

$\Delta G/G$ measurements at COMPASS

Konrad Klimaszewski

Soltan Institute for Nuclear Studies, Warsaw
on behalf of the COMPASS Collaboration

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COMPASS

Muon programme

Beam:

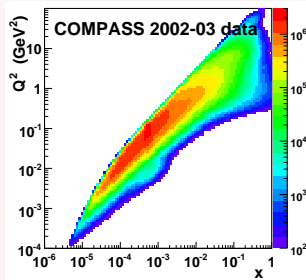
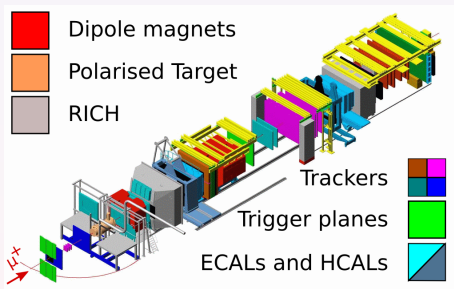
- Momentum: 160 GeV/c
- Polarisation μ^+ : -80%

Target:

- Polarised both longitudinally and transversely
- Material: ${}^6\text{LiD}$, (NH_3)
- Polarisation: $\sim 50\%$, (90%)
- Two target cells

Data taking

- 2002-2004, 2006-2007, ...



The gluon search ...

- **Open Charm**

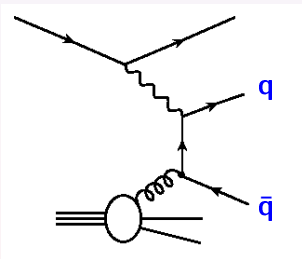
- Search for D^0 meson in the final state
- Almost no charm quarks in the nucleon
- Charm is produced only via PGF (LO)
- Perturbative region ensured by charm mass
- Weakly depends on MC simulations
- **Low statistics**

- **High p_T hadron pairs** ($Q^2 > 1 \text{ (GeV/c)}^2$)

- Search for two hadrons with high transverse momenta in the final state
- **Large statistics**
- **Perturbative region** - $Q^2 > 1 \text{ (GeV/c)}^2$
- **Background processes**
- **MC simulations essential**

- **High p_T hadron pairs** ($Q^2 < 1 \text{ (GeV/c)}^2$)

- 2002-2003 result published [PLB 633 (2006) 25-32]
- 2002-2004 presented on several conferences



PGF

Photon Gluon
Fusion

1 Open Charm

2 High p_T pairs

3 Summary

Asymmetry calculation

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

$$A_{exp} = \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}$$

P_t - Target polarisation

P_b - Beam polarisation

f - Dilution factor

S - signal events

B - background events

a_{LL} - partonic cross-section asymmetry -
parametrised using Neural Networks
based on Aroma MC. (correlation
 $\sim 80\%$)

\Rightarrow both obtained from fits to D mass spectra

Selection

Channels

- $D^0 \rightarrow K\pi$
- $D^* \rightarrow D\pi_{\text{soft}} \rightarrow K\pi\pi_{\text{soft}}$
- $\text{BR}(D \rightarrow K\pi) \sim 3.8\%$

- RICH PID
 - K, π identification
 - e rejection

Statistical weights

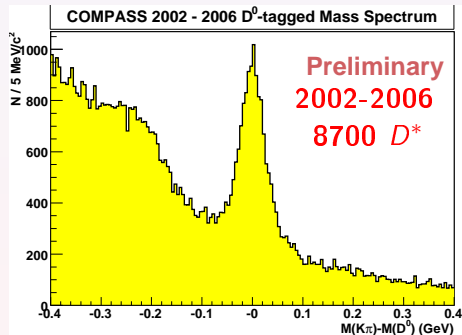
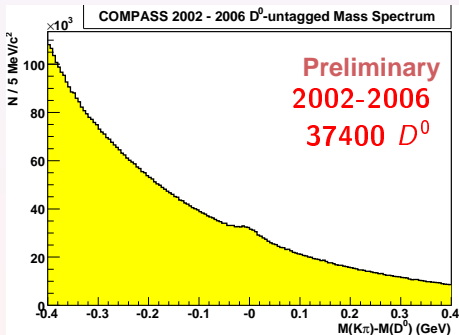
To increase the statistical gain a weighted estimator is used. Each event is applied a weight:

$$w = P_{bfaLL} \frac{S}{S+B}$$

The $\frac{S}{S+B}$ is parametrised as a function of kinematic variables and RICH response:

- available on event-by-event basis
- built from Data (fits to D spectra)

Mass spectra



Preliminary result for Open Charm

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

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

Systematic uncertainties

Source	False asymmetry	S/(S+B)	a_{LL}	f	P_b	P_t
$\delta(\Delta G/G)$ $D^0(D^*)$	0.05 (0.05)	0.07 (0.01)	0.05 (0.03)	0.02	0.02	0.02

1 Open Charm

2 High p_T pairs

3 Summary

High p_T asymmetries

$$A_{||} \approx \frac{\Delta G}{G} a_{LL}^{PGF} R_{PGF} + A_1^{LP}(x_{QCDC}) a_{LL}^{QCDC} R_{QCDC} + A_1^{LP}(x_{Bj}) a_{LL}^{LP} R_{LP}$$

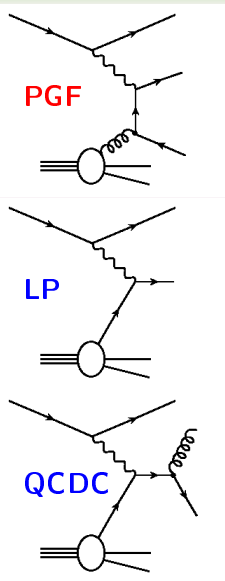
where:

$$A_{||} = A_{exp}/P_t P_b f$$

R_n - fraction of process "n" (MC)

a_{LL}^n - partonic asymmetries (QCD)

$$A_1^{LP} = \frac{\sum_i e_i^2 \Delta q_i}{\sum_i e_i^2 q_i} - \text{taken from } A_1 \text{ measurement}$$



$\Delta G/G$ extraction

Taking into account contributions of the three processes to A_1 we obtain expression for $\Delta G/G$:

$$\frac{\Delta G}{G}(x_G^{avg}) = \frac{A_{||} + A_{corr}}{\beta}; \quad \beta \sim a_{LL}^{PGF} R_{PGF} + \alpha$$

$$A_{corr} = -A_1(x_{Bj})\gamma + A_1(x_{QCDC})\delta$$

- $\alpha, \beta, \gamma, \delta$ - depend on “Inclusive” and “High p_T ” R_s and a_{LLS}
- R_s, a_{LLS}, x_{QCDC} and x_G are parametrised using MC simulation

Weighted method

- For each event a weight is constructed based on: $f, D, P_b, \beta, \alpha, \gamma, \delta$
- Parametrisation: Neural Network
 - Obtained event-by-event
- Input variables for Neural Network:
 - Inclusive case: x_{Bj} and Q^2
 - High p_T case: $x_{Bj}, Q^2, p_{L1,2}$ and $p_{T1,2}$

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Data sample selection

Kinematic cuts

- $Q^2 > 1 \text{ (GeV/c)}^2$
events are in perturbative region
- $p_{T1} > 0.7 \text{ GeV/c}$; $p_{T2} > 0.7 \text{ GeV/c}$
enhance fraction of PGF events

