COMPASS results on the nucleon longitudinal spin structure

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on the behalf of COMPASS collaboration

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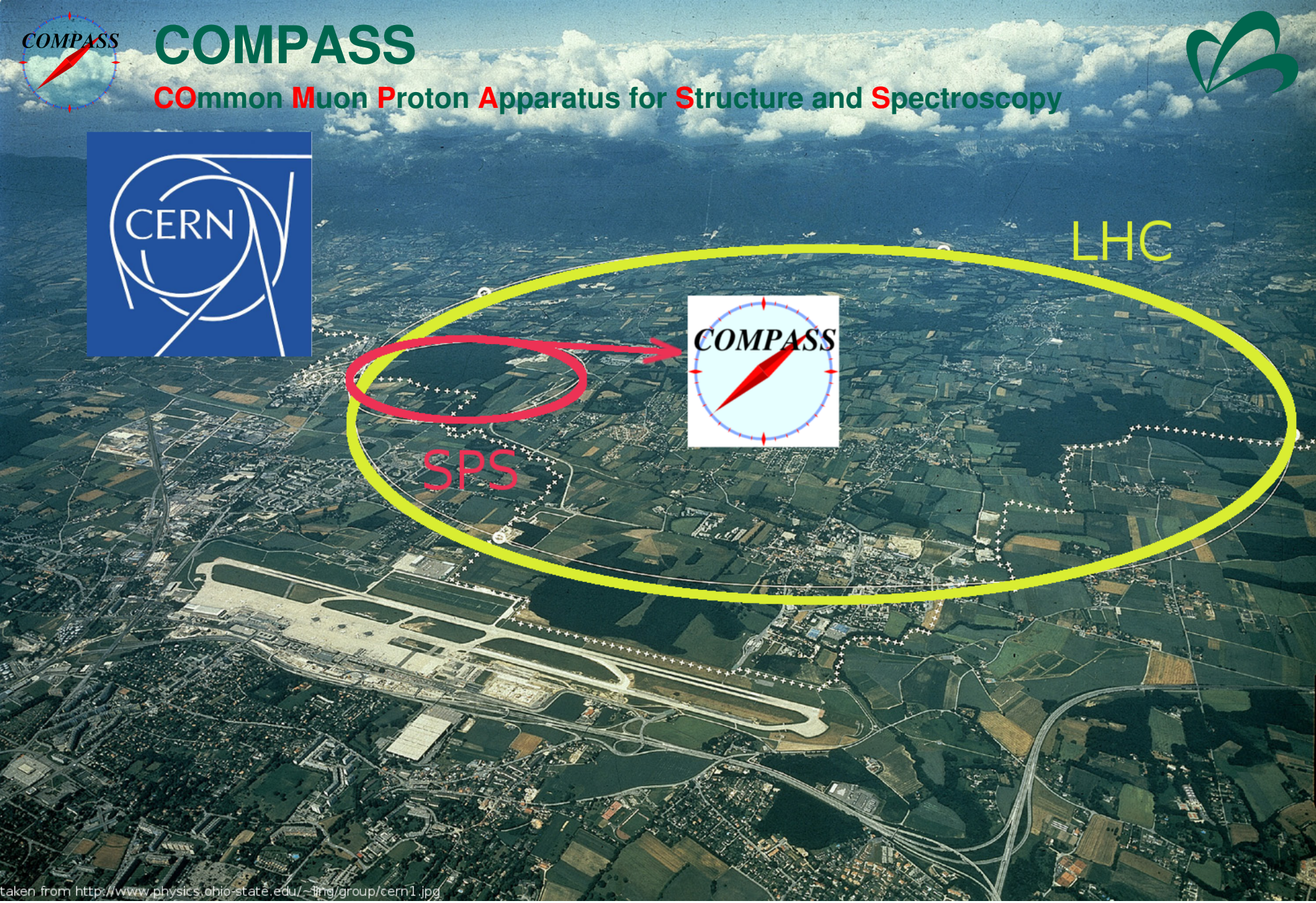
25.AUG.2014

Outline

Outline

COMPASS

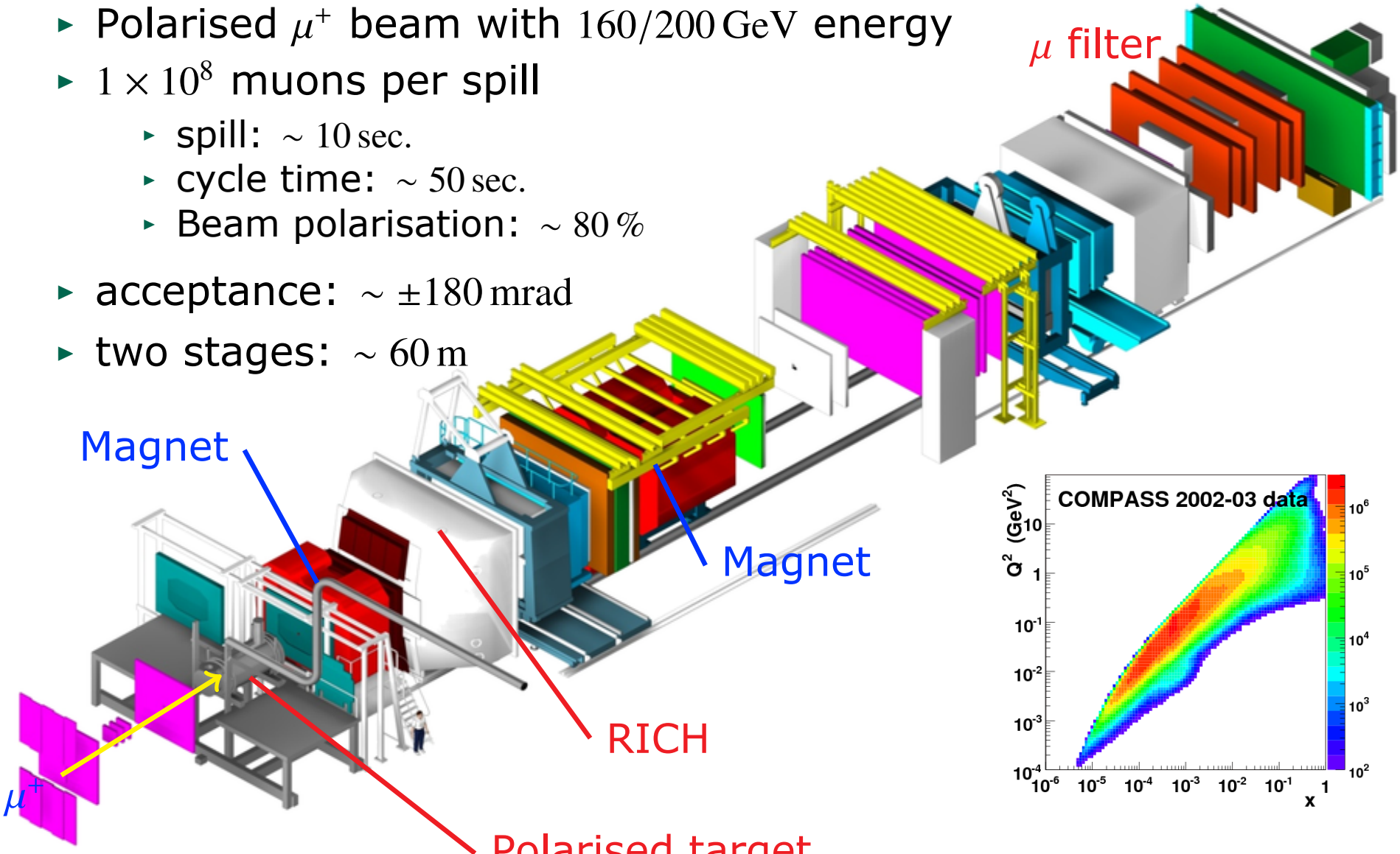
COmmon **M**uon **P**roton **A**pparatus for **S**tructure and **S**pectroscopy



COMPASS

Setup

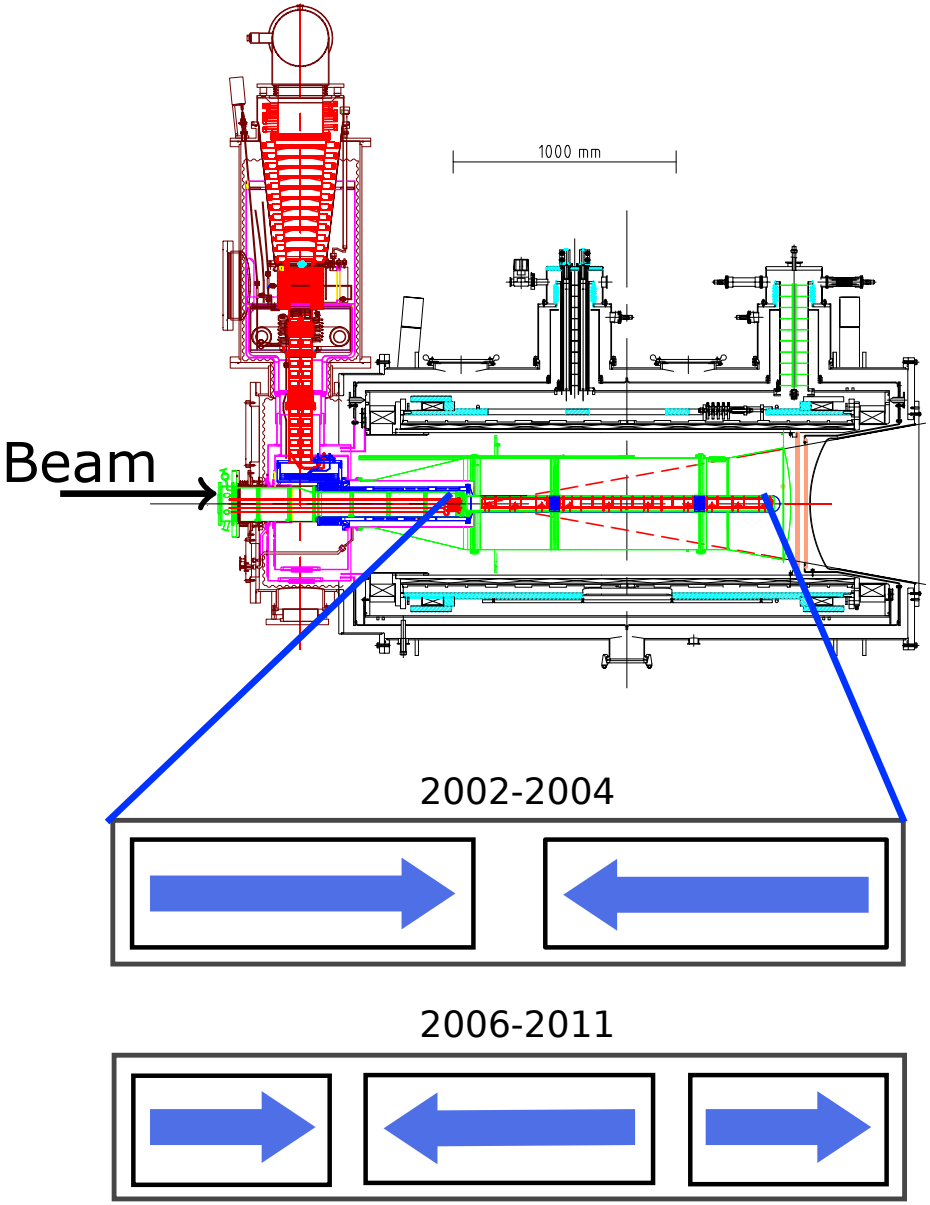
- Polarised μ^+ beam with $160/200\,\mathrm{GeV}$ energy
- 1×10^8 muons per spill
  - spill: $\sim 10\,\mathrm{sec.}$
  - cycle time: $\sim 50\,\mathrm{sec.}$
  - Beam polarisation: $\sim 80\,\%$
- acceptance: $\sim \pm 180\,\mathrm{mrad}$
- two stages: $\sim 60\,\mathrm{m}$



