NLO QCD result for the gluon polarization from open-charm D^0 meson production @COMPASS

on behalf of the COMPASS Collaboration

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SPIN2010
Forschungszentrum Jülich (Germany)
September 27 - October 2, 2010

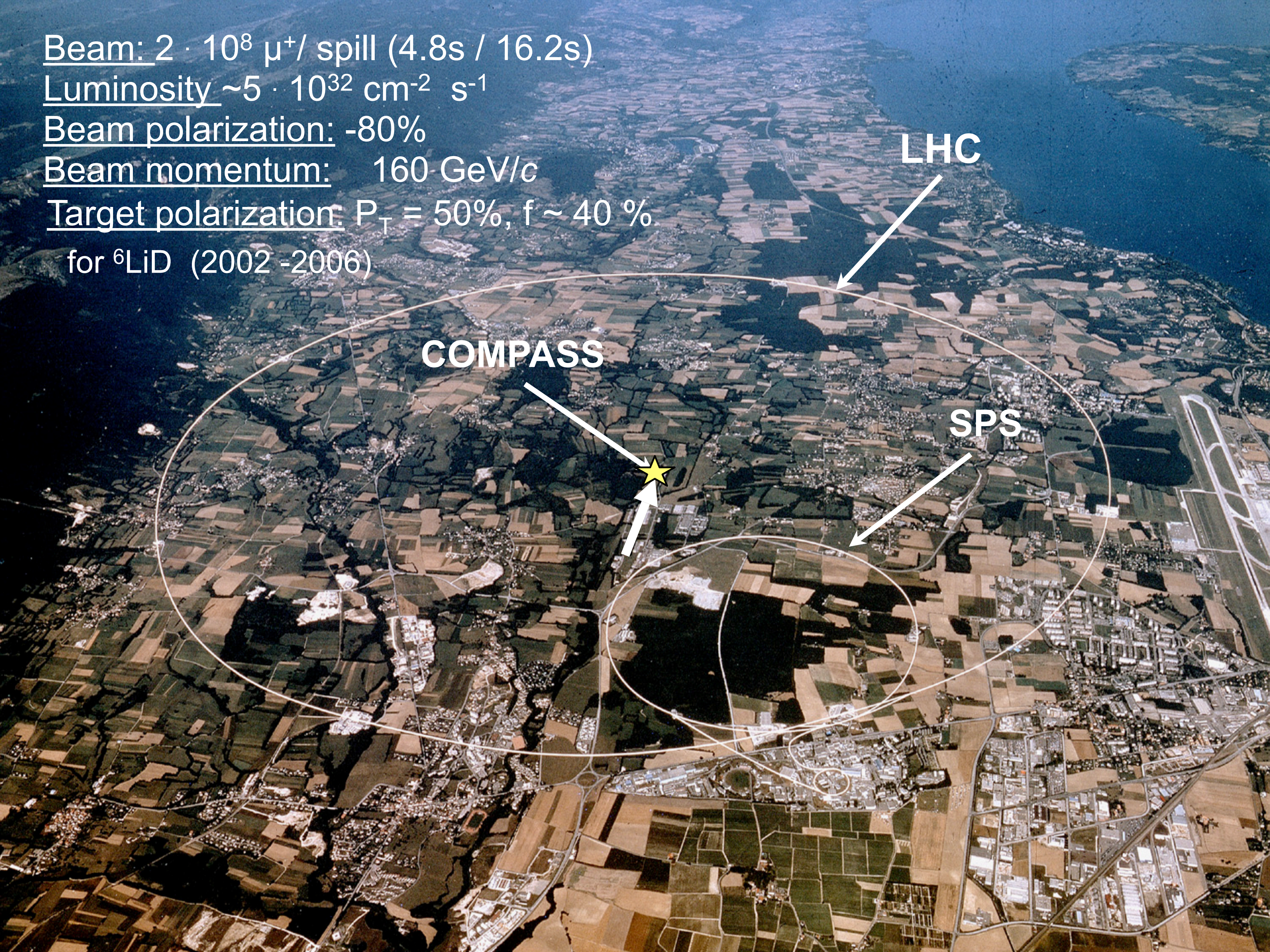
COMPASS Collaboration at CERN

Common Muon and Proton Apparatus for Structure and Spectroscopy

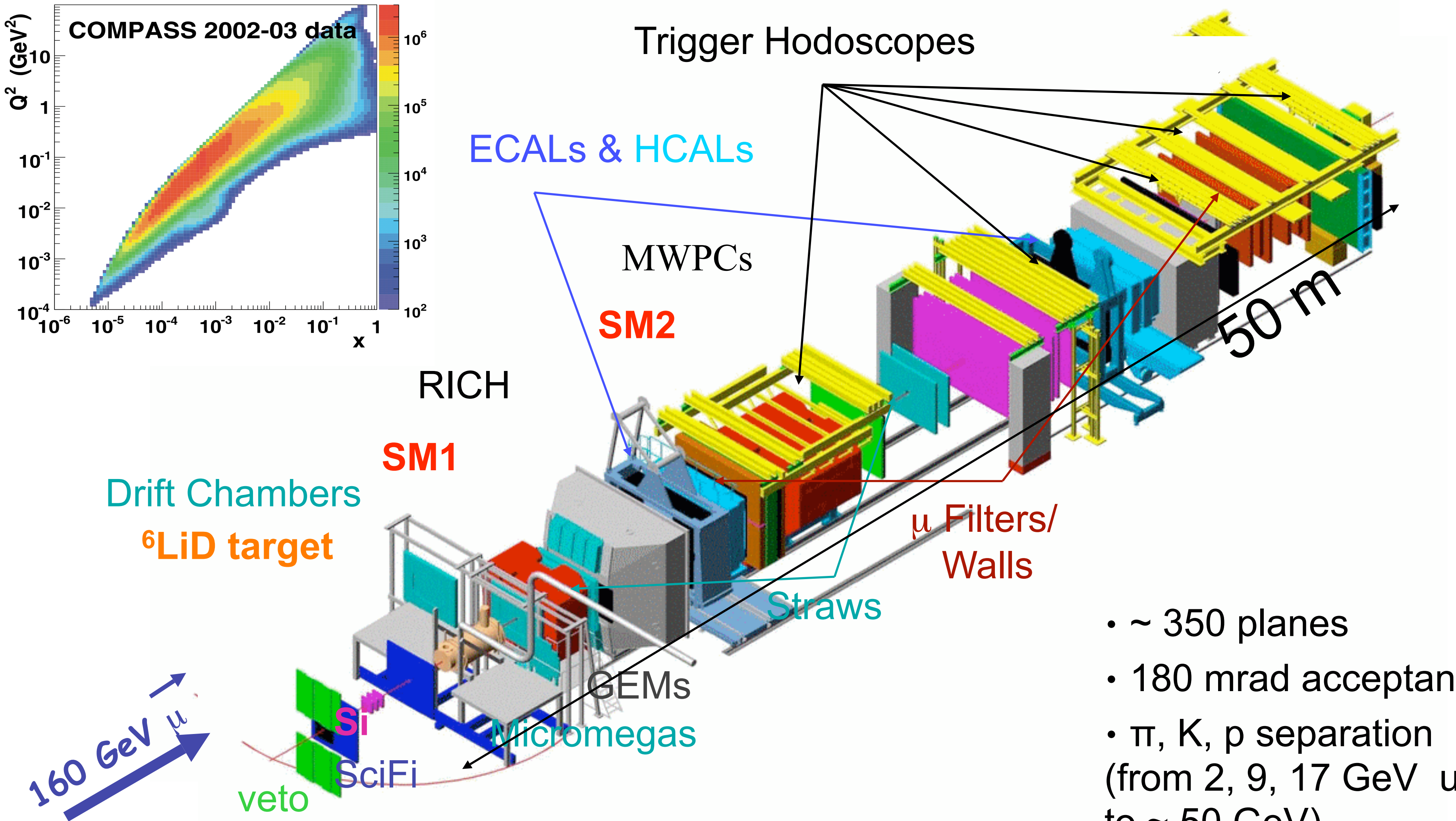
Czech Rep., France, Germany, India, Israel, Italy, Japan, Poland, Portugal, Russia and CERN

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

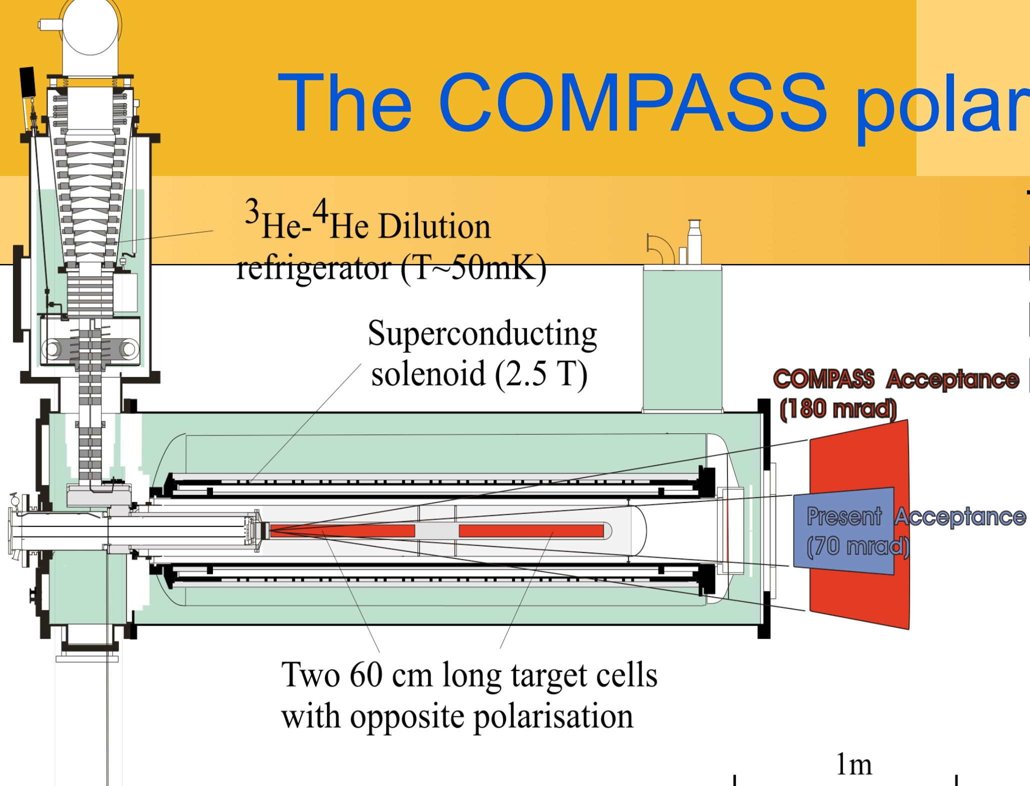

Beam: 2 · 10^8 μ^+/ spill (4.8s / 16.2s)
Luminosity ~5 · 10^{32} cm^{-2} s^{-1}
Beam polarization: -80%
Beam momentum: 160 GeV/c
Target polarization: P_T = 50%, f ~ 40 %
for ^{6}LiD (2002 -2006)
LHC
COMPASS
SPS

The COMPASS spectrometer



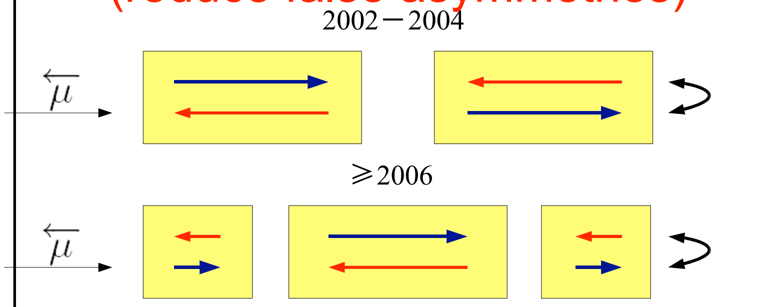
- ~ 350 planes
- 180 mrad acceptance
- π, K, p separation (from 2, 9, 17 GeV up to ~ 50 GeV)

