Measurement of the gluon polarization in the nucleon via spin asymmetries of charmed mesons at COMPASS

Jörg Pretz

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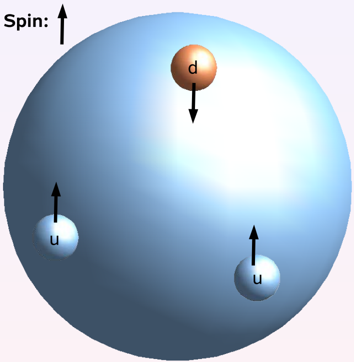
on behalf of the
COMPASS collaboration

Hamburg, May 2009

Proton Spin Structure . . .



- . . . looks simple in static quark model

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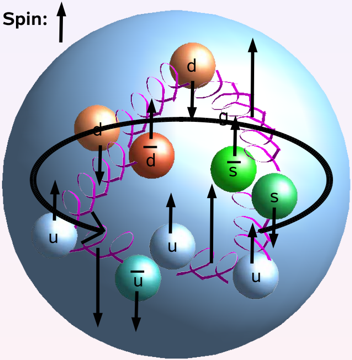

- . . . looks simple in static quark model
- . . . much more complicated in QCD

Proton Spin Structure

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

Spin: Quarks, Gluons

orbital angular momentum: Quarks, Gluons

Proton Spin Structure

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

Spin: $\frac{1}{2}\Delta\Sigma$ (Quarks), ΔG (Gluons)

orbital angular momentum: L_q (Quarks), L_g (Gluons)

Focus in this talk:

Measurement of the helicity contribution of gluons, ΔG!

- from open charm double spin asymmetries
- at the COMPASS experiment

Outline

1. Motivation: Where does the Nucleon Spin come from?

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4. ΔG: Analysis & Results

Outline

Motivation:
Where does the Nucleon Spin come from?

Nucleon Spin Puzzle

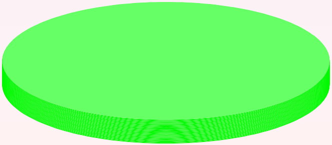
$SU_{spin}(2) \times SU_{flavor}(3)$ wave function:

$$|p\uparrow> = \frac{1}{\sqrt{18}}(2|u\uparrow u\uparrow d\downarrow> - |u\uparrow u\downarrow d\uparrow> - |u\uparrow d\uparrow u\downarrow> + \text{permutations})$$

$$\begin{aligned}
\Delta u &= <p\uparrow|N_{u\uparrow} - N_{u\downarrow}|p\uparrow> = \frac{30}{18} - \frac{6}{18} = \frac{4}{3} \\
\Delta d &= <p\uparrow|N_{d\uparrow} - N_{d\downarrow}|p\uparrow> = \frac{6}{18} - \frac{12}{18} = -\frac{1}{3}
\end{aligned}$$

$$\Delta\Sigma = \Delta u + \Delta d = 1$$

Static Quark Model ($\Delta\,\Sigma$ = 1)



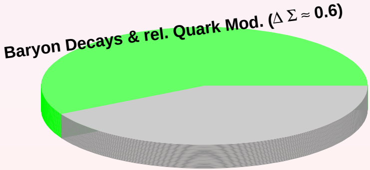
Nucleon Spin Puzzle

Weak Baryon decays are related to Δq:

$n \rightarrow p$:	$(\Delta u + \Delta\bar{u}) - (\Delta d + \Delta\bar{d})$	$= g_A = 1.2601 \pm 0.0025$
$\Xi^- \rightarrow \Lambda$:	$(\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) - 2(\Delta s + \Delta\bar{s})$	$= 0.58 \pm 0.03$

Assumption $\Delta s + \Delta\bar{s} = 0 \Rightarrow$

$$\Delta\Sigma = (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) = 0.58 \pm 0.03$$



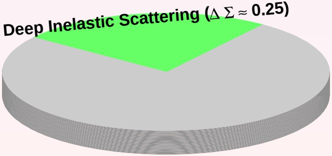
Nucleon Spin Puzzle

Polarized Deep Inelastic Scattering (**p**DIS)

$$\vec{l} + \vec{N} \rightarrow l' + X$$

provides additional equation.

