Systems Tests: Overview & Resources

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Muon Accelerator Program Review

Fermilab, 24–26 August 2010

Outline

- System Tests (past, present, & future)
- Task Organization
- More on Ionization Cooling
- MICE
- 6D Experiment
- Resources

Systems Tests

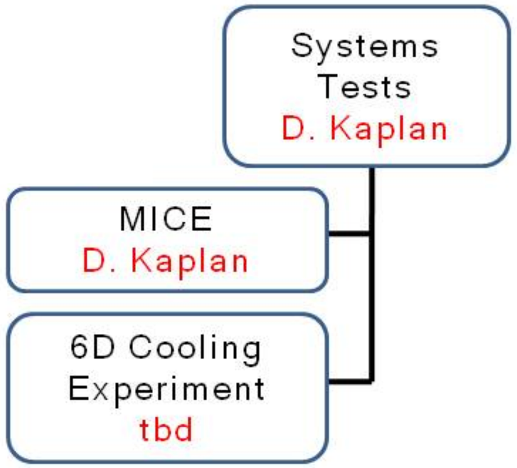
- Goals:
  - Demonstrate feasibility and performance of muon ionization cooling by building and testing actual sections of cooling channels
  - Validate Monte Carlo models
  - Understand performance well enough to reliably extrapolate cost of muon cooling for MC or NF

Syst. Tests Org Chart

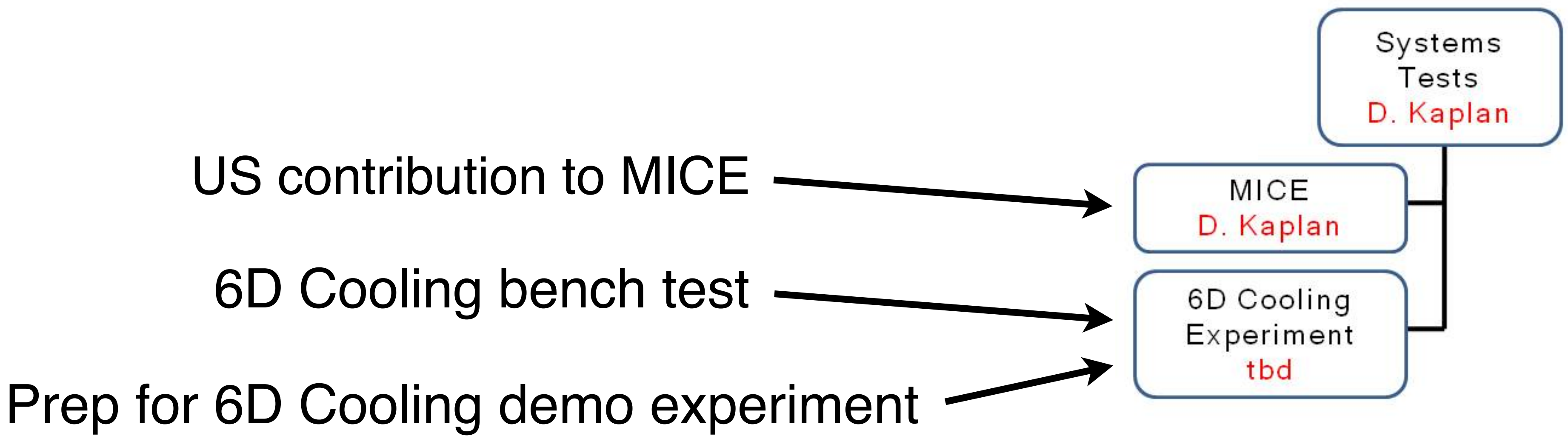
US contribution to MICE

6D Cooling bench test

Prep for 6D Cooling demo experiment



Syst. Tests Org Chart



- Note: I recently took over from A. Jansson

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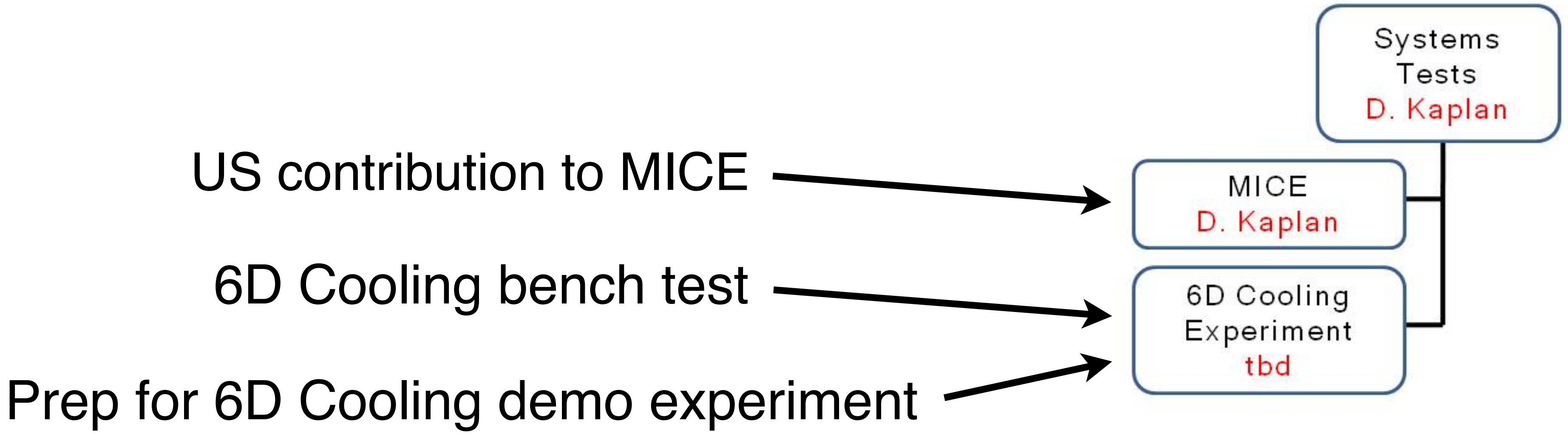

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  (he's here to answer any hard questions! ;-)