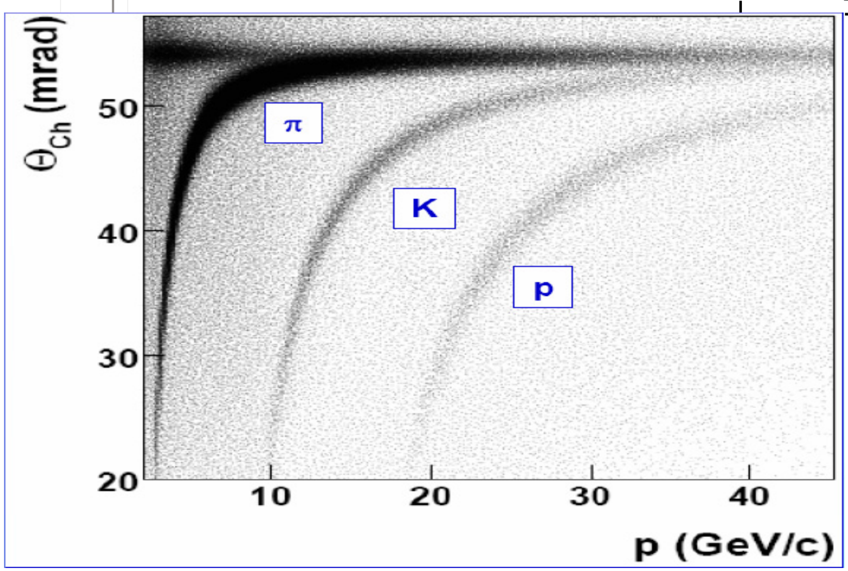
The COMPASS polarized target and PID



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

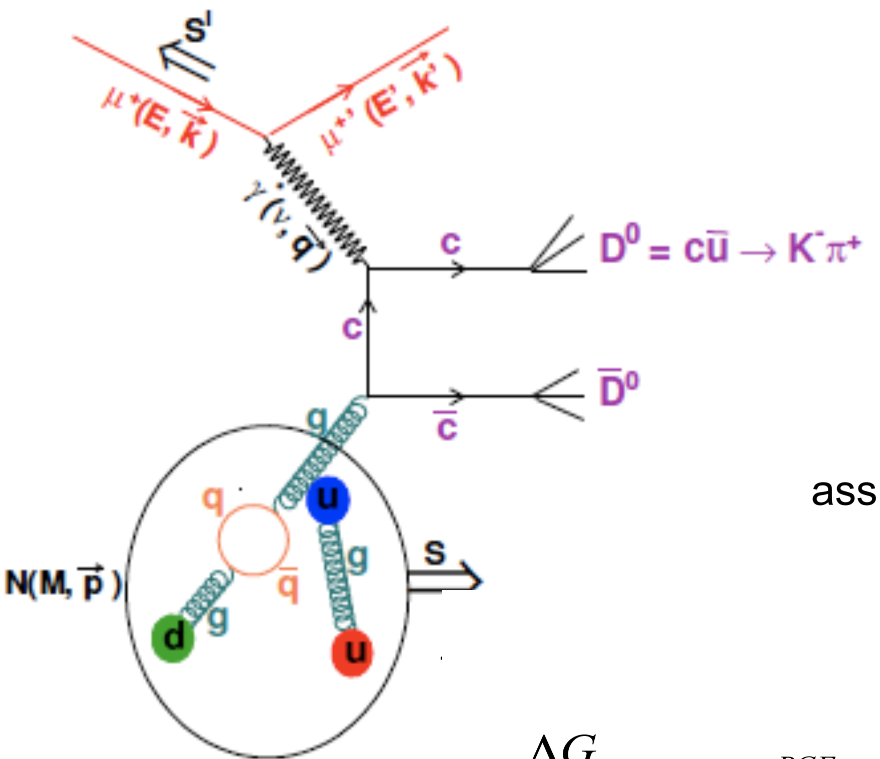
APV electronics in periphery

Contents

- Introduction: open-charm and gluon polarization
- Gluon polarization measurement @ COMPASS: the method
- Final LO QCD result from COMPASS open-charm data
- NLO QCD corrections and prediction for gluon polarization
- Future plans

D^0 meson production

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



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

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

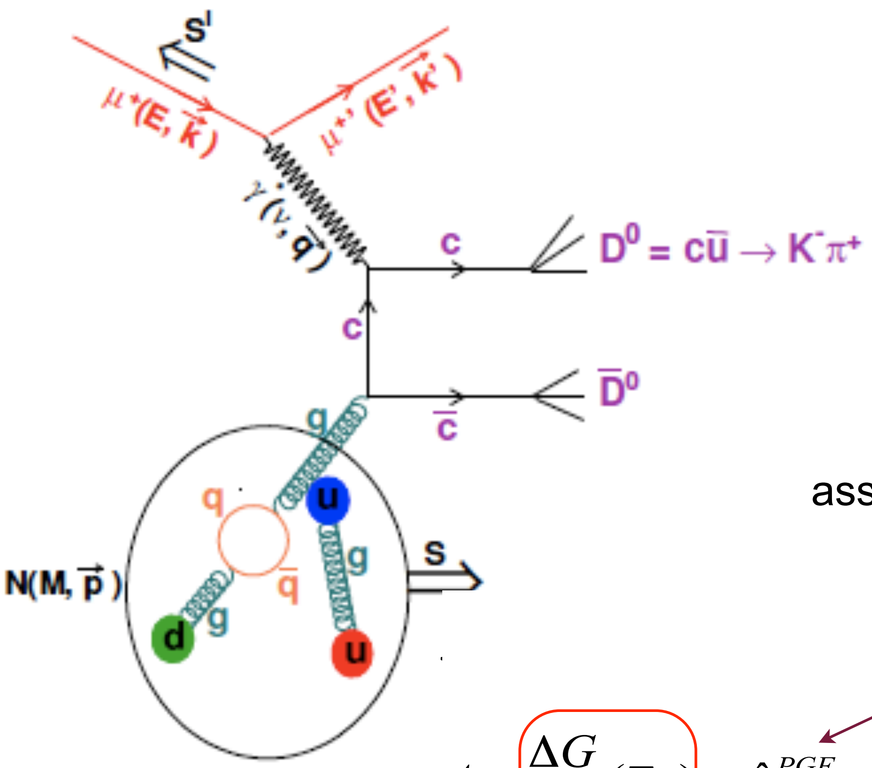
assumption: $$\frac{\Delta G}{G}(x) \approx a(x - \bar{x}) + b$$

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

D^0 meson production

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.



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

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

from MC

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

signal asymmetry from data

notice:

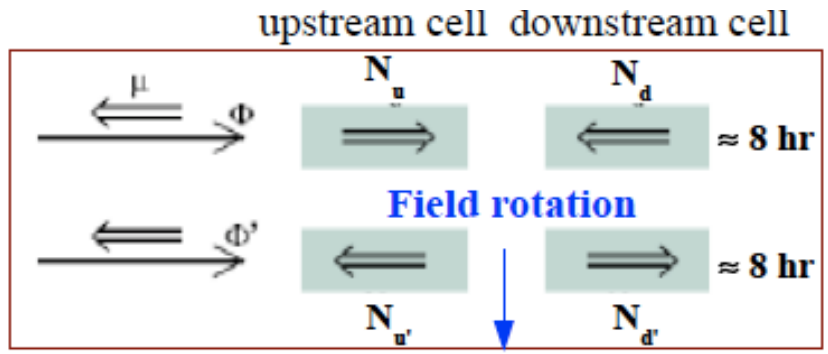
$$A^{measured} = fP_T P_b \left(\frac{S}{S+B} A^{signal} + \frac{B}{S+B} A^B\right)$$

Measuring D^0 asymmetries to extract ΔG/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 $\omega = (f \cdot P_\mu \cdot S/(S+B) \cdot a_{LL})$: → 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:

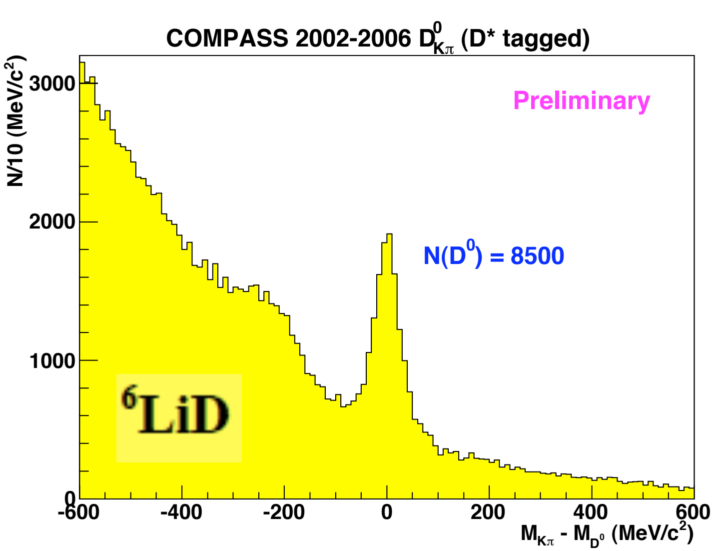
- $D^0 \rightarrow K\pi$ *(BR: 4%)*
- $D^* \rightarrow D^0\pi_s$ *(30% D^0 tagged with a D^*)*
  - $D^0 \rightarrow K\pi$
  - $D^0 \rightarrow K\pi\pi^0$ *(BR: 13%)* → **not directly reconstructed** π^0
  - $D^0 \rightarrow K\pi\pi\pi$ *(BR: 7.5%)*
  - $D^0 \rightarrow sub(K)\pi$ → **no RICH ID for Kaons**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

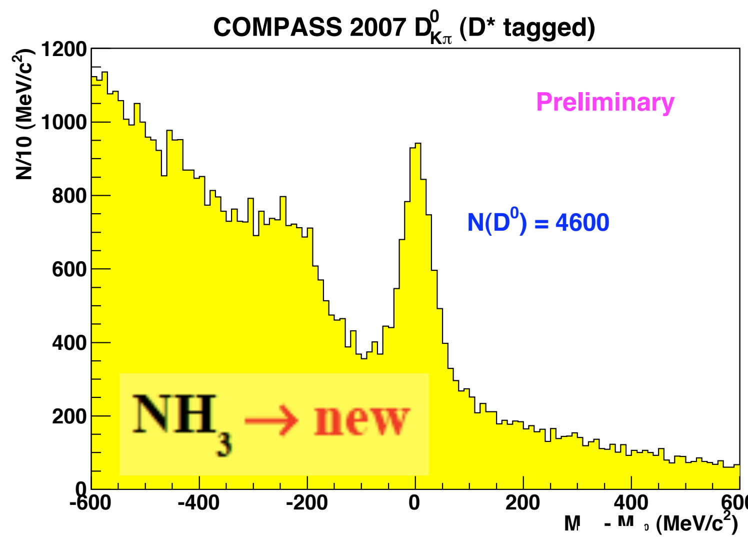
Selection to reduce the combinatorial background

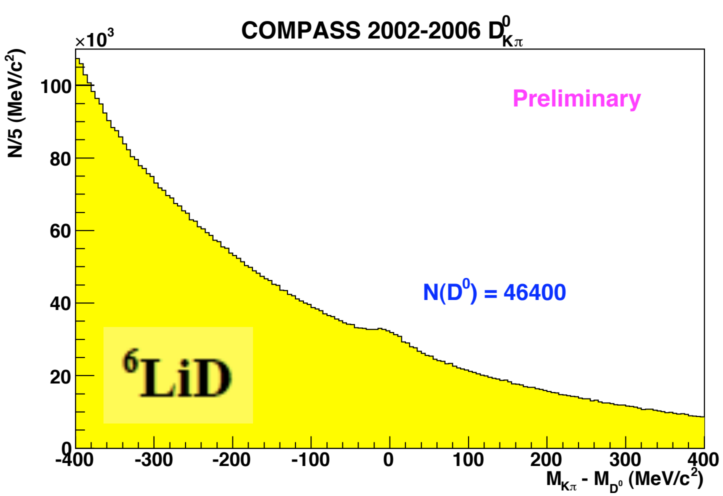
- **Kinematical cuts:** z_D and D^0 decay angle *(to reject colinear events with γ^* coming from the nucleon fragmentation)*, K and π momentum
- **RICH identification:** K and π ID + electrons rejected from the π_s sample
- Mass cut for the D^* tagged channels *($M[K\pi\pi_s] - M[K\pi] - M[\pi]$)*
-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

