Status of the Physics Analysis

V. Blackmore
MICE Project Board

29th April, 2014

Contents

Organisation

Physics Co-ordinator

V. Blackmore (JAI/Oxford)

Analyses

MICE Collaboration

Production Manager

[...]

Generation of MC data & reconstruction of data

Configuration Manager

R. Bayes (Glasgow)

Calibration constants and experimental configurations

Beamline Simulation Manager

J. Pasternak (Imperial)

Derivation of beamline settings for operations

Analysis 'Philosophy'

Analysis 'Framework'

A full and definitive exploration of the ionisation cooling equation
Proof that we can *predict* it + proof that we can *measure* it

Depends on upstream beam line (mostly diffuser)

Depends on magnetic lattice

Ionisation Cooling

Multiple scattering

$$\frac{d\varepsilon}{ds} = \frac{-\varepsilon_n}{\beta^2 E}\left\langle\frac{dE}{dX}\right\rangle + \frac{\beta_t (13.6\text{ MeV})^2}{2\beta^3 E m_\mu X_0}$$

Measure a change in emittance

$\frac{p}{E} = \beta$, $E = \sqrt{p^2 + m_\mu^2}$

➔ depends on D2 selection

Depends on material

Depends on particle species → backgrounds!

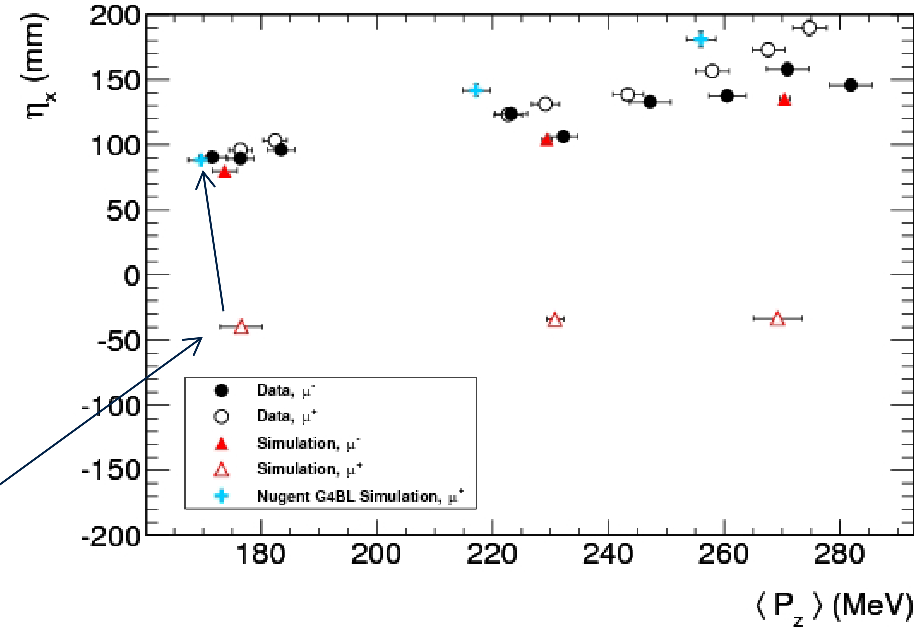
+ RF, an additional requirement for other facilities, + canonical angular momentum, +...

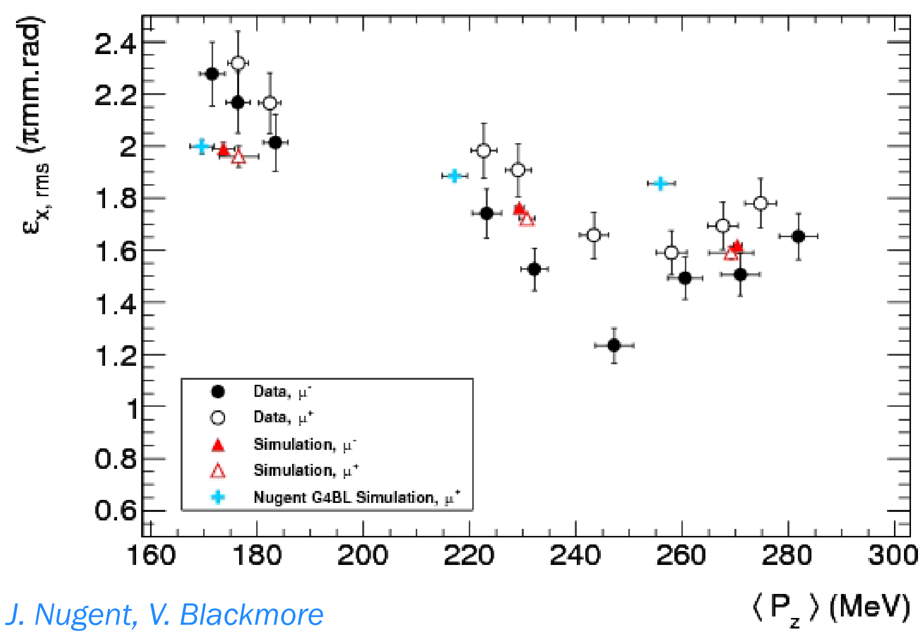
Current Topics

- Conclusion of Step I physics analyses
- Preparation for Step IV

Step I Analyses

- Step I results published in EPJC (October 2013)
- Identified discrepancy in dispersion between positive beam line simulation and data
  - Simulation of upstream beam line uses G4Beamline
  - Resolved with precise modelling of beam line
- Characterised beams are a valuable resource for Step IV analyses
- Implementation of a “realistic beam library” as input to MAUS simulations





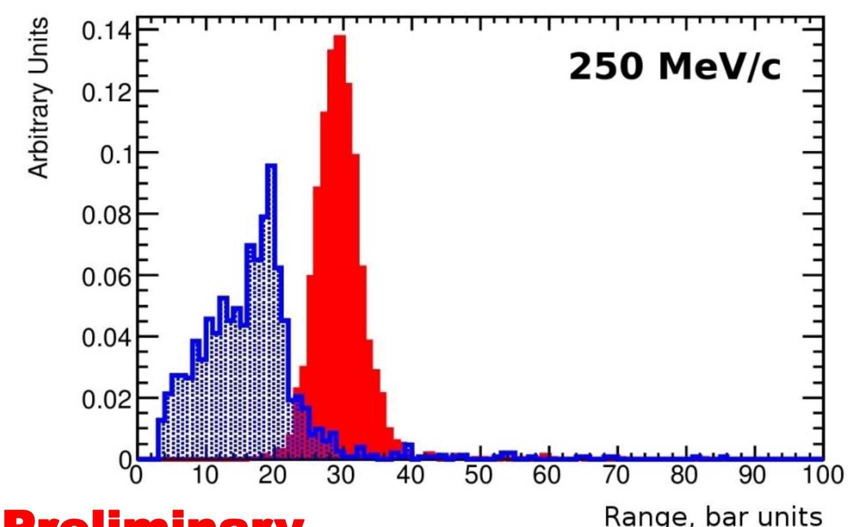
J. Nugent, V. Blackmore

Step I Analyses: EMR Commissioning

- Clear distinction between particle types over full momentum range
  - Identified by range in EMR and deposited charge
- EMR implemented in MAUS
- Publication *in progress*

