

Status of Systematic MCS momentum measurement

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Contents

- Consistency check by Spectrometer
 - Using 80 tracks(57 muon and 23 others)
- Module 1,3 and 8
 - Module 1: 293 out of 363 tracks has tried
 - Rest of them are down stream event or short tracks
 - Module 3 : 99 out of 124 tracks has tried
 - Module 8 : 126 out of 189 tracks has tried
- Module by module systematic
- Summary and Outlook

Keywords in this analysis

- **Cell : cell length**
 - To get a single scattering information, we need 3 plate. In the case of using every series of plate, cell is 1(p11-2-3). Using every two plate cell=2(p11-3-5),. Then cell=3(p11-4-7).
 - Then, to get one cell=3 data, we need at least series of 7 plates.
- **Limit : Maximum detectable momentum for a m-file.**
 - Maximum detectable momentum is defined from the maximum cell length where could get in the data.
 - Note : In this analysis, maximum cell length has no direct link to number of plate in a m-file. Because, data has taken along a track. (See next slide)
 - Limit is defined where maximum cell's 2nd difference will have factor 2 larger 2nd difference than that of cell=1. And also depend on module type because X_0 and Gap is difference.

$$Limit = \frac{0.0136}{\sqrt{3/2} \left(\sqrt{3} \Delta Y_{CELL=1} \right)} \Delta x_{CELL=n} \sqrt{\frac{X_{CELL=n}}{X_0}} + 0.038 \log \left(\frac{X_{CELL=n}}{X_0} \right)$$

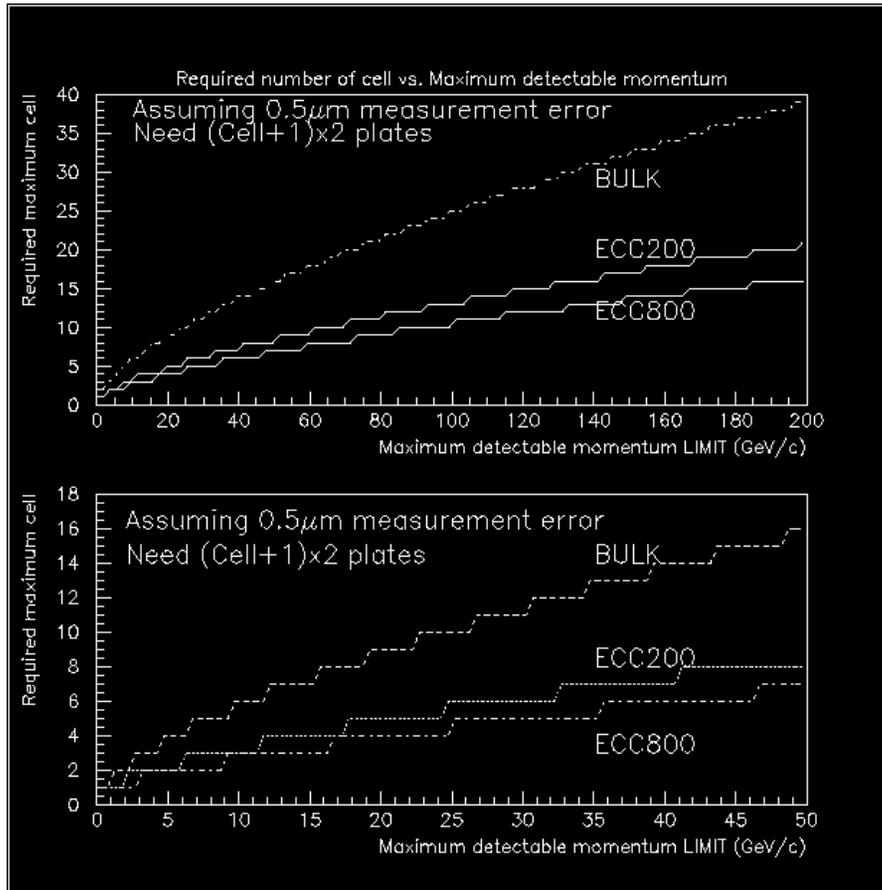
Where $\Delta Y_{CELL=1}$ is 2nd difference at CELL=1, $\Delta x_{CELL=n}$ is gap for nth cell and $X_{CELL=n}$ is radiation length for nth cell.

NOTE1 : $\Delta x_{CELL=n} / X_{CELL=n}$ is different for module type BULK,ECC200 and ECC800.

NOTE2 : Additional sqrt(2) in equation is due to get 2nd difference using 3 point.

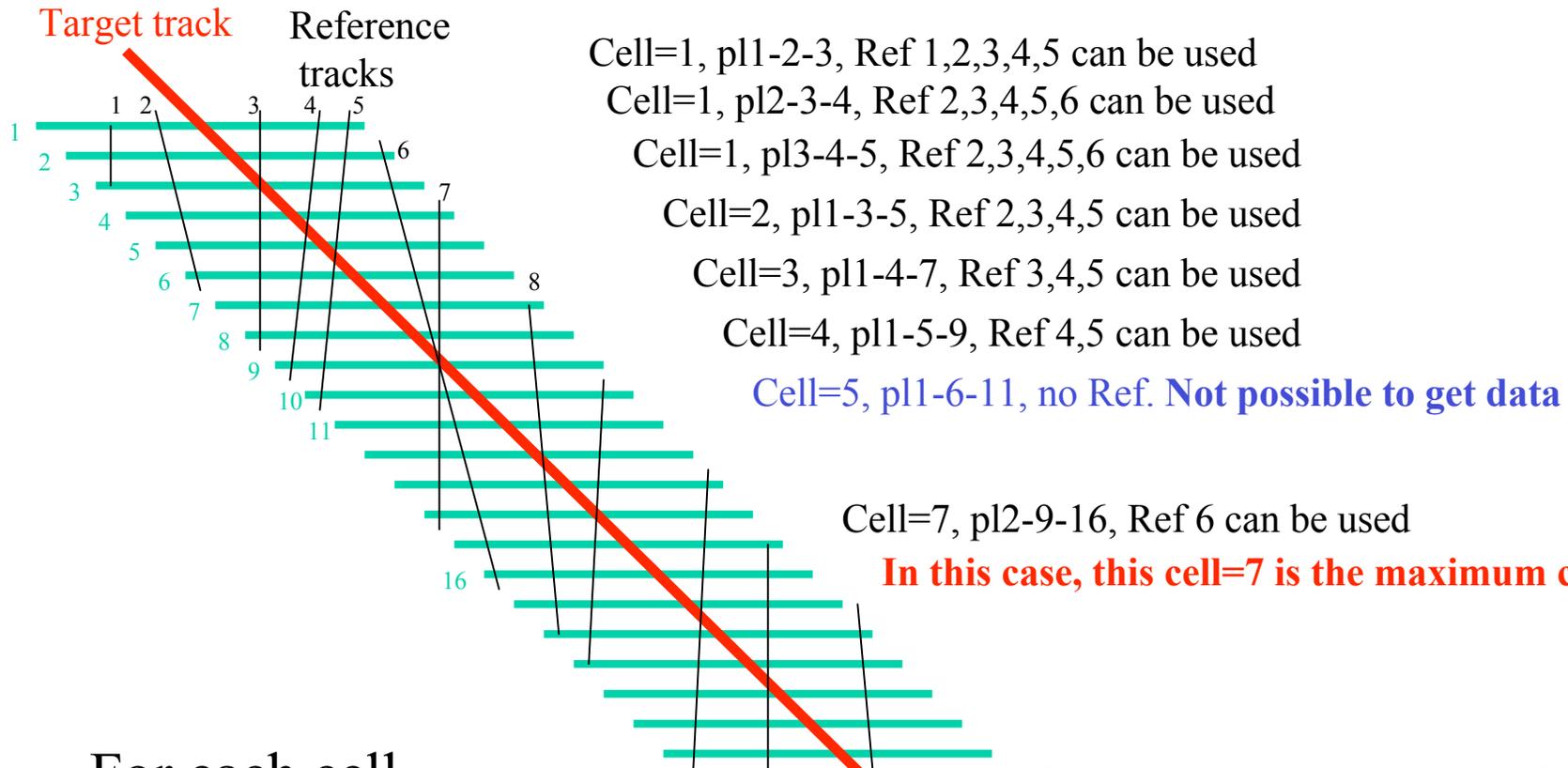
In angle method, sqrt(2) does not need.

Keywords in this analysis



Cell length vs. Limit is plotted
As a function of Limit.

Method for inclined m-file



Cell=1, pl1-2-3, Ref 1,2,3,4,5 can be used
 Cell=1, pl2-3-4, Ref 2,3,4,5,6 can be used
 Cell=1, pl3-4-5, Ref 2,3,4,5,6 can be used
 Cell=2, pl1-3-5, Ref 2,3,4,5 can be used
 Cell=3, pl1-4-7, Ref 3,4,5 can be used
 Cell=4, pl1-5-9, Ref 4,5 can be used
 Cell=5, pl1-6-11, no Ref. **Not possible to get data**

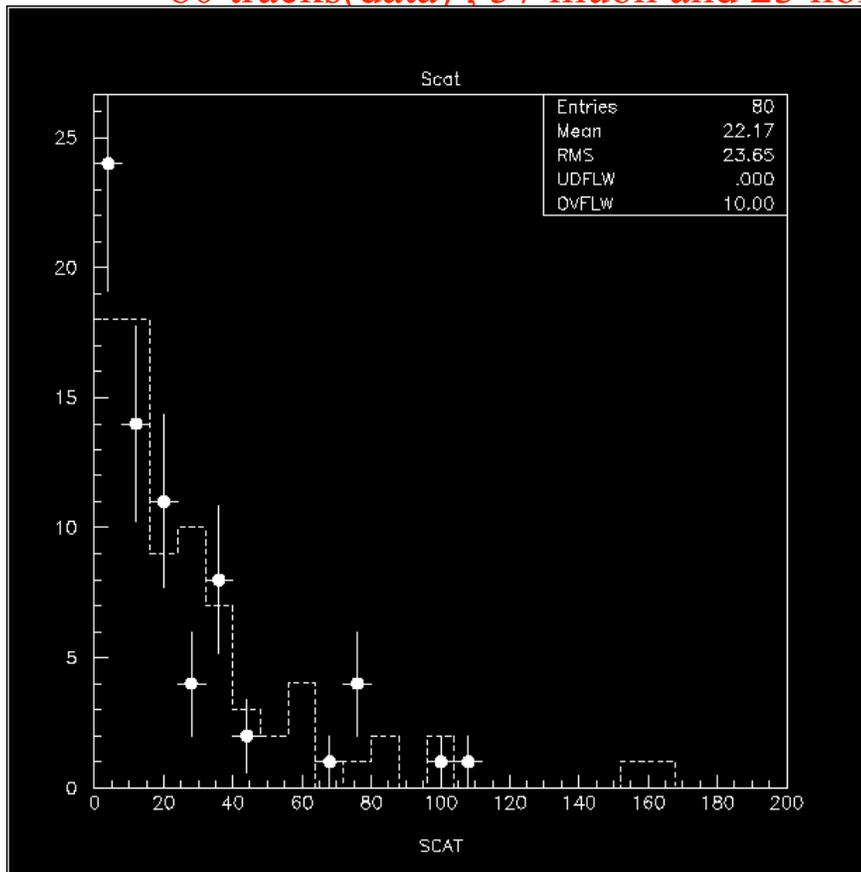
Cell=7, pl2-9-16, Ref 6 can be used
In this case, this cell=7 is the maximum cell.

For each cell
 Use possible reference.

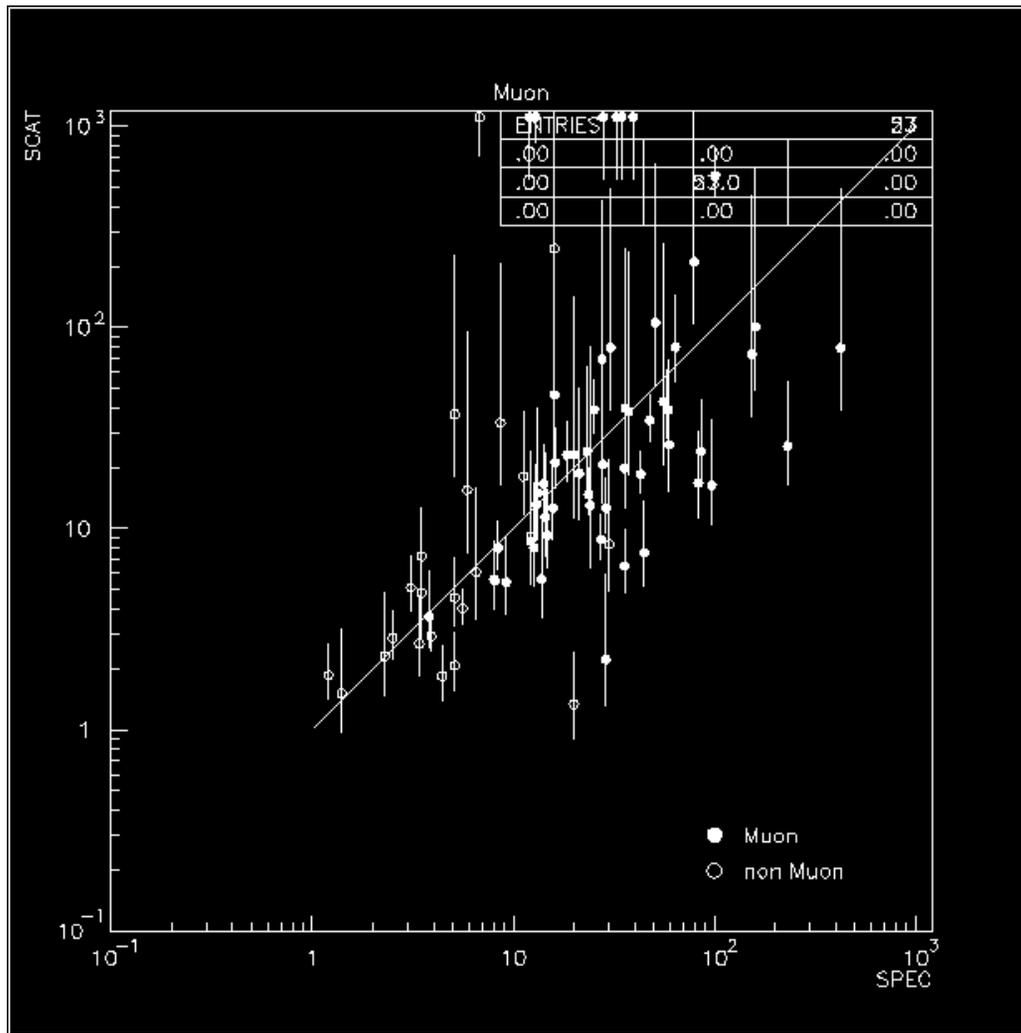
Maximum detectable momentum is limited by this cell=7. Using even longer data, not possible to improve maximum detectable momentum(Limit), but possible to improve momentum measurement error.

Consistency check by spectrometer

- **Data set**
 - M-files for electron ID data which Nonaka has taken.
 - Tracks which has spectrometer momentum.
 - 80 tracks(data) , 57 muon and 23 non muon.



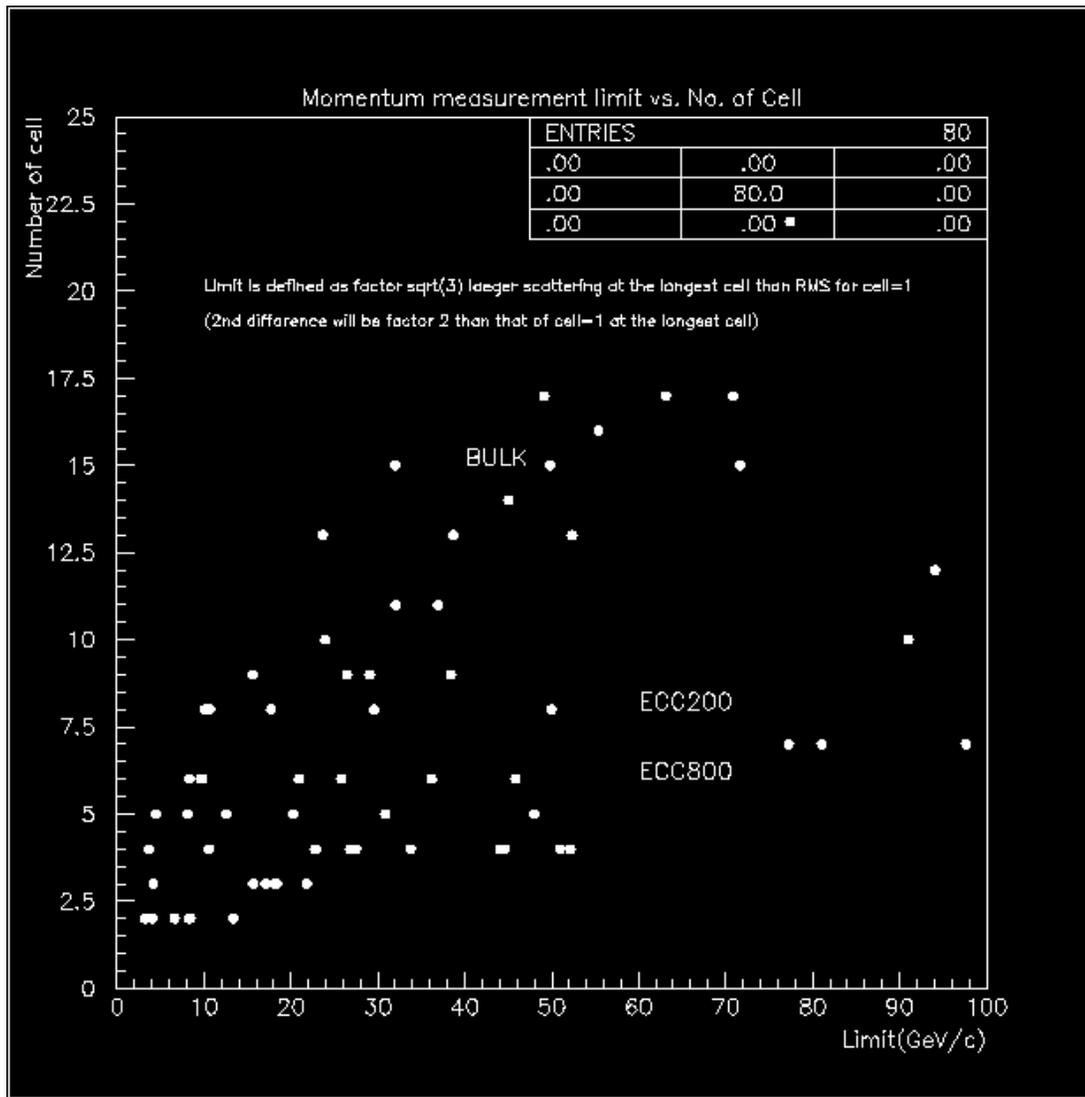
Consistency check by spectrometer



Most of them are consistent but tracks where spectrometer momentum higher region does not have consistency.

