CERN's Potential for Spin-Flavour studies of the Nucleon

- Short term
- Medium term
- Long term

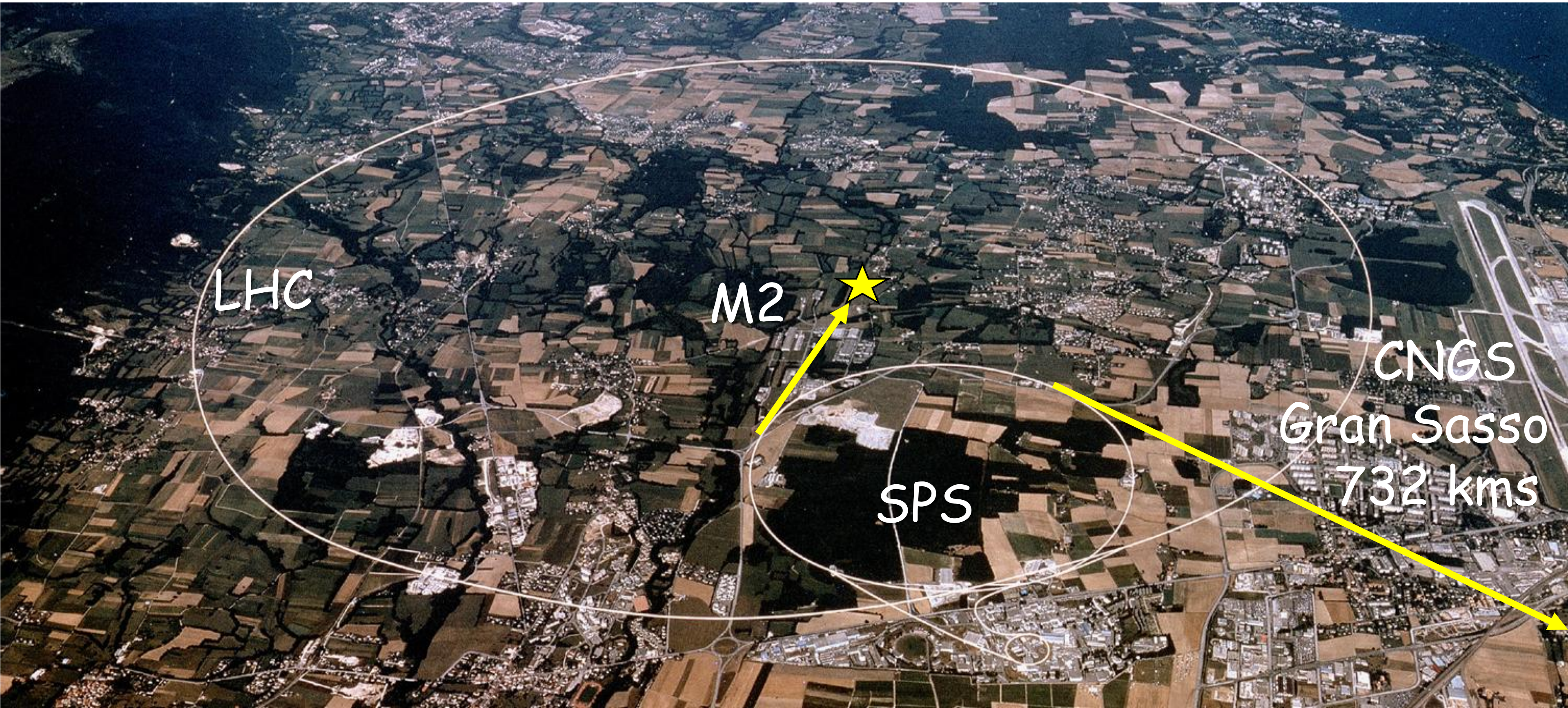
Many slides based on CERN Workshop May 11-13, 2009
http://indico.cern.ch/conferenceDisplay.py?confId=51128

CERN's DIS experiments

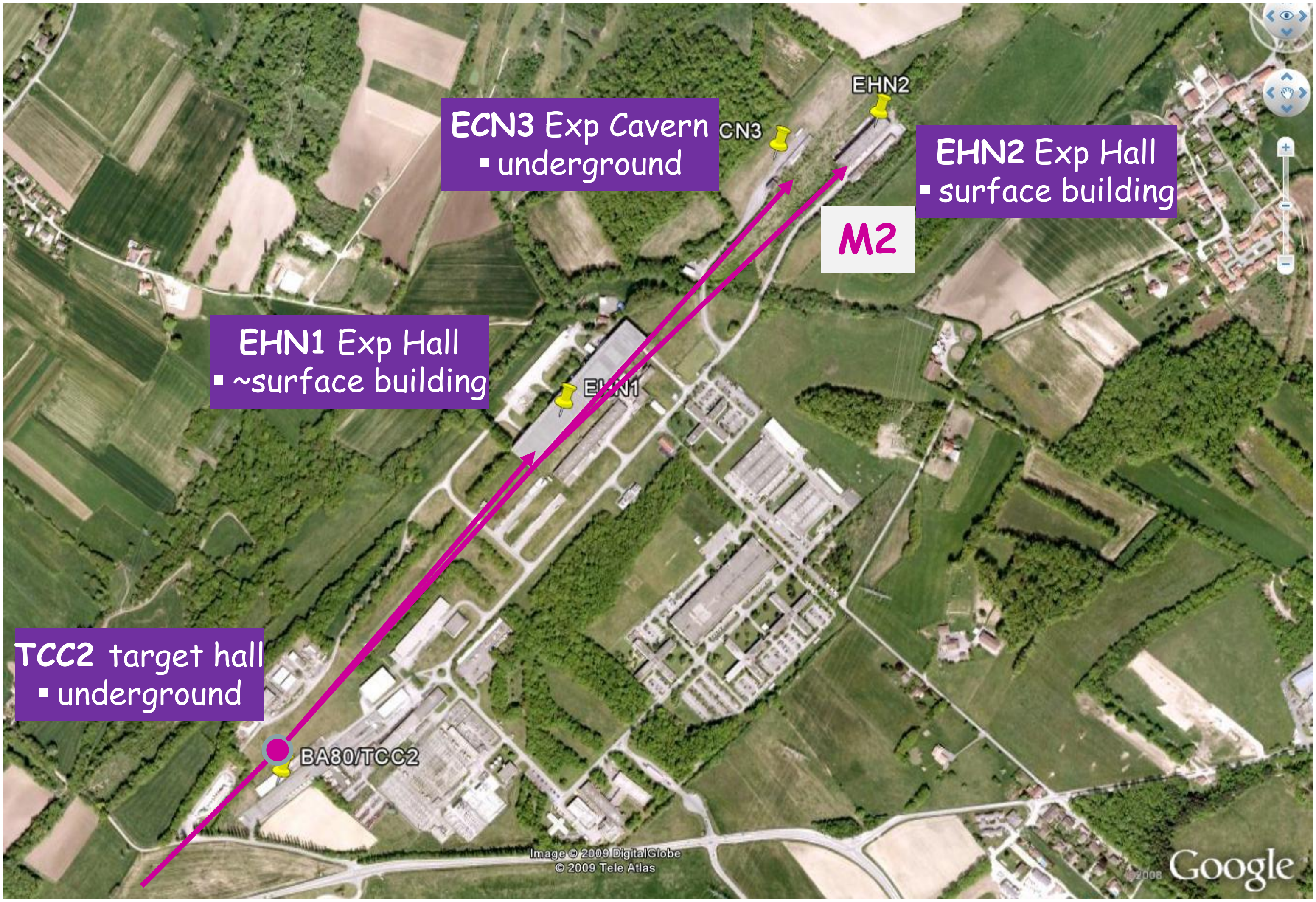
- Long standing tradition @ CERN
  - North Area experiments at M2 muon beam line since late 1970s
  - EMC, BCDMS, NMC, SMC, COMPASS
- Is there still a role to play for CERN in spin-flavour studies?
- What can be improved, where are the limits?

M2 Muon beam line

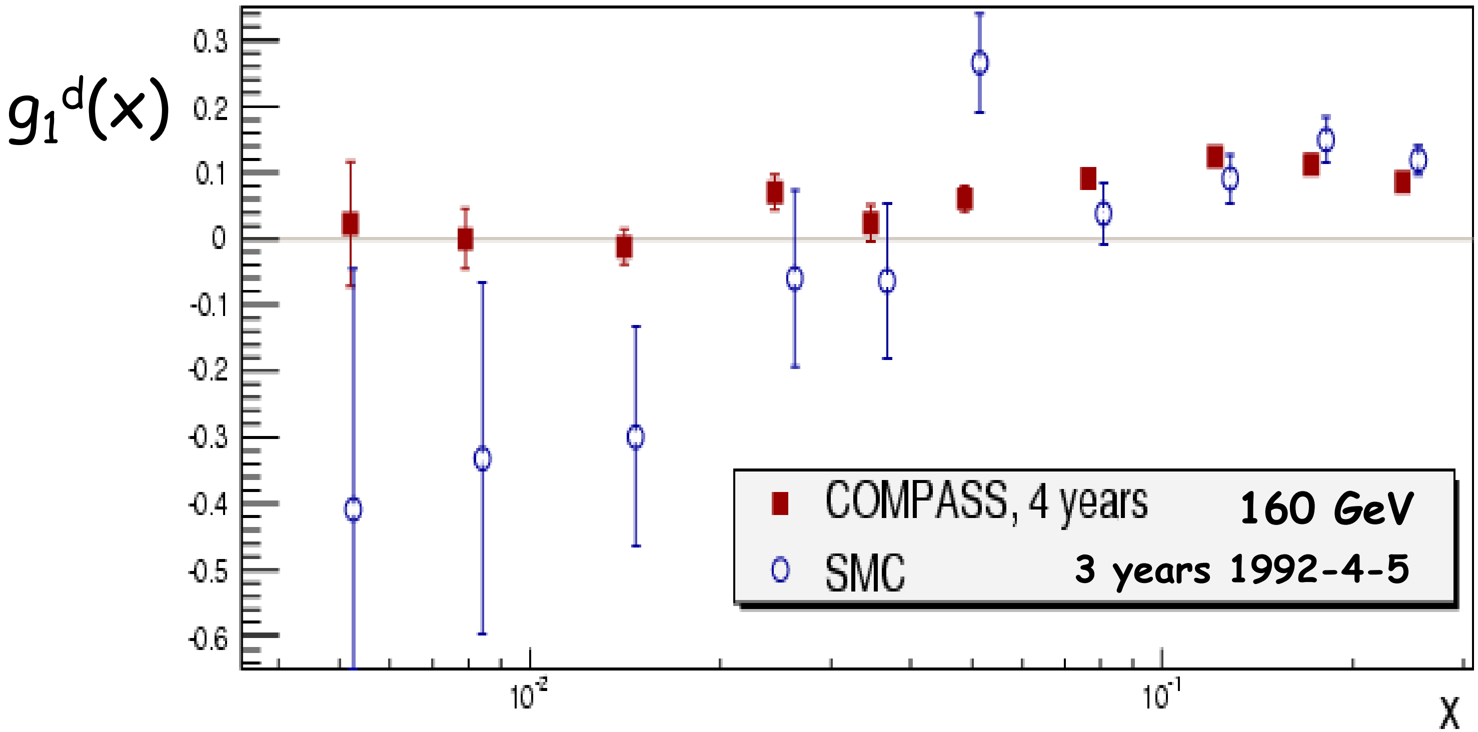
SPS proton beam: $1.4\ 10^{13}$/spill, 400 GeV/c
Secondary hadron beams (π, K, …): 2.10^{8} /spill, 150-270 GeV/c
Tertiary muon beam (80% pol): 2.10^{8} /spill, 100-200 GeV/c
(numbers for 4.8 s spill)



