MICE Demonstration of Ionisation Cooling – Alternate Lattice

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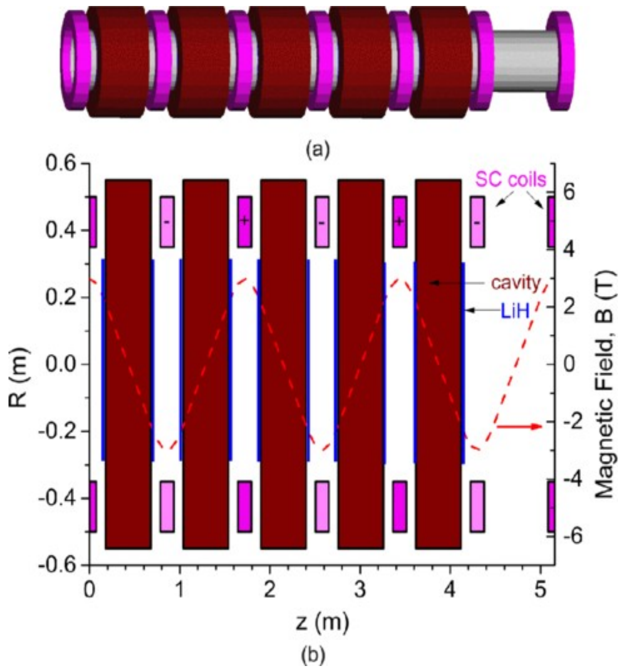
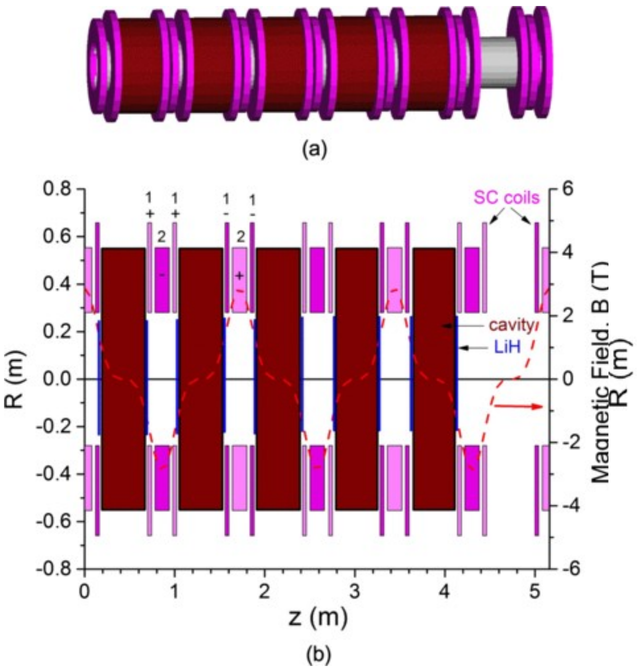
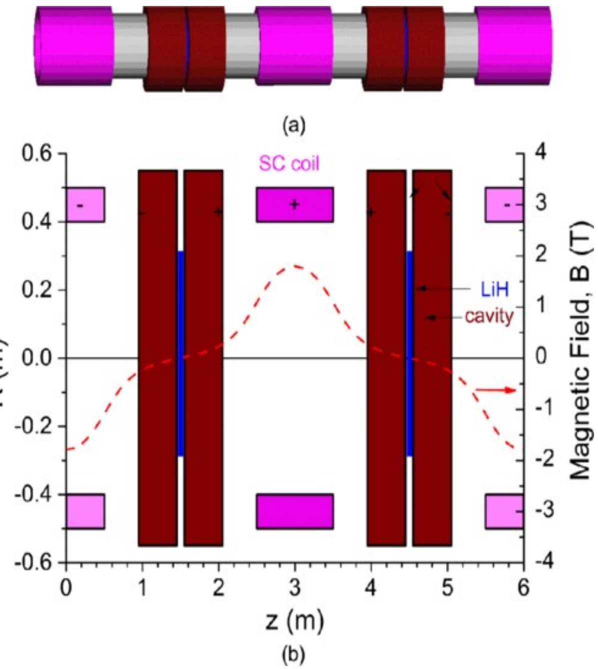
IDS-NF Muon Front End



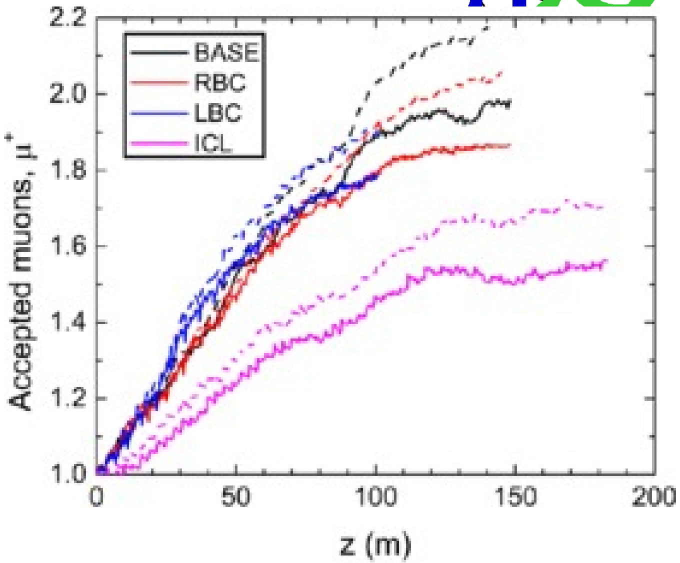




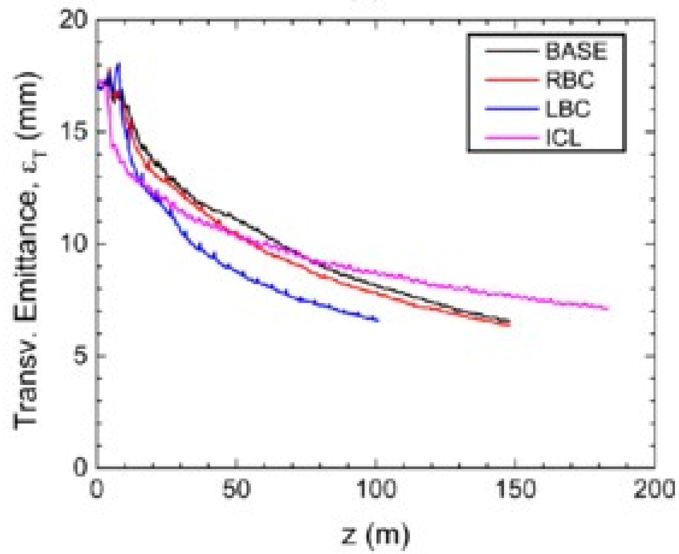
- Baseline lattice for IDS-NF Muon Front End
  - Three designs studied
  - All have principally the same coil arrangement
  - Singlet lattice with alternating +- coils
  - Cell length ranging between 75 cm and 300 cm
- This has been the essential NF design since ~2005

