GEM TN-92-176

The Muon System of the GEM Detector at the SSCL as Presented at the 3rd International Conference on Advanced Technology and Particle Physics - Villa Olma, Como (Italy), June 22-26, 1992

Frank E. Taylor
Massachusetts Institute of Technology

August 10, 1992

Abstract:

The GEM Muon System is based on a large super conducting solenoidal magnet with no magnetic flux return. Three superlayers of muon tracking chambers are deployed outside the calorimeter to reconstruct the sagitta of the muon trajectory in the magnetic field. Iron flux concentrators are placed along the central axis of the magnet to create a radial component of the magnetic field, thereby increasing the momentum resolution at small angles. The muon system can be triggered, based on transverse momentum, and muon trajectories can be reconstructed from $|\eta| = 0$ to 2.5.

The Muon System of the GEM Detector at the SSCL

GEM Muon Collaboration*

Presented by

F.E. Taylor
Laboratory for Nuclear Science
Massachusetts Institute of Technology
Cambridge, MA 02139
August 10, 1992

Abstract

The GEM Muon System is based on a large super conducting solenoidal magnet with no magnetic flux return. Three superlayers of muon tracking chambers are deployed outside the calorimeter to reconstruct the sagitta of the muon trajectory in the magnetic field. Iron flux concentrators are placed along the central axis of the magnet to create a radial component of the magnetic field, thereby increasing the momentum resolution at small angles. The muon system can be triggered, based on transverse momentum, and muon trajectories can be reconstructed from $|\eta| = 0$ to 2.5.

1. Introduction

Several interesting processes, such as the production of standard Higgs particles, heavy QQ pairs, heavy W' and Z' bosons, and supersymmetric particles, have a lepton signature. Most of these processes are expected to have small cross sections times leptonic branching ratios, but the decay muons will be quite distinctive. Thus the detection of muons will be a powerful tool to investigate fundamental processes at the SSCL.

Higgs particle production and subsequent decay into 4 muons in the mass range of 100 to 200 GeV/c^2 will yield muons in the transverse momentum range of 5 to 100 GeV/c. On the other hand, the production and decay of a massive Z' in the mass range of 2 TeV/c^2, for example, will produce muons up to 1.5 TeV/c transverse momentum. Thus our muon system must be capable of reconstructing transverse momentum from 5 GeV/c to the multi-TeV/c range amid a large background. Given the expected rarity of these events, the ideal muon system at the SSC should be capable of operating at luminosity in the 10^{34} $cm^{-2}s^{-1}$ range. Hence the muon system should be well shielded thereby requiring that all of its elements lie outside the calorimeter.

With the above mentioned processes in mind we have designed the muon system for the GEM-SSCL detector to provide the following functions:

• Muon Identification:

Track identified as a muon if it penetrated 12 to 14 λ calorimeter (> 140 X0 of Cu). Good solid angle coverage from polar angles 9.5 to 90 degrees.

• P_t trigger:

Typical threshold range 10 GeV/c < P_t < 50 GeV/c. Level 1 trigger rate: < 3×10^3Hz @ L = 10^{33} $cm^{-2}s^{-1}$

• Beam crossing tag:

Beam crossing time is 16 ns, hence the trigger resolve a small fraction of this time.

• Muon momentum reconstruction:

Resolution design goals: $\delta P_t/P_t = 5$ % at $\eta = 0$ and $\delta Pt/Pt = 12$ % at $|\eta| = 2.5$

• Muon charge assignment

Design goal: 95 % confidence level for $P_t <$ 2.8 TeV/c for $0 < |\eta| < 2.5$.

2. Elements of Design

The GEM muon system is based on a large open solenoid concept where the momentum is determined by means of a 3 point sagitta measurement. In terms of the position measurements along the muon trajectory, y_i, the magnetic field strength, B, the path length, L, and the momentum transverse to the B field, P_t, the sagitta is approximately given by:

$$s = \frac{y_1+y_3}{2} - y_2 = \frac{qBL^2}{8P_t}$$

Hence good momentum resolution can be achieved even with a modest magnetic field strength, B, for large enough path length, L. To improve the momentum resolution in the forward direction where a solenodial magnet has a diminished bending power, large iron cones are mounted concentrically around the beam pipe. These large iron cones, called Forward Field Shapers (FFS)[1], distort the magnetic field by creating an inward pointing radial magnetic field component.