Experimental areas



Improvements COMPASS/SMC



2002-2006
w/o 2005

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

Short term: 2010 - 2011/2

Plans with exisiting COMPASS spectrometer

(Completion of original muon part of proposal)

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

Bradamante

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

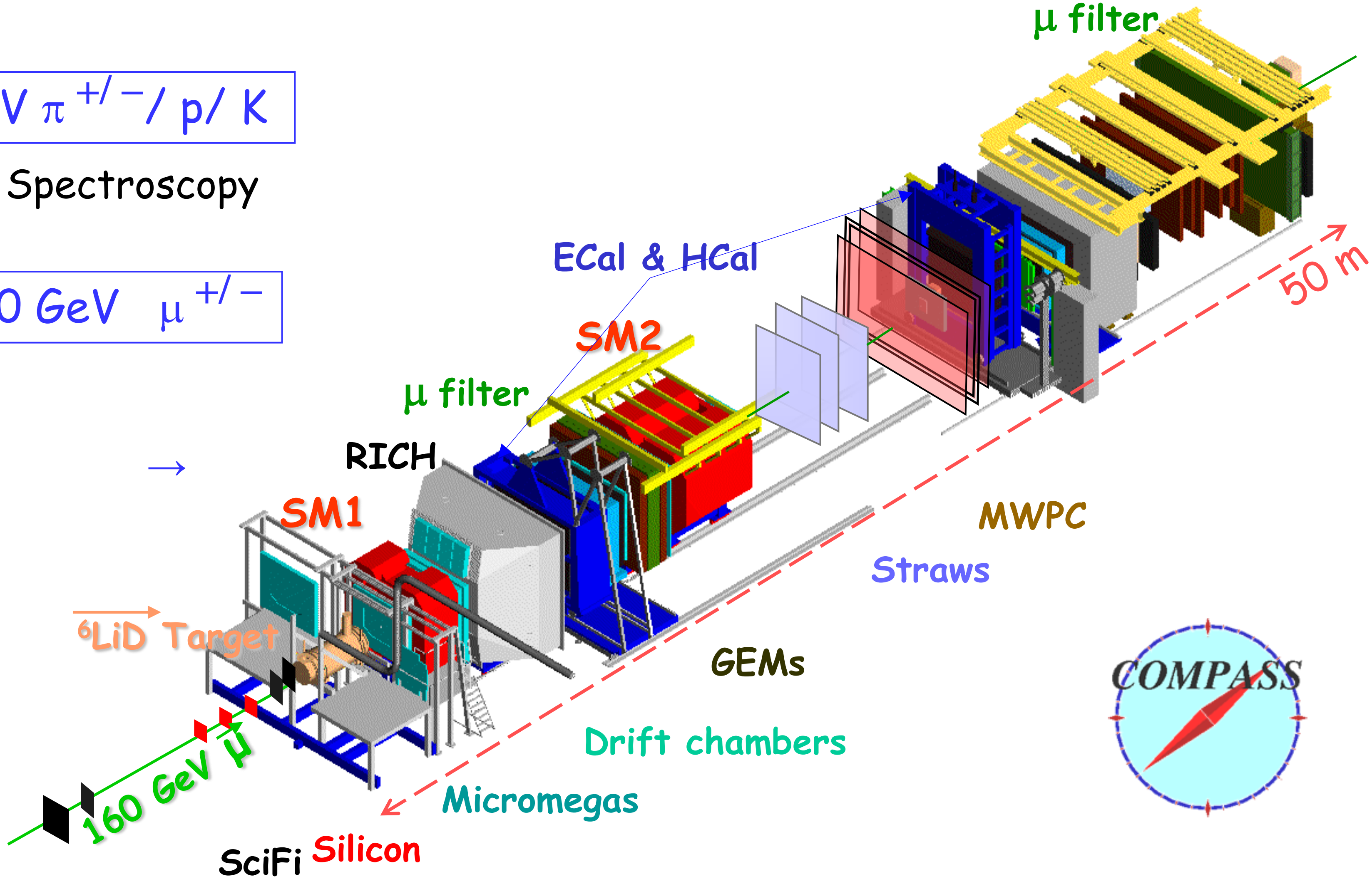
d'Hose

COMPASS

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

Hadron Spectroscopy

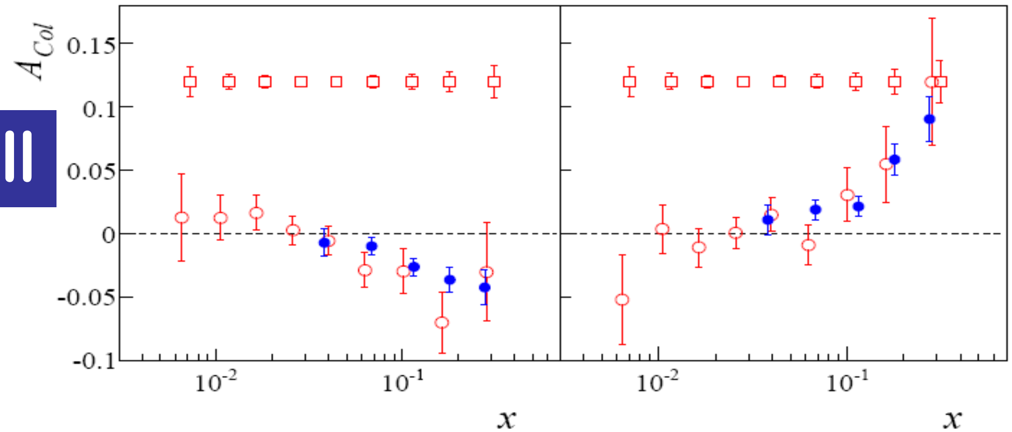
100-200 GeV $\mu^{+/-}$



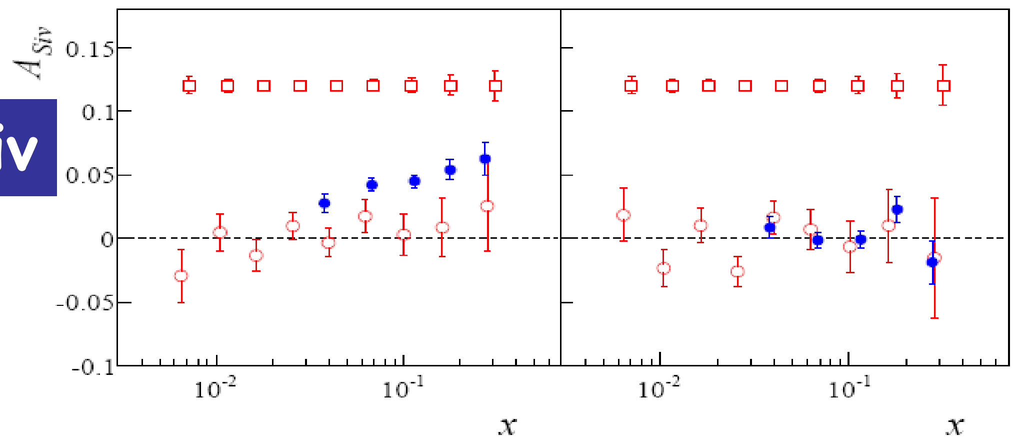
Transverse polarisation (short term)

h+ h-

Coll



Siv

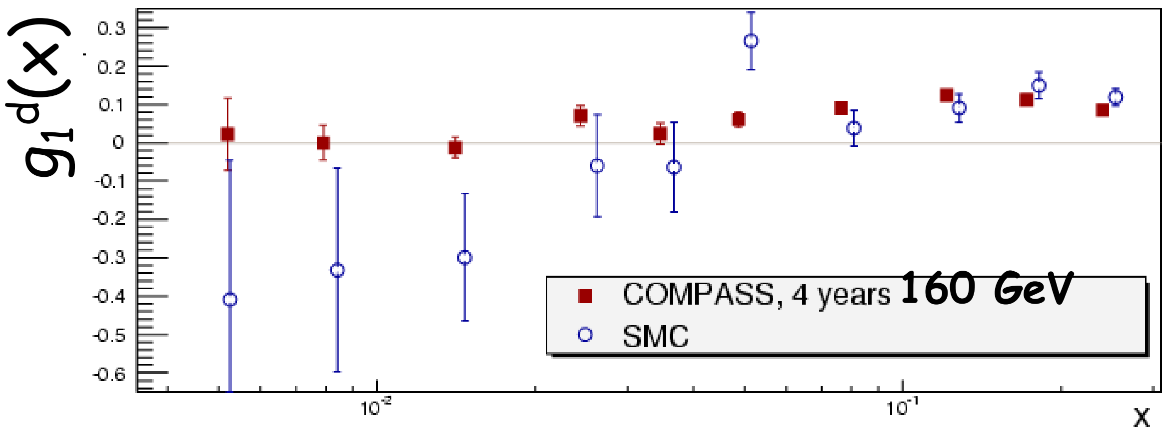


□ COMPASS 2010 proj.
○ COMPASS 2007 (part)
HERMES

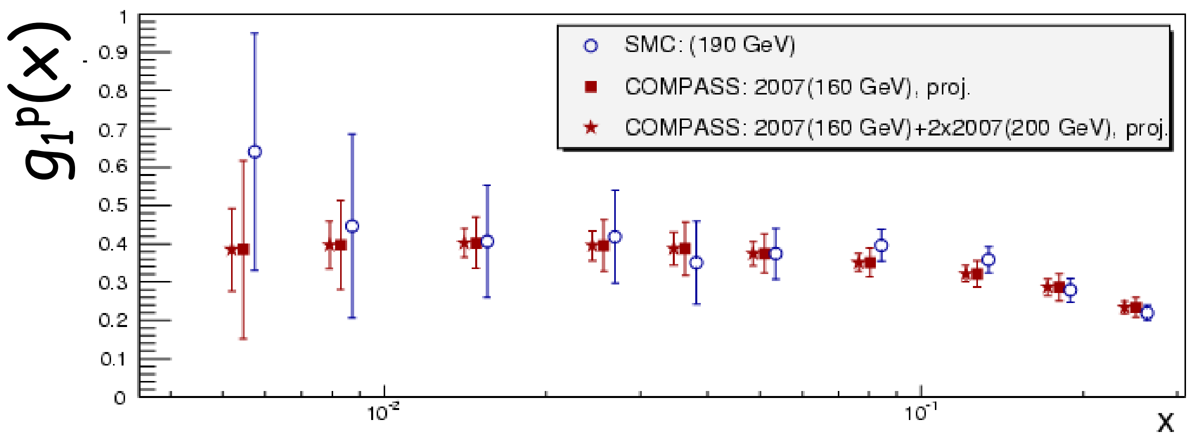
projected precision

Is Sivers non-zero for the proton?