Muons
Pions
Electrons

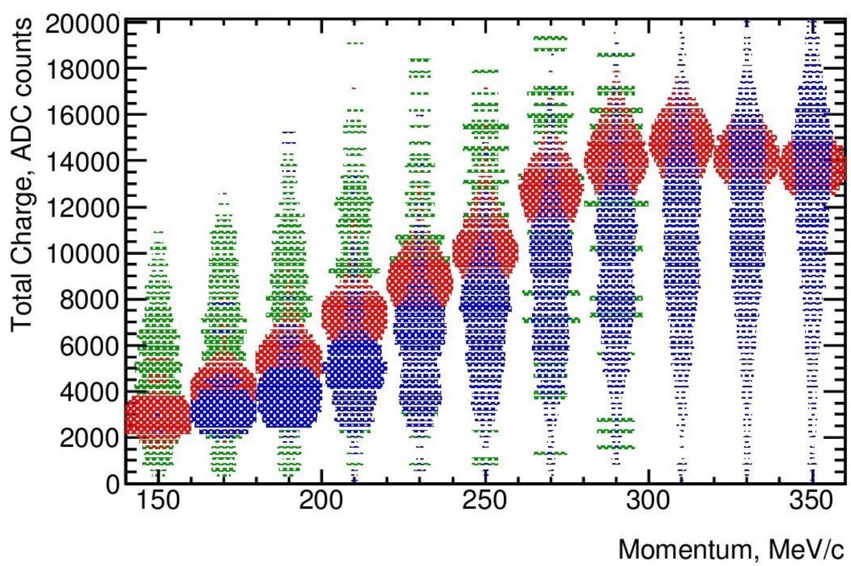
Range measurement



Preliminary

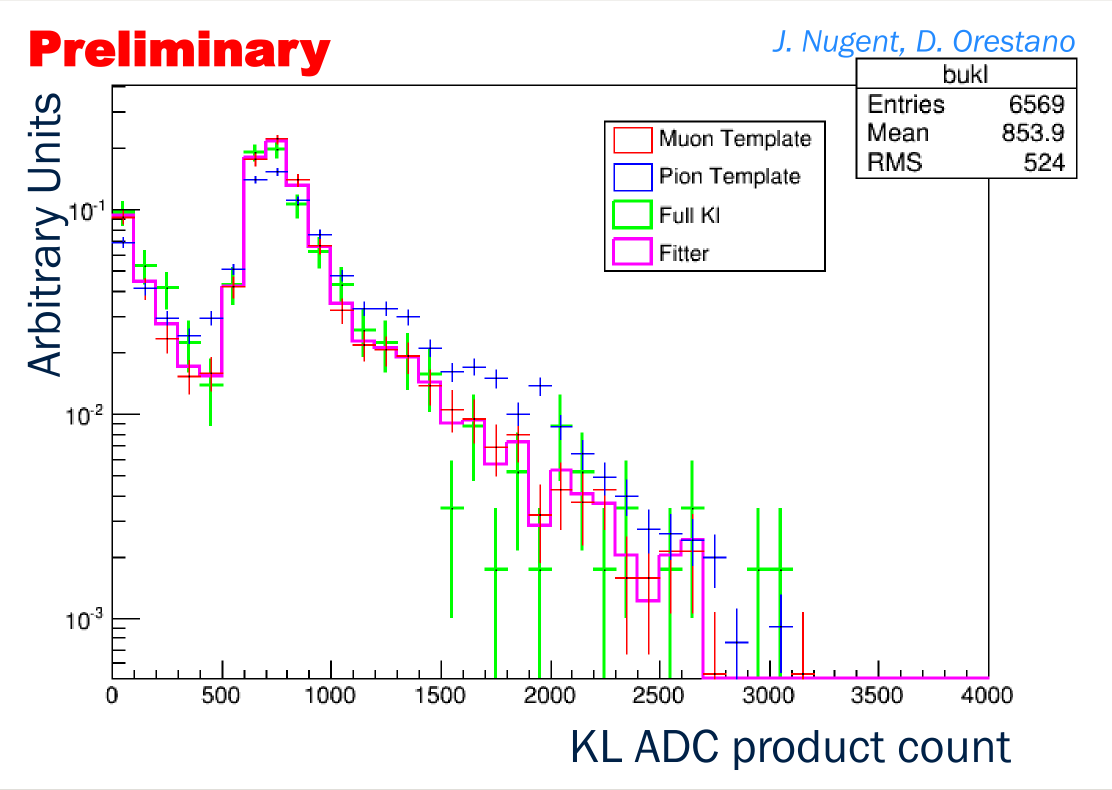
Total Deposited Charge

R. Asfandiyarov, F. Drielsma



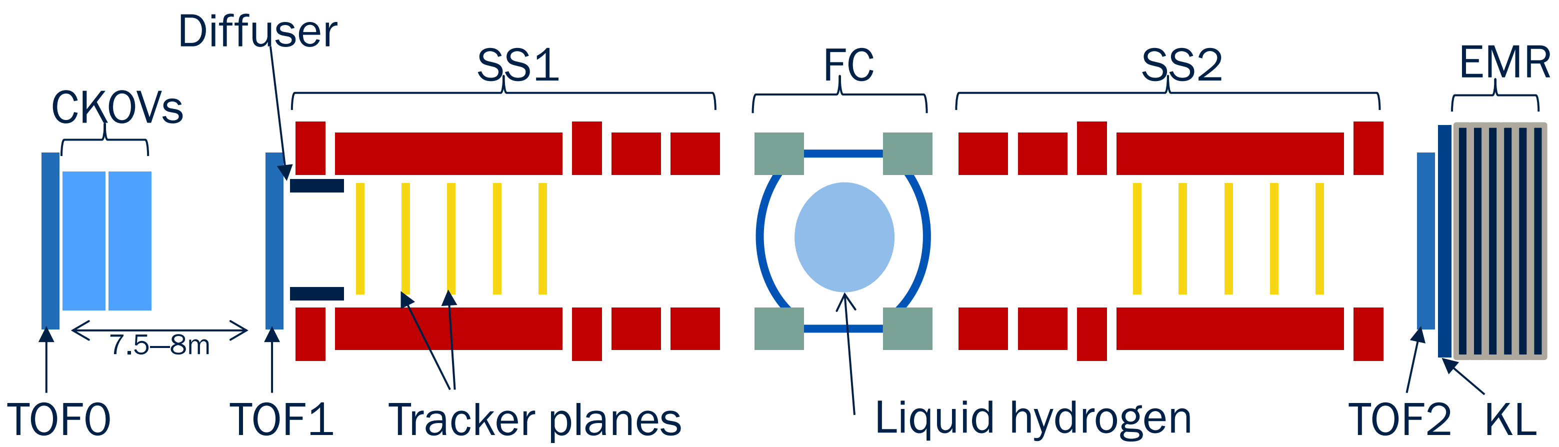
Step I Analysis: Pion Contamination

- Identify proportions of pions in muon beams using time-of-flight and charge deposited in the KL
- Required implementation of KL detector in MAUS (completed)
- Publication drafted and nearing conclusion



Step IV Analyses

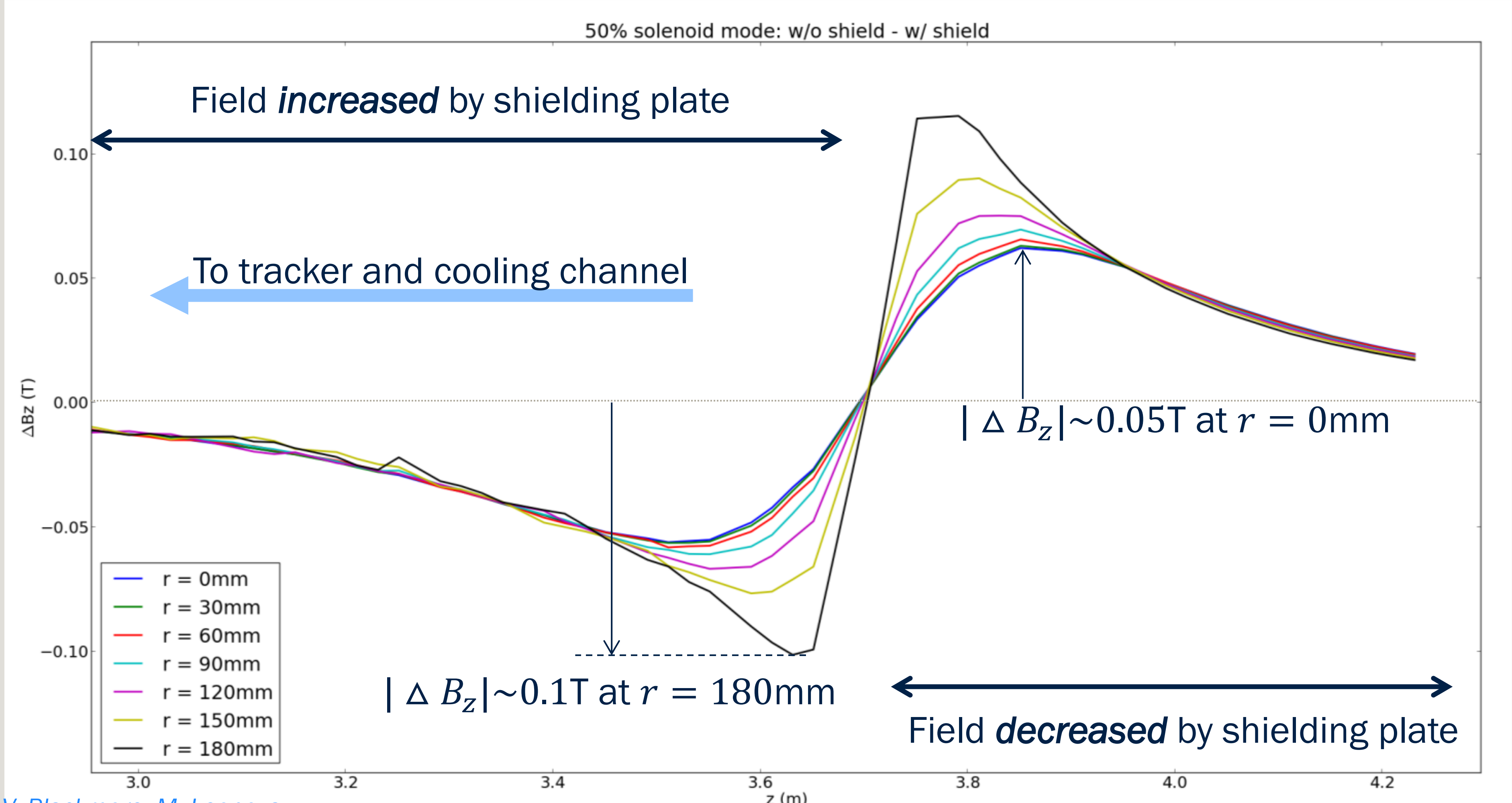
MICE Step IV



- One absorber
- No RF, no restoration of longitudinal momentum
- Aim: Demonstrate ionisation cooling without re-acceleration

Field Mapping

Example plot from field mapping of the upstream Spectrometer Solenoid with and without the iron shielding plate

