Future measurements at CERN with higher energy and higher intensity muon and hadron beams

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On behalf of the COMPASS collaboration

Symmetries and Spin, Advanced Study Institute Prague, Czech Republic, July 26 - Aug. 2, 2009

In the context of the CERN
Workshop May 11-13, 2009
http://indico.cern.ch/conferenceDisplay.py?confId=51128

Interest in future upgrades for higher energy and higher luminosity beams

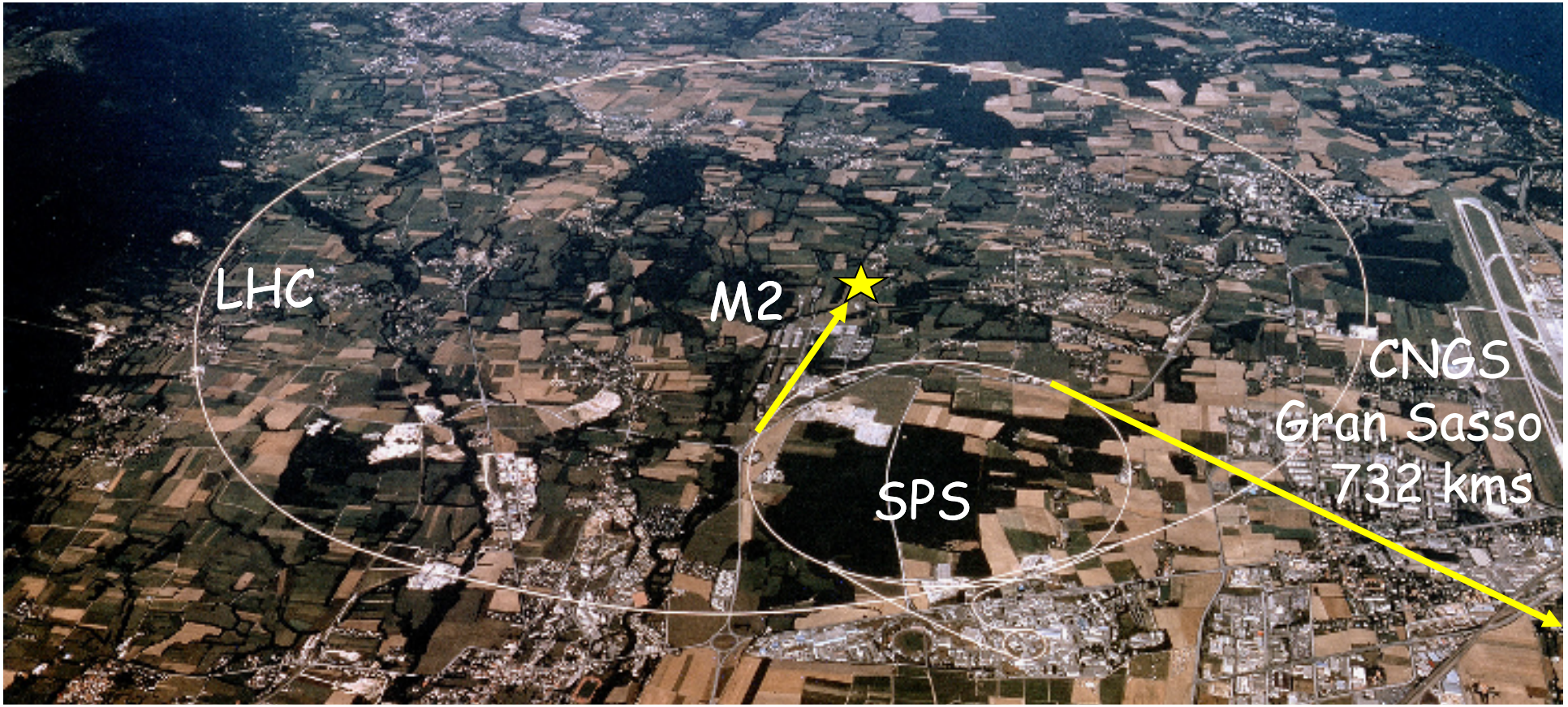
Potential at CERN for further study of :

- Nucleon Spin (Transverse and Longitudinal)
- Spatial distribution of quarks and gluons
- Hadron spectroscopy

- Projections for short term future
- Interest in long term future upgrades

M2 Muon and Hadron beam line

SPS proton beam: 1.4 10^{13}/spill, 400 GeV/c
Secondary hadron beams (π, K, ...): 2.10^{8} /spill, 150-270 GeV/c
Tertiary muon beam (80% pol): 2.10^{8} /spill, 100-200 GeV/c
(numbers for 4.8 s spill)



COMPASS

M2 beam line, versatile setup with muon & hadron beams
+ various targets polarized or not

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

160 GeV $\vec{\mu}^{+/-}$

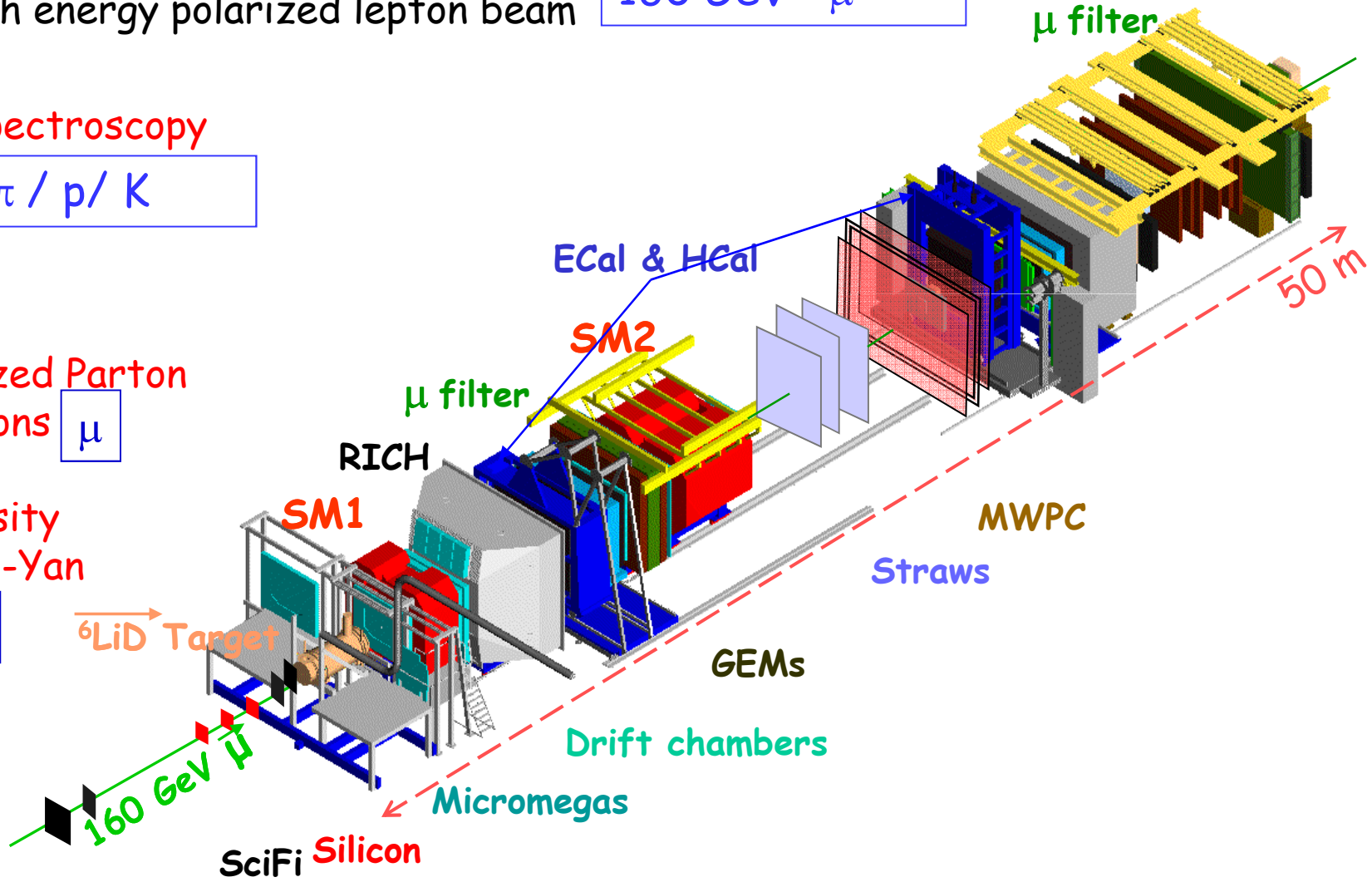
Hadron Spectroscopy

190 GeV π / p/ K

Future:

- Generalized Parton Distributions μ
- Transversity from Drell-Yan

π, pbar



COMPASS short term plans with muons

2010/2011

(Completion of original muon part of proposal)

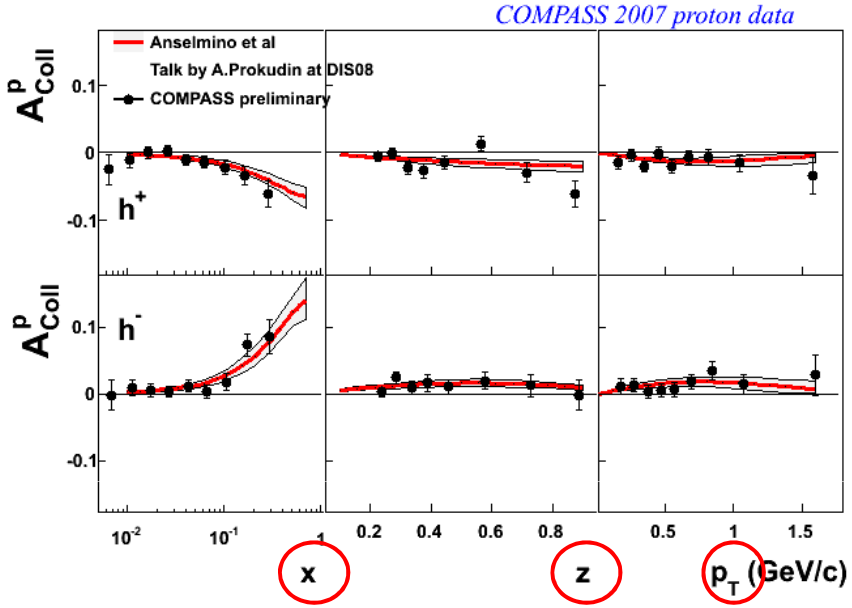
- transverse target polarisation:
  - proton target (NH_3), one year data taking
  - Collins & Sivers asymmetries and others

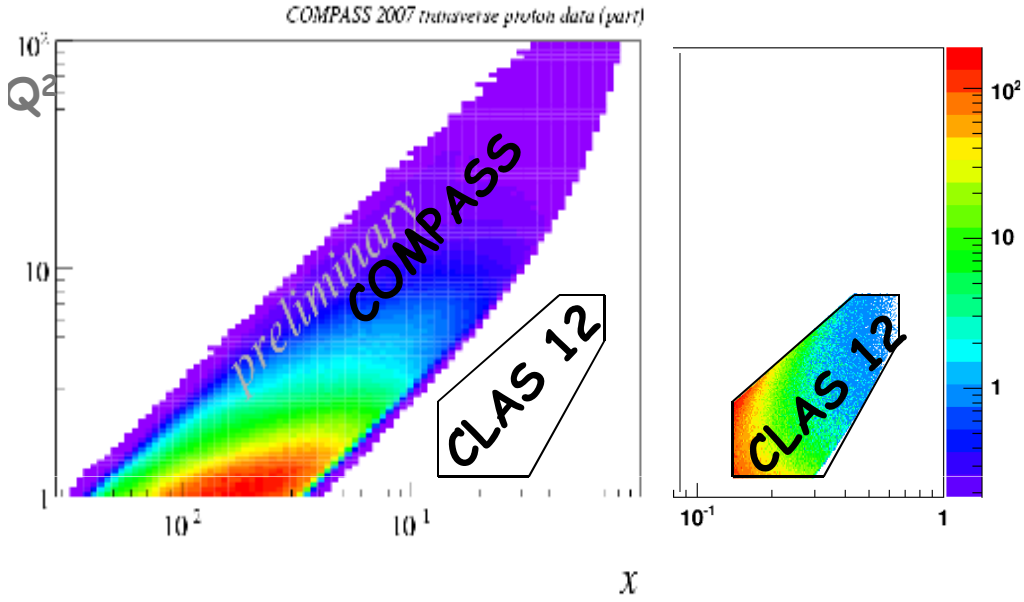
- longitudinal target polarisation:
  - proton target (NH_3), one year data taking
  - g_1^p, g_1^{ns}, $\Delta\bar{u} - \Delta\bar{d}$

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

Transversity - Collins

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



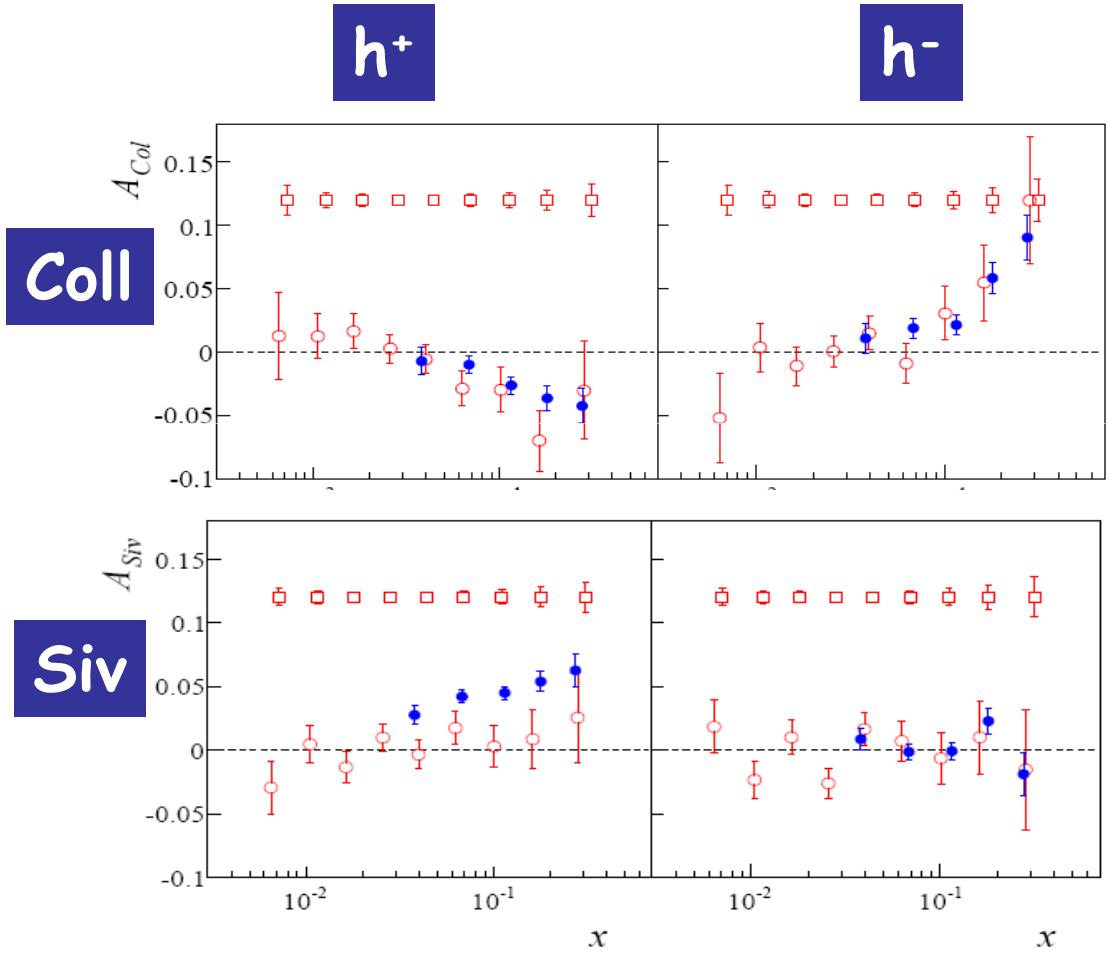


- Sizable quark transverse spin and "Collins analyzing power"
- Need full x, z and p_T separation
  while now summed over two other variables
  → Need higher luminosity
- Higher Q^2 than JLab or HERMES

Collins and Sivers, short term projections

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

Projections 1 year : 2010
Collins & Sivers asymmetries vs x (summed over z and p_T)



projected precision

- □ COMPASS 2010 proj.
- ○ COMPASS 2007 (part)
- ● HERMES

Is Sivers non-zero for the proton?