In our design, all the muon tracking and triggering elements are located in three superlayers (SL) and all lie outside of the calorimeter. This deployment has the advantage of shielding the muon system from the tremendous backgrounds expected for the rare physics processes of interest, but has the disadvantage of forcing us to contend with the unresolvable fluctuation of the muon energy loss as the muon traverses the calorimeter absorber material.

The superlayers of muon chambers are held in space frames (one for each half of the barrel and one for each endcap) which are attached to the magnet. In order to achieve our momentum resolution goal stated above, the space frames must be stable and rigid so that the muon chambers can be aligned to a small fraction of the track sagitta. To set the scale for the stability, alignment, and chamber resolution, the total sagitta for a P_t = 500 GeV/c track is only 1500 μm for B=0.8T and L = 5m. To measure this transverse momentum to 5%, our design goal for $\eta = 0$, we must not allow the total error (combined systematic and stochastic) of the sagitta to exceed 75μm. This tiny error budget makes heavy demands on the muon chamber resolution, alignment, and mechanical stability of the chamber support system.

Fig. 1 is an overview of the GEM Muon System design. The essential features are a three point sagitta measurement (3 superlayers (SL) of chambers) in both the barrel and endcap regions, where all muon tracking and triggering elements lie outside of the calorimeter to make the system more robust, and the FFS to improve the momentum resolution in the forward direction.

2.1 Momentum Resolution

The essential task of designing the GEM Muon System is to specify a practical set of parameters which will achieve the baseline performance.

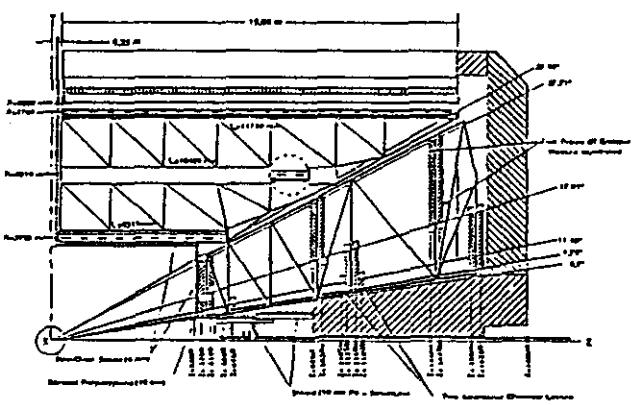
The first consideration is the choice of the magnetic field strength and size. These parameters must be balanced against the

practical limits of tracking chamber resolutions and costs. There is a premium in choosing a large diameter magnet. The magnetic field strength is kept to a modest value to manage the mechanical stresses on the coils, which increase as B^2. Under these considerations the field strength is taken to be B=0.8 T. The outside radius of the calorimeter, determines the inner radius of the muon system. The present design has this dimension at 3.6m (corresponding to a total of 12 λ at η = 0). For B=0.8T we need roughly 5 meters of bend path to have a reasonable size sagitta at our highest momentum. This fixes the inside diameter of the magnet to be 9m. Similarly, the length of the magnet is determined by our resolution requirements in the forward direction and the size of the calorimeter along the beam axis. From these considerations we find the magnet length must be 30m.

The flux lines of the magnetic field are shown in Fig. 2. Note the radial magnetic field in the forward direction generated by the FFS.