If spectrometer momentum is greater than Limit(Max), measured momentum will saturate.

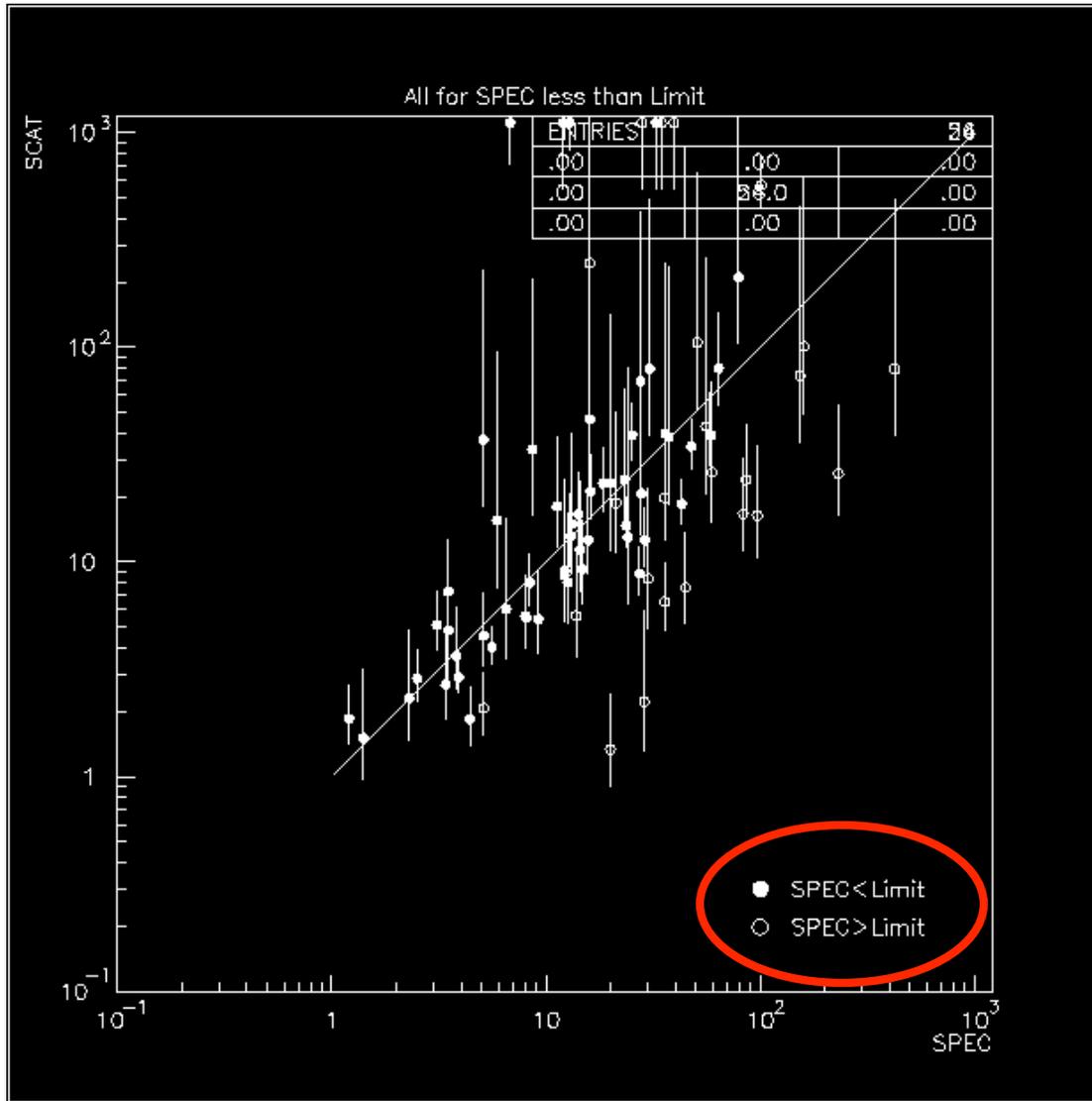
Consistency check by spectrometer



Scatter plot of Limit vs. maximum cell length for each data. **ECC and BULK will populate differently, Because X_0 and gap is different.**

Bulk data will saturate at lower momentum than that of ECC.

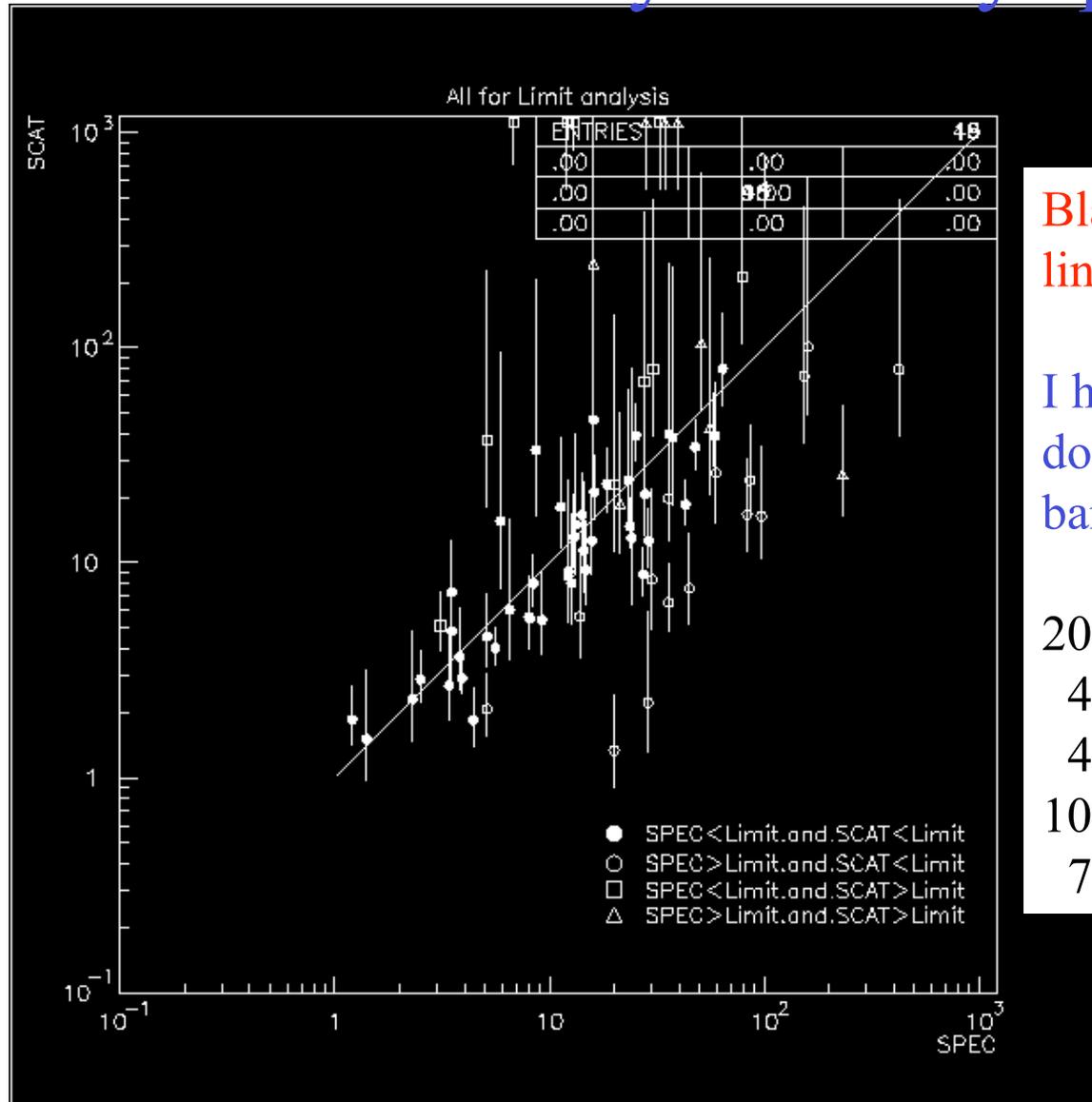
Consistency check by spectrometer



Most of the data below line exceed error bar is due to maximum detectable momentum(Limit).

It is possible to plot 4 pattern,
SPEC < Limit && SCAT < Limit
SPEC > Limit && SCAT < Limit
SPEC < Limit && SCAT > Limit
SPEC > Limit && SCAT > Limit

Consistency check by spectrometer

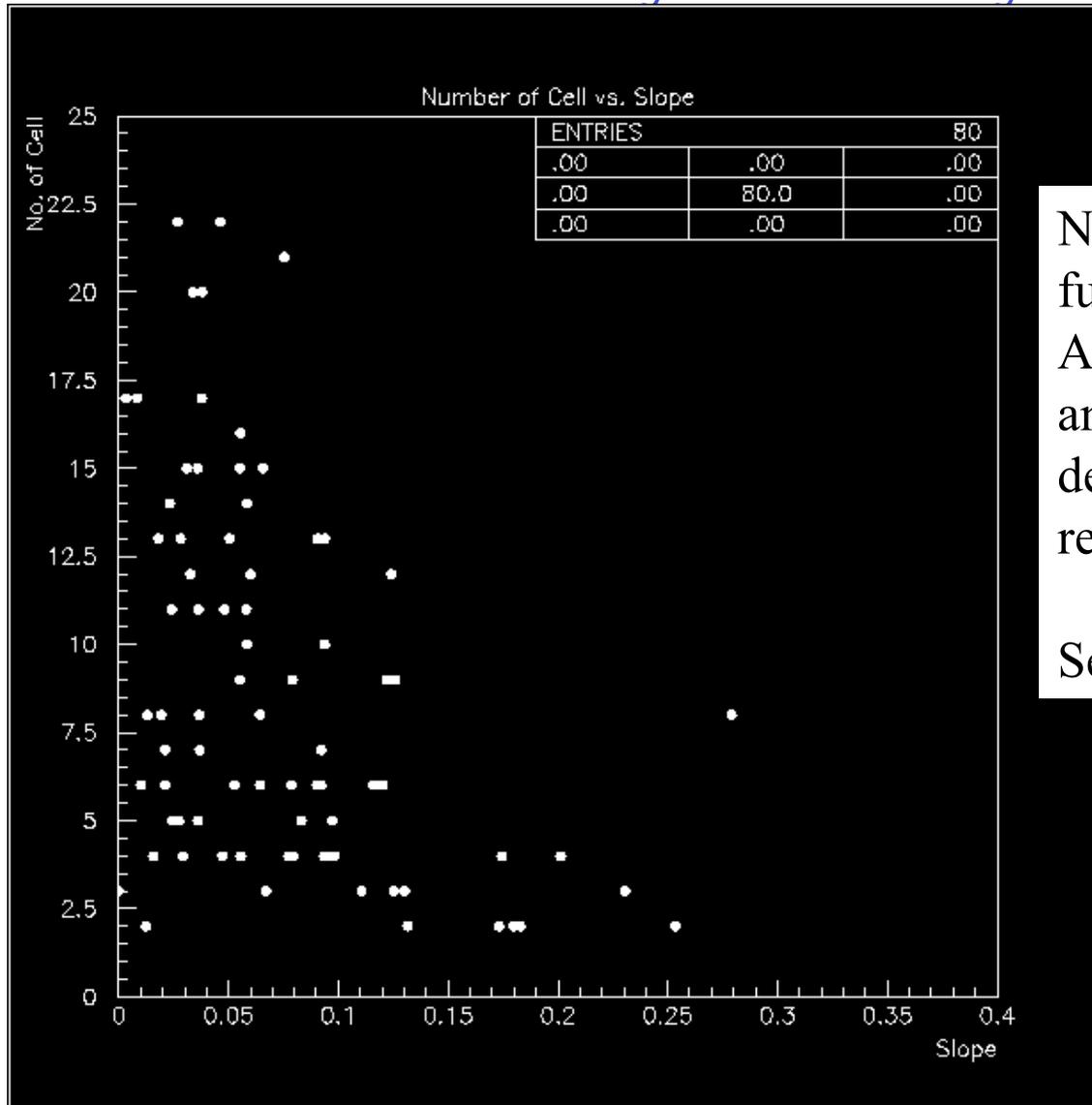


Black dots are populated on the line as expected.

I have checked 45 tracks which does not consistent within error bar.

- 20 : Spectrometer could be wrong
- 4 : Data quality is wrong
- 4 : Software could be wrong(fit)
- 10 : Slightly out of error bar. OK.
- 7 : Really greater than Limit. OK.

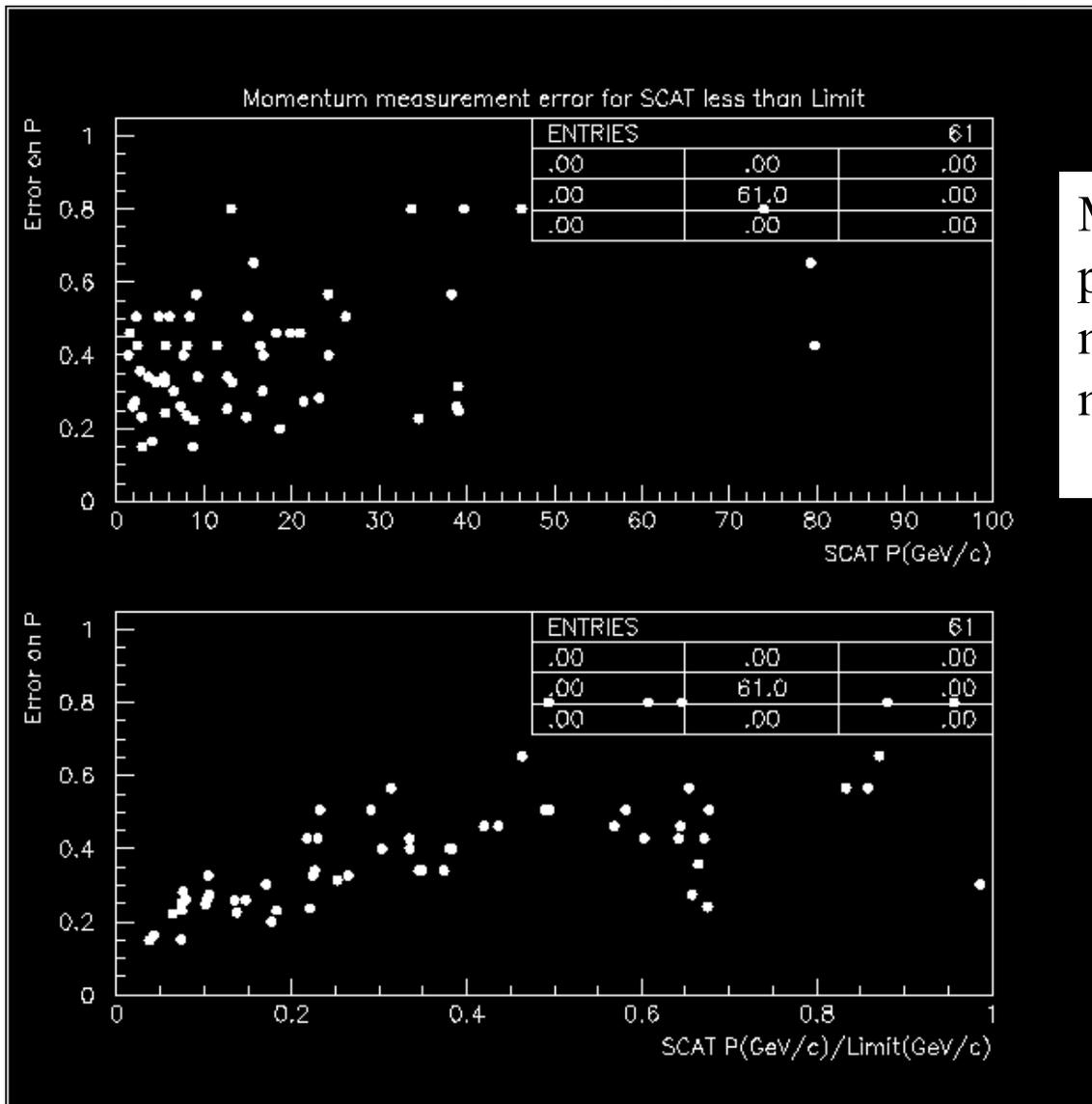
Consistency check by spectrometer



Number of cells are plotted as a function of track slope.
As I already mentioned in page 3 and 5, measurable number of cell depend on its track slope due to reference tracks in inclined m-file.

See also page 8, Limit vs. cell.

Consistency check by spectrometer



Momentum measurement error is plotted as a function of measured momentum and measured momentum divided by their limit.