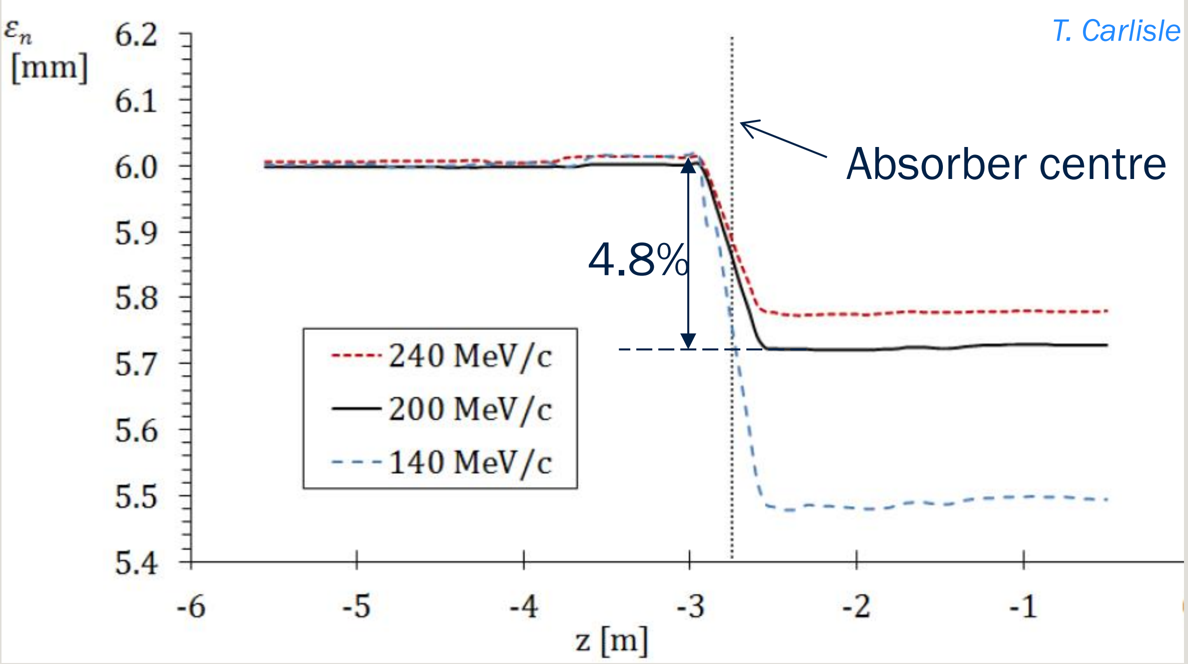


V. Blackmore, M. Leonova

De-rating Step IV

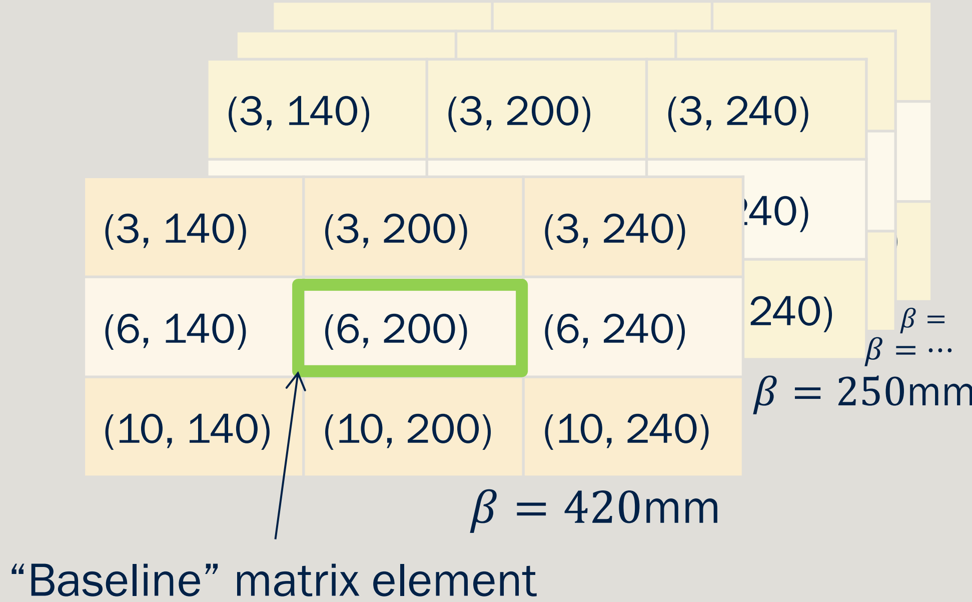
- FC1 has ***just*** reached baseline (200MeV/c) current. Could we use it in Step IV?
- Require an operational 'overhead' of approximately 11%
  - Accounts for the influence of Spectrometer Solenoids
  - "De-rate" the FC by this amount, see what happens.

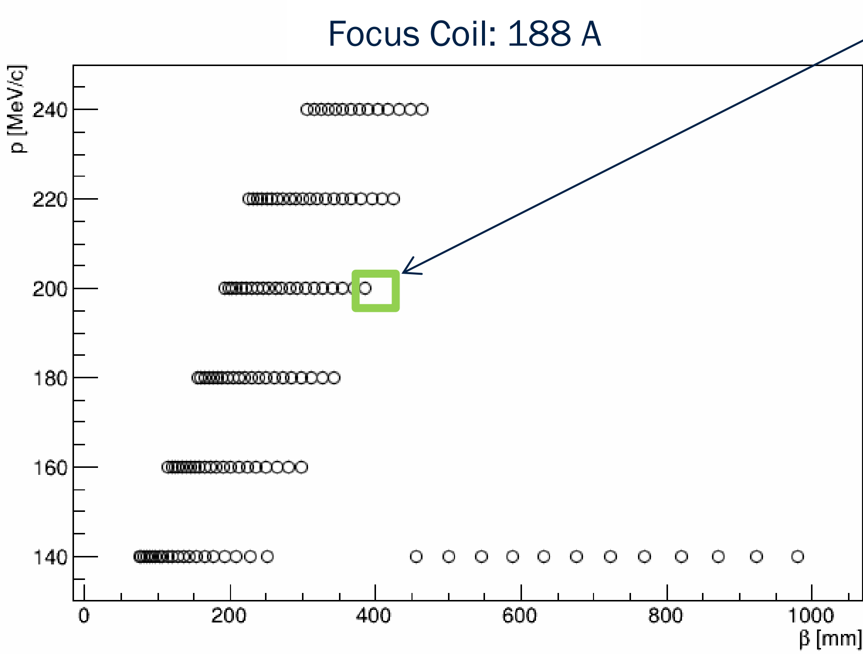
- Baseline Step IV simulations, $\sigma_{pz} = 1\text{MeV}/c$, expect 4.8% reduction in emittance

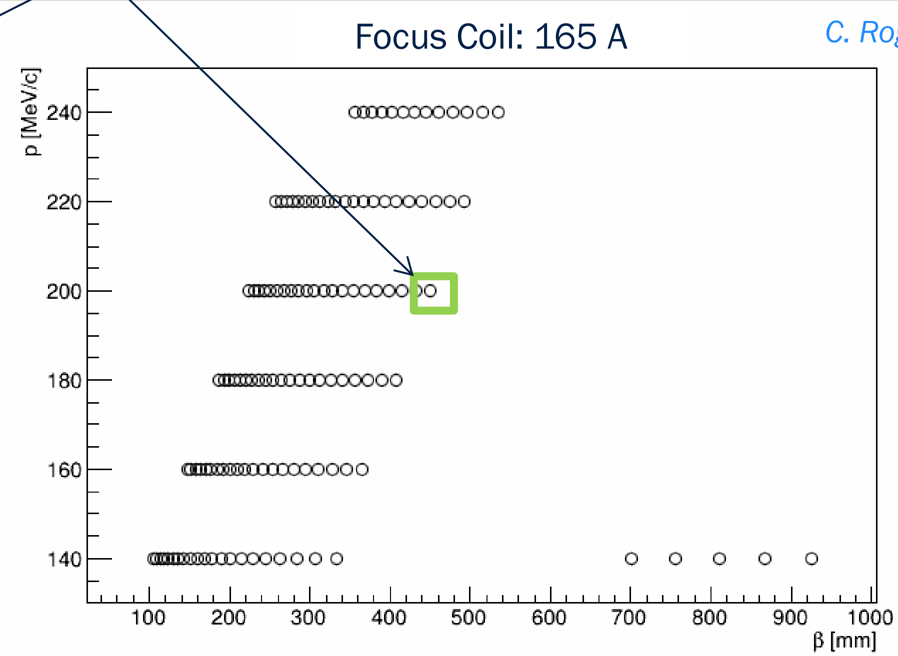


De-rating Step IV

- Step IV will explore a 3x3x... matrix of input emittance, momentum and β-function at the centre of the absorber
- Begin with linear optics and look for matched solutions with the de-rated FC
- Large available parameter space!



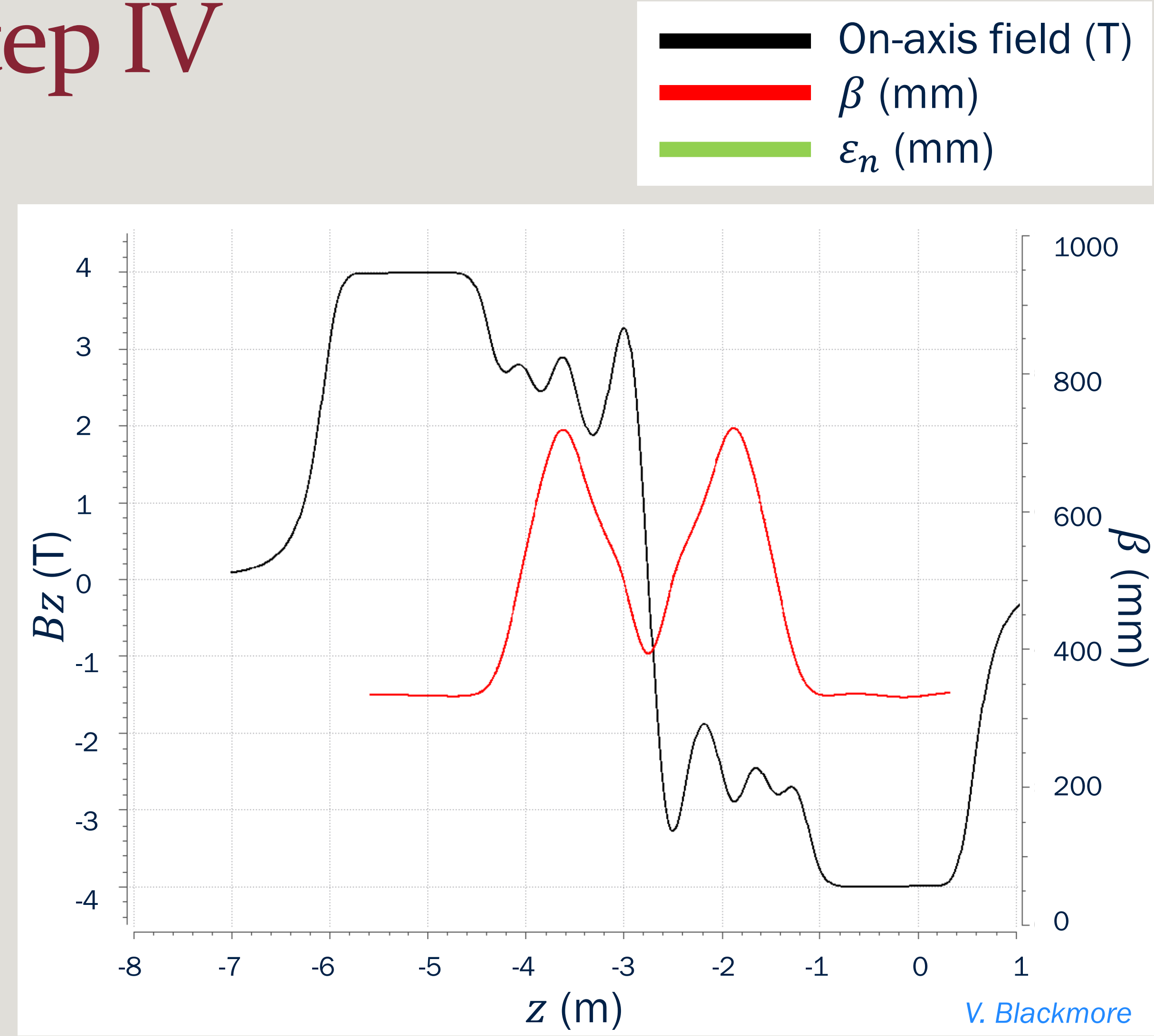




C. Rogers

De-rating Step IV

- Very easy to de-rate the focus coil with our linear optics tool
- Start with nominal coil, $\varepsilon_n = 6\text{mm}$, $p_z = 200\text{MeV}/c$



