“Longitudinal spin physics COMPASS results”

D.Peshekhonov

JINR, Dubna

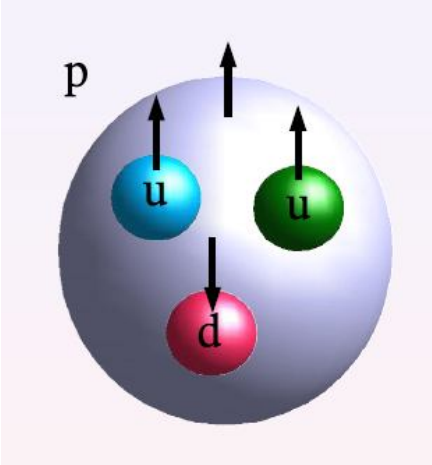
on behalf of the COMPASS collaboration

Plan

- Introduction
  - *nucleon spin & status of the problem*
  - *COMPASS experiment*
- Inclusive measurement of PDF
- Semi-inclusive measurement of PDF
- Gluon polarization measurement
- Conclusion
- Future plans of COMPASS
- Spin physics at NICA

Nucleon spin

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



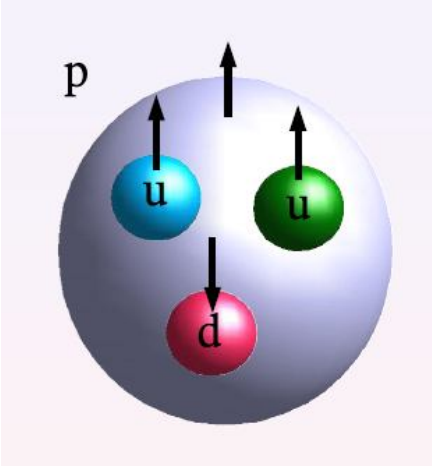
SQM: up and down quarks carry the nucleon spin!

EMC: Quarks spins contribute little (1987/88)

$\Delta\Sigma = 0.12$

Nucleon spin

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

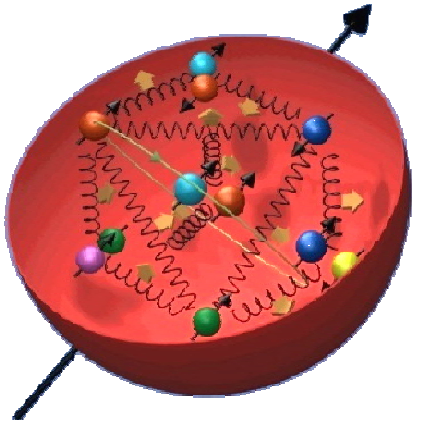


SQM: up and down quarks carry the nucleon spin!

EMC: Quarks spins contribute little (1987/88)

$\Delta\Sigma = 0.12$

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

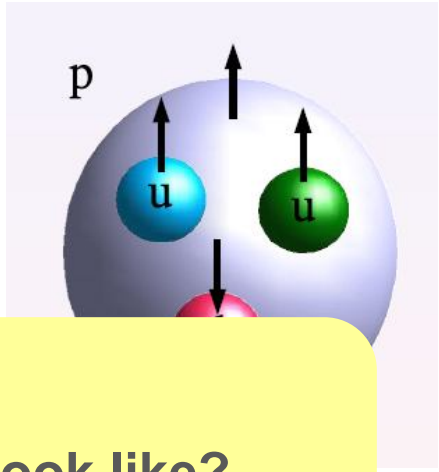


quarks — small ~0.15

gluons — Still poorly known

orbital — unknown

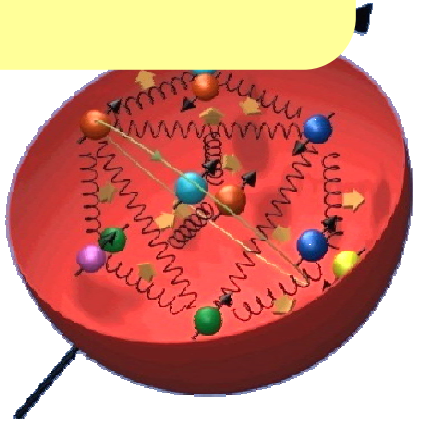
Nucleon spin



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

Questions:

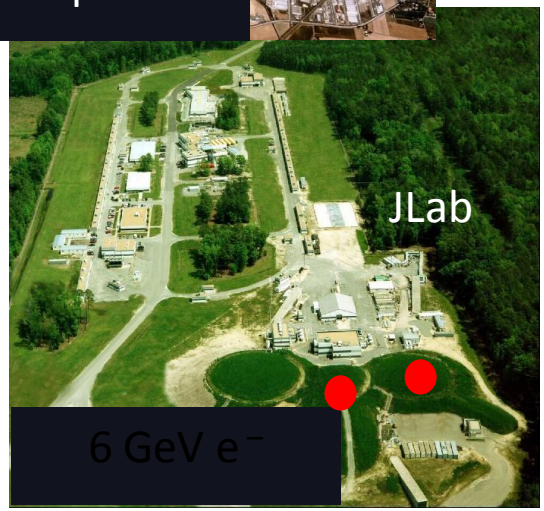
- **How do contributions of different flavors Δq(x) look like?**
- **How does Δg(x) look like?**



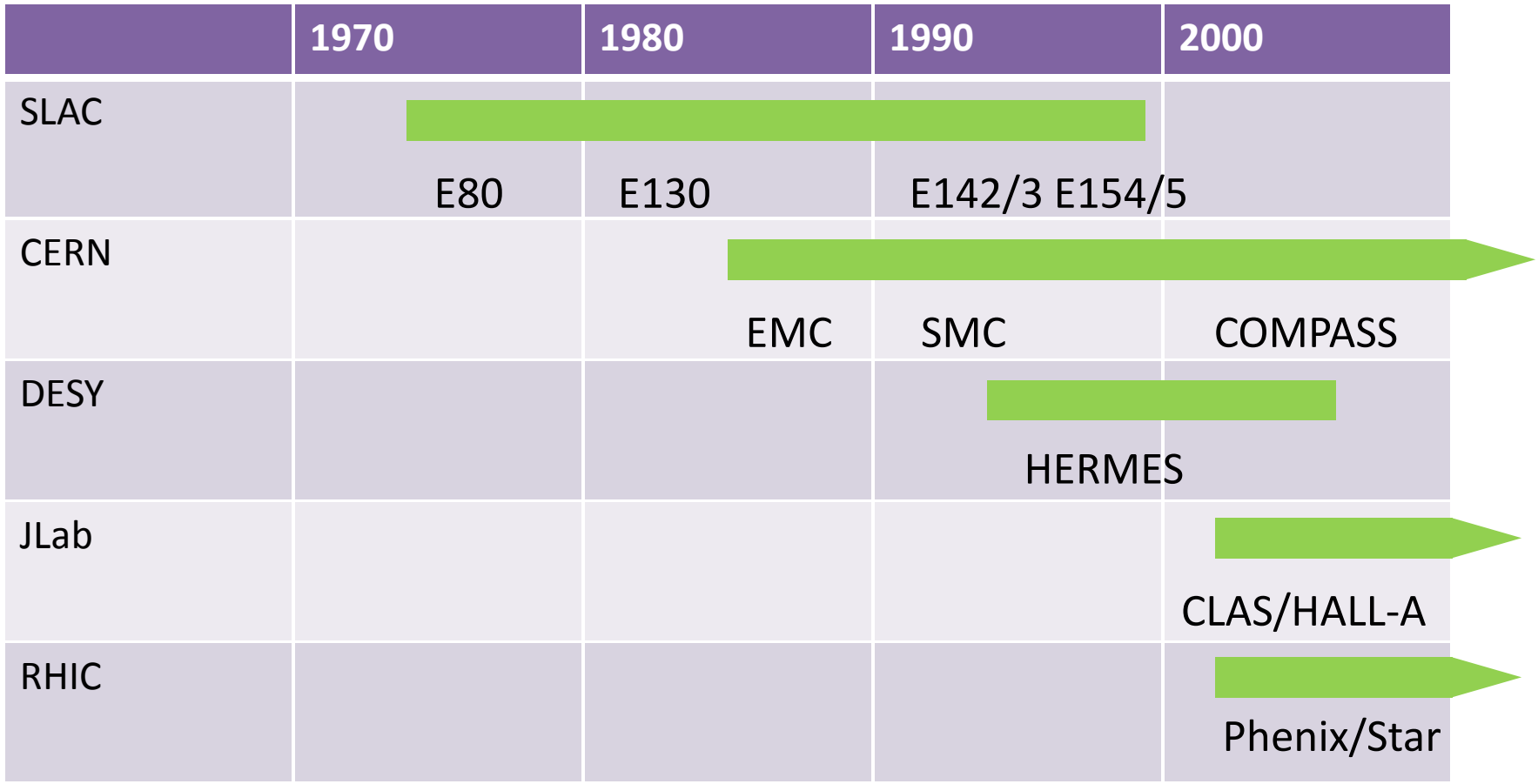
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

