The MICE Measurement Programme

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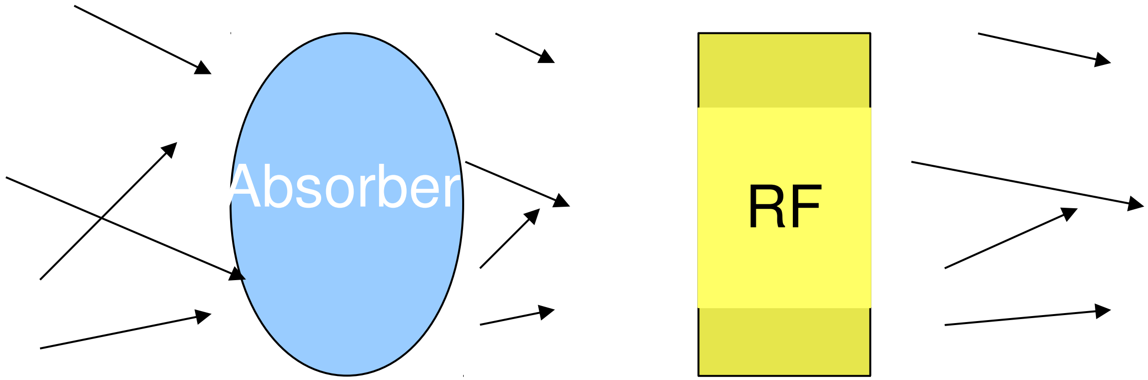
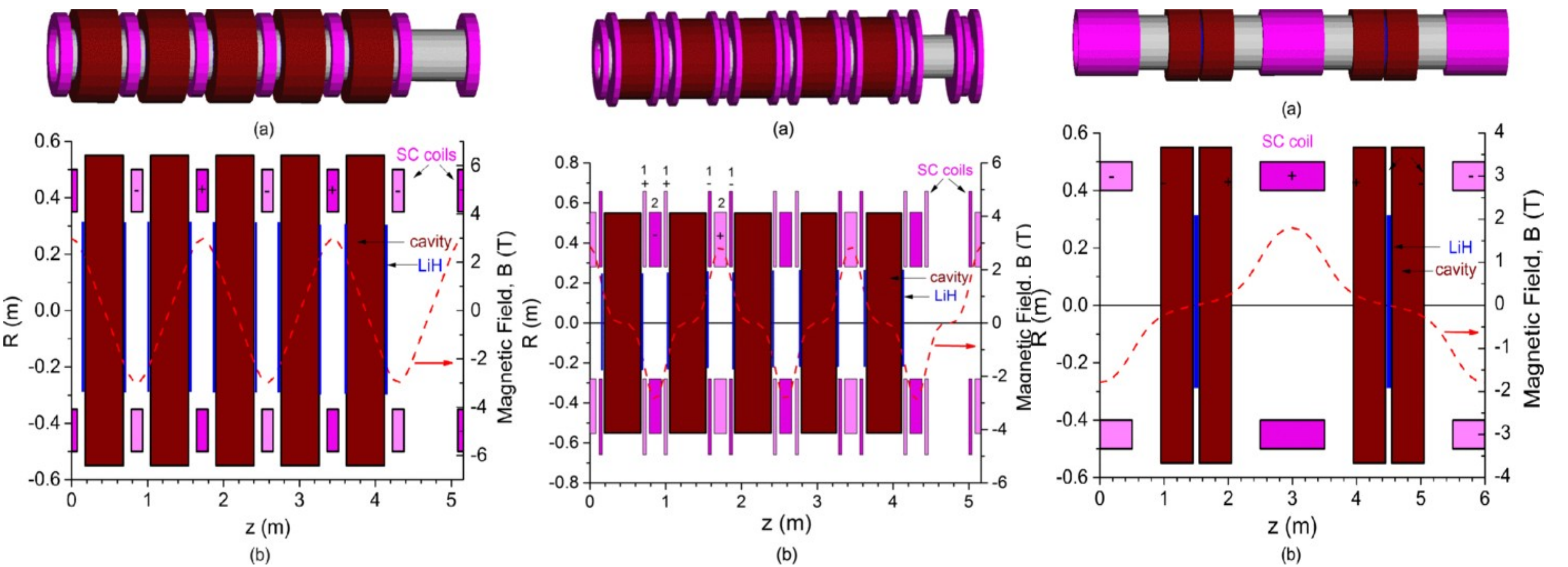
4D Ionisation Cooling



