Flip mode emittance analysis

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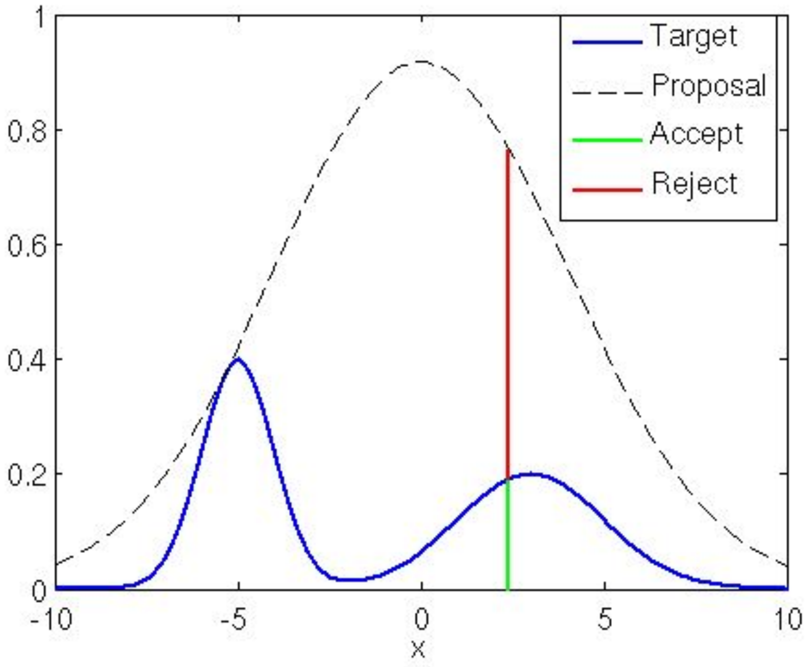
Overview

- Current status of refining the beam selection routines: Rejection Sampling
- Attempted an alternative: (Independence) Metropolis Markov Chain MC Sampling
- Analysis with full transmission imposed: DATA VS MC
- For the results presented here FULL LH2 and NO ABSORBER 6 mm, 140 MeV/c, FLIP mode data were used

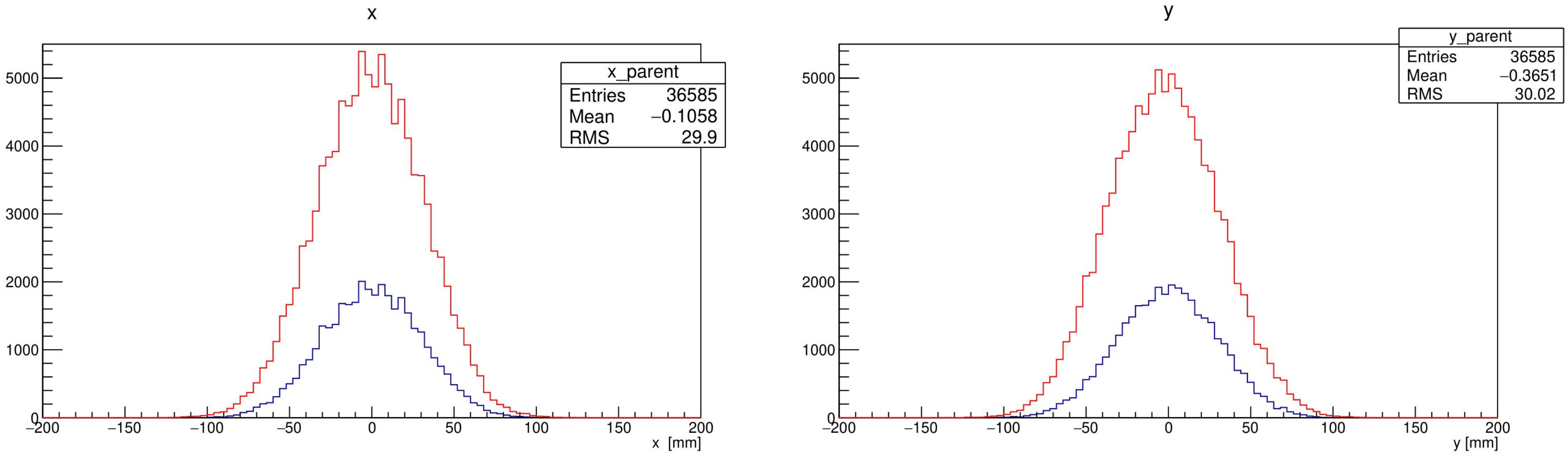
Beam Selection: Rejection Sampling

- $P_{selection}(x) = Norm * Target(x) / Parent(x)$
- Draw u from $U[0,1]$. If $u < P_{selection}(x)$ then accept event. Otherwise reject it.
- Normalisation calculation:
    - for a set large number of times (10k) randomly draw a sample x from the target distribution and take the minimum of *Parent (x) / Target (x)*
    - Normalisation ensures that $P_{selection}(x) <= 1$.

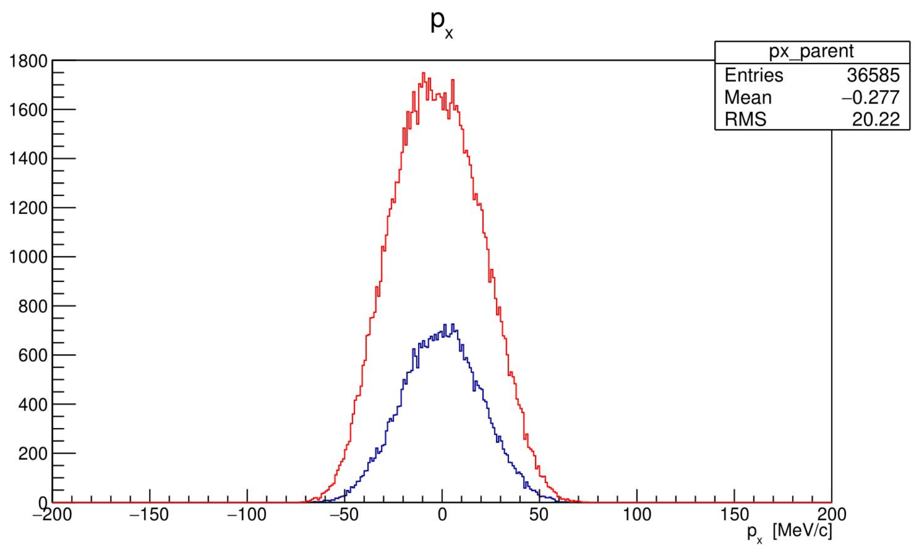


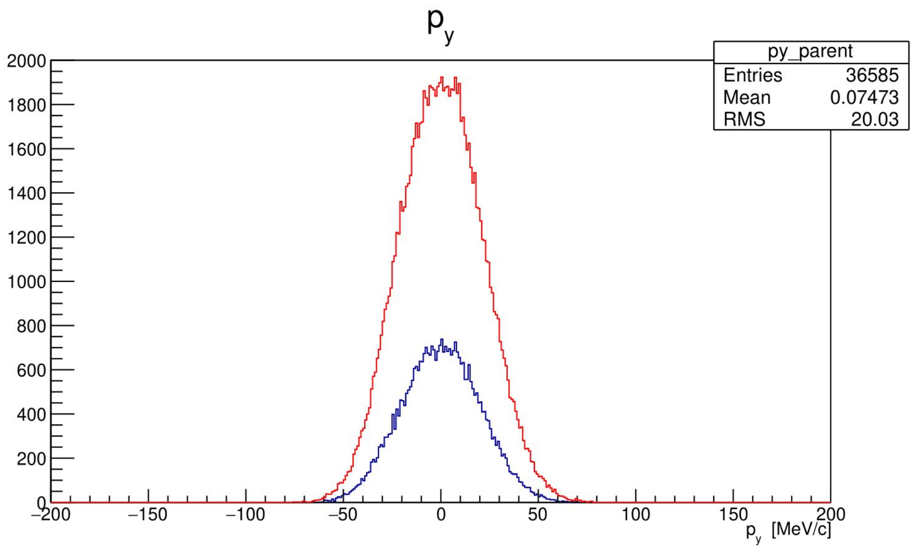
Parent VS Target (Full LH2 MC)

- RED - Parent; BLUE - Target
- ~ 4 mm emittance sampled target beam

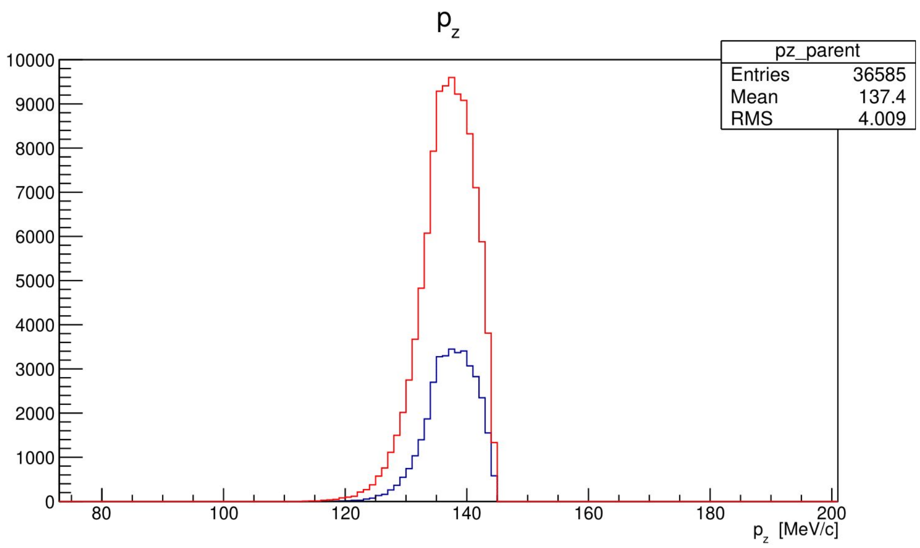


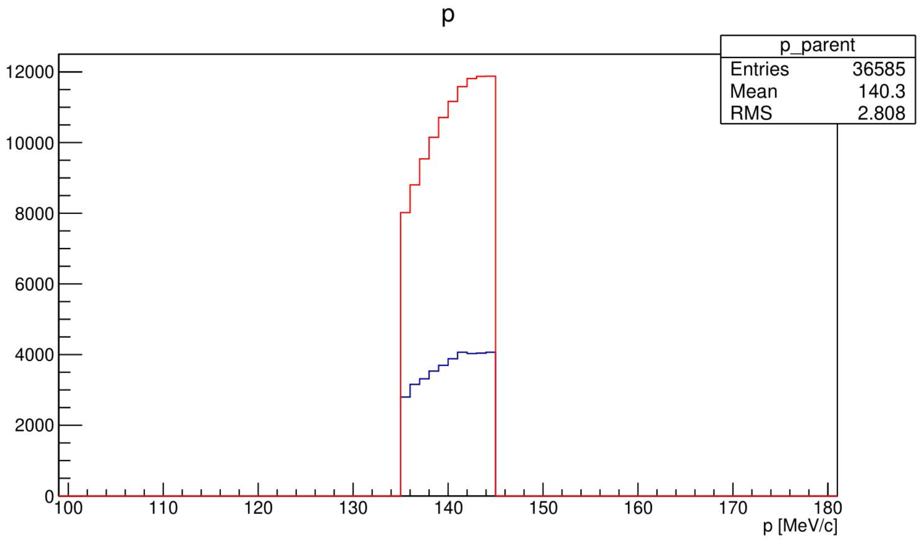
Parent VS Target (Full LH2 MC)





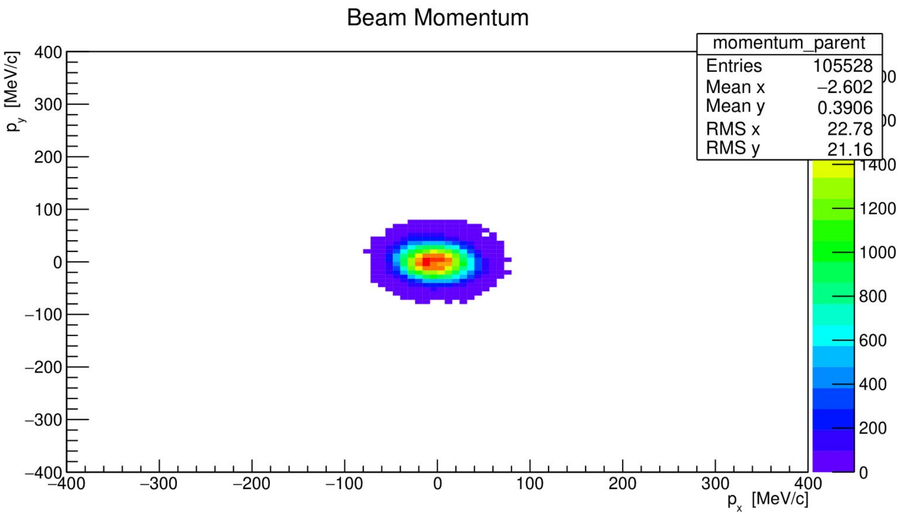
Parent VS Target (Full LH2 MC)



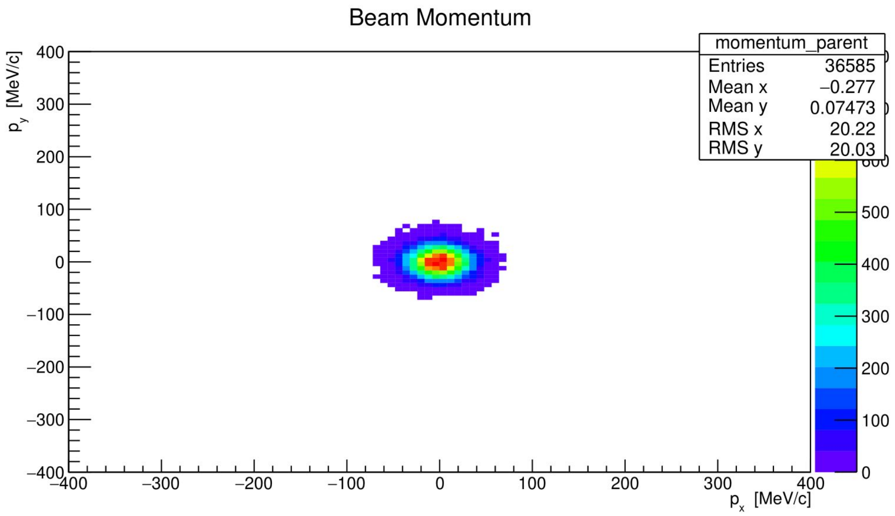


Parent VS Target (Full LH2 MC)

Parent

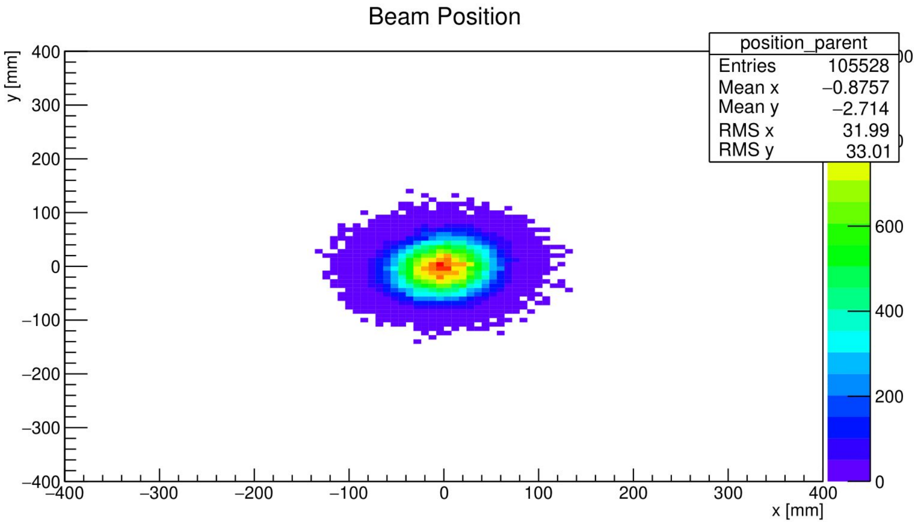


Target

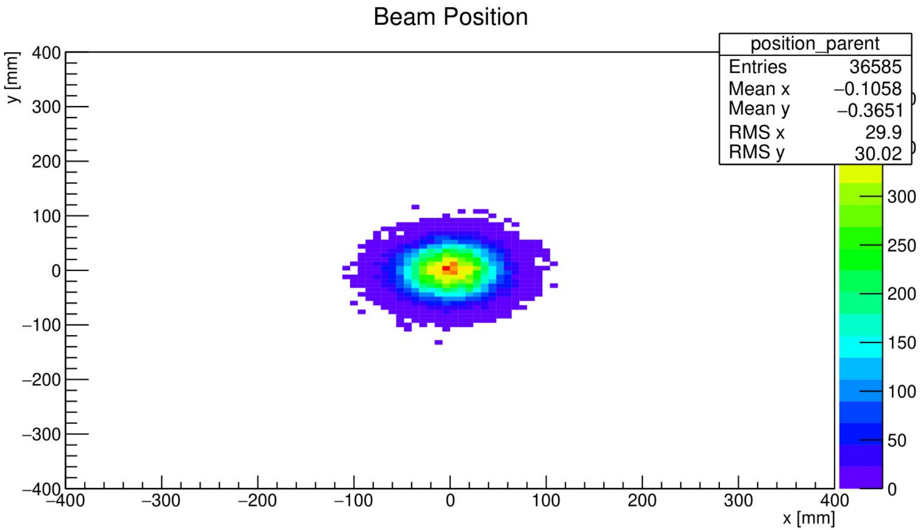


Parent VS Target (Full LH2 MC)

Parent



Target



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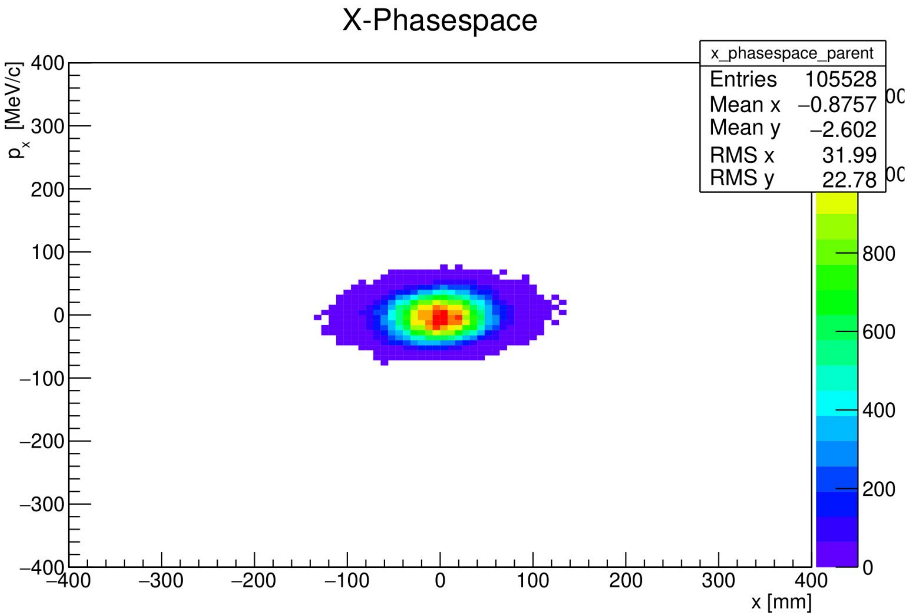
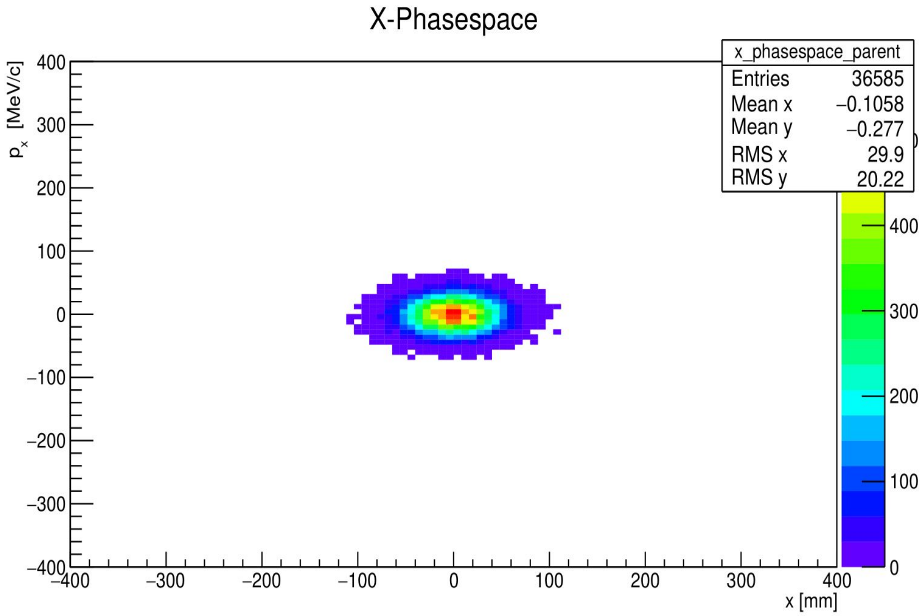
Parent VS Target (Full LH2 MC)