Consistency check by spectrometer

- Summary for consistency check
 - There is no serious systematic momentum shift or saturation.
 - Previously(in March), momentum is saturated at lower momentum due to alignment procedure for these electron ID data. While aligning several ten plates, **data was twisted due to accumulated rotation error** by connecting about $1 \times 1 \text{mm}^2$ data.
- This electron ID data and latest beta version software can measure momentum.
 - But, **be careful on Limit.**

Module 1

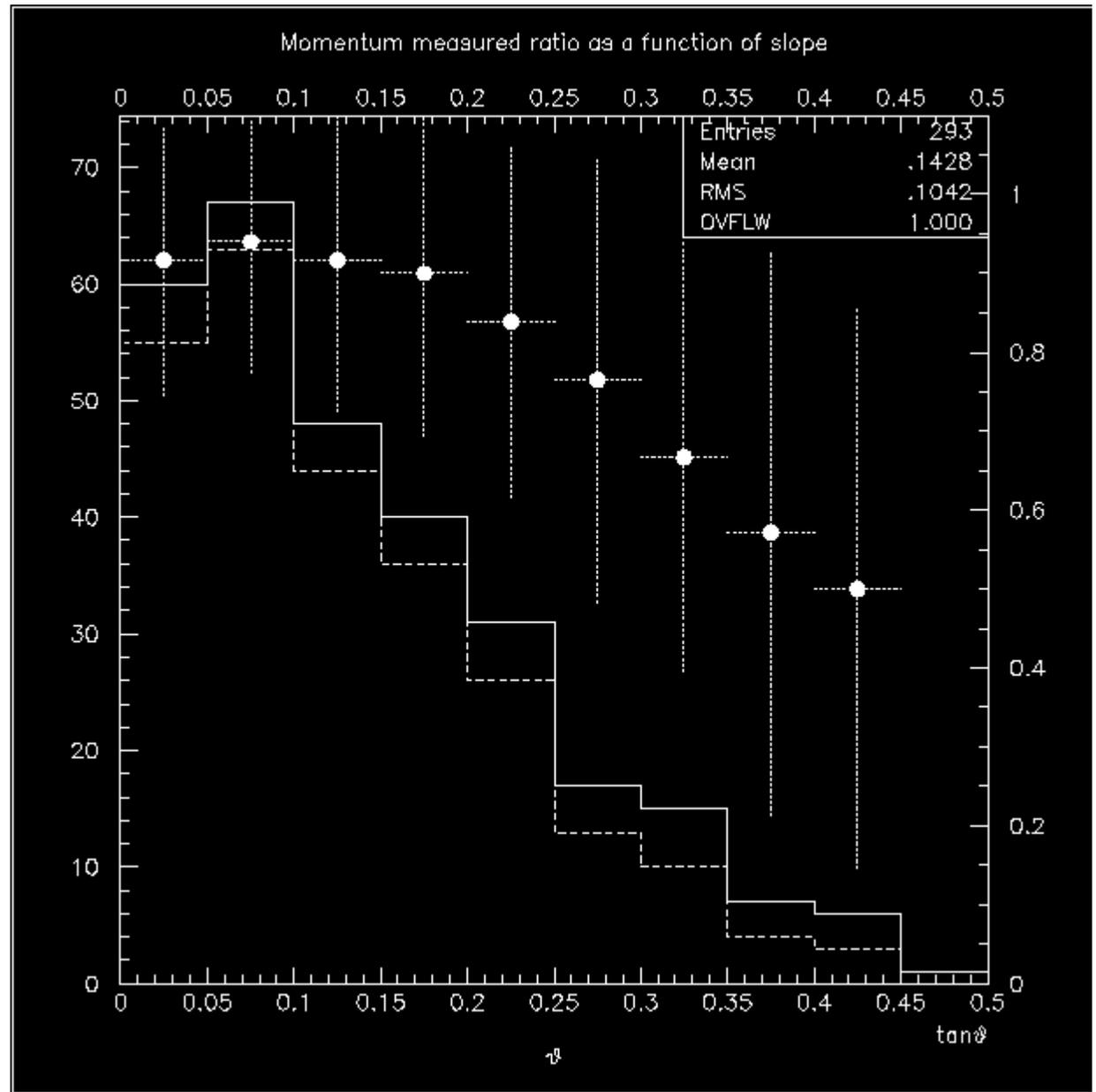
- Data set
 - M-files for Electron ID
 - Inclined m-file along to the target track.
 - For each track has own m-file.
 - 293 out of 363 tracks has tried for momentum measurement.
 - Rest of 70 tracks are short due to re-interaction or tracks of downstream events.(Nonaka selected)
 - 254 out of 293 has successfully measured
 - Data quality check(Residuals) and requirement for at least two cells to evaluate momentum.
 - 86.7% of momentum has measured. Reasons for the rest of 39 tracks will be mentioned later.

Module 1

Momentum measured ratio is plotted as a function of the track slope. Solid line is for 293 tracks and dashed line is for measured 254 tracks. Dots are measured ratio.

Ratio is going down for larger track slope.

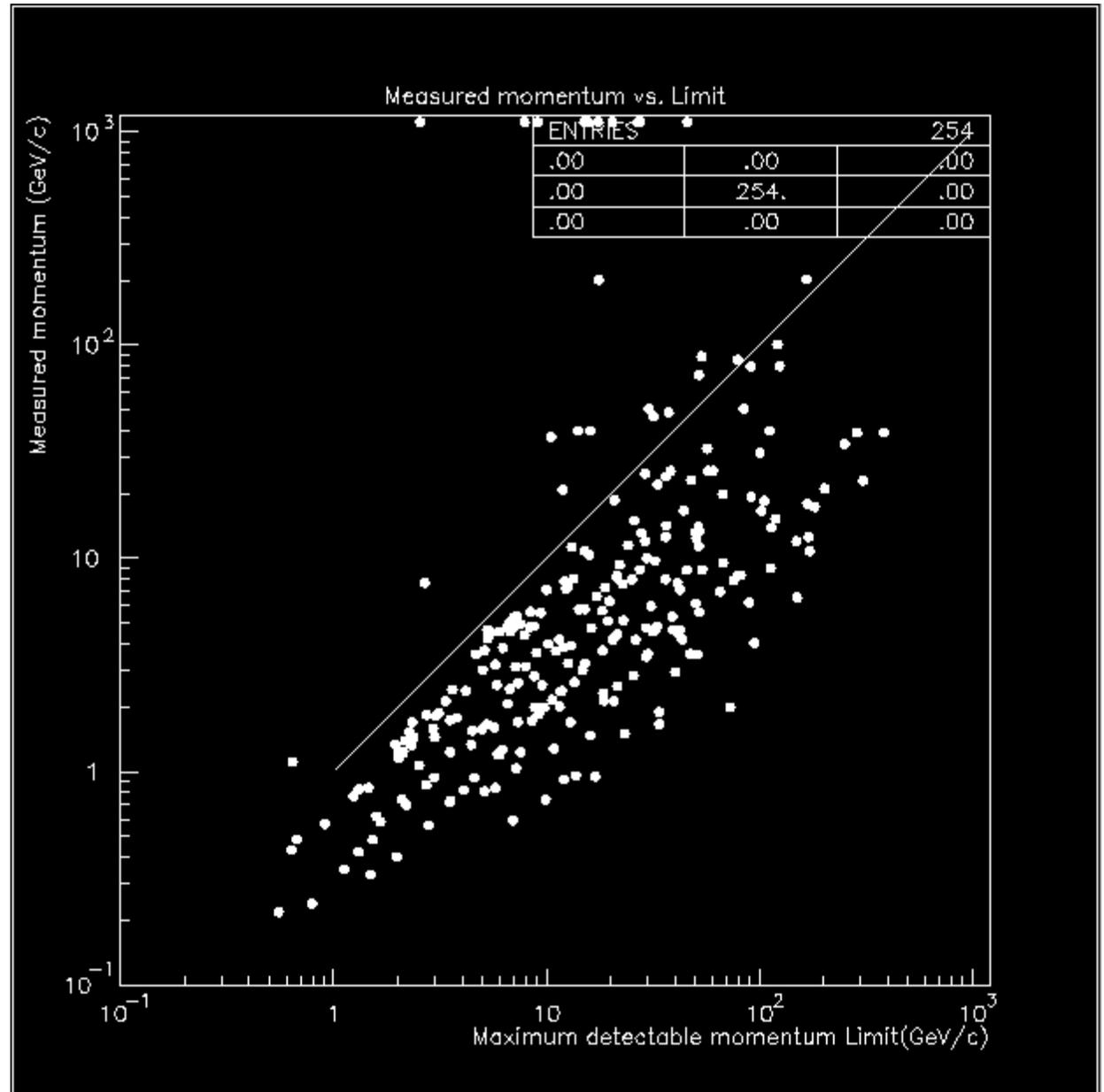
This measured ratio as a function of track slope is used for MC comparison.



Module 1

Measured momentum vs. limit are plotted for 254 tracks. Dots populated below line could be good measurement.

Momentum distribution will be plotted with MC prediction according to previous measured rate as a function of the track slope.



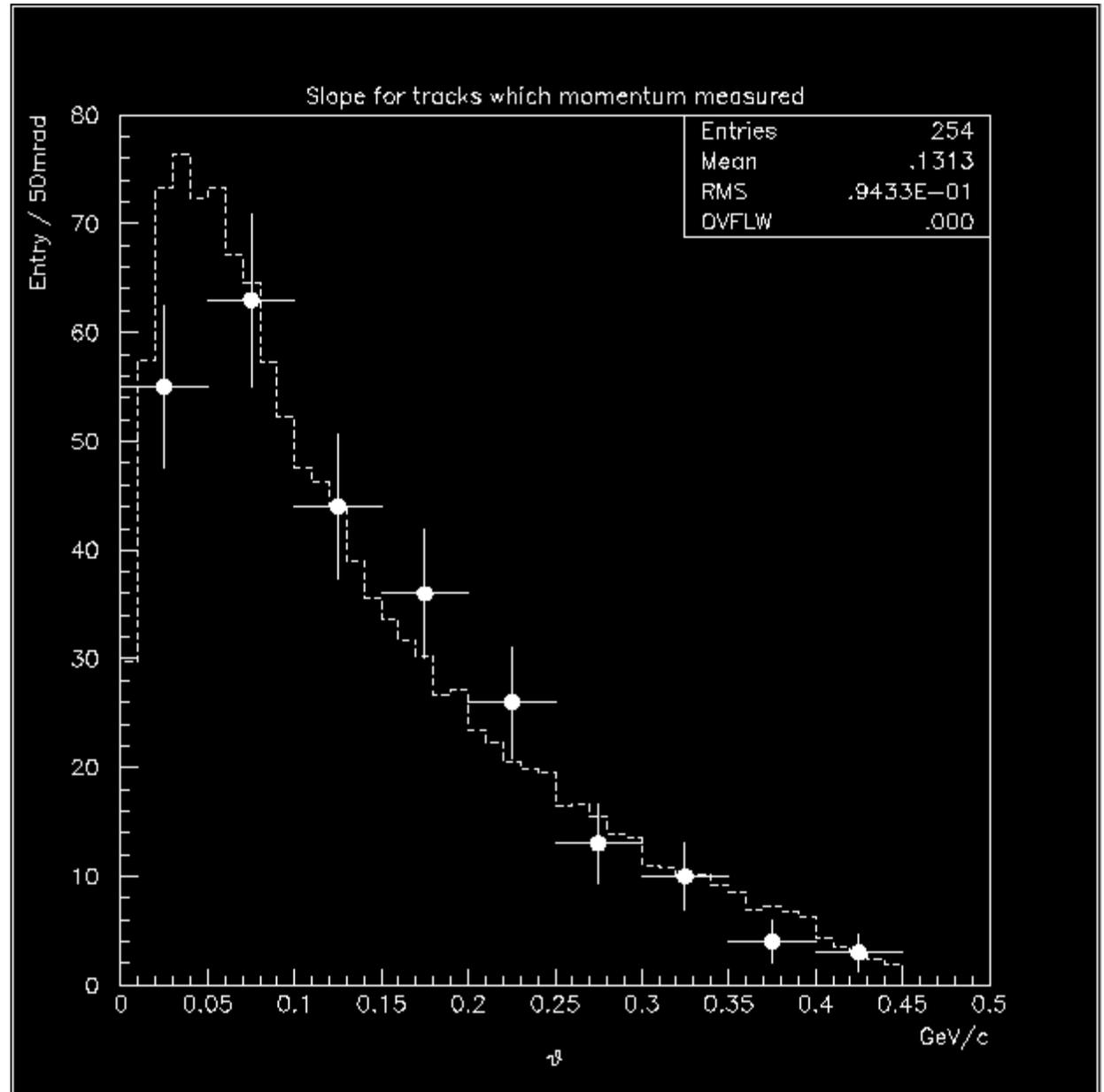
Monte Carlo

- Data set
 - Only muon neutrino events are produced by PYTHIA5.7 with DONUT neutrino energy spectrum.
 - Mixture of CC,NC and anti neutrinos
$$\sigma_{\mu}^{CC} : \sigma_{\mu}^{NC} : \sigma_{\bar{\mu}}^{CC} : \sigma_{\bar{\mu}}^{NC} = 1.00 : 0.31 : 0.50 : 0.19$$
 - 77,921 charged tracks within $\tan(h) < 0.4$ for 20,000 events. 66,688 survived by applying momentum measured ratio as a function of slope for MODULE 1.
 - Normalization has done by 254/66,688
 - MC truth is used for comparison for this analysis.
- For event based analysis, 19,251 events has at least one momentum measured tracks. 19,251 is used for event based analysis normalization.

Module 1

Slope distribution for momentum measured tracks and MC normalized by just number of tracks.

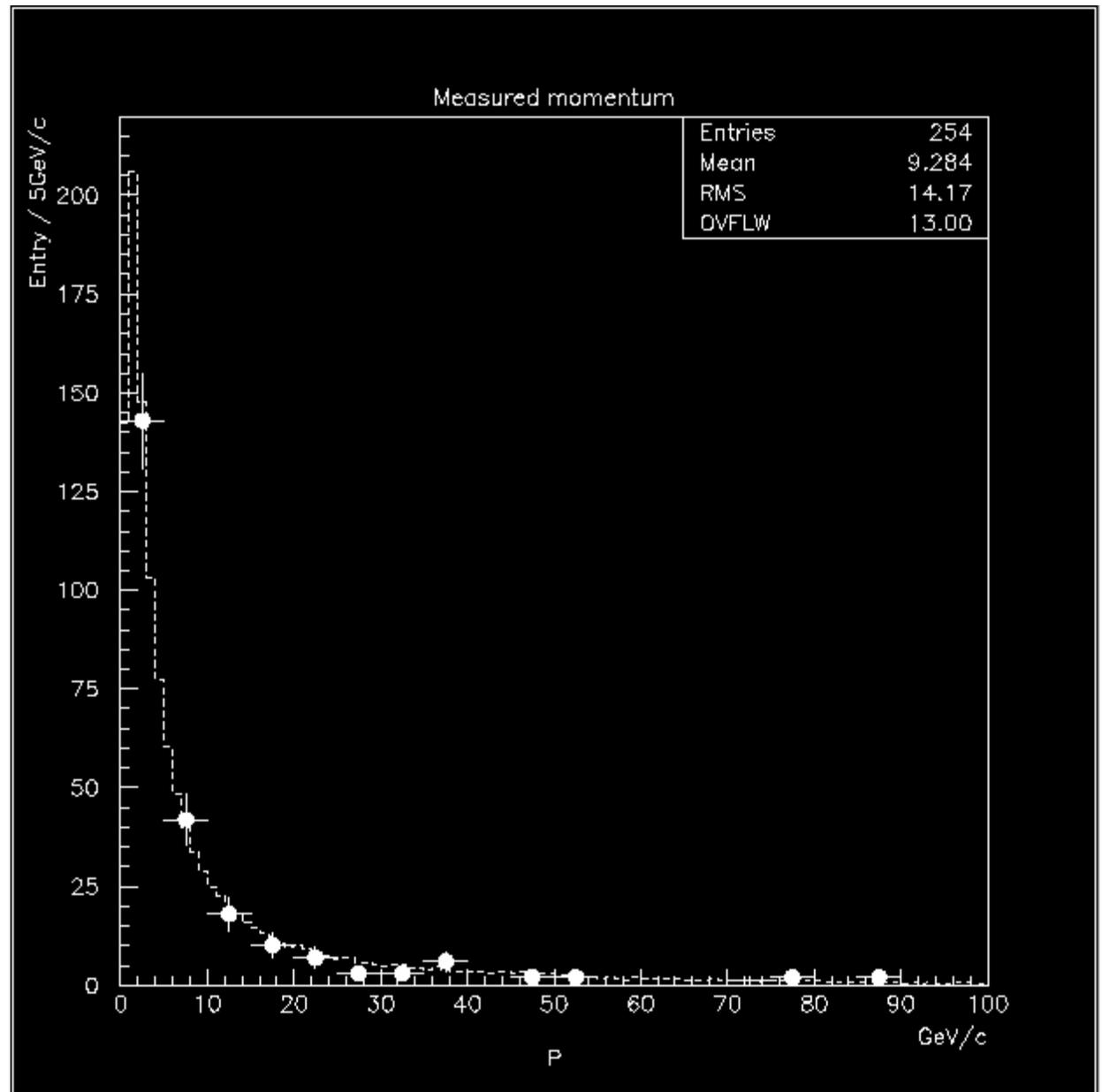
Dots with error bar is data and dashed line is MC.



Module 1

Measured momentum for each 5GeV/c bins.