- Assumption $\Delta s + \Delta\bar{s} = 0$ can be dropped.
- In addition: Information on $\Delta q(\mathbf{x})$, where $0 < x < 1$ is the momentum fraction of quark in the nucleon ($\Delta q = \int_0^1 \Delta q(\mathbf{x})\, dx$)



Nucleon Spin Puzzle

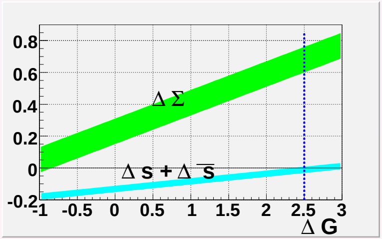
But NLO[1] QCD [2] corrections make interpretation of $\Delta\Sigma$ difficult:

LO	$\rightarrow$	NLO
$\Delta\Sigma$	$\rightarrow$	$\Delta\Sigma - \frac{3\alpha_s}{2\pi}\Delta G$
Δs	$\rightarrow$	$\Delta s - \frac{\alpha_s}{2\pi}\Delta G$

α_s : strong coupling constant

$\Delta g(x_g) = g^{\uparrow}(x_g) - g^{\downarrow}(x_g)$, **polarized gluon distribution**

$\Delta G = \int_0^1 \Delta g(x_g) dx_g$



[1] next-to-leading order

[2] Quantum Chromo Dynamics

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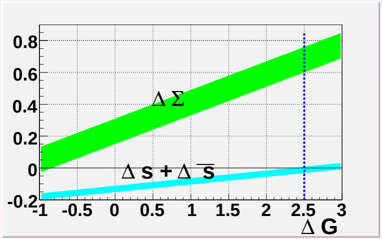


For $\Delta G \approx 2.5 \to$,
$\Delta\Sigma \approx 0.6$ and $\Delta s \approx 0$

$\to$ Measure ΔG !!!

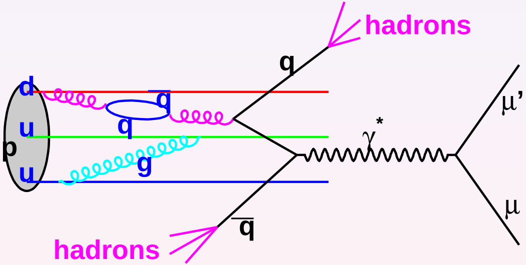
[1] next-to-leading order
[2] Quantum Chromo Dynamics

How to measure ΔG?

How to access the gluon distribution?

Use hadronic final state in deep inelastic scattering:

$$\vec{\mu} + \vec{N} \rightarrow \mu' + \text{hadrons} + X$$



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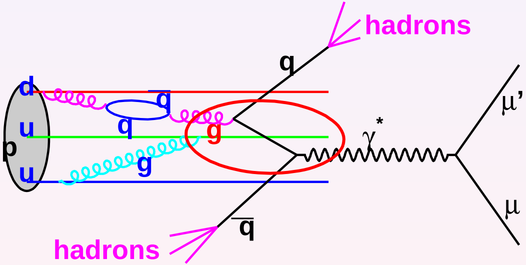
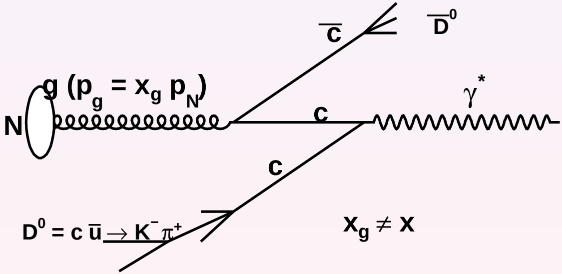


How to tag Photon -Gluon- Fusion sub-process

$$\gamma^* g \rightarrow q\bar{q}\ ?$$

How to tag $\gamma^* g \rightarrow q\bar{q}$?

hadrons	advantage	disadvantage
open charm	clean tag*	low statistics
high p_T hadron (pairs)	higher statistics	background processes



* no intrinsic charm, no charm quarks in string fragmentation

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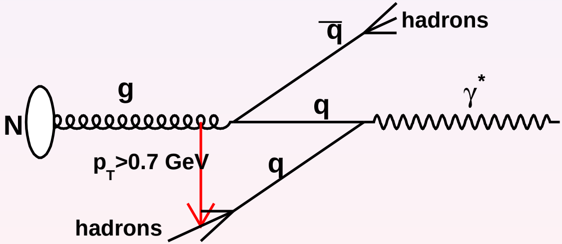

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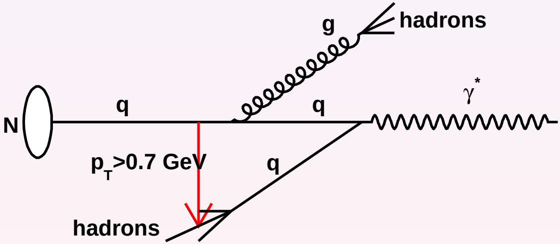

QCD Compton process ($q\gamma^* \rightarrow qg$)one of background processes

What is needed to measure ΔG?

- to allow interpretation in Quark Parton Model and perturbative QCD
  $\longrightarrow$ high energy lepton beam

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What is needed to measure ΔG?

