THE COMPASS EXPERIMENT AT CERN

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On Behalf of the COMPASS Collaboration

Abstract. The COMPASS experiment at the CERN SPS has a broad physics program focused on the study of the spin structure of the nucleon and on hadron spectroscopy. Key measurements for the spin program are the gluon contribution to the spin of the nucleon, flavor dependent quark spin distribution, and the measurement of the transverse spin structure function. The apparatus consists of a two-stage spectrometer designed for high data rates and equipped with high-resolution tracking, particle identification, electromagnetic and hadronic calorimetry. Data taking has started in 2002. Following the CERN SPS shut down in 2005, the experiment will resume data taking in 2006 and is planned to continue (at least) until 2010. Few hundreds of Terabytes of data are put on tape each year. Out of this large amount of data first important physics results have been obtained.

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INTRODUCTION

The COMPASS Collaboration brings together about 250 physicists from 27 Institutes from Europe, Russia, Japan and India. The experiment [1] is located at the M2 beam line at the CERN SPS. The primary physics goals are twofold:

1- A rich spin program with a polarised muon beam and a polarised target. It is aimed to provide a direct measurement of the gluon polarisation $\Delta G/G$ by measuring the spin dependent asymmetry of the photon gluon fusion process, that can be accessed by detecting open-charm events and high-p_T correlated hadron pairs. The flavour separated spin structure functions of the nucleon in Deep Inelastic Scattering (DIS) are also measured in the longitudinal polarisation mode. With transverse target polarisation, the still unmeasured transversity spin structure function h_1 will be investigated. Not requiring polarisation, diffractive vector meson production can be studied in parallel. Finally the prospect to study the Generalized Parton Distribution functions by the means of Deep Virtual Compton Scattering and also Highly Exclusive Meson Production in the scattering of high energy muons is investigated for the future.

2- A wide program of hadron spectroscopy will be performed by using hadronic beams. COMPASS plans to study π and K polarisabilities (Primakoff reaction), allowing for a test of chiral perturbation theory predictions; extensive meson spectroscopy to investigate the presence of exotics states; collection of large samples of semi-leptonic decays of charmed mesons and baryons to determine form factors and test the predictions of heavy quark effective theory.

The first construction phase ended with a commissioning run in 2001. Data were taken during 2002, 2003 and 2004. Following the SPS shut down during 2005, data taking will resume in 2006 and will continue beyond 2006.

QUARK AND GLUON SPIN

The spin of the nucleon is the total angular momentum of its constituents. For a nucleon with a spin projection $+1/2$ along its flight direction, we have: $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z^q + L_z^g$ where $\frac{1}{2}\Delta\Sigma$ is the contribution from the spin of quarks, ΔG is the contribution from the spin of gluons, and $L_z^q + L_z^g$ is the orbital angular momentum of quarks and gluons. EMC, SMC and SLAC have obtained for the flavor singlet axial matrix element a_0 the following value: $a_0 = 0.27 \pm 0.13$ [2]. The naive approach which assumes $a_0 = \Delta\Sigma$ leads to the surprising result that the spin of the quarks accounts for only a small fraction of the nucleon spin. However, it has been shown that a_0 gets contribution from both $\Delta\Sigma$ and ΔG. Therefore, as shown in Fig. 1 the small a_0 is compatible with a sizeable $\Delta\Sigma$ if ΔG is large.

