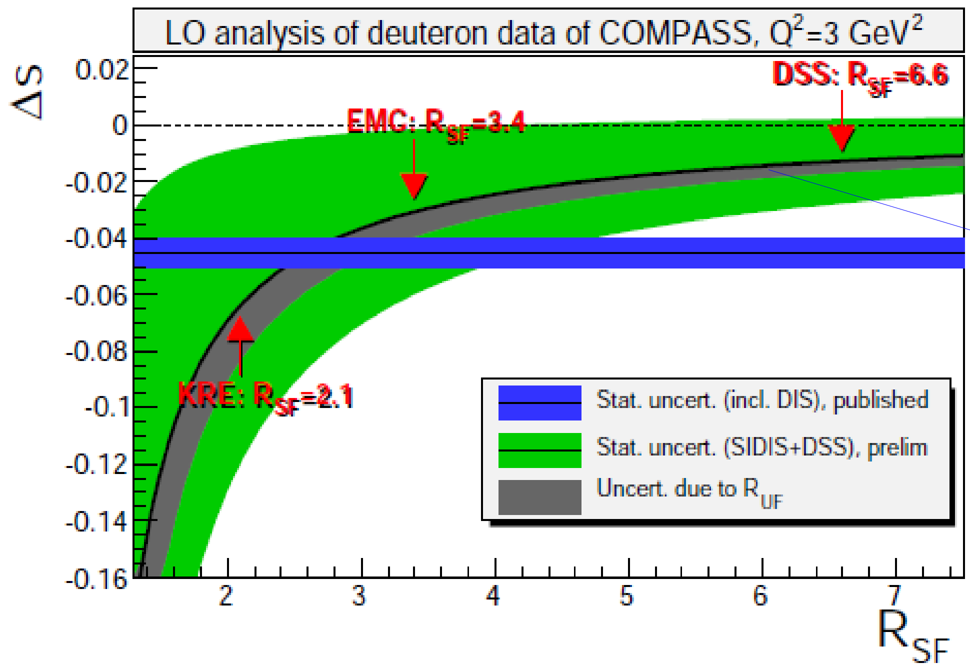
Assume $\Delta s = \Delta\bar{s}$

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

Δs dependence on Fragmentation Functions (FFs)

- The relation between the semi-inclusive asymmetries and Δs depends only on the following ratios:

$$R_{UF} = \frac{\int_{0.2}^{0.85} D_d^{K^+}(z)\,dz}{\int_{0.2}^{0.85} D_u^{K^+}(z)\,dz}, \quad R_{SF} = \frac{\int_{0.2}^{0.85} D_{\bar{s}}^{K^+}(z)\,dz}{\int_{0.2}^{0.85} D_u^{K^+}(z)\,dz}$$



R_{UF} is varied linearly from 0.13 (DSS) at R_{SF} = 6.6 to 0.35 (EMC) at R_{SF} = 3.4 (to maintain constant the K^+ multiplicity)

- Determination of R_{SF} from hadron multiplicities on the way

A first look on hadron multiplicities

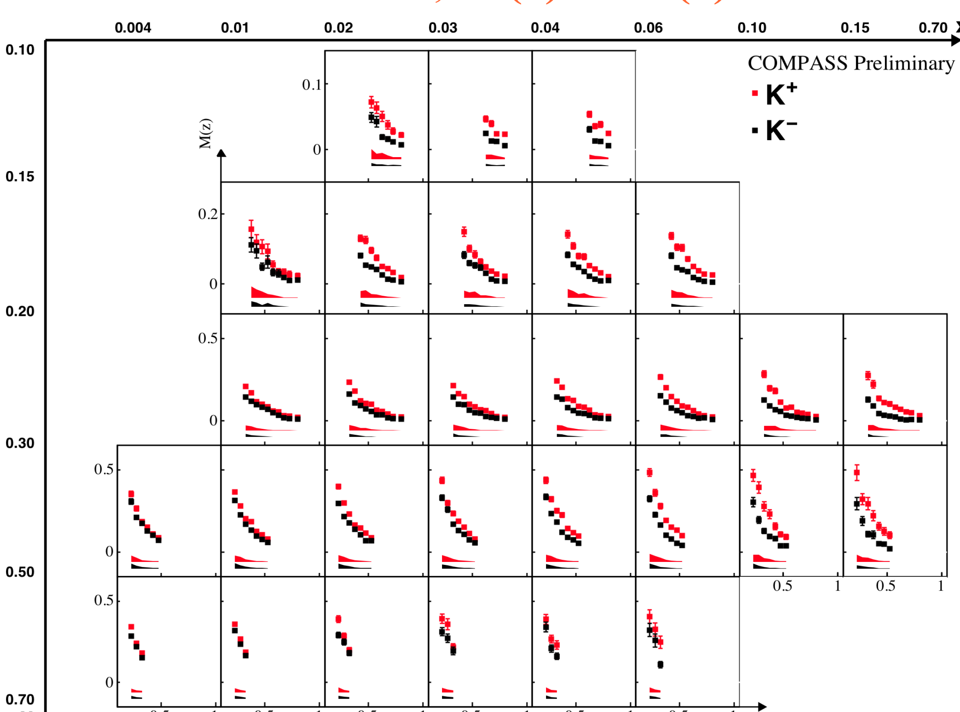
- **Assuming the quark parton model** (leading order)**:**

PDF **FF**

$$\frac{dM^h(x,Q^2,z)}{dz} = \frac{\sum_q e_q^2 f_q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 f_q(x,Q^2)} = \frac{\text{hadron yields}}{\text{DIS events yields}}$$

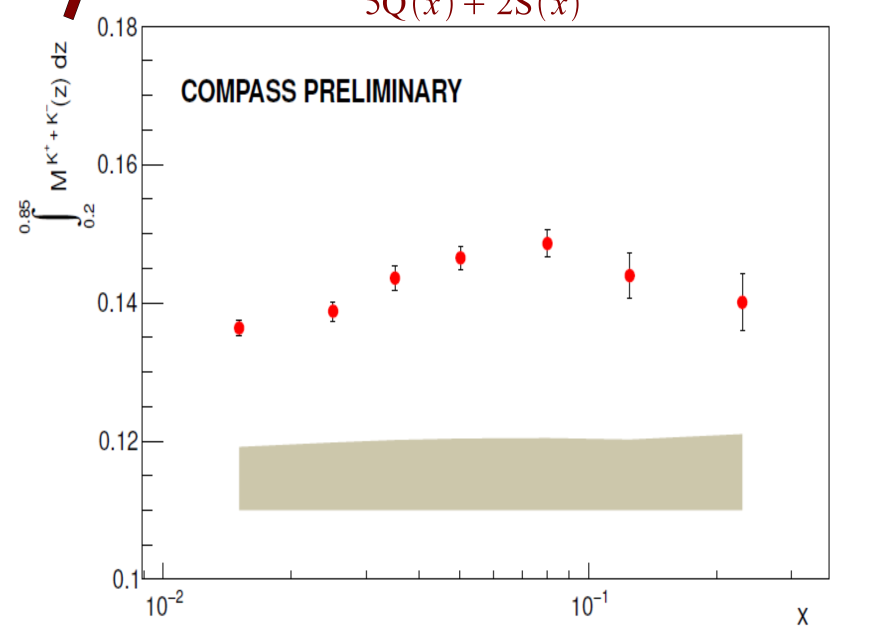
Experimental definition

Data can be used to improve our knowledge on **FFs**, **Δs(x)** and **s(x)**



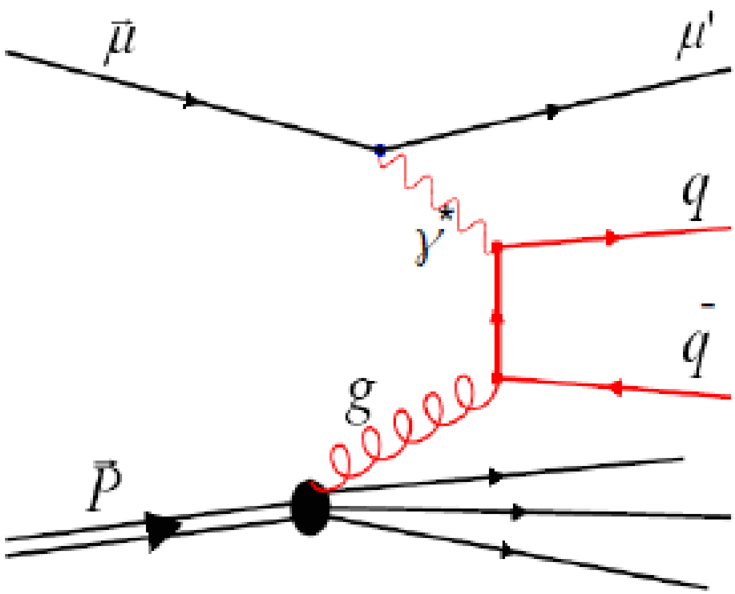
s (x) + $\bar{s}$ (x)

$$\frac{Q(x)\int(4D_u^K(z)+6D_d^K(z))dz + S(x)\int(2D_{\bar{s}}^K(z)+2D_d^K(z))dz}{5Q(x)+2S(x)}$$



Direct measurement of Δg/g at LO in QCD

photon-gluon fusion process (PGF)



$$A_{\mu N}^{PGF} = \frac{\int d\hat{s}\,\Delta\sigma^{PGF}\,\Delta g(x_g,\hat{s})}{\int d\hat{s}\,\sigma^{PGF}\,g(x_g,\hat{s})} \approx \langle a_{LL}^{PGF} \rangle \frac{\Delta g}{g}$$

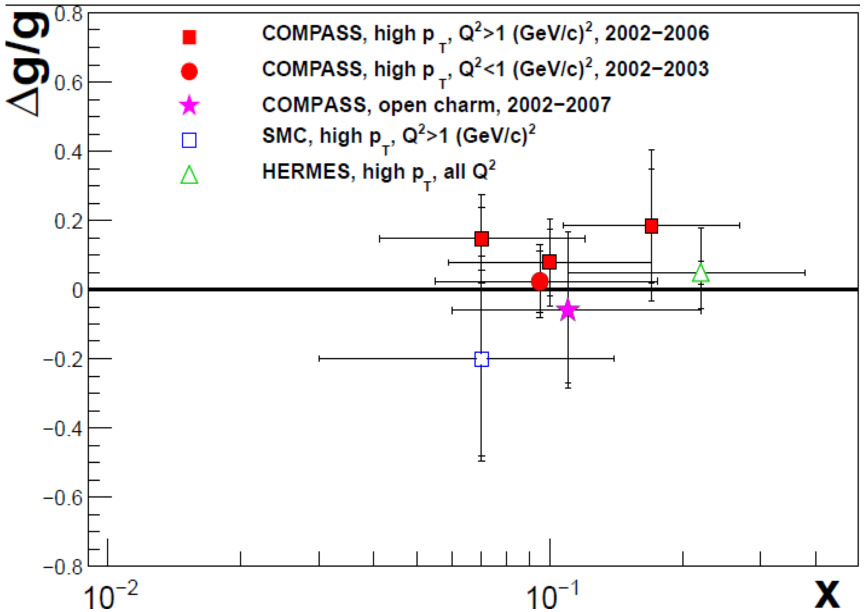
Obtained from Monte Carlo and parameterised by a Neural Network (to be used on data)

There are two methods to tag this process:

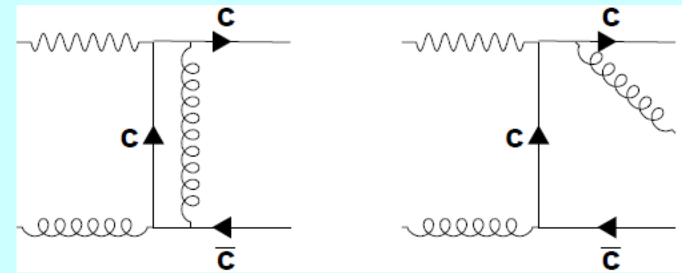
- **Open Charm production**
  - $\gamma^* g \rightarrow c\bar{c} \quad \Rightarrow$ reconstruct D^0 mesons
  - Hard scale: M_c^2
  - No intrinsic charm in COMPASS kinematics
  - No physical background
  - Weakly model dependent
  - Low statistics
- **High-p_T hadron pairs**
  - $\gamma^* g \rightarrow q\bar{q} \quad \Rightarrow$ reconstruct 2 jets or h^+h^-
  - Hard scale: Q^2 or Σp_T^2 [$Q^2 > 1$ or $Q^2 < 1$ $(GeV/c)^2$]
  - High statistics
  - Physical background
  - Strongly model dependent