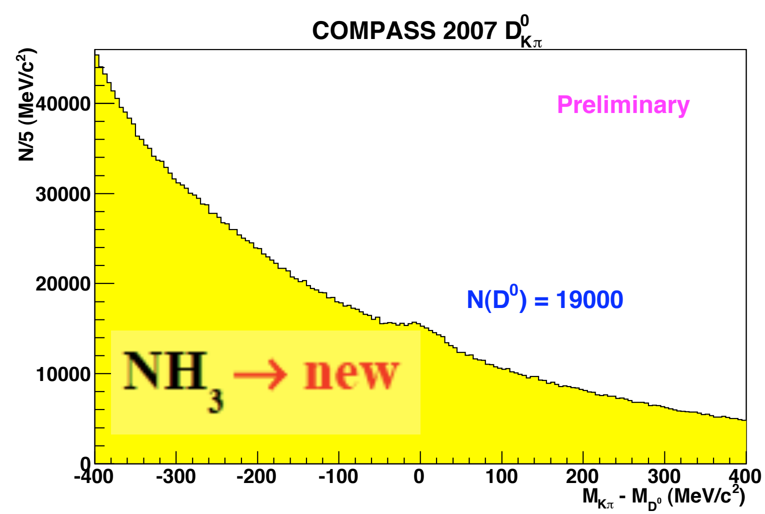
D^0 meson reconstruction

Invariant mass spectrum D^0 mesons reconstruction



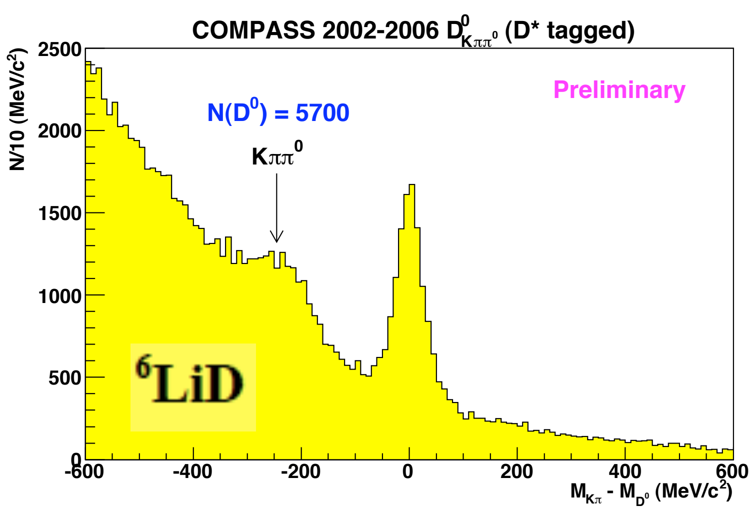


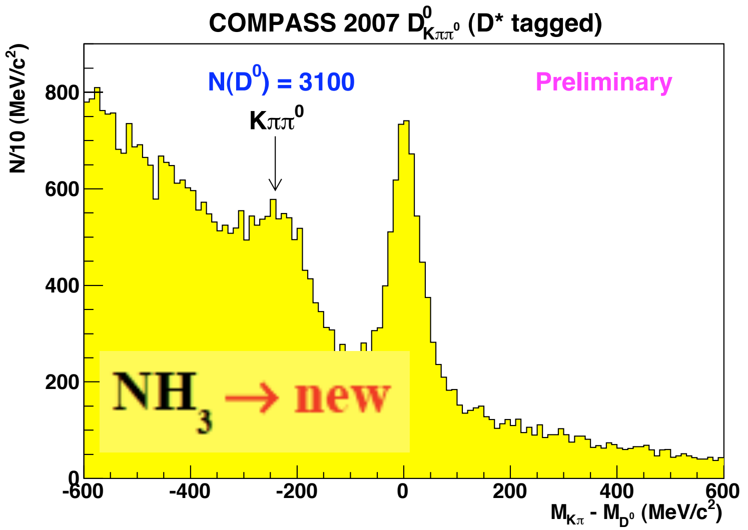


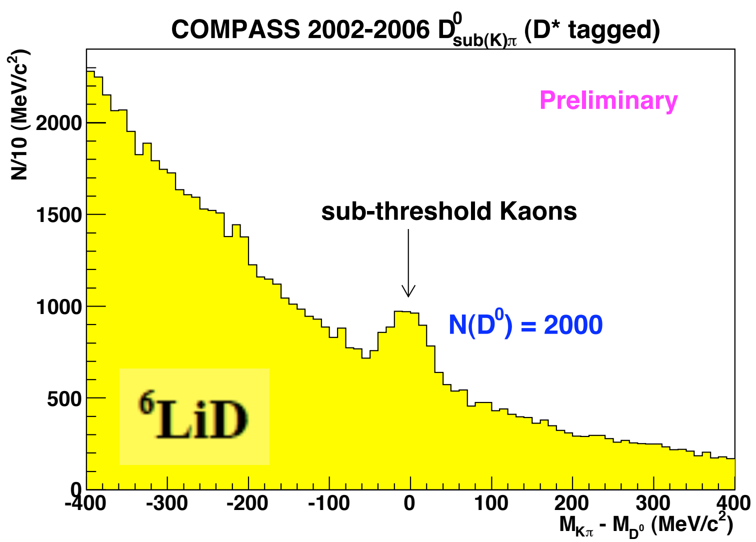


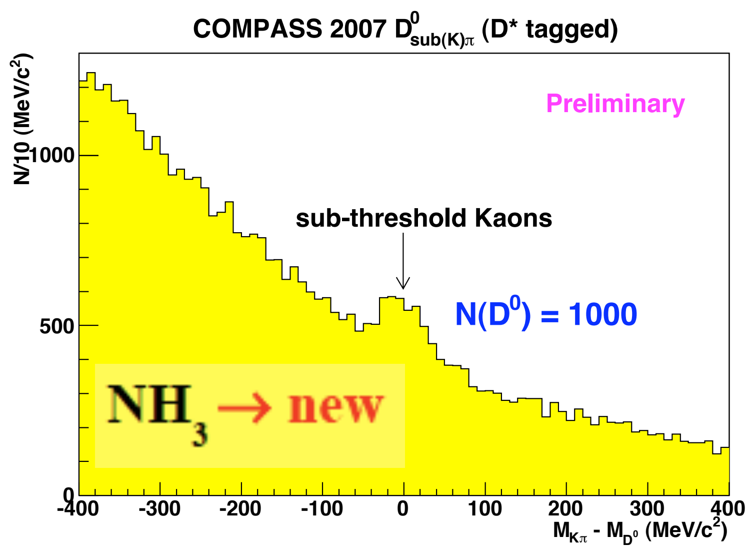
D^0 meson reconstruction

Invariant mass spectrum D^0 mesons reconstruction









D^0 meson reconstruction

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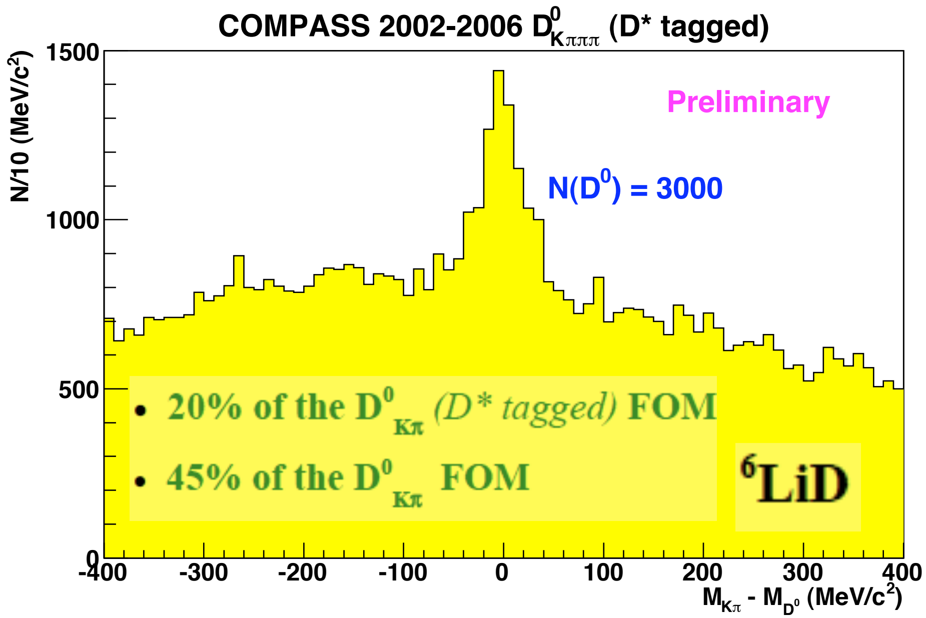
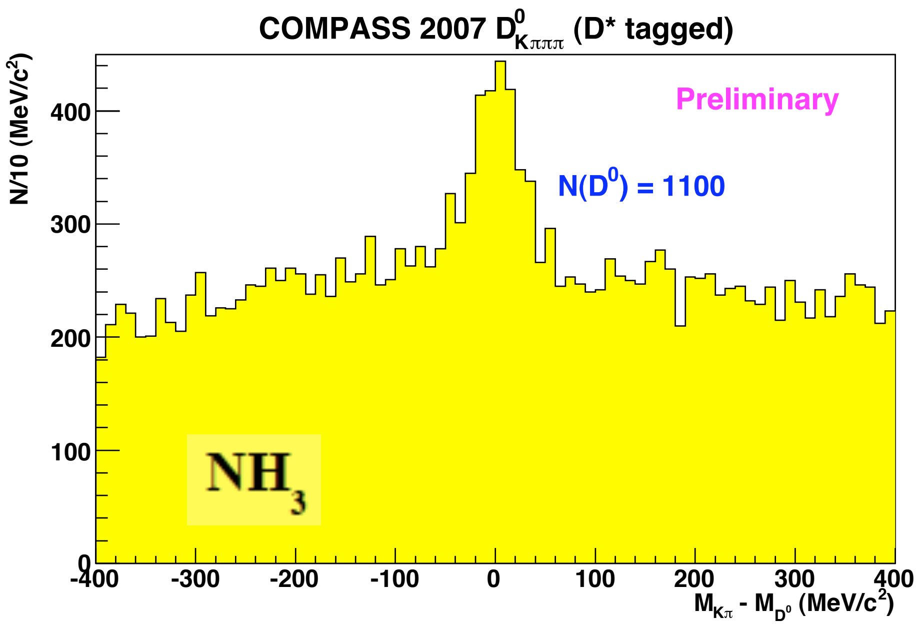




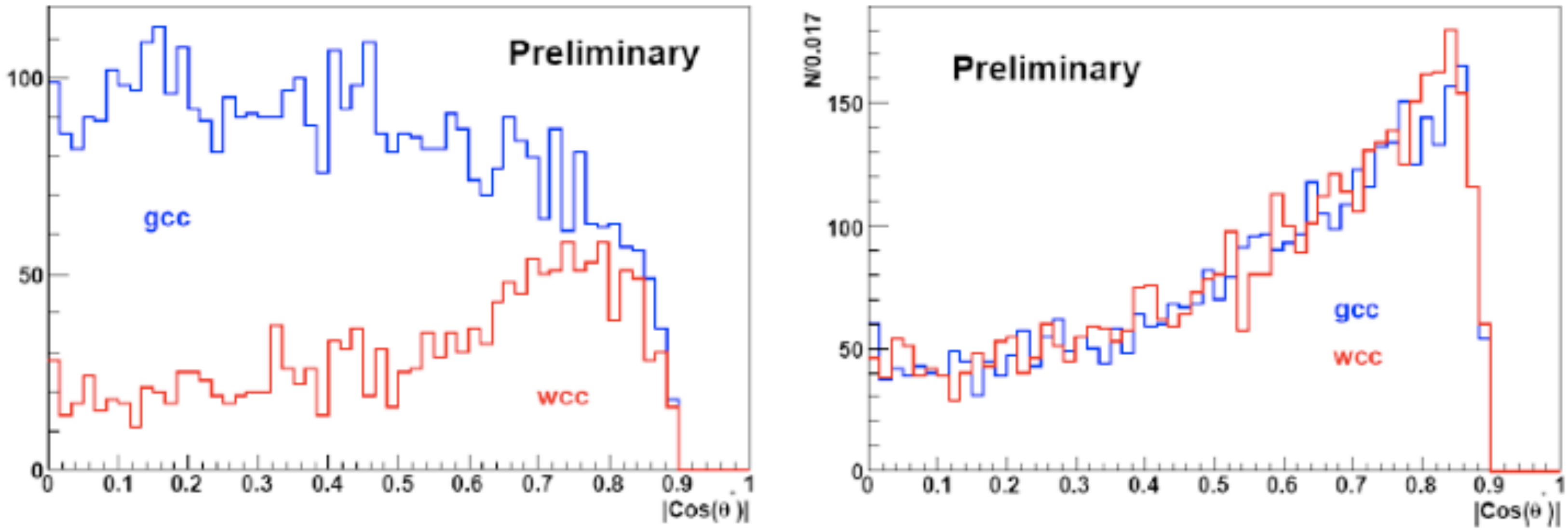
Signal to background estimation

Neural Network qualification of events

- **Signal model** → **gcc** = $K^+\pi^-\pi_s^- + K^-\pi^+\pi_s^+$ *(D^0 spectrum: signal + background)*
- **Background model** → **wcc** = $K^+\pi^+\pi_s^- + K^-\pi^-\pi_s^+$ *(no D^0 is allowed)*