Systems Tests

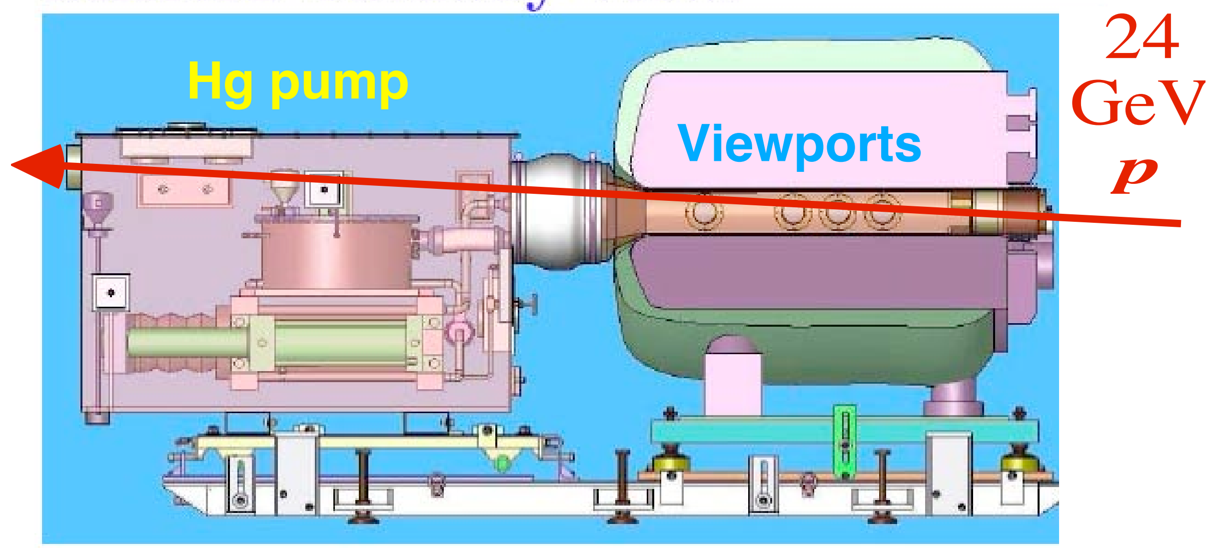
- NFMCC has already completed a successful system test:
  - MERIT (MERcury Intense Target)
  - NF/MC require ~4 MW proton beam on target
    - would destroy almost any solid target
    - is mercury jet feasible?
    - answer: YES!

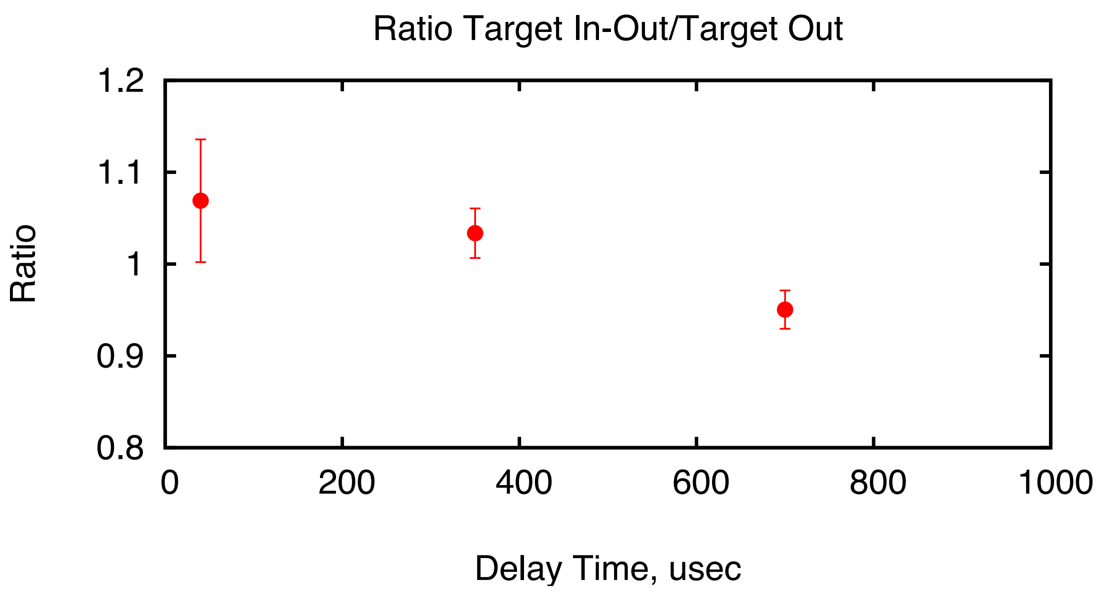
MERIT

- Experiment carried out @ CERN nTOF facility in 2007
- BNL/CERN/KEK/ORNL/ Princeton collaboration
  - Hg jet, 1 cm diam, 20 m/s, jet axis at 33 mrad to magnet axis (B ≤ 15 T)
  - concept demonstrated workable up to ≈8 MW

[K. McDonald et al., IPAC'10]

MERIT cutaway view:





Ionization Cooling

- Two* general types of ionization cooling:
  - transverse
    - tested in MICE
  - 6D (combination of transverse cooling & emittance exchange)
    - to be tested in 6D experiment to be designed
    - initial test planned as part of MICE

*3rd type, frictional – seems impractical for high-$\mathcal{L}$ collider (not part of MAP)

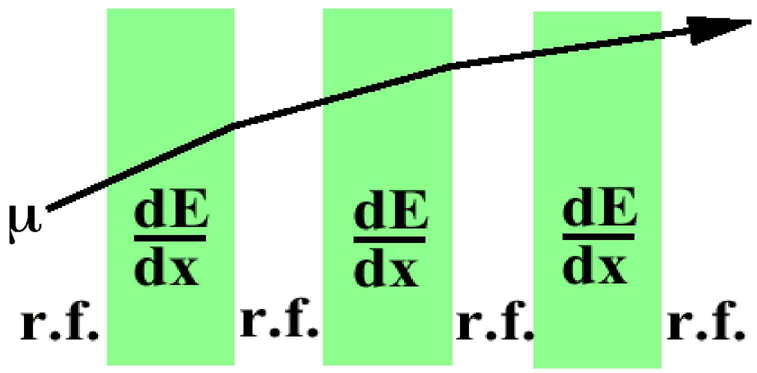
Ionization Cooling

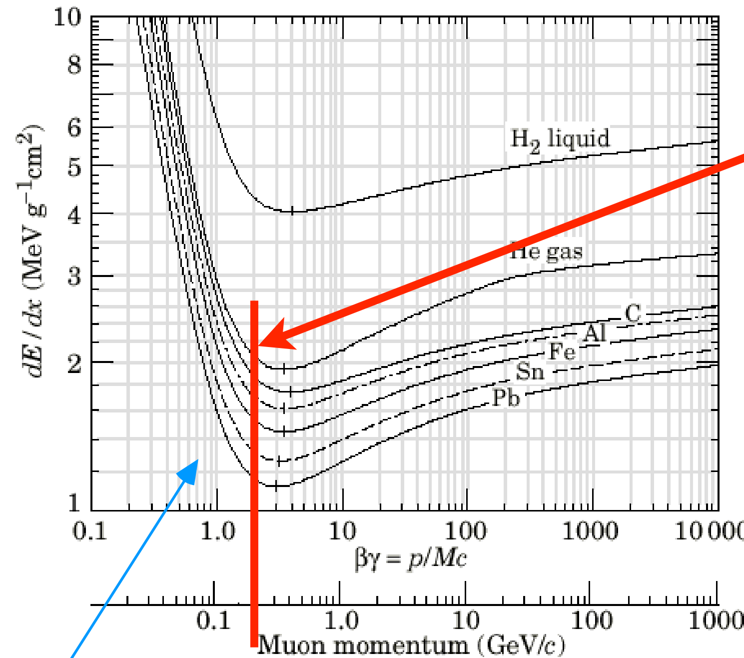
Reminder:

Ionization Cooling

Reminder:

- Muons cool via dE/dx in low-Z medium





- ionization minimum is ≈ optimal working point

  - Absorbers:

$$\begin{cases} E \rightarrow E - \left\langle \dfrac{dE}{dx} \right\rangle \Delta s \\ \theta \rightarrow \theta + \theta^{rms}_{space} \end{cases}$$

ionization energy loss

multiple Coulomb scattering

- 2 competing effects ⇒ ∃ equilibrium emittance

  - RF cavities between absorbers replace ΔE
  - Net effect: reduction in $p_\perp$ at constant $p_\parallel$, i.e., transverse cooling

$$\frac{d\epsilon_N}{ds} = -\frac{1}{\beta^2}\left\langle\frac{dE_\mu}{ds}\right\rangle\frac{\epsilon_N}{E_\mu} + \frac{\beta_\perp (0.014\ \mathrm{GeV})^2}{2\beta^3 E_\mu m_\mu X_0}$$

(emittance change per unit length)

- Only efficient way to cool within muon lifetime

Ionization Cooling

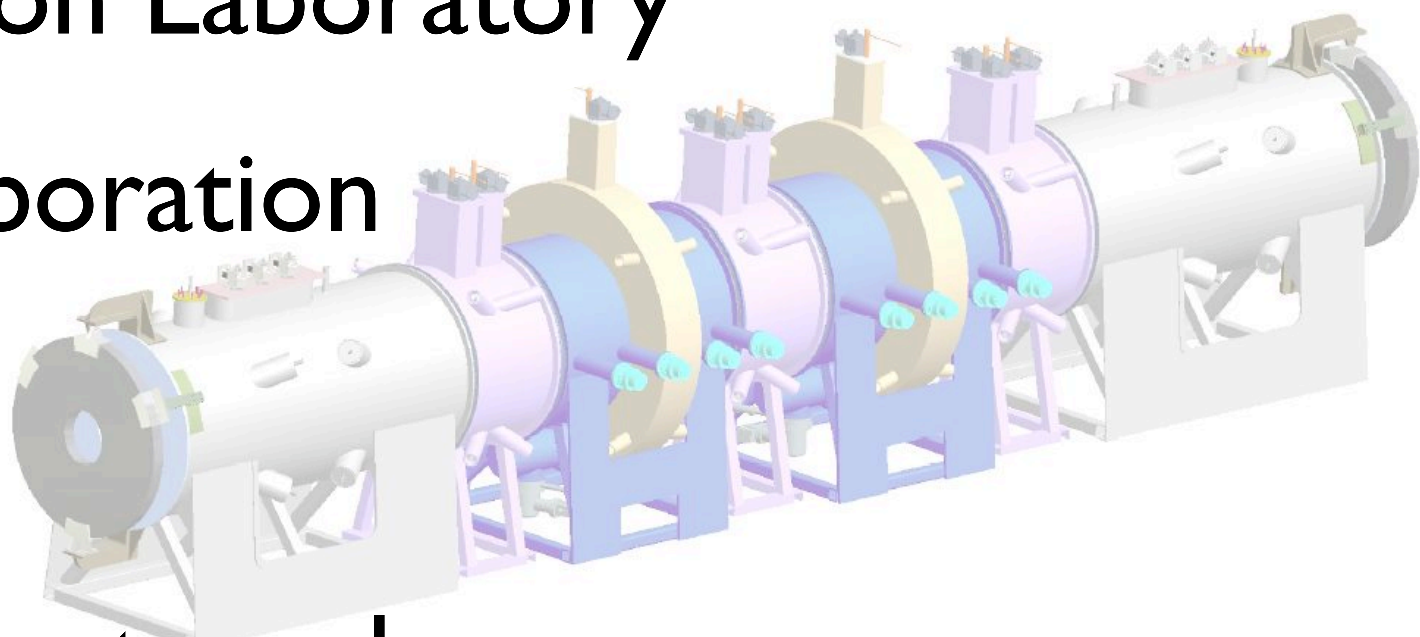
- Important: dE/dx cooling mechanism is inherently transverse
  - reduces momentum in all 3 spatial directions while acceleration replaces only p_z

    $\Rightarrow$ cools only beam divergence
  - variable focusing couples this to transverse beam area

    $\rightarrow$ 4D transverse cooling
- Demonstration in progress (MICE)

MICE

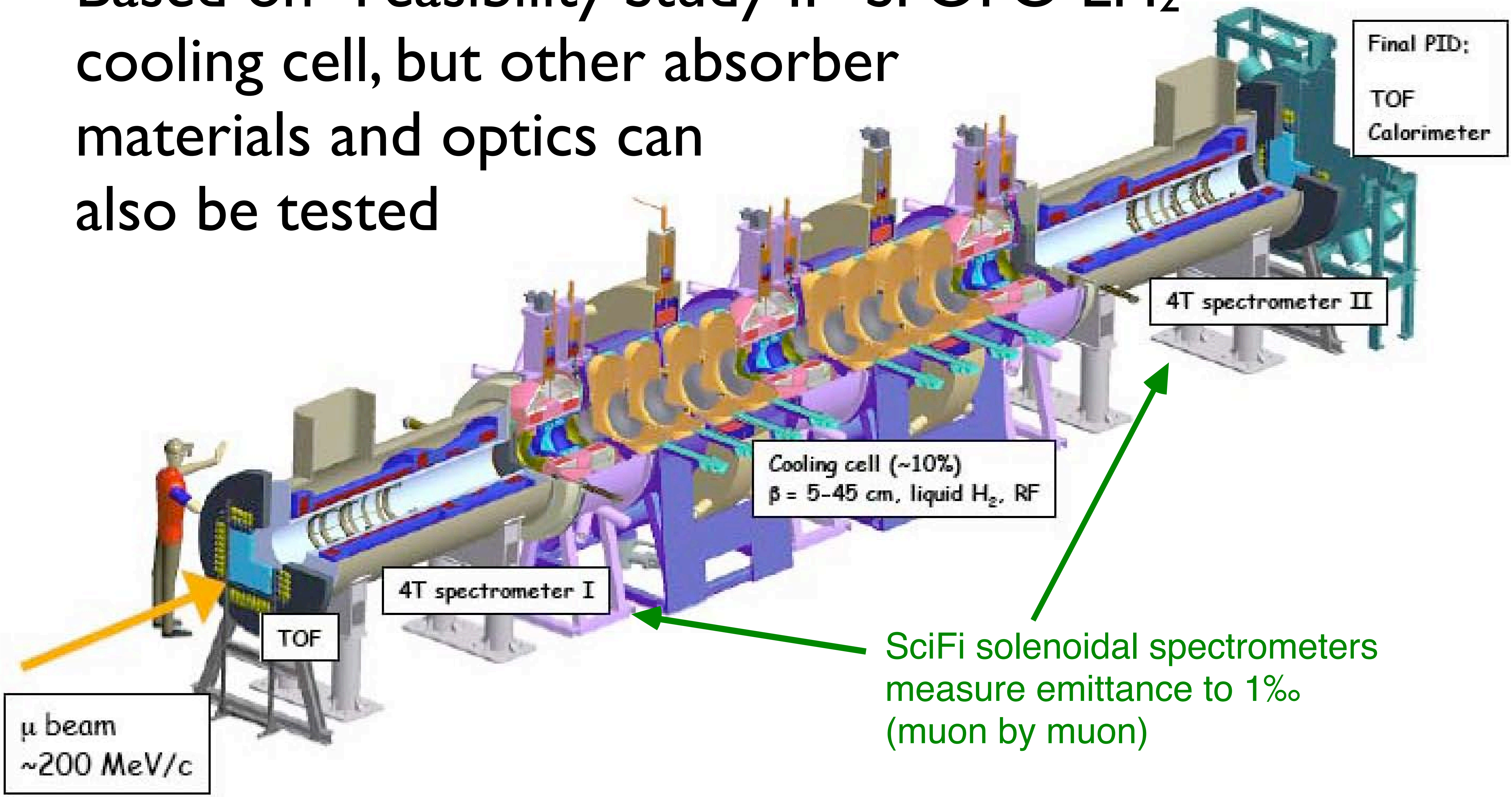
- Muon Ionization Cooling Experiment at UK's Rutherford Appleton Laboratory
- International collaboration
- MAP institutions building key hardware components and participating in commissioning and integration