quarks	gluons	orbital
small ~0.15	Still poorly known	unknown

Laboratories &



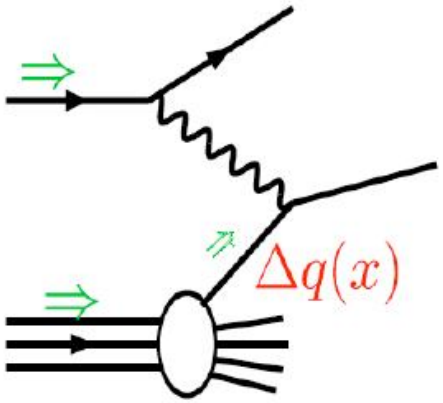
& Experiments



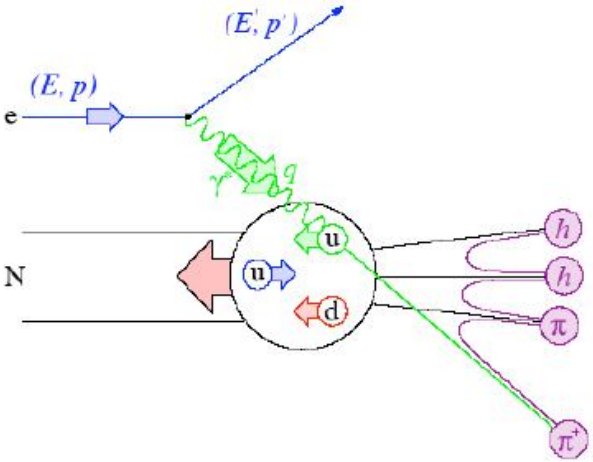
A worldwide effort since decades

Tools to study the spin structure

DIS



SIDIS



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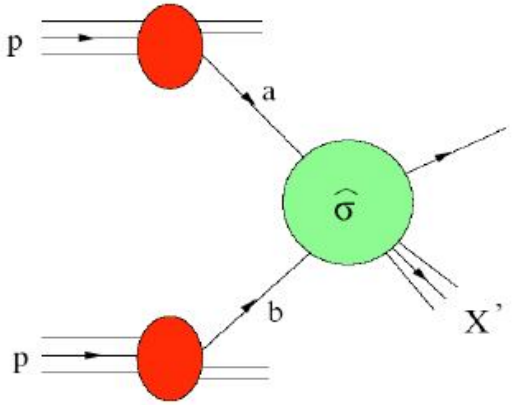
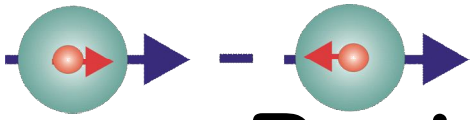




Parton Distribution Functions

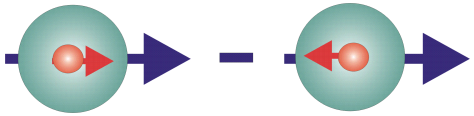
q(x)
$f_1^q(x)$

unpolarised PDF

quark with momentum *xP* in a nucleon

well known – unpolarized DIS

Δq(x)
$g_1^q(x)$

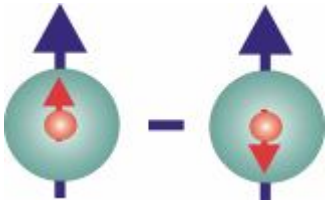


helicity PDF

quark with spin parallel to the nucleon spin in a longitudinally polarised nucleon

known – polarized DIS

$\Delta_T q(x)$
$h_1^q(x)$

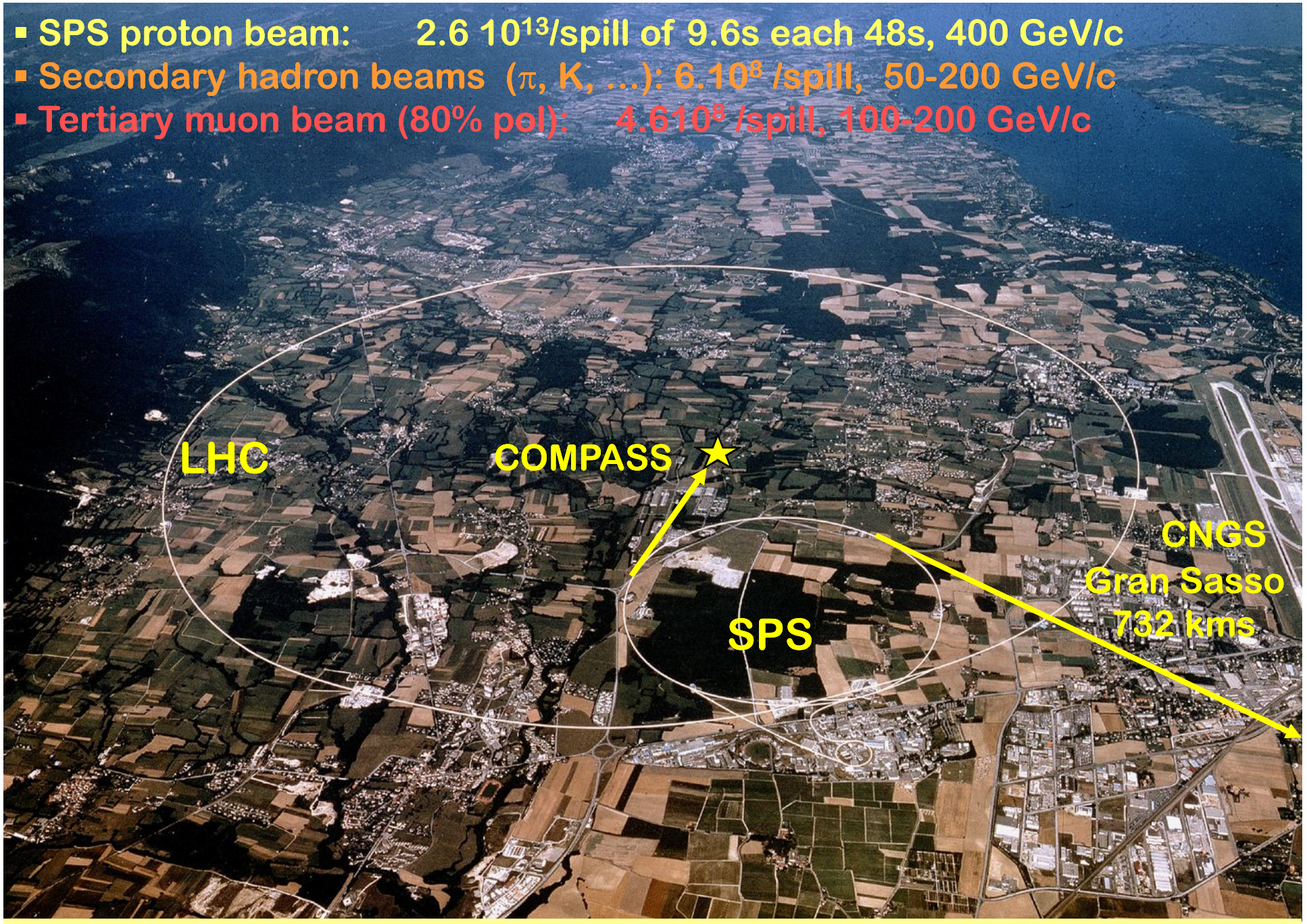


transversity PDF

quark with spin parallel to the nucleon spin in a transversely polarised nucleon

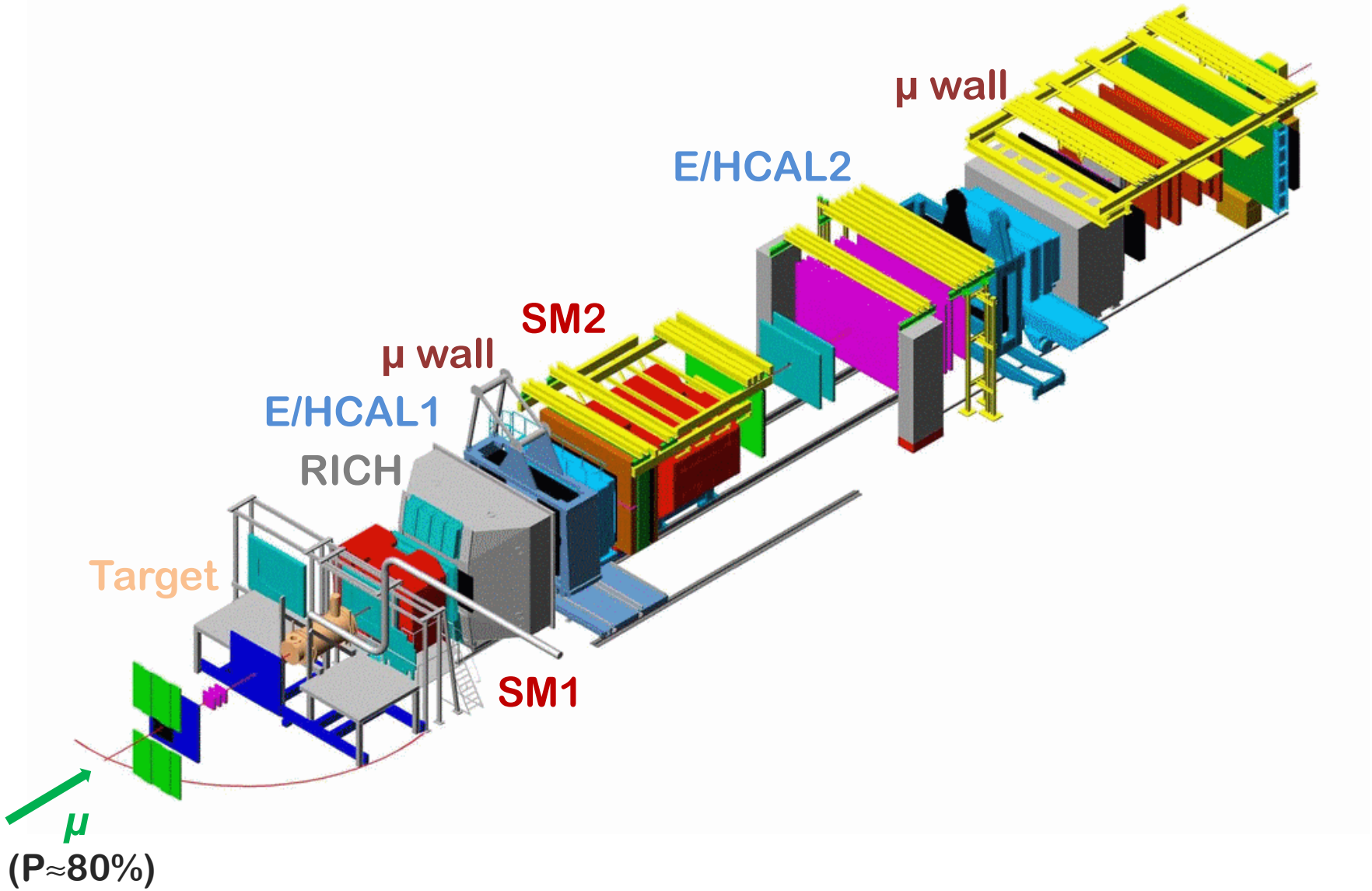
chiral odd, poorly known

- SPS proton beam: 2.6 10^{13}/spill of 9.6s each 48s, 400 GeV/c
- Secondary hadron beams (π, K, …): 6.10^{8} /spill, 50-200 GeV/c
- Tertiary muon beam (80% pol): 4.6$10^{8}$ /spill, 100-200 GeV/c

