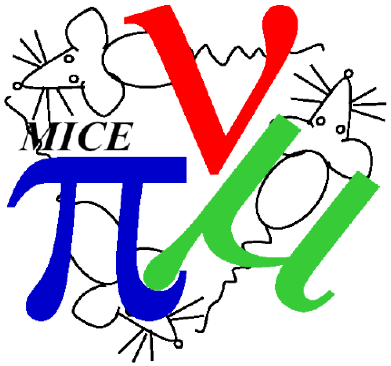
Emittance Evolution



C. Rogers,
ISIS Intense Beams Group
Rutherford Appleton Laboratory

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
- Thanks as always to MOMs
  - Ed Overton 9th November - 28th November 2016
  - Melissa Uchida 26th November - 16th December 2016
- Analysis
  - Rogers – 1.2
  - Ao – 1.5
  - Francois – 1.2

Overview

- Focus of this talk will be detector validation
  - How do we know that any of the detectors work?
  - Focus of the validation will be data
- Analysis using MAUS 2.7.0
- Cooling channel tag 2016/04 1.2
  - Run 8681:- beamline tag “3-140+M3-Test2”
  - Run 8699:- beamline tag “6-140+M3-Test2”
  - Run 8685:- beamline tag “10-140+M3-Test3”
- All plots are “MICE Internal”

In this talk

- Internal Tracker validation
  - Hall probes vs MAUS
  - Kalman P-Value
- Global validation
  - Extrapolated tracks and residuals
  - Misses and downstream efficiency
  - Beam-based alignment
- Cuts
- Amplitude plots ← this is the main result
- Comparison with MC

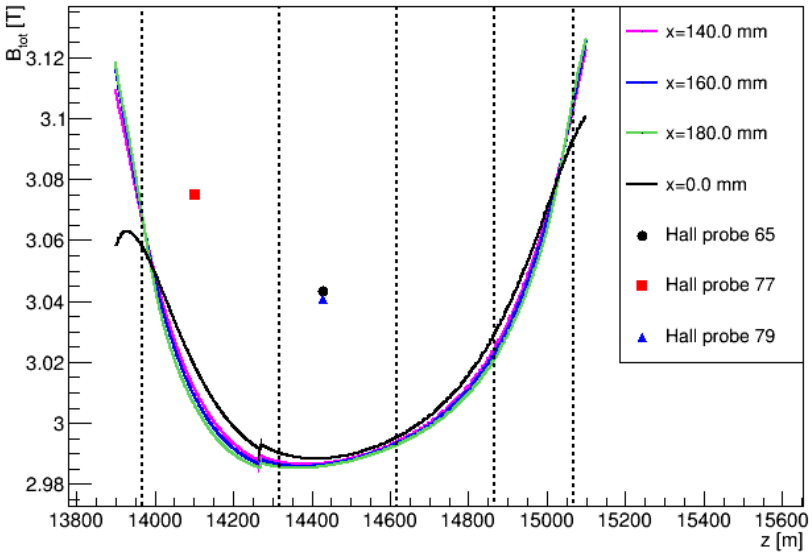
Biases and Uncertainties

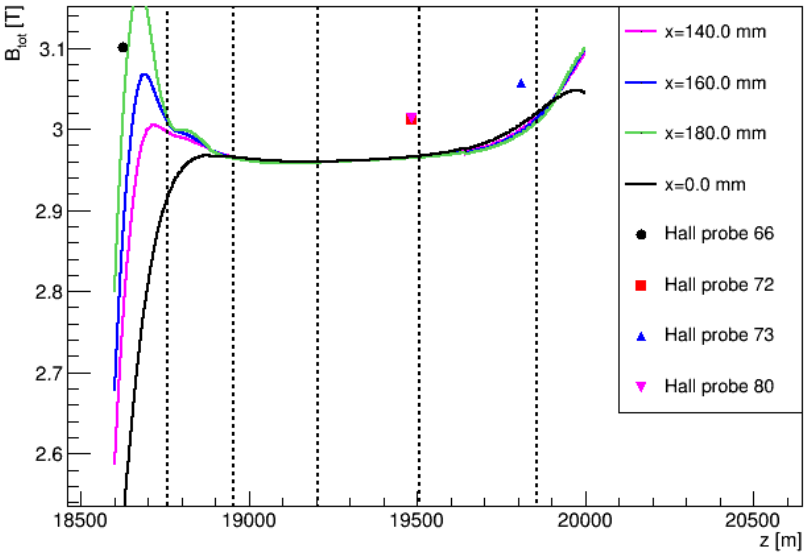
- Seek to measure emittance change across the absorbers
- What are the biases and uncertainties?
- Bias on the measured x/px/y/py phase space and transmission
  - Intrinsic detector resolution (scattering and spatial resolution)
  - Detector efficiency
  - Magnetic field in reconstruction region
- Bias on the model of the channel
  - (Magnet) alignment
  - Absorber material
  - (Other) material budget

“Internal” Tracker Validation

- Validate tracker by checking that the internals are self-consistent
  - Field measured in hall probes is consistent with reconstruction
  - Fitted tracks are not pulled too much (Kalman P-value)

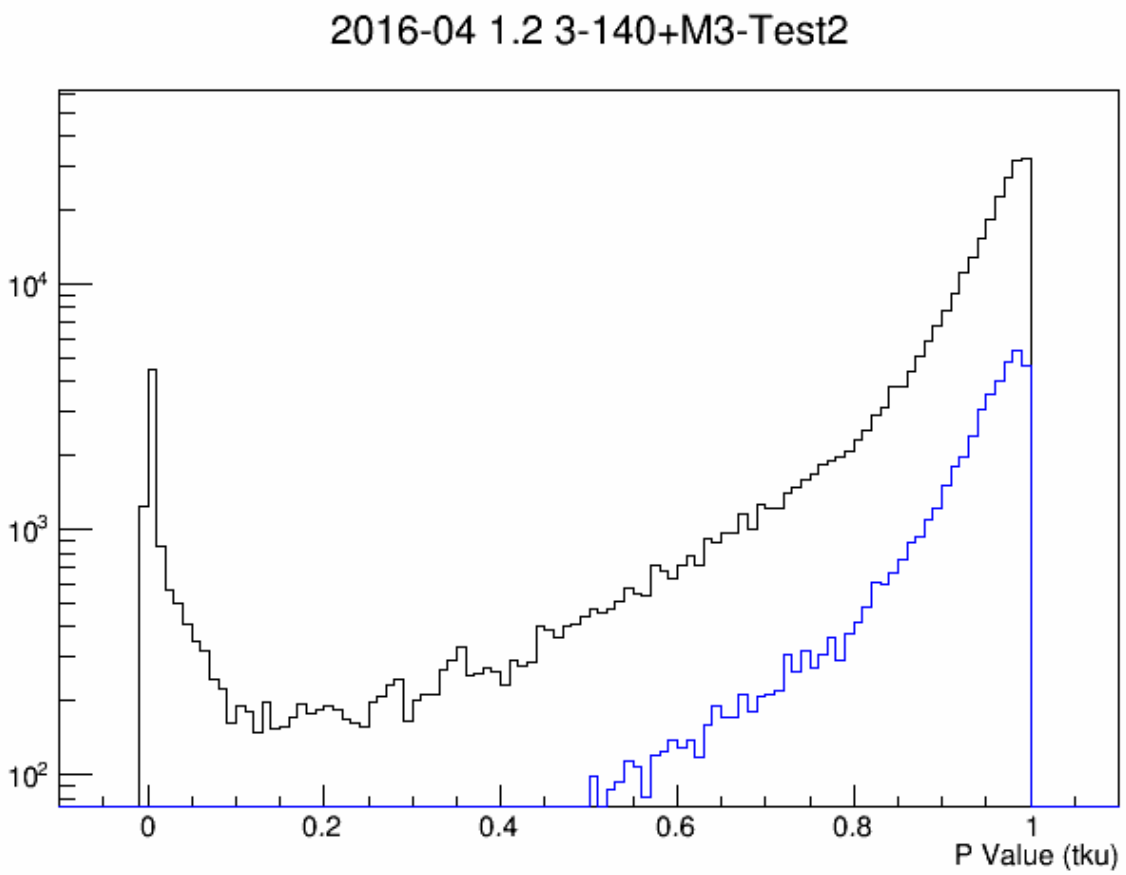
Hall Probes vs MAUS





- Hall probes are mounted at r ~ 160 mm
- Approx 2 % discrepancy between MAUS and hall probes
- Nb: trajectory in B-field scales with B/p
  - i.e. if we get B-field high by 10 %, it looks exactly like a track with 10 % higher momentum

P-Values



- P-Value reflects the probability that a track is observed
- 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

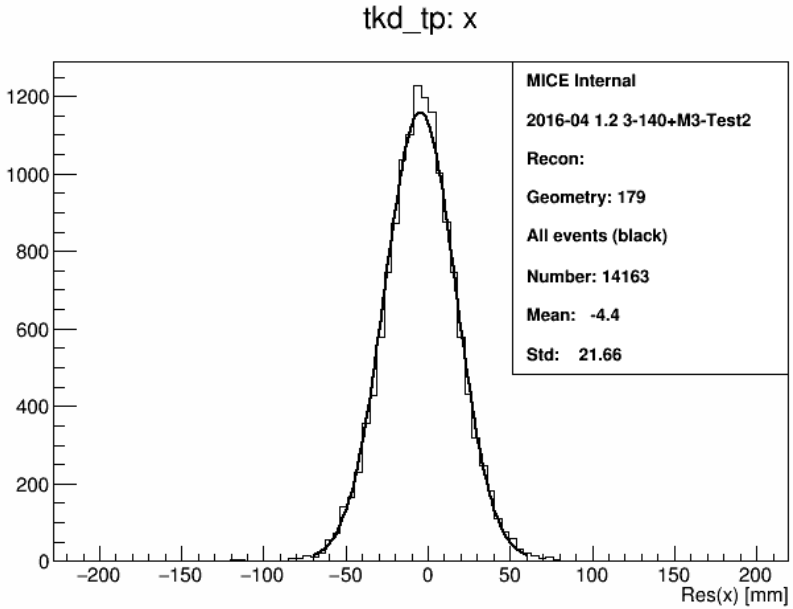
Global Validation

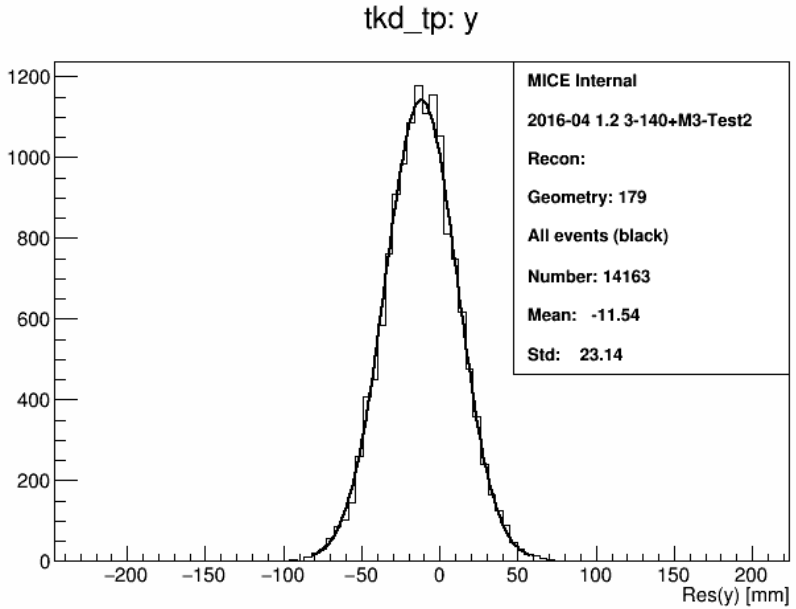
- We can validate measurements by comparing tracks with other detectors
- Take TKU as “reference” position, momentum
- Take TOF1 as “reference” time
- Extrapolate to TOF0, TOF2, TKD
  - Look at the difference between measured and extrapolated track

Track Extrapolation Routines

- Extrapolation of centroid uses
  - 4th order Runge Kutta to integrate Lorentz force law
  - Bethe-Bloch to estimate dE/dz
- Propagation of errors uses
  - Calculate Jacobian of Lorentz force law for error propagation
    - + Integration using 4th order RK
  - PDG formula for scattering (for error propagation)
  - Derivative of Bethe Bloch + Fano formula for energy straggling
- Two geometry models
  - Either use the on-axis materials and assuming infinite radius cylinders – in this talk
  - Or use full G4 geometry – but it is slow
  - Choose step size dynamically to step to geometry boundary