Longitudinal polarisation (short term)



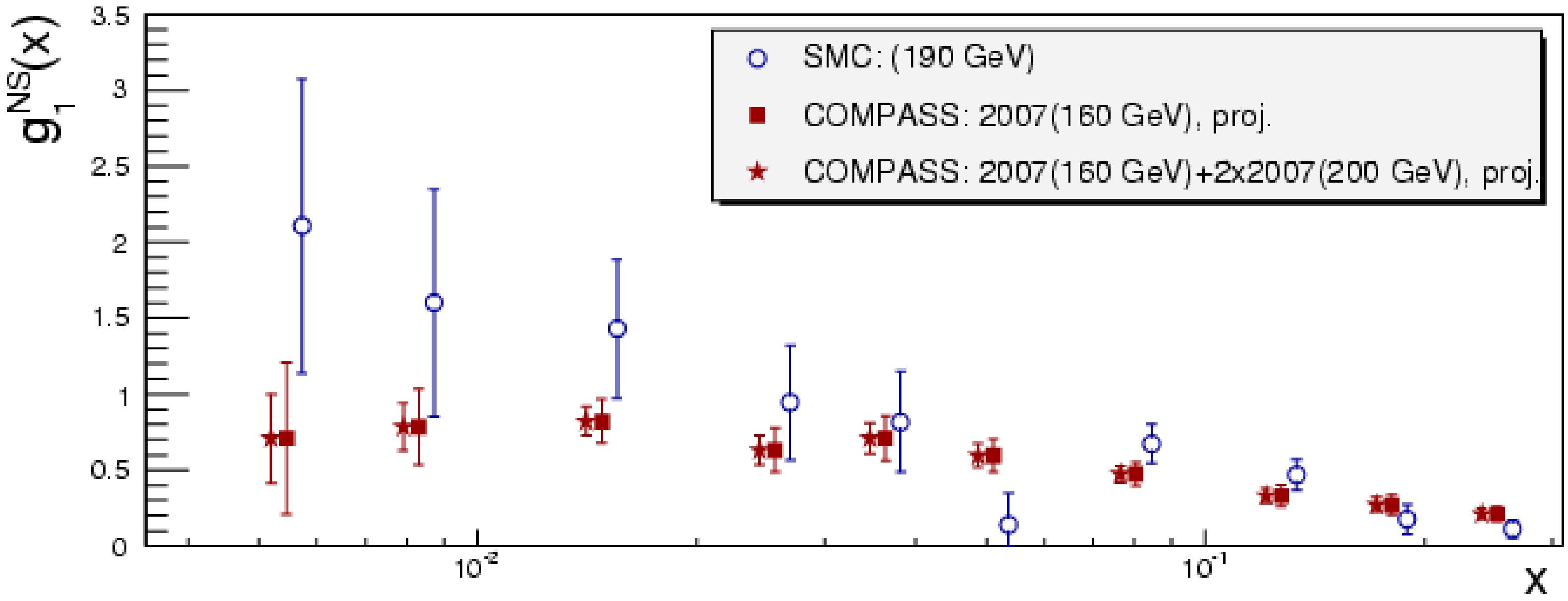
COMPASS data
SMC data



COMPASS proj. 2007
* COMPASS proj. 2007 plus 1 year
SMC data

Longitudinal polarisation (short term)

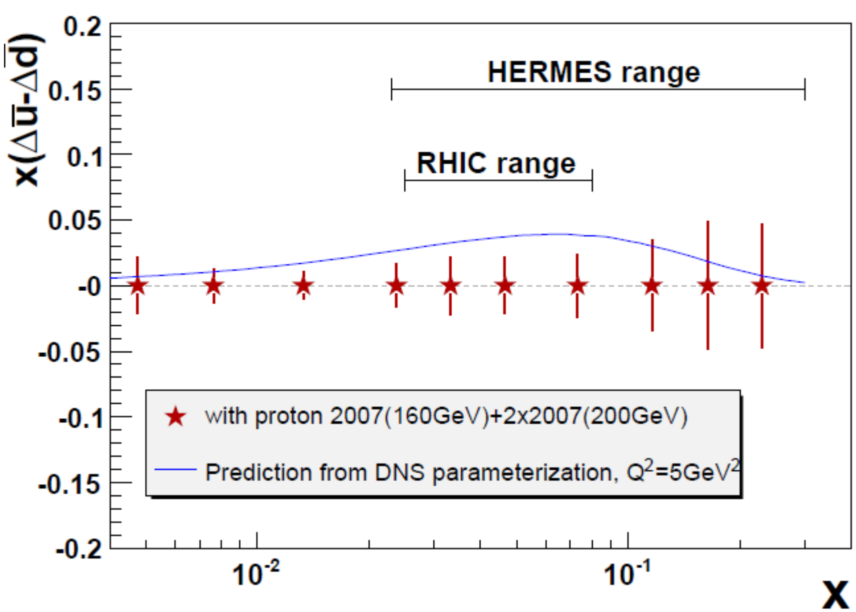
$g_1^{NS} \approx 2(g_1^p - g_1^d)$ non-singlet spin structure function



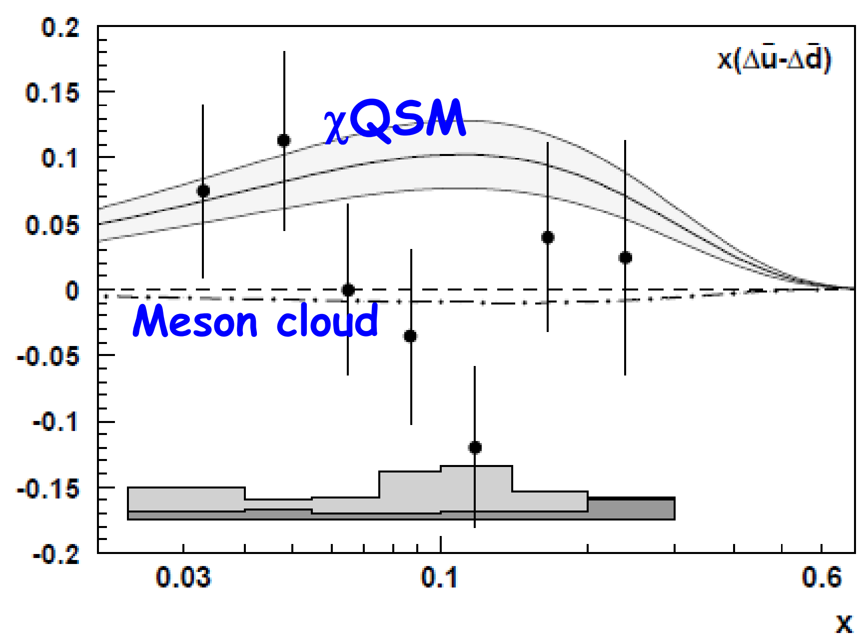
→ Precise shape determination at low x
→ More reliable extrapolation to x=0
→ Reduced statistical and systematic errors in the test of the Bjorken sum rule (fundamental result of QCD)

Longitudinal polarisation (short term)

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



* COMPASS Projection
with 1 additional year of proton



HERMES

Medium term: 2012/3 - 2015/6 (?)

Modified COMPASS spectrometer

- GPD DVCS and DVMP
  - 2.5 m liquid hydrogen target, 1 year
  - transversely polarised target, 1 year
  - BCA

d'Hose

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

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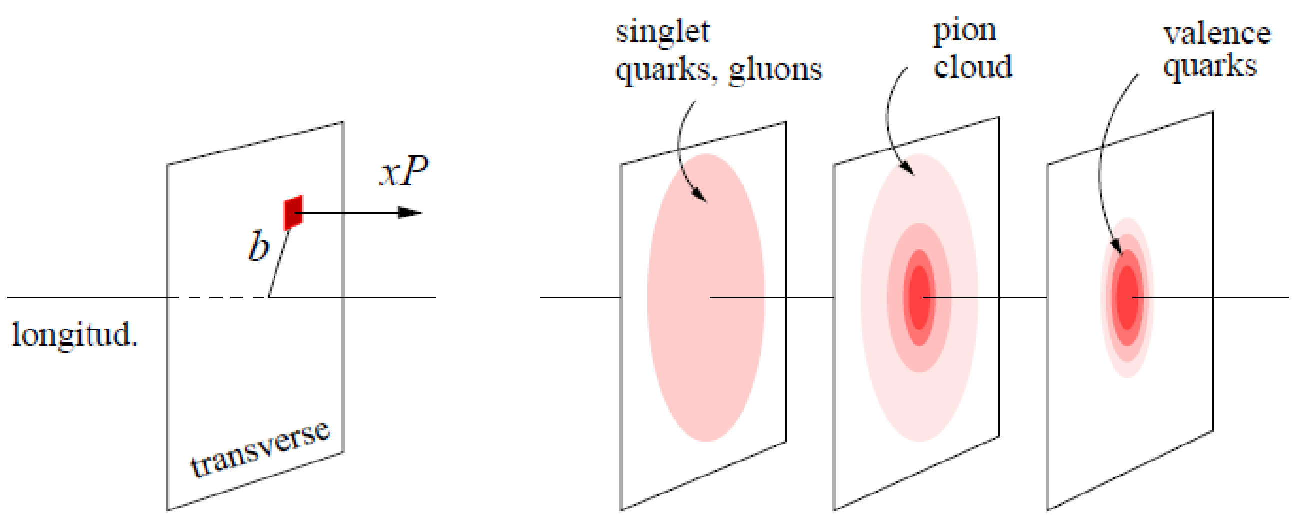
Generalised Parton Distributions

