Measurements of Generalized Parton Distributions with COMPASS at CERN (CERN-SPSC-2005-007, SPSC-EoI-005)
Letter of Intent, in framework of the theme 02-0-1025-98/2008

The JINR-COMPASS[1] group in collaboration with groups from Saclay[2], France and Technical University of Munich[3], Germany

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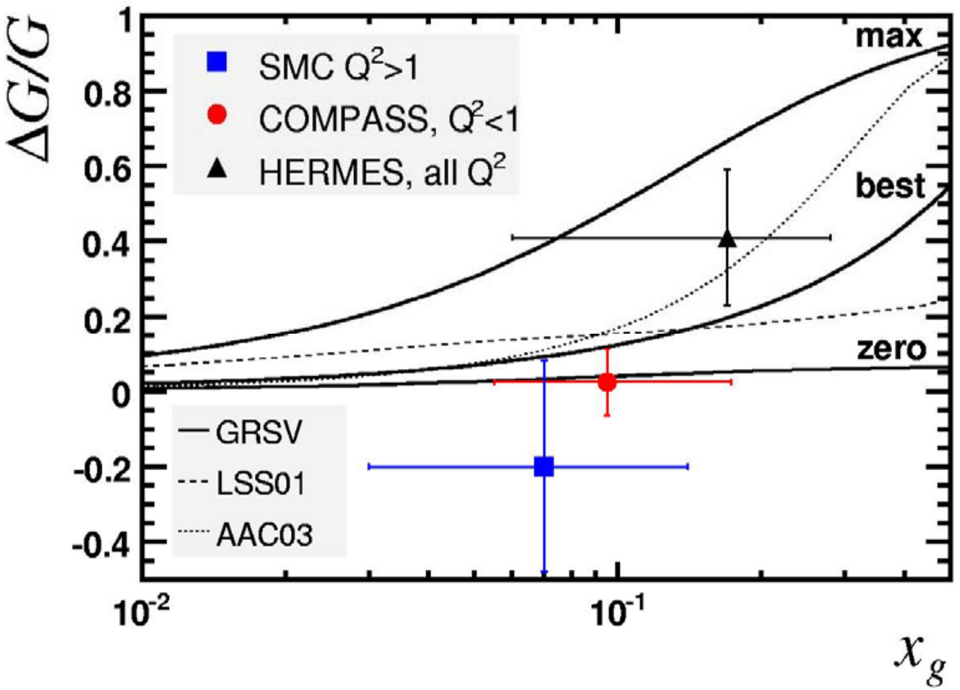
The kinematical range provided by the high-energy muon beam available at CERN in the COMPASS experiment is unique in order to study Generalized Parton Distributions (GPD) in the intermediate x_{Bj} , where both valence, sea quarks and gluons are involved, via reactions of Hard Exclusive Meson Production (HEMP) and Deeply Virtual Compton Scattering (DVCS) which can be performed at the same time in a future COMPASS program (after 2010 year). These measurements will require a recoil detector and electromagnetic calorimeter to upgrade the COMPASS set up in order to insure the exclusivity. Some feasibility studies were already undertaken.

PROTON "SPIN CRISIS"