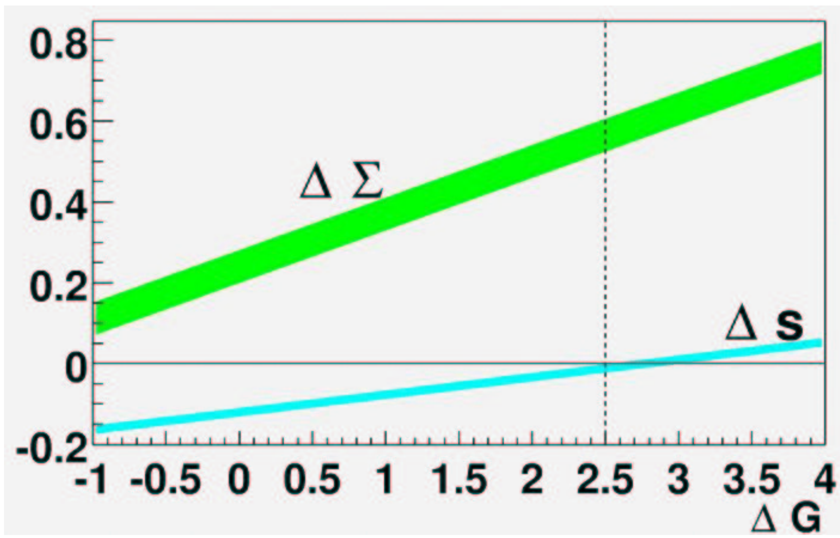


FIGURE 1. Allowed values for $\Delta\Sigma$ and Δs as a function of the hypothesis made for ΔG.

As ΔG is involved in the DGLAP evolution equations [3] of the spin structure function g_1, it can, in principle, be obtained by a QCD fit to the g_1 data. However, g_1 was up to now only measured in fixed target experiments where the small lever arm in Q^2 as well as the present data accuracy prevent to obtain significant constraints on ΔG [4]. It is therefore imperative to perform direct measurements of ΔG. Such measurements of $\frac{\Delta G}{G}$ have been started by four experiments: HERMES and COMPASS using polarised lepton-nucleon scattering on fixed target and STAR and PHENIX at RHIC using polarised p-p scattering.

THE COMPASS SPECTROMETER

The COMPASS spectrometer shown in Fig. 2 is an about 50 m long two-stage set-up [5]. Muons of 160 GeV/c momentum and 80 % average polarisation impinge on a double-cell solid-state polarised target filled with polarised ^6LiD [6]. $2 \cdot 10^8$ muons are delivered during the 4.8 s long spill with a repetition time of 16.8 s. Their momenta are measured individually and their trajectory are determined by scintillating fiber hodoscopes and silicon strips detectors upstream of the target. The first stage, the Large Angle Spectrometer is arranged around a first spectrometer magnet SM1. Particles emerging from the target are tracked by gazeous detectors: GEM and MicroMegas detectors for the innermost region close to the beam and by Drift Chambers and straw trackers for the outer region. The innermost region is again covered by scintillating fiber hodoscopes. The first spectrometer ends with particle identification detectors: the RICH, the hadronic calorimeter HCAL1 and the muon identification wall MW1.

