6D Cooling in MICE

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Longitudinal ~~6D~~ Cooling in MICE

'Normal' MICE Reduces and Measures 6D Emittance

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Longitudinal ~~6D~~ Cooling in MICE + some other stuff

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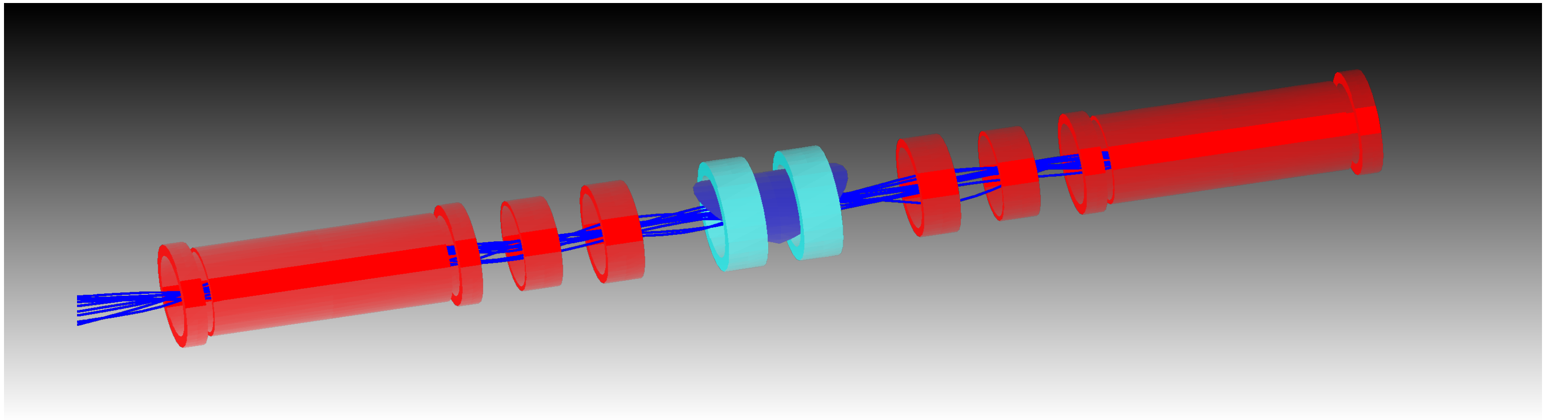
Possible Experimental Goals

	MICE	
Accelerator Demonstration		
Ionisation Cooling Demo		
Emittance Exchange Demo		
Reverse Emittance Exchange Demo		
Physics Processes		
H2 Physics Processes		
He Physics Processes		
LiH Physics Processes		
Be Physics Processes		
Physics Processes in High Bz		
Beam Dynamics		
Straight Solenoid Beam Dynamics		
Tilted Solenoid Beam Dynamics		
Helical Solenoid Beam Dynamics		
Magnetically Insulated Beam Dynamics		
PIC Beam Dynamics		
Energy Recovery		Limited by available RF Gradient
Longitudinal Dynamics		Limited by available RF Gradient
Engineering		
Liquid H2 Safety		
Liquid Vessel Window Design/Operation		
High Pressure Gaseous H2 Safety		
Pressure Window Design/Operation		
Be Window Design + Handling		
LiH absorber Design + Handling		
Integration of RF Equipment		
Integration of magnetically insulated RF		
Integration of high pressure RF		
Integration of HCC RF		
HCC Construction		

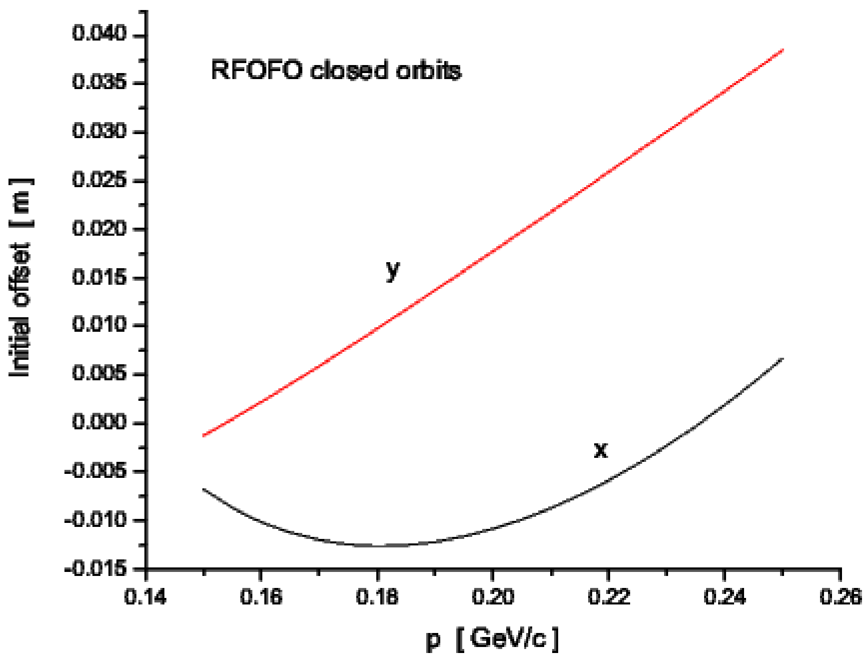
Simple Wedge

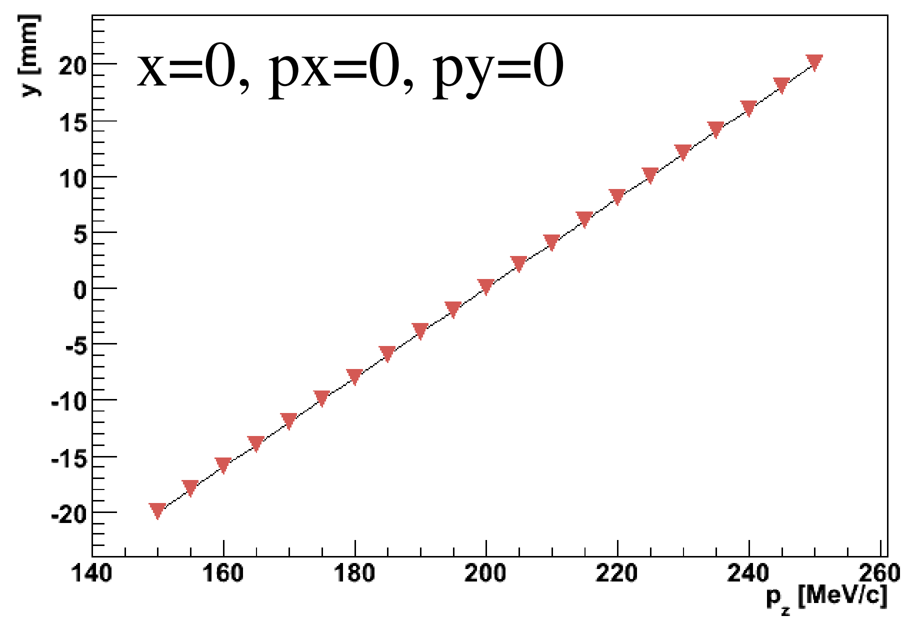
- Simple wedge
  - Induce dispersion in input beam
  - Measure (reverse) emittance exchange
- To what purpose?
  - “Proof-of-principle” - demo for wider community
  - Test material physics model in a different geometry
- Open questions
  - Which material?
  - What opening angle?
  - Can we measure an effect?



RFoFo Model

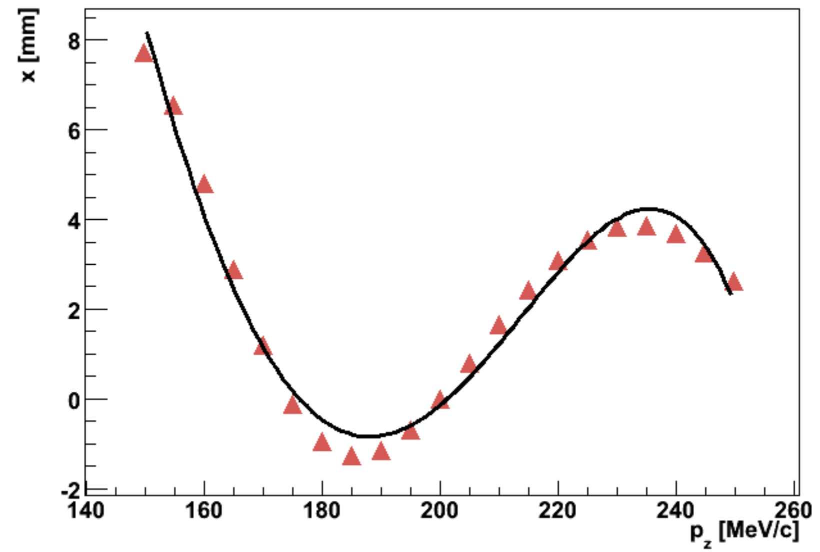
- Induce some y-pz correlation in particles at the wedge
  - Working to approximately follow RFoFo lattice - MUCOOL Note 314

