Spin Physics with COMPASS

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Outline:

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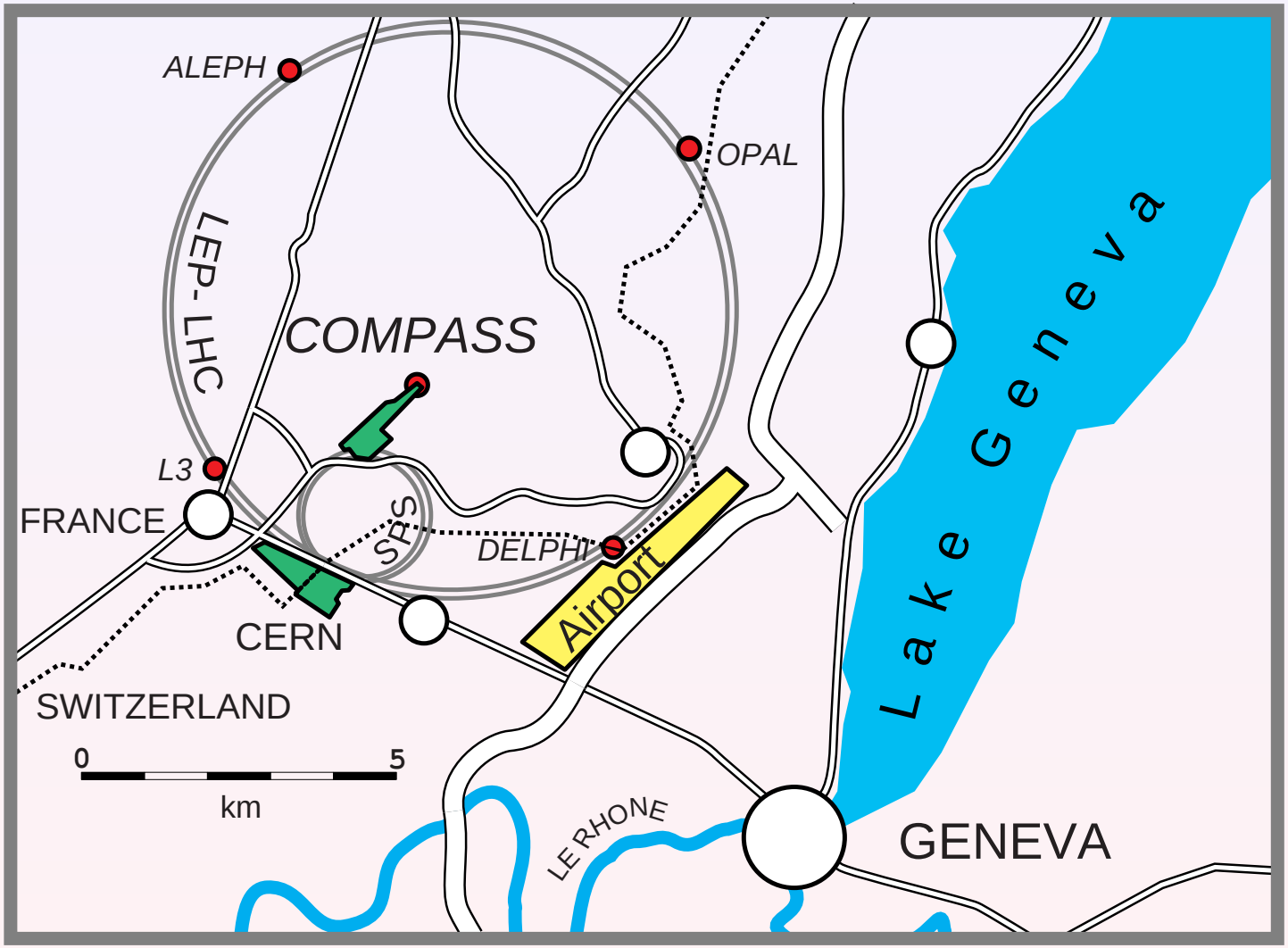
The COMPASS experiment

COMPASS

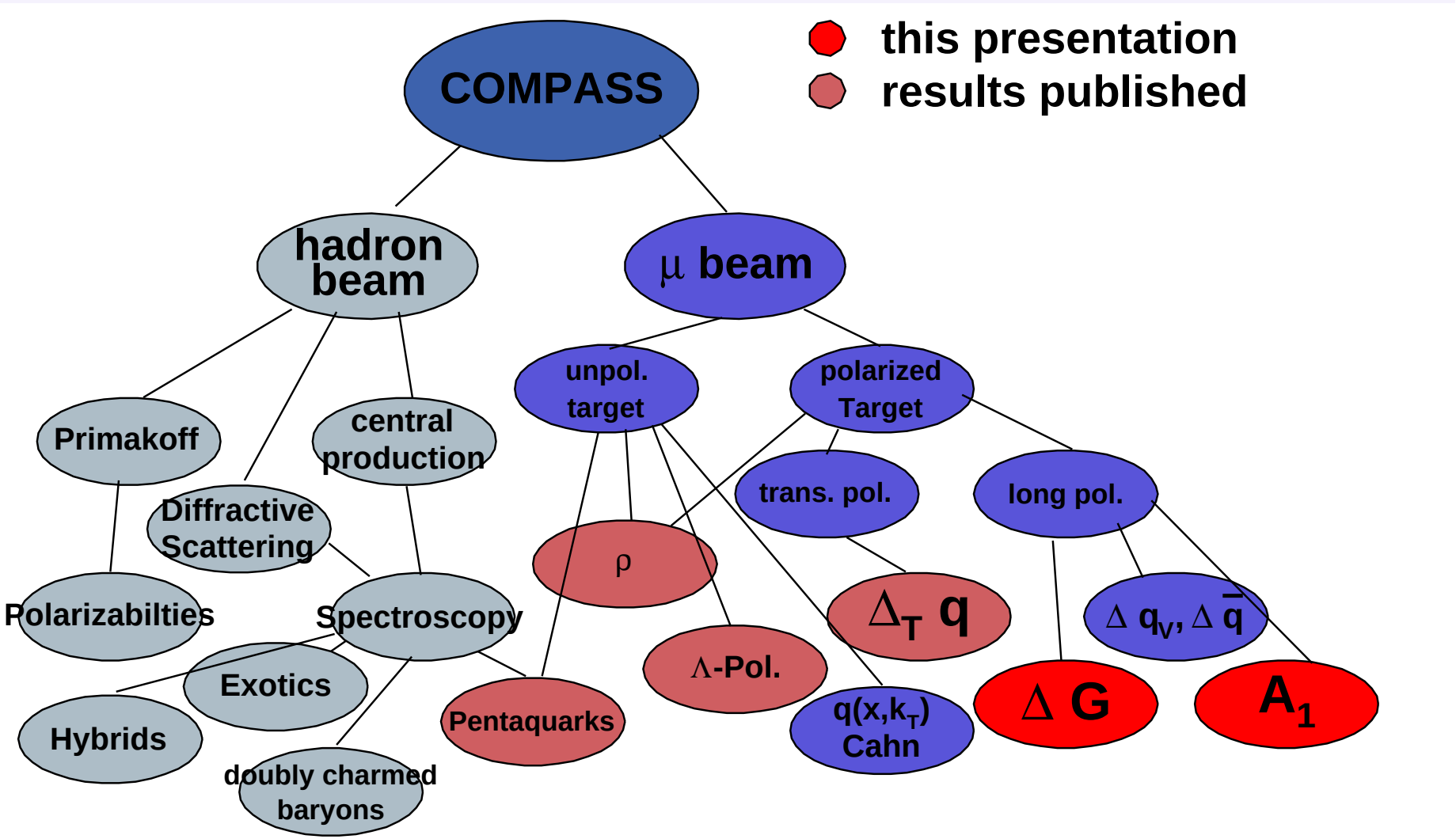
CO mmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

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

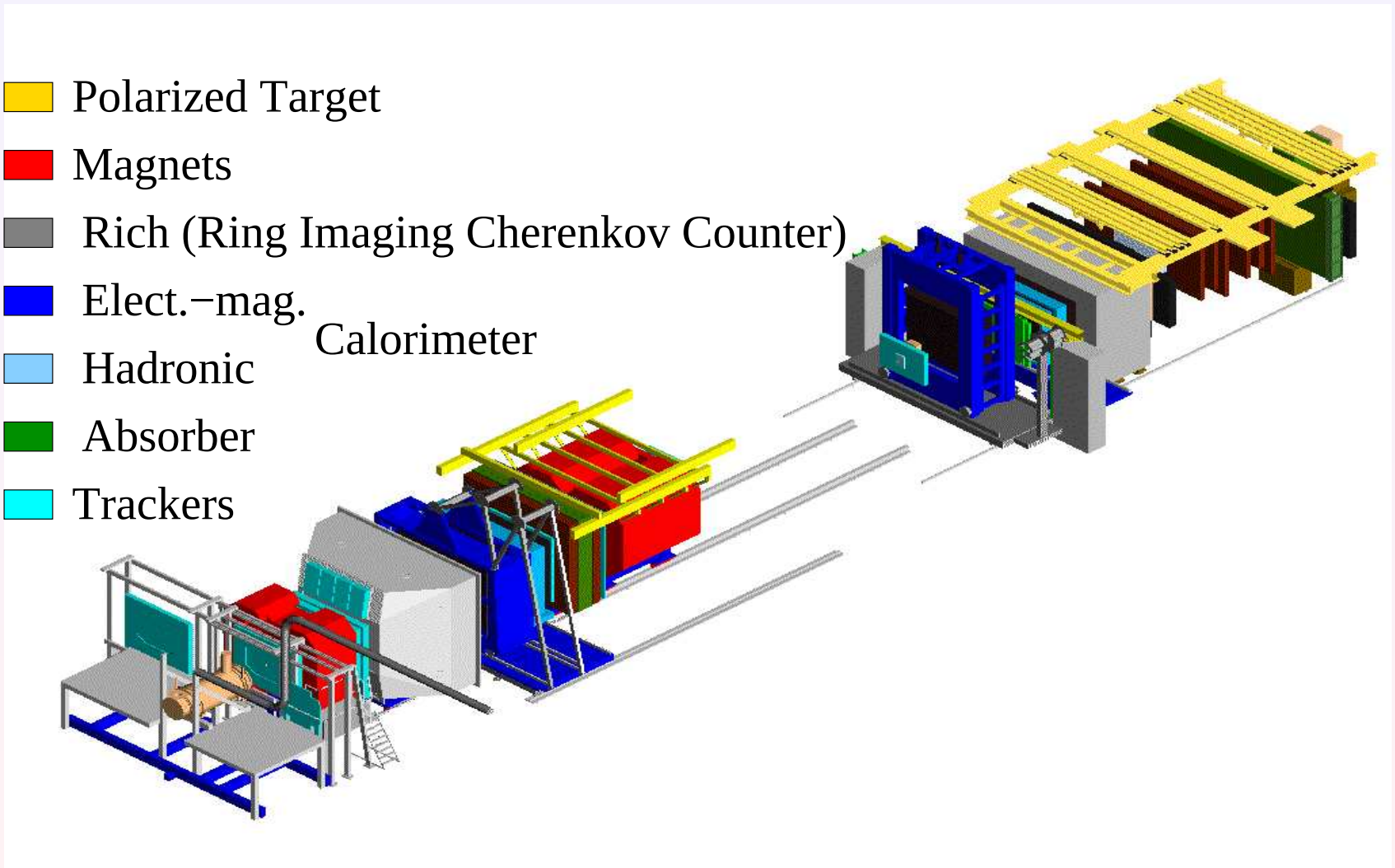
COMPASS@CERN



Physics Goals



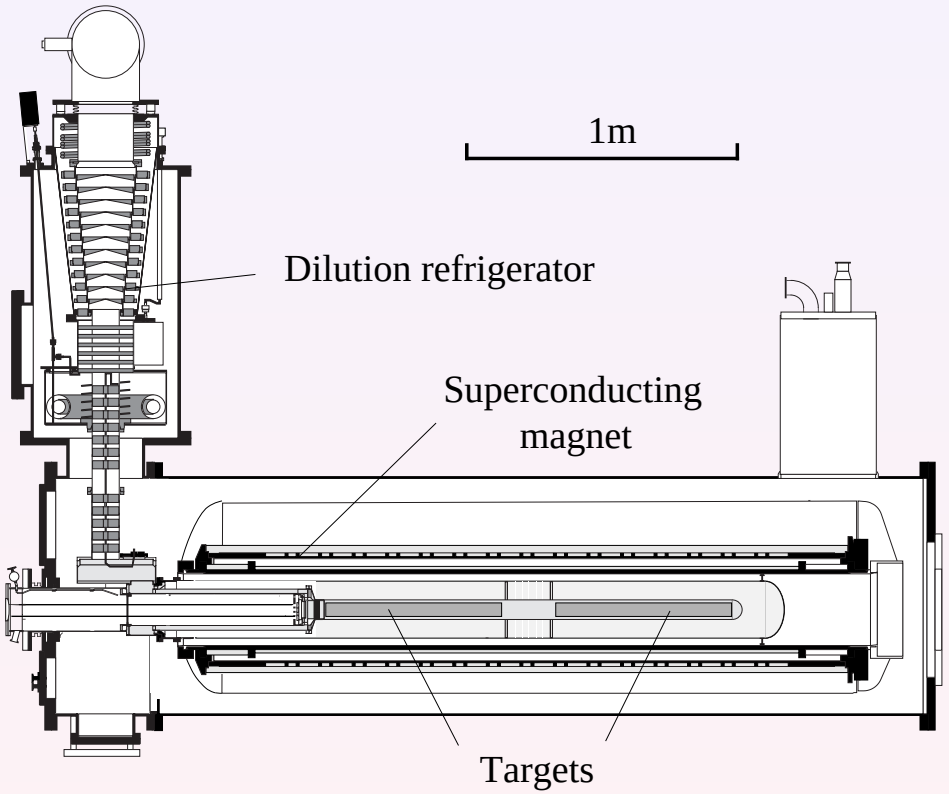
The COMPASS Experiment



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
Beam:	160 GeV μ , $2 \cdot 10^8/5$s, naturally polarized Pol = –0.76 $\pm$ 0.04 190 GeV π , $5 \cdot 10^6/5$s
pol. Target:	2×65 cm cells, oppositely polarized ^{6}LiD, Pol ≈ 0.5, DNP