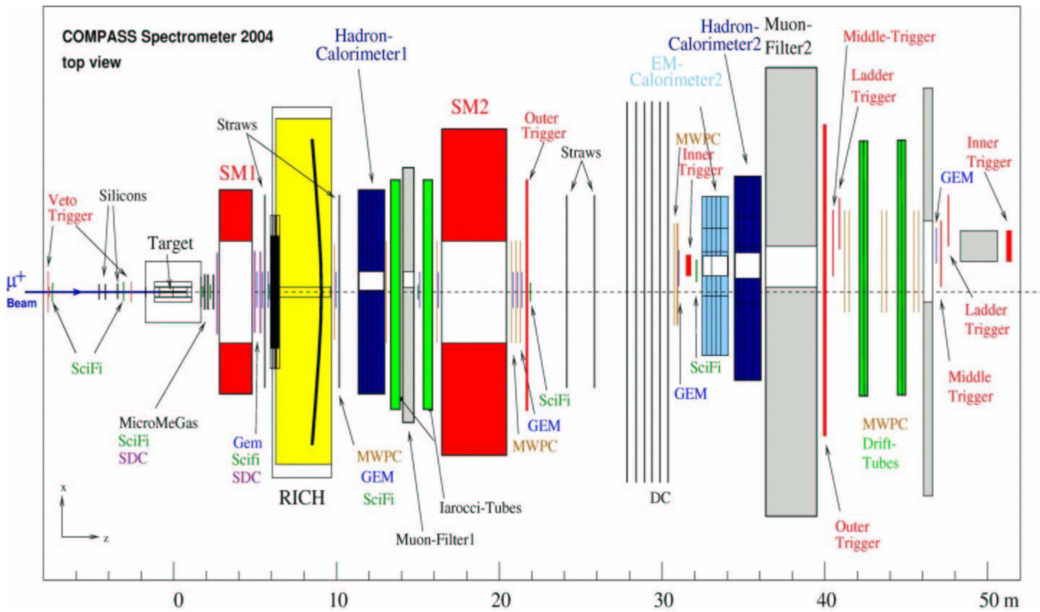


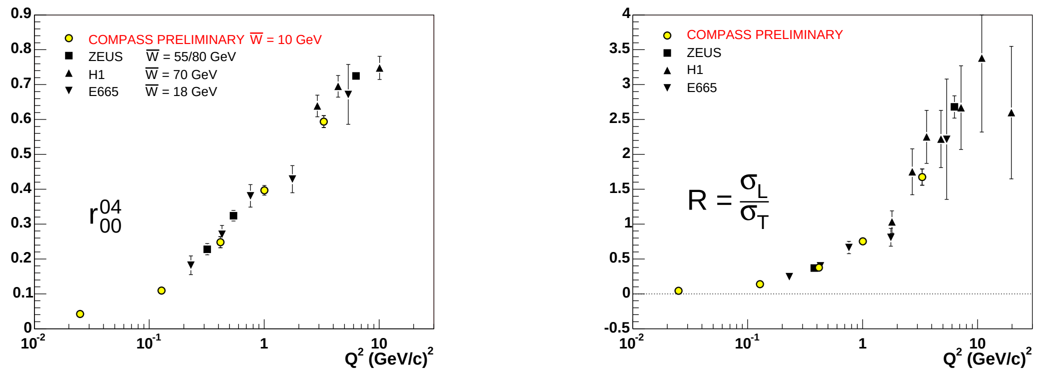
FIGURE 2. The COMPASS spectrometer.

The second stage, the Small Angle Spectrometer, is arranged around the SM2 spectrometer magnet and tracking is performed by multi-wire proportional chambers and GEM detectors. Again, a hadron calorimeter HCAL2 and a muon identification MW2 complete the setup. Trigger hodoscopes and a subsequent logics select the interesting phase space of scattered muon. Calorimeter information is added for a certain class of triggers.

FIRST PHYSICS RESULTS FROM 2002 AND 2003 DATA

Exclusive ρ^0 production

A large number of ρ^0 and also Phi mesons are recorded which allows us, by putting a narrow cut on the missing energy, to select highly exclusive events. In the case of ρ^0 mesons, analysis of the angular distributions of the decay products allows us to perform high precision measurements of spin density matrix elements. An illustration is shown in Fig. 3 a) where the values obtained for the matrix element r^{04}_{00} which describes the production of longitudinally polarised ρ^0 from longitudinally polarised virtual photons are compared to existing results. Assuming s-channel helicity conservation one can express the ratio of Longitudinal to Transverse cross-section for that process $R = \sigma_L/\sigma_T$ as a function of r^{04}_{00}. The results for R are shown in Fig. 3 b) compared with existing results [7] [8]. The COMPASS results extend the existing ones to lower Q^2, by about one order of magnitude. In the region of overlap they have an improved accuracy.



a) b)

FIGURE 3. a) the spin density matrix element r^{04}_{00} and, b) the ratio of Longitudinal to Transverse cross-sections for exclusive ρ^0 meson production.

Transverse spin Collins asymmetry

Semi-inclusive DIS provides the possibility to measure the transverse polarised parton distribution function $\Delta_T q(x)$. This function generates a modulation in the yield of produced hadrons which can be expressed as $(1 + A_{Coll} \cdot sin(\Phi_C))$ where Φ_C and A_{Coll} are the Collins angle and Collins asymmetry respectively [9]. A_{Coll} has been measured on our ^6LiD target polarised in the transverse mode. Fig. 4 shows the preliminary values of A_{Coll} obtained from our 2002 data when a positive or a negative leading hadron is selected, as a function of x_{Bj} and as a function of the fraction of energy z carried by the leading hadron [10]. Given the present accuracy, all measured values for A_{Coll} are compatible with zero.

