Generalized Parton Distributions @ COMPASS

« Expression of Interest » SPSC-EOI-005 and presentation to SPSC

→ writing of the proposal for the next months
preparation of the future GPD program ~2010

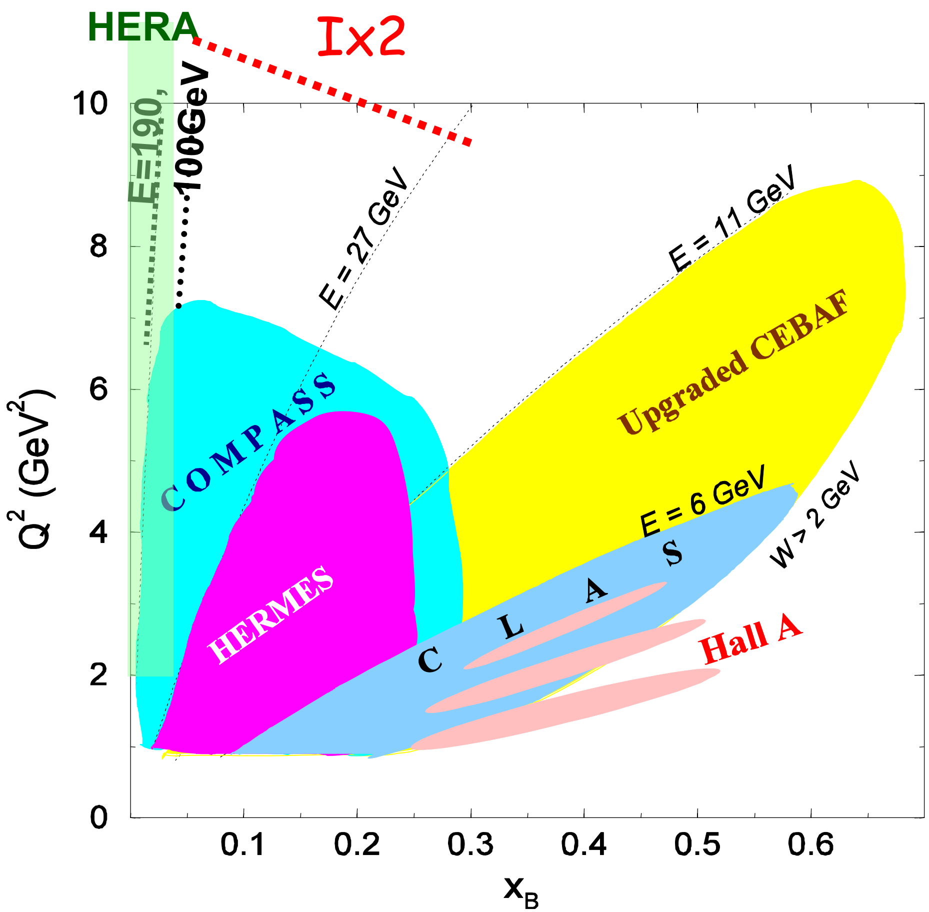
1- Now with a polarized target and without recoil detector

2- After 2010 with a H_2 (or D_2) target and a recoil detector

Exclusive reactions,
JLab, 21 May 2007

Nicole d'Hose, Saclay, CEA/DAPNIA
On behalf of the COMPASS collaboration

Competition in the world and COMPASS role



Gluons

valence quarks and sea quarks and gluons

valence quarks

COMPASS 2010

JLab 12 GeV 2014

COMPASS at CERN-SPS

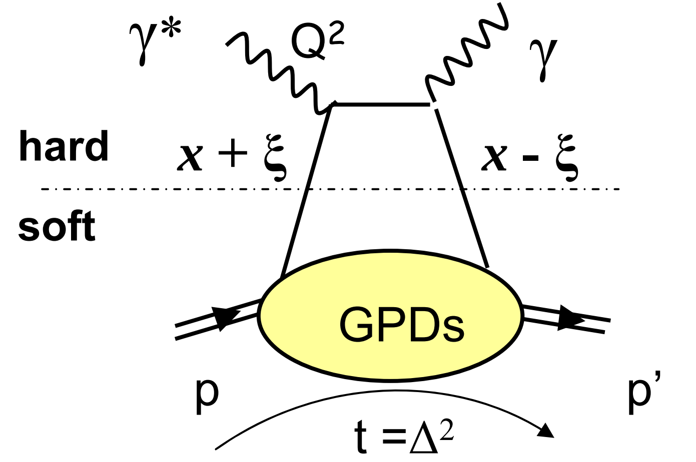
High energy muon
100/190 GeV

Pol 80%
μ+ or μ-
Change each 8 hours

2.10^8 μ per SPS cycle

in 2010 ?
new Linac4
(high intensity H^- source)
as injector for the PSB
+ improvements
on the muon line

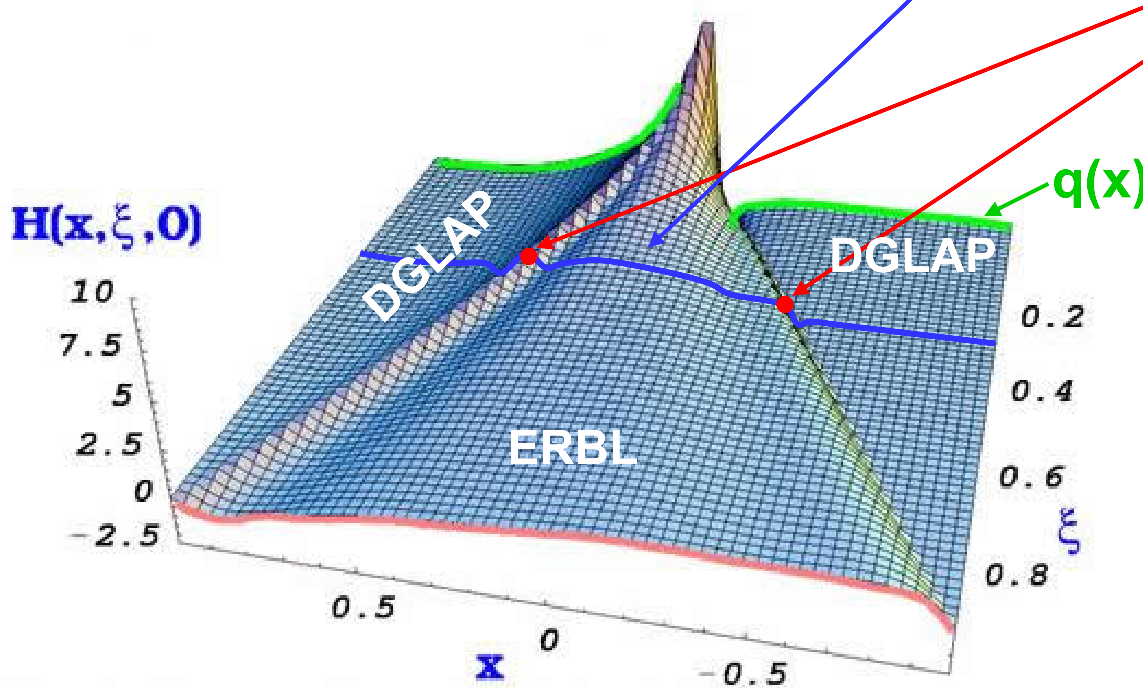
In DVCS and meson production
we measure Compton Form Factor



For example at LO in α_s:

$$\mathcal{H} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi} - i\pi H(x=\xi,\xi,t)$$

t, $\xi \sim x_{Bj/2}$ fixed

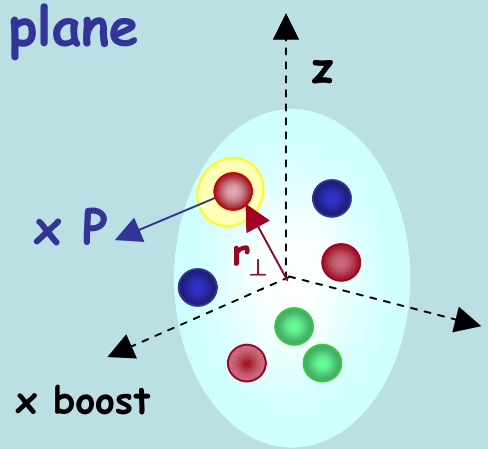


the ultimate goals or the « Holy-Grail »:

- GPD= a 3-dimensional picture of the partonic nucleon structure or spatial parton distribution in the transverse plane

$H(x, \xi, t)$ ou $H(P_x, r_{y,z})$

→ measurement of Re(H) via VCS and BCA or Beam Charge Difference

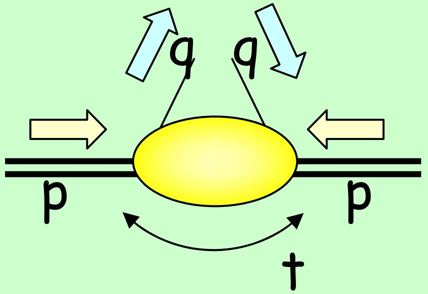


- Contribution to the nucleon spin knowledge

E related to the angular momentum

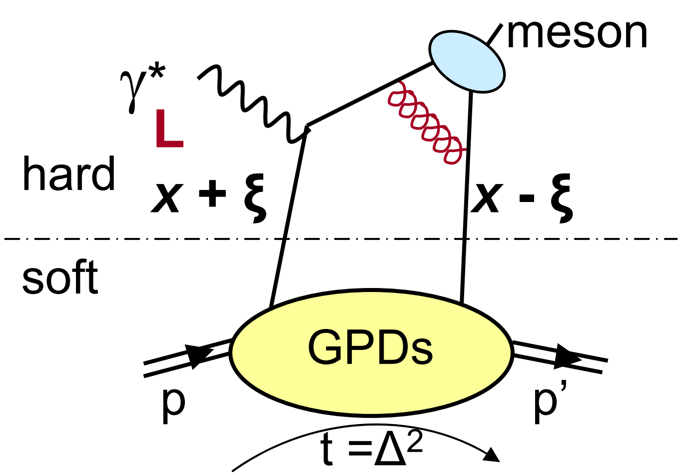
$$2J_q = \int x \,(H^q(x,\xi,0) + E^q(x,\xi,0))\, dx$$

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \langle L_z^q \rangle + \langle L_z^g \rangle$$

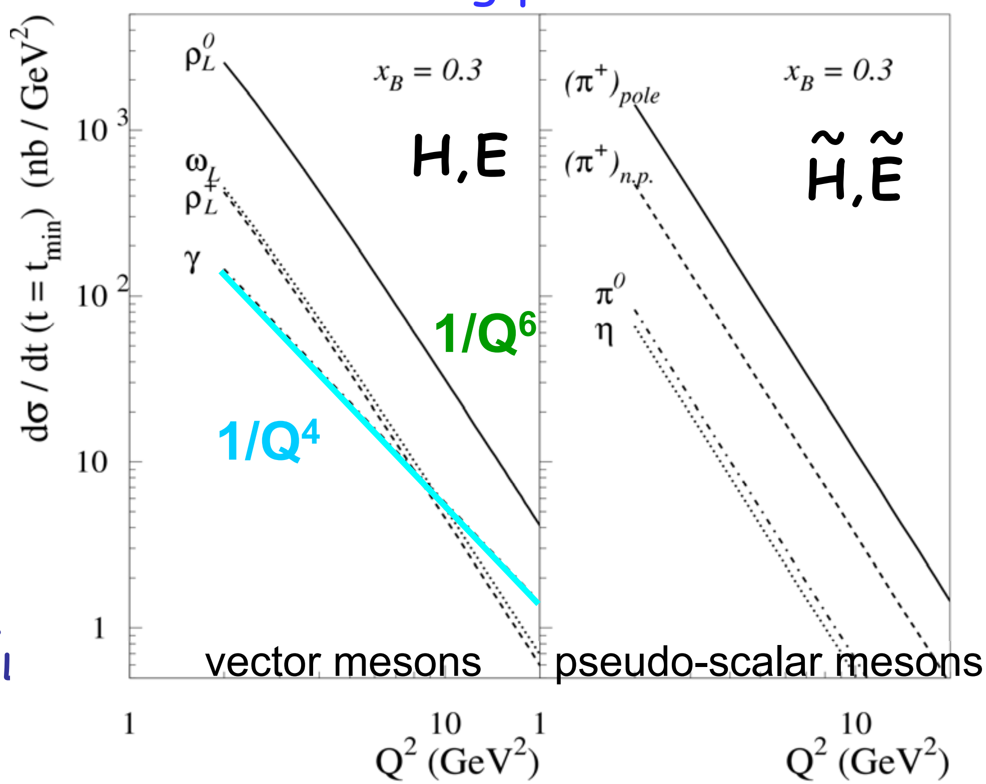


→ with a transversely polarized target DVCS et MV
→ with a deuterium or neutron target DVCS

1- Hard exclusive meson production



Scaling predictions:



Collins et al. (PRD56 1997):
- factorization applies only for γ^*_L
- probably at a larger Q^2

Different flavor contents:

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

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

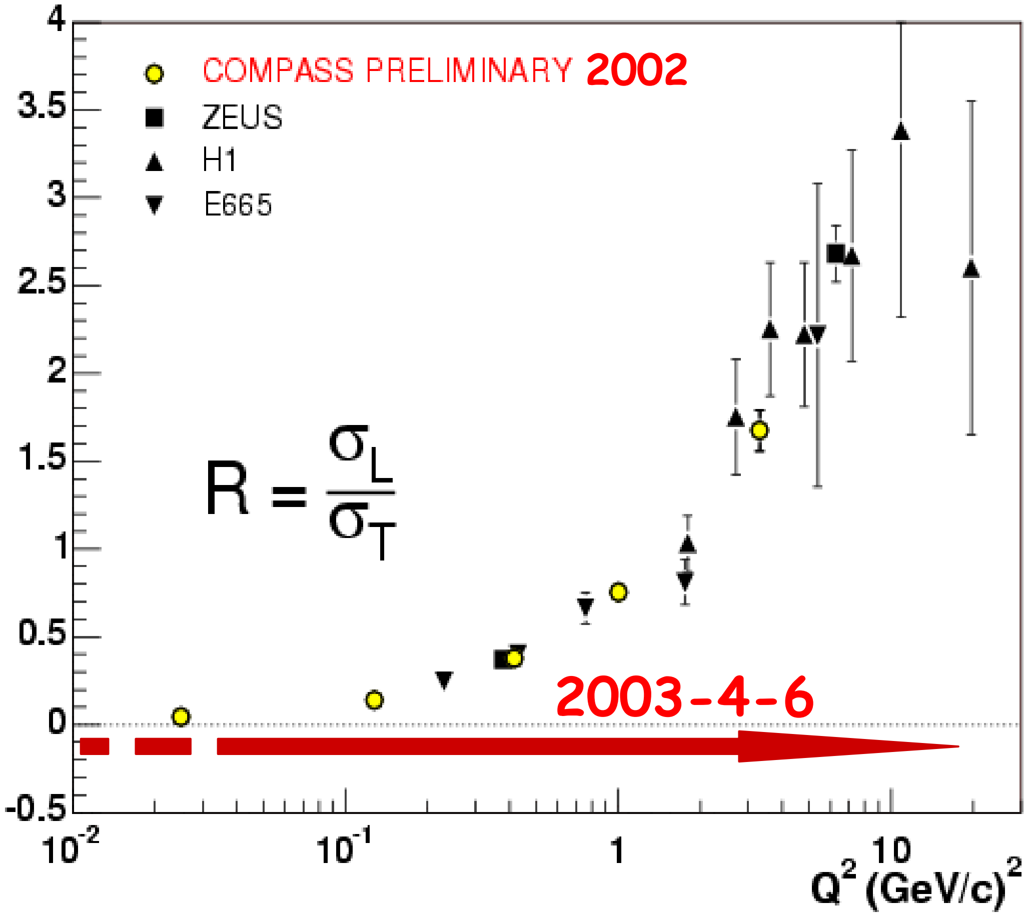
$H\phi = -1/3\ H^s - 1/8\ H^g$

under study with present COMPASS data

Determination of $R_{\rho^\circ} = \sigma_L/\sigma_T$

With COMPASS + $\vec{\mu}$

Complete angular distribution $\Rightarrow$ Full control of SCHC



- High statitics from γ-production to hard regime
- Better coverage at high Q^2 with 2003-4-6 data

Impact on GPD study:

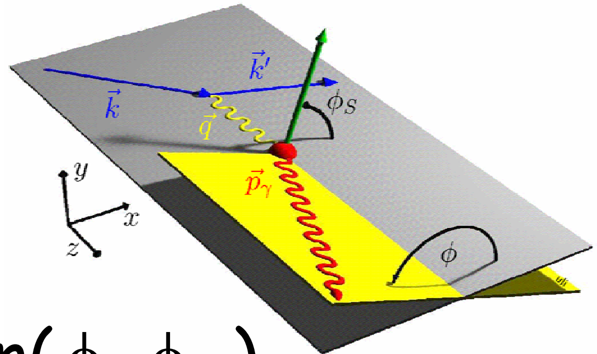
easy determination of σ_L

factorisation only valid for σ_L

σ_L is dominant at Q^2>2 GeV^2

Model-Dependent Constraint on J_u and J_d

Through the modeling of GPD E



1-Transversaly polarised target

In Meson production :

$$d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi) \propto \Im m(H\ E)\cdot \sin(\phi-\phi_S)$$

with COMPASS Li6D deuteron Data 2002-3-4-6 (J.Kiefer, G.Jegou)
NH3 proton Data 2007

In DVCS :

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

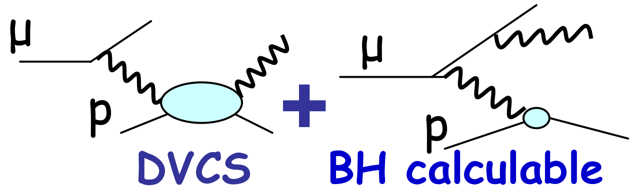
but… no recoil detection around the polarized target

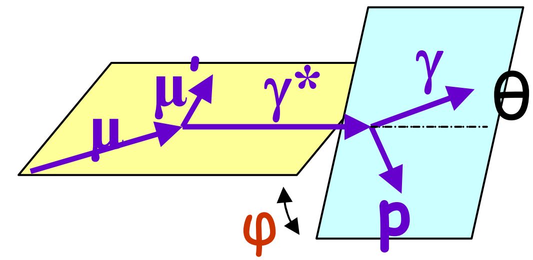
2-Neutron target - liquid deuterium target

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

for the complete program after 2010

2-DVCS with polarized and charged muons and unpolarized target





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

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

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

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

$$e_\mu \times a^{BH}\,\Re e\, A^{DVCS} = \frac{e^6}{xy^3 t P_1(\varphi)P_2(\varphi)}\left(c_0^{Int} + c_1^{Int}\cos\varphi + c_2^{Int}\cos 2\varphi + c_3^{Int}\cos 3\varphi\right)$$

$$e_\mu\, P_\mu \times a^{BH}\,\Im m\, A^{DVCS} = \frac{e^6}{xy^3 t P_1(\varphi)P_2(\varphi)}\left(s_1^{Int}\sin\varphi + s_2^{Int}\sin 2\varphi\right)$$

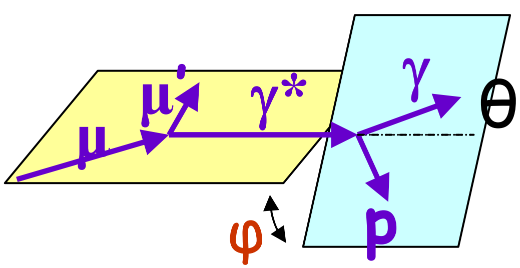
Twist-2 M^{11} >> Twist-3 M^{01} Twist-2 gluon M^{-11}

Belitsky, Müller, Kirchner

Advantage of $\overleftarrow{\mu}^{+}$ ($P_{\mu+}$=-0.8) and $\vec{\mu}^{-}$ ($P_{\mu-}$=+0.8) for Deeply virtual Compton scattering (+Bethe-Heitler)

$$d\sigma_{(\mu p \to \mu p \gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu \, d\sigma^{DVCS}_{pol}$$

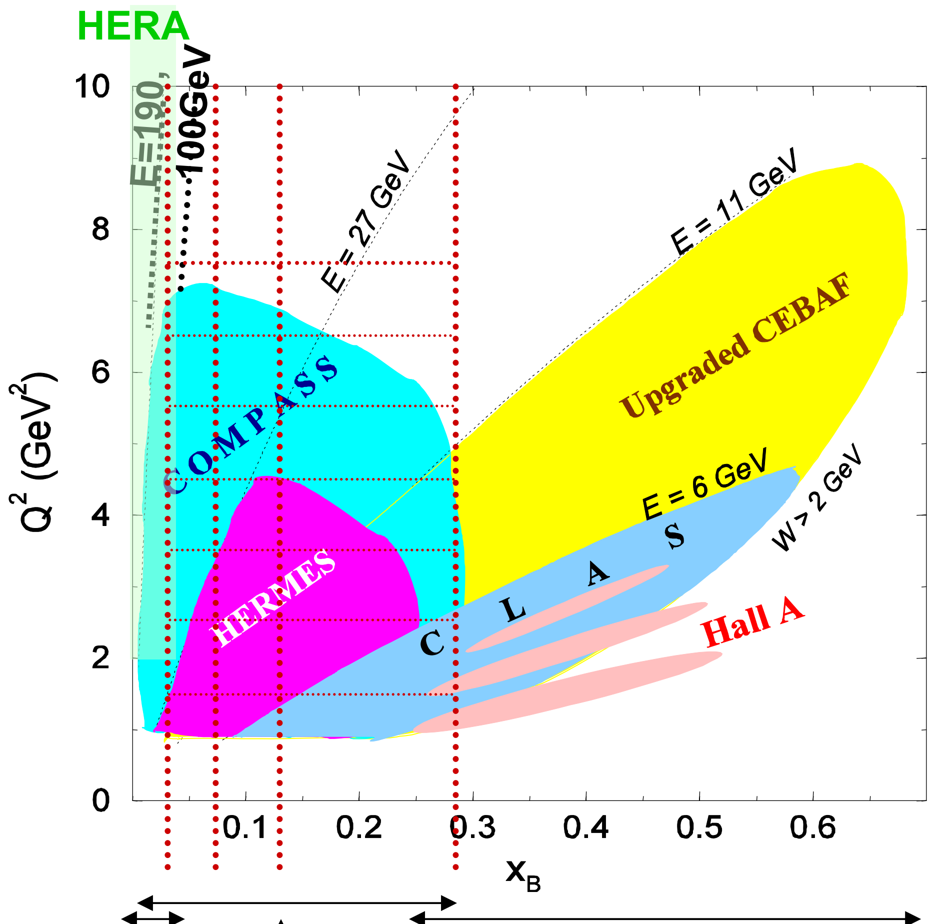
$$+ e_\mu \, a^{BH} \, \mathcal{R}e \, A^{DVCS} \times \cos n\varphi \qquad + e_\mu \, P_\mu \, a^{BH} \, \mathcal{I}m \, A^{DVCS} \times \sin n\varphi$$



$$\sigma^{\overleftarrow{\mu}+} + \sigma^{\vec{\mu}-} \sim H(x = \xi, \xi, t)$$

$$\sigma^{\overleftarrow{\mu}+} - \sigma^{\vec{\mu}-} \sim \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}$$

Competition in the world and COMPASS role



Gluons

valence quarks and sea quarks and gluons

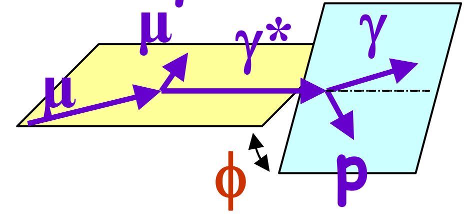
valence quarks

COMPASS 2010

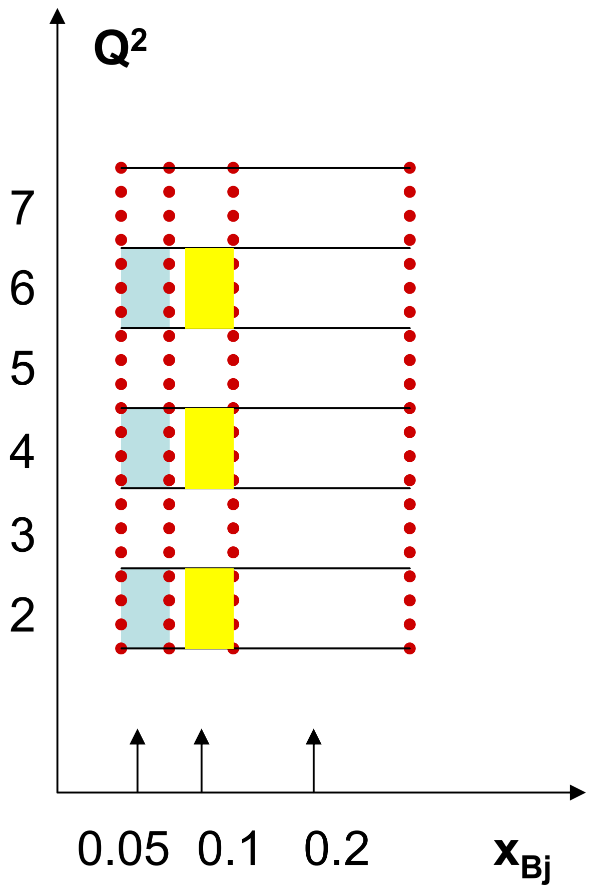
JLab 12 GeV 2014

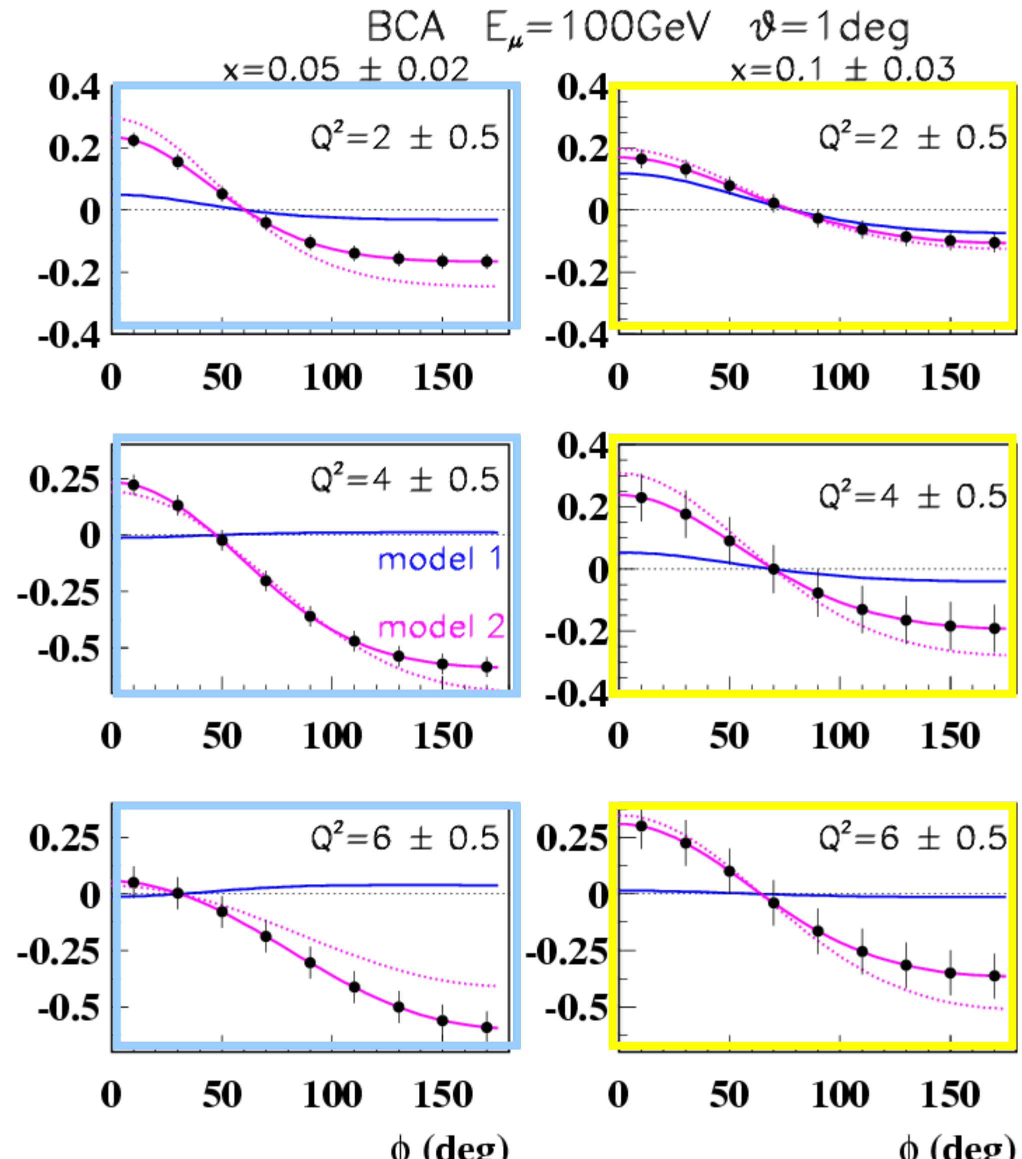
Beam Charge Asymmetry at E_μ = 100 GeV

COMPASS prediction



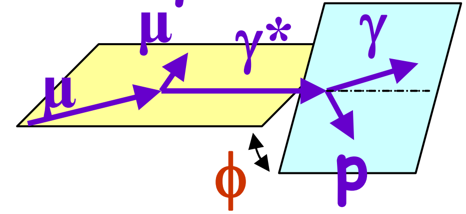
6 month data taking in 2010
250cm H2 target
25 % global efficiency