Kinematic acceptance

COMPASS

Polarised target



- Target cell
  - -2004: 2 cells
  - 2006-: 3 cells
- Target material
  - -2006: ^{6}LiD
  - 2007-: NH_3
- Polarisation
  - $^{6}LiD \sim 50\,\%$
  - $NH_3 \sim 90\,\%$
- Rotate magnetic field to cancel acceptance difference
- Reverse microwave once in a while to cancel corelations

COMPASS data taking

Year	Target	E_{beam}	Detail
2002	Deuteron	160	Longitudinal mode(~20 % transverse mode)
2003	Deuteron	160	Longitudinal mode(~20 % transverse mode)
2004	Deuteron	160	Longitudinal mode(~20 % transverse mode)
2005			Shutdown & upgrade
2006	Deuteron	160	New setup, longitudinal mode
2007	Proton	160	1/2 longitudinal, 1/2 transverse
2008			Hadron physiscs
2009			Hadron physiscs
2010	Proton	160	Transverse
2011	Proton	200	Longitudinal
2012	Hydrogen		Hadron physics(Primakoff) + DVCS test run and SIDIS
2013			Shutdown & upgrade
2014	Proton		Drell-Yan
2015	Proton		Drell-Yan
2016	Hydrogen		DVCS
2017	Hydrogen		DVCS

Phase-I

Phase-II

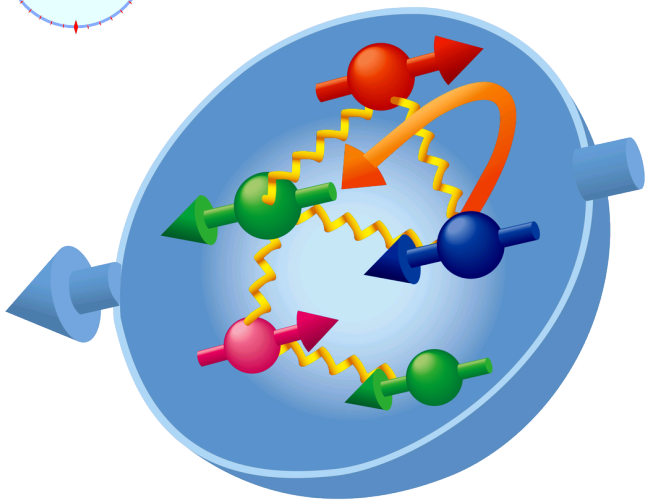
List of talks related to COMPASS

in PANIC2014

Date	Title
25.Aug	Transverse structure of the nucleon at COMPASS
25.Aug	Polarised Drell-Yan measurement in the COMPASS experiment at CERN
25.Aug	COMPASS polarized target for pion-induced Drell-Yan experiment
25.Aug	COMPASS results on the nucleon longitudinal spin structure
26.Aug	The GPD physics program at COMPASS: present results and future perspectives
28.Aug	Studies of light mesons at COMPASS
28.Aug	Test of the OZI rule and spin alignment measurements with the COMPASS > experiment at CERN

Outline

Spin crisis



$$S_N = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{q,g}$$

Quarks

Well known

$\Delta\Sigma = 0.30 \pm 0.01 \pm 0.02$

PLB 647 (2007) 8

Gluons

Poorly known

$\Delta G = 0?, \neq 0?, > 0?, < 0?$

COMPASS, HERMES, CLAS, STAR, PHENIX give hints.

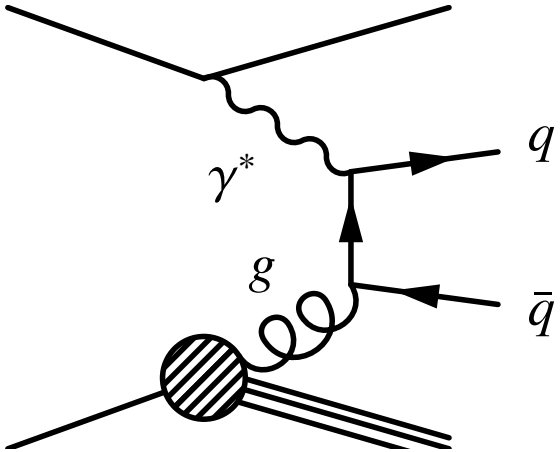
Angular Orbital Moment

unknown

Future GPDs measurements give hints.

Access to gluon polarisation

Photon Gluon Fusion



$$A_{PGF} = \frac{N^{\leftrightarrows}_{PGF} - N^{\rightrightarrows}_{PGF}}{N^{\leftrightarrows}_{PGF} + N^{\rightrightarrows}_{PGF}}$$

$$\Rightarrow \Delta G/G$$

N_{PGF}: the number of PGF events

Methods

- High-p_T hadron pair($Q^2 > 1$ and $Q^2 < 1$)

  $\gamma^* g \rightarrow q\bar{q} \Rightarrow h^+h^-$ or 2 jets

  ☺High statistics

  ☹large physical backgrounds, strong MC dependence

- Open charm meson

  $\gamma^* g \rightarrow c\bar{c} \Rightarrow D^0$ meson

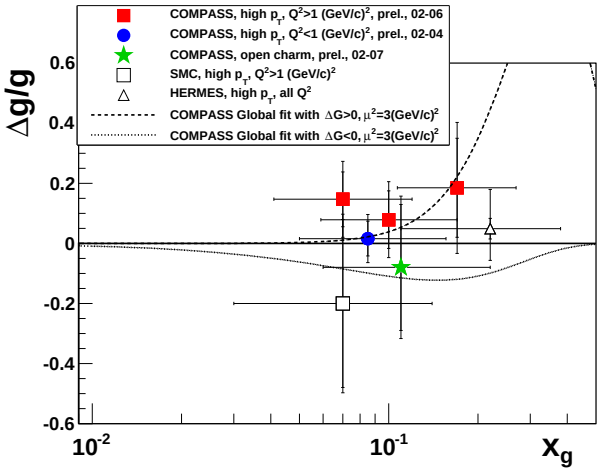
  ☺Pure PGF events, weak MC dependence

  ☹Low statistics

$\Delta g/g$ results @ COMPASS

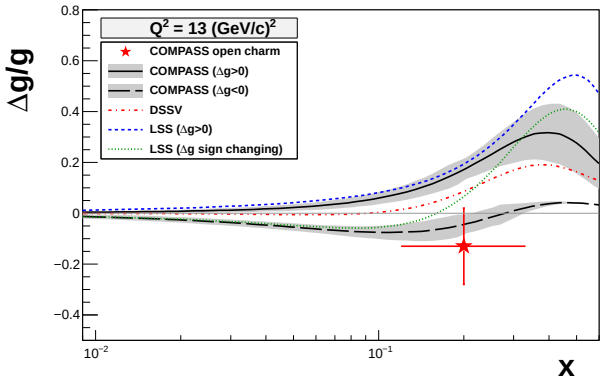
Recent published results

LO @ high-p_T hadron pair



PLB 718 (2013) 922

NLO @ open charm



PRD 87 (2013) 052018

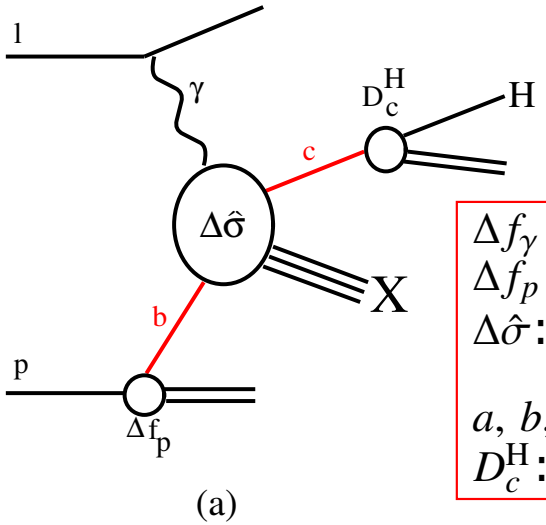
$\Delta g/g$ @ COMPASS

- $+0.02 \pm 0.09 \pm 0.06$ @ $x_g = \langle 0.01 \rangle$ LO, high-p_T pair, $Q^2 < 1$, PLB 633 (2006) 25
- $+0.13 \pm 0.06 \pm 0.06$ @ $x_g = \langle 0.09 \rangle$ LO, high-p_T pair, $Q^2 > 1$, PLB 718 (2013) 922
- $-0.47 \pm 0.44 \pm 0.15$ @ $x_g = \langle 0.11 \rangle$ LO, open charm, arXiv:0802.3023
- $-0.49 \pm 0.27 \pm 0.11$ @ $x_g = \langle 0.11 \rangle$ LO, open charm, PLB 676 (2009) 31
- $-0.06 \pm 0.21 \pm 0.08$ @ $x_g = \langle 0.20 \rangle$ LO, open charm, PRD 87 (2013) 052018
- $-0.13 \pm 0.15 \pm 0.15$ @ $x_g = \langle 0.11 \rangle$ NLO, open charm, PRD 87 (2013) 052018

Theoretical framework

- based on JSV framework (EPJ C44 (2005) 533)
- collinear pQCD analysis at NLO
- photoproduction of single inclusive hadrons: $l + N \rightarrow l' + H + X$
  $Q^2 < 1\,(\mathrm{GeV/c})^2$

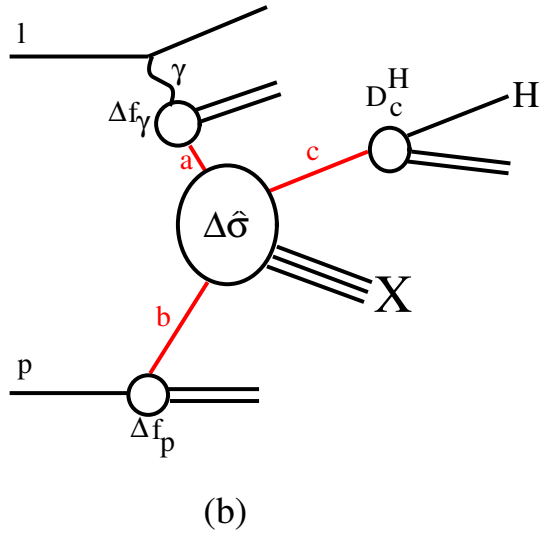
Direct γ-contribution



(a)

Δf_γ: Photon's parton density
Δf_p: Nucleon p's parton density
$\Delta\hat{\sigma}$: spin-dependent partonic hard scattering cross section
$a, b, c = q, \bar{q}, g$
D_c^H: fragmentation function