Collected statistics

2002-2004: $\sim 500\text{k}$ events

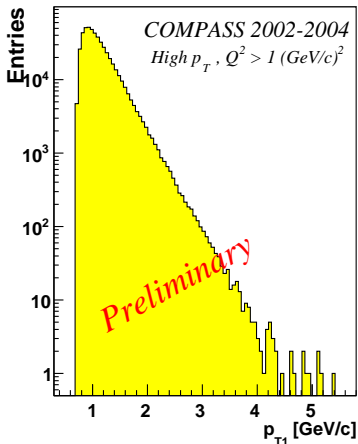
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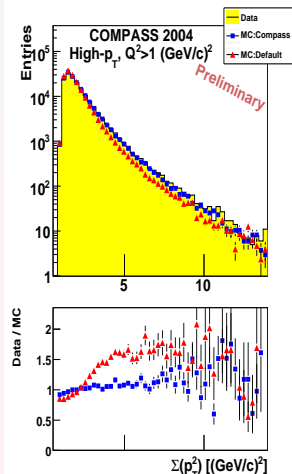
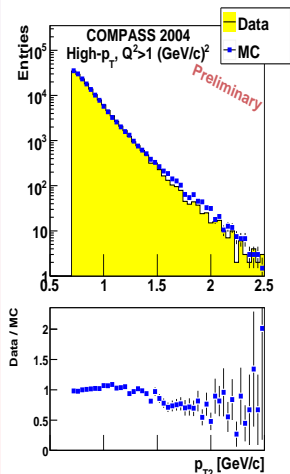
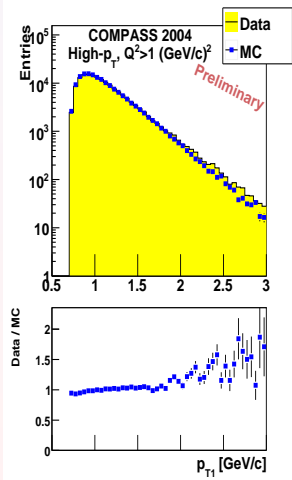
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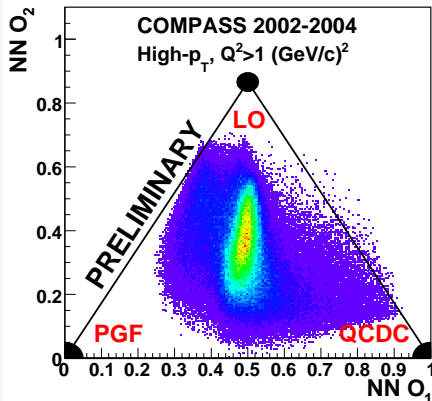
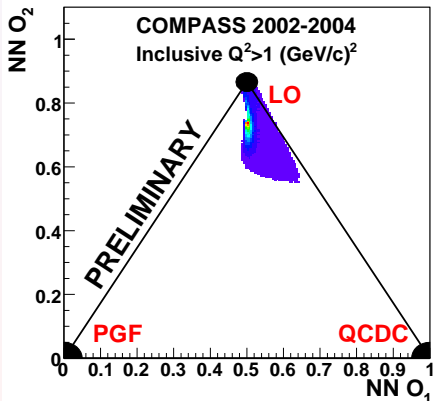
Monte Carlo

- LEPTO with JETSET fragmentation
- Parton Shower - part of NLO corrections
- PDFs: MRST2004 LO
- Tuning of JETSET fragmentation



Parametrisation of R_s

NN with two output variables o_1 and o_2 is used - R_s sum up to 1.



$$R_{PGF} = 1 - o_1 - \frac{1}{\sqrt{3}}o_2; \quad R_{QCDC} = o_1 - \frac{1}{\sqrt{3}}o_2; \quad R_{LP} = \frac{2}{\sqrt{3}}o_2$$

Systematics studies

- false asymmetries
- NN stability
- Systematic errors due to MC
- δf , δP_B , δP_T
- A_1^d parametrisation
- formula assumptions

$\delta(\Delta G/G)_{NN}$	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
$\delta(\Delta G/G)_{A_1}$	0.008
$\delta(\Delta G/G)_{formula}$	0.013
Total	0.045

MC systematics

- 4 different MCs have been used
 - COMPASS tuning PS on
 - COMPASS tuning PS off
 - Default tuning PS on
 - Default tuning PS off
- For each sample $\Delta G/G$ was calculated

