GEM TN-92-243

Simulation of Various GEM Forward Calorimeter Options Using a Mixture Level Description of the Detector

Michael Shupe
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December 3, 1992

Abstract:

Seven representative forward calorimeter options for GEM are simulated in order to map out the behavior of the P and Pt response function for different placements and various beam hole sizes.

SIMULATION OF VARIOUS GEM FORWARD CALORIMETER OPTIONS USING A MIXTURE LEVEL DESCRIPTION OF THE DETECTOR

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I. Overview: GEM Calorimeter Mixture Level Description in GEANT

At Arizona, we are using a newly developed package, UAZMIX, which simulates the GEM Baseline II calorimeter as a set of "mixture" volumes. That is, sensitive volumes such as the EM accordion and the FH and OH sections are each described as a homogeneous mixture of atoms, including absorber, sensitive medium, structural, and electrode materials. Mixture descriptions run considerably faster than those where all the pieces are individual GEANT volumes. We are currently running GEANT 3.14 with standard cuts, and using GHEISHA for hadronic showers.

All volumes are described as TUBE or CONE shapes with no cracks in phi. These shapes are used for calorimeter sensitive volumes, cryostat walls, beam structures, major structural members, central tracking chambers, and muon chambers. Many of these reduce to cylinders or "washers" by changing dimensions of the basic TUBE shape. No provision is made for misalignment: the detector is perfect in this description. In reality the GEM EM calorimeter has no phi cracks, nor does the forward calorimeter. The hadronic calorimeter sections may have cracks, but we assume at this level that their effect is negligible compared to intrinsic shower fluctuations. So TUBE and CONE volumes are used to represent entire sections: CCEM, CCFH, ECEM, ECFH, ECCH, FCXX, etc.

Segmentation will be included in the near future, but was not used in the current study. In the forward region we expect segmentation to make little difference (within the range of designs which have been proposed), because the Pt resolution is dominated by the theta resolution, which in turn is dominated by fluctuations in transverse hadronic shower development.

Mixtures correctly model hadronic shower fluctuations due to binding energy losses and neutrinos, but will otherwise act as fully sampling detectors. Mixtures do not model sampling fraction or sampling frequency effects, and will thus get resolutions, e/h and e/MIP wrong.

Tuning of the mixtures must be done by (in descending order of attractiveness): (A) Using test beam data, and/or, (B) Detailed GEANT simulations, and/or, (C) Guessing. For the current study, the method used was (C). This will improve as results become available from the other sources.

II. The Method of the Current Study

The following sequence of steps was taken in performing the current simulation:

A. 200 GeV pi-plus showers were generated over the eta range from zero to 7.0. The aim of this study is to map out the influence of dead material and edges on the Pt resolution and to find the magnitude of the Pt crossover effect. In the future, studies will be done at different energies to look at the energy dependence of these effects. For each event, one pion was given to GEANT and showered using GHEISHA.

B. For each event, sums were formed for each sensitive volume of the components of energy Ex, Ey, and Ez (energy is NOT a vector, but who cares?). The sums are maintained separately for EM and hadronic energy. The mixtures measure the EM energy perfectly, and the hadronic energy is subject to nuclear binding losses and other losses, and their fluctuations.

C. At the end of each event, the summed energies are treated to several steps of correction. The first is to restore the response to that of a fully compensating detector. This is done by multiplying the hadronic energy in each volume by a boost factor to make up for the binding losses. This boost factor is mixture dependent (slightly), and was determined from separate simulation runs. The following were found from these runs:

		BOOST
EM accordion	- Pb/liquid krypton	2.22
EM accordion	- Pb/liquid argon	2.00
Fine hadronic	- Pb/liquid krypton	2.01
Fine hadronic	- Cu/liquid argon	2.00
Coar. hadronic	- (unknown)	2.00
Outer hadronic	- Cu/scintillator	2.00
Forw. hadronic	- W/liquid argon	1.94

D. As the next step of energy correction, the hadronic energies were divided by the assumed e/h factor for each mixture. The following guesses were used:

		e/h
EM accordion	- Pb/liquid krypton	1.8
EM accordion	- Pb/liquid argon	1.8
Fine hadronic	- Pb/liquid krypton	1.6
Fine hadronic	- Cu/liquid argon	1.8
Coar hadronic	- (unknown)	1.4
Outer hadronic	- Cu/scintillator	1.2
Forw. hadronic	- W/liquid argon	1.4

Note that one could have been more realistic my multiplying the EM energy by e/MIP times the dE/dx weighted sampling fraction, and the hadronic energy by the dE/dx weighted sampling fraction alone, but the current method takes all these "into account" and leaves the EM energy calibrated. This makes quick scanning of the results less confusing, and amounts to nothing more than an arbitrary choice of scale--a calibration constant applying to the whole detector.

E. As the final step of correction, the EM and hadronic energies in each volume are smeared by the expected EM and hadronic stochastic terms (respectively), then summed and smeared by the constant term --thus, in quadrature. The following were assumed:

		EM-samp	Had-samp	Const
EM accordion	- Pb/liquid krypton	.06	.60	.004
EM accordion	- Pb/liquid argon	.075	.60	.004
Fine hadronic	- Pb/liquid krypton	.16	.60	.02
Fine hadronic	- Cu/liquid argon	.16	.60	.02
Coar. hadronic	- (unknown)	.16	.60	.02
Outer hadronic	- Cu/scintillator	.16	.60	.02
Forw. hadronic	- W/liquid argon	.40	.80	.04

As with the e/h factors, these need to be tuned from test beam and detailed GEANT simulation. The hadronic sampling smearings are intentionally lower that the full observed smearing. Recall that the EM energy is unsmeared by mixtures, so all smearing comes from the EM-samp factor, whereas the hadronic energy is already subject to binding energy fluctuations, so the Had-samp factor must combine in quadrature to give the total net resolution on the hadronic component.

F. The corrected energies from each sensitive volume are then treated as 3-vectors and summed to give the momentum vector for the event. Since events consist in this case of single particle showers, the resultant is the measured momentum vector corresponding to the 200 GeV pion incident at the eta and phi of the event.

G. Histograms are made of P-observed vs. eta and Pt-observed/sin(theta-generated) vs. eta as the run progresses. The first is sensitive to all three components of momentum, and the latter, just to the x-y components. Both are useful for understanding the detector response. The latter is divided by sin(theta) as a convenience, so that it lies on the same general line as P-observed.

H. As a generation run is made, histogram files are written to disk every 50 events so that they may be analyzed while the run is in progress until sufficient statistics have been accumulated. A second pass program reads the histogram file to calculate P, Pt, and dPt/Pt for each eta bin of the two-dimensional histogram from the one dimensional histogram in that bin.

III. Description of the Simulated Options

The following options have evolved from a systematic categorization of the GEM forward calorimeter possibilities by John Rutherfoord and the author, and from design work on Baseline II by David Lissauer, Howard Gordon, Bill Willis, Lyle Mason, and others. The list is still under development, as new ideas occur to people, and we expect to be simulating new or refined options in the future.

It should be noted that for speed and convenience we have mapped out all options with tungsten/liquid-argon modules, but that we have at the same time covered the possibilities which would be accessible to a liquid scintillator or quartz fiber forward calorimeter. This will be pointed out in the options below as the discussion proceeds.

In the current study, the following have been simulated:

1. Option 1 - Near FCAL with small (5 cm diameter) cold wall beampipe if liquid argon, or a warm wall beampipe otherwise. In either case, the sensitive calorimeter begins just outside this pipe. This option is a benchmark, and is close to what we would desire if the some of the current engineering constraints on the beam pipe can be overcome. In this option the eta=3 transition is cylindrical with projective edges on the individual endcap calorimeter modules (see picture).

2. Option 3 - Near FCAL with 8 cm diameter warm wall beampipe and the sensitive FCAL edge at 12 cm diameter. This represents the opposite extreme: a beam pipe large enough to satisfy all engineering constraints with margin to spare, for the FCAL option. Same eta=3 treatment as option 1. (Option 2 was not simulated this round. It has an intermediate beam pipe diameter.)

3. Option 4 - Same as option 1, but with a conical eta=3 transition to compare dead material and Pt crossover effects in that region. (Options 5 and 6 have the beam pipe diameters of 2 and 3, and were not simulated this round.)

4. Option 7 - This option is closest to the Baseline II design. It includes a small FCAL module integral to the endcap with inner edge at 12 cm diameter (corresponding to the "large" pipe in the above options), backed by a "medium" pipe 8 cm diameter calorimeter. Though simulated as W/LAr, this edge is at the same place as the edge for a W/liq-scint or W/quartz-fiber warm wall calorimeter. The edge response function for this option will be almost technology independent assuming these dimensions are maintained for the sensitive volumes. Cylindrical eta=3 transition. (Option 8, with conical eta=3 not simulated.)

