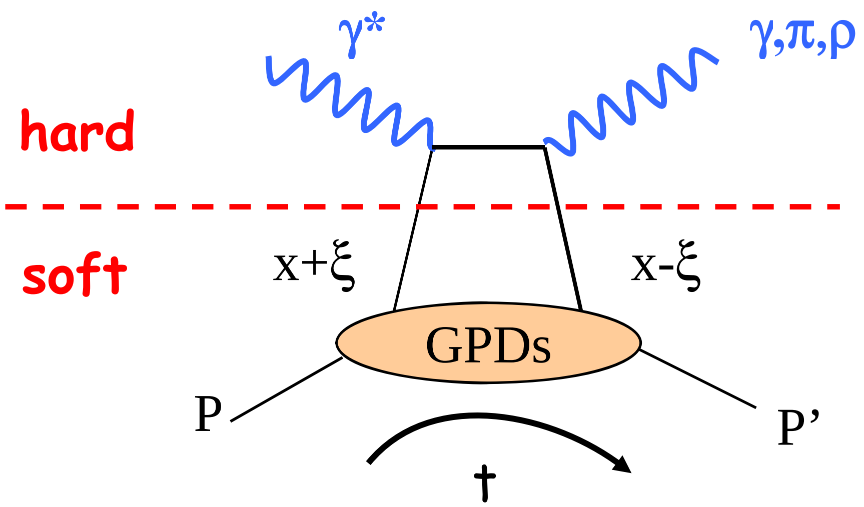
Towards a GPDs measurement with COMPASS

E. Burtin, CEA/Saclay - Dapnia/SPhN
for the COMPASS Collaboration
Monthly subgroup GPD meetings
Expression of Interest SPSC-EOI-2005

- **Physics motivations & context**
- **Experimental realisation**
- **Simulation of the recoil detector & Calorimeters**
- **Tests of recoil detector Prototype**

International Workshop on Structure and Spectroscopy
Freiburg im Breisgau, March 21, 2007

Generalized Parton Distributions



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

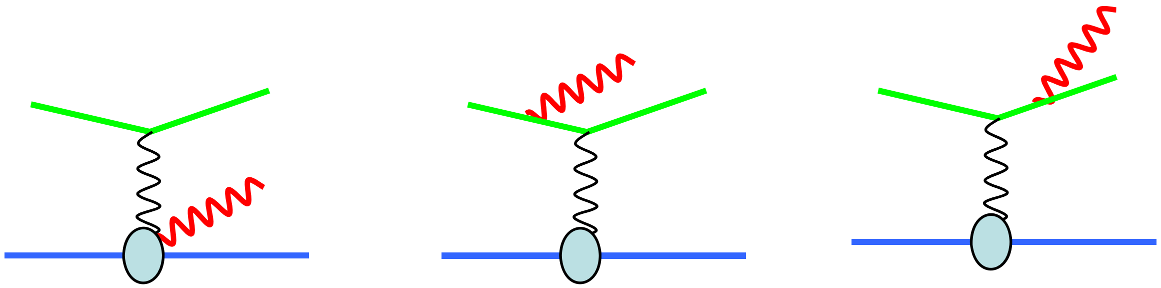
Generalized Parton Distributions

for quarks :
4 functions $H(x,\xi,t)$

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

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

DVCS observables



Deep VCS

Bethe-Heitler

High energy beam

Lower energy => use interference - holography

Cross section

$$\sigma_{DVCS} = \left| \mathcal{P}\int_{-1}^{1} dx \frac{H(x,\xi,t)}{x-\xi} + i\pi H(\xi,\xi,t) \right|^2$$

Single Spin Asymmetry

$$\sigma^{\Uparrow} - \sigma^{\Downarrow} \approx H(x=\xi,\xi,t)$$

Polarised beam

Beam Charge Asymmetry

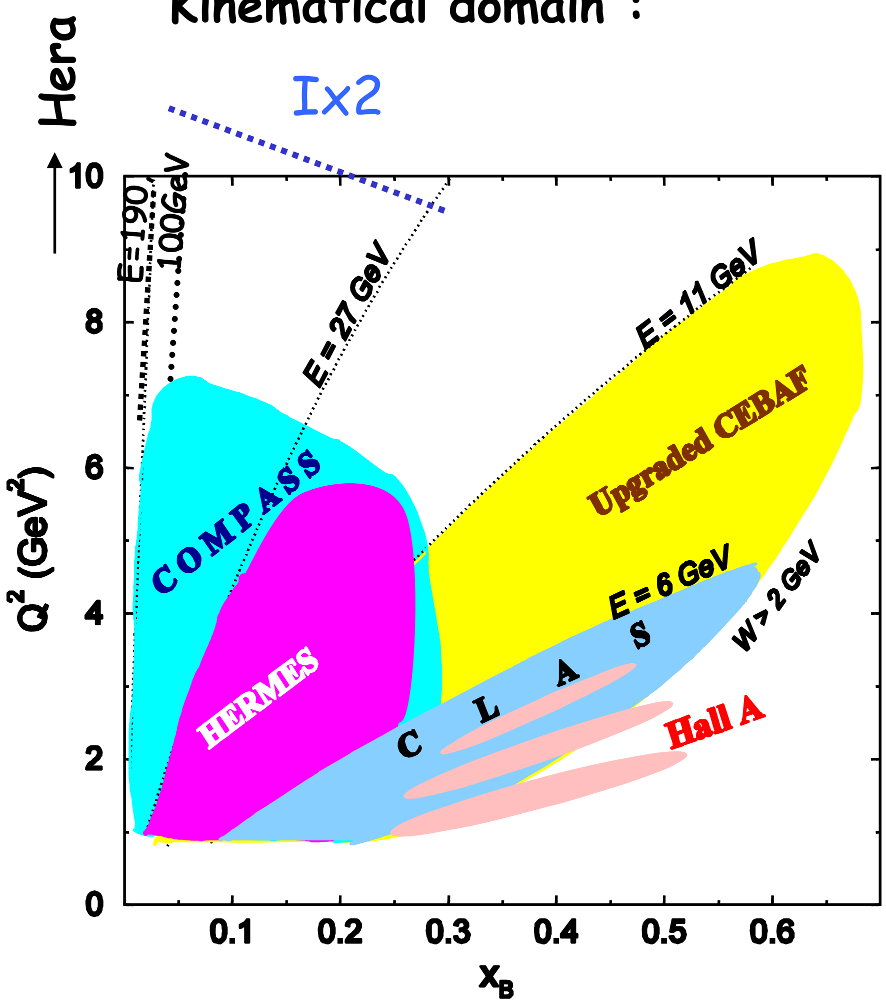
$$\sigma^{+} - \sigma^{-} \approx \mathcal{P}\left(\int_{-1}^{1} dx \frac{H(x,\xi,t)}{x-\xi} \right)$$

+/- charged beam

Quote from J.Ellis : COMPASS can do everything !

What makes Compass a special place ?

Kinematical domain :



Valence + sea + gluons

High energy muon beam (L. Gatignon)

- 100 / 190 GeV
- 80% Polarisation
- +q and -q available (change once/day)
  - ✓Same intensity
  - ✓Same scrapper settings

Spatial distribution of partons

Targets

- liquid Hydrogen & Deuterium
- Polarised target (no recoil)

Contribution of J_u & J_d to nucleon spin

Calendar

Now : COMPASS with polarised target

2010-2015 : Extensive program with Recoil detection & Calo

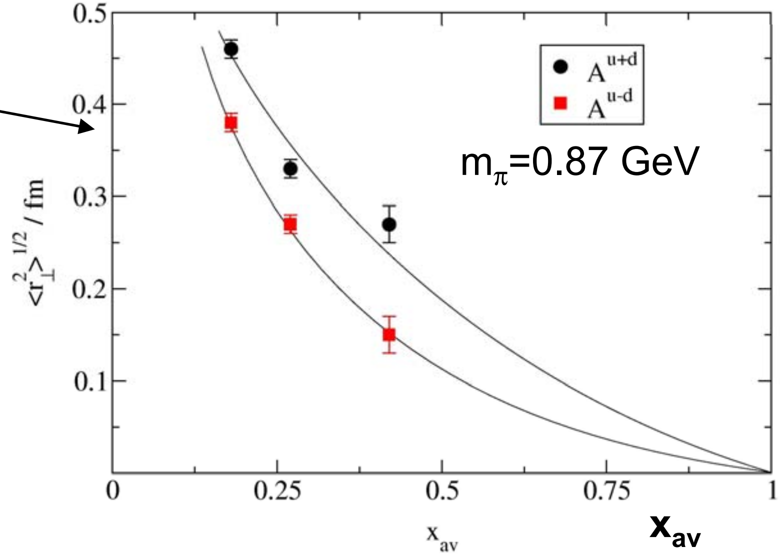
2014+ : Jlab 12 and GSI/FAIR startup

Hints on the 3-D nucleon picture ($P_x, r_{y,z}$)?

Lattice calculation (unquenched QCD):

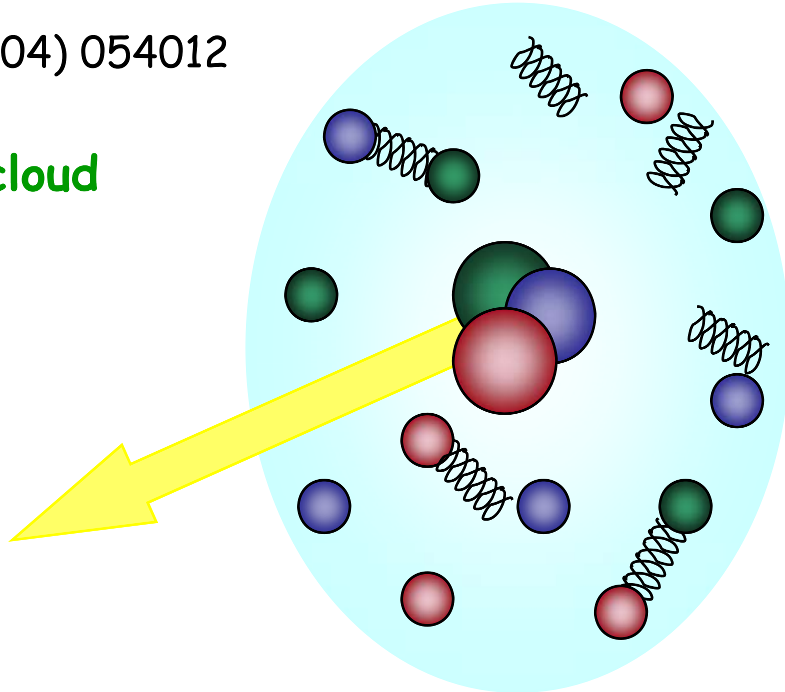
Negele *et al.*, NP B128 (2004) 170
Göckeler *et al.*, NP B140 (2005) 399

- fast parton close to the N center
  ≡ small valence quark core
- slow parton far from the N center
  ≡ widely spread sea q and gluons



Chiral dynamics: Strikman *et al.*, PRD69 (2004) 054012

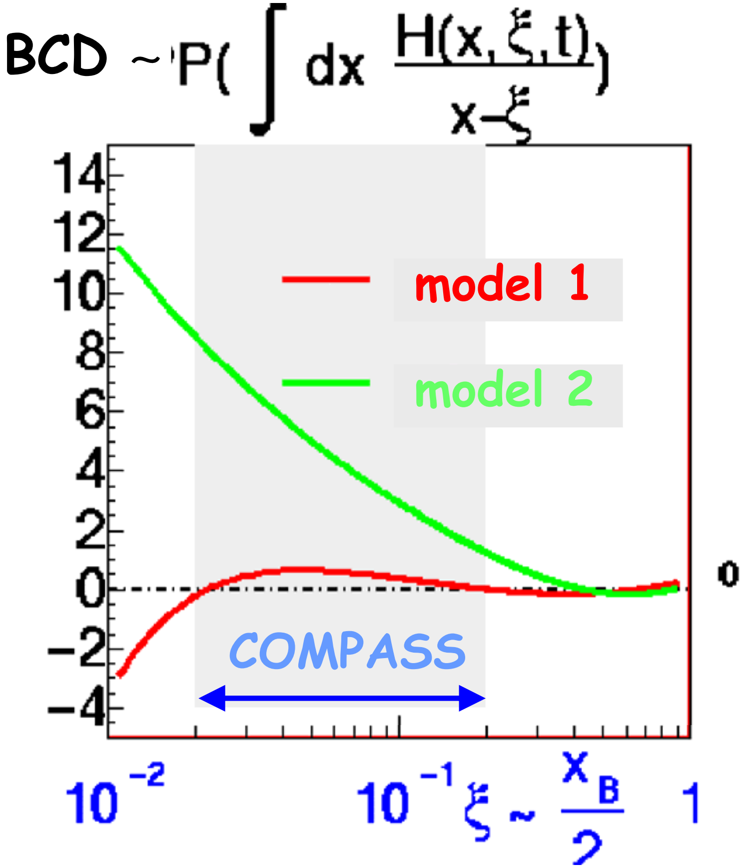
at large distance :
gluon density generated by the pion cloud
increase of the N transverse size
for $x_{Bj} < m_\pi/m_p = 0.14$