Capture Performance

- Capture performance
  - Shorter cell length performs better
  - But magnetic field on the RF is higher
- Lattices are quite well-studied
  - **Stratakis et al, Phys. Rev. ST Accel. Beams 17, 071001, 2014**
  - Rogers et al, Phys. Rev. ST Accel. Beams 16, 040104, 2013
  - Alekou and Pasternak, JINST 7 P08017, 2012
- Questions of interest
  - Do the lattices perform as expected?
  - Do we model the dynamic aperture correctly?
  - Can we align the magnets okay?
- Can we explore these lattices with MICE?



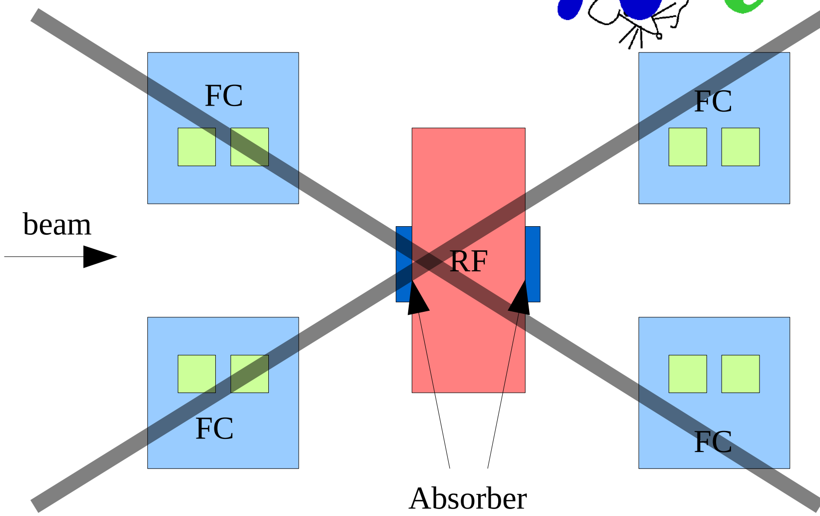
(a)

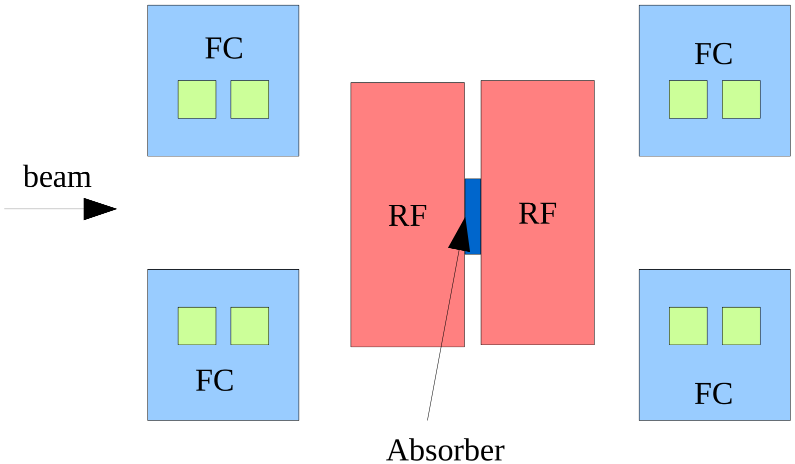


(b)

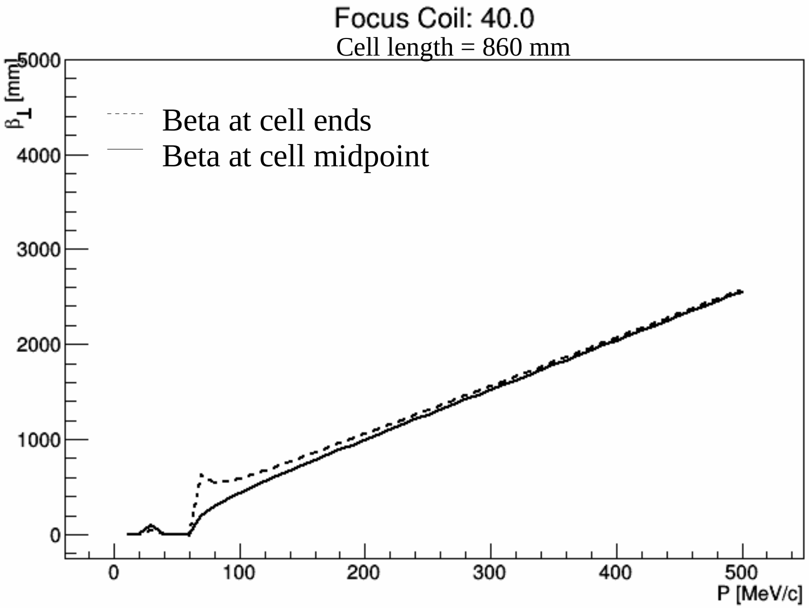
Realisation in MICE (2)

