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

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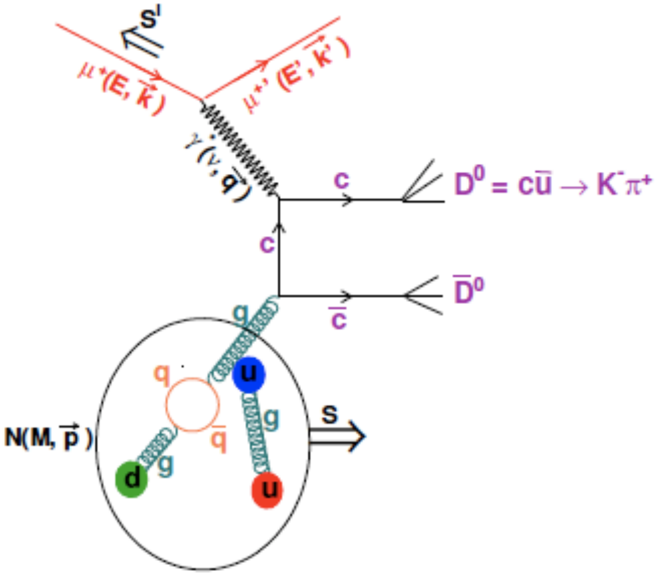
in collaboration with COMPASS

DIS10, XVIII International Workshop on Deep Inelastic Scattering and Related Subjects, 19-23 April, 2010, Florence

Contents:

- Introduction: open-charm and gluon polarization
- QCD NLO corrections to open-charm production
- Asymmetry decomposition for open-charm channel
- Role of MC, PS concept and application to QCD NLO approach
- Aroma MC generator results, gluon and light quark's parts
- Predictions for gluon polarization in QCD NLO approximation at COMPASS (based on published asymmetries)

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

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

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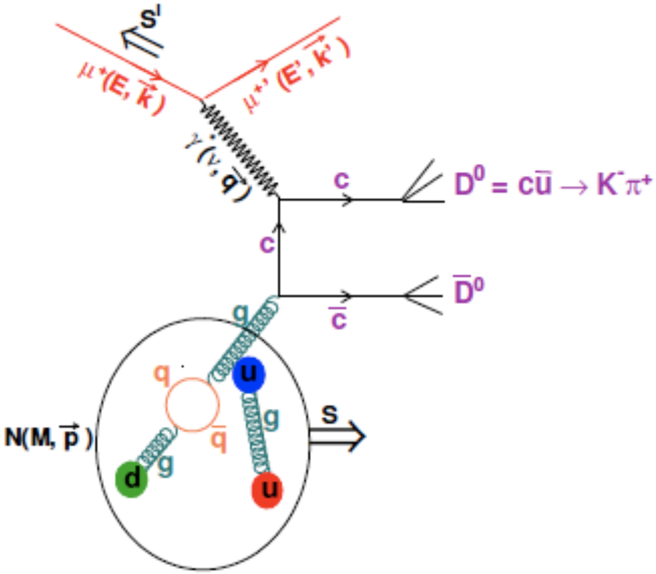

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from MC

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

from data

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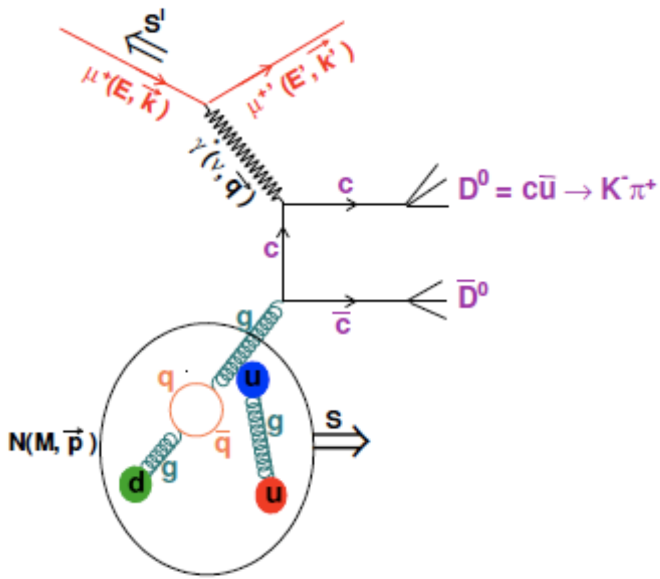

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$$A \approx \frac{\Delta G}{G}(\bar{x}_G) < \hat{a}_{LL}^{PGF} >$$

from data → A

from MC → $< \hat{a}_{LL}^{PGF} >$

COMPASS LO analysis in details: see presentation of Celso Franco

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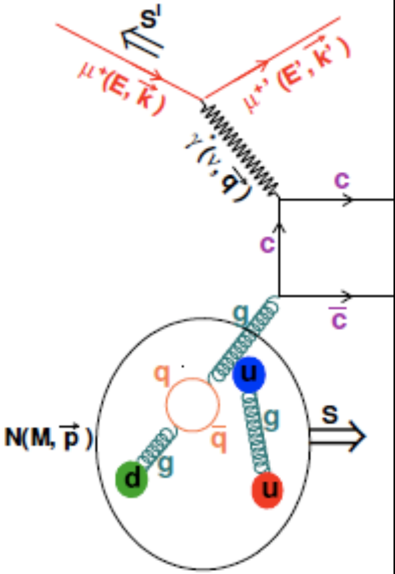


charm channel:
1. in LO QCD approach pure PGF events
but
1. Low statistics
2. Huge combinatorial background to fight
For details and method: Phys.Lett.B 676 (2009)31

Notice: here A is a signal asymmetry only;

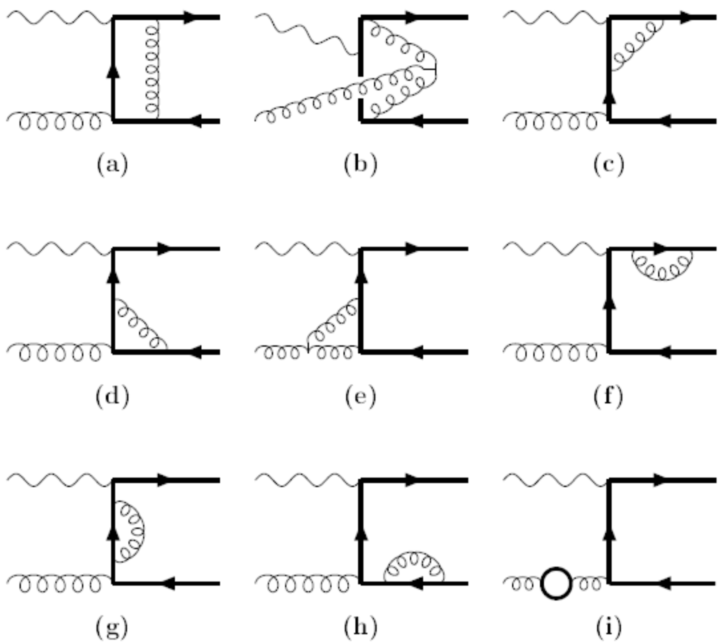
$A^{meas} = s/(s+b)A^D + b/(s+b)A^B$

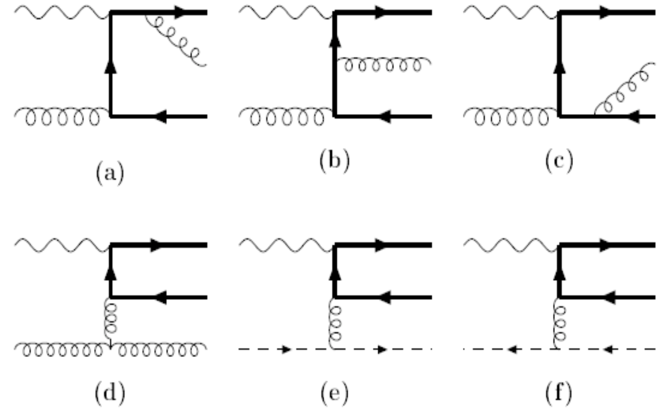
a_{LL} *parameterized (with neural network) using only observed quantities* (x, y, Q^2, z_D, p_T^D) *and calculated from real data*

