Proposal for GPD studies at COMPASS

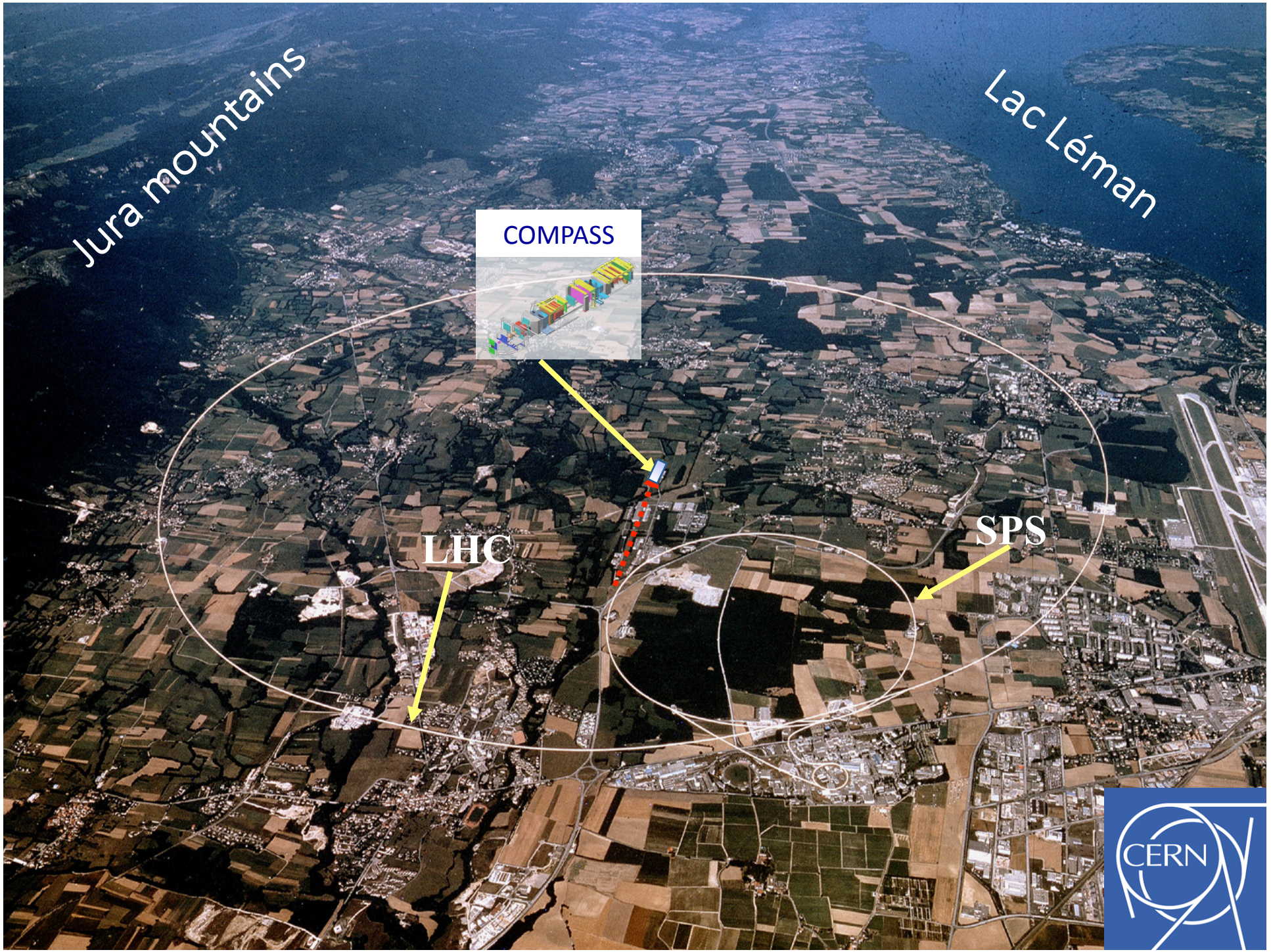
E. Burtin CEA-Saclay Irfu/SPhN
On behalf of the COMPASS Collaboration
MENU 2010 – College of William & Mary
Williamsburg - June 2nd, 2010

Proposal submitted to the SPS comittee (May 17,2010)

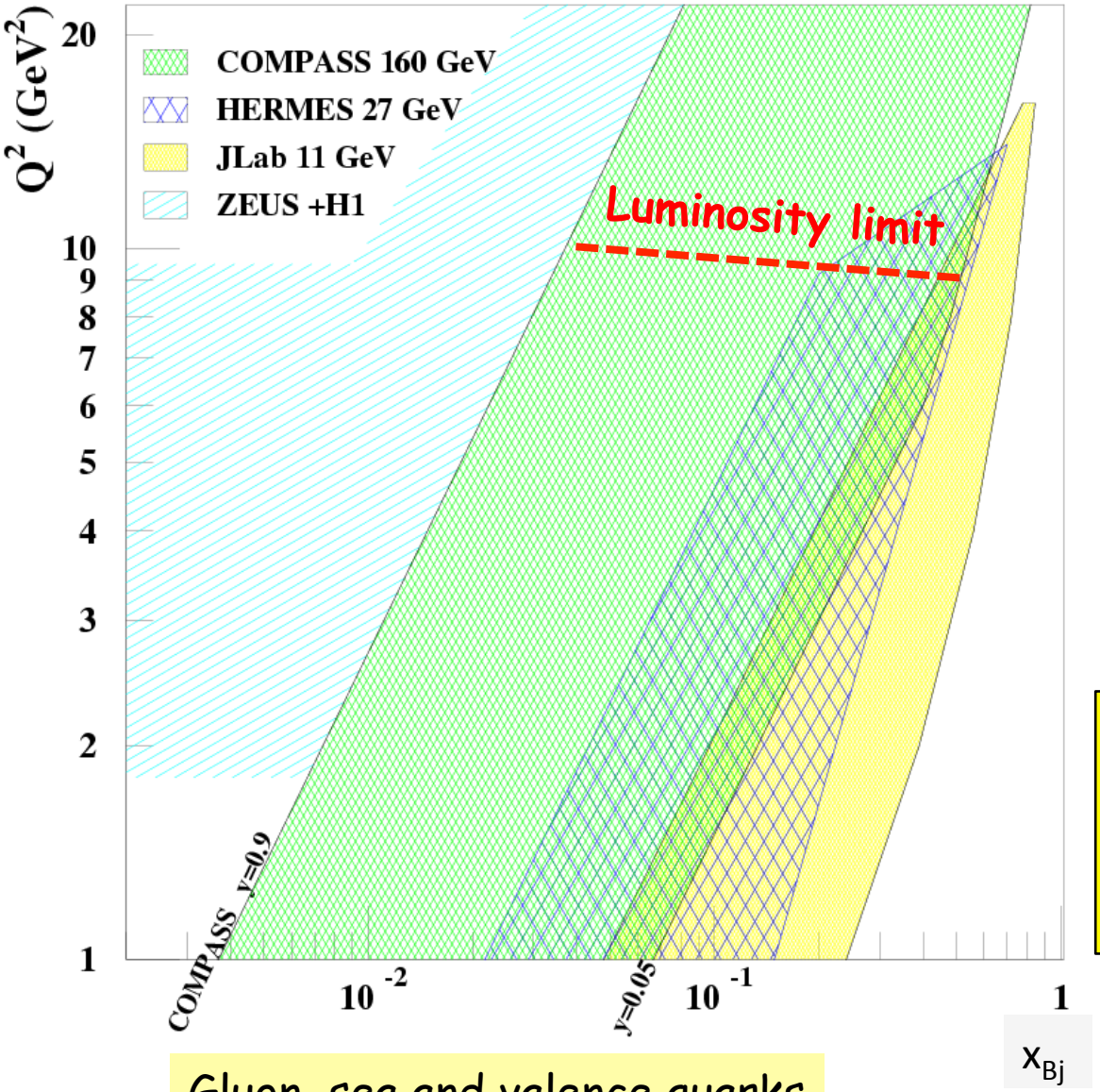
Physics topics:

- **Hard exclusive photon and meson production**
- **Unpolarized PDFs and TMD effects in SIDIS**
- **Pion induced Drell-Yan muon pair production (TMD)**
- **Experimental studies of chiral perturbation theory**

COMPASS II proposal available at : CERN-SPSC-2010-014 preprint
http://cdsweb.cern.ch/record/1265628/files/SPSC-P-340.pdf


Jura mountains
Lac Léman
COMPASS
LHC
SPS
CERN

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

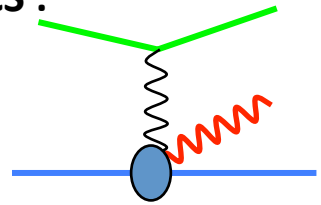
Foreseen program :
DVCS and meson production off a liquid H2 target (unpolarized)

⇒ Will explore the intermediate x_{Bj} region

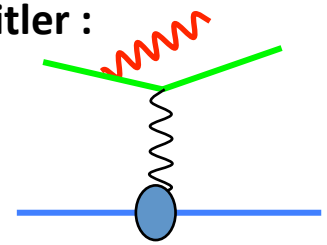
⇒ Uncovered region between ZEUS+H1 and HERMES+Jlab

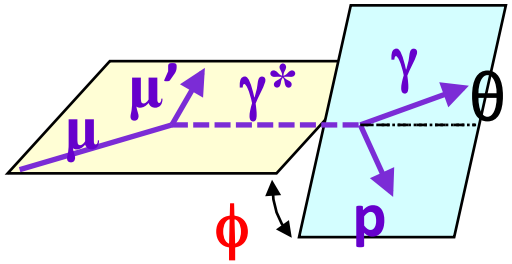
Comparison of BH and DVCS at 160 GeV

DVCS :

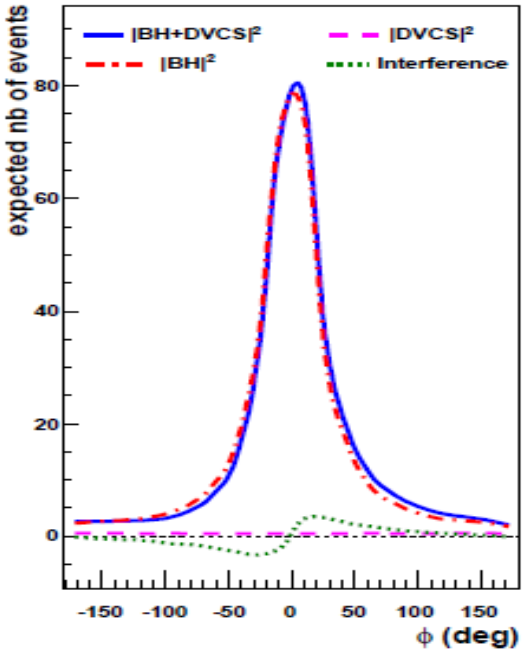


Bethe-Heitler :





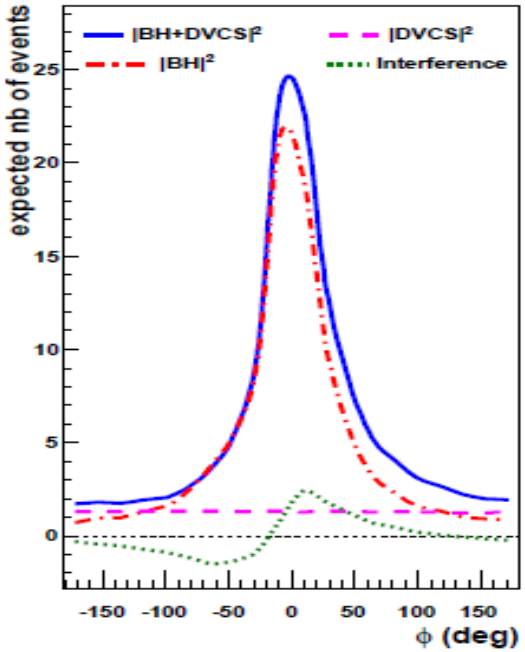
$0.005 < x_{Bj} < 0.01$



BH dominates

excellent reference yield

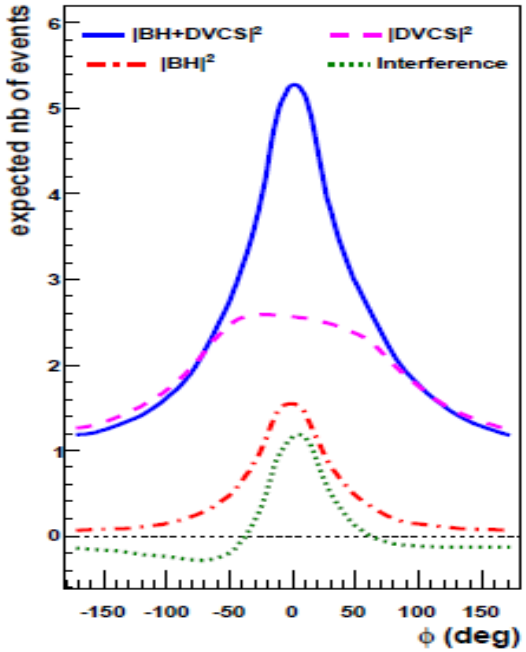
$0.01 < x_{Bj} < 0.03$



BH and DVCS at the same level

access DVCS **amplitude** through the interference

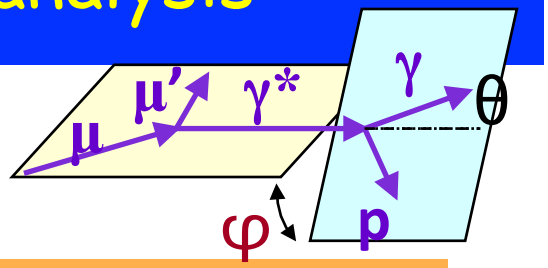
$x_{Bj} > 0.03$



DVCS dominates

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

Azimuthal angular dependence analysis



from Belitsky, Kirchner, Müller :