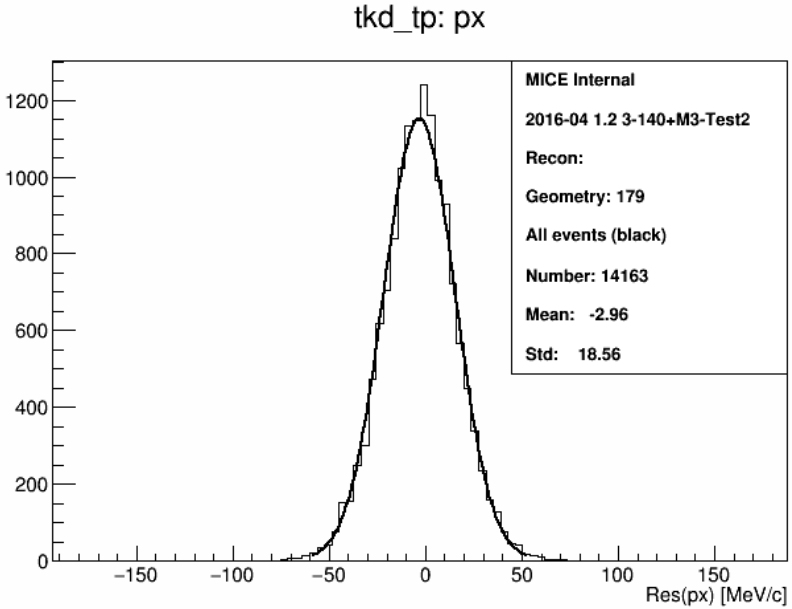
TKU vs TKD

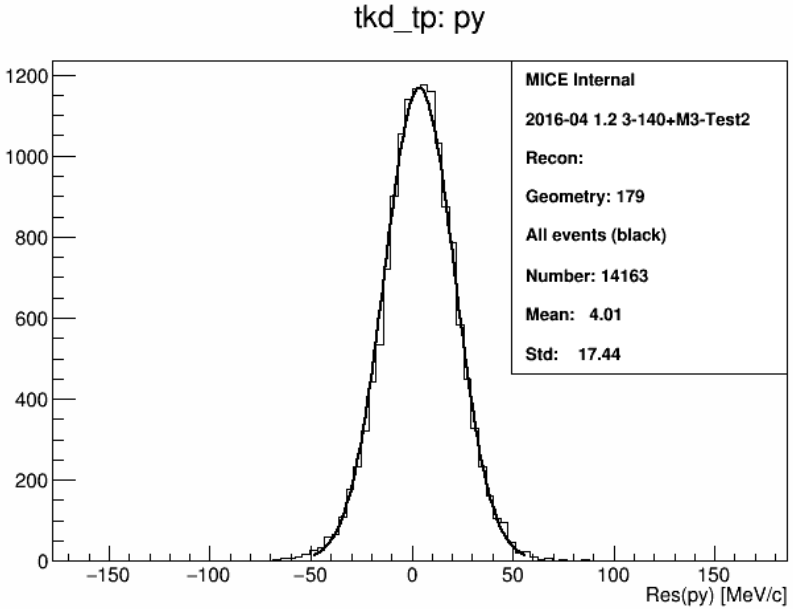


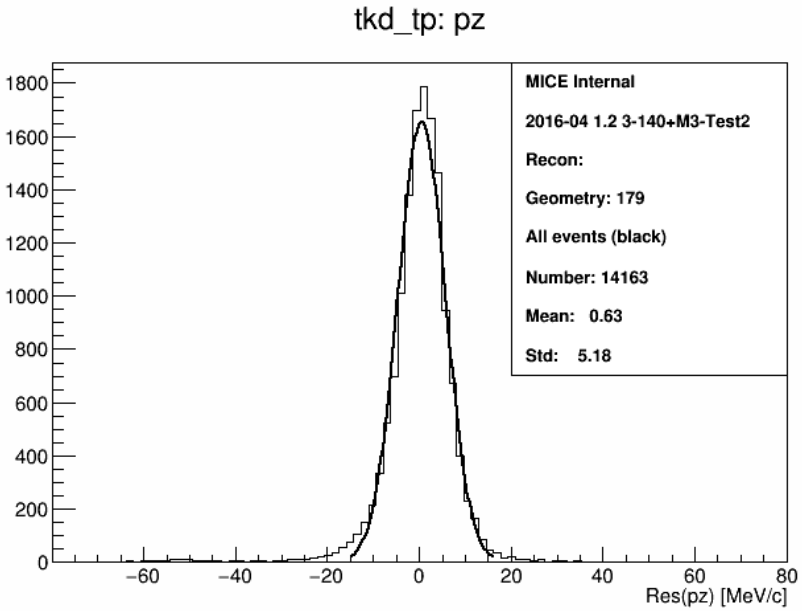


- Extrapolated position
  - Indicative of some misalignment (of magnets presumably)

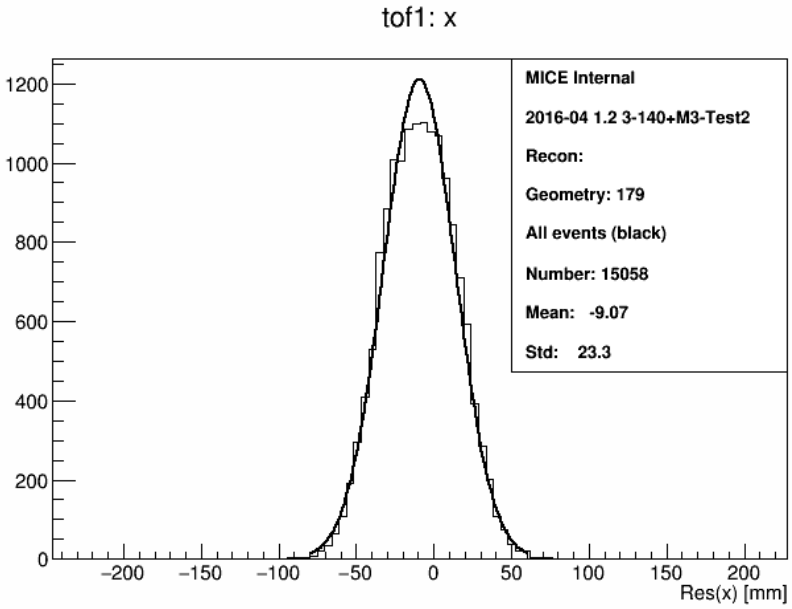
TKU vs TKD

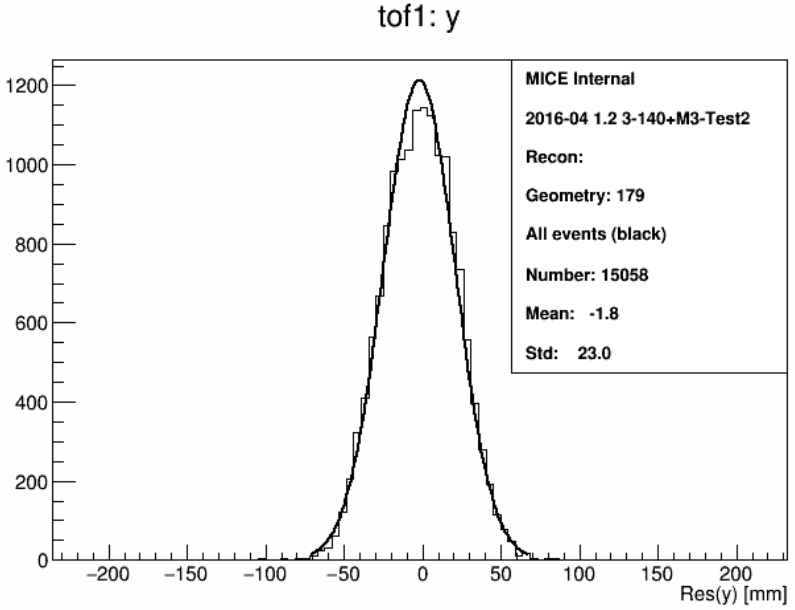

tkd_tp: px
MICE Internal
2016-04 1.2 3-140+M3-Test2
Recon:
Geometry: 179
All events (black)
Number: 14163
Mean: -2.96
Std: 18.56
Res(px) [MeV/c]

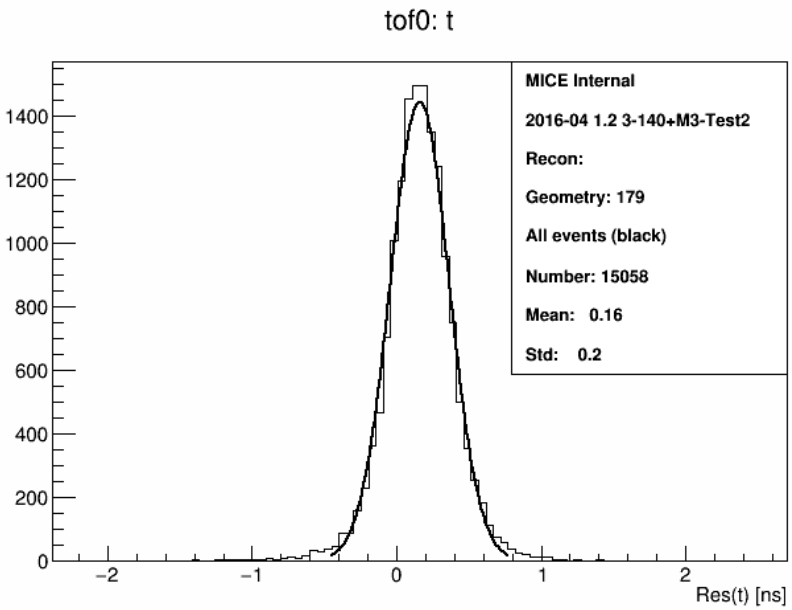

tkd_tp: py
MICE Internal
2016-04 1.2 3-140+M3-Test2
Recon:
Geometry: 179
All events (black)
Number: 14163
Mean: 4.01
Std: 17.44
Res(py) [MeV/c]


tkd_tp: pz
MICE Internal
2016-04 1.2 3-140+M3-Test2
Recon:
Geometry: 179
All events (black)
Number: 14163
Mean: 0.63
Std: 5.18
Res(pz) [MeV/c]

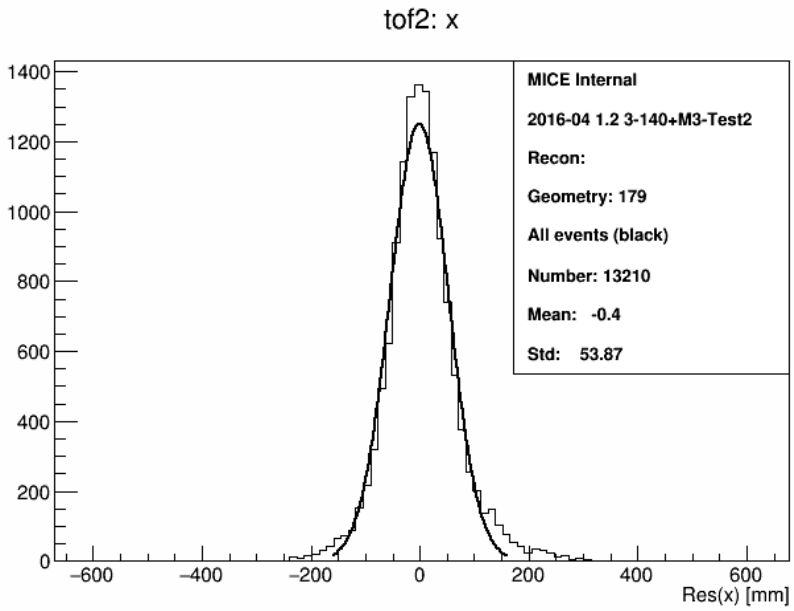
TKU vs TOF01

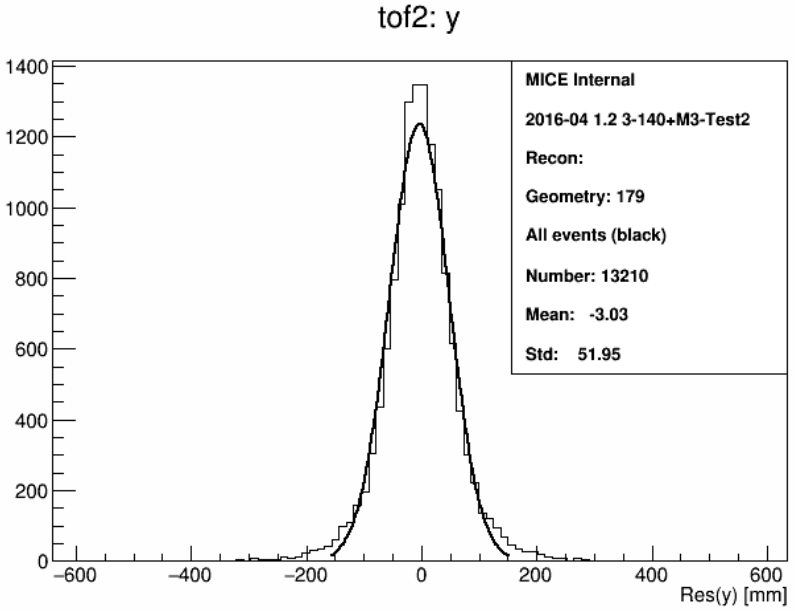

tof1: x
MICE Internal
2016-04 1.2 3-140+M3-Test2
Recon:
Geometry: 179
All events (black)
Number: 15058
Mean: -9.07
Std: 23.3
Res(x) [mm]

