U.S. DEPARTMENT OF ENERGY | Office of Science

Responding to P5: The Muon Accelerator Program

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Outline

- **A brief and selective history of muon cooling and acceleration research**
- **The P5 recommendation on muon acceleration research**
- **The HEP response to P5**
- **Results of the review**

Muon Accelerator Research

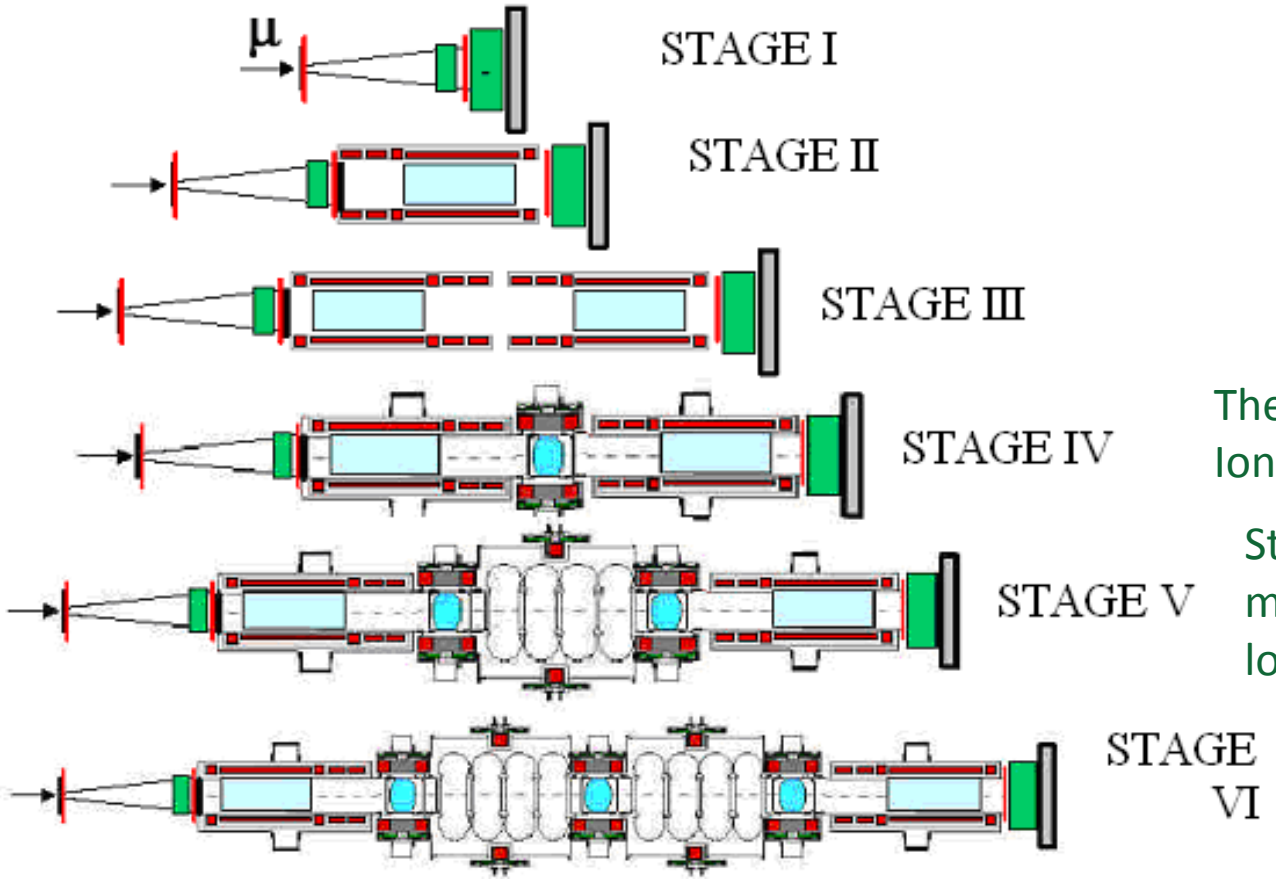
- **HEP began supporting research on muon accelerator concepts in the late 1990s.**
- **Neutrino Factory and Muon Collider Collaboration became formal entity at Orcas Island meeting (≈100 scientists and engineers) in May 1997**
  - requested funding from DOE
- **A Neutrino Factory uses stored muons to produce intense and neutrino beams with precisely known mixture of neutrinos.**
- **A Muon Collider is an lepton collider with much smaller synchrotron radiation losses than an circular e^+e^-**
  - Can produce s-channel Higgs bosons.
- **A major experimental effort is the Muon Ionization Cooling Experiment (MICE).**

