$\Delta G/G$ measurements at COMPASS

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COMPASS

Muon programme

Beam:

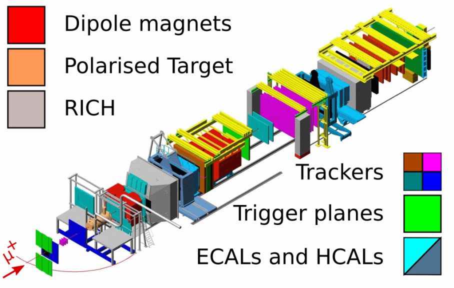
- Momentum: 160 GeV/c
- Polarisation μ^+: -80%

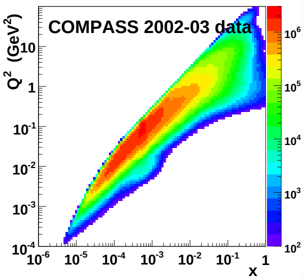
Target:

- Polarised both longitudinally and transversely
- Material: ^6LiD, (NH_3)
- Polarisation: ∼50%, (90%)
- Two target cells

Data taking

- 2002-2004, 2006-2007, …



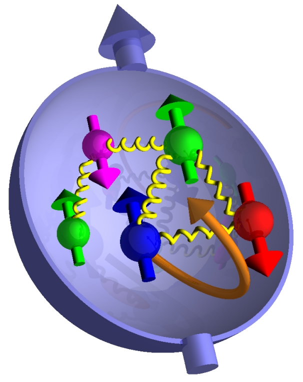


Physics motivation

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

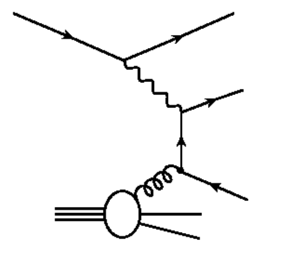
"Spin Crisis"

- In a naive Quark Parton Model we expect: $\Delta\Sigma = 1$
- Taking into account relativistic effects we expect: $\Delta\Sigma \approx 0.6$
- The EMC first measured quark contribution: $\Delta\Sigma = 0.12 \pm 0.17$ [1]
- COMPASS NLO QCD fit to the world data: $\Delta\Sigma = 0.30 \pm 0.01(\text{stat.}) \pm 0.02(\text{evol.})$ [2]
- Direct measurements can answer what is the contribution of gluons and orbital momentum ...



[1] Nucl. Phys. B 328 (1989) 1
[2] PLB 647 (2007) 8-17

The gluon search ...



PGF

Photon Gluon Fusion

- **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** $(Q^2 > 1\,(\mathrm{GeV/c})^2)$
  - Search for two hadrons with high transverse momenta in the final state
  - Large statistics
  - Perturbative region - $Q^2 > 1\,(\mathrm{GeV/c})^2$
  - Background processes
  - MC simulations essential
- **High p_T hadron pairs** $(Q^2 < 1\,(\mathrm{GeV/c})^2)$
  - 2002-2003 result published [PLB 633 (2006) 25-32]
  - 2002-2004 presented on several conferences

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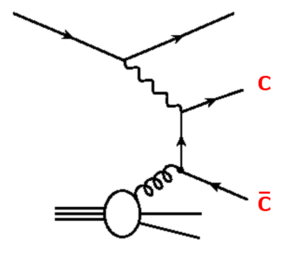

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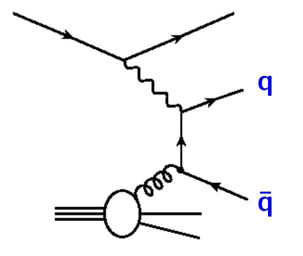

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1. Open Charm
2. High p_T pairs
3. Summary

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

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

S - signal events
B - background events

$\Rightarrow$ both obtained form fits to D mass spectra

Selection

Channels

- $D^0 \to K\pi$
- $D^* \to D\pi_{soft} \to K\pi\pi_{soft}$
- BR($D \to K\pi$) ~3.8%

