Gluon polarization from COMPASS

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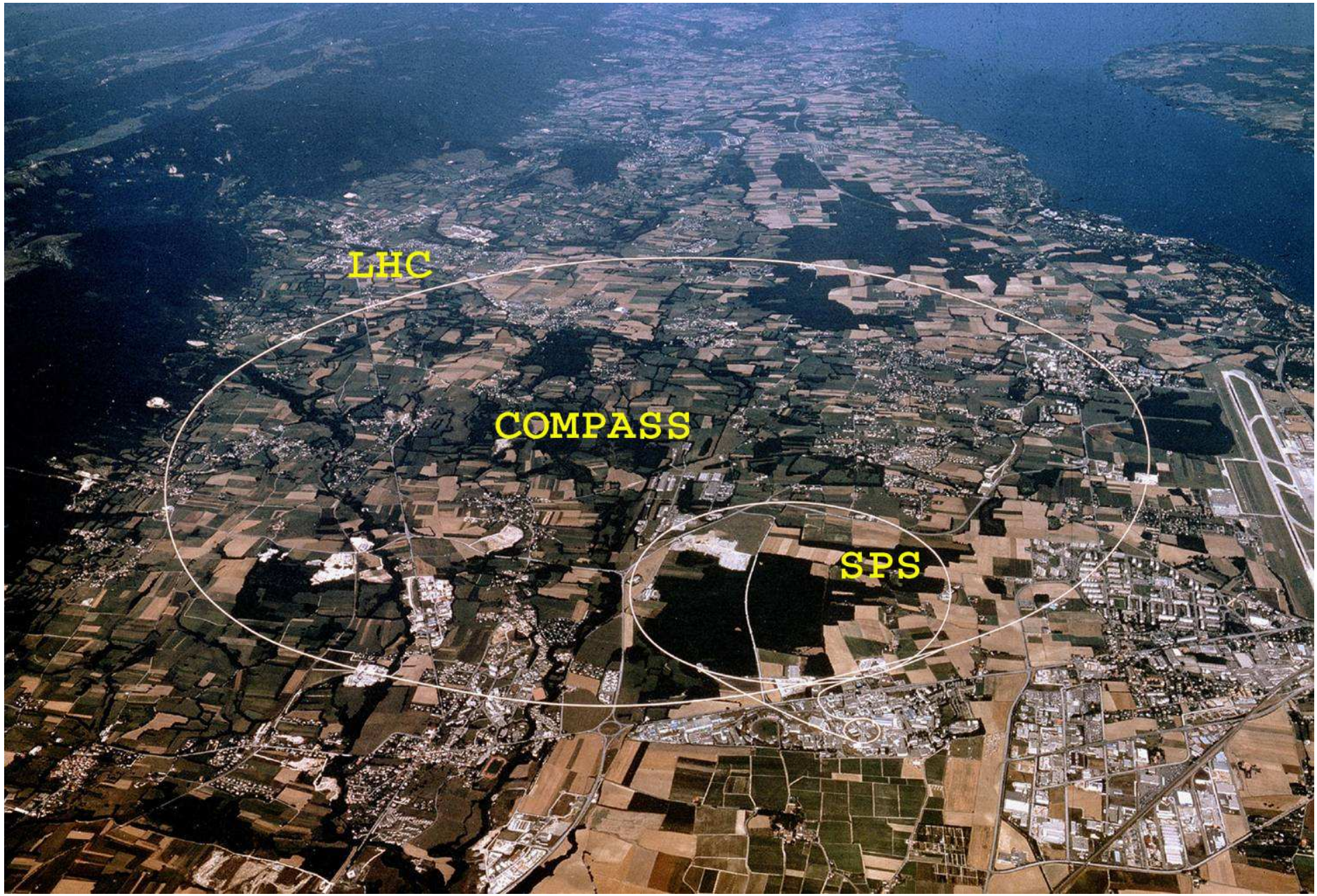
on behalf of COMPASS collaboration

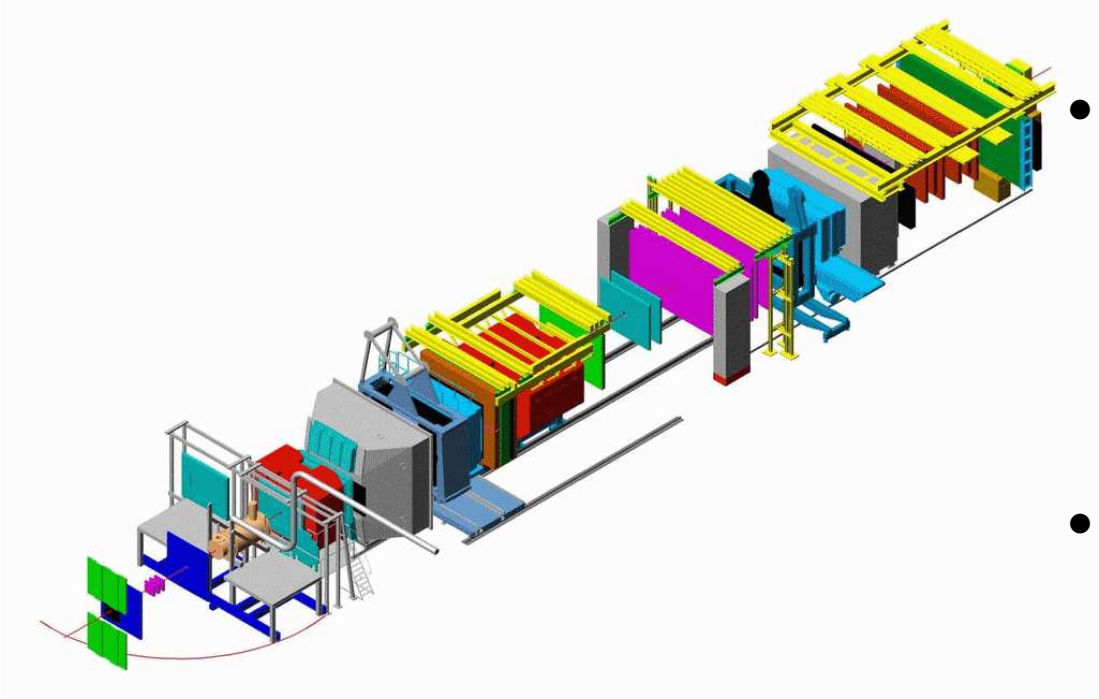
16 VI 2008

Gluon Polarization in the Nucleon
Joint Illinois-MIT-RBRC Workshop June 16-17 2008, Urbana, IL

- results of open charm analysis
- results of high-p_T hadrons pair analyzes
- prospects of $\Delta G/G$ from COMPASS

COMPASS @ CERN





- COLLABORATION
  - about 240 physicists
  - 29 institutes
- DETECTOR
  - 60 m length
  - 2 (3) magnets
  - about 350 detector planes

- POLARIZED TARGET
  - ^{6}LiD target
  - 2 cells (60 cm long each)
  - $\pm$ 50% polarization
  - polarization reversal every 8h
- POLARIZED BEAM
  - positive muons at 160 GeV/c
  - polarization –80 %
- FEATURES
  - acceptance: 70 mrad
  - track reconstruction: $p > 0.5$ GeV
  - identification: π, K, p (RICH) above 2, 9, 18 GeV respectively

Major hardware updates for 2006 run

- RICH upgrades
  - MAPMT & fast electronics
  - less pileup
  - more photons per ring
  - important upgrade for open charm analysis
- new COMPASS solenoid
  - acceptance increase 70 $\rightarrow$ 130 mrad
- three target cells
  - upstream and downstream cells (30cm) polarized in opposite direction than a middle cell (60cm)
  - reduction of possible false asymmetries

COMPASS scientific program

- muon program
  - gluon polarization
  - spin dependent structure function
  - polarized quark distributions
  - transversity
  - Lambda polarization
  - vector meson production
- hadron program
  - Primakoff reaction
  - hadron spectroscopy
  - exotics searches (glueballs)
  - central production

$\Delta G/G$ from open charm analysis 2002-2006 data

$\Delta G/G$ from open charm analysis

- clean source of PGF
- hard scale $\approx 4m_c^2$, even though $Q^2 < 1$ (GeV/c)^2
- low statistics
  - $D^0 \to K\pi$
  - $D^* \to D\pi_{soft} \to K\pi\pi_{soft}$
  - in total $\sim 5\%$ of D^{0}s decay branching ratio