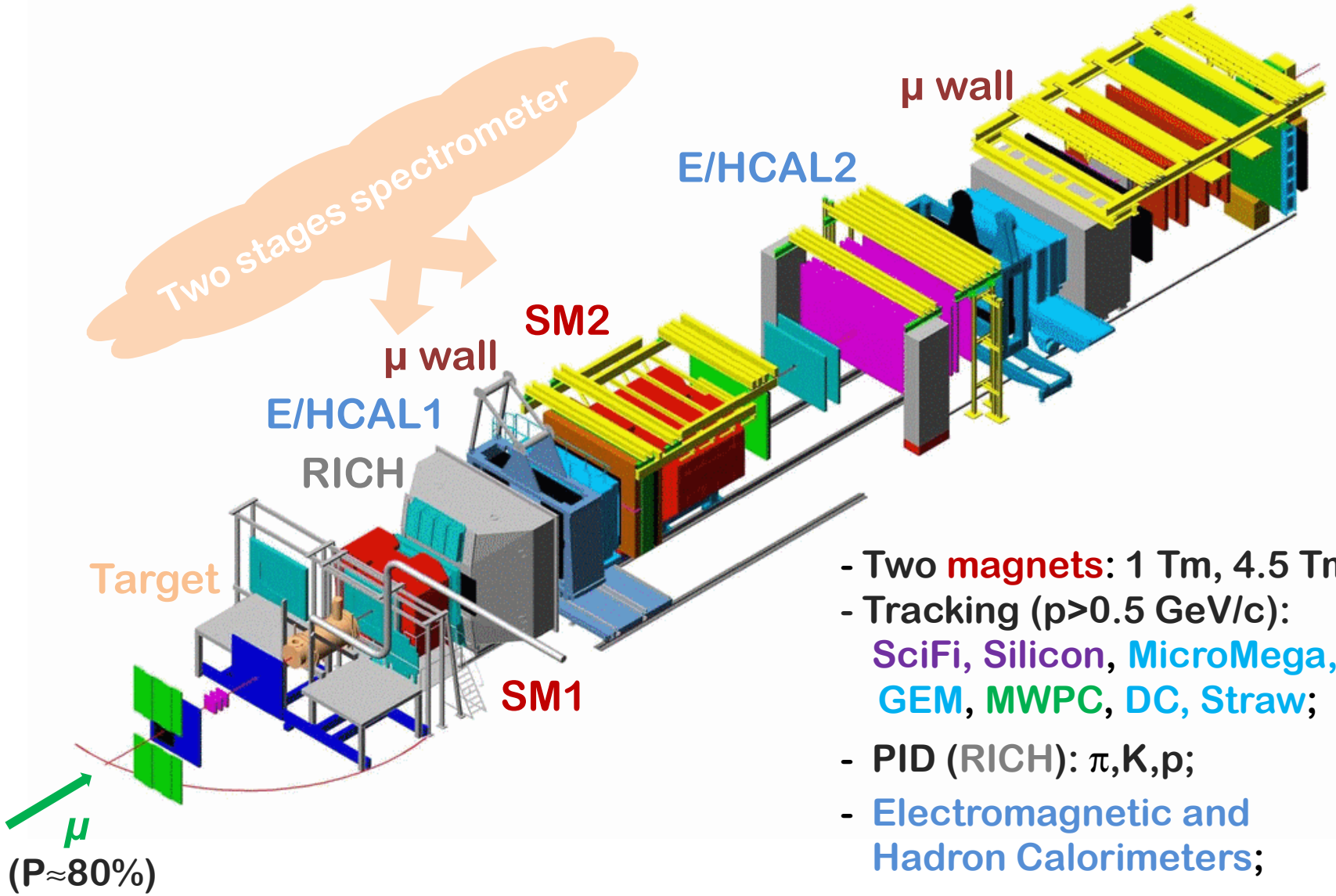


high energy beams, broad kinematic range, large angular acceptance

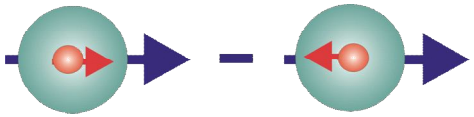
COMPASS spectrometer



COMPASS spectrometer



- Two magnets: 1 Tm, 4.5 Tm;
- Tracking (p>0.5 GeV/c): SciFi, Silicon, MicroMega, GEM, MWPC, DC, Straw;
- PID (RICH): π,K,p;
- Electromagnetic and Hadron Calorimeters;



COMPASS scientific program

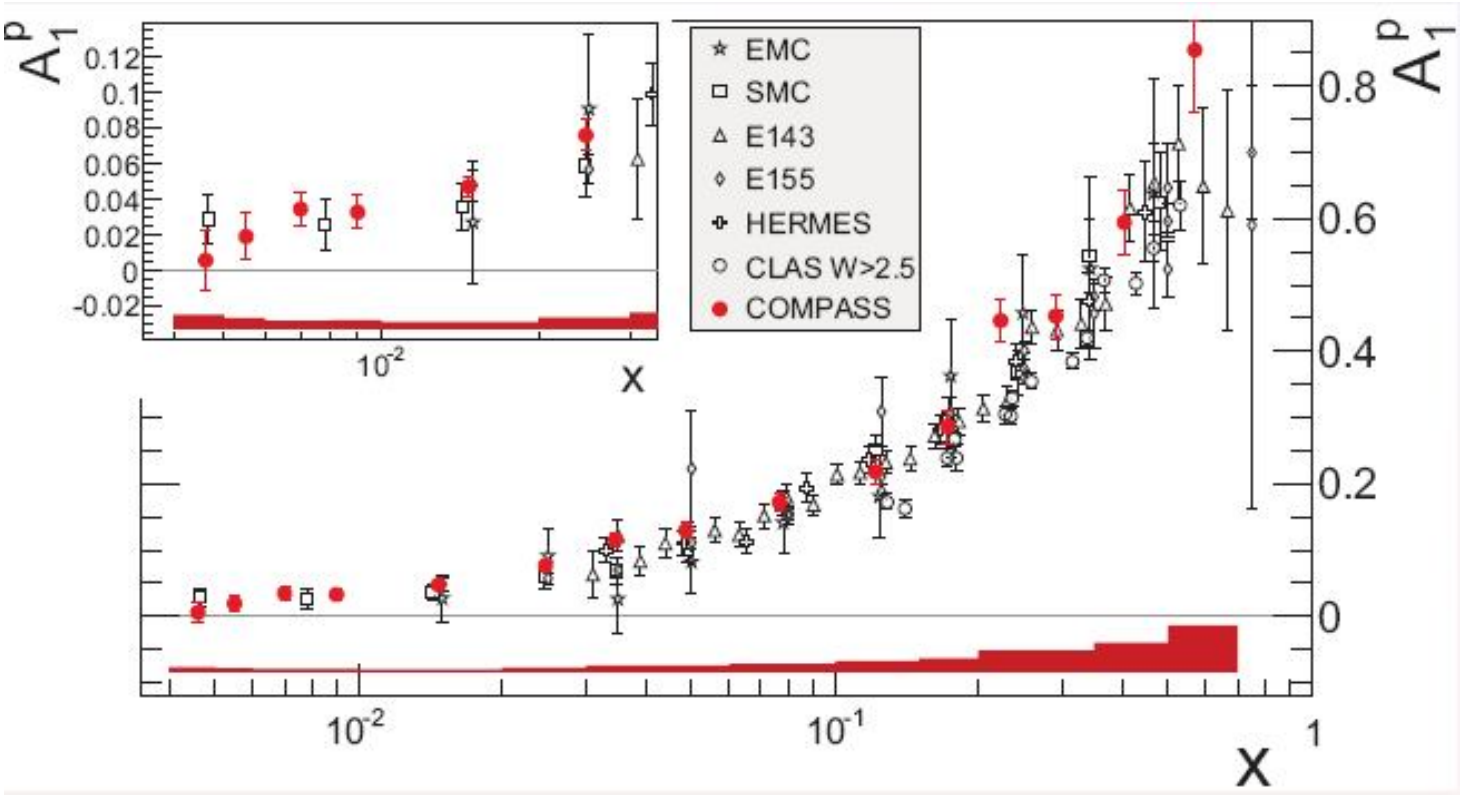
- Nucleon spin structure studies – muon beam
  - Parton distributions
  - Data taking:
    - 2002 – 2004, 2006 : Polarized deuteron target (^{6}LiD)
    - 2007, 2010, 2011 : Polarized proton target (NH_3)

- Structure and spectroscopy studies – hadron beams (π, (K), p)
  - Hybrid mesons, Gluonic excitations, Polarizabilities
  - Data taking:
    - 2004 : Test run : 2 weeks pion beam with a ^{208}Pb target
    - 2008, 2009 : Various solid and liquid targets, from H_2 to ^{208}Pb

