Prospects for GPD studies at COMPASS

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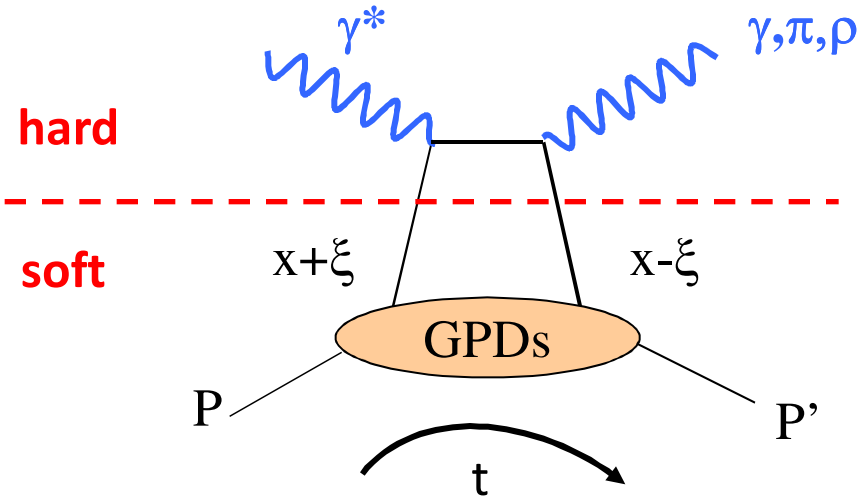
On behalf of the COMPASS Collaboration
CERN , March 4th, 2010

- Physics Motivations
- Sensitivity of observables
- Experimental issues
- Beam tests results

Generalized Parton Distributions



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

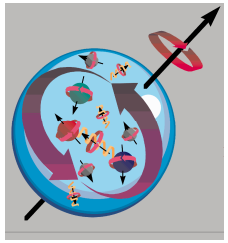
Generalized Parton Distributions

for quarks :

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

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

contains form factors
$$F(t) = \int \mathrm{d}x H(x,\xi,t)$$
measured in elastic scattering



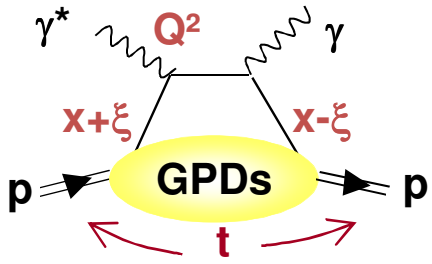
contains information on the nucleon spin :

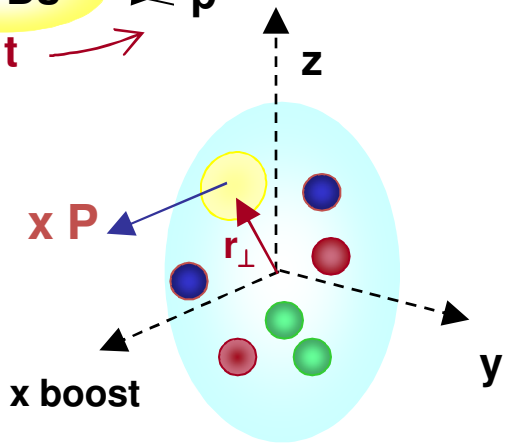
Ji's sum rule :
$$\int x(H^q(x,\xi,t=0) + E^q(x,\xi,t=0))\mathrm{d}x = J^q$$

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

Hard Exclusive Scattering
Deeply Virtual Compton Scattering

$ep \rightarrow ep\gamma$





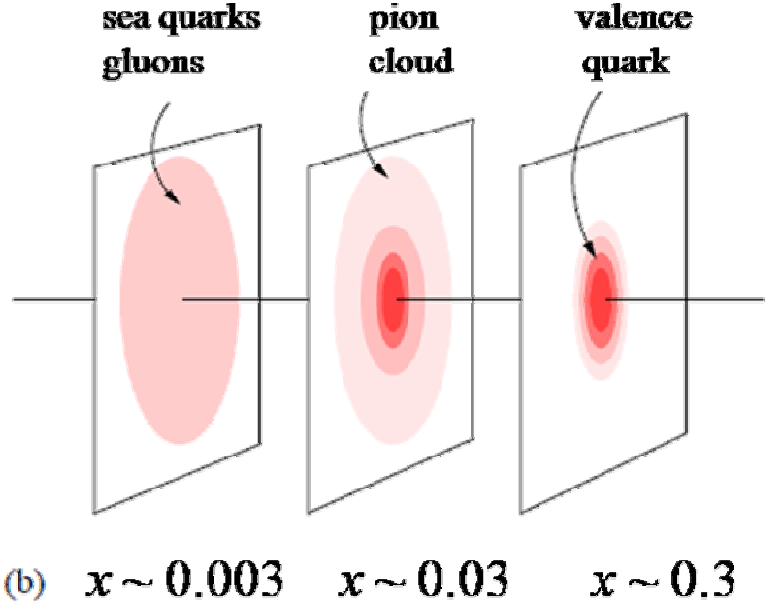
GPDs : H(x,ξ,t)

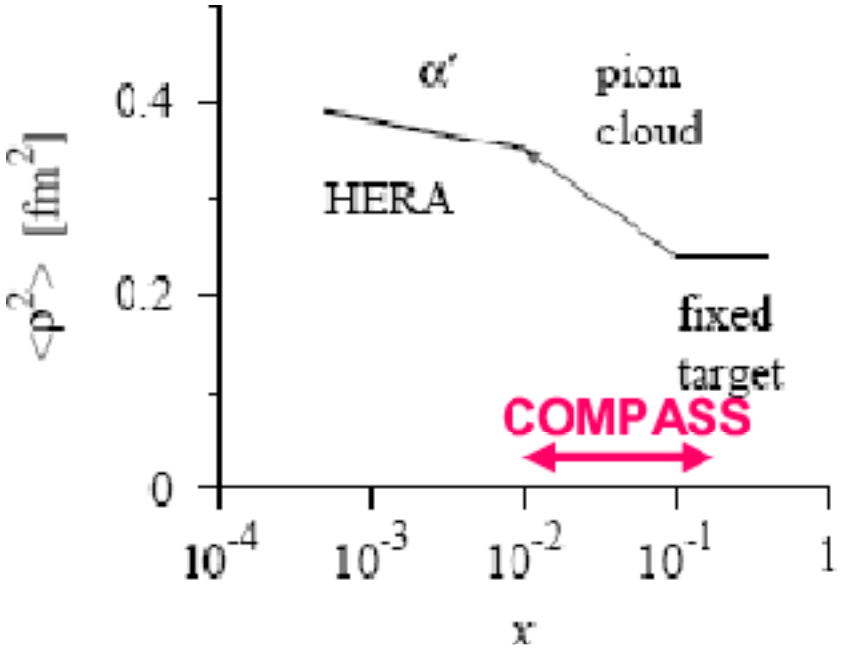
Fourier (ξ=0)

access to correlations :

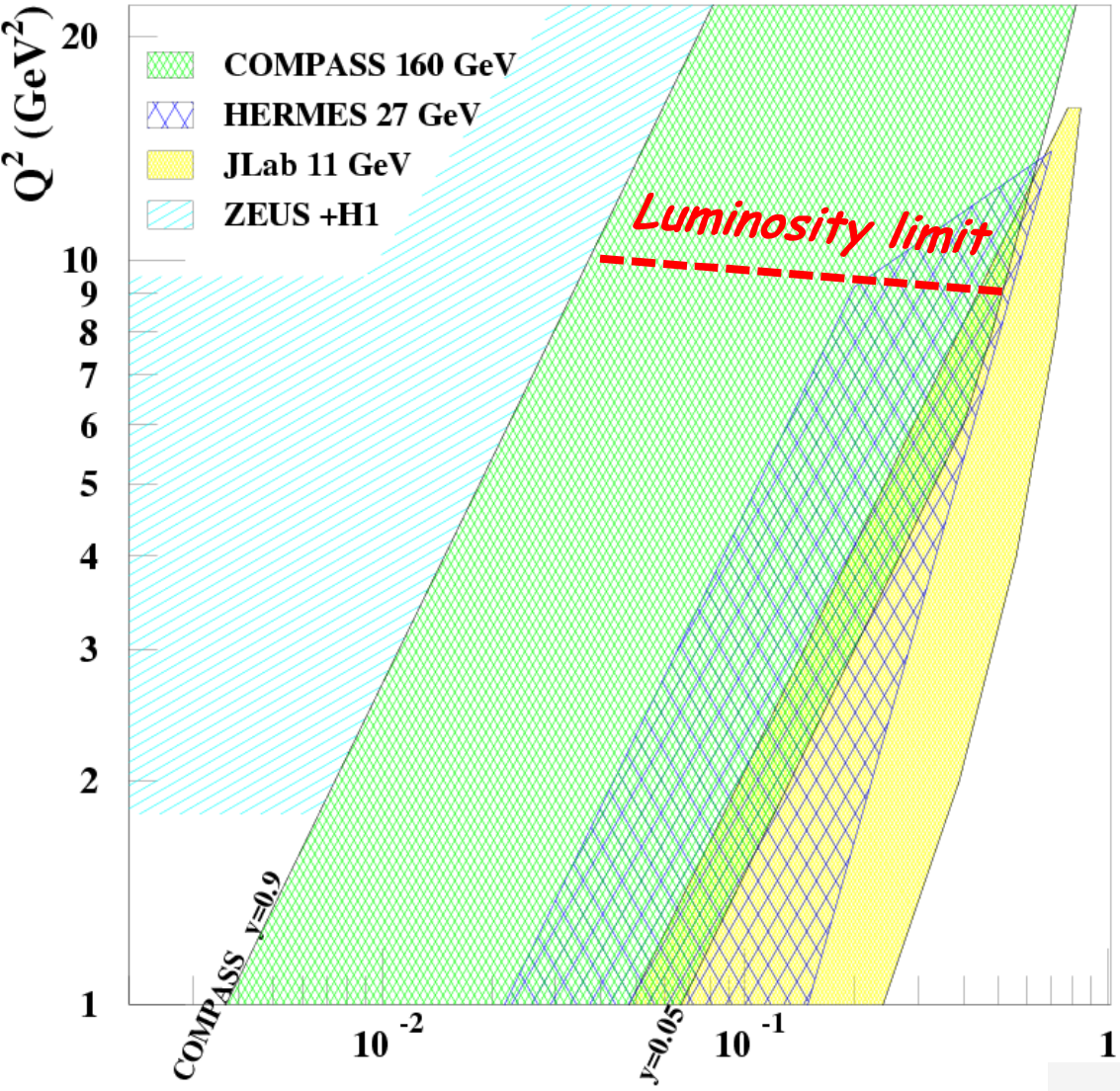
(P_x, $r_{y,z}$)

Burkardt,Belitsky,Müller,Ralston,Pire





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

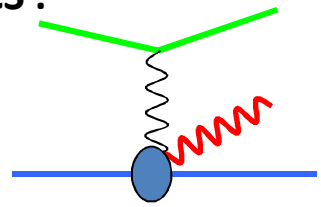
Foreseen program :
DVCS and meson production off a liquid H2 target (unpolarized)

⇒ Will explore the intermediate x_{Bj} region

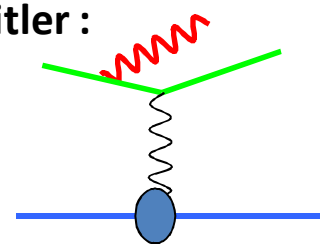
⇒ Uncovered region between ZEUS+H1 and HERMES+Jlab

