



Flip mode emittance analysis

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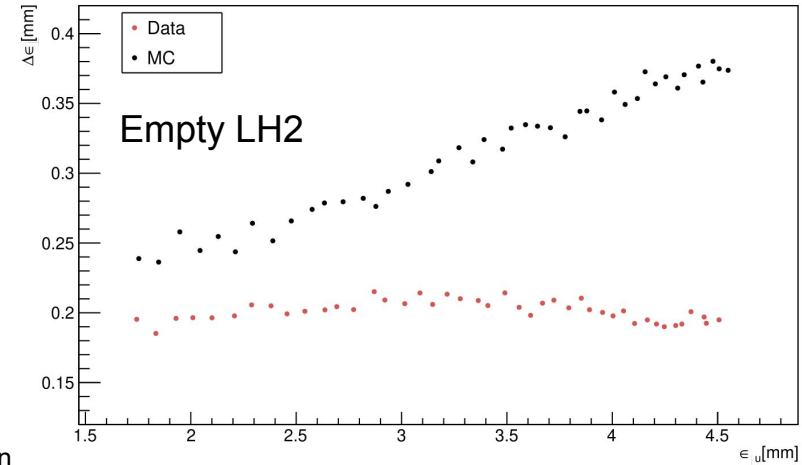
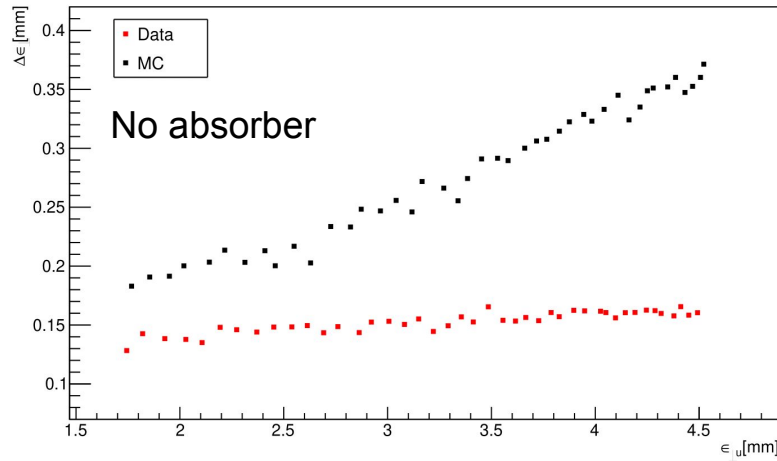
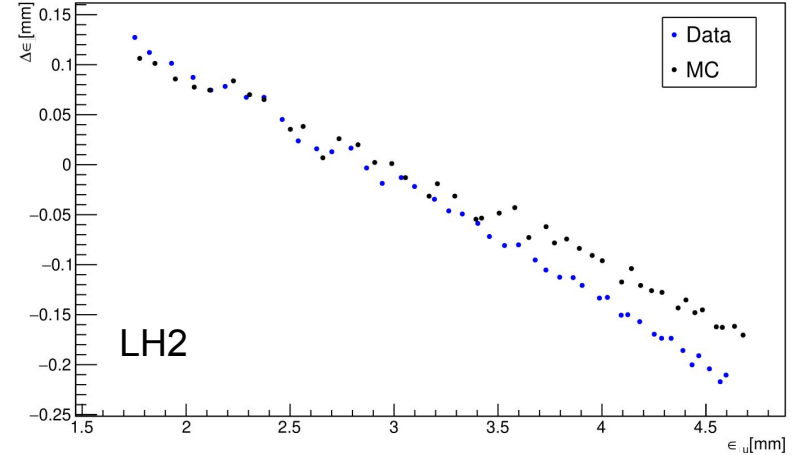
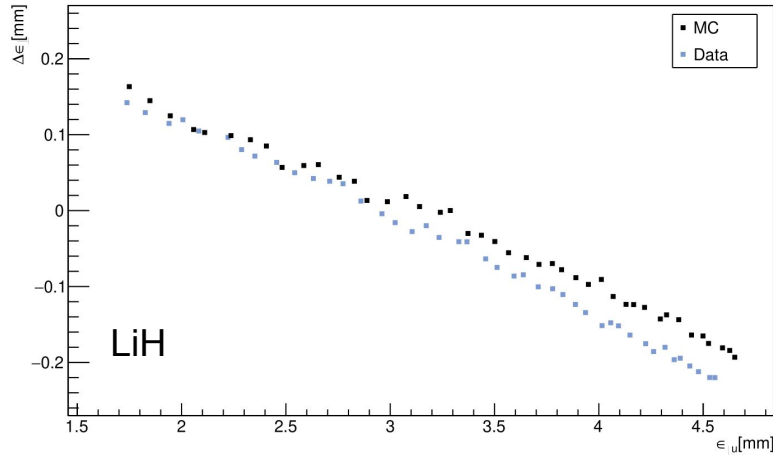
MICE Analysis Workshop



Overview

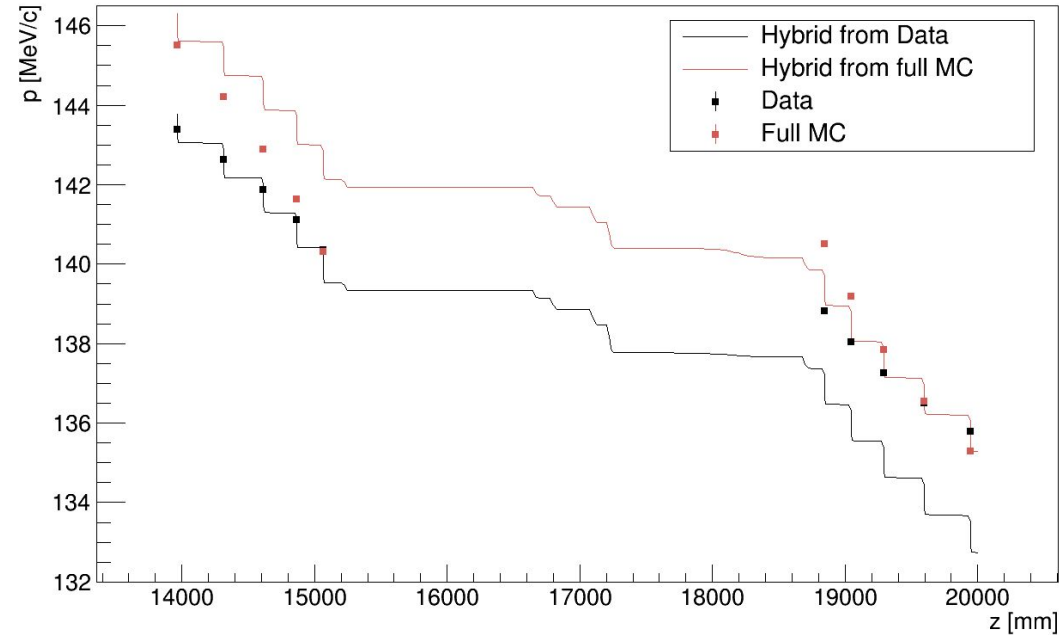
- Current status
 - Updated MC
- Outstanding issues
- Next steps

Data vs MC: Emittance change (old)



Data / MC disagreement

- large disagreements seen in *No absorber* and *Empty LH2* in the absolute emittance change
- search for potential causes revealed issues with the mean total momentum evolution in the channel: potential energy loss model discrepancy at tracker stations





MC digging

- SciFiParams_Density was the root of the problem
- it sets the density of the scintillating fibres used in the Kalman filter energy loss model
- default value in MAUS is 1.06 g/cm^3 (also used for data reconstruction in this analysis)
- in the old MC, SciFiParams_Density = 2.0 g/cm^3



MC tuning

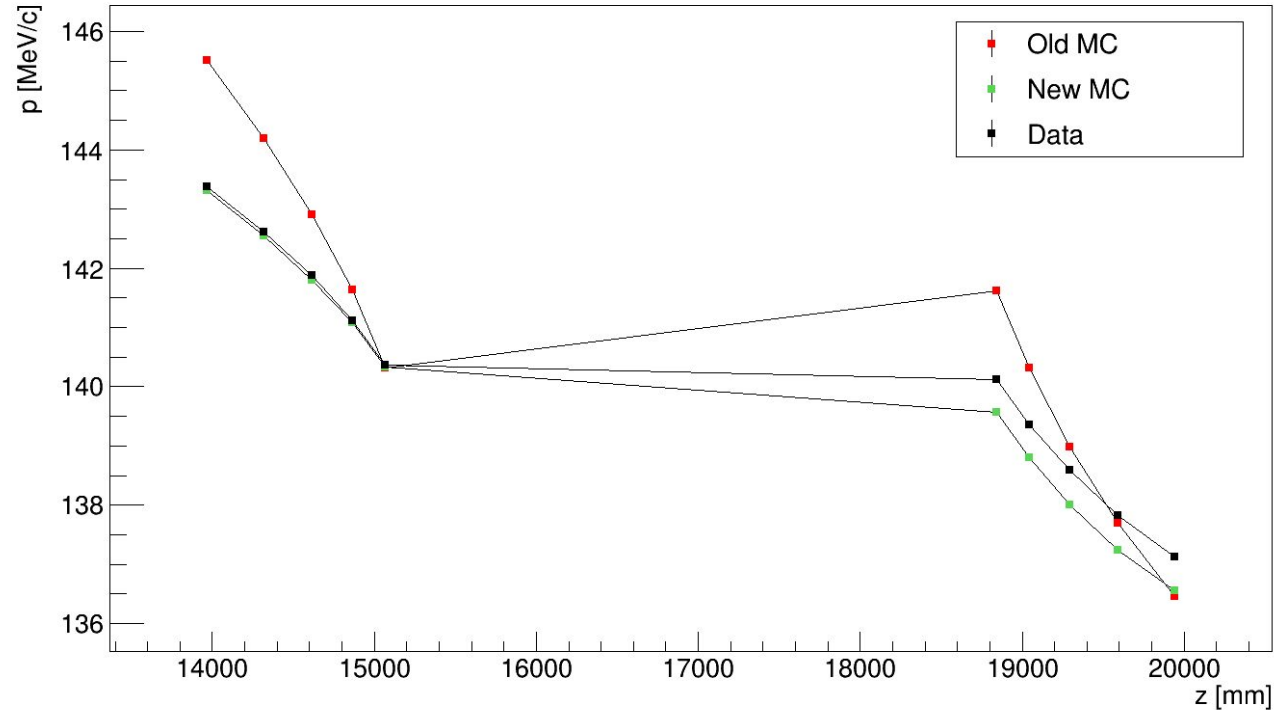
- setup a MC production routine on the IC HEP cluster
- D1, D2 dipole current tuning required to match momentum in TKU
- compromise between momentum distribution shape, momentum mean (after cuts) and x , p_x , y , p_y at TKU reference plane
- converged on the current values, but anticipate further refining needed
- produced samples for all 6-140 analyses with $\sim 125k$ particles in the parent distributions (after cuts)

Momentum evolution in trackers (NEW MC)

NO ABSORBER (NA)
case shown here

Good energy loss at
stations agreement
between data and new MC

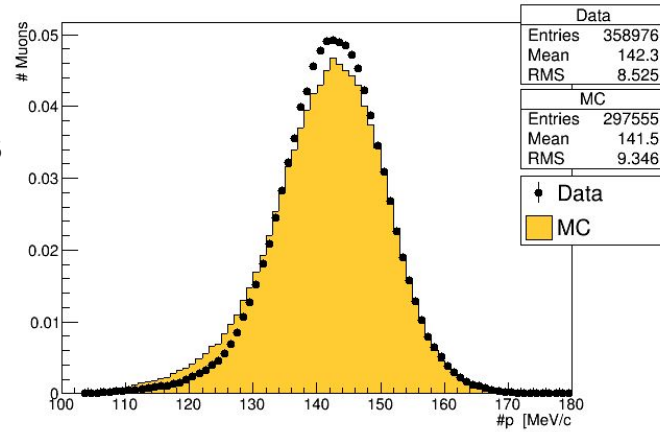
There is still a $\sim 0.2 - 0.6$
MeV/c offset in TKD,
depending on the absorber
setting



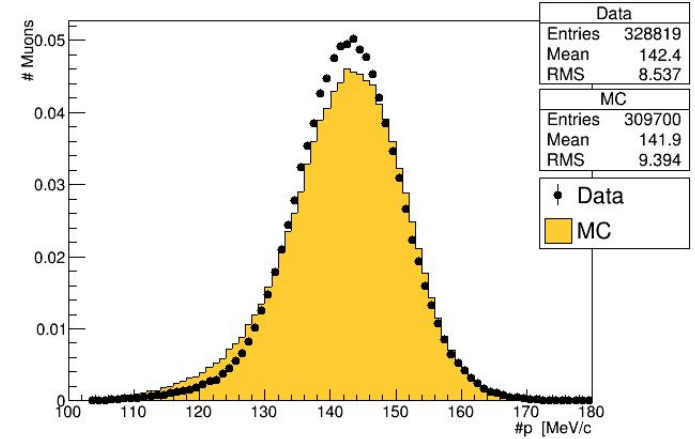


Updated MC: TKU momentum

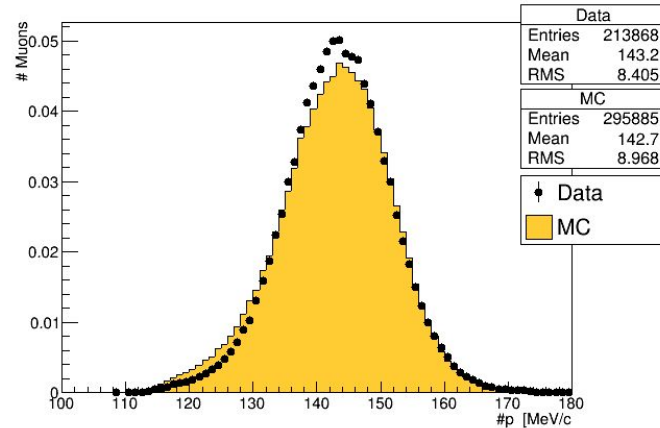
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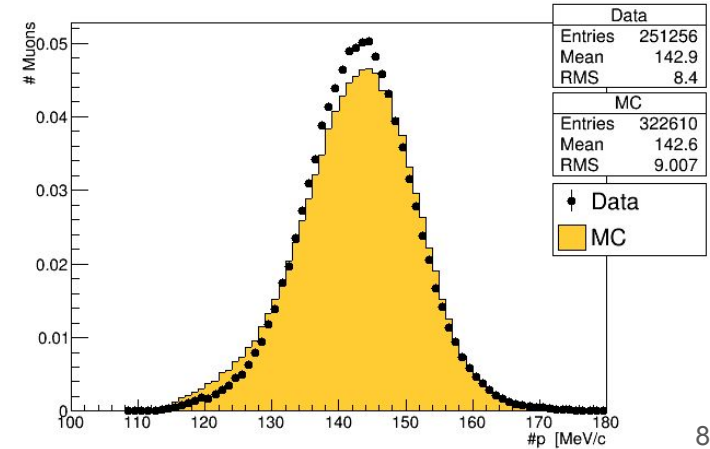
Empty LH2



LiH



LH2

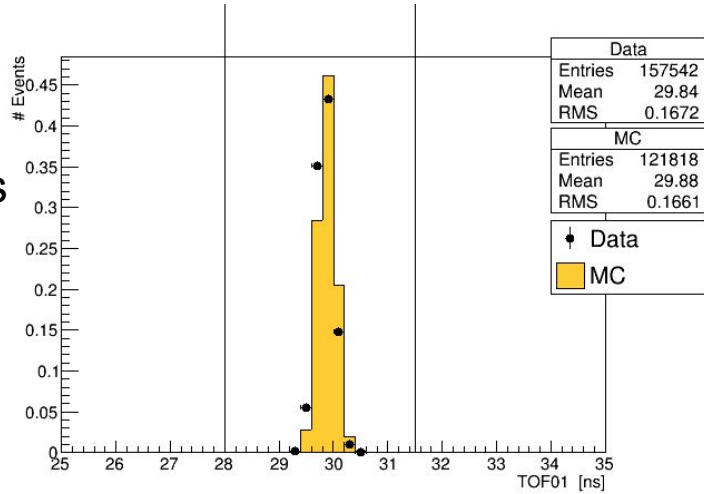




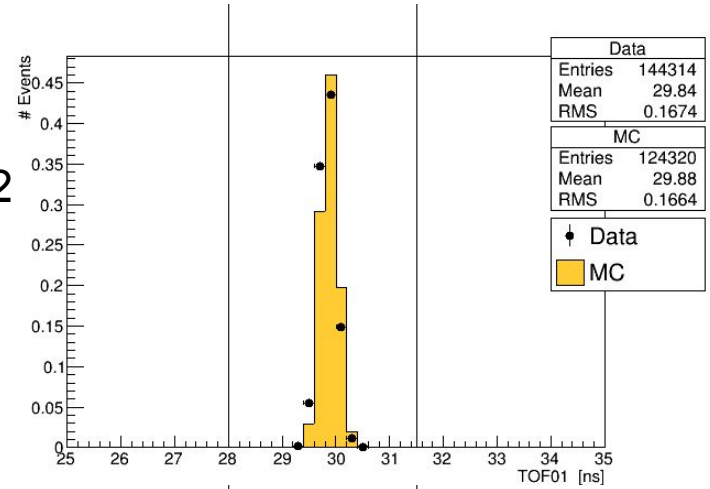
Updated MC: cuts

TOF01 time

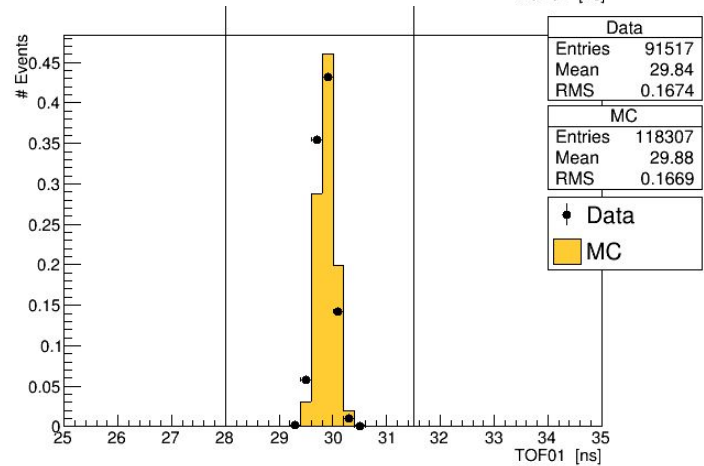
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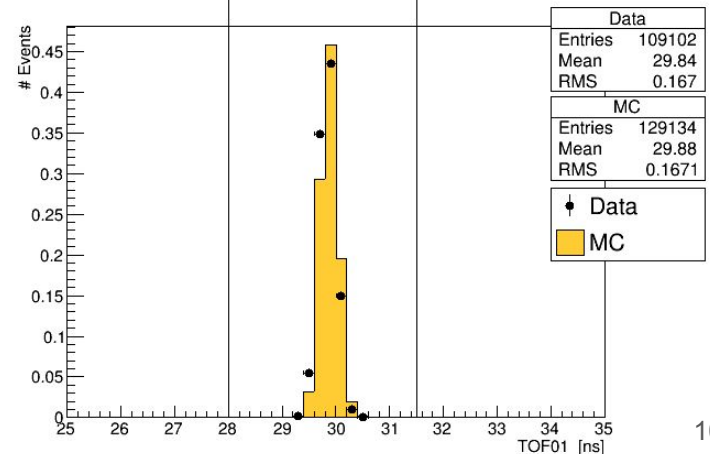
Empty LH2



LiH



LH2

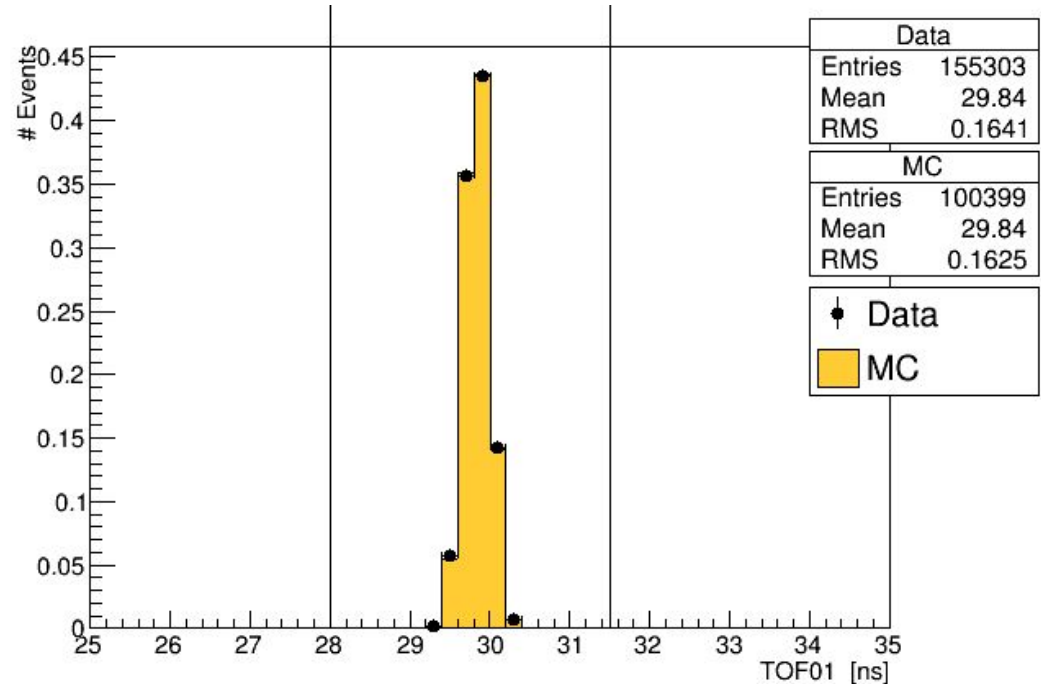


Better agreement observed with the old MC, shown here

~40ps slower muons in new MC

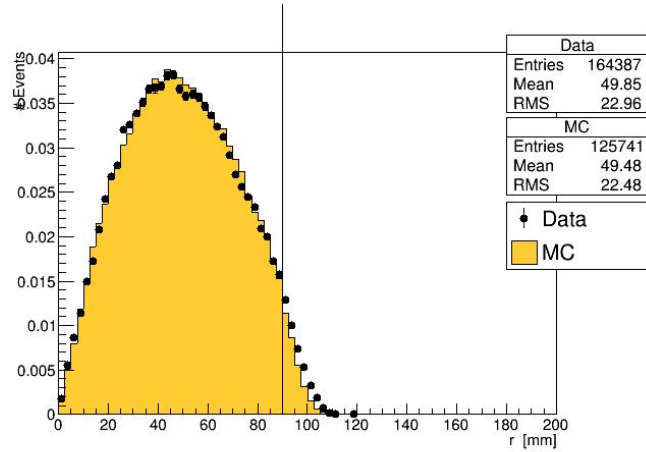
(also in simulations that had identical dipole currents)

Did not spot any differences in the configuration files between the new and old MC yet

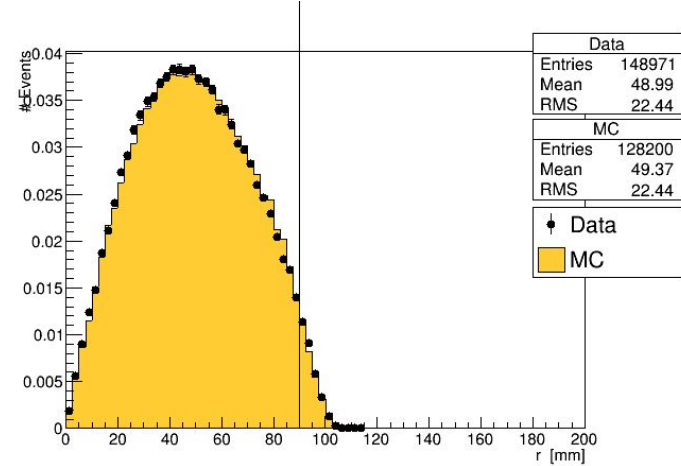


Radius at diffuser

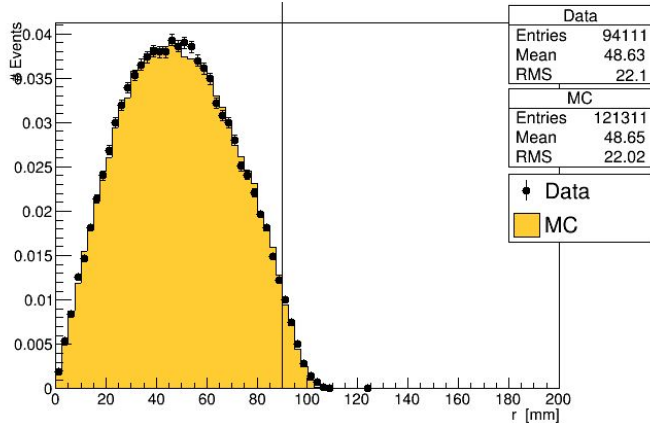
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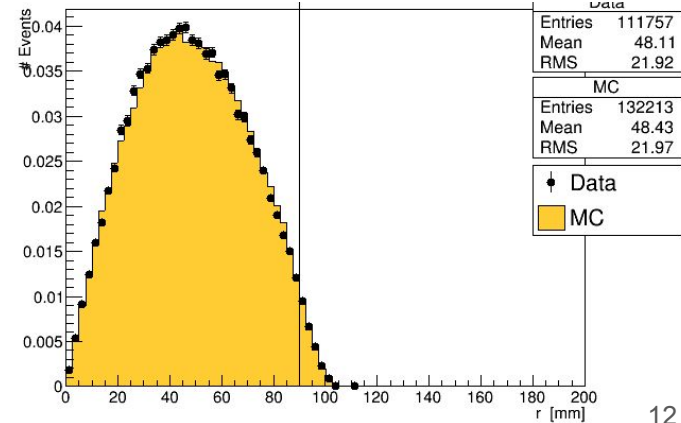
Empty LH2



