

The longitudinal spin structure of the nucleon at **COMPASS**

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Outline

- **Introduction**
- **The COMPASS experiment**
- **Longitudinal Spin: 2011 data**
- **ΔG**
 - Open charm: Update, NLO corrections
 - High p_T photoproduction: X-section *vs.* p_T

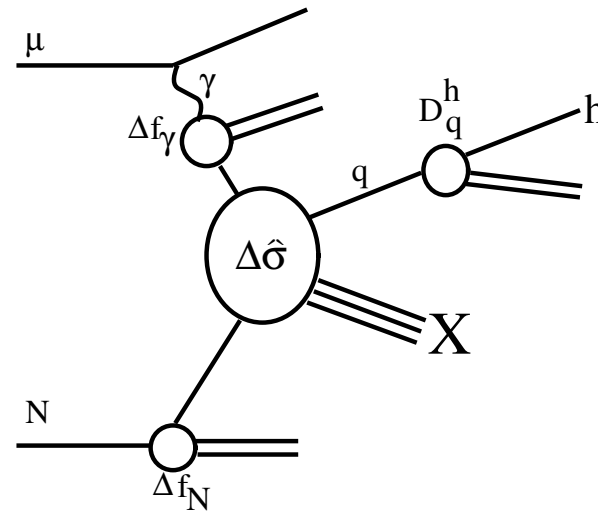
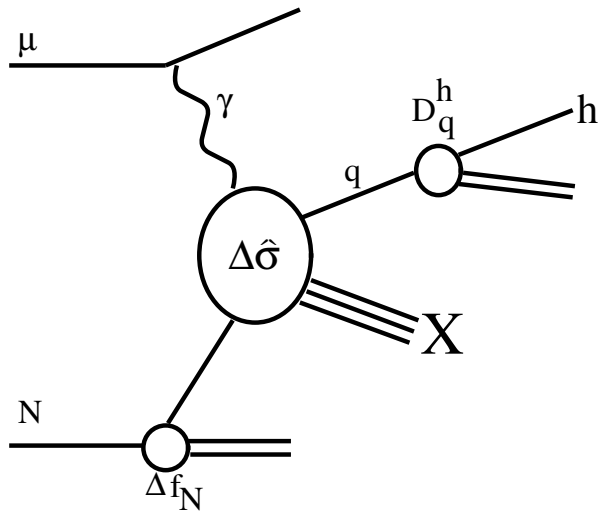
Introduction

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

○ Inclusive DIS:

- $\Delta\Sigma$ small.
- $\Delta\Sigma \simeq 0.58 + 3\Delta S \Rightarrow \Delta S$ negative and large.
- ΔG uncertain.

⇒ Semi-inclusive measurements (in DIS and photoproduction regimes)



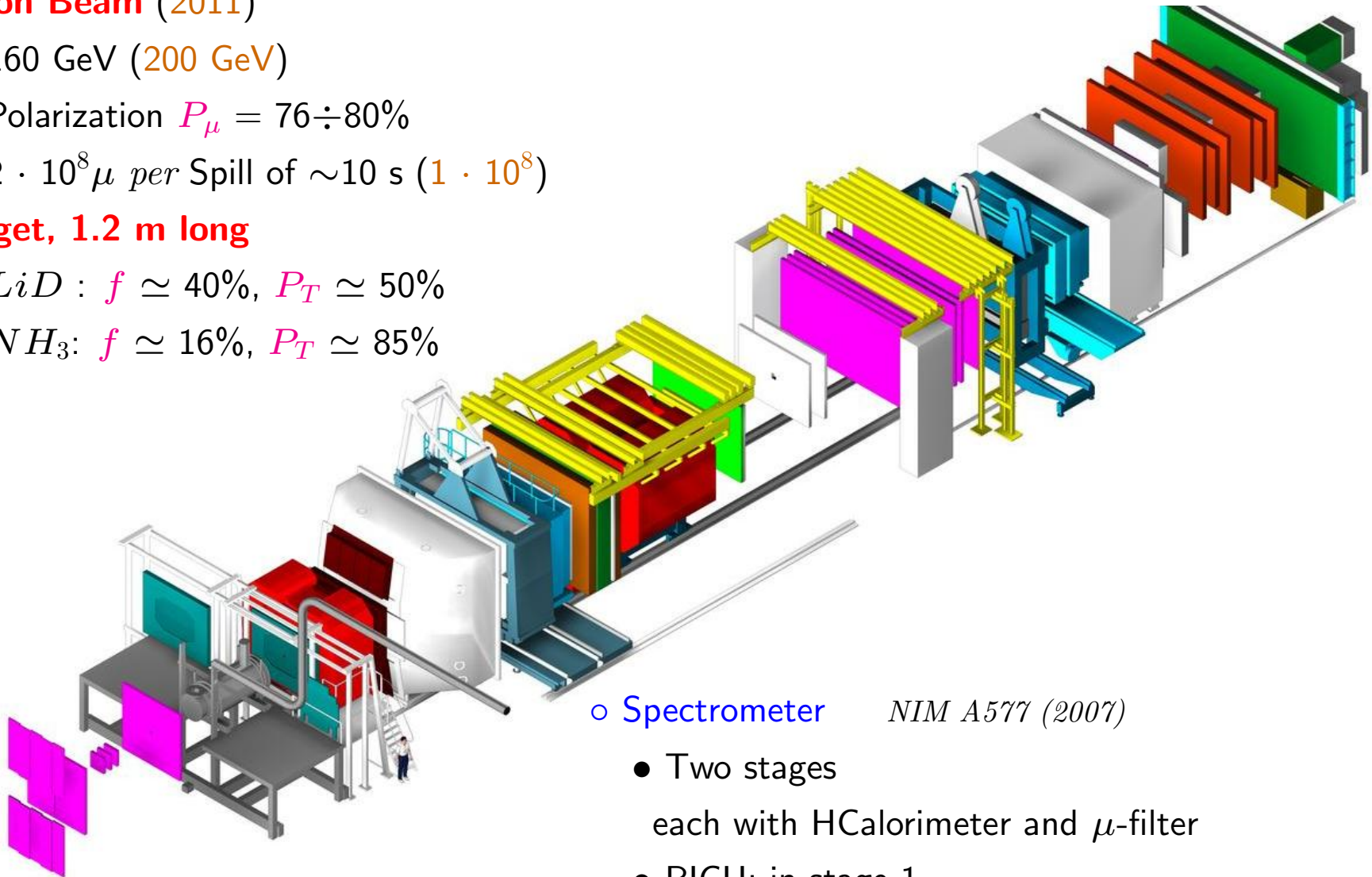
COMPASS: Spectrometer

○ Muon Beam (2011)

- 160 GeV (200 GeV)
- Polarization $P_\mu = 76 \div 80\%$
- $2 \cdot 10^8 \mu$ per Spill of ~ 10 s ($1 \cdot 10^8$)