COMPASS domain

Spatial distribution of partons

Observable : Beam charge Difference BCD=σ(μ+)-σ(μ-)



E = 100 GeV

Double Distibutions based Models :

Model 1: $H(x,\xi,t) \sim q(x)\,F(t)$

Model 2: DD + Regge approach

Goeke, Polyakov and Vanderhaeghen

$$H(x,0,t) = q(x)\, e^{t\,\langle b_\perp^2\rangle}$$
$$= q(x) / x^{\alpha' t}$$

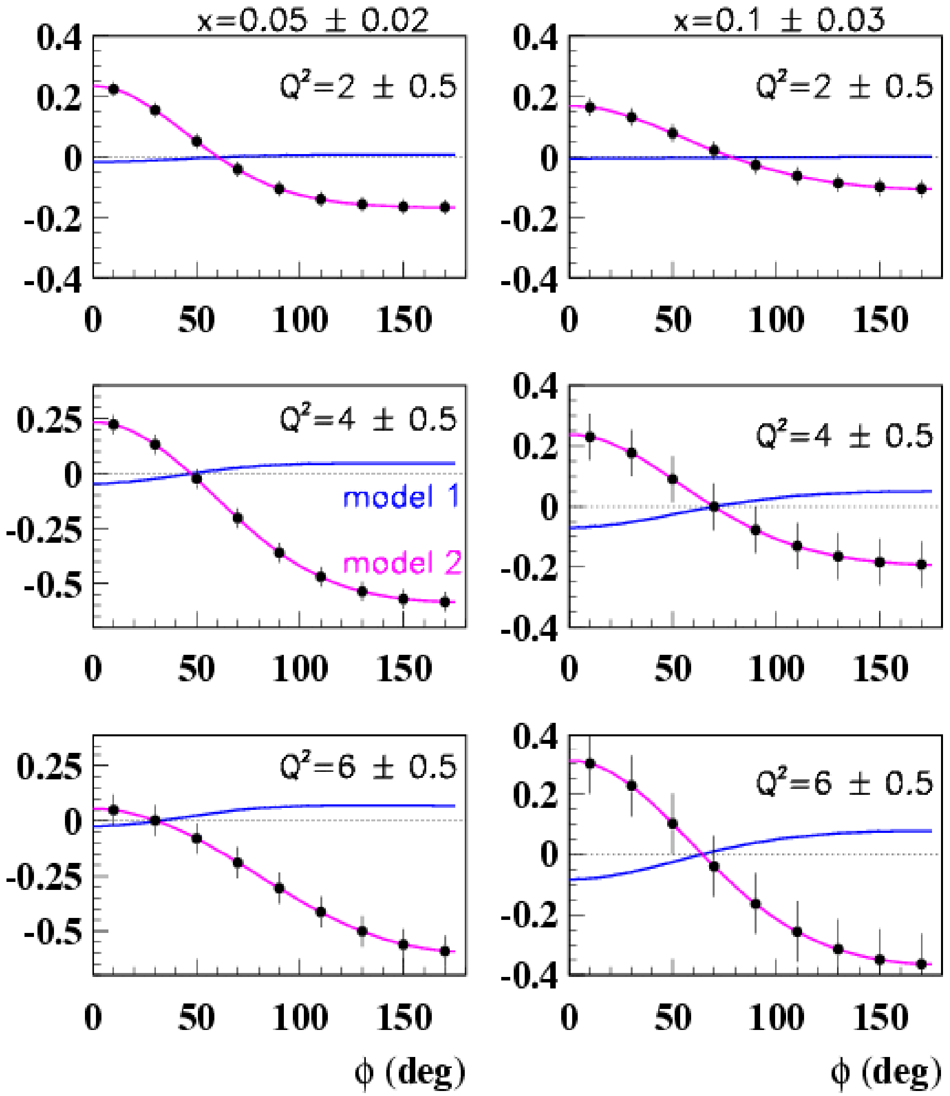
sensitivity to the different spatial distribution of partons ↗ when x_{Bj} ↘

Good sensitivity to models in COMPASS x_{Bj} range

Need to be able to measure absolute Cross section difference to a good precision

Projected errors of a possible DVCS experiment

Beam Charge Asymmetry



$\mathcal{L}$ = 1.3 10^{32} cm^{-2} s^{-1}

E_{beam} = 100 GeV

6 month data taking

25 % global efficiency

6/18 (x, Q^2) data samples

3 bins in x_{Bj} = 0.05, 0.1, 0.2

6 bins in Q^2 from 2 to 7 GeV^2

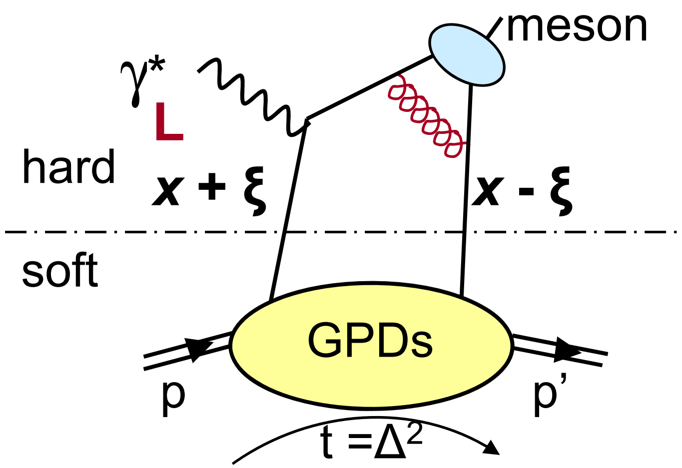
Model 1 : $H(x,\xi,t) \sim q(x)\, F(t)$

Model 2 : $H(x,0,t) = q(x) / x^{\alpha' t}$

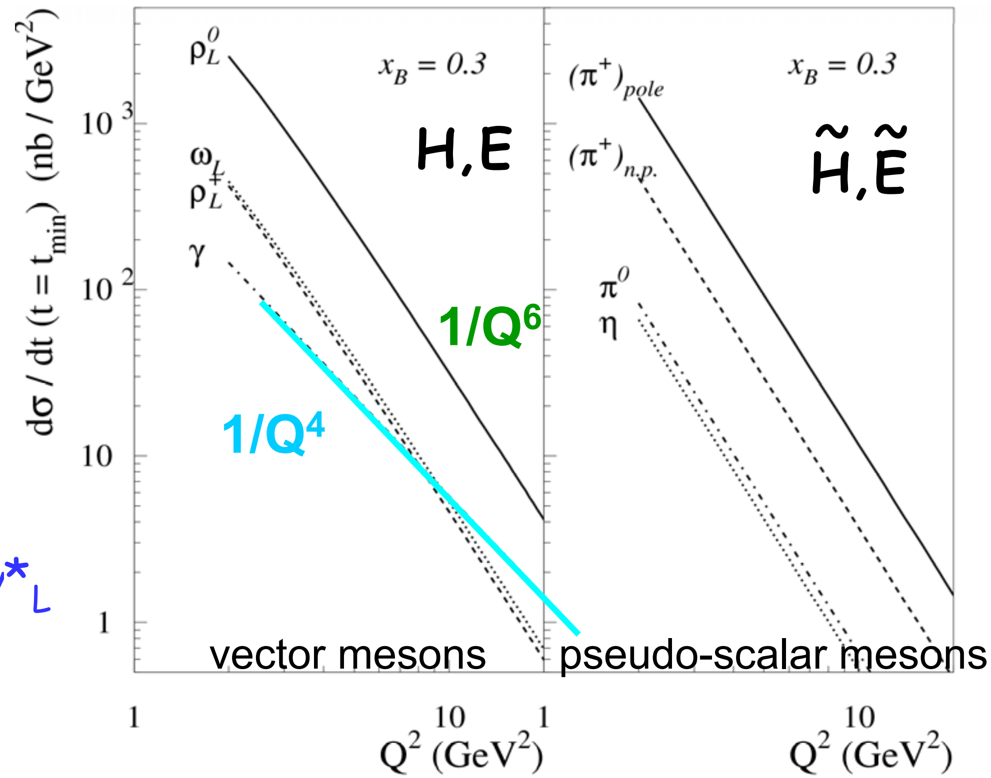
Good constrains for models.
Work with up-to-date
models in progress.

Hard exclusive meson production

It comes for free !



Scaling predictions:



Collins et al. (PRD56 1997):

1. factorization applies only for γ^*_L
2. Probably at a larger Q^2

Different flavor contents:

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

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

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

under study with present COMPASS data

Contribution of J_u and J_d to the nucleon spin

Through the modeling of GPD E in Double Distribution formalism

1-Transversaly polarised target and unpolarized beam

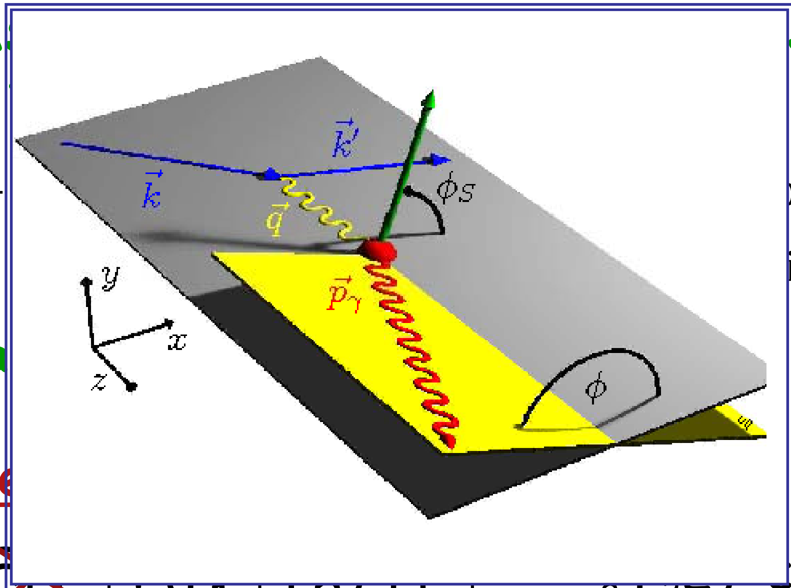
In Meson production : $d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi) \propto \Im m(F_2 H - F_1 E)\cdot \sin(\phi-\phi_S)\cos\phi$

