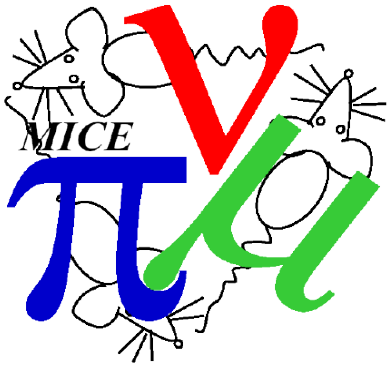
MICE Goals and Optics Options



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Introduction

- Review of principles of ionisation cooling
  - MICE as a test of ionisation cooling principles
  - Physics goals of MICE at Step IV
  - Physics goals of MICE for the Demonstration of Ionisation Cooling
- Step IV Programme in the absence of M1 in SSD
- Options for the Demonstration of Ionisation Cooling

Ionisation Cooling

- Cooling achieved by ionisation energy loss
  - Absorber removes momentum in all directions
  - RF cavity replaces momentum only in longitudinal direction
  - End up with beam that is less divergent
- Stochastic effects limit cooling
  - Multiple Coulomb Scattering increases transverse emittance
- Tight focus reduces relative effect of scattering
- Low Z material causes less scattering
  - E.g. lithium hydride or liquid hydrogen
- Equilibrium emittance where the two effects balance

Cooling Equation

- One can write the change in emittance as a function of z:

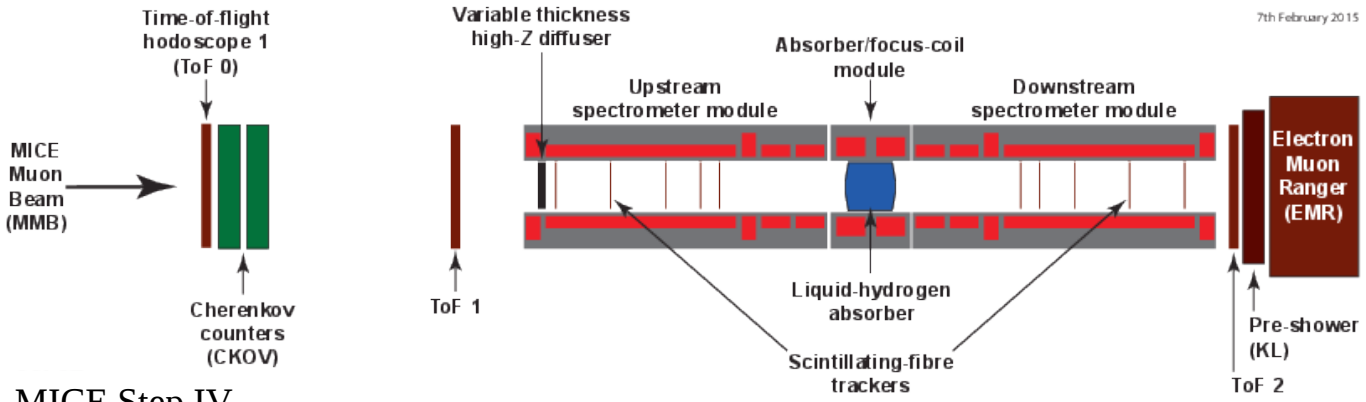
$$\frac{d\epsilon_n}{dz} \approx \frac{1}{E}\left\langle\frac{dE}{dz}\right\rangle\epsilon_n + \frac{1}{2m}\frac{13.6^2}{L_R}\frac{\beta_\perp}{\beta_{rel}^3 E}$$

- There exists an equilbrium emittance where the heating and cooling terms balance:

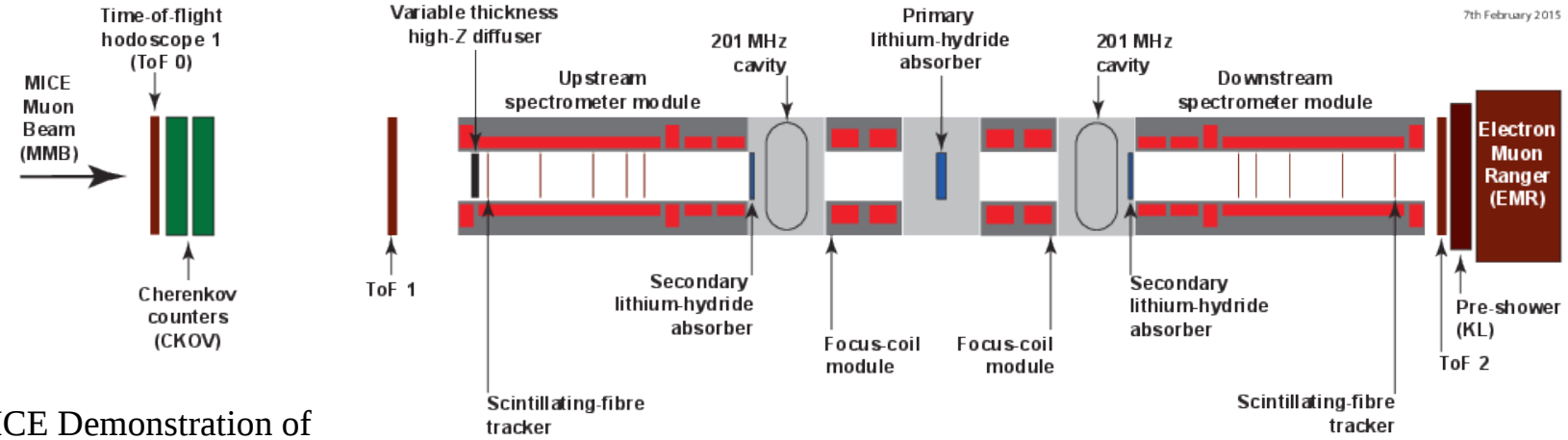
$$\epsilon_n(equilibrium) = \frac{1}{2m}\frac{13.6^2}{L_R}\frac{\beta_\perp}{\beta_{rel}<\frac{dE}{dz}>}$$

- MICE seeks to measure
  - The material physics parameters that make up the cooling effect
  - The change in emittance as a function of momentum and $\beta_\perp$
  - For a range of lattice scenarious
  - Reacceleration and sustainable cooling

The MICE Steps



MICE Step IV

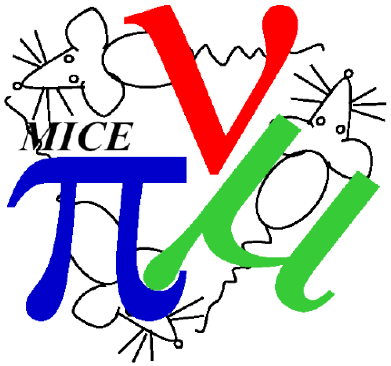


MICE Demonstration of Ionisation Cooling

MICE Physics Goals

- MICE physics goals at Step IV – demonstrate material physics properties
  - Measurement of multiple Coulomb scattering
  - Measurement of energy loss
  - Measurement of transverse normalised emittance reduction
- MICE physics goals for Cooling Demo – demonstrate sustainable ionisation cooling
  - Show transverse emittance reduction in absorbers
  - Show energy replenishment in the RF cavities

