A Collaboration of 240 Physicists of 12 countries

A Facility to study QCD

COMMON
MUON and
PROTON
APPARATUS for
STRUCTURE and
SPECTROSCOPY

Future Plans : LoI submitted to CERN/SPSC in January 2009
Proposal in preparation

With the high energy polarised muon beam:

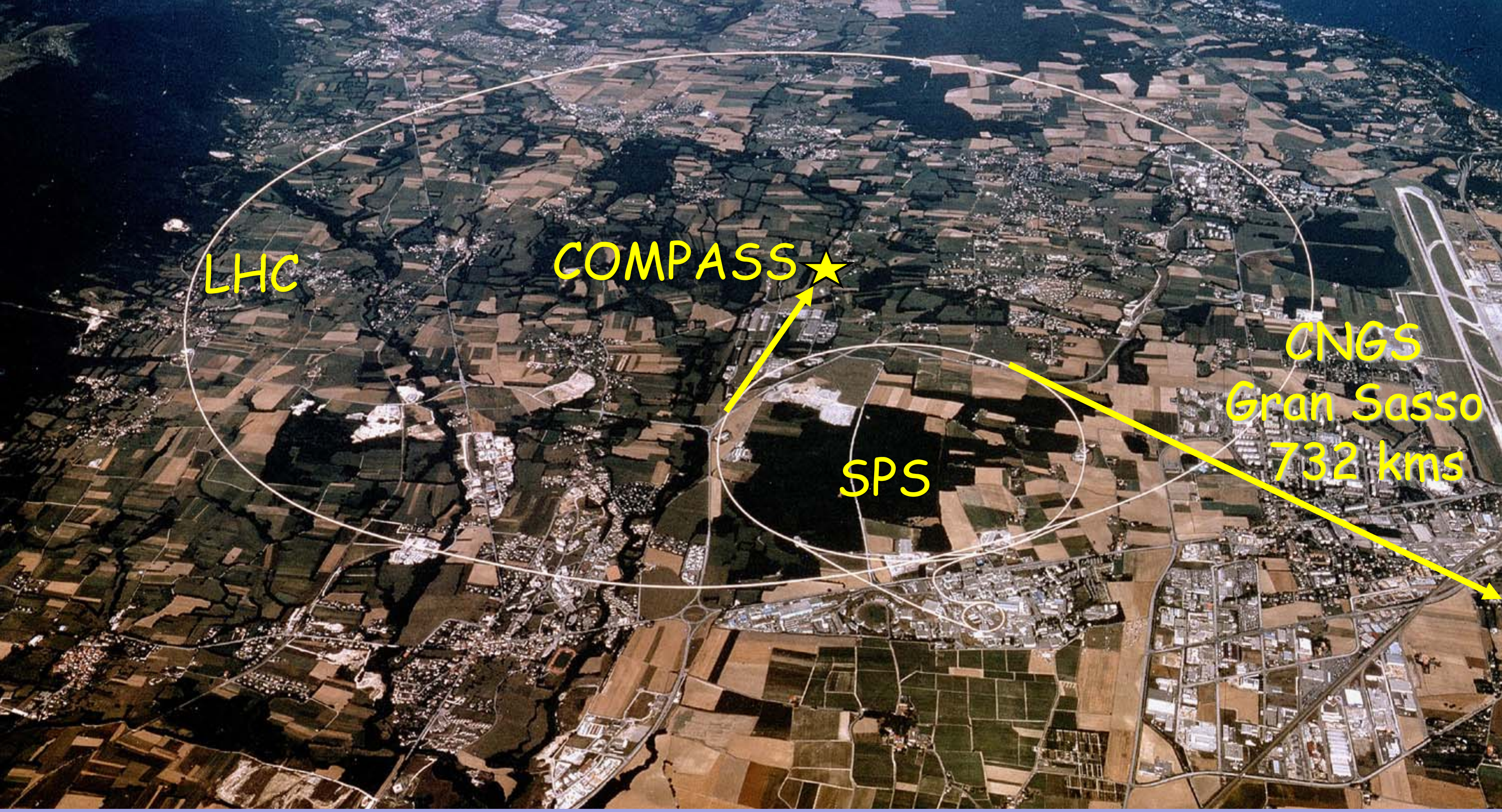
1- Longitudinal Spin Structure
2- Generalized Parton Distributions
3- Transverse Spin Structure (next talk)

New Opportunities in the Physics Landscape at CERN, 11-13 May 2009

Nicole d'Hose CEA-Saclay
On behalf of the COMPASS Collaboration

SPS beam: protons up to 400 GeV/c, 4.8s/16.2s spills

- Secondary hadron beams (π, K,…): 2.10^8 /spill, 150-270 GeV/c
- Tertiary muons: 2.10^8 /spill, 100-190 GeV/c, 80% polarisation
  -> Luminosity ~ 5×10^{32} cm^{-2} s^{-1} with polarised targets

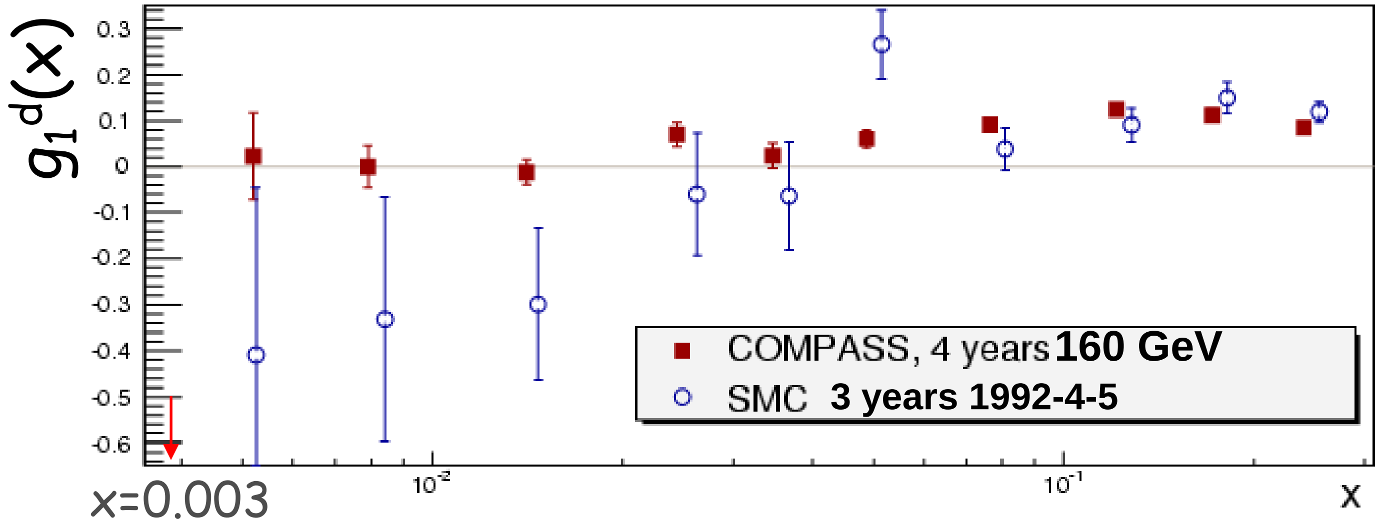


high energy beam(s), broad kinematical range, large angular acceptance

Longitudinal Spin Structure Function of the Deuteron

Inclusive measurements on a longitudinally polarised deuteron target in 2002-3-4-6

$$g_1(x) = \frac{1}{2} \sum_{q=u,d,s} e_q^2 \Delta q(x) \qquad \Delta q = \overrightarrow{q} - \overleftarrow{q}$$



