

Flip mode emittance analysis update

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MICE Analysis Workshop

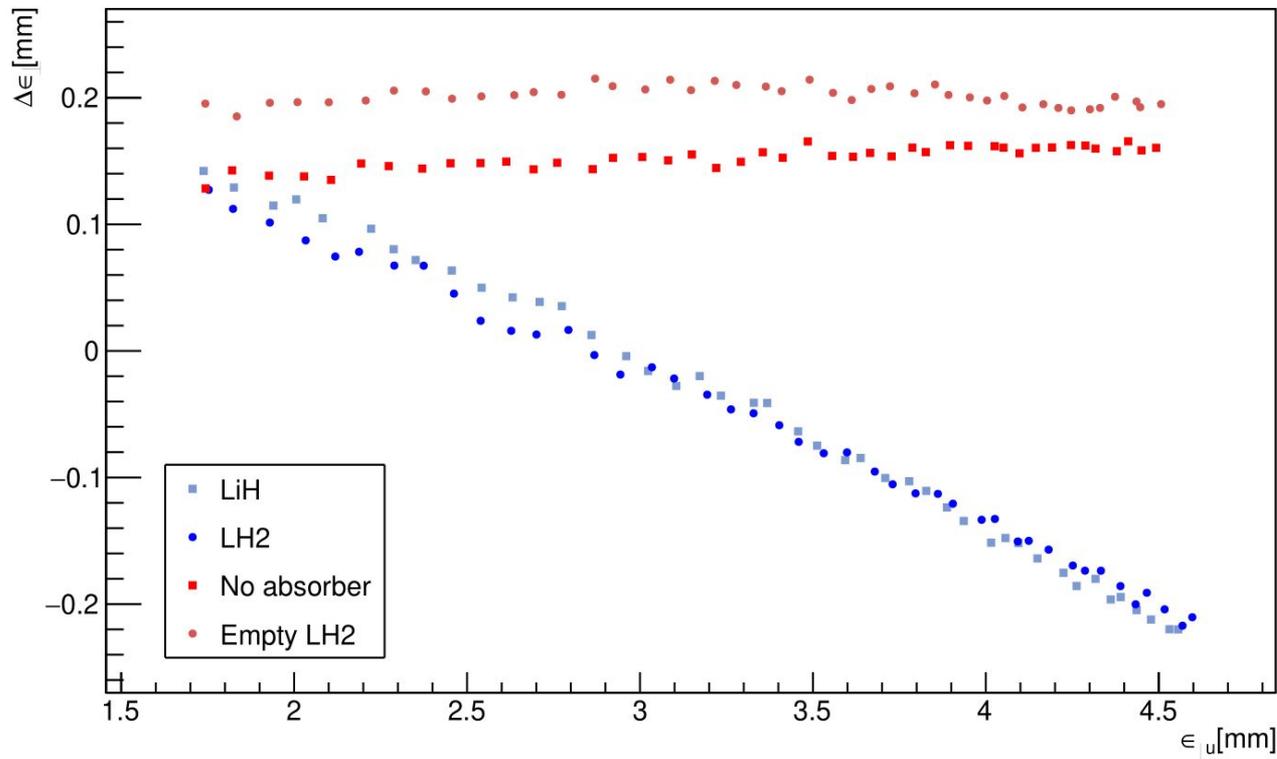
Overview

- Analysis update: Emittance change for the 6 mm 140 MeV/c flip mode beams
- Data vs MC discrepancy
- Sampling routine update: Normalisation + Target parameter corrections
- LiH, empty LH2 updates using the refined beam sampling routine

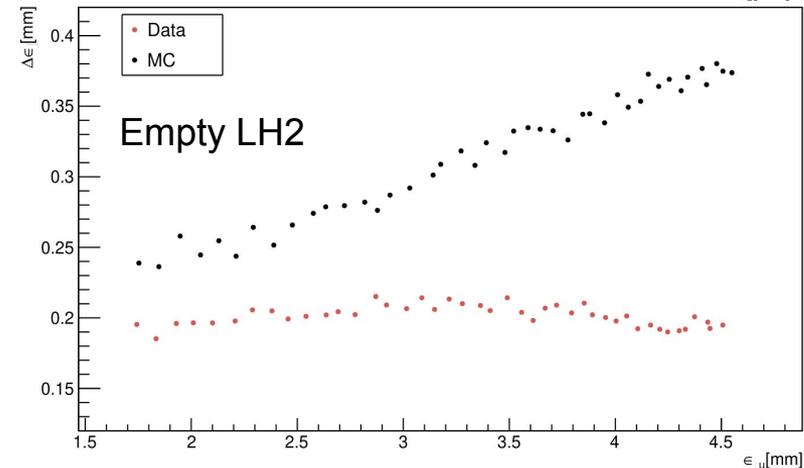
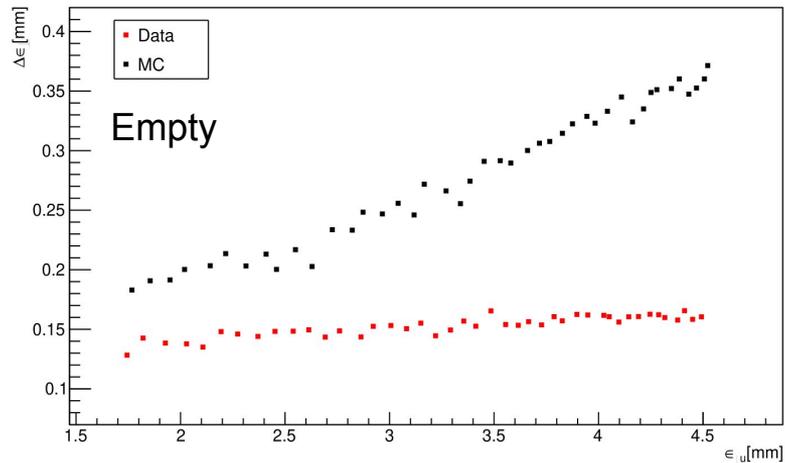
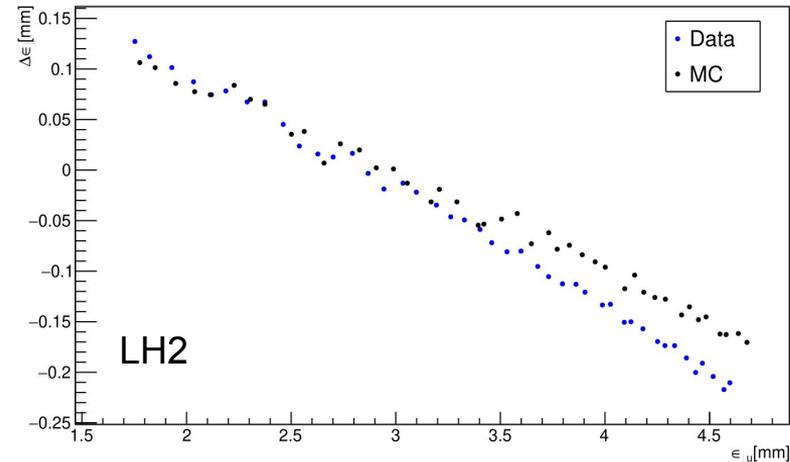
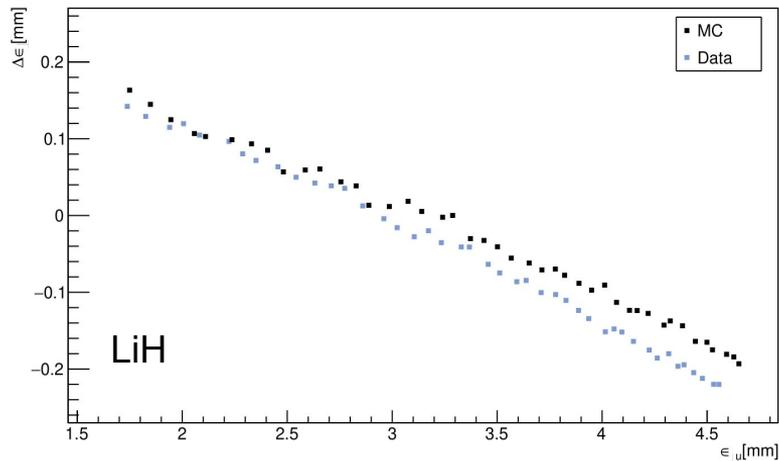
Analysis update: Emittance change

LiH analysis added

Data, 6 mm 140
MeV/c, flip mode
parent beams

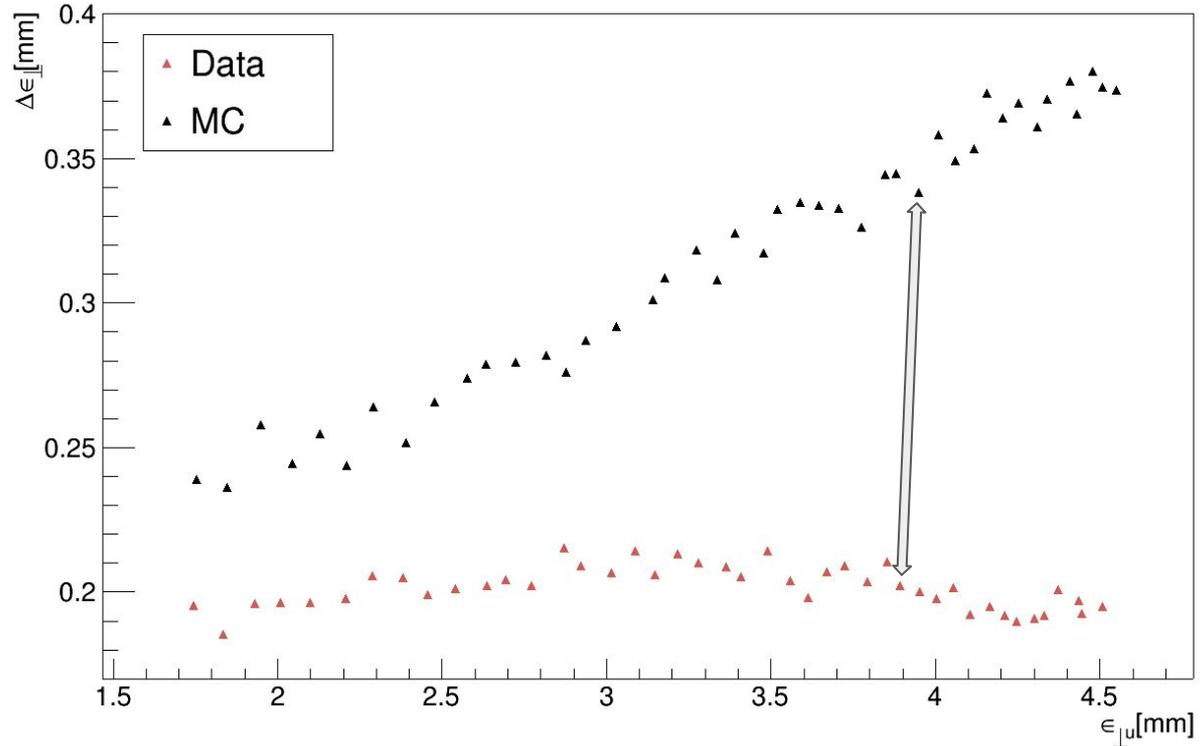


Emittance change: Data vs MC



Empty LH2: Sampled beam phase space

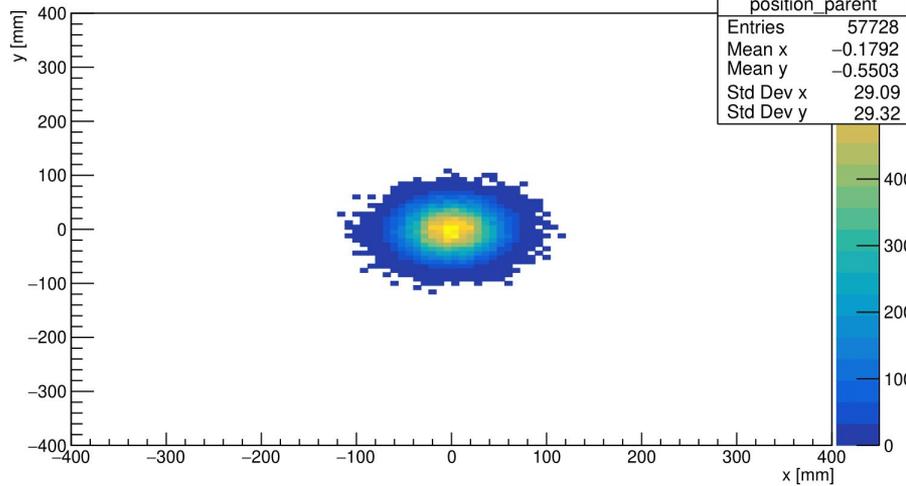
- look at a pair of Data/MC sampled beams with the same target parameters
- the target sampling parameters are [$\epsilon = 4.6$ mm, $\beta = 310$ mm, $\alpha = 0$, $L = 1.1$]
- next slides show the sampled (daughter) beam phase-space at the two reference planes



