Possible experiments on GPDs with COMPASS

1.Goal of an experiment with the high energy muon beam

2.General requirements for COMPASS

3.A pragmatic solution with the present setup

Hard Exclusive Meson Production ρ°, π° (HEMP)

Sandacz, Mankiewicz, Moinester,
Piller,Pochodzalla,Vanderhaeghen
COMPASS Note 2000–1

4.An ideal solution with a completed setup

Deeply Virtual Compton Scattering (DVCS)

Burtin, d'Hose,Guichon,Kerhoas,
Marroncle, Mossé,Vanderhaeghen

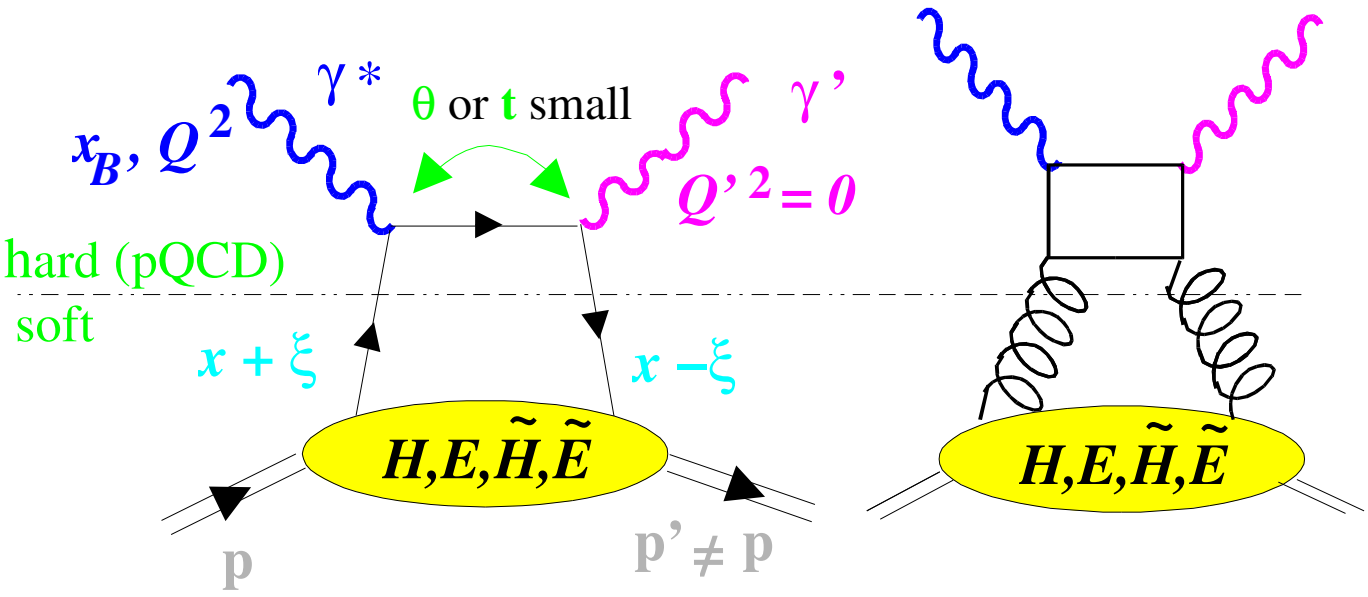
+ all the Saclay COMPASS group
+von Harrach...

1. Goal of an experiment dedicated to GPDs

to select the leading order (twist−2)

factorization: Q^2 large, x_B fixed, t small(<1 GeV²)

DVCS:



Quark contribution Gluon contribution

HEMP:

selection of $\gamma^*_L \longrightarrow \rho^\circ_L$ by the angular distribution of the decay products + SCHC

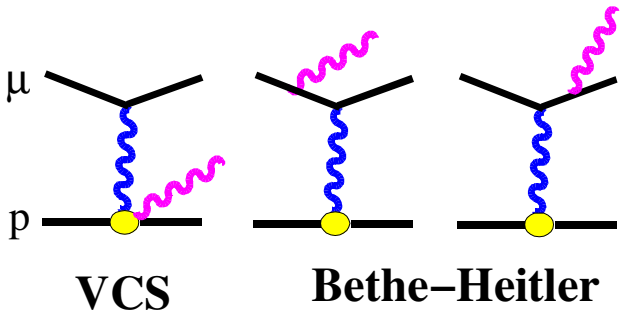
$\longrightarrow \pi^\circ$ by Rosenbluth separation

separation of quark flavors

Vector Meson $\rho^\circ_L, \omega_L, \Phi_L \longrightarrow H, E$

Pseudo Scalar Meson $\pi^\circ, \pi^\pm, \eta \longrightarrow \tilde{H}, \tilde{E}$

DVCS observables *at leading order*



If E_{Beam} is large: **DVCS >> Bethe–Heitler**

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

If not, we take advantage of **the DVCS–BH interference**:

- **Single spin asymmetry:**

$$\sigma^{\Uparrow} - \sigma^{\Downarrow} \sim H(\xi,\xi,t)$$

- **Beam charge asymmetry:**

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

complete information at the amplitude level

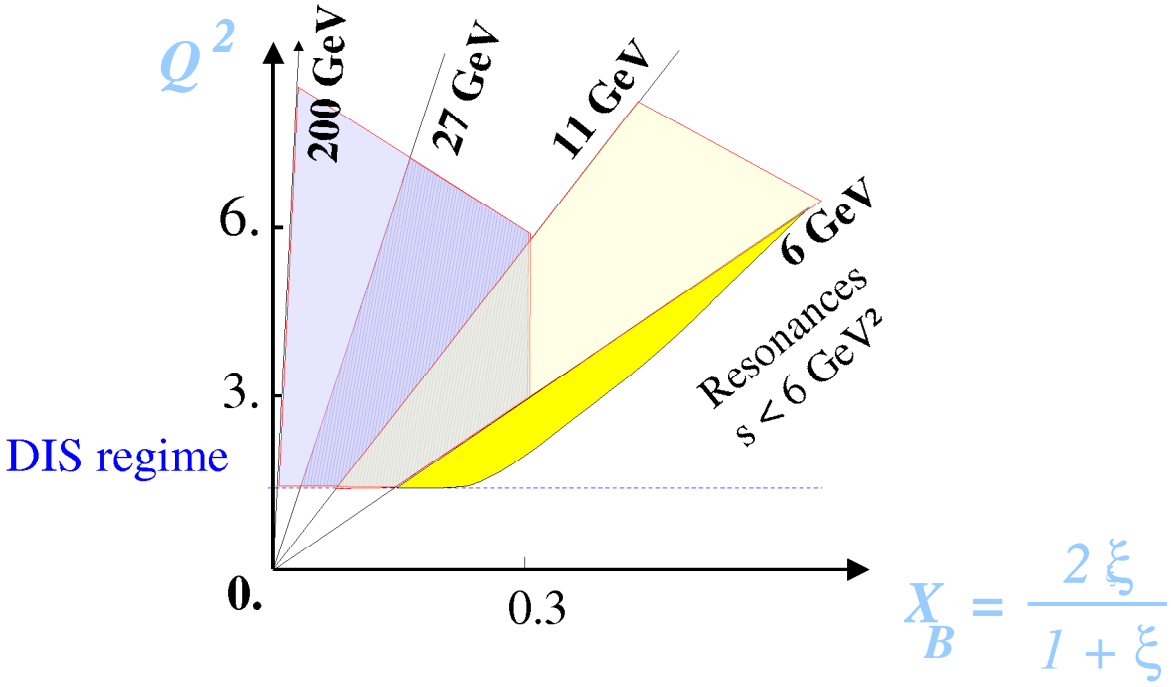
1. to control the twist–2 dominance and to disentangle the higher–twists we can use the **SSA** or the **BCA** and their **azimuthal angle** ϕ and Q^2 dependences.

(*Diehl et al., Belitsky et al.*)

2. to deconvolute and extract GPDs

we have to consider **models**.

Experimental Plans



Experiments:

at very small x_B : $0.0001 < x_B < 0.01$
Collider H1 & ZEUS

6–11 GeV Jlab
27 GeV HERMES

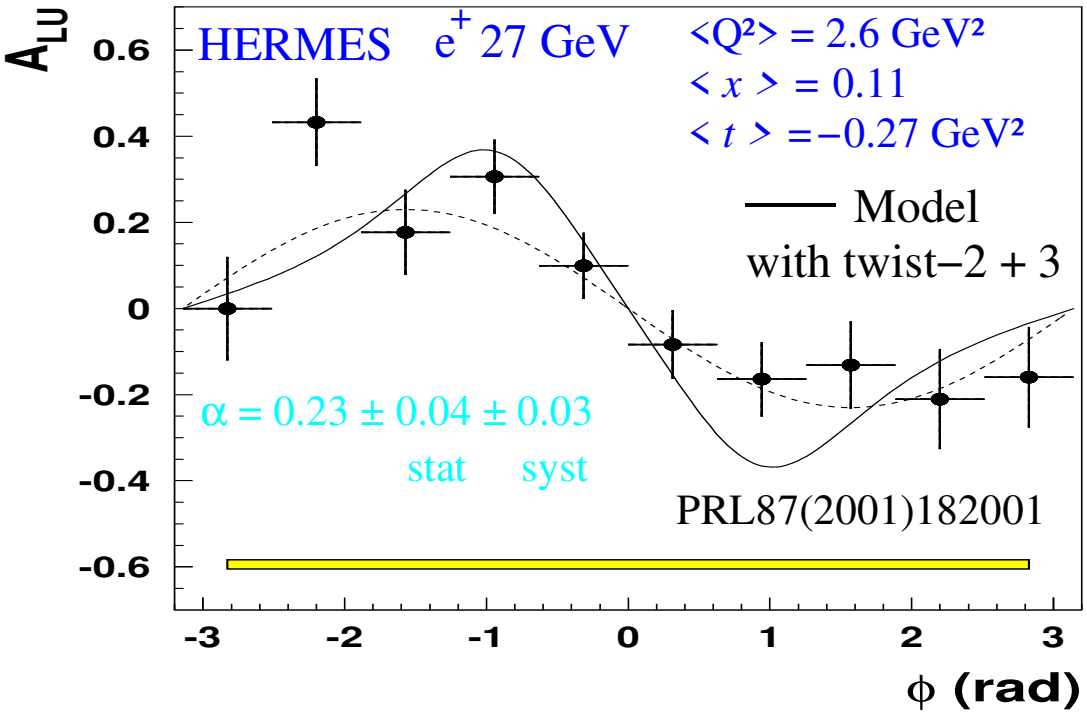
> 100 GeV COMPASS (≥ 2006)
large range in Q^2
large domaine in x_B
for valence and sea quarks and gluons