- Only place for high energy polarized lepton beams → low x and high Q2

-Precise measurement + impact at small x → systematics from the extrapolation for the unmeasured low x contribution to $\int_0^1 g_1(x)\,dx$ considerably reduced

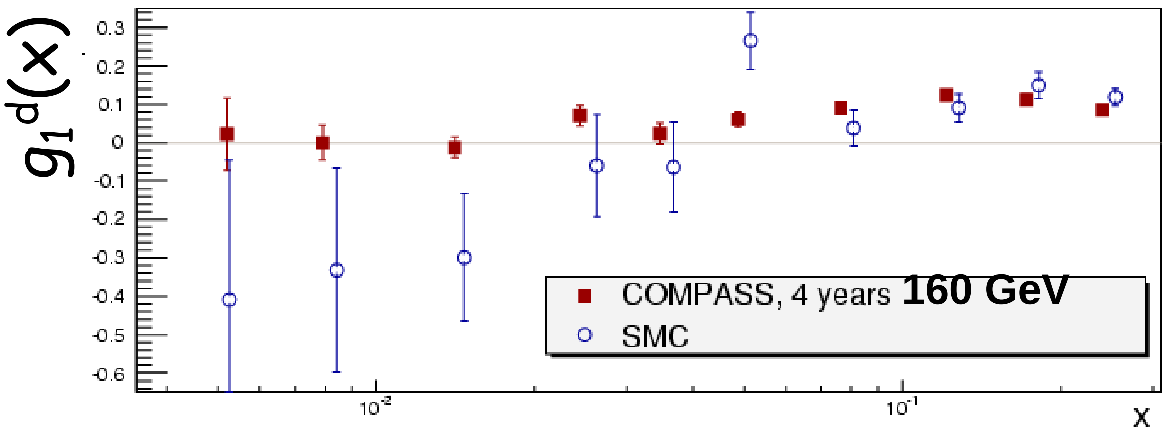
Quark helicity $Q^2=3\ GeV^2$ PLB 647 (2007) 8

$$\Delta\Sigma = \sum_q \int_0^1 \Delta q(x)\,dx = 0.30 \pm 0.01\ (stat) \pm 0.02\ (\underline{extrapolation})$$

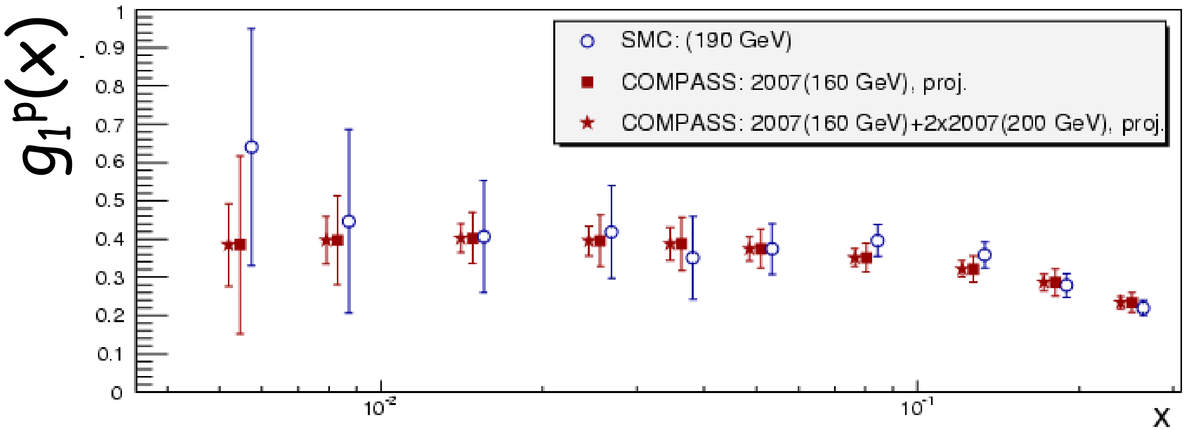
Longitudinal Spin Structure Function of the Proton

Necessity of a balanced statistics between proton and deuteron data

Inclusive measurements on a longitudinally polarised deuteron target in 2002-3-4-6



Inclusive measurements on a longitudinally polarised proton target in 2007



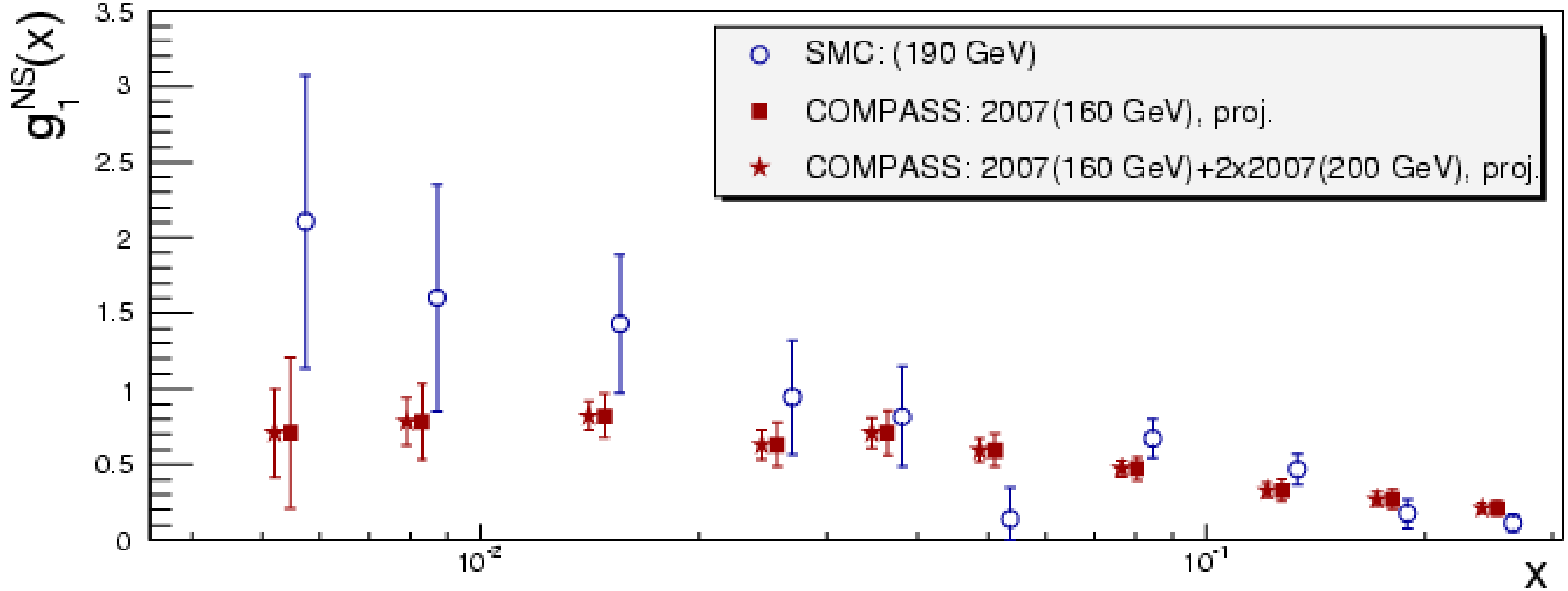
+ **150 days** (1 year) of SPS beam (preferably 200 GeV if same intensity as 160 GeV ?)

