Upgrading Step IV to Cooling Demo

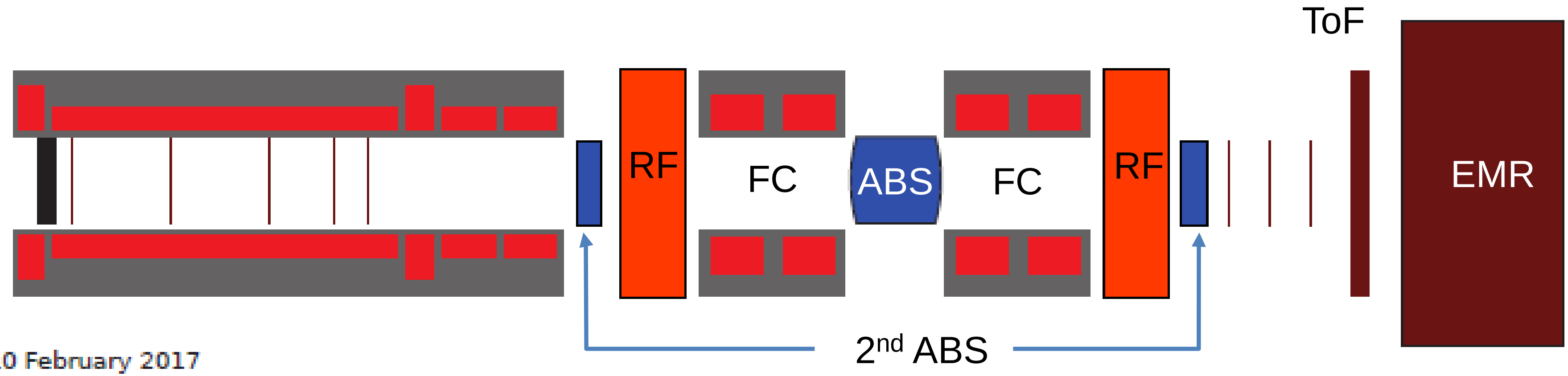
The MICE Collaboration

Overview

- Step IV is performing extremely well
  - High confidence in upstream SC magnets and Beamline
  - Measuring background physics of ionisation cooling
  - Will not prove utility of method
- Propose modest upgrade, mitigating risk substantially
  - Reuse known robust SC magnets
  - Use detectors already in hand
    - Modest requirements for detector development
  - Use STEP IV return Yoke (with minor modification)
  - Use operational RF amplifier chain
  - Cavities currently completing at LBL
  - Completion of RF controls
- Demonstration of SUSTAINABLE ionisation cooling

