ΔG from open charm (LO and NLO) including D* production cross sections

on behalf of the COMPASS Collaboration

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XIX International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS 2011)
April 11-15, 201, Newport News Marriott at City Center Newport News, VA USA

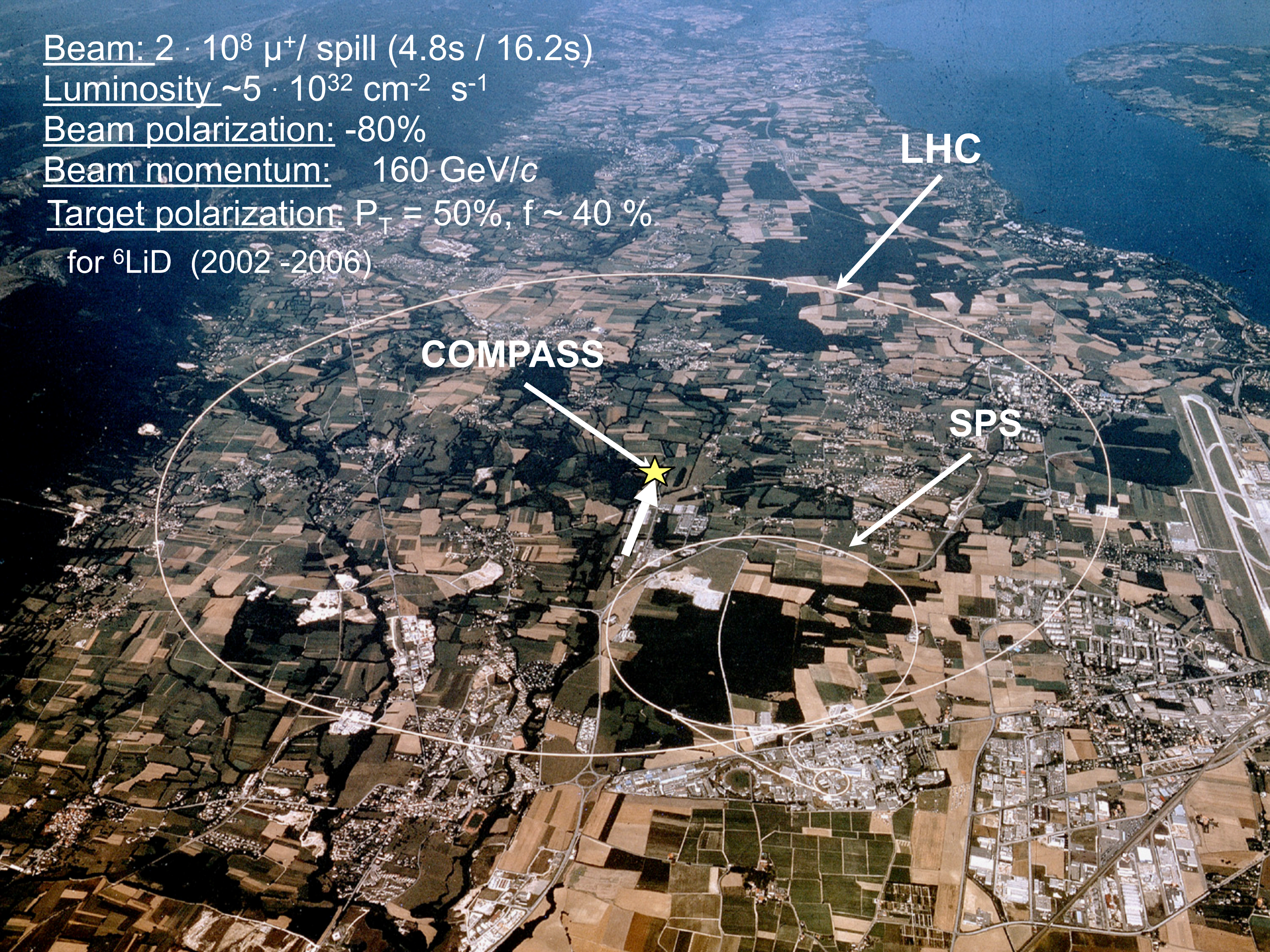
COMPASS Collaboration at CERN

Common Muon and Proton Apparatus for Structure and Spectroscopy

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

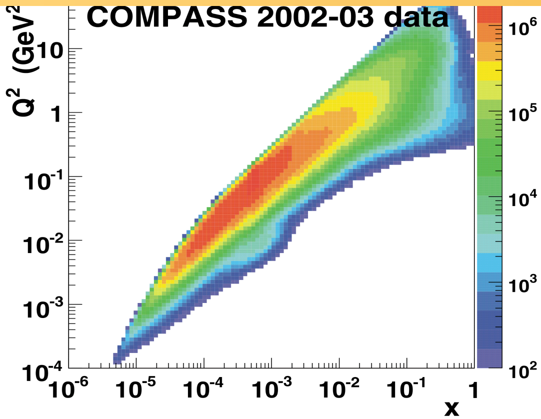
Bielefeld, Bochum, Bonn, Burdwan and Calcutta, CERN, Dubna, Erlangen, Freiburg, Lisbon, Mainz, Moscow, Munich, Prague, Protvino, Saclay, Tel Aviv, Torino, Trieste, Warsaw, Yamagata