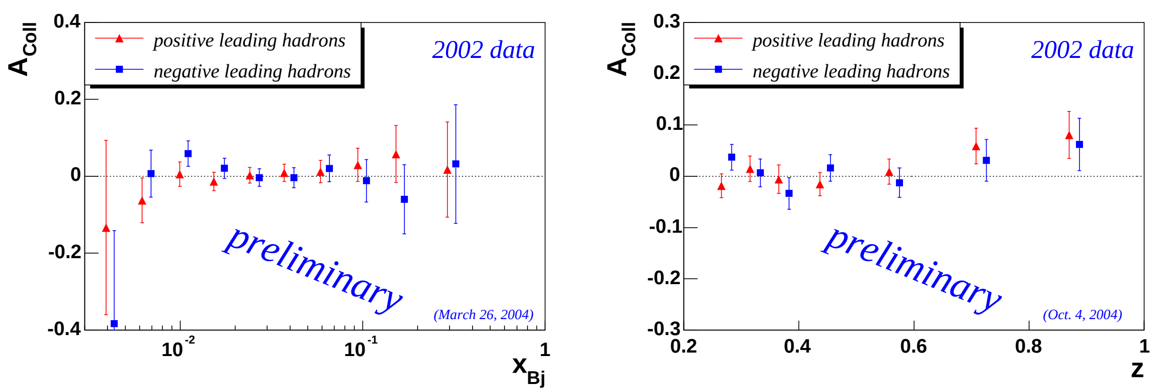


FIGURE 4. The A_{Coll} transverse spin asymmetry for h^+ and h^- leading hadrons.

Double spin longitudinal inclusive asymmetry A_1^d

By requiring only a high energy scattered muon, one can measure the double spin longitudinal inclusive asymmetry on the deuteron A_1^d from which one derives the first spin structure function g_1^d of deuteron. Fig. 5 shows the results, from the 2002 and 2003 data, obtained from the scattering of longitudinally polarised muons on a longitudinally polarised ^6LiD target [11]. The much shorter overall data taking time used by COMPASS, compared to SMC is more than compensated by the higher luminosity of COMPASS and the higher dilution factor of the polarised material. A significant improvement of the errors in the low x_{Bj} region has been achieved.

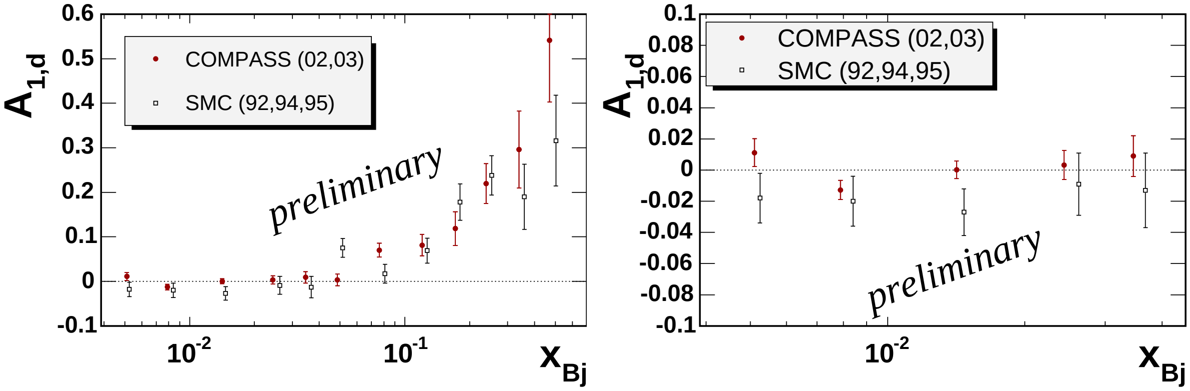
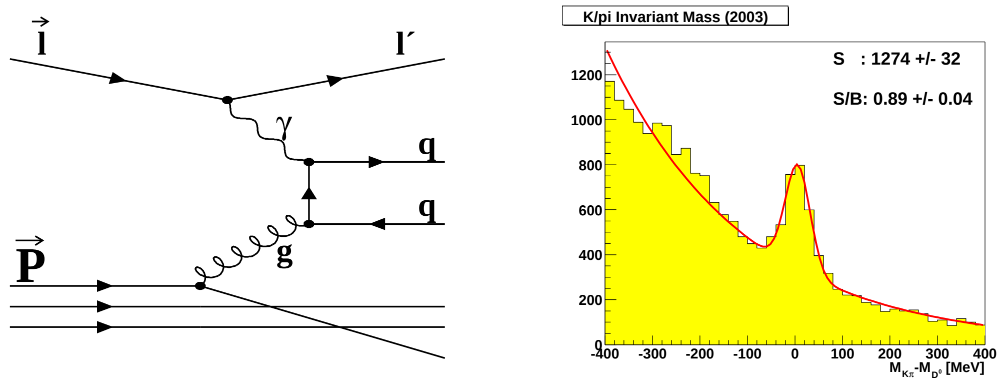


FIGURE 5. Double spin longitudinal inclusive asymmetry A_1^d from 2002 and 2003 data.