polarized beam off unpolarized target

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

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

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

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

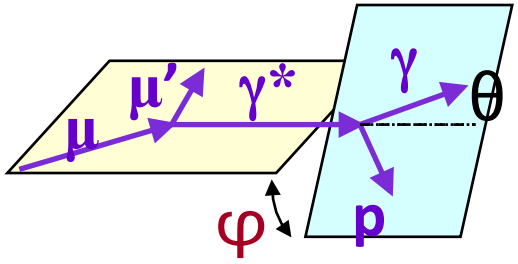
$$e_\mu \times a^{BH}\Re e A^{DVCS} = \frac{e^6}{xy^3tP_1(\varphi)P_2(\varphi)}\left(c_0^{Int} + c_1^{Int}\cos\varphi + c_2^{Int}\cos 2\varphi + c_3^{Int}\cos 3\varphi\right)$$

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

Twist-2 M^{11} >> Twist-3 M^{01} Twist-2 gluon M^{-11}

Angular dependence analysis

Case of COMPASS : $\mu^+(P=-0.8)$ *and* $\mu^-(P=+0.8)$
unpolarized H_2 *target*



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

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

=> dσ/dt

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

=> $\mathcal{I}m\,(F_1\mathcal{H})$

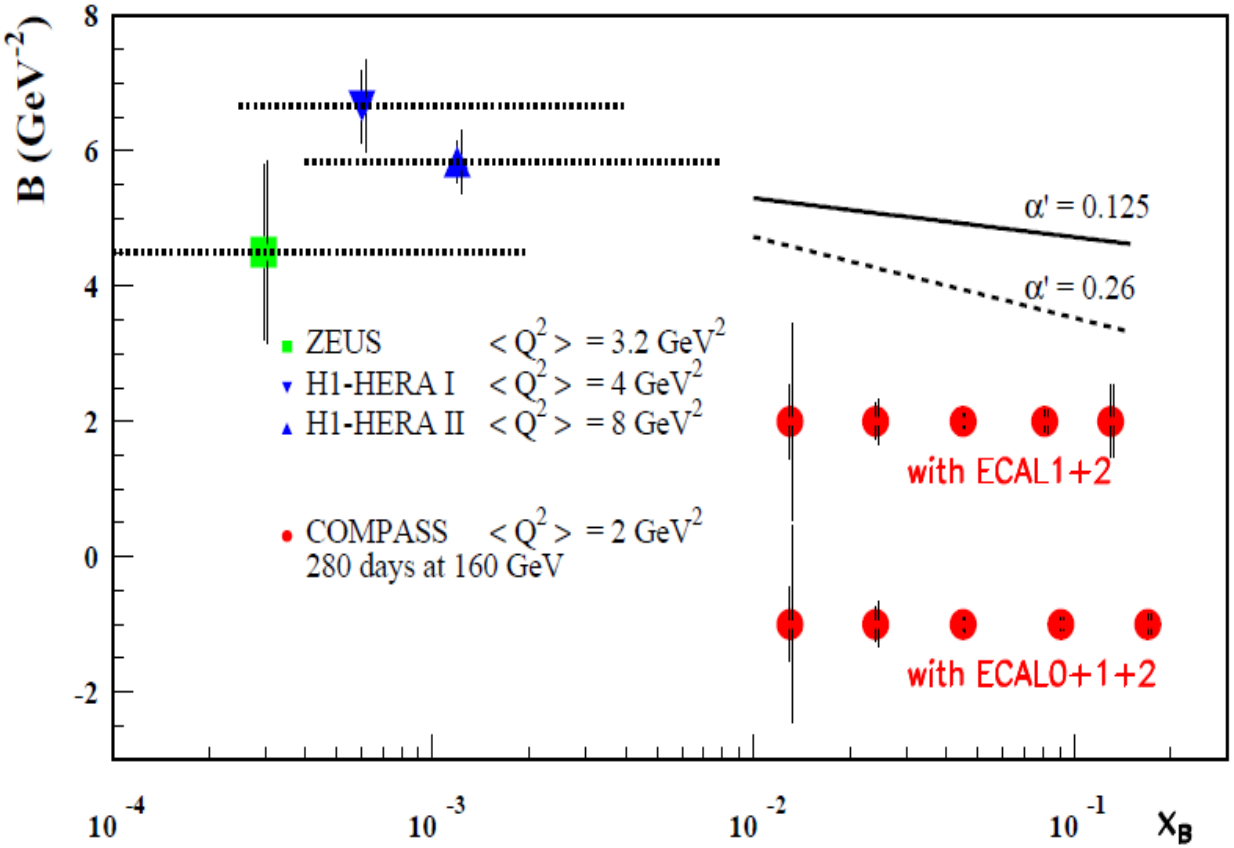
$$\mathcal{D}_{U,CS} : d\sigma_{\mu^+} - d\sigma_{\mu^-} = 2\, P_\mu\, d\sigma^{DVCS}_{pol} + e_\mu\, a^{BH}\, \mathcal{R}e\, A^{DVCS}$$

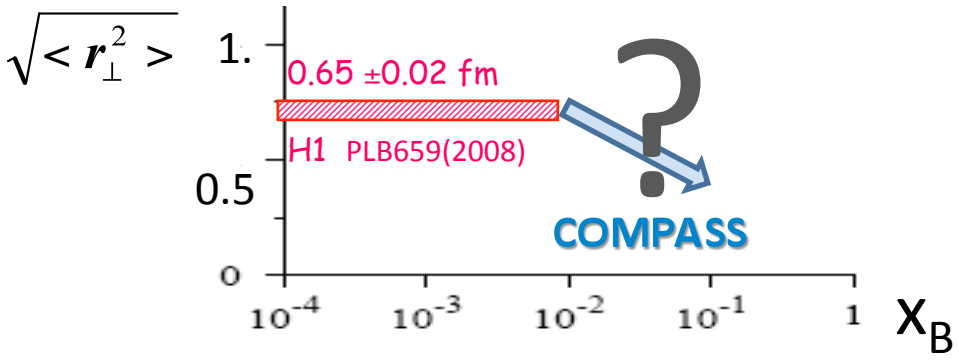
$$s_1^{DVCS}\sin\varphi$$

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

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

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





Using $S_{U,CS}$:

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

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

<u>Ansatz at small x :</u>

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

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

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

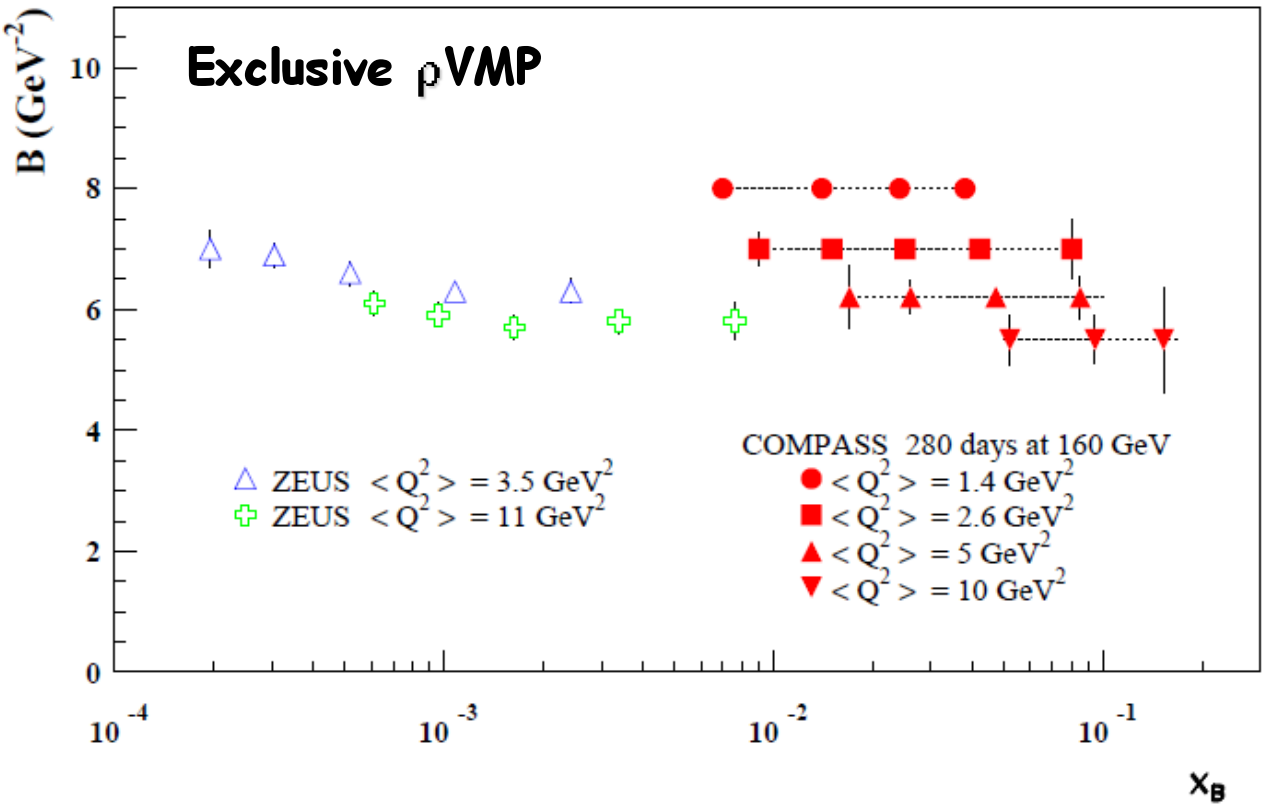
Assuming 3% syst. error on BH subtraction

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 Sandacz
Normalised according Goloskokov and Kroll

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

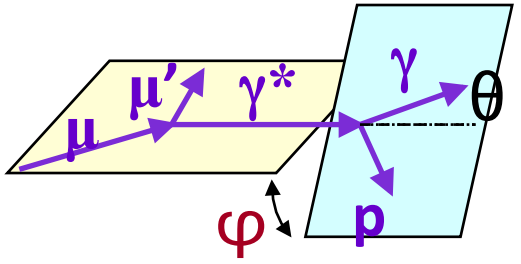
Sensitive to the nucleon size
+ the transverse size of the meson