Analysis cuts

- $0.1 < y < 0.9$
- no Q^2 cuts
- $K\pi$ invariant mass close to D^0 mass
- cuts on z_D, D^0 decay angle, πs momenta
- RICH PID
  - identification of K, π
  - rejection of e (fake π_{soft})
- for D^* cuts on $m_{D^*} - m_{D^0}$

Number of D^0 events : 37398

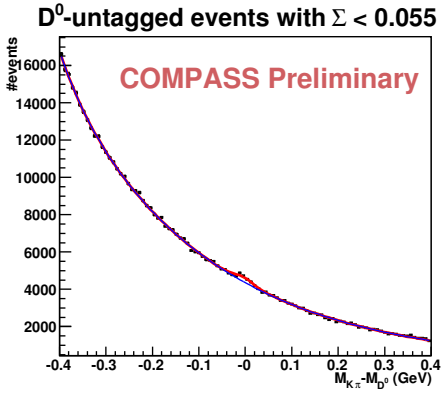
Number of D^* events : 8675

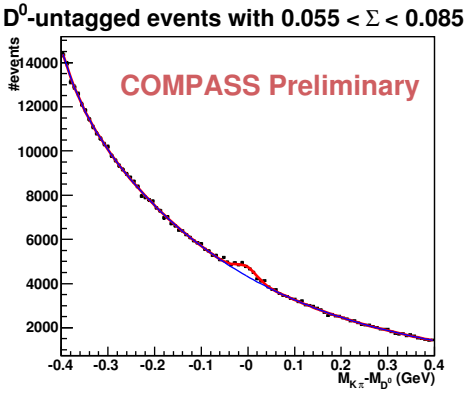
Gluon Polarization

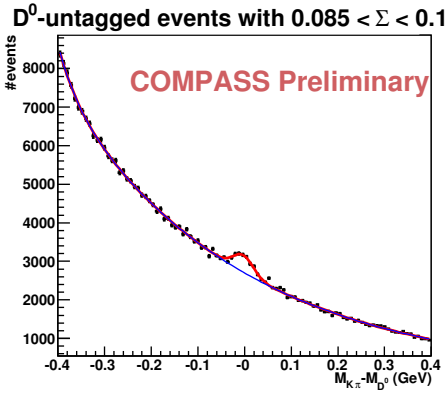
$$\frac{\Delta G}{G} = \frac{1}{P_t P_b f a_{LL} \frac{S}{S+B}} A_{raw}$$

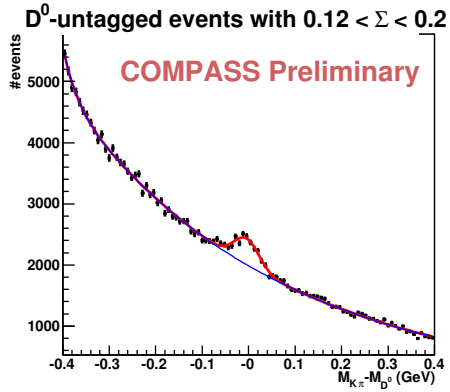
- in the analysis we use weight $P_b f a_{LL} \frac{S}{S+B}$ to gain in *figure of merit*
- in OLD analysis $\frac{S}{S+B}$ obtained from fit on D^0 mass spectra in a_{LL} bins
- in NEW analysis $\frac{S}{S+B}$ is parametrized (Σ) as a function of kinematics variables and RICH response
  - build on DATA only (fits to D^0 mass spectra)
  - available on event-by-event basis
- NOTE: $A_{bcgr} = \frac{1}{P_t P_b f D \frac{B}{S+B}} A_{raw}$ can be obtained simultaneously

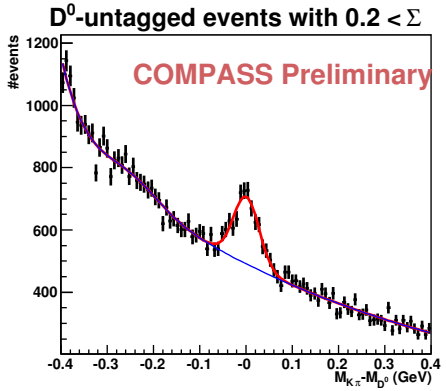
impact of Σ parametrization



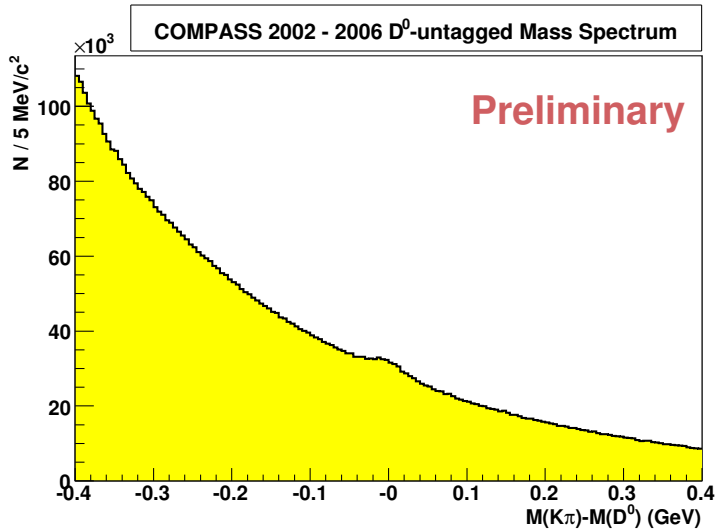


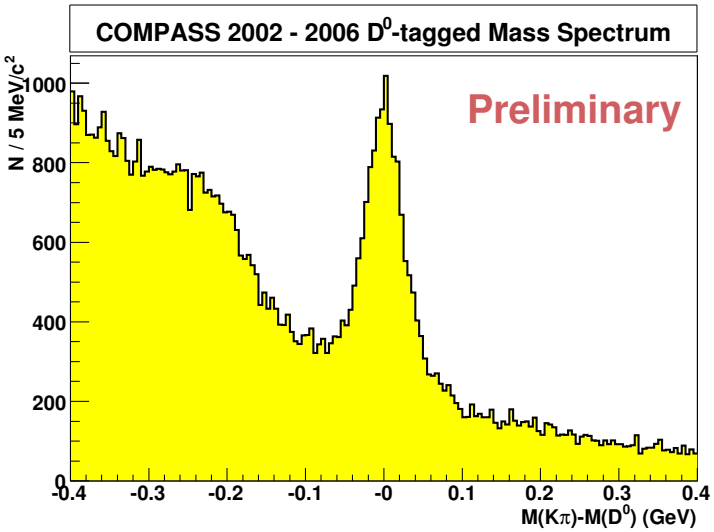


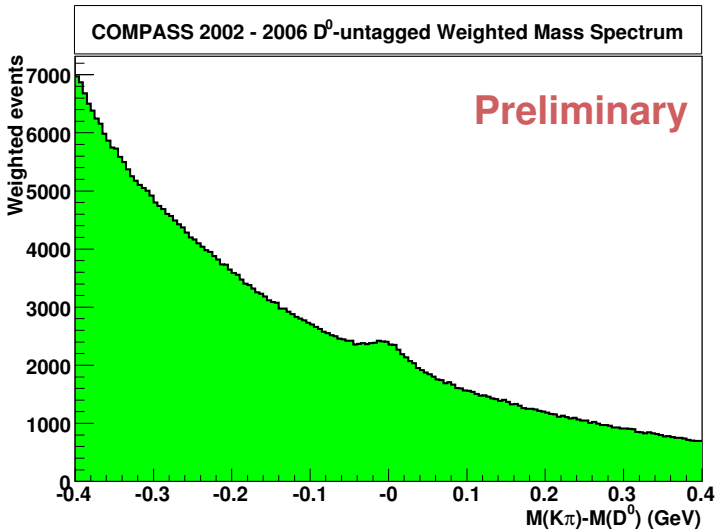


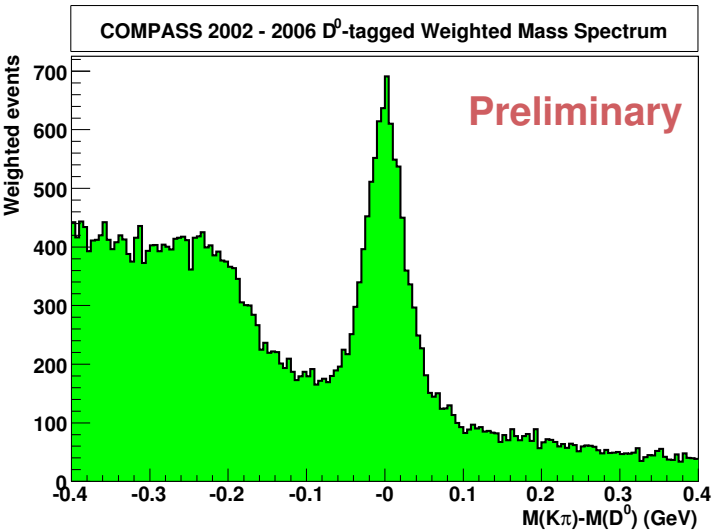


Σ parametrization cont.