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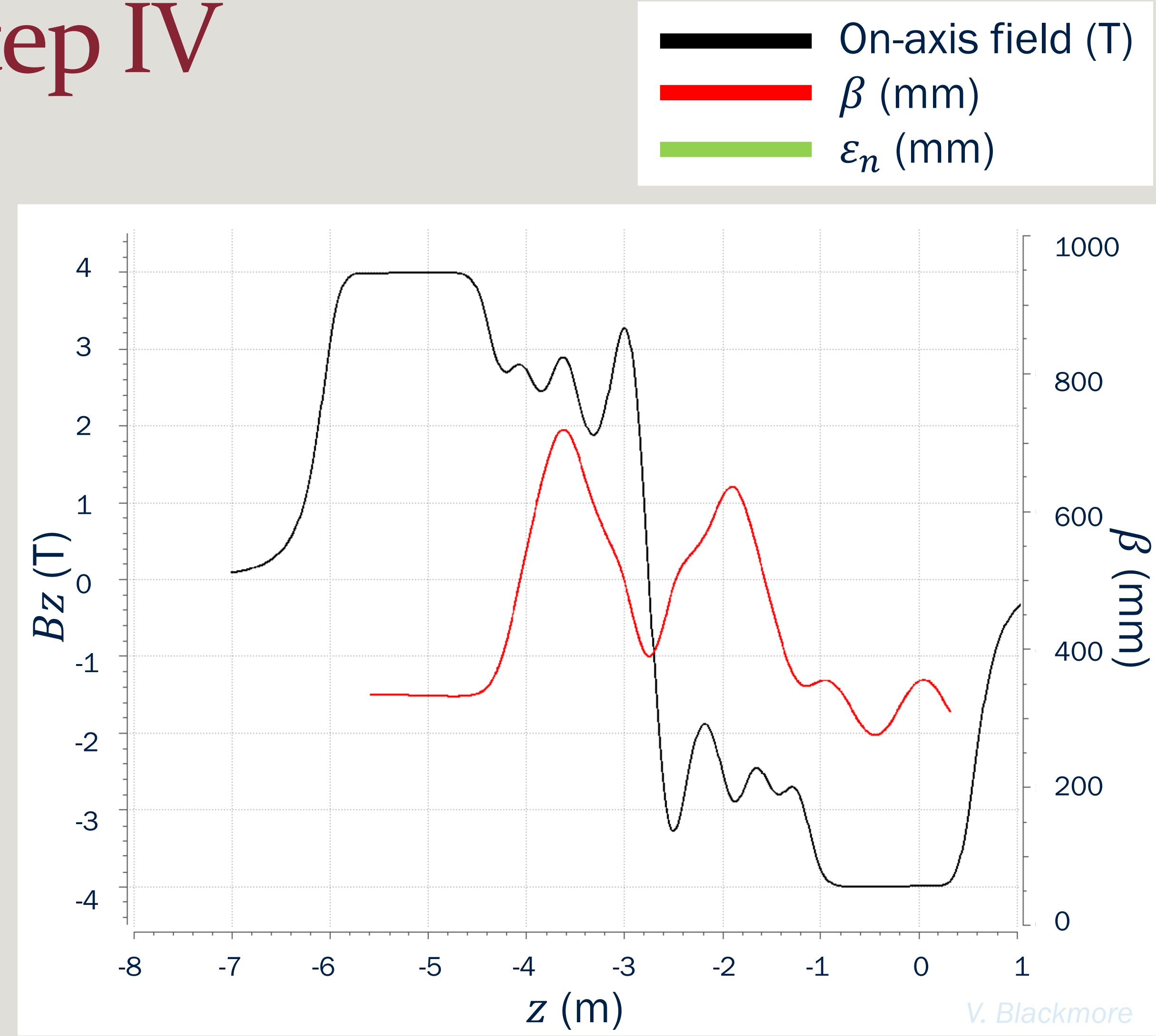
- Very easy to de-rate the focus coil with our linear optics tool
- Start with nominal coil, $\varepsilon_n = 6\text{mm}$, $p_z = 200\text{MeV}/c$
- Add 35cm LH2 (will lose 10MeV)



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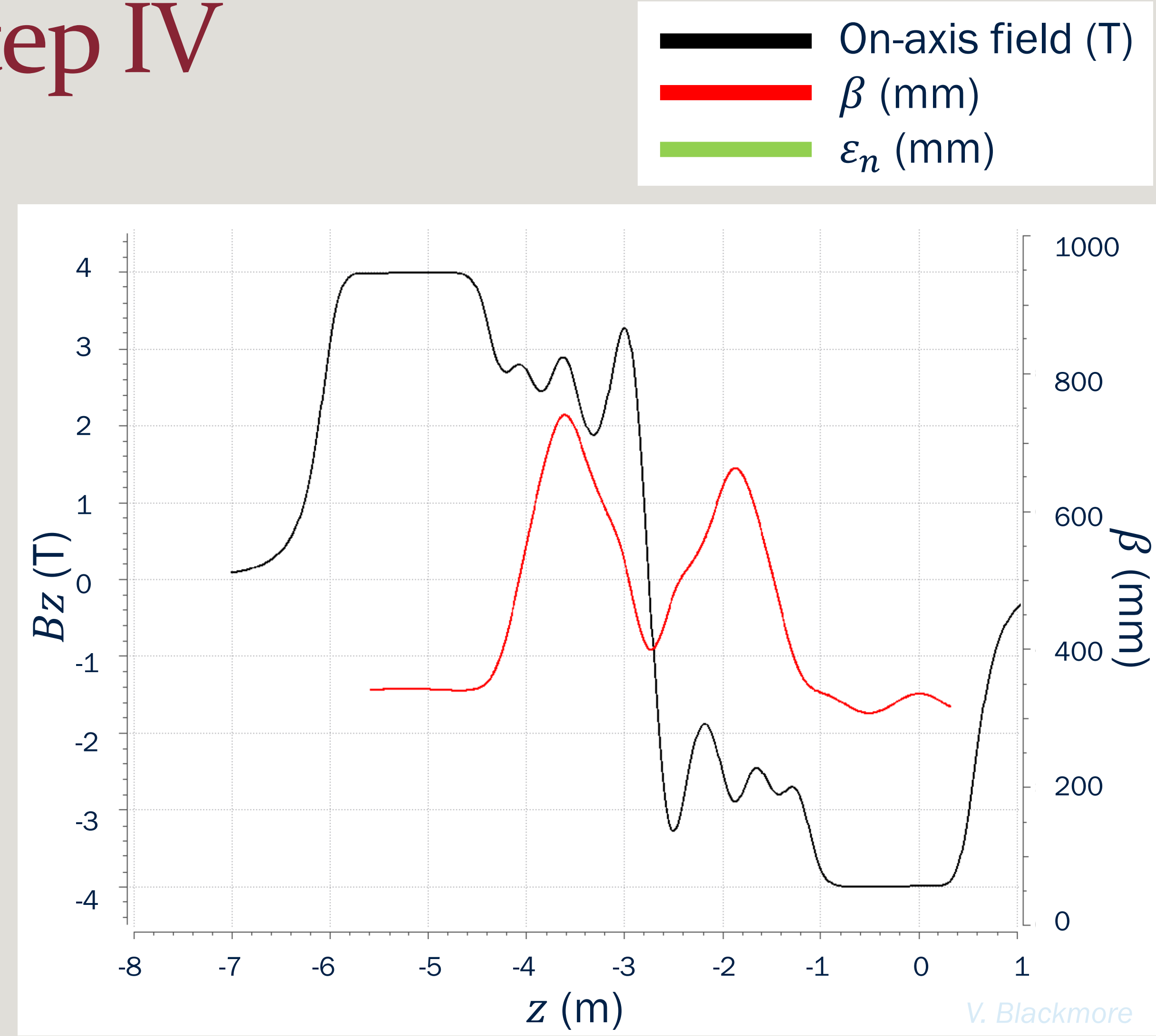