Preliminary result for High p_T pairs $Q^2 > 1(\text{GeV}/c)^2$

$$\frac{\Delta G}{G} = 0.08 \pm 0.10(\text{stat.}) \pm 0.05(\text{syst.})$$

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

$Q^2 < 1(\text{GeV}/c)^2$ results

2002-2003 [PLB 633 (2006) 25-32]:

$$\frac{\Delta G}{G} = 0.024 \pm 0.089(\text{stat.}) \pm 0.057(\text{syst.})$$

2002-2004 (preliminary):

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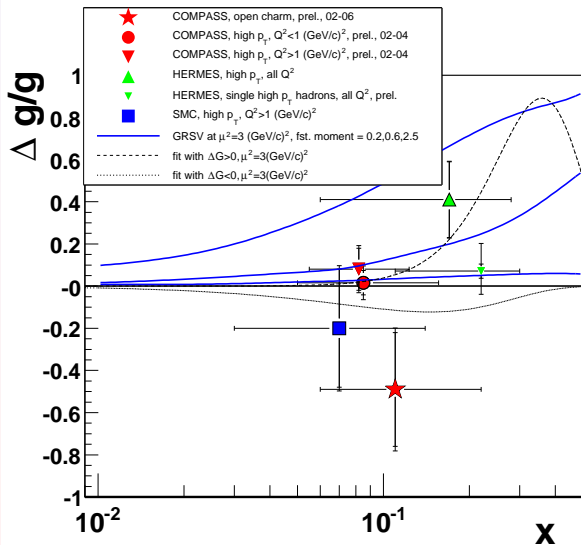
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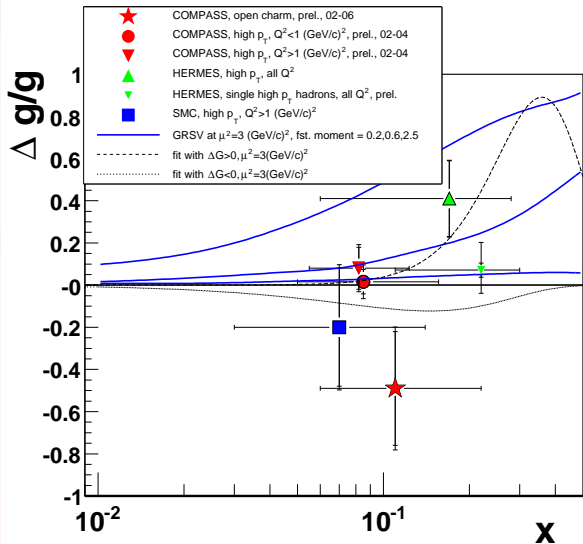
Direct measurements summary



- GRSV $\Delta G = 2.5$
- GRSV $\Delta G = 0.6$
- GRSV $\Delta G = 0.2$

Results from RHIC experiments are compatible with GRSV $\Delta G = 0$ scenario (comparison of predictions with precise measurements of asymmetries as a function of p_T)

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Summary

- Summary
 - Recent results of $\Delta G/G$ from COMPASS were presented
 - Errors of the measurements were significantly reduced due to usage of additional data and new methods of analysis
 - Present measurements indicate that $\Delta G/G$ is consistent with zero at $x_g \approx 0.1$
- Outlook Open Charm
 - Add 2007 data
 - Improvements to tagging method
 - NLO analysis
- Outlook High p_T pairs
 - Add 2006 and 2007 data (both $Q^2 > 1$ and < 1 (GeV/c)²)
 - Explore $0.4 < p_T < 0.7$ GeV/c region (for $Q^2 > 1$ (GeV/c)²)
 - 1-hadron analysis
 - NLO analysis