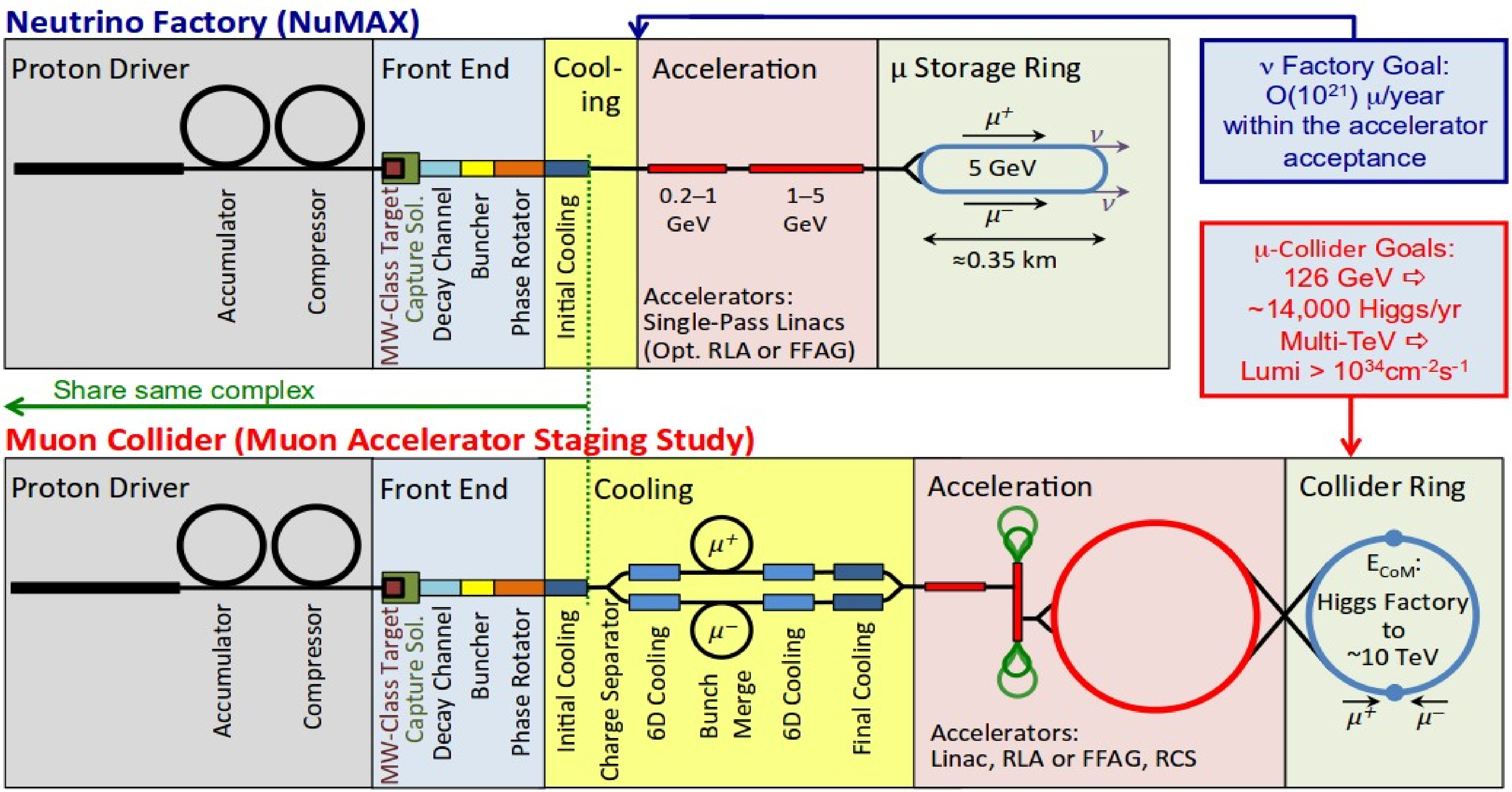
- 4D (transverse) cooling achieved by ionisation energy loss
  - Absorber removes momentum in all directions
  - RF cavity replaces momentum only in longitudinal direction
  - End up with beam that is more straight
- Stochastic effects ruin cooling
  - Multiple Coulomb Scattering increases transverse emittance
  - Energy straggling increases longitudinal emittance
- Needed in IDS-NF to improve muon capture
- Needed in Muon Collider to provide luminosity

IDS-NF Muon Front End

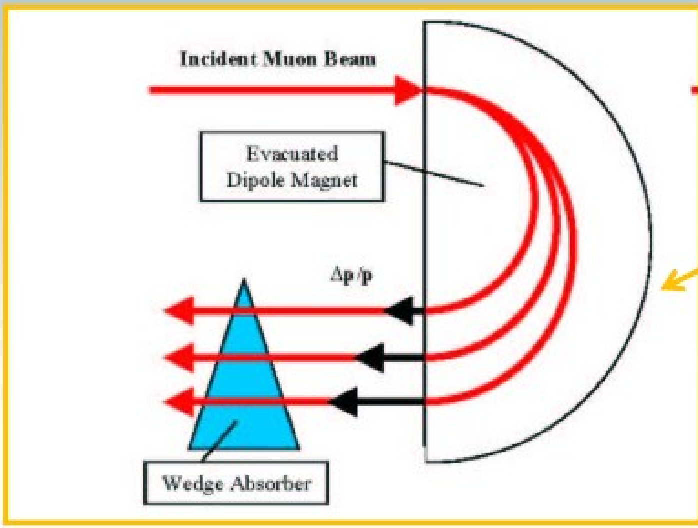


- Baseline lattice for IDS-NF Muon Front End
  - Three designs studied
  - All have principally the same coil arrangement
  - Singlet lattice with alternating +- coils
  - Cell length ranging between 75 cm and 300 cm
- This has been the essential NF design since ~2005

