NLO predictions for gluon polarization from open-charm channel at COMPASS

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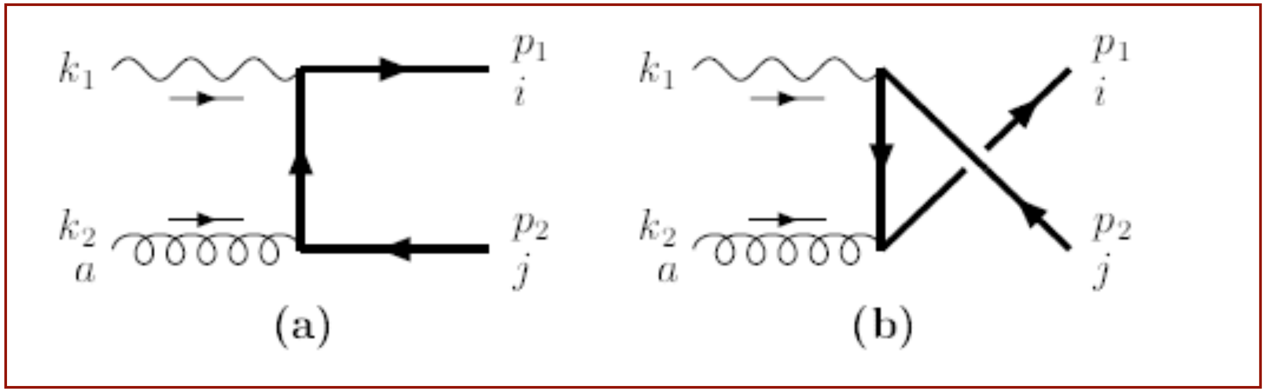
Contents

- LO and NLO QCD processes for open-charm production
- The role of MC in the COMPASS open-charm analysis
- NLO corrections and the MC approach
- $\Delta G/G$ in the NLO approximation from COMPASS open-charm asymmetries
- Summary

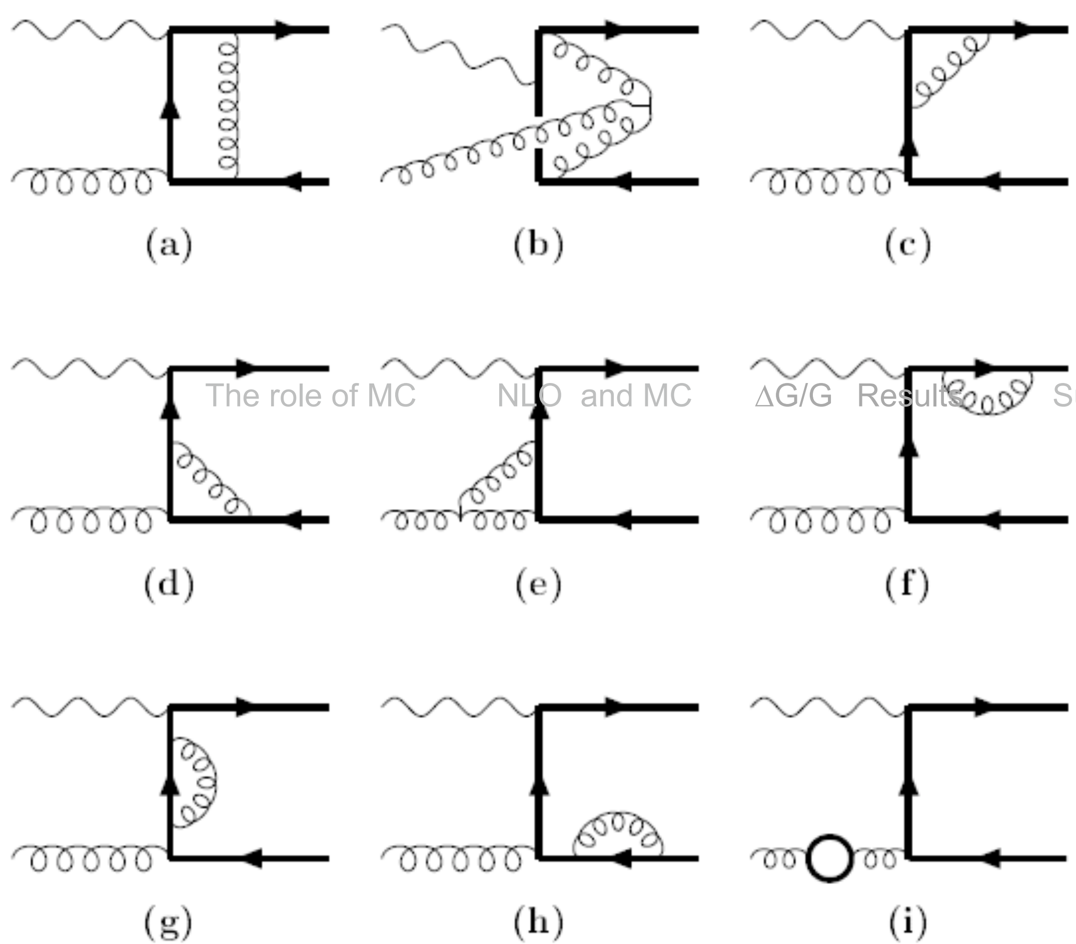
LO subprocesses for charm production – only PGF,
No light quarks contribution – means no „physical background"



Simple expresion for analysing power even if mass of muon and Q^2 dependence is taken into account – used in the present COMPASS analysis (published)

NLO calculations for partonic cross sections – much more complicated. Here Feynmamn diagrams for „virtual +soft" corrections are presented.

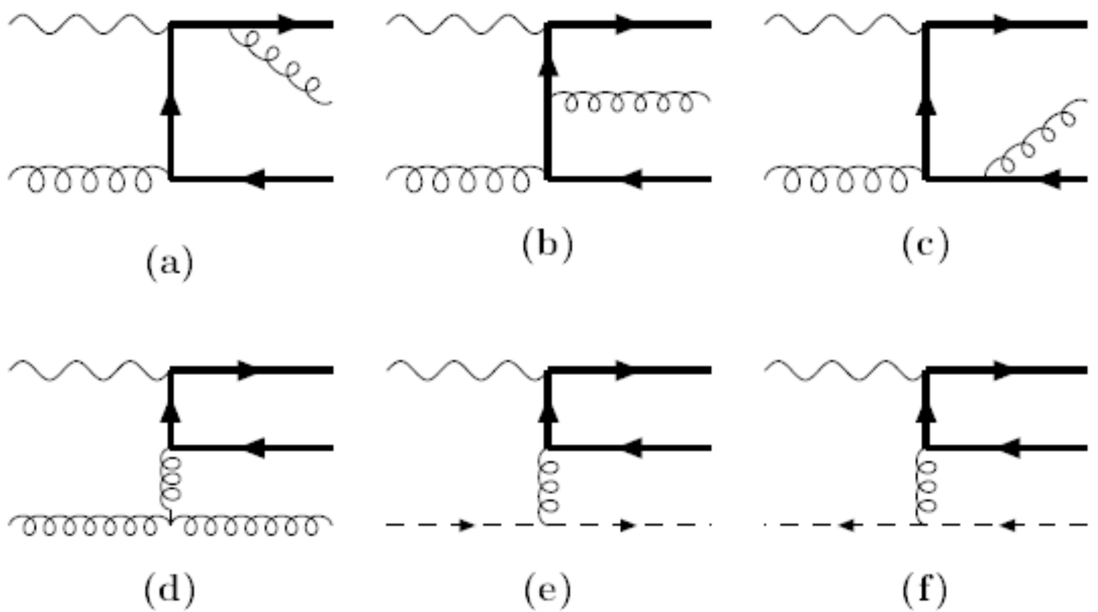
Loops produce divergences:
UV – removed by renormalization procedure,
IR - related to „zero" momenta of Internal loop particles



NLO calculations for partonic cross sections.