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

Angular dependence analysis

Case of COMPASS : $\mu^+ (P=-0.8)$ *and* $\mu^- (P=+0.8)$

unpolarized H_2 *target*



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

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

=> dσ/dt

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

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

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

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

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

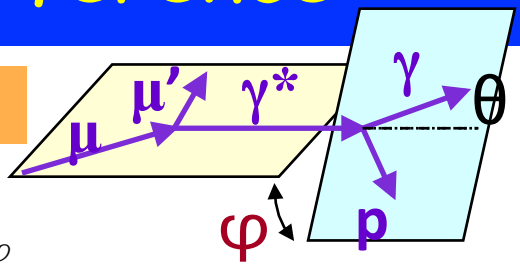
=> $\mathcal{R}e\,(F_1\mathcal{H})$

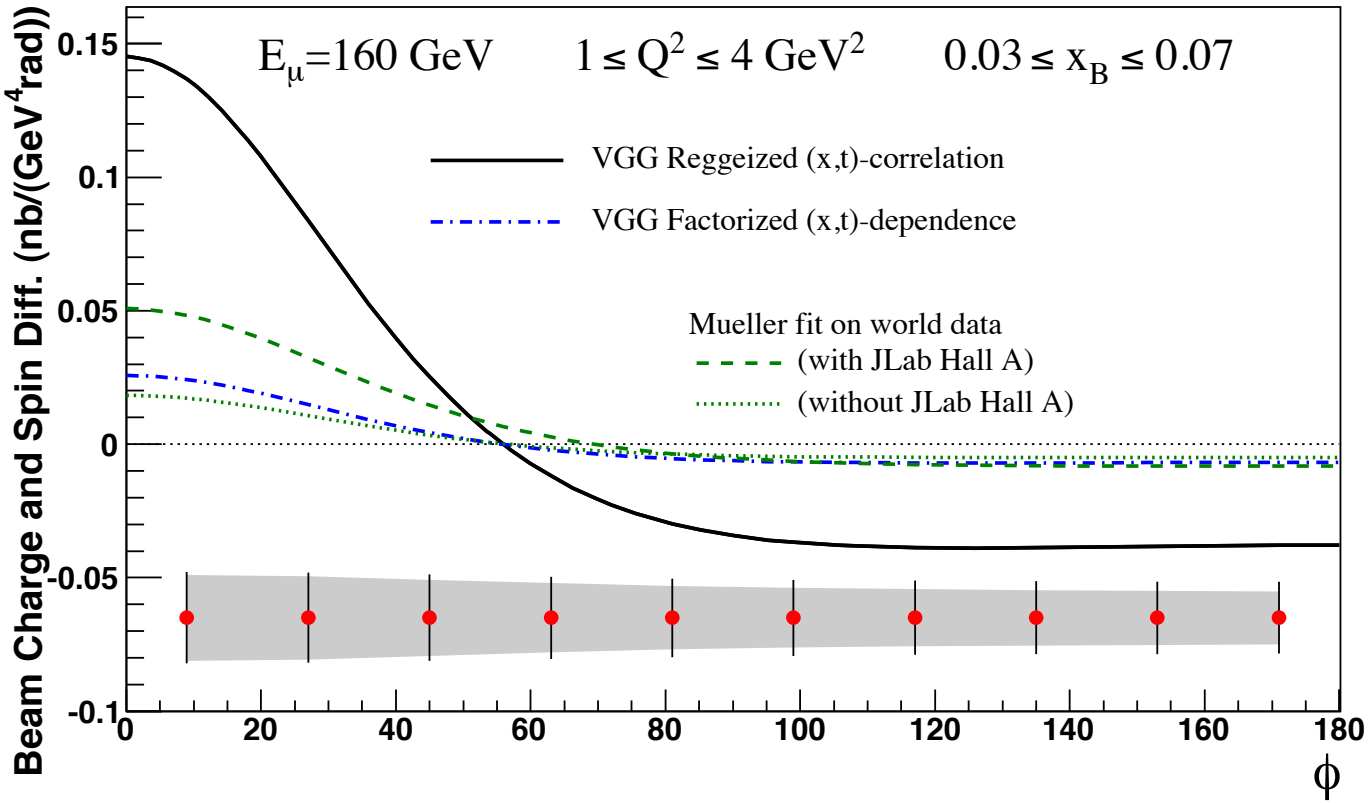
$\mathcal{D}_{U,CS}$: Beam Charge & Spin Difference

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

$s_1^{DVCS} \sin\varphi$

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





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

$\ldots + c_1^{Int}\cos\varphi + \ldots$

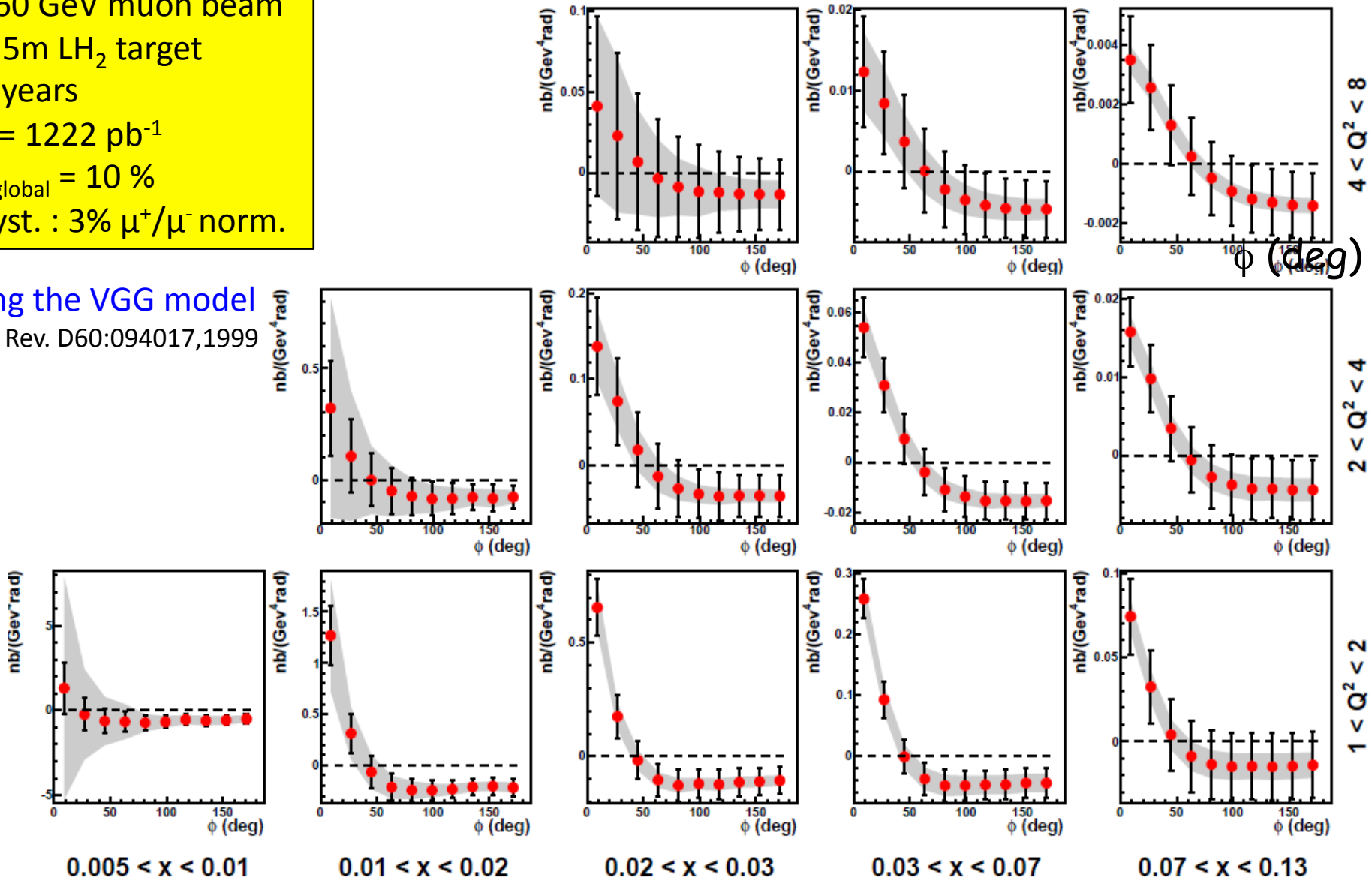
$\Rightarrow \mathcal{R}e\,(F_1\mathcal{H})$

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

$\mathcal{D}_{u,cs}(\phi)$ 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

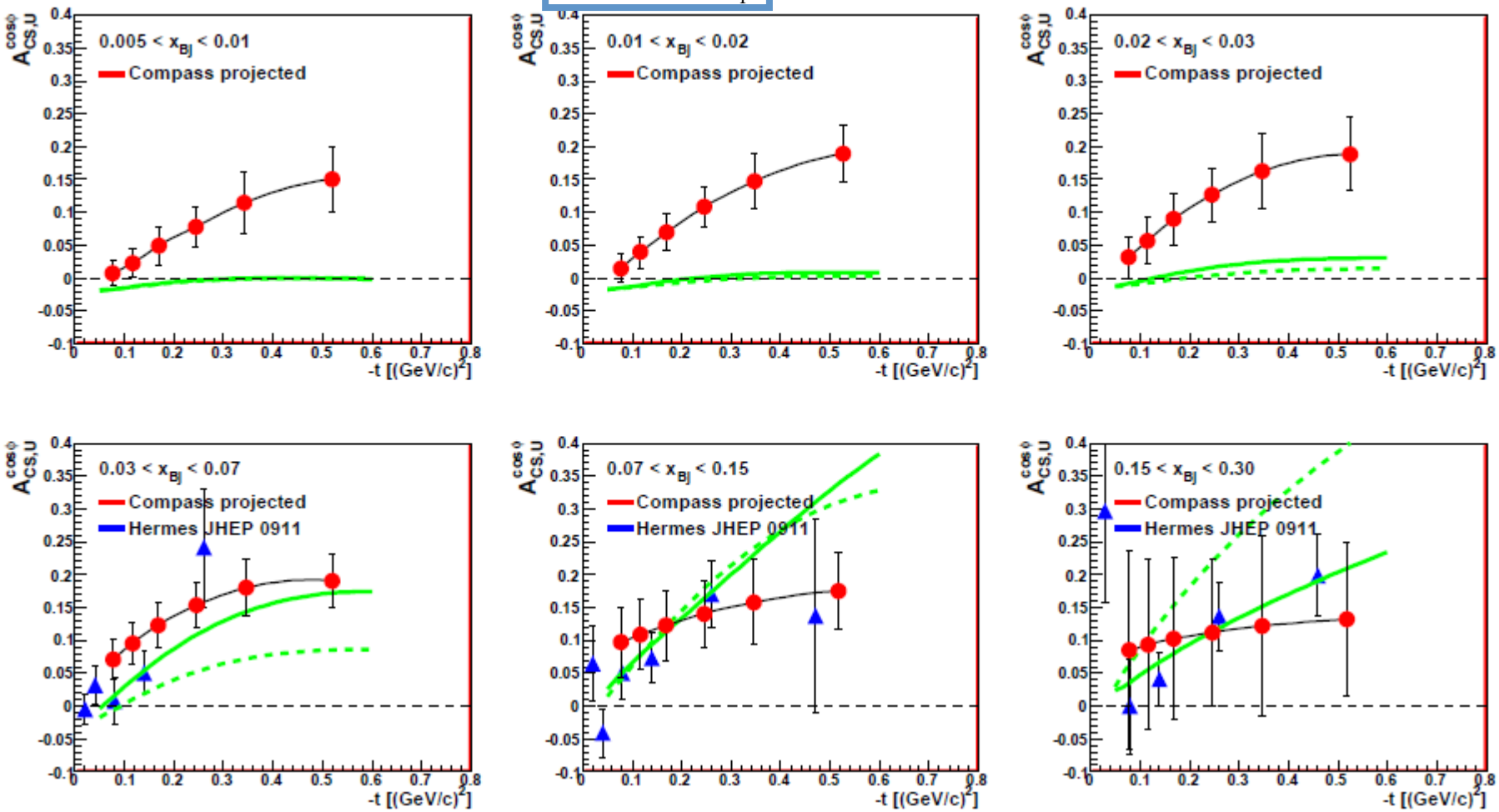


Sensitivity of COMPASS: cosϕ modulation

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

$\Rightarrow$ related to c_1^{Int}

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

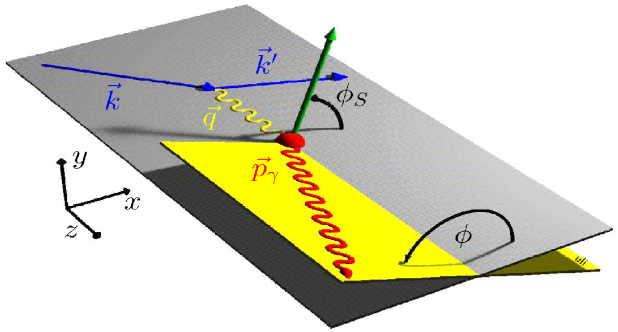


Continuation of the GPD program : constrain the GPD E

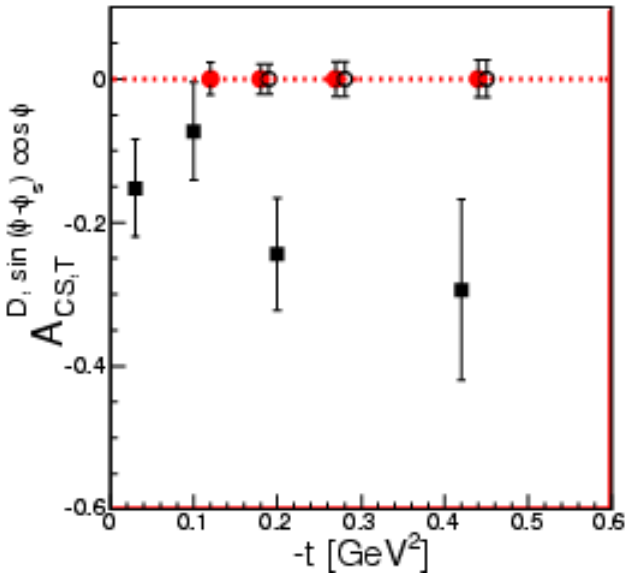
with $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ beam and transversely polarized NH3 (proton) target