Polarized Target



- polarization via **D**ynamic **N**uclear **P**olarisation

- solid state target
  ^6LiD, $P_{tgt} = 0.50$, f= 0.5
  NH_3, $P_{tgt} = 0.85$, f= 0.176
- two cells oppositely polarized
- Solenoid (B = 2.5T)
- Dipole (0.5 T)
- ^{3}He-^{4}He - cryostat ($T_{min} = 50$ mK)
- measurement of polarization with 10 NMR - coils ($\frac{\sigma_P}{P} = 0.03$)

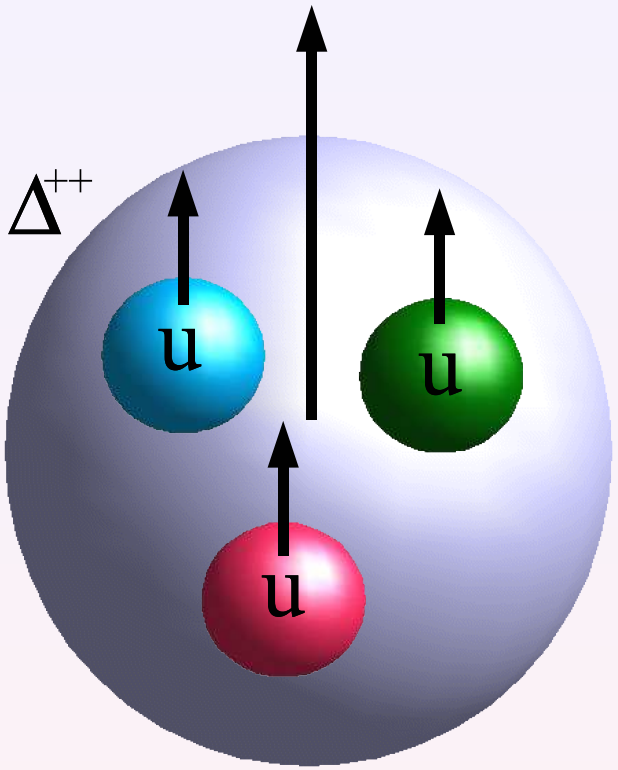
Summary: Experiment

- polarized μ beam of 100-200 GeV $\rightarrow$ Deep Inelastic scattering
- polarized target
- Two stage spectrometer
  - momentum range 1-200 GeV
  - particle id.

Fulfills all requirements to study ...

Spin Structure of the Nucleon

Spin Structure of Baryons



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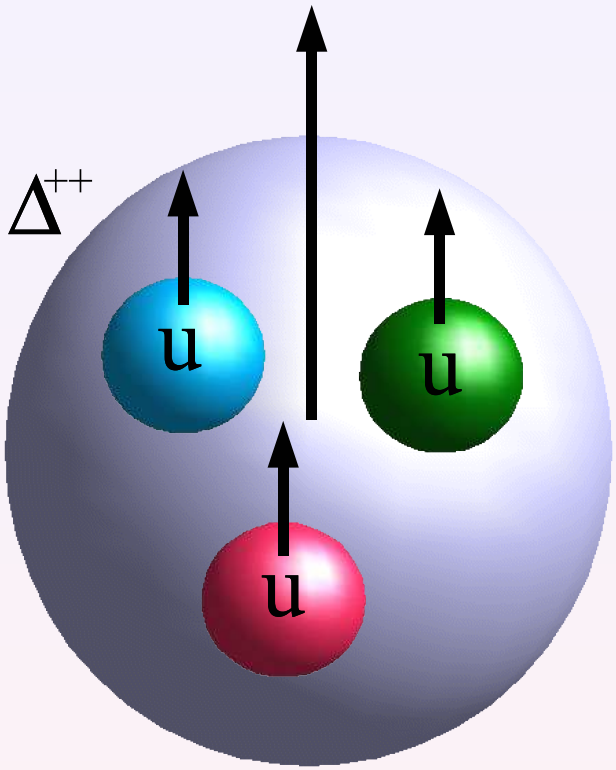
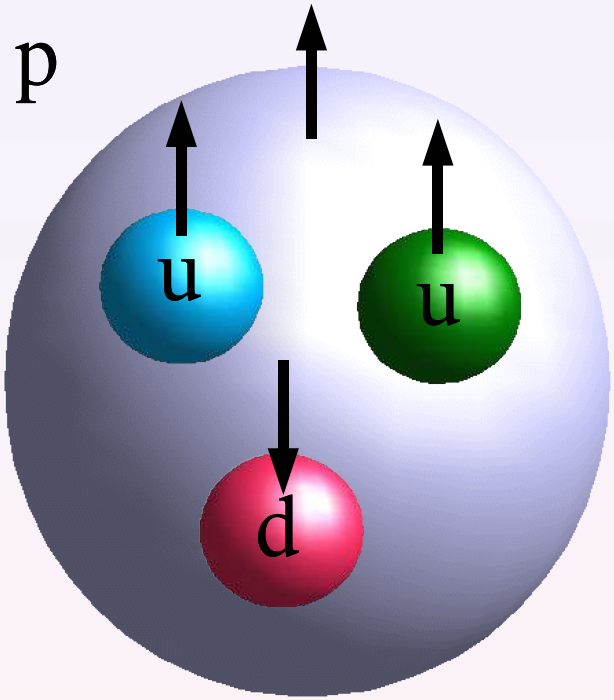




Static Quark Model

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

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

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

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

Weak Baryon Decays

Weak Baryon decays are related to Δq:

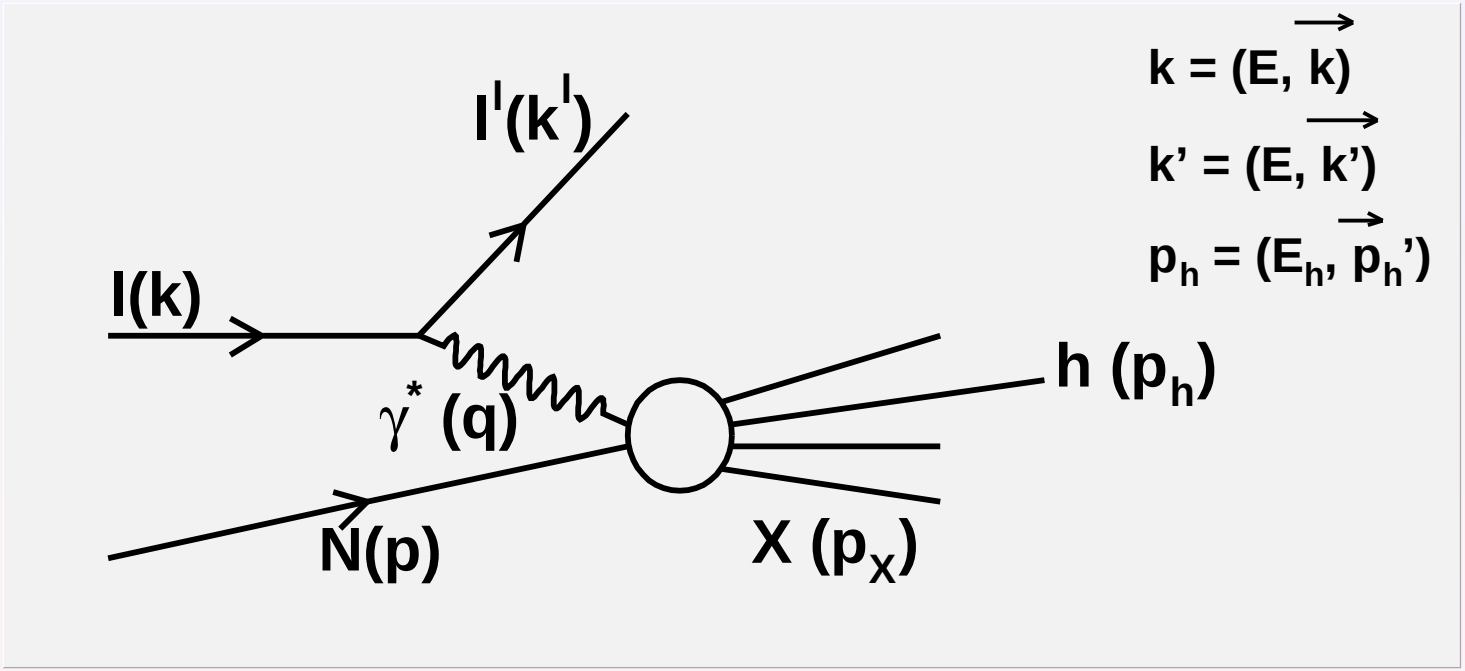
$n \to p$:	$(\Delta u + \Delta\bar{u}) - (\Delta d + \Delta\bar{d})$	$= g_A = 1.2601 \pm 0.0025$
$\Xi^- \to \Lambda$:	$(\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) - 2(\Delta s + \Delta\bar{s})$	$= 0.58 \pm 0.03$

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

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

Polarized Deep Inelastic Scattering (**p**DIS) provides additional equation, assumption $\Delta s + \Delta\bar{s} = 0$ can be dropped

Deep Inelastic Scattering $l + N \longrightarrow l' + X$

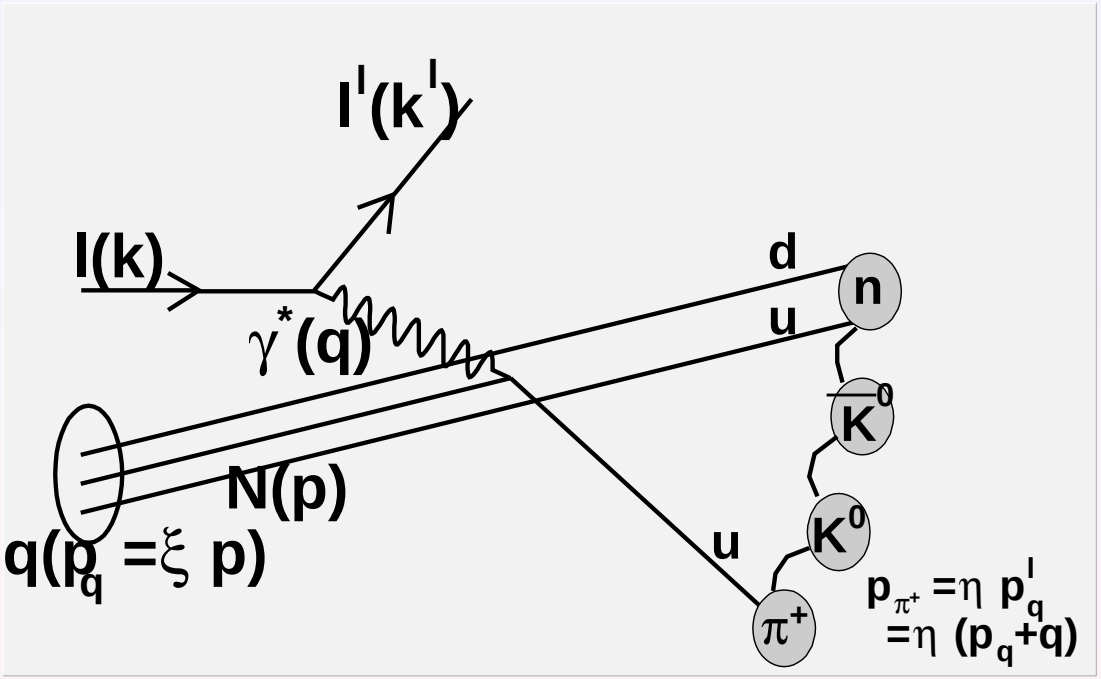


$l + N \longrightarrow l' + X$:	inclusive process
$l + N \longrightarrow l' + h + X$:	semi-inclusive process

Deep Inelastic Scattering $l + N \rightarrow l' + h + X$

For inclusive process:	
$Q^2 = -(k - k')^2 = -q^2$	4 momentum transfer
$\nu = \frac{p \cdot q}{M} = E - E'$	energy transfer in LAB (TRF)
$x = \frac{Q^2}{2p \cdot q} = \frac{Q^2}{2M\nu}$	Bjorken variable $(0 < x < 1)$ momentum fraction of quark in QPM
$y = \frac{p \cdot q}{p \cdot k} = \frac{\nu}{E}$	rel. energy transfer
$W^2 = (p + q)^2$	mass of hadronic final state W $\approx>$ 2 GeV $\Rightarrow$ DIS
For semi-inclusive process:	
$z = \frac{p \cdot p_h}{p \cdot q} = \frac{E_h}{\nu}$	energy fraction of virtual photon carried by hadron $(0 < z < 1)$
p_T	transverse momentum with respect to virtual photon