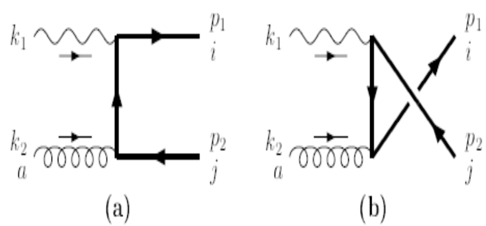
from data

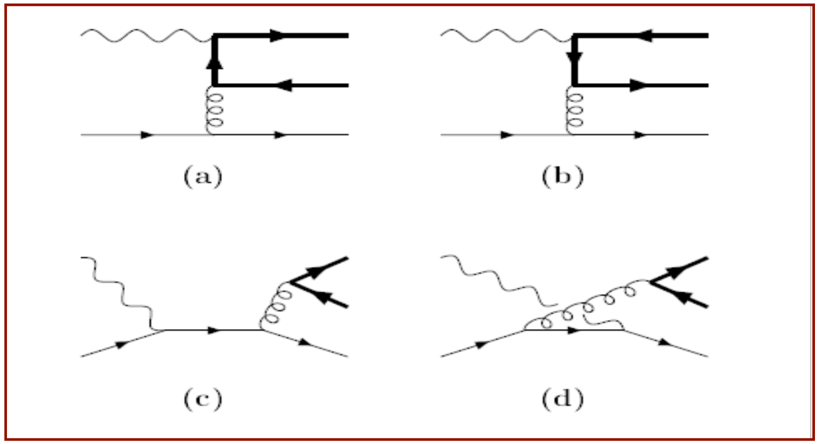
G

COMPASS LO analysis in details:
see presentation of Celso Franco


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)


(a)
(b)
(c)
(d)
(e)
(f)


k_1
p_1
i
k_2
a
p_2
j
(a)
(b)


(a)
(b)
(c)
(d)

$$2 \rightarrow 2 \quad \Rightarrow \quad g(k_1) + \gamma(k_2) \rightarrow c(p_1) + \bar{c}(p_2)$$

$$2 \rightarrow 3 \quad \Rightarrow \quad g(k_1) + \gamma(k_2) \rightarrow c(p_1) + \bar{c}(p_2) + g(k_3)$$

$$s_1 = (k_1 + k_2)^2 + Q^2 = 2k_1k_2$$

$$t_1 = (k_2 - p_2)^2 - m^2 = -2p_2k_2$$

$$u_1 = (k_1 - p_2)^2 - m^2 = -2p_2k_1$$

$$s_4 = (k_3 + p_1)^2 - m^2 = 2k_3p_1$$

$$x_g = \frac{s_1}{2Pq} = \frac{s_4 - t_1 - u_1}{2MEy}$$

k_1 - photon
k_2 - gluon/quark
p_1 ,p_2 - charm quarks

$$2 \rightarrow 2 \quad \Rightarrow \quad s_1 + t_1 + u_1 = 0$$

$$2 \rightarrow 3 \quad \Rightarrow \quad s_1 + t_1 + u_1 = s_4$$

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

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

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

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

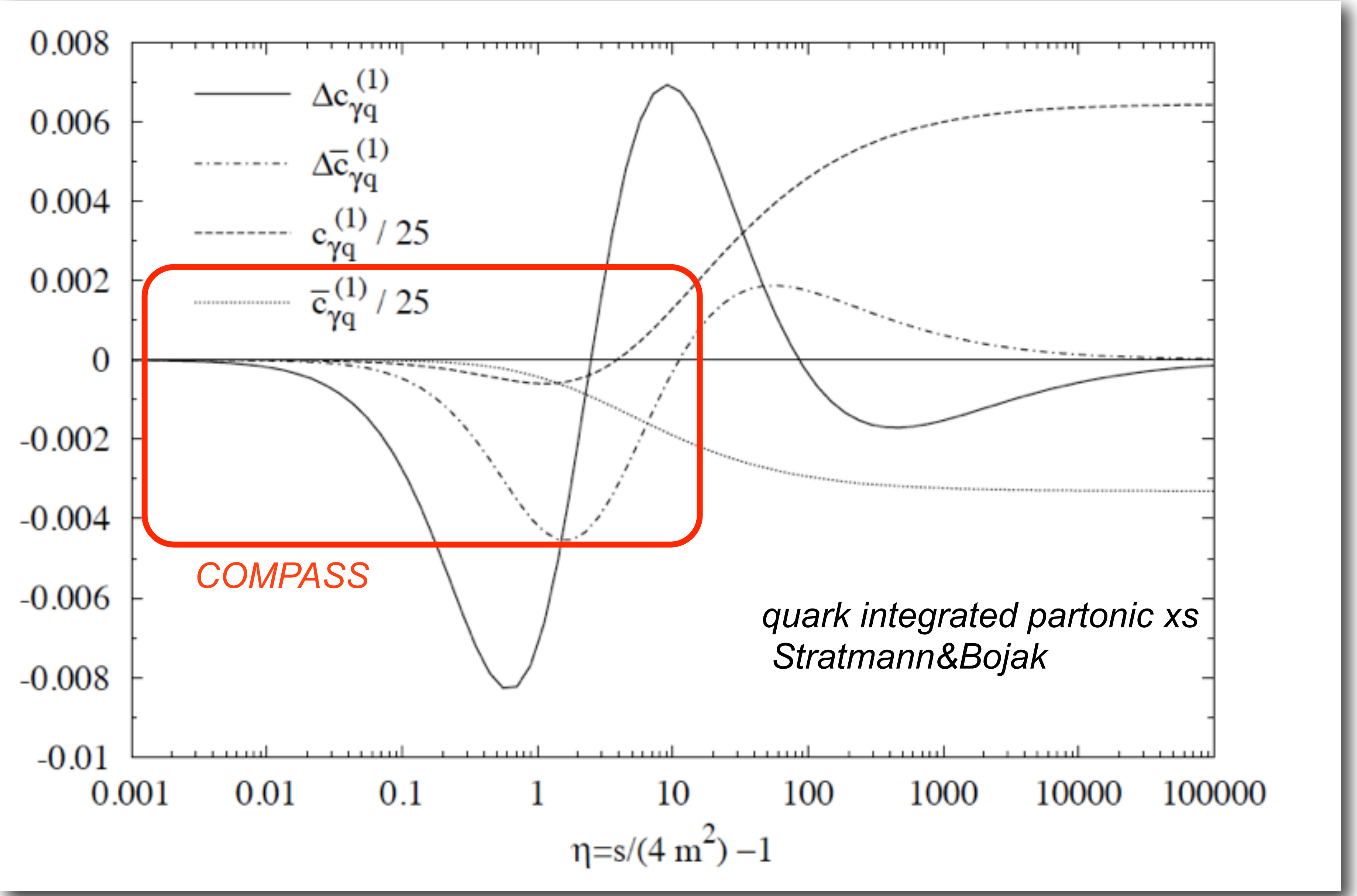
Q^2 neglected in this parts - very good approximation

