Optimization of the MICE beamline w/o M1 in SSD

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Outline

- Motivations
- Introductions to the optimization setup
- Results
- Conclusion and Q&A

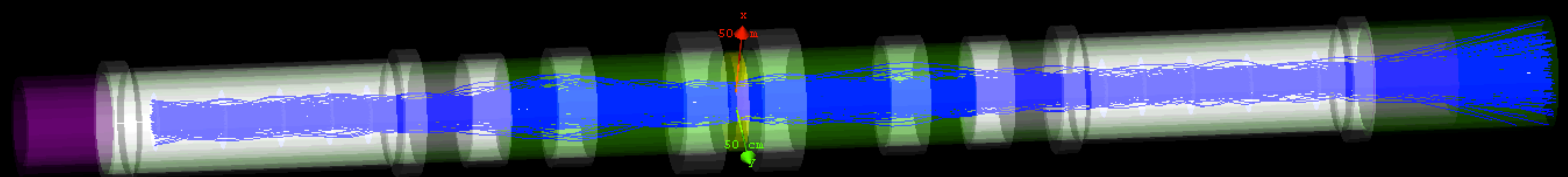
Motivations

- Understand the performance of MICE Step IV and beyond without M1 in SSD
  – Currently focus on Step IV first
  – Use results directly from beam tracking
- Simulation of the beamline using G4Beamline 2.16
  – Previously done by Pavel Snopok about a year ago
  – G4Beamline simulation is fast, parallelized and has been tested by many cases within the muon community

Optimization setup – tracking tool

- Tracking tool
  - MAUS was tried first, however
    - It was slow if beam is started at the tracker0 ref plane (i.e. -3000 mm from the absorber) (reported)
    - MAUS is not installed on NERSC (www.nersc.gov), which is a powerful platform to run MPI-based algorithms (later).
  - G4Beamline
    - Installed on NERSC, was used to simulate nuSTORM, neutrino factory, rectilinear cooling channel, nuPIL, etc. Has MPI and runs fast.
    - A simulation input file on the Step IV cooling channel was investigated by P. Snopok (issue tracker: http://micewww.pp.rl.ac.uk/issues/1543)

Optimization setup – G4Beamline



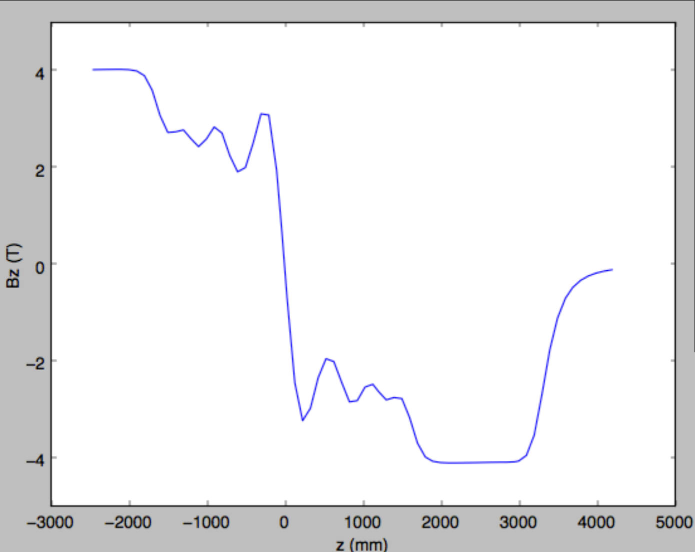
Modified from Pavel's original G4BL input

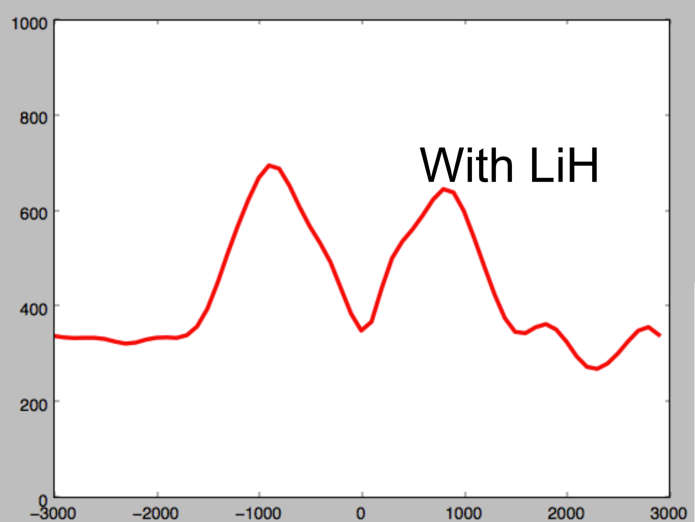
- MICE coils and currents – both SS and FC, geometry ID 70
- Materials in channel to match MAUS as accurately as possible:
  - SciFi tracker planes (2 mm Polystyrene each), 6.5 cm LiH absorber;
  - TOF2 added at the end of the channel (+4200 mm from the absorber);
  - Added beam pipe to kill particles hitting it (r=258 mm);
  - No PRY; vacuum in beam pipes
- Use initial beam generated by constant solenoid mode Penn beam matrix, which matches the B_z at the starting point.
  - Beam starts at z=-3000 mm from the absorber (tracker0).

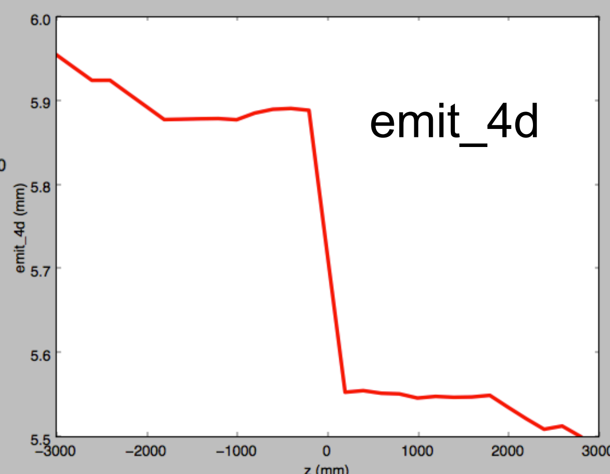
Optimization setup – G4Beamline (cont'd)

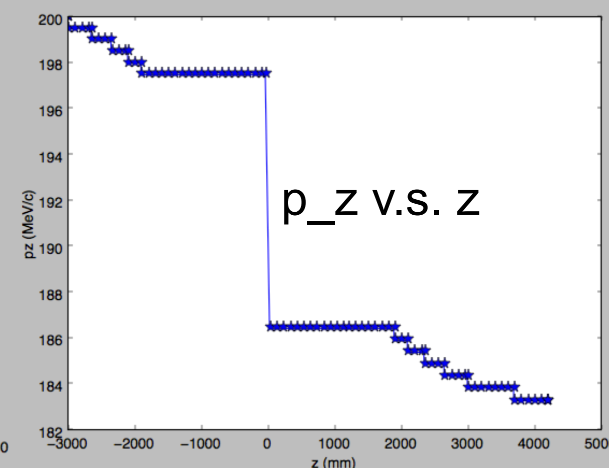
Comparing p=200 MeV/c nominal baseline setting (from Tim Carlisle's thesis) using:

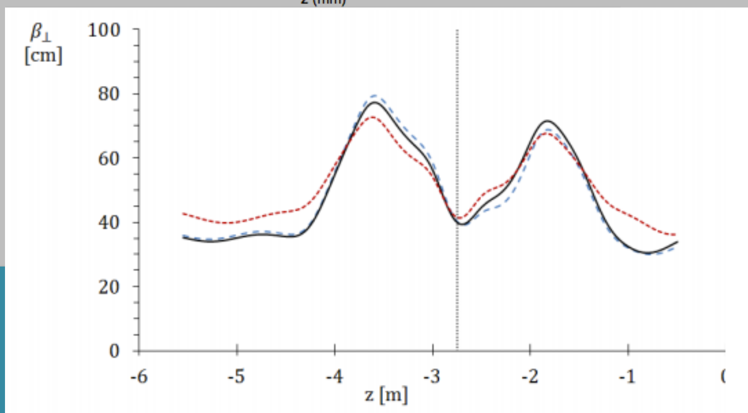
- No δp/p, 6 mm, start with p=207 MeV/c (as Tim did)
- With LiH absorber and scifi;
- No stochastic processes;
- Transmission from tracker 0 to 1 is ~100%