MASS/NuMax Neutrino Factory

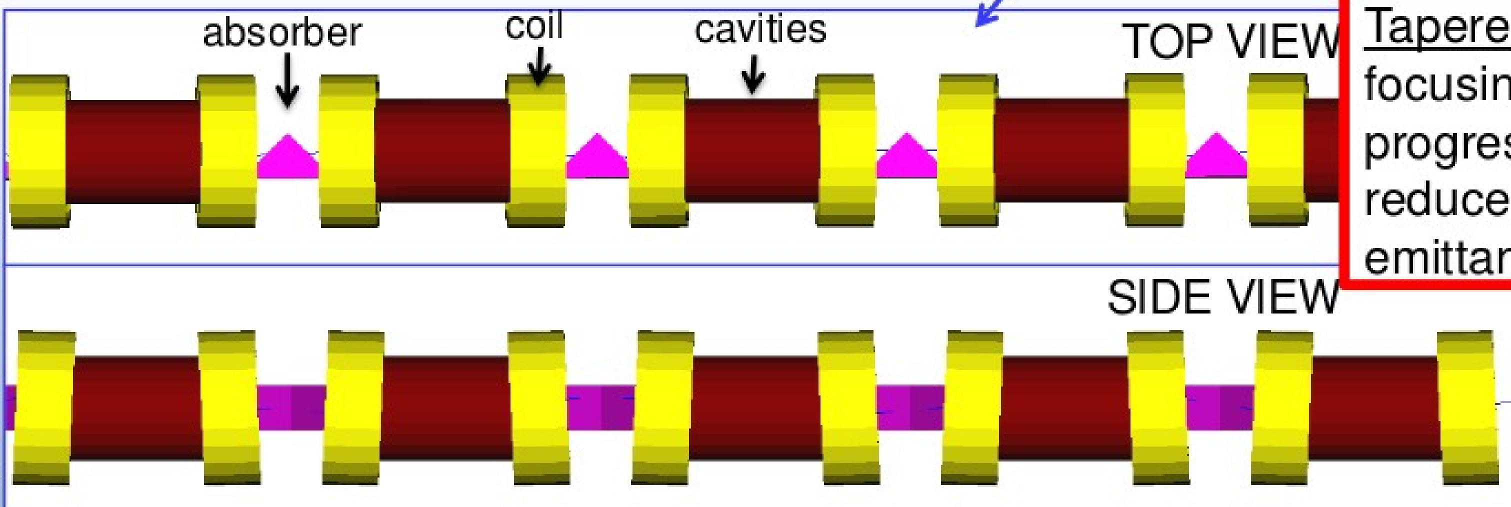


Vacuum RF Cooling Channel



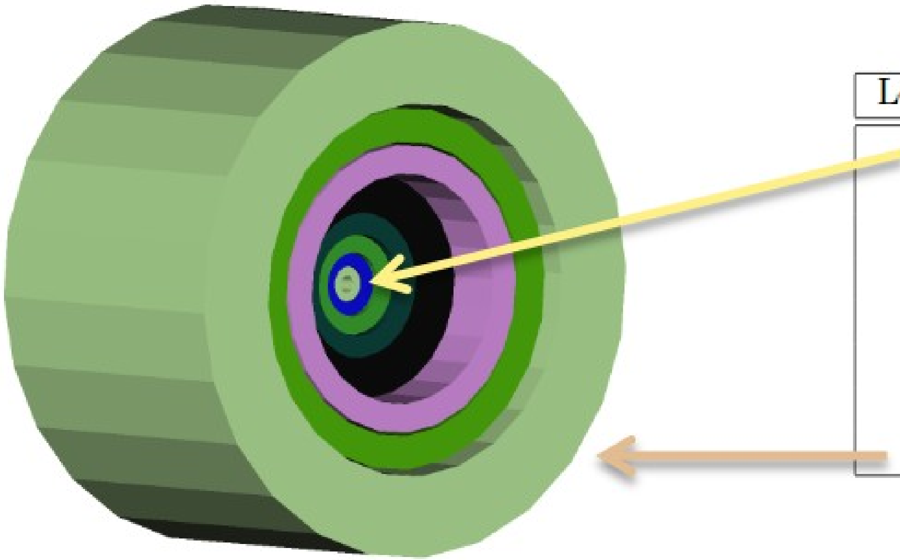
Concept: Generate dispersion and cool via emittance exchange in a wedge absorber

Proposed solution: Rectilinear channel with tilted alternating solenoids and wedge absorbers



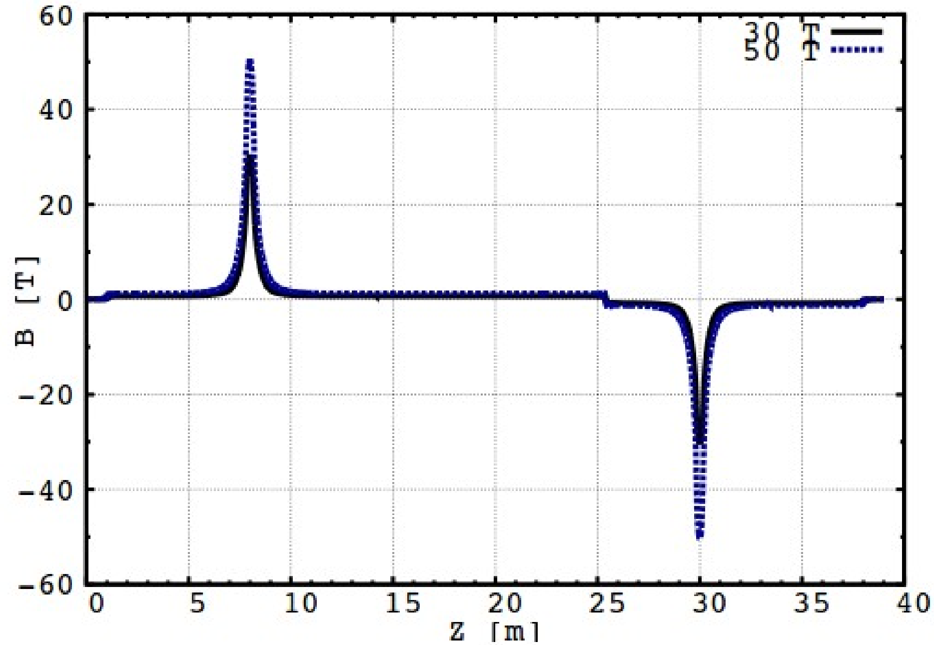
Tapered channel: The focusing field becomes progressively stronger to reduce the equilibrium emittance.

Lattice Proposed by Valeri Balbekov (FNAL)



Length [m]	Inner radius [m]	Thickness [m]	I/A [A/mm^2]
0.317	0.025	0.029	164.26
0.337	0.055	0.041	142.43
0.375	0.098	0.056	125.88
0.433	0.157	0.067	119.07
0.503	0.228	0.120	85.99
0.869	0.355	0.089	39.60
0.868	0.454	0.104	44.30
0.992	0.575	0.252	38.60

R. Palmer – B. Weggel



Questions

- Questions to answer
  - Step IV stuff is in **bold**
  - I only list beam-based questions
- Magnetics
  - **Did we do the alignment well enough?**
  - **Do we understand the linear beam optics?**
  - **Do we understand the non-linear beam optics?**
  - Do we understand the resonance structure/stop bands?
- Absorber
  - **Do we understand MCS?**
  - **Do we understand Energy Loss?**
  - **What about longitudinal-transverse correlations?**
  - **What about high Bz?**
  - **What about polarisation?**
  - **What about funny absorber geometry? And materials?**

Questions (2)

- RF
  - Do we understand the RF beam dynamics when RF is superimposed on solenoids
    - Probably no one has studied this problem
    - Certainly not higher order terms
  - What about alignment?
  - What about stability across the RF pulse?
- Integration
  - **Do we see the expected emittance change?**
    - **Transverse?**
    - **Longitudinal?**
    - **Emittance exchange?**
  - Do we see the expected transmission
    - **Have we correctly modelled our apertures?**