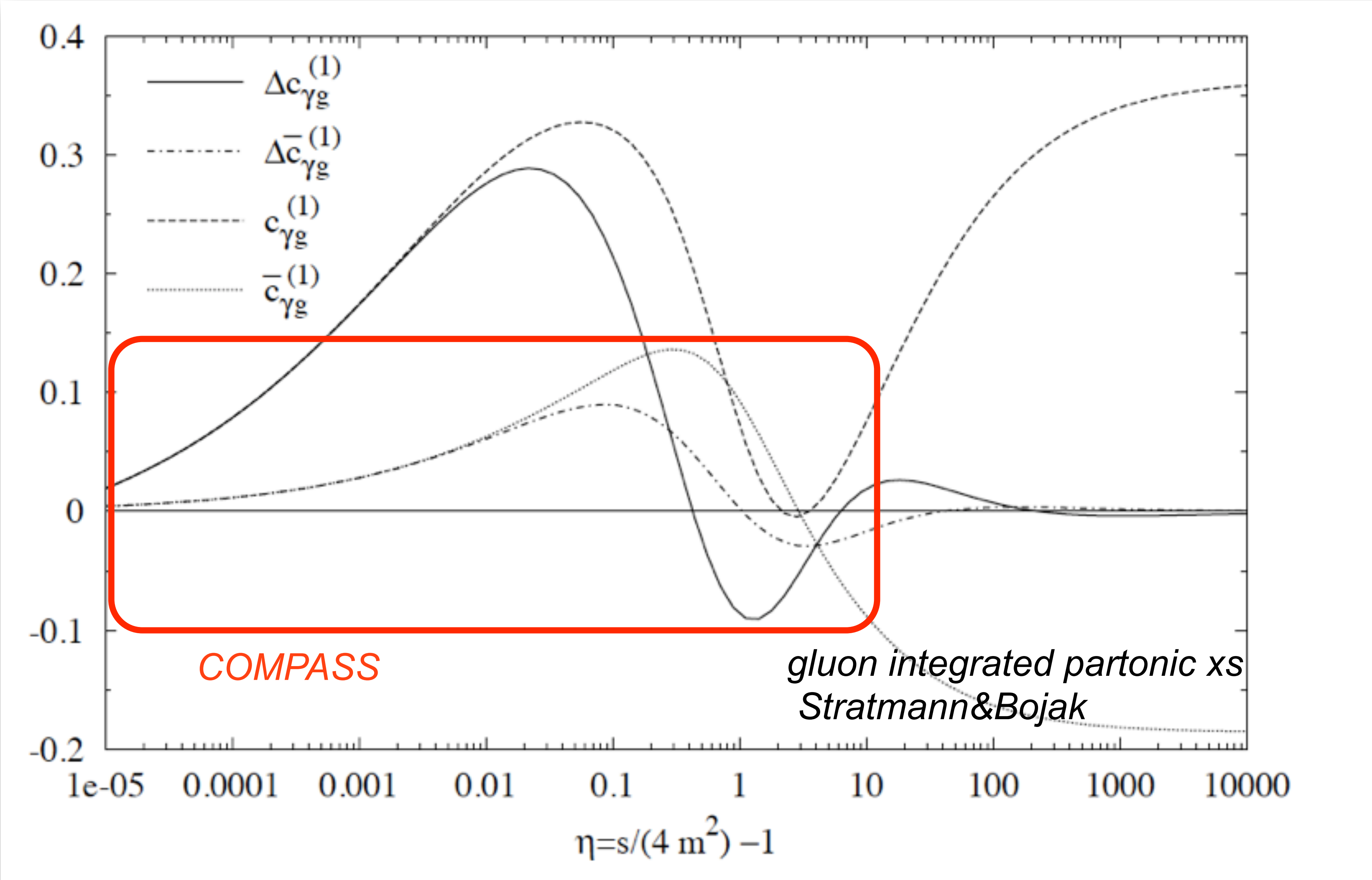
1. *MC events used for establish parton kinematics event-by-event basis*
2. *PS-on allows to have "room" for integration over s_4*

MC is used for simulating Phase Space for NLO/LO calculations

3. *Including light quark channel new background (hidden in signal events) is present. At the first look the situation is similar to high-p_T : unwanted processes which should be subtracted. There is however a big difference: The quark channel cross section is a "reduced" cross section (NLO) and mostly negative in the COMPASS kinematical range*

Also gluon NLO xs can be negative - the physical meaning has total xs: LO+NLO


0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
$\Delta c_{\gamma q}^{(1)}$
$\Delta \bar{c}_{\gamma q}^{(1)}$
$c_{\gamma q}^{(1)}$ / 25
$\bar{c}_{\gamma q}^{(1)}$ / 25
COMPASS
quark integrated partonic xs
Stratmann&Bojak
0.001
0.01
0.1
1
10
100
1000
10000
100000
$\eta = s/(4\,m^2) - 1$


0.4
0.3
0.2
0.1
0
-0.1
-0.2
$\Delta c_{\gamma g}^{(1)}$
$\Delta \bar{c}_{\gamma g}^{(1)}$
$c_{\gamma g}^{(1)}$
$\bar{c}_{\gamma g}^{(1)}$
COMPASS
gluon integrated partonic xs
Stratmann&Bojak
1e-05
0.0001
0.001
0.01
0.1
1
10
100
1000
10000
$\eta = s/(4\ m^2) - 1$

$$\sigma^{signal} = \left(G \otimes (\hat{\sigma}^{PGF,LO} + \hat{\sigma}^{PGF,NLO}) + \sum_q e_q^2 q \otimes \hat{\sigma}^{quark,light} + \sum_q q \otimes \hat{\sigma}^{quark,charm} \right) \otimes H$$

$$\sigma^{signal} = \left(G \otimes \hat{\sigma}^{Gluon} + \sum_q q \otimes \hat{\sigma}^{quark} \right) \otimes H$$

$$\hat{\sigma}^{Gluon} = \hat{\sigma}^{PGF,LO} + \hat{\sigma}^{PGF,NLO} \qquad \hat{\sigma}^{quark} = \hat{\sigma}^{quark,charm} + \tfrac{5}{18} \hat{\sigma}^{quark,light}$$

$$\Delta\sigma^{signal} = \left(\Delta G \otimes \Delta\hat{\sigma}^{Gluon} + \sum_q \Delta q \otimes \Delta\hat{\sigma}^{quark} \right) \otimes H$$

thanks to deuteron target

$$A^{signal} = \frac{\Delta\sigma^{signal}}{\sigma} = \frac{\left(\frac{\Delta G}{G} G \otimes \Delta\hat{\sigma}^{Gluon} + A_1^{d,c} \sum_q q \otimes \Delta\hat{\sigma}^{quark} \right) \otimes H}{\sigma^{signal}}$$

$$A^{measured} = f P_T P_b \left(\frac{S}{S+B} A^{signal} + \frac{B}{S+B} A^B \right) \qquad A_1^{d,c} = \frac{A_1^d}{1 - \frac{3}{2}\omega_D}$$

H - fragmentation,
⊗ - convolution integral

$$\sigma^{signal} = \left(G \otimes (\hat{\sigma}^{PGF,LO} + \hat{\sigma}^{PGF,NLO}) + \sum_q e_q^2 q \otimes \hat{\sigma}^{quark,light} + \sum_q q \otimes \hat{\sigma}^{quark,charm} \right) \otimes H$$

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$$A_1^{d,c} = \frac{A_1^d}{1 - \frac{3}{2}\omega_D}$$

H - fragmentation,
⊗ - convolution integral

$$A^{signal} = \frac{\int \left(\frac{\Delta G}{G} + \frac{A_1^{d,c} \sum_q q\Delta\hat{\sigma}^{quark}}{G\Delta\hat{\sigma}^{Gluon}}\right)\left(\frac{G\Delta\hat{\sigma}^{Gluon}}{G\hat{\sigma}^{Gluon} + \sum_q q\hat{\sigma}^{quark}}\right)\left(G\hat{\sigma}^{Gluon} + \sum_q q\hat{\sigma}^{quark}\right)H}{\sigma^{signal}} =$$

