Analysis Overview and Emittance Evolution

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MICE Analysis

- MICE aims at Step IV to
  - Demonstrate the underlying physics that can effect muon cooling
  - Study emittance evolution through a single absorber
- To this end, the MICE analysis seeks to:
  - Validate the performance of the individual detectors
  - Validate the performance of the magnetic lattice by comparing measurements in different detectors
  - Measure the underlying physics processes, namely multiple Coulomb scattering and energy loss
  - Measure the increase in phase space density of the beam on passing through the absorber

Papers Status

- Three papers in progress
- Demo paper sent to PRAB
  - Demo paper describes the upgraded MICE lattice including RF cavities
  - Journal referees comments received, and response in preparation
- Direct measurement of emittance using the MICE scintillating fibre tracker (V. Blackmore)
- Multiple Coulomb Scattering of muons in Lithium Hydride (R. Bayes)
- Results presented at ICHEP for both papers

Further analyses

- Several further analyses in progress
  - Field-on measurement of scattering (A. Young, J. Greis)
  - Measurement of energy loss (S. Wilbur)
  - Emittance evolution (F. Drielsma, C. Hunt, A. Liu, C. Rogers)
  - Beam-based alignment (Y. Song, C. Rogers)
  - Phase space density and volume estimation (T. Mohayai, F. Drielsma)
- Focus here is on emittance evolution of 2016/04 data

Data taking in 2016/04

Date	Name	Subject
18 Nov – 23 Nov	2016/04 1.3	Beta ~ 1200 mm; p = 140 MeV/c
28 Nov – 5 Dec	2016/04 1.2	Beta ~ 800 mm; p = 140 MeV/c
5 Dec – 8 Dec	2016/04 1.5	Beta ~ 580 mm; p = 140 MeV/c
8 Dec – 12 Dec	2016/04 2.3	Beta ~ 700 mm; p = 200 MeV/c
12 Dec – 14 Dec	2016/04 2.4	Beta ~ 1200 mm; p = 240 MeV/c

- 2016/04
  - Beta function scan at 140 MeV/c
  - Best available settings at 200 and 240 MeV/c
- Analysis currently targeted at setting 1.2
  - MC indicates good transmission compared to cooling

Data taking in 2016/04

- 2 beamline settings considered in this talk
- Beamline setting 3-140+M3-Test2
  - 140 MeV/c beam with about 3 mm emittance
  - 1.8 M incident particles accumulated
- Beamline setting 10-140+M3-Test3
  - 140 MeV/c beam with about 10 mm emittance
  - 2.9 M incident particles accumulated
- Data accumulated over about 3 days

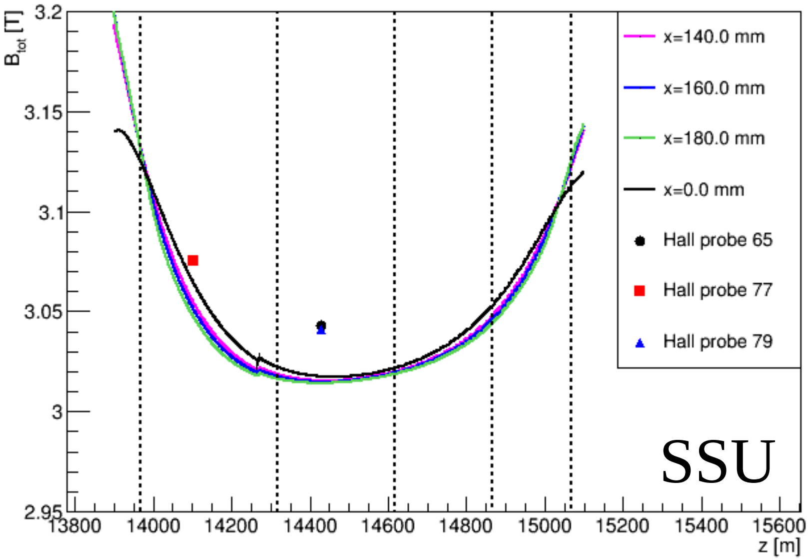
In this talk

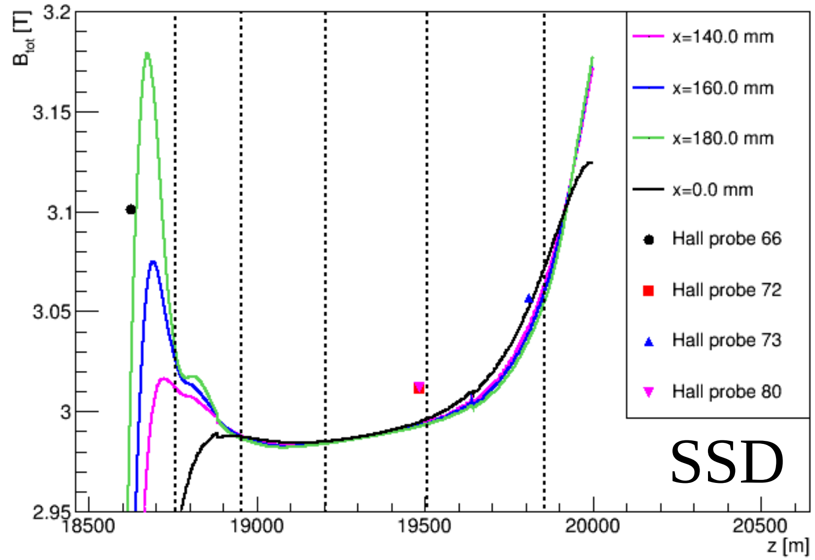
- Internal Tracker validation
  - Hall probes vs MAUS
  - Kalman P-Value
- Internal TOF validation
  - Study slab time difference
- Global validation
  - Extrapolated tracks and residuals
- Subsampling
- Amplitude plots ← this is the main result
- Comparison with MC

Biases and Uncertainties

- Seek to measure phase space density evolution across the absorber
- What are the biases and uncertainties?
- Bias on the measured x/px/y/py phase space and transmission
  - Intrinsic detector resolution (scattering and spatial resolution)
  - Detector efficiency
  - Magnetic field in reconstruction region
  - *Biases the measurement*
- Bias on the model of the channel
  - Alignments
  - Absorber material
  - Other material budget
  - *Biases the simulation*