Step IV



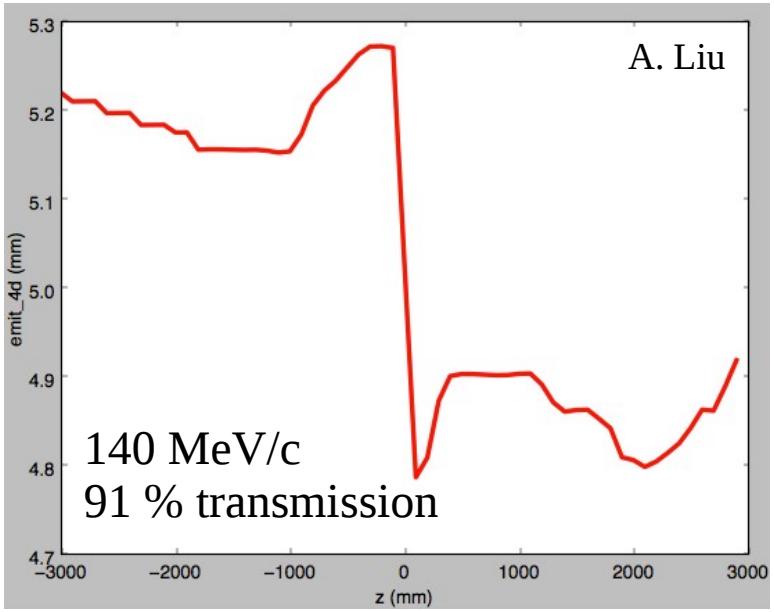
Measurement of scattering

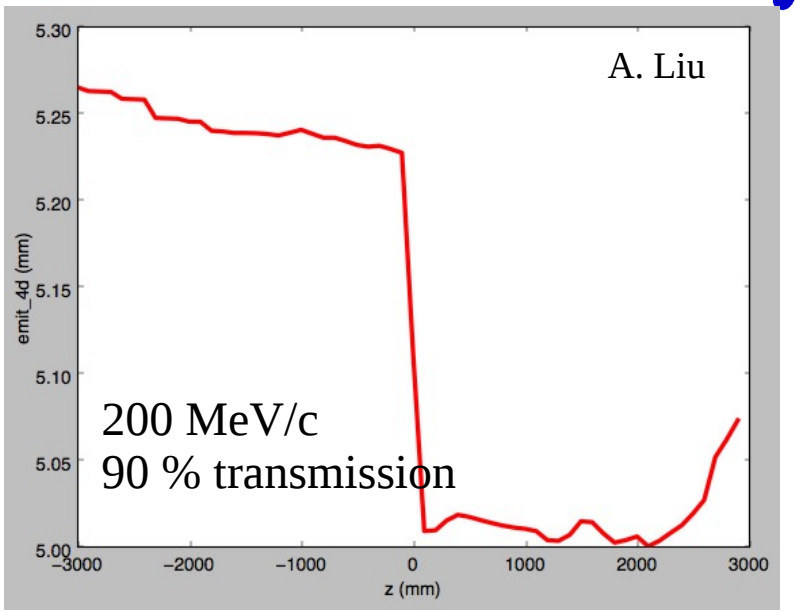
- Field-off route
  - Measure tracks upstream of absorber
  - Measure tracks downstream of absorber
  - Select momentum bite using TOF12
  - Study the transverse kick
- Field-on route
  - Extrapolate tracks upstream to the absorber through the fields
  - Extrapolate tracks downstream to the absorber through the fields
  - Select momentum bite using tracker pz reconstruction
- Seek to improve on measurements made in MuScat
  - Systematics limited at ~ 10-100k events
  - Field-off data gets around 10k through-going muons per hour
  - Magnets can be set to improve on rate even without M1 in SSD
- Detector resolutions are comparable to MuScat
  - Field-off transverse resolution is better than field-on data
  - Field-off pz resolution is worse than field-on data (pz selection)

Measurement of energy loss

- No prior measurement of muon energy loss in liquid Hydrogen or Lithium Hydride in the MICE energy regime
- Measurement of mean energy loss is expected to confirm Bethe-Bloch formula
  - Hope to measure minimum ionising energy in Lithium Hydride
  - Hope to measure energy straggling
  - Tracker pz resolution is similar width to the energy straggling distribution
- Require a lattice with reasonable through put and SSU/SSD at 4 T
  - This is possible even without M1/SSD operational