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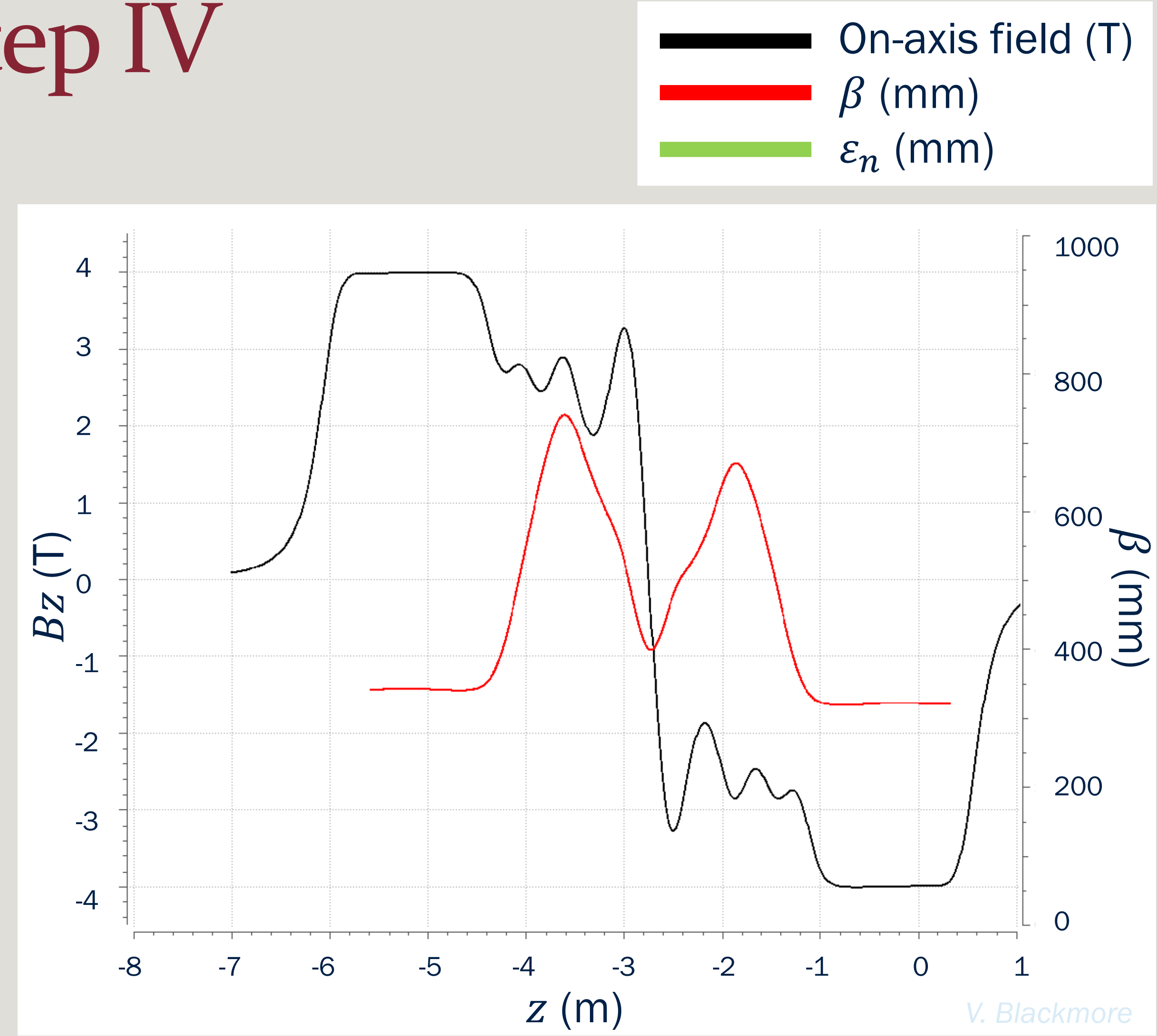
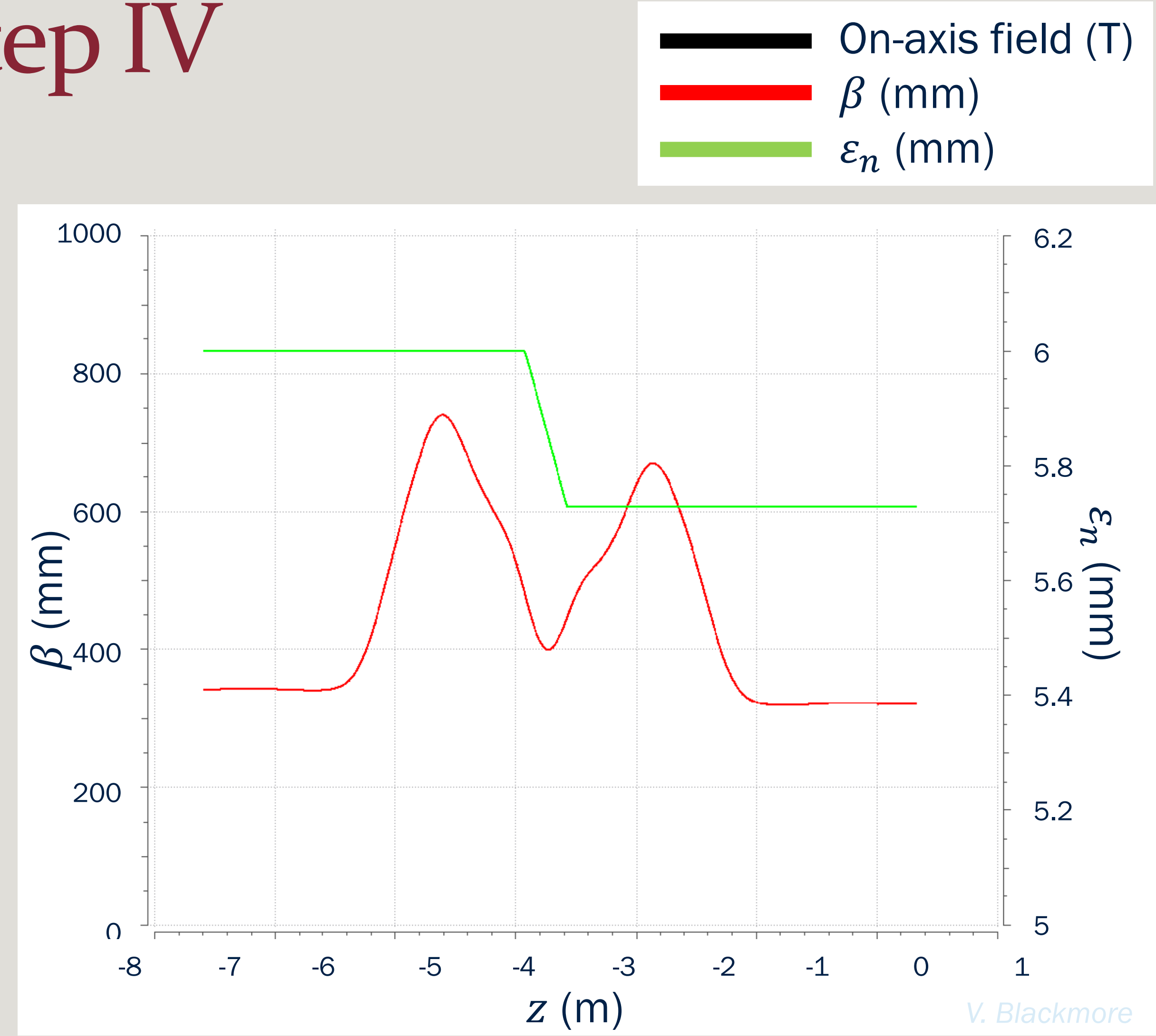
- Rematch upstream to $p_z = 205\text{MeV}/c$
- Tune downstream match coils