Beam Charge Asymmetry at E_μ = 100 GeV

COMPASS prediction



VGG *PRL80 (1998), PRD60 (1999)*
Prog.Part.NP47 (2001), PRD72 (2005)

double-distribution in x, ξ

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

Model 2: correlation x and t

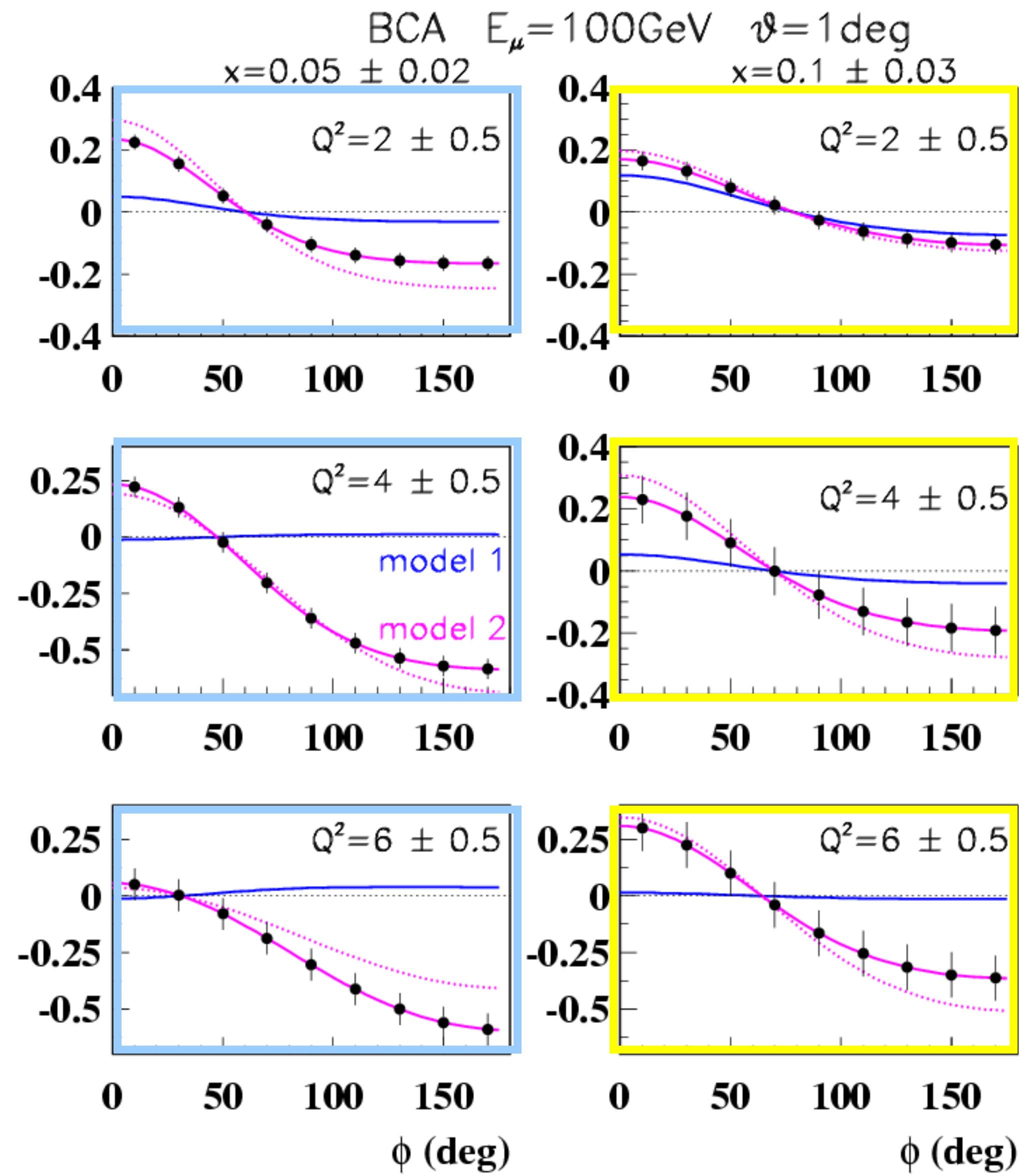
$\langle b^2_\perp \rangle = \alpha' \ln 1/x$

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

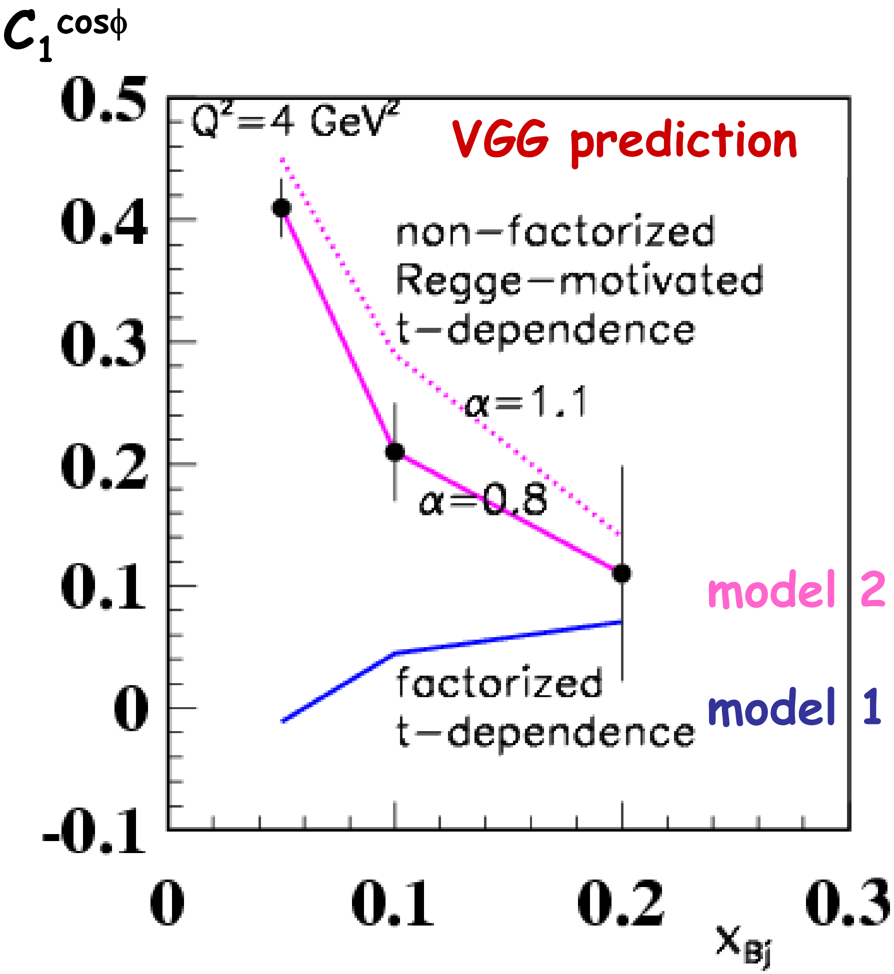
α' slope of Regge traject.

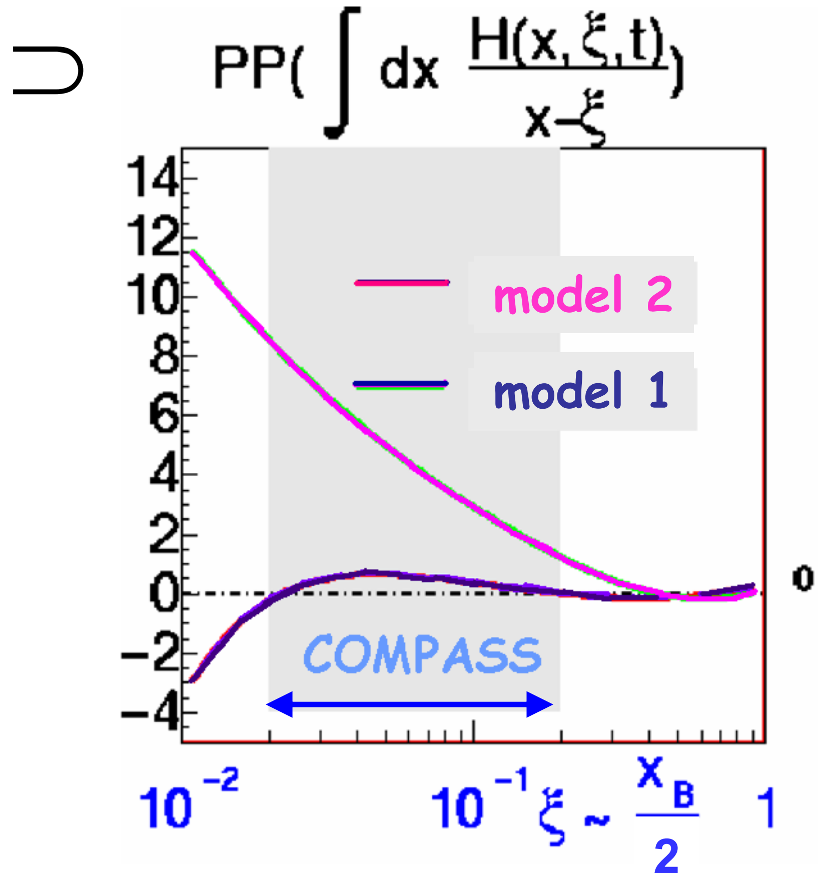
—— α'=0.8

.... α'=1.1



$$BCA = \frac{c_0^{int} + c_1^{int}\cos\Phi + c_2^{int}\cos 2\Phi + c_3^{int}\cos 3\Phi}{\text{denominator(BH+DVCS)}}$$





Superiority of a Beam Charge Difference measurement

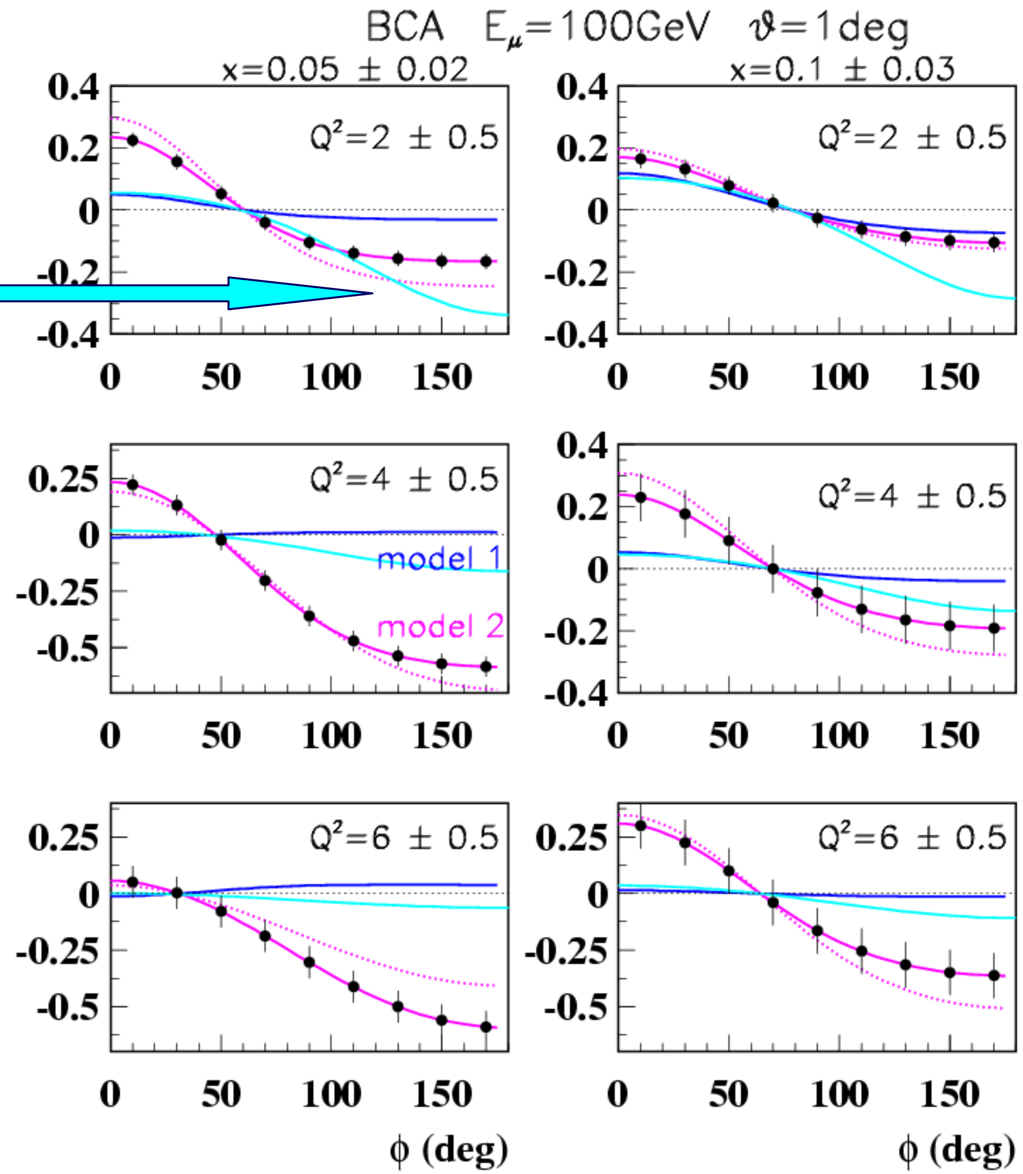
α' determined within an accuracy of ~10% at xBj =0.05 and 0.1

