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Physics Motivation for an Improved Tracker for GEM

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Abstract:

In order to take advantage of the "no lose" scenario [1], it is essential that GEM be able to measure the charge of electrons to better than 1 to 10^5 at 250 GeV momentum. The "no lose" scenario points out that if no Higgs is found in the SSC energy range, then the longitudinal W scattering should become strongly interacting and the cross section will be enhanced to a measurable value if unitarity is conserved. An improvement to the present GEM tracker design is suggested which enables the best possible momentum resolution to be achieved under the existing boundary conditions of volume and magnetic field.

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1 Abstract

In order to take advantage of the "no lose" scenario [1], it is essential that GEM be able to measure the charge of electrons to better than 1 in 10^5 at 250 GeV momentum. The "no lose" scenario points out that if no Higgs is found in the SSC energy range, then the longitudinal W scattering should become strongly interacting and the cross section will be enhanced to a measurable value if unitarity is conserved. An improvement to the present GEM tracker design is suggested which enables the best possible momentum resolution to be acheived under the existing boundary conditions of volume and magnetic field.

2 The physics motivation

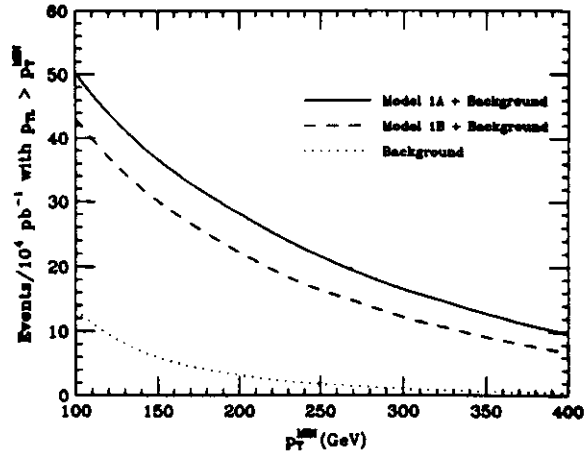
If the SSC is lucky enough to come upon the Higgs particle somewhere in the energy range below 800 GeV, after the initial furor dies down, it will undoubtedly be necessary to search in the $W_L W_L$ channel to check that the cross section is indeed consistent with the mass of the aforementioned Higgs. On the other hand, if there is no Higgs particle to be found, the SSC may not turn up any "New Physics" *without* a measurement of the $W_L W_L$ scattering cross section which, in this case, should be strongly interacting if unitarity is not violated and our present understanding of particle physics is correct.

Figure 1 shows a plot from a recent paper by Berger and Chanowitz [2] where two models of $W_L^+ W_L^+$ scattering modes are described. The signal of two like sign leptons is expected to be on the order of 20 events for stongly interacting W_Ls over a background of about 2 events which has been calculated using a Higgs of 100 GeV. There are additional events to be had from $Z_L Z_L$ and $Z_L W_L$, but the rates are down due to the branching fraction $Br(Z_L \rightarrow l^+ l^-) \approx 3\%$ compared to $Br(W_L \rightarrow l^+ \nu) \approx 11\%$, and also production of Zs is suppressed compared to production of Ws.

Considering, then, only $W_L W_L$ events, the like sign events have a substantial background from 150 million $t\bar{t}$ events. Approximately 3 million events decay:

$$t\bar{t} \rightarrow W^+ W^- b\bar{b} \tag{1}$$

where one b decays to l^+ and one W decays to l^+. Following the estimates of Dicus et al. [3] this background can be reduced to a negligible ($<$ 1 event) level by jet cuts and isolation cuts, although this estimate ignores a number of experimental issues whose effect must be studied.



Events per 10^4 pb^{-1} with $y_t < 2$ and $z < -0.975$ for models 1A and 1B. The branching ratio to electrons and muons is included. Signal curves represent the total number of events (i.e., signal plus background) for $p_{Tt} > p_{T\,MIN}$ as a function of $p_{T\,MIN}$. The dotted line shows the background alone.