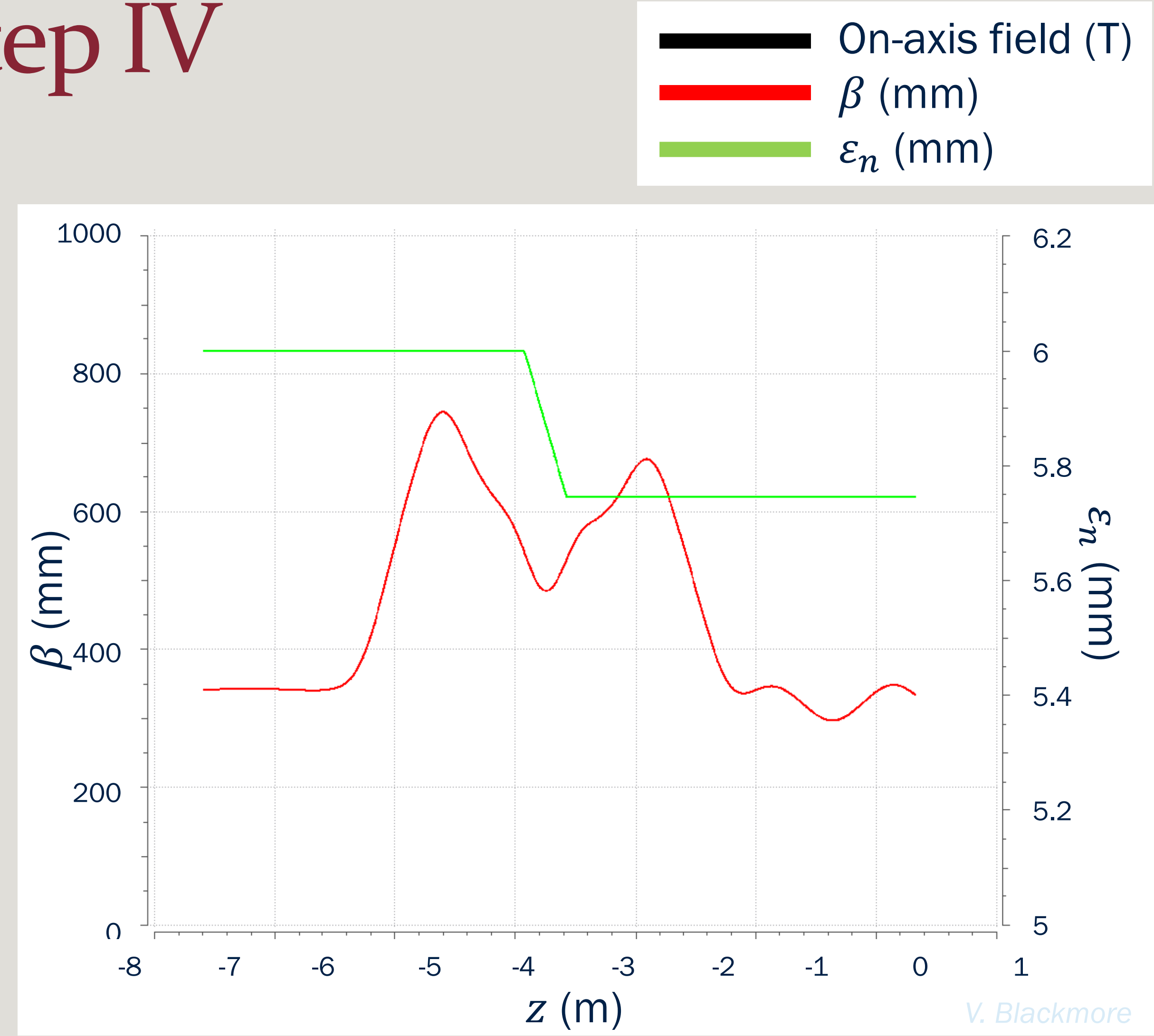
De-rating Step IV

- Approx. 5% emittance reduction



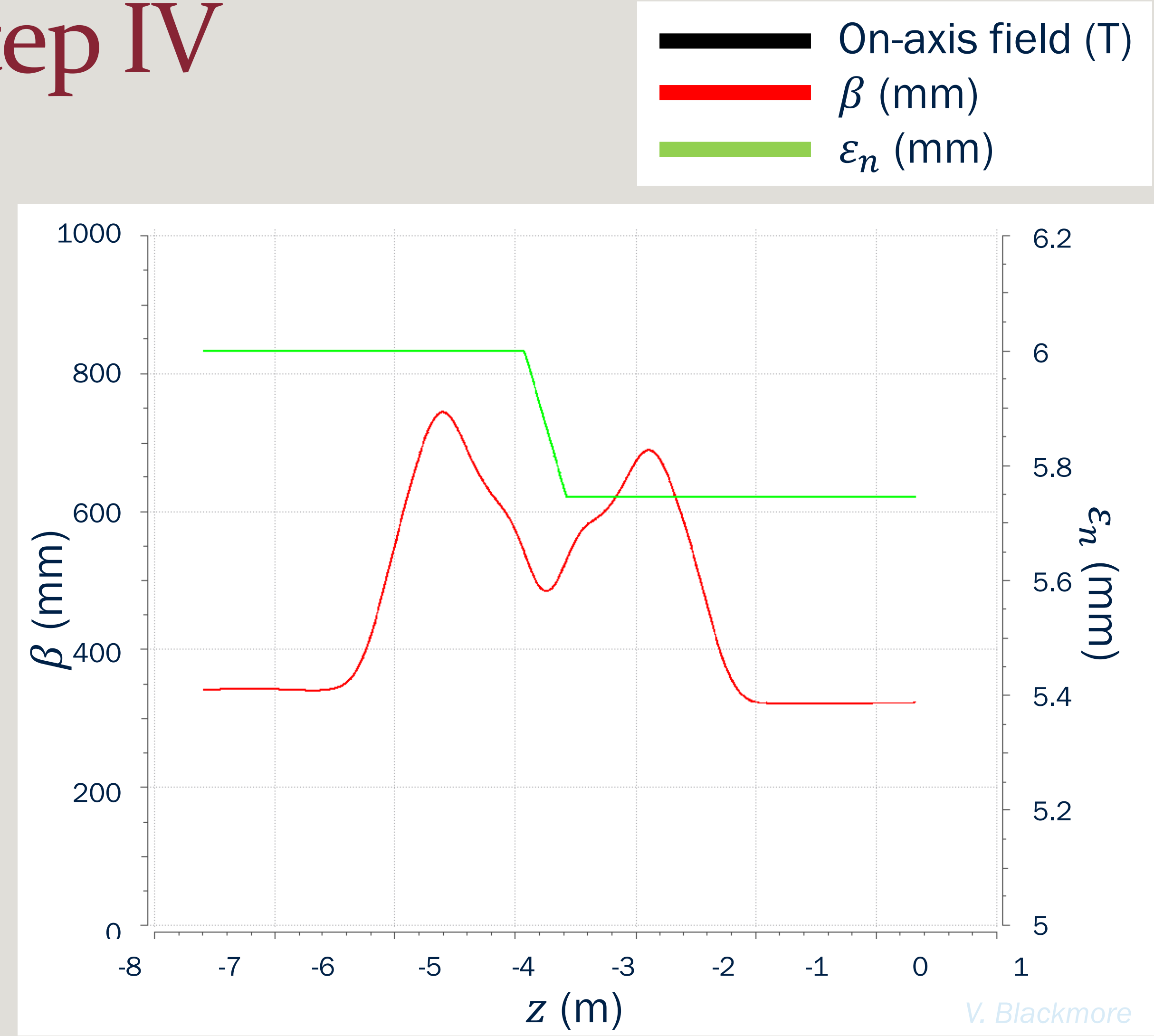
De-rating Step IV

- Approx. 5% emittance reduction
- Next, de-rate focus coil only (188A → 165A)



De-rating Step IV

- Approx. 5% emittance reduction
- Next, de-rate focus coil only (188A → 165A)
- Rematch with downstream match coils.
  - Emittance reduction ~ 4.2%
  - β increased to 50cm



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- Approx. 5% emittance reduction
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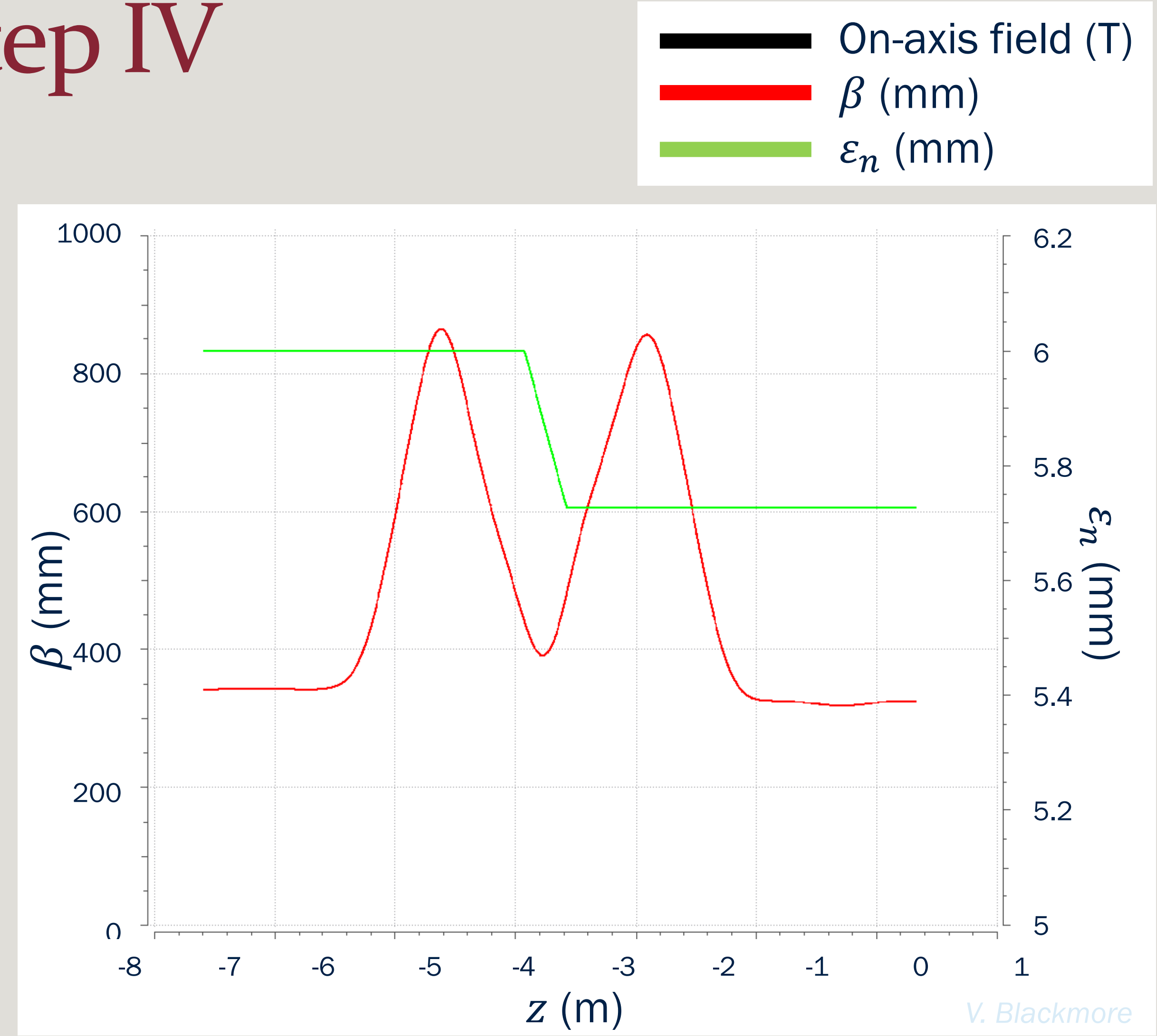
- Rematch with downstream match coils.
  - Emittance reduction ~ 4.2%
  - β increased to 50cm
- Retune upstream and downstream match coils
- Emittance reduction and β restored.