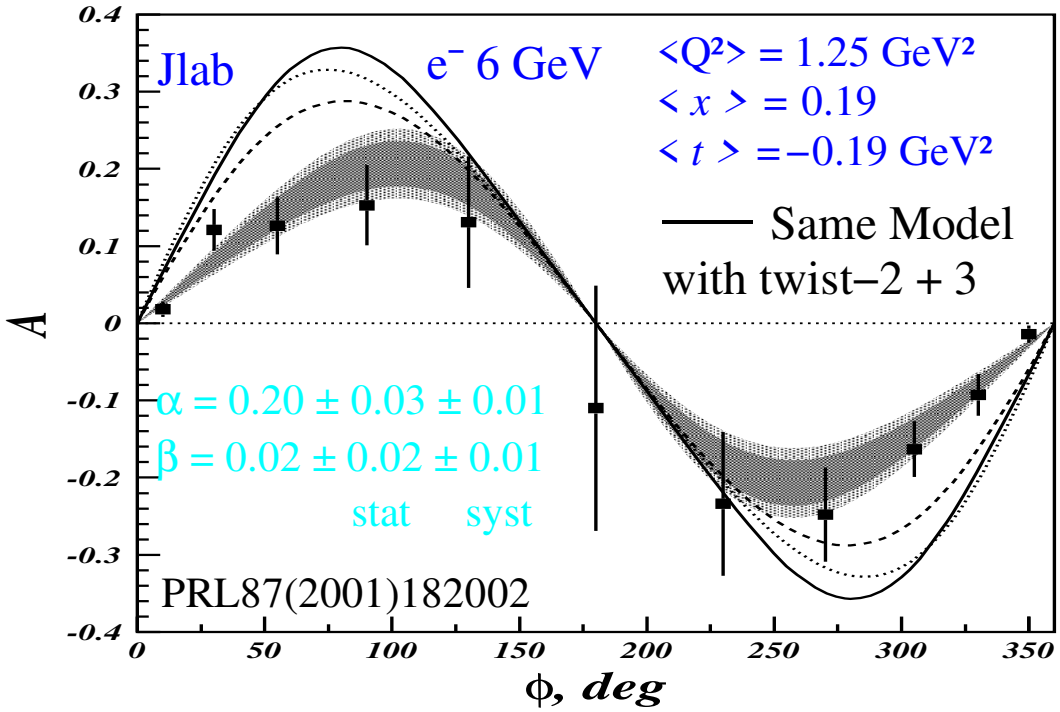
SSA measured at HERMES and JLab

$$\sigma^{\Uparrow} - \sigma^{\Downarrow} \propto \Im m T^{DVCS} \times T^{BH}$$
$$\propto a\ \Im m\tilde{M}^{11}\ sin\Phi + b\ \Im m\tilde{M}^{01}\ sin2\Phi + \mathcal{O}(1/Q^2)$$
$$\downarrow \qquad\qquad \downarrow$$
$$\text{twist } 2 + \ldots \qquad \text{twist } 3 + \ldots$$

$$SSA = \frac{\alpha\ sin\Phi + \beta\ sin2\Phi}{\sigma^{\Uparrow}+\sigma^{\Downarrow}}$$

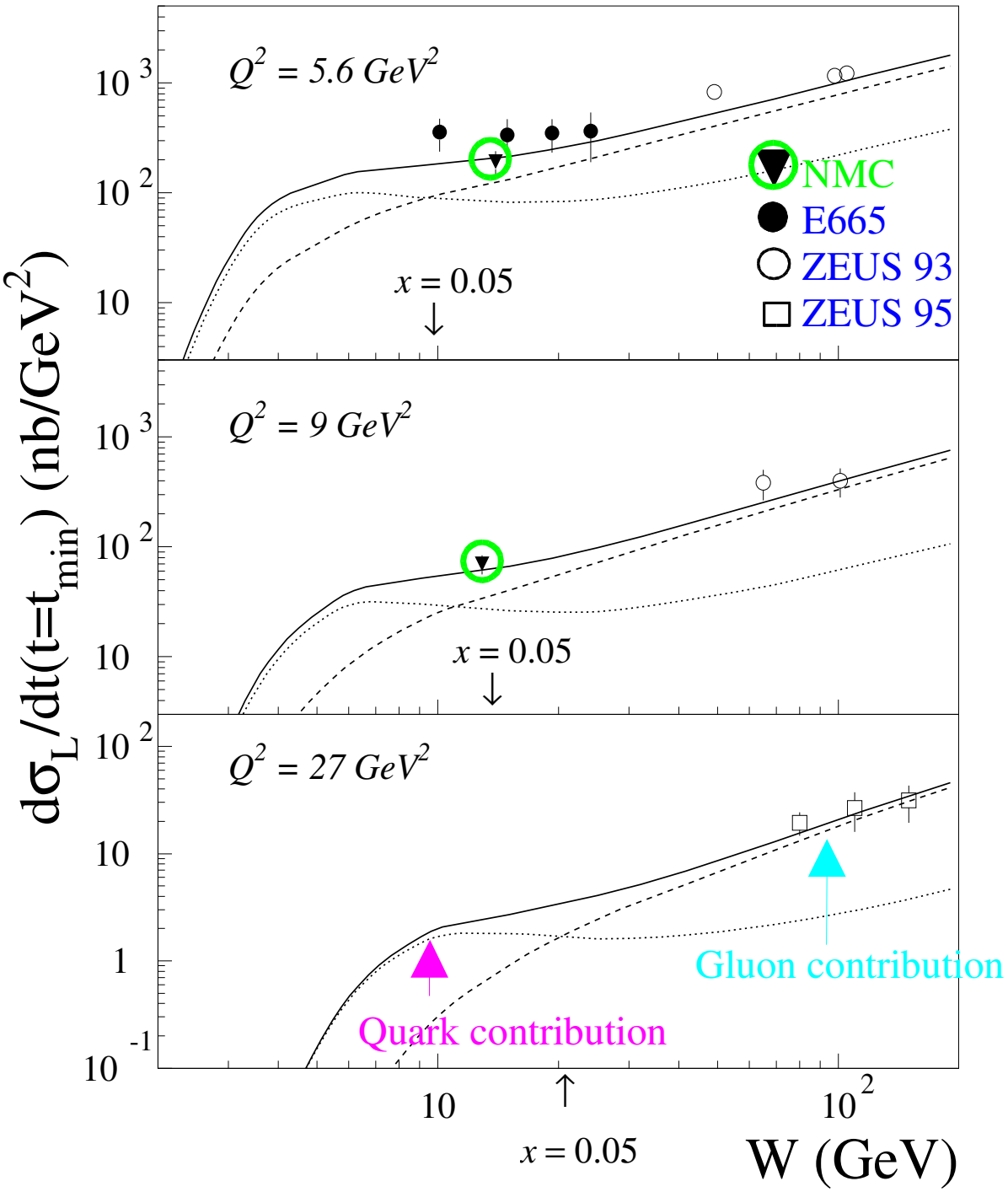
The twists can be disentangled with the Φ and Q^2 dependences