- Assuming background model to be good enough *Neural Network (NN)* 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



example of "good" training variable mass window where signal is expected (left) and for sidebands (right)

Signal to background estimation

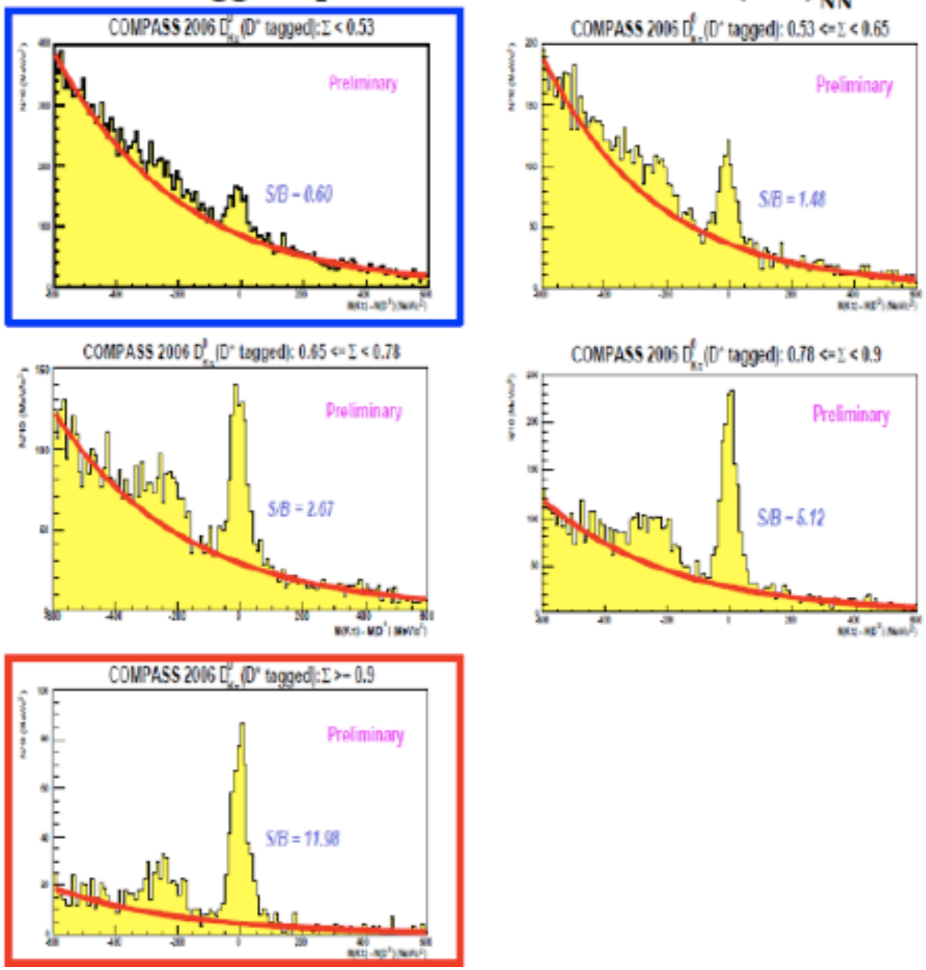
s/(s+b): obtaining final probabilities for D^0 candidate

- **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 $\Sigma = s/(s+b)_{NN}$



Signal to background estimation

s/(s+b): comparison of wcc and gcc background

- **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)*

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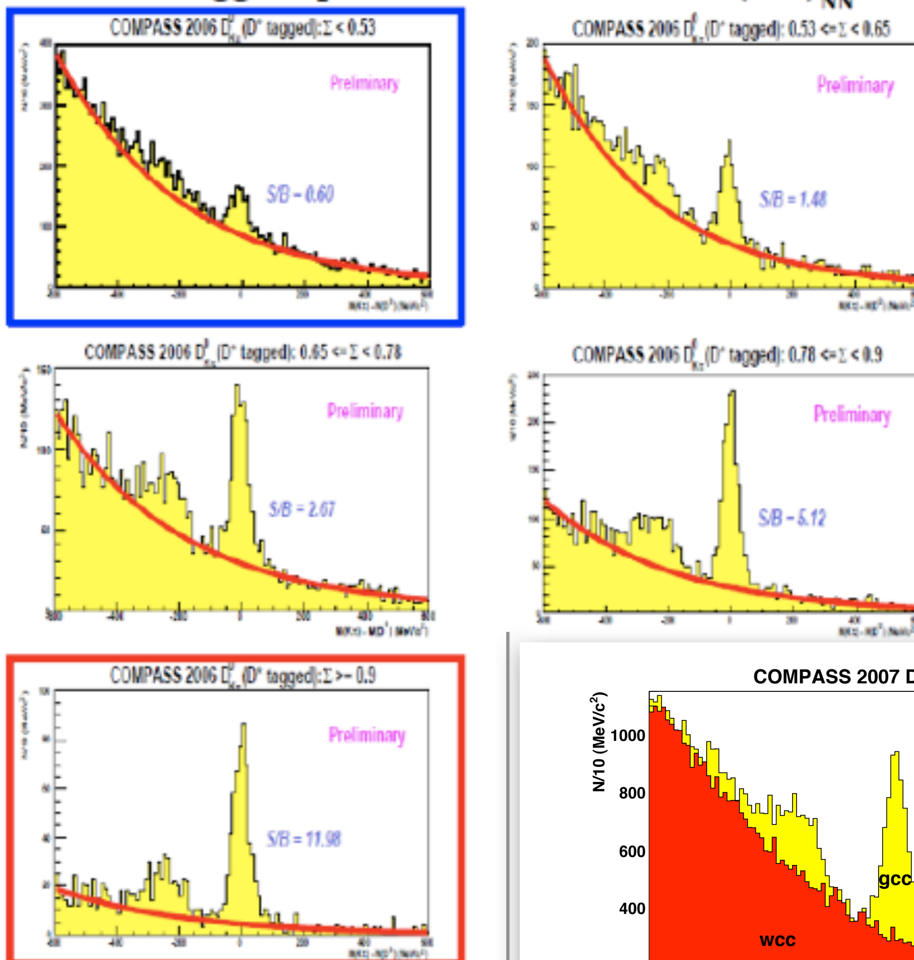
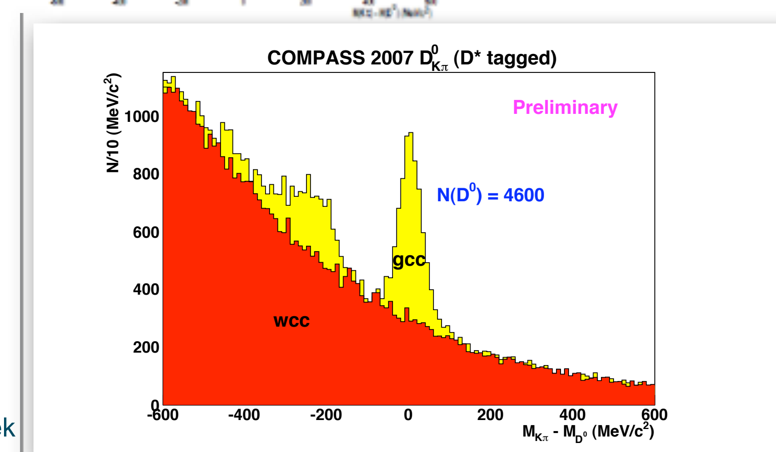
D^0 tagged spectrum in bins of $\Sigma = s/(s+b)_{NN}$

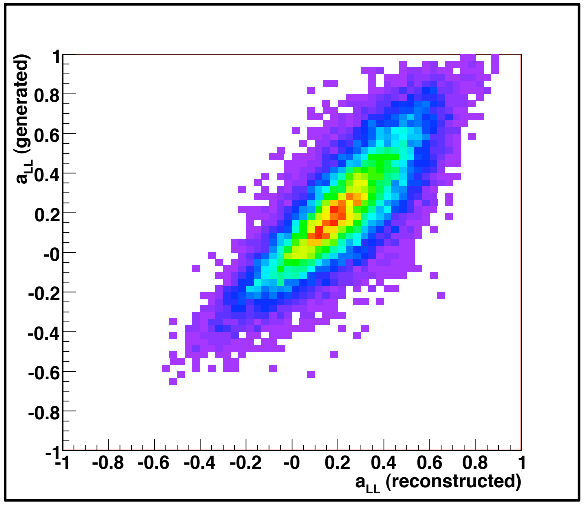


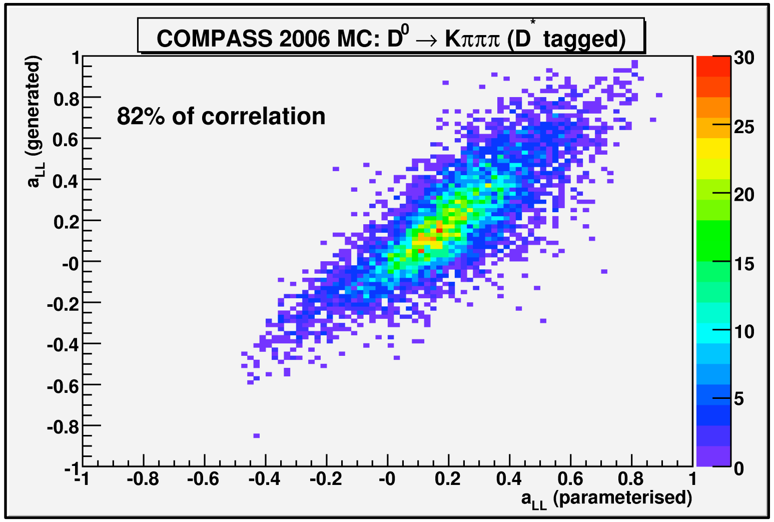


Analyzing power a_{LL}

Partonic muon-gluon asymmetry and NN parameterization

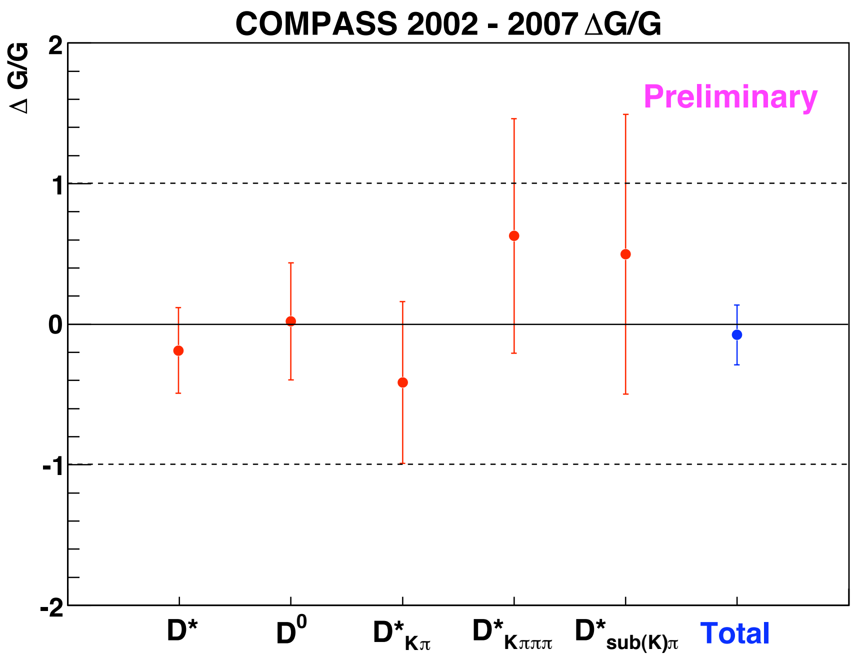
- a_{LL} is dependent on the knowledge of the partonic kinematics and can not be experimentally obtained - only one charmed meson is reconstructed
- a_{LL} is calculated with the help of MC (in LO QCD) and parameterized by measured quantities using NN approach
- As a training vector kinematical variables: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