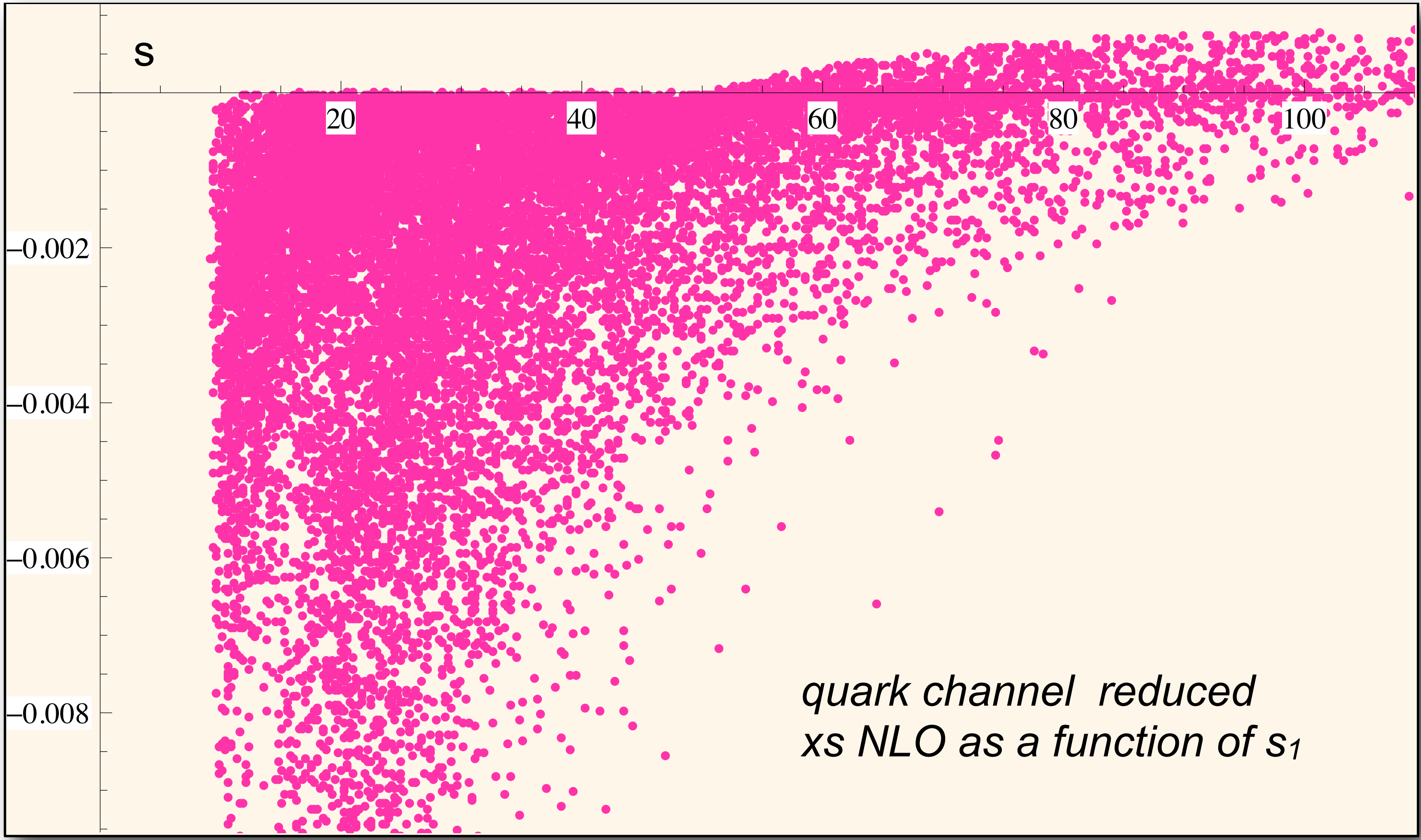
$$= \left\langle \left(\frac{\Delta G}{G} a_{LL} + A_1^{d,c} a_{LL}^q\right)\right\rangle = \left\langle \frac{\Delta G}{G} \right\rangle_{a_{LL}} \left\langle a_{LL} \right\rangle + \left\langle A_1^{d,c} a_{LL}^q \right\rangle = \left\langle \frac{\Delta G}{G} + A_1^{d,c} \frac{a_{LL}^q}{a_{LL}} \right\rangle_{a_{LL}}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

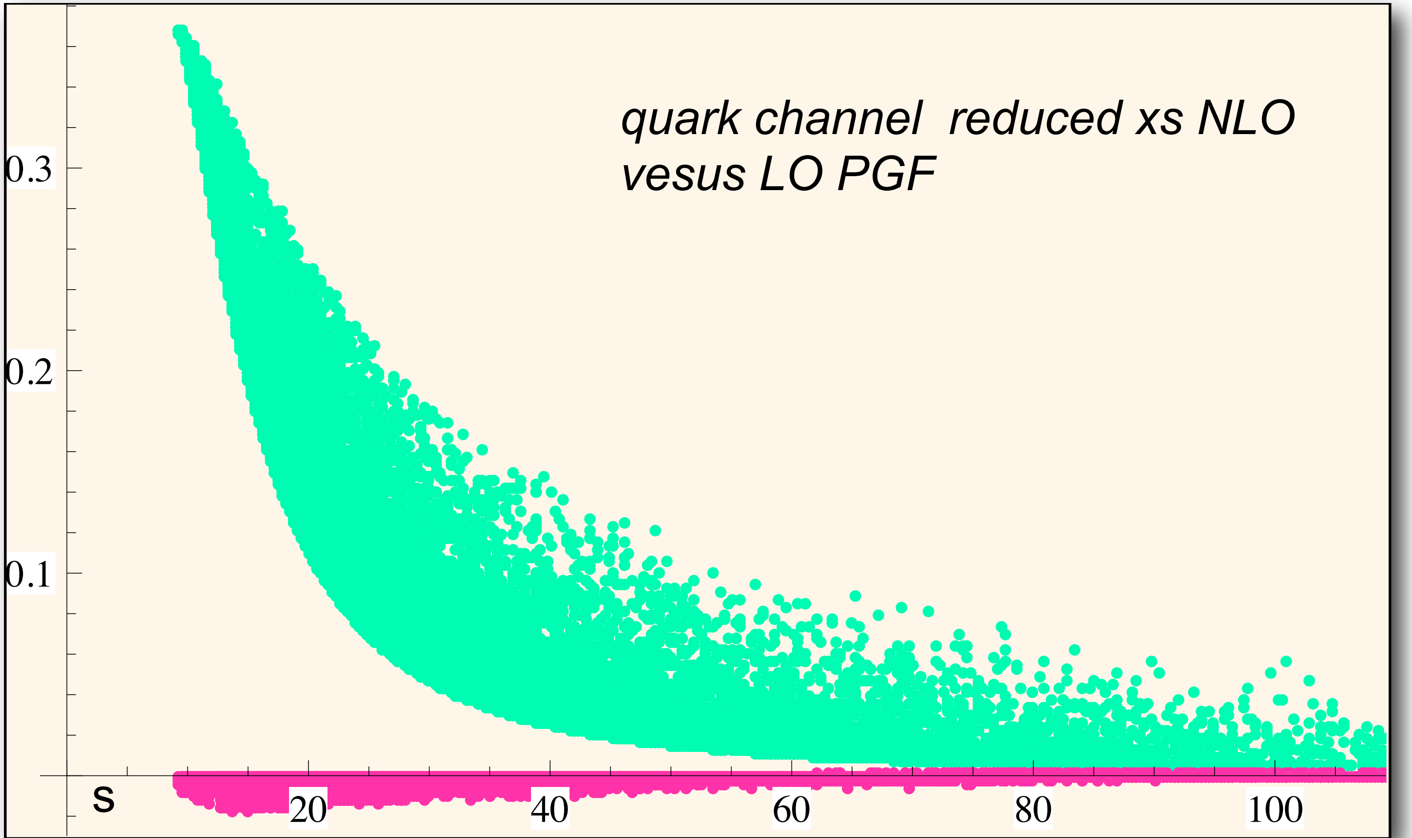
$$a_{LL} = \frac{G\Delta\hat{\sigma}^{Gluon}}{G\hat{\sigma}^{Gluon} + \sum_q q\hat{\sigma}^{quark}} \qquad a_{LL}^q = \frac{\sum_q q\Delta\hat{\sigma}^{quark}}{G\hat{\sigma}^{Gluon} + \sum_q q\hat{\sigma}^{quark}}$$