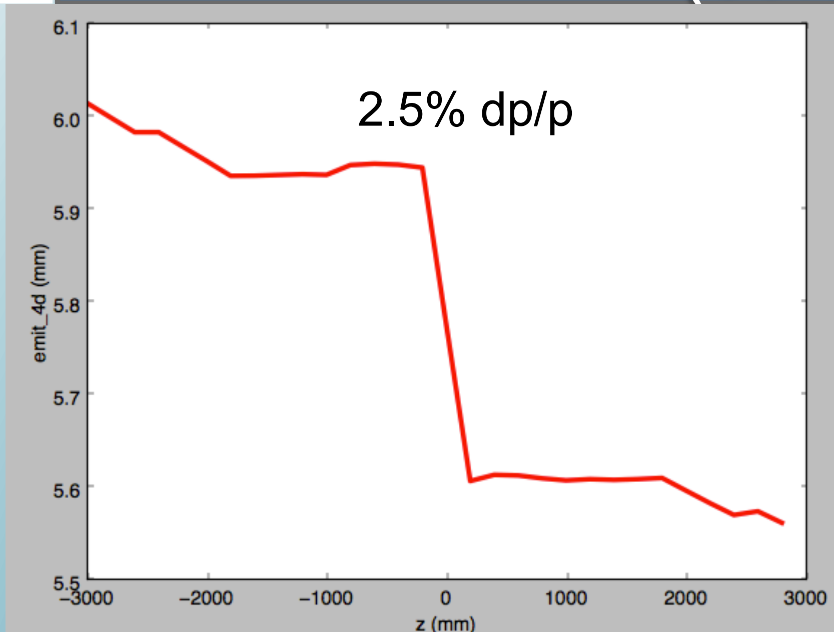


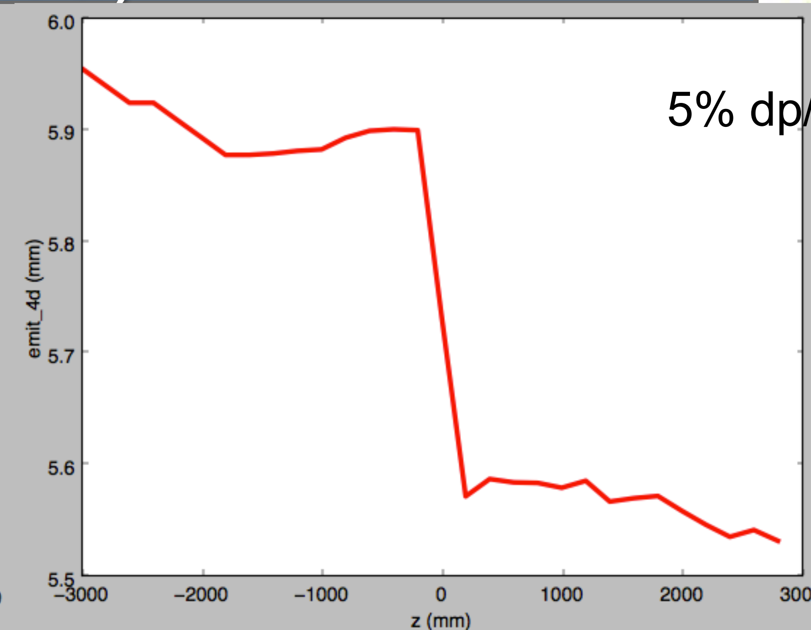


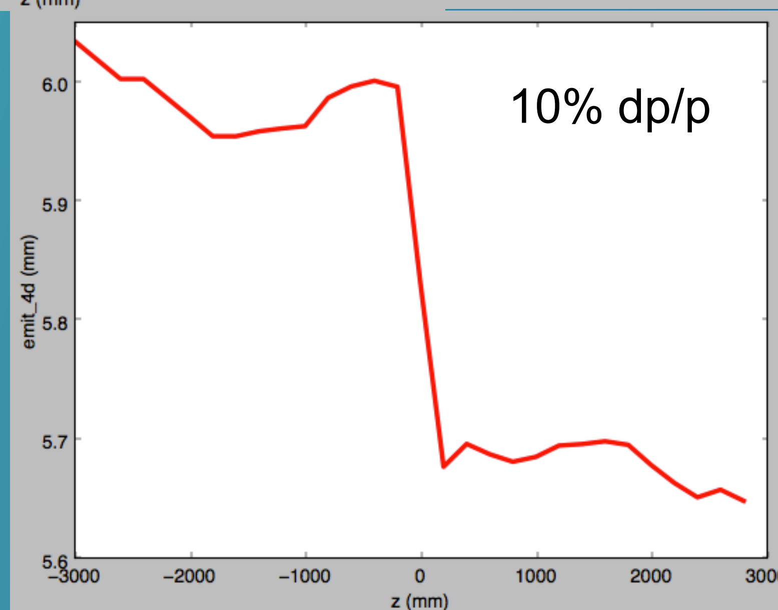


Left: Tim's thesis;
Black: 200 MeV/c;
LH2 absorber

Optimization setup – G4Beamline (cont'd)