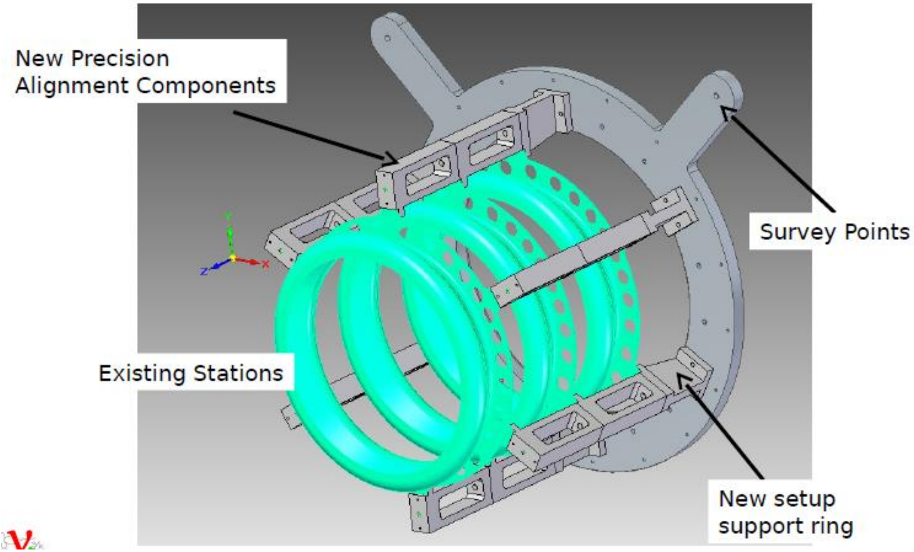
Geometry Overview

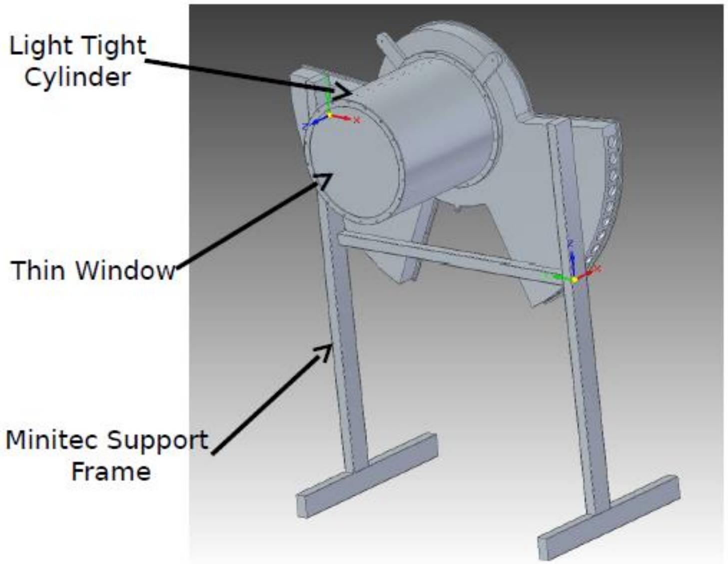
- Remove DS Spectrometer
  - LiH module, 2 cavities, 2 focus coils inside Step IV yoke
  - Upstream measurements as Step IV
  - Downstream measurements using EMR and compact tracker
  - Compact tracker placed in low field region outside Yoke



Compact tracker

- Three or four station tracker
  - Mounted outside the Yoke
  - Relatively field free region
  - Keep short- maximise transmission to EMR
  - EMR performs downstream axial momentum measurement
  - Component construction by Nikhef





Context

- Step IV is performing extremely well
  - High confidence in upstream SC magnets and Beamline
- New collaborators
  - “Ulsan” National Institute of Science and Technology, Korea
    - Application to join approved in February at CM47
  - Uppsala University, Sweden
    - Discussions with Spokesperson: Collaboration to take forward
  - Both have RF expertise, opportunity to bring in effort
  - Korean team have direct experience of MICE RF tests at MTA

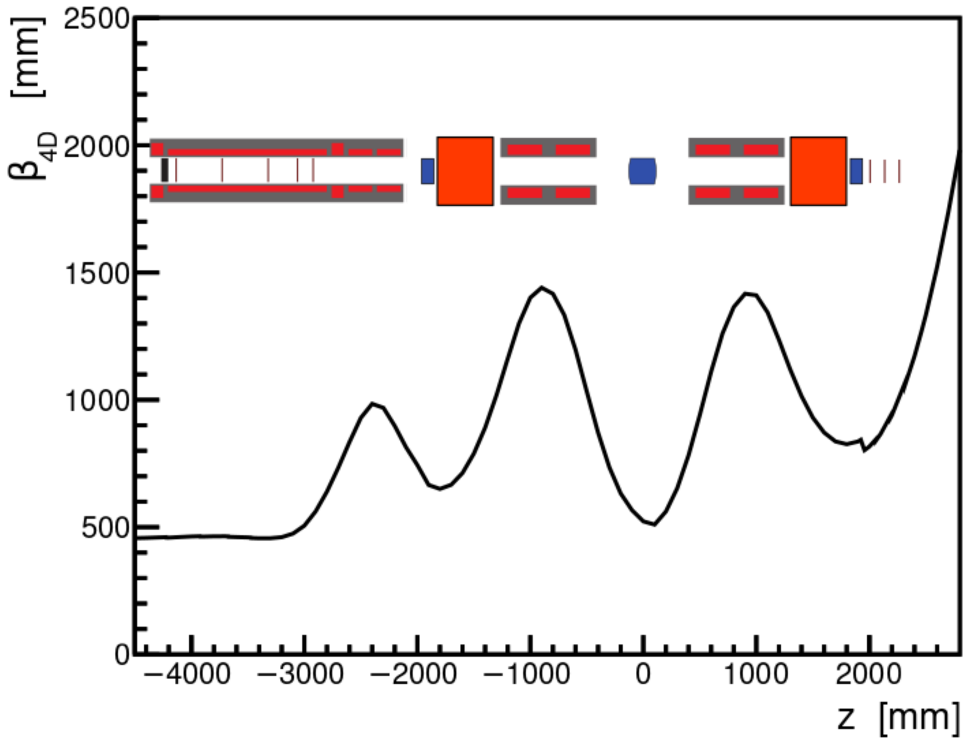
Modelling the Step IV Upgrade

Hardware Optimisations	Baseline	Additonal
Downstream Tracker Configuration	3 Stations	4 Stations
AFC – Tracker Separation	2056mm	2005mm: Contracted-I 1968mm: Contracted-II
Secondary Absorbers	32.5mm LiH	25mm Polyethylene