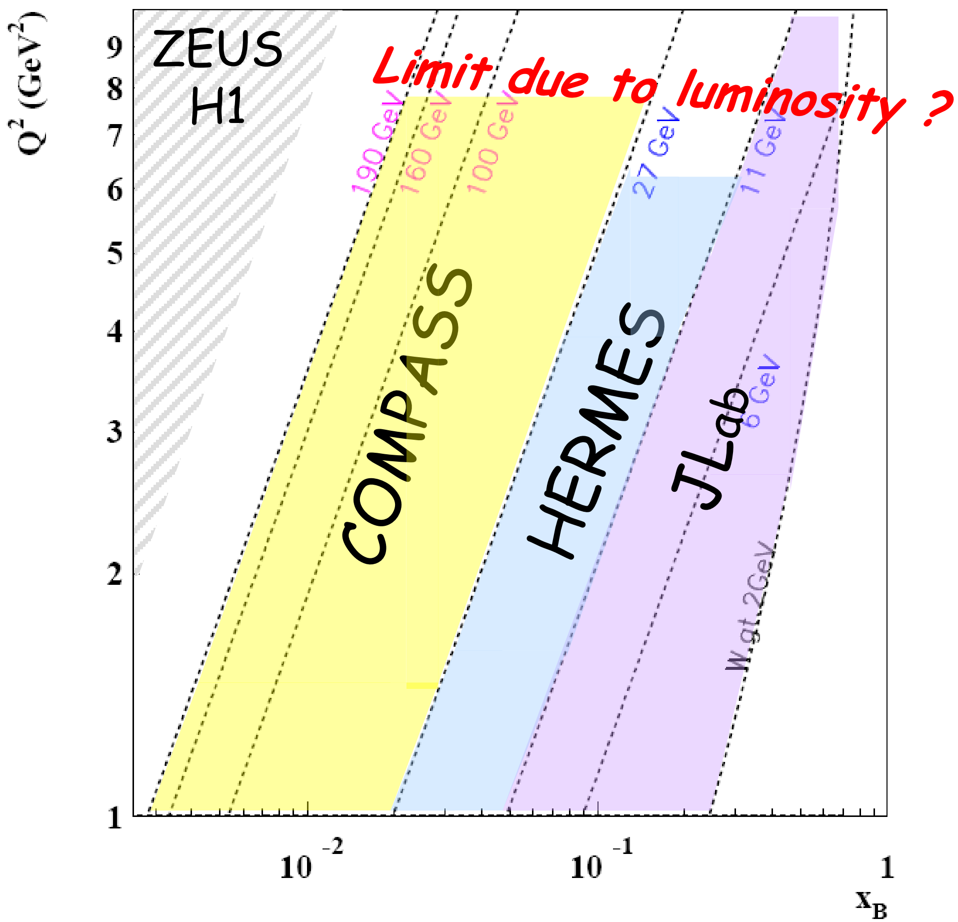
- Unified description of form factors and parton distribution
- Transverse imaging (nucleon tomography) and to access the quark angular momentum



Impact parameter b $x < 0.01$ $x \sim 0.1$ $x \sim 0.3$

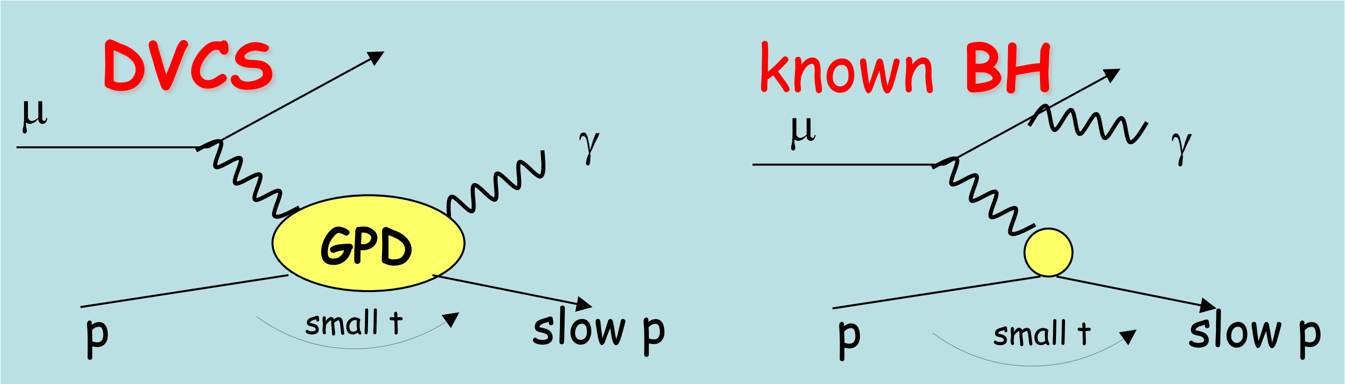
Longitudinal momentum fraction x Tomographic parton images of the nucleon

COMPASS GPD Programme



- μ+ and μ- beam with opposite polarisation 80%
- 2.5m long LH2 target
  $L = 10^{32}\ cm^{-2}\ s^{-1}$
- Lumi limits Q^2 to 8 GeV^2
  upgrades welcome
- ENC@FAIR with
  E_p=15GeV, E_e=3GeV is
  equivalent to $E\mu$ = 100GeV

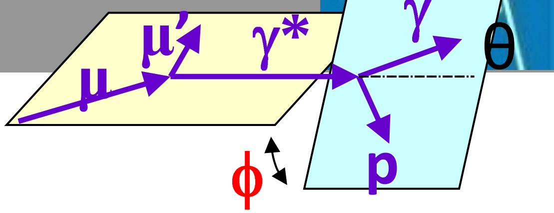
DVCS & BH interference



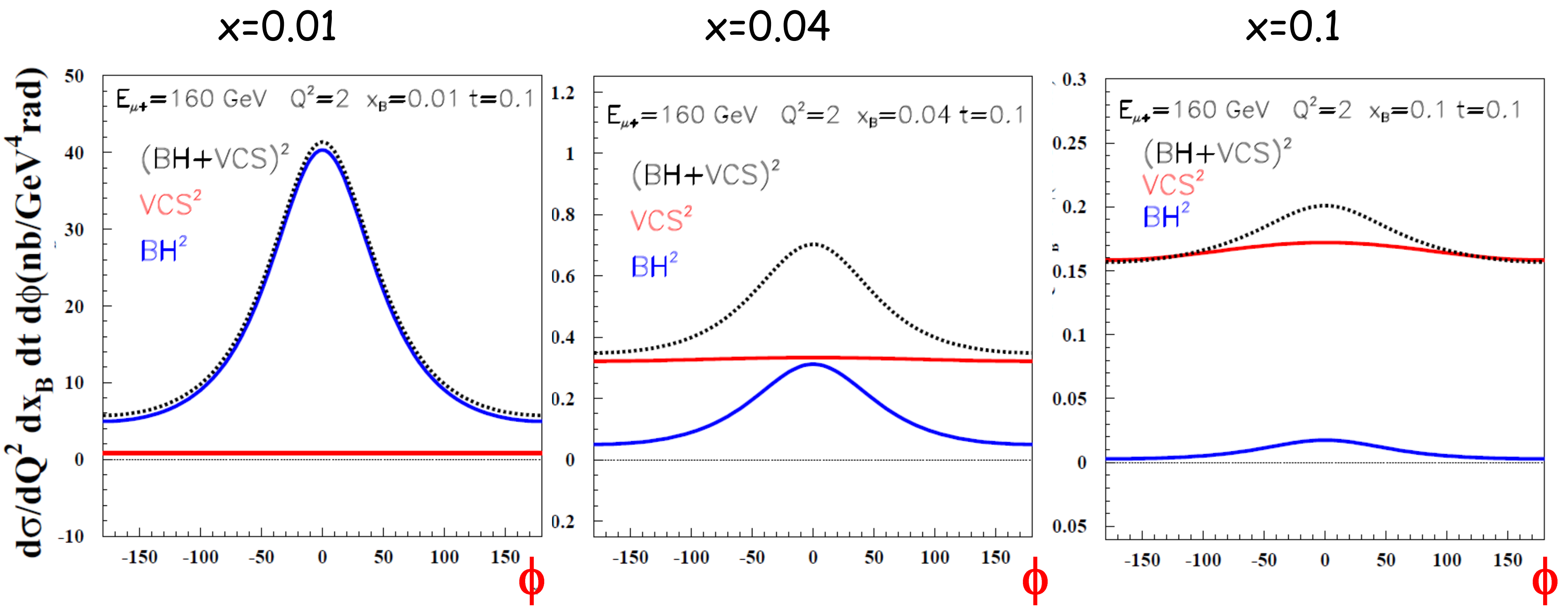
$$d\sigma \propto |T_{DVCS}|^2 + |T_{BH}|^2 + \text{interference term}$$

the three terms dominate in different kinematic regions

Comparison BH and DVCS

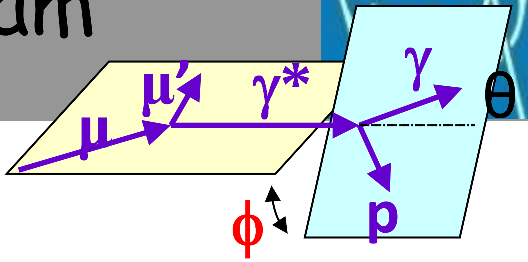


E_μ=160 GeV At Q^2=2 GeV^2 |t|=0.1 GeV^2



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

DVCS + BH with $\mu+\downarrow$ and $\mu-\uparrow$ 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

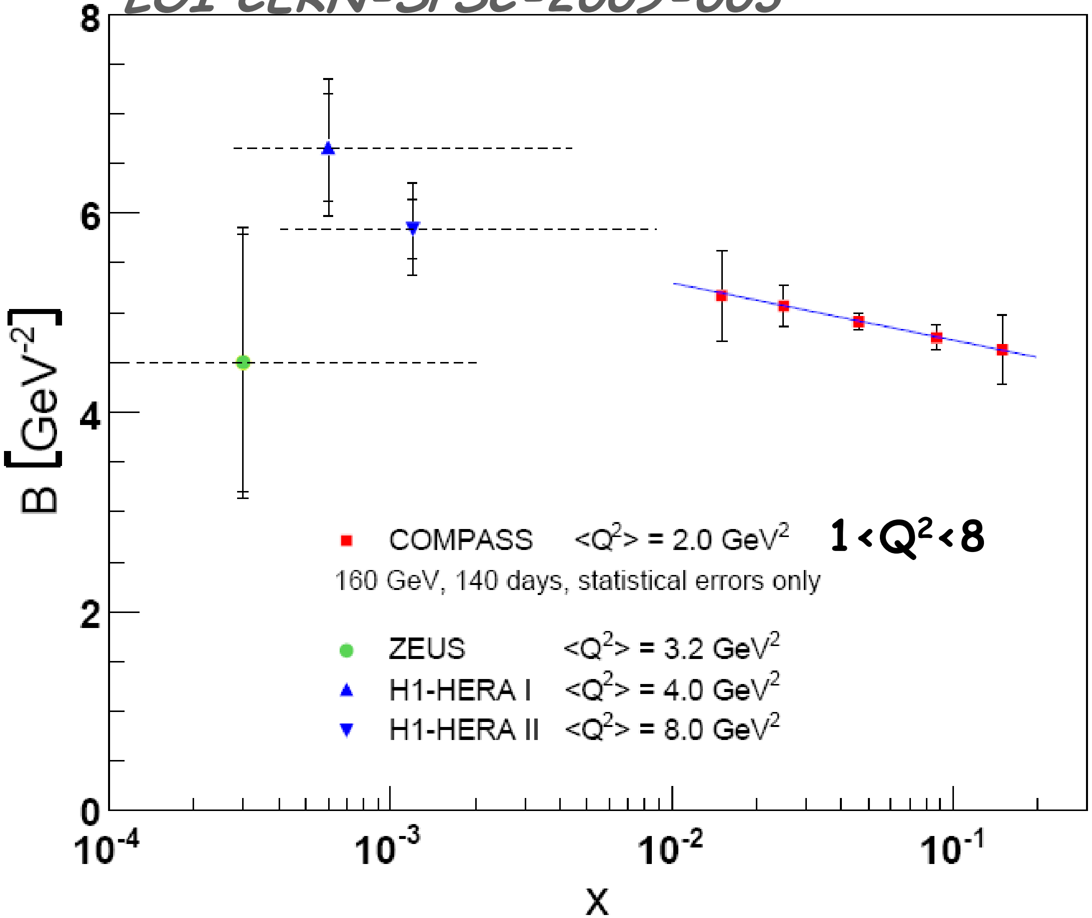
$$\mathcal{D}_{U,CS}(\phi) \equiv d\sigma(\mu^{+}\downarrow) - d\sigma(\mu^{-}\uparrow)$$