- RICH PID
  - K, π identification
  - e rejection

Statistical weights

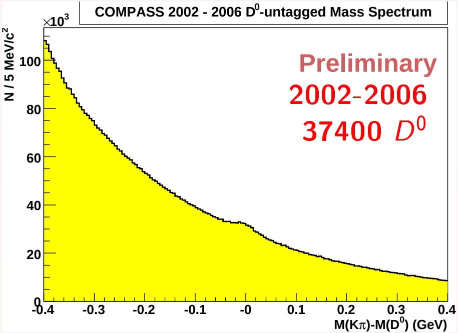
To increase the statistical gain a weighted estimator is used. Each event is applied a weight:

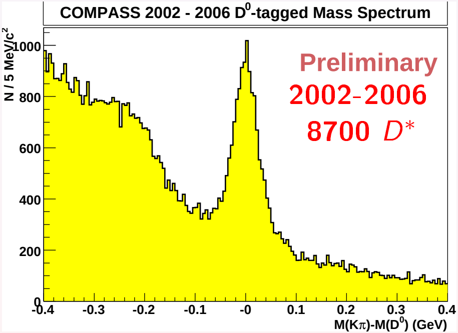
$$w = P_b f a_{LL} \frac{S}{S+B}$$

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

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

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

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

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High p_T asymmetries

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

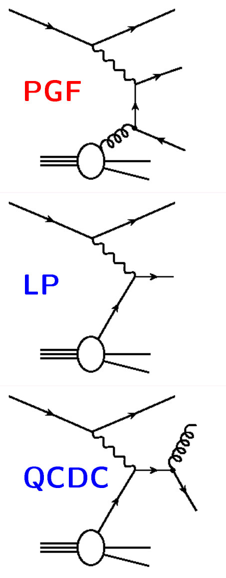
where:

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

R_n - fraction of process "n" (MC)

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

$A_1^{LP} = \frac{\sum_i e_i^2 \Delta q_i}{\sum_i e_i^2 q_i}$ - taken from A_1 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" Rs and a_{LL}s
- Rs, a_{LL}s, 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, β, α, γ, δ
- 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

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

Collected statistics

2002-2004: $\sim$ 500k events

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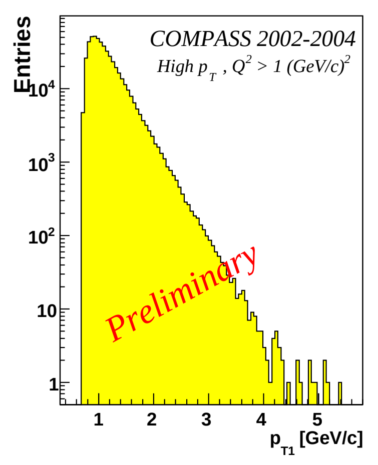
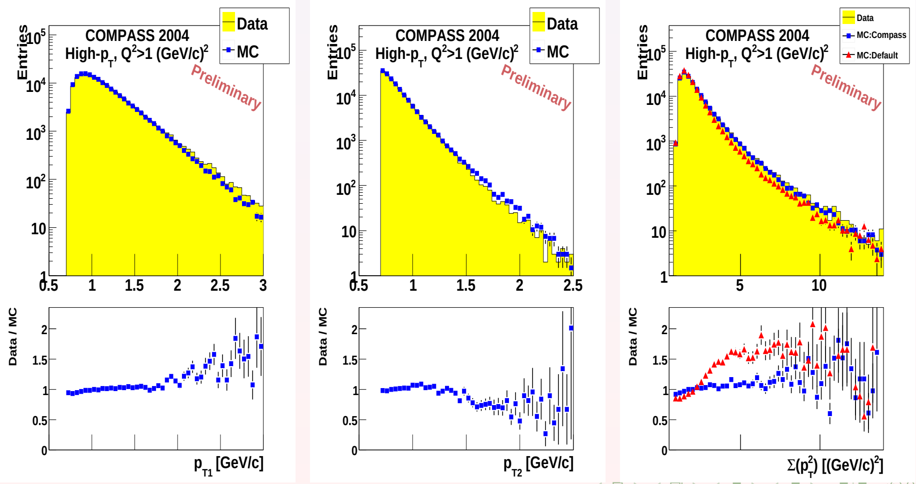