Measurement of Emittance Reduction

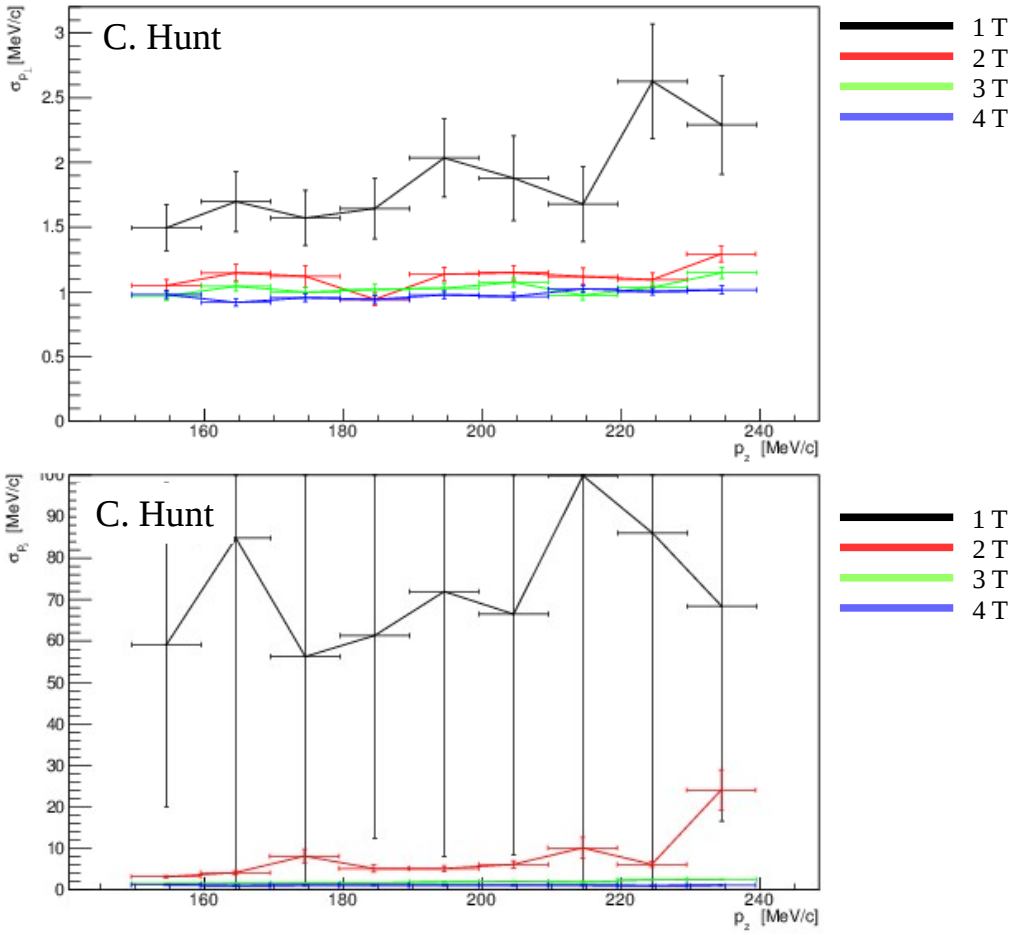




- We have lattices without M1 in SSD for 140 MeV/c and 200 MeV/c that demonstrate cooling
  - 3 T field in the trackers
  - Some mismatch in TKD
- We are preparing a lattice at 240 MeV/c
  - This is harder, but expect that it is possible

Tracker resolution

- Momentum resolution of the tracker is okay at 3 T
  - P_z resolution dramatically worse at < 1-2 T
- Possible to use TOF and EMR to get p_z
  - Requires software development



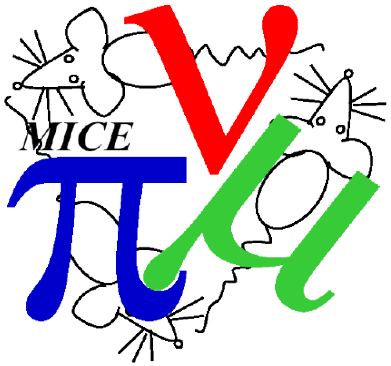
Run plan

- Plan is to make a cross shape in parameter space
  - 5 emittances + 5 beta + 5 momenta = 15 settings
    - Pending optics without M1 in SSD
  - Run with antisymmetric fields - “flipped”
  - Run with symmetric fields - “solenoid”
  - Reduced solenoid mode for lH_2
    - No momentum scan or emittance scan in solenoid mode
    - This is done in flip mode
- Enables better understanding of the trends (more points)
- Extrapolate to get to parameter space corners
  - Material physics is only “new physics”, and this will be well studied in a number of configurations
  - Optics is specific to MICE Step IV, i.e. we seek to demonstrate understanding