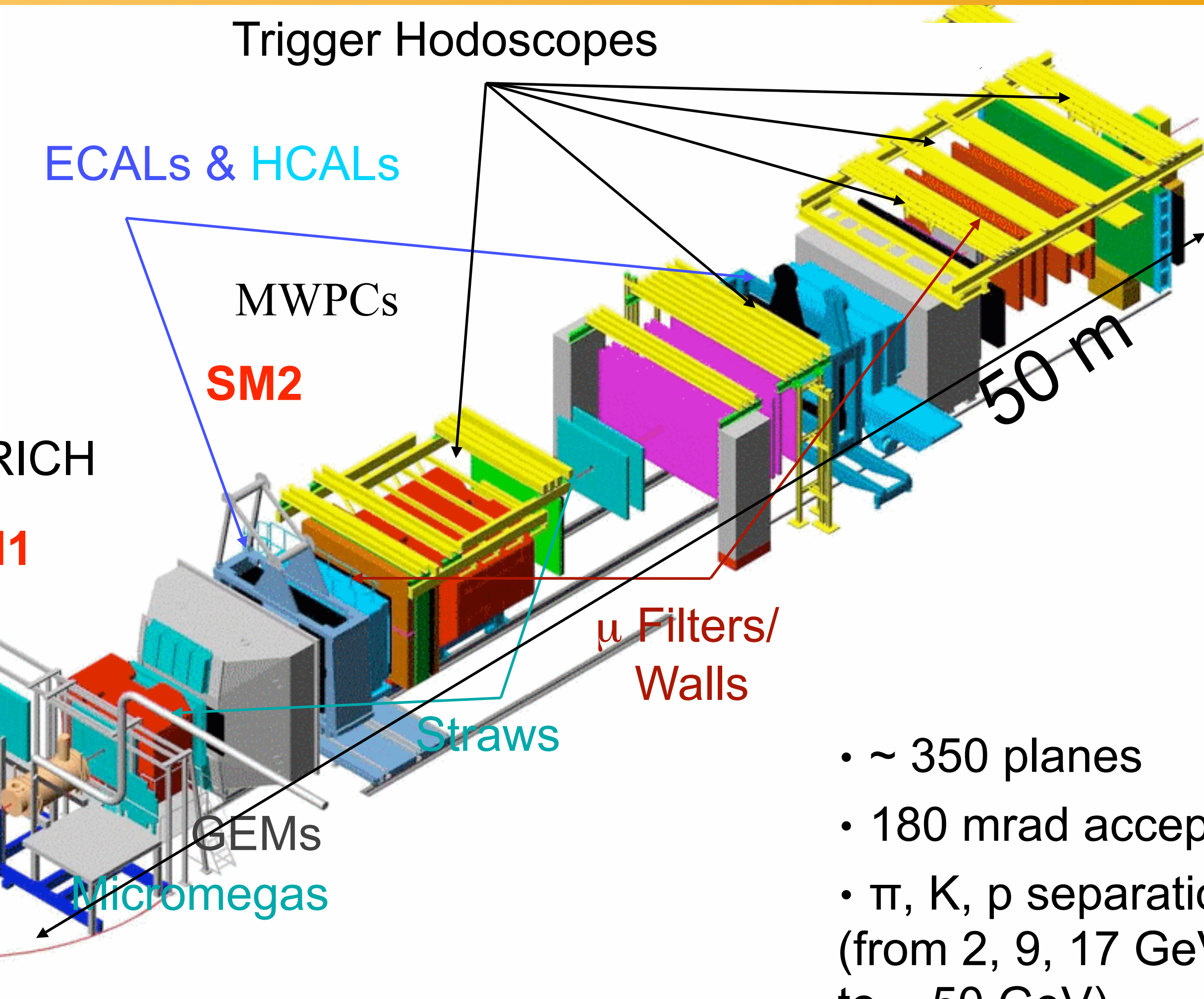
~240 physicists, 30 institutes


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)
LHC
COMPASS
SPS

The COMPASS spectrometer

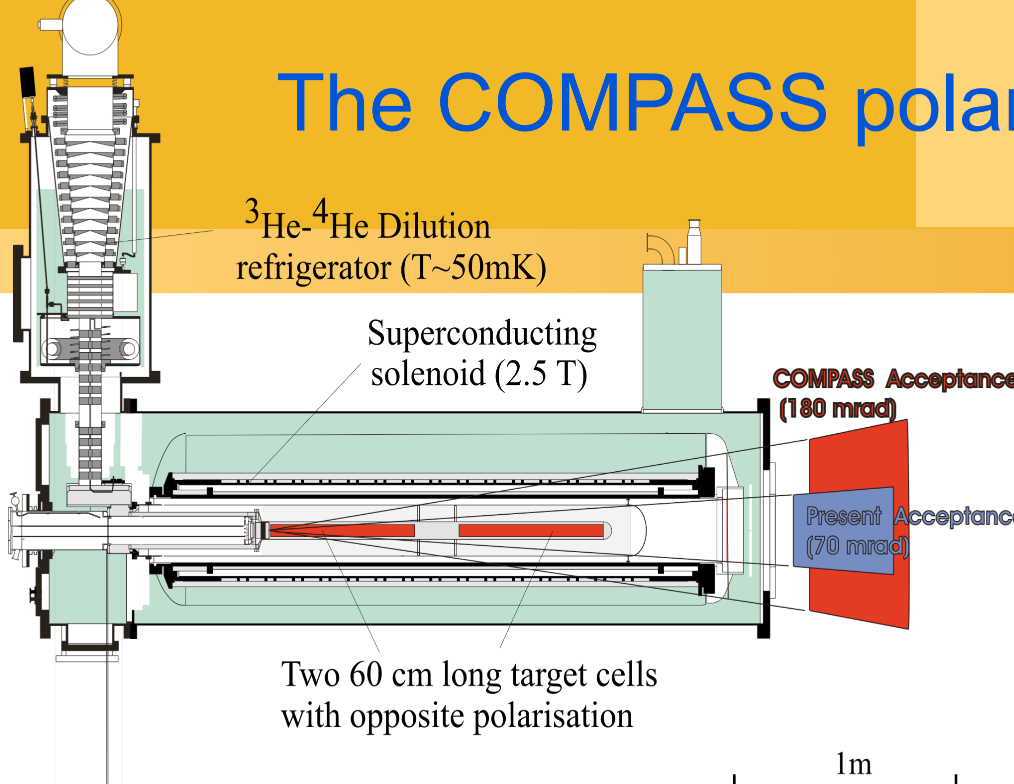
COMPASS in muon run
NIM A 577(2007) 455





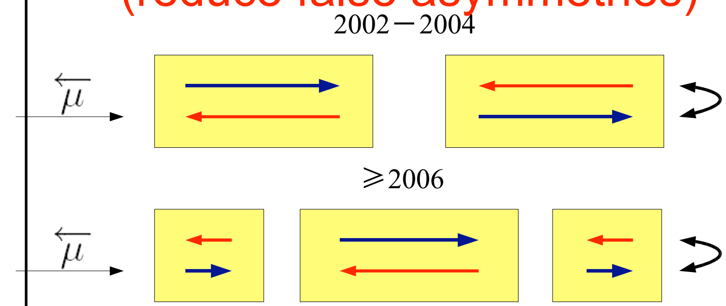
- ~ 350 planes
- 180 mrad acceptance
- π, K, p separation (from 2, 9, 17 GeV up to ~ 50 GeV)

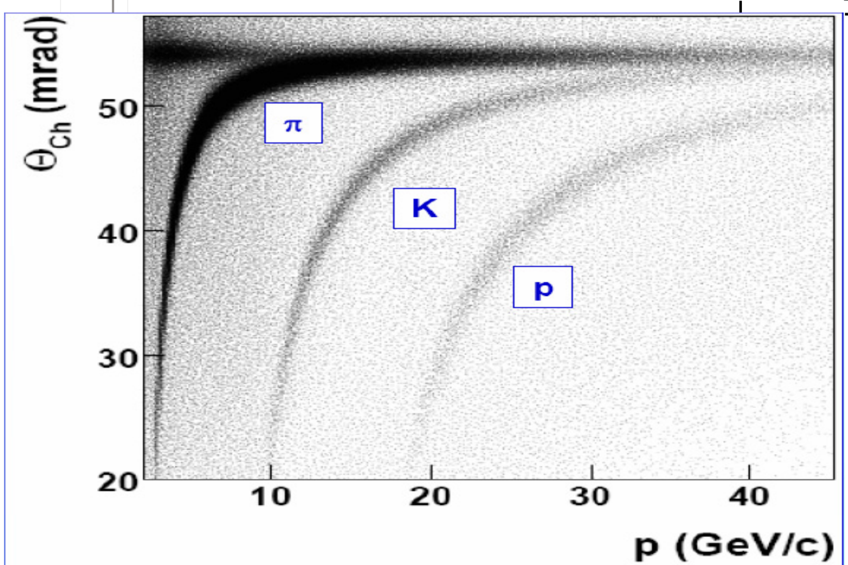
The COMPASS polarized target and PID



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

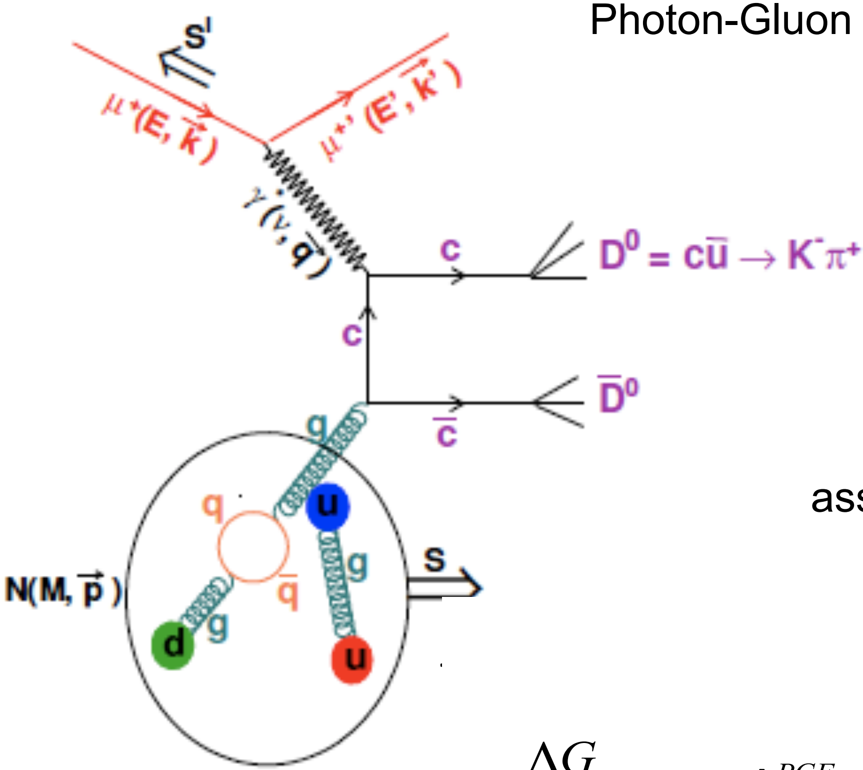
Contents

- Introduction: open-charm and gluon polarization
- Gluon polarization measurement @ COMPASS: the method
- Final gluon polarisation LO QCD result from COMPASS open-charm data
- Final D^0 asymmetries in D^0 energy and p_T bins
- Preliminary NLO QCD results for gluon polarization
- D* meson production cross section

D^0 meson production

Low statistics! Huge combinatorial background to fight with! *Phys.Lett.B 676 (2009)31*

Open-charm production@COMPASS -
Photon-Gluon Fusion (PGF) - the only process in LO QCD.



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

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

assumption: $$\frac{\Delta G}{G}(x) \approx a(x - \bar{x}) + b$$

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

D^0 meson production

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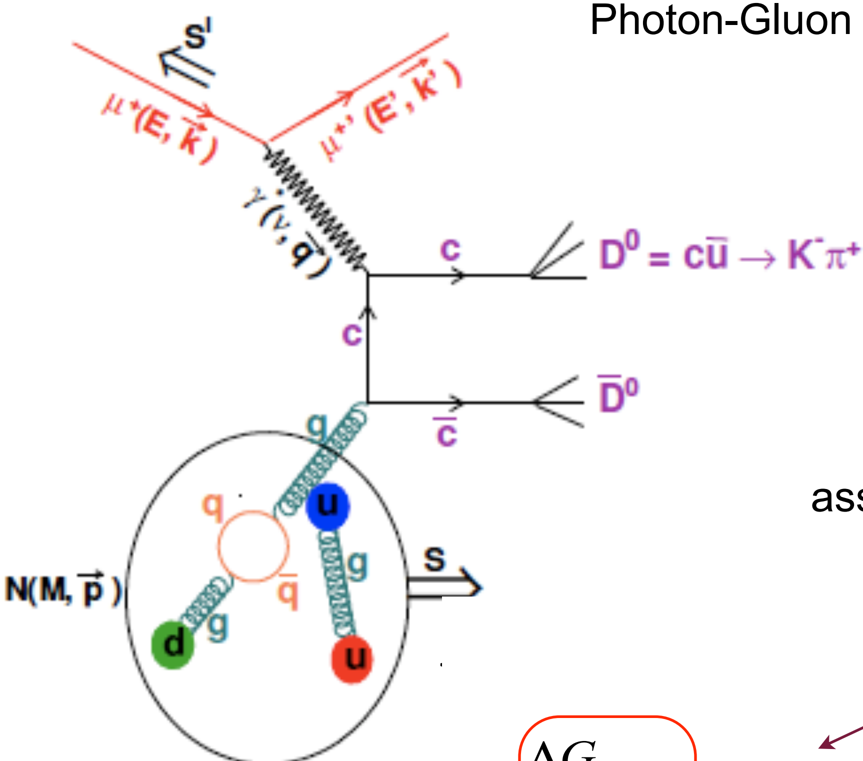


$$\sigma^{PGF} = G \otimes \hat{\sigma}^{PGF} \otimes H$$

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

assumption: $$\frac{\Delta G}{G}(x) \approx a(x - \bar{x}) + b$$

from MC

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

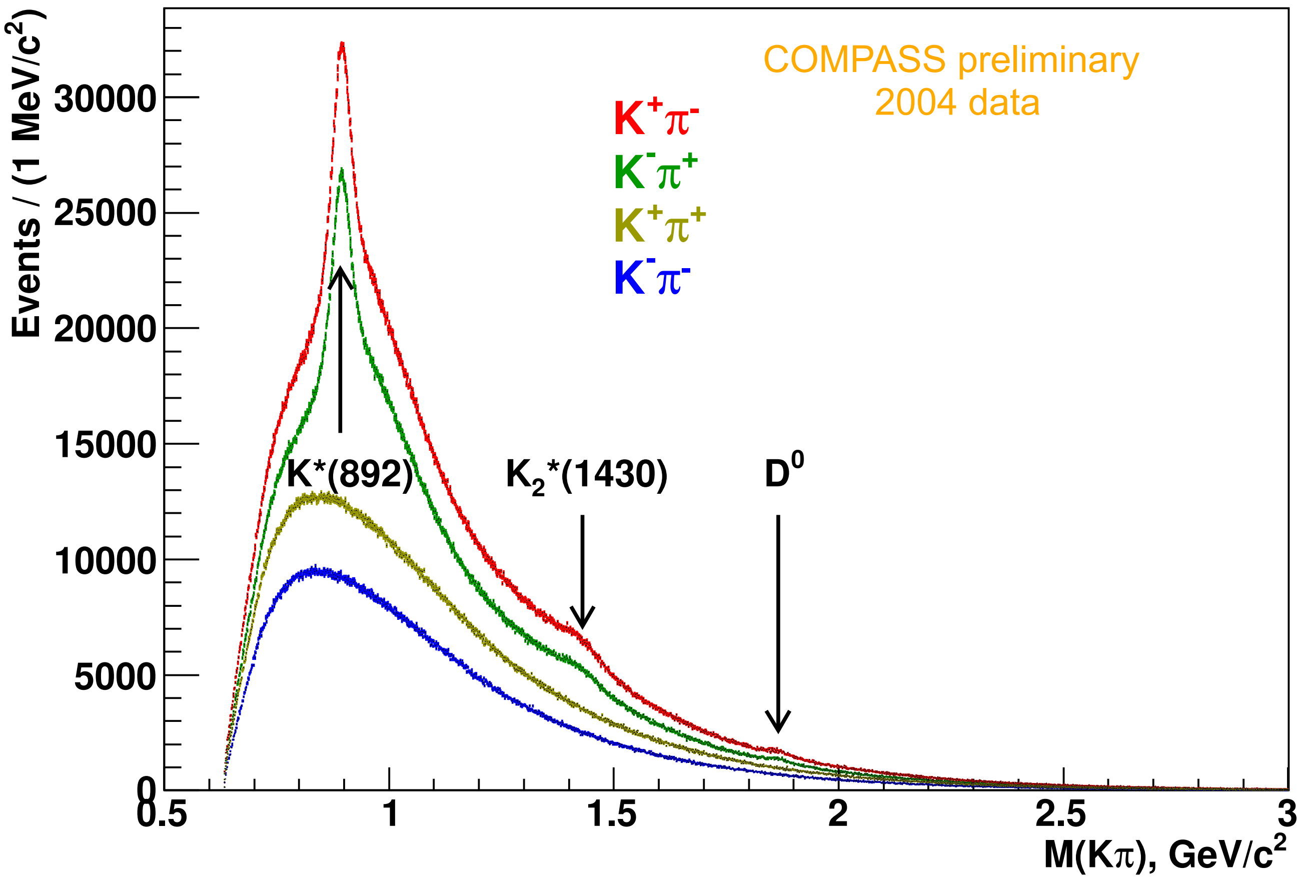
signal asymmetry from data

notice:

$$A^{measured} = fP_T P_b\left(\frac{S}{S+B}A^{signal} + \frac{B}{S+B}A^B\right)$$

D^0 meson production

Low statistics! Huge combinatorial background to fight with!