COMPASS Projection with 1 additional year of proton

At small x
→precise measurement
→better extrapolation

New evaluation of the non-singlet spin structure function $g_1^{NS} \approx 2(g_1^p - g_1^d)$

COMPASS Projection with 1 additional year of proton



→ Precise shape determination at low x

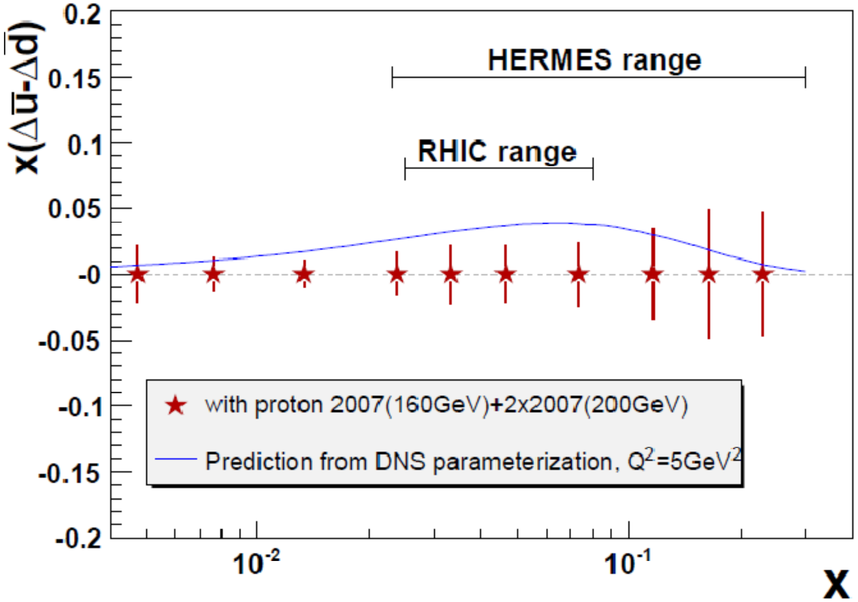
→ More reliable extrapolation to x=0

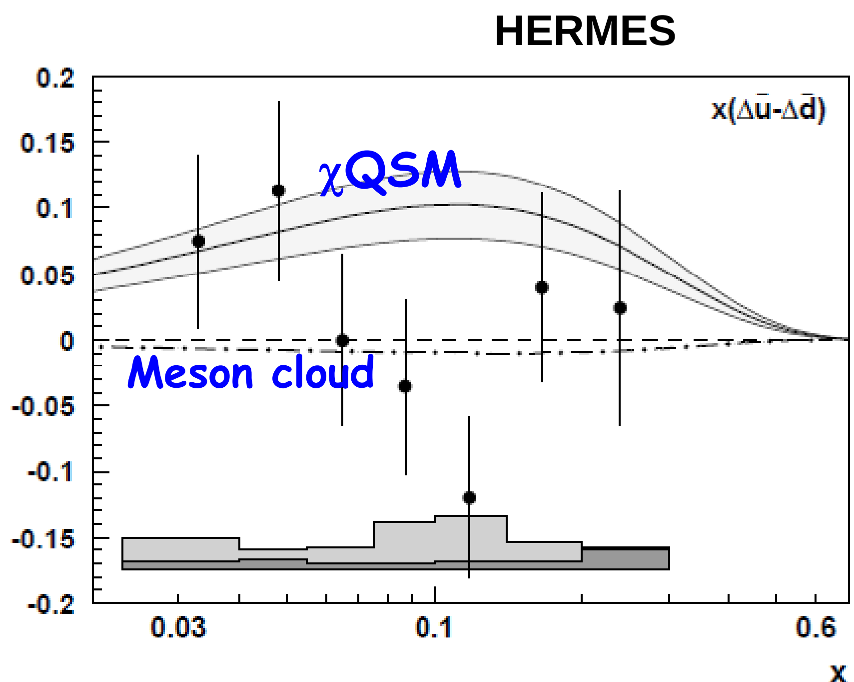
→ Reduced statistical and systematic errors in the test of the Bjorjen sum rule (fundamental result of QCD)

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

With Semi-Inclusive Hadron Asymmetries

COMPASS Projection
with 1 additional year of proton





→Separation between extreme models

→enters in NLO global fits

"Spin crisis", possible scenarios

ΔG Gluon helicity: - from production of high p_T pairs, open charm
- from g_1^p Q^2 evolution

From COMPASS & RHIC, ΔG not large:

- $\Delta G = |\int \Delta G(x_G)| < 0.4$
- $\Delta\Sigma \approx a_0 = 0.3$

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

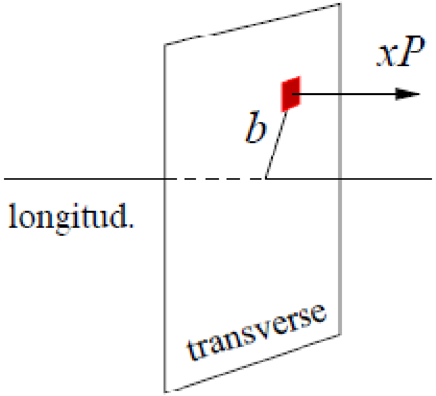
$\frac{1}{2}$ =	$\frac{1}{2}$	$\Delta\Sigma$	+	ΔG	+	L_Z
$\frac{1}{2}$ =	$\frac{1}{2}$ ×	0.3	+	0.35	+	0
$\frac{1}{2}$ =	$\frac{1}{2}$ ×	0.3	+	0.0	+	0.35
$\frac{1}{2}$ =	$\frac{1}{2}$ ×	0.3	-	0.35	+	0.70

Complementary approach for Orbital Angular Momentum:
- Sivers function (next talk)
- Generalized Parton Distributions

GPDs program @ COMPASS

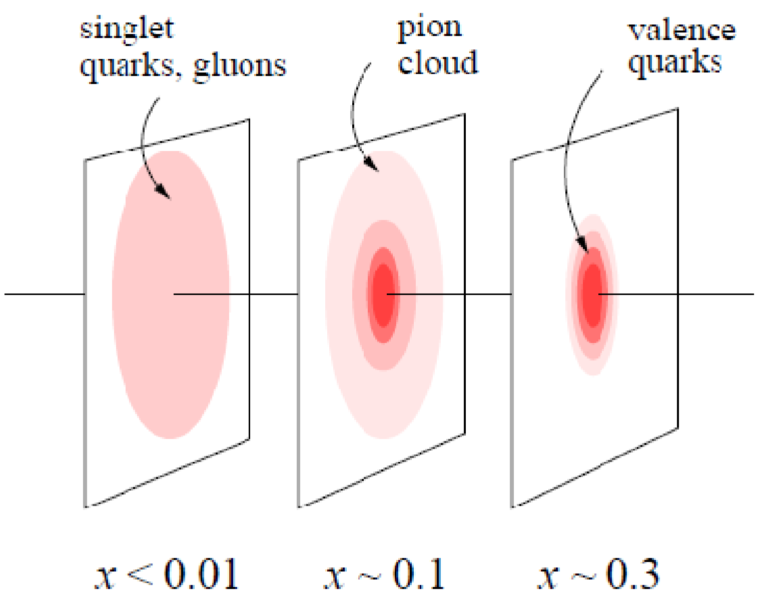
Generalised Parton Distribution functions:

- Allow for a unified description of form factors and parton distribution
- Allow for transverse imaging (nucleon tomography) and to access the quark angular momentum



Impact parameter b

Longitudinal momentum fraction x



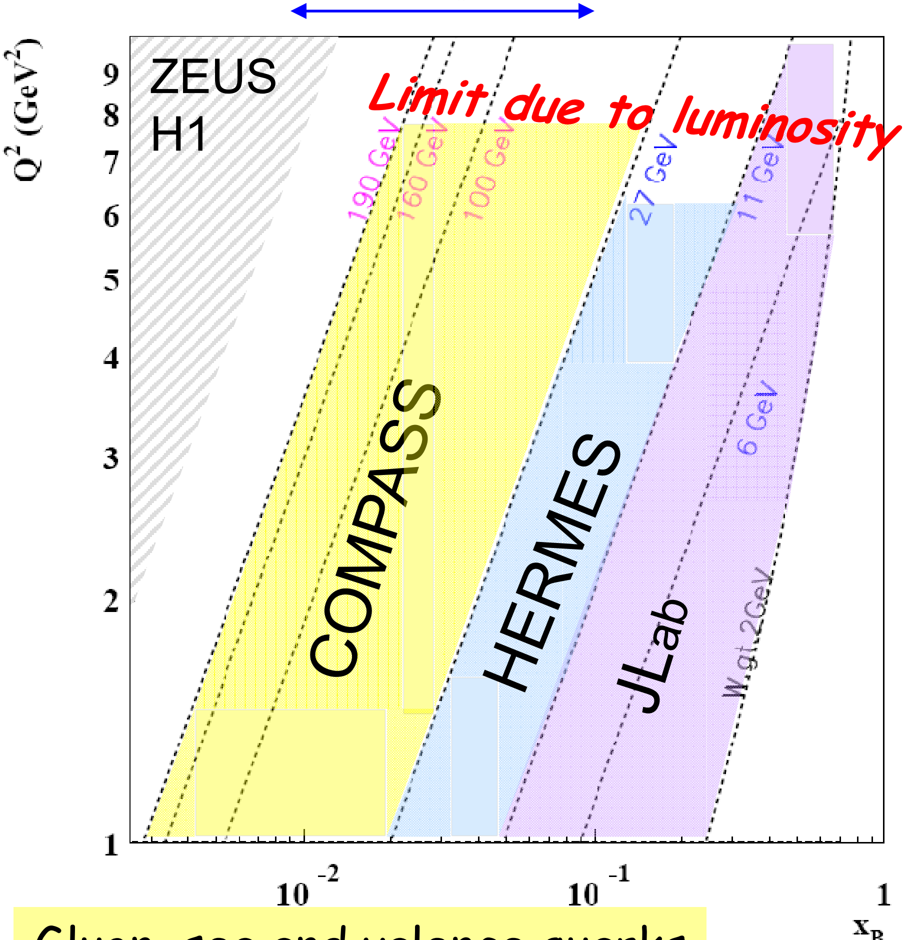
Tomographic parton images of the nucleon

What makes COMPASS a unique case?

1- CERN SPS high energy muon beam 100/190 GeV

Kinematic domain

$10^{-2} < x < 10^{-1}$



Gluon, sea and valence quarks

2- availability of μ+ and μ- with opposite polarisation polarisation=80%

3- with a 2.5m long LH2 target
Lumi= 10^{32} cm^{-2} s^{-1}
(limit for a collider without R&D)
→ Q^2 up to 8 GeV^2

→Any lumi upgrade extents the reach of the proposed measurements

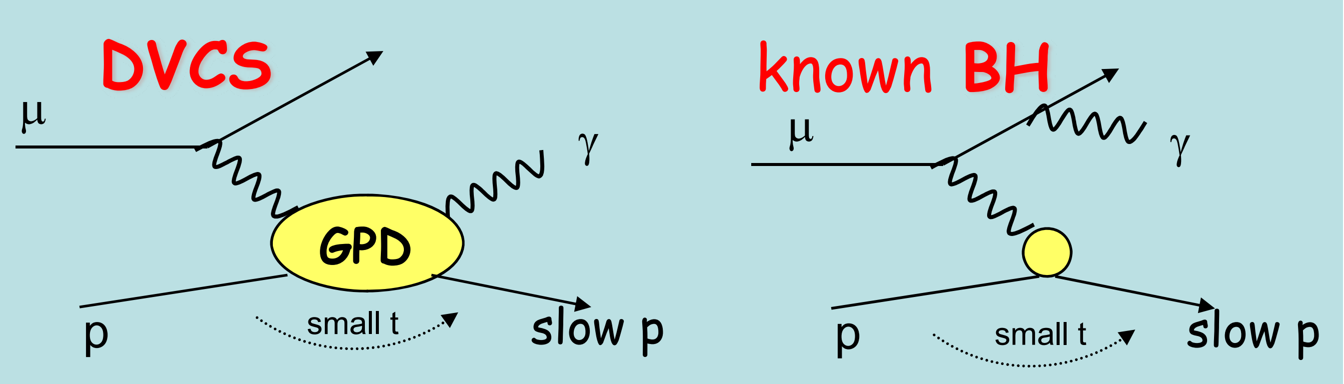
if Lumi × 4 → more comfortable statistics for Q^2 up to 12 GeV^2

Note: ENC@FAIR E_p=15GeV E_e=3GeV equivalent to Eμ @ CERN=100GeV

2 channels studied:

- **exclusive meson production**
- **exclusive single-photon production**

$$\mu\ p \rightarrow \mu\ \gamma\ p$$

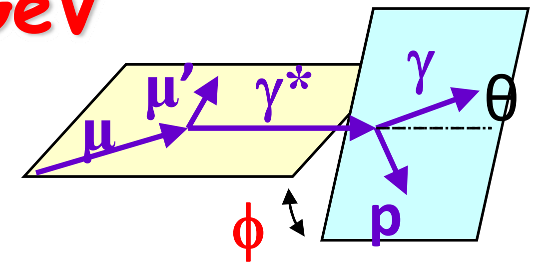


$$d\sigma \ \alpha\ |T_{DVCS}|^2 + |T_{BH}|^2 + \text{Interference Term}$$

at COMPASS we can deal with

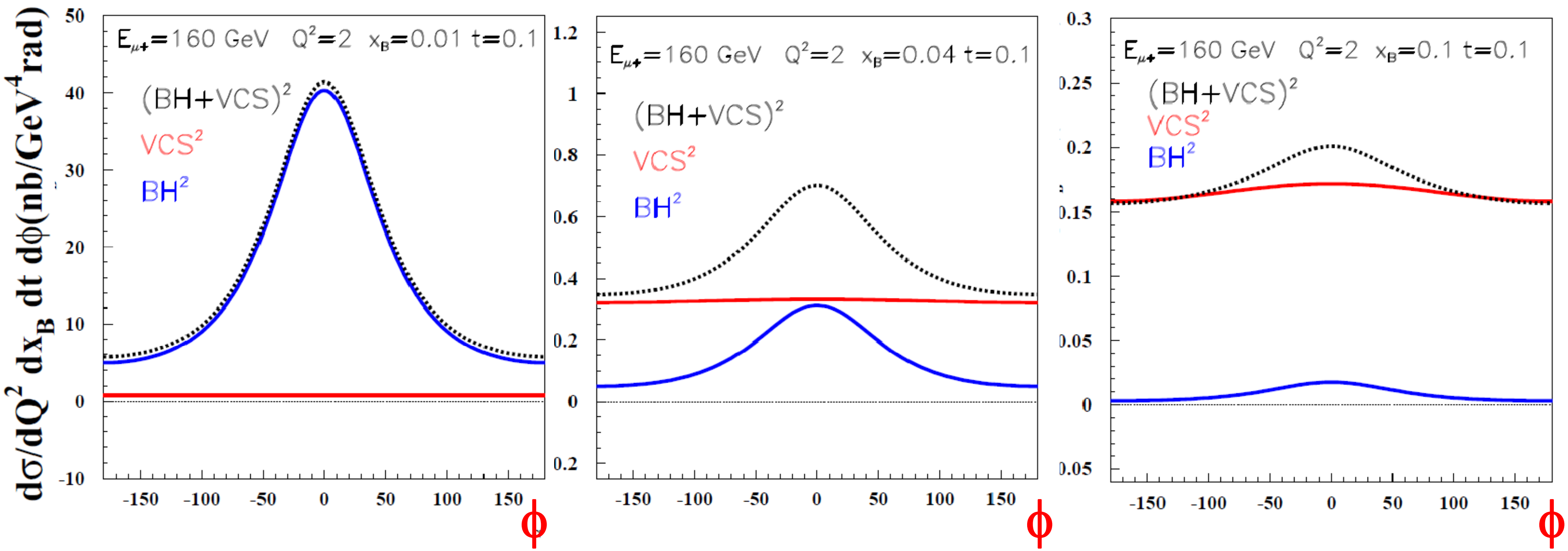
- ✓ either BH
- ✓ either DVCS
- ✓ or the interference

Comparison BH and DVCS at 160 GeV



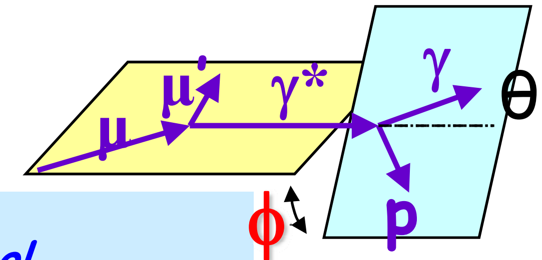
At Q^2=2 GeV^2 |t|=0.1 GeV^2

x=0.01 x=0.04 x=0.1



BH dominates	BH and DVCS at the same level	DVCS dominates
excellent reference yield	DVCS *boosted by interference* → Re T^{DVCS} or Im T^{DVCS}	*study of* $d\sigma^{DVCS}/dt$ *(not possible at JLab)*

DVCS + BH with μ+↓ and μ-↑ beam



$$d\sigma_{(\mu p\to\mu p\gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu\, d\sigma^{DVCS}_{pol}$$
$$+\, e_\mu\, a^{BH}\, \mathcal{R}e\, T^{DVCS} + e_\mu\, P_\mu\, a^{BH}\, \mathcal{I}m\, T^{DVCS}$$

Beam Charge & Spin Difference

$$\mathcal{D}_{U,CS} \equiv d\sigma(\mu^{+\downarrow}) - d\sigma(\mu^{-\uparrow}) = 2(e_\mu\, a^{BH}\, \mathcal{R}e\, T^{DVCS} + P_\mu\, d\sigma^{DVCS}_{pol})$$

$$\mathcal{R}e\, T^{DVCS} \rightarrow c_0^{Int} + c_1^{Int}\cos\phi + c_2^{Int}\cos 2\phi + c_3^{Int}\cos 3\phi$$

$$d\sigma^{DVCS}_{pol} \rightarrow s_1^{DVCS}\sin\phi$$

Beam Charge & Spin Sum

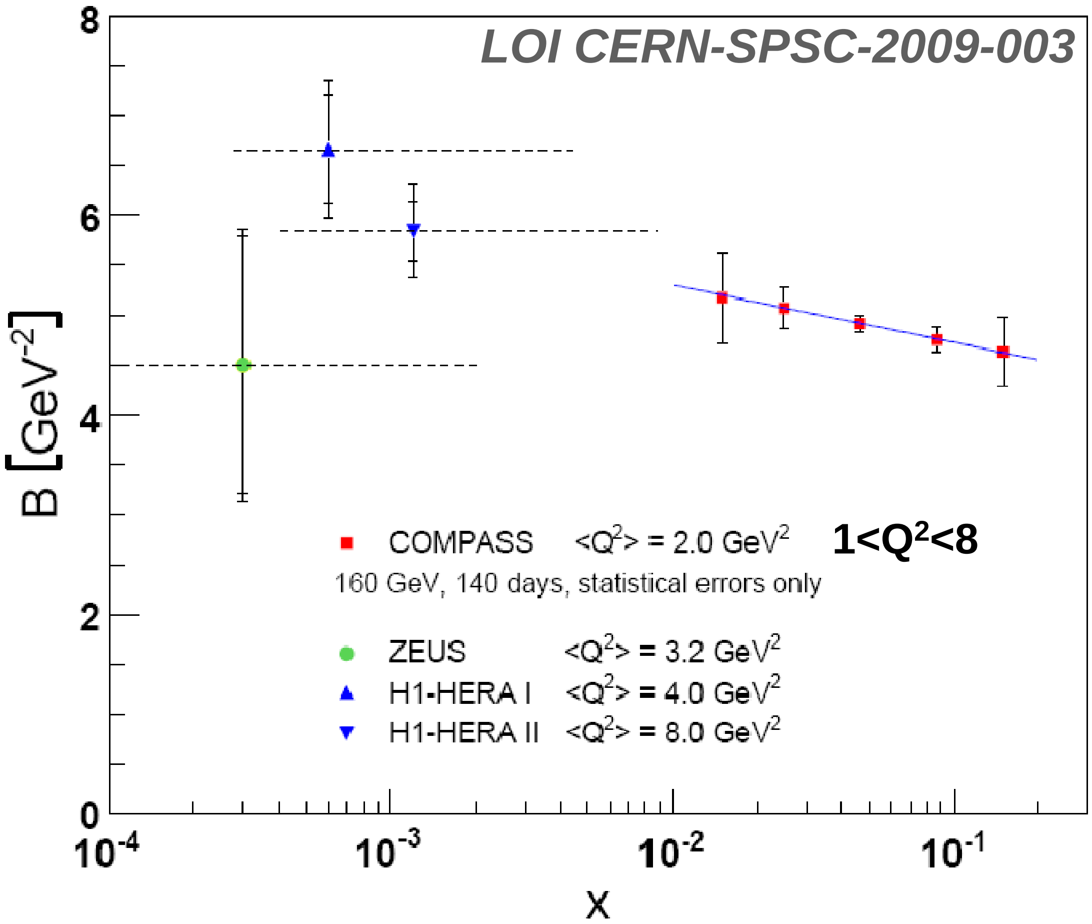
$$\mathcal{S}_{U,CS} \equiv d\sigma(\mu^{+\downarrow}) + d\sigma(\mu^{-\uparrow}) = 2(\underline{d\sigma^{BH}} + d\sigma^{DVCS}_{unpol} + e_\mu P_\mu\, a^{BH}\, \mathcal{I}m\, T^{DVCS})$$