Here Feynmamn diagrams for „hard gluon emissions" corrections.

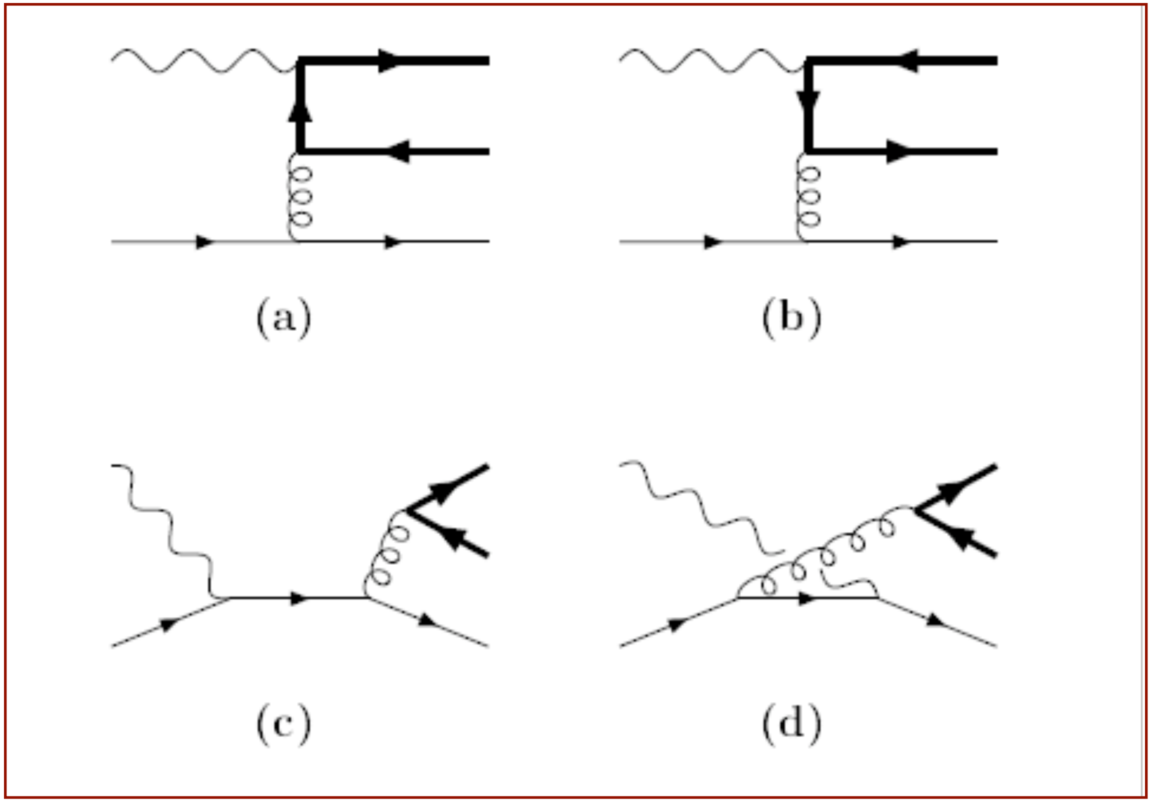
IR - related to „soft" momenta of gluon emissions. Here there is also colliner divergency for 3-gluons coupling



„VS" and „Hard" parts contain so-called double pole: $\sim \frac{1}{\varepsilon_{UV}} \frac{1}{\varepsilon_{IR}}$

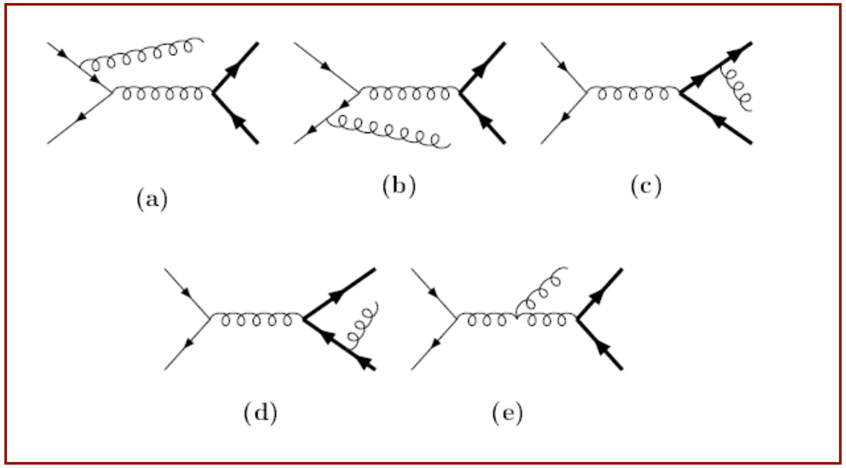
These terms MUST cancell Factorization.

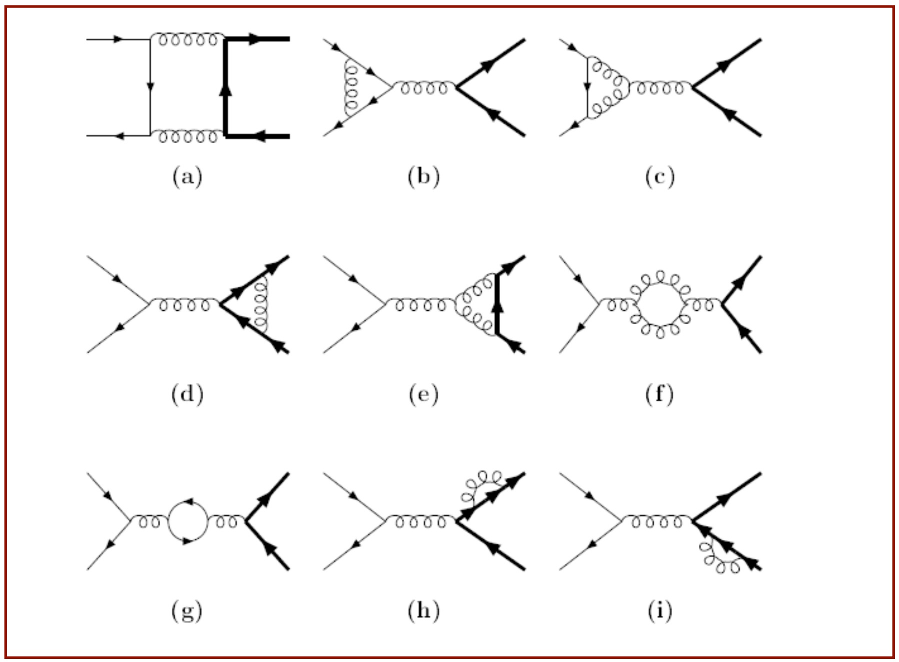
NLO calculations for partonic cross sections originated from light quarks.
No LO corresponding process!
New channel which produces „physical background”