Gluon polarization

Final gluon polarization from open-charm in LO QCD

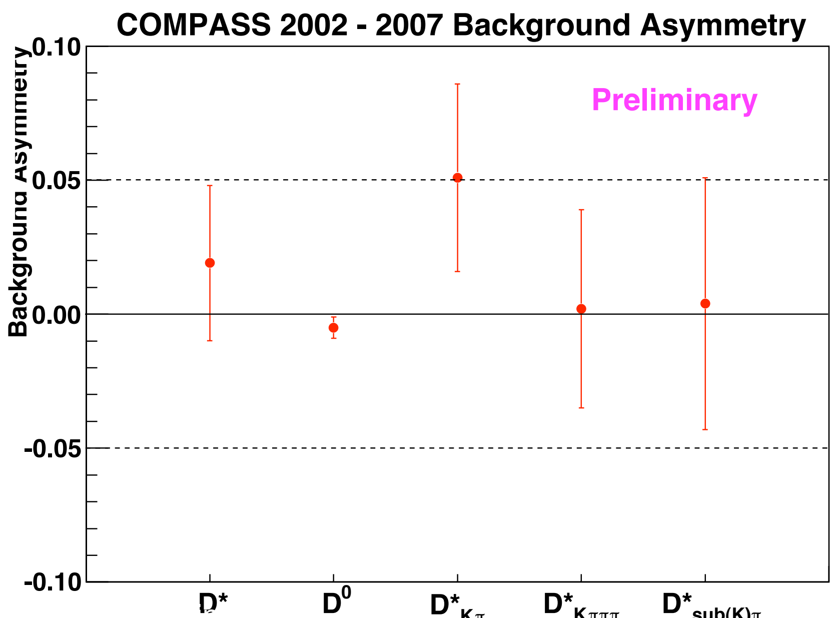


$$\frac{\Delta G}{G} = -0.08 \pm 0.21 \pm (0.11)$$

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

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

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



Model independent asymmetries

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

COMPASS Phys. Lett. B 676 (2009) 31

- Model independent asymmetries were extracted from data only

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

- $\dfrac{\Delta g}{g}$ can be extracted using a_{LL}^{PGF} calculated at LO :

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

- Similar analysis, but with weight $w = f\, P_B \dfrac{S}{S+B} a_{LL}$

  instead of $w = f\, P_B \dfrac{S}{S+B} D$

Model independent asymmetries

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

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D^0 asymmetries in bins of E_{D^0} and p_{T,D^0} *COMPASS Phys. Lett. B 676 (2009) 31*

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Asymmetries in bins allow to perform independent analysis

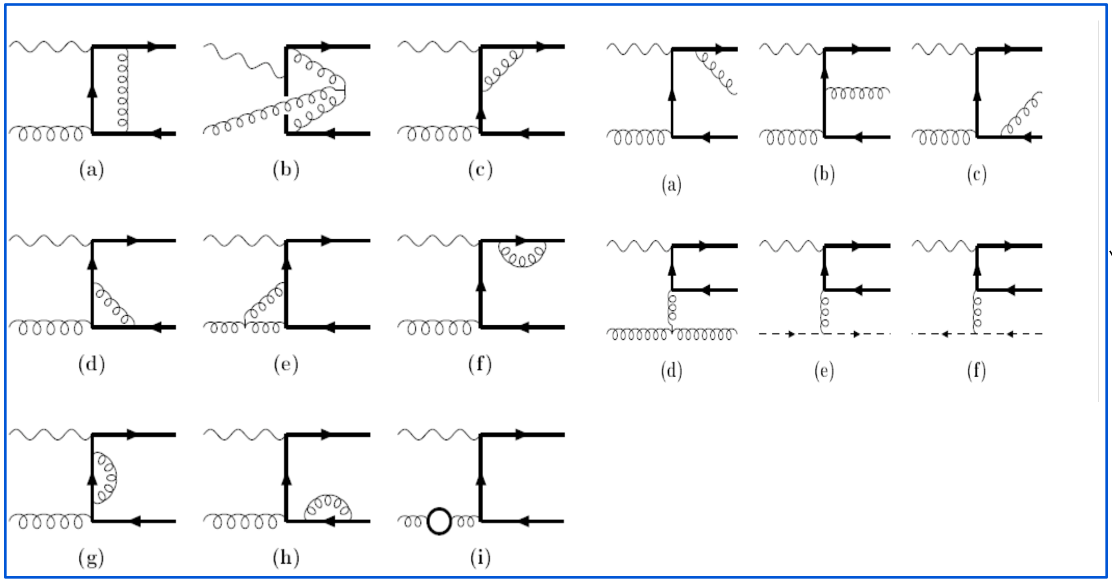
Presented NLO QCD result is based on published asymmetries in bins

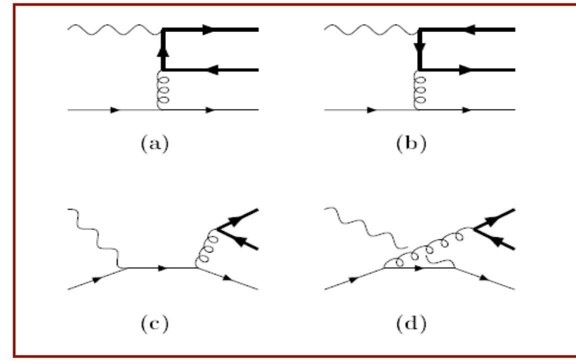
- Similar analysis, but with weight $w = f\, P_B \frac{S}{S+B} a_{LL}$

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

NLO QCD corrections

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





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

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

Analyzing powers in NLO

Procedure for NLO calculations:

1. *Aroma* MC generator with PS-on describes COMPASS data very well
2. PS simulate phase space for NLO correction - a_{LL} can be calculated on a event-by-event basis from theoretical formulas (like in LO case)
3. Warning: MC with PS is not fully equivalent to NLO. Micky-Mouse MC generated with flat kinematical distributions and re-weighted by correct NLO QCD cross section was also used to “crosscheck” the result
4. In this case BELLE FF was used for D^0 (independent fragmentation)
5. A_1 taken directly from data

Analyzing powers in NLO

Gluon polarization in NLO QCD - MC approach for simulating Phase Space

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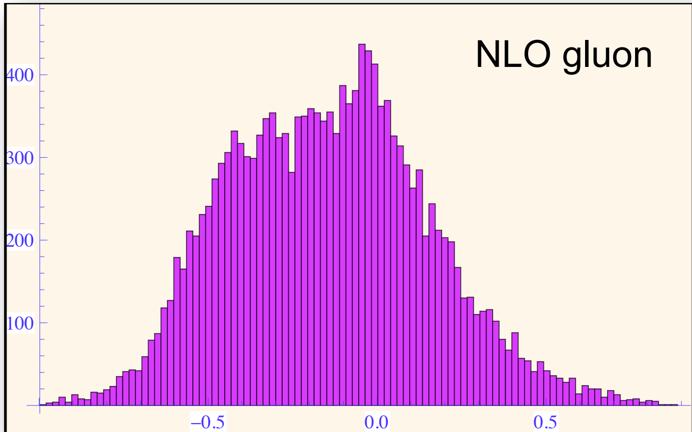
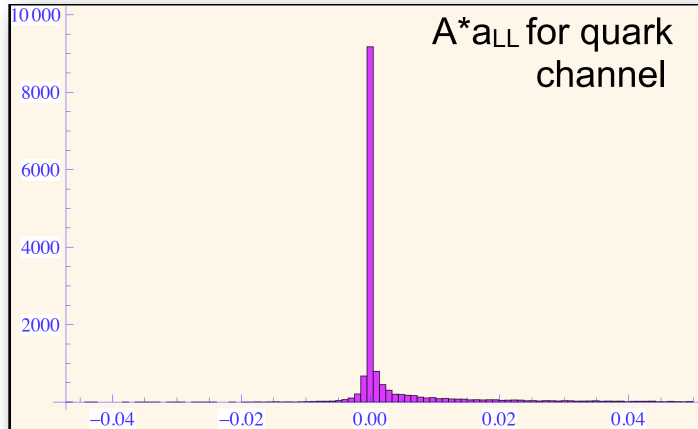
5. A_1 taken directly from data

Light quark contribution are very small - no strong dependence on unpolarized PDFs

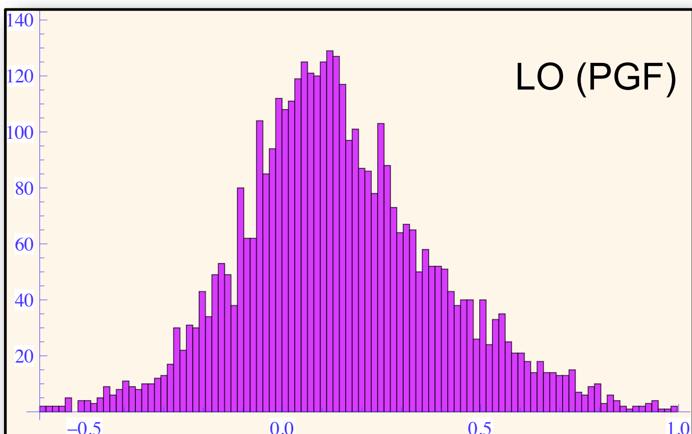
Analyzing powers in LO & NLO

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!

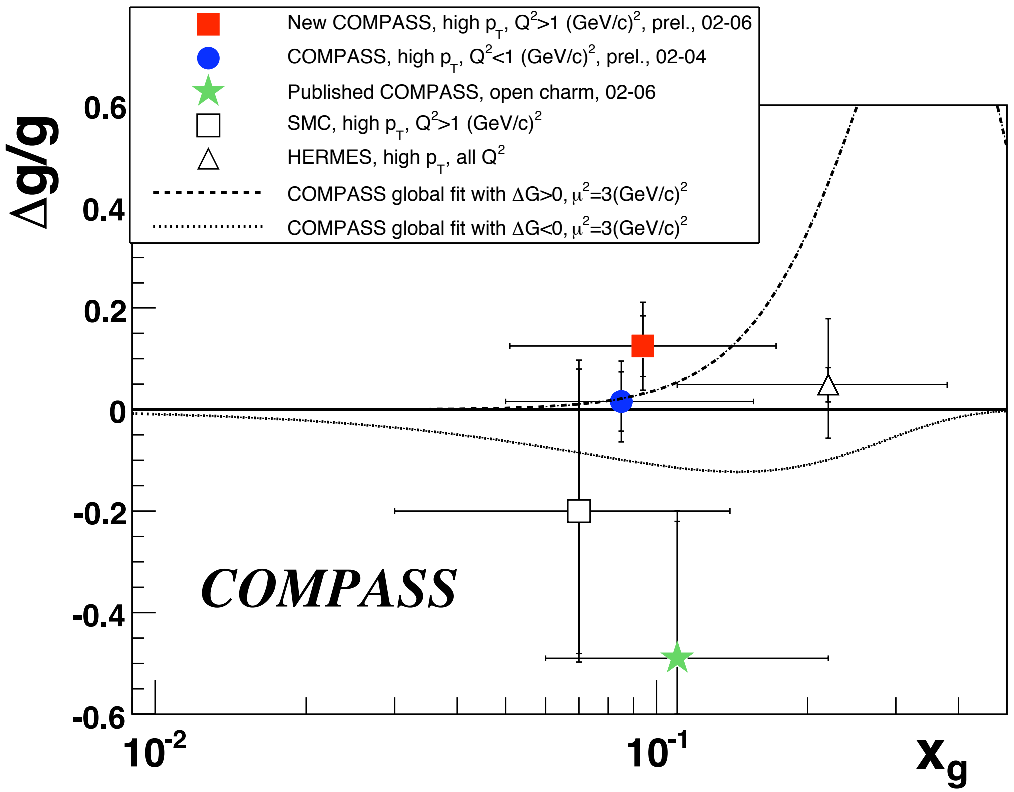
The effective average x_G depends on the a_{LL}

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

Gluon polarization @ LO and NLO

Gluon polarization from open-charm in LO QCD - published result *COMPASS Phys. Lett. B 676 (2009) 31*

