Spin Overview

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Overview

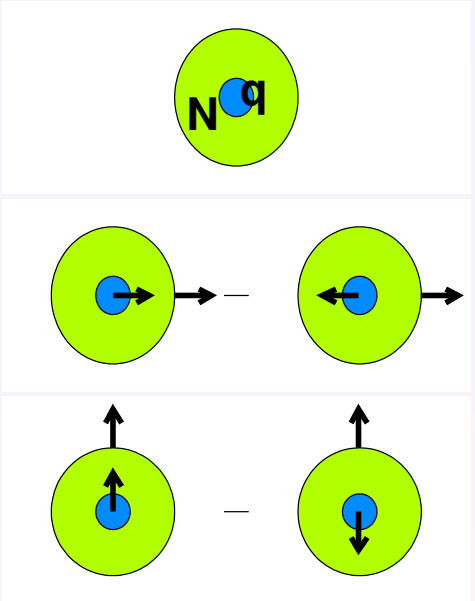
- Motivation
  - Quark Distributions
  - Spin Puzzle
- Gluon Polarization $\Delta G/G$, (Spin 1,2,3)
- Quark Helicity Distributions Δq, (Spin 1,3)
- Transversity Distributions $\Delta_T q$ (Spin 4,5,8,9)
- Generalized Parton Distribution (GPD)
  (Spin 6,7, Future of DIS 1,2, DIFF 9)

Quark Distributions

$q(x)$,
$q = u, d, s, \bar{u}, \bar{d}, \bar{s}, G(x)$

$\Delta q(x), \Delta G(x)$ (helicity)

$\Delta_T q(x)$ (transversity)



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  (at leading twist, integrated over p_T)

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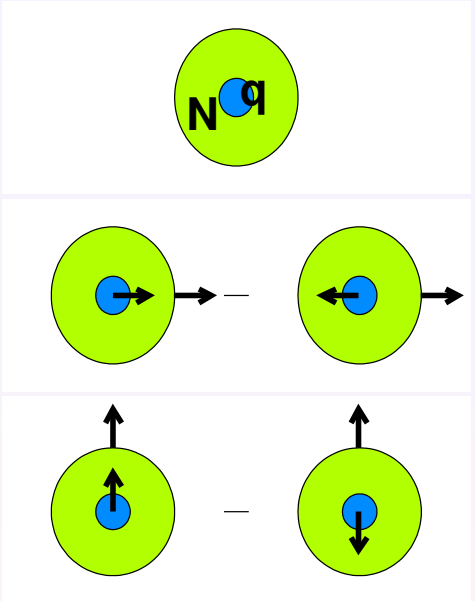

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good

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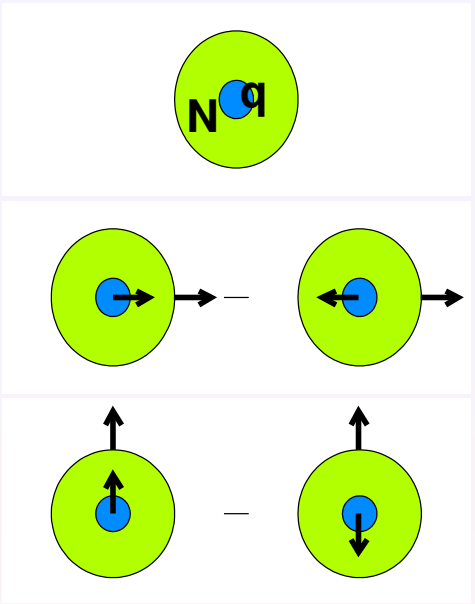

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fair,poor

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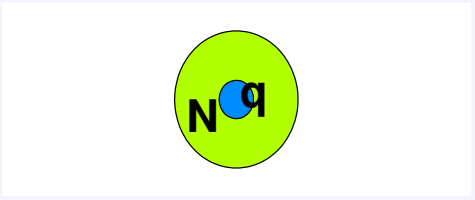

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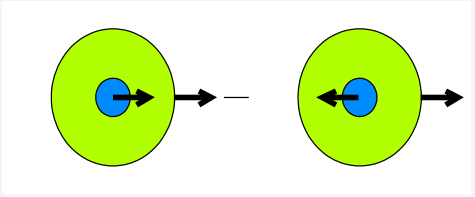

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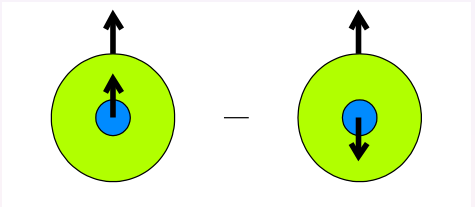

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Nucleon Spin Puzzle

$$\underbrace{\frac{1}{2}}_{\text{Spin}} = \underbrace{\tfrac{1}{2}\Delta\Sigma}_{\text{quarks}} + \underbrace{\Delta G}_{\text{gluons}} + \underbrace{L_q}_{\text{orbital angular momentum quarks}} + \underbrace{L_g}_{\text{gluons}}$$

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$$\begin{aligned}\Delta\Sigma &= \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s} \\ &= \Delta u_v + \Delta d_v + 2(\Delta\bar{u} + \Delta\bar{d}) + \Delta s + \Delta\bar{s}\end{aligned}$$

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$$\Delta u = \int_0^1 \Delta u(x_{Bj})\,\mathrm{d}x_{Bj}$$

What do we know?/What did we know?

- $\Delta\Sigma_{inclDIS} = 0.2 - 0.3 \quad \leftrightarrow \quad \Delta\Sigma_{rel.QM} \approx 0.75$
- large first moment $\Delta G = \int_0^1 \Delta G(x)\, dx \approx 2.5$ would reconcile $\Delta\Sigma_{inclDIS}$ and $\Delta\Sigma_{rel.QM}$ results
- L_q, L_g unknown

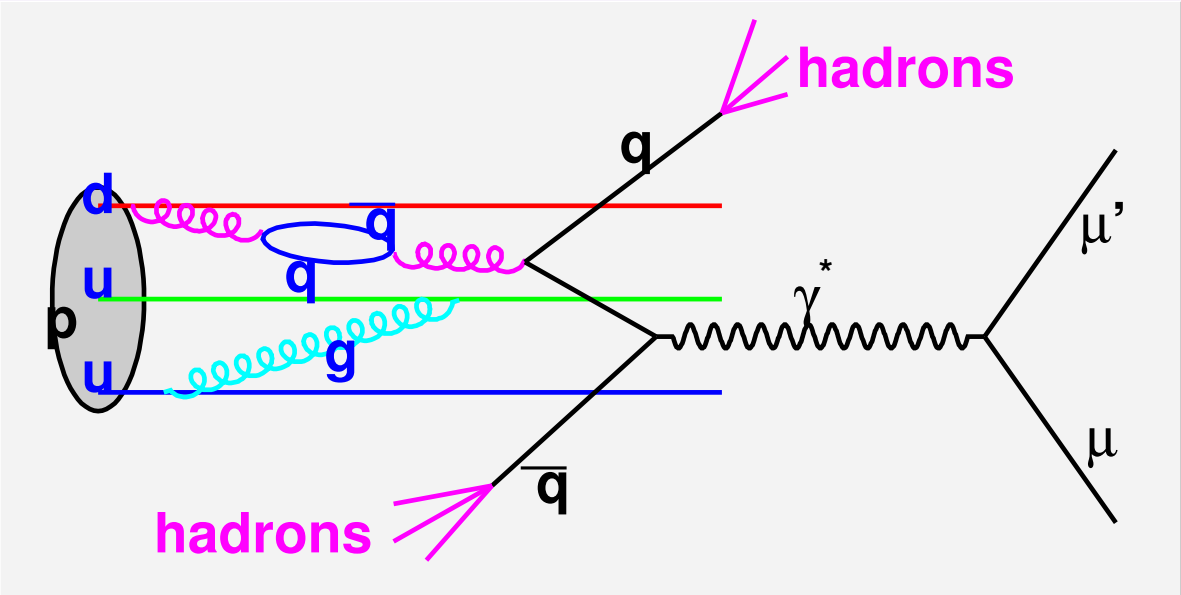
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

ΔG

How to measure ΔG?

Use hadronic final state in DIS to tag gluon!