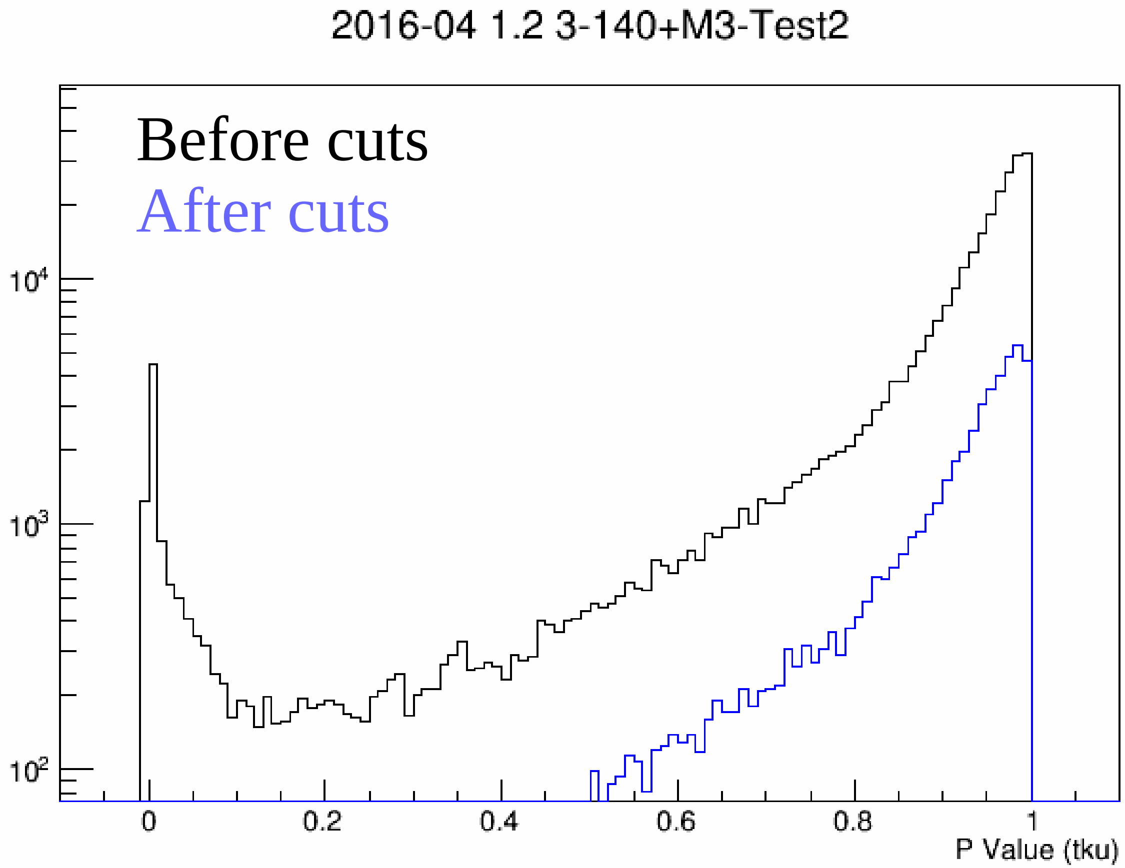
Hall Probes vs MAUS





- Hall probes are mounted at r ~ 160 mm
- Less than 1 % discrepancy between MAUS and hall probes
  - Excepting Hall probe 66
  - Includes correction factor for PRY that has not yet been included in MAUS

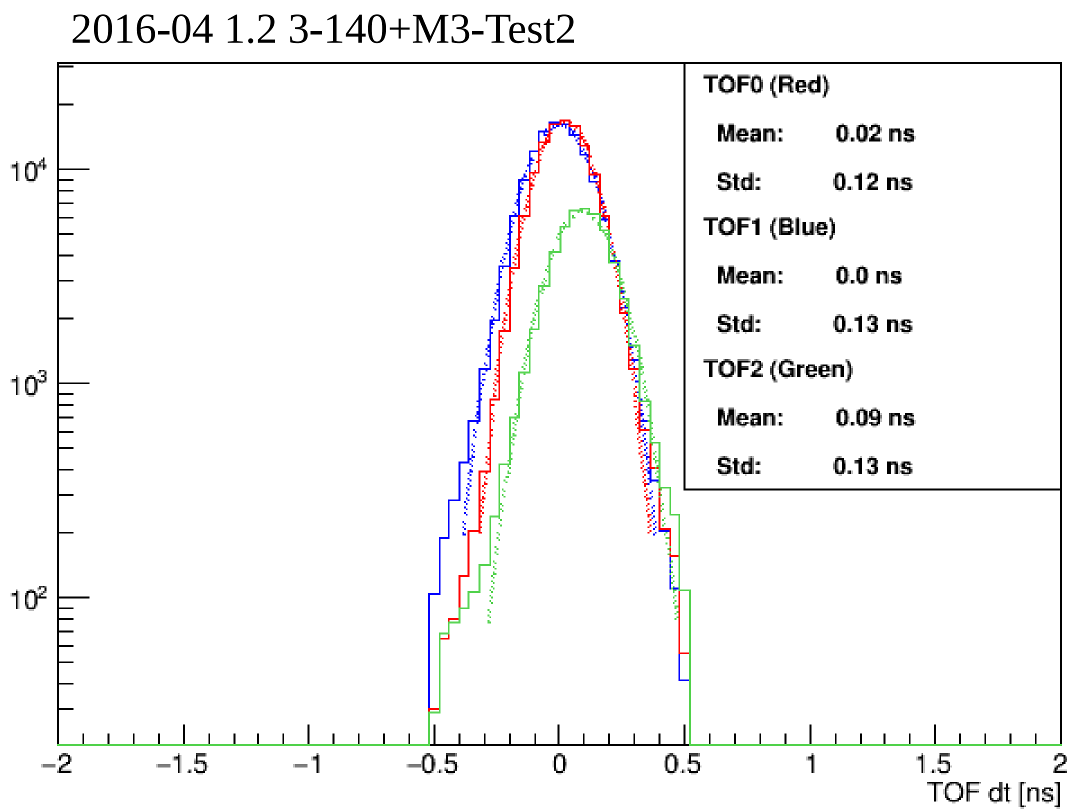
P-Values



- P-Value reflects the goodness of fit
- For an ideal detector, should be uniform between 0 and 1
  - "Ideal" means measurement uncertainty is normally distributed about the true value with a well known RMS