Figure 1: $W_L^+ W_L^+$ scattering yield as a function of p_T cut for two different models.

Another potential background, which is totally ignored in the papers by Dicus et al [3], is the 3 million $t\bar{t}$ events where both Ws decay semileptonically and both b quarks decay to jets. If either one of the leptons has its charge misidentified then the event topology in some fraction of the events will look exactly like the signal. An estimate by Wang [4] gives 20,000 as the most optimistic estimate of the number of events remaining, but this could be as high as 100,000 events.

In GEM, the muons are identified with sign selection of $\approx 100\%$ efficiency at 250 GeV, but for electrons the efficiency is only $\approx 97\%$ (2σ sign selection). Taking the most optimistic number, a background of 500 events on a signal of 20 is to be expected. Using muons only, the predicted signal rate is down by a factor 4 amounting to a signal of about 5 events over an irreducible background of equal magnitude. The background from mismeasured $t\bar{t}$ events is negligible for muons due to the much better momentum resolution afforded them.

3 The GEM tracker

In an ideal tracker, some layers are needed close to the beam spot for reconstruction of the beam spot position, which in turn is necessary for momentum resolution. In the middle region, a measurement with high resolution is necessary at the maximum of the sagitta for momentum resolution and then going out in radius, layers here are used mostly for pattern recognition. Finally, at large radius, one or more points are needed with high resolution to complete the measurement over the full lever arm for the maximal momentum resolution. GEM has proposed, at present, the inner and middle sections for their tracker, but the final measurment at the outer layer with high resolution is missing.

The measured quantity is the sagitta, which is given by

$$s = \frac{Bl^2}{266.p_T} \tag{2}$$

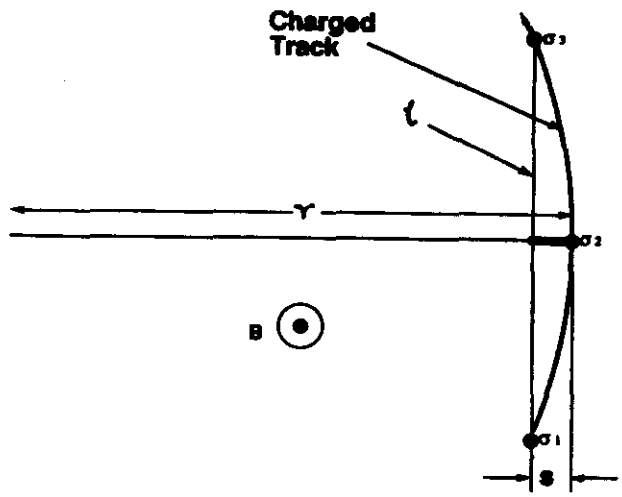


Figure 2: The sagitta, s, of a track segment can be related to the track length, l, and to the radius of curvature, r.

and for l = 0.65 m, p_T = 250 GeV and B = 8 KG, a value of 51μm is acheived. This value is defined by the boundary conditions of the tracker and it is how well we measure this value which determines the momentum resolution. The error on the sagitta is a slightly complicated function of the number of layers, the positioning of those layers and the alignment uncertainties, but using the approximation that for momentum resolution the three important points on the track are at the origin (σ_1 in Figure 2), the mid-point (σ_2) and the outer point (σ_3), the error on the sagitta is given by [5]

$$\delta s = \sqrt{\frac{\sigma_1^2 + \sigma_3^2}{4} + \sigma_2^2} \tag{3}$$

σ_2 and σ_3 are weighted averages over two layers of silicon microstrip with σ_{Si} = 13μm and of IPCs with σ_{IPC} = 56μm per layer respectively and for the present design of six inner layers of silicon microstrip σ_1, the uncertainty in the beam spot measurement is estimated conservatively to be 15μm. The given error for σ_{Si} is composed of 8μm intrinsic resolution added in quadrature with 10μm alignment error. σ_{IPC} is composed of 50μm intrinsic resolution added in quadrature with 25μm alignment error.[1] This yields δs of 23μm. It is easily seen that this puts the 2σ sign selection at approximately 275 GeV meaning that *at least* 2.5% of all tracks above 275 GeV *will* have their charge mismeasured, where this number takes into account only tracks travelling through the central rapidity region of the detector (the full transverse distance through the magnetic field). It should be noted here that to date, the momentum quoted for GEM's 2σ sign selection is 400GeV [7].