$\Delta G/G$ determination from open-charm

The gluon polarisation $\Delta G/G$ is studied using the Photon Gluon Fusion (PGF) process $g\gamma^* \rightarrow q\bar{q}$ shown in Fig.6 a).



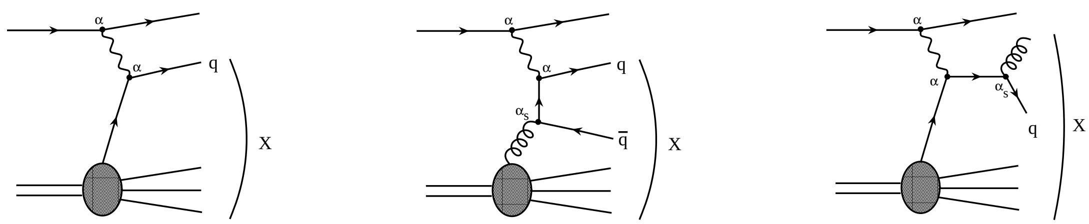
a) Photon-Gluon Fusion process b) D^0 signal in $K\pi$ invariant mass

FIGURE 6. a) the Photon Gluon Fusion process. b) observation of the PGF in the open-charm channel via $D^* \rightarrow D^0\pi \rightarrow K\pi\pi$ production (invariant mass of $K\pi$ pairs).

The production of charmed mesons D^0 provides a clean identification of the PGF process. However, D^0 are difficult to detect because in our long targets, the charm production vertex cannot be reconstructed with sufficient accuracy. D^0 detection is helped by requiring that they originate from a "parent" D^*: $D^* \rightarrow D^0\pi \rightarrow K\pi\pi$ called D^* tagging. Fig. 6 b) shows for the 2003 data [12], the invariant mass plot for D^0 using D^* tagging. The longitudinal spin asymmetry has not yet been evaluated from this limited sample of open charm events. However, from this sample, we are able to draw a projection (subsection below) for the uncertainty on $\Delta G/G$ expected from the full statistics on open charm events available at the end of 2004.

$\Delta G/G$ determination from high p_T hadrons pairs

The PGF process can also be tagged by the production of a pair of hadrons with high transverse momenta (high-p_T). This process is more abundant but plagued by a background from competing processes. The photon can interact with the nucleon directly or be resolved to a hadronic state (Vector Meson or $q\bar{q}$) where a parton from this hadronic state interacts perturbatively with a parton from the nucleon. Selecting events with $Q^2 > 1$ (GeV/c)^2 strongly reduces the contribution from resolved photons which can then be neglected. Fig. 7 shows the three main direct processes which contribute to the cross-section for production of a pair of hadrons.



a) Leading order DIS b) Photon-Gluon Fusion c) QCD Compton

FIGURE 7. The 3 direct processes contributing at order α_s to the hadrons pair production

The gluon polarisation in the nucleon $\frac{\Delta G}{G}$ is extracted from the cross-section asymmetry of the PGF: $A_{LL}^{\gamma^* d(PGF)} =< \hat{a}_{LL}^{PGF} > \frac{\Delta G}{G}$ where the asymmetry $< \hat{a}_{LL}^{PGF} >$ of the partonic (photon-gluon) reaction can be calculated. Selecting events with a pair of high-p_T hadrons, one removes most of the Leading Order DIS background. However, the QCD Compton and a fraction of LO DIS processes remain and a Monte-Carlo simulation is necessary to estimate their contribution. The following cuts have been applied: $x_F > 1$ and $z > 0.1$ to select current fragmentation; $Q^2 > 1$ (GeV/c)^2, $x_{Bj} < 0.05$, $0.1 < y < 0.9$ on the lepton kinematics; $p_{t1(2)} > 0.7$ GeV/c, $p_{t1}^2 + p_{t2}^2 > 2.5$ (GeV/c)^2, $m(h_1 h_2) > 1.5$ GeV/c^2 on the leading (h_1) and the next-to-leading (h_2) hadrons. With this selection and combining the 2002 and 2003 data, the (virtual-photon) longitudinal double-spin asymmetry for high-p_T hadron pairs at $Q^2 > 1$ (GeV/c)^2 is [12]:

$$A^{\gamma^* d} = -0.015 \pm 0.08(stat.) \pm 0.013(syst.) \quad (1)$$

Using LEPTO Monte-Carlo a determination of the fraction of PGF events leads to $\sigma^{PGF}/\sigma^{tot} = 0.34 \pm 0.07(syst.)$ where the systematic error is estimated by varying the p_t^2 cut and using standard and modified sets of fragmentation functions. Using this estimate, one obtains for the gluon polarisation:

$$\frac{\Delta G}{G} = 0.06 \pm 0.31(stat.) \pm 0.06(syst.) \qquad (2)$$

corresponding to an average value for gluon x of $< x_G >= 0.13$

Projections for $\sigma(\Delta G/G)$

Analysis of the additional data from the 2004 run combined with some recent improvements in the hardware and more importantly in the analysis software will enhance the overall figure of merit of the experiment. Concerning the high-p_T events, releasing the $Q^2 > 1$ (GeV/c)^2 cut increases the statistics by a factor of $\simeq 10$. The statistical error quoted below for this case was obtained by taking into account the dilution due to resolved photons, however it does not include their contribution to the asymmetry. The projections for the achievable error on $\Delta G/G$ from the 2002 to 2004 data are as follows:

$$\sigma(\Delta G/G) = 0.05 \;\; (high\ p_T \text{ all } Q^2); \;\; \sigma(\Delta G/G) = 0.16 \;\; (high\ p_T\ Q^2 > 1) \qquad (3)$$

$$\sigma(\Delta G/G) = 0.25 \;\; (open\ charm) \qquad (4)$$

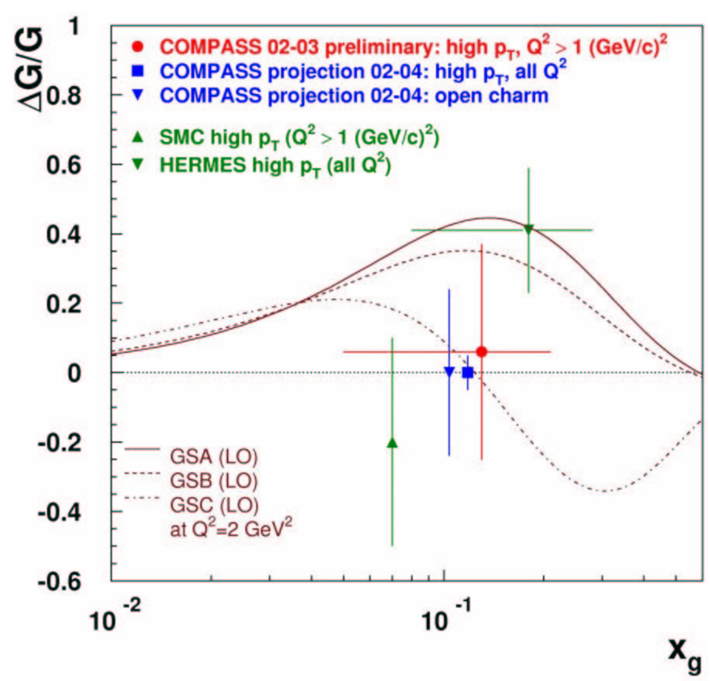


FIGURE 8. First COMPASS result on $\Delta G/G$, compared with existing results and projections

The COMPASS preliminary determination of $\Delta G/G$ from high-p_T hadrons pairs using $Q^2 > 1$ (GeV/c)^2 events is shown in Fig. 8 along with a result derived from a similar analysis of all the SMC data [13] and also a HERMES result [14] obtained without Q^2 cut. Note that the uncertainty quoted by HERMES does not include any systematic error from possible background subtraction. The above projections are also shown.

COMPASS BEYOND 2005

COMPASS is expected to resume data taking in 2006, following the shut down of CERN accelerators in 2005 required for LHC installation. An important meeting, organized by CERN SPSC will examine the future of fixed target experiments at CERN at the end of September [15]. Both the ongoing program with muon beam and the program with hadron beam will be reviewed. In addition, an expression of interest to study GPDs using high energy muon beyond 2010 will also be discussed.

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