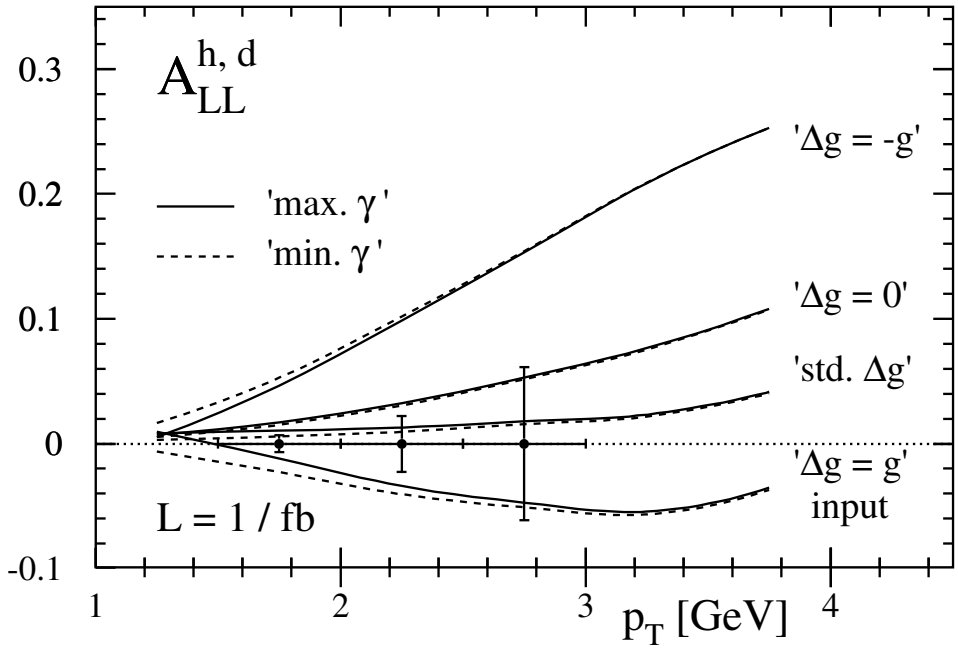
Resolved γ-contribution

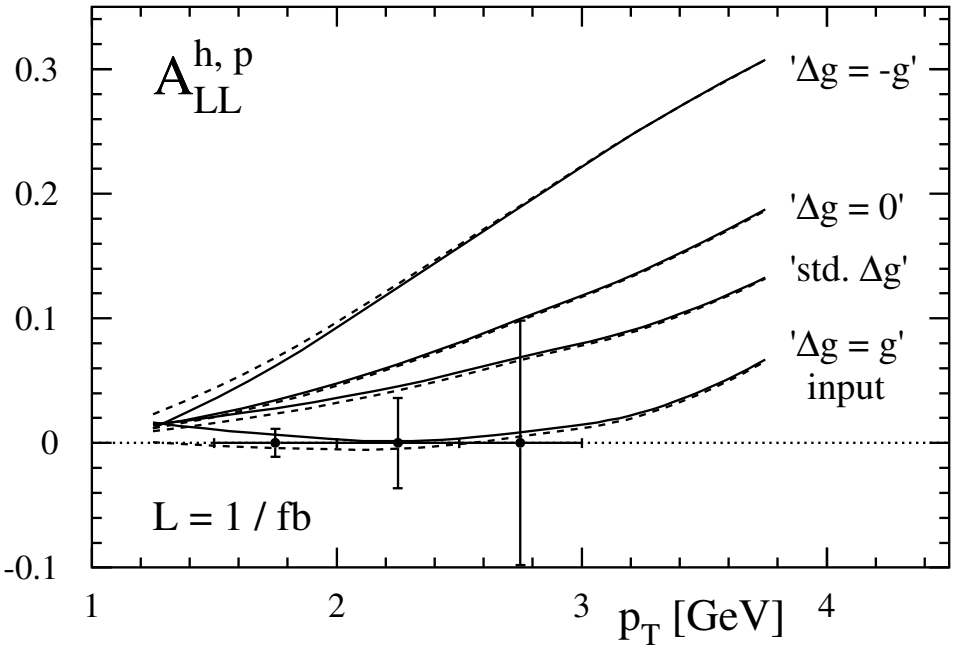


(b)

Theoretical estimations of A_{LL}

Ref: EPJC 44 (2005) 533, Fig. 7





- $A_{LL} \equiv \dfrac{d\Delta\sigma}{d\sigma}$
- Small impact of resolved photon PDF uncertainty at low-p_T
- Luminosity is estimated as $4\,\mathrm{fb}^{-1}$
  $\Rightarrow$ error bars becomes half

Comparison unpolarised cross section

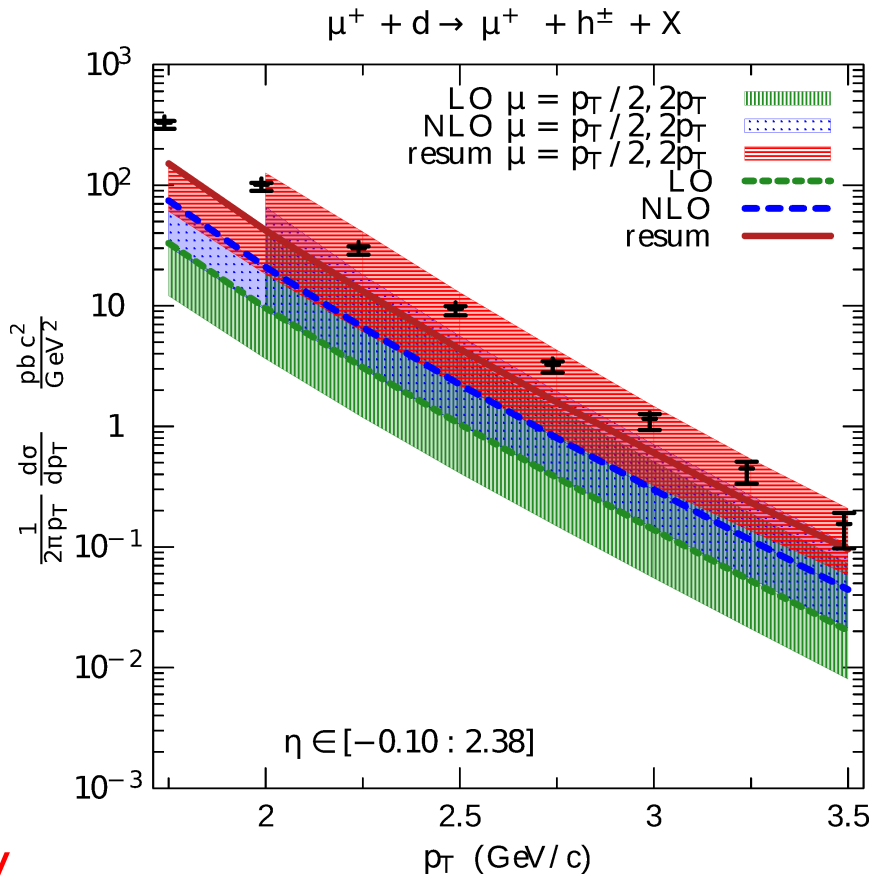
COMPASS data v.s. theoretical calculation

COMPASS data in 2004

- C. Adolph, *et. al.*, PRD 88 (2013) 091101
- $\mu + d \to \mu' + h^{\pm} + X$ cross section at $Q^2 < 0.1\,(\mathrm{GeV/c})^2$

Theoretical calculations

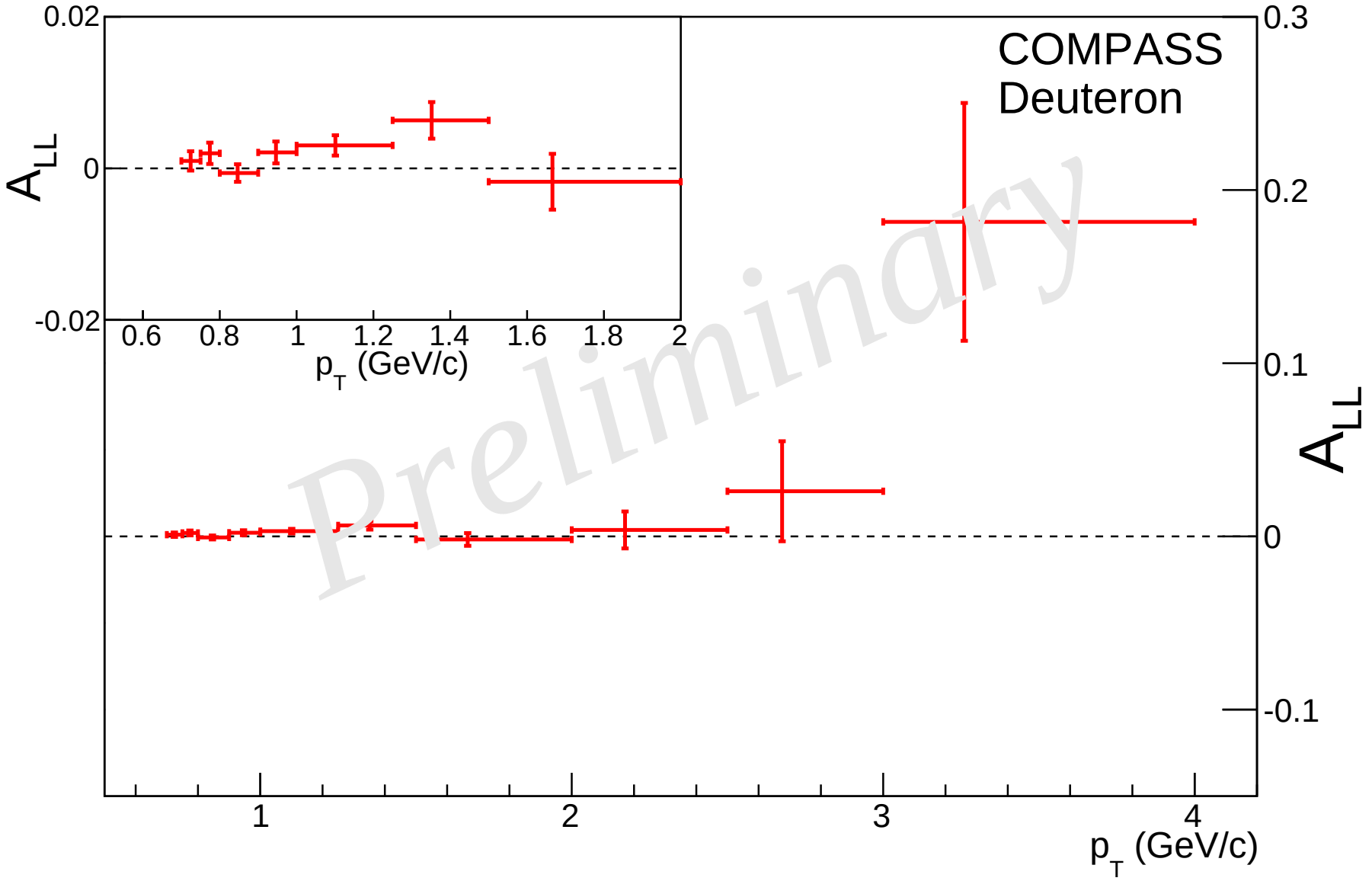
- D. Florian, *et. al.*, PRD 88 (2013) 014024
- Higher-order QCD corrections to the cross section
- Large logarithmic "threshold" corrections
  → improved the agreement between data and theory