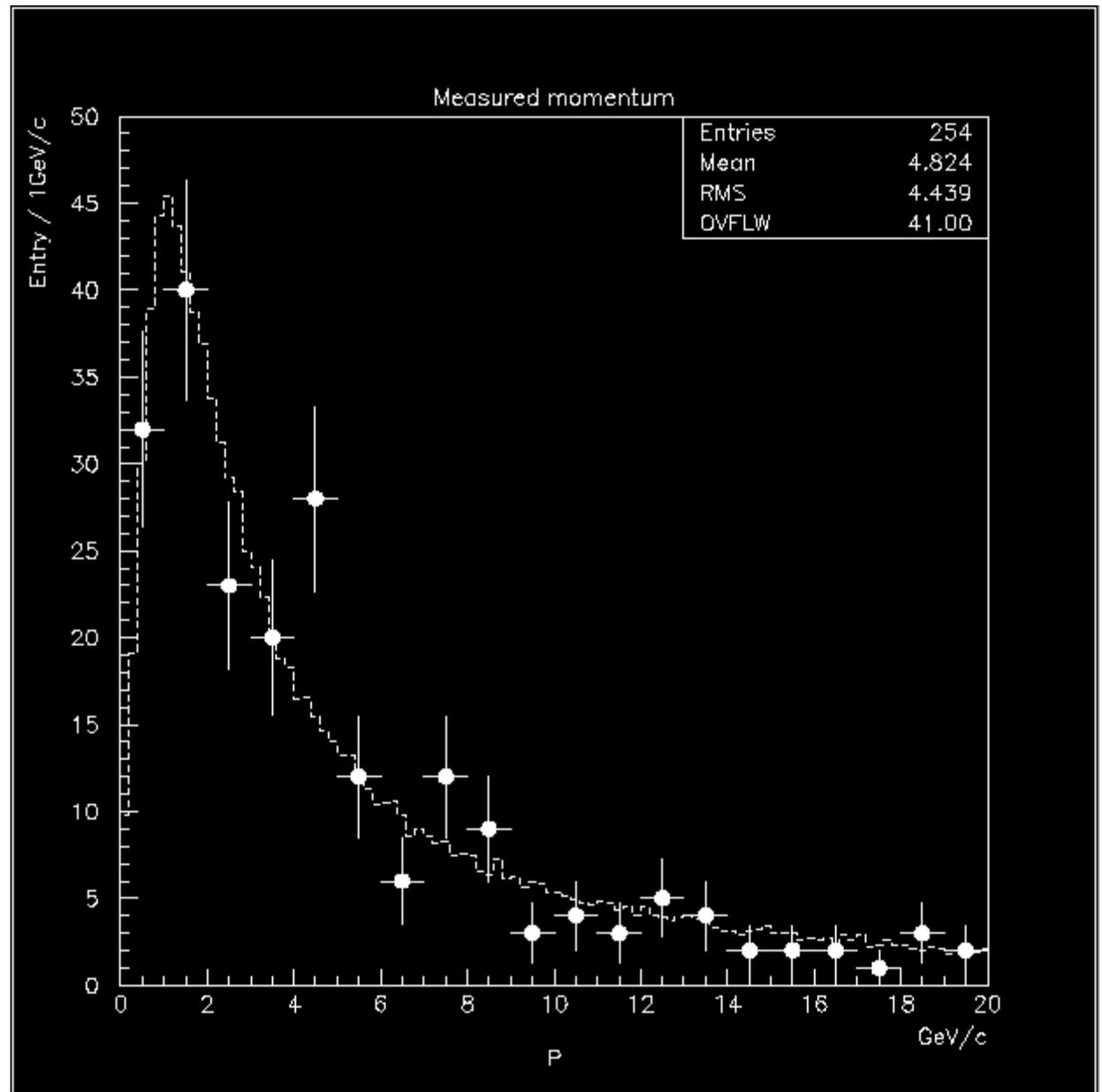
Dots with error bar is data and dashed line is MC.



Module 1

Same plot with previous page, up to 20GeV/c with 2GeV/c bin.

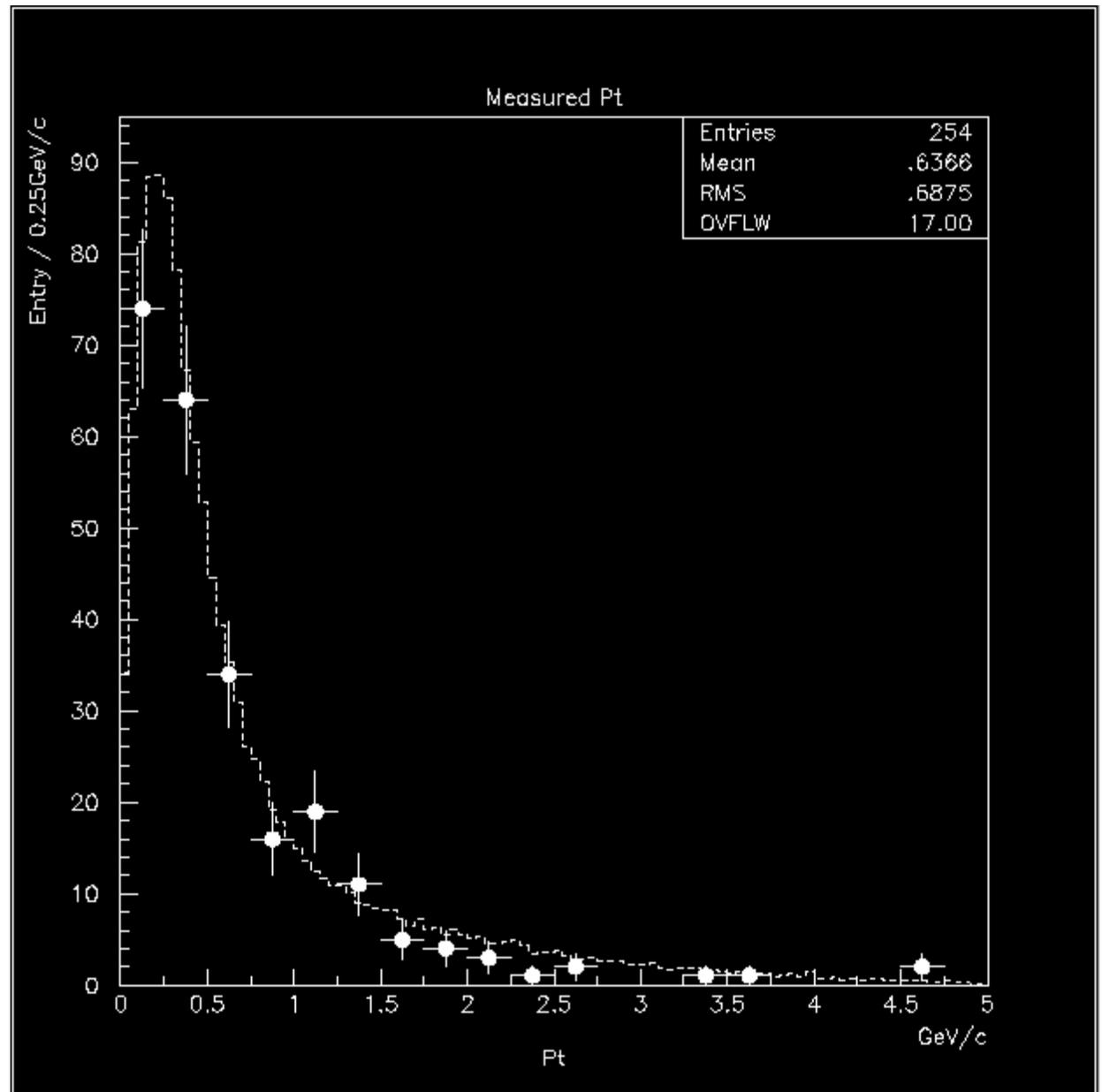
Dots with error bar is data and dashed line is MC.



Module 1

Measured P_T for each
250MeV/c bins.

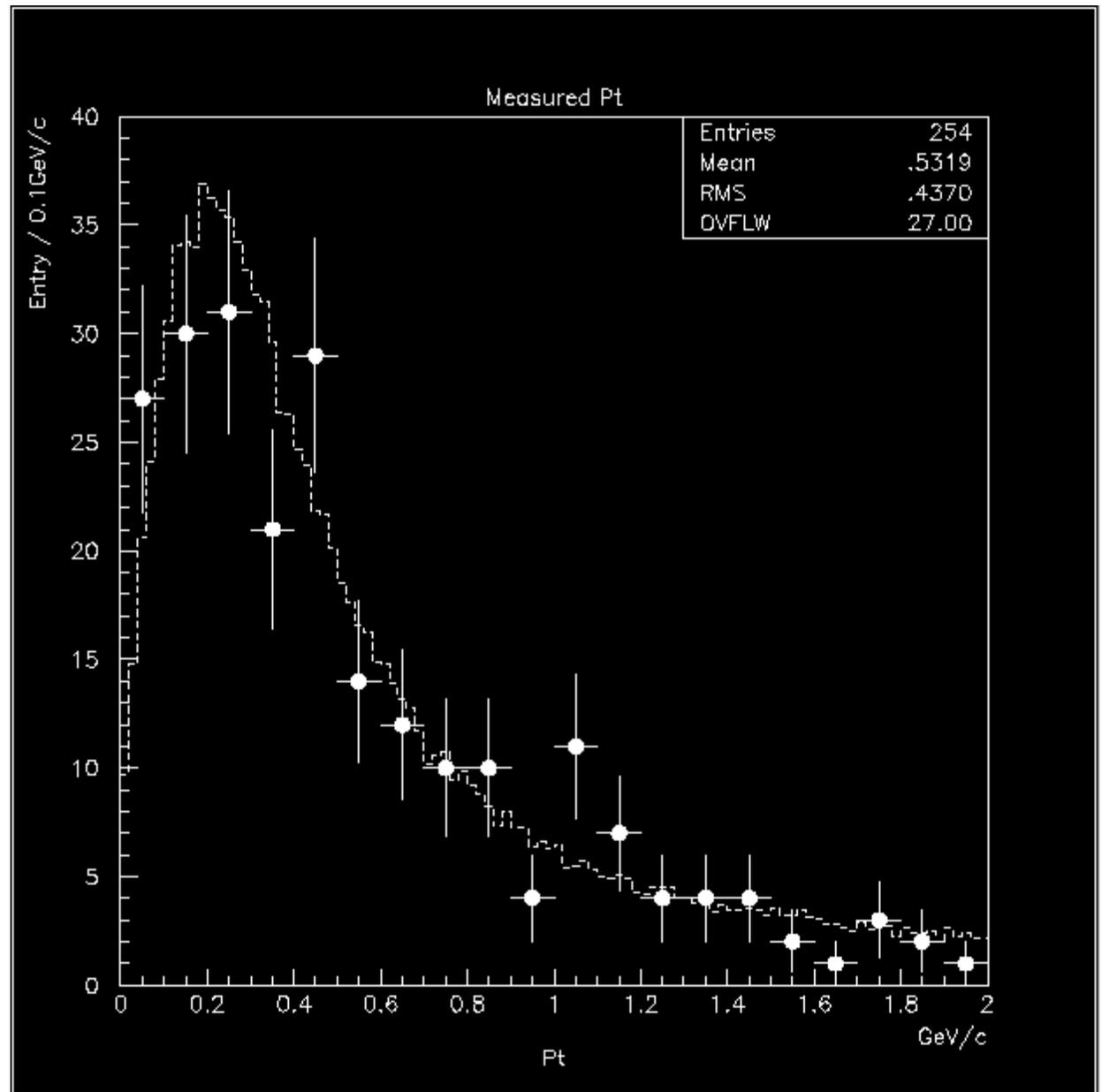
Dots with error bar is data
and dashed line is MC.



Module 1

Measured P_T for each
100MeV/c bins.

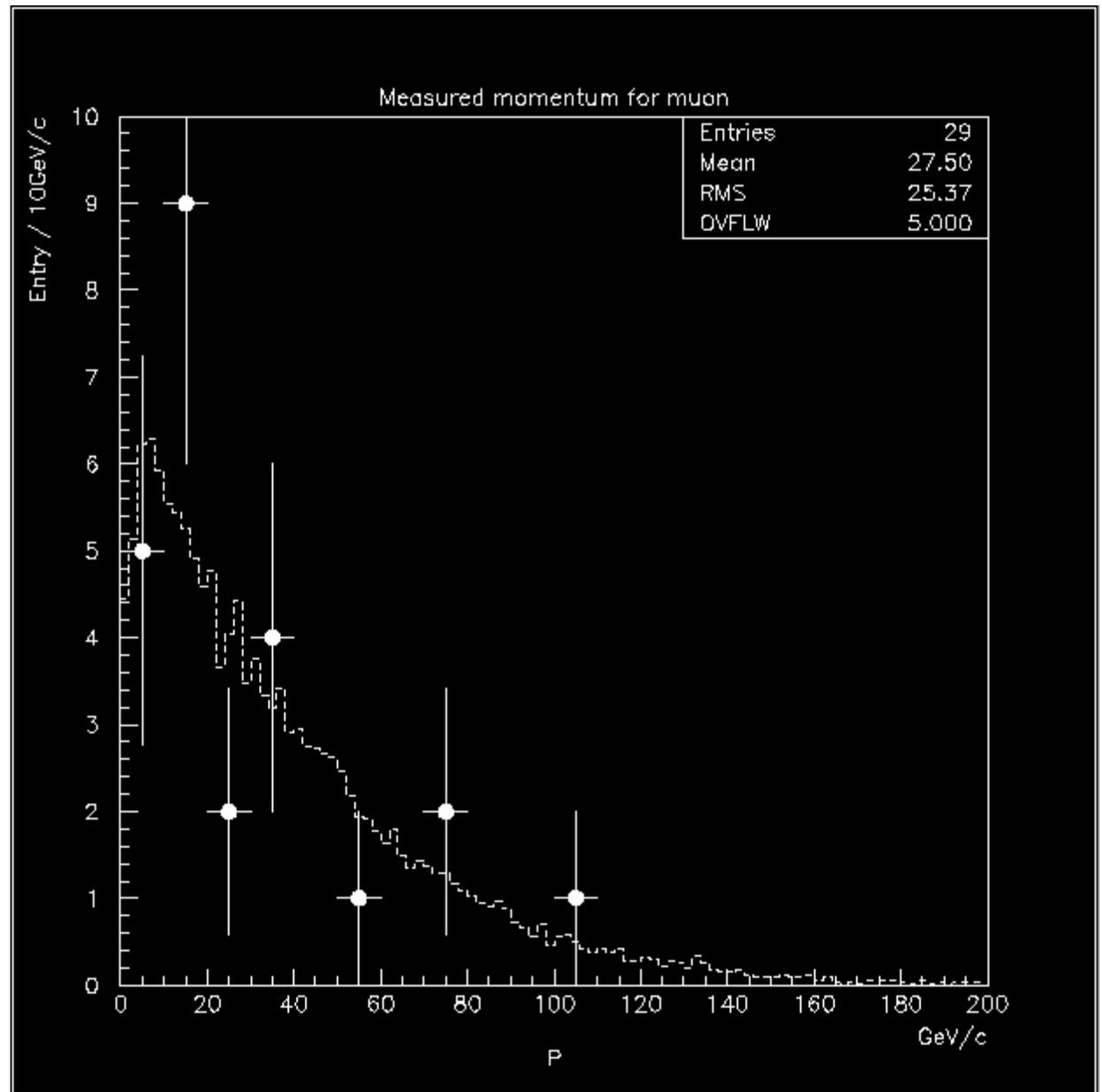
Dots with error bar is data
and dashed line is MC.



Module 1

Measured momentum for muons for each 10GeV/c bins.

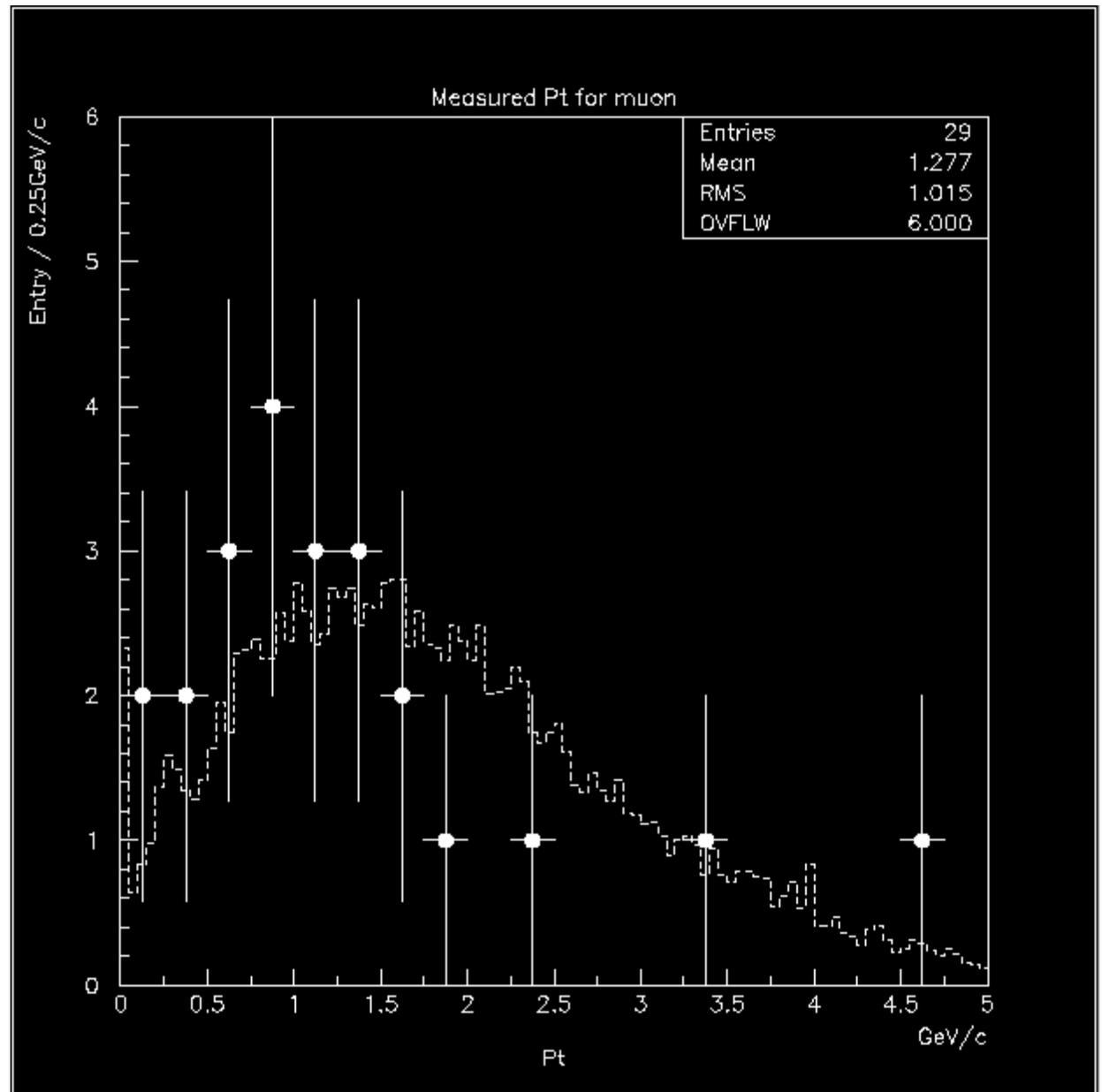
Dots with error bar is data and dashed line is MC.