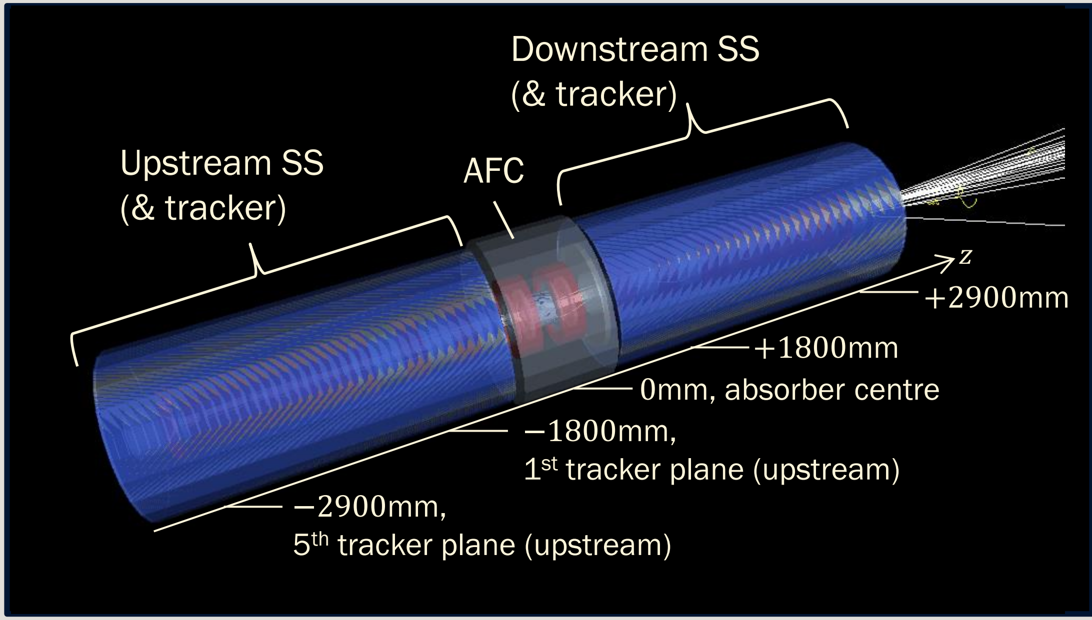
De-rating Step IV

- Linear optics gives us confidence that we could use FC1 in Step IV, but…

- Cannot have $\sigma_{pz} \neq 0$
- Does not include all material (inc. aperture sizes)
- Does not include dispersion
- Does not include measurement resolution
- Cannot account for non-linear effects

- Solution: A full Monte Carlo simulation using MAUS, with reconstructed muon tracks

J. Pasternak, J-B. Lagrange, C. Hunt



Step IV simulated geometry with (annotated) approximate positions of first and last tracker planes in the upstream and downstream Spectrometer Solenoids.

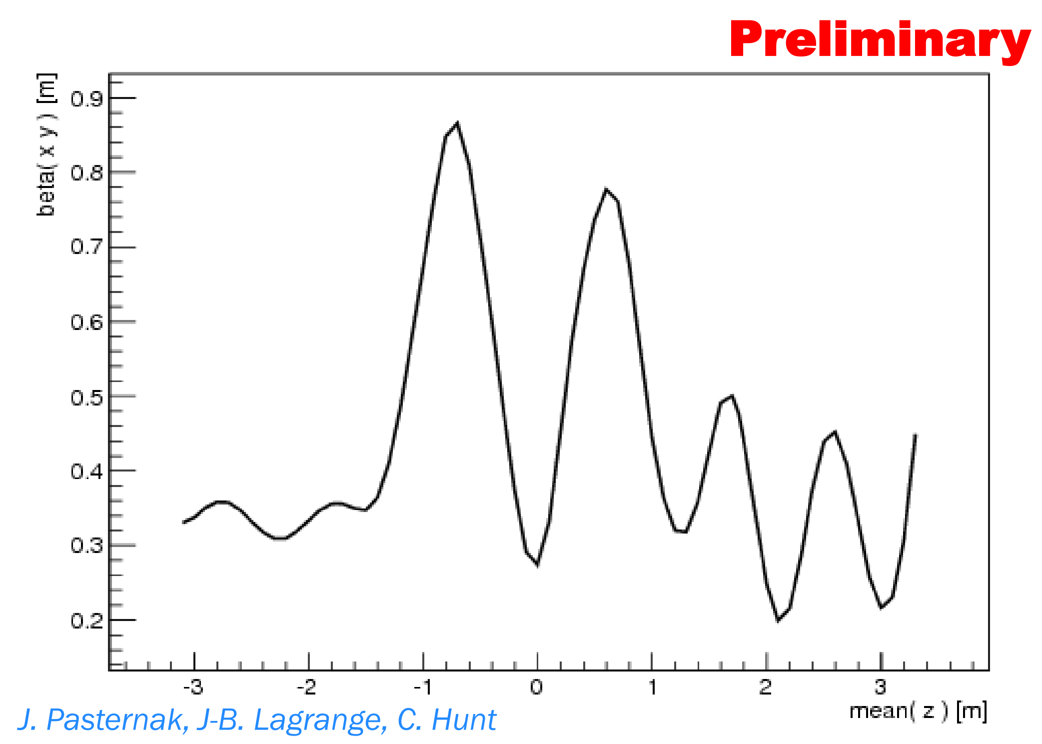
De-rating Step IV

Initial assumptions:

- $\sigma_{pz} = 5\text{MeV}$
- $\varepsilon_N = 6\pi\text{mm}$
- $p_z = 200\text{MeV}/c$

Take coil currents from matched linear optics solution (without absorber)

- p_z lost in absorber causes mismatch
- Retune downstream currents (M1 and M2 only)
- σ_{pz} causes additional mismatch that must be tuned.

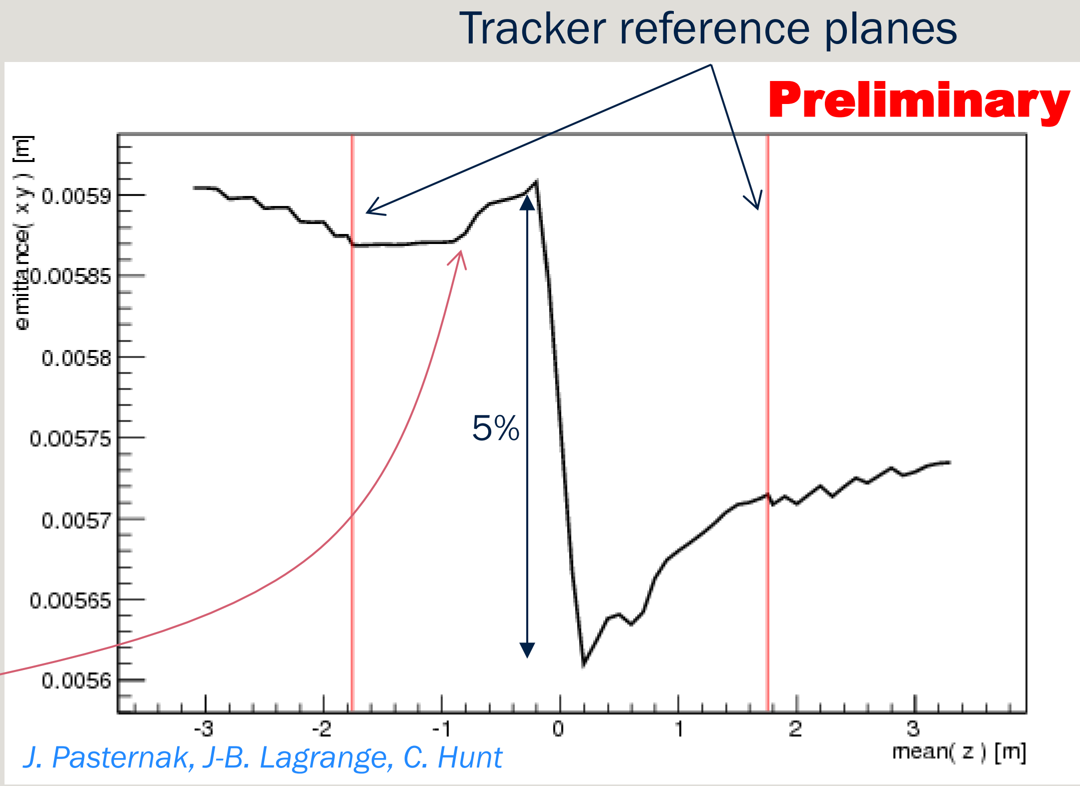


β-function after detuning FC1 and retuning downstream lattice. Achieved β~28cm at the centre of the absorber (baseline is 42cm)

The following analysis is <u>in progress</u>, and all plots are <u>highly preliminary</u>.