$$1/2 = 1/2\ \Delta\Sigma + \Delta G + L^{q,g}$$

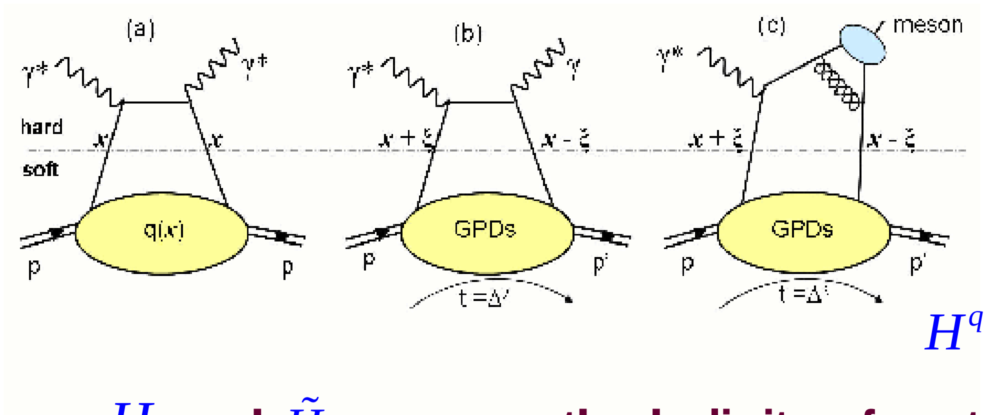
Measured $\Delta\Sigma$=0.2 instead of 0.6 ⟶ $\Delta G \sim 3$



If ΔG small

$L^{q,g} \sim$??

Formalism of GPD



GPD: $H, \tilde{H}, E, \tilde{E}$ **are function of** x, ξ, t

In the forward limit:

$$H^q = q(x),\ \tilde{H}^q = \Delta q(x),\ H^g = g(x),\ \tilde{H}^g = \Delta g(x)$$

H **and** $\tilde{H}$ **conserve the helicity of proton,** E **and** $\tilde{E}$ **allow proton helicity flip. In this case the overall helicity is not conserved: proton changes helicity but the massless quark does not. The angular momentum conservation implies a transfer of orbital angular momentum. So, GPD involve the orbital momentum**

$$\frac{1}{2}\sum_q \int_{-1}^{+1} dx\, x(H(x,\xi,t=0)+E(x,\xi,t=0)) = J^{quark}$$

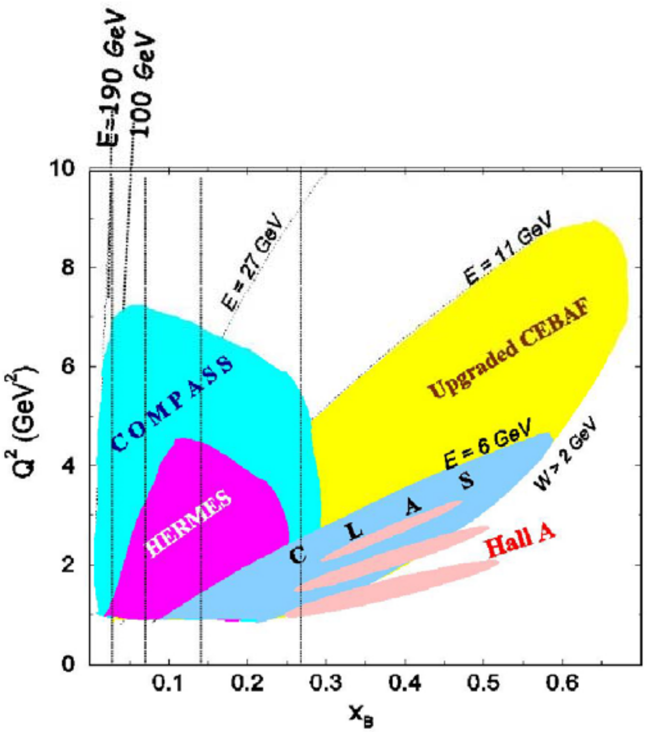
The GPD involve the orbital angular momentum of the partons is epitomized in Ji's sum rule, which states that the second moment at t = 0 gives the total (spin + orbital) angular momentum carried by the quarks.

$$\sum_q e_q \int_{-1}^{+1} dx H^q(x,\xi,t) = F_1(t), \qquad \sum_q e_q \int_{-1}^{+1} dx \tilde{H}^q(x,\xi,t) = g_A(t),$$

$$\sum_q e_q \int_{-1}^{+1} dx E^q(x,\xi,t) = F_2(t), \qquad \sum_q e_q \int_{-1}^{+1} dx \tilde{E}^q(x,\xi,t) = h_A(t)$$