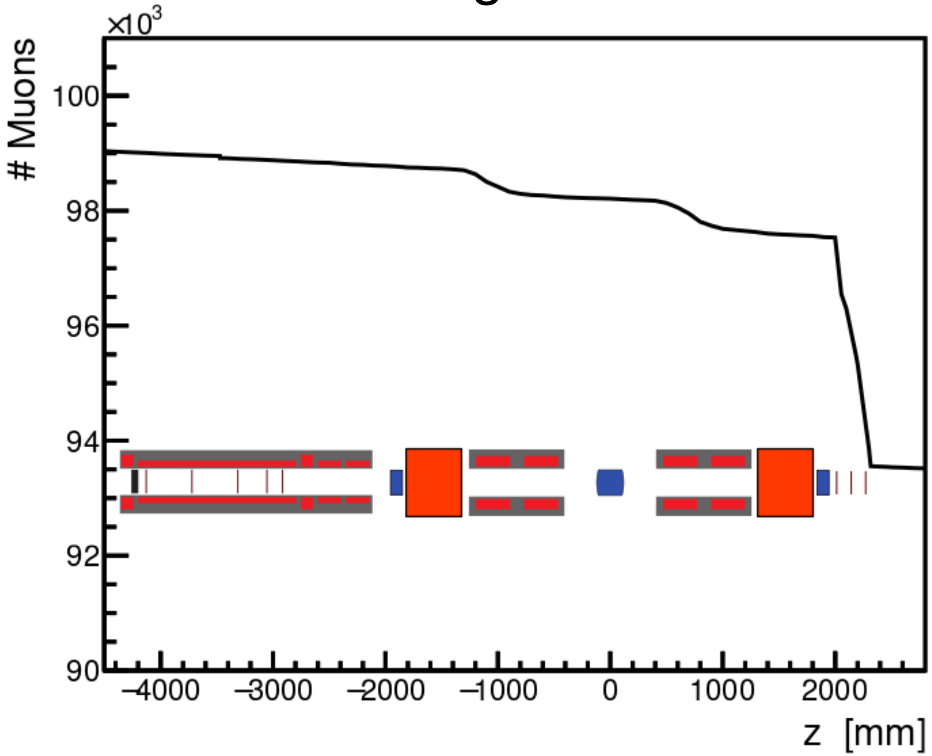
- Reconstruction Performance
  - Track Finding Efficiency/Purity
  - RF induced electrons:
    - Assessment of noise rejection in reconstruction