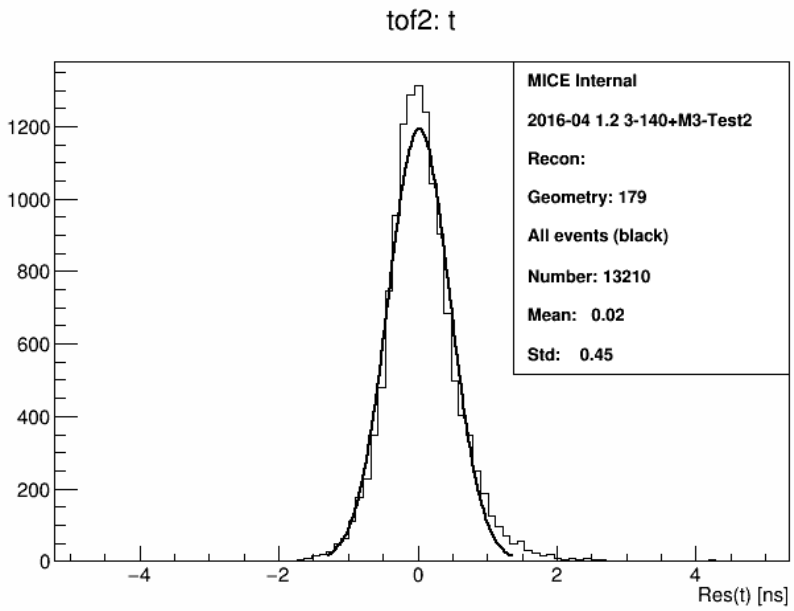

tof1: y
MICE Internal
2016-04 1.2 3-140+M3-Test2
Recon:
Geometry: 179
All events (black)
Number: 15058
Mean: -1.8
Std: 23.0
Res(y) [mm]


tof0: t
MICE Internal
2016-04 1.2 3-140+M3-Test2
Recon:
Geometry: 179
All events (black)
Number: 15058
Mean: 0.16
Std: 0.2
Res(t) [ns]

TKU vs TOF2


tof2: x
MICE Internal
2016-04 1.2 3-140+M3-Test2
Recon:
Geometry: 179
All events (black)
Number: 13210
Mean: -0.4
Std: 53.87
Res(x) [mm]

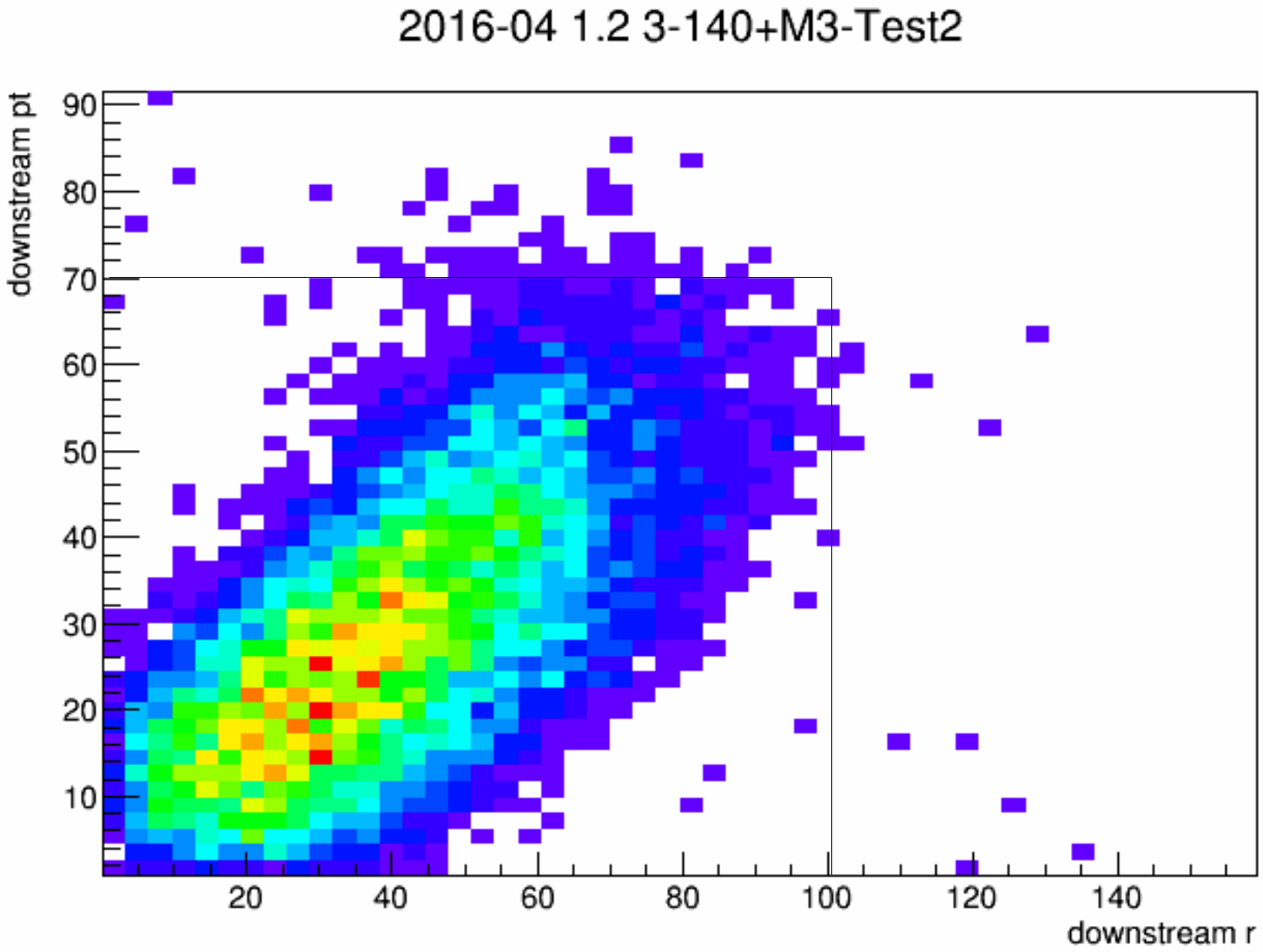

tof2: y
MICE Internal
2016-04 1.2 3-140+M3-Test2
Recon:
Geometry: 179
All events (black)
Number: 13210
Mean: -3.03
Std: 51.95
Res(y) [mm]


tof2: t
MICE Internal
2016-04 1.2 3-140+M3-Test2
Recon:
Geometry: 179
All events (black)
Number: 13210
Mean: 0.02
Std: 0.45
Res(t) [ns]

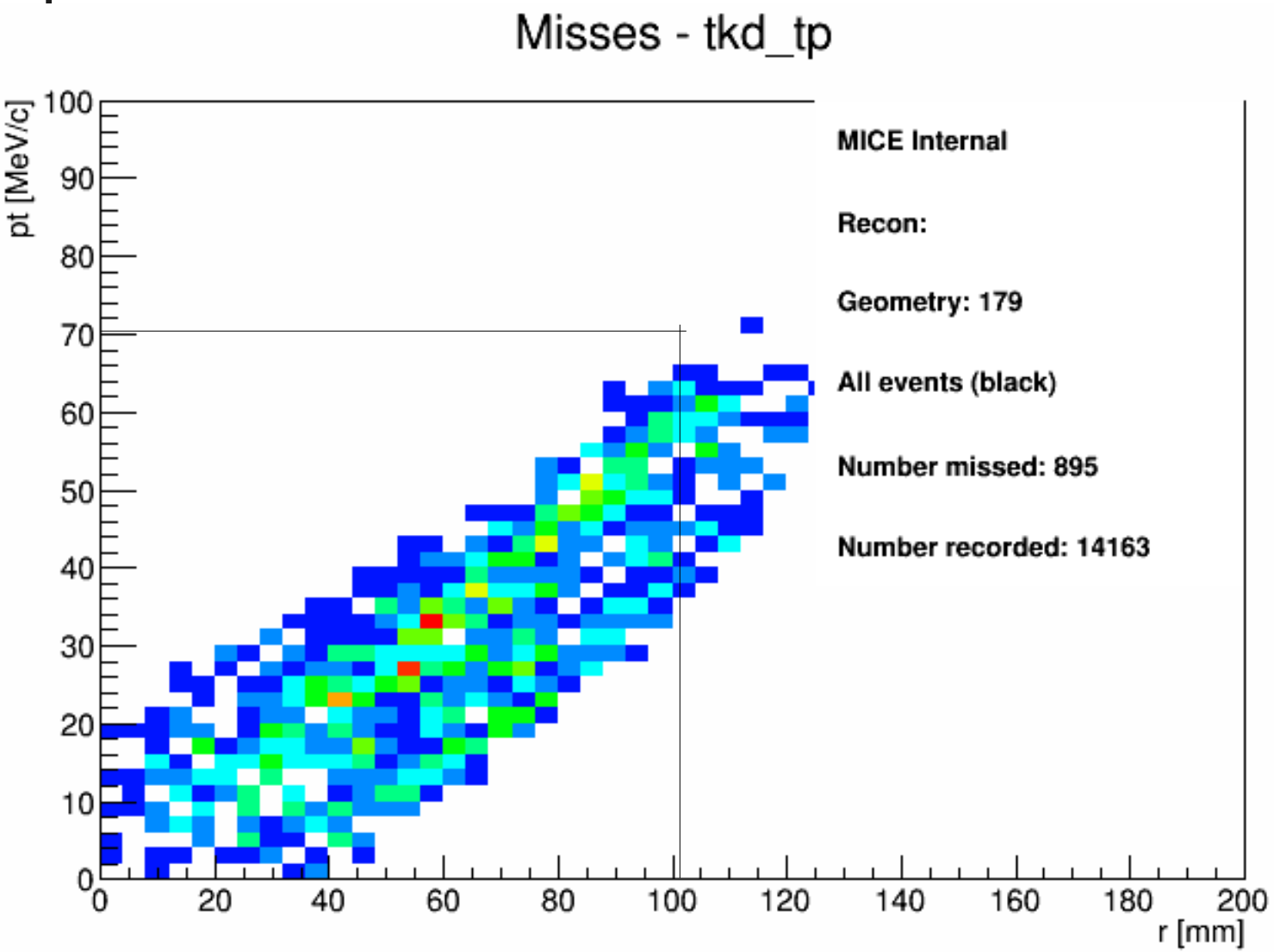
Misses

- We can estimate efficiency by looking for missing tracks
  - i.e. take tracks to TKD; if we don't see them, something happened (inefficiency)
  - Some tracks on the edge may be unluckily scattered off trajectory into an aperture
    - These will be registered as misses
    - Future -> weight/cut events according to how close they go to the edge