The first moments of the GPD are related to the standard hadronic form- factors

Goal of GPD measurements at COMPASS



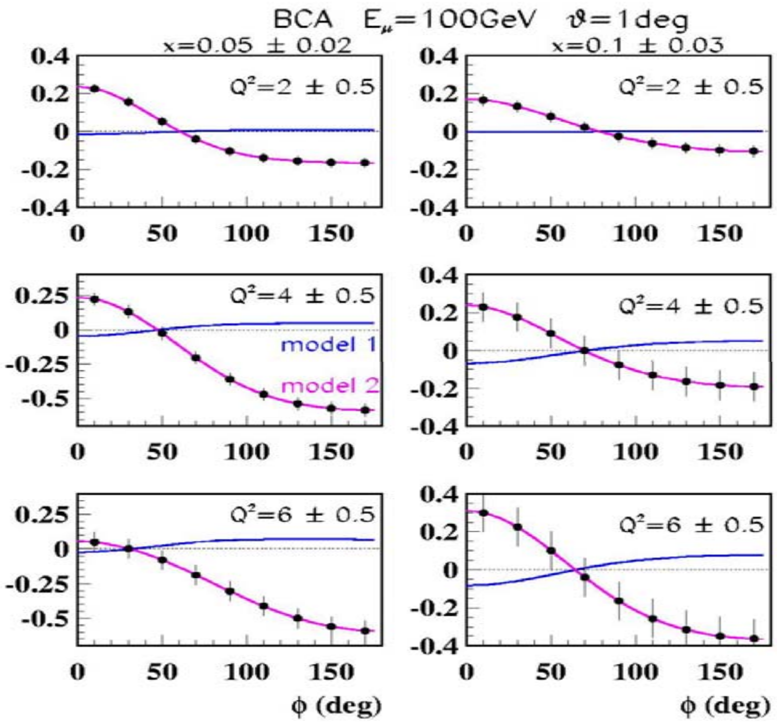
A complete experiment of both <u>Hard Exclusive Meson Production (HEMP)</u> with a large set of mesons ($\rho,\omega,\phi,\pi,\eta\ldots$) and <u>Deeply Virtual Compton Scattering (DVCS)</u> can be performed with the 100 GeV muon beam and the high resolution COMPASS spectrometer complemented by a recoil detector.

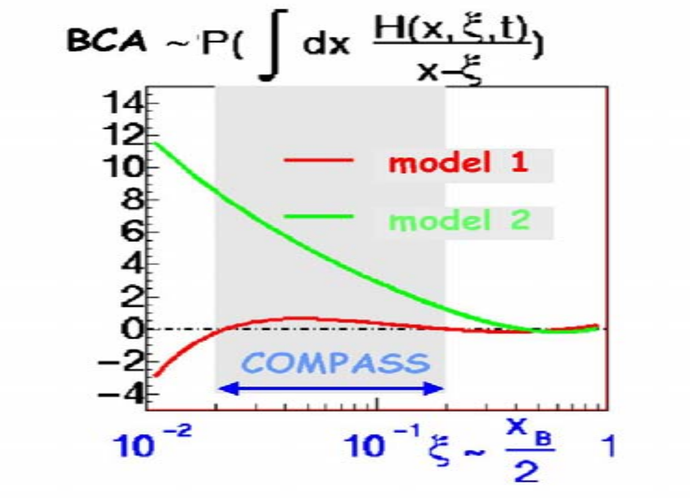
The experimental program using COMPASS at CERN with a muon beam of 100 GeV will give access mainly to three bins in x_{Bj}:

$$x_{Bj} = 0.05 \pm 0.02, \quad x_{Bj} = 0.1 \pm 0.03, \quad x_{Bj} = 0.2 \pm 0.07$$

in a range of Q^2 ($1.5 \le Q^2 \le 7.5$ GeV^2). The range in Q^2 for COMPASS is at present limited up to 7.5 GeV^2 not due to the energy of the muons but due to a reasonable time of 6 months for data taking to realize a DVCS experiment, assuming a muon flux of $2 \cdot 10^8$ μ per SPS spill. It has to be noted that an increase of the number of muons per spill by a factor 2 would increase the range in Q^2 up to about 11 GeV^2.