5. Option 9 - Far FCAL with a conical transition at eta=3 between the endcap and forward calorimeter. In this option the FCAL is nested in the front of the field shaper. It's sensitive radius is 10 cm larger than the radius where the eta=3 line intercepts the front face. The inner FCAL diameter is 12 cm in this and all other options, corresponding to the conservative beampipe. The purpose of these far FCAL options is to see if eta coverage can be recovered by getting farther from the interaction region if we are forced to the large beam pipe diameter.

6. Option 10 - Far FCAL. Endcap has cylindrical transition at eta=3 (with "coverage" to eta=3.8). FCAL picks up at eta=3.6 (with 10 cm outer radius margin as in 9).

7. Option 11 - Near AND far FCAL. Endcap as in option 1. Near FCAL ends with conical transition at eta=4.4. Far FCAL picks up at 4.4 (plus 10 cm outer radius margin, as usual).

IV. Comparison of the Options. Observations.

On the following pages, each option is shown, along with its P response, its Pt/sin(theta) response, and dPt/Pt, all as functions of eta. All options have been run so far for about 200 events per bin of eta (with the exception of 7, which has about 100 events per bin due to a hardware induced bomb). This is sufficient statistics to show the effects of the transition region at eta=1.2 and the various transitions starting at eta=3.0 in all plots.

Much can be learned by comparing the P and Pt response plots. The P response is degraded by three effects: losses in dead materials, punchthrough out the back of the calorimeter, and losses out cracks. (The only possible "cracks" in these options appear to be in the transition to the far FCAL in those options which have one, and this issue will be investigated by summing the energy there.) The Pt response however includes one additional effect: Pt "feeddown" or "crossover." When edges are present, the spray from these edges will usually intercept the detector face on the same side of the beam at higher eta, or may even cross to the other side of the beam line. Thus, the Pt response curve should mirror the P response if this is negligible, and be worse than the P response if it is not. Both cases are seen in the options simulated.

Summary, going option by option:

Option 1 -
1. P response shows small effects at eta=1.2 and eta=4.0 due to cylindrical transition.
2. Pt response exhibits some Pt crossover at eta=4.0.
3. dPt/Pt acceptable to about eta=5.7.

Option 3 -
1. Same P and Pt effects within statistics (no change in this region).
2. Large beam pipe moves the eta coverage edge in to 5.0.

Option 4 -
1. Same eta coverage as option 1, as expected.
2. P and Pt response dip moved down to eta=3.0 by change to conical transition, but may not be lessened compared to 1.
3. Hard to tell if Pt crossover has been reduced compared to 1. More statistics will help.

Option 7 -

1. P and Pt response show some drooping at high eta compared to other options. May just amount to a calibration adjustment vs. eta.
2. Eta coverage to 5.3 or 5.4, intermediate between 1 and 3, as expected.

Option 9 -

1. P, Pt and dPt/Pt all show effects of leakage out the transition at eta=3.0 and crossover due to the long lever arm to the front face of the far FCAL.
2. Eta coverage to 5.8, comparable to option 1, as hoped.

Option 10 -

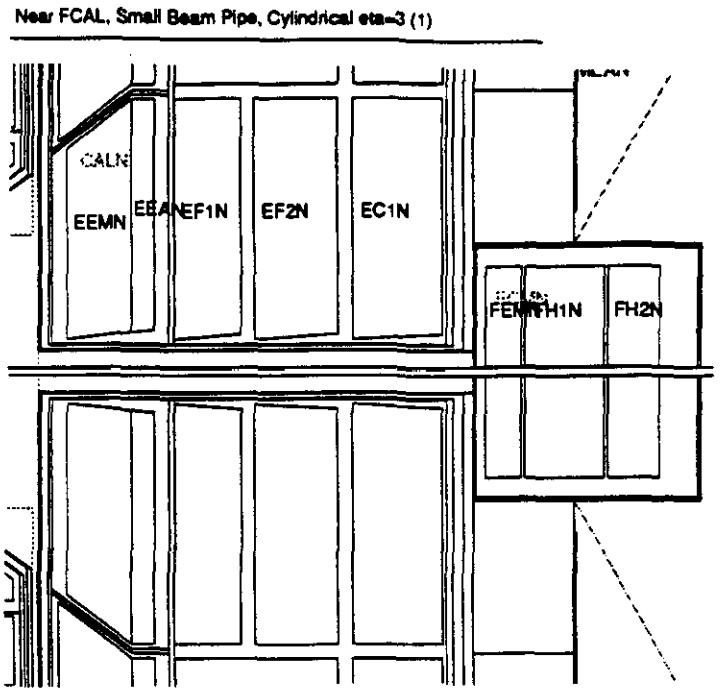
1. Similar P, Pt, and dPt/Pt effects as 9, but now at eta=3.8.
2. Simular eta coverage to 9.

Option 11 -

1. Similar P, Pt, and dPt/Pt effects as 9, but now at eta=4.0.
2. Simular eta coverage to 9, but dPt/Pt distribution may be choppier. Statistics will help here.

V. Conclusion

None of the more "realistic" options look particularly good at present. All the far FCAL designs suffer from leakage and/or Pt crossover at the transition. Making the far FCAL bigger will drive up the cost. The near designs with large beam pipe lose .4 to .8 units in rapidity compared to the 5 cm diameter version, and this may hurt the missing Et physics. We should press on all fronts to improve the far FCAL options while at the same time working with the engineers on the beam pipe design to see if the smallest acceptable pipe has actually been achieved.


Near FCAL, Small Beam Pipe, Cylindrical eta=3 (1)
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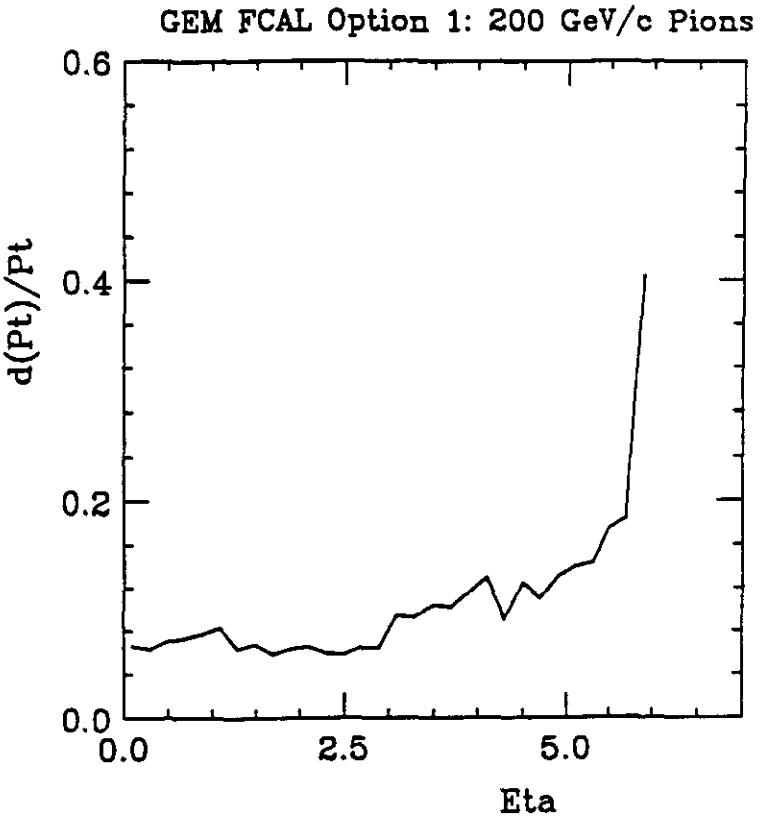
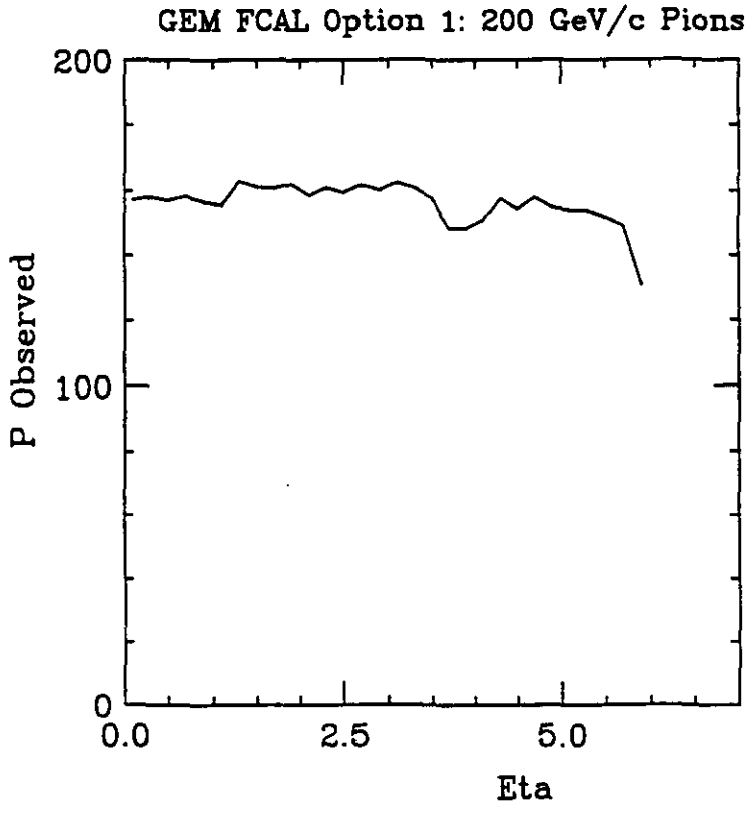
EF1N
EF2N
EC1N
FH1N
FH2N


