Neues vom COMPASS Experiment

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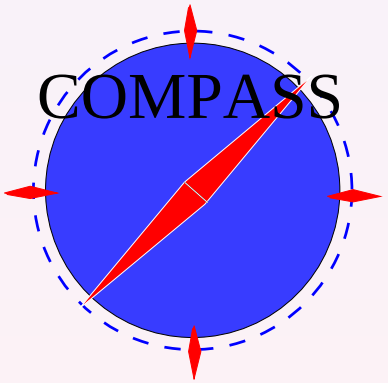
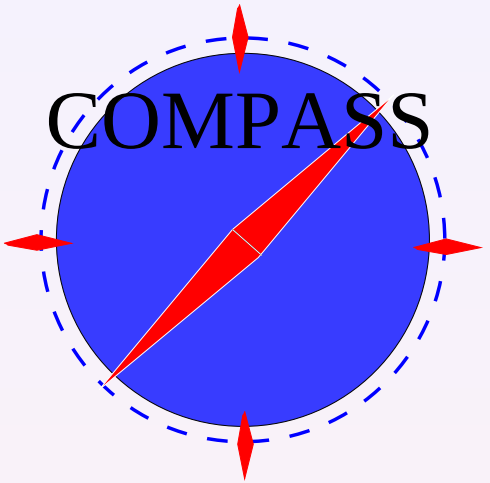


Bad Honnef, Dez. 2008

COMPASS

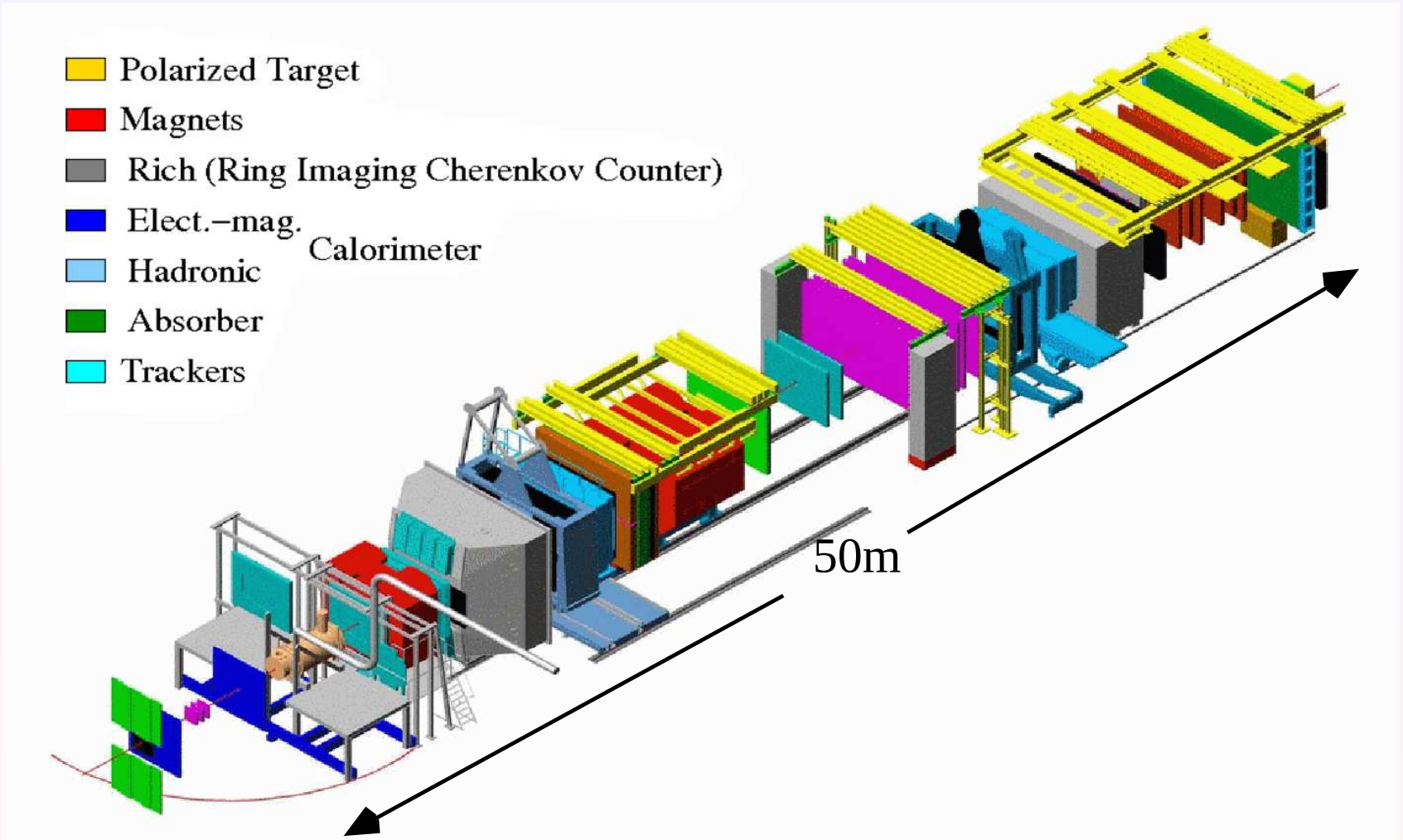
CO mmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy



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


COMPASS

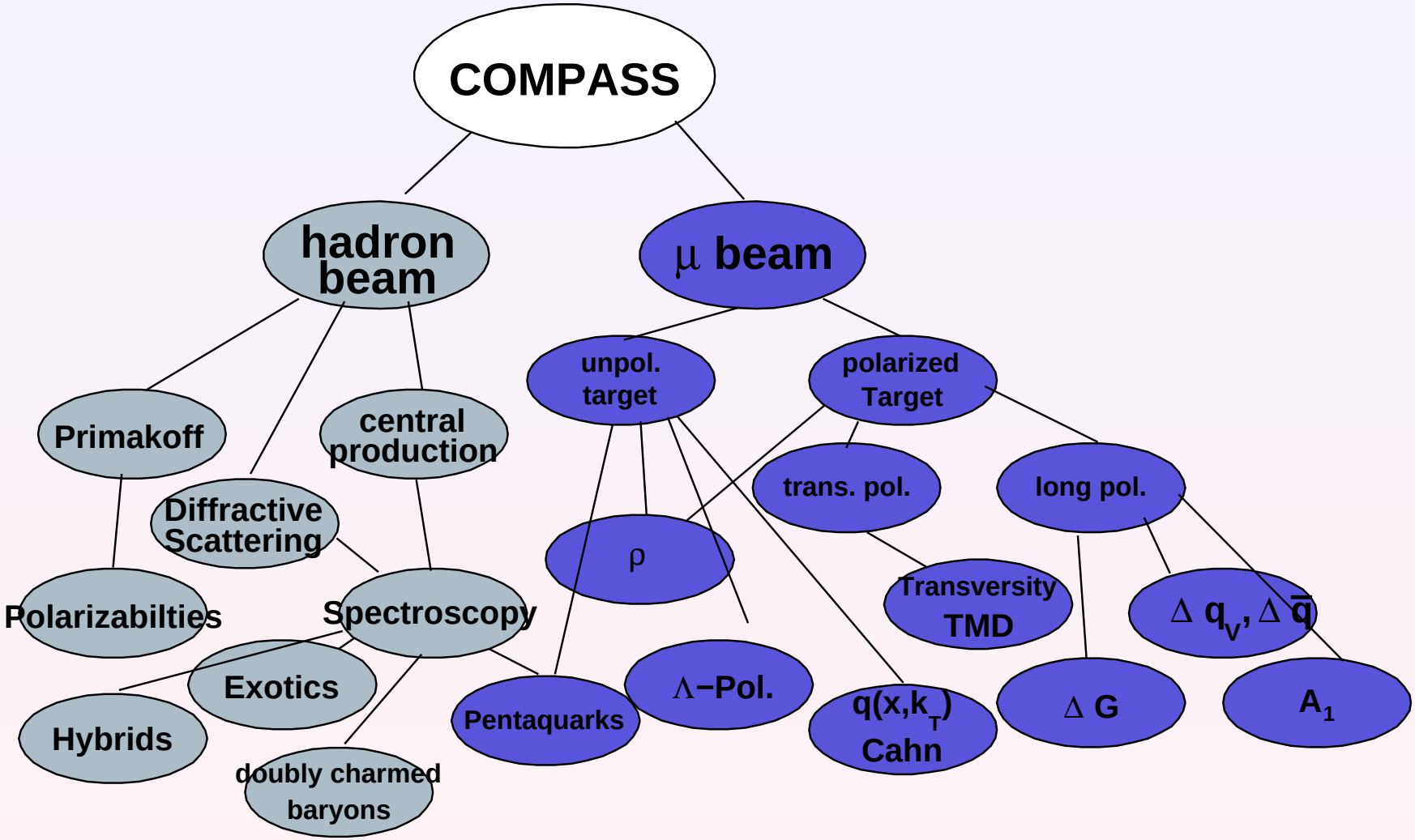
The COMPASS Experiment



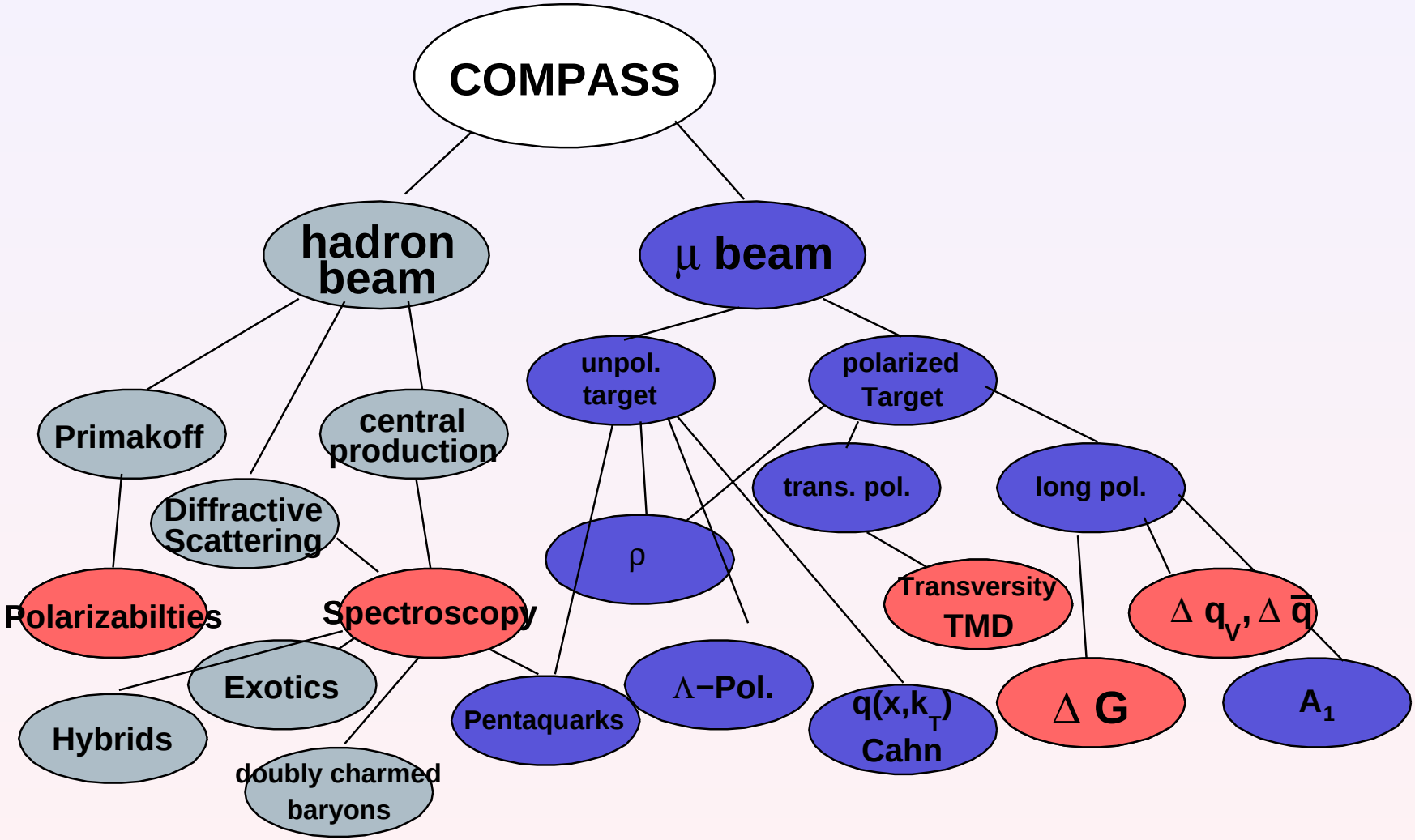
Parameters of Experiment

Spectrometer:	Two stages $1\ \text{GeV} < p < 200\ \text{GeV}$ 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, ...

Physics Goals



Physics Goals



Beam Sharing

year	Beam	target
2002	$\vec{\mu}^+$	$\vec{d}$
2003	$\vec{\mu}^+$	$\vec{d}$
2004	$\vec{\mu}^+$	$\vec{d}$
	π^-	lead, carbon
2005	-	-
2006	$\vec{\mu}^+$	$\vec{d}$
2007	$\vec{\mu}^+$	$\vec{p}$
2008	π^-	LH_2

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2007	$\vec{\mu}^+$	$\vec{p}$
2008	π^-	LH_2

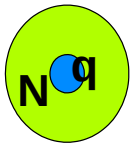
Future		
2009	π^-	LH_2
2010	$\vec{\mu}$	$\vec{p}$
2011	$\vec{\mu}$	$\vec{p}$
2011	π^-	LH_2
>2012	GPD, Drell-Yan*	

* Proposal being prepared

Helicity Distributions, Δg, Δs

Quark Distributions

$q(x), x =$ momentum fraction
$q = u, d, s, \bar{u}, \bar{d}, \bar{s}, g$



Quark Distributions

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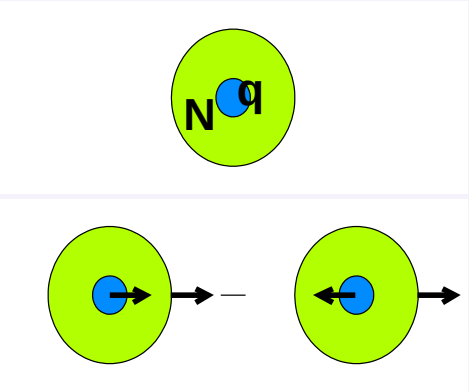
$\Delta q(x), \Delta g(x)$ (helicity)



Nucleon Spin Puzzle

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

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Spin

orbital angular momentum

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

Nucleon Spin Puzzle

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$$\Delta s = \int_0^1 \Delta s(x)\,\mathrm{d}x$$

Spinpuzzle

- $\Delta\Sigma_{inclDIS} = 0.2 - 0.3 \quad \leftrightarrow \quad \Delta\Sigma_{rel.QM} \approx 0.75$

Spinpuzzle

- $\Delta\Sigma_{inclDIS} = 0.2 - 0.3 \quad \leftrightarrow \quad \Delta\Sigma_{rel.QM} \approx 0.75$
- 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

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

Helicity distributions

How to measure helicity distributions?

Principle:
Measure double spin asymmetries of various hadronic final states h in $\vec{\mu} + \vec{N} \rightarrow \mu' + X + h$

$$A^h = \frac{N_h^{\uparrow\downarrow} - N_h^{\uparrow\uparrow}}{N_h^{\uparrow\downarrow} + N_h^{\uparrow\uparrow}} \propto \frac{\Delta f}{f}$$

$f = u, d, s, \bar{u}, \bar{d}, \bar{s}, g$

Helicity distributions

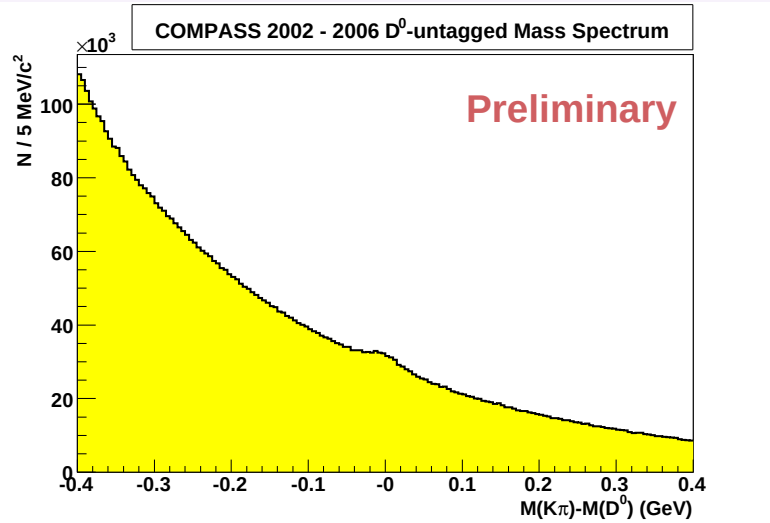
Selecting different final states h in $\mu + N \rightarrow \mu' + X + h$ selects different flavors f:

hadronic final state h	Δf
inclusive	$\sum e_q^2(\Delta q + \Delta \bar{q})$
kaons	mainly Δs, $\sum e_q^2(\Delta q D_q^K + \Delta \bar{q} D_{\bar{q}}^K)$
hadrons with large transverse momentum	$\frac{\Delta g}{g} + \sum e_i^2 \Delta q$
Charmed mesons	$\frac{\Delta g}{g}$