Results on Δg/g and xΔg

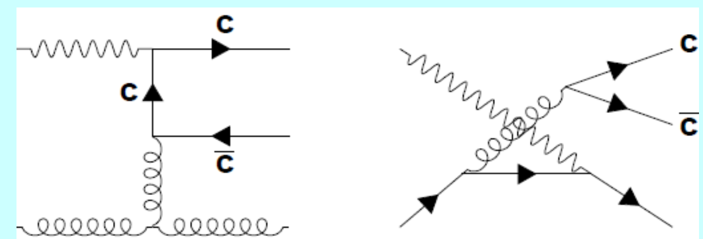
World data at LO

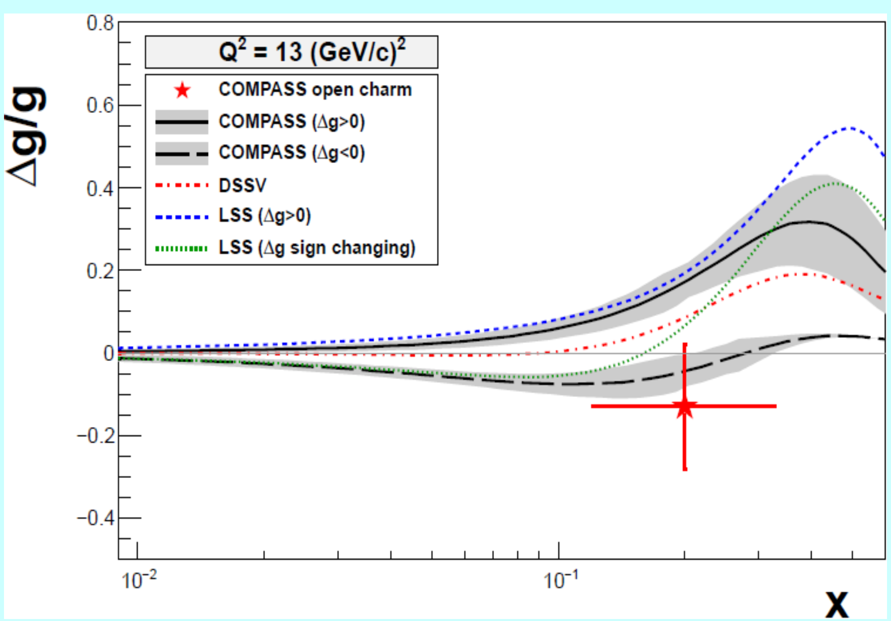


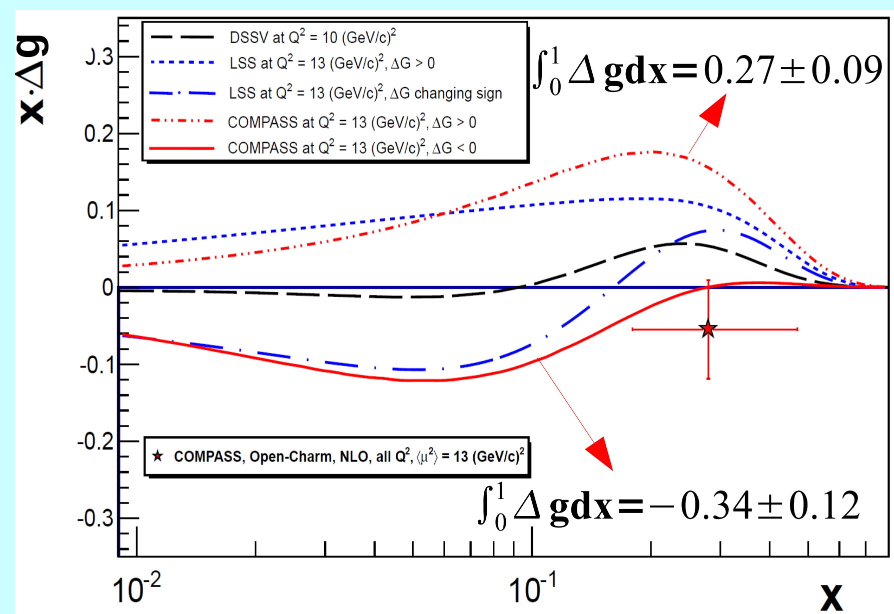
COMPASS Open-Charm at NLO



Example of NLO diagrams







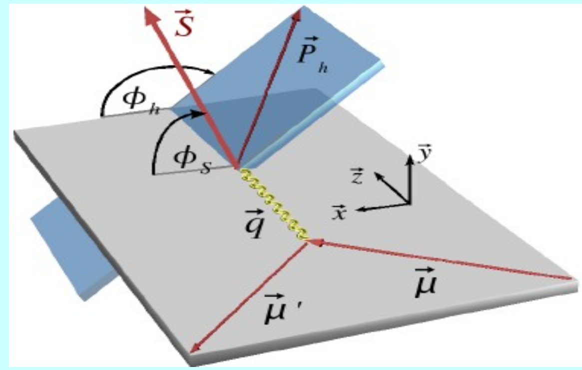
COMPASS results with a transversely polarised target

Interpretation of Collins & Sivers asymmetries in terms of TMDs

Studies from SIDIS

Depends on spin!

$$A_{Coll} \approx \frac{\sum_q e_q^2\, h_1^q \otimes H_{1q}^{\perp h}}{\sum_q e_q^2\, f_1^q \otimes D_{1q}^h}$$



$$A_{Siv} \approx \frac{\sum_q e_q^2\, f_{1T}^{\perp q} \otimes D_{1q}^h}{\sum_q e_q^2\, f_1^q \otimes D_{1q}^h}$$

measured by fitting the corresponding (ϕ_h, ϕ_S) distributions *(from σ^{SIDIS})* in different x, z, p_T^h bins

Collins Angle

$\sin(\Phi_h + \Phi_S)$

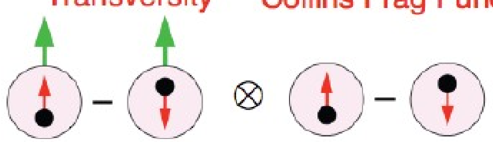
Angle of hadron / initial quark spin

The "Collins Effect"

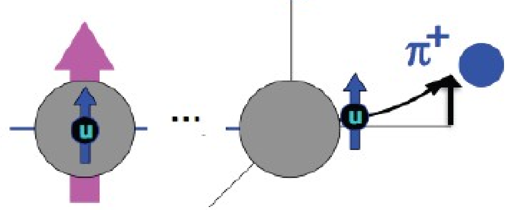
$h_1(x) \otimes H_1^\perp(z, p_T)$

Transversity

Collins Frag Func^n



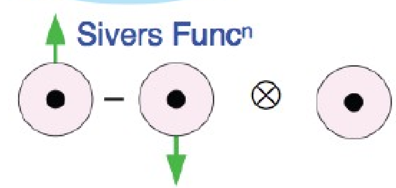
sensitive to ***transversity*** *and* ***spin-orbit*** *effects in* ***fragmentation***



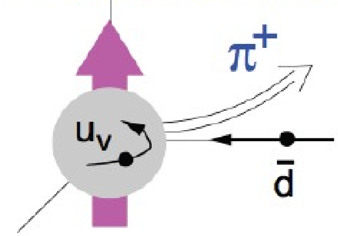
The "Sivers Effect"

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

Sivers Func^n



sensitive to ***quark orbital motion***



Sivers Angle

$\sin(\Phi_h - \Phi_S)$

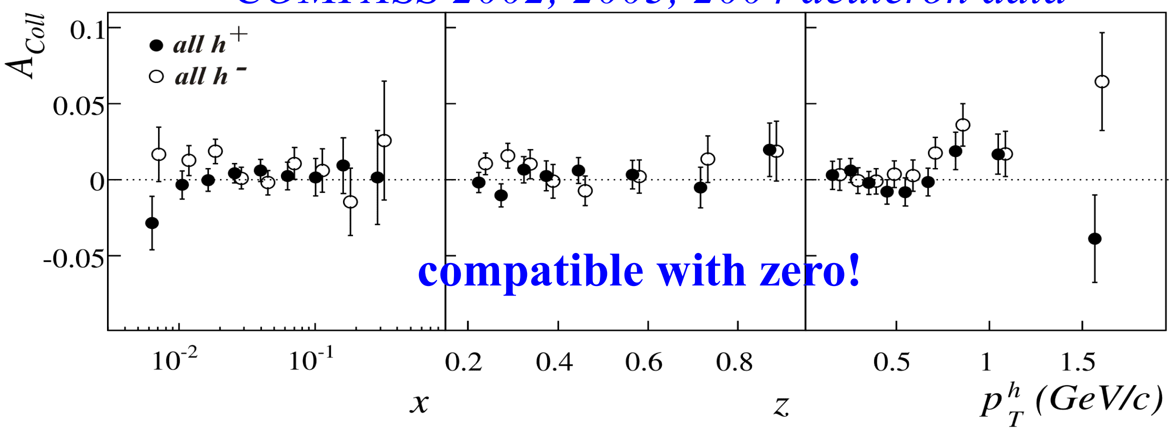
Angle of hadron / final quark spin

$\otimes$ denotes **convolution** over intrinsic quark k_T & fragmentation p_T

Results on the Collins asymmetry

(correlation between the hadron p_T & the quark transverse spin in a transversely polarised nucleon)

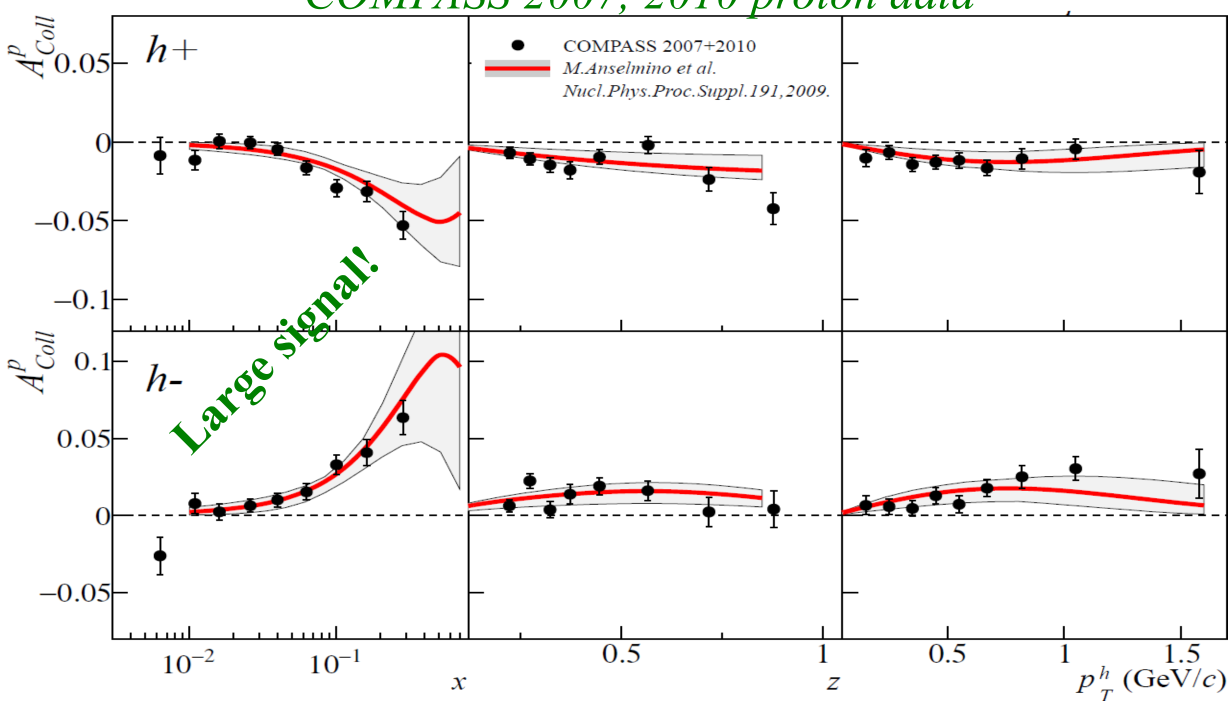
COMPASS 2002, 2003, 2004 deuteron data



Understood as:

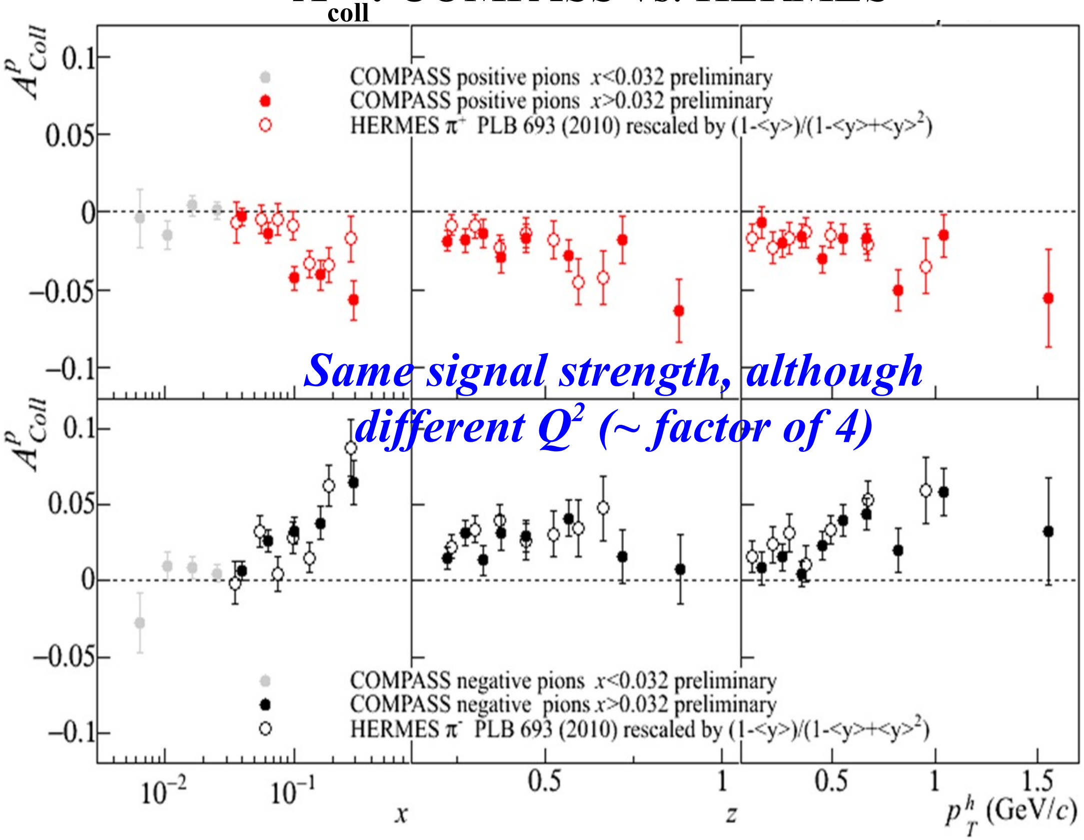
- u - d cancellation
- favored/unfavored Collins FF

COMPASS 2007, 2010 proton data



Transversity from Collins asymmetry

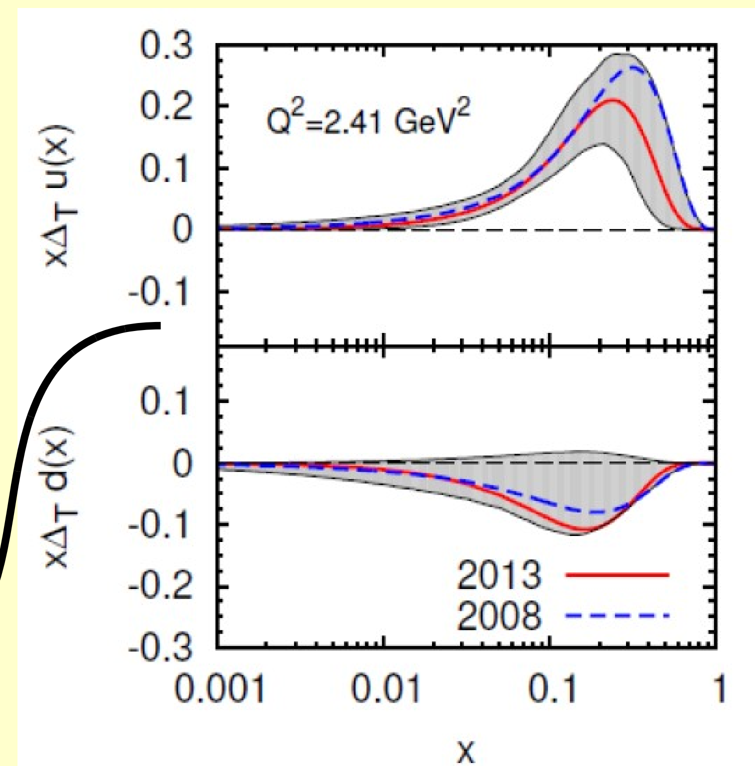
A^{p}_{coll}: COMPASS vs. HERMES



Same signal strength, although different Q^2 (~ factor of 4)

- Combined analysis of **HERMES-proton**, **COMPASS-deuteron** and **BELLE FF** data:

M. Anselmino et al. arXiv:0812.4366

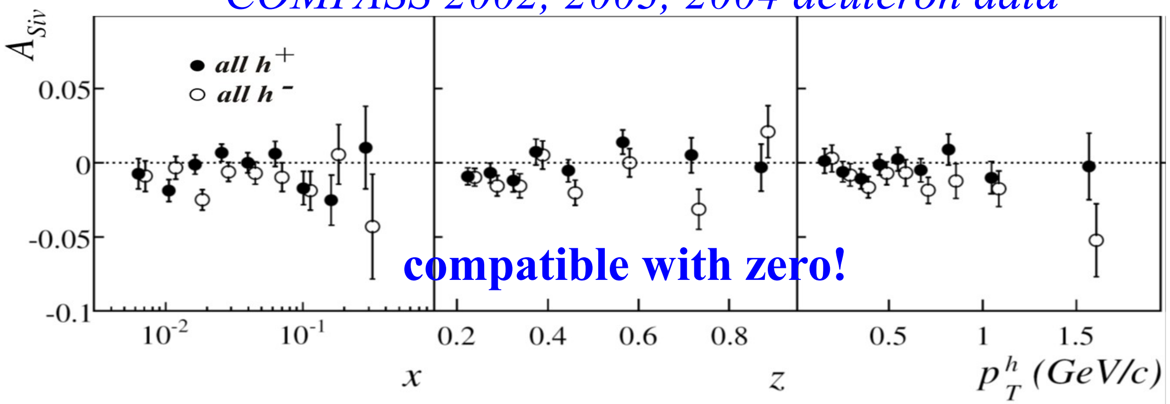


- **$\Delta_T u > 0$ and $\Delta_T d < 0$**
  (u quark transversity along nucleon spin)
- Smaller amplitudes than helicity

Results on the Sivers asymmetry

(correlation between the nucleon transverse spin and the quark k_T)

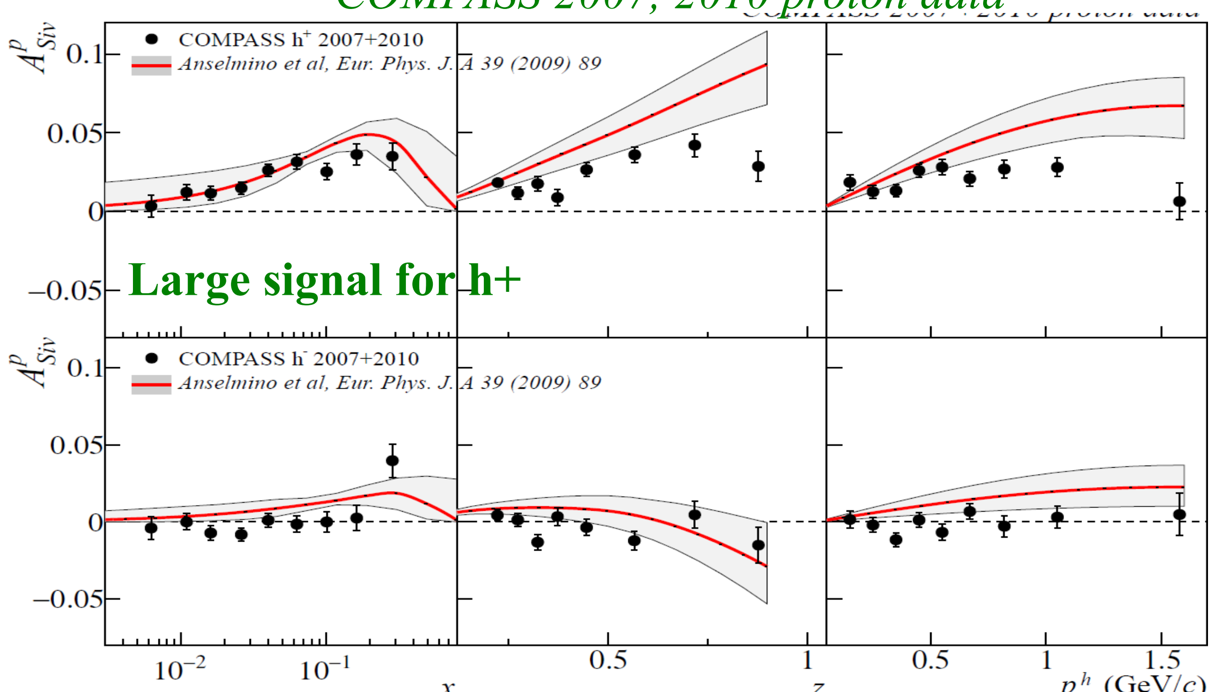
COMPASS 2002, 2003, 2004 deuteron data



Understood as:

- u - d cancellation

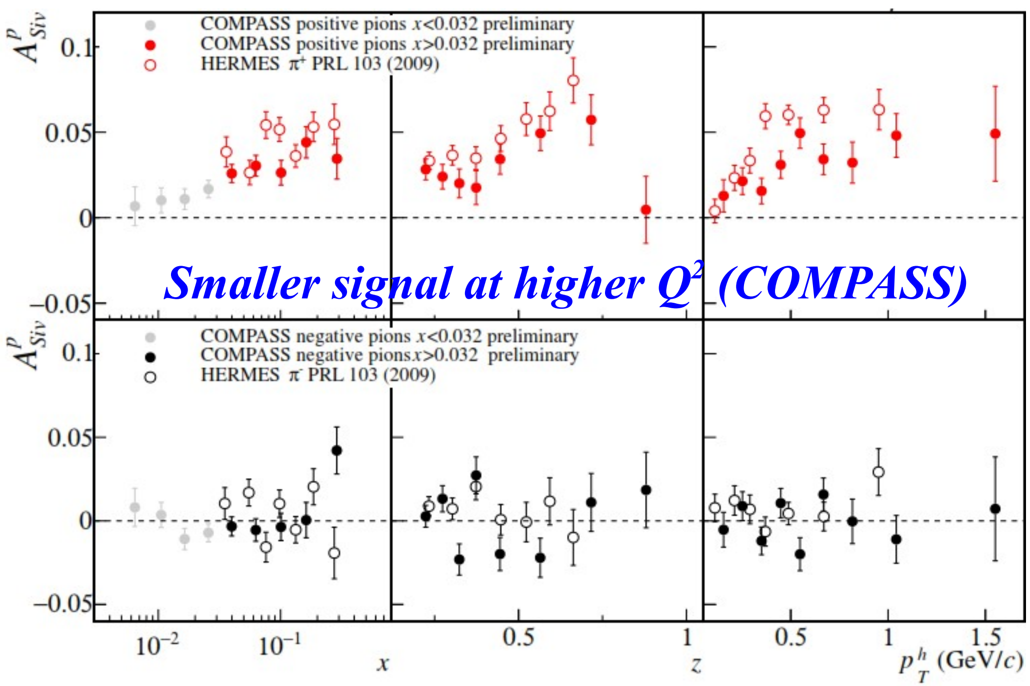
COMPASS 2007, 2010 proton data



Sivers function and Orbital Angular Momentum (OAM)

(Ji sum rule: $J^q = \frac{1}{2}\Delta\Sigma + L^q = \frac{1}{2}\int_0^1 dx\, x\left[H^q(x,0,0) + E^q(x,0,0)\right] = \frac{1}{2} - J^g$)

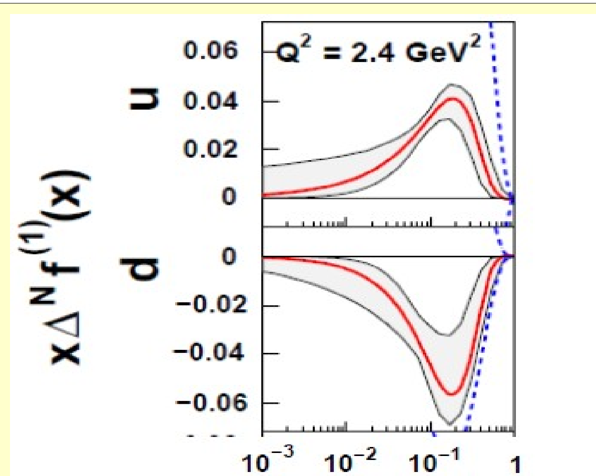
Usual PDF q(x)



Smaller signal at higher Q^2 (COMPASS)