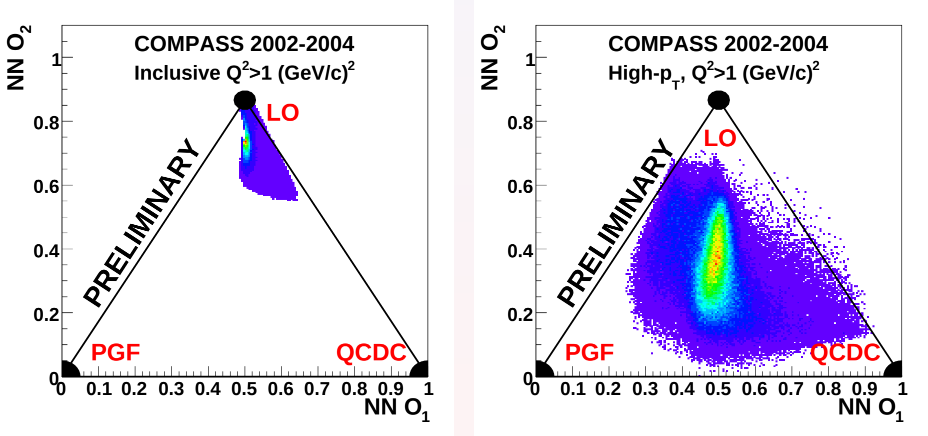
Monte Carlo

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



Parametrisation of Rs

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



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

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
$\delta(\Delta G/G)_{A1}$	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 $Q^2 > 1(\mathbf{GeV/c})^2$

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

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

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

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

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2002-2004 (preliminary):

$\frac{\Delta G}{G} = 0.016 \pm 0.058(stat.) \pm 0.054(syst.)$

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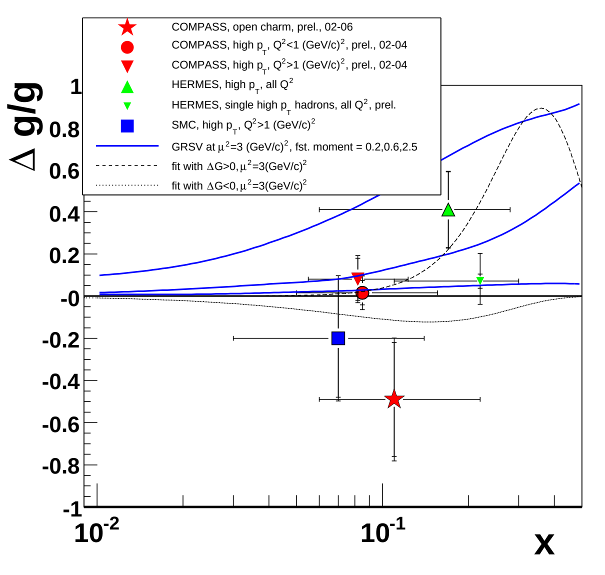
Direct measurements summary



- 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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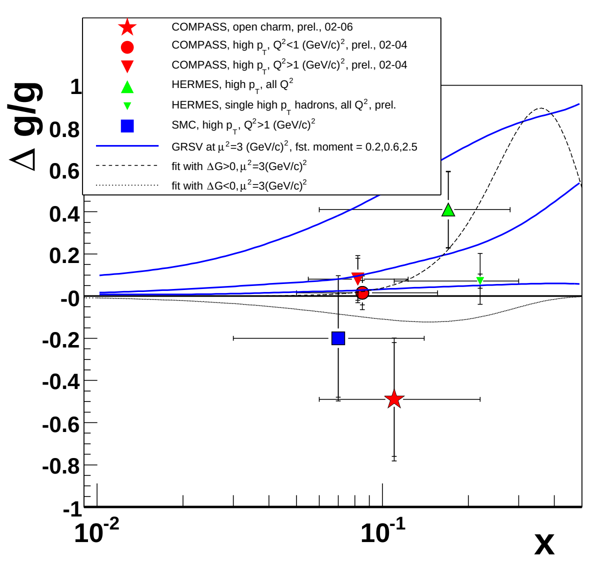

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Summary

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  - 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 $< 1\,(\mathrm{GeV/c})^2$)
  - Explore $0.4 < p_T < 0.7\,\mathrm{GeV/c}$ region (for $Q^2 > 1\,(\mathrm{GeV/c})^2$)
  - 1-hadron analysis
  - NLO analysis