Module 1

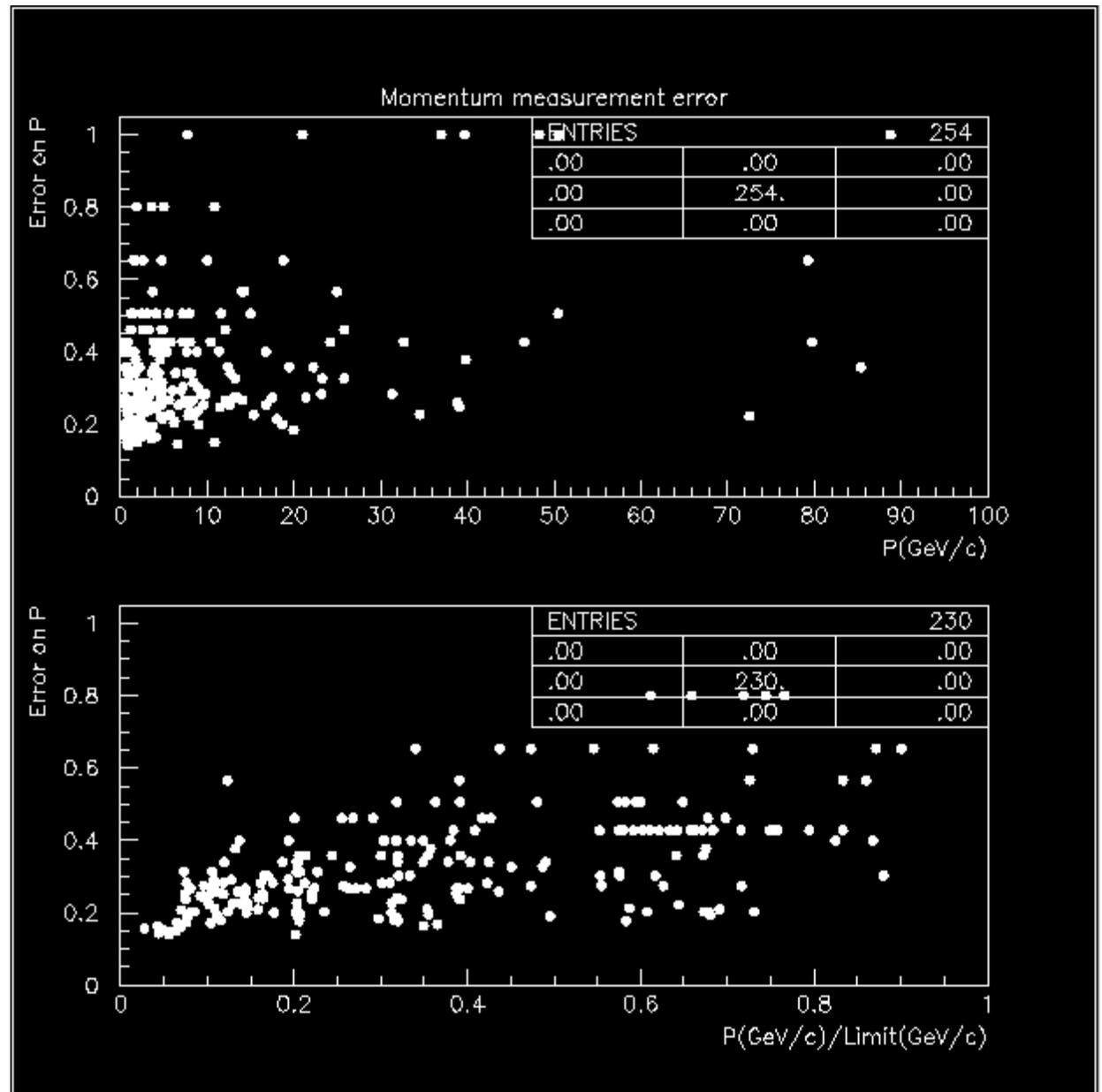
Measured P_T for **muons** for each 250MeV/c bins.

Dots with error bar is data and dashed line is MC.



Module 1

Measured momentum error is plotted as a function of measured momentum and its normalized by Limit.



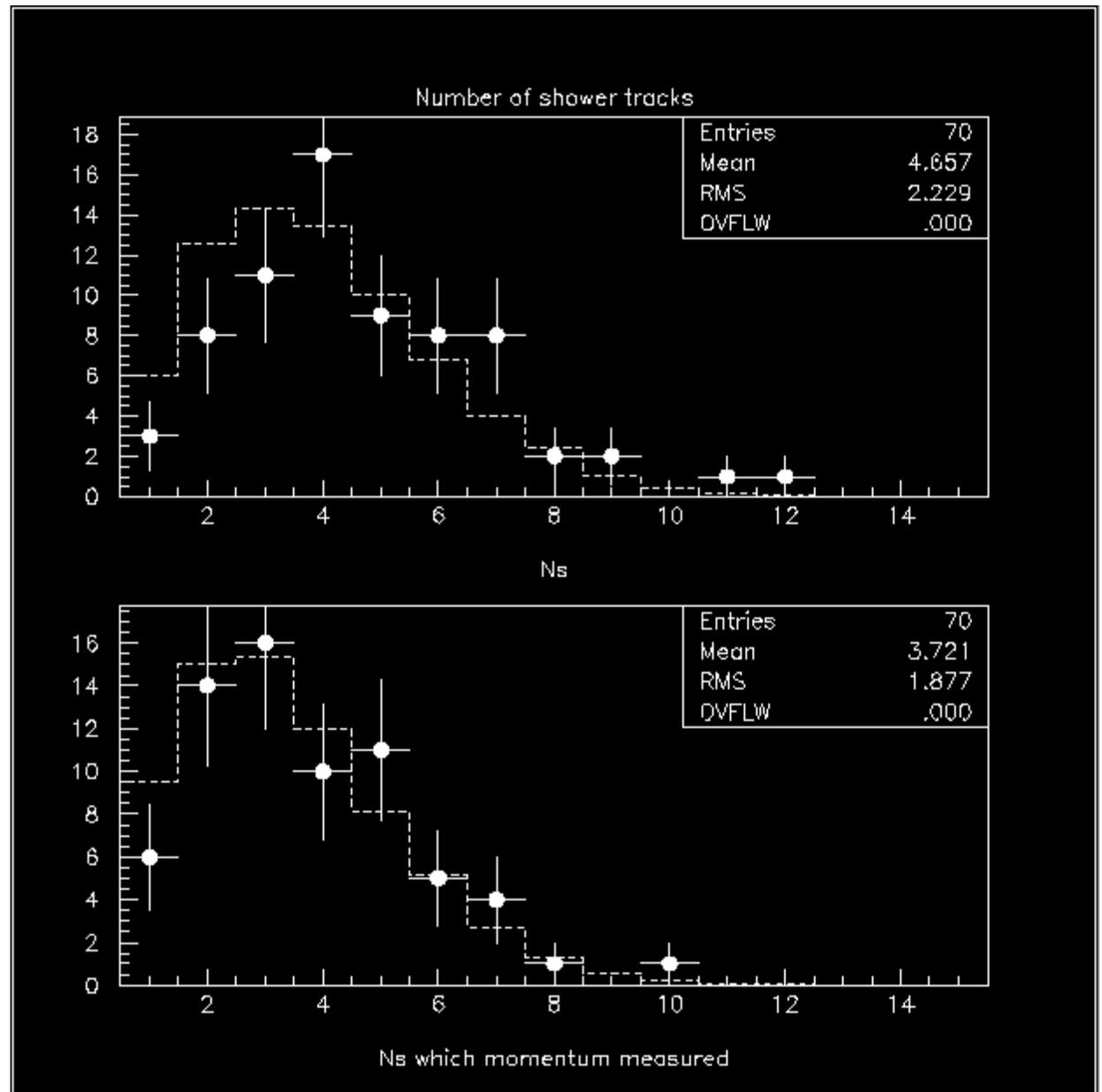
Event based analysis

- Event based analysis quantity
 - Number of shower tracks, visible momentum of the event and missing P_T of the event.
- Data
 - To get visible momentum and missing P_T , saturated momentum which measured momentum is higher than Limit, Limit is used for the track momentum in this case. (Otherwise, saturated 1TeV/c tracks make large discrepancy from MC.)
 - 70 event out of 78 event can be used for this analysis. Rest of 8 events are all tracks has flag ≥ 7 or no momentum measured track exist.
- MC
 - Momentum measured rate as a function of the track slope is applied for event based analysis also.
 - 19,251 out of 20,000 events has at least one track which momentum measured. Normalization has done by 70/19,251.
 - Saturation is not take into account for MC tracks. Then, this comparison is PRELIMINARY!

Module 1

Number of shower tracks and number of tracks which momentum measured are plotted.

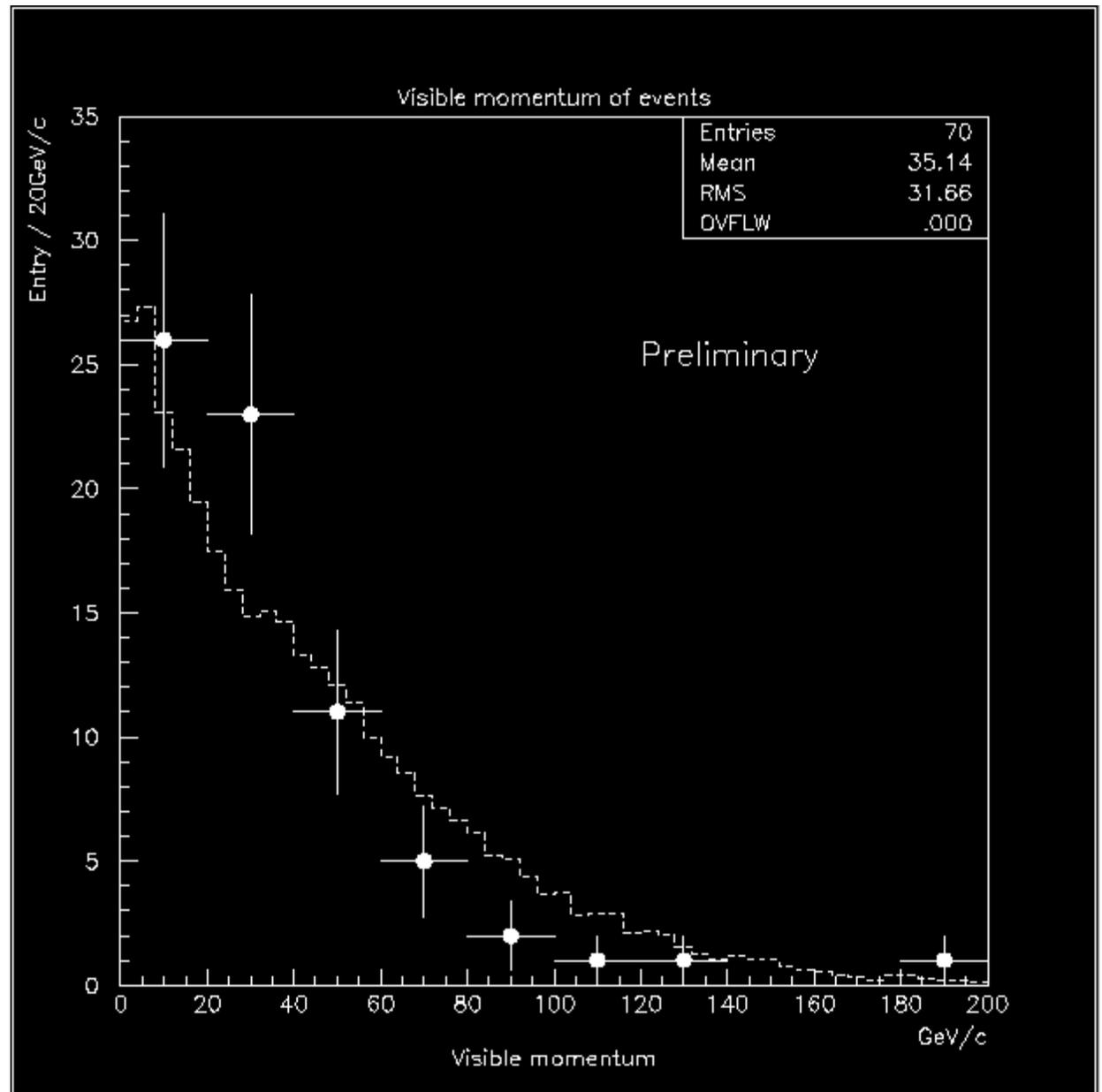
Dots with error bar is data and dashed line is MC.



Module 1

Visible momentum of events are plotted for each 20GeV/c bins.

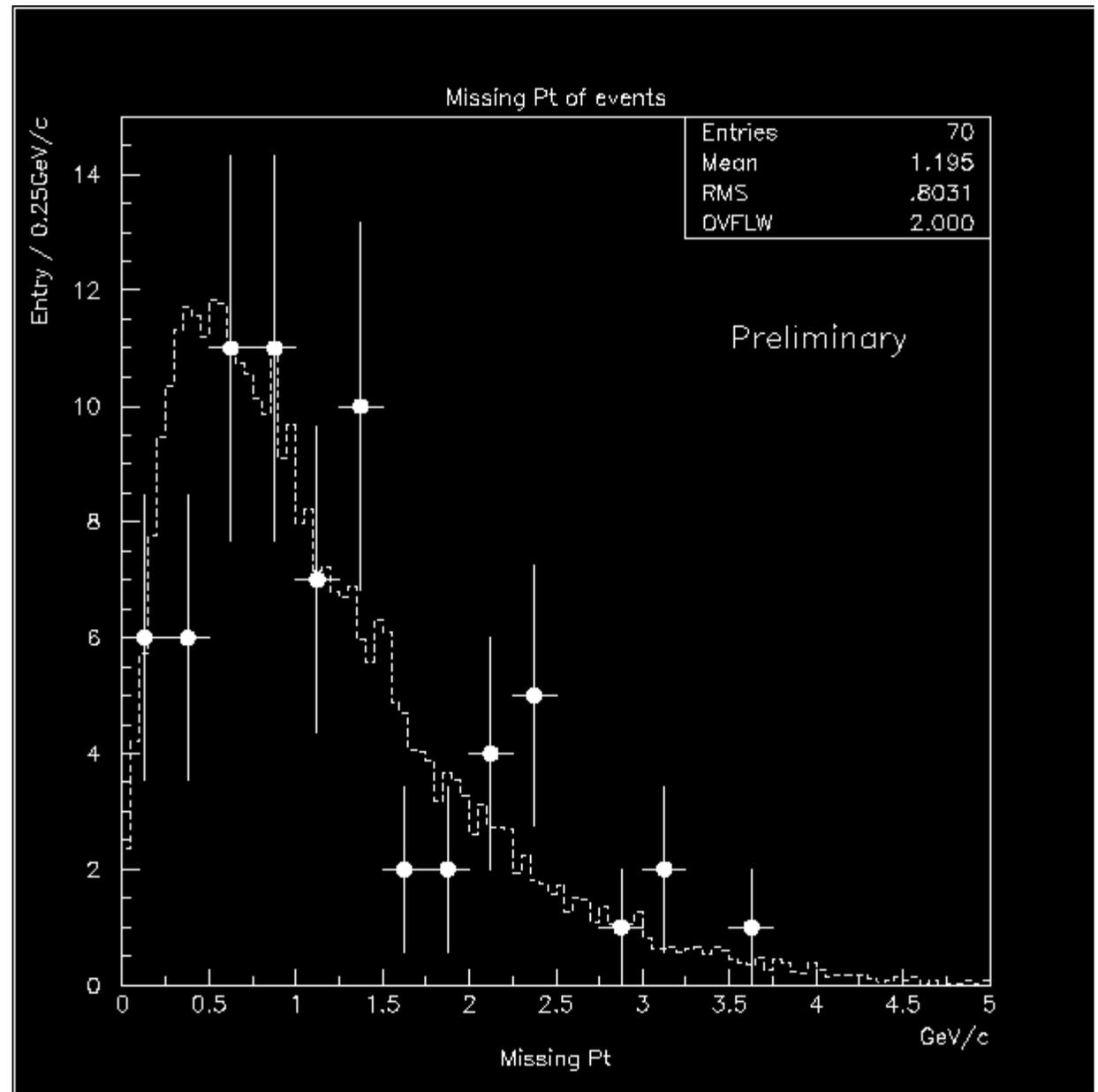
Dots with error bar is data and dashed line is MC.



Module 1

Missing P_T of events for each 250MeV/c bins.

Dots with error bar is data and dashed line is MC.



Summary for MODULE 1

- 254 out of 293 tracks successfully processed.
 - 39 tracks which not possible to measure momentum
 - Downstream event : 5
 - No such track : 2
 - Too short : 7
 - Alignment bad : 13
 - Software crash : 3
 - Too small scanning area : 9 (Large angle track, See page 5)
 - Details are listed in the other file.
- MCS measured momentum and MC seems consistent.
 - If you agree this result, we can go on this track.

