A New LO Extraction of Gluon Polarisation from DIS Data

M. Stolarski
LIP

On behalf of the COMPASS Collaboration

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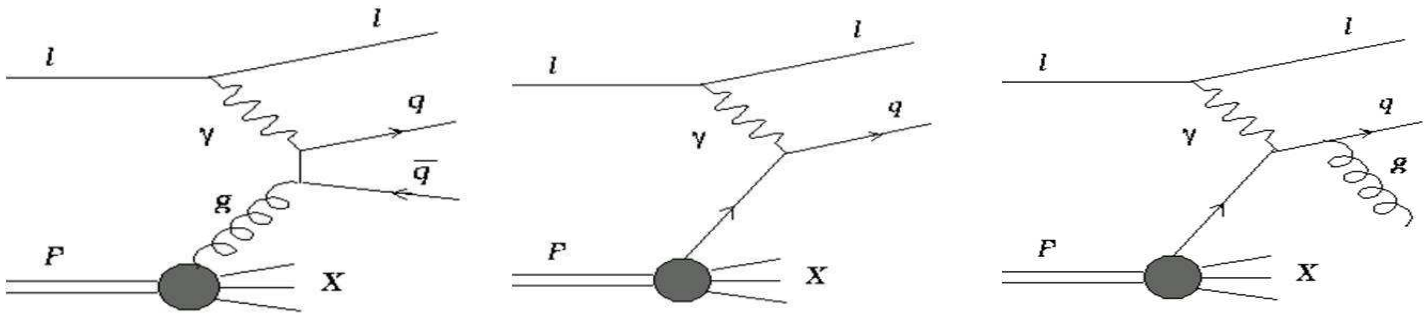
Outline

Motivation

- Spin of the proton ($S_p = 1/2\hbar$) can be decomposed as:
  - $\Delta\Sigma$ - quark contribution to the nucleon spin
  - ΔG - gluon contribution
  - ΔL_q,ΔL_g - orbital momentum of quarks and gluons
- $S_p = 1/2\hbar = 1/2\Delta\Sigma + \Delta G + \Delta L_q + \Delta L_g$
- In the simplest QPM model: $S_p = 1/2\Delta\Sigma$
- The direct measurement: $\Delta\Sigma \approx 0.3$
- How much is then ΔG?
- So far (NLO) QCD fits of DIS data **do not** constrain ΔG
- Possible direct measurement of ΔG in photon-gluon fusion
  - asymmetries in open-charm production
  - asymmetries for events with high transverse momentum hadrons
    - this talk $\rightarrow$ analysis of DIS region
    - for low Q^2 analysis $\rightarrow$ see talk by Maxime Levillain

The Analysis Method of High-p_T Events in the DIS Region

- Contribution from 3 processes to the observed asymmetry is assumed:



PGF LP QCDC

- $A_{LL}^h(x_{Bj}) = R_{PGF}\, a_{LL}^{PGF}\, \Delta g/g(x_G) + R_{LP}\, DA_1^{LO}(x_{Bj}) + R_{QCDC}\, a_{LL}^{QCDC}\, A_1^{LO}(x_C)$ where:
  - $A_1^{LO} \equiv \frac{\sum_i e_i^2 \Delta q_i}{\sum_i e_i^2 q_i}$
  - the fraction of the processes (R_i) and partonic cross-section asymmetries (a_{LL}^i) are obtained from MC and parametrized by NN
- Idea: larger $p_T \rightarrow$ larger $R_{PGF} \rightarrow$ larger sensitivity to $\Delta g/g$

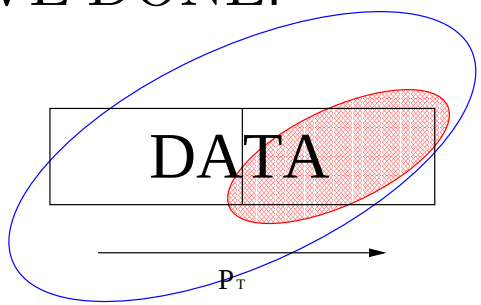
The Analysis Method cont.

- $A_{LL}^{h}(x_{Bj}) = R_{PGF}\, a_{LL}^{PGF}\, \Delta g/g(x_G) + R_{LP}\, DA_1^{LO}(x_{Bj}) + R_{QCDC}\, a_{LL}^{QCDC}\, A_1^{LO}(x_C)$
- A_1^{LO} is unknown, an additional information is needed in order to extract $\Delta g/g$
- Several possibilities exists:
  - take existing polarised LO PDF (biased result and error)
  - take existing polarised NLO PDF (depends upon ΔG!, higher order)
  - use inclusive A_1^d - done previously, PLB 718, (2013) 922
  - extract A_1^{LO} simultaneously with $\Delta g/g$ - done NOW
    - the idea of the method proposed by J. Pretz and J.-M. Le Goff, NIMA 602 (2009) 594
    - the method used in COMPASS Open Charm $\Delta g/g$ analysis, PRD 87 (2013) 052018

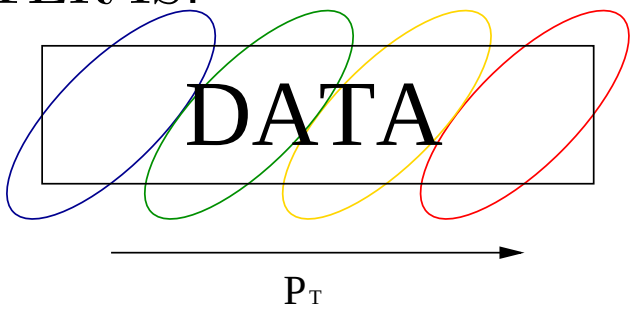
All-p_T Method

- Basic ideas:
  - treat all processes on the same footing!
  - calculate and minimize $\chi^2 = (N_{exp} - N_{obs}) cov^{-1} (N_{exp} - N_{obs})^T$
    - N_{exp} and N_{obs} are calculated separately for the three processes
    - $N_{exp,i}$ is a function of a_{LL}^i, R_i, beam flux, acceptance, unpolarized cross-section, A_1^{LO} and $\Delta g/g$
    - $N_{obs,i} \sim R_i$, the same same event is counted three times - a covariance matrix with non zero off diagonal elements is needed
- To optimize statistical error of $\Delta g/g$ we need
  - a clean source of PGF and QCDC events - high p_T region
  - **a clean source of LP** events - low p_T region
- The optimal case: Use all data without p_T cut! $\Rightarrow$ all-p_T method

WE HAVE DONE:



BETTER IS:



Why low-p_T events are used

- A_1^{LO} is needed to extract $\Delta g/g$
- Let us consider asymmetry in 2 regions: low and high p_T
  - for simplicity only PGF and LP are considered
  - numbers like 0.4, 0.6,... are R_{PGF}, R_{LP}
  - low-p_T region can substituted by A_1^d - inclusive asymmetry

SIMPLIFIED ANALYSIS

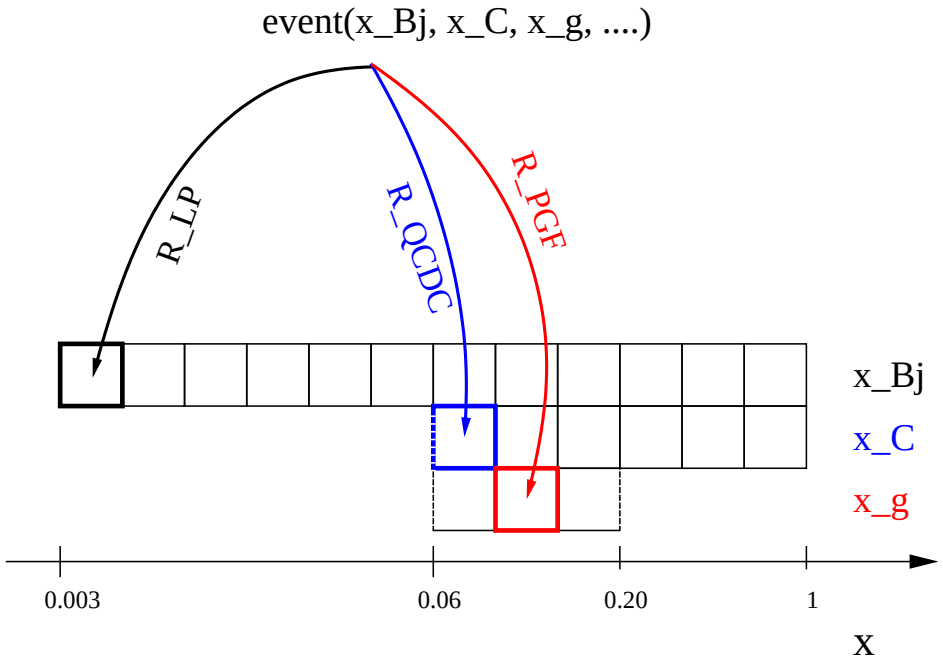
$$0.4\,\Delta g/g + 0.6\,A_1^{LO} = x \pm 0.10$$
$$0.0\,\Delta g/g + 1.0\,A_1^{LO} = y \pm 0.00$$
$$\delta\Delta g/g = 0.25$$