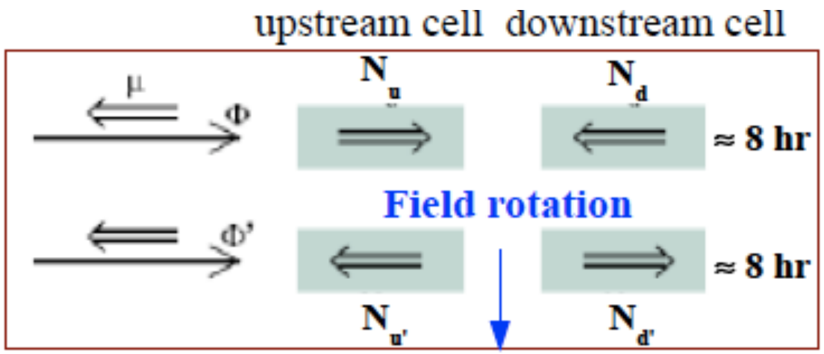
Good charge combinations
Wrong charge combinations

Measuring D^0 asymmetries to extract $\Delta G/G$

The number of reconstructed D^0 ($N^{u,d}$) is used to measure an open-charm asymmetry for the PGF process

$$A^{exp} = \frac{1}{2}\left(\frac{N^{u}-N^{d}}{N^{u}+N^{d}} + \frac{N^{d'}-N^{u'}}{N^{u'}+N^{d'}}\right) = f \cdot P_{\mu} \cdot P_{T} \cdot \frac{s}{s+b} \cdot A^{\mu,T}$$

Open-Charm event probability



equal acceptance for both cells

Weighting each event with the weight $\omega = (f.P_{\mu}.S/(S+B) \cdot a_{LL})$: → needed for every event

$$\frac{\Delta G}{G} = \frac{1}{2P_T} \times \left(\frac{\omega_u - \omega_d}{\omega_u^2 + \omega_d^2} + \frac{\omega_{u'} - \omega_{d'}}{\omega_{u'}^2 + \omega_{d'}^2}\right) \text{ with a statistical gain : } \frac{<\omega^2>}{<\omega>^2}$$

D^0 meson reconstruction

Considered events:

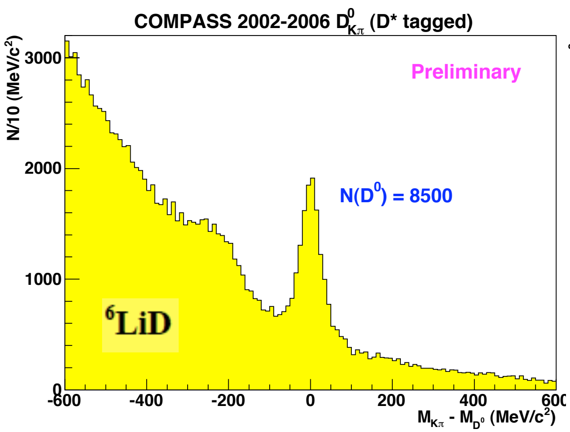
- $D^0 \rightarrow K\pi$ *(BR: 4%)*
- $D^* \rightarrow D^0\pi_s$ *(30% D^0 tagged with a D^*)*
  - $D^0 \rightarrow K\pi$
  - $D^0 \rightarrow K\pi\pi^0$ *(BR: 13%)* → **not directly reconstructed** π^0
  - $D^0 \rightarrow K\pi\pi\pi$ *(BR: 7.5%)*
  - $D^0 \rightarrow sub(K)\pi$ → **no RICH ID for Kaons** *(p < 9 GeV/c)*

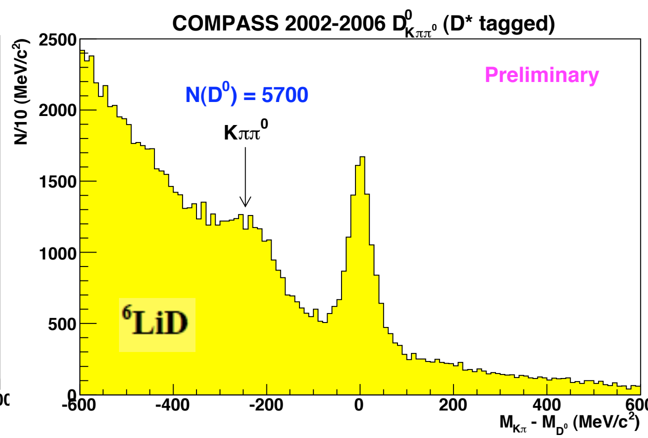
Selection to reduce the combinatorial background

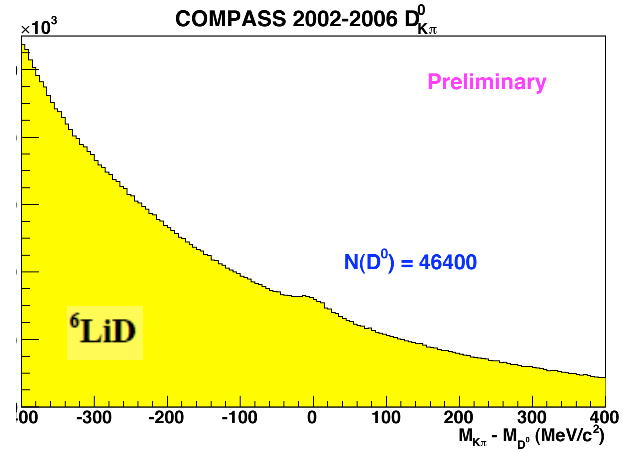
- **Kinematical cuts:** z_D and D^0 decay angle *(to reject colinear events with γ^* coming from the nucleon fragmentation)*, K and π momentum
- **RICH identification:** K and π ID + electrons rejected from the π_s sample
- Mass cut for the D^* tagged channels *($M[K\pi\pi_s] - M[K\pi] - M[\pi]$)*
- Neural Network qualification of events

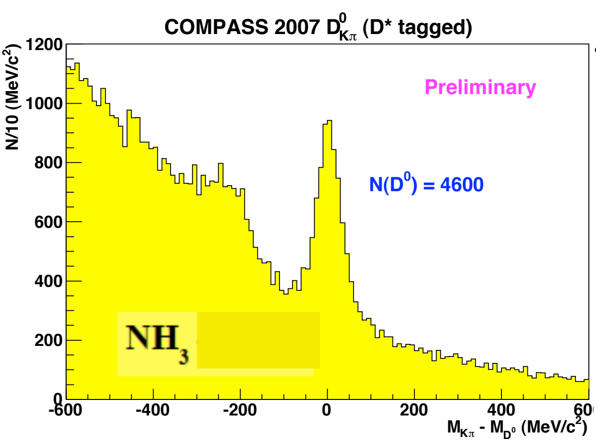
D^0 meson reconstruction

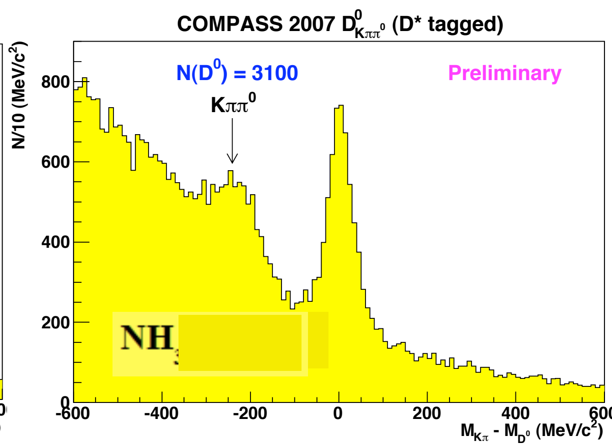
Invariant mass spectrum D^0 mesons reconstruction