Gluon helicity $\Delta g/g$

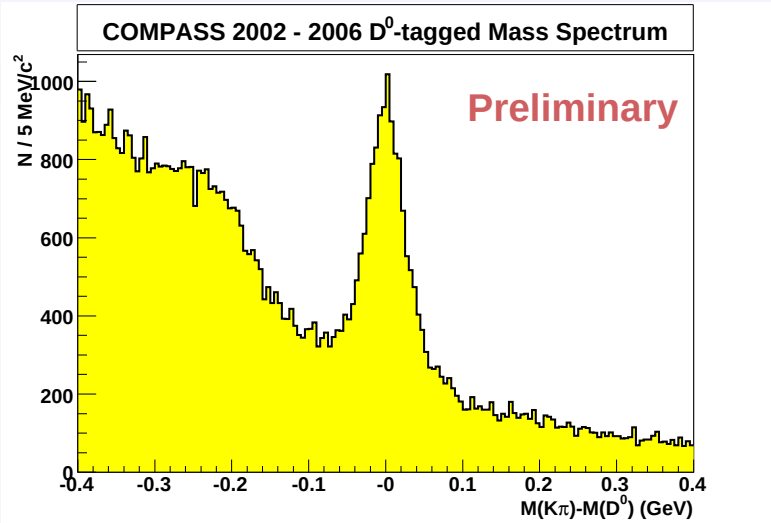
$K\pi$ invariant mass spectra

$D^0 \rightarrow K^-\pi^+ + c.c$

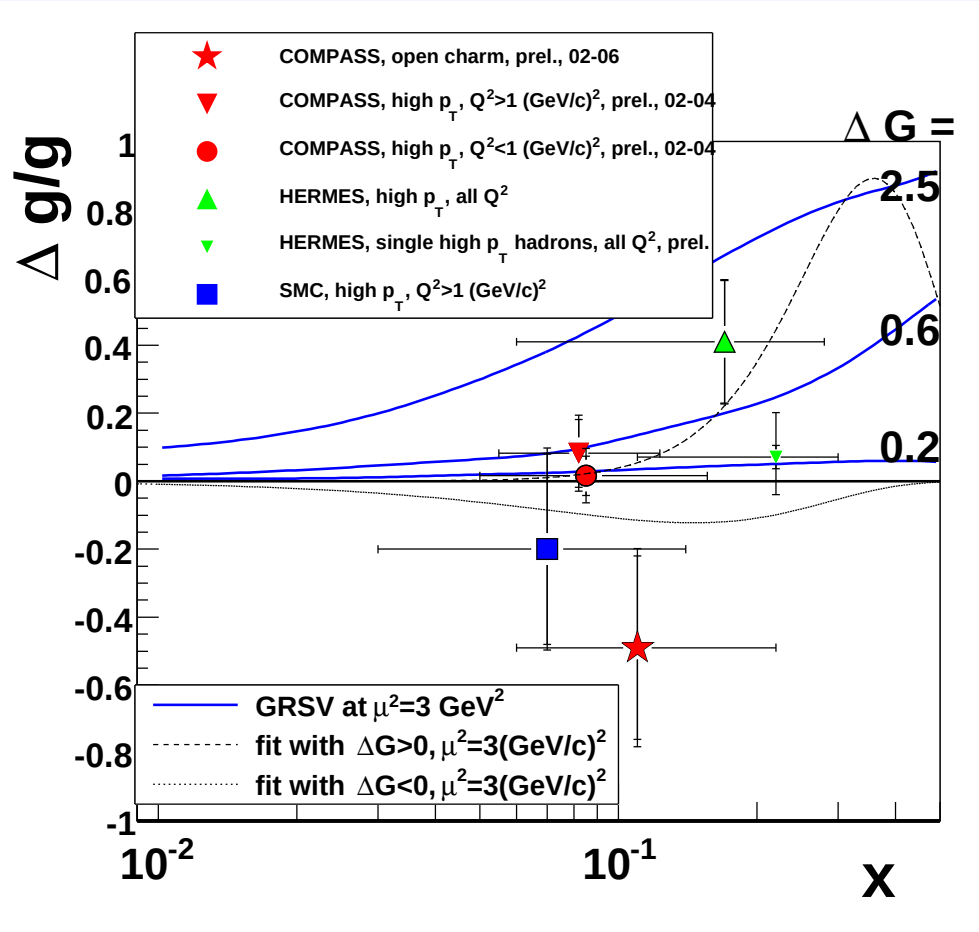


D^0 from $D^{*+} \rightarrow D^0 + \pi^+$

$\rightarrow K^-\pi^+\pi^+$



Gluon helicity $\Delta g/g$



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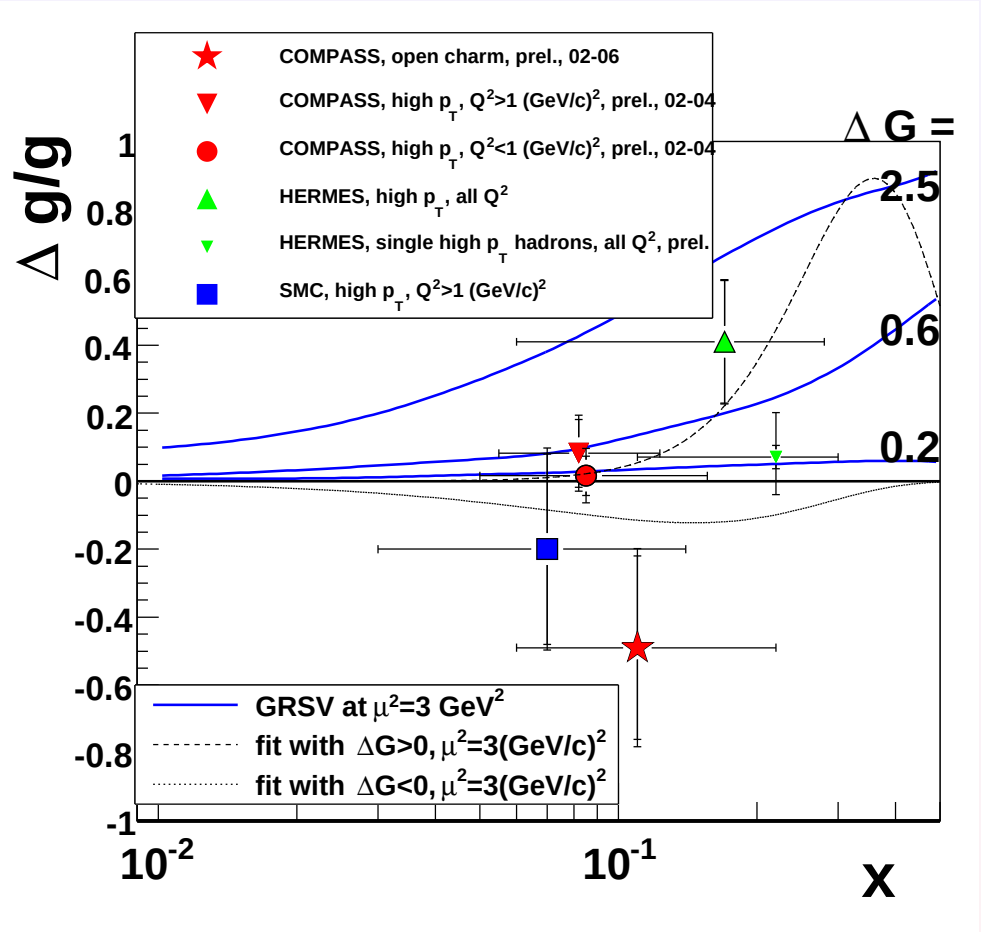
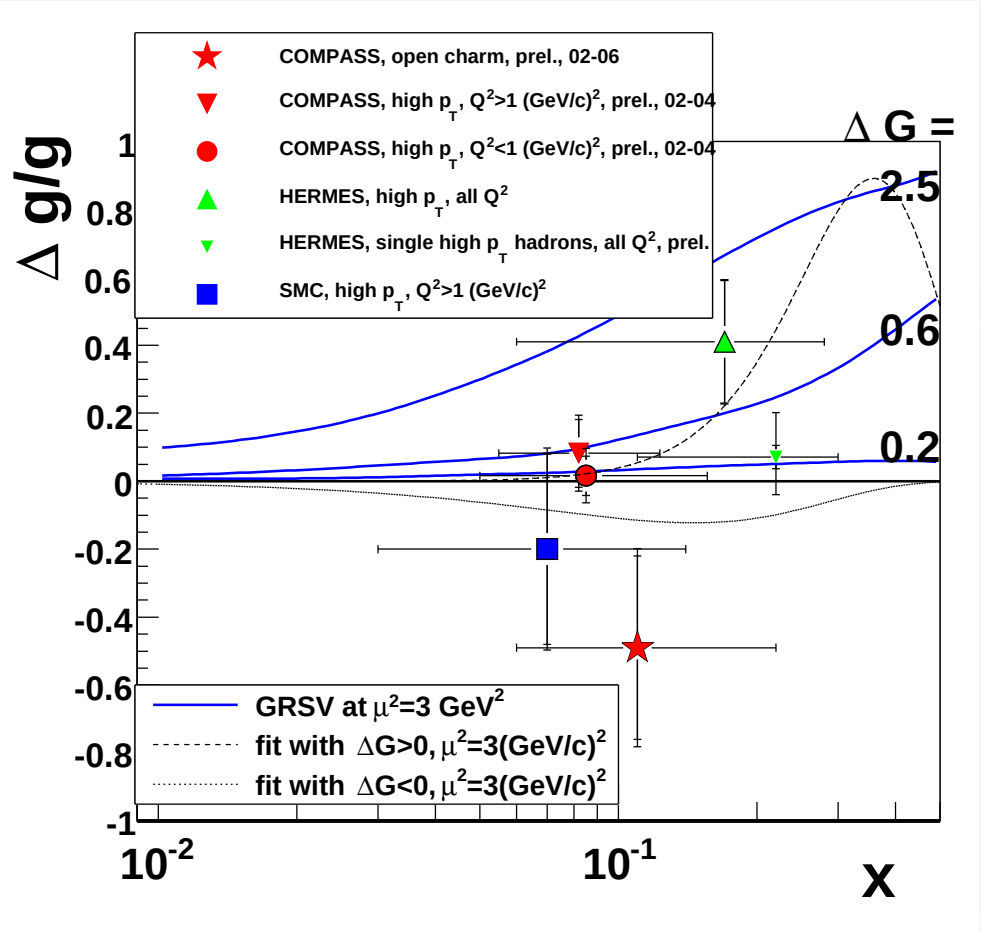


- Data show small values of $\Delta g/g$ at $x_g \approx 0.1$, compared to $\Delta G \approx 2-3$

