Searching For Cooling

C Hunt

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Note: This is not currently my active focus while we are preparing for IPAC.
There are some obvious improvements and tweaks still to come once I have time.

Concept

We know the matching in Step IV is not ideal.

But can we find a beam that is both well transmitted and cooled...

Selection must be upstream only - no bias on cooling!

Can we reproduce the MC performance using Gaussian beams by selecting Gaussian beams?

The difficulty comes in selecting and tuning the parameterisation of the parent and daughter distributions.

The Goal

1. To develop and test the algorithms required to perform an unbiased beam selection in the upstream tracker.

2. To investigate whether a simple application of these routines, without additional reconstruction or treatment of systematics, will demonstrate emittance reduction at high transmission.

Basics of Rejection Sampling

Assume a parent probability distribution, X described by $f(\mathbf{x})$, and a daughter probability distribution, Y described by $g(\mathbf{y})$.

If we sample events from the parent distribution $\mathbf{x} \sim X$, we can calculate the probability of finding one in the parent distribution: $f(\mathbf{x})$, and in the daughter distribution: $g(\mathbf{x})$.

Now introduce a uniform-distributed variable, $u \sim Uniform(0, 1)$.

Now if we only accept events, x, that satisfy, $u < \frac{g(\mathbf{x})}{f(\mathbf{x})}$ the resulting distribution will be the required daughter distribution, Y.

Successfully Tested Algorithms

1. **Analytical 4D Gaussian Sampler**

   Assume the parent distribution is Gaussian and described perfectly by a covariance matrix and select a Gaussian daughter distribution.

2. **Binned Gaussian Momentum Selection**

   Select a Gaussian momentum distribution from the raw momentum distribution.

3. **Amplitude Selection**

   Gaussian beam has SPA distribution described by a χ^2-Distribution - 1D binned selection algorithm.

4. **2D Binned Phase Space Selections**

   Only analyse x-p_x and y-p_y distributions. Use binned 2D histograms as parent distribution.

5. **4D Correlation Phase Space Selections**

   Parent distribution described by six 2D histograms. A 4D daughter covariance is selected.

Does it Work?

Yes - with some caveats.

Fewer dimensions, simpler problems, more statistics: works very well.

Higher dimensions, lower statistics: more of a problem and requires careful tuning.

Currently I use a Gaussian momentum selection to reduce chromatic effects and the Single Particle Amplitude selection to select the beam.

With this there is no control over optical functions, however there are very good statistics, and it works without any tuning.

The Analysis

1. Perform initial analysis - make histograms of relevant parameters and determine approximate emittance, etc.
2. Repeat process including a Gaussian momentum selection in the upstream tracker, based on the initial assessment. $\sigma = 5$MeV/c.
3. Repeat again, with the chosen transverse beam selection in the upstream tracker.
4. Calculate the emittance, SPA and transmission in the downstream tracker.

Whole process in then repeated for difference values of emittance that are to be selected and analysed.

Want to see if we can find a beam that both experiences cooling and is efficiently transported.

The Data

So far concentrated on the last user cycle - flip mode LiH data.

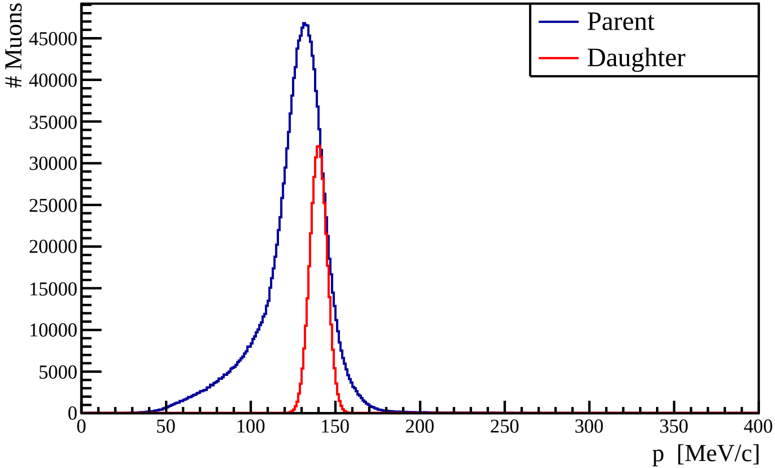
Concentrated on Analysis Runs H13 (2016-05-1) and H15 (2016-05-2).

Solenoid mode to come next, after IPAC.

Only Real Data is shown in what follows.
No MC Simulation Necessary!