Muon Ionization Cooling Experiment

- **Researchers desired to test their ideas on muon cooling.**
  - proposal submitted to RAL in January, 2003
  - international review held February, 2003
    - (recommended approval)
  - scientific approval from RAL in October, 2003
  - estimated hardware cost is £11M (total cost £25M)
- **Half of the funding would be from the UK.**
- **Dominantly a US-UK effort with some participation from other European countries and Japan.**
- **Cooling demonstration aims:**
  - to design, engineer, and build a section of cooling channel capable of giving the desired performance for a Neutrino Factory
  - to place this apparatus in a muon beam and measure its performance in a variety of modes of operation and beam conditions

Material from a presentation by M. Zisman to HEP in 9/2005

MICE Steps



There is a absorber to produce Ionization losses in Step IV

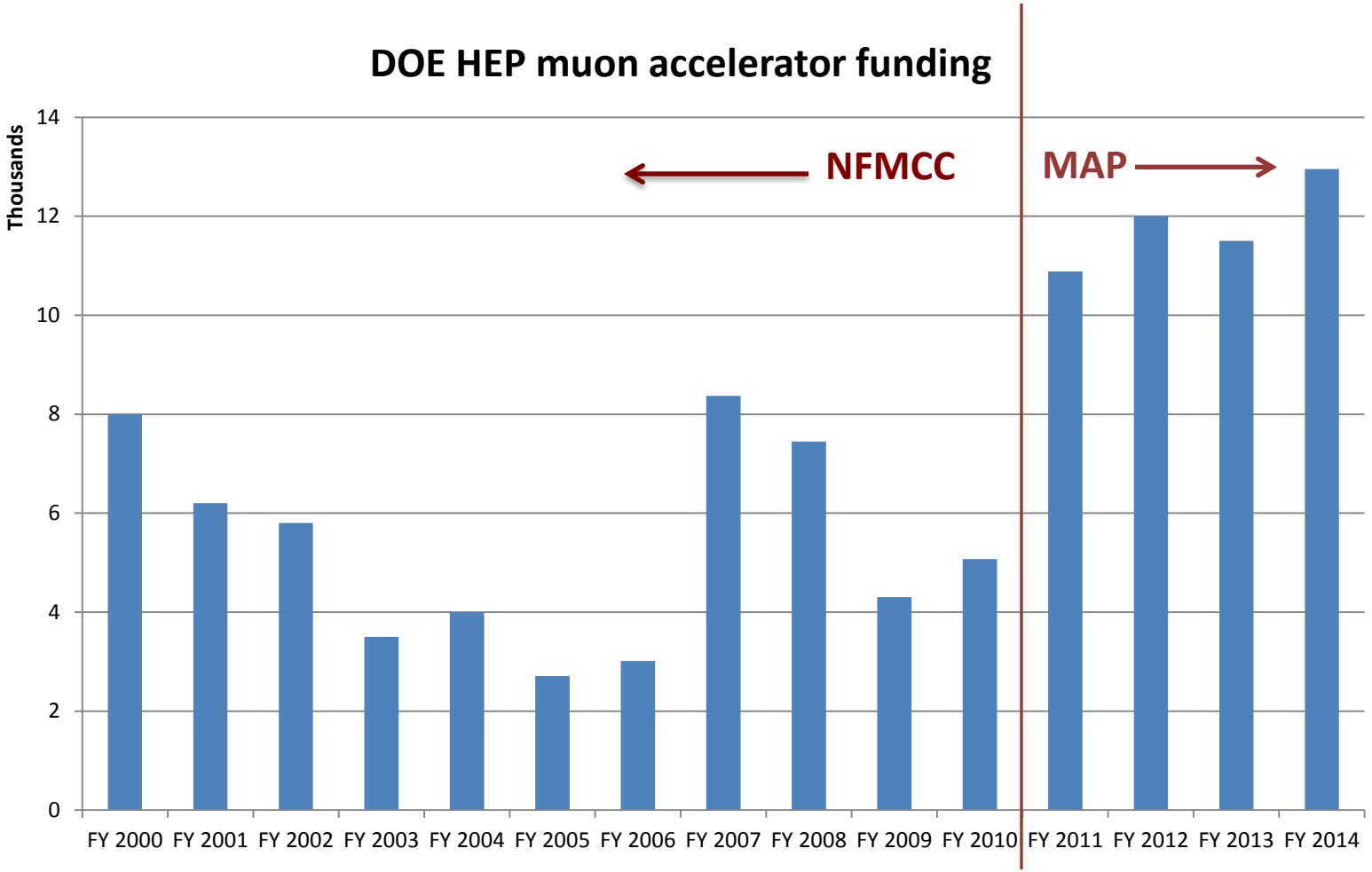
Step V reaccelerates the muon beam restoring lost longitudinal momentum.