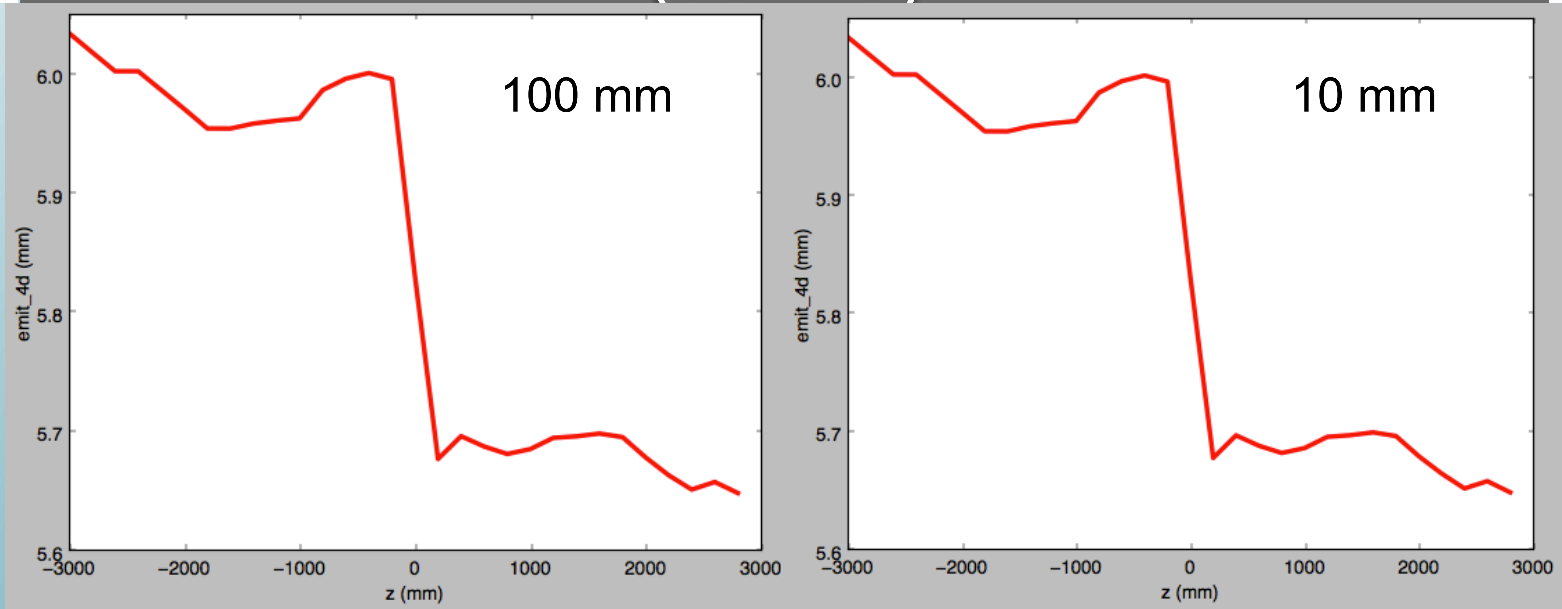


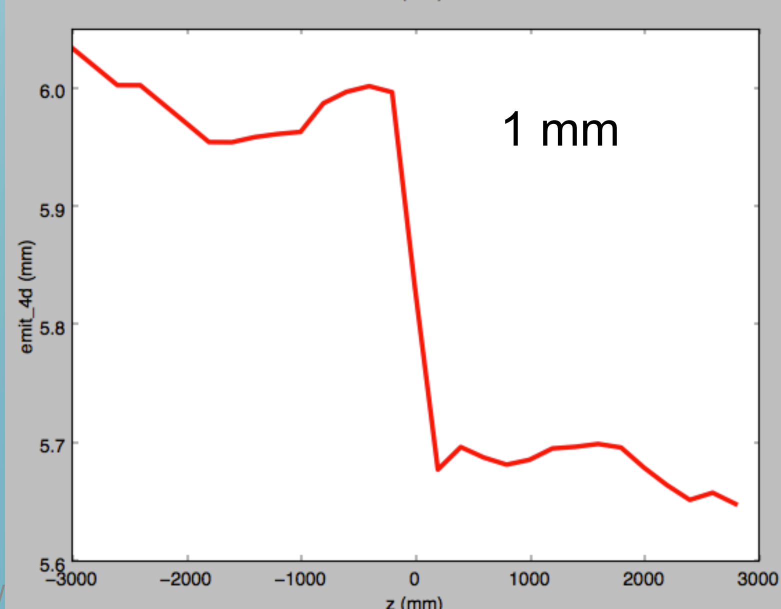




Add momentum spread to the beam reduces the emittance reduction;

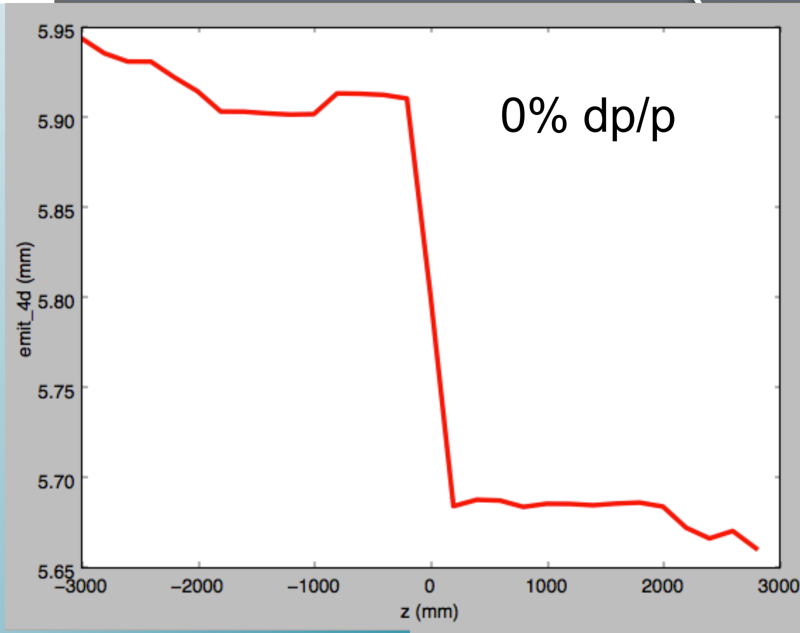
Optimization setup – G4Beamline (cont'd)

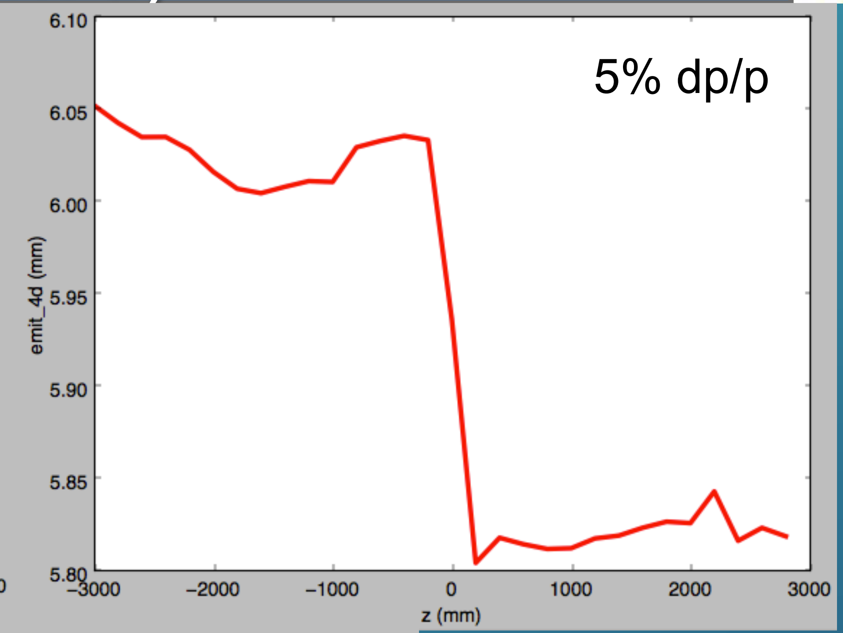


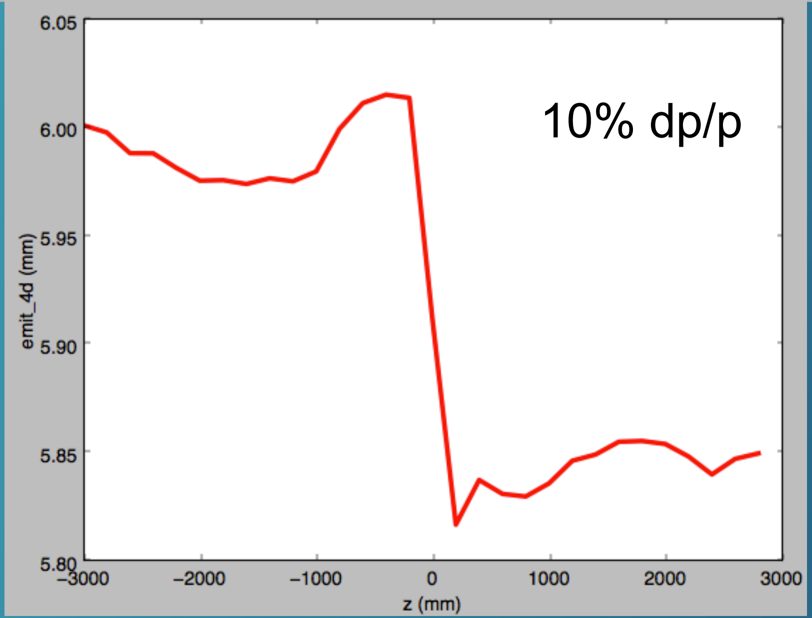


Changing the maxStep size makes no virtually noticeable difference but takes much longer to simulate:
Use 100 mm

Optimization setup – G4Beamline (cont'd)