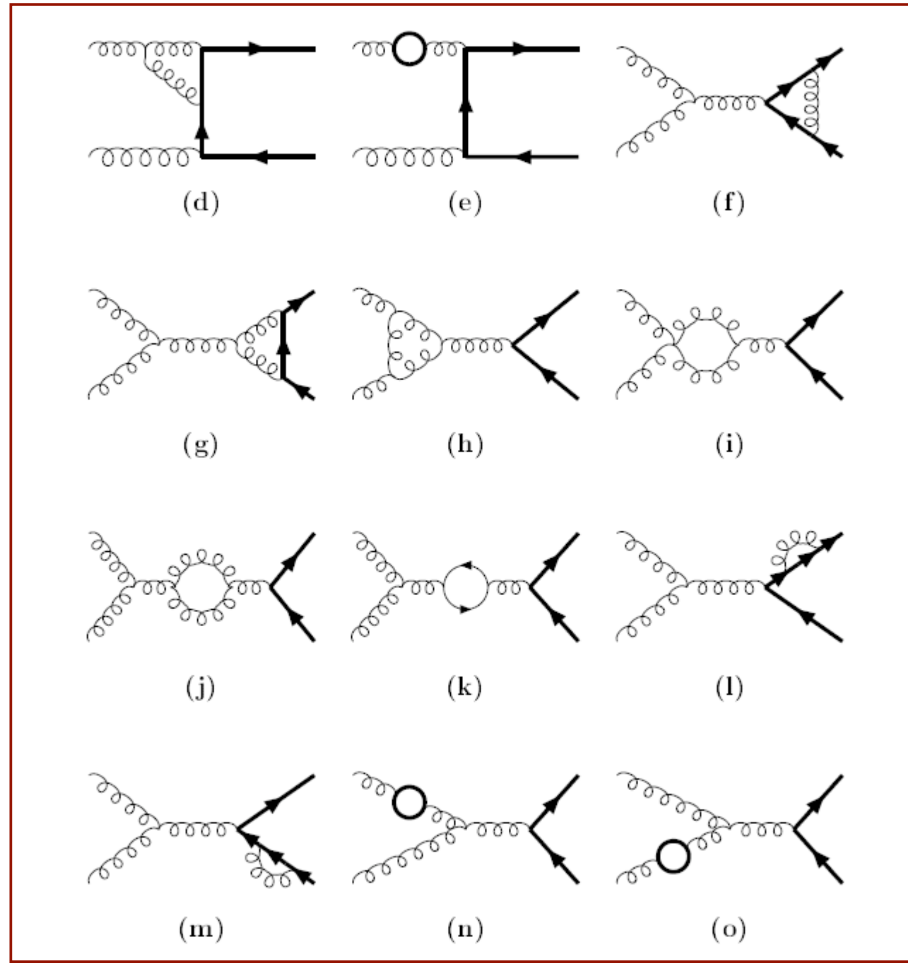


Not discussed in this talk - only NLO to PGF.

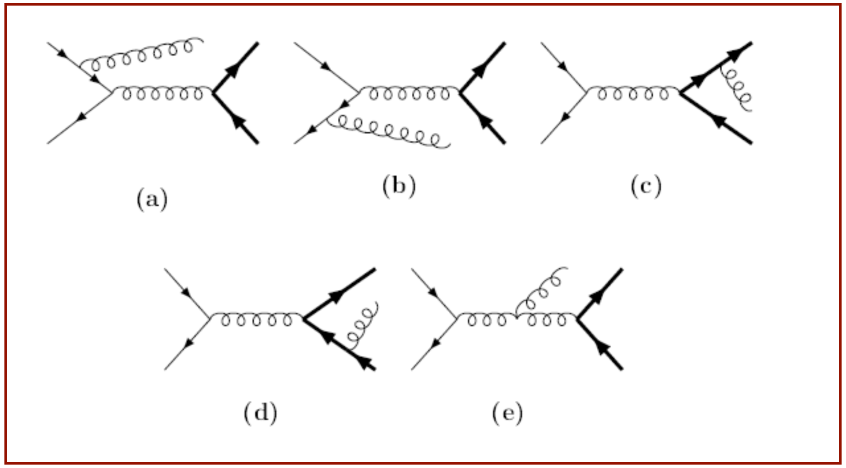
Finally – resolved photon NLO corrections