○ Target, 1.2 m long

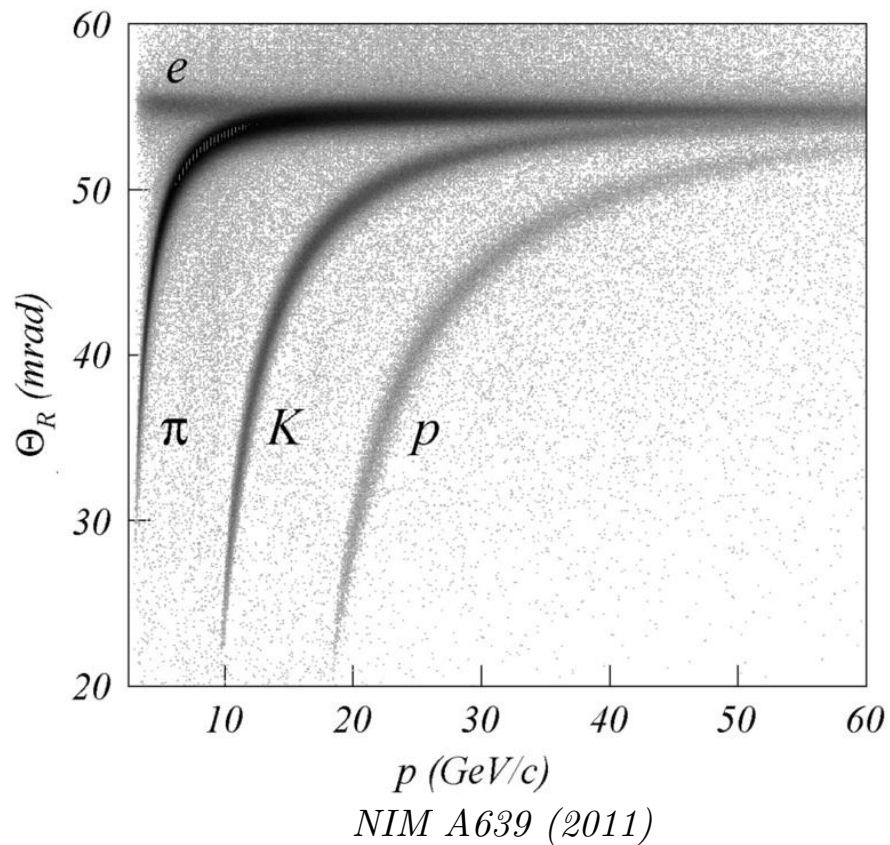
- LiD : $f \simeq 40\%$, $P_T \simeq 50\%$
- NH_3 : $f \simeq 16\%$, $P_T \simeq 85\%$



○ Spectrometer *NIM A577 (2007)*

- Two stages
each with HCalorimeter and μ -filter
- RICH: in stage 1
- ECalorimeters(1&2): added lately

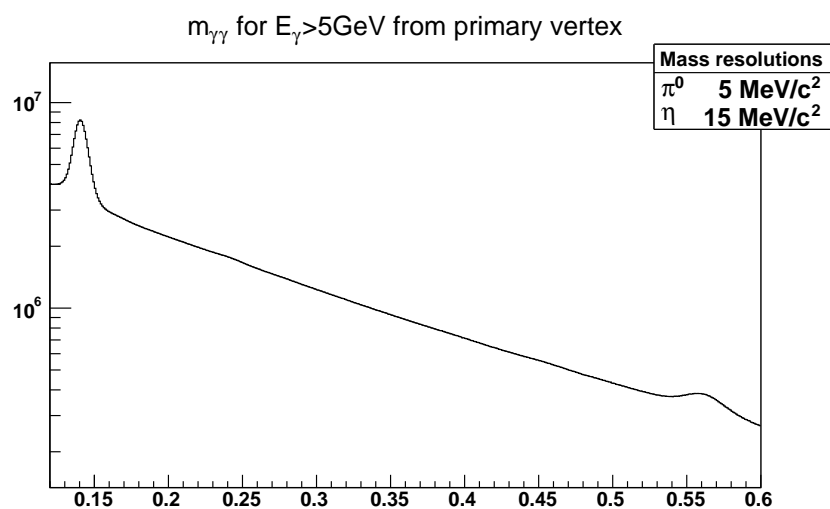
COMPASS: RICH



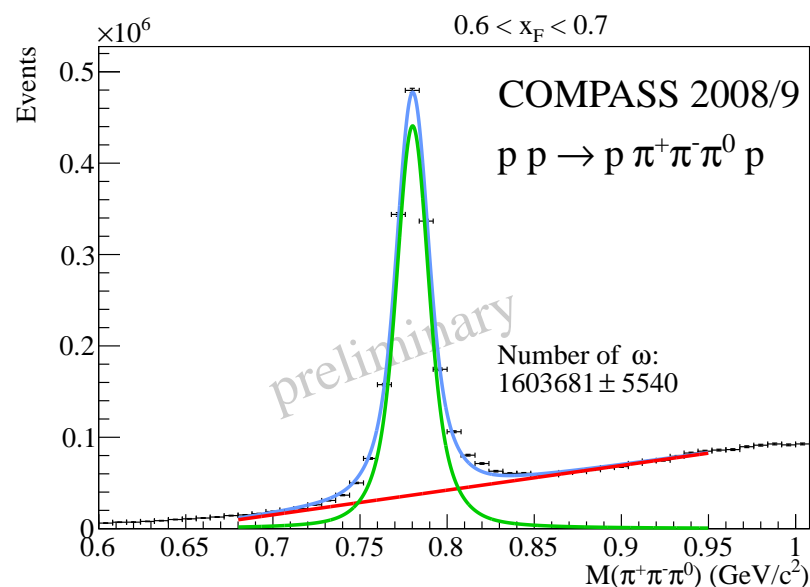
- Used to . . .
 - . . . ID final state hadrons in SIDIS
 - . . . Veto electrons in open charm production
- **K range: $10 \lesssim P \lesssim 50$ GeV**
- No **K/p** resolution below ~ 10 GeV

COMPASS: ECalorimeters

- No reconstruction of neutrals yet in any Spin physics analyses
- But used in our “hadron” programme (exotics search, χ PT tests)
Cf. presentation of Boris Grube



- Inclusive π^0, η from π beam on 40 cm LH_2



- Exclusive ω (40 cm LH_2)

- Caveat: Thickness of polarised targets along beam axis $\simeq 1 \times X_0$.

COMPASS: Asymmetry Measurement

- **Simultaneous** recording of the two spin states in oppositely polarised target cells
 - Reversal by field rotation to cancel acceptance diff

$$\begin{aligned} \dots \text{ 2 cells: } & \quad 1/2 \uparrow 1/2 \downarrow \quad \Longleftarrow 8 \text{ hours} \Longrightarrow \quad 1/2 \downarrow 1/2 \uparrow \\ \dots \text{ 3 cells: } & \quad 1/4 \uparrow 2/4 \downarrow 1/4 \uparrow \quad \Longleftarrow 24 \text{ hours} \Longrightarrow \quad 1/4 \downarrow 2/4 \uparrow 1/4 \downarrow \end{aligned}$$

$$\frac{A^{\parallel}}{D} = \frac{1}{|P_{\mu}P_T|fD} \frac{1}{2} \left(\frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} + \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} \right) \quad D = \text{Depolarisation factor}$$

$$LiD: P_{\mu} \times D \times P_T \times f \simeq 80\% \times 60\% \times 50\% \times 40\% \simeq 10\% \quad (\text{typical values})$$

$$NH_3: \dots P_T \times f \simeq \dots 85\% \times 16\% \simeq 6\%$$

- Reversal *via* micro-wave once per year of data taking to cancel field/acceptance correlation