Parent

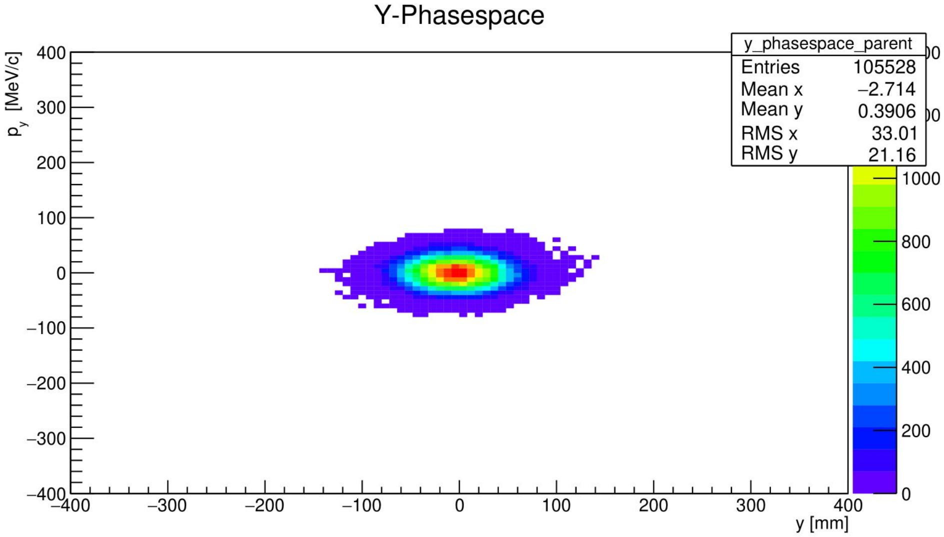


Target

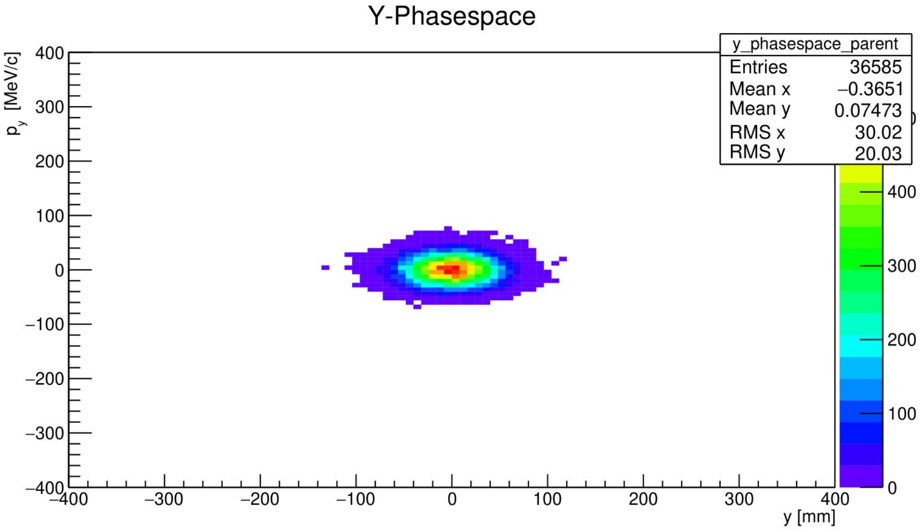


Parent VS Target (Full LH2 MC)

Parent



Target



Cooling performance comparison
Unmatched vs Matched/Improved Optics

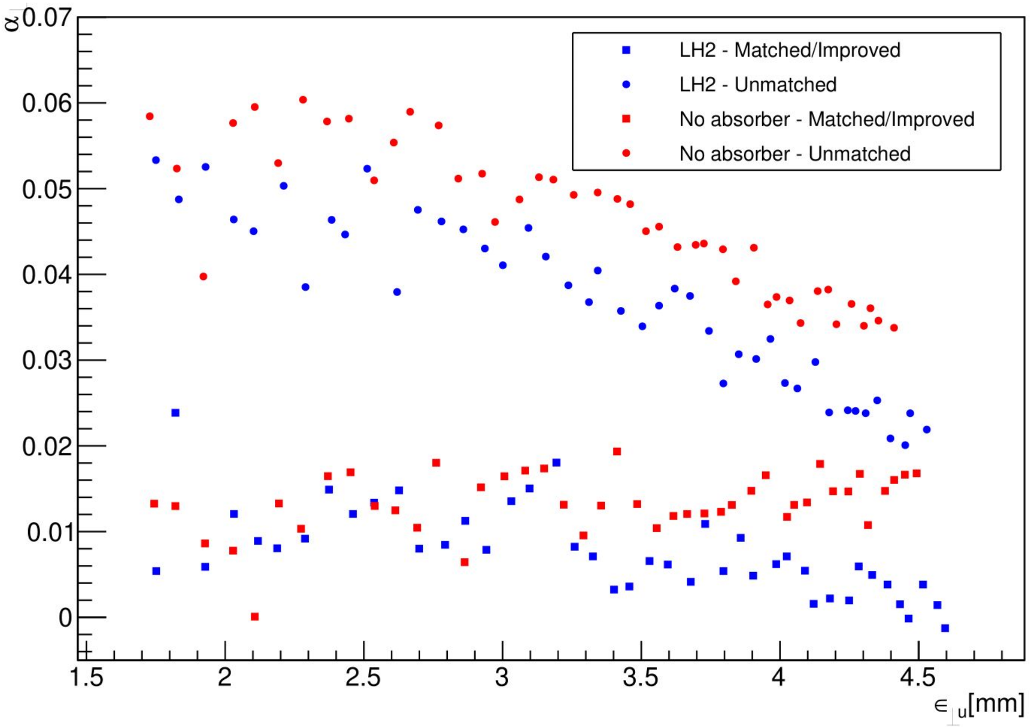
- Sampled a set of beams by requesting the same optics parameters as those of the parent beam (aim to preserve the original optics), but only varied the target emittance.

- Compared with a set of sampled beams with same targets emittances, but matched target optics parameters.

- Results presented in the form of relative emittance change between the two reference planes.

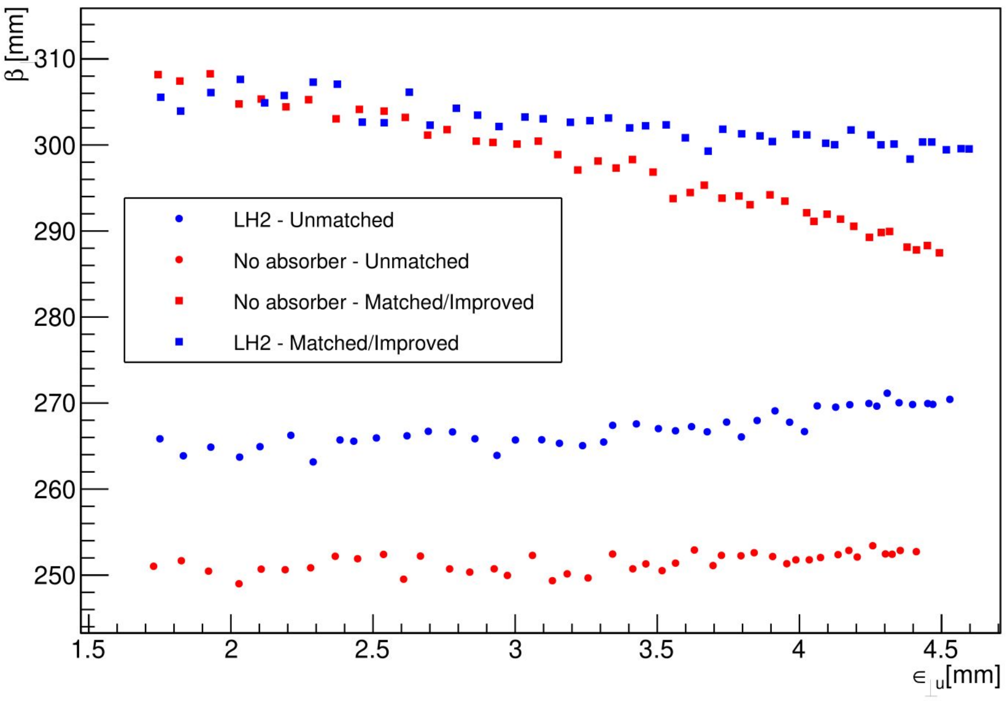
Target alpha TKU reference plane

- For the matched optics, α = 0.0 was requested
- For the unmatched optics, α = 0.04 (LH2) and α = 0.051 (No absorber) were requested



Target beta TKU reference plane

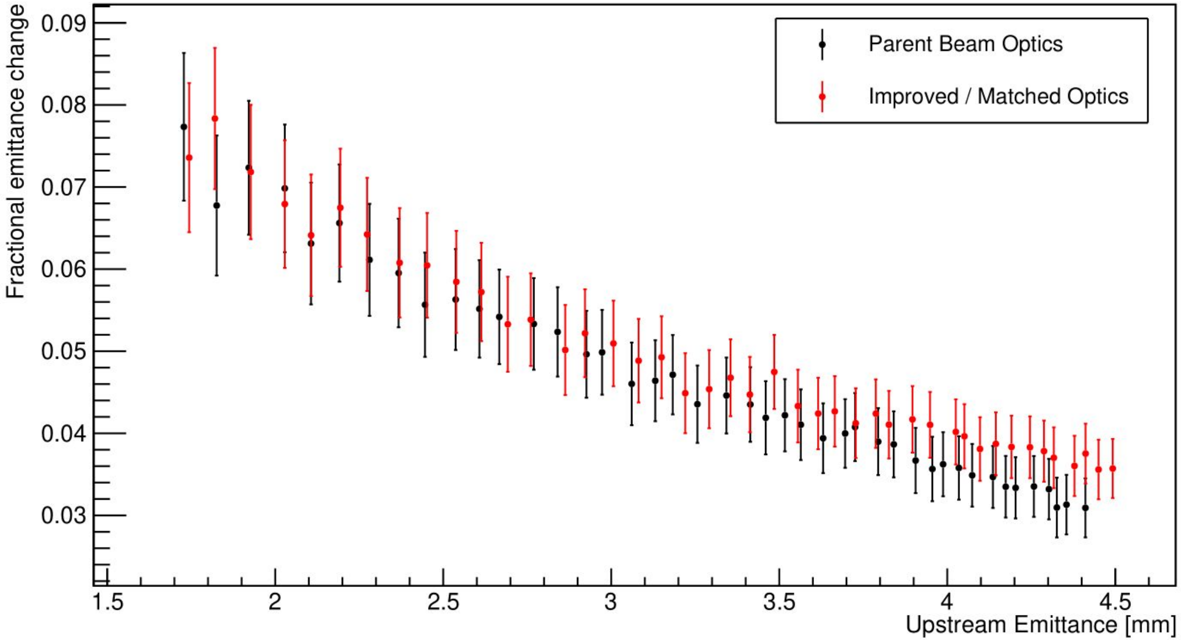
- For the matched optics, β = 310 mm was requested
- For the unmatched optics, β = 268 mm (LH2) and β = 252 mm (No absorber) were requested
- In the matched case, it can be observed that as the target emittance increases, beta converges towards the beta of the parent beam. As the target emittance approaches the parent emittance, the parent optics characterististics become noticeable



No absorber Data

Slightly more heating present in the matched optics sampled beams at higher emittances.

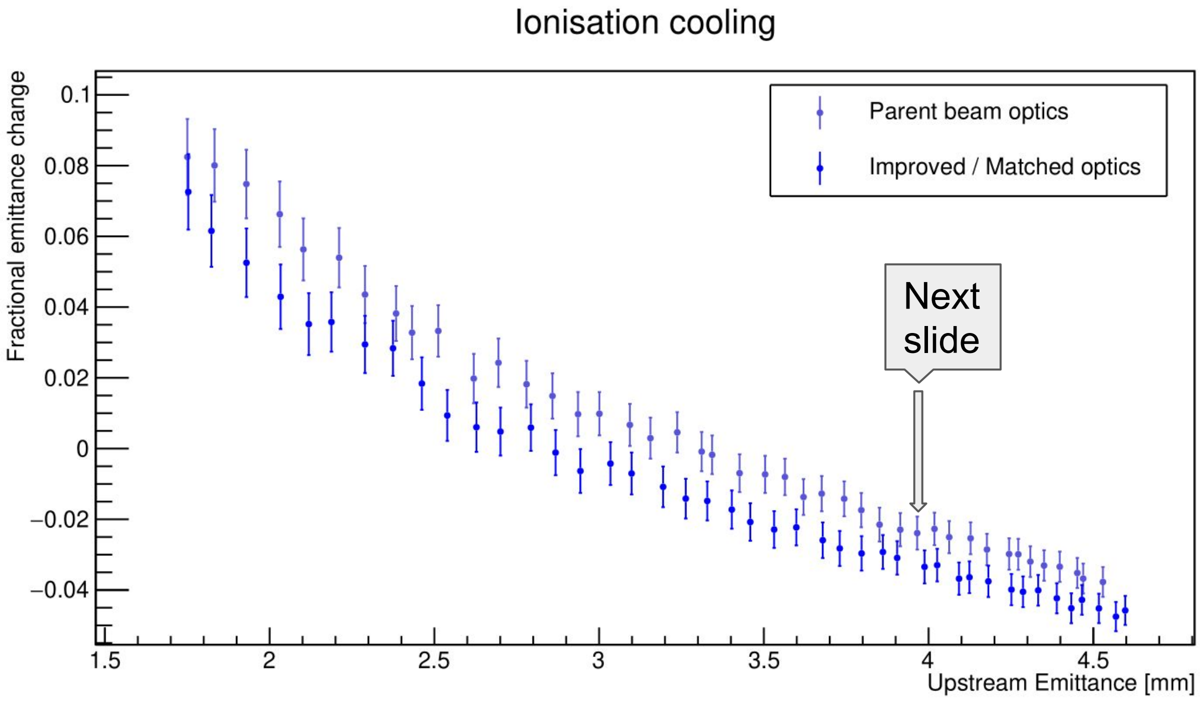
Need to study the optics between the trackers using hybrid MC.



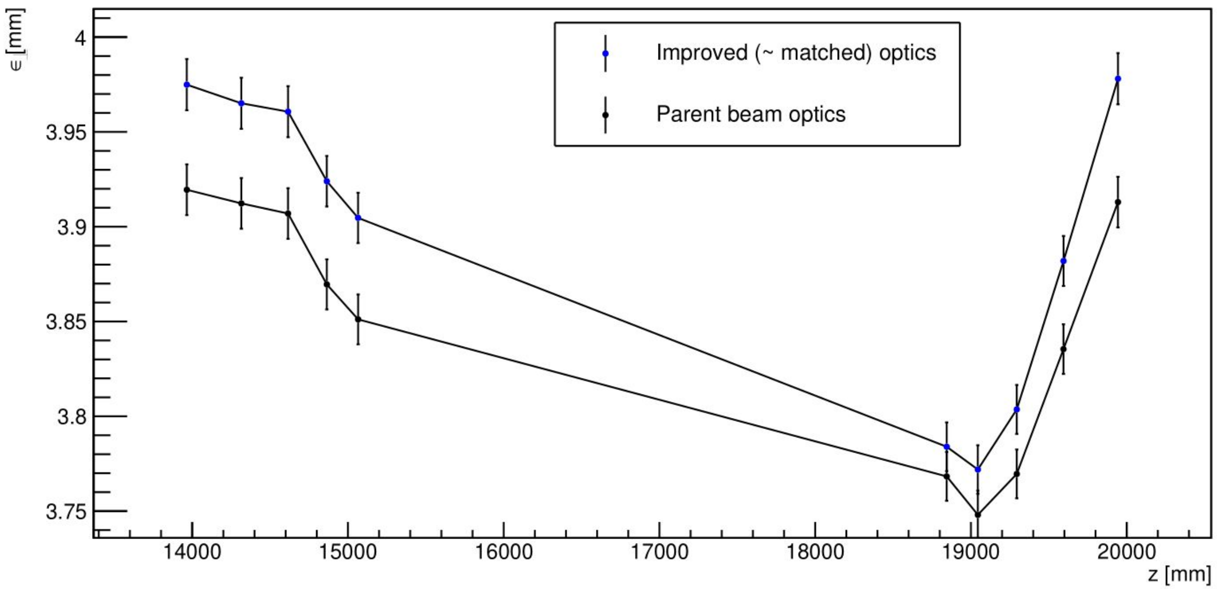
Full LH2 Data

Consistently more cooling seen in the sampled beams with improved optics.

This indicates that beta at the absorber is reduced, resulting in less MCS heating.



Greater emittance decrease observed for the beam with improved (~ matched) optics.

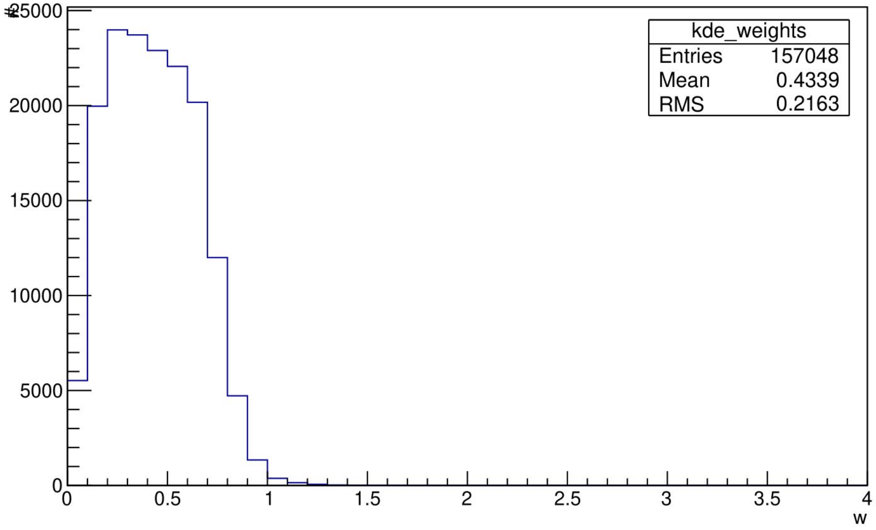


Rejection Sampling: Limitations

- Method suffers from the curse of dimensionality. As the number of dimensions increases the rate of rejection increases and algorithm becomes inefficient.

- Rate of rejection (~ normalisation) is also affected if the target distribution has heavier tails than the parent. In this case the normalisation and thus the rate of acceptance $\rightarrow 0$. One such case would be when the emittance of the target is similar to the parent emittance.

- However, this is not observed. Instead, in such cases the normalisation is actually not small enough and the probability of selection for some events > 1. Will need to further dig into the normalisation calculation.
- Currently the normalisation calculation takes 10k iterations, seemingly not enough to estimate the normalisation accurately.
- However, method works well at target emittances smaller than the parent emittance.