1. *Aroma with PS-on describes COMPASS data very well*

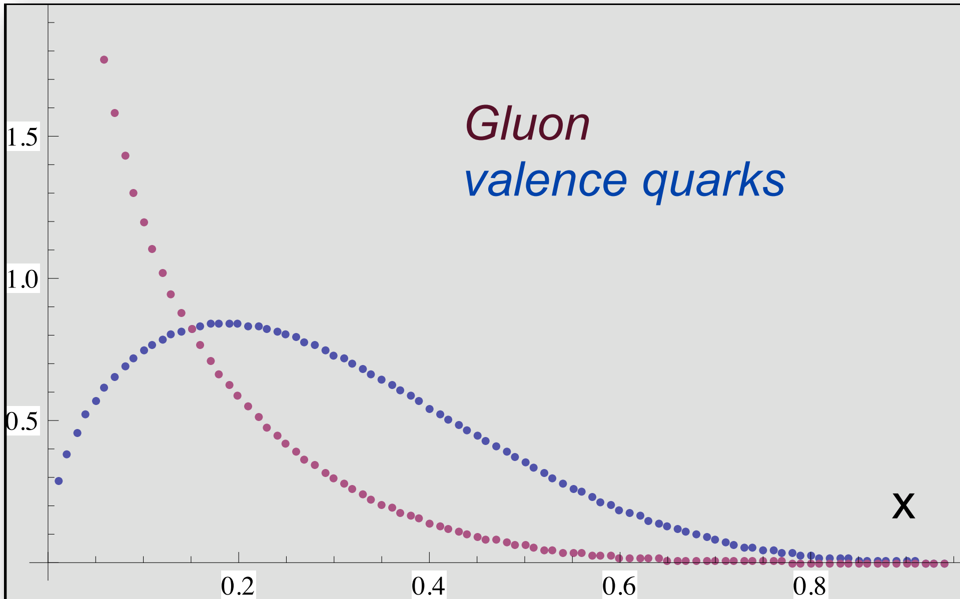
2. *every event from MC has s.t.u variables fixed what allows to calculate xs in LO (unique) and in NLO: partially integrated over one charm quark.*
3. *Integration over energy of emitted gluon (s_4) is performed event-by-event from 0 to $s_1+t_1+u_1$. After integration over s_4 xs depends only on two variables as in LO and can be combined with LO result*
4. *All reduced NLO xs should be added together to avoid numerical instabilities*

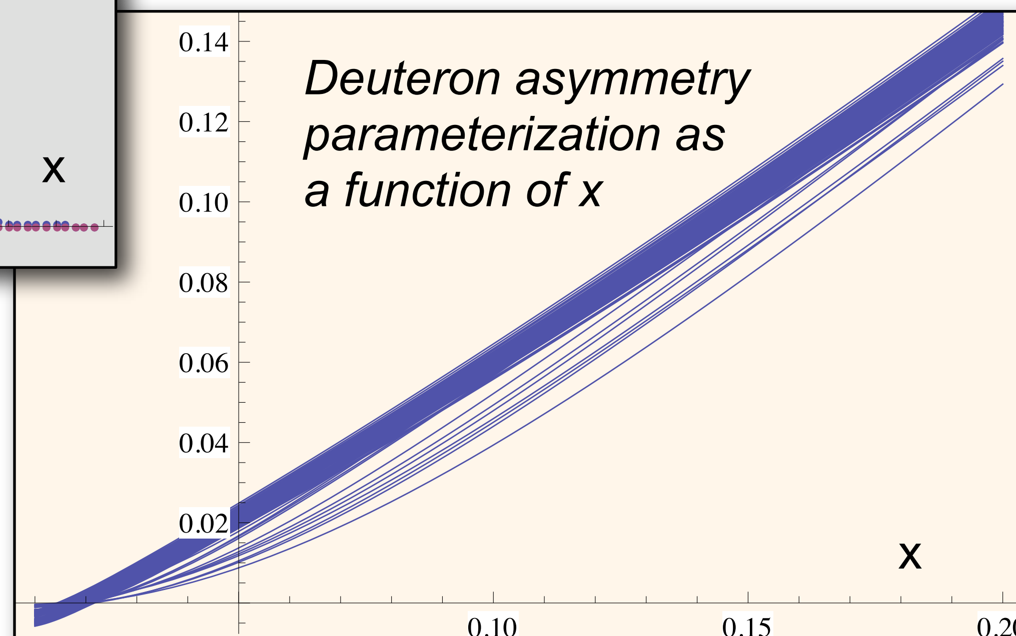
Used sample: PS-on/off (Aroma)
2004/2006 setups, of COMPASS used in MC

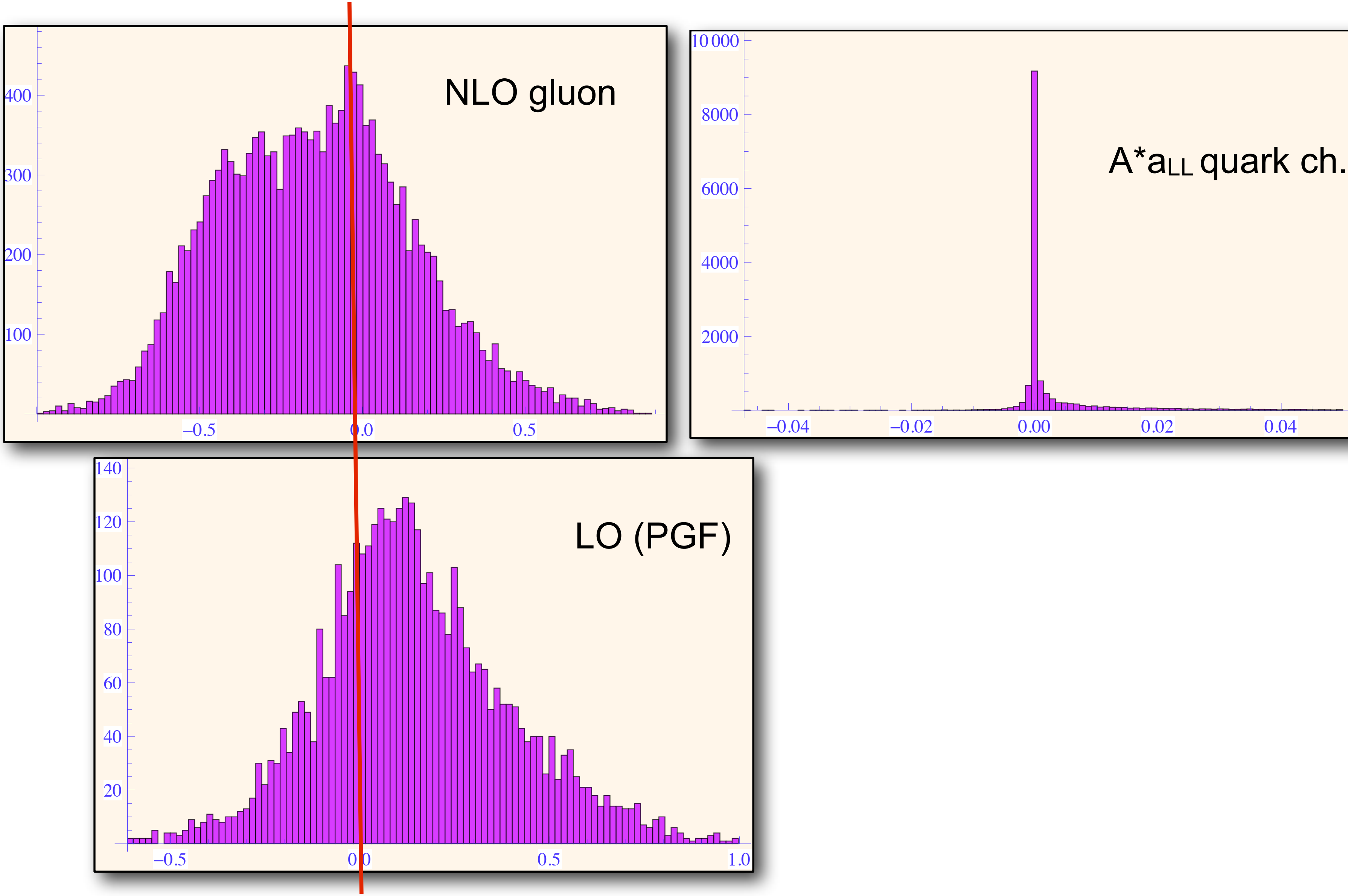

s
20
40
60
80
100
–0.002
–0.004
–0.006
–0.008
quark channel reduced
xs NLO as a function of s1


quark channel reduced xs NLO
vesus LO PGF
0.3
0.2
0.1
s
20
40
60
80
100

The correction for gluon polarization - a_{LL} for quark is convoluted with unpolarized quark pdf and deuteron asymmetry






NLO gluon
400
300
200
100
–0.5
0.0
0.5
10 000
8000
6000
4000
2000
A*aLL quark ch.
–0.04
–0.02
0.00
0.02
0.04
LO (PGF)
140
120
100
80
60
40
20
–0.5
0.0
0.5
1.0

- *Model independent asymmetries were extracted from data only*

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

- $\frac{\Delta g}{g}$ *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* $w = f \, P_B \frac{S}{S+B} a_{LL}$