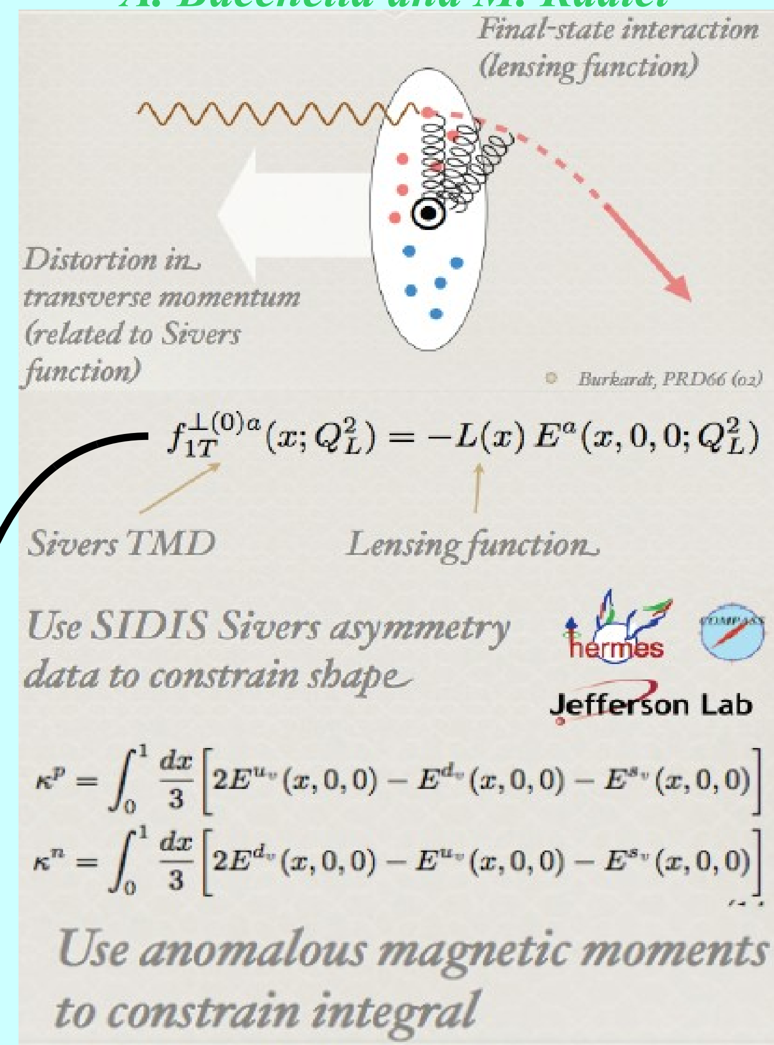
- Combined analysis of **HERMES-p** and **COMPASS-d**:

Sivers TMD



M. Anselmino et al. arXiv:0812.4366

A. Bacchetta and M. Radici

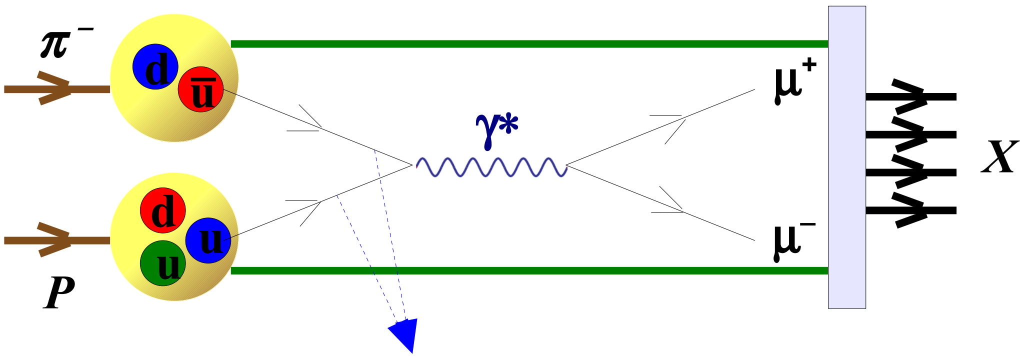


Possibility to estimate the orbital angular momentum from E^q

COMPASS future

COMPASS future I (2015): TMDs from polarised Drell-Yan

DRELL-YAN PROCESS



Large acceptance in the valence region where large single spin asymmetries (SSA) are expected

- **Convolution of 2 TMDs** *(no FF involved):*

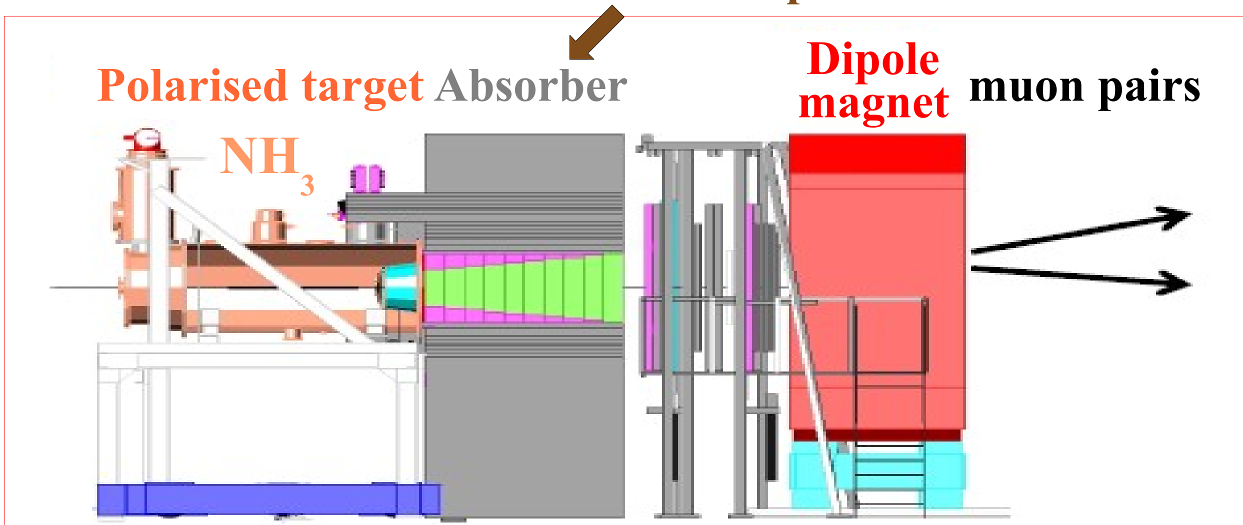
$$\sigma_{DY} \propto f_{\bar{u}/\pi^-} \otimes f'_{u/P}$$

- **Test of the TMD universality factorization approach** *(for the description of SSA)*:

$$f_{1T}^{\perp}\big|_{DY} = -f_{1T}^{\perp}\big|_{DIS} \quad \& \quad h_1^{\perp}\big|_{DY} = -h_1^{\perp}\big|_{DIS}$$

- **Study the production mechanism and the polarisation of *J/Ψ***

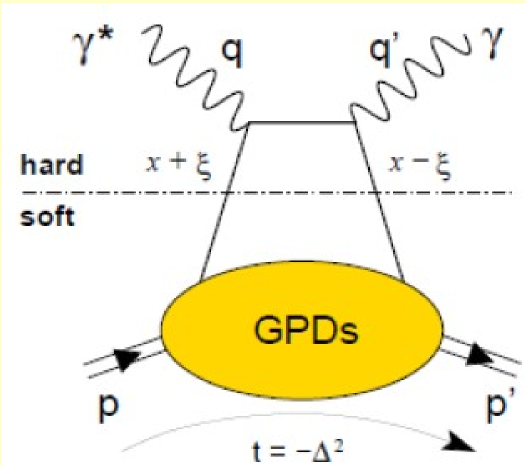
Main modifications in the spectrometer



Clean access to 4 azimuthal modulations

(Boer-Mulders, Sivers, Pretzelosity and Transversity)

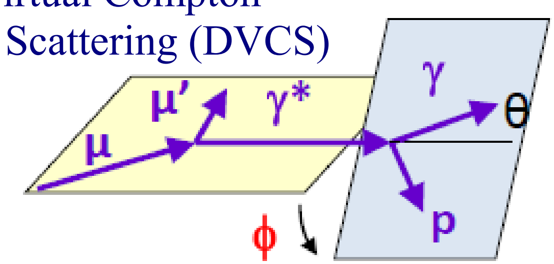
COMPASS future II (2016, 2017): GPDs and nucleon tomography



- **Measurement of 4 generalised parton distributions** *(GPDs)* **for quarks:** H, E, $\tilde{H}$, $\tilde{E}(x, \xi, t)$
  - Contain normal PDF and elastic form factor as limiting cases: $q(x) = H(x,0,0)$ and $F(t) = \int dx\, H(x, \xi, t)$
  - Correlates transverse spatial and longitudinal momentum degrees of freedom *(nucleon tomography)*
  - Access the OAM of quarks via the Ji sum rule

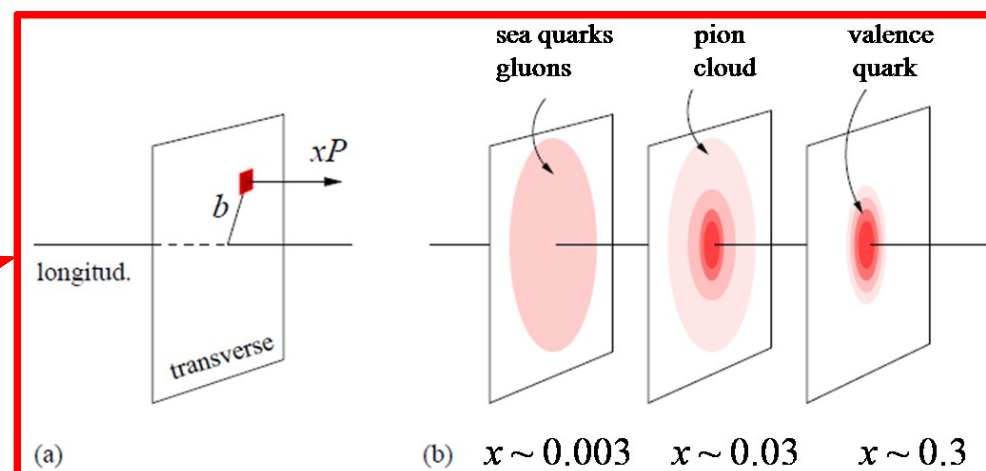
- The GPD ***H*** will be determined by studying the azimuthal dependence of the DVCS cross-section *(combining the data of μ^+ and μ^- beams on a liquid hydrogen target)*:

Deeply Virtual Compton Scattering (DVCS)



- **For the cases of $\xi = 0$, we have a purely transverse $\Delta_\perp^2$:**

Tomography!

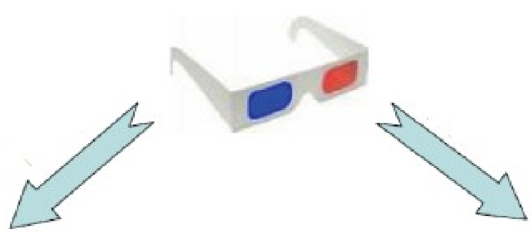


Summary

- **Gluon contribution to the nucleon spin:**
  - All measurements point to zero or small contribution
- **Quark contribution to the nucleon spin:**
  - Extraction for all flavours from SIDIS *(more knowledge on FF is needed for Δs)*
  - A global contribution of 30% was measured with high precision
- **Transversity and TMDs**
  - Precise results on Collins and Sivers asymmetries

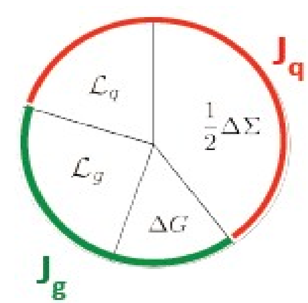
- **Exciting future program in preparation** *(polarised Drell-Yan and DVCS)*:

3D imaging of the nucleon



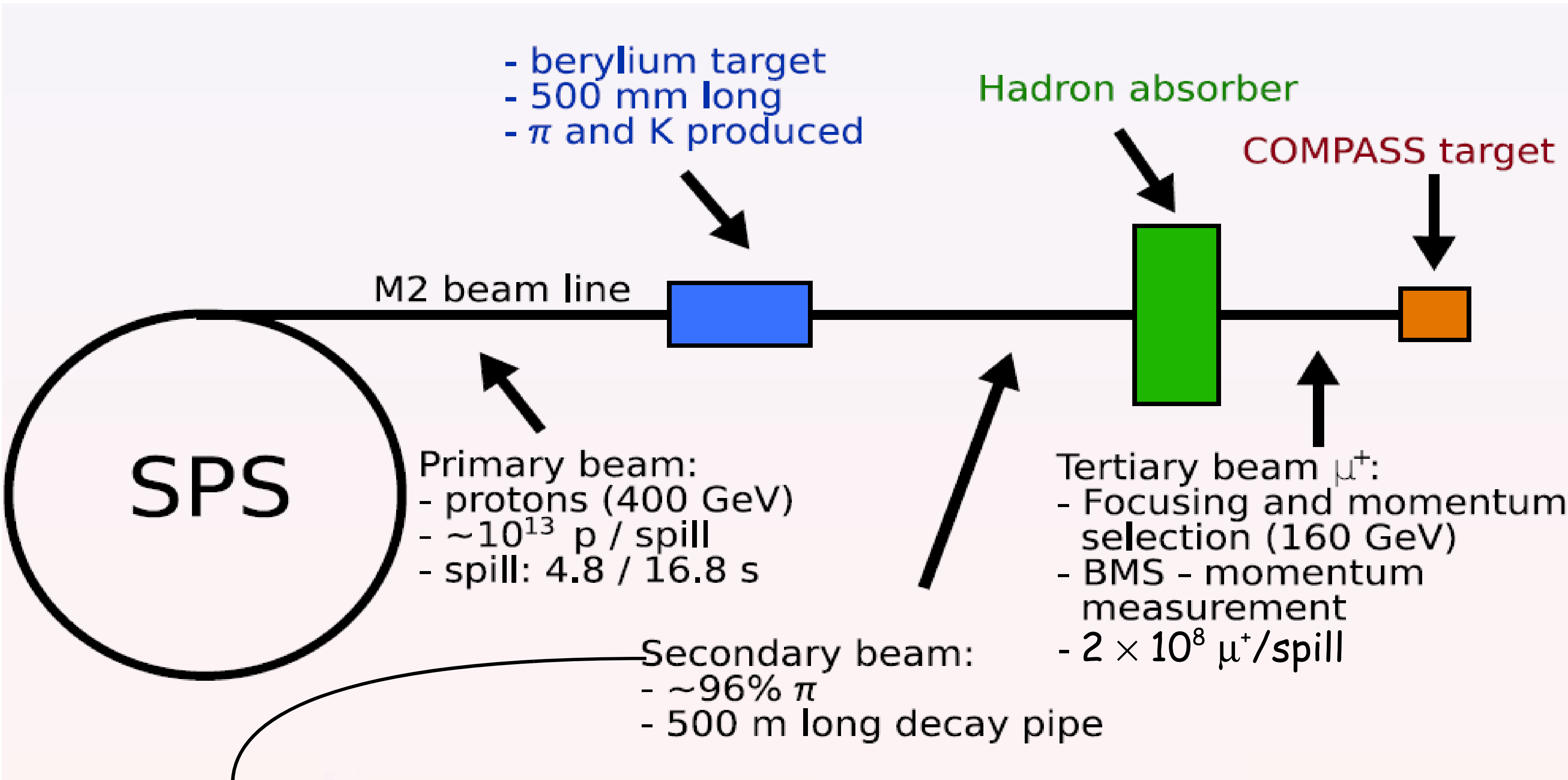
TMDs **GPDs**

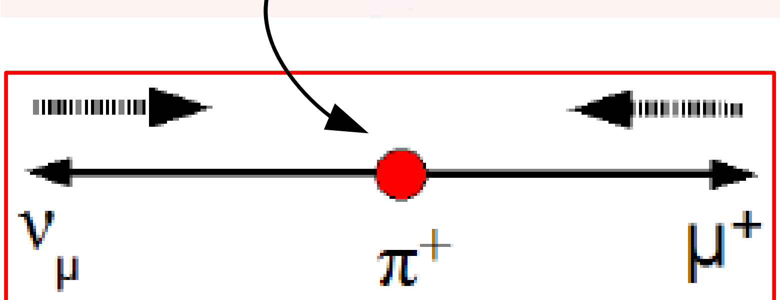
OAM



SPARES

The polarised beam

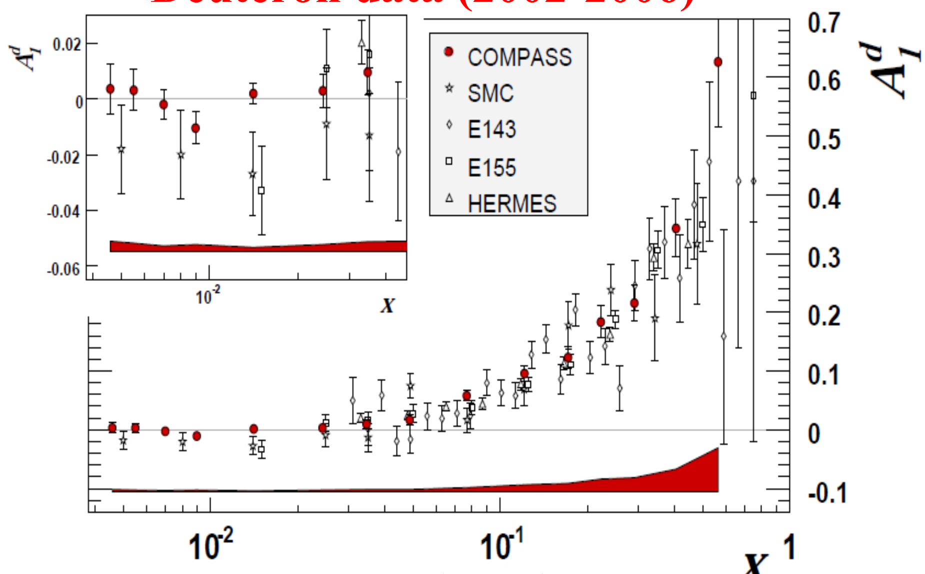




Naturally polarised muon beam: $P_{\mu} \sim 80\%$

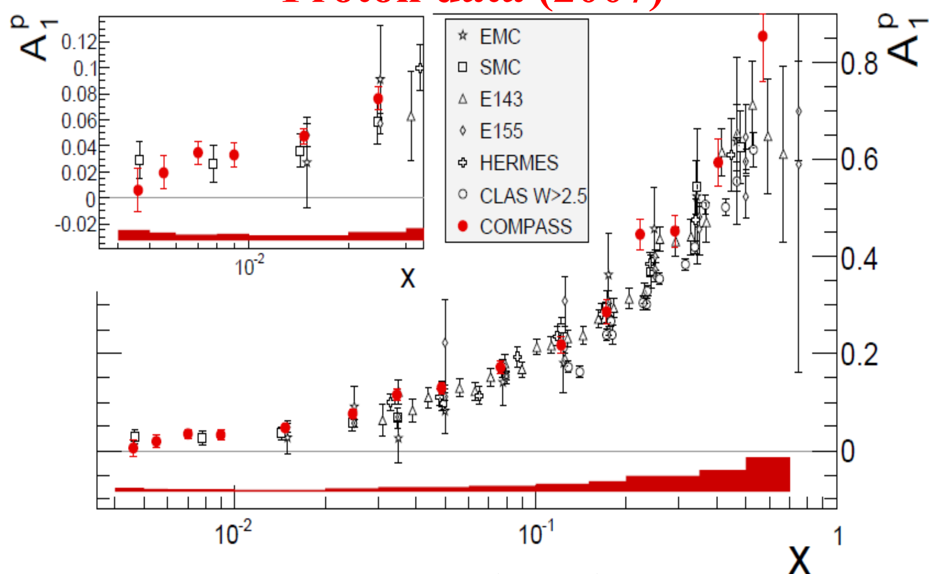
Inclusive asymmetries $A_1^{d/p}$: $Q^2 > 1$ (GeV/c)^2

Deuteron data (2002-2006)

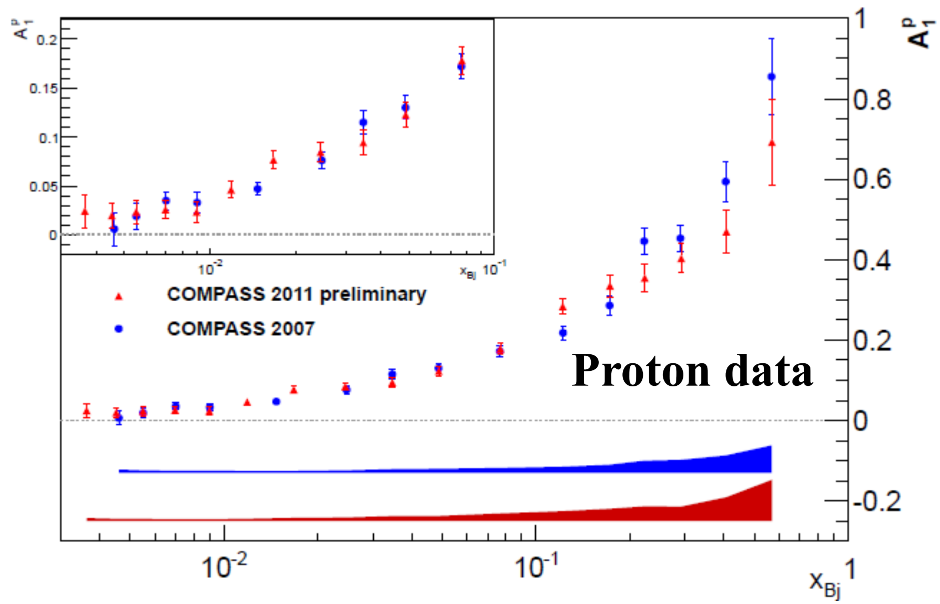


COMPASS, PLB 647 (2007) 330-340

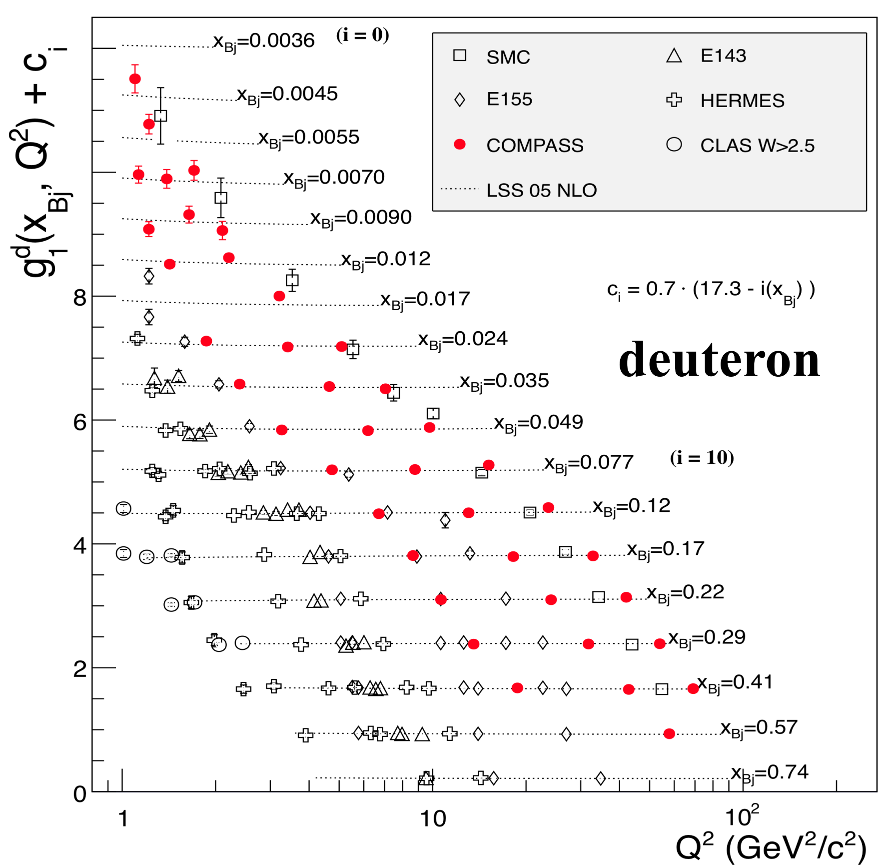
Proton data (2007)

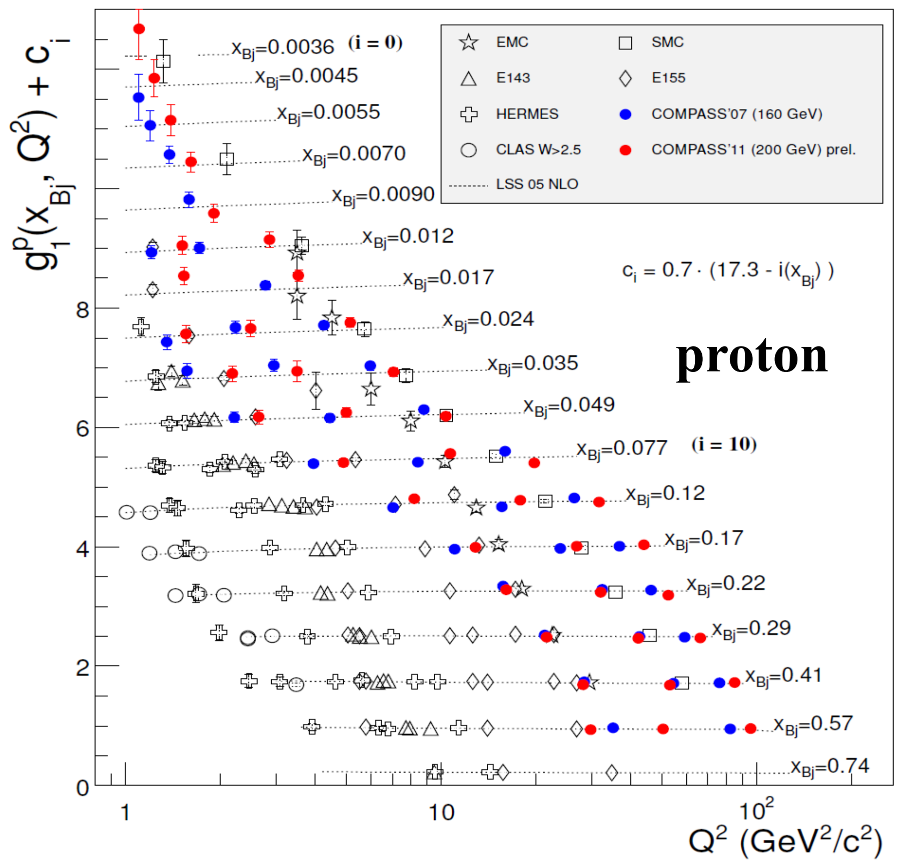


COMPASS, PLB 690 (2010) 466-472



Q^2 dependence of $g_1(x, Q^2)$ for DGLAP evolution





- **$\Delta\Sigma$ and ΔG can be extracted from Next-to-Leading Order** *(NLO)* **fits to the g_1 data** *($g_1 \propto \Delta\Sigma$ and ΔG)*, **using their Q^2 evolution obtained from the DGLAP equations:**

$$\frac{d}{d\ln Q^2}\Delta q^{NS} = \Delta P_{qq}^{NS} \otimes \Delta q^{NS}$$

$$\frac{d}{d\ln Q^2}\begin{pmatrix}\Delta q^S \\ \Delta g\end{pmatrix} = \begin{pmatrix}\Delta P_{qq}^S & \Delta P_{qg}^S \\ \Delta P_{gq}^S & \Delta P_{gg}^S\end{pmatrix} \otimes \begin{pmatrix}\Delta q^S \\ \Delta g\end{pmatrix}$$

