Future GPD measurements using COMPASS at CERN

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On behalf of the COMPASS Collaboration
DIS 2013 – Marseille, April 25, 2013

1. **Physics Motivations**
2. **Experimental setup**
3. **Results of beam tests**
4. **New detectors**

The COMPASS-II program

DVCS & HEMP measurements

Transverse Imaging of the proton

Beam charge & spin

sum, difference and asymmetry

GPD H, later GPD E

Tests in 2008-9, 1-month run in 2012

Data taking 2016 & 17

Drell-Yan measurements

Sivers PDF

Boer Mulders PDF

Test of factorization approach

Data taking 2015

Upgrade existing COMPASS Spectro @ CERN/SPS

SIDIS expts

PDFs and Frag.F

s(x), Kaon FF

Data taking in parallel

Primakoff expts

π and K Polarizability

Chiral Dynamics

Data taking 2012

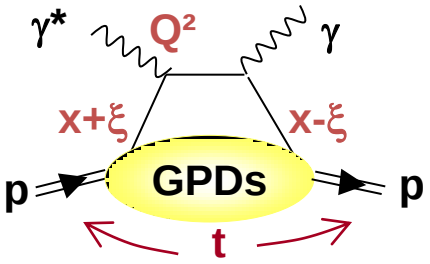
Proposal submitted to CERN: 05/2010

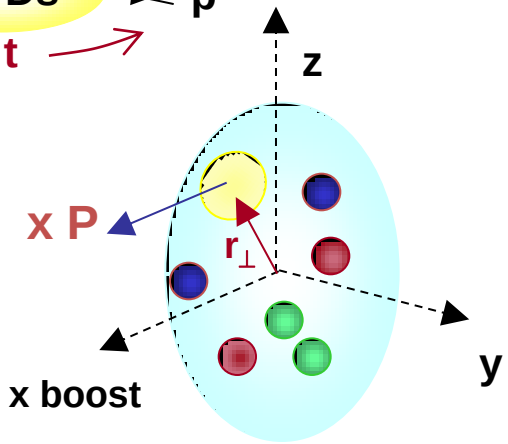
Approval 12/2010

Towards a 3-D nucleon picture ($P_{x}, r_{y,z}$)

Hard Exclusive Scattering
Deeply Virtual Compton Scattering

$ep \rightarrow ep\gamma$





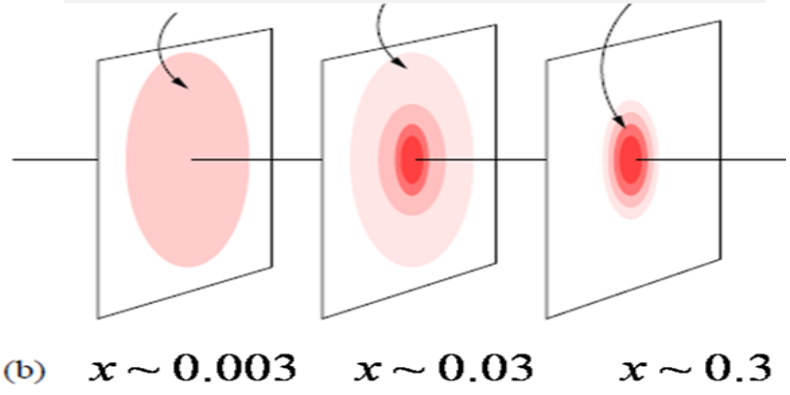
GPDs : H(x,ξ,t)

Fourier

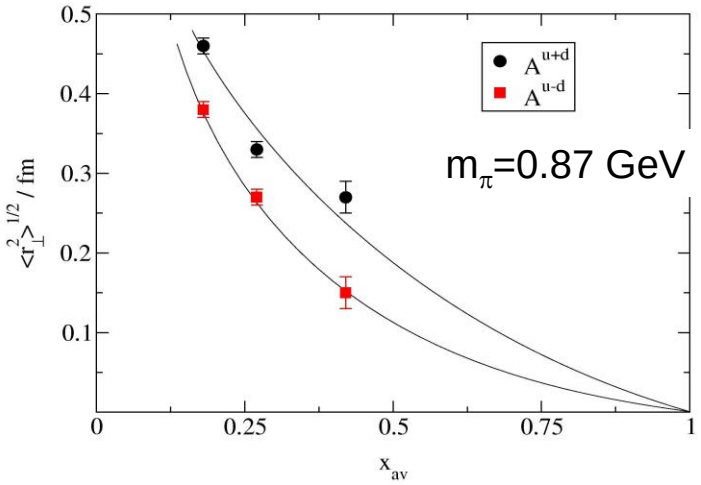
access to spatial distributions:

(P_x, $r_{y,z}$)

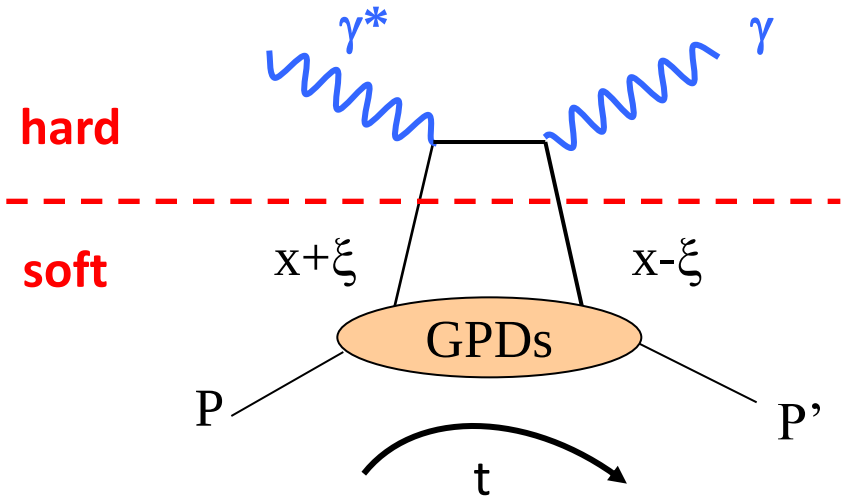
Nucleon tomography



Lattice calculation



Generalized Parton Distributions



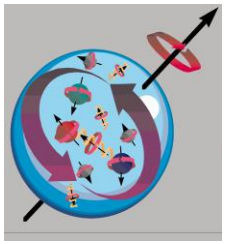
Factorisation:
Q^2 large, $-t<1$ GeV^2

Generalized Parton Distributions

for quarks :
4 functions $H, E, \tilde{H}, \tilde{E}(x,\xi,t)$
+ gluons
all also accessible with mesons

contains pdf
$H(x,0,0) = q(x)$
measured in DIS

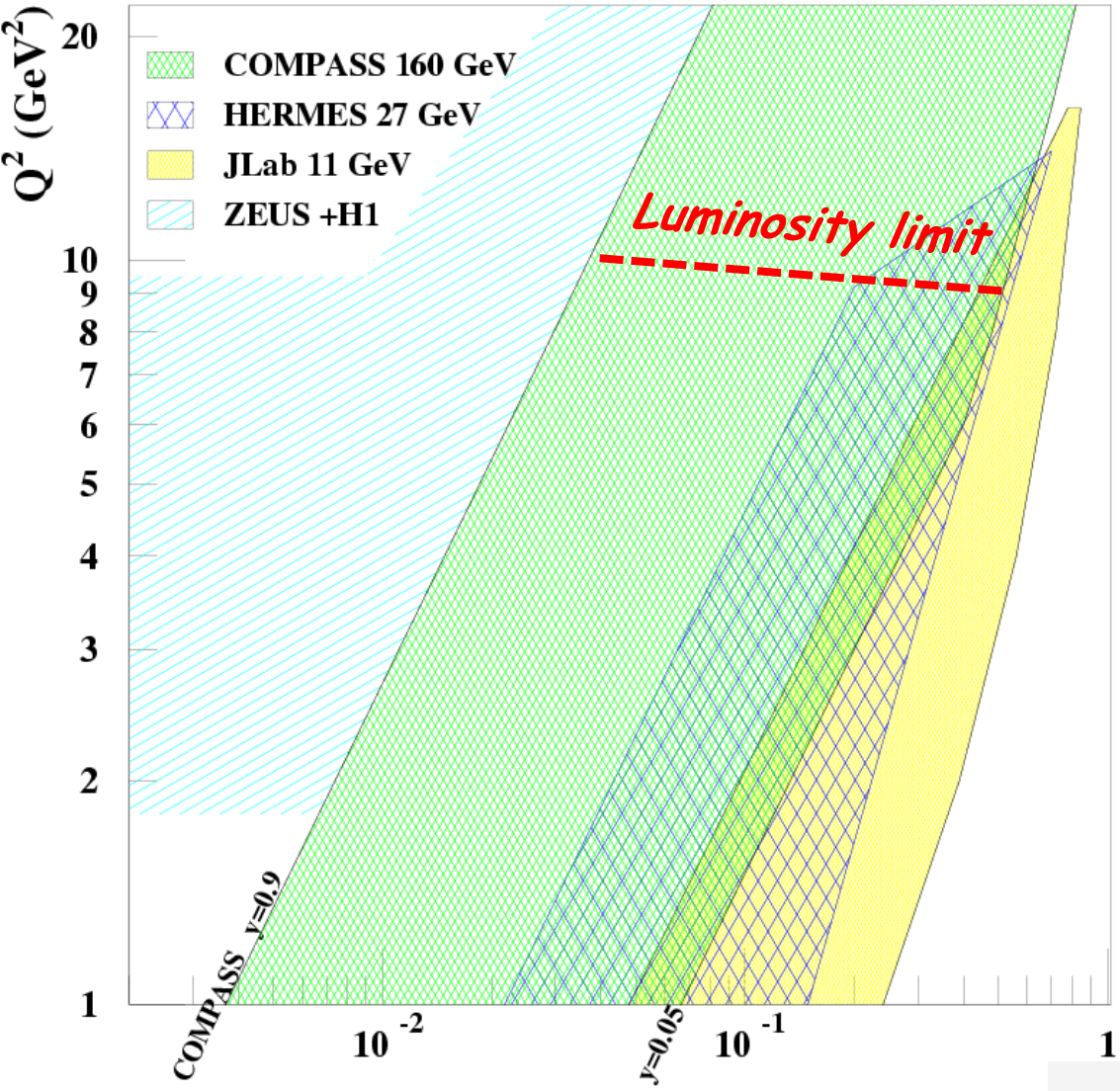
contains form factors
$$F(t) = \int dx H(x,\xi,t)$$
measured in elastic scattering



contains information on the nucleon spin :
Ji's sum rule :

$$\int x(H(x,\xi,t=0) + E(x,\xi,t=0))dx = J_z$$

What makes Compass unique ?



Gluon, sea and valence quarks

CERN High energy muon beam
- 100 - 190 GeV
- 80% Polarisation
- μ^+ and μ^- available
  - ✓Opposite polarization
  - ✓$I(\mu^+) = 2.4\ I(\mu^-)$

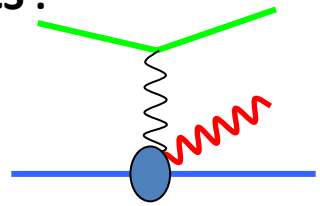
Foreseen program :
DVCS and meson production off a liquid H2 target (unpolarized)

⇒ Will explore the intermediate x_{Bj} region

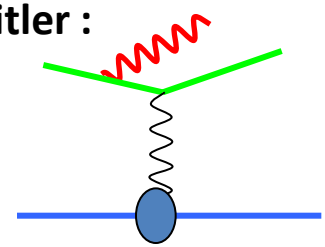
⇒ Uncovered region between ZEUS+H1 and HERMES+Jlab

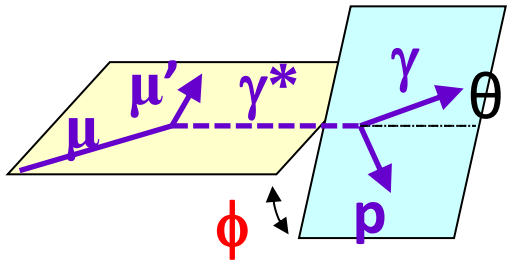
Comparison of BH and DVCS at 160 GeV (MC)

DVCS :

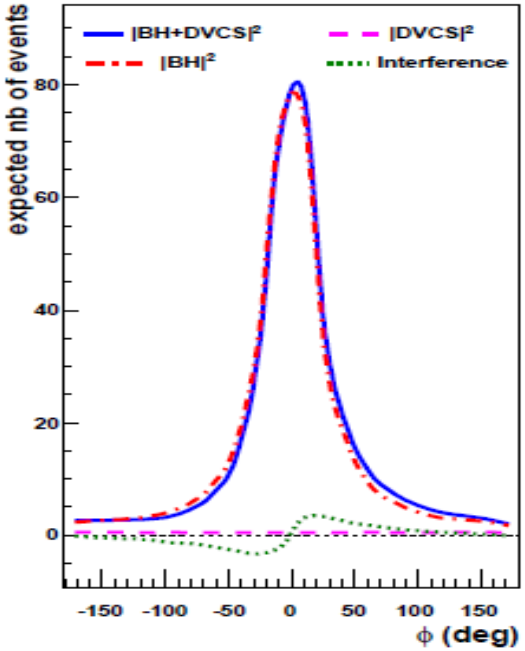


Bethe-Heitler :