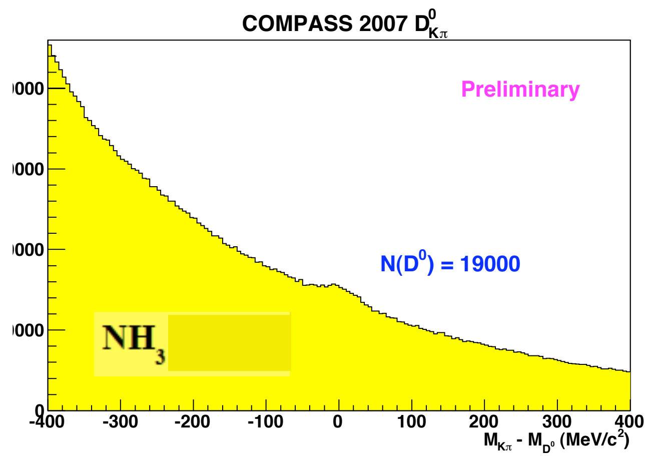






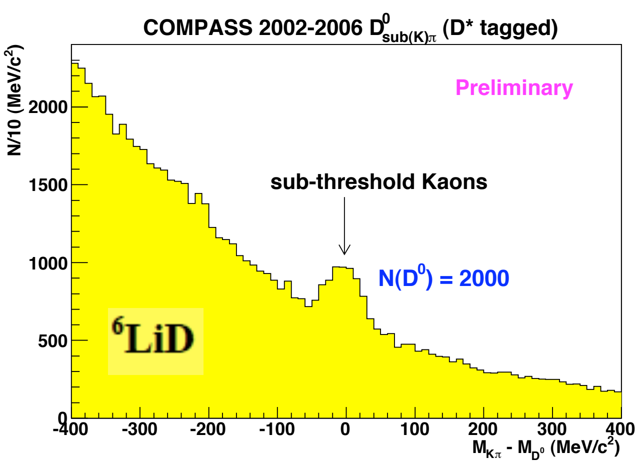


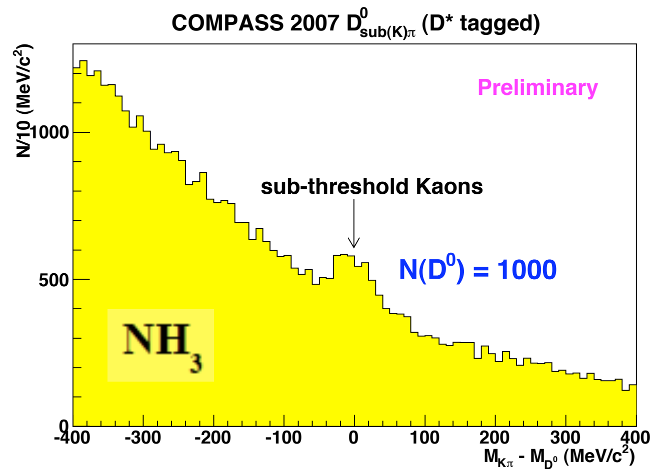


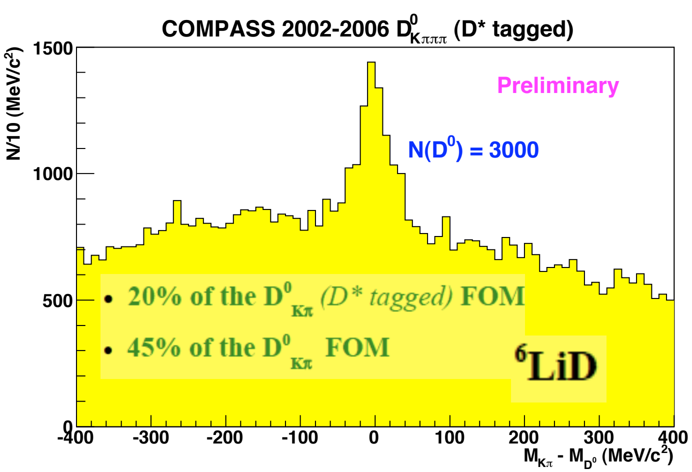


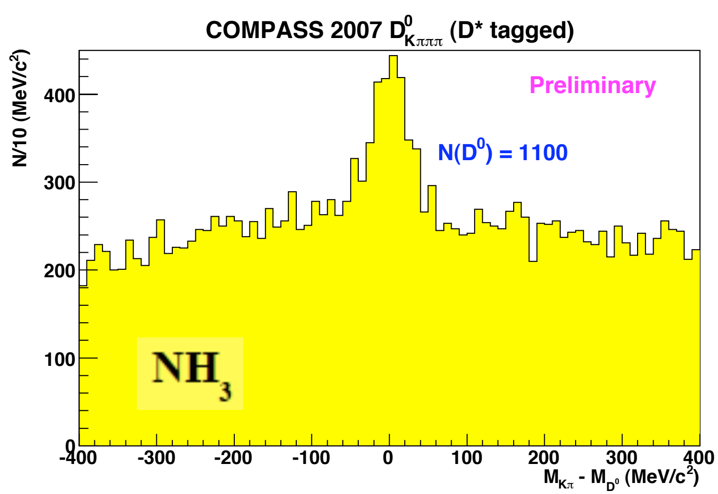
D^0 meson reconstruction

Invariant mass spectrum D^0 mesons reconstruction



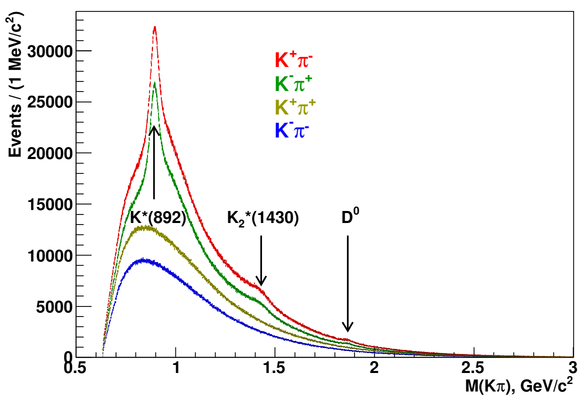




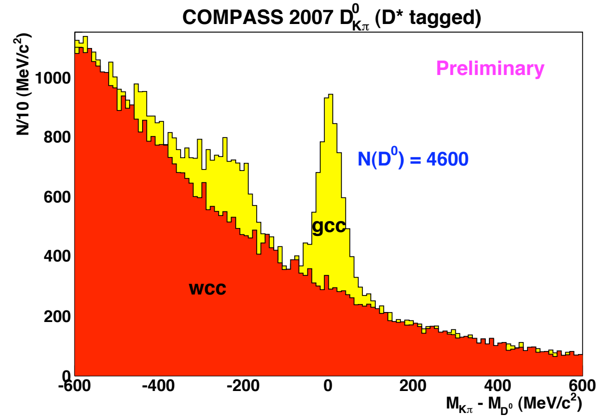


Signal to background estimation

Neural Network qualification of events

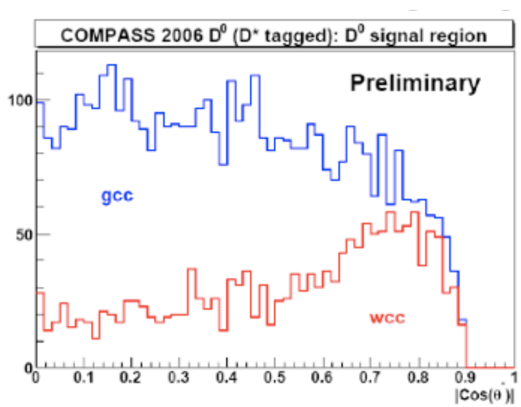


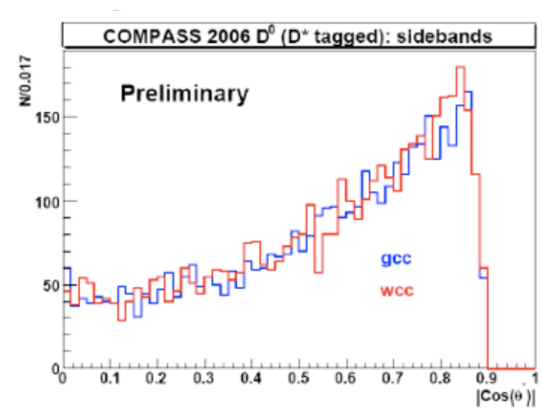
gcc: signal+background
wcc: pure background



- Assuming background model to be good *Neural Network* is able to find some differences between samples: *S+B* and *B*.
- This way the signal probability *S/(S+B)* is constructed event-by-event

An example of "good" training variable in signal region (left) and for sidebands (right)

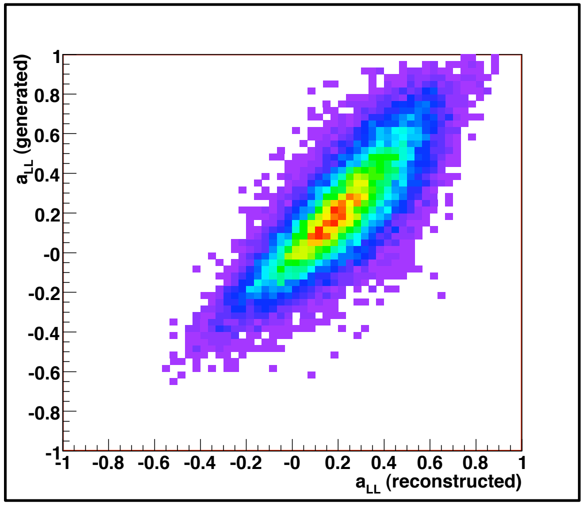


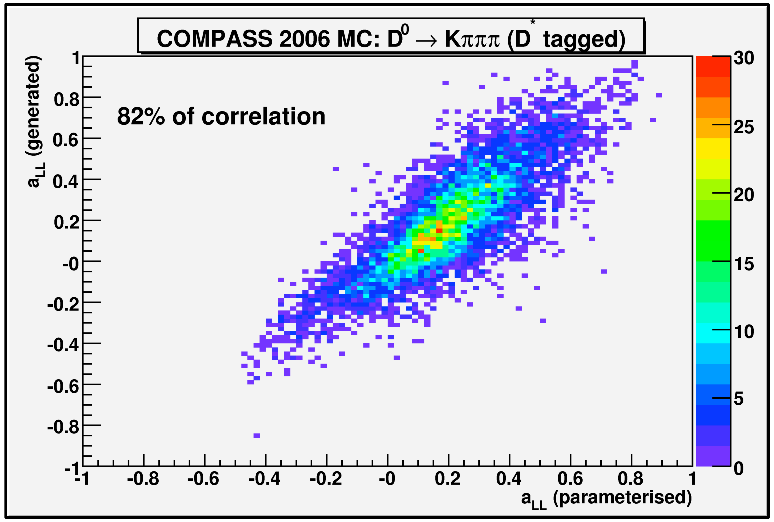


Analyzing power a_{LL}

Partonic muon-gluon asymmetry and NN parameterization

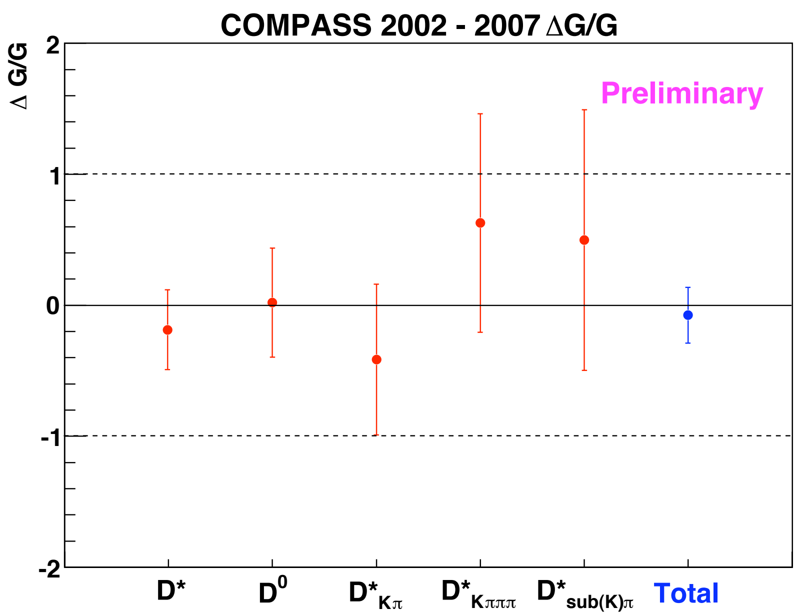
- a_{LL} depends on the knowledge of the partonic kinematics and can not be experimentally obtained - only one charmed meson is reconstructed
- a_{LL} is calculated with MC (in LO QCD) and parameterized by measured quantities using NN approach
- As a training vector kinematical variables: y, x_{Bjk}, Q^2, z_{D^0}, p_{T,D^0} are used