LiH



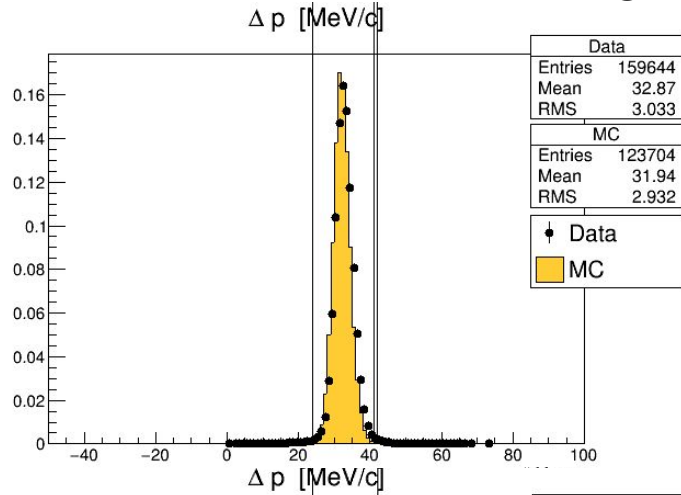
LH2



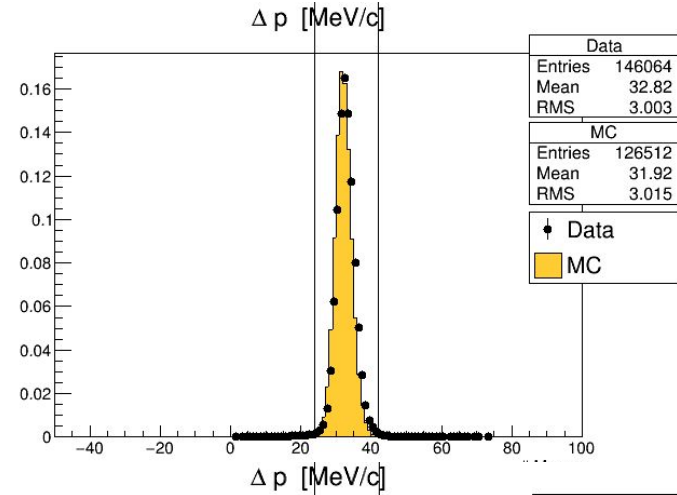


$$\rho_{\text{TOF01}} - \rho_{\text{TKU}}$$

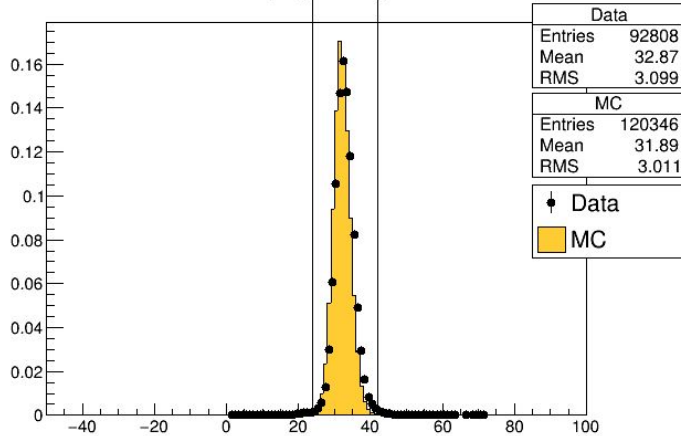
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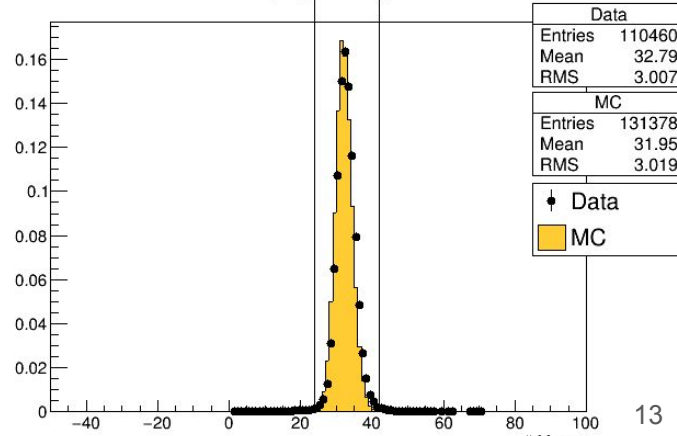
Empty LH2



LiH



LH2

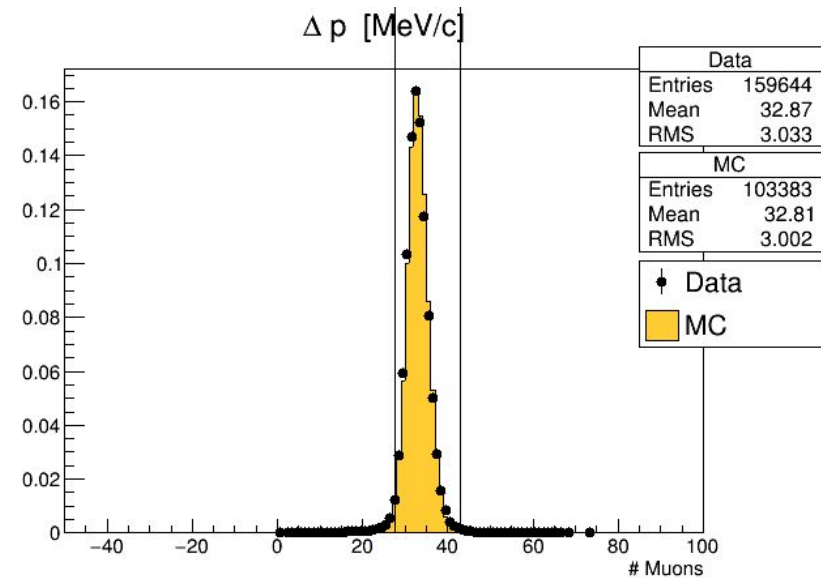


$$\rho_{TOF01} - \rho_{TKU}$$

$$\rho_{TOF01} = \frac{m_{\mu}c}{\sqrt{\frac{t_{TOF01}^2 c^2}{L_{TOF01}^2} - 1}}$$

Better agreement with old MC, shown here

~ 1 MeV/c discrepancy in new MC corresponding to the 40ps discrepancy in the time of flight

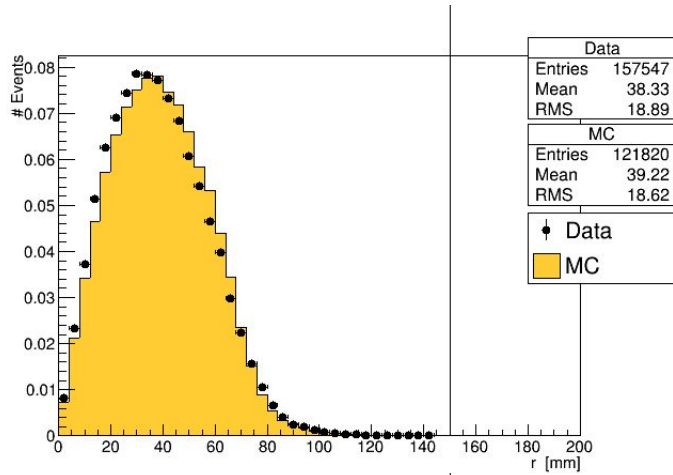


Old MC (No absorber)

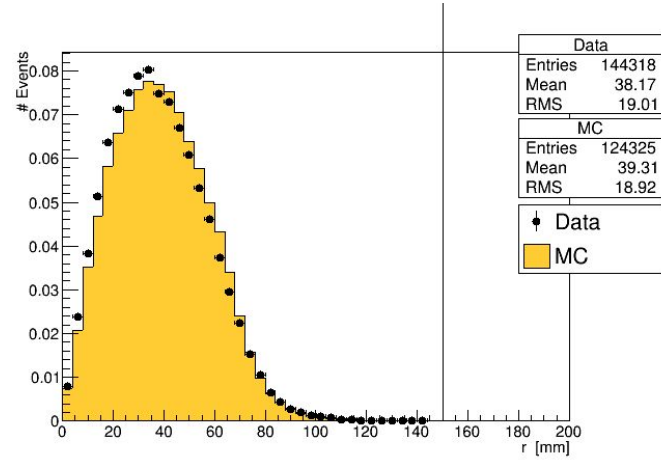


TKU fiducial cut

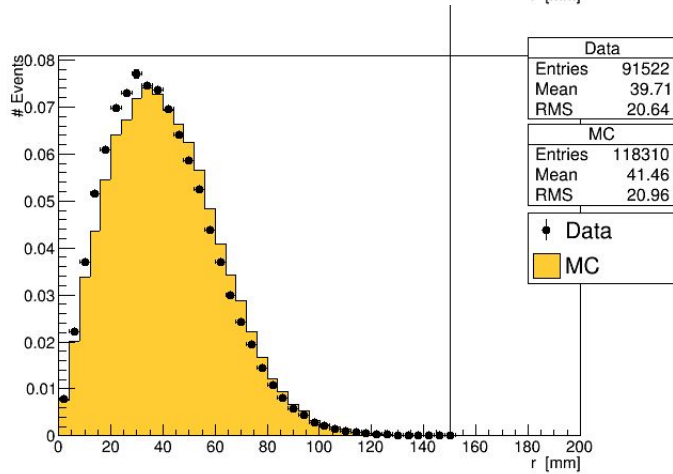
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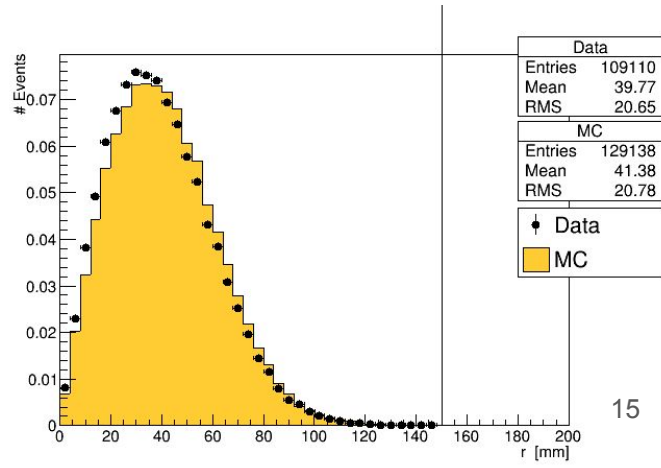
Empty LH2



LiH



LH2

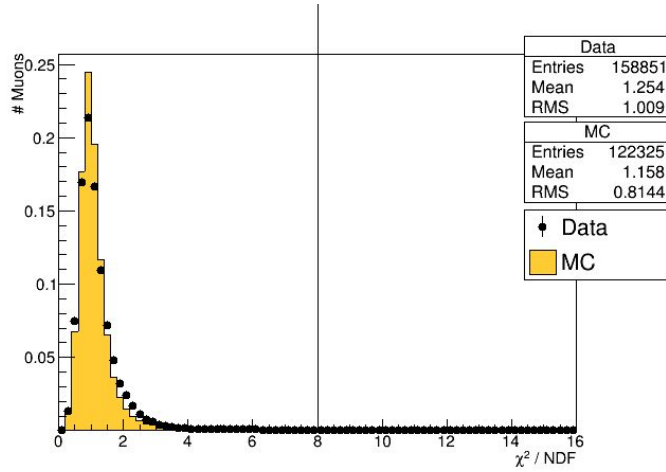


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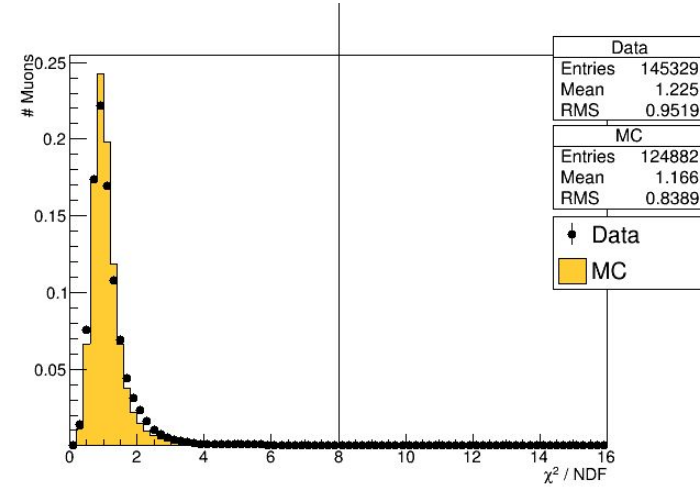


χ^2 / ndf TKU

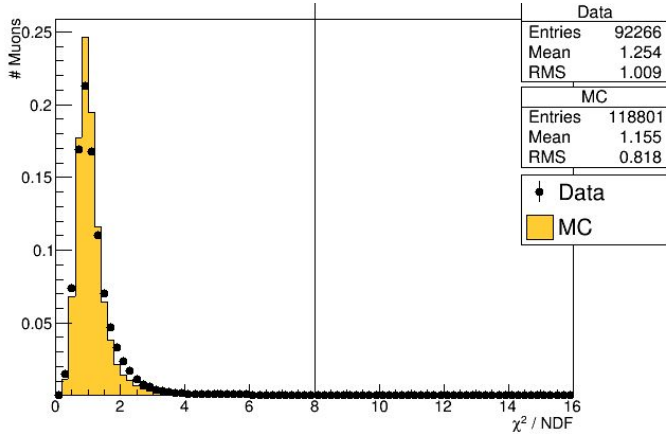
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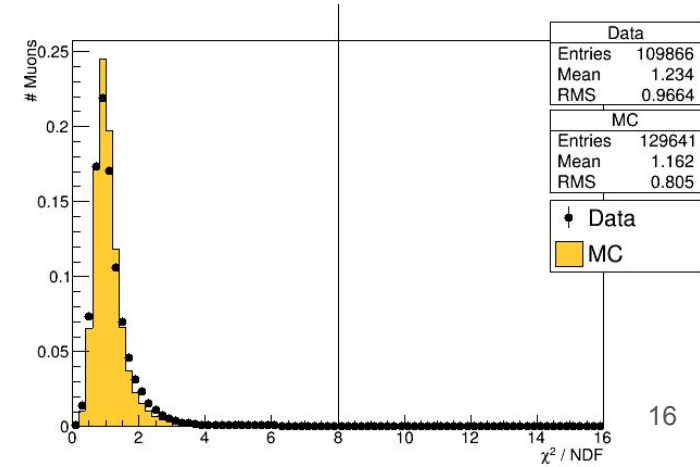
Empty LH2



LiH



LH2

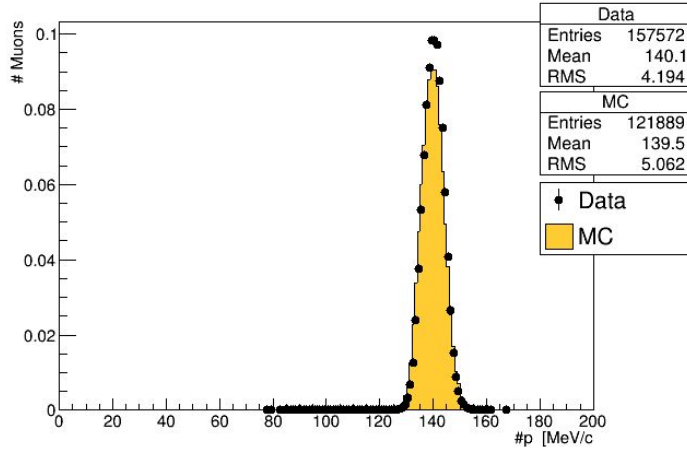


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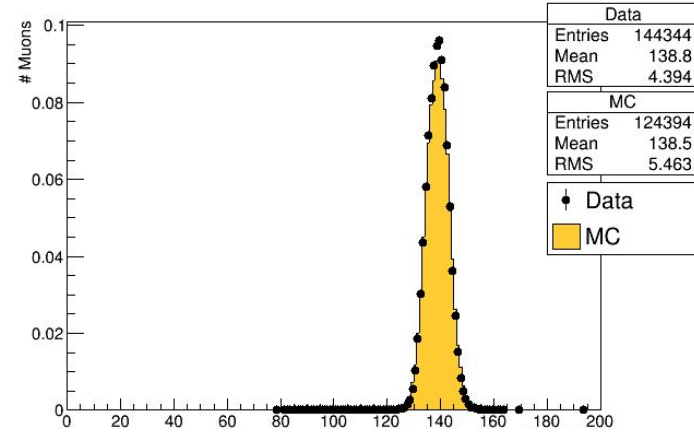


TKD momentum

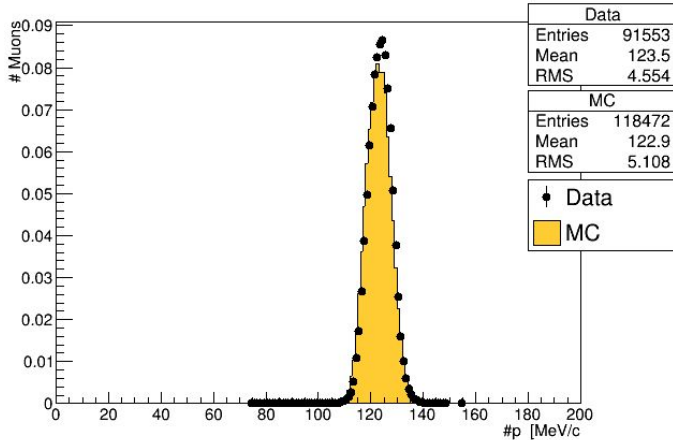
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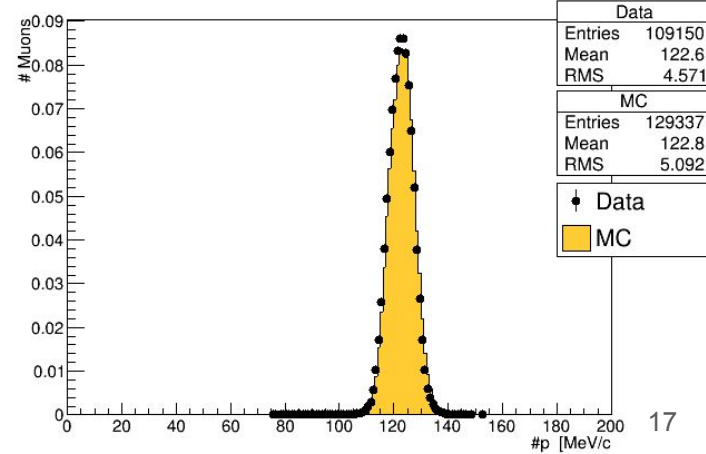
Empty LH2



LiH



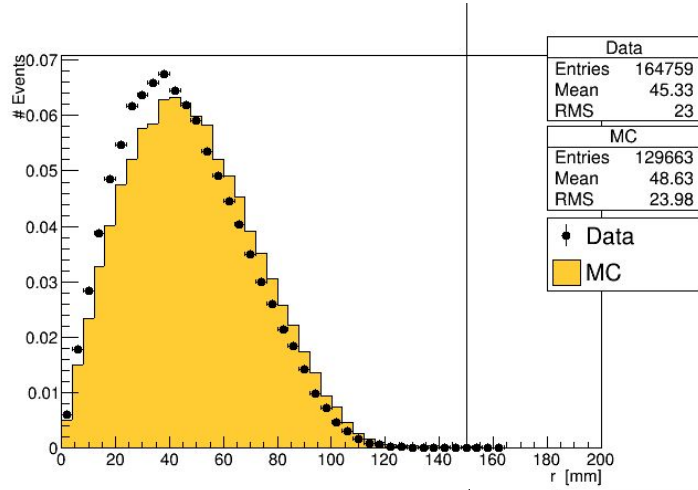
LH2



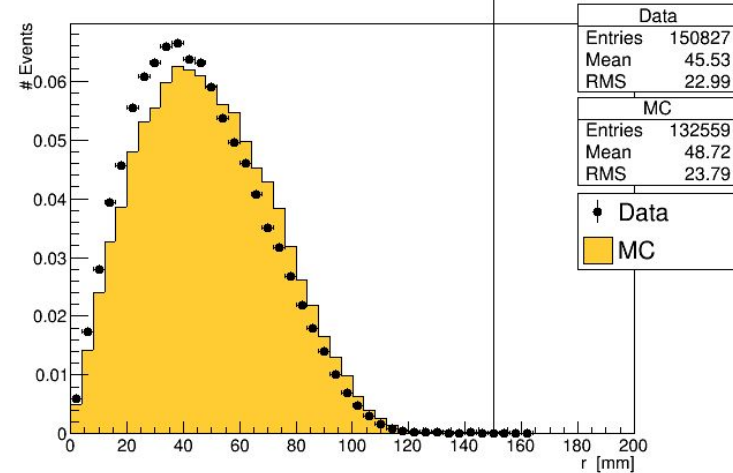


TKD fiducial cut

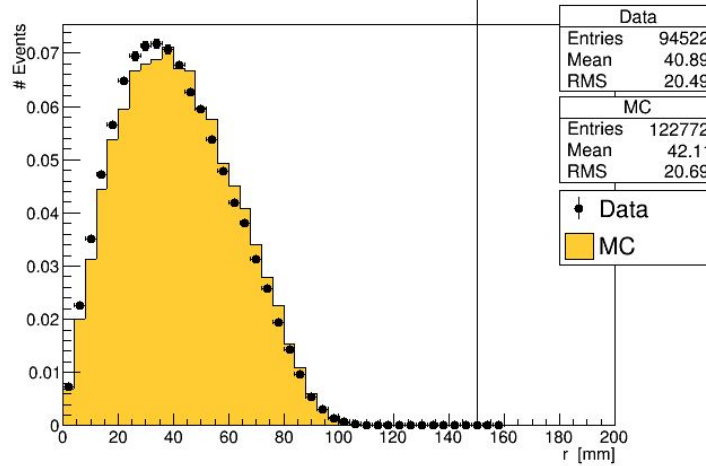
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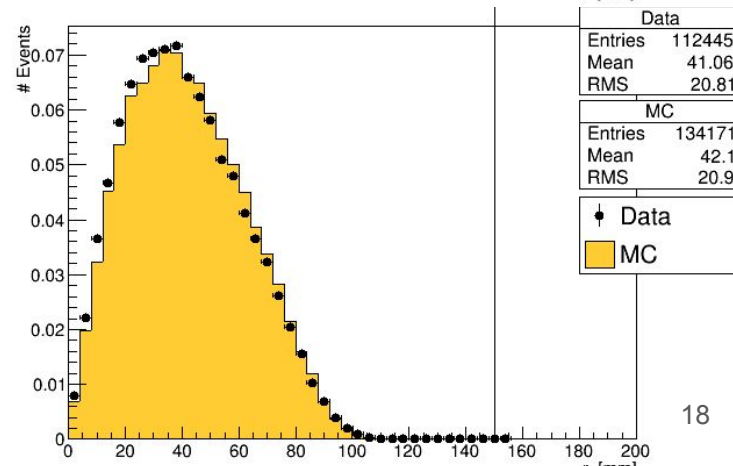
Empty LH2



LiH



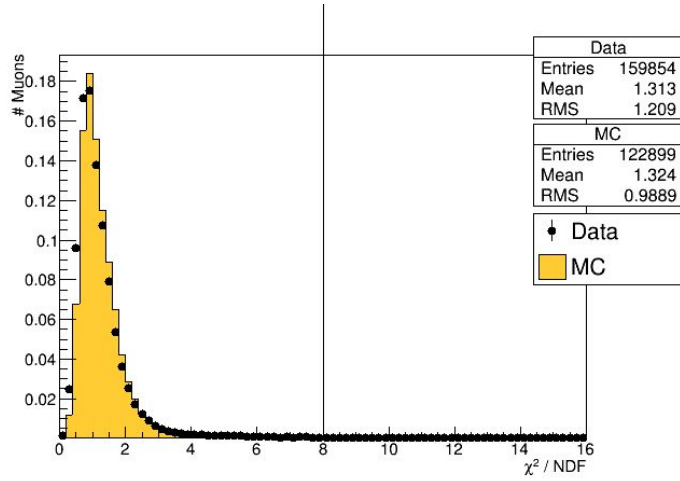
LH2



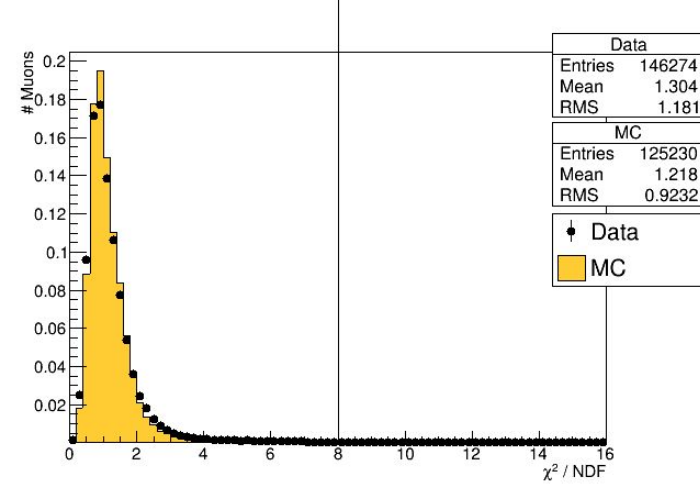


χ^2 / ndf TKD

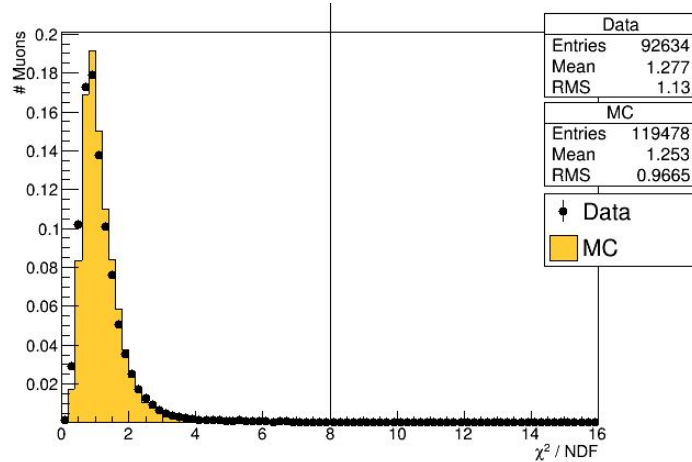
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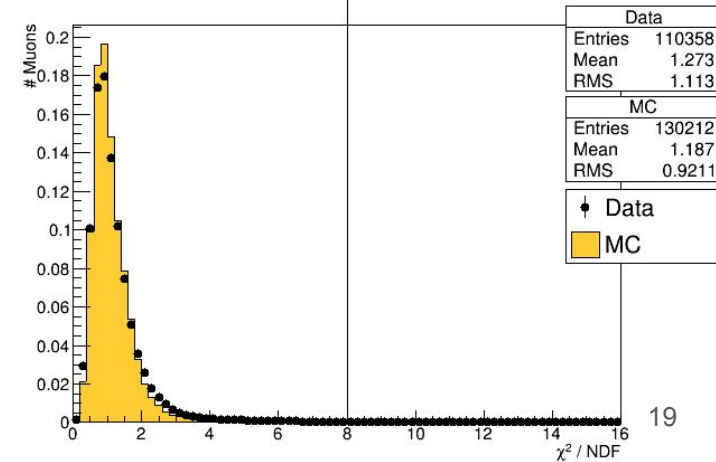
Empty LH2