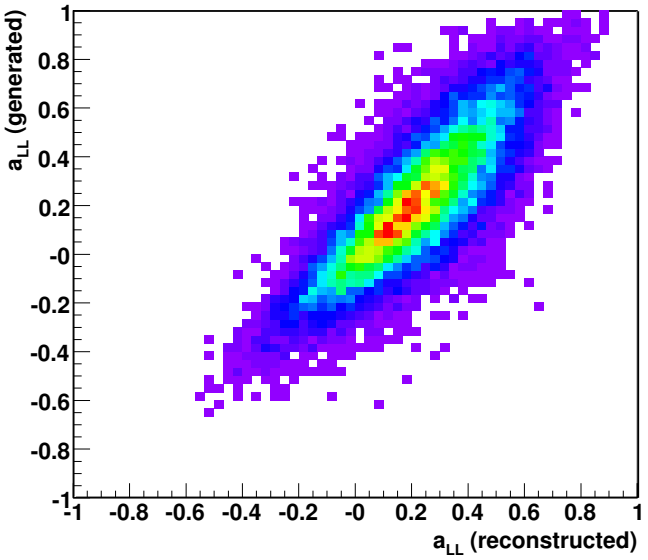






Analyzing power (a_{LL})

- analyzing power depends on the full parton kinematics
- in the experiment there is only indirect access to $c\bar{c}$ via D^0 kinematic
- using Neural Network and MC generated sample of D^0&D^* parametrization of a_{LL}/D is made
- correlation between $a_{LL,gen}$ and $a_{LL,rec}$ is about 0.80



Systematic studies

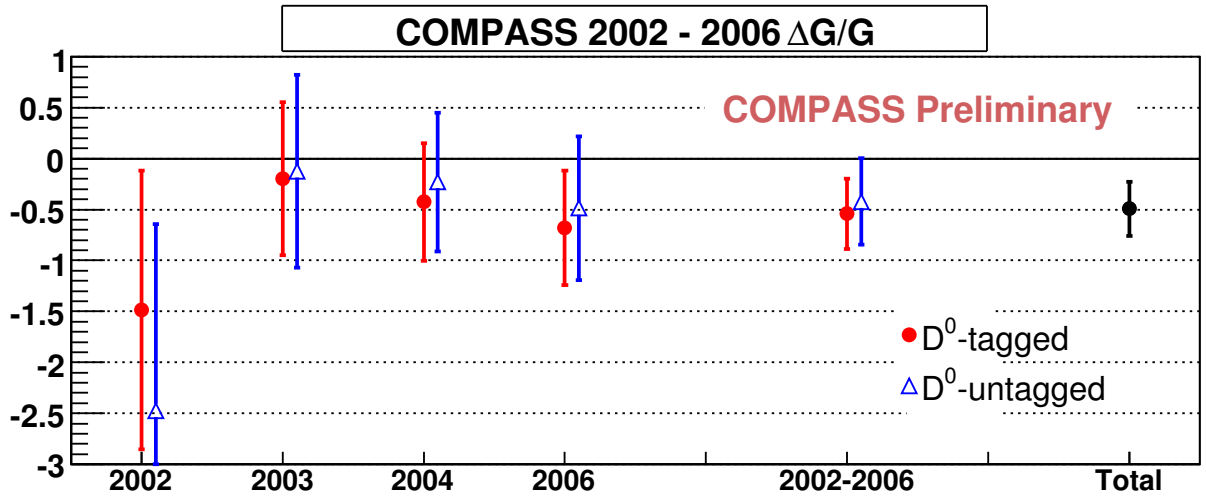
- some of components of systematic error are proportional to measured value of $\Delta G/G$ or $\delta\Delta G/G$
- the absolute value of the systematic error from open charm is larger than from high-p_T analyzes.
- theoretical uncertainties are lower for open charm than for high-p_T
- key point: $\delta\Delta G/G_{syst.} << \delta\Delta G/G_{stat.}$

Source	D^0	D^*
beam pol.	0.025	0.025
target pol.	0.025	0.025
dilution factor	0.025	0.025
false asymmetries	0.05	0.05
signal extraction (Σ)	0.07	0.01
a_{LL} (charm mass)	0.05	0.03
TOTAL	0.11	0.07

Preliminary results for $\Delta G/G$ from open charm analysis

$$\frac{\Delta G}{G} = -0.49 \pm 0.27(stat.) \pm 0.11(syst.)$$

$x_G = 0.11^{+0.11}_{-0.05}$; $\mu^2 \approx 13$ (GeV/c)^2

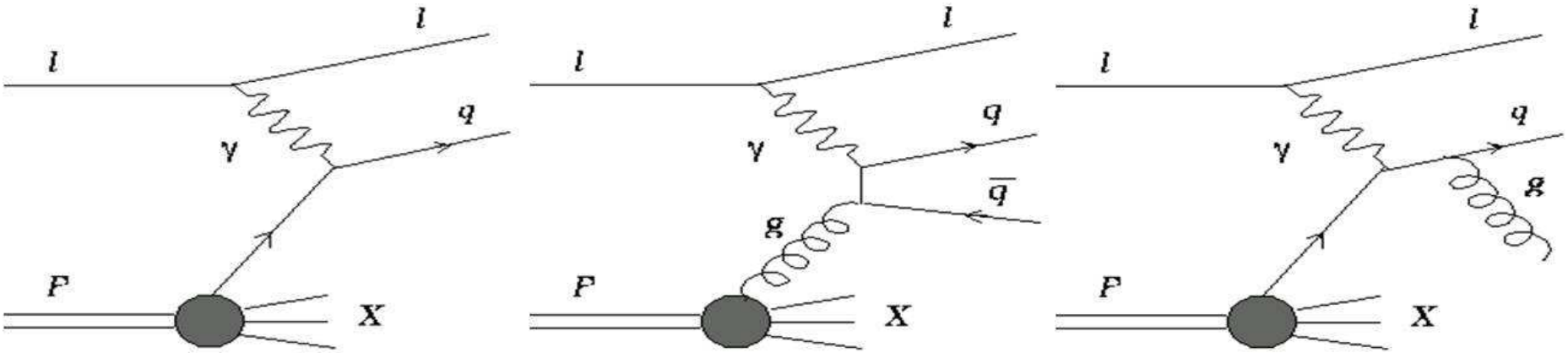


high-p_T hadron pairs analysis 2002-2004 data

Contents

- New results from $Q^2 > 1$ (GeV/c)^2 analysis
  - determination of the gluon polarization
  - data selection
  - neural Network (NN) approach
  - data and MC comparison
  - systematics studies and results
- $Q^2 < 1$ (GeV/c)^2 analysis

Determination of the gluon polarization from high-p_T hadron pairs



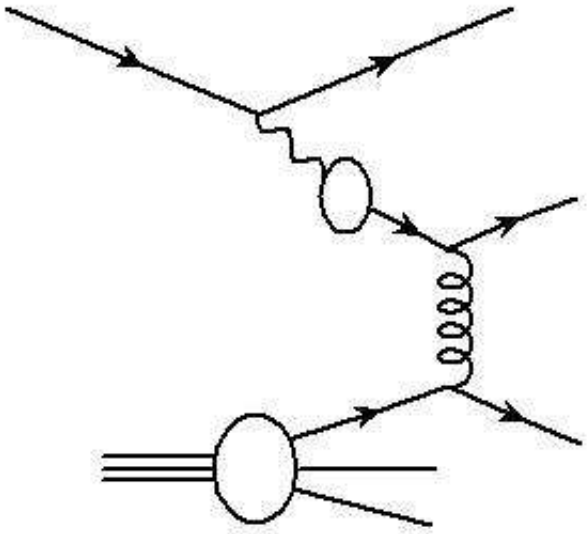
LO **PGF** **QCDC**

$$A_{LL}^{2h}(x_{Bj}) \approx \frac{\Delta G}{G}(x_G) a_{LL}^{\hat{PGF}} R_{PGF} + A_1^{LO}(x_C) a_{LL}^{\hat{C}} R_C + A_1^{LO} D R_L; \qquad A_1^{LO} \equiv \frac{\sum_i e_i^2 \delta q_i}{\sum_i e_i^2 q_i}$$