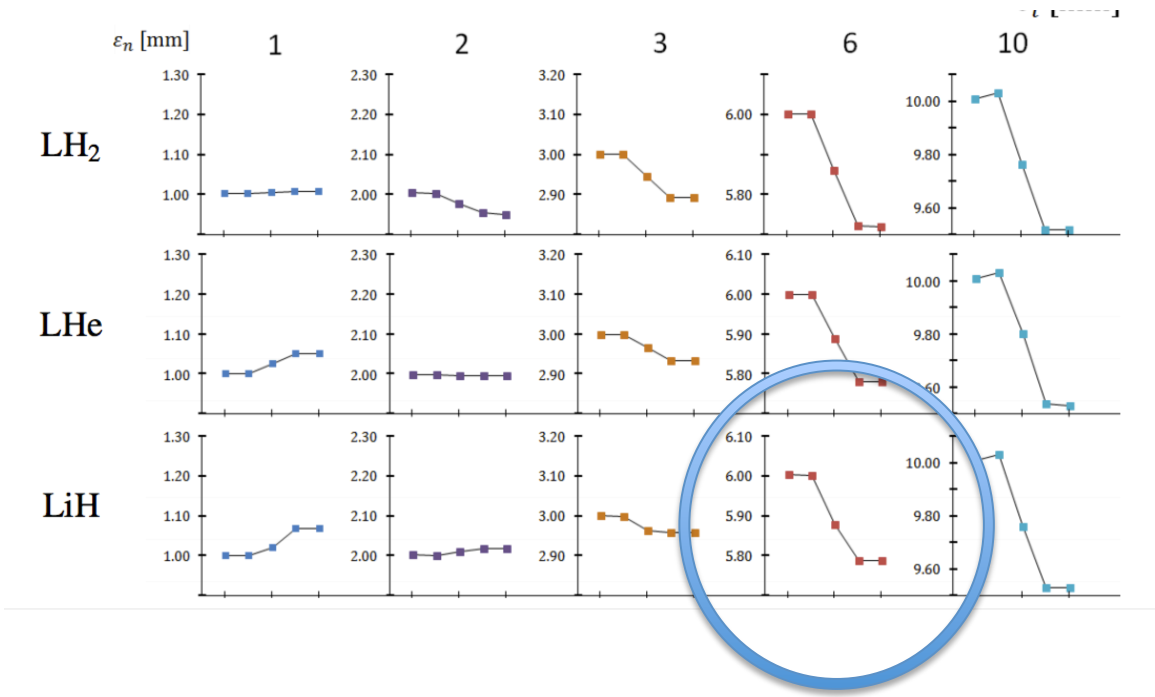


Adding the stochastic processes in G4BL simulation provides a more realistic model. The emittance reduction is smaller because of the multiple scattering effect is considered.

Optimization setup – G4Beamline (Conclusion)

- Considering the multiple scattering and stochastic processes in G4Beamline, the results agreed with the plots found from Tim Carlisle's thesis

Emittance reduction was obvious without stochastic processes, which reduce the emittance reduction but preserve the reducing trend.



Optimization setup – Genetic Algorithm

- Genetic Algorithm (GA) mimics the Darwin's natural selection process in the deterministic

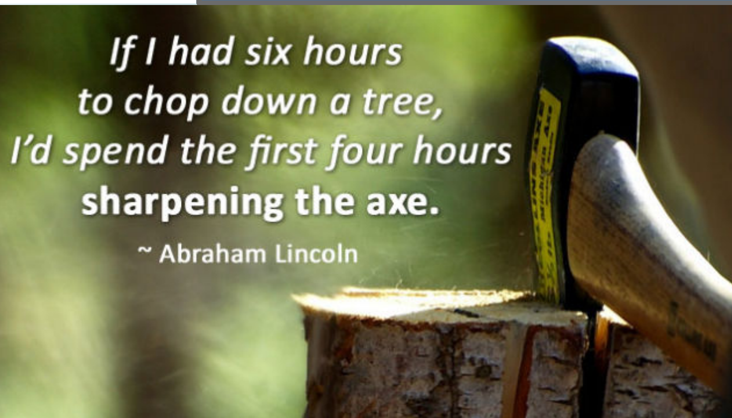
Big but friendly

Aggressive but small

Survives well, but not always.
What if their genes crossover?

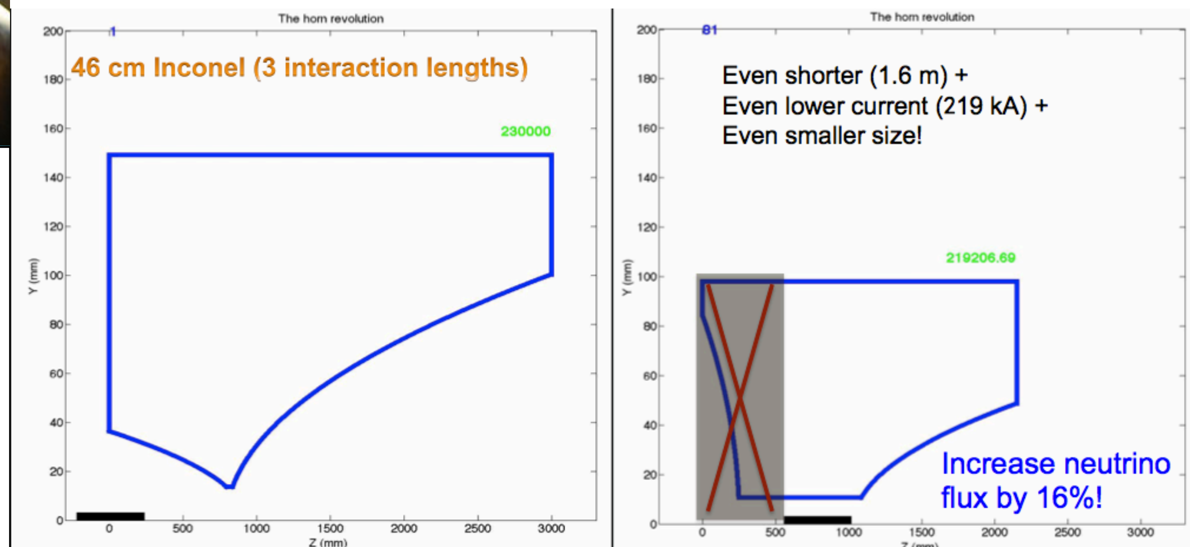
Many generations

Optimization setup – Genetic Algorithm (Cont'd)



- pyGAmpi, a python-mpi code to run the Genetic Algorithm (GA), implementable on multicore systems with Python built
  - MPI (Message Passing Interface) implemented and tested with major test functions
  - Simple to use.
  - Was applied to the nuSTORM horn optimization and ring design

- Heuristic, genetic.
  - Improves the population quality by generating similar solutions like the elite candidates.
  - Iteratively reaches a global optimum for one or more objectives (Multi-Objective GA, MOGA)



A MOGA run on the horn optimization can improve the neutrino flux from muon decay by 16%! (Compared with a 2.5 IL Inconel target, original horn shape and length)

Optimization setup – GA (for our case)

GA starts, use a number of random individual current settings produced as the first generation

Set up G4Beamline using the currents, calculate the B_z -3000 mm, generate the initial beam

Track the muons from -3000 mm to TOF2 (4196 mm). Select the good muons, calculate the emittance at the trackers

Select the best individuals, make the offspring. A child generation is generated

When the maximum generation number is reached, or the population stops improving, stop the algorithm

10 parameters
or
7 parameters
(reviewed later)

A scan of 5 different values for each parameter is 9 MILLION (or 78,000) runs!