Goal of GPD measurements at COMPASS: DVCS





The azimuthal distribution of the Beam Charge Asymmetry (BCA) which could be measured at COMPASS with 100 GeV muon beams for different (x_{Bj} , Q^2) domains. Statistical errors are evaluated for 150 days of data taking with a 25% global efficiency. The data allow a good discrimination between different models.

$$\frac{d\sigma(\ell p \to \ell p \gamma)}{d\varphi} = \tau_{BH}(\cos\varphi, \cos 2\varphi, \cos 3\varphi, \cos 4\varphi)$$

$$+\tau_{INT}(\cos\varphi, \cos 2\varphi)[e_\ell[c_1 \cos\varphi ReA(\gamma_T^*) + c_2 \cos 2\varphi ReA(\gamma_L^*) + ...]$$

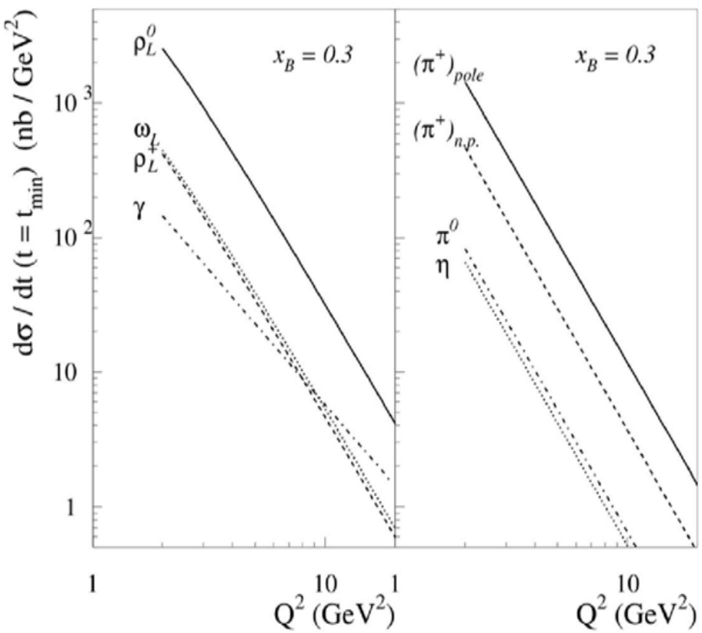
$$+e_\ell P_\ell[s_1 \sin\varphi ImA(\gamma_T^*) + s_2 \sin 2\varphi ImA(\gamma_L^*)]]$$

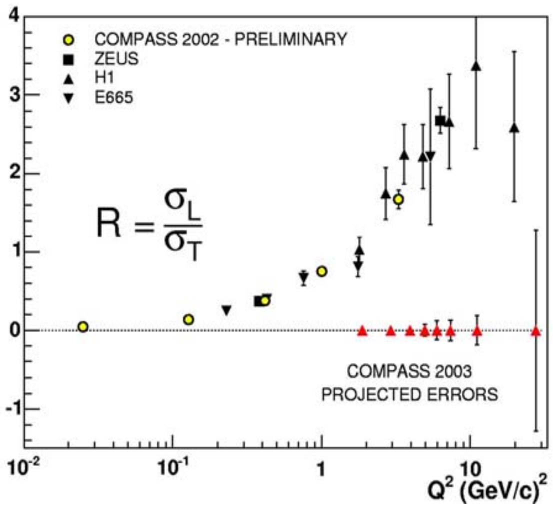
$$+\tau_{VCS}(\cos\varphi, \cos 2\varphi, P_\ell \sin\varphi)$$

$$\sigma^{+\downarrow} - \sigma^{-\uparrow} \sim \tau_{INT} \qquad \sigma^{+\downarrow} + \sigma^{-\uparrow} \sim \tau_{BH} + \tau_{VCS}$$

The domain of intermediate x_{Bj} reachable at COMPASS is related to the observation of sea quarks or meson "cloud" or also gluons and it provides a large sensitivity to this three-dimensional picture of partons inside a proton as we can see it in this Figure and as it was suggested by the chiral approach.