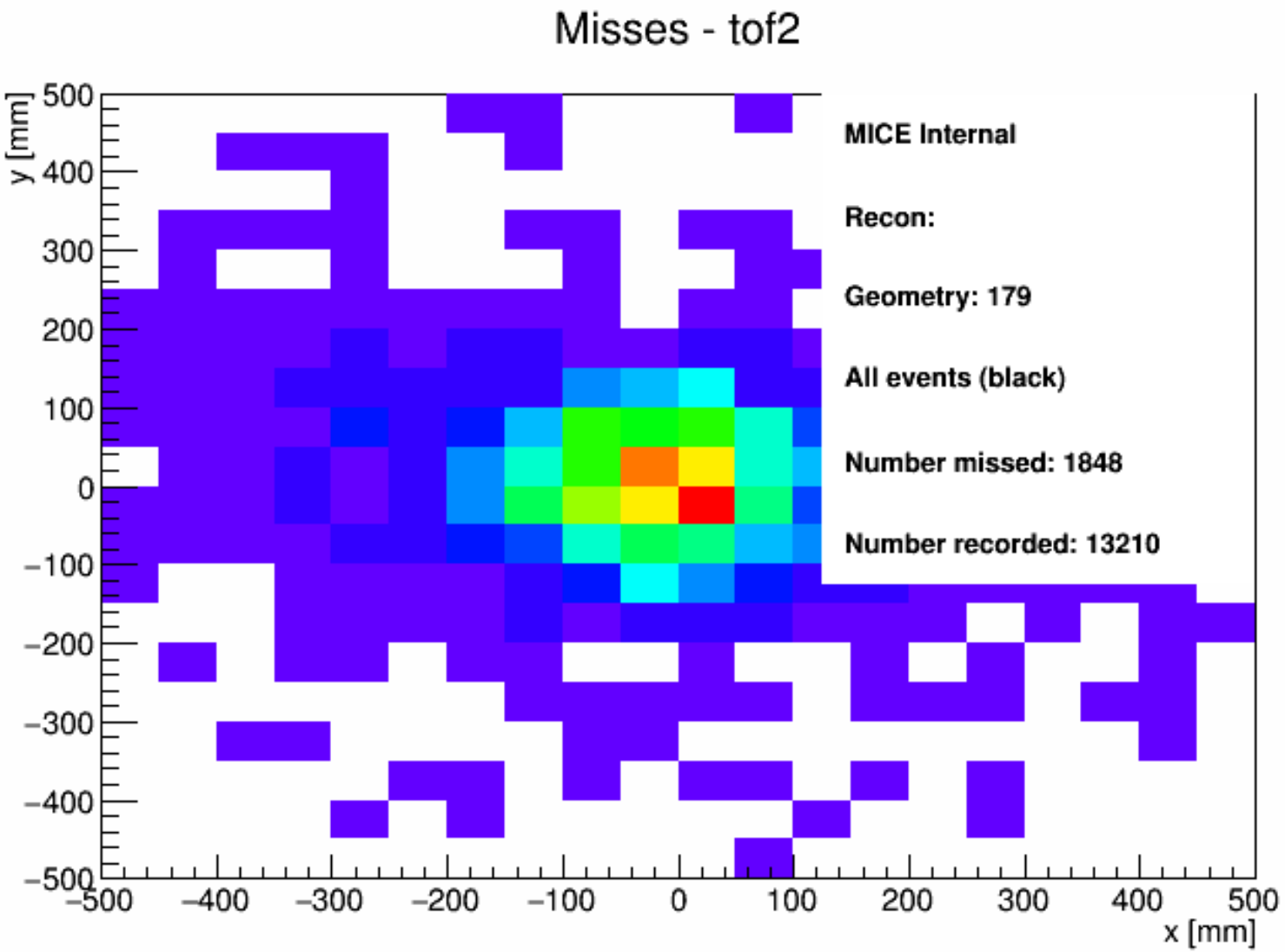
TKD Hits Distribution



TKD Misses Distribution



TOF2 Misses Distribution



Beam-Based Alignment

- Seek to build a self-consistent model for the experiment
- Track residuals should have mean 0, RMS 1 sigma
- We can use the tracks themselves to understand alignment of magnets
  - Try to find a set of magnet alignments that yield a mean position of 0
  - “Beam-based” alignment
- Algorithm
  - Extrapolate track from TKU to TOF1
  - Look at residual x, y
  - Try to find a solenoid alignment that yields 0 residual
  - 4 (or more) alignment parameters – so need to use several momenta to properly constrain the problem
- Repeat for TKD to TOF2 (SSD)
- Repeat for TKU to TKD (FC)

Beam-Based Alignment

- Misalignment calculation for solenoid

Solenoid misalignment: $\Delta x, \Delta y, \phi_x, \phi_y$

Center offsets due to misalignment: $x_{off}, y_{off}, x'_{off}, y'_{off}$

The length of the field map: L

Matrix element: m_{ij}

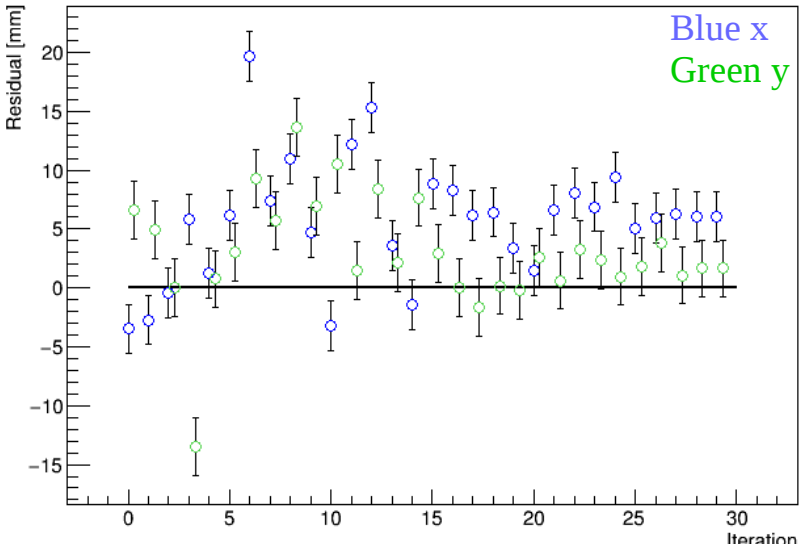
$$\begin{bmatrix} x_{off} \\ y_{off} \end{bmatrix} = \begin{bmatrix} (1-m_{11})\Delta x - m_{13}\Delta y + \left(m_{14} - \frac{m_{13}}{2}L\right)\phi_x + \left(\frac{1+m_{11}}{2}L - m_{12}\right)\phi_y \\ -m_{31}\Delta x + (1-m_{33})\Delta y + \left(m_{34} - \frac{1+m_{33}}{2}L\right)\phi_x + \left(\frac{m_{31}}{2}L - m_{32}\right)\phi_y \end{bmatrix}$$

$$\begin{bmatrix} x'_{off} \\ y'_{off} \end{bmatrix} = \begin{bmatrix} -m_{21}\Delta x - m_{23}\Delta y + \left(-\frac{m_{23}L}{2} + m_{24}\right)\phi_x + \left(\frac{m_{21}L}{2} - m_{22} + 1\right)\phi_y \\ -m_{41}\Delta x - m_{43}\Delta y + \left(-\frac{m_{43}L}{2} + m_{44} - 1\right)\phi_x + \left(\frac{m_{41}L}{2} - m_{42}\right)\phi_y \end{bmatrix}$$

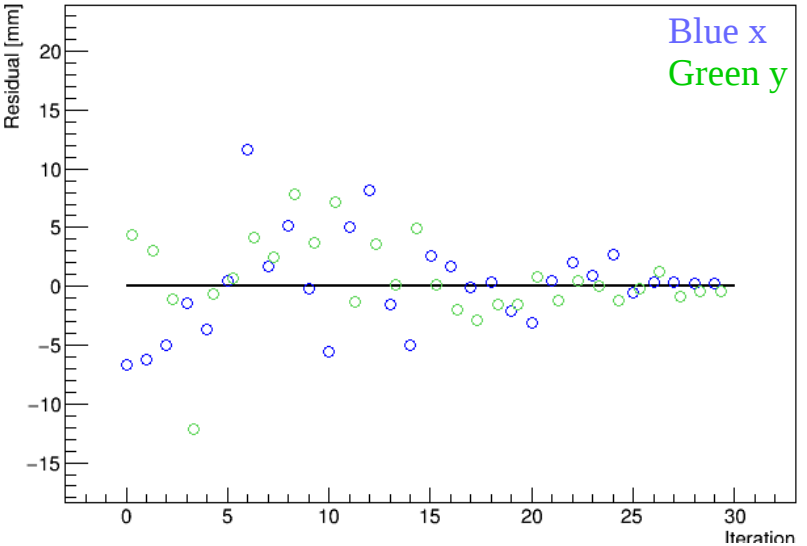
From Cai Meng , Error analysis and beam loss mechanisms of C-ADS linac , PhD thesis

Beam-Based Alignment (SSU)

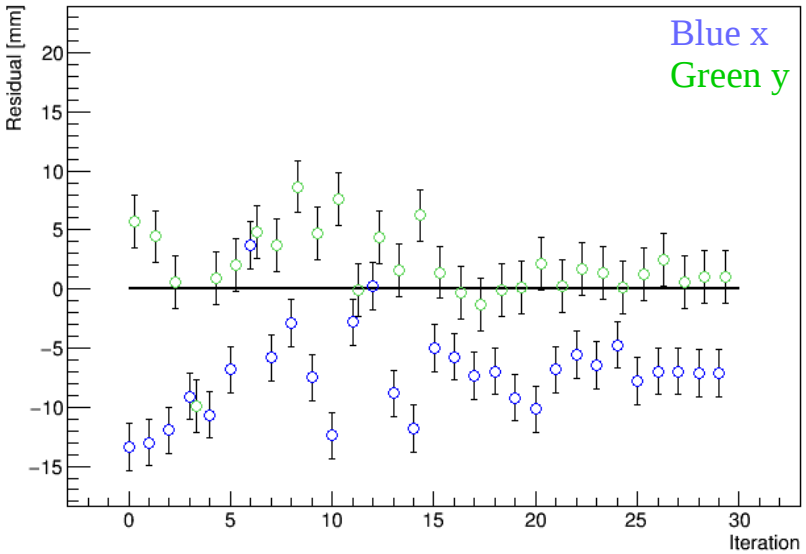
SSU p: 135.0 to 145.0 MeV/c



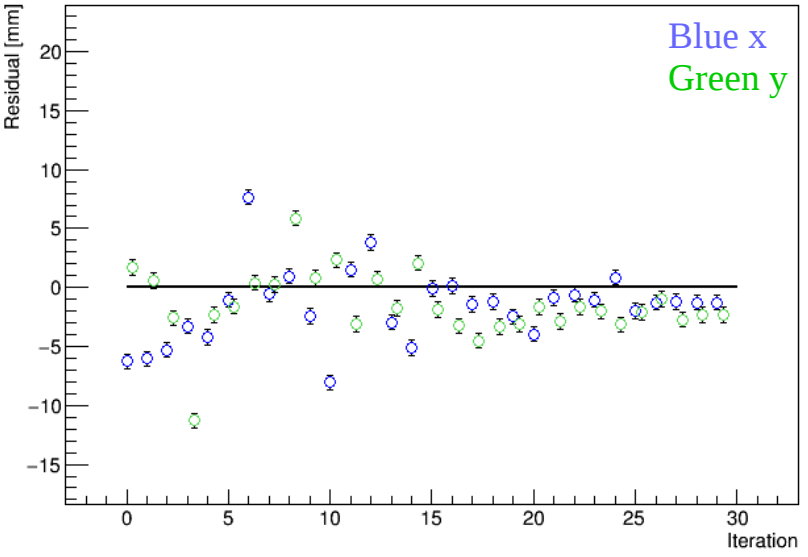
SSU p: 165.0 to 175.0 MeV/c



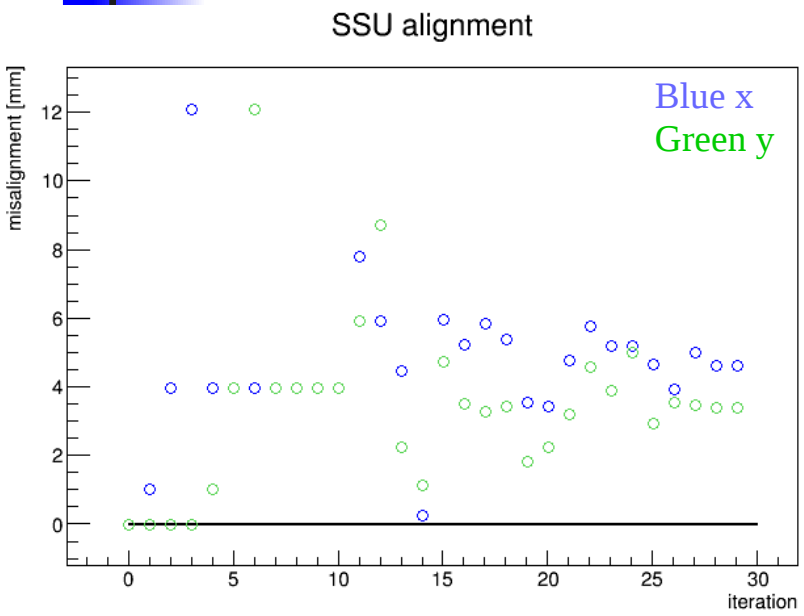
SSU p: 195.0 to 205.0 MeV/c

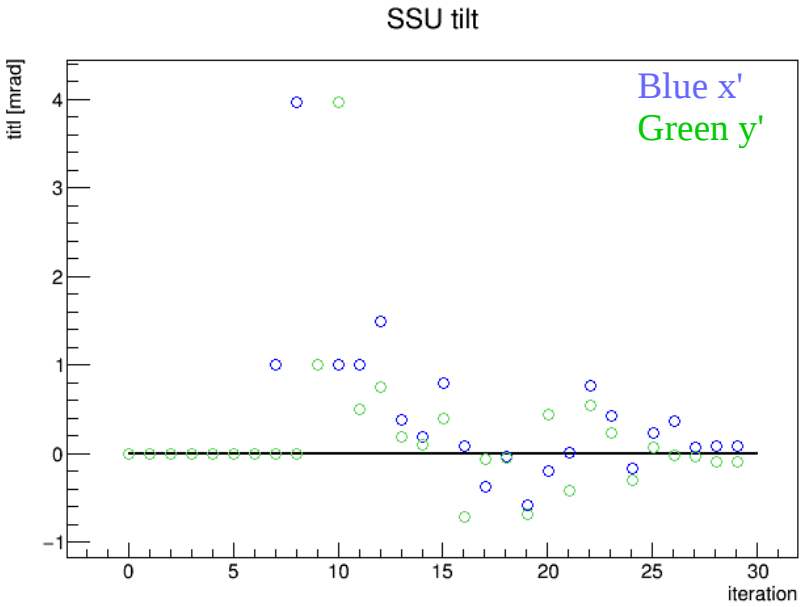


SSU p: 235.0 to 245.0 MeV/c



Beam-Based Alignment (SSU)