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



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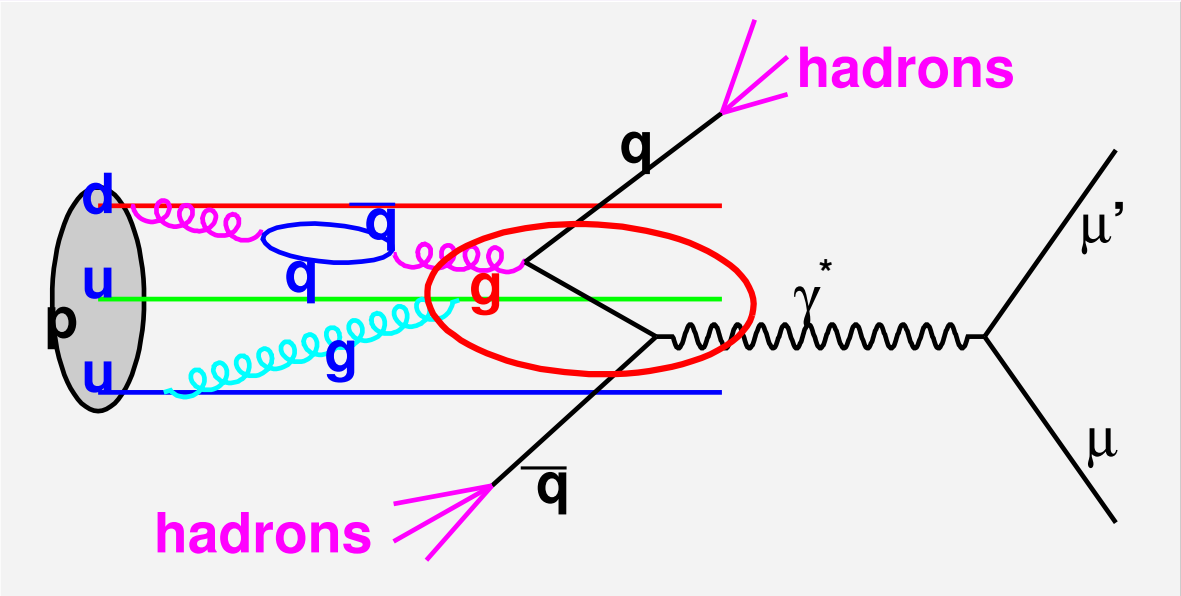
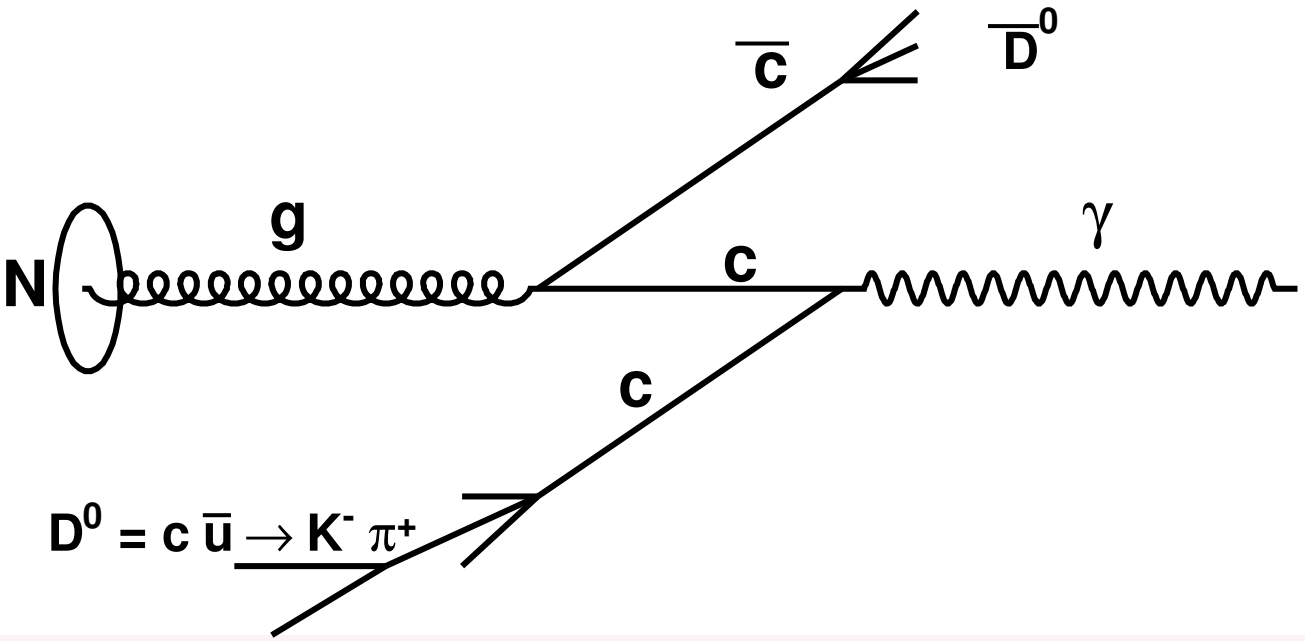


How to tag Photon -Gluon- Fusion sub-process

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

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

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



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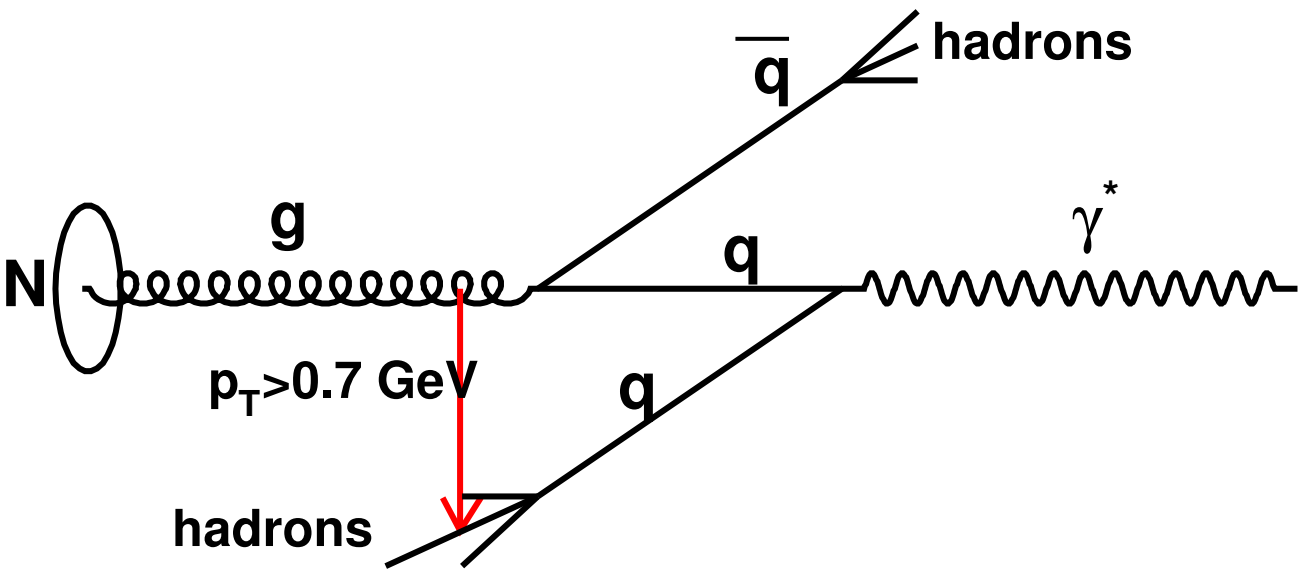

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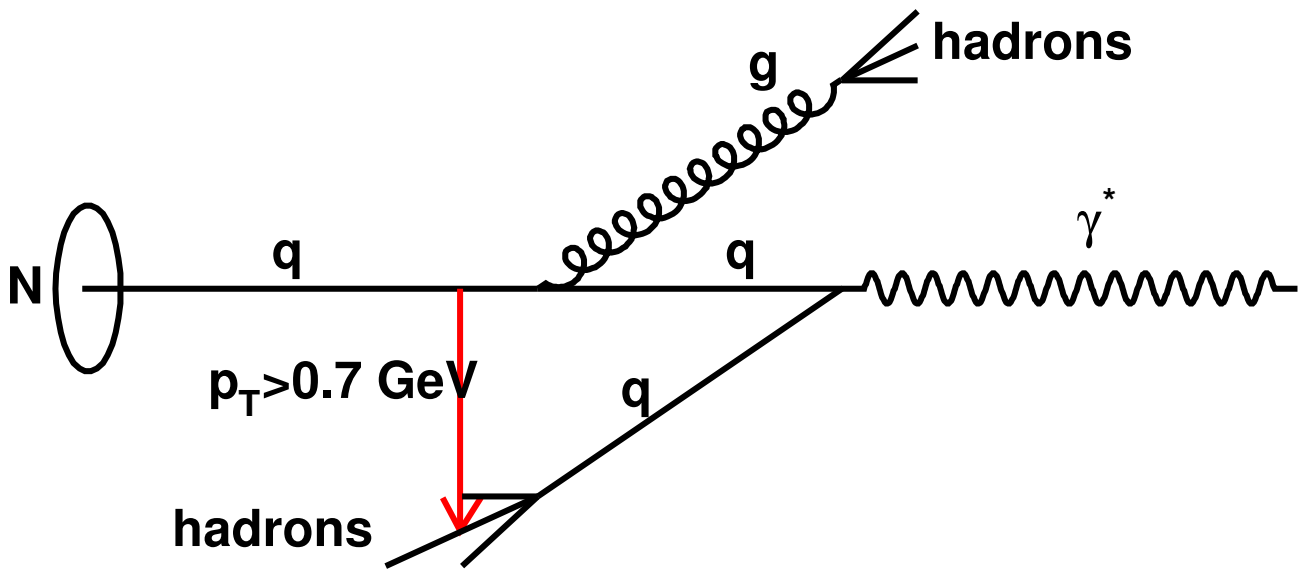