Inclusive asymmetry $A_1(x,Q^2)$

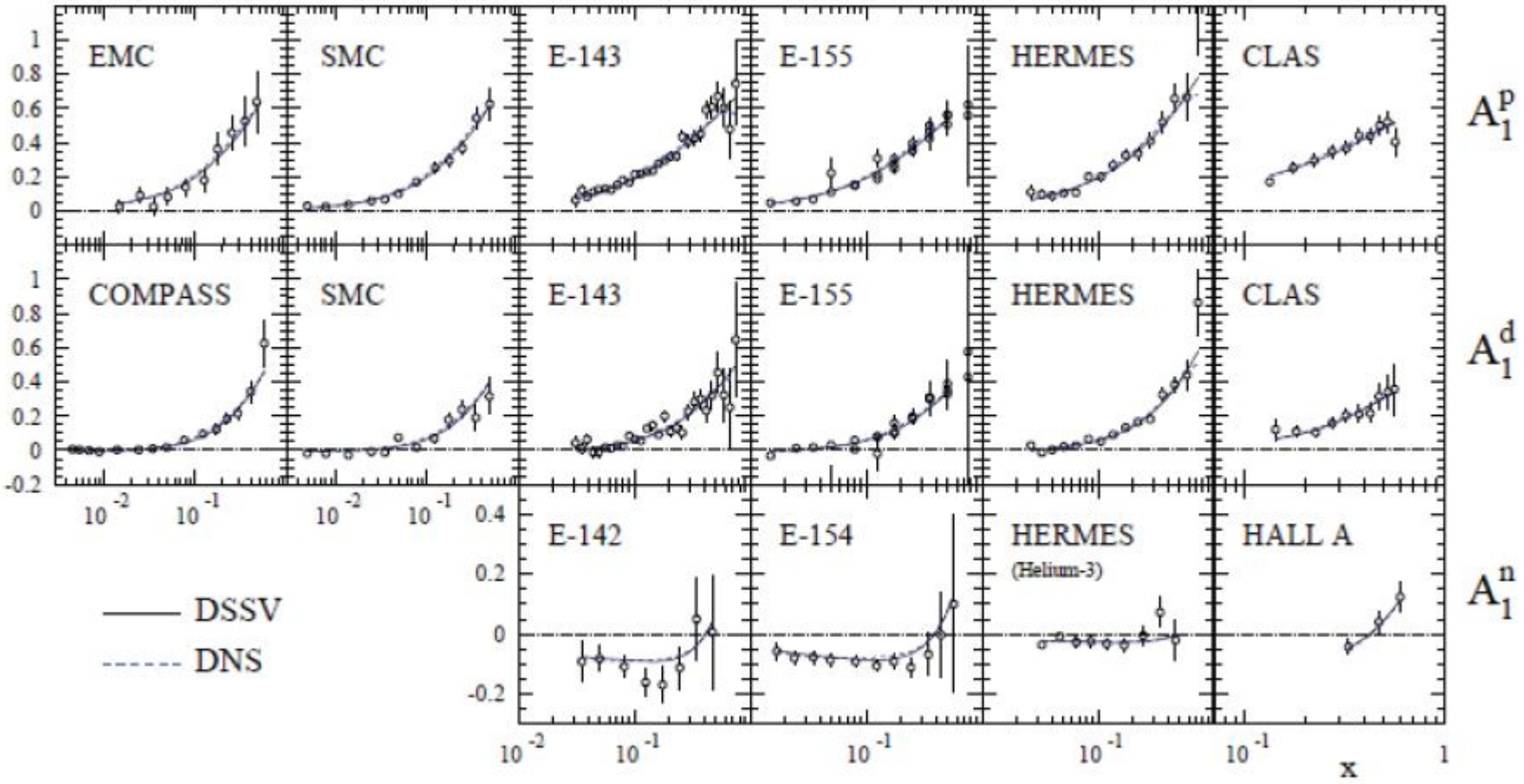
$$A_1 = \frac{\sum_q e_q^2 \Delta q(x,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

$$\frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} \propto A_1^p = \frac{g_1^p}{F_1^p} = \frac{4(\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) + (\Delta s + \Delta\bar{s})}{4(u+\bar{u}) + (d+\bar{d}) + (s+\bar{s})}$$



COMPASS data: another Q^2; good agreement

Inclusive asymmetry $A_1(x,Q^2)$



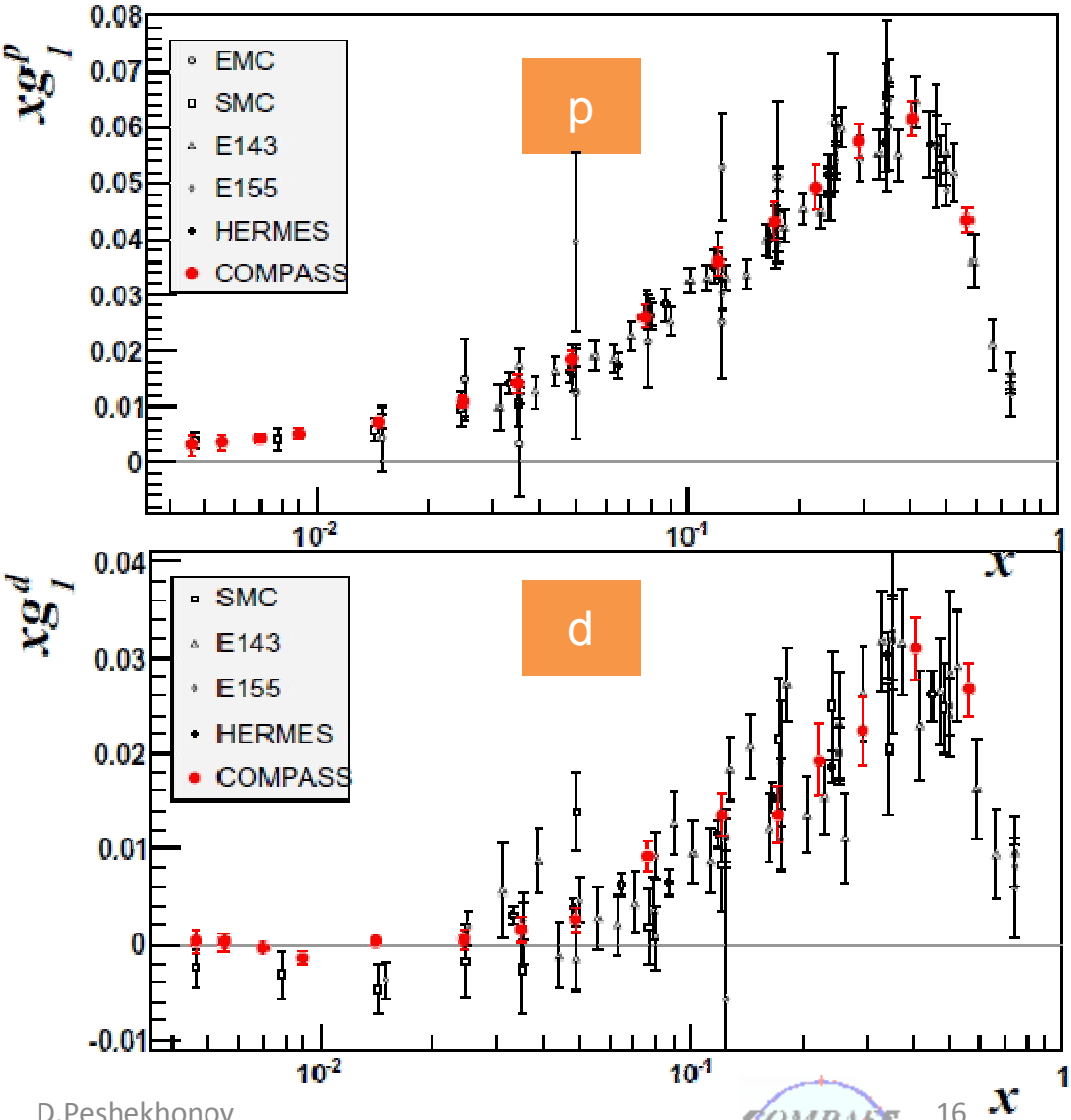
Structure function $g_1(x,Q^2)$

- very precise data
- only COMPASS for $x < 0.01$ ($Q^2 > 1$)
- proton & deuteron data, weak hyperon decay constants F & D:

  $\Delta\Sigma = 0.254 \pm 0.042$

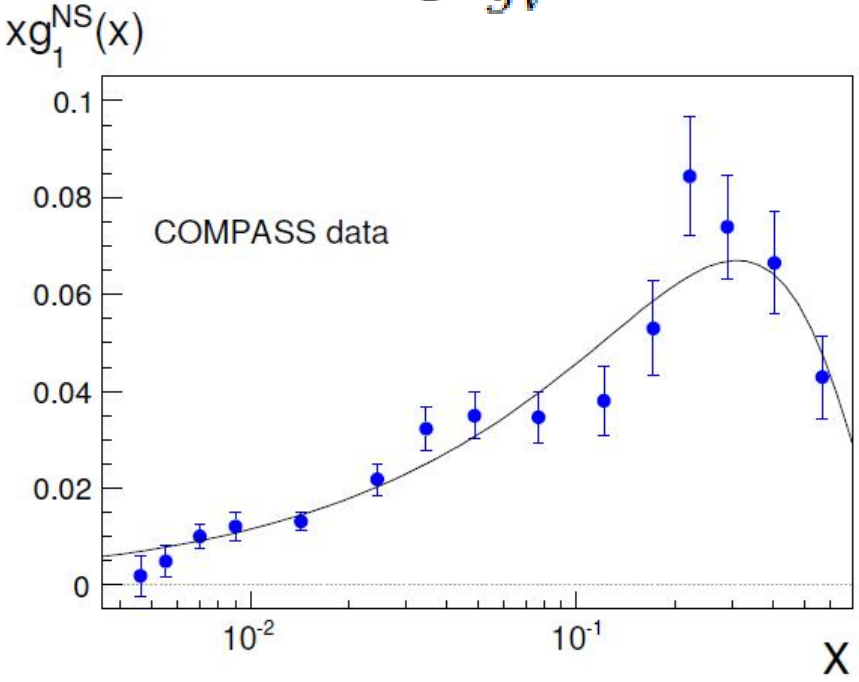
  $\Delta s + \Delta\bar{s} = = -0.110 \pm 0.012$