(Quark TMDs & Sensitive to Orbital Momentum)

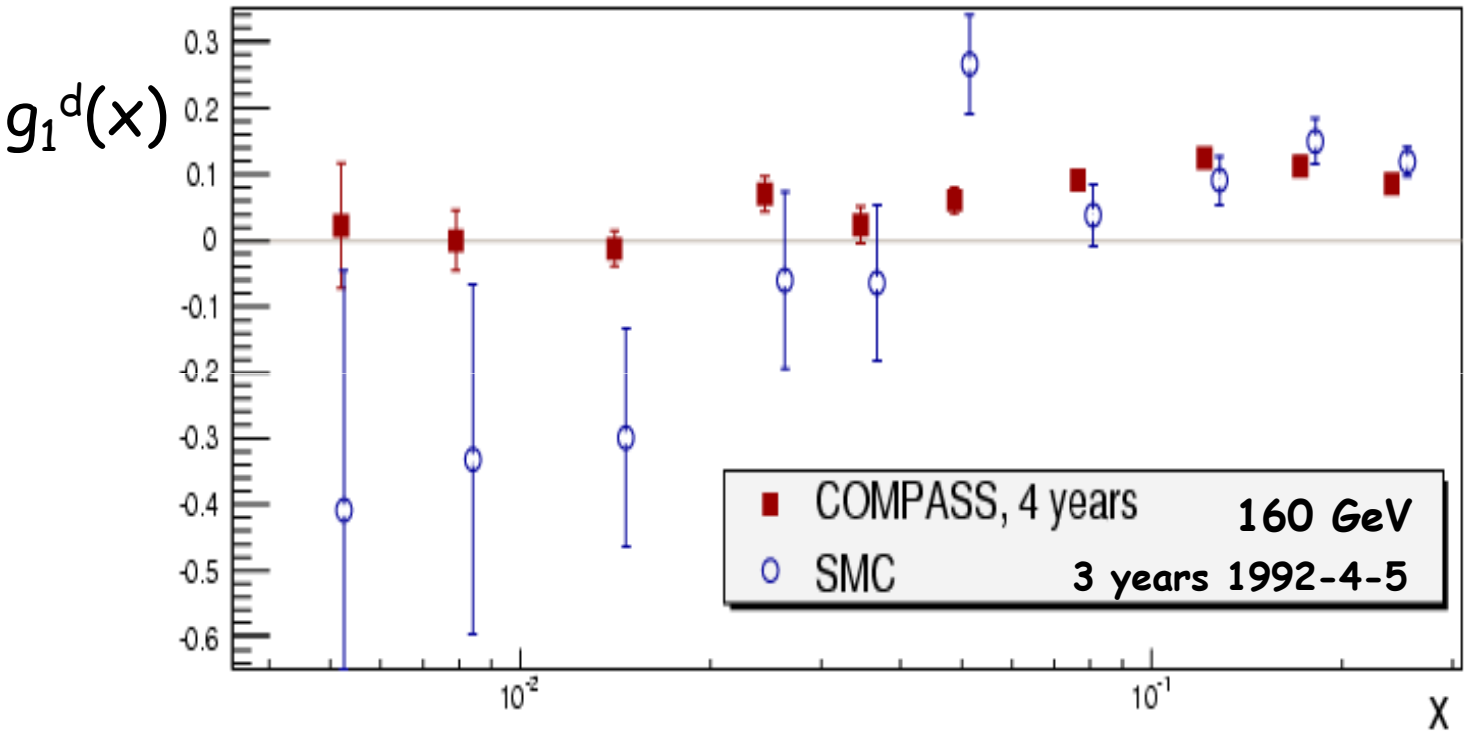
Higher luminosity: separation of variables (x, z, p_T) for Collins, Sivers and all other asymmetries

See talks of A.Martin and G.Pesaro

$\vec{\mu} + \vec{d}$

Longitudinal Spin - Inclusive

Improvements COMPASS/SMC : deuteron target

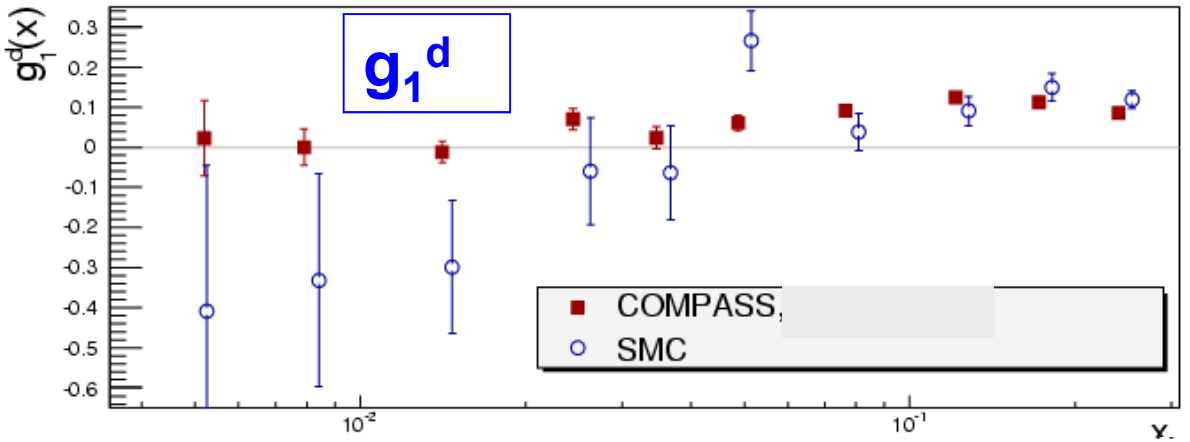


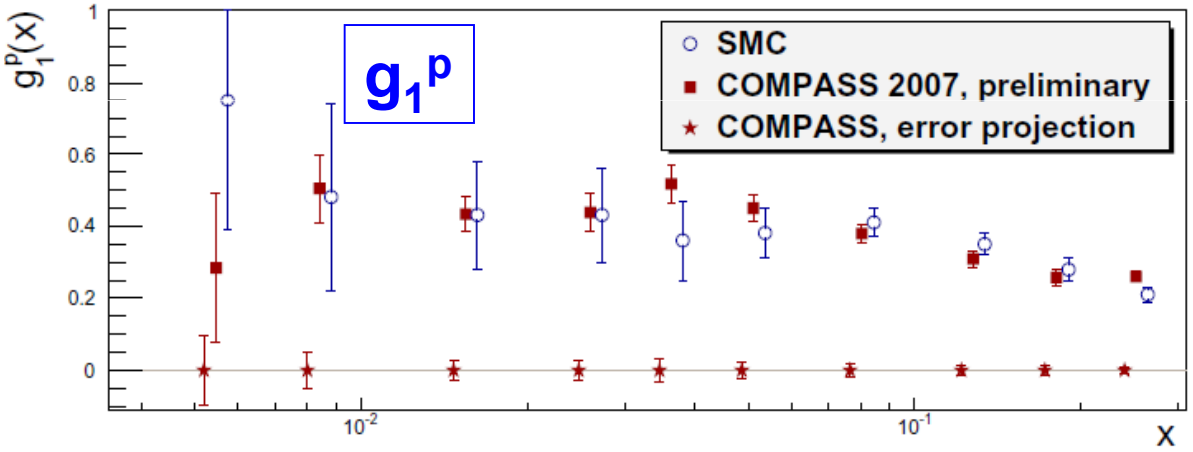
2002-2006
w/o 2005

- higher beam intensity (5x)
- DAQ (500 Hz -> 20 kHz)
- dead time
- target material (^{6}LiD)