[1] We feel it is worth noting that the intrinsic resolution errors are the best possible values which can be obtained from these detectors. Both alignment and intrinsic errors were obtained from reference [6].

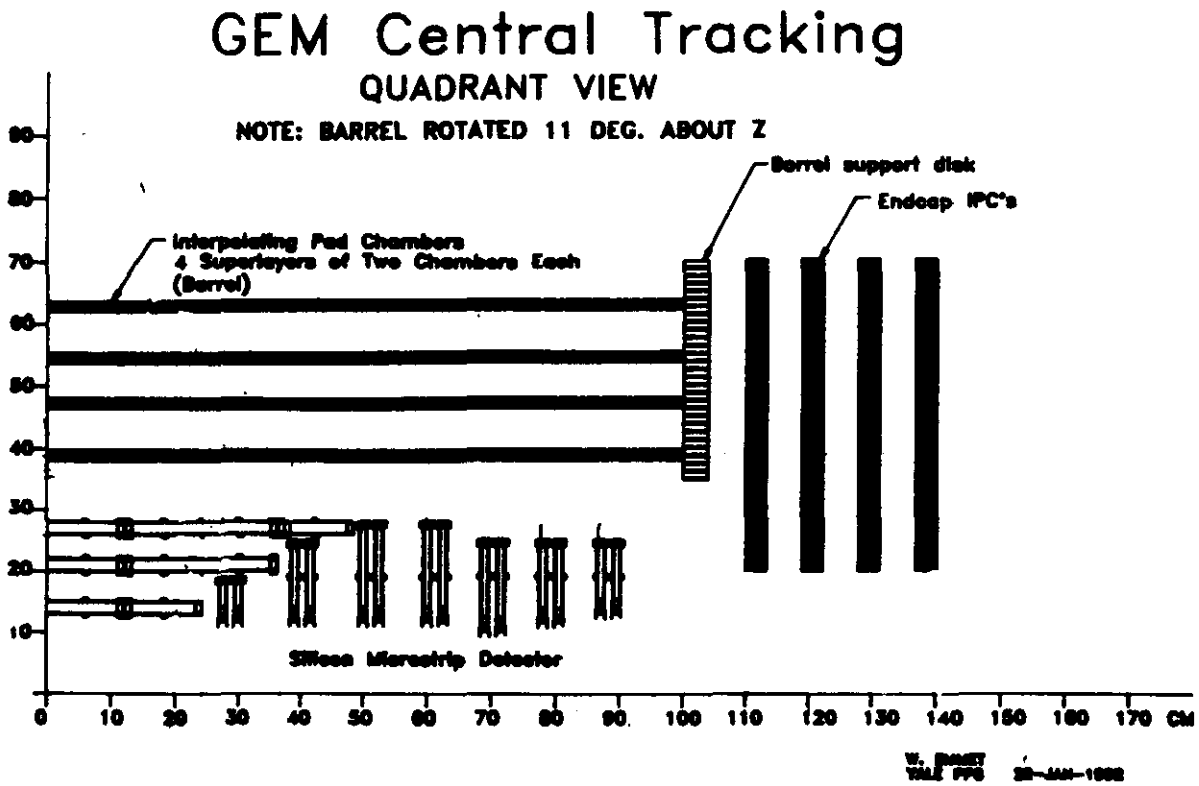


Figure 3: GEM geometry used in the simulation.