Under study with COMPA… …Jegou)
COMPASS 2007 Data on …

In DVCS : $d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S +$ … …s ϕ

…in ϕ

But… no recoil detection a…

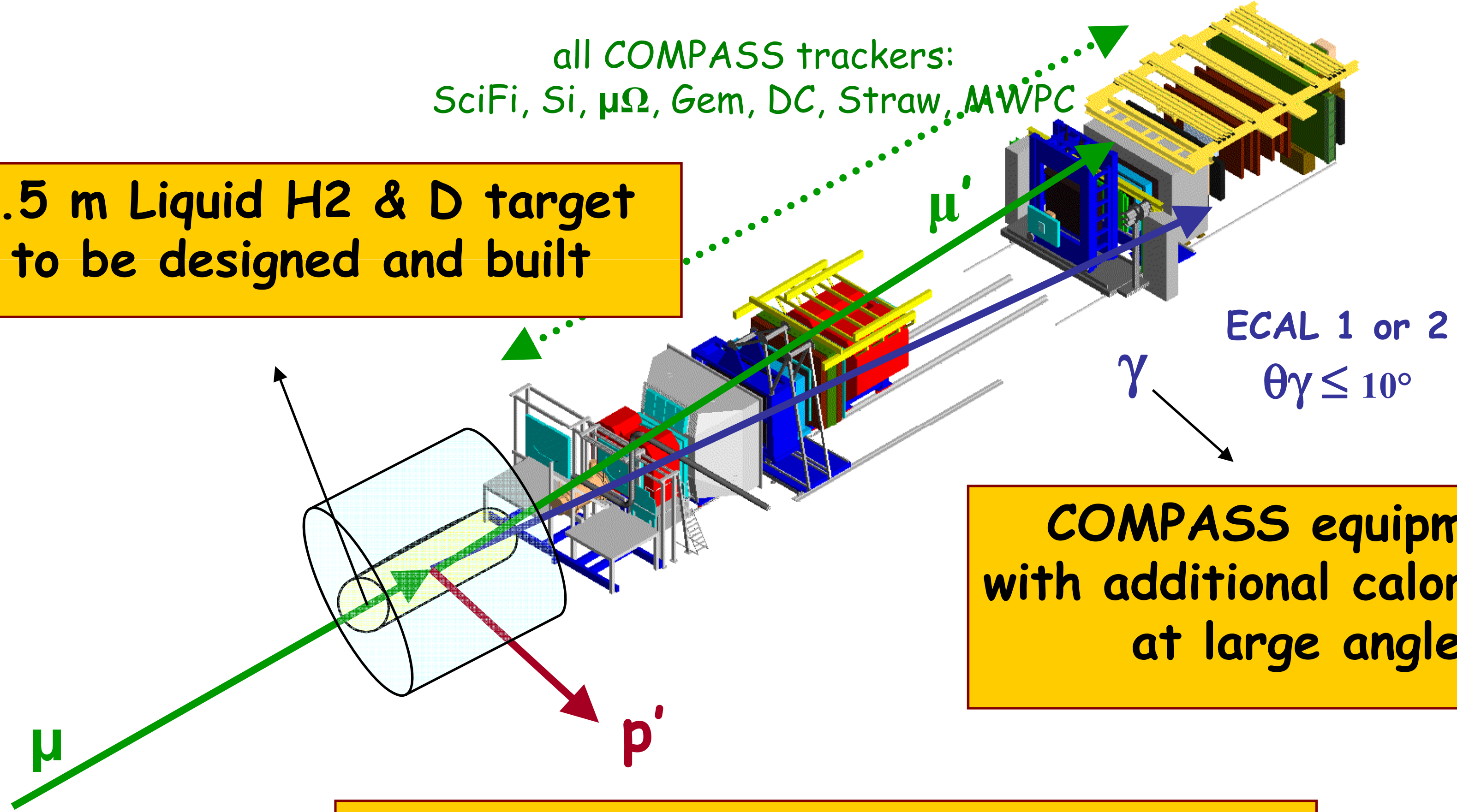


2-Neutron target - liquid deute…

$d\sigma(\ell^+,\phi) - d\sigma(\ell^-,\phi) \propto \Re e(F$ … $4m^2$ … $\cos\phi$

- need to have a deuterium target
- be able to detect recoiling neutrons

Experimental realisation

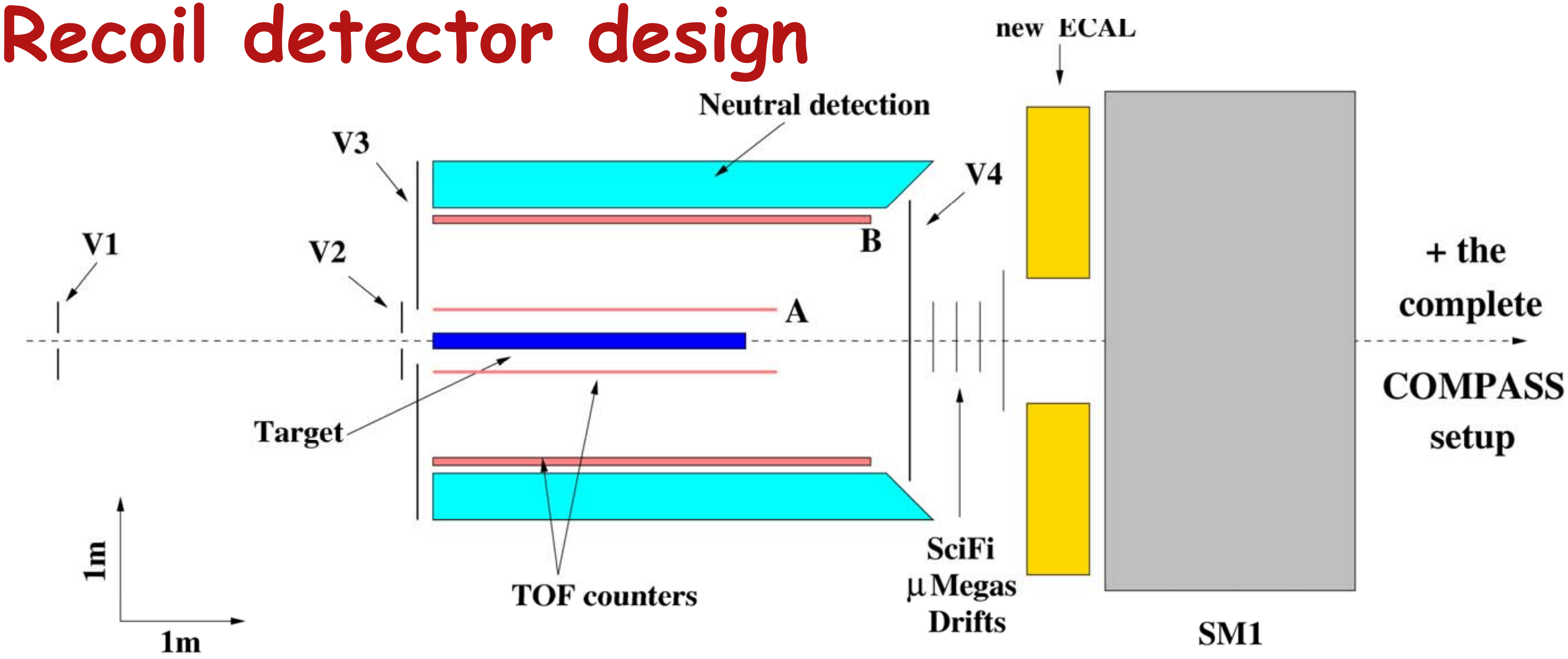


2.5 m Liquid H2 & D target
to be designed and built

COMPASS equipment
with additional calorimetry
at large angle (π^0 bkg)

Recoil detector to insure exclusivity
to be designed and built

Recoil detector design



Goals: Detect protons of 250-750 MeV/c

t resolution => σ_{TOF} < 300 ps

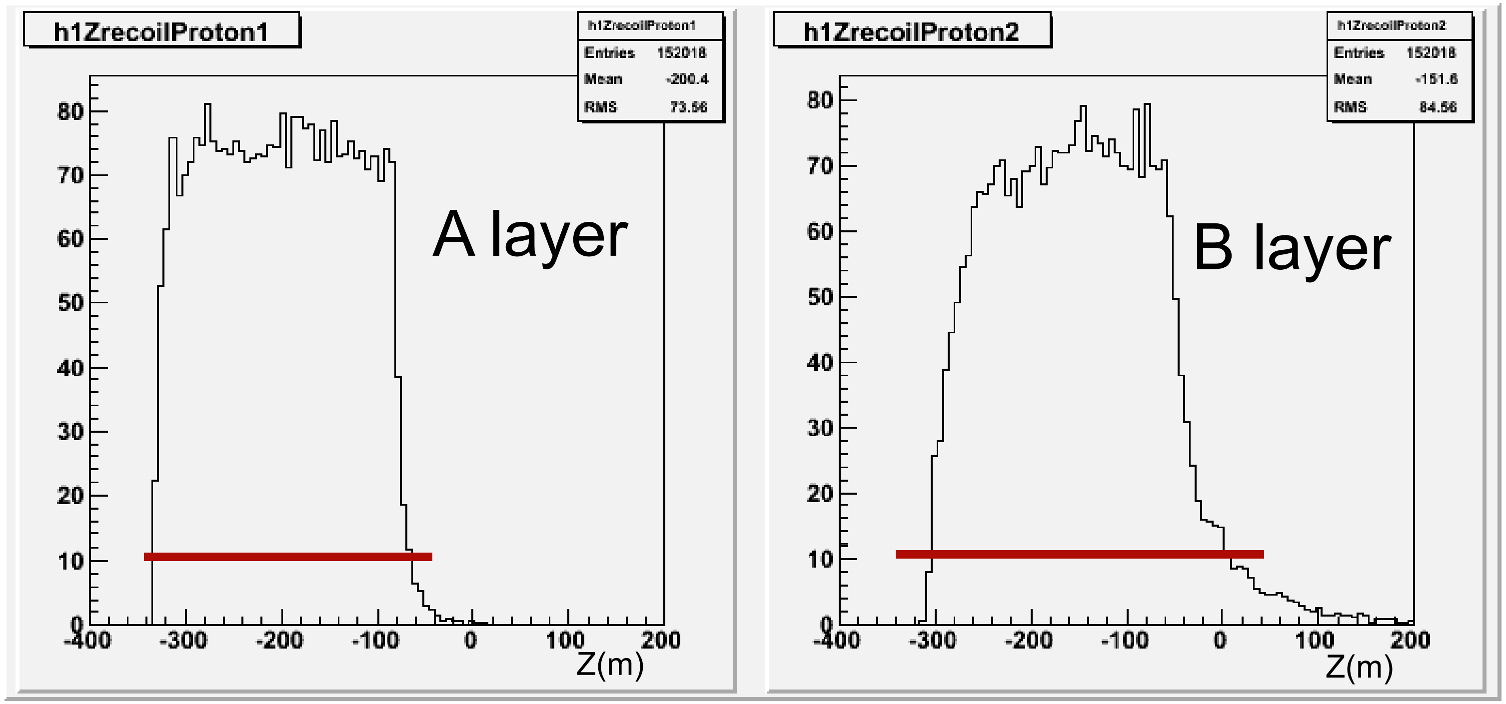
exclusivity => Hermetic detector

Design :

2 concentric barrels of 24 scintillators counters read at both sides

European funding through a JRA for studies and construction of a prototype (Bonn, Mainz, Saclay, Warsaw)