With another model - just received yesterday evening

V. Guzey
PRD74 (2006) 054027

Dual parametrization
Mellin moments decomposition
QCD evolution
separation x, ξ and ξ, t

Non-factorized
Regge-motivated
t-dependence

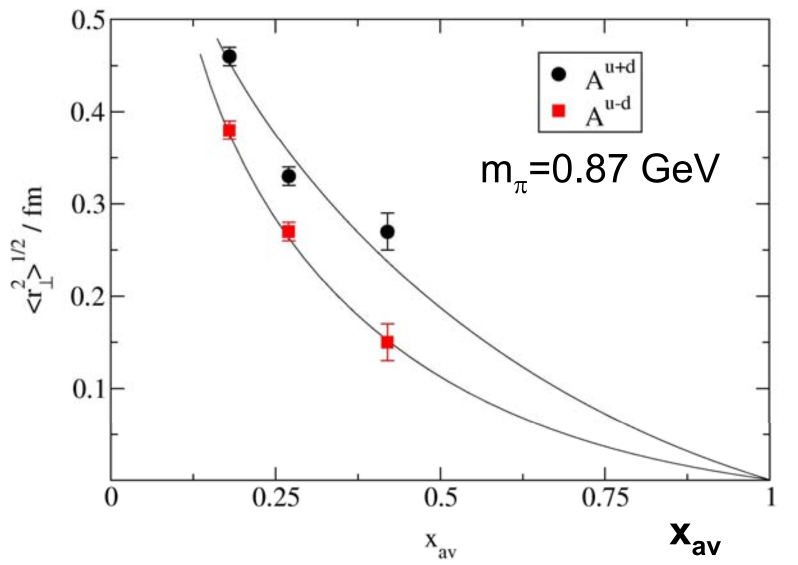


Sensitivity to the 3-D nucleon picture

Lattice calculation (unquenched QCD):

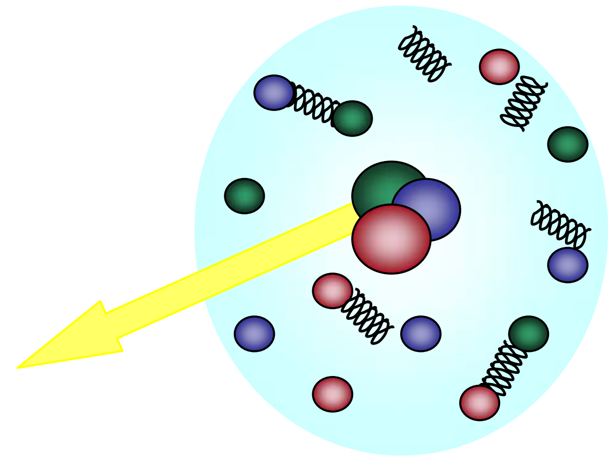
Negele et al., NP B128 (2004) 170
Göckeler et al., NP B140 (2005) 399

- 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*

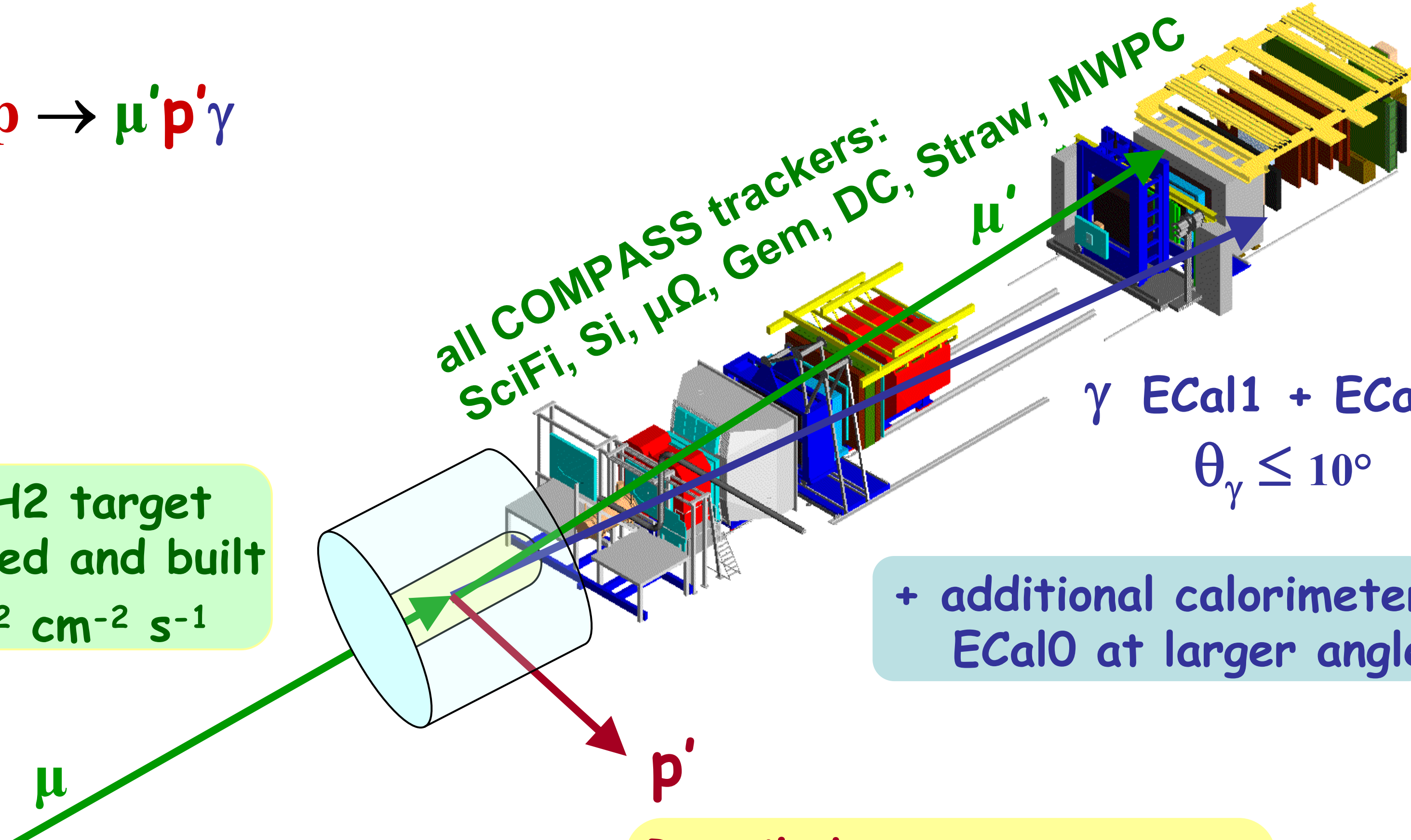
at large distance :
gluon density generated by the pion cloud
increase of the N transverse size
for $x_{Bj} < m_\pi/m_p$=0.14



Promising COMPASS domain

Additional equipment to the COMPASS setup

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



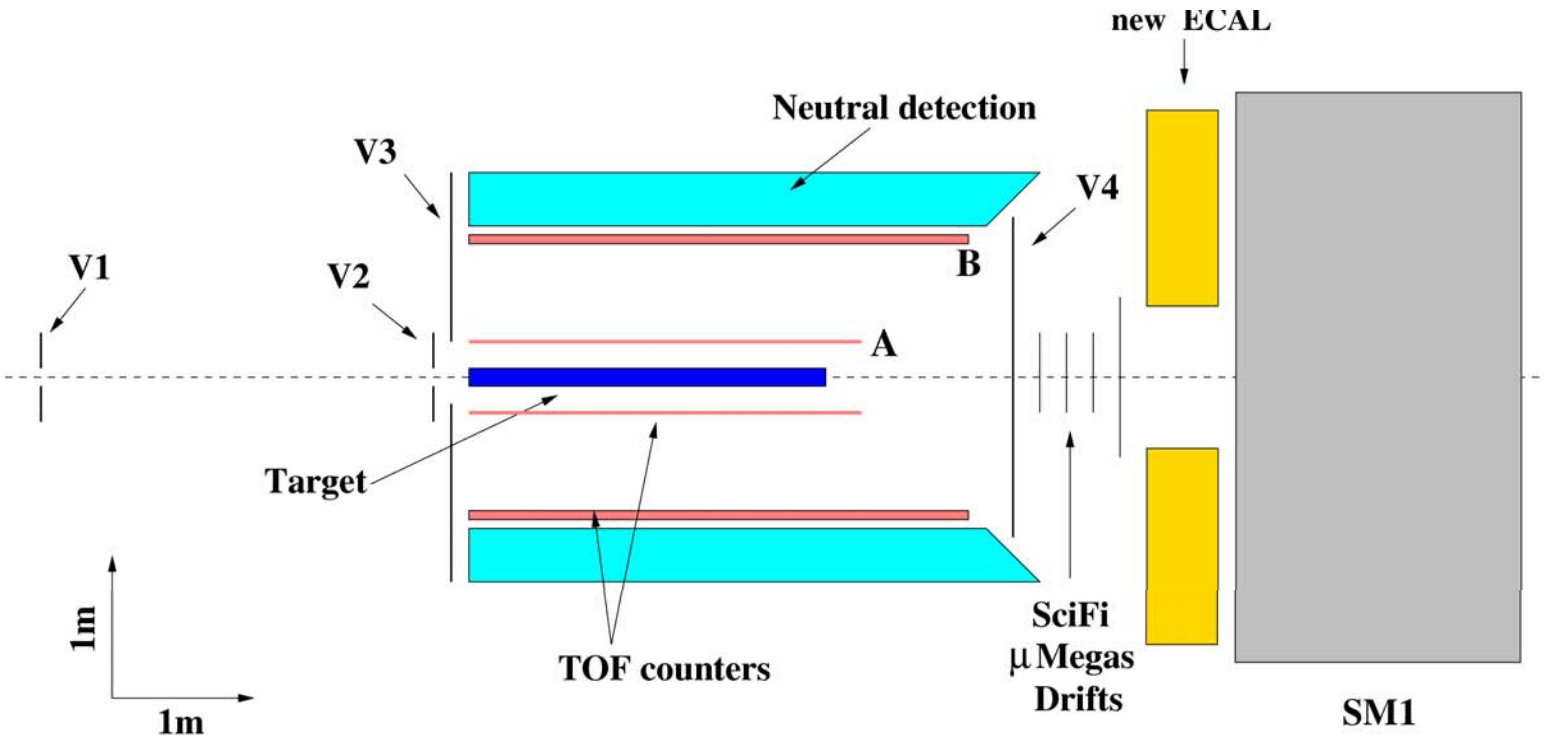
2.5m liquid H2 target
to be designed and built
$\mathcal{L}$ = 1.3 10^{32} cm^{-2} s^{-1}

+ additional calorimeter
ECal0 at larger angle

Nμ=2.10^8/SPS cycle
(duration 5.2s, each 16.8s)