Goal of GPD measurements at COMPASS:HEMP(1)



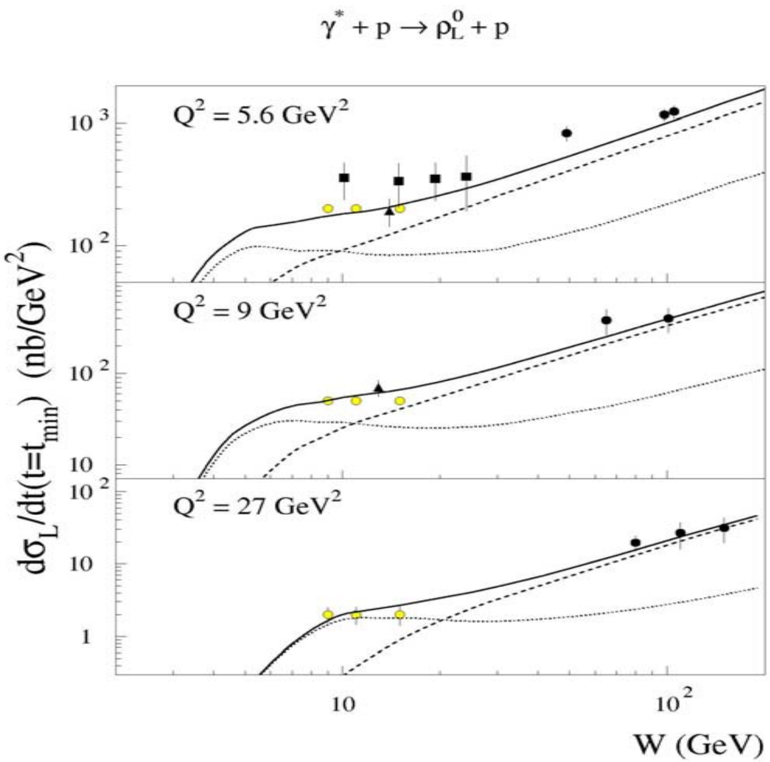


The GPD reflect the structure of the nucleon independently of the reaction which probes the nucleon. In this sense they are universal quantities and can also be accessed, through DVCS (just previously reviewed) or through the hard exclusive leptoproduction of mesons as $\pi^{0,\pm}$, η, …$\rho^{0,\pm}$, ω,ϕ,…

The different scaling predictions for photon and meson production are shown in the top Figure. In leading twist the DVCS cross section $d\sigma/dt$ is predicted to behave as $1/Q^4$ whereas the meson longitudinal cross sections will obey a $1/Q^6$ scaling due to the "extra" gluon exchange for the mesons. It is clear that the production of ρ^0 vector meson provides the largest counting rates compared to other mesons. With its decays in 2 charged particles whose invariant mass gives a clear resonance signal, this channel can be easily selected with the present COMPASS spectrometer and is already under investigation.

The bottom figure presents the ratio $R=\sigma_L/\sigma_T$ determined by the decay angular distribution. The 2002 COMPASS data are limited to Q^2 up to about 5 GeV^2 while the 2003 data due to the enlarged Q^2 trigger will provide results up to 27 GeV^2. The ratio R increases with Q^2 and reaches a value larger than 1 at Q^2 around 2 or 3 GeV^2, providing a favorable case for GPD study that the longitudinal contributions become dominant. This is in agreement with Collins predictions.