Compton process one of background processes

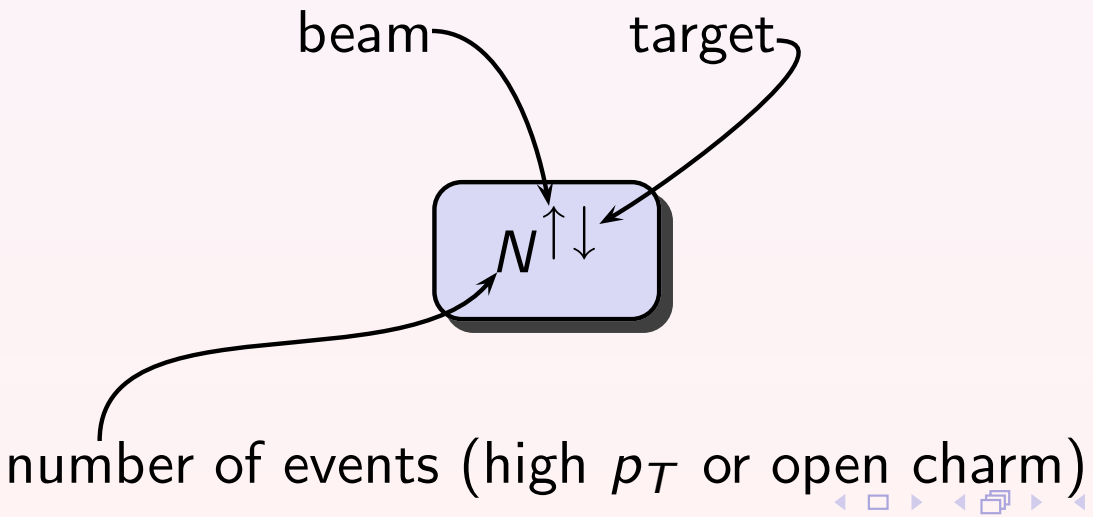
How to measure ΔG

- To tag gluon look at
  - charmed hadrons
  - hadrons with large transverse momentum

How to measure ΔG

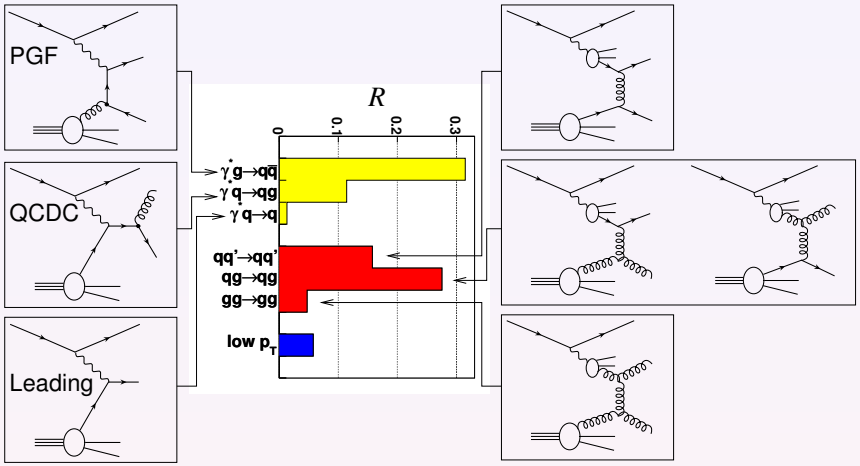
- To tag gluon look at
  - charmed hadrons
  - hadrons with large transverse momentum
- To learn something about spin measure double spin asymmetries