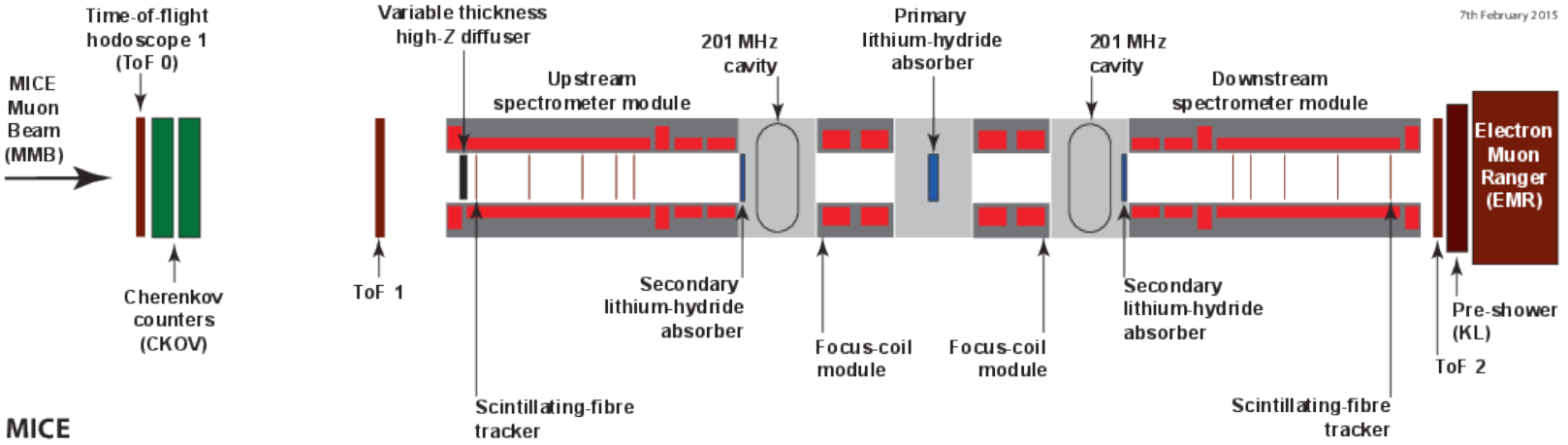
Step IV – Conclusions

- M1 coil on SSD is **not** required for successful operation of Step IV
  - We have lattices that can give “direct” measurement for all Step IV momenta
  - We have lattices that function at 140 MeV/c and 200 MeV/c
  - We have not yet designed lattices for a $\beta_\perp$ scan, but expect that this is possible
- ECE coils on SSD are required to operate at > 2 T for tracker reconstruction in pz
  - Required for energy loss measurement
  - Required for emittance reduction measurement