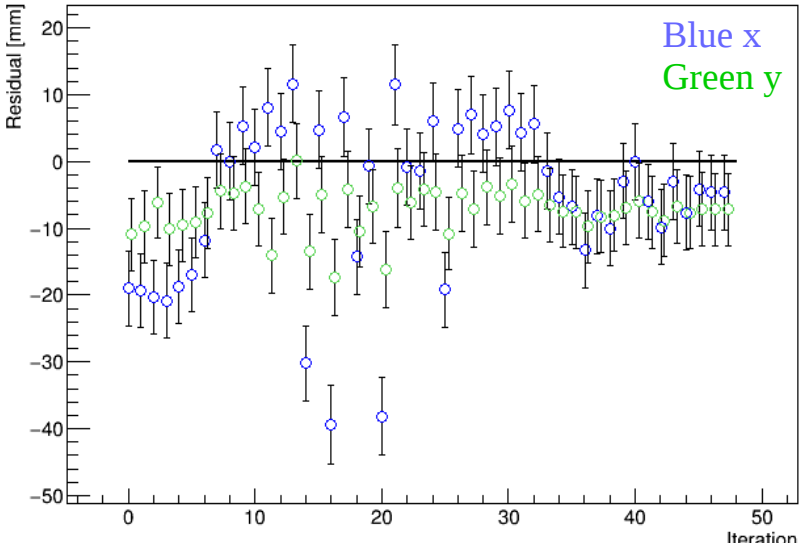




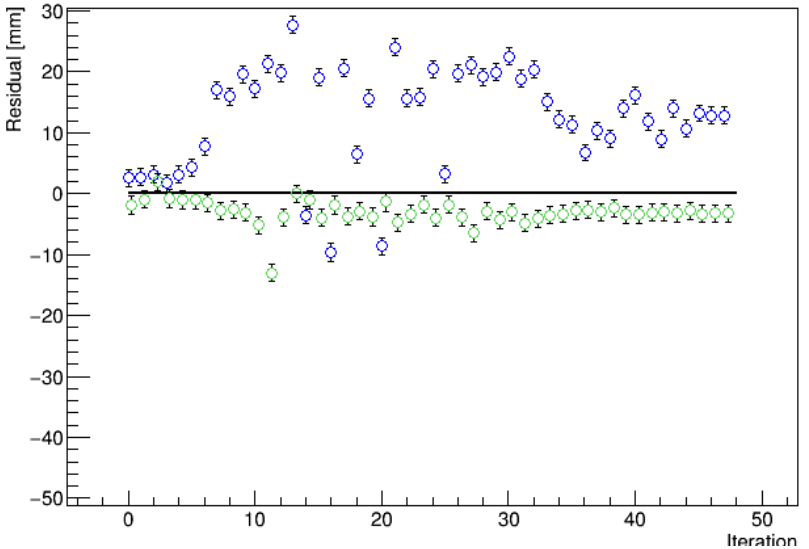
- Optimisation converges on
  - ~ 4 mm offset in SSU x and y
  - No tilt
- Sensitivity to current?
- Sensitivity to z misalignment?
- Need more statistics in 140 and 200 MeV/c bins

Beam-Based Alignment (SSD)

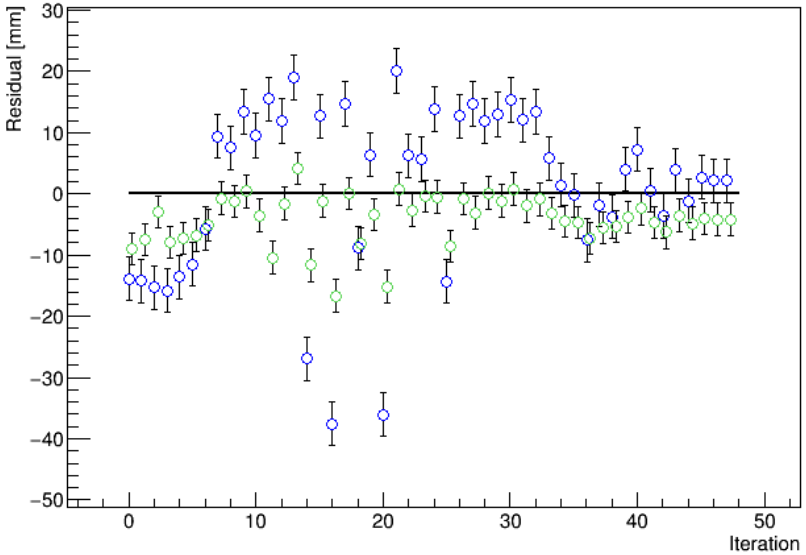
SSDCoils p: 135.0 to 145.0 MeV/c



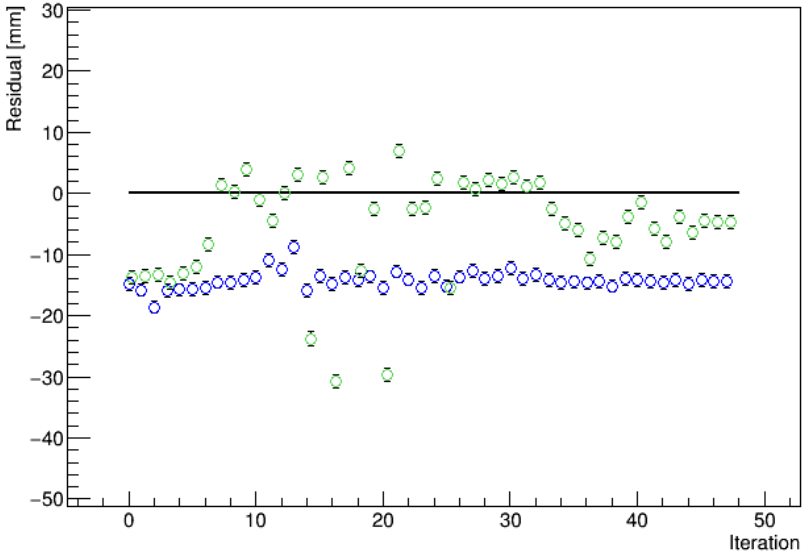
SSDCoils p: 165.0 to 175.0 MeV/c



SSDCoils p: 195.0 to 205.0 MeV/c



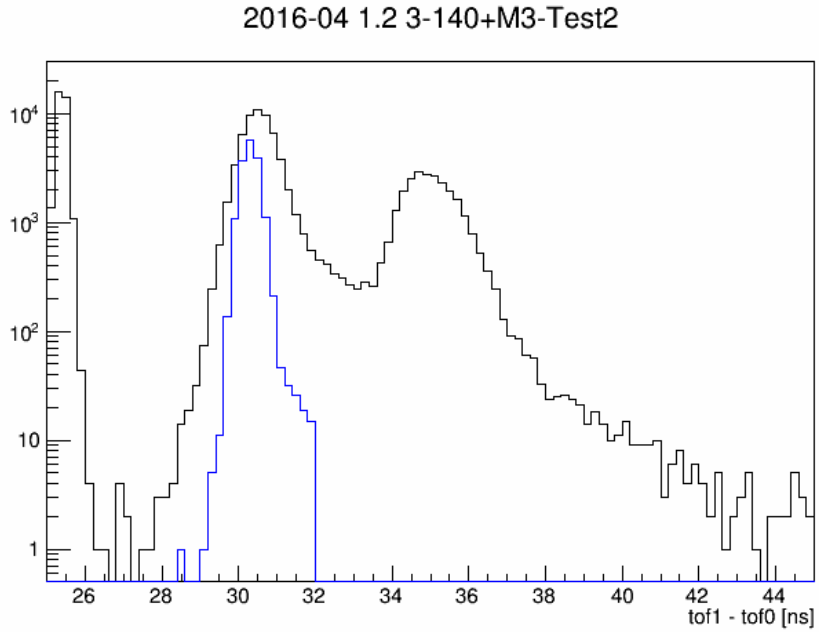
SSDCoils p: 235.0 to 245.0 MeV/c

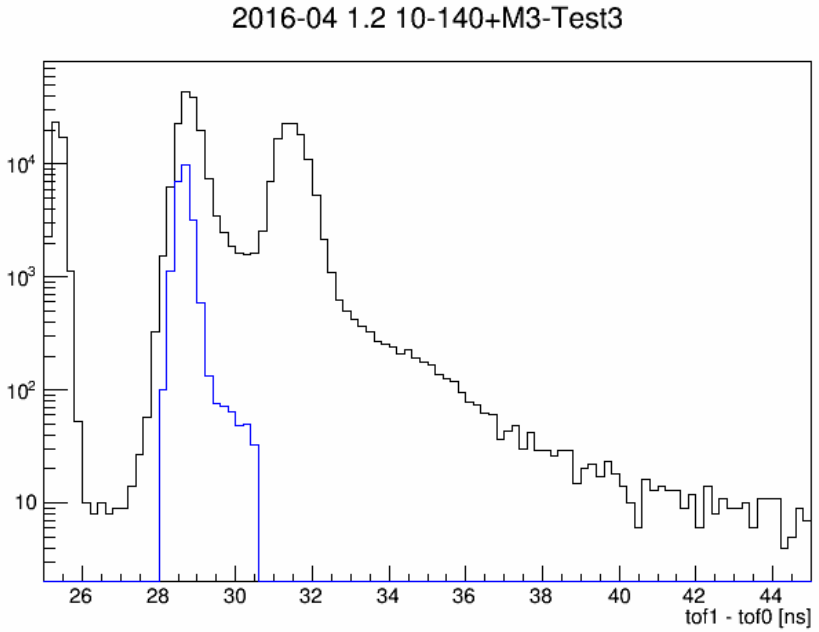


Cuts

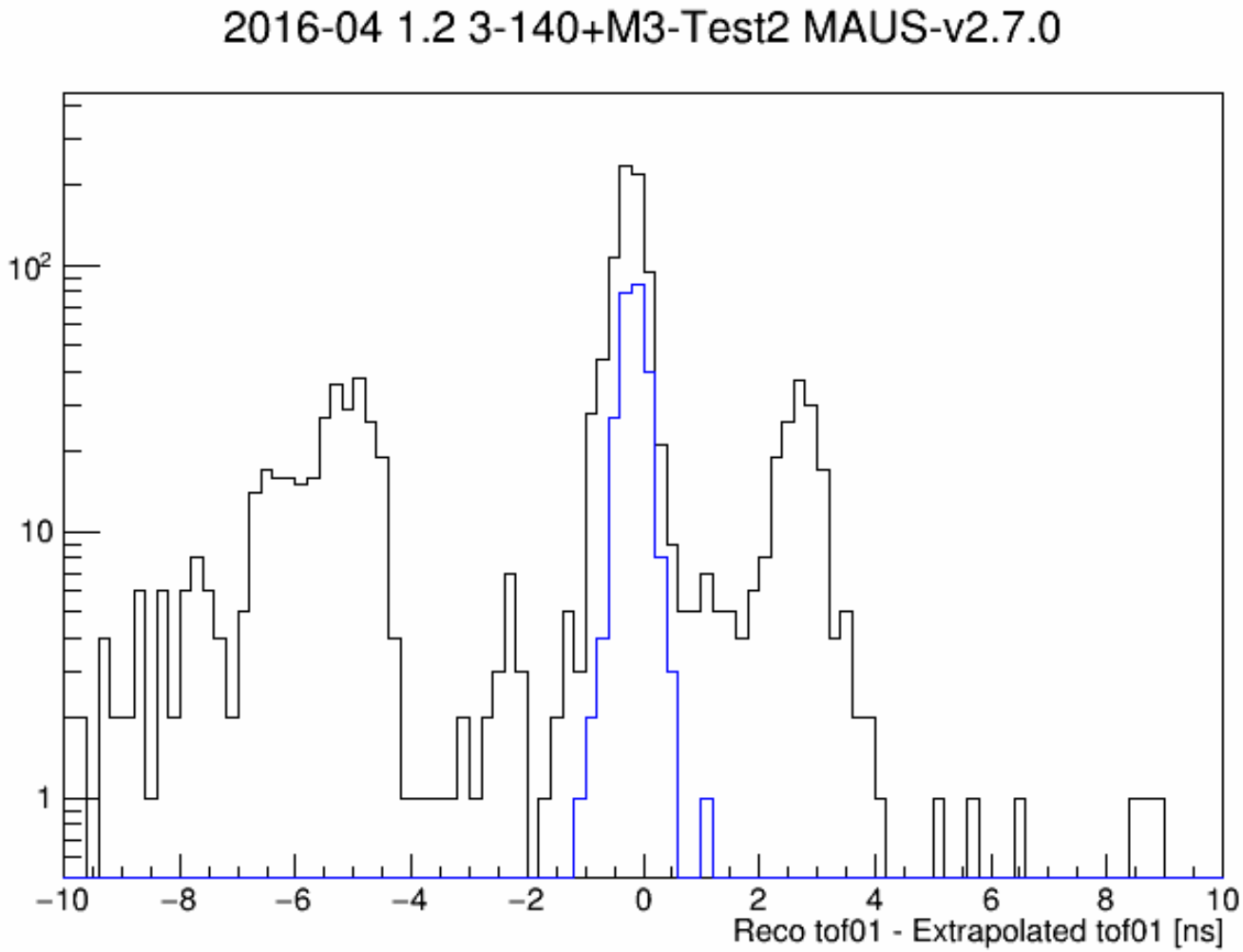
- Onto the analysis proper...
- Following cuts are enabled:
  - Exactly one track in TKU
  - Exactly one space point in TOF0
  - Exactly one space point in TOF1
  - TKU p-value > 0.02
  - tof01 > 28 ns
  - tof01 < 32 ns for run 8681 and 8699
  - tof01 < 30.5 ns for run 8685
  - Require abs(tof01 (measured) – tof01 (extrapolated)) < 5 ns
  - Require 135 < p(tku) < 145 MeV/c