- $(\Delta u + \Delta\bar{u})$ and $(\Delta d + \Delta\bar{d})$ are well constrained by the data (*LSS PRD 80 2009*)
- Despite of the higher Q^2 measurements by COMPASS, the kinematic coverage is not yet sufficient for **ΔG**

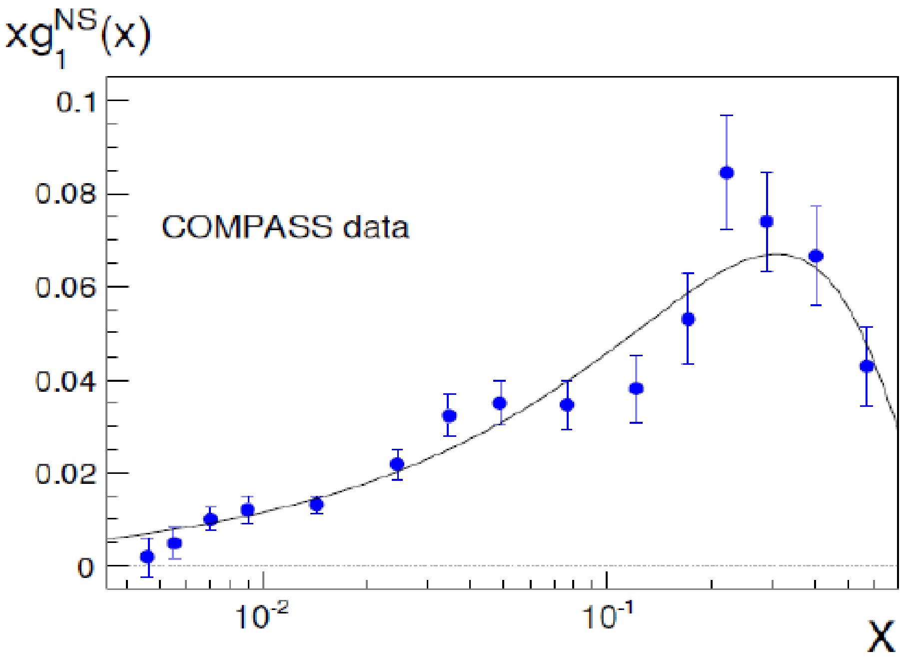
Bjorken sum rule

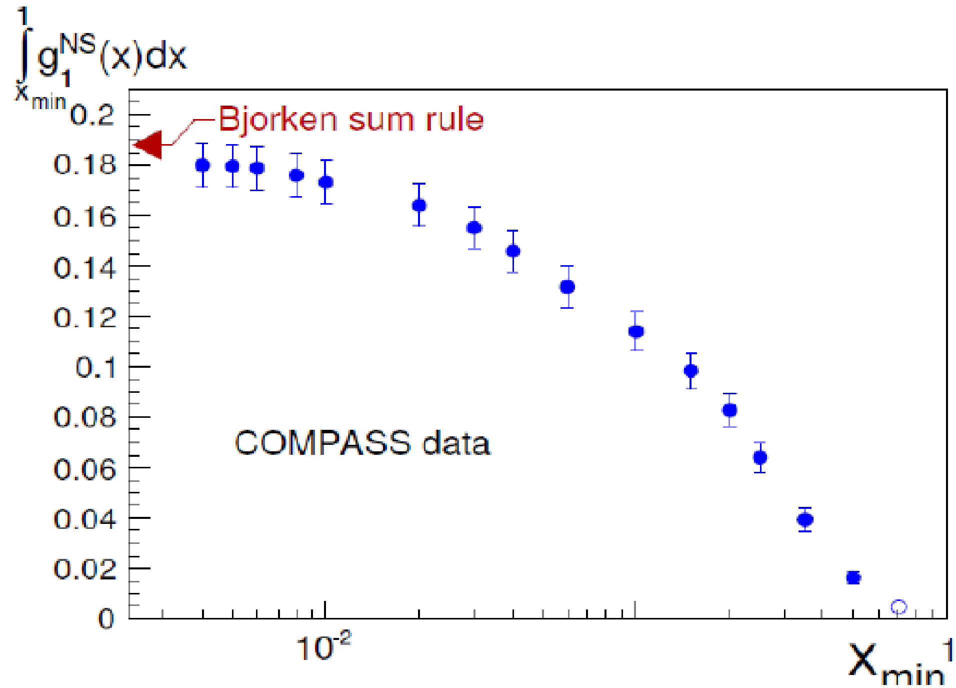
- According to the Bjorken sum rule the first moment of the non-singlet spin structure function, g_1^{NS}, is proportional to the ratio of axial and vector coupling constants g_A/g_V:

$$\int_0^1 g_1^{NS}(x,Q^2)\,dx = \frac{1}{6}\left|\frac{g_A}{g_B}\right| C_1^{NS}(Q^2)$$

using →

$$g_1^{NS}(x,Q^2) = g_1^p(x,Q^2) - g_1^n(x,Q^2) = 2g_1^p - 2g_1^d/(1-1.5\omega_D)$$





- QCD fit of COMPASS data using $\Delta q^{NS} = |g_A / g_V|\, x^{\alpha}(1 - x)^{\beta}$:

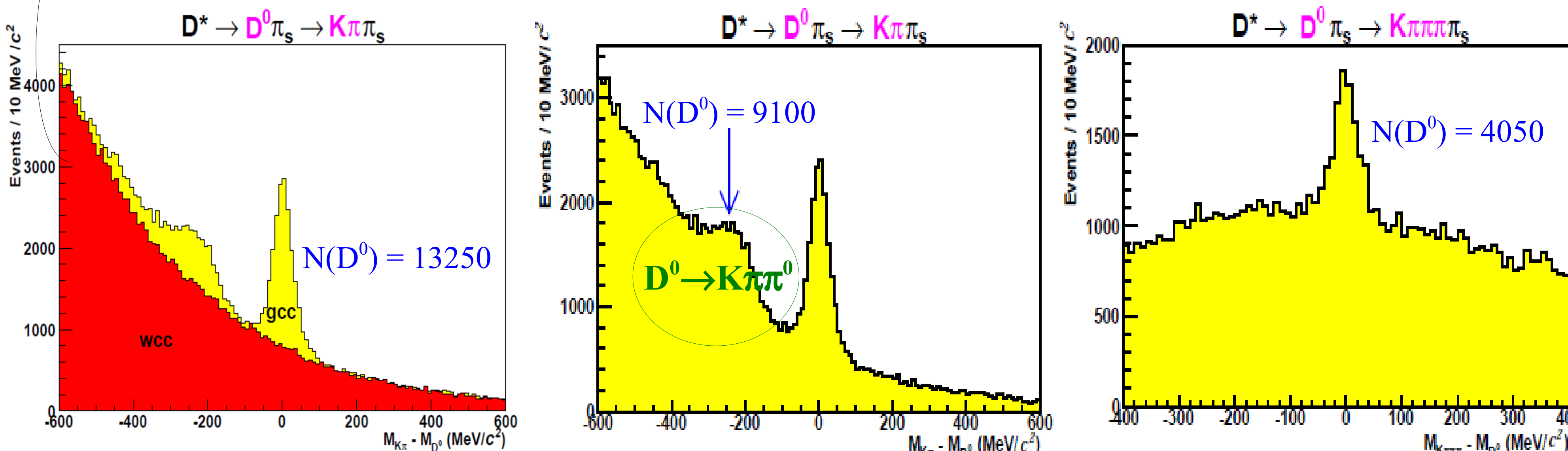
$$\left|\frac{g_A}{g_V}\right| = 1.28 \pm 0.07(\text{stat}) \pm 0.10(\text{sys})$$

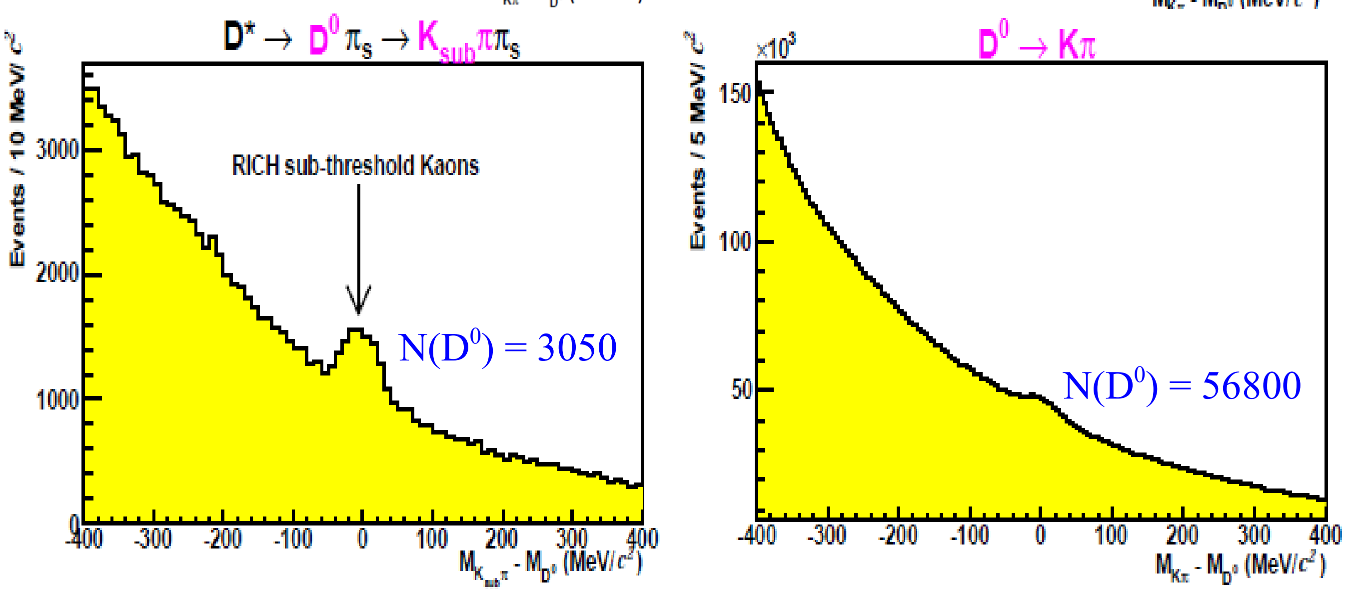
(PDG value : $|g_A/g_V| = 1.269 \pm 0.003$)

D^0 mass spectra (all samples): $\left(A^{exp}_{D^0} = f P_\mu P_T \frac{S}{S+B} A^{PGF}_{\mu N} \right)$

D^0 probability

- **Wrong Charge Combination of Kπ pairs:** Example of a background model used for the multidimensional kinematic parameterisation (performed by a Neural Network) of S/(S+B)



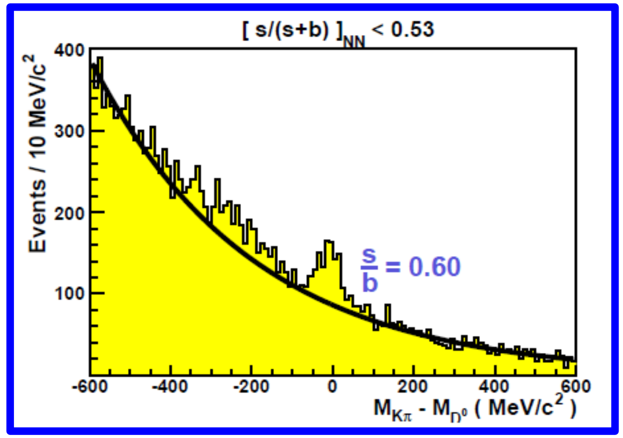


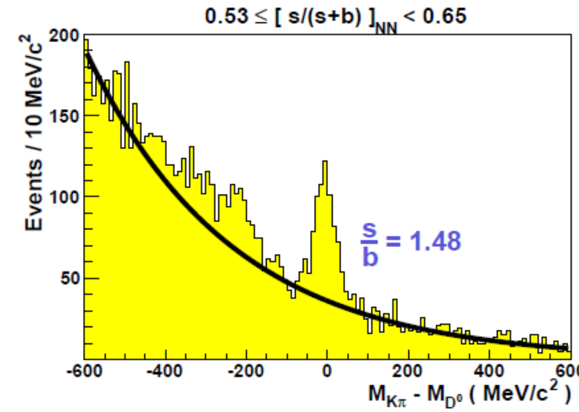
Number of D^0:

- Total → 86250
- ^{6}LiD → 57400
- NH_3 → 28850

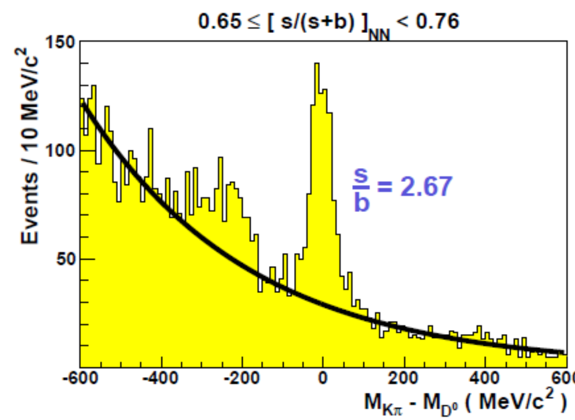
s/(s+b): Obtaining final probabilities for a D^0 candidate

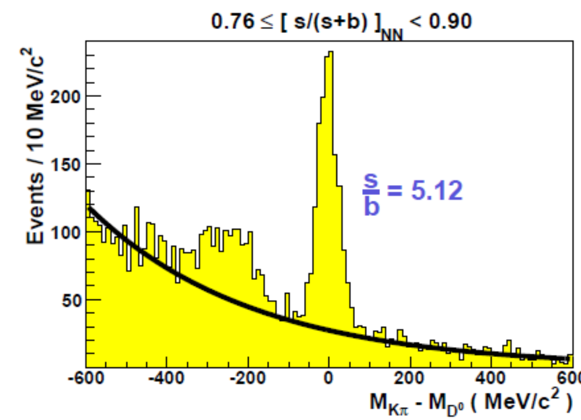
- **Events with small $[s/(s+b)]_{NN}$**
  - Mostly combinatorial background is selected



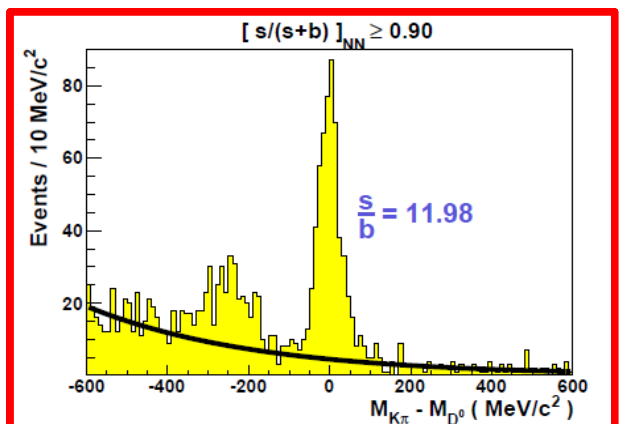


<u>s/(s+b) is obtained from a fit to these spectra</u> *(correcting all events with the corresponding values of $[s/(s+b)]_{NN}$)*



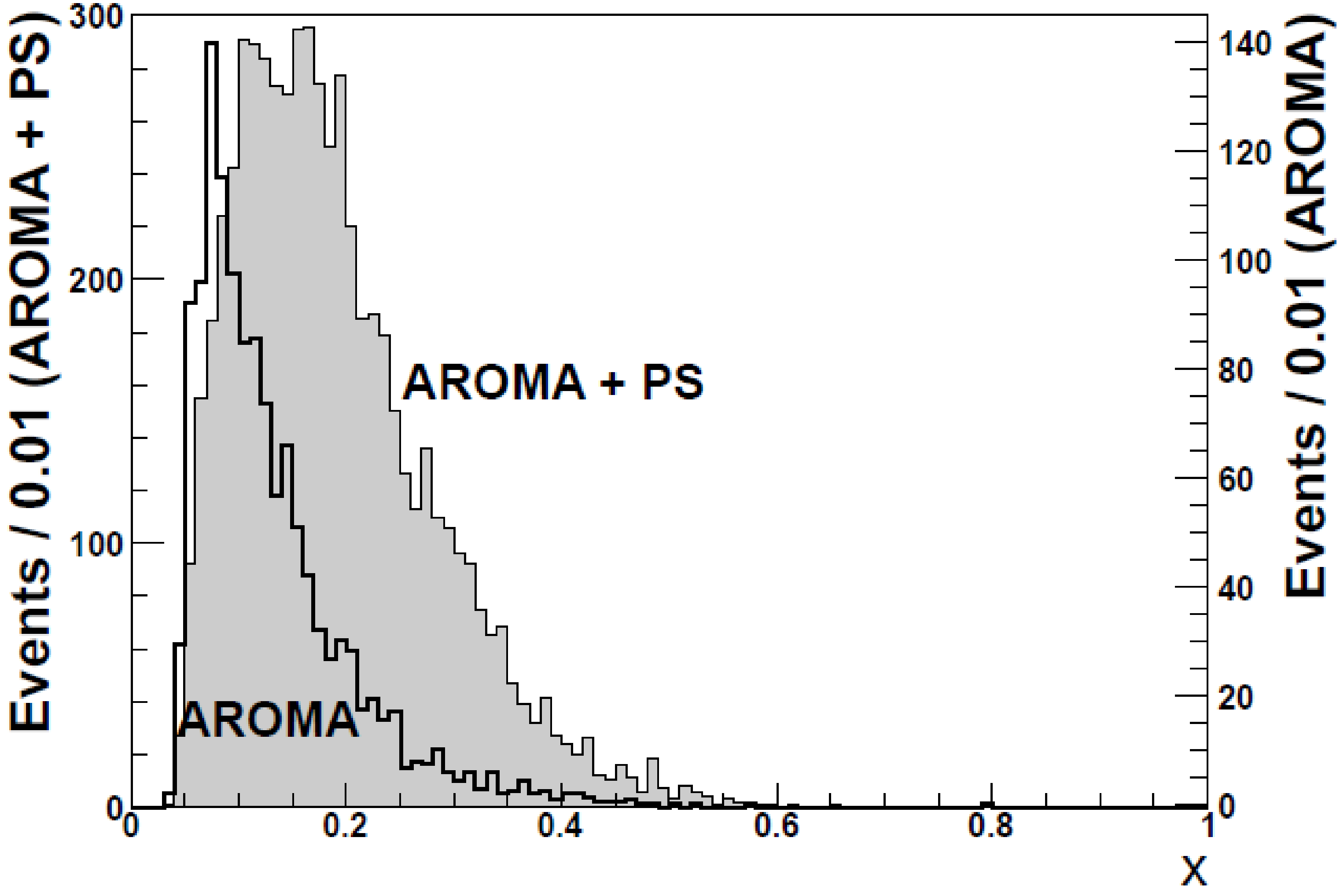


- **Events with large $[s/(s+b)]_{NN}$**
  - Mostly Open Charm events are selected



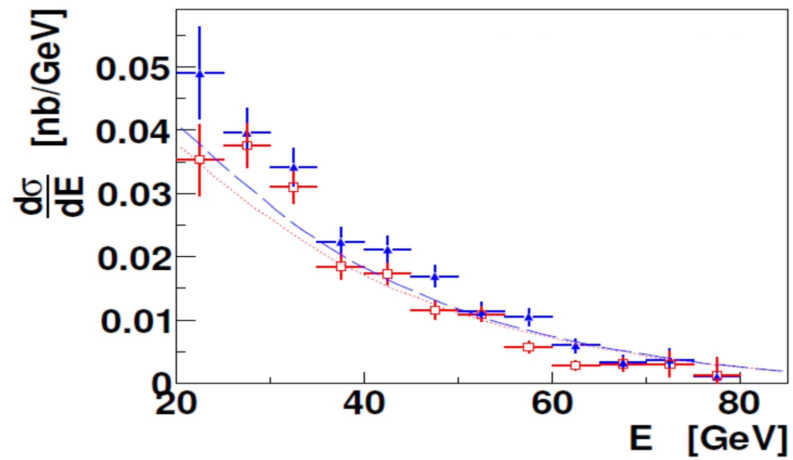
$$\delta\left(\frac{\Delta g}{g}\right) = \frac{1}{FOM}$$

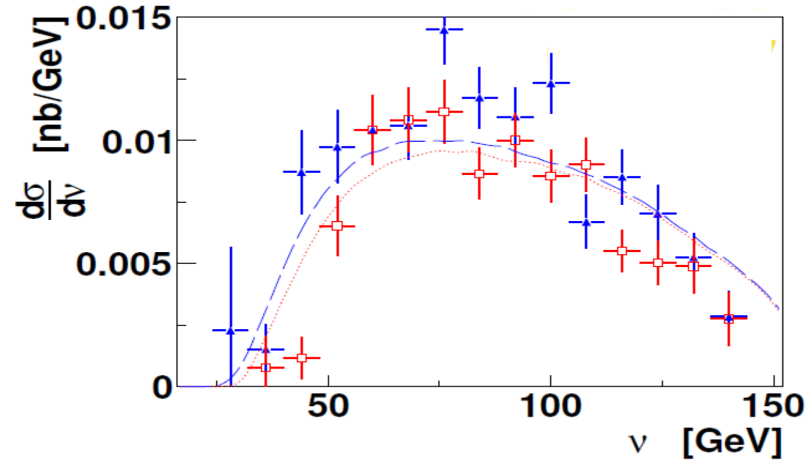
X_g from Open Charm



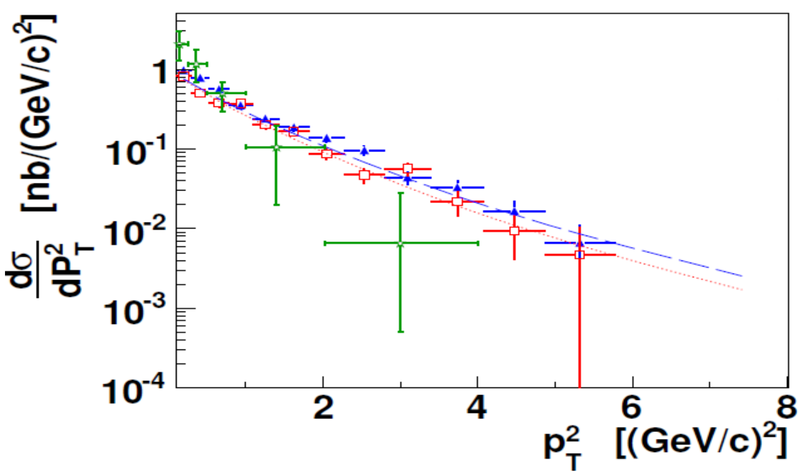
AROMA with PS-ON versus COMPASS data

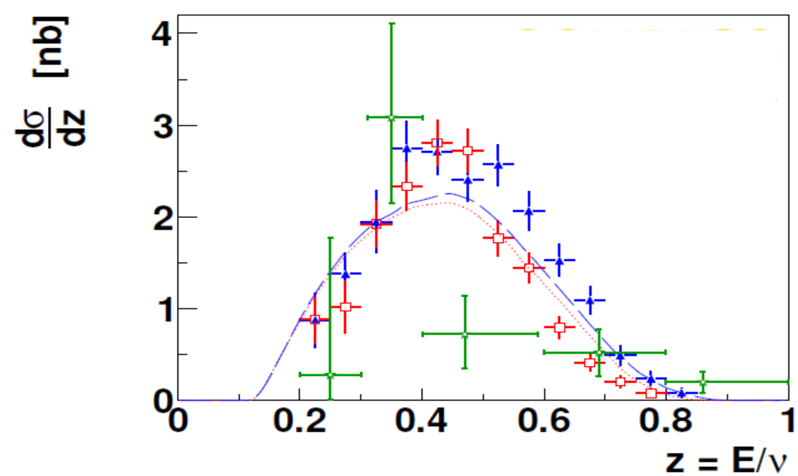
- **Differential cross section for D^* meson production** ($D^0_{K\pi}(2004)$ from D^{*+} and D^{*-} COMPASS data)**:**