- **From the MICE TDR**
- **Stages are called Steps.**

MAP

- **In 2010, HEP reviewed the various muon acceleration efforts including MICE.**
  - Conclusion the effort needed more funding and more organization.
- **In FY 2011, the MAP program was formed to make the effort more focused on demonstrating that the fundamental technology challenges could be solved.**
  - Very high field magnets
    - 50 Tesla solenoids were once considered necessary
    - Later it was shown that 30 Tesla solenoids could do the job.
  - Operating RF cavities in magnetic fields
  - Develop new cooling designs and vet them with detailed simulations.
  - Pick up the US obligations to MICE.
- **Management of MAP was assigned to Fermilab**
  - Fermilab hired Mark Palmer to manage MAP.

Funding History



Funding was increased with MAP, but never reached the levels requested by MAP management.

The P5 Recommendation

"Recommendation 25: Reassess the Muon Accelerator Program (MAP). Incorporate into the GARD program the MAP activities that are of general importance to accelerator R&D, and consult with international partners on the early termination of MICE."

P5's Reasoning

- P5 based their recommendation on physics arguments and not on an evaluation of the quality of the work being done.
- The large value of $\sin^2(2\theta_{13})$ enables the next generation of oscillation experiments to use conventional neutrino beams, pushing the time frame when neutrino factories might be needed further into the future.
- The small Higgs mass enables study at more technically ready e^+e^- colliders, reducing the near-term necessity of muon colliders.

HEP Response

- **MICE is an international effort that we could not unilaterally withdrawal from.**
- **Consulted with the Science and Technology Facilities Council (STFC)**
  - Funding agency for Rutherford Appleton Laboratory the home of MICE.
  - STFC has made substantial investment in MICA along with the US.
  - Expressed a desire to see Step V completed.
- **Produced a completion funding profile for MICE**
  - Ramps down over three years and spend ½ of constant level.
    - FY 15: $9 M, FY 16: $6 M, FY 17: $3 M.

Review Charge: MICE elements

- **The status and future plans for the MICE experiment as well as MAP interactions with international collaborators. Elements of this evaluation should include:**
  - A review of the detailed resource loaded plan for achieving all deliverables to MICE at the Rutherford-Appleton Laboratory (RAL);
  - Consideration of a number of funding profiles including those of other partners to achieve Step IV and/or Step V of the MICE experiment;
  - An assessment of the availability of the required expert personnel to accomplish these goals;
  - An assessment of whether the milestones provided domestically and by MICE partners for hardware assembly, testing, and delivery are suitable for tracking progress in this plan;
  - A discussion of any technical challenges that might be expected for designed but not yet constructed technical components;
  - An evaluation of risk both technically and financial and the contingency considerations for the construction, installation, commissioning and experimental activities;
  - An evaluation of what threshold would constitute a successful conclusion of the MICE effort.

Review Charge: Transfer to GARD

- **Plans being presented for the orderly continuation, transfer or termination of other core MAP activities such as:**
  - Design studies and simulations of the accelerator systems required for intense sources of neutrinos and cold muons;
  - Design studies and simulations for muon collider capabilities
  - The study of the operation of RF cavities in strong magnetic fields as part of the experimental program in the MuCool Test Area (MTA) experimental facility at Fermilab;
  - Technology R&D and demonstration efforts for high power proton targets, pion capture systems, muon cooling, high field magnets, rapid cycling magnets, and superconducting RF.