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

Longitudinal Spin - Inclusive





■ COMPASS
○ SMC

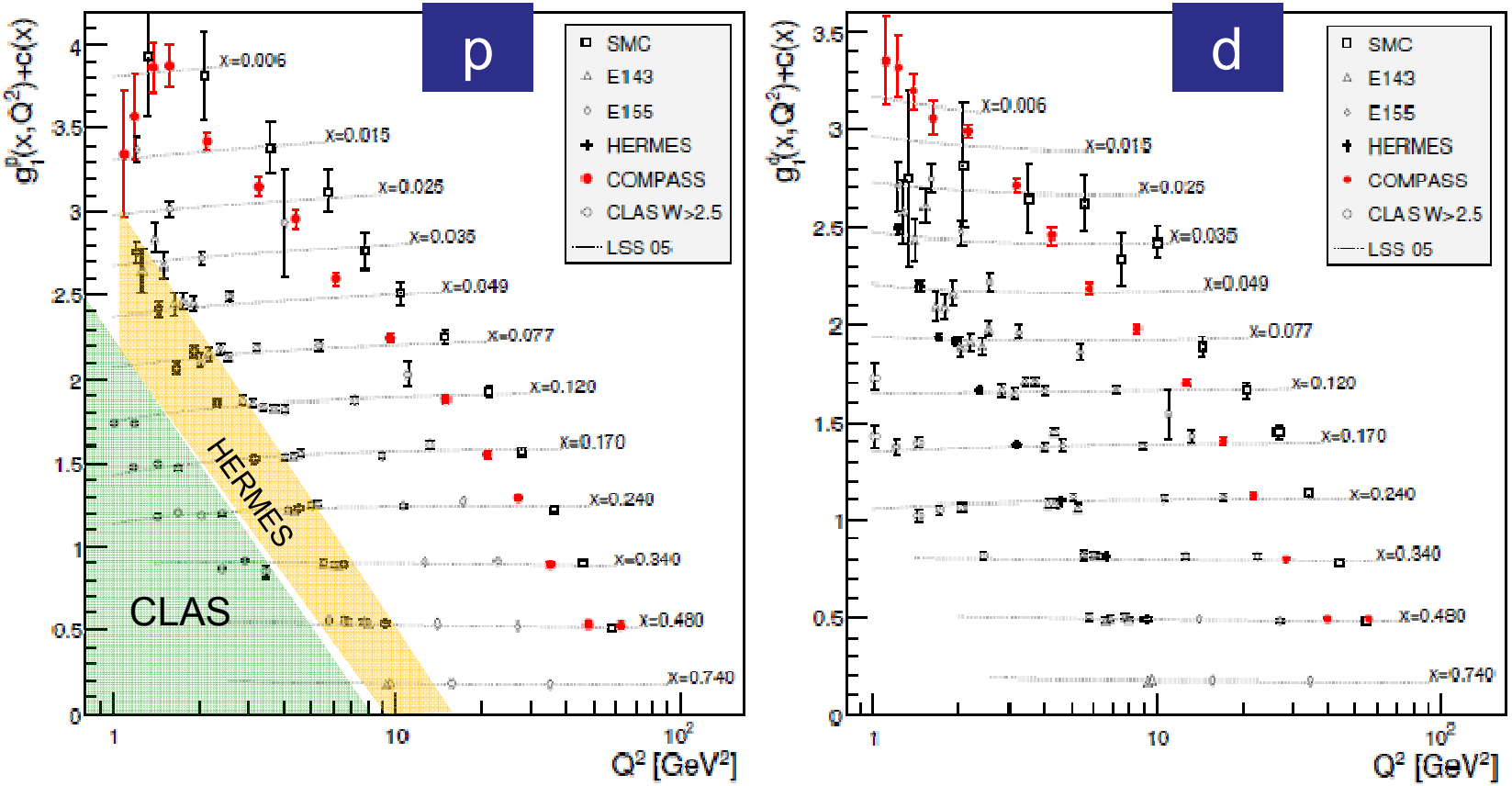
■ COMPASS 2007 prelim
• COMPASS proj 1 year
○ SMC

- $\Delta\Sigma$ Quark helicity
- ΔG Gluon helicity from g_1^p Q^2 evolution?

Present limitations:
- Q^2 coverage
- Unmeasured low x region

→ Need higher energy & luminosity

World data for proton & deuteron $g_1(x,Q^2)$



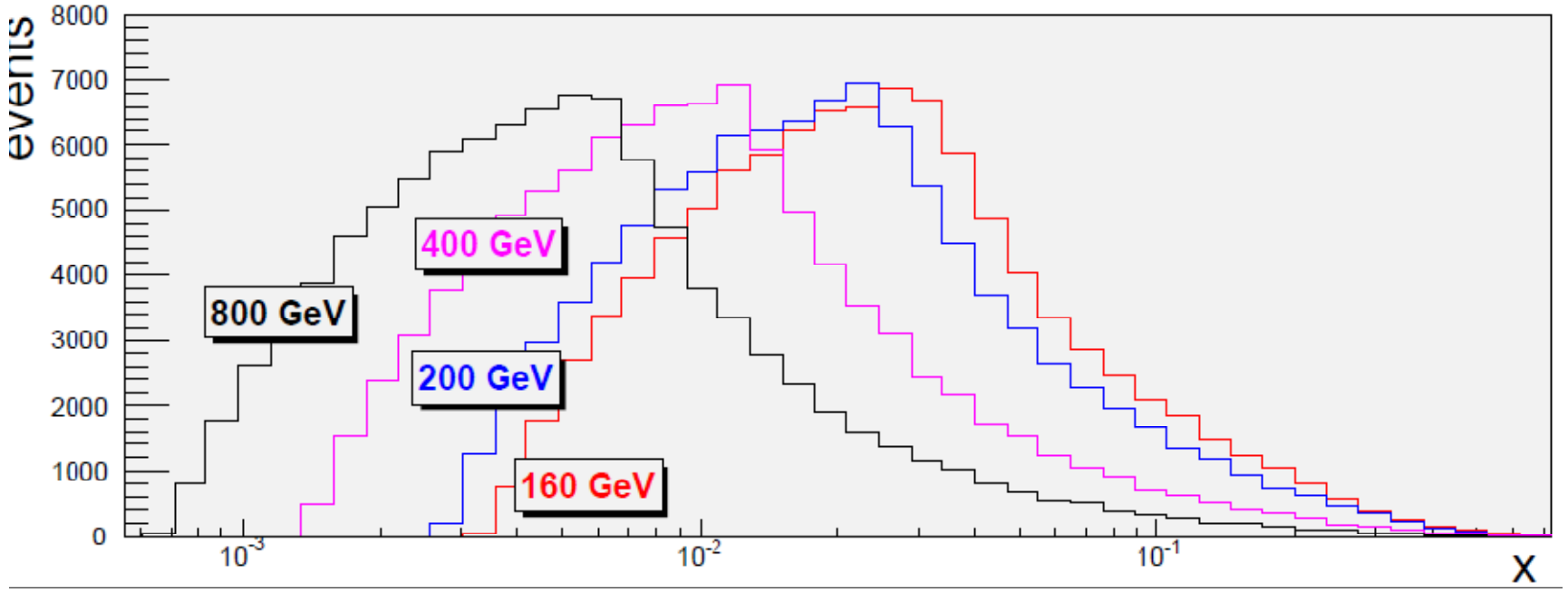
COMPASS : unique kinematic domain
important for global QCD analyses

Can extend x and Q^2 range with higher energy beam

COMPASS acceptance for higher energy μ beam

Longer term future

x_{Bj} coverage

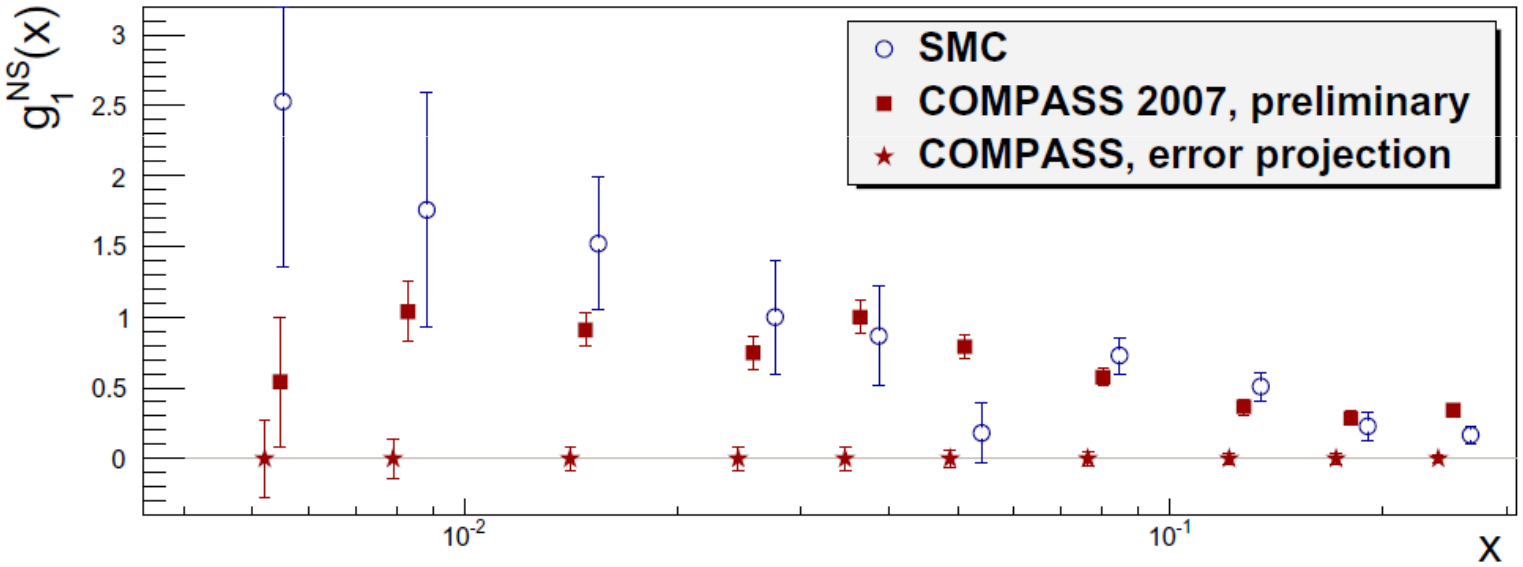


Longitudinal Spin - Inclusive

$g_1^{NS} = (g_1^p - g_1^n)$ non-singlet spin structure function

→ Test of the Bjorken sum rule (fundamental result of QCD)

$$\Gamma_1^{NS} = \Gamma_1^p - \Gamma_1^n = \frac{1}{6}\left|\frac{g_A}{g_V}\right|$$



