Gluon polarisation in the Nucleon from high transverse momentum hadron pairs in COMPASS

on behalf of the COMPASS Collaboration

Krzysztof Kurek,
National Centre for Nuclear Reserch
Warsaw

XIV Workshop on High Energy Spin Physics (DSPIN 2011)
September 20-24, 2011, Dubna, Russia

COMPASS Collaboration at CERN

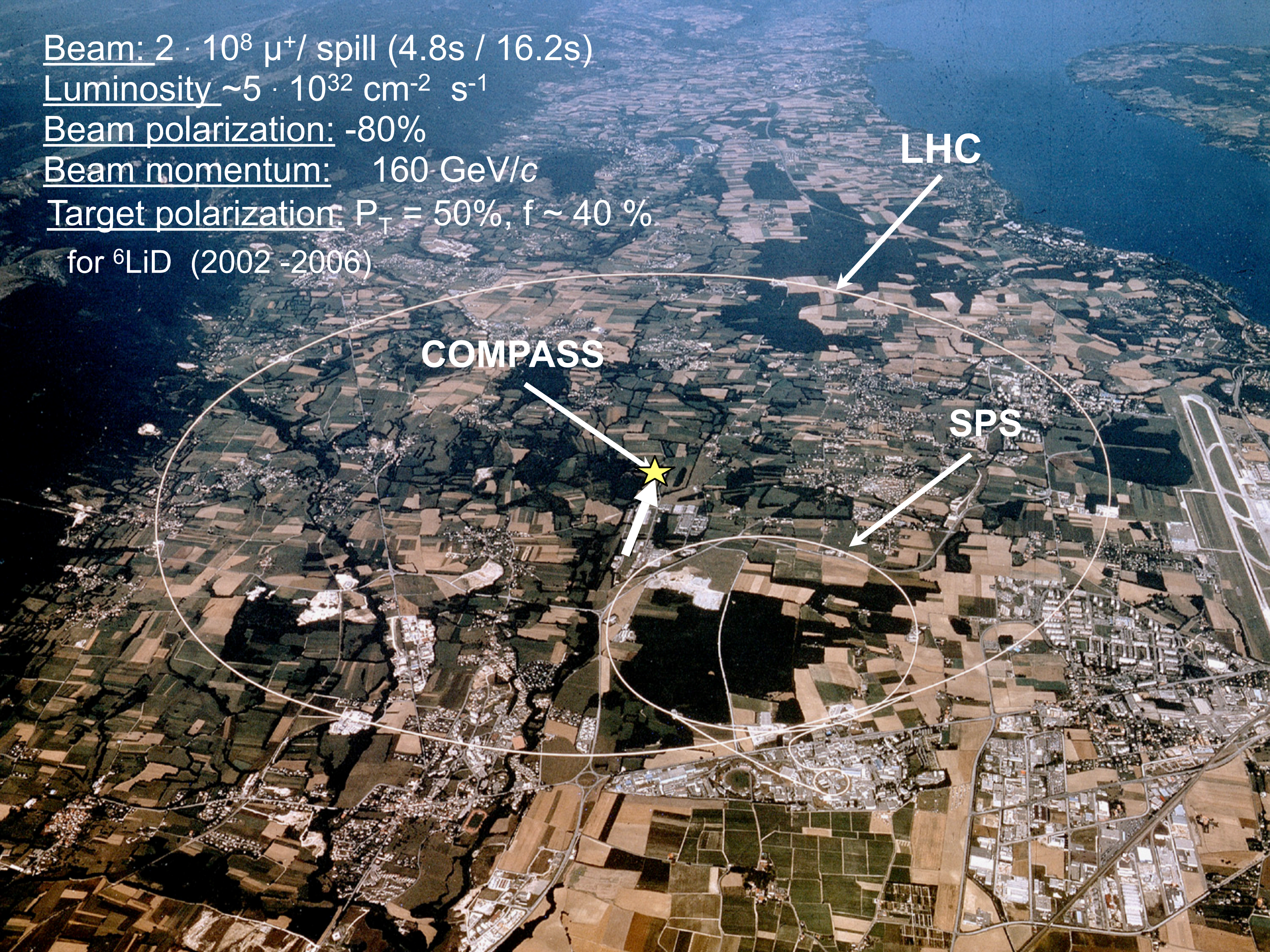
Common Muon and Proton Apparatus for Structure and Spectroscopy

Czech Rep., France, Germany, India, Israel, Italy, Japan, Poland, Portugal, Russia and CERN

Bielefeld, Bochum, Bonn, Burdwan and Calcutta, CERN, Dubna, Erlangen, Freiburg, Lisbon, Mainz, Moscow, Munich, Prague, Protvino, Saclay, Tel Aviv, Torino, Trieste, Warsaw, Yamagata

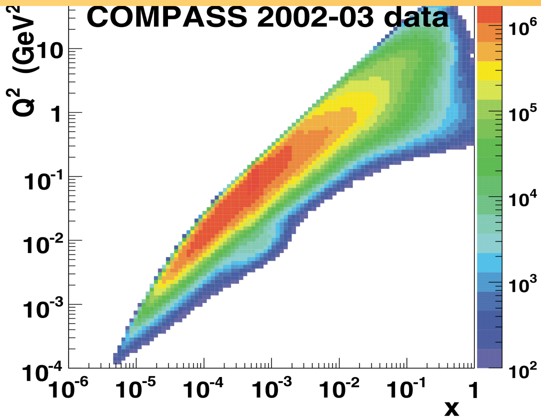
~240 physicists, 30 institutes

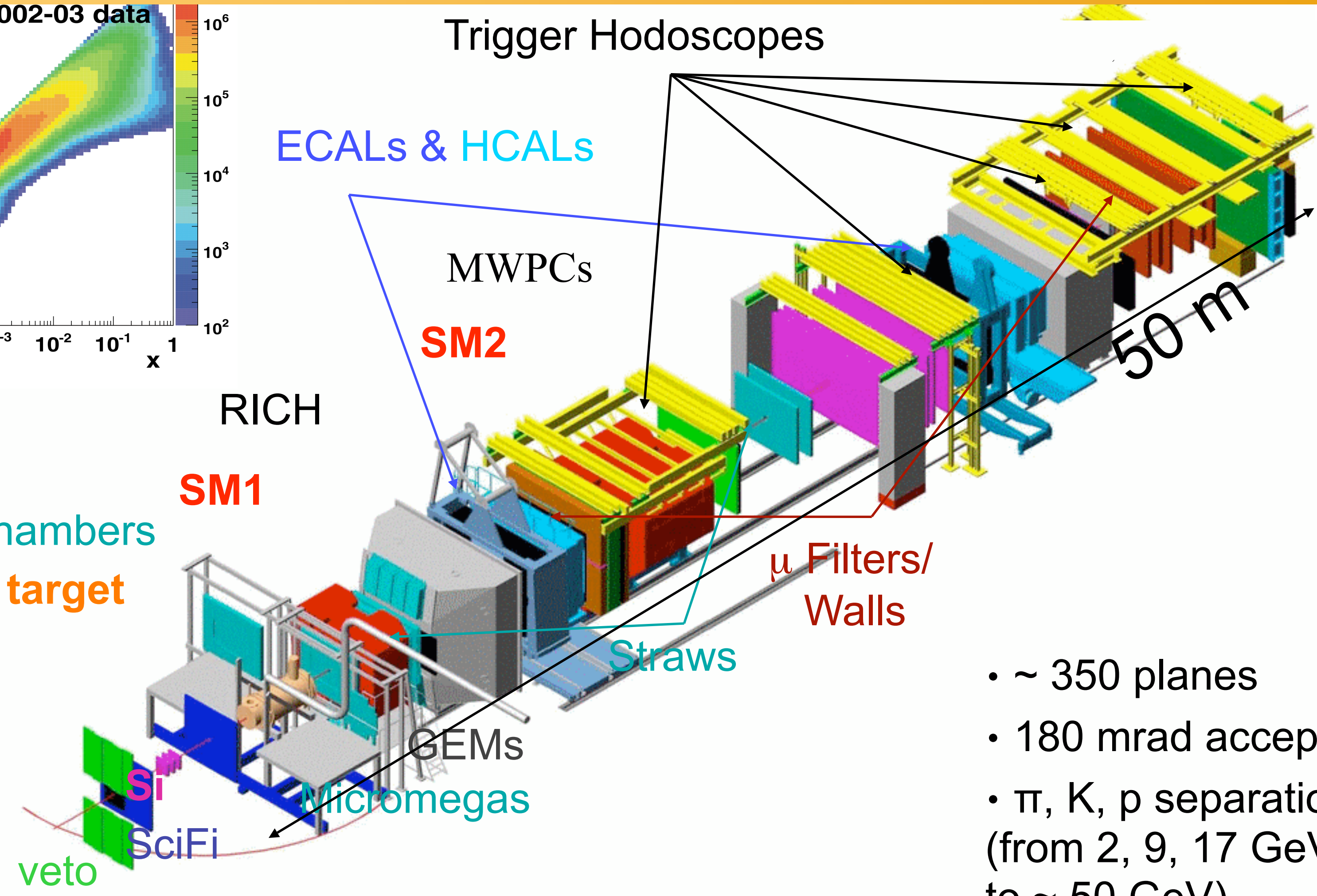
Beam: $2 \cdot 10^8$ μ^+/ spill (4.8s / 16.2s)
Luminosity ~$5 \cdot 10^{32}$ cm^{-2} s^{-1}
Beam polarization: -80%
Beam momentum: 160 GeV/c
Target polarization: P_T = 50%, f ~ 40 %
for ^{6}LiD (2002 -2006)