Backup Slides

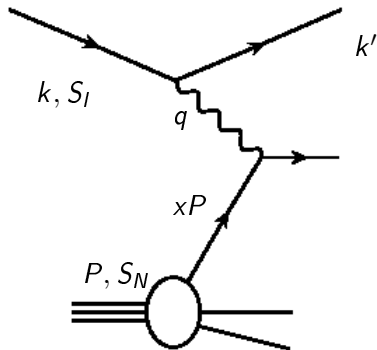
Deeply Inelastic Scattering - DIS

Variables

$$Q^2 = -q^2 = -(k - k')^2$$

$$y = \frac{P \cdot q}{P \cdot k} \stackrel{lab}{=} \frac{E - E'}{E} = \frac{\nu}{E}$$

$$x = \frac{Q^2}{2P \cdot q} \stackrel{lab}{=} \frac{Q^2}{2M\nu}$$



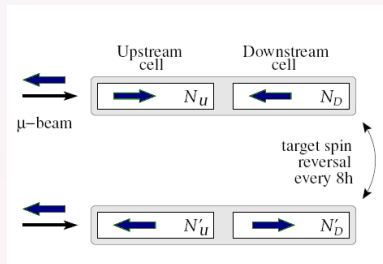
Asymmetry calculation

$$A_{exp} = \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}$$

Experimental asymmetry is related to cross-section asymmetry $A_{||}$:

$$A_{exp} = P_T P_B f A_{||}$$

P_T - Target polarisation; P_B - Beam polarisation; f - Dilution factor



High p_T asymmetries

$$A_{||} \approx \frac{\Delta G}{G} a_{LL}^{PGF} R_{PGF} + A_1^{LP} (x_{QCDC}) a_{LL}^{QCDC} R_{QCDC} + A_1^{LP} (x_{Bj}) a_{LL}^{LP} R_{LP}$$

where:

$$A_{||} = A_{exp} / P_t P_{bf}$$

R_n - fraction of process "n" (MC)

a_{LL}^n - partonic asymmetries (QCD)

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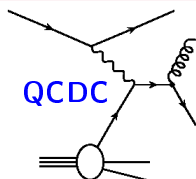
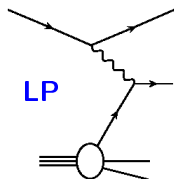
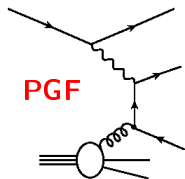
Also to A_1 all 3 processes contribute:

$$A_{||}^{incl} \approx \frac{\Delta G}{G} a_{LL}^{PGF, incl} R_{PGF}^{incl} + A_1^{LP} (x_{QCDC}) a_{LL}^{QCDC, incl} R_{QCDC}^{incl} + A_1^{LP} (x_{Bj}) a_{LL}^{LP, incl} R_{LP}^{incl}$$

where:

$$A_{||}^{incl} \approx D A_1 - \text{inclusive asymmetry}$$

$$D(y) = a_{LL}^{LP, incl} - \text{depolarisation factor}$$



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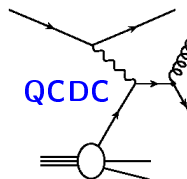
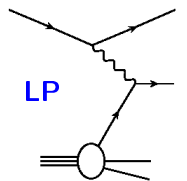
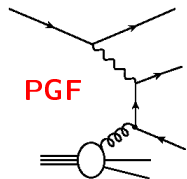
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$\Delta G/G$ High p_T formula

Solving this set of two equations
we obtain expression for $\Delta G/G$:

$$\frac{\Delta G}{G}(x_G^{avg}) = \frac{A_{||} + A_{corr}}{\beta}; \quad \beta = a_{LL}^{PGF} R_{PGF} - a_{LL}^{PGF, incl} \frac{R_{PGF}^{incl}}{R_{LP}^{incl}} \left(R_{LP} + a_{LL}^{QCDC} R_{QCDC} \right)$$

$$A_{corr} = -A_1(x_{Bjk}) \frac{R_{LP}}{R_{LP}^{incl}} - A_1(x_{QCDC})\alpha_1 + A_1(x'_{QCDC})\alpha_2$$

$$\alpha_1 = \frac{1}{R_{LP}^{incl}} \left(a_{LL}^{QCDC} R_{QCDC} - a_{LL}^{QCDC, incl} R_{QCDC}^{incl} \frac{R_{LP}}{R_{LP}^{incl}} \right)$$

$$\alpha_2 = a_{LL}^{QCDC, incl} \frac{R_{QCDC}^{incl}}{R_{LP}^{incl}} \frac{R_{QCDC}}{R_{LP}^{incl}} a_{LL}^{QCDC}$$