CORRECT ANALYSIS

$$0.4\,\Delta g/g + 0.6\,A_1^{LO} = x \pm 0.10$$
$$0.1\,\Delta g/g + 0.9\,A_1^{LO} = y \pm 0.00$$
$$\delta\Delta g/g = 0.30$$

- Neglecting presence of PGF in low-p_T or inclusive sample, leads to wrong error of $\Delta g/g$! Obtained errors are too small!
- Depending upon p_T cut, the bias can be 20-30%!
- The same happens if LO PDF are used as A_1^{LO}

A_1 Compatibility Test

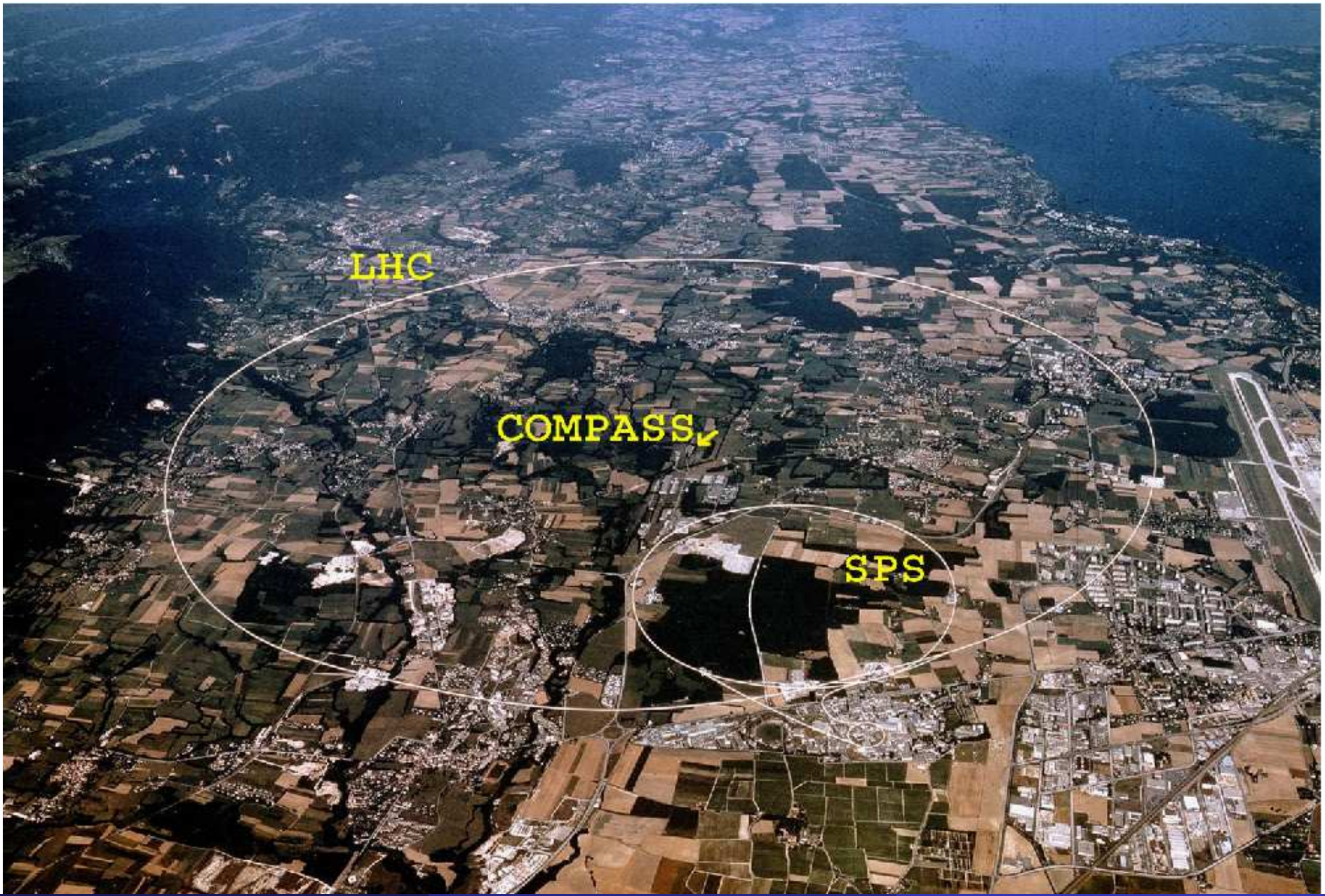


- A_1 asymmetry for QCDC process is extracted as a function of x_C
- A_1 asymmetry for LP process is extracted as a function of x_{Bj}
- $A_1^{QCDC}(x_C) = A_1^{LP}(x_{Bj}) = A_1^{LO}(x)$; for $x_C = x_{Bj}$
- We can verify equality of the two asymmetries by performing χ^2 test
- The χ^2 test can fail when our R_i or a_{LL}^i taken from MC are wrong!
- New method give us possibility to reject wrong MC tunings!

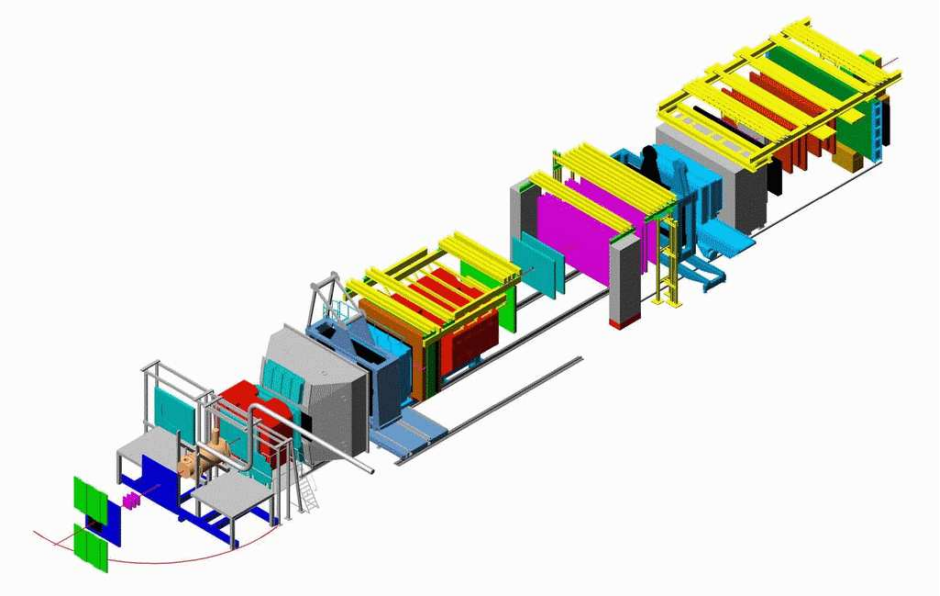
Comparison of The New Method to The Published One

- Both methods are correct!
- In both methods $\Delta g/g$ is extracted on the event by event basis
- We use event weighting to improve statistical error of $\Delta g/g$
- The new method has a few interesting features worth to consider:
  - allows additional check of the underlying model
  - some of the systematics uncertainties are reduced:
    - no error related to simplification of the formula for $\Delta g/g$ extraction
    - no A_1^d parametrization and error related to it
    - reduced experimental false asymmetries
    - easier way to deal with MC systematics
  - the weight for PGF process is simpler and more intuitive
    - $w_{new} \sim a_{LL}^{PGF} R_{PGF}$
    - $w_{old} \sim a_{LL}^{PGF} R_{PGF} - a_{LL}^{incl,PGF} R_{PGF}^{incl} \left(\frac{R_{LP} + R_{QCDC} a_{LL}^{QCDC} / D}{R_{LP}^{incl}} \right)$
  - gives more flexibility *e.g.* fit of A_1^d or even $\Delta g/g$ by a functional form
  - reduced statistical error of $\Delta g/g$