The COMPASS spectrometer

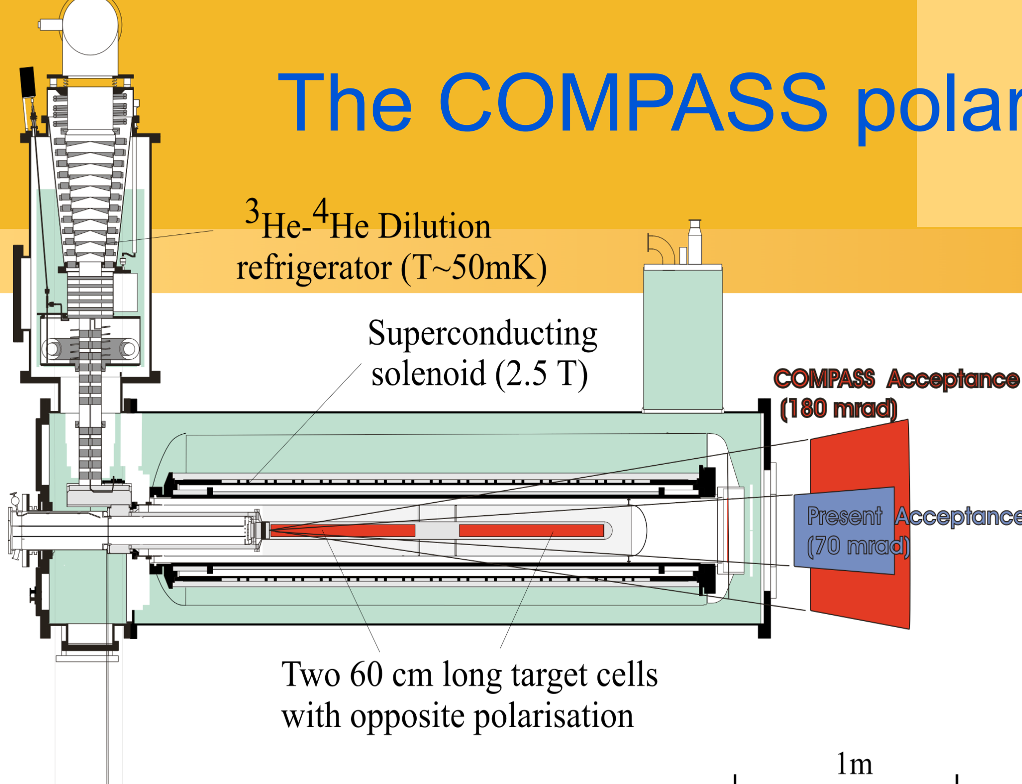
COMPASS in muon run
NIM A 577(2007) 455





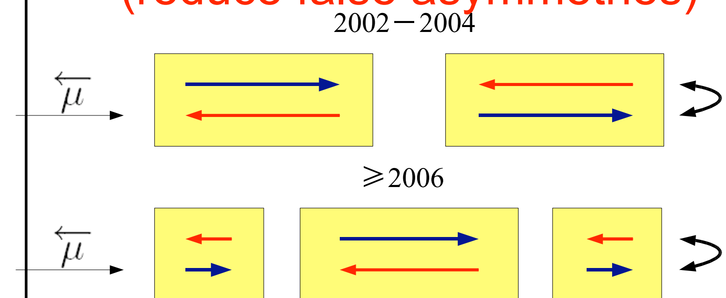
- ~ 350 planes
- 180 mrad acceptance
- π, K, p separation (from 2, 9, 17 GeV up to ~ 50 GeV)

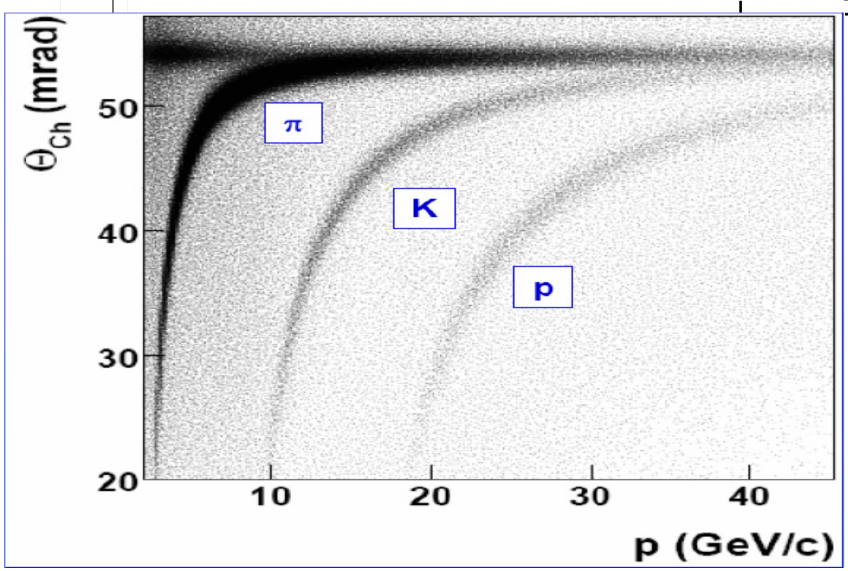
The COMPASS polarized target and PID



Target material: ^{6}LiD
Polarisation: >50%
Dilution factor: ~0.4
Dynamic Nuclear Polarization

2006 - new solenoid
with acceptance 180 mrad
3 target cells
(reduce false asymmetries)





RICH 2006 upgrade : better PID

MAPMTs in central region

APV electronics in periphery

Contents

- Introduction
- Gluon polarization measurement @ COMPASS
- High transverse momentum hadron pairs for large and low Q^2
- Data selection
- Artificial Neural Network approach
- Data and Monte-Carlo comparison
- Systematic studies
- Results

First moment of g_1 structure functions

Compass only

from Y. Goto *et al.*, PRD62 (2000) 034017:
($SU(3)_f$ assumed for weak decays)
$a_8 = 0.585 \pm 0.025$

$$\Gamma_1^N(Q^2) = \frac{1}{9}\left(1 - \frac{\alpha_s(Q^2)}{\pi} + O(\alpha_s^2)\right)\left(a_0(Q^2) + \frac{1}{4}a_8\right)$$

$$a_{0|Q_0^2=3(GeV/c)^2} = 0.35 \pm 0.03(stat) \pm 0.05(syst)$$

QCD NLO

$$\Gamma_1^N(Q^2) = \frac{1}{9}C_1^S(Q^2)\widehat{a}_0 + \frac{1}{36}C_1^{NS}(Q^2)a_8$$

beyond NLO

C_1 calculated behind 3 loops app.
S.A.Larin *et al.*,Phys.Lett.B404(1997)153

$$\hat{a}_{0|Q^2\to\infty} = 0.33 \pm 0.03(stat) \pm 0.05(syst)$$

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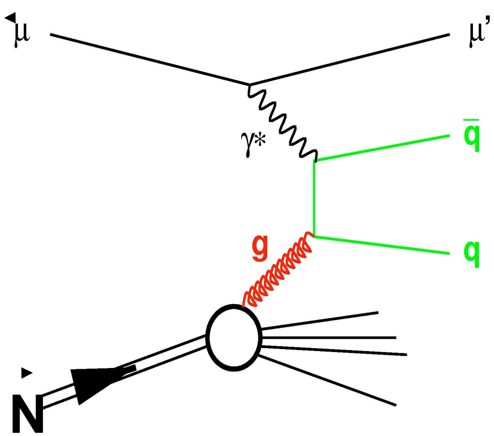
quark contribution to the proton spin: ~ 1/3

Direct gluon polarisation measurement via tagging PGF process



$$\sigma^{PGF} = G \otimes \hat{\sigma}^{PGF} \otimes H$$

$$\Delta\sigma^{PGF} = \Delta G \otimes \Delta\hat{\sigma}^{PGF} \otimes H$$

To select PGF process two methods are used @COMPASS:

- Open-charm D meson production:
  charm quark pairs produced in PGF, "clean" channel however with huge combinatorial background, low statistics but analysis weakly MC dependent

- High transverse momentum hadron pairs production:
  light quark pairs produced, high statistics but physical background; strongly model and MC dependent analysis, requires a very good agreement between data and MC

$$A \approx \frac{\Delta G}{G}(\bar{x}_G) < \hat{a}_{LL}^{PGF} >_G$$

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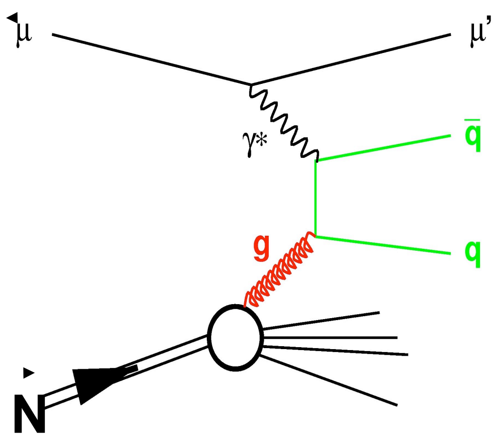

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from MC

$$A \approx \boxed{\frac{\Delta G}{G}(\bar{x}_G)} < \hat{a}_{LL}^{PGF} >_G$$

signal asymmetry from data

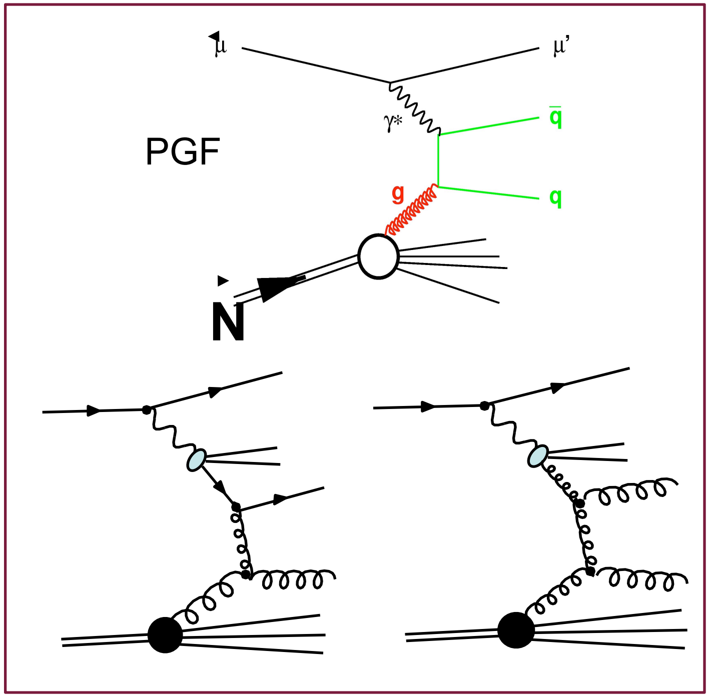
Low Q^2 : $Q^2 < 1\ (GeV/c)^2$

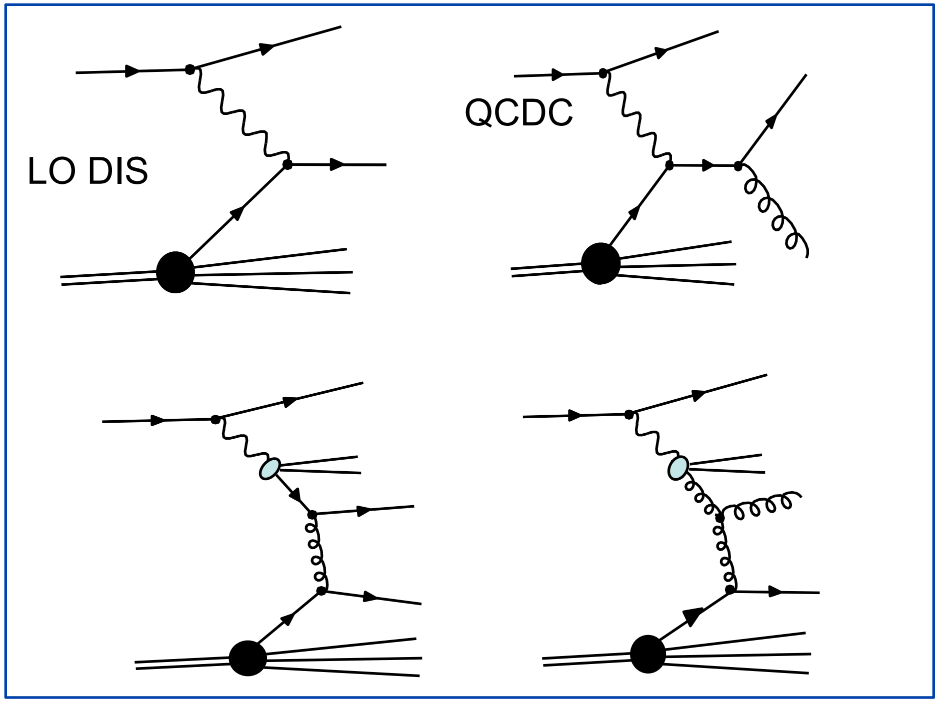
COMPASS@Low Q^2 - Phys. Lett. B 633 (2006) 25-32