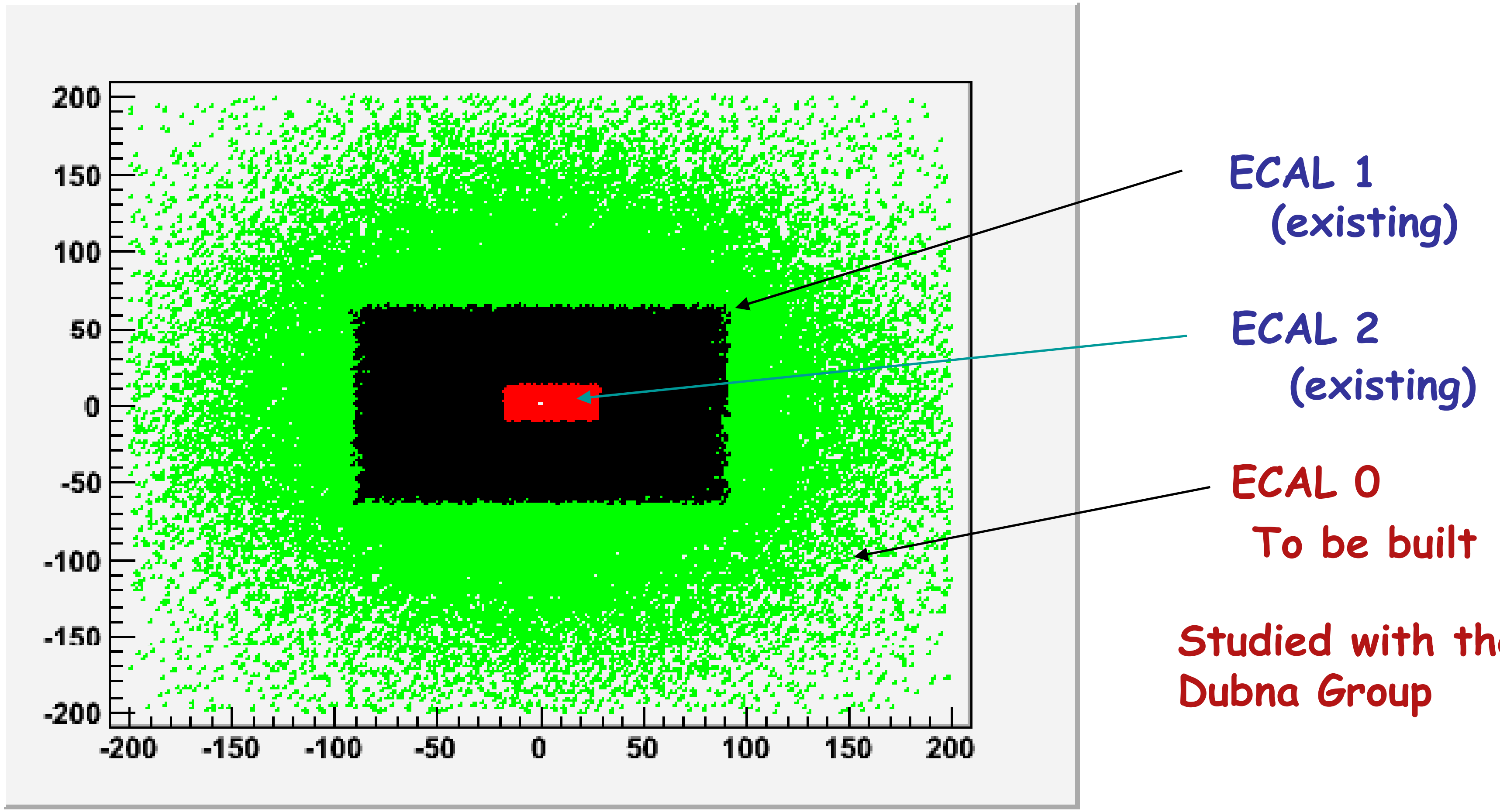
Recoil proton detection



Impact point on recoil detector
(weighted by cross section)

Calorimeter coverage foreseen

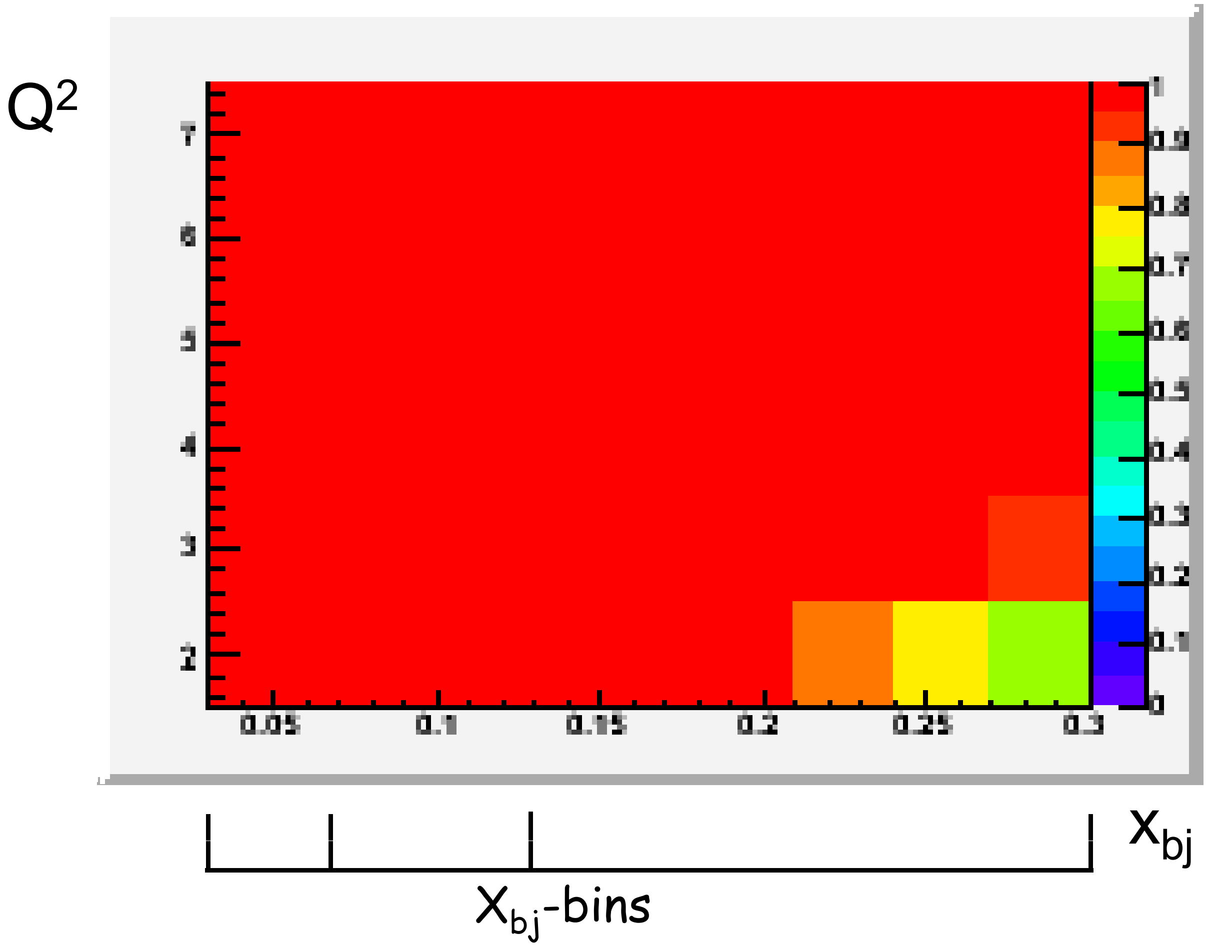
Goals : Detect DVCS photons & π^0



Studied with the Dubna Group

DVCS γ impact point at ECAL 0 location

Calorimeter acceptance



Existing Calorimeters

+ 3m x 3m ECAL0

+ 4m x 4m ECAL0

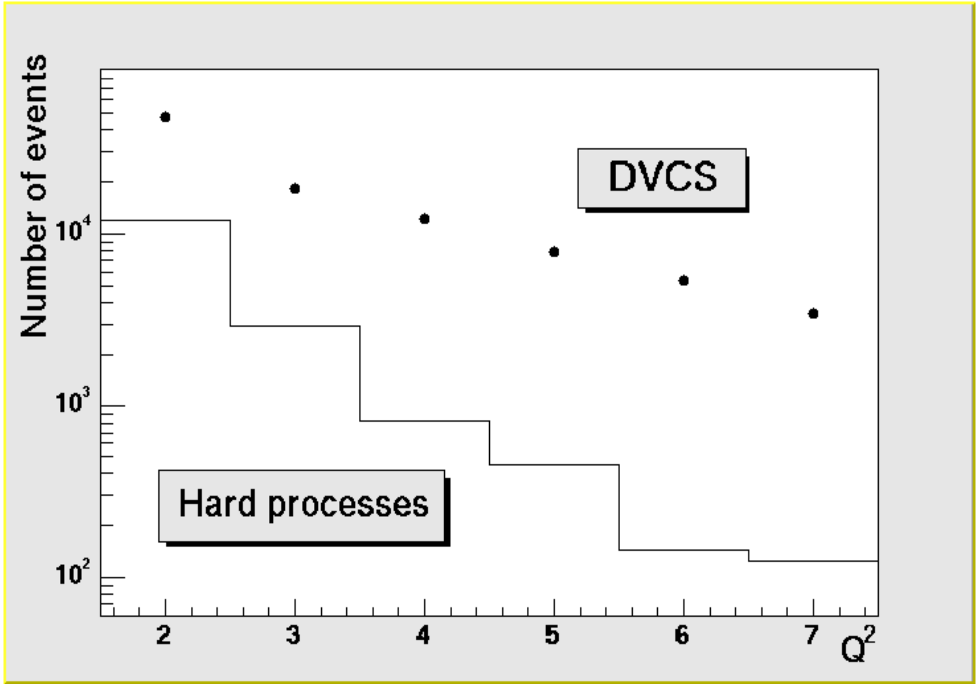
Physical Background to DVCS

Source : Pythia 6.1 generated DIS events

Apply DVCS-like cuts

one μ',γ,p in DVCS range

no other charged & neutral in active volumes



detector requirements:

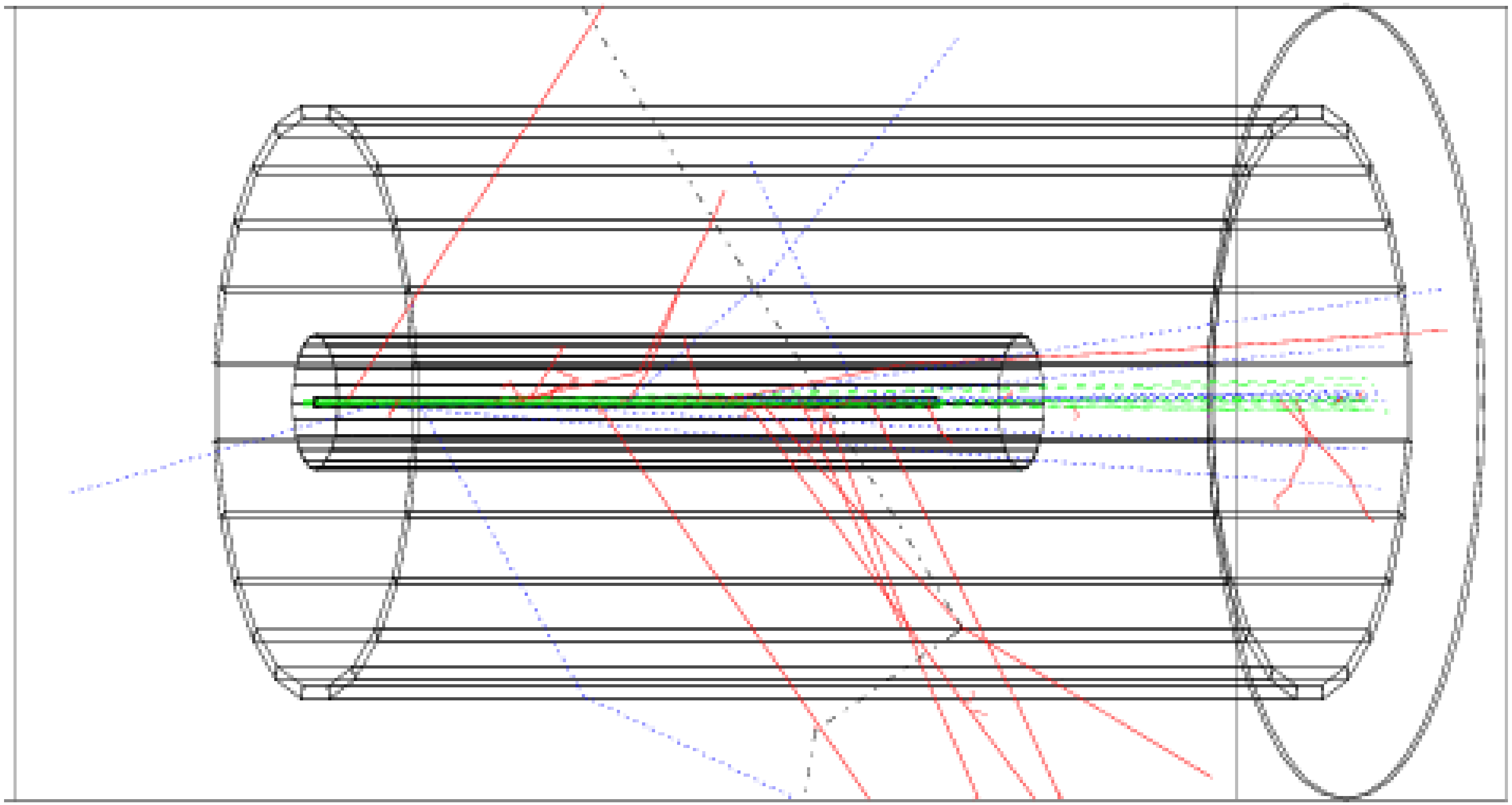
24° coverage for neutral

50 MeV calorimeter threshold

40° for charged particles

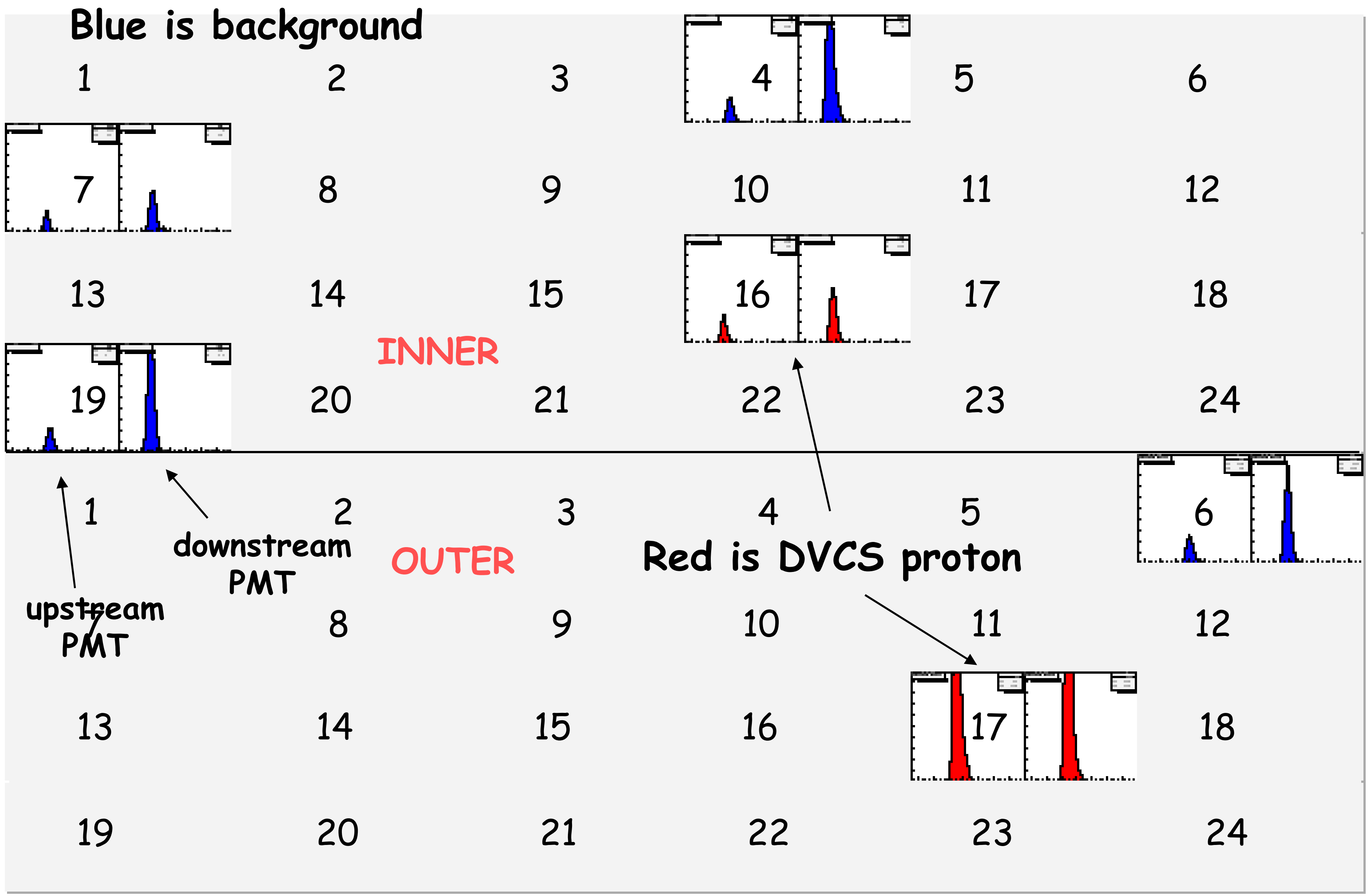
in this case DVCS is dominant

Geant Simulation of recoil detector

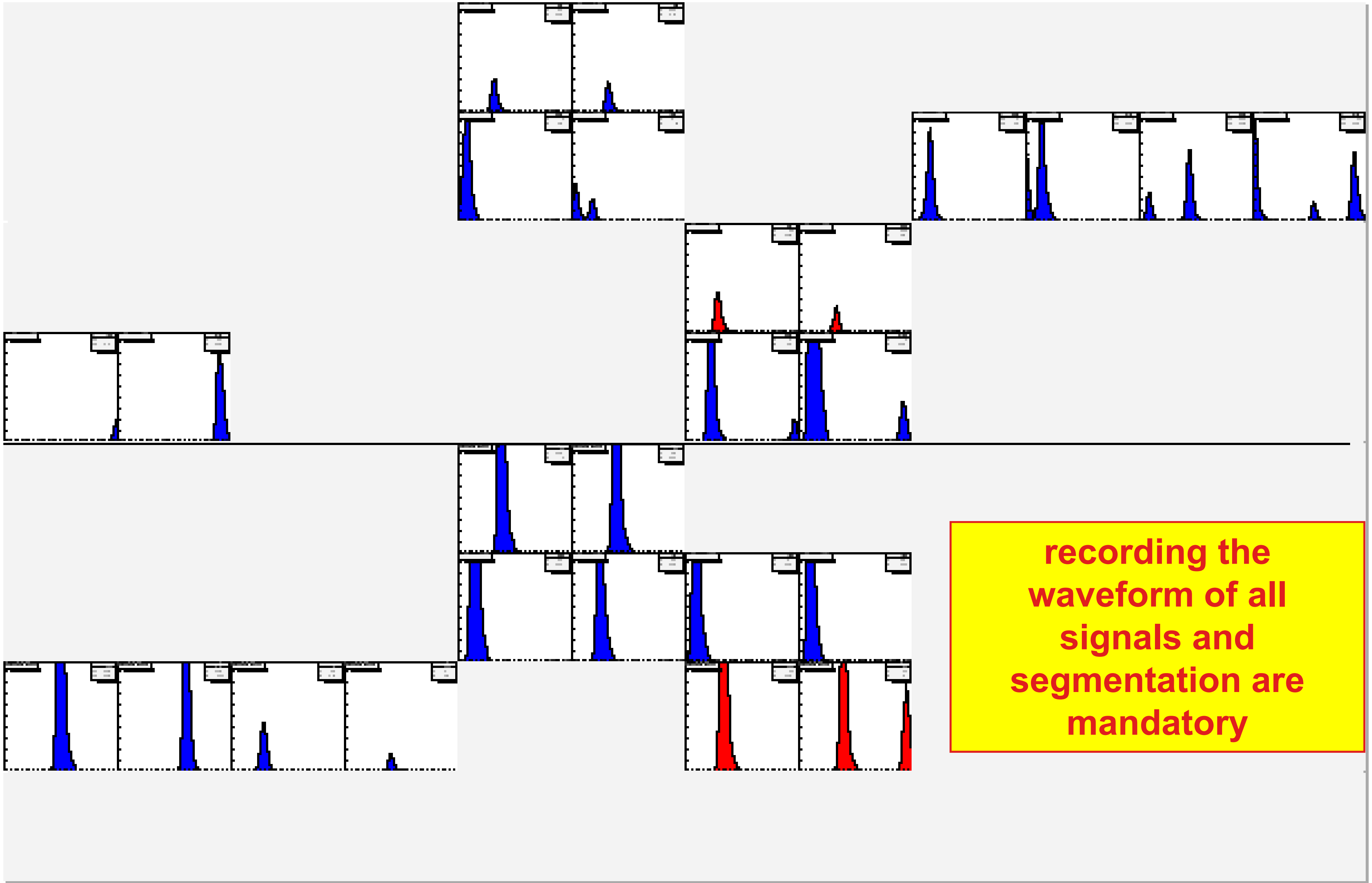


With simulation of δ-rays

PMT signals : only 1μ in the set-up

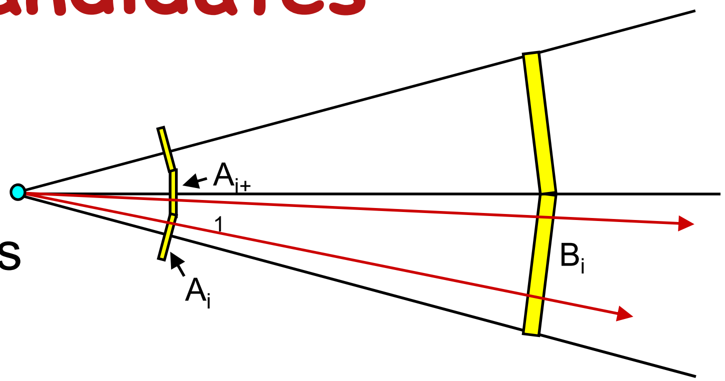


PMT signals : 2 10^8 μ/spill (5s)



recording the waveform of all signals and segmentation are mandatory

Criteria for proton candidates

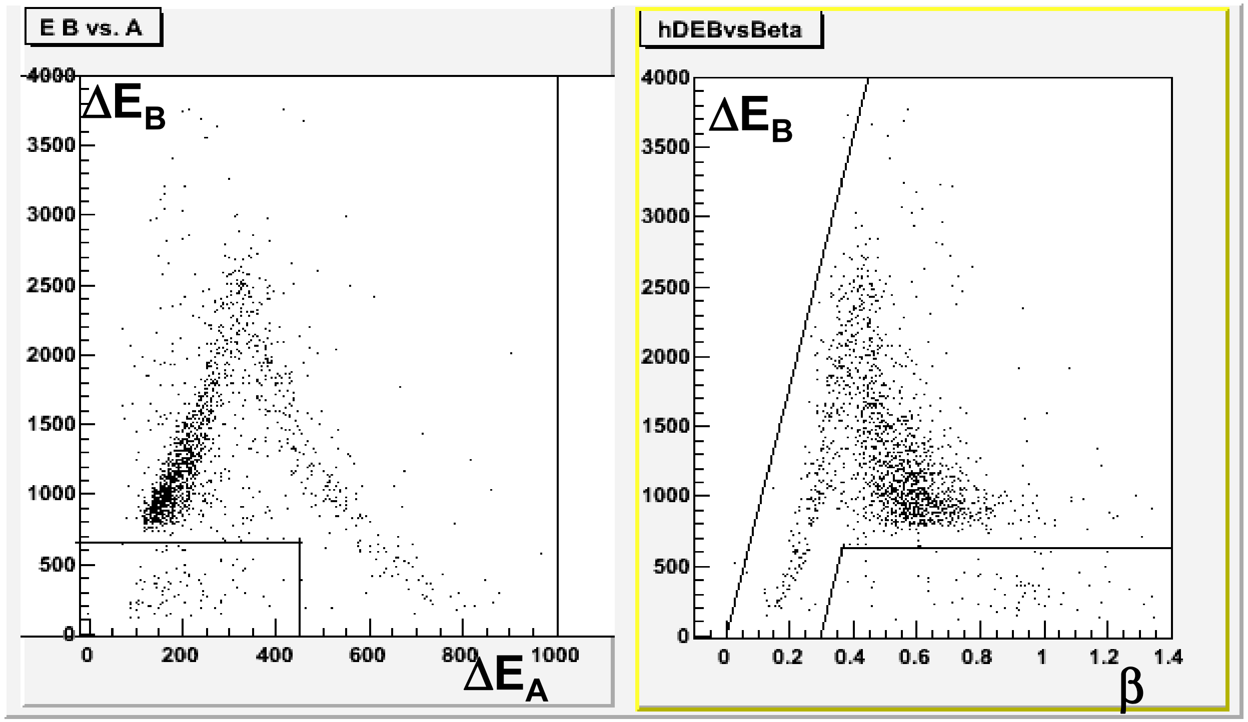


- Crude Waveform analysis

- Have points in corresponding A and B counters

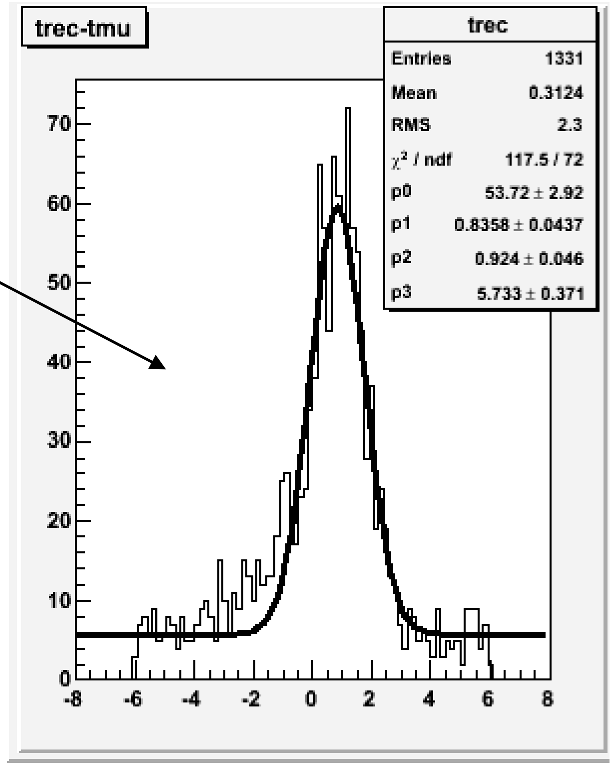
- For each pair of "points"
  - Energy loss correlation
  - Energy loss vs β_{meas} correlation