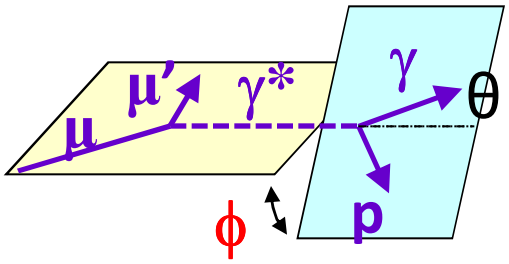
Comparison of BH and DVCS at 160 GeV

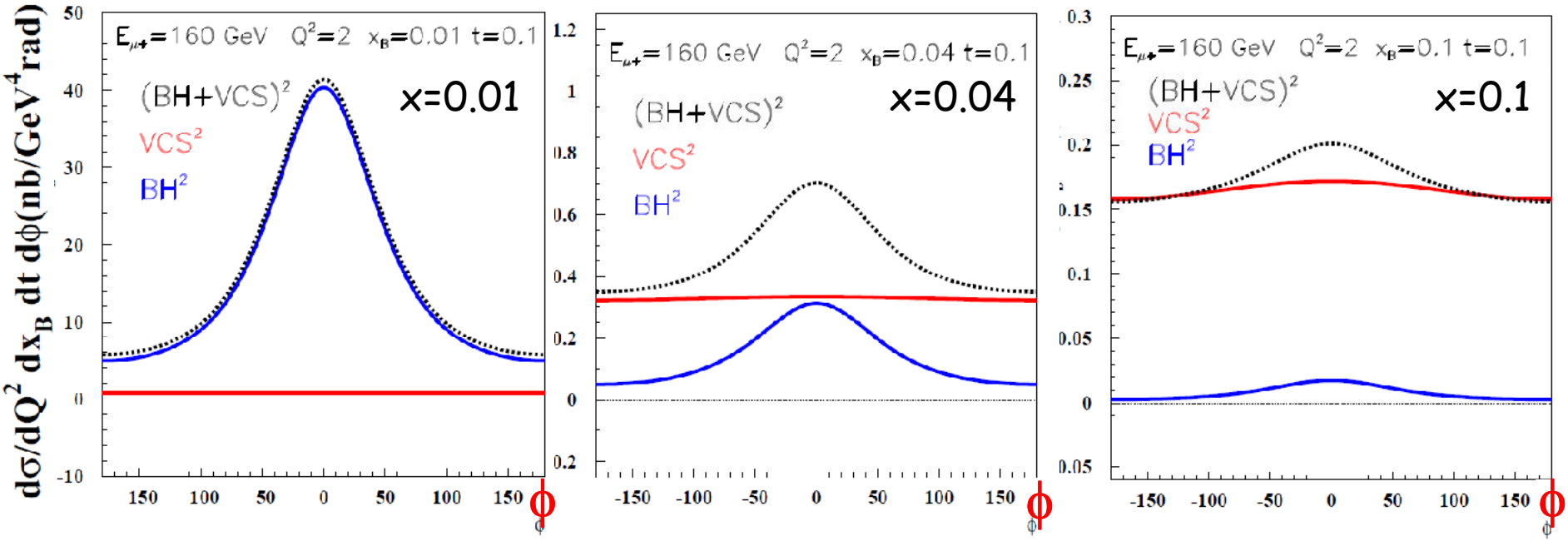
DVCS :



Bethe-Heitler :







BH dominates

excellent
reference yield

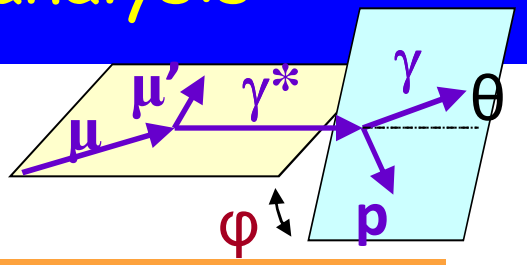
BH and DVCS at the same level

access DVCS *amplitude*
through the interference

DVCS dominates

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

Azimuthal angular dependence analysis



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

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

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

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

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

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

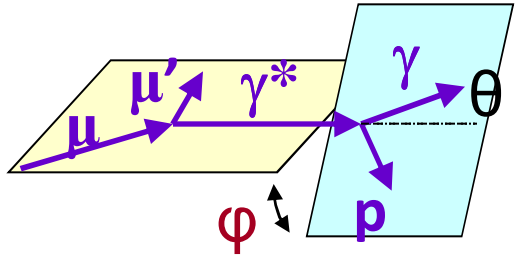
$$e_\mu P_\mu \times a^{BH}\,\mathcal{I}m A^{DVCS} = \frac{e^6}{xy^3tP_1(\varphi)P_2(\varphi)}\left(s_1^{Int}\sin\varphi + s_2^{Int}\sin 2\varphi\right)$$

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

Angular dependence analysis

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

unpolarized H_2 target



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

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

=> dσ/dt

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

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

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

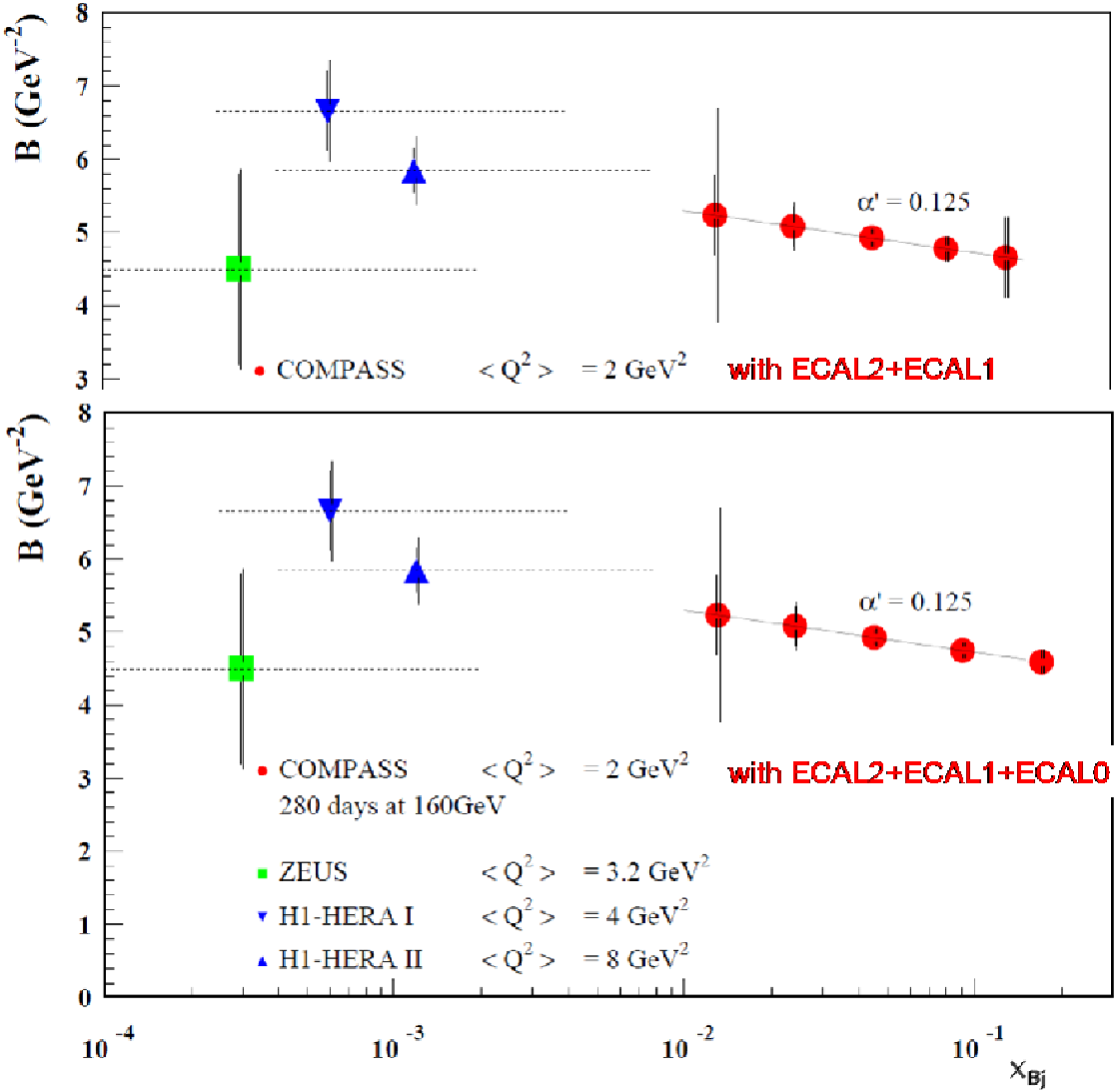
$s_1^{DVCS}\sin\varphi$

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

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

From $S_{U,CS}$: t-slope measurement

Assuming 3% systematic error on BH



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
$L = 1222\ pb^{-1}$
$\varepsilon_{global} = 10\ \%$

3 σ slope measurement for :

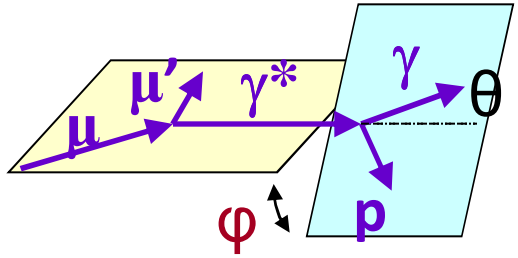
$\alpha' > 0.30$ (ECAL 1+2)

$\alpha' > 0.16$ (ECAL 0+1+2)

Angular dependence analysis

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

unpolarized H_2 target



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

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

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

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

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

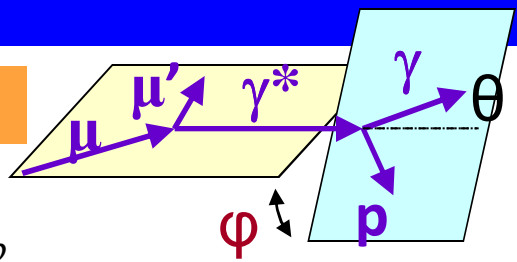
$$c_0^{Int} + c_1^{Int}\cos\varphi + c_2^{Int}\cos 2\varphi + c_3^{Int}\cos 3\varphi \;\Rightarrow\; \mathcal{R}e(F_1\mathcal{H})$$

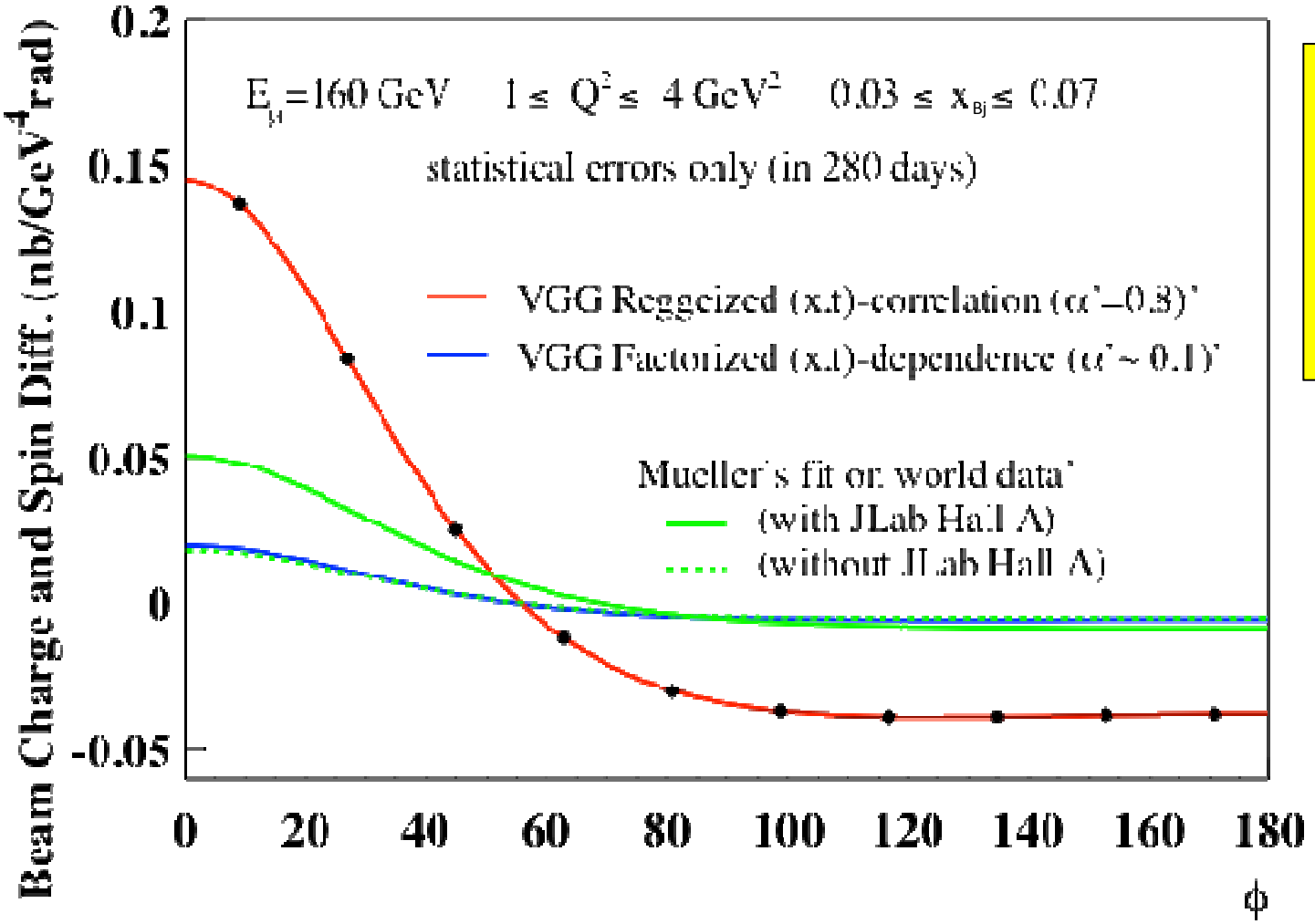
$\mathcal{D}_{U,CS}$: Beam Charge & Spin Difference