“Internal” TOF Validation

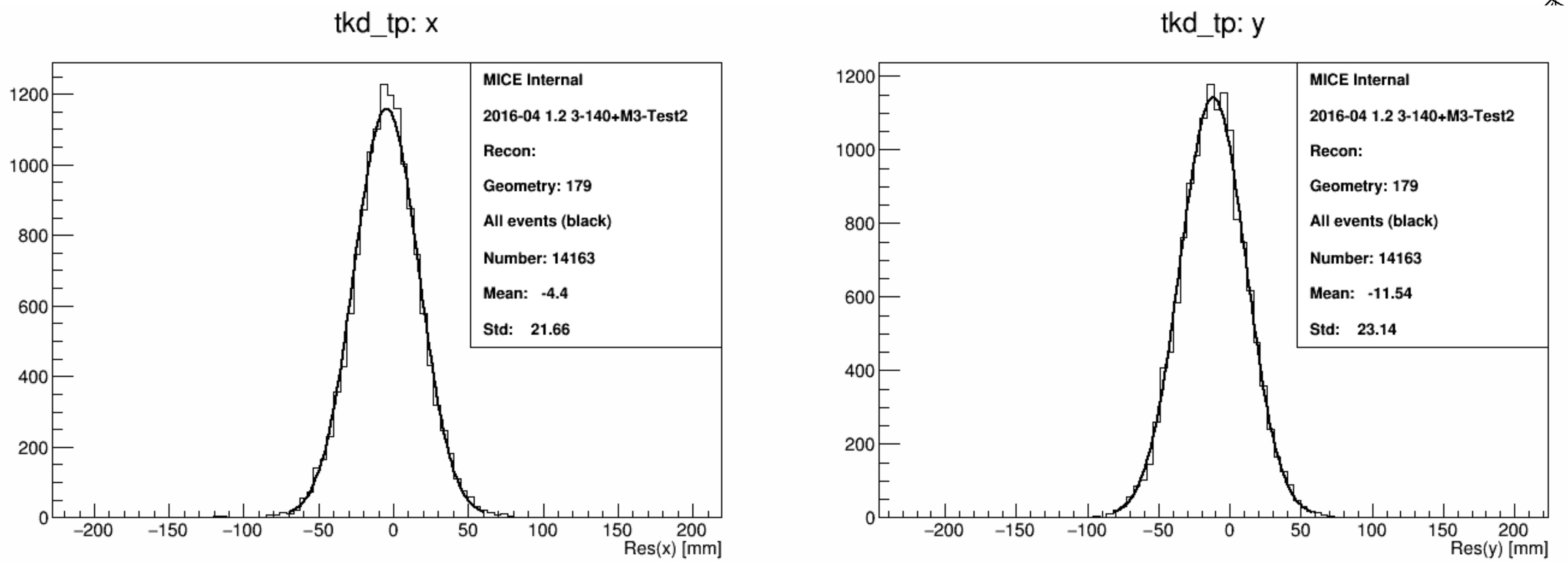
- Validate TOF by comparing the measured time in each slab
  - Consistent with time resolution of 0.06 ns.
  - Bias is to be understood



Global Validation

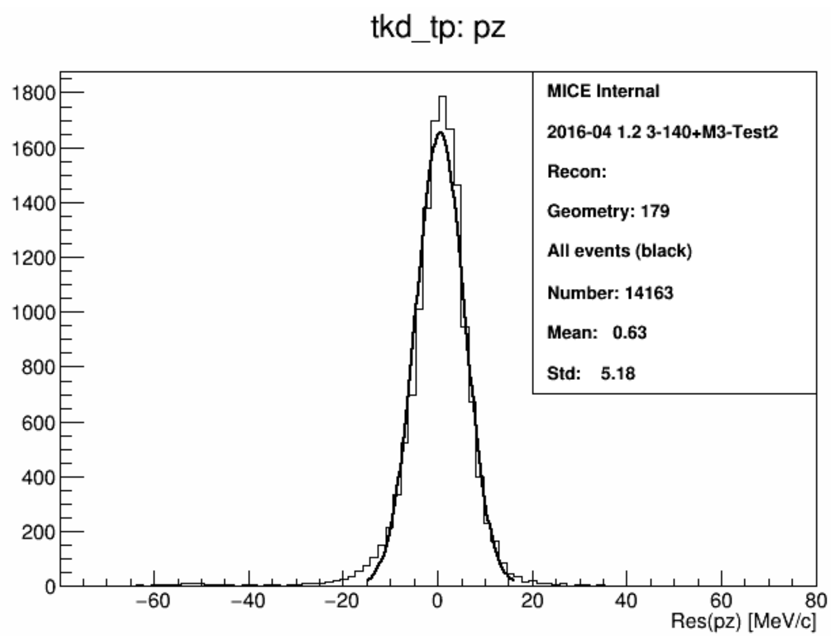
- We can validate measurements by comparing tracks with other detectors
- Take TKU as “reference” position, momentum
- Take TOF1 as “reference” time
  - Use extrapolated time-of-flight between TOF1 and TKU to calculate reference time at TKU
- Extrapolate tracks to TKD, TOF2
  - Use MAUS internal field map and integrate Lorentz force law
  - Use Bethe-Bloch formula for mean energy loss in materials
  - Look at the difference between measured and extrapolated track