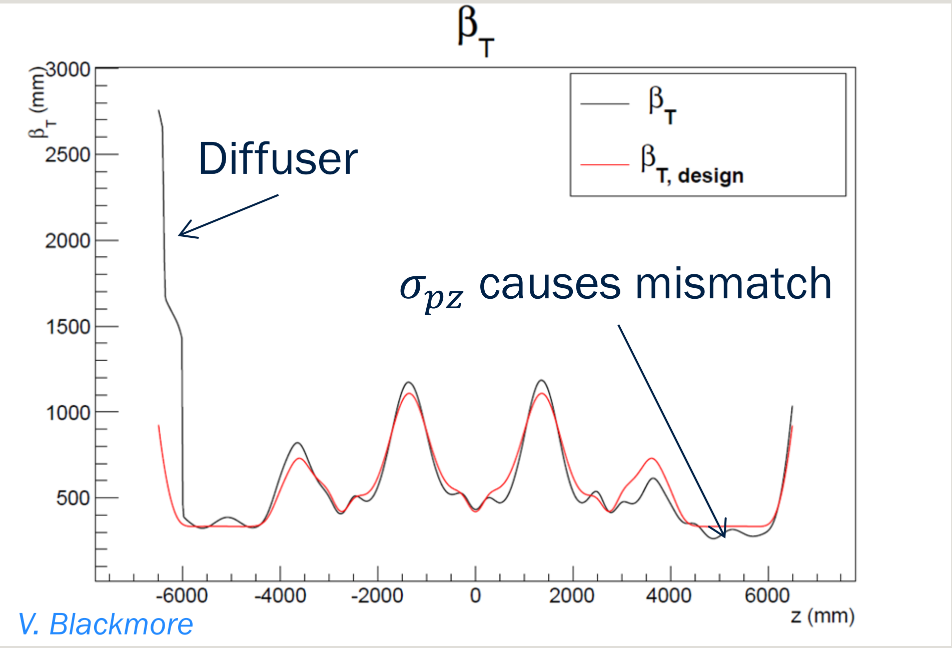
De-rating Step IV

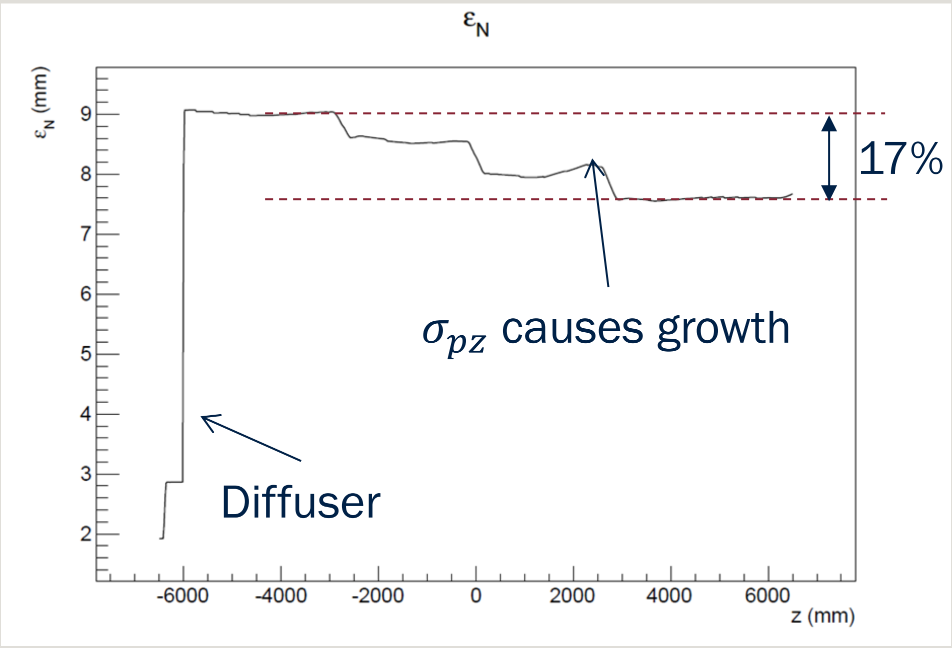
- Peak-to-peak emittance reduction of 5%
- Trackers reconstruct emittance at tracker reference planes (red)
- Emittance reduction at intersection ~ 3%
- Reconstructed emittance is under study.
- σ_{pz} causes emittance growth



De-rating Step IV

- Compare with a previous **Step VI** study (full cooling channel)
- Cooling seen with **real** muons (i.e. muons measured in Step I)
- Selected by p_z with $\sigma_{pz} = 20\text{MeV}/c$, no other selection criteria
- Momentum spread causes mismatch in β-function
- Emittance decreases (non-flat steps) → expected (or better) cooling performance





Recommendations

- Consider the impact of a pessimistic long-term funding scenario that requires MICE operations to cease at Step IV or V.
- Identify the maximum scientific achievements that could be made in Step IV, in comparison to Step VI.
- Following the good work done on establishing the criteria for the successful conclusion of Step IV, the project now needs to focus on looking at how to decide for Step V versus Step VI as it no longer looks like going to V and then VI sequentially is the most optimum option (this is not critical at this point but that decision point and the science trade-offs needs to be continually borne in mind by the project and the funding agencies)

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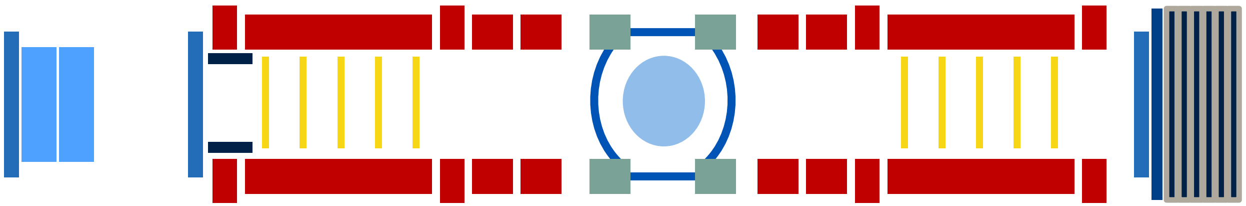
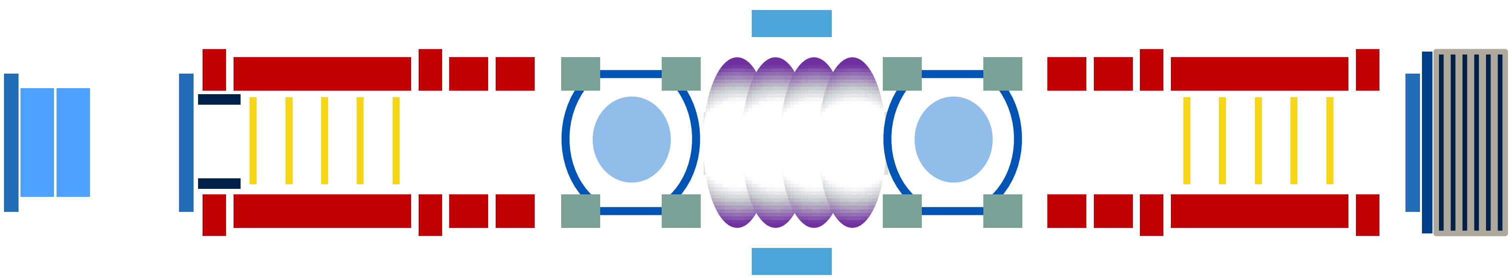
MICE Steps

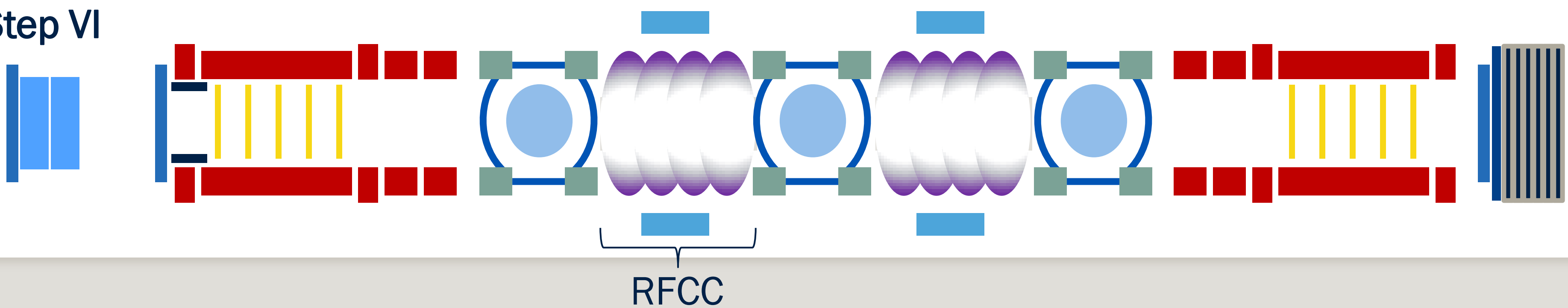
Step IV



Step V



Step VI



The MICE Physics Program

Definition of terms:

<u>Essential:</u> This result must be measured for MICE to achieve its goals. It cannot be delayed until a later Step.

<u>Core:</u> A critical result that could be delayed until a later Step given careful planning.

<u>Optimal:</u> An important result that could be better explored in a later Step.

Step	Result	Type	Dependencies
IV	1. First demonstration of ionisation cooling	Essential	--
	2. Measurement of ionisation cooling with LH2 and LiH absorbers	Core	1.
	3. Initial study of factors affecting performance of ionisation cooling lattices	Optimal	1, 2
	4. Initial study of emittance exchange in an ionisation cooling lattice	Optimal	1, 2
V	5. First demonstration of ionisation cooling with re-acceleration	Essential	1
	6. Measurement of transverse emittance reduction and longitudinal emittance preservation in an ionisation cooling lattice	Core	1, 2
	7. Study of factors affecting the performance of ionisation cooling lattices	Core	1, 2, (3)
	8. Management of canonical angular momentum in an ionisation cooling lattice	Optimal	1, (3), 5, (6, 7)
VI	9. Detailed study of the optics of ionisation cooling lattices	Core	1, 2, (3), 5, (6, 7, 8, 9)

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Step V or Step VI?

Both Step V and Step VI demonstration ionisation cooling with reacceleration.

Step V:

- 1 RFCC module
- 2 absorbers
- ½ lattice
- 0—2 field flips

Step VI:

- 2 RFCC modules
- 3 absorbers
- Full lattice
- 0—3 field flips

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Step VI:

- 2 RFCC modules
- 3 absorbers
- Full lattice
- 0–3 field flips

Step	Flips	Absorbers	RF	$d\varepsilon/ds$
IV	1	1	0	~5%
V	2	2	1	~10%
VI	3	3	2	~15%

Depends on magnetic lattice

$$\frac{d\varepsilon}{ds} = \frac{-\varepsilon_n}{\beta^2 E}\left\langle\frac{dE}{dX}\right\rangle + \frac{\beta_t (13.6\text{ MeV})^2}{2\beta^3 E m_\mu X_0}$$

Depends on material

Pick the Step that exploits these parameters **best**.

\+

Canonical angular momentum (field flips)

\+

Stabilisation of longitudinal phase space

Summary

Summary

- Step I physics analyses drawing to a close
  - Provides useful input to Step IV analyses
  - Use data to tune beam line for Step IV
- Step IV analyses in progress
  - Field mapping of magnets
  - Alignment & systematic error studies in progress
  - Other analyses planned/beginning, exploiting "cooling formula" framework
  - De-rated Step IV analyses progressing
    - Could use FC1 in Step IV
    - Requires understanding the reconstructed emittance
    - Next steps: Compare with "ideal" FC, improve matching to lattice, use 'measured' Step I beam
- Step V/VI question approached via simulation and linear optics
- Mantra: *Simulate twice, measure once.*