$$d\sigma^{DVCS}_{unpol} \rightarrow c_0^{DVCS} + c_1^{DVCS}\cos\phi + c_2^{DVCS}\cos 2\phi$$

$$\mathcal{I}m\, T^{DVCS} \rightarrow s_1^{Int}\sin\phi + s_2^{Int}\sin 2\phi$$

Transverse imaging at COMPASS

Using $\mathcal{S}_{U,CS}$ and integration over ϕ and BH subtraction $\longrightarrow$ $d\sigma_{DVCS}/dt \sim \exp(-B|t|)$



$$B(x) = b_0 + 2\,\alpha' \ln(x_0/x)$$

α' =0.125 GeV^{-2}

FFS model

160 GeV muon beam
2.5m LH_2 target
ε_{global} = 10%, 140 days
Lumi=1222pb^{-1}

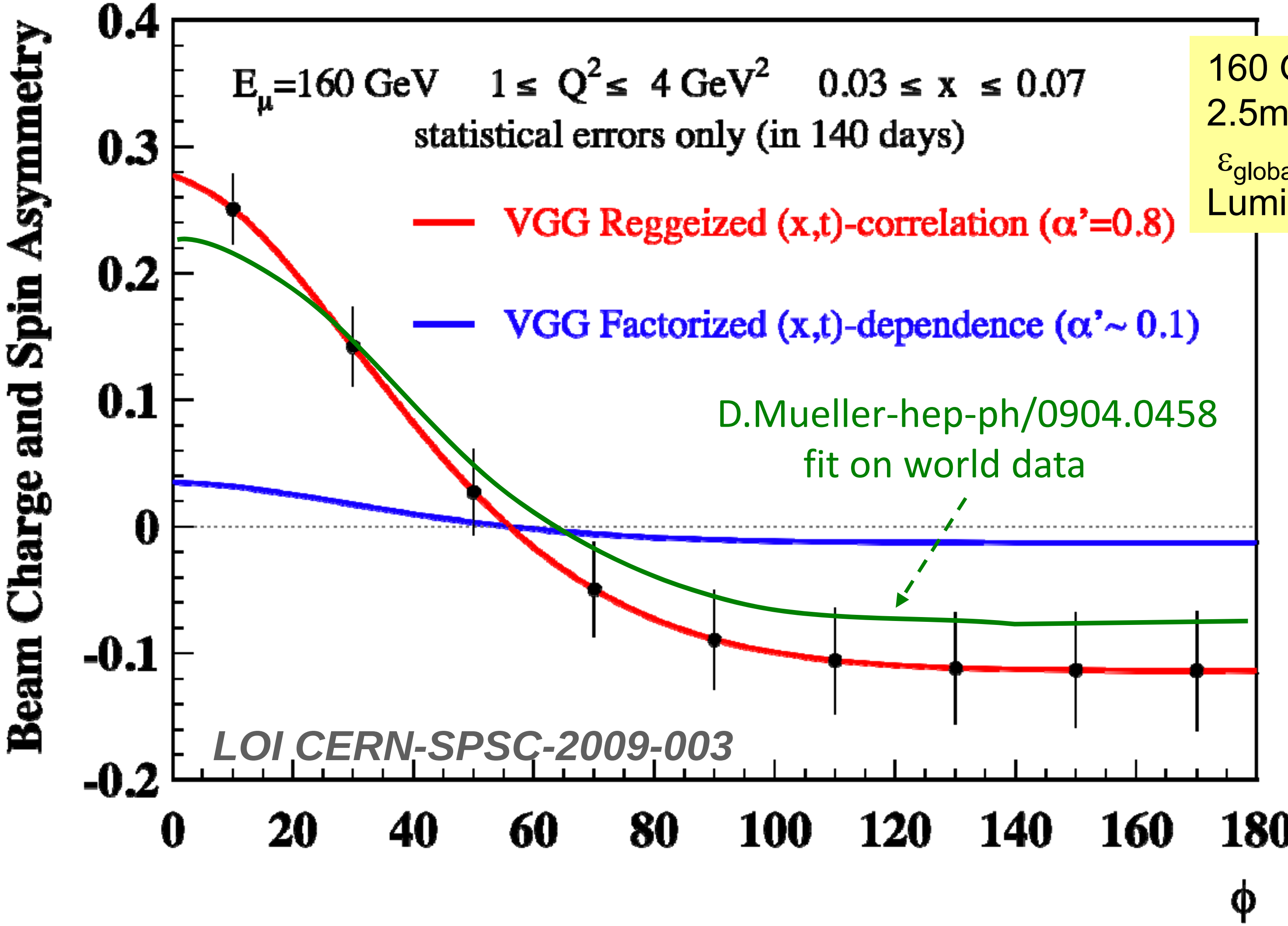
for valence quark α' ~ 1 GeV^{-2} to reproduce FF $\cong$ meson Regge traj.

for gluon α' ~ 0.164 GeV^{-2} (J/Ψ at Q^2=0) $\ll$ α' ~ 0.25 GeV^{-2} for soft Pomeron

α' ~ 0.02 GeV^{-2} (J/Ψ at Q^2=2-80 GeV^2)

Using $\mathcal{D}_{U,CS}$ / $\mathcal{S}_{U,CS}$: Beam Charge and Spin Asymmetry