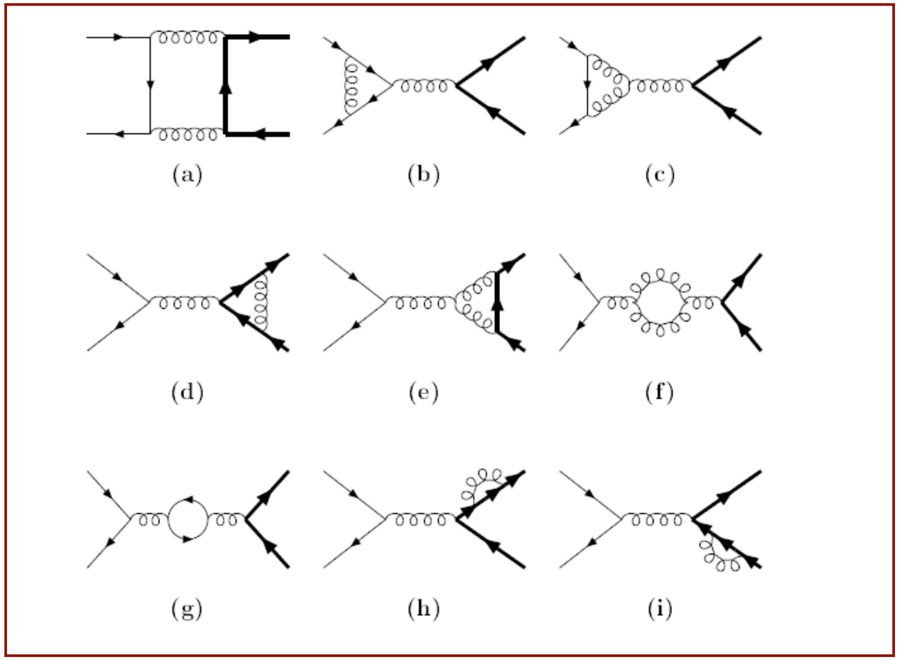


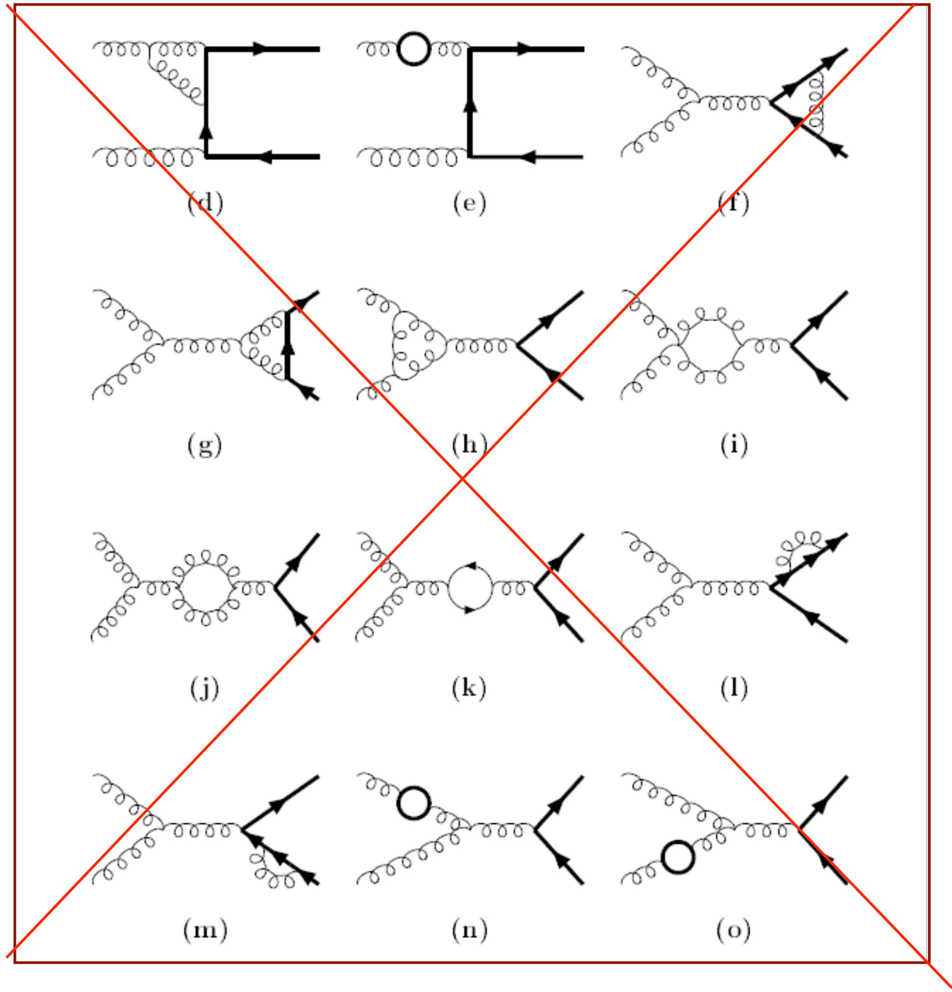




Finally – resolved photon NLO corrections







gg channel tested with RAPGAP – non-important

The structure of the cross sections in NLO QCD

$$\frac{\sigma^{NLO}}{dt_1 du_1} = \frac{\alpha\alpha_S^2 e_q^2}{s^2}\left(\sigma_{Hard}^{non-abelian} + \sigma_{Hard}^{QED} + \sigma_{SV}^{non-abelian} + \sigma_{SV}^{QED} + \sigma^F \log(\frac{\mu_f^2}{m^2})\right)$$

$$\frac{\Delta\sigma^{NLO}}{dt_1 du_1} = \frac{\alpha\alpha_S^2 e_q^2}{s^2}\left(\Delta\sigma_{Hard}^{non-abelian} + \Delta\sigma_{Hard}^{QED} + \Delta\sigma_{SV}^{non-abelian} + \Delta\sigma_{SV}^{QED} + \Delta\sigma^F \log(\frac{\mu_f^2}{m^2})\right)$$

Kinematics:

$s + t_1 + u_1 = 0$ ⟵ for LO and „SV" NLO part

$s + t_1 + u_1 = s_4$ ⟵ for „Hard" NLO part (integration over s_4)

$t_1 = t - m^2 \qquad u_1 = u - m^2$

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 big problem for COMPASS: D – depolarization factor

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

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

Neglecting Q^2 in this parts is not a big sin – unimportant effect ☺

$a_{LL}^{NLO,\gamma g}$ Calculated in NLO with the assumptions of photo-production.

kinematics

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

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

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

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

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

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

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

$$2 \to 2 \qquad \Rightarrow \qquad s_1 + t_1 + u_1 = 0$$

$$2 \to 3 \qquad \Rightarrow \qquad s_1 + t_1 + u_1 = s_4$$

Procedure in LO

$$A = \frac{\int \Delta G(x_g)\Delta\hat{\sigma}^{LO} du_1 dt_1}{\int G(x_g)\hat{\sigma}^{LO} du_1 dt_1} = \frac{\int \frac{\Delta G}{G}\frac{\Delta\hat{\sigma}^{LO}}{\hat{\sigma}^{LO}} G(x_g)\hat{\sigma}^{LO} du_1 dt_1}{\int G(x_g)\hat{\sigma}^{LO} du_1 dt_1}$$

$$A = < \frac{\Delta G}{G}\frac{\Delta\sigma^{LO}}{\sigma^{LO}} > = < \frac{\Delta G}{G} >< \frac{\Delta\hat{\sigma}^{LO}}{\hat{\sigma}^{LO}} > = < \frac{\Delta G}{G} >< a_{LL}^{LO} >$$

$$< \frac{\Delta G}{G} > = \frac{\int \frac{\Delta G}{G} a_{LL}^{LO} G(x_g)\hat{\sigma}^{LO} du_1 dt_1}{\int a_{LL}^{LO} G(x_g)\hat{\sigma}^{LO} du_1 dt_1} = \frac{\Delta G}{G}(< x_g >)$$

$$\frac{\Delta G}{G} \approx a(x_g - < x_g >) + b \qquad b = \frac{\Delta G}{G}(< x_g >)$$

$$< x_g > = \frac{\int x_g a_{LL}^{LO} G(x_g)\hat{\sigma}^{LO} du_1 dt_1}{\int a_{LL}^{LO} G(x_g)\hat{\sigma}^{LO} du_1 dt_1}$$

$$< a_{LL}^{LO} > = \frac{\int a_{LL}^{LO} G(x_g)\hat{\sigma}^{LO} du_1 dt_1}{\int G(x_g)\hat{\sigma}^{LO} du_1 dt_1}$$

event in MC:
PS off - u_1 and t_1 define event
$s_1+u_1+t_1=0$

The role of MC and theoretical input

- a_{LL} alows to calculate gluon polarization from measured asymmetries
- COMPASS is using weighted method - and a_{LL} (theory input) is used in the weight. To calculate a_{LL} MC generator with simulation of the apparatus + reconstruction is used; then a_{LL} is parameterized and run on real data to estimate a_{LL} event by event.
- The weight has impact on value, statistical error and $\langle x_G \rangle$!
- Changing approximation (from a_{LL} in LO to NLO) can have a serious consequence on importance and precision of the COMPASS result!