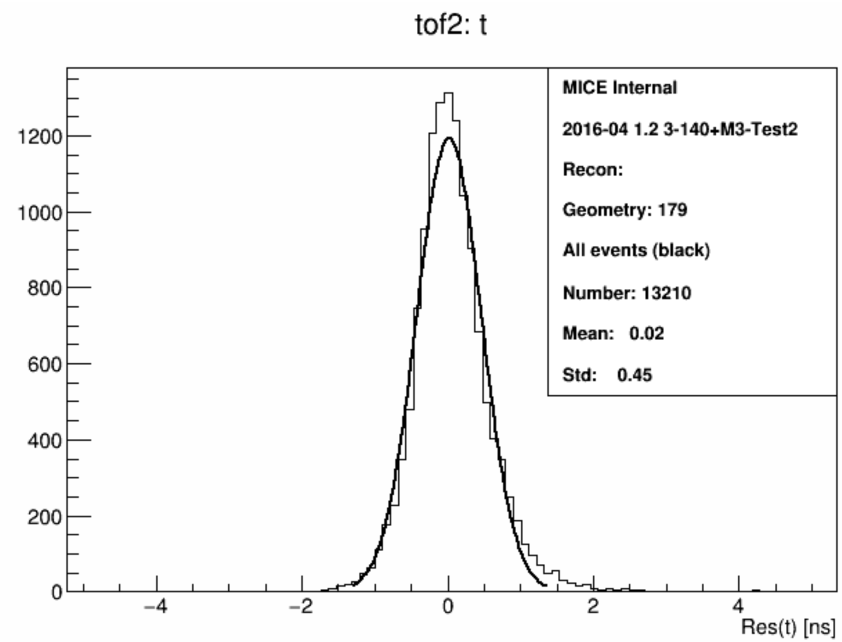
Extrapolated Position



- Extrapolate measured track at TKU to TKD
- Compare extrapolated position with measured position
- Extrapolated position indicative of magnetic field misalignment

Extrapolated Momentum



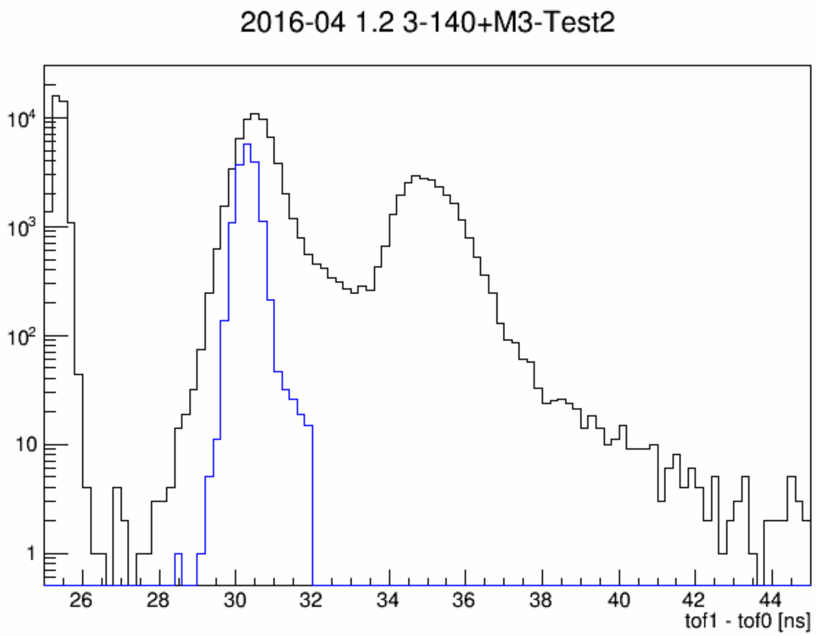


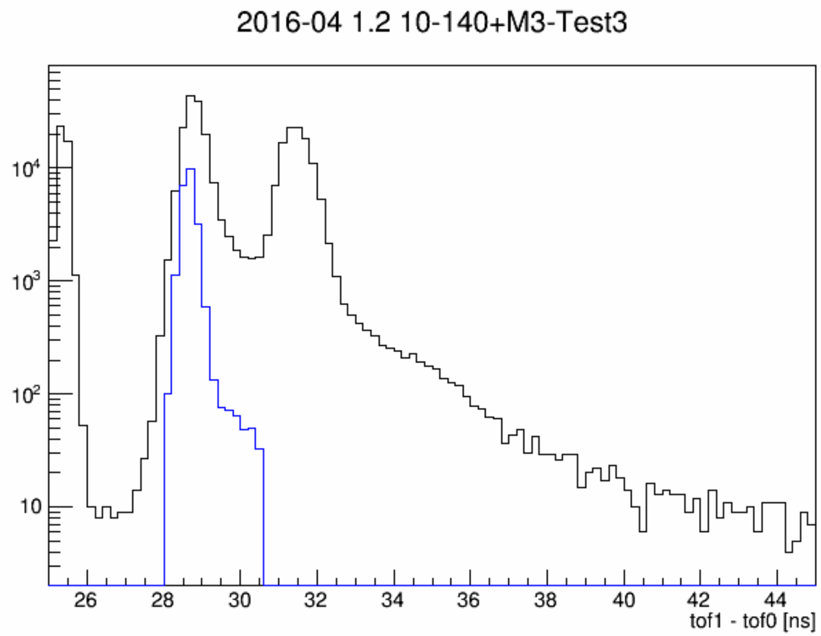
- Extrapolate TKU track to TKD and TOF2
- Extrapolated momentum consistent on average at sub-MeV/c level
- Extrapolated time consistent on average at 20 ps level
  - 1 MeV/c bias corresponds to about 30 ps bias in TOF12

