More intense and higher energy
muon and hadron beams
for nucleon structure and spectroscopy

F.Kunne
CEA Saclay
On behalf of the COMPASS collaboration

New opportunities in the physics landscape of CERN, May 11-13 2009

COMPASS

M2 beam line, versatile setup with muon & hadron beams
+ various targets unpolarized / polarized

$\mathcal{L}$ ~5.10^{32} $cm^{-2}s^{-1}$ (FoM reduced by factor 50-100 for polarized case)

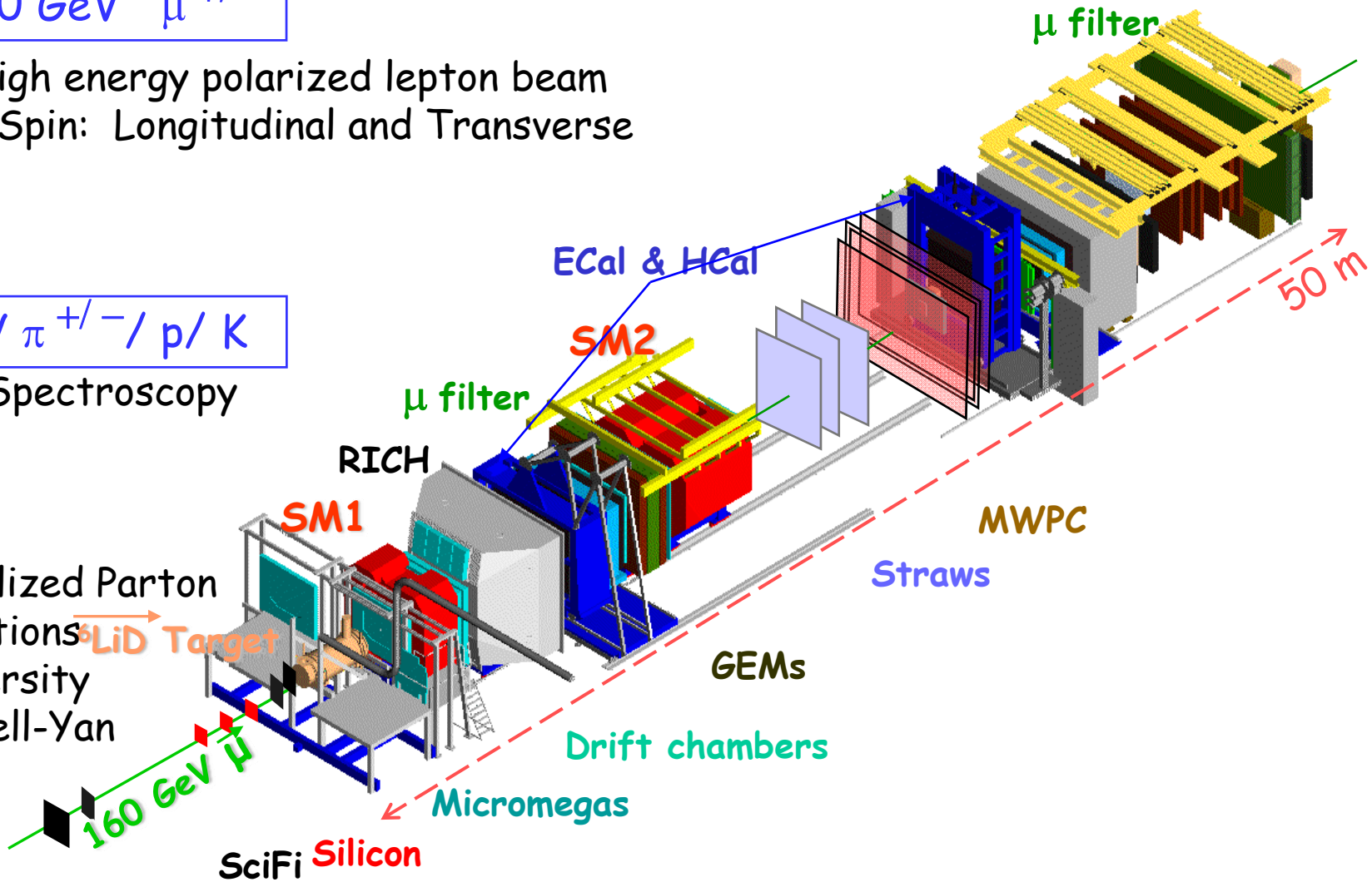
100-200 GeV $\vec{\mu}^{+/-}$

Unique high energy polarized lepton beam
Nucleon Spin: Longitudinal and Transverse

190 GeV $\pi^{+/-}$/ p/ K

Hadron Spectroscopy

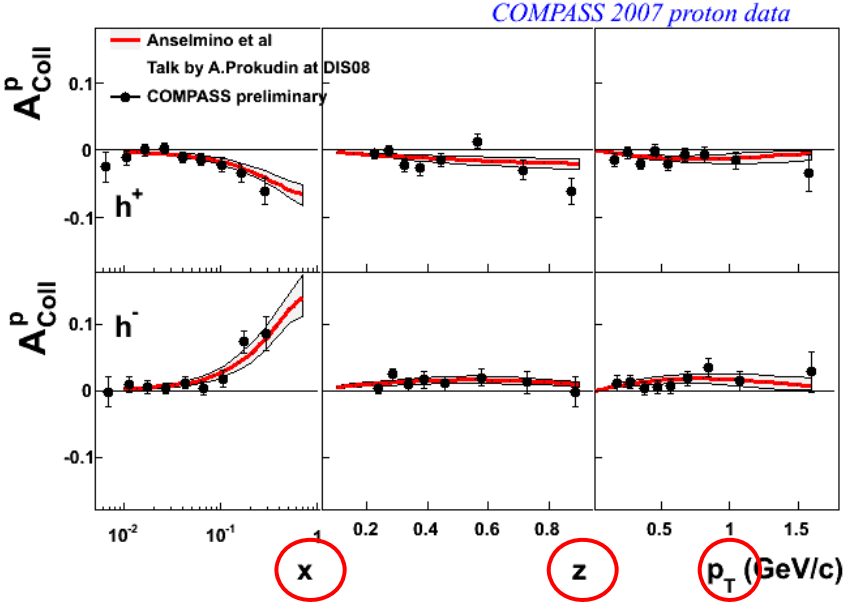
Future:
- Generalized Parton Distributions
- Transversity from Drell-Yan