An alternative (?): (Indpendent) Metropolis Markov Chain MC

Essentially a random walk through the parent distribution phase-space and accepts events into the target distribution according to the following algorithm:

- Draw a first sample from the parent distribution. Then for all the particles in the parent distribution proceed as follows:
  - Randomly draw another particle (proposal). Calculate the acceptance coefficient as follows:

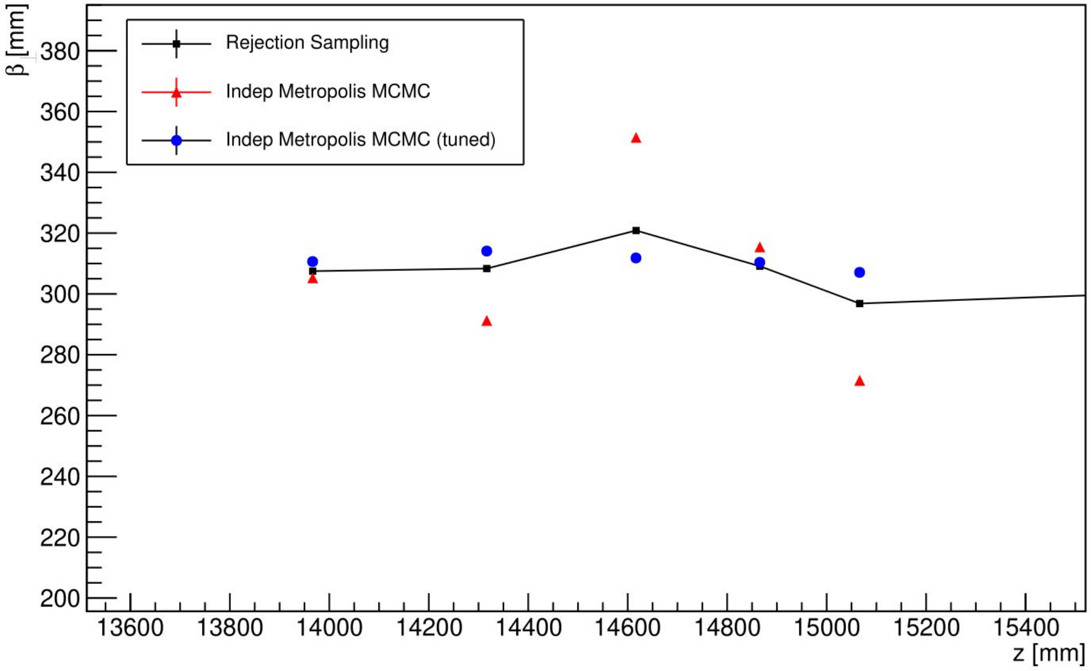
$$a = min(1, \frac{P_{target}(proposal)}{P_{target}(current)} \frac{P_{parent}(current)}{P_{parent}(proposal)})$$

- Draw *u* from *U[0,1]*. If *u* < *a* then accept event and update *current* = *proposal*. Otherwise reject it and keep *current* state the same.

- So far this algorithm does not seem to match the performance of Rejection Sampling, unless fiddled with / tuned (draw u from U[0.5, 1))

Sampled Beams Beta Comparison (TKU)

- All the sampled beams have a 4 mm target emittance, 310 mm target beta
- In terms of matching, the standard MCMC algorithm performs worse than Rejection Sampling, as oscillations are observed
- The tuned version of the MCMC however, shows better matched optics than RS.
- However, the same improvement is not observed for beams with 2, 3, 5 mm target emittance.



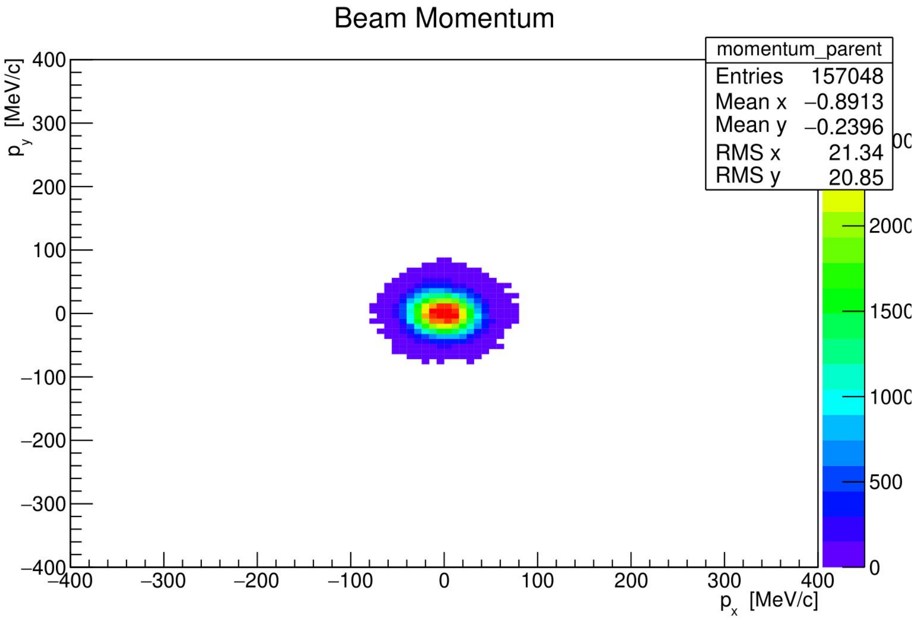
MCMC: Parent VS Target

- Overall, the particular Metropolis MCMC algorithm employed here has a better acceptance rate than Rejection Sampling, but this costs in terms of matching performance.

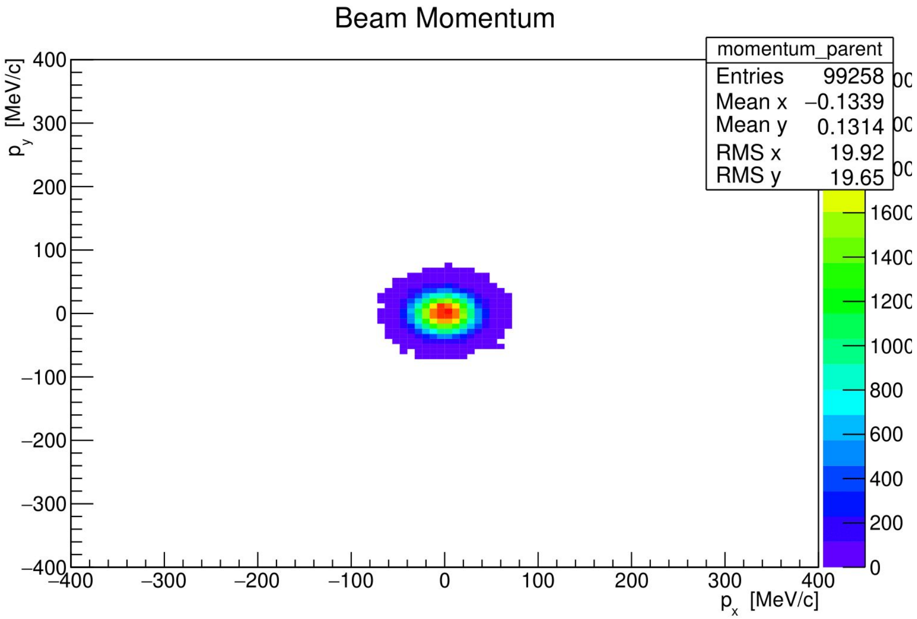
- Next two slides - Parent / Target comparisons using No absorber data. The target has ~ 4 mm emittance.

Parent VS Target (No absorber Data)

Parent

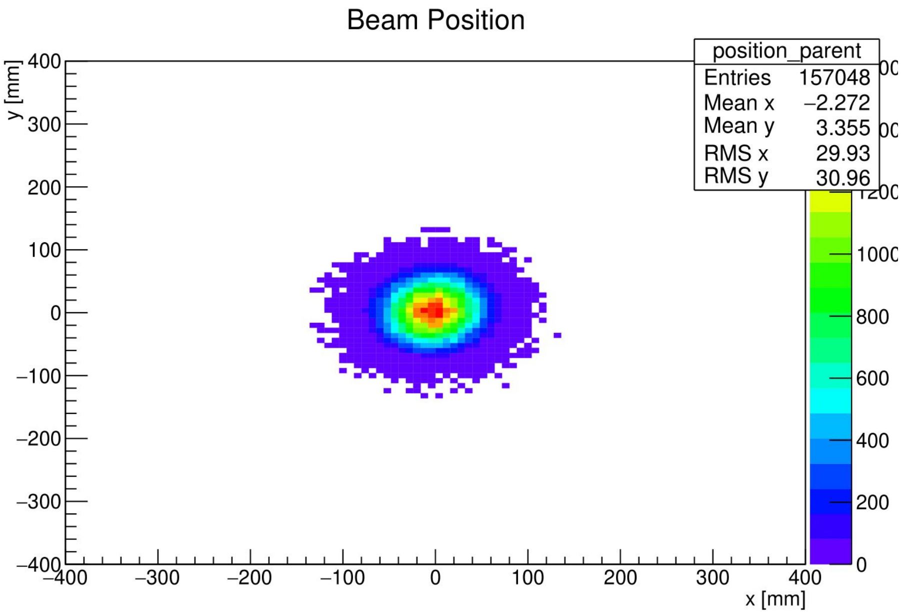


Target

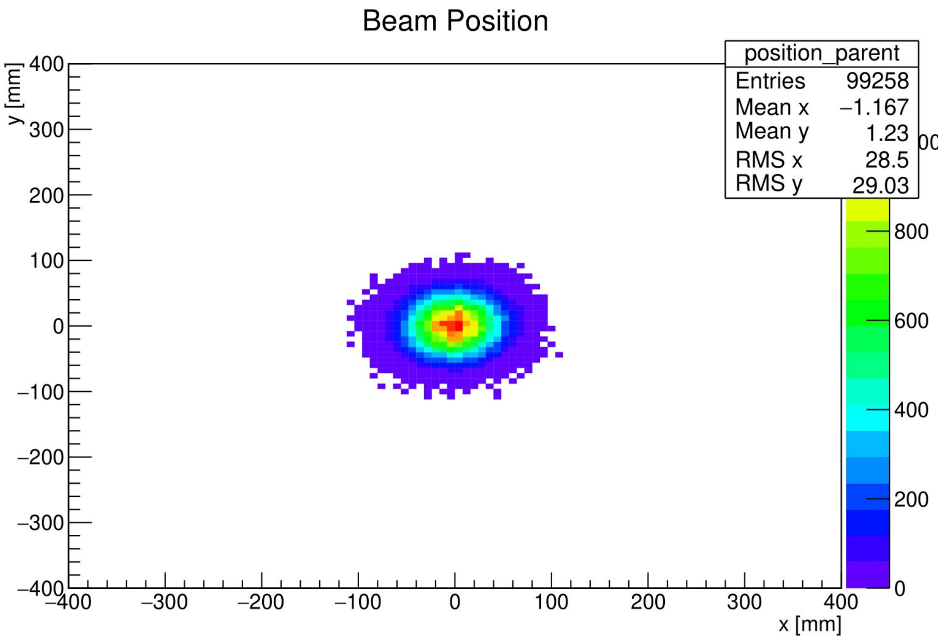


Parent VS Target (No absorber Data)

Parent



Target

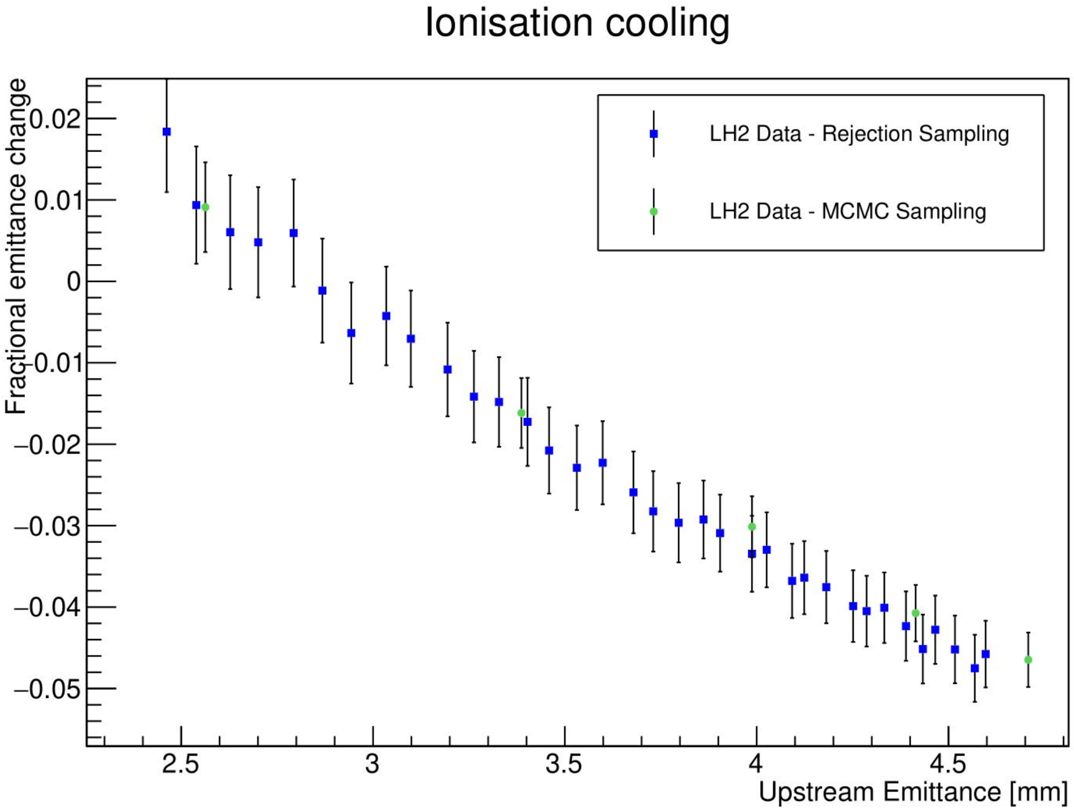


MCMC Sampling Cooling Performance

Cooling performance similar to the one obtained via Rejection Sampling at target emittances below < 3.5 mm.

At target emittances above ~ 4 mm, performance not as good (however, still better than the case of unmatched optics).

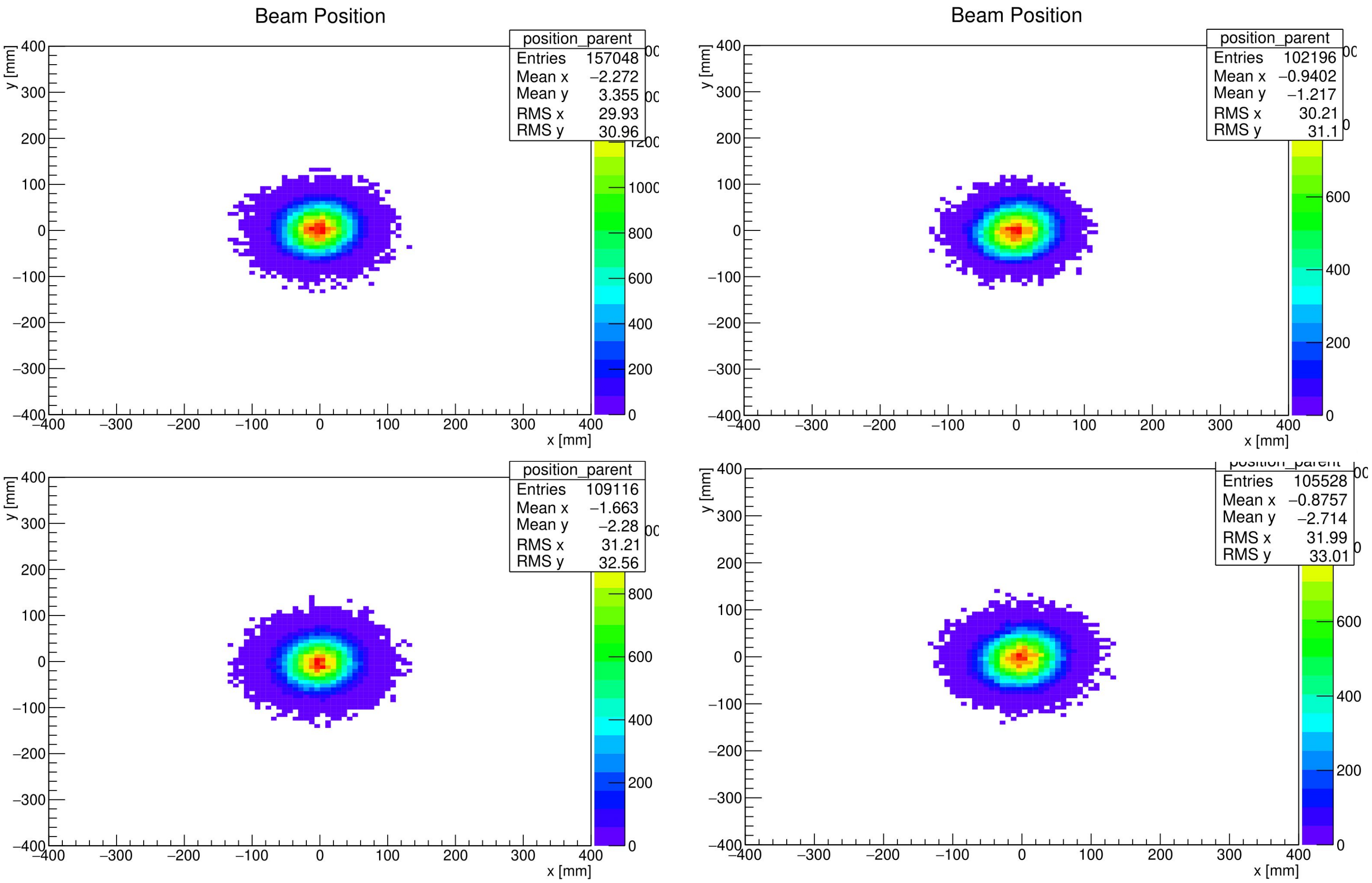
Next to consider the Random-Walk Metropolis algorithm.