Demonstration of Ionisation Cooling

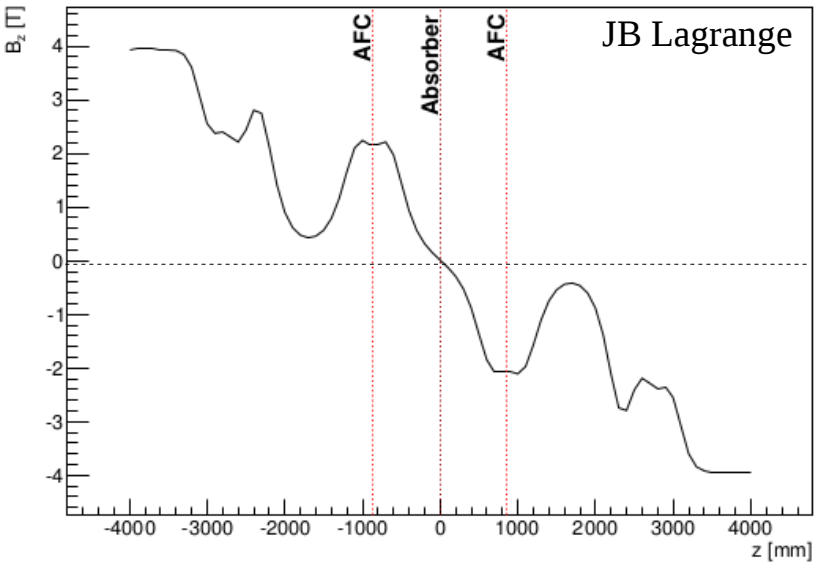


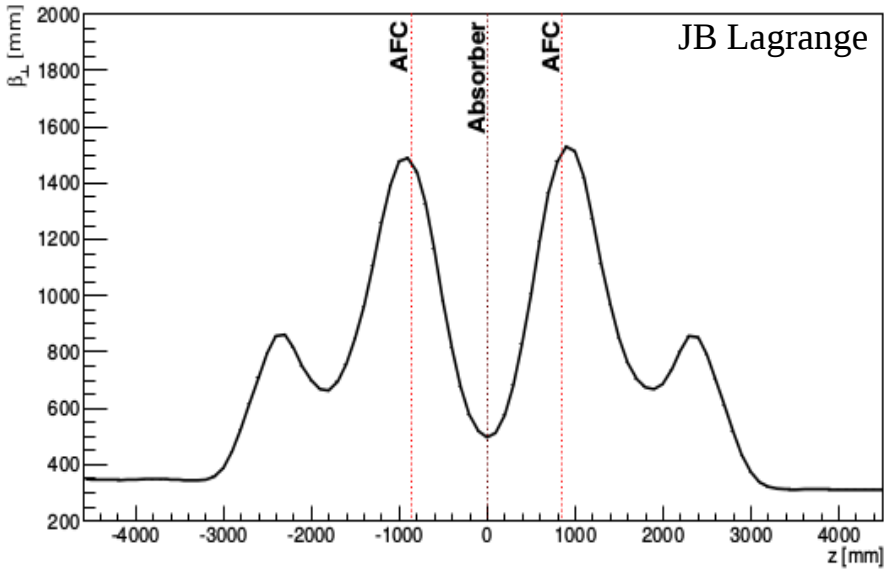
Demonstration of Ionisation Cooling



- MICE “Demonstration of Ionisation Cooling”
  - Redesign of MICE Step VI given lessons learnt during Step IV construction
  - Includes a full cooling half-cell
  - Includes RF cavities
- Shows emittance reduction including reacceleration