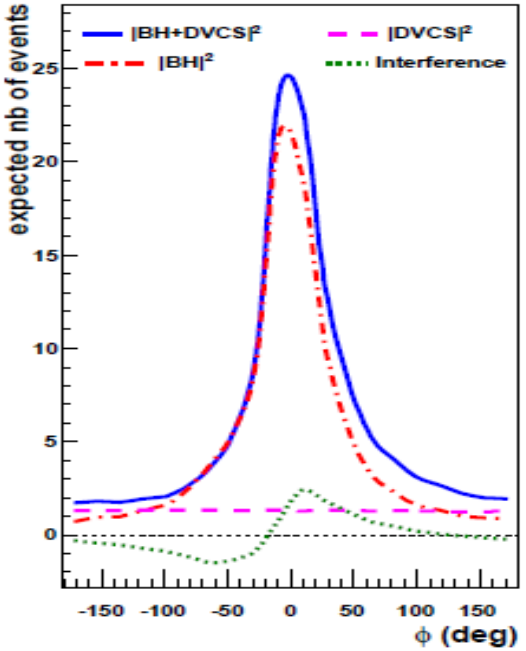
$0.005 < x_{Bj} < 0.01$



BH dominates

excellent
reference yield

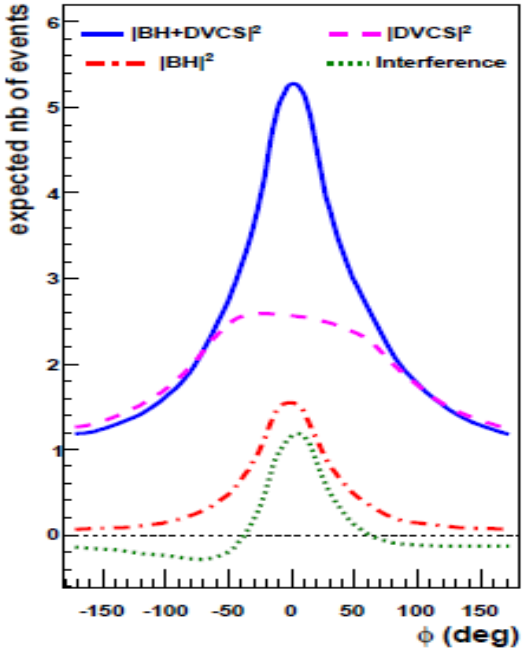
$0.01 < x_{Bj} < 0.03$



BH and DVCS at the same level

access DVCS *amplitude*
through the interference

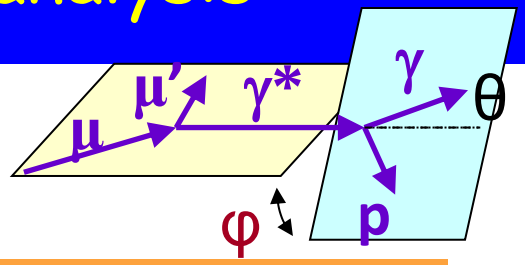
$x_{Bj} > 0.03$



DVCS dominates

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

Azimuthal angular dependence analysis



from Belitsky, Kirchner, Müller :
polarized beam off unpolarized target

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

$$d\sigma^{BH} = \frac{\Gamma(x_B, Q^2, t)}{P_1(\varphi)P_2(\varphi)}\left(c_0^{BH} + c_1^{BH}\cos\varphi + c_2^{BH}\cos 2\varphi\right) \leftarrow \text{Known expression}$$

$$d\sigma^{DVCS}_{unpol} = \frac{e^6}{y^2Q^2}\left(c_0^{DVCS} + c_1^{DVCS}\cos\varphi + c_2^{DVCS}\cos 2\varphi\right)$$

$$P_\mu \times \quad d\sigma^{DVCS}_{pol} = \frac{e^6}{y^2Q^2}\left(s_1^{DVCS}\sin\varphi\right)$$

$$e_\mu \times a^{BH}\,\mathcal{R}e\,A^{DVCS} = \frac{e^6}{xy^3tP_1(\varphi)P_2(\varphi)}\left(c_0^{Int} + c_1^{Int}\cos\varphi + c_2^{Int}\cos 2\varphi + c_3^{Int}\cos 3\varphi\right)$$

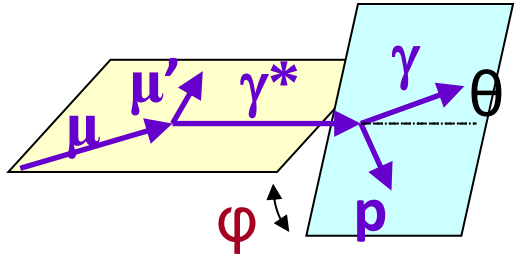
$$e_\mu P_\mu \times a^{BH}\,\mathcal{I}m\,A^{DVCS} = \frac{e^6}{xy^3tP_1(\varphi)P_2(\varphi)}\left(s_1^{Int}\sin\varphi + s_2^{Int}\sin 2\varphi\right)$$

Twist-2 >> Twist-3 Twist-2 gluon

Angular dependence analysis

Case of COMPASS : *μ+(P=-0.8) and μ-(P=+0.8)*

unpolarized H_2 target



$S_{U,CS}$: $d\sigma_{\mu+} + d\sigma_{\mu-} = 2(d\sigma^{BH} + d\sigma^{DVCS}_{unpol}) + 2\, e_\mu P_\mu a^{BH}\, Im\, A^{DVCS}$

$c_0^{DVCS+BH} + c_1^{DVCS+BH}\cos j + c_2^{DVCS+BH}\cos 2j$

=> dσ/dt

$s_1^{Int}\sin j + s_2^{Int}\sin 2j$

=> $Im(F_1\mathcal{H})$

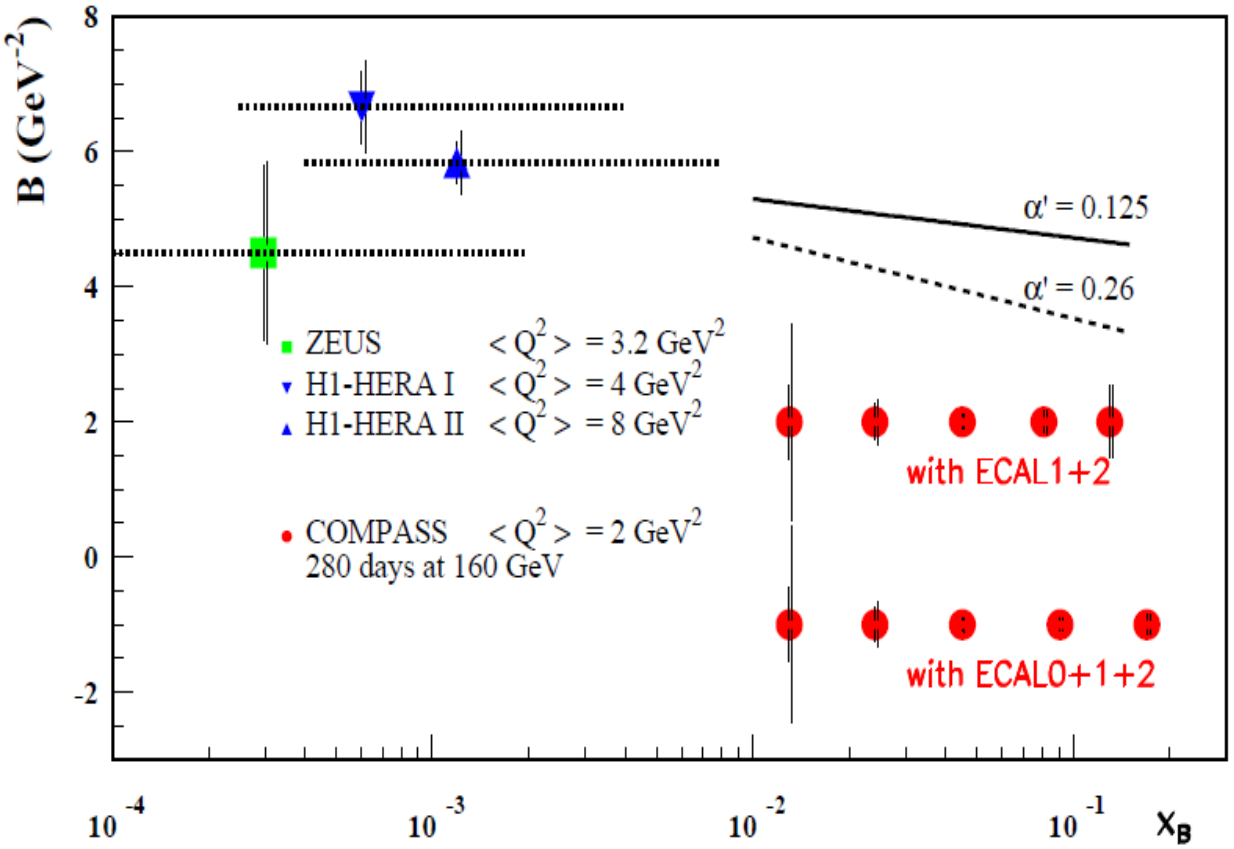
$\mathcal{D}_{U,CS}$: $d\sigma_{\mu+} - d\sigma_{\mu-} = 2\, P_\mu\, d\sigma^{DVCS}_{pol} + e_\mu\, a^{BH}\, \mathcal{R}e\, A^{DVCS}$

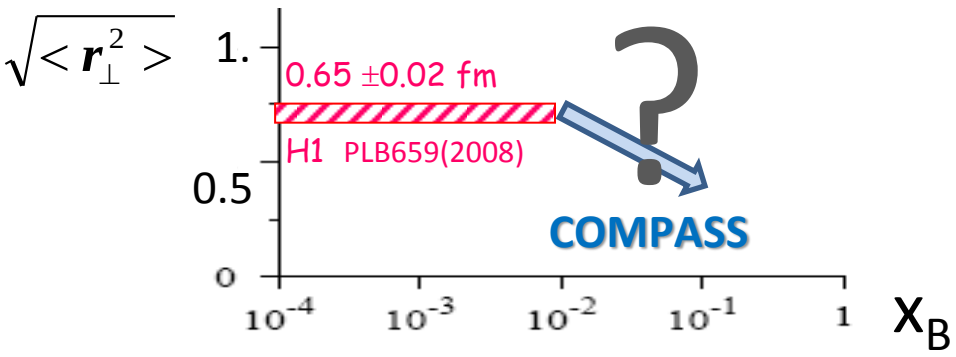
$s_1^{DVCS}\sin j$

$c_0^{Int} + c_1^{Int}\cos j + c_2^{Int}\cos 2j + c_3^{Int}\cos 3j$

=> $\mathcal{R}e(F_1\mathcal{H})$

From $S_{U,CS}$: transverse imaging





Using $S_{U,CS}$:

$d\sigma_{DVCS} / dt \sim \exp(-Bt)$

$B \sim \frac{1}{2} \langle r^2 \rangle$

Ansatz at small x :

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

$\alpha' = 0.125$ GeV^{-2} (FFS)

160 GeV muon beam
2.5m LH_2 target
2 years
L = 1222 pb^{-1}
ε_{global} = 10 %

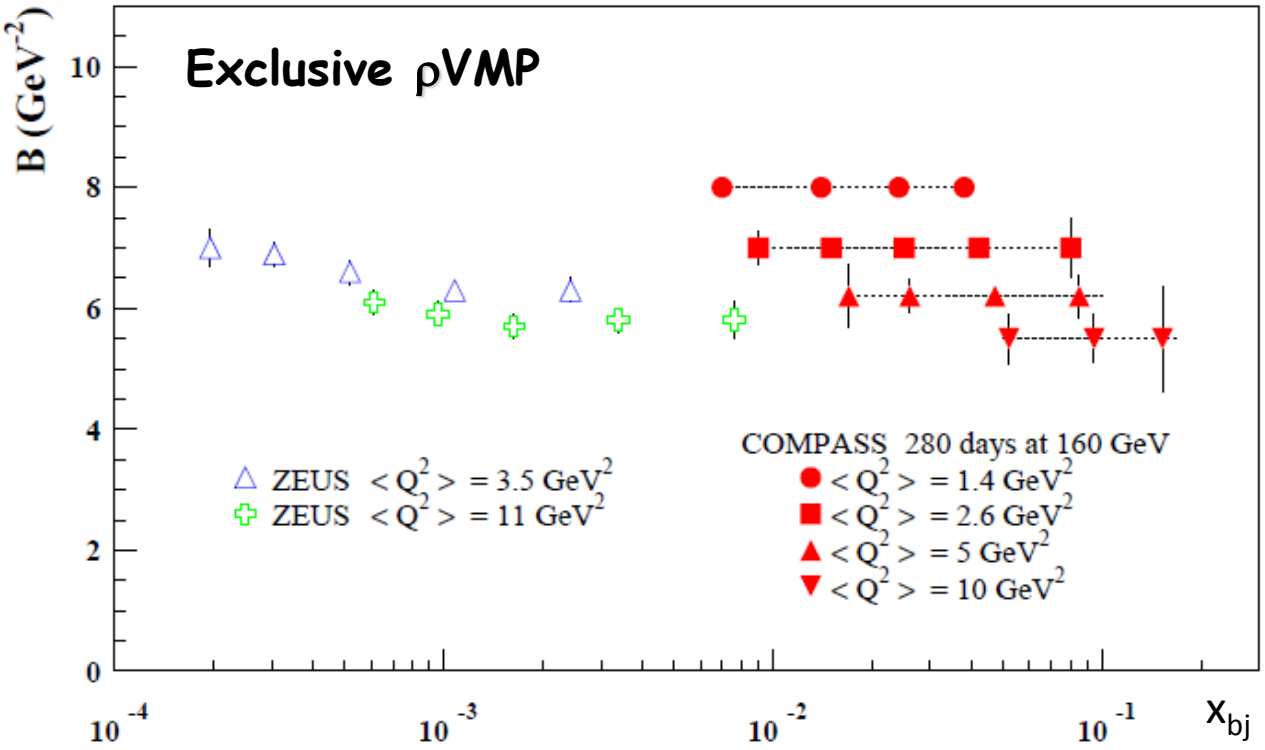
Assuming 3% syst. error on BH subtraction

2.5 σ slope meas. for :

$\alpha' > 0.26$ (ECAL 1+2)

$\alpha' > 0.125$ (ECAL 0+1+2)

Exclusive production of rho mesons



$d\sigma_{\rho VMP} / dt \sim \exp(-Bt)$

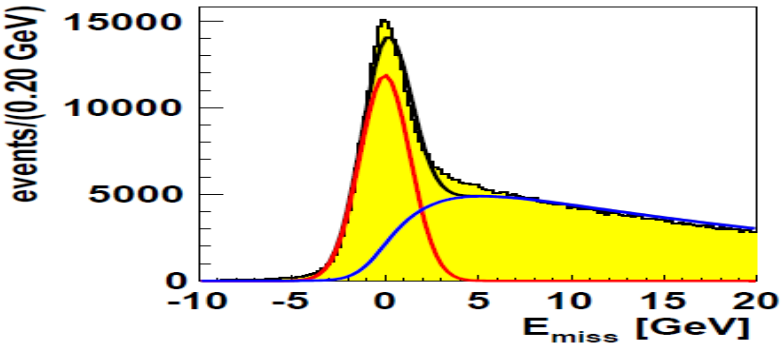
ρVMP model developed by A. Sandacz
Normalised according Goloskokov and Kroll

160 GeV muon beam
2.5m LH_2 target
2 years
L = 1222 pb^{-1}
ε_{global} = 10 %

Sensitive to the nucleon size + the transverse size of the meson

Q^2=1 GeV^2 B ~ 8 GeV^{-2}
Q^2=10 GeV^2 B ~ 5.5 GeV^{-2}

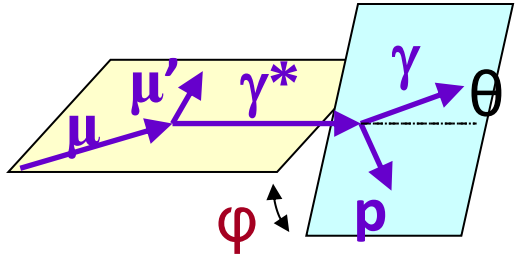
Already studied at Compass (without RPD)