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

$s_1^{DVCS} \sin\varphi$

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





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

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

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

BCSA(□) over the kinematical domain

$BCSA = \mathcal{D}_{U,cs} / S_{U,cs}$

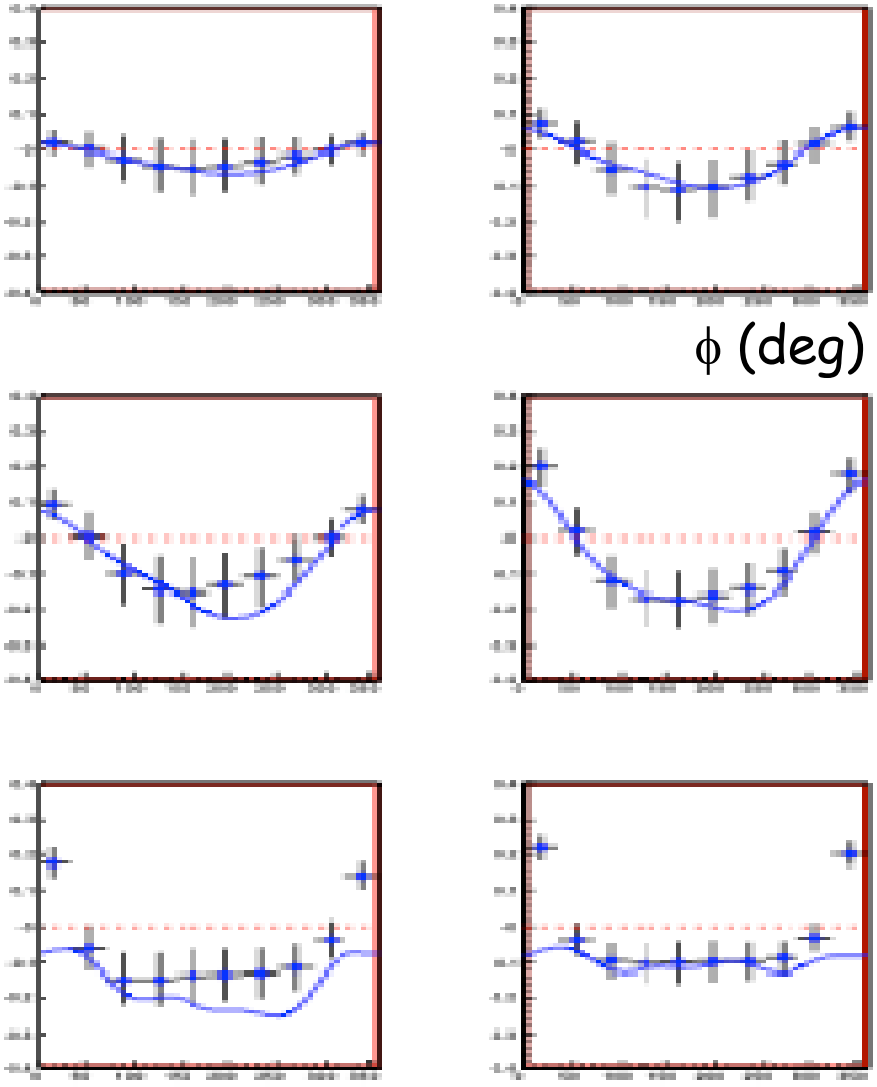
Points: VGG prediction Phys. Rev. D60:094017,1999
Statistical errors only
Curves: FFS prediction Phys. Rev. D59:119901,1999

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

$4 < Q^2 < 8$

$2 < Q^2 < 4$

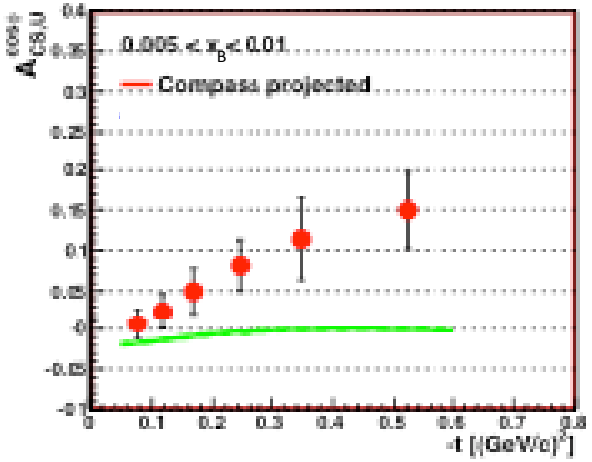
$1 < Q^2 < 2$

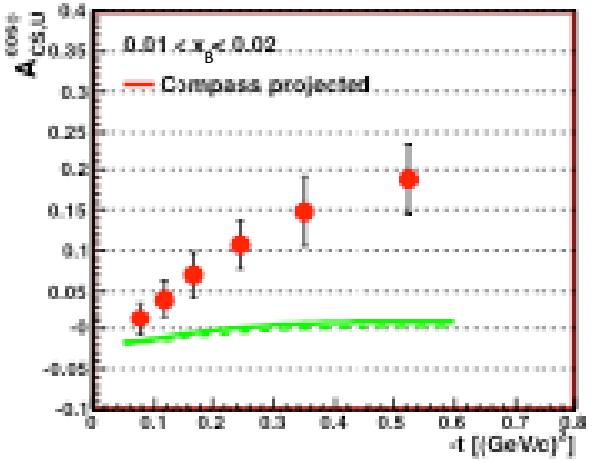


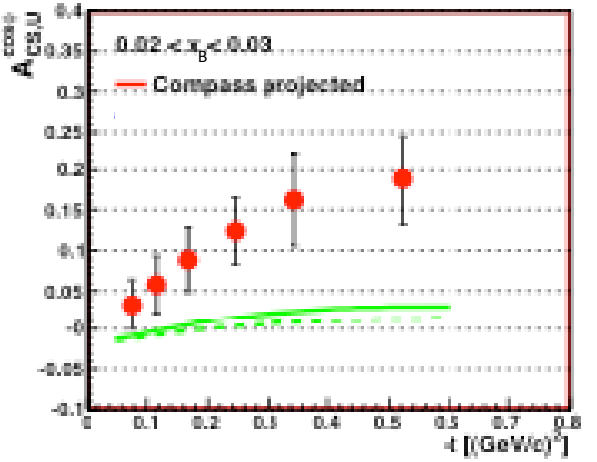
statistical precision of the cosϕ modulation

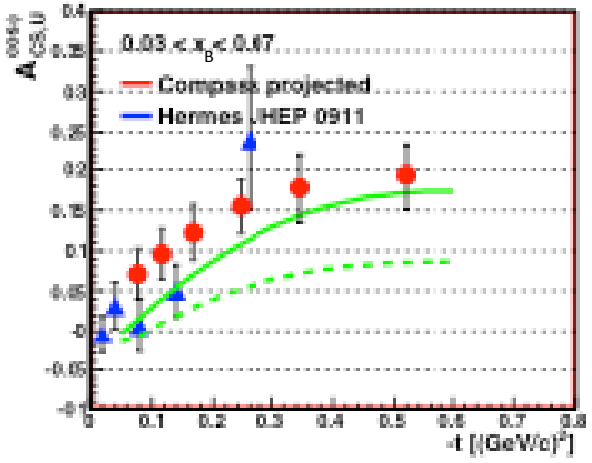
$BCSA = \mathcal{D}_{U,cs} / \mathcal{S}_{U,cs} = A_0 + A_{CS,U} \cos\phi + A_2 \cos 2\phi$

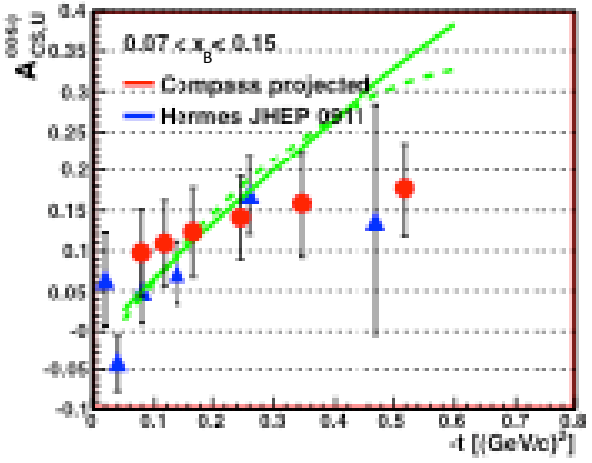
Mueller's fit on world data'
(with JLab Hall A)
(without JLab Hall A)

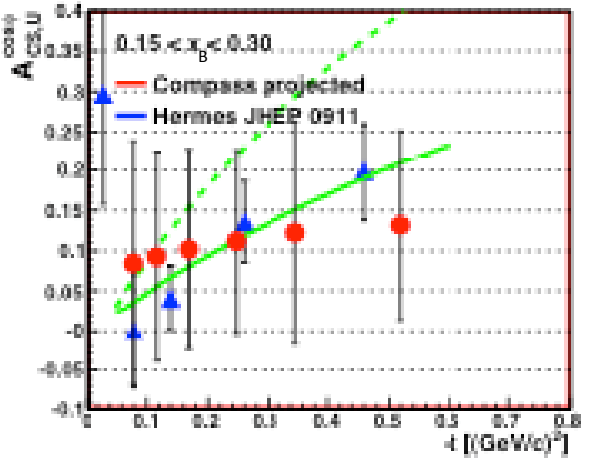




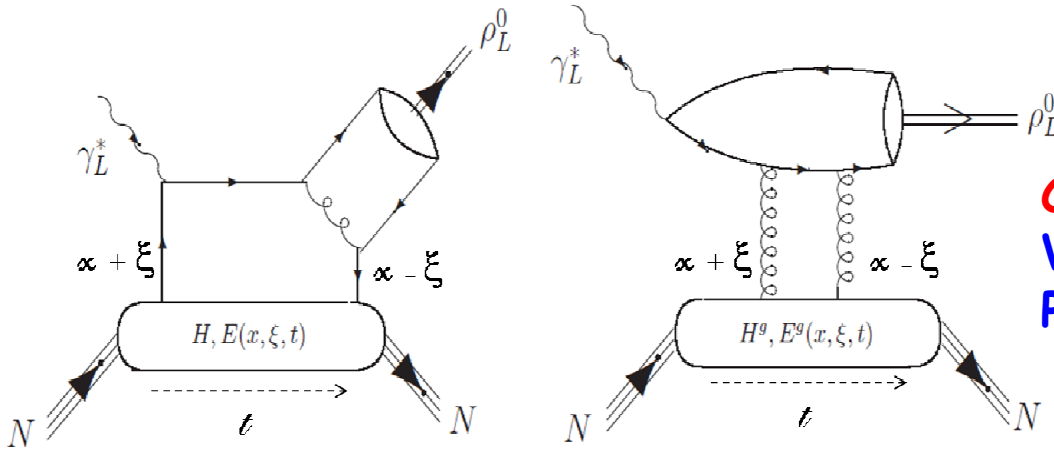








Meson production : filter of GPDs



Cross section measurement :

Vector meson : ρ,ω,ϕ... ⇒ H & E

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

Would allow for flavor separation :