Beam Position Upstream

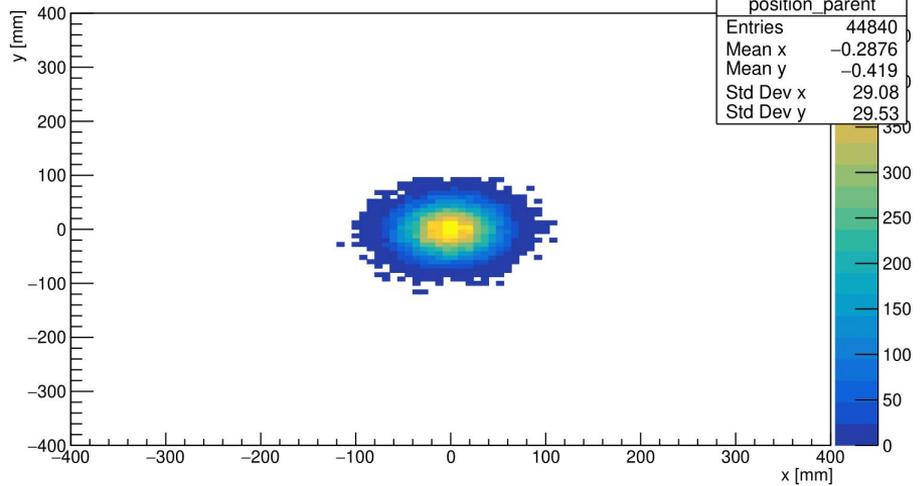
Data

Beam Position



MC

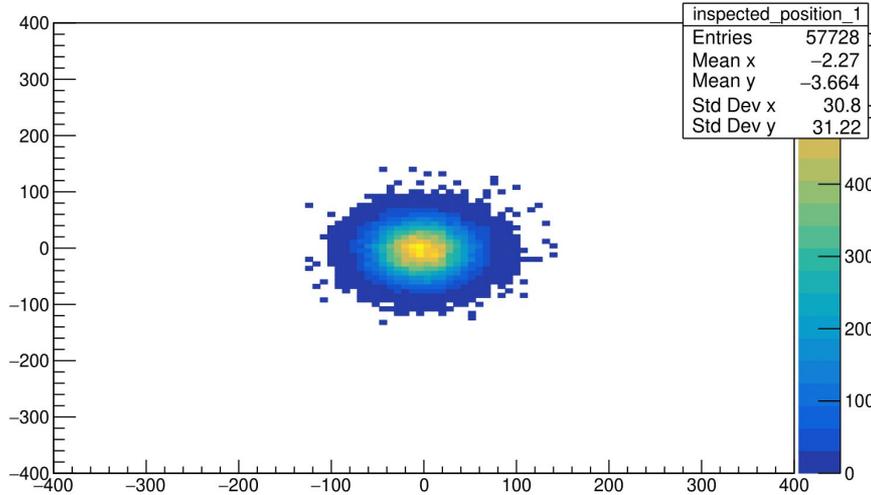
Beam Position



Beam Position Downstream

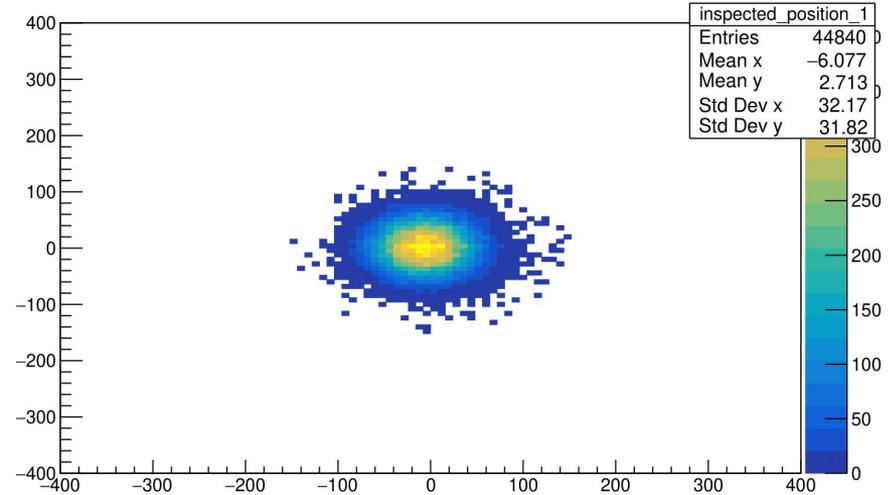
Data

Beam Position



MC

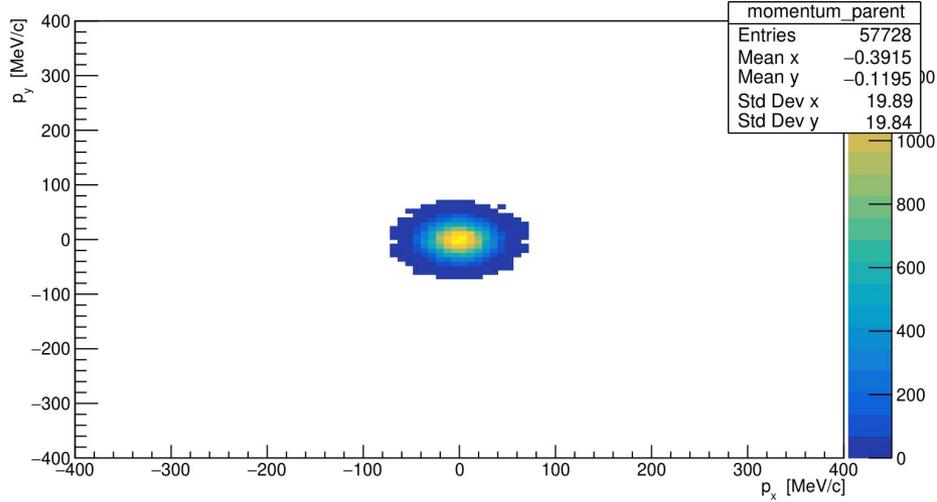
Beam Position



Beam Momentum Upstream

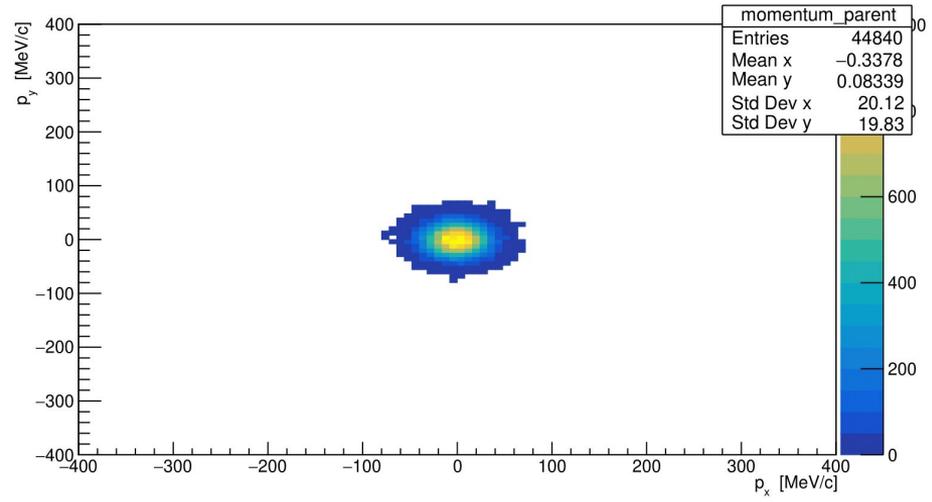
Data

Beam Momentum



MC

Beam Momentum

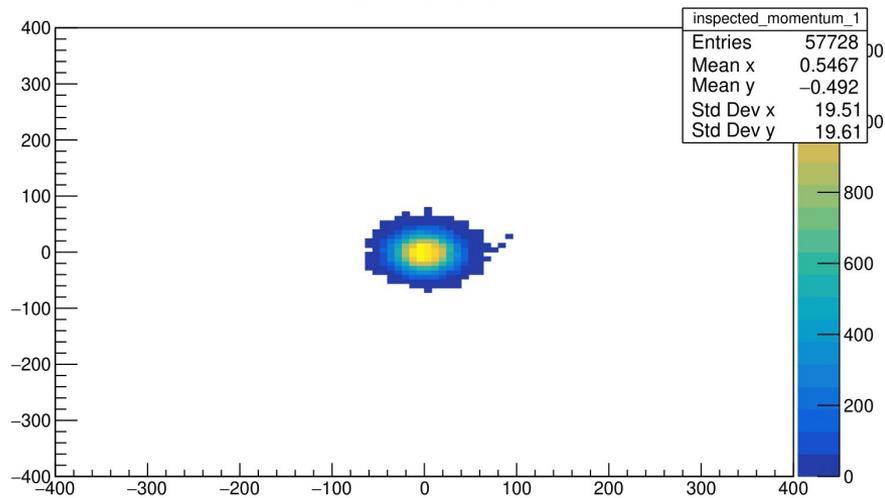


Beam Momentum Downstream

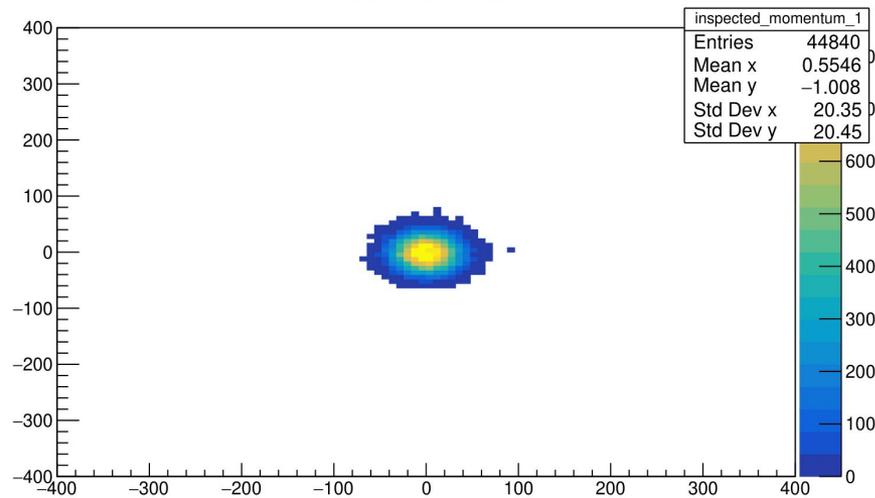
Data

MC

Beam Momentum

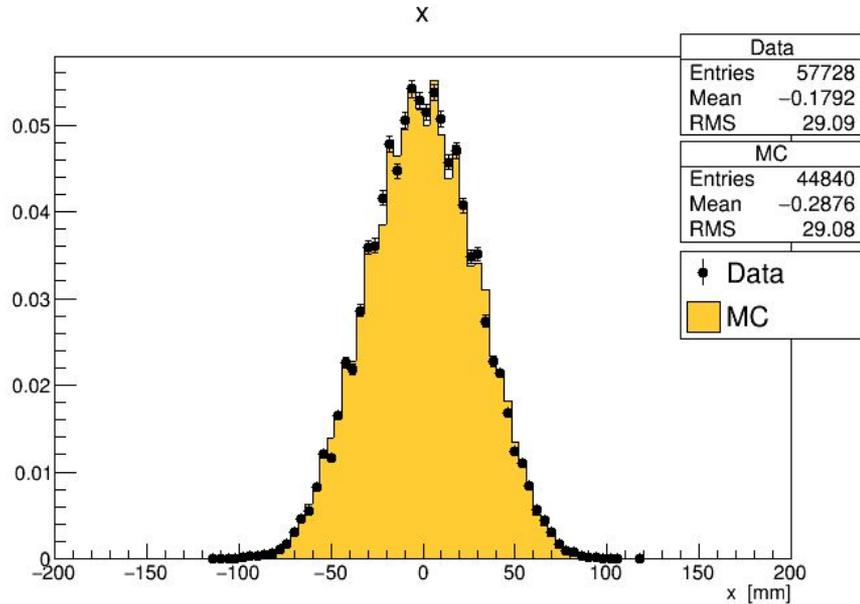


Beam Momentum

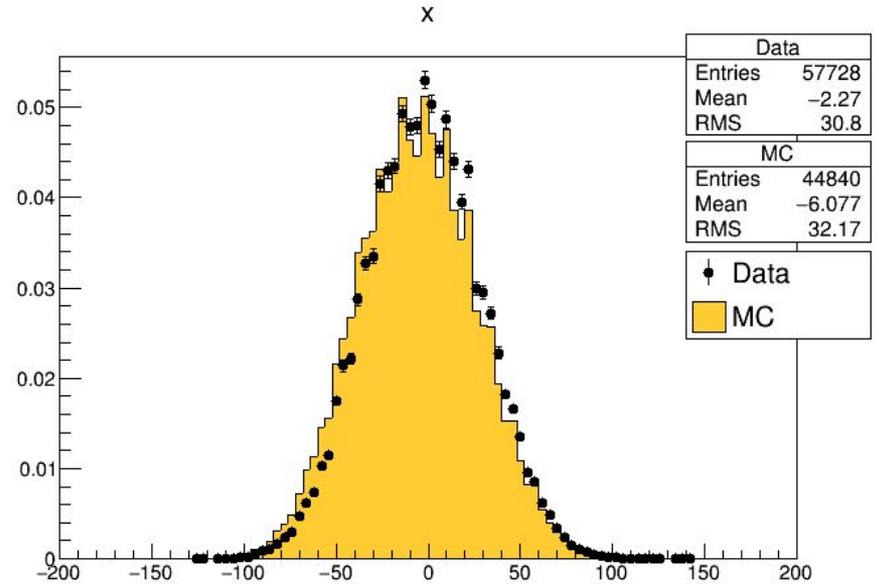


Beam Position: X

Upstream

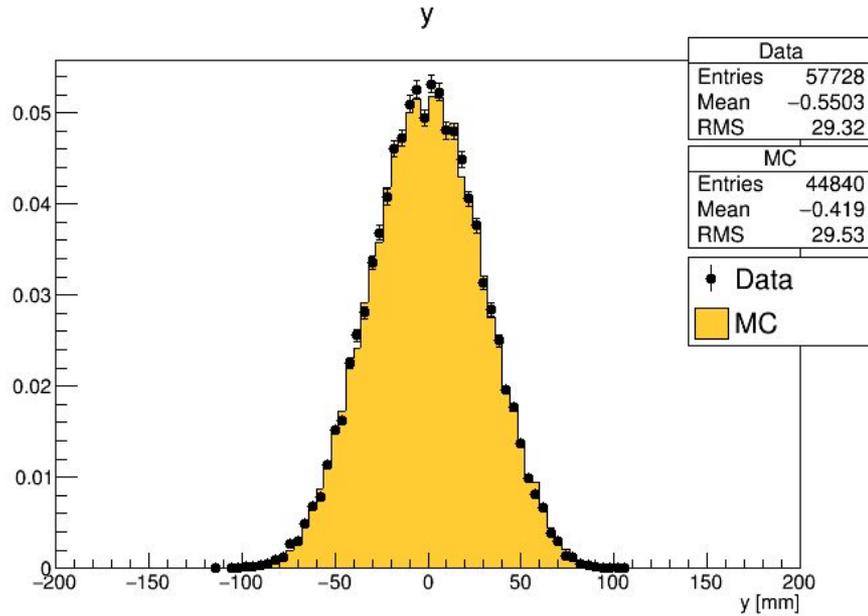


Downstream

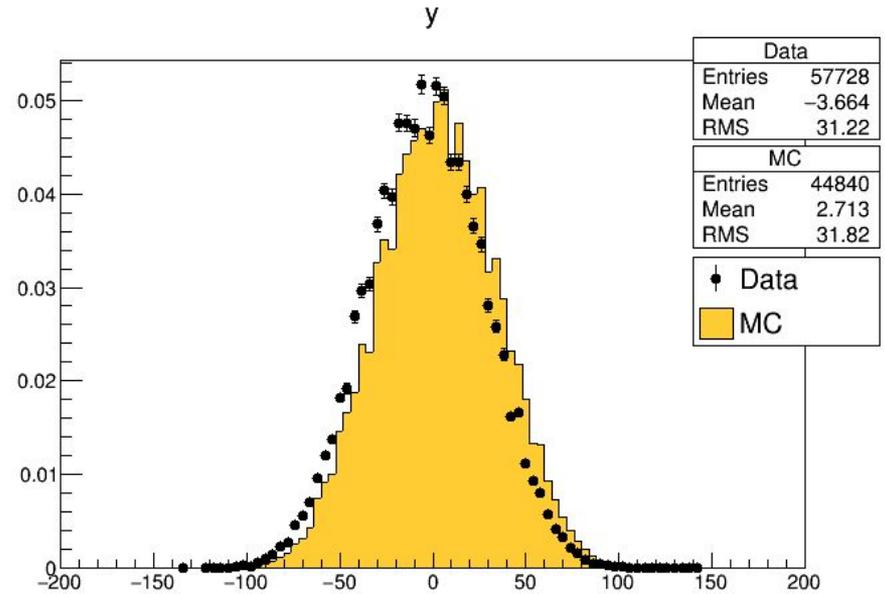


Beam Position: Y

Upstream

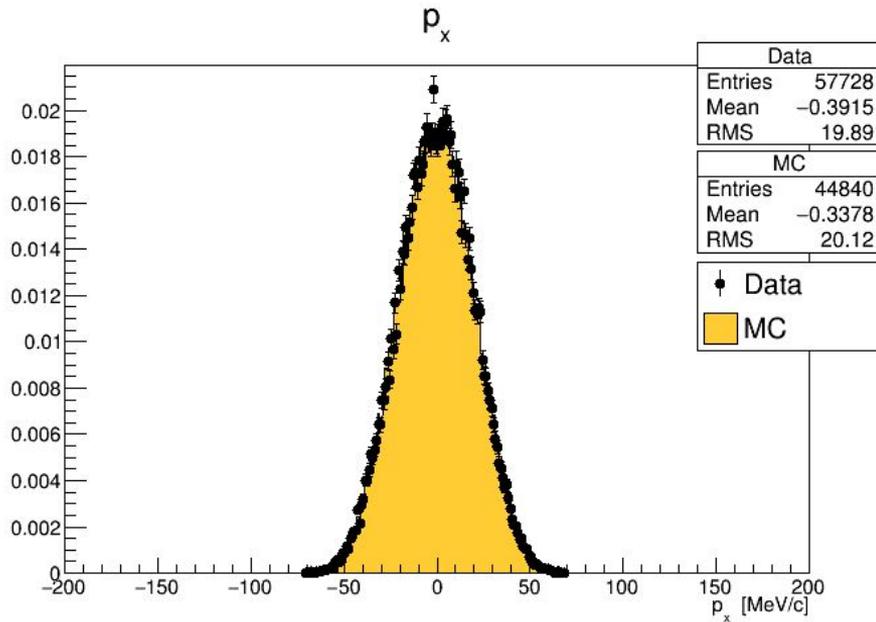


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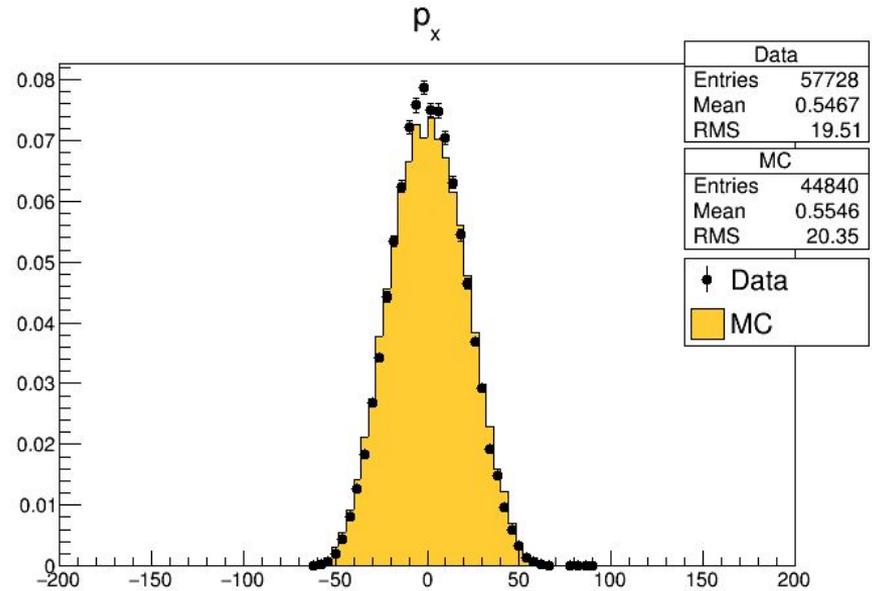