GEM FCAL Option 1: 200 GeV/c Pions
d(Pt)/Pt
0.0
0.2
0.4
0.6
0.0
2.5
5.0
Eta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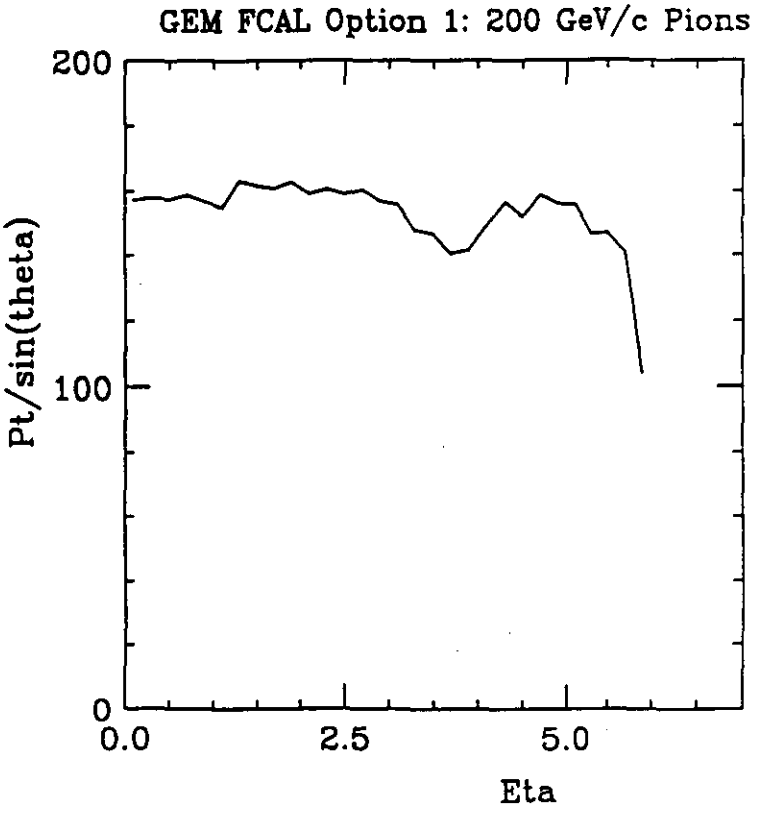
P Observed
0
100
200
0.0
2.5
5.0
Eta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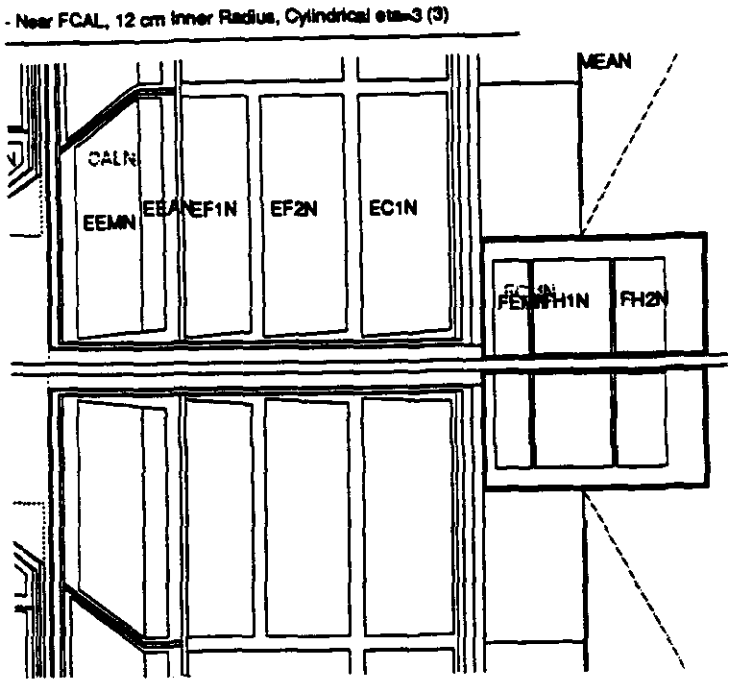
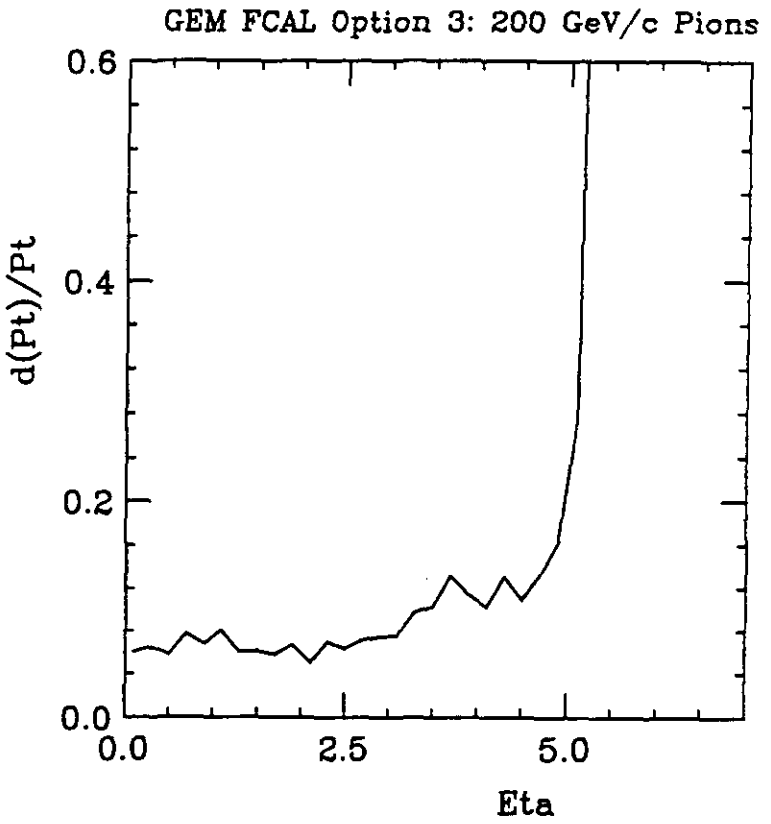
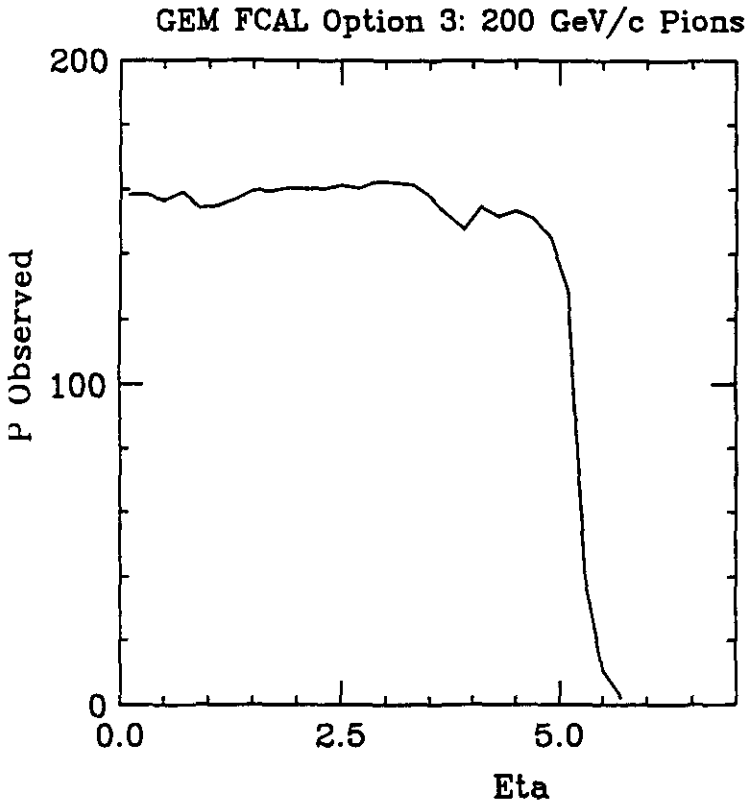
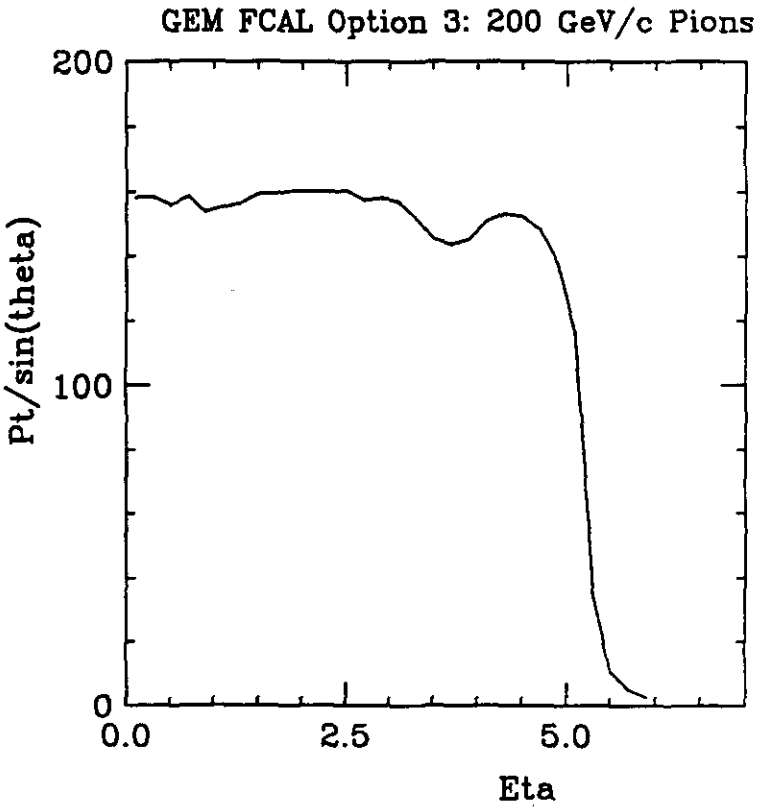
Pt/sin(theta)
0
100
200
0.0
2.5
5.0
Eta