⇒ Valid within theoretical uncertainty

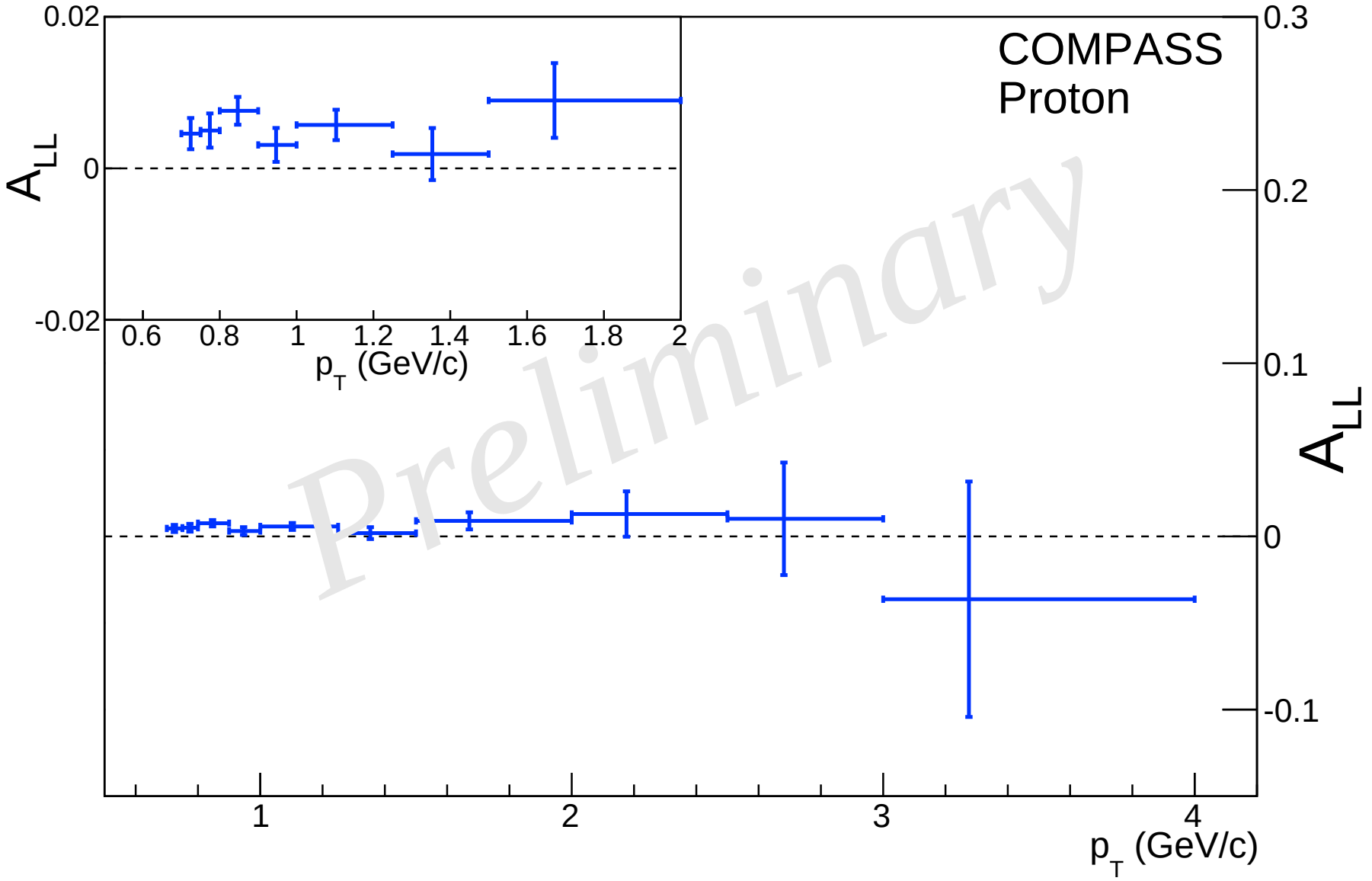
Results: asymmetry

Deuteron



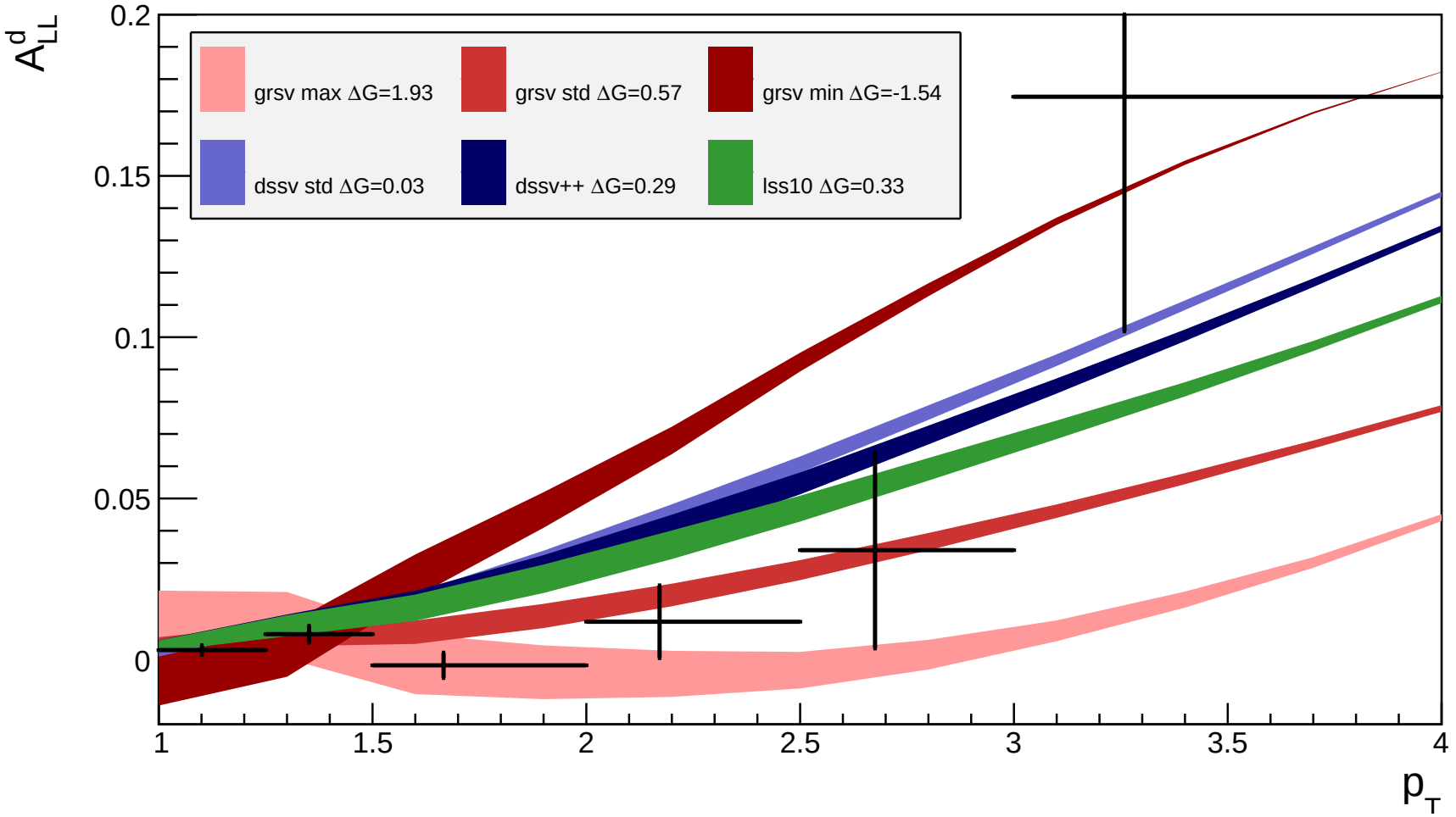
Results: asymmetry

Proton



Comparison: Deuteron A_{LL}

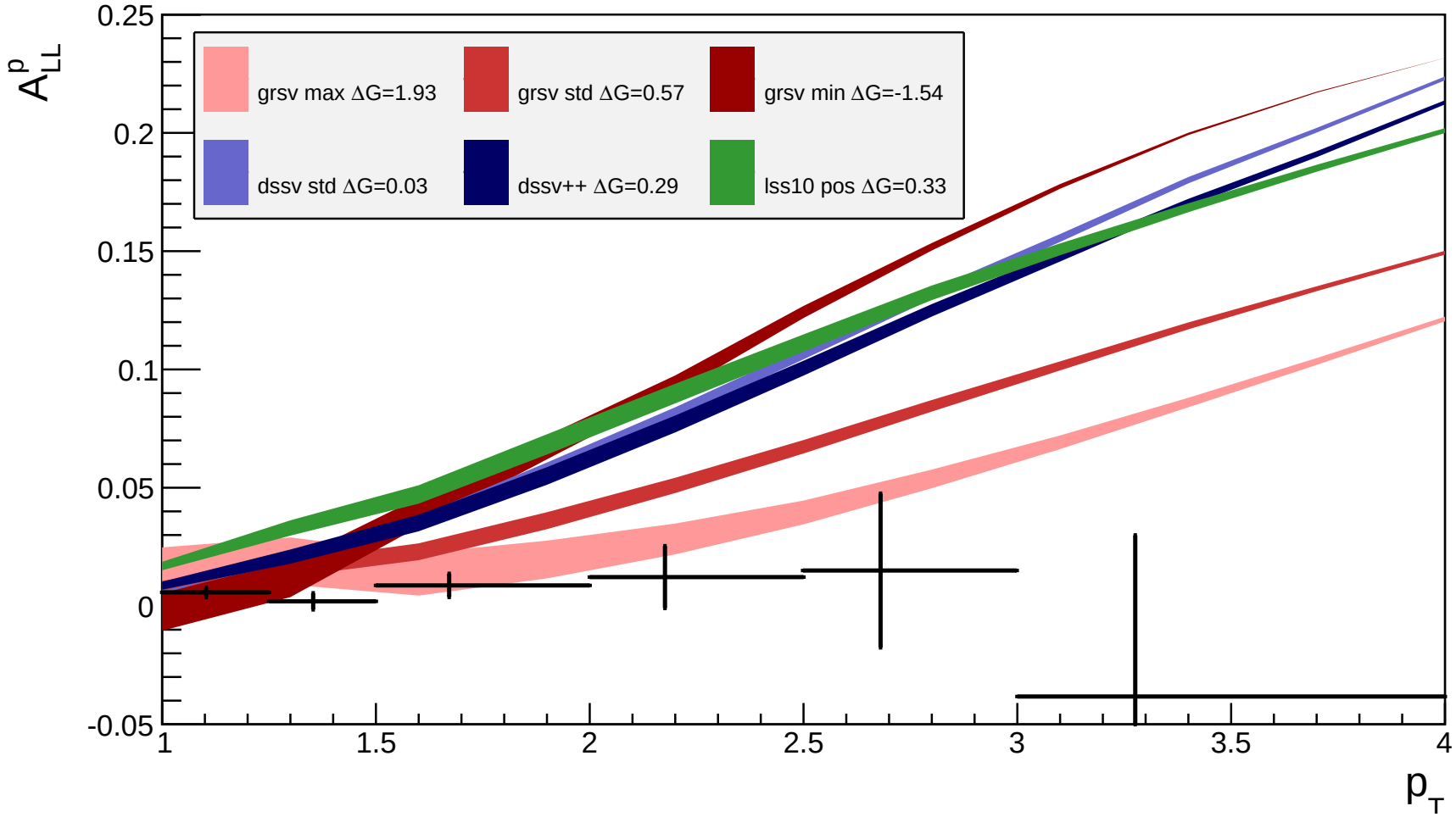
NLO calculation from W. Vogelsang, M. Stratmann and B. Jäger codes



- Calculations suggest a high positive ΔG
- No calculations drawn with gluon resummation
  → to be available in the very near future