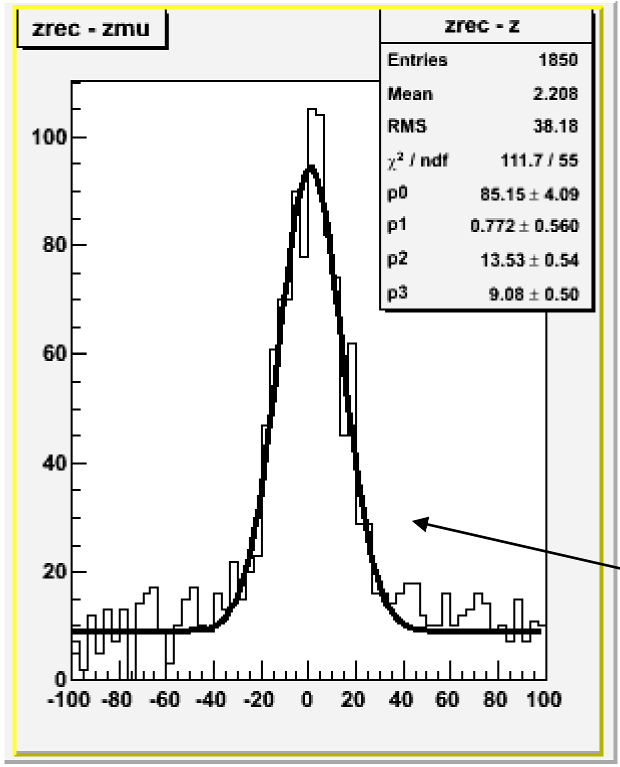
(no additional beam muons in this plot – just for pedagogy)



Coincidence with the scattered muon

Use reconstructed muon vertex time to constraint proton candidates





Use vertex position to evaluate the effective signal

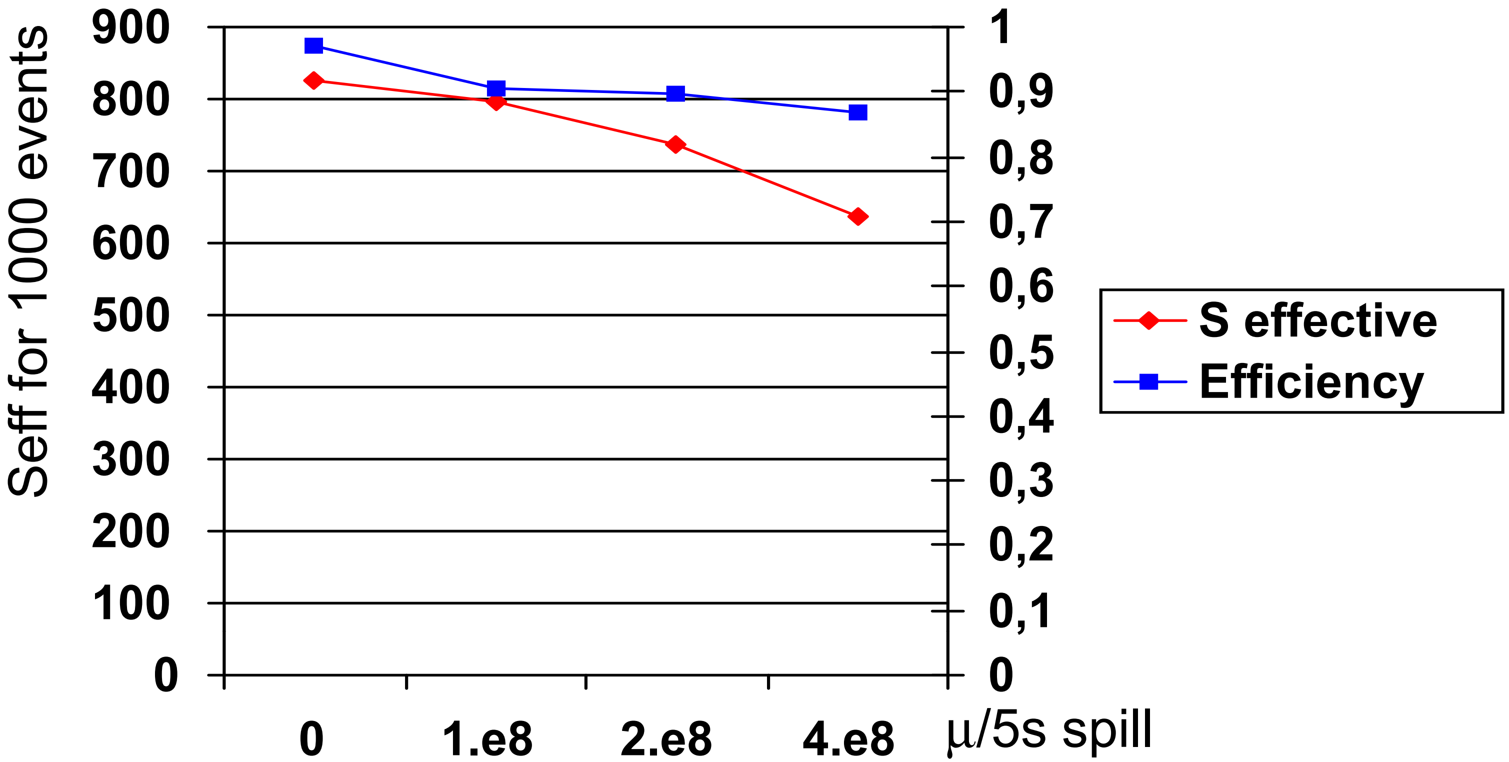
$$S_{eff} = \frac{S}{1 + B/S}$$

Reconstruction studies (M.Stolarski) show that $\sigma(z_{vertex})$~2cm from muon tracking
Should be taken as a constrain in analysis

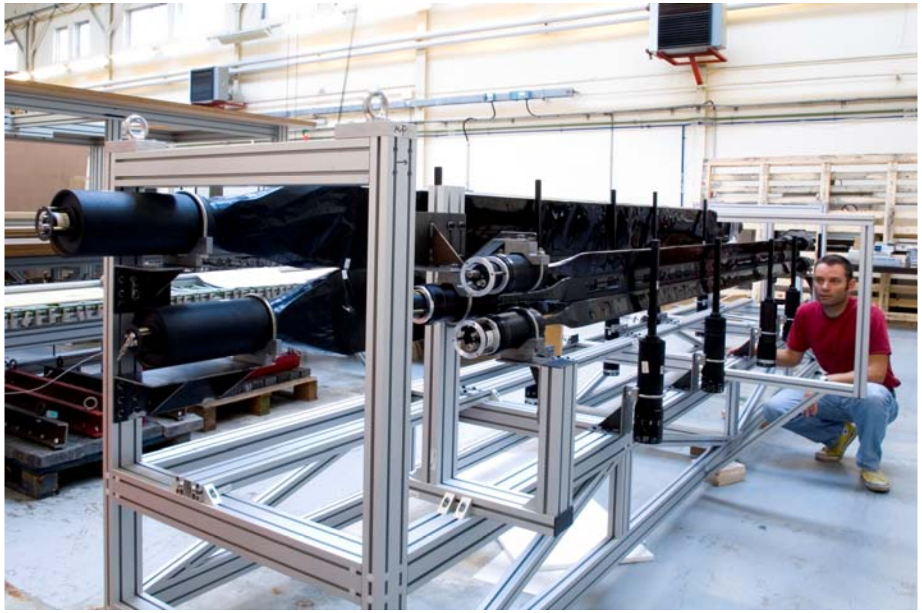
Proton detection efficiency

$$\text{Efficiency} = \frac{\text{number of events with proton identified}}{\text{number of “triggers”}}$$

trigger = one event with at least one good combination of A and B with hits
identified proton = ϕ of proton candidate matches ϕ of generated proton

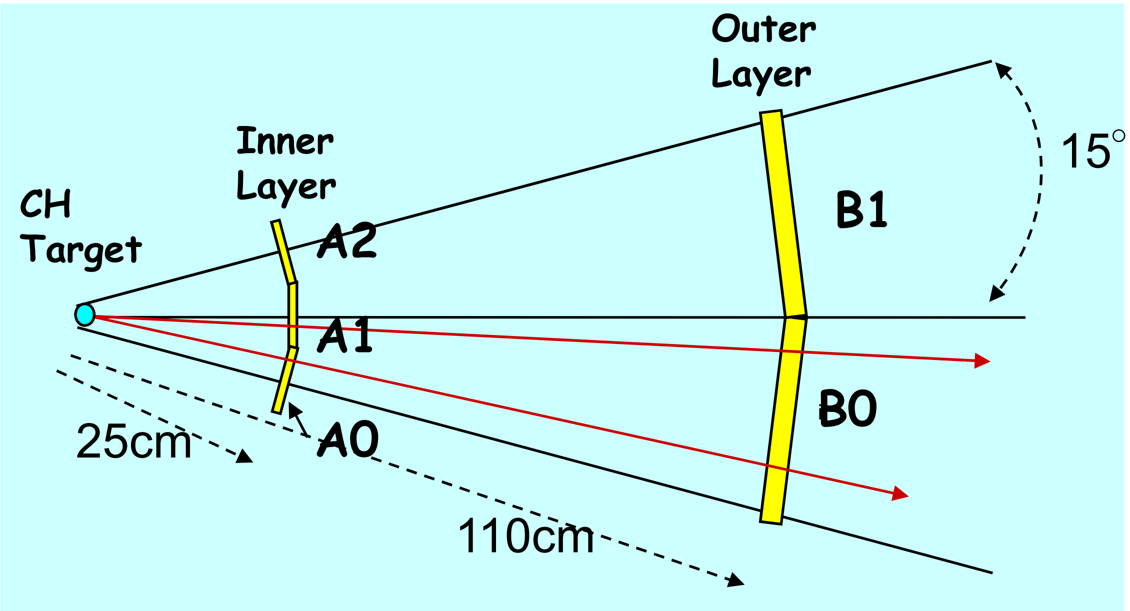


Recoil Detector Prototype Tests (2006)



All scintillators are BC 408
A: 284cm x 6.5cm x 0.4cm
Equiped with XP20H0 (screening grid)
B: 400cm x 29cm x 5cm
Equiped with XP4512