ρ_L^0 production

$$\gamma^* + p \rightarrow \rho_L^0 + p$$

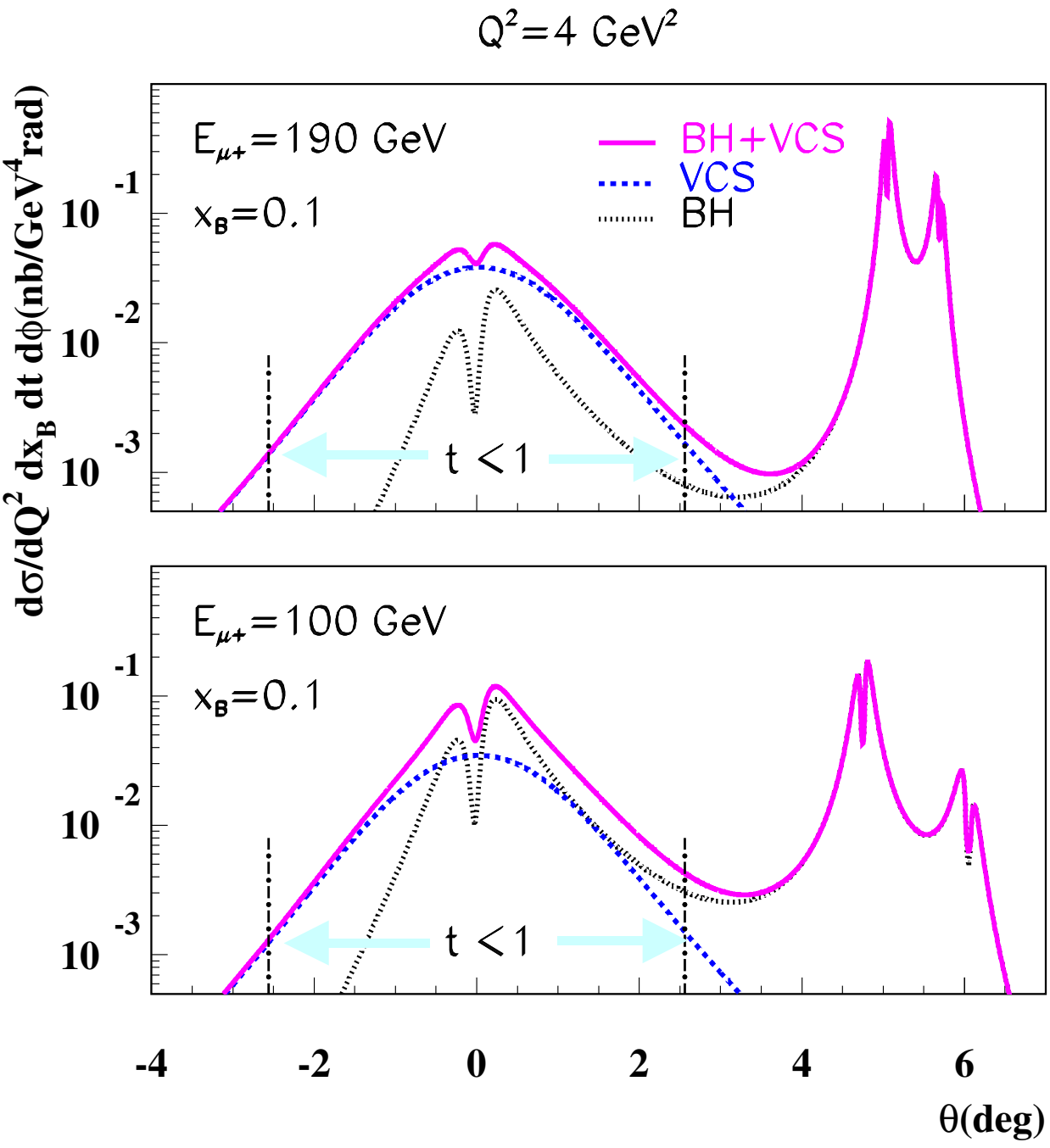


Expertise of NMC for absolute measurement of ρ_L° production

DVCS @ COMPASS

190 GeV is appropriate for cross section measurement

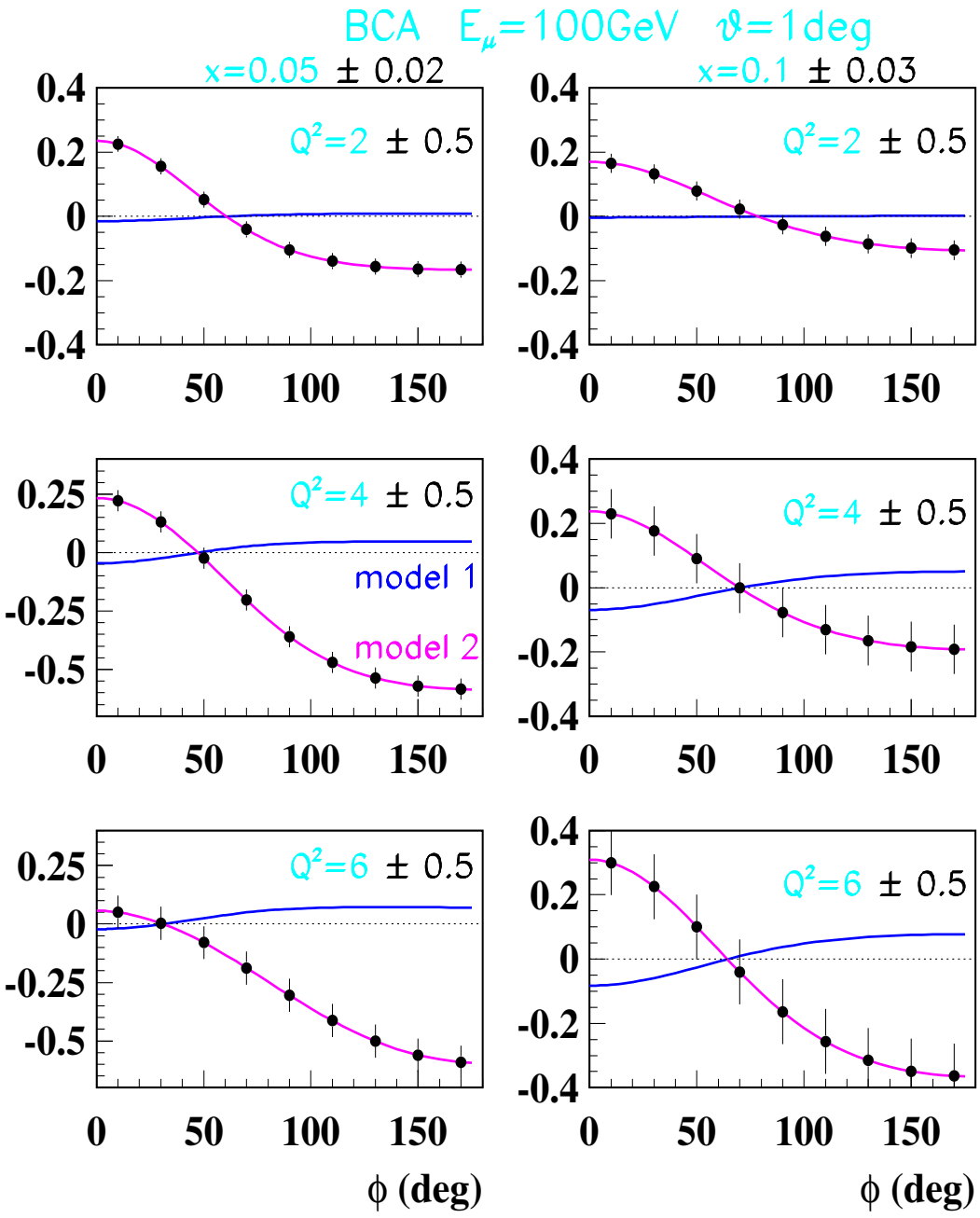
100 GeV is appropriate for Beam Charge Asymmetry



Predictions for BCA @ COMPASS

Model 1 traditional
Model 2 *t* evolution
correlated with *x*

Statistics reached in 6 months
with a global efficiency of 25%



(Mossé, Guichon, Vanderhaeghen)

What do we learn from models 1 and 2 ?

model 1 is based on general properties and symmetries

$H(x,\xi,t) = a(x,\xi)\, b(t)$

model 2 considers also that GPDs measure

➤ **the contribution of the quark q with momentum fraction *x* to the corresponding form factor**

as $\int dx\, H^q(x,\xi,t) = F_1^q(t)$

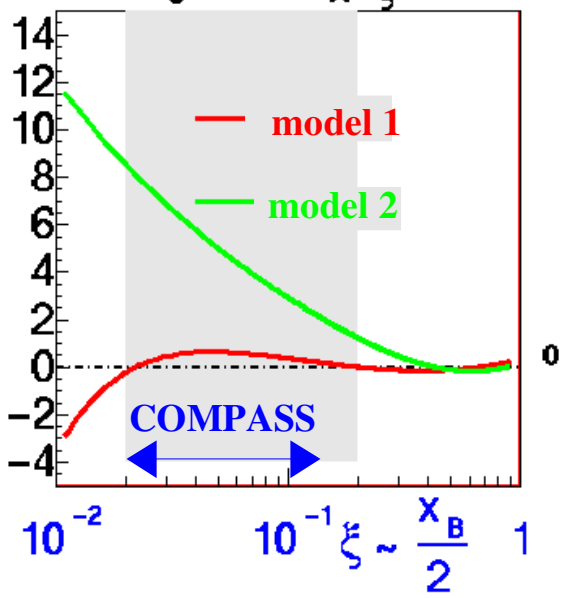
➤➤ **the Parton distribution in transverse position space**

when x ↘ spatial distribution ↗
small valence core; wider meson cloud

(Burkardt, Pire, Ralston)

transverse size ~ $\alpha \ln(1/x)$
x **and t correlated**

BCA ~ P($\int dx \frac{H(x,\xi,t)}{x-\xi}$)



x_B ↘ sensitivity ↗

range of COMPASS

(Mossé, Guichon, Vanderhaeghen)

2. General Requirements

Luminosity

$N\mu = 2.10^8\ \mu$ per SPS cycle (RadioProtection limit)

duration 5.2s repetition each 16.8s

with the present 1.2m ^{6}LiD or NH_3 target $\rightarrow \mathscr{L} = 5.10^{32}\ cm^{-2}s^{-1}$

with a future 2.5m liquid H_2 target $\rightarrow \mathscr{L} = 1.3\ 10^{32}\ cm^{-2}s^{-1}$

$\Rightarrow$ necessity of a 'long' liquid Hydrogen target

Precise absolute Luminosity measurement

with NMC it has been achieved within a 1% accuracy

The integrated muon flux is measured continously by 2 methods

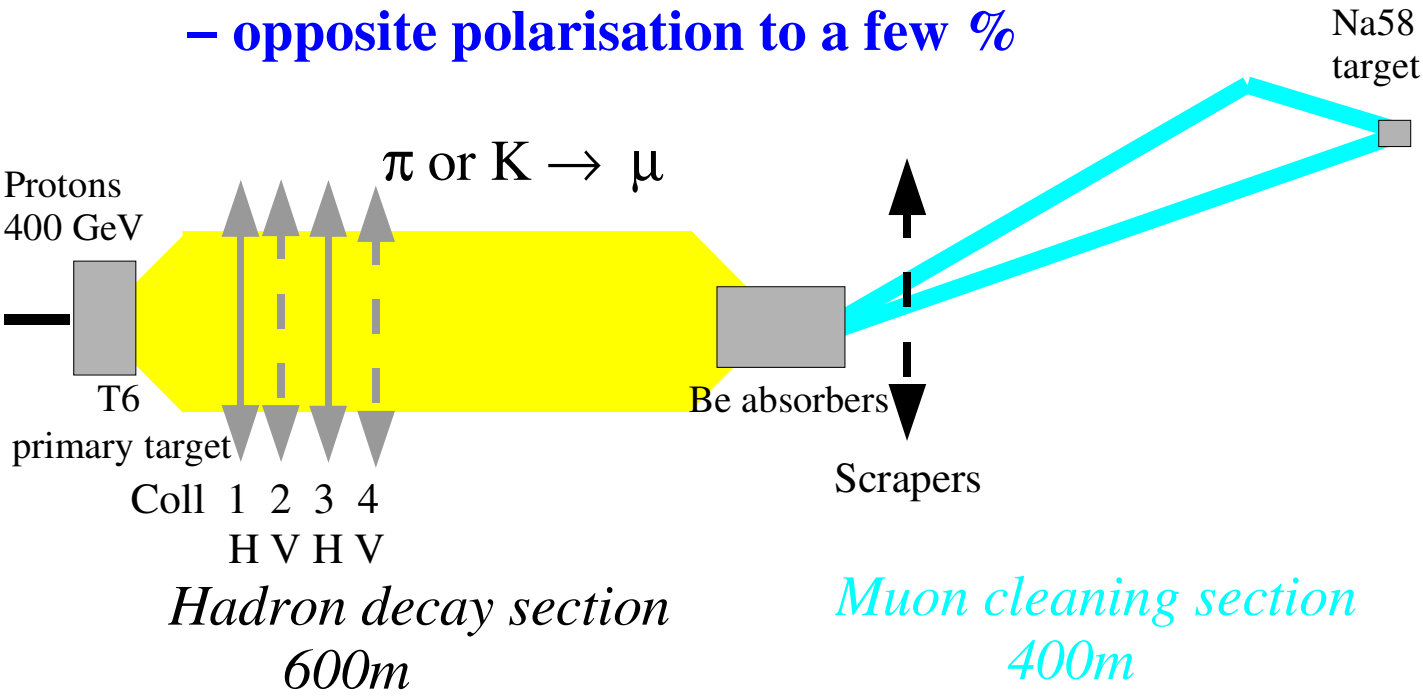
1) by sampling the beam with a random trigger (α emitter Am 241)
2) by sampling the counts recorded in 2 scint. hodoscope planes used to determine incident beam tracks.

The beam tracks are recorded off–line, as the scattered muon tracks to determine the integrated usable muon flux

μ^+ and μ^- beams

Requirements :

- **same energy**
- **same and maximum intensity**
- **opposite polarisation to a few %**



Hadron decay section
600m

Muon cleaning section
400m

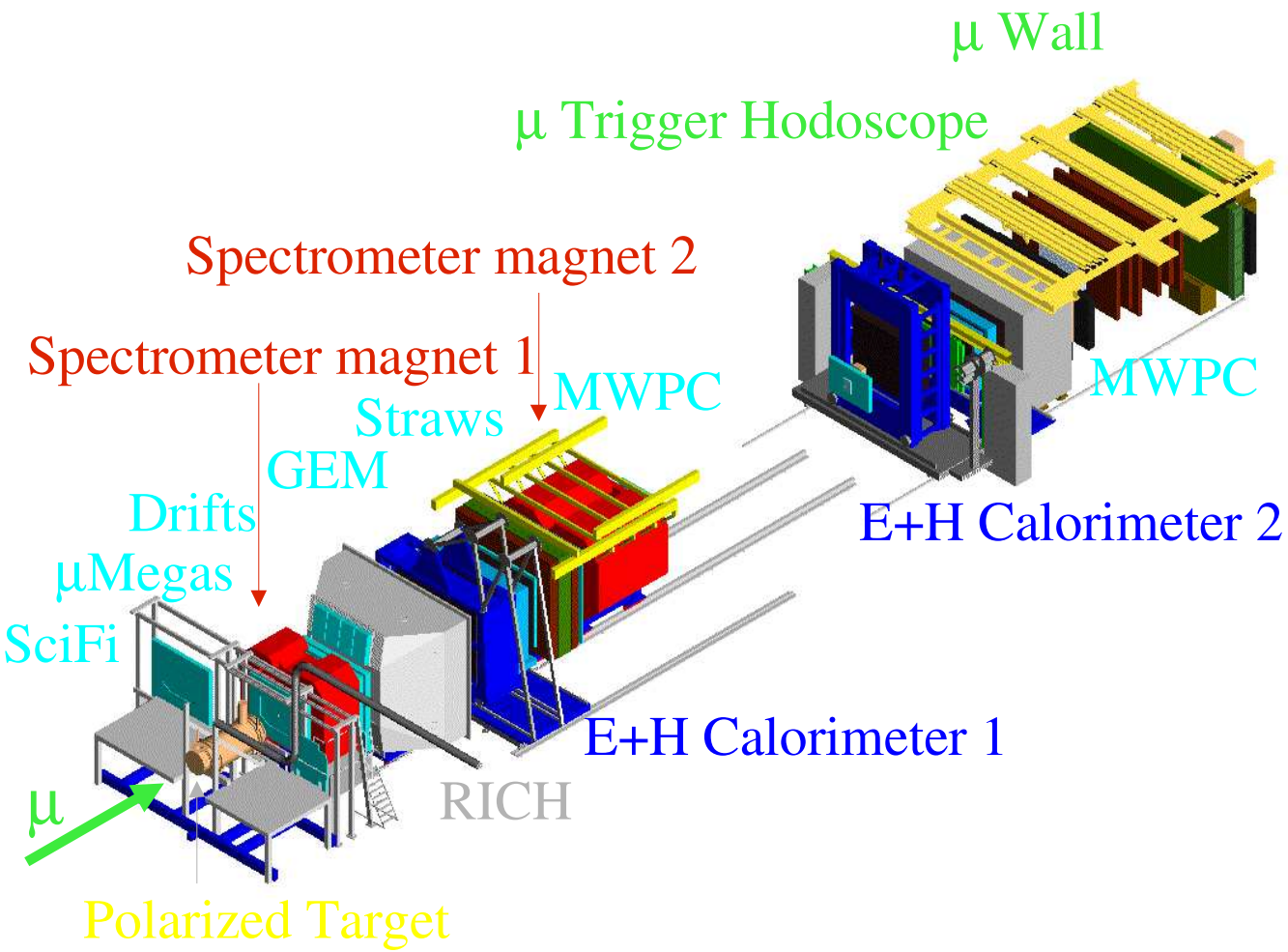
Solution (*cf. Lau Gatignon*):