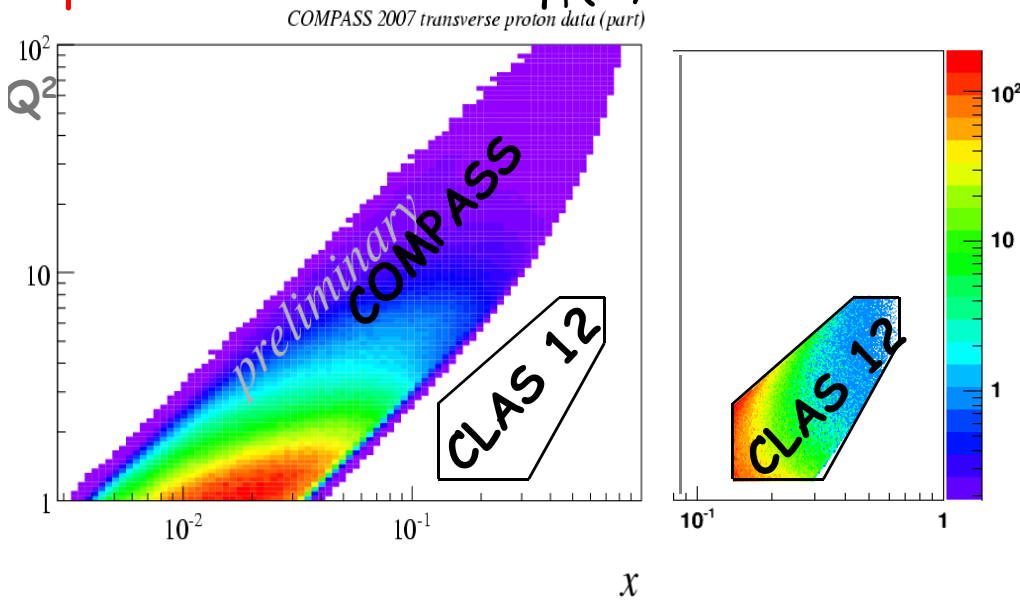


$\vec{\mu} + p\uparrow$

Transversity - Collins

→ Quark Transverse Spin Distributions $\Delta q_T(x,Q^2)$

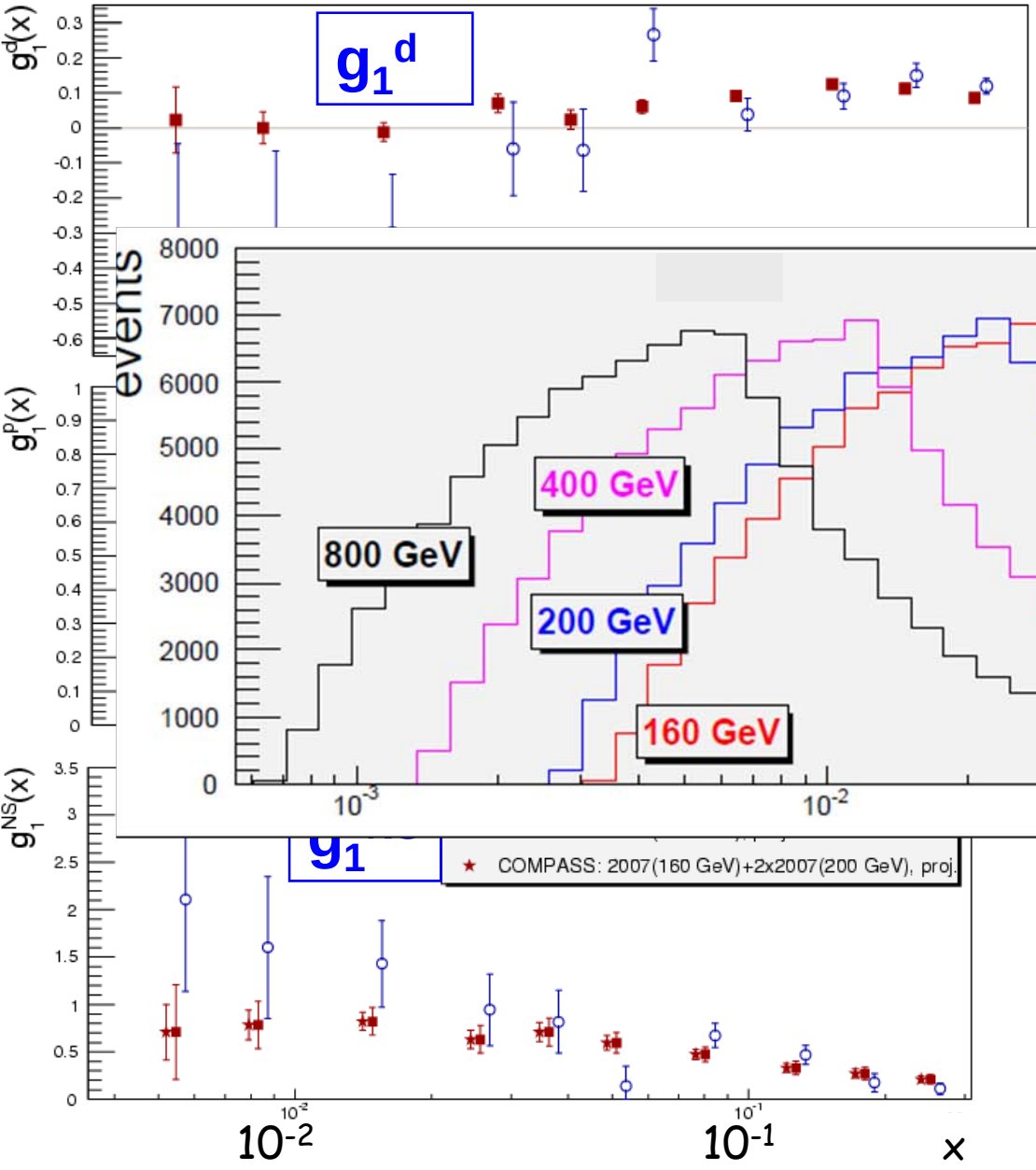




- Sizable quark transverse spin and "Collins analyzing power"
- Need full x, z and p_T separation
  while now summed over two other variables
  → Need higher luminosity
- Higher Q^2 than JLab or HERMES

$\vec{\mu} + \vec{p}$

Longitudinal Spin - Inclusive



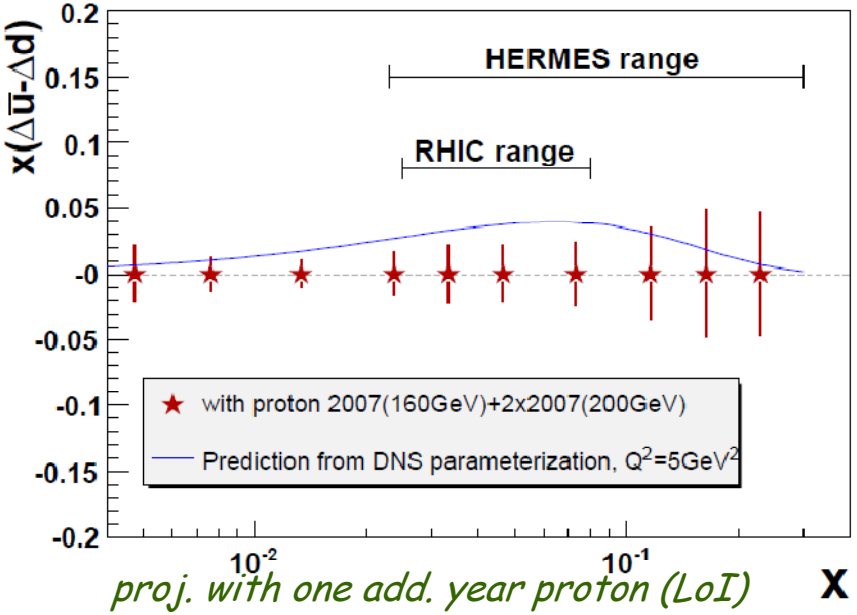
- $\Delta\Sigma$ Quark helicity
- Bjorken sum rule