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

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

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

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

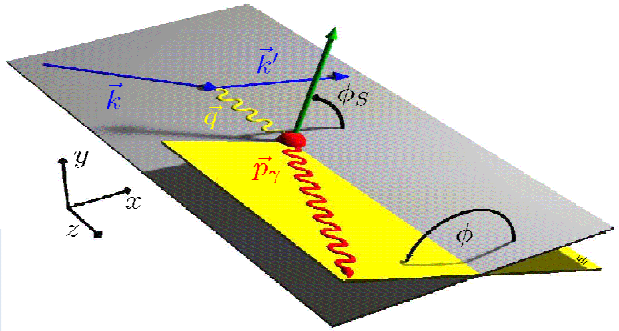
Transversely polarized target asymmetry on vector meson :

⇒ E/H (studied at COMPASS without RPD)

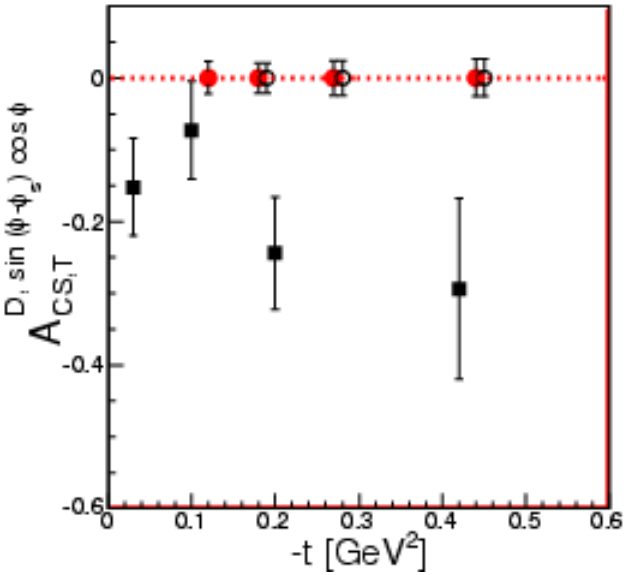
Continuation of the GPD program : constrain the GPD E

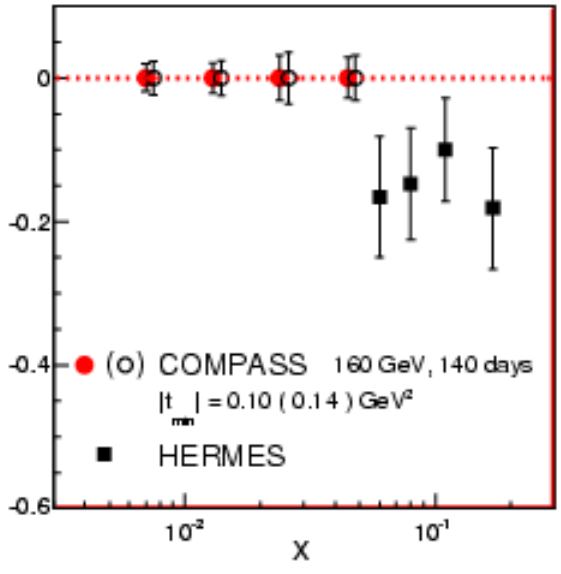
with $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ beam and **transversely** polarized NH3 (proton) target

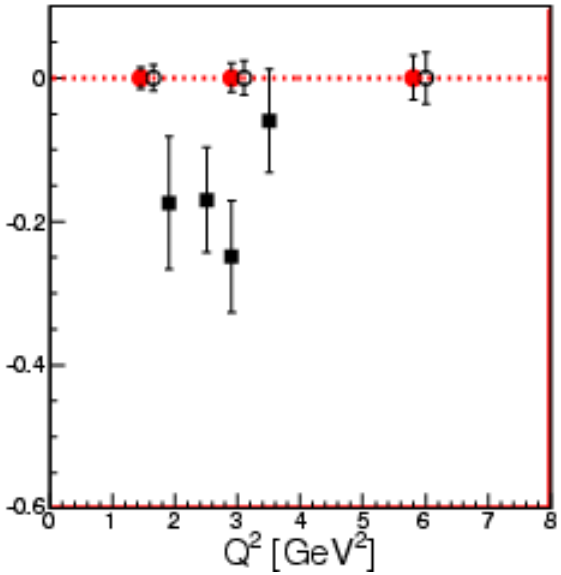
$$\mathcal{D}_{T,CS} \equiv d\sigma_T(\mu^{+\downarrow}) - d\sigma_T(\mu^{-\uparrow}) \propto Im(F_2\mathcal{H} - F_1\mathcal{E}) \sin(\phi - \phi_S)\cos\phi$$



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

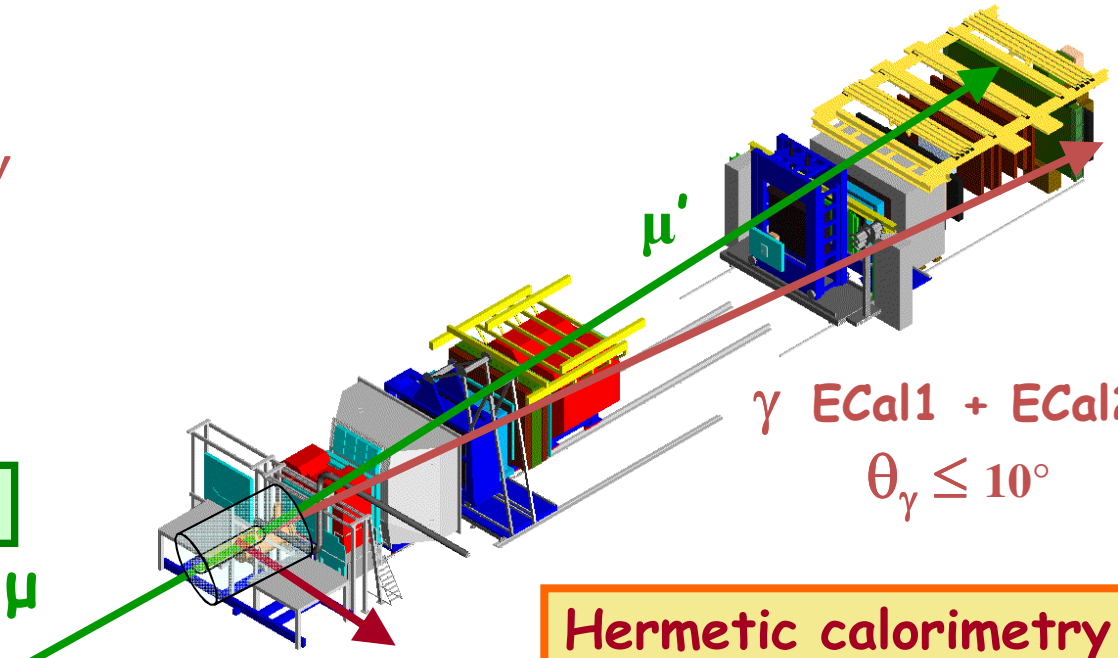






GPD program : new equipments

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



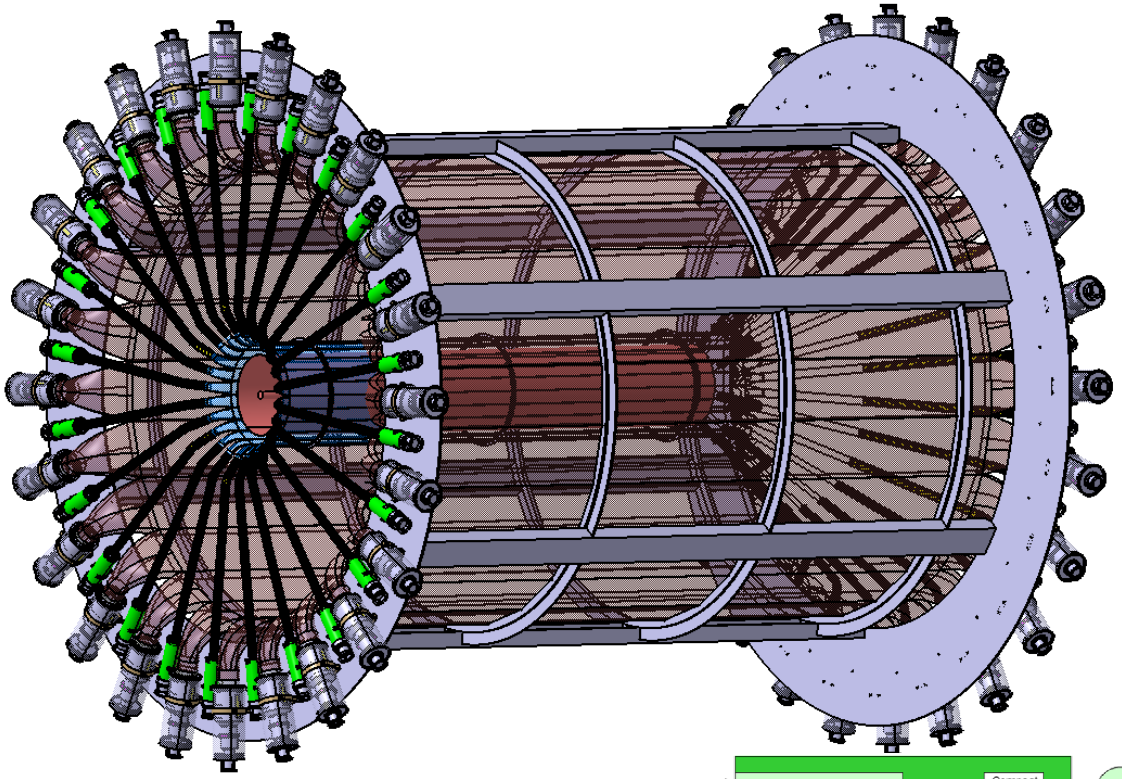
2.5 m liquid H_2 target

Hermetic calorimetry
new ECAL0

4m long Recoil Proton Detector

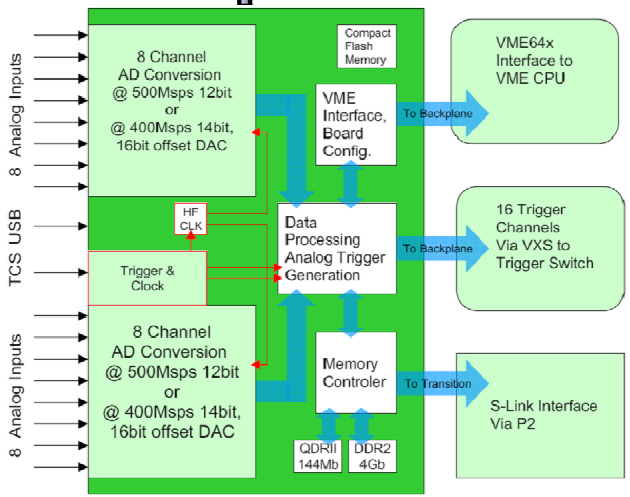
Later stage…
Transversely polarized target
Associated RPD

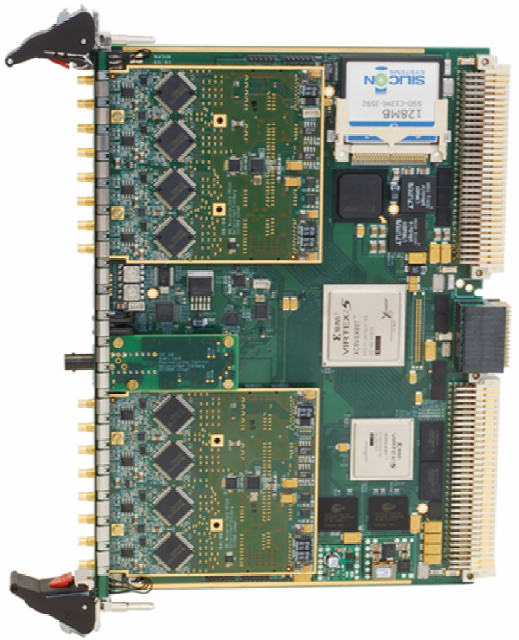
Recoil Proton Detector



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

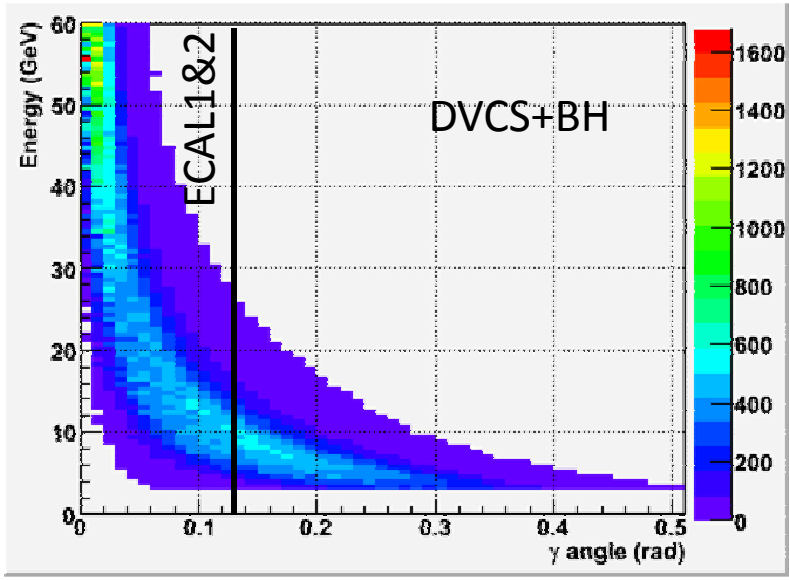
Gandalf Project:
1 GHz digitalisation of the PMT signal to cope for high rate