DIS in Quark Parton Model



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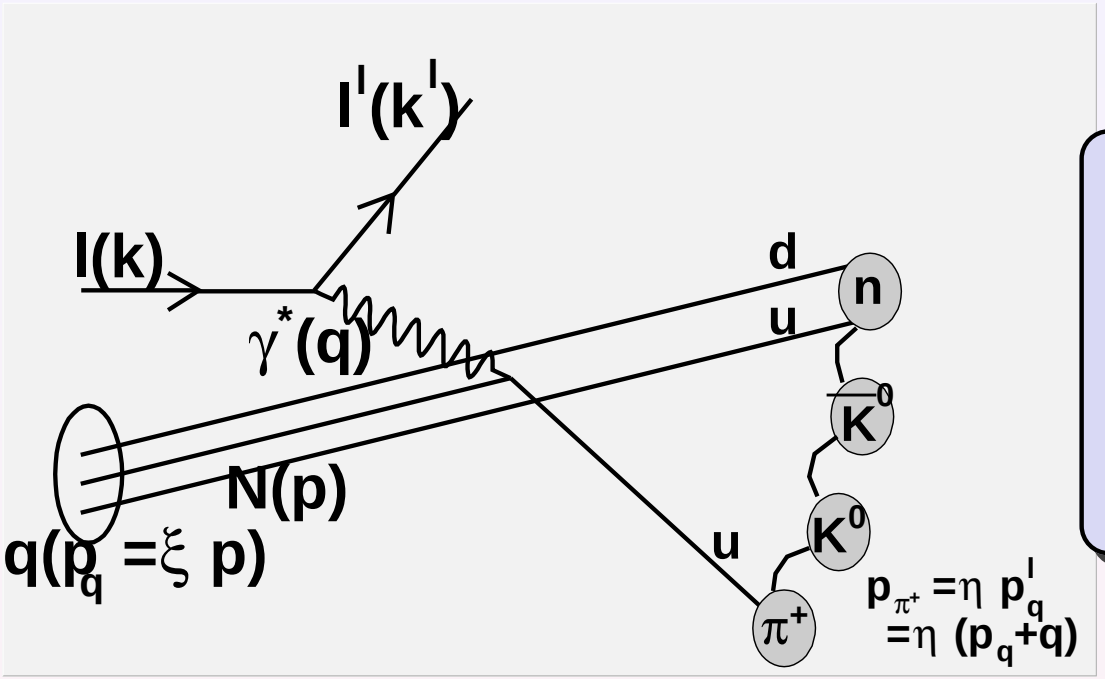
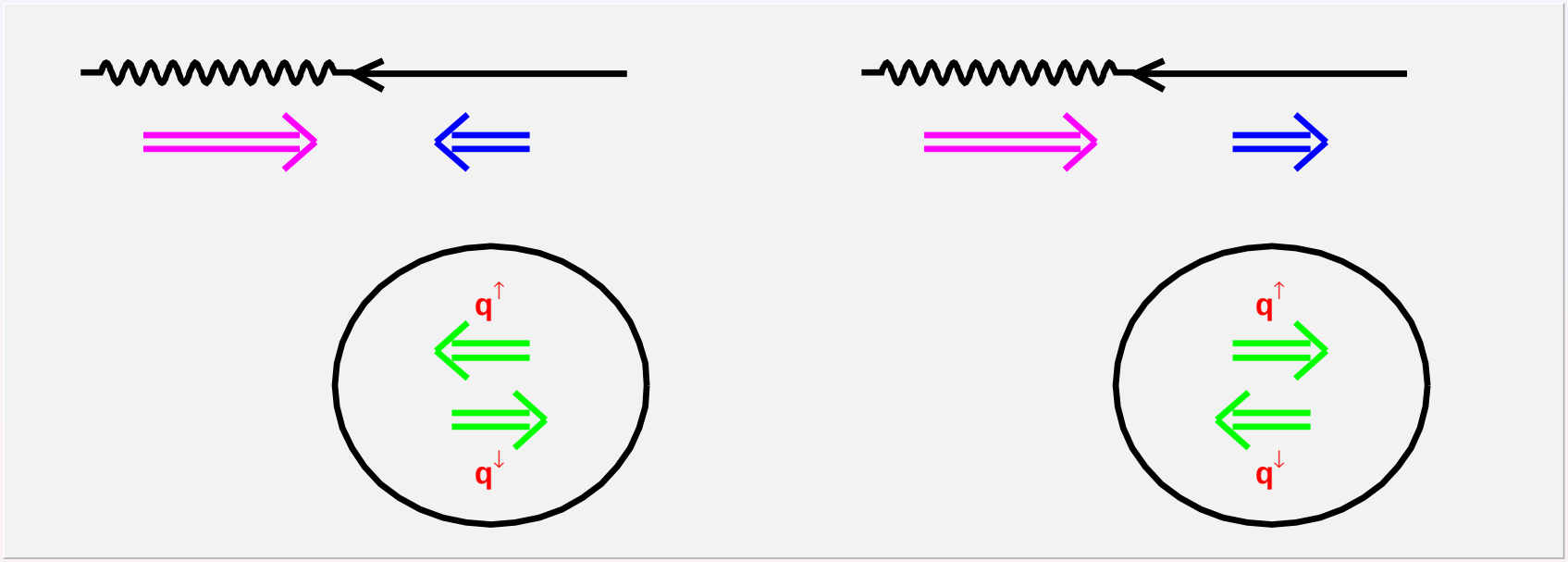


Scattering off the Nucleon is incoherent sum of elastic scattering off Quarks!

Polarized DIS

$\sigma_{\gamma N}^{\uparrow\downarrow} \propto q^{\uparrow}$ $\sigma_{\gamma N}^{\uparrow\uparrow} \propto q^{\downarrow}$



Measure double spin asymmetry:

$$A_1 = \frac{\sigma_{\gamma N}^{\uparrow\downarrow} - \sigma_{\gamma N}^{\uparrow\uparrow}}{\sigma_{\gamma N}^{\uparrow\downarrow} + \sigma_{\gamma N}^{\uparrow\uparrow}} = \frac{\Sigma_q e_q^2 \Delta q}{\Sigma_q e_q^2 q}$$

Results from pDIS

Add information from deep inelastic scattering

$\Delta u + \Delta \bar{u}$	$=$	0.82	$\pm$	0.03
$\Delta d + \Delta \bar{d}$	$=$	-0.45	$\pm$	0.05
$\Delta s + \Delta \bar{s}$	$=$	-0.11	$\pm$	0.03
$\Delta\Sigma$	$=$	0.25	$\pm$	0.06

Leader, Sidorov, Stamenov, Eur. Phys. J. C23(2002)479

The Nucleon Spin Puzzle

Static Quark Model: $\Delta\Sigma = 1$

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Weak Baryon decays: $\Delta\Sigma = 0.58 \pm 0.03$

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DIS: $\Delta\Sigma = 0.25 \pm 0.06$

$\Delta s = -0.11 \pm 0.02$

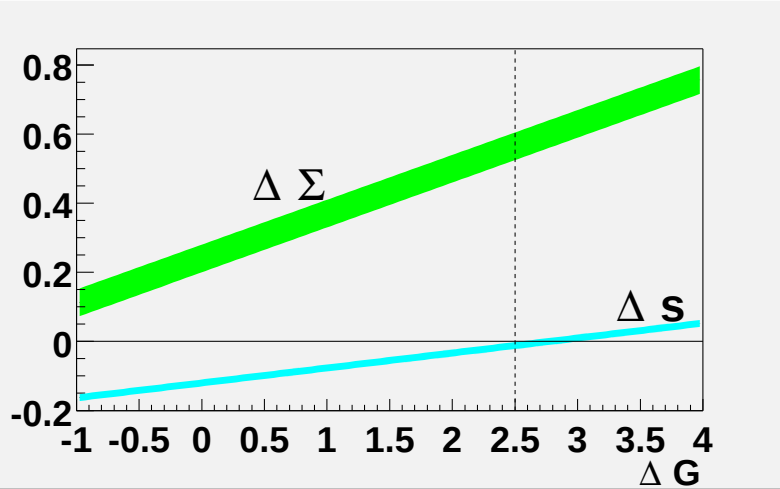
The Nucleon Spin Puzzle

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

$\Delta\Sigma \longrightarrow \Delta\Sigma - \frac{3\alpha_s}{2\pi}\Delta G$,

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

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



[1] next-to-leading order

[2] Quantum Chromo Dynamics

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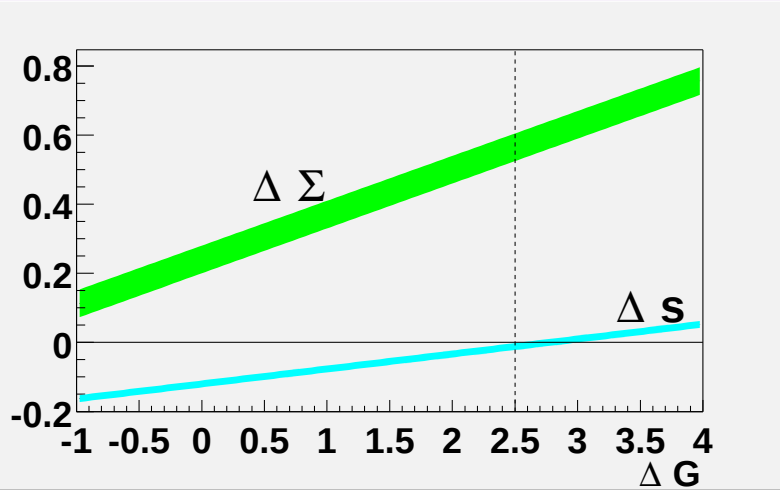


For $\Delta G \approx 2.5 \rightarrow$,
$\Delta\Sigma \approx 0.6$ and $\Delta s \approx 0$

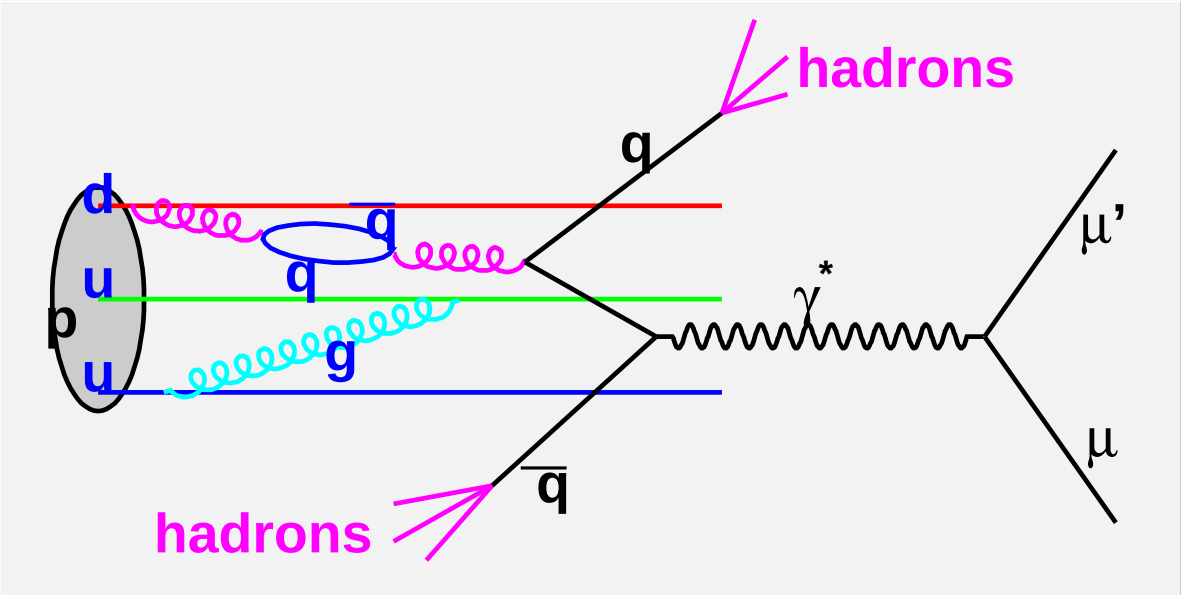
$\rightarrow$ Measure ΔG !!!

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

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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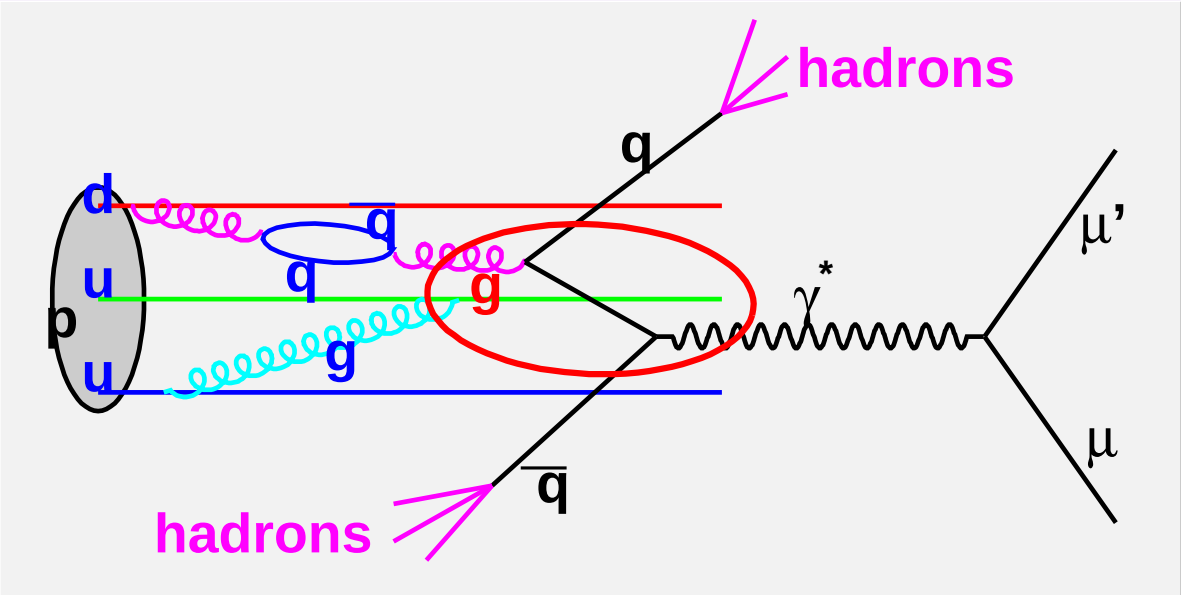
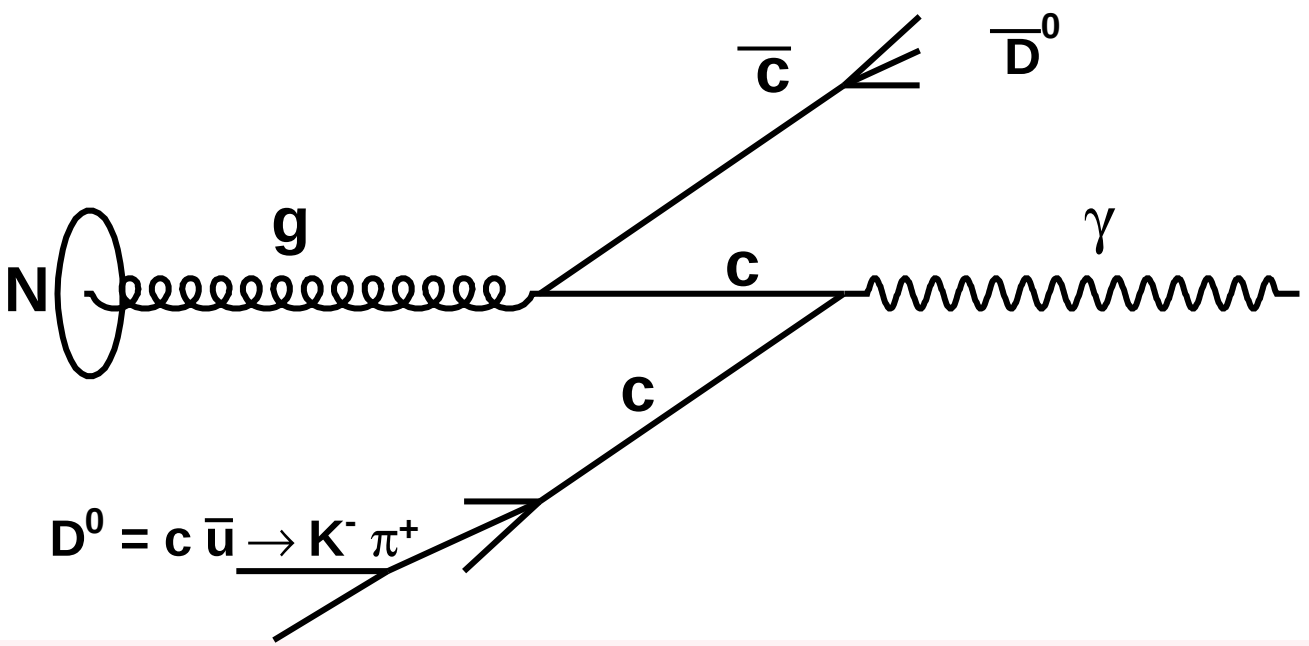