Lattice Design

Beta Function evolution through the Cooling Channel

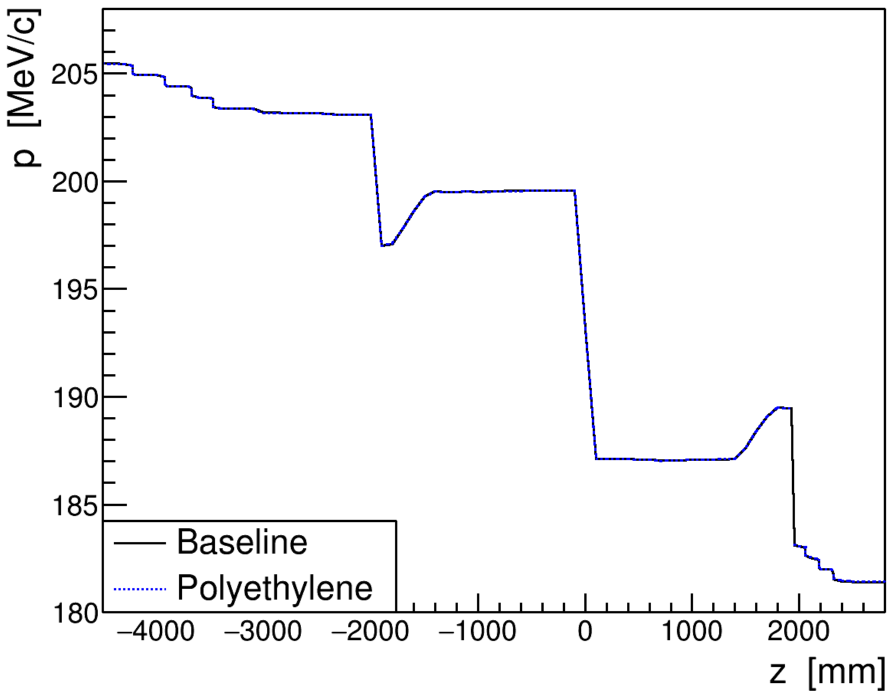


Transmission through the Cooling Channel

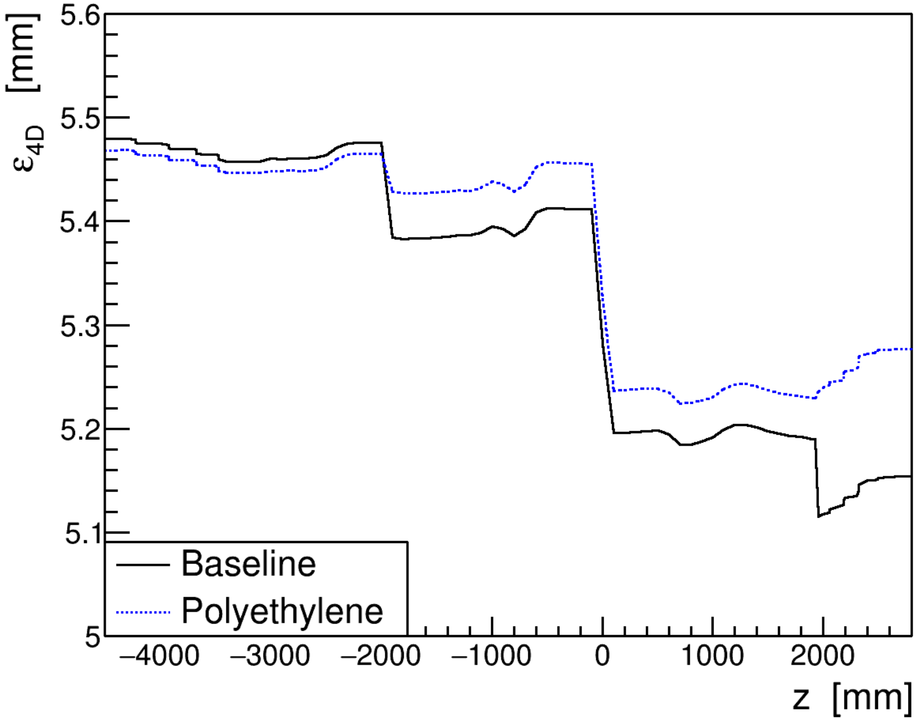


Lattice Design

Momentum evolution through the cooling channel

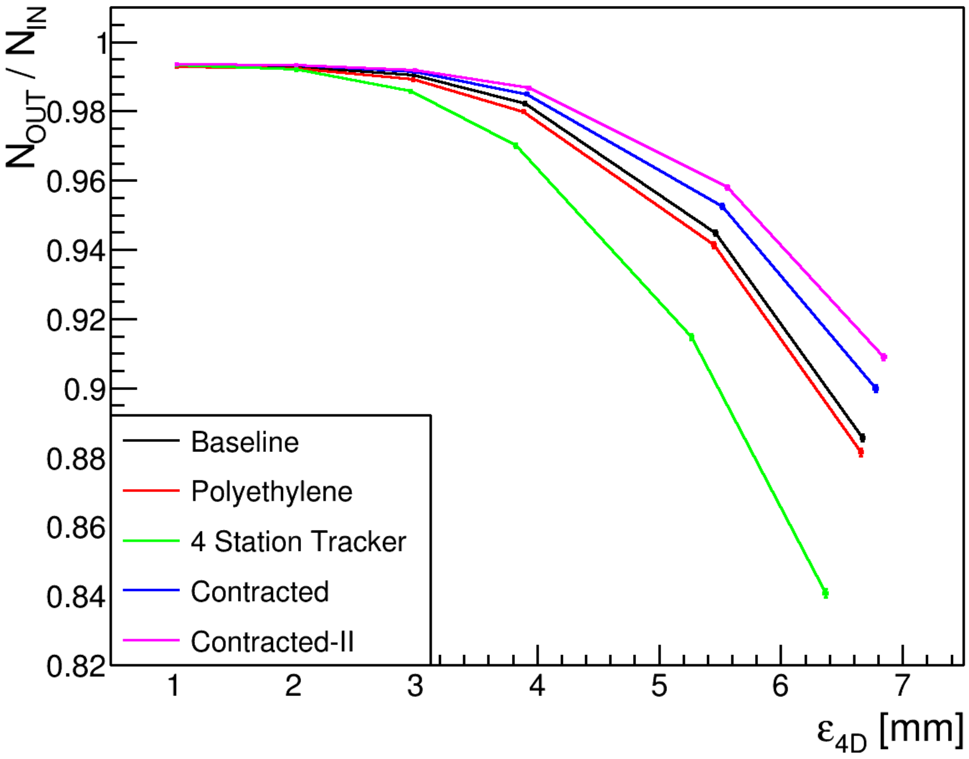


Emittance evolution through the cooling channel

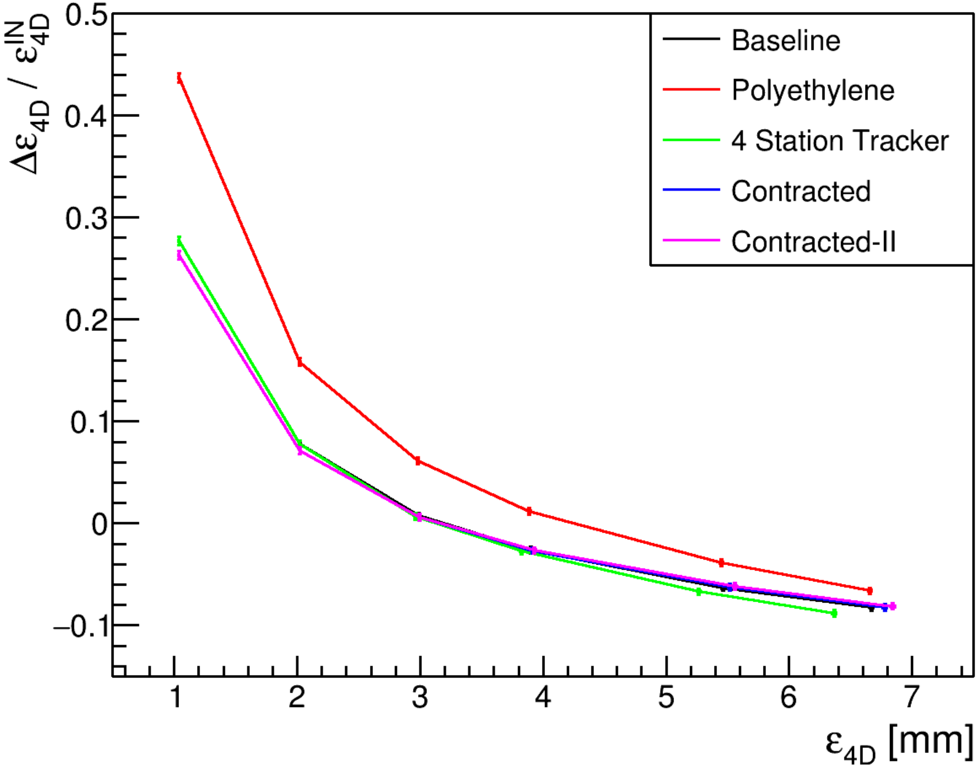