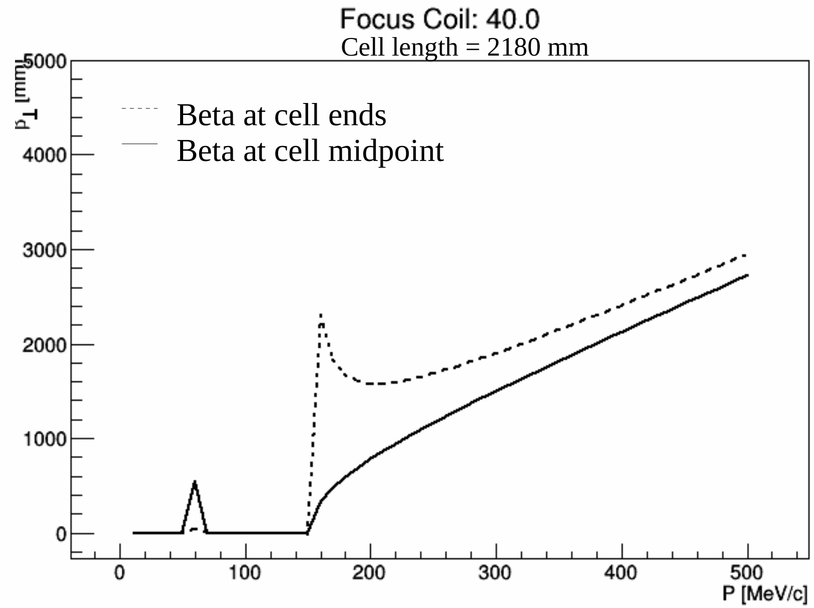
- What can such a cell look like?
  - One RF option was investigated
  - Did not look so attractive
- Preferred two RF option
  - Absorber can be at centre of lattice
  - More accelerating gradient can be available
  - Not much difference in cell length
    - Shorter cell could make one RF preferable
- Jason Tarrant assessment ~ 2 months ago
  - 2 m cell length okay
- Alan Bross assessment
  - Jaroslaw says Bross prefers 2.18 m
  - Victoria says Bross prefers 2.08 m
  - Yesterday





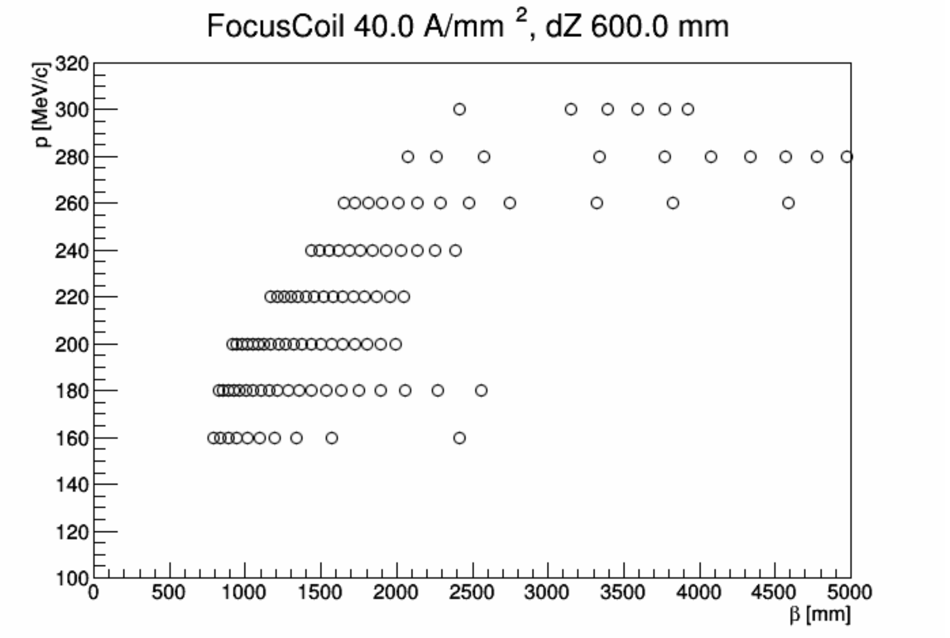
Realisation in MICE





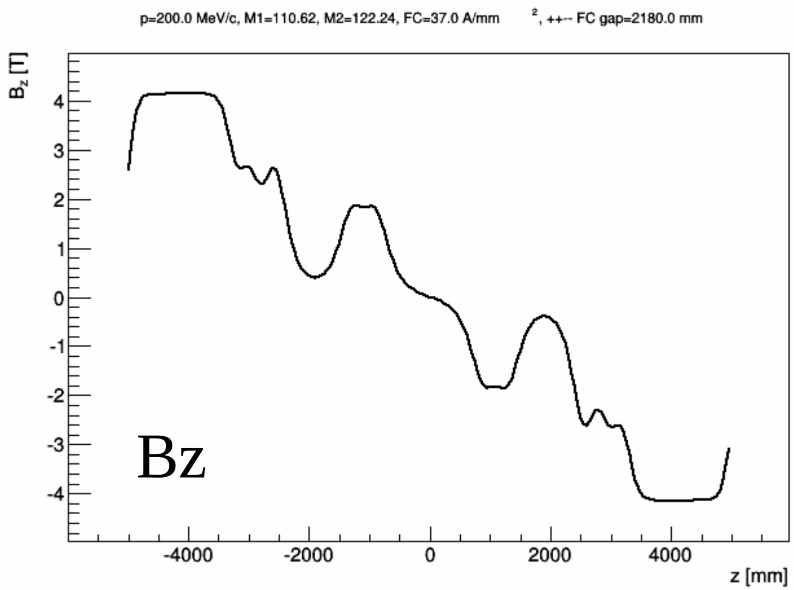
- What does the cooling cell optics look like?
  - Looks okay, even for larger cell lengths
- Issues:
  - Match from the spectrometer solenoid
  - Focus coil aperture
    - $r_{mdc}/r_5 \sim [\beta_{mdc}/\beta_5]^{1/2}$
    - Physical aperture ~ 10 % smaller
  - Equilibrium emittance
    - Equilibrium emittance ~ β ~ 1.5x bigger