TOF01

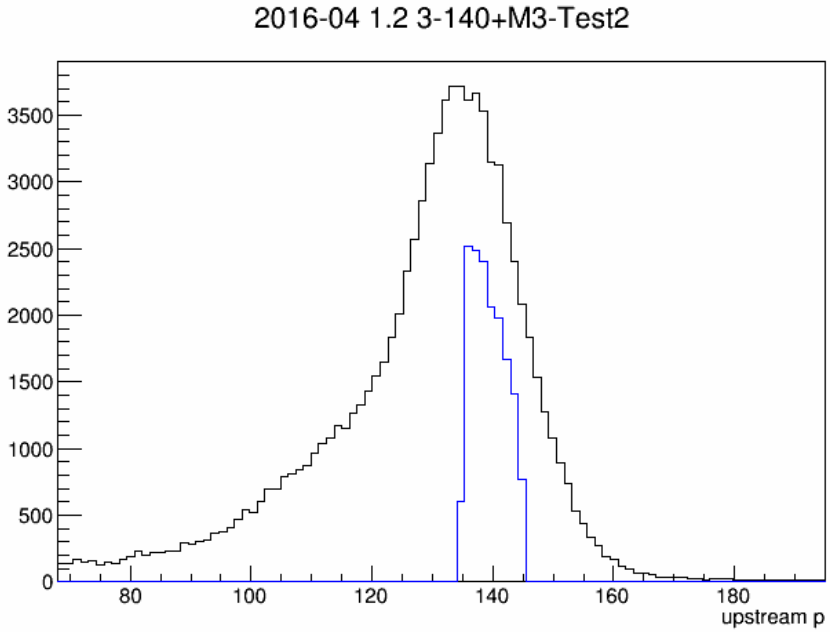

2016-04 1.2 3-140+M3-Test2
10^4
10^3
10^2
10
1
26
28
30
32
34
36
38
40
42
44
tof1 - tof0 [ns]

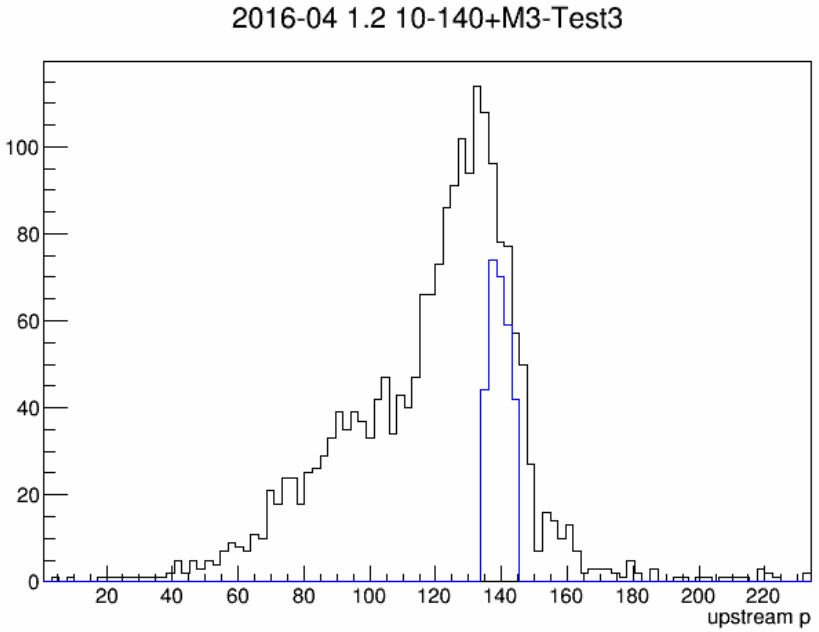

2016-04 1.2 10-140+M3-Test3
10^4
10^3
10^2
10
26
28
30
32
34
36
38
40
42
44
tof1 - tof0 [ns]

To Do: Delta TOF01



Upstream p

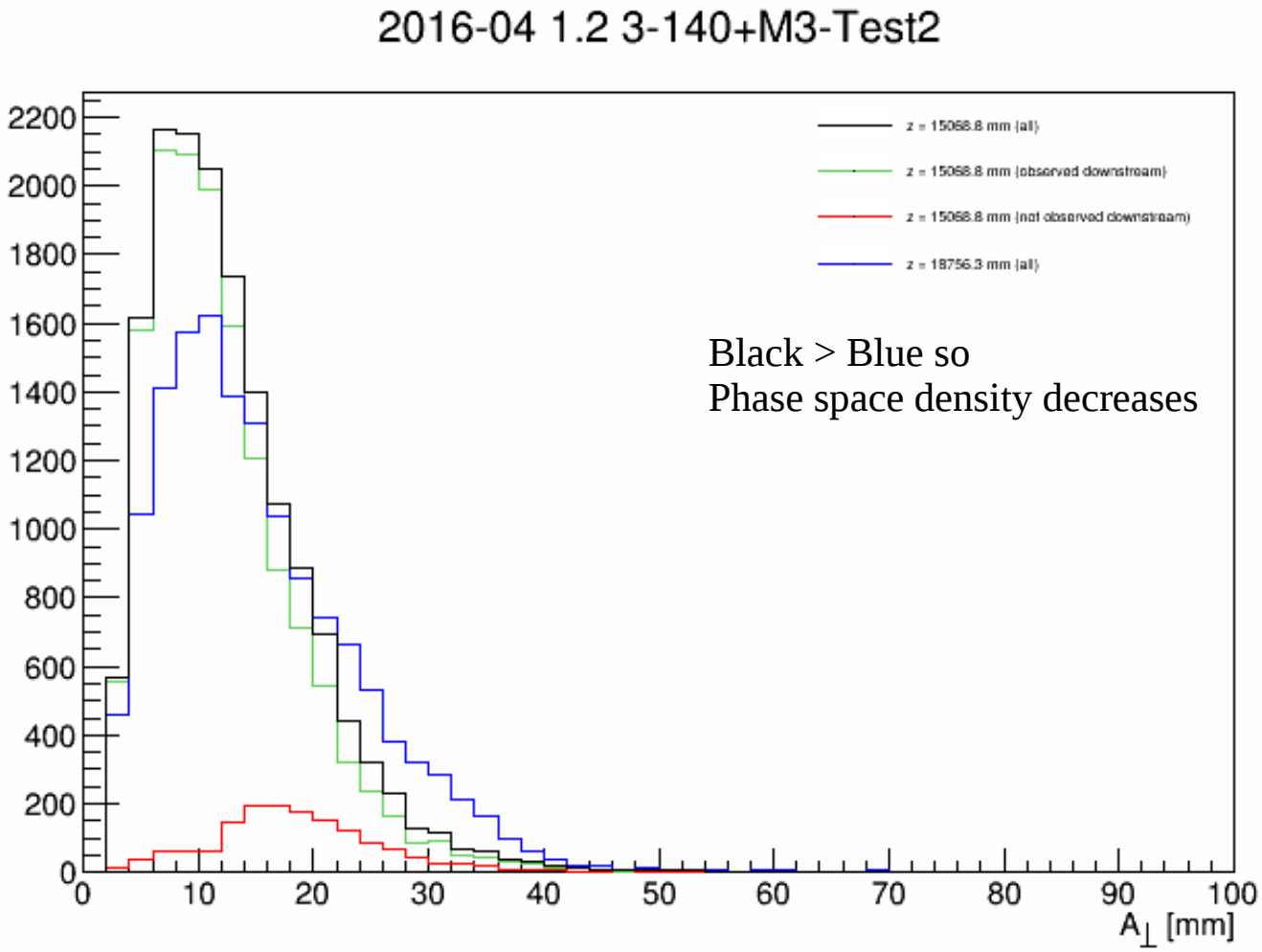

2016-04 1.2 3-140+M3-Test2
3500
3000
2500
2000
1500
1000
500
0
80
100
120
140
160
180
upstream p