- a_{LL}^n , R_n - depend on partonic kinematics (not accessible in experiment)
- a_{LL}^n , R_n , x_C , x_G are parametrised using MC simulation
- In order to maximise the statistical efficiency a weighted estimator is used
- For each event a statistical weight is constructed
- Weights are constructed from: f , D , P_B , β , α_1 , α_2

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Selection

Open Charm

D^* event selection

$$0.1 < y < 0.9$$

$$z_{D^0} > 0.2$$

$$|\cos(\theta^*)| < 0.9$$

$$3.2\text{MeV} < m(K\pi\pi_{soft}) - m(D^0) - m(\pi) < 8.9\text{MeV}$$

π , K , e identification based on RICH

$$p < 50 \text{ GeV}/c$$

No other D^* in the same event

D^0 event selection

$$0.1 < y < 0.9$$

$$z_{D^0} > 0.2$$

$$|\cos(\theta^*)| < 0.65$$

π , K , e identification based on RICH

$> 7 \text{ GeV}/c$ for pions and for both $< 50 \text{ GeV}/c$

No other D^* or D^0 in the same event

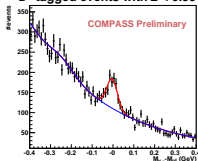
High p_T

- $Q^2 > 1 \text{ GeV}^2$
- $p_T > 0.7 \text{ GeV}$ (for both hadrons)
- $0.1 < y < 0.9$
- $x_F, z > 0.0$
- $m(h_1, h_2) > 1.5 \text{ GeV}$:
remove ρ resonance
- $\Sigma z < 0.95$: remove exclusive events

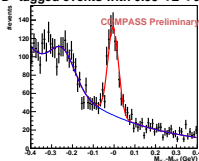
$$\frac{S}{S+B}$$

parametrisation in action

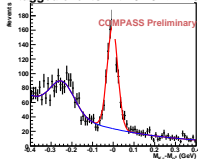
D^0 -tagged events with $\Sigma < 0.55$



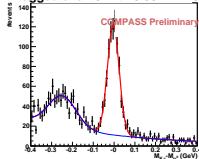
D^0 -tagged events with $0.55 < \Sigma < 0.73$



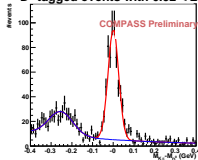
D^0 -tagged events with $0.73 < \Sigma < 0.85$



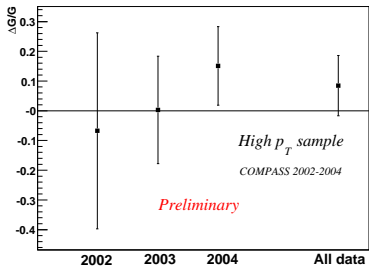
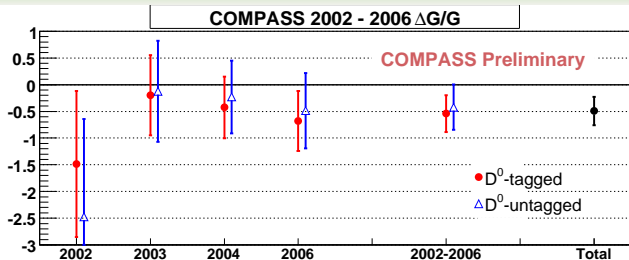
D^0 -tagged events with $0.85 < \Sigma < 0.92$