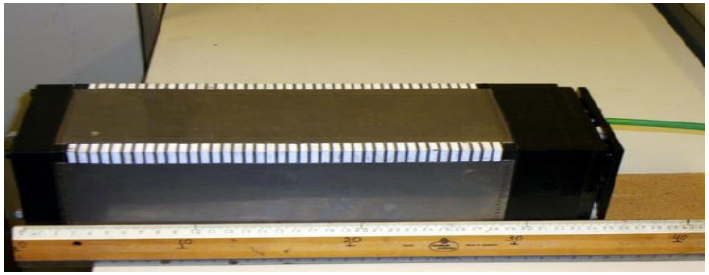


ECAL 0

Requirements
- Photon energy range 0.2- 30 GeV
- Size: 320cm x 320cm ;
- Granularity 4x4 – 6x6cm^2
- Energy resolution < 10.0%/√E (GeV)
- Thickness < 50 cm,
- Insensitive to the magnetic field.

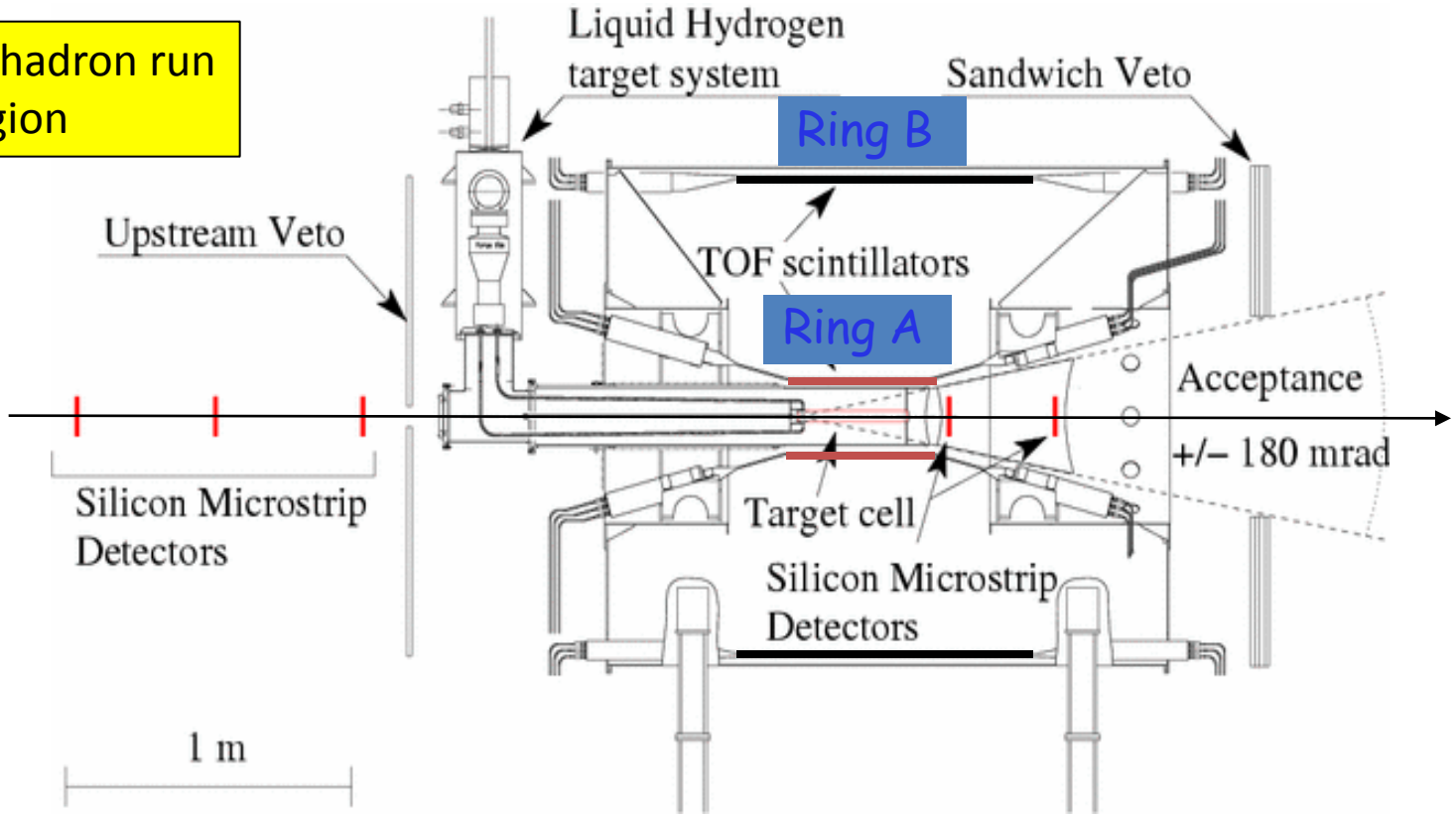


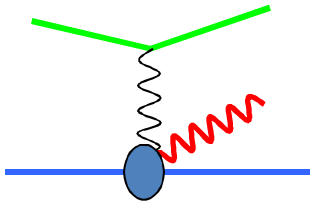
Prototype under studies
- Shaschlyk module with AMPD readout
- Tested



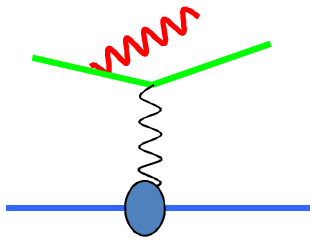
2008 beam test

Compass hadron run
Target region





DVCS

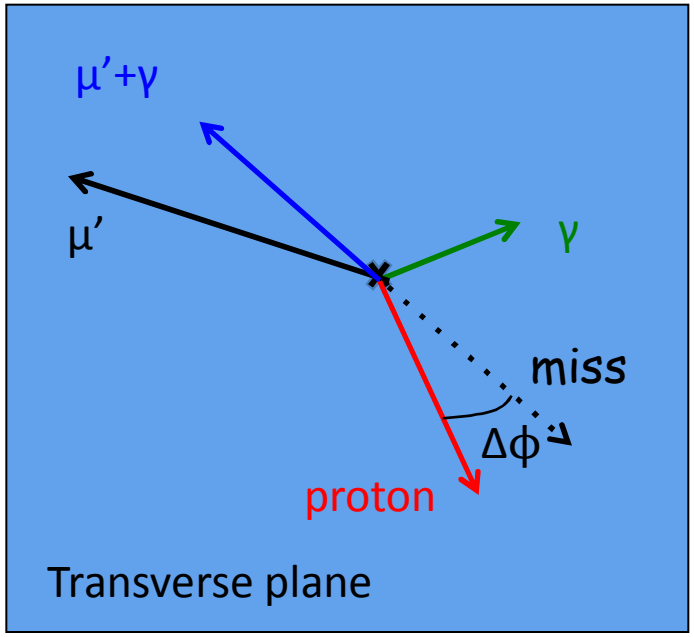


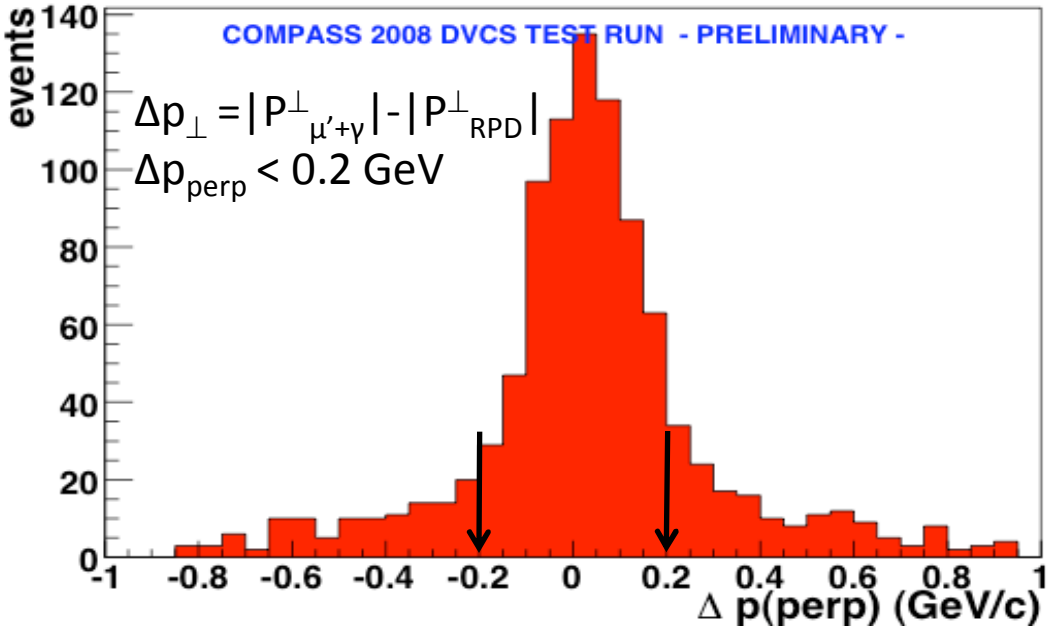
Bethe-Heitler

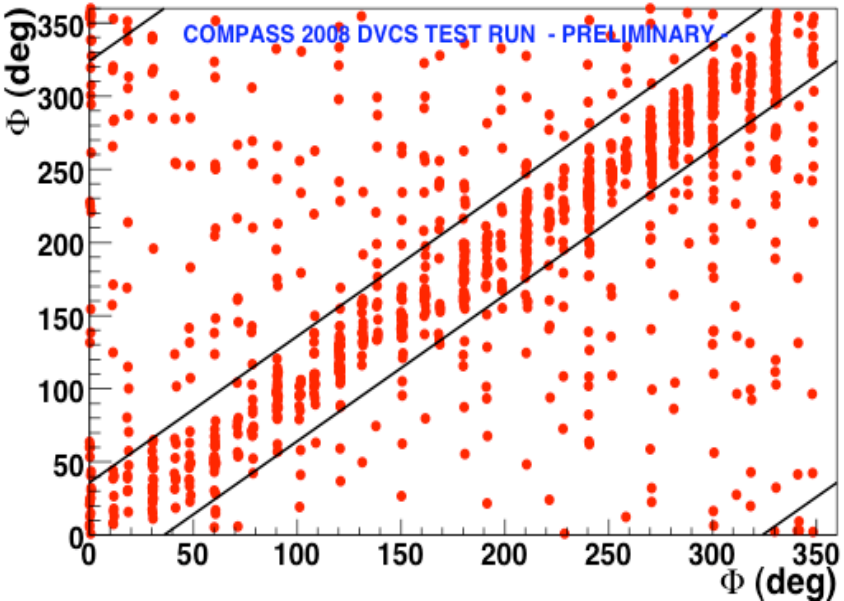
Selection of events :