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



High p_T ↔ open charm

High p_T

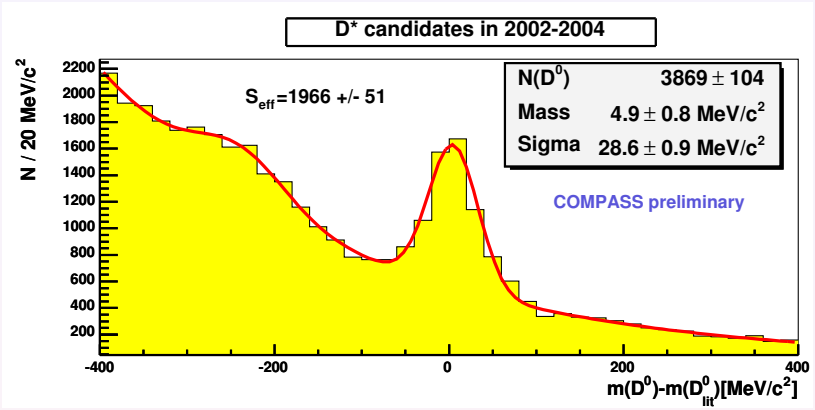


$$R = \frac{\sigma_{PGF}}{\sigma_{PGF}+\sigma_{bgd}} \approx 0.3$$

from PYTHIA/LEPTO MC

Open Charm

$D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$



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

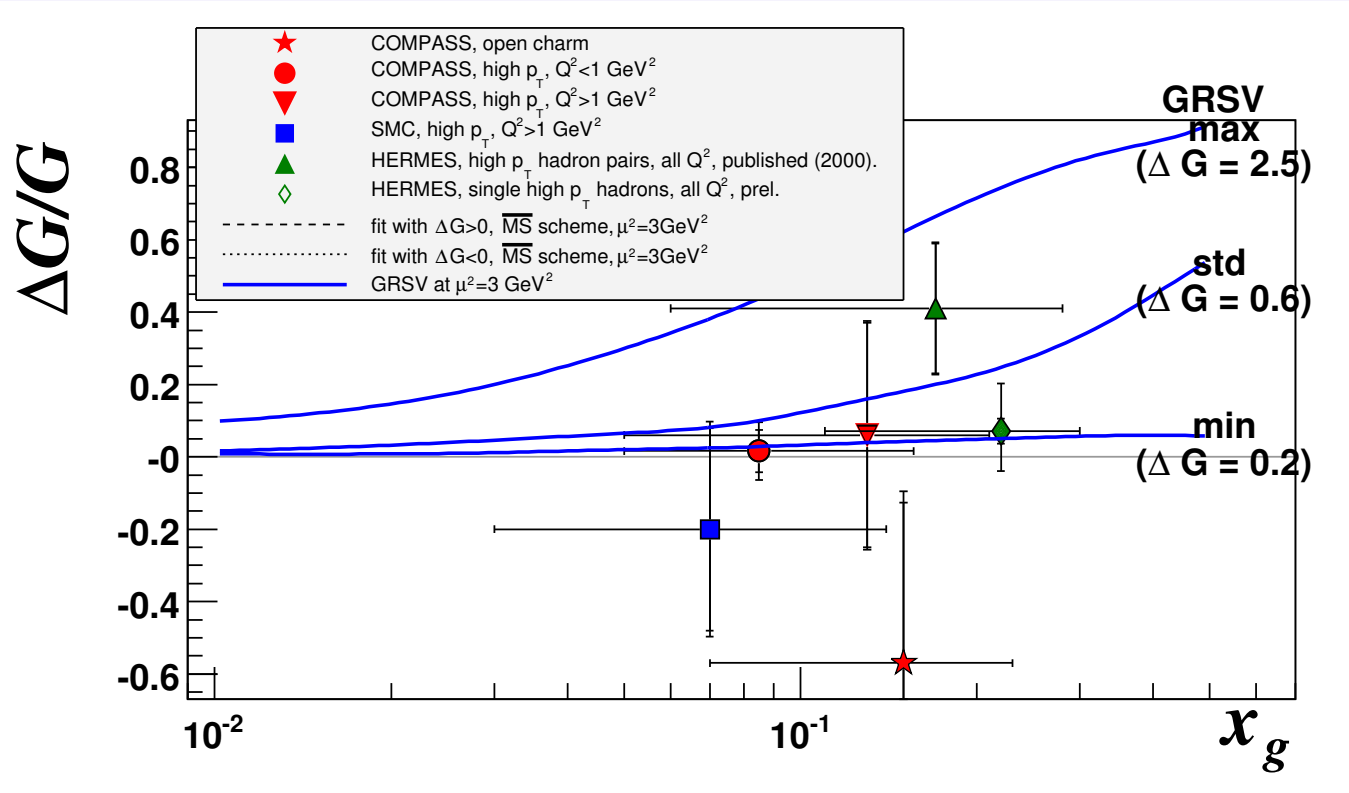
from data

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

Experiments

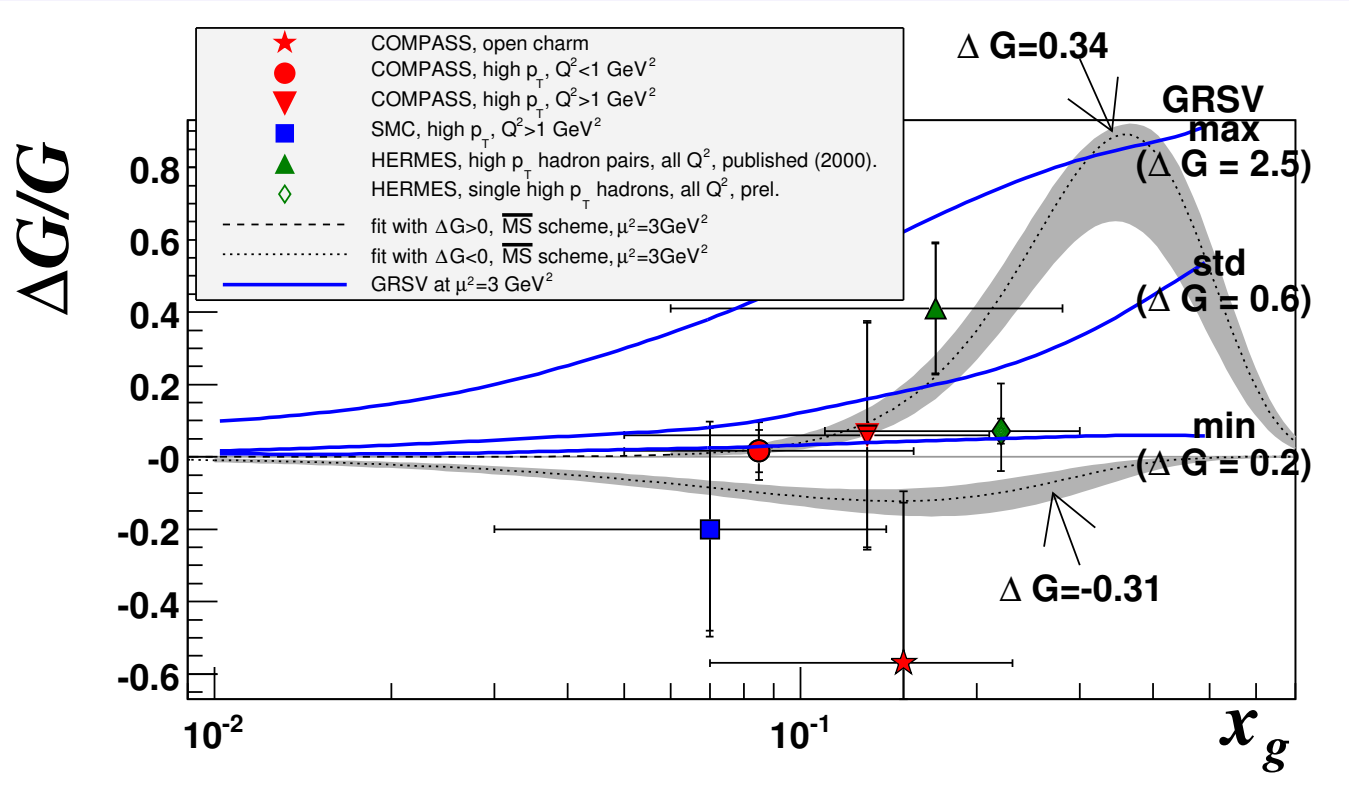
Experiment	method	$\sqrt{s}$/GeV
SMC ($\vec{\mu}\vec{N}$)	high p_T pairs	19
HERMES ($\vec{e}\vec{N}$)	high p_T pairs single high p_T hadrons	7
COMPASS ($\vec{\mu}\vec{N}$)	high p_T pairs open charm	17
STAR ($\vec{p}\vec{p}$)	JET	200
PHENIX ($\vec{p}\vec{p}$)	π^0	200

Results on ΔG from DIS



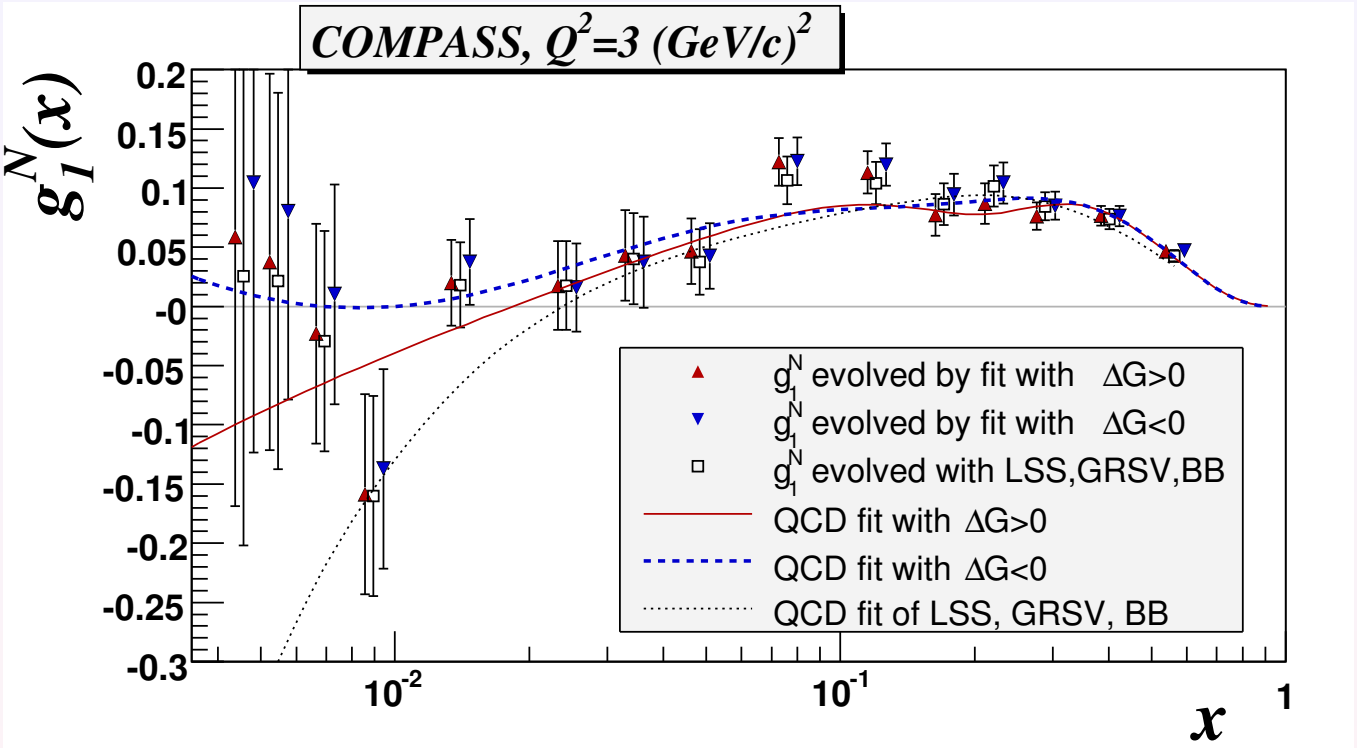
- Data show small values of $\Delta G/G$ at $x_g \approx 0.1$