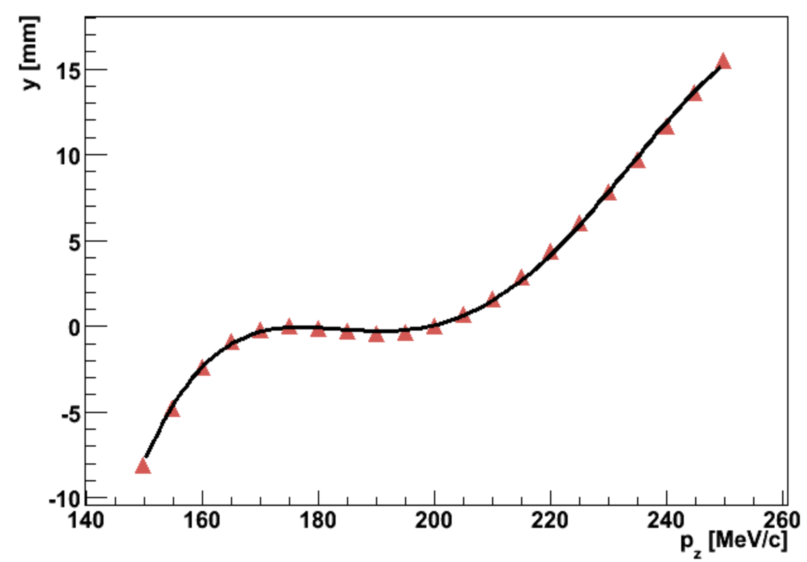




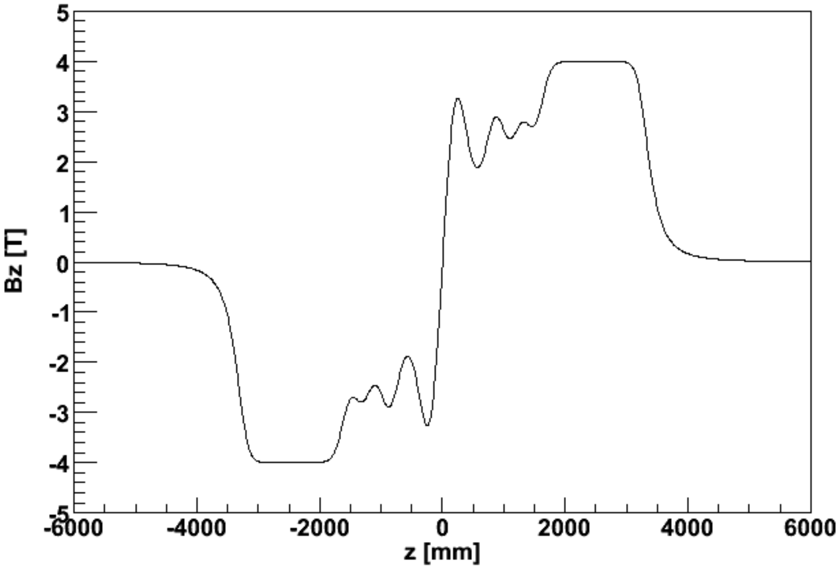
Non-Linearity

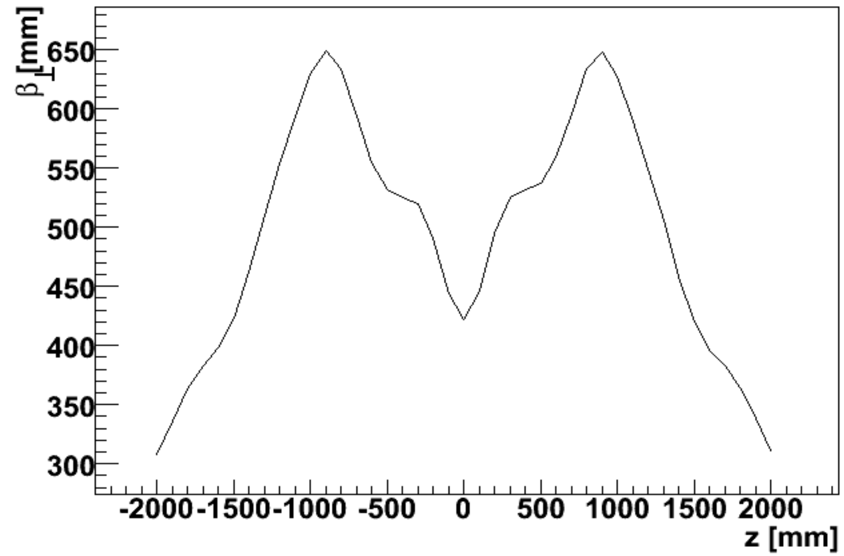
- Look at these particles at tracker
  - Tells us what correlation we need at the tracker to get dispersion at the wedge
- Pretty non-linear
  - Fit using 4th order polynomials
  - Probably needs 5th order...
  - This is probably generated by Larmor angle as a function of p_z
- To get a “non-linear” match
  - Insert beam at wedge center
  - No material processes
  - Transport to tracker
  - Apply px, py, t -> -px, -py, -t
    - Time Parity operator + reflection in z