Angular dependence analysis

Case of COMPASS : *μ+(P=-0.8) and μ-(P=+0.8)*

unpolarized H_2 target



$$\mathcal{S}_{U,CS} : d\sigma_{\mu+} + d\sigma_{\mu-} = 2(d\sigma^{BH} + d\sigma^{DVCS}_{unpol}) + 2\, e_\mu P_\mu a^{BH}\, Im\, A^{DVCS}$$

$$c_0^{DVCS+BH} + c_1^{DVCS+BH}\cos j + c_2^{DVCS+BH}\cos 2j \;\Rightarrow\; d\sigma/dt$$

$$s_1^{Int}\sin j + s_2^{Int}\sin 2j \;\Rightarrow\; Im\,(F_1\mathcal{H})$$

$$\mathcal{D}_{U,CS} : d\sigma_{\mu+} - d\sigma_{\mu-} = 2\, P_\mu\, d\sigma^{DVCS}_{pol} + e_\mu\, a^{BH}\, \mathcal{R}e\, A^{DVCS}$$

$$s_1^{DVCS}\sin j$$

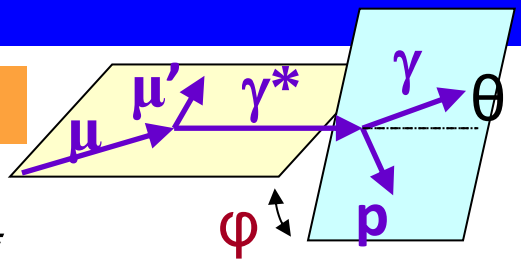
$$c_0^{Int} + c_1^{Int}\cos j + c_2^{Int}\cos 2j + c_3^{Int}\cos 3j \;\Rightarrow\; \mathcal{R}e\,(F_1\mathcal{H})$$

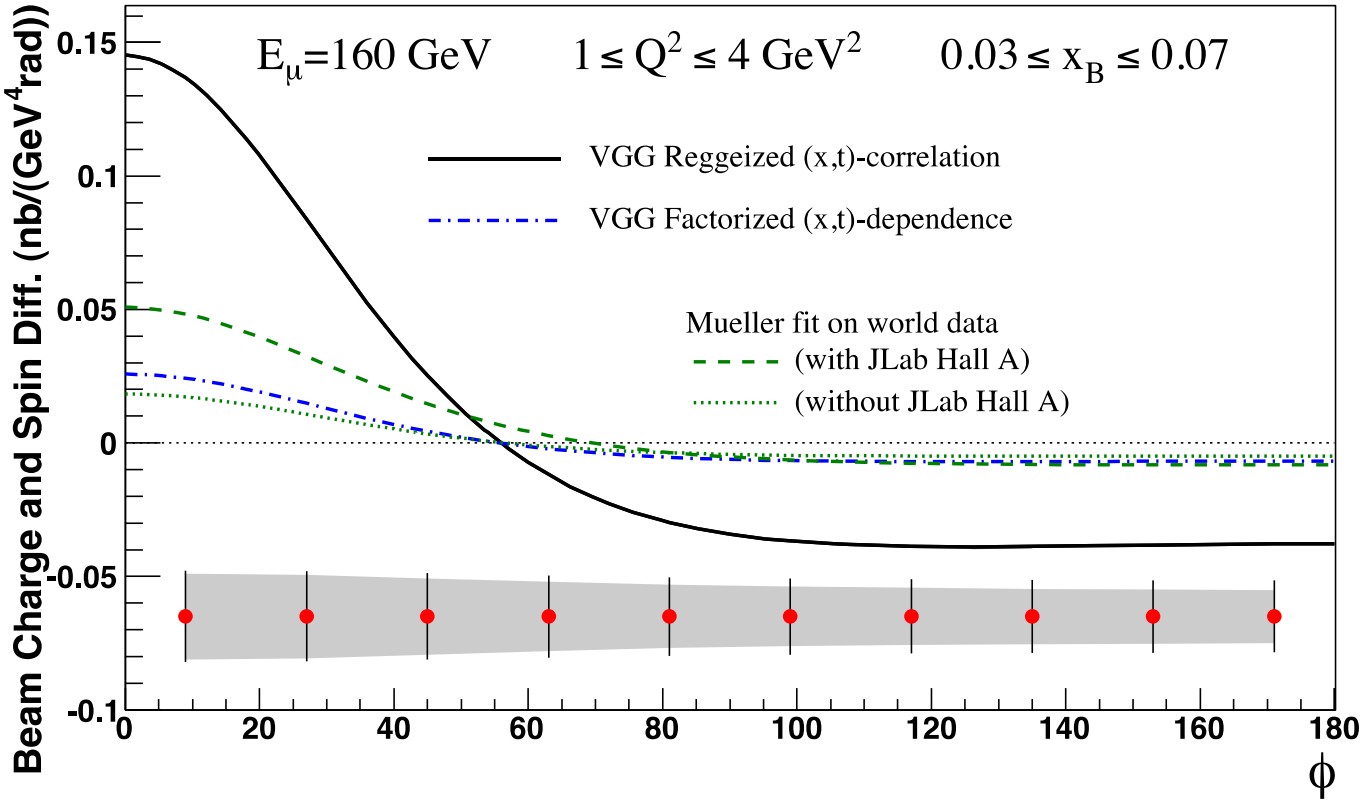
$\mathcal{D}_{U,CS}$: Beam Charge & Spin Difference

$\mathcal{D}_{U,CS}$: $d\sigma_{\mu^+} - d\sigma_{\mu^-} = 2\, P_\mu\, d\sigma^{DVCS}_{pol} + e_\mu\, a^{BH}\, \mathcal{R}e\, A^{DVCS}$

$s_1^{DVCS} \sin j$

$c_0^{Int} + c_1^{Int} \cos j + c_2^{Int} \cos 2j + c_3^{Int} \cos 3j$





160 GeV muon beam
2.5m LH_2 target
2 years
$L = 1222\ pb^{-1}$
$\varepsilon_{global} = 10\ \%$

$.... + c_1^{Int} \cos j + ...$

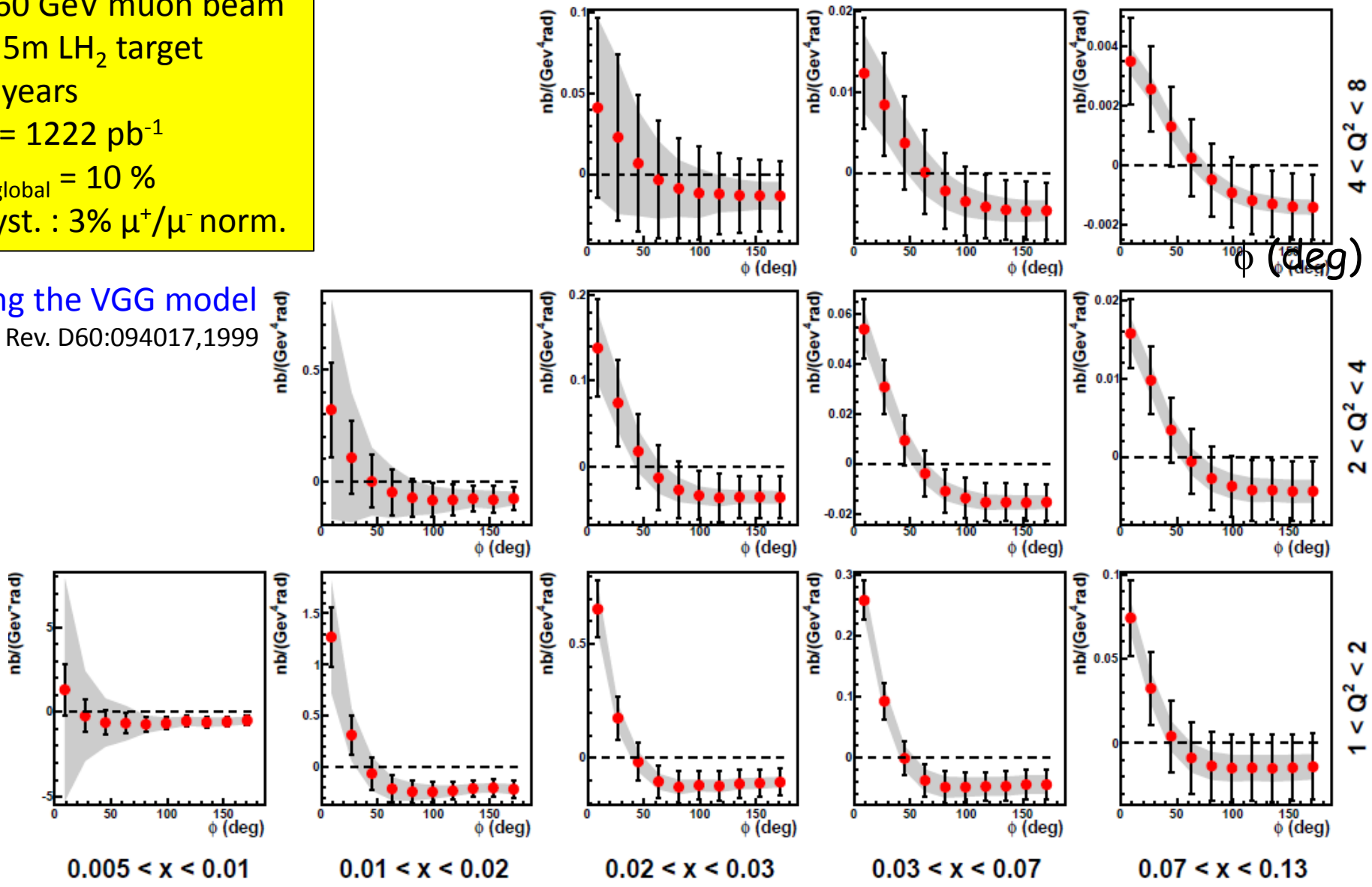
$\Rightarrow \mathcal{R}e\,(F_1\mathcal{H})$

Systematic errors : 3% charge-dependent effect between μ+ and μ-

$\mathcal{D}_{u,cs}$ (□) over the kinematical domain

160 GeV muon beam
2.5m LH_2 target
2 years
$L = 1222\ pb^{-1}$
$\varepsilon_{global} = 10\ \%$
Syst. : 3% μ^+/μ^- norm.

using the VGG model
Phys. Rev. D60:094017,1999

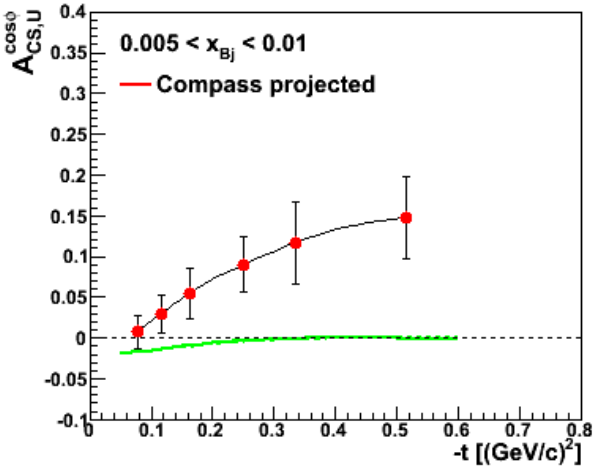


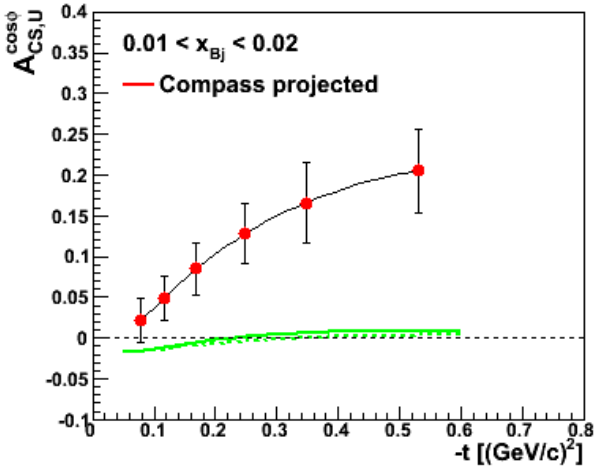
Sensitivity of COMPASS: cosϕ modulation

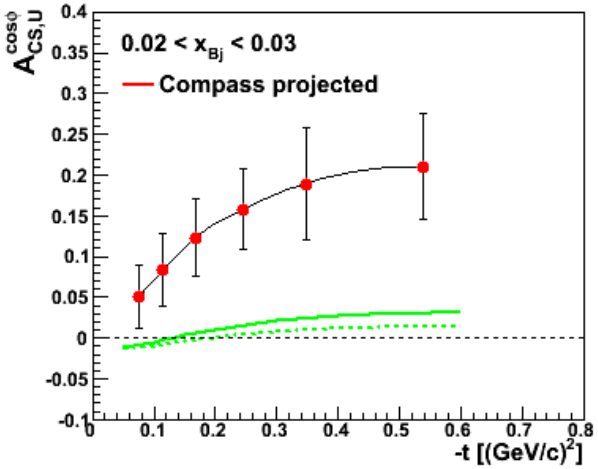
$BCSA = \mathcal{D}_{U,CS} / S_{U,CS} = A_0 + A_{CS,U} \cos\phi + A_2 \cos 2\phi$

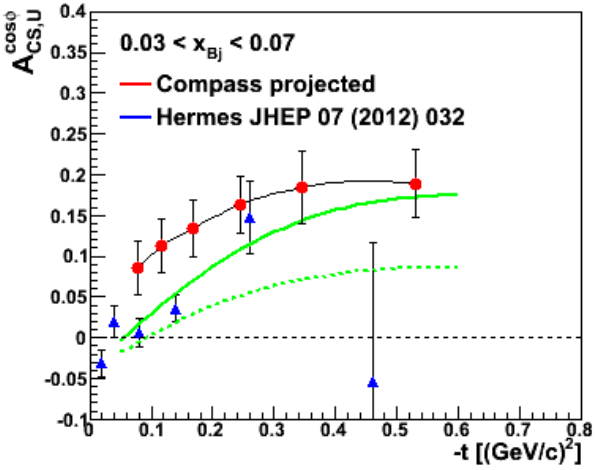
Þ related to c_1^{Int}

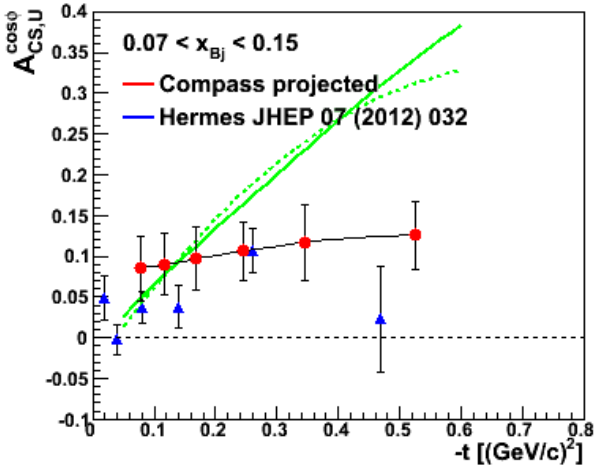
Mueller's fit on world data'
(with JLab Hall A)
(without JLab Hall A)