One objective (SOGA):
The transmission to TOF2 multiplies the emittance reduction
($\varepsilon_{4D\_tracker0}/\varepsilon_{4D\_tracker1}$)

Guarantees a good transmission

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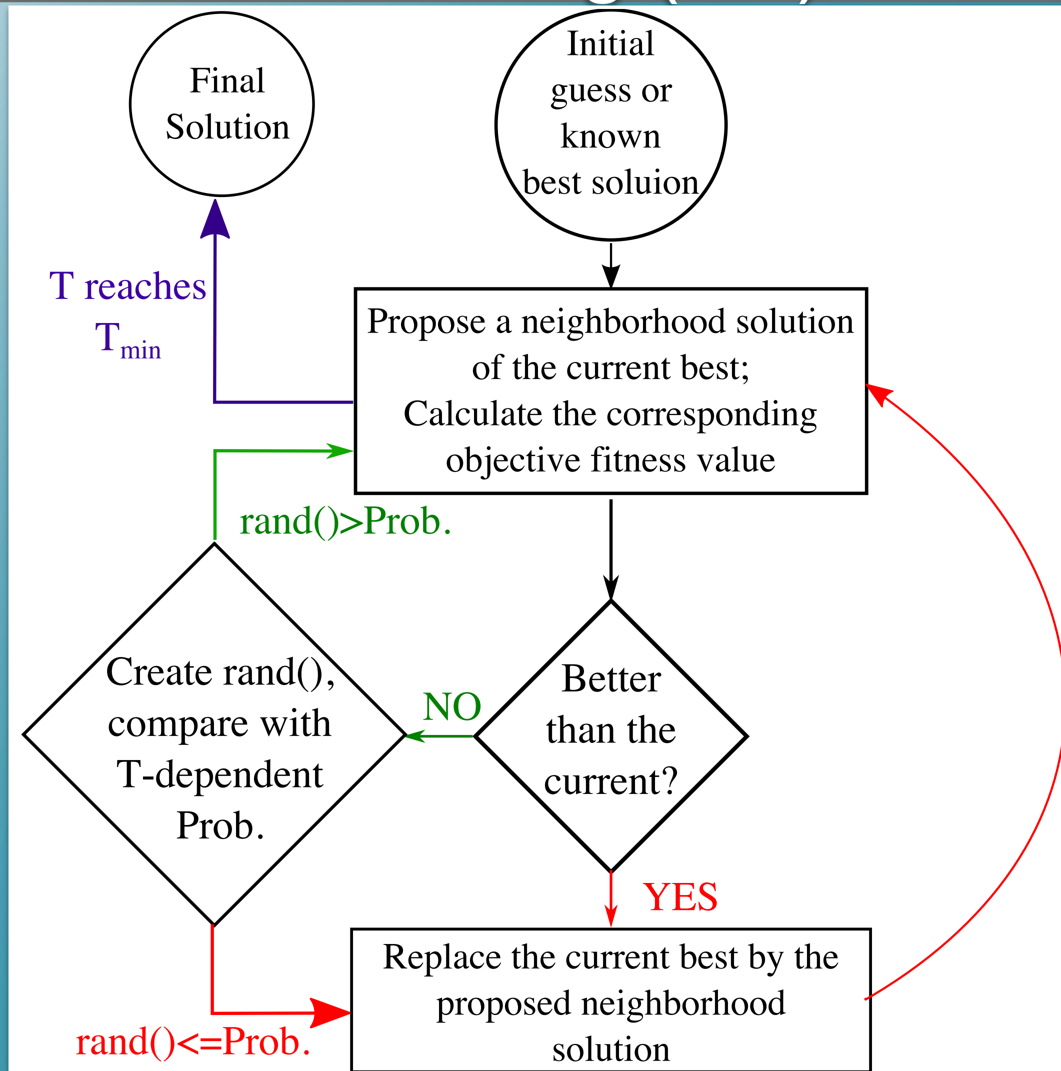
Optimization setup – Simulated annealing (SA)

- Another metaheuristic algorithm to find the global optimum in a large search space.
  - It is an algorithm to quickly approach the global optimum;
  - Mimics the annealing in metallurgy
    - Reduces the crystal defects with controlled, slow cooling;
    - "Temperature" T controls the probability of accepting a worse solution: $Prob(T)=\exp(-\Delta f/T)$, Δf is the old fitness – new fitness
      - T decreases with iterations → probability to accept a solution decreases → search is "frozen" inside a small area in the parameter space
- Faster approach than Single-Objective GA (in general)
- MPI-enhanced: keeps track of the best solution for all generations – elite candidate is not lost
- Was used on the nuSTORM ring design optimization and improved the acceptance of the ring by 17%.

Optimization setup – Simulated annealing (SA)



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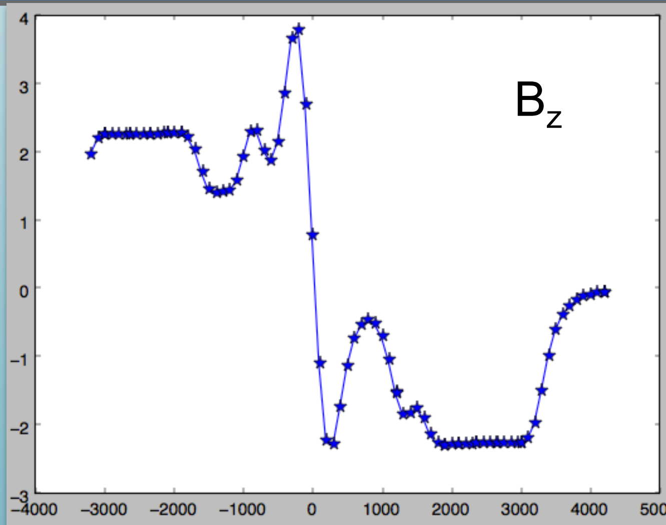
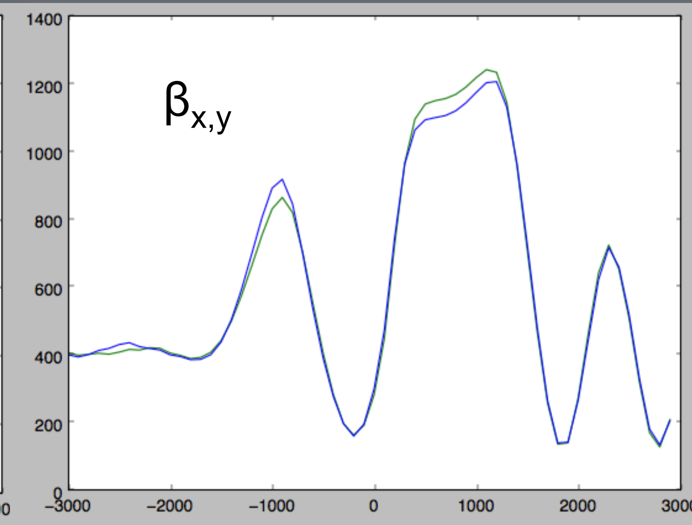
Optimization result – GA on NERSC

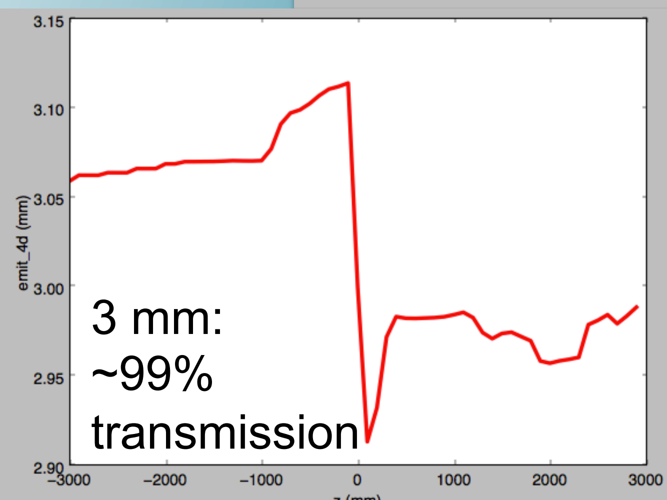
- GA was set up on NERSC to run
  - 120 individuals in each generation
  - 80 generations maximum
- Look at cases where uniform B_z is required in the trackers.
  - All with 6.5 cm LiH, decay disabled, hit-pipe-kill policy, simulate all the way to TOF2, stochastic processes enabled.
  - Try to increase the transmission*$\varepsilon_{4D\_tracker0}/\varepsilon_{4D\_tracker1}$