D^0 -tagged events with $0.92 < \Sigma$



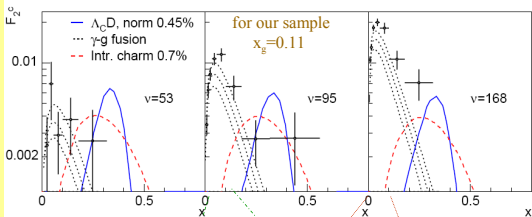
$\Delta G/G$



Open Charm

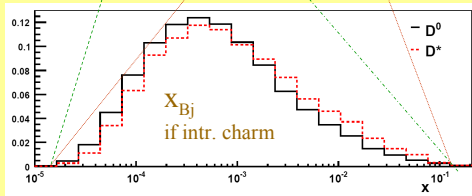
High p_T

Intrinsic Charm



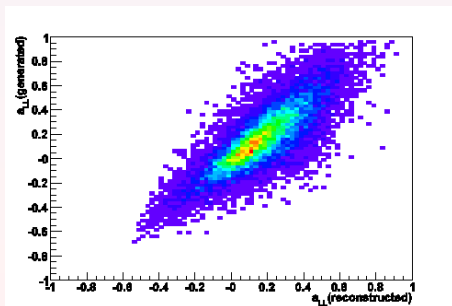
Ref. hep-ph/0508126 and hep-ph/9508403
Data from EMC: Nucl. Phys. B213, 31 (1983)

For our data: average ν (70-120 GeV),



a_{LL} parametrisation for Open Charm

- 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

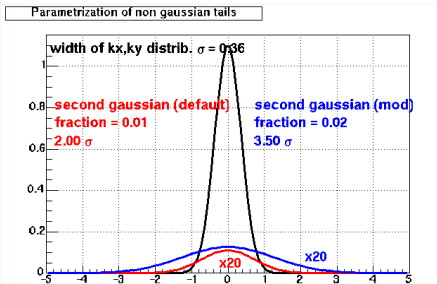
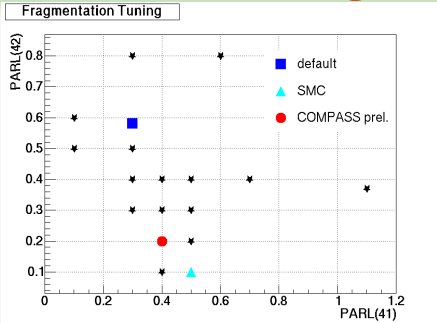


High p_T Monte Carlo

Avarage values of a_{LL} s and R s	Final MC
$\langle a_{LL}^{LP} \rangle$	0.63
$\langle a_{LL}^{QCDC} \rangle$	0.50
$\langle a_{LL}^{PGF} \rangle$	-0.36
R_{LP}	0.40
R_{QCDC}	0.29
R_{PGF}	0.31

JETSET parameters	Default	COMPASS
PARJ(41)	0.3	0.6
PARJ(42)	0.58	0.1
PARJ(21)	0.36	0.3
PARJ(23)	0.01	0.02
PARJ(24)	2.0	3.5

Tuning of fragmentation



- LUND fragmentation

$$f(z) = z(1-z)^a e^{-bm_T^2/z}$$

$$m_T^2 = m^2 + p_T^2$$
- with variable parameters a (PARJ(41)) and b (PARJ(42))

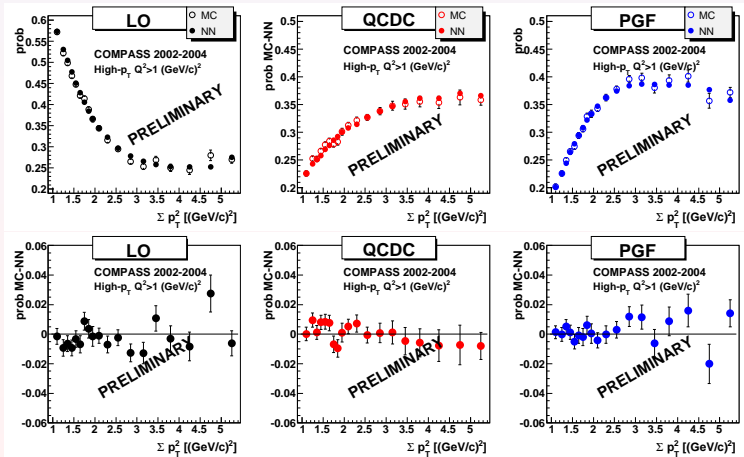
-
- String between two outgoing quarks
 - $q\bar{q}$ pairs created with transverse momentum k_T
 - width of the gaussian $k_{x,y}$