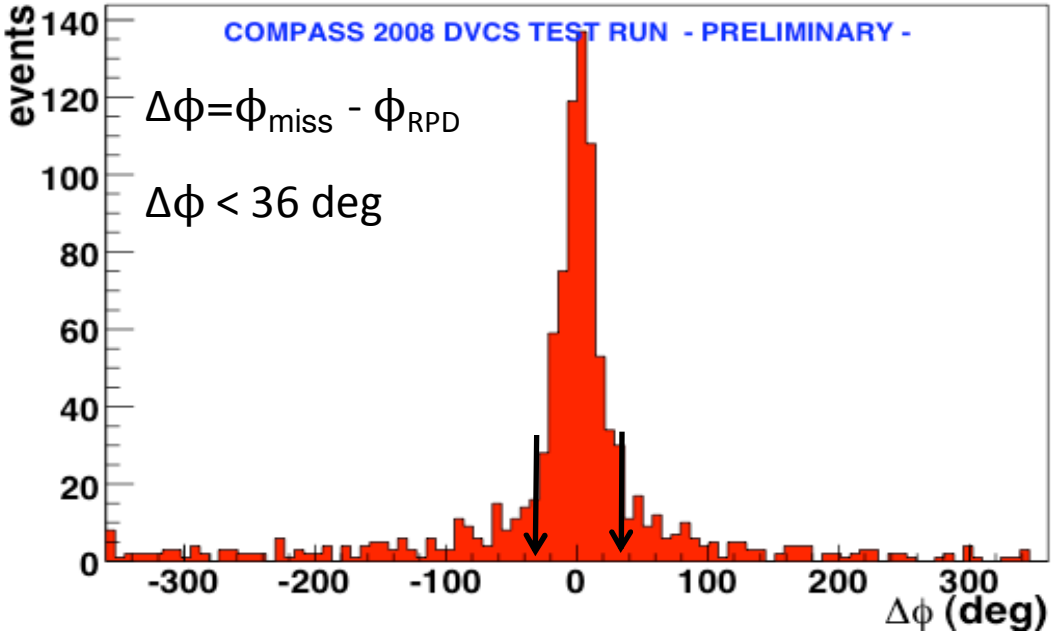
- one vertex with μ and μ'
- no other charged tracks
- only 1 high energy photon ($\Delta t < 5ns$)
- 1 proton in RPD with $p < 1.$ GeV/c

2008 beam test : exclusivity cuts

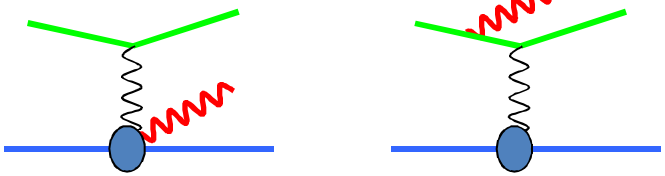








2008 beam test : Bethe-Heitler signal

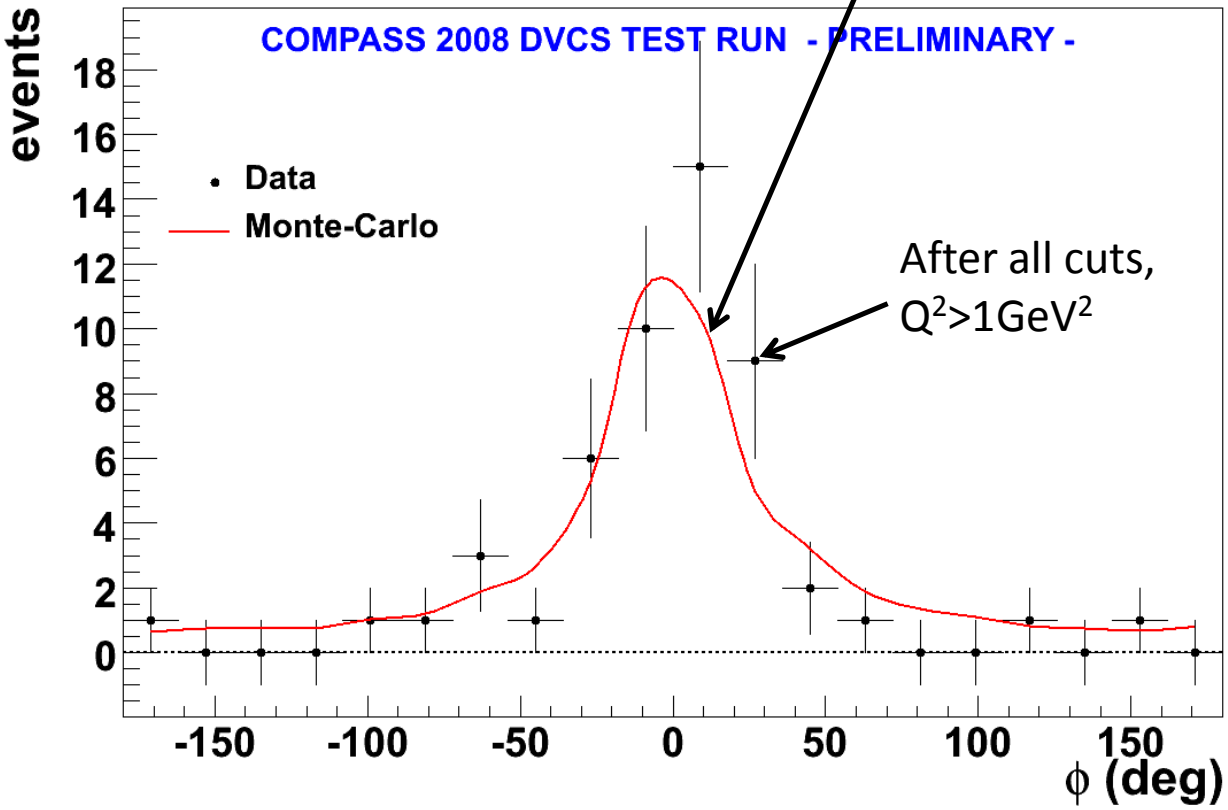


Deep VCS

Bethe-Heitler

Monte-Carlo simulation
of BH (dominant) and DVCS

=> Bethe-Heitler observed



~ 10 times more data taken in 2009

Detection efficiency :

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

Global efficiency :

- μ+p->μ+p+γ efficiency
- SPS & COMPASS availability
- Dead time
- trigger efficiency

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

Projections of errors are realistic

Conclusions & perspectives

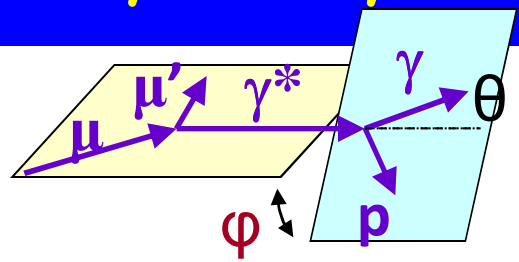
COMPASS has a great potential in GPDs physics

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

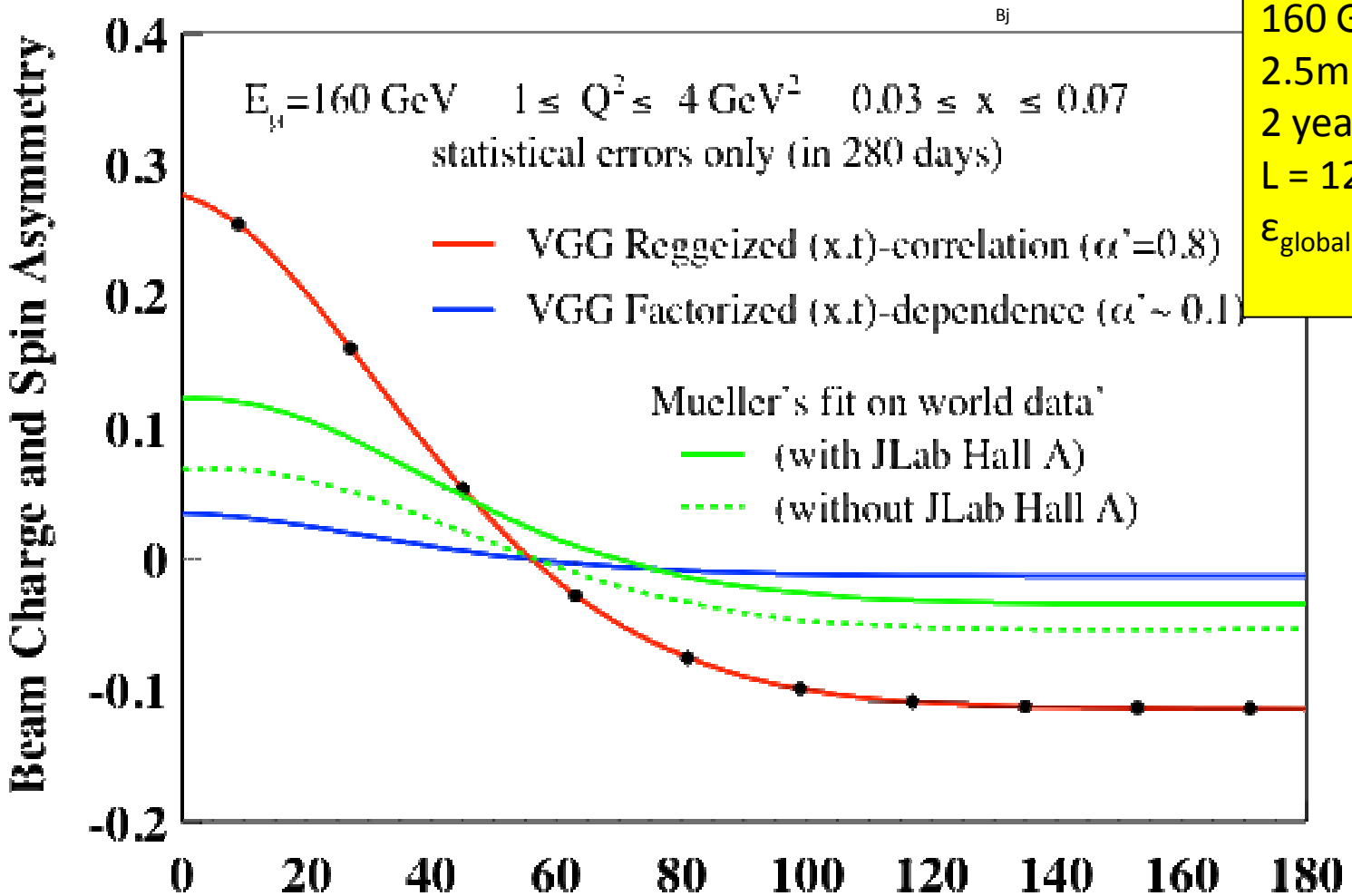
- at a later stage :
  study of the GPD E with a transversely polarized target

$\mathcal{D}_{U,cs}/\mathcal{S}_{U,cs}$: Beam Charge & Spin Asymetry

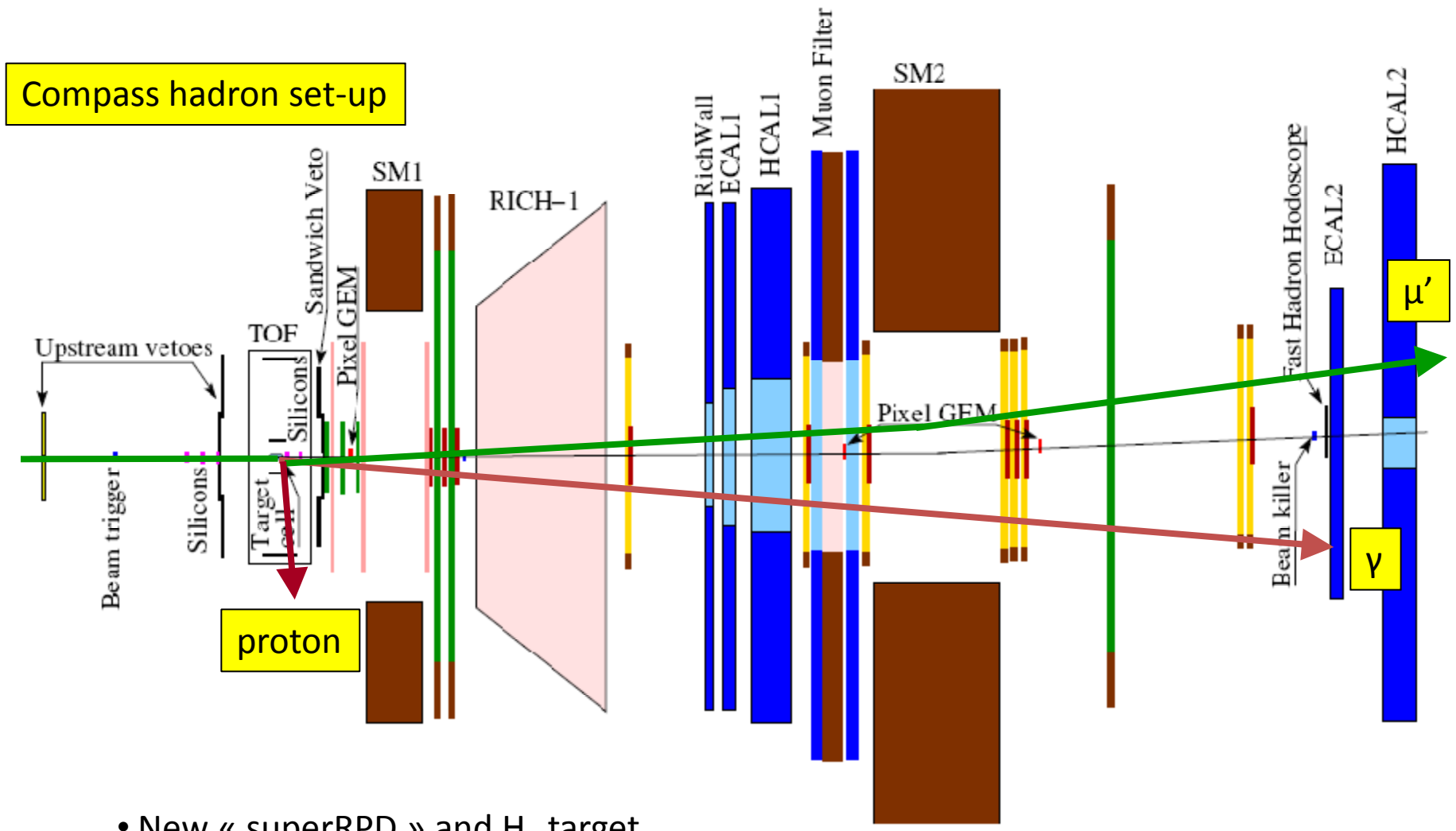
$BCSA = \mathcal{D}_{U,cs}/\mathcal{S}_{U,cs}$