– to select $P\pi = 110$GeV and $P\mu = 100$GeV
to maximise the muon flux

–to keep the collimator settings which define the π and μ momentum spreads constant
(fixed Coll 1H and 3H and Scrapers 4V and 5V)
→ Pol $\mu+ = -0.8$ and Pol $\mu^- = +0.8$

–to fix $N\mu^- \sim 2.10^8$ per cycle with the 500mm Be T6 target
–to use a shorter target to find $N\mu+ \sim 2.10^8$ per cycle

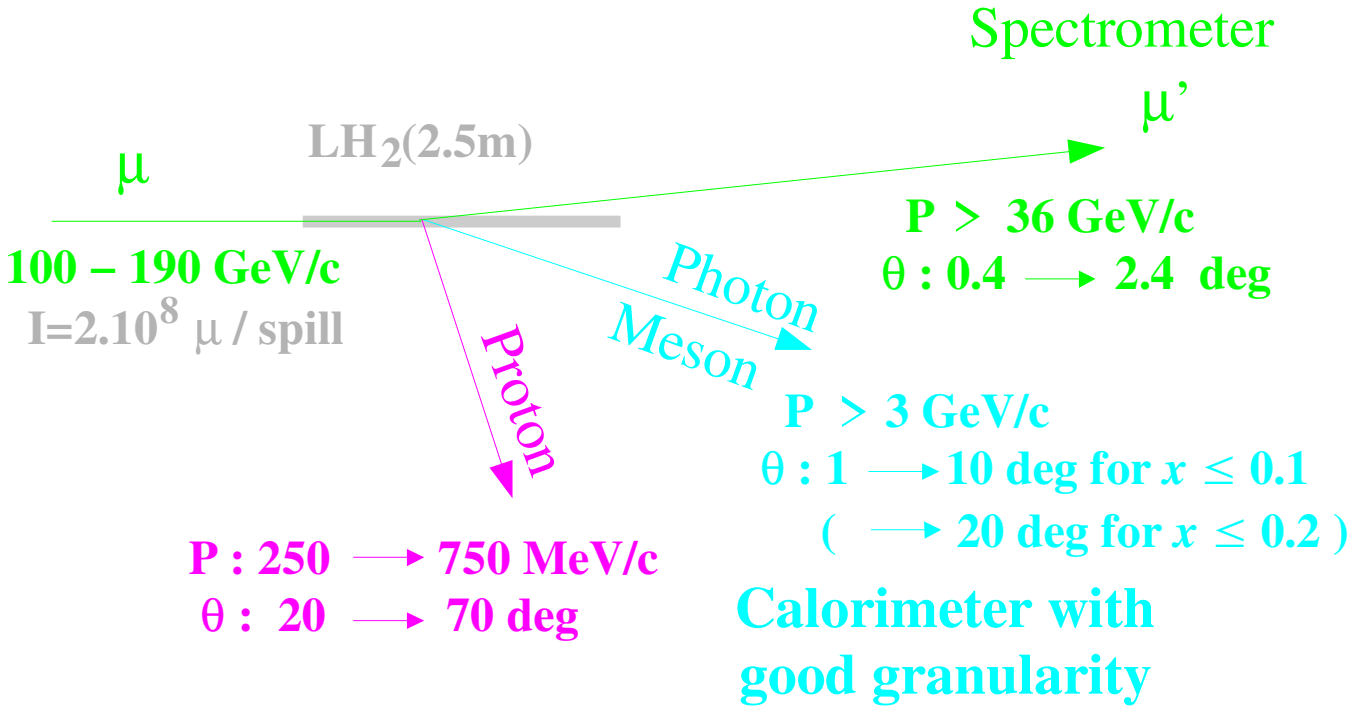
The COMPASS spectrometer in 2002



θ scattered particles ≤ 180mrad (Oxford magnet)
or 70mrad (SMC magnet)

Experimental Constraints for DVCS and HEMP @ COMPASS

$Q^2 \geq 1.5$ GeV^2 and $t \leq$ 1 GeV^2



At these energies (for μ, μ' and γ)
the missing mass technique is not adapted

$$\Delta M^2_{required} = (m_p + m_\pi)^2 - m_p^2 = 0.25\ GeV^2$$

$$\Delta M^2_{observed} > 1\ GeV^2$$

Need a dedicated recoil / proton detector

3. A pragmatic solution with the present COMPASS setup

Hard Exclusive Meson Production

$$\mu\ N \rightarrow \mu\ N\ \rho^{\circ}$$

$$\mu\ N \rightarrow \mu\ N\ \pi^{\circ}$$

Good expertise of exclusive ρ° production in the NMC and SMC experiments

Data during the first main μ runs

Constraints and Limits of these experiments

Present polarized target ^{6}LiD or NH_3
$\rightarrow$ coherent + quasi–free production

Need precise Luminosity determination
(already performed for NMC)

Scattered μ and final particles detected
in the COMPASS spectrometer

θ **charged or neutral particles** $\leq$ 180 mrad

DIS muon trigger:
1) **medium Q^2 (MT)**
2) **full range in Q^2 (FT)**

Selection of ρ°_{L} by the angular distribution of the decay product

No Rosenbluth separation for π°

No recoil detector

Experimental Method at 190 (100) GeV

$\rho^\circ \rightarrow \pi^+\pi^-$

1) $2 < Q^2 < Q^2_{max}$
$35(20) < \nu < 170(90)$GeV

2) $\mu\ \mu'$ + only 2 charged particles of same vertex

3) identification of 2 π in the RICH

4) $P_\pi > 2$ GeV/c

5) selection of exclusive events

cut on inelasticity
$-0.05 < I < 0.05$

cut on the invariant mass of 2π
$0.62 < M_{\pi\pi} < 0.92$

$\pi^\circ \rightarrow \gamma\gamma$

1) $1 < Q^2 < Q^2_{max}$
$15(10) < \nu < 170(85)$GeV

2) $\mu\ \mu'$ + only 2 γ

3) identification of 2 γ
in ECAL2 $0.4^\circ \rightarrow 2^\circ$
in ECAL1 $2^\circ \rightarrow 10^\circ$