Gluon polarization

Final gluon polarization result from open-charm in LO QCD



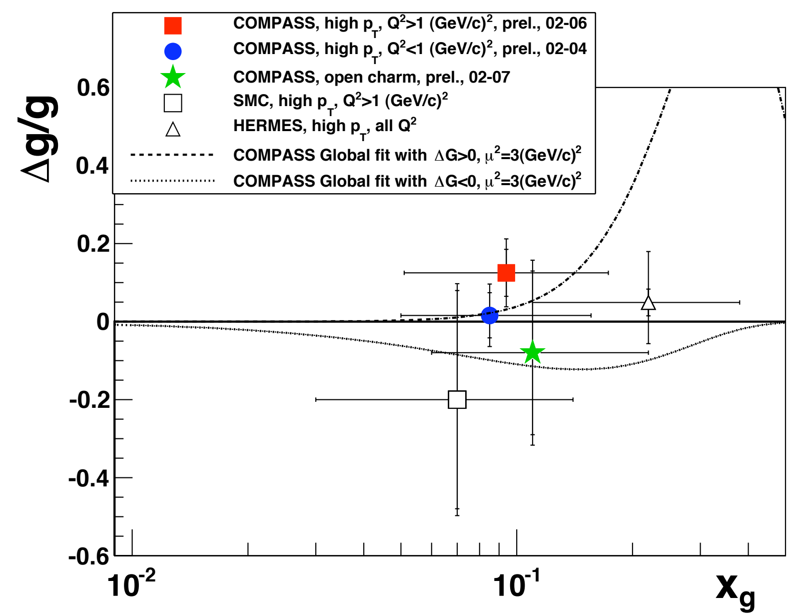
Notice: signal and background asymmetries are extracted in the same time

$$A^{measured} = fP_T P_b \left(\frac{S}{S+B} A^{signal} + \frac{B}{S+B} A^B\right)$$

$$\frac{\Delta G}{G} = -0.08 \pm 0.21(stat.) \pm 0.08(syst.)$$

$$\langle x_G \rangle = 0.11^{+0.11}_{-0.05} \qquad \mu^2 \approx 13 \frac{GeV^2}{c^2}$$

Source	$\delta\left(\langle\frac{\Delta g}{g}\rangle\right)$	Source	$\delta\left(\langle\frac{\Delta g}{g}\rangle\right)$
Beam polarisation P_μ	0.004	$s/(s+b)$	0.006
Target polarisation P_t	0.004	a_{LL}	0.008
Dilution factor f	0.002	False asymmetry	0.081
Total uncertainty 0.082			



Model independent asymmetries

D^0 asymmetries in bins of E_{D^0} and p_{T,D^0}

- Model independent asymmetries were extracted from data only
- Gluon polarisation can be extracted using a_{LL}^{PGF} calculated at QCD :

$$A_{\exp} = P_B P_T f\left[R_{PGF} \boxed{D A^{\gamma N \to DX}} + (1 - R_{PGF}) A_{bkg}\right]$$

$$A_{\exp} = P_B P_T f\left[R_{PGF} \boxed{a_{LL}^{PGF} \frac{\Delta g}{g}} + (1 - R_{PGF}) A_{bkg}\right]$$

- Similar analysis, but with weight

$$w = f\, P_B \frac{S}{S+B} a_{LL} \quad \text{instead of} \quad w = f\, P_B \frac{S}{S+B} D$$

Bin limits		$A^{\gamma N \to D^0 X}$	$\langle y \rangle$	$\langle Q^2 \rangle$ $(\mathrm{GeV}/c)^2$	$\langle p_T^{D^0} \rangle$ (GeV/c)	$\langle E_{D^0} \rangle$ (GeV)	$\langle D \rangle$
$p_T^{D^0}$ (GeV/c)	E_{D^0} (GeV)						
0–0.3	0–30	-0.90 ± 0.63	0.50	0.46	0.19	24.3	0.62
0–0.3	30–50	-0.19 ± 0.48	0.60	0.69	0.20	39.1	0.74
0–0.3	> 50	$+0.07 \pm 0.68$	0.69	1.17	0.20	59.2	0.84
0.3–0.7	0–30	-0.18 ± 0.37	0.51	0.47	0.51	24.6	0.63
0.3–0.7	30–50	$+0.10 \pm 0.26$	0.60	0.62	0.51	39.5	0.75
0.3–0.7	> 50	-0.04 ± 0.36	0.69	0.73	0.51	59.0	0.83
0.7–1	0–30	-0.42 ± 0.44	0.50	0.45	0.85	24.7	0.62
0.7–1	30–50	-0.36 ± 0.29	0.61	0.60	0.85	39.2	0.75
0.7–1	> 50	$+1.49 \pm 0.42$	0.69	0.76	0.84	58.6	0.83
1–1.5	0–30	-0.30 ± 0.35	0.54	0.41	1.23	25.3	0.66
1–1.5	30–50	$+0.13 \pm 0.23$	0.64	0.55	1.24	39.2	0.77
1–1.5	> 50	-0.20 ± 0.33	0.71	0.73	1.24	58.3	0.85
> 1.5	0–30	$+0.38 \pm 0.49$	0.56	0.47	1.84	25.6	0.69
> 1.5	30–50	0.00 ± 0.25	0.65	0.70	1.92	39.9	0.79
> 1.5	> 50	$+0.36 \pm 0.33$	0.69	0.60	1.95	59.9	0.86

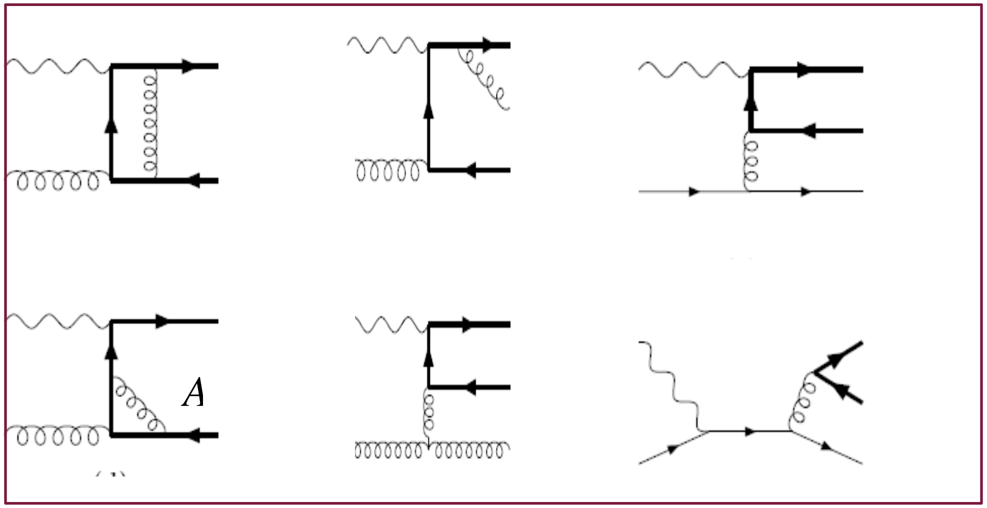
Table 7: Combined asymmetries $A^{\gamma N \to D^0 X}$ for the $D^0_{K\pi}$, $D^*_{K\pi}$ and $D^*_{K_{sub}\pi}$ samples in bins of ($p_T^{D^0}$, E_{D^0}), together with the weighted (with w_S^2) averages of several kinematic variables. Errors are statistical.

Asymmetries in bins are available on the request; They will be published soon (paper in preparation)

NLO QCD corrections

I.Bojak, M.Stratmann, Nucl.Phys.B 540 (1999) 345, I.Bojak, PhD th.

J.Smith, W.L.Neerven, Nucl.Phys.B 374 (1992)36),W.Beenakker, H.Kuijf, W.L.Neerven,,J.Smith, Phys.Rev.D40(1989)54



$$A^{signal} = \left\langle \left(\frac{\Delta G}{G} a_{LL} + A_1^{d,c} a_{LL}^q\right)\right\rangle = \left\langle \frac{\Delta G}{G} \right\rangle_{a_{LL}} \langle a_{LL} \rangle + \langle A_1^{d,c} a_{LL}^q \rangle$$

$$a_{LL} = \frac{G\Delta\hat{\sigma}^{Gluon}}{G\hat{\sigma}^{Gluon} + \sum_q q\hat{\sigma}^{quark}} \qquad a_{LL}^q = \frac{\sum_q q\Delta\hat{\sigma}^{quark}}{G\hat{\sigma}^{Gluon} + \sum_q q\hat{\sigma}^{quark}}$$