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

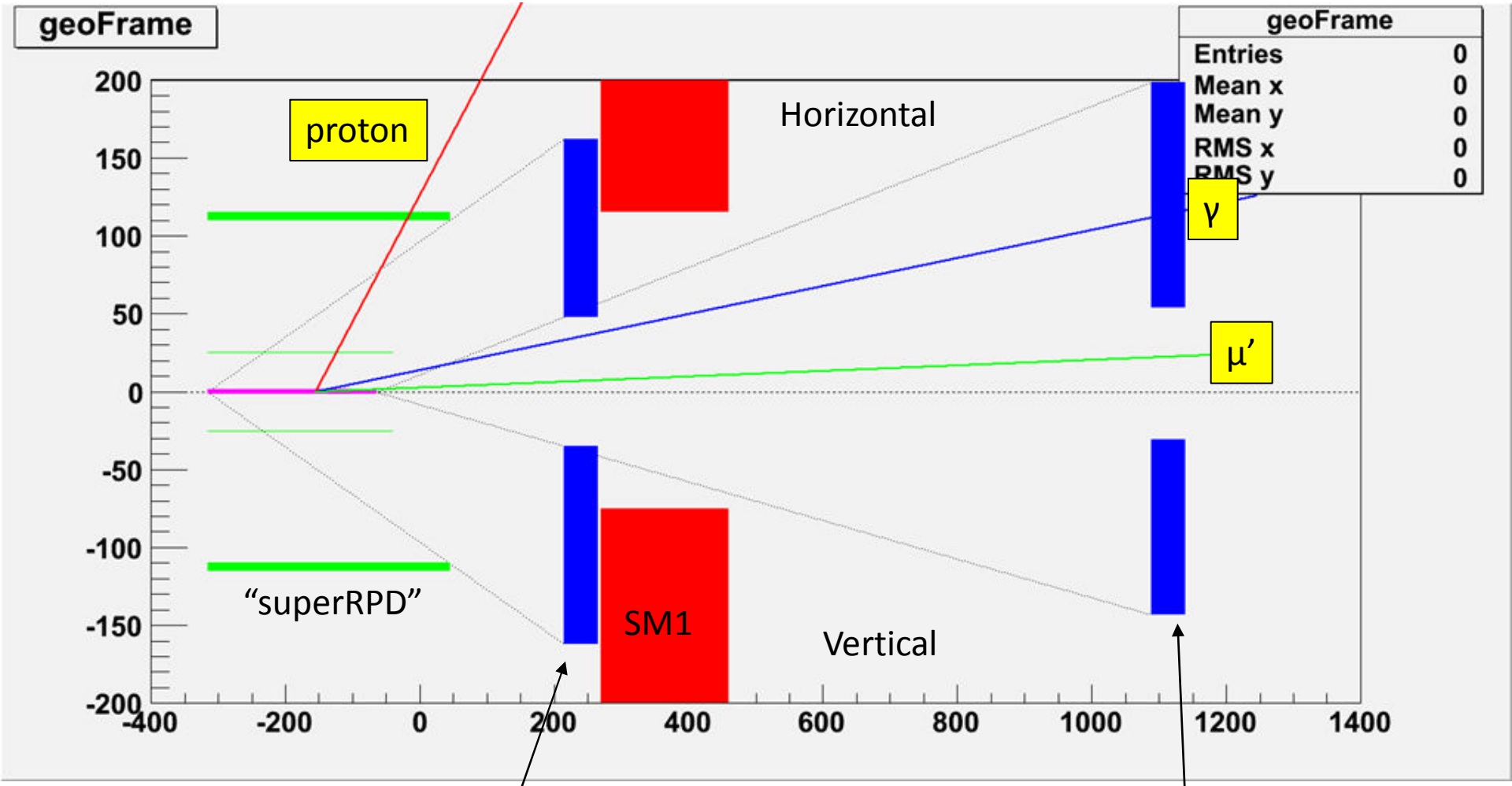


Experimental realisation

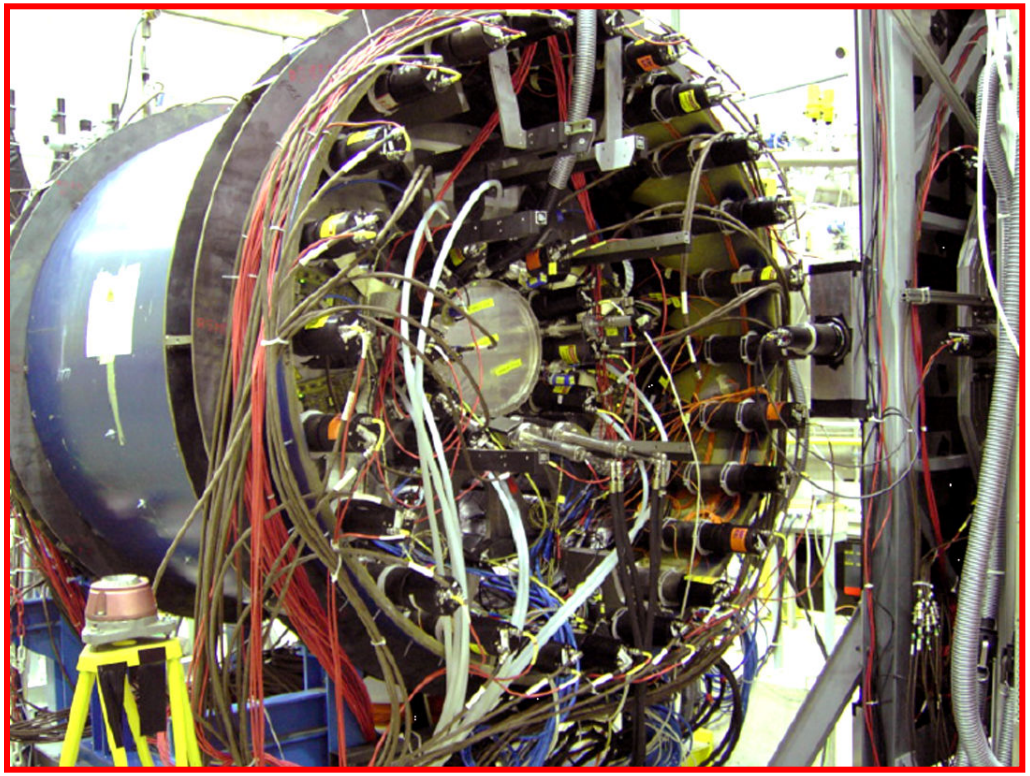


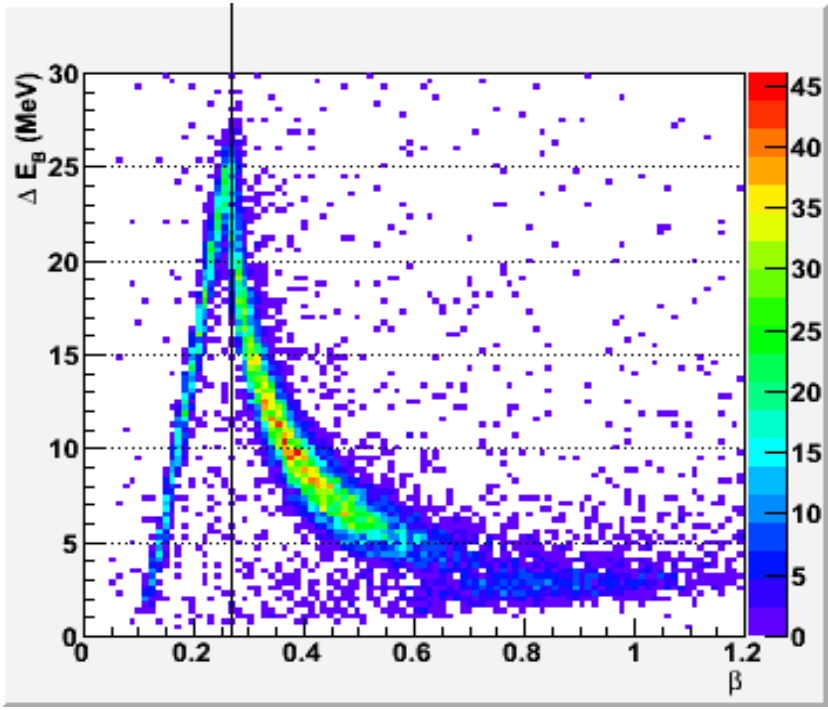
- New « superRPD » and H_2 target
- Hermetic calorimetry : Move ECALs upstream and/or complete ECAL2
- New ECAL0 upstream of SM1

ECAL0 and ECAL1



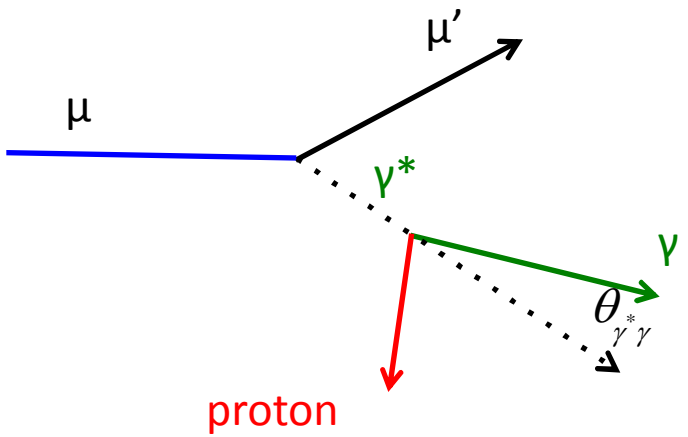
Hadron program RPD





Proton identification in RPD
Elastic scattering (hadron beam)