- to allow interpretation in Quark Parton Model and perturbative QCD
  $\rightarrow$ high energy lepton beam
- To tag gluon, look at
  - charmed hadrons
  - hadrons with large transverse momentum
    $\rightarrow$ good hadron identification
- To learn something about spin, measure double spin asymmetries
  $\rightarrow$ polarized beam and target

$$A^{raw} = \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} \propto \frac{\Delta g}{g}$$

$N^{\uparrow\downarrow}$: beam ($\uparrow$), target ($\downarrow$)

number of events (high p_T or open charm)

The COMPASS Experiment

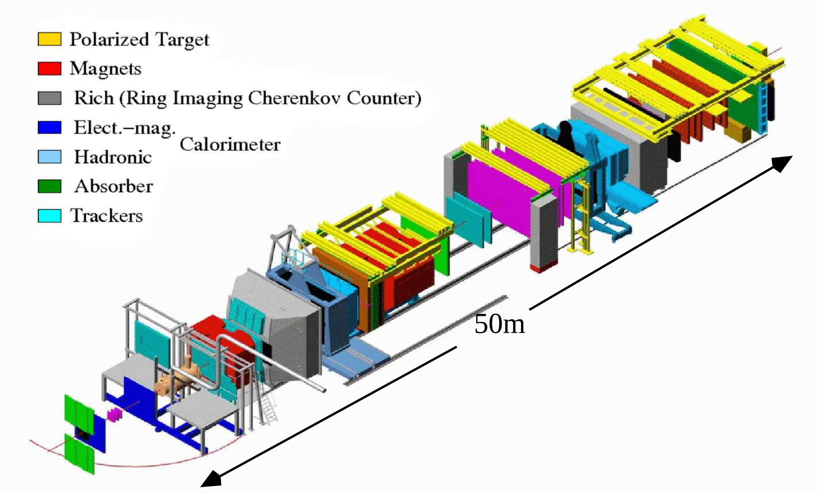
COMPASS

CO mmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

$\approx$ 200 physicists
$\approx$ 30 institutes,
at CERN SPS

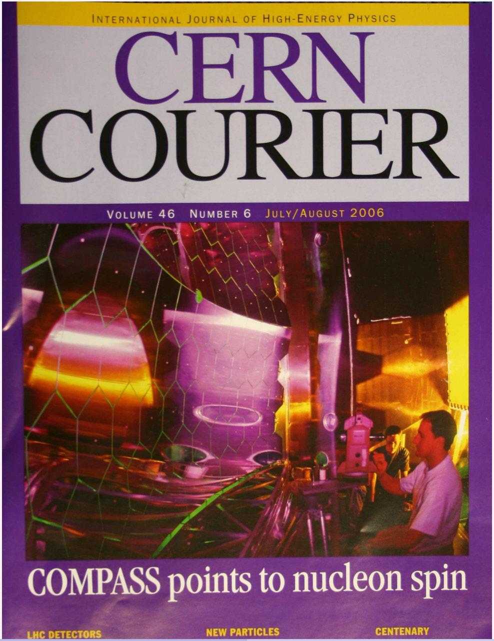

COMPASS

The COMPASS Experiment



Parameters of Experiment

Spectrometer:	Two stages 1 GeV $< p <$ 200 GeV tracking: Scifis, GEMs , Micromegas, Straws particle id.: K, π separation $9 < p < 60$ GeV with RICH ECAL,HCAL,μFilter Trigger on μ' and hadrons
Beam:	160 GeV μ , $2 \cdot 10^8/5$s, naturally polarized Pol $= -0.80 \pm 0.04$ 190 GeV hadrons, $2 \cdot 10^7/5$s,
pol. Target:	2×65 cm cells, oppositely polarized ^{6}LiD, Pol ≈ 0.5, DNP
unp. Target:	LH_2, Lead, ...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CERN
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COMPASS points to nucleon spin
LHC DETECTORS
NEW PARTICLES
CENTENARY

Summary: Experiment

- polarized μ beam of 160 GeV $\rightarrow$ Deep Inelastic scattering
- polarized target
- Two stage spectrometer
  - momentum range 1-200 GeV
  - particle id.

Fulfills all requirements to study
The Spin Structure of the Nucleon,
especially ΔG

Analysis & Results

Analysis

Simple: Measure double spin asymmetry

$$A^{raw} = \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} \propto \frac{\Delta g}{g}$$

and extract gluon polarisation $\frac{\Delta g}{g}$. But ...