How to tag sub-process

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

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

	advantage	disadvantage
open charm	clean tag	low statistics
high p_T hadron	higher statistics	background processes



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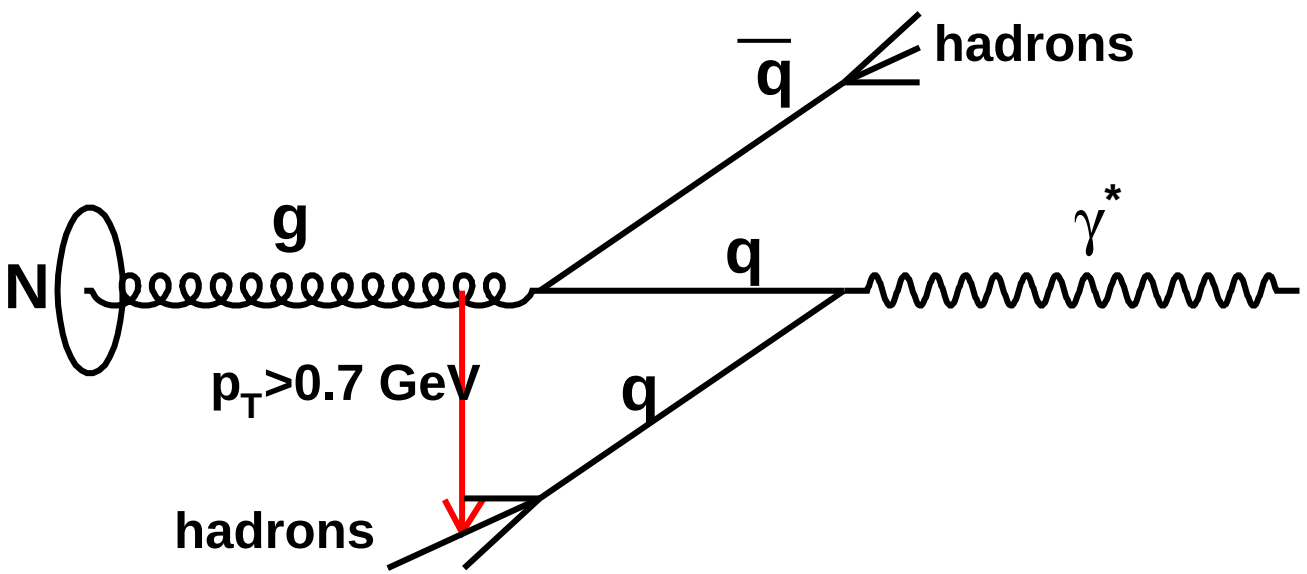

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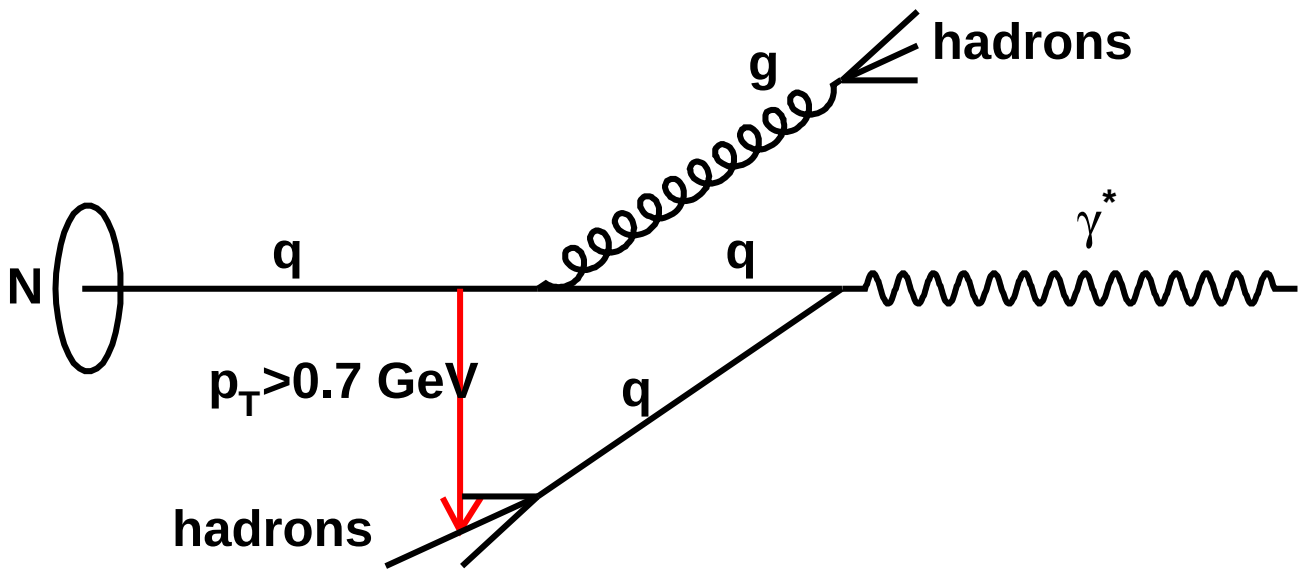

Compton process one of background processes

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

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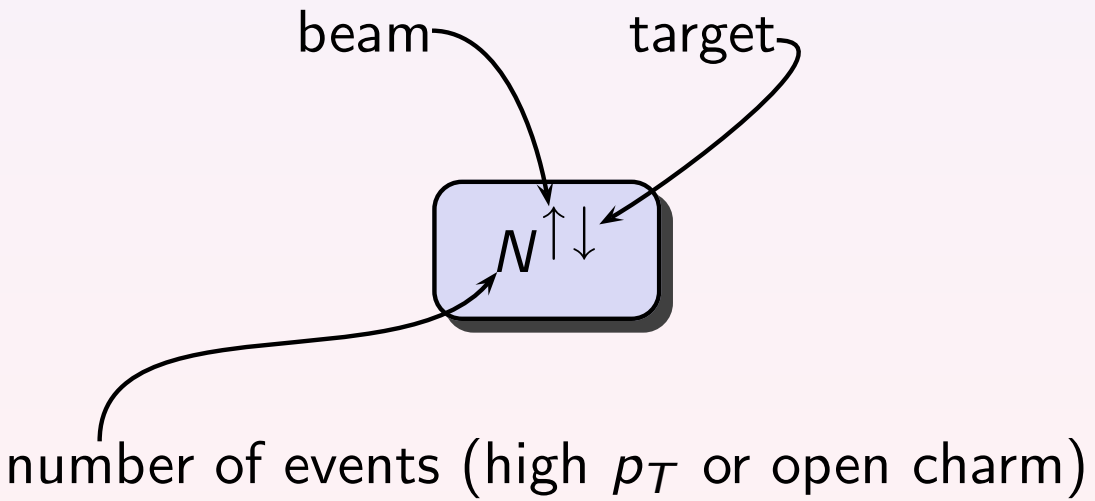
  - charmed hadrons
  - hadrons with large transverse momentum
- To learn something about spin measure double spin asymmetries

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



high p_T $\leftrightarrow$ open charm

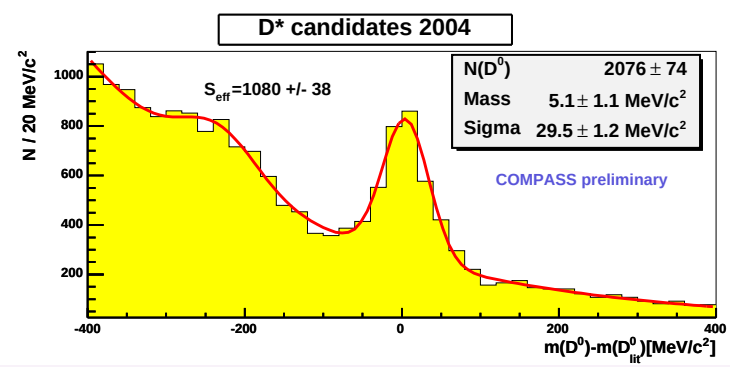
$$A^{raw} = \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} = P_B\, P_T\, f\, a_{LL} \frac{\sigma_{PGF}}{\sigma_{PGF} + \sigma_{bgd}} \frac{\Delta G}{G} + A^{bgd}$$

	high p_T pairs	open-charm
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 $\vec{\gamma} + \vec{g} \rightarrow q + \bar{q}$	
	≈ -0.4	-0.5 to 0.5
$\frac{\sigma_{PGF}}{\sigma_{PGF} + \sigma_{bgd}}$	fraction of photon-gluon fusion process	
	0.3	0.5(D^*) 0.1 (D^0)
source of background	Compton, resolved photon, ..	combinatorial background
determination of bgd	LEPTO/PYTHIA MC	from D^* (D^0) mass spectrum
A^{bgd}	background asymmetry ≈ 0	

Results

$\Delta G/G$ via Open Charm

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



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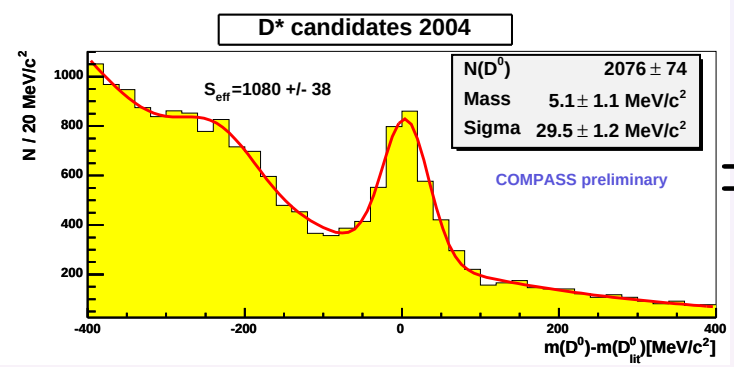

$$\Rightarrow$$

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

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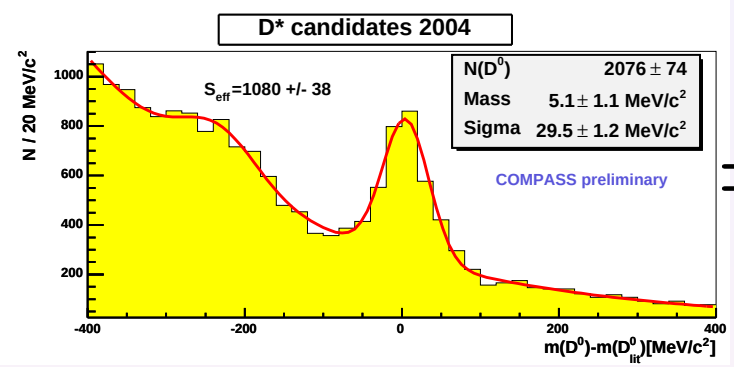

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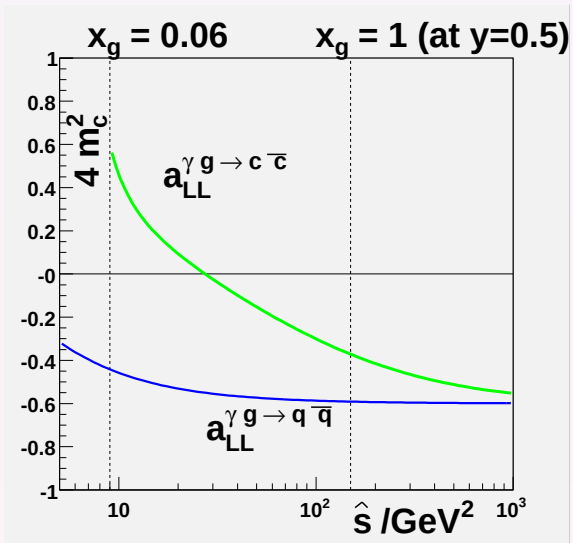

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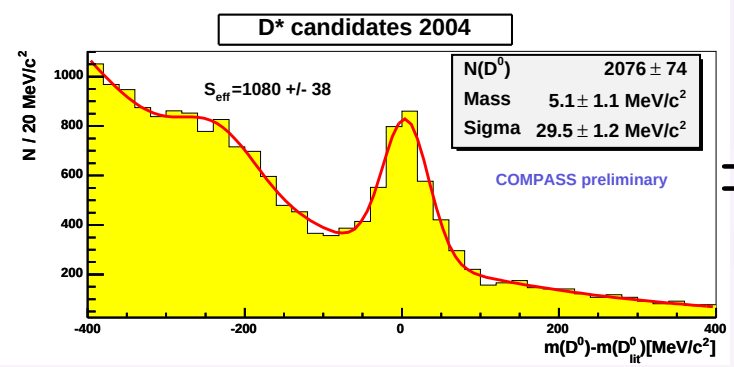