Comparison: Proton A_{LL}

NLO calculation from W. Vogelsang, M. Stratmann and B. Jäger codes



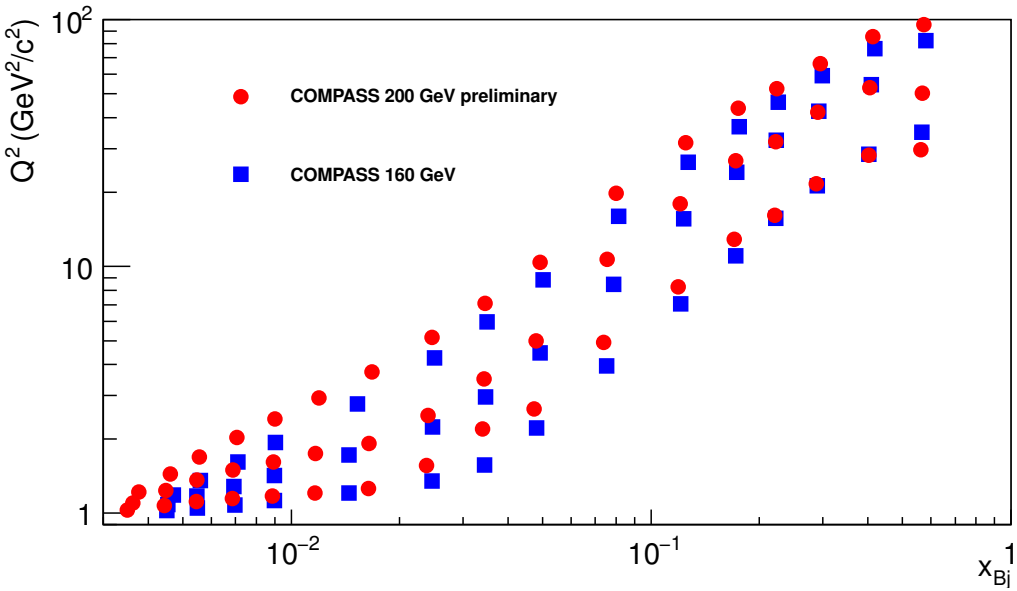
- no PDF can yet explain A_{LL}^{p} at quite high ΔG
- No calculations drawn with gluon resummation
  → to be available in the very near future

Outline

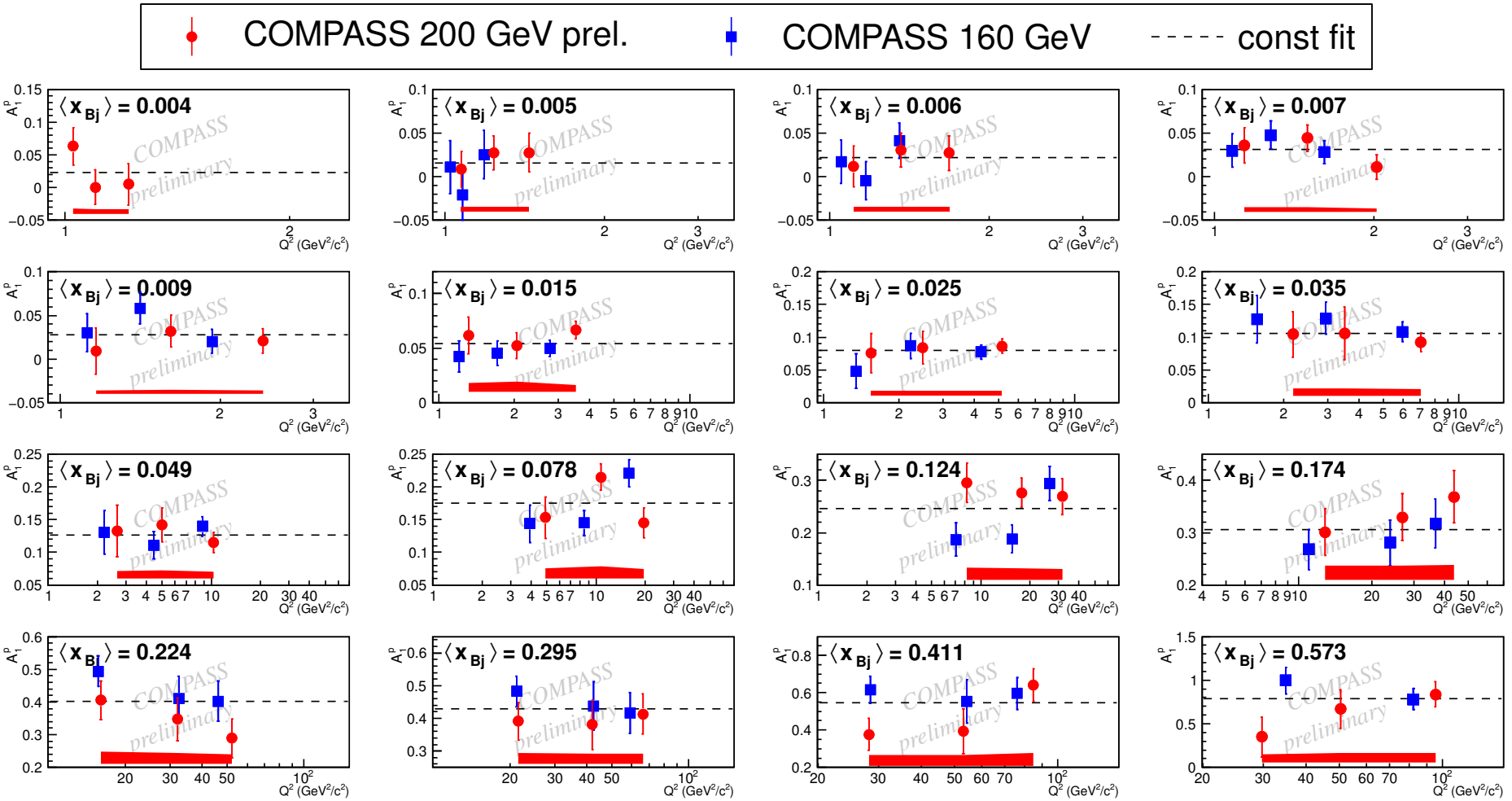
A_1, g_1 extraction from double spin asymmetry

- $A_{LL} = \frac{1}{P_{beam} \cdot P_{target} \cdot f} \cdot \frac{N^{\leftrightarrows} - N^{\rightrightarrows}}{N^{\leftrightarrows} + N^{\rightrightarrows}} = D(A_1 + \eta A_2) \simeq D A_1$
- $A_1 = \frac{g_1 - \gamma^2 g_2}{F_1} \simeq \frac{g_1}{F_1}$
- $g_1 = \frac{F_2}{2x(1+R)} A_1, \quad R \equiv \frac{\sigma_L}{\sigma_T}$