$$\text{PARJ}(21) = 0.36$$
 - non gaussian tails modelled by second broader gaussian
 - width = $\text{PARJ}(24) \times \text{PARJ}(21)$
 - fraction $\text{PARJ}(23) = 0.01$ of first gaussian

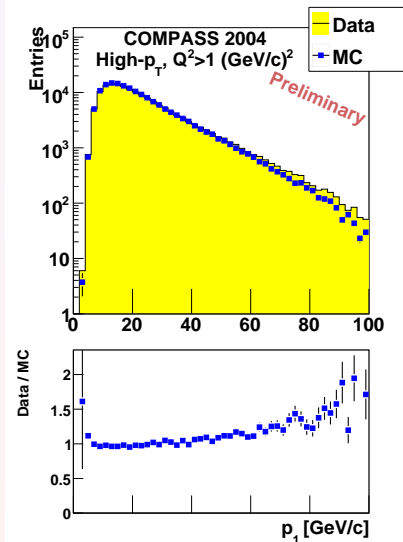
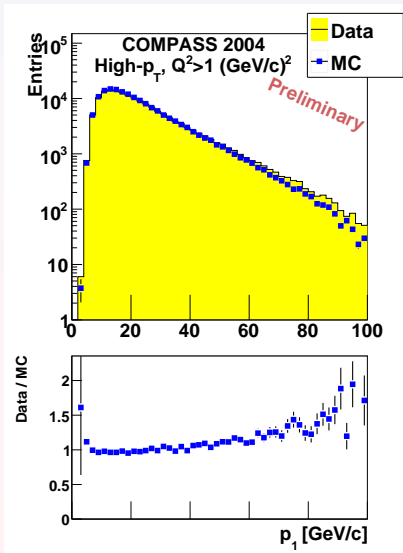
NN validity

Fractions of the three processes as a function of Σp_T^2

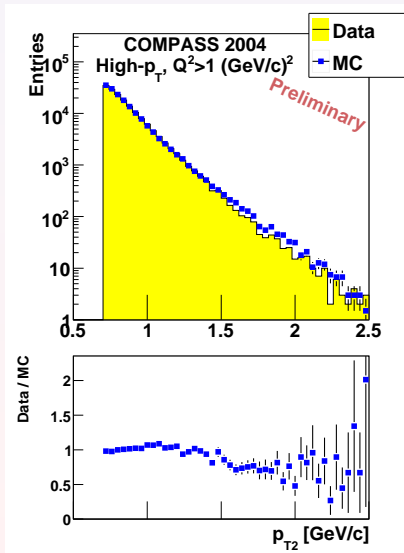
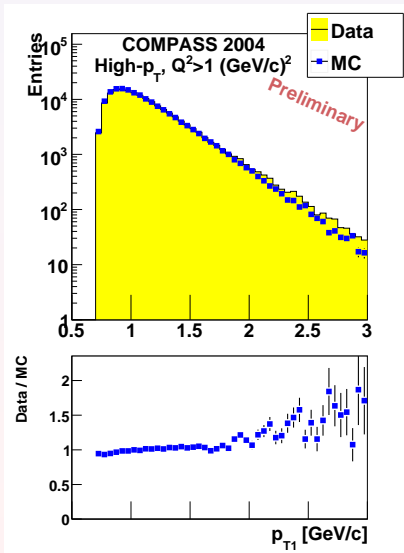
- Empty points - directly taken from MC
- Full points - estimated using NN



High p_T Data/MC



High p_T Data/MC



High p_T Data/MC