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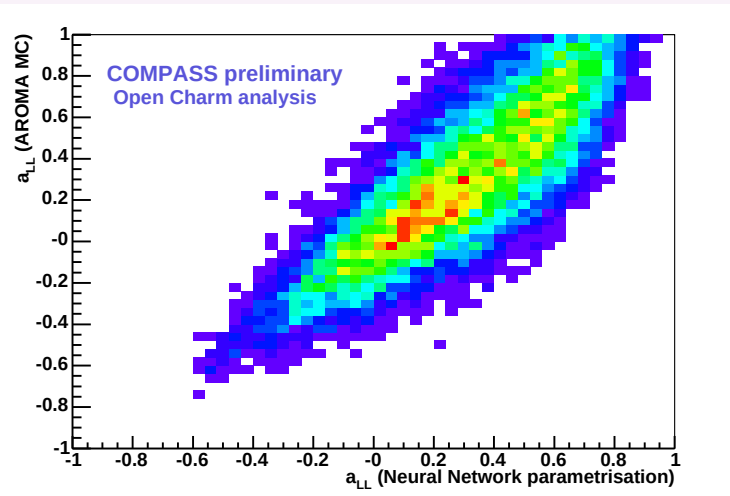

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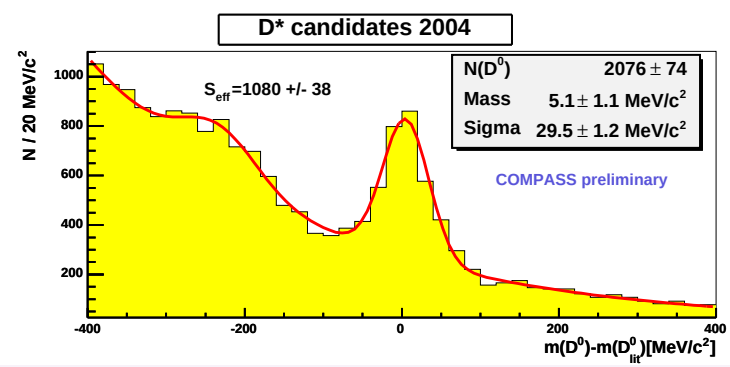
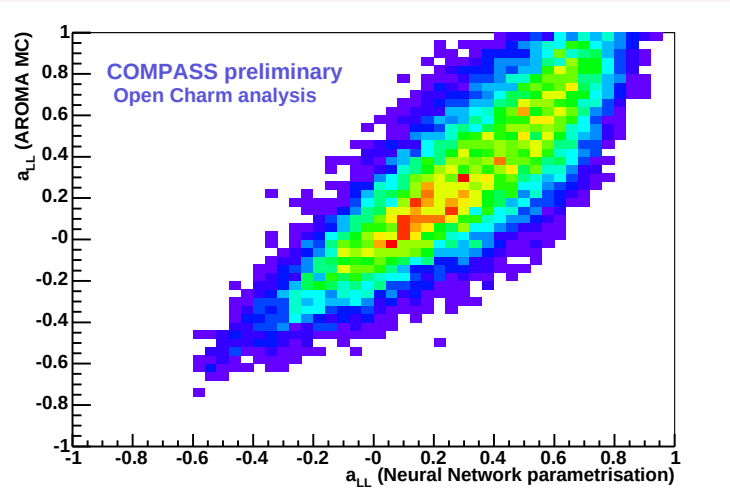
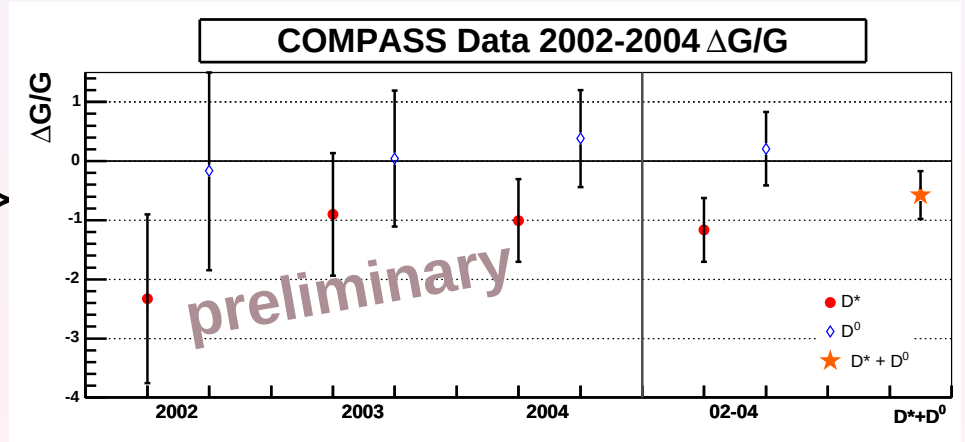


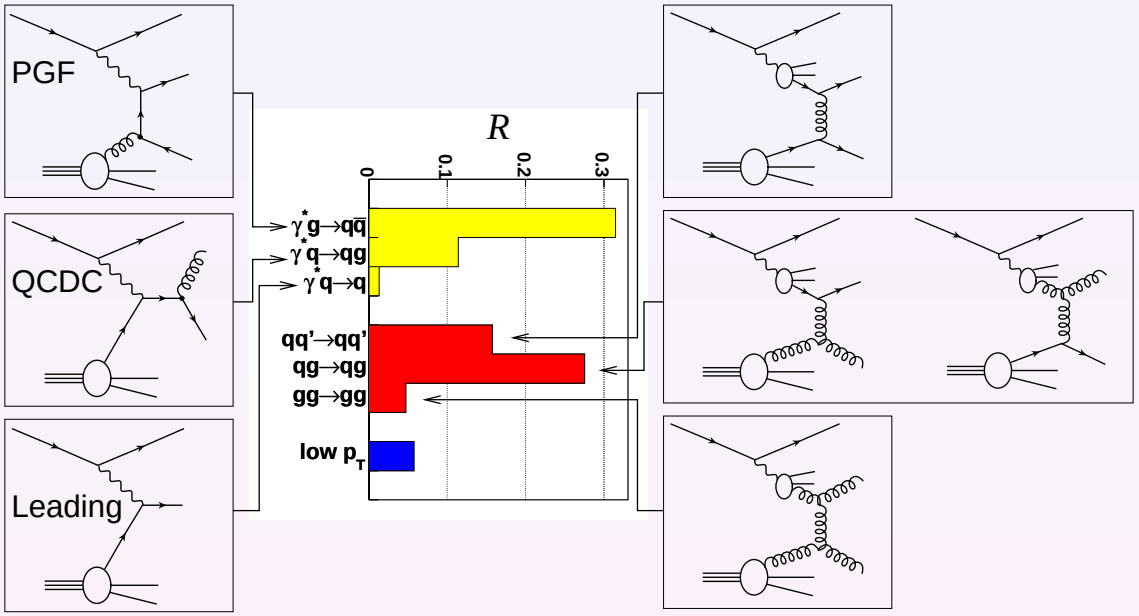
$$\frac{\Delta G}{G} = \frac{1}{P_B f P_T} \frac{\sum w^{\uparrow\downarrow} - w^{\uparrow\uparrow}}{\sum w^{\uparrow\downarrow 2} - w^{\uparrow\uparrow 2}}$$

$$w = a_{LL} \frac{\sigma_{PGF}}{\sigma_{PGF} + \sigma_{BGD}}$$



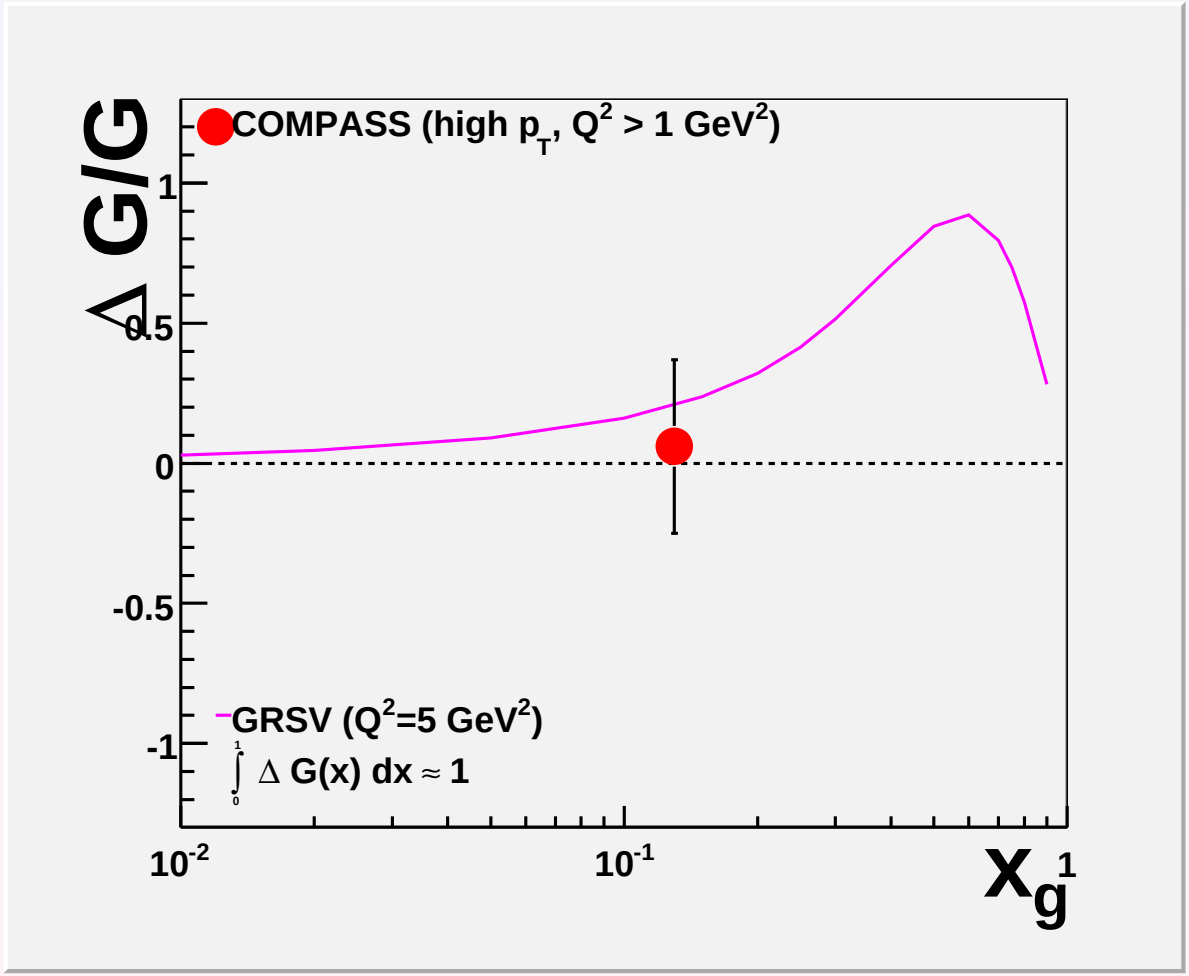


$\Delta G/G$ from high p_T Hadrons

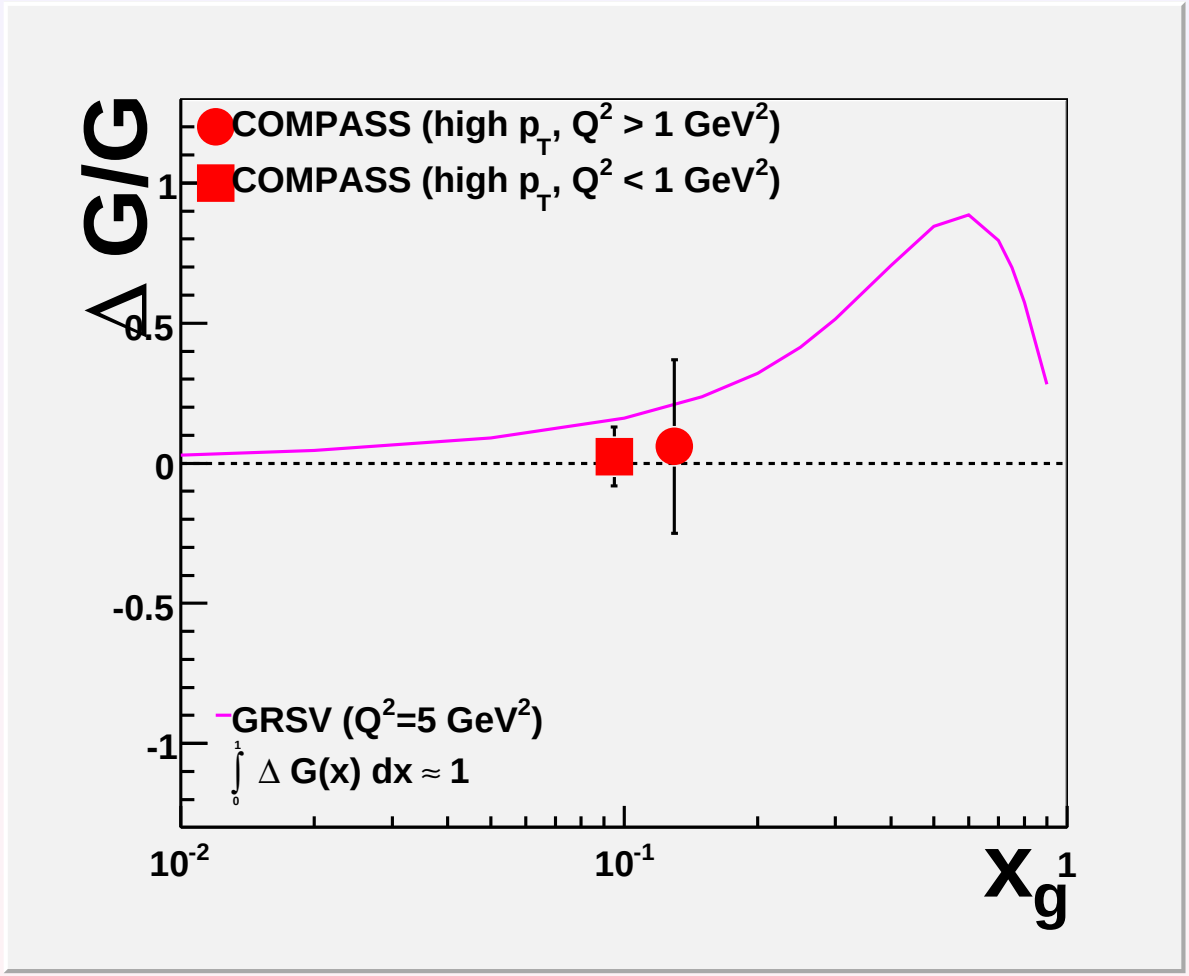


- Tune kinematic cuts to enhance $\gamma g \longrightarrow q\bar{q}$
- use generator to determine contributions from background processes
  (PYTHIA for $Q^2 < 1$ GeV^2, LEPTO for $Q^2 > 1$ GeV^2)