LiH

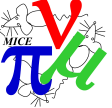


LH2



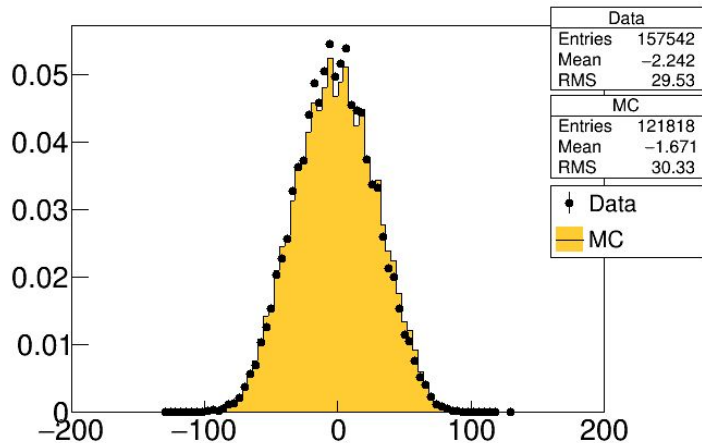


Updated MC: parent distributions phase space

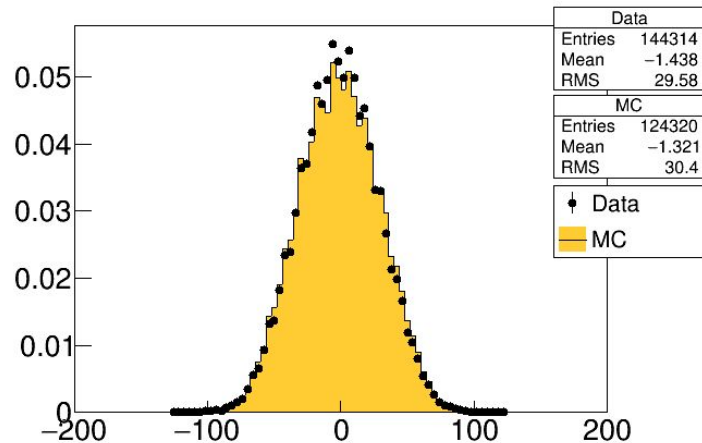


X TKU

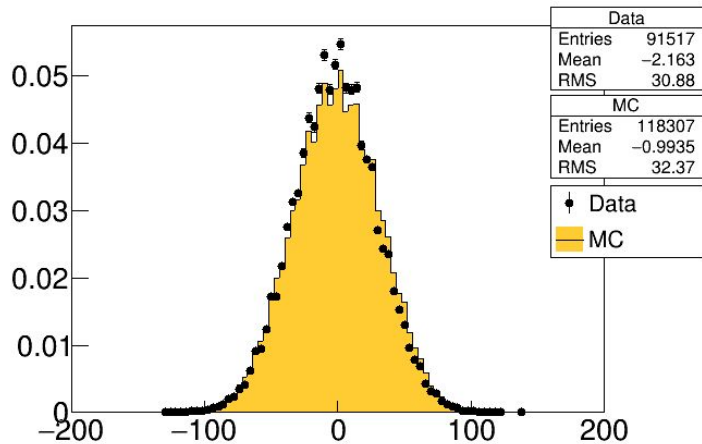
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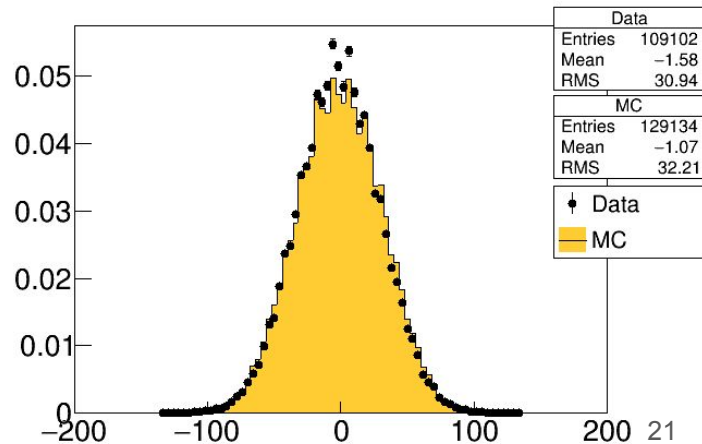
Empty LH2



LiH



LH2



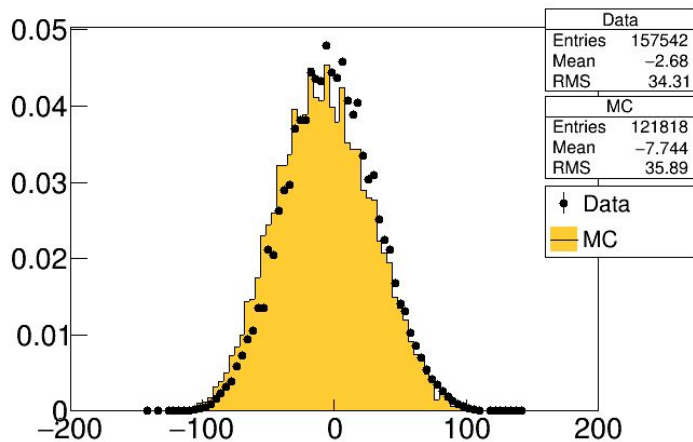
x at TKU Reference Plane [mm]

x at TKU Reference Plane [mm]

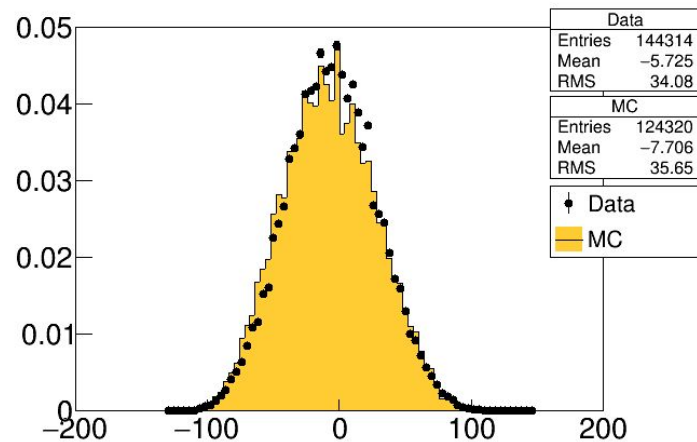


X TKD

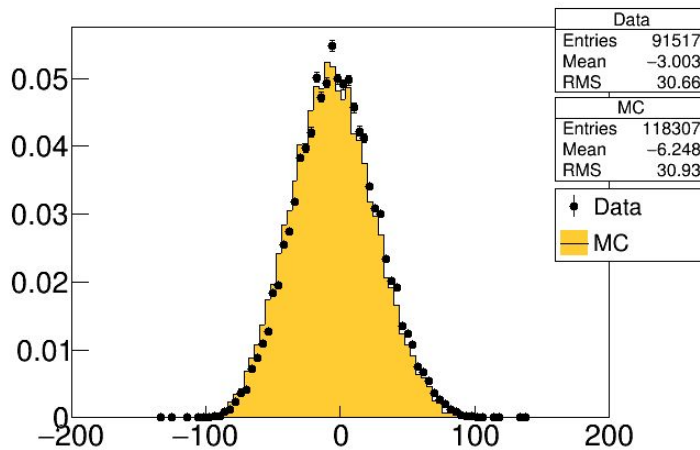
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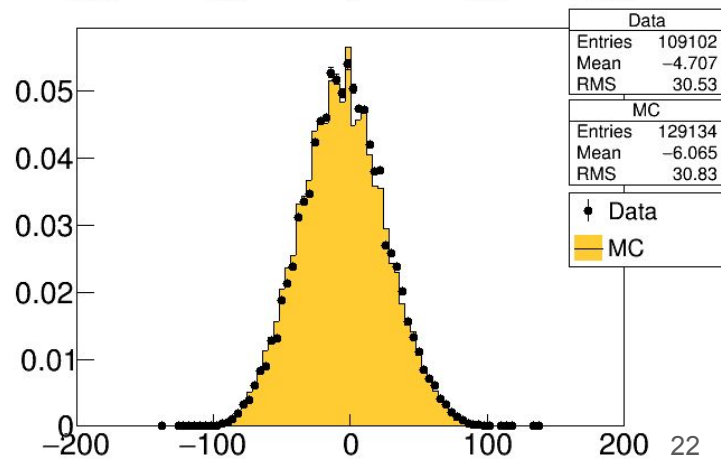
Empty LH2



LiH



LH2

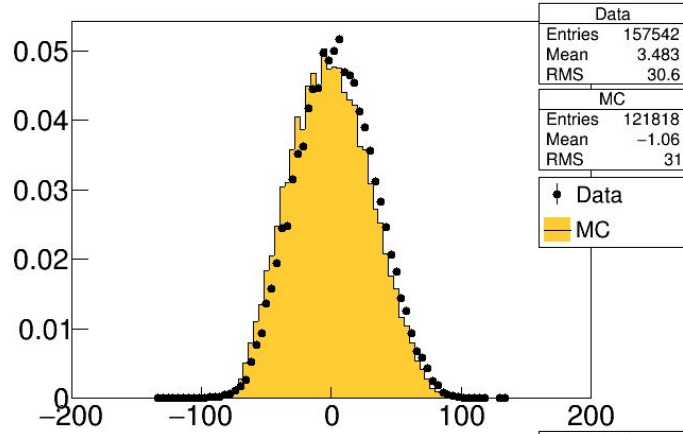


x at TKD Reference Plane [mm]

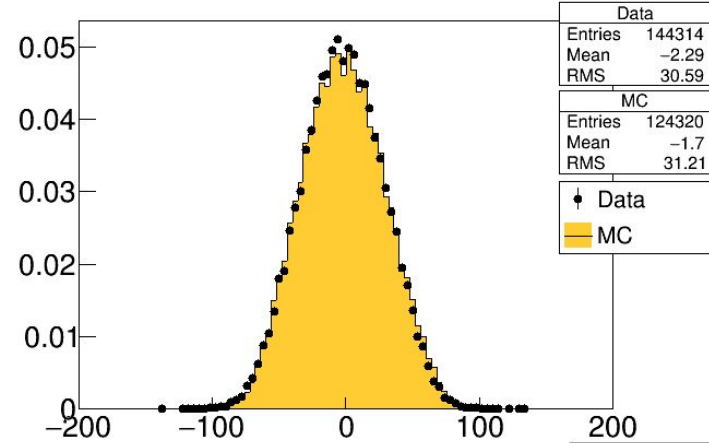
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x at TKD Reference Plane [mm]

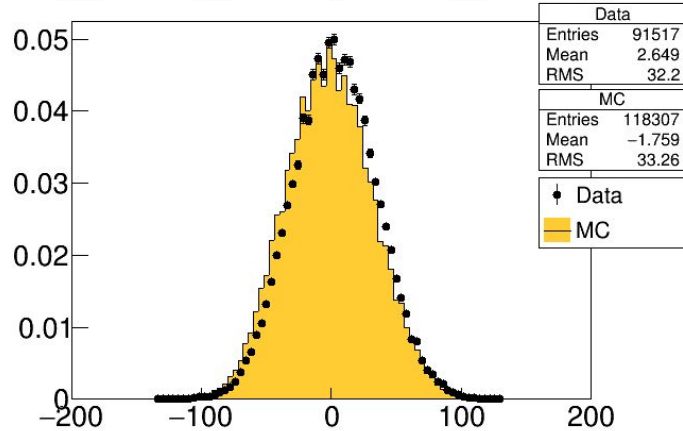
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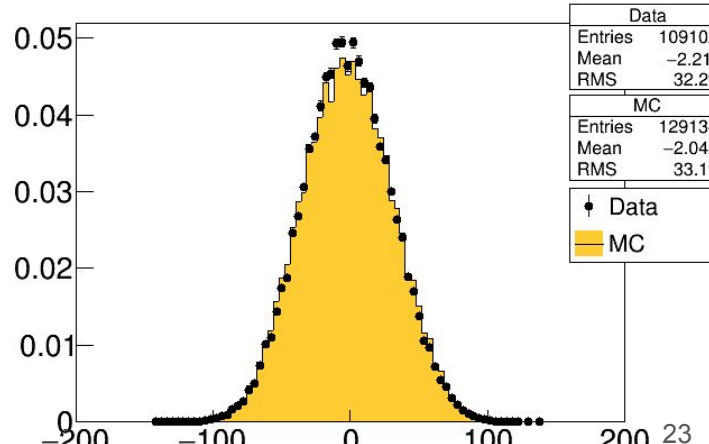
Empty LH2



LiH

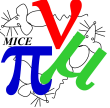


LH2



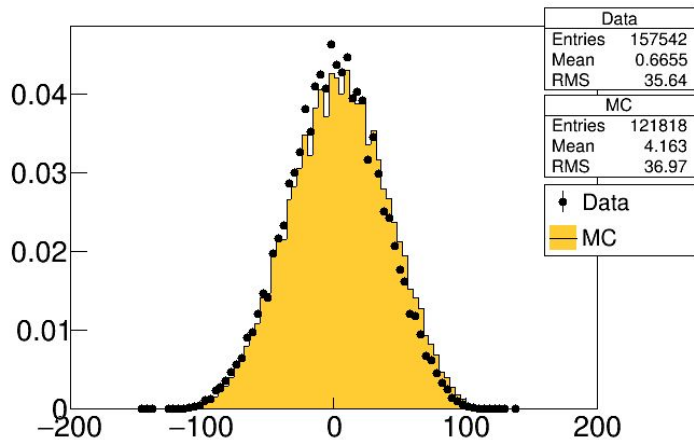
y at TKU Reference Plane [mm]

y at TKU Reference Plane [mm]

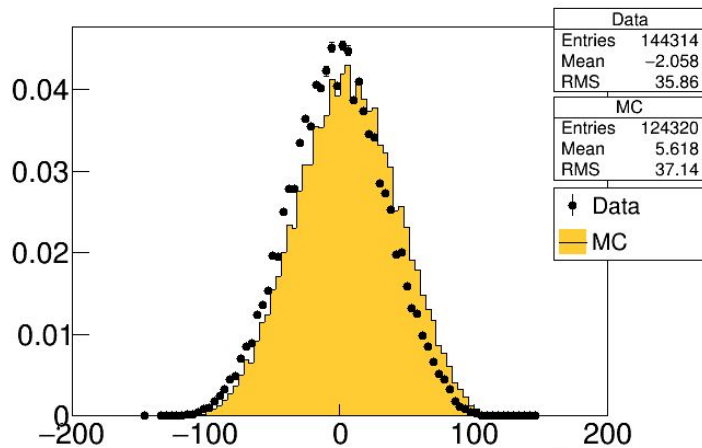


Y TKD

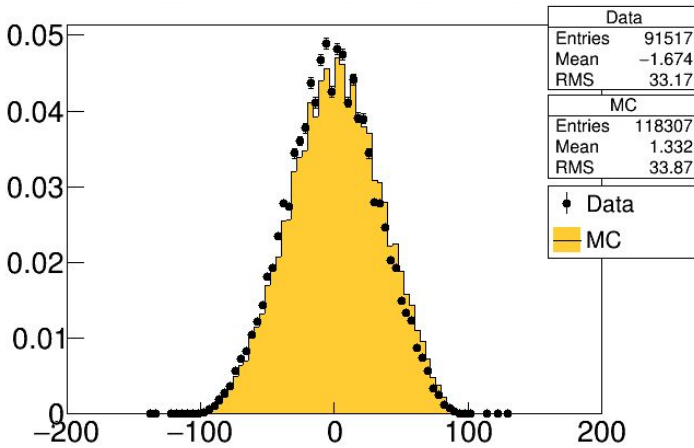
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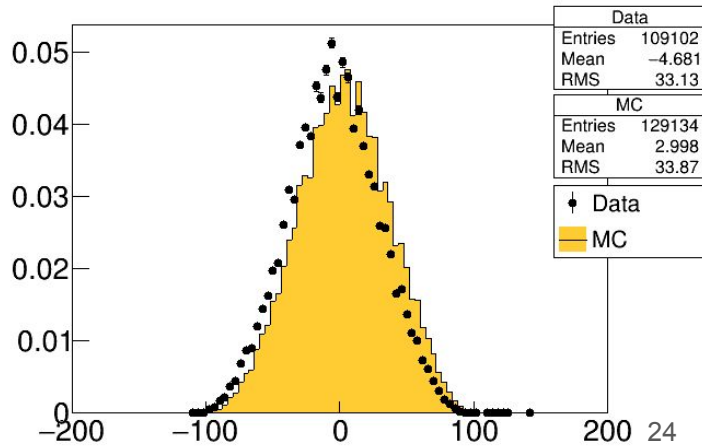
Empty LH2



LiH



LH2



y at TKD Reference Plane [mm]

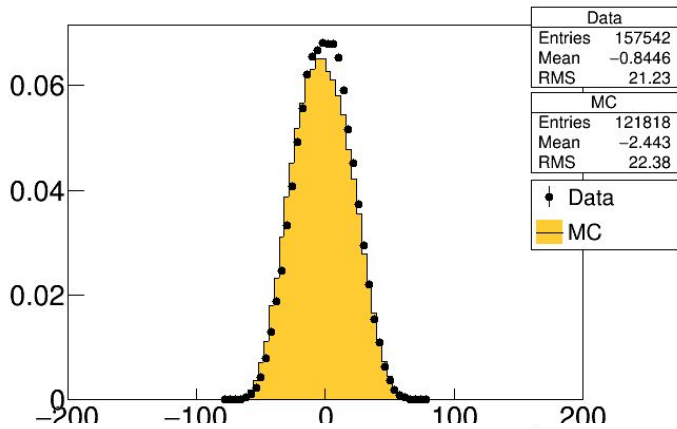
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y at TKD Reference Plane [mm]

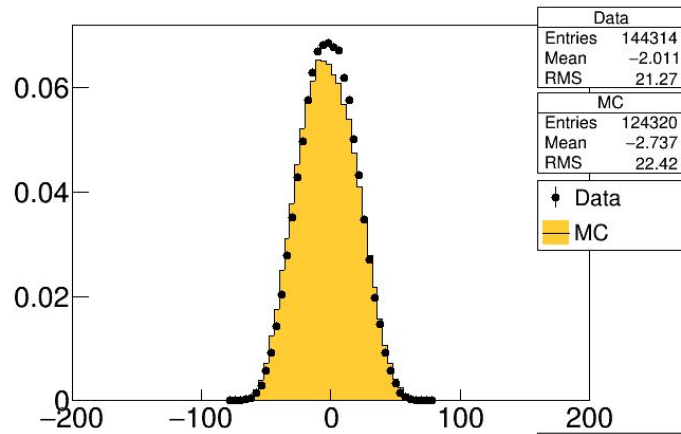


P_x TKU

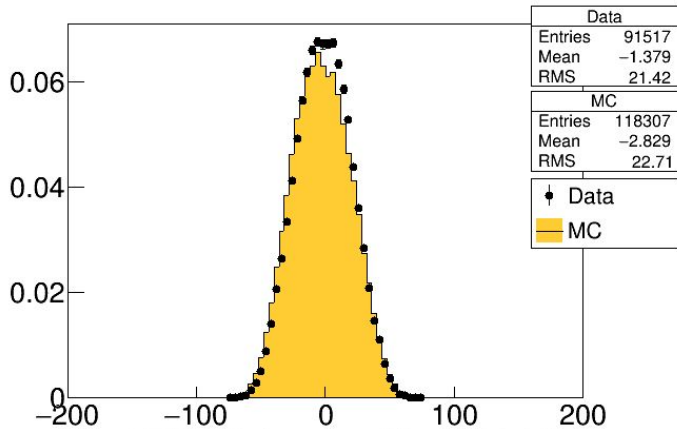
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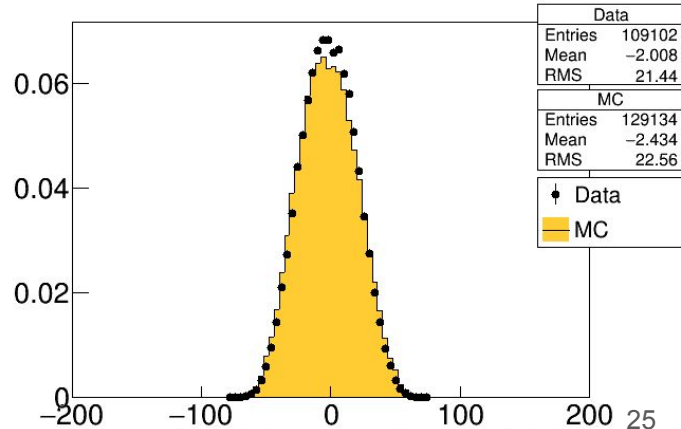
Empty LH2



LiH



LH2



p_x at TKU Reference Plane [MeV/c]

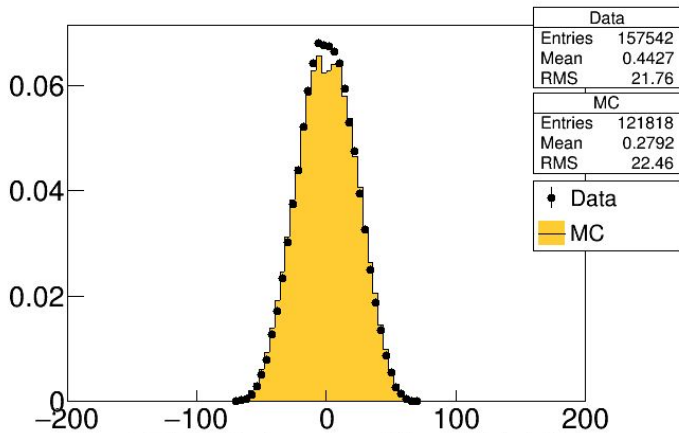
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p_x at TKU Reference Plane [MeV/c]

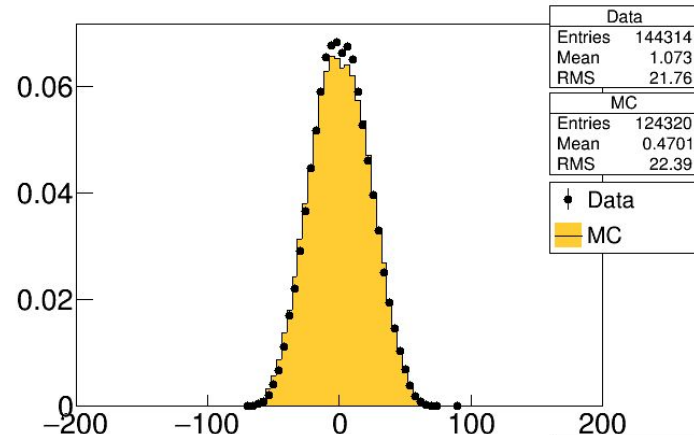


P_x TKD

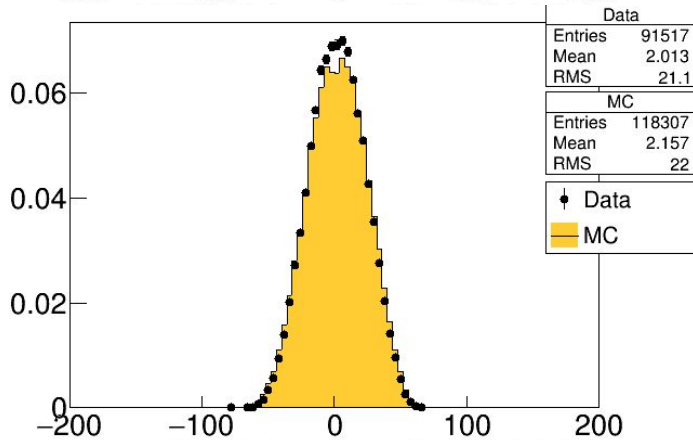
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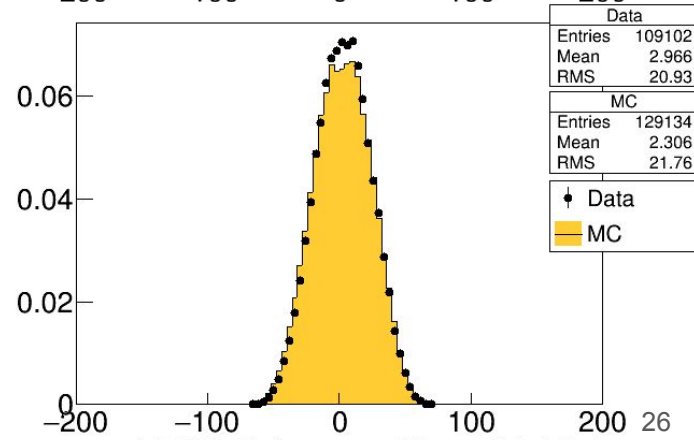
Empty LH2