Beam Momentum: P_x

Upstream

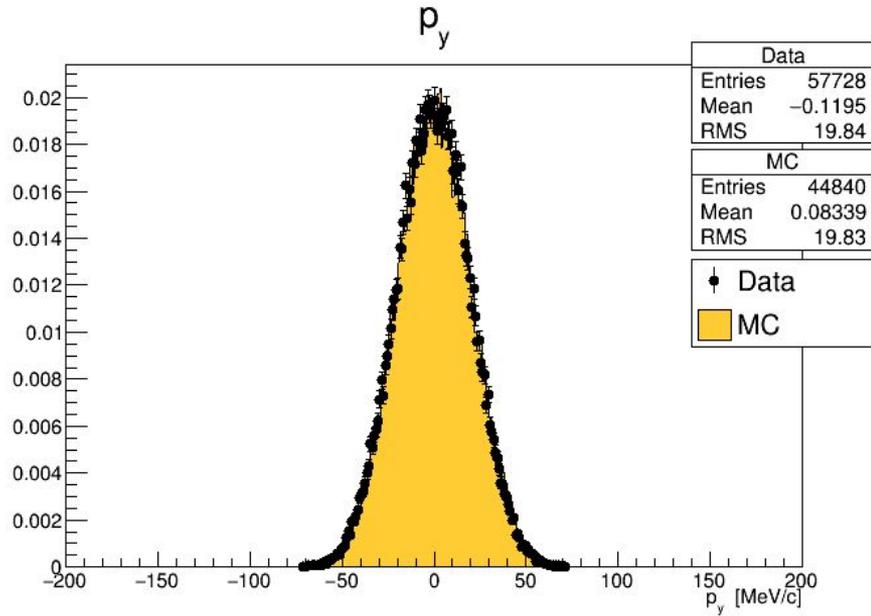


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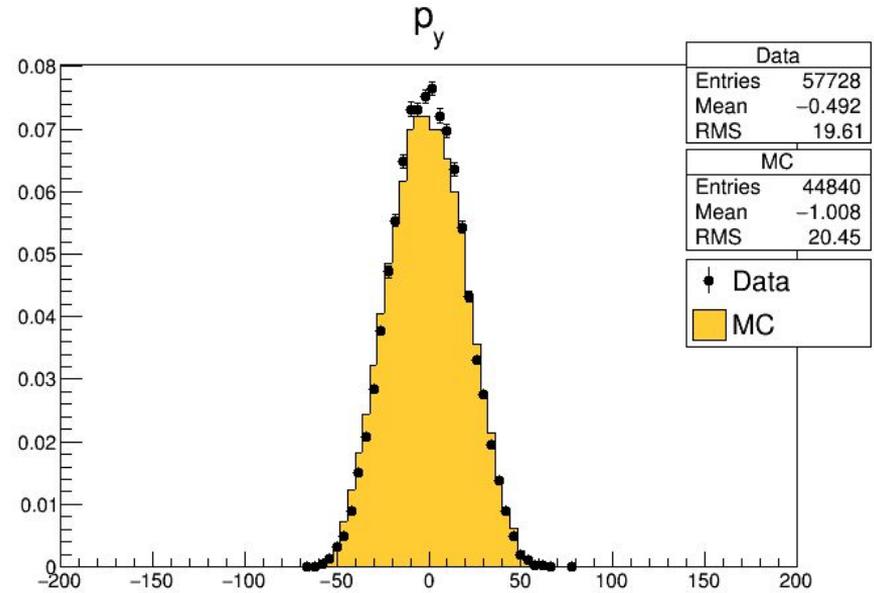


Beam Momentum: P_y

Upstream

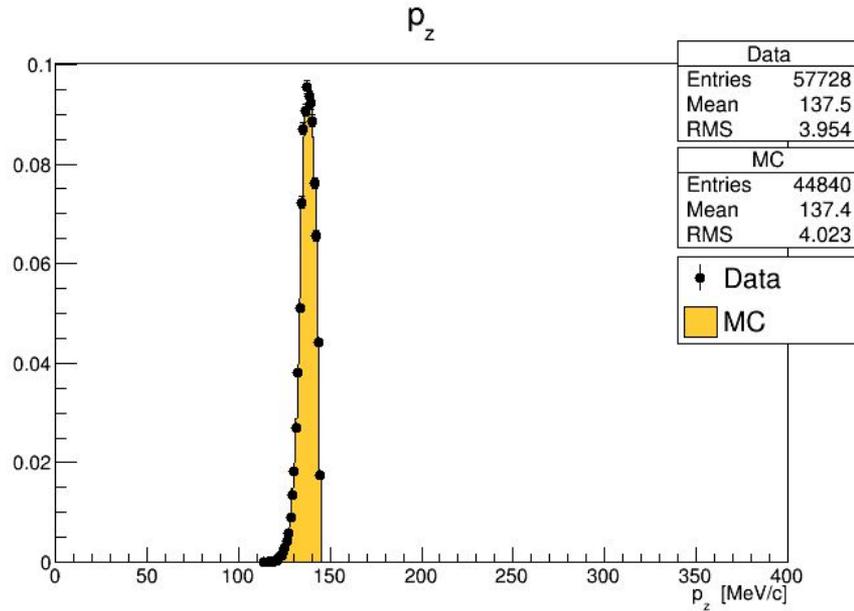


Downstream

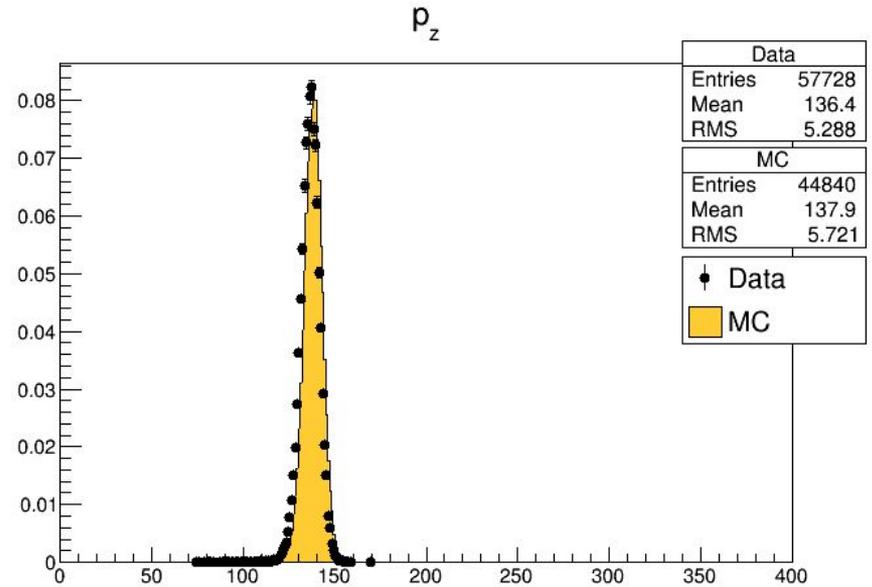


Beam Momentum: P_z

Upstream

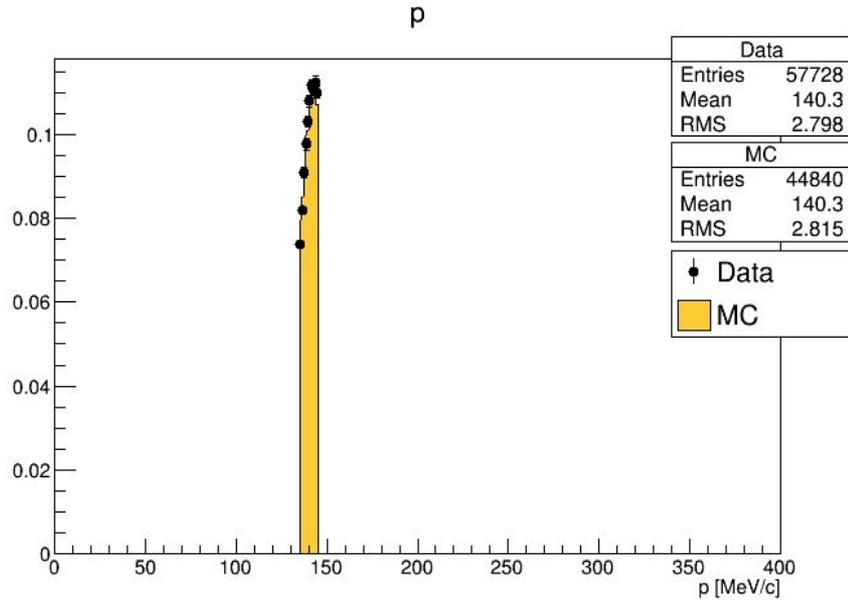


Downstream

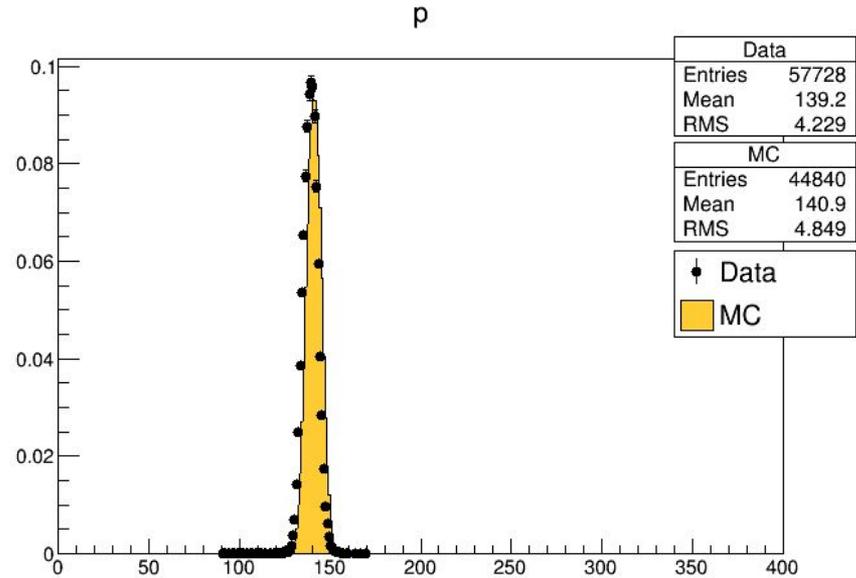


Beam Momentum: P

Upstream



Downstream



Data VC MC discrepancy

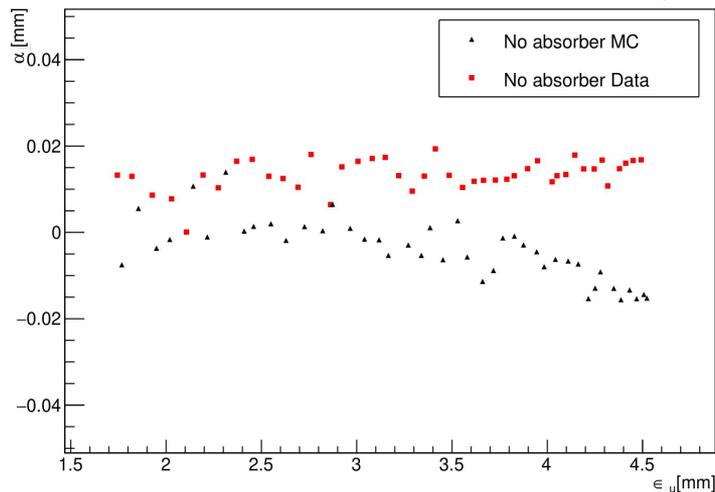
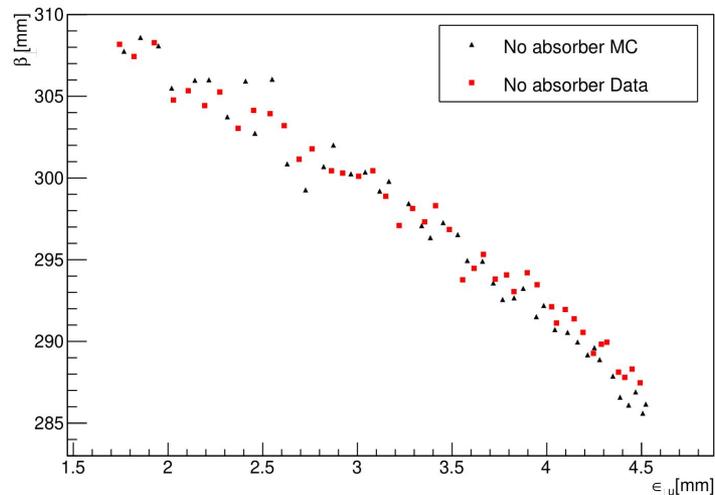
Currently, discrepancy between Data and MC parent beam optics.

Beam sampling should theoretically allow us to (i) impose matched beam optics to all of the sampled beams and (ii) get rid of the optics discrepancy in the parent beams.

However, this is not the case: the closer the sampled beam emittance is to the parent beam emittance, the more the sampled beam β is pulled towards the parent beam β , away from the matched condition.

Also, the sampled beams α is overall biased by the parent beam α .

So if the Data and MC parent beam optics parameters are different, this discrepancy is carried over to the sampled beams to a certain extent.