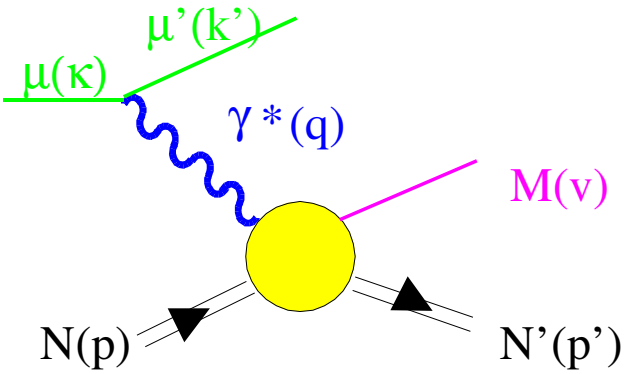
4) $P_\gamma > 2$ GeV/c

5) separation of 2 tracks at the entrance of ECALs
$d > 4$ cm

Stronger constraints on charged channels

$\mu p \rightarrow \mu p \rho^{\circ}$

$\hookrightarrow \pi^{+}\pi^{-}$



$$W^2 = (p+q)^2$$

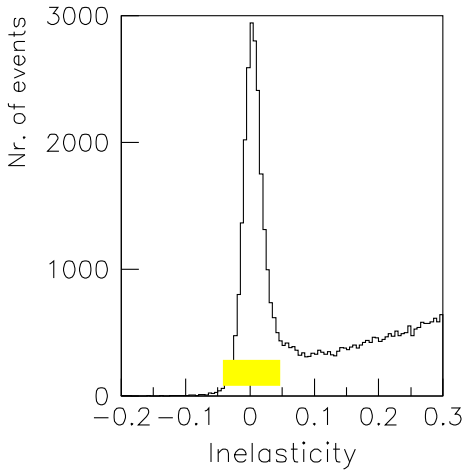
$$Mx^2 = (p+q-v)^2$$

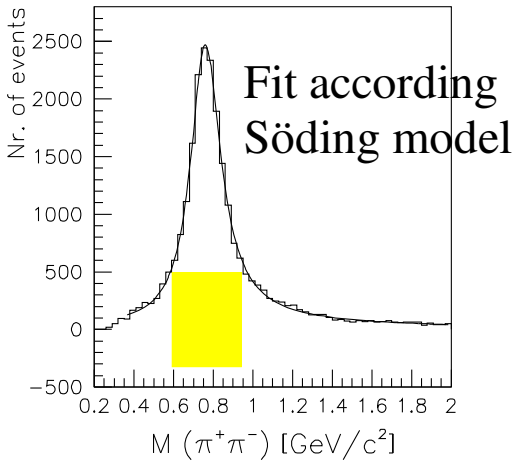
Inelasticity

$$I = \frac{Mx^2 - Mp^2}{W^2}$$

Invariant Mass

$M\pi^{+}\pi^{-}$





Data SMC 1995 A.Tripet et al. NPB, ps79

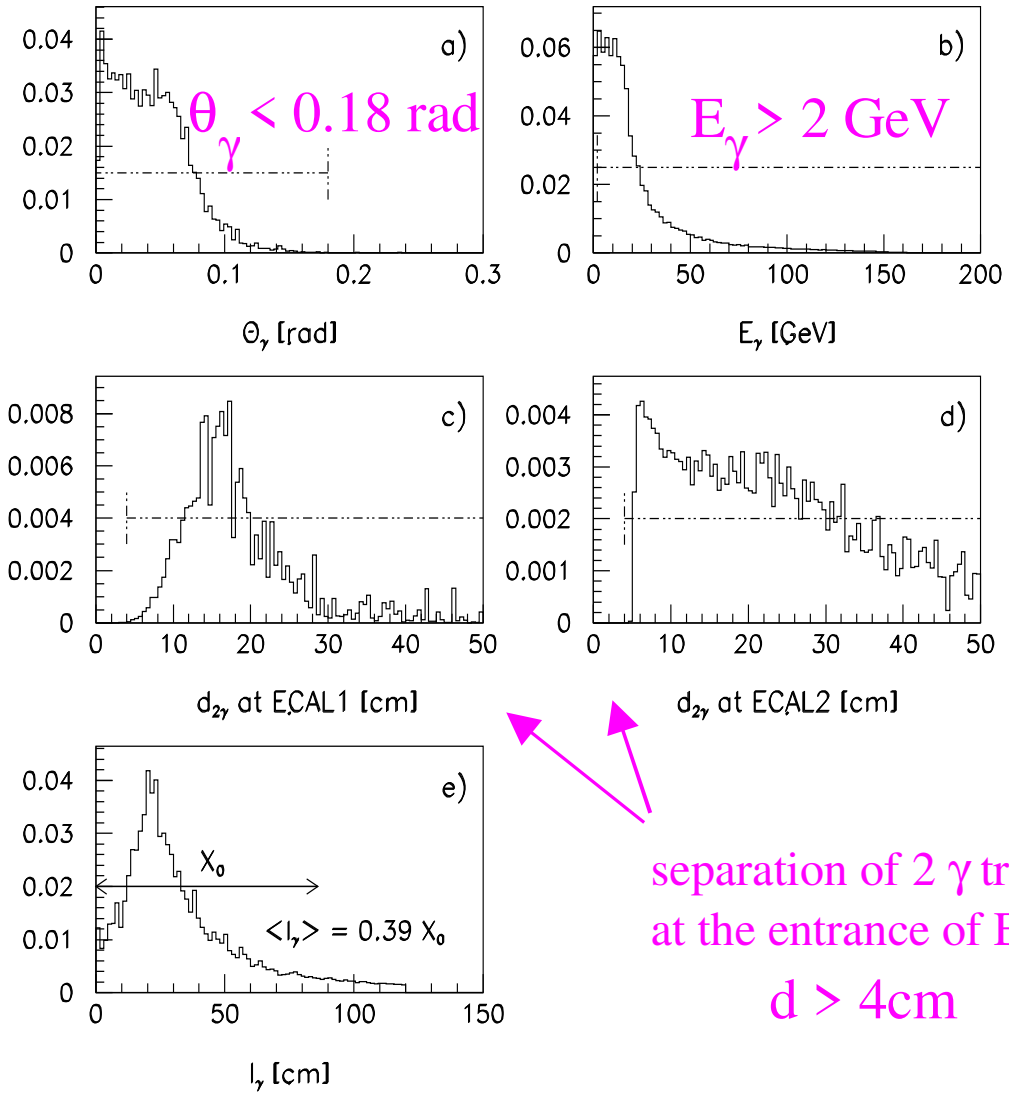
10% of background for SMC

$\mu p \rightarrow \mu p \pi^{\circ}$

$\hookrightarrow \gamma\gamma$

γ angular distribution

γ energy distribution



separation of 2 γ tracks
at the entrance of ECALi

$d > 4$cm

Length of the potential path of
the γ within the target of χ_0

The calorimeters are key elements for this reaction

Simulation and Efficiencies at 190 (100) GeV

Event generator

ρ° : traditional parametrization on NMC data

π° : 2 models with GPDs

Second interactions of decay $\pi\pm$ and γ in the target

Kinematical smearing based on experimental resolution

Acceptance for μ , $\pi\pm$, γ

ρ° $\quad$ ε sec int $\times$ ε 3 tracks $\times$ ε 2 π accept $\times$
ε cut in M$\pi\pi$ $\times$ ε μ trig accept = 0.21 (0.04) with MT
0.36 (0.30) with FT

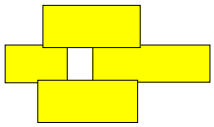
π° $\quad$ ε sec int $\times$ ε 2 γ accept $\times$ ε μ trig accept ~ 0.30

Counting Rates (even with the MT)
in 150 days with a global SPS+COMPASS efficiency of 25%

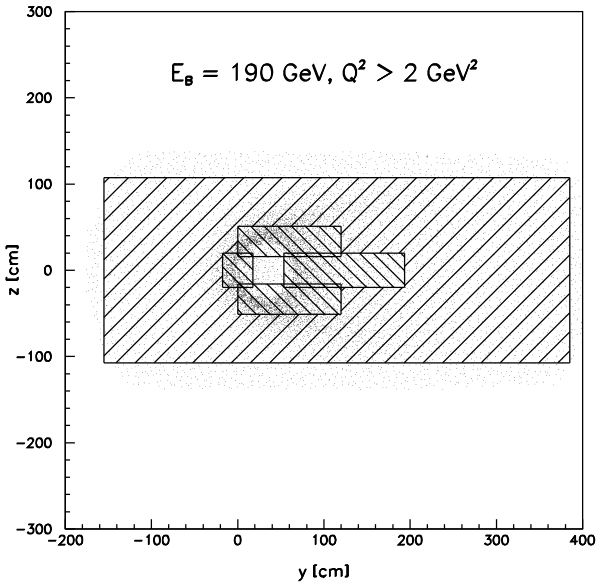
	190 GeV	100 GeV	
σ DIS	48 nb	38 nb	
σ ρ°	286 pb	246 pb	$< Q^2 > \sim 2.9$
N ρ° (~ 1.5 Nρ°_L)	97 K	15 K	$< x > \sim 0.034$
σ π°	1.3 to 5.2 pb	5.8 to 23 pb	$< Q^2 > \sim 1.6$
N π°	625 to 2500	1860 to 7440	$< x > \sim 0.04$

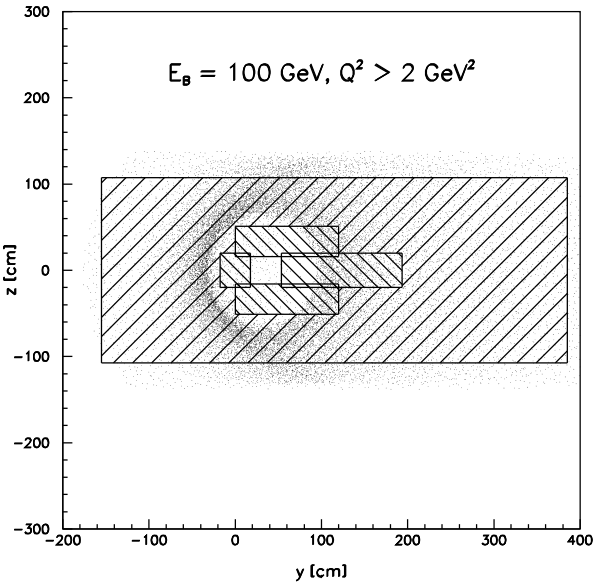
Muon Trigger Acceptance

MT: Medium Q^2



FT: Full Range Q^2



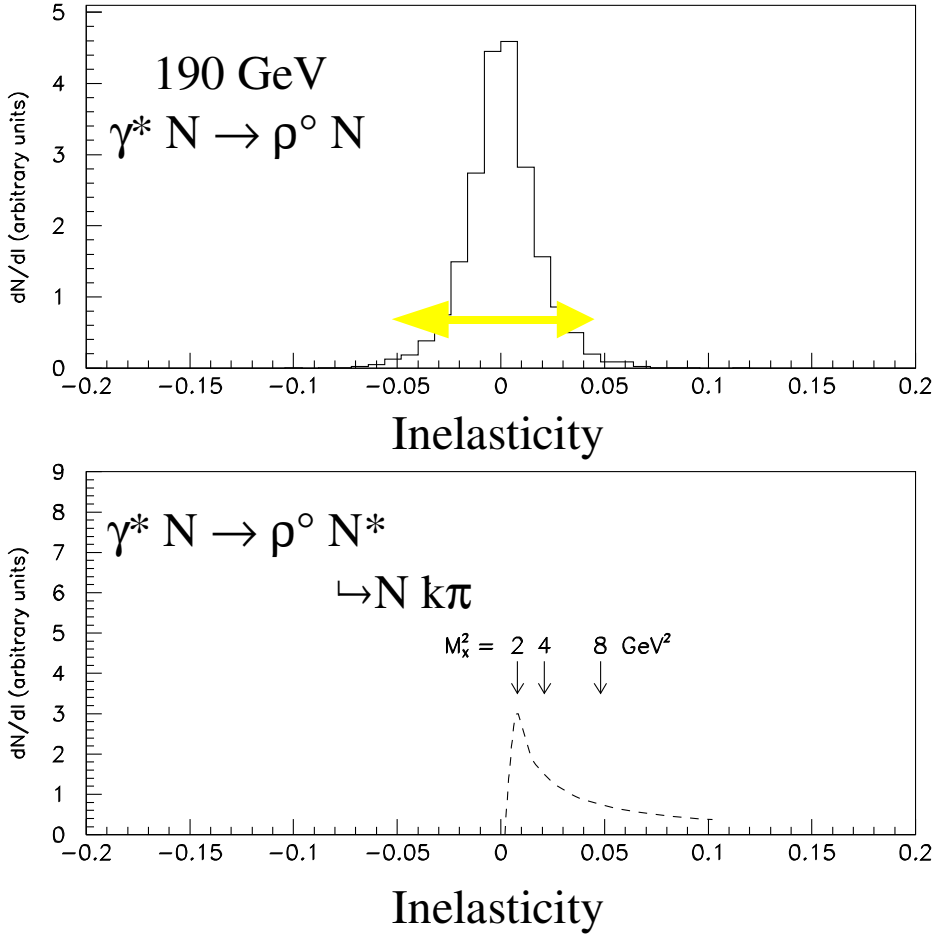


when E μ ↘ θμ min (Q^2 min) ↗

at 100 GeV necessity of the FT

Background Studies

1) From diffractive dissociation of the target



Poor separation ⇒ background ~ 20%

2) From DIS

LEPTO+JETSET + 5000 evts + beam halo

→ 9 evts in Mππ cut

→ 1 evt in the ΔI range

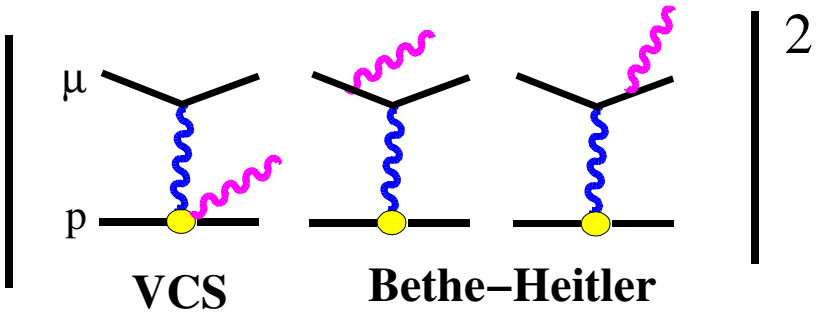
but this evt is μ N → μ ρ° N*

→ 0 evt ↪ π+ n

⇒ (at 90% confidence level) background ≤ 20%

4. DVCS and competing reactions

DVCS =



Hard Eclusive π° production

$$\mu\, p \rightarrow \mu\, p\, \pi^{\circ}$$
$$\hookrightarrow \gamma\, \gamma$$