- Also participating in running and data analysis
  - with NSF support for postdoc, student participation

MICE

- Based on "Feasibility Study II" SFOFO LH_2 cooling cell, but other absorber materials and optics can also be tested



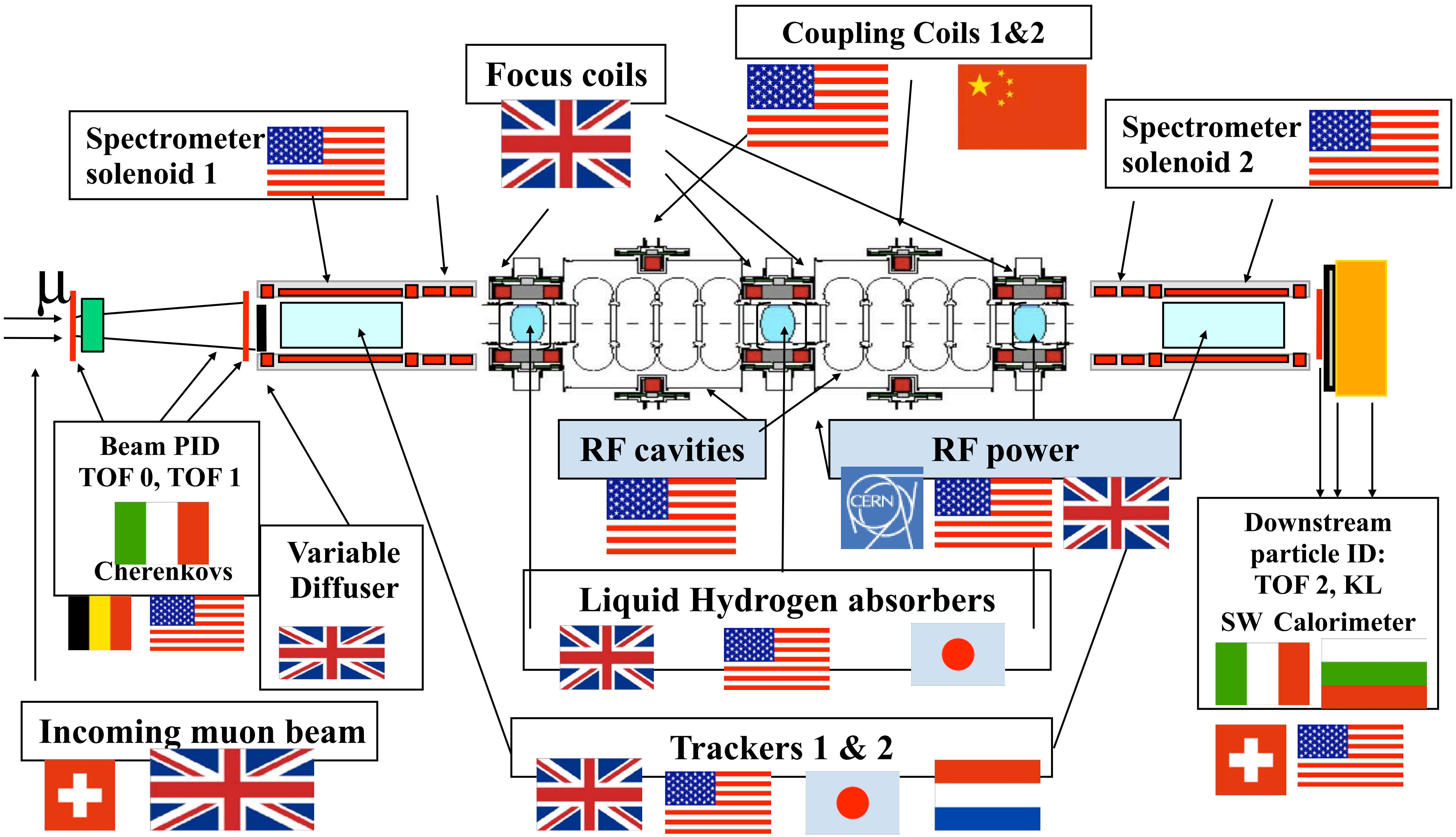
Principles of MICE

- Build as long a cooling channel as we can fund
  - 1 complete lattice cell → ≈10% cooling effect
- Measure emittance with 0.1% precision
  - allows even small cooling effects near equilibrium emittance to be well measured

  ⇒ need to measure muon beam 1 muon at a time
- Vary all parameters to explore full performance range, validate simulation tools

MICE

- Participating countries:



US MICE deliverables

- Done:
  - Assembly of scintillating-fiber planes (15) for fiber-tracking spectrometers
  - AFE-IIt readout boards, VLPCs, and VLDS interface modules for fiber tracking readout
  - Design, fabrication, and commissioning of VLPC cryostats (4) for fiber tracking spectrometers
  - Fiber-tracking readout system integration and commissioning
  - Fabrication, installation, and commissioning of two Cherenkov counters
  - Scintillating-fiber beam position/profile monitors (4 planes)
  - Beam line optimization
- In progress::
  - Spectrometer solenoids (2), including engineering, fabrication, testing, and field-mapping
  - RFCC modules (2), each comprising 4 rf cavities and 1 coupling coil
  - Design and fabrication of LiH absorbers
  - Participation in MICE operation and analysis

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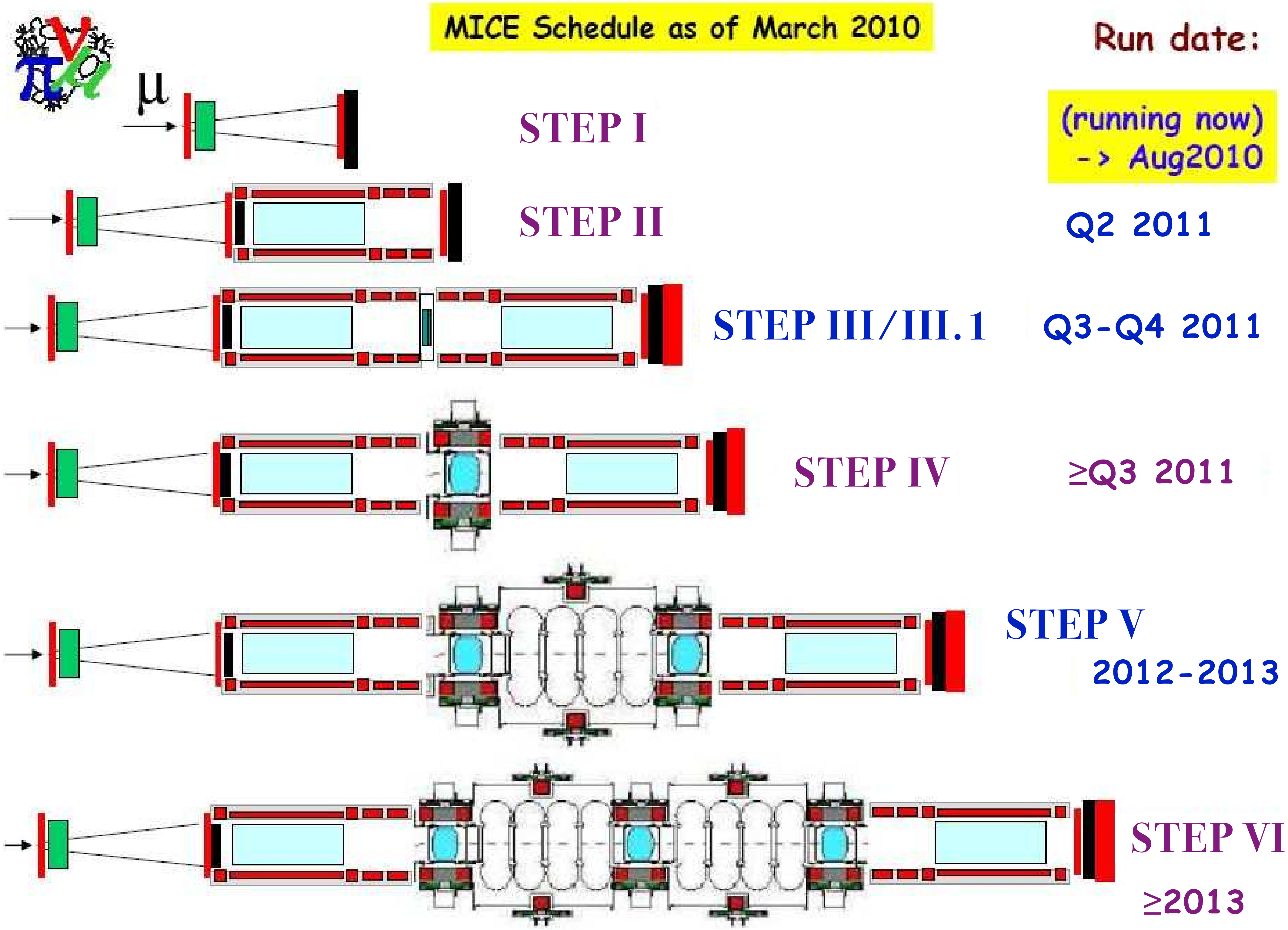
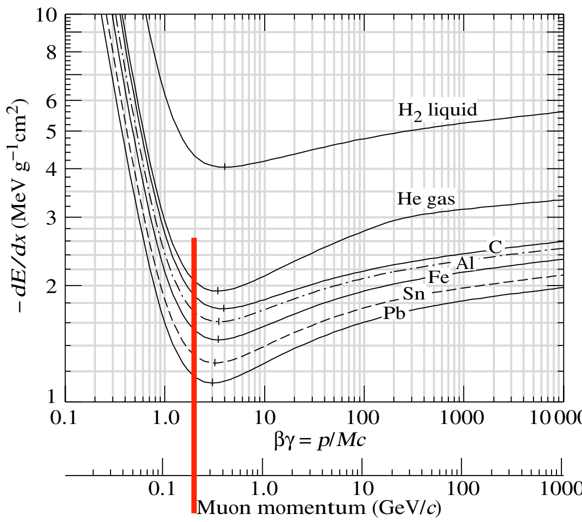
*NSF-supported in whole or in part

MICE Schedule



Longitudinal Cooling?

- Work above ionization minimum to get negative feedback in p_z?



Longitudinal Cooling?

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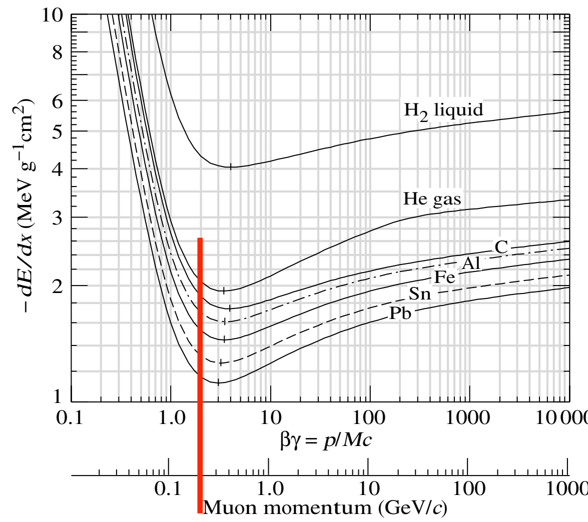
- No – ineffective due to straggling