$\Delta G/G$


COMPASS (high p_T, $Q^2 > 1$ GeV^2)
$\Delta G/G$
1
0.5
0
-0.5
-1
GRSV (Q^2=5 GeV^2)
$\int_0^1 \Delta G(x)\,dx \approx 1$
10^{-2}
10^{-1}
1
x_g

$\Delta G/G$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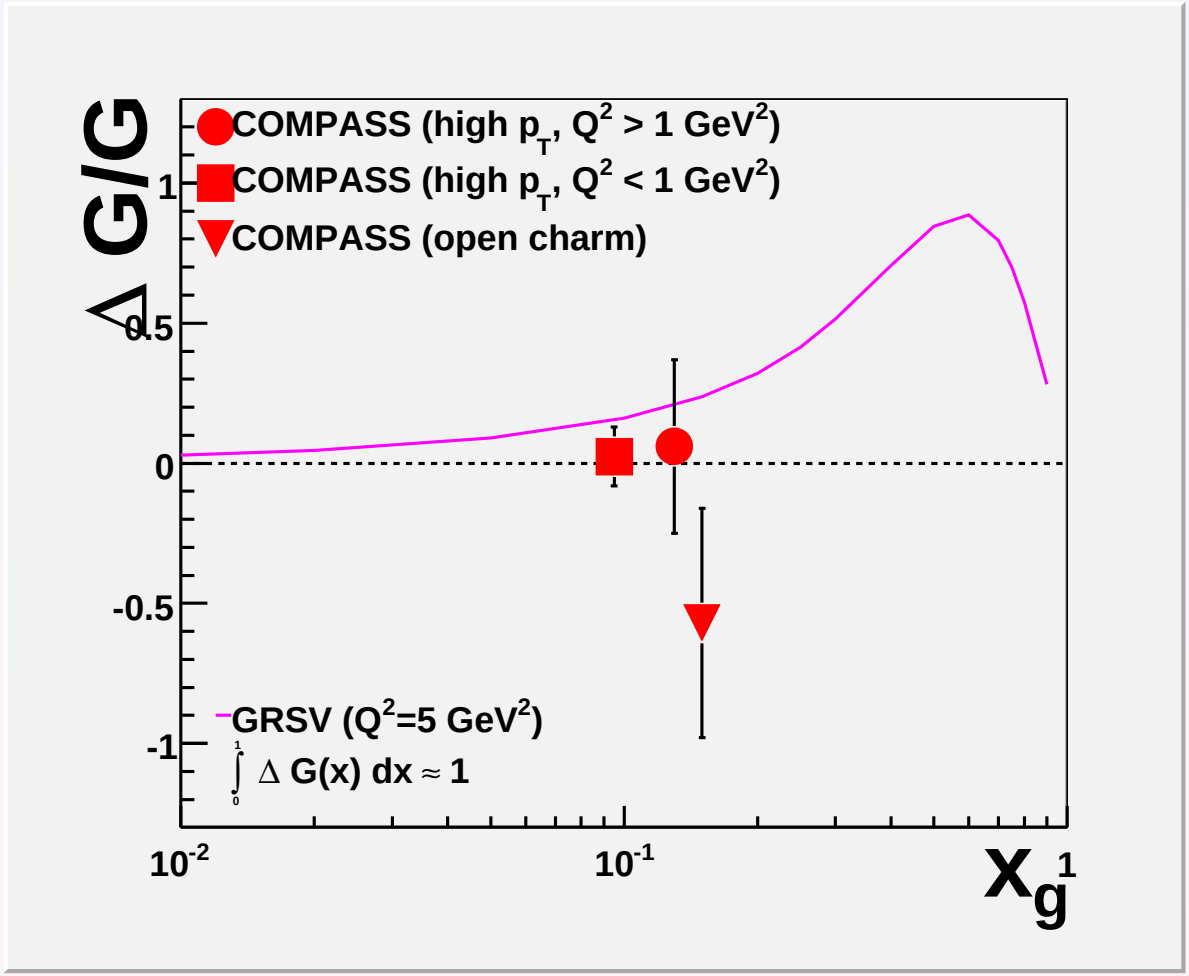
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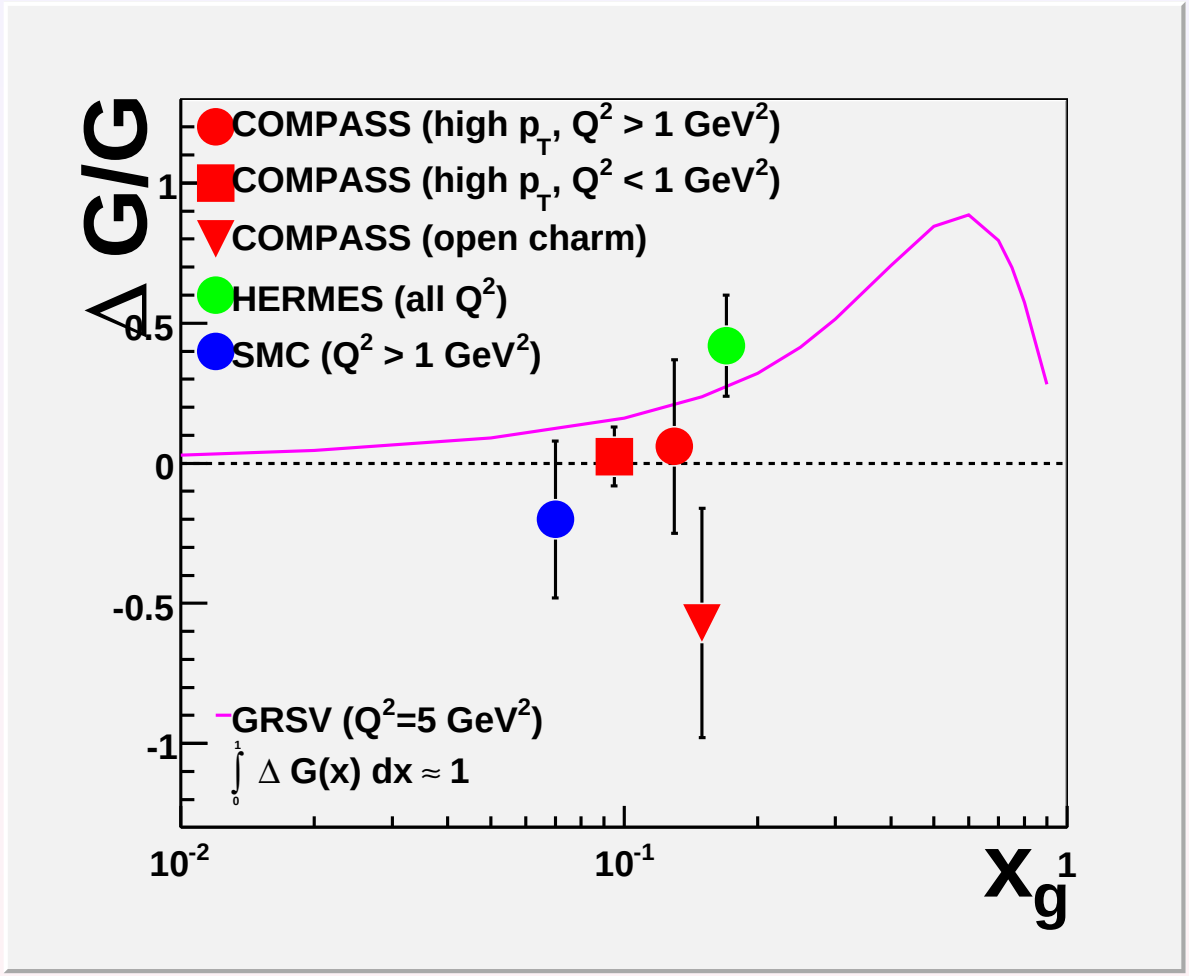
COMPASS (open charm)
GRSV (Q^2=5 GeV^2)
$\int_0^1 \Delta G(x)\,dx \approx 1$
$\Delta G/G$
1
0.5
0
-0.5
-1
10^{-2}
10^{-1}
x_g
1

$\Delta G/G$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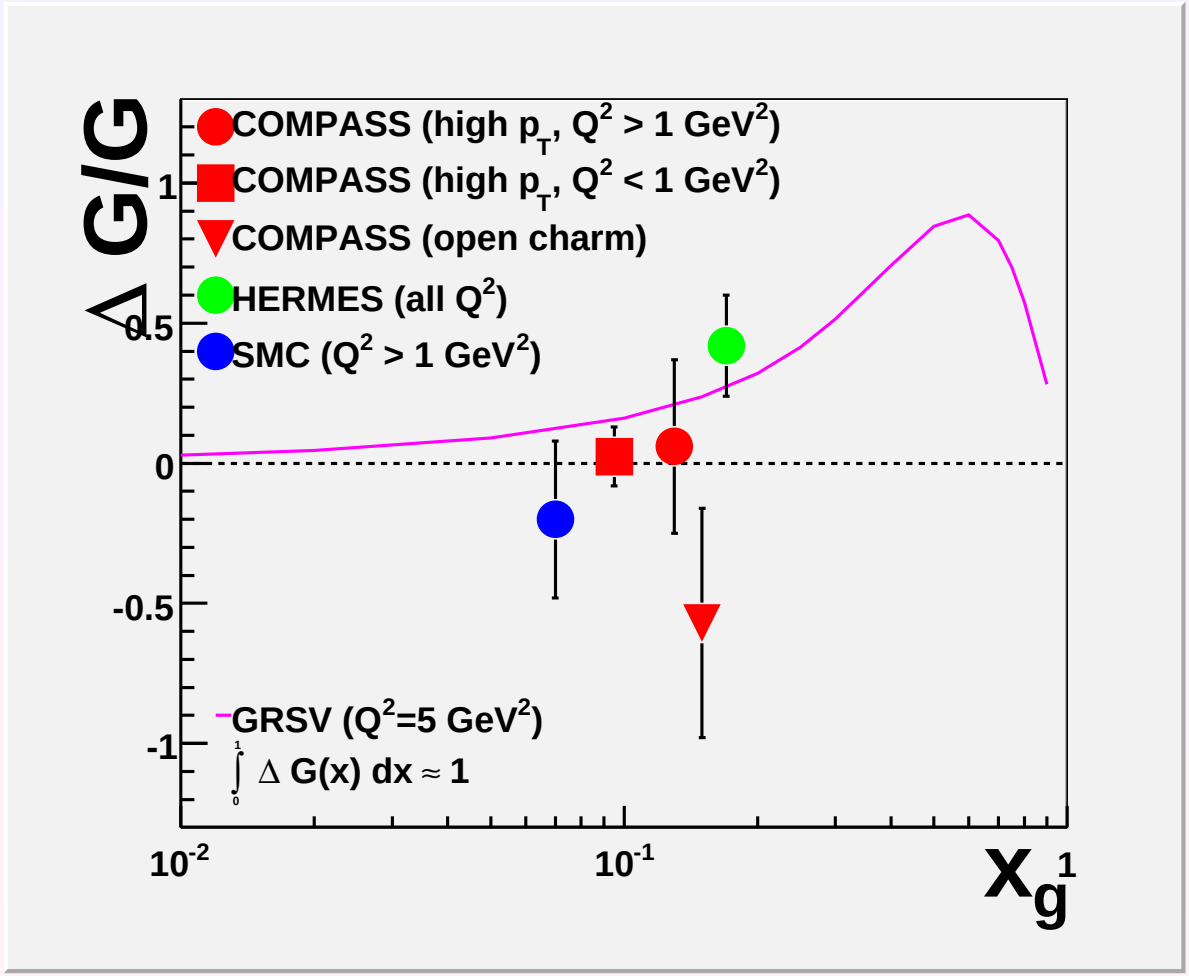
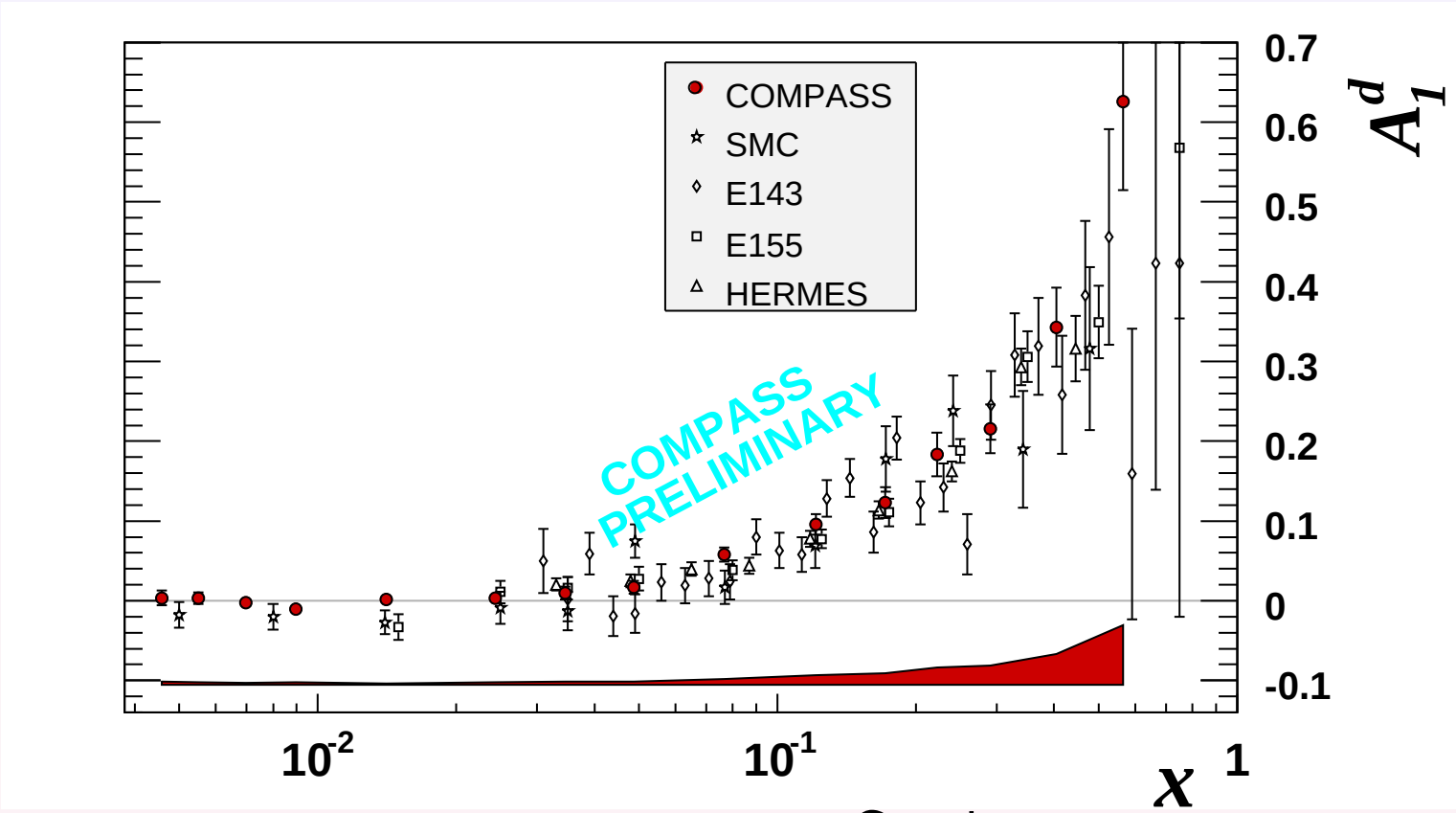
HERMES (all Q^2)
SMC ($Q^2 > 1$ GeV^2)
GRSV (Q^2=5 GeV^2)
$\int_0^1 \Delta G(x)\,dx \approx 1$
$\Delta G/G$
1
0.5
0
-0.5
-1
10^{-2}
10^{-1}
x_g