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

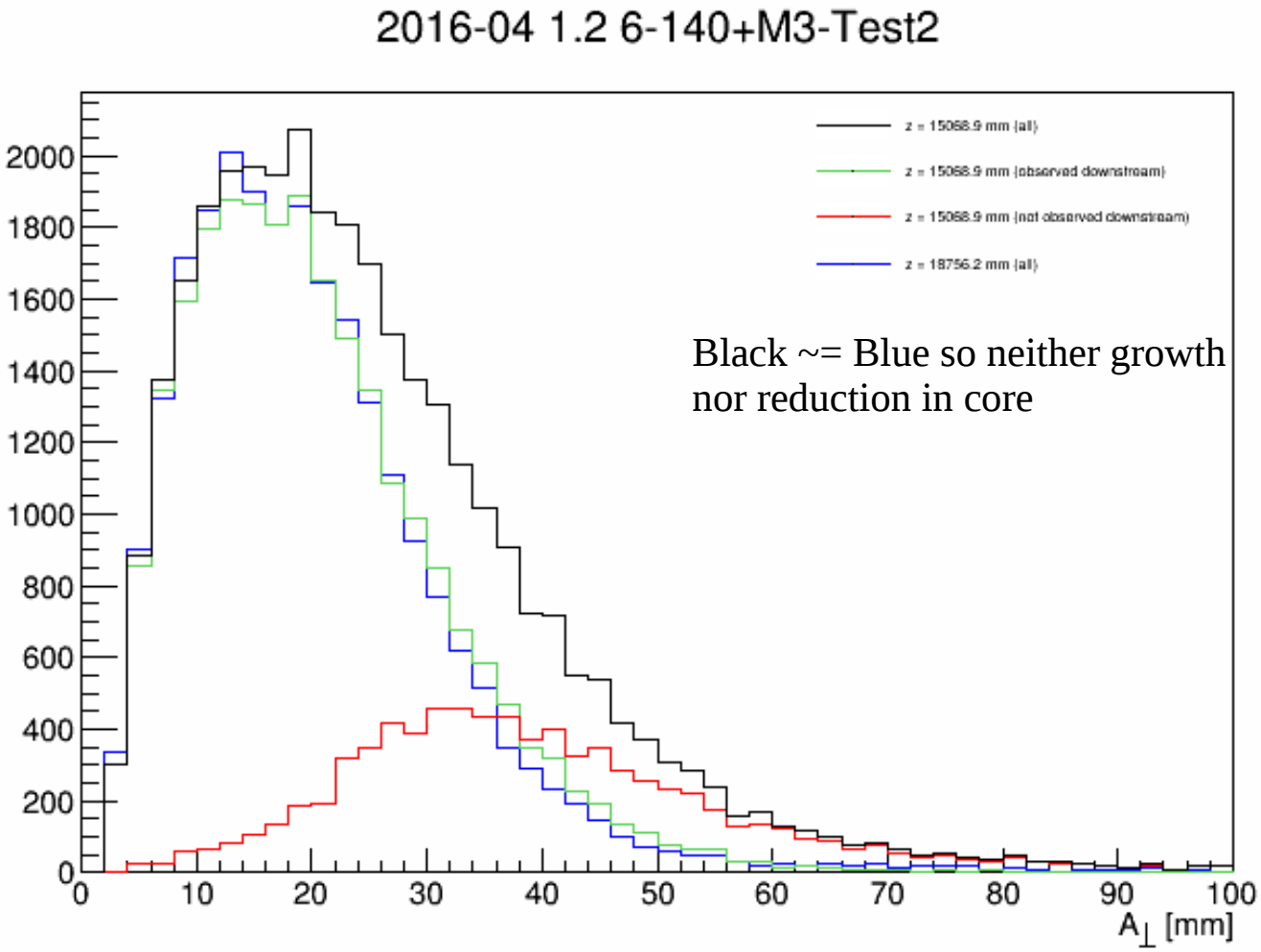
Performance

- Histograms of particle amplitude follow

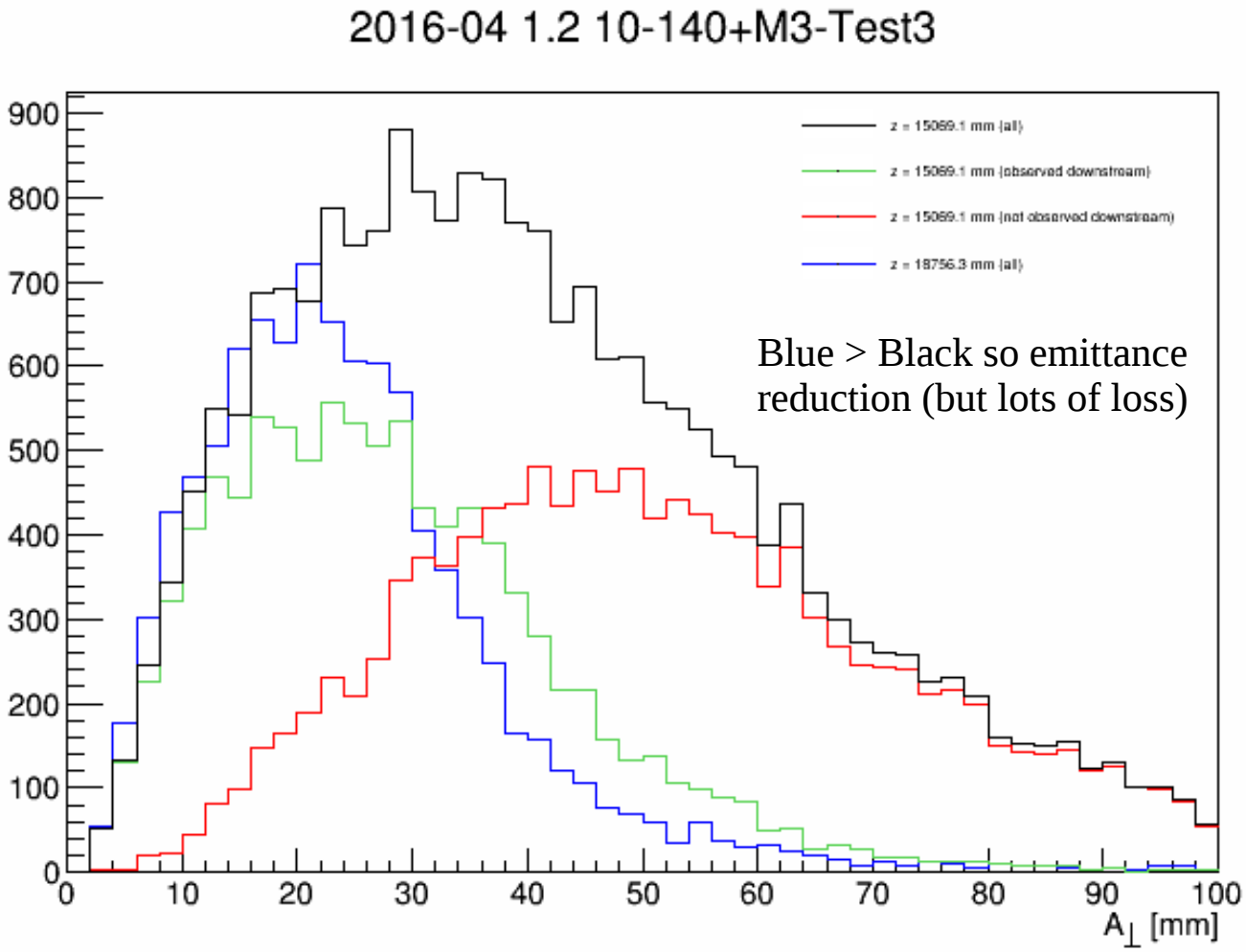
Measured Amplitude Change



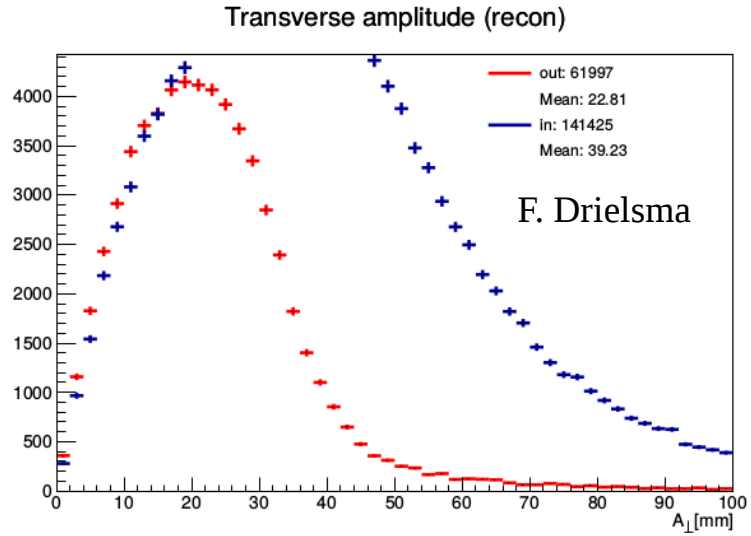
Measured Amplitude Change

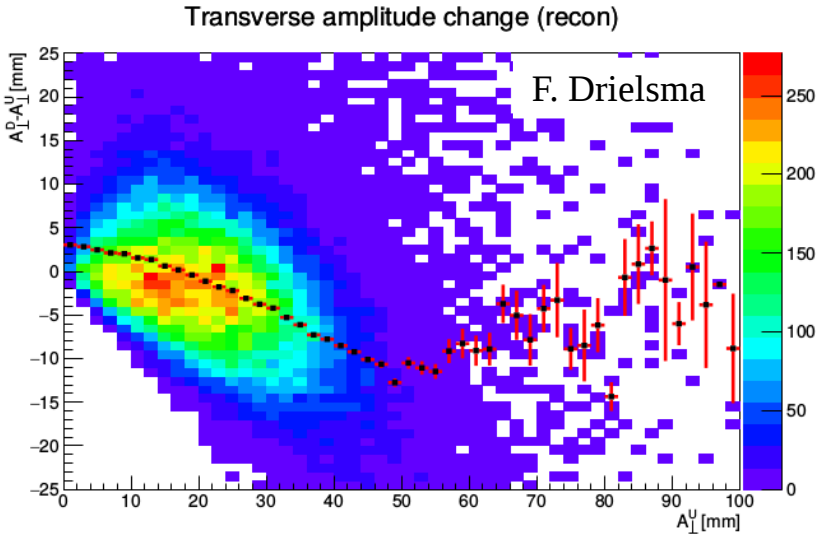


Measured Amplitude Change



Measured Amplitude Change

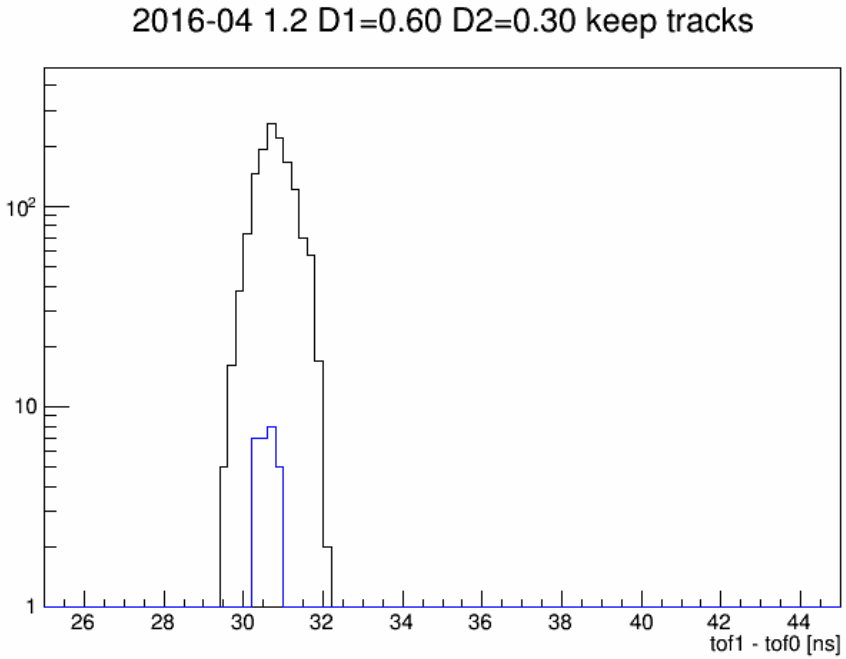


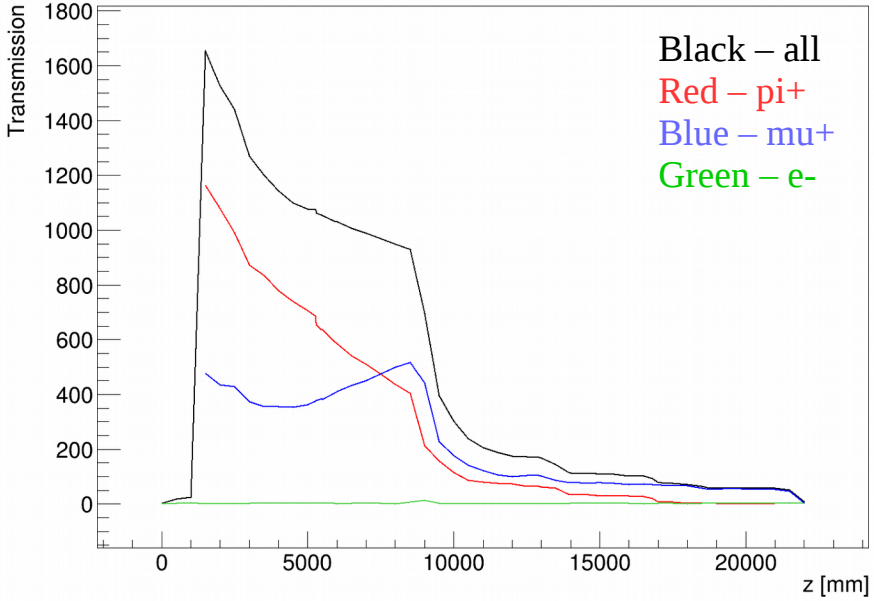


MC

- Monte Carlo is useful for understanding errors
- Process
  - Run MC
  - Check that input beam distributions are the same
  - Check that expected performance == measured performance
  - Look at detector resolutions and residuals ←
- Using MAUS 2.5.0
  - Nb reconstruction uses MAUS 2.7.0
- First – attempt to tune momentum scale of beamline

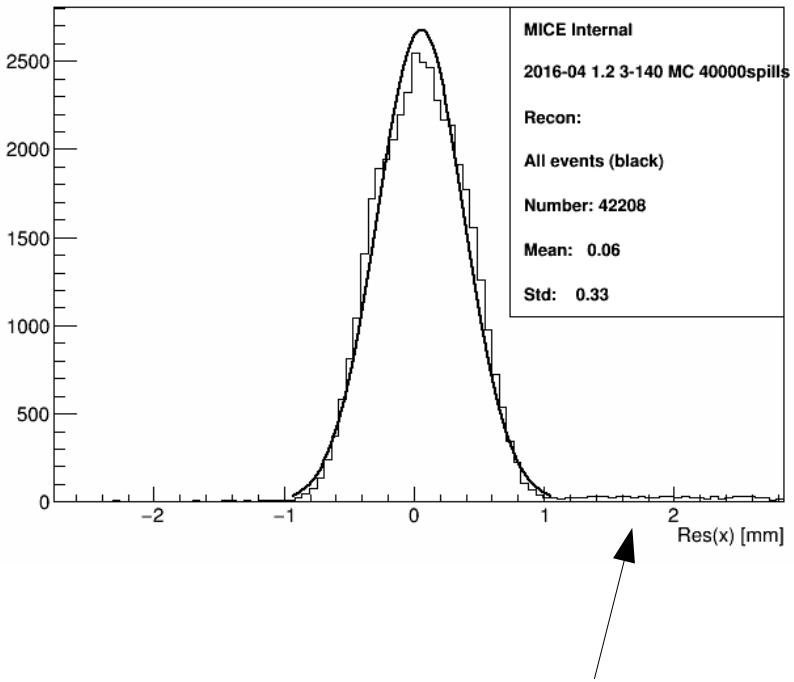
Where are the pions?