$N^{\uparrow\downarrow}, N^{\uparrow\uparrow} \rightarrow \Delta g/g$

$$A^{raw} = \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} = P_B\, P_T\, f\, a_{LL} \frac{\sigma_{PGF}}{\sigma_{PGF} + \sigma_{bgd}} \frac{\Delta g}{g} + A^{bgd}$$

P_B	beam polarization ≈ -0.8
P_T	target polarization ≈ 0.5
f	dilution factor ≈ 0.4 for ^{6}LiD target
a_{LL}	asymmetry of partonic process $\vec{\mu} + \vec{g} \rightarrow \mu' + q + \bar{q}$ -0.5 to 0.6
$\frac{\sigma_{PGF}}{\sigma_{PGF}+\sigma_{bgd}}$	fraction of photon-gluon fusion process
	$0.5(D^*)$ 0.1 (D^0)
source of background	combinatorial background
determination of bgd	from D^* (D^0) mass spectrum
A^{bgd}	determined simultaneously

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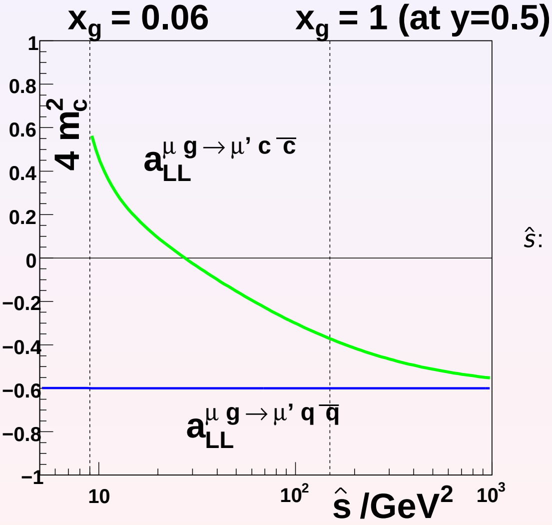
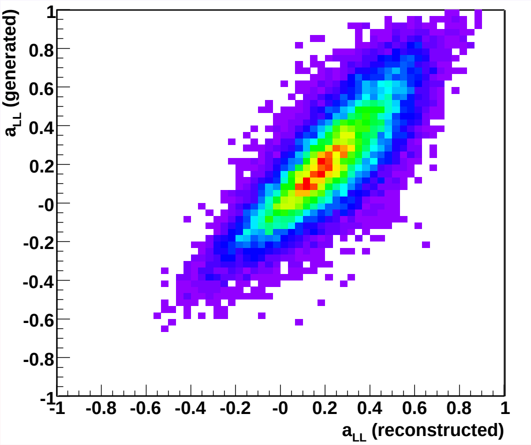


$\hat{s}$: CMS energy of $\gamma^* g$ system

$N^{\uparrow\downarrow}, N^{\uparrow\uparrow} \rightarrow \Delta g/g$

Determination of a_{LL}



- a_{LL} depends on kinematic variables not accessible experimentally
- a_{LL} is obtained from neural network trained on AROMA MC sample using LO QCD

$N^{\uparrow\downarrow}, N^{\uparrow\uparrow} \rightarrow \Delta g/g$

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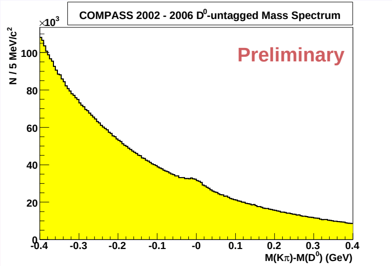
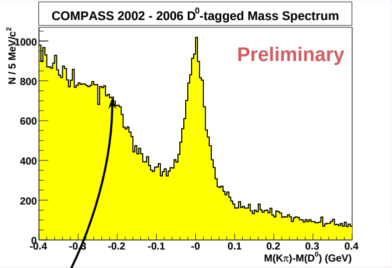
$D^0 \to K^-\pi^+$



$D^{*+} \to D^0\pi^+_{soft} \to K^-\pi^+\pi^+_{soft}$



$$R = \frac{\sigma_{PGF}}{\sigma_{PGF}+\sigma_{bgd}} \approx 0.1$$

$$R = \frac{\sigma_{PGF}}{\sigma_{PGF}+\sigma_{bgd}} \approx 0.5$$

+2 more channels :

- $D^0 \to K^-\pi^+ + (\pi^0)$
- $D^{*+} \to D^0\pi^+_{soft} \to K^-\pi^+\pi^+_{soft}$
  (with kaons below RICH threshold of 9 GeV)

$N^{\uparrow\downarrow}, N^{\uparrow\uparrow} \rightarrow \Delta g/g$

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- $\frac{\sigma_{PGF}}{\sigma_{PGF}+\sigma_{bgd}}$ is parameterized in terms of 10 variables, not just as a function of the reconstructed mass.