- Data taken in 2007 with 160 GeV/c and 2011 with 200 GeV/c

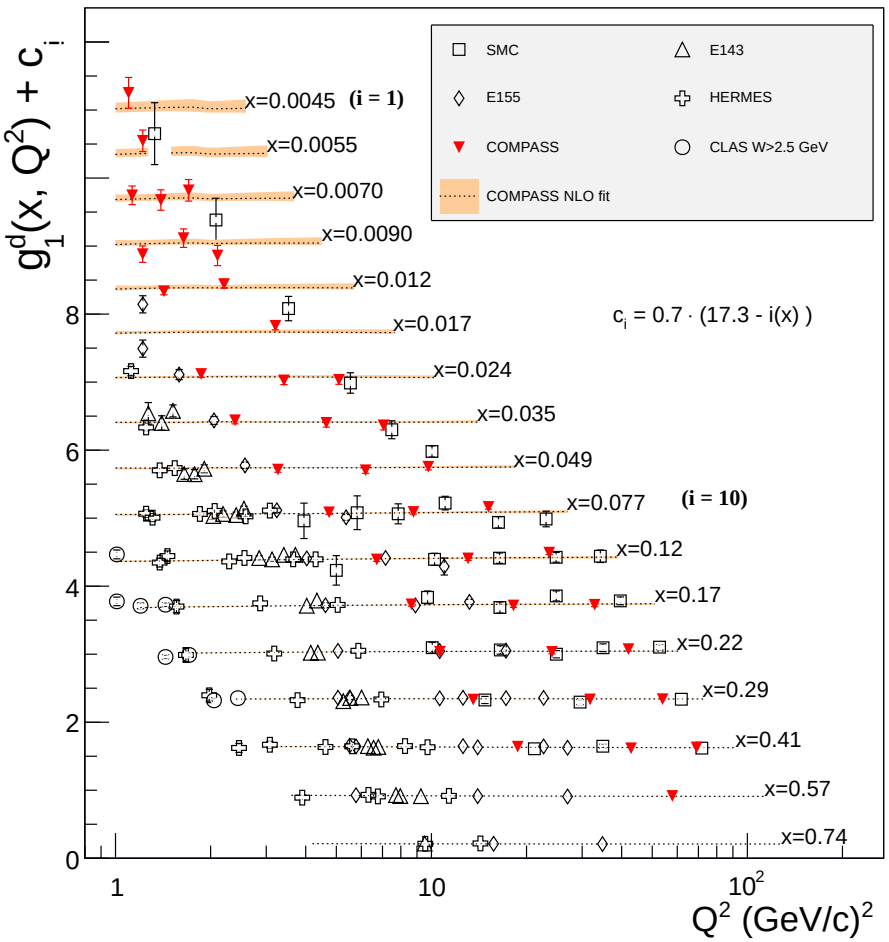


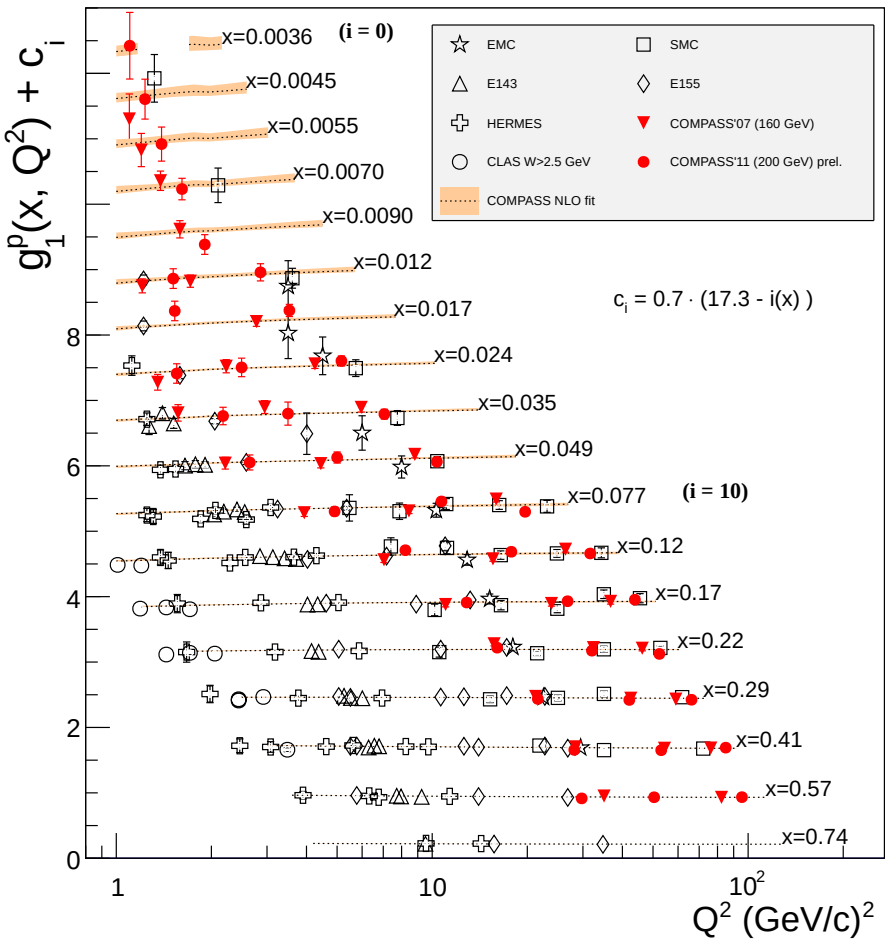
A_1 results



- New asymmetries at low x
- No Q^2 dependencies

World data of g_1^d and g_1^p

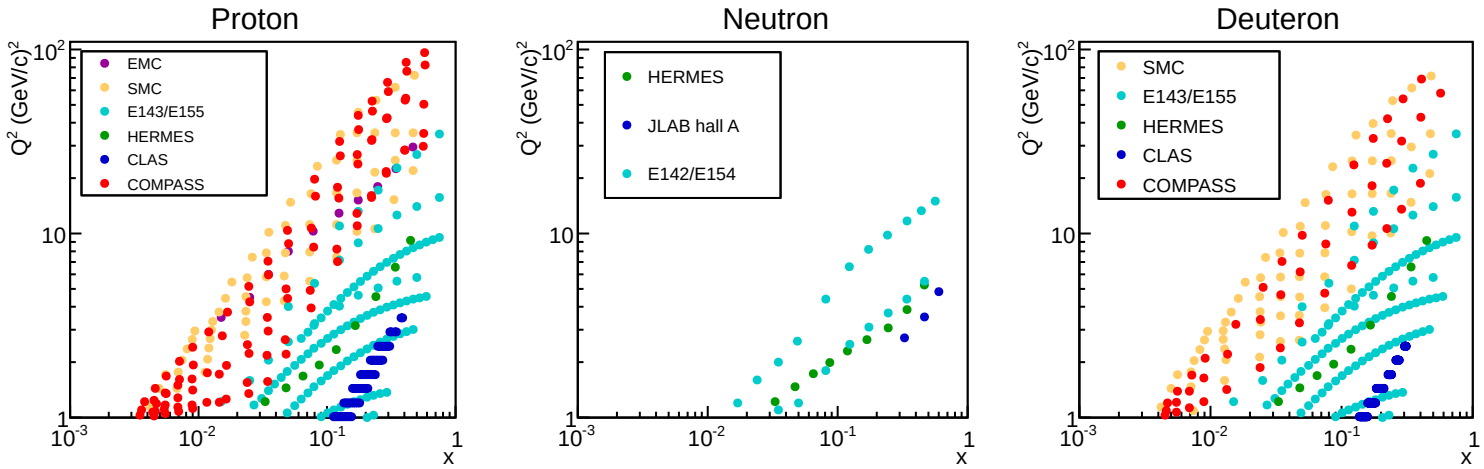




- New COMPASS point for the proton at low x
- New COMPASS NLO QCD fit describes the data well

NLO QCD fit

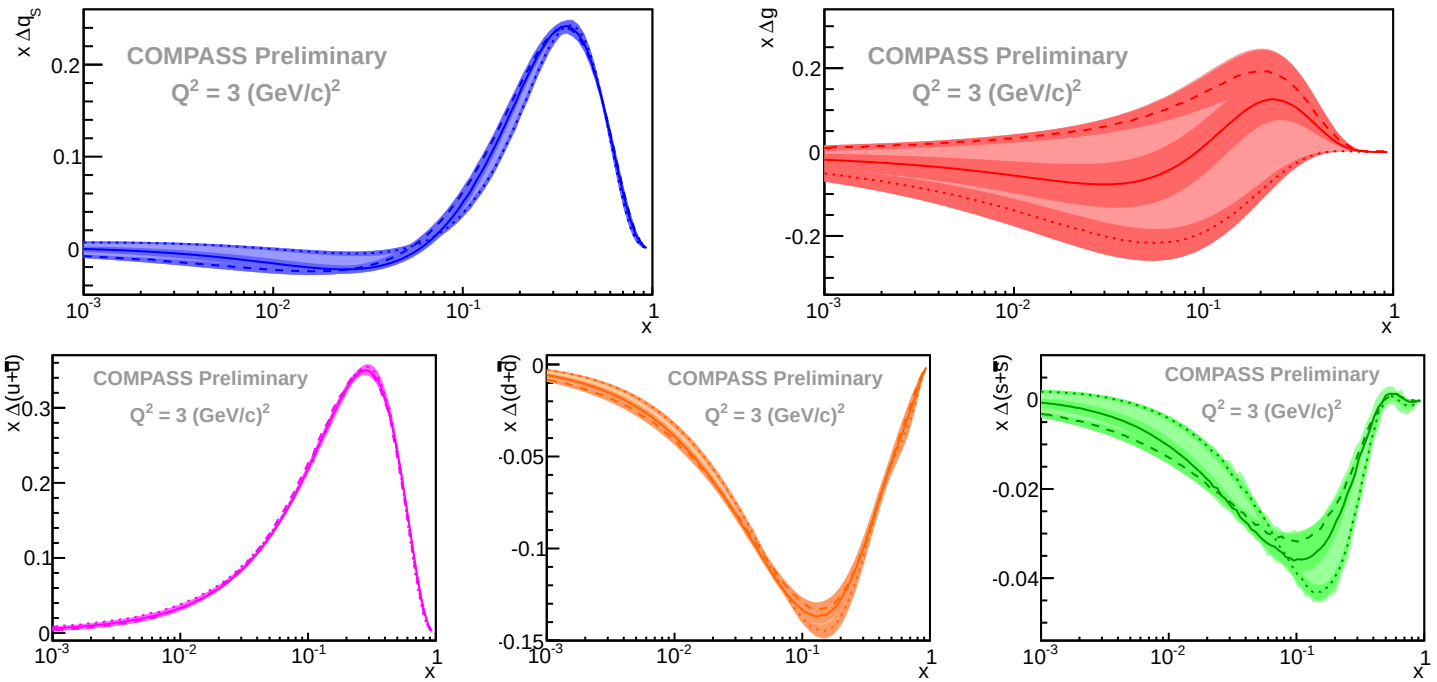
Inputs and constrains



- 139 out of 679 data points
- $g_1^{p(n)} = \frac{1}{9}\left(C_s \otimes \Delta q_s + C_{NS} \otimes \left[\pm\frac{3}{4}\Delta q_3 + \frac{1}{4}\Delta q_8\right] + C_g \otimes \Delta g\right)$
  - $\Delta q_s = \Delta u + \Delta d + \Delta s$
  - $\Delta q_3 = \Delta u - \Delta d$
  - $\Delta q_8 = \Delta u + \Delta d - 2\Delta s$
  - $C_s,\ C_{NS},\ C_g$: Wilson coefficients
- Positivity constrains: $|\Delta(s+\bar{s})| < (s+\bar{s})$, $|\Delta g| < g$

NLO QCD fit

Results



- Depending on ΔG solutions: $\Delta G > 0$, $\Delta G \sim 0$, $\Delta G < 0$
- $0.256 < \Delta\Sigma < 0.336$ at $Q^2 = 3\ (\mathrm{GeV/c})^2$
- Uncertainty comes from the lack of
  - knowlage of functional form
  - data point to constrain gluon distribution

Outline

Introduction

Gluon polarisation

Proton spin structure function

Summary

Summary

Gluon polarisation

- A_{LL} for single hadron photoproduction at high-p_T on proton and deuteron targets
- Present NLO calculations do not agree simulateneously with deuteron and proton data
- Extraction of ΔG from A_{LL} done after the inclusion of soft gluon resummation

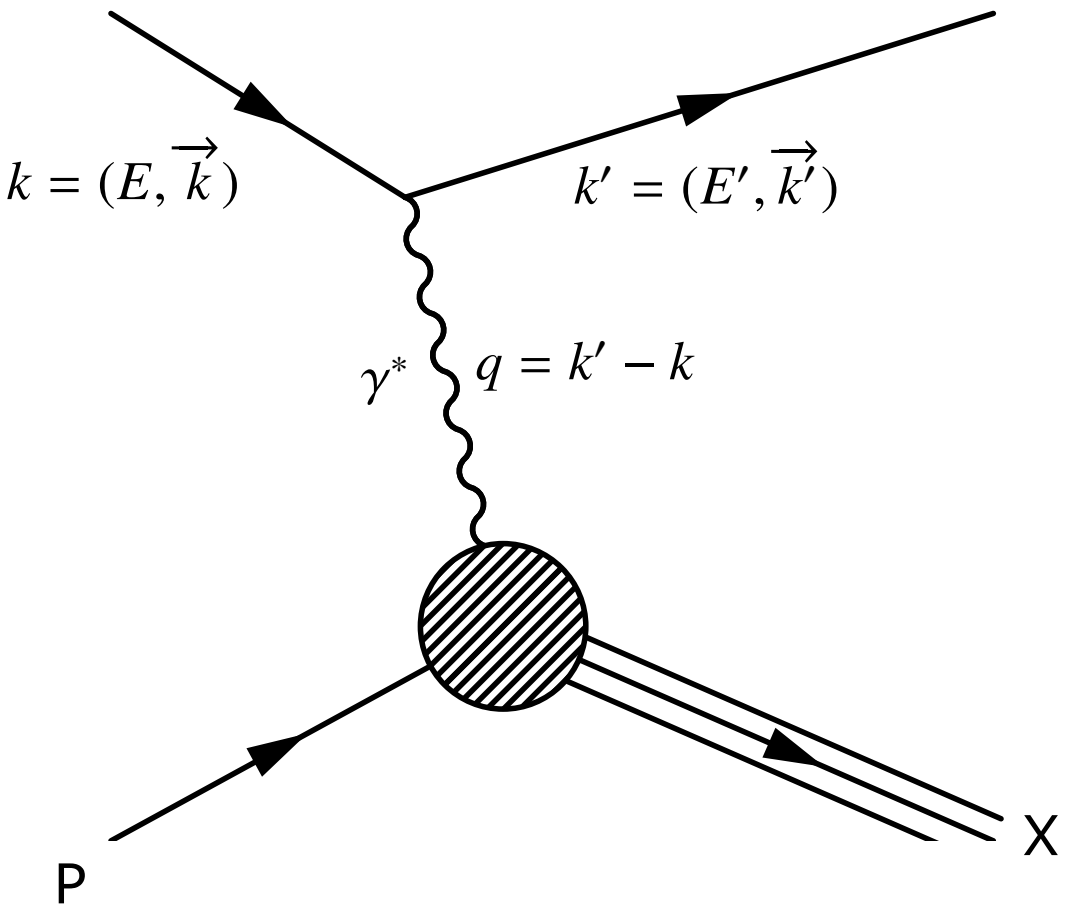
Proton spin structure function

- New measurements of A_1^p and g_1^p at $200\ \mathrm{GeV/c}$
- Updated NLO QCD fit for g_1 world data
- Extraction of polarised PDF for each flavour