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

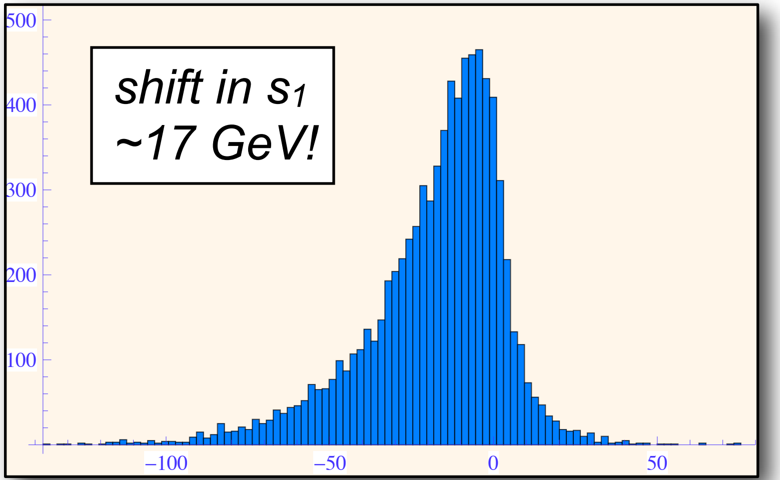
LO published: ΔG/G=-0.49±0.27

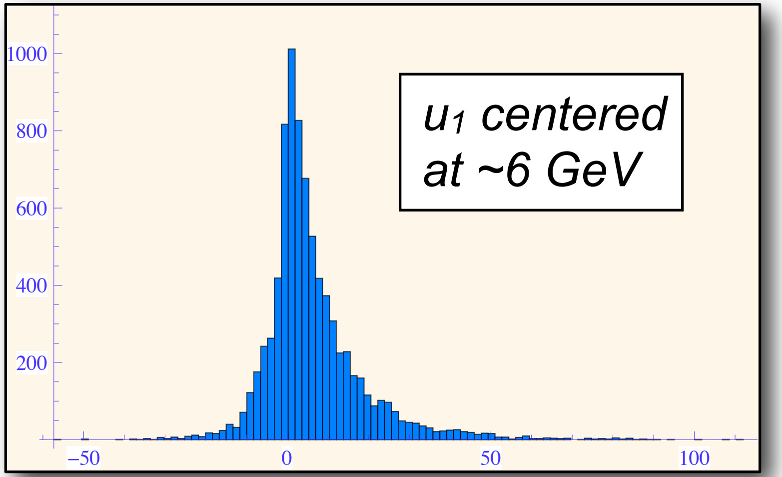
NLO: based on asymmetries in bins

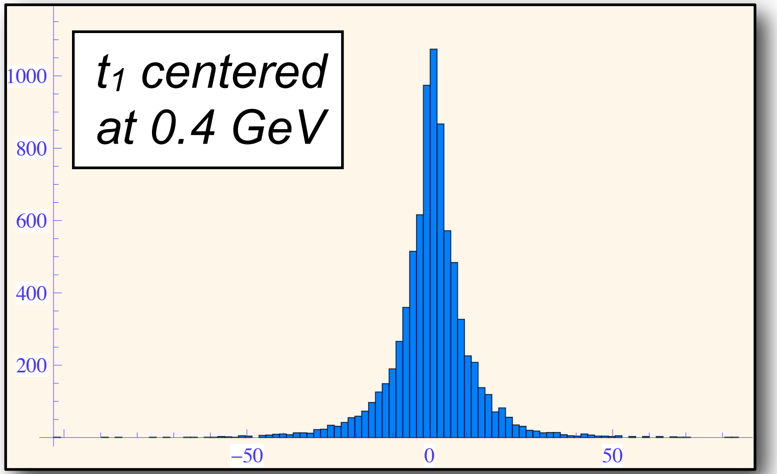
- *ΔG/G=+0.008±0.25*

- *ΔG/G=const : ΔG/G= -0.018±0.31*
- *ΔG/G>0, Compass NLO QCD fit: ΔG/G= -0.083±0.4*
- *ΔG/G<0, Compass NLO QCD fit: ΔG/G= -0.18±0.31*

NLO: simple MC weighted NLO xs
ΔG/G= +0.005 ±0.22

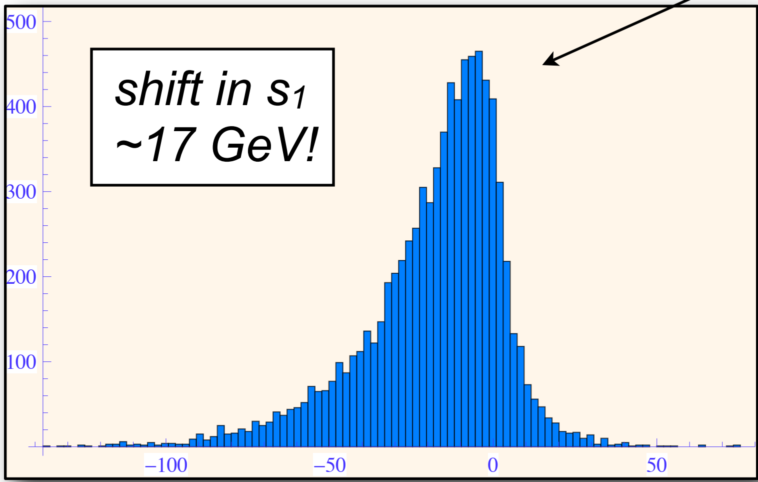


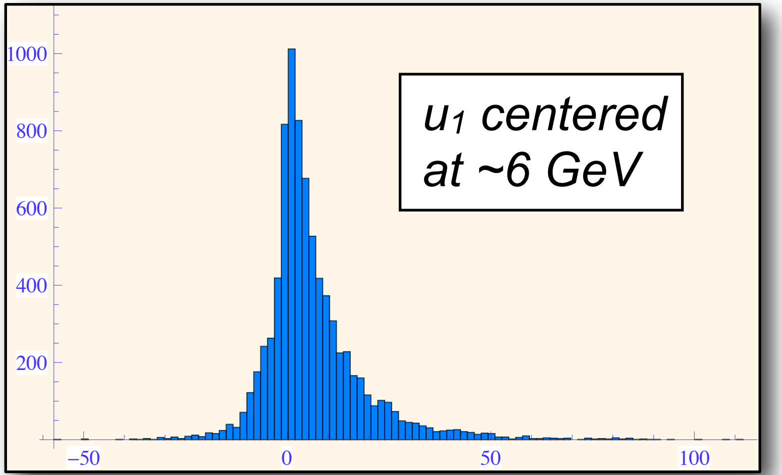


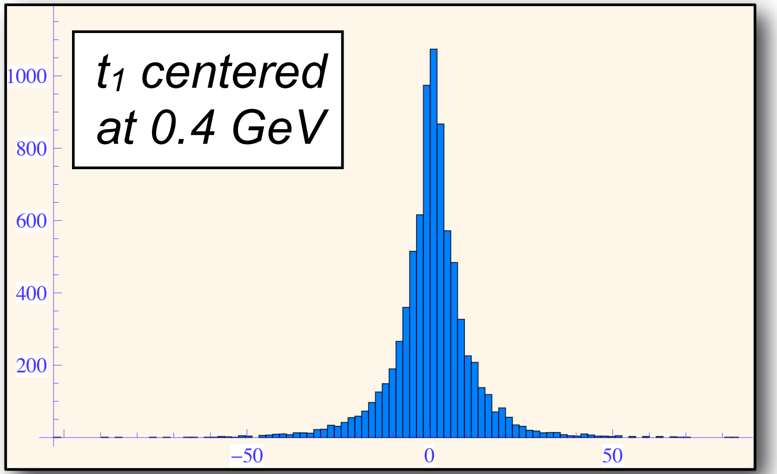


events from MC with PS-on and PS-off "paired" to have a pair of events with the same observed quantities (x,y, Q^2,z_D, p_T^D). Differences in s,t,u are shown