R.D.Carlitz, J.C.Collins and A.H.Mueller, Phys.Lett.B 214, 229 (1988)
Revisited by A.Bravar,D.von Harrach and A.Kotzinian, Phys.Lett.B 421, 349 (1998)
Applied by SMC, HERMES and COMPASS

Two kinematical regions:low and large Q^2

- low Q^2 - $Q^2<1\ (GeV/c)^2$ - here p_T is a perturbative scale, also resolved photon contribution important (~50%) - COMPASS 2002-2003 data published





Large Q^2 : Q^2> 1 $(GeV/c)^2$

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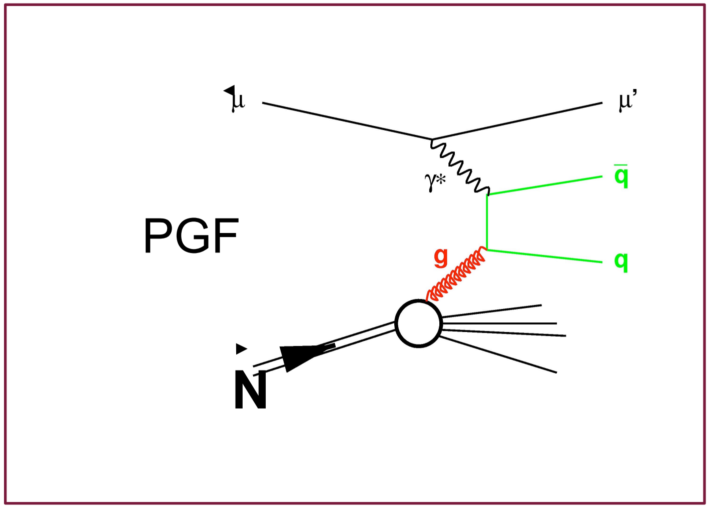
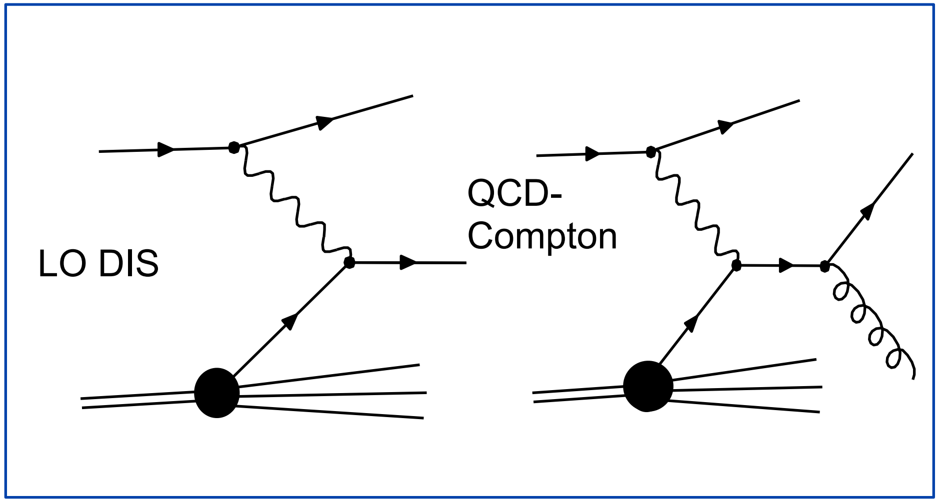
Two kinematical regions: low and large Q^2

- large Q^2 - Q^2>1 $(GeV/c)^2$ - scale Q^2 - 2002-2006 COMPASS data, method based on Neural Network approach used





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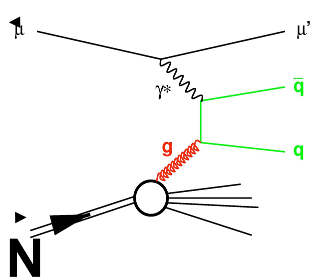
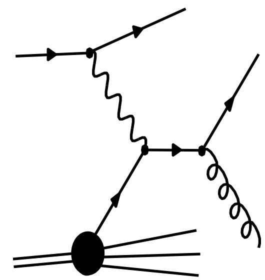
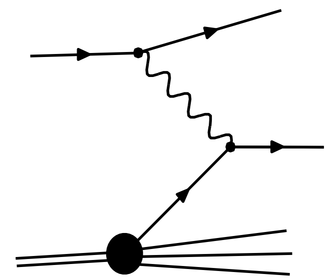


PGF



QCD-Compton



LO-DIS

$$A_{LL}^{2h}(x_{Bj}) \approx \frac{\Delta G}{G}(x_G)\,\hat{a}_{LL}^{PGF} R_{PGF} + A_1^{LO}(x_C)\,\hat{a}_{LL}^{C} R_C + A_1^{LO}(x_{Bj})\,D R_L$$

$$A_1^{LO} \equiv \frac{\sum_i e_i^2 \Delta q_i}{\sum_i e_i^2 q_i}$$

Same decomposition for inclusive sample to determine A_1^{LO}

Q: “clean” (more PGF “pure”) sample with limited statistics or
less PGF populated but larger sample ?

Formula for a determination of the gluon polarisation

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

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

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

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

R's are fractions of the sub-processes (LO,PGF, QCDC) in high-p_T and inclusive samples, respectively
a_{LL} 's are so-called analyzing powers for LO,PGF and QCDC (the ratio of partonic polarized and unpolarized cross sections for sub-processes)
D is a depolarization factor.

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- The polarized quark contribution (LO+QCDC) are taken directly from inclusive A_1 asymmetry (pure data)
- To determine $\Delta G/G$ ($<x_G>$) from $<\Delta G/G>$, $\Delta G/G$ has been assumed to be a linear function of x_G in measured bin (very well justified assumption)

Large Q^2 : $Q^2 > 1\ (\mathrm{GeV}/c)^2$

Event selection:

- Interaction vertex with an incoming and an outgoing muons
- $Q^2 > 1\ (\mathrm{GeV}/c)^2$ and $0.1<y<0.9$ (inclusive sample)
- Events with at least 2 hadrons in the final state (2h sample)
- The hadrons which form the high-p_T pair:

$$p_{T1} > 0.7\ \mathrm{GeV}/c \quad p_{T2} > 0.4\ \mathrm{GeV}/c$$

$$z_1 + z_2 < 0.95$$

these cuts define high-p_T sample

Years	2002	2003	2004	2006	all
Statistics	450 K	1.3 M	2.8 M	2.7 M	7.3 M

events

Weighted method to increase statistical precision
$w = fDP_b\beta$

β contains fractions & analysing powers

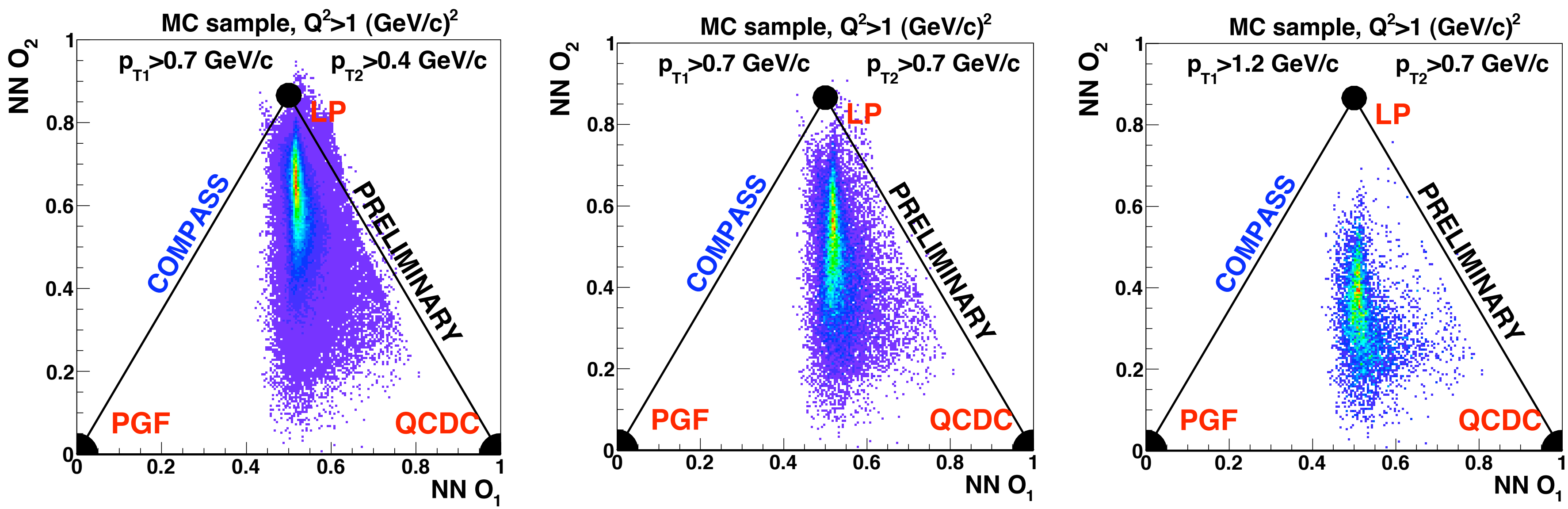
The following factors must be known on the event by event basis:

$$\boxed{\begin{array}{l} R_{PGF}, R_C, R_L, R^{incl}_{PGF}, R^{incl}_C, R^{incl}_L, \\ a^{PGF}_{LL}, a^{PGF,incl}_{LL}, a^{C}_{LL}, a^{C,incl}_{LL}, \\ x_C, x_G, \quad f, D, P_b \end{array}}$$

- f, D, P_b can be directly obtained from data
- Remaining factors have to be obtained from MC
- ANN trained on MC samples, then used on real data
- Input variables for ANN trainning:
  - 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