Magnetics

- Magnetics
  - **Did we do the alignment well enough?**
  - **Do we understand the linear beam optics?**
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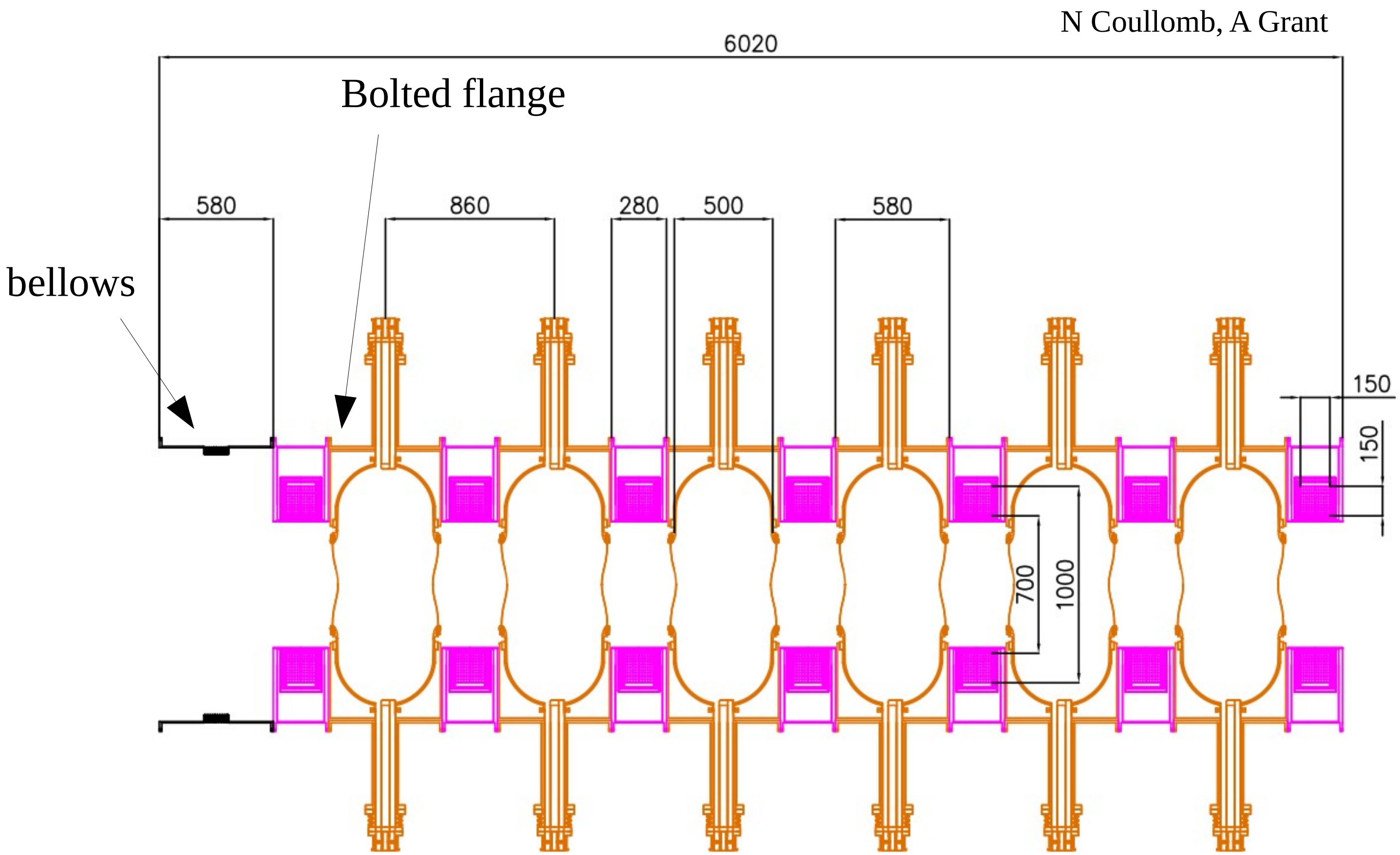
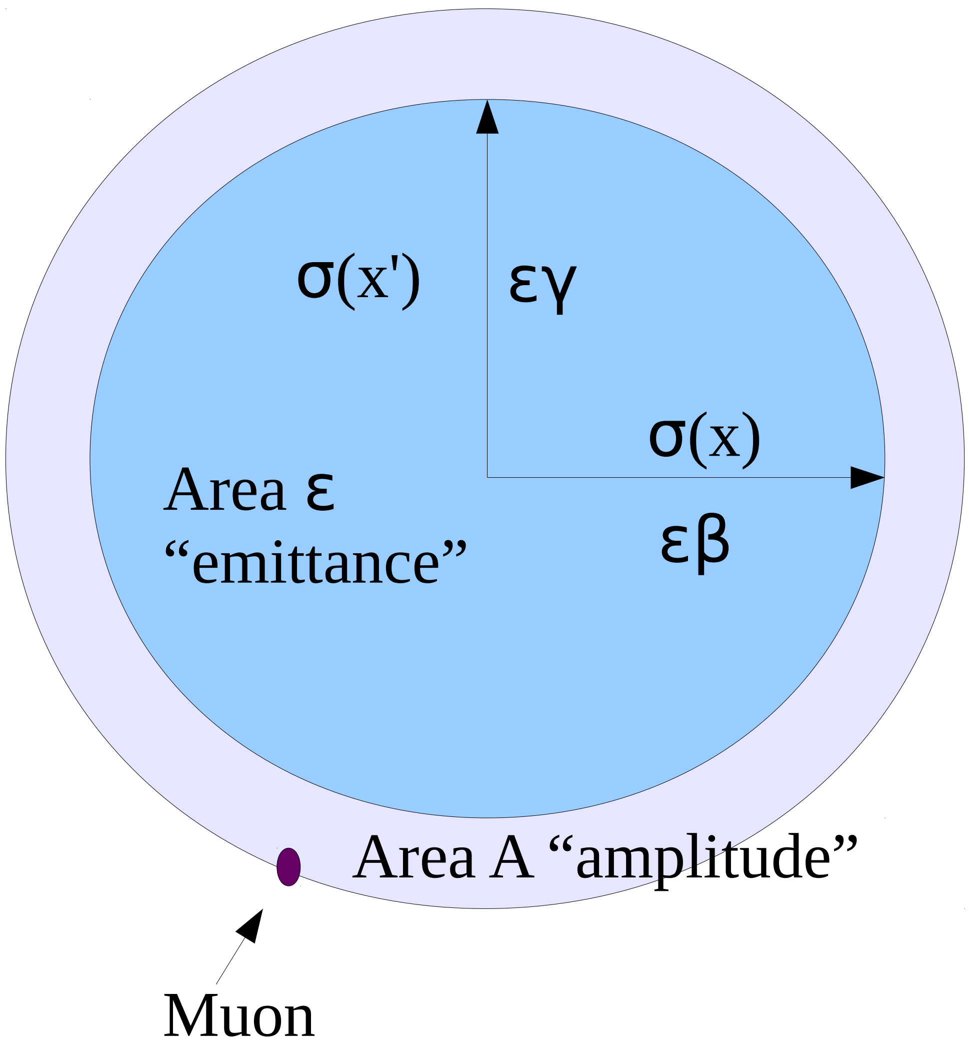
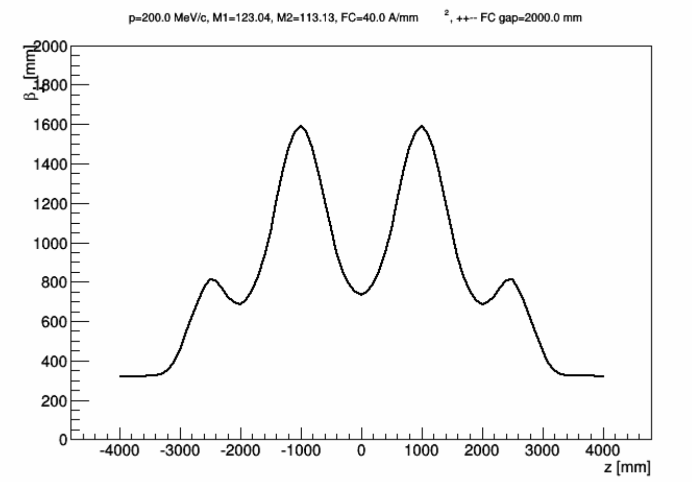
Magnetics