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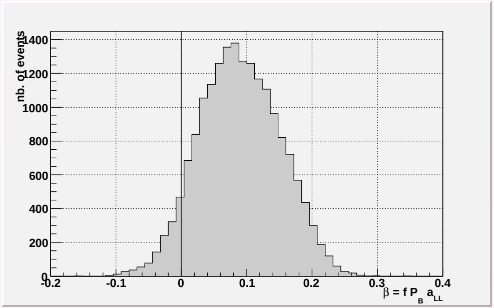
- $\frac{\sigma_{PGF}}{\sigma_{PGF}+\sigma_{bgd}}$ is parameterized in terms of 10 variables, not just as a function of the reconstructed mass.
- each event is weighted with its full analyzing power:

  $$f\ P_B\ a_{LL}\ \frac{\sigma_{PGF}}{\sigma_{PGF}+\sigma_{bgd}}$$

  $\approx$ 25% gain in FOM ,a_{LL} has positive and negative values:

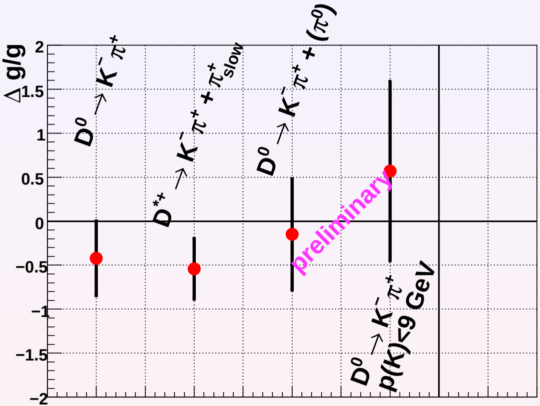


Highlights of the Analysis

- events are simultaneously weighted with "background" weight $(\ldots\frac{\sigma_{bgd}}{\sigma_{PGF}+\sigma_{bgd}})$
  $\Rightarrow$ allows simultaneous extraction of signal and background asymmetries,
  more efficient than side band subtraction
  details: J. P. & J. M. Le Goff, NIM A **602** (2009) 594, arXiv:0811.1426

Results

Results on $\Delta g/g$



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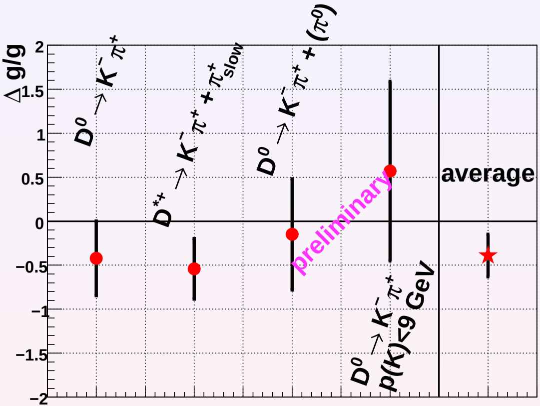
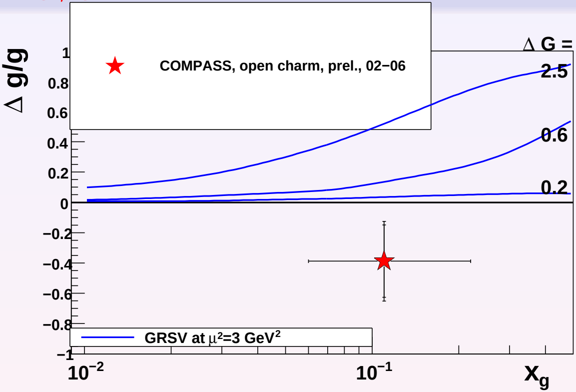


- First two results published in arXiv:0904.3209, acc. by PLB
- last two results are new
- Combined result: $\frac{\Delta g}{g} = -0.39 \pm 0.24(\text{stat}) \pm 0.11(\text{sys})$

Results on $\Delta g/g$



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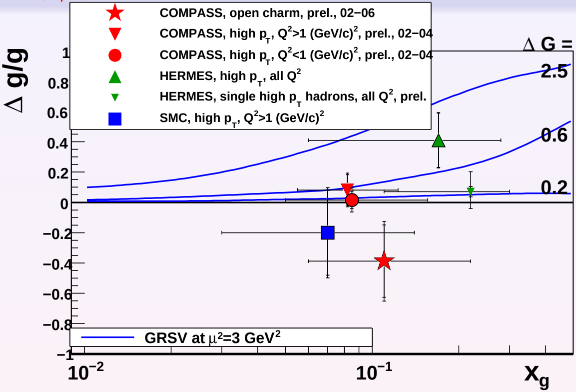

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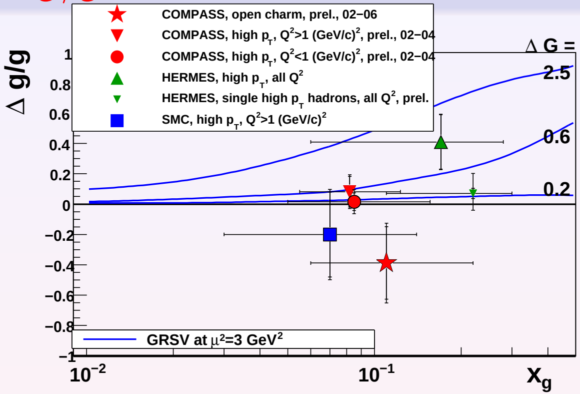