Comparison to different models



160 GeV muon beam
2.5m LH_2 target
ε_{global} = 10%, 140 days
Lumi=$1222 pb^{-1}$

Beam Charge and Spin Asymmetry over the kinematic domain

Prediction with VGG

160 GeV muon beam
2.5m LH_2 target
ε_{global} = 10%, 140 days
Lumi=1222pb^{-1}

Q^2 = 12 GeV^2

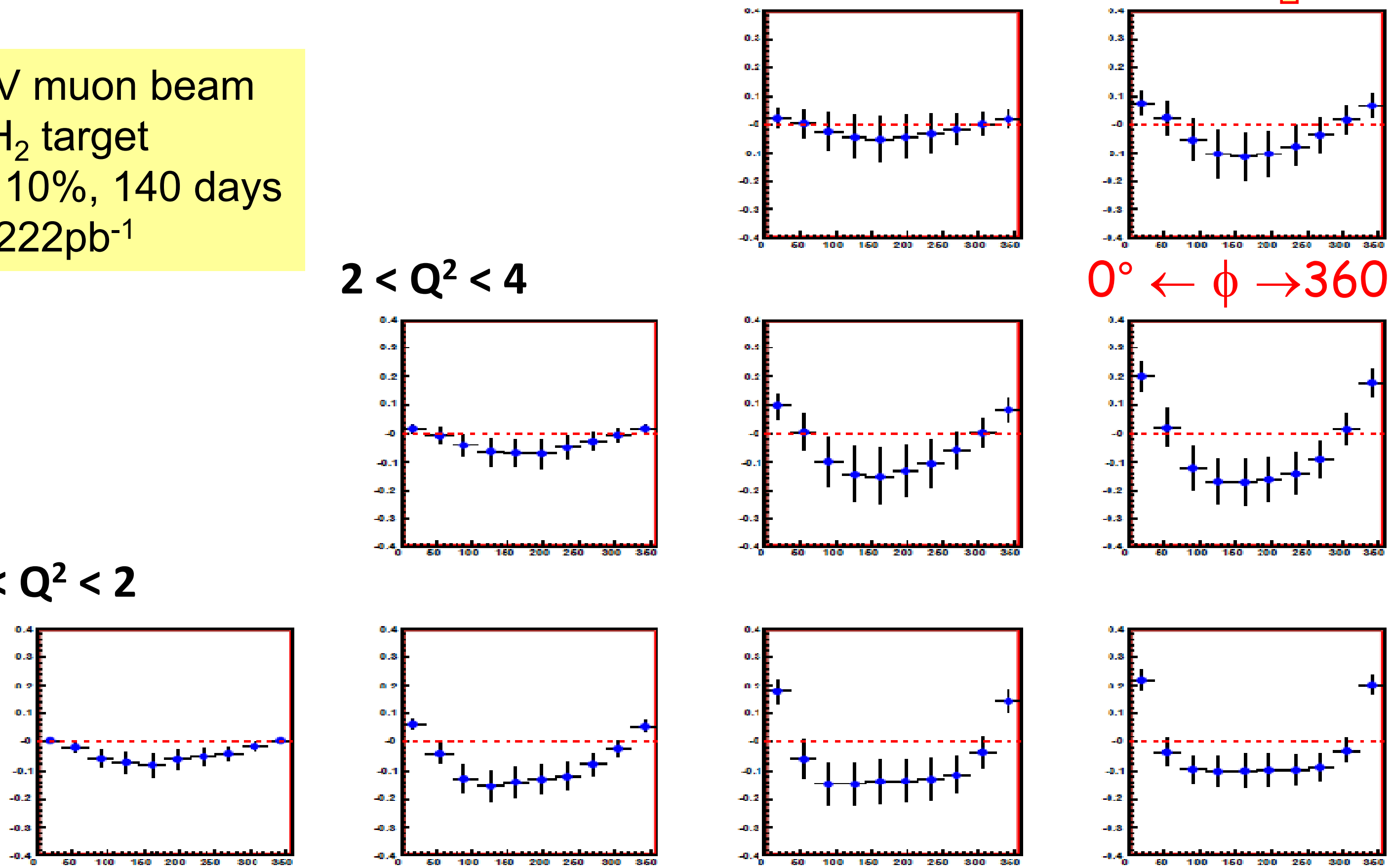
x = 0.15

4 < Q^2 < 8

2 < Q^2 < 4

1 < Q^2 < 2

0° ← ϕ →360°



0.005< x < 0.01 | 0.01< x < 0.02 | 0.02 < x < 0.03 | 0.03< x < 0.07

If Lumi × 4 → statistics errors divided by 2
more bins up to Q2 = 12 GeV2

Proposal to study "GPDs @ COMPASS" in 2 phases

Phase 1: DVCS experiment in ~2012 to constrain GPD H

with $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ beam + unpolarized long LH2 (proton) target

$d\sigma/dt$ → *transverse imaging*

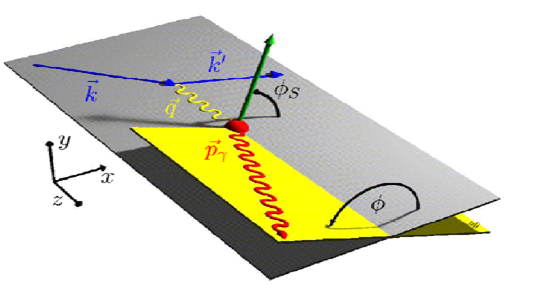
$$\mathcal{D}_{U,CS} \equiv d\sigma(\mu^{+\downarrow}) - d\sigma(\mu^{-\uparrow}) \propto c_0^{Int} + c_1^{Int}\cos\phi \quad \text{and} \quad c_{0,1}^{Int} \sim Re(F_1\mathcal{H})$$

$$\mathcal{S}_{U,CS} \equiv d\sigma(\mu^{+\downarrow}) + d\sigma(\mu^{-\uparrow}) \propto s_1^{Int}\sin\phi \quad \text{and} \quad s_1^{Int} \sim Im(F_1\mathcal{H})$$

Phase 2: DVCS experiment in ~2014 to constrain GPD E

with μ^{+} and transversely polarized NH3 (proton) target

$$d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi) \propto Im(F_2\mathcal{H} - F_1\mathcal{E})\sin(\phi-\phi_S)\cos\phi$$



Experimental setup upgrade (for DVCS)