LiH



LH2



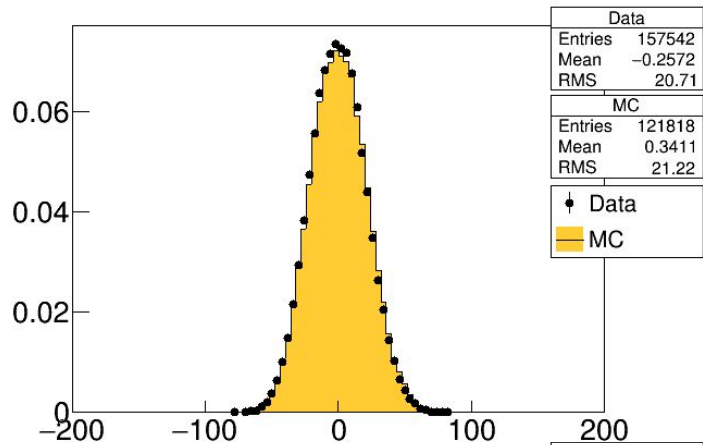
p_x at TKD Reference Plane [MeV/c]

p_x at TKD Reference Plane [MeV/c]

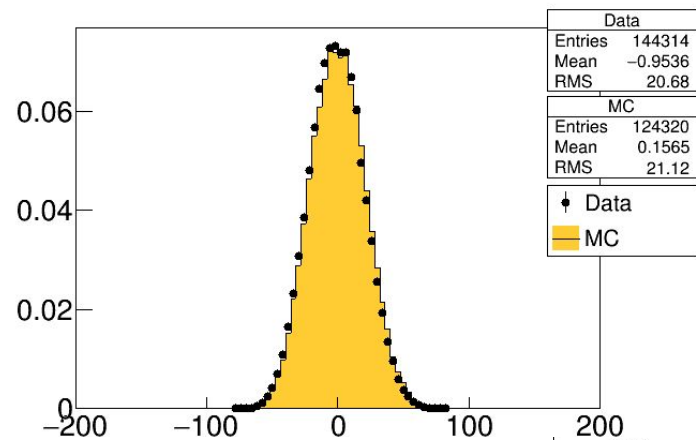


P_y TKU

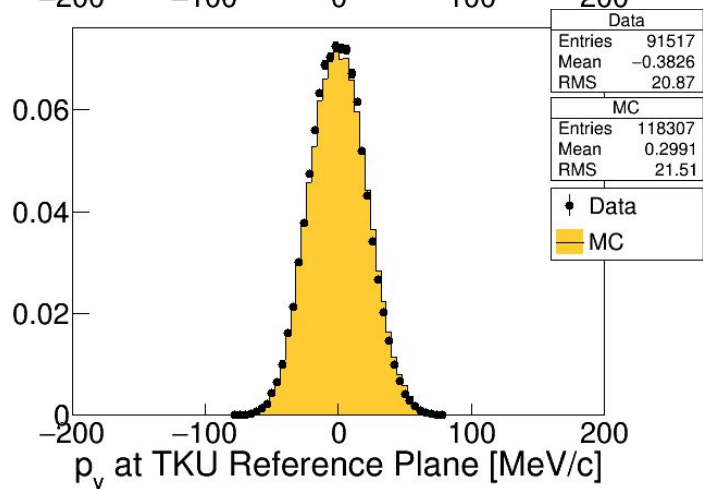
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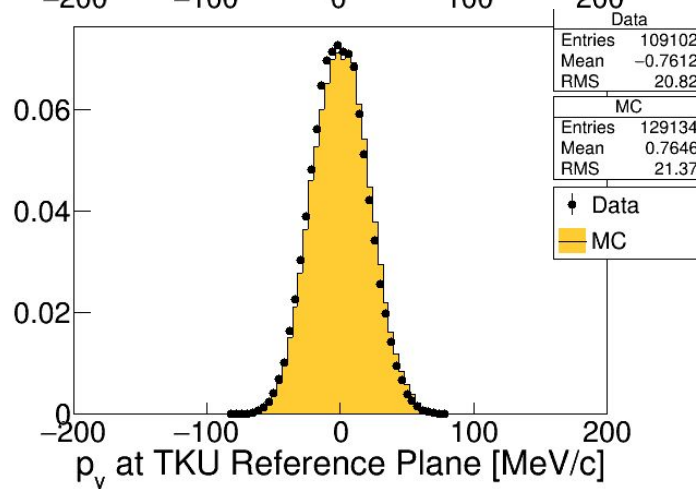
Empty LH2



LiH



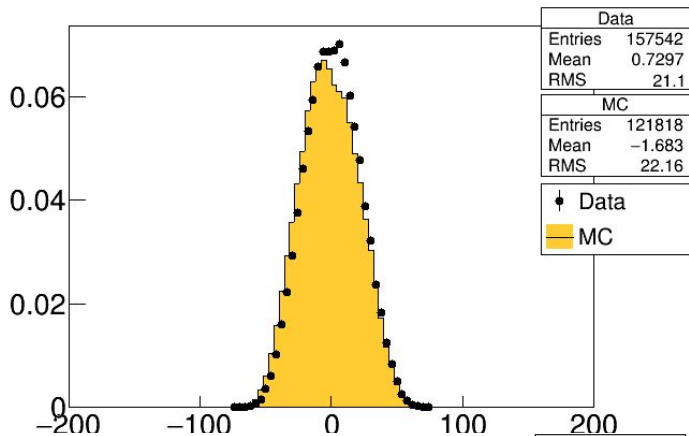
LH2



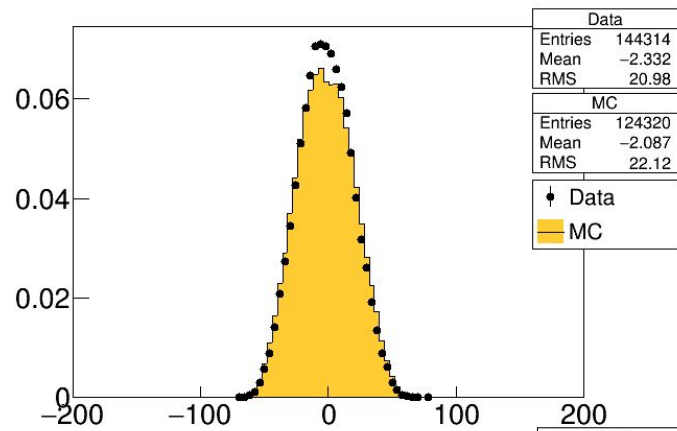


P_y TKD

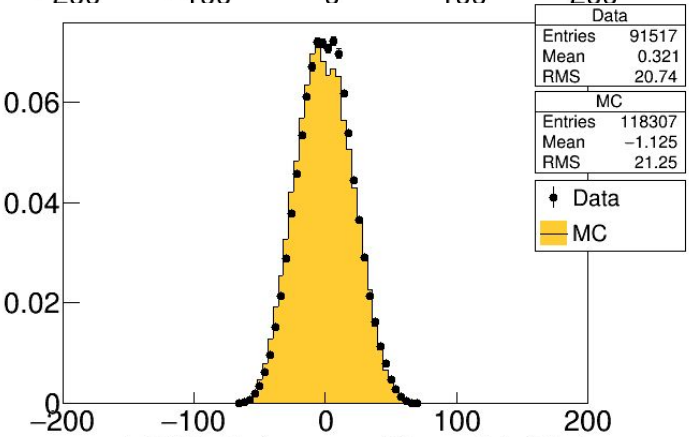
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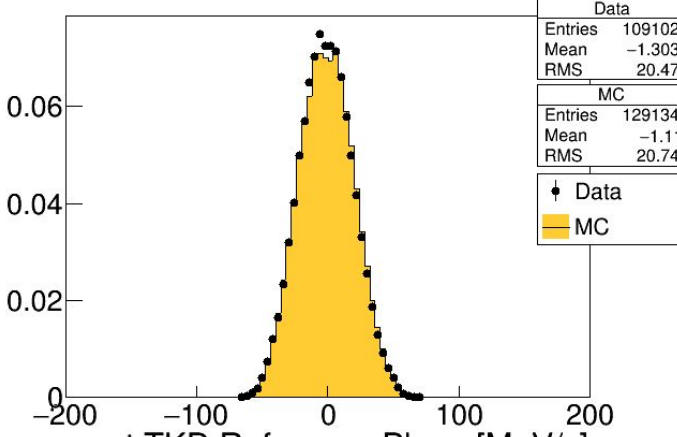
Empty LH2



LiH



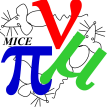
LH2



p_y at TKD Reference Plane [MeV/c]

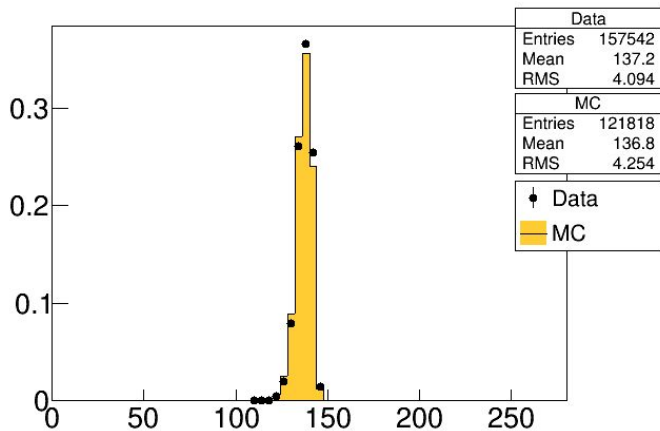
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p_y at TKD Reference Plane [MeV/c]

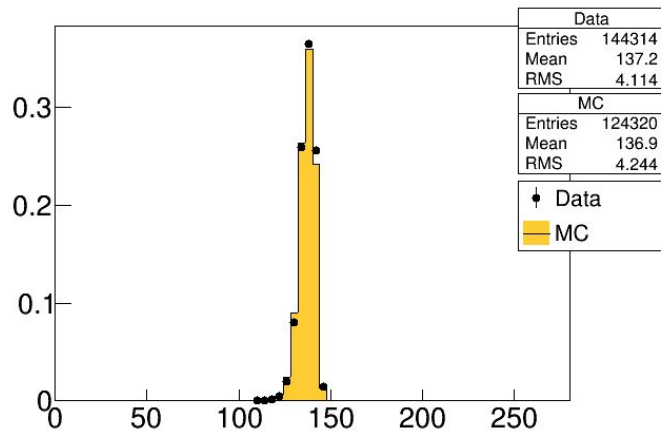


P_z TKU

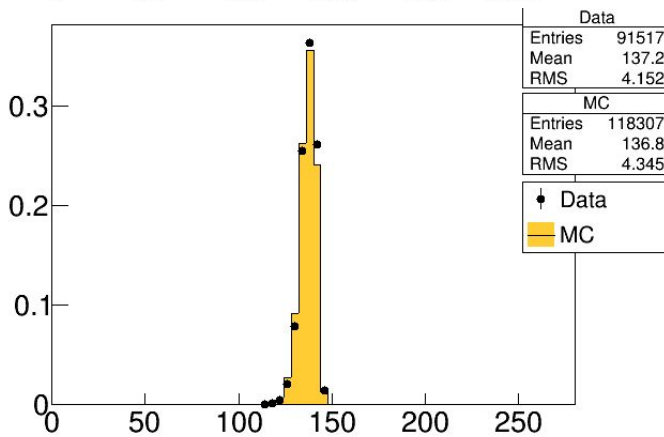
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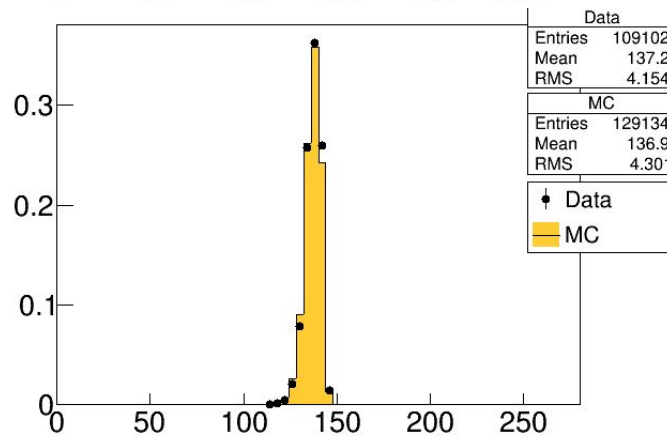
Empty LH2



LiH



LH2



p_z at TKU Reference Plane [mm]

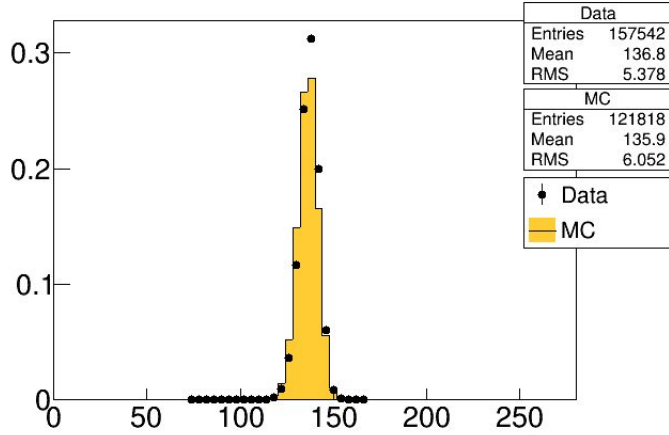
gdan Jurj

p_z at TKU Reference Plane [mm]

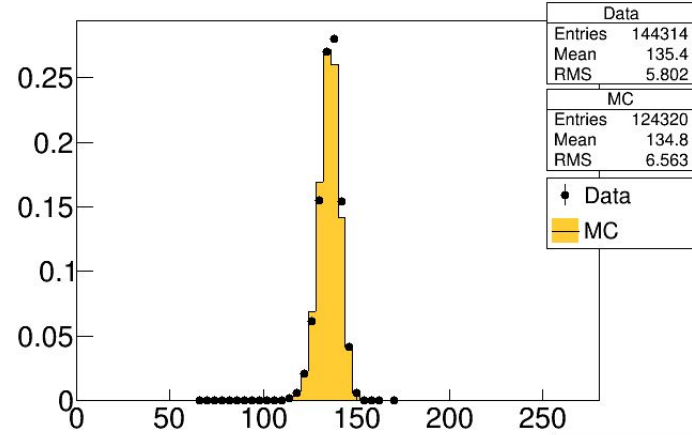


P_z TKD

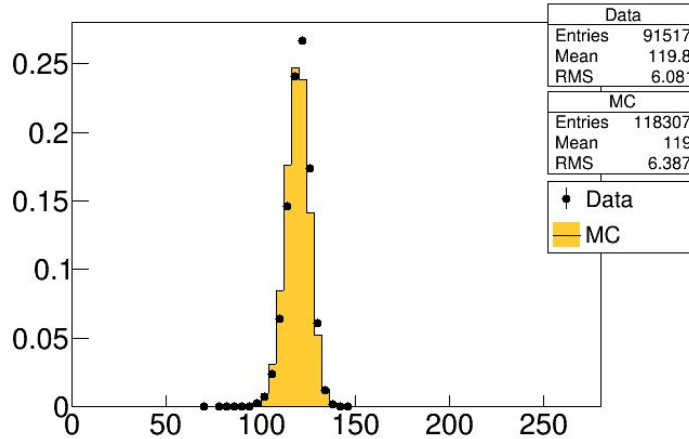
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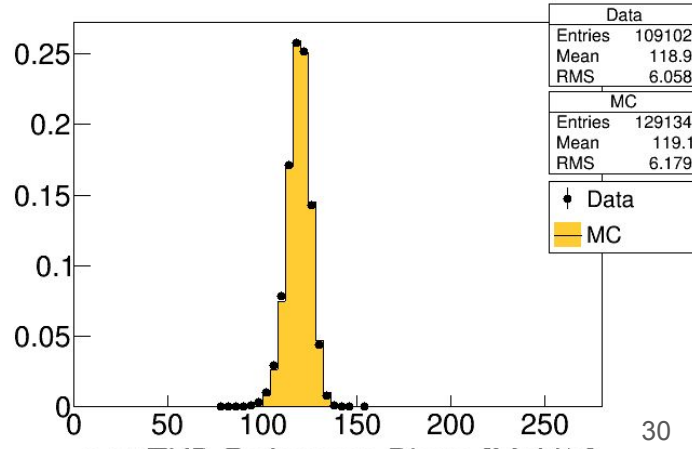
Empty LH2



LiH



LH2



p at TKD Reference Plane [MeV/c]

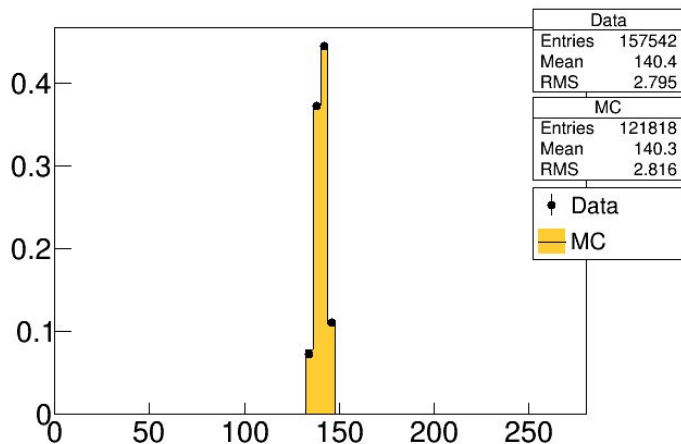
gdan Jurj

p at TKD Reference Plane [MeV/c]

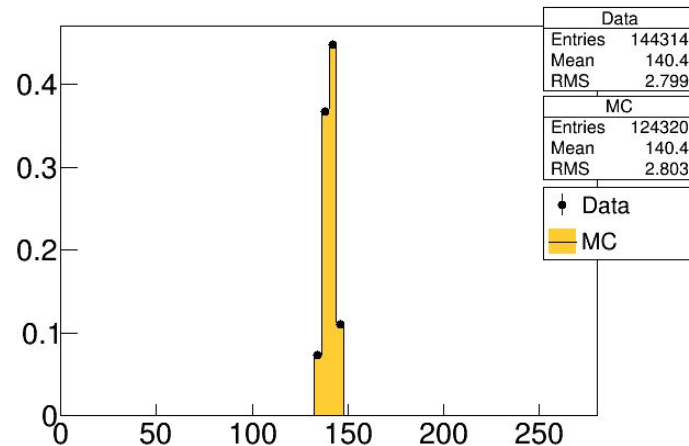


P TKU

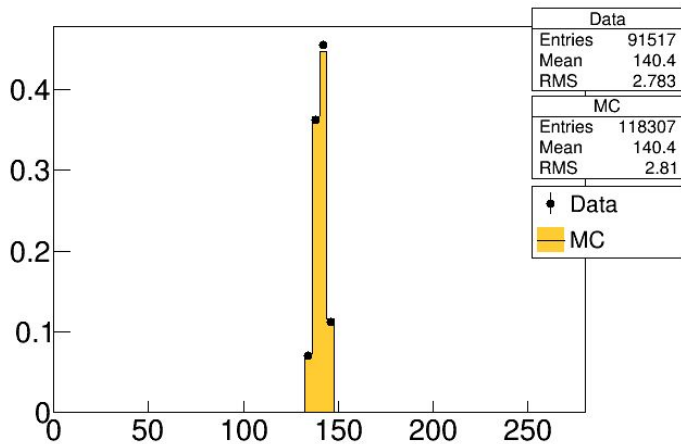
No abs



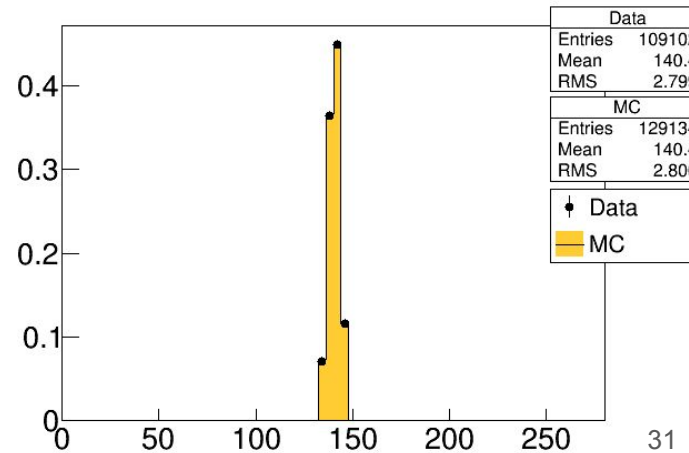
Empty LH2



LiH



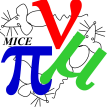
LH2



p at TKU Reference Plane [MeV/c]

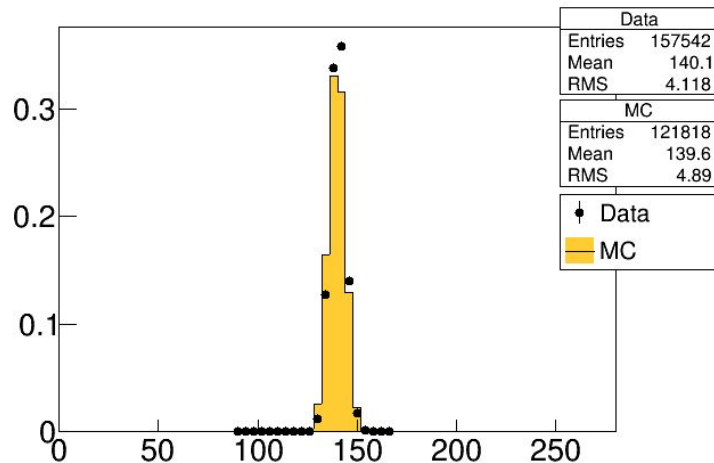
ogdan Jurj

p at TKU Reference Plane [MeV/c]

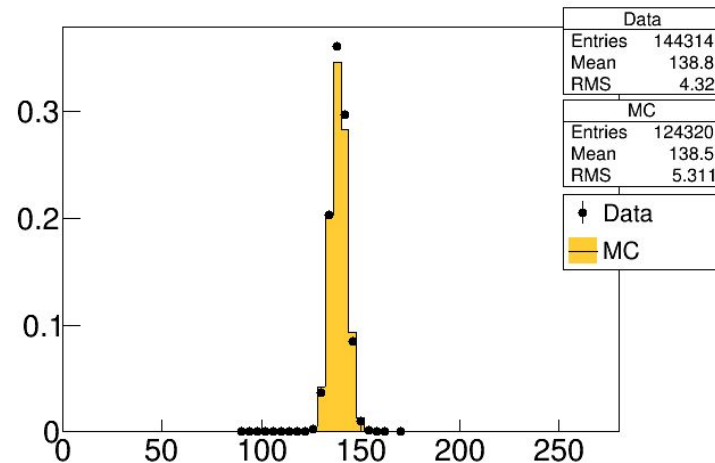


P TKD

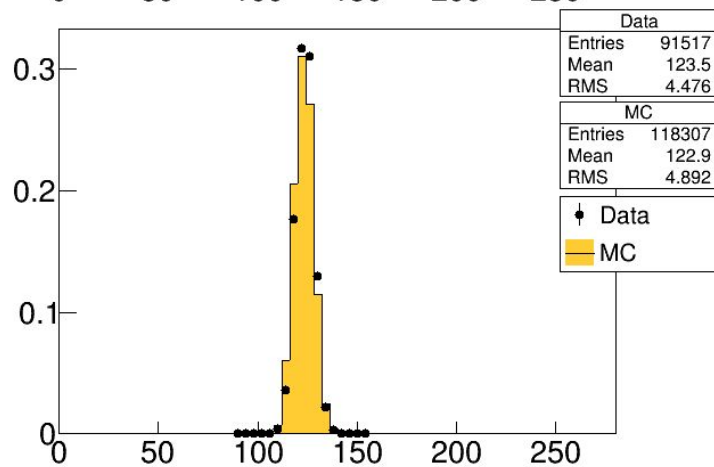
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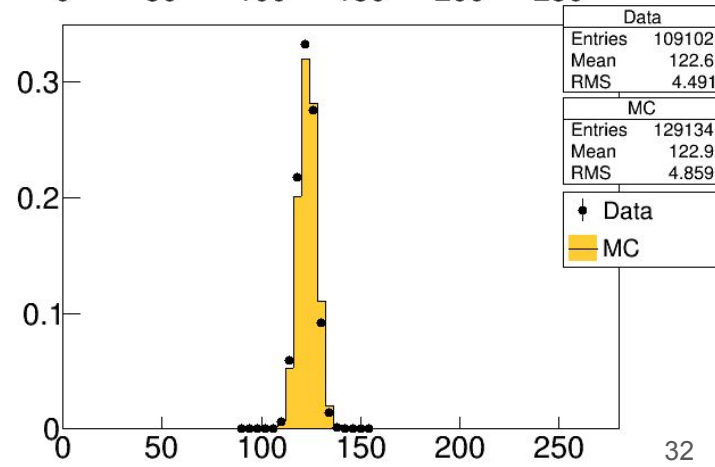
Empty LH2