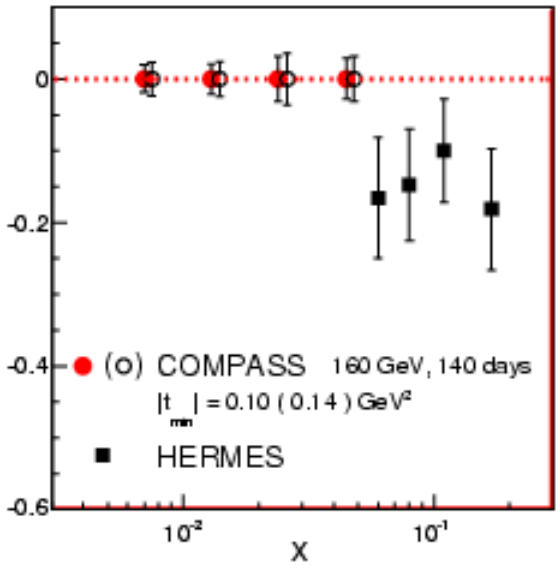
$$\mathcal{D}_{T,CS} \equiv d\sigma_T\,(\mu^{+\downarrow}) - d\sigma_T\,(\mu^{-\uparrow})$$

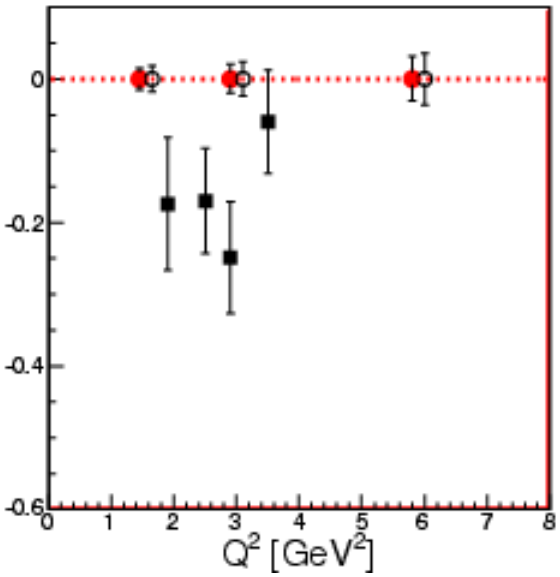
$$\propto Im(F_2\mathcal{H} - F_1\mathcal{E})\,\sin(\phi - \phi_S)\cos\phi$$



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



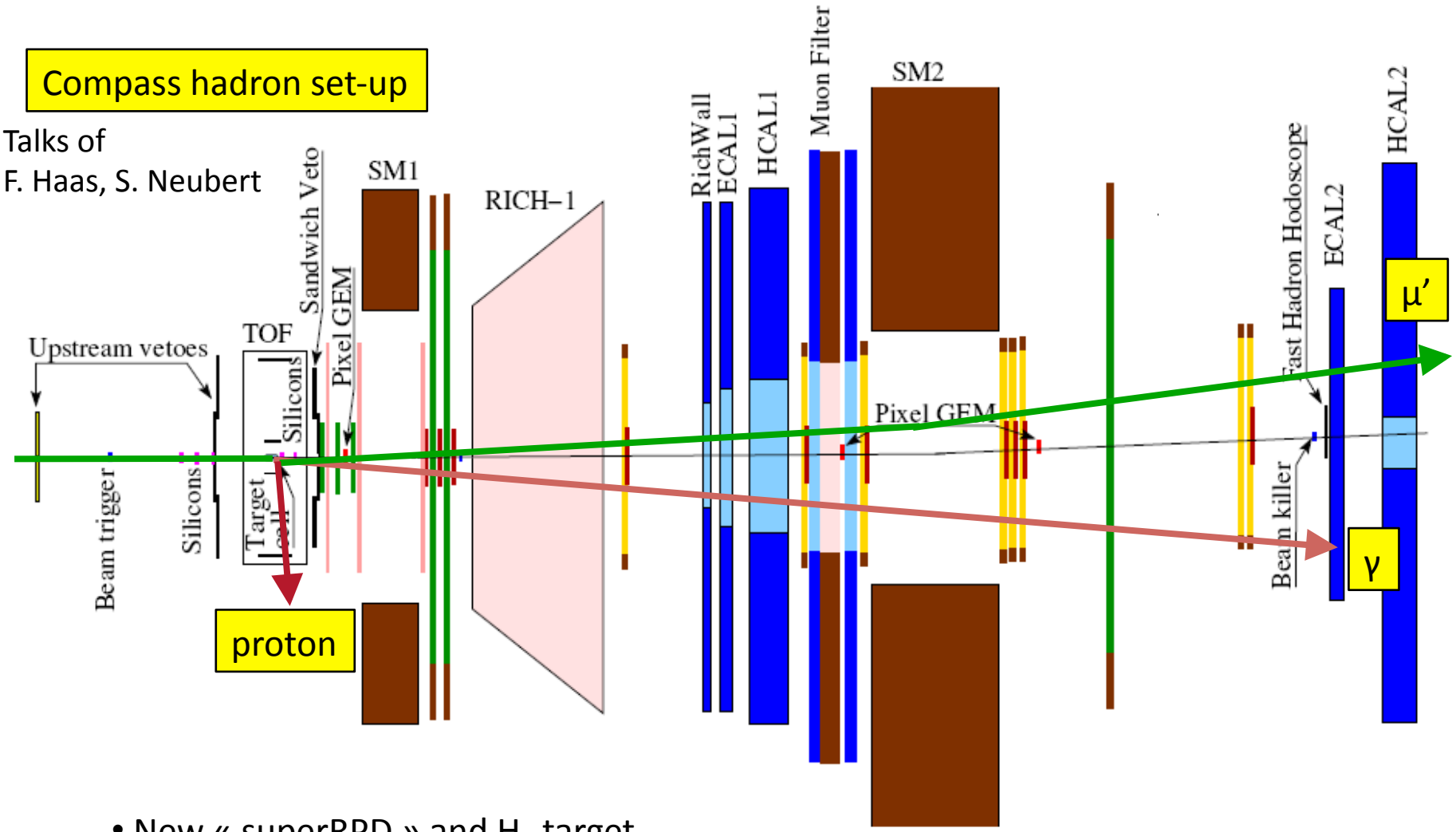




Experimental realisation

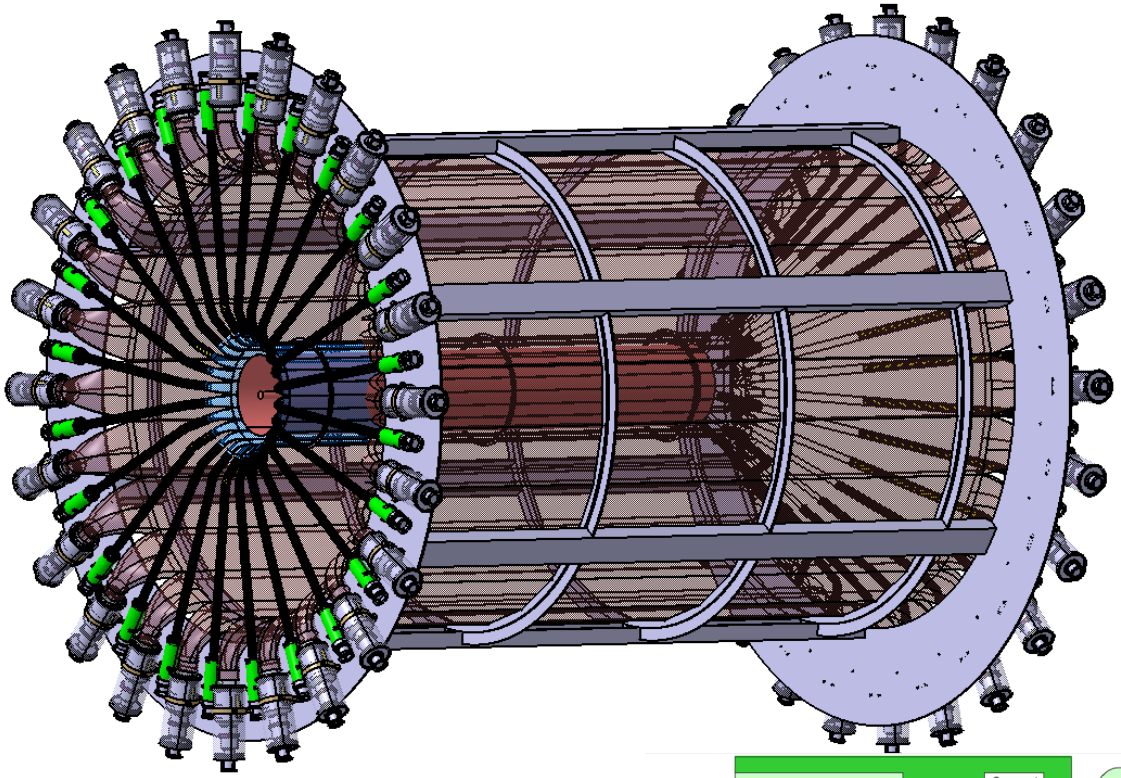
Compass hadron set-up

Talks of
F. Haas, S. Neubert



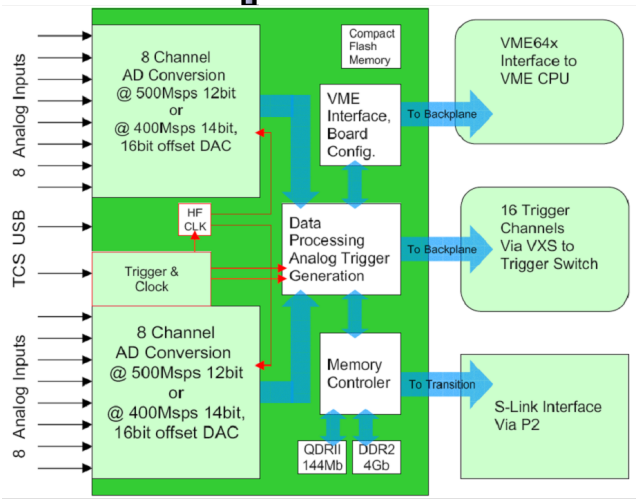
- New « superRPD » and H_2 target
- Hermetic calorimetry : Move ECALs upstream and/or complete ECAL2
- New ECAL0 upstream of SM1

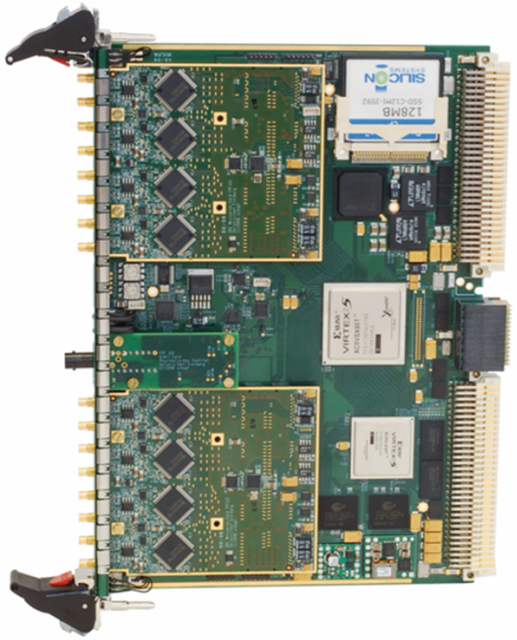
Recoil Proton Detector



- 4 m long scintillator slabs
- ~ 300ps timing resolution
- Full scale prototype tested successfully

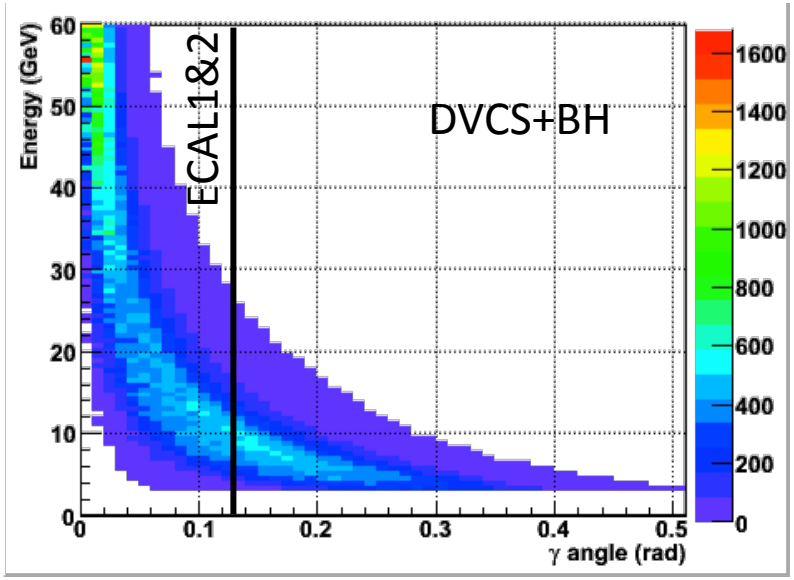
Gandalf Project:
1 GHz digitalisation of the PMT signal to cope for high rate



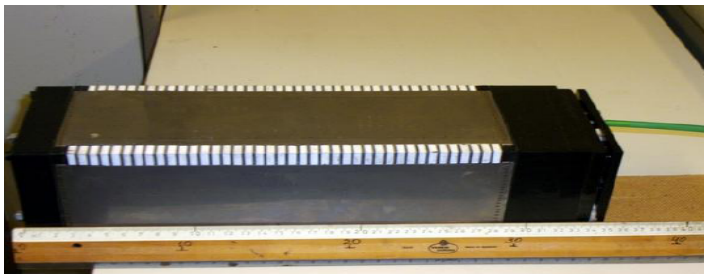


ECAL 0

Requirements
- Photon energy range 0.2- 30 GeV
- Size: 320cm x 320cm ;
- Granularity 4x4 – 6x6 cm^2
- Energy resolution < 10.0%/√E (GeV)
- Thickness < 50 cm,
- Insensitive to the magnetic field.