LO published: $\Delta G/G = -0.49 \pm 0.27$



Gluon polarization @ LO and NLO

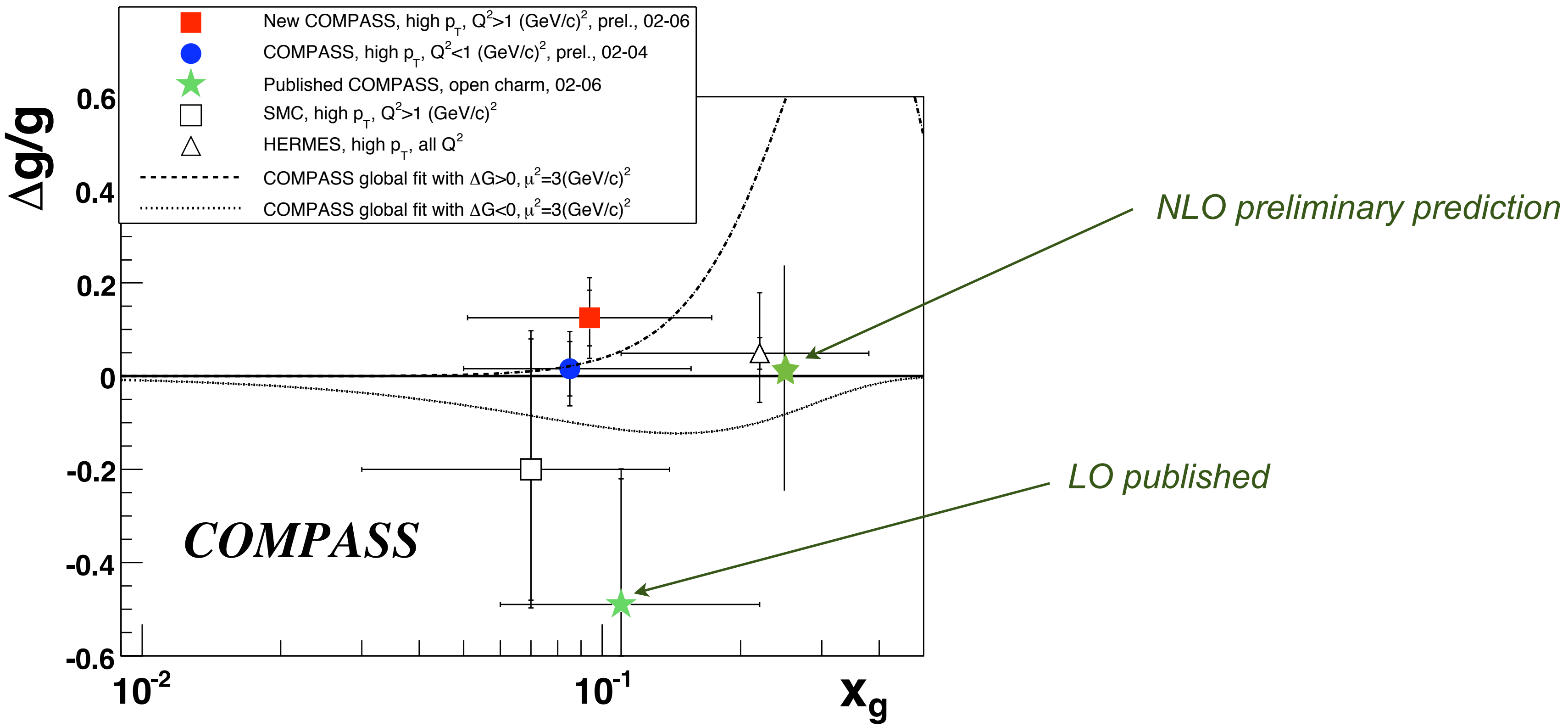
Gluon polarization from open-charm in LO QCD - published result *COMPASS Phys. Lett. B 676 (2009) 31*

LO published: ΔG/G=-0.49±0.27

NLO (based on published asymmetries): ΔG/G=+0.008±0.25

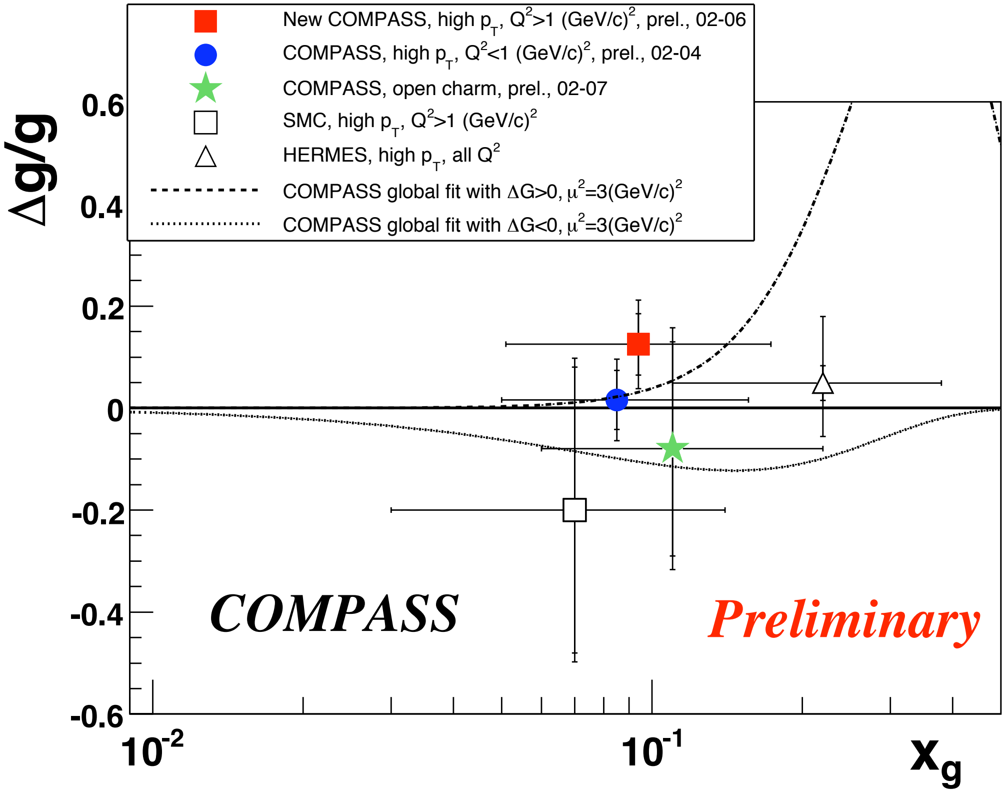
test: NLO M-M MC: ΔG/G= +0.005 ±0.22

Significant effect on published data; New LO result smaller and the effect of NLO corrections will be smaller



Gluon polarization @ LO and NLO

Final gluon polarization from open-charm in LO QCD



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

Gluon polarization @ LO and NLO

Final gluon polarization from open-charm in LO QCD vs NLO result from published asymmetries set

LO published: ΔG/G=-0.49±0.27

NLO (based on published asymmetries): ΔG/G=+0.008±0.25

test: NLO M-M MC: ΔG/G= +0.005 ±0.22

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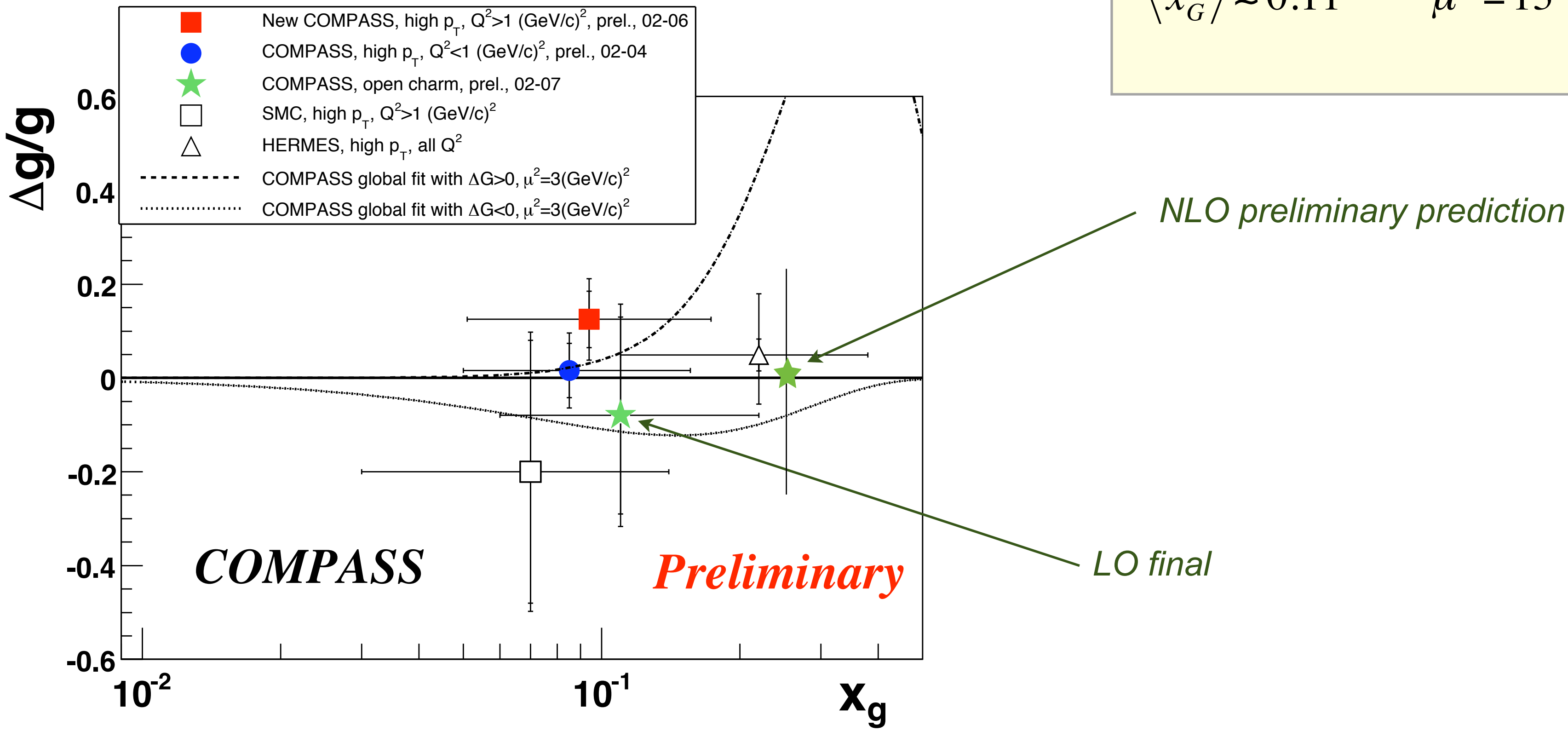


Summary and plans

Summary:

- New result on gluon polarization (in LO QCD) from open-charm analysis @ COMPASS has been presented.
- The preliminary NLO QCD result based on the published set of asymmetries in bins in p_{T,D^0} and E_{D^0} has been obtained.
- LO MC generator with PS on has been used to simulate NLO Phase Space needed for calculating analyzing powers in NLO approximation.

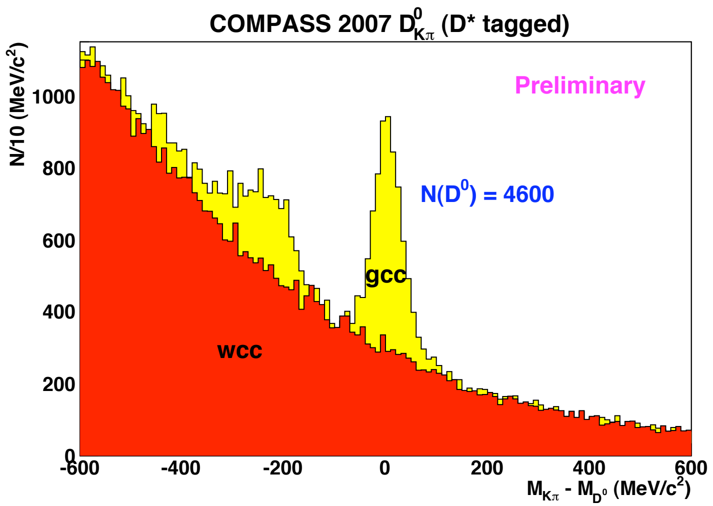
Plans:

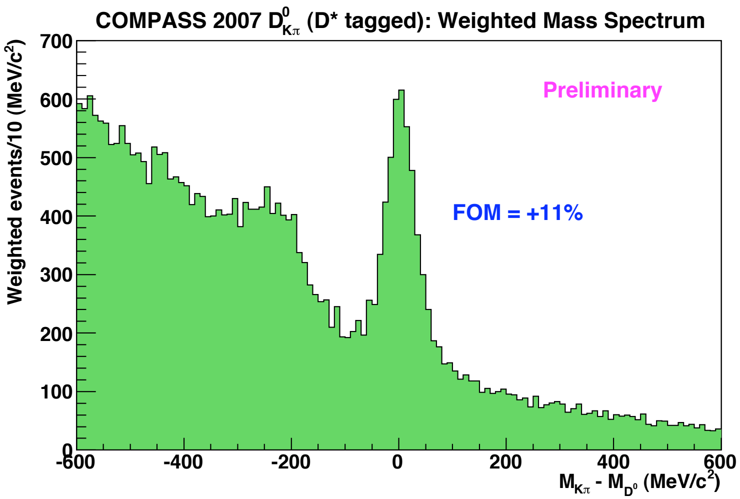
- Unpolarized D^0 cross section, data/MC comparison and D^0 production characteristic (new COMPASS paper).
- New tool - NLO MC for heavy quark photo-production available now for a_{LL} calculations *(PhD, Tobias Töll, based on HERWIG generator, full NLO MC, PS+subtraction to avoid double counting, soft + virtual correctios as well)*
- New set of asymmetries in bins corresponding to the presented new LO result.
- Final NLO result based on these asymmetries with systematics error.