Neural Network parameterization - correlation 80%

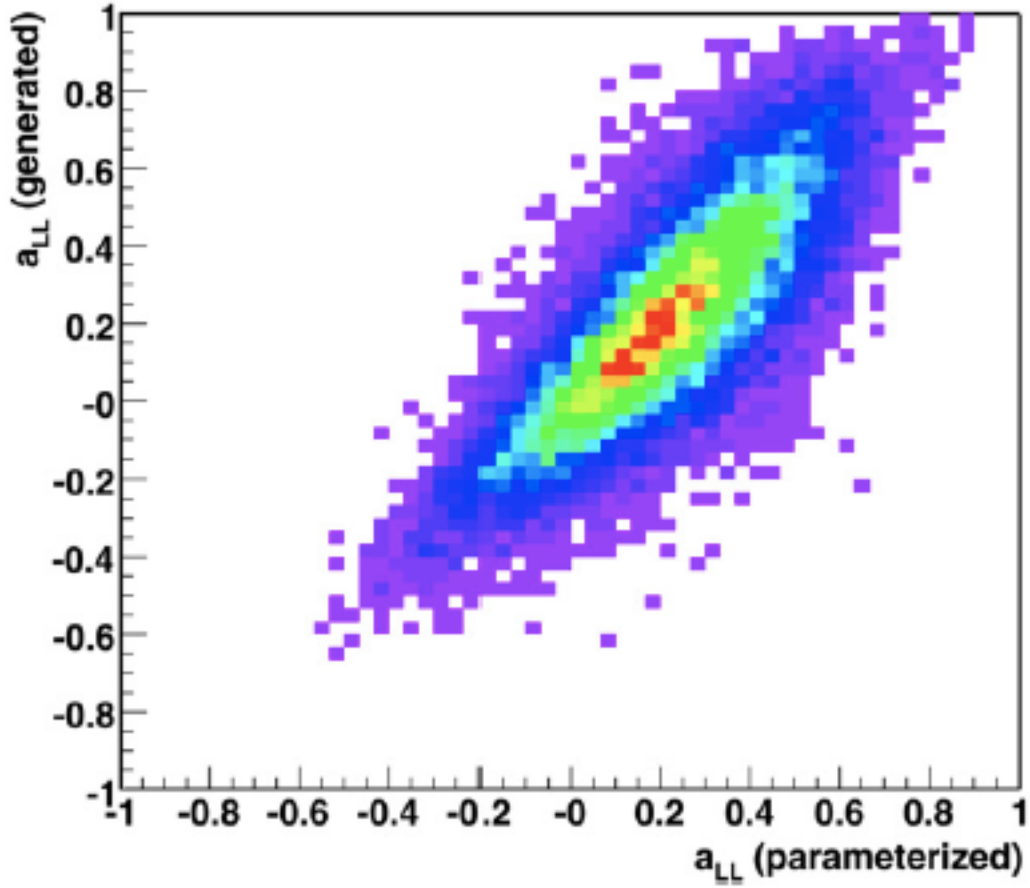


Fig. 2. Correlation between the generated analysing power a_{LL}^{gen} and the analysing power parameterised by neural network a_{LL}^{par}.

Procedure in NLO

- MC with PS on to simulate phase space for real emissions
- events have s_1,u_1 and t_1 and $s_1+t_1+u_1 \neq 0$
- Method 1:
  event is defined by cc_{bar} system: u_1 and t_1 define event.
  Integrations over s_4 is performed from 0 up to $s_1+t_1+u_1$
- Method 2:
  event is defined by s_1 and $t_1(u_1)$ - only one charm observed.
  Integration over s_4 is performed from 0 up to $s_1+t_1+u_1$

$$A = \frac{\int \Delta G(x_g)(\Delta\hat{\sigma}^{LO} + \Delta\hat{\sigma}^{NLO}_{SV}) du_1 dt_1 + \int \Delta G(x'_g) \Delta\hat{\sigma}^{NLO}_{hard} ds_4 du_1 dt_1}{\int G(x_g)(\hat{\sigma}^{LO} + \hat{\sigma}^{NLO}_{SV}) du_1 dt_1 + \int G(x'_g) \hat{\sigma}^{NLO}_{hard} ds_4 du_1 dt_1}$$

$$= \frac{\int \Delta G(x_g) \left[\Delta\hat{\sigma}^{LO} + \Delta\hat{\sigma}^{NLO}_{SV} + \int \frac{\Delta G(x'_g)}{\Delta G(x_g)} \Delta\hat{\sigma}^{NLO}_{hard} ds_4 \right] du_1 dt_1}{\int G(x_g) \left[\hat{\sigma}^{LO} + \hat{\sigma}^{NLO}_{SV} + \int \frac{G(x'_g)}{G(x_g)} \hat{\sigma}^{NLO}_{hard} ds_4 \right] du_1 dt_1}$$

$$\hat{\sigma}^{NLO}(t_1, u_1) = \hat{\sigma}^{LO} + \hat{\sigma}^{NLO}_{SV} + \int \frac{G(x'_g)}{G(x_g)} \hat{\sigma}^{NLO}_{hard} ds_4$$

$$\Delta\hat{\sigma}^{NLO}(t_1, u_1) = \Delta\hat{\sigma}^{LO} + \Delta\hat{\sigma}^{NLO}_{SV} + \int \frac{\Delta G(x'_g)}{\Delta G(x_g)} \Delta\hat{\sigma}^{NLO}_{hard} ds_4$$

$$A = \frac{\int \frac{\Delta G}{G} \frac{\Delta\hat{\sigma}^{NLO}(t_1, u_1)}{\hat{\sigma}^{NLO}(t_1, u_1)} G(x_g) \hat{\sigma}^{NLO}(t_1, u_1) du_1 dt_1}{\int G(x_g) \hat{\sigma}^{NLO}(t_1, u_1) du_1 dt_1}$$

$$A = \frac{\int \frac{\Delta G}{G} a^{NLO}_{LL} G(x_g) \hat{\sigma}^{NLO}(t_1, u_1) du_1 dt_1}{\int G(x_g) \hat{\sigma}^{NLO}(t_1, u_1) du_1 dt_1}$$

NLO - method 1
event is defined by u_1 and t_1
$s_1^{el} = -u_1 - t_1$ define x_g

method 1

- Advantage: similar to theoretical calculations in bins - gluons convoluted with hard part in the integration over s_4 - good for collinear divergence removal procedure
- Disadvantage: shape of gluon distribution is required - model of gluon polarization needed!
- Assumption done: MC with PS on reproduces correctly the event distributions produced according to $\sigma^{NLO} * G(s_1^{el})/G(s_1)$

$$A = \frac{\int \Delta G(x_g)(\Delta\hat{\sigma}^{LO} + \Delta\hat{\sigma}^{NLO}_{SV})ds_1 dt_1 + \int \Delta G(x'_g)\Delta\hat{\sigma}^{NLO}_{hard} ds_4 ds_1 dt_1}{\int G(x_g)(\hat{\sigma}^{LO} + \hat{\sigma}^{NLO}_{SV})ds_1 dt_1 + \int G(x'_g)\hat{\sigma}^{NLO}_{hard} ds_4 ds_1 dt_1}$$

$$\hat{\sigma}^{NLO}(t_1, s_1) = \hat{\sigma}^{LO} + \hat{\sigma}^{NLO}_{SV} + \int \hat{\sigma}^{NLO}_{hard} ds_4$$

$$\Delta\hat{\sigma}^{NLO}(t_1, s_1) = \Delta\hat{\sigma}^{LO} + \Delta\hat{\sigma}^{NLO}_{SV} + \int \Delta\hat{\sigma}^{NLO}_{hard} ds_4$$

$$A = \frac{\int \frac{\Delta G}{G} \frac{\Delta\hat{\sigma}^{NLO}(t_1, s_1)}{\hat{\sigma}^{NLO}(t_1, s_1)} G(x_g)\hat{\sigma}^{NLO}(t_1, s_1) dt_1 ds_1}{\int G(x_g)\hat{\sigma}^{NLO}(t_1, s_1) dt_1 ds_1}$$

$$A = \frac{\int \frac{\Delta G}{G} a^{NLO}_{LL} G(x_g)\hat{\sigma}^{NLO}(t_1, s_1) dt_1 ds_1}{\int G(x_g)\hat{\sigma}^{NLO}(t_1, s_1) dt_1 ds_1}$$

NLO - method 2
event is defined by s_1 and $t_1(u_1)$
s_1 define x_g

method 2

- Advantage: model of gluons is not needed. Method is similar to LO approach
- Disadvantage: hard part is not convoluted with gluon distribution what is slightly inconsistent. Kinematics of the second charm in the event ignored - not observed as in real data.
- Assumption done: MC with PS on reproduces correctly the event distributions produced according to σ^{NLO}

method 1 - examples

- Model of the gluon polarization:
  1. $\Delta G/G$=const,
  COMPASS QCD fits:
  2 - positive gluons
  3 - negative gluons
- used to demonstrate the potential differences between methods based on the same MC events, good for systematic studies

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Gluon polarisation in the nucleon and longitudinal double spin asymmetries from open charm muoproduction

COMPASS Collaboration

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- LO analysis recently published (PLB 676(2009)31)
- Weighted asymmetries in bins also published!