LiH



LH2



p at TKD Reference Plane [MeV/c]

gdan Jurj

p at TKD Reference Plane [MeV/c]

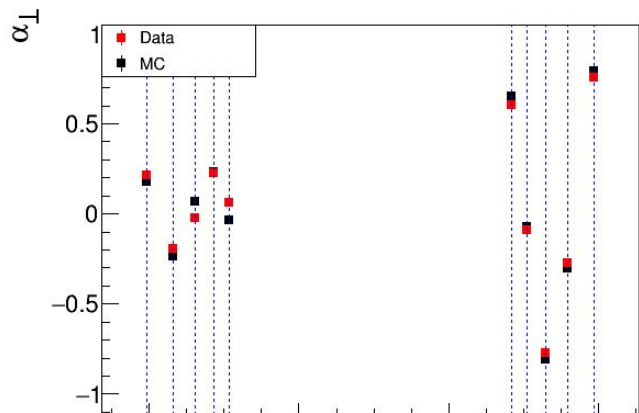


Updated MC: parent distributions optics

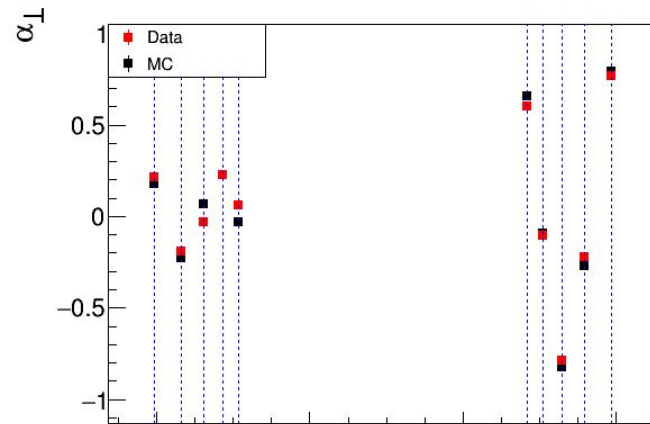


Alpha

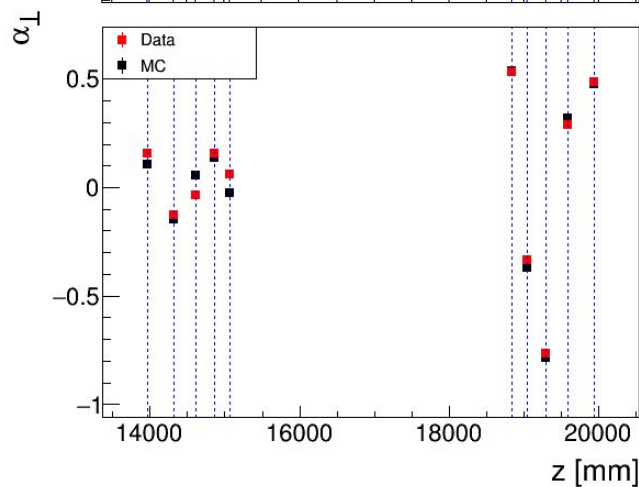
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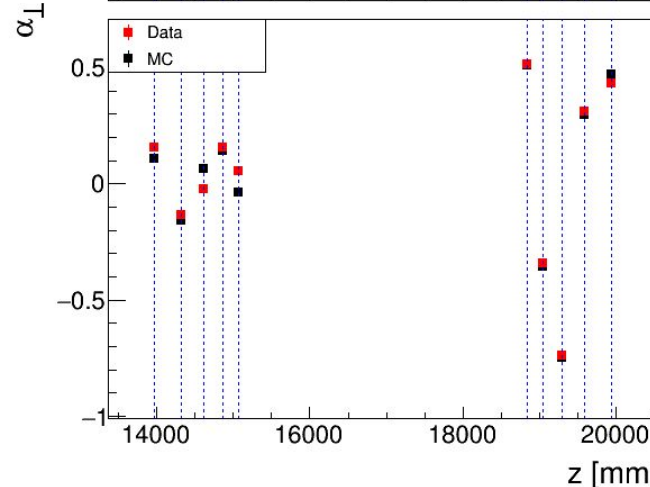
Empty LH2



LiH



LH2

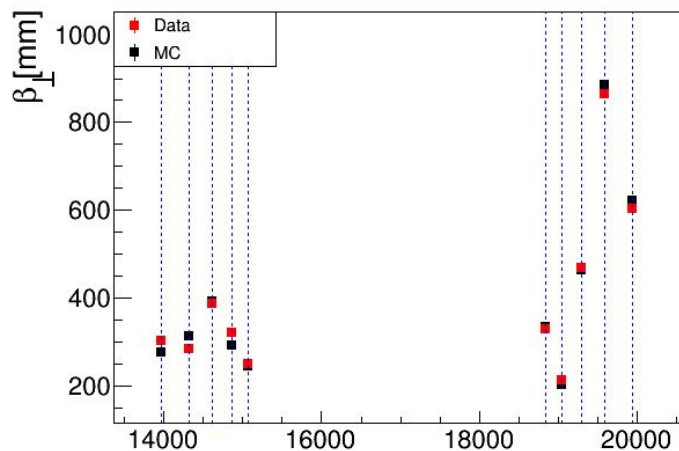


Jurj

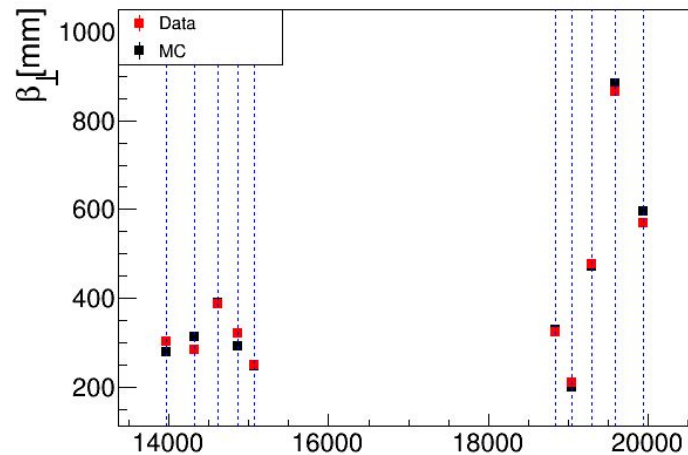


Beta

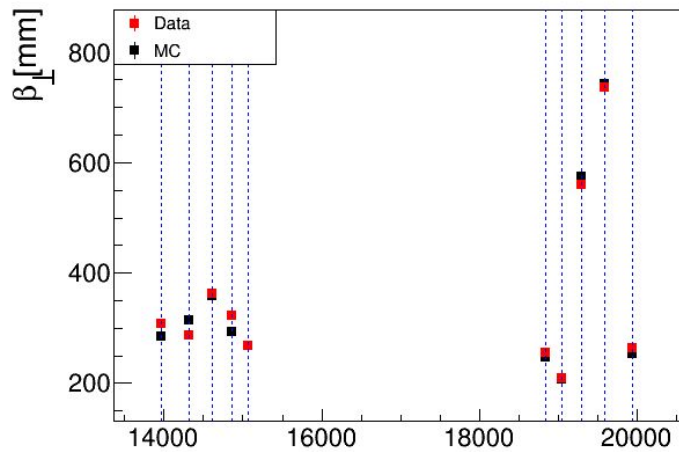
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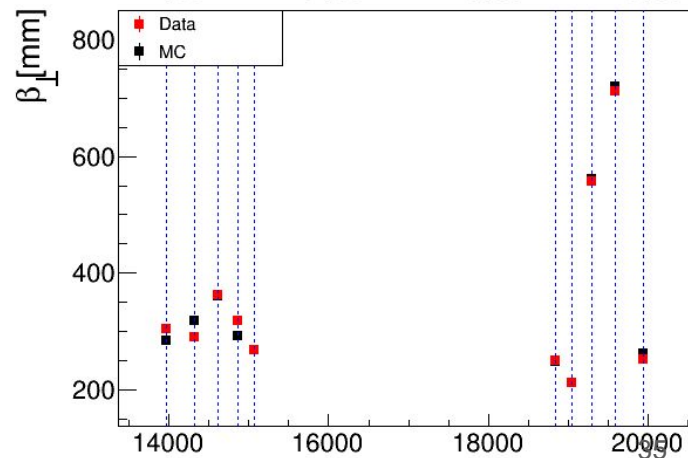
Empty LH2



LiH



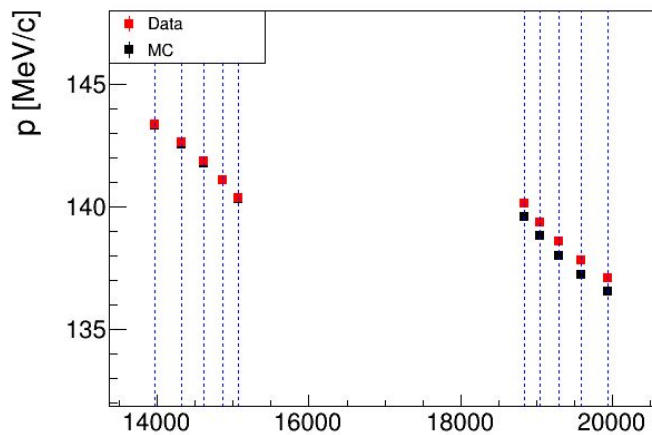
LH2



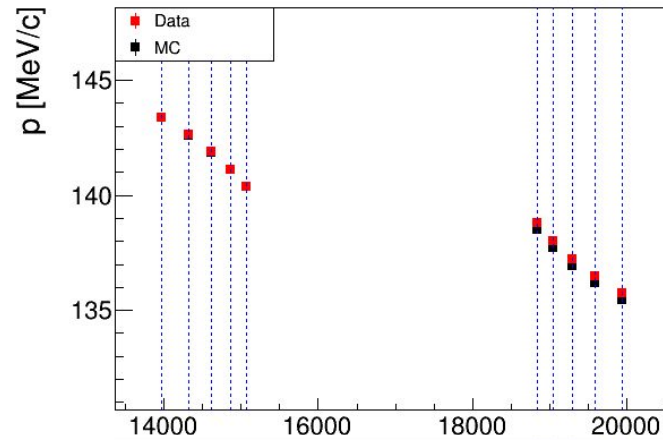


Momentum

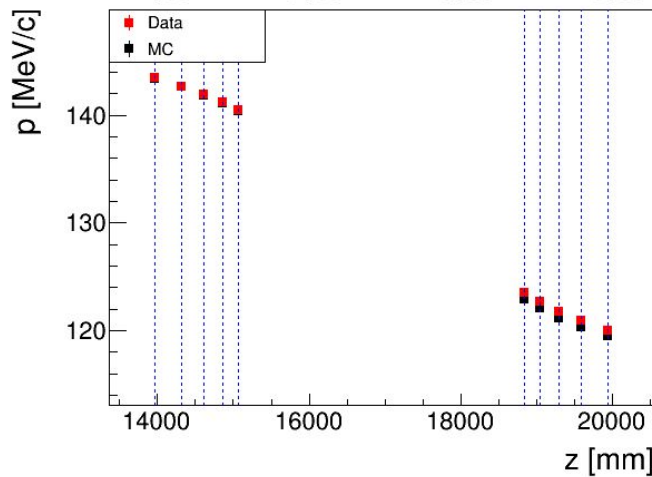
No abs



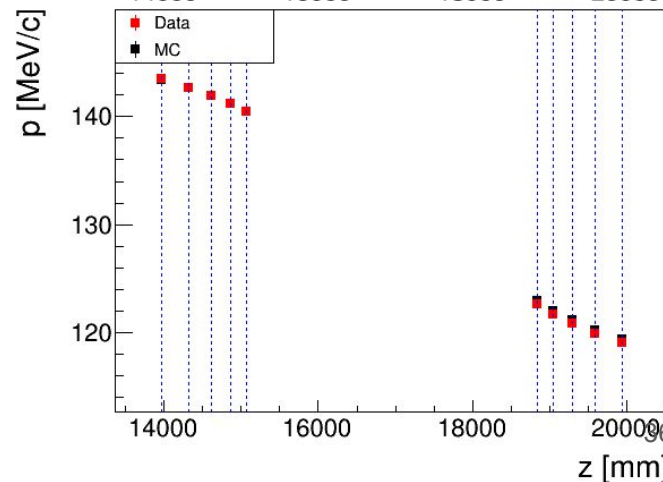
Empty LH2



LiH



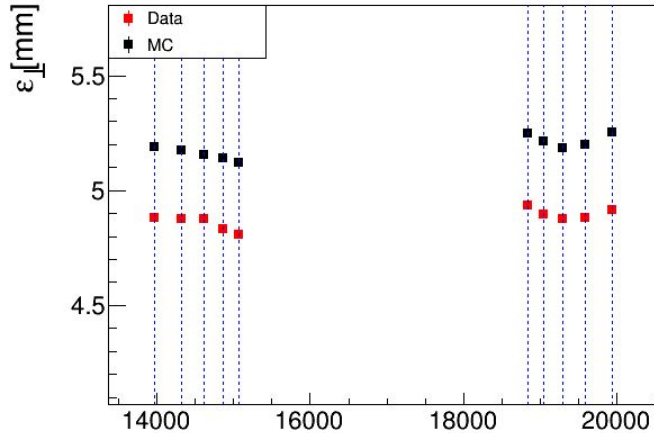
LH2



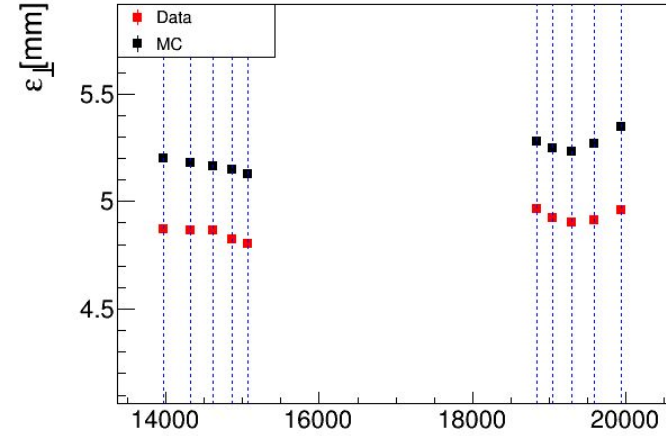


Emittance

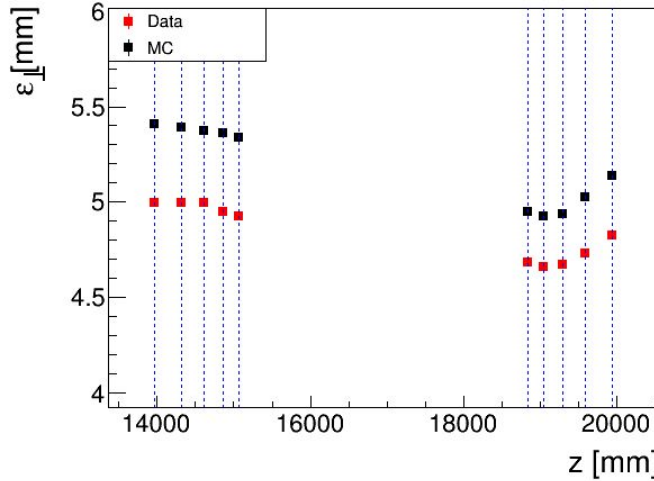
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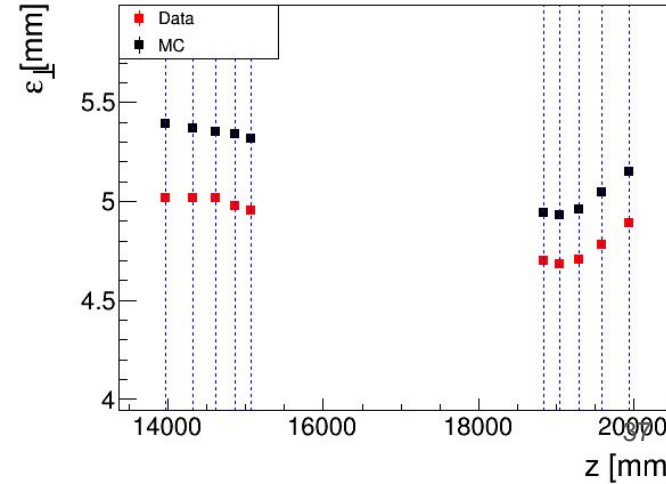
Empty LH2



LiH

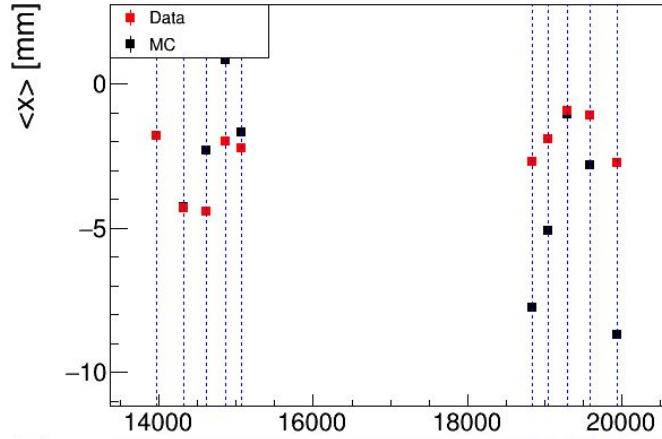


LH2

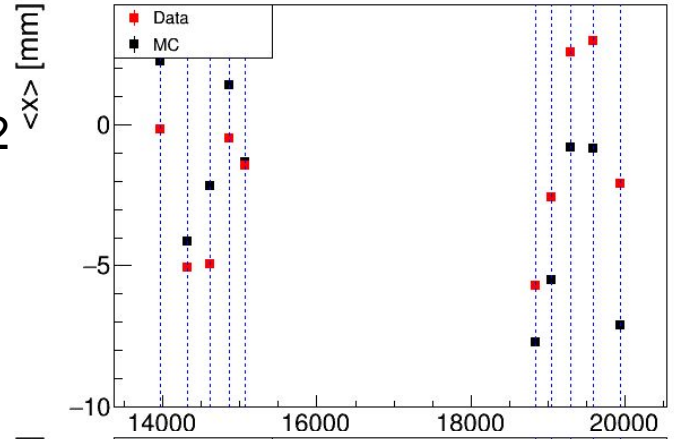


Jurj

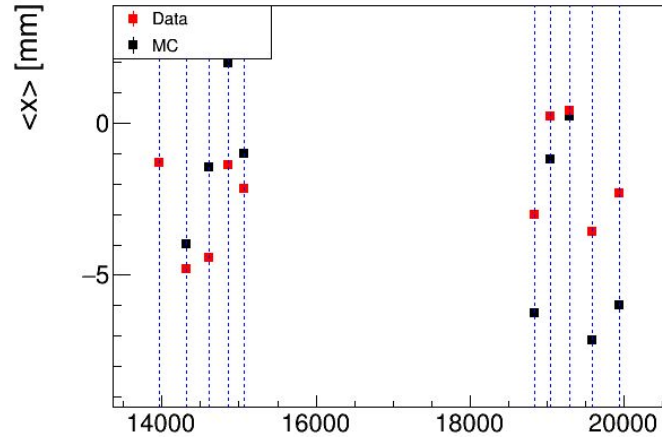
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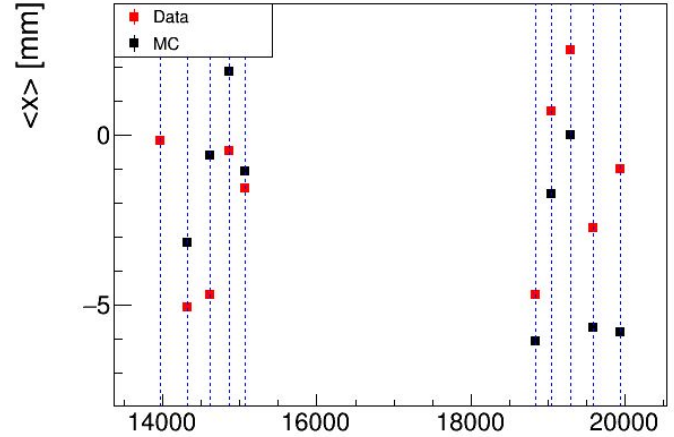
Empty LH2



LiH

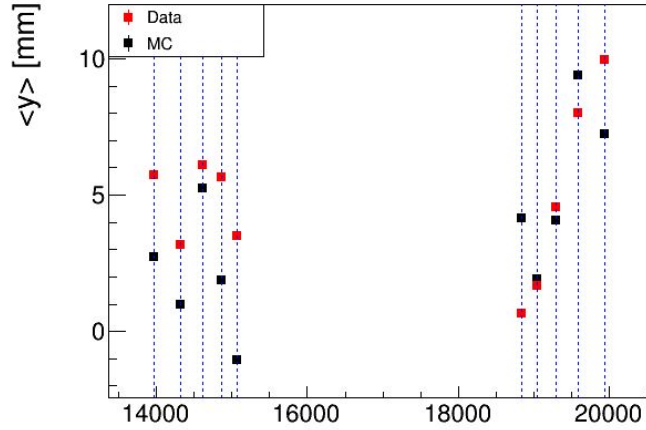


LH2

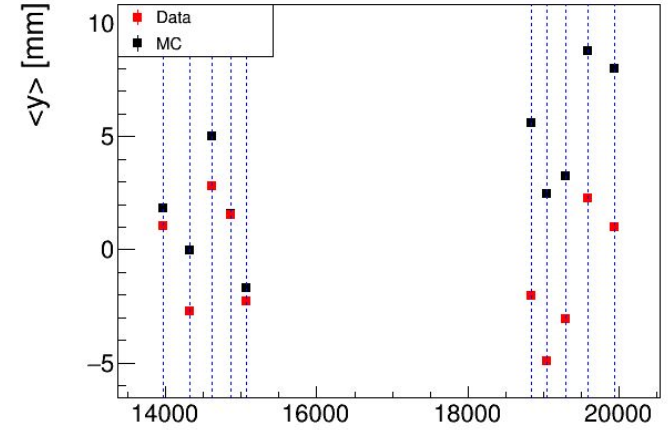


in Jurj

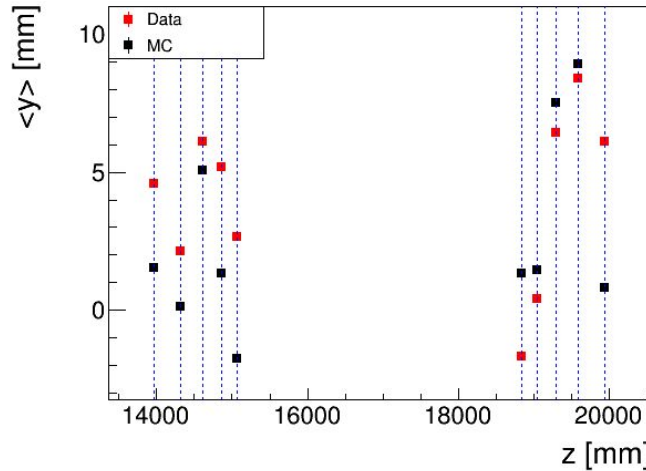
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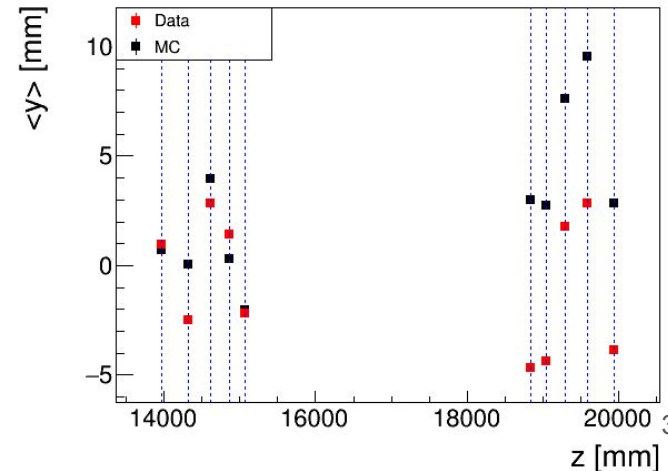
Empty LH2