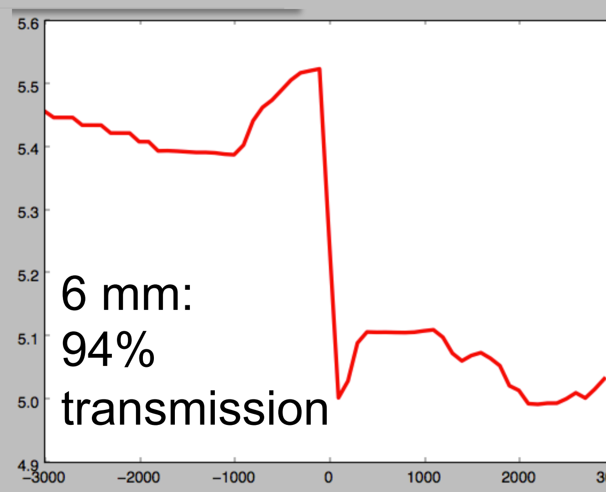
Results – Uniform B_z in the trackers

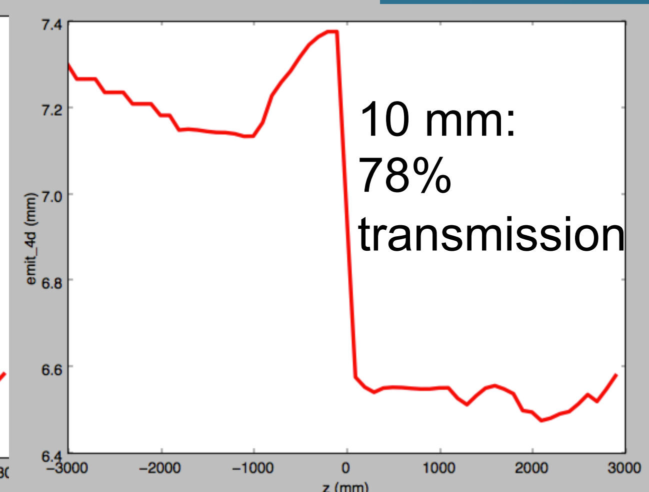




Good muons used in calculation only!

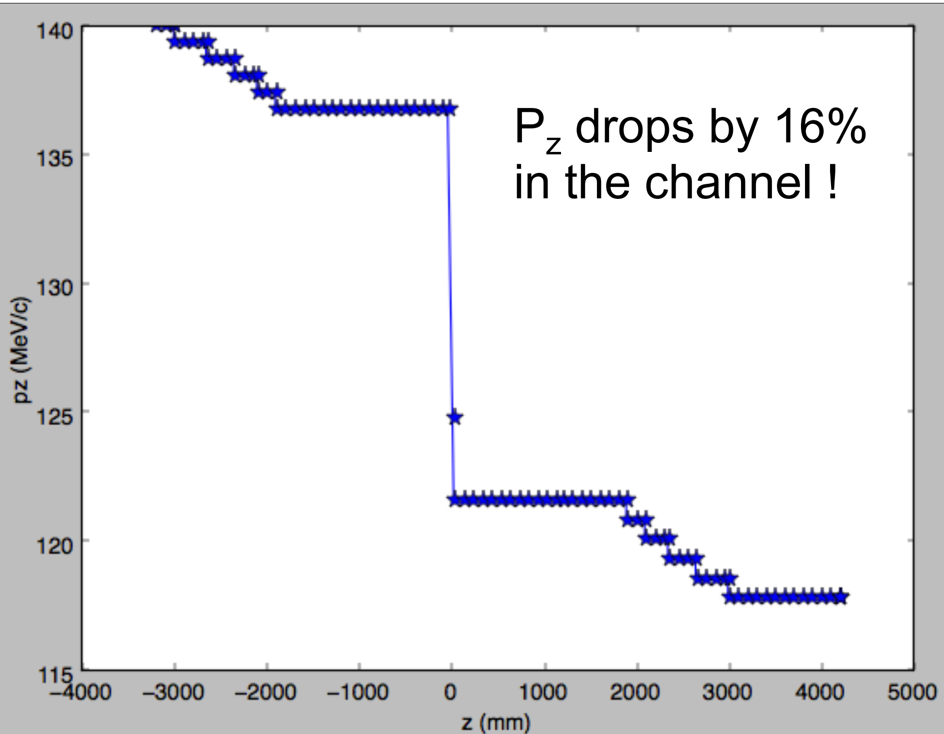


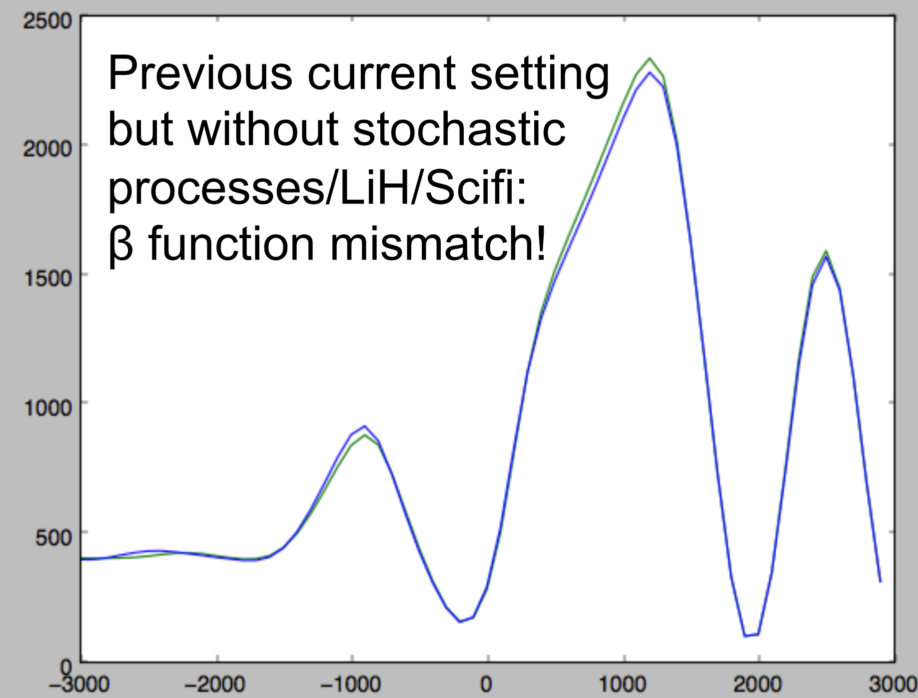




Results – Uniform B_z in the trackers (Cont'd)

- Notice that we have to consider the stochastic processes, LiH and Scifi materials in the optimization, since:





Multivariate optimization with materials necessary!!