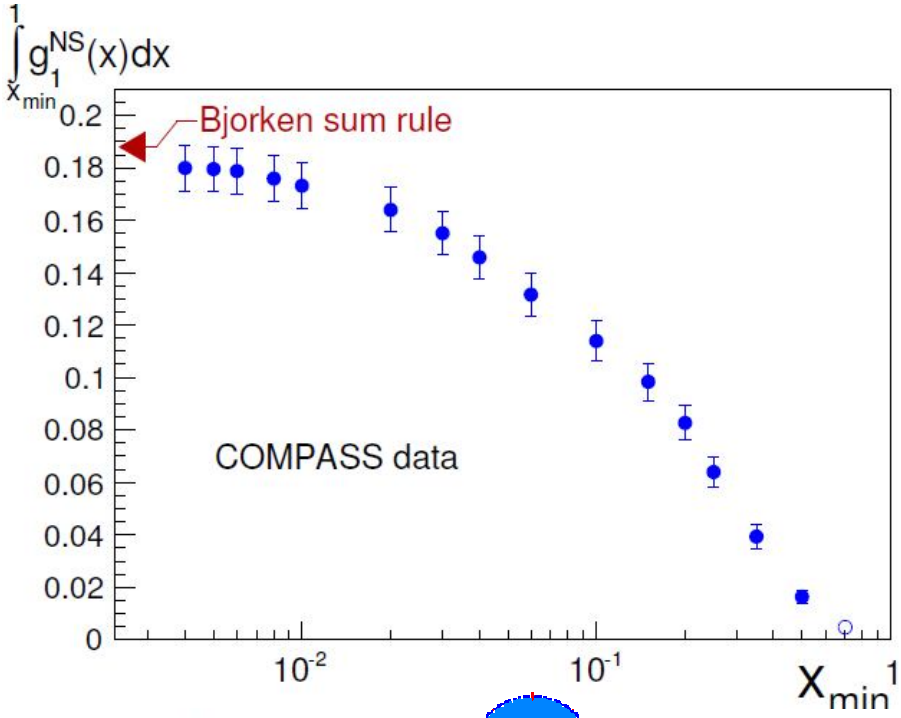
  E.Leader,A.Sidorov,D.Stamenov arXiv:1010.0574(hep-ph)
- only $\Delta q + \Delta\bar{q}$



Bjorken sum rule

$$\Gamma_1^{NS}(Q^2) = \frac{1}{6}\left|\frac{g_A}{g_V}\right| C_1^{NS}(Q^2) \qquad g_1^{NS}(x,Q^2) = g_1^p(x,Q^2) - g_1^n(x,Q^2)$$



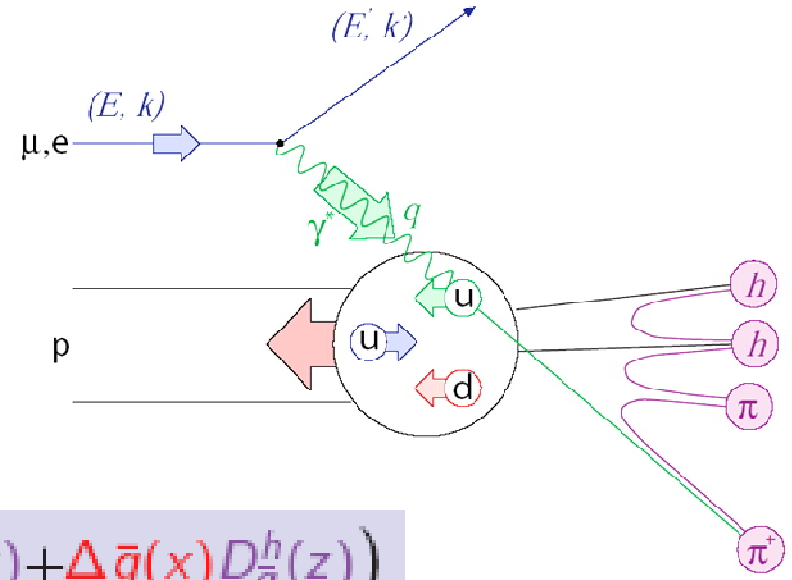


$$|g_A/g_V| = 1.28 \pm 0.07(\text{stat.}) \pm 0.10(\text{syst.})$$

$$|g_A/g_V| = 1.269$$ from neutron β decay

Helicity distributions

$$l + N \rightarrow l' + X + hadrons$$



$$A_1^h = \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}$$

$$\frac{N_h^{\uparrow\downarrow} - N_h^{\uparrow\uparrow}}{N_h^{\uparrow\downarrow} + N_h^{\uparrow\uparrow}} \propto A^h = \frac{\sum_q e_q^2 \left(\Delta q(x) D_q^h(z) + \Delta \bar{q}(x) D_{\bar{q}}^h(z)\right)}{\sum_q e_q^2 \left(q(x) D_q^h(z) + \bar{q}(x) D_{\bar{q}}^h(z)\right)}$$

D_q^h: fragmentation function

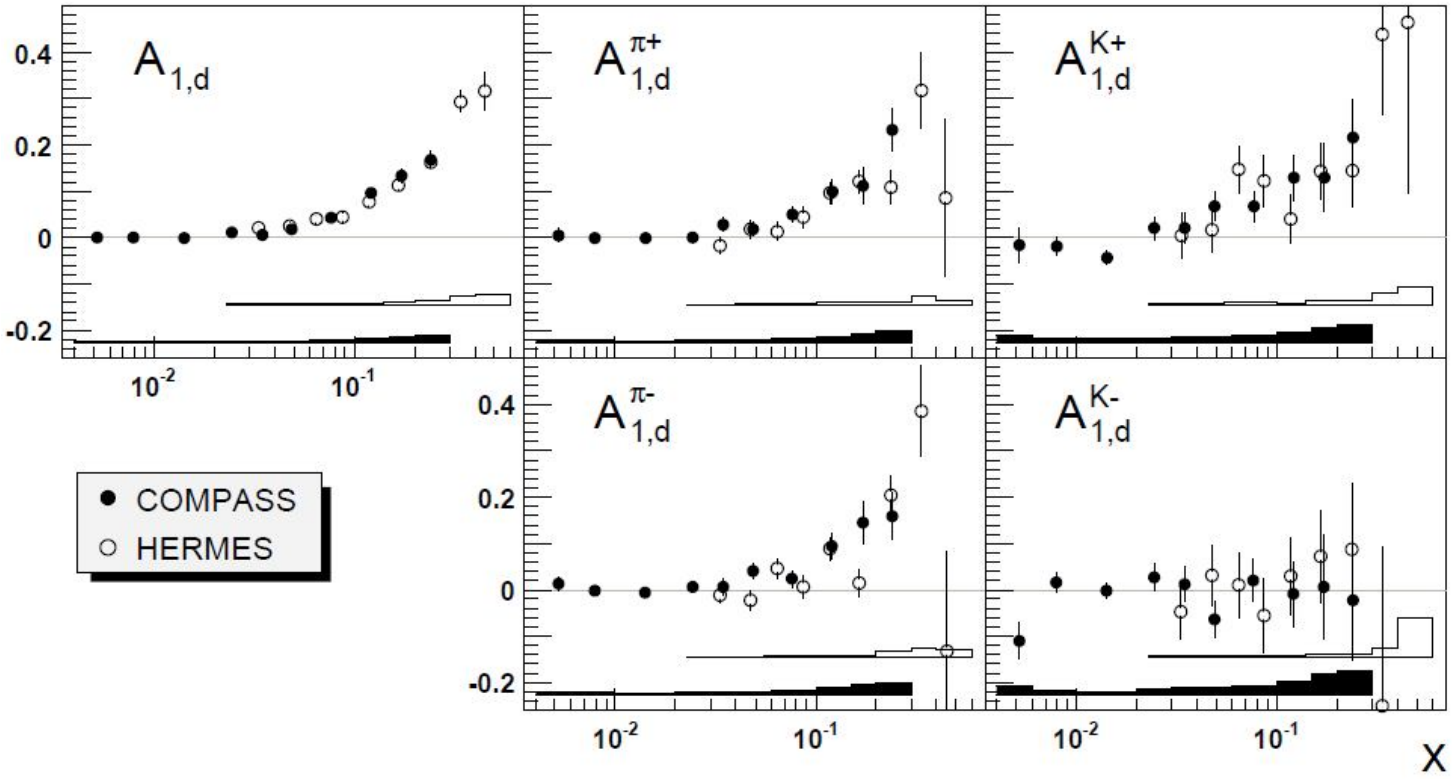
$D_q^h(z)\mathrm{d}z$ = number of hadrons of type h produces from a quark q with energy fraction in $[z, z+\mathrm{d}z]$