COMPASS at CERN



COMPASS Spectrometer 2002-2006



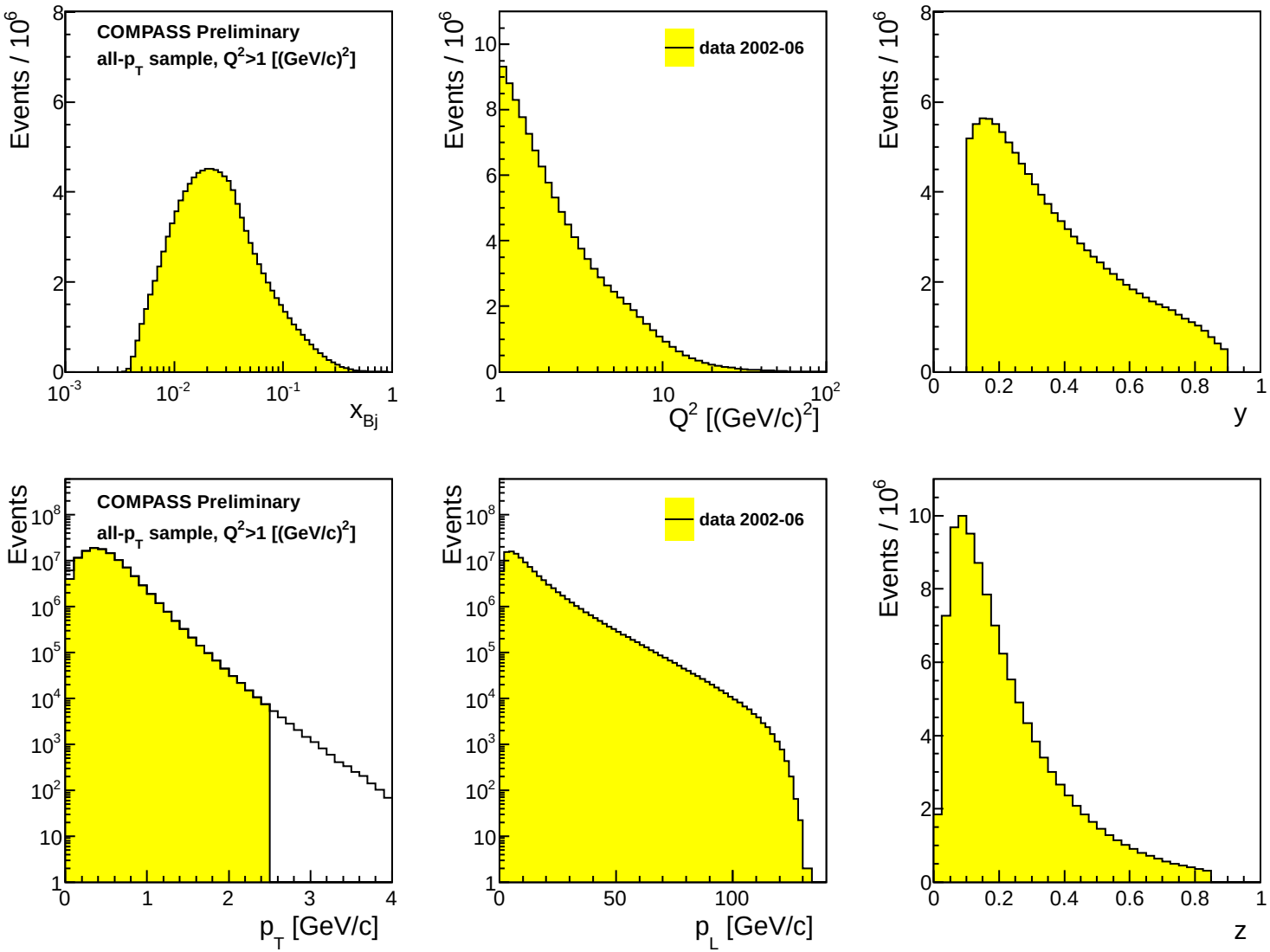
- COLLABORATION
  - about 210 physicists
  - 27 institutes
- DETECTOR
  - two stage spectrometer
  - 60 m length
  - about 350 detector planes

- POLARIZED TARGET
  - ^{6}LiD target
  - 2-3 cells (120 cm total length)
  - $\pm$ 50% polarization
  - pol. reversal every 8h-24h
- POLARIZED BEAM
  - μ^+ at 160 GeV/c
  - polarization –80 %
- FEATURES
  - angular acceptance: $\pm$70 mrad ($\pm$180 mrad from 2006)
  - track reconstruction: $p > 0.5$ GeV/c
  - identification h, e, μ: calorimeters and muon filters
  - identification: π, K, p (RICH) $p > 2$, 9, 18 GeV/c respectively

Data Selection

- Inclusive variables
  - $Q^2 > 1$ (GeV/c)^2
  - $0.1 < y < 0.9$
- Hadron variables
  - at least one charged hadron is detected
  - NO minimal p_T required
  - event is not a diffractive candidate
    - $z < 0.85$ for all hadrons (also removes bad μ')
    - for multiplicity 2 events: $z_1 + z_2 < 0.95$ or $q_1 \neq q_2$
- Information about the leading p_T hadron is used in the analysis
  - variables p_T, p_L or z are always for the leading p_T hadron
- $p_T < 2.5$ GeV/c (secondary interaction in the target, FLUKA vs GEISHA)
- Total Statistics 113M events