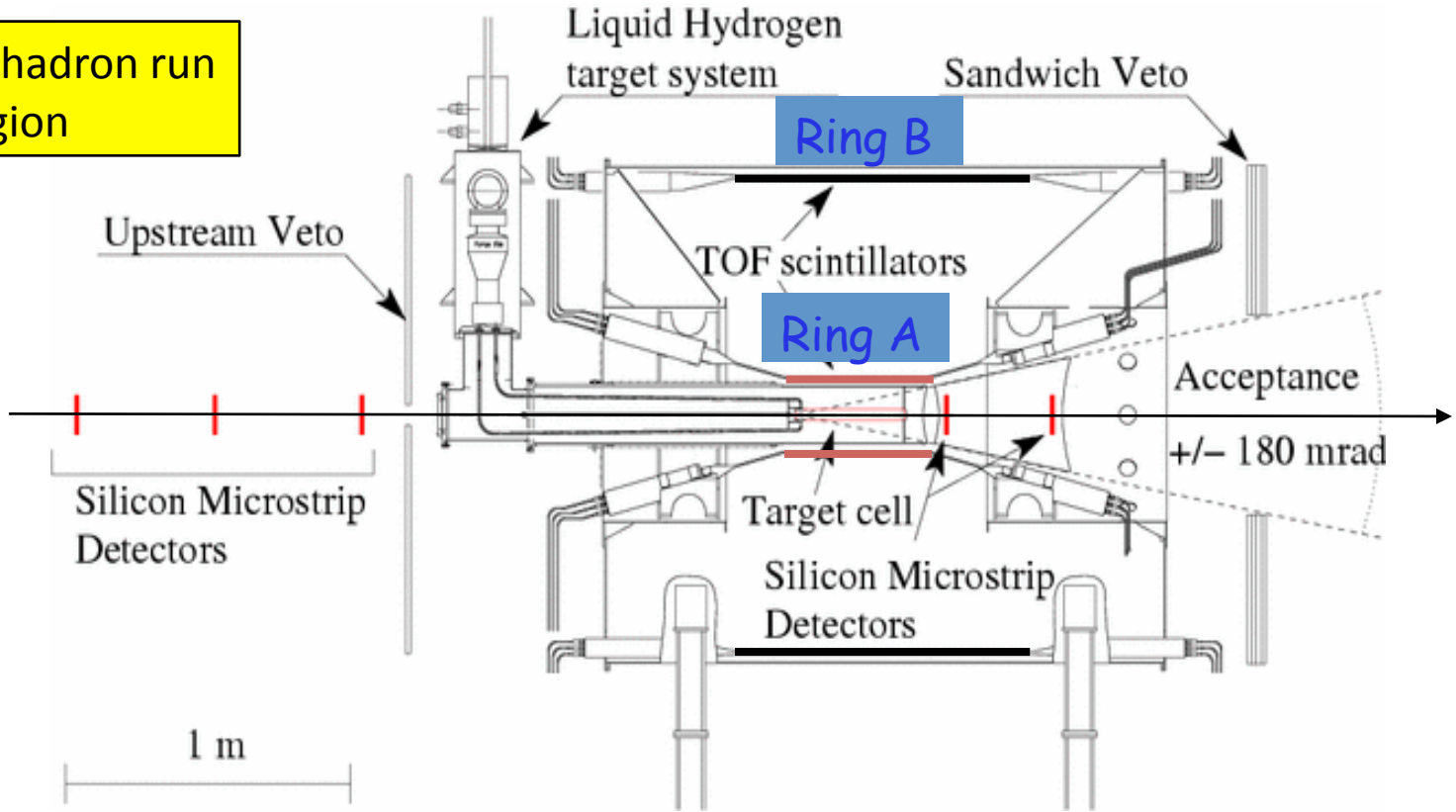


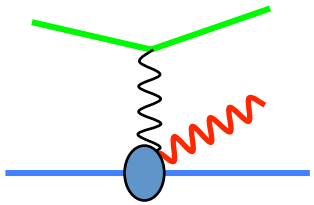
Prototype under studies
- Shaschlyk module with AMPD readout
- Tested



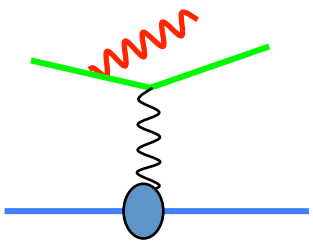
2008-2009 DVCS tests

Compass hadron run
Target region





DVCS

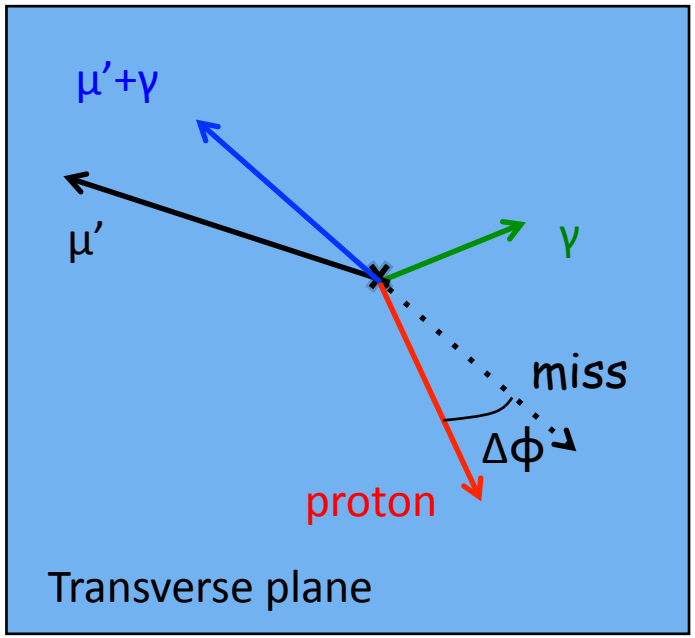


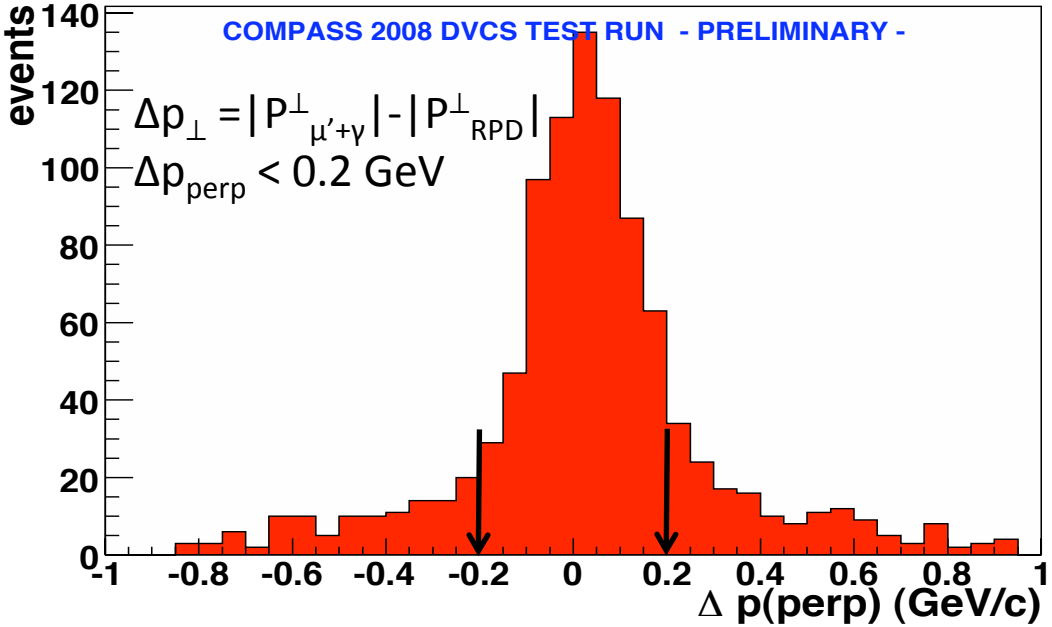
Bethe-Heitler

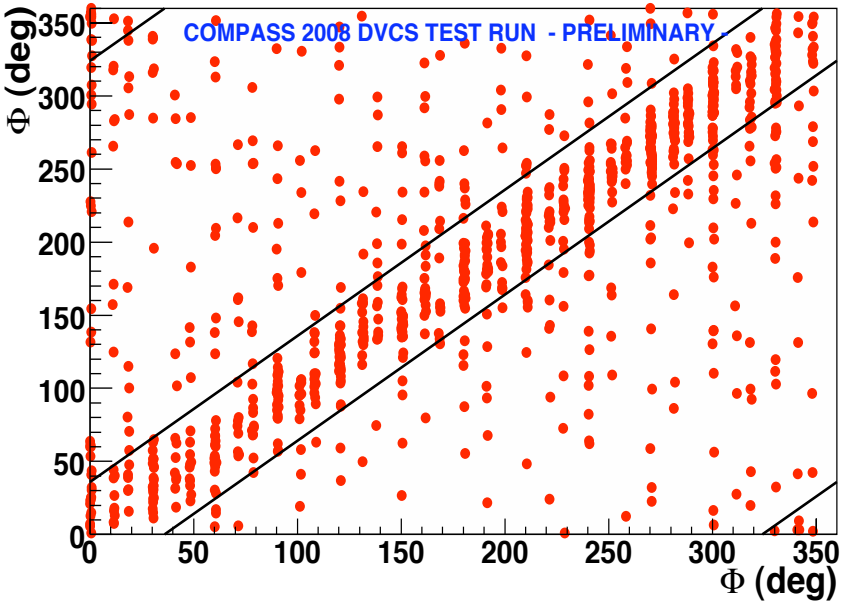
Selection of events :

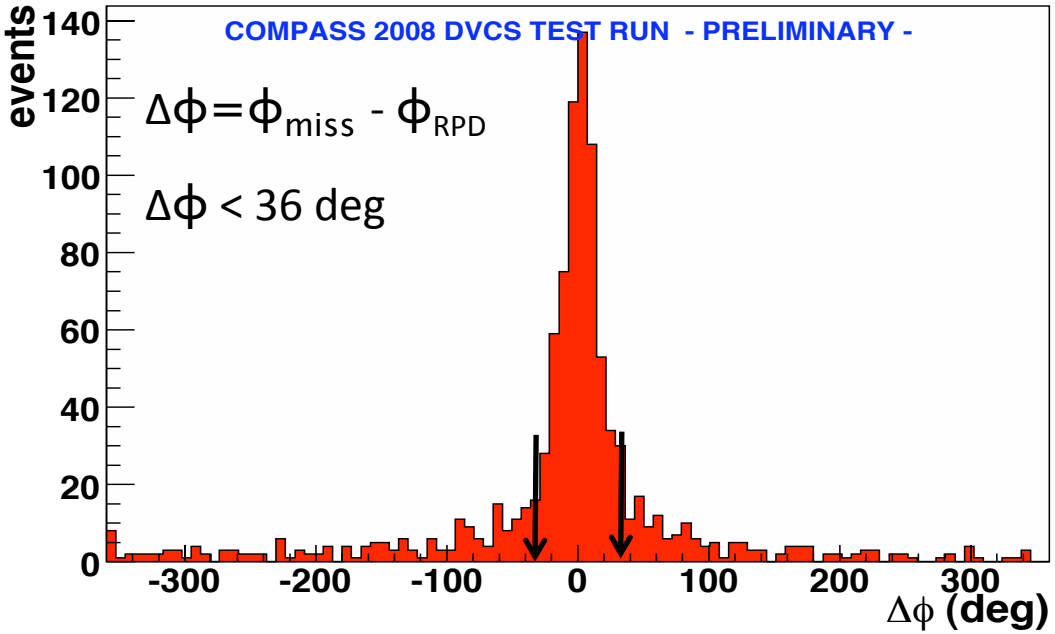
- one vertex with μ and μ'
- no other charged tracks
- only 1 high energy photon ($\Delta t < 5$ns)
- 1 proton in RPD with $p < 1.$ GeV/c