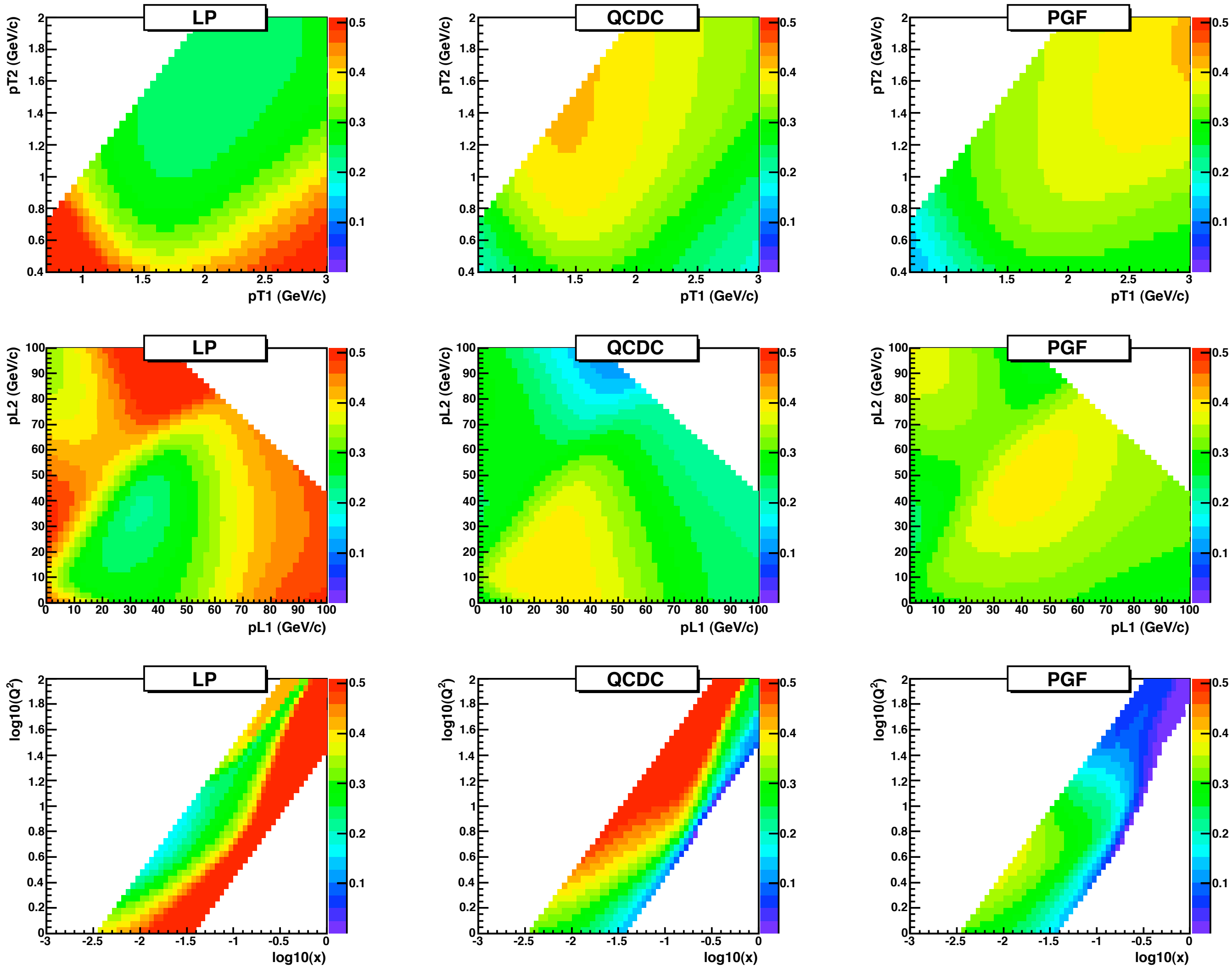
ANN results for fractions

2 variables o_1 and o_2 are used (R's sum up to 1)

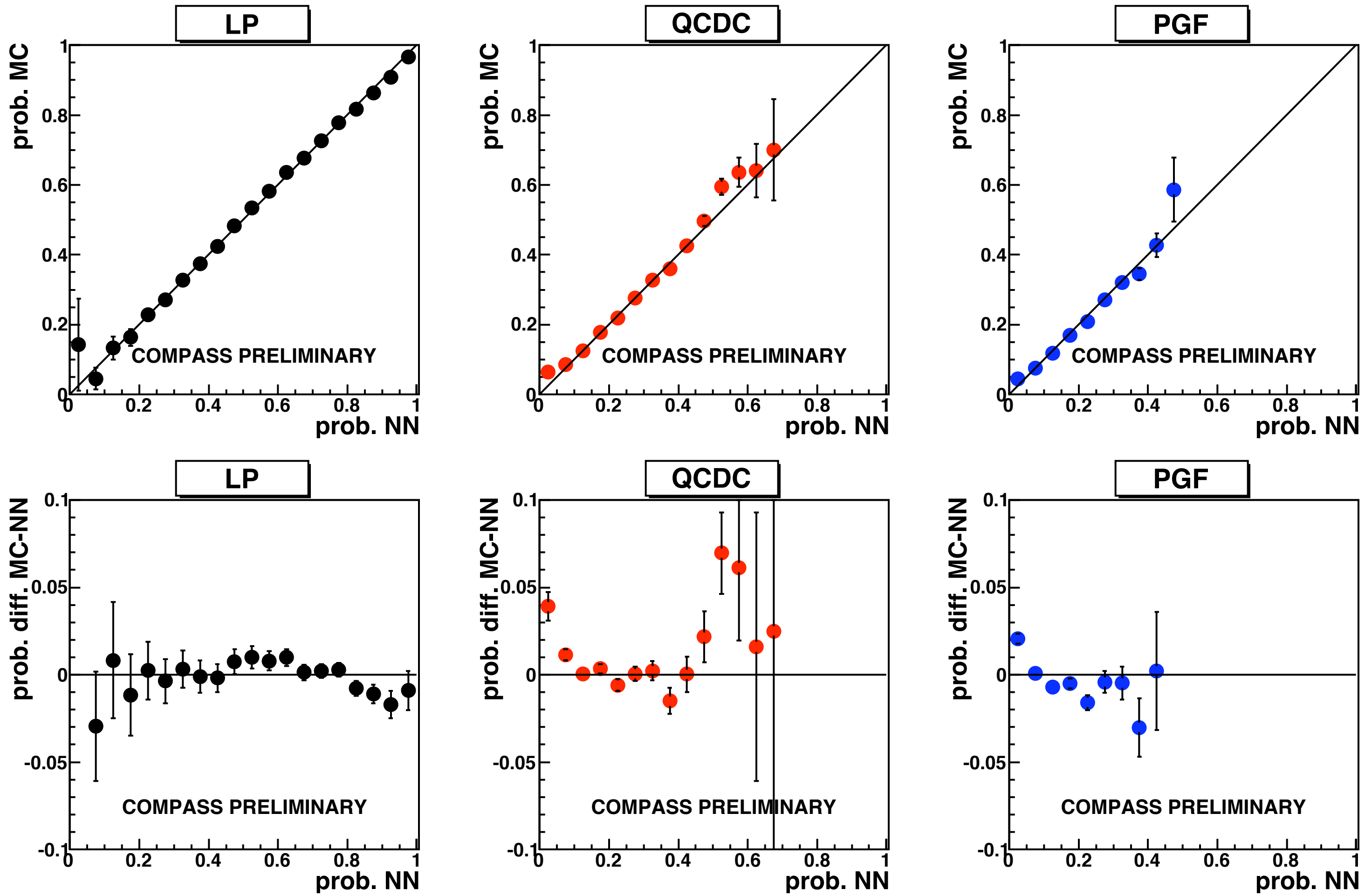


$$R_{PGF} = 1 - o_1 - \frac{1}{\sqrt{3}} o_2 \qquad R_C = o_1 - \frac{1}{\sqrt{3}} o_2 \qquad R_L = \frac{2}{\sqrt{3}} o_2$$

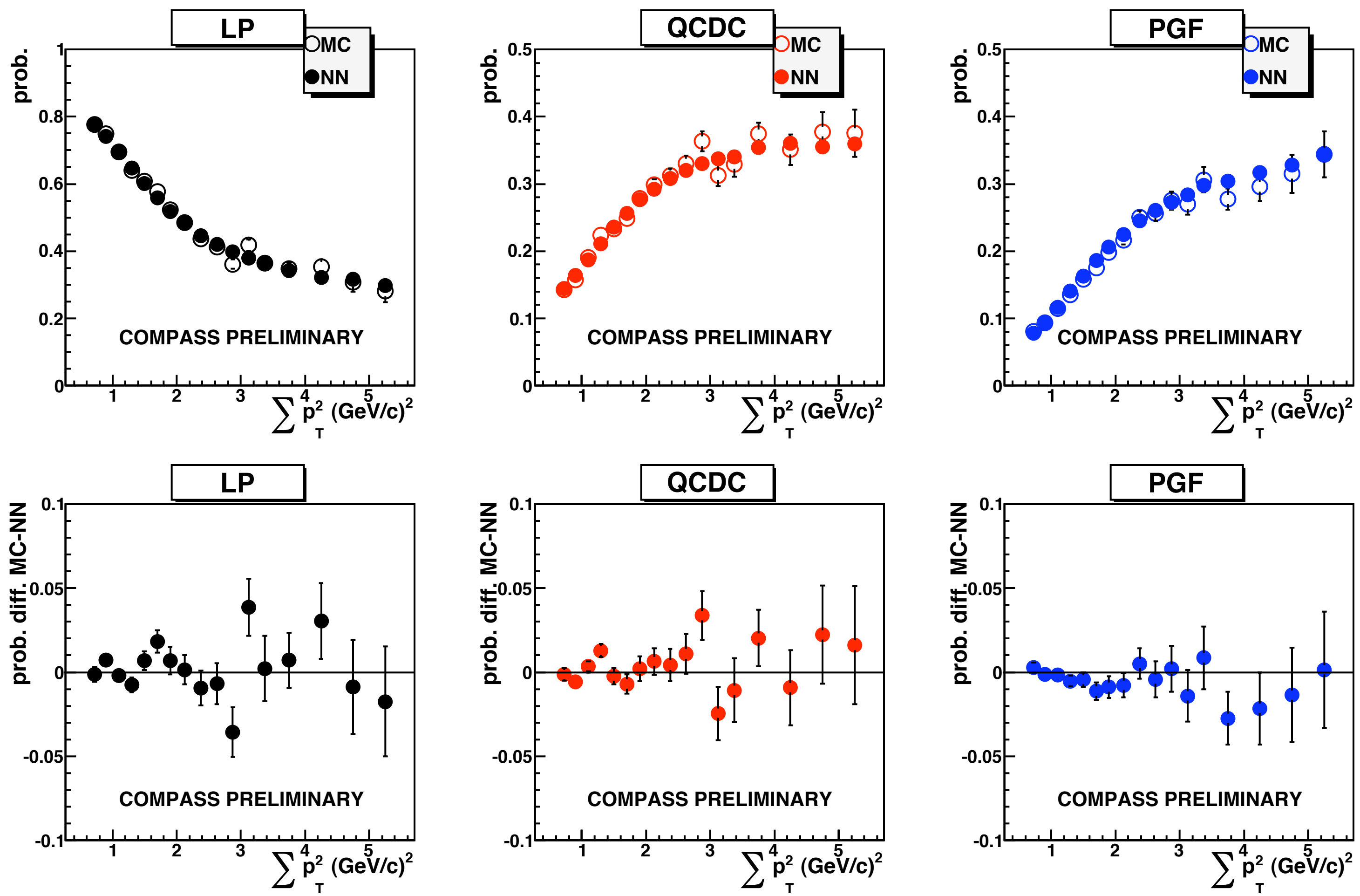
ANN results (cont.)



ANN results - stability



ANN results - stability cont.