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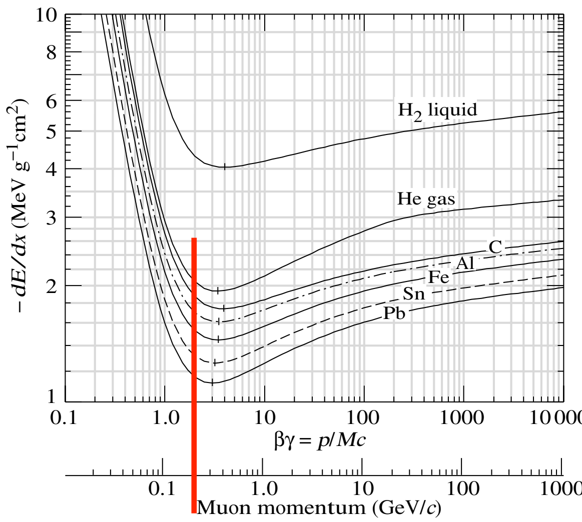
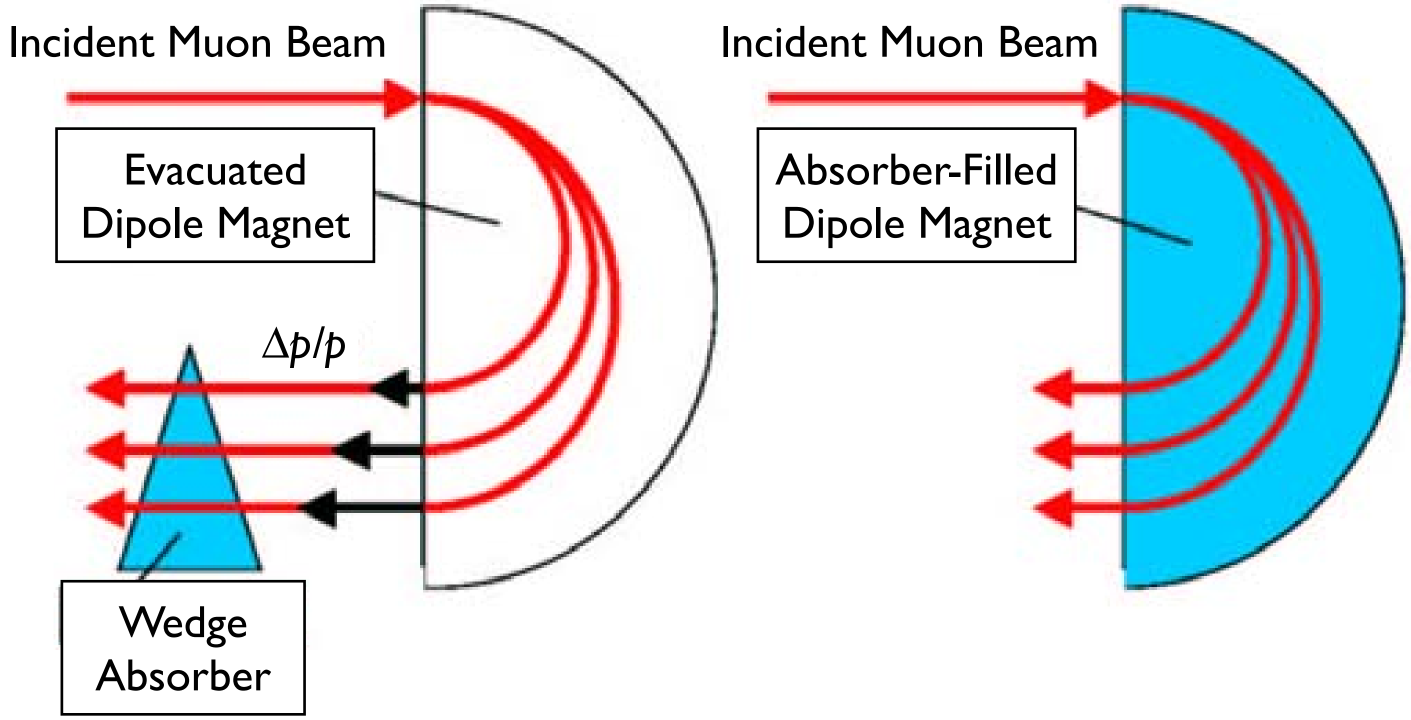


⇒cool longitudinally via *emittance exchange:*



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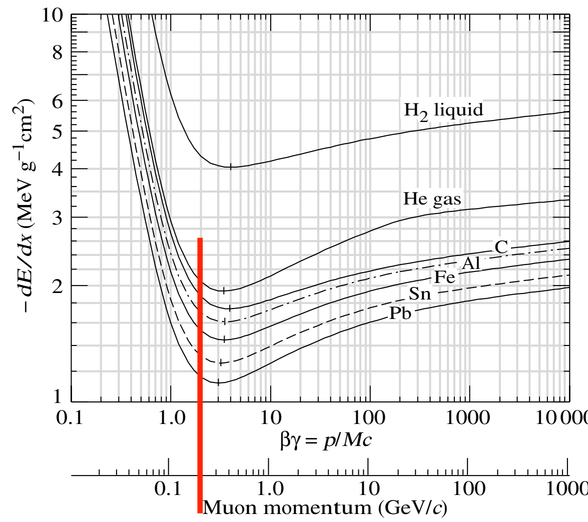