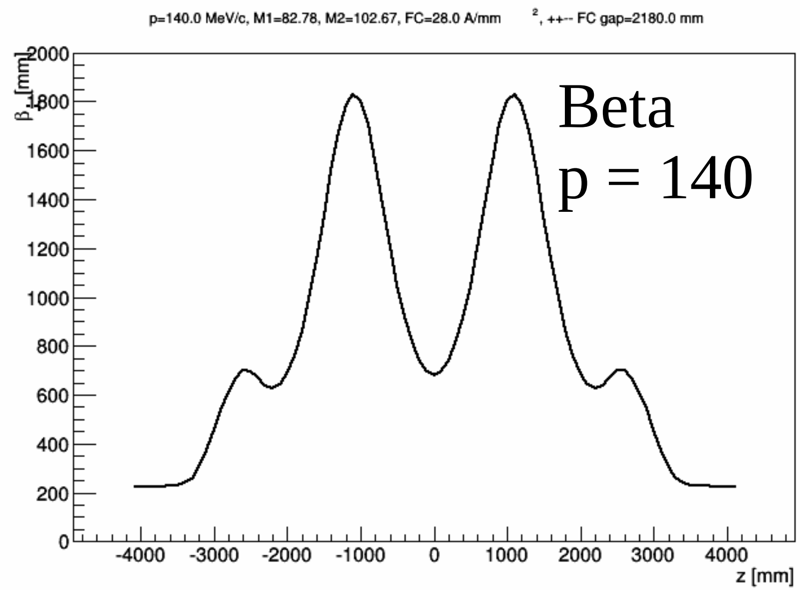
Matching

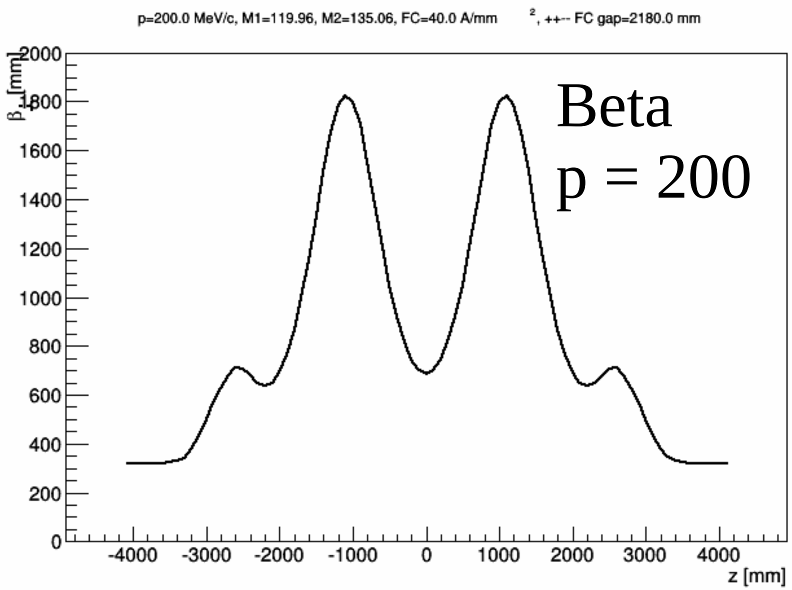


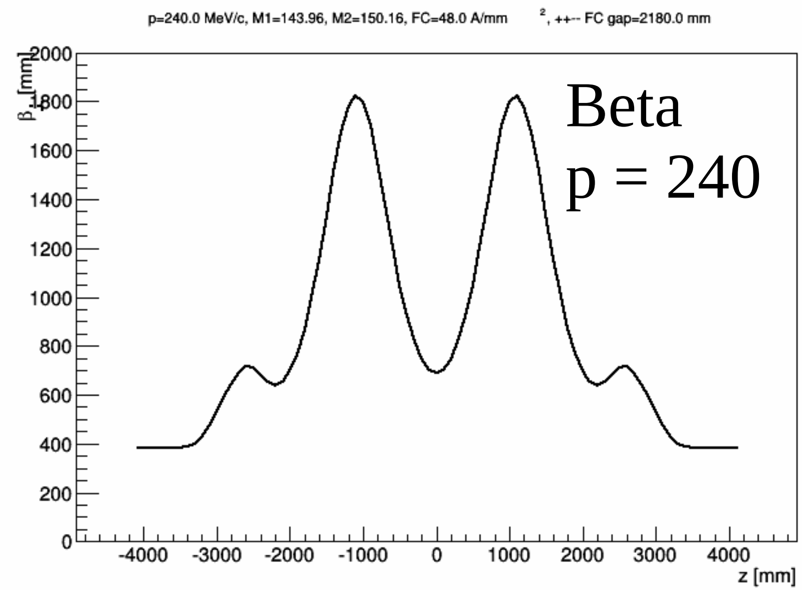
- Can we match into these lattices? **No!**
  - For Step V, beta at absorber ~ 400 mm
  - Now beta at absorber ~ 1600 mm
  - We know this is out of range for as-designed SS
- Insert a gap between SS and AFC
  - Give the beam a chance to grow to get into AFC
- **Yes**