Lattice Performance

Transmission through Cooling Channel



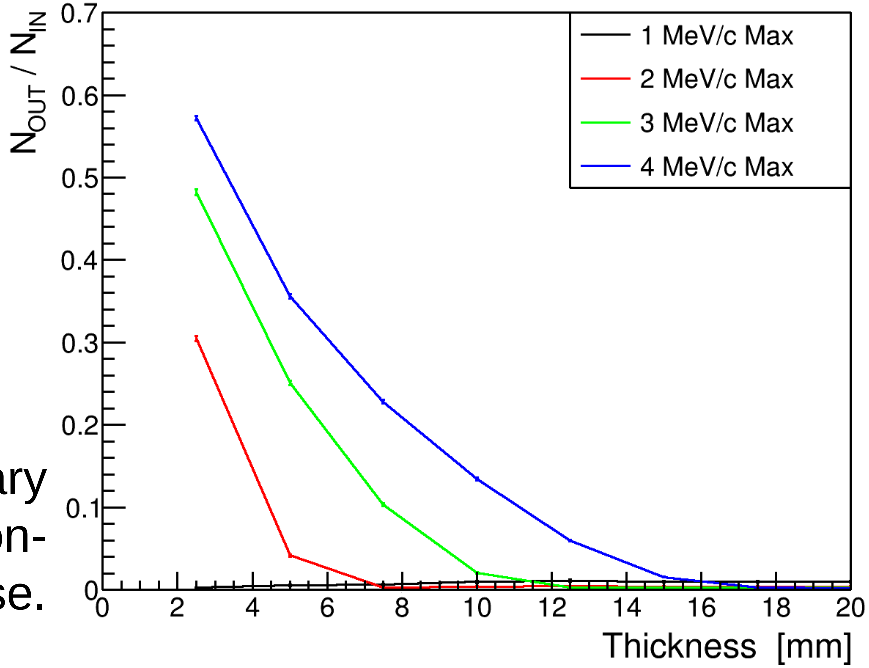
Fractional Emittance Change Between Reference Planes



Reconstruction Concerns

- RF Cavities are sources of e^- & $h\nu$
  - Track finding has been tested with noise.
    - For realistic $h\nu$ exposures
  - 99.5% of reconstructed tracks map to simulated tracks