MC Simulation

Two MC samples have been used:
- inclusive one
- high-p_T

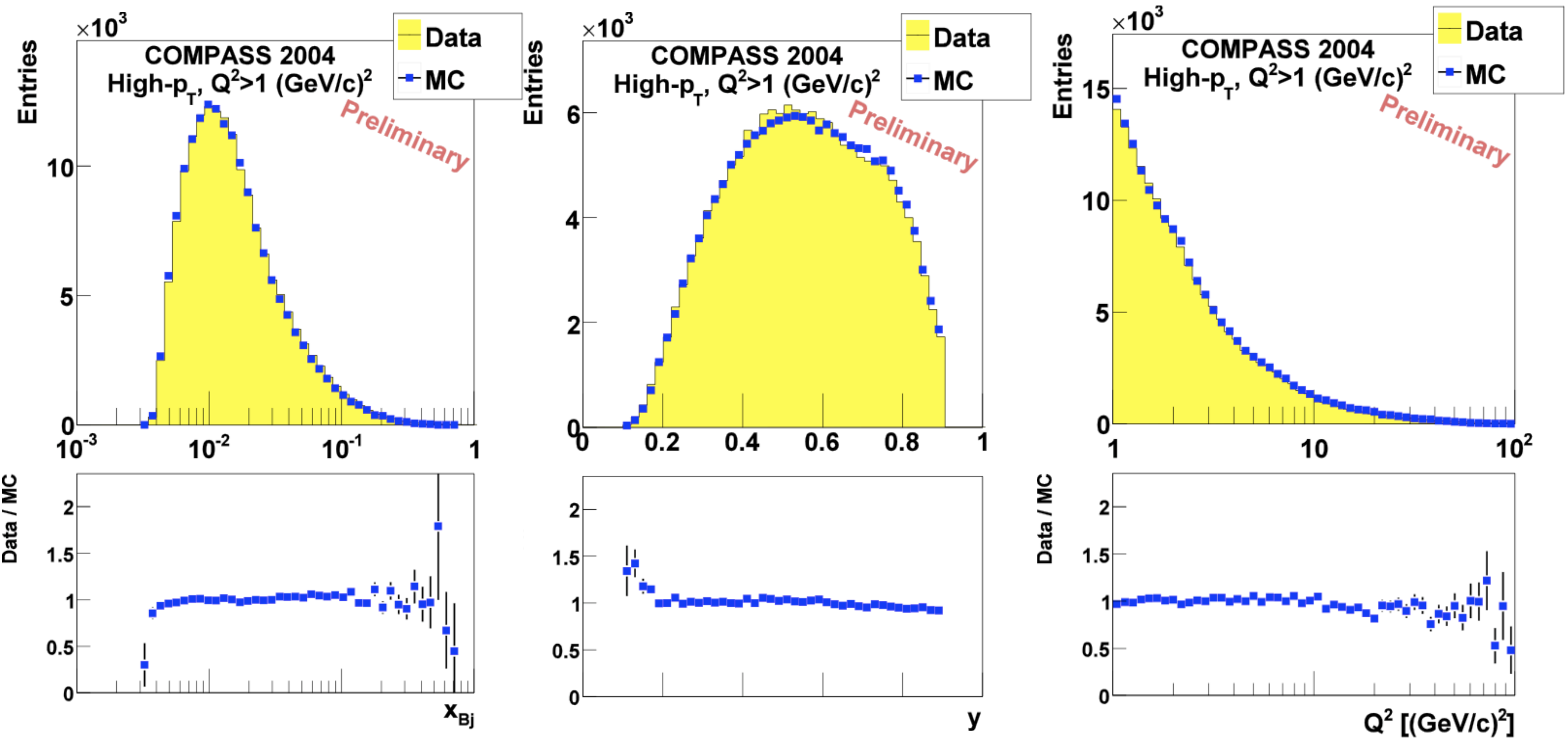
Full chain of MC simulation:
LEPTO+JETSET + GEANT (apparatus) + Reconstrucion (as for real data)

- PDF - MSTW2008LO
- high-p_T sample:
  - LEPTO Parton Shower on
  - MC tuning to improve hadron production description:

shapes (momenta) and multiplicity (fragmentation)

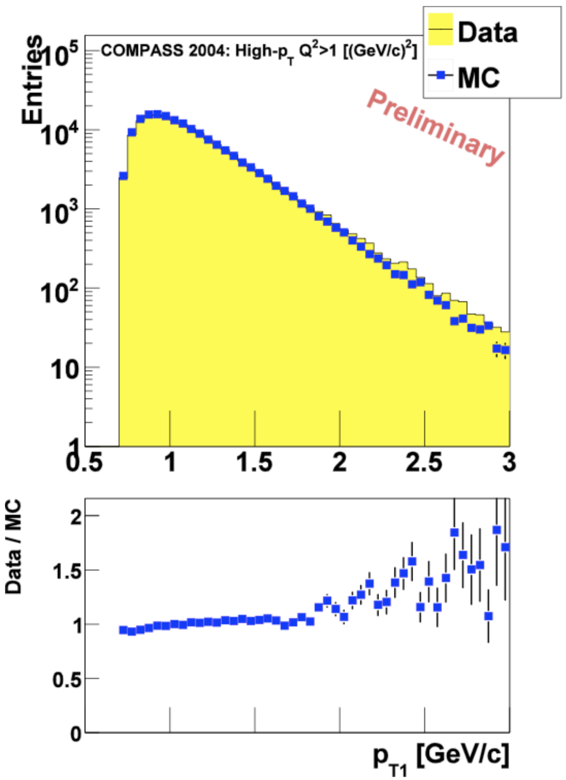
PARJ(21)	PARJ(23)	PARJ(24)	PARJ(41)	PARJ(42)
Transverse momentum of the hadron fragmentation			Fragmentation function	