2008 beam test : exclusivity cuts

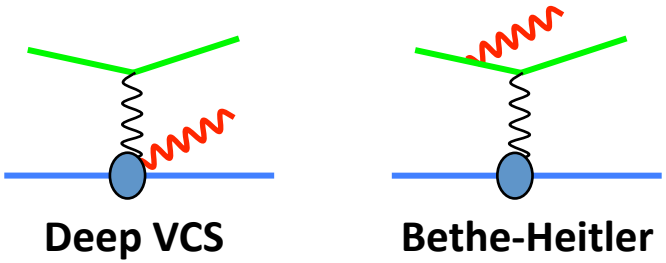




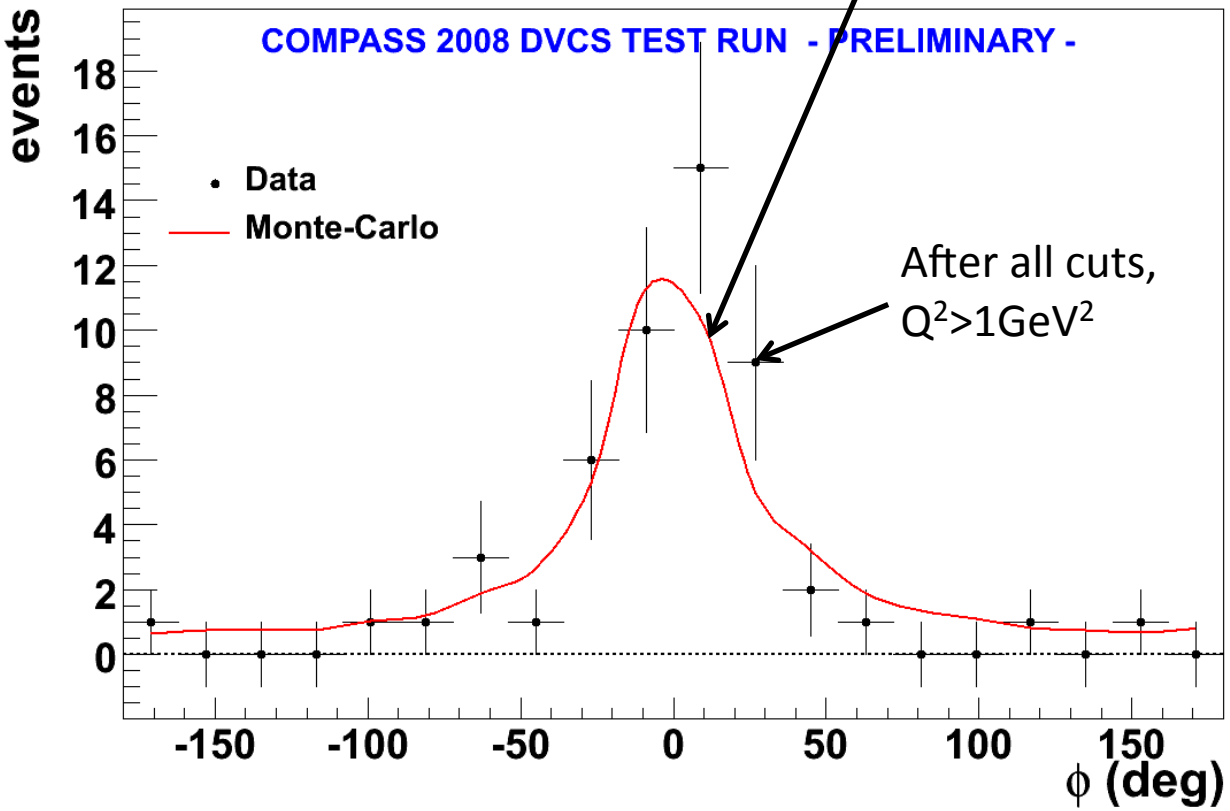




2008 beam test : Bethe-Heitler signal



Monte-Carlo simulation
of BH (dominant) and DVCS



~ 10 times more data taken in 2009

=> Bethe-Heitler observed

Detection efficiency :

$\varepsilon_{\mu+p\to\mu+p+\gamma}$ = 0.32 +/- 0.13

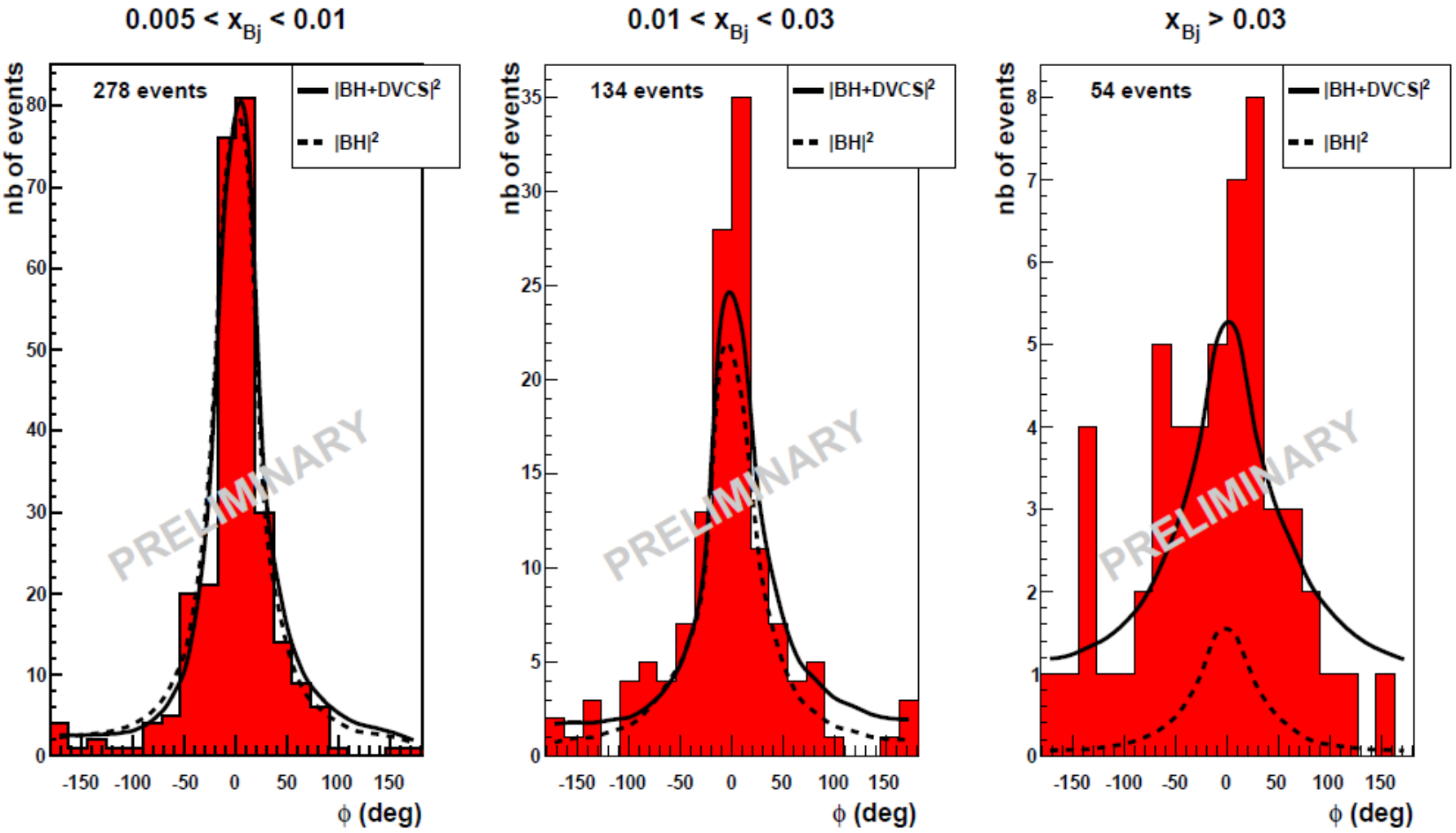
Global efficiency :

- $\mu+p\to\mu+p+\gamma$ efficiency
- SPS & COMPASS availability
- Dead time
- trigger efficiency

$\Rightarrow \varepsilon_{global}$ = 0.13 +/- 0.05

Projections of errors are realistic

2009 beam test : DVCS signal



~ 10 times more data taken than in 2008

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

Conclusions & perspectives

the COMPASS-II proposal has been submitted

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

- SPS Committee meets at the end June

COMPASS has a great potential in GPDs physics

- Study of the GPD H with a LH2 target: 2013-
  measurement ot t-slopes – transverse partonic structure of the nucleon
  measurement of Beam Charge and Spin differences & asymmetries
- Equipments needed :
  4m long RPD, 2.5m LH2 target, Extended & improved calorimetry

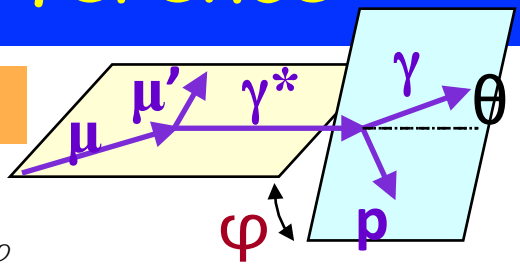
- at a later stage :
  study of the GPD E with a transversely polarized target

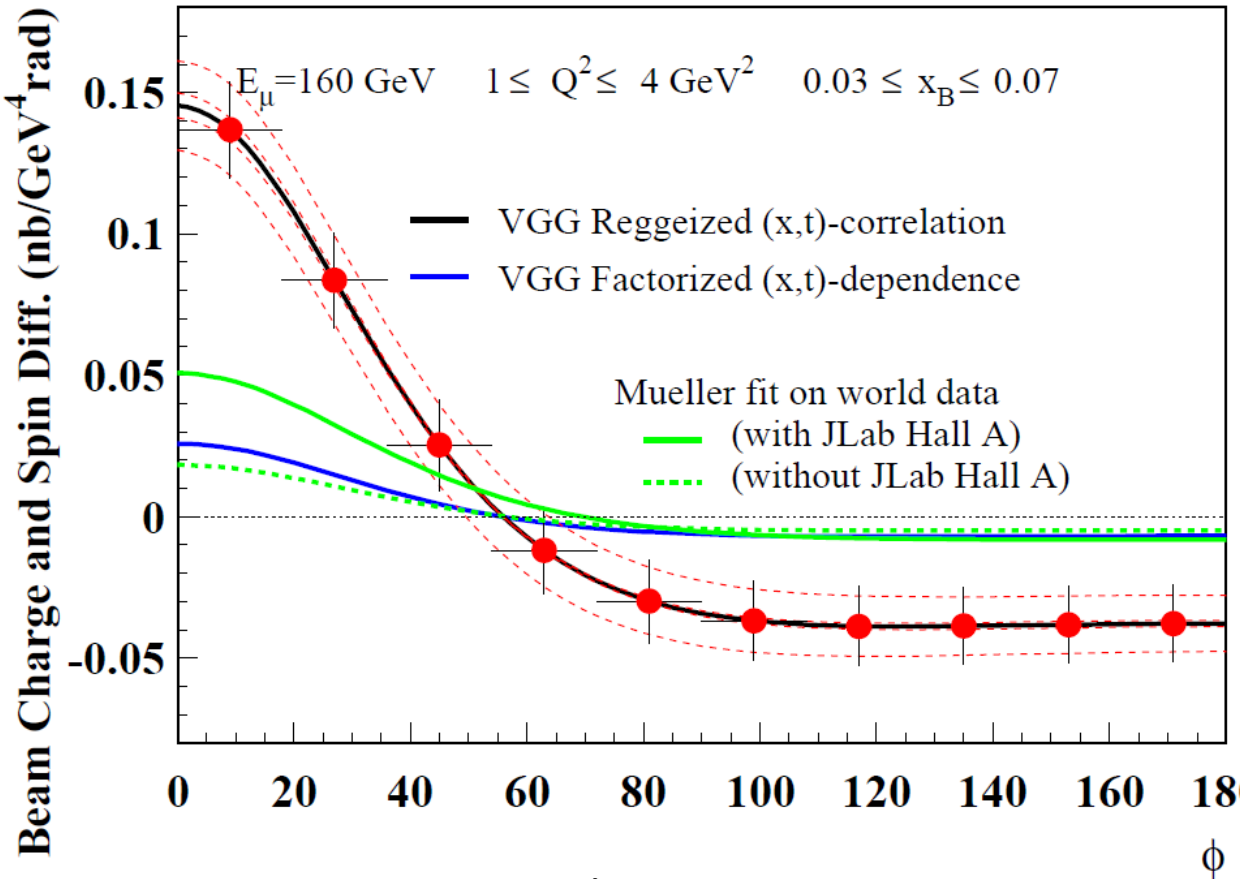
$\mathcal{D}_{U,CS}$: Beam Charge & Spin Difference