Backup Slides

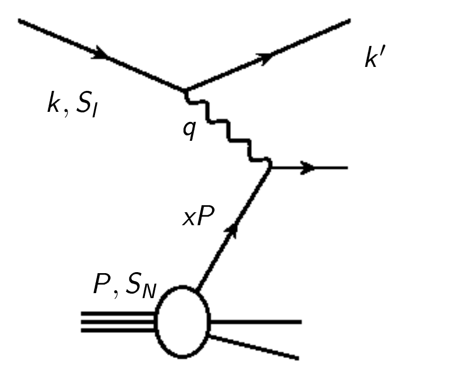
Deeply Inelastic Scattering - DIS

Variables

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

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

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

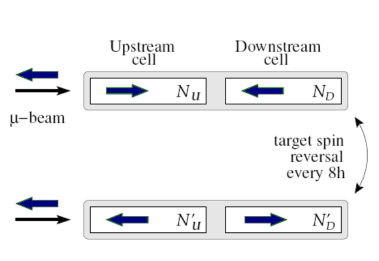


Asymmetry calculation

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

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:

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

R_n - fraction of process "n" (MC)

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

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

Also to A_1 all 3 processes contribute:

$$A_{||}^{incl} \approx \frac{\Delta G}{G} a_{LL}^{PGF,incl} R_{PGF}^{incl}$$
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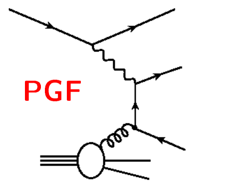
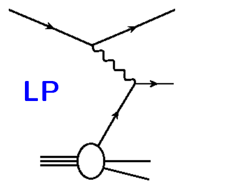
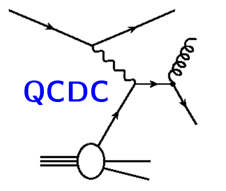
where:

$A_{||}^{incl} \approx DA_1$ - inclusive asymmetry

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







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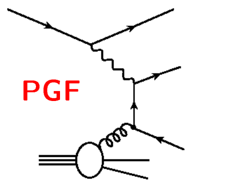

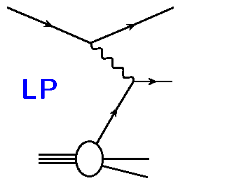

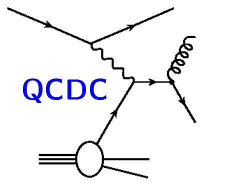

$\Delta G/G$ High p_T formula

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

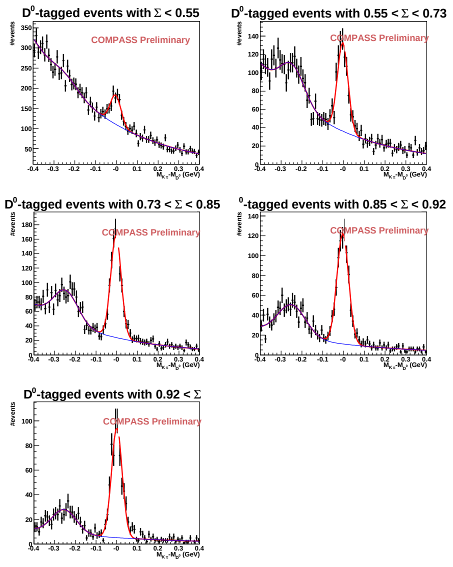
D^* event selection
$0.1 < y < 0.9$
$z_{D^0} > 0.2$
$\|cos(\theta^*)\| < 0.9$
$3.2\text{MeV} < m(K\pi\pi_{soft}) - m(D^0) - m(\pi) < 8.9\text{MeV}$
π, K, e identification based on RICH
p<50 GeV/c
No other D^* in the same event

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 GeV/c for pions and for both <50 GeV/c
No other D^* or D^0 in the same event