Backup

DIS

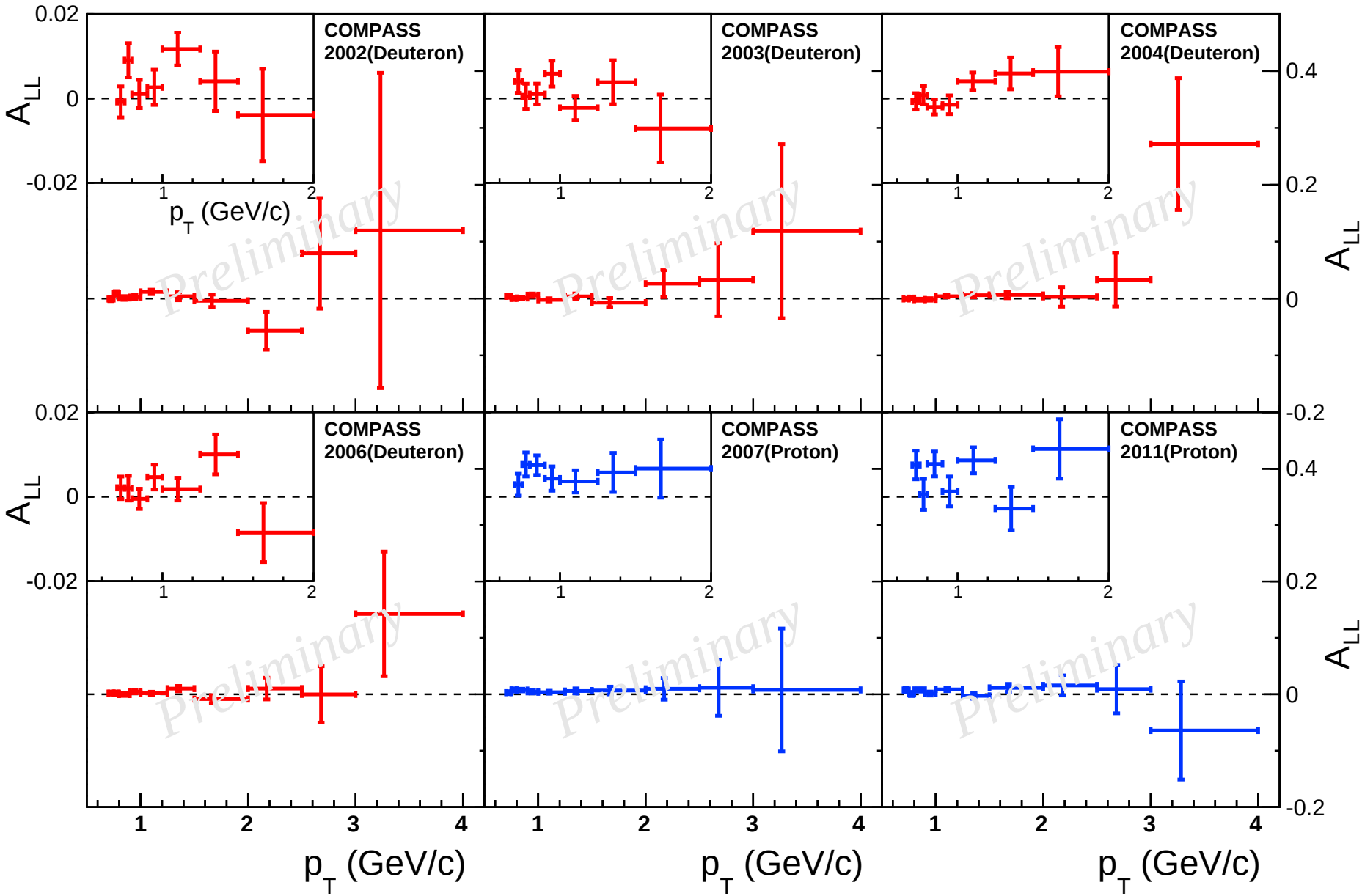
observables



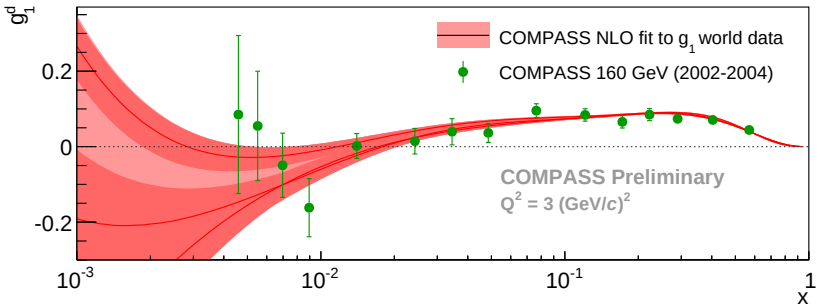
- $k = (E, \vec{k})$
- $k' = (E', \vec{k'})$
- $q = k' - k$
- $Q^2 = -q^2$
- $\nu = E - E'$
- $x_{Bj} = \frac{Q^2}{2M\nu}$
- $y = \frac{E-E'}{E}$