With higher energy beam, lower x data:

→ Precise shape determination at low x

→ More reliable extrapolation to x=0

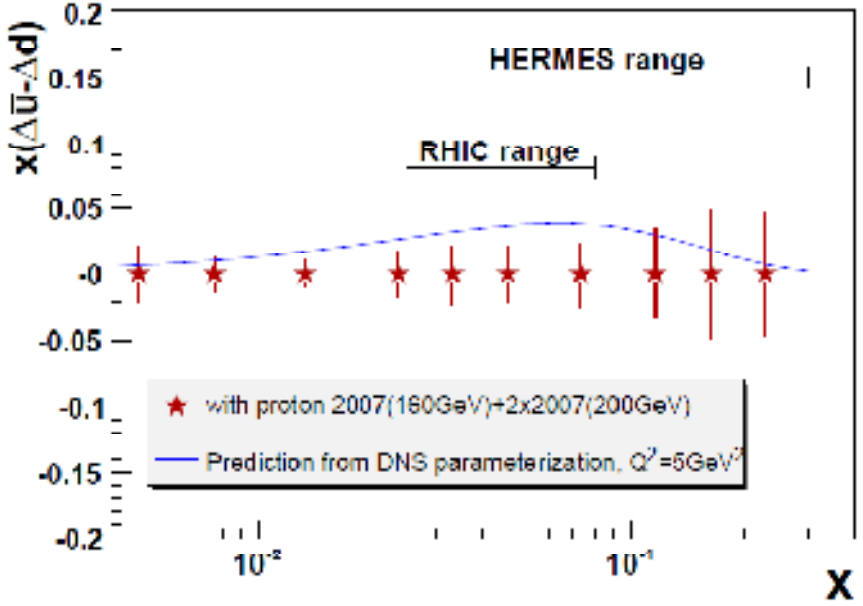
→ Reduced statistical and systematic errors in the Bjorken Sum

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

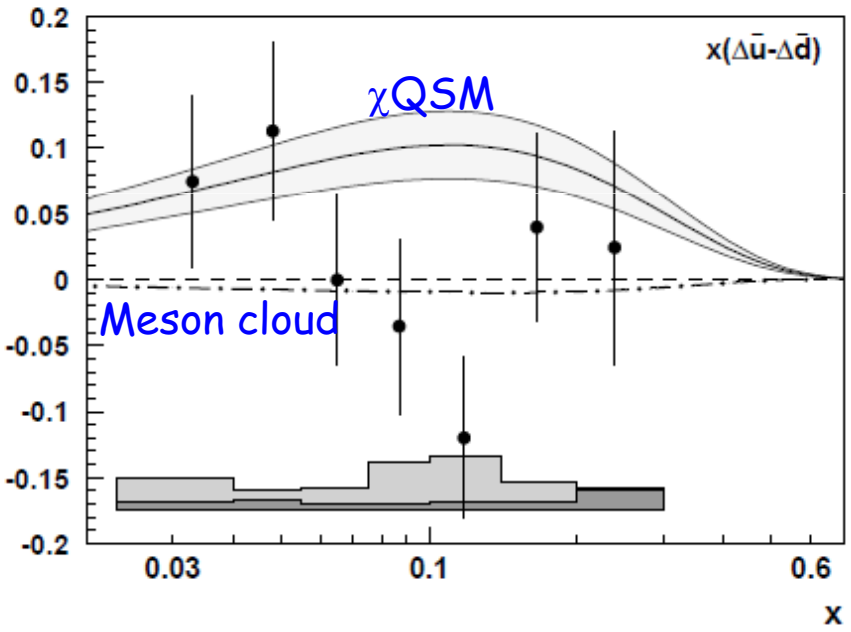
Longitudinal Spin – Sea quarks

Flavour asymmetry of the polarised light sea $\Delta\bar{u} - \Delta\bar{d}$

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



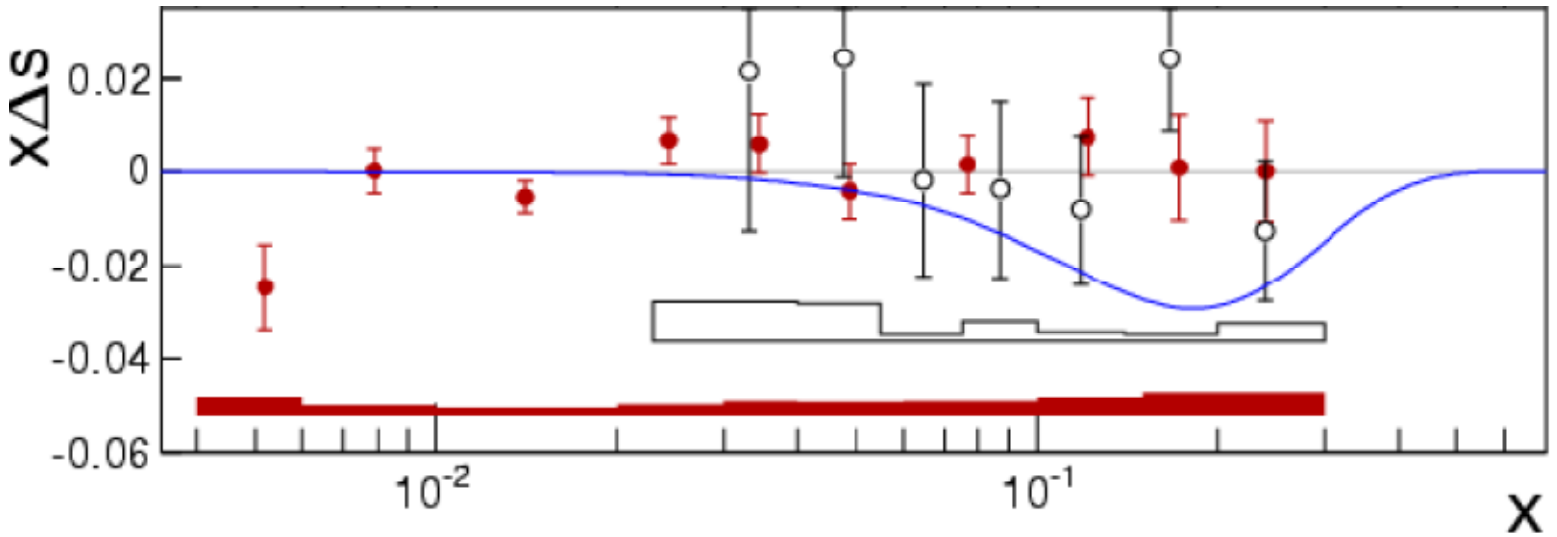
* COMPASS Projection
with 1 additional year of proton



• HERMES

Longitudinal Spin – Strange quarks

$x\Delta s(x)$



• COMPASS preliminary

○ HERMES

— DNS LO fit

First moment of Δs :

- ~zero from semi inclusive measurement
- negative - 0.045 ± 0.005 ± 0.010 from inclusive data

Need higher energy beam for low x coverage

See talk of E.Zemlyanishkina & B.Pawlukiewicz for Compass results on SIDIS (Δs) and ΔG

Competition in polarized lepton nucleon scattering

Projects for future electron ion colliders under discussion in other labs.
However not available before ~ 10 years.