6mm Full LH2 & No absorber
Data / MC comparison

- Used Chris' MC

- Applied the beam sampling routine (Rejection Sampling) to the parent beam that survived the same set of cuts as the data



No absorber

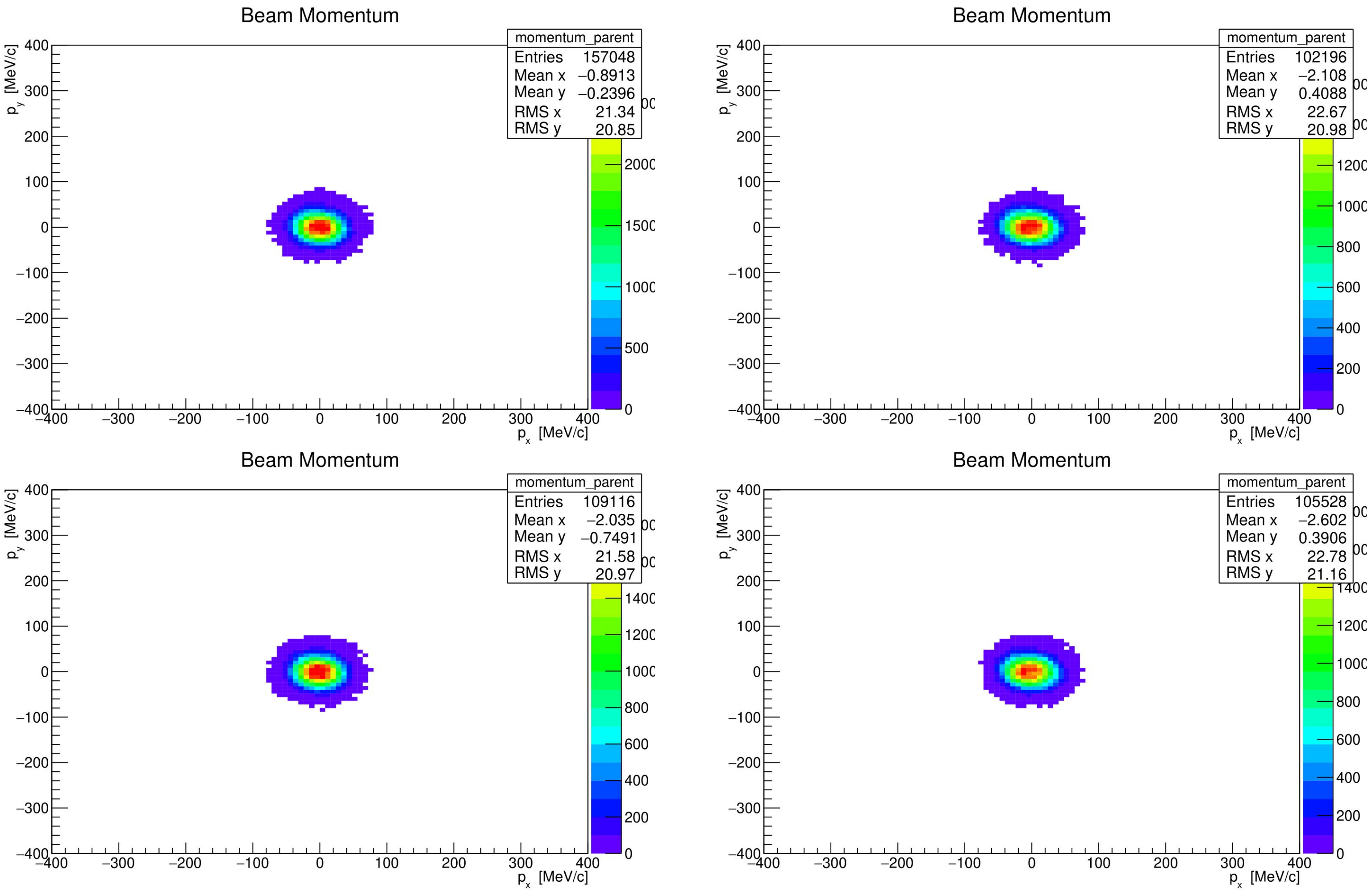
LH2

Data

MC

No absorber

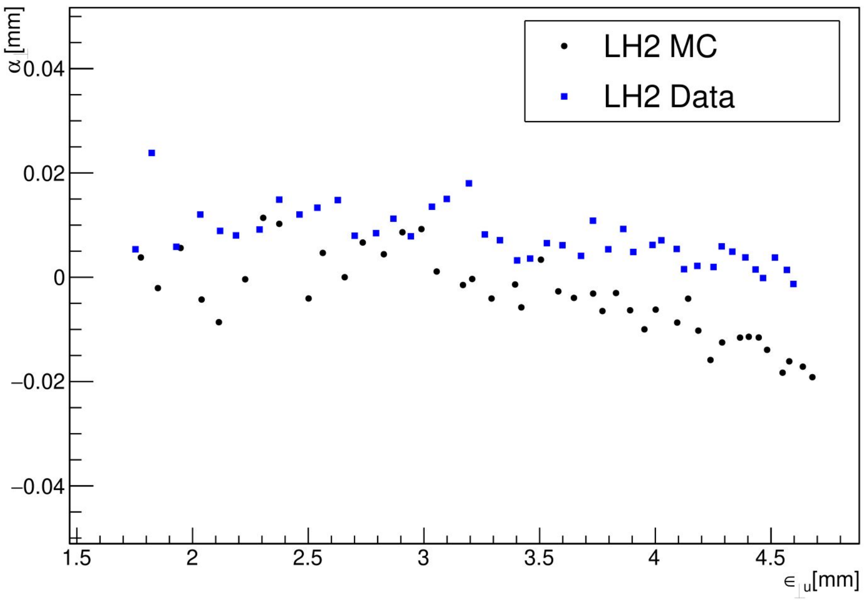
LH2

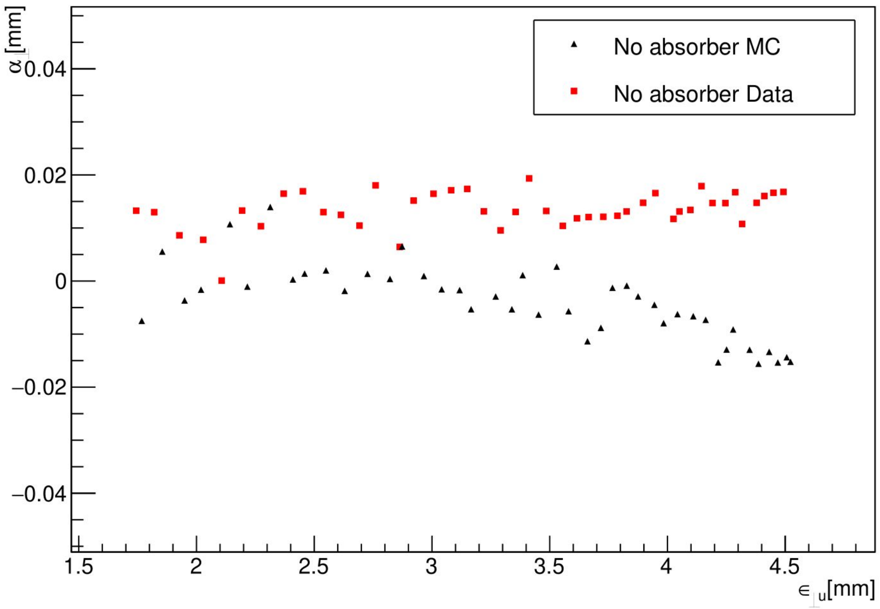


Data

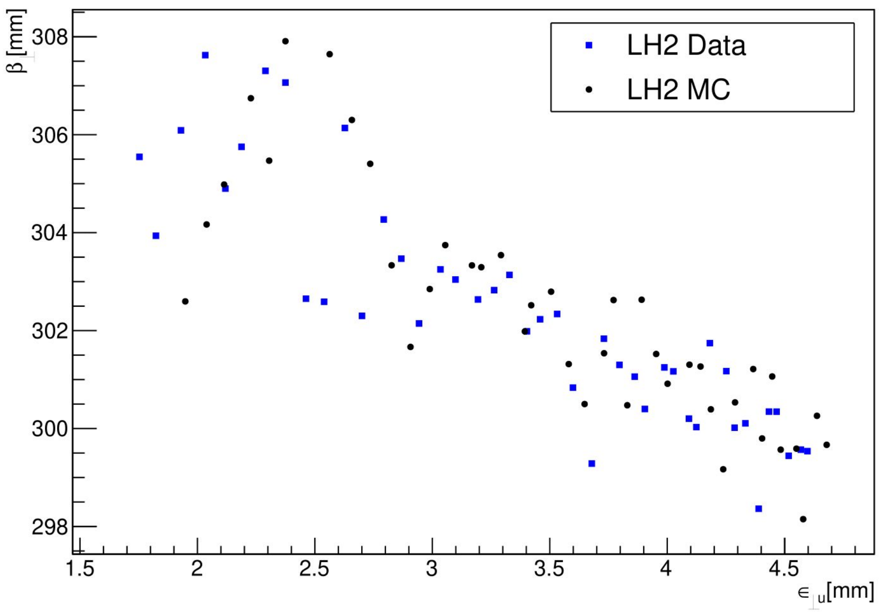
MC

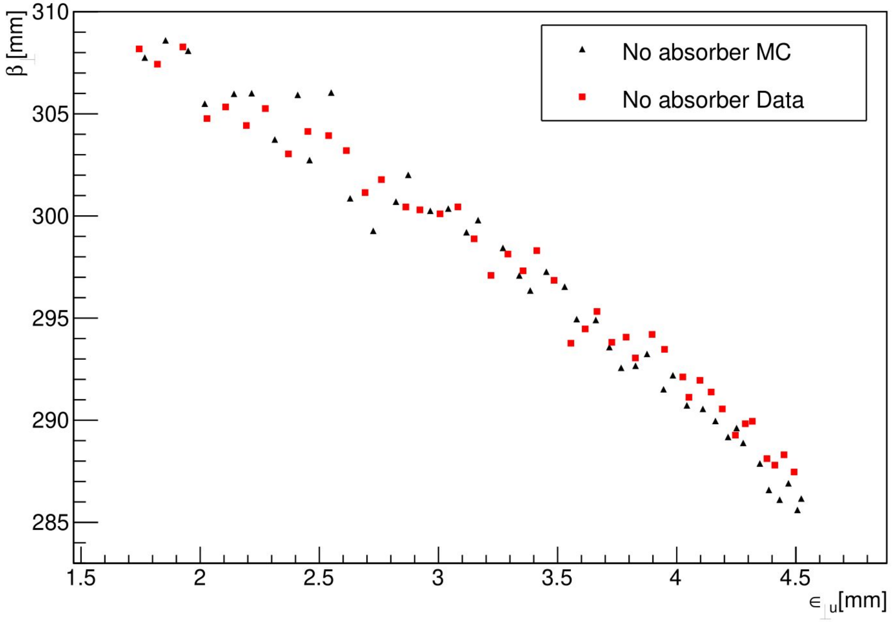
TKU reference plane: target alpha



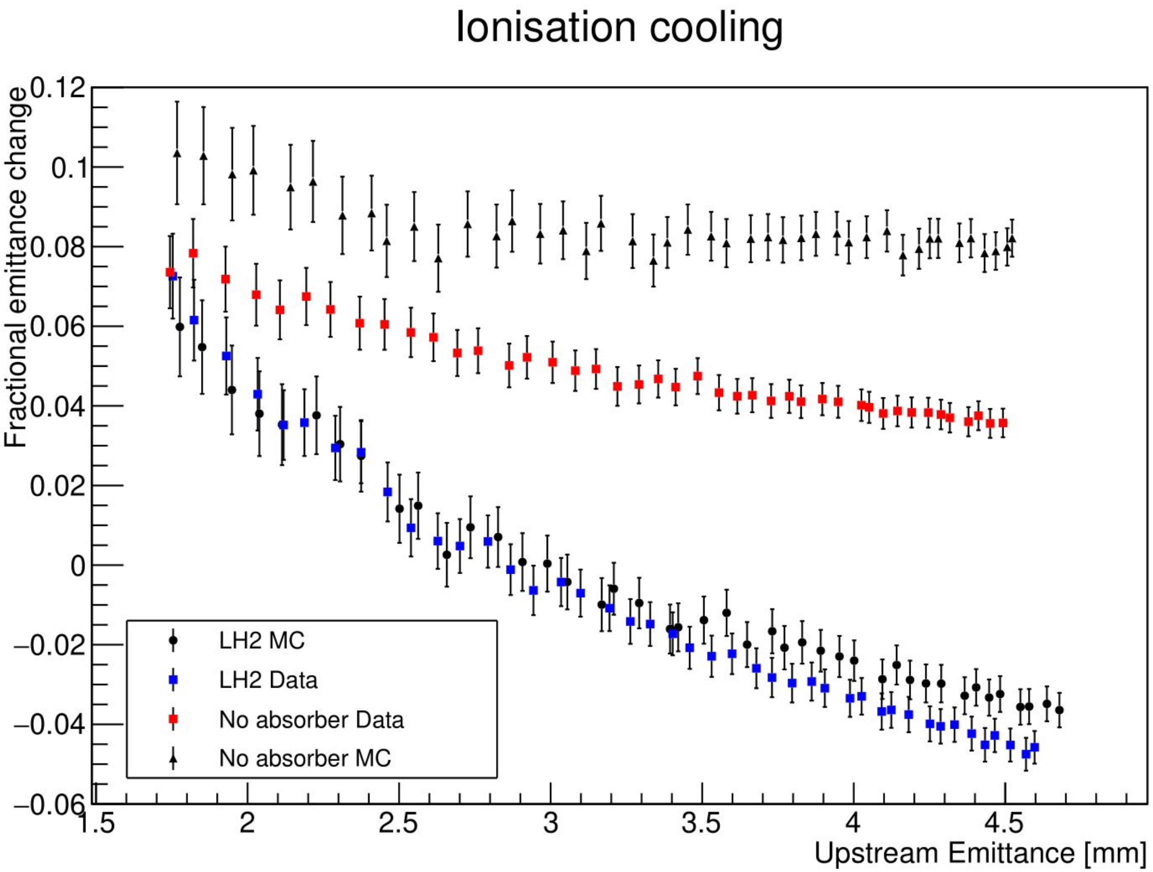


TKU reference plane: target beta





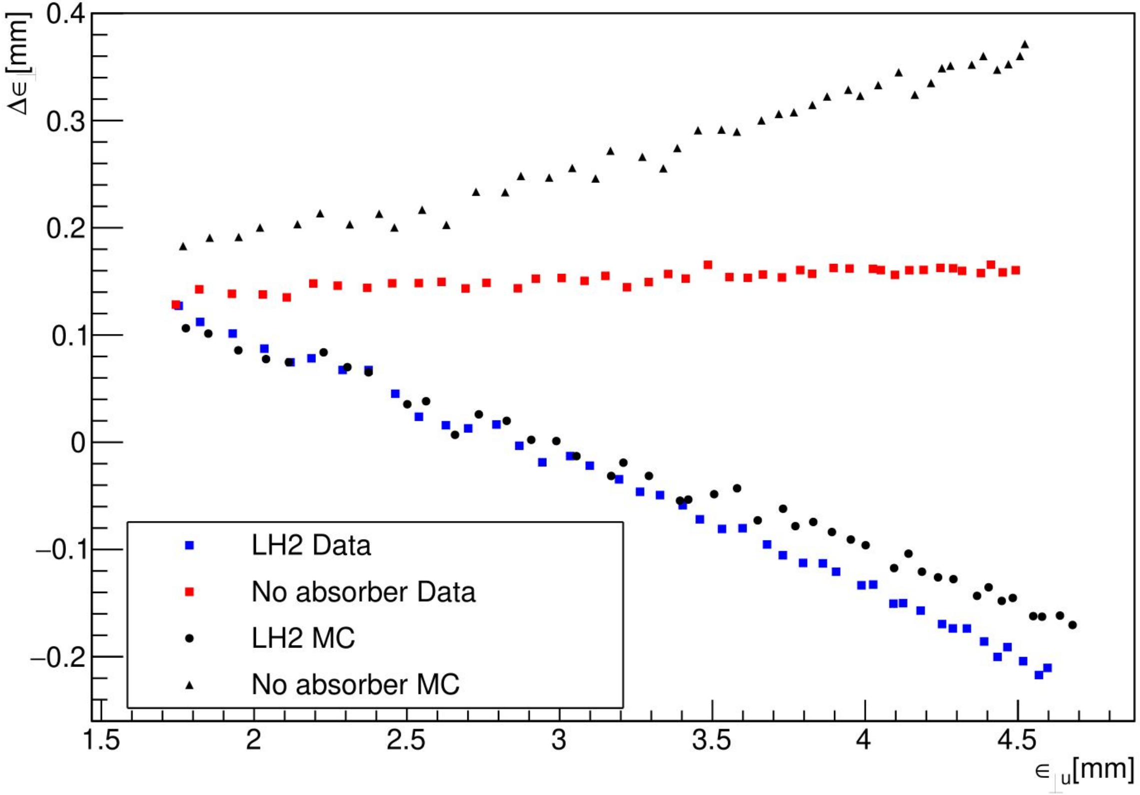
Relative emittance change



Above 3.5 mm, more cooling observed in data than MC. Consistent otherwise.

In the No absorber case, consistently more heating seen in MC. Apparent cause are tail events that are pulling the emittance downstream. Need to double check.

Absolute emittance change



No absorber - in data, heating slightly dependent on emittance. Correlation stronger in MC. Possible cause could be the difference in optics at the upstream -> enhanced exposure to non-linear effects.

LH2 - discrepancy between data and MC occurs for beams with emittance above 3.5 mm. Needs digging.

Hybrid MC (truth) studies required.

Emittance change via core Amplitude Mobility

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 follows:

$$\lim_{A_\perp \to 0} \frac{f^d(A_\perp)}{f^u(A_\perp)} = \left(\frac{\varepsilon^u_\perp}{\varepsilon^d_\perp}\right)^2$$

This can then be used to calculate the relative emittance change as follows:

$$\Delta\epsilon_{\perp rel} = \sqrt{(f^u / f^d)} - 1$$

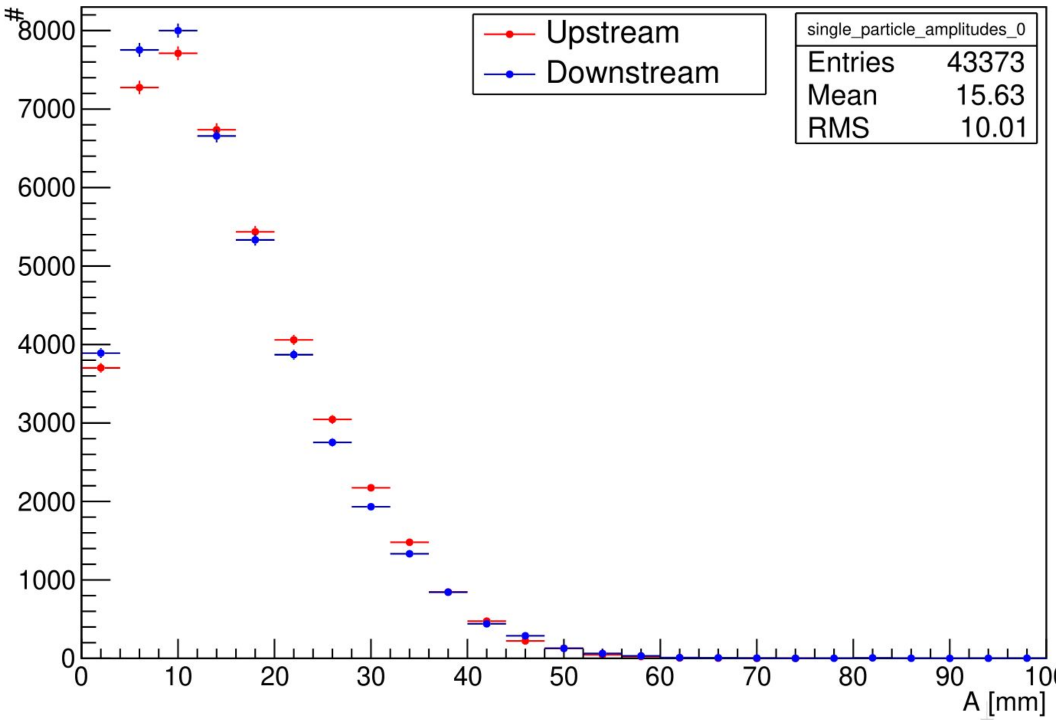
Amplitude distributions - LH2 Data

~ 4 mm emittance sampled beam

Amplitude bin size is 4 mm

Net migration into the core of the beam is observed

NOTE: here amplitudes calculated using the full ensamble covariance matrix

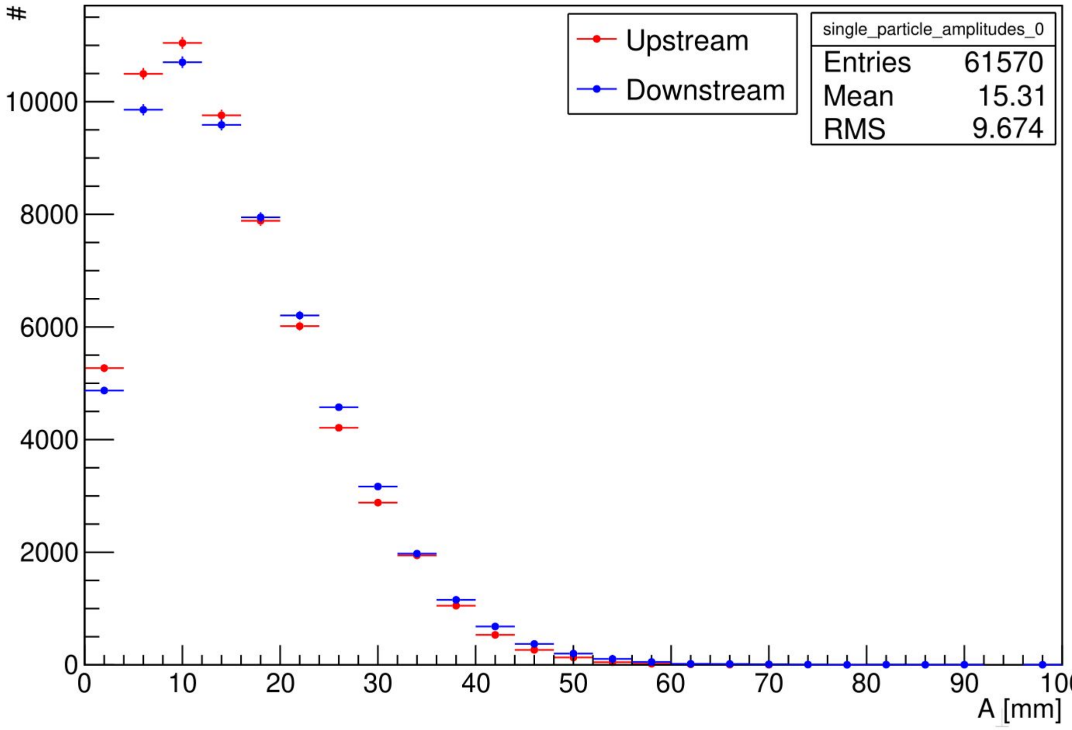


Amplitude distributions - No absorber Data

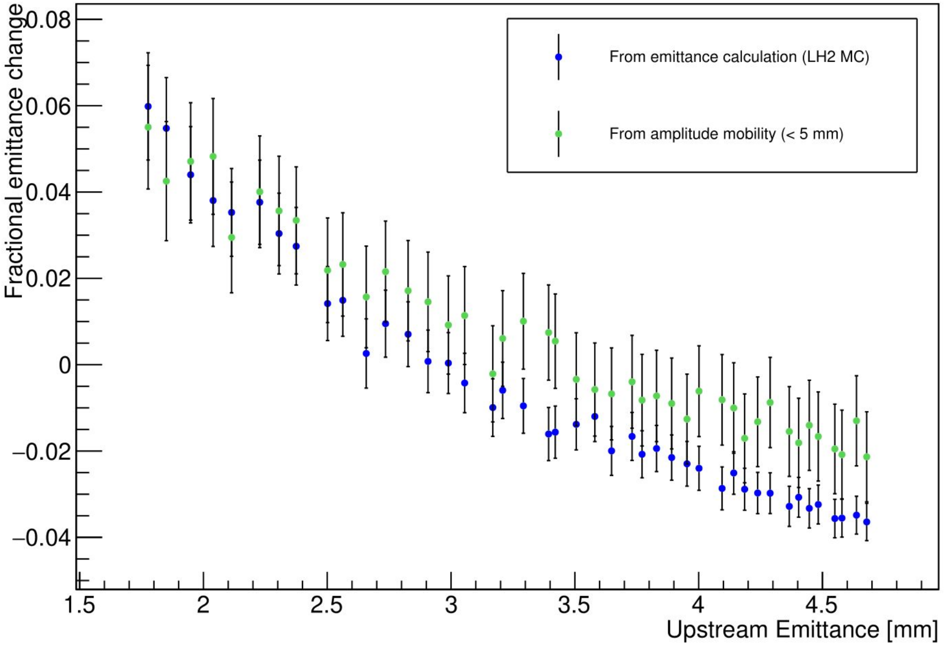
~ 4 mm emittance sampled beam

Amplitude bin size is 4 mm

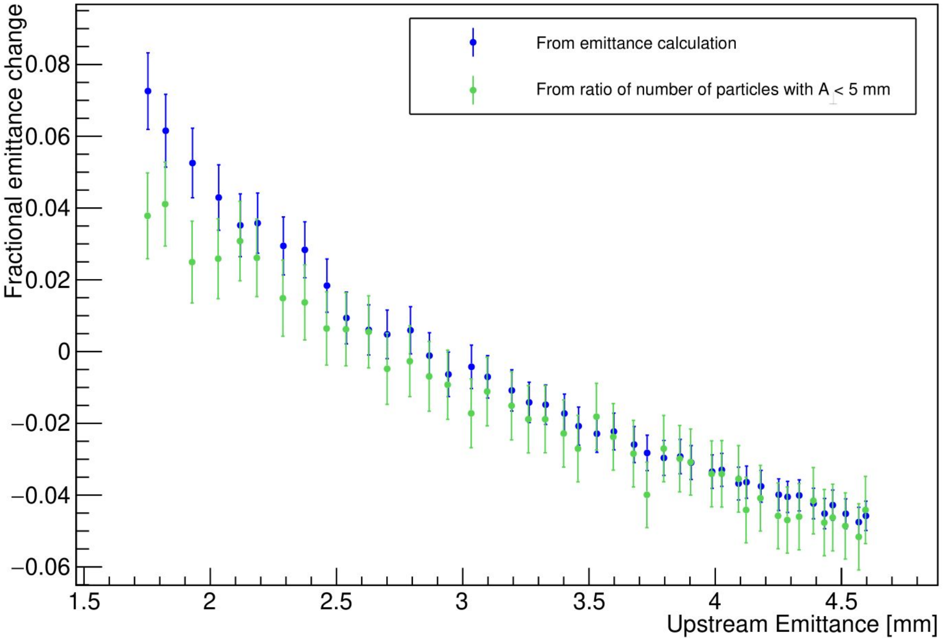
Net migration out of the beam core is observed