Review Committee

An International Committee of Accelerator and Management experts

- **Dr. Howard Gordon – Brookhaven National Laboratory**
- **Dr. Leigh Harwood – Thomas Jefferson National Accelerator Facility**
- **Dr. Erk Jensen – CERN**
- **Mr. David McGinnis – European Spallation Neutron Source**
- **Prof. Ian Robson – STFC-UK**
- **Mr. Claus Rode – Thomas Jefferson National Accelerator Facility**
- **Prof. Mike Syphers – FRIB / Michigan State University**
- **Mr. Thomas Taylor – CERN**
- **Prof. Mark Thomson – Cambridge University**
- **Dr. Bruce Strauss – DOE and Chair of the committee**

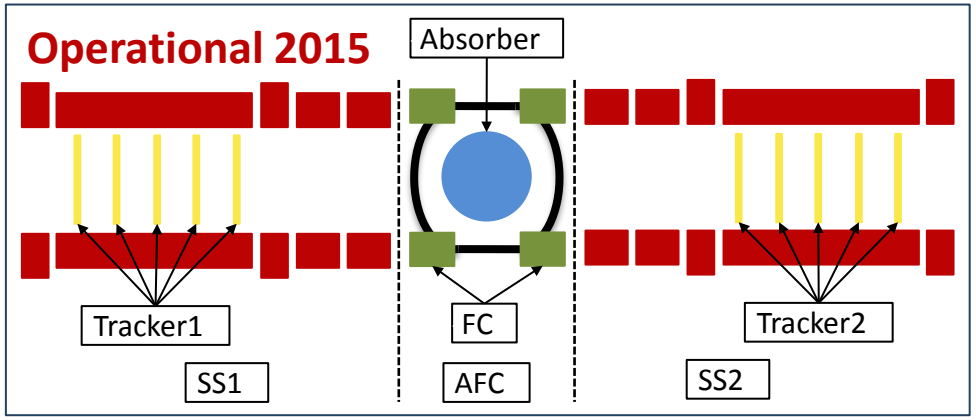
Agency Observers

- **Ms. Charlotte Jamieson – STFC-UK**
- **Dr. LK Len – DOE-OHEP**
- **Dr. Michael Procario – DOE-OHEP**

Results

- **The committee did not recommend that any activities be transferred to HEP General Accelerator R&D.**
- **The committee believed that Step IV was easily achievable with the given profile.**
- **The committee found that there were significant risks to achieving Step V with the given profile.**
- **On the last day of the review, the MAP team presented a new option that they dubbed Step π.**
  - The committee dubbed it Step 3π/2, since it seemed fall between Steps IV and V.

Step IV



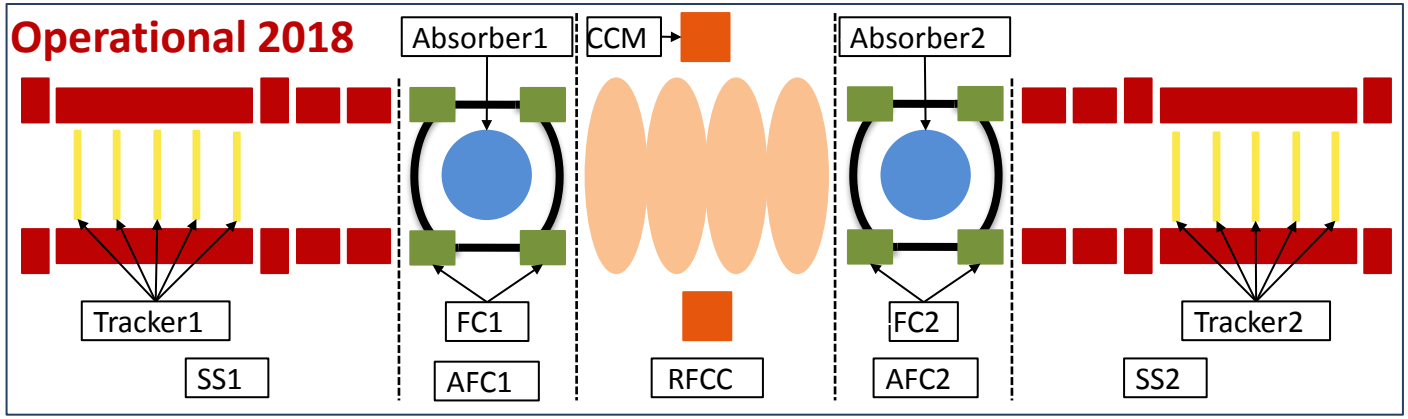
Legend:

SS	=	Spectrometer Solenoid
FC	=	Focus Coil
AFC	=	Absorber-Focus Coil Module
CCM	=	Coupling Coil Magnet
RFCC	=	RF-Coupling Coil Module

MICE Step IV Configuration

- **Features two spectrometers to measure the input and output muons.**
  - Muons are measured individually
- **There is an absorber between them.**
- **Step IV measures energy loss and momentum change due to absorber.**

Step V

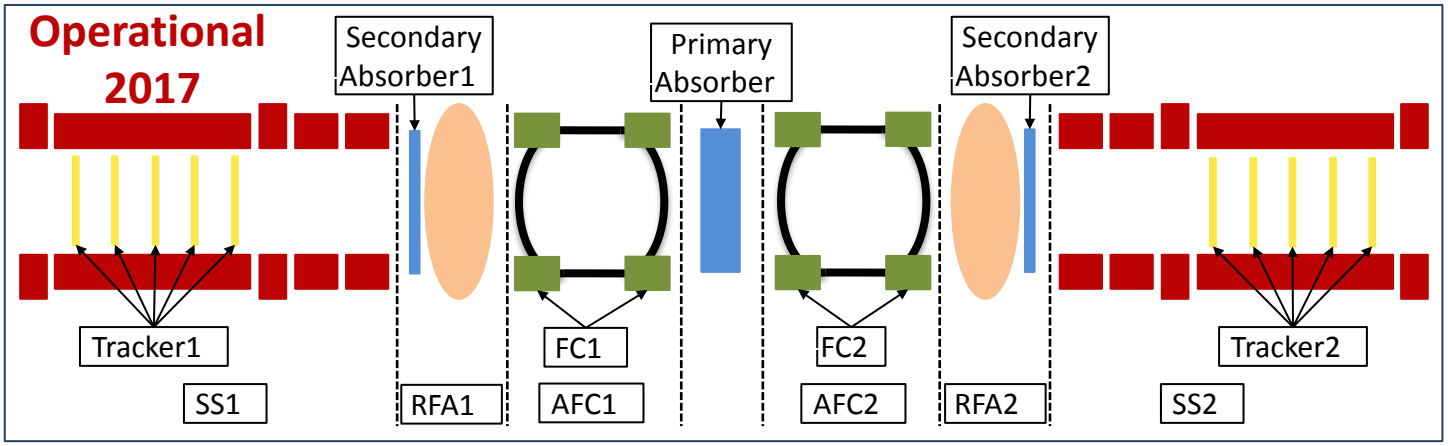


MICE Step V Configuration

- **Adds another absorber in a solenoid.**
- **Add RF cavities in a solenoid to restore the lost longitudinal momentum.**
- **Still measures individual muons**
- **The spectrometers are capable of measuring change in emittance with better than 1% accuracy.**
  - It may achieve 0.1% accuracy.

Step 3π/2

Represents reduced cost and technical risk relative to MICE Step V



NEW Expedited MICE Final Configuration

- **RF cavities have performed better than the original design, so fewer can be used.**
- **Cavities sit next to the solenoids, which is the exact configuration tested at Fermilab Muon Test Area.**
- **The RFCC is not needed, which reduces risk. It has not yet been shown to work.**
- **Reduces the need for magnetic shielding at RAL. Saves time and money.**
- **This configuration looks more like current muon cooling channel designs.**

Conclusion

- **The committee recommended that the MAP team go and complete the plan to implement Step 3π/2.**
- **Our review report has been completed.**
- **MAP has submitted a draft plan that confirms what was said at the review.**
  - The are fleshing it out with more milestones for tracking.
- **HEP plans to support the completion of the *Expedited MICE Final Configuration***
  - No one may call it Step 3π/2 again.
- **We have continued to consult with STFC as we have completed the report and they are satisfied with the results.**