→ Need higher energy & luminosity

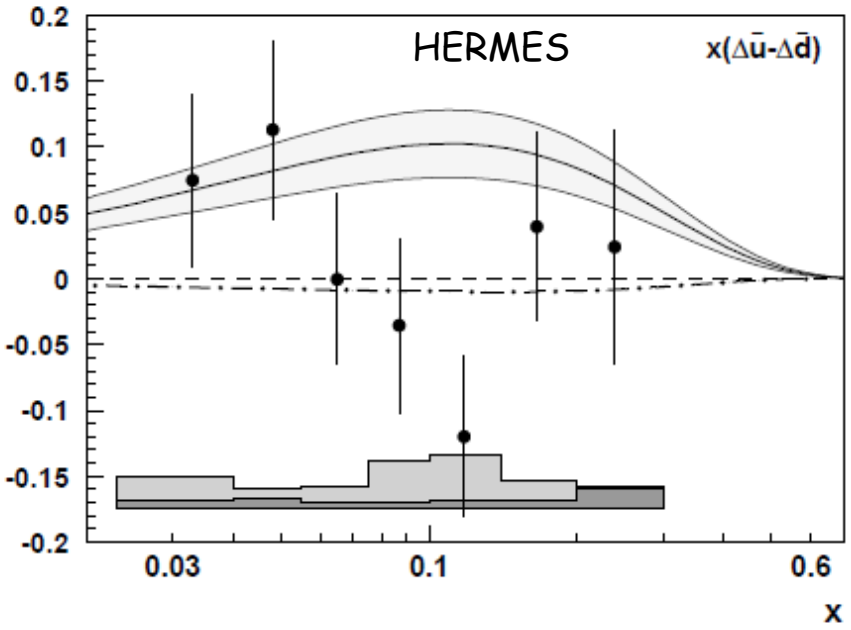
$\vec{\mu} + \vec{p}$

Longitudinal Spin – Sea quarks

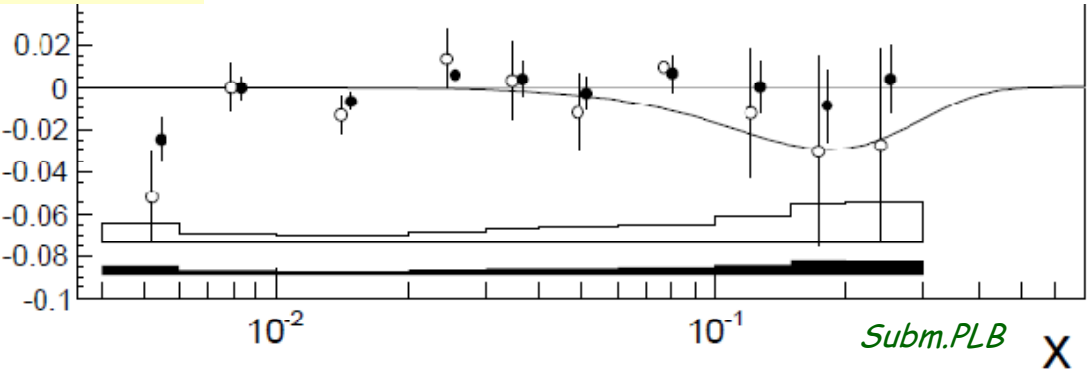
$x(\Delta\bar{u}(x)-\Delta\bar{d}(x))$

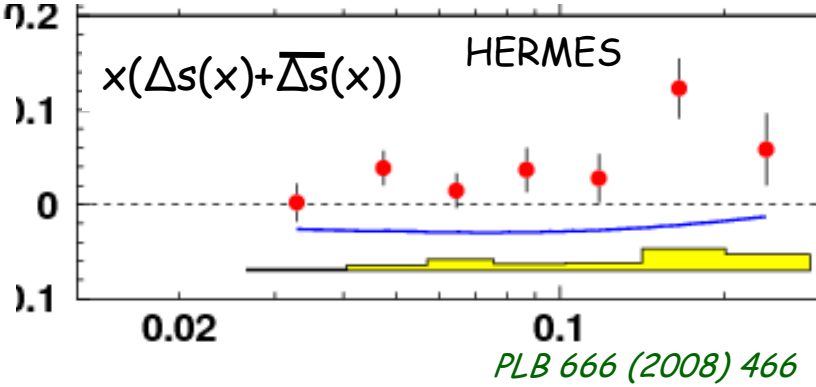


proj. with one add. year proton (LoI)



$x\Delta s(x)$





Recall: first moment of Δs negative - 0.045 ± 0.005± 0.010
from inclusive data + values of F&D

Competition in polarized lepton nucleon

EIC/ENC

Projects for future electron ion colliders under discussion in other labs.
Not available before 10 or 15 years.

Long term goals EIC $\mathcal{L}$ up to 10^{33} $cm^{-2}s^{-1}$ sqrt(s)=20-100 GeV

ENC $\mathcal{L}$ up to $1\text{-}5.10^{32}$ $cm^{-2}s^{-1}$ sqrt(s)=13 GeV

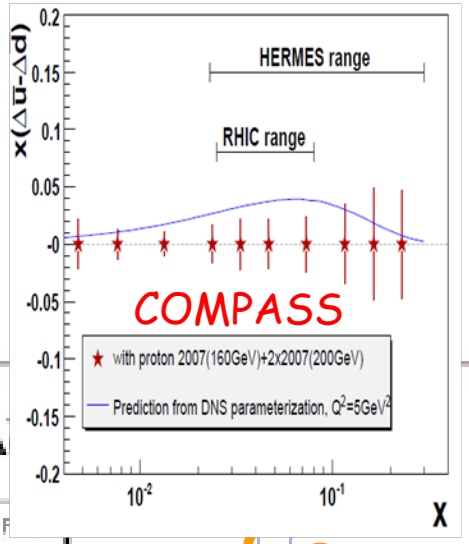
(Recall COMPASS at 200 GeV $\mathcal{L} \sim 5.10^{32}$ $cm^{-2}s^{-1}$ (unpol.) sqrt(s)= 20 GeV)

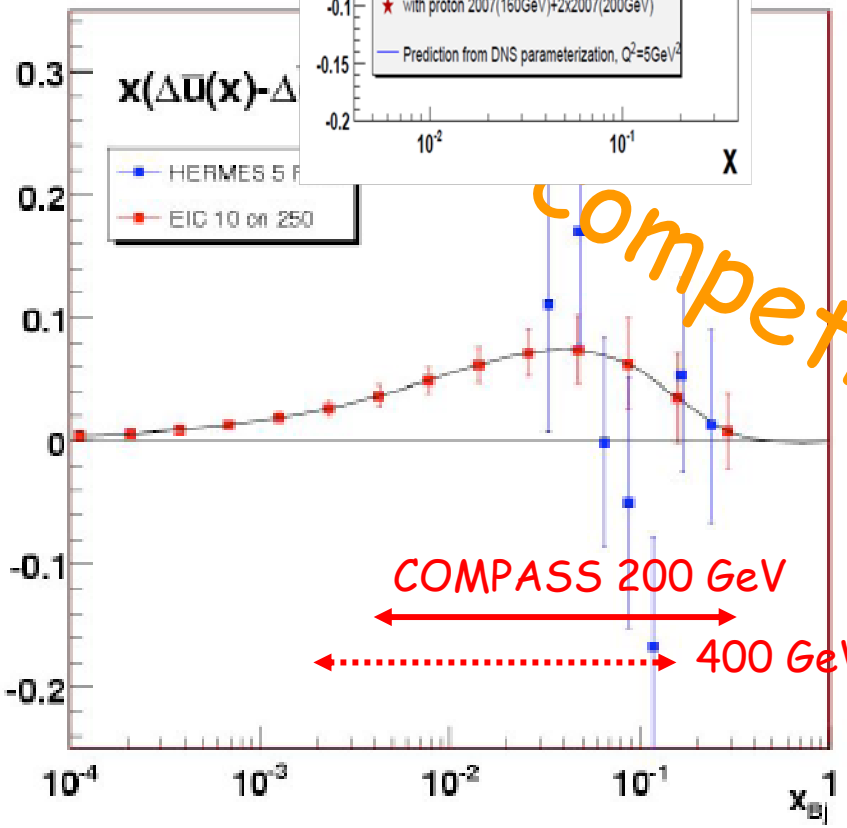
CERN is a potential major competitor in this physics domain meanwhile