4 Simulations

In order to asses how good the "back of the envelope" calculation is here, a GEANT simulation of the GEM tracker was undertaken. The geometry which was used is shown in Figure 3. Tracks of various momenta were sent through the tracker and smeared by the resolutions quoted above depending on the type of detector. Multiple scattering occurred at each layer and the total amount of material was taken to be 10% r.l. for silicon and 10% r.l. for the IPCs. A circle fitter adapted from TASSO was used to fit the points using a vertex contraint as above, and reconstruct the momentum of the track. The results were the same with or without multiple scattering which is to be expected. The results are shown for the measured curvature (1/r) in Figure 4. For a momentum of 275GeV, the mean of the curvature distribution is 2.09σ away from zero (the percentage of wrong sign tracks is about 2% : 2σ sign selection predicts 2.2% of the tracks will have the wrong sign). At a momentum of 400GeV it can be seen that the mean of the curvature is only 1.54σ away from zero (about 7% of tracks have the wrong sign) which disagrees with the number quoted in the GEM LOI. It should be noted also, that this is the ideal situation where only one track is used per event and this track goes at 90 degrees through the detector. No pattern recognition problems are encountered.

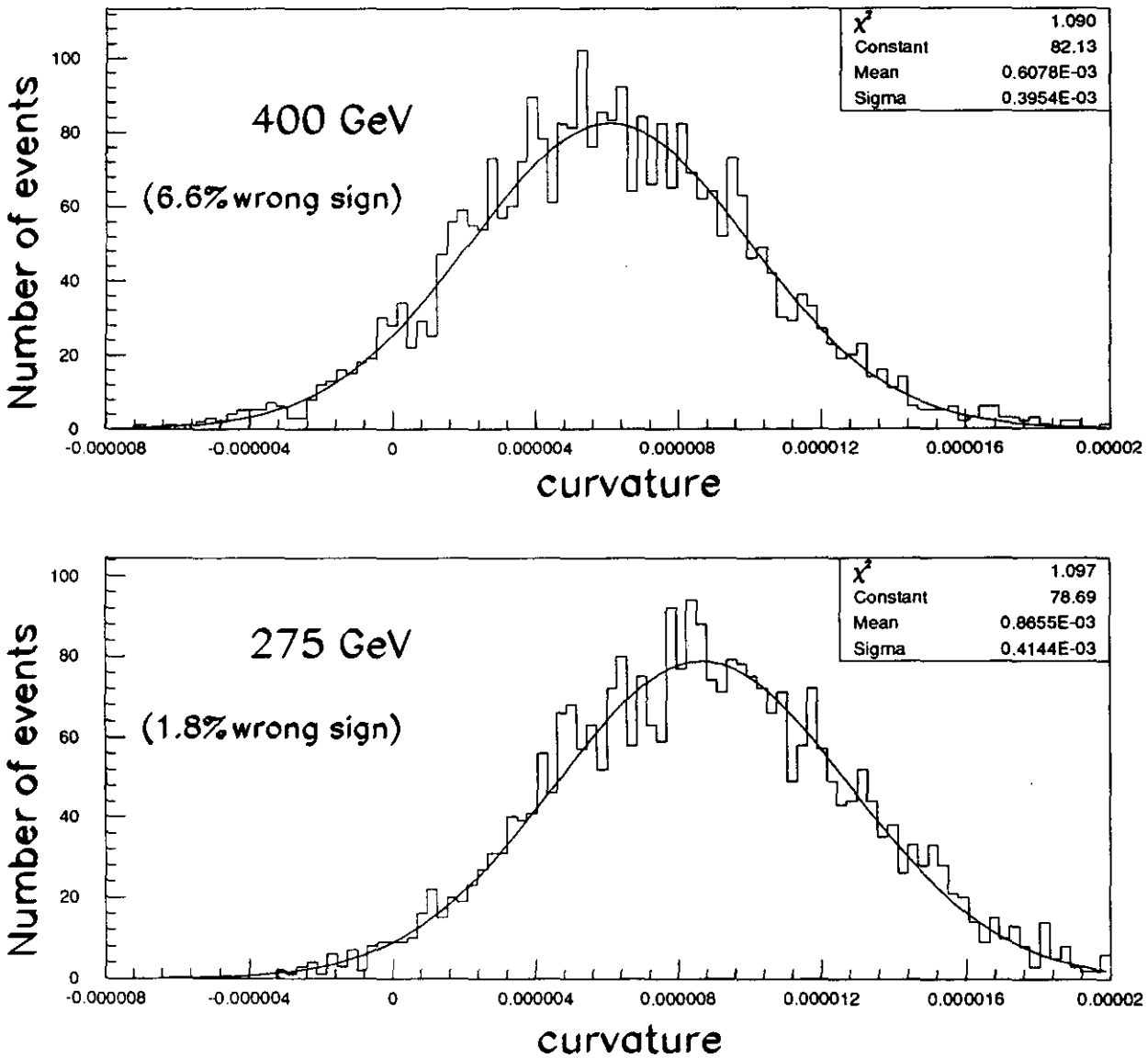


Figure 4: Measured curvature

5 Possible Solutions

There are three possible solutions.

- Higher field
- Larger tracking volume
- Improved tracker

The first option involves a complete redesign of GEM which might be deemed impractical at this stage, and possibly very expensive, although it might be argued that a total redesign could eventually save money. A 20% improvement in the momentum resolution could be achieved by going to the highest possible field available with the present magnet of 10 KG, but this falls very short of that needed for the $W_L W_L$ measurement.

The second option of increasing the tracking volume out to a radius of 1 metre would also mean a change in the GEM geometry, which might also be expensive. The increase in the cost of the IPCs would be minimal as the pads can be made larger for a bigger radius with no increase in the number of channels and no increase in occupancy. If the lever arm were extended to 1m, the sagitta for a 250 GeV p_T track would increase from 51μm to 120μm with a resulting percentage of wrong sign tracks of less than .02%. Quoting a percentage rather than number of sigma reduces any confusion due to the mismeasurement affecting only one side of the curvature distribution and eliminates some of the assumtions about gaussian confidence intervals which are limited in usefulness due to non-gaussian tails.