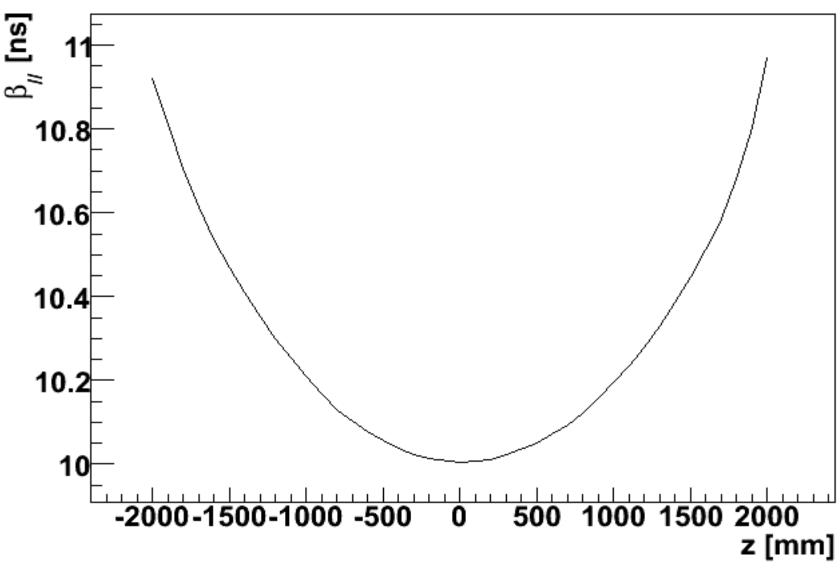


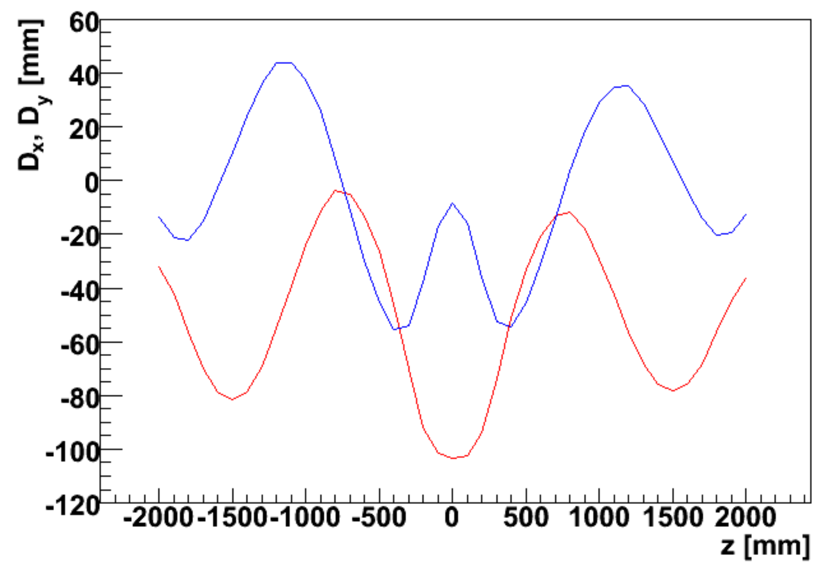


Beam Transport



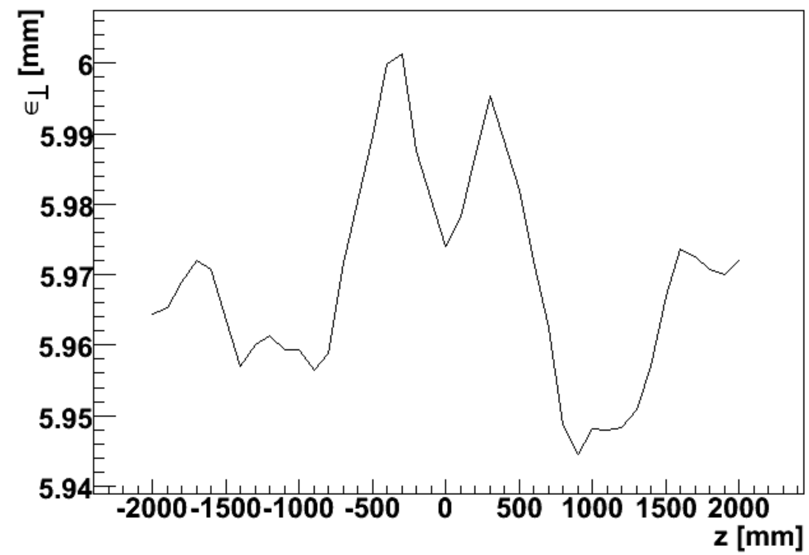


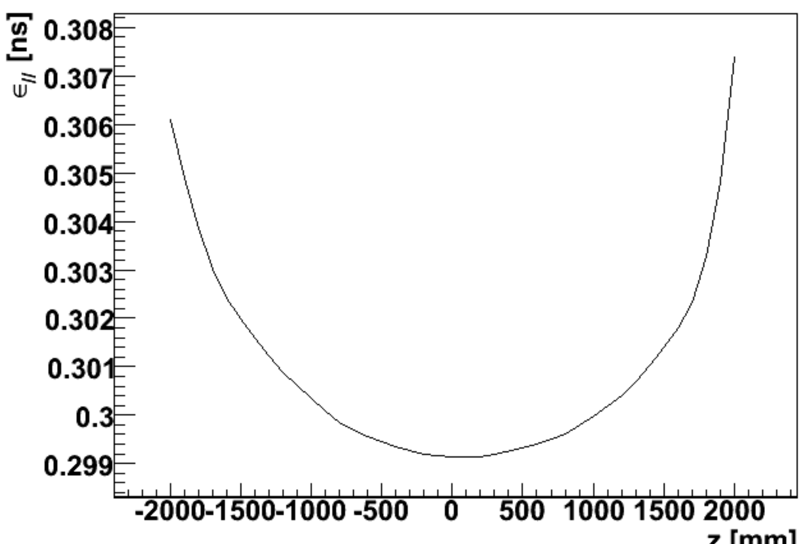


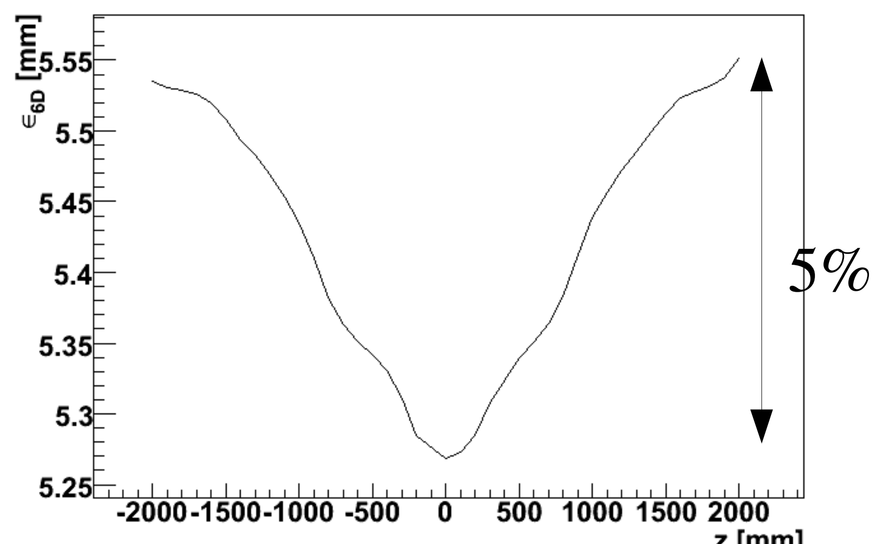


Emittances (no material)

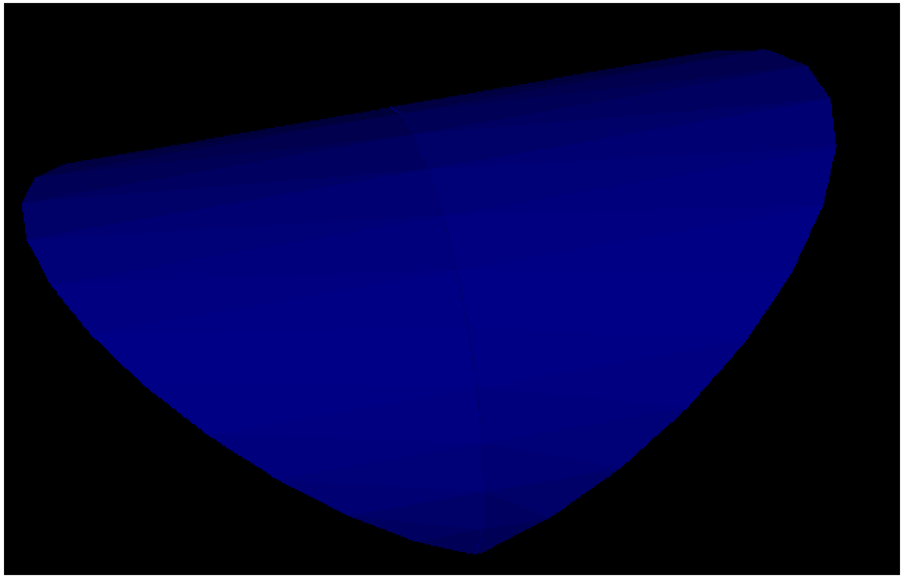
- ~Few percent emittance change from non-linearities
  - By making beam optics symmetric, emittance change is symmetric
  - How sensitive to initial beam?
  - How sensitive to magnet misalignment etc?

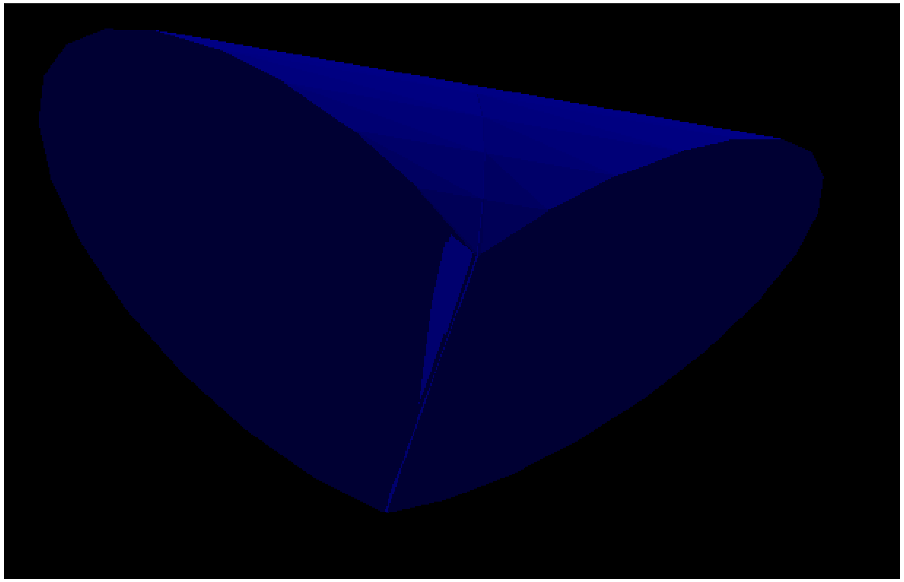


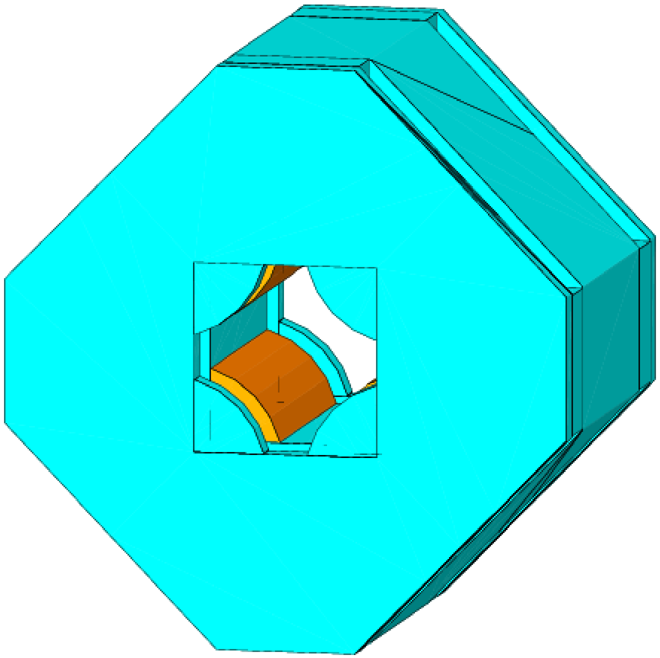




Wedge Geometry (G4MICE)