- Near FCAL, 12 cm Inner Radius, Cylindrical eta=3 (3)
MEAN
CALN
EEMN
EEAN
EF1N
EF2N
EC1N
FH1N
FH2N


GEM FCAL Option 3: 200 GeV/c Pions
d(Pt)/Pt
0.6
0.4
0.2
0.0
0.0
2.5
5.0
Eta


GEM FCAL Option 3: 200 GeV/c Pions
P Observed
200
100
0
0.0
2.5
5.0
Eta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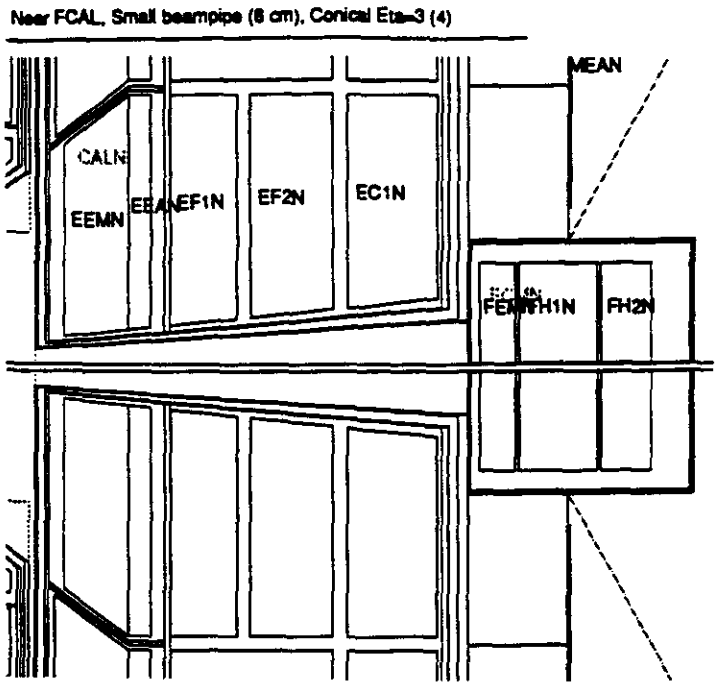
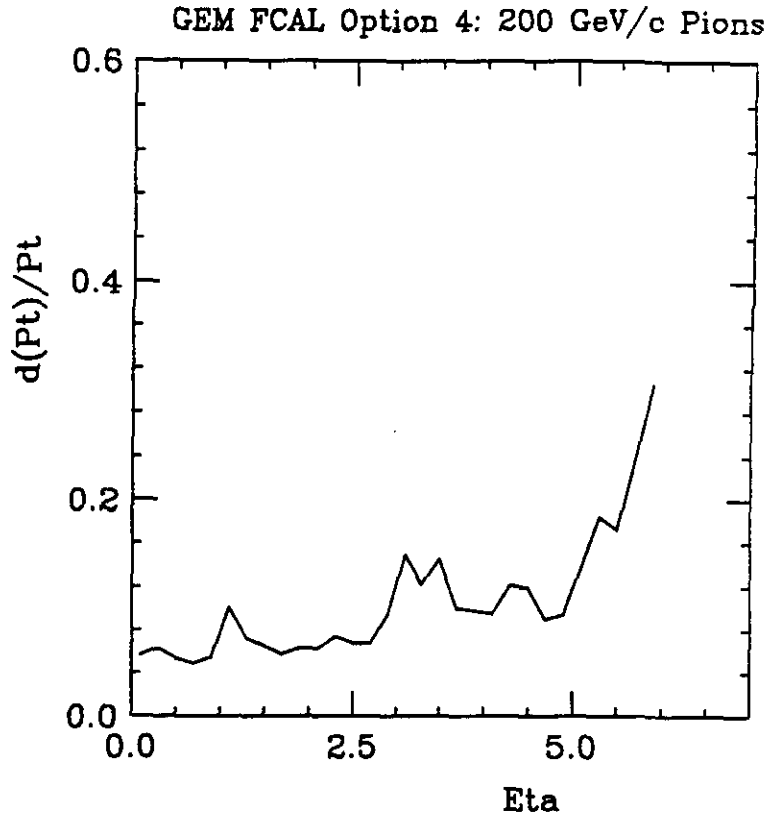
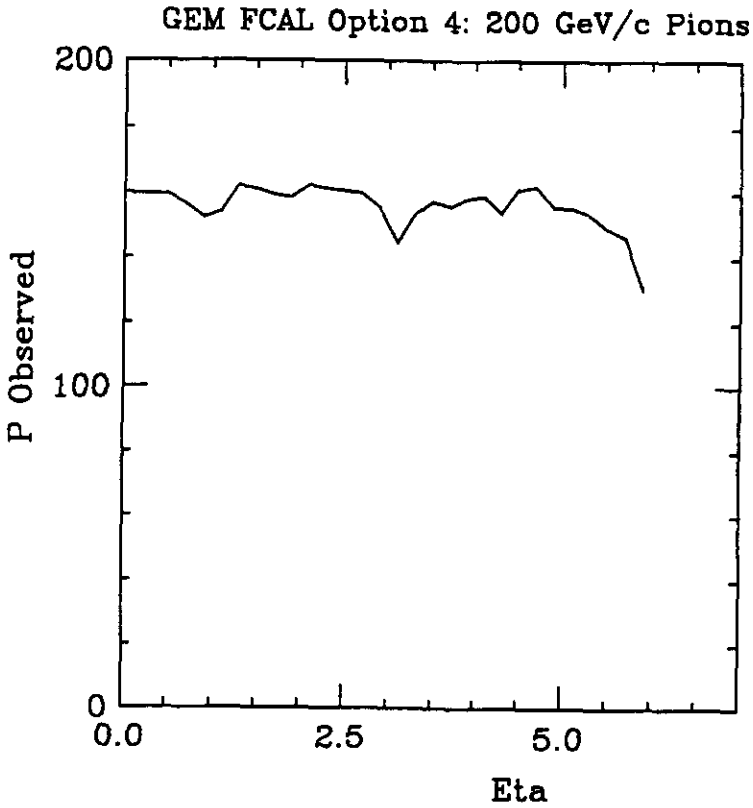
Pt/sin(theta)
200
100
0
0.0
2.5
5.0
Eta


Near FCAL, Small beampipe (8 cm), Conical Eta=3 (4)
MEAN
CALN
EEMN
EEAN
EF1N
EF2N
EC1N
FEMN
FH1N
FH2N