Results – Uniform B_z in the trackers (Cont'd)

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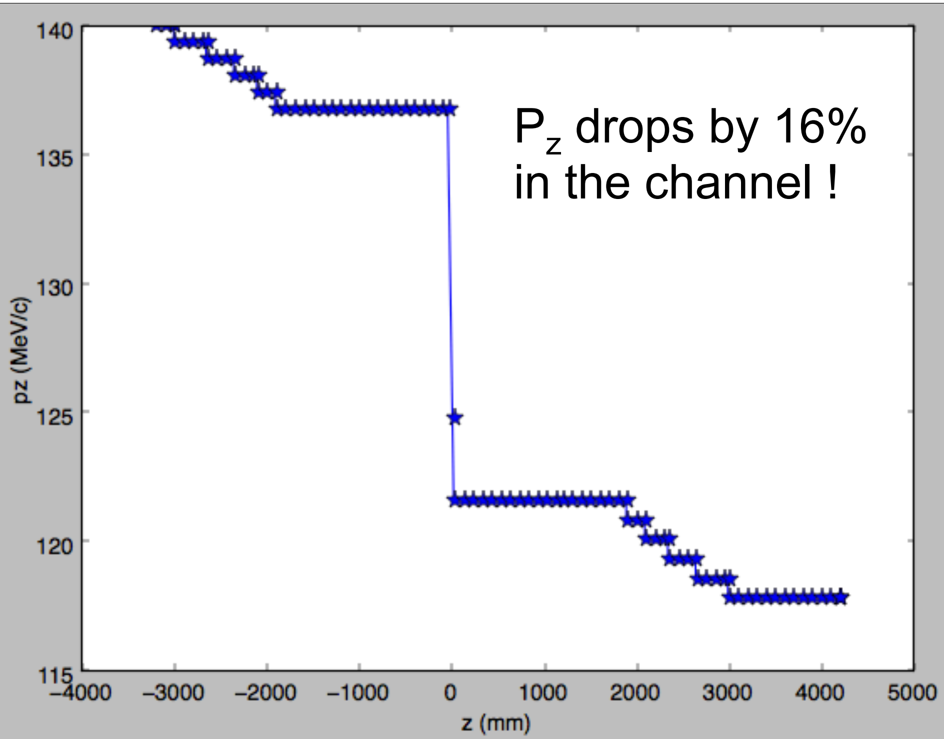
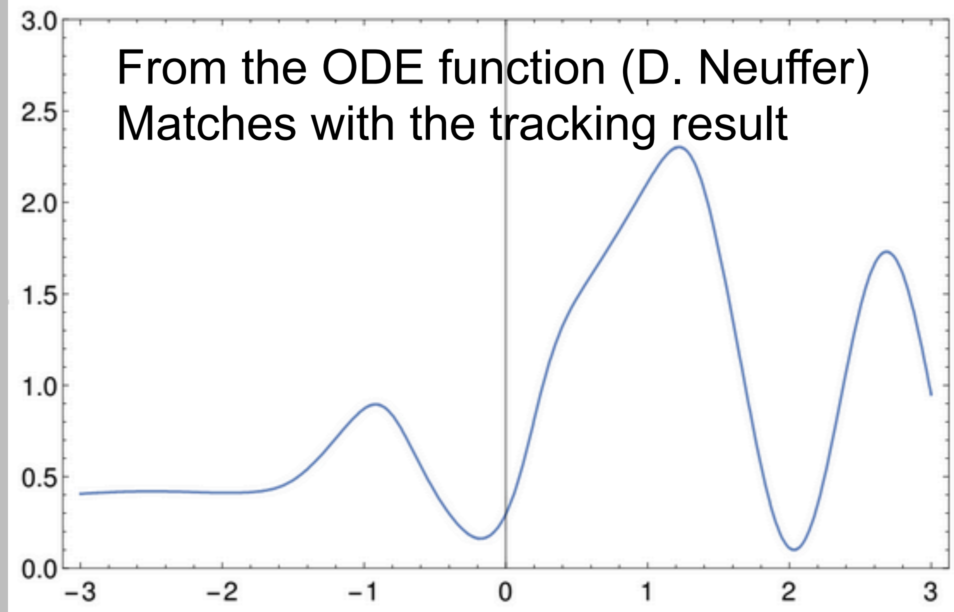


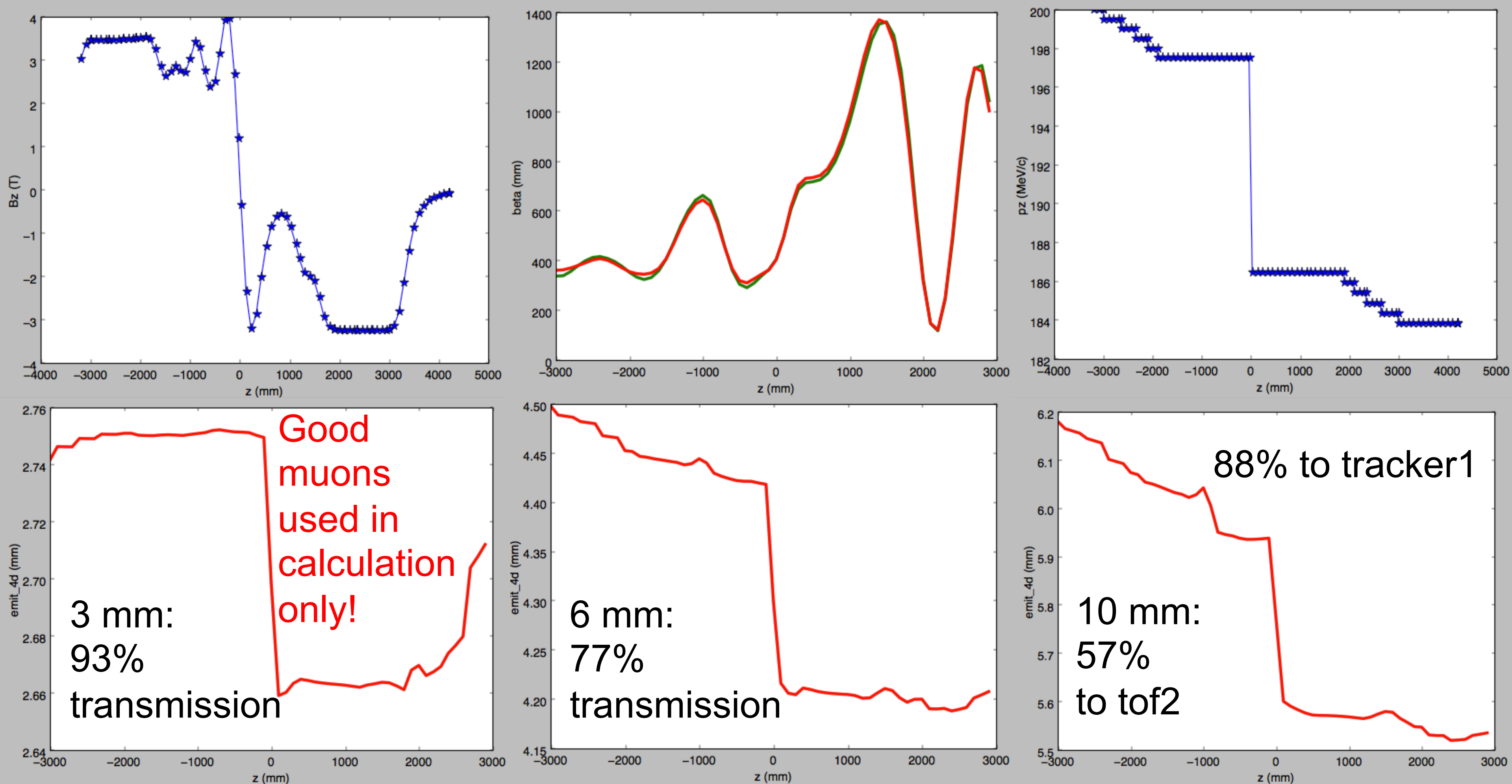
P_z drops by 16% in the channel !