$D_u^{\pi^+} > D_{\bar{u}}^{\pi^+}$

Kaon asymmetries are for example are sensitive to Δs

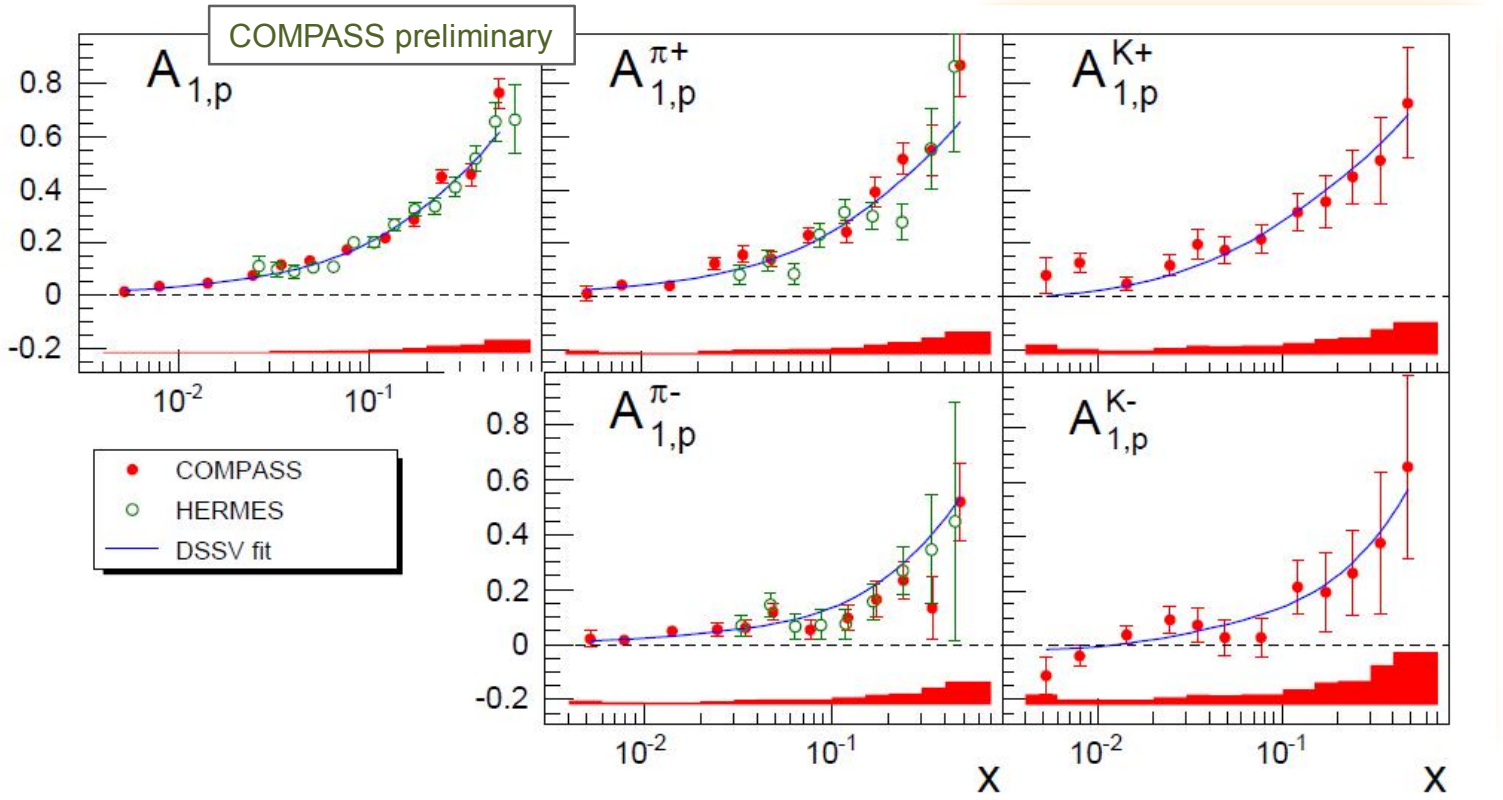
SIDIS asymmetries - deuteron

Deuteron data: 2002 – 2004, 2006



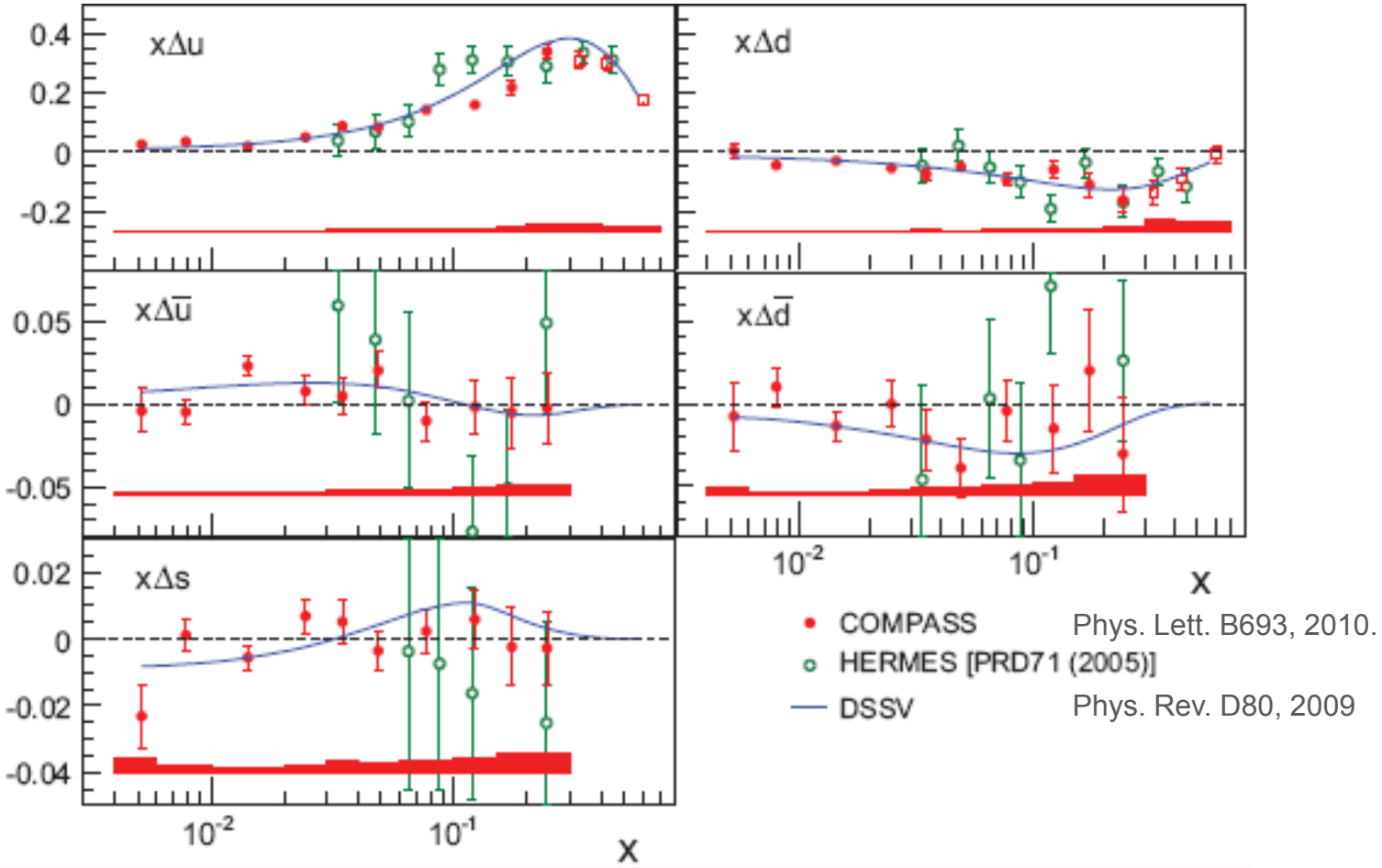
SIDIS asymmetries - proton

Proton data: 2007 (Phys. Lett. B693, 2010.)



- Leading Order (LO) fit of the 10 asymmetries (2x5)
- Determine 6 flavor separated PDFs : $\Delta u, \Delta d, \Delta \bar{u}, \Delta \bar{d}, \Delta s, \Delta \bar{s}$

Helicity distributions

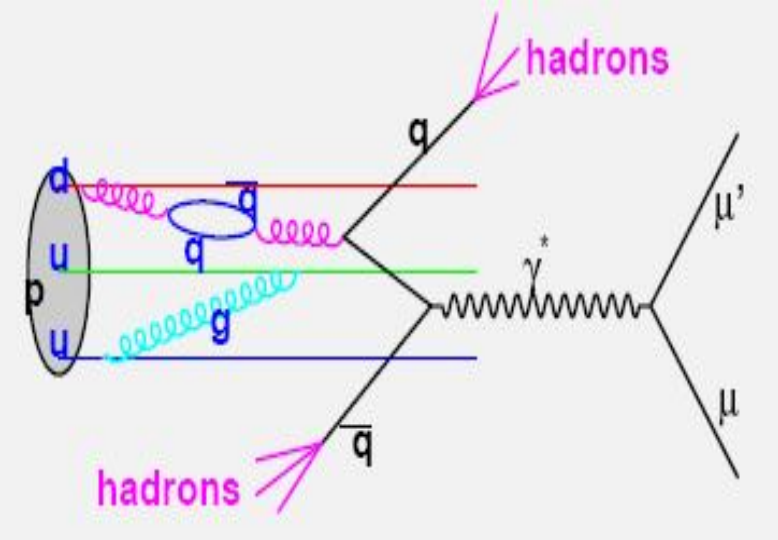


Δs: Truncated first moment: $\int_{0.004}^{0.3} \Delta s(x)dx = -0.01 \pm 0.01 \pm 0.01$

ΔΣ= 0.32 ± 0.03

Results depend on the FF (mainly Δs)