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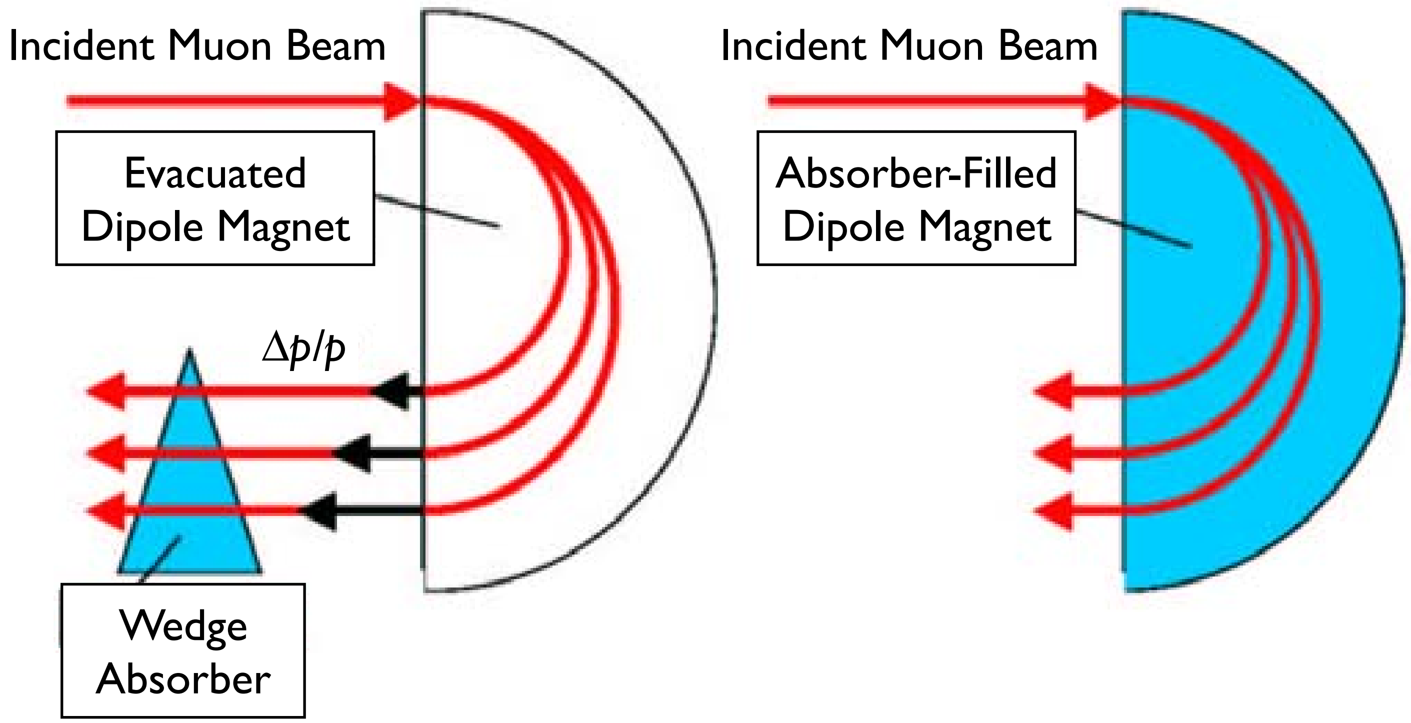
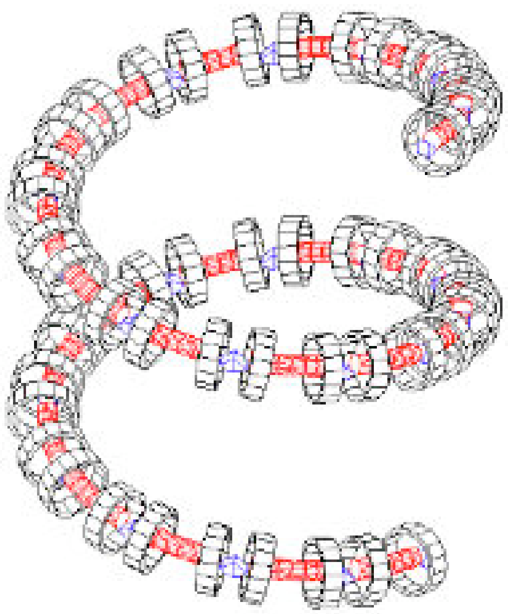


- Cool $\varepsilon_\perp$, exchange $\varepsilon_\perp$ & $\varepsilon_{||}$ → 6D cooling

Longitudinal Cooling?

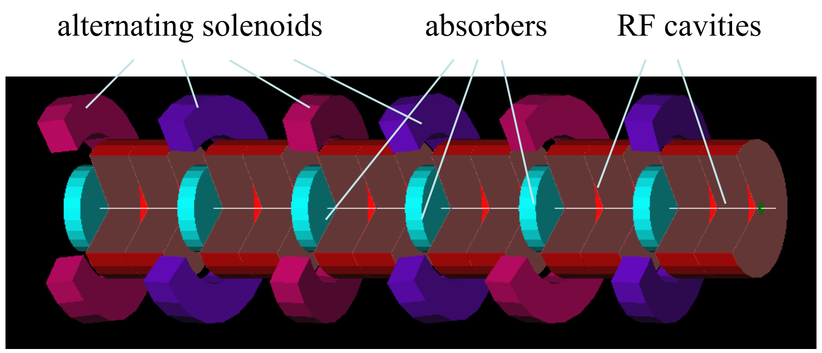
- Tricky beam dynamics: must handle dispersion, angular momentum, nonlinearity, chromaticity, & non-isochronous beam transport
- After >10 years of work, 3 viable 6D solutions:

RFOFO “Guggenheim”



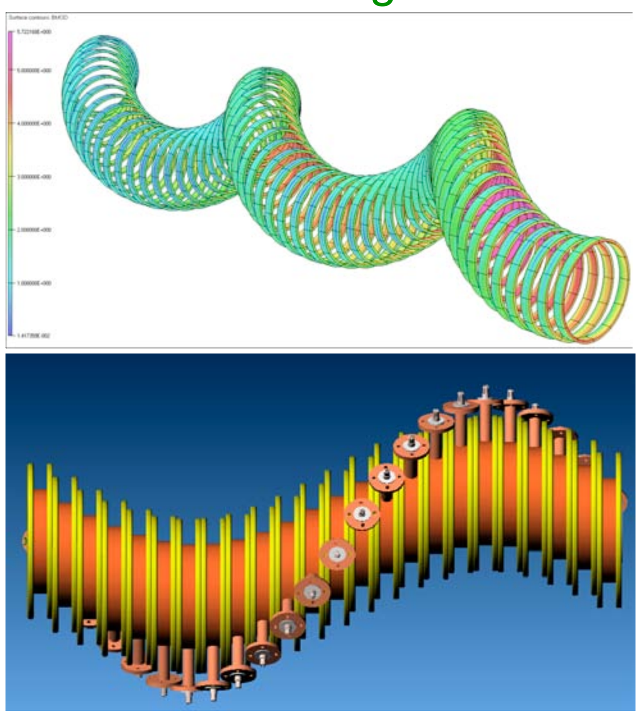
UCR & BNL

FOFO Snake



Y. Alexahin, FNAL

Helical Cooling Channel



Muons, Inc. & FNAL

6D Cooling Expt

- 6D cooling more complex than transverse

  ⇒ some kind of demonstration will be needed
- Difficult to design the experiment in detail before MAP 6D cooling down-selection
  - but can do initial demo of wedge absorber
- MICE completion a deliverable of MAP
- 6D experiment *design* a deliverable of MAP
  - experiment itself is beyond 7-year MAP plan

6D Expt Strategy

- Strategy:
  - Not yet clear whether dedicated 6D expt required
    - maybe MICE + wedge + bench-test will suffice?
  - If expt required, not clear yet what it should be