Results on ΔG from DIS



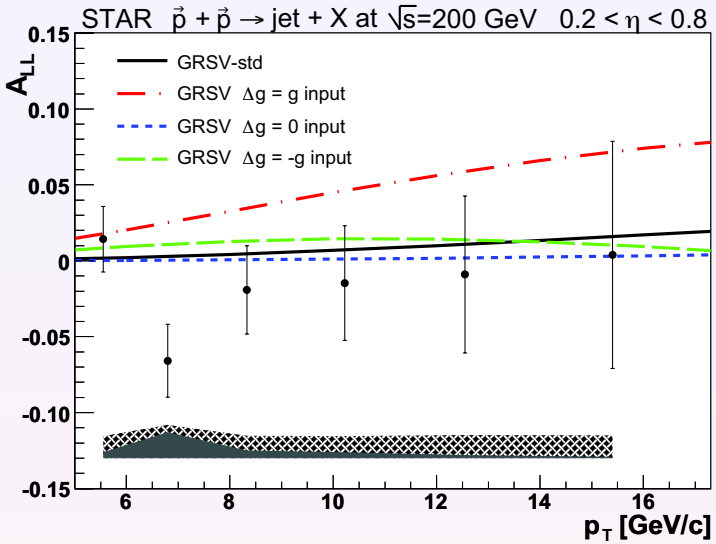
- Data show small values of $\Delta G/G$ at $x_g \approx 0.1$
- Gray bands: NLO QCD fits to inclusive $g_1^{p,n,d}$

ΔG from NLO analysis of SF g_1



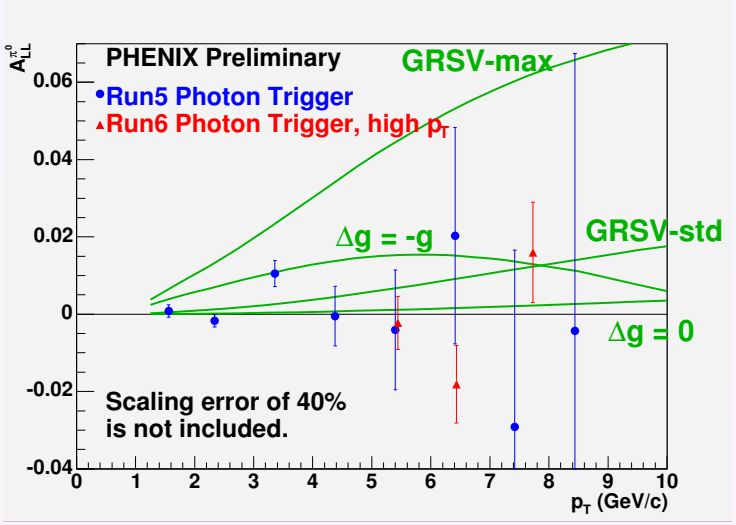
- data from SLAC exp., SMC, HERMES, COMPASS, JLab
- NLO QCD analysis leads to two solutions with similar χ^2
- LSS, GRVS, BB fit done before new COMPASS data were published

Results on ΔG from $\vec{p}\vec{p}$



STAR:

$\vec{p} + \vec{p} \rightarrow Jet + X$



PHENIX:

$\vec{p} + \vec{p} \rightarrow \pi^0 + X$

Partonic subprocesses:

$$\vec{g}\vec{g} \rightarrow gg: \quad A_{LL} \propto \Delta G^2$$
$$\vec{q}\vec{g} \rightarrow qg: \quad A_{LL} \propto \Delta G \Delta q$$

Summary: ΔG

- direct measurements show: $\Delta G/G$ small at $x_g \approx 0.1$
- confirmed by indirect measurements
  - Scaling violation of $g_1^{p,n,d}$ structure function
  - $\vec{p}\vec{p}$ scattering at RHIC
- Large first moments $\Delta G = \int_0^1 \Delta G(x)dx \approx 2-3$ ruled out by data
- $\Delta G = \int_0^1 \Delta G(x)dx \approx \frac{1}{2}$ (gluon carries 100% of nucleon spin) still possible
- shape of $\Delta G(x)$ not well constrained

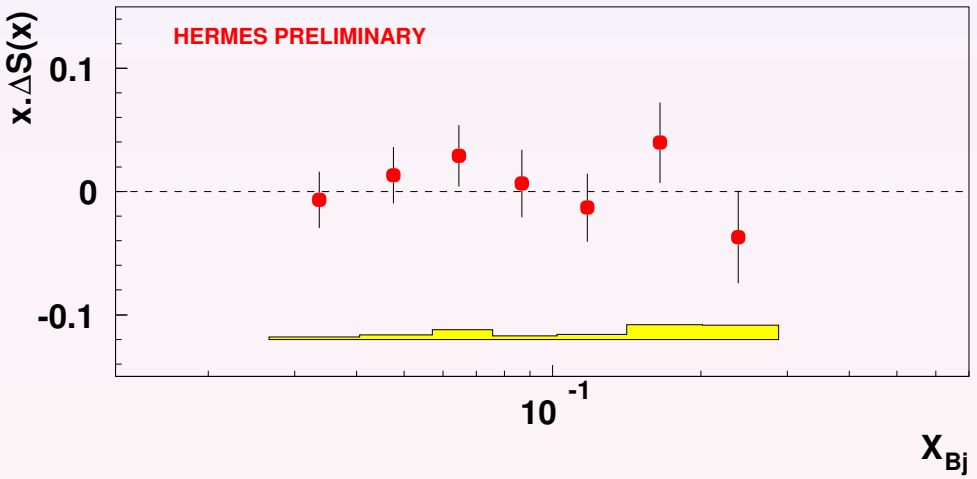
Δq

Helicity Distributions Δq

Look at double spin asymmetries of specific hadrons:

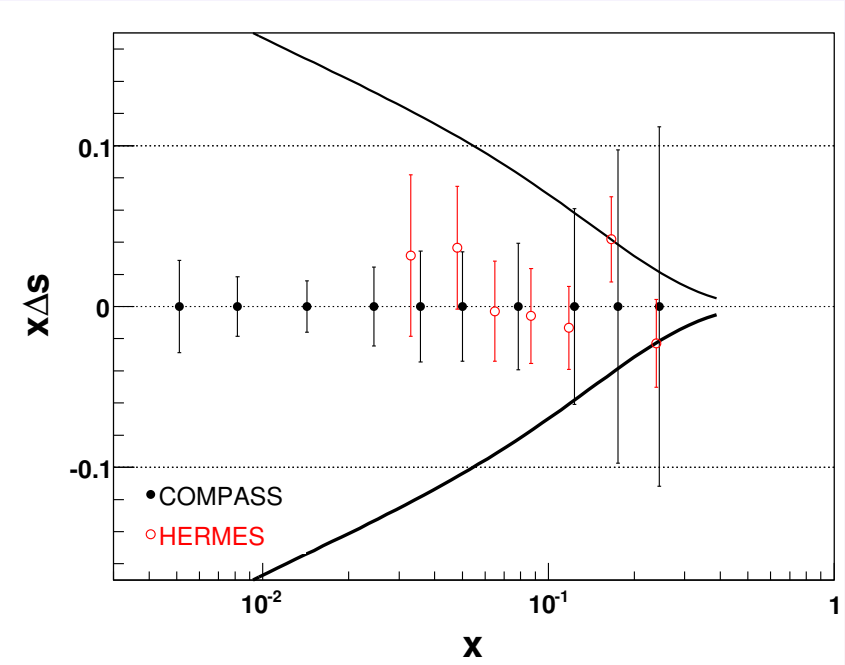
$$A^h = \frac{\sum_q e_q^2 (\Delta q\, D_q^h + \Delta \bar{q}\, D_{\bar{q}}^h)}{\sum_q e_q^2 (q\, D_q^h + \bar{q}\, D_{\bar{q}}^h)}$$

HERMES:
K^+, K^-:



- $\int_{0.02}^{1} (\Delta s + \Delta \bar{s}) dx = 0.006 \pm 0.029 \pm 0.007$ in contrast to
- $\int_{0}^{1} (\Delta s + \Delta \bar{s}) dx = -0.08 \pm 0.01 \pm 0.02$ from inclusive DIS
- $\Rightarrow \Delta s + \Delta \bar{s} < 0$ at low x