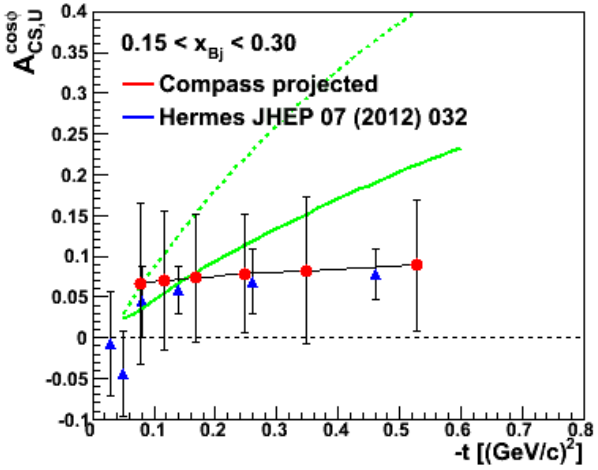


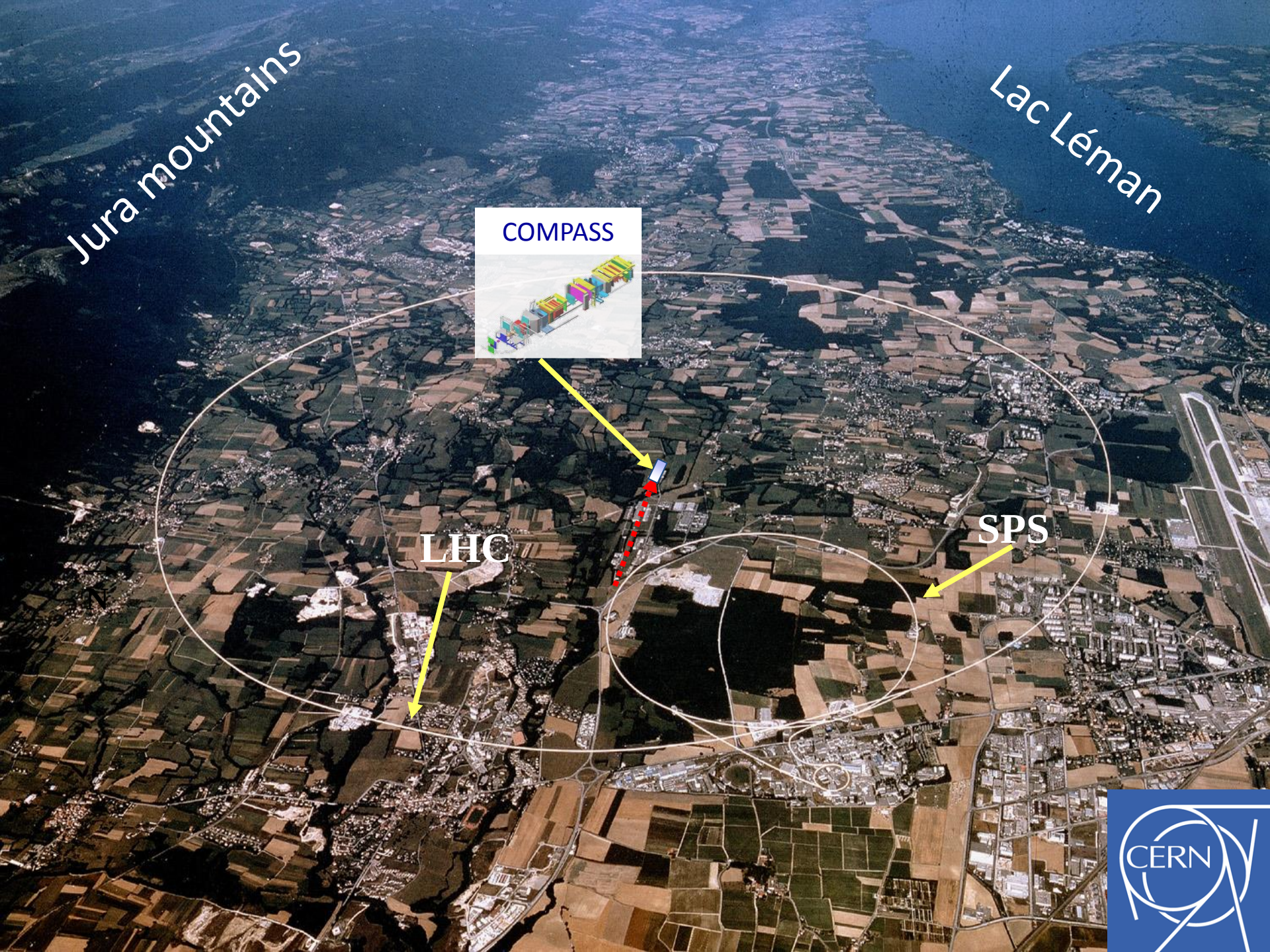




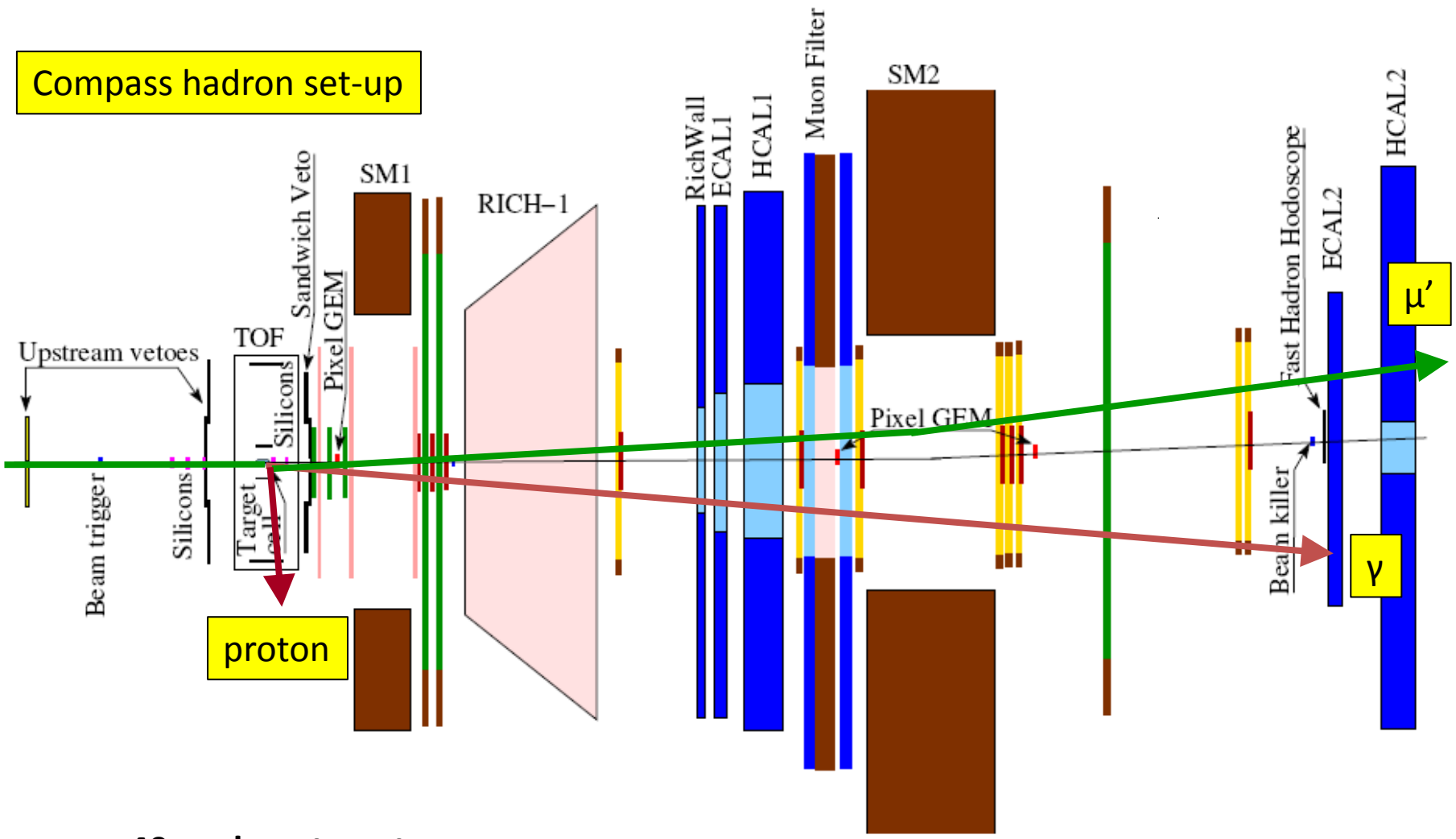






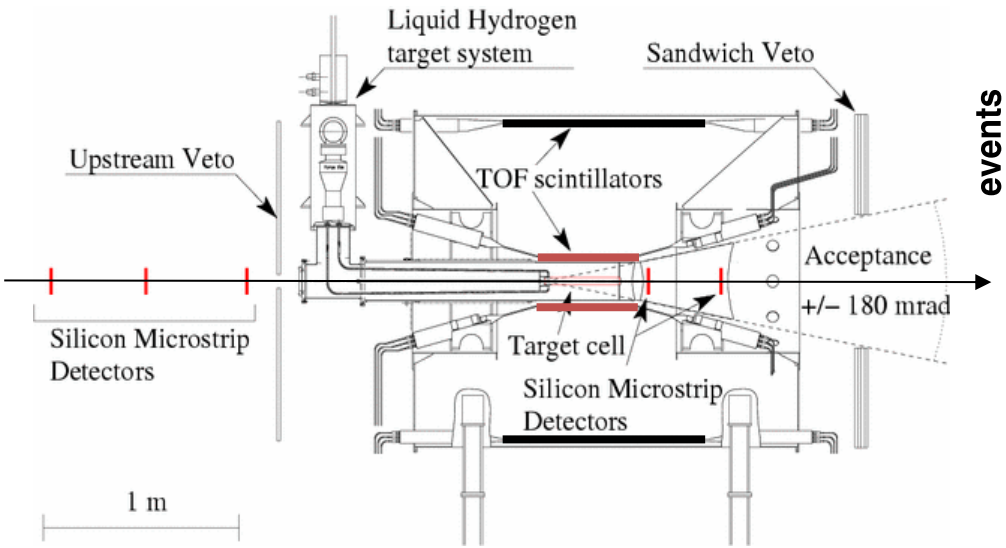

Jura mountains
Lac Léman
COMPASS
LHC
SPS
N
CERN

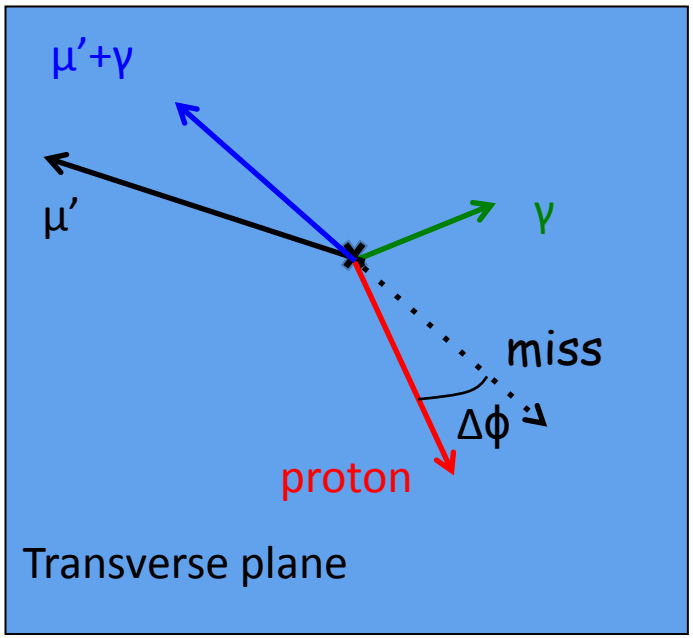
2009 Experimental setup

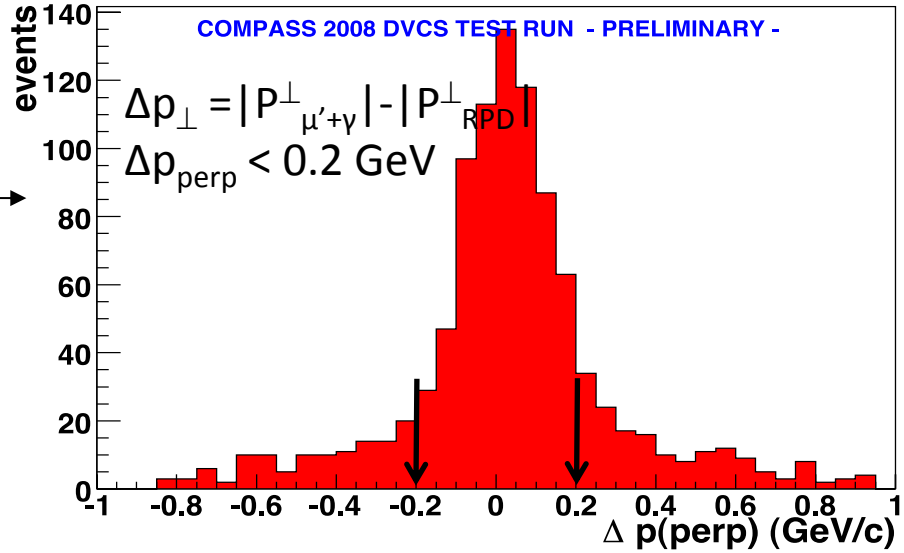


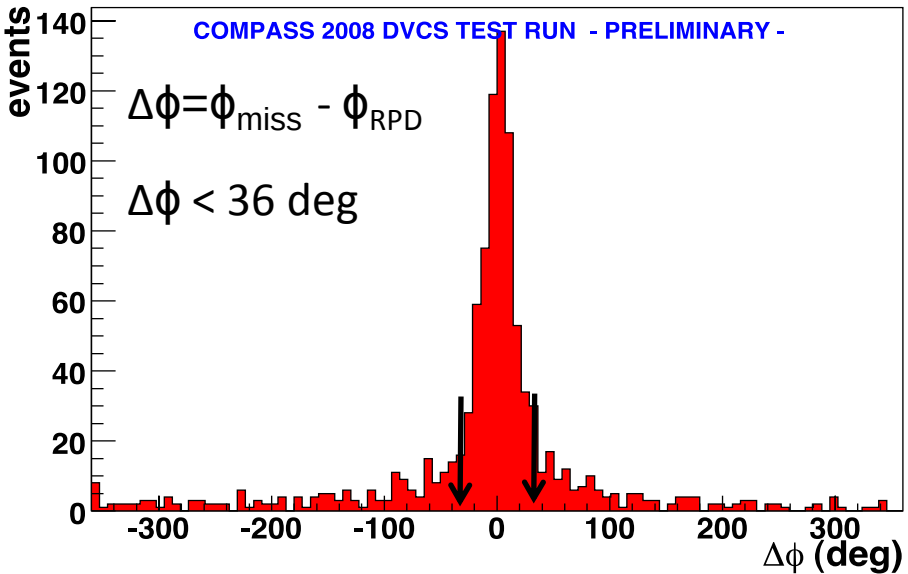
- 40 cm long target
- « Small » Recoil Proton Detector