COMPASS: Data Taking

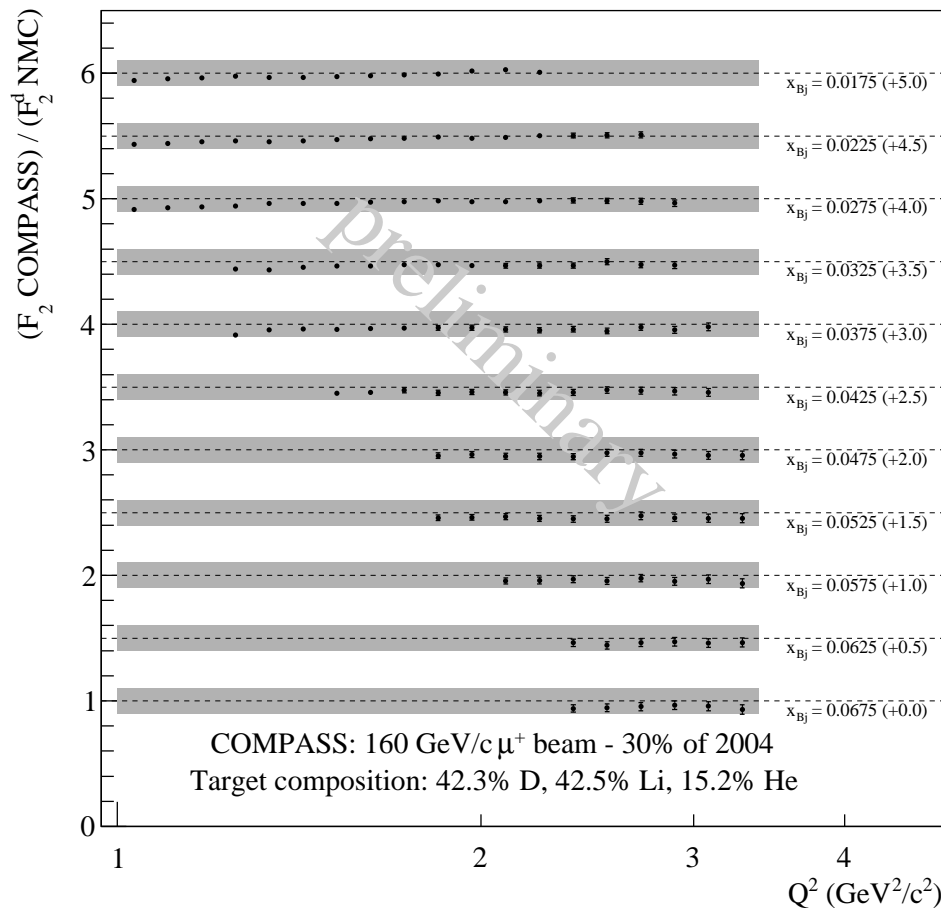
- [2002,2004], 2006: 160 GeV
 - *Deuteron* target
 - $\sim 20\%$ of data taking in transverse mode
 - Longitudinal luminosity

	2002	2003	2004	2006
Integrated Luminosity (fb^{-1})	0.43	0.58	0.92	0.85

- 2007: *Proton* target. 1/2 longitudinal, 1/2 transverse. 160 GeV
- 2008,2009: Hadron physics
- 2010: Transverse proton 160 GeV
- 2011: Longitudinal proton 200 GeV
- 2012: Hadron physics (*Primakoff*)
 - + muon beam on *LH2* target: DVCS test run and SIDIS

COMPASS: Luminosity Measurement

- Precise luminosity plays an important role in part of our programme
 - ... in our future DVCS programme
 - ... in our measurement of hadron photo-production X-section *vs.* p_T



arXiv:1104.2926 [hep-ex]

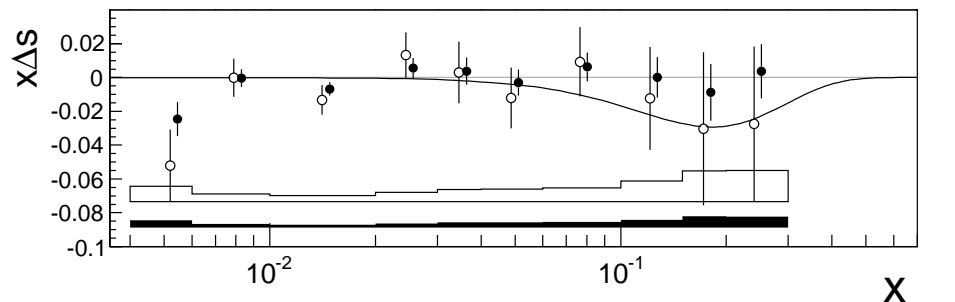
- As an evaluation exercise: F2 X-check

⇒ **Systematics (=10%)**
most likely pessimistic.

Longitudinal Spin: Motivations for 2011 data taking

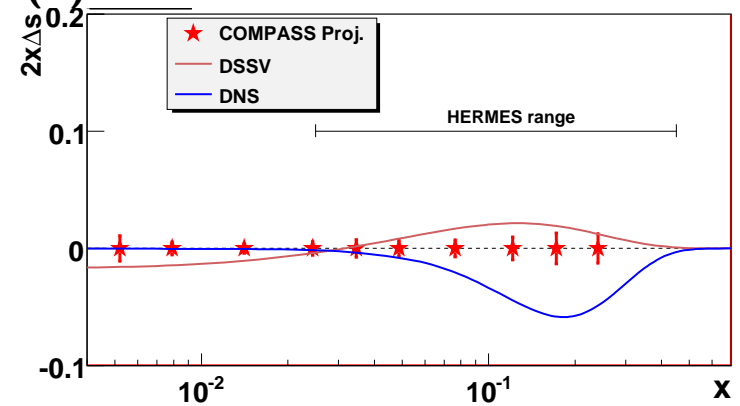
- More statistics on polarized protons
- so as to restore somewhat the balance between p and d .
 ⇒ Particularly interesting for the analyses mixing both.
- *E.g.* Strange Quark Polarisation Puzzle

ΔS puzzle: SIDIS \neq Inclusive DIS + SU(3)



LO analysis using DSS (●) or EMC (○) FFs
 compared to DNS global fit of Incl. DIS

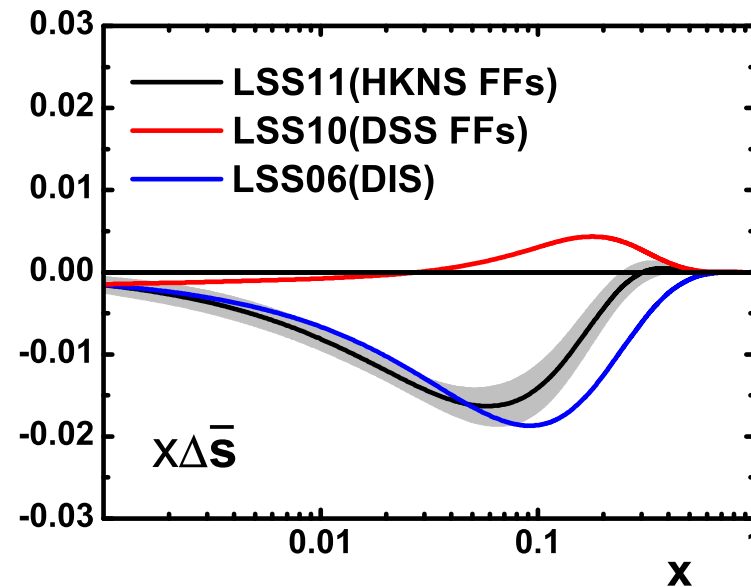
Phys. Lett. B **693** (2010) *arXiv:1007.4061 [hep-ex]*



Projection including 2011 data

($DSSV = DIS + SIDIS + pp$)