5 mm amplitude bins

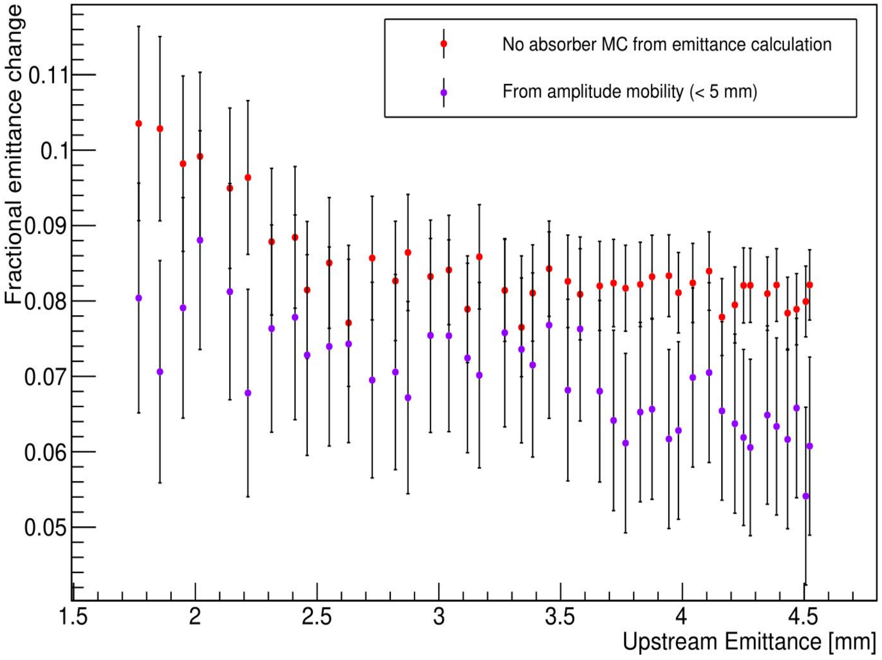


LH2 - MC

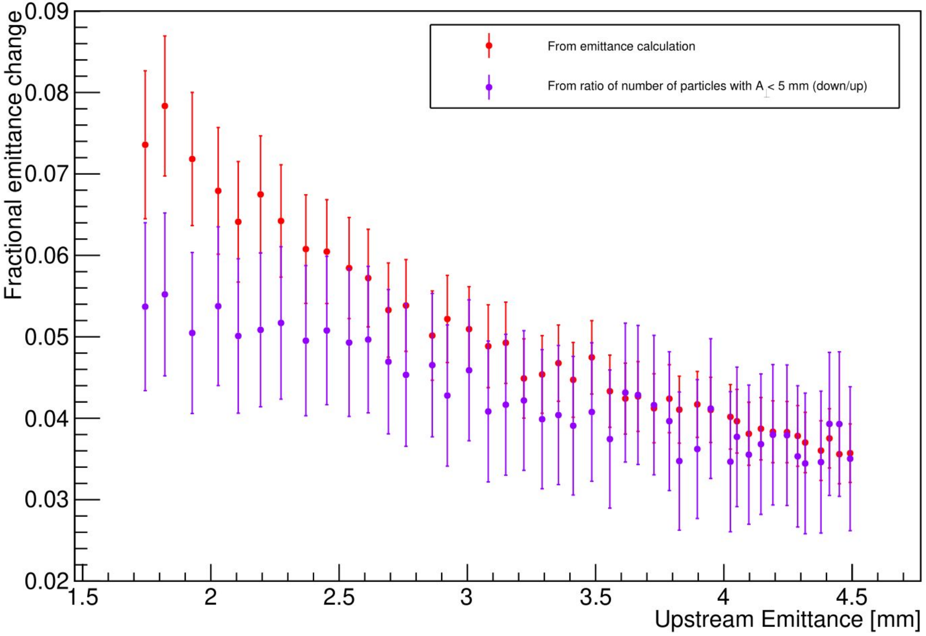


LH2 - Data

5 mm amplitude bins

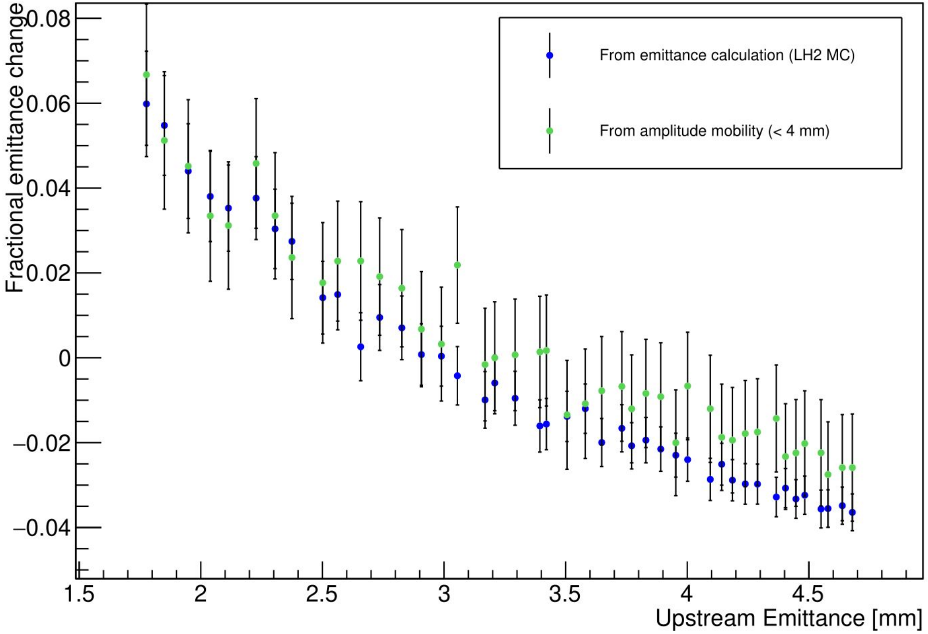


No absorber - MC

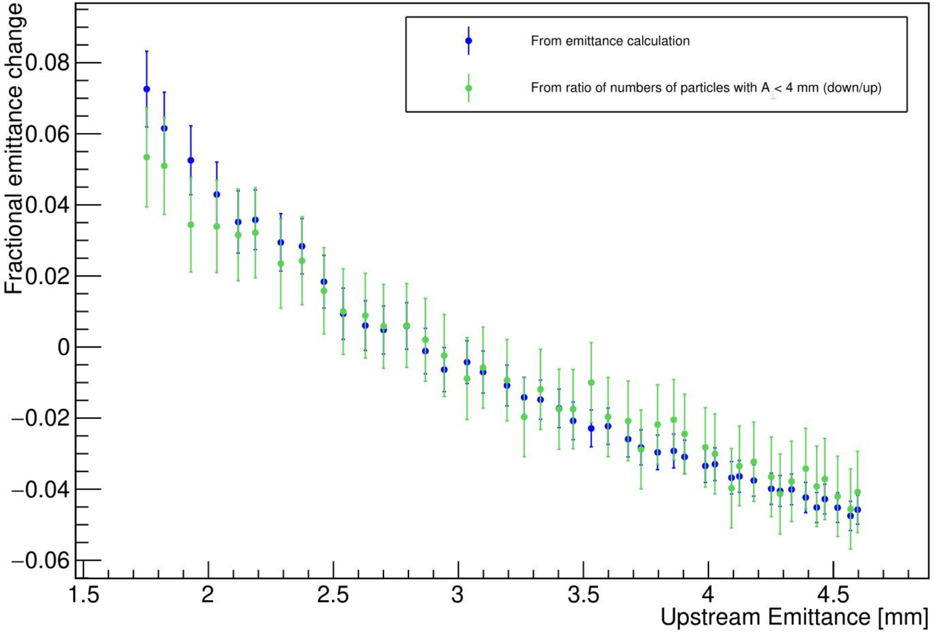


No absorber - Data

4 mm amplitude bins

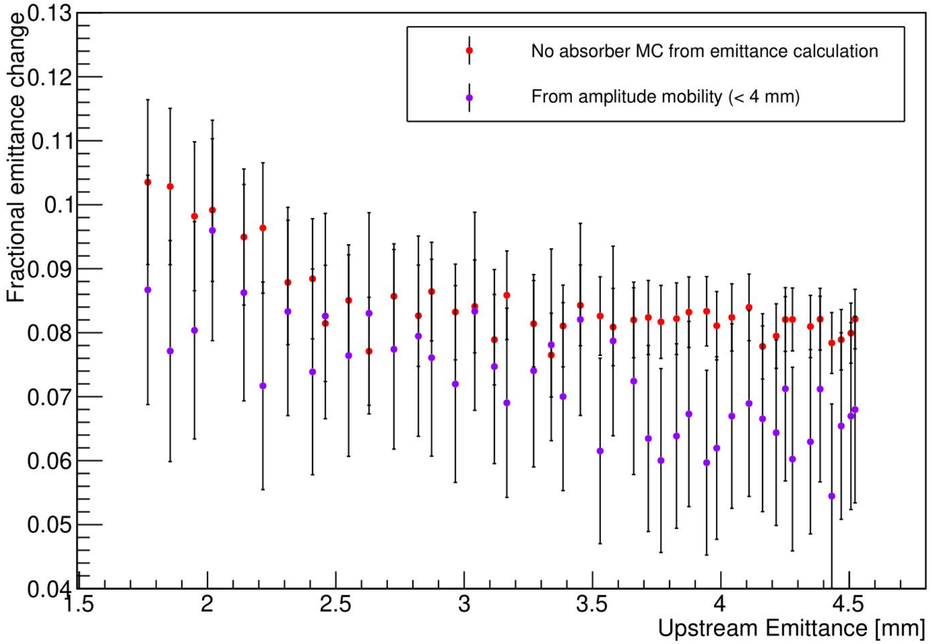


LH2 - MC

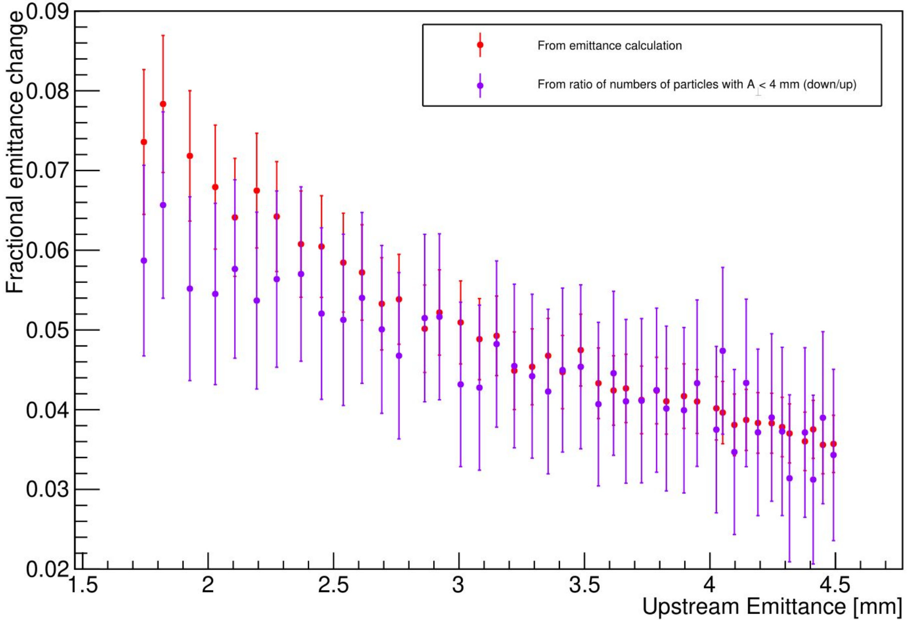


LH2 - Data

4 mm amplitude bins

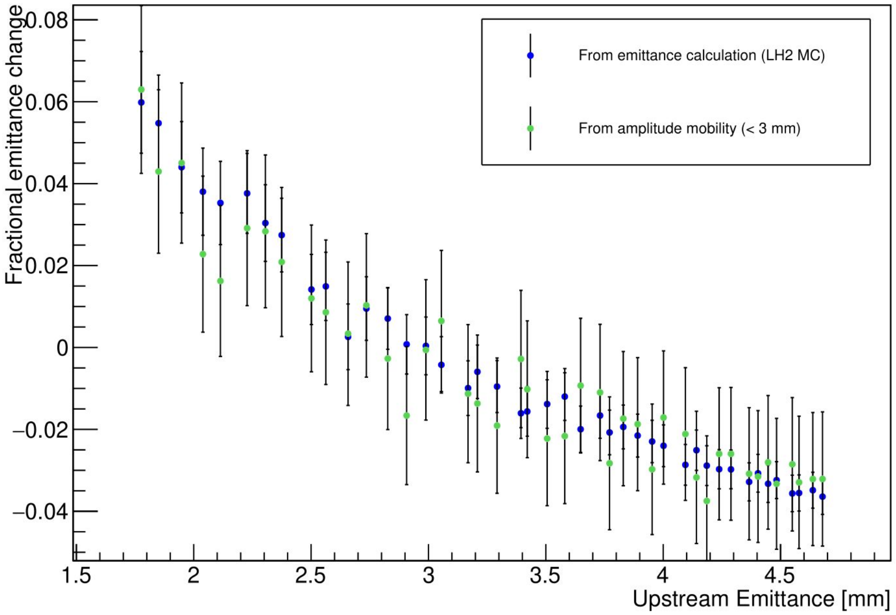


No absorber - MC

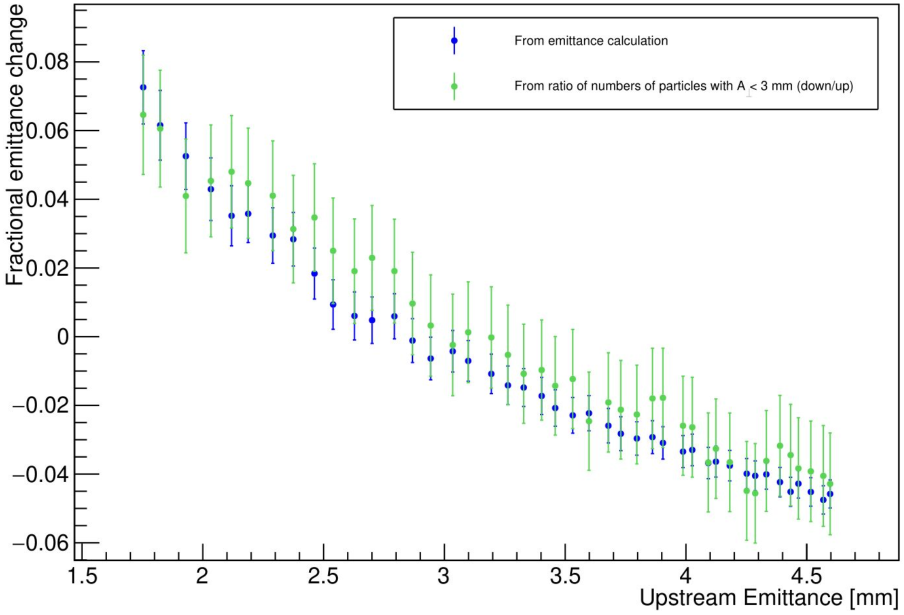


No absorber - Data

3 mm amplitude bins

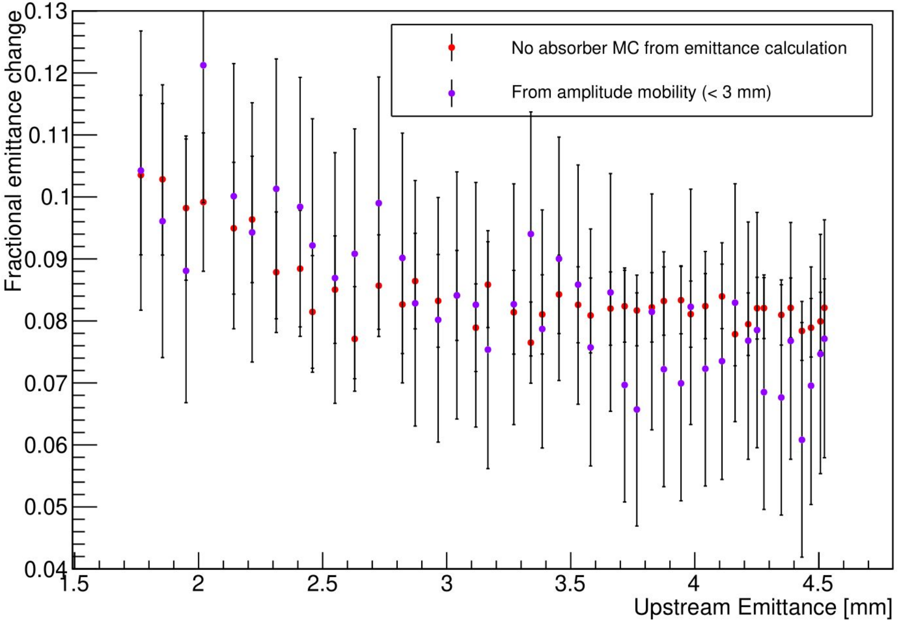


LH2 - MC

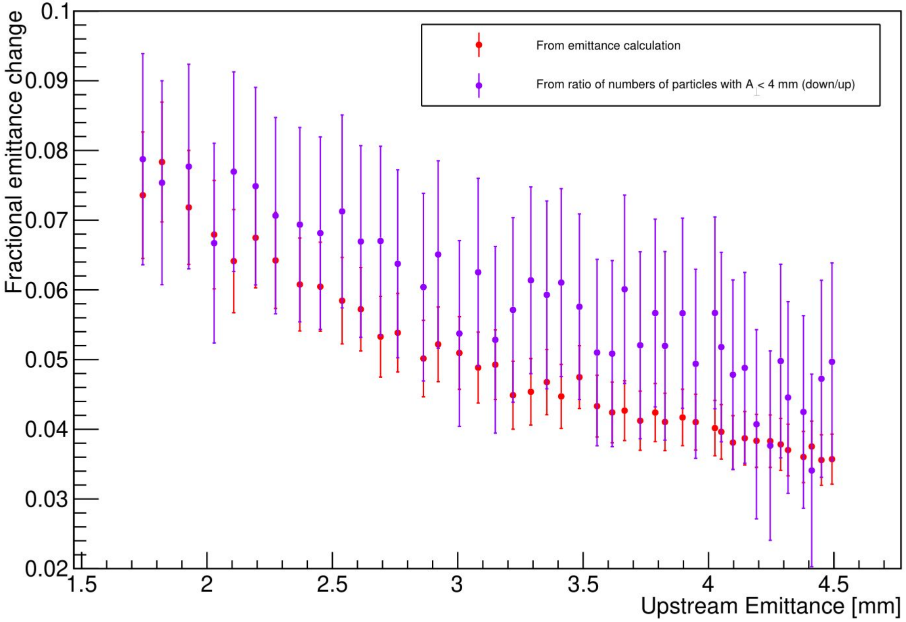


LH2 - Data

3 mm amplitude bins



No absorber - MC



No absorber - Data

Summary

- implemented an Metropolis MCMC sampler in an attempt to improve the selection routines; did not perform as well as rejection sampling
- compared the performance of matched vs unmatched beam optics : cooling is improved. This is probably due to a reduction of beta at the absorber, rather than optical heating suppression
- DATA / MC comparison: partially good agreement of cooling; In the absence of an absorber, complete disagreement. Enhanced tails develop in MC ->more heating
- Emittance calculation from amplitude: promising results. Needs further work.
- next steps:
  - hybrid MC production - needs TOF Tracker combined fit. Run simulations from just upstream of TOF0 (?)
  - Use hybrid MC to study beam optics between trackers
  - Improve amplitude calculation - implement Chris R algorithm
  - MC production - increase stats; COMPARISON PLOTS ON THE WAY (cuts, phase space etc)
  - continue trying to improve beam selection: Random-Walk Metropolis MCMC sampling

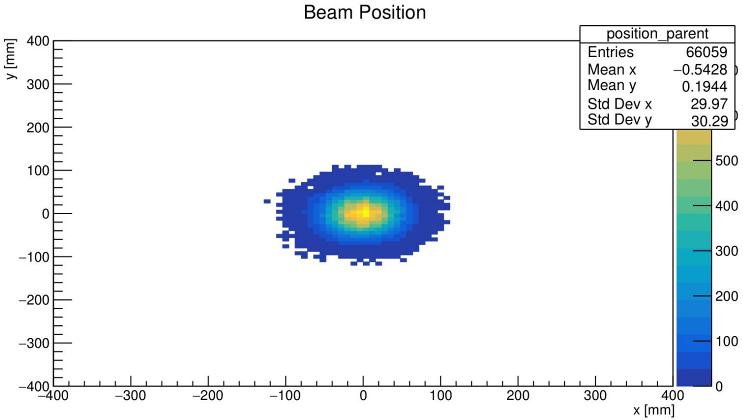
BACK UP

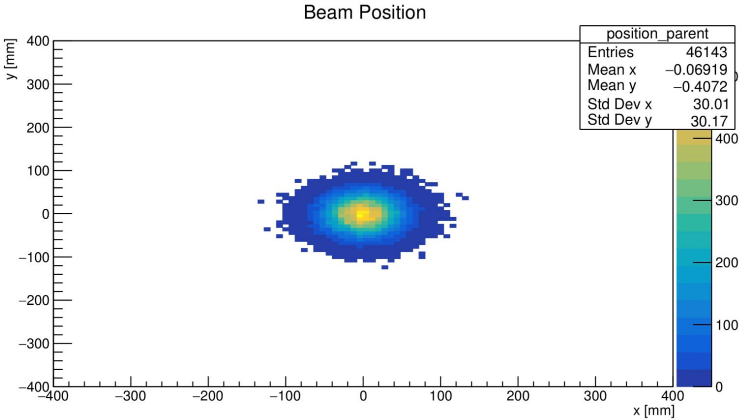
Sampled Beam Evolution - xy

NO ABSORBER

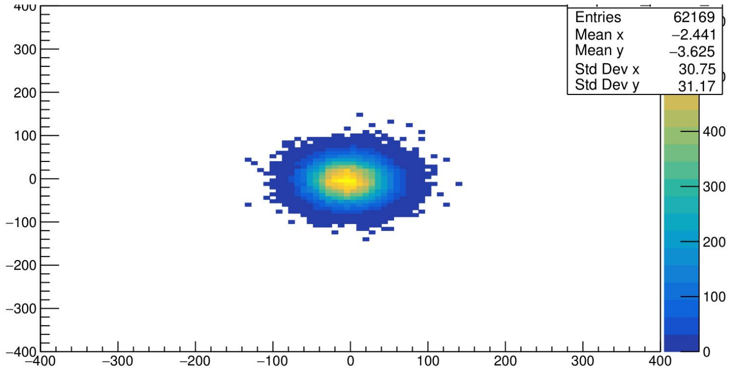
LH2

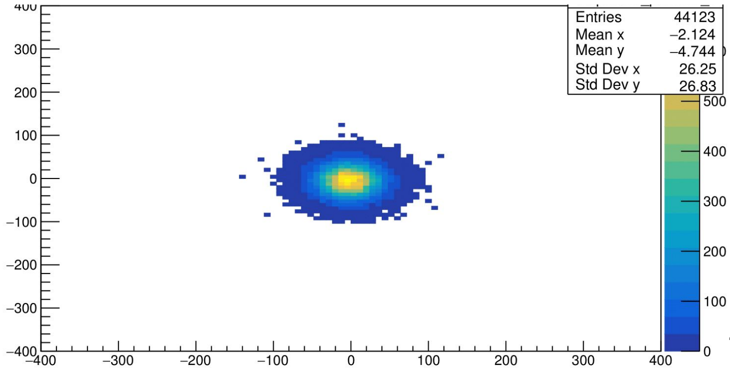
Upstream





Downstream





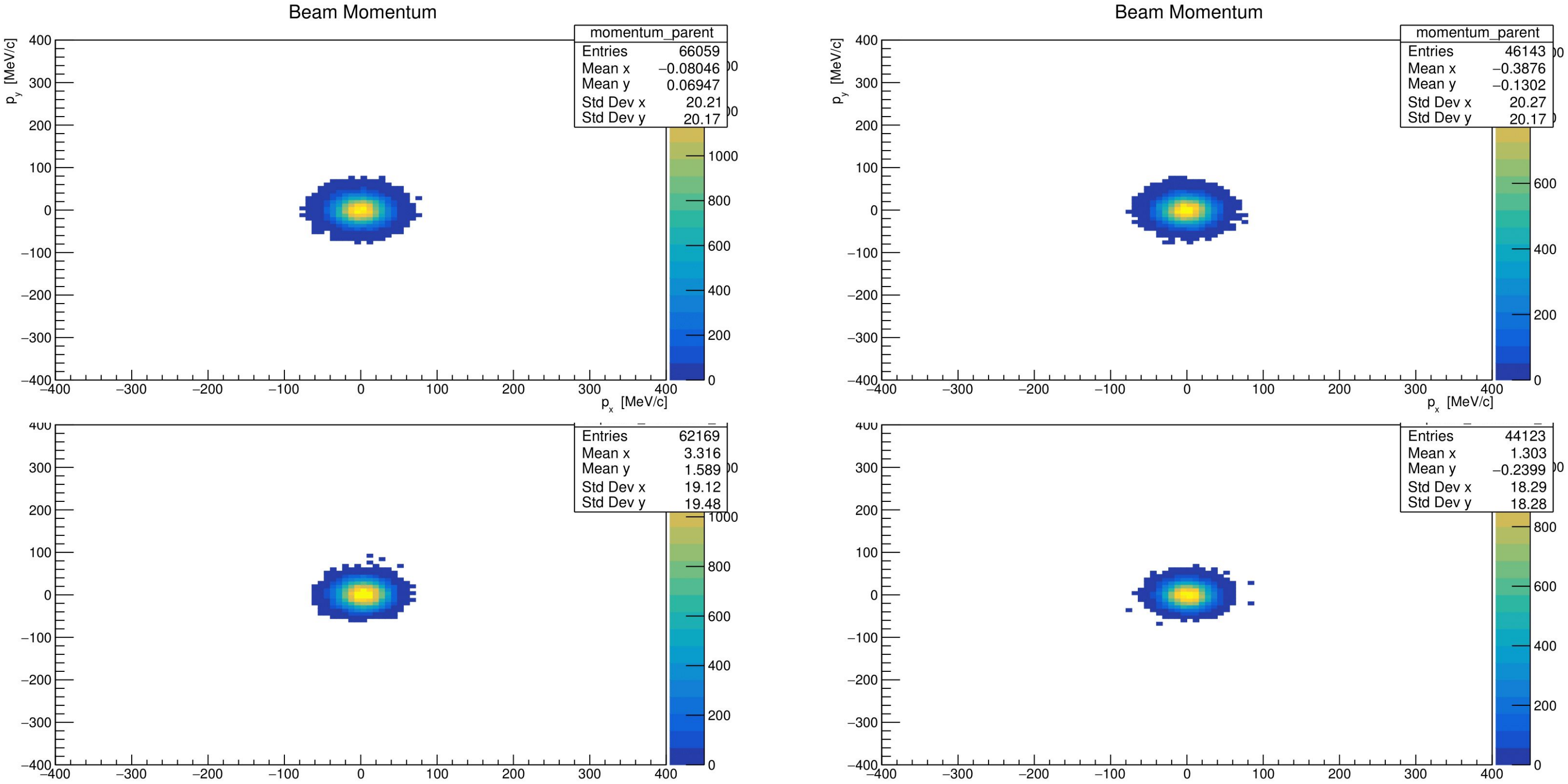
Sampled Beam Evolution - PxPy

NO ABSORBER

LH2

Upstream

Downstream



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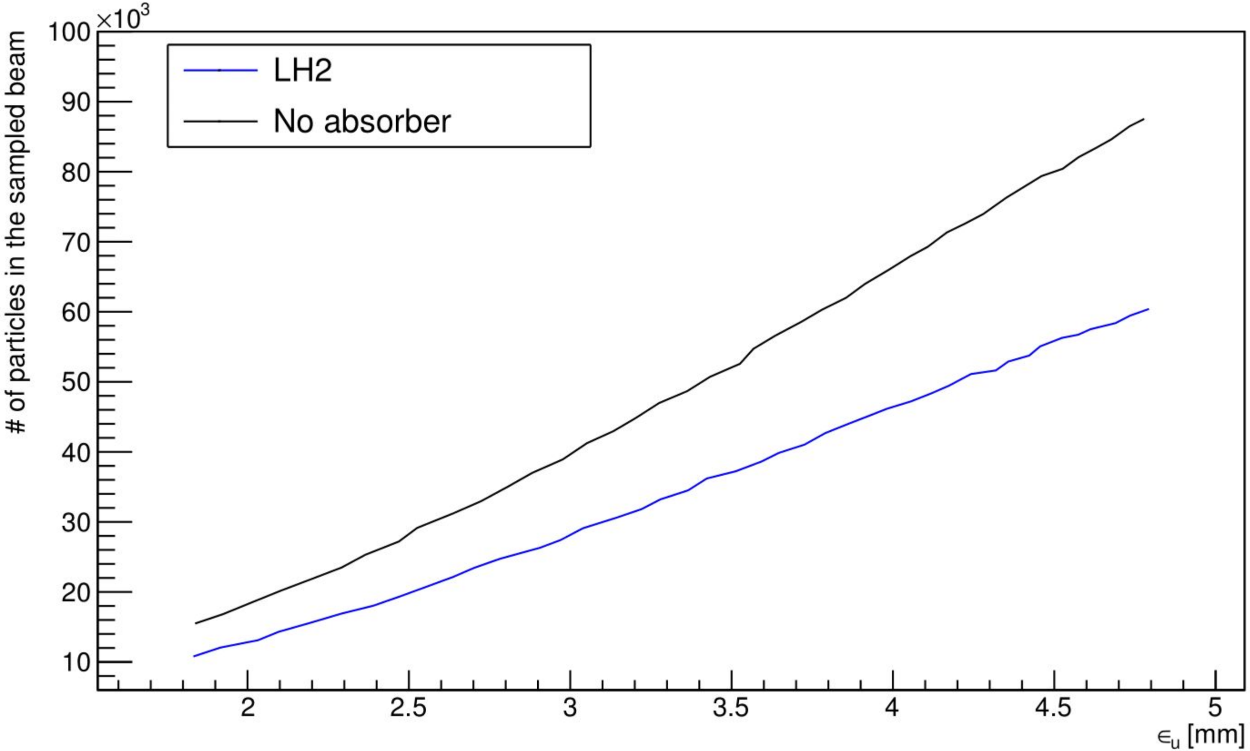
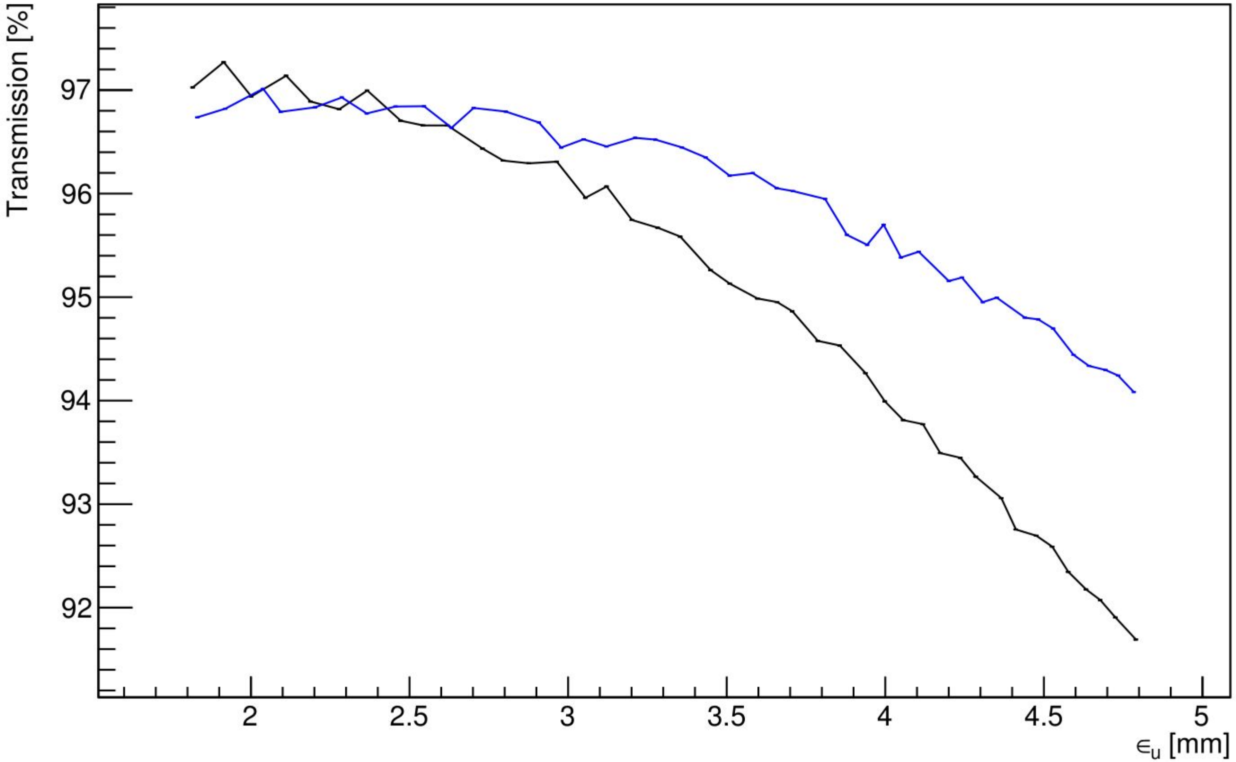
- Number of particles in the sampled beams
- Relatively low statistics (at low emittance) can be improved by using the 4 mm and potentially the 10 mm beams for the parent distribution



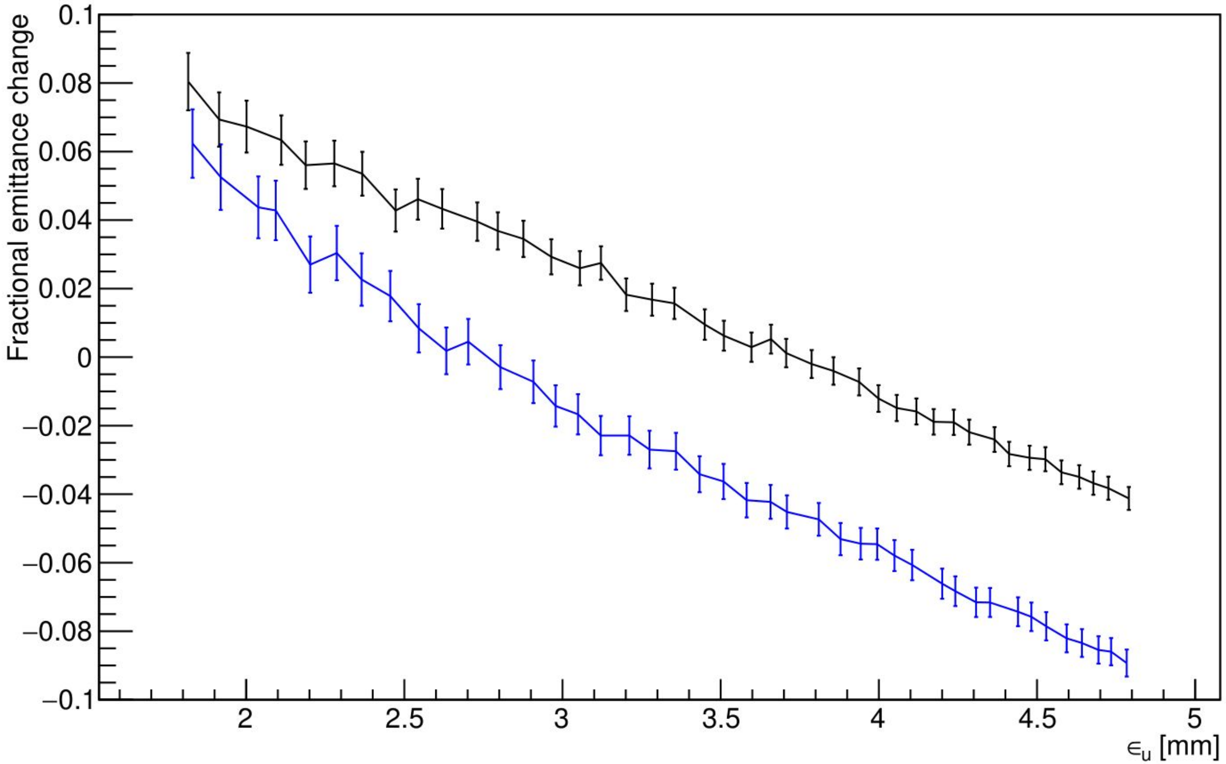
Transmission

- Blue - LH2
- Black - No absorber
- Trends cross at about [2
  2.6] mm
- Calculated equilibrium emittance (for β ~ 540 mm) is ~ 2.3 mm
- Cooled beams present lower transmission loss above the equilibrium emittance