Determination of the gluon polarization from high-p_T hadron pairs

LOW Q^2 analysis:

Additional contribution from resolved-photon processes ($\sim 50\%$ of cross-section)



The extraction formula for the gluon polarization

$$\frac{\Delta G}{G}(\bar{x_G}) = \frac{A_{LL}^{2h}(x_{Bj}) + A^{corr}}{\beta}$$

$$\beta = a_{LL}^{PGF} R_{PGF} - a_{LL}^{PGF,incl} R_{PGF}^{incl} \left(\frac{R_L}{R_L^{incl}} + \frac{R_C}{R_L^{incl}} \frac{a_{LL}^C}{D} \right)$$

$$A^{corr} = -A_1(x_{Bj}) D \frac{R_L}{R_L^{incl}} - A_1(x_C)\beta_1 + A_1(x'_C)\beta_2$$

$$\beta_1 = \frac{1}{R_L^{incl}} \left(a_{LL}^C R_C - a_{LL}^{C,incl} R_C^{incl} \frac{R_L}{R_L^{incl}} \right) \quad \beta_2 = a_{LL}^{C,incl} \frac{R_C R_C^{incl}}{(R_L^{incl})^2} \frac{a_{LL}^C}{D}$$

Rs - fractions of the sub-processes (LO, PGF, QCDC)

a_{LL}s - analyzing powers for LO,PGF and QCDC

Data selection for $Q^2 > 1$ (GeV/c)^2

- cuts on inclusive variables
  - $Q^2 > 1$ (GeV/c)^2 (scale of the process)
  - $0.1 < y < 0.9$
- cuts on hadron variables
  - $p_{T1} > 0.7$ GeV/c and $p_{T2} > 0.7$ GeV/c
  - $x_{F1,2} > 0,\ z_{1,2} > 0,\ z_1 + z_2 < 0.95$
  - inv. mass of two hadrons > 1.5 GeV/c^2

Total number of events in the selected sample: $\approx$ 500k

Weighted method for $\Delta G/G$ extraction

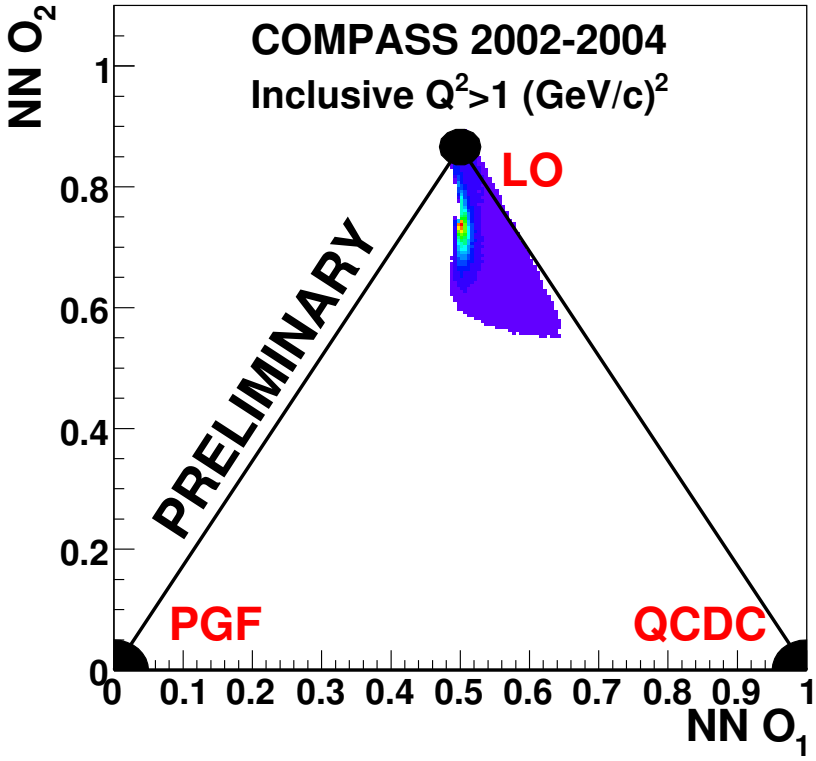
The following factors we need to know on the event by event basis:

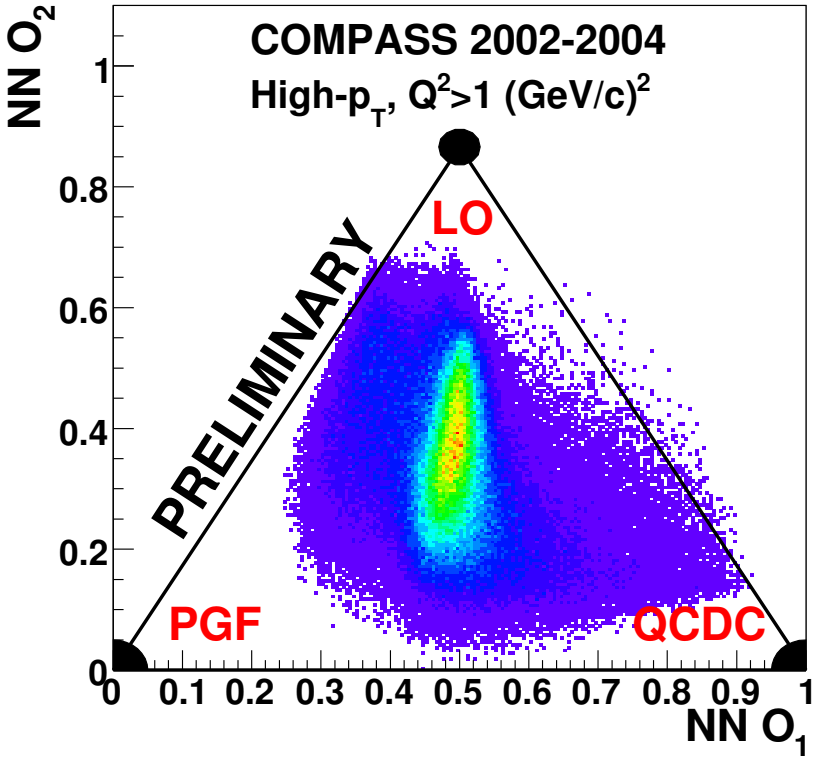
- $R_{PGF}, R_C, R_L, R_{PGF}^{incl}, R_C^{incl}, R_L^{incl}$
- $a_{LL}^{PGF}, a_{LL}^{C}, a_{LL}^{PGF,incl}, a_{LL}^{C,incl}$
- x_G, x_C, f, D, P_b

- f, D, P_b can be directly obtained from data
- remaining factors have to be obtained from MC
- NN trained on MC samples is used for parametrization of these quantities
- Input variables for NN:
  - inclusive case: x_{Bj} and Q^2
  - high-p_T: $x_{Bj}, Q^2, p_{L1,2}, p_{T1,2}$
- weight used: $fDP_b\beta$
- good data description with MC is a "key point" of the analysis

NN parametrization of Rs

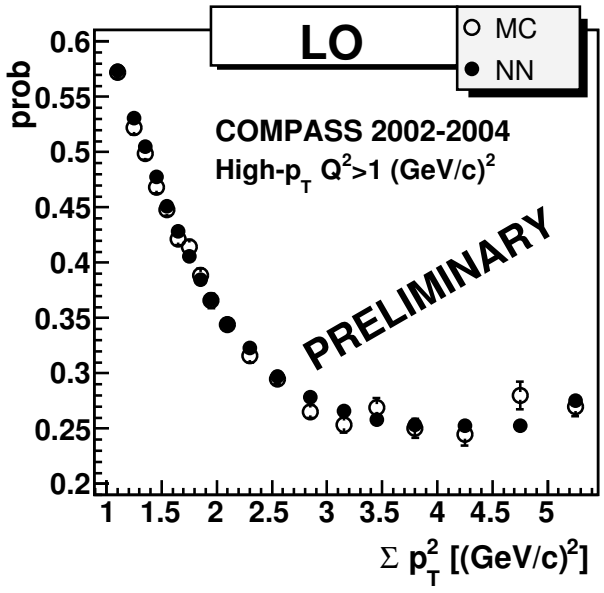
2 variables o_1 and o_2 are used (Rs sum up to 1)