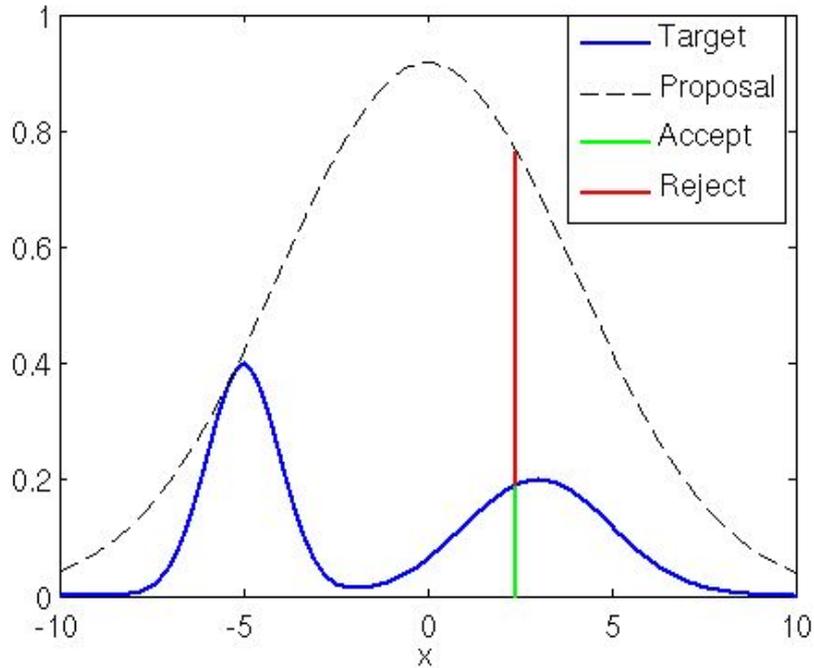


Possible mitigation

1. Have Data vs MC parent beam optics agreement. However, the sampled beams optics parameters would still deviate from the matched condition
2. Improve the sampling routine -> for each sampled beam retrieve the desired (matched) optics irrespective of the parent optics

Decided to look into the sampling routine as there was another outstanding issue that needed improvement - the number of particles in the sampled (daughter) beams was relatively low.

Rejection Sampling



- $P_{selection}(x) = Norm * Target(x) / Parent(x)$
- Draw u from $U[0,1]$. If $u < P_{selection}(x)$ then accept event. Otherwise reject it.
- Normalisation calculation:
 - draw samples from the parent beam and take the minimum of $Parent(x) / Target(x)$
 - Normalisation ensures that $P_{selection}(x) \leq 1$
 - **# of particles in the daughter beam ~ Norm** (currently rejection rate relatively high - can we improve?)

Normalisation: Event likelihoods

Draw an particle from the parent distribution.

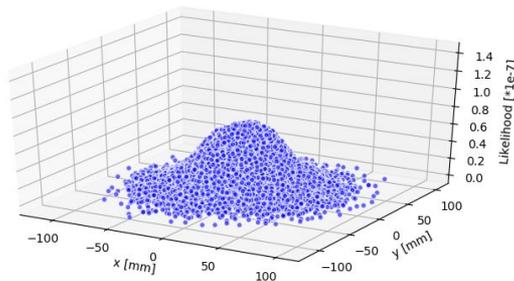
Calculate its likelihood of being sampled from the parent (KDE) and target (analytical 4D Gaussian) PDFs.

Here, likelihoods projected on the (x,y) and (p_x, p_y) subspaces.

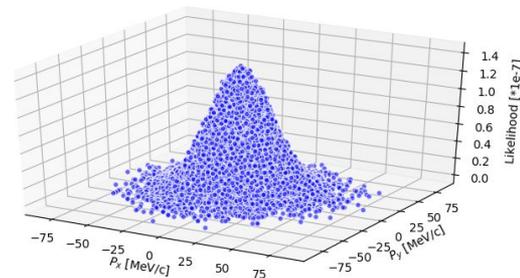
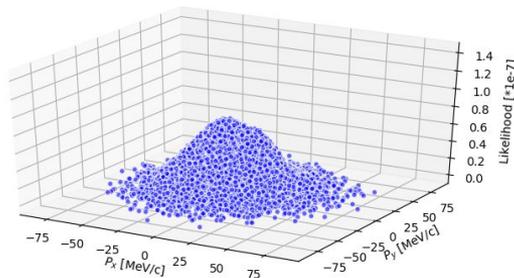
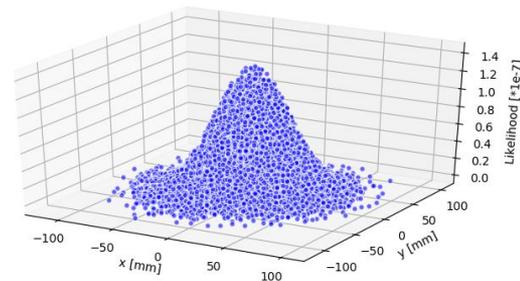
Beam parameters:

- Parent: [$\epsilon=4.85$ mm, $\beta = 282$ mm, $\alpha = 0.045$, $L = 1.1$]
- Target: [$\epsilon=4$ mm, $\beta = 310$ mm, $\alpha = 0$, $L = 1.1$]

Parent (KDE)

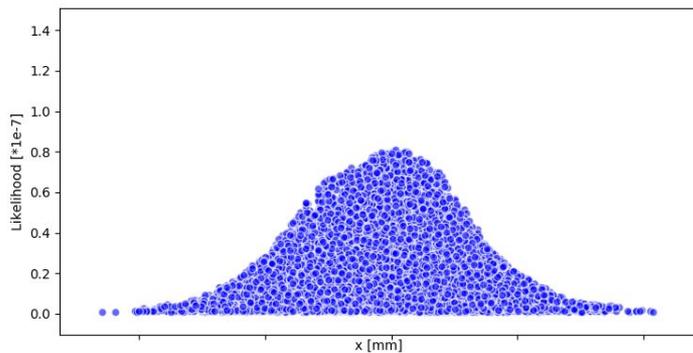


Target (4D Gaussian)

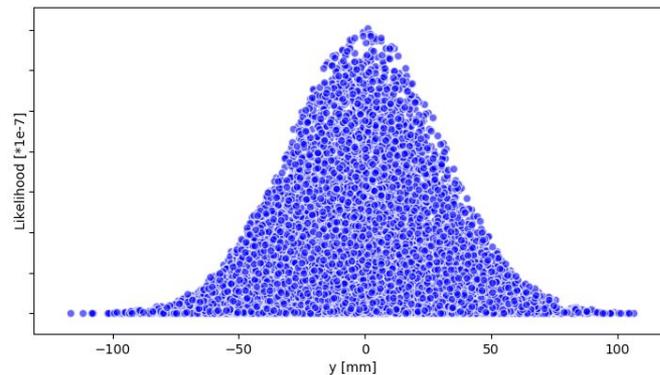
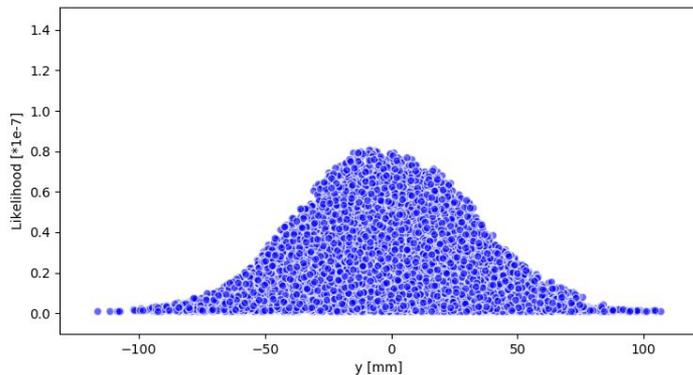
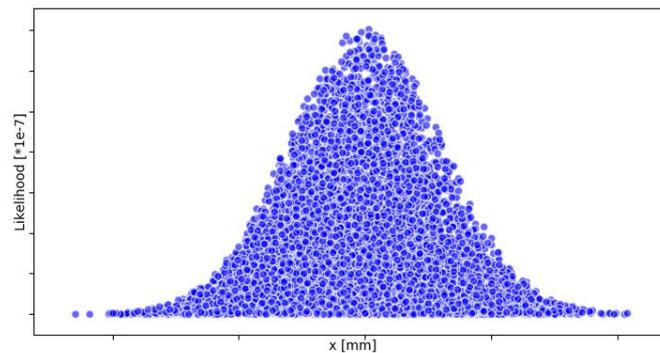


Event likelihood: 1D projections (position space)

Parent (KDE)

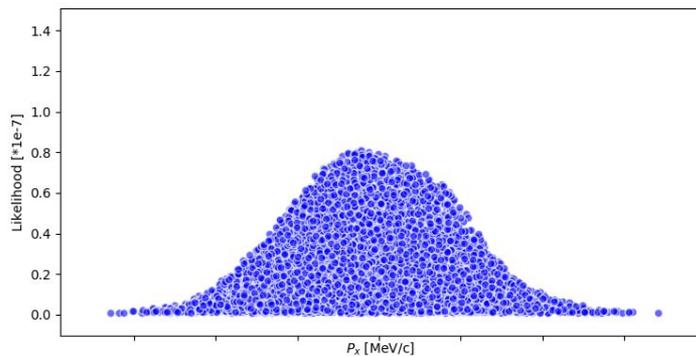


Target (4D Gaussian)

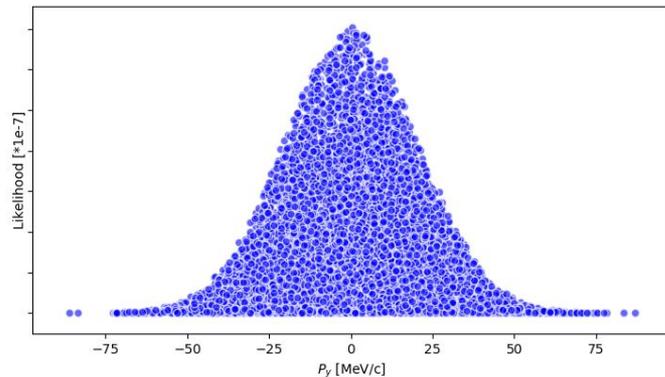
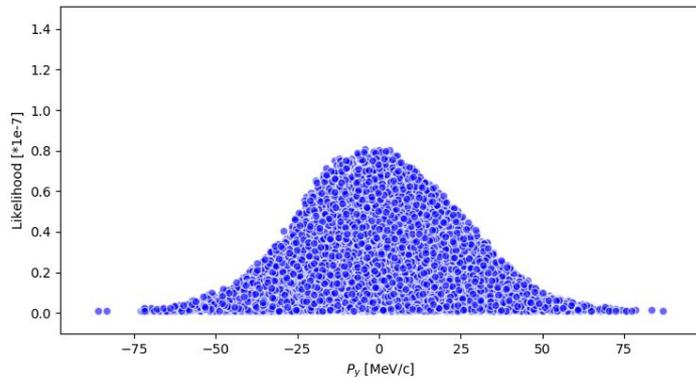
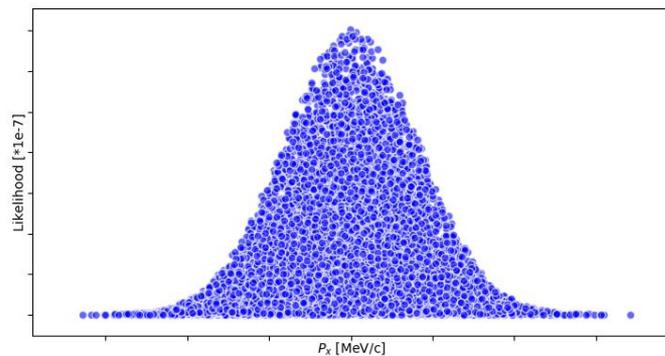


Event likelihood: 1D projections (momentum space)

Parent (KDE)



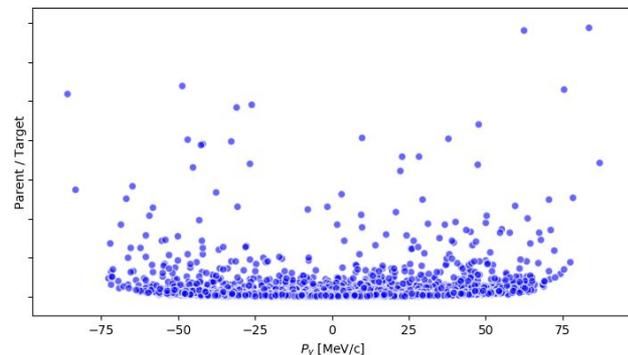
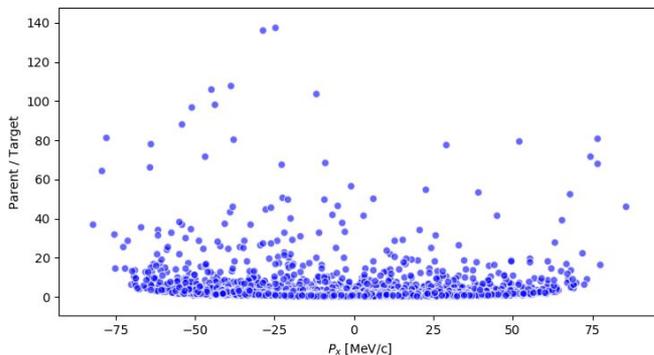
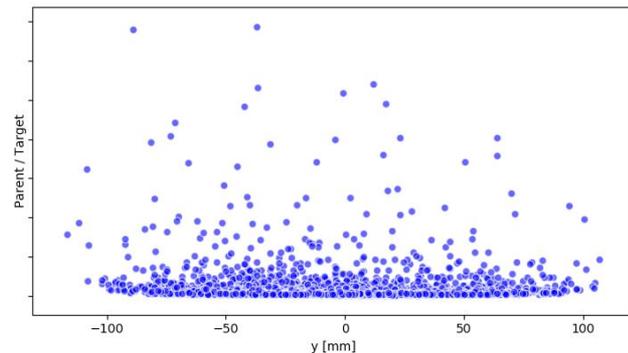
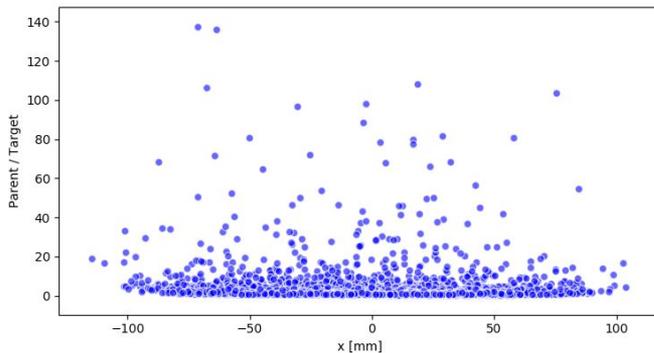
Target (4D Gaussian)



Parent (x) / Target (x)

Ratio of likelihoods projected on the 4D phase-space components.

Current procedure takes the normalisation as the minimum of these ratios.

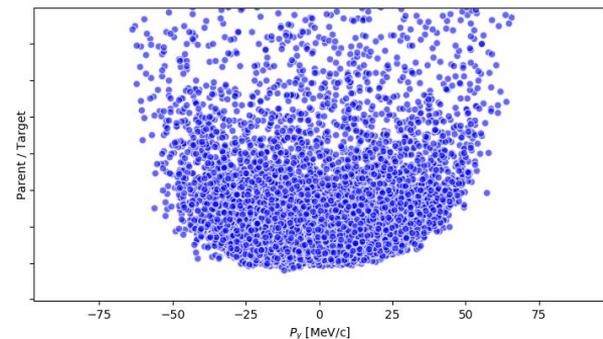
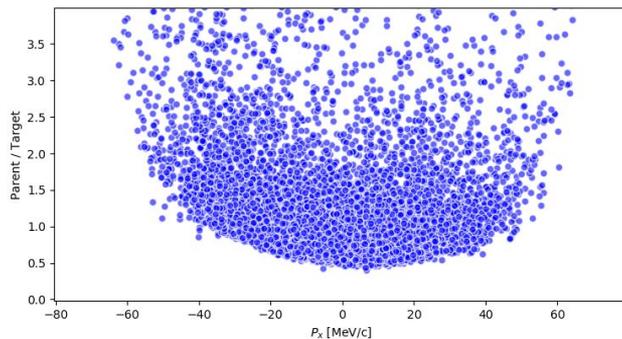
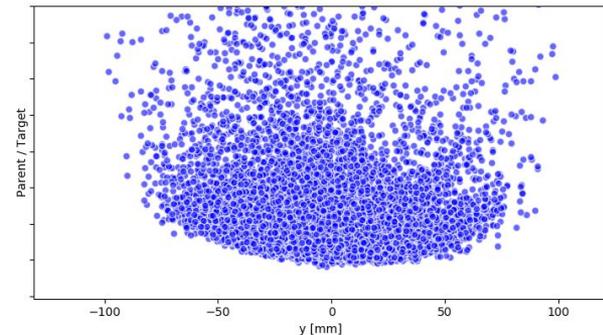
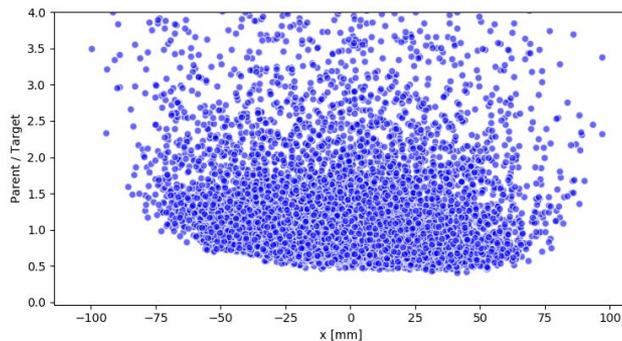


Rejection Sampling Normalisation - Parent (x) / Target (x)

The higher likelihood of particles coming from the target distribution leads to $N < 1$. In this case $N \sim 0.5$.