Electron Penetration Through Polyethylene

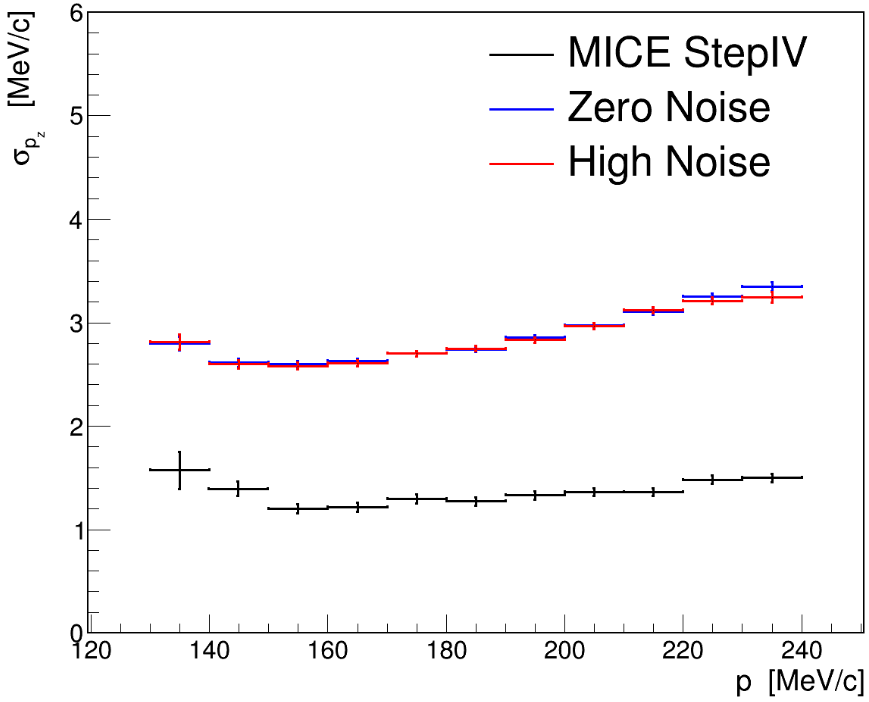


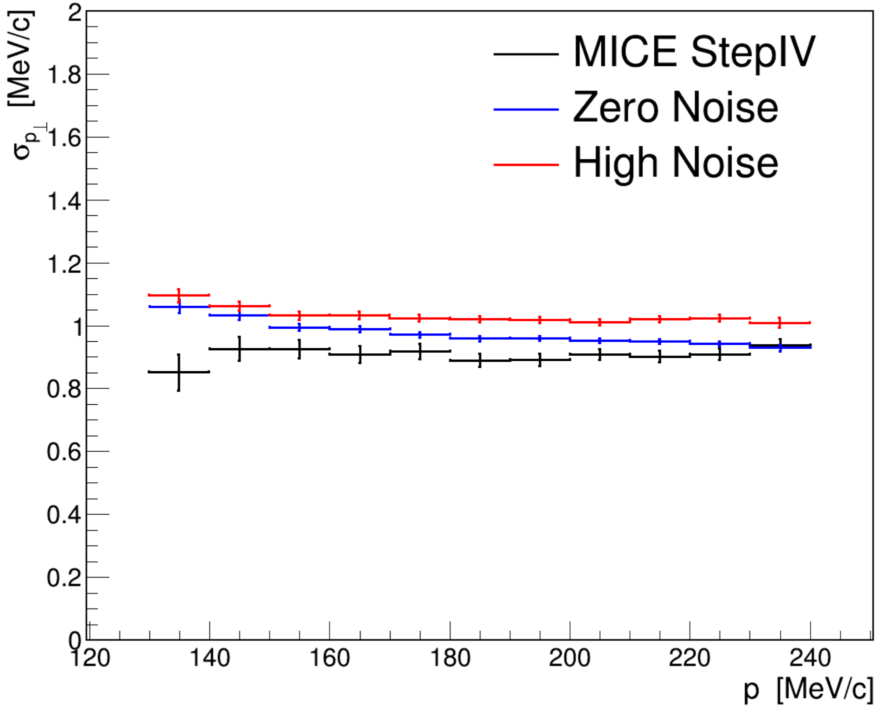
Electrons are stopped by secondary absorbers. Only need to model photon-induced noise.

Reconstruction Performance

No changes made to existing reconstruction.
Momentum calculated from EMR and propagated to the tracker.

(High Noise = 3x Expected Photon Rate)





Expectations from Simulations

- Currently predict $\Delta\varepsilon_{4D}$ ~ 6.3% for nominal 6mm beam using Baseline Lattice

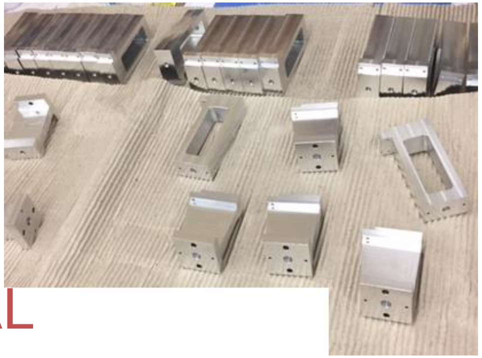
- Dealing with systematic error correction for Step IV so should not be a concern.