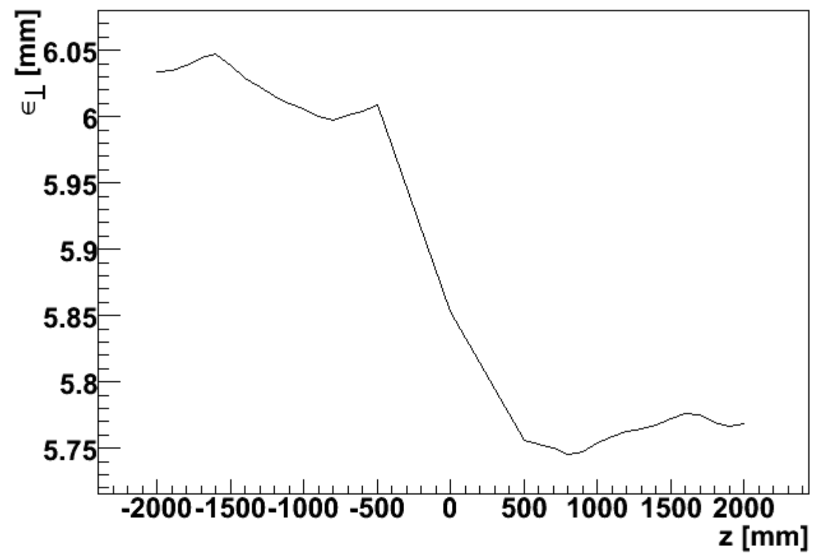


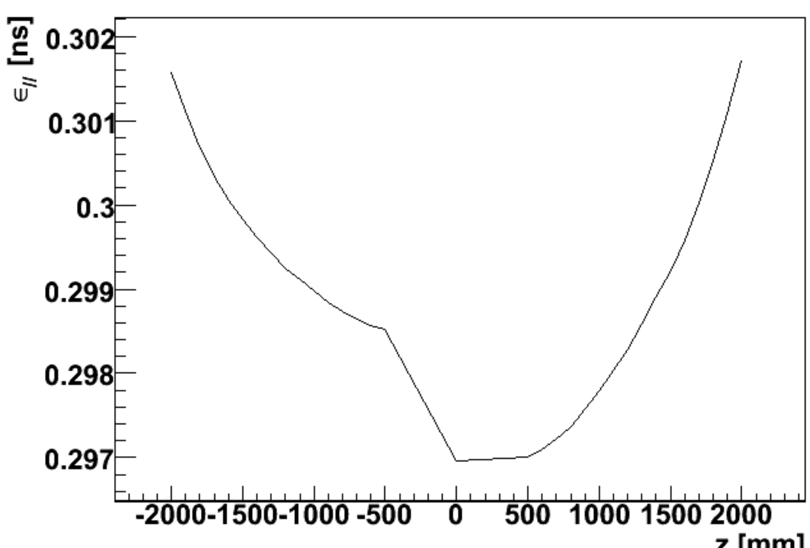


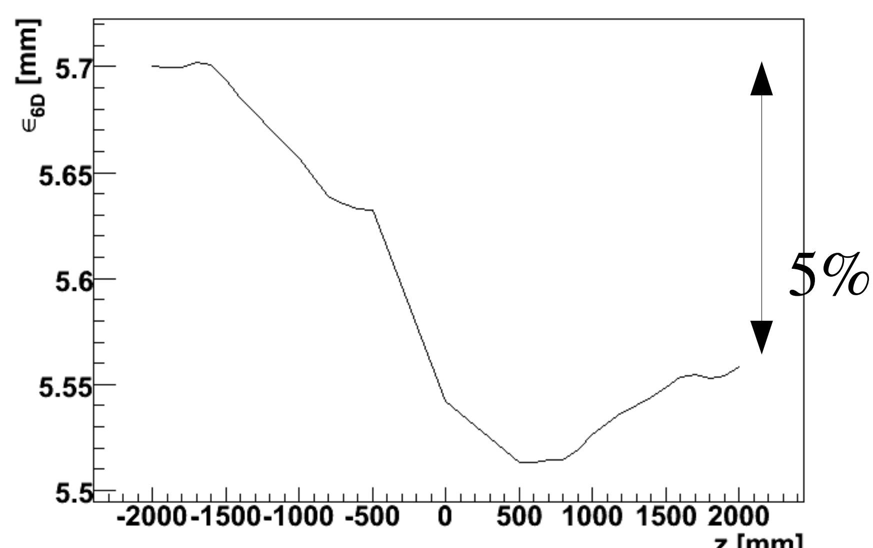
Fancier geometries are available

Emittances 100º LH2 Wedge

- D_y = 100 mm
- 100º ~ RFoFo wedge
  - No windows
- Small longitudinal cooling
- Drowned by non-linearities
- Overall ~ 5% 6d emittance reduction







More cooling?

- What can we do to get more longitudinal cooling?
  - Wang and Kim, MUCOOL Note 224

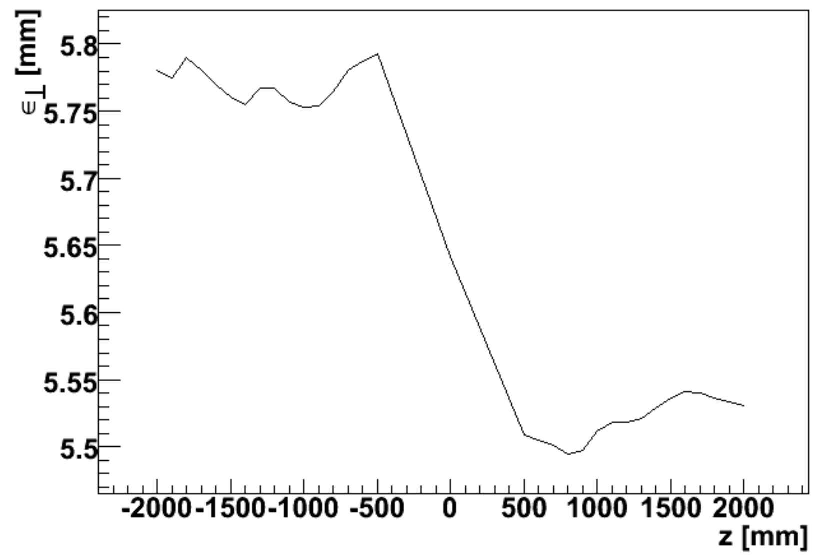
$$\epsilon'_y = -\eta\epsilon_y + (\partial_x\eta)D_y\epsilon_y + \frac{1}{2}\eta\hat{b}_s\beta_T L + \frac{1}{2}\beta_T\chi + \frac{1}{2}\mathcal{H}_y\chi_\delta,$$

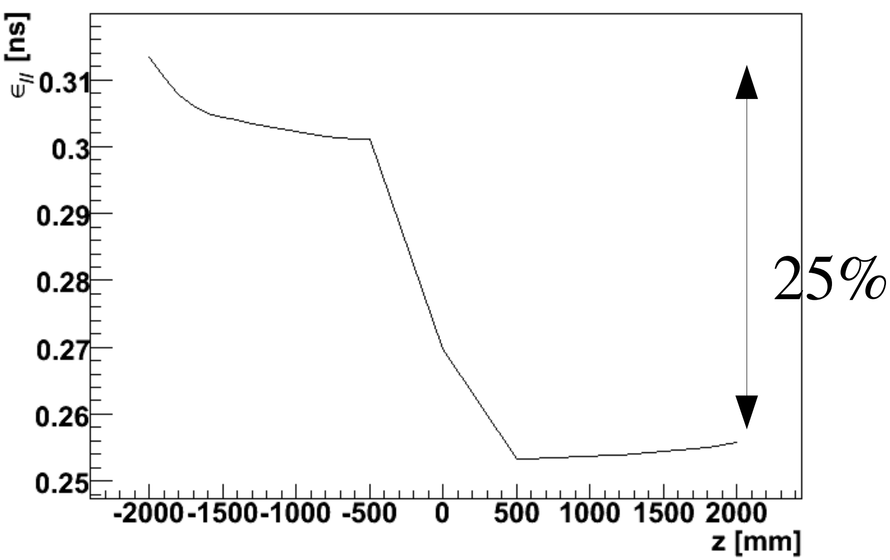
$$\epsilon'_z = -(\partial_x\eta)D_x\epsilon_z + \frac{1}{2}\beta_L\chi_\delta + \frac{1}{2}\gamma_L(D_x^2 + D_y^2)\chi,$$

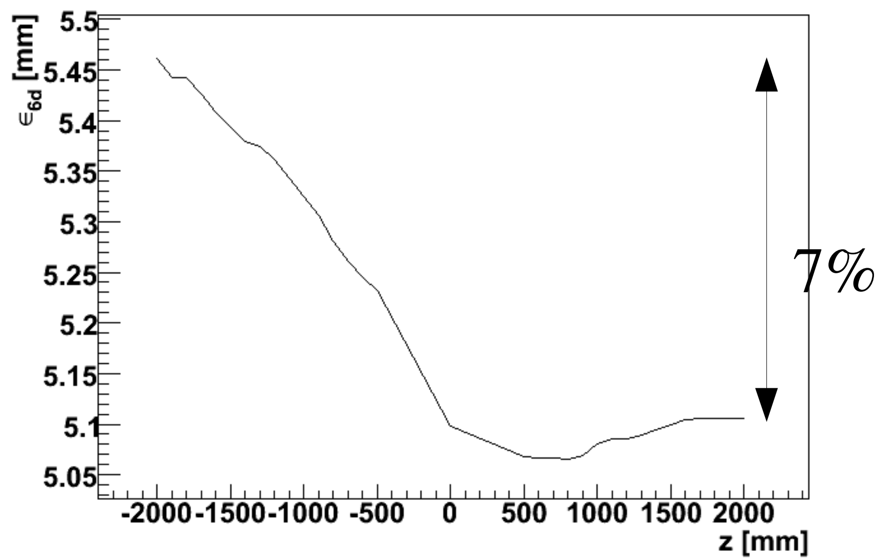
- More dispersion
- Bigger dE/dz => Bigger d/dx (dE/dz)
- Bigger wedge angle
  - Geometrically challenging
- Bigger longitudinal emittance
  - Non-linearities are already tough

Emittances 90° LiH Wedge

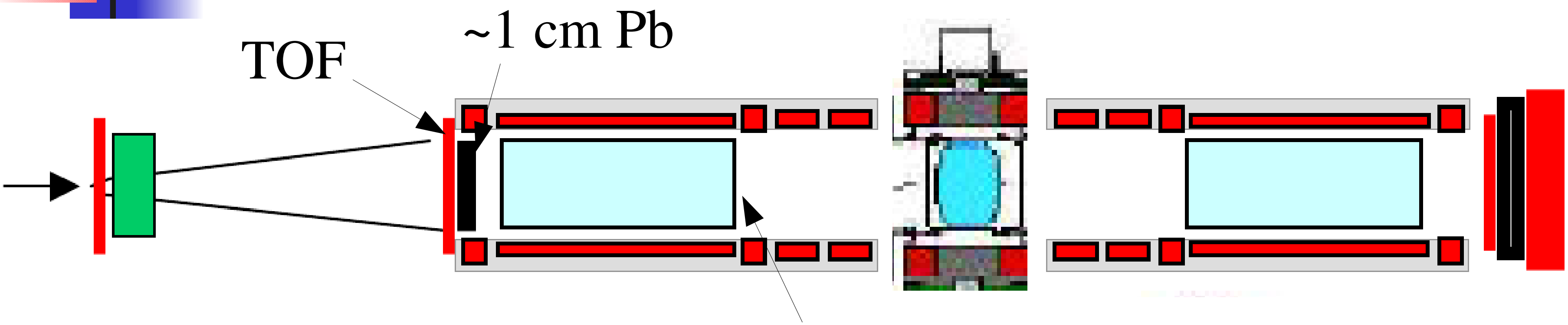
- D_y=200 mm this time
- ~ 25% longitudinal emittance reduction
- 6D emittance reduction
  - 7 % in mm
  - 20 % in mm^3
  - lH2 is much worse
  - Plastic is similar