Module 3

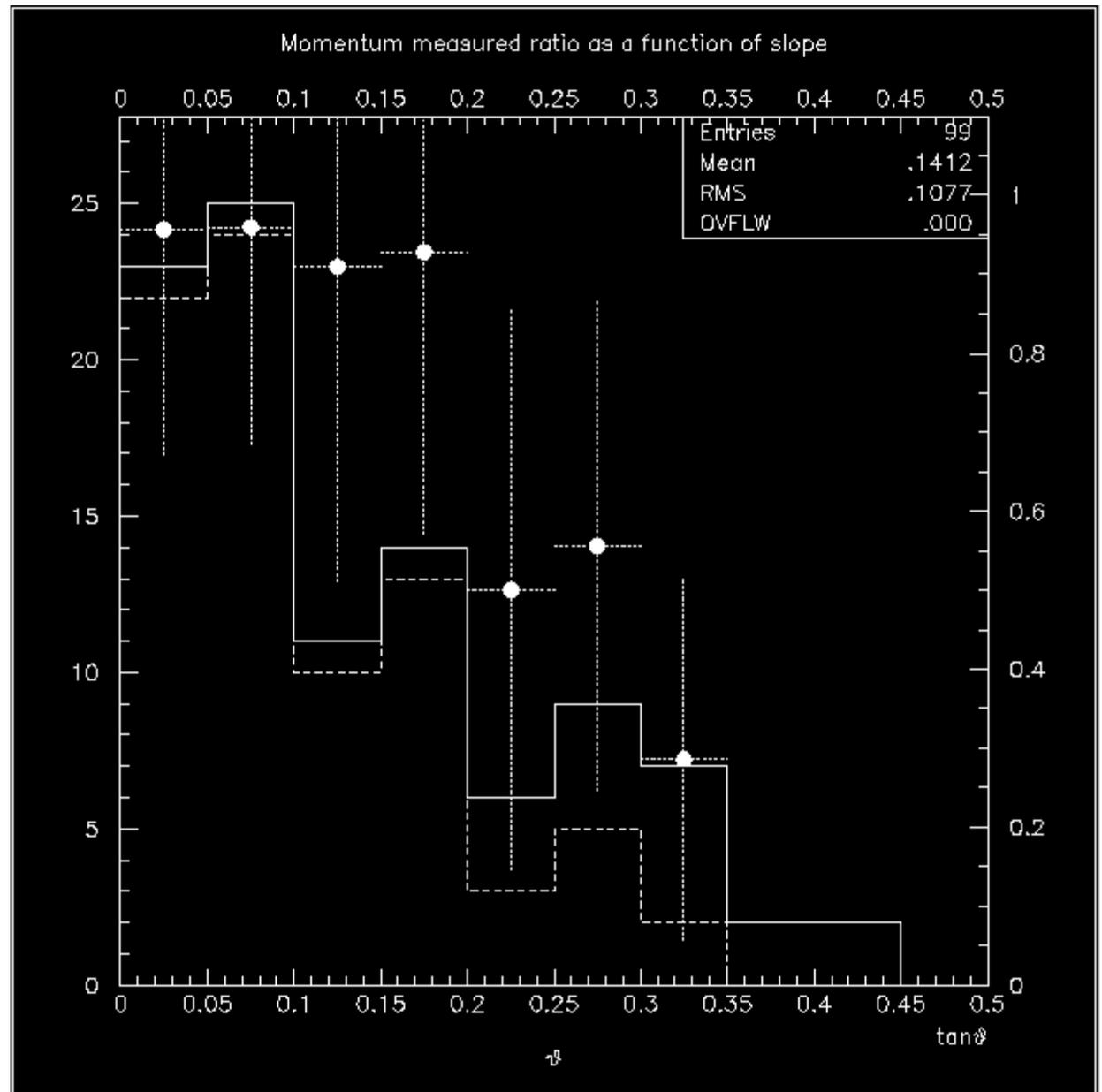
- Data set
 - M-files for Electron ID
 - Inclined m-file along to the target track.
 - For each track has own m-file.
 - 99 out of 124 tracks has tried for momentum measurement.
 - Rest of 25 tracks are short due to re-interaction or tracks of downstream events.
 - 79 out of 99 has successfully measured
 - Data quality check(Residuals) and requirement for at least two cells to evaluate momentum.
 - 79.8% of momentum has measured. Reasons for the rest of 20 tracks will be mentioned later.

Module 3

Momentum measured ratio is plotted as a function of the track slope. Solid line is for 99 tracks and dashed line is for measured 79 tracks. Dots are measured ratio.

Ratio is going down for larger track slope.

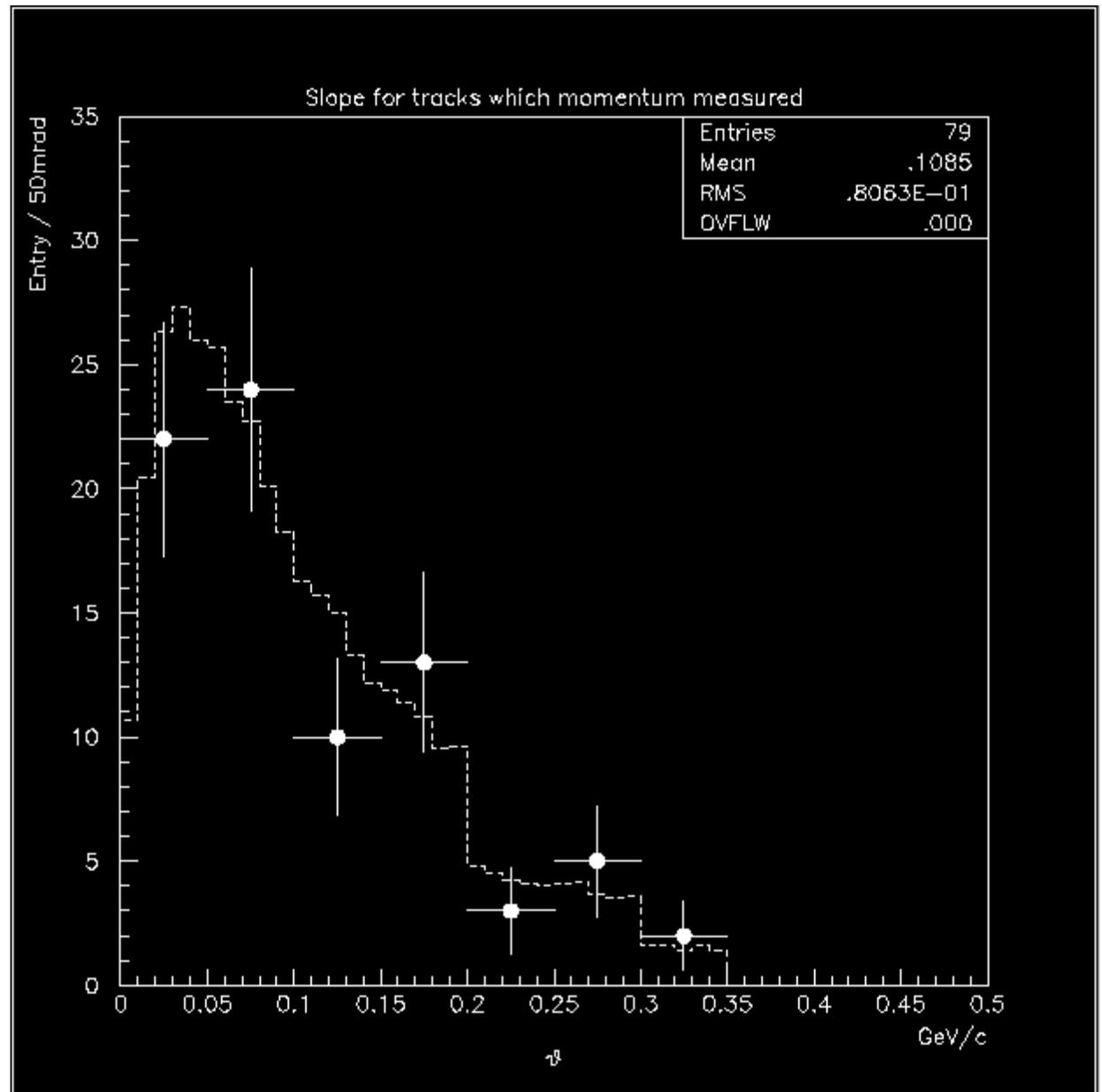
This measured ratio as a function of track slope is used for MC comparison.



Module 3

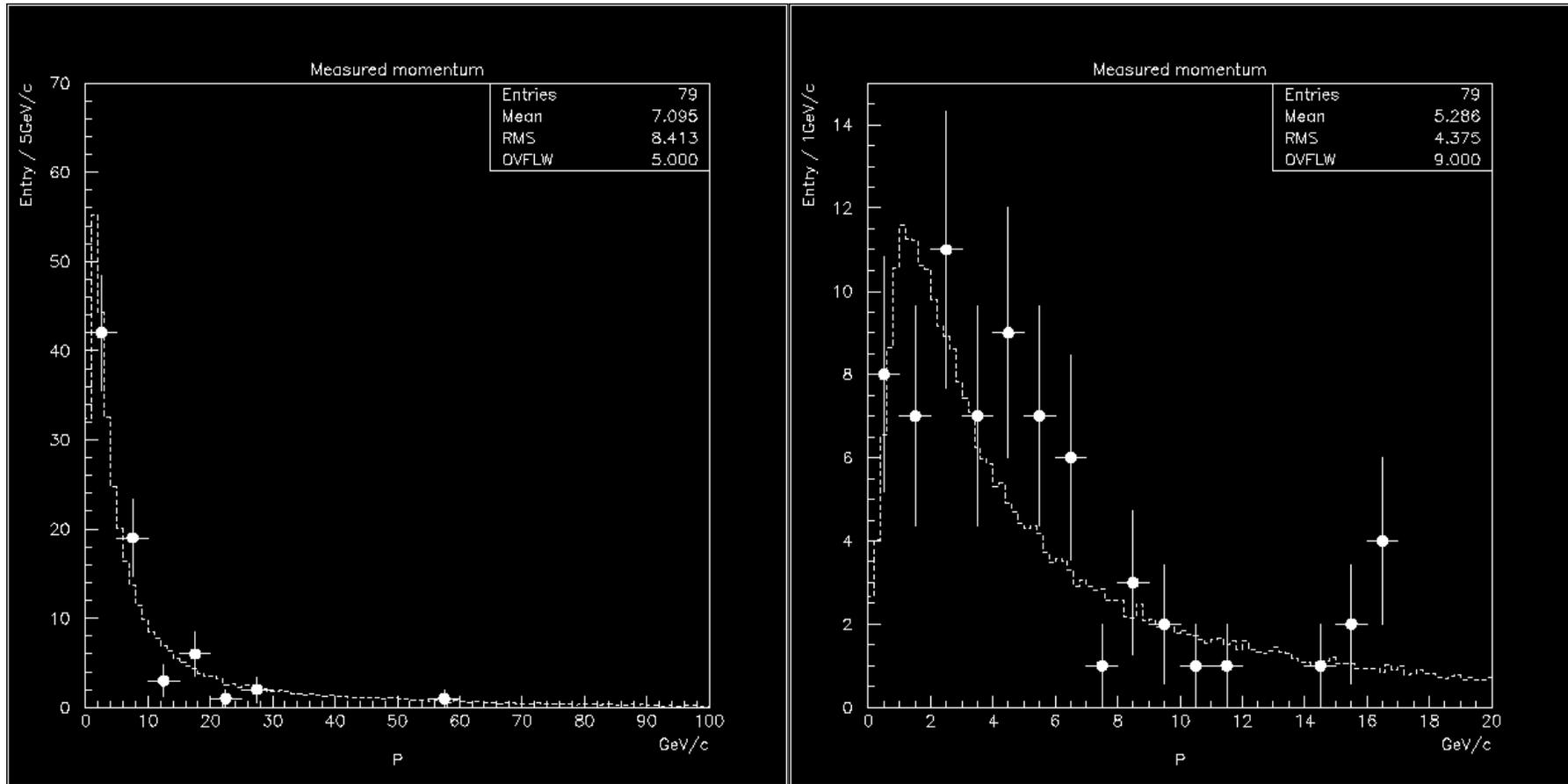
Slope distribution for momentum measured tracks and MC normalized by just number of tracks.

Dots with error bar is data and dashed line is MC.