Cuts

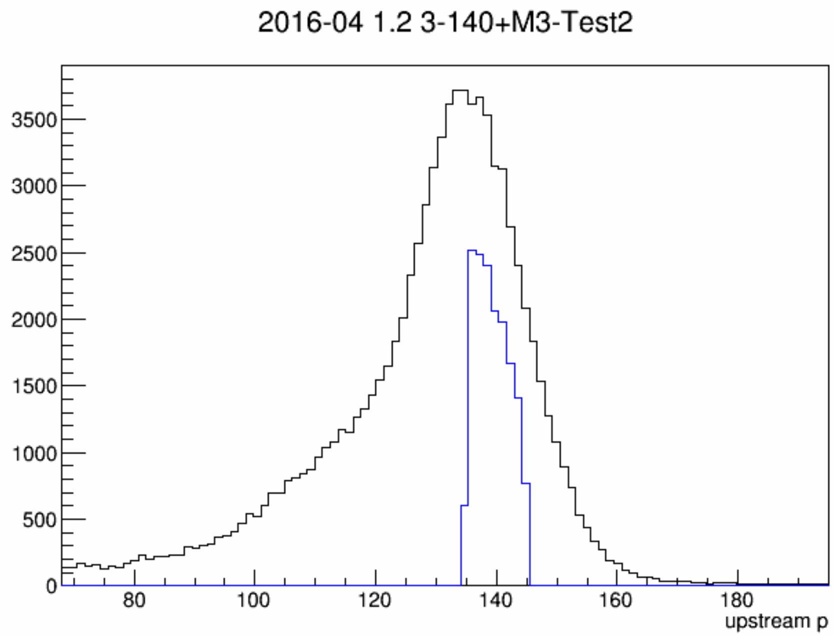
- Subsample upstream but not downstream
  - Downstream sampling biases the measurement
- Subsampling at the moment consists of basic data quality cuts
- Following cuts are enabled:
  - Exactly one track in TKU
  - Exactly one space point in TOF0
  - Exactly one space point in TOF1
  - TKU p-value > 0.02
  - tof01 > 28 ns
  - tof01 < 32 ns for 3-140+M3-Test2
  - tof01 < 30.5 ns for 10-140+M3-Test3
  - Require 135 < p(tku) < 145 MeV/c

TOF01

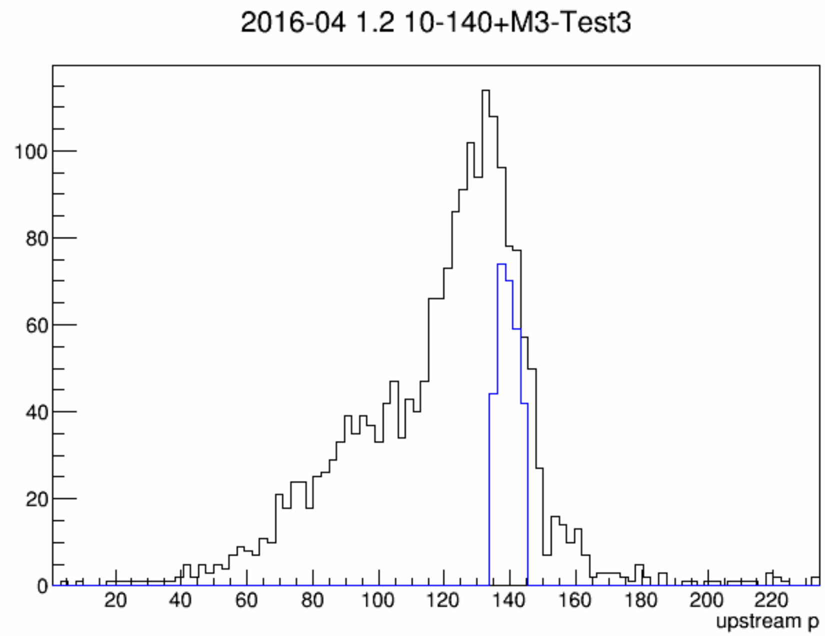

2016-04 1.2 3-140+M3-Test2
tof1 - tof0 [ns]


2016-04 1.2 10-140+M3-Test3
tof1 - tof0 [ns]

Upstream p



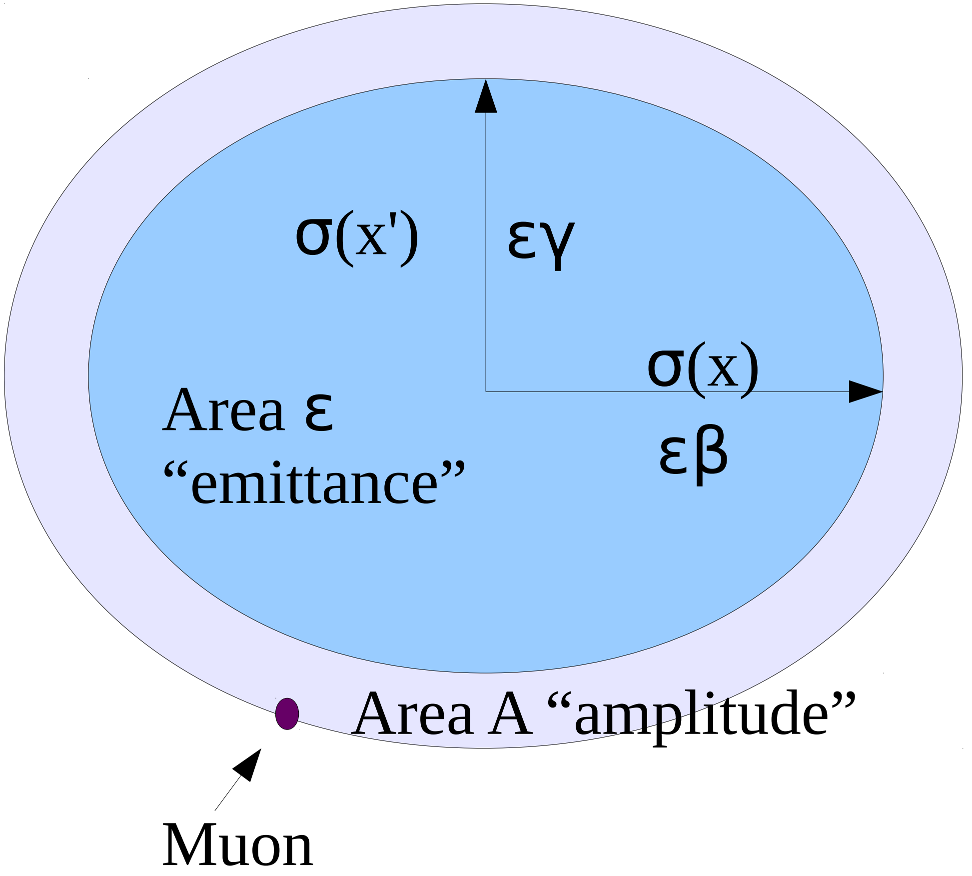
2016-04 1.2 3-140+M3-Test2
0
500
1000
1500
2000
2500
3000
3500
80
100
120
140
160
180
upstream p