Recoil detector
to insure exclusivity
to be designed and built

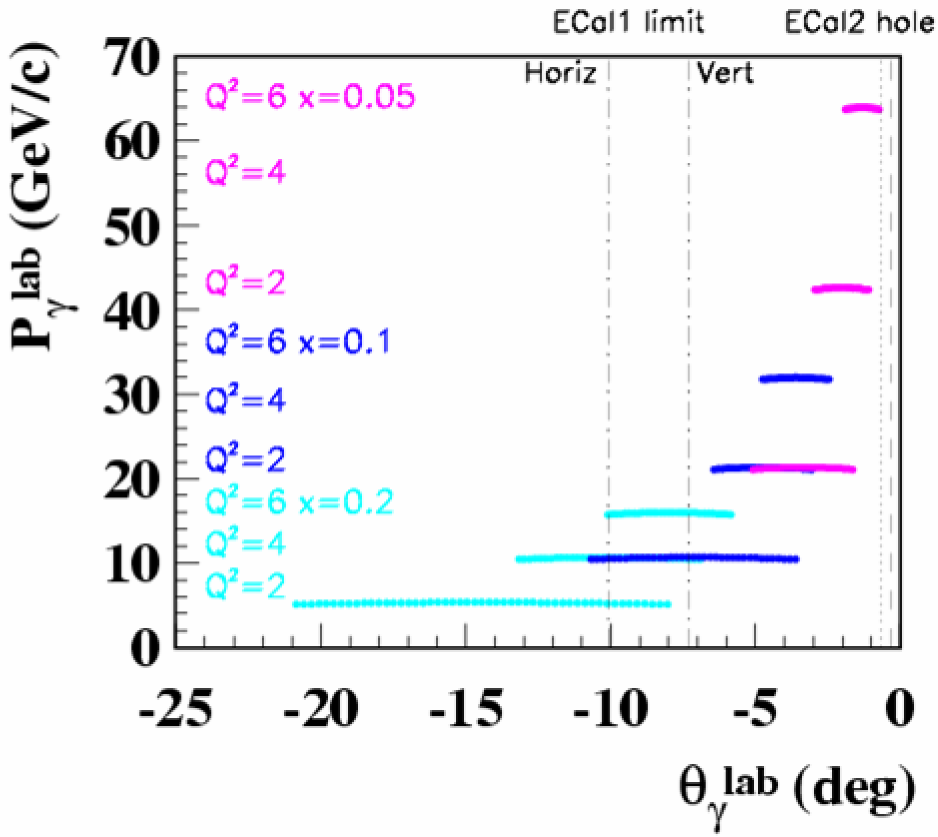
Recoil detector + extra calorimetry



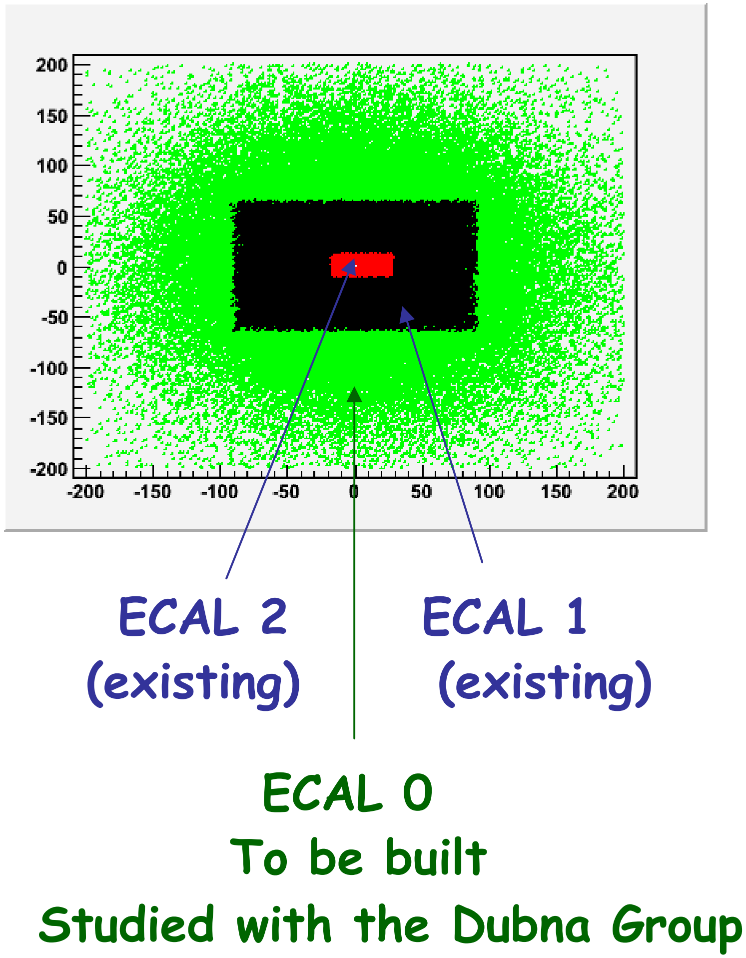
+ the complete COMPASS setup

Calorimeter coverage foreseen for DVCS γ and π°

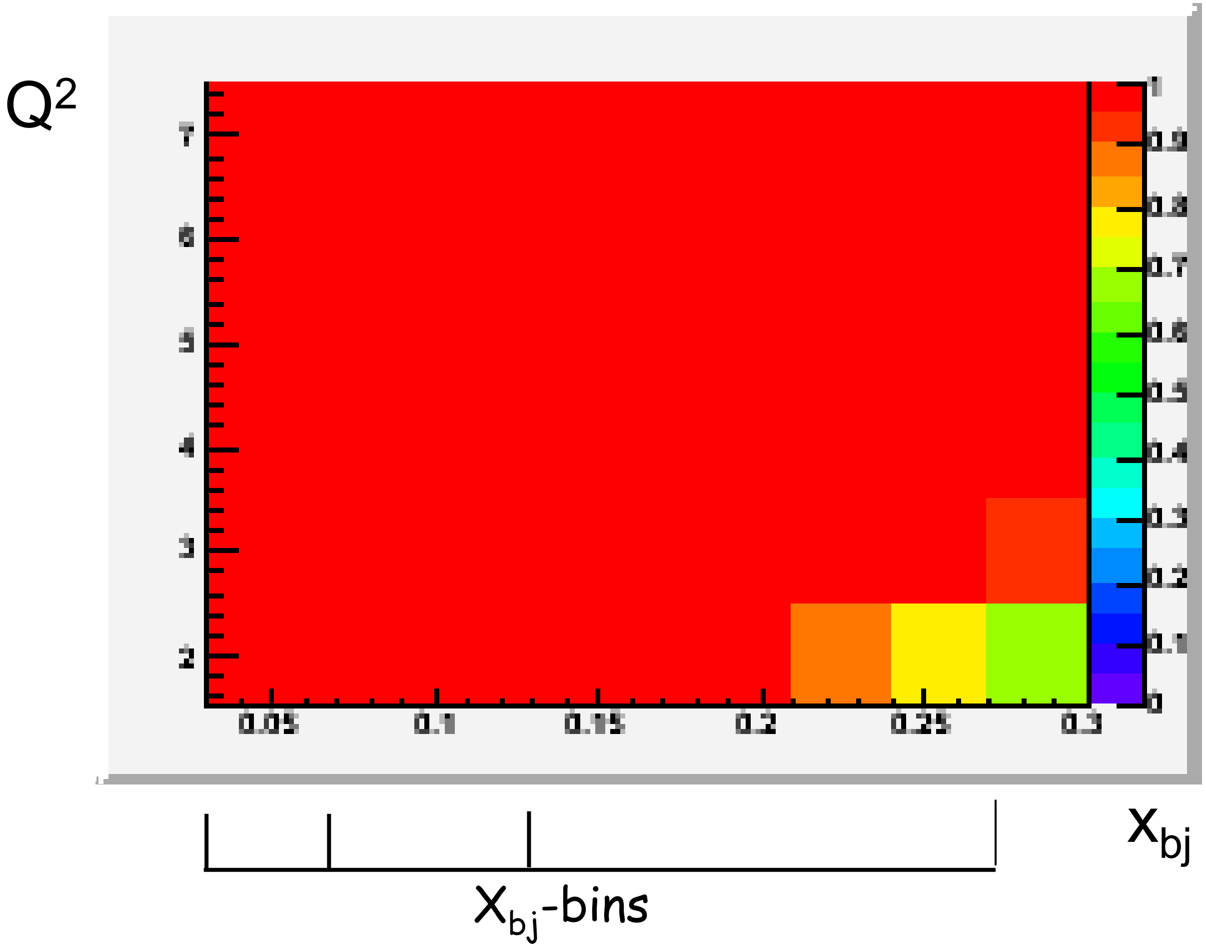
DVCS γ kinematics



DVCS γ impact point at ECAL 0 location



Calorimeter acceptance



Existing Calorimeters

+ 3m x 3m ECAL0

+ 4m x 4m ECAL0

Requirements for the recoil proton detector

1) Time of Flight measurement

σ(ToF) < 300 ps $\rightarrow \Delta P/P \sim$ 3 à 15 %

$t = (p-p')^2 = 2m(m-Ep')$

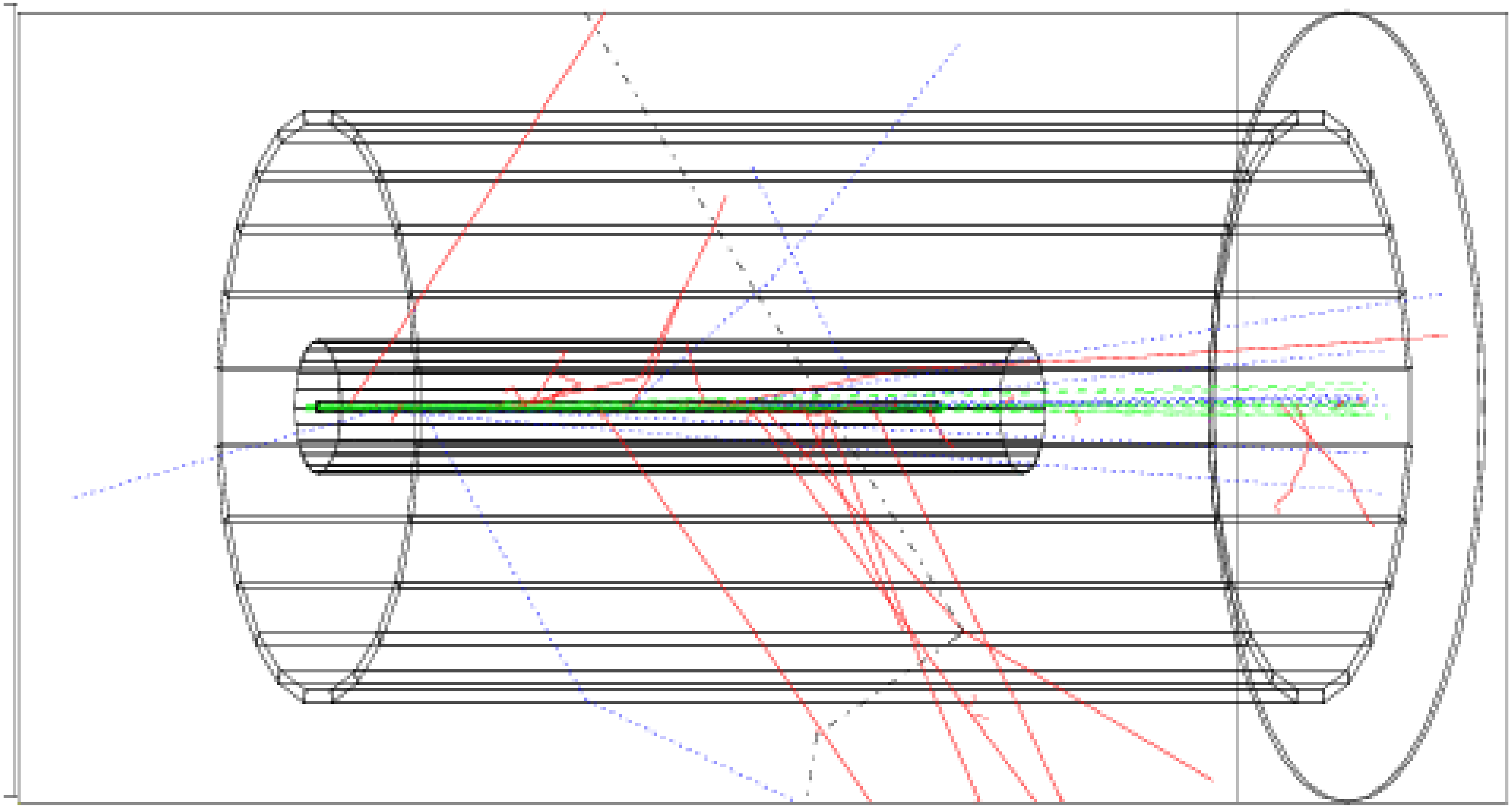
$\Delta t/t \sim 2 \Delta P/P \Rightarrow$ 10 bins in t from t_{min} to 1 GeV^2

t is the Fourier conjugate of the impact parameter $r_\perp$
t is the key of the measurement

2) Hermiticity + huge background + high counting rates

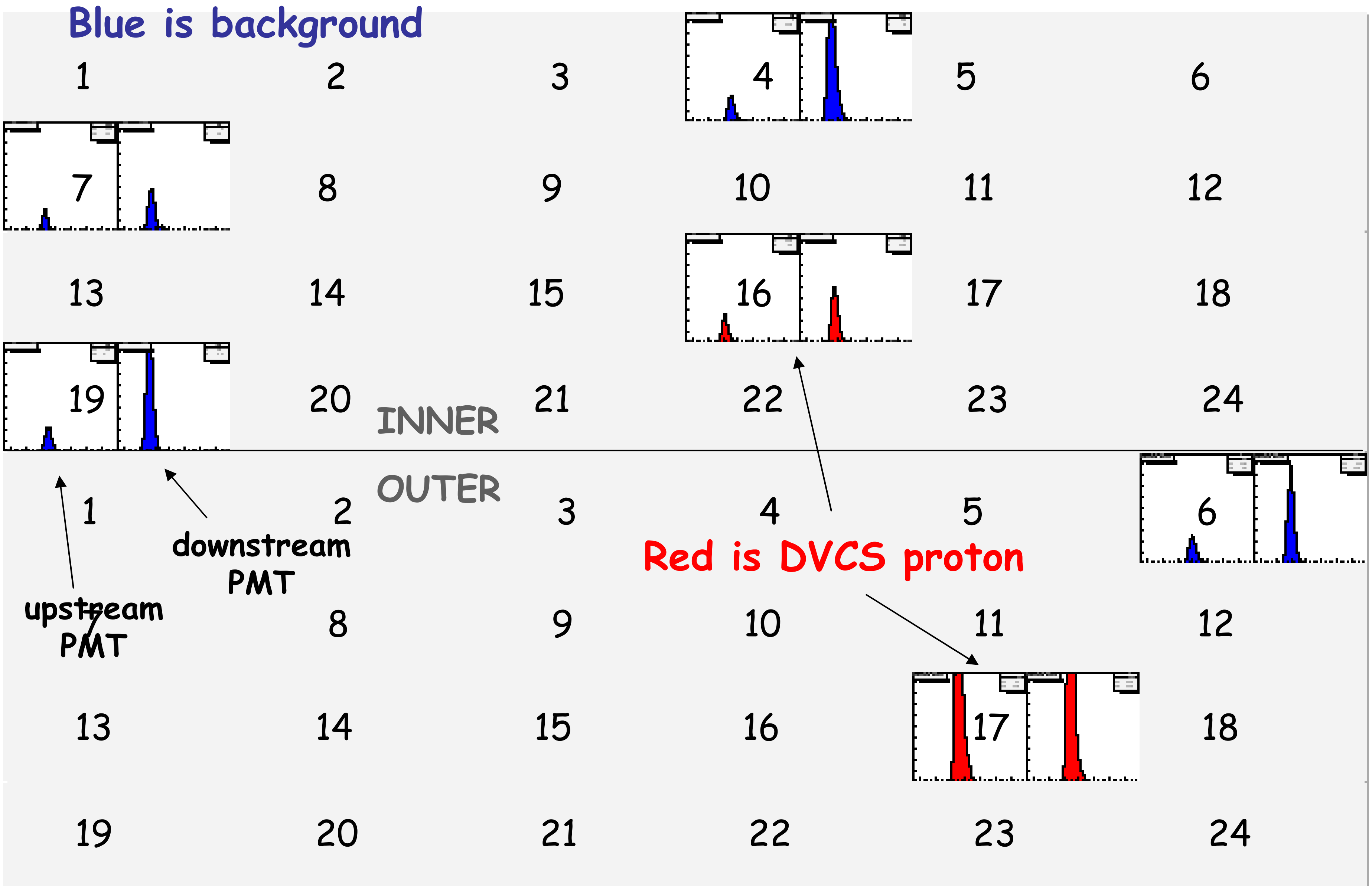
Geant Simulation of recoil detector

2 concentric barrels of 24 scintillators counters read at both sides around a 2.5m long H_2 target