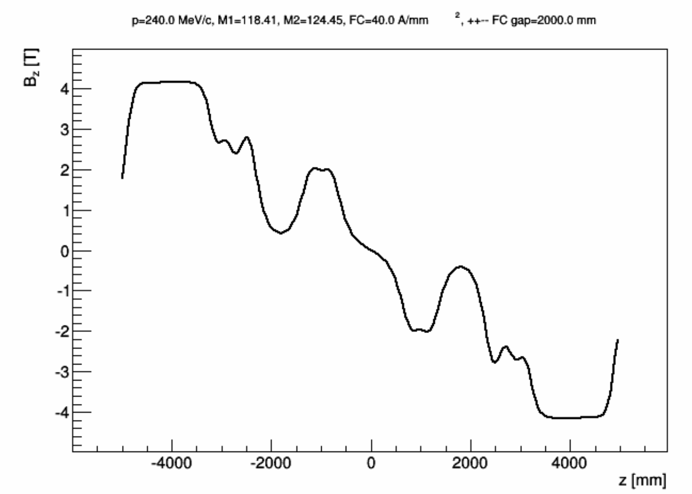


- MICE should be easier to align than NF-IDS
  - In NF-IDS we have 5 cells bolted together followed by a bellows every sixth cell for alignment
- How well can we align MICE?