Dissociation of the proton

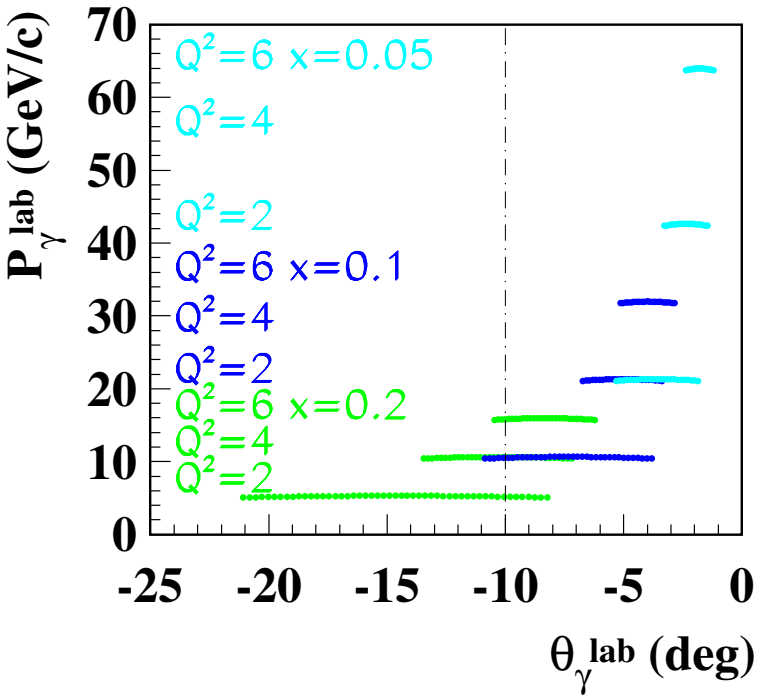
$$\mu\, p \rightarrow \mu\, N^{*}\, \gamma$$
$$\hookrightarrow N\pi$$

Deep Inelastic Scattering

$$\mu\, p \rightarrow \mu\, p\, X$$
with 1γ, $1\pi^{\circ}$, $2\pi^{\circ}$, η...

Beam halo with hadronic contamination
Beam pile–up
Secondary interactions
External Bremsstrahlung

Key role of the Calorimeters



ECAL2: from 0.4° to 2°
ECAL1: from 2° to 10°

Characteristics of ECAL1 and ECAL2
mainly lead–glass GAMS
cell size 38.4× 38.4 mm²

–energy resolution: $\sigma E / E = 5.5 / \sqrt{E} + 1.5$ [%]

–position resolution: $\sigma x = 6.0 / \sqrt{E} + 0.5$ [mm]

–two photon separation: 100% for $r\gamma\gamma \geq 40$mm

–high rate capability: 90% of signal within 50ns, no dead time

–effective light yield: about $1\gamma e^-$ /MeV

low energy γ detection as 20MeV

How to maximise DVCS/ DIS for an ideal experiment?

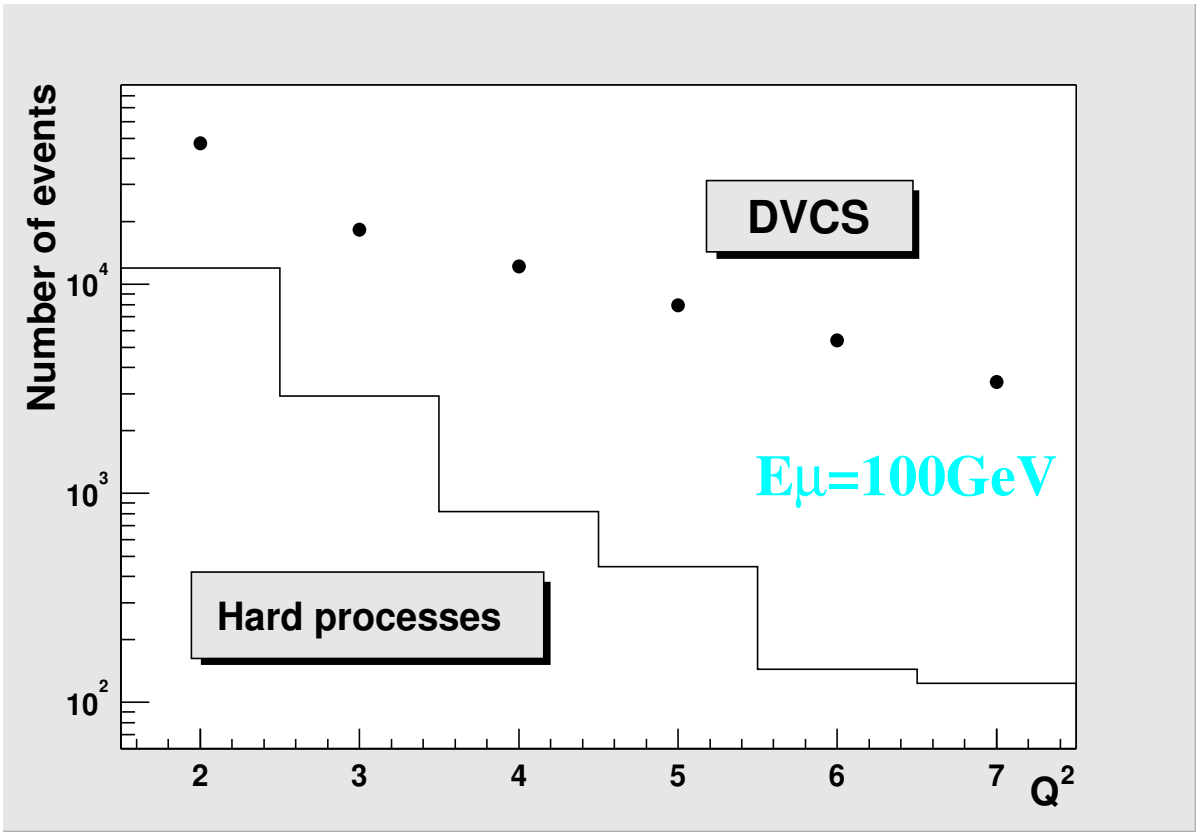
Goal : which processes can mimic DVCS ?

p π°, p $\pi^\circ \pi^\circ$, p η ...

Use Pythia 6.1 which contains up–to–date γ^* – p cross section

Tune parameters :

- maximum angle for photon detection **24 deg**
- threshold for photon detection **50 MeV**
- maximum angle for charged particle detection **40 deg**



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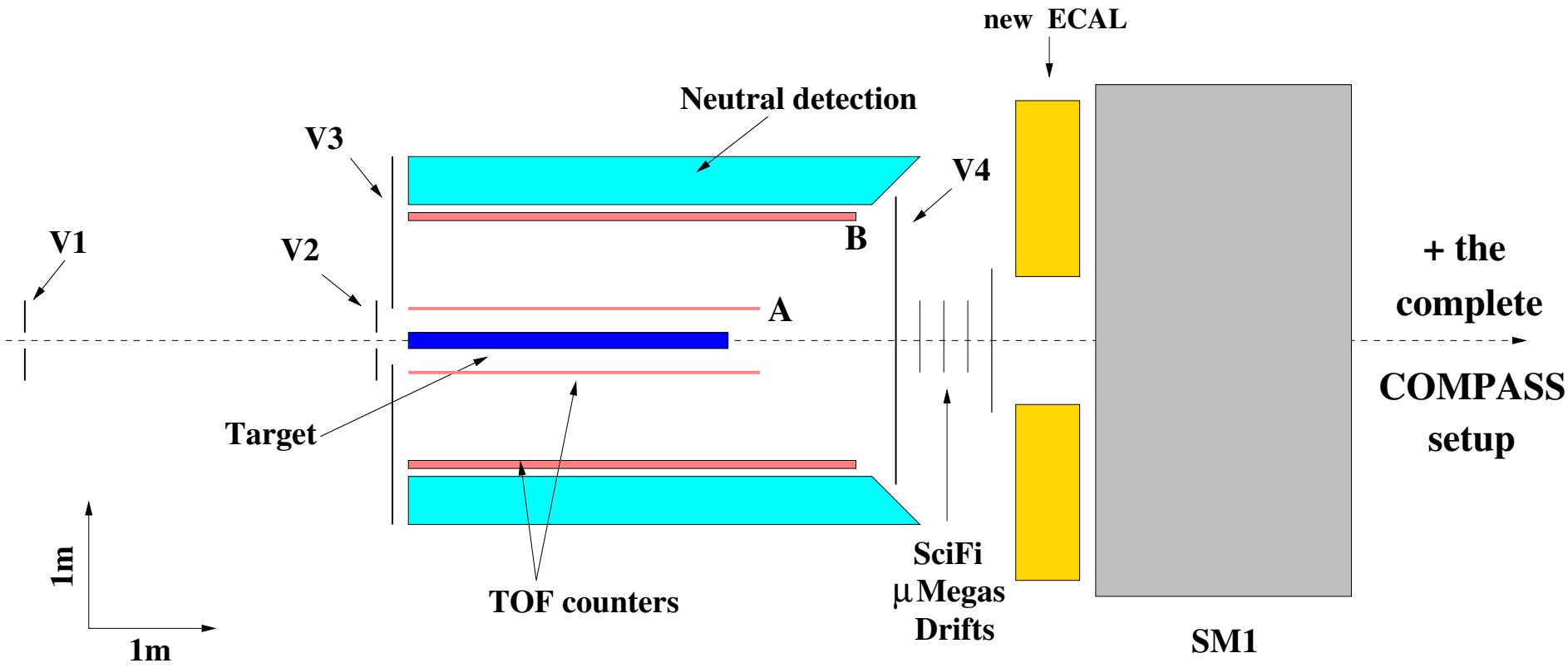
One possible solution to study further



Recoil Detector

Proton Detection:

- Identify and measure β of protons:

$$270 < P < 750 \text{ MeV/c}$$

for target ϕ = 3cm
walls 3mm equiv. scint.
scint. A 4mm

for separation
proton/ pion

$t\ min \geq 0.07\ \text{GeV}^2$

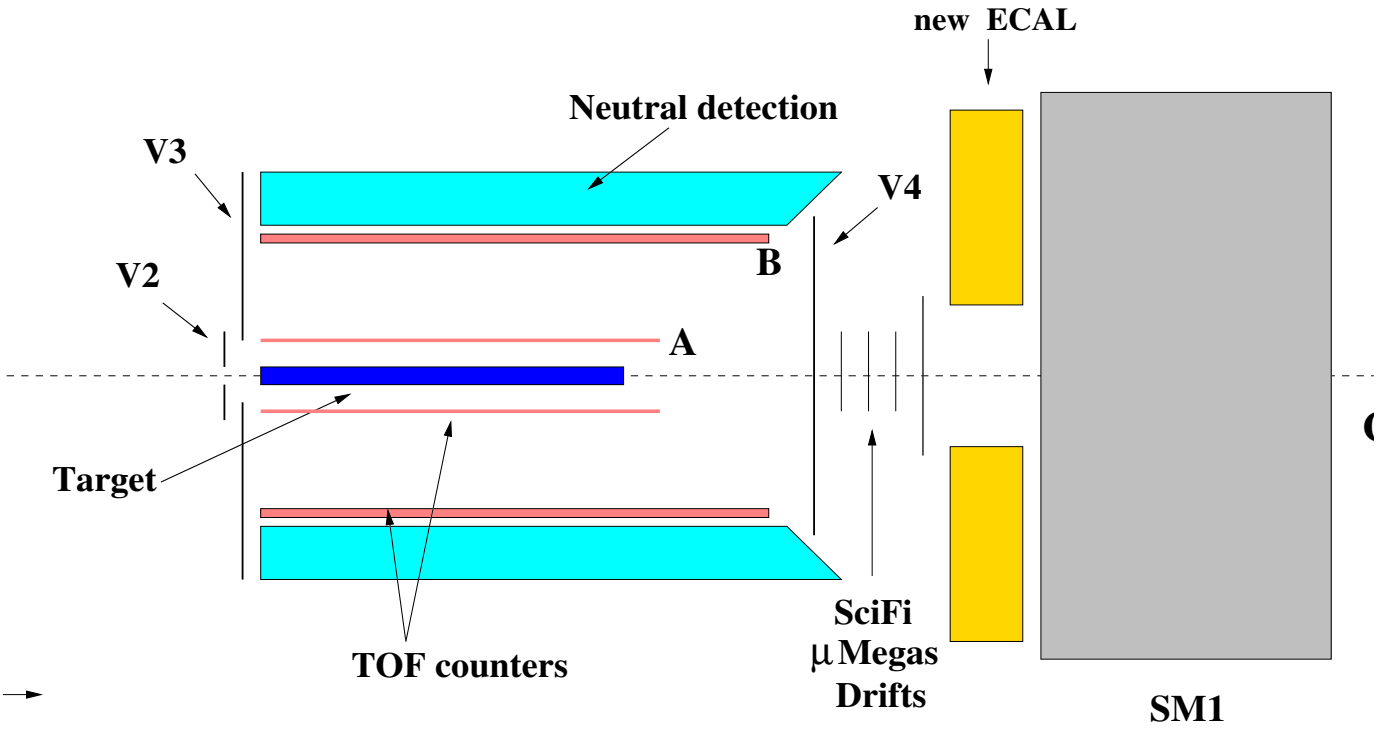
- Expected and measured resolutions:

σ *position* ~ 2 cm
σ *tof* ~ 340 ns

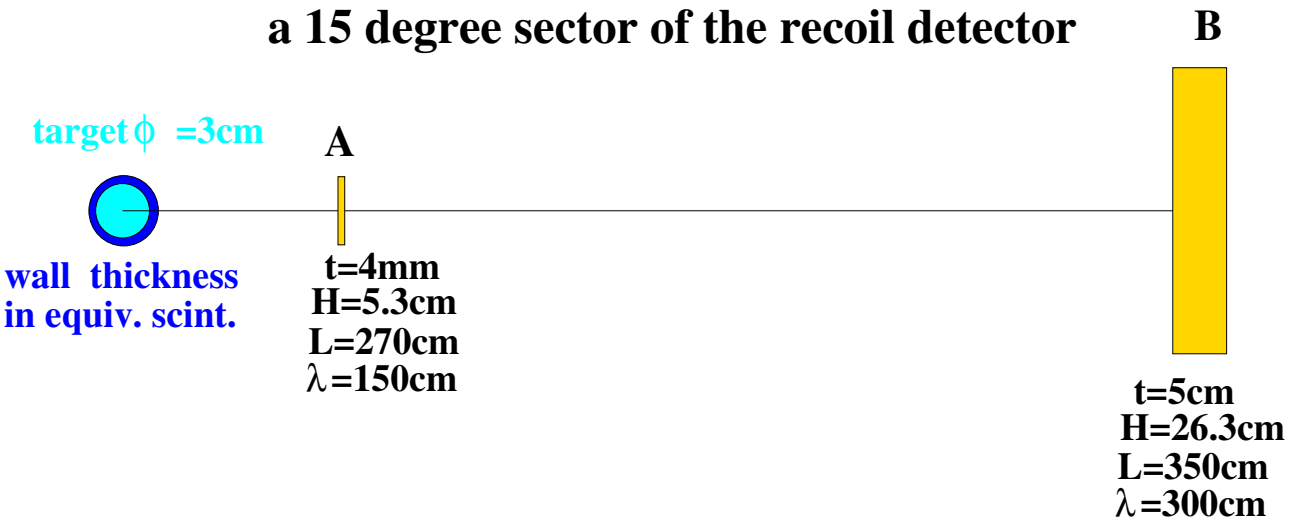
→ $\sigma P / P$: 0.03 – 0.1
$\sigma t / t$: 0.06 – 0.2

Global Properties:

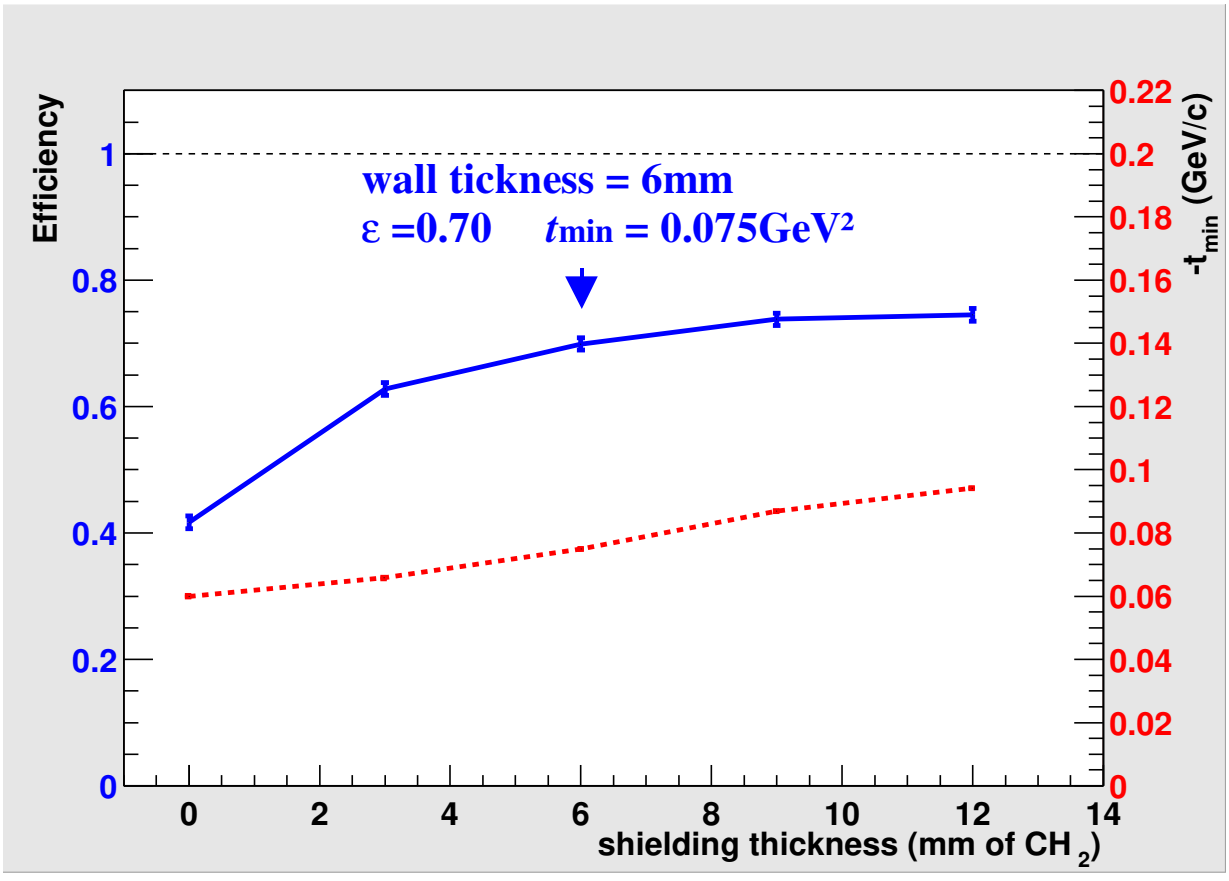
- Identify neutrals $\Delta^+ \rightarrow n\,\pi^+$, $p\,\pi^0 \rightarrow p\,\gamma\,\gamma$
- Be large and hermetic
- Do this in high rate environment



Efficiency of such a TOF recoil detector



Simulation with GEANT which takes into account
–the complete answer of scintillators with their attenuation length
–the large background of Möller e^-



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Counting Rates in 6 months
with a global SPS+COMPASS efficiency of 25%

for $\theta\gamma < 10°$ and $t < 0.64$ GeV²

Eμ=190 GeV

	x=0.05 ± 0.02	x=0.10 ± 0.03	x=0.20 ± 0.07
Q²= 2+0.5	N= 10058	N=8897	N=2000
Q²= 3+0.5	N= 3860	N=2540	N=1300
Q²= 4+0.5	N= 2058	N=1136	N= 600
Q²= 5+0.5	N= 1472	N= 677	N= 520
Q²= 6+0.5	N= 875	N= 459	N= 357
Q²= 7+0.5	N= 642	N= 299	N= 242

Eμ=100 GeV

	x=0.05 ± 0.02	x=0.10 ± 0.03	x=0.20 ± 0.07
Q²= 2+0.5	N= 13670	N=9921	N=4300
Q²= 3+0.5	N= 5933	N=3200	N=2000
Q²= 4+0.5	N= 4532	N=1537	N= 770
Q²= 5+0.5	N= 3000	N= 995	N= 600
Q²= 6+0.5	N= 1806	N= 885	N= 499
Q²= 7+0.5	N= 810	N= 870	N= 352