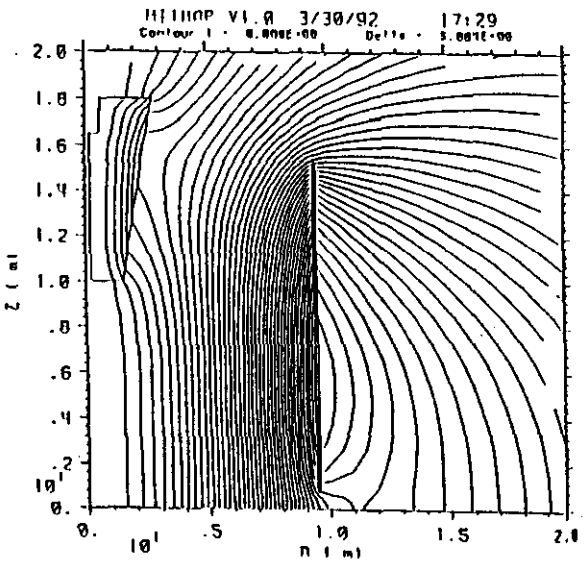
The second consideration is the choice of chamber and trigger technologies. At this time several chamber technologies are being considered either employing drift technology, or charge interpolation (cathode strip chambers-CSC) for tracking, and resistive plate chambers for triggering in the barrel region. Each has its own advantages and disadvantages and we have undertaken an R&D program to choose the best technology. All the tracking technologies have demonstrated a single layer resolution of order 100 μm in small prototype chambers. However further reduction of this error is needed to meet our total error budget. This is accomplished by employing several chamber planes (4 to 8 layers) in a superlayer (SL). This should reduce the tracking error by $1/\sqrt{N}$, where N is the number of planes in a SL.

Given these considerations we have developed a set of parameters which specify the performance of the system.



GEM MUON SYSTEM (BASELINE I)

Fig. 1



CONTOURS OF CONSTANT FLUX

Fig. 2

Parameters of the GEM Muon System

Geometry:	
B-field at the IP	0.8 T
Barrel region: ($29.6^o < \theta < 85.8^o$)	$0.074 < \lvert\eta\rvert < 1.33$
Endcap region: ($9.75^o < \theta < 27.71^o$)	$1.40 < \lvert\eta\rvert < 2.46$
Inner radius of magnet cryostat	9.0 m
Length of magnet cryostat	30 m
Forward Field Shaper (FFS):	
Front position from IP	10.0 m
Rear position from IP	18.0 m
OD-half angle of steel	8.7^o
ID	0.4 m
Outer radius of calorimeter	3.60 m
Calorimeter thickness at $\lvert\eta\rvert = 0$	12 λ
Calorimeter thickness at $\lvert\eta\rvert = 2.5$	14 λ
Calorimeter material (hadronic section)	Cu
Half-length of calorimeter along Z	5.50 m
Number of sectors in ϕ	16
Location of neutron shield	$3.60\ m < R < 3.70\ m$
Barrel lever arm	> 4.78 m
Endcap lever arm	> 8.64 m
Chamber Parameters: (typical values)	
Spatial resolutions:	
Chamber single-layer resolution	75 to 100 μm (RMS)
Internal chamber alignment	50 μm
Superlayer-to-superlayer alignment	25 μm
Radiation length/chamber layer	1.0 %
No. of chamber planes per SL (SL1:SL2:SL3)	8:8:4

Using these parameters we simulate the momentum reconstruction performance. Consideration is given to the non-uniform magnet field (especially important in the forward direction near the FFS), multiple scattering in the muon chambers, fluctuations of the energy loss in the calorimeter, spatial resolution of the tracking chambers, and alignment errors. The results are shown in Fig. 3. In the low momentum region (< 75 GeV/c) the resolution is dominated by the fluctuations of the energy loss in the calorimeter, and in the high momentum range spatial resolution

and alignment errors are the largest contributors.