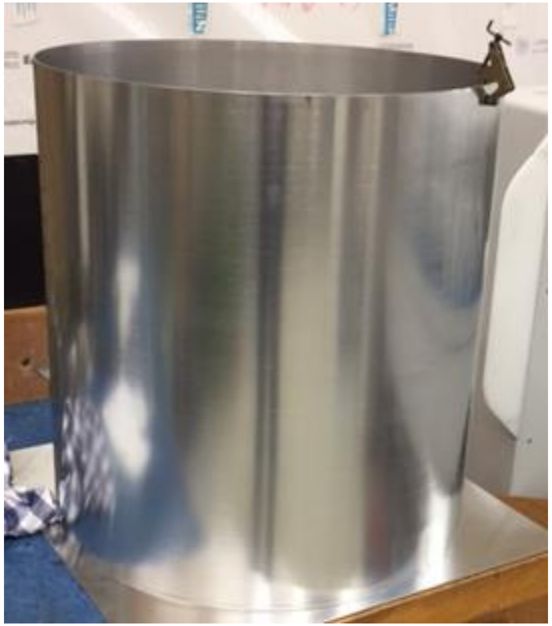
- Optimisations are still possible:
  - Moving the upstream secondary absorber
  - Further magnetic setting optimisation

- An easy as Step IV but with RF acceleration

Hardware: Compact Tracker

- Tracker constructed by Nikhef (simple modular design).

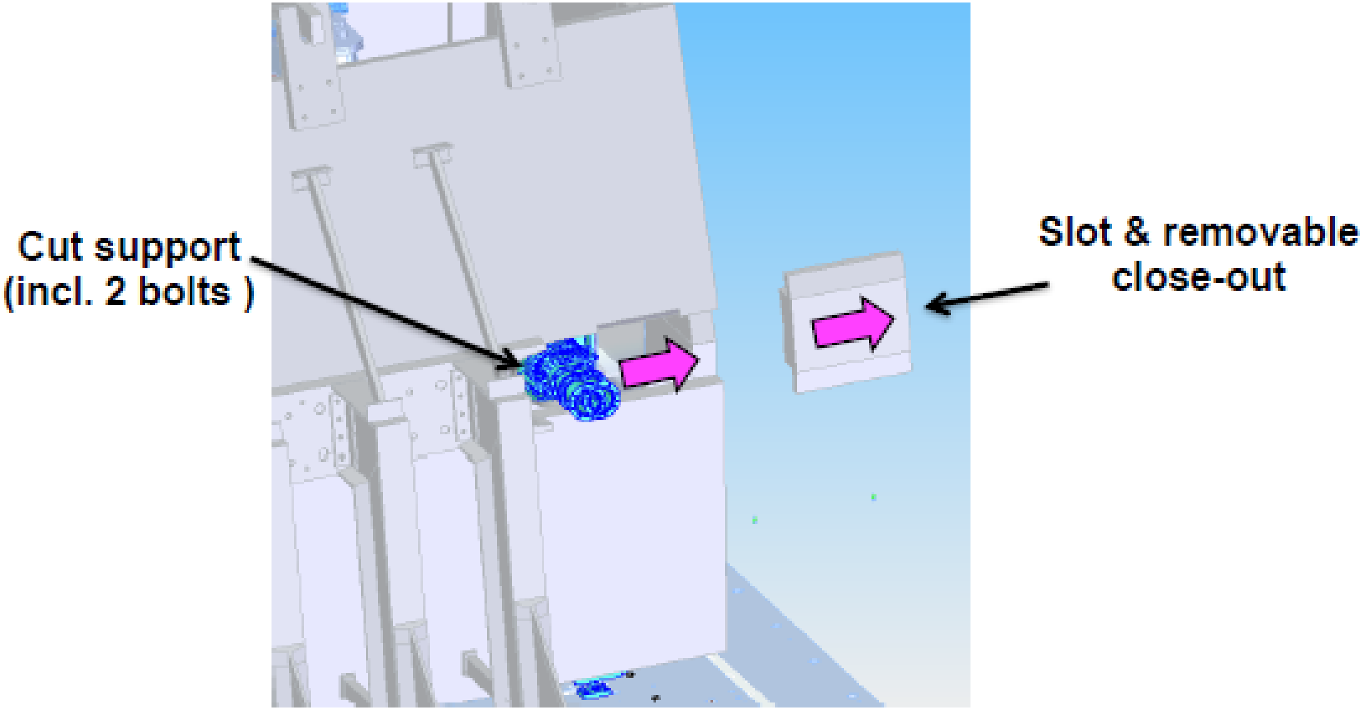




- Module to be assembled in RAL
- Key Requirements:
  - Primarily to measure geometric components: $\frac{p_x}{p_z}, \frac{p_y}{p_z}$
  - Must be short - rapidly divergent beam
  - Relies on EMR for total momentum reconstruction
  - Existing stations identical to those in Step IV
  - No helium system required and no vacuum interfaces

Hardware: Return Yoke

- Step IV yoke reused
  - U/S Cavity module can be removed by cut-out for Step IV FC
  - D/S Cavity module: access via the D/S yoke end
  - Cut-outs to allow RF coupler to slide into position