Momentum Selections

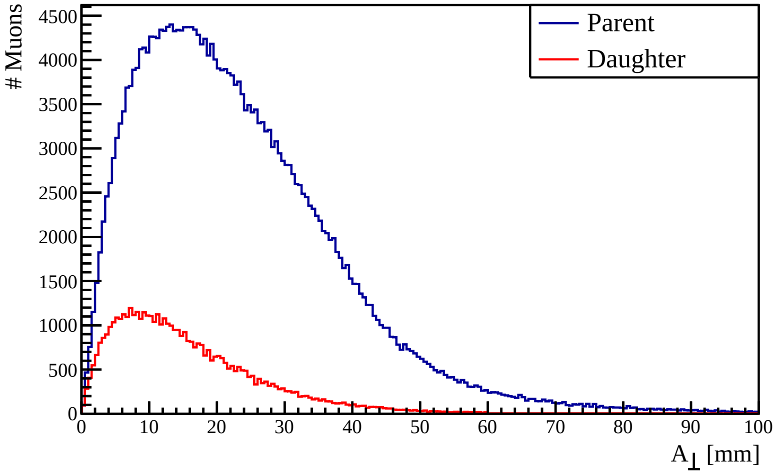
5MeV/c RMS Gaussian Total Momentum



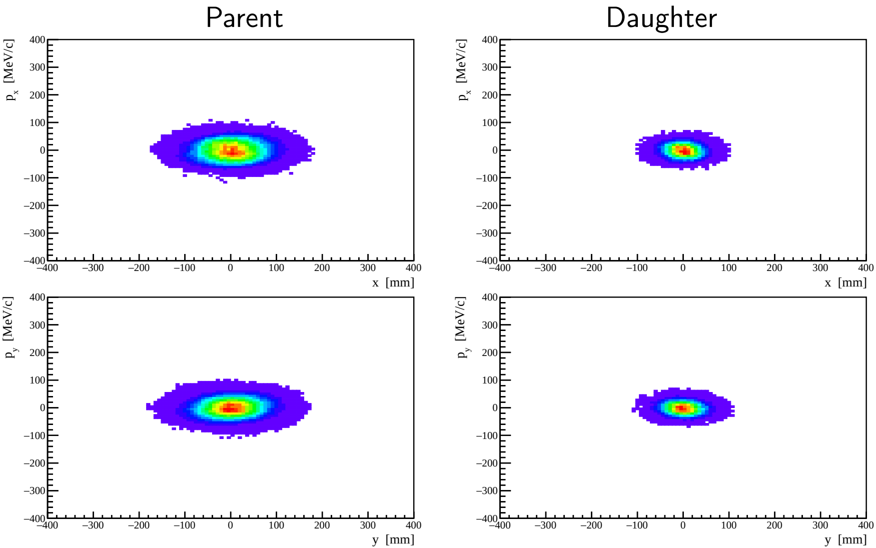
Amplitude Selections

$\varepsilon = 4\mathrm{mm}$ from Analysis H13b

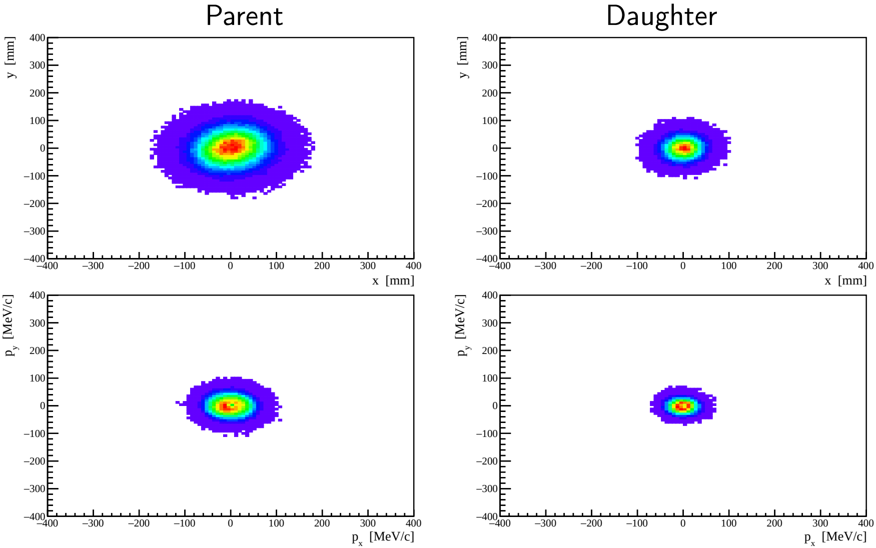
This is the selection of the emittance.