Δ_s in SIDIS: Sensitivity to D_s^K FF



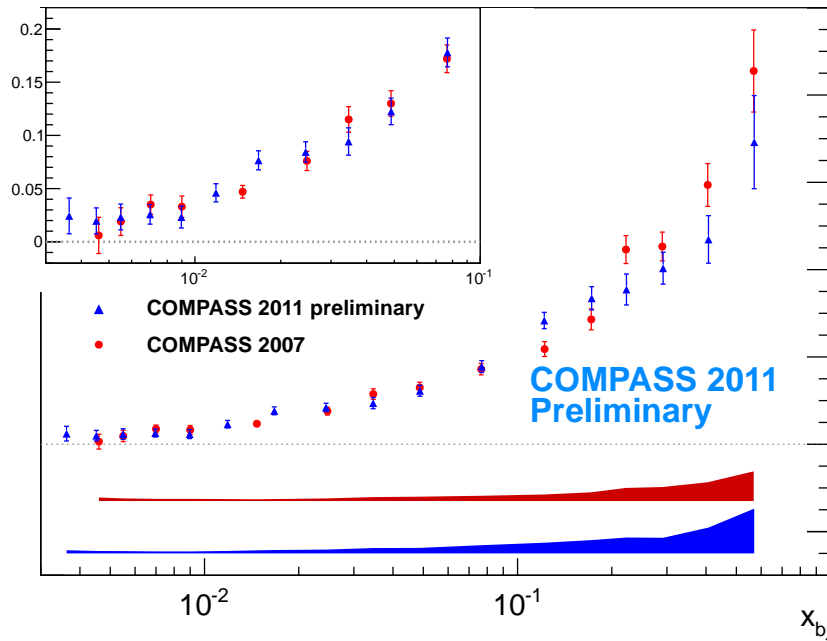
*Leader, Sidorov, Stamenov: DIS+SIDIS fits using various FFs
compared to purely incl. DIS fit.*

arXiv:1103.5979 [hep-ph]

⇒ Programme of Hadron Multiplicities in SIDIS @ COMPASS, to contribute to FF global effort

Cf. presentation of Luigi Capozza

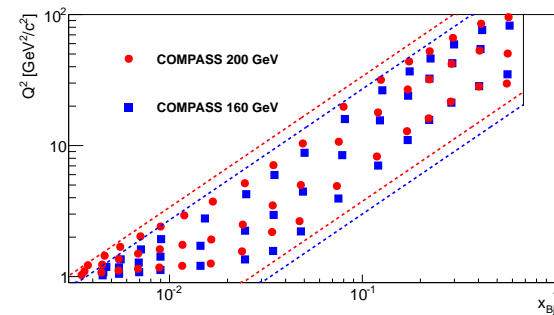
Longitudinal Spin: 2011 preliminary results



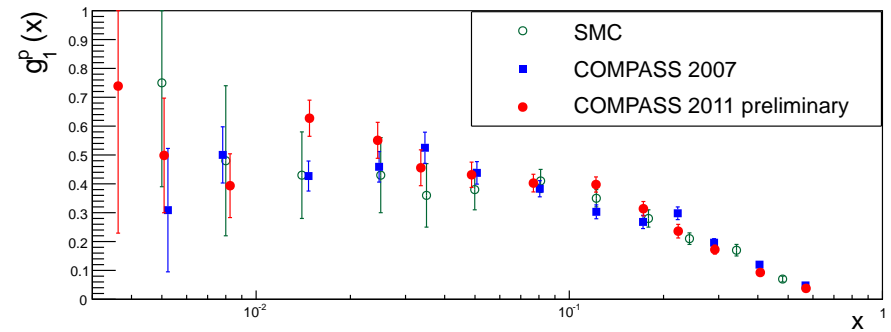
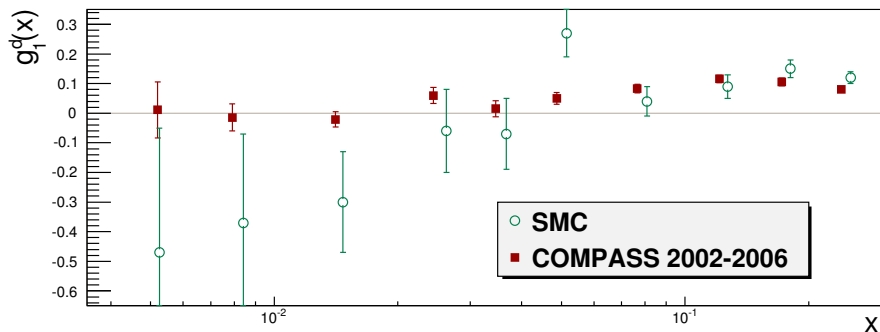
- Only inclusive so far:

$$A_1^P(\mathbf{x}) \simeq \frac{A_{||}}{D} \text{ w/ good precision in COMPASS}$$

2007 and 2011 at (slightly) different Q^2

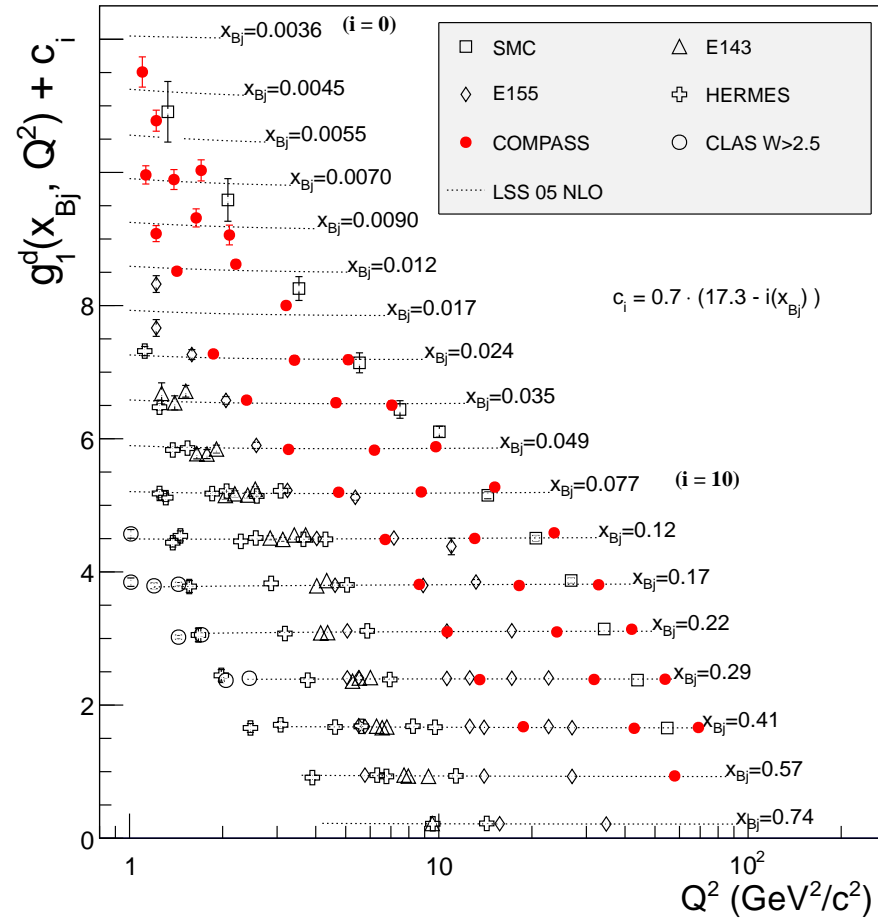
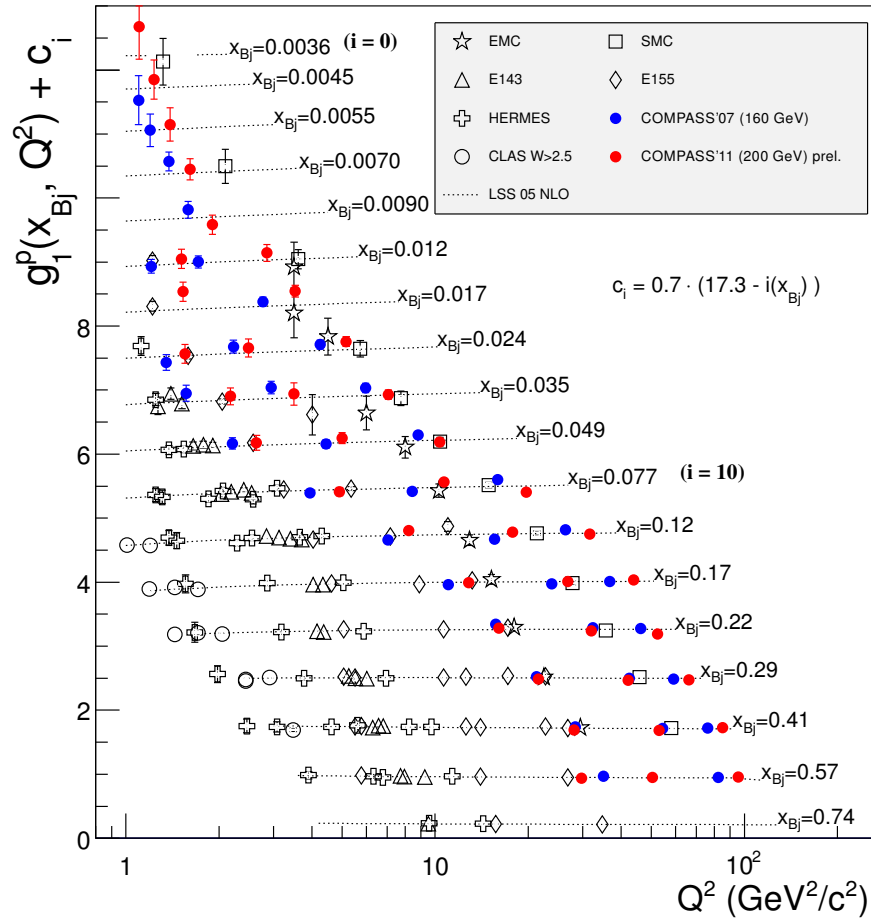