Projection for COMPASS

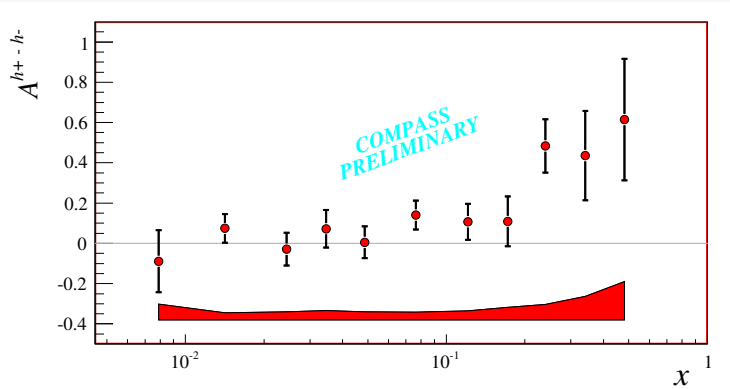


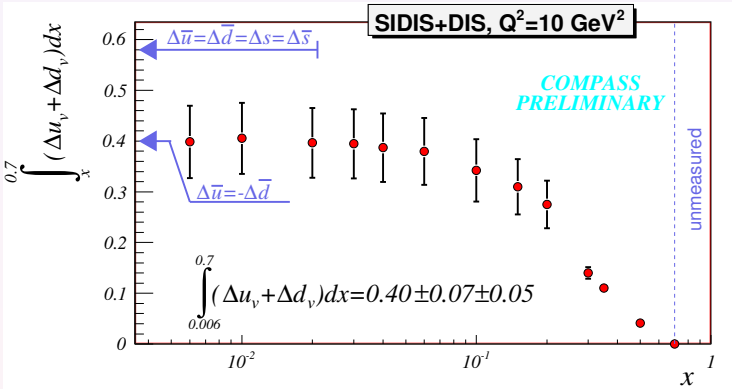
- HERMES data are older published data!
- Projection COMPASS existing deuteron data + 2 year proton
- Extraction of $\Delta s + \Delta \bar{s}$ also possible using only deuteron data

Helicity Distributions Δq

$$A_d^{h^+-h^-} \approx \frac{\Delta u_V + \Delta d_V}{u_V + d_V}$$

independent of fragmentation functions





- $A_d^{h^+-h^-}$ measures valence quark polarisation
- inclusive A_1^d measures valence+sea quark polarisation
  $\Rightarrow$ Difference tells you something about sea:
  $\Delta\bar{u} + \Delta\bar{d} = 3\Gamma_1^N(A_1^d) - \frac{1}{2}\Gamma_v(A_d^{h^+-h^-}) + \frac{1}{12}a_8$

Transversity

Transversity distributions

$$\text{Azimuthal Asymmetry} \propto \Sigma_q e_q^2 \Delta_T q(x) \times \text{analyzing power}$$

To measure transverse polarization of quarks different "polarimeters" proposed:

Collins Asymmetry	$\propto$	$\Sigma_q e_q^2 \Delta_T q(x)$	$\Delta_T^0 D_q^h(z, \lvert p_T^h \rvert)$
2 hadron correlation	$\propto$	$\Sigma_q e_q^2 \Delta_T q(x)$	$H_q^{\angle h}(z, M_h)$
Λ - Polarization	$\propto$	$\Sigma_q e_q^2 \Delta_T q(x)$	$\Delta_T D_q^\Lambda(z)$

Analyzing power does not depend on x!

- Analyzing power is different for different processes and sometimes even not very well known $\longrightarrow$ important to try different methods.

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- Results of combined analysis of HERMES, COMPASS & BELLE data

Combined Analysis (Anselmino et al.)

Inputs:

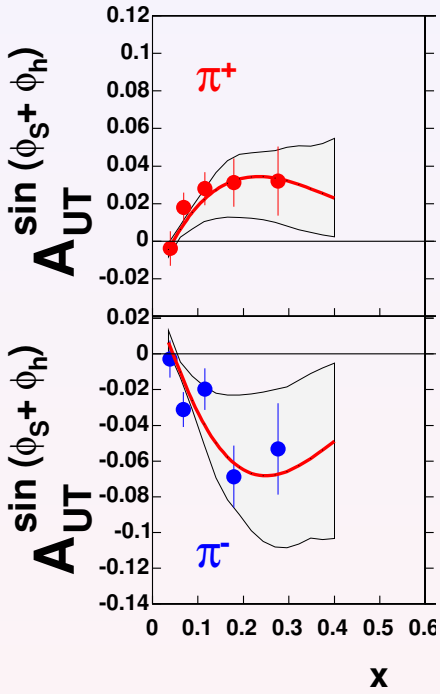
- Proton Collins Asymmetries from HERMES
- Deuteron Collins Asymmetries form COMPASS
- Fragmentation Function from BELLE

Output:

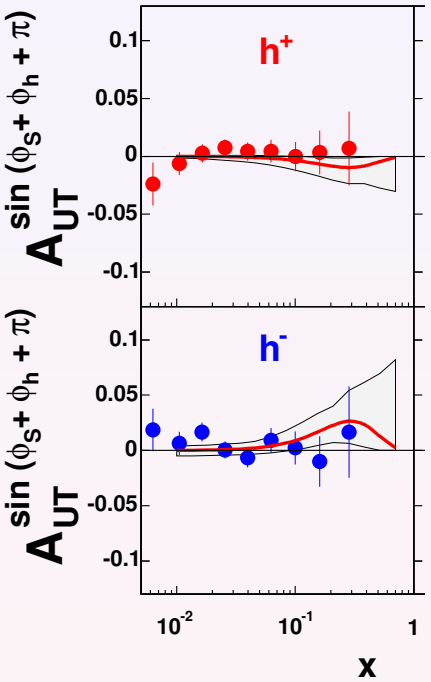
- $\Delta_T u(x), \Delta_T d(x)$

Collins Asymmetries

HERMES: proton target



COMPASS: deuteron target

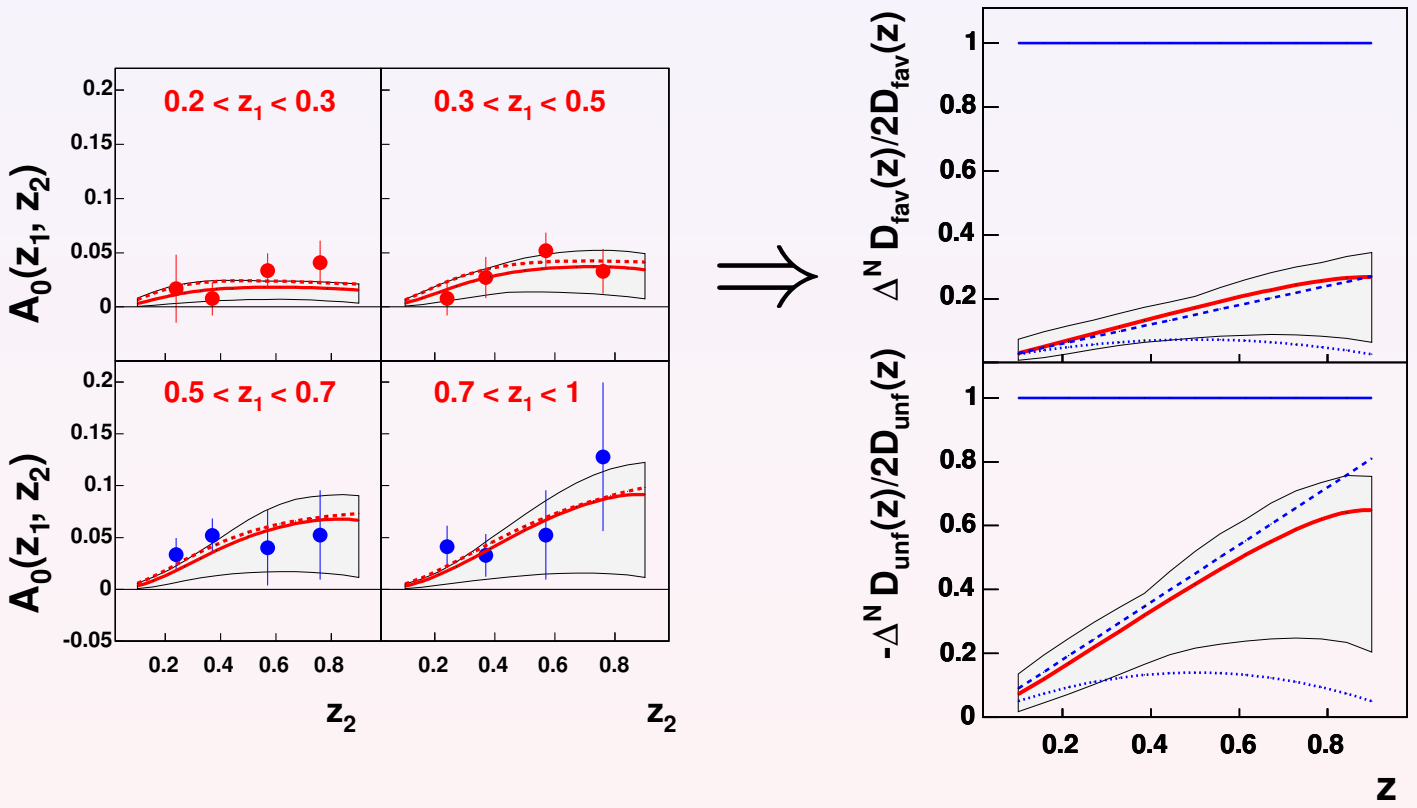


HERMES:
$\Delta_T q \neq 0$ and $\Delta_T^0 D_q^h \neq 0$

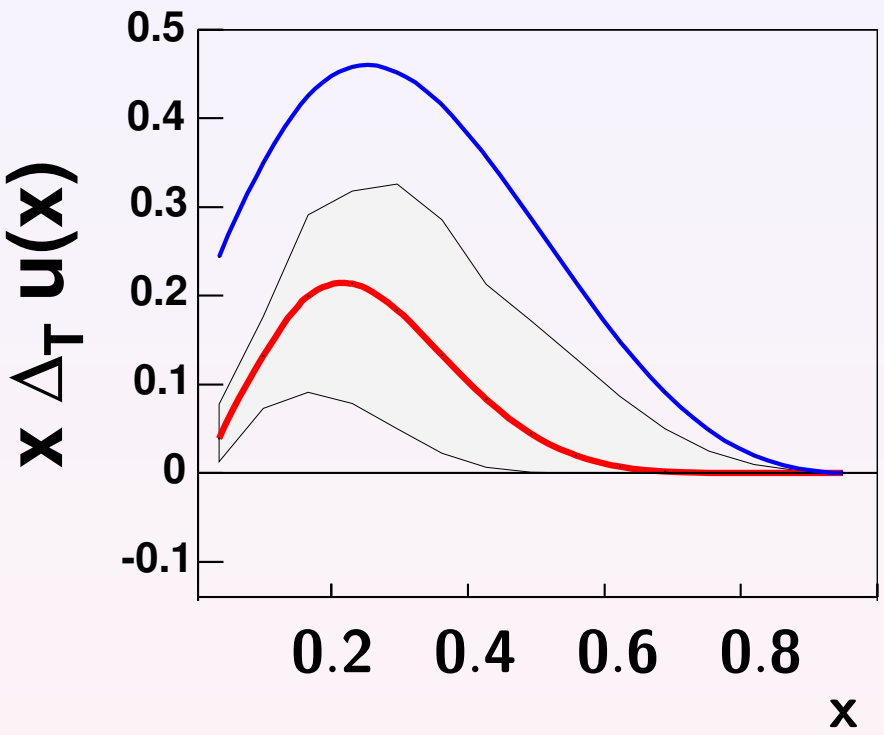
COMPASS:
$\Delta_T u \approx -\Delta_T d$

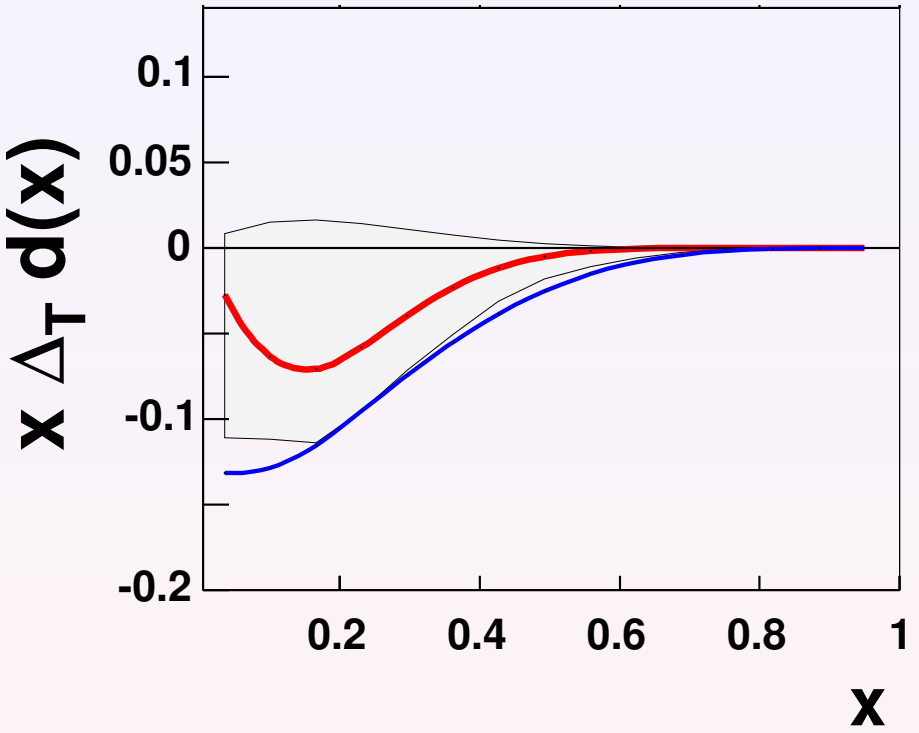
Fragmentation Function

Two hadron Correlation from Belle: $e^+e^- \to h_1 h_2 X$



Results (Anselminio et al., hep-ph/0701006)





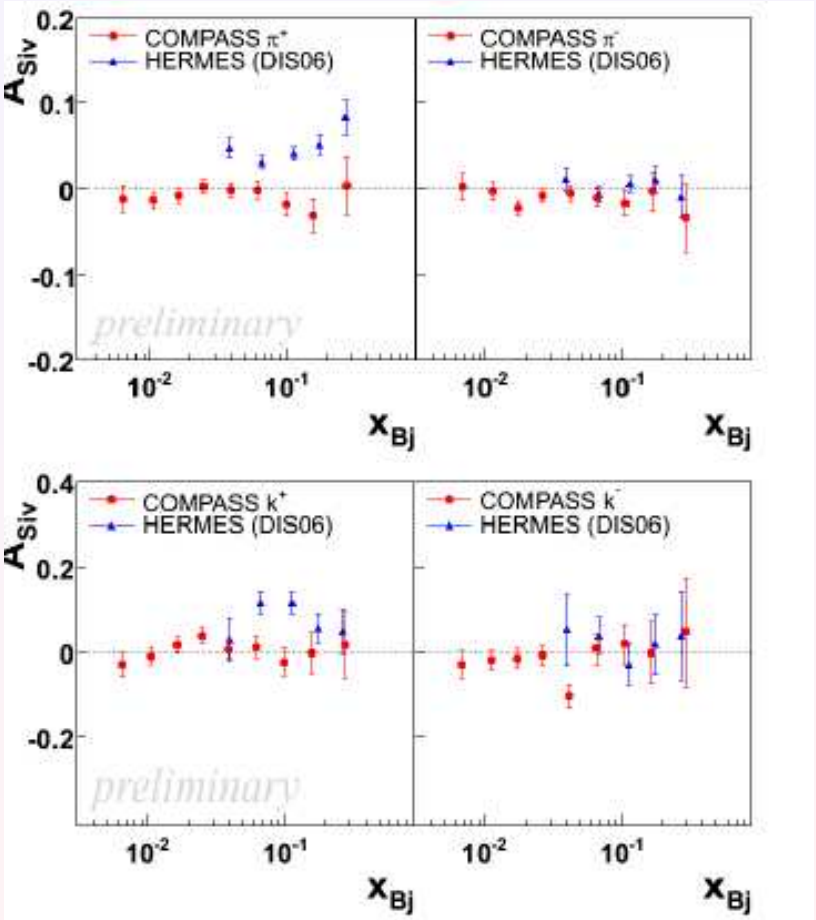
- $\Delta_T u(x) > 0$,$\Delta_T d(x) < 0$
- Soffer Bound: $|\Delta_T q(x)| < \frac{1}{2}(q(x) + \Delta q(x))$

More Transversity

- Identified Hadrons π^+, π^-, K^+, K^- (COMPASS & HERMES)
- Different access to $\Delta_T q(x)$:
  2 hadron correlation, Λ Polarization
- different asymmetries (Sivers, ...)
- Results from BELLE on fragmentation function
- Results form RHIC (PHENIX,STAR,BRAHMS)
- Future:
  - COMPASS runs on proton target in 2007 and beyond,
  - Plans to study transversity at JLAB