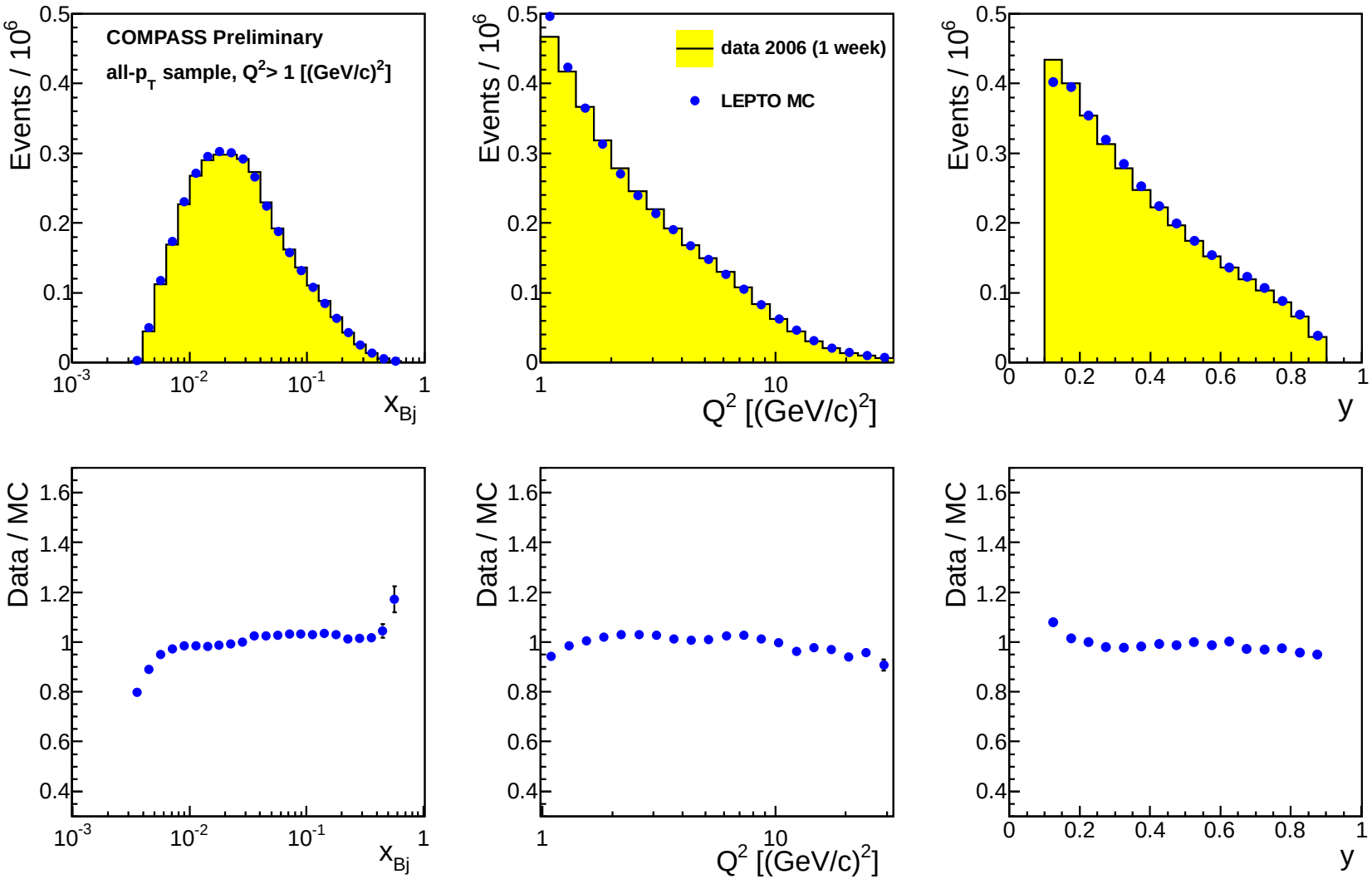
Kinematic Variables



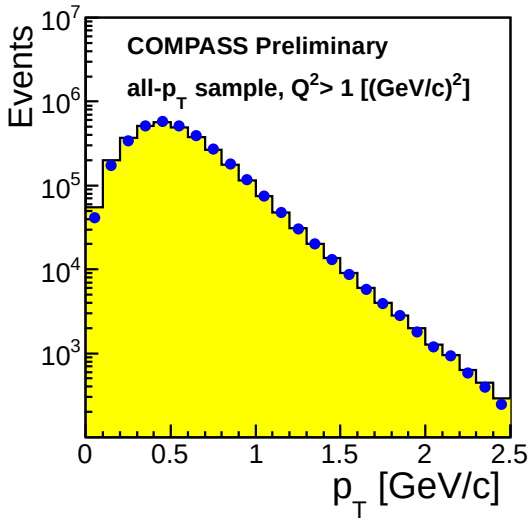
Monte Carlo

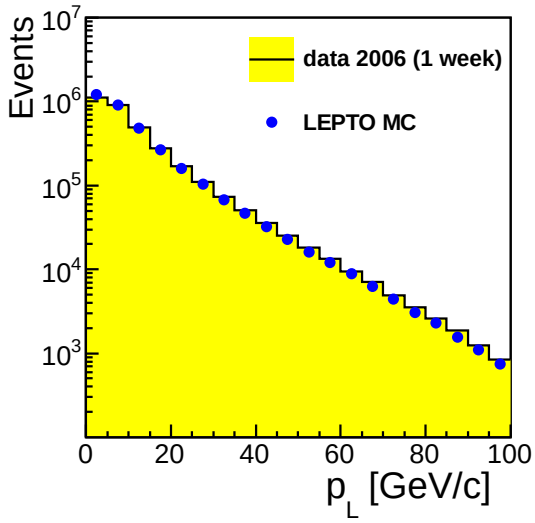
- Crucial variables in the analysis: R_i and a^i_{LL} and $x_{C,g}$ are estimated using MC
- Good description of data by MC is important for this analysis
- The same MC tuning as for previous analysis is used, but FLUKA simulation for secondary interactions
  - tuning done for high-p_T sample (6% of the total sample)
  - it reasonable well describe the data, without any p_T requirements
  - some improvements could be done for hadronic variables

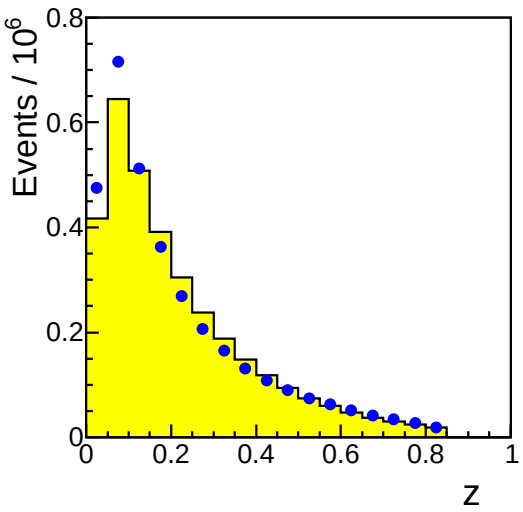
Data MC Comparison - Inclusive Variables