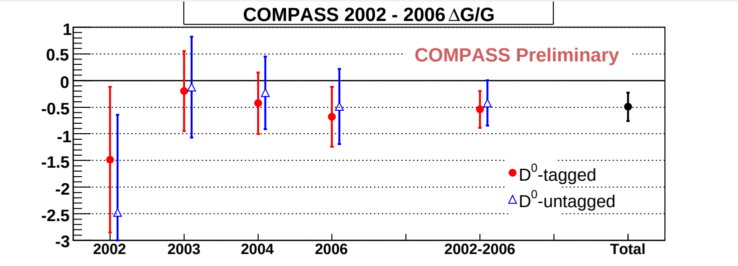
High p_T

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

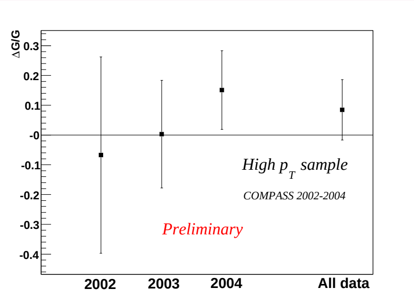
$\frac{S}{S+B}$ parametrisation in action



$\Delta G/G$

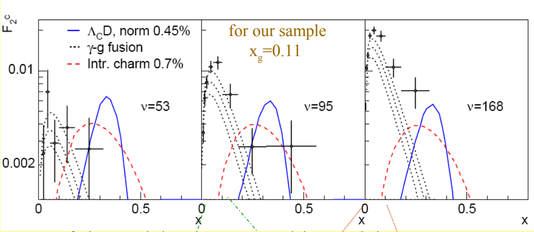


Open Charm



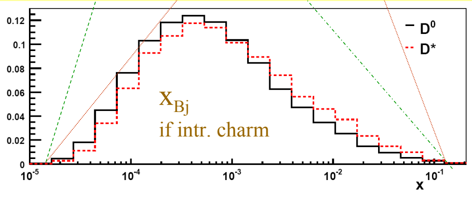
High p_T

Intrinsic Charm



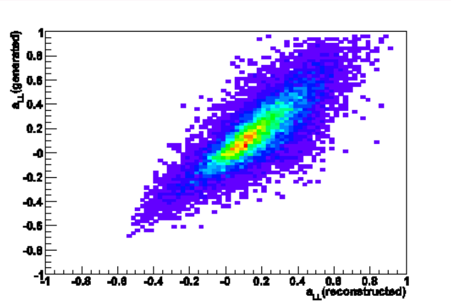
Ref. hep-ph/0508126 and hep-ph/9508403
Data from EMC:Nucl.Phys.B213, 31(1983)

For our data: average ν (70-120GeV),



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 aLL /D is made
- correlation between $a_{LL,gen}$ and $a_{LL,rec}$ is about 0.80

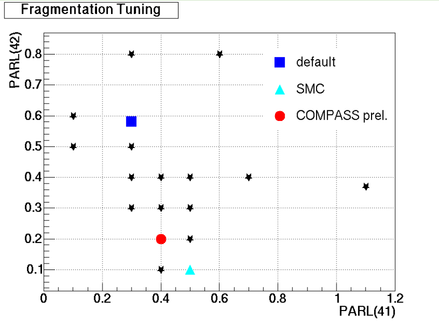


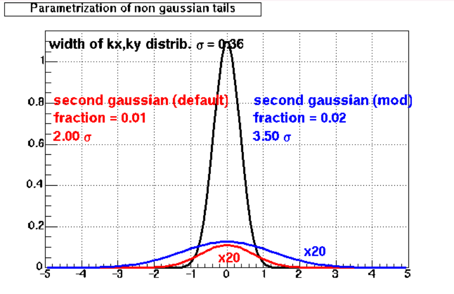
High p_T Monte Carlo

Avarage values of a_{LL}s and Rs	Final MC
$\left\langle a_{LL}^{LP} \right\rangle$	0.63
$\left\langle a_{LL}^{QCDC} \right\rangle$	0.50
$\left\langle a_{LL}^{PGF} \right\rangle$	-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