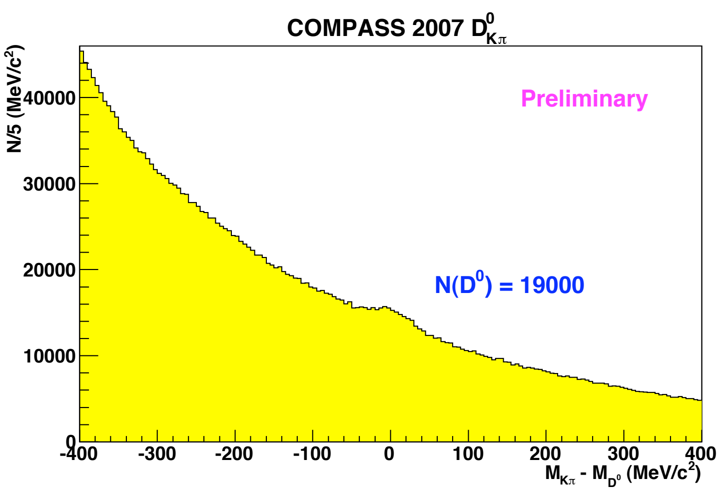
Spares

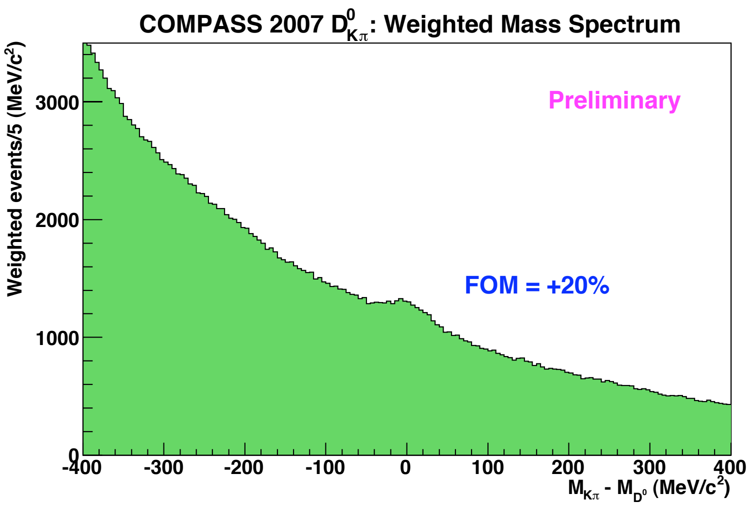
Signal to background: FOM

s/(s+b): FOM improvement for main channels



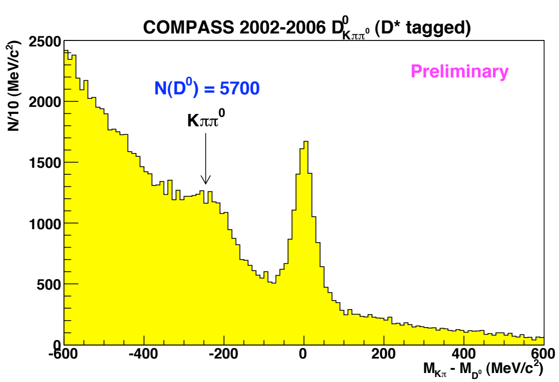


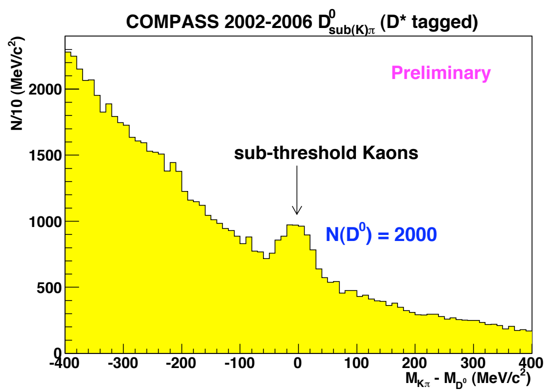


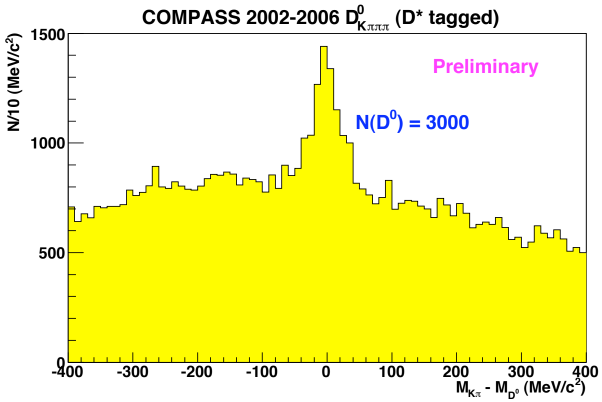


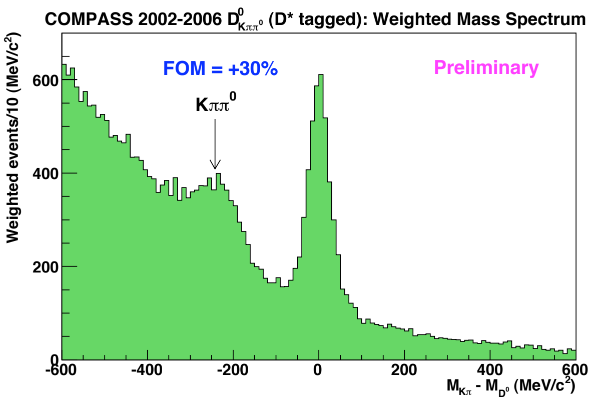
Signal to background: FOM

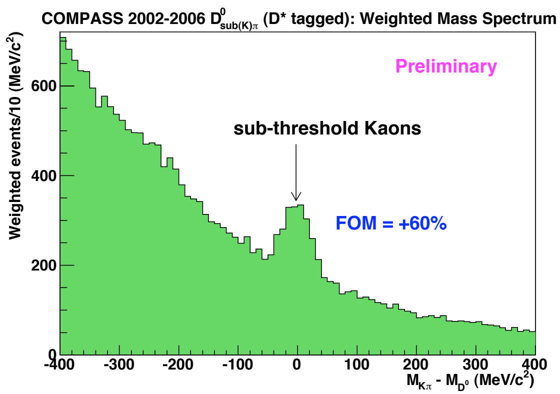
s/(s+b): FOM improvement for low purity channels

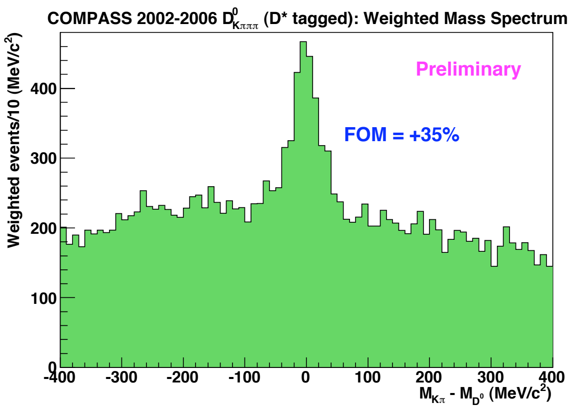




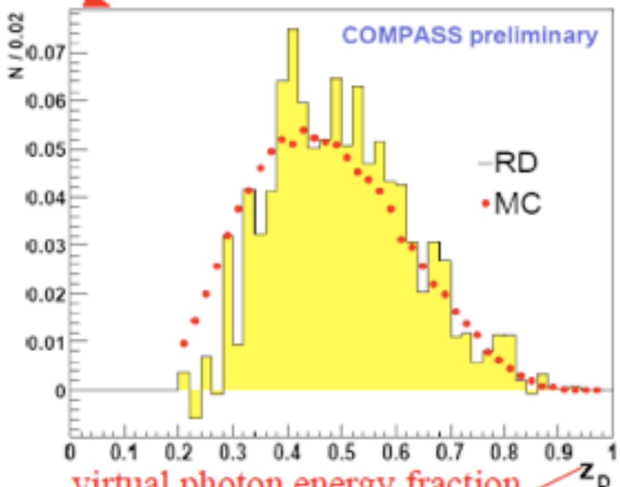


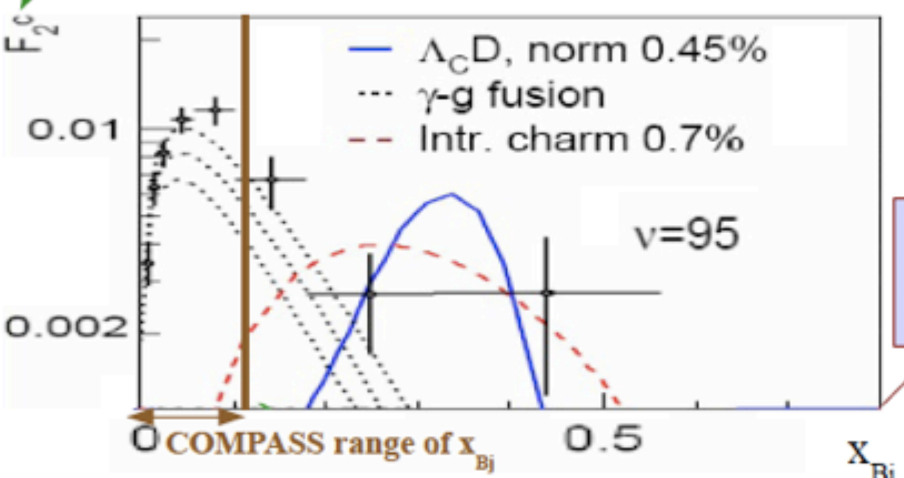






- $c\bar{c}$ **production is dominated by the PGF process, and** **free from physical background** *(ideal for probing gluon polarisation)*
  - In our center of mass energy, the contribution from intrinsic charm *(c quarks not coming from hard gluons)* in the nucleon is negligible
  - Perturbative scale 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)*