2008-9 beam test : exclusivity cuts

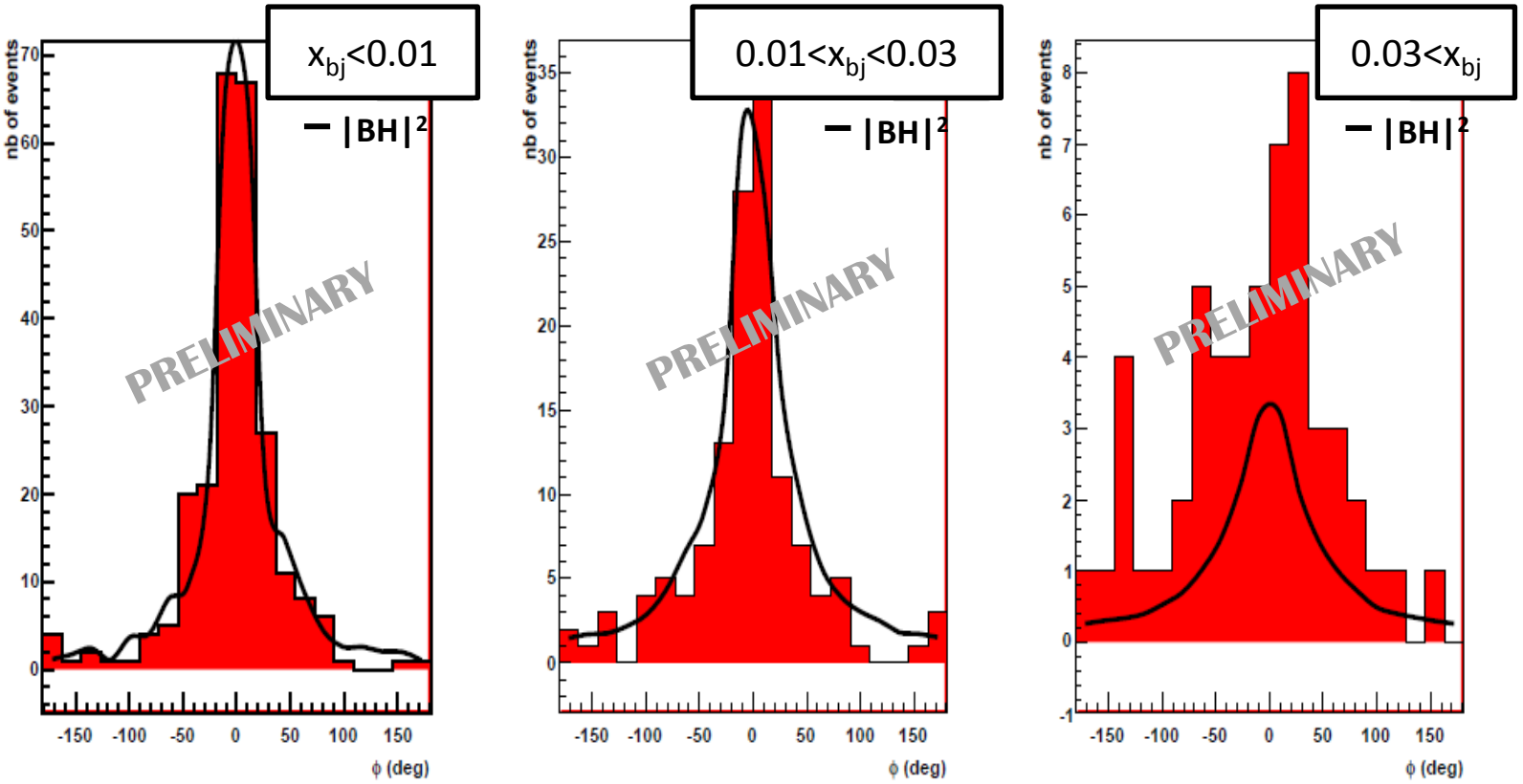








2009 beam test : DVCS signal



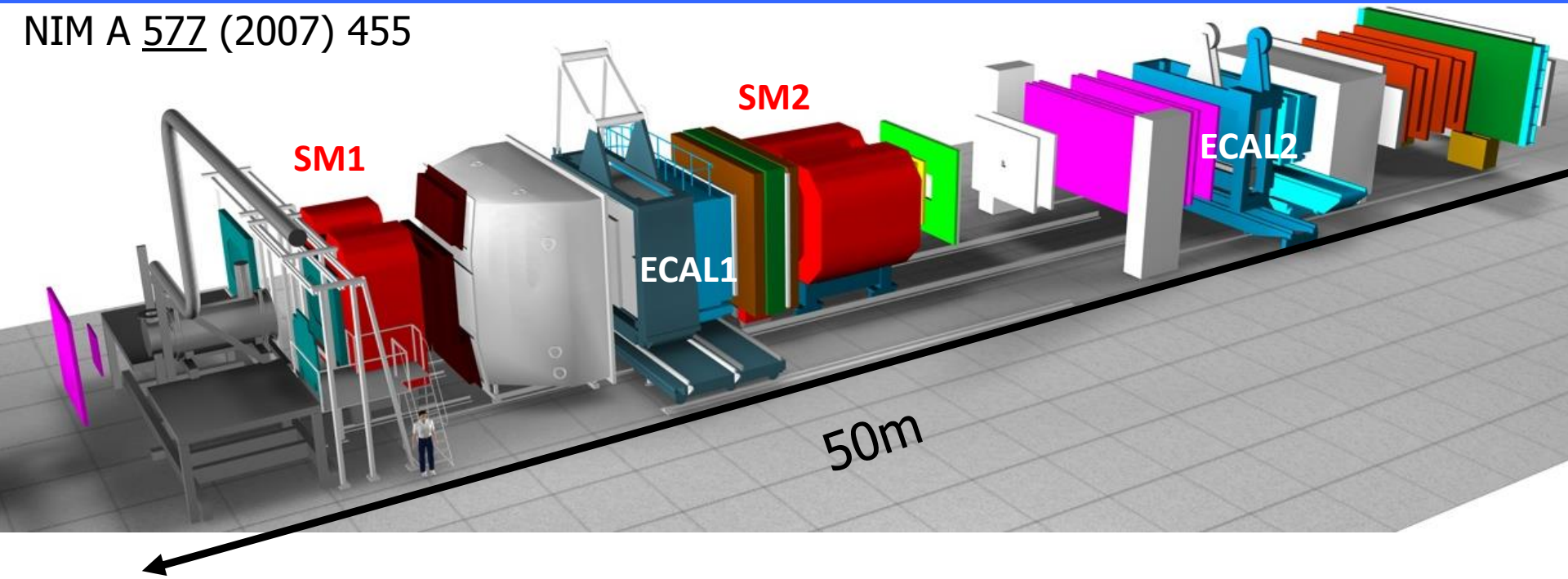
1 week data – 40 cm long target

=> Excess of events for x_{bj}>0.03 is a sign for DVCS

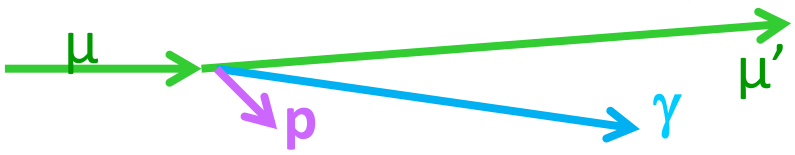
⇒ Efficiency as estimated in COMPASS-II proposal

The COMPASS experiment at CERN

NIM A 577 (2007) 455



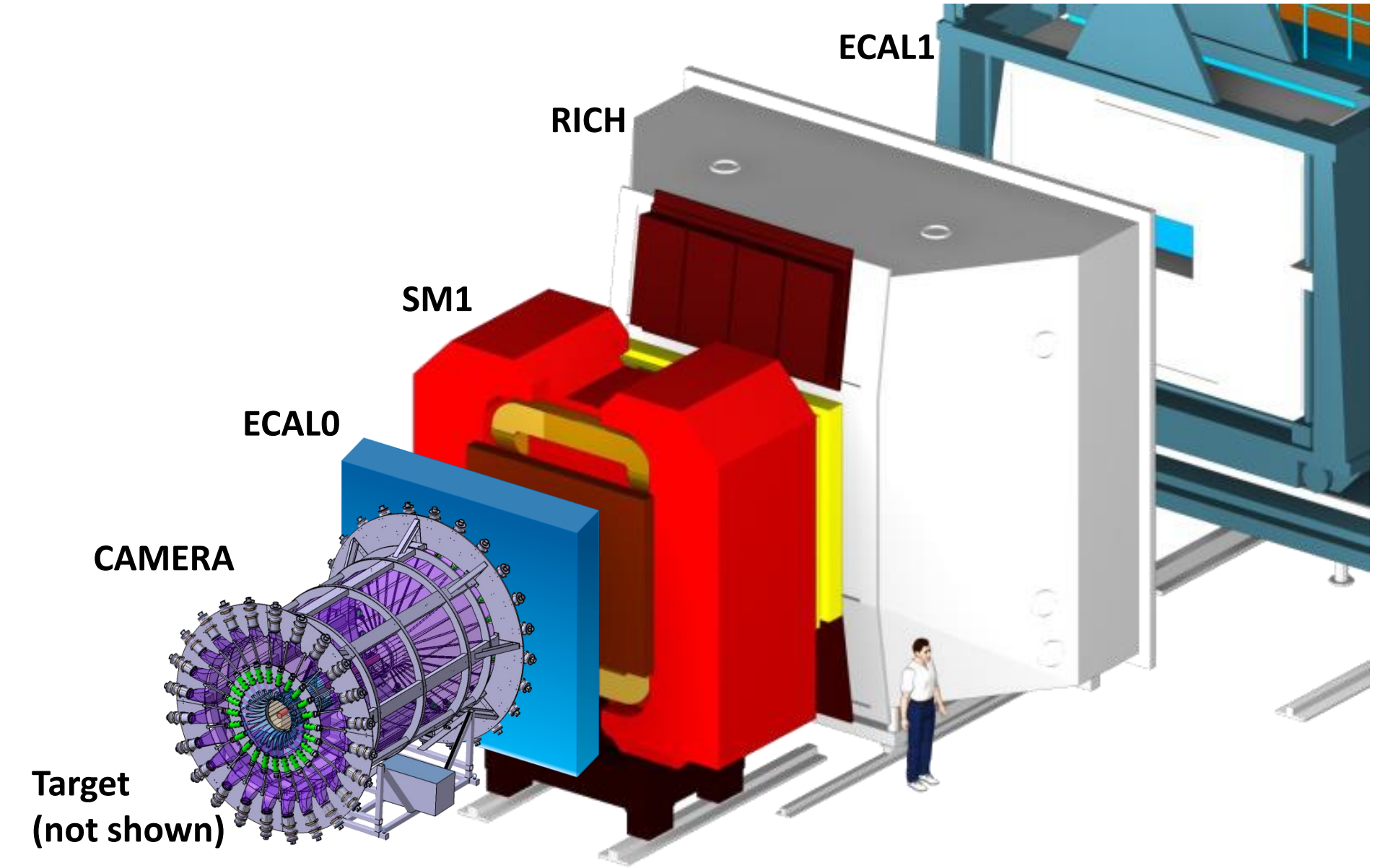
DVCS : μ p → μ' p γ



New equipements built :

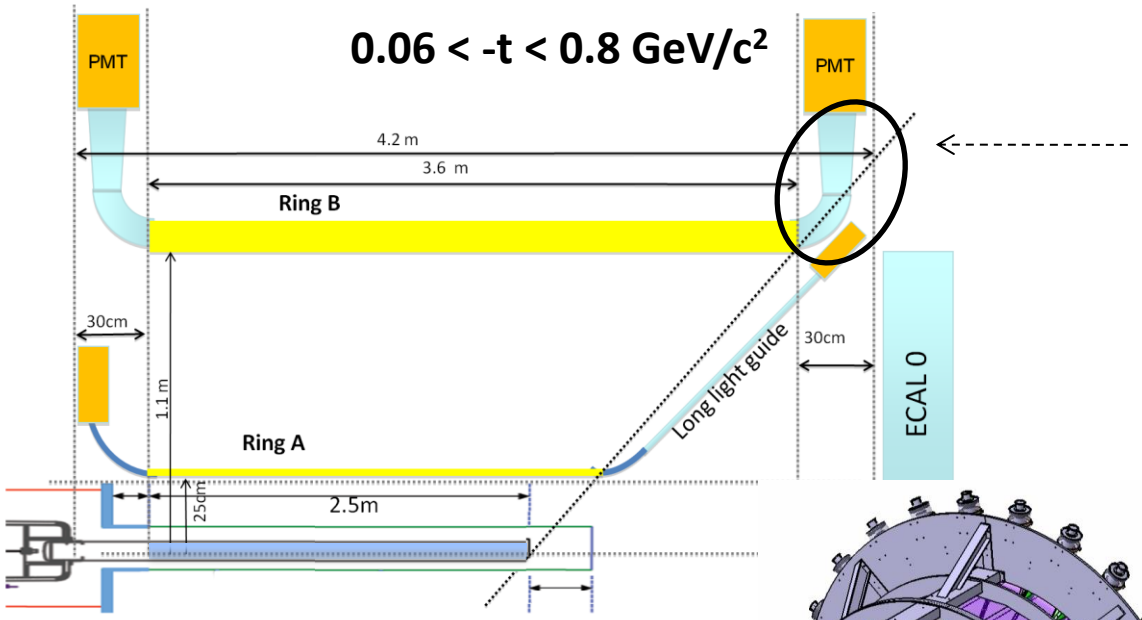
- ✓ 2.5m LH2 target
- ✓ 4m ToF Recoil particle detector
  - ✓ CAMERA
- ✓ ECAL0 (1/4 avail. for 2012 run)
- ✓ Rearrangement of ECAL1,2