	ENC@Fair	eRHIC light	COMPASS PT	COMPASS LH2 GPD
$L/10^{32}$ $cm^{-2}s^{-1}$	1-4	1-10	5	1
$\sqrt{s}$ / GeV	14	71	20	20
cost	100 M€	150M$	exists	beam exists

Table from G.Mallot at EIC/ENC GSI workshop 05/09

COMPASS FoM (w/o beam)

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

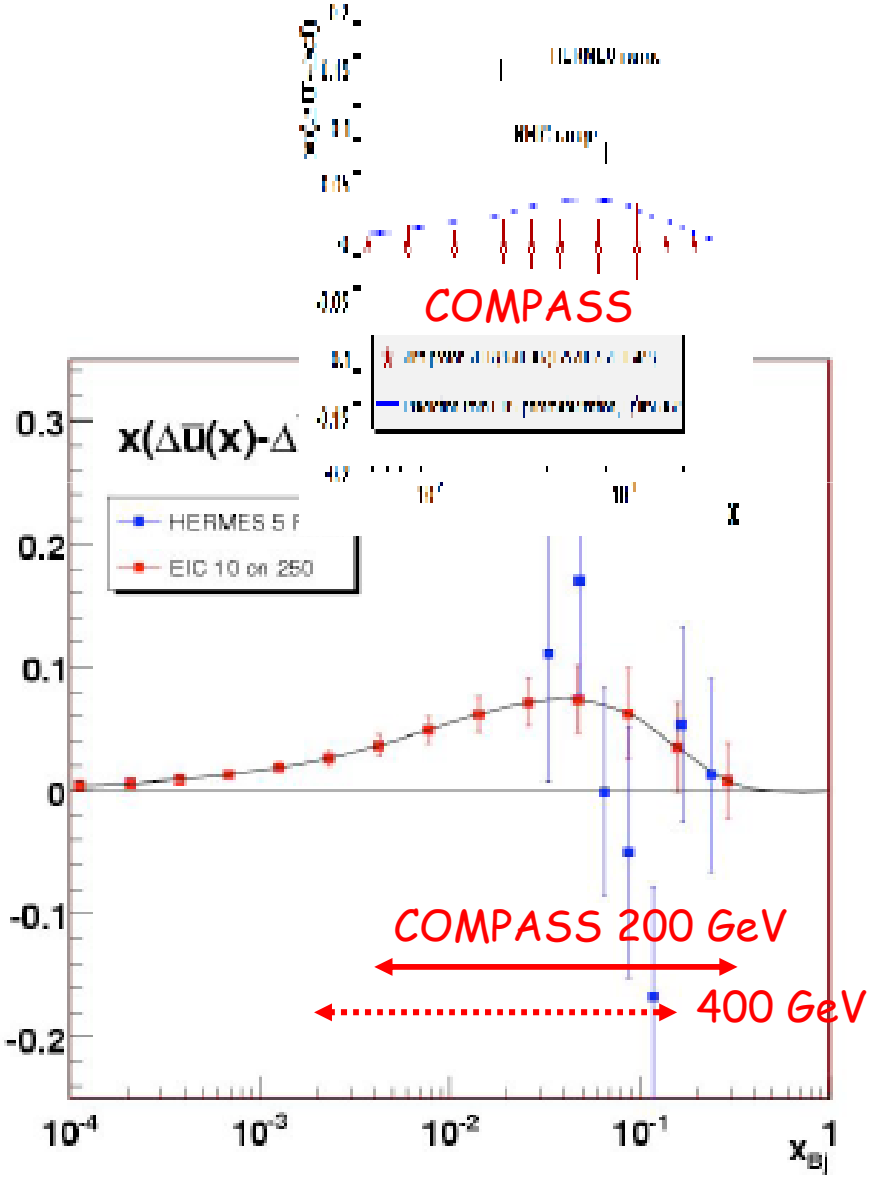
eRHIC p^{-2} ~ 0.4, ENC similar

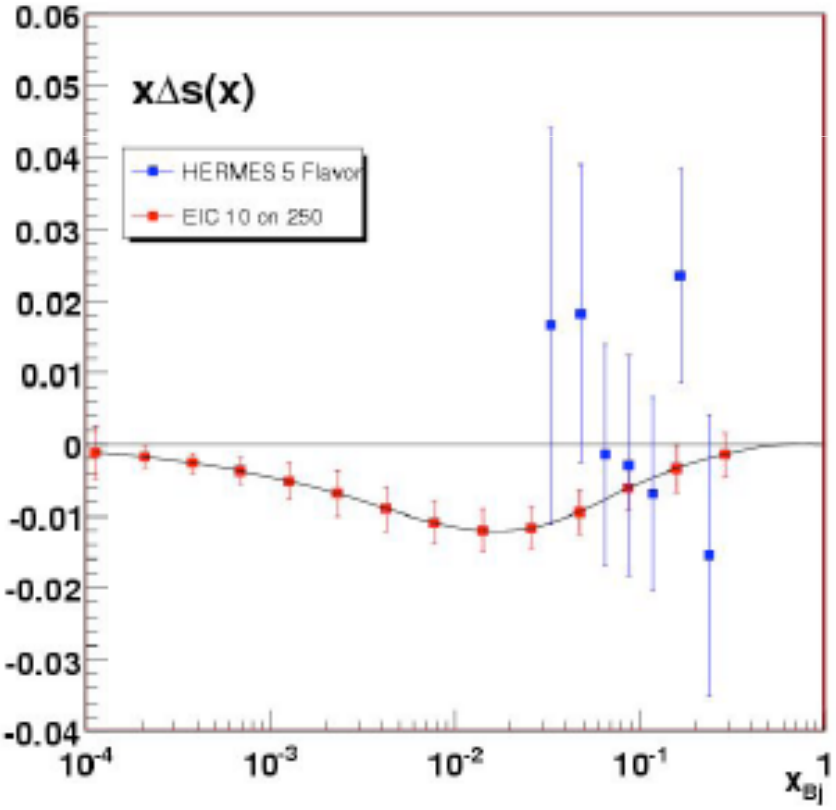
CERN is a potential major competitor in this physics domain meanwhile
And further increase of energy in the future will be a must

Projection for Future EIC

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

From Rolf Ent, ECT Trento, Oct 2008





Modified COMPASS spectrometer

Medium term future (New Proposal being prepared)

- GPD (Generalized Parton Distributions) $\mu p \rightarrow \mu p \gamma$ measured by exclusive reactions DVCS (Deep Virtual ComptonScattering) and DVMP (Meson production), 'Beam charge and Spin asymmetry'
  - 2.5 m liquid hydrogen target, 1 year
  - transversely polarised target, 1 year

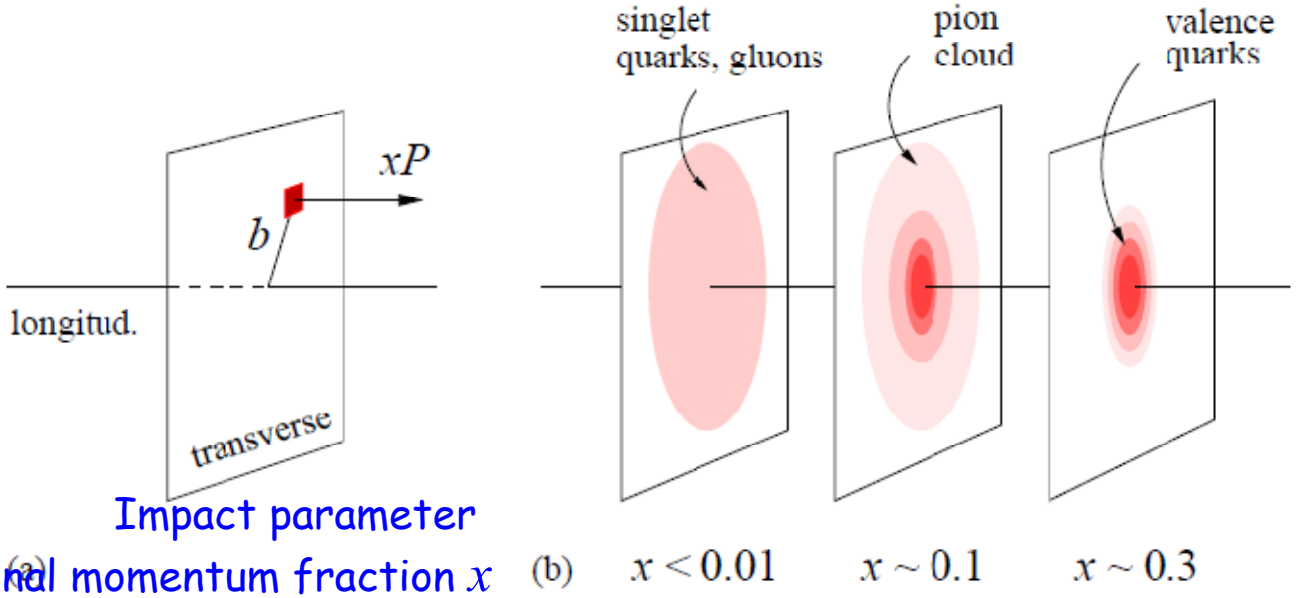
- Drell-Yan $\pi p^{\uparrow}$:
  - transversely polarised proton target, 2 years
  - Sivers/Boer-Mulders