$\Delta G/G$



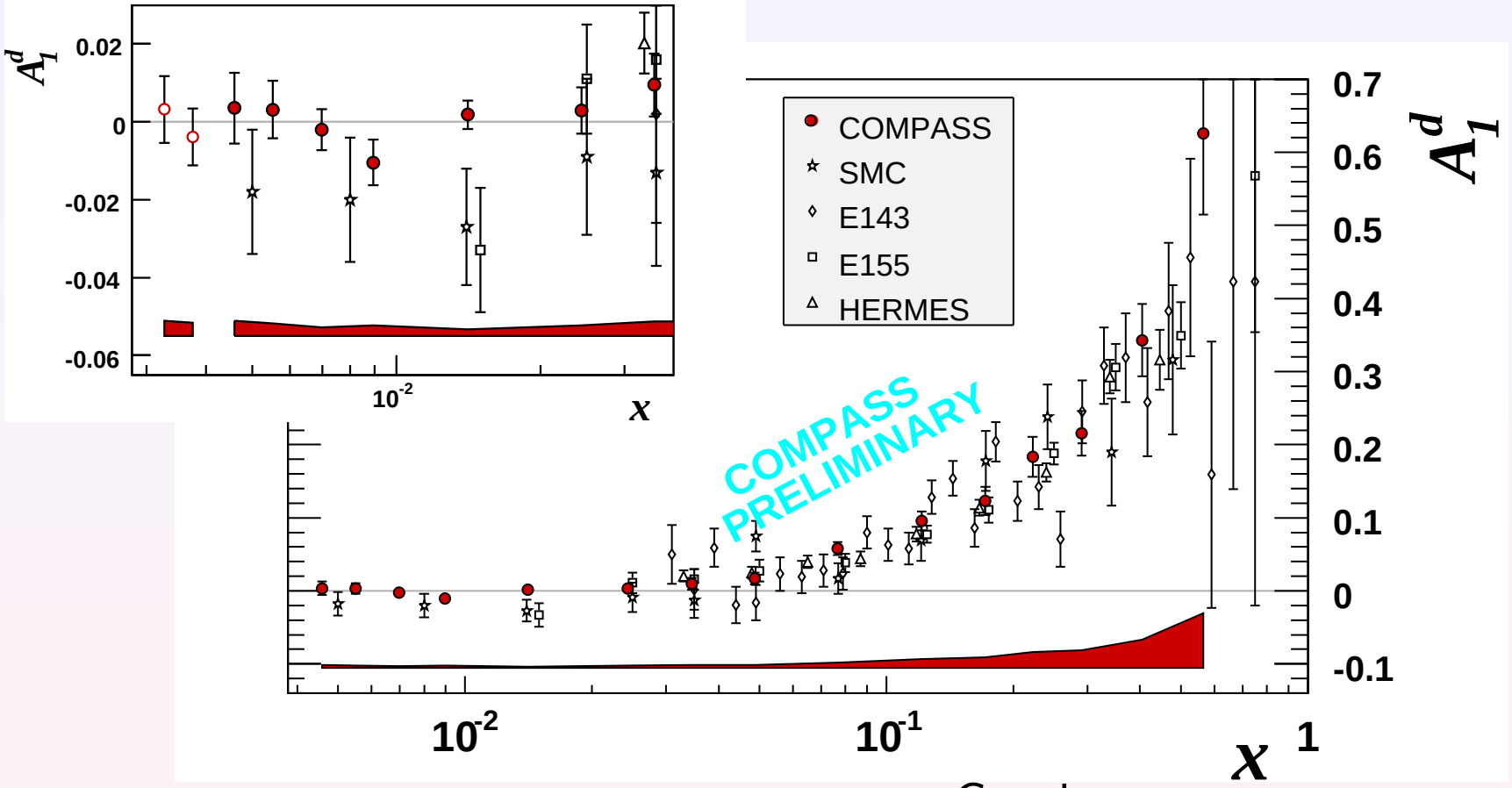
- Values of $\int_0^1 \Delta G(x)\,dx > 2$ are disfavored
- $\Delta G(x_g \approx 0.1)$ is small

Inclusive asymmetry $A_1^d \propto \Delta q$



- Good agreement at large x

Inclusive asymmetry $A_1^d \propto \Delta q$



- Factor 2 improvement at low x.
- Good agreement at large x

Inclusive asymmetry $A_1^d \propto \Delta q$

NLO QCD analysis with new COMPASS data on A_1^d yields:

$$\Delta\Sigma = 0.30 \pm 0.01(stat) \pm 0.02(evol) \text{ for whole data set}$$
error $\approx$ factor 2 larger without COMPASS data

QCD analysis allows also to determine $\frac{\Delta G}{G}$:
Fit to world data gives two solutions with similar χ^2:
$\int_0^1 \Delta G(x)\, dx \approx \pm 0.25 \pm 0.1$

Summary

Summary & Outlook

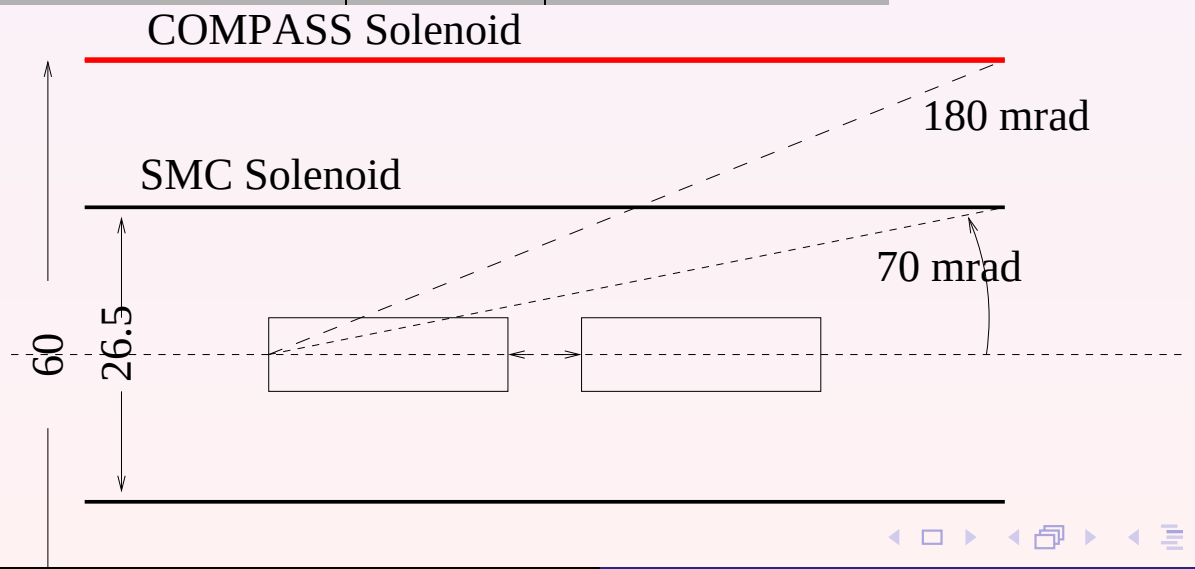
- COMPASS produced first results on $\frac{\Delta G}{G}$ from 2002 - 2004 data
- Several channels are followed to extract $\frac{\Delta G}{G}$
  - hadrons with large p_T,
  - open charm
- $\Delta G(x \approx 0.1)$ small
- large values of $\Delta G = \int_0^1 \Delta G(x) dx$ disfavored
- 2005: spectrometer upgrade (Target, RICH)
- 2006: resume data taking with muon beam (deuteron for longitudinal, proton target for transverse running)
- 2007 hadron beam

Spare

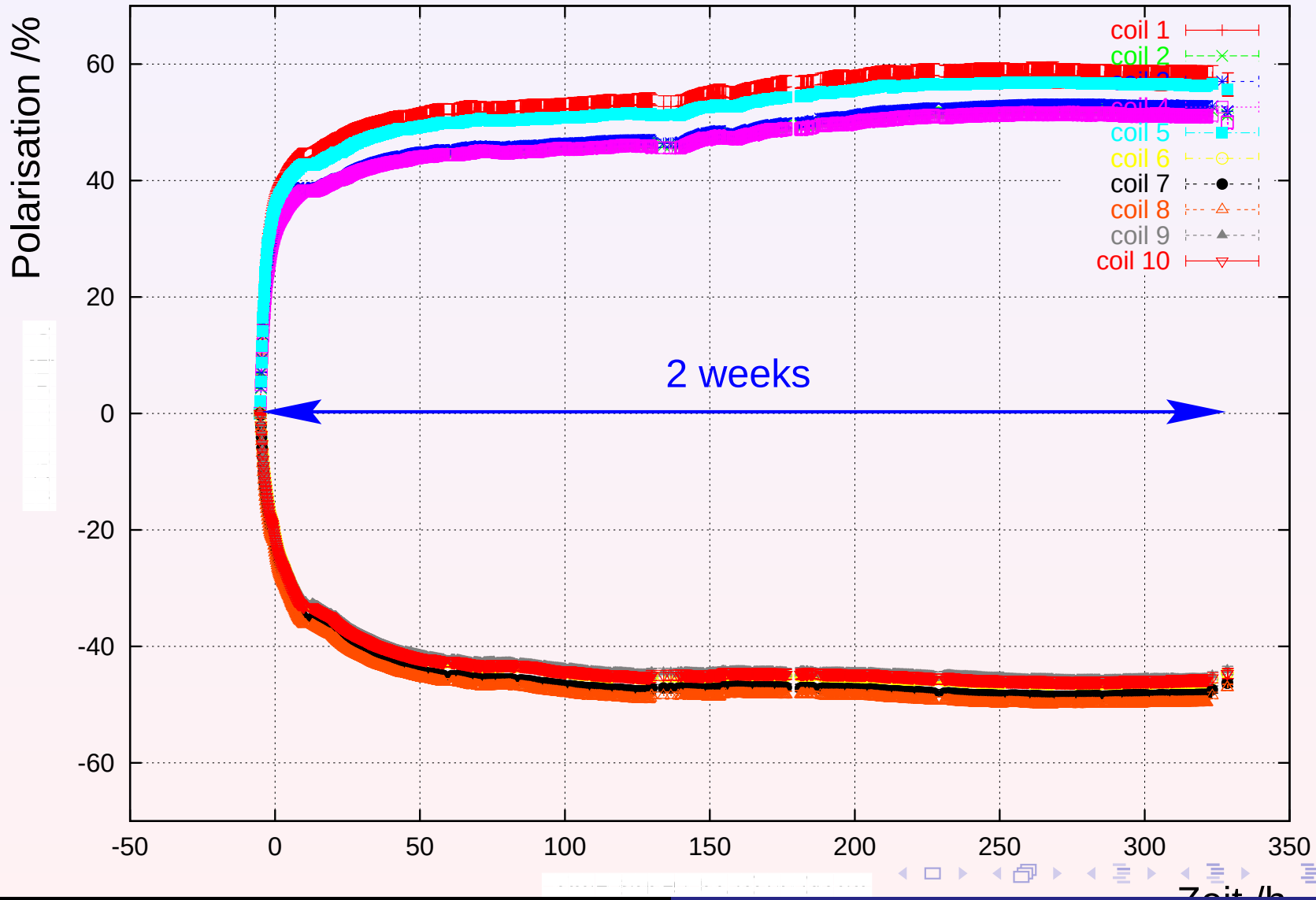
Polarized Target

For 2006 new target magnet

	SMC	COMPASS
diameter/cm	26	60
acceptance/mrad		
(from upstream end)	$\pm$ 70	$\pm$ 180
acc. for $D^0 \rightarrow K^- + \pi^+$ (160 GeV beam)	73 %	100 %



Polarization Build-up

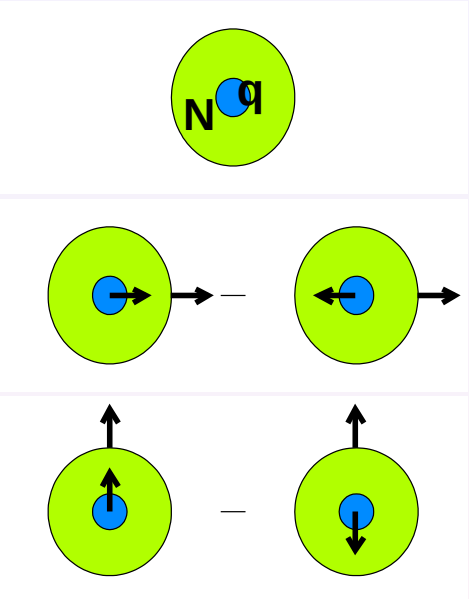


Transversity distributions

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

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

$\Delta_T q(x)$ (transversity)



- $\Delta_T q(x)$ as important as $\Delta q(x)$, less well known, because more difficult to access.
- $\Delta_T q(x)$ accessible in single spin asymmetries on a transversely polarized target

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

Results Transversity

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

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

Analyzing power does not depend on x!