GEM FCAL Option 4: 200 GeV/c Pions
d(Pt)/Pt
0.0
0.2
0.4
0.6
0.0
2.5
5.0
Eta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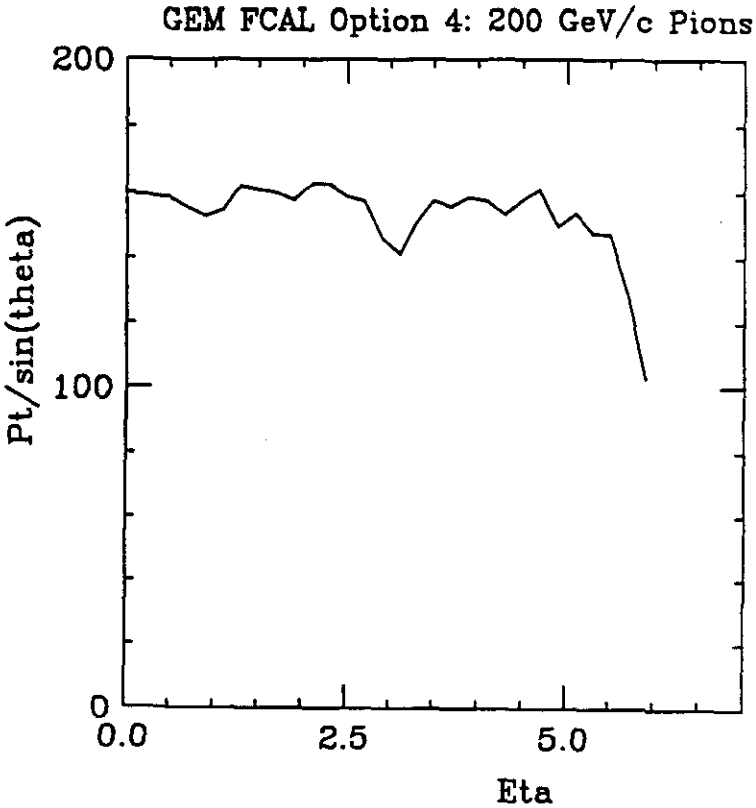
P Observed
0
100
200
0.0
2.5
5.0
Eta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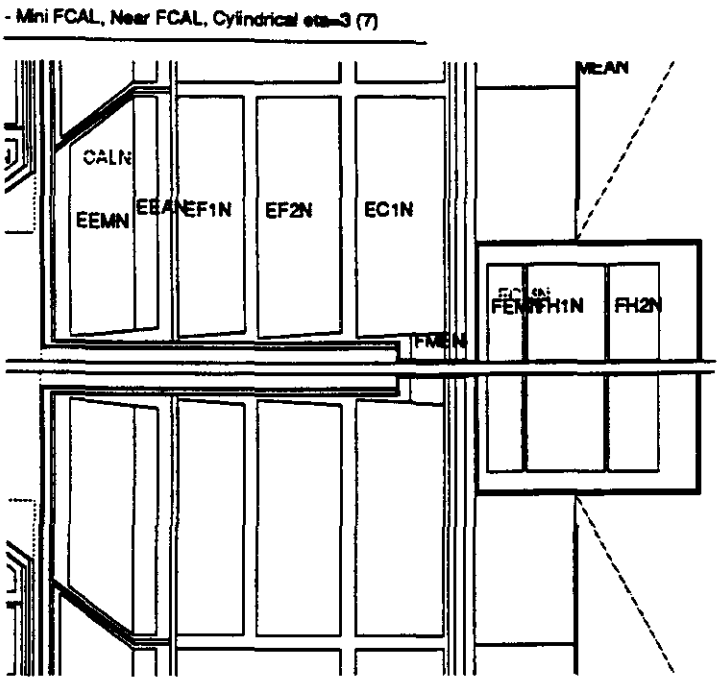
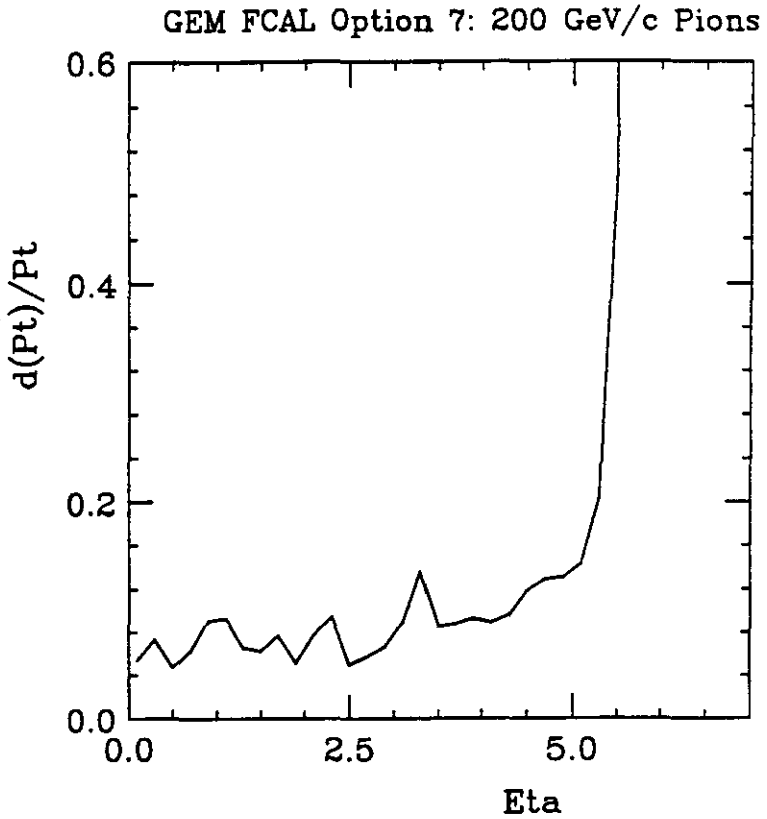
Pt/sin(theta)
0
100
200
0.0
2.5
5.0
Eta