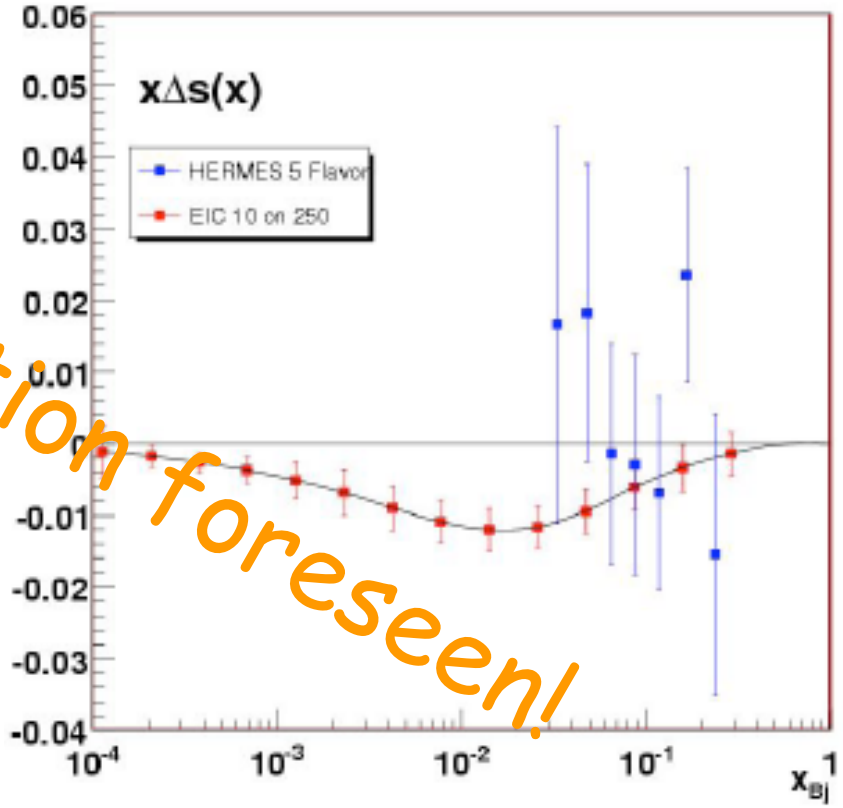
Projection for Future EIC

7 GeV e x 150 GeV p, 100 days at 10^{33},

From Rolf Ent, ECT Trento, Oct 2008

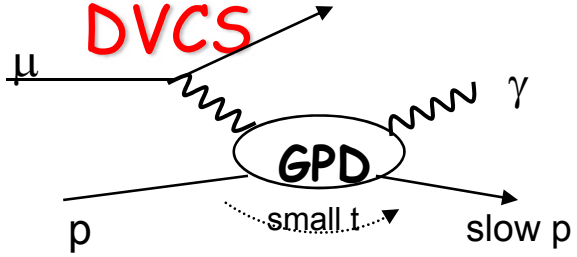


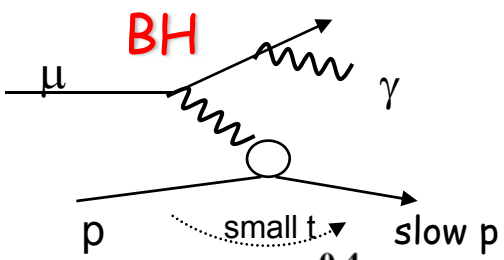


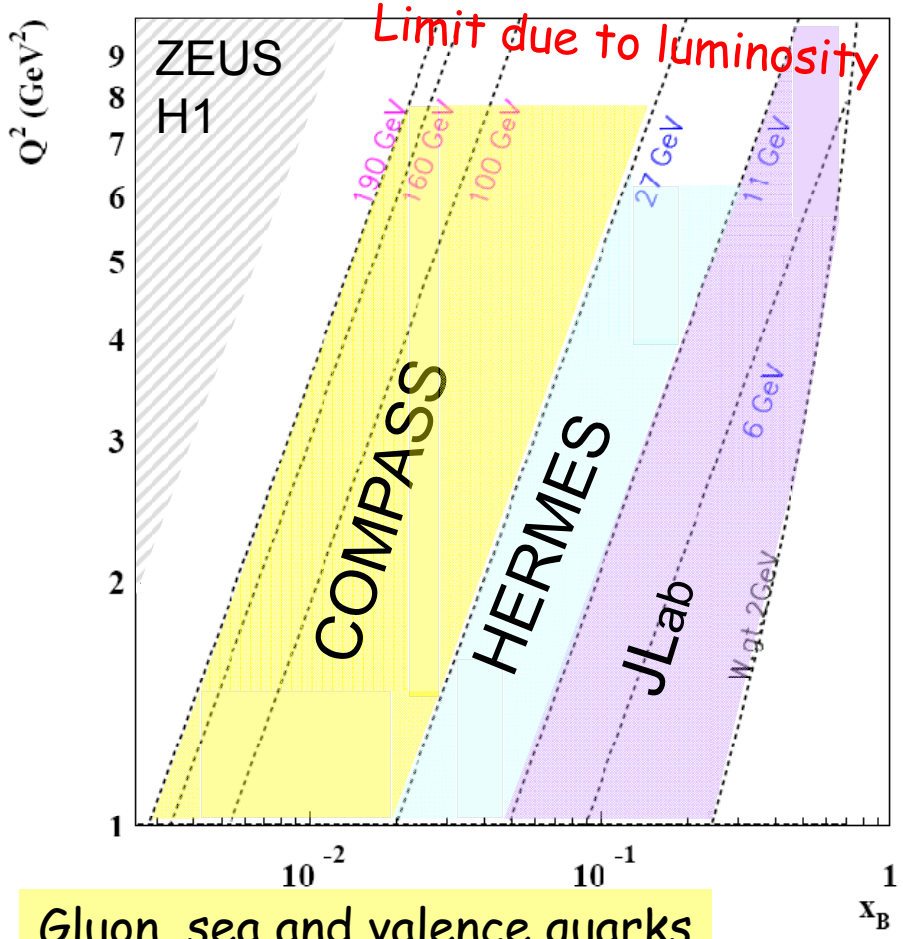


Competition foreseen!