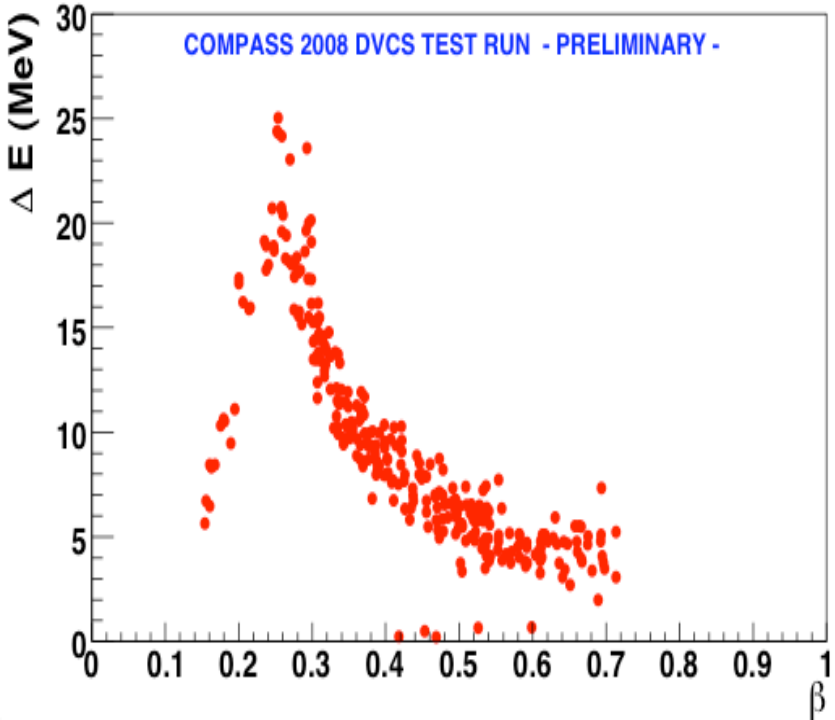
Kinematical consistency : $\vartheta_{\gamma^*\gamma}$

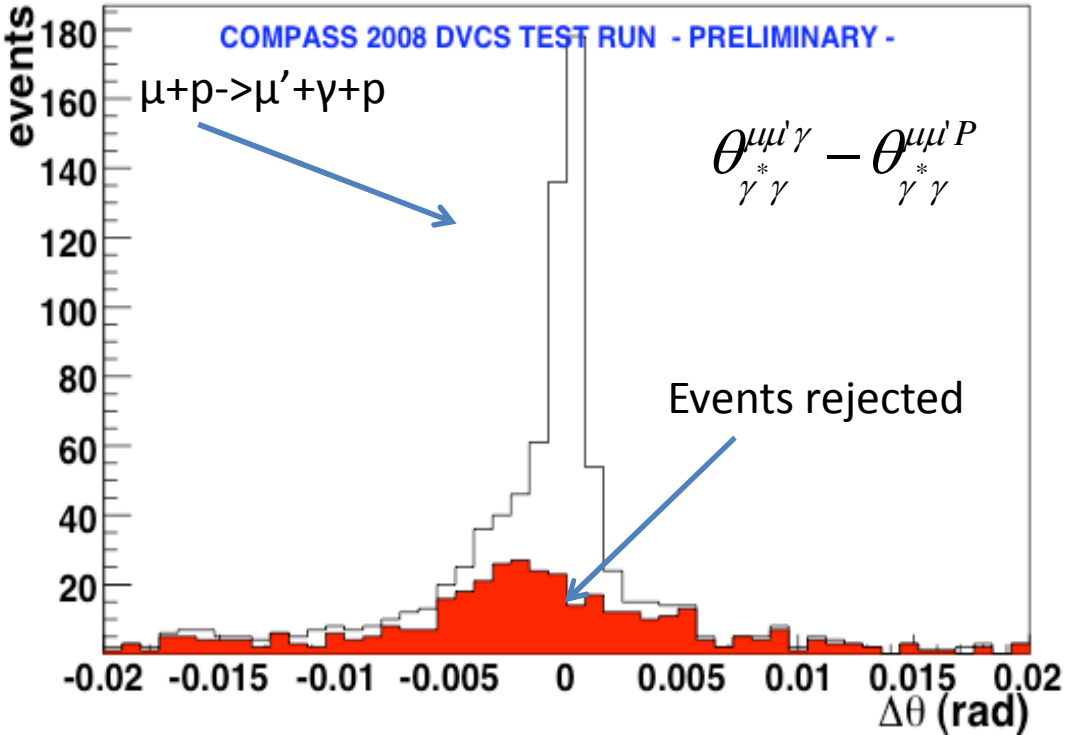


With μ, μ' and γ : $\theta^{\mu\mu'\gamma}_{\gamma^*\gamma}$

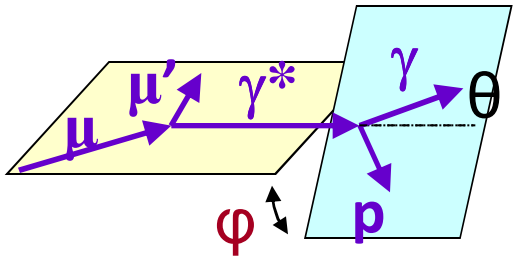
With μ, μ' and proton :

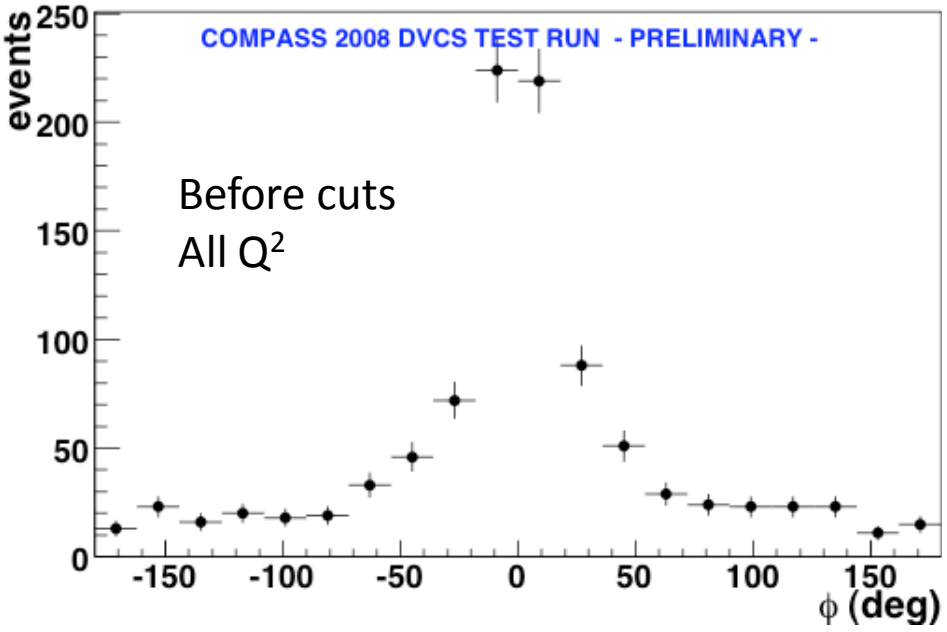
$$\cos\theta^{\mu\mu'P}_{\gamma^*\gamma} = \frac{1}{\sqrt{1+4M_P^2x^2/Q^2}}\left(1+\frac{2M_P^2x}{Q^2}\frac{t+Q^2}{t+Q^2/x}\right)$$

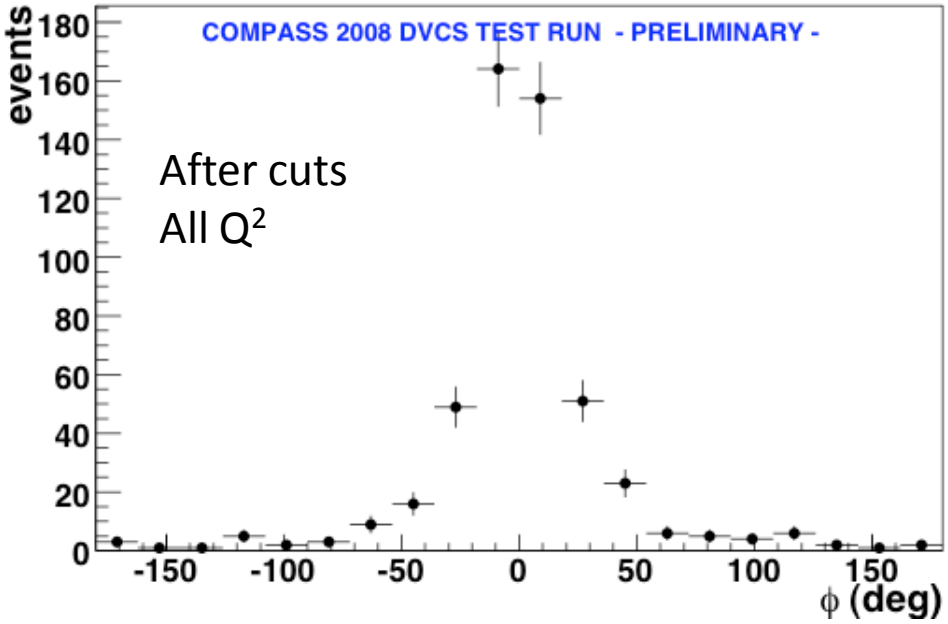




Exclusive photon production signal

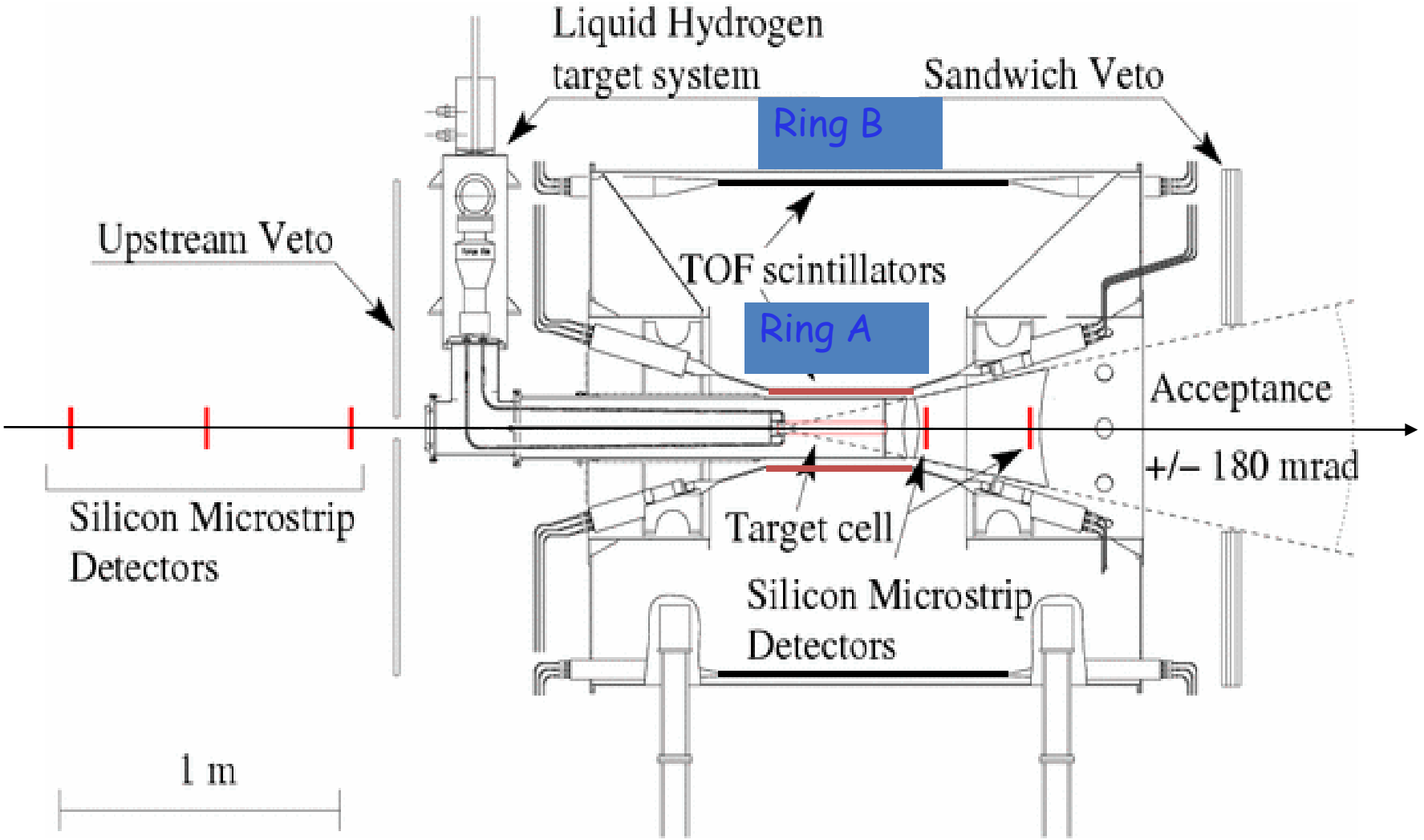






The peak at φ=0 remains
=> caracteristic of BH

Liquid H_2 Target & RPD



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