The third option of improving the tracker also gives a resolution improvement but will be expensive. One outer double layer of silicon microstrip with an intrinsic resolution of 10μm per layer might be imagined. An alignment error of about 25μm must be assumed in this scenario because the alignment error is mostly due to vibrations in the support structure which will be substantial at a radius of 65cm. This produces an effective resolution per layer of 27μm and a resulting sagitta error of 15μm from equation (3), excluding the IPCs from the calculation all together. This resolution results in .04% of wrong sign tracks at 250 GeV. The IPCs in the middle region of the tracking volume are used mainly for pattern recognition, although they can also be used to improve the momentum resolution slightly.

Some combination of options 2 and 3 would clearly give the best possible resolution. For example, an increase in the tracking volume to a radius of 80cm combined with an extra outer double layer of silicon, assuming again 25μm alignment error would improve the sign selection at 250GeV to less than .01% of wrong sign tracks. A careful cost estimate must be done to study the cheapest way to improve the resolution of the GEM tracker, but it is urged that some improvement be attempted in order that GEM will have some chance of doing the $W_L W_L$ scattering experiment.

6 Conclusion

$W_L W_L$ scattering cannot be done with the GEM detector because of the poor sign selection capability of the present tracker design. A more detailed analysis is certainly necessary to make a

convincing case to spend more money on the tracker in order to be able to make this measurement. In addition, further studies of this process in other parts of the detector such as those pertaining to b jet finding and lepton isolation are needed and will be carried out in the near future. Because the tracker is limited by a low field and a small volume, it is the main shortfall of the otherwise all-purpose GEM detector. It is urged that more money be found to improve the tracker so that a measurement of the very important $W_L W_L$ scattering experiment be possible if indeed the signal is measureable.

References

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