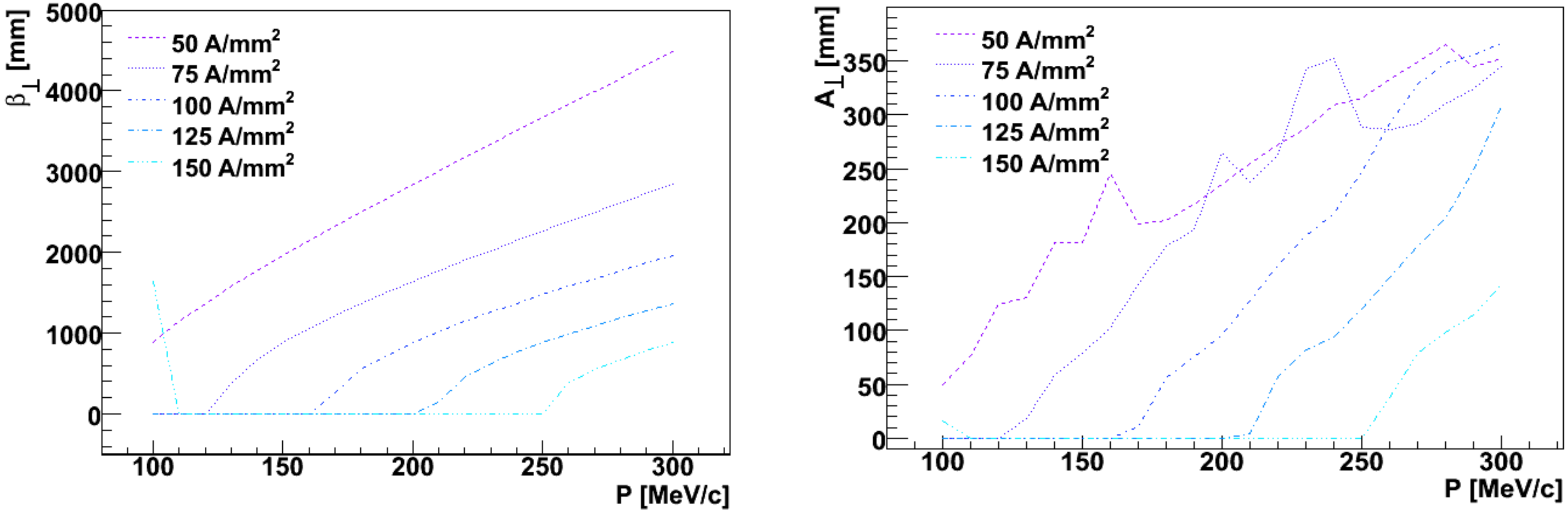
Beam ellipse





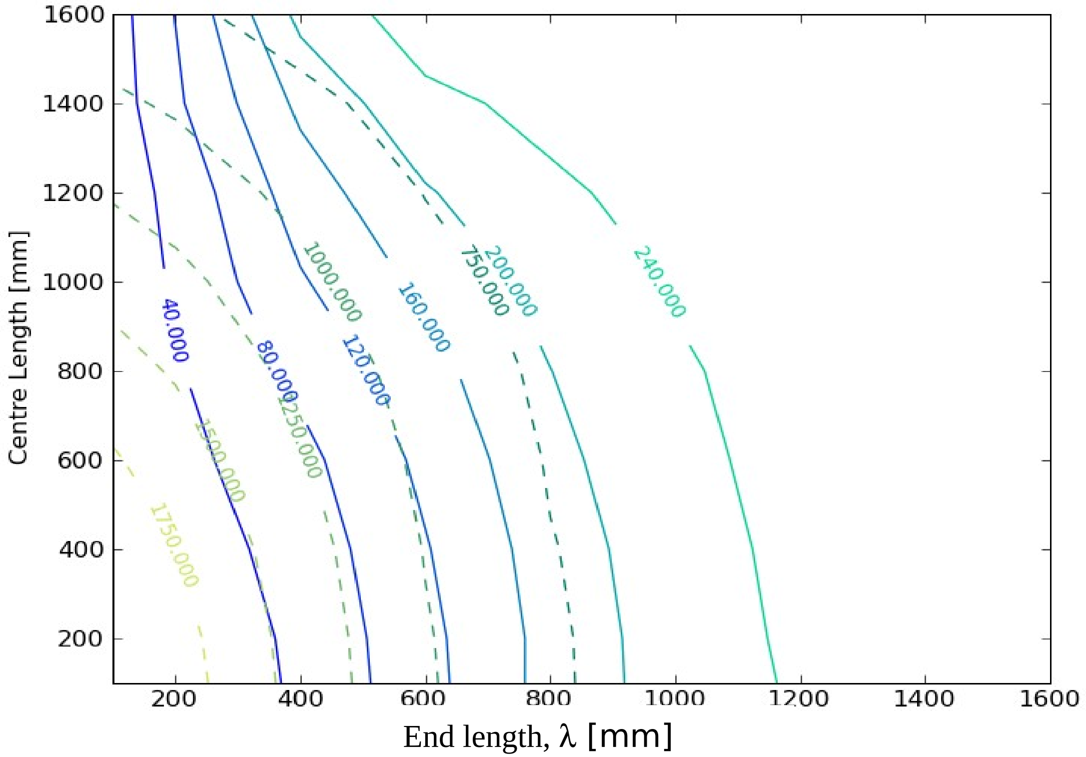


Dynamic Aperture vs current



- Calculate beta function at focus as a function of coil current
- Changing the current simply scales the momentum
  - Note that dbeta/dp gets smaller (better) at higher momenta/currents
  - Acceptance reaches ~ maximum
- Is our model for beta correct?
- Is the prediction for dynamic aperture correct?
  - Test by measuring D.A. for different current scalings

Non-Linear Terms vs End Field



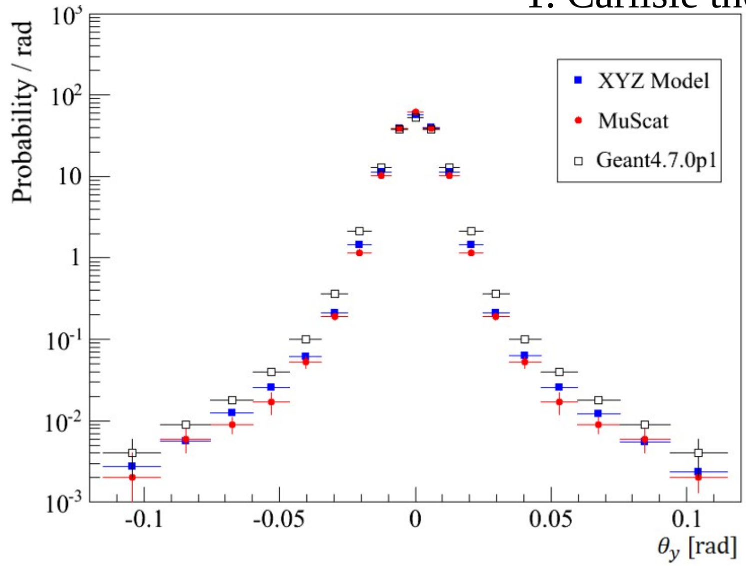
- Dynamic aperture is sensitive to amount of shielding
  - We can predict this dependence, is it right?
- Measure by comparing D.A. in flip mode vs non-flip mode
  - For same optics

Absorber

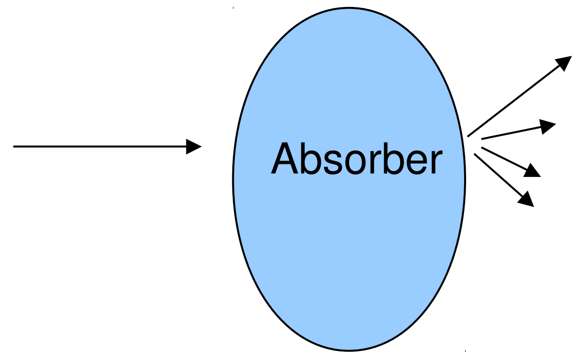
- Absorber
  - **Do we understand MCS?**
  - **Do we understand Energy Loss?**
  - **What about longitudinal-transverse correlations?**
  - **What about high Bz?**
  - **What about polarisation?**
  - **What about funny absorber geometry? And materials?**

Absorber - MCS

T. Carlisle thesis



(b) 12.78 mm Li.