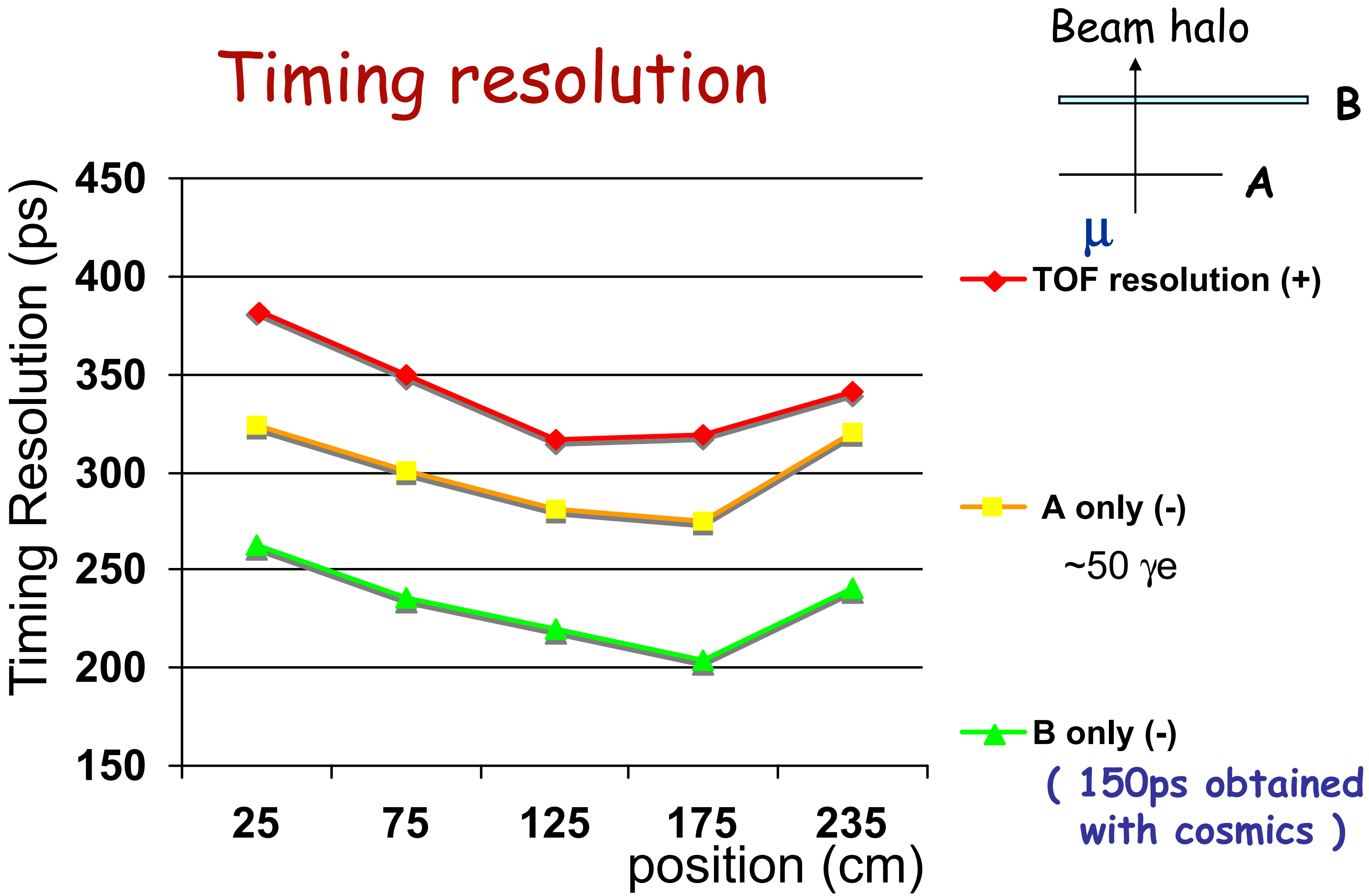
Use 1GHz sampler (300ns window)
Design by CEA-Saclay/LAL-Orsay



Installed downstream of COMPASS

Trigger:
A&B coincidences
finger pairs

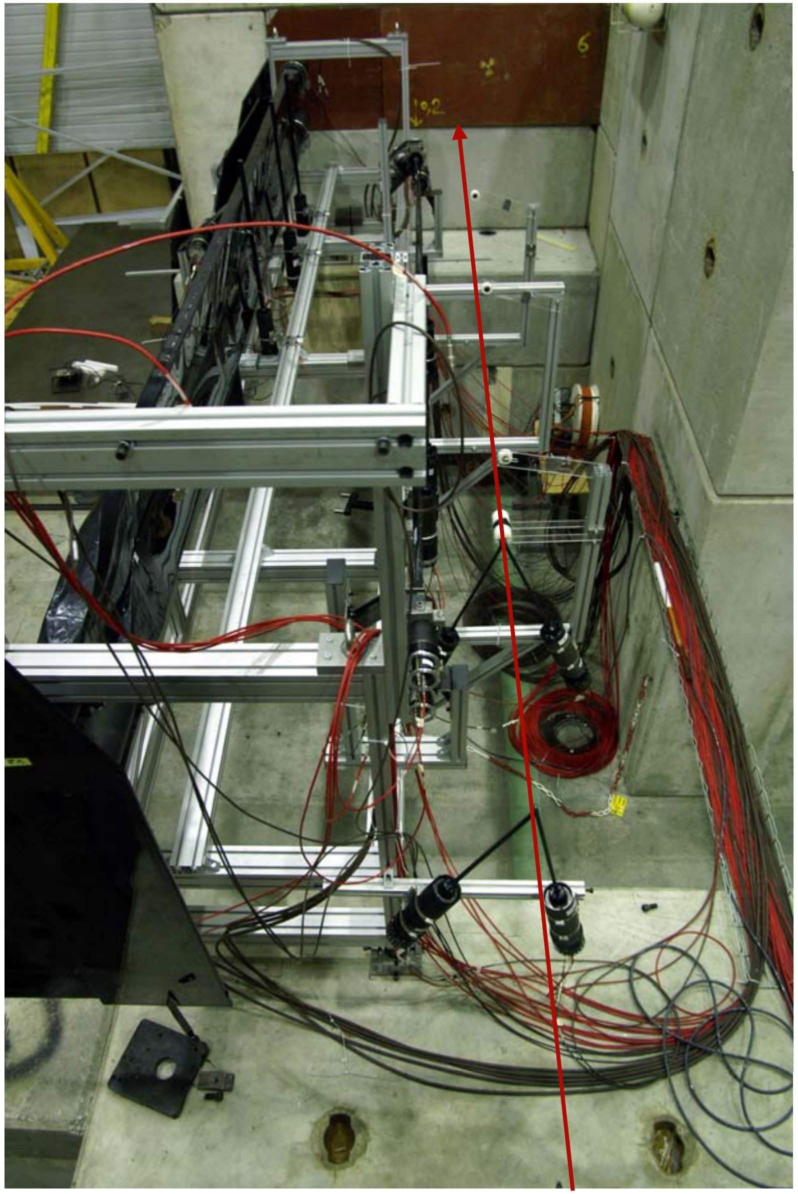
Timing resolution

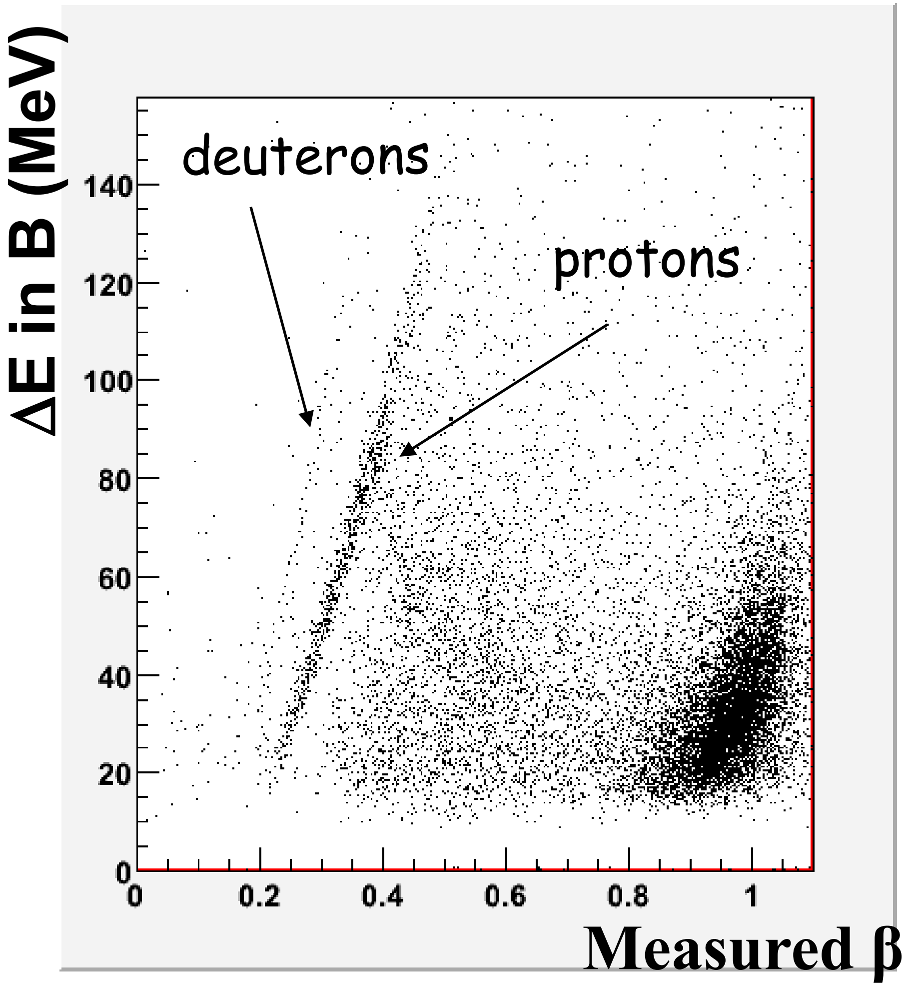


Reach 315 ps at the middle and 380 ps at the edges

Performed with 160 GeV muon (0.6*MIP in A)
Expect better resolution for slow protons

Proton signal





Target : 10 cm CH

Nominal beam intensity

8 hours of data

Analysis in progress

Conclusion & prospects

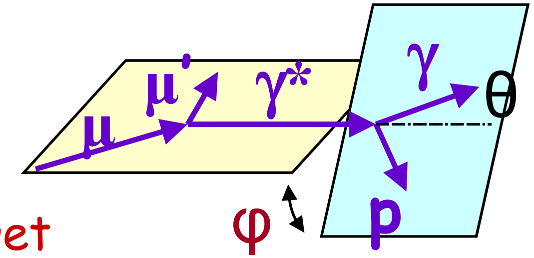
- Possible physics ouput
  - Sensitivity to spatial distribution of partons
  - Sensitivity to total spin of partons : J_u & J_d
  - Working on a variety of models (VGG, Müller, Guzey and FFS-Sch) to quantify the Physics potential of DVCS at COMPASS

- Experimental realisation
  - DVCS proton is accompanied by a high background
  - Recoil Detection is feasible (waveforms DAQ)
  - Extension of the calorimetry is desirable

- Roadmap
  - "exclusive" meson production on transverse target results soon…
  - Recoil proton detector for the hadron run 2007 (2 shifts in $\mu+/\mu-$)
  - Submission of a proposal as soon as possible
  - Get ready to take data with recoil detection and extended calorimetry from 2010 to 2015 before JLab12 & GSI/Fair

Harmonic structure

from Belitsky, Kirchner, Müller



Polarized and charged beam P_μ e_μ on an 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