LiH



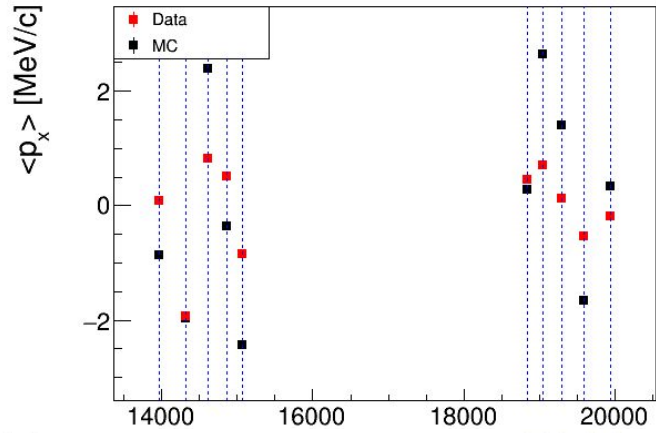
LH2



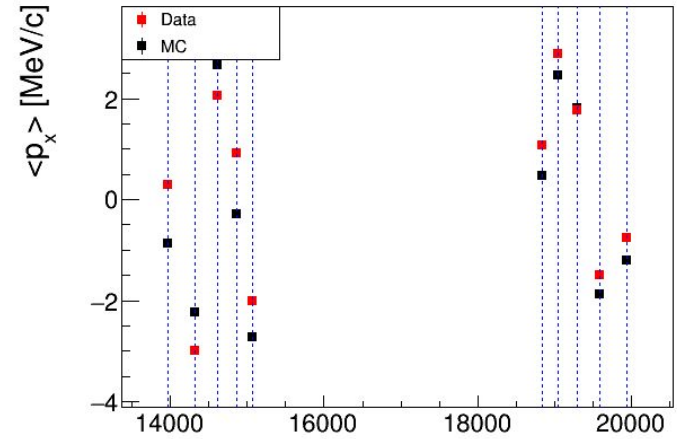


Mean P_x

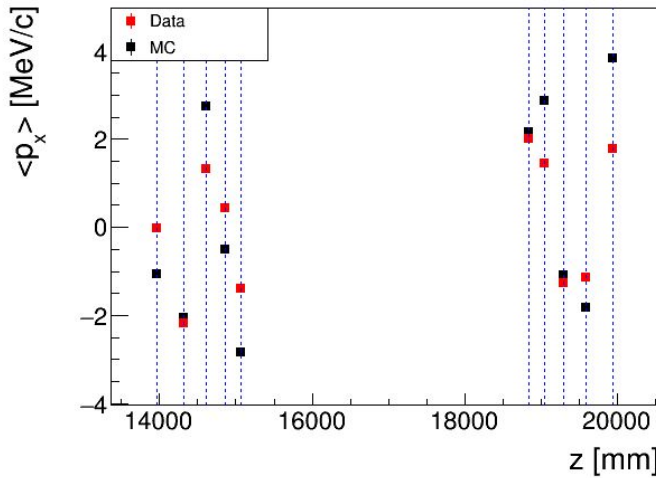
No abs



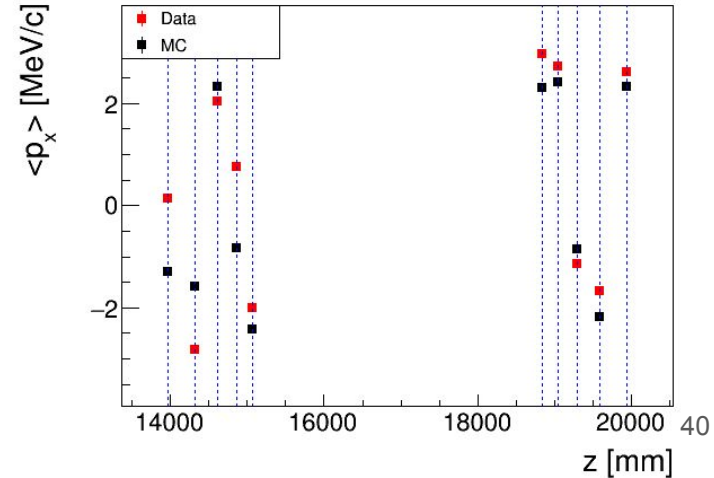
Empty LH2



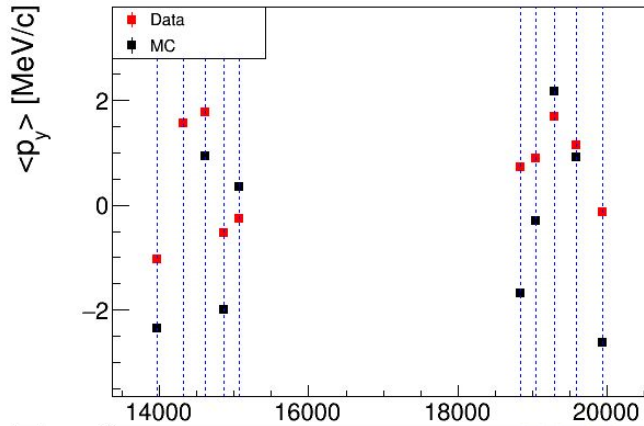
LiH



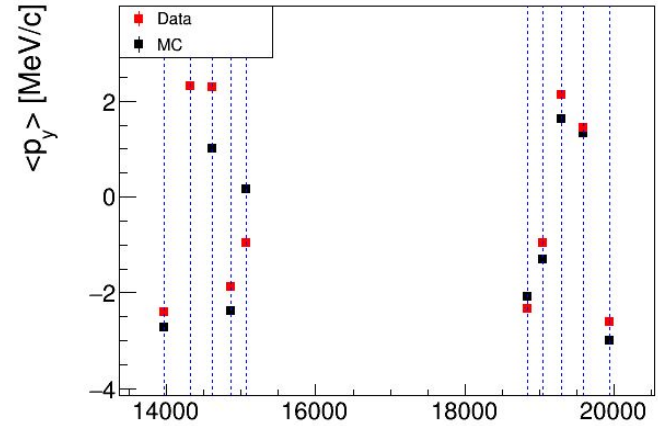
LH2



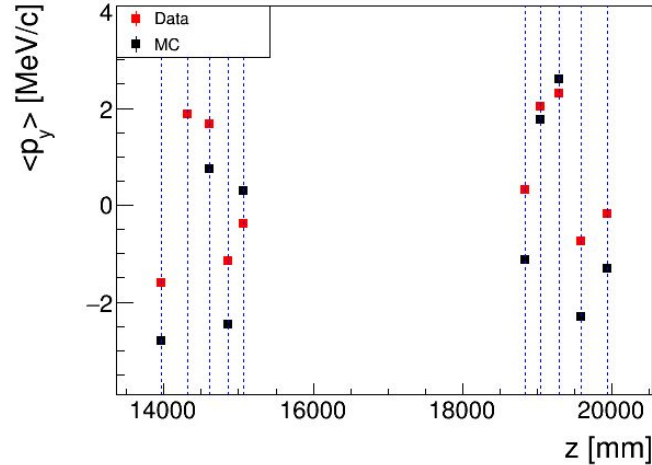
No abs



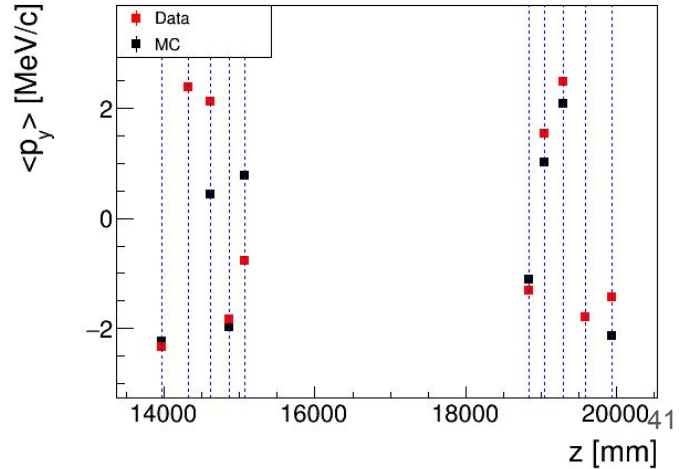
Empty LH2



LiH



LH2

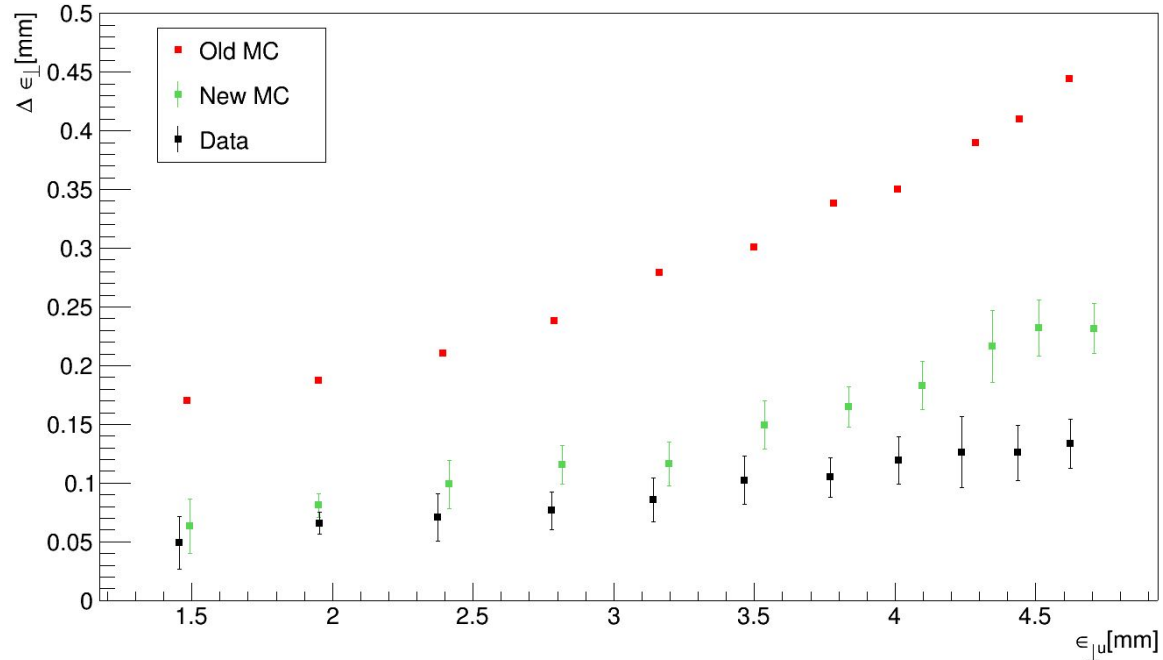


Emittance change: comparison with old MC

No absorber

Disagreement reduced, yet not fully

*corrections for reconstruction bias not applied here

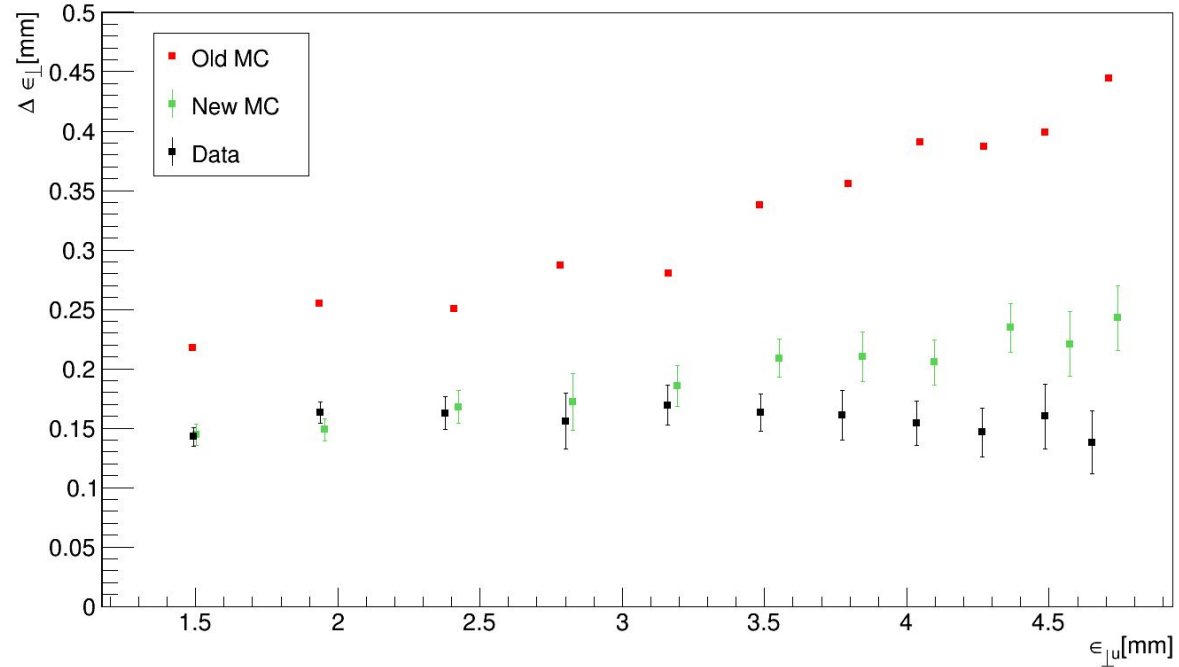


Emittance change: comparison with old MC

Empty LH2

Same as for the no
absorber case,
disagreement reduced, yet
not fully

*corrections for
reconstruction bias not
applied here





Reconstruction bias correction

Account for the bias in emittance reconstruction

Calculate bias at the TKU and TKD reference planes as:

$$bias = \epsilon_{RECO} - \epsilon_{TRUE}$$

For each of the sampled beams

Applied correction to both Data and MC

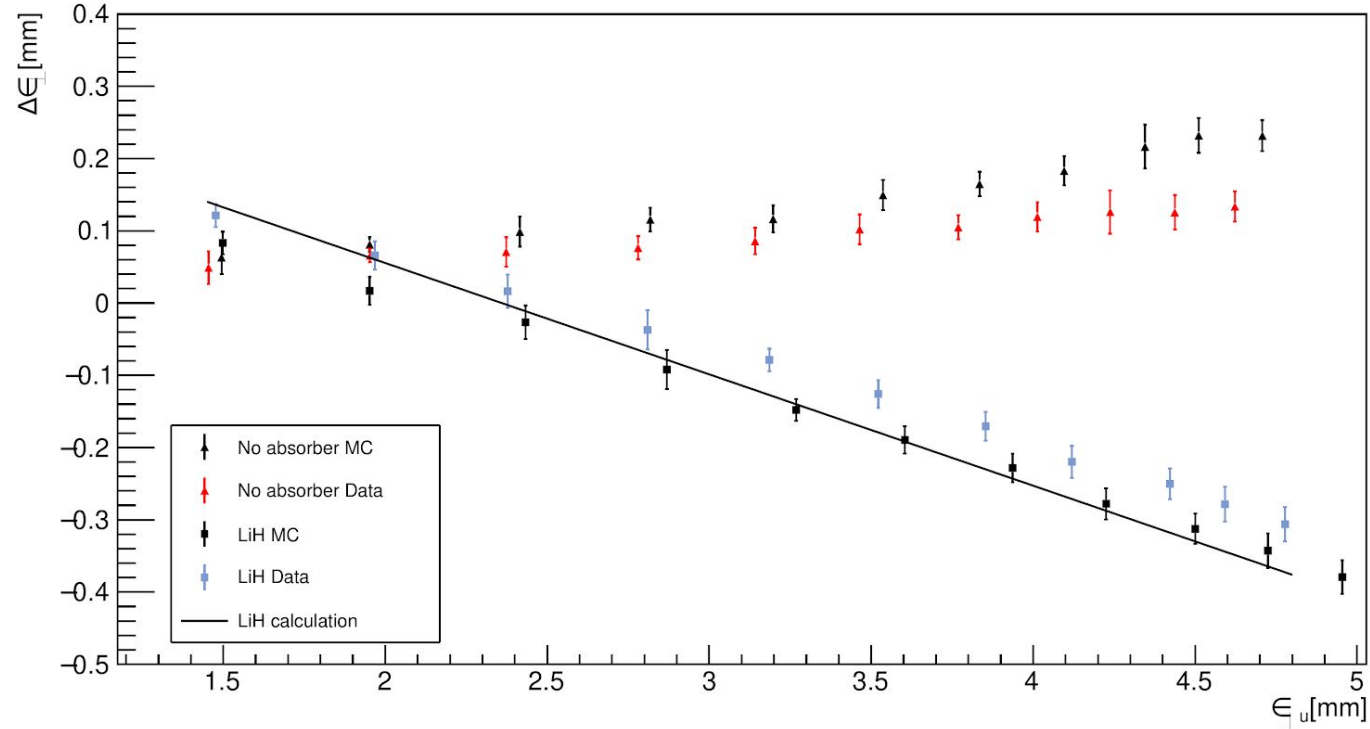


Emittance change

Slight overall offset in
LiH: more cooling in
MC

No absorber: more
heating in MC as
emittance increases

Statistical errors only

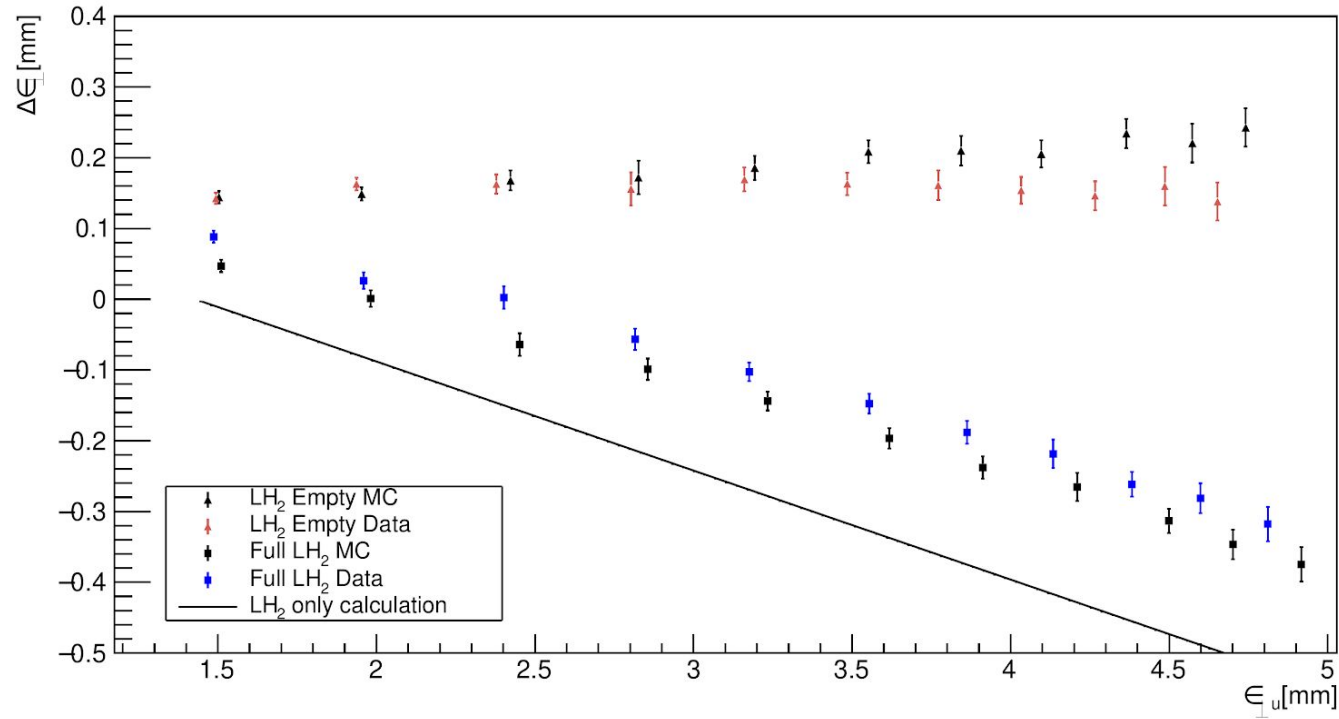


Emittance change

Slight overall offset in LH2: more cooling in MC, same as seen in LiH

Empty LH2: more heating in MC as emittance increases

Statistical errors only



Statistical errors on absolute emittance change

- Starting from John Cobb's derivation of statistical errors on relative emittance change in Note 268
- John has also worked on this derivation and came up with a result
- Currently our results are not identical, will take some time to revise



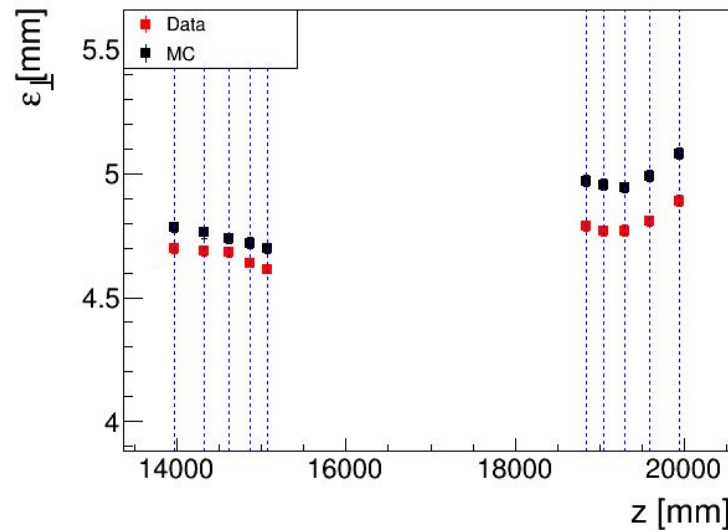
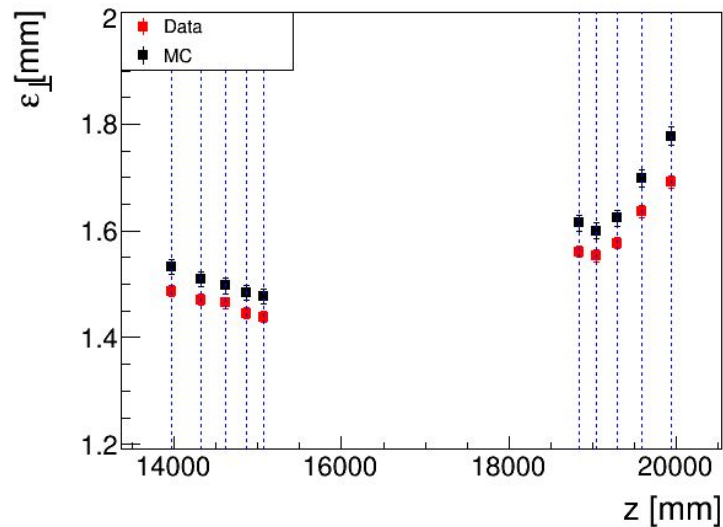
Sampled beams optics

Have seen that the parent beams have optics discrepancies both in TKU and TKD

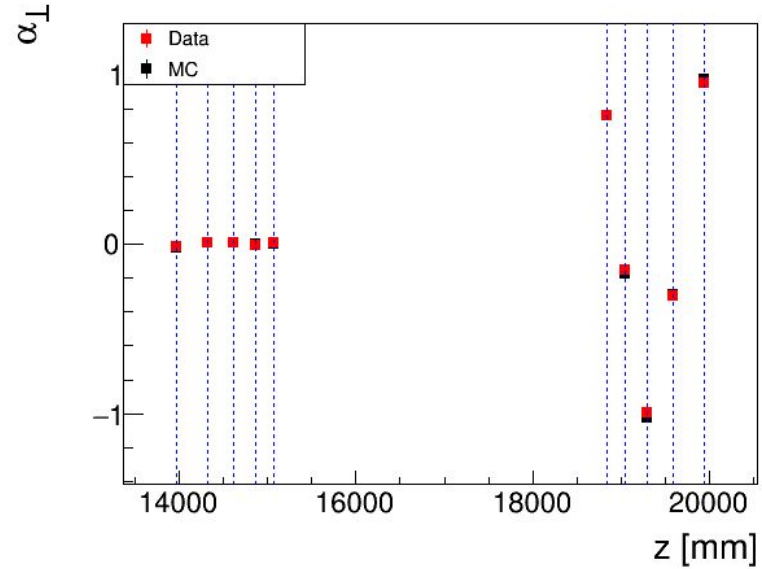
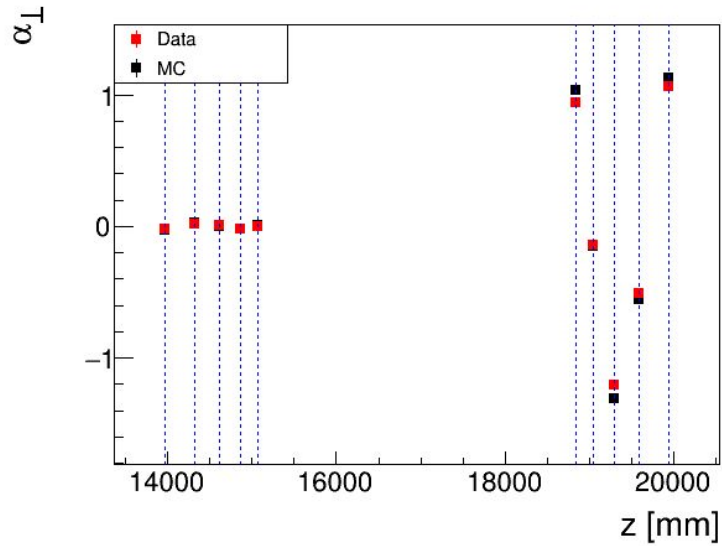
Beam sampling is supposed to largely iron out discrepancies in TKU

Next I will show the optics for the lowest and highest emittance sampled beams in the No absorber case

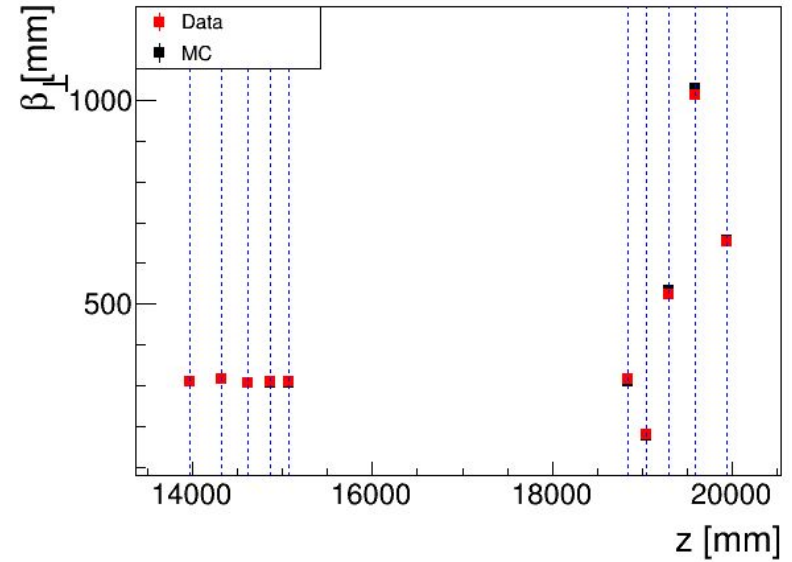
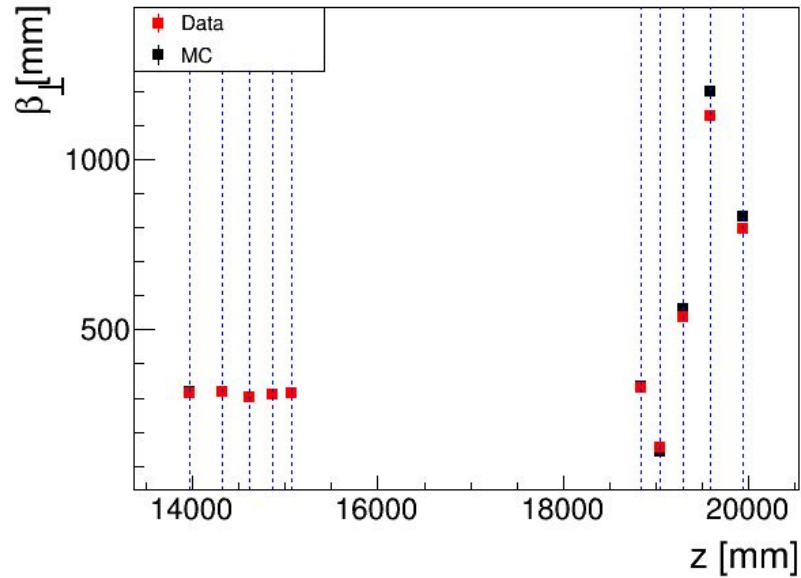
Emittance