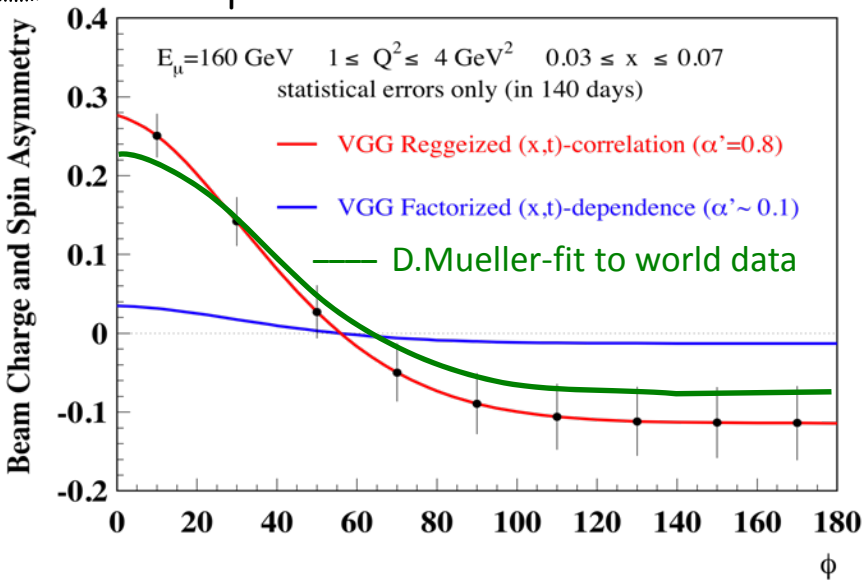
Generalized Parton Distribution functions







Gluon, sea and valence quarks

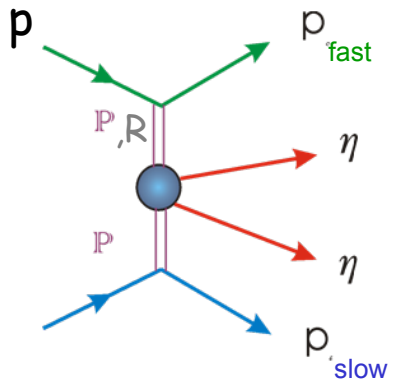


Need higher luminosity

- Higher statistics
- Large Q^2 range to assess validity of domain & limit NLO corrections

Hadron spectroscopy

Central Production of hadron resonances



Search for glue-rich states
Reggeon-Pomeron and
Pomeron-Pomeron scattering

Higher beam energy→ more Pomeron-Pomeron
Access higher energy resonance spectrum

Doubly charmed baryons

- Charm production cross sections rises fast with energy
- Can also be studied with hyperon beam
- High energy boosts the decay length (easier vertex separation) and increases yield of hyperons extracted

Highest energy desirable (450 GeV/c)

Main limitation: present transport line limited to 270 GeV/c (magnet power supplies)

Beam luminosity issues

Muon flux carefully optimized in the past years

Limiting factors :

- Number of protons/spill that can be
  - Accelerated in SPS : 4.3 10^{13}
  - Extracted from SPS, (then to experiment):
    3.2 10^{13} for 9.6s flat top (2.5 10^{13})
    2 4.8s (1.4 10^{13})
- Beam halo level in the experiment
- Radio protection issues at several places along the beam line
- Splitter magnet, transfer line (quadrupoles and other elements)
- Resistance of the T6 primary production target, dump

Some possible upgrades of the beam line

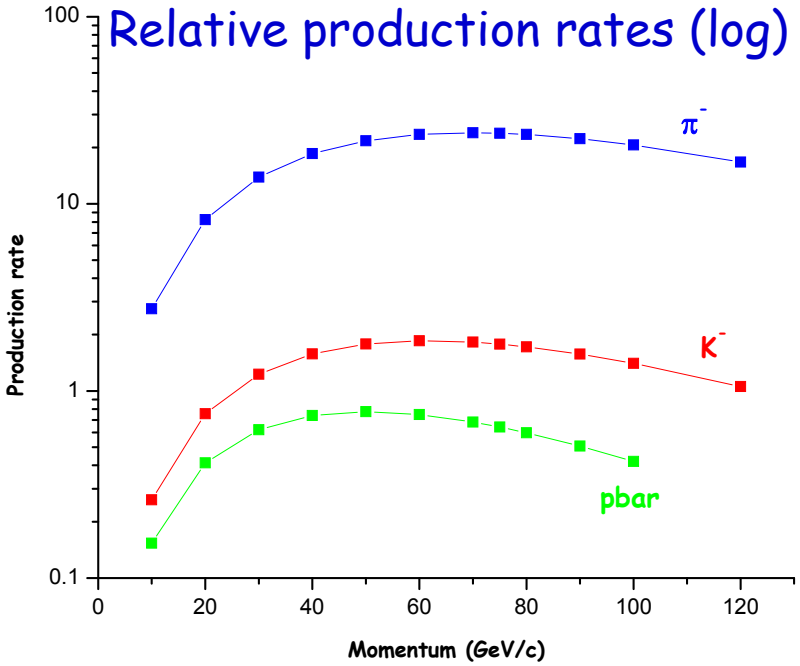
- Close the area (overcome halo limitation)
- Better beam line. With short and long decay sections (600-1800m)
- Underground installations

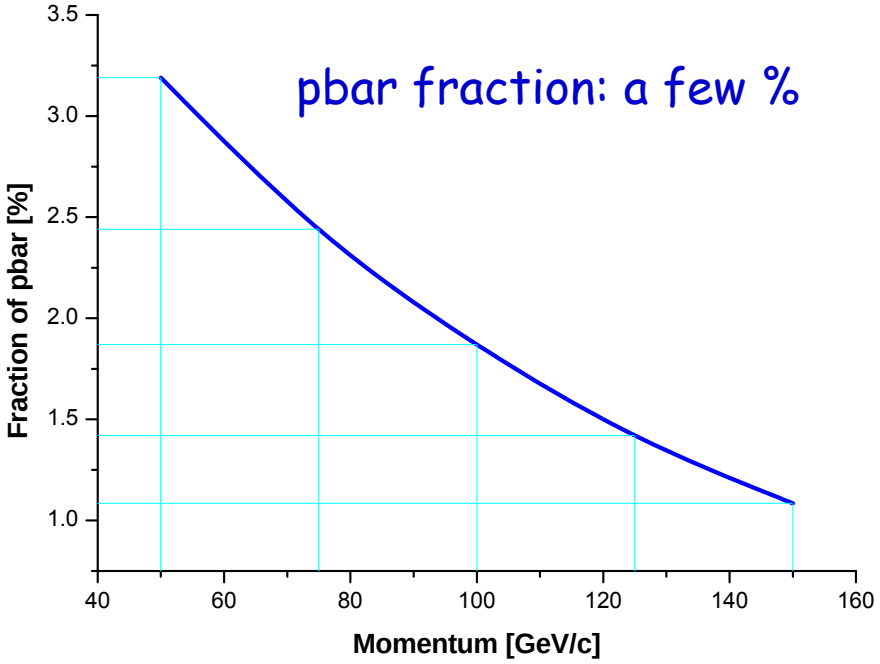
$\bar{p}$ beam ? for Drell-Yan processes

Secondary particle fluxes

Apply Atherton formula for 0 mrad (approximative only for p ≤ 60 GeV/c).