Gluon helicity $\Delta g/g$



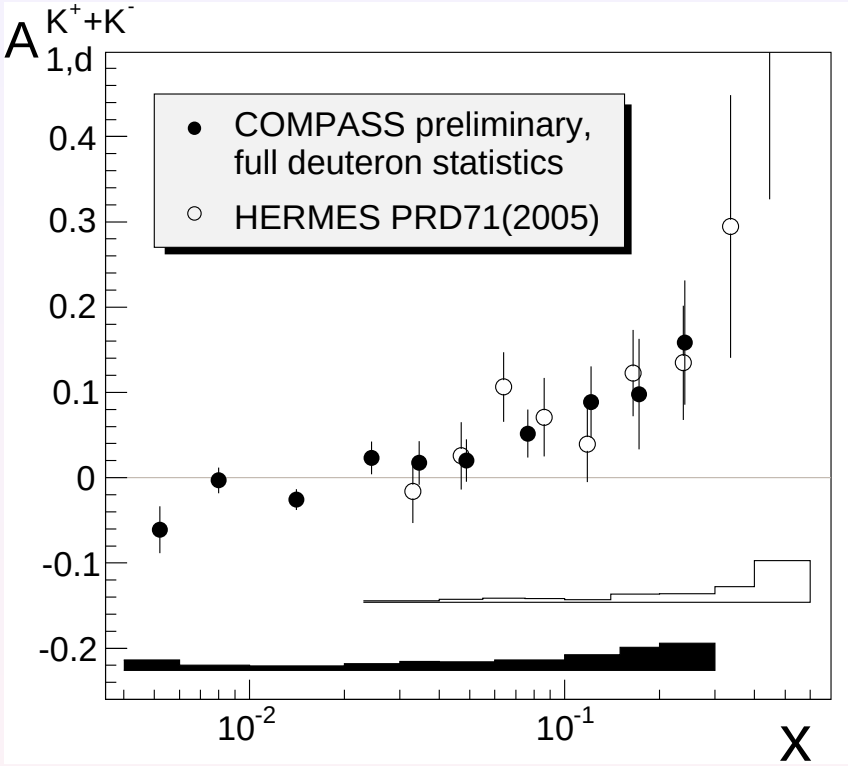
- Data show small values of $\Delta g/g$ at $x_g \approx 0.1$, compared to $\Delta G \approx 2-3$
- confirmed by indirect measurements
  - Scaling violation of $g_1^{p,n,d}$ structure function
  - $\vec{p}\vec{p}$ scattering at RHIC

Conclusion from $\Delta g/g$ measurement

(not only from COMPASS results)

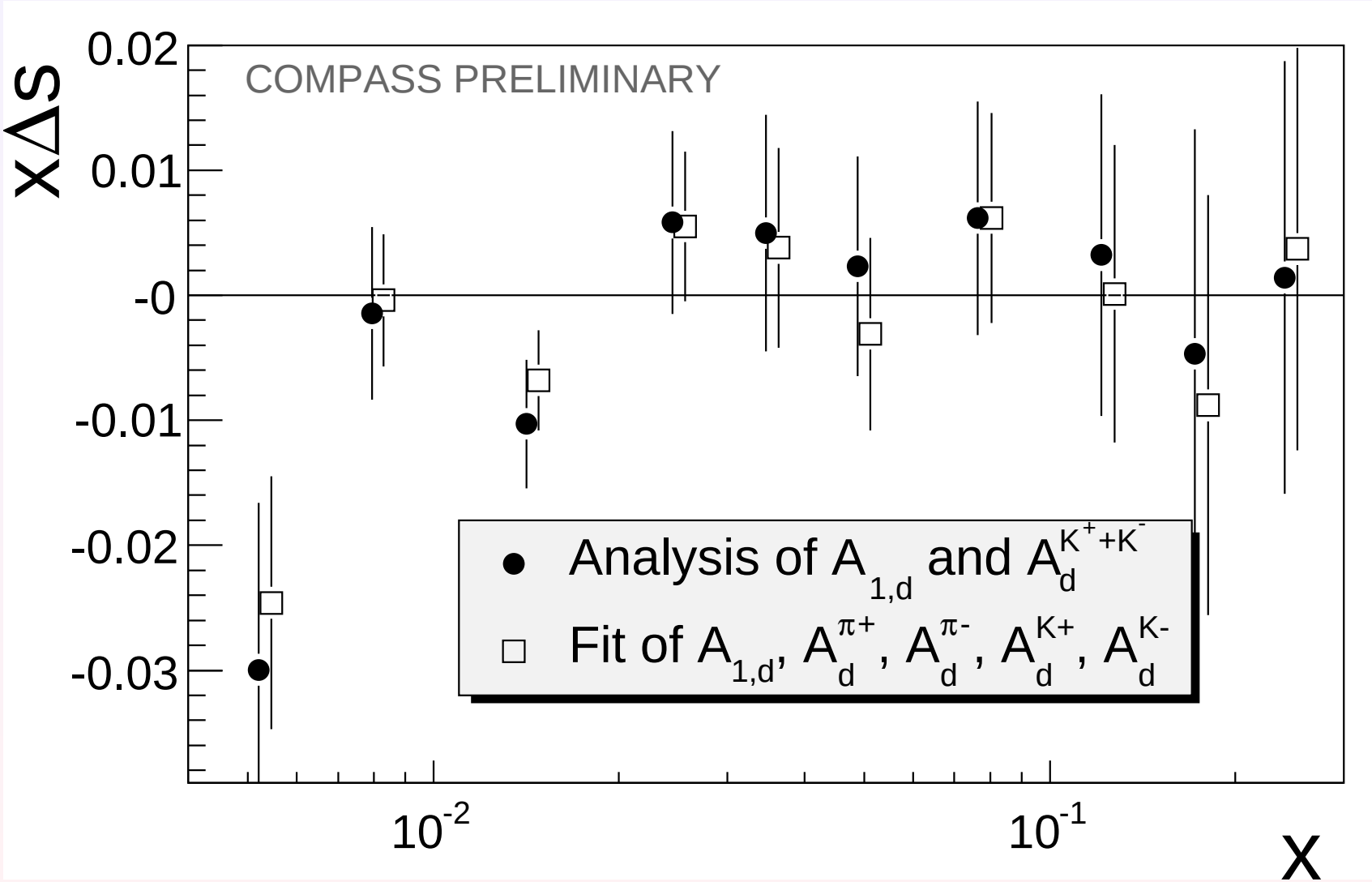
- $\Delta G = \int_0^1 \Delta g \mathrm{d}x$ small compared to initial expectation of 2-3
- but error on first moment is still large: $\int_0^1 \Delta g \mathrm{d}x \approx 0 \pm 0.5$
- i.e. gluon can still carry 100% of the nucleon spin
- shape of $\Delta g(x)$ not well determined

Strange Quark Helicity Distribution $\Delta s(x)$



$$A^{K^+ + K^-} = \frac{\sum e_q^2 \left(\Delta q (D_q^{K^+} + D_q^{K^-}) + \Delta \bar{q} (D_{\bar{q}}^{K^+} + D_{\bar{q}}^{K^-}) \right)}{\sum e_q^2 \left(q (D_q^{K^+} + D_q^{K^-}) + \bar{q} (D_{\bar{q}}^{K^+} + D_{\bar{q}}^{K^-}) \right)}$$

Strange Quark Helicity Distribution $\Delta s(x)$



Strange Quark Helicity Distribution $\Delta s(x)$

Results strongly depends on the ratio of fragmentation functions

$$R_{SF} = \frac{\int D_{\bar{s}}^{K^+}}{\int D_u^{K^+}} = \frac{\int D_s^{K^-}}{\int D_{\bar{u}}^{K^-}}$$