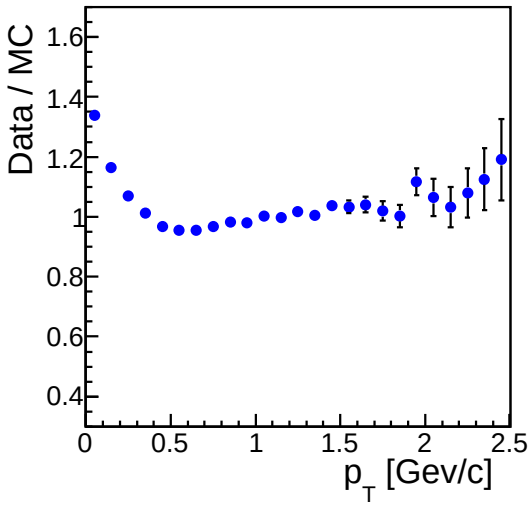


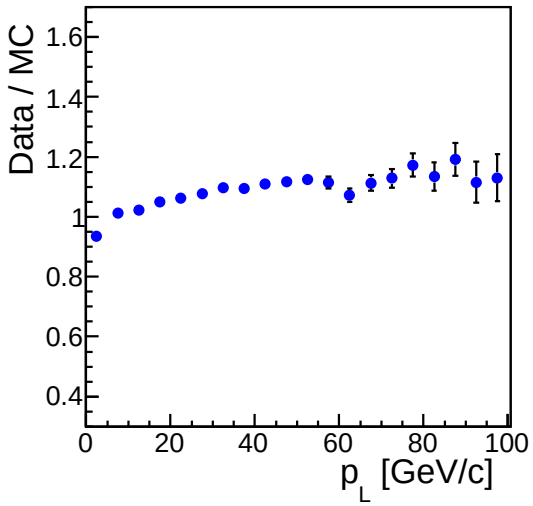
Data MC Comparison - Hadron Variables

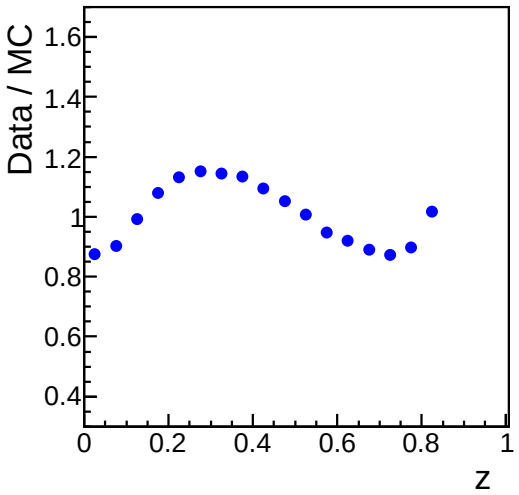






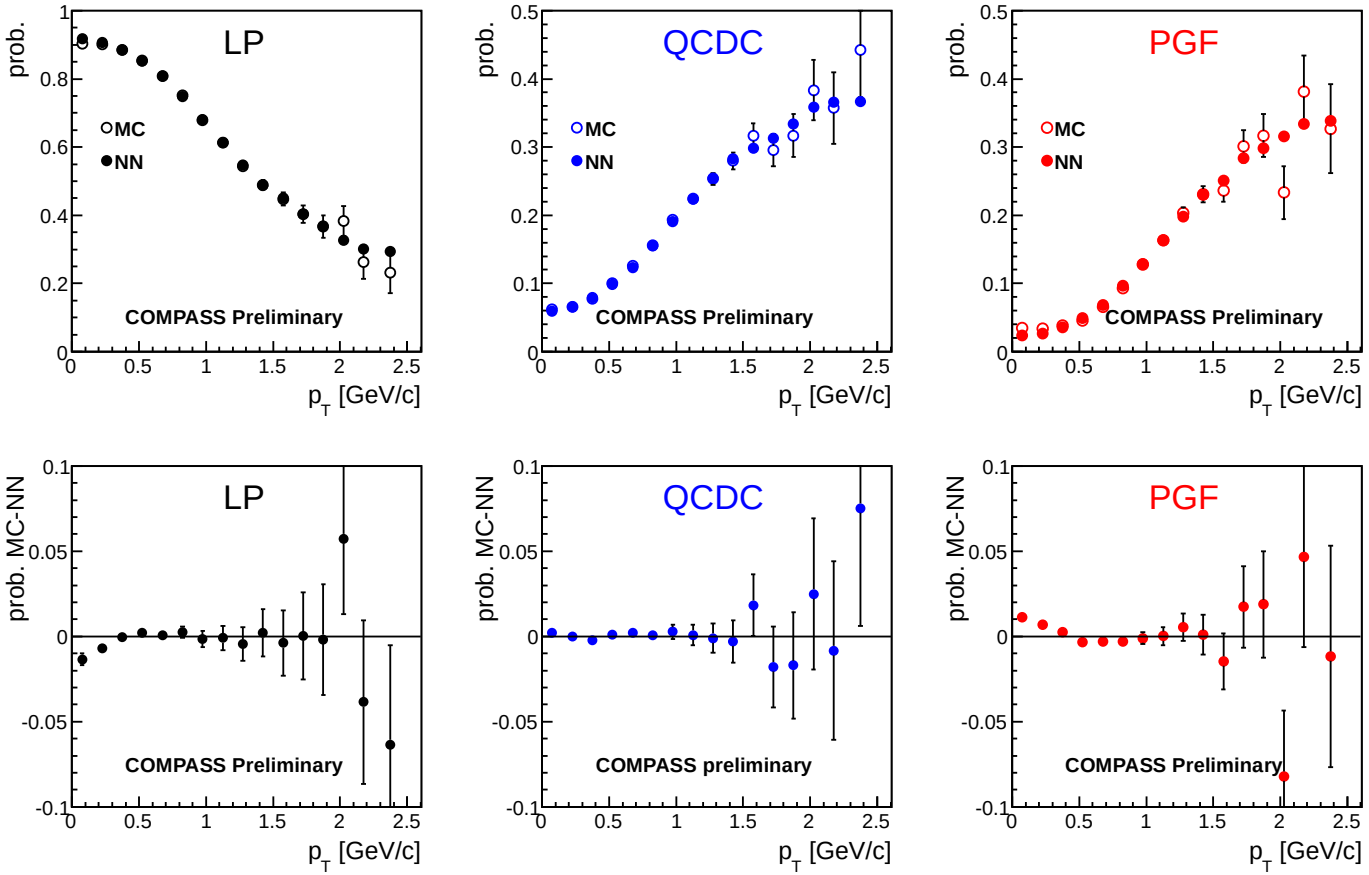






Neural Network Parametrizations

- Neural Network is trained on MC to parametrize R_i, a_{LL}^i and $x_{C,g}$
- As input parameters we use: x_{Bj}, Q^2, p_T and p_L
- One can use more variables to describe given event, we use only 4 input variables for simplicity reasons



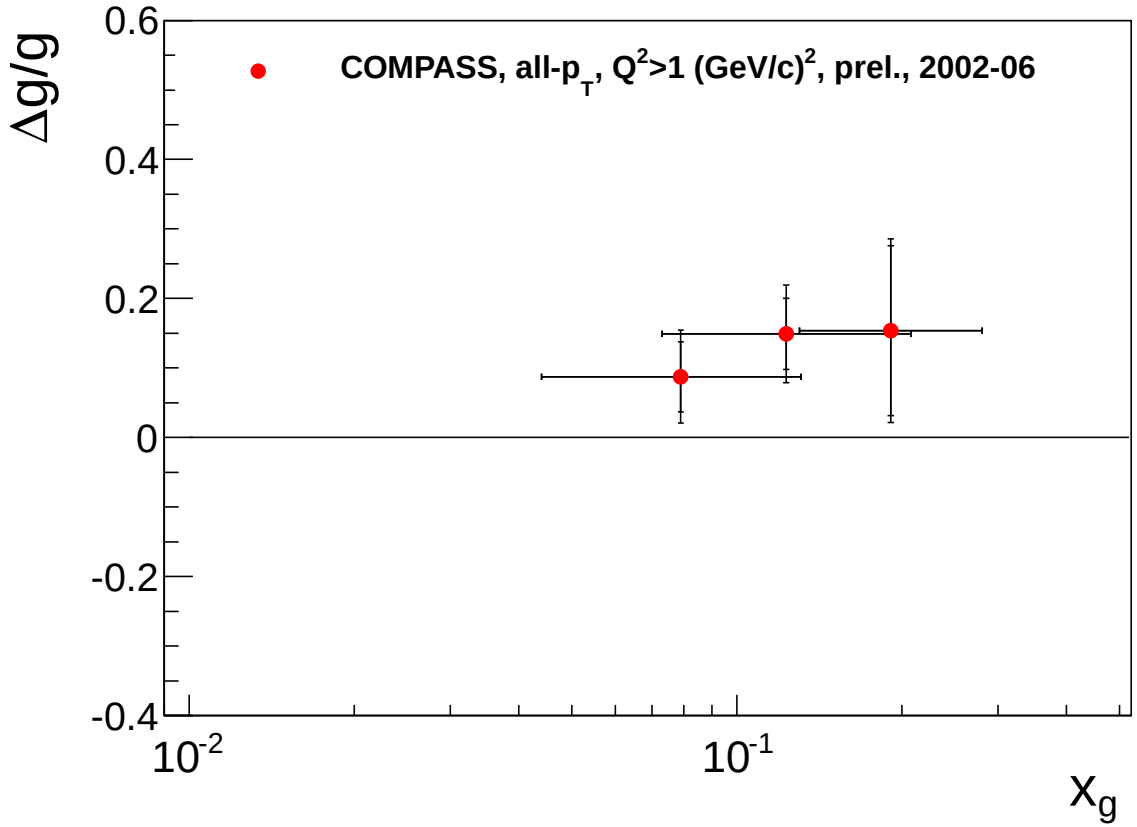
New $\Delta g/g$ Results

New $\Delta g/g$ Results

- $\Delta g/g = 0.113 \pm 0.038 \pm 0.035$ (Preliminary)
  - the scale, $\mu^2 =< Q^2 > \approx 3$ (GeV/c)^2, and $< x_g > \approx 0.10$
  - the result obtained under the assumption: $A_1^{QCDC}(x_C) = A_1^{LP}(x_{Bj})$ for $x_C = x_{Bj}$
- Comparison with previous result, PLB 718, (2013) 922
  - $\Delta g/g = 0.125 \pm 0.060 \pm 0.063$
  - good agreement between the two results
  - smaller uncertainties, by almost a factor of 1.6, for the new result