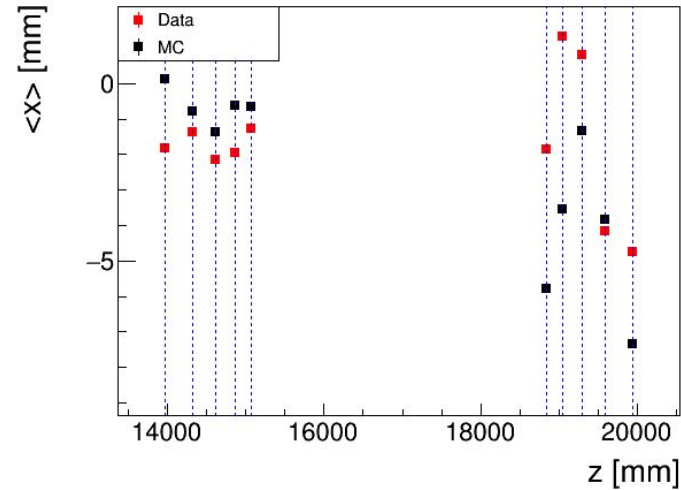
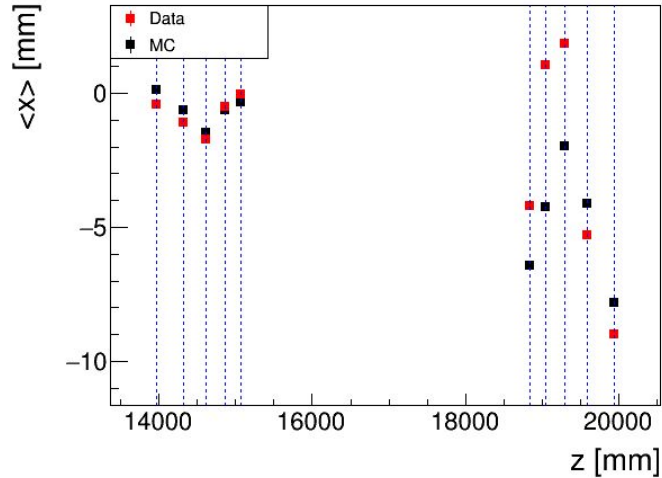
Alpha



Beta



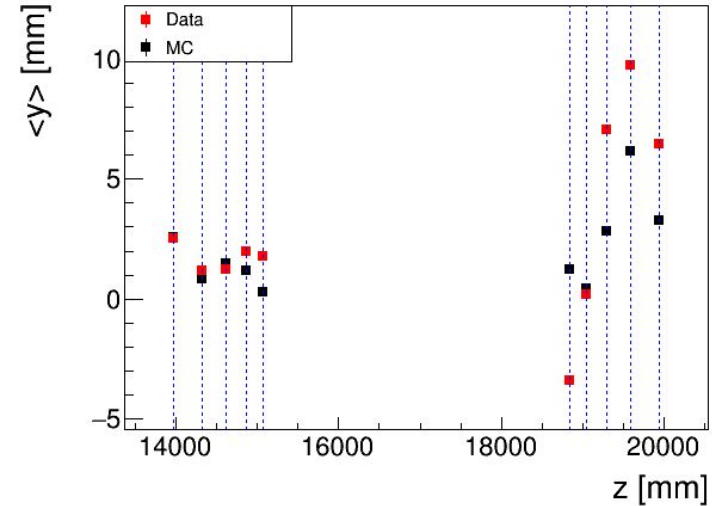
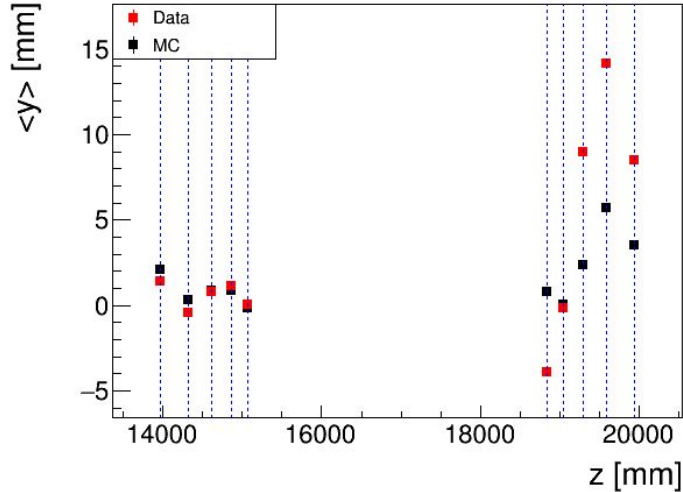
Mean X



TKU agreement better for lower emittance beams

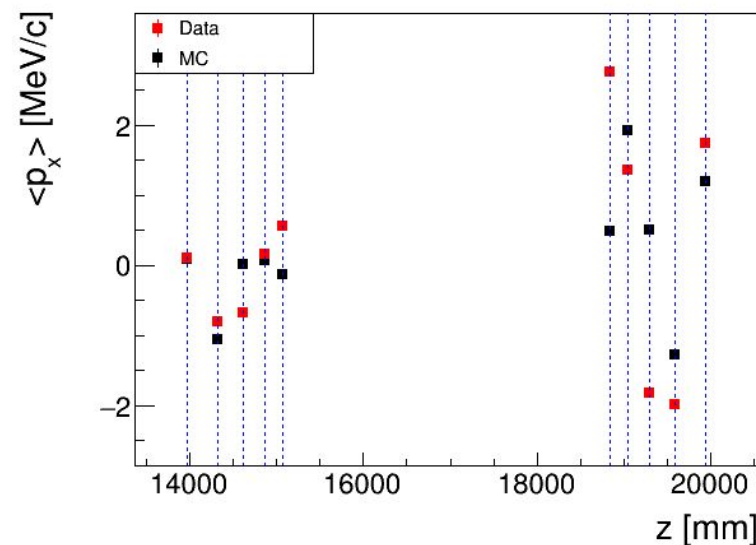
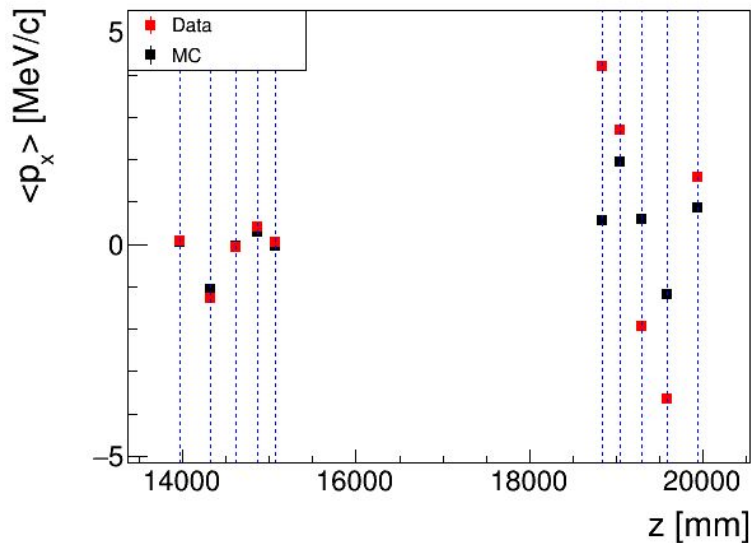
TKD discrepancies indicators of misalignment

Mean Y

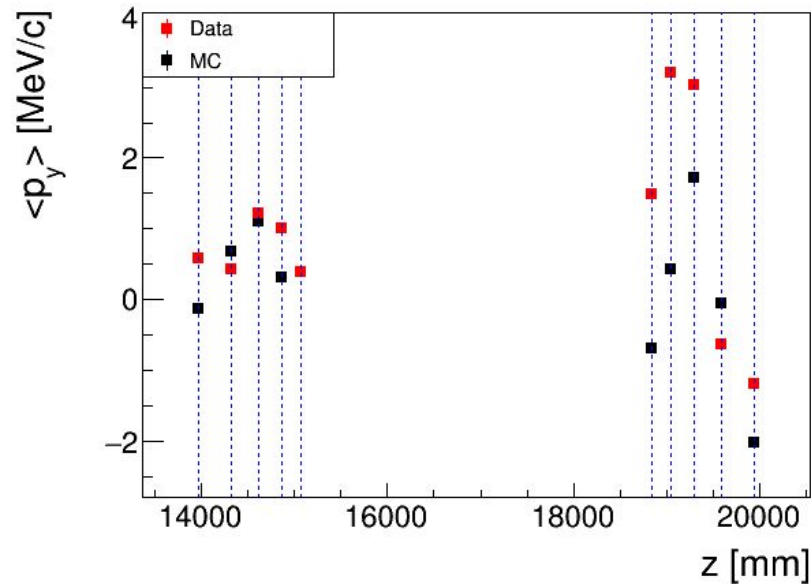
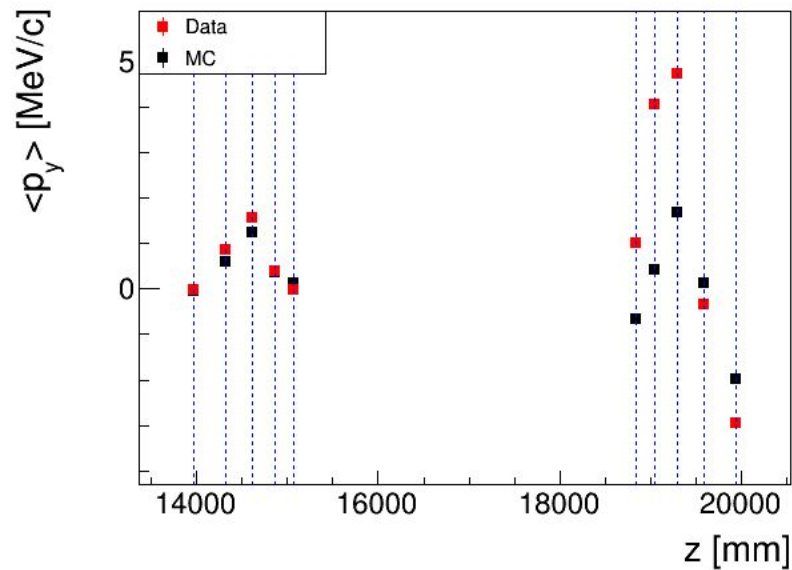


Misalignment generates differences in the amplitude and frequency of TKD oscillations

Mean P_x



Mean P_y





Summary

- New MC, better agreement with Data
- Room for improvement
 - on the agreement of beams entering the cooling channel
 - misalignment in AFC, M2D(?), TKD
 - TOF01
- Job list
 - TOF01
 - refine MC tuning for better upstream agreement
 - Systematics
 - Misalignment
 - Angular momentum
 - expand to other data sets (started 4 and 10 mm 140 MeV/c data analysis, MC due)



Back up



Equilibrium emittance calculation

- used Bethe's mean stopping power formula to calculate dE/dz at 140 MeV/c
- parameters used for eqm. emittance:

LiH

$$p = 140 \text{ MeV}/c$$

$$dE/dz = 1.925 \text{ MeV}/cm$$

$$X_0 = 102.04 \text{ cm}$$

$$\beta_{\perp} = 420 \text{ mm}$$

LH₂

$$p = 140 \text{ MeV}/c$$

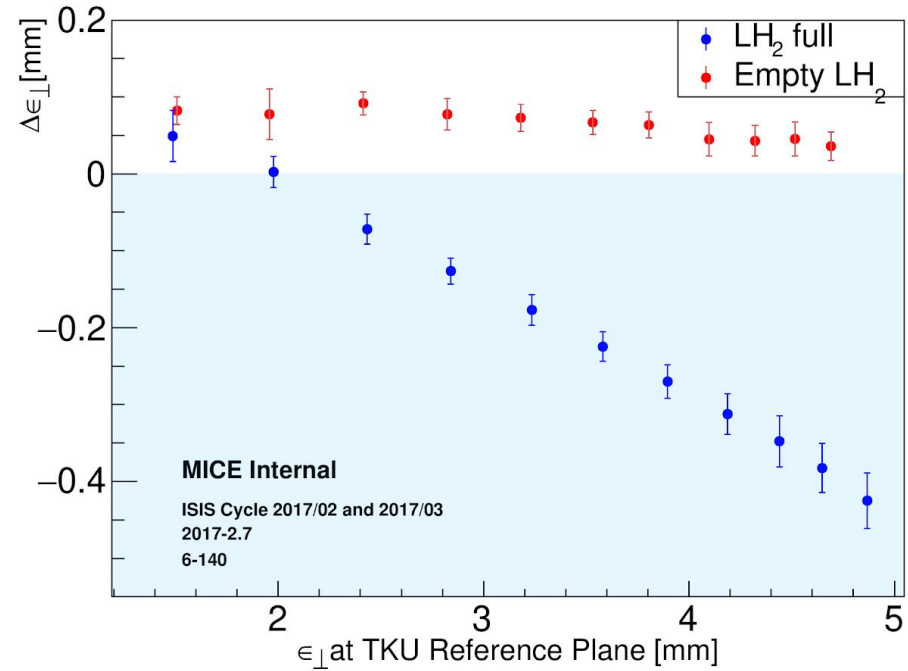
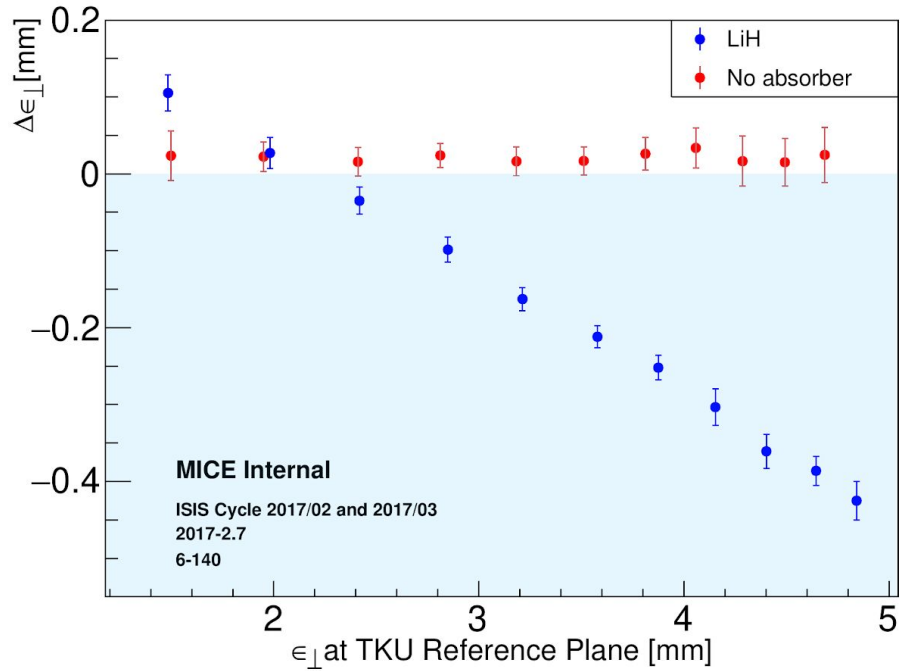
$$dE/dz = 0.361 \text{ MeV}/cm$$

$$X_0 = 890.4 \text{ cm}$$

$$\beta_{\perp} = 420 \text{ mm}$$



Previous iteration



Emittance change

- The main focus of the analysis is to measure the transverse emittance change of beams passing through the LH2 and LiH absorbers for a range of input emittances, momenta and optics configurations (β_{\perp} at the absorber)
- Used the 6mm - 140 MeV dataset while refining the analysis chain
- Study of all dataset available due soon
- Analysis chain:

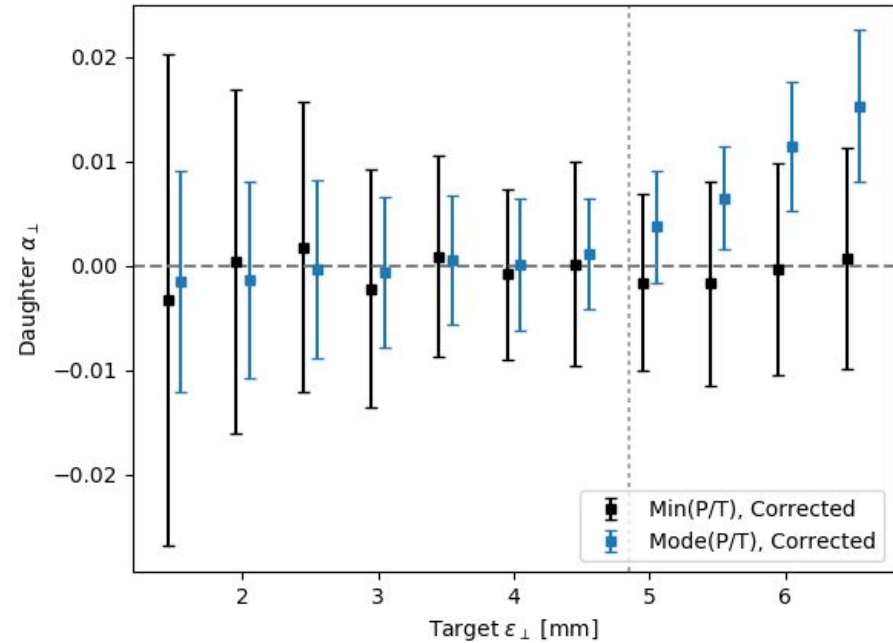
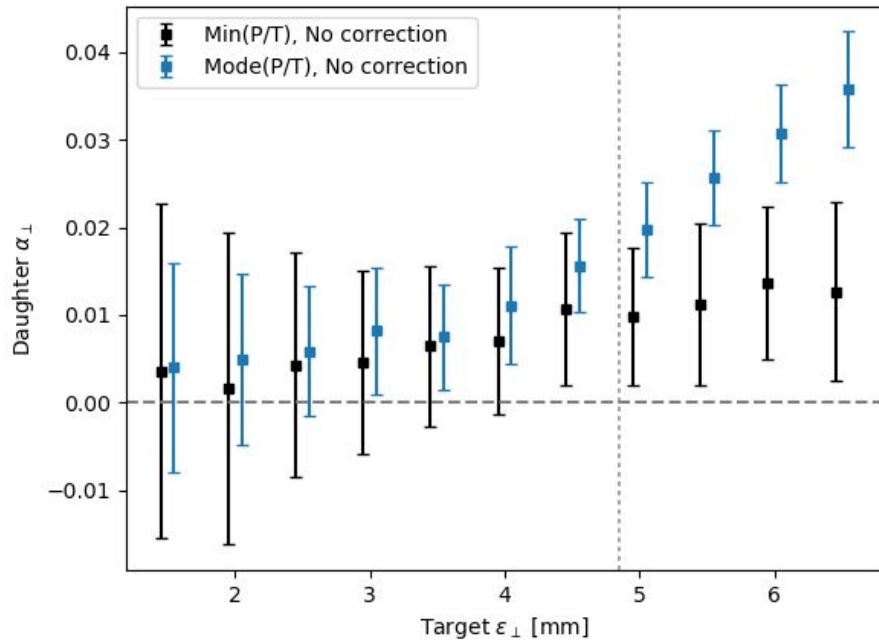
Data / MC -> Cuts -> Parent sample -> Beam selection -> Emittance change calculation
(applied to the improved optics sampled beams)



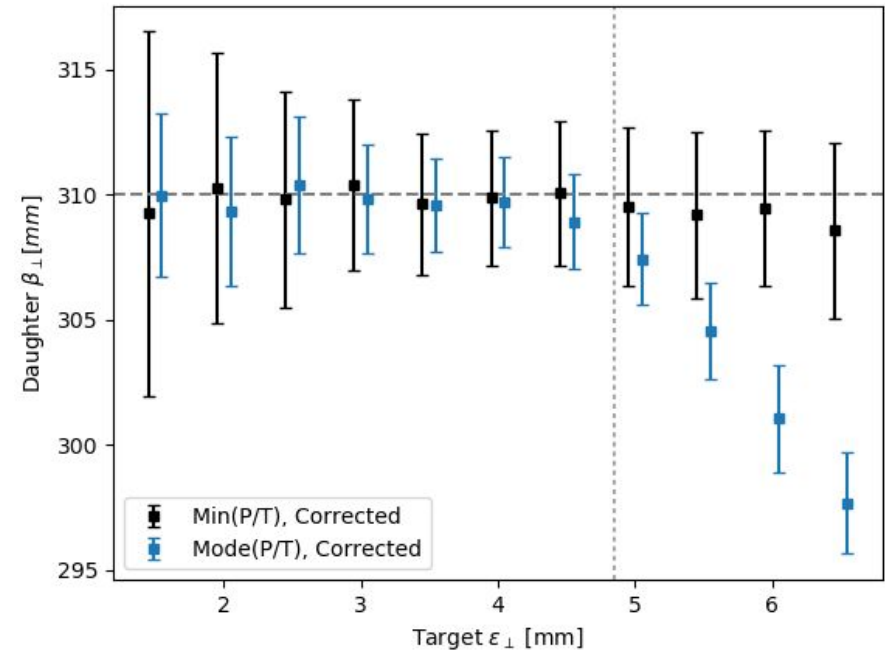
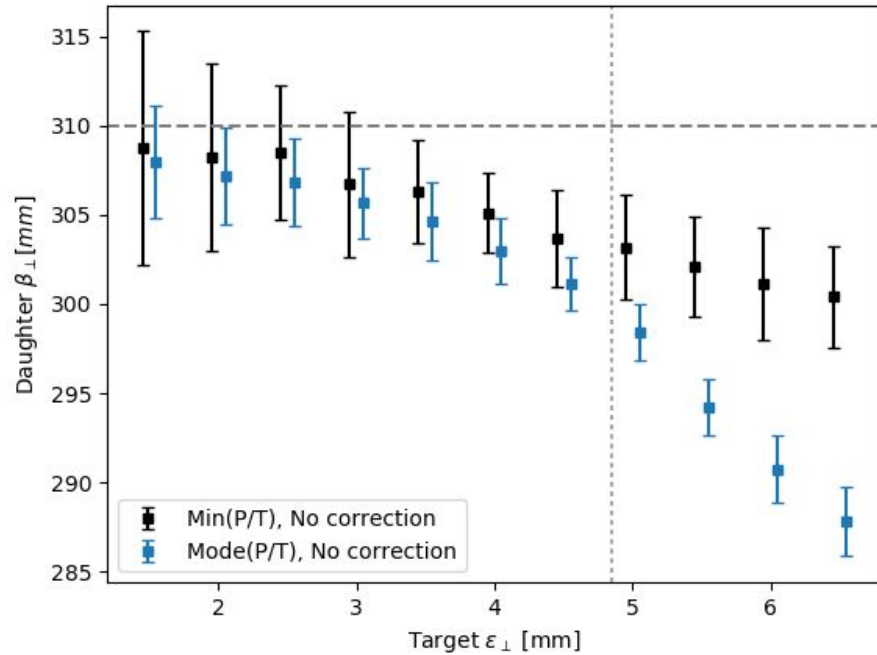
Beam selection

- Beam optics oscillates in the upstream tracker -> optics matching would reduce the betatron function at the absorber, improving the cooling measurement
- A beam selection algorithm based on rejection sampling is used to obtain beams with matched optics in TKU
- Recent efforts were dedicated towards improving the algorithm -> improved matching performance and (potentially) improved statistics in the sampled beams