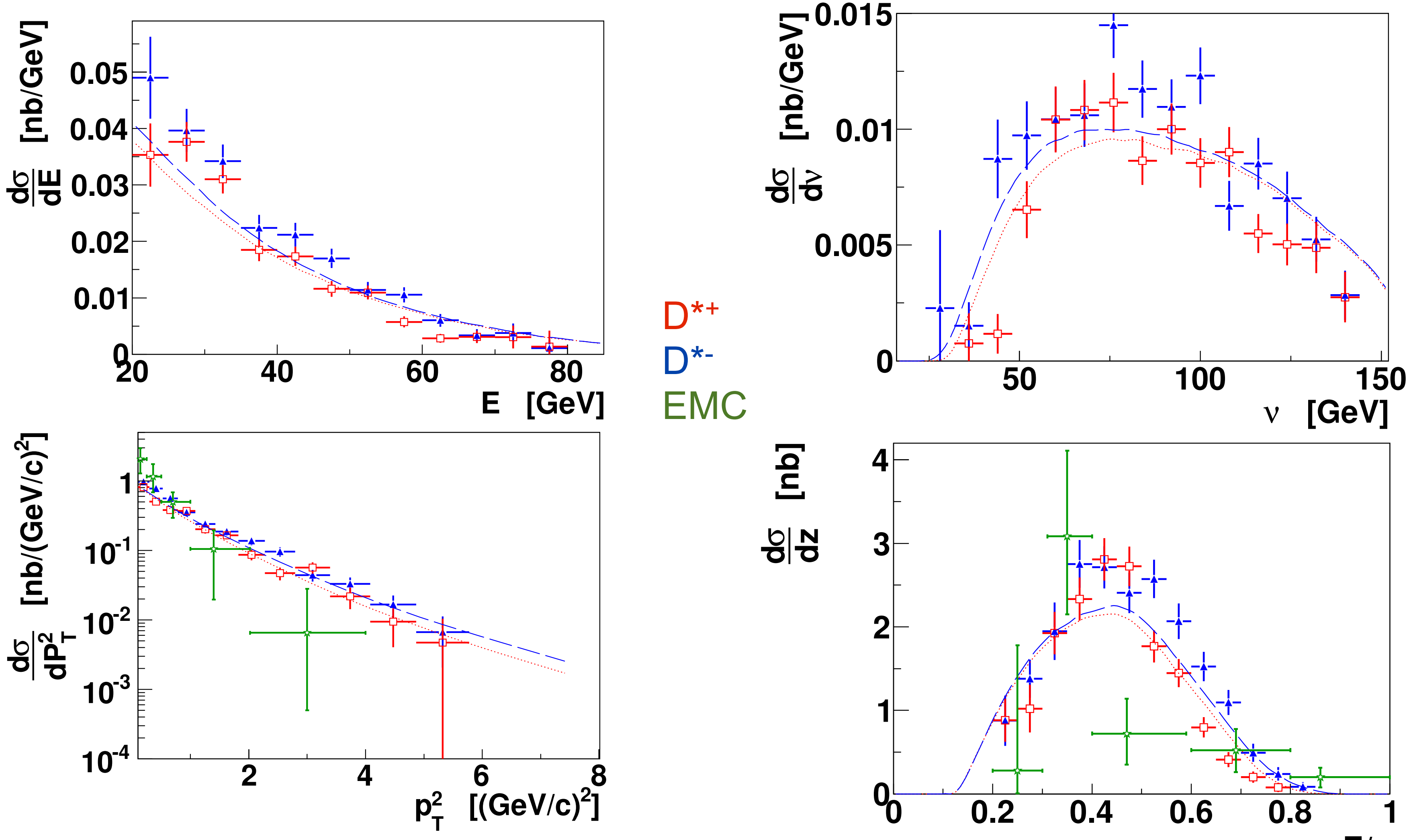
Procedure for NLO calculations:

1. *Aroma* MC generator with Parton Shower-on describes COMPASS data very well
2. PS simulates phase space for NLO correction - a_{LL} can be calculated event-by-event basis from theoretical formulas (as in LO case)
3. light quark correction ~ A_1 which is taken directly from data *)
4. Asymmetries in bins used

(*Light quark contribution very small - no dependence on unpolarized PDFs

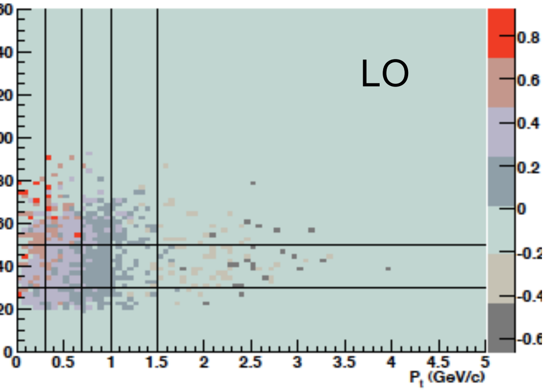
Aroma MC PS versus COMPASS data

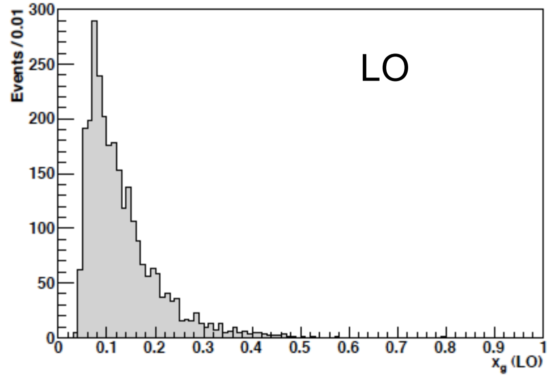
Differential cross section for D* meson production (D* 2004 COMPASS data)



Gluon polarization@NLO

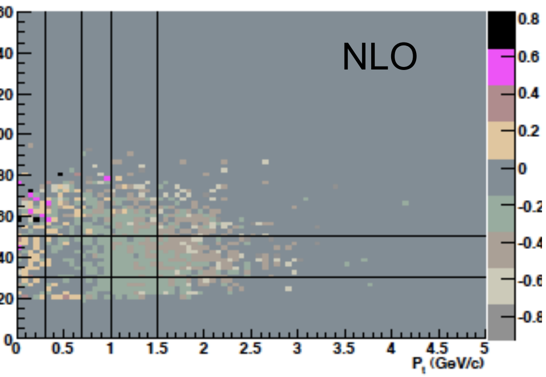
a_{LL} in bins for LO and NLO | X_G | preliminary NLO result

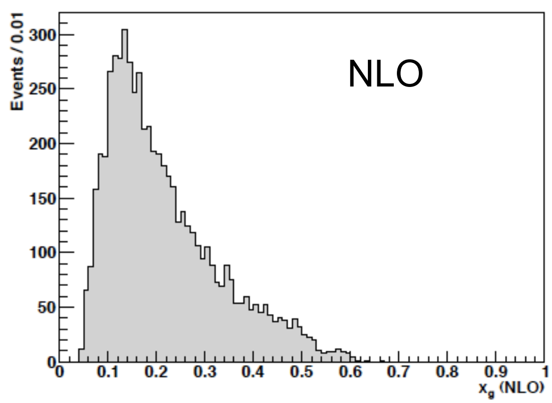


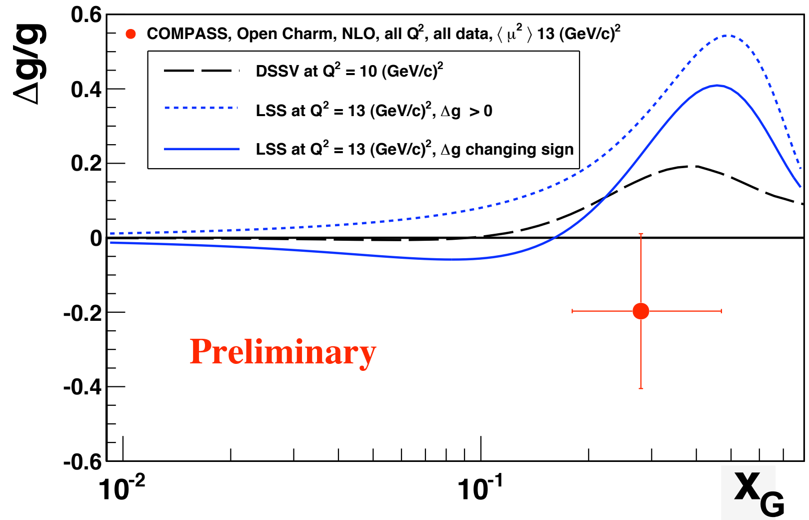


$$\frac{\Delta G}{G} = -0.20 \pm 0.21(stat.)$$

$$\langle x_G \rangle = 0.28^{+0.19}_{-0.10}$$



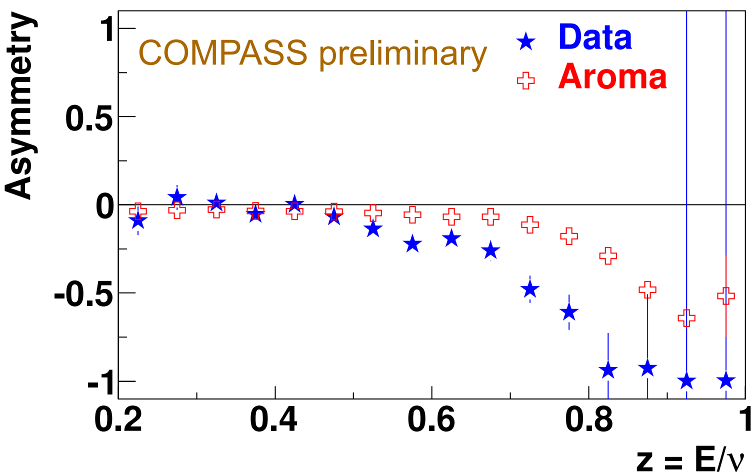


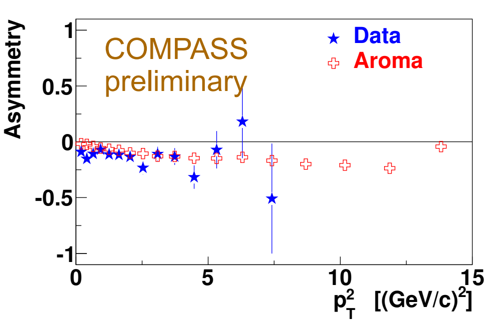


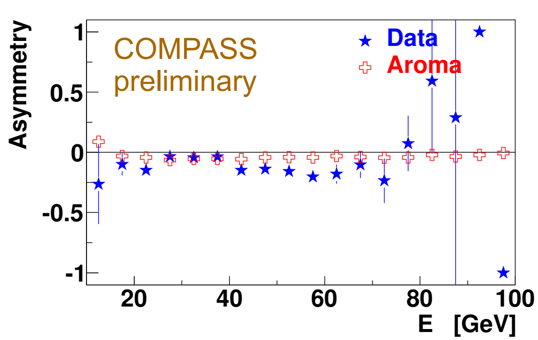
D* meson production

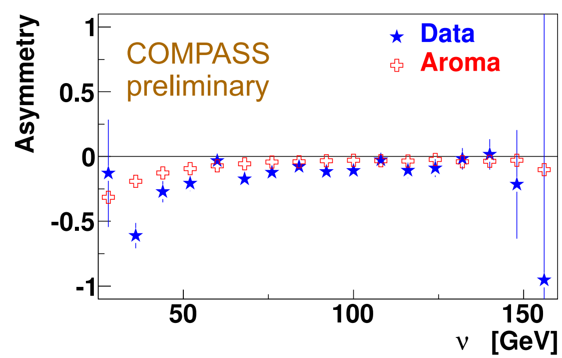
D^{*+}/D^{*-} asymmetry

$$A(X) = \frac{d\sigma^{D^{*+}}(X) - d\sigma^{D^{*-}}(X)}{d\sigma^{D^{*+}}(X) + d\sigma^{D^{*-}}(X)}$$









preliminary cross section result

$$\sigma^{D^{*\pm}}(nb) = 1.8 \pm 0.4$$

$$within \quad 20 < E_D < 80 GeV$$

Summary

- The final LO result on gluon polarization from open-charm analysis @ COMPASS has been presented.
- The preliminary NLO QCD result based on the asymmetries in bins in p_{T,D^0} and E_{D^0} has been obtained.
- The preliminary result on D^* meson production cross section has been shown.
- The asymmetry on D^{*+} and D^{*-} mesons production has been observed.