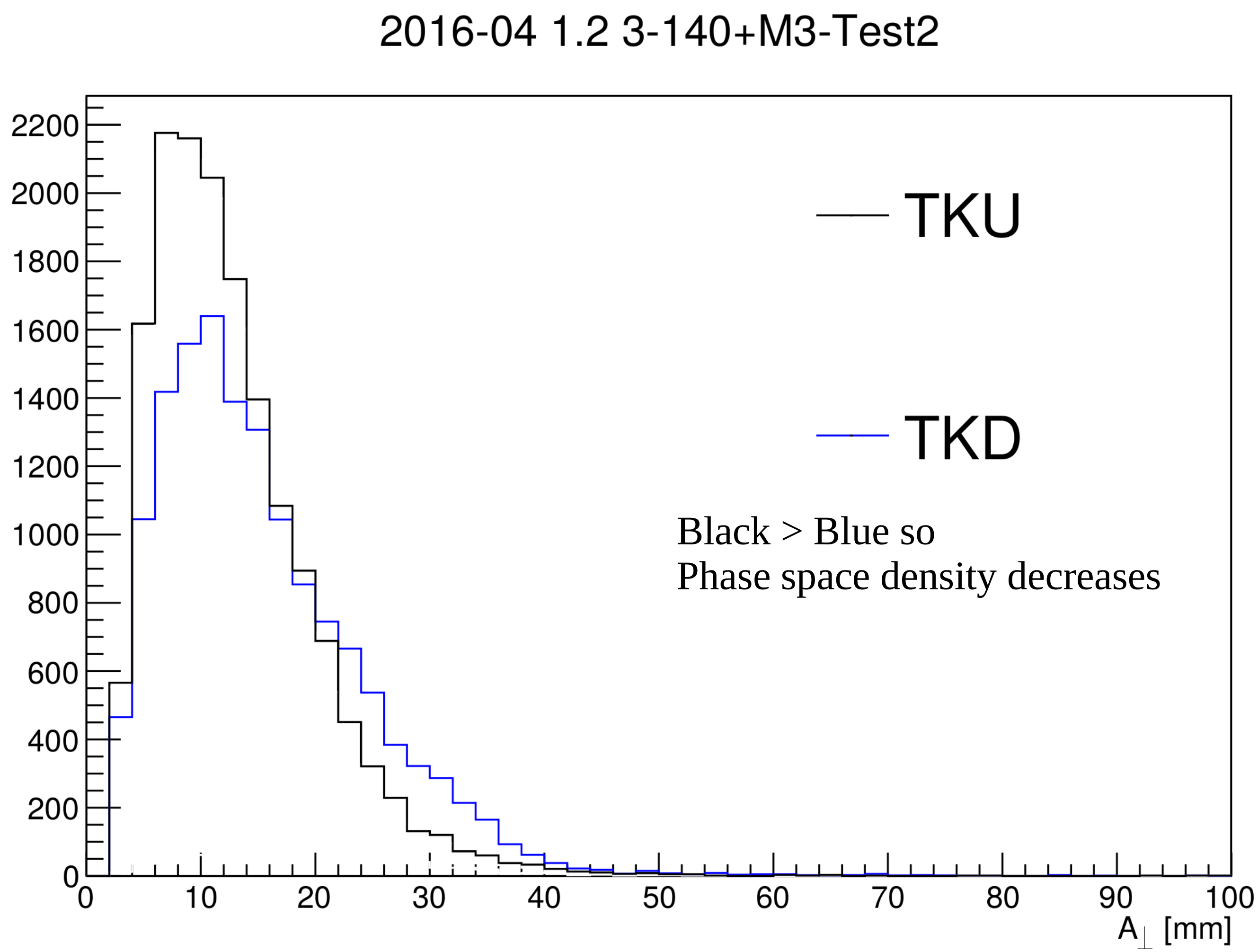
2016-04 1.2 10-140+M3-Test3
0
20
40
60
80
100
20
40
60
80
100
120
140
160
180
200
220
upstream p