- Beam Charge & Spin Sum

$$\mathcal{S}_{U,CS}(\phi) \equiv d\sigma(\mu^{+}\downarrow) + d\sigma(\mu^{-}\uparrow)$$

Transverse imaging

LOI CERN-SPSC-2009-003



$S_{U,CS}$ ϕ integrated, BH subtra cted

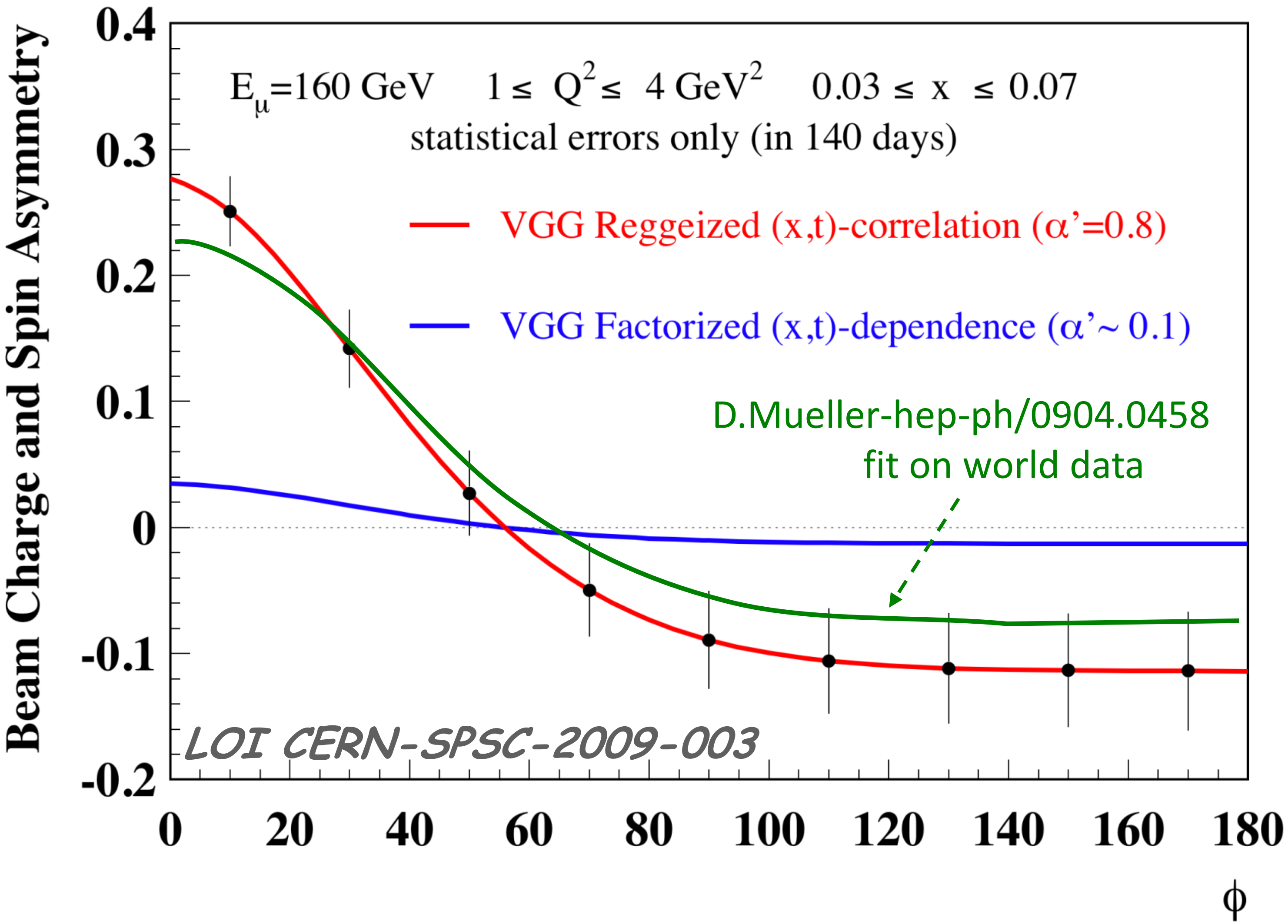
$d\sigma_{DVCS}/dt \sim \exp(-B|t|)$

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

FFS model: $\alpha' = 0.125\ \mathrm{GeV}^{-2}$

$$B^f(x) \sim 1/2\,\langle (b_\perp^f)^2 \rangle (x)$$

Beam Charge and Spin Asym. $\mathcal{D}_{U,CS}$ / $S_{U,CS}$



Proposal to study GPDs 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*

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

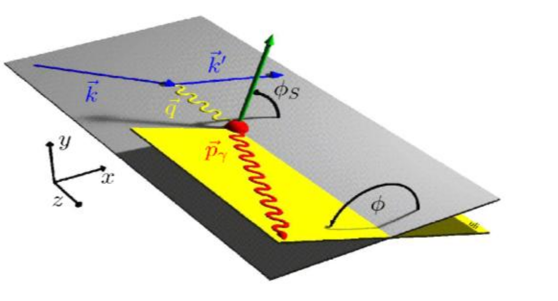
$$\mathcal{S}_{U,CS} \equiv d\sigma(\mu^{+\downarrow}) + d\sigma(\mu^{-\uparrow}) \propto s_1^{Int}\sin\phi \quad \text{and} \quad s_1^{Int} \sim Im(F_1\mathcal{H})$$

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

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

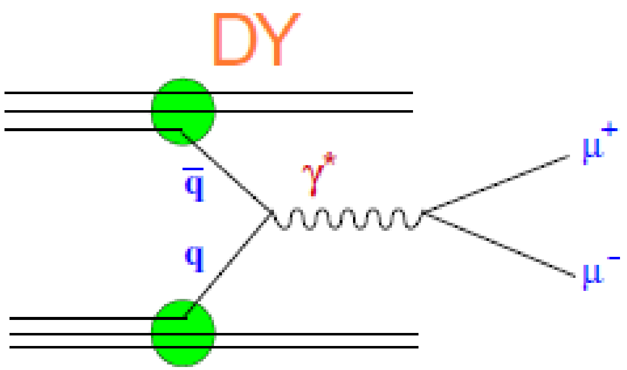
$$d\sigma(\phi, \phi_S) - d\sigma(\phi, \phi_S+\pi)$$

$$\propto Im(F_2\mathcal{H} - F_1\mathcal{E}) \sin(\phi - \phi_S)\cos\phi$$



Medium term: 2012/3 - 2015/6 (?)

- Drell-Yan in π^- p
- transversely polarised proton target, 2 years
- unpolarised liquid hydrogen target, optional



Slides from Bradamante , Denisov, Quintans

The Drell-Yan process in π^- p

very much like in SIDIS several azimuthal modulations are possible in the cross-section:

- **DY on unpolarized target**

$$d\sigma^{DY} \propto \bar{h}_1^{\perp}(x_1, k_{T1}^2) \otimes h_1^{\perp}(x_2, k_{T2}^2) \cos 2\phi$$

↑ Boer-Mulders ↑

- **DY on transversely polarized target**

$$d\sigma^{DY} \propto \bar{f}_1(x_1, k_{T1}^2) \otimes f_{1T}^{\perp}(x_2, k_{T2}^2) \sin(\phi - \phi_{S2}) +$$

↑ Sivers

$$+ \bar{h}_1^{\perp}(x_1, k_{T1}^2) \otimes h_1(x_2, k_{T2}^2) \sin(\phi + \phi_{S2}) +$$

↑ Boer-Mulders ↑ Transversity

$$+ \bar{h}_1^{\perp}(x_1, k_{T1}^2) \otimes h_{1T}^{\perp}(x_2, k_{T2}^2) \sin(3\phi - \phi_{S2})$$

↑ Boer-Mulders ↑ Pretzelosity

the amplitudes are convolutions of TMD PDFs

The Drell-Yan process in π⁻ p

in the valence region, u quark-dominance

$$\sigma^{DY} \propto f_{\bar{u}|\pi^-} \otimes f_{u|p}$$

where $f = h_1^\perp, f_1, f_{1T}^\perp, h_1, h_{1T}^\perp$

→ extraction of the u-quark Sivers function

→ model dependent extraction of transversity and Boer-Mulders functions

COMPASS can do it

Testing non-perturbative QCD

confronting Drell-Yan and SIDIS results provides a crucial test of non-perturbative QCD

→ check the predictions: $f_{1T}^\perp(DY) = -f_{1T}^\perp(SIDIS)$

$$h_1^\perp(DY) = -h_1^\perp(SIDIS)$$

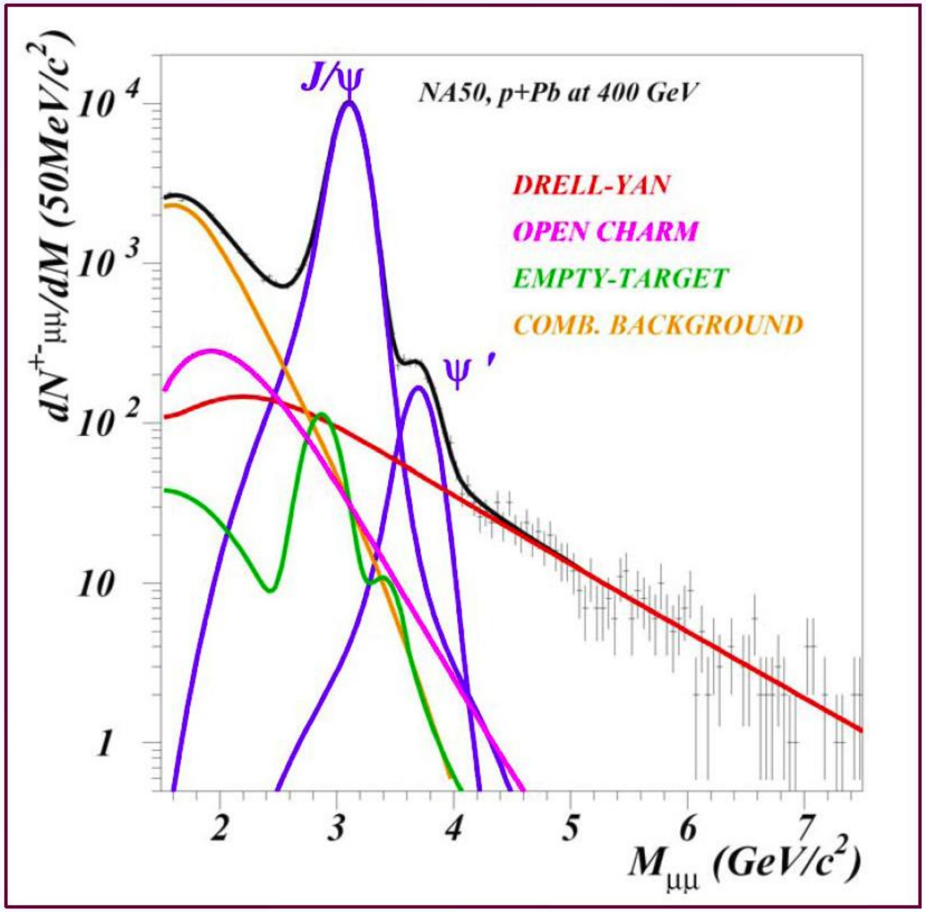
due to the T-odd character of the Sivers and Boer-Mulders functions