Sivers Asymmetries

for identified hadrons,



- HERMES proton target: effect is there!
- COMPASS deuteron target: $A^{Siv} = \frac{\Delta_0^T u + \Delta_0^T d}{u+d} \approx 0 \Rightarrow$ cancelation between u and d quark

GPD

GPD from Exclusicve Production of Photons (DVCS) or Mesons

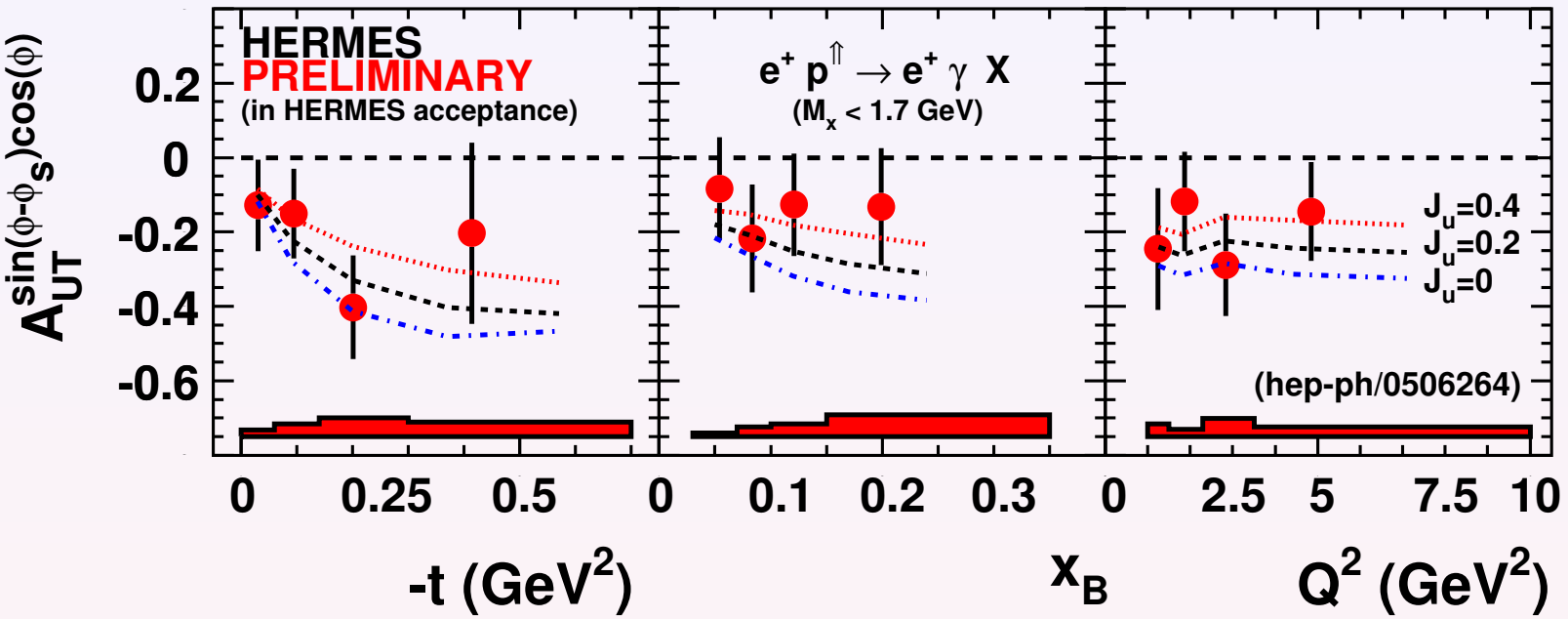
$$l + N \rightarrow l' + N + \gamma$$

gives access to generalized parton distributions (GPD)
H ,E, $\tilde{H}$ and $\tilde{E}$
Ji's sum rule:

$$\frac{1}{2} \int x(H_q + E_q)(x, \xi, 0)dx = J_u = \frac{1}{2}\Delta\Sigma + L_q$$

- Results HERMES, JLab, HERA
- near future COMPASS (exclusive ρ production on trans. pol. target)
- Future Plans COMPASS ($>$ 2010), JLab 12 GeV, FAIR(GSI) ($\approx$ 2014), EIC (?)

Transverse Target Spin Asymmetry for DVCS on the Proton



- Provides a model-dependent way to extract J_u with the assumption $J_d = 0$
- HERMES (proton target) more sensitive to J_u
- JLab, Hall A (deuteron target) more sensitive to J_d
  $\Rightarrow$ Extraction of J_u and J_d possible

Summary & Outlook

Summary:

- ΔG small at $x_g \approx 0.1$
- Semi-inclusive asymmetries used to determine $q_v(x)$ and $q_{sea}(x)$
- first results for $\Delta_T u > 0$ and $\Delta_T d < 0$ from an combined analysis of HERMES, COMPASS and BELLE data
- DVCS provides access to $J_q = \frac{1}{2}\Delta\Sigma + L_q$

Outlook:

- ΔG: COMPASS, RHIC
- $\Delta q, g_1$: COMPASS, JLab
- transversity: JLab, RHIC, COMPASS
- GPD: JLab, COMPASS

SPARE

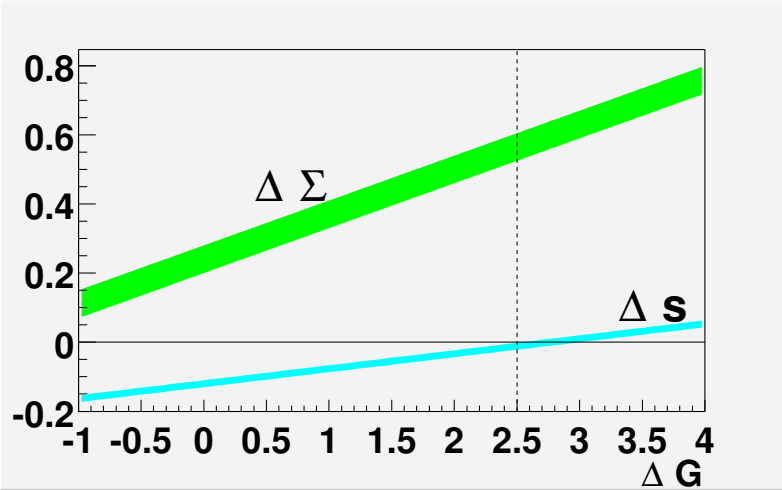
The Nucleon Spin Puzzle

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

$\Delta\Sigma \rightarrow \Delta\Sigma - \frac{3\alpha_s}{2\pi}\Delta G$, α_s : strong coupling constant

$\Delta s \rightarrow \Delta s - \frac{\alpha_s}{2\pi}\Delta G$

$\Delta G = G^{\uparrow} - G^{\downarrow}$, **polarized gluon distribution**



[1] next-to-leading order

[2] Quantum Chromo Dynamics

The Nucleon Spin Puzzle

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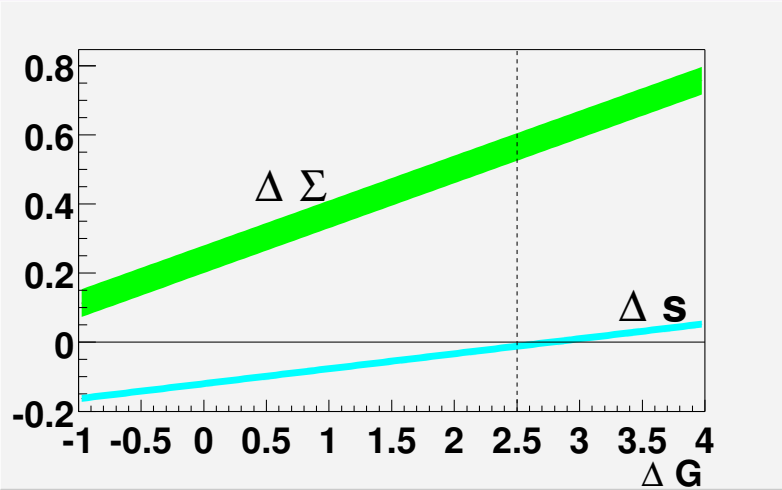

For $\Delta G \approx 2.5 \rightarrow$,
$\Delta\Sigma \approx 0.6$ and $\Delta s \approx 0$

$\rightarrow$ Measure ΔG !!!

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High p_T: Data $\leftrightarrow$ MC