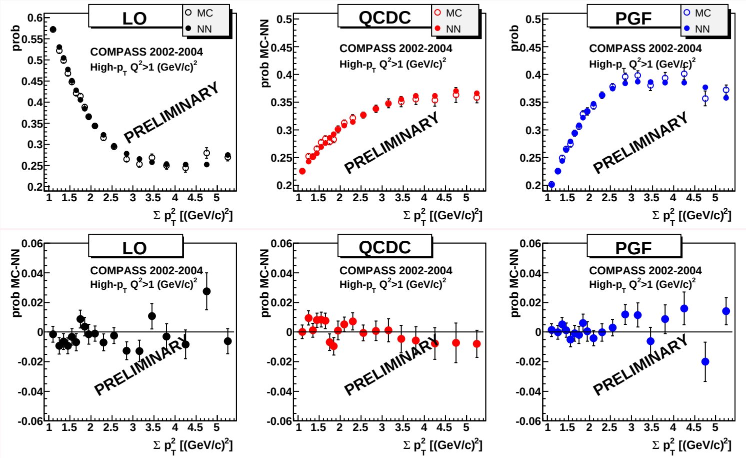
- LUND fragmentation
  $f(z) = z(1-z)^a e^{-bm_T^2/z}$
  $m_T^2 = m^2 + p_T^2$
- with variable parameters a (PARJ(41)) and b (PARJ(42))

- String between two outgoing quarks
- $q\bar{q}$ pairs created with transverse momentum k_T
- width of the gaussian $k_{x,y}$ PARJ(21) = 0.36
- non gaussian tails modelled by second broader gaussian
  - width = PARJ(24) x PARJ(21)
  - fraction PARJ(23) = 0.01 of first gaussian

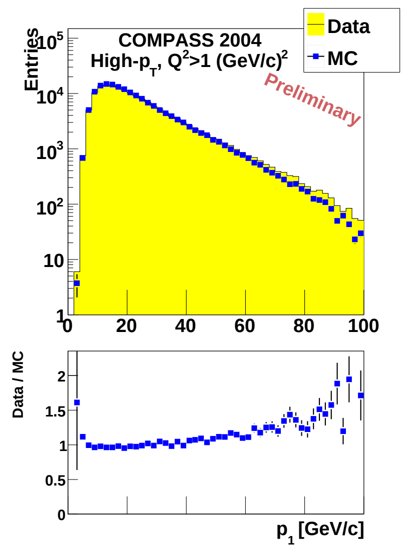
NN validity

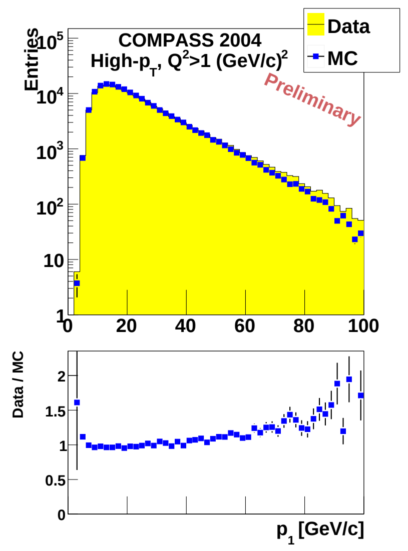
Fractions of the three processes as a function of Σp_T^2

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

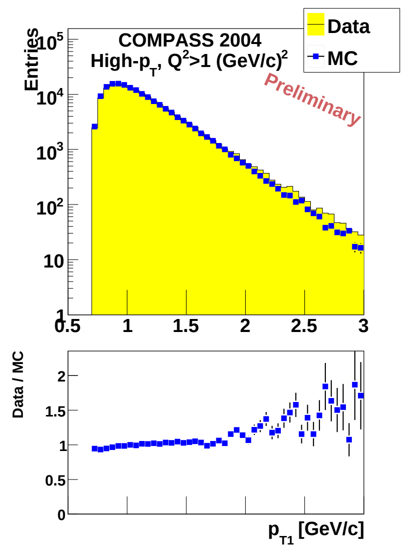


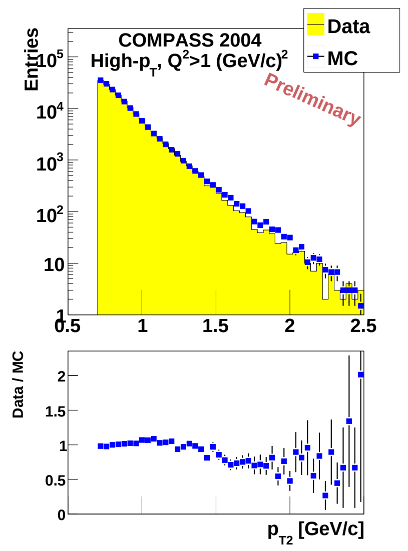
High p_T Data/MC





High p_T Data/MC





High p_T Data/MC