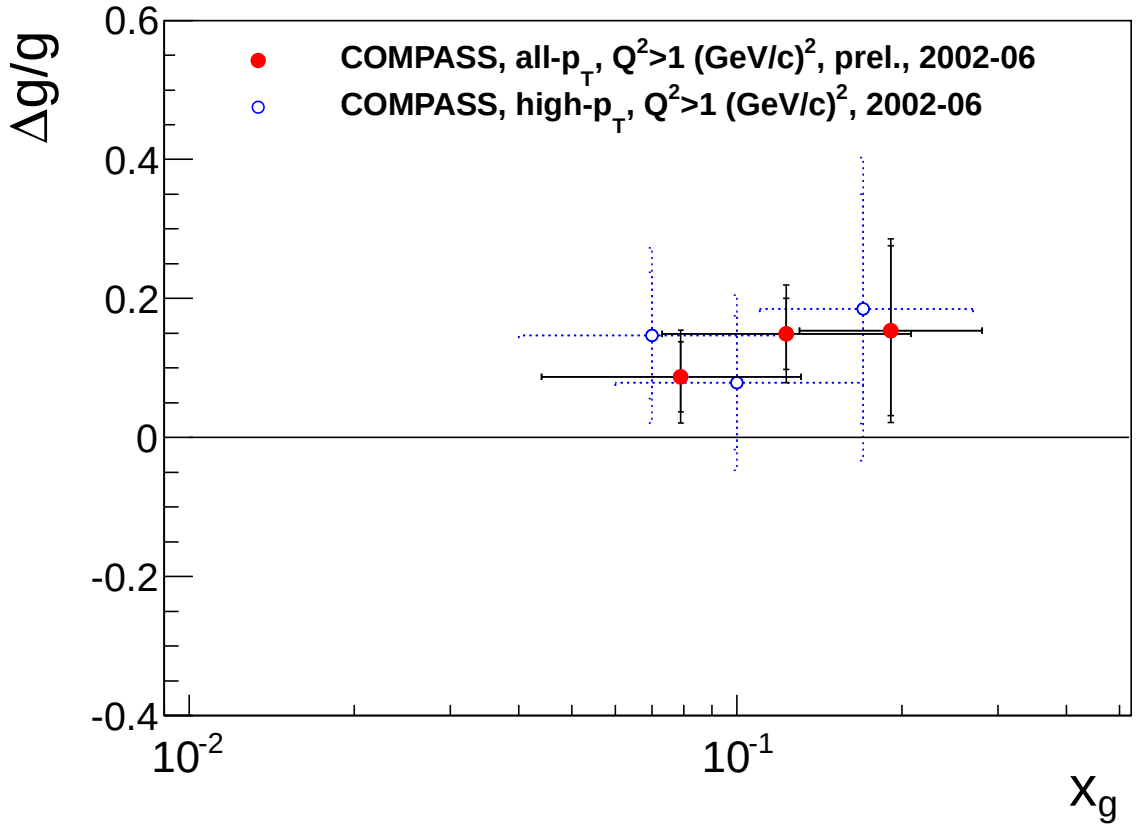
New $\Delta g/g$ Results cont.

- The $\Delta g/g$ results were obtained in 3 x_g bins
  - there is 30% correlation between results in 1^{st} and 2^{nd} bin (fit outcome)



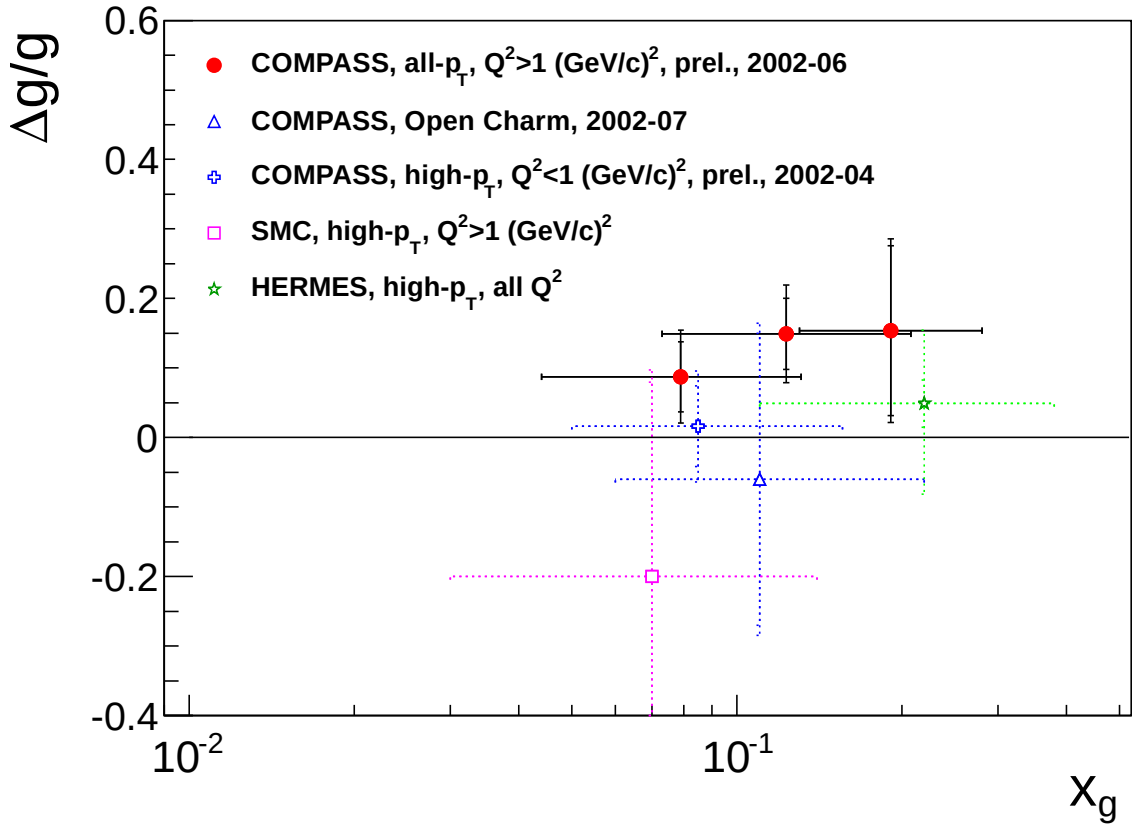
New $\Delta g/g$ Results and Comparison to PLB 718, (2013) 922

- The $\Delta g/g$ results were obtained in 3 x_g bins
  - there is 30% correlation between results in 1^{st} and 2^{nd} bin (fit outcome)
- Good agreement with previously published results
- In the new method slightly higher x_g are probed



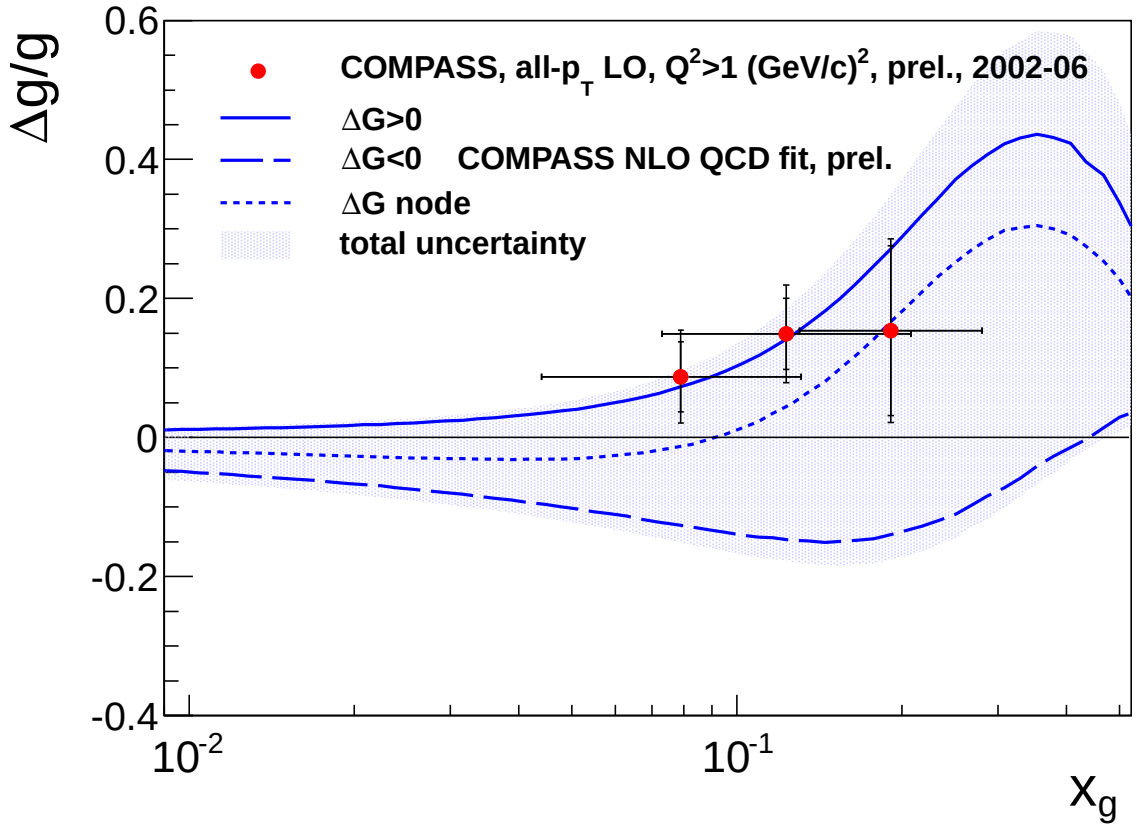
Comparison of New Results and The World $\Delta g/g$ Data