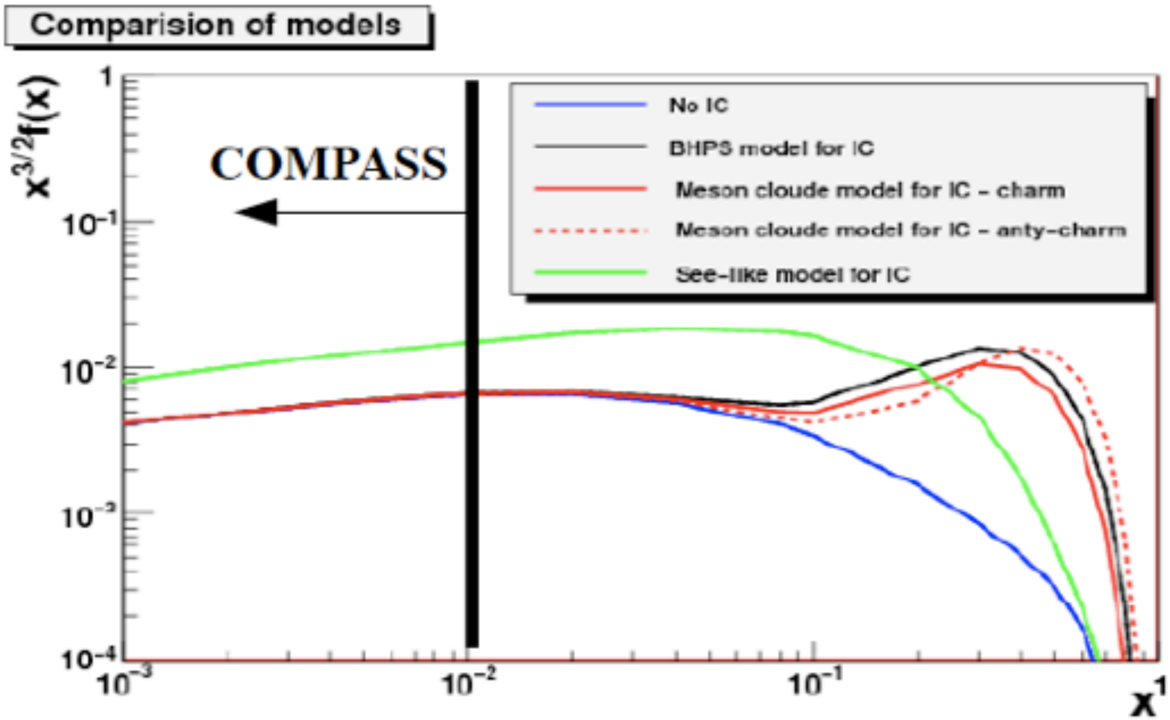




Ref. Hep-ph/0508126 and hep-ph/9508403
Phys. Lett. B93 (1980) 451
Data from EMC:Nucl.Phys.B213, 31(1983)

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)***



x_G

$$N = \alpha\left(1 + fPD\frac{s}{s+b}\left(\hat{a}_{LL}\frac{\Delta G}{G} + \hat{a}_{LL}^{q}A_1^{d}\right)\right)$$

$$N' = \alpha\left(1 - fPD\frac{s}{s+b}\left(\hat{a}_{LL}\frac{\Delta G}{G} + \hat{a}_{LL}^{q}A_1^{d}\right)\right)$$

$$A = \frac{N - N'}{N + N'} = fPD\frac{s}{s+b}\left(\hat{a}_{LL}\frac{\Delta G}{G} + \hat{a}_{LL}^{q}A_1^{d}\right)$$

$$v \equiv fPD\frac{s}{s+b}$$

$$< v > - < v' >= 2\alpha fPDv\frac{s}{s+b}\left(\hat{a}_{LL}\frac{\Delta G}{G} + \hat{a}_{LL}^{q}A_1^{d}\right) = 2\alpha v^2\left(\hat{a}_{LL}\frac{\Delta G}{G} + \hat{a}_{LL}^{q}A_1^{d}\right)$$

$$A \equiv \frac{< v > - < v' >}{< v^2 > + < v^2 >} = \frac{< v^2\left(\hat{a}_{LL}\frac{\Delta G}{G} + \hat{a}_{LL}^{q}A_1^{d}\right) >}{< v^2 >}$$

x_G

$$\frac{\Delta G}{G} = a(x - \bar{x}) + b$$

$$A \equiv \frac{<v> - <v'>}{<v^2> + <v^2>} = \frac{<v^2\left(\hat{a}_{LL}\frac{\Delta G}{G} + \hat{a}^q_{LL}A_1^d\right)>}{<v^2>} =$$

$$\frac{<v^2 a(x-\bar{x})\hat{a}_{LL}>}{<v^2>} + b\frac{<v^2\hat{a}_{LL}>}{<v^2>} + \frac{<v^2\hat{a}^q_{LL}A_1^d>}{<v^2>}$$

$$A = \frac{\Delta G}{G}(\bar{x}) <\hat{a}_{LL}>_{v^2} + <\hat{a}^q_{LL}A_1^d>_{v^2}$$

$$<v^2 a(x-\bar{x})\hat{a}_{LL}> = 0 \Rightarrow \bar{x} = \frac{<v^2\hat{a}_{LL}x>}{<v^2\hat{a}_{LL}>} = \frac{<\hat{a}_{LL}x>_{v^2}}{<\hat{a}_{LL}>_{v^2}}$$

Remark on D^0 anti-D^0 asymmetry

$LO:$

$$A^{\bar{D}^0/D^0} \approx -\tfrac{1}{4}\frac{\sigma^1 \otimes \frac{\Delta H^{\bar{D}^0}}{H^{\bar{D}^0}} H}{\sigma^0 \otimes H} = -\tfrac{1}{4}\frac{\int \frac{\Delta G}{G}\frac{\Delta H^{\bar{D}^0}}{H^{\bar{D}^0}} G\hat{\sigma}^{PGF,LO} H}{\int G\hat{\sigma}^{PGF,LO} H}$$

$$A^{signal} \approx \frac{\Delta\sigma^0 \otimes H + \tfrac{1}{2}\Delta\sigma^1 \otimes \Delta H^{\bar{D}^0}}{\sigma^0 \otimes H} = \frac{\int \left(\frac{\Delta G}{G} + \tfrac{1}{4}\frac{\Delta H^{\bar{D}^0}}{H^{\bar{D}^0}}\right) a_{LL}^{PGF,LO} G\hat{\sigma}^{PGF,LO} H}{\int G\hat{\sigma}^{PGF,LO} H}$$

Remark on D^0 anti-D^0 asymmetry

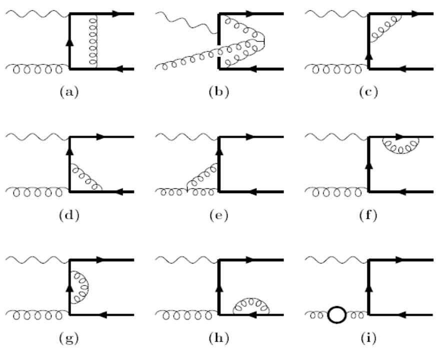
$LO:$

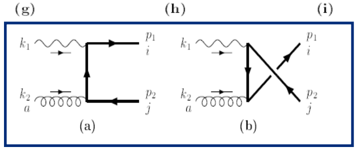
$$A^{\bar{D}^0/D^0} \approx -\frac{1}{4}\frac{\sigma^1 \otimes \frac{\Delta H^{\bar{D}^0}}{H^{\bar{D}^0}} H}{\sigma^0 \otimes H} = -\frac{1}{4}\frac{\int \frac{\Delta G}{G}\frac{\Delta H^{\bar{D}^0}}{H^{\bar{D}^0}} G\hat{\sigma}^{PGF,LO} H}{\int G\hat{\sigma}^{PGF,LO} H}$$

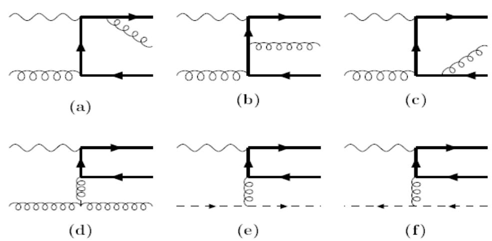
$$A^{signal} \approx \frac{\Delta\sigma^0 \otimes H + \frac{1}{2}\Delta\sigma^1 \otimes \Delta H^{\bar{D}^0}}{\sigma^0 \otimes H} = \frac{\int \left(\frac{\Delta G}{G} + \frac{1}{4}\frac{\Delta H^{\bar{D}^0}}{H^{\bar{D}^0}}\right) a_{LL}^{PGF,LO} G\hat{\sigma}^{PGF,LO} H}{\int G\hat{\sigma}^{PGF,LO} H}$$

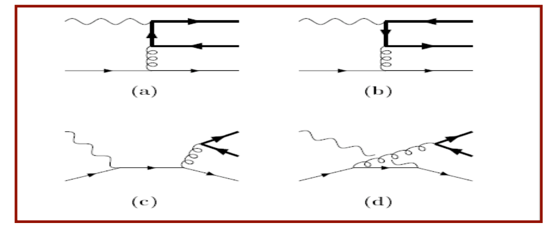
NLO QCD corrections

Gluon polarization in NLO QCD









I.Bojak, M.Stratmann, hep-ph/9807405,
Nucl.Phys.B 540 (1999) 345, I.Bojak, PhD thesis
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

NLO corrections available only for photo-producion limit. Q^2 =0
No problem for COMPASS: D – depolarization factor

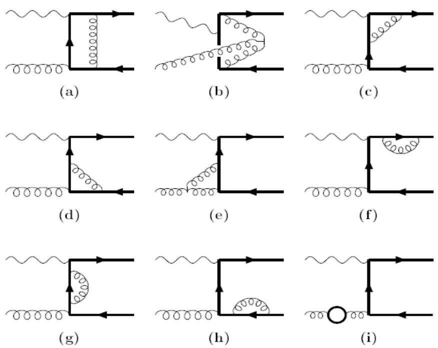
$$a_{LL}^{LO} = D a_{LL}^{LO,\gamma g}$$

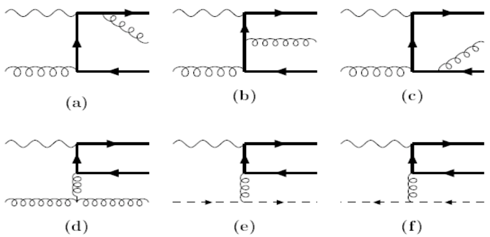
$$a_{LL}^{NLO} = D a_{LL}^{NLO,\gamma g}$$

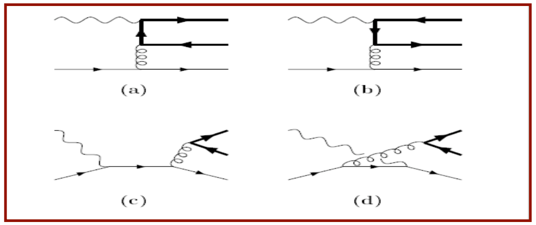
Q^2 neglected in this parts - very good approximation

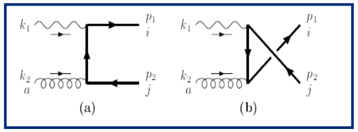
NLO QCD corrections

Gluon polarization in NLO QCD



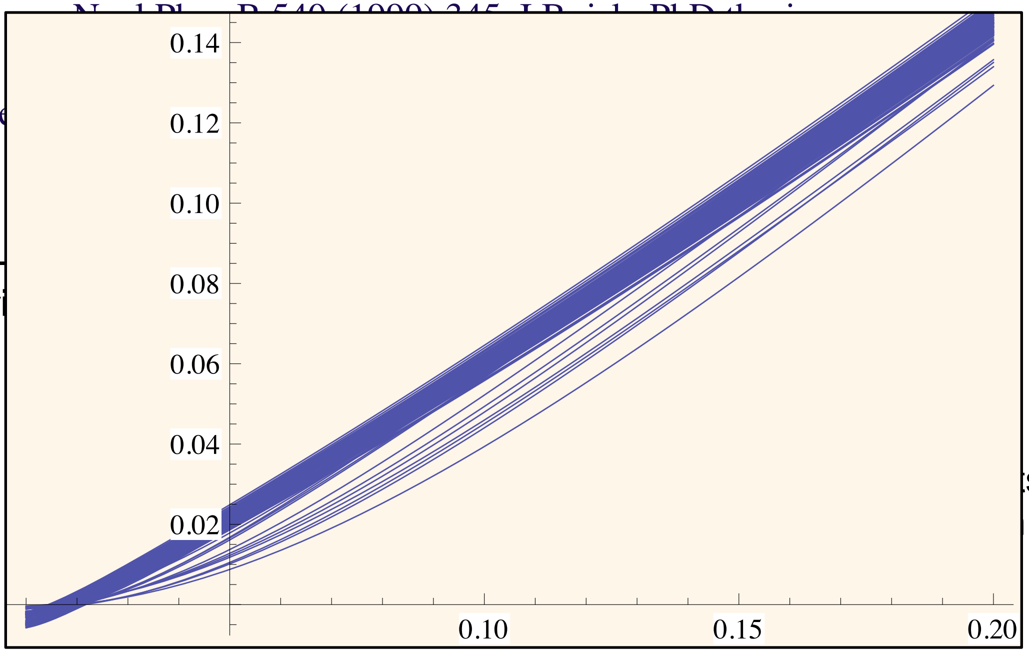






I.Bojak, M.Stratmann, hep-ph/9807405,

W.Be



NLO corrections available only for photo-
No problem for COMPASS: D – depolari

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