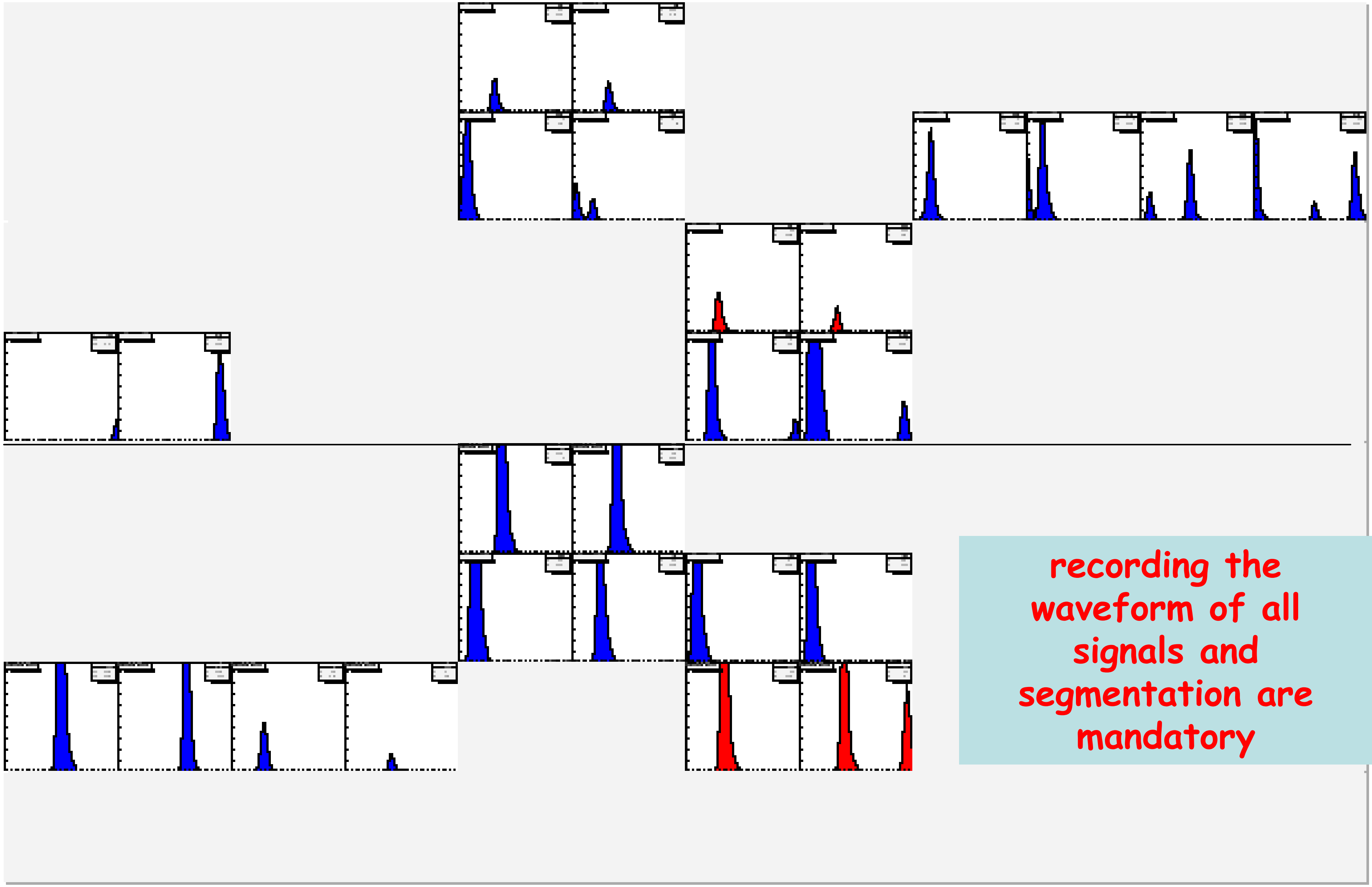


With simulation of δ-rays

PMT signals : only 1μ in the set-up



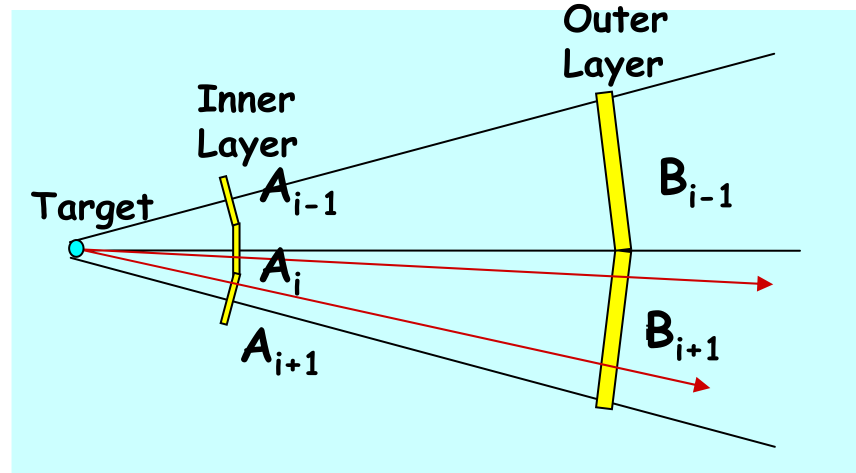
PMT signals : 2 10^8 μ/spill (5s)



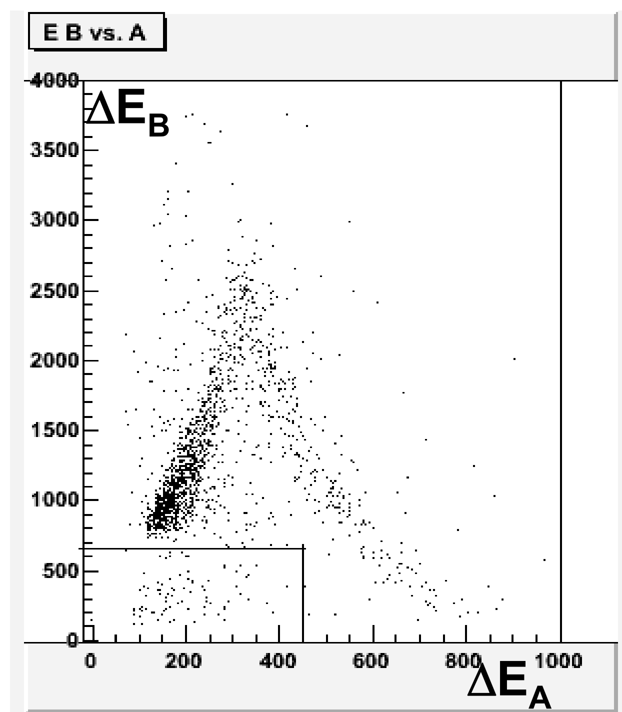
recording the waveform of all signals and segmentation are mandatory

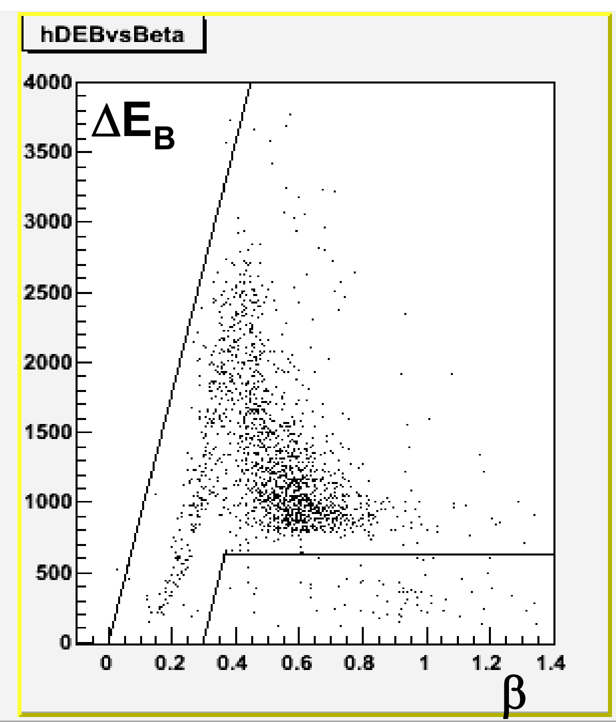
Criteria for proton candidates

- 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



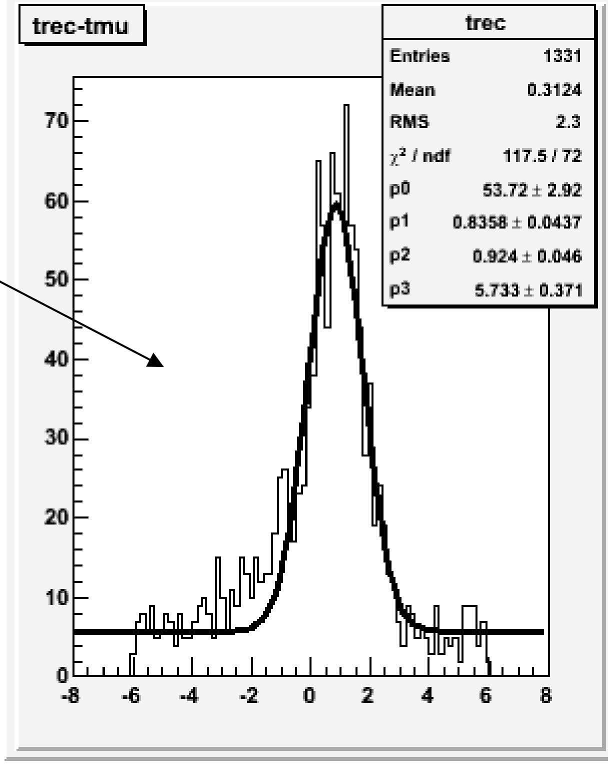
(no background in this plot – just for pedagogy)