Goal of GPD measurements at COMPASS:HEMP(2)



Longitudinal forward differential cross-section for ρ_L^0 production. Predictions reproduce quark contributions (dotted lines), gluon contributions (dashed lines) and the sum of both (full lines). The data are from NMC (triangles), E665 (squares), ZEUS 93 and ZEUS 95 (solid circles). Also are shown the expected errors for the COMPASS 2003 data (with the open circles at W=9, 11, 14 GeV).

Vector meson channels $\rho^{0,\pm}$, ω, ϕ,... are sensitive only to the GPD H and E while the pseudo-scalar channels $\pi^{0\pm}$, η,... are sensitive only to $\tilde{H}$ and $\tilde{E}$. So, meson production is complementary to DVCS, which depends on $H, \tilde{H}, E, \tilde{E}$.

Decomposition of flavor quark and gluon contribution can be realized through:

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

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

$$H_{\phi} = -\frac{1}{3}H^s - \frac{1}{8}H^g.$$

Beam and target requirements

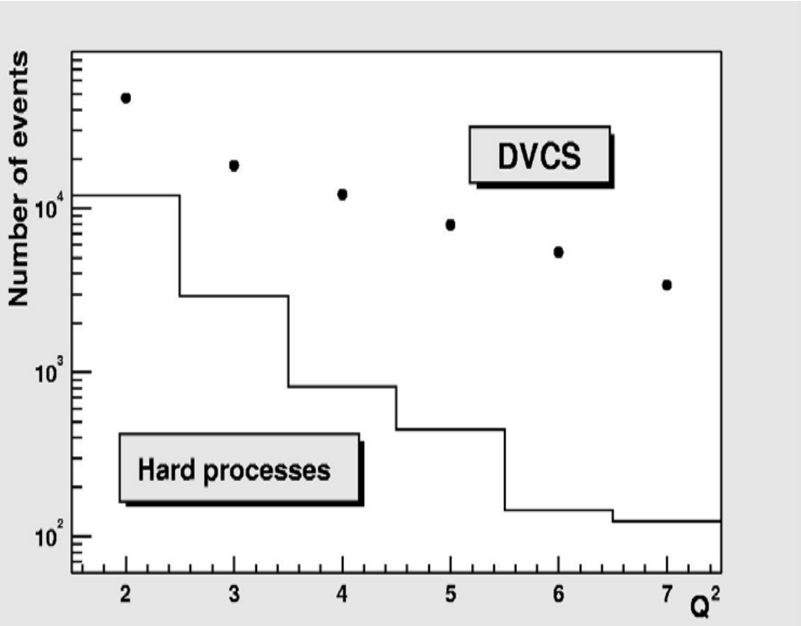
These experiments will use 100-190 GeV/c muons from the M2 beam line. Presently limits on radio protection in the experimental hall imply that the maximum flux of muons should not exceed $2 \cdot 10^8$ muons per SPS spill (5.2s spill duration, repetition rate 16.8 s). Under these circumstances, one can reach a luminosity of $L=4 \cdot 10^{32}$ $cm^{-2}s^{-1}$ with the present polarized ^6LiD or NH_3 target of 1.2 m length, and only $L = 1.3 \cdot 10^{32}$ $cm^{-2} s^{-1}$ with a new liquid hydrogen target of 2.5 m length which has to be designed for this proposal.

It is necessary to perform a precise absolute luminosity measurement. This has already been achieved by the BSDMC and NMC Collaborations within a 1% accuracy

The muons are provided by pion and kaon two-body decays and are naturally polarized. The pions and kaons come from the collision of the 400 GeV proton beam on a Be primary target. A solution is under study and consists in:

1) *selecting 110 GeV pion beams from the p-Be collision and 100 GeV muon beams after the π, $K-$ decay section in order to maximize the muon flux;*
2) *keeping constant the collimator settings which define the pion and muon momentum spreads (both the collimator settings in the hadron decay section and the scrapper settings in the muon cleaning section) in order to fix the μ^+ and μ^- polarizations at exactly the opposite value ($P_{\mu+}$ = -0.8 and $P_{\mu-}$ = +0.8);*
3) *fixing $N_{\mu-}$ close to $2 \cdot 10^8$ μ per SPS spill with the longest 500 mm Be primary target;*
4) *the number of $N_{\mu+}$ will be about a factor 2 larger than that of $N_{\mu-}$.*

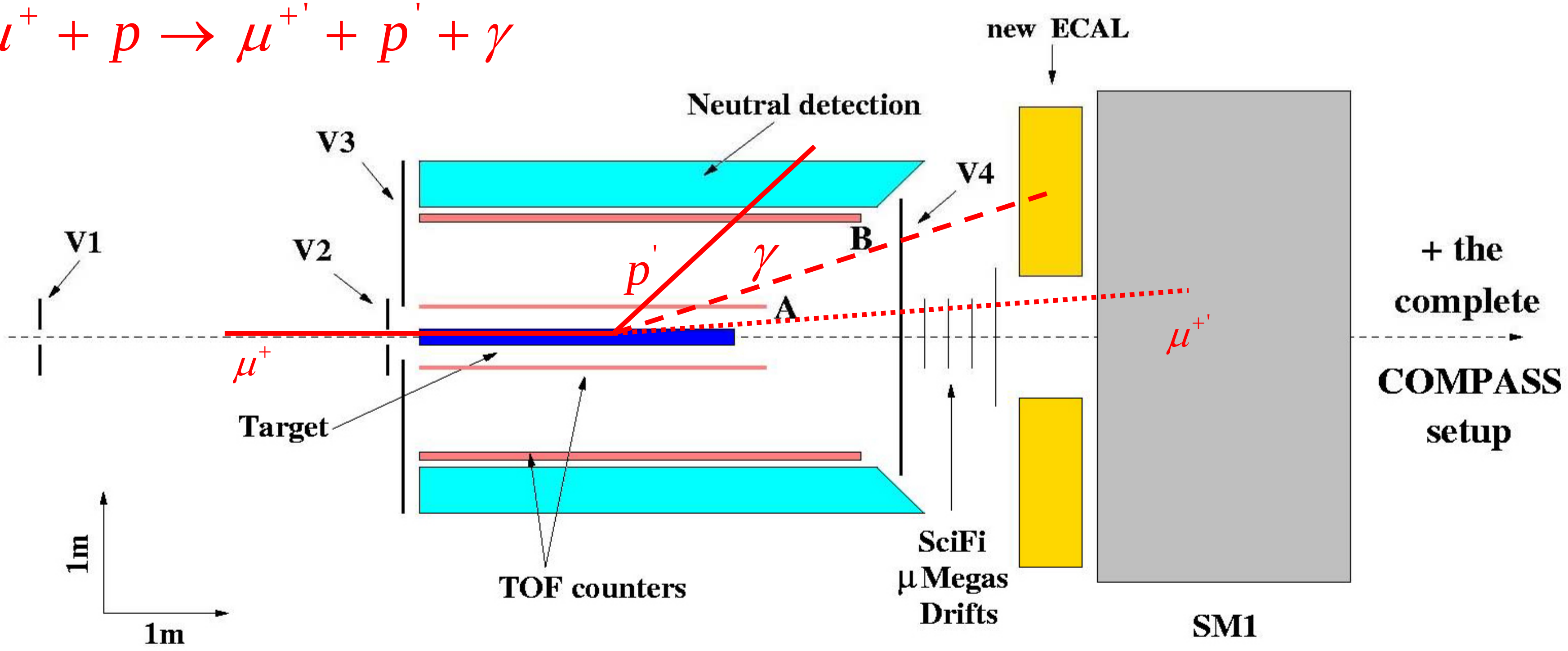
Simulation with PYTHIA



The goal was to maximize the ratio of DVCS events over DIS events for a sample of events with one muon and one photon in the COMPASS spectrometer acceptance plus only one proton of momentum smaller than 750 MeV/c and angle larger than 40º (typical DVCS kinematics). Using the event generator code PYTHIA 6.1 which generates all Deep Inelastic Scattering (DIS) processes with many γ and π^0 production possibilities, the experimental parameters such as maximum angle and energy threshold for photon detection and maximum angle for charged particle detection have been tuned. With photon detection extended up to 24º and above an energy threshold of 50 MeV and with charged particle detection up to 40º, one observes that the number of DVCS events as estimated with models is more than an order of magnitude larger than the number of DIS events over the whole useful Q^2 range.

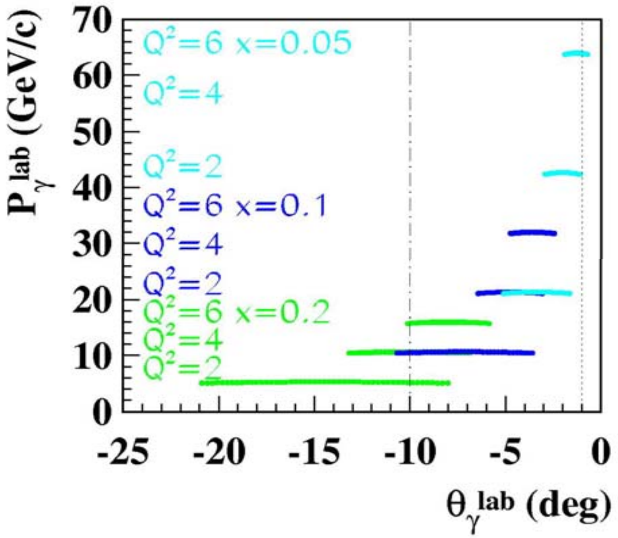
Recoil detection

$$\mu^{+} + p \rightarrow \mu^{+'} + p' + \gamma$$