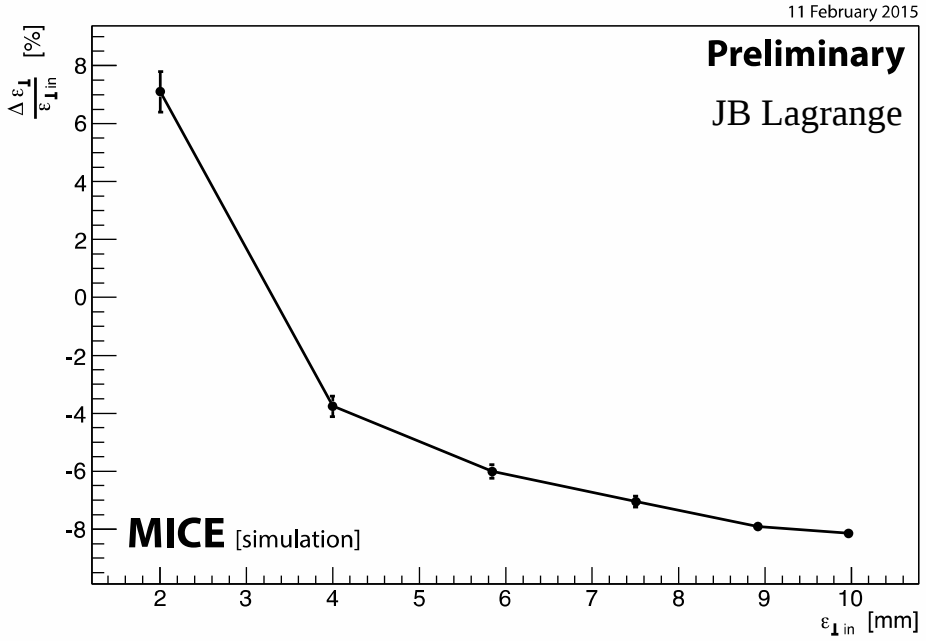
Demonstration of Ionisation Cooling





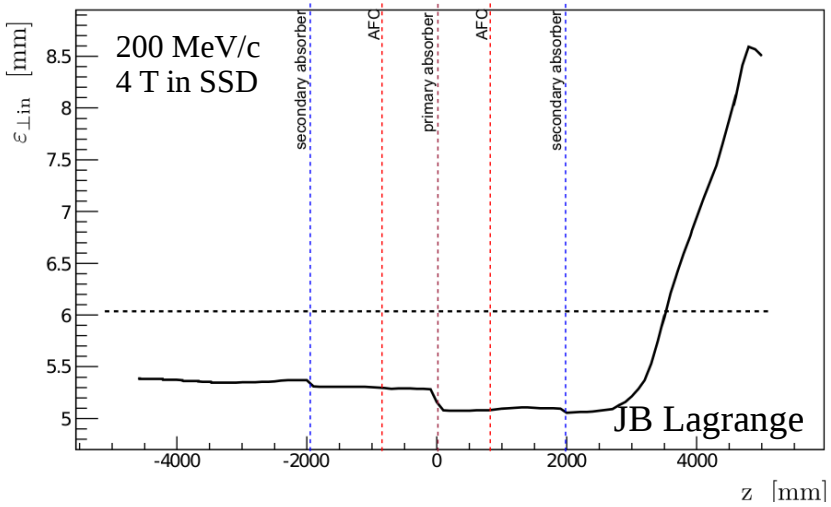
- Two Focus coil modules
- Lithium hydride absorber and two secondary absorbers
- Two RF cavities

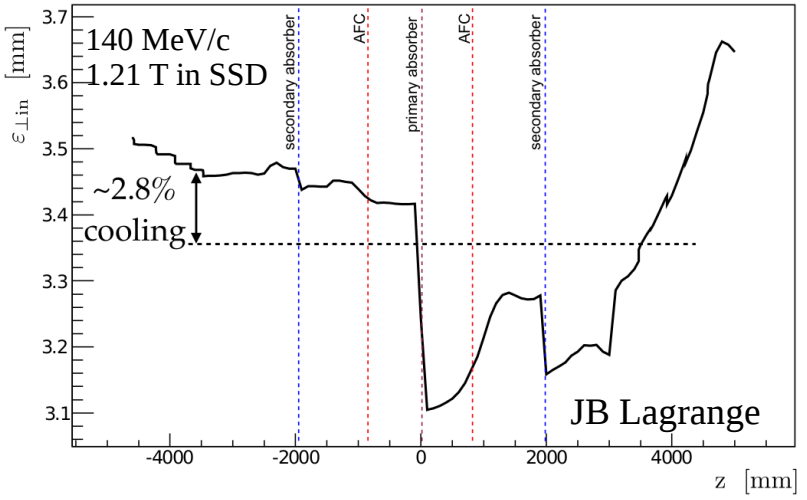
Performance



- Equilibrium emittance around 3 mm – to be measured
- Acceptance around 10 mm – to be measured