Spares

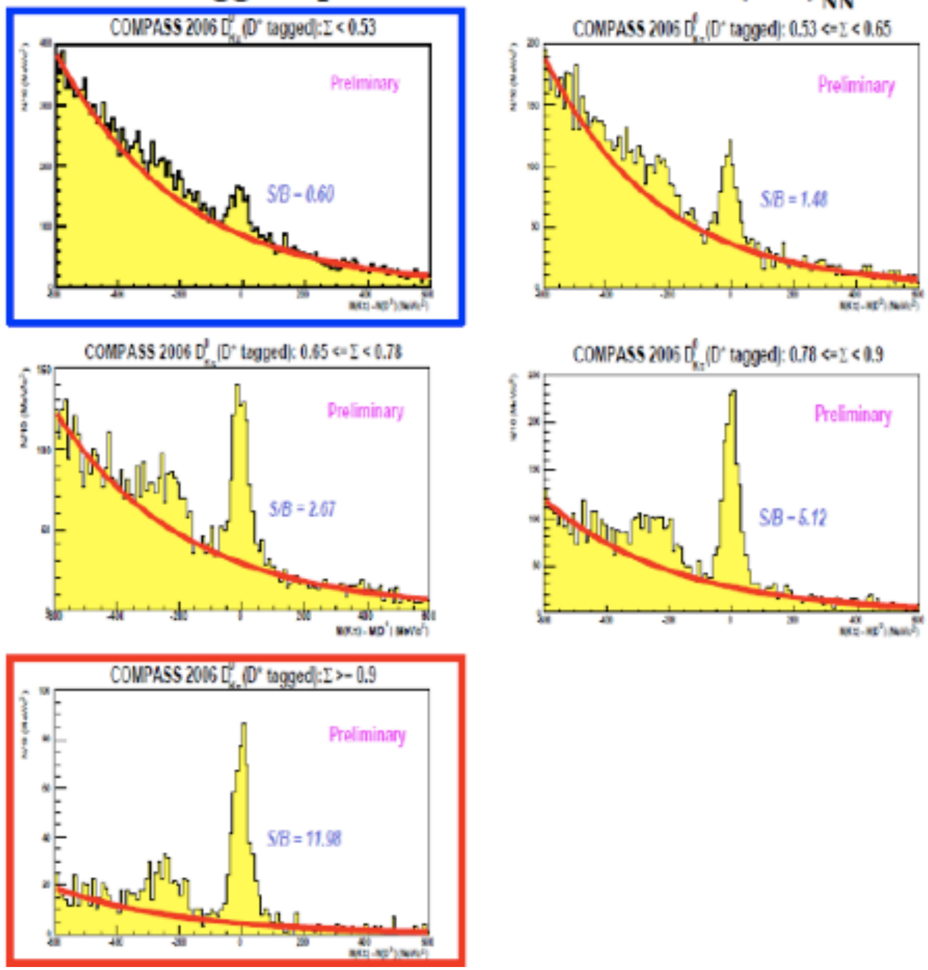
s/(s+b): obtaining final probabilities for D^0 candidate

- **Events with small $s/(s+b)_{NN}$**
  - Mostly combinatorial background is selected

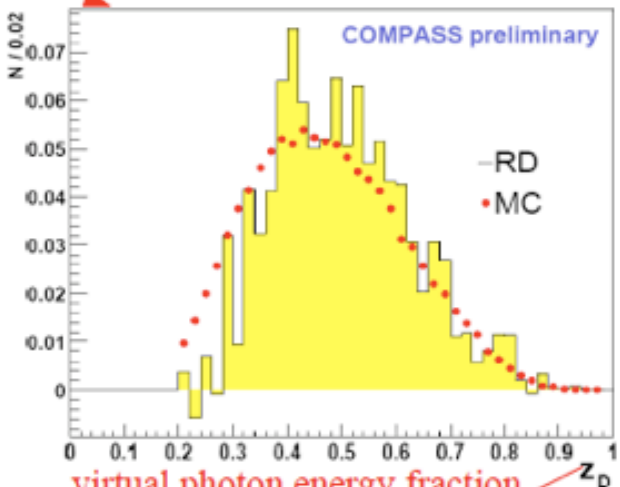
<u>s/(s+b) is obtained from a fit inside this bins</u> *(correcting with the NN parameterisation)*

- **Events with large $s/(s+b)_{NN}$**
  - Mostly Open-Charm events are selected

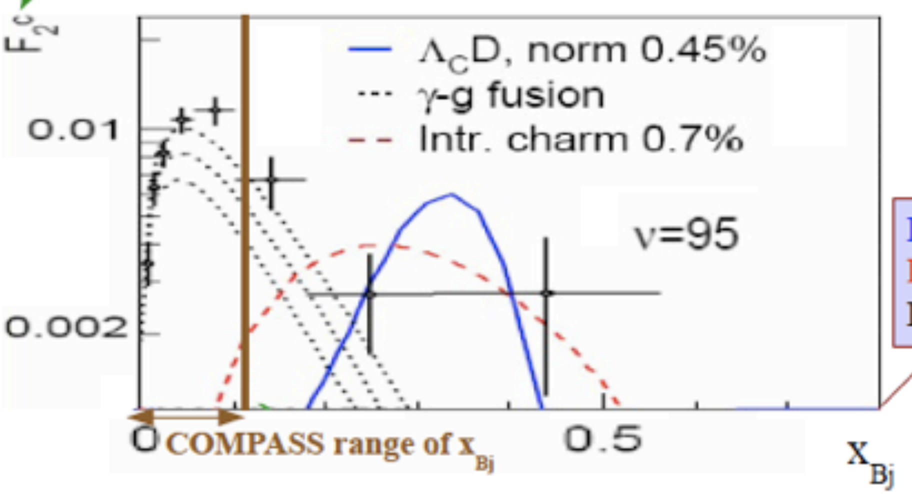
D^0 tagged spectrum in bins of $\Sigma = s/(s+b)_{NN}$



- $c\bar{c}$ production is dominated by the PGF process, and **free from physical background** *(ideal for probing gluon polarisation)*
  - In our center of mass energy, the contribution from intrinsic charm *(c quarks not coming from hard gluons)* in the nucleon is negligible
  - Perturbative scale set by charm mass $4m_c^2$
  - Nonperturbative sea models predict at most 0.7% for intrinsic charm contribution
    - Expected at high x_{Bj} *(compass x_{Bj} < 0.1)*
  - $c\bar{c}$ supressed during fragmentation *(at our energies)*



virtual photon energy fraction carried by D^0 meson

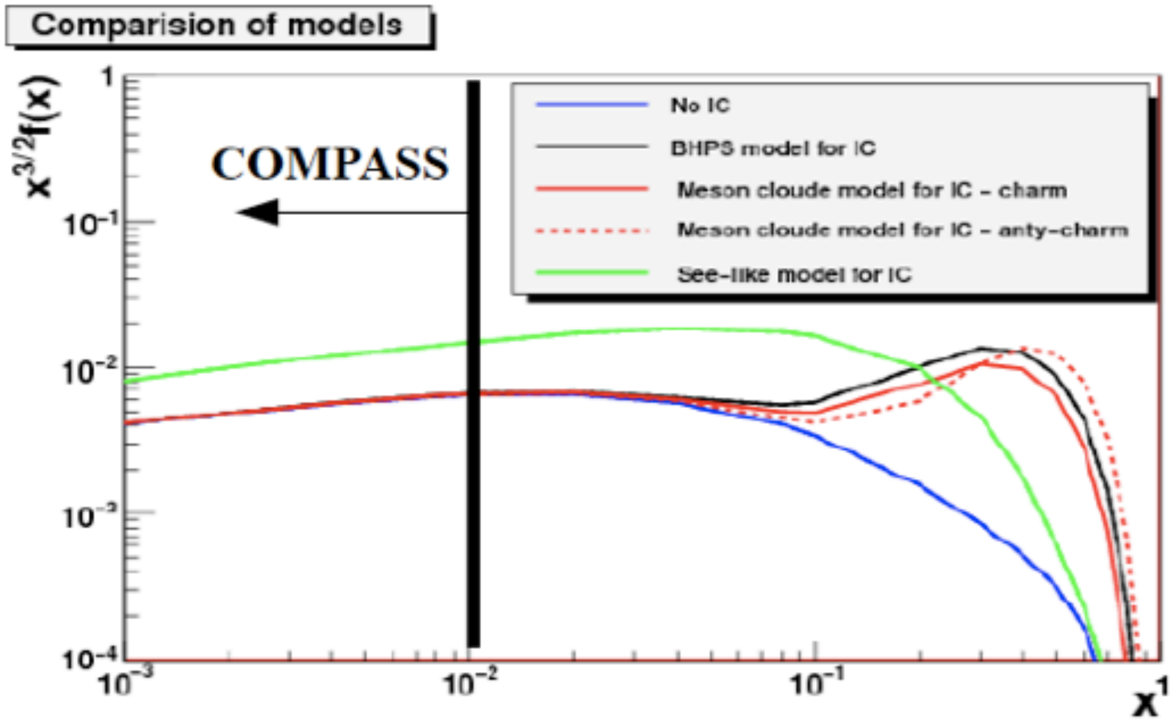


COMPASS range of x_{Bj}

Ref. Hep-ph/0508126 and hep-ph/9508403
Phys. Lett. B93 (1980) 451
Data from EMC:Nucl.Phys.B213, 31(1983)

Final Comments on intrinsic charm

- No intrinsic charm contamination is predicted by the theory driven results
- Only the more phenomenological *"See-like"* scenario should be taken into account *(under study)*



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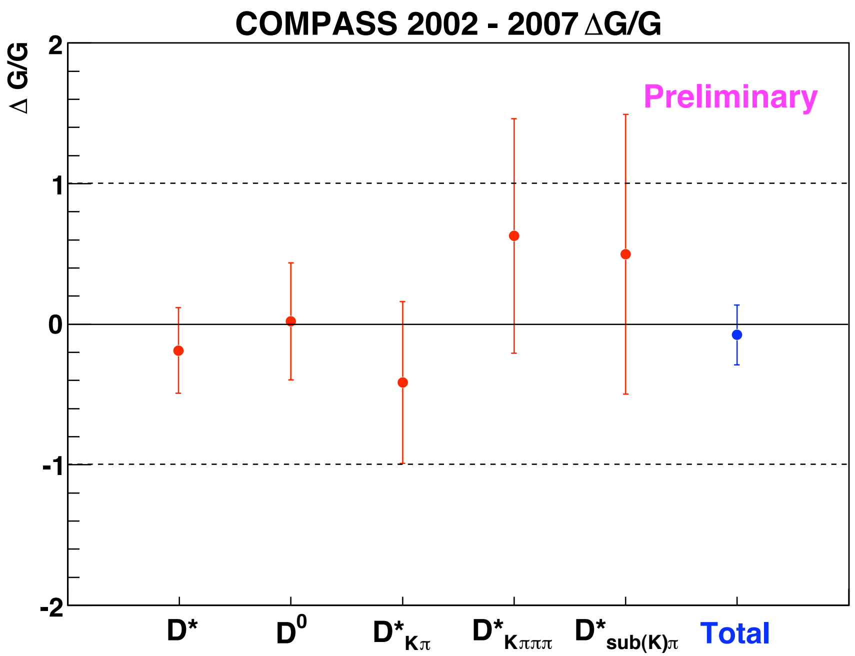
Final gluon polarization result from open-charm in LO QCD