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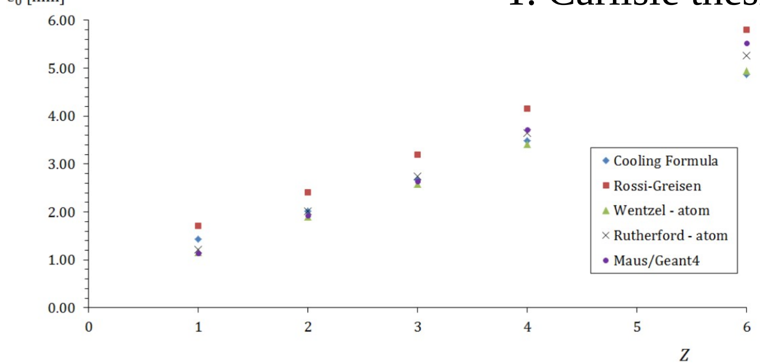
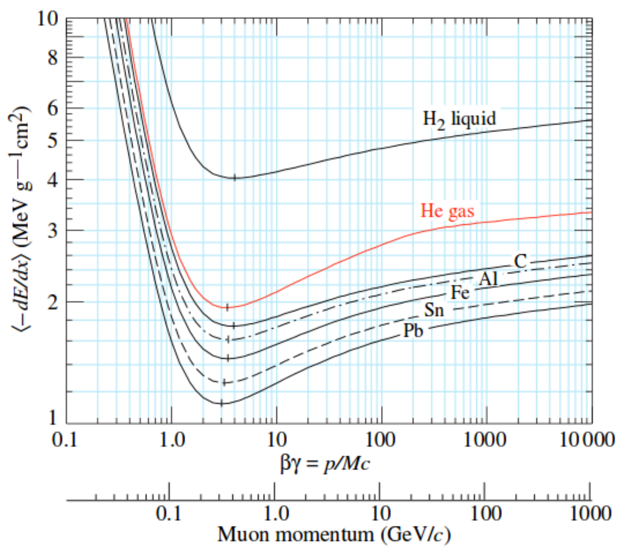


Figure 5.8: Equilibrium emittance predicted by formulae and obtained in MAUS

- Theoretical uncertainty in MCS models
  - Tim Carlisle indicates theoretical uncertainty on ~few % level for MCS probability

Absorber – Energy Loss

PDG – mean energy loss



PDG- straggling

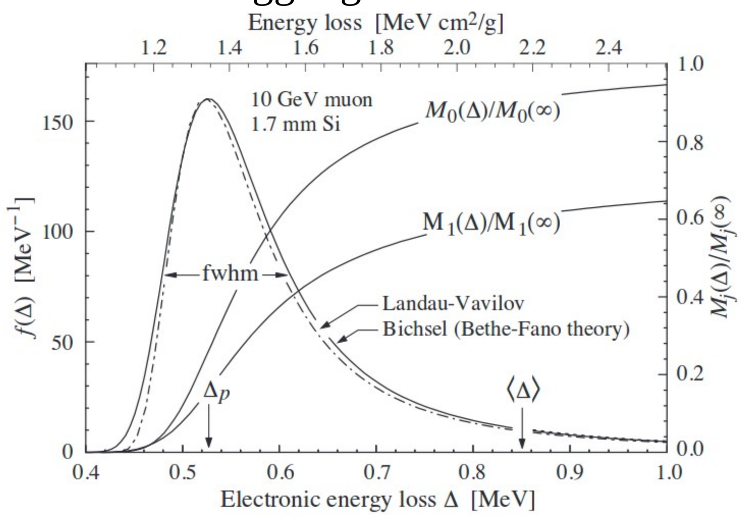


Figure 32.7: Electronic energy deposit distribution for a 10 GeV muon traversing 1.7 mm of silicon, the stopping power equivalent of about 0.3 cm of PVC

Aitken *et al.* (1969)			p/m		Theoretical fwhm		Measured fwhm	Theory Peak dE	Measured Peak dE
p	2 160	315	0.89	20	333.6	338.0	360	1246	1329
π	2 160	65.3	1.07	20	281.2	286.5	296	1031	1061
e	2 160	458	897	20	166.8	176.1	176	686	687
				10		169.2		683	
average differences						$\langle r_w \rangle = 3$			$\langle r_p \rangle = -3$

H. Bichsel, Rev. Mod. Phys. 60, 663 (1988),

No errors in Aitken et al (but few % is typical); No muons!

Mean energy loss is not well defined experimentally

Questions (2)

- Cooling
  - **Do we see the expected emittance change?**
    - **Transverse?**
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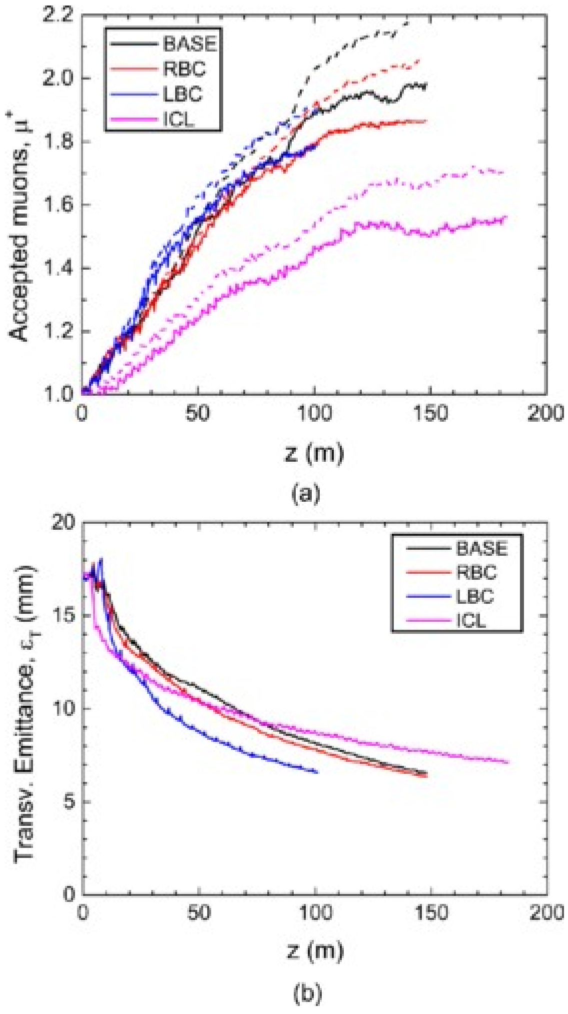
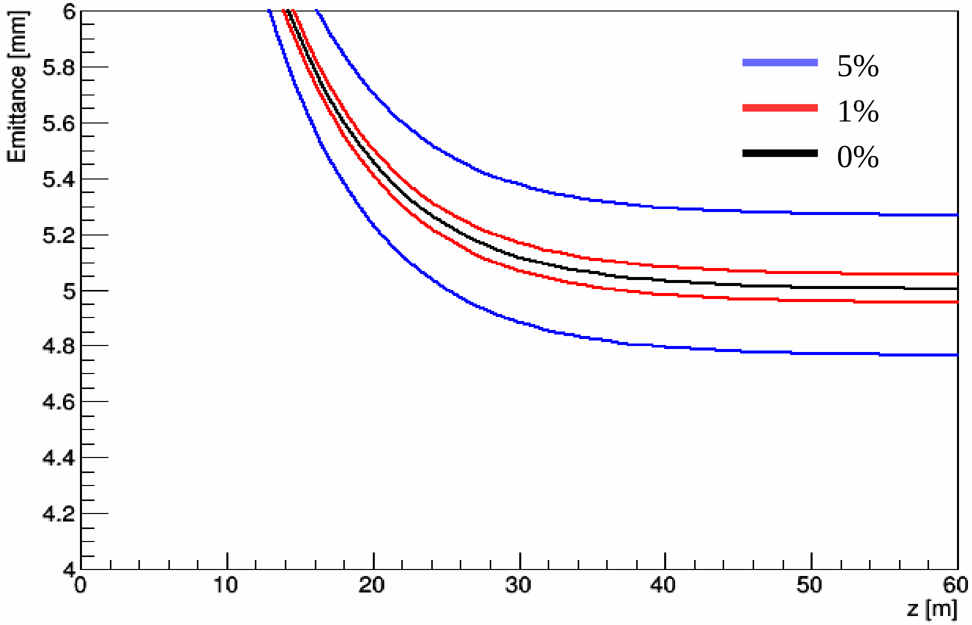
NF Performance