Table 2
The asymmetries $A^{\gamma N \to D^0 X}$ in bins of $p_T^{D^0}$ and E_{D^0} for the D^0 and D^* sample combined, together with the averages of several kinematic variables. Only the statistical errors are given. The relative systematic uncertainty is 20% which is 100% correlated between the bins.

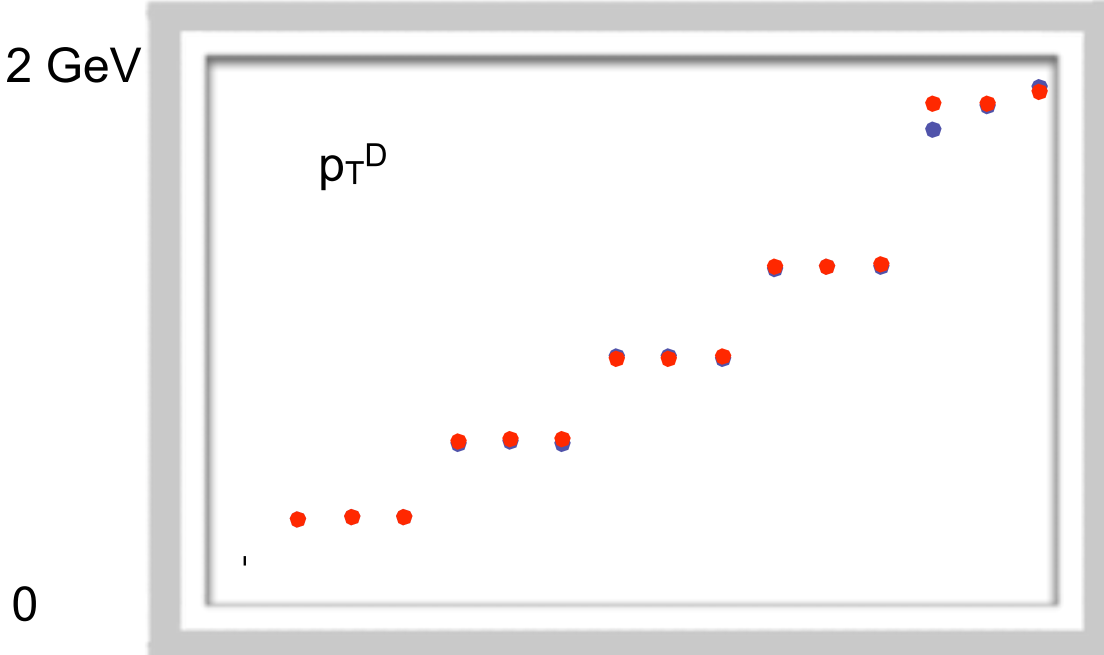
Bin limits		$A^{\gamma N \to D^0 X}$	$\langle y \rangle$	$\langle Q^2 \rangle$ (GeV/c)^2	$\langle p_T^D \rangle$ (GeV/c)	$\langle E_D \rangle$ (GeV)	$D(\langle X \rangle)$	$a_{LL}(\langle X \rangle)$
p_T^D (GeV/c)	E_D (GeV)							
0–0.3	0–30	−1.34 ± 0.85	0.47	0.50	0.19	24.8	0.57	0.37
0–0.3	30–50	−0.27 ± 0.52	0.58	0.75	0.20	39.2	0.70	0.48
0–0.3	> 50	−0.07 ± 0.66	0.67	1.06	0.20	60.0	0.80	0.61
0.3–0.7	0–30	−0.85 ± 0.51	0.47	0.47	0.50	25.1	0.56	0.26
0.3–0.7	30–50	0.09 ± 0.29	0.58	0.65	0.51	39.4	0.71	0.34
0.3–0.7	> 50	−0.20 ± 0.37	0.67	0.68	0.50	59.6	0.80	0.46
0.7–1	0–30	−0.47 ± 0.56	0.48	0.53	0.85	25.2	0.58	0.13
0.7–1	30–50	−0.49 ± 0.32	0.58	0.66	0.85	39.1	0.70	0.17
0.7–1	> 50	1.23 ± 0.43	0.68	0.73	0.84	59.4	0.81	0.26
1–1.5	0–30	−0.87 ± 0.48	0.50	0.49	1.21	25.7	0.60	0.01
1–1.5	30–50	−0.24 ± 0.25	0.60	0.62	1.22	39.5	0.73	0.00
1–1.5	> 50	−0.18 ± 0.34	0.69	0.77	1.22	59.3	0.83	0.04
> 1.5	0–30	0.83 ± 0.71	0.52	0.51	1.77	26.2	0.63	−0.13
> 1.5	30-50	0.18 ± 0.28	0.61	0.68	1.87	40.0	0.74	−0.20
> 1.5	> 50	0.44 ± 0.33	0.71	0.86	1.94	59.9	0.84	−0.24

Asymmetries from COMPASS

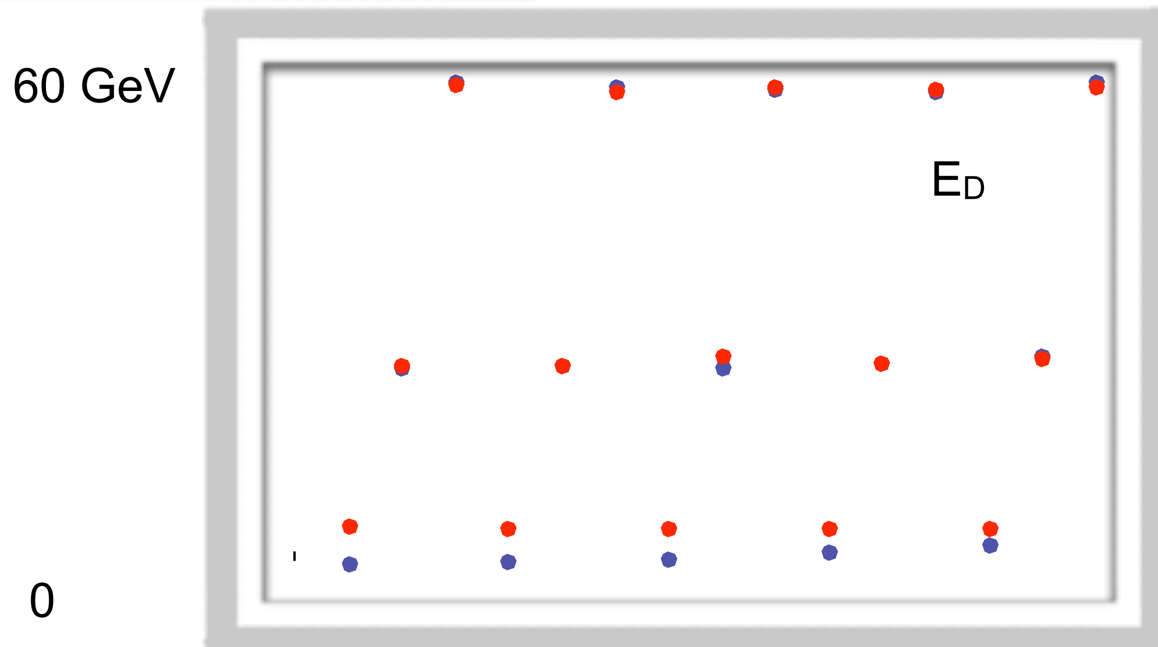
- 15 bins in E_D and p_T^D
- COMPASS LO result is weighted - $w = fP_b s/(s+b) a_{LL}$
- Asymmetries are weighted -$w = fP_b s/(s+b) D$ in the following way: $A \sim (\sum w - \sum w')/(\sum w^2 + \sum w'^2)$
- The weight does not contain a_{LL} to avoid "theory" input (LO); instead of D which is measured quantity is used
- Weighted asymmetries allow to minimize acceptance corrections
- Indeed: fully weighted result (event by event) and results obtained from bins with weighted asymmetries and given $\langle a_{LL} \rangle$ are nearly identical (higher error for second case)
- The weight in the asymmetry implies $A \sim \langle \Delta G/G \rangle \langle a_{LL}\, w^2 \rangle$!
- Also $\langle x_G \rangle$ is averaged effectively with a_{LL}^2 in the weight