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

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

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

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

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

What can Compass bring to the GPDs field?
#2 DVCS-BH interference

Beam charge difference

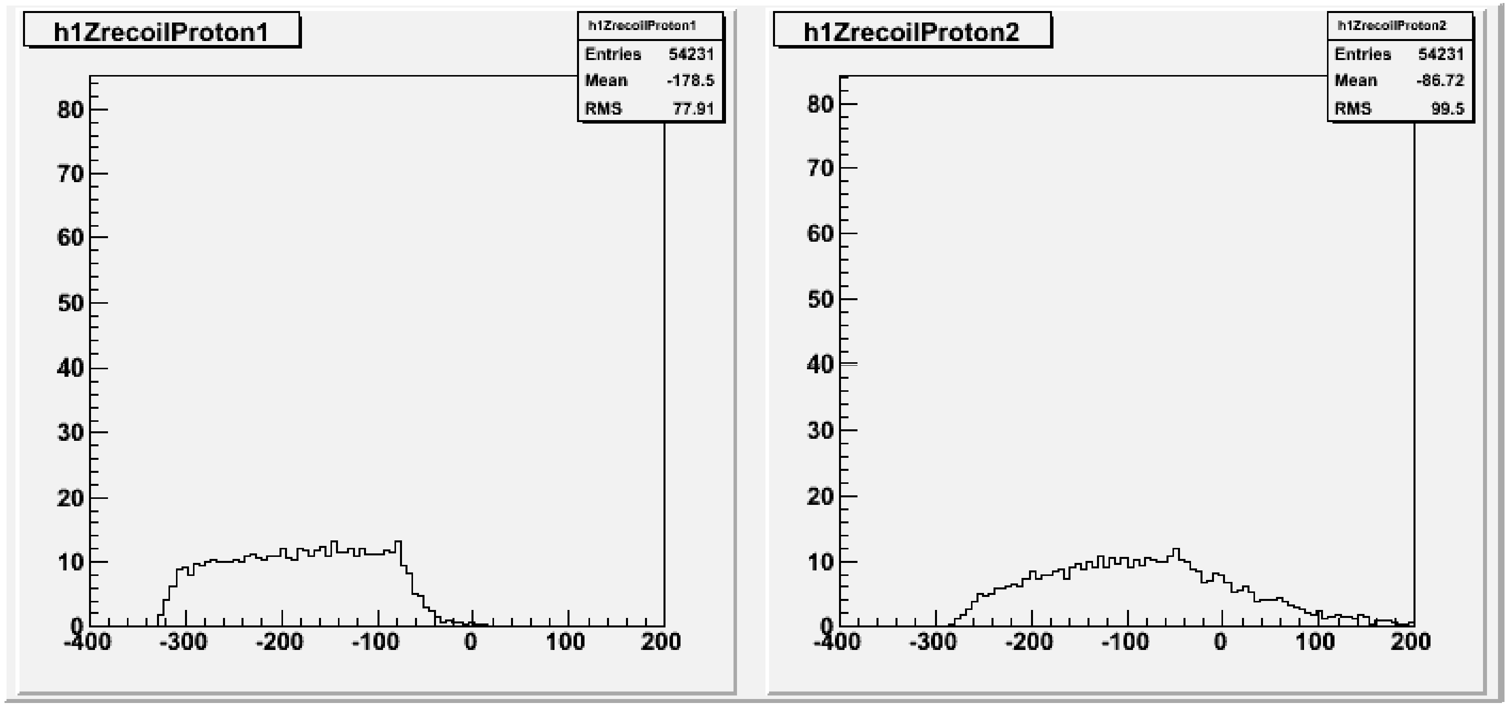
$$\frac{d\sigma^{\vec{\mu}^+} - d\sigma^{\vec{\mu}^-}}{dQ^2 dx_B dt d\varphi} = \frac{e^6}{xy^3 t P_1(\varphi) P_2(\varphi)} (c_0^{Int} + c_1^{Int} \cos\varphi + c_2^{Int} \cos 2\varphi + c_3^{Int} \cos 3\varphi)$$

$$+ \frac{e^6}{y^2 Q^2} (s_1^{DVCS} \sin\varphi)$$

use symmetrization $\varphi \to |\varphi|$ to get rid of the sin φ

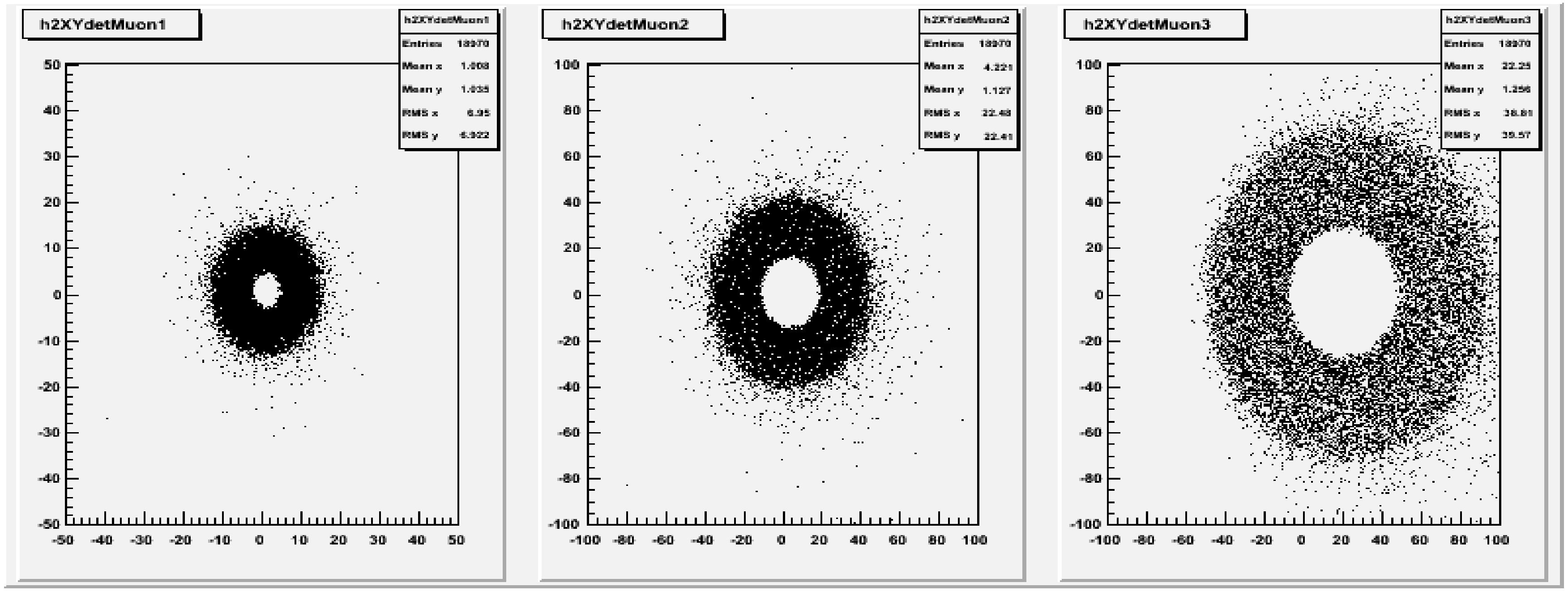
Main Goal → c_1^{Int} c_0^{Int}

Recoil proton detection



Impact point on recoil detector
(weighted by cross section)

Scattered muon

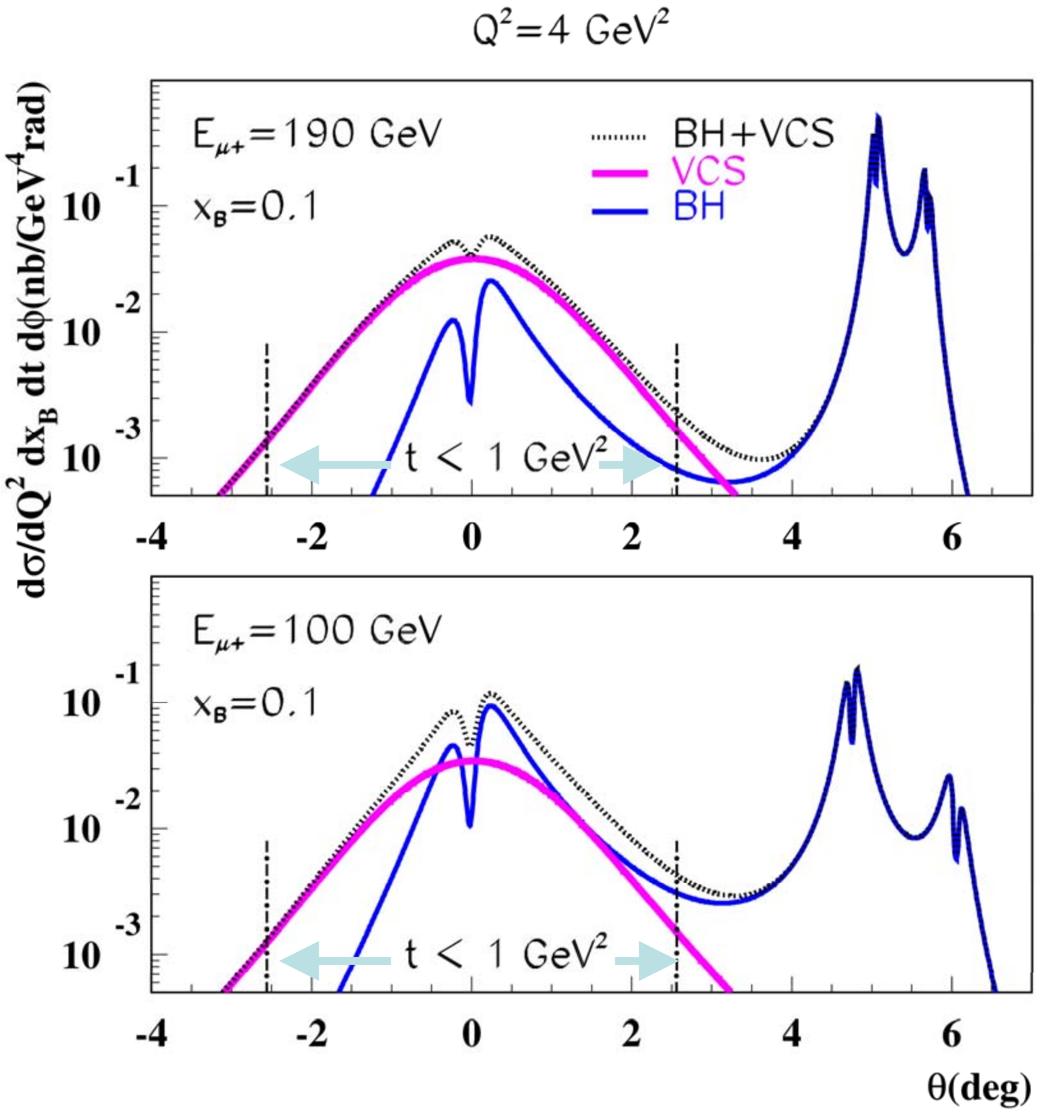


In SM1 In SM2 At z=34m

What can Compass bring to the GPDs field?
#1 DVCS cross section

At Ebeam = 190 GeV
DVCS is dominant

At 100 GeV
DVCS ~ BH



Towards a complete experiment on GPDs

DVCS:

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

Many independent observ. at leading twist in interference term:

Beam charge diff.

$$d\sigma(\ell^+,\phi) - d\sigma(\ell^-,\phi) \propto \Re e\left(F_1 H + \xi(F_1+F_2)\tilde{H} + \frac{t}{4m^2} F_2 E\right)\cdot\cos\phi$$

Beam spin diff

$$d\sigma(\vec{\ell},\phi) - d\sigma(\overleftarrow{\ell},\phi) \propto \Im m\left(F_1 H + \xi(F_1+F_2)\tilde{H} + \frac{t}{4m^2} F_2 E\right)\cdot\sin\phi$$

Long target-spin diff

$$d\sigma(\vec{P},\phi) - d\sigma(\overleftarrow{P},\phi) \propto \Im m\left(F_1 \tilde{H} + \xi(F_1+F_2)H - \frac{\xi}{1+\xi} F_2 \xi \tilde{E}\right)\cdot\sin\phi$$

with $\overleftarrow{\mu}^+$ and $\vec{\mu}^-$

Transv target-spin diff

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

Use of a Polarized Target ?

with **Proton target** **neutron target (F_1 <<)**

Prototype tests

Prototype of Recoil Detector

Prototype for a GPD experiment

- Low rates => Large detector
- High background => Sampling of Waveforms

Measure properties of the scintillator

- Speed of light, Attenuation length, light yield

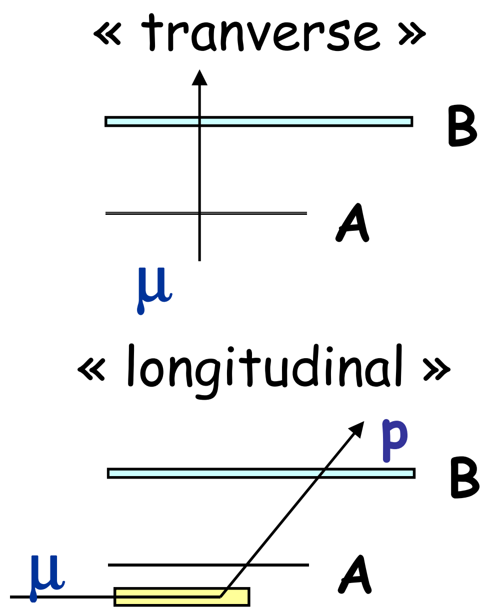
Measure timing and position resolutions in A and B

Detect protons and study background

- CH2 Targets of various width and length

Evaluate electronics chains

- 1GHz sampling of the signal
- 250MHz sampling + standard multihit TDC



Prototype Design