Obtain # particles per steradian per GeV/c and per 10^{12} interacting protons:





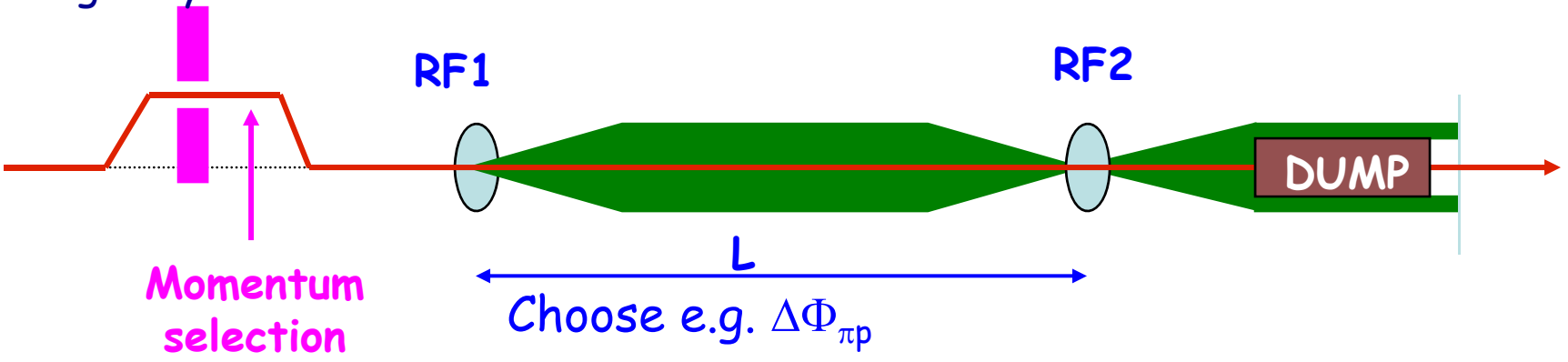
In present M2 hadron beam ≤ 5 10^6 $\bar{p}$

(due to 2x10^8 (π) limit on total beam flux for radio-protection)

Possible solution with RF separated $\bar{p}$ beam?

First and very preliminary thoughts, guided by
- recent studies for P326
- CKM studies by J.Doornbos/TRIUMF, e.g. http://trshare.triumf.ca/~trjd/rfbeam.ps.gz

E.g. a system with two cavities:



$\Delta\Phi = 2\pi\,(L\,f\,/\,c)\,(\beta_1^{-1} - \beta_2^{-1})$ with $\beta_1^{-1} - \beta_2^{-1} = (m_1^2 - m_2^2)/2p^2$

At 100 GeV. With 2×10^{13} primary protons /10 s spill on the production target get ~ 3×10^{8} total flux with purity about 50%,

→ antiproton flux ≈ **1.5 10^8 ppp**
comparable to present π and p flux

From slide of L.Gatignon, 17-10-2006 *Preliminary rate estimates for RF separated antiproton beams*

Conclusion

CERN is presently a major actor in QCD physics with unique high energy polarized muon and hadron beams

Luminosity and energy upgrades will open a large window on uncovered territories.

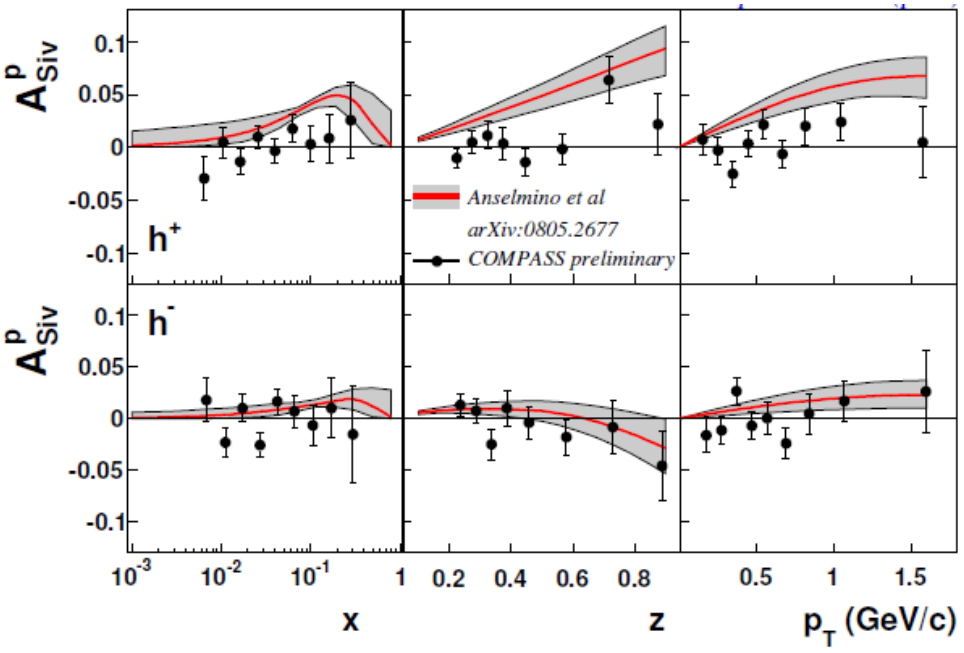
spares

$\vec{\mu} + p\uparrow$

Transversity - Sivers

→ Quark Transverse Momentum Distributions

Sensitive to orbital momentum

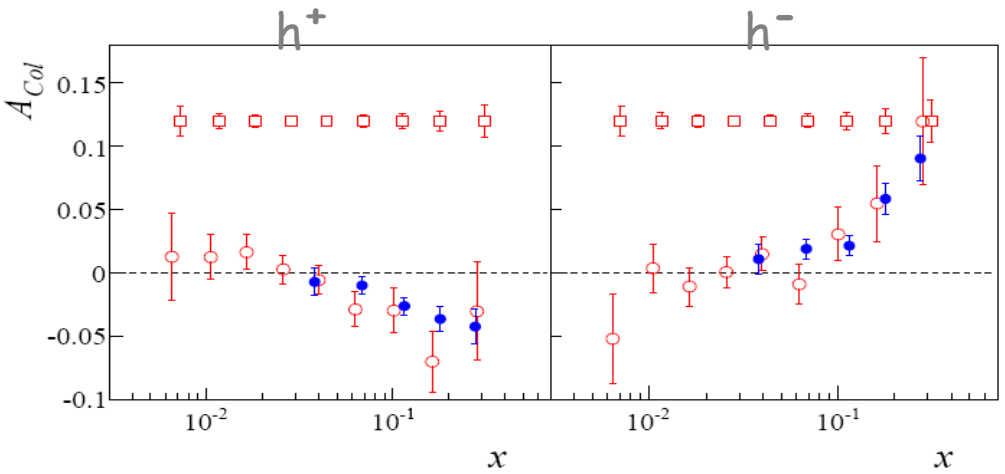


- Now summed over two other variables
- Need full x, z and p_T separation → highest luminosity