- Data show small values of $\Delta g/g$ at $x_g \approx 0.1$
  (at scale $\mu \approx \Sigma p_T^2 \approx 1 - 3$ GeV^2 (high p_T) and $\mu^2 \approx 4(m_c^2 + p_T^2) \approx 13$ GeV^2 (open charm))

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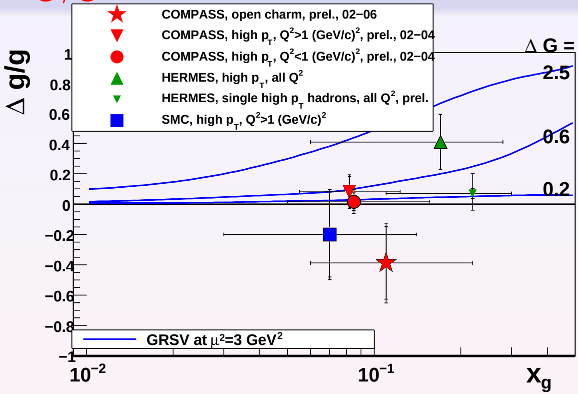

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- high p_T points are more model dependent because $R = \sigma_{PGF}/(\sigma_{PGF}+\sigma_{bgd})$ has to be determined from MC

Asymmetries

- Result is derived in LO QCD, because the partonic asymmetry a_{LL} is computed in LO.
- better to publish just asymmetry (in LO: $A = a_{LL}\frac{\Delta g}{g}$), which can be used by theorists to derive $\Delta g/g$ using their (NLO) a_{LL}.
- however: a_{LL}^{LO} varies a lot over our kinematic range, this is most likely also true for a_{LL}^{NLO}
- $\Rightarrow$ publish asymmetry in bins of E^{D^0} and $p_T^{D^0}$,
within bins a_{LL}^{LO} varies less (and hopefully a_{LL}^{NLO} too …?)
- Tables with asymmetries can be found in arXiv:0904.3209

Asymmetries

bin limits p_T^D / GeV/c^2	E_D / GeV	$A^{\gamma N \to D^0 X}$	$< y >$	$< Q^2 >$ / GeV/c^2	$< p_T^D >$ / GeV/c	$< E_D >$ / GeV	D	a_{LL}
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**

- systematic error 20%
- D^0 and D^* sample combined

Summary & Outlook

Summary & Outlook

Summary:

- Spin Puzzle $\Delta\Sigma_{DIS} \approx 0.25 \leftrightarrow \Delta\Sigma_{QM} \approx 0.6$ cannot be explained by large helicity contribution from gluons.
- $\Delta g/g$ small at $x_g \approx 0.1$
  scenarios with large $\Delta G \approx 2-3$ are excluded
- similar result form direct and indirect measurement (A_1 and $\vec{p}\vec{p}$)
- but error on first moment is so still large, that a gluon helicity contribution of 100% ($\Delta G = \int_0^1 \Delta g(x_g) dx_g = 0.5$) to the nucleon spin is not excluded
- shape $\Delta g(x_g)$ not well determined

Summary & Outlook

Outlook:

- COMPASS 2007 data not yet analyzed
- COMPASS opencharm NLO analysis in progress
- Global NLO analysis including all data
  (direct measurements are not yet included)
- Ideal tool to continue measurements on $\Delta g(x_g)$:
  Polarized Electron Nucleon Collider

Spare

Systematic Error: Open Charm

source	$\delta(\frac{\Delta g}{g})$	source	$\delta(\frac{\Delta g}{g})$
False asymmetry	0.05(**0.05**)	Beam polarisation P_μ	0.02
$S/(S+B)$	**0.07**(0.01)	Target polarisation P_t	0.02
a_LL	0.05(0.03)	Dilution factor f	0.02
	Total error	0.11(0.07)	
	stat. error	0.42(0.34)	

What's next?

How to improve our knowledge about $\Delta g(x_g)$?

- Ideal tool would be an polarized electron nucleon collider
- more physics cases: Generalized Parton Distributions, transversity, . . .

What's next?

collider	COMPASS
	(solid state target with 1 interaction length, BR($D^0 \to K\pi \approx 4\%$))
resolve D^0 decay vertex: clean D^0 sample	no secondary vertex: large comb. background
reconstruct both D mesons	reconstruction of 1 D meson

What's next?