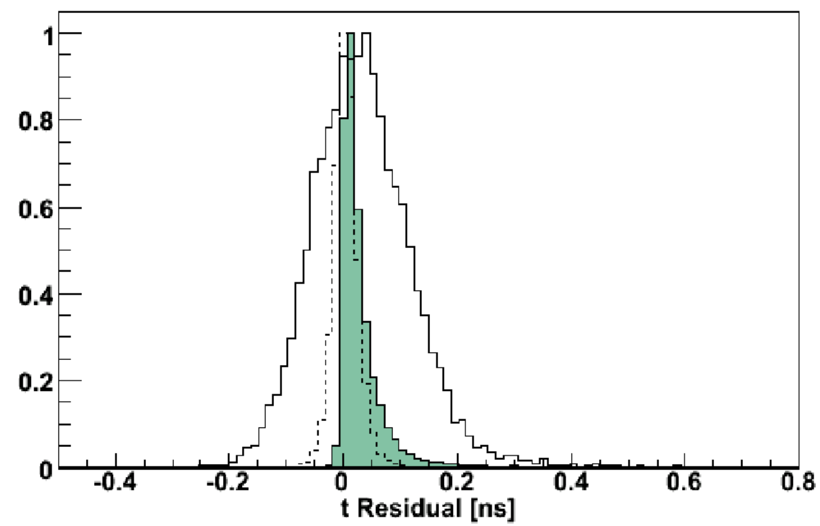




Measurement

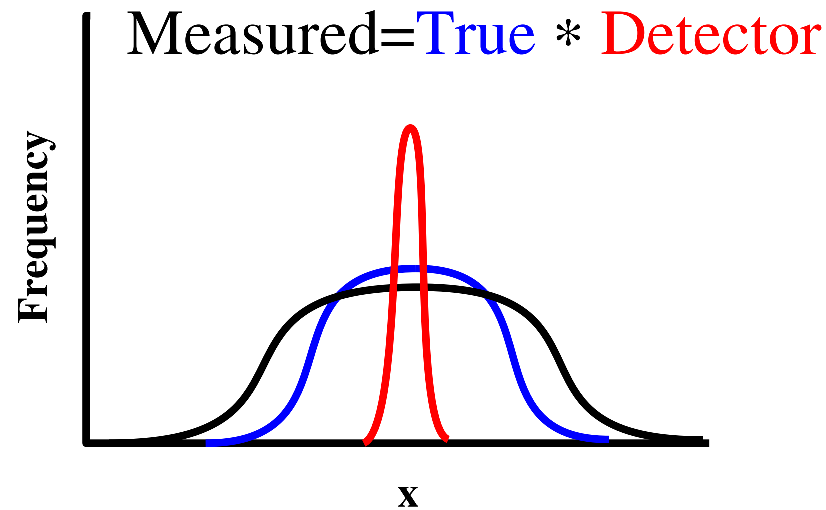


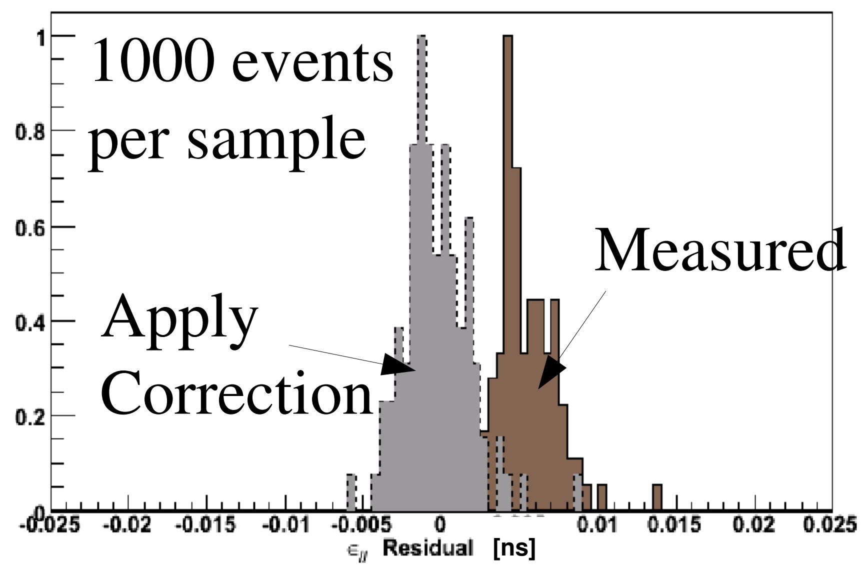
- MICE measures time at TOF
- Use measurements in tracker to extrapolate time to the tracker
  - Measure 6D phase space coordinates at a single z-plane
  - Gives a time resolution < 90 ps at tracker
    - Includes material effects esp diffuser
    - Includes tracker resolution
    - Assume pessimistic TOF resolution
    - Assume can't use TOF0-TOF1 dt to help
  - Note long tail



Longitudinal Emittance Measurement

- A statistical error in detector gives a systematic error in RMS emittance
  - Analogous to addition in quadrature
  - Complicated by correlations between truth and error
    - Not a pure convolution
  - If we understand the detector we may be able to correct this offset
    - In any case we can measure a clear cooling signal
- Statistical spread comes purely from statistical spread in true distribution
  - Due to stochastic processes
  - Due to initial beam distribution
  - **Nothing to do with detector error**
- $\varepsilon_{//}$ residual $\ll$ cooling in $\varepsilon_{//}$

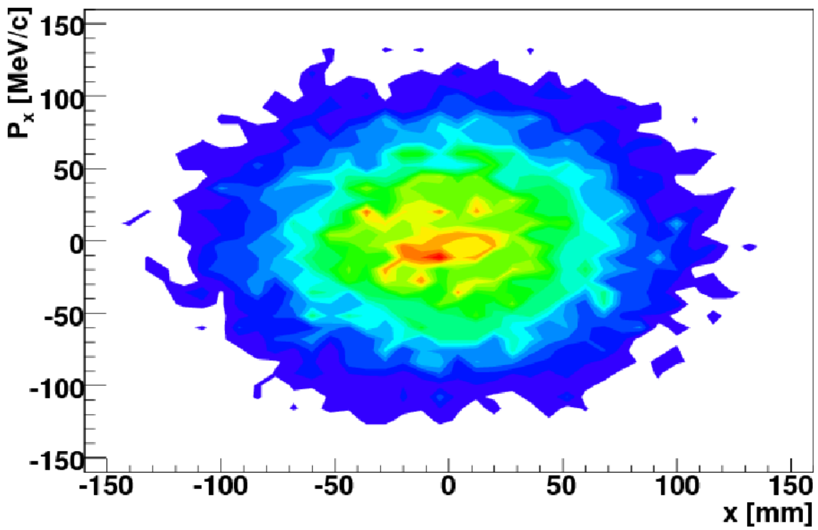


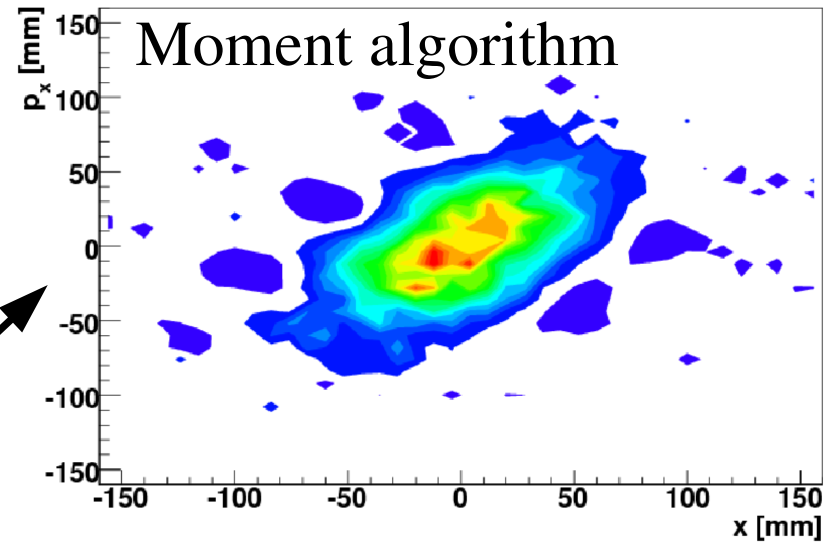


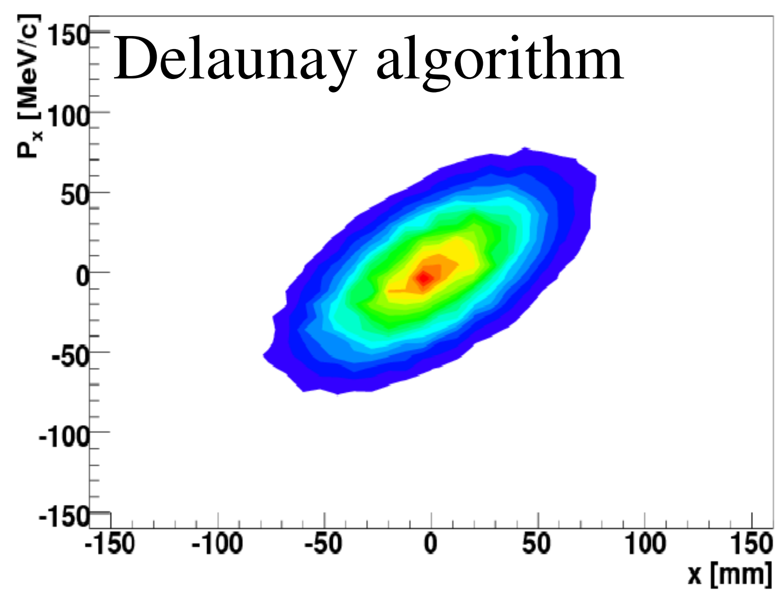
Beam Selection

- MICE beam has no time distribution and wide energy distribution
  - Nb one would have to allocate time at upstream tracker (no rf)!
- Beam setup was baroque in these simulations
  - Want to choose beam carefully to suppress optical heating (and cooling)
  - Baseline beam selection operates by selecting for beam moments
  - In principle can select arbitrary beam moments
  - In principle can derive non-linear beam heating from high beam moments
  - 4th order optics => 5th order (higher?) beam moments affect emittance
- Practical constraints may prevent this from working
  - Calculating high moments for a large selection of particles, in high dimensional spaces, needs some care
  - Also big matrix inversion required
- I would like to demonstrate to myself that I can do this to adequate precision