Selected Phase Space x-p_x & y-p_y

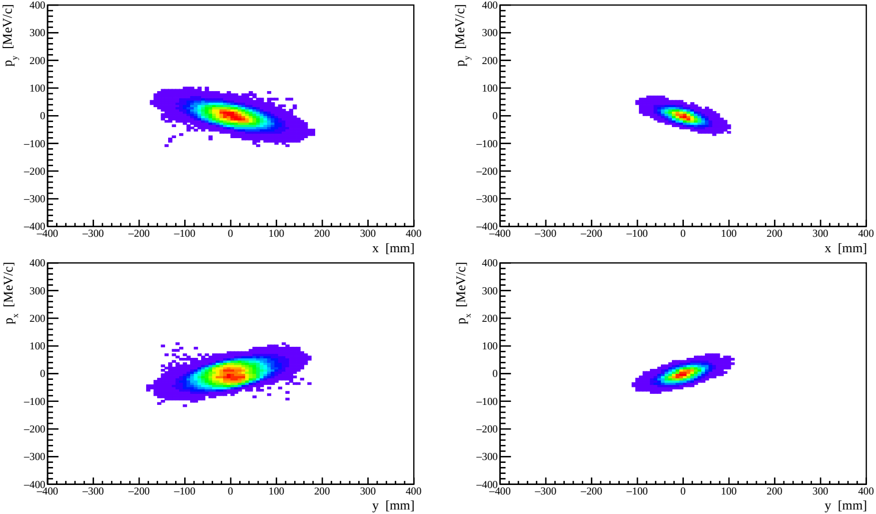


Selected Phase Space x-y & p_x-p_y



Selected Phase Space x-py & y-p_x

Parent | Daughter



Analysis of These Results

The Zero Canonical Angular Momentum Inefficiency is clearly biasing the results.
There are several ways to combat this:

- Particle weighting *not* selection - the core is more heavily weighted.
- Ignore it. It is only a small effect on the reconstruction, even though it heavily affects the selection.
- Apply a correction based on what we know. Needs investigation.

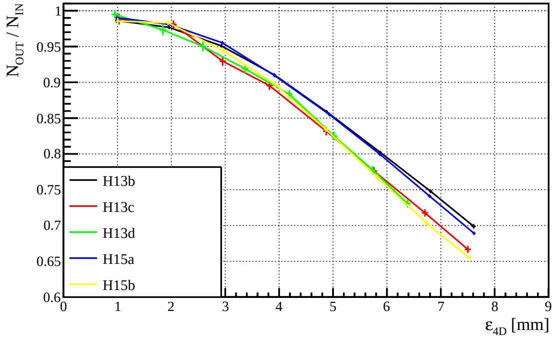
Selection routines work very well. The tails are removed.
Distributions are clean and well behaved.

Easy to apply and highly tunable.

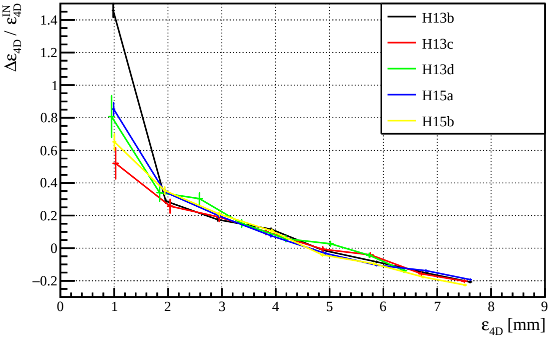
No control over the optical functions of the beam.

Performance Plots

H13: 2016-05-1 H15: 2016-05-2



Transmission



Emittance Change

Observations

We can see:

- Both cooling channel settings seem to have very similar performance,
- We are experiencing a lot of scraping at moderate emittances - this needs improvement,
- There is a splitting in the transmission behaviour,
- 90% transmission seems to occur at 4.2mm emittance,
- Cooling appears measurable at approximately 4.7mm emittance.

We are definitely missing some form of validation!

Conclusions

Need control of the optical functions

The transmission is splitting because the parent distributions have different values of α and β.

This needs some more work, even though the algorithm is working.

We need to improve the transmission and selection efficiency

Partly the optical functions, but also the selection efficiency could be improved.

Need to address the tracker inefficiencies and look at weighting the particles.

Need to know what beam to select

Maybe we should be selecting $\alpha \neq 0$.

This could improve transmission and performance. This is still in the early stages.

Conclusions

We need a validation procedure!

This is currently under development with 2 methods.

1. Pure MC Model: Use the geometry and G4Beamline Models to predict the full behaviour of the cooling channel, including what happens with the selection algorithms,
2. Data Seeded Model: Use the selected beam to seed a simulation that predicts how the tracks propagate through to the downstream tracker.

Need to look at any corrections for the reconstruction

Performance could be artificially lower than expected due to systematic corrections required for the track reconstruction. This is currently being investigated.

To Do List

1. Finish material required for IPAC17,
2. Provide implementation of the selection algorithms in MAUS, so that we can start testing the functionality and usability,
3. Finish studying the magnitude and calculation of corrections required for the track fit analysis,
4. Finish optimizing and tuning the selection routines and reproduce the performance plots shown above.

Questions/Suggestions?