Particle Amplitude

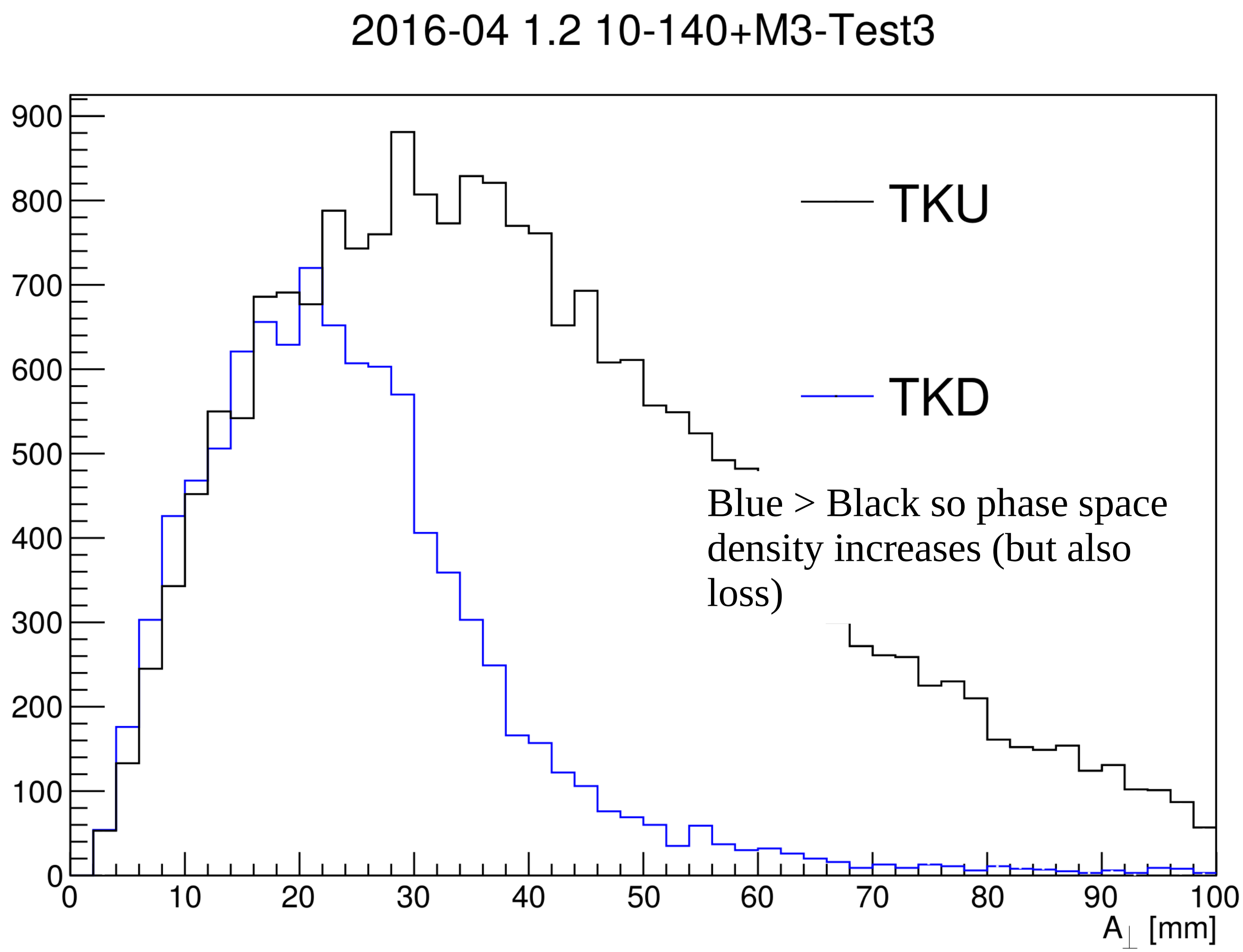
- Use particle amplitude to assess emittance reduction



Measured Amplitude Change



Measured Amplitude Change

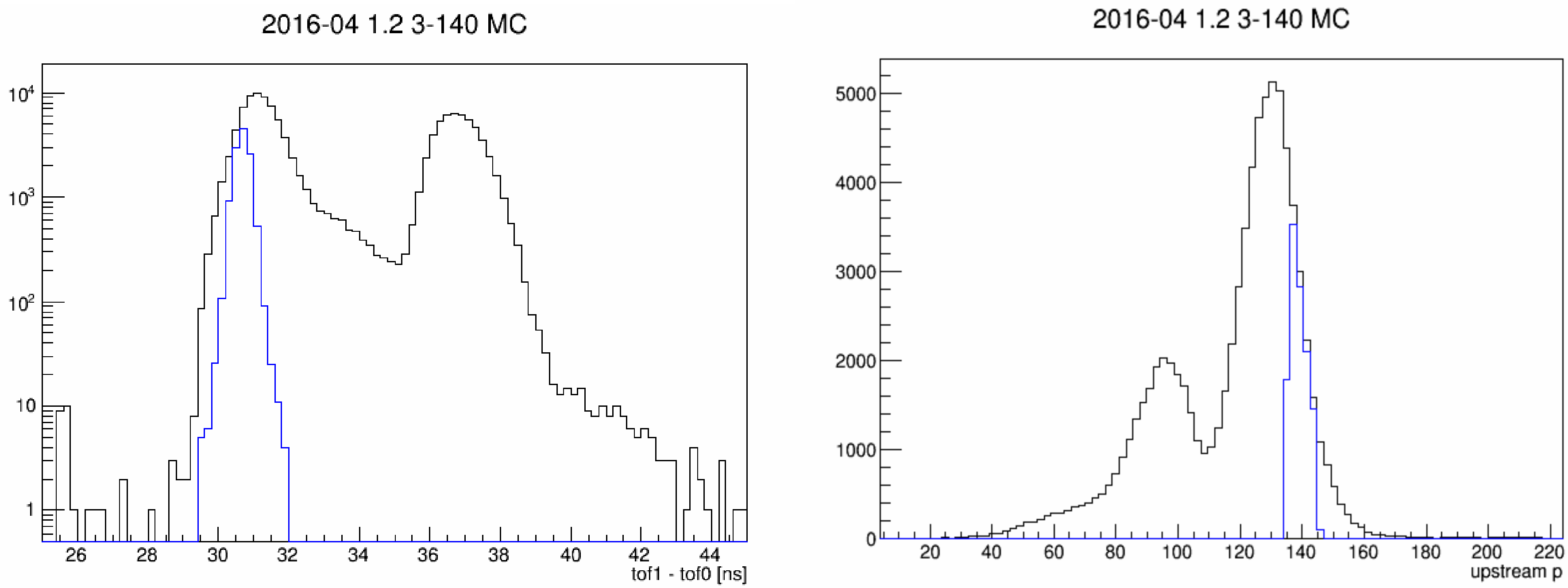


Blue > Black so phase space density increases (but also loss)