Tails seem not to impact the N estimation for this combination of parent and target parameters.

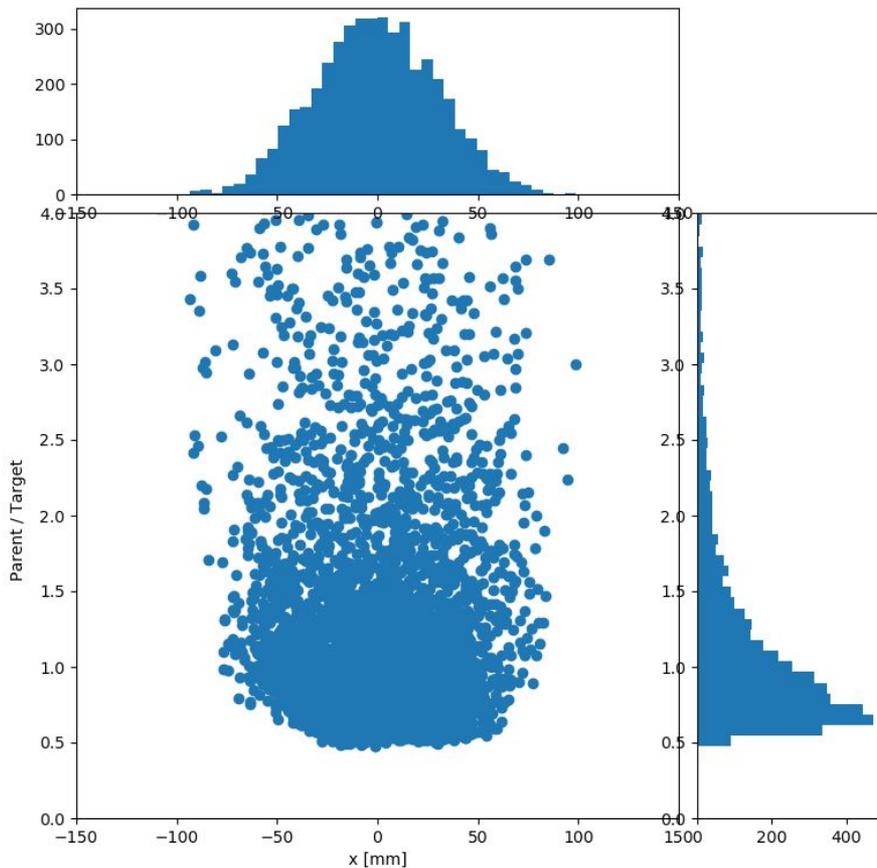
Seek to change the N estimation method such that more particles are accepted into the daughter beam, without significantly impacting the selection performance.



Mode?

Choose N as the *most probable value* of $\text{Parent}(x) / \text{Target}(x)$ distribution, rather than the minimum.

Study the improvement in the number of particles accepted in the daughter beams and the impact on the daughter beam parameters.



Normalisation: Toy study

Generate toy parent beams (10k particles) with a specific set of parameters: [$\epsilon=4.85$ mm, $\beta = 282$ mm, $\alpha = 0.045$, $L = 1.1$]

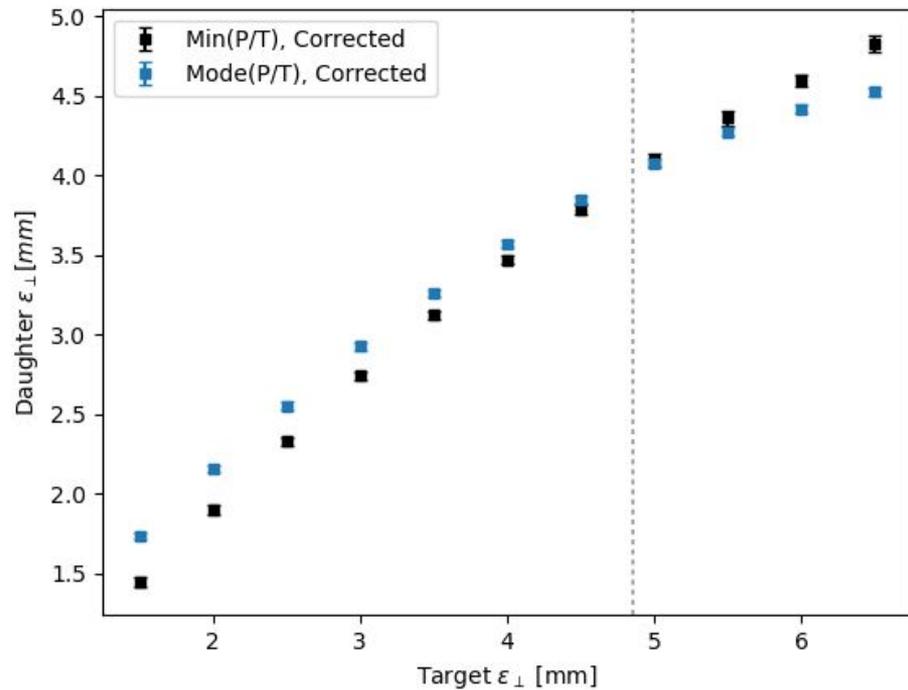
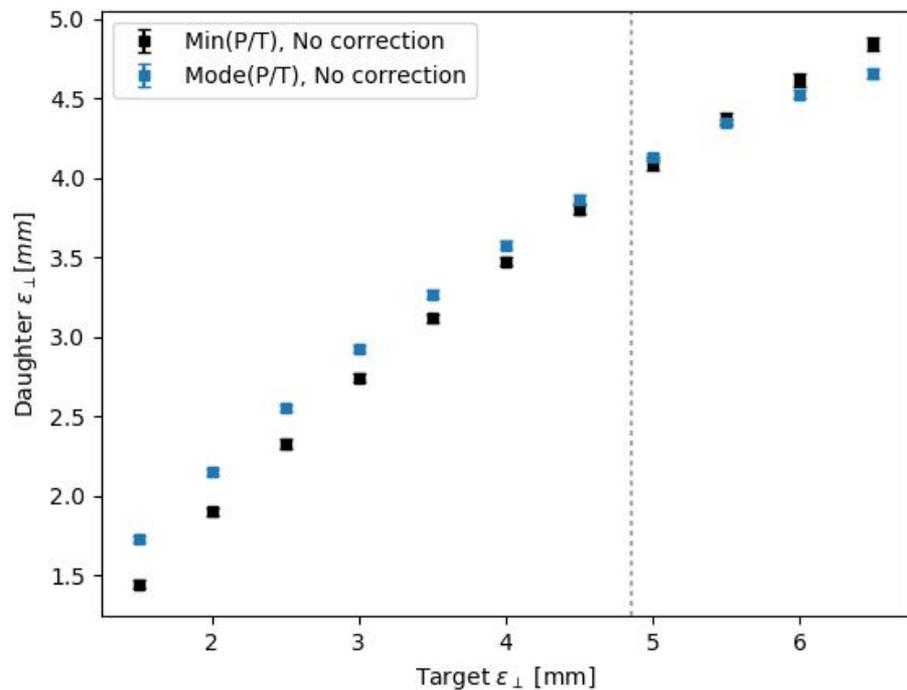
Target parameters: [$\epsilon= [1.5 - 6.5; 0.5]$ mm, $\beta = 310$ mm, $\alpha = 0.0$, $L = 1.1$]

For each combination of parent and target parameters, repeat procedure 100 times

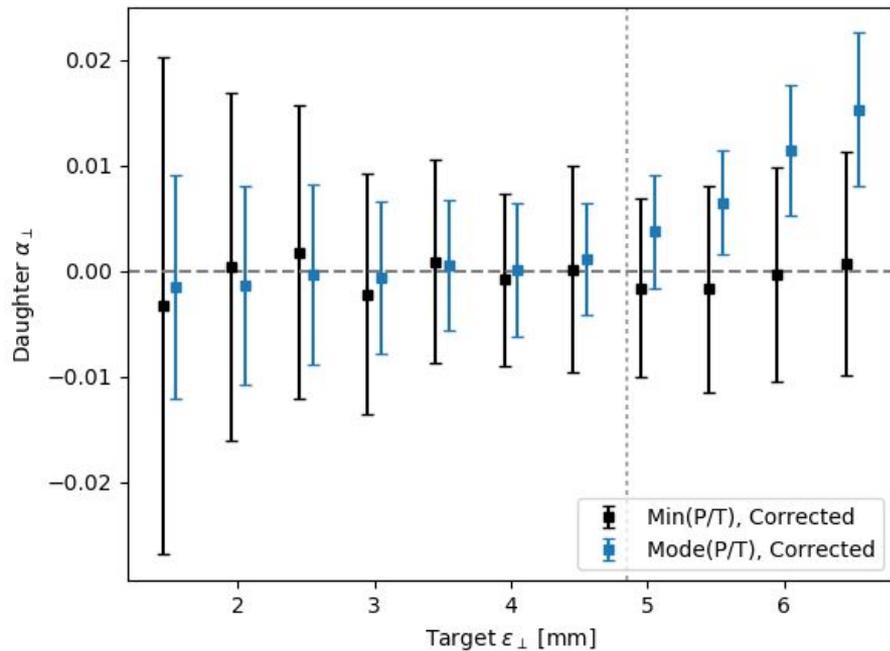
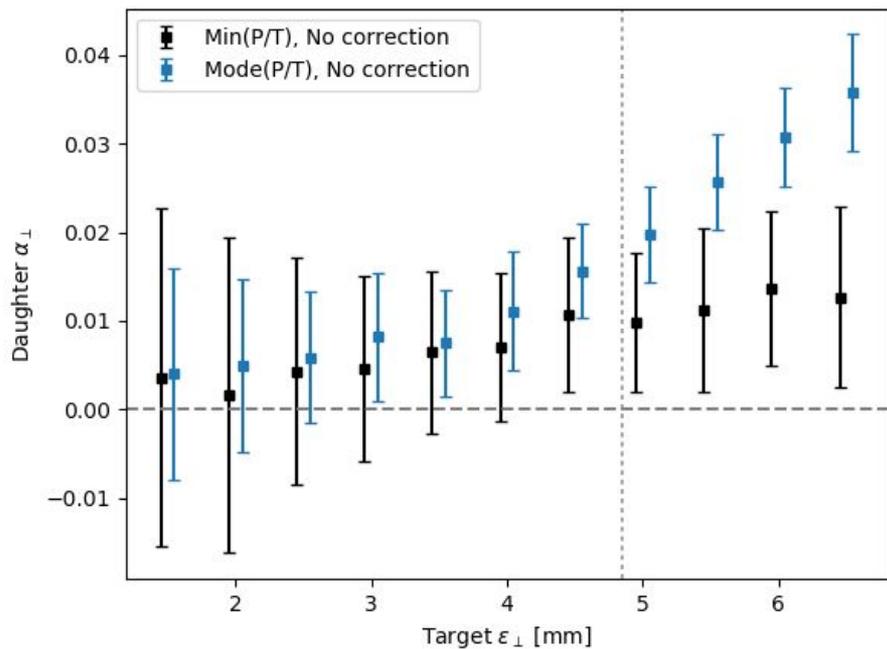
To both normalisation calculations ($\min(P/T)$ vs $\text{mode}(P/T)$) apply individual corrections in order to obtain daughter values close to $\alpha = 0.0$ and $\beta = 310$ mm ie remove the bias

Correction for α and β : *New target parameter = Old Target parameter (matched) +/- bias*

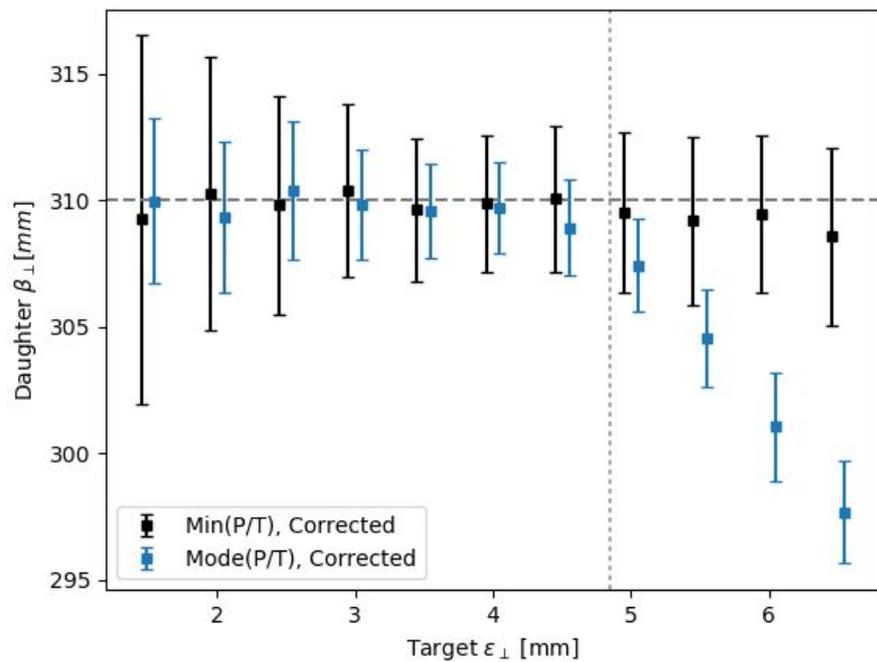
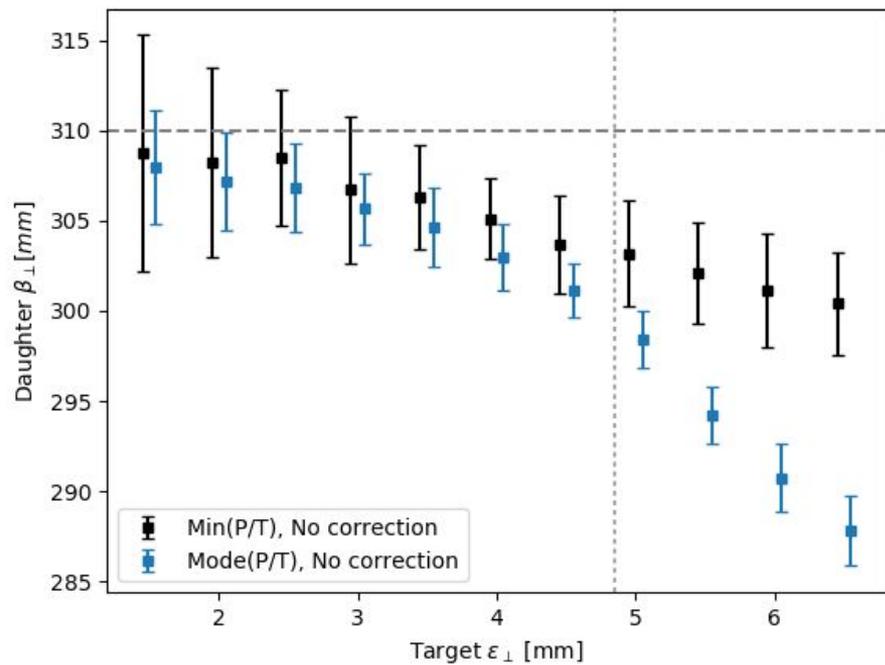
Emittance