MC for NLO calculations

- Talk is not on behalf of COMPASS - pure MC generator (aroma) has been used -no acceptance/reconstruction/ apparatus simulation used.
- But - it is not crucial thanks to weighting!
- Tested and compared for LO results
- PDF unpolarized used: MRST2004 LO/NLO, GRV98 LO
- Scale: $2m_c$
- No special cuts except cut on energy of the E_D
- MC used only for signal simulation: PSoff/on (LO/NLO)
- s/(s+b) assumed 1 (no background simulation) - therefore statistical error is smaller than in COMPASS analysis



p_T^D and E_D in bins from COMPASS
Comparison between pure MC generator Aroma PS on (blue) and measured by COMPASS (red)
(15 bins)

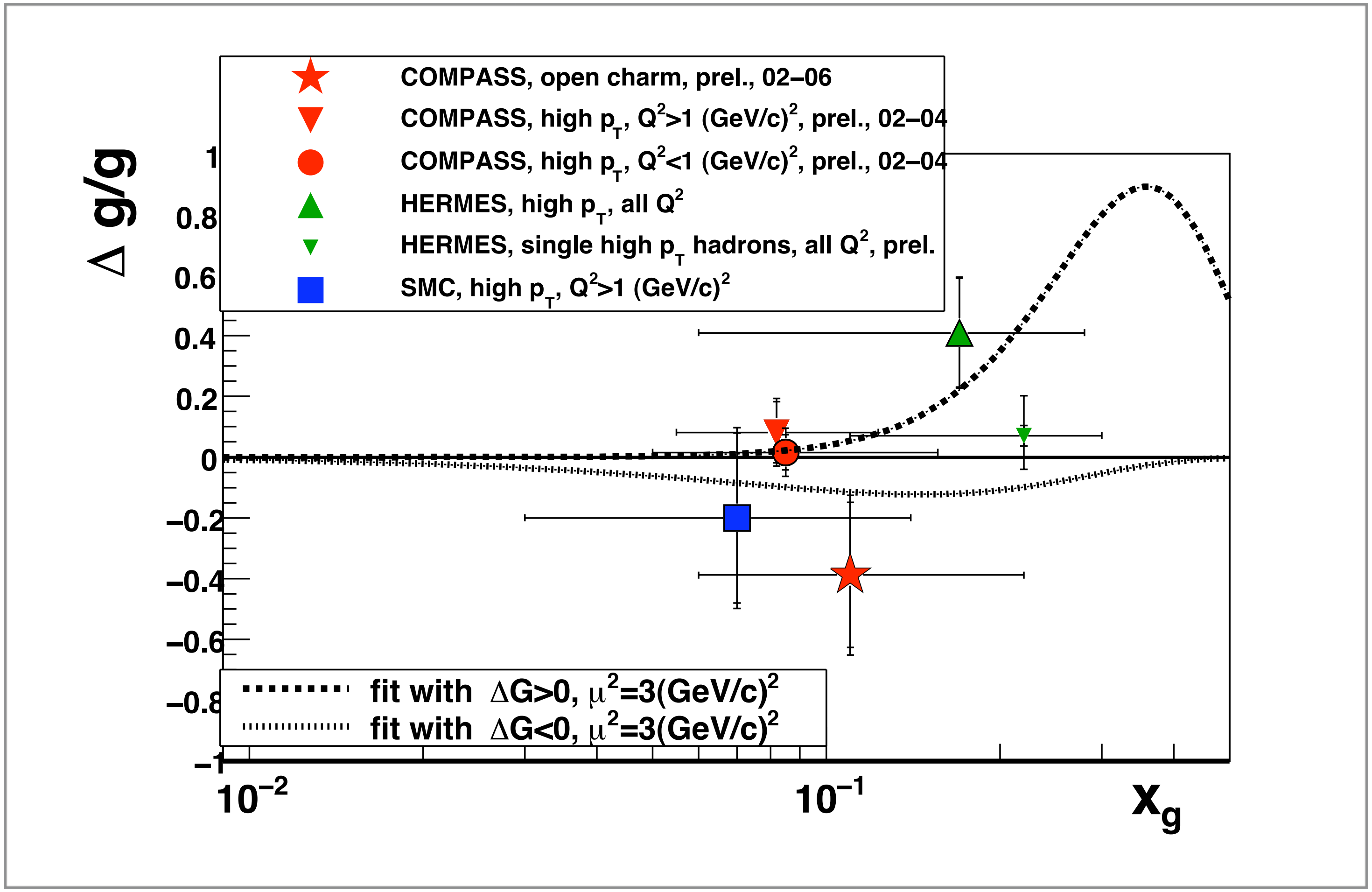


ΔG/G result in NLO approximation

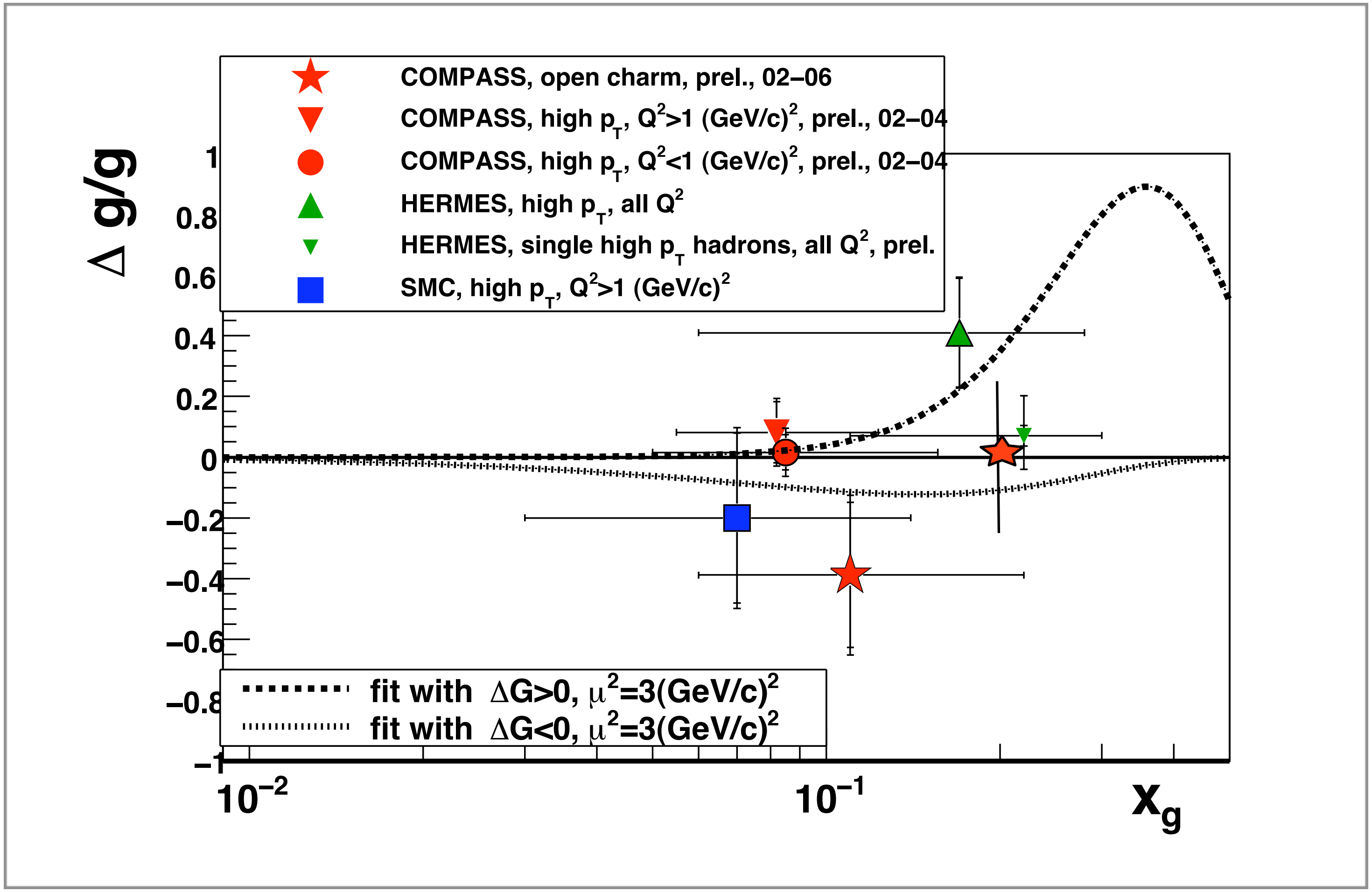
based on 2002-2006 COMPASS data and published asymmetries in bins (PLB 676(2009)31)

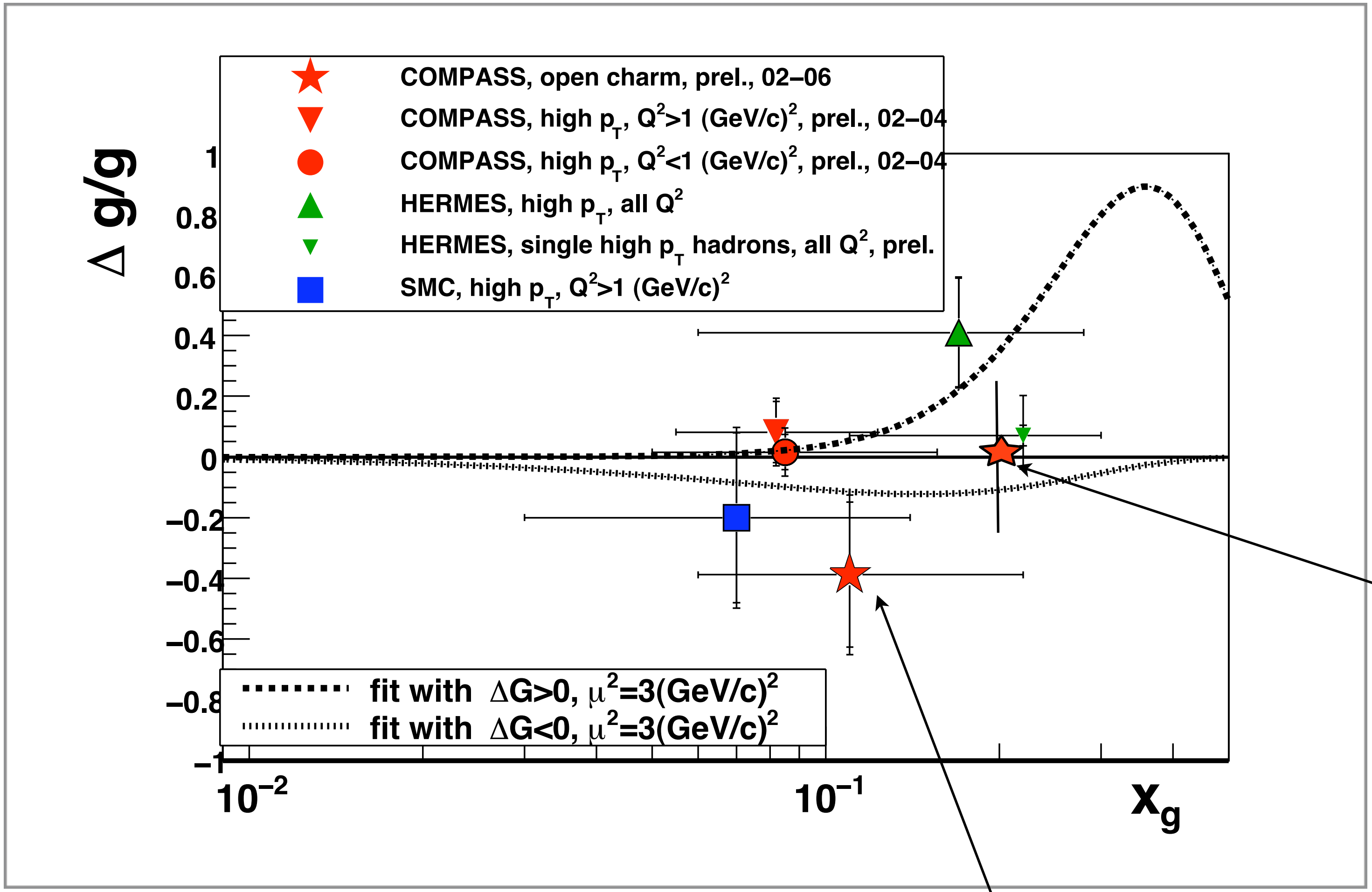
- LO weighted from PLB ΔG/G=-0.49±0.27
- LO (from asym. and a_{LL} from PLB) ΔG/G=-0.42±0.28
- LO (MC PSoff, asym. from PLB): ΔG/G=-0.47±0.23

- NLO (MC PSon, asym. from PLB)
- method 2: ΔG/G=+0.032±0.231
- ΔG/G=const (method 1): ΔG/G=-0.051±0.239
- ΔG/G>0, Compass fit (method 1): ΔG/G=-0.036±0.239
- ΔG/G<0, Compass fit (method 1): ΔG/G=-0.057±0.240



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
fit with ΔG>0, μ^2=3(GeV/c)^2
fit with ΔG<0, μ^2=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



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
Δ g/g
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
fit with ΔG>0, μ²=3(GeV/c)²
fit with ΔG<0, μ²=3(GeV/c)²
10⁻²
10⁻¹
x_g
NLO
LO

Conclusions

- NLO corrections for a_{LL} (PGF channel) for COMPASS open-charm analysis have been calculated based on MC PSon events
- Two methods have been discussed; one is independent on the assumption about shape of gluons
- Preliminary result for gluon polarization has been shown
- quark initiated processes - not yet taken into account
- More systematic studies are needed
- NN a_{LL} parameterization has been calculated; correlation is smaller: 58%