The Drell-Yan process in π^- p

signal and background

the dimuon mass spectrum is known from past DY experiments

spectrum from NA50



$M < 2.5$ GeV/c^2:
Large physics background from decays $D \to \mu^{\pm} X$

Combinatorial background
π and K decaying to $\mu\nu$
- Absorber option

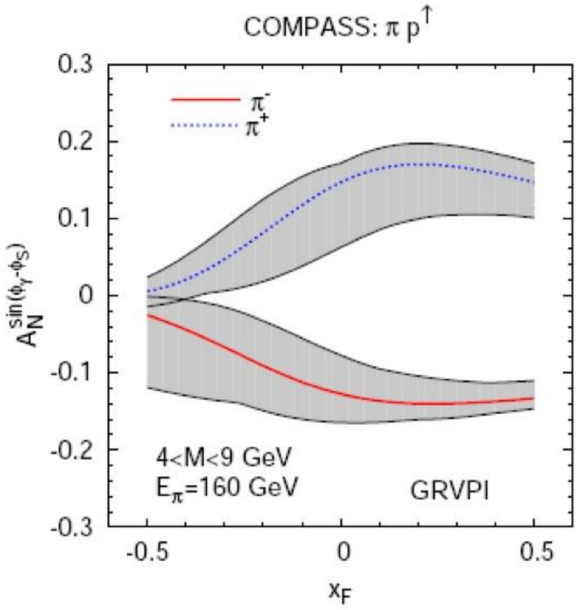
J/ψ and ψ' region: the charmonium polarization is itself a subject of research

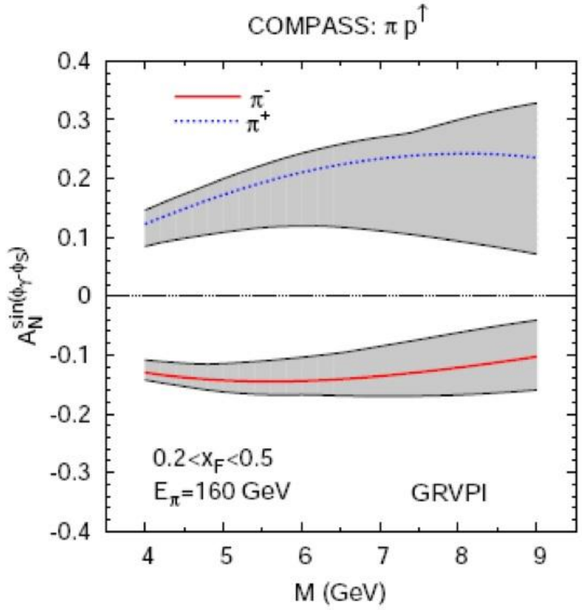
$M > 4.$ GeV/c^2: safe region to study Drell-Yan

Single Spin asymmetry

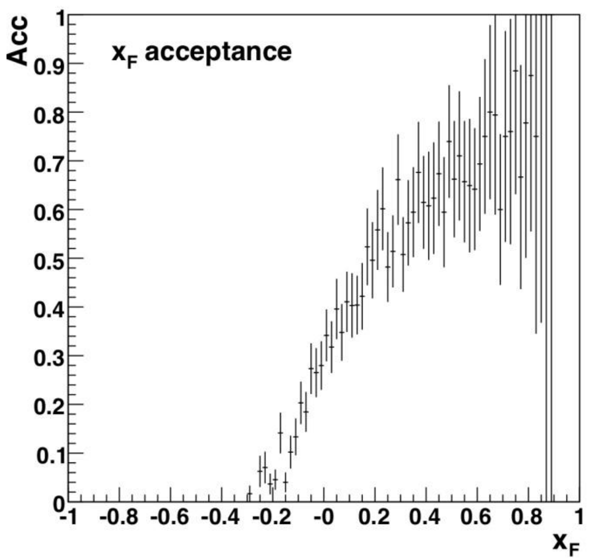
$$A_N^{\sin(\phi_{S2}-\phi)} = \frac{\int_0^{2\pi}(d\sigma^{\uparrow} - d\sigma^{\downarrow})\sin(\phi_{S2}-\phi)d\phi}{\frac{1}{2}\int_0^{2\pi}(d\sigma^{\uparrow} + d\sigma^{\downarrow})d\phi}$$

Anselmino et al. 2009 predictions





COMPASS acceptance



Sizeable spin asymmetries are expected

Drell-Yan: Projected results

expected precision in two years of data taking

with

- a transversely polarized NH_3 target (120 cm long)
- a π^- beam of 190 GeV/c with intensity $6 \cdot 10^7$ particles/second,

a luminosity of $1.7 \cdot 10^{33}$ $cm^{-2}s^{-1}$ can be obtained

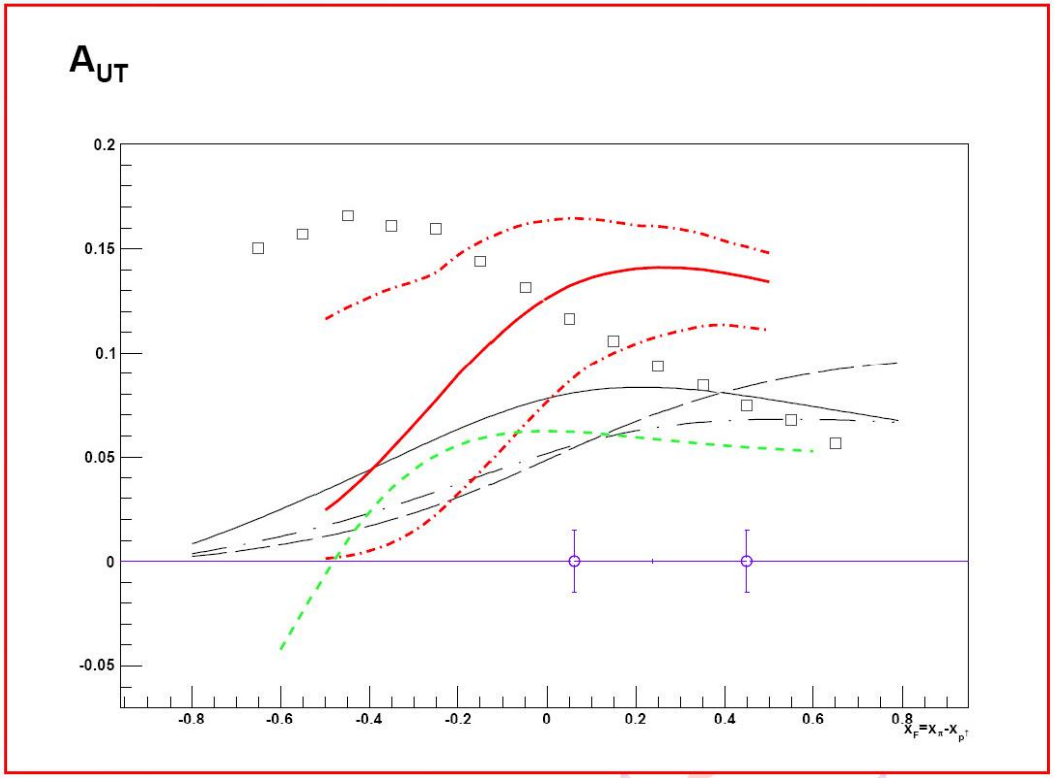
the statistical error in the asymmetries measured is expected to be

$$\delta A^{sin(\phi_{S2} - \phi)} \approx 1 - 2\,\%$$

predictions for the "Sivers asymmetry" (based on HERMES p Sivers asymmetry in SIDIS) in the COMPASS phase-space

mass region 4 < M < 9 GeV/c²

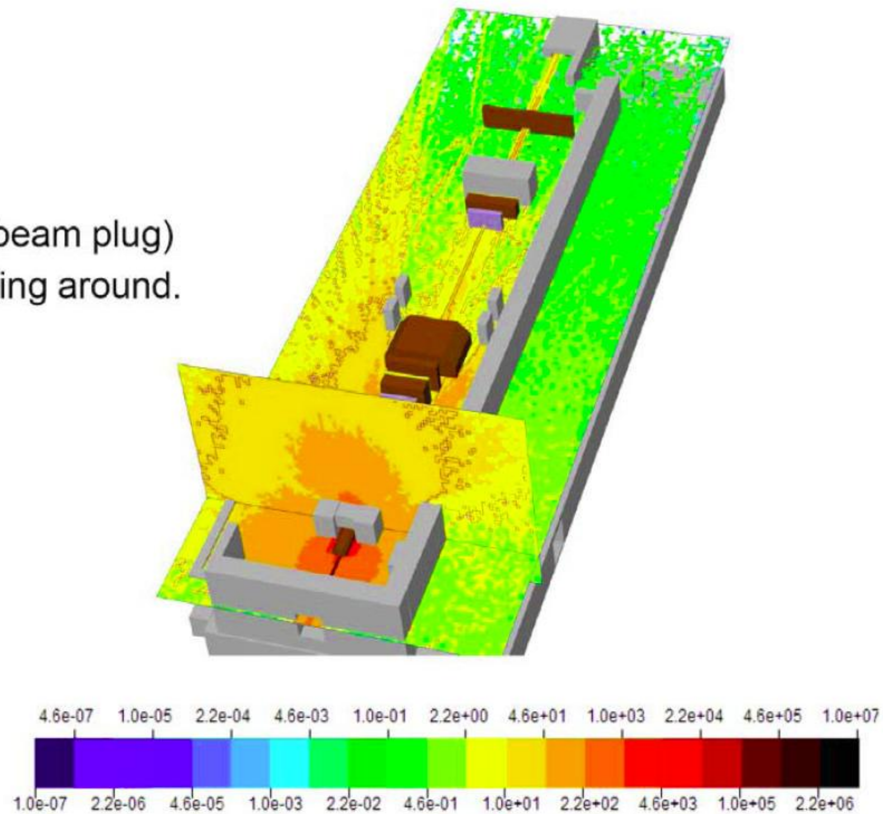
- solid and dashed: Efremov et al, PLB612(2005)233;
- dot-dashed: Collins et al, PRD73(2006)014021;
- solid, dot-dashed: Anselmino et al, PRD79(2009)054010;
- boxes: Bianconi et al, PRD73(2006)114002;
- short-dashed: Bacchetta et al, PRD78(2008)074010.