Results Transversity

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

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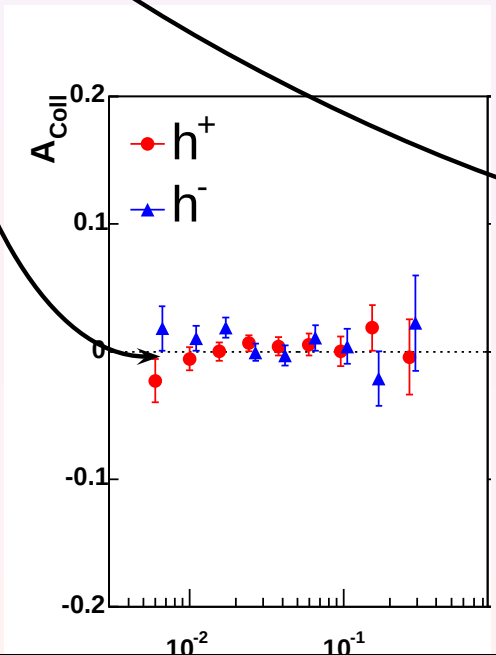
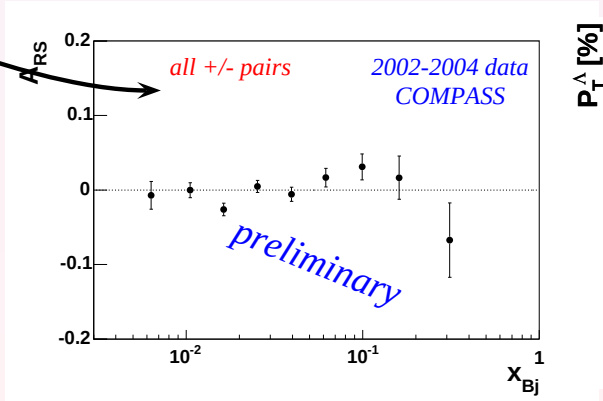
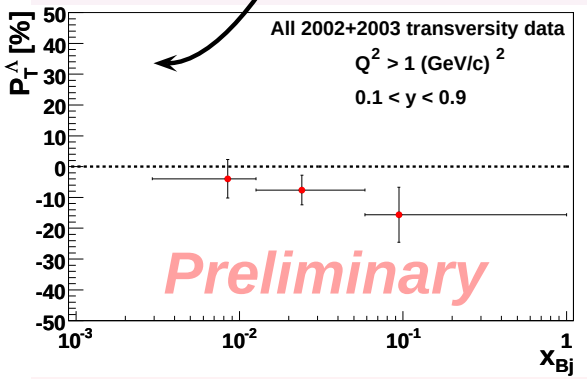
Analyzing power does not depend on x!







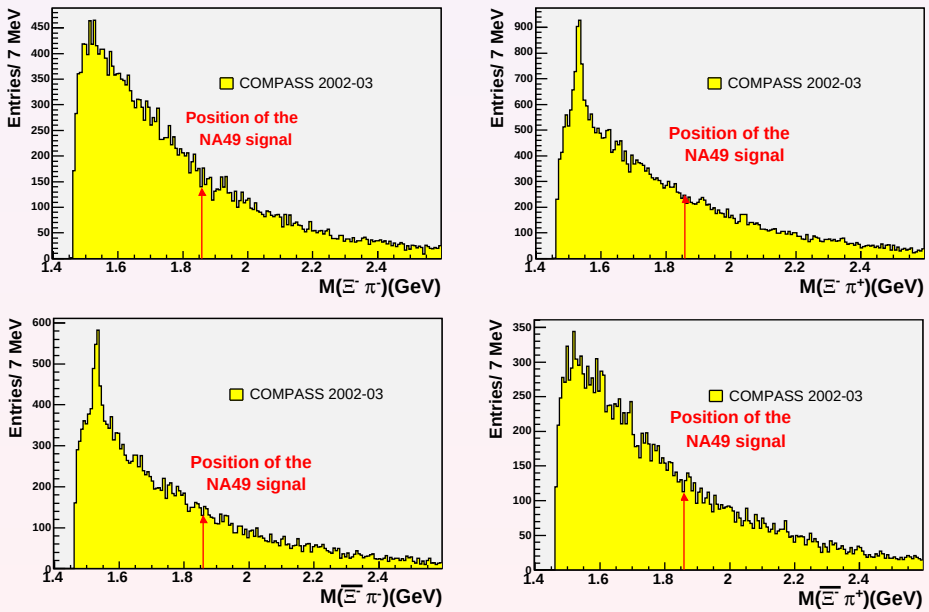
Results Transversity

- No sign of transversity observed
- either $\Delta_T q(x)$ or $\Delta_T^0 D_q^h, H_q^{\angle h}$ small
- cancellation between $\Delta_T u(x)$ and $\Delta_T d(x)$?
  $\hookrightarrow$ data on proton target needed

Spectroscopy

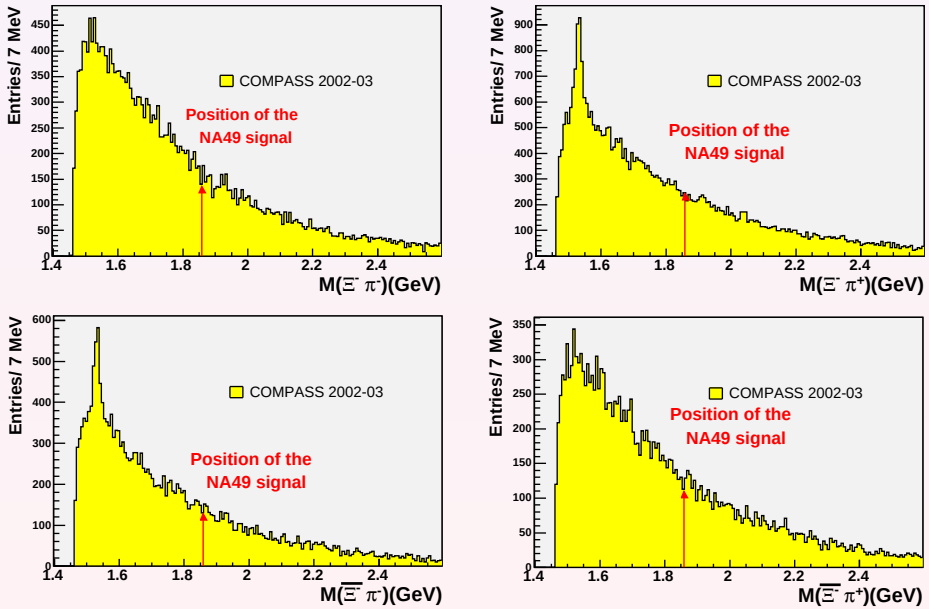
Search for pentaquark candidate $\Phi(1860)$ (was Ξ^{--}) in

$$\mu + N \rightarrow \Xi^{--} + X$$
$$\Xi^{--} \rightarrow \Xi^{-}\pi^{-}$$
$$\Xi^{-} \rightarrow \Lambda\pi^{-}$$
$$\Lambda \rightarrow p\pi^{-}$$



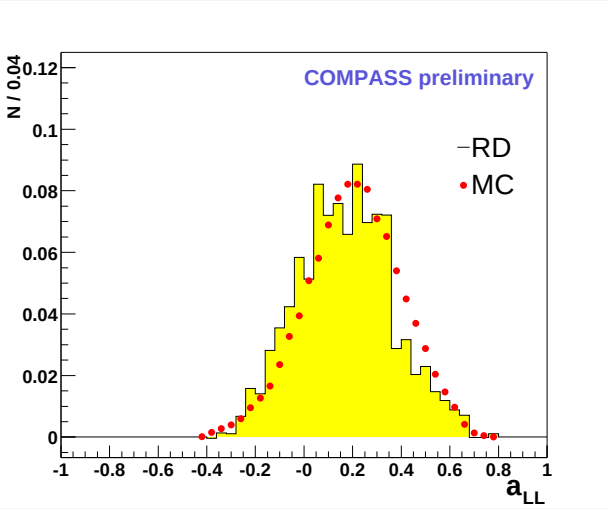
Spectroscopy

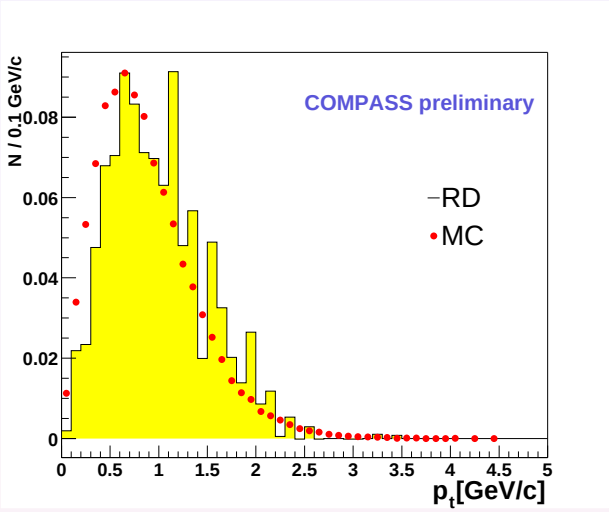
- Assuming the same $\Xi(1869)^{--}/\Xi(1320)^{-}$ as NA49 COMPASS should have observed ≈ 400 $\Xi(1869)^{--}$
- Negative signal (< 80 at 99% CL)

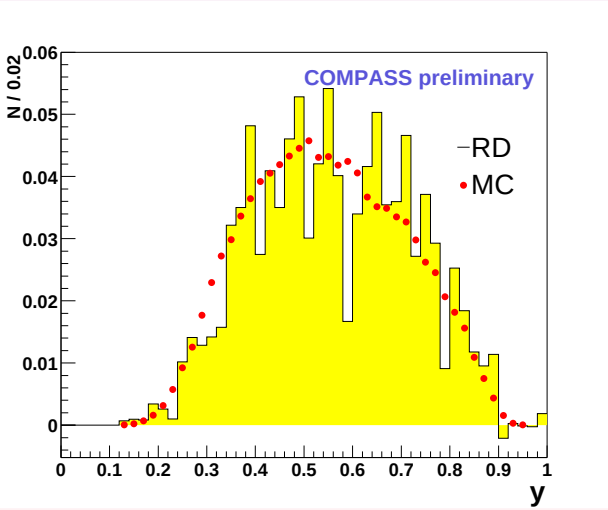


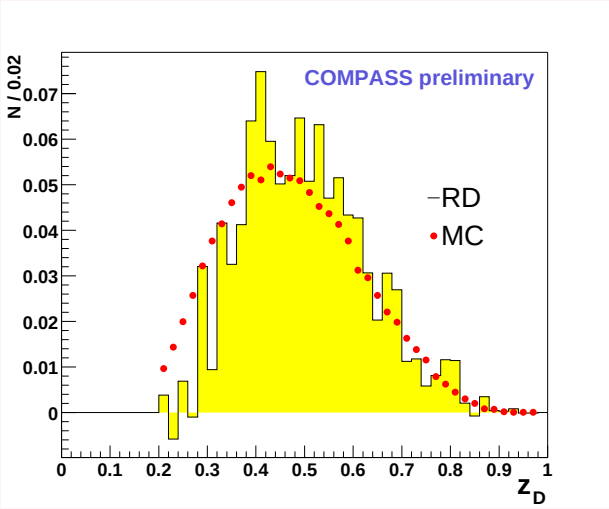
Open charm: Kinematic Distributions

Comparison data vs. MC

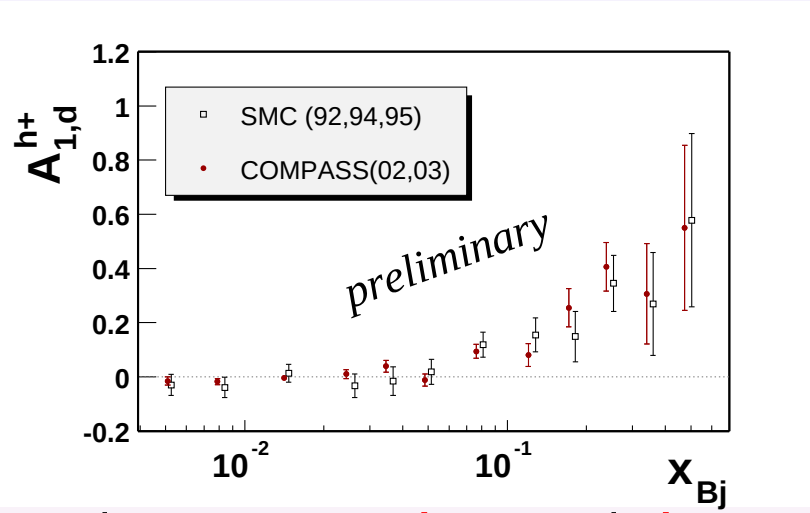


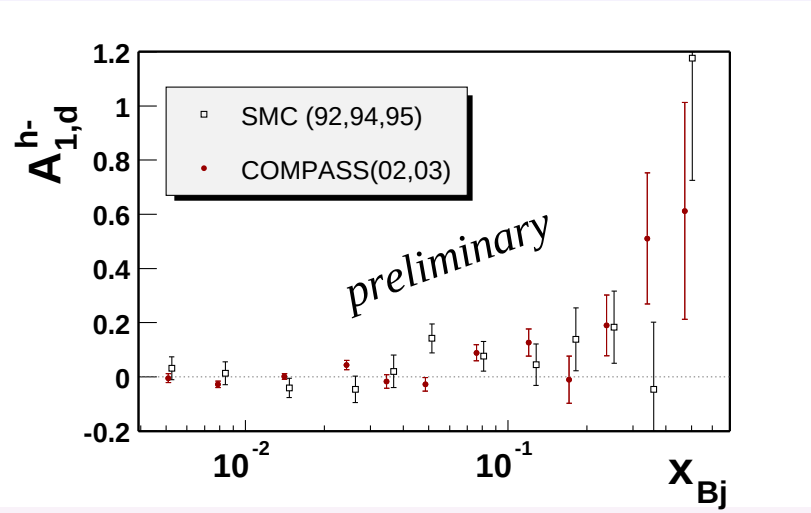






Semiinclusive Asymmetries





used to extravt Δq_v and $\Delta \bar{q}$.