NLO effect slightly overestimated

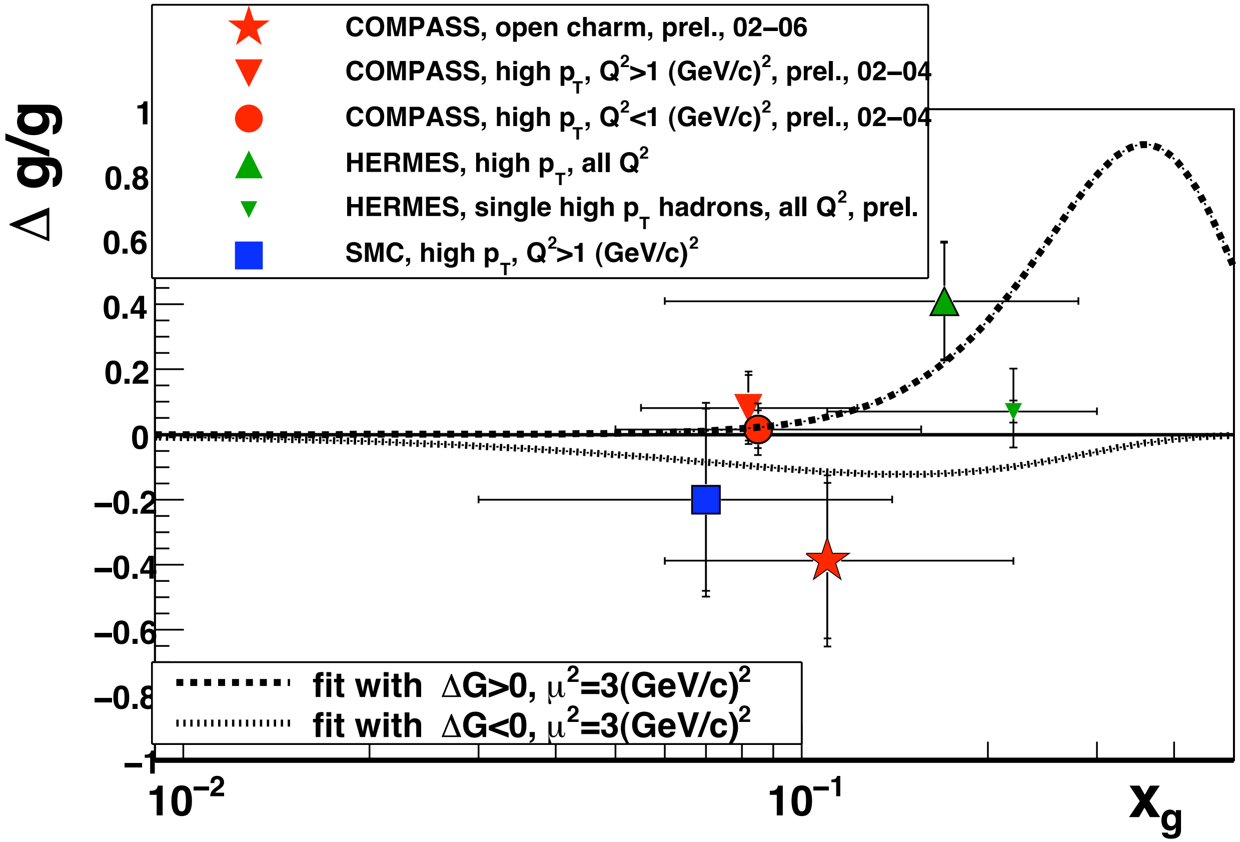


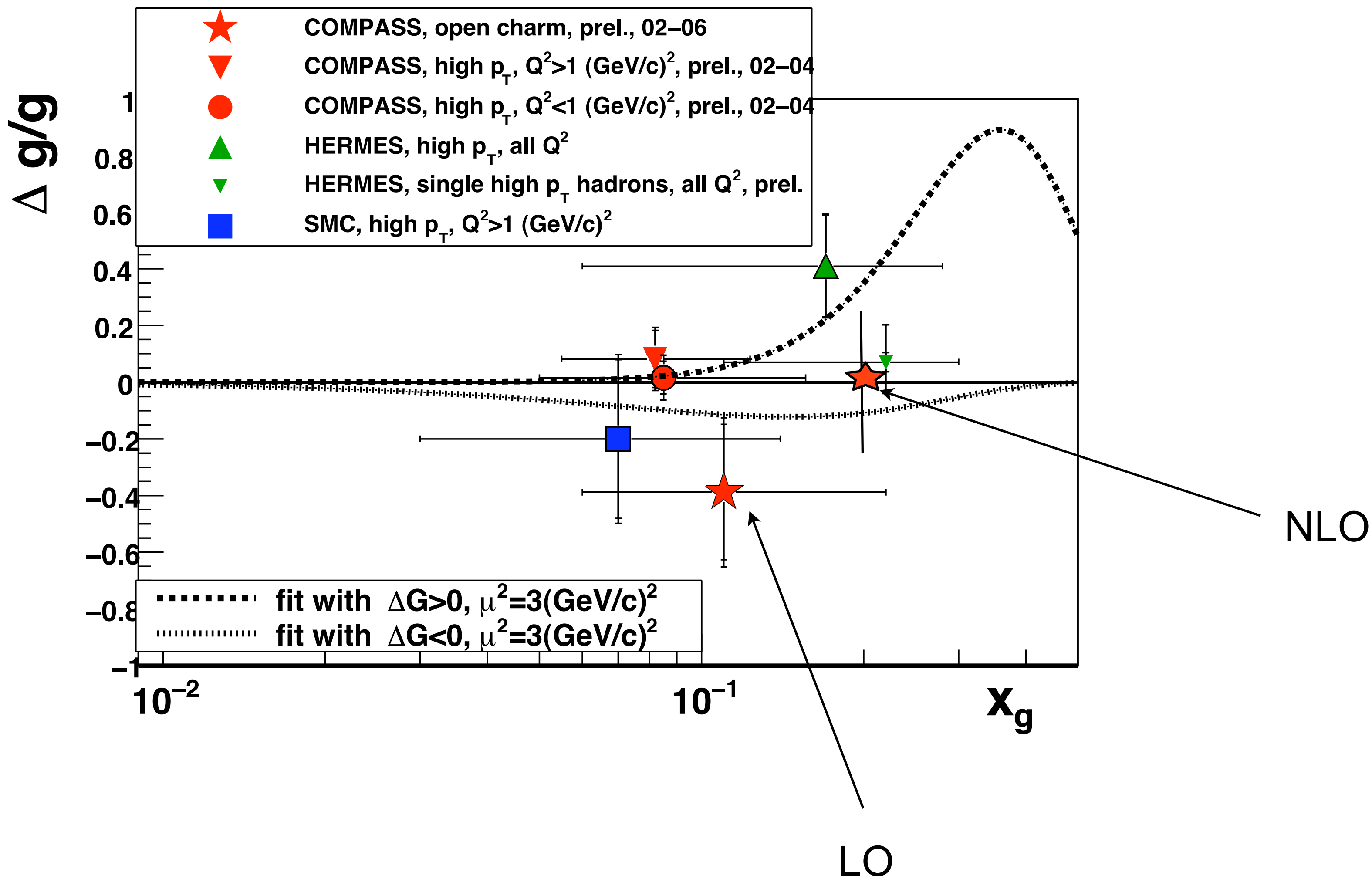




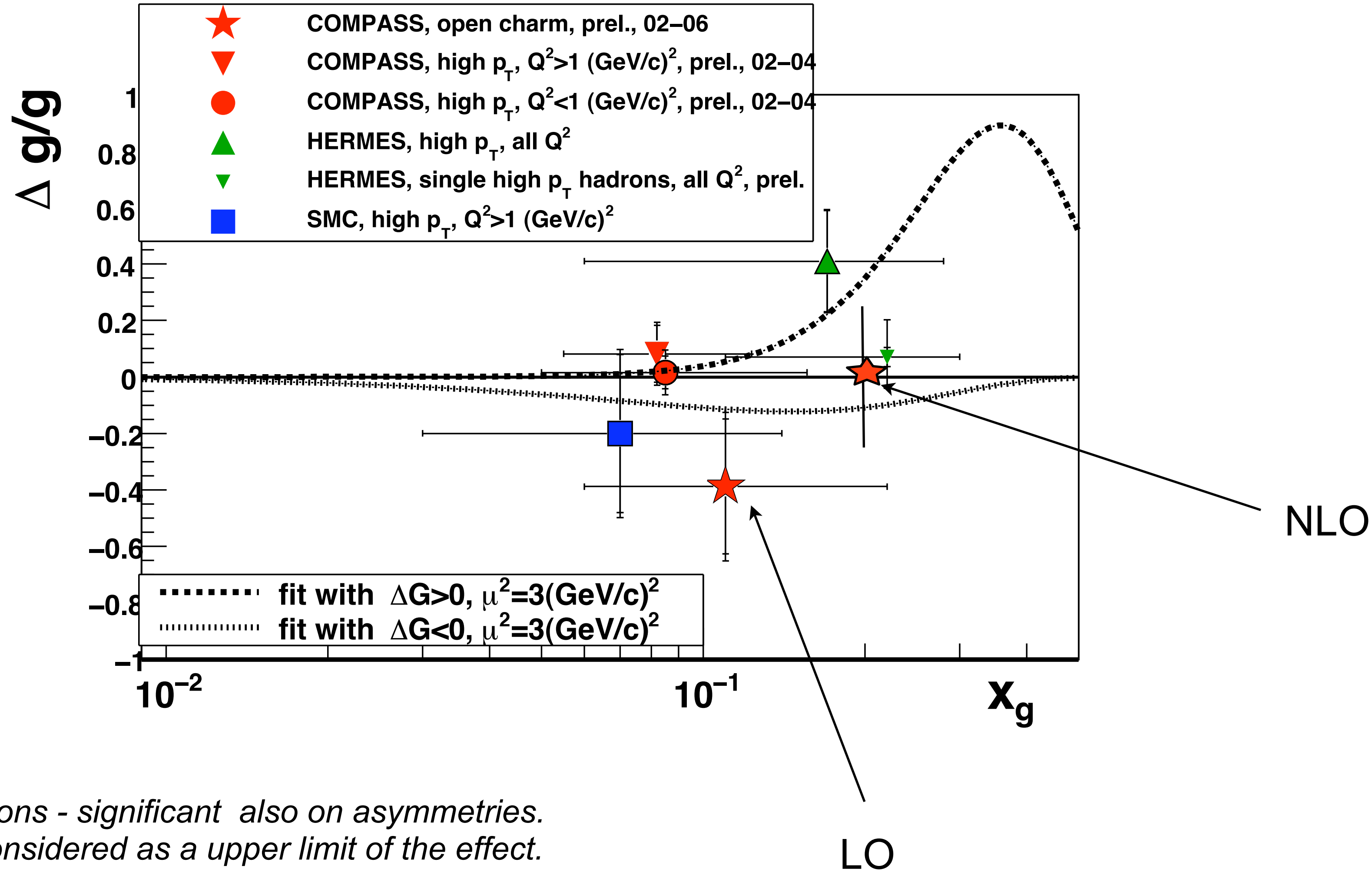
It is better to use t_1 and u_1
instead of s_1 and t_1
but it costs: polarized gluons model
needed to perform integration over s_4
to test the effect 3 models have been used
(see previous slide)

events from MC with PS-on and PS-off “paired” to have a pair of events with the same observed quantities (x,y, Q^2,z_D, p_T^D). Differences in s,t,u are shown


COMPASS, open charm, prel., 02–06
COMPASS, high p_T, Q²>1 (GeV/c)², prel., 02–04
COMPASS, high p_T, Q²<1 (GeV/c)², prel., 02–04
HERMES, high p_T, all Q²
HERMES, single high p_T hadrons, all Q², prel.
SMC, high p_T, Q²>1 (GeV/c)²
fit with ΔG>0, μ²=3(GeV/c)²
fit with ΔG<0, μ²=3(GeV/c)²
Δ g/g
x_g
1
0.8
0.6
0.4
0.2
0
–0.2
–0.4
–0.6
–0.8
–1
10⁻²
10⁻¹



COMPASS, open charm, prel., 02–06
COMPASS, high p_T, Q^2>1 $(GeV/c)^2$, prel., 02–04