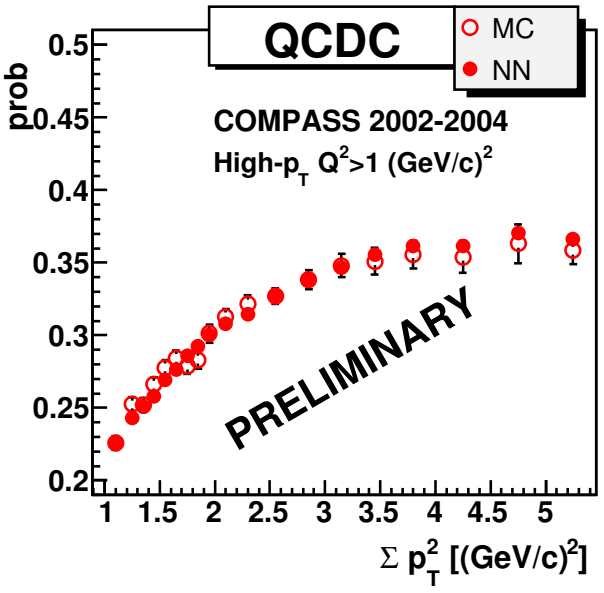


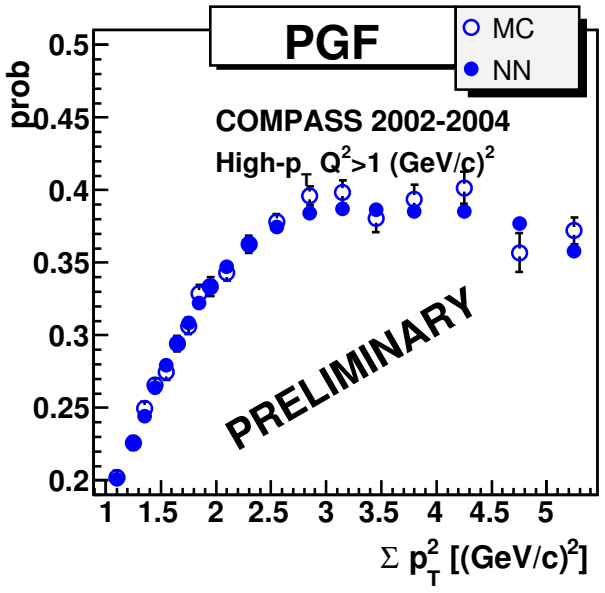


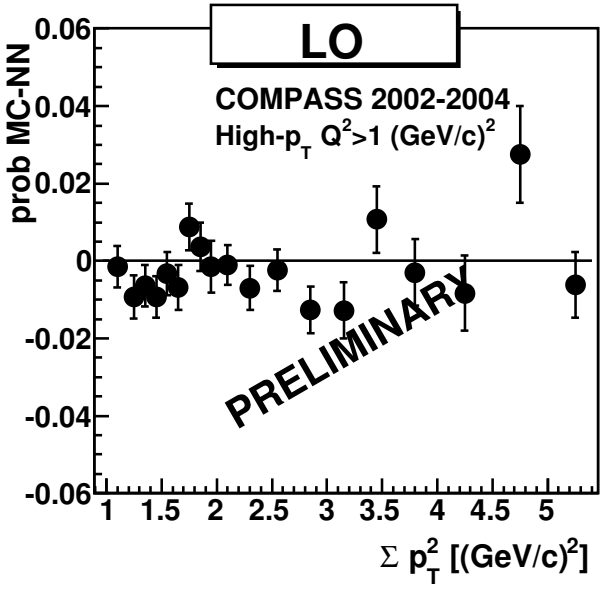
$$R_{PGF} = 1 - o_1 - \frac{1}{\sqrt{3}} o_2, \quad R_C = o1 - \frac{1}{\sqrt{3}} o_2, \quad R_L = \frac{2}{\sqrt{3}} o_2$$