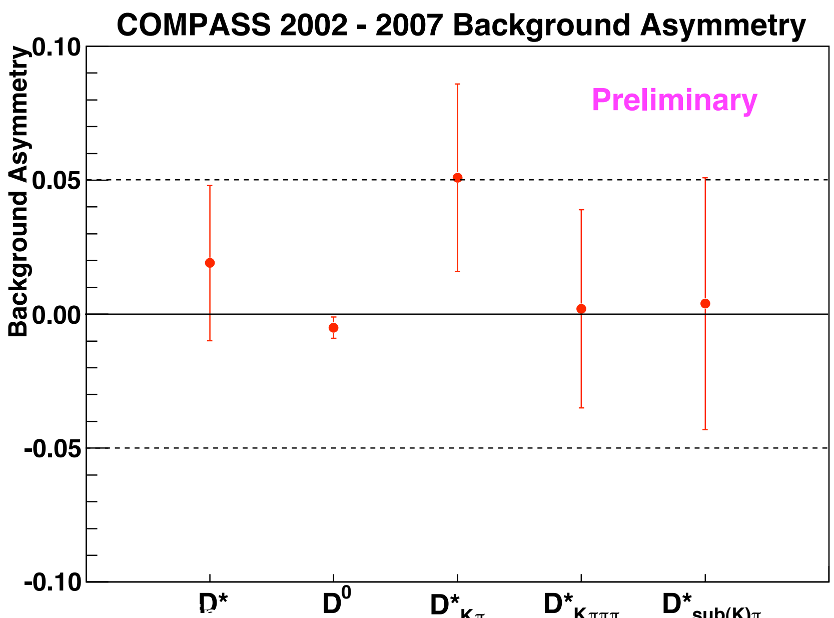


$$\frac{\Delta G}{G} = -0.08 \pm 0.21(stat.) \pm 0.08(syst.)$$

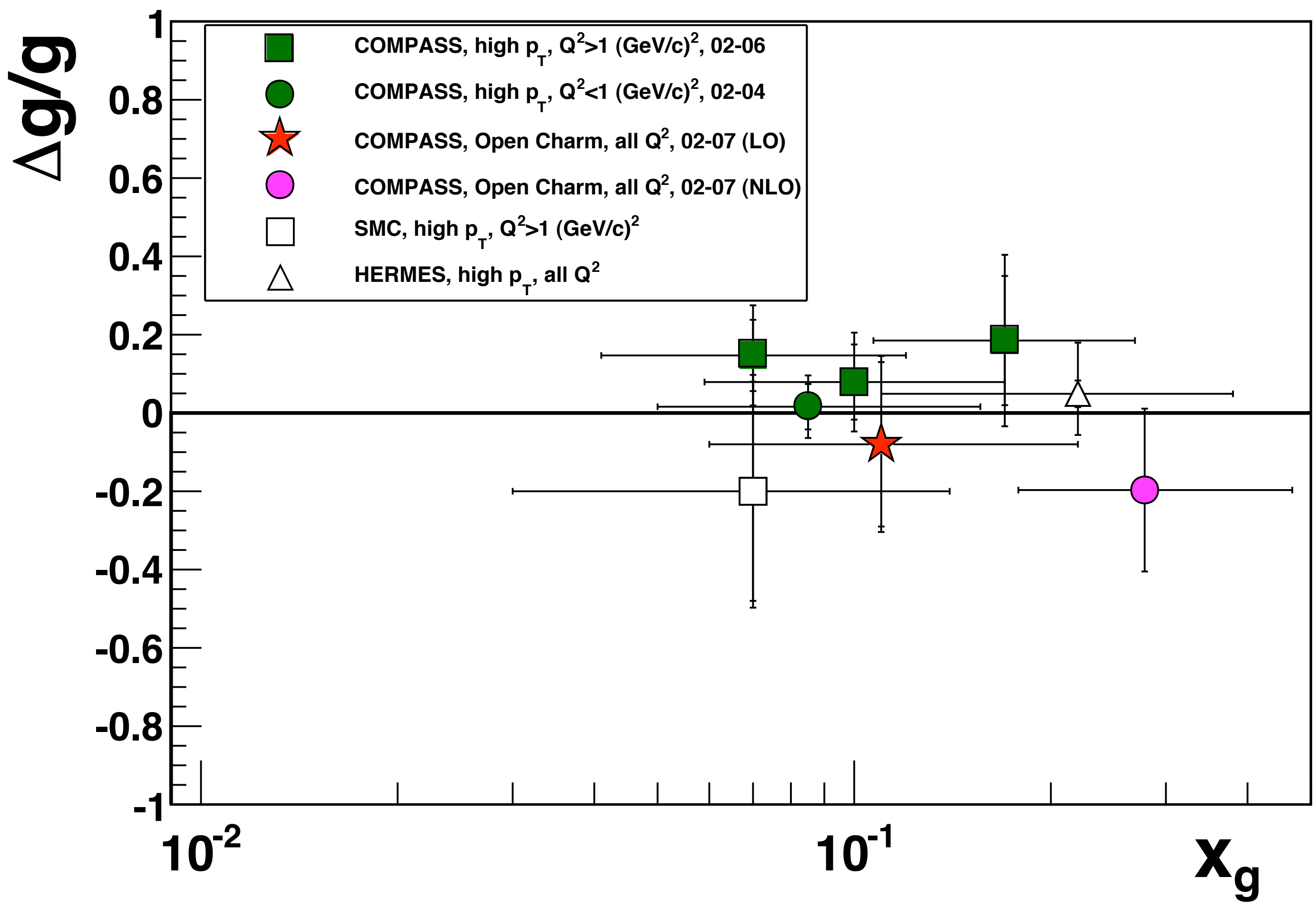
$$\langle x_G \rangle = 0.11^{+0.11}_{-0.05} \qquad \mu^2 \approx 13 \frac{GeV^2}{c^2}$$

Notice: signal and background asymmetries are extracted in the same time

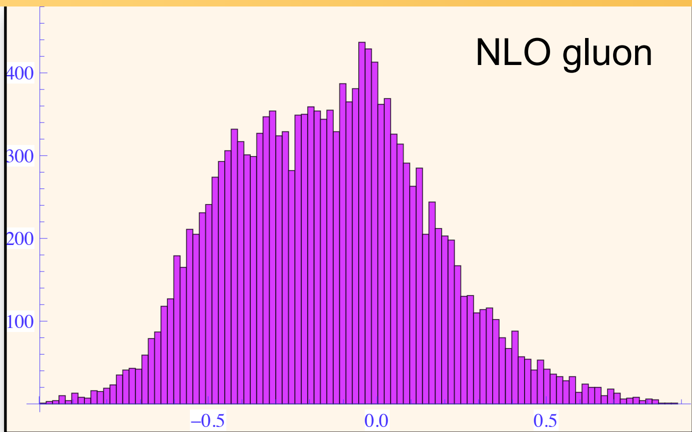
$$A^{measured} = fP_T P_b \left(\frac{S}{S+B} A^{signal} + \frac{B}{S+B} A^B\right)$$

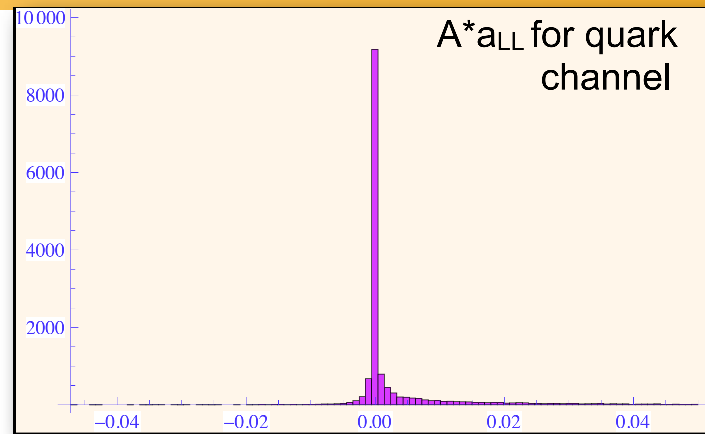


Gluon polarization@NLO

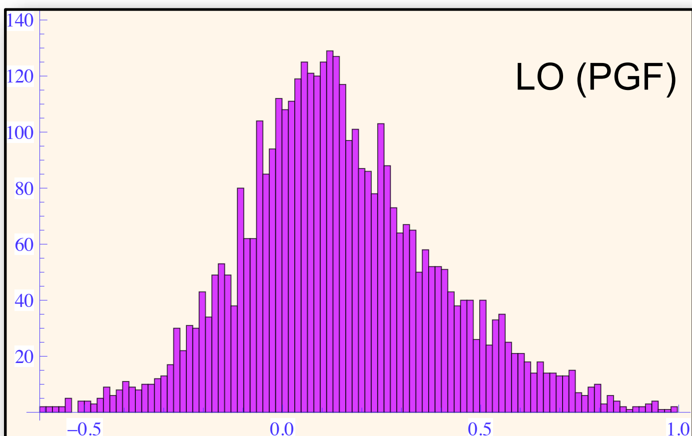


MC calculations: a_{LL}





effect of light quarks small
- dependence of unpolarized PDFs in a_{LL} calculations small



Averaged value of a_{LL} is shifted comparing LO and NLO

$<x_G>$ is also changed!

The effective average x_G depends on the a_{LL}

The x_G region where a_{LL} is close to 0 does not contribute to average x_G

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Channels	$\langle \Delta g/g \rangle$		
	Released analysis	A_S and a_{LL}^{LO}/D	A_S and a_{LL}^{NLO}/D
$D^* \to D^0_{K\pi}\pi_s$	-0.19 ± 0.31	-0.25 ± 0.32	$+0.04 \pm 0.32$
$D^* \to D^0_{K\pi\pi^0}\pi_s$	-0.41 ± 0.58	-0.37 ± 0.64	$+0.12 \pm 0.55$
$D^* \to D^0_{K_{sub}\pi}\pi_s$	$+0.50 \pm 1.00$	$+0.57 \pm 1.06$	-0.34 ± 1.21
$D^* \to D^0_{K\pi\pi\pi}\pi_s$	$+0.63 \pm 0.83$	$+0.58 \pm 0.85$	-0.96 ± 0.56
Untagged $D^0_{K\pi}$	$+0.02 \pm 0.42$	-0.04 ± 0.45	-0.34 ± 0.41
Total	-0.08 ± 0.21	-0.11 ± 0.23	-0.20 ± 0.21