FF model	R_{SF}
EMC* (naive string model):	≈ 3
DSS** :	≈ 7

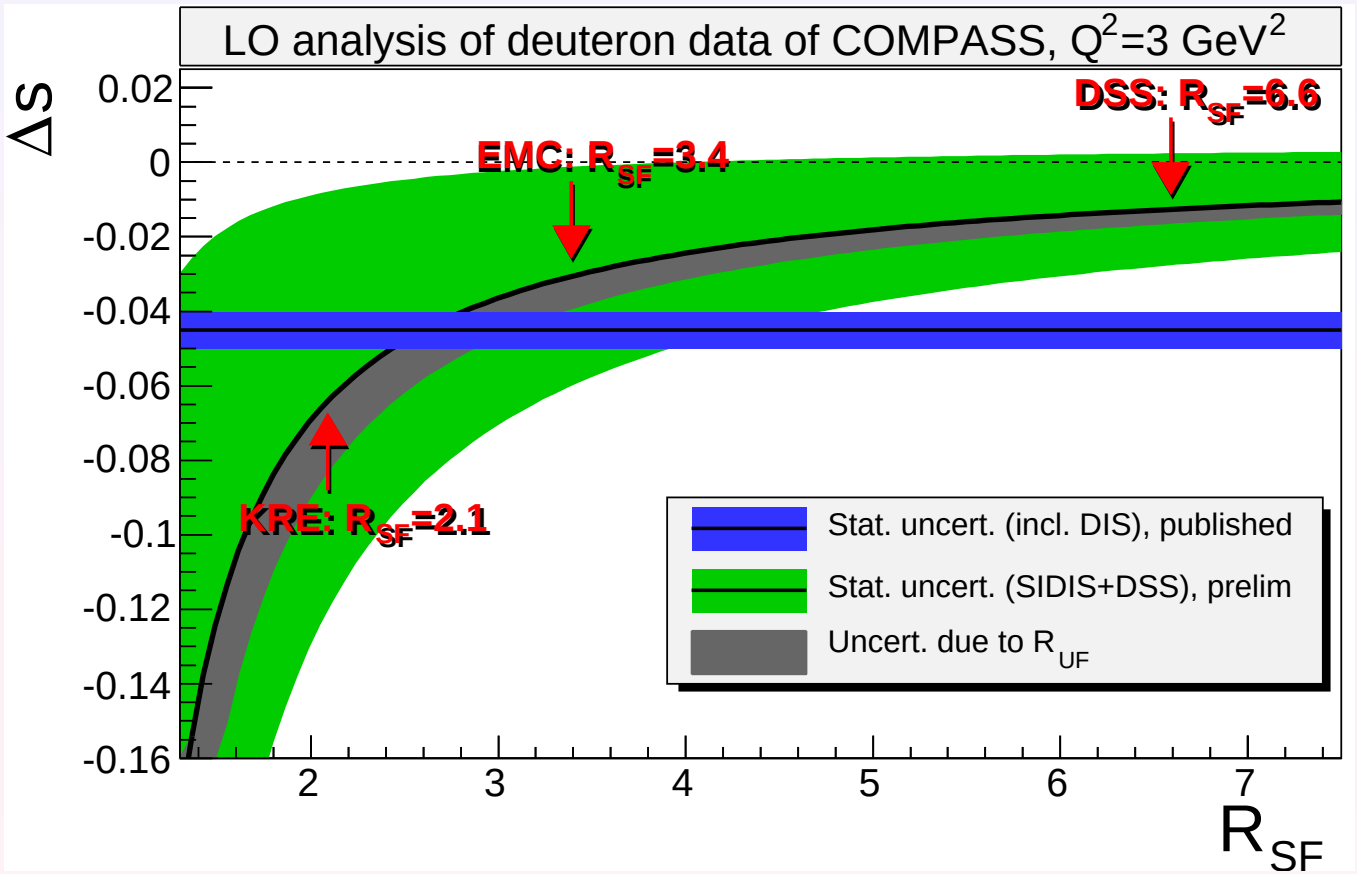
$\Rightarrow$ Measure $\frac{\int D_{\bar{s}}^{K^+}}{\int D_u^{K^+}}$ from kaon multiplicity at COMPASS

* EMC u, d-quark FF plus assumptions about s-quark FF

** de Florian, Sassot, Stratmann, PRL D75, 114010, 1-26 (2007)

First Moment of Δs vs. R_{SF}

$$\Delta s = \int_0^1 \Delta s(x)\mathrm{d}x$$



$$R_{SF} = \frac{\int D_{\bar{s}}^{K^+}}{\int D_u^{K^+}}$$

Transversity

Quark Distributions

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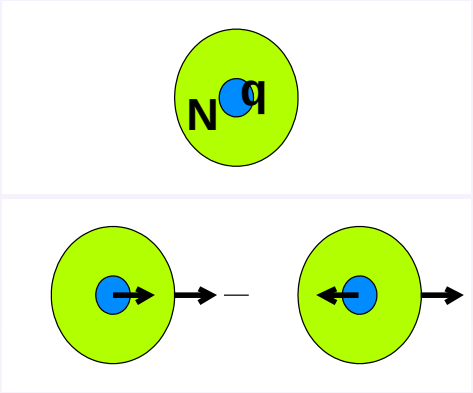
$\Delta q(x), \Delta g(x)$ (helicity)



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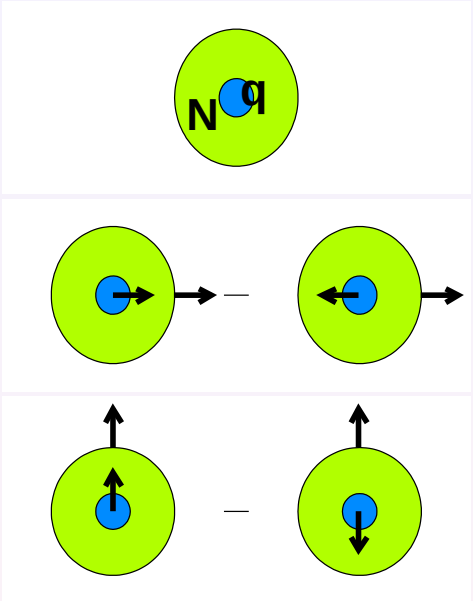
$\Delta_T q(x)$ (transversity)



- All three types of distributions needed to fully describe nucleon in terms of parton distributions
  (at leading twist, integrated over k_T)

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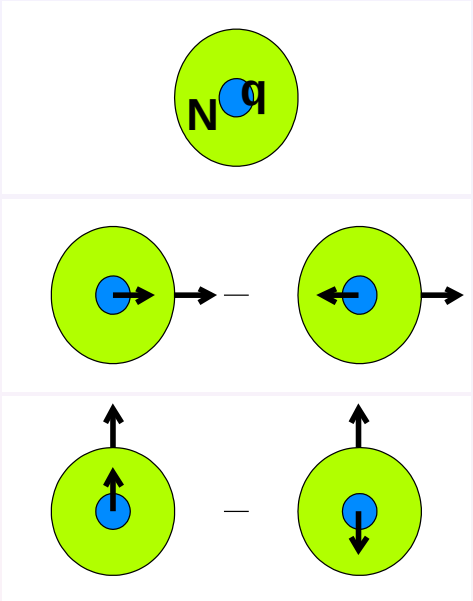

Our knowledge:
good

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

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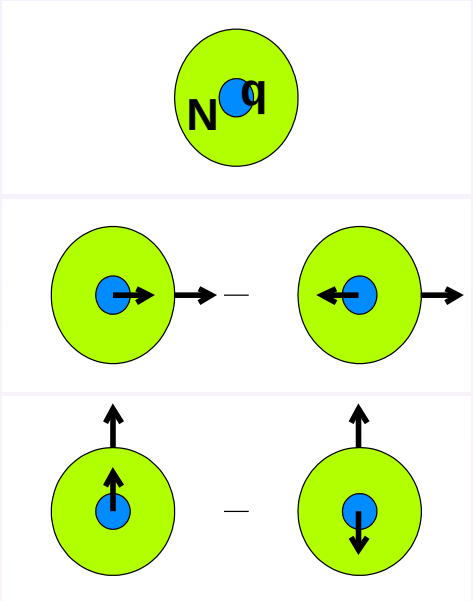

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fair,poor

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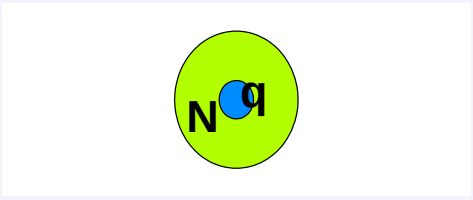

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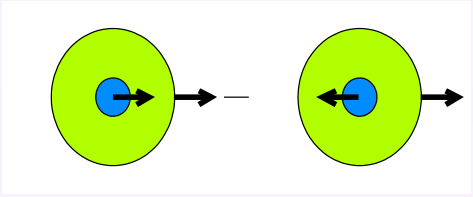
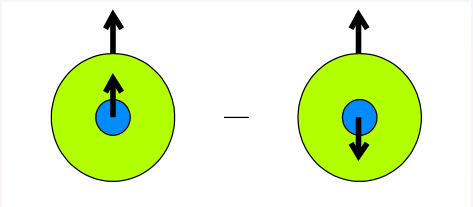
good

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



fair,poor

$\Delta_T q(x)$ (transversity)



poor

- All three types of distributions needed to fully describe nucleon in terms of parton distributions
  (at leading twist, integrated over k_T)

Transversity distributions $\Delta_T q(x)$

accessible in semi-inclusive deep inelastic scattering:

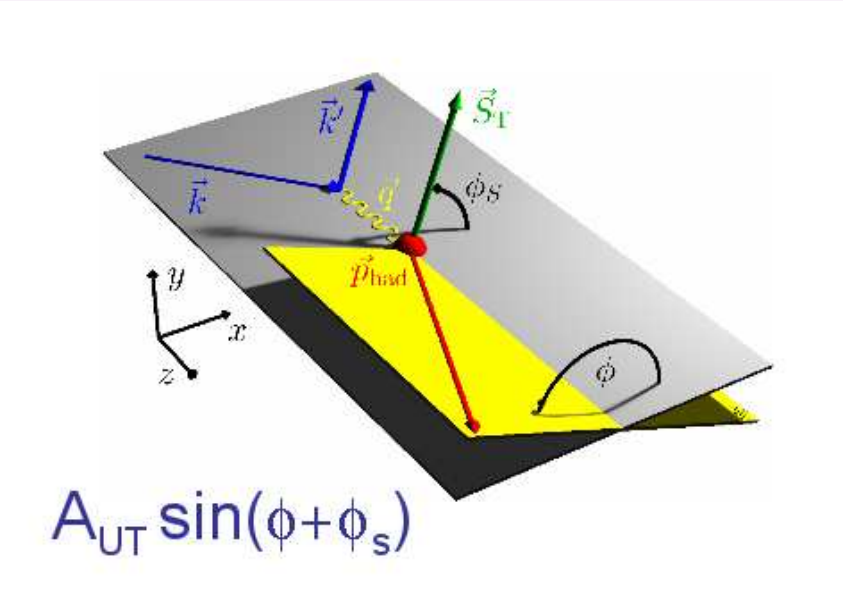
$$l + N^{\uparrow} \rightarrow l' + h + X$$

on transversely polarized targets.