- COMPASS boost in precision at low x now completed



Longitudinal Spin: Status of polarised DIS

- World polarised DIS data: $g_1(Q^2) + c(x)$



ΔG Dedicated Measurements: Direct extraction *vs.* Fit

o **Direct** *vs.* **Fit**, differing in:

- Folding partonic level pQCD calculations with. . .
- . . . the soft fragmentation process,
- Handling of the quark contributions

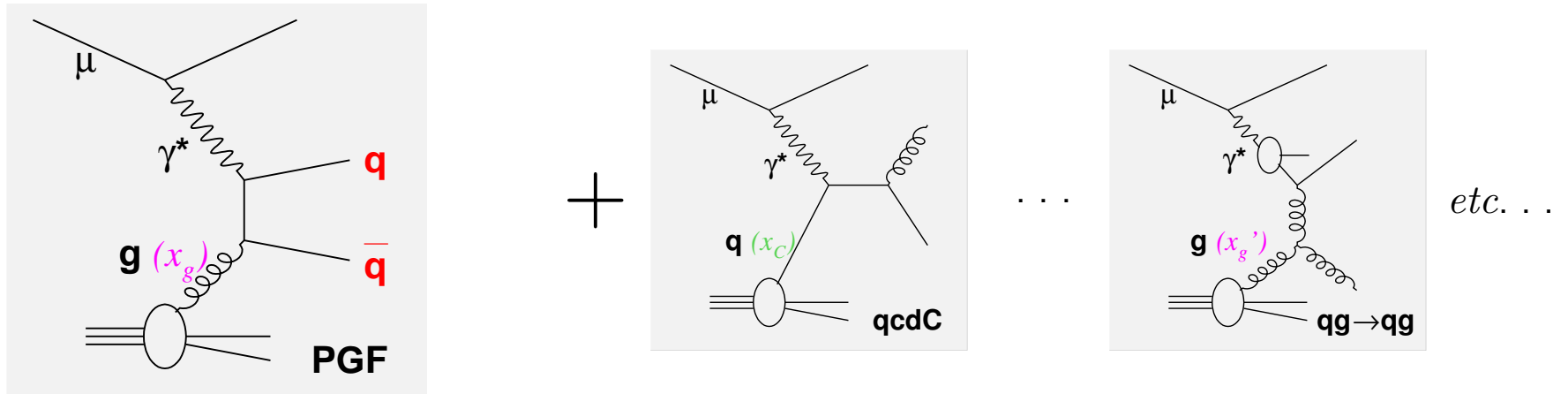
1. **Fit** *(Approach used at RHIC)*

- pQCD calculations w/. . .
 - . . . Independent collinear fragmentation
 - Quark contributions: from or w/in global fit
 - In COMPASS: Photo-production of charge hadrons at high p_T
- New:** Validation of the framework on unpolarised data

2. **Direct** extraction *(Approach also used at HERMES)*

- Based on MC generator
 - ⇒ Lund Fragmentation
 - Quark contributions autochthonous
 - . . . *(except in the high p_T low Q^2 case)*
 - In COMPASS: Approach mainly used so far (in both open-charm and high p_T)
- New:** NLO corrections to open charm

ΔG : Open charm *vs.* high p_T



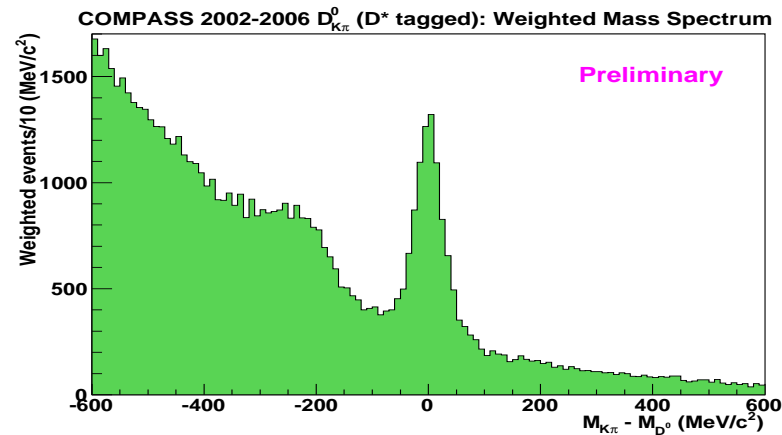
- **q = c: Open Charm** production
 - Generated by PGF at LO
 - Intrinsic charm neglectable (low x_{Bj})
 - Resolved γ small (high x_γ)
- ⇒ COMPASS Golden Channel
 - Experimentally difficult
 - pQCD scale set by $\hat{s} > 4m_c^2$
- **q = u,d,s,c: High- p_T** Hadrons
 - Competing LO-DIS, QCD-Compton
 - Competing resolved γ processes.
 - Higher statistics
 - pQCD scale set by p_T or Q^2

ΔG : Open charm

- Open charm selection.

$$E.g. D^* \rightarrow D^0 \pi \rightarrow K \pi \pi$$

- LO interpretation (2002-2007 data)



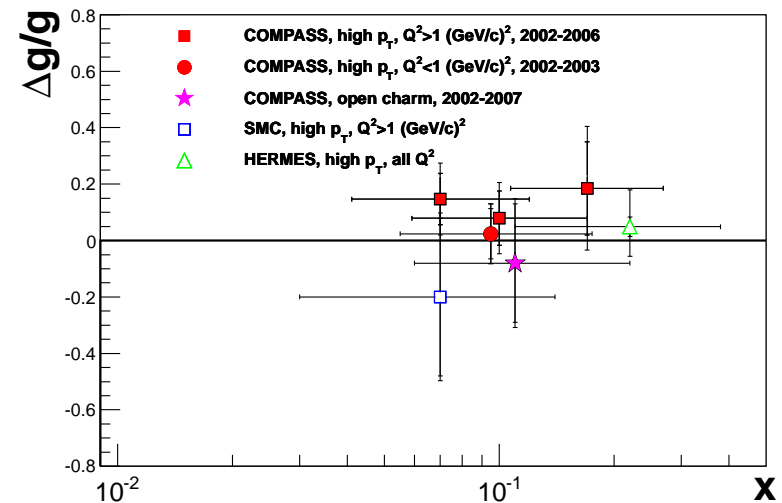
$$\Delta G/G = -0.08 \pm 0.21(\text{stat.}) \pm 0.11(\text{syst.}) \quad x_G = 0.11^{+0.11}_{-0.05}; \quad \mu^2 \approx 13 \text{ GeV}^2$$