MC

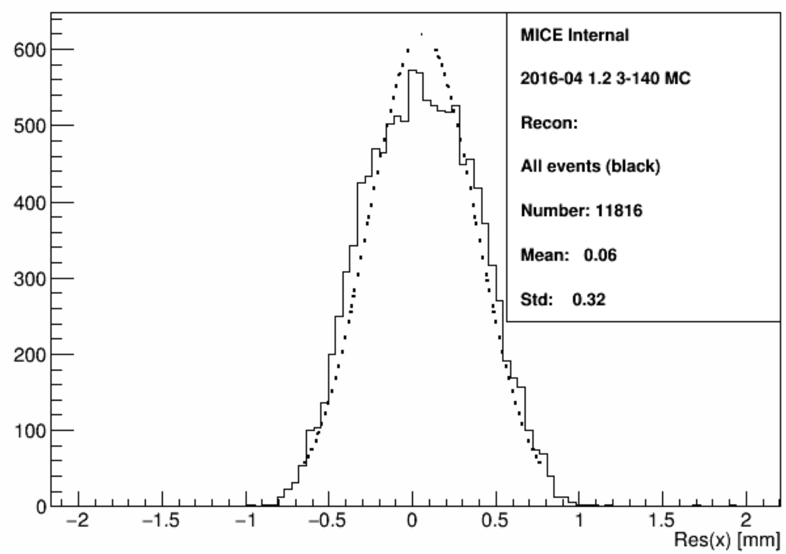
- Monte Carlo is useful for understanding errors
- Look at detector resolutions and residuals

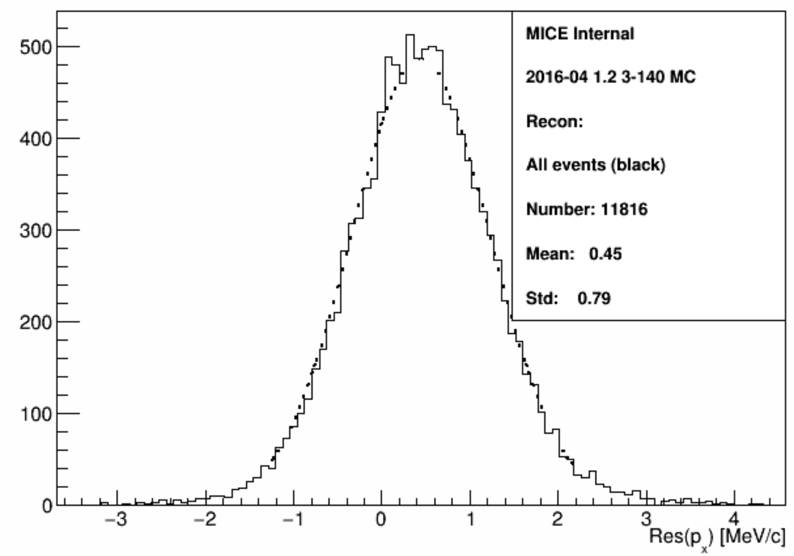
Monte Carlo Momentum



- Dipoles tuned according to Paolo's measured response

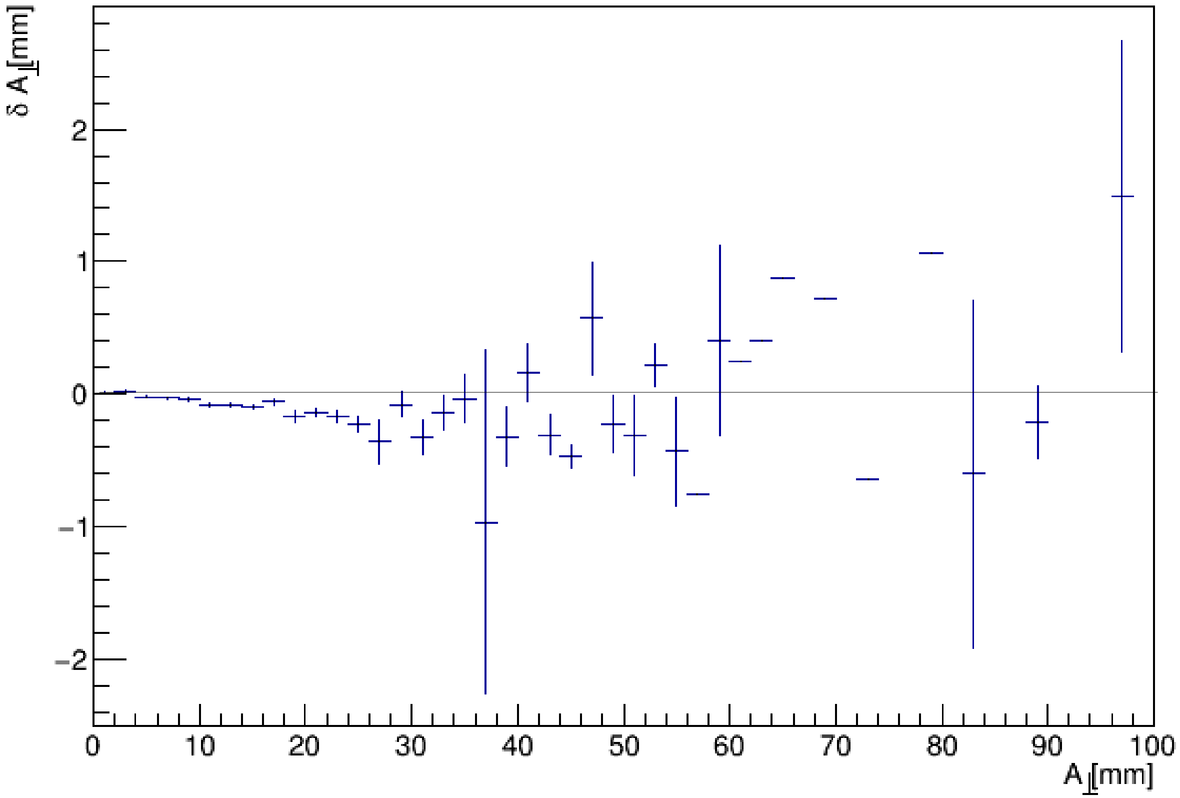
MC Residuals - horizontal





- Difference of Monte Carlo truth and reconstructed MC
  - Horizontal position and momentum
  - Show resolution and bias of order 1 MeV/c

Residuals - amplitude



- Slight bias in amplitude

Conclusions

- Many details still to be worked through
- Errors in momentum reconstruction are ~ MeV/c level
  - Validation from a number of independent cross-checks
- Errors in position reconstruction are ~ few hundred microns level
- MICE observes increase in phase space density