Transversity distributions $\Delta_T q(x)$

Single Spin asymmetry:

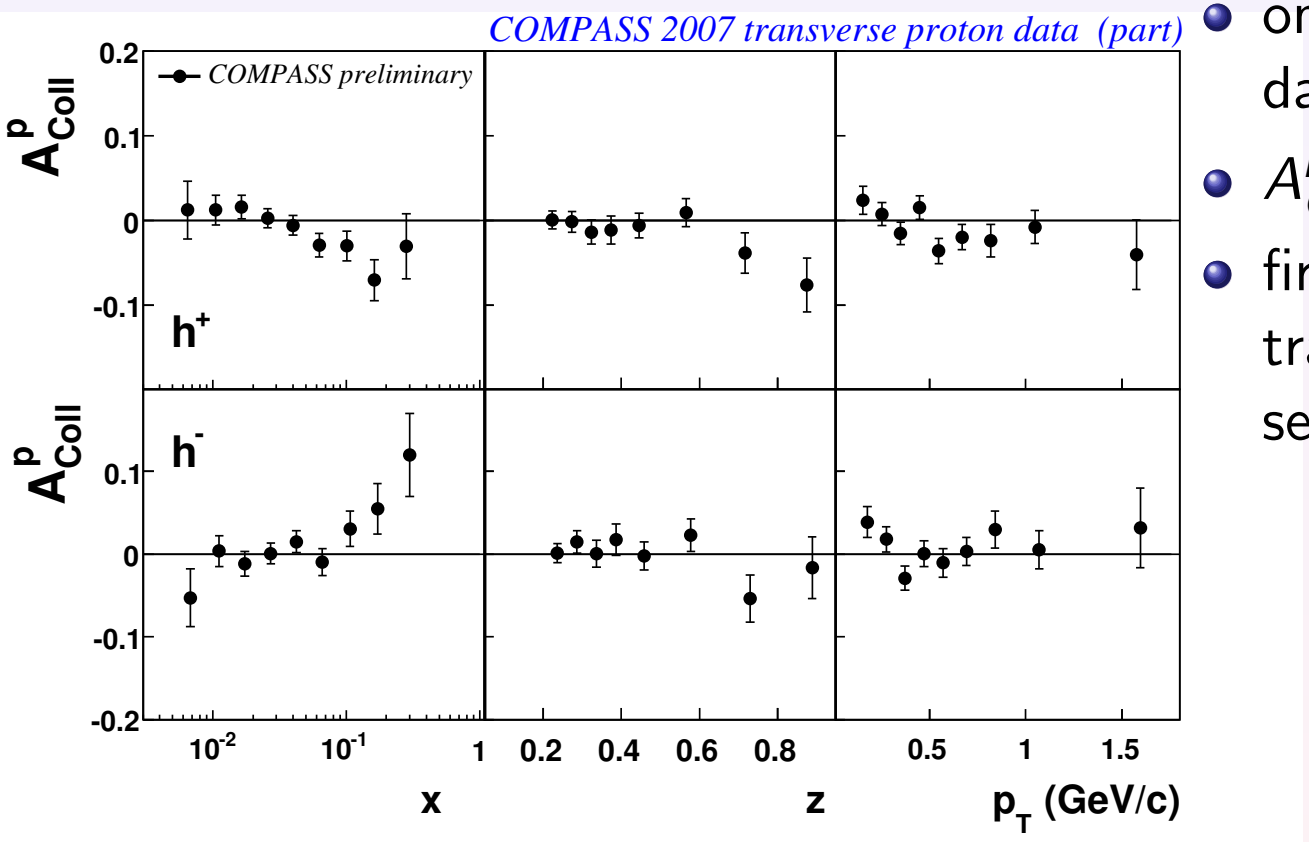
$$A_T^h = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow} \propto \frac{\Sigma_q e_q^2 \Delta_T q(x) \Delta_T^0 D_q^h(z)}{\Sigma_q e_q^2 q(x) D_q^h(z)} \sin(\Phi_S + \Phi) = A_{Coll} \sin(\Phi_C)$$



Collins asymmetry

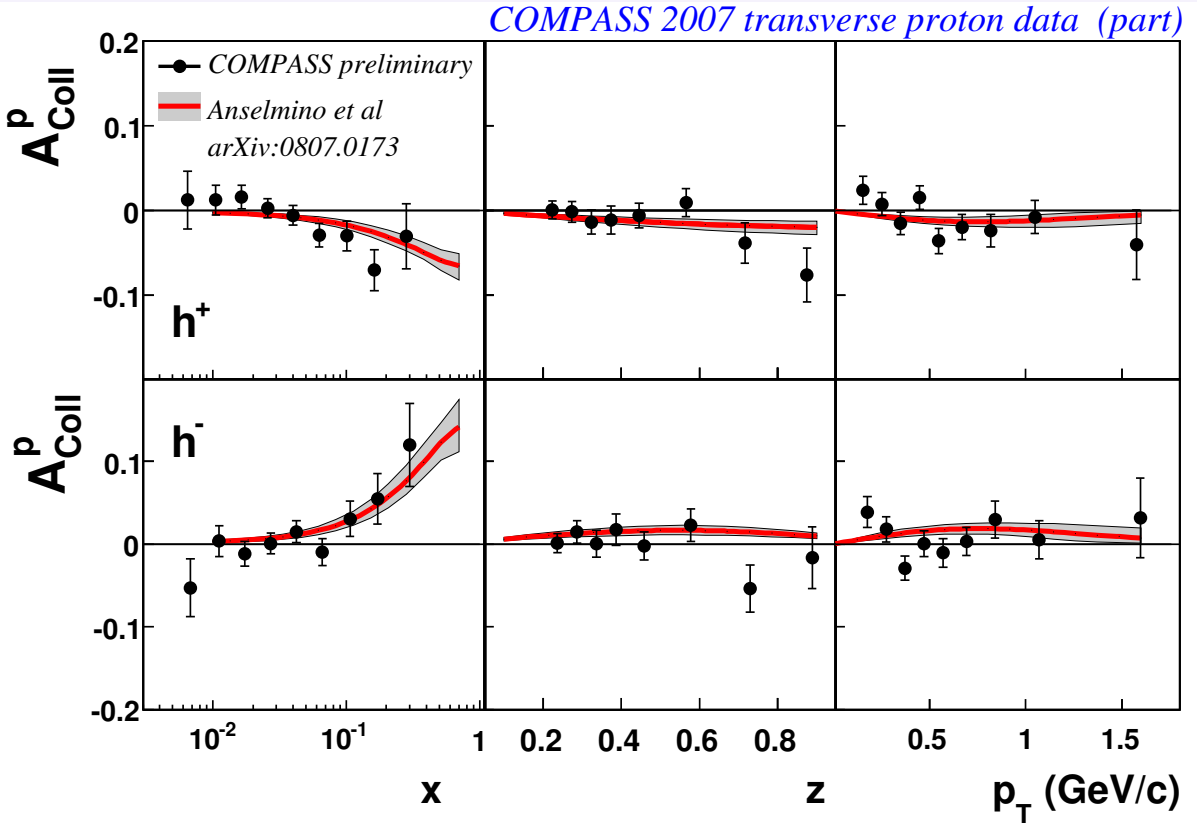
Coffee break discussion on spin conference

Collins Asymmetries from Proton Target



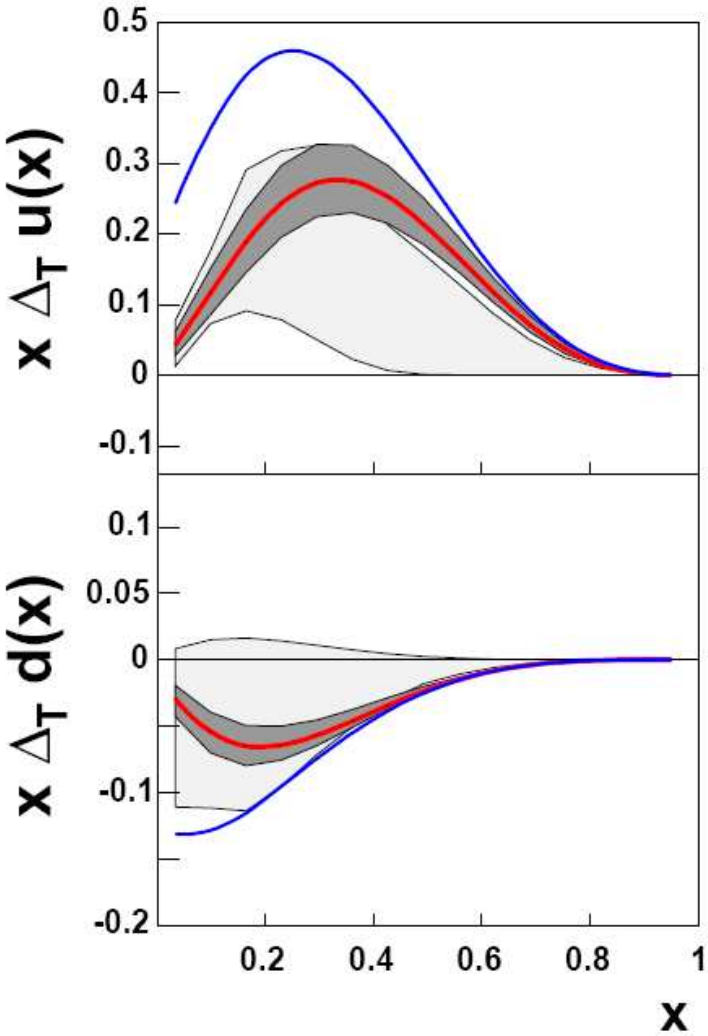
- only 20% of 2007 data!
- $A_{Coll}^{h^-} > 0$, $A_{Coll}^{h^+} < 0$
- first non-zero transversity signal seen by COMPASS