Drell-Yan: Radiation

Simulations from Heinz Vincke (Rad-Prot/CERN)

Beam I=8×10^7 π^-/s
Absorber (Al_2O_3 with W beam plug)
of 1.5 m. Concrete shielding around.



COMPASS is a radiation supervised area

- **the dose limits in the control room must stay < 3 μSv/h**
- **all the region around target and absorber must be shielded**

Further Drell-Yan measurements

what if COMPASS could dispose of a RF separated $\bar{p}/K^-$ beam?

from L. Gatignon: 3 · 10^8 ppp (limiting factor: radiation)
$\bar{p}:K^- = 1:1$

$(\bar{p}, p\uparrow)$ $\bar{p}$: $(\bar{u}\bar{u}\bar{d})$ p: (uud)

in this case $f_{\bar{u}|\bar{p}} = f_{u|p}$ thus $\sigma^{DY} \propto f_{u|p} f_{u|p}$

- **model independent extraction of the Sivers function**

$(K^-, p\uparrow)$ K^-: $(\bar{u}s)$ $\sigma^{DY} \propto f_{\bar{u}|K^-} f_{u|p}$

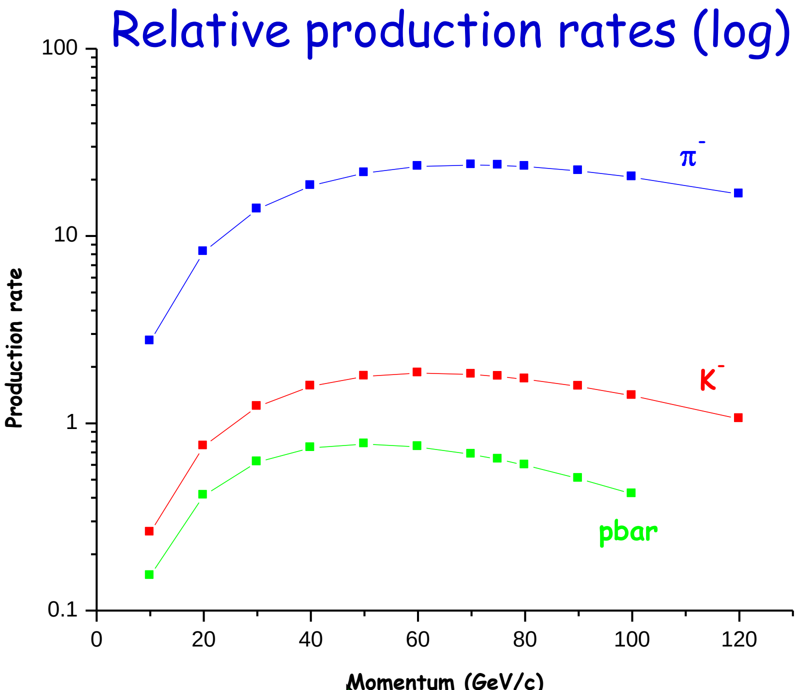
- **model dependent extraction of valence Sivers, transversity and Boer-Mulders functions**
- **access to unpolarized kaon distribution functions (poorly known)**

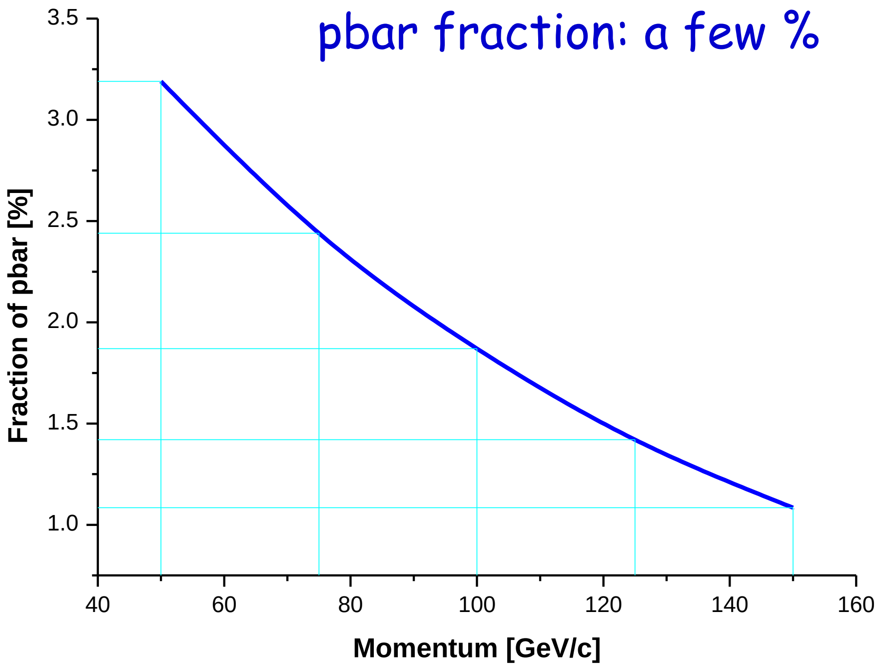
Anti-proton beam?

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:





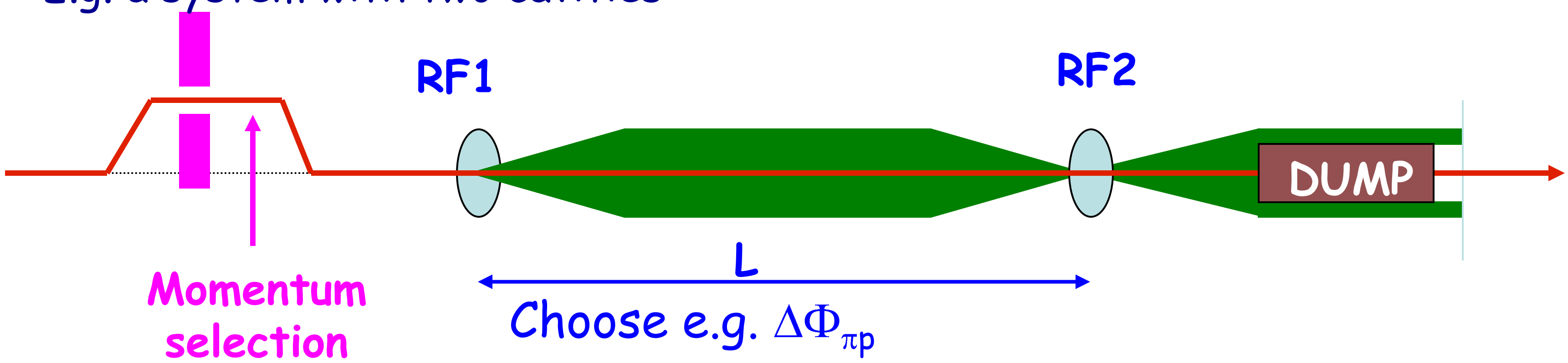
In present M2 hadron beam ≤ 5 10^6 $\bar{p}$

(due to 2×10^8 (π) limit on total beam flux for radio-protection)

RF separated p beam?

First and very preliminary thoughts, guided by recent studies for P326 and studies for CKM by J.Doornbos/TRIUMF, 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

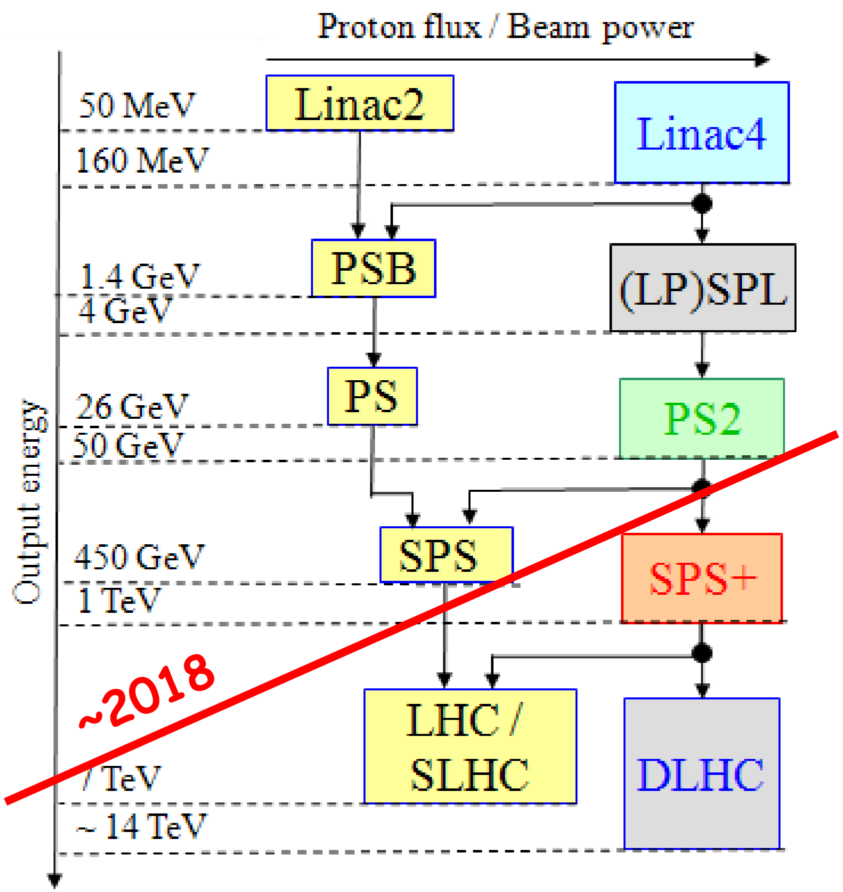
From slide of L.Gatignon, 17-10-2006

Long term: > 2018

CERN accelerator upgrade: new injectors

from Ilias Efthymiopoulos (CERN-EN/MEF)