Beam Selection







- E.g. introduce a correlation
- Moment algorithm is not so pretty
  - I understand its relation to beam optics
  - But can produce negative weightings
- Delaunay algorithm looks nice
  - But PC runs out of memory > 1e3-1e4 particles(!) in 6D
  - Not parallelisable

MICE Step IV - Summary

- We can certainly measure longitudinal cooling in MICE IV
  - We should probably scan over a few values of wedge opening angle
  - We should probably scan over some different materials
- Do we have time for lH2? Or LiH for that matter?
  - It is possible to go back to MICE IV at the end of MICE
  - Plastic absorber may be preferable
- Need to:
  - Select materials, parameters
  - Design absorber
    - Solid absorber could/should be very simple
  - Manufacture

Possible Experimental Goals

	MICE	MICE-IV Wedge	
Accelerator Demonstration			
Ionisation Cooling Demo			
Emittance Exchange Demo			
Reverse Emittance Exchange Demo			
Physics Processes			
H2 Physics Processes			
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Physics Processes in High Bz			
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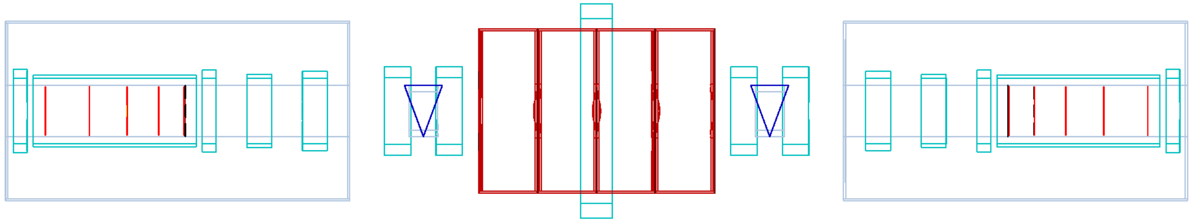
Engineering			
Liquid H2 Safety			
Liquid Vessel Window Design/Operation			
High Pressure Gaseous H2 Safety			
Pressure Window Design/Operation			
Be Window Design + Handling			
LiH absorber Design + Handling			
Integration of RF Equipment			
Integration of magnetically insulated RF			
Integration of high pressure RF			
Integration of HCC RF			
HCC Construction			

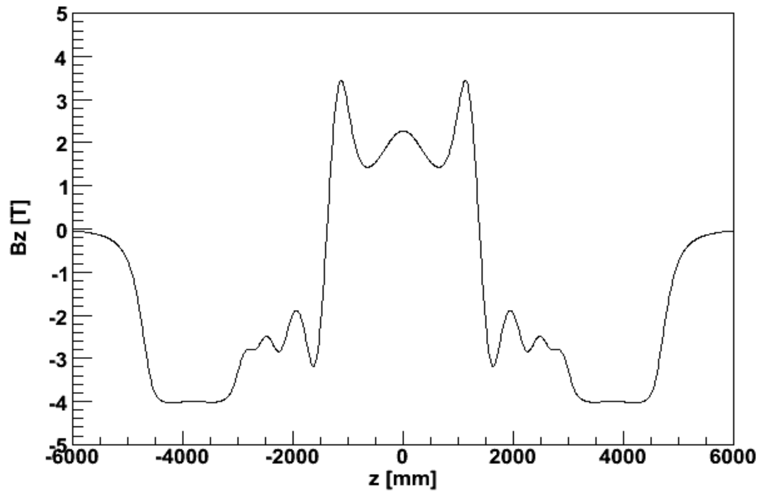
Wedge in MICE Step 5

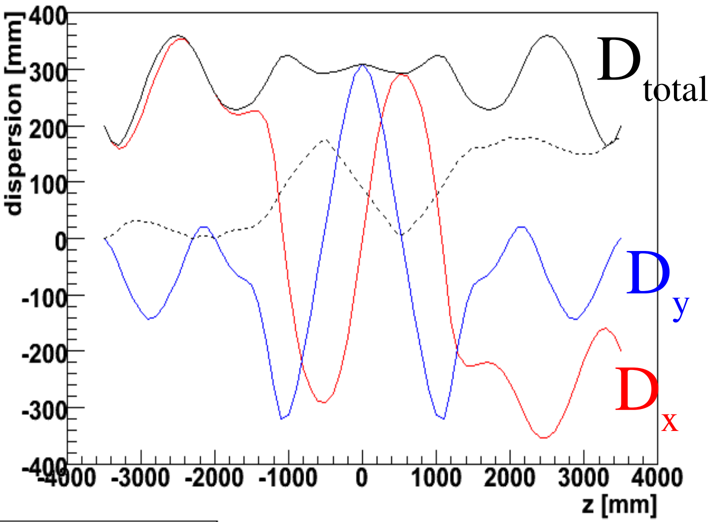
- Wedge with re-acceleration
  - Induce dispersion in input beam
  - Measure emittance exchange including reacceleration
- To what purpose?
  - Demo for wider community
  - Test integration of components in different arrangement
    - E.g. dark currents may pass through wedge ends
- Open questions
  - Can we get the beam dynamics to work?
  - Do the wedges shield detectors from RF cavity radiation?

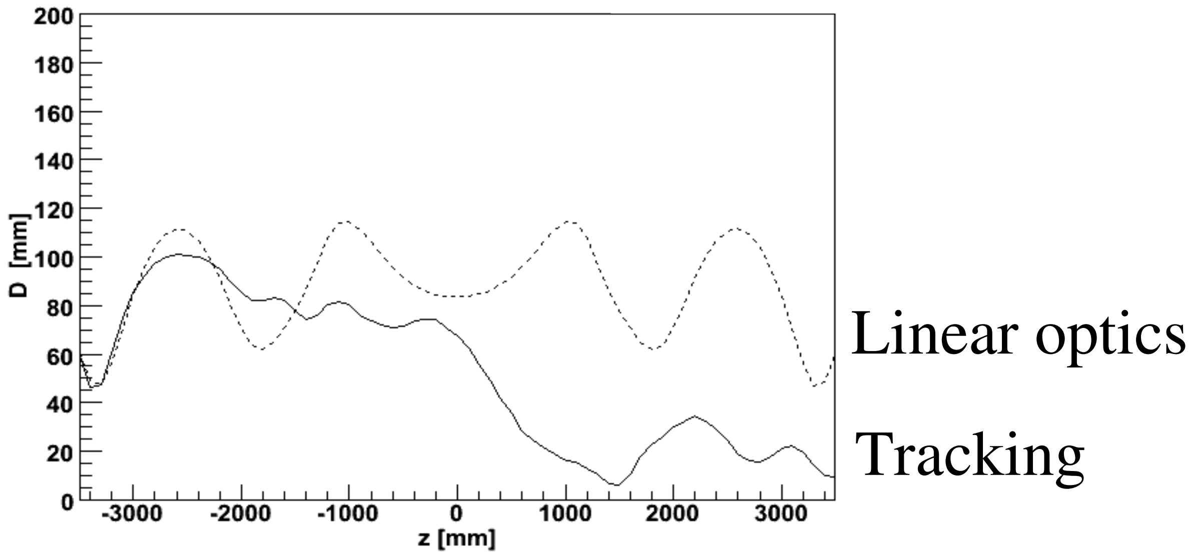


Concept (ii) - Simulations

- Beam dynamics is not straightforward - doesn't look promising!