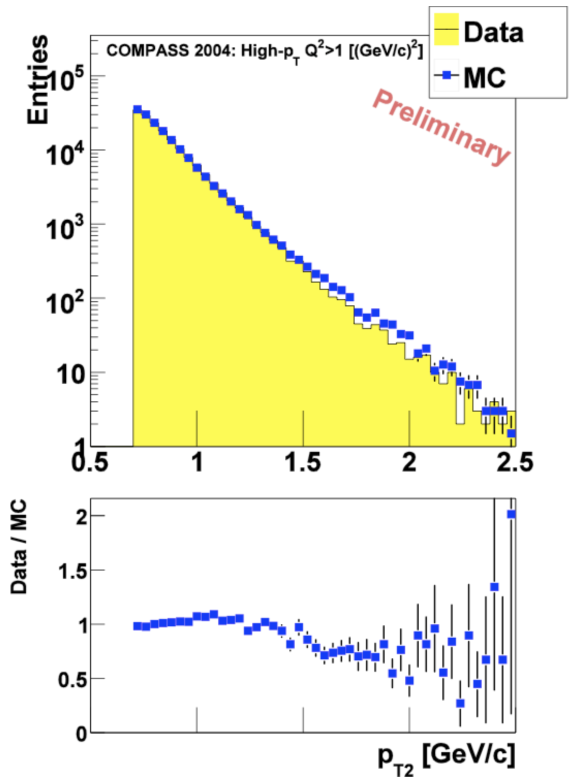
MC vs data 2004

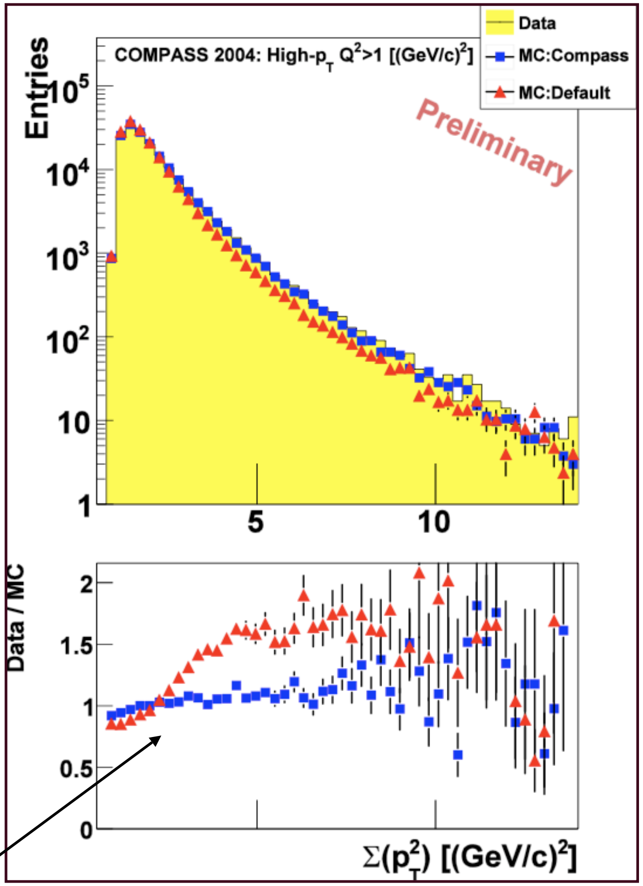


Comparison: MC/data for high p_T sample; x,y and Q^2

MC vs data 2004





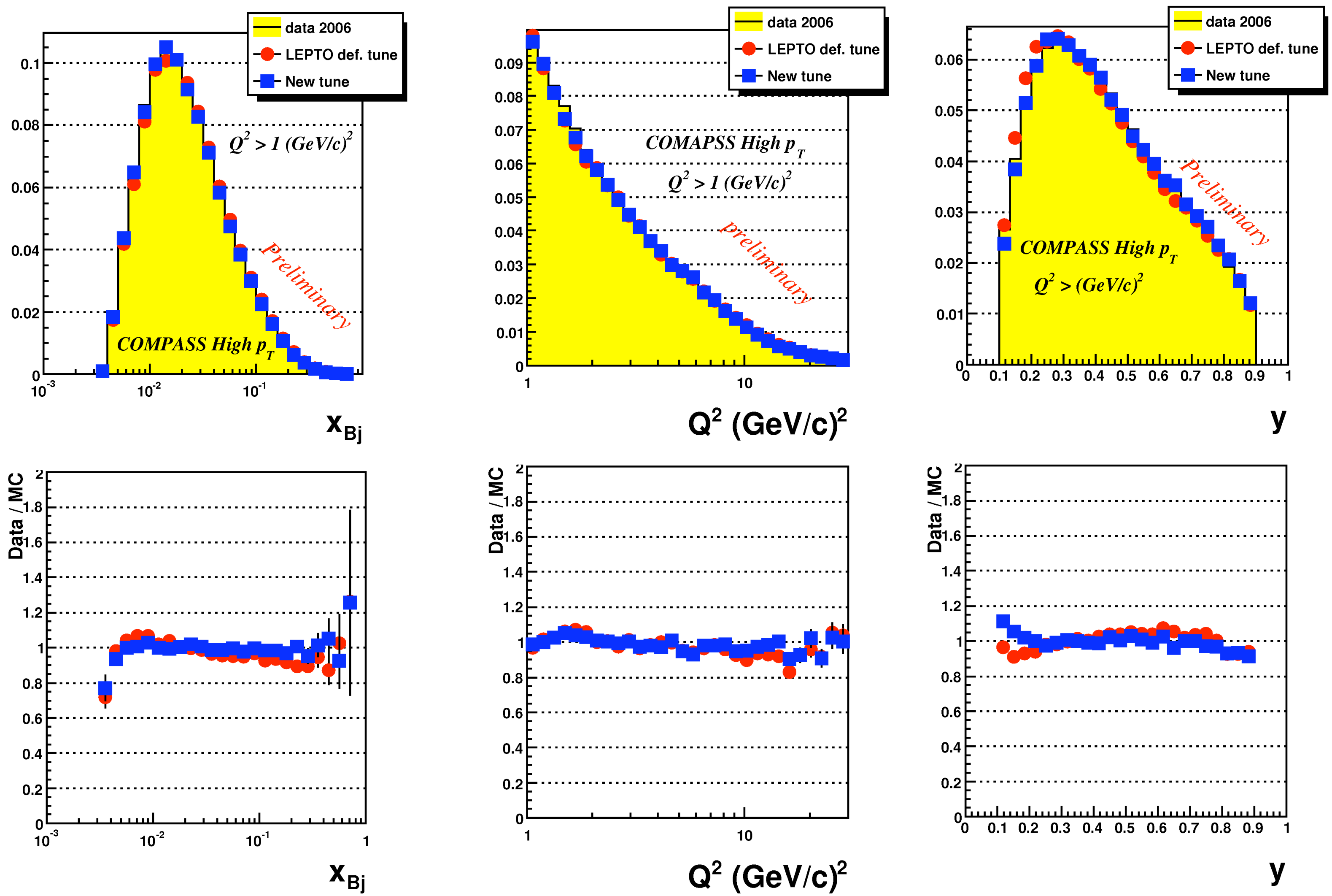


Comparison: MC/data for high p_T sample; transverse momenta of leading and sub-leading hadrons

Impact of MC tuning

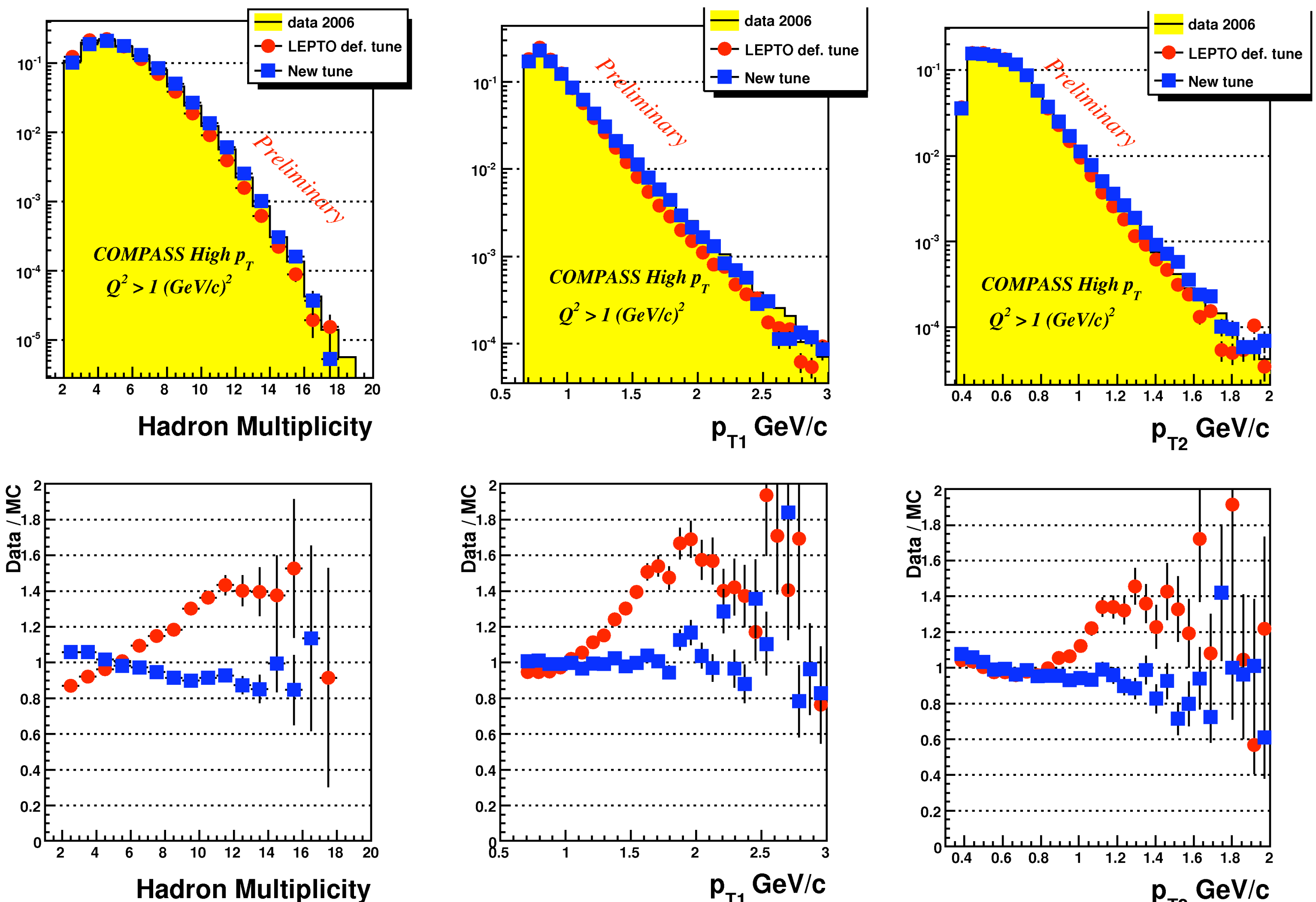
MC vs data 2006

No effect of tuning - inclusive variables



MC vs data 2006

effect of tuning clearly visible



Systematic summary

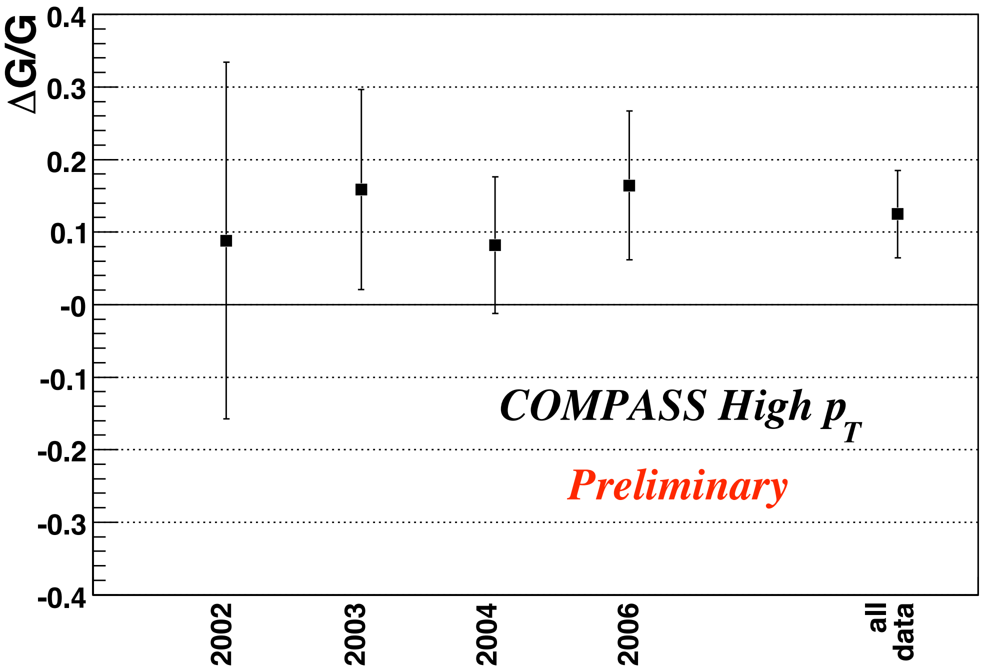
- Neural Network stability
- MC
- False Asymmetries
- δP_b , δP_t , δf
- A_1 parametrisation
- Simplification of the Formula for $\Delta G/G$

$\delta(\Delta G/G)_{NN}$	0.010
$\delta(\Delta G/G)_{MC}$	0.045
$\delta(\Delta G/G)_{false}$	0.019
$\delta(\Delta G/G)_{f,Pb,Pt}$	0.004
$\delta(\Delta G/G)_{A1}$	0.015
$\delta(\Delta G/G)_{formula}$	0.035
Total	0.063

Large Q^2 high-p_T 2h results

$$\frac{\Delta G}{G} = 0.125 \pm 0.060 \pm 0.063$$

$$x_G = 0.09^{+0.08}_{-0.04} \qquad \langle \mu^2 \rangle = 3.4 (GeV/c)^2$$



Large Q^2 high-p_T 2h results: 3 x_G points

All events have been divided, for the first time, for 3 independent subsamples, having each one its own x_G

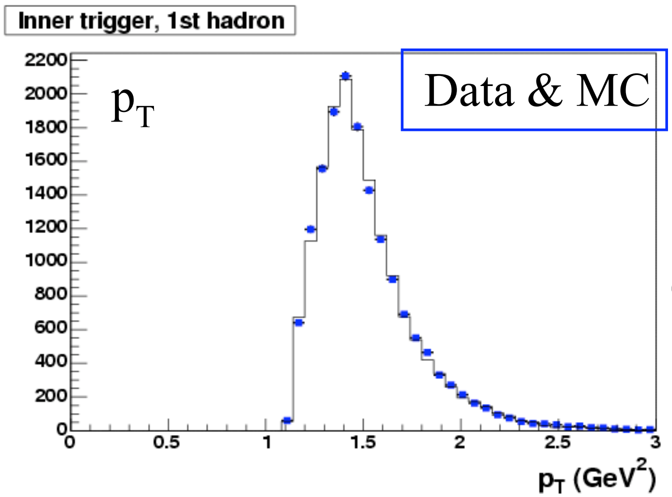
	1st point	2nd point	3rd point
$\Delta G/G$	0.15 ± 0.09 ± 0.09	0.08 ± 0.10 ± 0.08	0.19 ± 0.17 ± 0.14
$<x_g>$	$0.07^{+0.05}_{-0.03}$	$0.10^{+0.07}_{-0.04}$	$0.17^{+0.10}_{-0.06}$

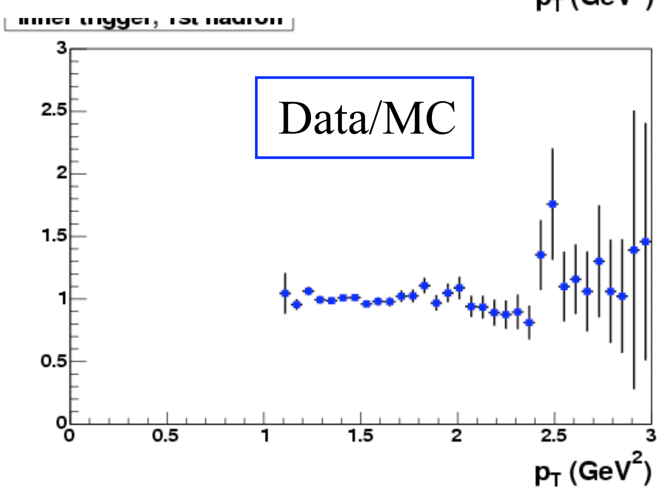
These 3 points show no x_G dependence (within errors)