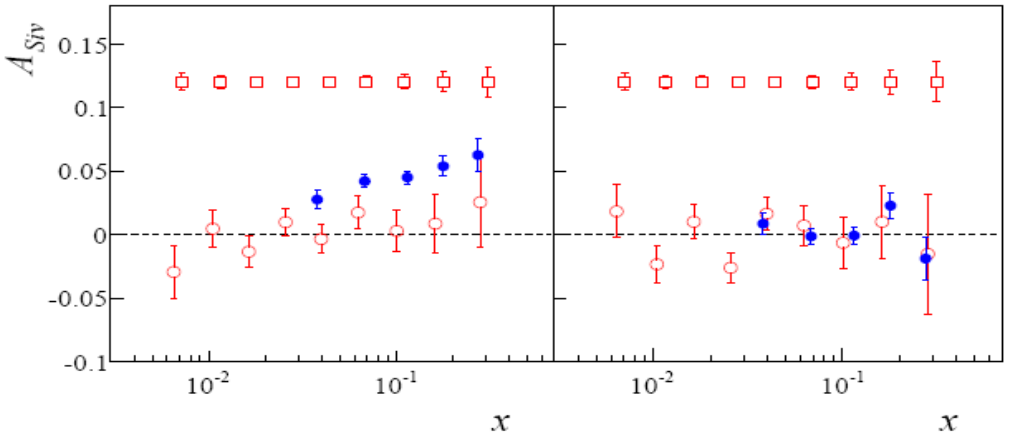
$\vec{\mu} + p\uparrow$

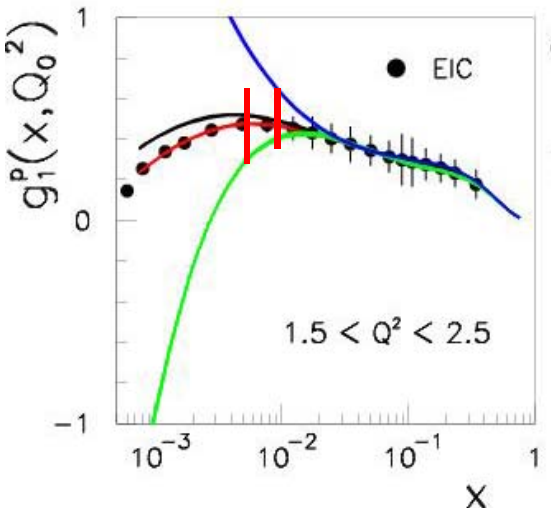
Transversity – Collins & Sivers

Projections 2010
Collins & Sivers
asymmetries vs x
(summed over z and p_T)



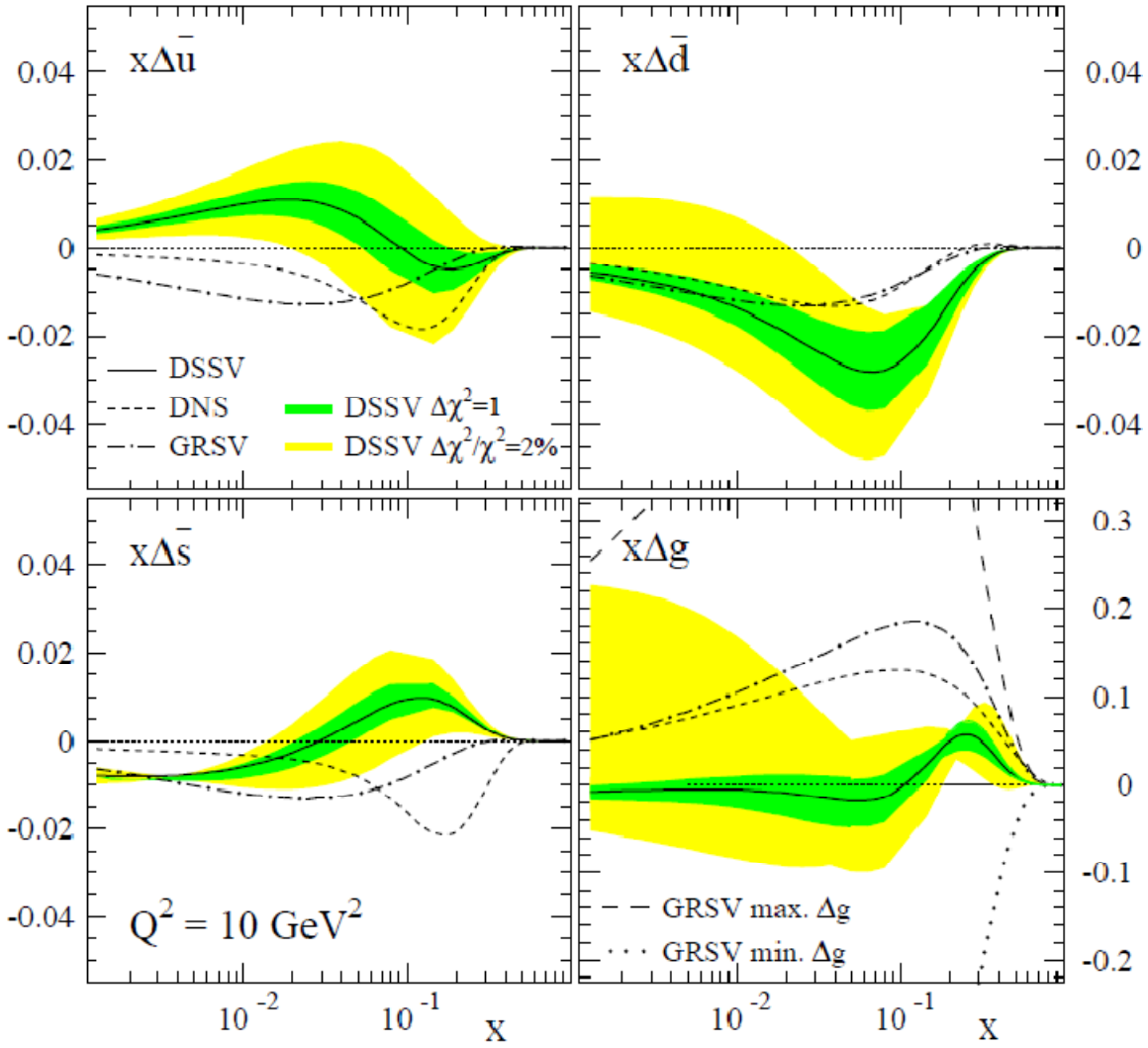
□ COMPASS projections ○ COMPASS 2007 (part) ● HERMES