Extended RF Section

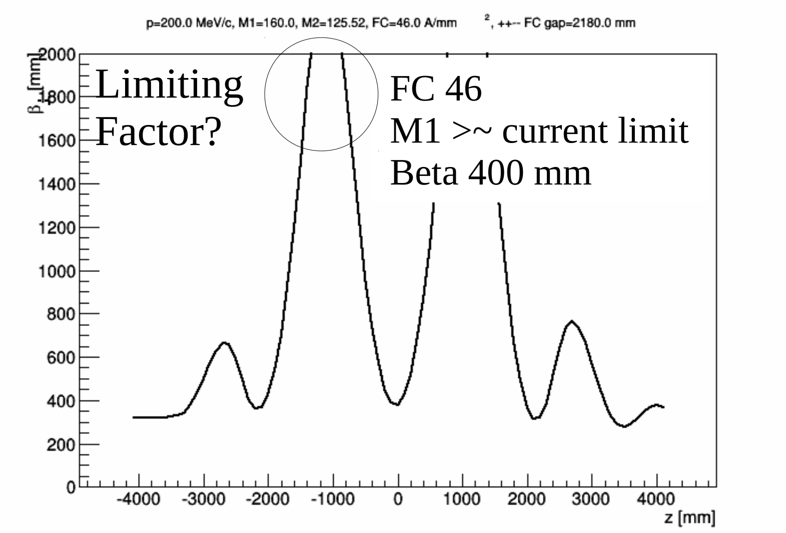








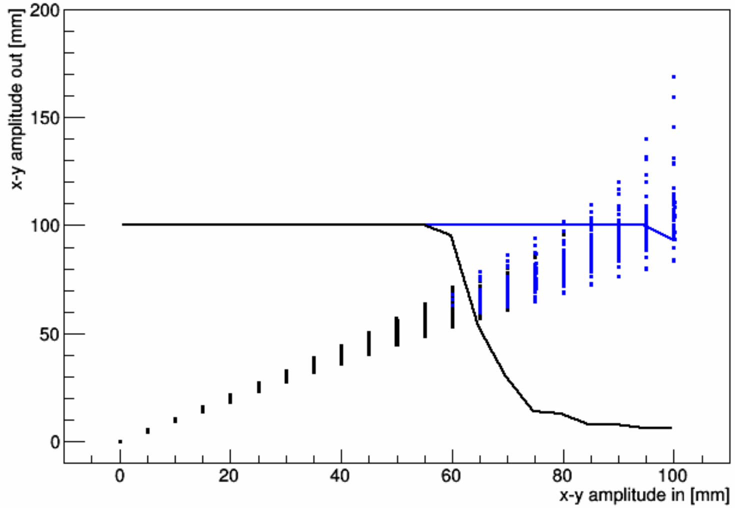
Tightest focus ++--



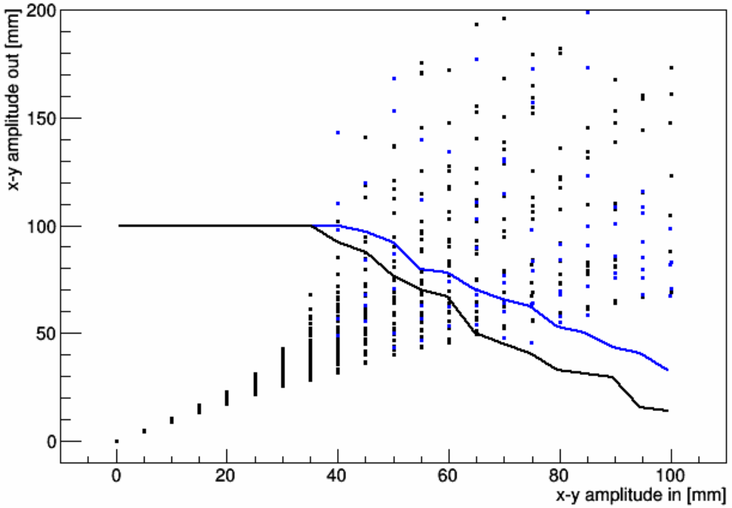
- What is the tightest focus we can get?
  - Limited by match coil currents
- Solution has beta ~ 400 mm
- But large beta in FC
  - Consequences...

Acceptance – tight focussing

++--, FC = 40 A/mm2



++--, FC = 47 A/mm2

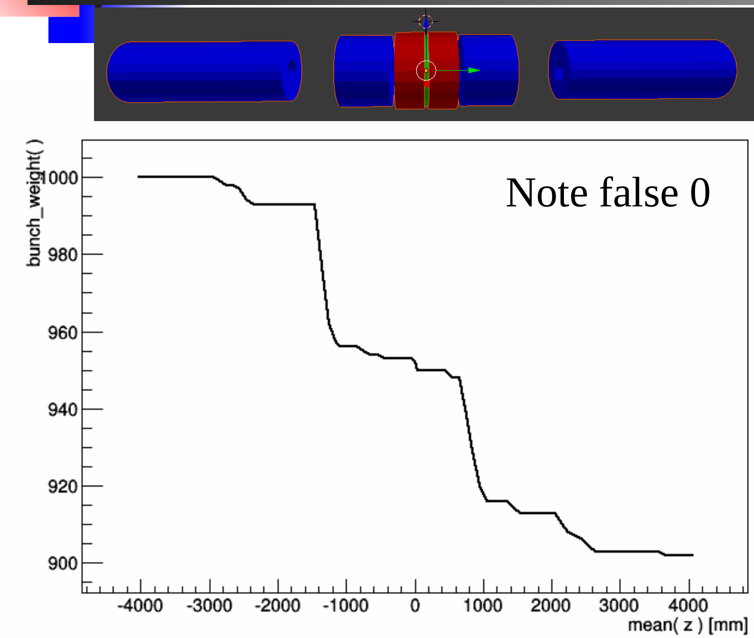


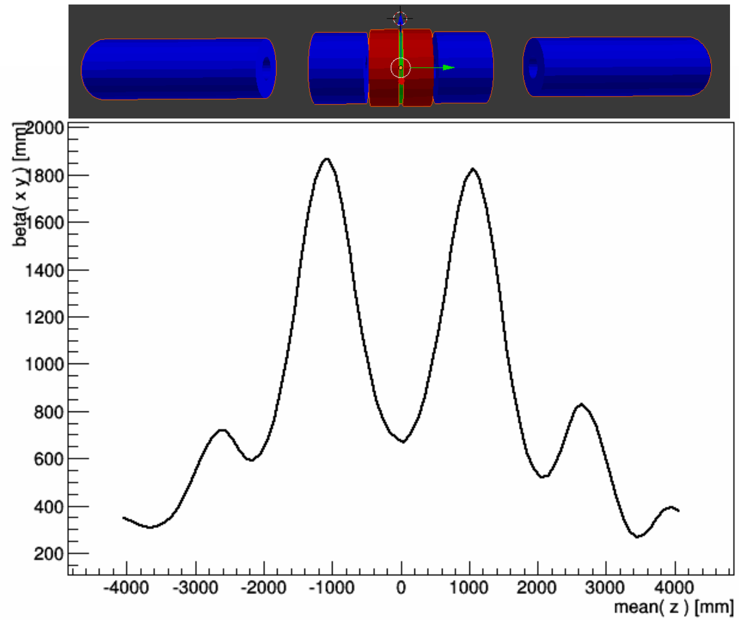
- What is the lattice acceptance at 200 MeV/c?
  - Line shows transmission vs input amplitude
  - Blue line is full transmission, black line is transmission after apertures
  - Points show output amplitude vs input amplitude
  - Blue points strike a physical aperture
- At 40 A/mm^2, acceptance is dominated by physical aperture
- At 47 A/mm^2, acceptance is dominated by dynamic aperture
- This is a phenomenon we should study

Cooling Simulation

- Simulate beam
  - No tracker volume or tracker He window simulated
  - Curved RF windows and LiH (65 mm) are in simulation
  - Assume FC bore radius 235.5 mm
  - 10.3 MV/m
  - 2180 mm cooling cell
- Cuts
  - Particles must be present in all output (virtual) planes
  - Radius < 150 mm in analysis plane
    - Tracker fiducial volume
    - Removes up to few % of particles
  - Amplitude < 72 mm
    - Roughly 3 sigma, removes up to 1% of particles