Matching: Alpha



Matching: Beta



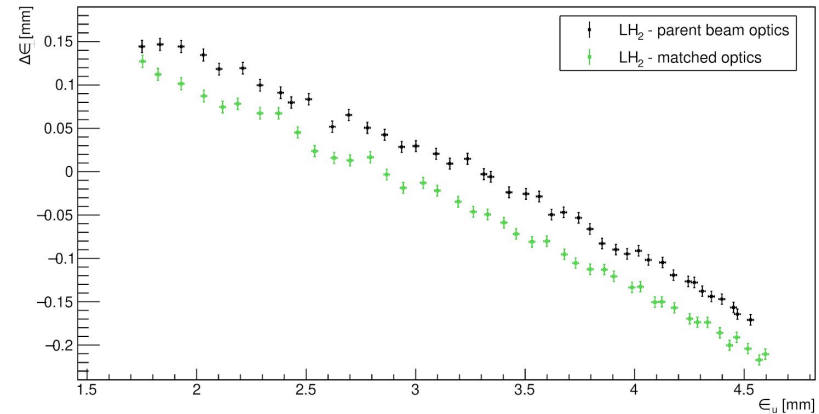
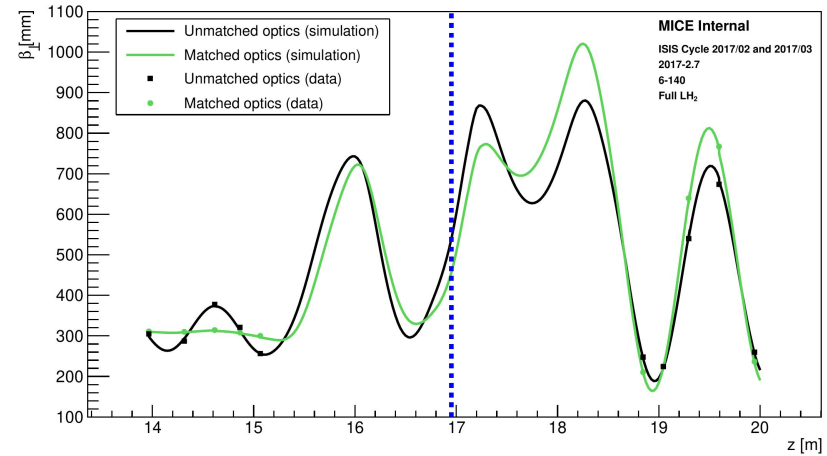
Black - parent beam optics (4.8 mm)

Green - sampled beam optics (4 mm)

Beta at absorber reduced from ~540 mm to ~450 mm (~17% reduction)

Results in an enhanced cooling effect, seen in the bottom plot

Bottom plot - absolute emittance change across the absorber for beams sampled from 6-140 LH2 data. More cooling observed in beams that have matched optics than for beams that keep the optics of the parent sample



Emittance change calculation

$$1) \quad \Delta\epsilon_{\perp} = \epsilon_d - \epsilon_u \quad \text{or} \quad \Delta\epsilon_{\perp rel} = (\epsilon_d - \epsilon_u) / \epsilon_u$$

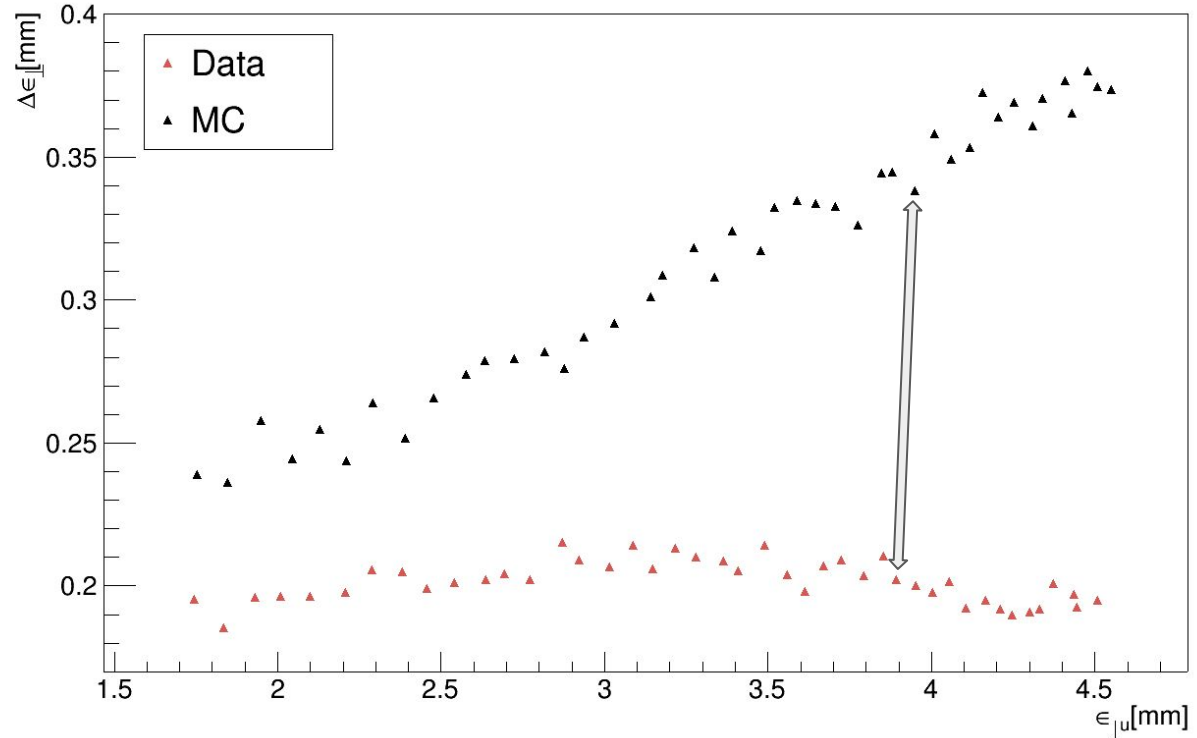
- 2) Amplitude migration at the core of the beam can also be used to estimate the emittance change. The ratio of the upstream and downstream emittances can be calculated from the ratio of upstream and downstream numbers of particles in the smallest amplitude bin (core), as shown below. (low statistics and efficiency in the core bin)

$$\lim_{A_{\perp} \rightarrow 0} \frac{f^d(A_{\perp})}{f^u(A_{\perp})} = \left(\frac{\epsilon_{\perp}^u}{\epsilon_{\perp}^d} \right)^2$$

Results shown here using the **first** method.

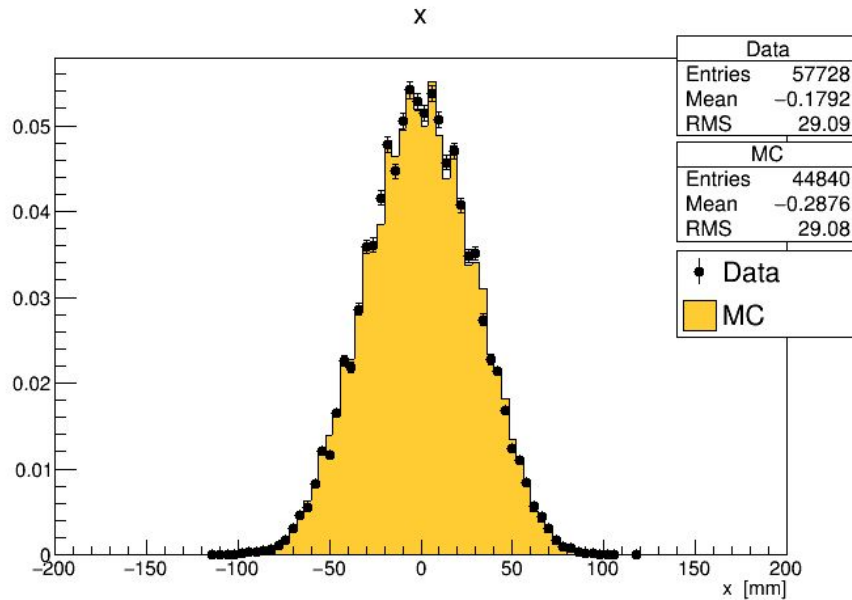
Empty LH2: Sampled beam phase space

- 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

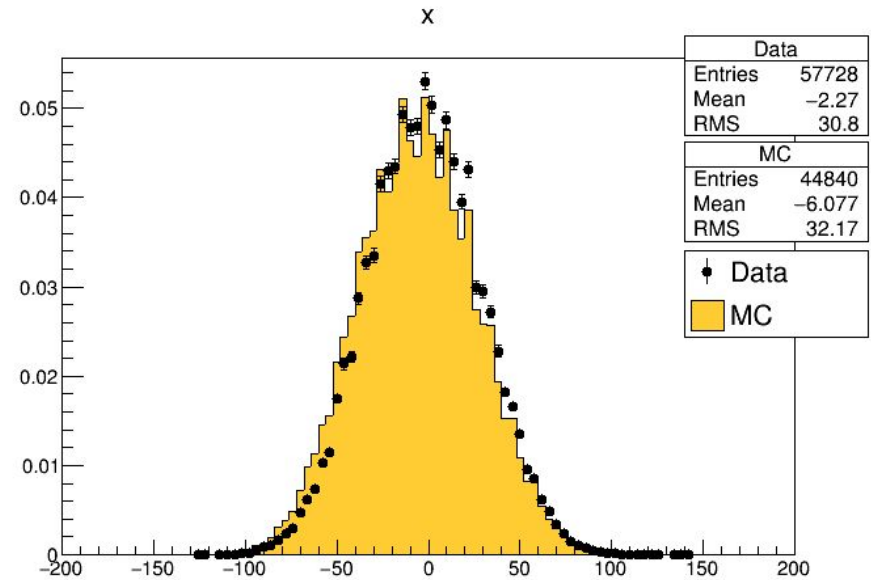


Beam Position: X

Upstream

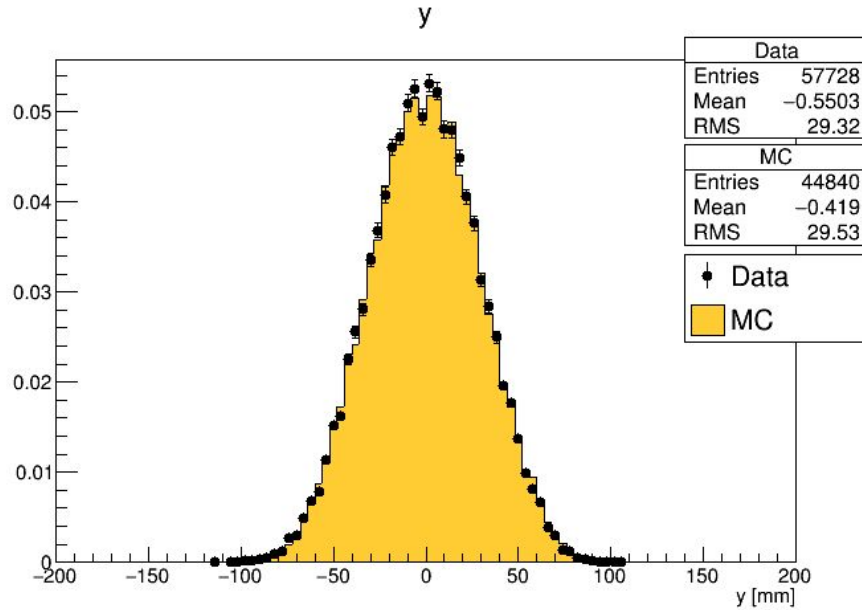


Downstream

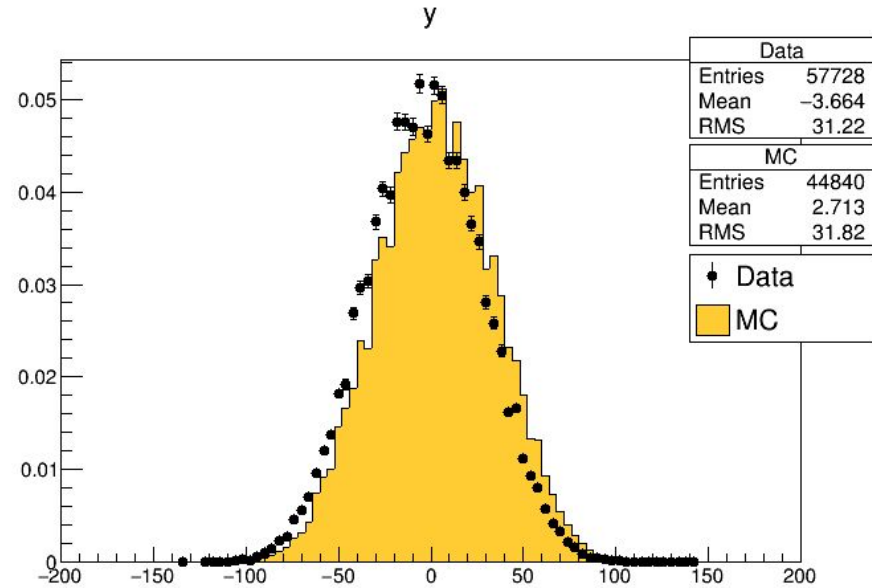


Beam Position: Y

Upstream

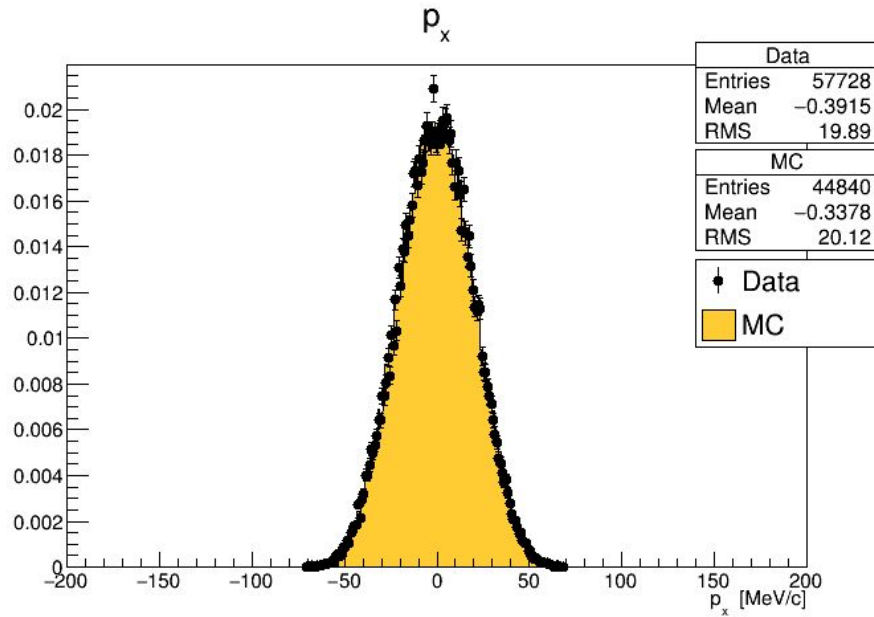


Downstream

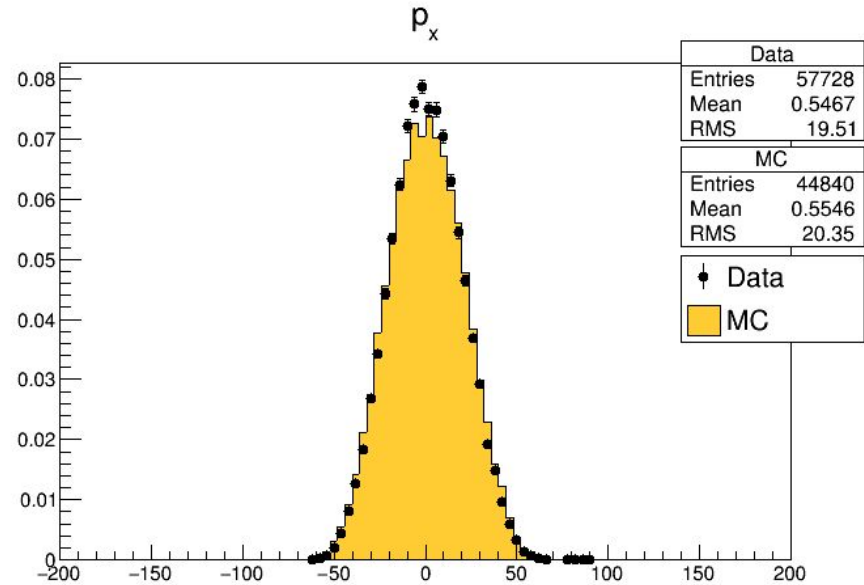


Beam Momentum: P_x

Upstream

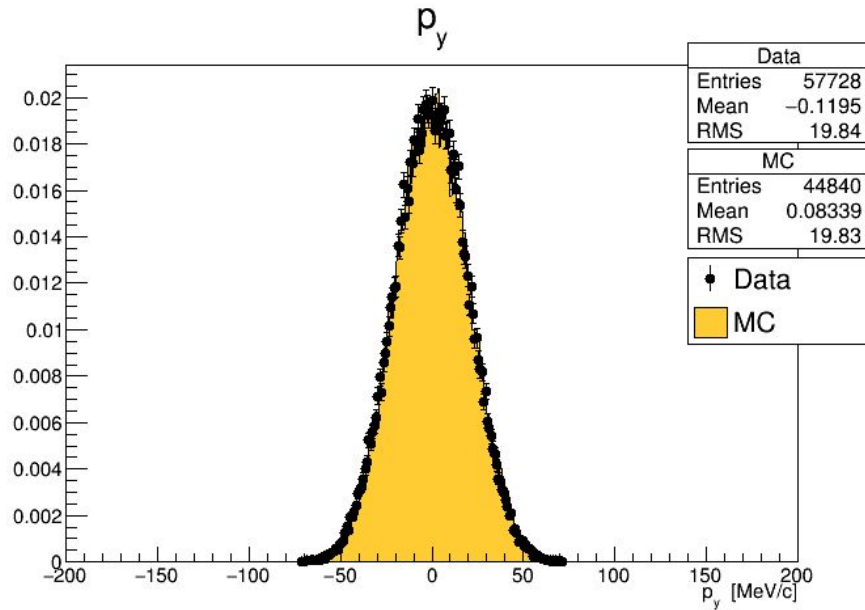


Downstream

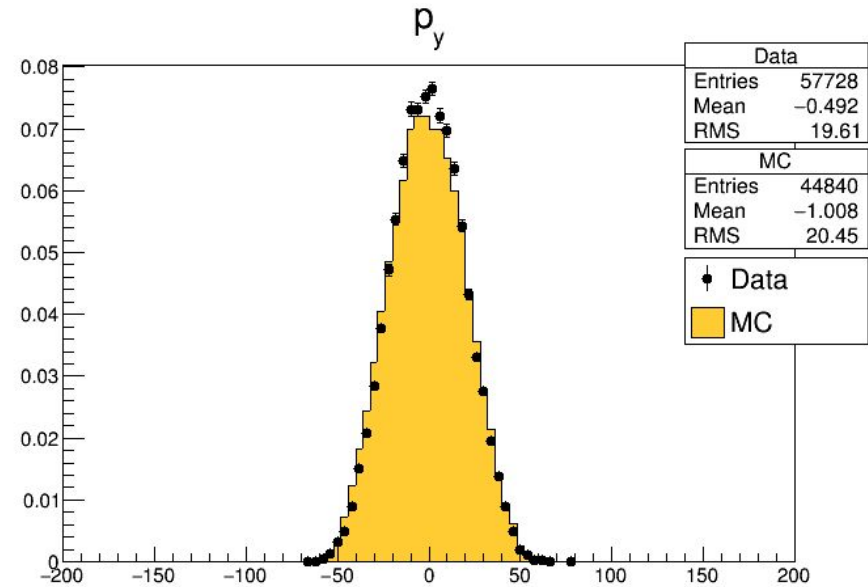


Beam Momentum: P_y

Upstream

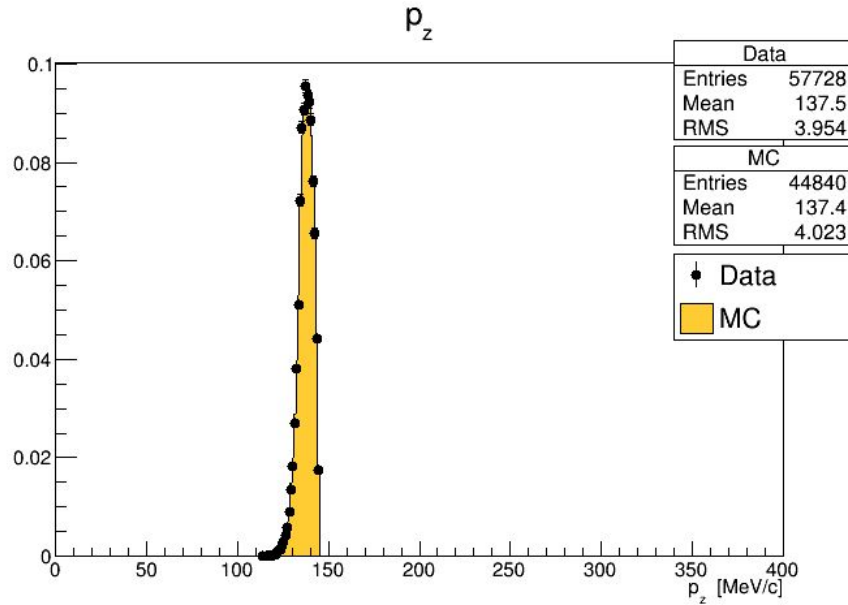


Downstream

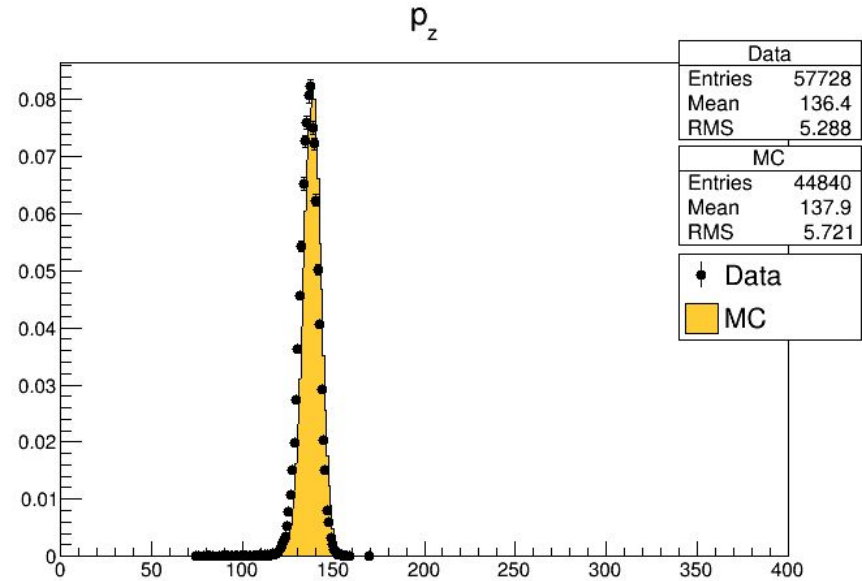


Beam Momentum: P_z

Upstream

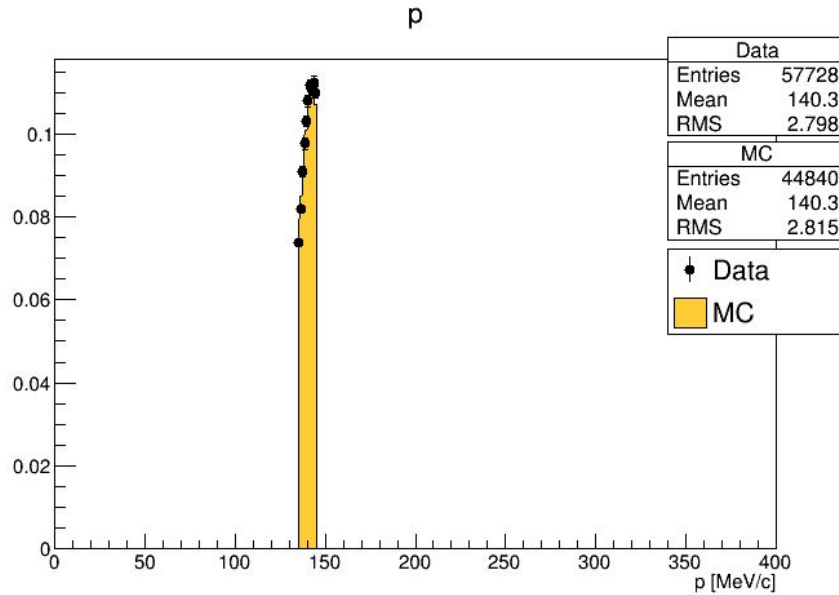


Downstream

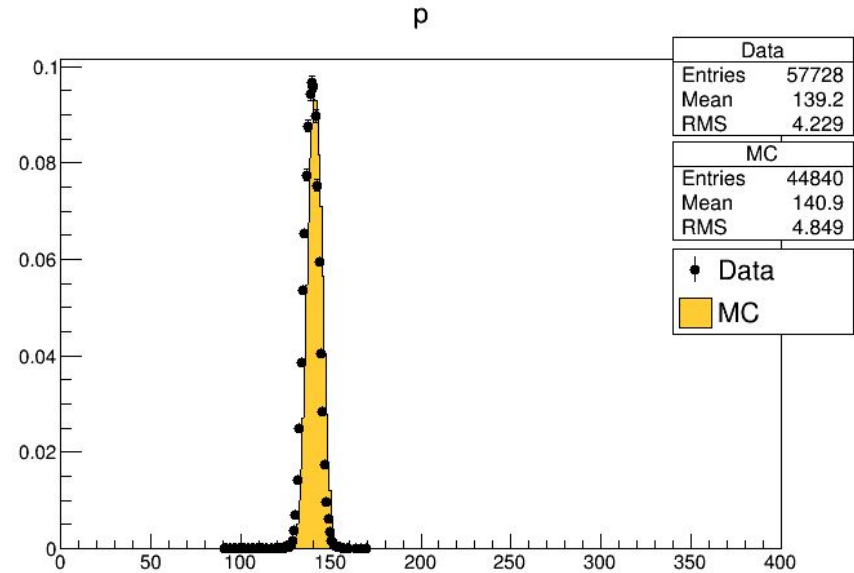


Beam Momentum: P

Upstream



Downstream





Data / MC disagreement

Good agreement upstream given by the sampling routines!

However, downstream:

- 1) Wider distributions seen in MC
- 2) x,y centroid discrepancies -> misalignment (AFC, TKD)
- 3) Higher momentum in reco MC than in reco data



$$\sigma_{\Delta\epsilon}^2 = \frac{1}{2n} [(\epsilon_d - \epsilon_u)^2 + \epsilon_u \epsilon_d - \alpha^2 \frac{\epsilon_u^3}{\epsilon_d}]$$