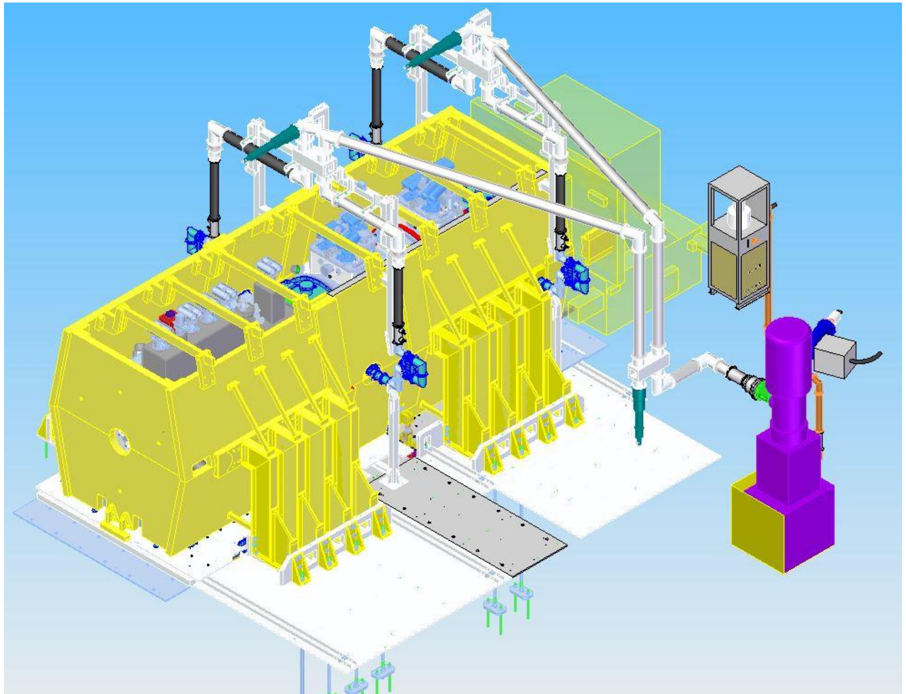


Hardware: RF Overview

- Propose to use ONE RF drive amplifier
  - Save cost, time and risk
  - Amplifier has already operated at MICE
  - Much work already done on remote control
    - Some work required to complete
  - Provides ~7.2MV/m acceleration
- Since last MBP RF work has been limited by approval only to Step IV
  - Some progress prior to the halt decision, some progress under risk mitigation
  - LLRF progress has continued as ISIS undertaking
    - Possible to realise benefit for MICE RF

Hardware: RF Distribution

- Single amplifier- will use 3 hybrids
- Viewgraph shows reasonable configuration
    - One hybrid on the shield wall
    - Phase may be set by a delay line in one arm
    - Laid along the length of the shield wall as ‘dogleg’
    - Little change to configuration from shield wall to cavities



Hardware: RF Drive

- RF Drive system has been subject to tests at Daresbury
  - Largely to test amplifier no 2 for original Demo experiment
  - 1MW achieved, but glitches observed when pre-amplifier > 50kW
    - Reported last MPB
  - Probably due to arc‘ing in second triode input circuit
  - This has NOT been dismantled for inspection SINCE:
    - We do not plan to use it in the current upgrade plan
    - It works well enough to shakedown the remote controls
    - Additional delay in controls development would incur if the amplifier were stripped

Hardware: RF Diagnostics

- Measurement of muon transit phase continued (PhD project)
- Subsample method reconstructing signals from MTA tests
  - Walks in systematic offset now understood
    - Due to walks in the RF drive frequency
    - Processing system refined to auto-compensate
    - Systematic offsets now ~5 ps with random variations ~10 ps
  - Most hardware in hand (40MHz precision clock required)
- RF monitoring system defined by Daresbury lab
  - Reported last MPB
  - Vast majority of procurement complete

Cost and Schedule

- At present this is represents statement of interest and intent
  - Can rapidly become a proposal
- Potential timetable- if approved
  - Commence installation end October
  - Operational for ISIS 2018/02: Sept ’18
  - ISIS long shutdown 2020 or later
    - No risk of running into this timetable
  - Data taking complete end FY ‘18/19
  - Physics Analysis to follow in 2019
- Cost to complete build and take data ~ £3M
- Potential to accelerate preparations in summer shutdown ‘17

Summary

- Predictions show a 6% reduction in ~ 6mm beam
  - Reduces to 4% with plastic 2nd absorbers
  - Measureable effect (10 x systematic error, 100 x statistical error), good transmission
  - Options to enhance transmission and performance further

- One RF amplifier- 800kW to each cavity, 7.2MV/m
  - Means MTA tests are very vigorous derisking (nearly twice gradient)

- Substantial reduction in risk of equipment availability
  - All major RF and magnet equipment in hand
  - Some additional control, clock and diagnostic work required
  - Yoke can be re-used from STEP IV
  - LLRF, muon timing diagnostics developed in parallel

- Demonstrate viability of sustained ionisation cooling