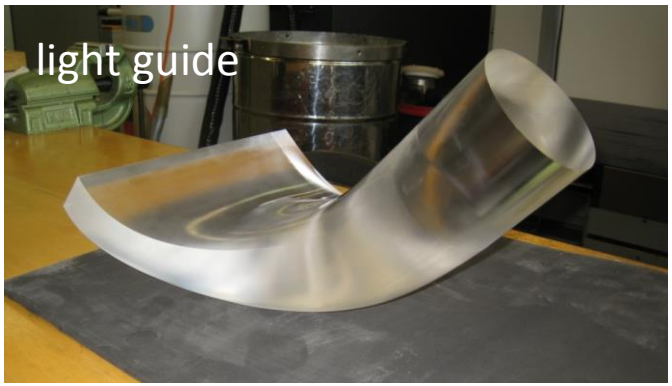
Upgrades of COMPASS spectrometer

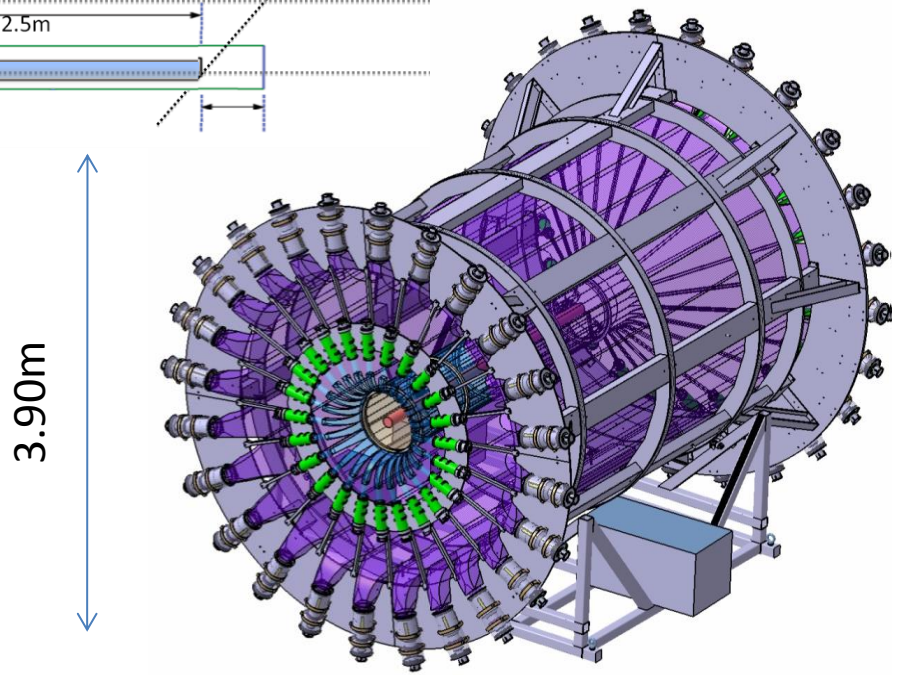


Recoil Proton Detector CAMERA

ToF between 2 rings of plastic scintillators σ(ToF) < 350ps







Specifications

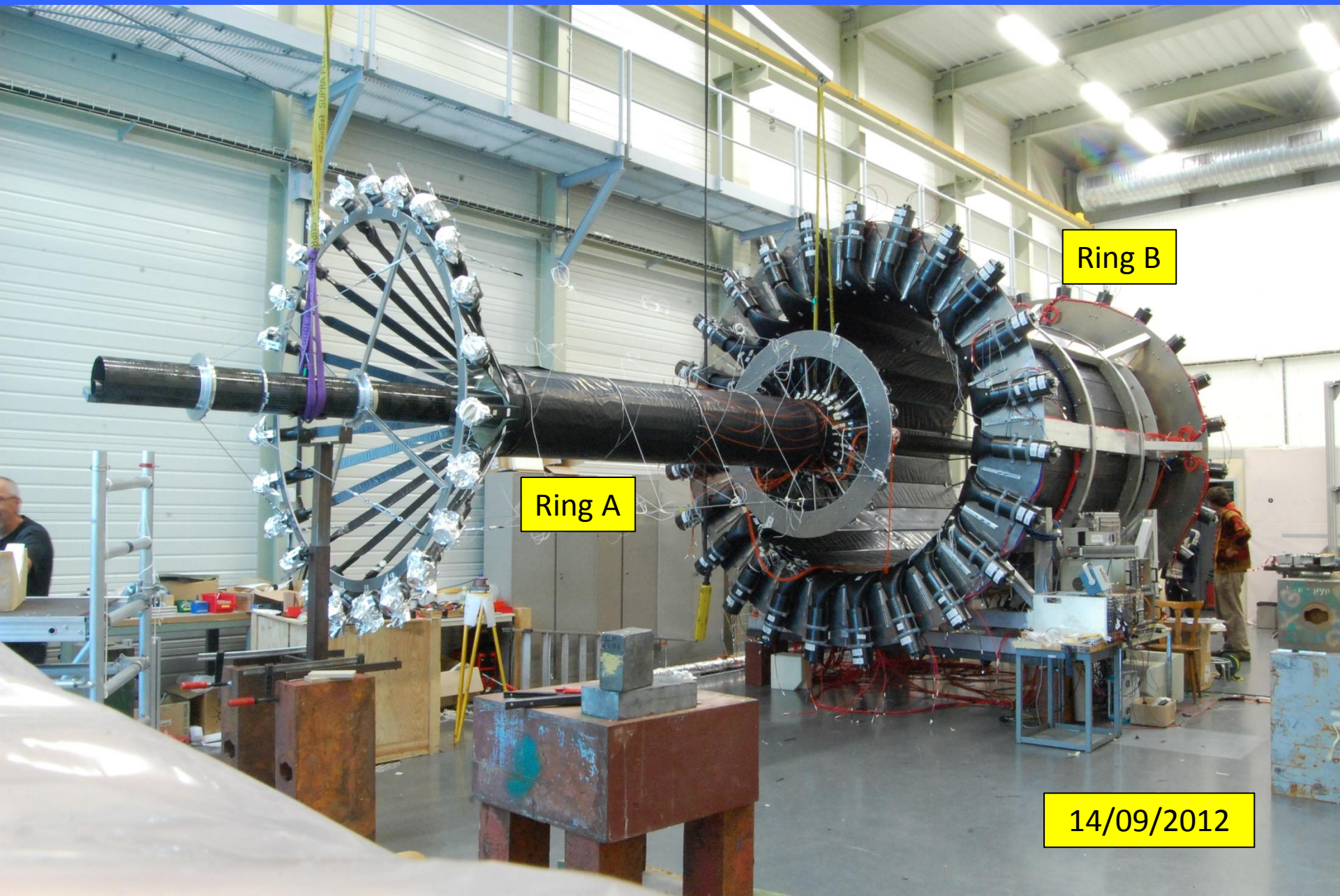
Ring A :

- 4mm thick, 280 cm long
- 310 ps
- Light holding structure

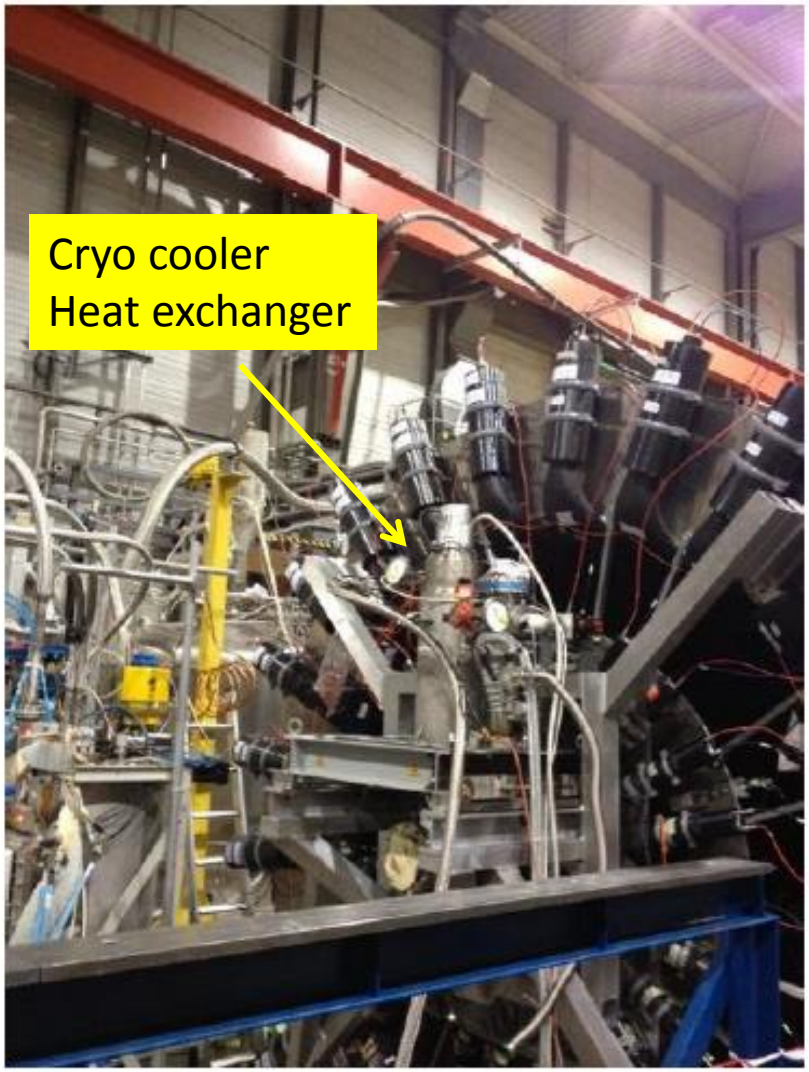
Ring B :

- 5cm thick, 360 cm long
- 180ps

Mounting in clean room at CERN



2.5 m long Liquid Hydrogen Target



CAMERA read out : Gandalf Boards

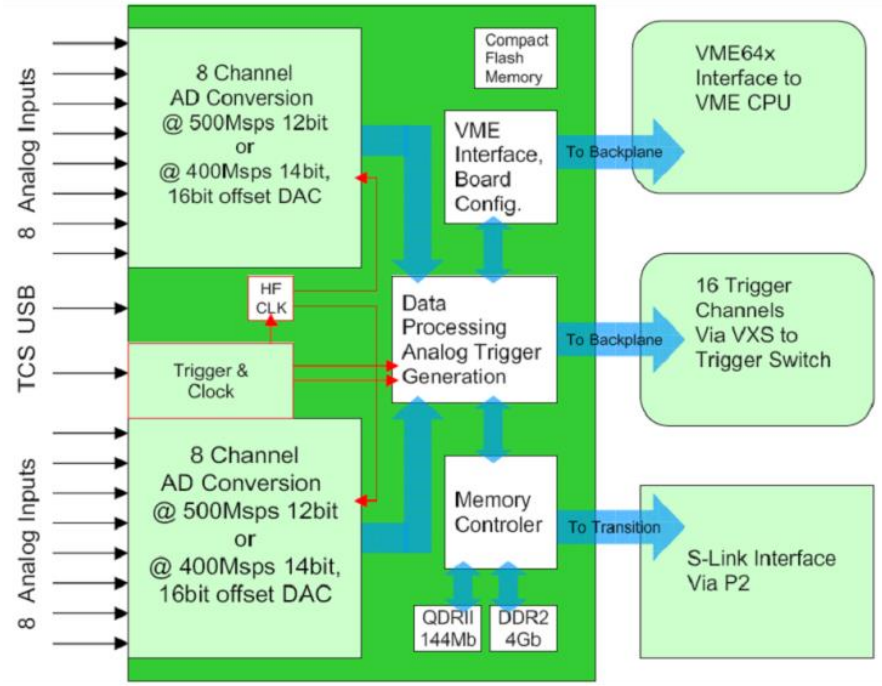
1 GHz digitization of the 96 PMT signals

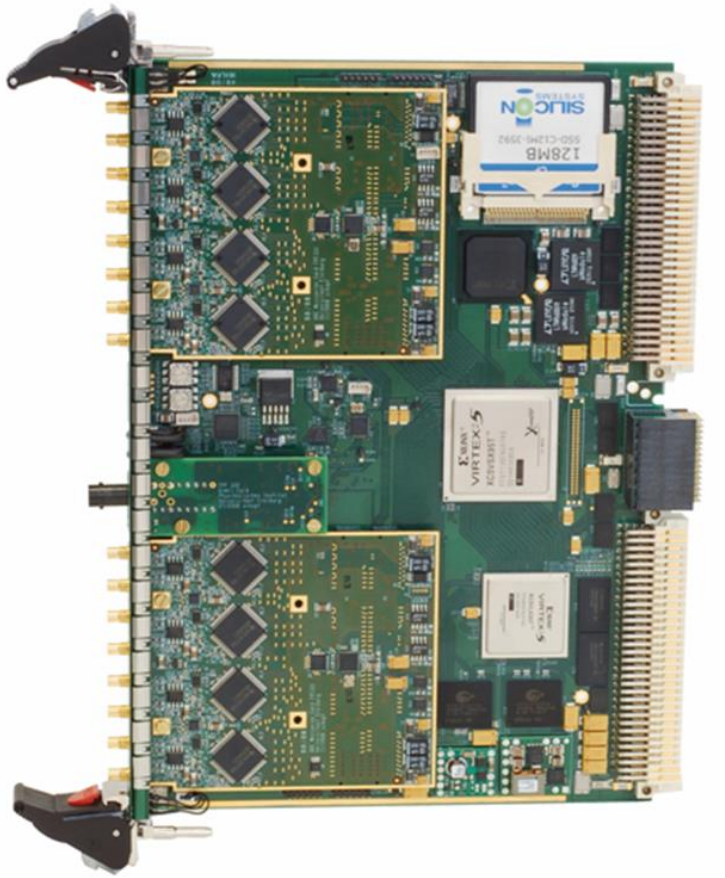
Waveform treatment performed and the board