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

$s_1^{DVCS} \sin\varphi$

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





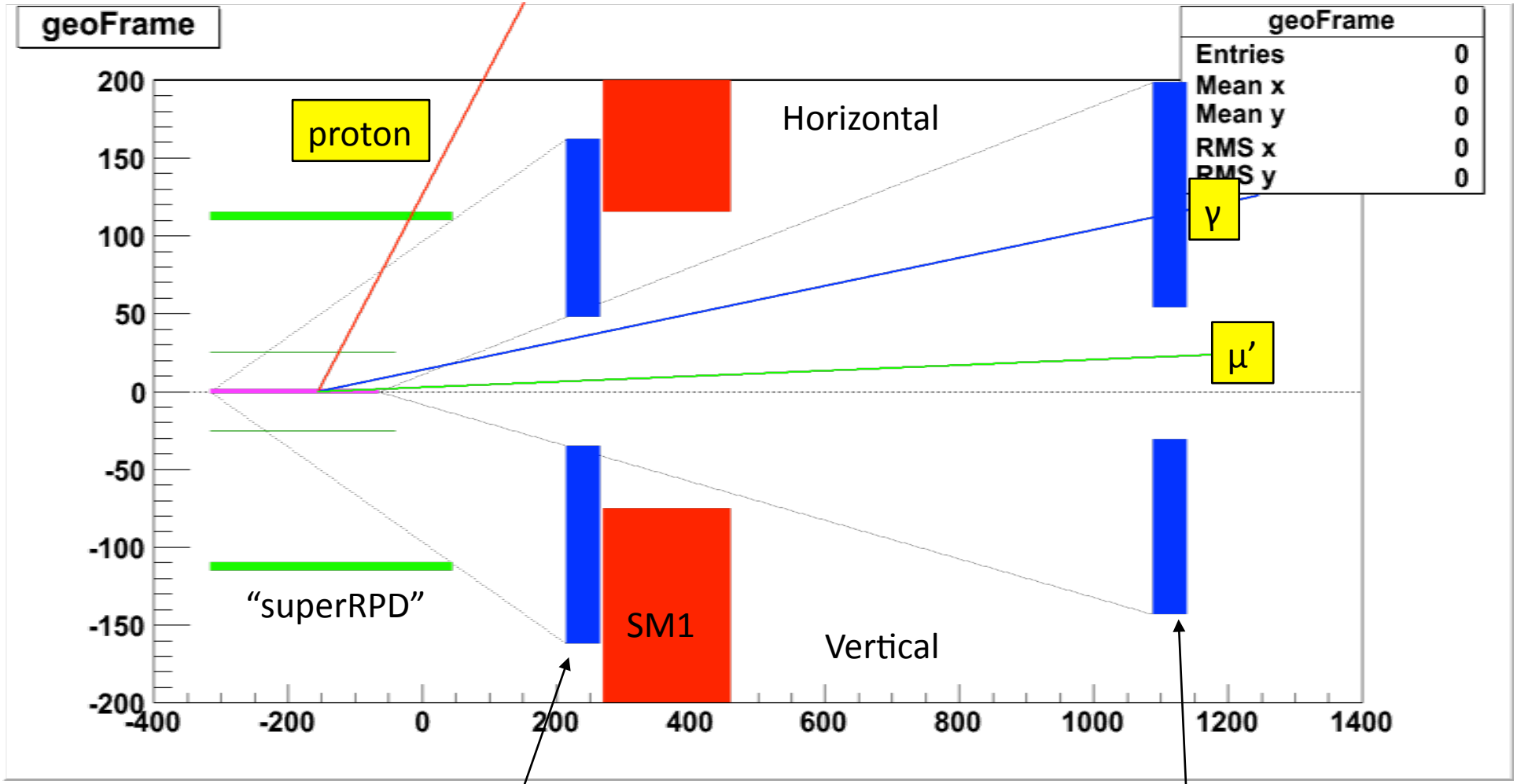
160 GeV muon beam
2.5m LH_2 target
2 years
$L = 1222\ pb^{-1}$
$\varepsilon_{global} = 10\ \%$

$\ldots + c_1^{Int}\cos\varphi + \ldots$

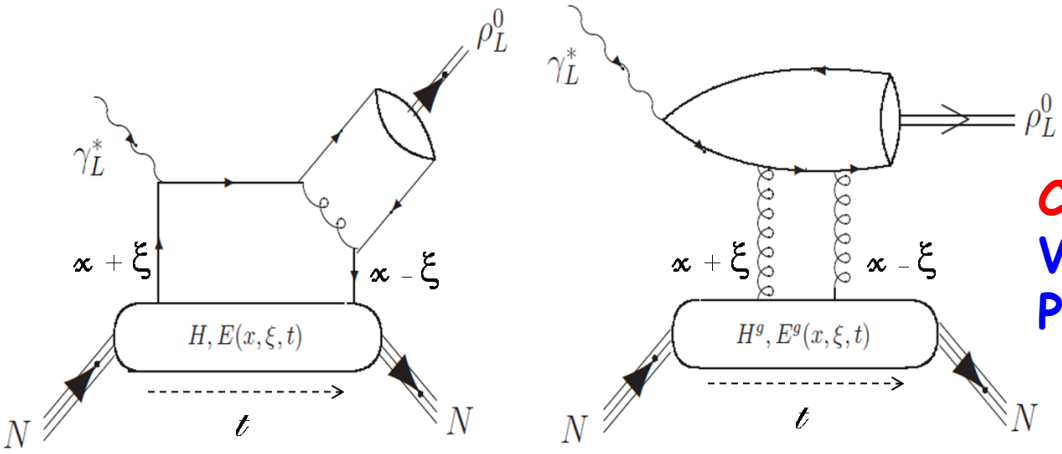
$\Rightarrow \mathcal{R}e\,(F_1\mathcal{H})$

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

ECAL0 and ECAL1



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 :

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

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

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

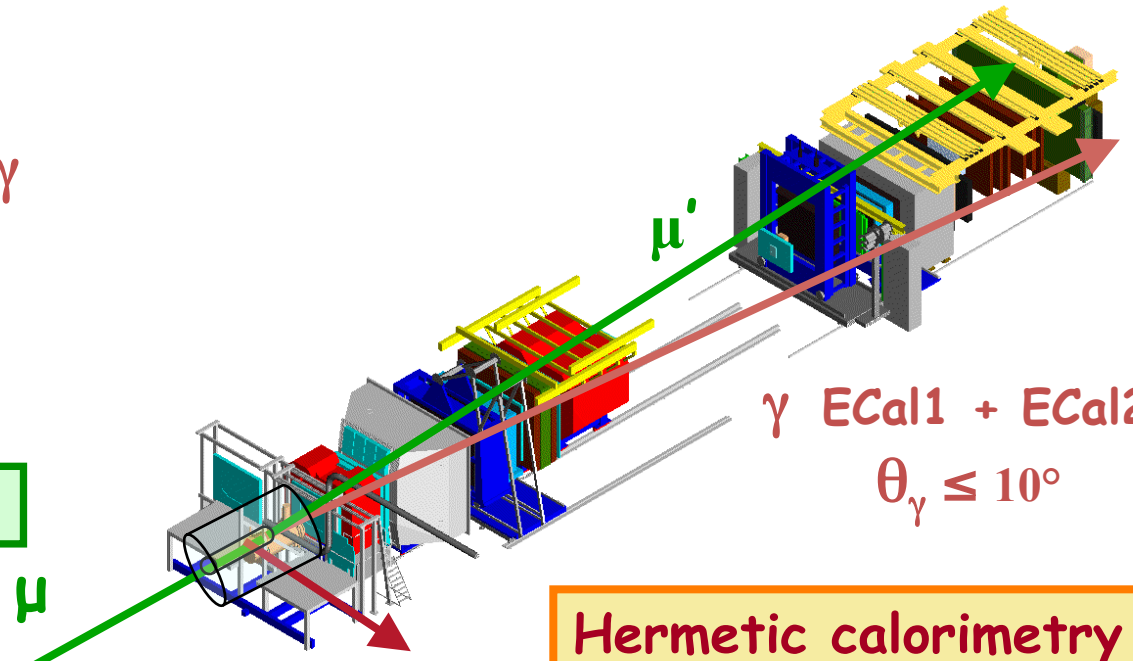
⇒ ρ : ω : ϕ ~ 9 : 1 : 2 at large Q^2

Transversely polarized target asymmetry on vector meson :

⇒ E/H (studied at COMPASS without RPD)

GPD program : new equipments

DVCS $\mu p \rightarrow \mu' p' \gamma$



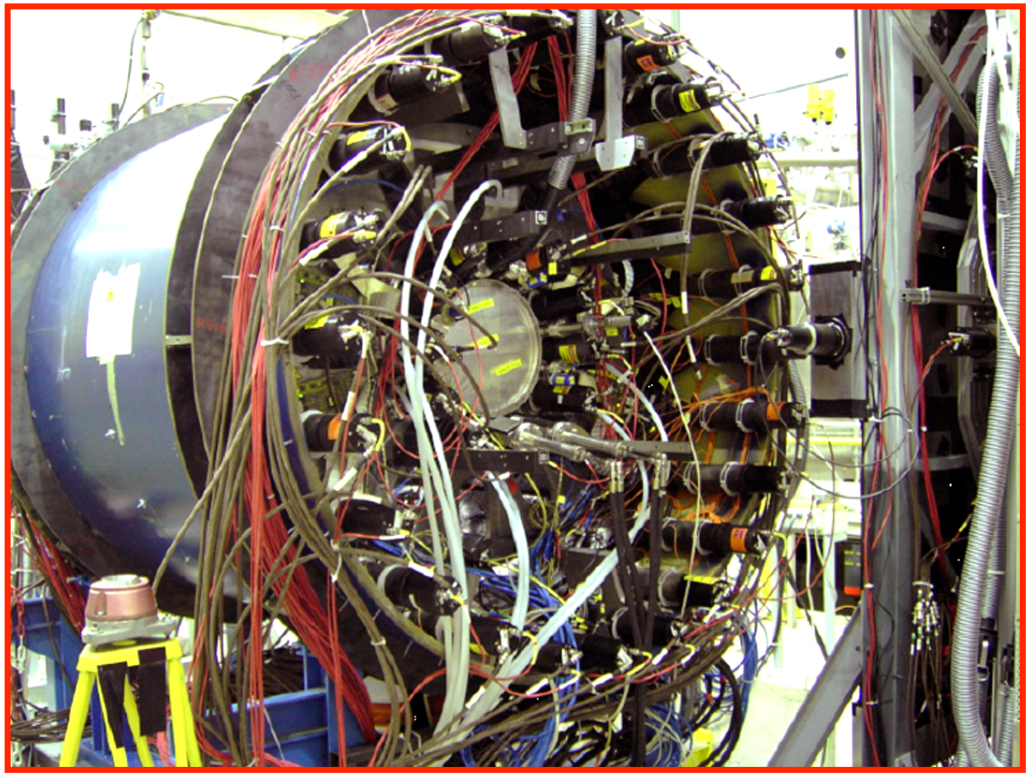
2.5 m liquid H_2 target

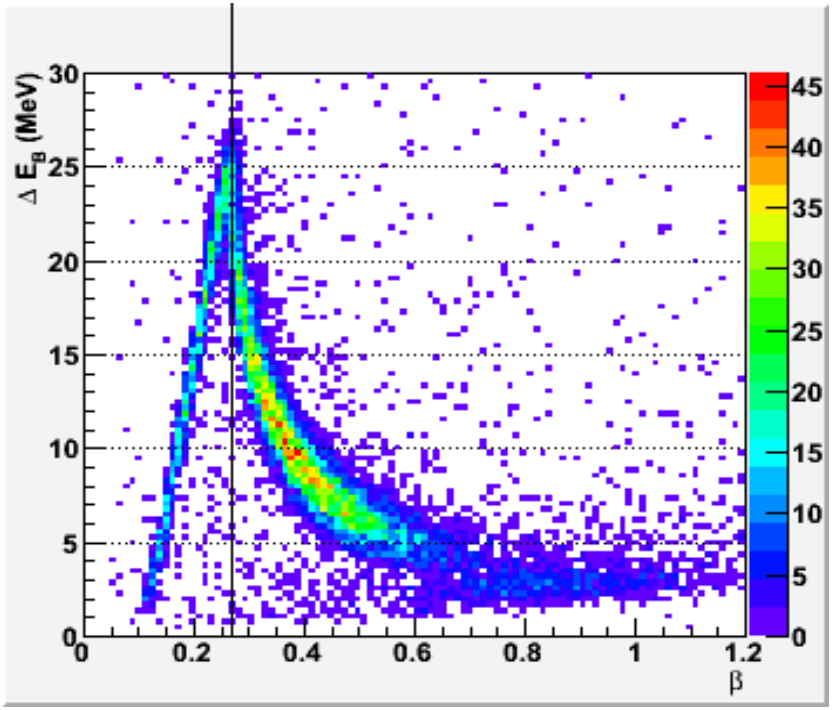
4m long Recoil Proton Detector

Hermetic calorimetry
new ECAL0

Later stage…
Transversely polarized target
Associated RPD

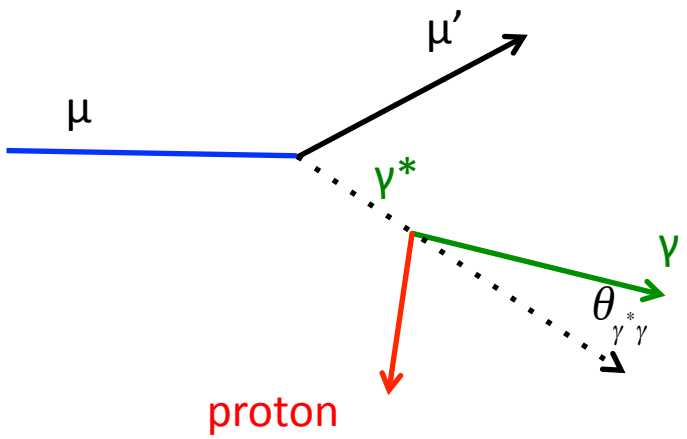
Hadron program RPD





Proton identification in RPD
Elastic scattering (hadron beam)