- Mini FCAL, Near FCAL, Cylindrical eta=3 (7)
MEAN
CALN
EEMN
EEAN
EF1N
EF2N
EC1N
FEMN
FH1N
FH2N
FMEN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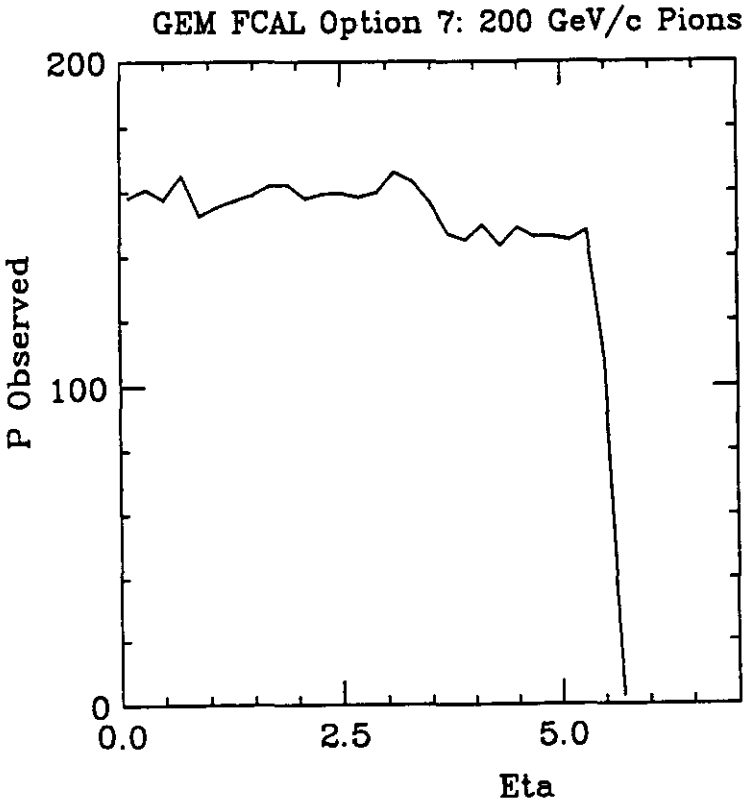
d(Pt)/Pt
0.0
0.2
0.4
0.6
0.0
2.5
5.0
Eta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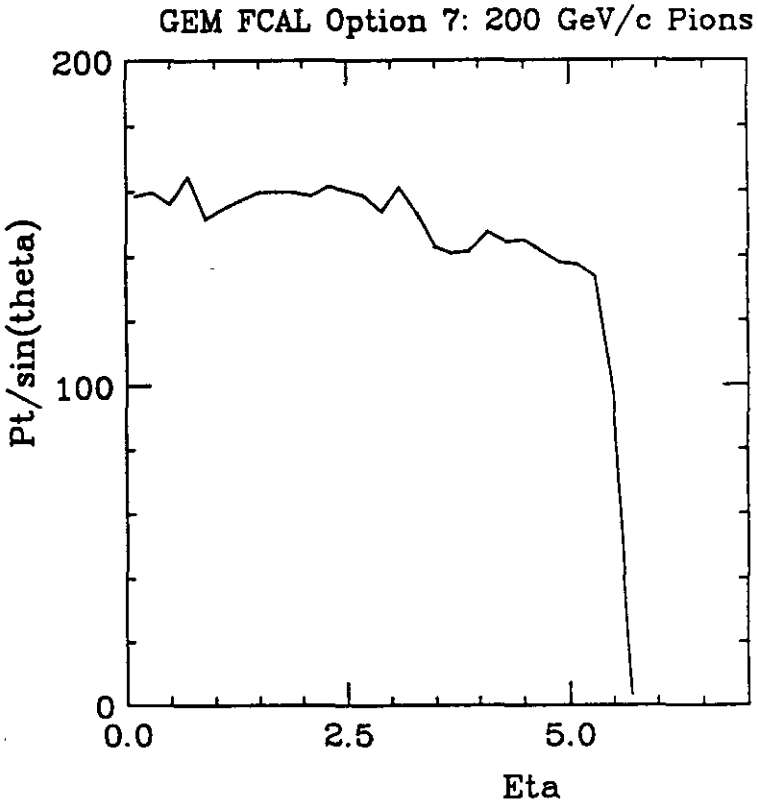
P Observed
0
100
200
0.0
2.5
5.0
Eta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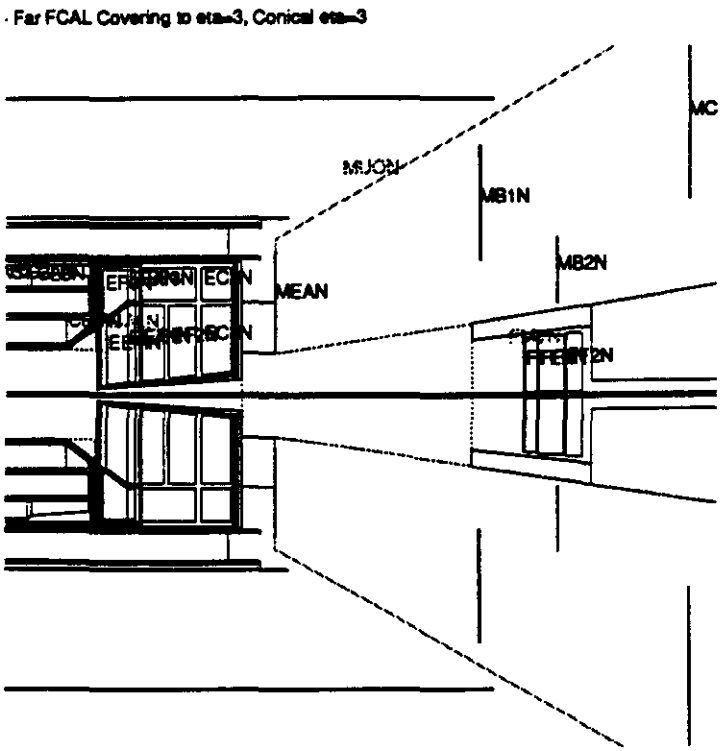
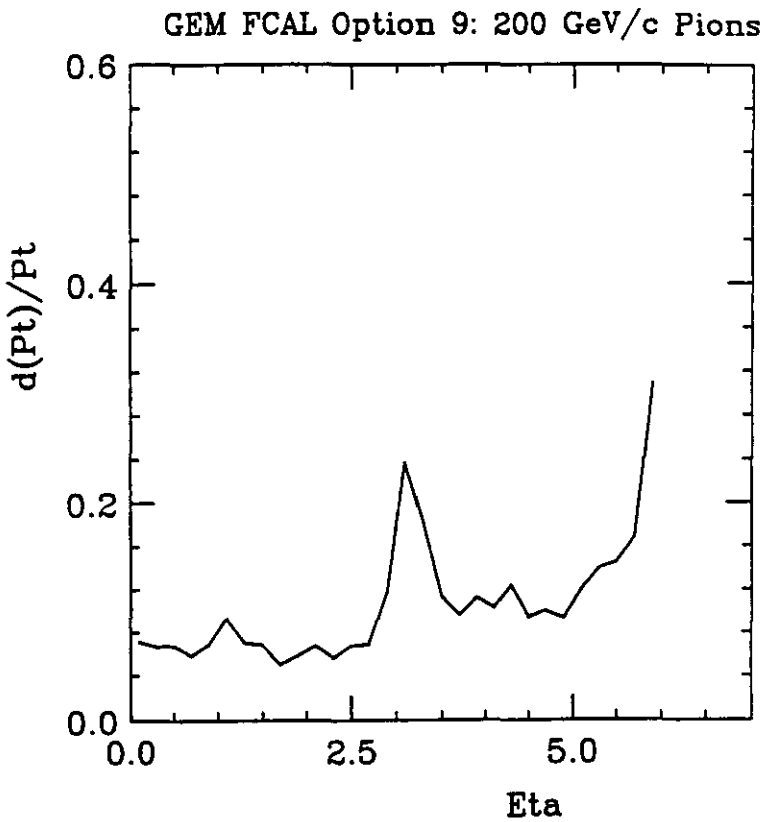
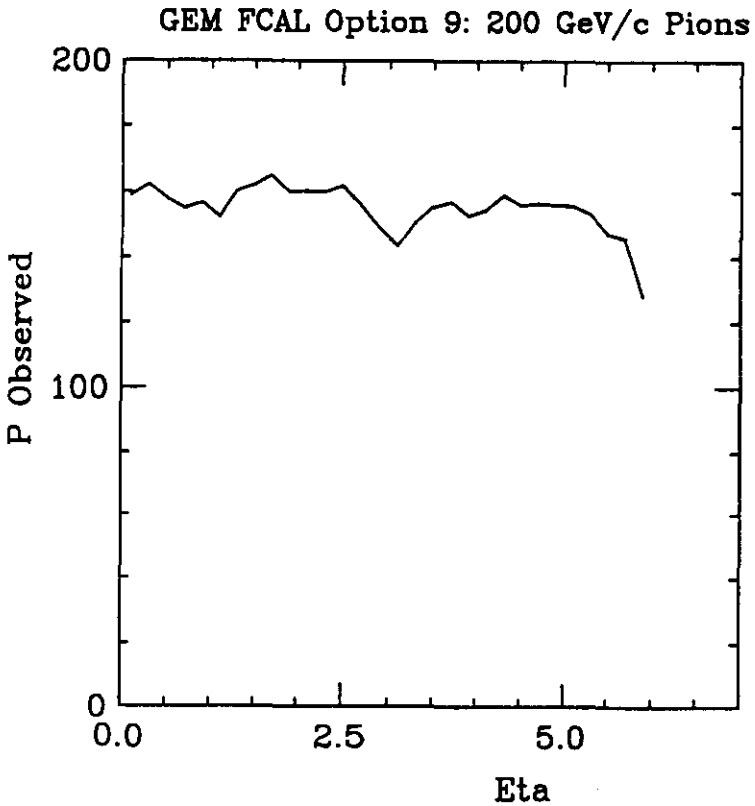
Pt/sin(theta)
0
100
200
0.0
2.5
5.0
Eta