The recoil detector is based on a time of flight (ToF) measurement between two barrels of scintillating slats read at both ends. The inner barrel (noted A) (2.8m length) surrounding the target should be made of slats as thin as possible (4mm) to allow low momentum proton detection. Thicker (5 cm) and longer (4m) slats should be used for the outer barrel (noted B). An accurate t measurement implies to achieve a timing resolution of 200 ps . External layers of scintillator and lead interleaved should be added to detect extra neutral particles and give an estimate of background. The combination of time of flight measurement and the energy loss in the various sensitive detectors would provide discrimination of events in this fully hermetic detector.

Preliminary Requirements for ECAL0



- *threshold energy for photon detection:50 MeV;*
- *photon energy range for linear responce:5-50 GeV;*
- *energy resolution: about 6% at 1 GeV;*
- *position resolution: about 10 mm;*
- *two-photon resolution: few sm ;*
- *granularity: 4-5 sm;*
- *counting rate:up to 10^7/sec;*
- *rectangular shape: 4.5 m (horisontal)x3 m (vertical) with the central hole 1.5x1 m^2;*

- *fast readout, about 50 kH trigger rate.*

The main role of the new calorimeter ECAL0 for COMPASS is to detect photons up to 40 degrees and above from the center of the target and above a threshold of 50 MeV in order to separate events with only one photon, two photons and more. This calorimeter has to have reasonable photon energy and position resolutions. Dimensions of the ECAL0 are connected with its position in COMPASS. We can mention that a calorimeter of 2.8 m high (as it is for ECAL1) allows photon detection up to only 35 degrees at 2 m from the edge of the target. The position of the ECAL0 along the beam will be also compromised with the position resolution and its granularity. Counting rates have to be estimated taking into account a low threshold of 50 MeV and various background processes.

Plans for 2006

- ***Dedicated MC***

- ***Evaluations of several ECALO options:***
  - ***Si preshower and crystals(scintillators)***
  - ***Sampling calorimeter with Si PM with preshower section***
  - ***Other options … ?***

- ***Design of the ECALO Prototype***