- COMPASS open charm at LO (\star) and other direct measurements (@ 3 GeV²)

$\Rightarrow \Delta G/G$ small

Axial anomaly scenario definitely excluded

- LO \Rightarrow not into global fits



ΔG: NLO corrections to open charm

- *Bojak and Stratmann, Nucl. Phys. B* **540** (1999) *arXiv:hep-ph/9807405*

Collinear fragmentation: Charm quark is "measured" via measured D meson

$$\gamma + N \rightarrow Q[\bar{Q}] + X \quad @ \quad Q^2 = 0 \quad \text{w/ Mandelstam invariants } U_1 \text{ and } T_1$$

$d^2\hat{\sigma}/dU_1dT_1$ and $d^2\Delta\hat{\sigma}/dU_1dT_1$ including virtual + soft and real gluon corrections

- *K. Kurek, J. Phys. Conf. Ser.* **295** (2011)

Analytical integration over U_1 .

MC integration over x using AROMA w/ Parton Shower

$$\Rightarrow \langle a_{LL} \rangle(p_T)$$

- Asymmetries binned along p_T (also available in (p_T, E) bins)

$$\langle a_{LL} \rangle(p_T) A^{\gamma N}(p_T) = \langle a_{LL}^g \rangle(p_T) \Delta G/G + \langle a_{LL}^q \rangle(p_T) A_1$$

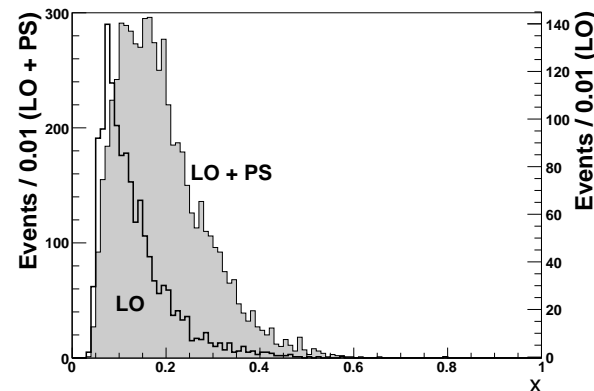
$$\Rightarrow \Delta G/G = -0.13 \pm 0.15(\text{stat.}) \pm 0.15(\text{syst.}) \quad x_g = 0.20_{-0.08}^{+0.13} \quad \mu^2 \approx 13 \text{ GeV}^2$$

- **Significant impact on x_g**

Note: Dissent w/ x_g result in

Riedl, Stratmann, Schäfer, EPJ C **73** (2013)

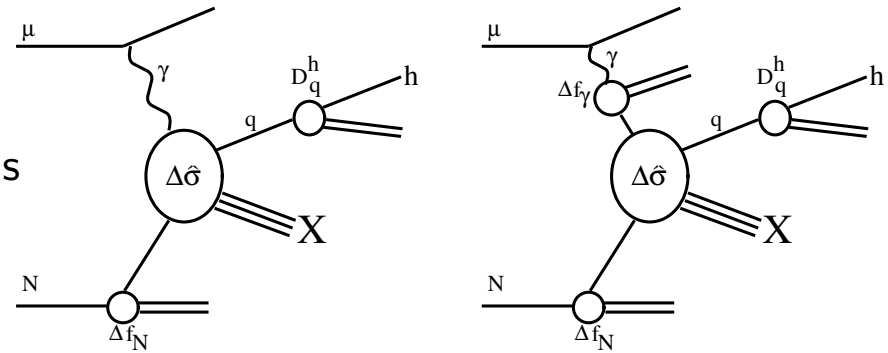
arXiv:1212.1319 [hep-ph]



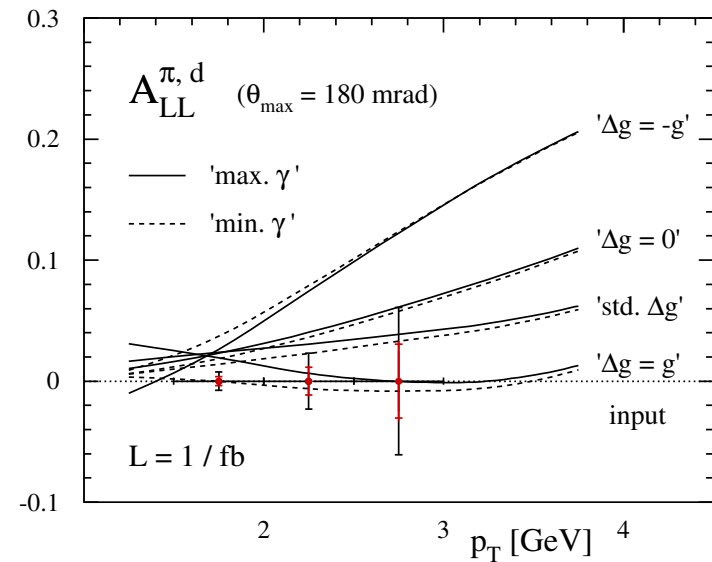
ΔG : High p_T Hadron Photo-production

- NLO pQCD for
[Polarised] Photoproduction of Inclusive Hadrons

Jäger et al., EPJ. C44 (2005)
[arXiv:hep-ph/0505157]

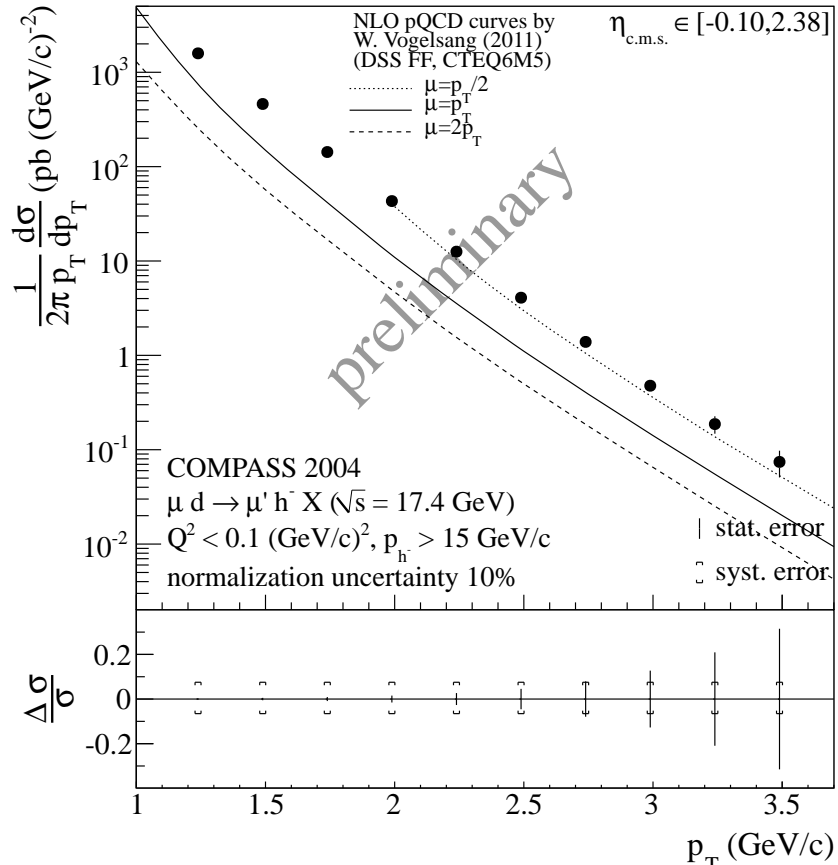


- Projections (1 fb^{-1}) compared to GRSV options
Polarised photon structure explored based on extreme scenarios: limited impact
- Total COMPASS integrated luminosity: $\sim 4 \text{ fb}^{-1}$
- “Threshold Resummation”
X-section 3÷4 higher