Data sent to 2 logic units (VXS backplane) : TIGER boards

⇒ One board for data concentration and DAQ

⇒ One board for level 1 trigger

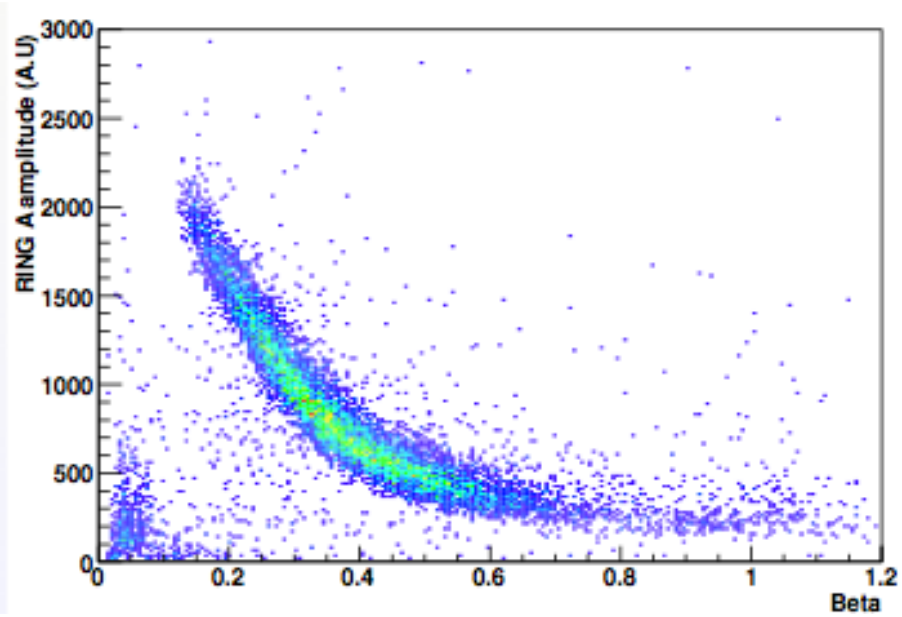


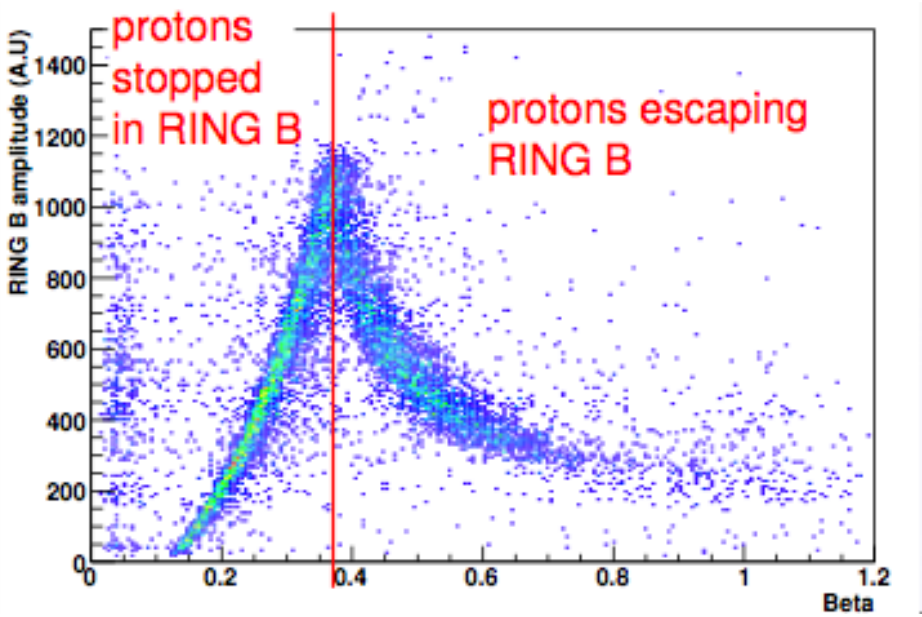


CAMERA performances

Calibration with the pion beam with elastic events ($\pi p \rightarrow \pi p$)

➔ Similar pictures for 2 x 24 pairs of scintillator counters



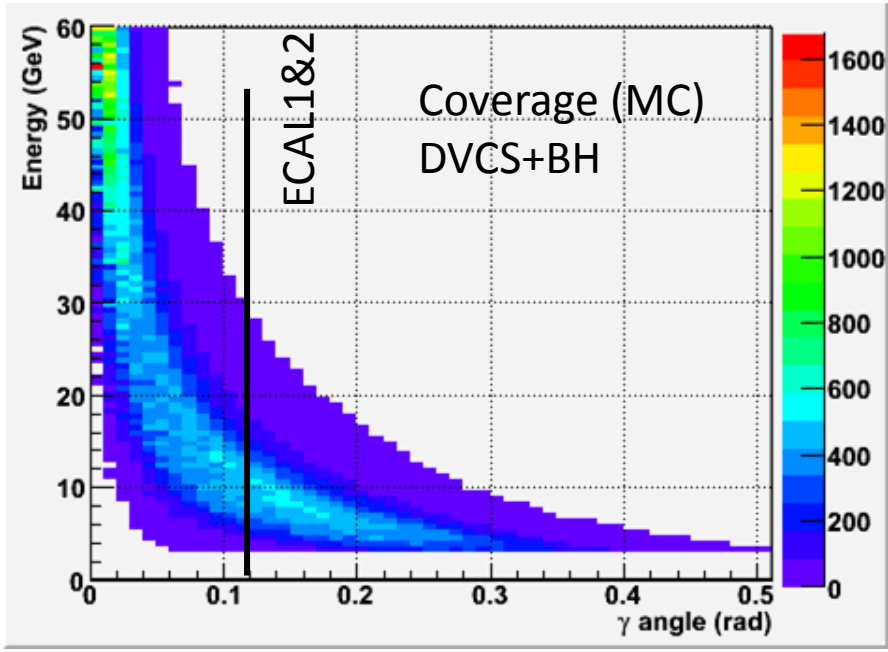


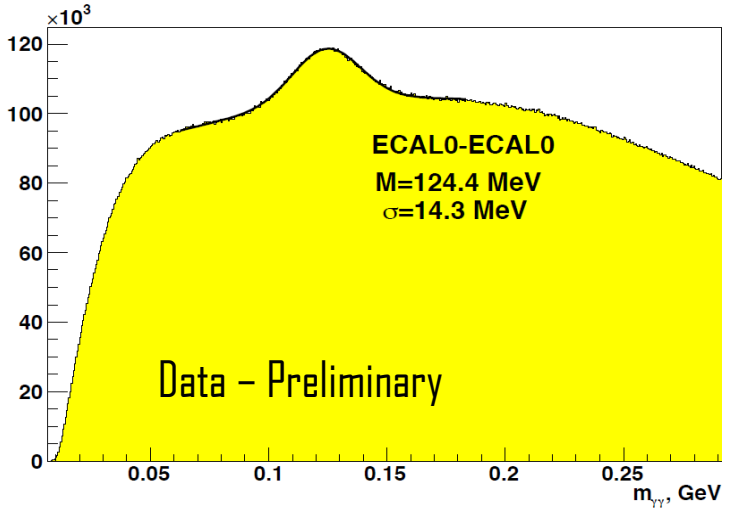
ECAL 0

Requirements

- Photon energy range 0.2- 30 GeV
- Size: 240cm x 240cm ;
- Granularity 4x4 cm^2
- Shaschlyk module with MAPD readout
- Energy resolution < 10.0%/√E (GeV)
- Thickness < 50 cm,
- Insensitive to the magnetic field.

Reduced setup in 2012 (1/4 of total)





Conclusions & perspectives

the COMPASS-II experiment has started

- Wide physics case proposed :
  GPDs, TMDs, Chiral perturbation theory, unpolarized PDFs

COMPASS has a great potential in GPDs physics

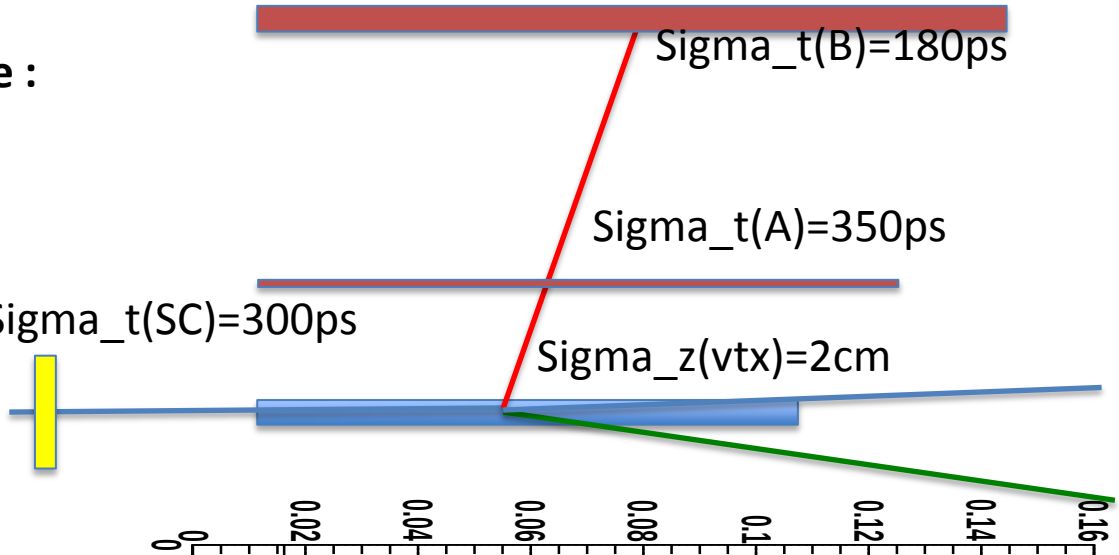
- Study of the GPD H with a LH2 target: 2016-2017
  measurement ot t-slopes – transverse partonic structure of the nucleon
  measurement of Beam Charge and Spin differences & asymmetries
- Equipments built for this program:
  4m long RPD, 2.5m LH2 target, Extended & improved calorimetry
  2012 test run – full experiment evaluation

Future possible developments:
study of the GPD E with a transversely polarized target

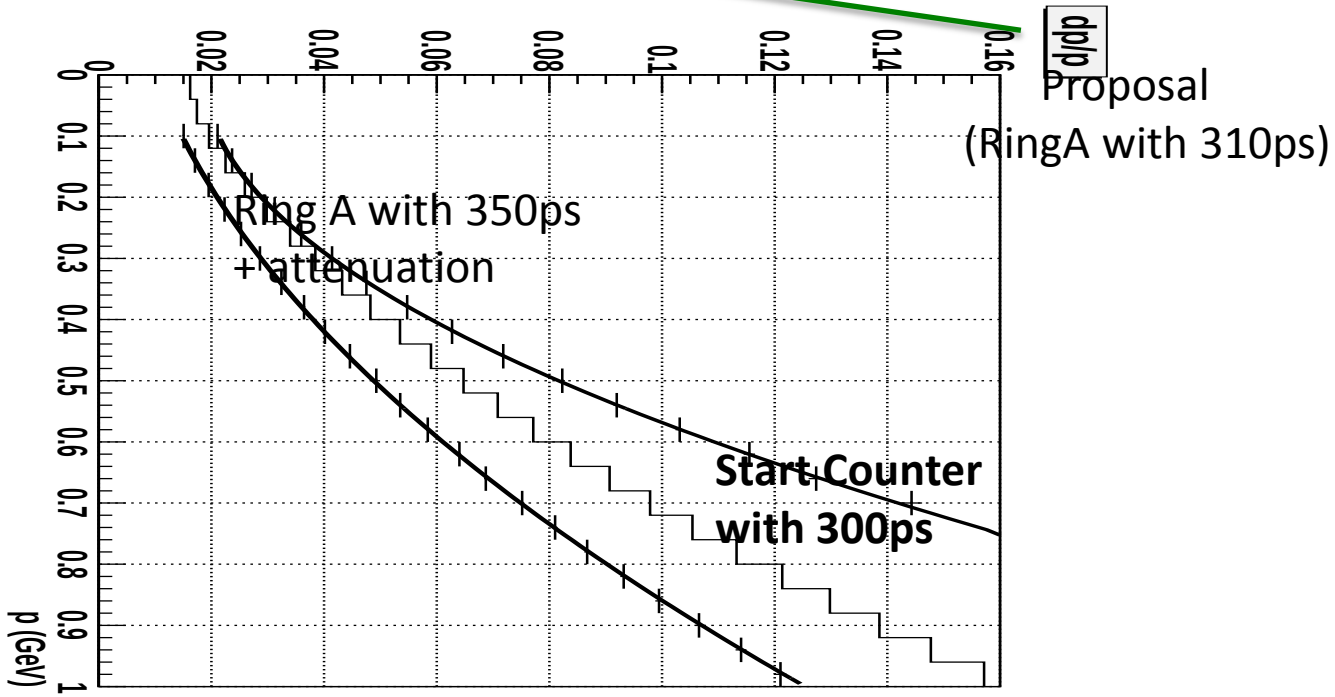
Spare slides

Proton momentum resolution with SC

Principle :



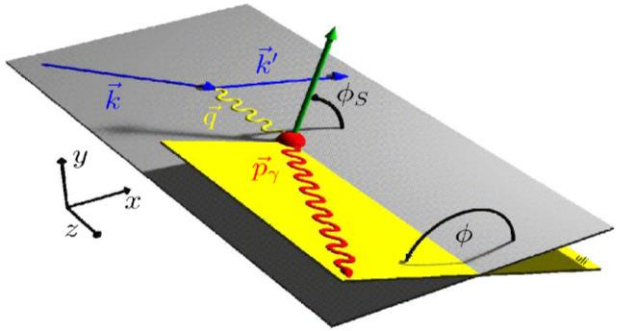
Simulations



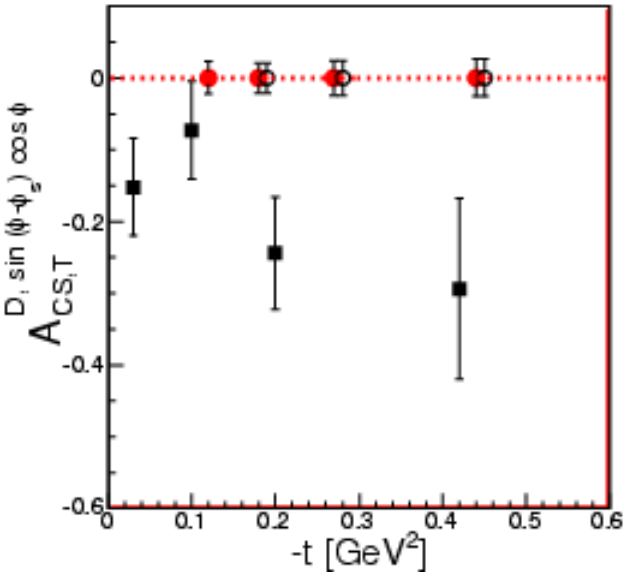
Continuation of the GPD program : constrain the GPD E

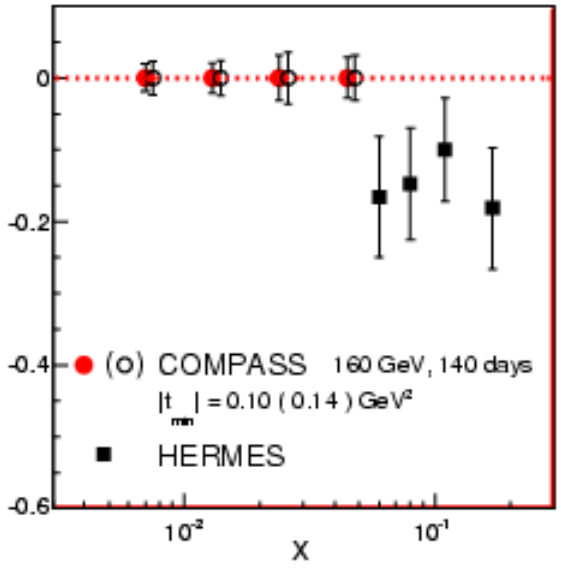
with $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ beam and **transversely** polarized NH3 (proton) target