Far FCAL Covering to eta=3, Conical eta=3
MC
MB1N
MB2N
MEAN


GEM FCAL Option 9: 200 GeV/c Pions
d(Pt)/Pt
0.0
0.2
0.4
0.6
0.0
2.5
5.0
Eta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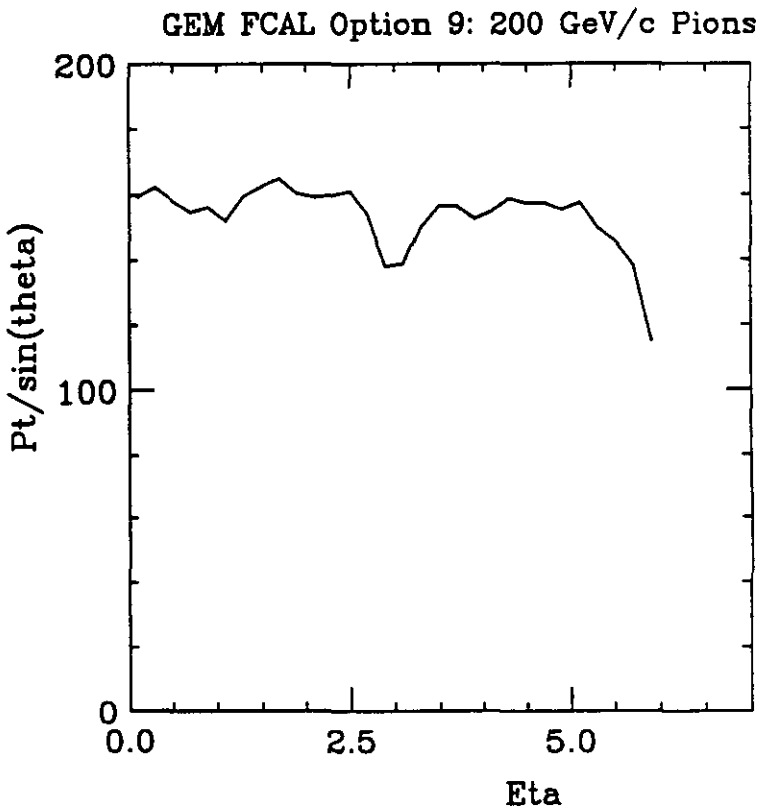
P Observed
0
100
200
0.0
2.5
5.0
Eta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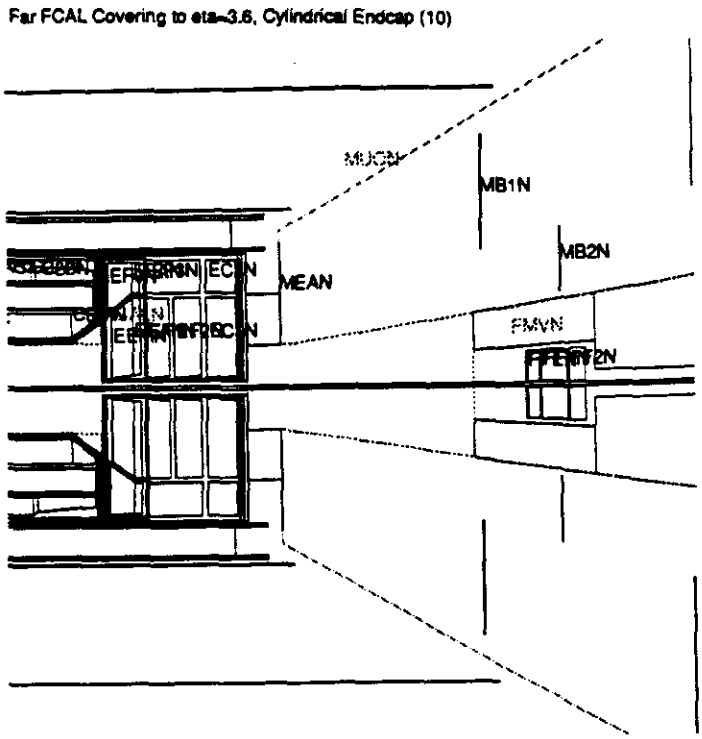
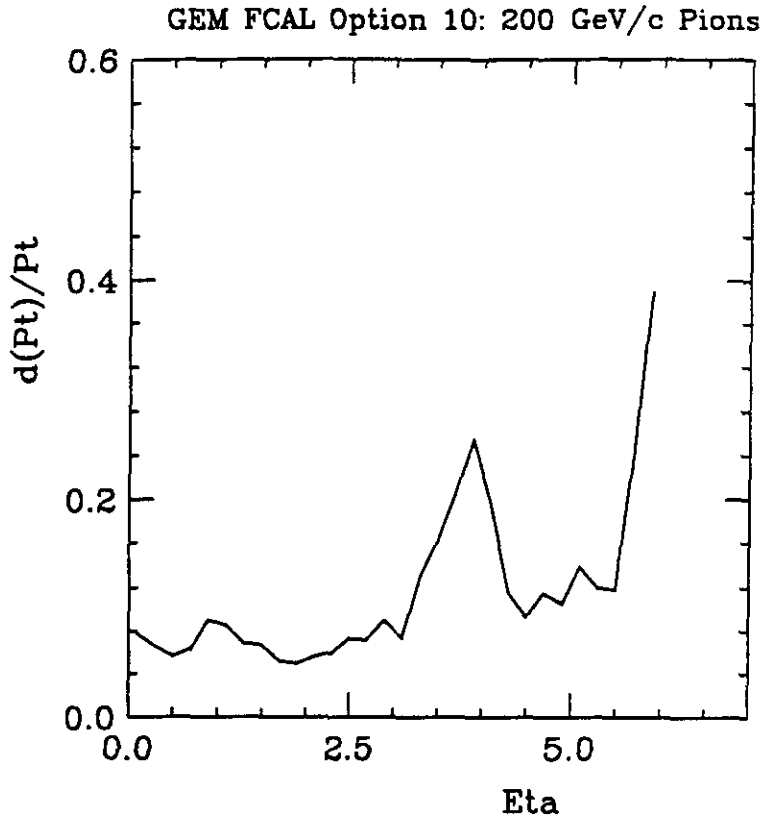
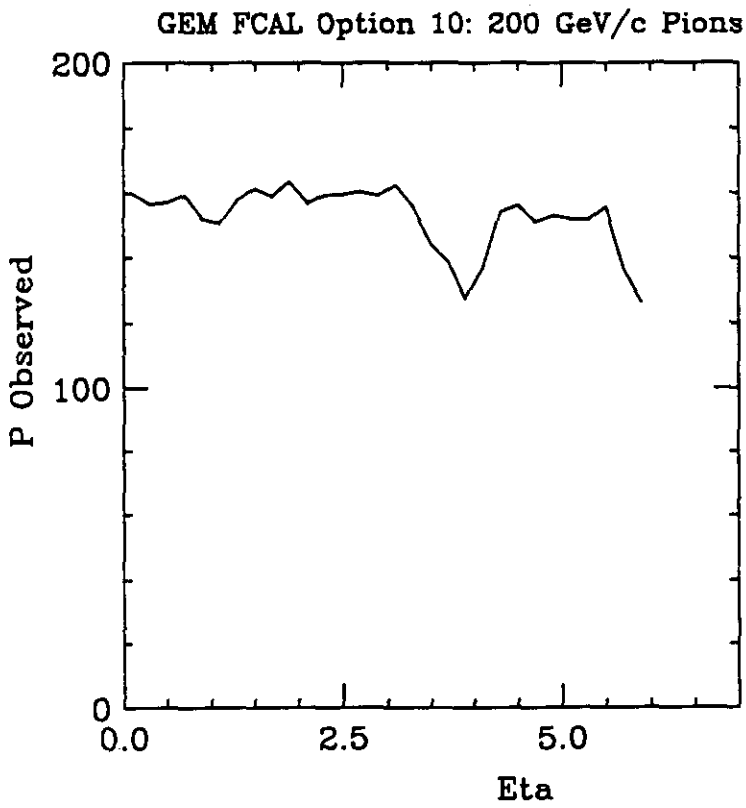
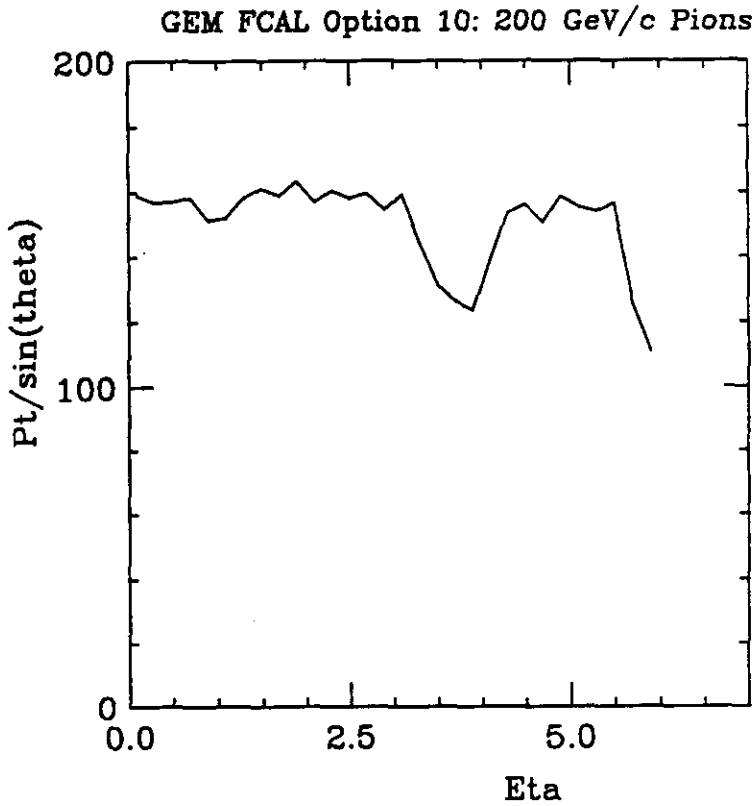
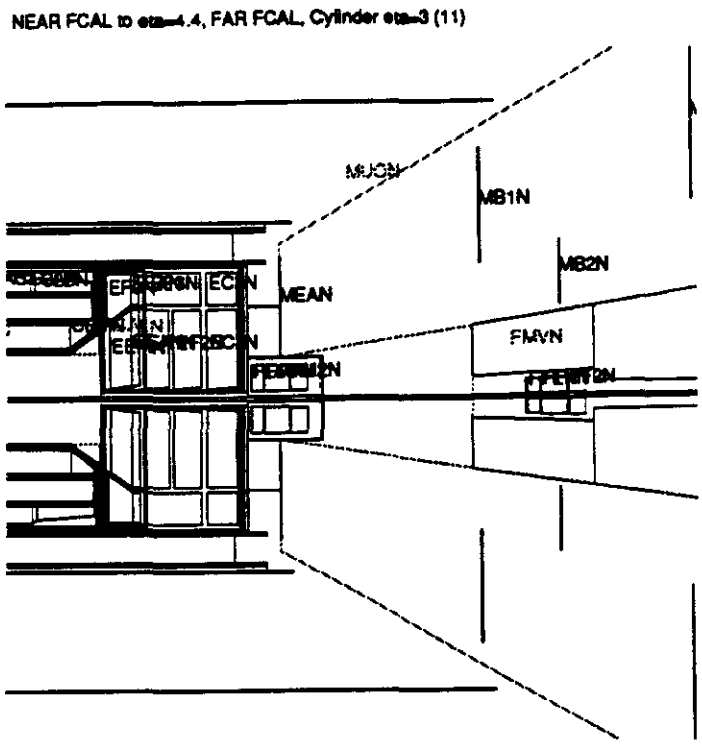
Pt/sin(theta)
0
100
200
0.0
2.5
5.0
Eta