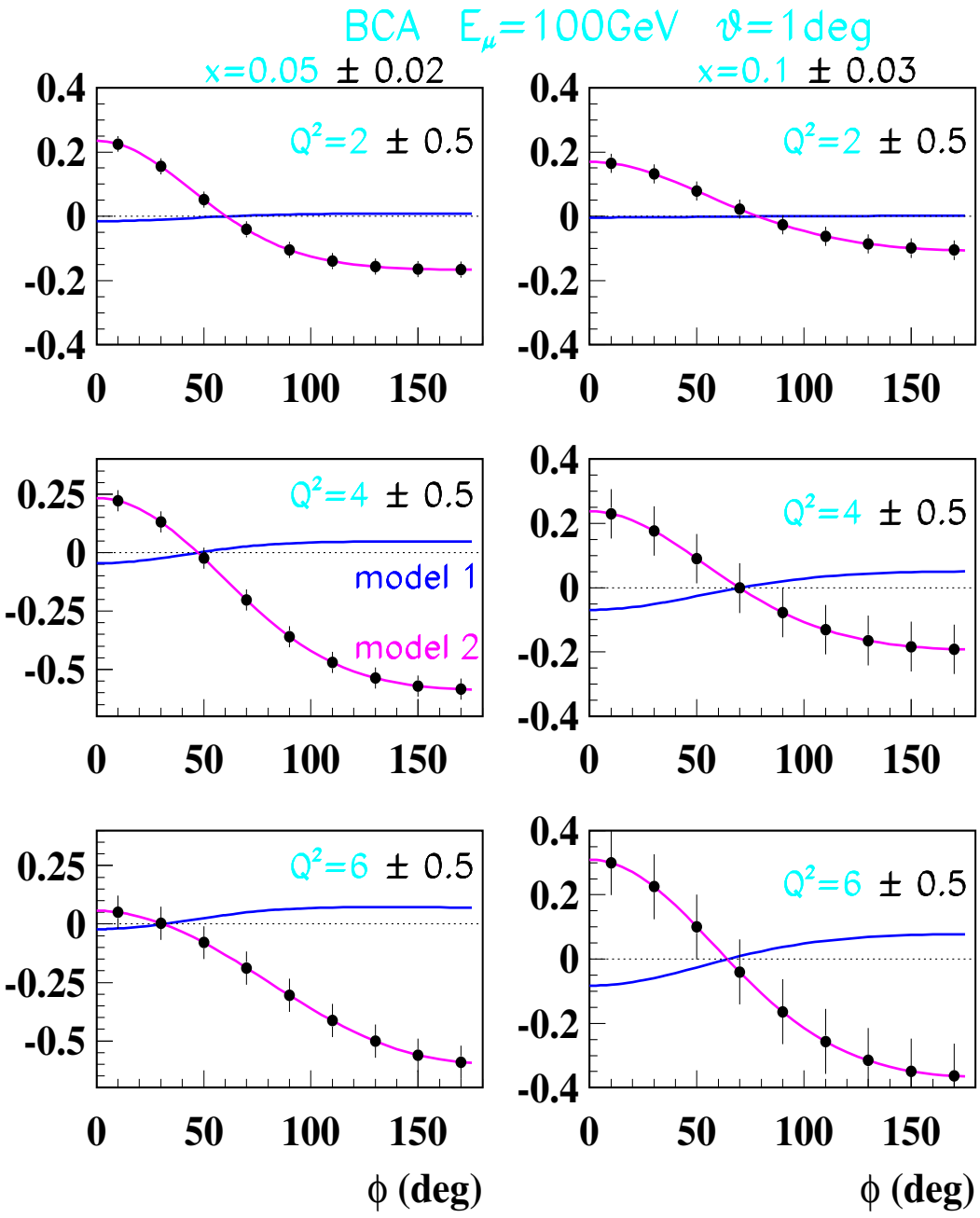
9 bins in ϕ × 2 bins in t

presentation of this statistics as a function of ϕ for the BCA

Predictions for BCA @ COMPASS

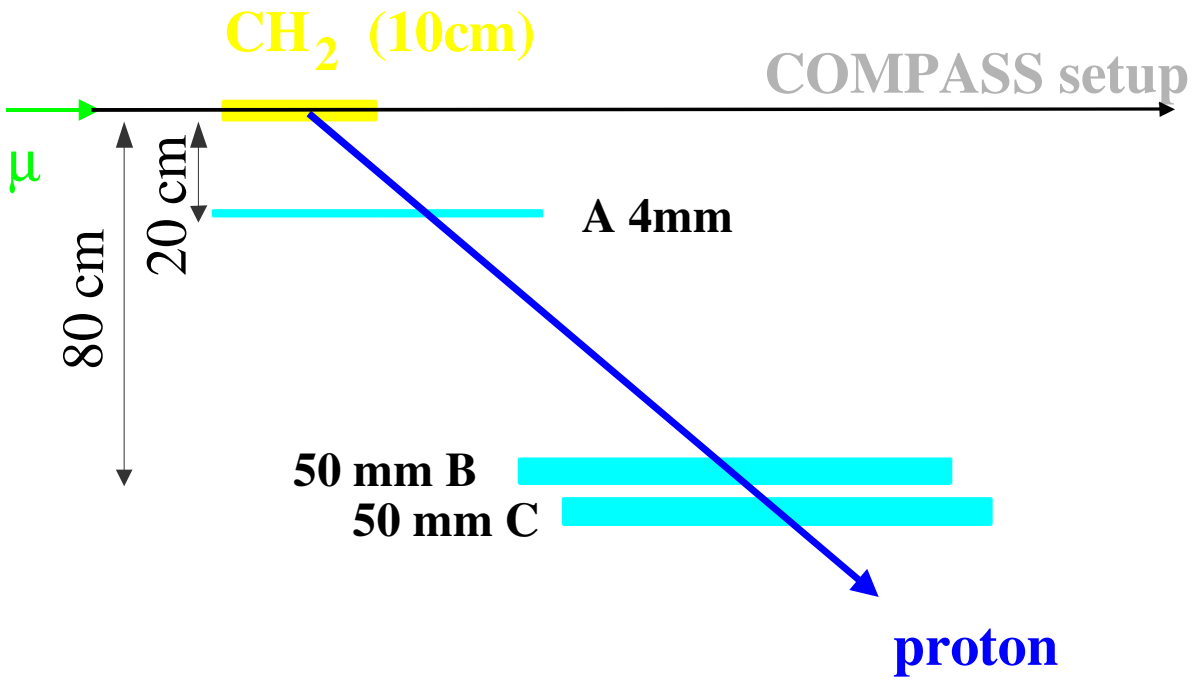
Model 1 traditional
Model 2 *t* evolution
correlated with *x*

Statistics reached in 6 months
with a global efficiency of 25%



(Mossé, Guichon, Vanderhaeghen)

Tests at CERN in 2001



Identification :

Time of flight : $\beta = L_{AB} / tof$

ΔE_A and ΔE_B

CH_2 Target : L=10 cm ϕ = 3cm

350 < P < 470 & 470 < P < 750 MeV/c

protons stopped in B

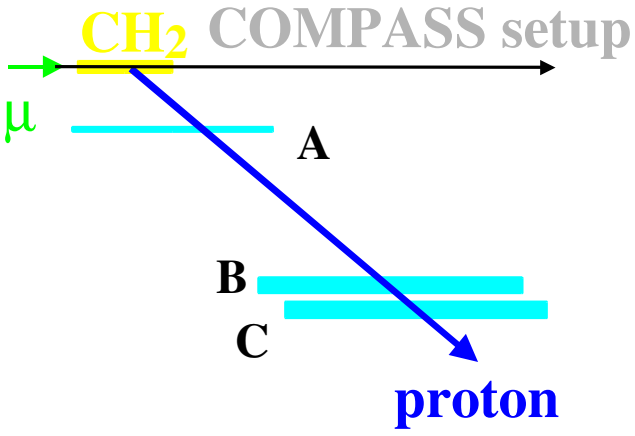
Radiation Length 0.8 x (2.5m of LH2)

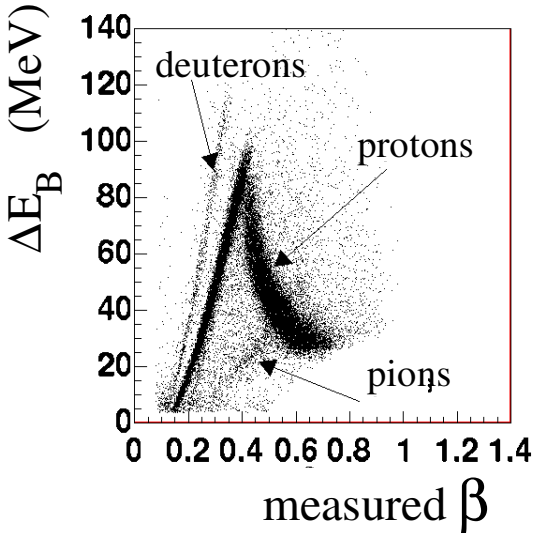
Rates at nominal beam intensity 2.10^8 μ/spill

in A : 1 MHz mainly Möller e^-

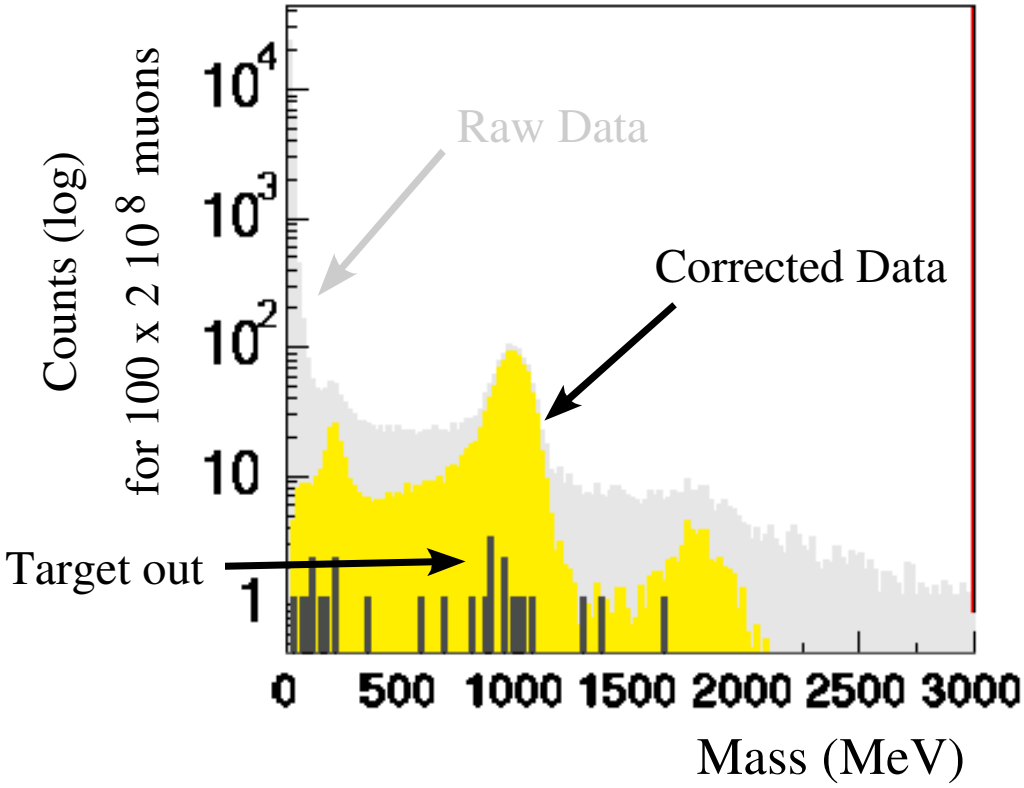
in B : 0.2 MHz

Proton Identification





For stopped particles in B : $\Delta E_B = (\gamma - 1)\, Mc^2$



Conclusions and Prospects

Roadmap:

1. Hard Exclusive Meson Production
as soon as possible with the present setup

$\rho^\circ \rightarrow \pi^+\pi^-$ is the easiest channel to isolate
$\pi^\circ \rightarrow \gamma\gamma$ more difficult, but good for calorimetry study
we need an absolute measurement of the luminosity

comfortable ρ°_L production (a few 10K evts in 6 months)

2. Complete experiment with both
Hard Exclusive Meson Production with a large set of mesons
and Deeply Virtual Compton Scattering
with a completed COMPASS setup

we need a 'long' Hydrogen target
a recoil detector
an extension of the calorimetry at larger angles

The Beam Charge Asymmetry seems very promising to disentangle models

COMPASS is the unique place which provides μ^+ and μ^- of 100GeV

for x=0.05 ±0.02 and x =0.10 ±0.03
× 6 bins in Q^2 (from 2 to 7 GeV^2)
× 9 bins in ϕ
× 2 bins in t