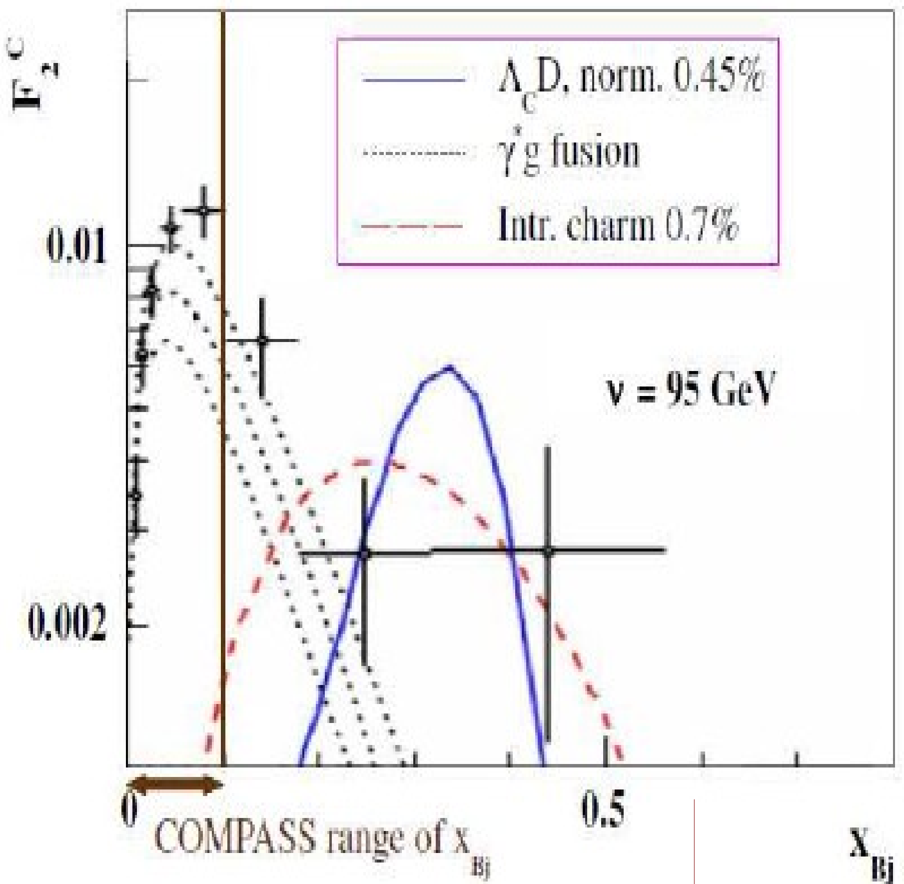
D*+
D*−
EMC

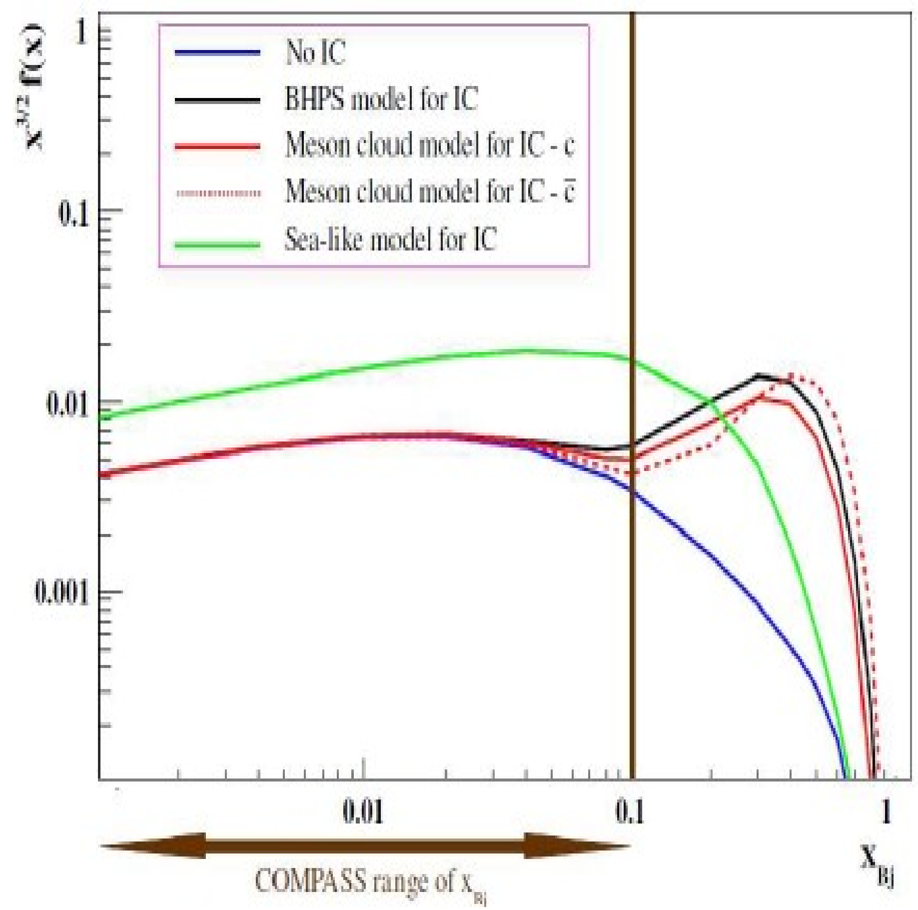




$\sigma(D^{*\pm}) = 1.8 \pm 0.4$ nb
within 20 GeV < E_D < 80 GeV

Intrinsic charm models





Ref. Hep-ph/0508126 and hep-ph/9508403
Phys. Lett. B93 (1980) 451
Data from EMC:Nucl.Phys.B213, 31(1983)

High-p_T asymmetries (2002-2006): $Q^2 > 1\ (\mathrm{GeV}/c)^2$

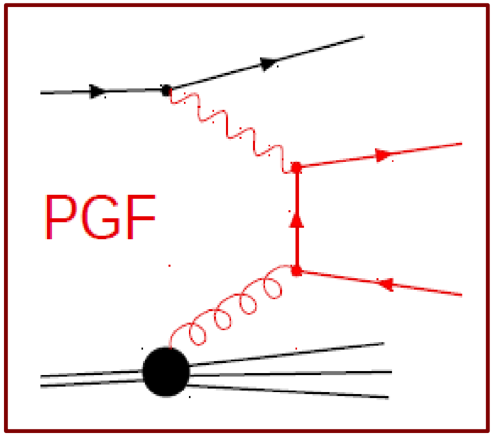
- **Two samples are considered** (fractions of the processes are estimated from MC):

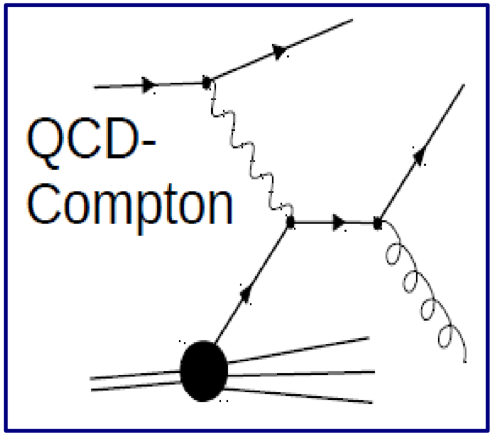
Inclusive asymmetry

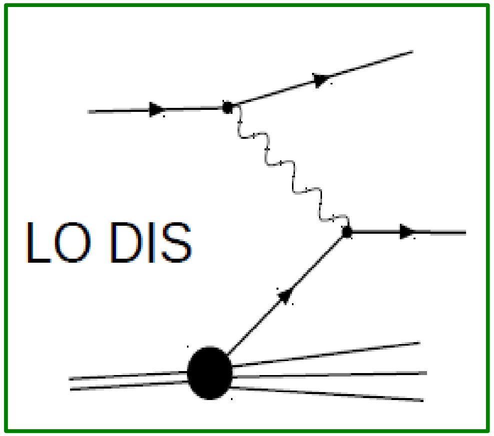
$$A_1^d(x) = \frac{\Delta g}{g}(x_g)\left(a_{LL}^{PGF,inc}\frac{\sigma^{PGF,inc}}{\sigma^{Tot,inc}}\right) + A_1^{LO}(x_C)\left(a_{LL}^{C,inc}\frac{\sigma^{C,inc}}{\sigma^{Tot,inc}}\right) + A_1^{LO}(x_{Bj})\left(D\frac{\sigma^{LO,inc}}{\sigma^{Tot,inc}}\right)$$

$$A_{LL}^{2h}(x) = \left(\frac{A^{exp}}{f\,P_\mu P_T}\right) = \frac{\Delta g}{g}(x_g)\left(a_{LL}^{PGF}\frac{\sigma^{PGF}}{\sigma^{Tot}}\right) + A_1^{LO}(x_C)\left(a_{LL}^{C}\frac{\sigma^{C}}{\sigma^{Tot}}\right) + A_1^{LO}(x_{Bj})\left(D\frac{\sigma^{LO}}{\sigma^{Tot}}\right)$$

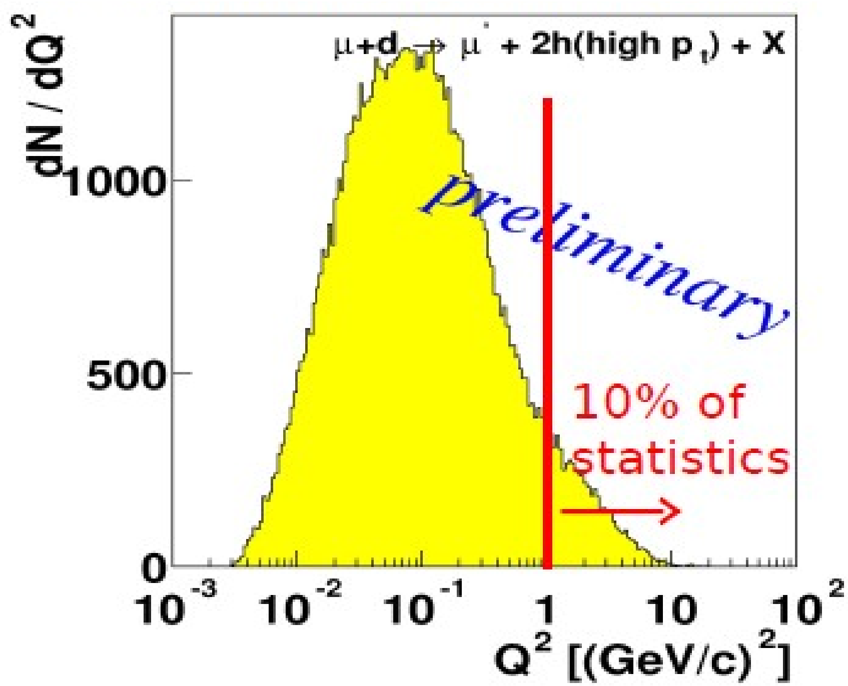
high-p_T hadron pairs (p_{T1} / p_{T2} > 0.7 / 0.4 GeV/c) ⇒ enhancement of the PGF contribution

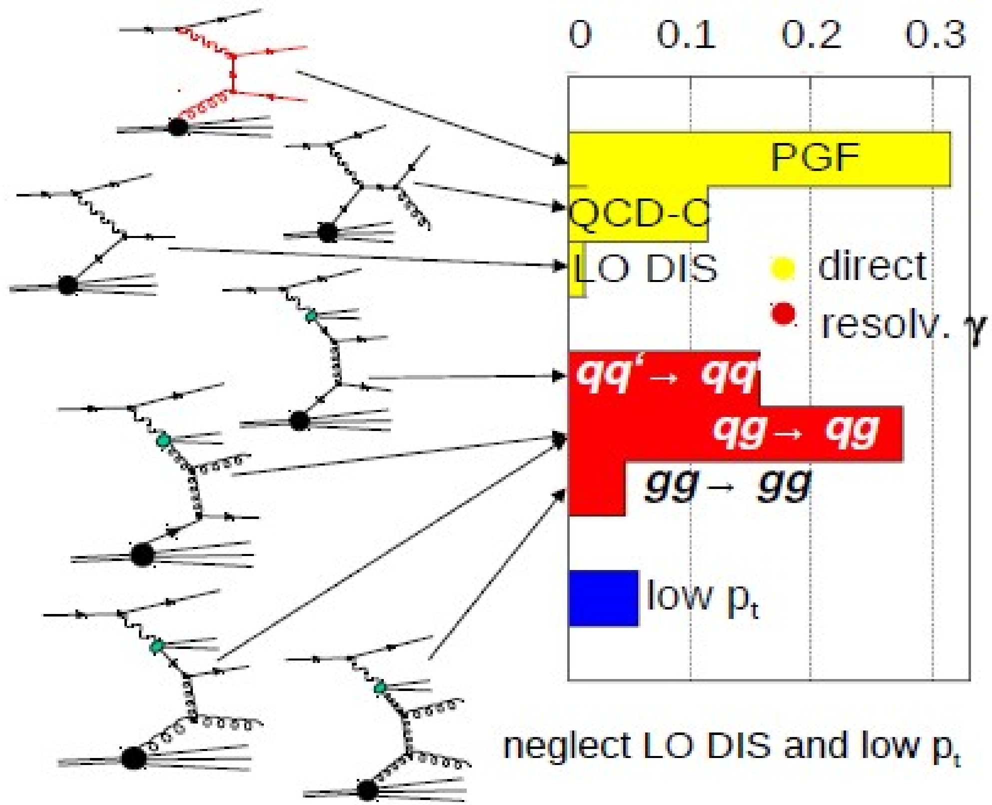






High-p_T analysis: $Q^2 < 1$ (GeV/c)^2





2002-2004 Preliminary:

$\Delta G/G$ = 0.016 ± 0.058 (stat) ± 0.055 (syst)

2002-2003 Published:

$\Delta G/G$ = 0.024 ± 0.089 (stat) ± 0.057 (syst) → *Phys. Lett. B 633 (2006) 25 - 32*