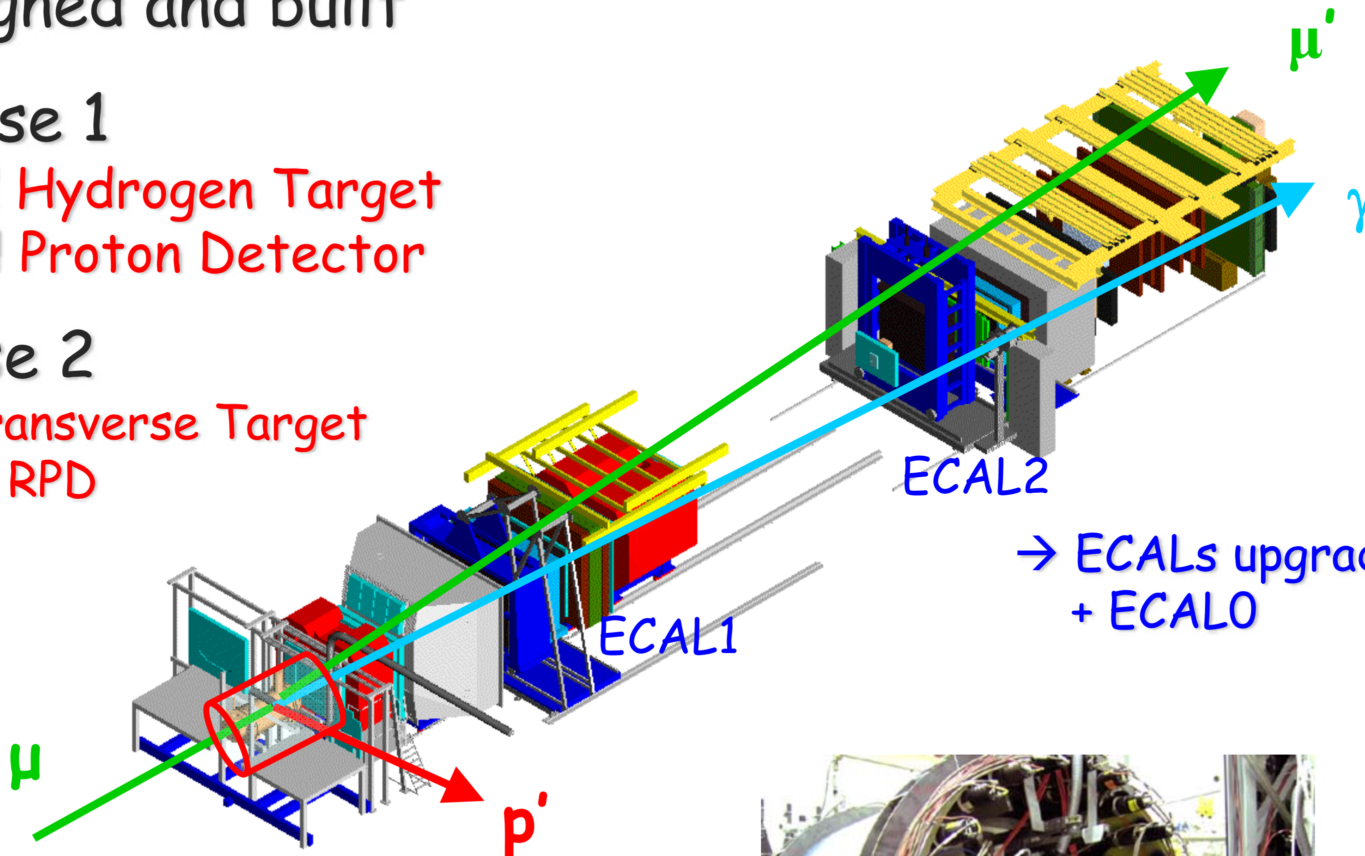
To be designed and built

Phase 1

~ 2.5 m Liquid Hydrogen Target
~ 4 m Recoil Proton Detector

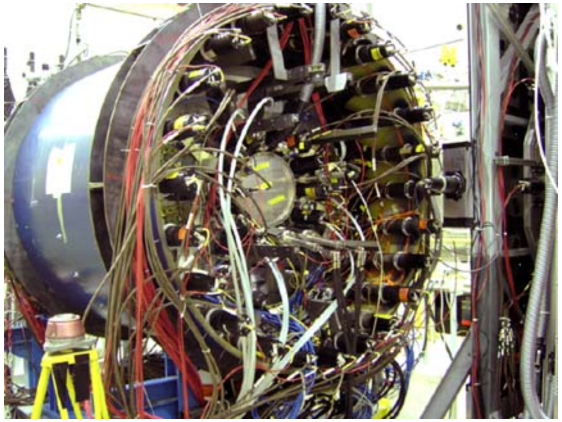
Phase 2

Polarised Transverse Target
Associated RPD



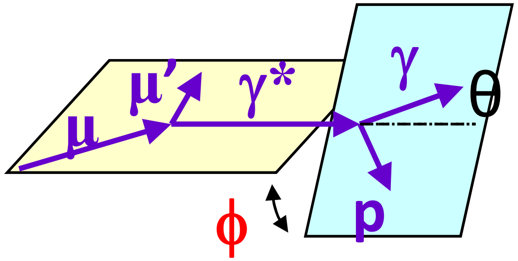
→ ECALs upgraded
+ ECAL0

Small Recoil Proton Detector
and a 40cm LH2 target available in 2008

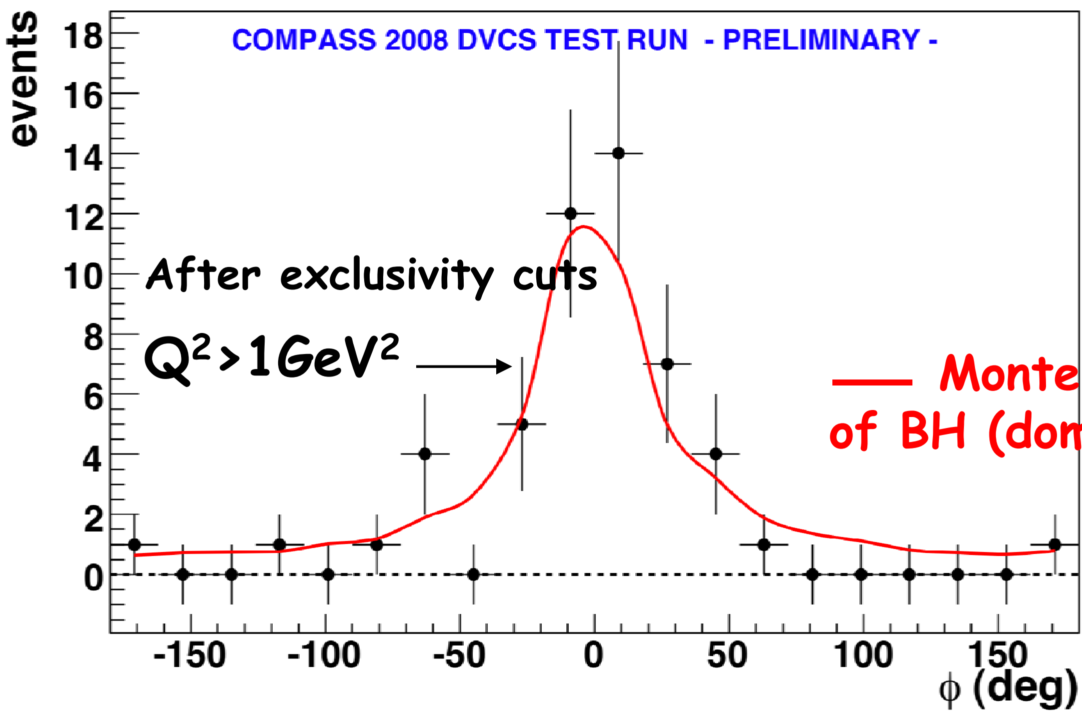


Already DVCS test in 1 day in 2008

with 1/3 nominal μ intensity, 1/6 target length
(using the present recoil proton detector)



angular distribution in φ



— Monte-Carlo simulation of BH (dominant) and DVCS

$\varepsilon_{global} = 13\% \pm 5\%$

dominance of the small x contributions:

- **clear signature of BH events**
- DVCS events are expected with a flat distribution

Looks encouraging, 2 weeks measurements in 2009

Conclusions

the unique **high energy polarised muon** beam at COMPASS allows very precise measurements in Longitudinal Spin Structure at low x

- test of Bjorken sum rule
- flavor asymmetry of the polarised light sea
- impact on QCD fits

the availability of both $\mu+\downarrow$ and $\mu-\uparrow$ beams is the decisive assets for the GPD program @ COMPASS

- unique and large domain $10^{-2} < x < 10^{-1}$
- BH, DVCS and Re T^{DVCS} or Im T^{DVCS}

could be nicely completed by a substantial increase of

- *luminosity (to increase the GPD domain in Q^2)*
- *energy (to still increase the domain at small x)*

(Possible upgrade of the M2 beam line discussed today)