Fractional emittance change

- Blue - LH2
- Black - No absorber
- In the No absorber case the trend is caused solely by transmission loss
- In the LH2 case the trend is due to cooling and transmission loss
- Equilibrium emittance ~ 2.6 mm



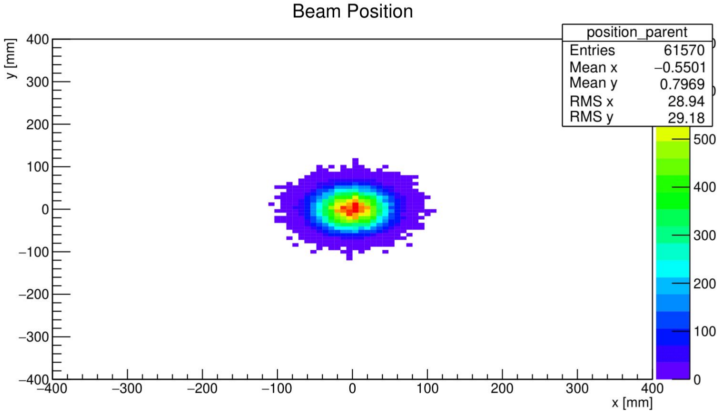
FULL TRANSMISSION ANALYSIS

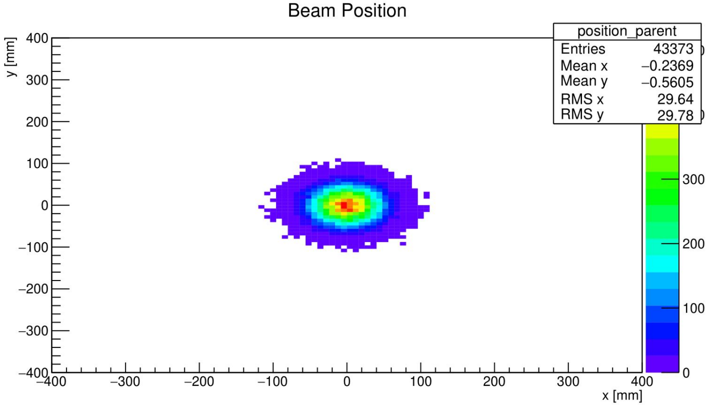
(Only events that have one track upstream and downstream are kept)

Sampled Beam Evolution - xy

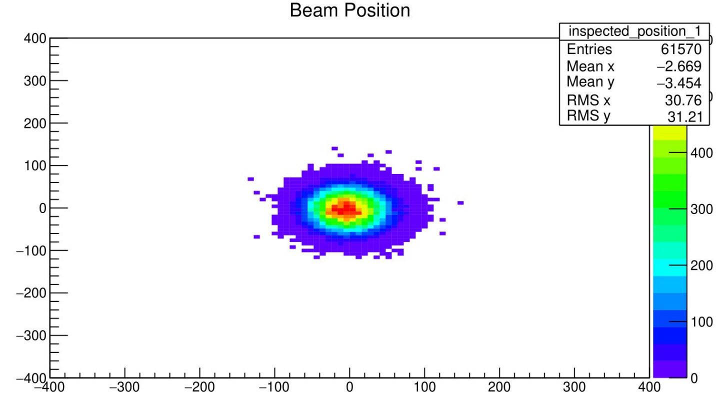
NO ABSORBER | LH2

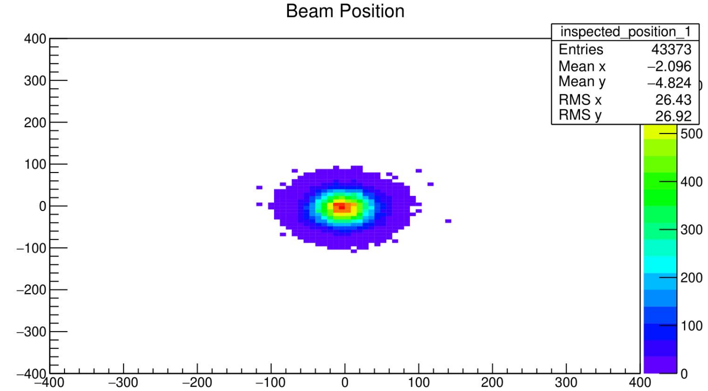
Upstream





Downstream



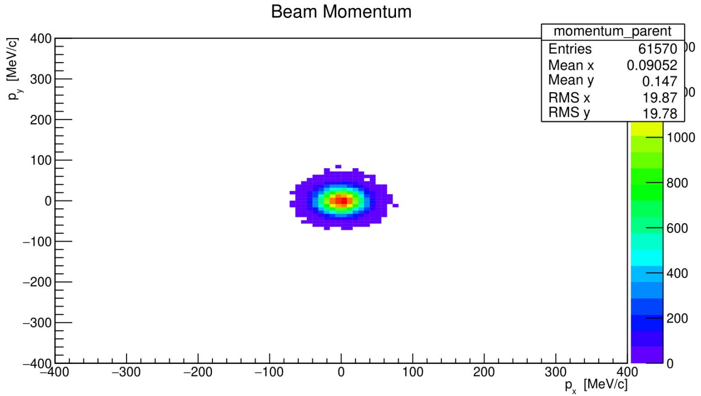


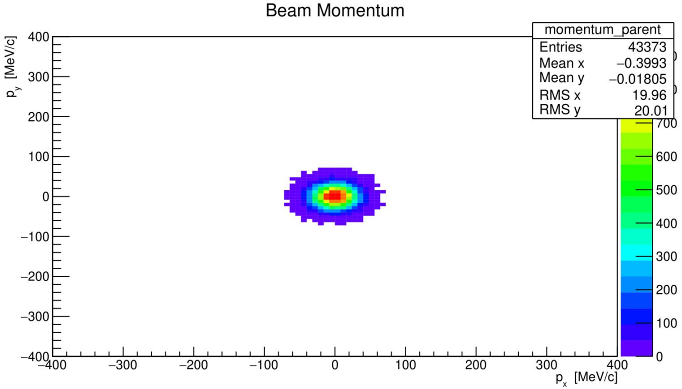
Sampled Beam Evolution - PxPy

NO ABSORBER

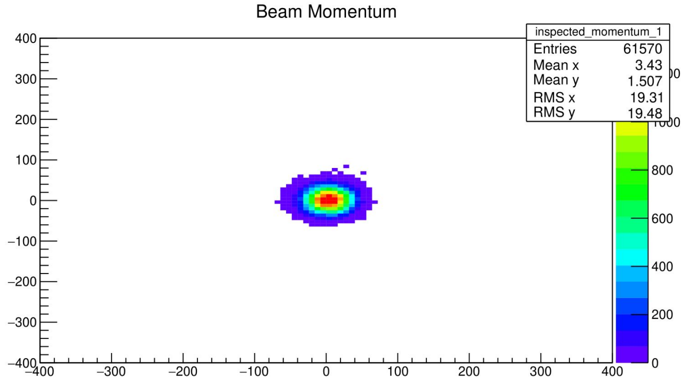
LH2

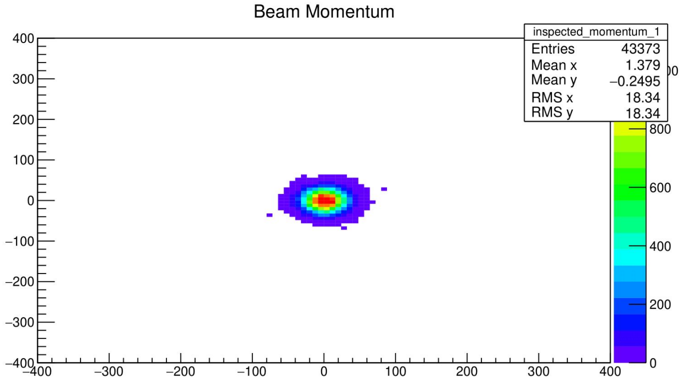
Upstream



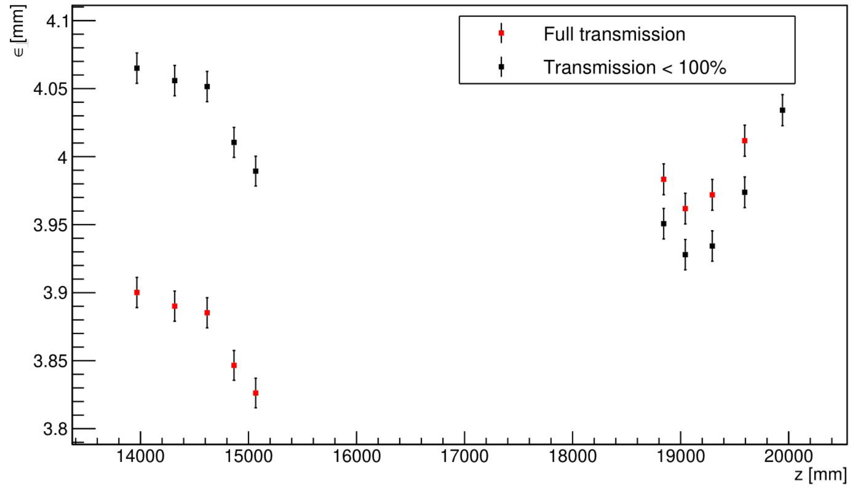


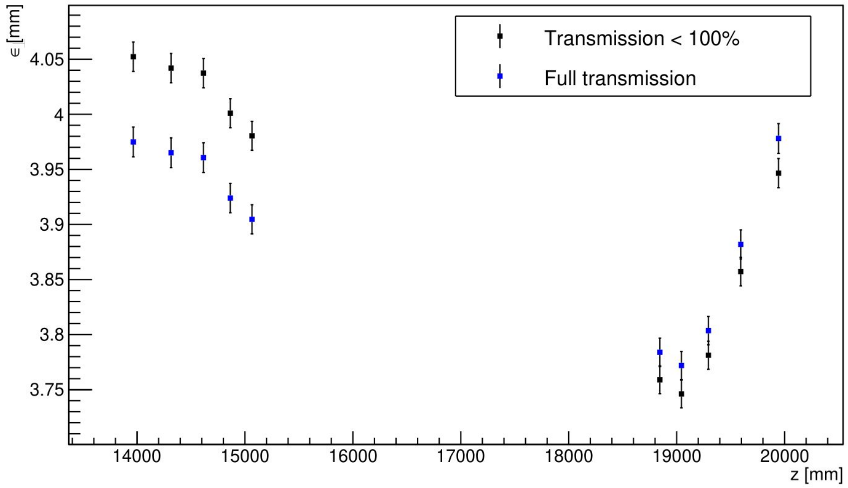
Downstream





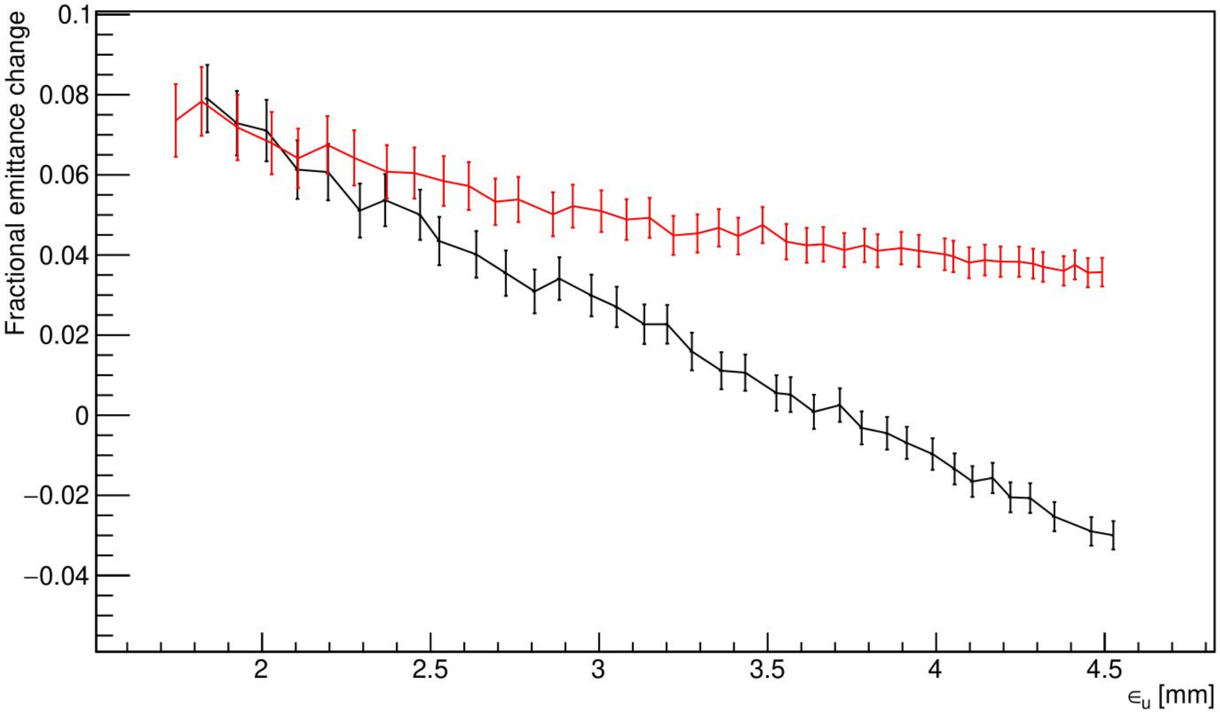
Effect on reconstructed emittance





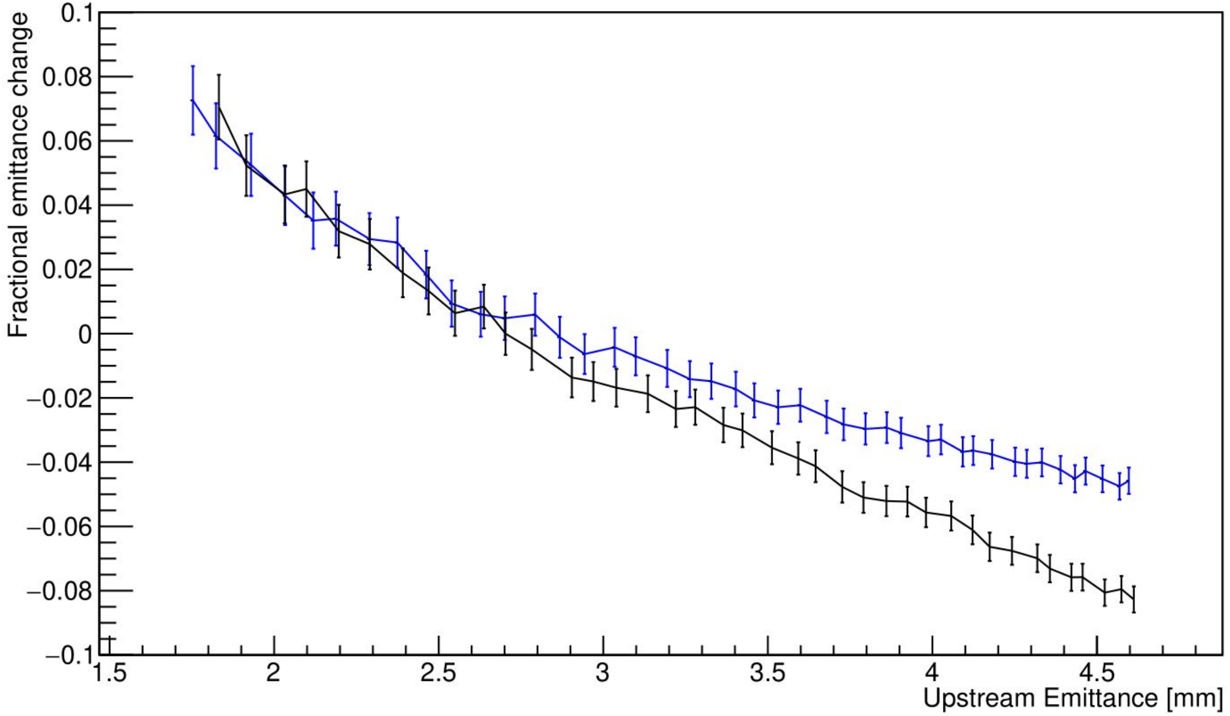
NO ABSORBER

- Black - limited transmission
- Red - 100% transmission; shows (optical) heating is present for all the beams, decreases with increasing upstream emittance
- Possible cause could be the varying optics (see slide 15)
- To be studied with hybrid MC



LH2

- Black - limited transmission
- Blue - 100% transmission



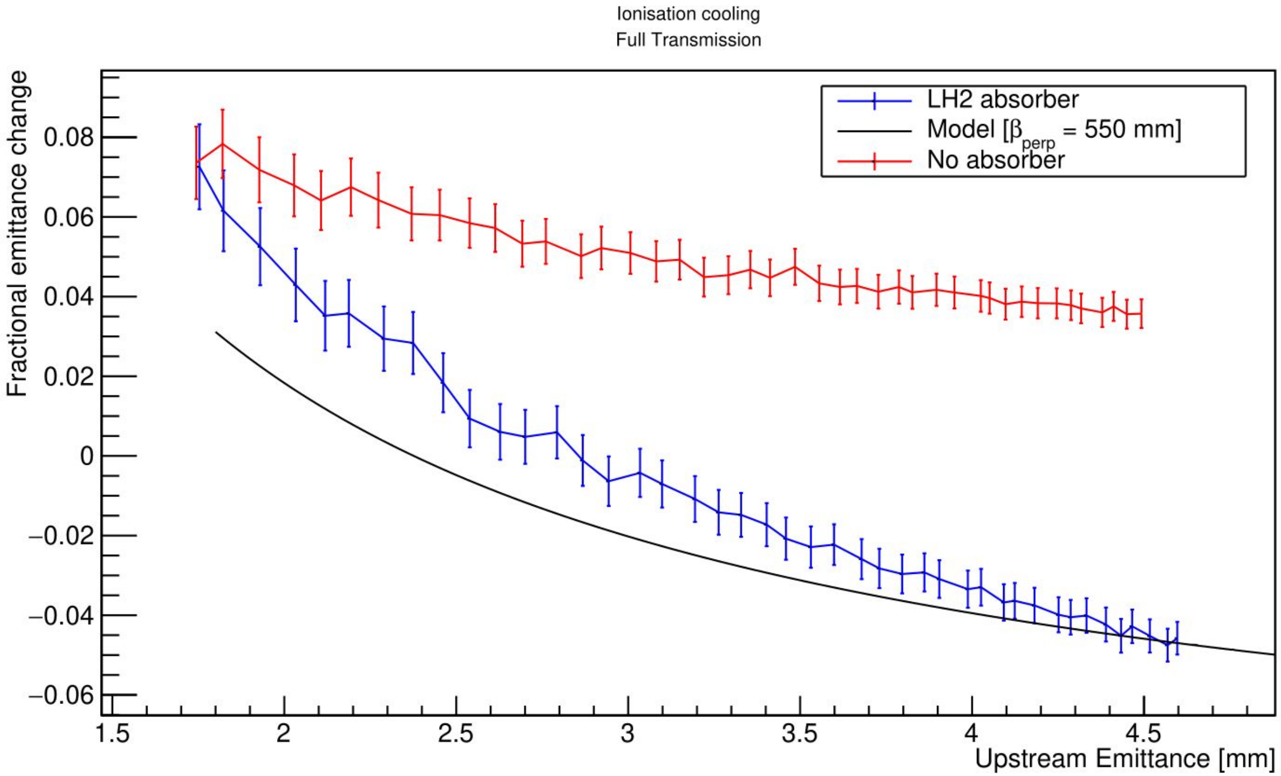
Full transmission - LH2 vs No Abs vs Theory

- Black line - Theoretical calculation

$$\frac{\Delta\epsilon}{\epsilon_u} = (1 - e^{-az})(\frac{\epsilon_{eqm}}{\epsilon_u} - 1)$$

where ***a*** is the cooling term in the cooling term in the cooling eqn. and ***z*** is the mean path length through the absorber