Resuts for low Q^2 : $Q^2 < 1\ (GeV/c)^2$

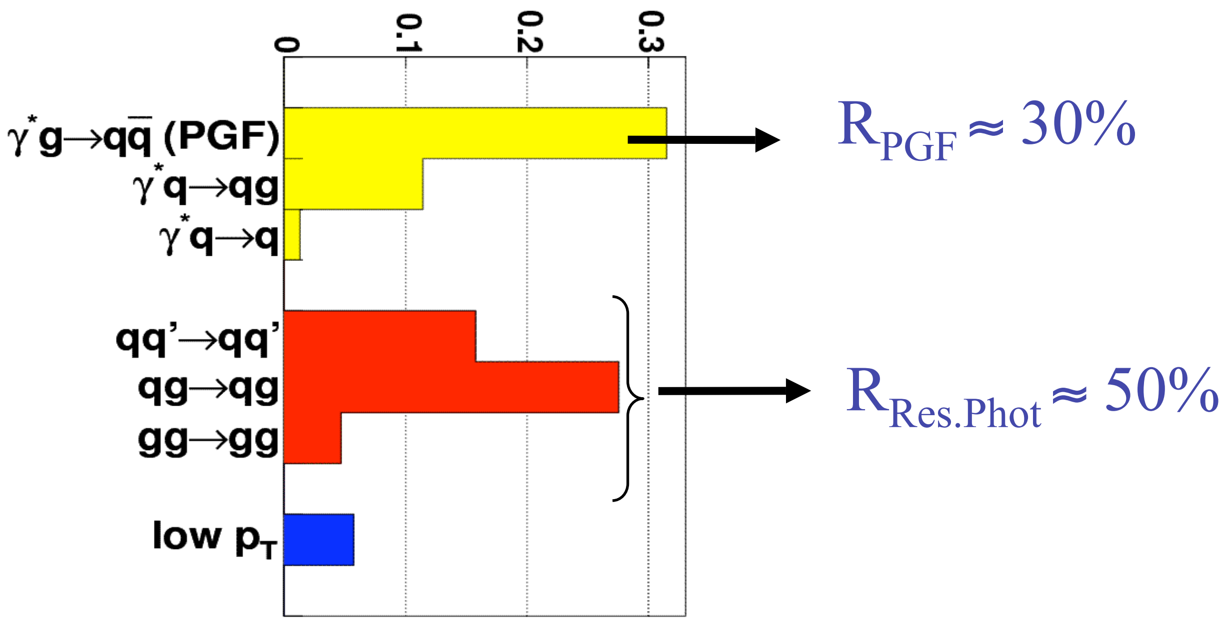
Cuts used – cut on $\Sigma p_T^2 > 2.5\ (GeV/c)^2$

90% of statistics!





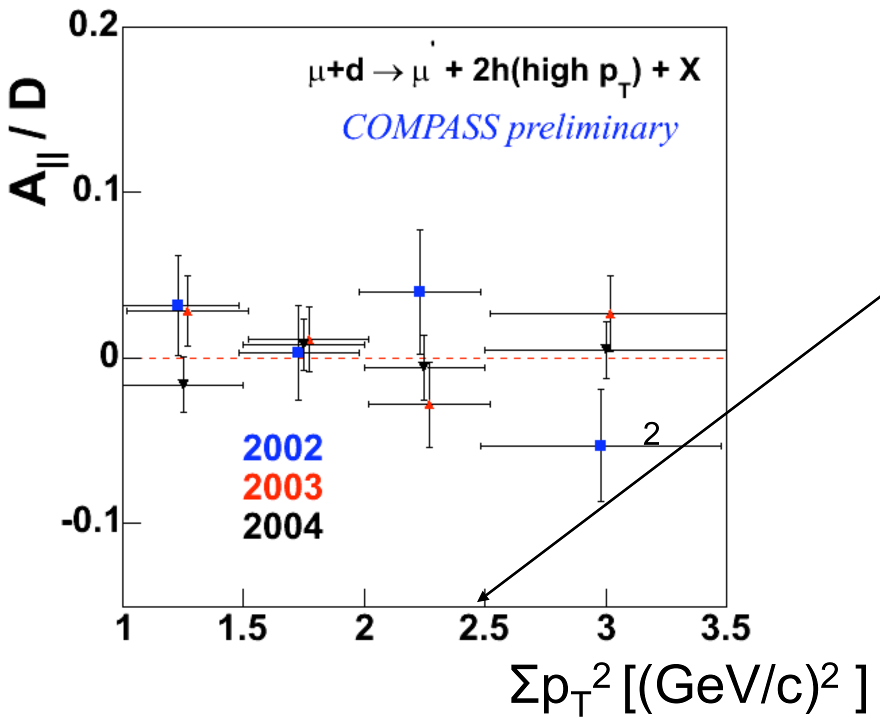
PYTHIA generator for low Q^2 + spectrometer simulation.



Here LO processes as well as low p_T part have been neglected in the analysis

Resuts for low Q^2 : $Q^2 < 1$ $(GeV/c)^2$

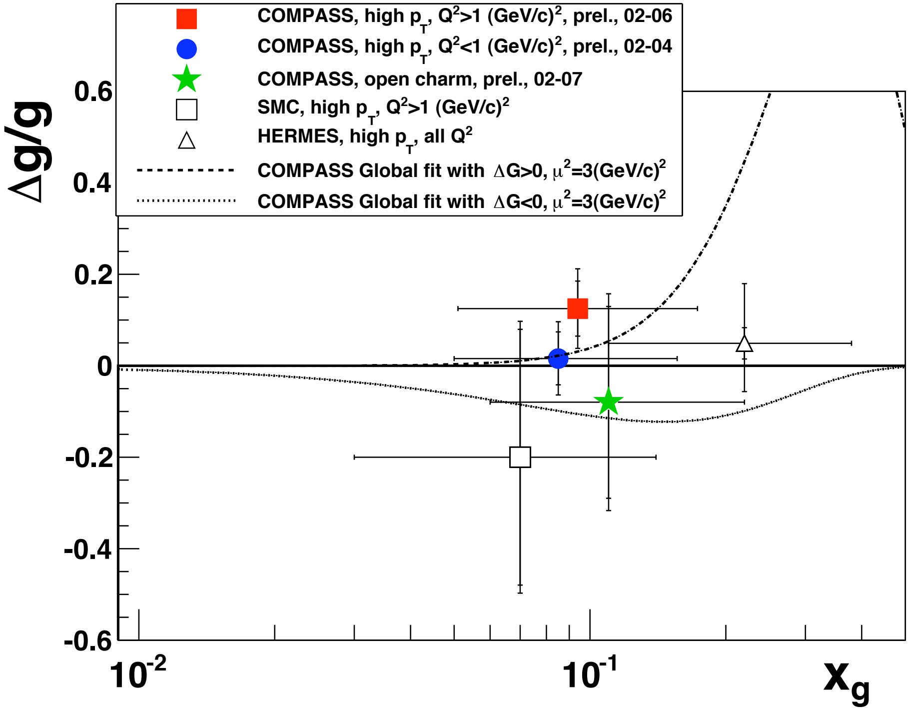
2002-03 results published: Phys. Lett. B 633 (2006) 25-32

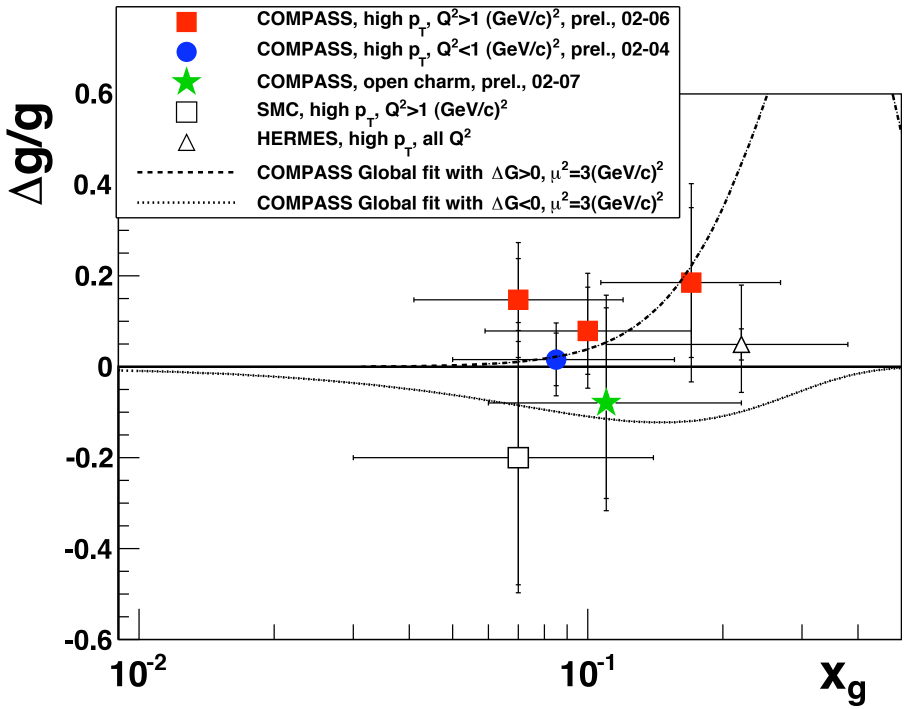


Cuts and asymmetry used for $\Delta G/G$ extraction

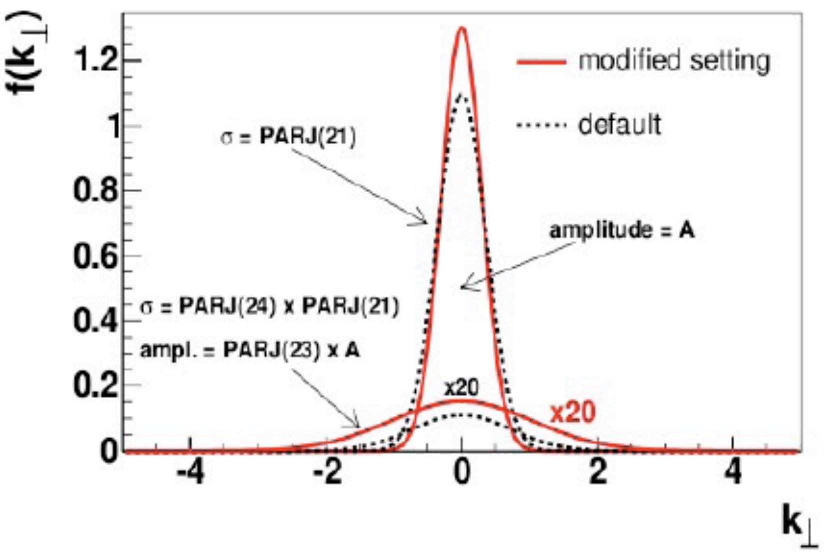
Data	$(\Delta G/G)(x_g)$	stat	exp.syst	MC.syst	resolved photon
02-03	0.024	0.089	0.014	0.052	0.018
02-04	0.016	0.058	0.014	0.052	0.013