See talk of A.Martin

Longer term future: Drell-Yan with pbar beam: pbar-$p^{\uparrow}$

Generalised Parton Distributions

- Unified description of form factors and parton distribution functions
- Transverse imaging (nucleon tomography) and sensitivity to the quark angular momentum

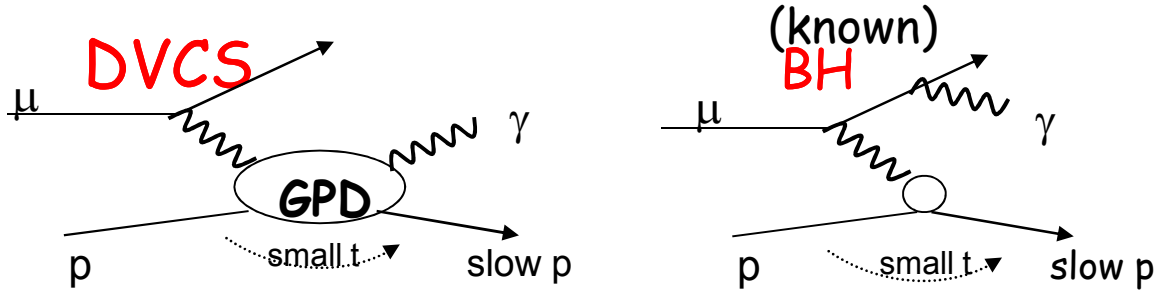


Impact parameter

Longitudinal momentum fraction x

Tomographic parton images of the nucleon

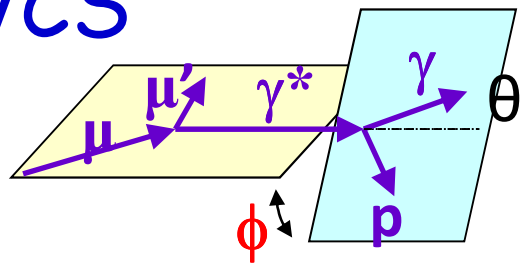
Generalized Parton Distribution functions



$$d\sigma \alpha |T_{DVCS}|^2 + |T_{BH}|^2 + \text{interference term}$$

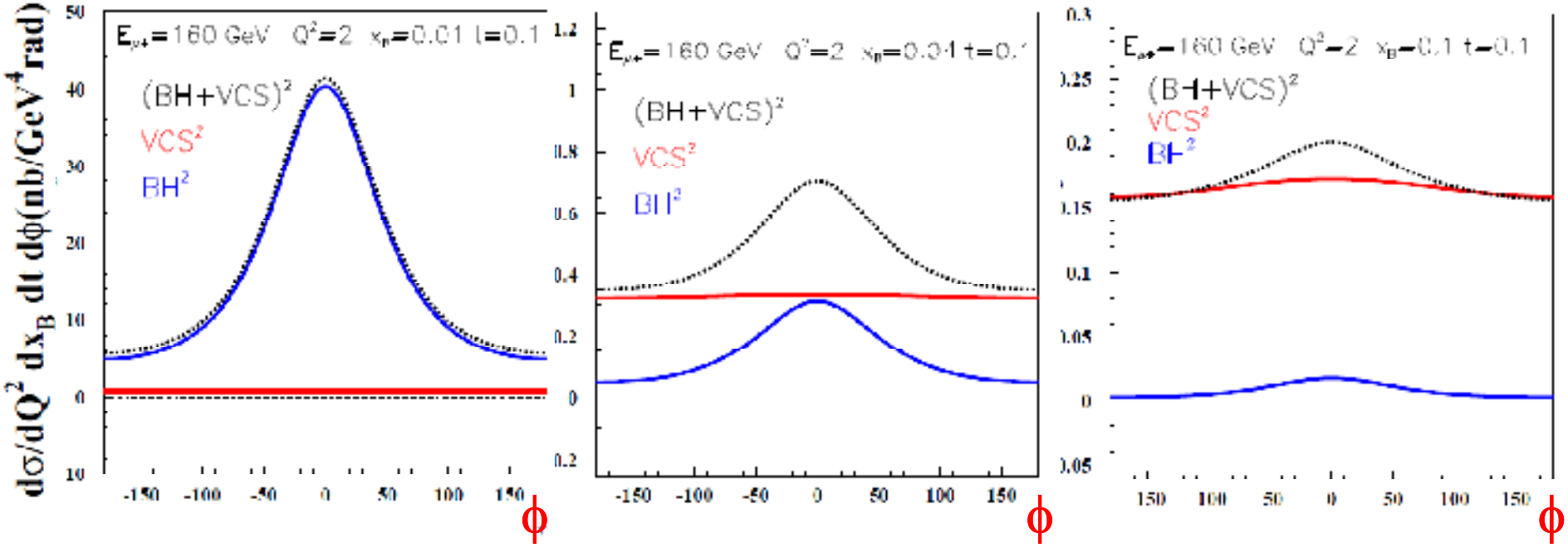
The three terms dominate in different kinematic regions

Comparison BH and DVCS



E_μ=160 GeV at Q^2=2 GeV^2 $|t|$=0.1 GeV^2

x=0.01 x=0.04 x=0.1



BH dominates

(reference)