Gluon polarization

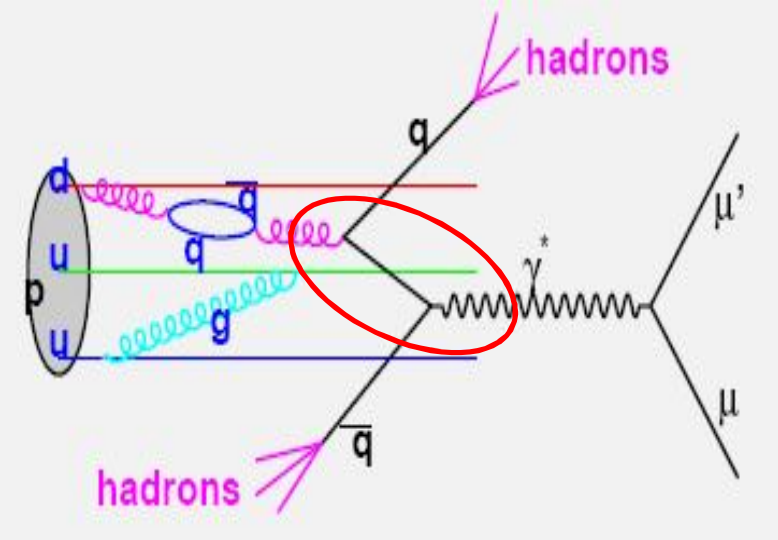


Photon-Gluon Fusion

How to measure:

$$L + N \rightarrow l' + hadrons + X$$

Gluon polarization



Photon-Gluon Fusion

How to measure:

$$L + N \rightarrow l' + hadrons + X$$

$$\gamma^* + g \rightarrow high\ p_T\ hadrons + X$$

A ~ Δq & Δg
Contribution of Δg enhanced due to selection of high p_T

$$\gamma^* + g \rightarrow charmed\ meson + X$$

A ~ Δg clean tag of glue

QCD analysis:
NLO analysis of inclusive and semi-inclusive asymmetries

Gluon polarization

High-p_T hadron pairs (q=u, d, s)

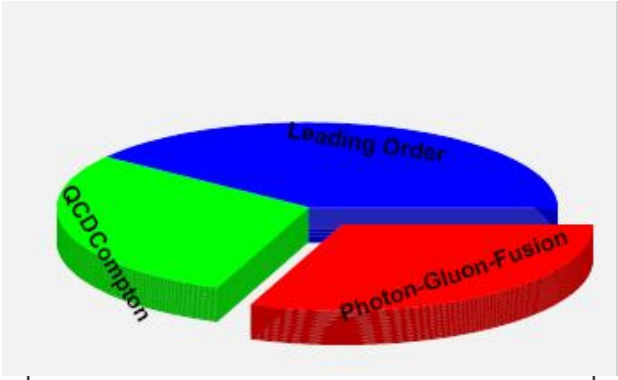
- Physical background
- Rely on MC estimates

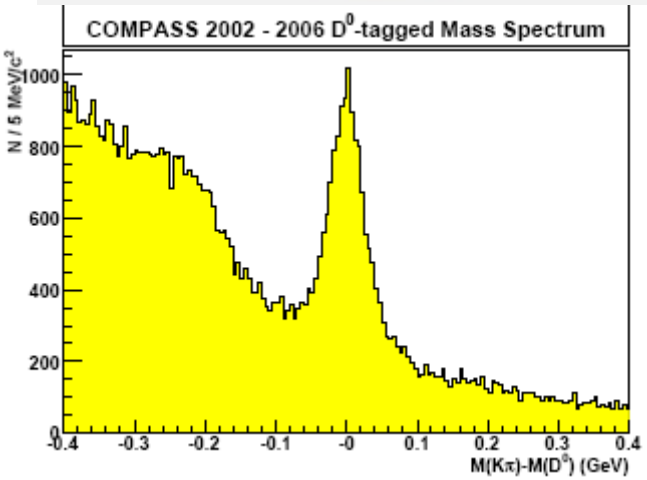
Open Charm production (q=c)

- Detect D° → $K^-\pi^+$ and $D^* \rightarrow D°\pi^+$
- Clean channels (no u, d, s quarks)
- Low statistics

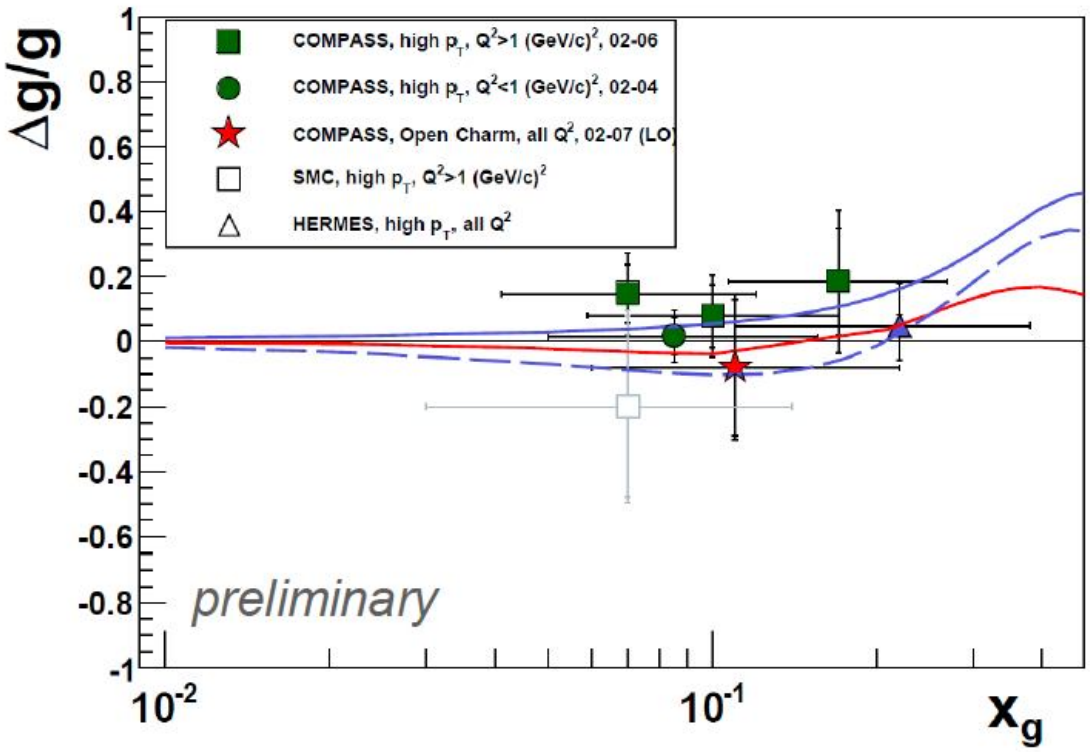
COMPASS data:

- hi-p_T, $Q^2>1$: 3 points, data from 2002-2007
- Hi-p_T, $Q^2<1$: 1 point, data from 2002-2004
- Open charm: 1 point, data from 2002-2007





ΔG: summary of measurements

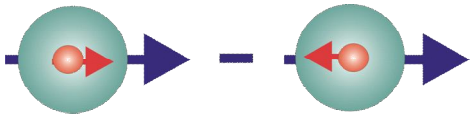


LSS '10
DSSV '08

Measurements are compatible with 0 – large values of ΔG seem excluded

But: Sign of ΔG is yet ambiguous

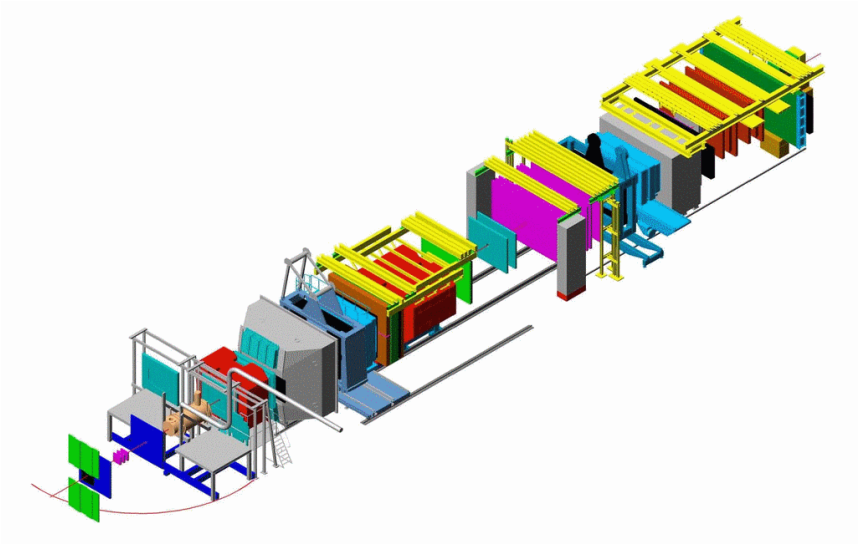
The shape of ΔG(x) is still unknown, data constrain a limited region



Summary

- New results on the helicity distributions Δq and Δg
- Full flavor decomposition Δu, Δd, Δs and antiquarks
  - Δu and Δd rather well known
  - open questions: $\Delta u = \Delta \bar{d}$ and $\Delta s = \Delta \bar{s}$?
- $\Delta\Sigma = 0.25 \pm 0.05$; $\Delta G \approx 0 \pm 0.5$
  - certainly small compared to large values
    $\Delta G \approx 2 \div 3$ proposed to explain $\Delta\Sigma \approx 0.25\%$
  - not small compared to the total spin of the nucleon
- Nucleon spin puzzle still is not solved

What's next?



COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

COMPASS-II

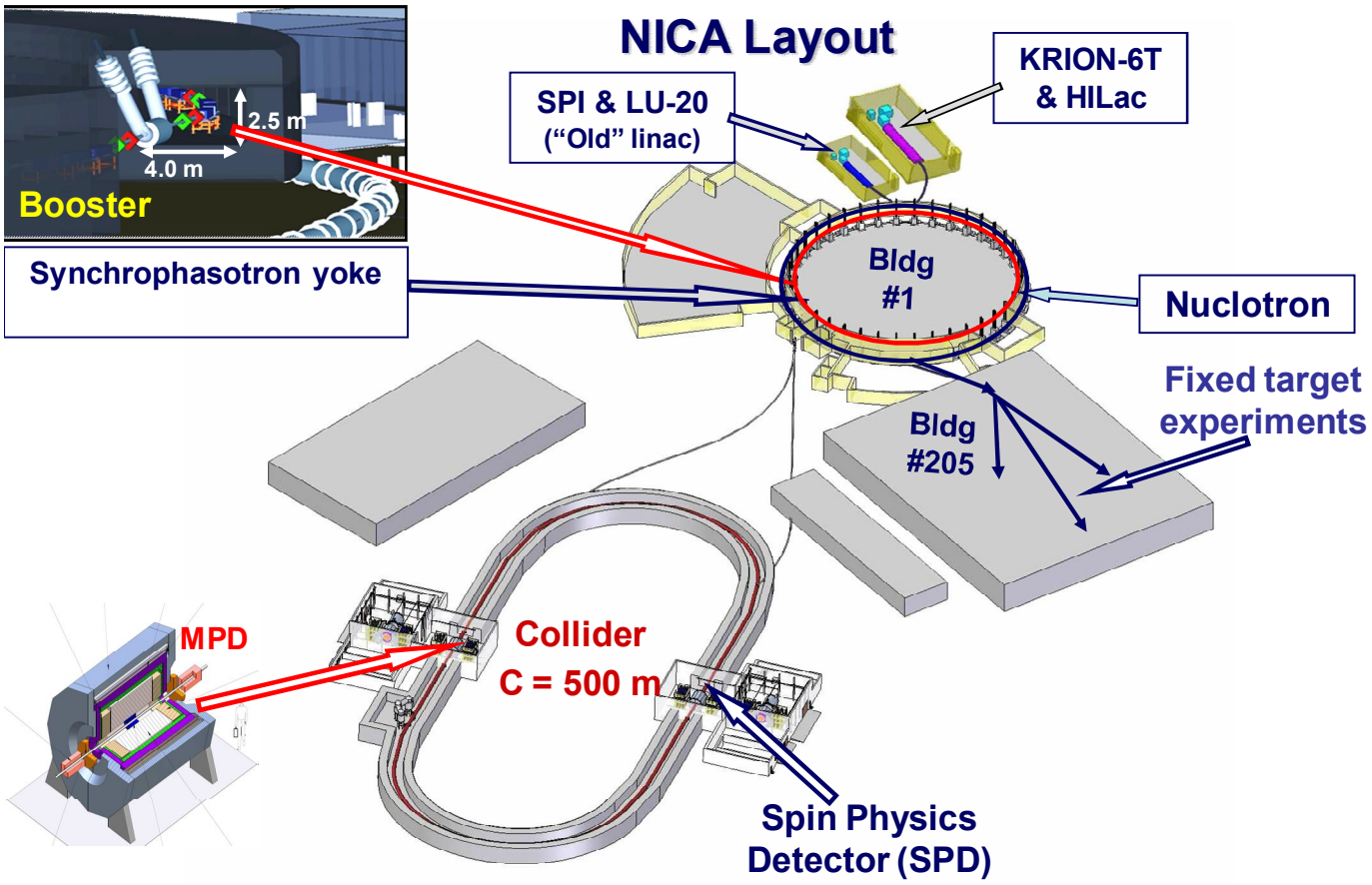
COMPASS-2

- **COMPASS-2 is a new experiment**
  - Recommended by the CERN SPSC: Sept. 29, 2010.
  - Approved by the CERN Research Board: Dec. 1, 2010.

- **COMPASS-2 physics – 4 main topics**
  1. DVCS and DVMP : Study GPDs, "nucleon tomography"
  2. Unpolarized SIDIS : Fragmentation Functions, s-PDFs, TMDs
  3. Drell-Yan : Universality of TMDs
  4. Primakoff scattering : Polarizabilities of π and K

- **Data taking**
  - 2012, SPS/LHC shutdown, 2014, 2015, 2016

Spin physics at NICA (JINR)



Spin Physics at NICA

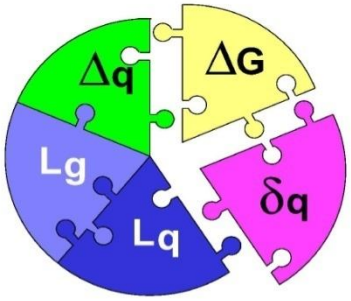
The spin program at NICA is under preparation. The main topics are:

- Studies of Drell-Yan processes with longitudinally and transversely polarized p and D beams. Extraction of unknown and poor known PDFs
- PDF from J/Ψ production processes
- Spin effects in baryon, meson and photon production
- Study of spin effects in various exclusive processes
- Diffractive processes studies
- Cross sections, helicity amplitudes and double spin asymmetries (Krisch effect) in elastic reactions
- Spectroscopy of quarkonium

Thank you for attention

Spare

3.Main Results: Gluon Polarization

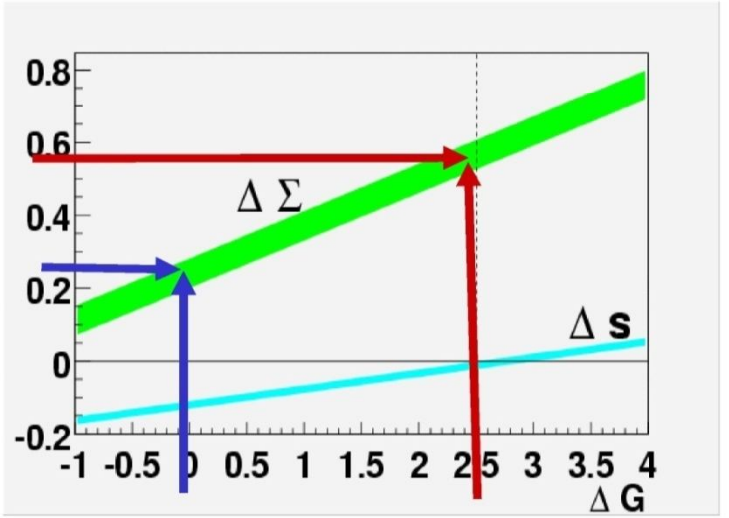


$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \underbrace{\Delta G + \langle L_q \rangle + \langle L_g \rangle}$$

Measurement of ΔG important :

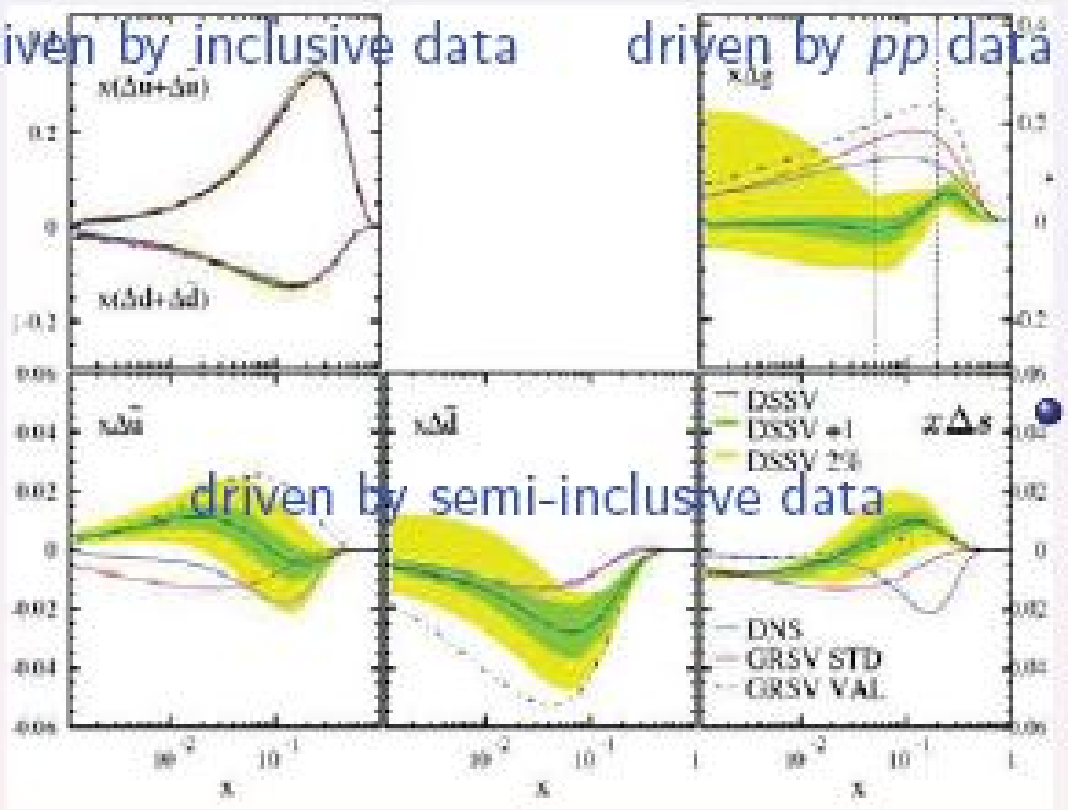
1 – How are gluons polarized ?

2- Low value of a_0 could be due to axial anomaly if ΔG is large.
(A. Efremov O.Teryaev, G. Altarelli – G. Ross)



3 – How large is parton orbital angular momentum

$$a_0 = \Delta\Sigma - \frac{3\alpha_s}{2\pi}\Delta G$$



- about 500 data points fitted, inclusive & semi-inclusive asymmetries, RHIC *pp* data
- analysis does not (yet) include direct measurements from DIS, because NLO calculation are not available, (except for open charm)

M. Stratmann, DIS 2011
D. de Florian, R. Sassot, M. Stratmann and W. Vogelsang, Phys. Rev. D 80 (2009) 034030, [arXiv:0904.3821 [hep-ph]]