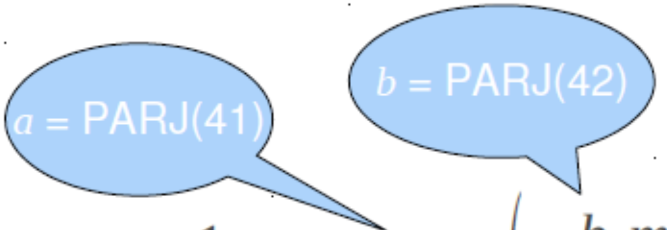
Gluon polarisation@LO: summary





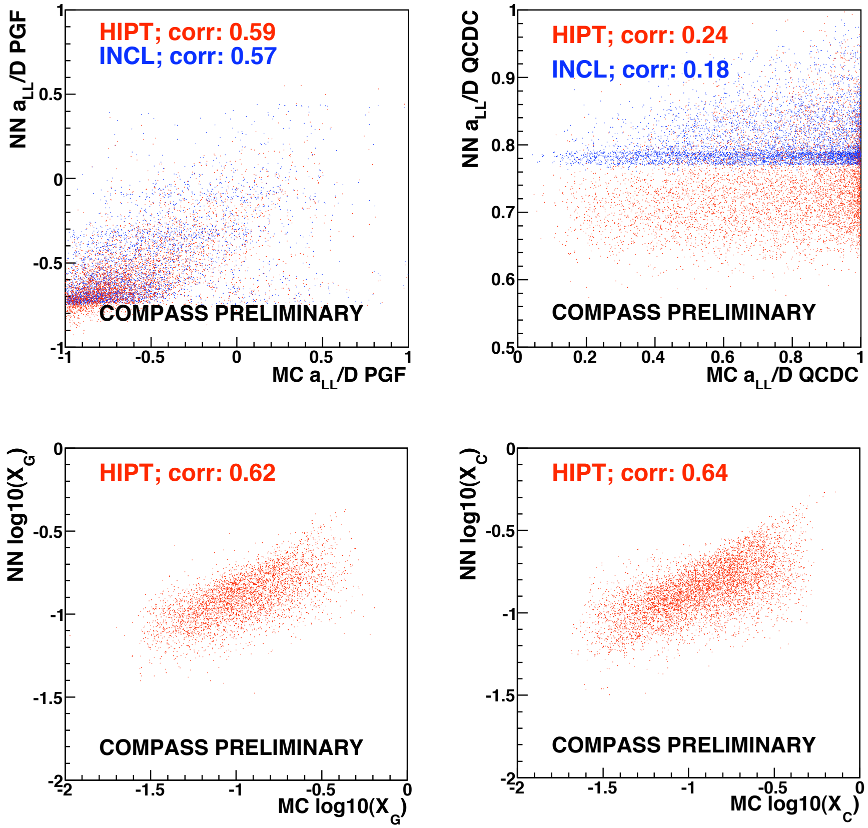
Spares





$$f(z) \propto \frac{1}{2}(1-z)^a \exp\left(-\frac{b\ m_T^2}{z}\right)$$

	PARJ(21)	PARJ(23)	PARJ(24)	PARJ(41)	PARJ(42)
COMPASS new tuning	0.34	0.04	2.8	0.025	0.075
LEPTO default tuning	0.36	0.01	2.0	0.3	0.58
	Transverse momentum of the hadron fragmentation			Fragmentation function	


HIPT; corr: 0.59
INCL; corr: 0.57
COMPASS PRELIMINARY
NN a_LL/D PGF
MC a_LL/D PGF
HIPT; corr: 0.24
INCL; corr: 0.18
COMPASS PRELIMINARY
NN a_LL/D QCDC
MC a_LL/D QCDC
HIPT; corr: 0.62
COMPASS PRELIMINARY
NN log10(X_G)
MC log10(X_G)
HIPT; corr: 0.64
COMPASS PRELIMINARY
NN log10(X_C)
MC log10(X_C)

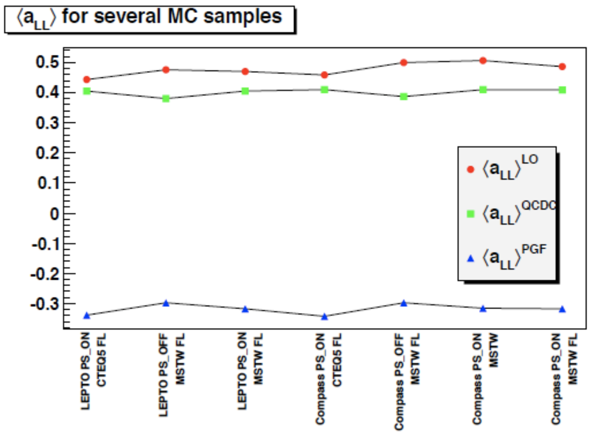


Figure 8: analyzing power *per* process, a_{LL}, for several high p_T MC samples.

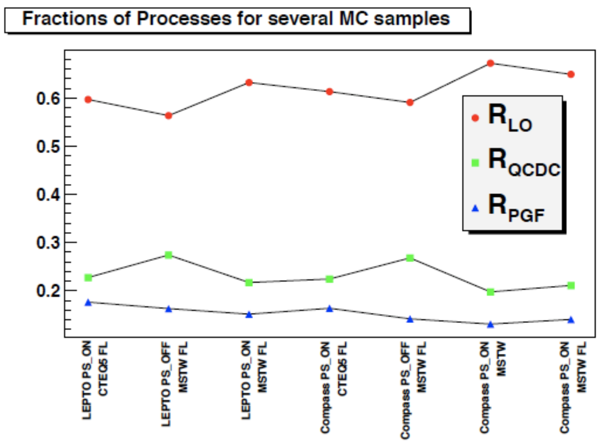


Figure 7: Fractions of processes, R, for several high p_T MC samples.

Other MC samples were produced for systematic studies (sec. 5.7). Namely:

1. LEPTO DEF. tuning, parton shower ON, PDF=CTEQ5L
2. LEPTO DEF. tuning, parton shower OFF, PDF=MSTW08
3. LEPTO DEF. tuning, parton shower ON, PDF=MSTW08
4. COMPASS tuning, parton shower ON, PDF=CTEQ5L
5. COMPASS tuning, parton shower OFF, PDF=MSTW08
6. COMPASS tuning, parton shower ON, PDF=MSTW08, NO F_L
7. COMPASS tuning, parton shower ON, PDF=MSTW08

Systematic summary

For first time gluon polarisation @ 3 different points in x_G have been determined; here the systematic summary point-by-point is given:

	total	$x_G < 0.10$	$0.1 < x_G < 0.14$	$x_G > 0.14$
$\delta(\Delta G/G_{NN})$	0.010	0.010	0.010	0.010
$\delta(\Delta G/G_{MC})$	0.045	0.077	0.067	0.129
$\delta(\Delta G/G_{f,P_b,P_t})$	0.004	0.007	0.007	0.010
$\delta(\Delta G/G_{false})$	0.025	0.030	0.021	0.016
$\delta(\Delta G/G_{A_1^d})$	0.015	0.021	0.014	0.017
$\delta(\Delta G/G_{formula})$	0.035	0.026	0.039	0.057
TOTAL	0.065	0.090	0.082	0.144

Table 14: Summary of the major systematic contributions.

version	$\Delta G/G$
v1	0.131 ± 0.056
v2	0.134 ± 0.056
v3	0.162 ± 0.056
v4	0.155 ± 0.056

Table 8: Results for $\Delta G/G$ using various A_1^d parametrization.

PDF	$\Delta G/G$
standard method	0.083 ± 0.101
COMPASS ΔG+	0.074 ± 0.083
COMPASS ΔG-	0.073 ± 0.083
DNS	0.083 ± 0.083
LSS	0.058 ± 0.083
ACC	0.081 ± 0.083
GRSV	0.086 ± 0.083
DSSV	0.093 ± 0.083

Table 9: Results for $\Delta G/G$ using various LO PDF parametrization. Note that improvement in the error bar is a results of the formula over-simplification! The exercise was performed on old sample and old MC tuning!

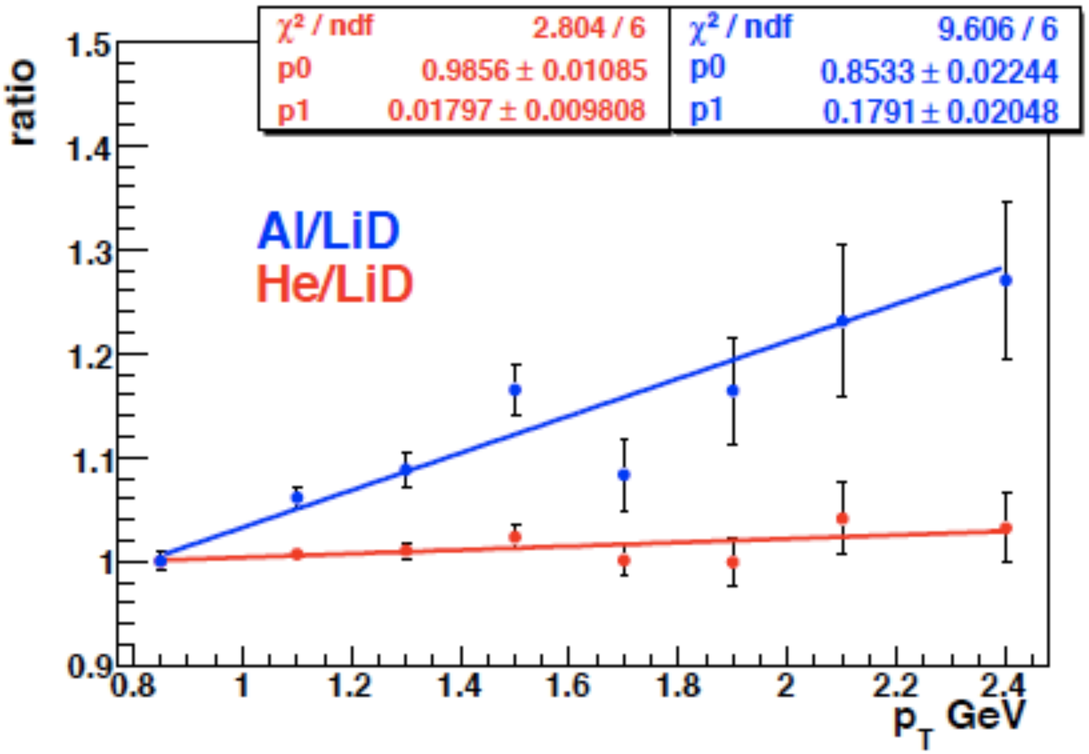


Figure 25: The ratio of the observed number of events for different nuclei in bins the hadron pT.