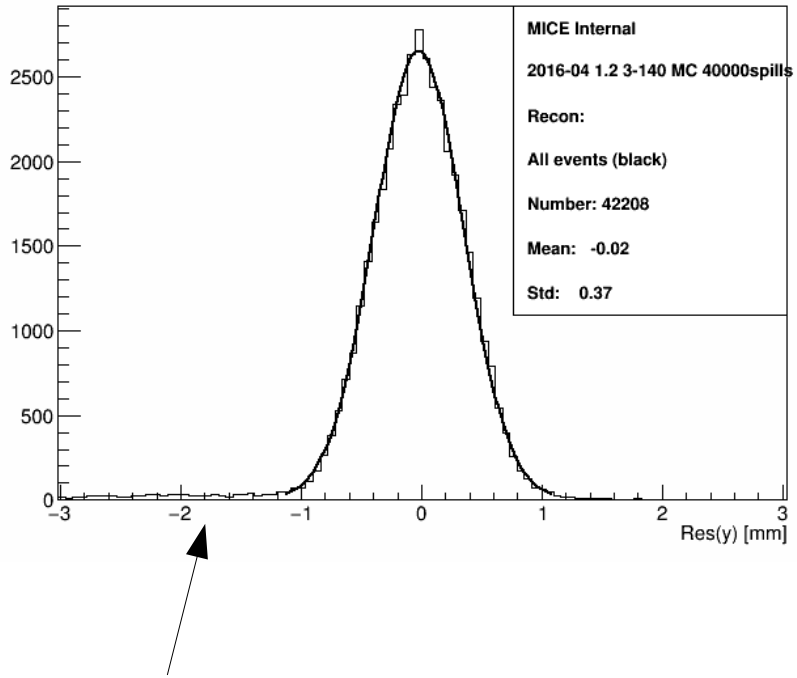




- Tune dipoles by hand to give a pionic beamline
  - For some reason I see no pions in MC TOF
  - Under investigation…
- For now, resolutions are indicative
  - I have only plotted TKU

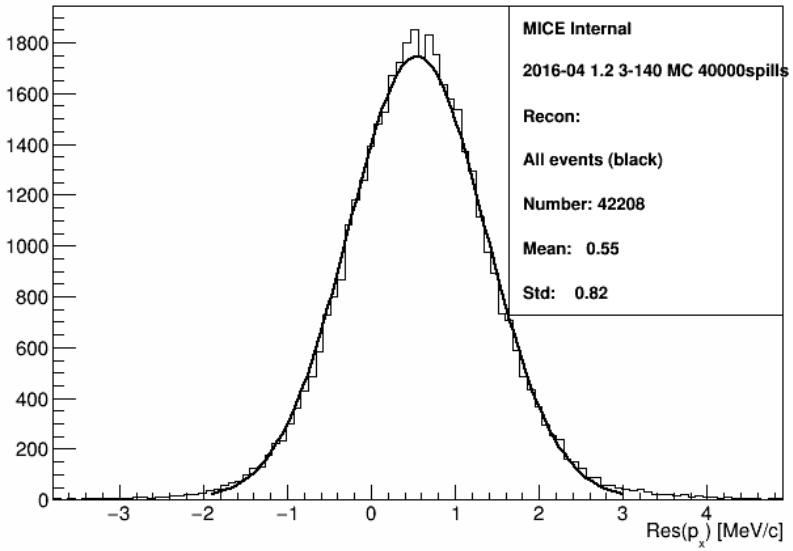
Residuals - position

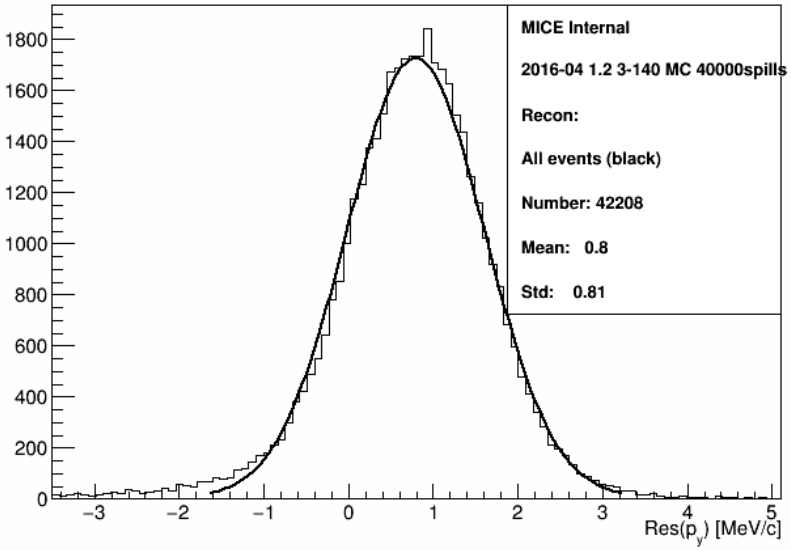


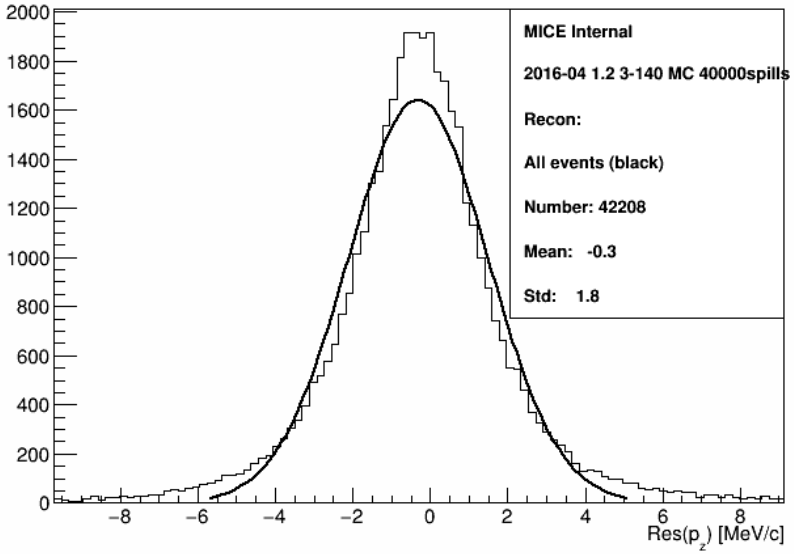


- Note the tail

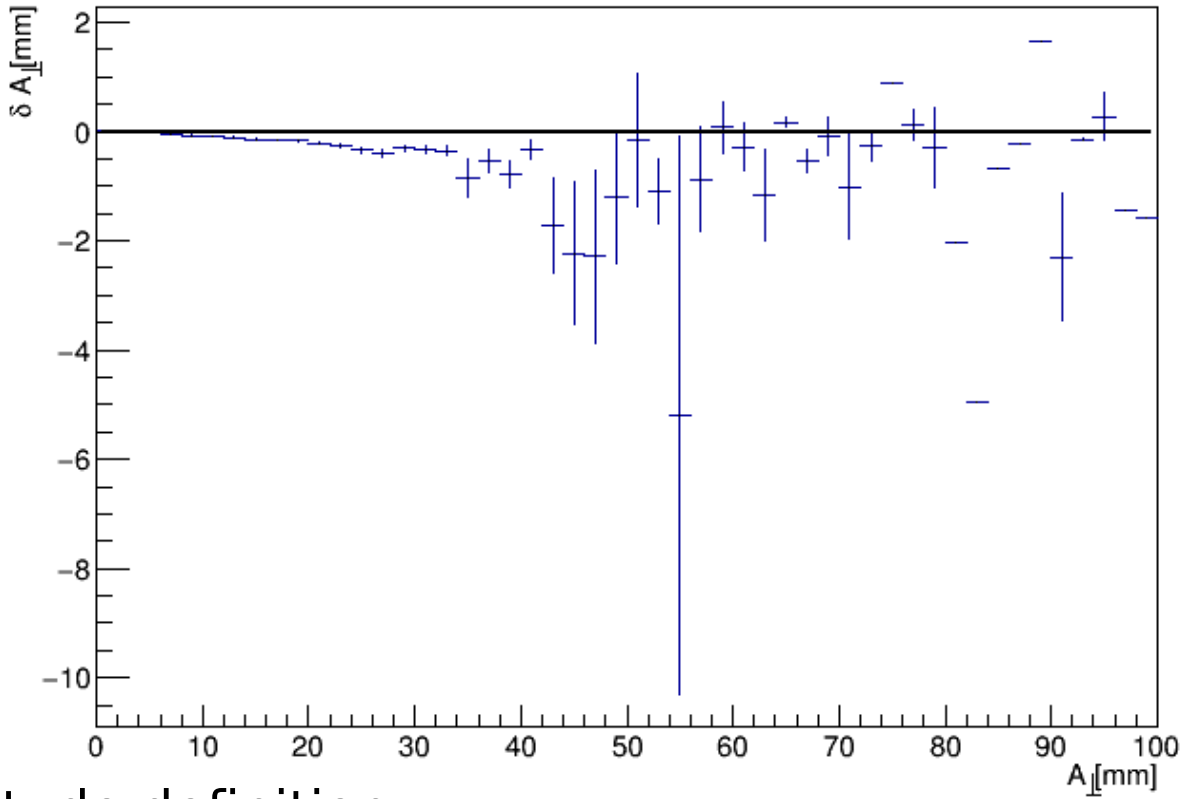
Residuals - position







Residuals - amplitude



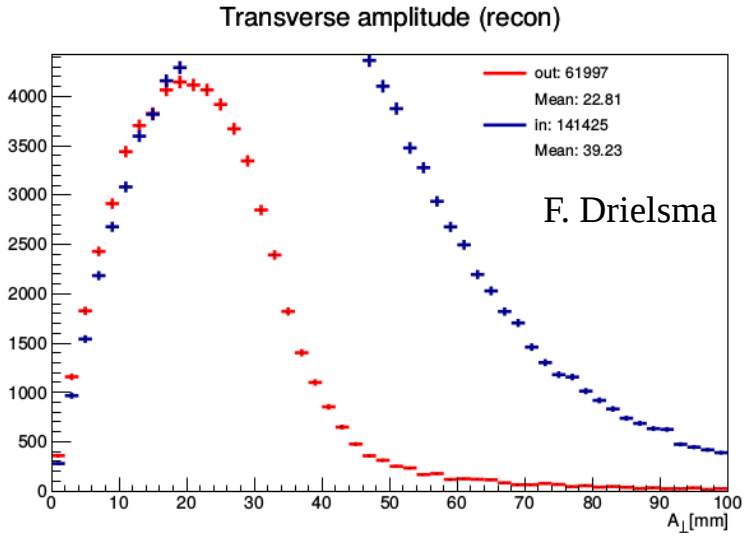
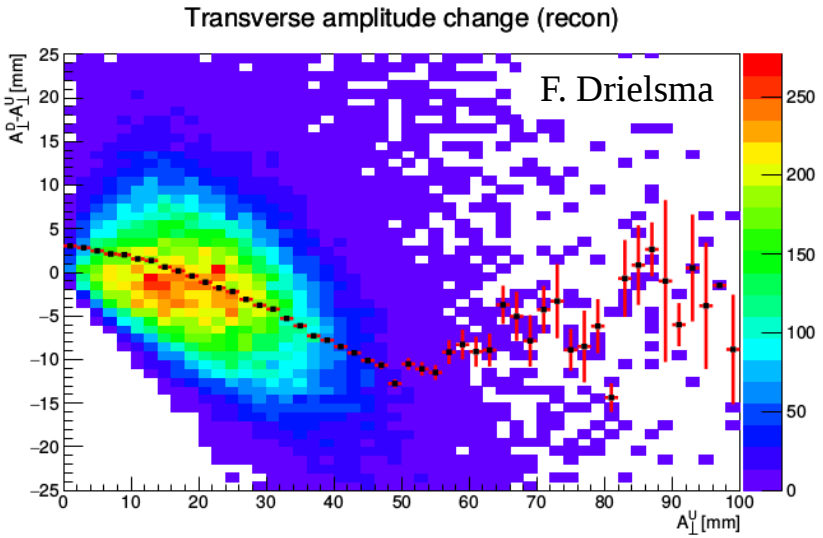
- Amplitude definition

$$\mathrm{A} = \epsilon_n \vec{U}^T \mathbf{V}^{-1} \vec{U}$$

- Amplitude resolution
  - MC Recon – MC Truth

Job List

- Detector inefficiency is still the main issue
  - TKD and possibly TOF2
- Discrepancy between TKD and TOF2 is interesting
  - Could be TKD reconstruction
  - Could be alignment/z-position issues
  - PRY effect has not been accounted
  - Then pursue beam-based alignment
- Implement Holger's field maps
  - PRY effect
- MC momentum scale tuning (and pions)
  - PID purity
  - Statistical and systematic error on amplitude calculation
- ...

Summary

- We have a great measurement of phase space density increase
- The devil is in understanding, and resolving the details
- Aim to show
  - Self-consistent data
  - Correct estimation of errors