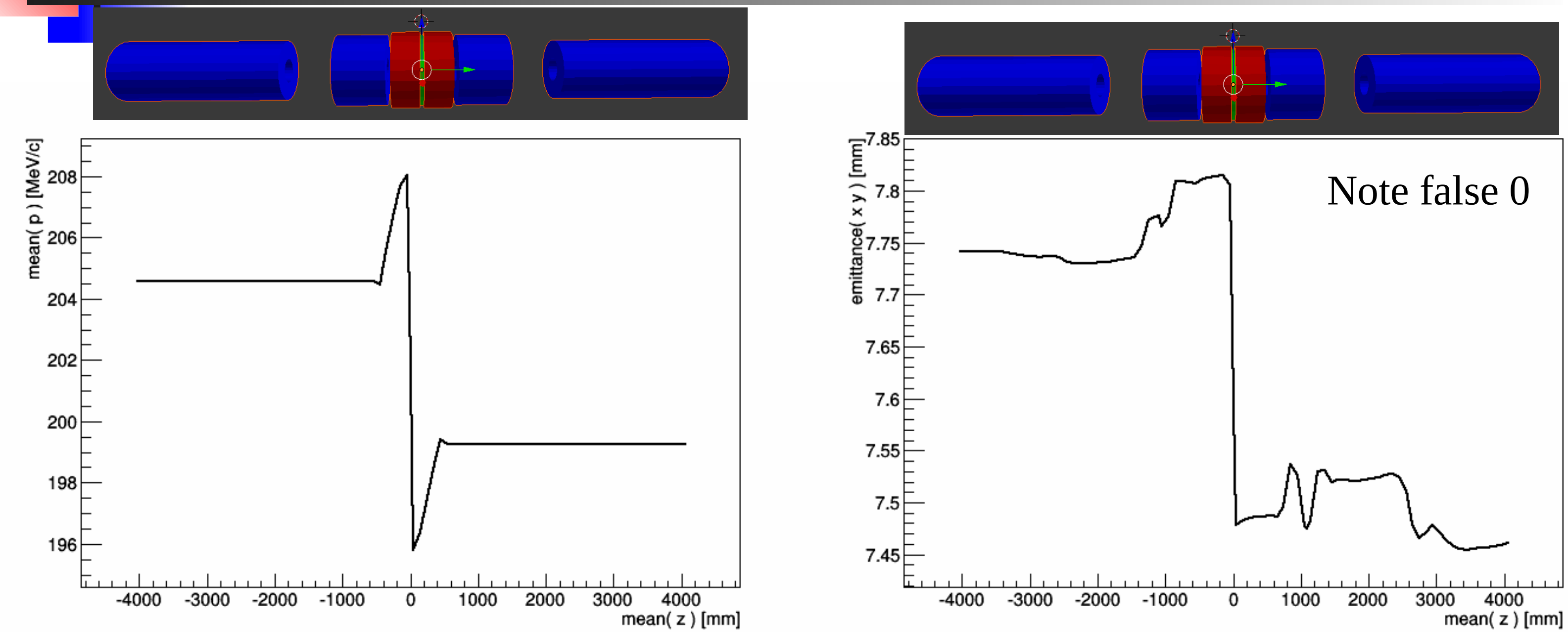
Cooling - FC = 40 A/mm^2 case





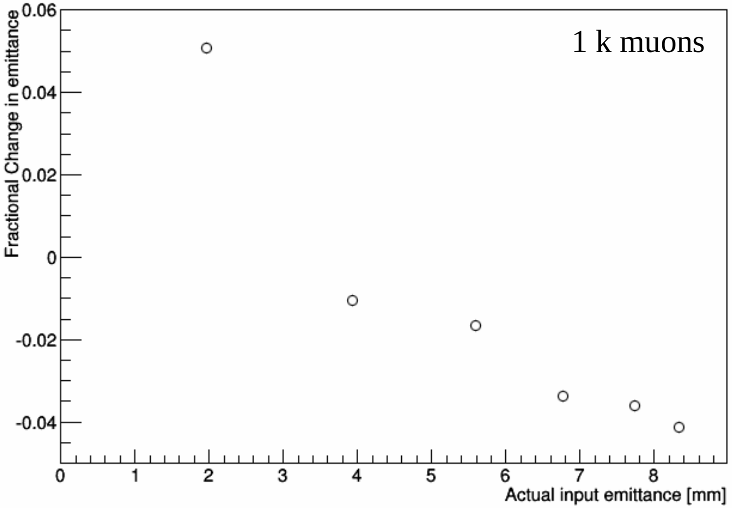
- Simulate beam
  - No tracker volume or tracker He window simulated
  - Curved RF windows and LiH (65 mm) are in simulation
  - Assume FC bore radius 235.5 mm
  - 10.3 MV/m
- Transmission and average momentum vs z
  - Main transmission losses are in the FC
  - This is the limiting aperture
  - Note that cuts are not represented in transmission plot

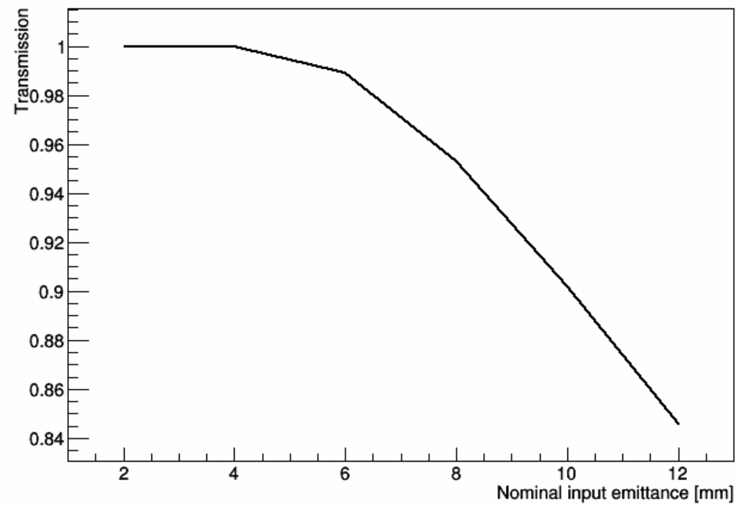
Cooling - FC = 40 A/mm^2 case



- Momentum and emittance as a function of z
  - Nominal multivariate gaussian 6 mm beam, ~monochromatic
  - No great surprises
  - Some optical aberrations
  - 4 % emittance reduction