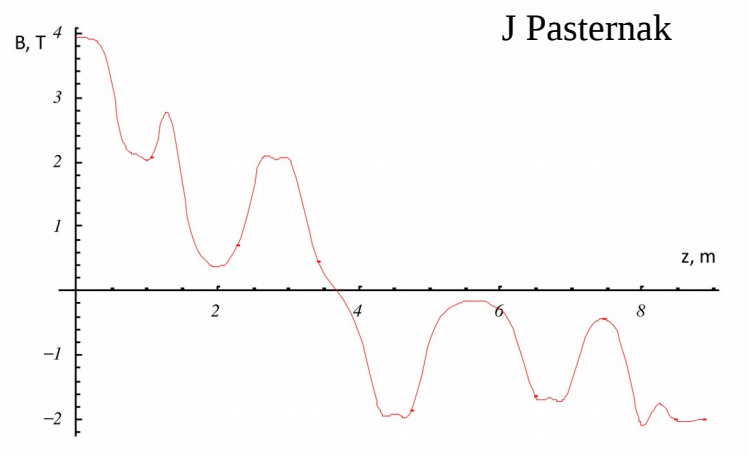
“Do Nothing” Option

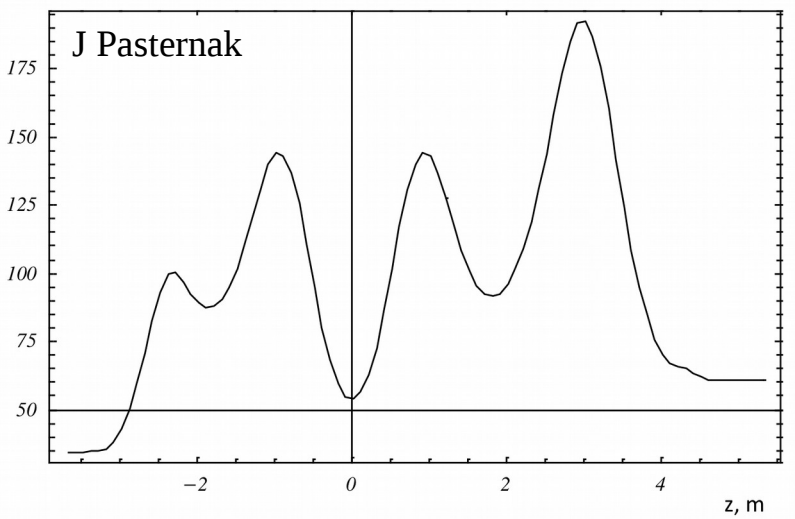




- Marginal reduction of RMS emittance
- Mitigate by extrapolating tracks upstream of SSD/M1
  - Introduce systematic error from knowledge of field
- Mitigate by more sophisticated phase space volume analysis
  - May be challenging due to high curvature of phase space
- Mitigations are not possible in context of 1.2 T field in SSD
- Mitigations incur unacceptable risk due to suspected damage to SSD feedthrough

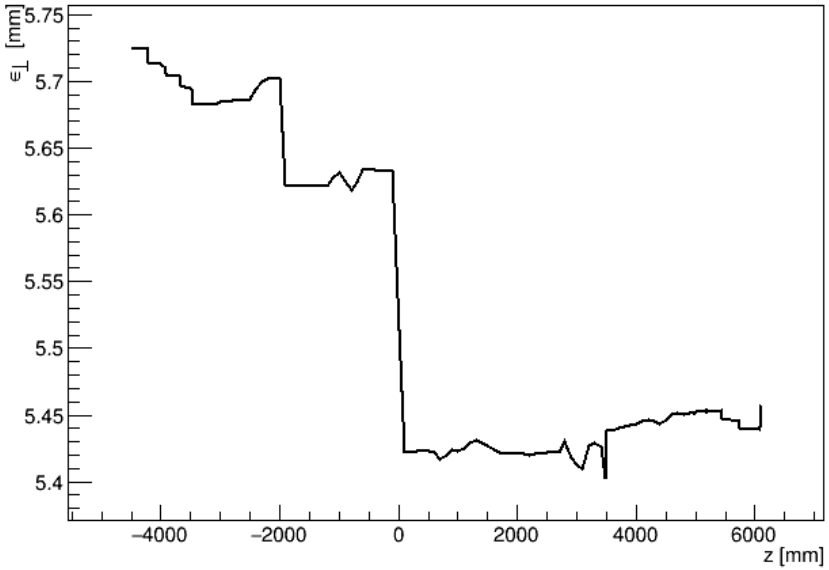
“Additional Coil” option





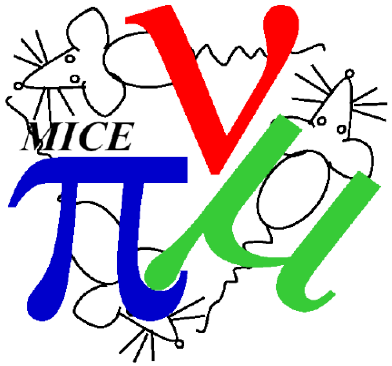
- Introduce an additional Focus coil pair to aid matching
  - Minimum space between FCD and additional Focus coil
  - Minimum space between additional Focus coil and SSD
- To attain flat $\beta_\perp$ in SSD
  - Reduced B_z in SSD to 2 T
  - Large $\beta_\perp$ excursion in additional Focus coil

“Additional Coil” option



- Emittance reduction readily measurable
  - Note that B_z was degraded to achieve this performance
- Leaves risk due to suspected damage to SSD feedthrough

Conclusions



Conclusions

- M1 coil on SSD is not required for successful operation of Step IV
- Baseline for MICE demonstration of ionisation cooling will
  - Show transverse emittance reduction in absorbers
  - Show energy replenishment in the RF cavities
- Three options were shown in the light of the failure of M1/SSD
- Baseline lattice with repaired SSD
- Baseline lattice without repaired SSD
  - Requires challenging analysis to make it work
  - Leaves risk due to suspected damage to SSD feedthrough
- Baseline lattice with additional FC for matching
  - Does require some reduction in SSD field, hindering reconstruction
  - Leaves risk due to suspected damage to SSD feedthrough