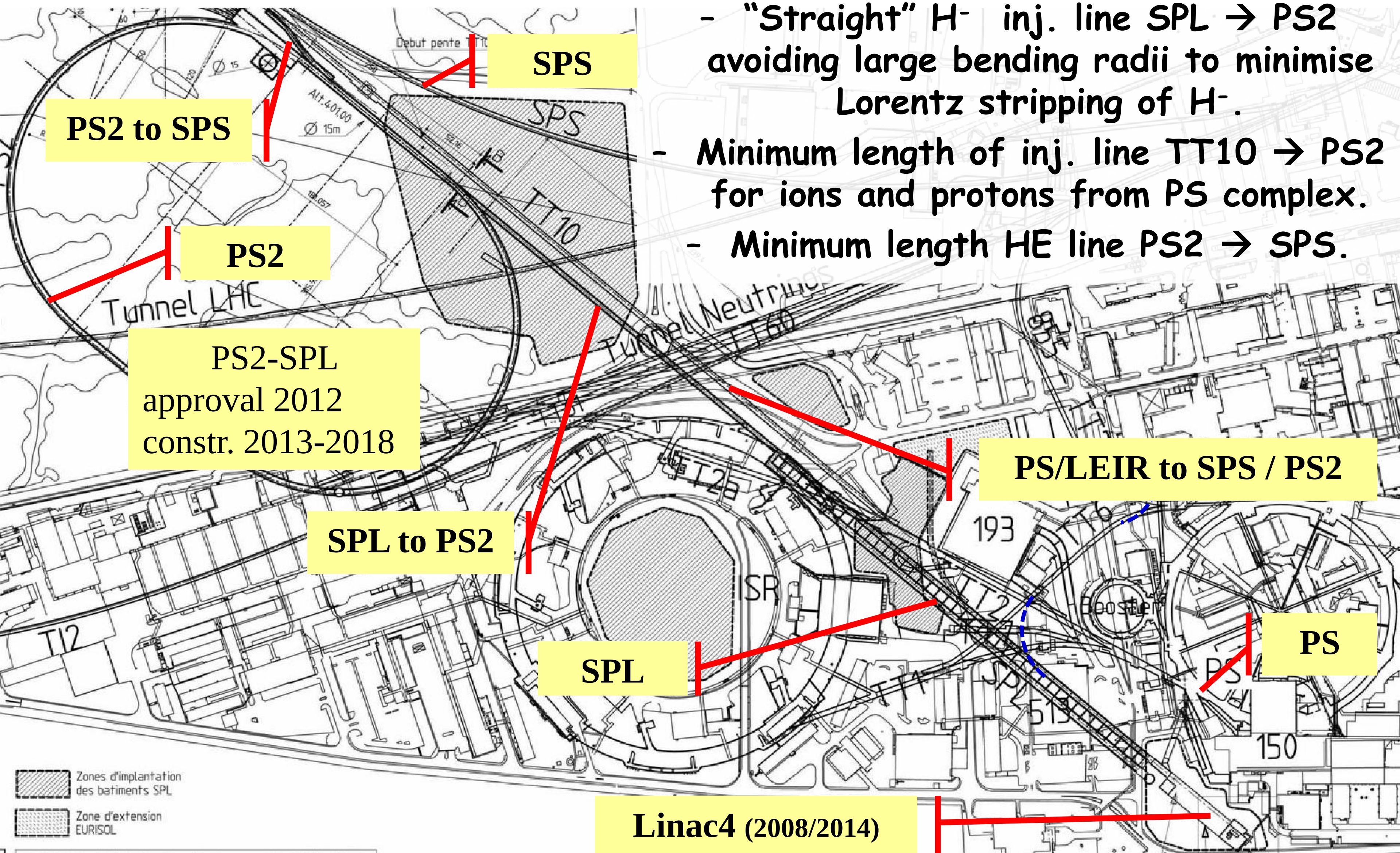
LHC Injector upgrade program



- **PS2 replaces PS**
  - ~5 ÷ 50 GeV/c beams
  - 1.0×10^{14} ppp
- **SPS Upgrade**
  - Single injection form PS2 → shorter cycles
  - The machine is upgraded and can handle the PS2 delivered intensity!

PS2 integration (M. Benedict)

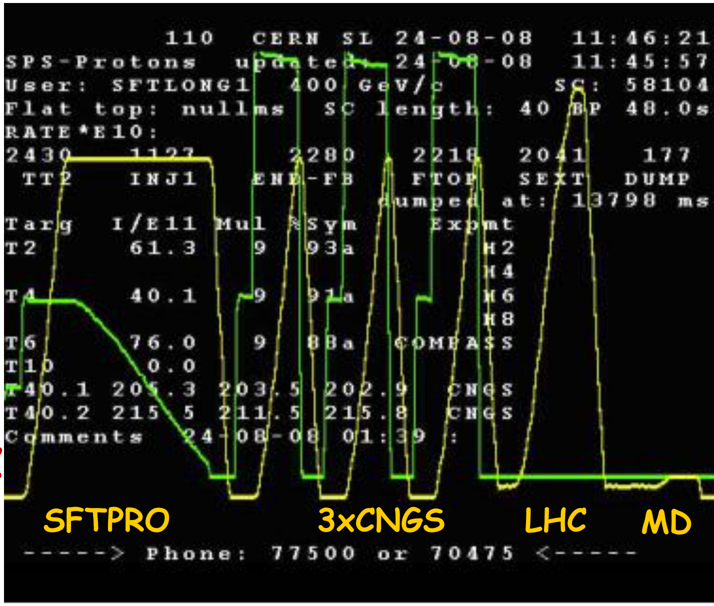
- "Straight" H^- inj. line SPL → PS2 avoiding large bending radii to minimise Lorentz stripping of H^-.
- Minimum length of inj. line TT10 → PS2 for ions and protons from PS complex.
- Minimum length HE line PS2 → SPS.



Implications for SPS North Area

Today

- I_{max} (integrated) : **3.5×10^{13} ppp / 9.6s flat-top**
  - instantaneous rate : 3.6×10^{12} pHz



- I_{max} (instantaneous) = **5.0×10^{12} pHz**
  - 2.4 × 10^{13} ppp / 4.8s flat-top

Future

- The foreseen intensity from PS2/SPSU (**1.0 × 10^{14} ppp**) represents a factor **2.85 increase in overall beam intensity**
  - In reality ~10% less due to losses at SPS and extraction line
  - Note this is the total – intensity, i.e. for all targets that then is split, etc.

*Can the NA infrastructure accept the **×2.5 intensity increase** and the shorter super-cycle (no CNGS, LHC? Is even higher intensity possible if requested for future experiments ?*

Implications for SPS North Area

Beam cycles

Today

FT flat top	Additional users	Super-cycle	FT duty cycle
9.6(4.8)s	3×CNGS + LHCs + MD	48.0(43.2)s	20(11)%
9.6(4.8)s	LHCs + MD	30.0(25.2)s	32(19)%

Future

FT flat top	Additional users	Super-cycle	FT duty cycle
7.2(9.6)(14.4)s	3×CNGS + LHCs + MD	40.8(43.2)(48.0)s	18(22)(30)%
7.2(9.6)(14.4)s	LHCs + MD	26.4(28.8)(33.6)s	27(33)(43)%

- The single injection from PS2 implies a gain up to **~10%** in cycle length
  - e.g. 43.2s instead of 48.0s for the case of a 9.6s flat top
- The 14.4s flat top, if technically possible, would correspond to **6.95×10^{12} pHz,** 40% more of today's maximum instantaneous rate for the experiments , and a **×2.15** gain in duty cycle compared to today
- *Note: The MD cycle (and LHCs) are needed to maintain the average power in the magnets within limits*

Implications for SPS North Area

Limitations – *main issues*

Long flat-top:
- average power to magnets and magnetic extraction septa

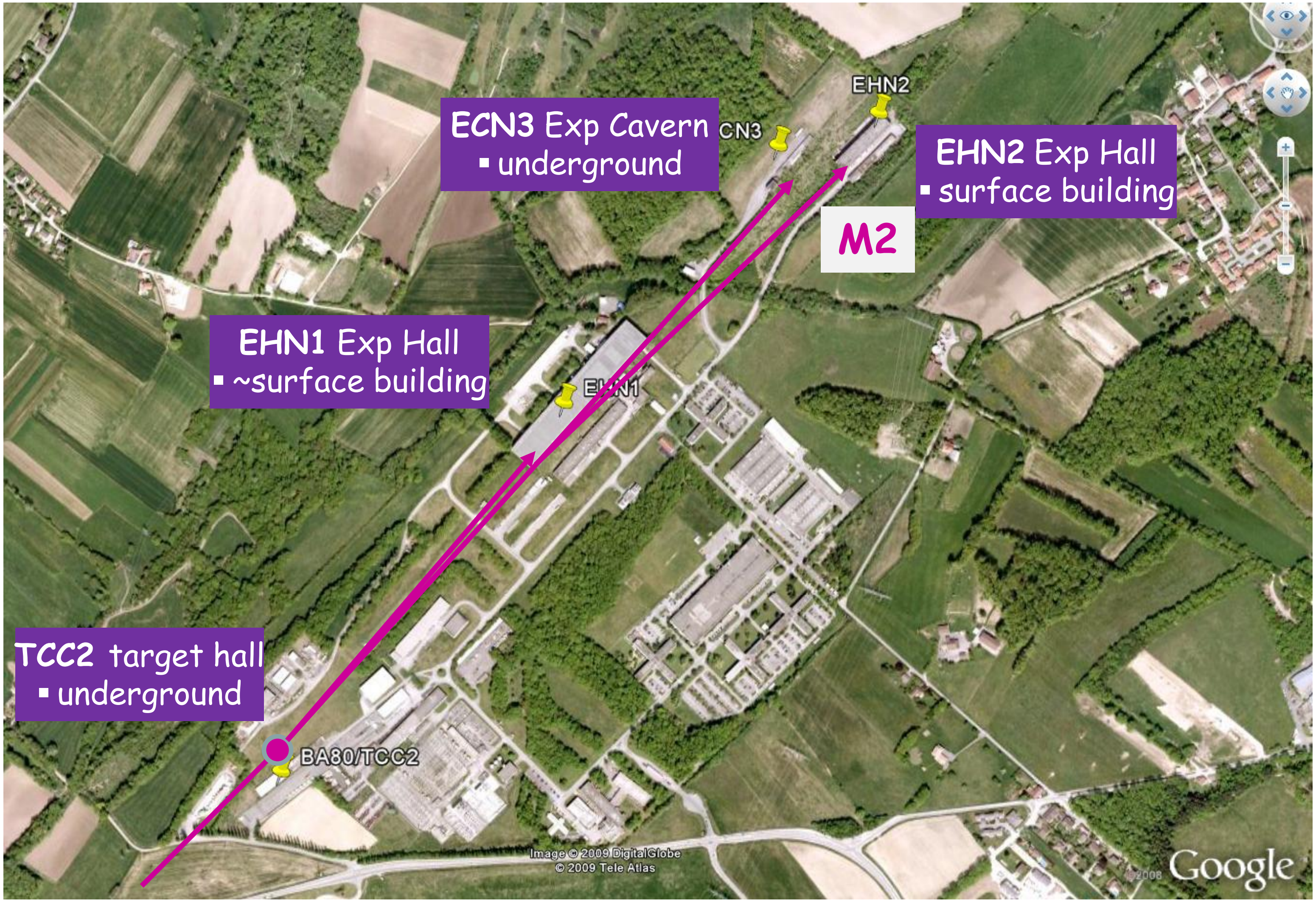
Intensity increase:
- Electrostatic septa:
  - beam losses and induced activation
  - temperature of the wires; sparks
  - Heating and deformation of ion-trap plates

- Losses in beam splitters

- Cooling of targets and TAX blocks :

- Shielding in surface experimental areas (intensity, muons, dumps)
  - EHN1, and EHN2 experimental halls

Experimental areas



Further possible improvements

- Radiation: Underground experimental area
- Increase of pion decay region, e.g. from 600 m to 1800 m would increase muon intensity by a factor ~3

Further physics opportunities

- LeHC
- extracted beams from LHC
- Neutrinos, CERN workshop in October 2009

Comparison

	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 MEUR	150M$	exists	beam exists

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

Summary

- CERN will remain a major player in spin flavour structure
- The existing facilities are in the same ball park as ENC@Fair and eRHIC light
- The biggest difference is the CMS energy of eRHIC light, which will allow to access lower x values.
- The injector upgrade ~ 2018 will provide a major intensity increase, provided the experimental areas and transfer lines are upgraded.
- More work is needed