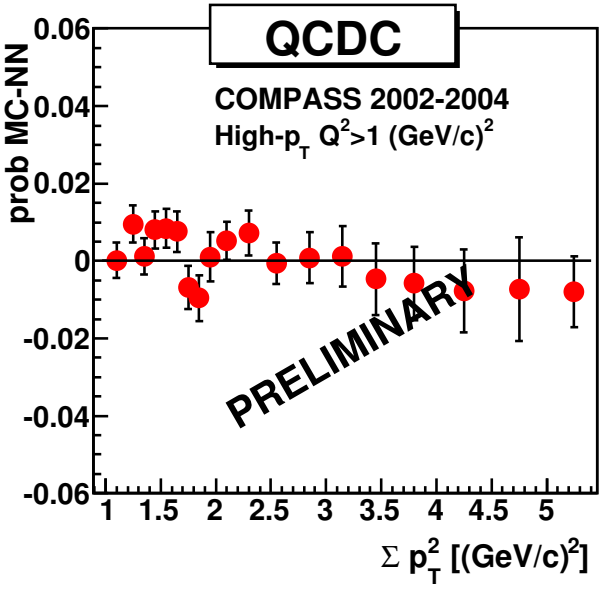
NN stability

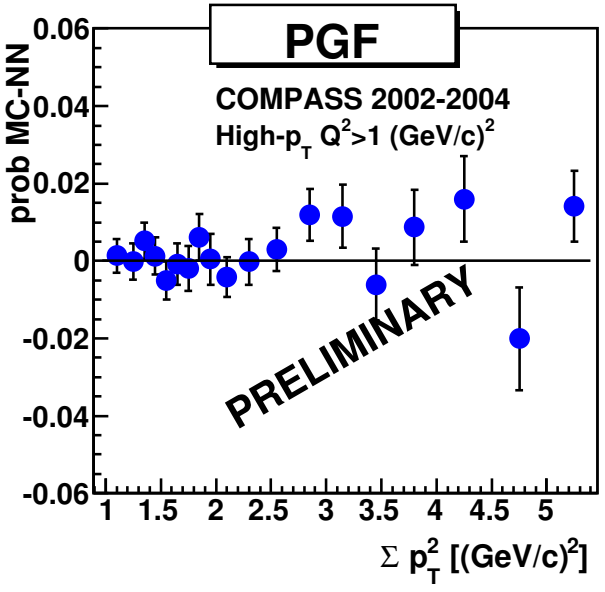












MC simulations

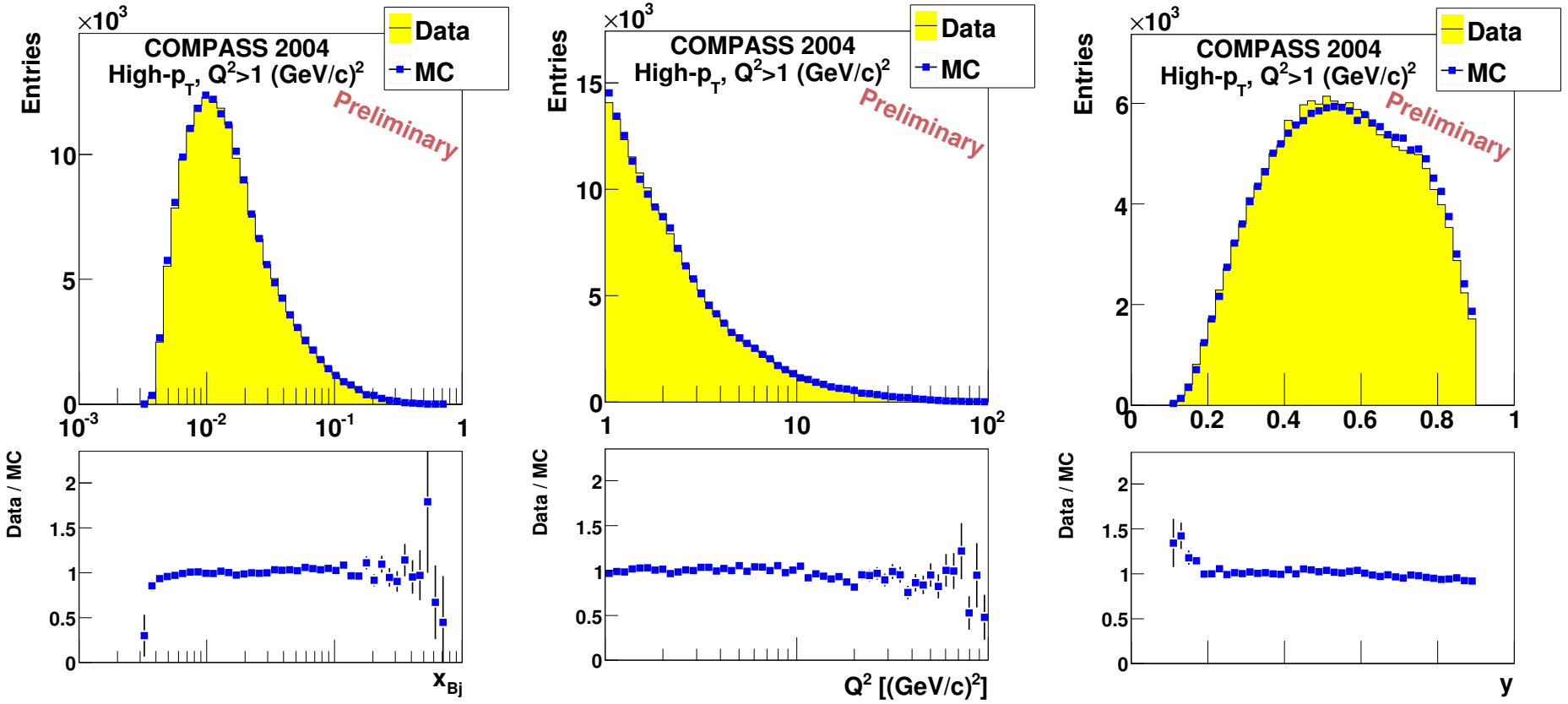
- 2 MC samples were used in the analysis: high-p_T and inclusive
- input: LEPTO generator and full simulation of the detector
  PDFs: MRST2004LO
- gluon radiations - simulation of the part of NLO corrections:
  - parton shower on were used for $\Delta G/G$ extraction (*i.e.* NN training)
  - parton shower off were tested and included in the systematics
- to improve data/MC agreement - LEPTO was tuned
  (k_T and parameters of fragmentation)
- default MC parameters were used in systematics studies

	PARJ21	PARJ23	PARJ24	PARJ41	PARJ42
Default	0.36	0.01	2.0	0.3	0.58
Compass	0.3	0.02	3.5	0.6	0.1

	Final MC
$< a_{LL}^{LO} >$	0.63
$< a_{LL}^{C} >$	0.50
$< a_{LL}^{PGF} >$	-0.36
R_L	0.40
R_C	0.29
R_{PGF}	0.31