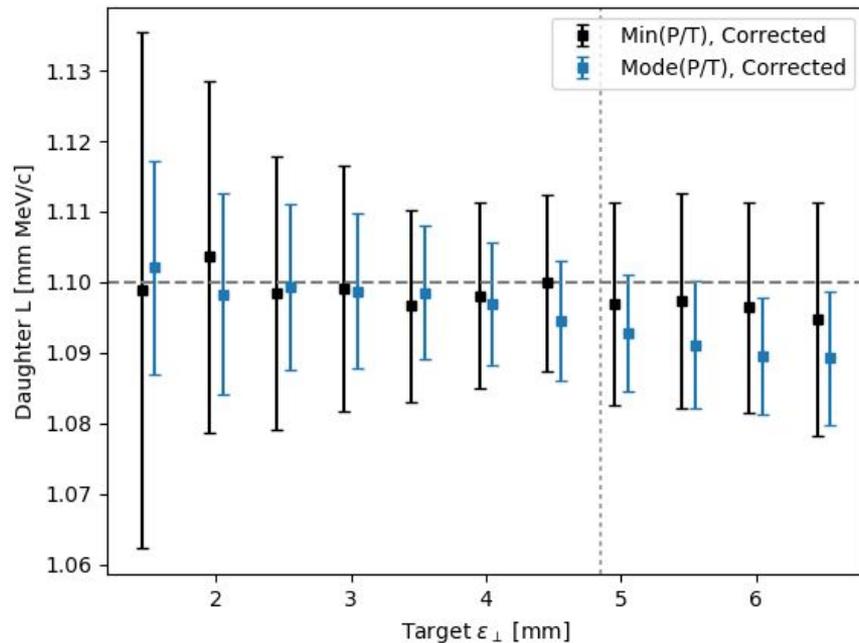
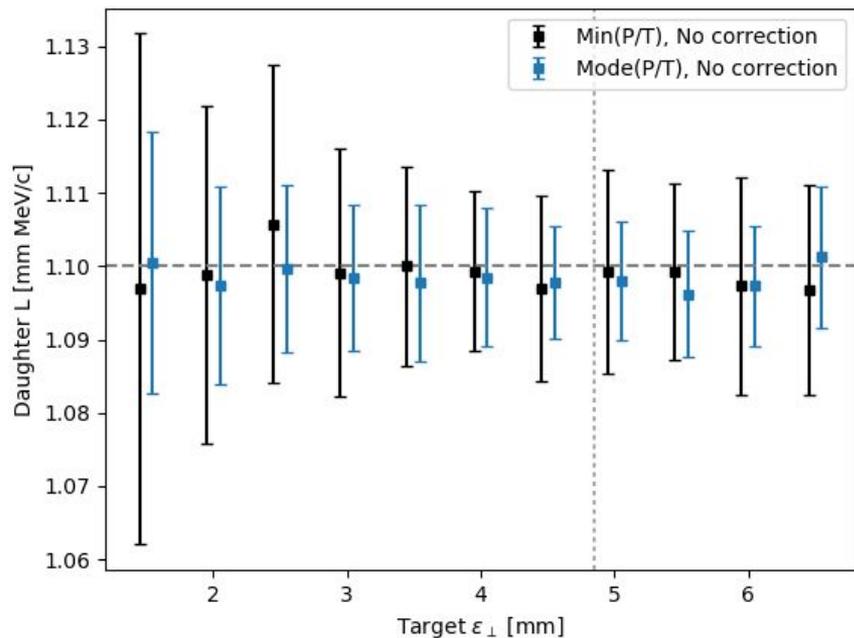
Alpha



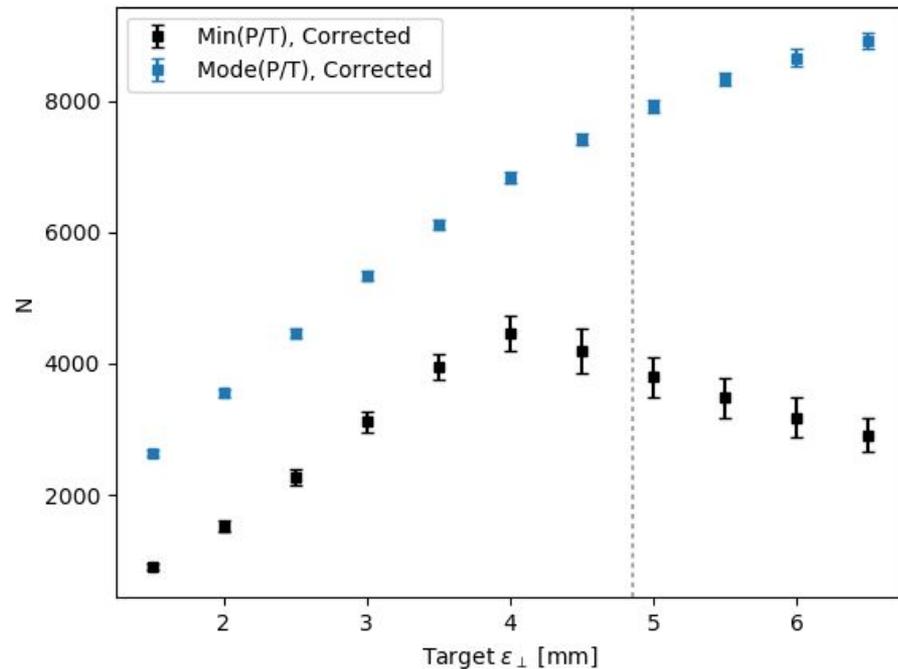
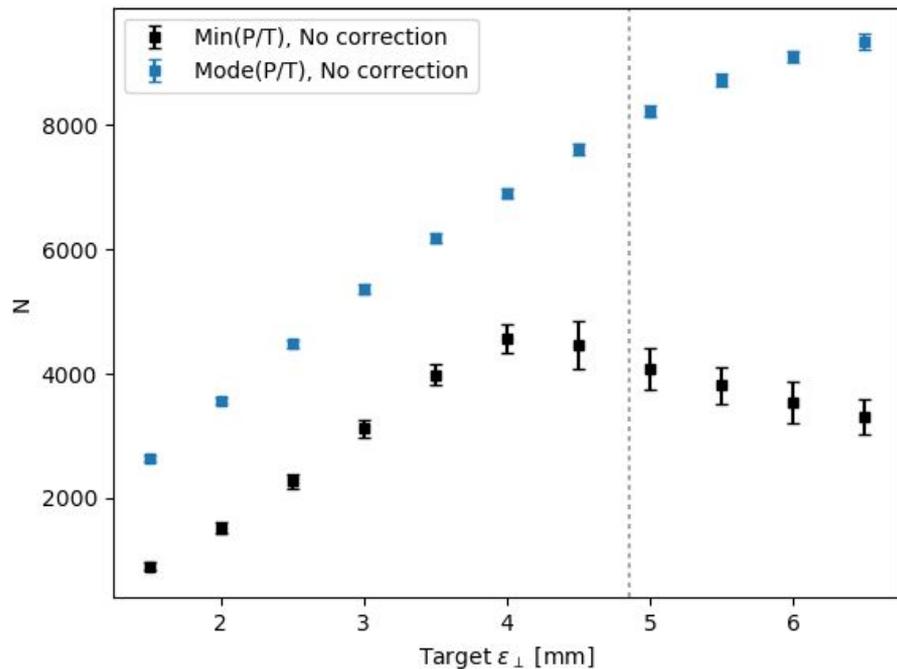
Beta



Angular momentum term



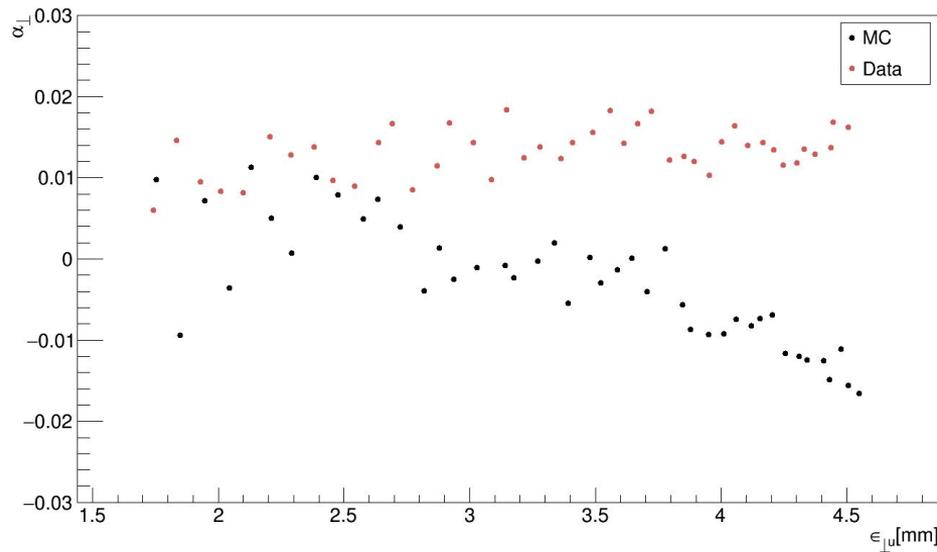
Number of particles in the sampled beams



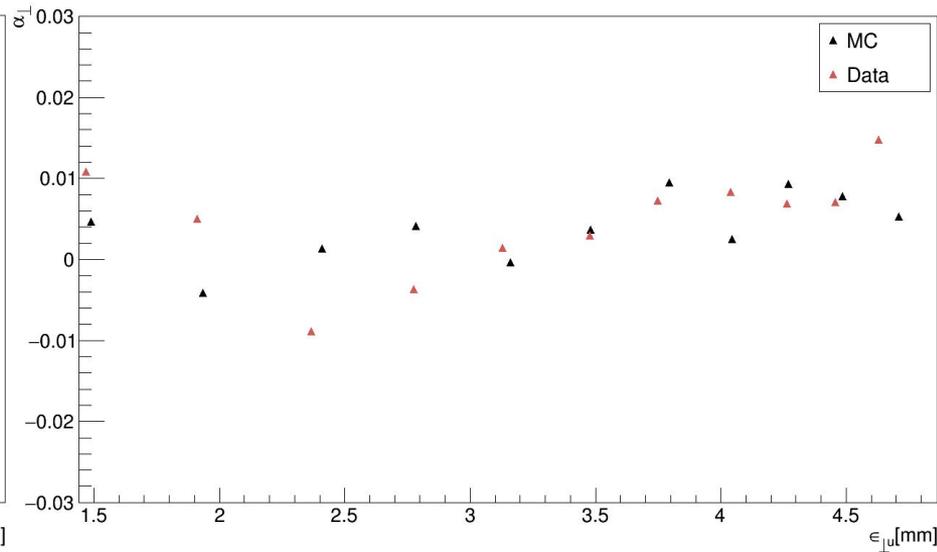
Empty LH2: Optics corrections applied

- preliminary results
- Target parameters: [$\epsilon = [1.5 - 6.5; 0.5]$ mm, $\beta = 310$ mm, $\alpha = 0.0$, $L = 1.1$], corrections applied to α and β target values
- Normalization as $\min(P/T)$ in this study

Alpha



No correction

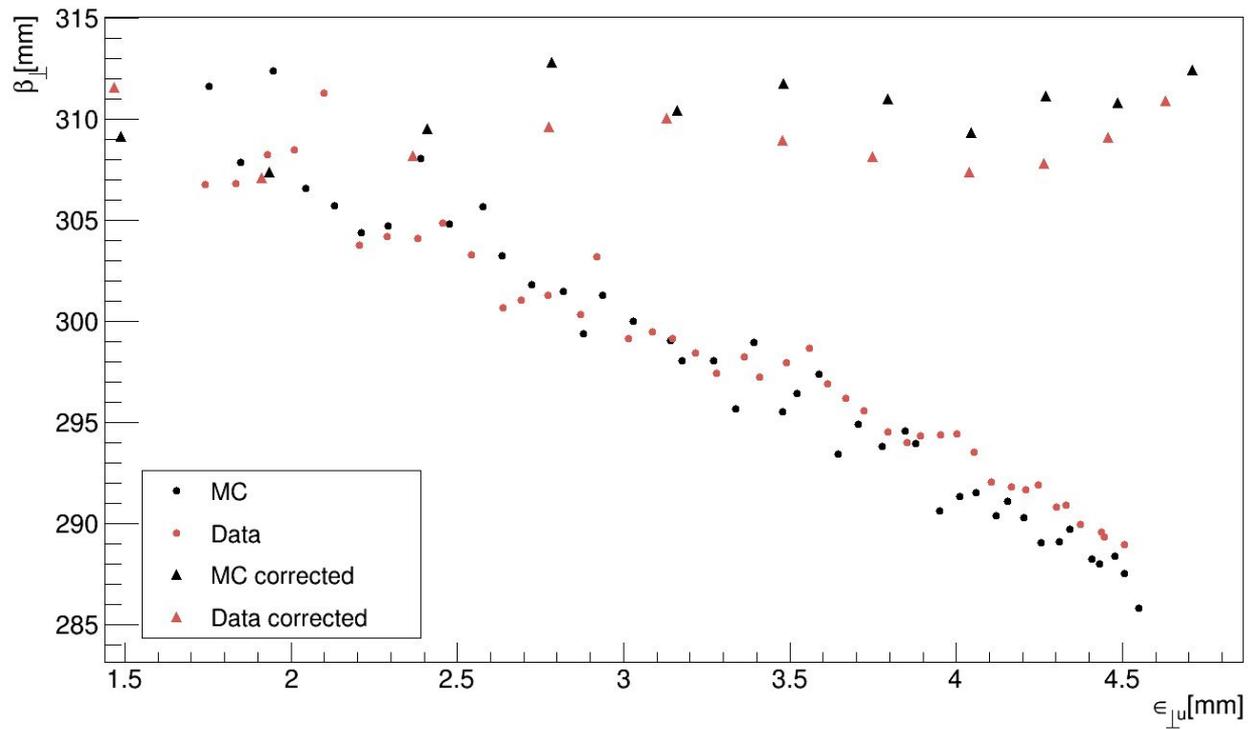


Corrected

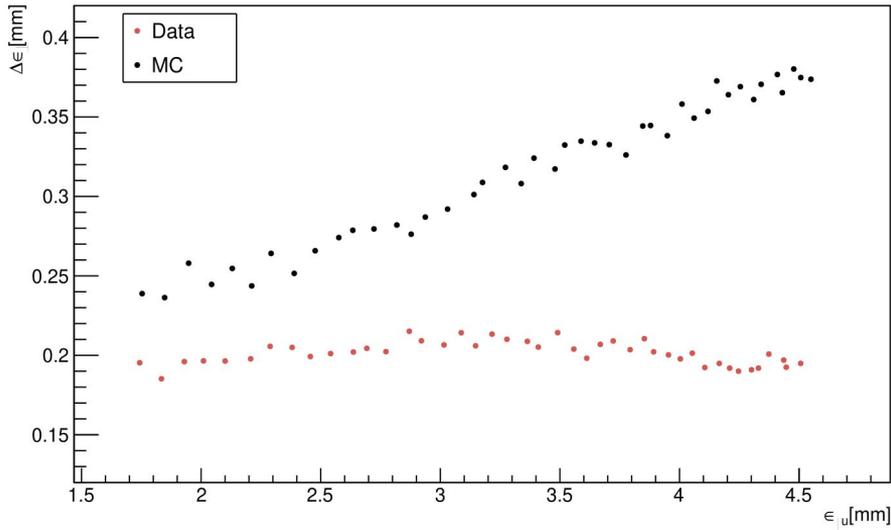
Aims: (a) Data - MC agreement, (b) Agreement with the matched optics values ($\alpha = 0.0$)