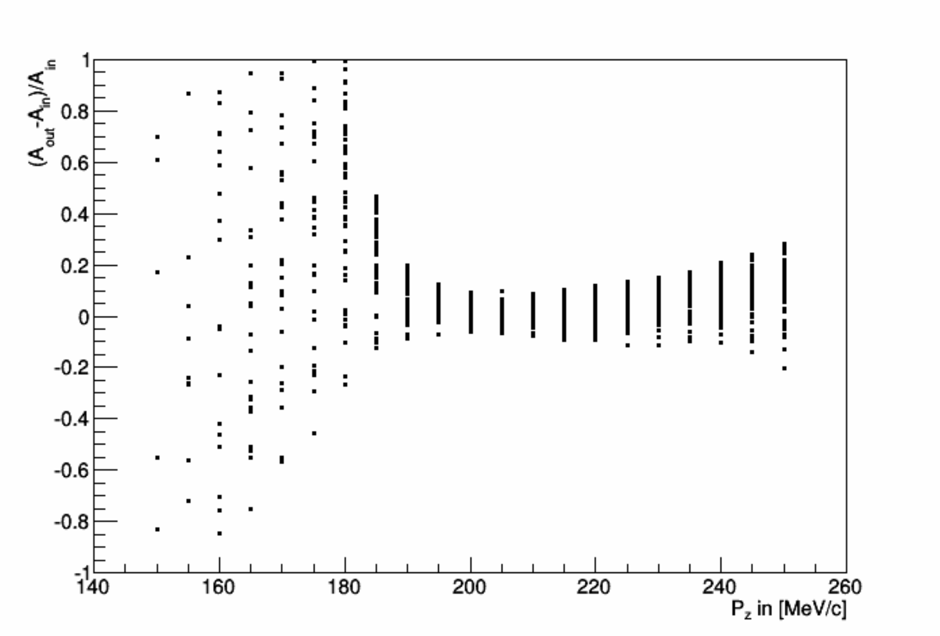
Cooling - FC = 40 A/mm^2 case





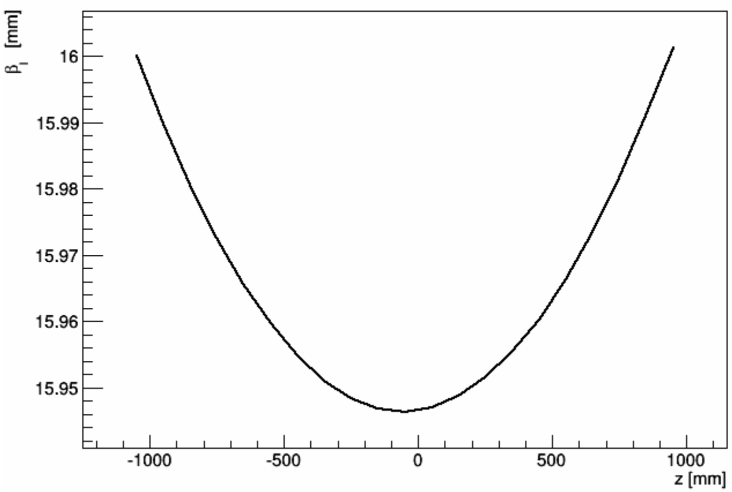
- Cooling performance as a function of input emittance
  - No great surprises
  - Equilibrium around 3 mm
  - > 10 % scraping above 8 mm input emittance
    - Dominated by FC aperture
  - Best cooling performance ~ 4 % reduction in emittance
    - RF shielding would make this better

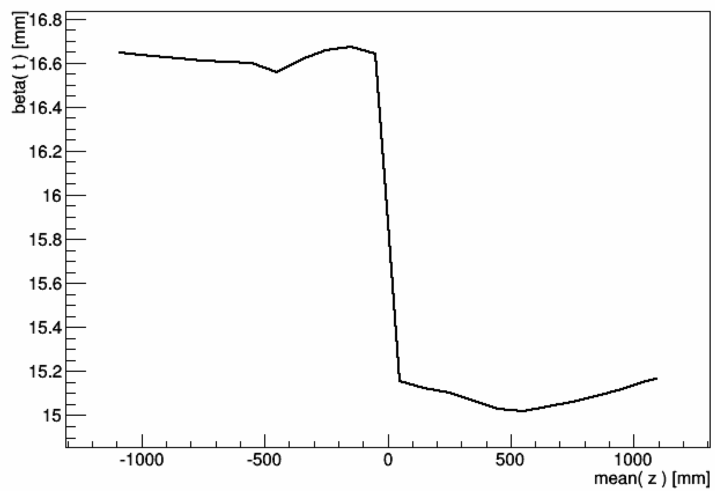
Longitudinal Acceptance



- Amplitude growth as a function of momentum
  - 25 mm amplitude shell propagated with different momenta
  - Calculate amplitude out vs amplitude in
- As we move to lower pz, move into unstable region
  - This is the stop band, beta at absorber becomes high and eventually the lattice is not focusing
- Consider “momentum acceptance” pz +/- 15 MeV/c