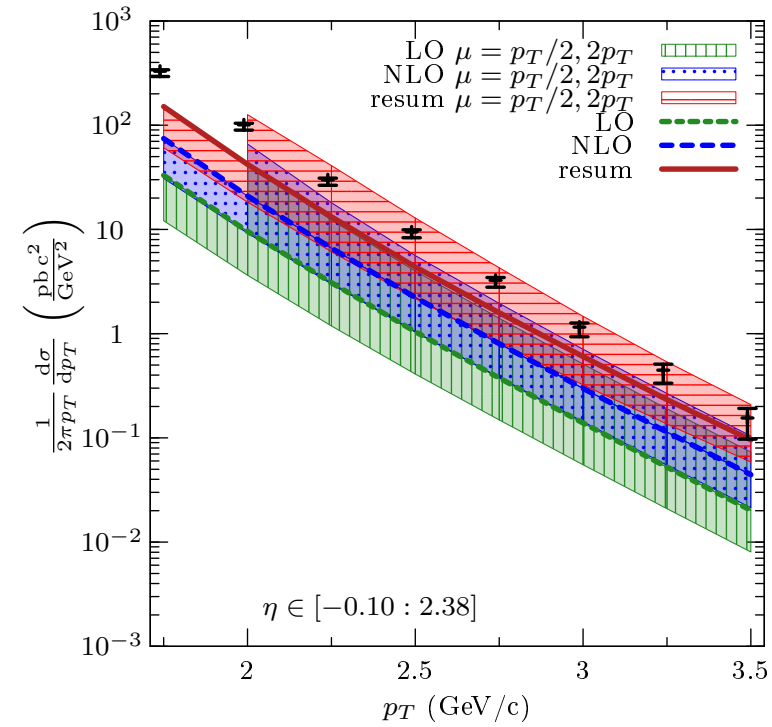
$\sim 4 / \text{fb}$ for all of COMPASS

ΔG : Hadron Photo-production X-section *vs.* p_T



Measured X-section
(*compared to NLO calculation*)

arXiv:1207.2022 [hep-ex]



New calculation w/ “threshold resummation”
(*compared to data and old-calculation*)

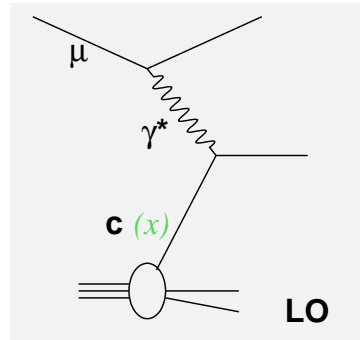
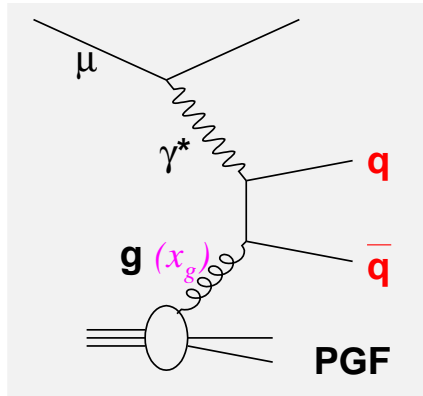
de Florian, Pfeuffer, Schäfer, Vogelsang
arXiv:1305.6468 [hep-ph]

Outlook

- Promising first results from 2011 Longitudinal data taking
- $\Delta G/G$ toward NLO accuracy
- The 2011 polarized proton run closes the first phase of COMPASS.
COMPASS-II proposal approved by CERN Research Board.
Including GPD dedicated measurements:
 - Short test run in 2012.
 - Data taking in 2016/17.

SPARES

ΔG : Open charm *vs.* high p_T



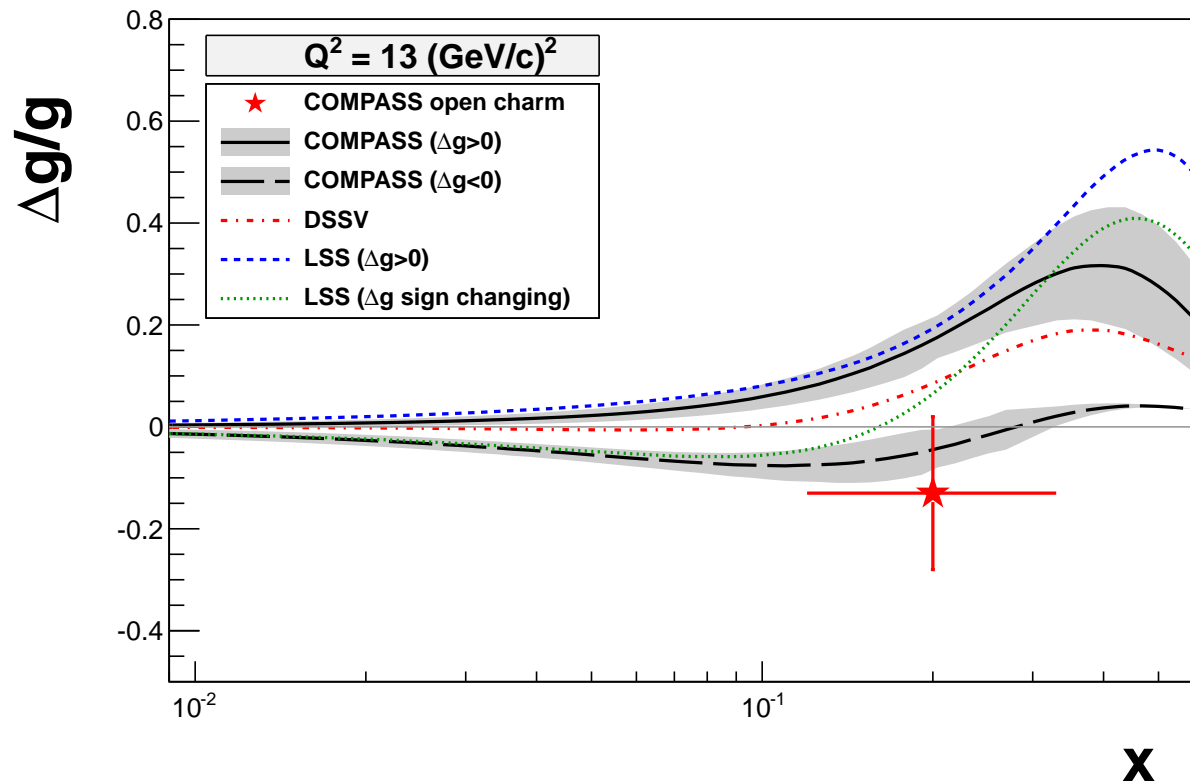
Intrinsic charm: Expected at large x
(Brodsky et al., Phys.Lett. B93 (1980))
 Probed here at $x = 10^{-4} \div 10^{-2} \ll x_g$
 \Rightarrow Neglect intrinsic charm

- $q = c$: **Open Charm** production
 - Generated by PGF at LO
 - Resolved γ small (high x_γ) \Rightarrow COMPASS Golden Channel
 - Experimentally difficult
 - pQCD scale set by $\hat{s} > 4m_c^2$