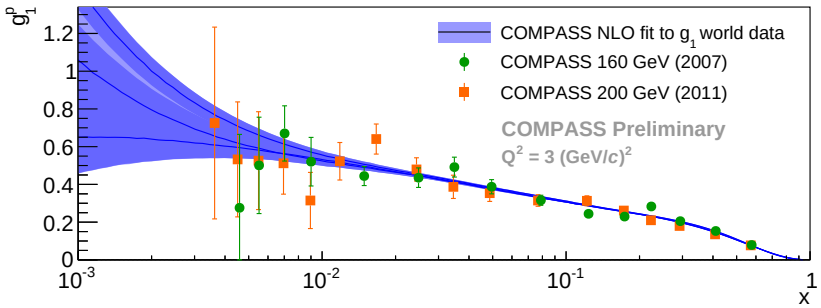
Results: asymmetry

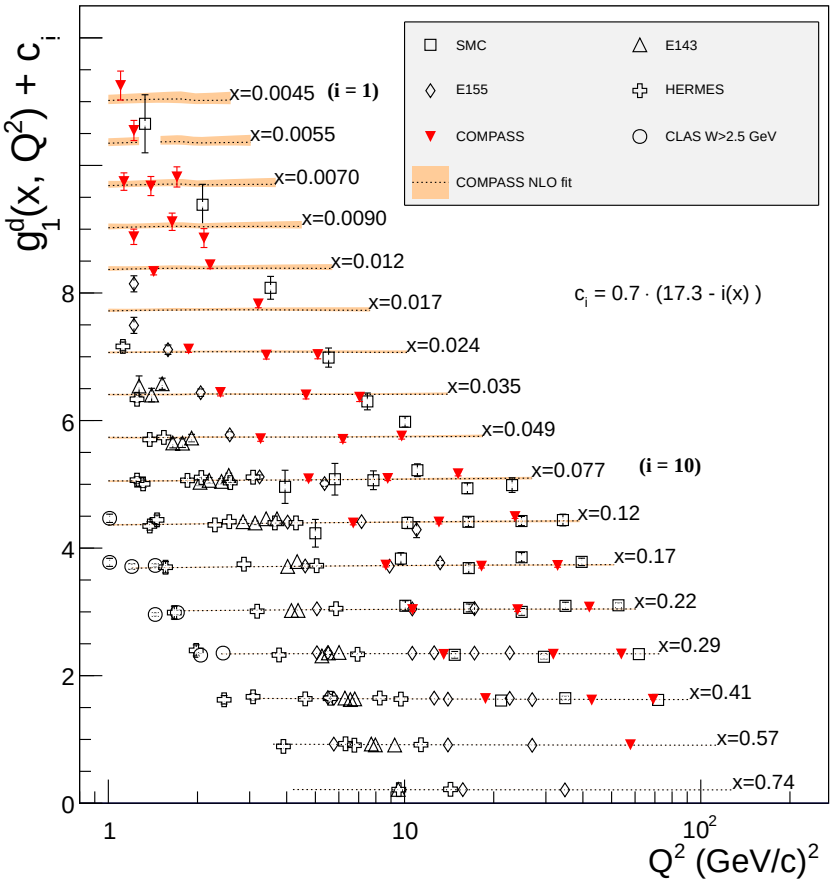
Year by year

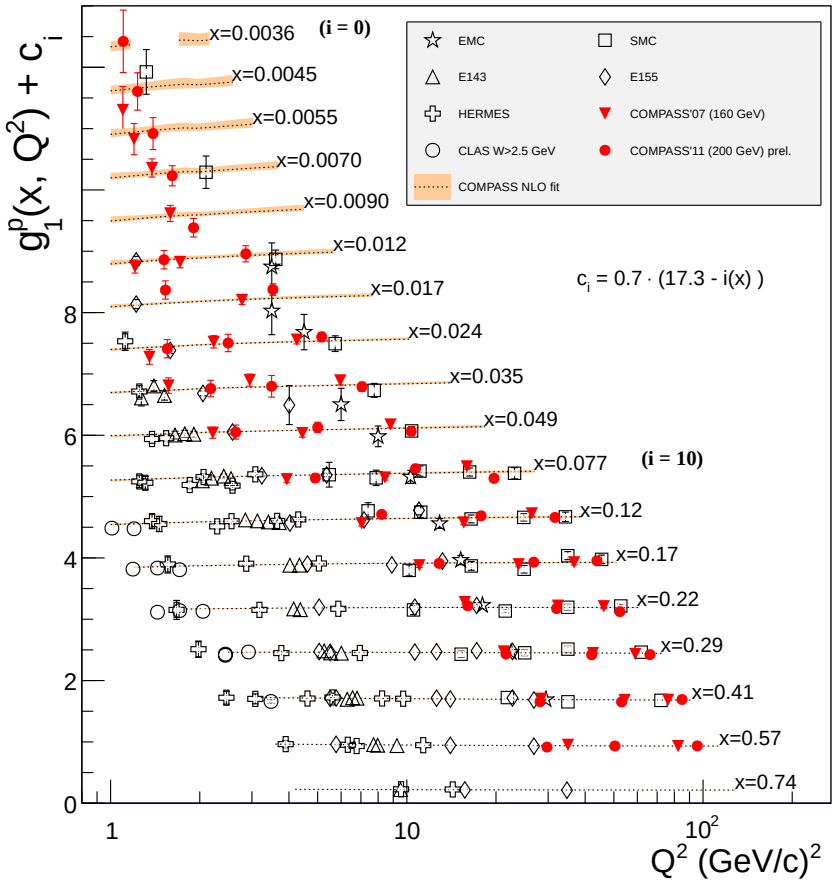


g_1 NLO fit results



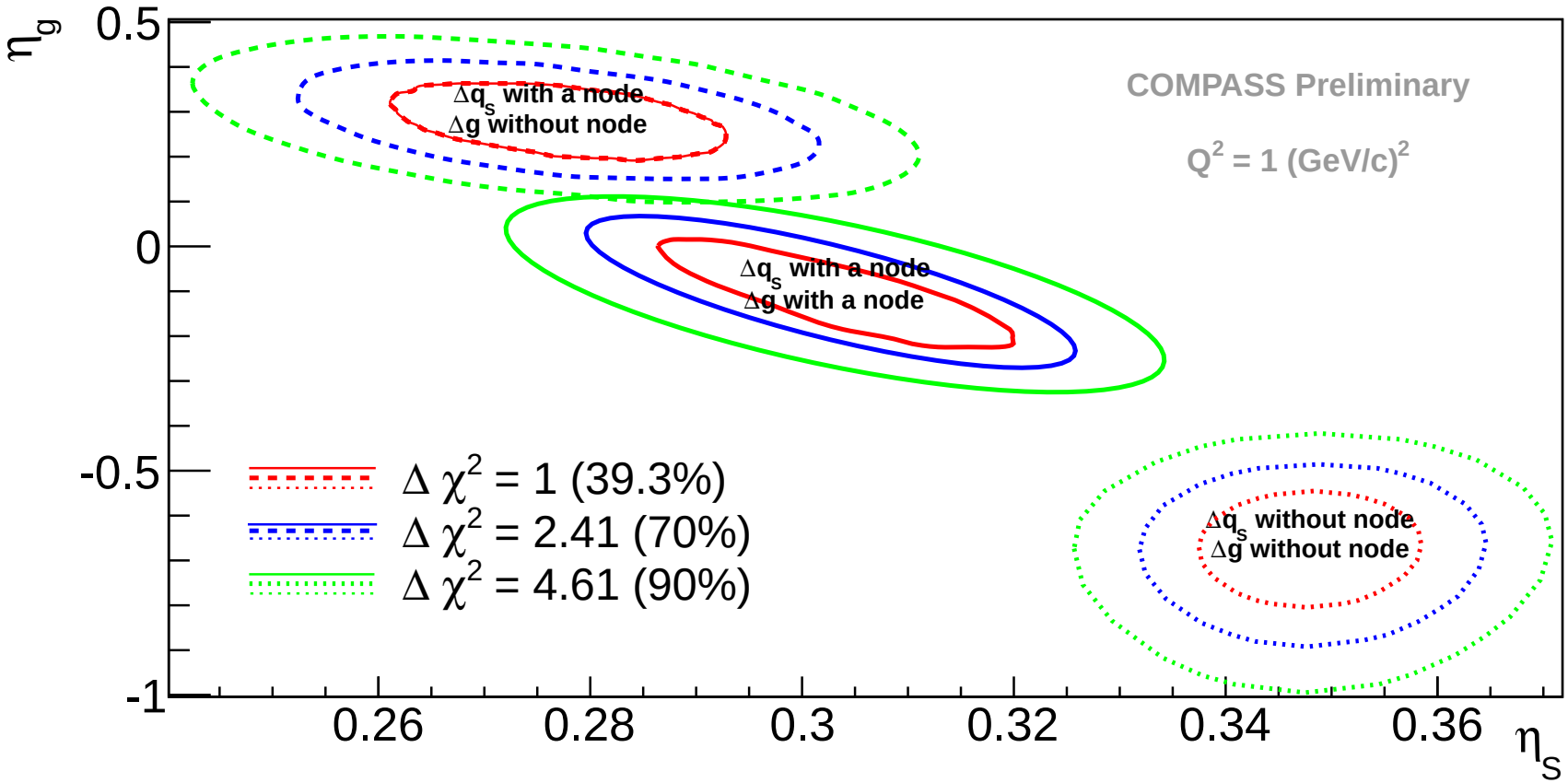






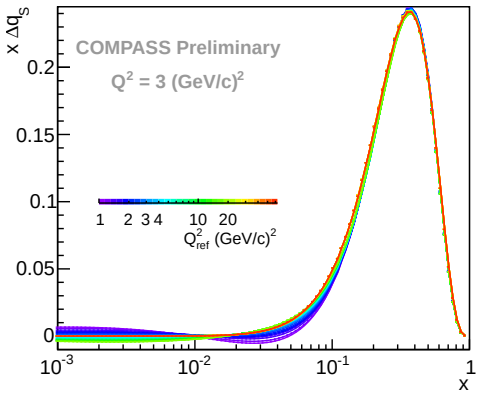
ΔG v.s. $\Delta\Sigma$

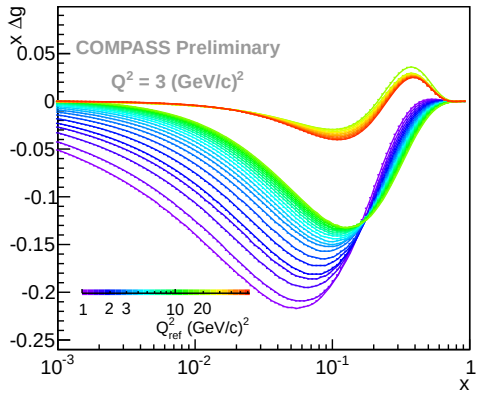
$\eta_g \rightarrow \Delta G$
$\eta_s \rightarrow \Delta\Sigma$
$Q^2 = 1\ (\mathrm{GeV/c})^2$



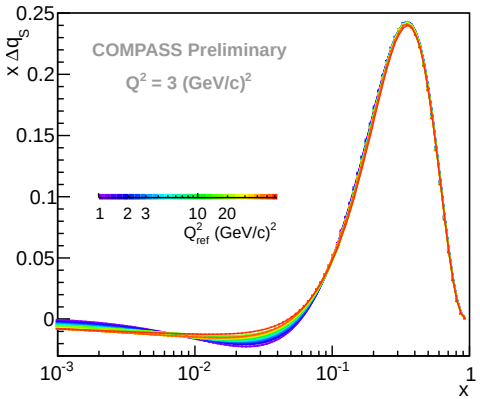
$x\Delta g$ with difference Q_0^2 inputs

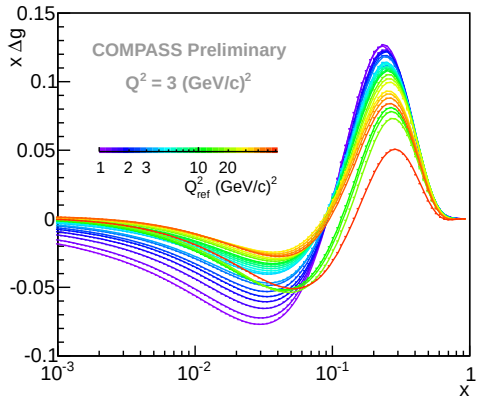
$\Delta G < 0$



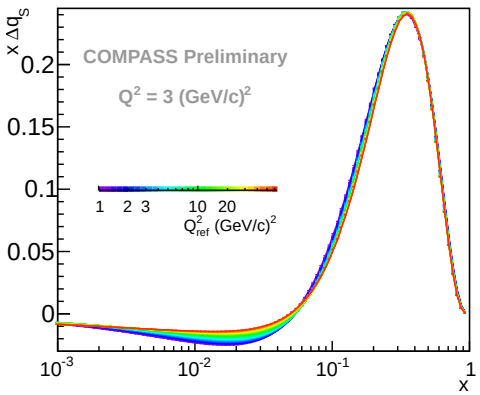


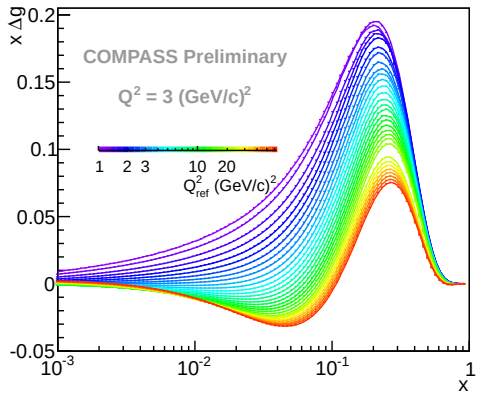
$\Delta G = 0$





$\Delta G > 0$





Bjorken sum rule

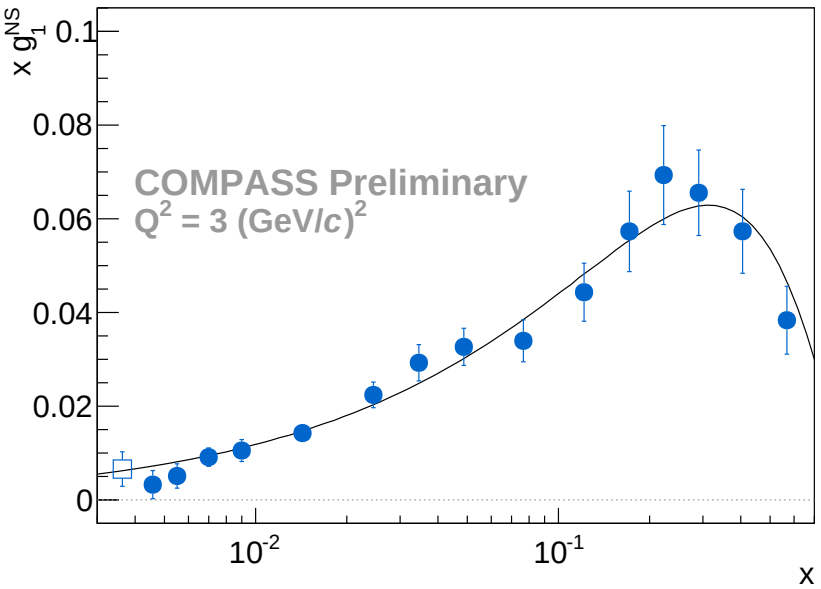
Bjorken sum rule

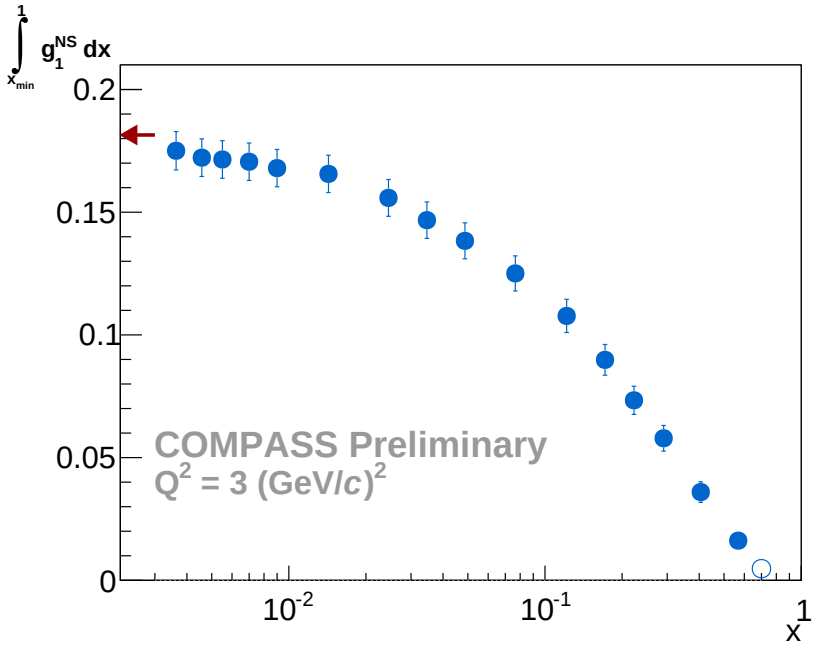
$$\Gamma_1^{NS} = \int_0^1 g_1^{NS}(x, Q^2)dx = \frac{1}{6}\left|\frac{g_A}{g_V}\right| C_1^{NS}(Q^2)$$

- Fundamental QCD prediction connecting p and n
- Decorrelated from ΔG
- $g_1^{NS} = g_1^p - g_1^n = 2\left[g_1^p - \frac{g_1^d}{1 - 1.5\omega_D}\right]$, $\omega_D = 0.05 \pm 0.01$
- $C_1^{NS} = 1 - \left(\frac{\alpha_s}{\pi}\right)$ @ NLO
- $C_1^{NS} = 1 - \left(\frac{\alpha_s}{\pi}\right) - p_1 \cdot \left(\frac{\alpha_s}{\pi}\right)^2$ @ NNLO

Bjorken sum rule

results





- $\left|\frac{g_A}{g_V}\right| = 1.2701 \pm 0.002$ from neutron β decay
- $\left|\frac{g_A}{g_V}\right| = 1.220 \pm 0.053(\text{stat.}) \pm 0.095(\text{syst.})$ with C_1 at NLO
- $\left|\frac{g_A}{g_V}\right| = 1.256 \pm 0.054(\text{stat.}) \pm 0.098(\text{syst.})$ with C_1 at NNLO
- Bjorken sum rule validated within 4%

Bjorken sum rule

$$C_1^{NS} = 1 - \left(\frac{\alpha_s}{\pi}\right) - p_1 \cdot \left(\frac{\alpha_s}{\pi}\right)^2 - p_2 \cdot \left(\frac{\alpha_s}{\pi}\right)^3$$

n_f	p_1	p_2
3	3.58333	20.21527
4	**3.25000**	**14.85026**

mass of charm quark: $m_c \sim 1.5$ GeV/c