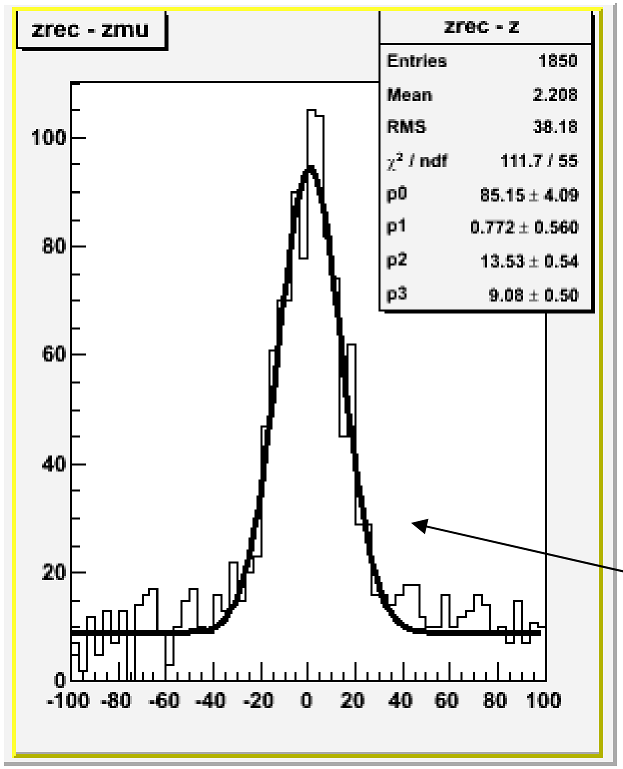




Coincidence with the scattered muon

Use reconstructed muon vertex time to constraint proton candidates





Use vertex position to evaluate the effective signal

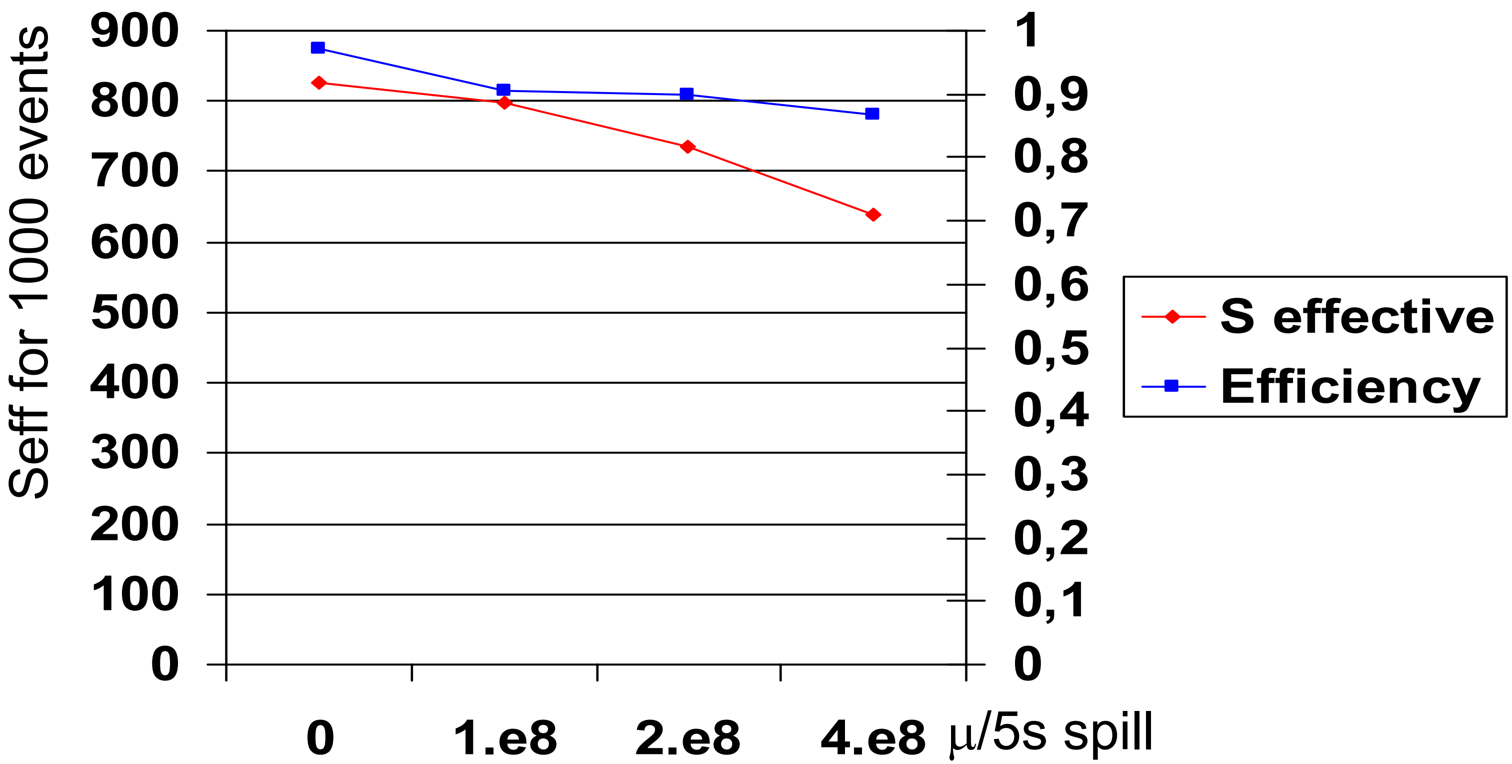
$$S_{eff} = \frac{S}{1+B/S}$$

Proton detection efficiency

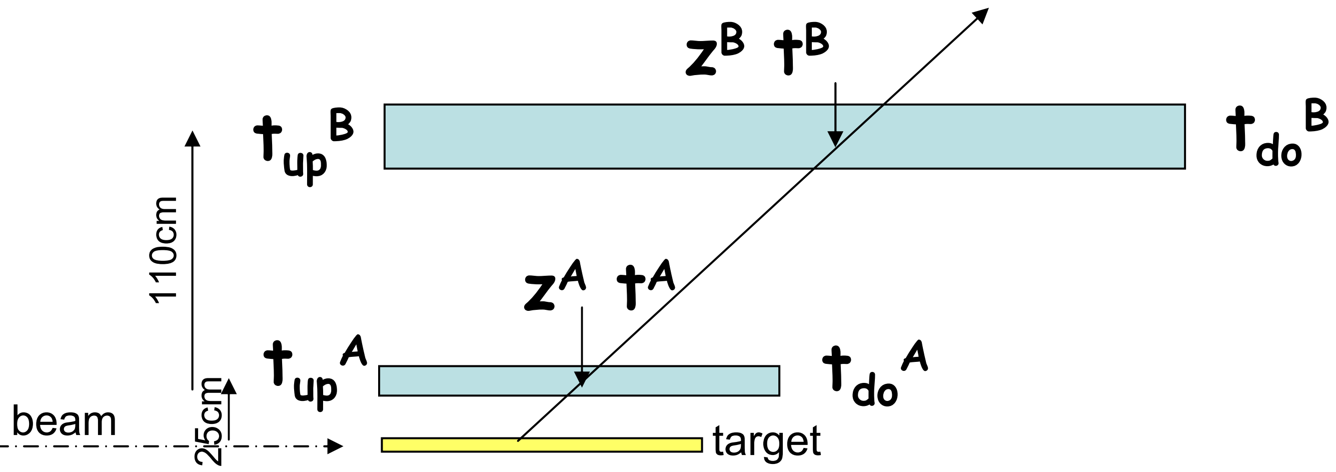
$$\text{Efficiency} = \frac{\text{number of events with proton identified}}{\text{number of “triggers”}}$$

trigger = one event with at least one good combination of A and B with hits

identified proton = proton of good A and B combination, good energy correlation, and good timing with the muon



Time of Flight measurement

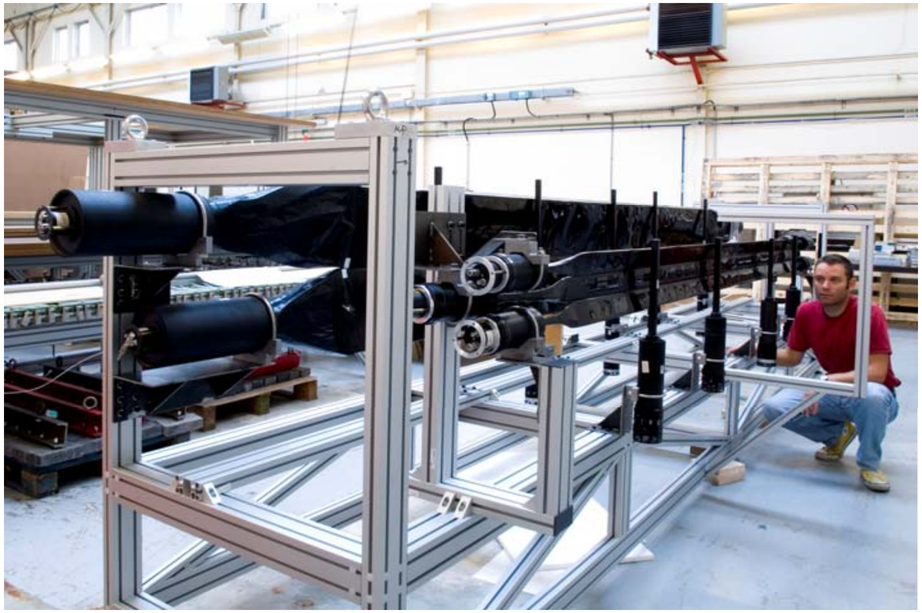


$$z^B = (t_{up}^B - t_{down}^B)\, V^B/2 + L^B/2 + Cor_{up}^{tw} - Cor_{down}^{tw} + Off_{up} - Off_{down}$$

$$t^B = (t_{up}^B + t_{down}^B)/2 \quad + \underbrace{L^B/2V^B + Cor_{up}^{tw} + Cor_{down}^{tw} + Off_{up} + Off_{down}}_{\text{To be precisely determined (tw= time walk correction)}}$$

$$ToF = (t_{up}^B + t_{down}^B)/2 - (t_{up}^A + t_{down}^A)/2 + \ldots$$

Recoil Detector Prototype Tests (2006)



All scintillators are BC 408

A: 284cm x 6.5cm x 0.4cm

Equiped with XP20H0 (screening grid)

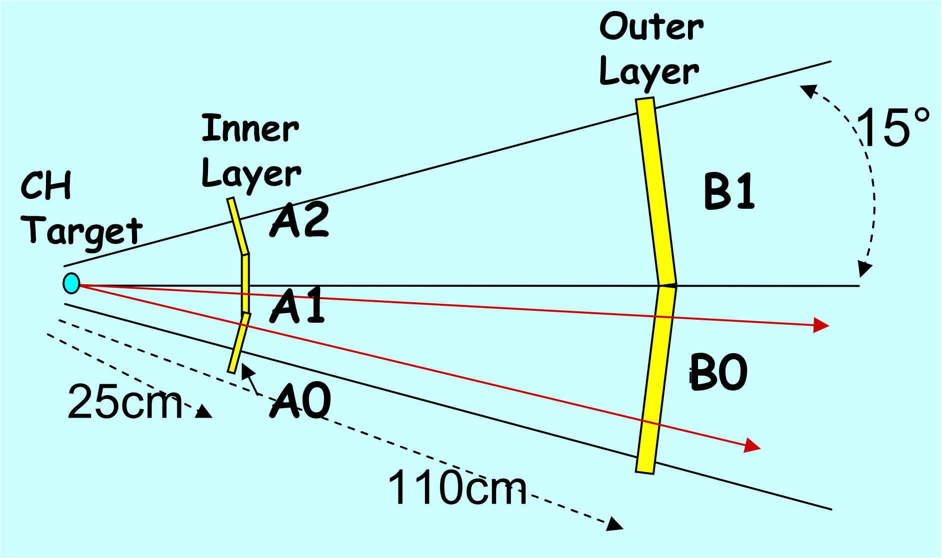
B: 400cm x 29cm x 5cm

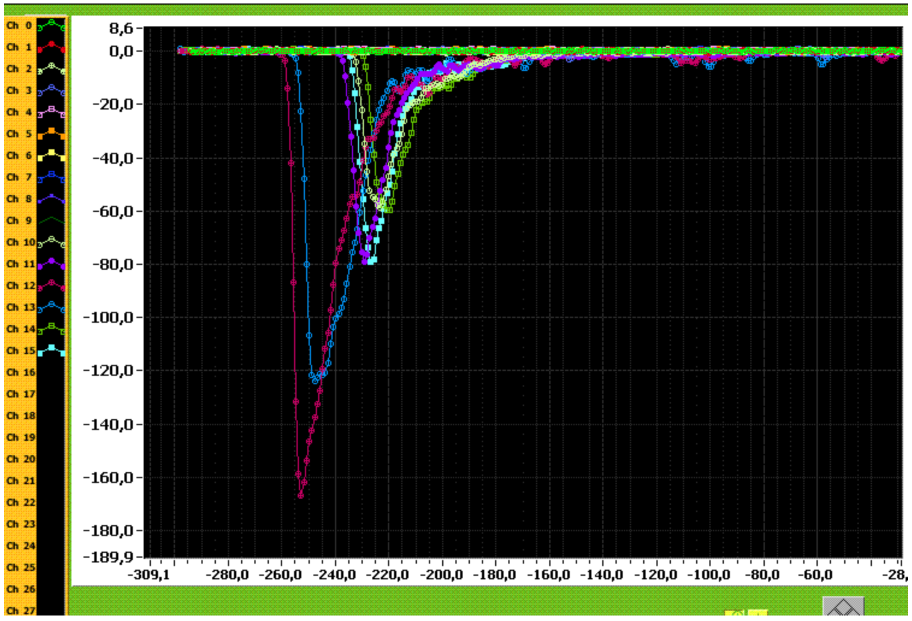
Equiped with XP4512

Use 1GHz sampler (300ns window)

MATACQ board

Designed by CEA-Saclay/LAL-Orsay





Obtained results with the prototype in 2006 with the MATACQ

at CERN (muon halo)

$\sigma(t_{up}^{B} - t_{down}^{B}) = 200 \pm 6$ ps

$\sigma(t_{up}^{A} - t_{down}^{A}) = 270 \pm 6$ ps

at Saclay (cosmics) with external time references

$\sigma(t_{up}^{B} + t_{down}^{B}) = 145$ ps ± 10 ps

$\sigma ToF = \sigma\,[\,(t_{up}^{B} + t_{down}^{B}) - (t_{up}^{A} + t_{down}^{A})]$

$= 315 \pm 12$ ps

to be still improved but intrinsic limit due to the thin layer A

Conclusion & prospects

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

- Experimental realisation
  - Recoil Detection is feasible with a waveform analysis due to the high background
  - Extension of the calorimetry is desirable

- Roadmap
  - Now with the transversely polarized targets:
    Li6D (→ 2006) and NH3 (2007)
  - 2008-9: A small RPD and a liquid H2 target will be available
    for the hadron program (ask for 2 shifts $\mu+$ and $\mu-$)
  - > 2010: A complete GPD program at COMPASS
    with a long RPD + liquid H2 target

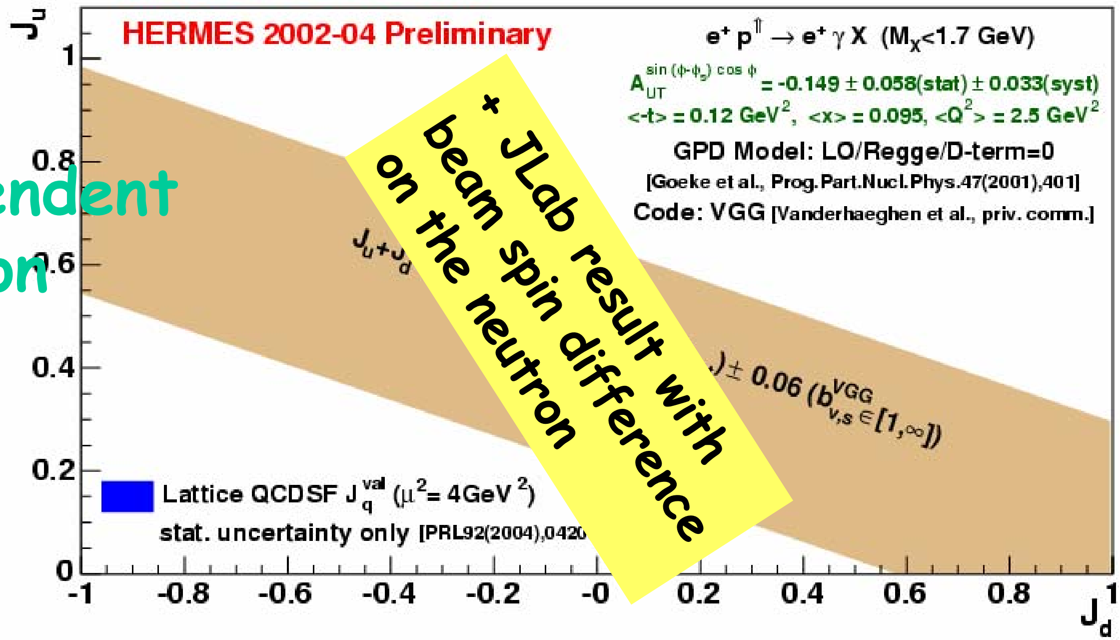
    before the availability of JLab 12 GeV, EIC, FAIR…