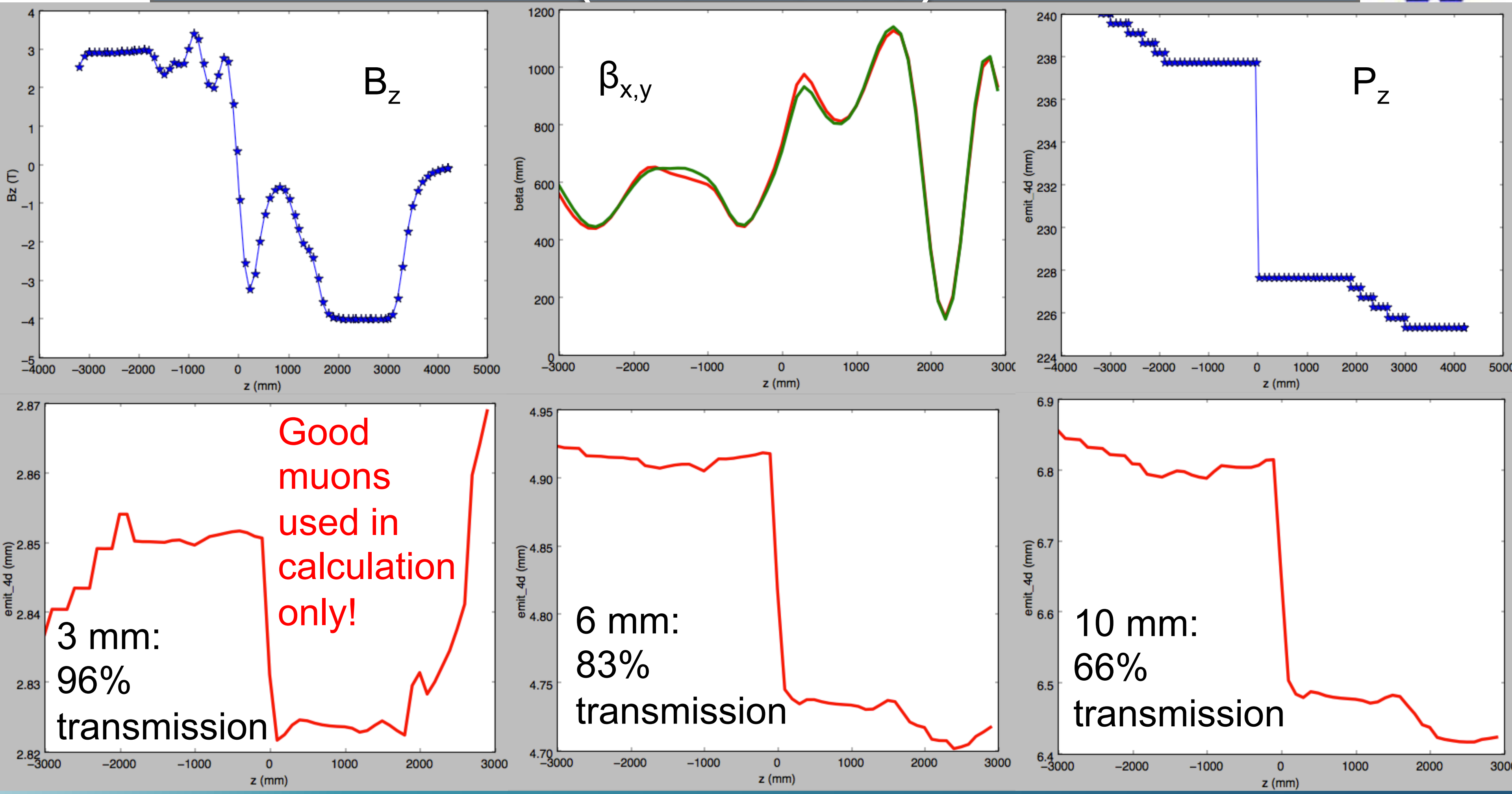
From the ODE function (D. Neuffer) Matches with the tracking result

Multivariate optimization with materials necessary!!

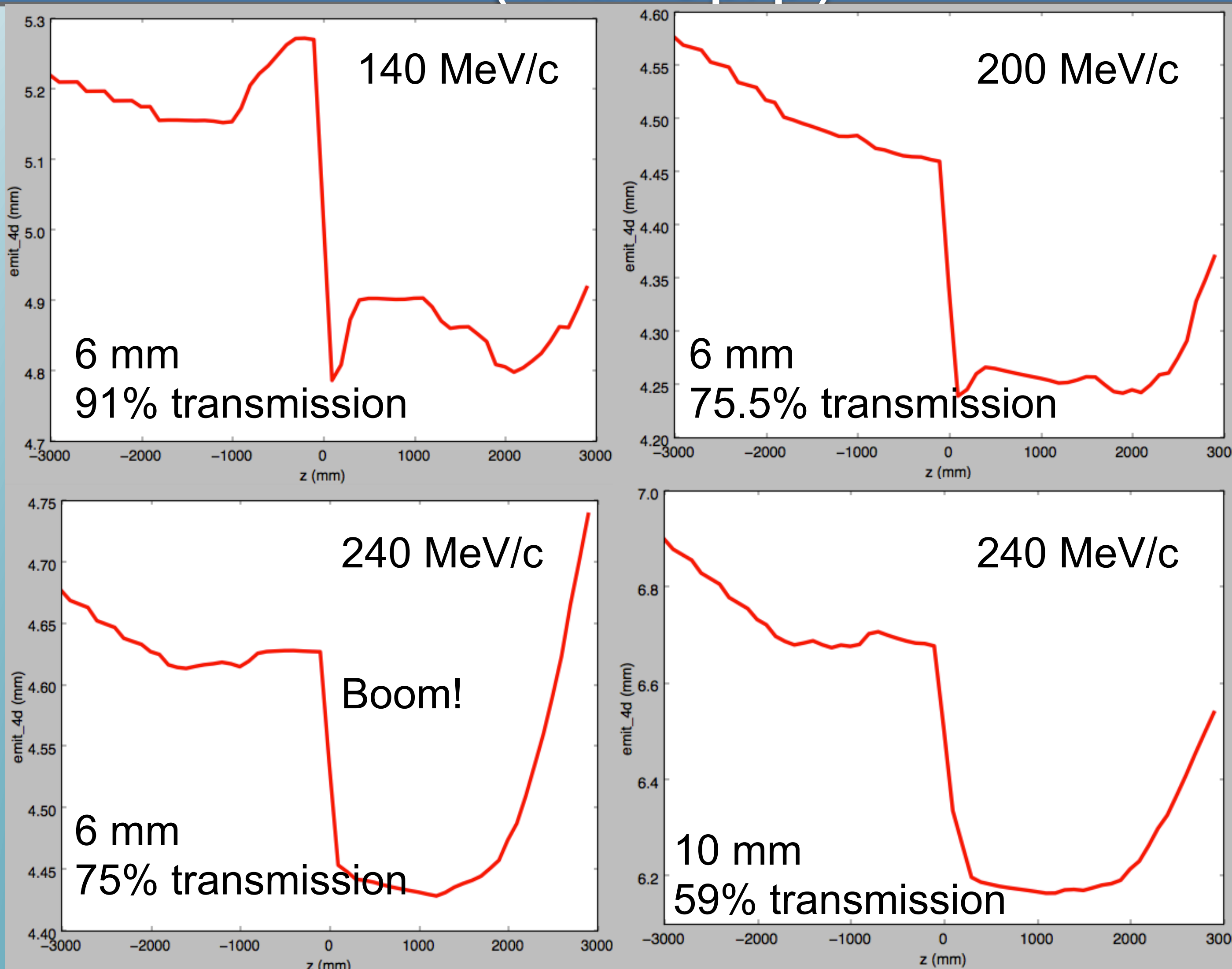
Results – Uniform B_z in the trackers (200 MeV/c)



Results – Uniform B_z in the trackers (240 MeV/c)



Results – Uniform B_z in the trackers (with $\delta p/p$)



$\delta p/p=0.05$

This is an optimization based on tracking, so another optimization can be done with $\delta p/p$!

Conclusions

- Demonstrated a G4Beamline simulation environment for the Step IV cooling channel
  - With Scifi, absorber, B field
  - With stochastic processes, obtained results that match the baseline well: simulation and calculation can be trusted
- Using a Genetic Algorithm, demonstrated that decent cooling with good transmission can be achieved for Step IV without M1 in SSD
  - FC upstream and downstream may have different currents, but can be modified to have the same values in the future optimizations;
  - Heuristic algorithm: if you don't like the best one, there are other options available to be looked at.

Questions?

YES OR NO, THANKS!