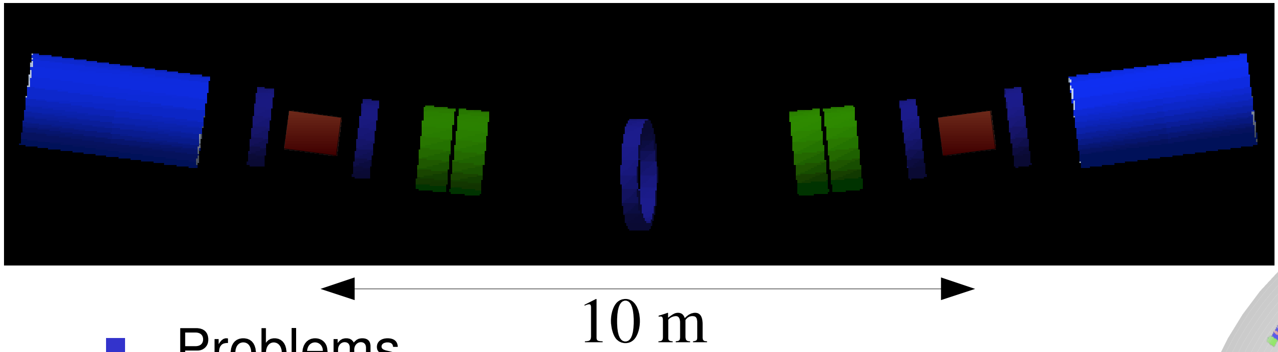




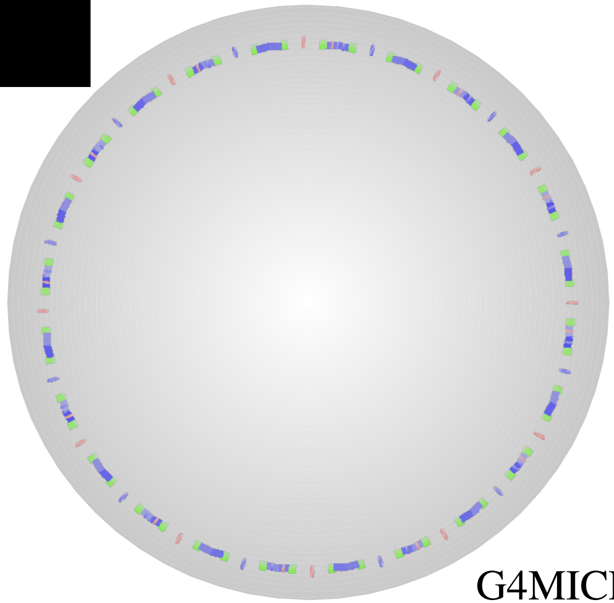


Tilted Solenoid Version of MICE

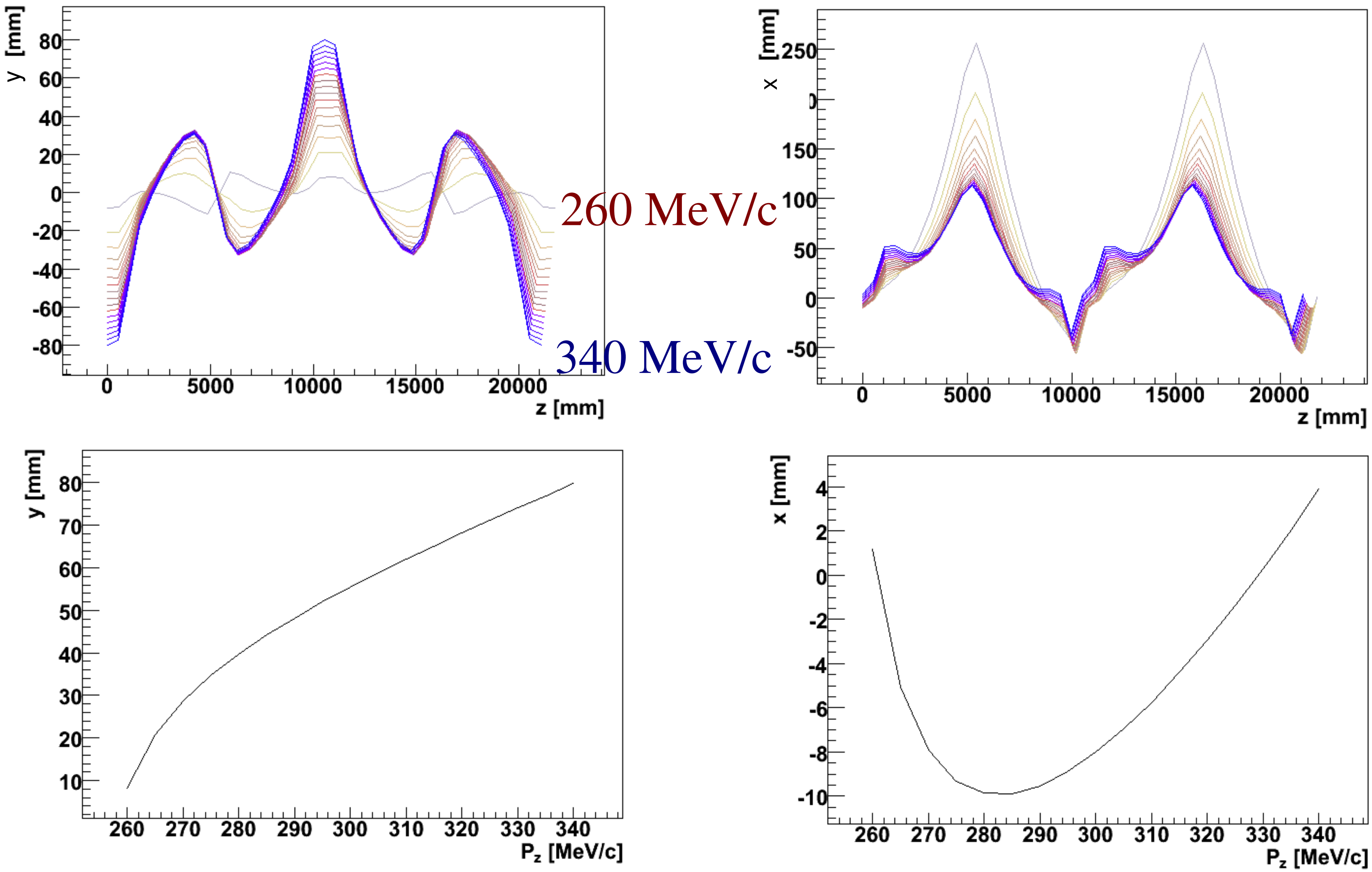
- More complicated:
  - Can we leverage the equipment used in MICE to build a tilted solenoid type cooling cell?
  - Test emittance exchange including energy recovery
  - Test tilted solenoid beam optics



- Problems
  - Focus coils bigger than MICE
    - Should be able to fix this
  - Forces on coils?
  - Cooling performance?
- Nb part of a ring with feasible injection and low B-Field RF

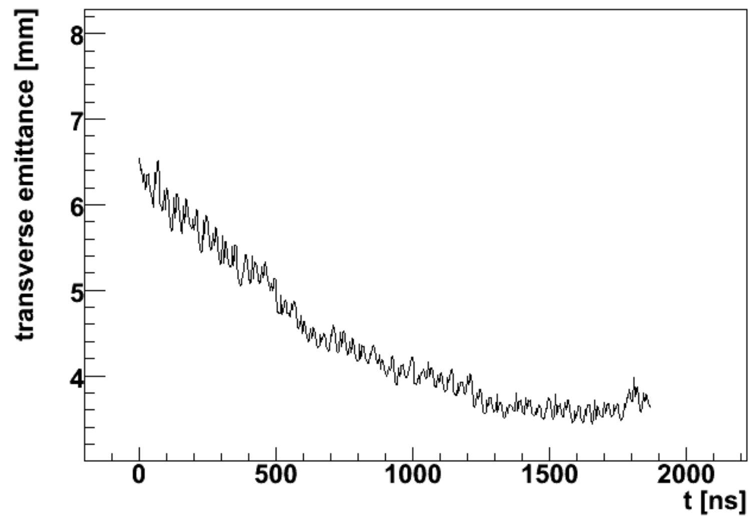


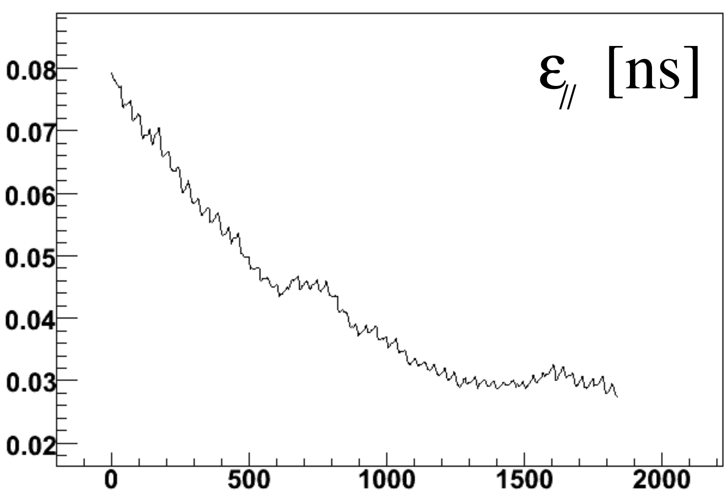
Closed Orbit and Dispersion

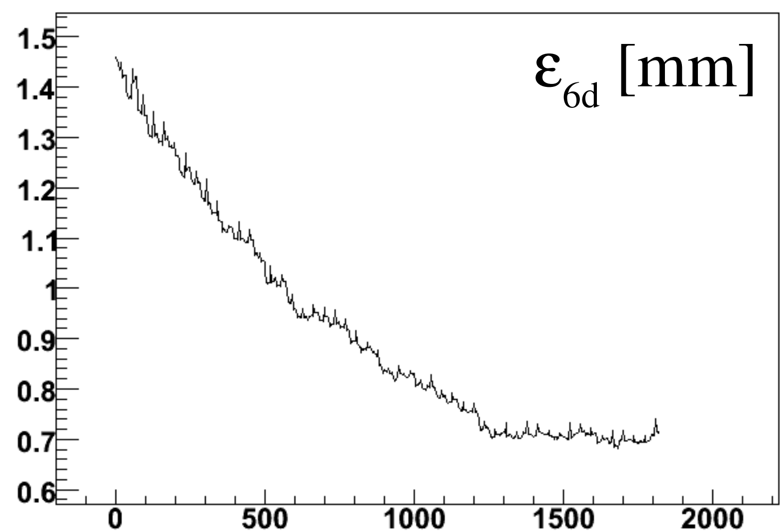


Cooling Performance

- ~Reasonable performance
  - Equilibrium emittance is good
  - Acceptance is too low
  - Work in progress







Interim Report on expts after MICE

Preamble

Several presentations related to the uses of the MICE infrastructure after MICE PHASE II were made at MICE CM22.