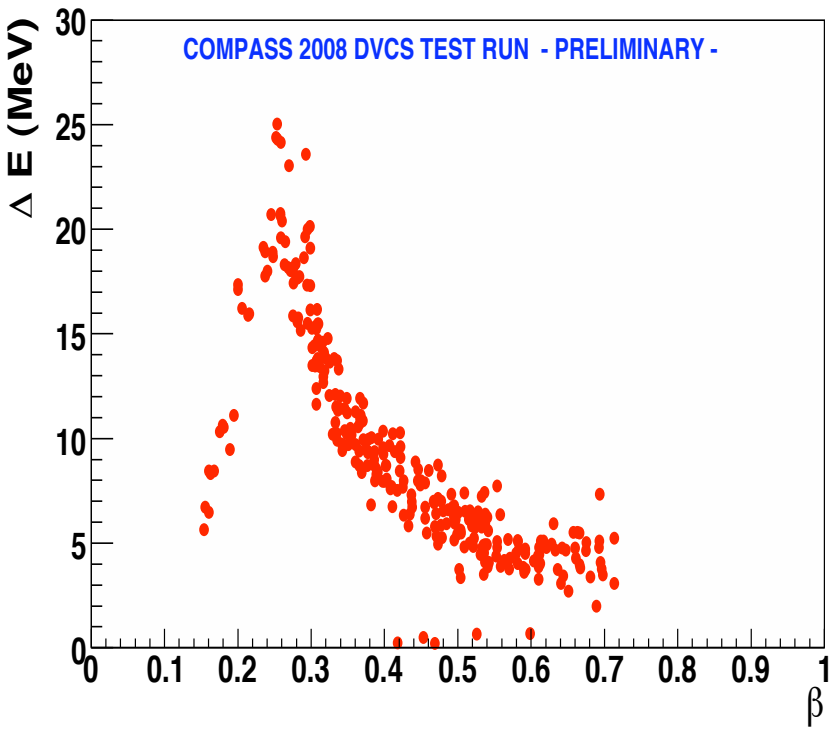
Kinematical consistency : $\vartheta_{\gamma^*\gamma}$

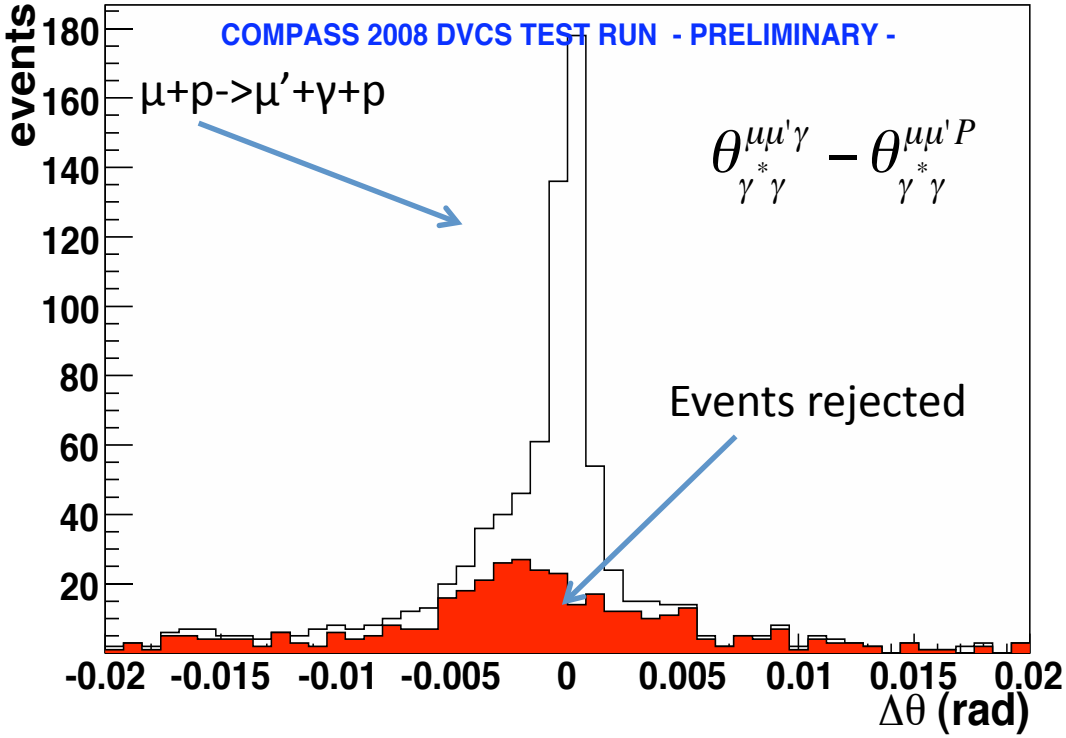


With μ, μ' and γ : $\theta^{\mu\mu'\gamma}_{\gamma^*\gamma}$

With μ, μ' and proton :

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





Measurements and Estimations for resolution

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

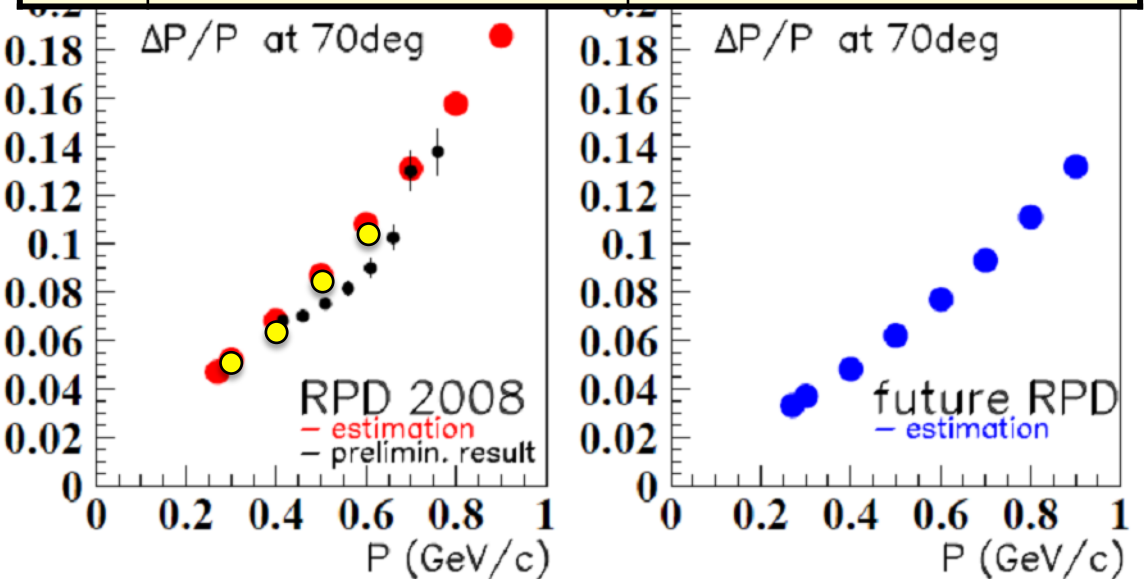
$$\frac{\Delta t}{t} \approx 2\frac{\Delta P}{P}$$

	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

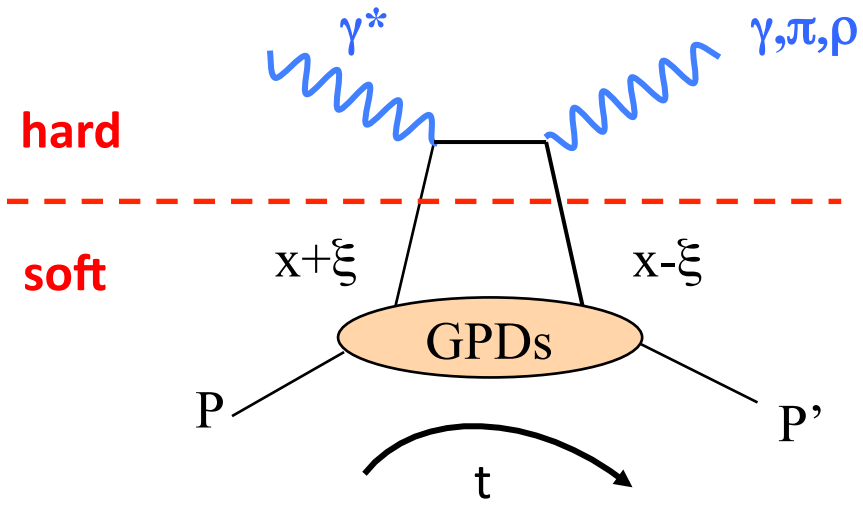
$t_{m\ in}$=-0.06 GeV^2

Good resolution in t

Importance for the the transverse imaging



Generalized Parton Distributions



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

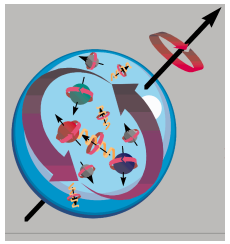
Generalized Parton Distributions

for quarks :

4 functions $H,E,\widetilde{H},\widetilde{E}(x,\xi,t)$

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

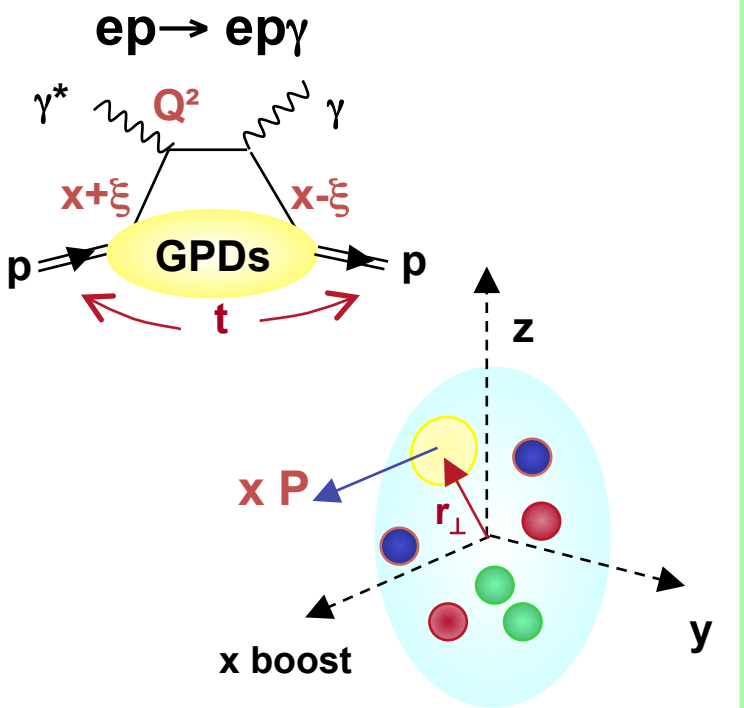


contains information on the nucleon spin :

Ji's sum rule :
$$\int x(H^q(x,\xi,t=0) + E^q(x,\xi,t=0))dx = J^q$$

3-D partonic structure of the nucleon ($P_z, r_{y,z}$)

Hard Exclusive Scattering
Deeply Virtual Compton Scattering



GPDs : H(x,ξ,t)

Fourier (ξ=0)

access to correlations :

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

Burkardt,Belitsky,Müller,Ralston,Pire