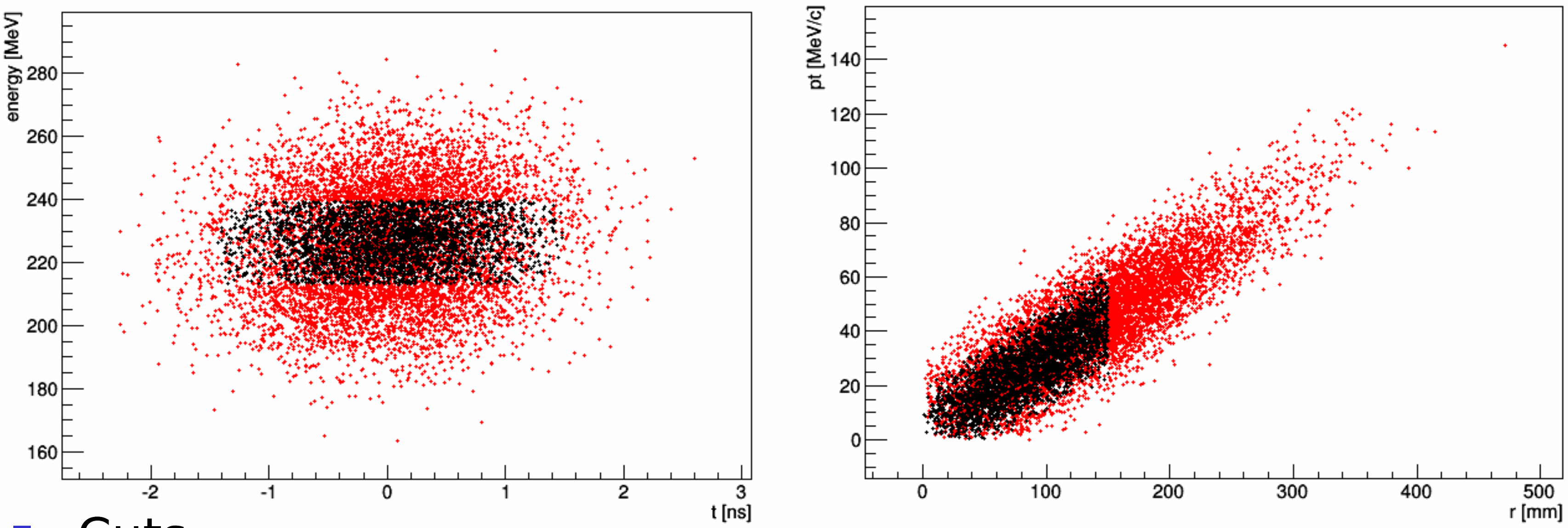
Longitudinal matching





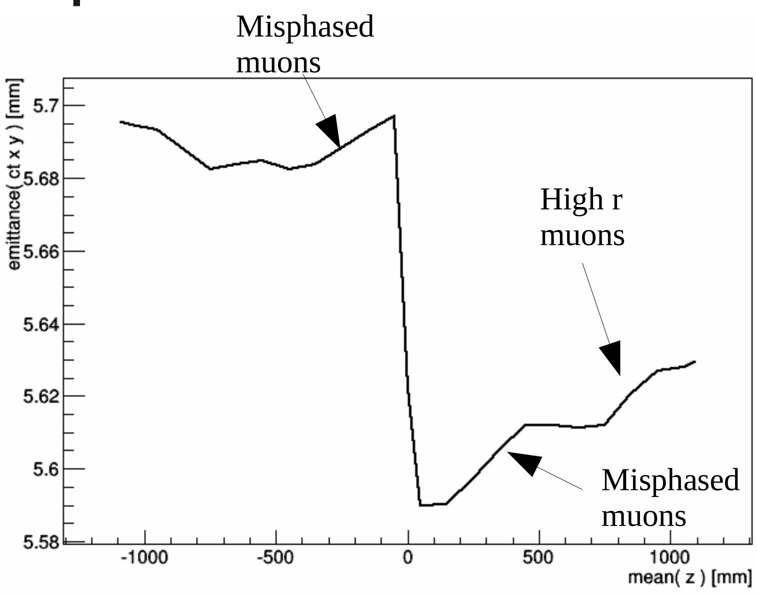
- We have no real longitudinal bucket or phase space
  - Longitudinal phase space is dominated by the absorber
- I seek to make the beta function symmetric about z=0
- I now consider only the cooling cell

Cuts



- Cuts
  - Particles must be present in all output (virtual) planes
  - Radius upstream and downstream
  - Transverse amplitude upstream and downstream
  - Longitudinal amplitude upstream and downstream
  - Momentum upstream and downstream
- Results are sensitive to tails
- Results are sensitive to lattice instability

6D cooling



weights in
no cut: 10000.0 8680.0
transmission cut: 8675.0 8675.0 **

upstream

	cut	u/s	d/s
cut r:	150.0	6500.0	6500.0
cut amp_trans:	72.0	6465.0	6465.0
cut amp_trans:	72.0	6462.0	6462.0
cut amp_long:	50.0	3647.0	3647.0
cut amp_long:	50.0	3641.0	3641.0
cut 190.5 < p < 215.5		2535.0	2535.0

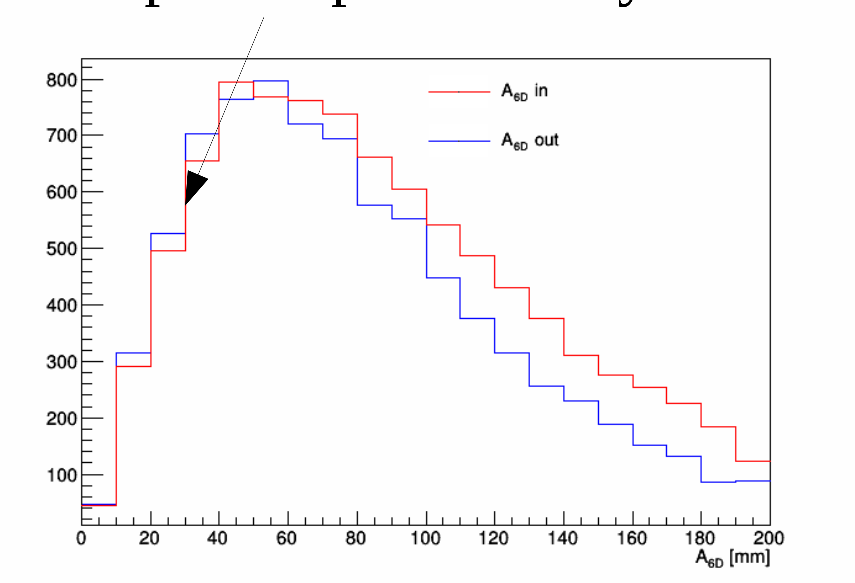
downstream

	cut	u/s	d/s
cut r:	150.0	1996.0	1996.0
cut amp_trans:	72.0	1991.0	1991.0
cut amp_trans:	72.0	1991.0	1991.0
cut amp_long:	150.0	1991.0	1991.0
cut amp_long:	150.0	1991.0	1991.0
cut 181.2 < p < 226.2		1985.0	1985.0

- Cooling performance
  - 1.1 % cooling
- Upstream cuts are significant but that is okay
  - “beam selection”
- Downstream cuts are tails except radial cut
  - Is this allowed? Have I deselected emittance growth particles?

6D cooling

Growth in phase space density!



- Downstream cuts are tails except radial cut
  - Is this allowed? Have I deselected emittance growth particles?
- This is allowed, we really see increase in 6D phase space density
- I have not yet tried amplitude momentum correlation
  - It will likely improve things

Alternative Design

- We have a fully worked and tracked design
- Lattice quality
  - Transverse cooling ok
  - 6D cooling ok
  - Cell optics ok
  - Momentum restoration 2 cavities is the best we can get?
  - Similarity to a buildable cooling channel yes, very close
  - Quality of match to spectrometer looks ok
  - Scraping aperture / transverse acceptance a bit worse than Step V
  - Momentum acceptance looks ok
  - Canonical angular momentum effects looks ok

Alternative Design

- Engineering issues
  - Current limits of magnets looks ok
  - Incremental cost of any hardware new beam pipe
  - Radiation load on tracker may be issue, mitigate with shields
  - RF breakdown in magnetic fields probably ok
- Proved robustness to small changes

Conclusions

- From an optics perspective, symmetrical lattice looks very neat
- Cooling performance is good
  - We have 6D cooling
- This is essentially the same as the cooling lattices that we considered in the IDS
  - A great test for one of the most loved cooling channel design
- Final thought:
  - Timing is everything!