The MICE executive board "*concluded that it would be good if a smaller group of MICE physicists would take the time to go through these various proposals*".

The question *"which is the most relevant R&D program after MICE"* was excluded as not being within MICE competence.

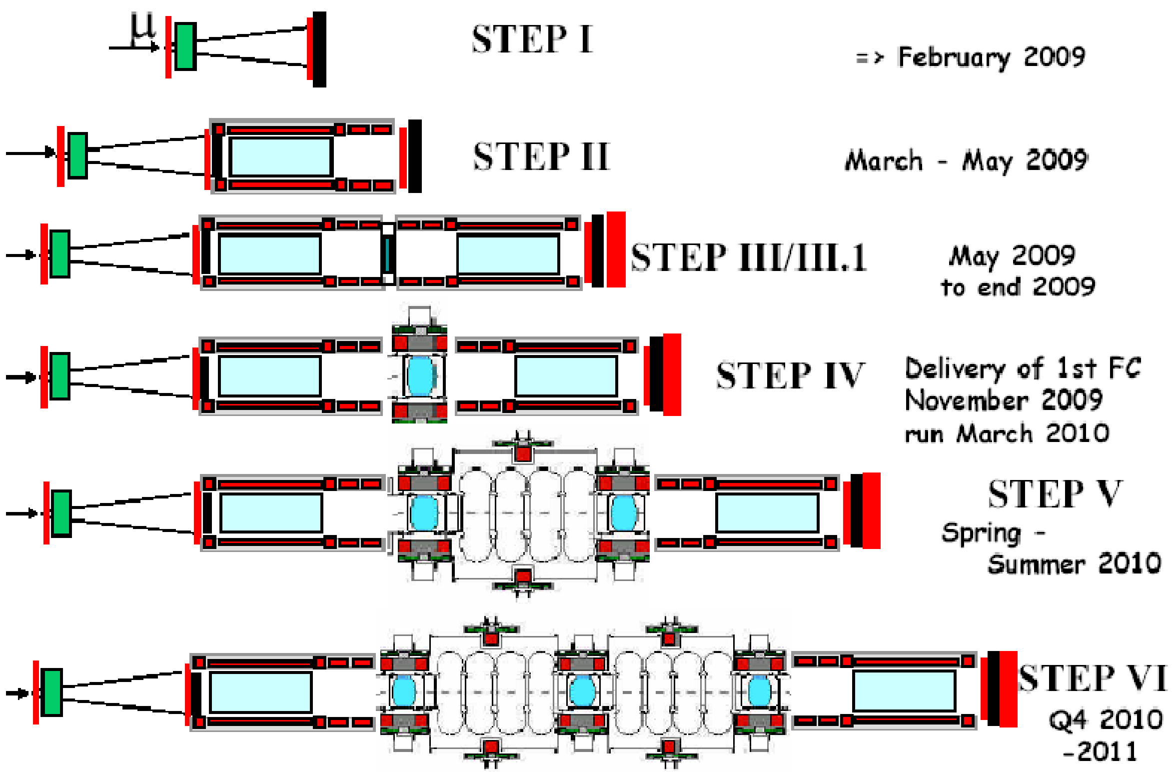
John Cobb (chair)
Chris Rogers
Malcolm Ellis
Yoshi Kuno

To be published as a MICE note shortly

MICE Timeline (Zisman, 21-10-2008)

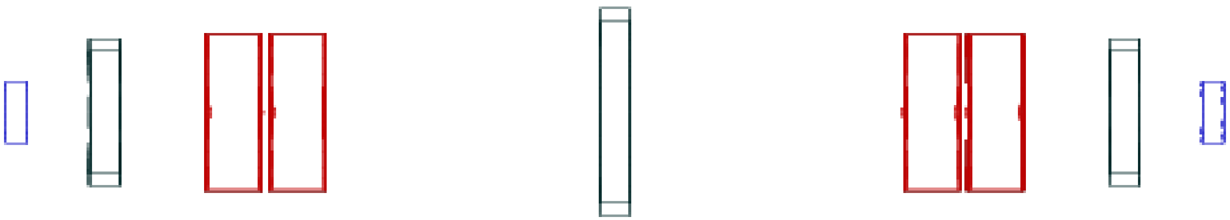
- Best present estimate

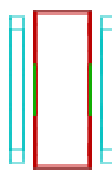
Probable Aspirational MICE Schedule as of October 2008

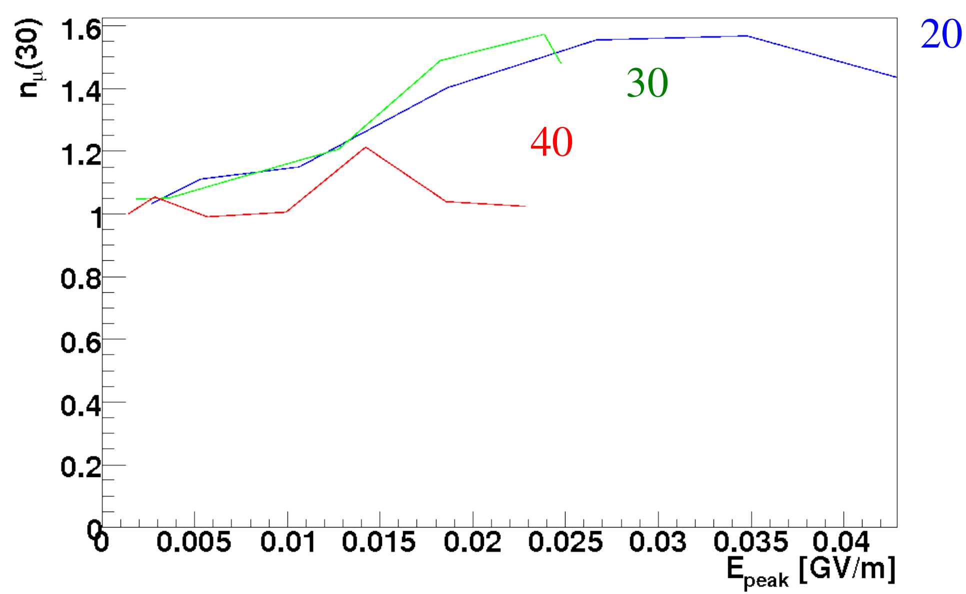


Low B-Field vs RF Cooler

- If RF Cavities are *very* sensitive to B-field MICE may not work
- Can we hack MICE to reduce the B-field?
  - Important if dE/dB > dB/dz

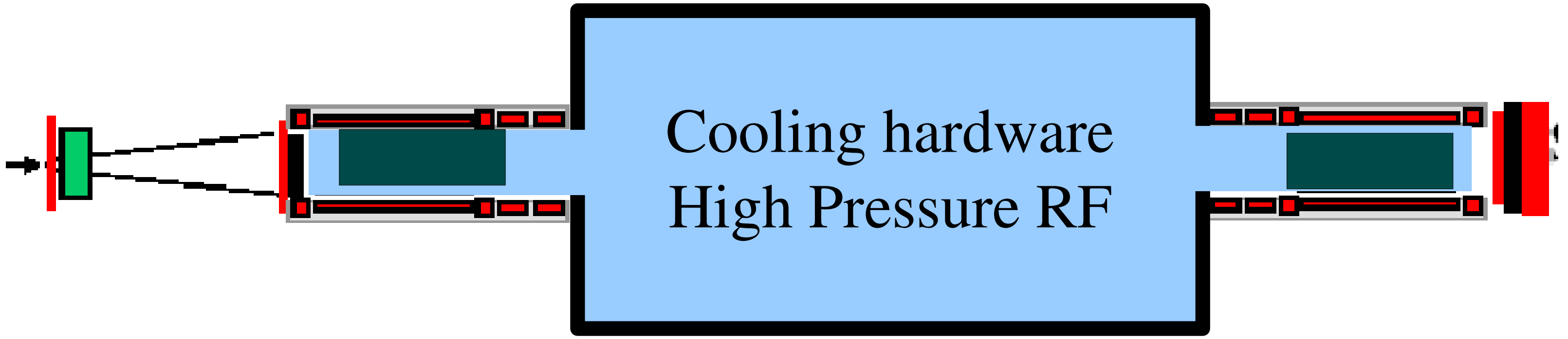






High Pressure Gaseous H2

- Place trackers in high pressure gas
- Add pressure vessel windows before and after tracker
- Retrofit spectrometer solenoids as pressure vessels?
  - Probably not possible
  - Issue - knock-on electrons, in tracker, coincident with muons
    - Also issue for MANX detectors in HCC
- Test “downstream window” of a high pressure cooling channel
  - Thinner, smaller radius
- Test “upstream window”
  - Thicker, higher radius
- Try to get a cavity working in beam first!



High Field MuScat

- Multiple scattering effects change at high field
  - Early MuCool note - not conclusive
  - B field effects tracks between scatters on microscopic scale
    - dx' from B ~ dx' from scatters
  - Effect kicks in ~ 10 T
  - Can (and should) be simulated
  - One would want to verify with experiment I think
- NFMCC has access to some ~10 T solenoids...
- Is MICE sensitive to such effects at ~4T?

Possible Experimental Goals

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