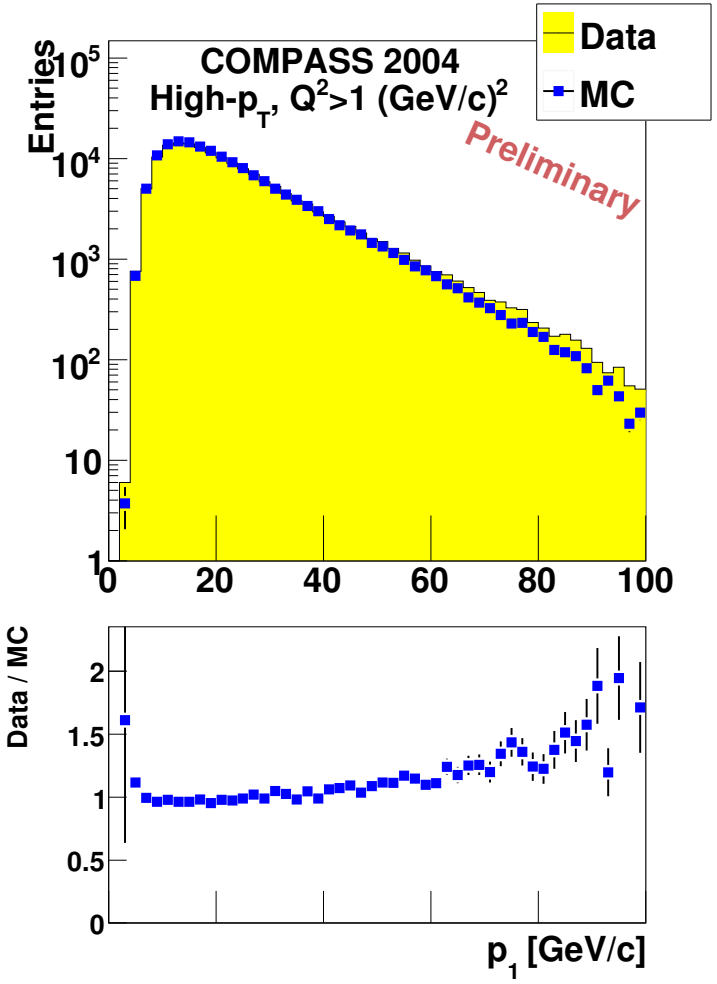
Data and MC comparison

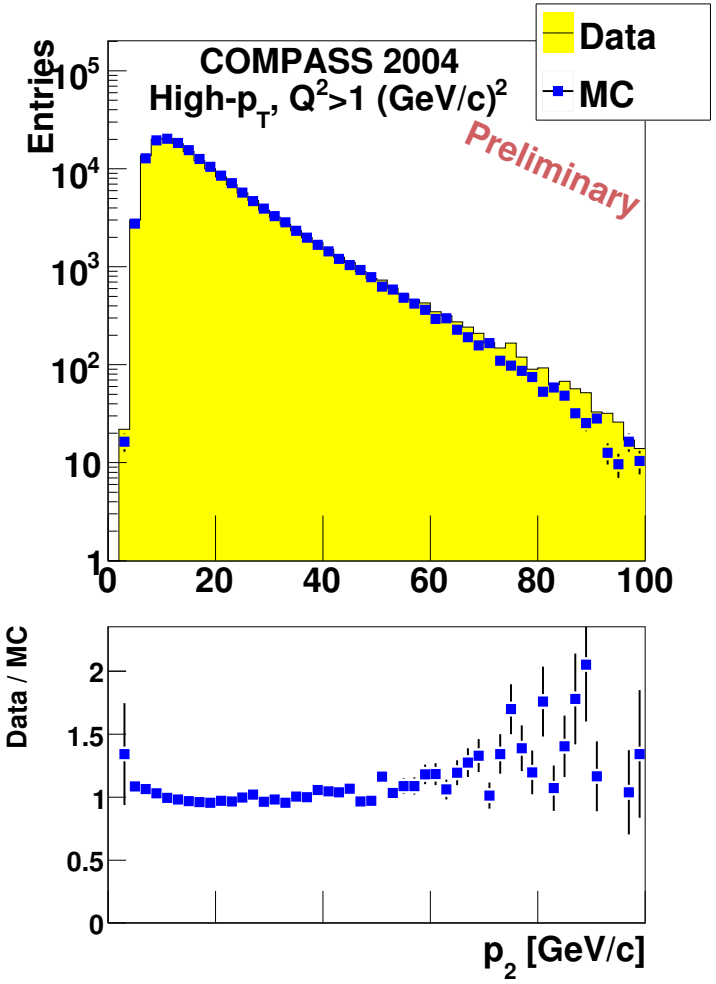
comparison for x, Q^2, y



Data and MC comparison

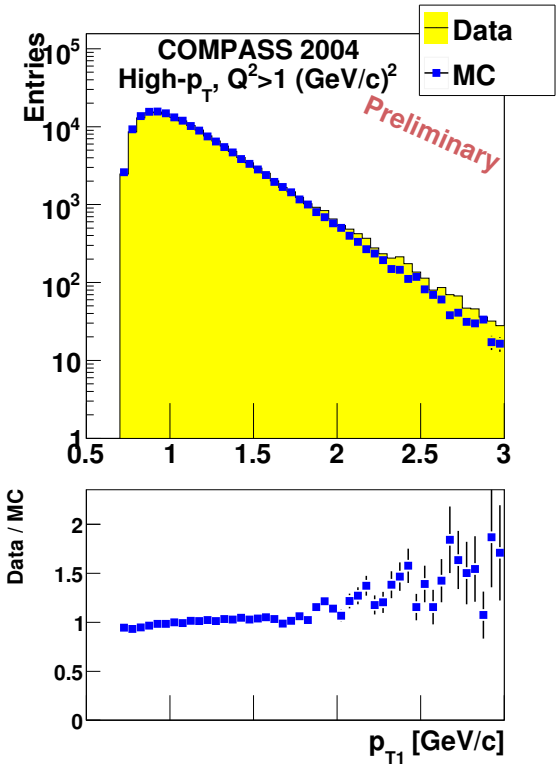
comparison for p_1, p_2

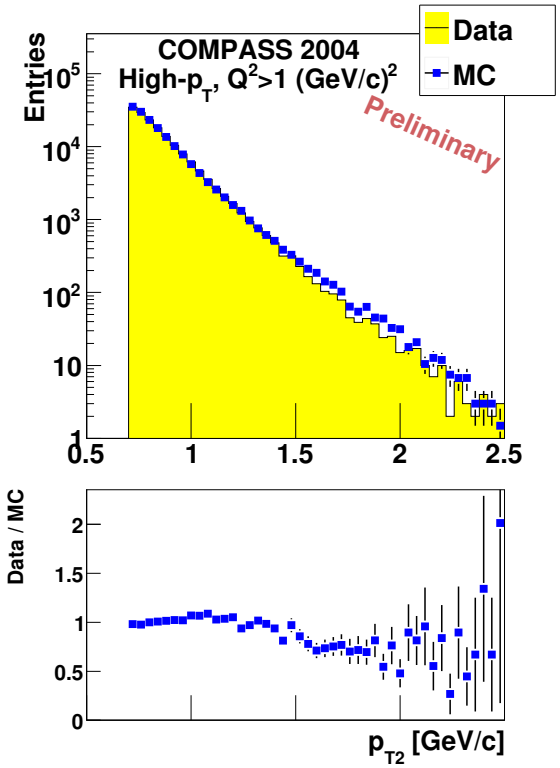


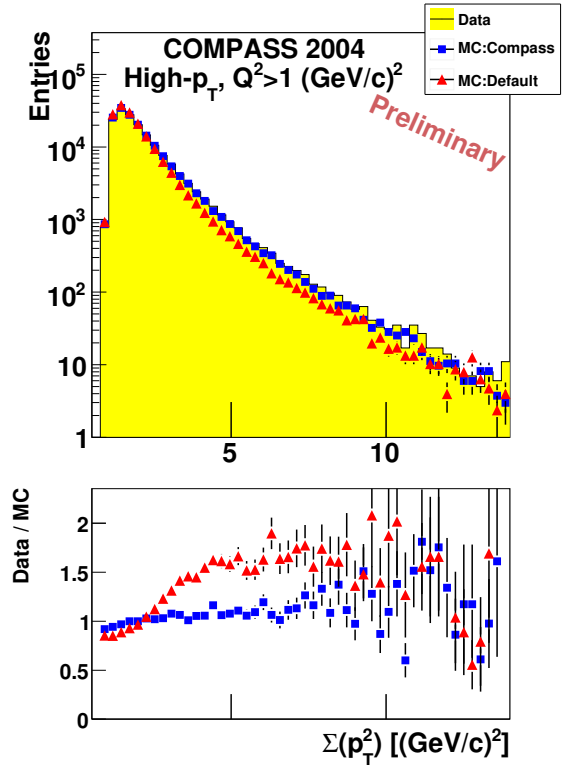


Data and MC comparison

comparison for $p_{T1}, p_{T2}, \sum P_T^2$, impact of MC tuning shown for $\sum P_T^2$







Systematic Studies

- false asymmetries
- NN stability
- systematic errors due to MC
- $\delta P_b, \delta P_t, \delta f$
- radiative corrections
- simplification of the formula for $\Delta G/G$
- A_1^d parametrization

$\delta(\Delta G/G)_{NN}$	0.006
$\delta(\Delta G/G)_{MC}$	0.040
$\delta(\Delta G/G)_{f,P_b,P_t}$	0.006
$\delta(\Delta G/G)_{false}$	0.011
$\delta(\Delta G/G)_{A1}$	0.008
$\delta(\Delta G/G)_{formula}$	0.013
TOTAL	0.045

Systematic error due to MC

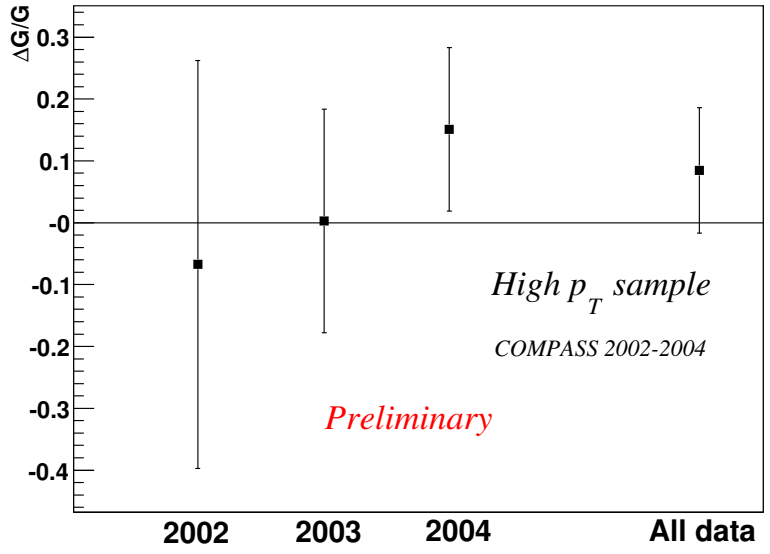
- 4 different MCs have been used
  - COMPASS tuning PS on
  - COMPASS tuning PS off
  - standard tuning PS on
  - standard tuning PS off
- for each MC sample 3 different analysis were performed to extract $\Delta G/G$
  - standard MC events were used
  - limited sample was used (events with good data/MC agreement)
  - MC events re-weighted to obtain the ratio of data/MC=1

final result for the systematic error due to MC: 0.04

Preliminary result for $\Delta G/G$ for $Q^2 > 1$ $(\mathrm{GeV/c})^2$

$$\frac{\Delta G}{G} = 0.08 \pm 0.10 \pm 0.05$$

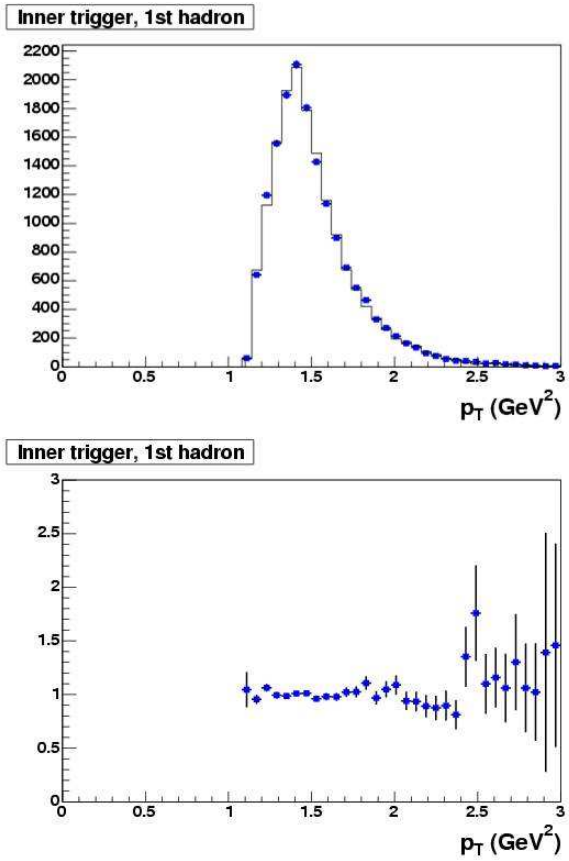
$$x_G = 0.082^{+0.041}_{-0.027} \text{ @ } \mu^2 \approx 3 \ (\mathrm{GeV/c})^2$$