BH and DVCS comparable

DVCS *boosted by interference*

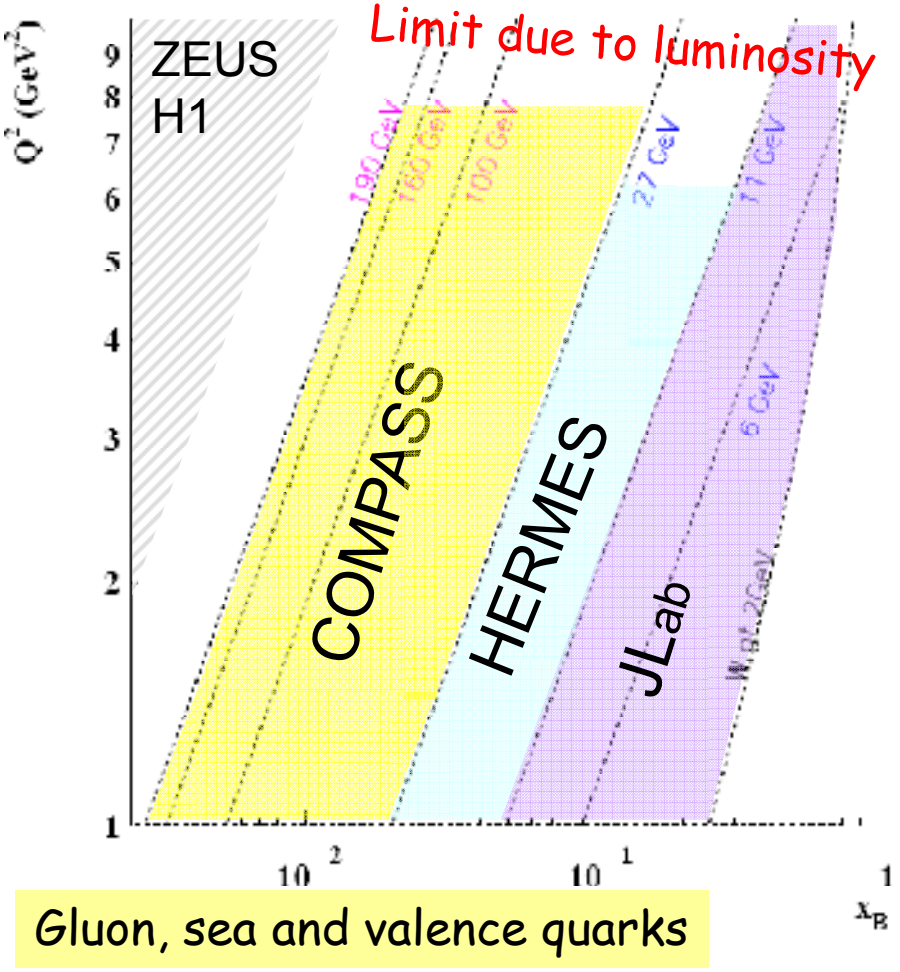
→ Re T^{DVCS} or Im T^{DVCS}

DVCS dominates

study of $d\sigma^{DVCS}/dt$

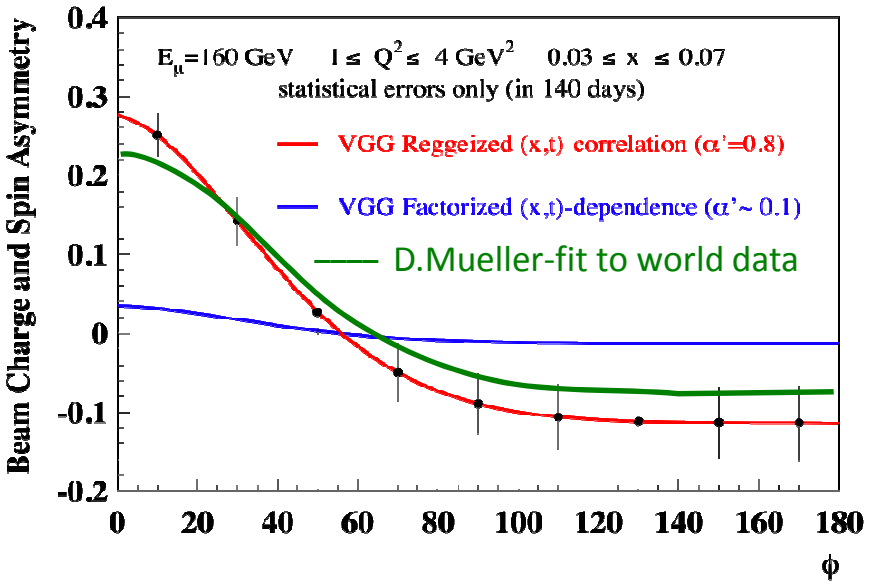
(not possible at JLab)

Generalized Parton Distribution functions



Gluon, sea and valence quarks

Medium term (2012?)



For longer term future:

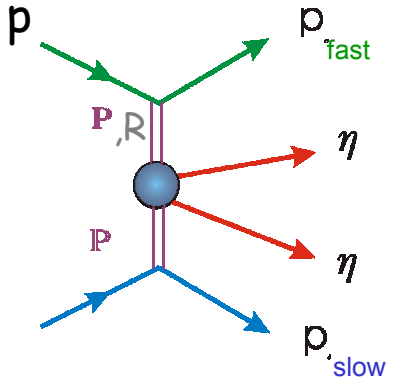
Need higher luminosity

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

Hadron spectroscopy

See talks of S.Grabmuller, J.Bernhard, P.Jasinski, & T.Schlueter for present Compass results

Central Production of hadron resonances



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

For future:
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

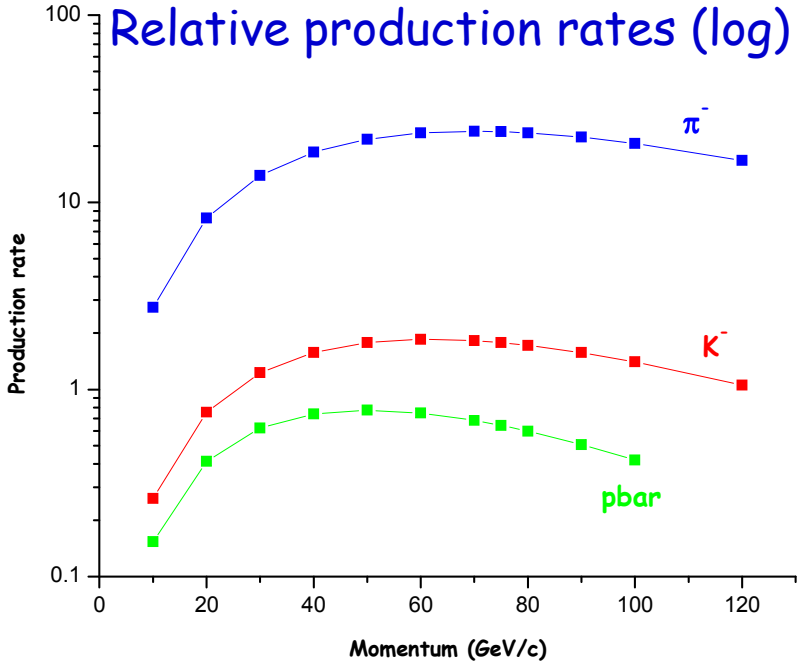
- Close the area (overcome halo limitation)
- Better beam line with short and long decay sections (600-1800m)
- Underground installations

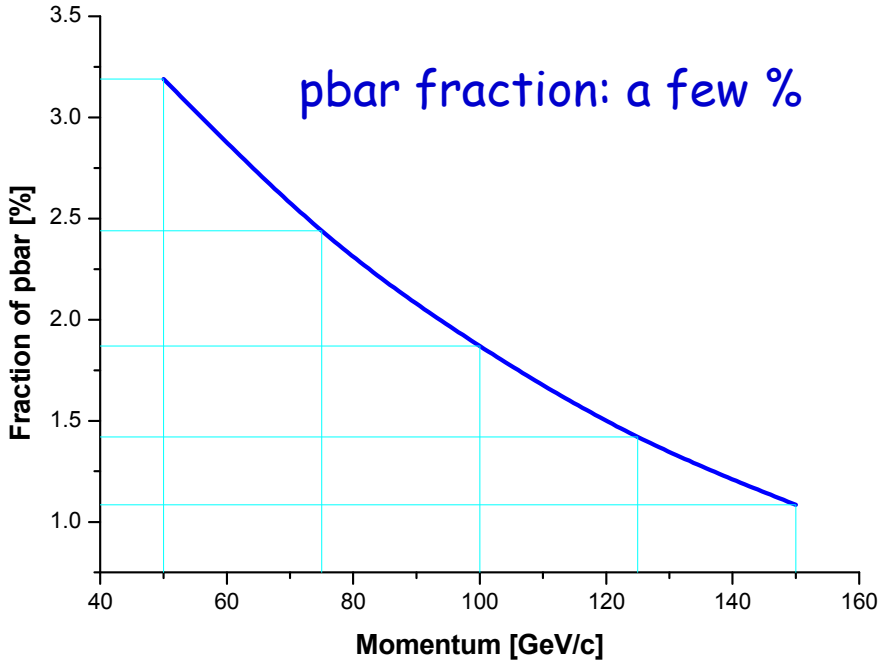
$\bar{p}$ beam ? for Drell-Yan processes

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:





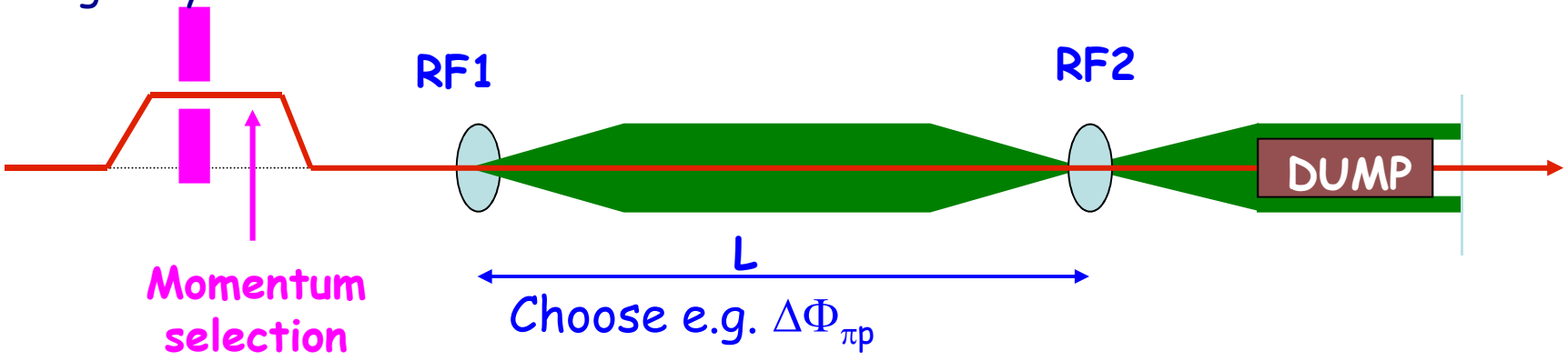
In present M2 hadron beam ≤ 5 10^6 $\bar{p}$

(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.