- Equilibrium emittance expected at 2.4 mm; observed at ~2.85 mm

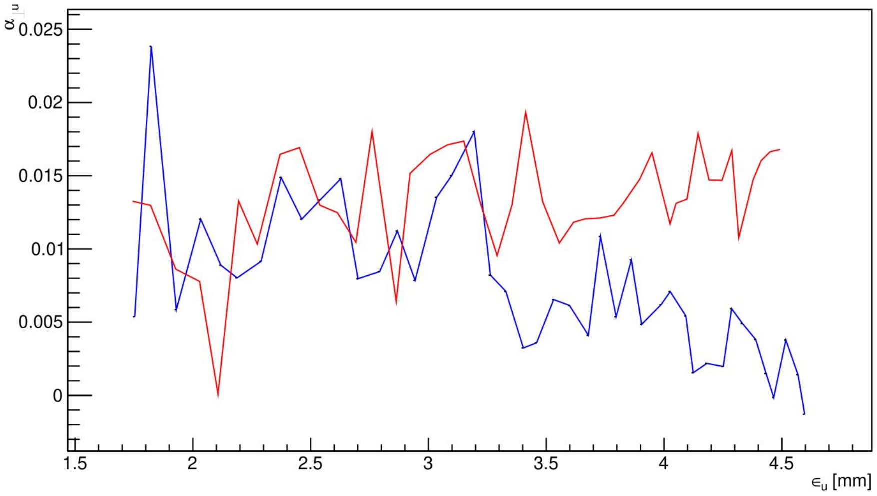


Optics at the upstream reference plane

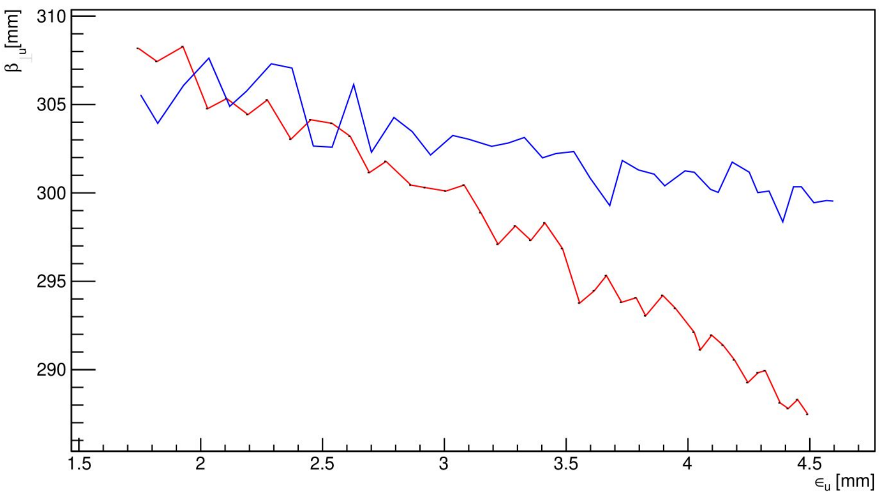
Imperial College London

RED - no absorber, BLUE - LH2

Alpha



Beta

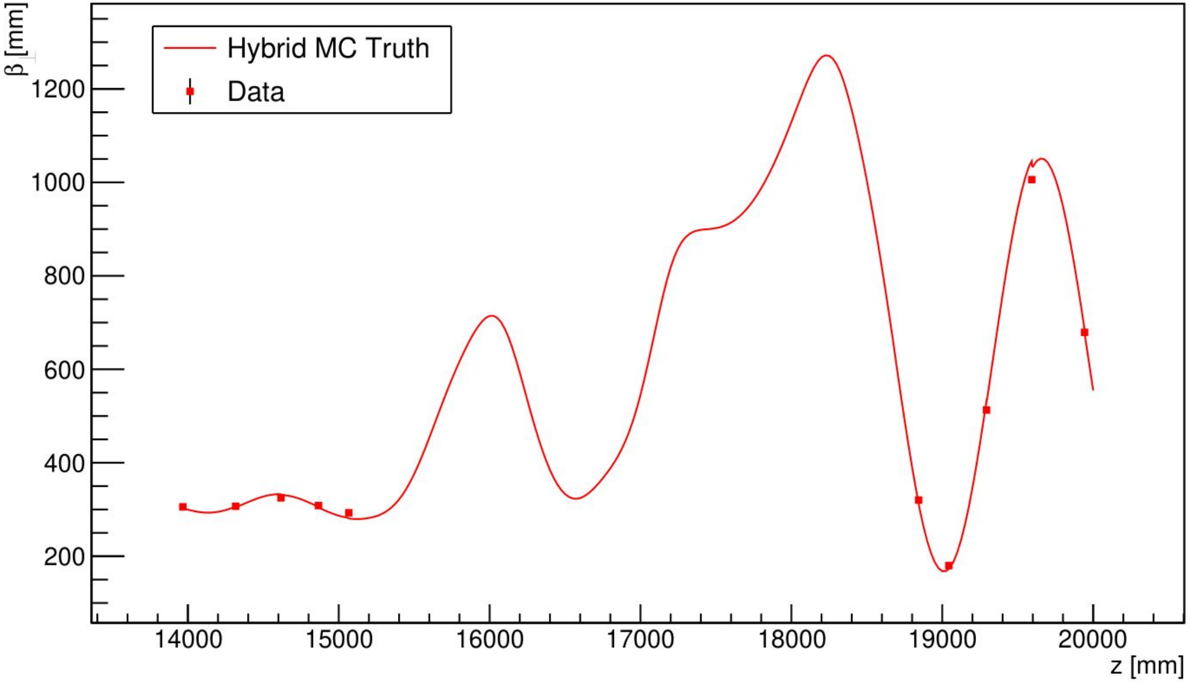


Hybrid MC comparisons

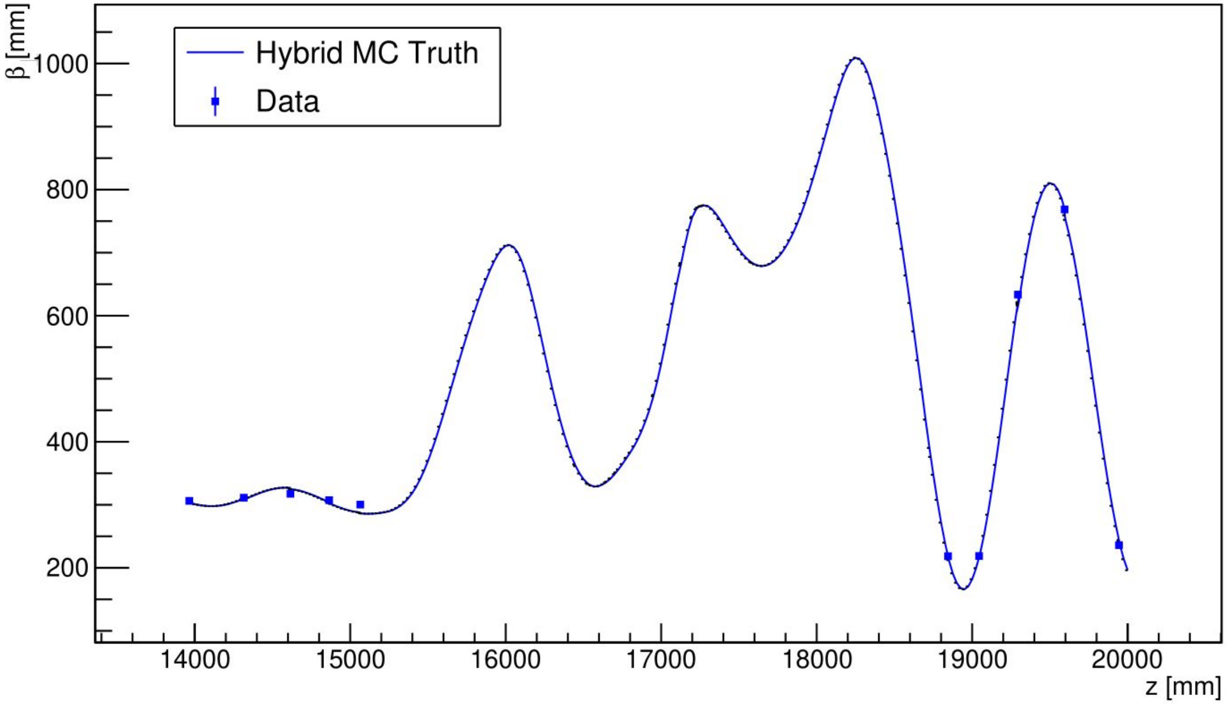
- preliminary comparisons with hybrid MC truth

- however, p_T hole at low transverse momenta is present; the current hybrid MC production routine does not include the TOF Tracker patch

Beta - No absorber

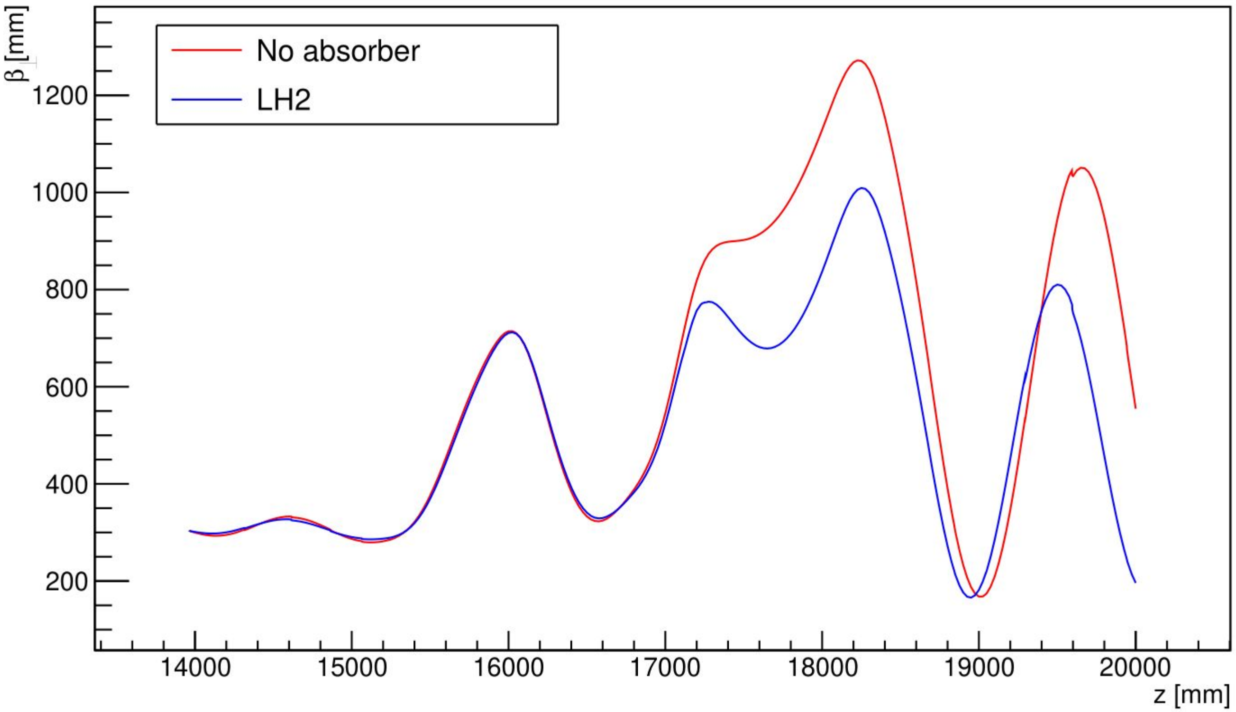


Beta - LH2

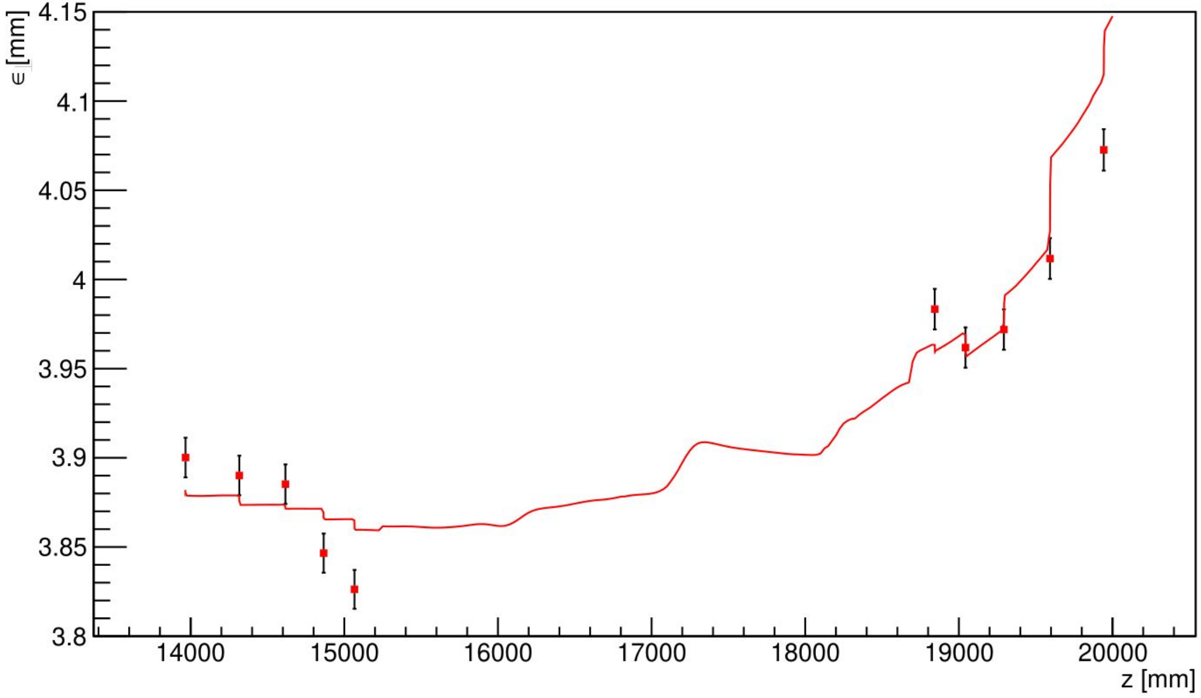


β [mm]
1000
800
600
400
200
Hybrid MC Truth
Data
14000
15000
16000
17000
18000
19000
20000
z [mm]

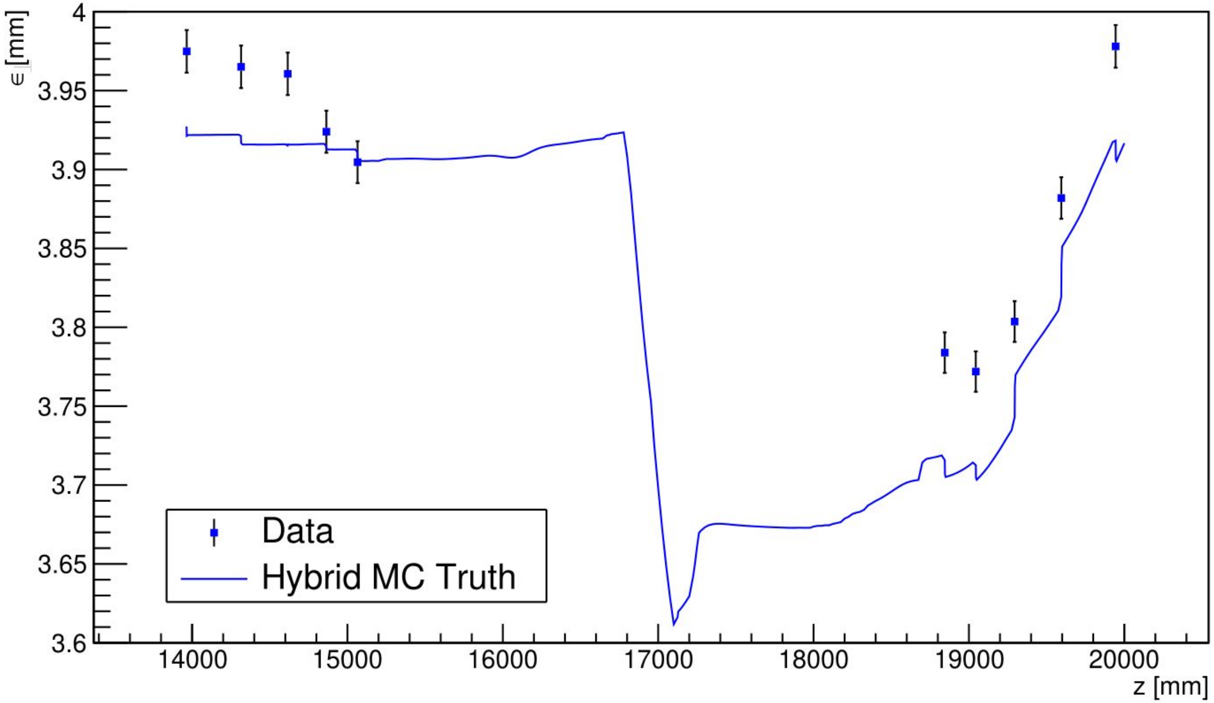
Beta - No absorber VS LH2 (truth)



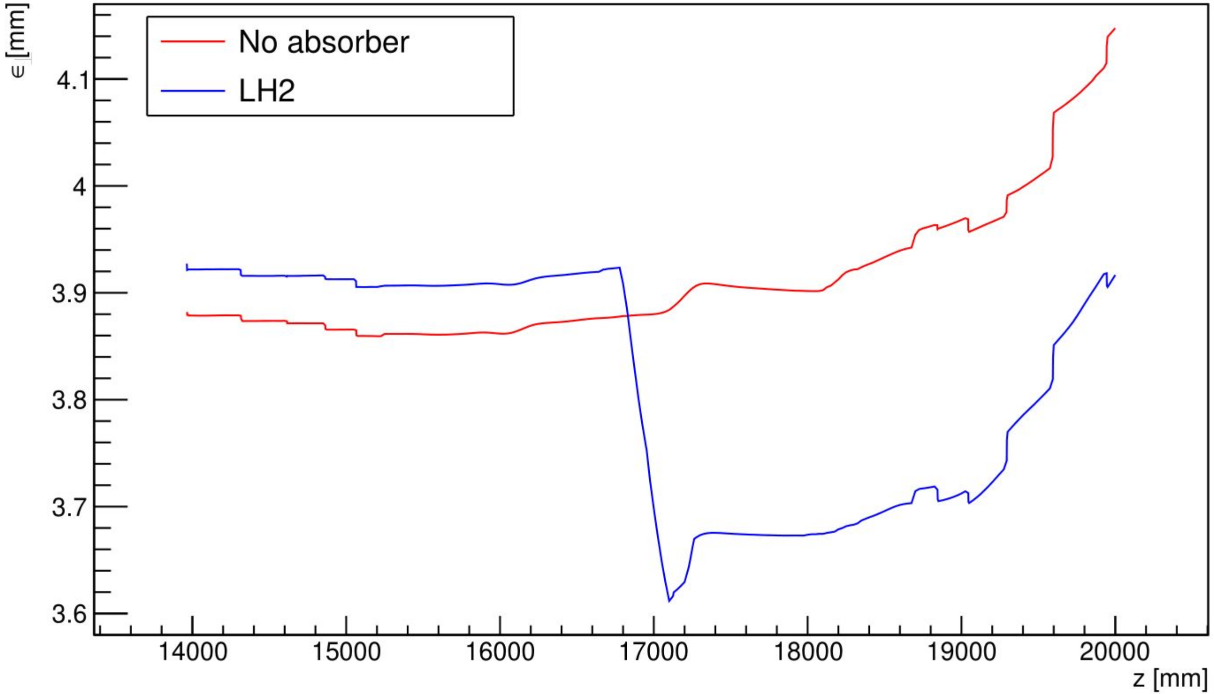
Emittance - No absorber



Emittance - LH2



Emittance - No absorber VS LH2 (truth)



Summary

- the full transmission requirement removed the emittance change bias due to particle loss
- there is still optical heating dependence on initial emittance
- Good optics agreement bewteen data and MC truth; emittance not completely understood (low transverse momentum hole)
- next steps:
  - study optical heating as function of optics and initial emittance (both for no absorber and absorber case)
  - hybrid MC production - needs TOF Tracker combined fit
  - MC production
  - improve beam selection: MCMC Hastings-Metropolis sampling?