- The new results are in good agreement with the world $\Delta g/g$ extracted in LO analyses
- They have the best combined systematical and statistical uncertainty



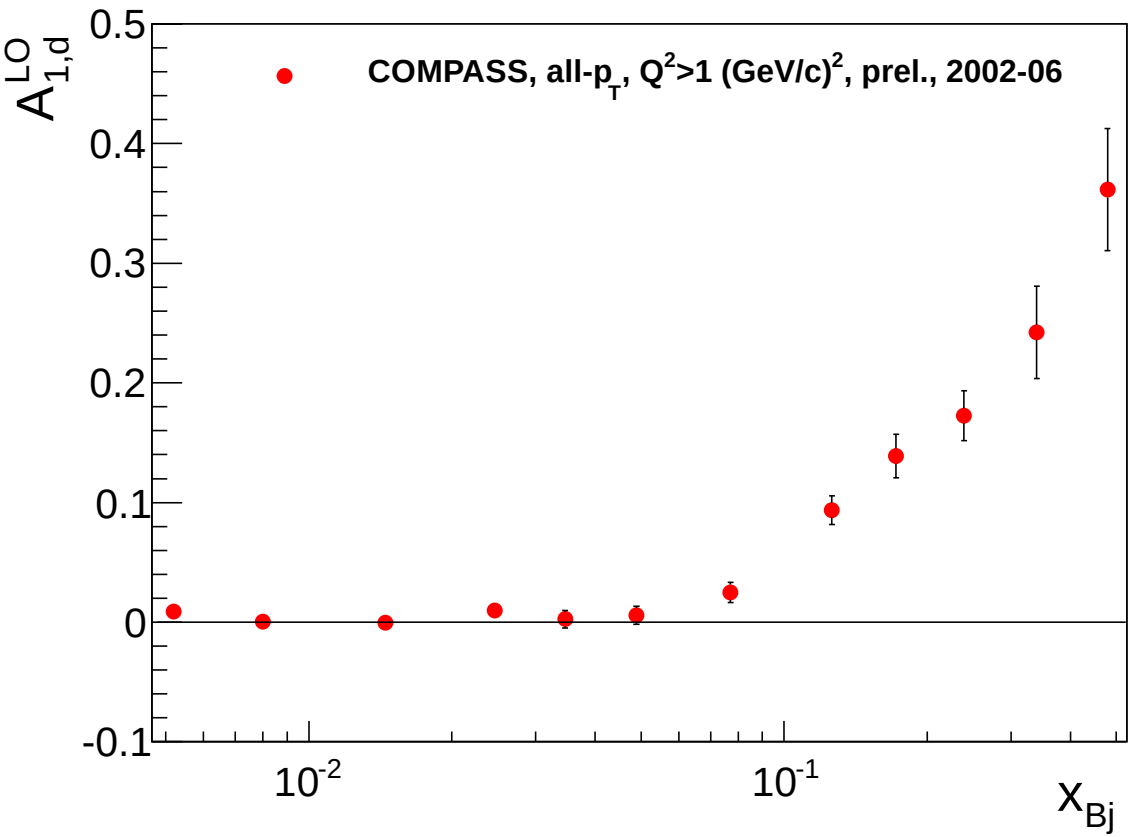
Comparison of New Results and NLO QCD Fits

- Comparison of the new $\Delta g/g$ results obtained in LO analysis with COMPASS NLO QCD fit to the world g_1 data
  - For details of the QCD fit see talk by Malte Wilfert
- Uncertainty of $\Delta g/g$ could be reduced if results of all-p_T analysis could be used in NLO fits



Extracted A_1^{LO}

- For completeness A_1^{LO} results are shown
  - extracted asymmetries are compatible with zero for low x_{Bj}
  - positive value is obtained for higher x_{Bj}, as expected

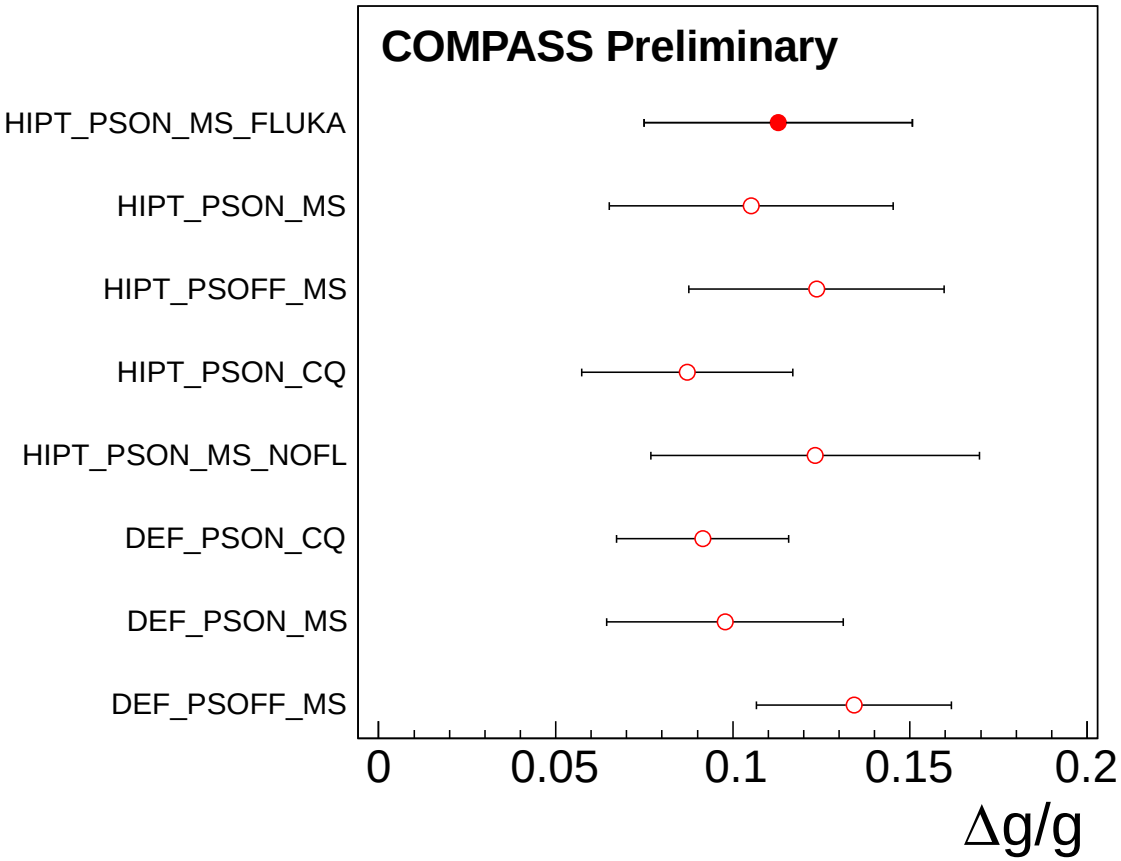


Systematic Studies

- Systematic studies done for PLB 718, (2013) 922 are valid
- Only the most important contributions were re-evaluated
- Two sources of systematic uncertainty were eliminated:
  - simplification of the formula for $\Delta g/g$ extraction
  - A_1^{incl} parametrization uncertainty
- Remaining crucial contributions:
  - dilution factor and target and beam polarization - 0.008
  - NN parametrization - 0.007
  - apparatus false asymmetries - 0.029
  - MC systematic - 0.017 $\longrightarrow$ details given in this talk
- Total systematic uncertainty - 0.035 (preliminary)

MC Systematic Studies

- Presented analysis is MC dependent
- 8 MC samples are used to study systematic uncertainty of $\Delta g/g$
- The extracted values of $\Delta g/g$ for each of MC are shown in figure
- The RMS of the obtained results was taken as a systematic error