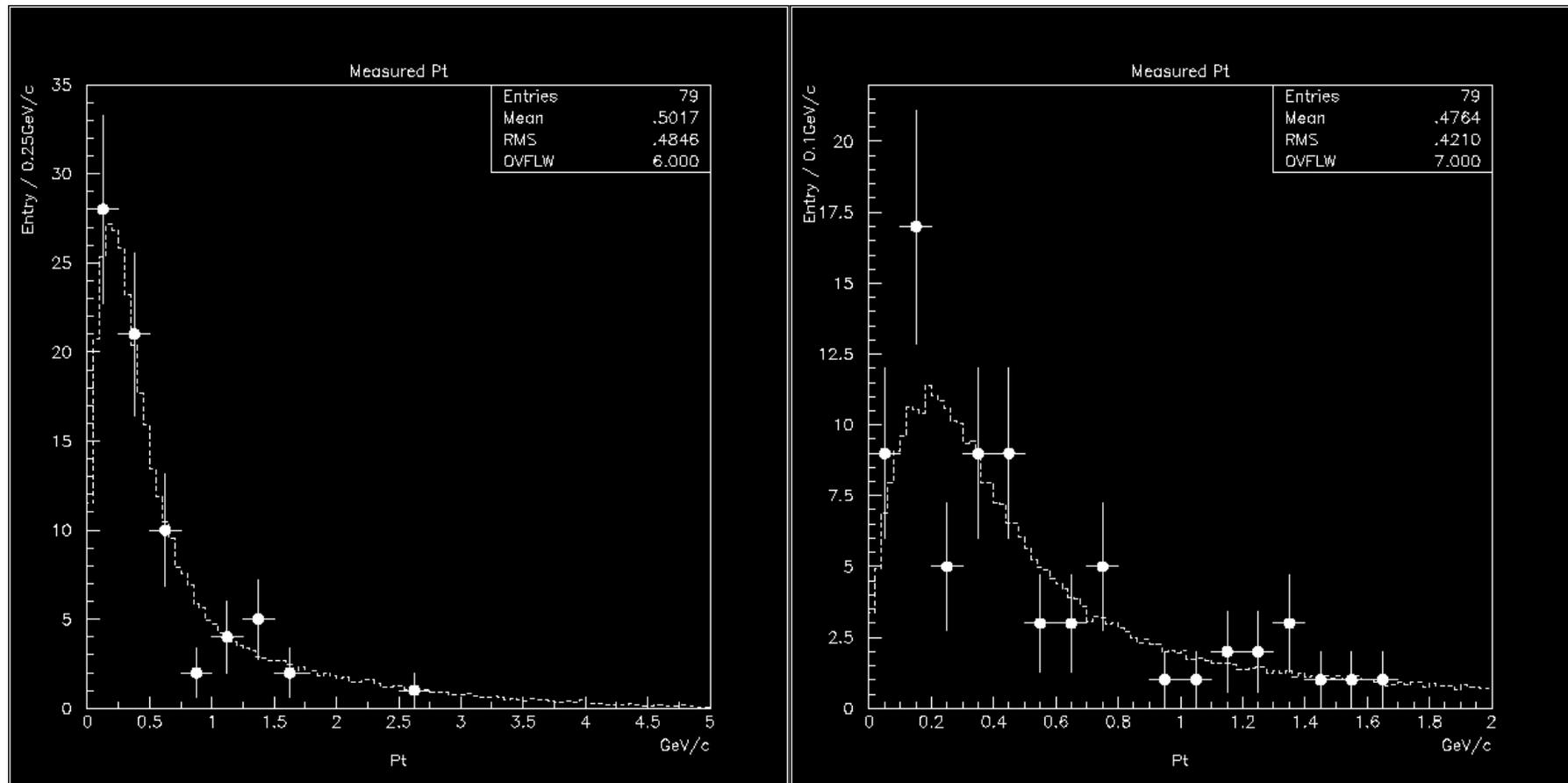
Module 3

Measured momentum up to 100GeV/c and up to 20 GeV/c



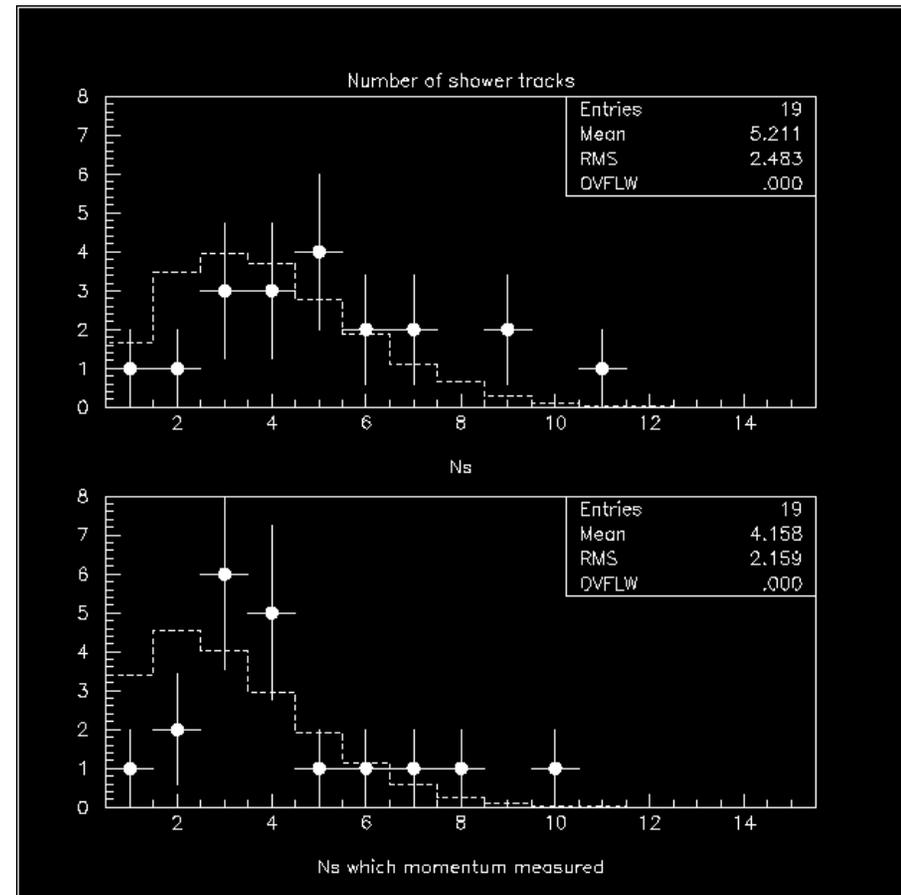
Module 3

Measured Pt up to 5GeV/c and up to 2GeV/c



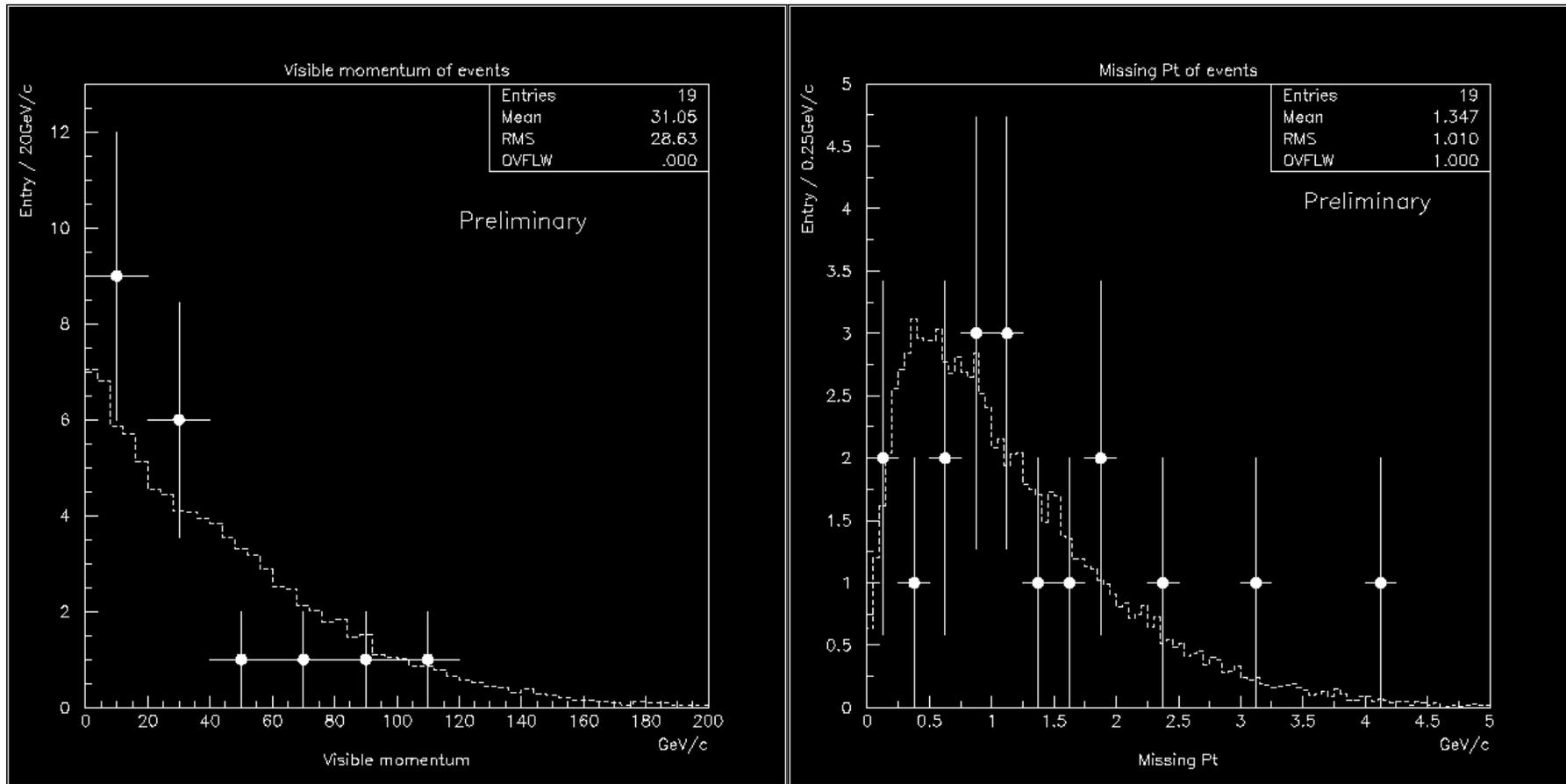
Event based analysis for MODULE 3

- Data
 - 19 event out of 24 event can be used for this analysis. Rest of 5 events are all tracks has flag ≥ 7 or no momentum measured track exist.
- MC
 - 18,903 out of 20,000 events has at least one track which momentum measured. Normalization has done by 19/18,903.



Module 3

Visible momentum and missing Pt of events.



Summary for MODULE 3

- 79 out of 99 tracks successfully processed.
 - 20 tracks which not possible to measure momentum
 - Downstream event : 0
 - No such track : 1
 - No such m-file : 1
 - Too short : 2
 - Alignment bad : 3
 - Software crash : 2
 - Too small scanning area : 11 (Large angle track, See page 5)
 - Details are listed in the other file.
- MCS measured momentum and MC seems consistent.

Module 8

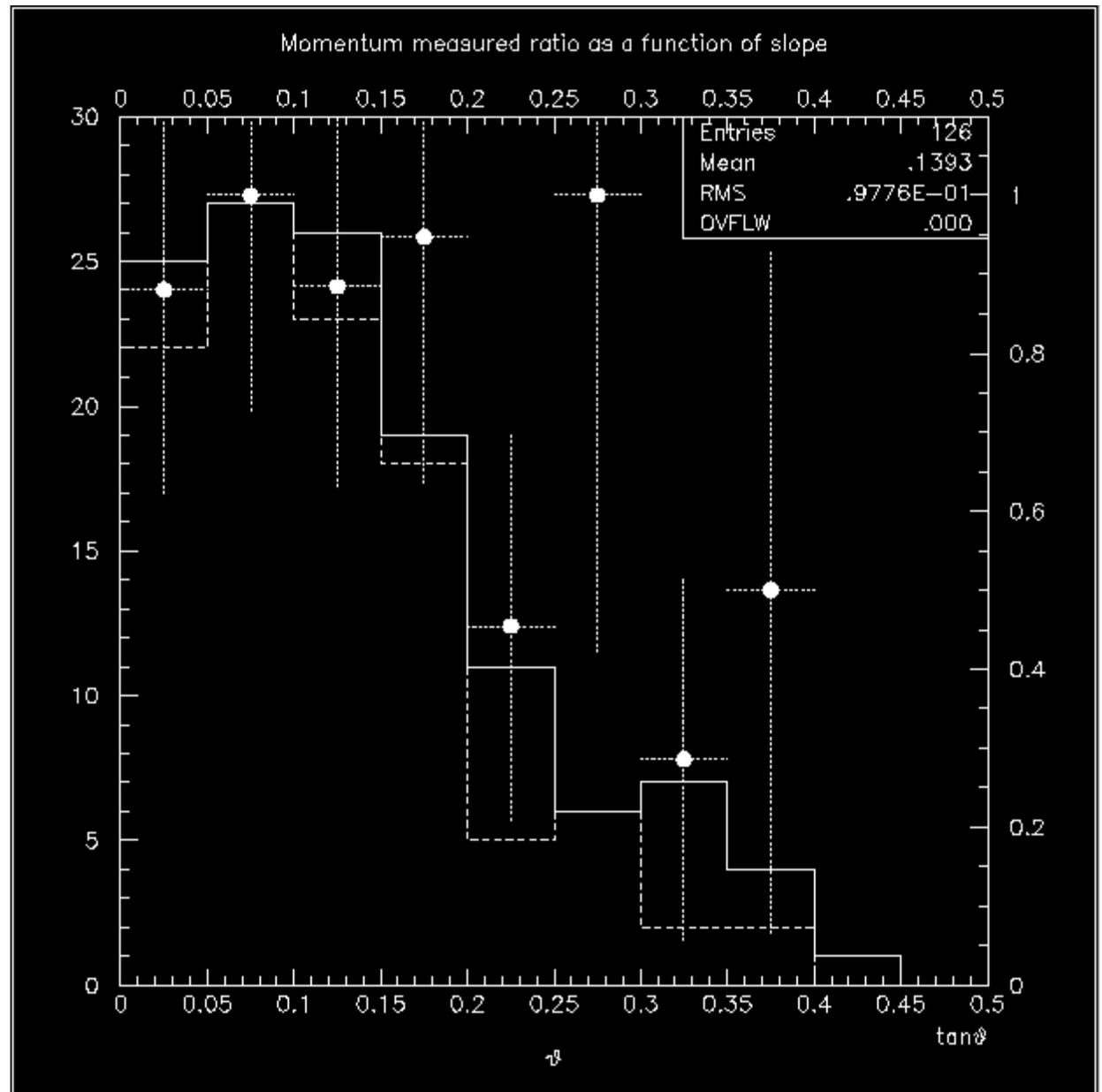
- Data set
 - M-files for Electron ID
 - Inclined m-file along to the target track.
 - For each track has own m-file.
 - 126 out of 189 tracks has tried for momentum measurement.
 - Rest of 63 tracks are short due to re-interaction or tracks of downstream events.
 - 105 out of 126 has successfully measured
 - Data quality check(Residuals) and requirement for at least two cells to evaluate momentum.
 - 83.3% of momentum has measured. Reasons for the rest of 21 tracks will be mentioned later.
 - For subdivided dataset due to “Slip”, highest Limit data is used.

Module 8

Momentum measured ratio is plotted as a function of the track slope. Solid line is for 126 tracks and dashed line is for measured 105 tracks. Dots are measured ratio.

Ratio is going down for larger track slope.

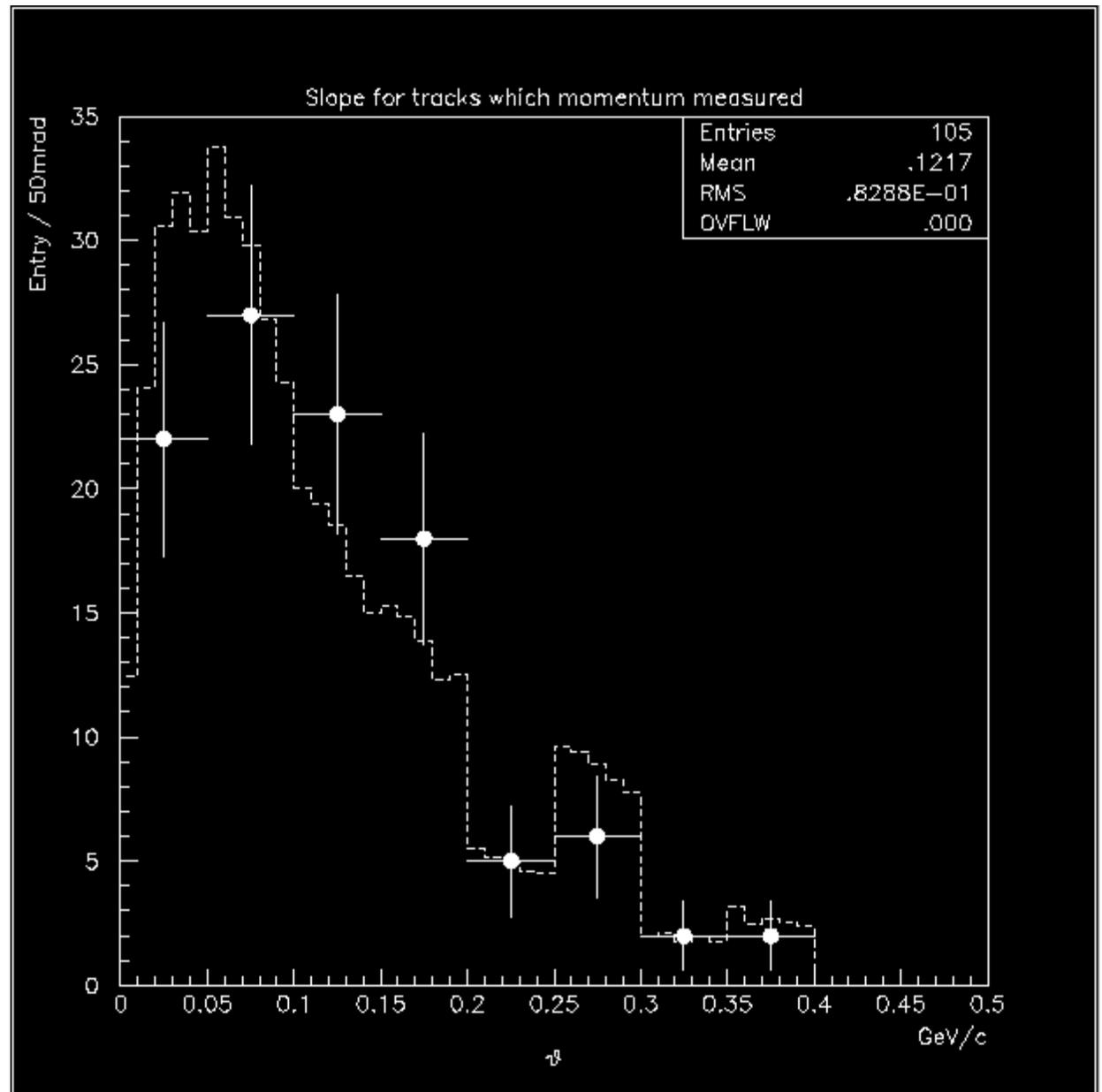
This measured ratio as a function of track slope is used for MC comparison.



Module 8

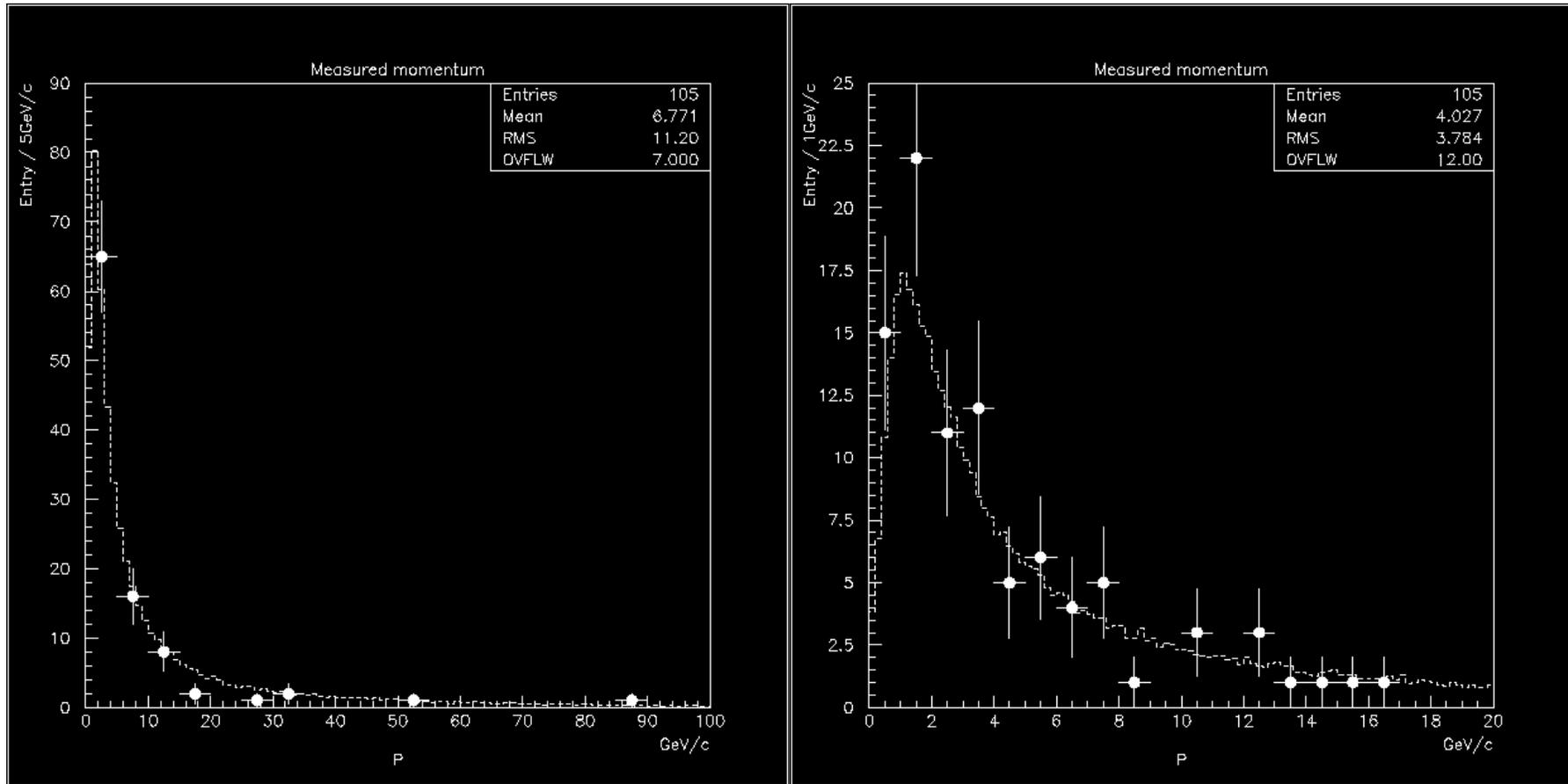
Slope distribution for momentum measured tracks and MC normalized by just number of tracks.

Dots with error bar is data and dashed line is MC.