Collins Asymmetries from Proton Target



- only 20% of 2007 data!
- $A^{h^-}_{Coll} > 0$, $A^{h^+}_{Coll} < 0$
- first non-zero transversity signal seen by COMPASS
- curves: predictions from Anselmino et al., based on data which do not yet include COMPASS proton data

Transversity Distribution $\Delta_T q(x)$



- Fit to BELLE,COMPASS and HERMES data (Anselmino et al, arXiv:0807.0173)
- COMPASS proton data not yet included

Hadron Run

Hadron Programme

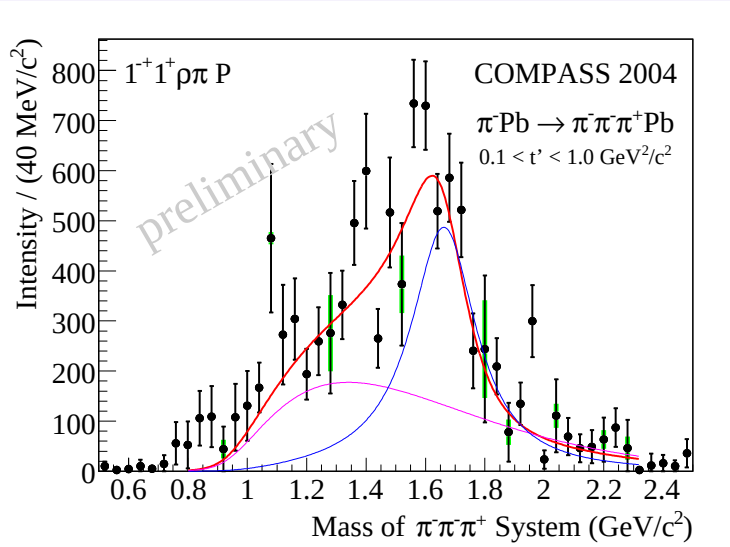
Main Goals:

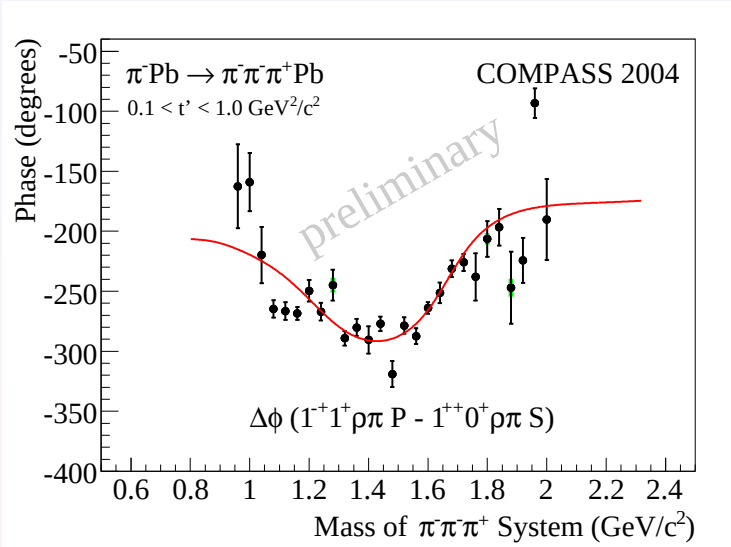
- Meson Spectroscopy: $\pi^- \mathrm{Pb} \rightarrow \mathrm{Pb}\, \pi^- \pi^- \pi^+$
- Polarizibilties: $\pi^- \mathrm{Pb} \rightarrow \mathrm{Pb}\, \pi^- \gamma$

Pilot Run in 2004

- Pilot Run in 2004 showed that measurement of polarizabilities and spectroscopy are possible
- Problems identified for polarizability measurement (dead cells in electromagnetic calorimeter, saturation for high energies photons, ...)
  $\Rightarrow$ No significant result from 2004 data, run planed in 2009
- 3 days of data taking on diffractive pion production yielded statistics of existing measurements
- First "real" hadron run this year

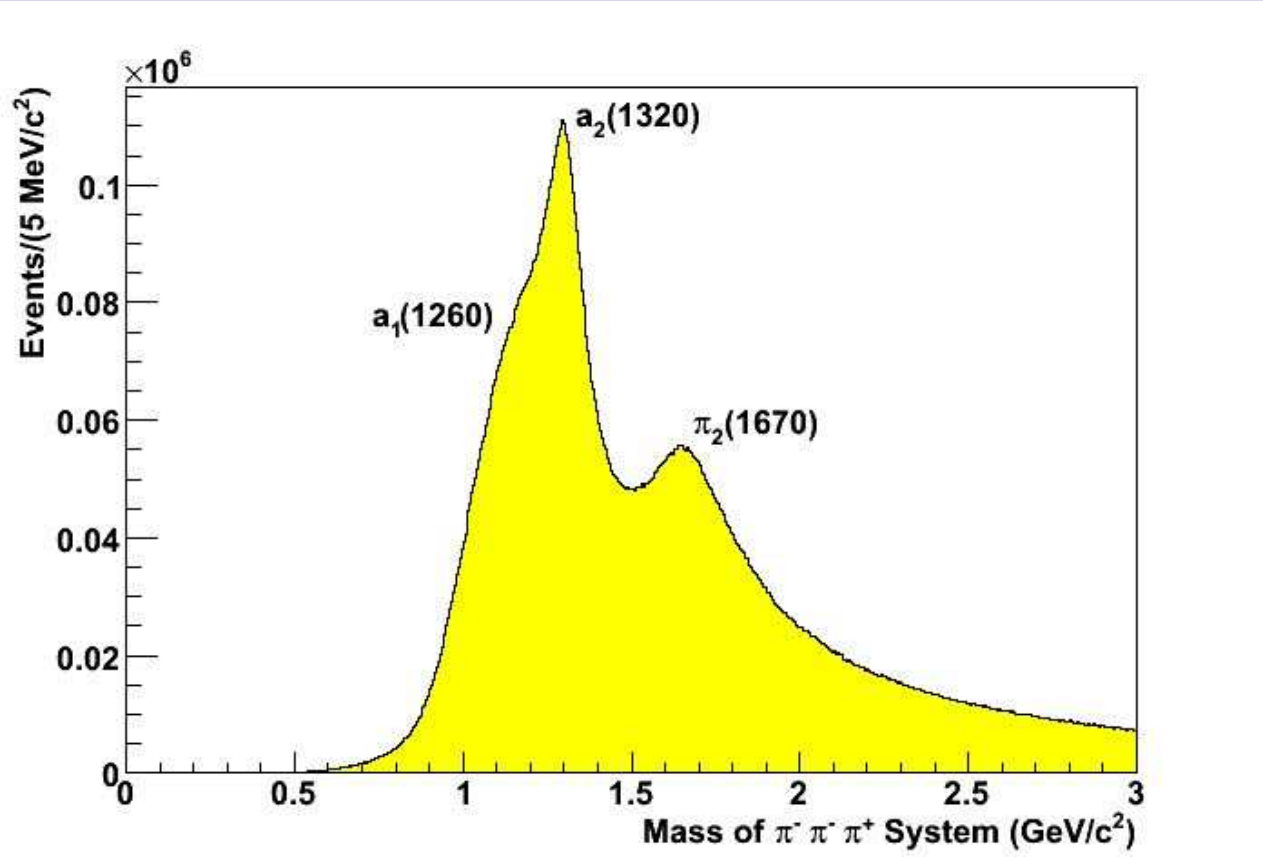
Partial Wave Analysis of 2004 data





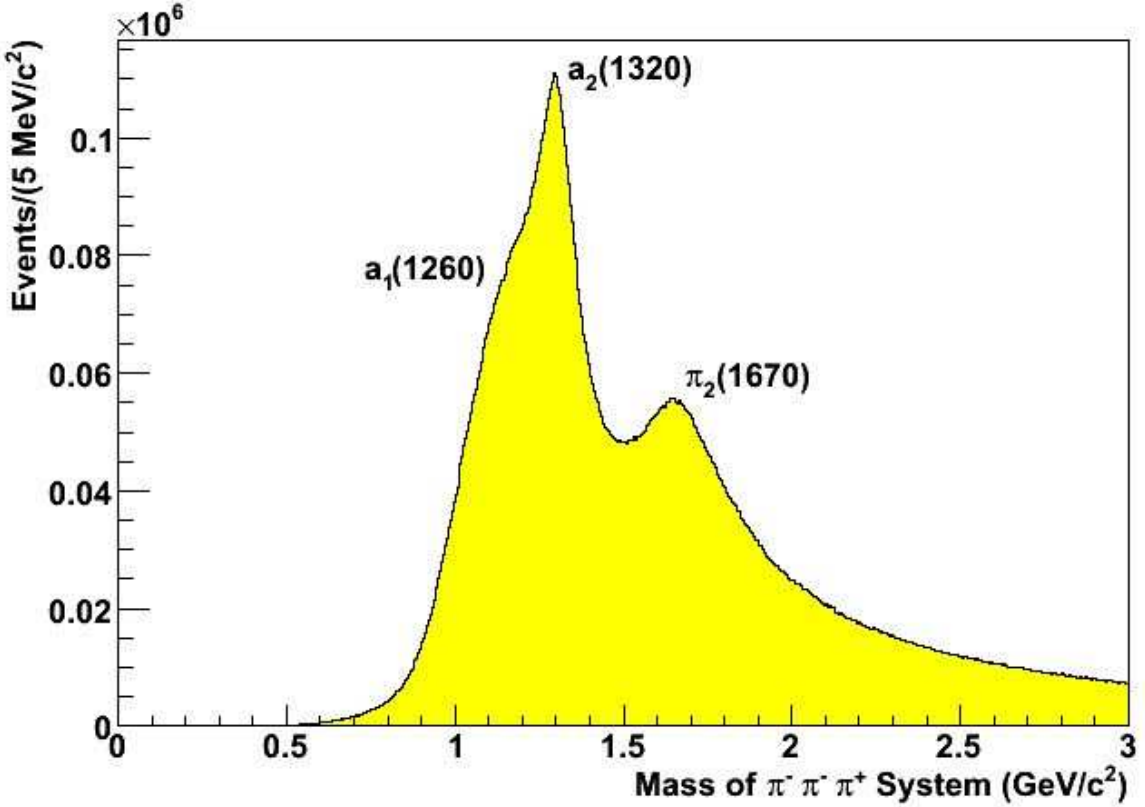
- Known resonances reconstructed
- Significant exotic 1^{-+} amplitude consistent with $\pi(1600)$
- $M = 1.660 \pm 0.010^{+0.000}_{-0.064}$ GeV, $\Gamma = 0.269 \pm 0.021^{+0.042}_{-0.064}$ GeV,