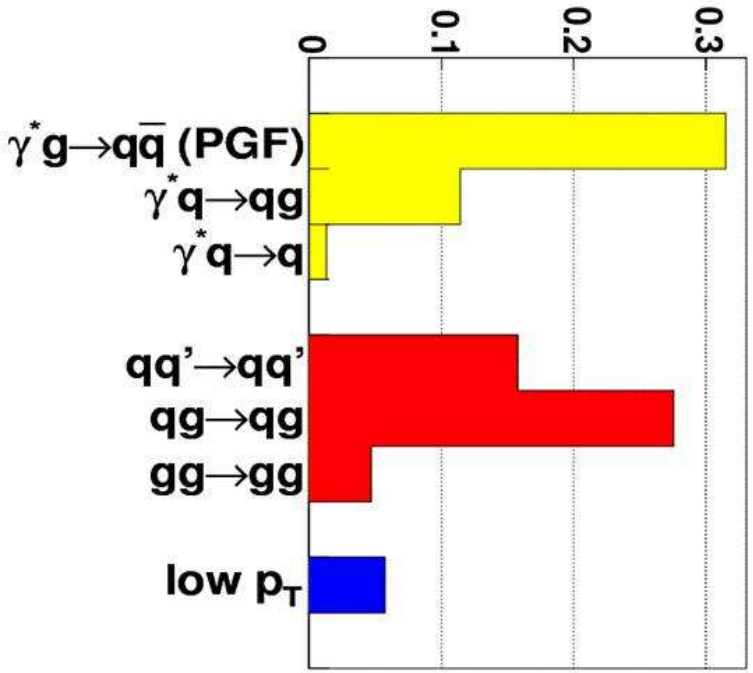


High-p_T hadrons pair analysis for low Q^2 data 2002-2004 data

Low Q^2 analysis ($Q^2 < 1$ (GeV/c)^2)

- cuts approach used - cut of $\sum P_T^2 > 2.5$ (GeV/c)^2
- hard scale assured by large cut on $\sum P_T$s
- MC - PYTHIA generator for low Q^2 + spectrometer simulation



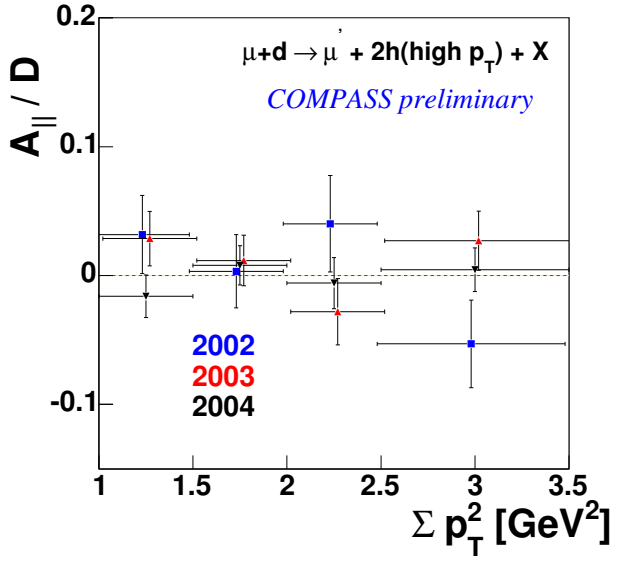


$R_{PGF} \approx 30\%$

$R_{res.ph.} \approx 50\%$

Low Q^2 analysis ($Q^2 < 1$ (GeV/c)^2) RESULTS

2002-2003 RESULTS PUBLISHED: PLB 633 (2006) 25-32



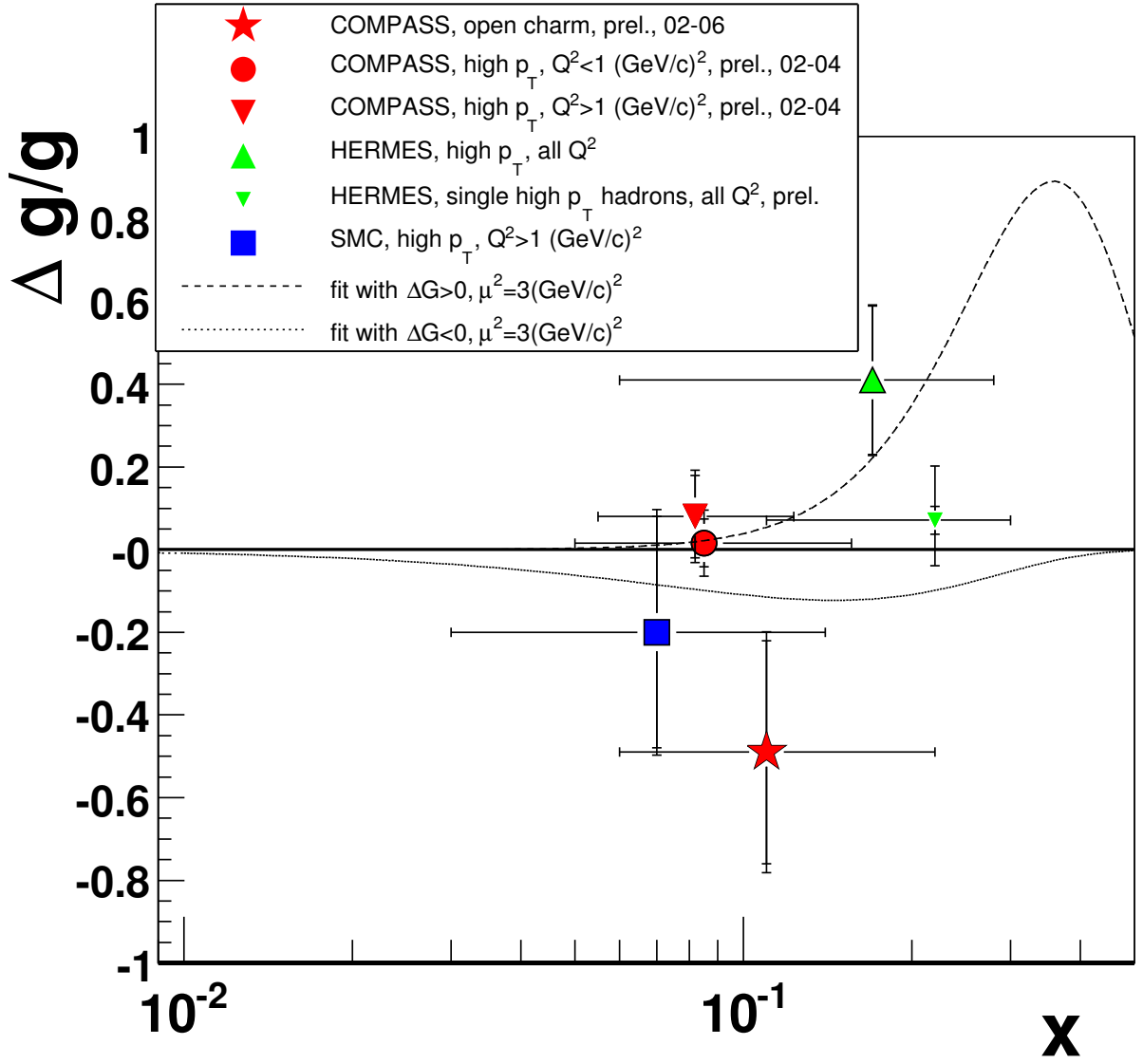
CUT 2.5 (GeV/c)^2 used in the analysis

Data	$\Delta G/G(X_g)$	stat	exp.syst	MC.syst	resolved photon
02-03	0.024	0.089	0.014	0.052	0.018
02-04	0.016	0.058	0.014	0.052	0.013

SUMMARY

- new results from open charm and high-p_T hadrons pair analyzes have been shown
- errors of the measurements were significantly reduced due to usage of additional data and new methods of analysis
- summary of the results
  - open charm: $\Delta G/G = -0.49 \pm 0.27 \pm 0.11$
  - high-p_T high Q^2: $\Delta G/G = 0.08 \pm 0.10 \pm 0.05$
  - high-p_T low Q^2: $\Delta G/G = 0.016 \pm 0.058 \pm 0.054$

SUMMARY cont.



OUTLOOK

- Open Charm
  - publication in preparation
  - try to upgrade analysis method
  - NLO analysis
  - look on other decay channels of D^0, different tagging method
  - add 2007 data
- high-p_T $Q^2 > 1(\mathrm{GeV/c})^2$
  - add 2006 data
  - explore p_T region $0.4 < p_T < 0.7$, no inv mass cut
  - with the two above points hope to double available statistics
  - split data to have two points in x_g
  - 1 hadron analysis
  - NLO analysis
  - 2007 data

OUTLOOK cont.

- high-p_T low Q^2
  - pending, two analyzes above have higher priority
- 1 high-p_T hadron, low Q^2
  - analysis ongoing
  - preliminary results this/next year
- Cross-sections
  - checking compatibility between COMPASS and NMC F_2s
  - σ^{D0} studies in progress
  - $\sigma^{2h,1h}$ high-p_T studies in progress