COMPASS, high p_T, Q^2<1 $(GeV/c)^2$, prel., 02–04
HERMES, high p_T, all Q^2
HERMES, single high p_T hadrons, all Q^2, prel.
SMC, high p_T, Q^2>1 $(GeV/c)^2$
$\Delta g/g$
1
0.8
0.6
0.4
0.2
0
–0.2
–0.4
–0.6
–0.8
–1
fit with $\Delta G>0$, $\mu^2=3(GeV/c)^2$
fit with $\Delta G<0$, $\mu^2=3(GeV/c)^2$
10^{-2}
10^{-1}
x_g
NLO
LO

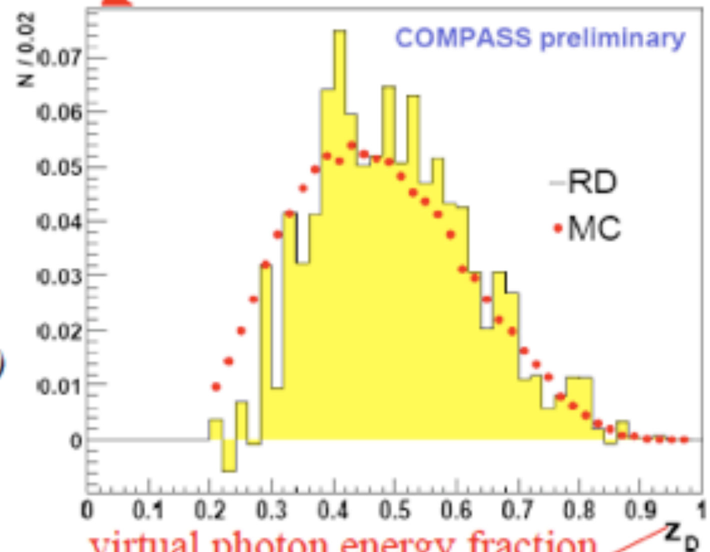


NLO corrections - significant also on asymmetries.
Should be considered as a upper limit of the effect.
Final COMPASS LO result - closer to zero (see Celso Franco talk)
- new asymmetries soon - NLO analysis ongoing

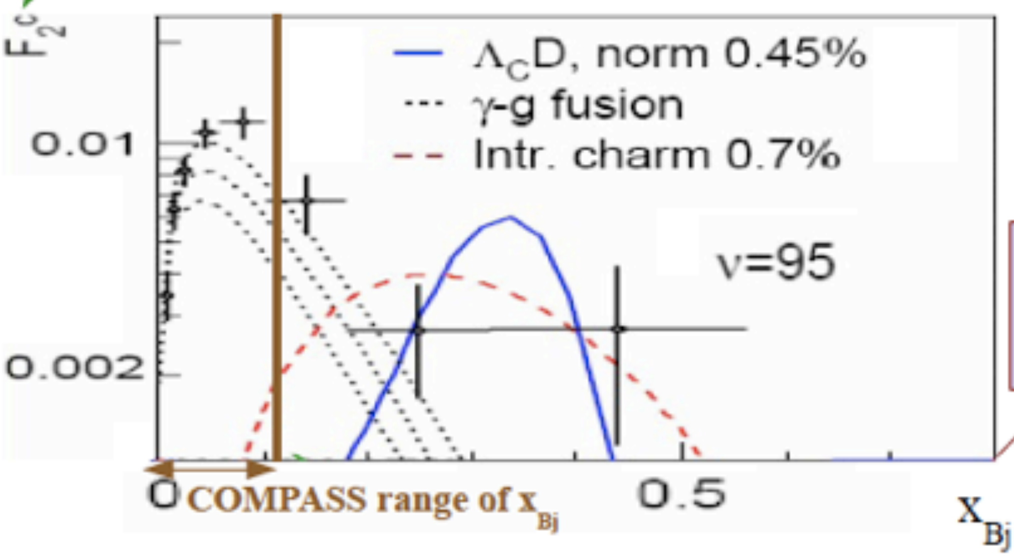
Spares

Why measure gluon spin from Open-Charm?

- $c\bar{c}$ 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



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

Intrinsic charm predictions: CTEQ6.5c

- **In the COMPASS kinematic domain:**
  - **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)***