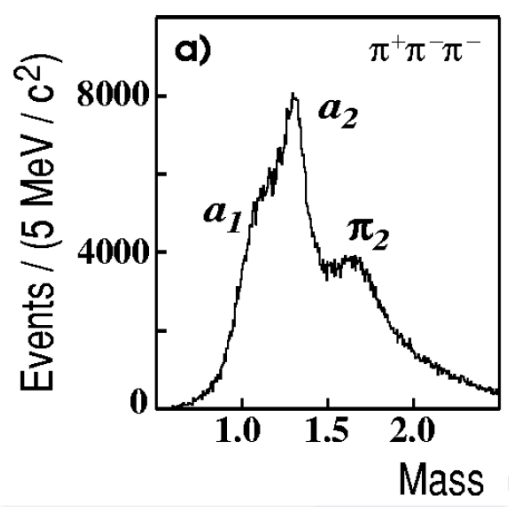
Hadron Run 2008



- 15% of available statistics collected in 2008
- Increase in statistics compared to BNL
- partial wave analysis ongoing
- acceptance correction are small (BNL spectrum is acceptance corrected)

Hadron Run 2008





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Summary

Summary & Outlook

- muon programme on deuteron target completed, many results on ΔG, Δs, A_1^d, Δq_v, A_{Coll}^d, Λ, ...
- first muon run on polarized proton (A_{Coll}^p, A_1^p, Δq)
- First "real" hadron run in 2008,
  first mass spectra look promising
- Continue data taking with hadron beams and muon beam on polarized protons in next 4 years
- Plans beyond 2012:
  Generalized Parton Distributions, Drell-Yan

Spare

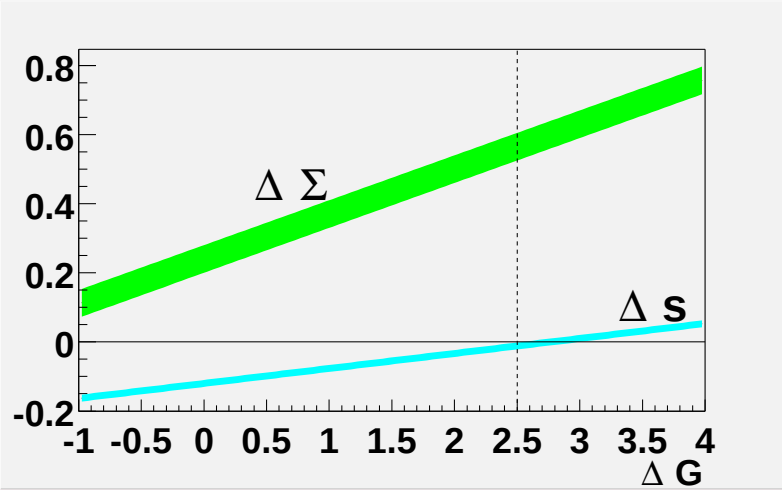
The Nucleon Spin Puzzle

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

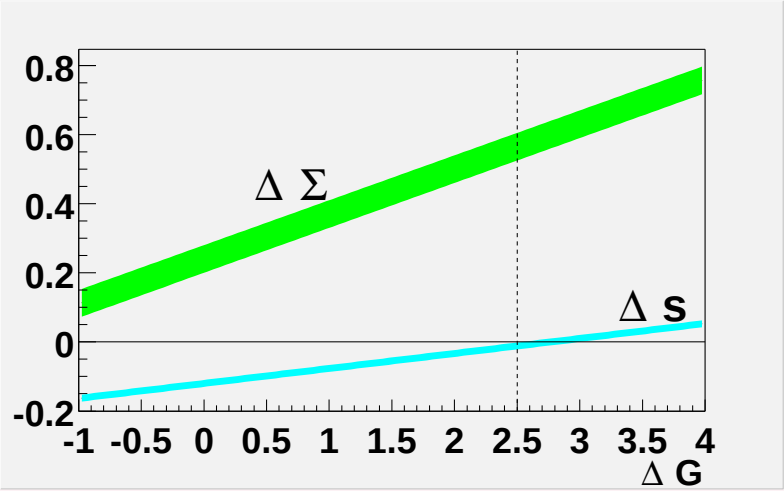
The Nucleon Spin Puzzle

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**

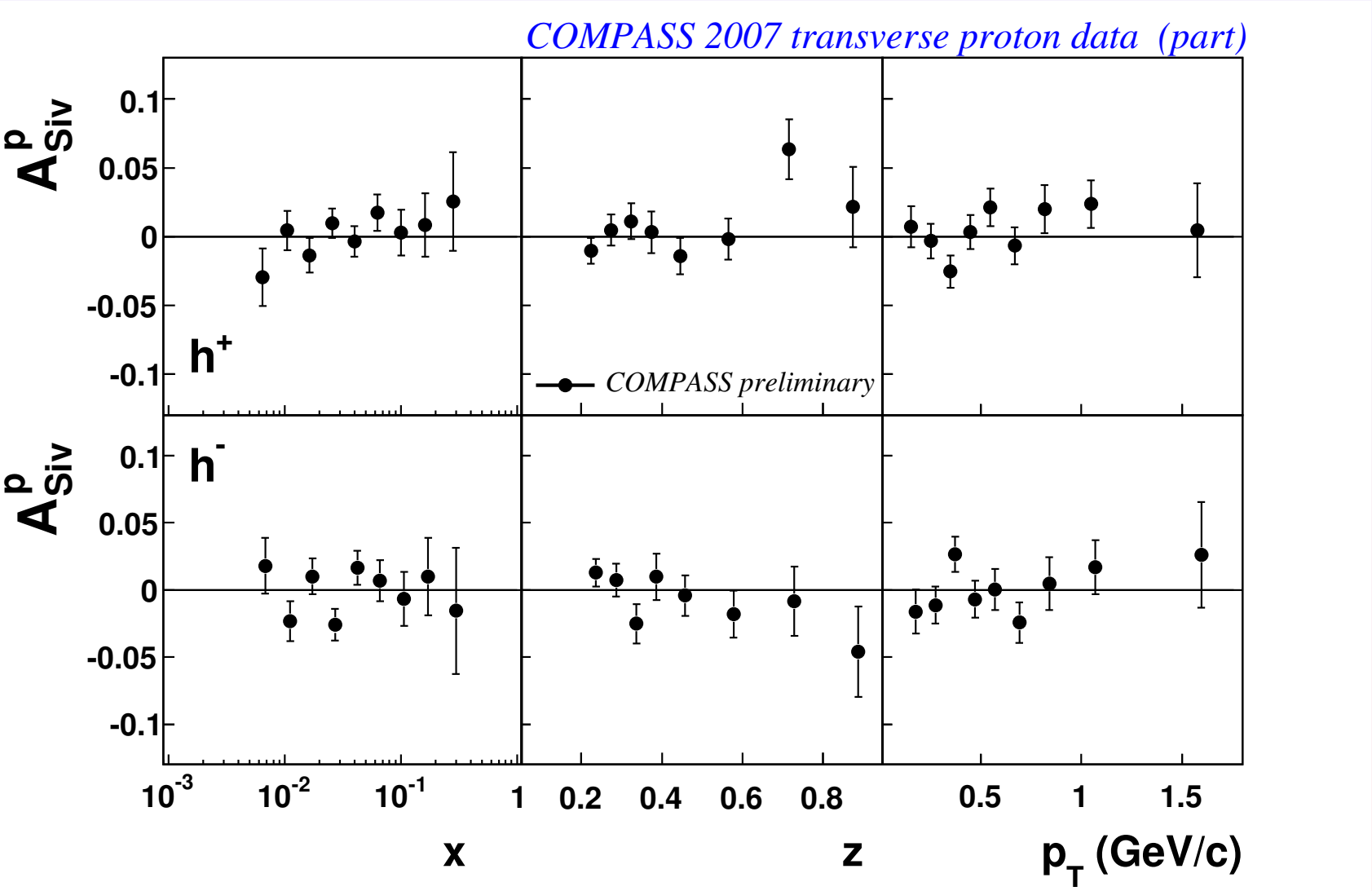


For $\Delta G \approx 2.5 \rightarrow$,
$\Delta\Sigma \approx 0.6$ and $\Delta s \approx 0$

$\rightarrow$ Measure ΔG !!!

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

Sivers Asymmetries



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