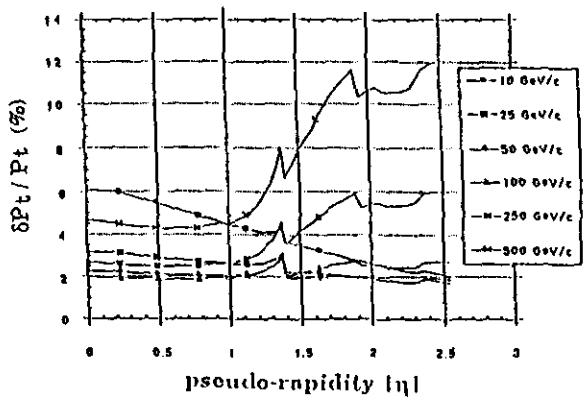


Fig. 3

2.2 Trigger Design

In our present design the barrel trigger and beam crossing tag is based on Resistive Plate Chambers (RPC)[2], which will be instrumented with both ϕ (bend plane) and Z (non-bend plane) coordinate readout. The RPCs will be constructed in two-gap modules and will be located in each of the three super-layers. This arrangement will enable both a Level 1 momentum-dependent trigger to be formed as well as a measurement to be made of the orthogonal coordinate of the muon track. The RPCs have a measured time jitter of < 1.4 ns, which is sufficiently fast to unambiguously tag the beam crossing. The bend plane strips will be 1.3 cm wide, while the non-bend plane channel segmentation varies from 3.9 to 8.9 cm.

Both the endcap trigger and beam crossing tag will be provided by the Cathode Strip Chambers (CSC)[3]. The bend plane strip segments which are used to form the trigger are the 0.5 cm wide strips read out digitally at trigger time. The non-bend plane measurement is provided by means of the anode wires which will be segmented in 5 cm wide electronic channels. Since the maximum drift time of the CSC is < 24 ns per plane, several planes in a superlayer must be"ORed" together to achieve sufficient resolution for the beam crossing tag.

The Level 1 muon trigger is based on hits in superlayers 2 and 3, and uses the change of the phi angle, $\Delta\phi$, to measure the curvature (momentum) of the track originating from the interaction point. $\Delta\phi$ is given in terms of the number of readout strips of the RPCs (1.3 cm wide) for a barrel muon, or the number of CSC pickup strips (ave. 0.5 cm wide) for an endcap muon. The line formed by the hit in SL2 and the interaction point extrapolated to SL3 gives the position of the muon track for infinite momentum. The difference measured in the experimental quantity of trigger strips, ΔN_{strip}, between the hit in SL3 and the extrapolated point is a measure of the muon momentum. The concept for Level 1 is shown in Fig. 4.

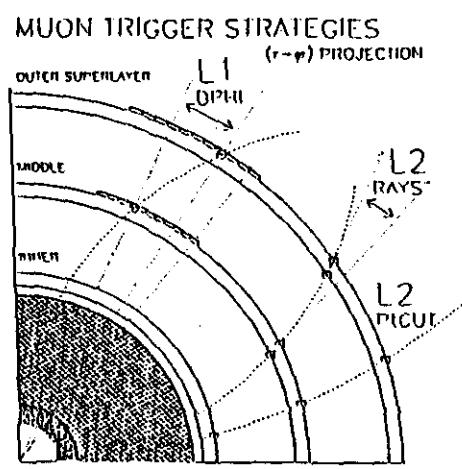


Fig. 4

The Level 2 trigger is developed by either a measurement of the difference in track angles as determined from SL2 and SL3, or a rough trajectory determination using all three superlayers. (See Fig. 4.) Level 3 employs the full track resolution of the muon system.

The operation of the Level 1 trigger is illustrated in Fig. 5. Shown is the difference in the ϕ angle as it would be measured at trigger Level 1 by strips in the CSC bend planes in the most demanding forward angle region for various momenta. Manageable ounting rates in the range of 10^2 to 10^3 Hz at $L=10^{33} cm^{-2} s^{-1}$ are obtained in this scheme.