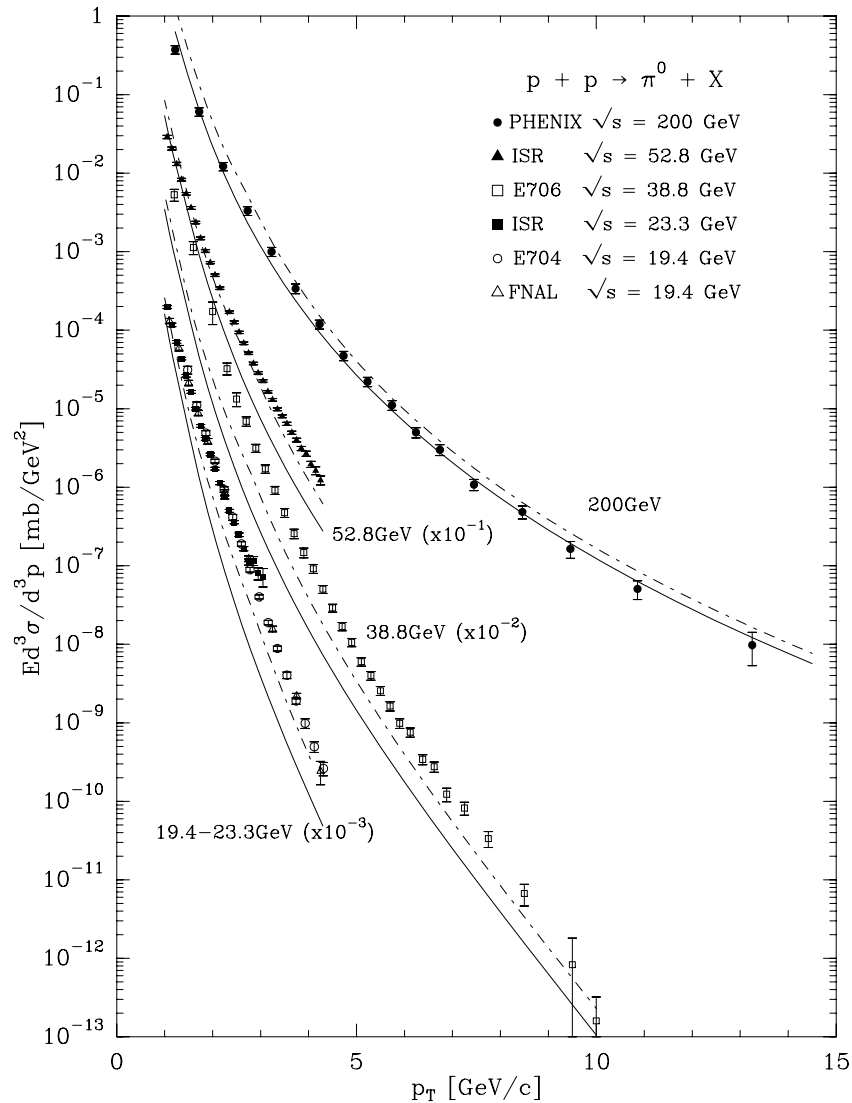
- $q = u, d, s, c$: **High- p_T** Hadrons
 - Competing LO-DIS, QCD-Compton
 - Competing resolved γ processes.
 - Higher statistics
 - pQCD scale set by p_T or Q^2

ΔG : Global DIS + open charm NLO fit

- NLO corrected $\Delta G/G$ included in NLO QCD fit of polarised parton distributions



ΔG : High p_T Hadron $p + p$ production *vs.* \sqrt{s}



Bourrely and Soffer,

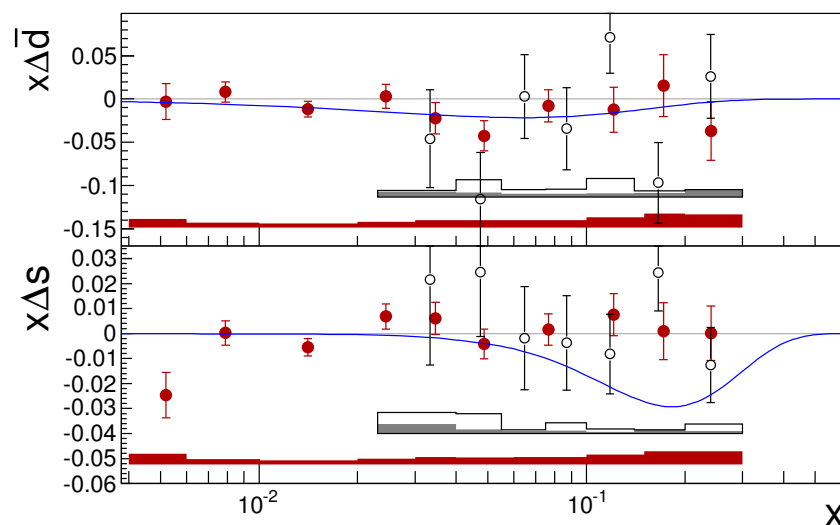
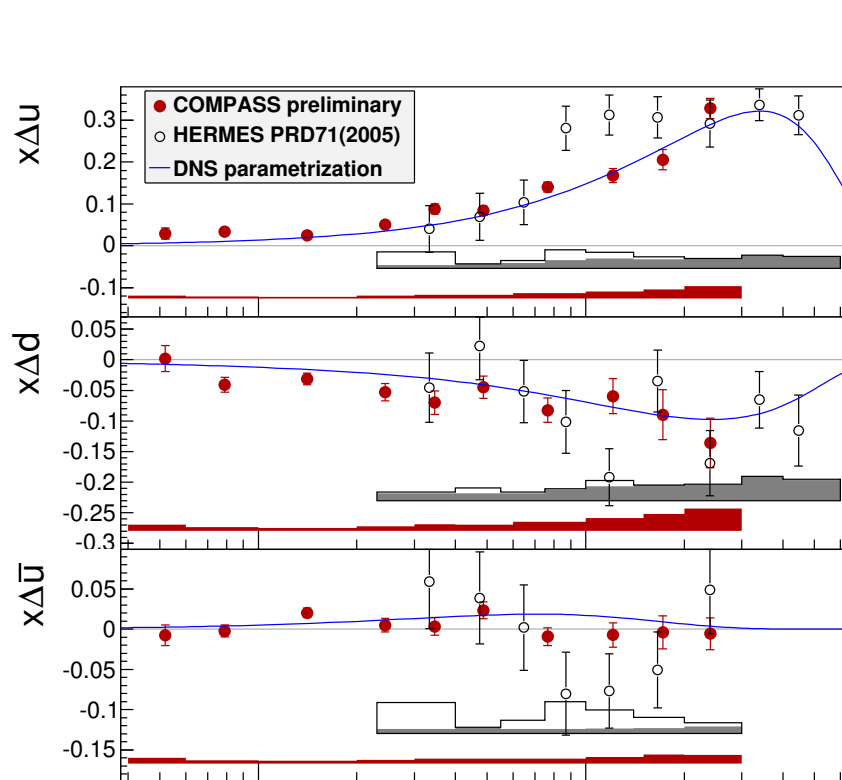
Eur. Phys. J. C **36** (2004)

[*arXiv:hep-ph/0311110*]

⇒ Need validate pQCD framework
in COMPASS ($\sqrt{s} \simeq 17$ GeV) case

SIDIS: Flavor separation

- SIDIS can make up for lack of ν and Drell-Yan polarized data.
- QPM fit to COMPASS data, using LO unpolarized PDFs and FFs.



- Δs compatible w/ 0, at variance to QCD fit of Incl. data.
- Δs very sensitive upon choice of FF.

- Global QCD fit including SIDIS: DSSV [[arXiv:0904.3821](https://arxiv.org/abs/0904.3821) [*hep-ex*]].

Open charm vs. x_{Bj} 