- Obtained $\Delta g/g$ results are very stable, RMS $= 0.017$
- Results are stable while the error of $\Delta g/g$ changes by up to a factor 2

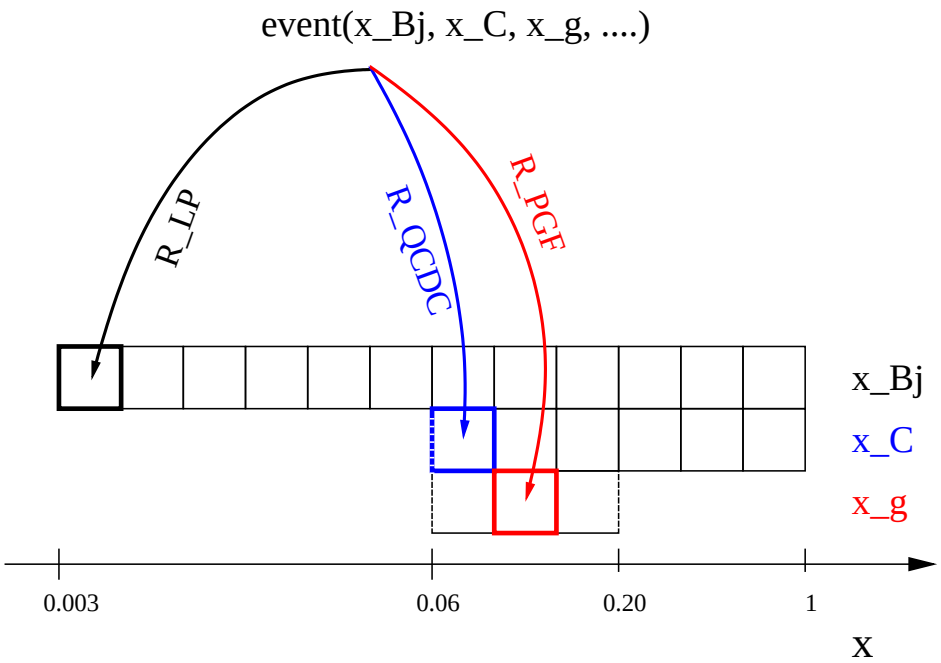
Why $\Delta g/g$ Results Are so Stable?!

$$A_{LL}^{h}(x_{Bj}) = R_{PGF}\, a_{LL}^{PGF}\, \Delta g/g(x_G) + R_{LP}\, DA_1^{LO}(x_{Bj}) + R_{QCDC}\, a_{LL}^{QCDC}\, A_1^{LO}(x_C)$$

- Let $A_1^{LO} = A_{LL}^{h} = 0$ for low $x_{Bj} \Rightarrow \Delta g/g = ?$
- $\Delta g/g = -\frac{a_{LL}^{QCDC} R_{QCDC}}{a_{LL}^{PGF} R_{PGF}} A_1^{LO}(< x_C >= 0.14) \approx 0.13$
- COMPASS result: $\Delta g/g = 0.113 \leftarrow$ close to 0.13!
- Systematic dominated by stability of $\frac{a_{LL}^{QCDC} R_{QCDC}}{a_{LL}^{PGF} R_{PGF}}$
  - a_{LL}^{i} are very stable for all MC samples
  - thus, systematic is dominated by stability of R_{QCDC}/R_{PGF}
    - the α_S cancels as both higher order processes
    - p_T for both processes is dominated by partonic x-section calculable in LO, and not by p_T of the fragmentation (which was tuned)
    - clearly R_{QCDC}/R_{PGF} more stable than *e.g.* R_{LO}/R_{PGF} or R_{PGF} itself
- Since $\frac{a_{LL}^{QCDC} R_{QCDC}}{a_{LL}^{PGF} R_{PGF}}$ is rather stable $\Rightarrow$ so is extracted $\Delta g/g$

A_1 Compatibility Check

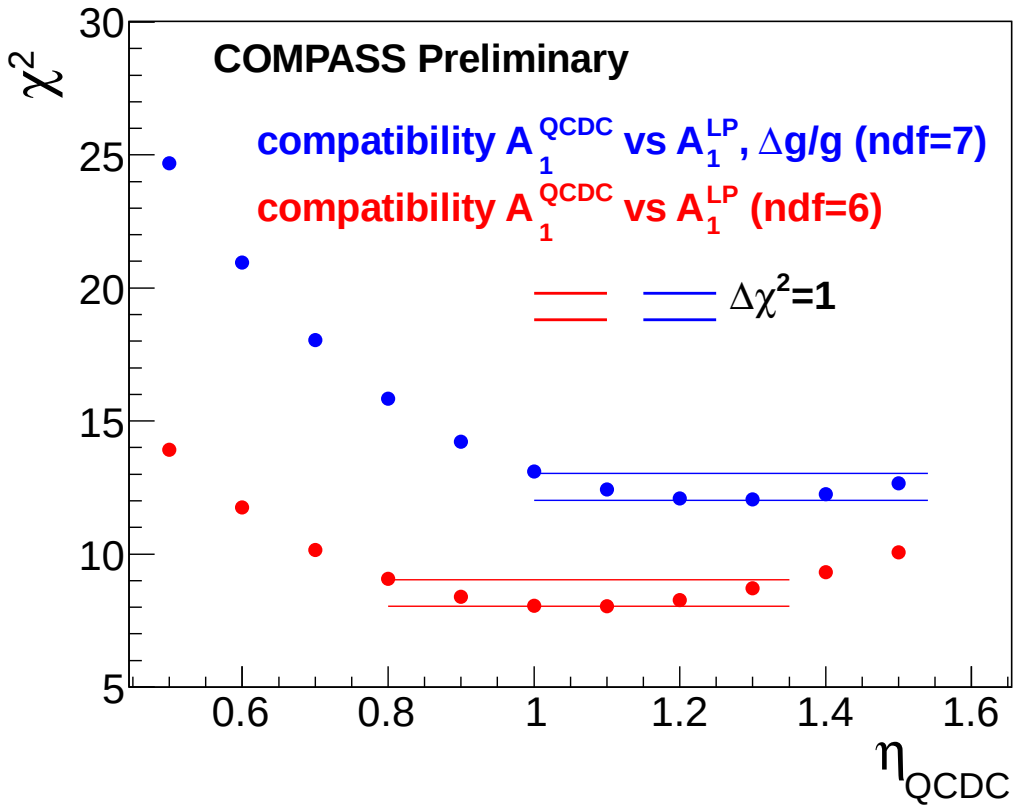
- $A_1^{QCDC}(x_C) = A_1^{LP}(x_{Bj}) = A_1^{LO}(x)$; for $x_C = x_{Bj}$
- We can verify equality of the two asymmetries by performing χ^2 test
- The χ^2 test can fail when our R_i and a_{LL}^i taken from MC are wrong!
- $\chi^2 < 12.6$ on 95% CL and ndf=6
- The χ^2/ndf for the main MC sample is 8.1/6 $\rightarrow$ reasonable



	name	χ^2
1	HIPT_PSON_MS_FLUKA	8.1
2	HIPT_PSON_MS	8.8
3	HIPT_PSOFF_MS	3.9
4	HIPT_PSON_CQ	10.1
5	HIPT_PSON_MS_NOFL	6.9
6	DEF_PSON_CQ	13.1
7	DEF_PSON_MS	10.7
8	DEF_PSOFF_MS	9.9

Knowledge of $a_{LL}^{QCDC} R_{QCDC}$ from Data

- What if we change $a_{LL}^{QCDC} R_{QCDC}$ predicted by MC...
- The χ^2 profile of A_1 compatibility test can be studied
- Simple example with scaling of $a_{LL}^{QCDC} R_{QCDC}$ presented, $\eta_{QCDC} = 1 \rightarrow$ what is in MC
- Lower values of $a_{LL}^{QCDC} R_{QCDC}$, which decrease $\Delta g/g$ are not preferred



Summary

Summary

- A reanalysis of $\Delta g/g$ COMPASS data from DIS region was presented, using the so called all$-p_T$ method
- New consistency checks are possible in the new method
- $\Delta g/g = 0.113 \pm 0.038 \pm 0.035$
- Reduction of statistical and systematic uncertainties by a factor of 1.6 with respect to PLB 718, (2013) 922
- The obtained result is in very good agreement with the world data