HERMES: transverse target-spin asymmetry in DVCS

Unbinned maximum likelihood fit to $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ at average kinematics (fitting prel. HERMES data against VGG-model based calculations), leaving J_u and J_d as free parameters $\Rightarrow$ model-dependent 1-σ constraint on J_u vs. J_d:

Model-dependent constraint on J_u vs J_d

(VGG code)



- Quenched lattice calculation done with pion masses 1070, 870, and 640 MeV, and then extrapolated linearly in m_π^2 to the physical value
- Uncertainties on VGG model parameters shown as separate uncertainty (± 0.06)

Ellinghaus, Nowak, Vinnikov, Ye (2005) EPJC46 (2006)

Parametrization $GPD(x, \xi, t, Q^2)$

VGG M.Vanderhaeghen et al.
PRL80 (1998) 5064
PRD60 (2006) 094017
Prog.Part.Nucl.Phys.47(2001)401-515

Double distribution x, ξ

V. Guzey
PRD74 (2006) 054027
hep-ph/0607099v1

Dual parametrization
Mellin moments decomposition

QCD evolution

separation x, ξ and ξ, t

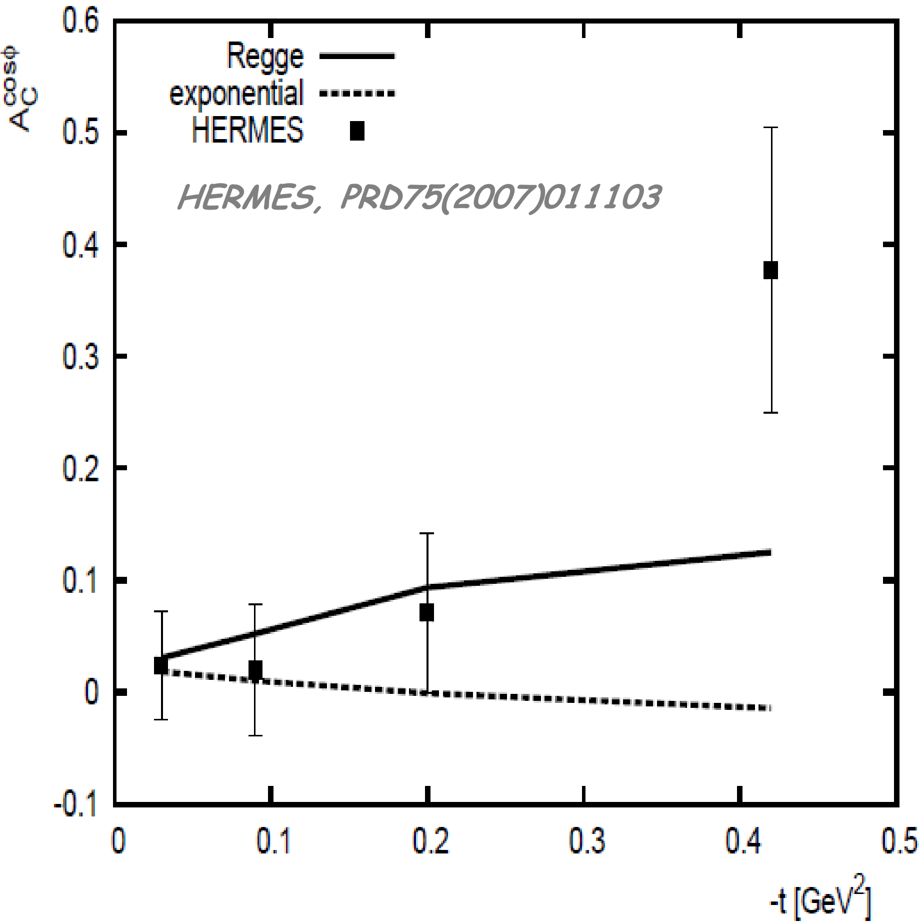
\+ Factorized t dependence

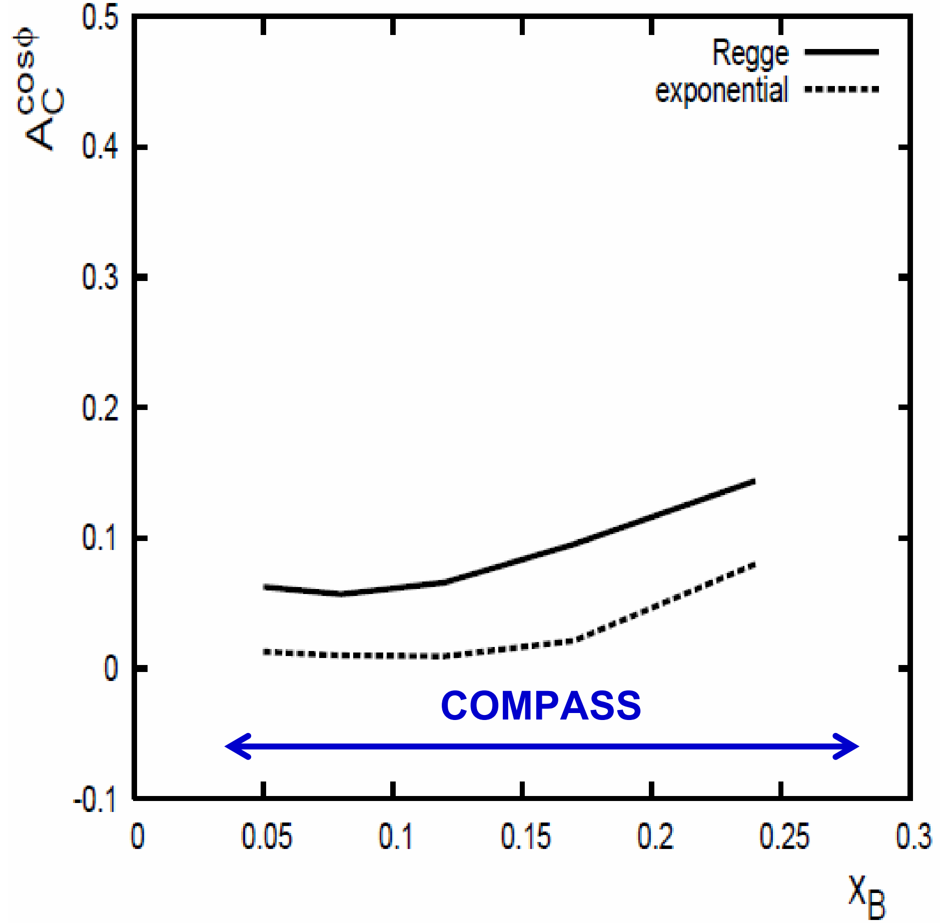
Or Non-factorizable Regge-motivated t-dependence

Beam Charge Asymmetry: Other Model and HERMES

- Dual parameterization
- Mellin moments decomposition, QCD evolution
- separation of x, ξ and ξ, t

Guzey, Teckentrup PRD74(2006)054027





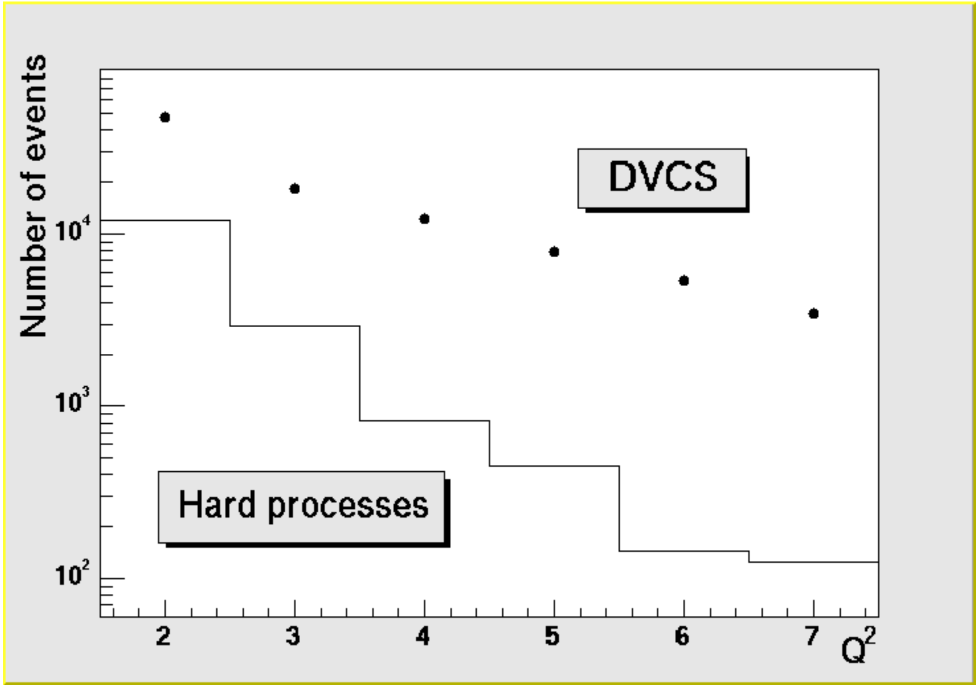
Physical Background to DVCS

Competing reactions: Deep pi0, Dissociative DVCS, DIS…

Study of DIS with Pythia 6.1 event generator

Apply DVCS-like cuts: one μ',γ,p in DVCS range

no other charged & neutral in active volumes

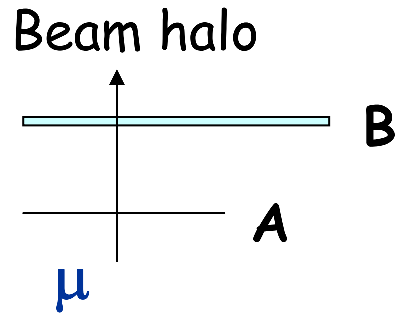


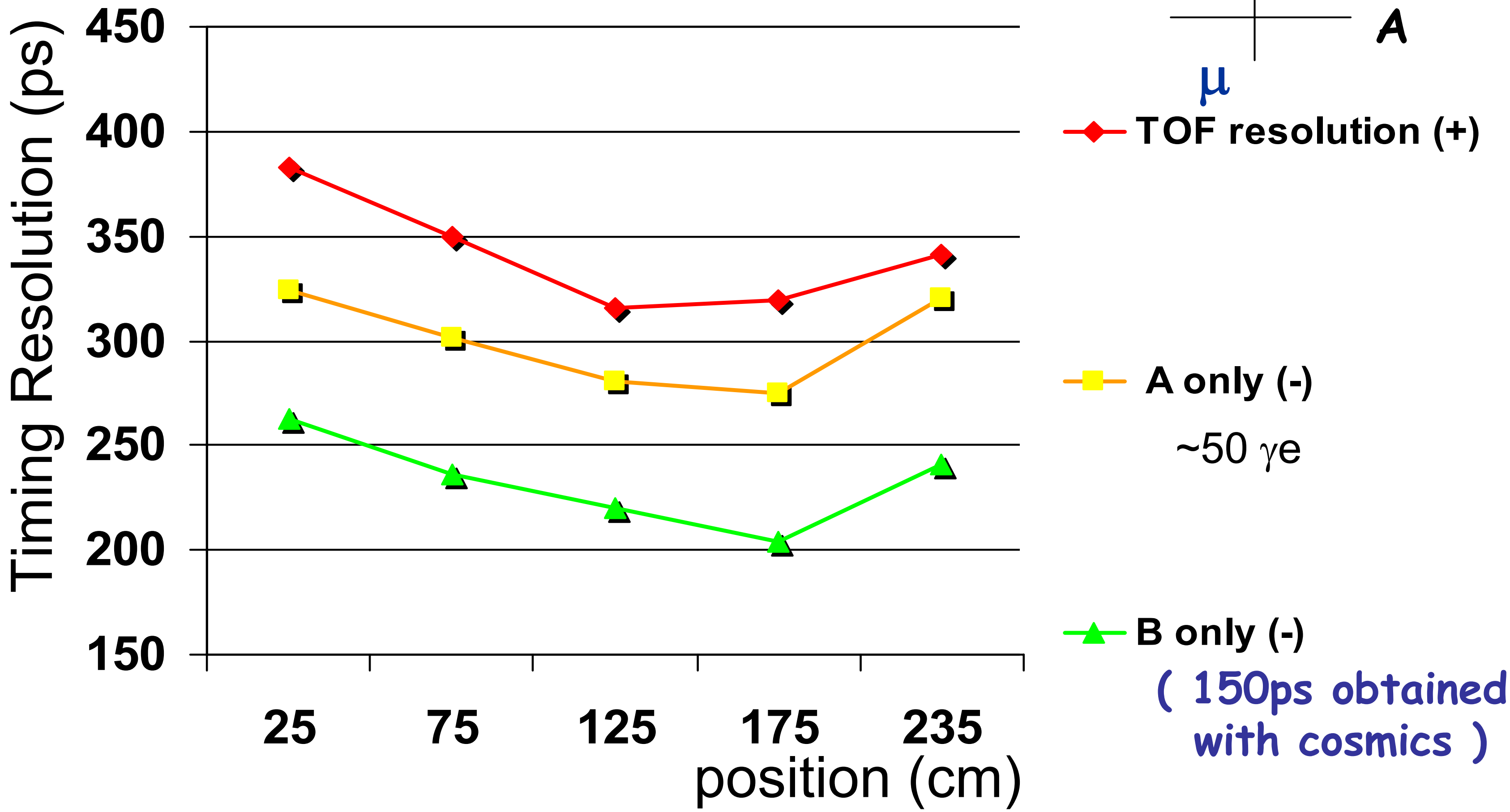
detector requirements:

- 24° coverage for neutral
- 50 MeV calorimeter threshold
- 40° for charged particles

in this case DVCS is dominant

Timing resolution





Reach 315 ps at the middle and 380 ps in the worst case at the edge

Performed with 160 GeV muon (0.8*MIP in A)
Expect better resolution for slow protons