- Cooling performance in NF is assessed in two ways
  - Number of muons in a 15 or 30 mm ellipse
  - Transverse emittance reduction
- What happens if we mis-estimated X0?
  - Uncertainty ~ few %
- What happens if we mis-estimate dE/dz
  - Uncertainty ~ few %



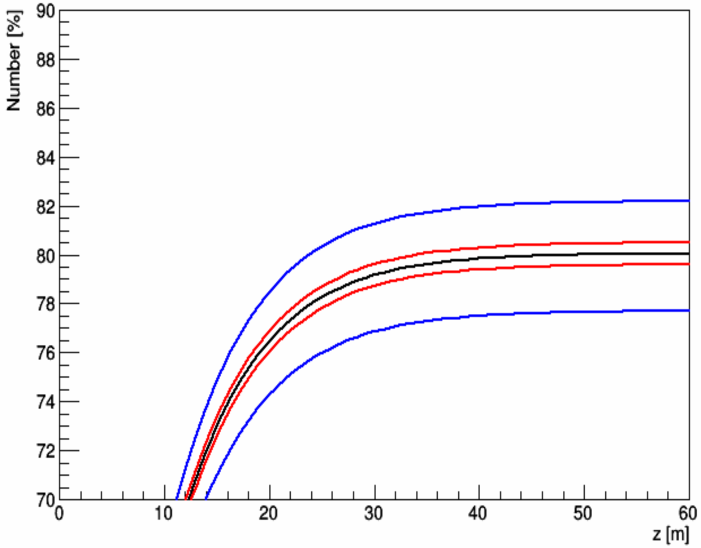
Back to Cooling



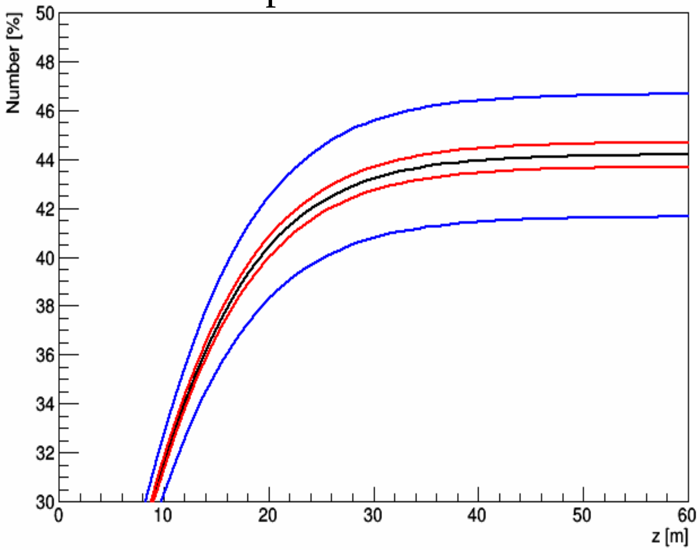
- Apply the standard formulae
  - Introduce a theoretical uncertainty in X0
  - Equivalent to theoretical uncertainty in <dE/dz
- 5% error in X0 leads to 5% error in emittance
  - (beta = 800 mm, PDG LiH, IDS lattice)

And Capture Performance...

30 mm acceptance



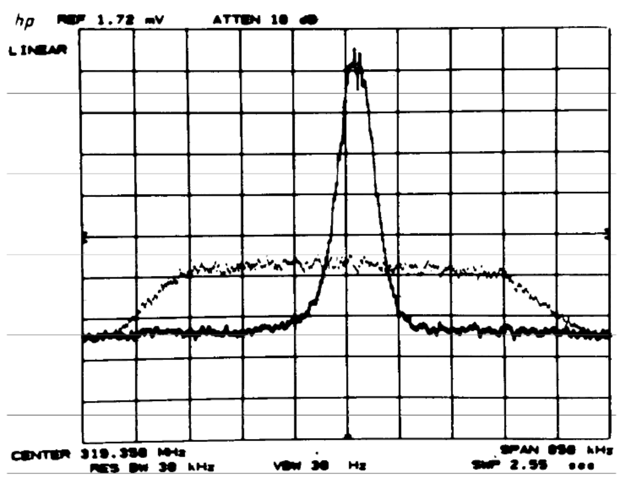
15 mm acceptance



- Really we care about number of good muons in accelerator acceptance
  - IDS-NF baseline accelerator had 30 mm acceptance
  - Also considered 15 mm acceptance accelerator
  - Assume Gaussian beam and look at Chi2 with 4 dof
- Note sensitivity to the cut!
- What about apertures and non-linear effects

Conclusions

- MICE will be the essential demonstration of ionisation cooling
  - Demonstrate engineering of the channel
  - Demonstrate beam propagation through the channel
  - Demonstrate ionisation cooling
- MICE is a unique experiment with potential to make several unique contributions to accelerator physics
- There are many fun, interesting challenges to be had



S. Van Der Meer, Nobel Lecture