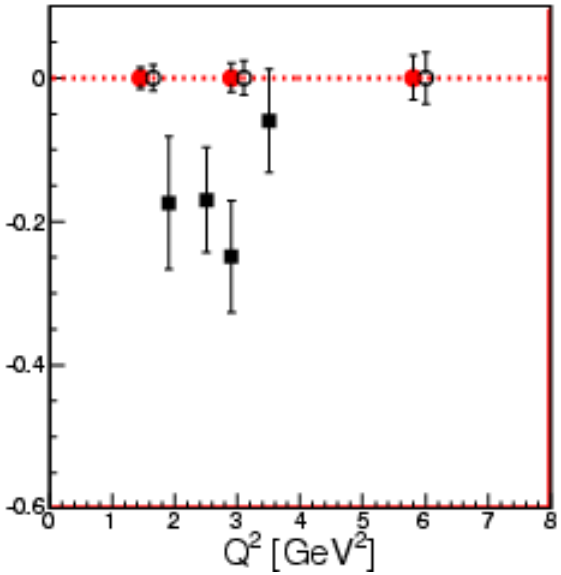
$$\mathcal{D}_{T,CS} \equiv d\sigma_T(\mu^{+\downarrow}) - d\sigma_T(\mu^{-\uparrow}) \propto Im(F_2\mathcal{H} - F_1\mathcal{E}) \sin(\phi - \phi_S)\cos\phi$$



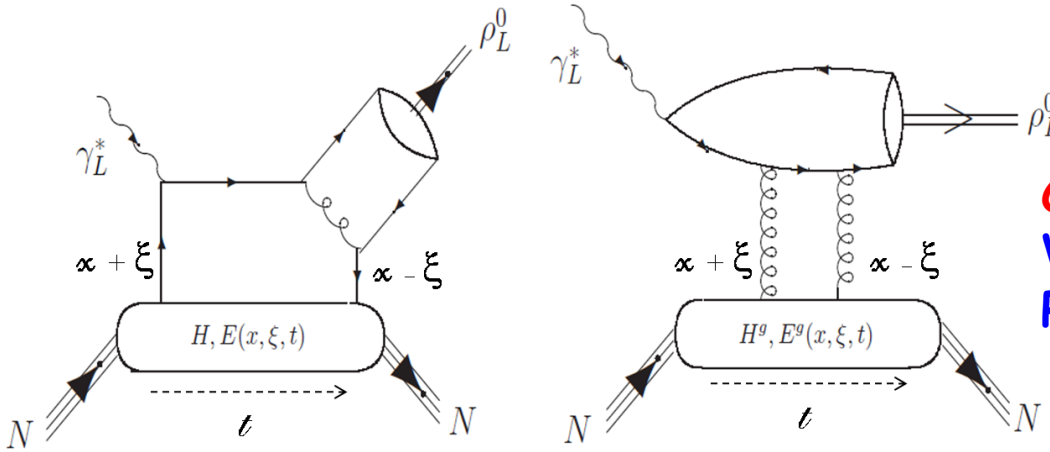
160 GeV muon beam
1.2 m polarized NH3 target (f=0.26)
2 years - ε_{global} = 10 %







Meson production : filter of GPDs



Cross section measurement :

Vector meson : ρ,ω,ϕ... ⇒ H & E

Pseudo-scalar : π,η... ⇒ $\tilde{H}$ & $\tilde{E}$

Would allow for flavor separation :

$$H\rho^0 = 1/\sqrt{2}\,(2/3\,H^u + 1/3\,H^d + 3/8\,H^g)$$

$$H\omega = 1/\sqrt{2}\,(2/3\,H^u - 1/3\,H^d + 1/8\,H^g)$$

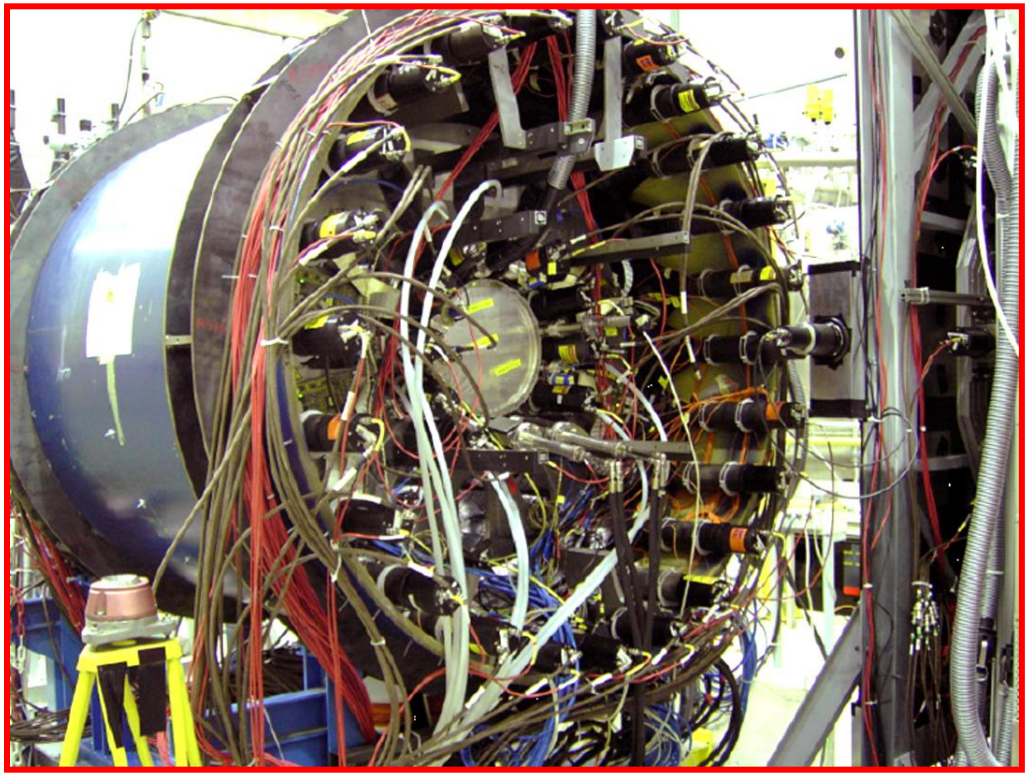
$$H\phi = -1/3\,H^s - 1/8\,H^g$$

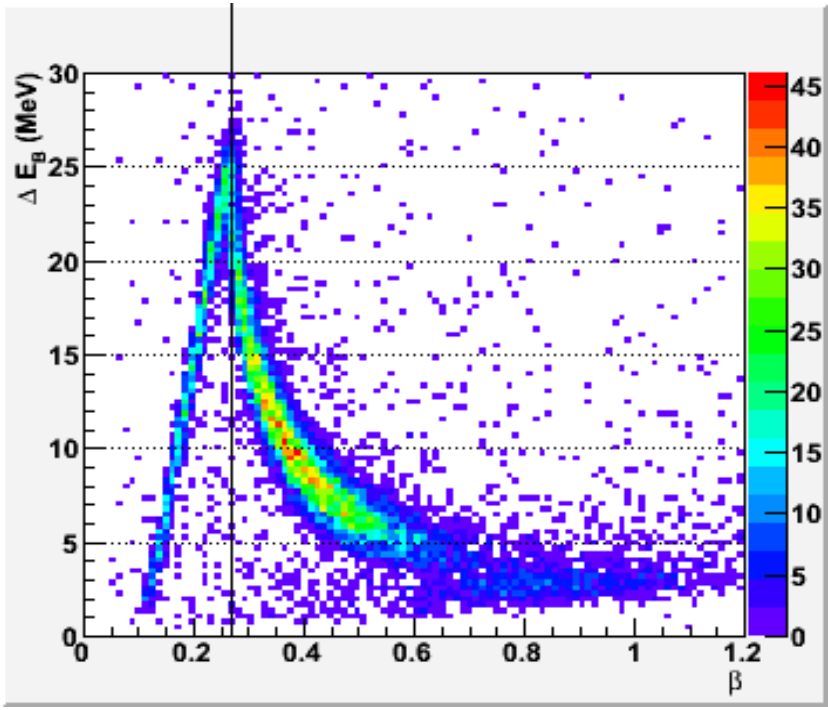
$$\Rightarrow \quad \rho : \omega : \phi \sim 9 : 1 : 2 \text{ at large } Q^2$$

Transversely polarized target asymmetry on vector meson :

⇒ E/H (studied at COMPASS without RPD)

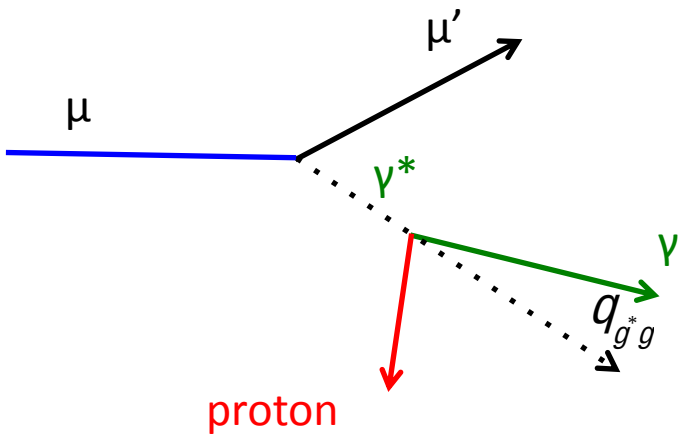
Hadron program RPD





Proton identification in RPD
Elastic scattering (hadron beam)

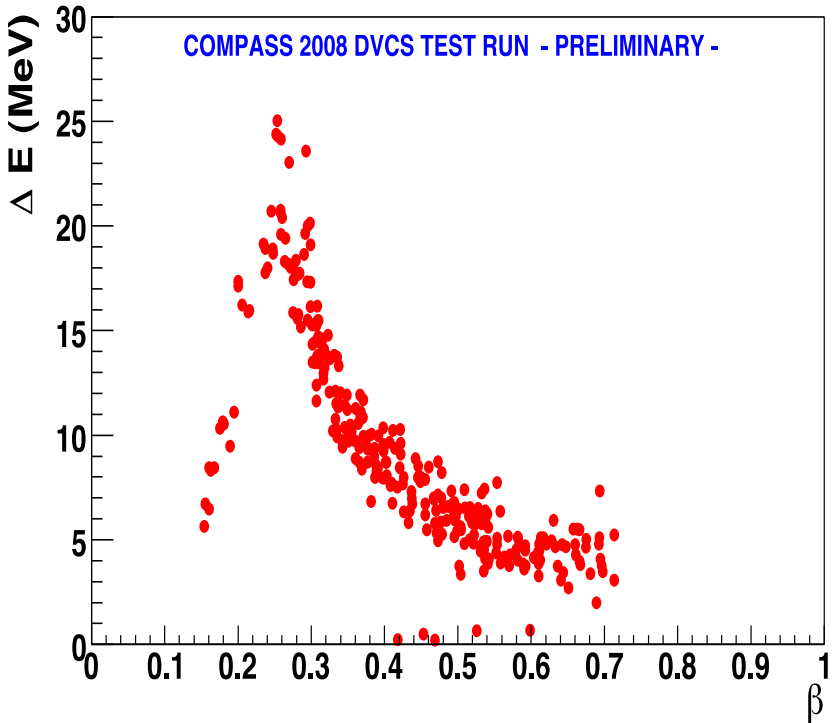
Kinematical consistency : $\vartheta_{\gamma^*\gamma}$

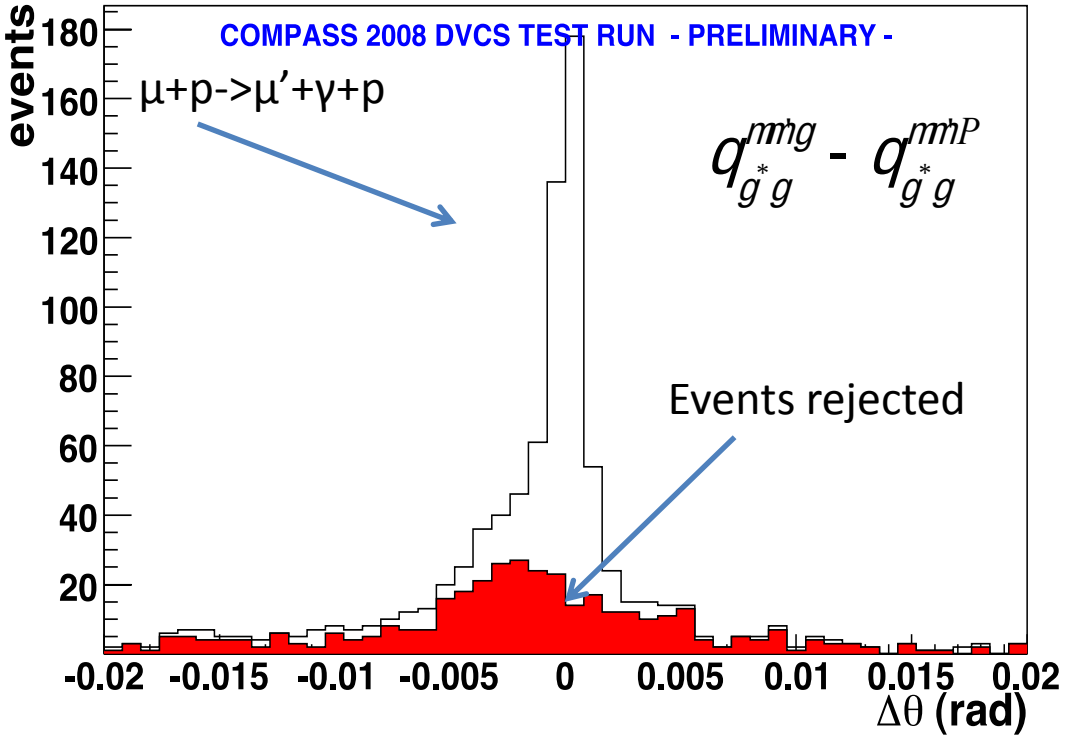


With μ, μ' and γ : $q^{\mu\mu'g}_{g^*g}$

With μ, μ' and proton :

$$\cos q^{\mu\mu'P}_{g^*g} = \frac{1}{\sqrt{1+4M_P^2x^2/Q^2}}\left(1+\frac{2M_P^2x}{Q^2}\,\frac{t+Q^2}{t+Q^2/x}\right)$$





Measurements and Estimations for resolution

$$\frac{\Delta P}{P} \approx \frac{1}{1-\beta^2}\frac{\sin^2\vartheta}{R_B - R_A}\sqrt{\cos^2\vartheta(v_A^2\sigma_A^2 + v_B^2\sigma_B^2) + \beta^2 c^2 \sigma_{ToF}^2}$$

$$\frac{\Delta t}{t} \approx 2\frac{\Delta P}{P}$$

	RPD(2008)	MuRex (2006)
B	L=1m; th=1cm Atten length = 0.7m σ_B = 300 ps	L=4m; th=5cm Atten length = 4m σ_B = 200 ps
A	L=50cm; th=5mm σ_A = 180 ps	L=2.83m; th=4mm σ_A = 270 ps
ToF	σ_{ToF} = 350 ps R_B-R_A= 85-12 = 63 cm	σ_{ToF} = 310 ps R_B-R_A= 110-25 = 85cm

t_{min}=-0.06 GeV^2

Good resolution in t

Importance for the the transverse imaging