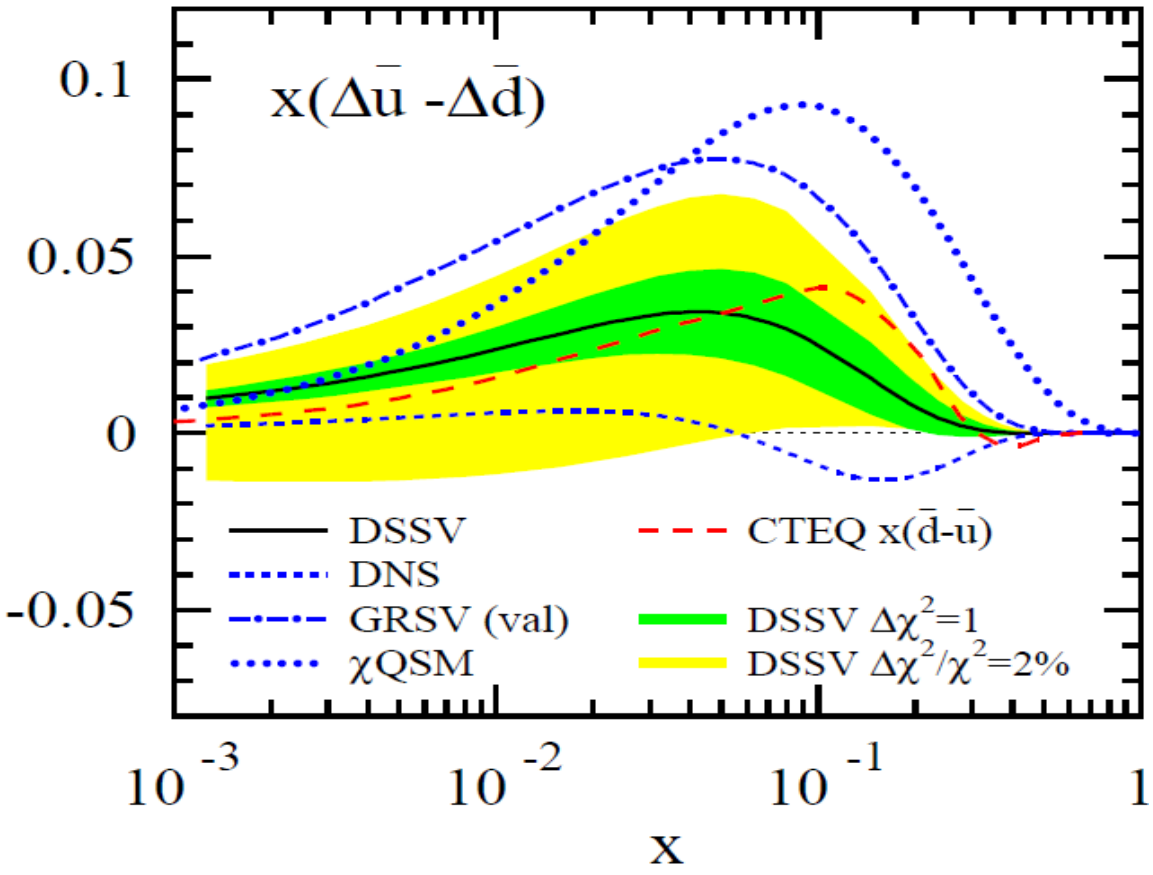




COMPASS LoI
ΔG min <0
ΔG std
ΔG =0
ΔG max >0

Original plot for EIC from : Rolf Ent, Trento 2008
(calc : Antje Bruell, Abhay Deshpande)


xΔū
xΔd̄
xΔs̄
xΔg
DSSV
DNS
GRSV
DSSV Δχ²=1
DSSV Δχ²/χ²=2%
GRSV max. Δg
GRSV min. Δg
Q² = 10 GeV²
x
0.04
0.02
0
-0.02
-0.04
0.3
0.2
0.1
-0.1
-0.2
10 -2
10 -1



DSSV arXiv 0904.3821

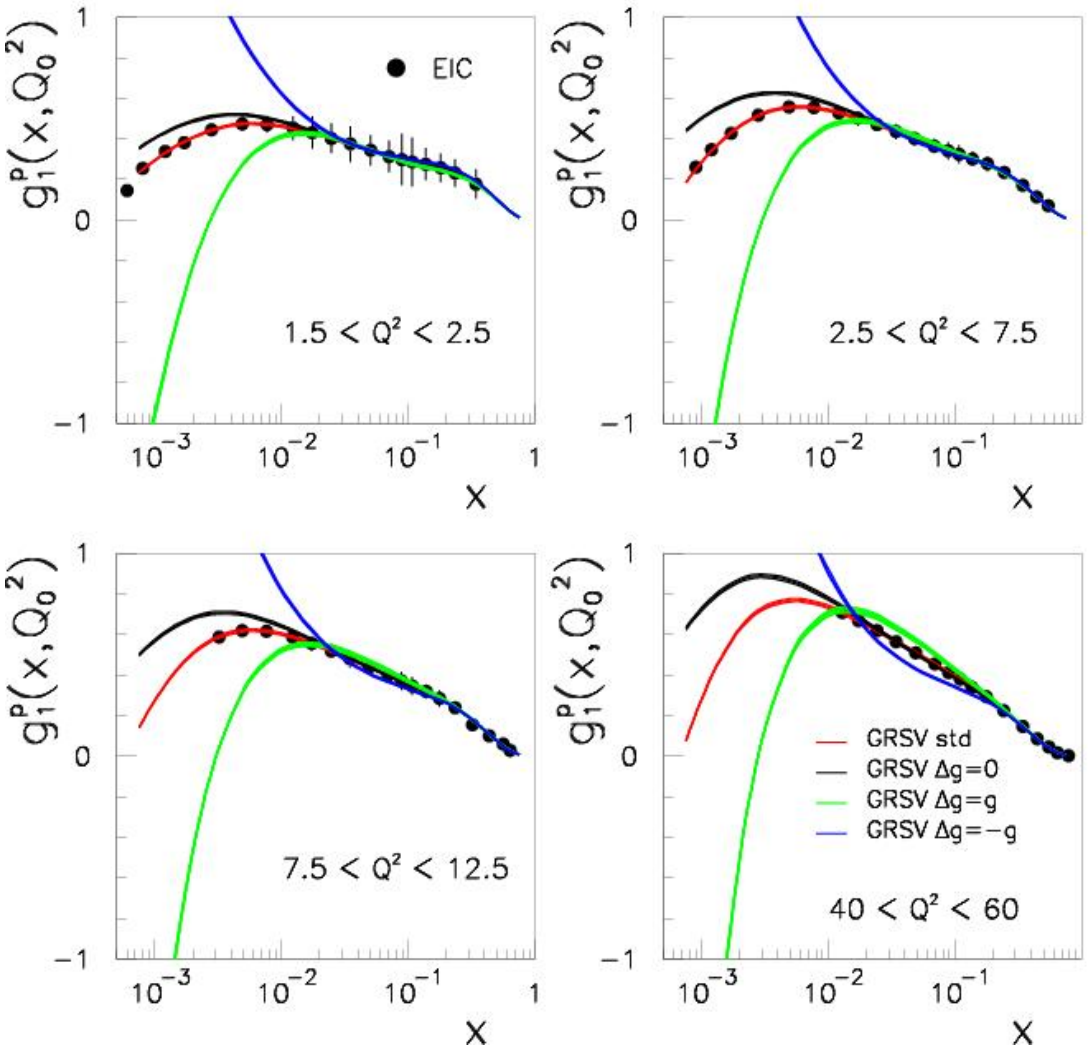
The Gluon Contribution to the Proton Spin

Slide taken from : Rolf Ent, Trento 2008

(Antje Bruell, Abhay Deshpande)

$$\frac{d\,g_1}{d\log(Q^2)} \propto -\Delta g(x,Q^2)$$

at small x



Superb sensitivity to Δg at small x!

Polarized muon beam

COMPASS is unique:

Only place for high energy polarized lepton beams

Important for low x and high Q^2 coverage

inclusive, semi-inclusive and exclusive reactions

However, clear limitations have been reached

Now: $\mathcal{L} \sim 5.\ 10^{32}\ s^{-1}cm^{-2}$ $E\mu = 100\text{-}200$ GeV

FoM reduced by beam polarization $0.8^2 = 0.64$

& target dilution/polarization

target	f_{dil}	P	$f^{-2}P^{-2}$
p	0.18	0.8	**0.02**
d	0.4	0.5	**0.04**

A substantial increase of $\mathcal{L}$ would allow us to make a decisive step in:

- Transverse spin structure & transverse momentum
- Role of gluons and sea quarks in Nucleon spin
- Spatial distribution of quarks and gluons

Higher beam energy $E\mu$ would allow us to enlarge the kinematic domain

New results with beam Luminosity and/or Energy increase

Muons	T	lumi
	L	lumi and energy
	GPDs	lumi
Hadrons	Drell-Yan	pbar beam
	spectroscopy	energy