Beta

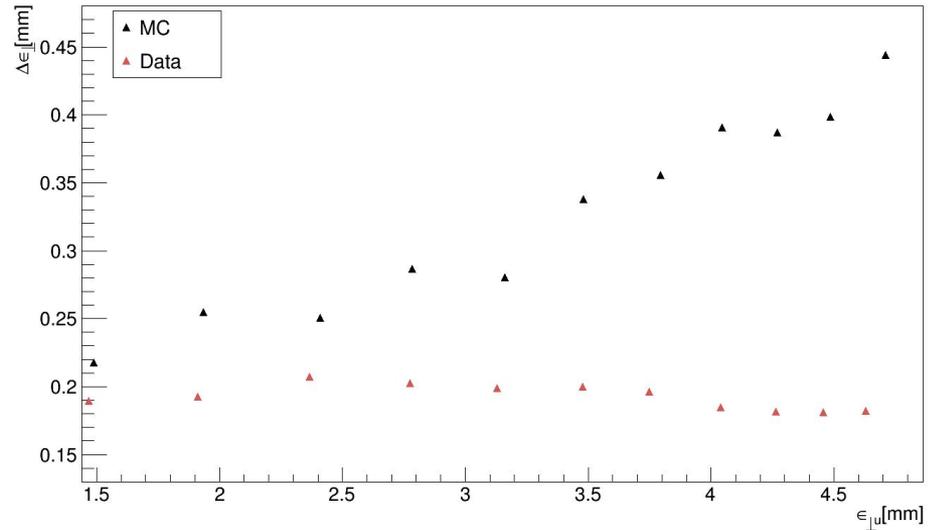
Improved agreement with the
 $\beta = 310$ mm target value



Emittance change



No correction

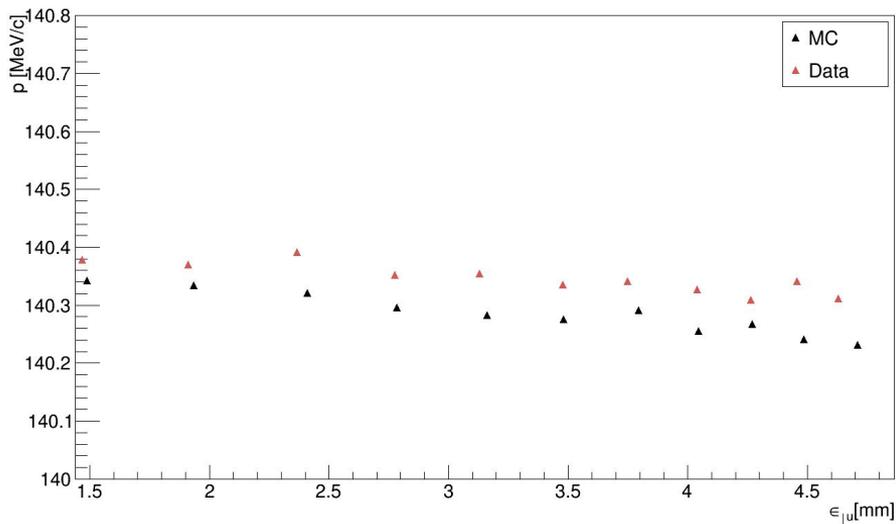


Corrected

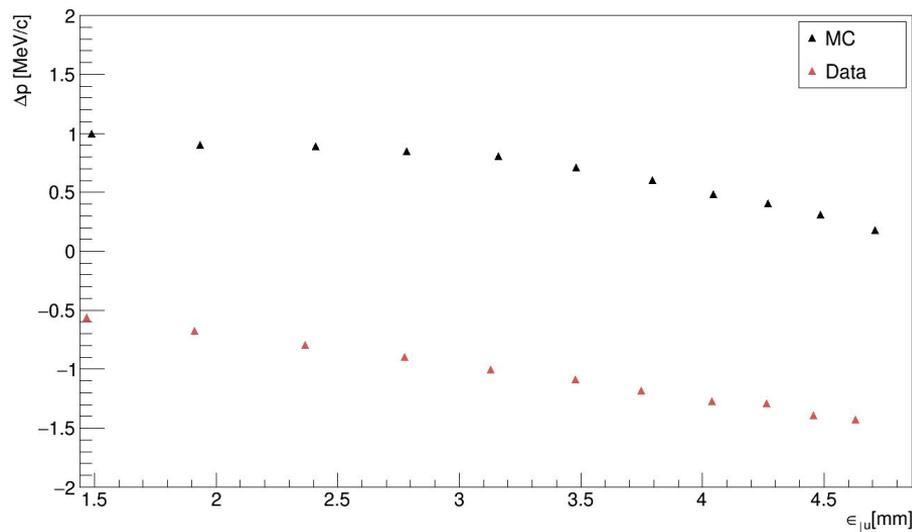
Discrepancy still present. The initial optics discrepancy at TKU ref plane does not explain the difference in emittance growth between Data and MC.

Slightly less heating observed in corrected data and more heating observed at higher emittances in corrected MC.

Momentum (only corrected)



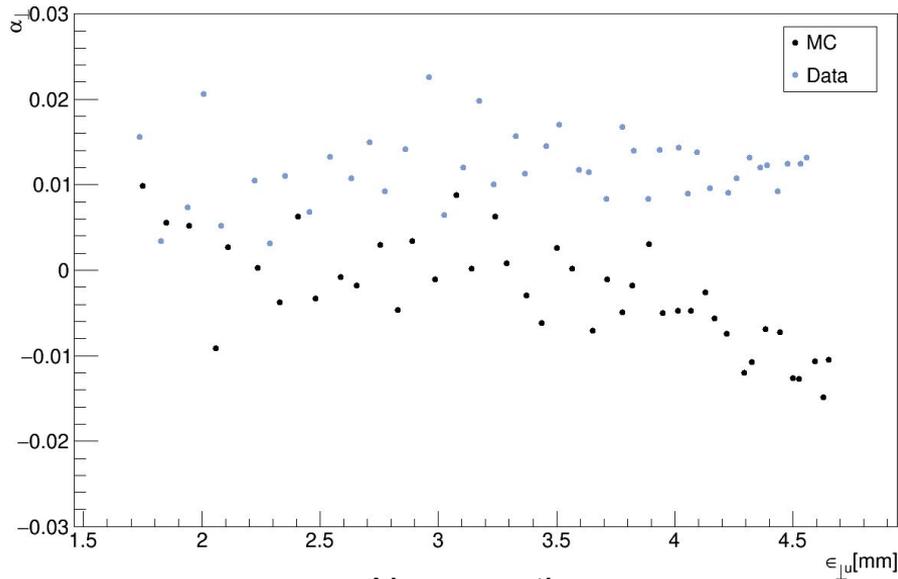
TKU momentum



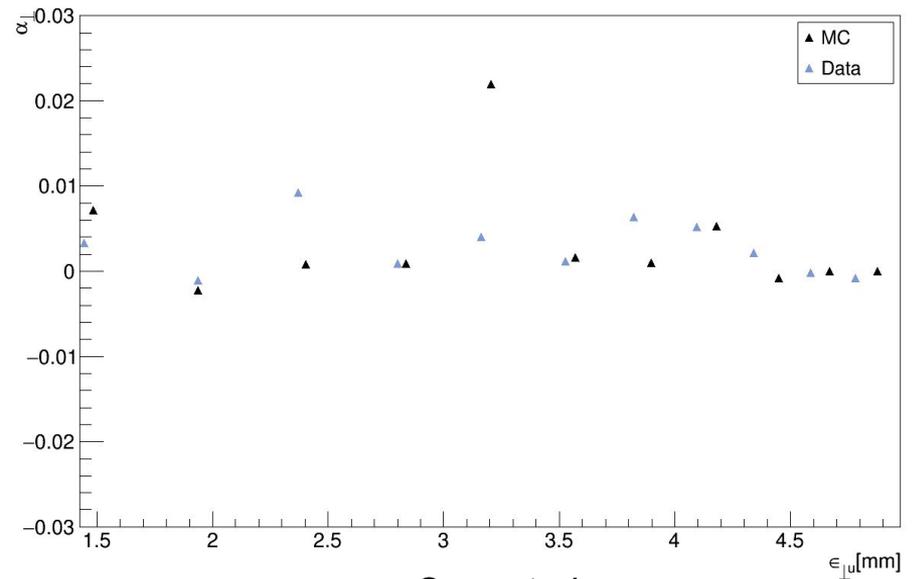
Momentum change

Apparent no momentum loss in MC, indicates reconstruction issues.
More momentum loss seen at higher emittances (data).

LiH: Optics corrections applied - Alpha



No correction



Corrected

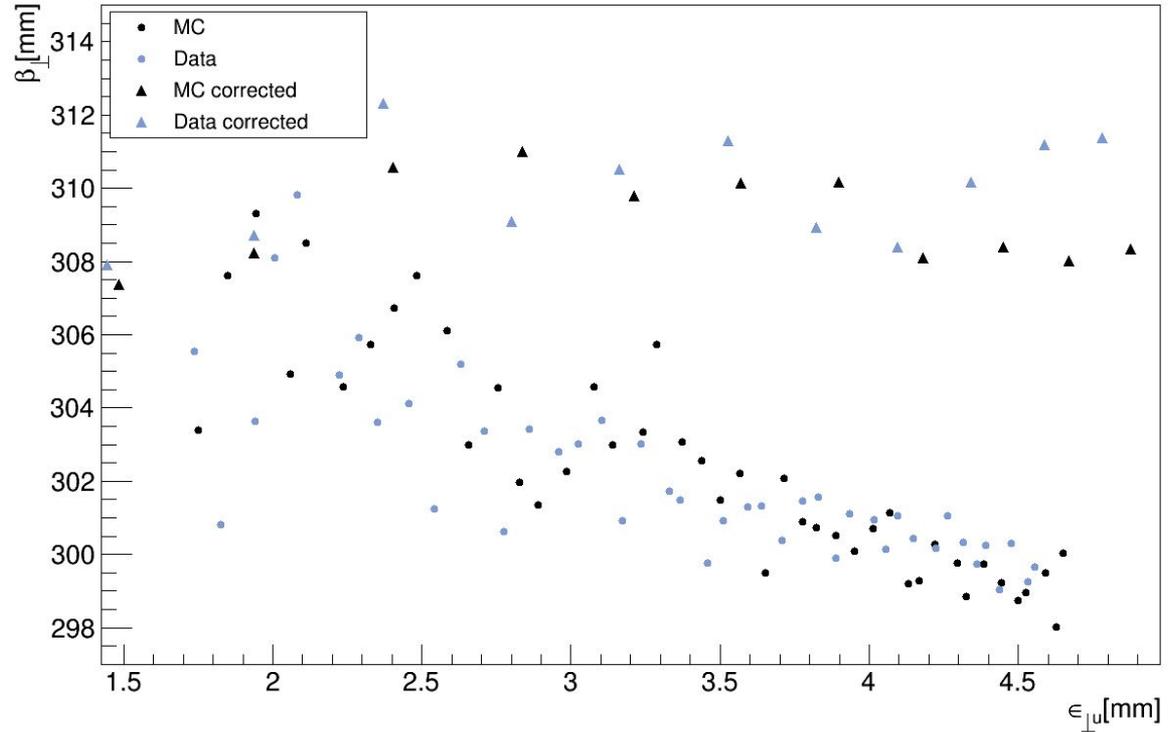
Improved agreement with the $\alpha = 0.0$ target value

RHS plot: MC point at $\epsilon \sim 3.2$ mm, wrong correction applied, one order of magnitude larger

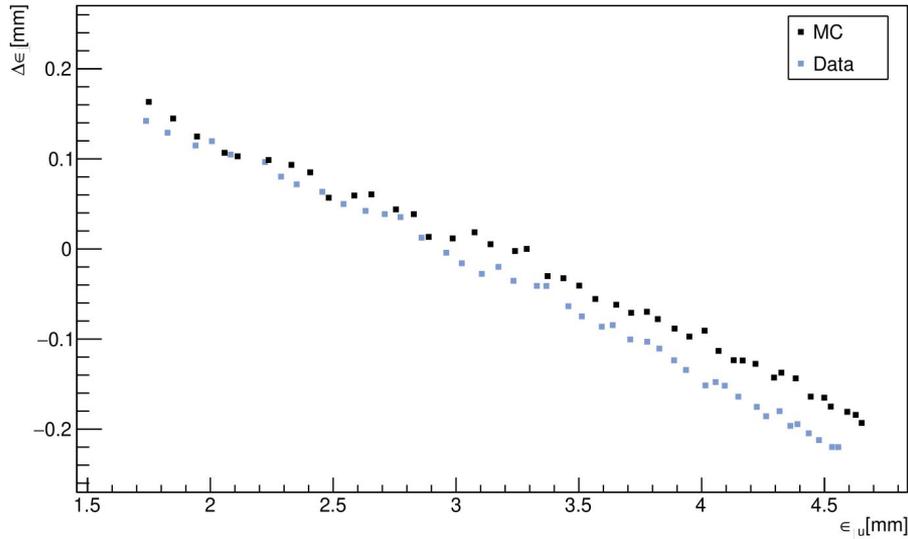
Beta

Improved agreement with the
 $\beta = 310$ mm target value

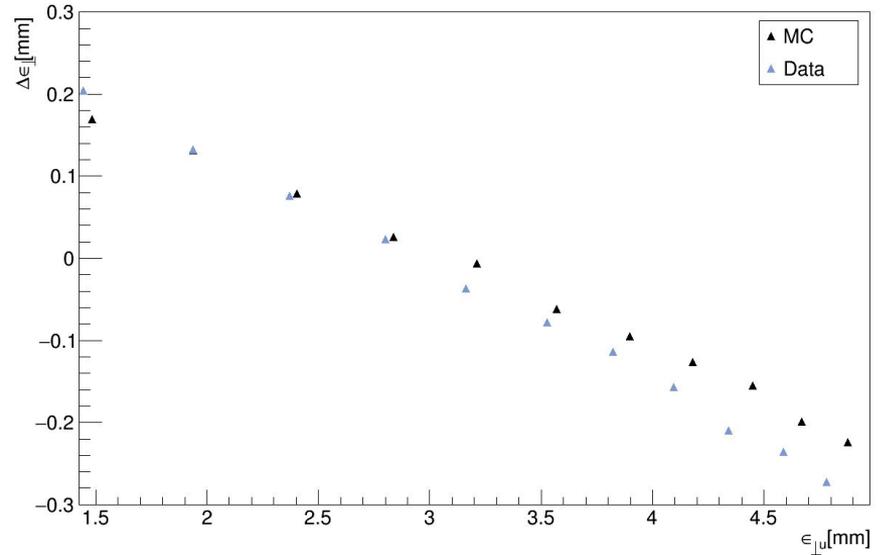
Still scope for improvement on
Data / MC agreement