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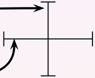
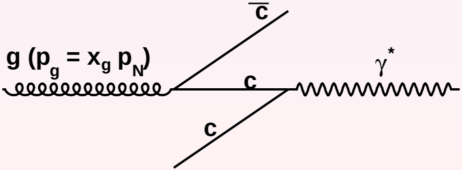
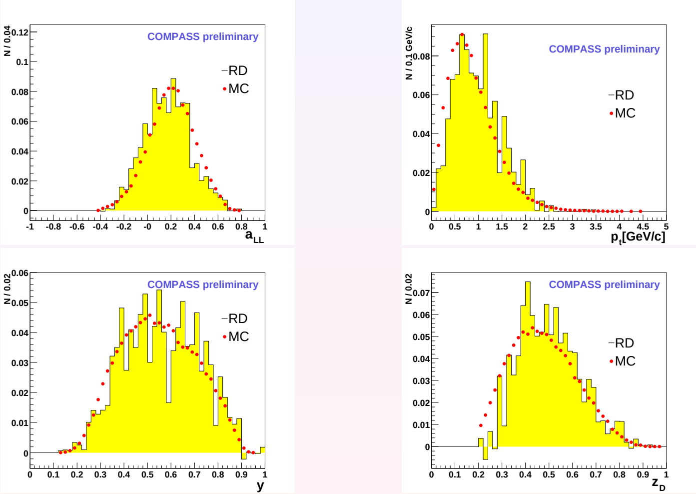
- Higher Figure of merit
- Better determination of x_g



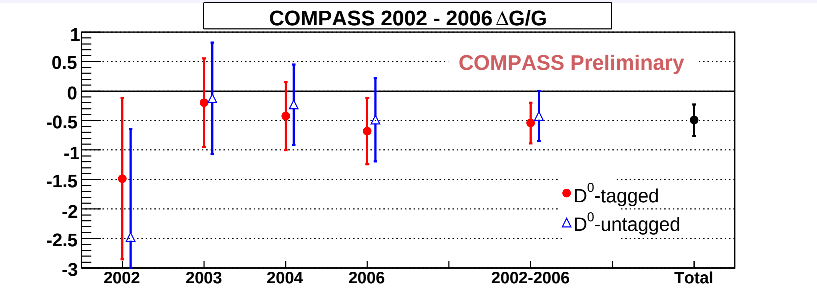


Open charm: Kinematic Distributions

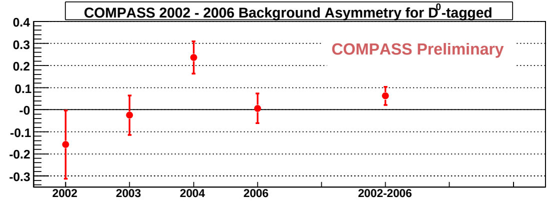
Comparison data vs. MC

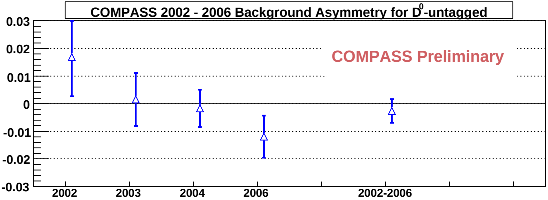


Result per year

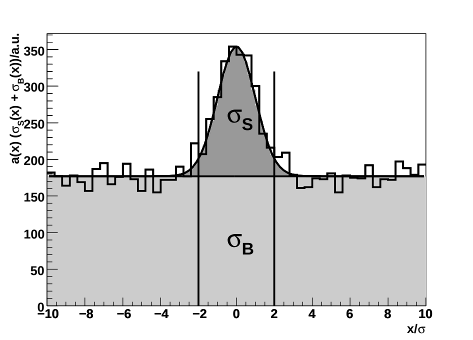


Res


COMPASS 2002 - 2006 Background Asymmetry for D0-tagged
COMPASS Preliminary
0.4
0.3
0.2
0.1
-0
-0.1
-0.2
-0.3
2002
2003
2004
2006
2002-2006


COMPASS 2002 - 2006 Background Asymmetry for D0-untagged
COMPASS Preliminary
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
2002
2003
2004
2006
2002-2006

How to determine an asymmetry?