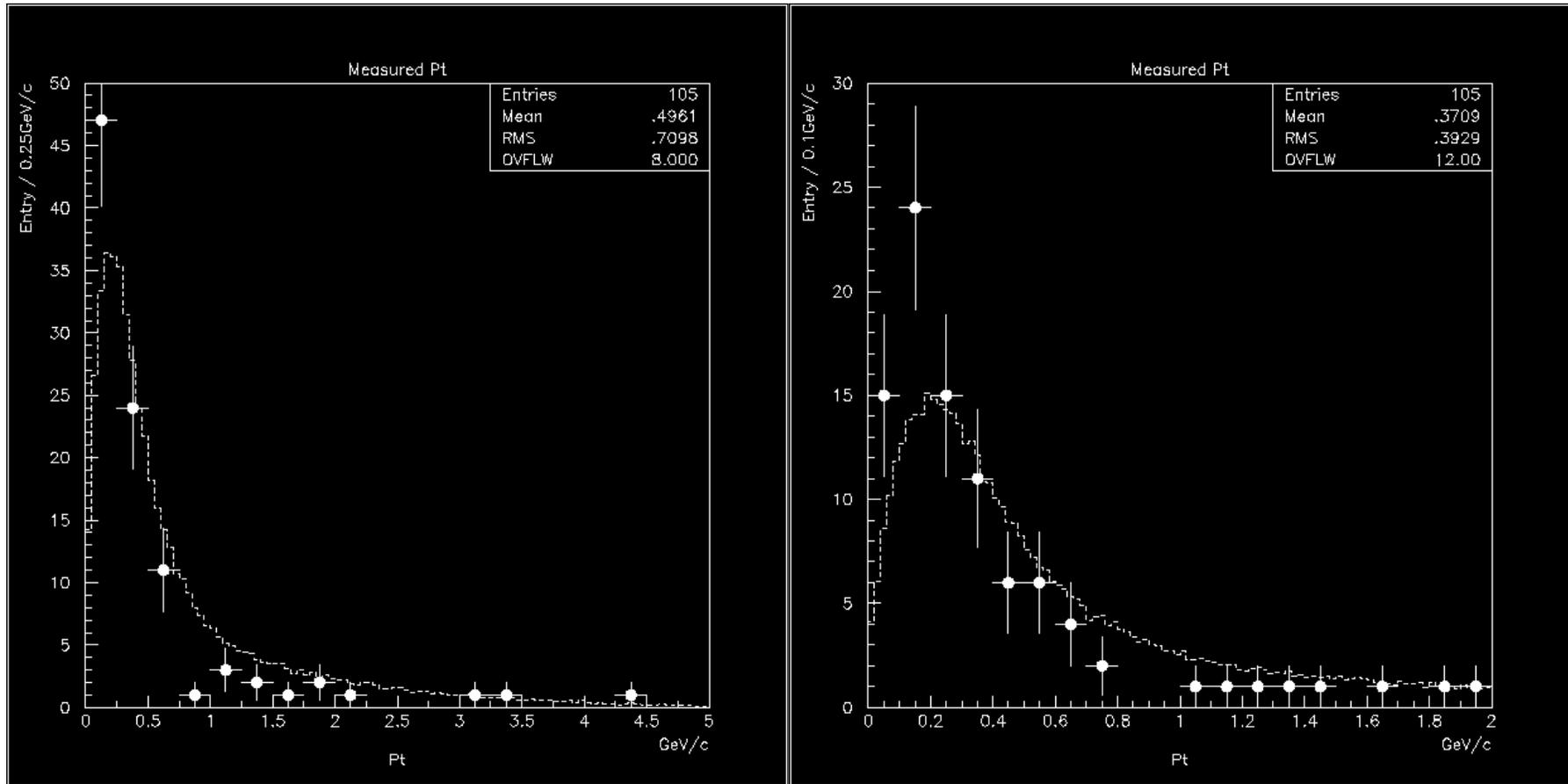
Module 8

Measured momentum up to 100GeV/c and up to 20 GeV/c



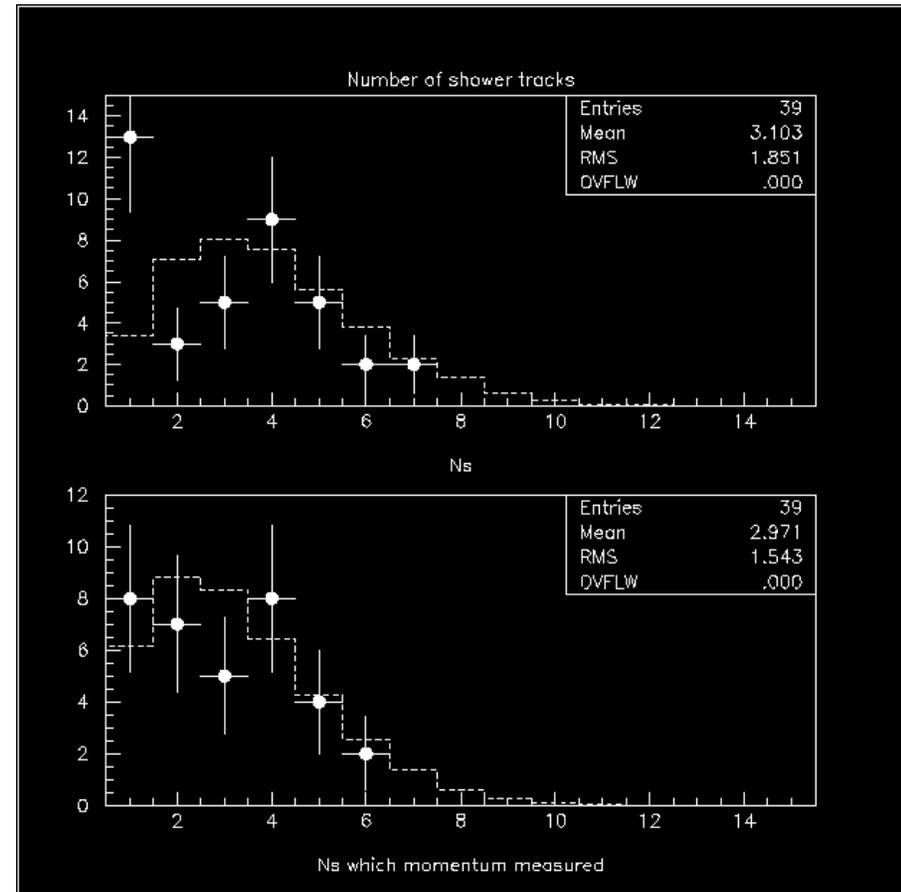
Module 8

Measured Pt up to 5GeV/c and up to 2GeV/c



Event based analysis for MODULE 8

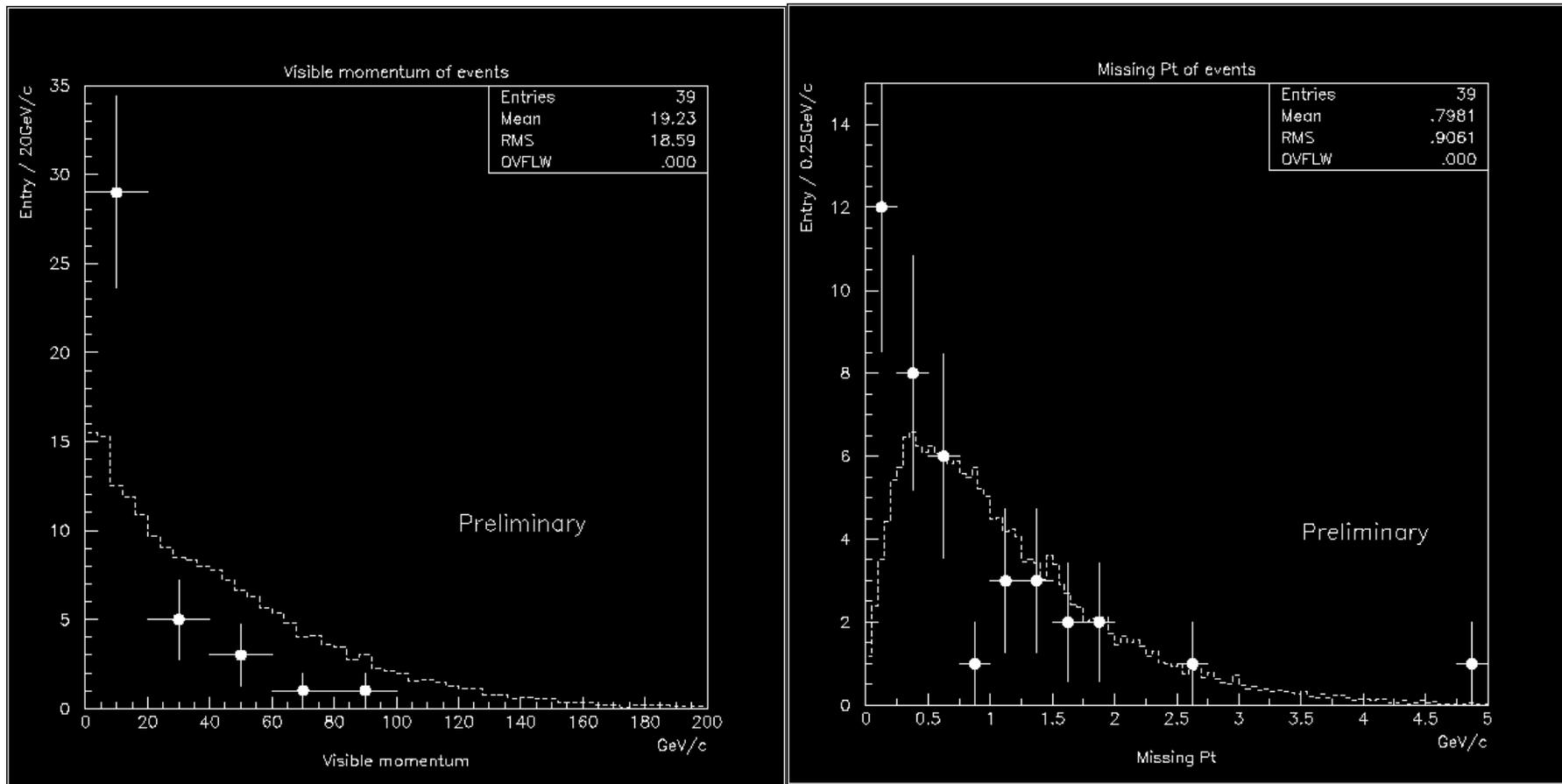
- Data
 - 39 event out of 55 event can be used for this analysis. Rest of 16 events are all tracks has flag ≥ 7 or no momentum measured track exist.
- MC
 - 19,060 out of 20,000 events has at least one track which momentum measured. Normalization has done by 39/19,060.



Module 8

Visible momentum and missing Pt of events.

It seems not consistent with MC.(Discussion in next slide)

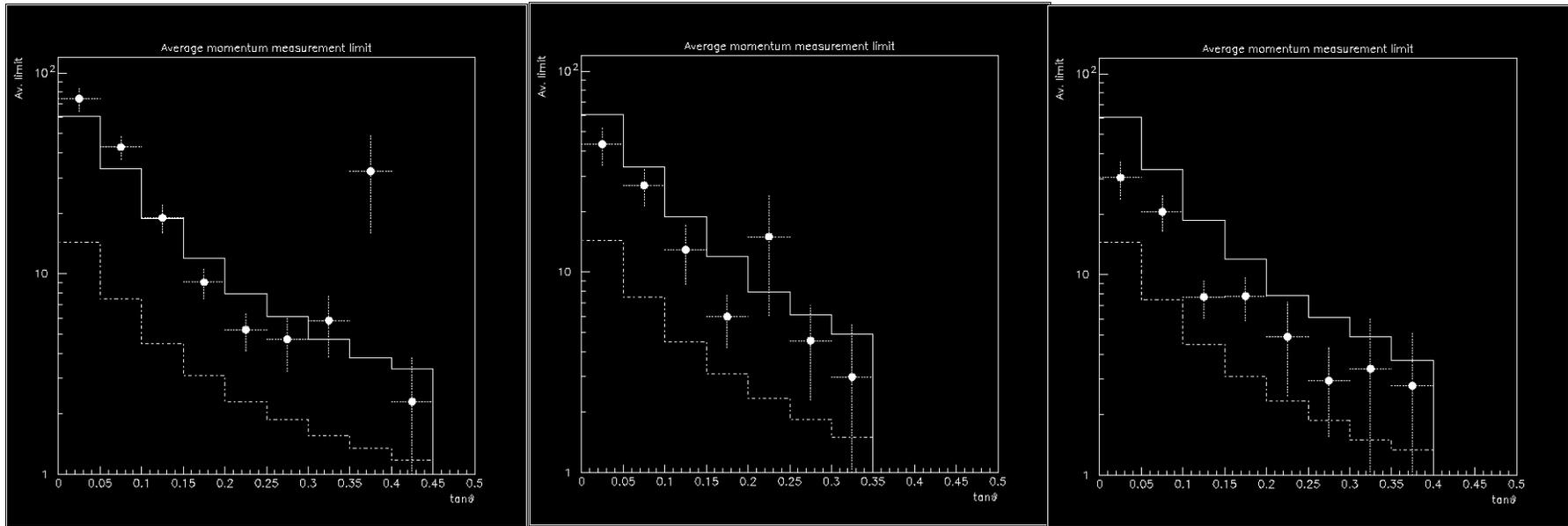


Summary for MODULE 8

- 105 out of 126 tracks successfully processed.
 - 21 tracks which not possible to measure momentum
 - No such track : 1
 - No such m-file : 3
 - Too short : 2
 - Alignment bad : 12
 - Too small scanning area : 3 (Large angle track, See page 5)
 - Details are listed in the other file.
- MCS measured momentum and MC seems not consistent especially in event based analysis.(See page 44,45). Track momentum below 20GeV/c seems OK.(See page 42)
 - Possibly due to enhancement of $N_s=1$ event(Page 44). Other reason could be “Limit” because module 8 is BULK.

Systematics in MODULEs

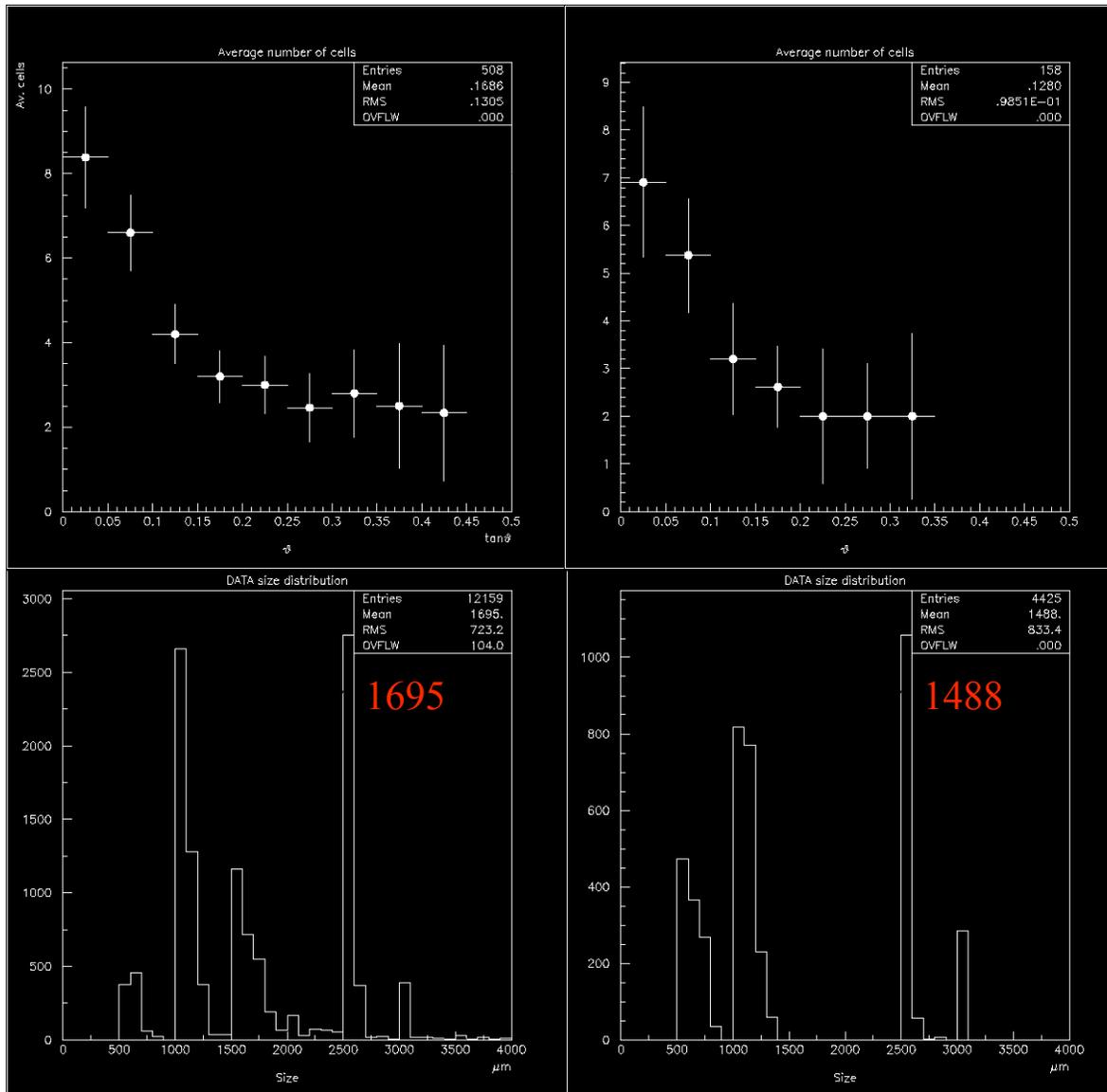
- Already mentioned in previous page, module by module systematics are there because radiation length and gap is different.



Averaged “Limit” are plotted as a function of track slope. Dots are Av. Limit, solid line is averaged muon momentum and dashed line is that of hadrons. In module 1, Limit is more or less above av. muon momentum. But In the case of module 8, av. Limit is far below av. muon momentum, and above hadron momentum. It is not possible to measure muon momentum in module 8, but possible to measure hadrons. In the case of event based analysis, I used Limit if measured momentum is higher than limit. Muon momentum in module 8 is estimated systematically lower because of muon.(Compare page 28 and 45)

Averaged Limit is lower in module 3 than that of module 1 even both are ECC200.

Systematics in MODULEs



Averaged number of cells are plotted as a function of track slope. In module 3, av. Number of cells are systematically lower than that of module 1.

Bottom figures are showing scanned area size for all data for module 1 and 3. Averaged size of module 1 is slightly larger than that of module 3. This can be a reason of difference. (See page 5)

Summary

- Spectrometer and MCS momentum consistency is confirmed.
- Module 1,3 and 8 momentum measurement using electron ID data has done.
- About 80% of track can measure MCS momentum in electron ID data set.
- Hadron momentum can be reliably measured
 - See page 47, Limit is far above average hadron momentum in all modules.
- In BULK, it is not sufficient to measure muon momentum properly.

Outlook

- Process for module 2,4,5 and 7 in same way.
 - I need software development to avoid slip problem.
- Recovery for not measured tracks
 - ”no such track” and “no such m-file” will be solved.
 - “Bad alignment” is just a few plate in the data, skip these plate for momentum measurement (Software development).
 - “Too short” and “downstream” was just check miss.
 - “Too small scanning area”: additional scanning or ignore.
 - $(9+11+3)/(293+99+126)=4.4\%$ (fraction will be higher in ECC800)
- To perform event based analysis properly , muon momentum should be measured by spectrometer.
- Could you give me four month to do recovery, improvements and processing for the other 4 modules?