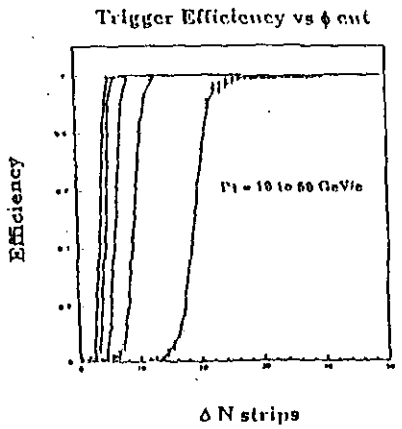


Fig. 5

2.3 Support Structure and Alignment

The support structures for both the barrel and endcaps are each arranged into 16 sectors. These will either be individually mounted to the magnet or tied together to form large space frames mounted as an entity to the magnet - one for each half of the barrel and one for each endcap. In either design the frames will consist of aluminum tubes that are bolted and pinned into truss structures. Fig. 6 shows the individual sector concept for the barrel region during installation phase. In order to minimize distortions of the internal chamber alignment caused by deflection of the support structure, the chamber superlayers will be mounted with kinematic hardware. The support structure must have sufficient stability so that the location of the chambers will always be known to the desired accuracy.

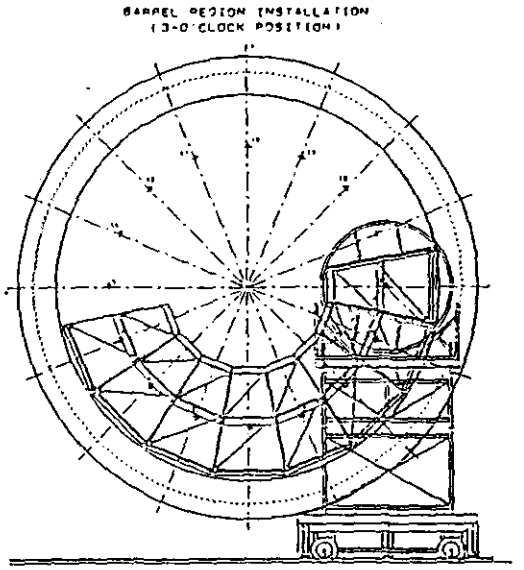


Fig. 6

The GEM Muon System design calls for very good alignment of our chambers. Note from the table above that the superlayers have to be aligned to 25 μm systematic error in order to meet our resolution design goal. We also require that the random internal alignment of the measuring elements of the chambers (such as strips for the CSC technology) be known to better than 50 μm within the local chamber coordinate system. Such exacting criteria will present a considerable challenge to every aspect of the tracking chamber, support, and alignment mechanical designs.

The philosophy adapted for the alignment system is to place chambers within 5 mm of their nominal exact position but measure the position to the desired accuracy. The alignment system will consist of many alignment devices, located along projective paths, that will link each corner of the superlayer triplets which measure the muon track sagitta. The design calls for constantly monitoring the chamber positions to be always ahead of irreducible mechanical and thermal distortions.

Several alignment technologies are under consideration. Two attractive candidates are optical straight-line monitors, based on a LED-Lens-Photodiode arrangement[4], and a stretched wire with proximity monitors mounted along its length[5]. Each is capable of the required precision and an R&D program is presently underway to evaluate the best choice.

3. Backgrounds

The GEM Muon System is designed to be stand-alone (i.e. not requiring the central tracker) and is located entirely outside a large calorimeter. Nevertheless there are several backgrounds with which we must contend. 1. Muon associated background such as δ rays and muon generated showers, 2. Hadron punch-through, and 3. Neutrons arising primarily from absorption of the hadron shower in the calorimeter.

3.1 Muon Associated Backgrounds:

These were studied by means of data taken with a drift chamber placed in a 0.5 TeV/c muon beam at Fermilab[6] as well as by GEANT-based Monte Carlo. The results require: a) The muon chambers must be at least 6 cm behind the absorber material of the calorimeter-neutron shield, b) The chambers must be made of low Z material and have a small number of radiation lengths, and c) The first superlayer should consist of at least 8 chamber layers.