- Classical Method:
  Select signal region:
  Determine

$$\frac{N^{\uparrow\downarrow}-N^{\uparrow\uparrow}}{N^{\uparrow\downarrow}+N^{\uparrow\uparrow}} = \alpha A_S + \beta A_B$$

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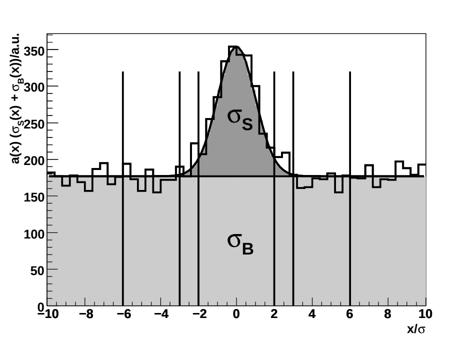

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  to determine A_B

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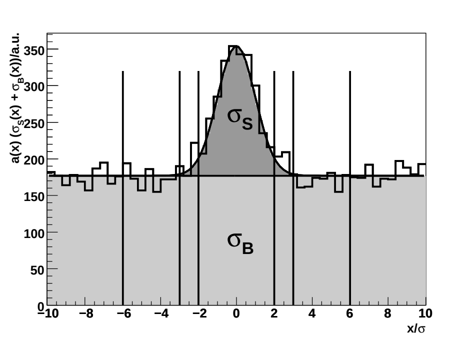

- Classical Method:
  Select signal region:
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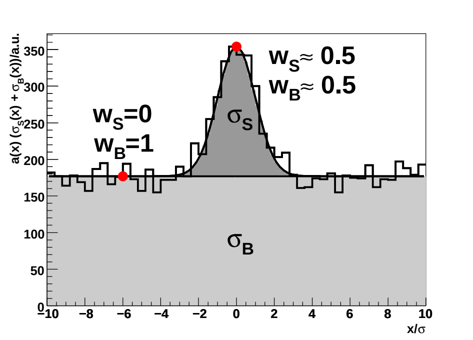
  $$\frac{N^{\uparrow\downarrow}-N^{\uparrow\uparrow}}{N^{\uparrow\downarrow}+N^{\uparrow\uparrow}} = \alpha A_S + \beta A_B$$
- select side bands
  to determine A_B
- Extract A_S

How to determine an asymmetry?

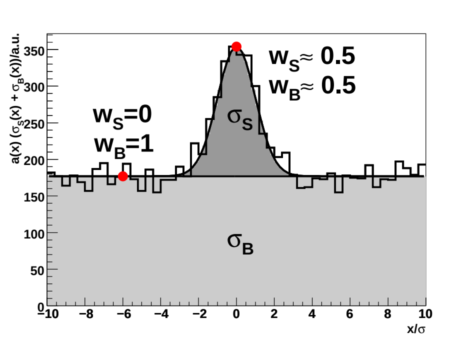


- Better Method:
  Weight every event:

$$w_S = \frac{\sigma_S}{\sigma_S+\sigma_B} \quad \text{signal,}$$

$$w_B = \frac{\sigma_B}{\sigma_S+\sigma_B} \quad \text{bgd}$$

How to determine an asymmetry?



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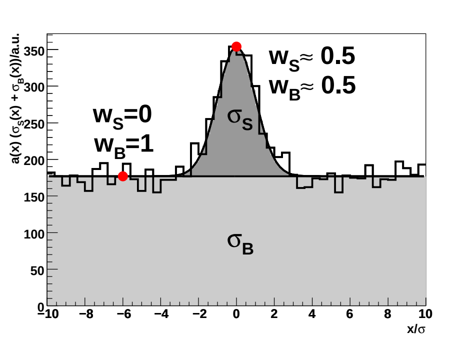
- determine

$$a_S = \frac{\sum^{\uparrow\downarrow} w_S - \sum^{\uparrow\uparrow} w_S}{\sum^{\uparrow\downarrow} w_S + \sum^{\uparrow\uparrow} w_S},$$

$$a_B = \frac{\sum^{\uparrow\downarrow} w_B - \sum^{\uparrow\uparrow} w_B}{\sum^{\uparrow\downarrow} w_B + \sum^{\uparrow\uparrow} w_B}$$

How to determine an asymmetry?



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- determine

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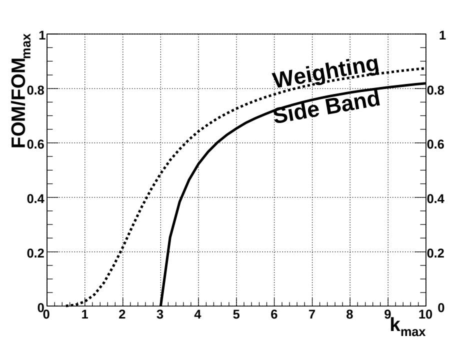
$$a_B = \frac{\sum^{\uparrow\downarrow} w_B - \sum^{\uparrow\uparrow} w_B}{\sum^{\uparrow\downarrow} w_B + \sum^{\uparrow\uparrow} w_B}$$

- $\Rightarrow A_S$ (and A_B)

How to determine an asymmetry?



data used: $-k_{max} - +k_{max}$

Advantages

- No arbitrary choice of background region
- Higher figure of merit (FOM$=1/\sigma^2_{A_S}$)
- This method reaches the FOM of the unbinned maximum likelihood method

J. P. & J. M. Le Goff, arXiv:0811.1426