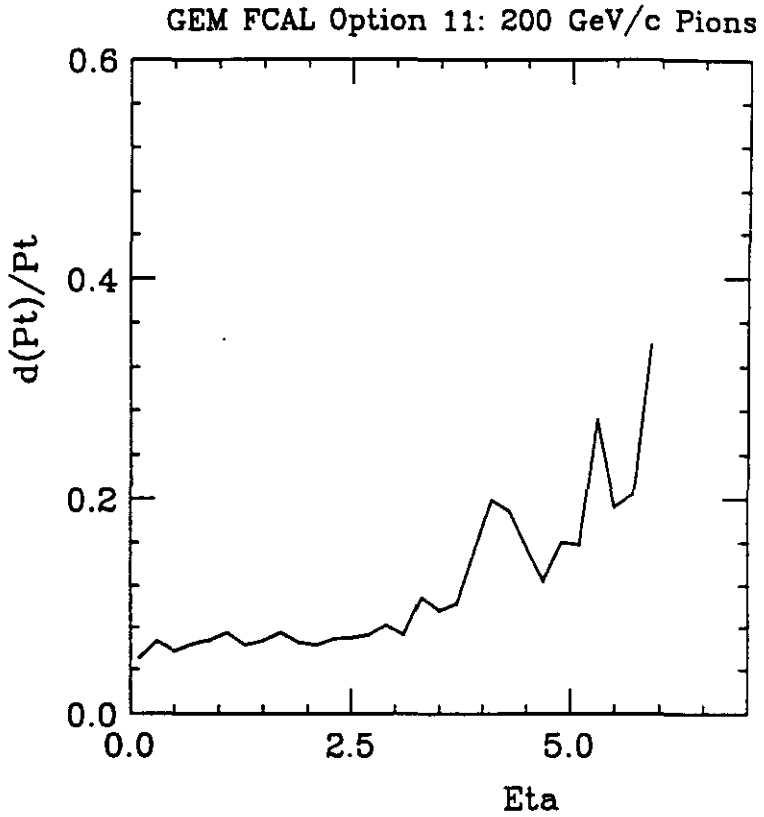

Far FCAL Covering to eta=3.6, Cylindrical Endcap (10)
MB1N
MB2N
MEAN
FMVN

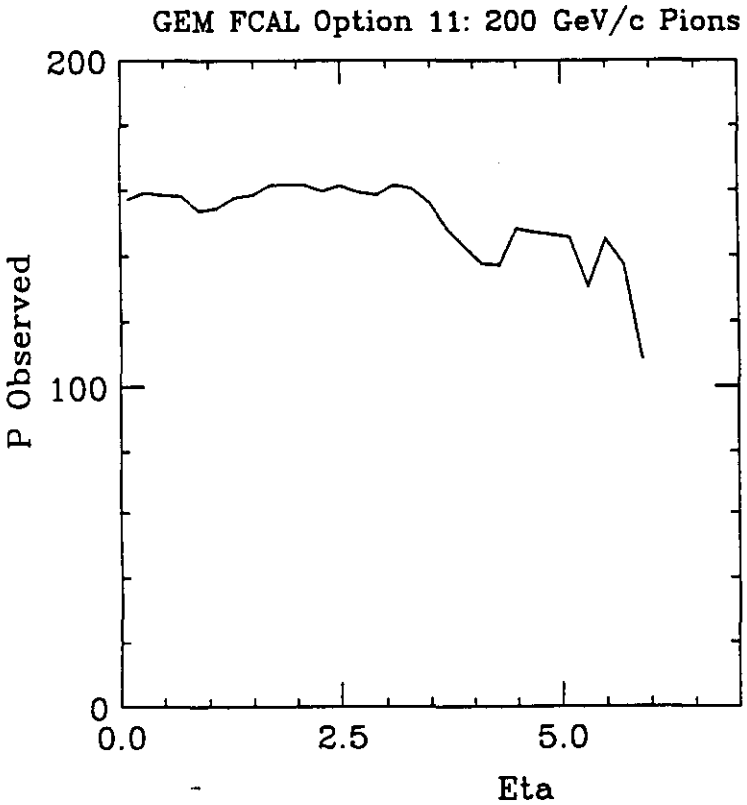

GEM FCAL Option 10: 200 GeV/c Pions
d(Pt)/Pt
0.6
0.4
0.2
0.0
0.0
2.5
5.0
Eta

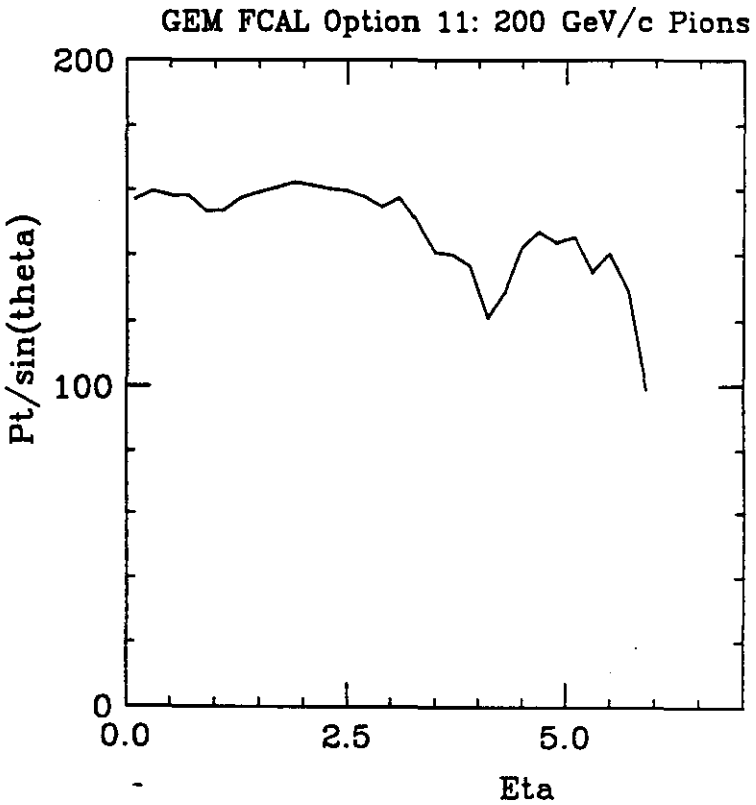

GEM FCAL Option 10: 200 GeV/c Pions
P Observed
200
100
0
0.0
2.5
5.0
Eta


GEM FCAL Option 10: 200 GeV/c Pions
Pt/sin(theta)
200
100
0
0.0
2.5
5.0
Eta


NEAR FCAL to eta=4.4, FAR FCAL, Cylinder eta=3 (11)
MB1N
MB2N
MEAN
FMVN


GEM FCAL Option 11: 200 GeV/c Pions
d(Pt)/Pt
0.0
0.2
0.4
0.6
0.0
2.5
5.0
Eta


GEM FCAL Option 11: 200 GeV/c Pions
P Observed
0
100
200
0.0
2.5
5.0
Eta


GEM FCAL Option 11: 200 GeV/c Pions
Pt/sin(theta)
0
100
200
0.0
2.5
5.0
Eta