Emittance change



No correction

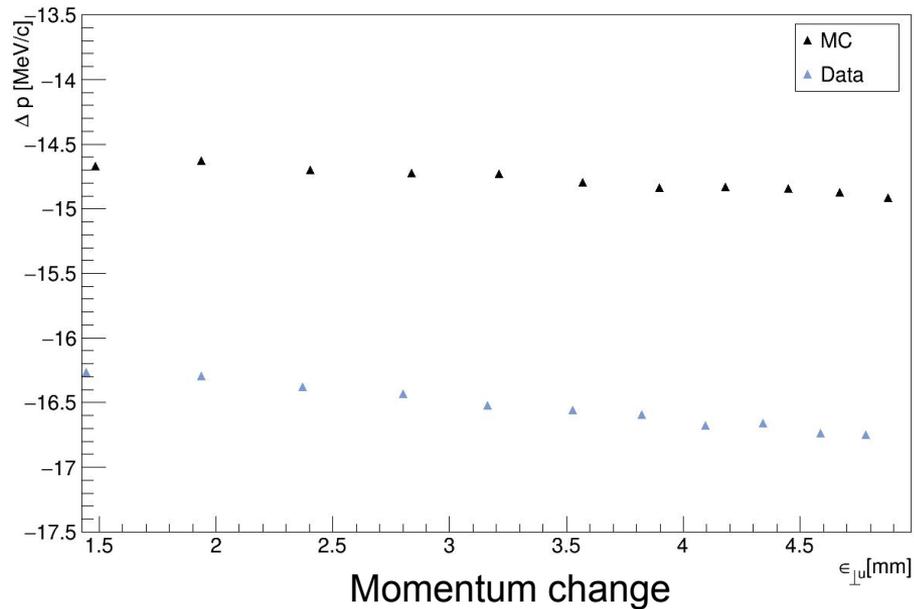
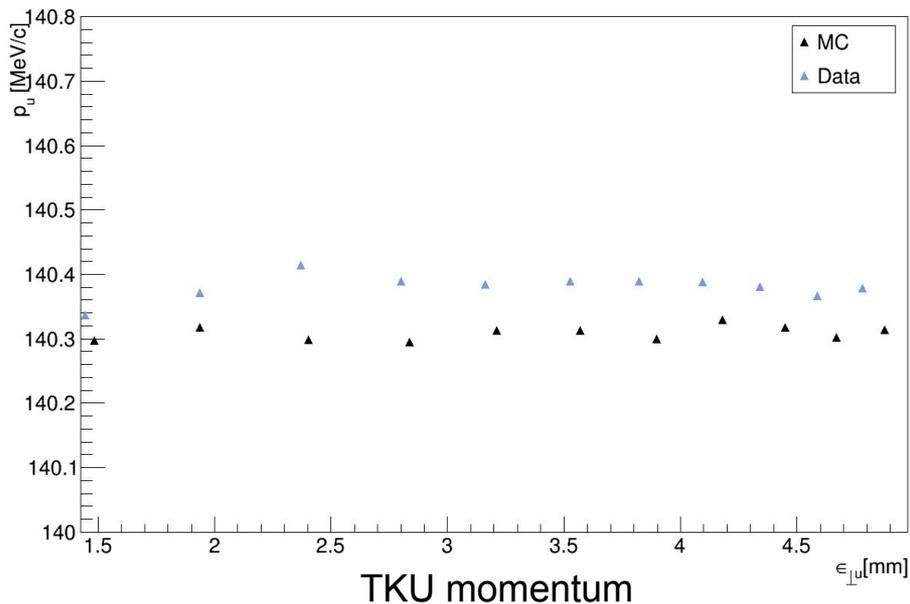


Corrected

Discrepancy still present. The initial optics discrepancy at TKU ref plane does not explain the difference in emittance growth between Data and MC.

Slightly more cooling observed in corrected data at higher emittances.

Momentum (only corrected)



Again, less momentum loss observed in MC.

Hybrid MC (Truth)

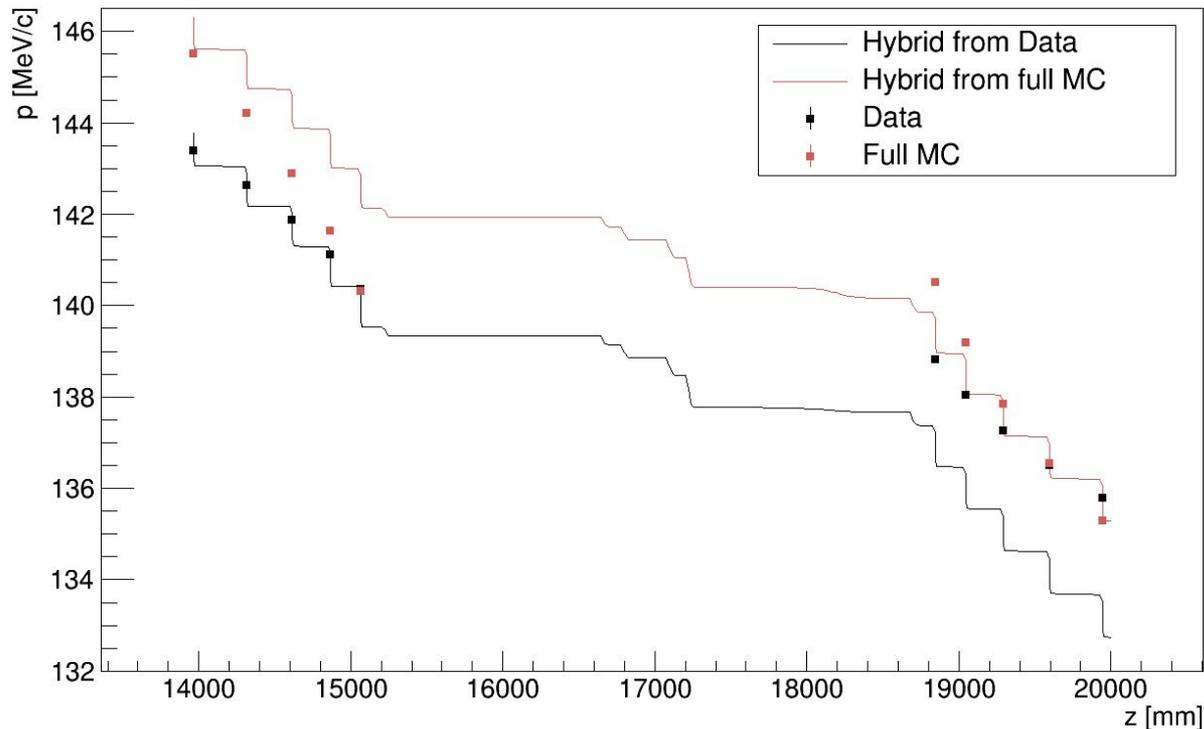
- Extracted Data and full MC parent beams at TKU5 and produced hybrid MC simulations
- Simulated 15k particles

Momentum

More energy/momentum loss at tracker stations observed in the full MC than in Data. However, while in Data the beam losses 1.6 MeV/c by passing through the vessel windows, there is no loss (0.2 MeV/c 'gain') in the full MC.

Also, the energy loss at *tracker stations* in the full MC is greater than the loss observed in the Hybrid MC. I am aware the glue density in the tracker stations was changed in the full MC -> are the trackers descriptions the same in CR's full MC and my Hybrid MC? YES.

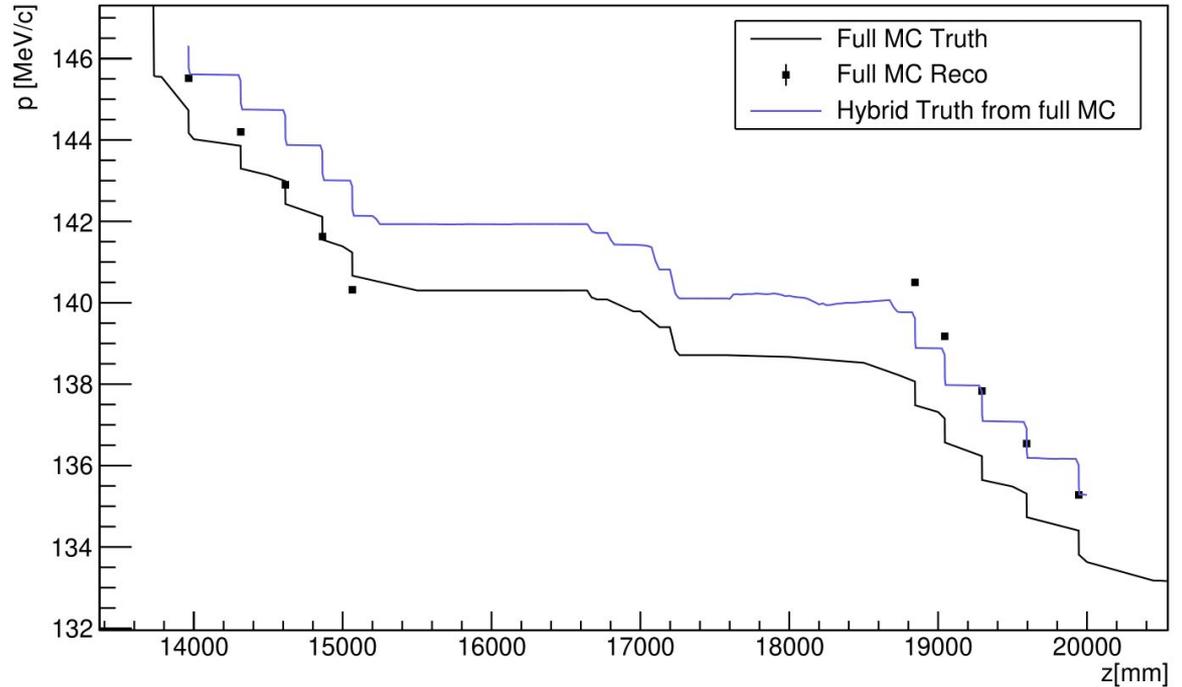
Also, the Hybrid MC observes the presence of the vessel.



Full MC: Momentum Update

Same momentum loss observed in Full MC Truth and Hybrid Truth -> geometry descriptions consistent between the two

Biased reconstruction

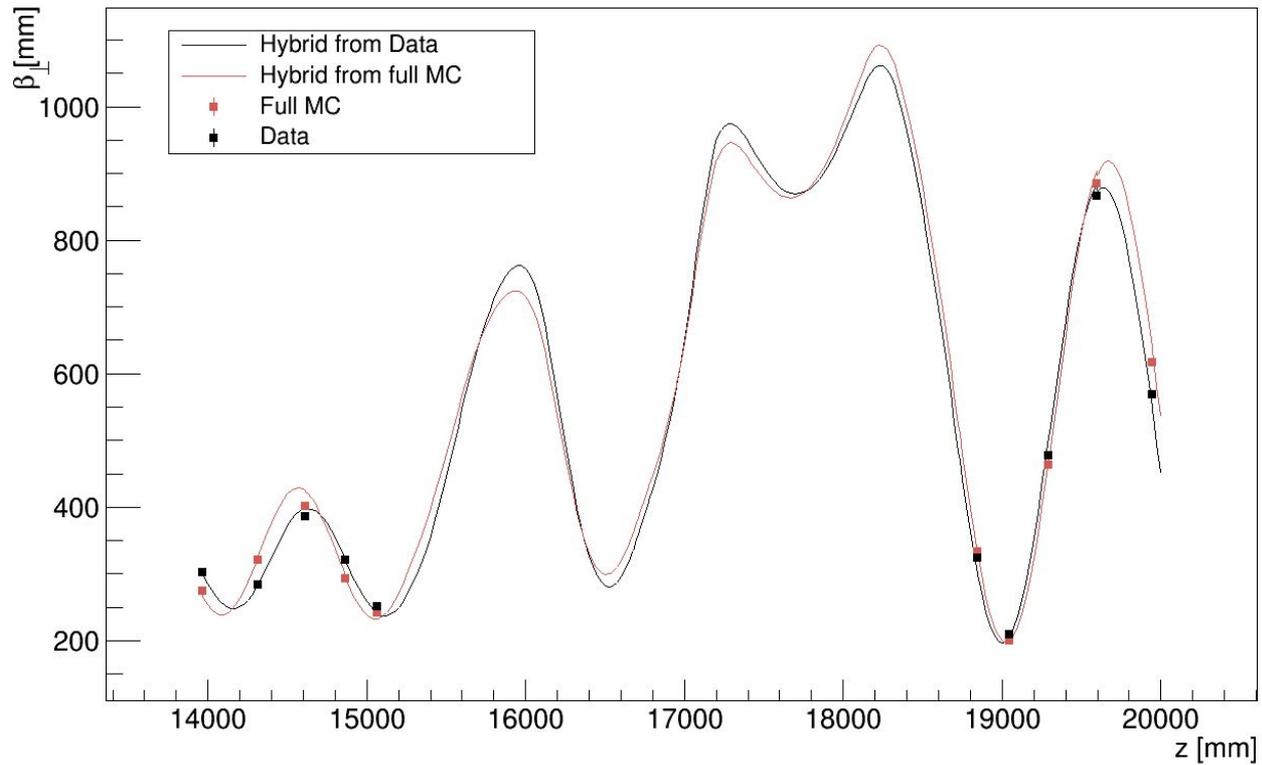


Job List

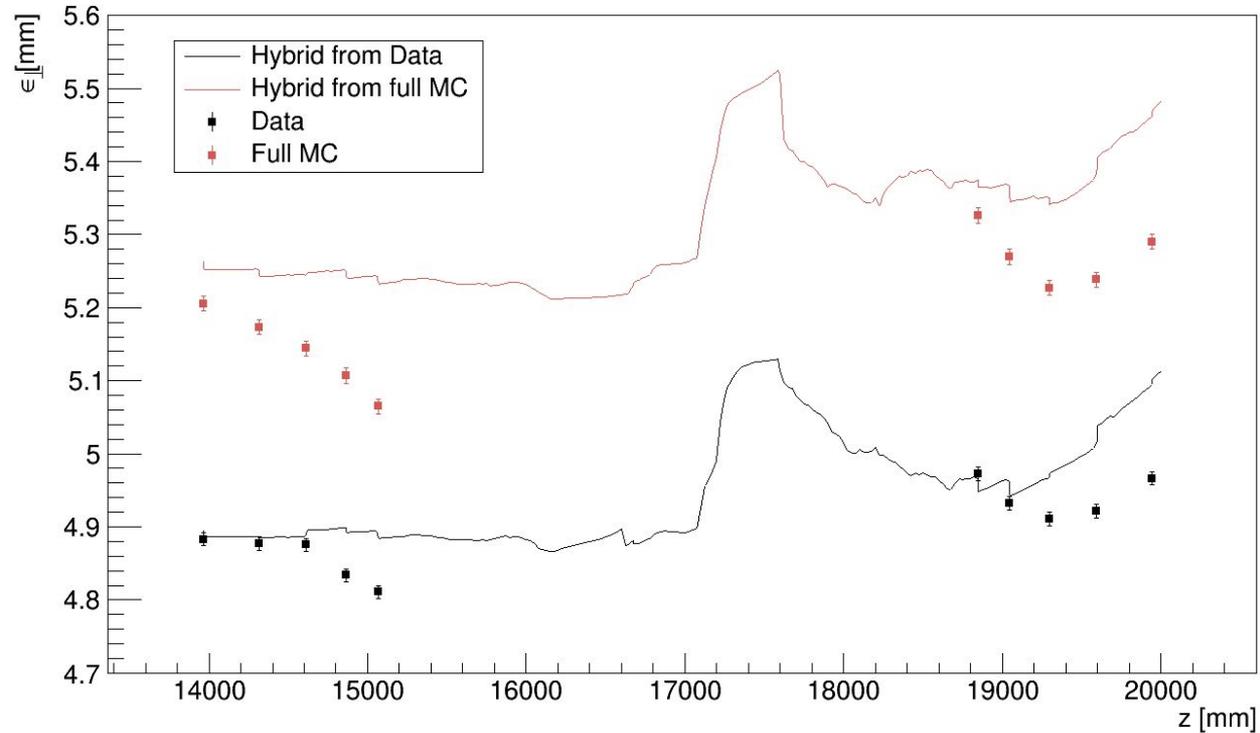
- Apply corrected optics sampling to all the analyses
- Attempt to apply alternative normalization procedure for higher statistics in the sampled beams
- DATA MC disagreement
 - look into momentum reconstruction disagreement
 - produce new MC

Backup

Betatron function



Emittance including particle losses in Hybrid MC



Full MC: Emittance Update