3.2 Hadron Punch-through:

Two criteria determine the thickness of the calorimeter[7]. 1. We require that all elements of the muon system function at an SSC luminosity of 10^{34} $cm^{-2}s^{-1}$. Hence the flux of charged particles in the barrel region should be less than 50 to 100 Hz/cm^2, and in the endcaps less than about 3 kHz/readout strip. 2. The rate of charged particles penetrating the calorimeter from punch-through should be much less than the prompt muons and those from π/K decay in the central tracker and calorimeter. By Monte Carlo studies we find that Criterion 2 determines that the calorimeter should be at least 12 λ thick in the barrel region. And in the endcap region Criterion 1 demands the calorimeter be at least 14 λ thick.

3.3 Neutron Background:

The neutrons impinging upon the muon system arise primarily from spallation neutrons created in the absorption of the hadron showers in the calorimeter[8]. As such, the neutron background will be proportional to the energy deposited in the calorimeter. Thus the neutron fluence will be greater in the endcap region than in the barrel. The preliminary conclusions are: 1) Borated polyethylene (at least 10 cm thick) with a lead cladding must be placed around the calorimeter and beam pipe to absorb neutrons and shield the γ rays arising from neutron-nuclear capture. 2) The chambers should be built of non-hydrogenous materials and should use non-hydrogenous gases. We are engaged in studies to measure chamber sensitivities to neutrons[9] and we are performing detailed Monte Carlo calculations of the background.

4. R&D Program

We have initiated an R&D program to determine the best tracking and triggering technologies, develop an alignment system with appropriate precision and dynamic range, and design the support structure with the required stability. A brief list of our present activities are as follows:

- Develop chamber technologies. This involves construction of several prototype chambers to measure their spatial resolution, rate capability, sensitivity to neutrons, alignment characteristics, cost

of construction, etc. We are considering the following chamber technologies.

a. Cathode Strip Chambers (CSC) for triggering and tracking in the endcap region. This technology is also being considered for the same application in the barrel.

b. Pressurized Drift Tubes (PDT) for tracking in the barrel region.

c. Limited Streamer Drift Tubes for tracking and Z-coordinate measurement in barrel region.

d. Resistive Plate Chambers (RPC) for triggering and Z-coordinate measurement in barrel region.

• Develop straightness monitors to study their precision, dynamic range, and stability.

• Engineering studies of the chamber support structure and attachment hardware. This work will culminate in the construction and testing of a prototype where we will evaluate the stability of the structure and study the alignment of chambers mounted in the structure.

To evaluate the various chambers a large cosmic ray test rig has been constructed at the SSC Lab. In addition beam tests are underway at CERN to learn more of the CSC chamber properties and hadron punch-through. We expect to make choices among the various chamber technologies for further concentrated development in the Fall of 1992.

5. Summary

The GEM Muon System is designed to operate at the highest luminosity expected at the SSC. All of the triggering and tracking elements are behind the calorimeter. Good momentum resolution and a reliable trigger are obtained with this design. An R&D program is underway to develop the best chamber tracking and triggering technologies and support structure and alignment systems.

References

* A list of authors may be found in the GEM Letter of Intent, submitted to the SSCL, November 30, 1991; B. Barish and W. Willis, Contact Persons.

[1] E. Dolgosheina, T. Taylor, W.J. Willis, NIM A301 (1991) 451.

[2] R. Cardarelli et al., NIM A263 (1988) 20.

[3] R. Debbe et al., IEEE Trans. on Nucl., Sci. V37, No. 2 (1990); B. Yu et al., BNL-44748 (Oct.1990).

[4] J. Paradiso, GEM-TN-92-124, and GEM TN-92-125; G. Mitselmakher and A. Ostapchuk, "New Approach to Muon System Alignment", GEM Muon Meeting Proceedings, Aug. 4, 1992.

[5] E. Ables, "Results of Wire Detector Tests", GEM Muon Meeting Proceedings, Aug. 4, 1992.

[6] A. Korytov et al., Toroidal Spectrometer Group Progress Report-218 (Sept. 15, 1991).

[7] R. McNeil, GEM TN-92-68 (1992); M. Mohammadi in GEM TN-92-131.

[8] D. M. Lee, R.E. Prael, and L. Waters, GEM TN-92-91.

[9] A. Korytov et al., GEM TN-92-122.