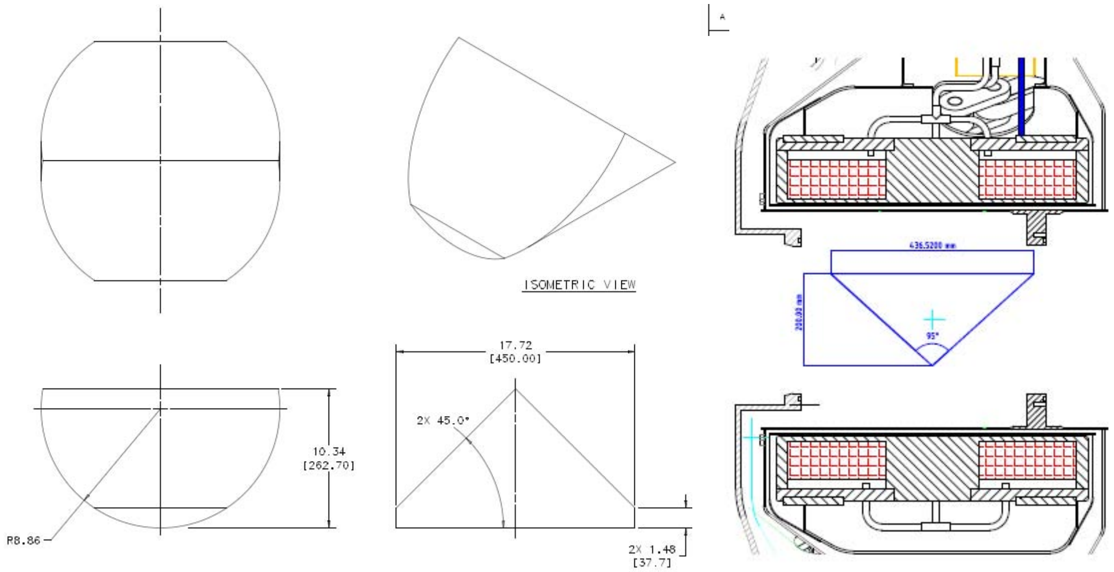
⇒Focus first on developing information needed for 6D-cooling down-selection

⇒Initial system test activity should focus on MICE & understanding 6D bench-test issues

MICE Extensions

- Some aspects of 6D cooling can be tested by inserting wedges in MICE
- Now part of MICE program
  - Studied by MAP collaborators
  - LiH wedge has been ordered

see Snopok talk



6D Demo Strategy

- MICE is both technology demo and beam experiment
- Once MICE demonstrates transverse cooling and emittance exchange, we believe most of remaining 6D-cooling-channel risk is technological (i.e., can we build and operate the channel as designed)

→ Separate 6D cooling bench-test (technology demo) from beam test

6D Demo Strategy

- Bench-tested 6D channel section should be long enough to address key integration issues
  - Cavities should be operated in their design B field
  - Enough components should be installed to verify spatial compatibility of plumbing etc.
- Bench-tested channel section may be different (shorter?) than that needed for a beam test
  - Try to maintain compatibility

6D Demo Strategy

- Experiment design optimization requires
  - Simulations to clarify appropriate cooling-channel performance measures and needed precision
    - best cooling-channel length, beam parameters, and analysis approach
  - Diagnostics/detector study to determine how best to measure the muon beam to required precision
  - Design/integration study to specify and lay out experiment
    - coordinate to ensure bench-test hardware also suitable for beam test
    - find suitable location and design needed muon beam line (unless MICE hall and beam suitable and available)
- Many details undefined until baseline channel selected
  - In the short term, focus on making MICE a success

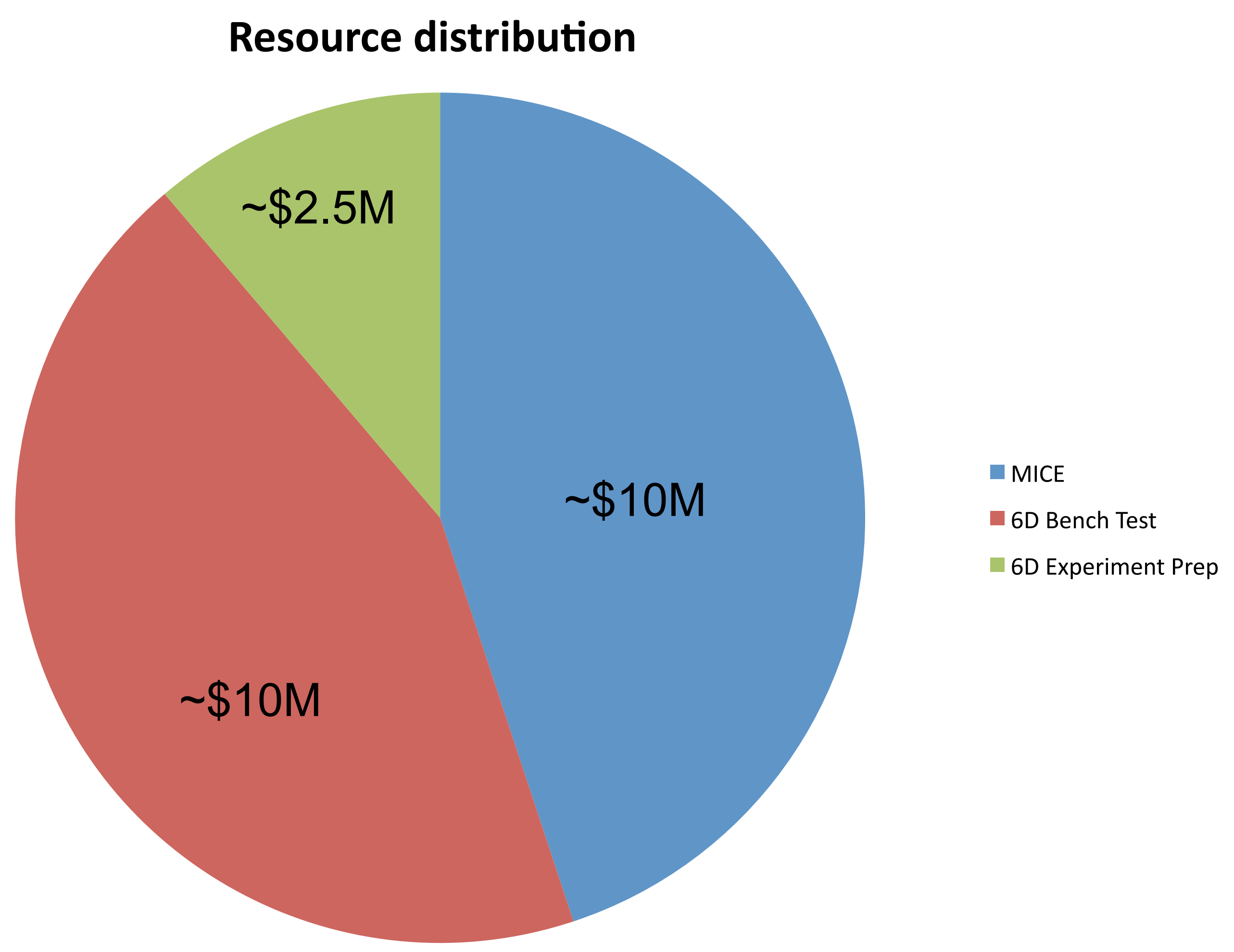
Milestones

Table 2. System test task milestones and deliverables.

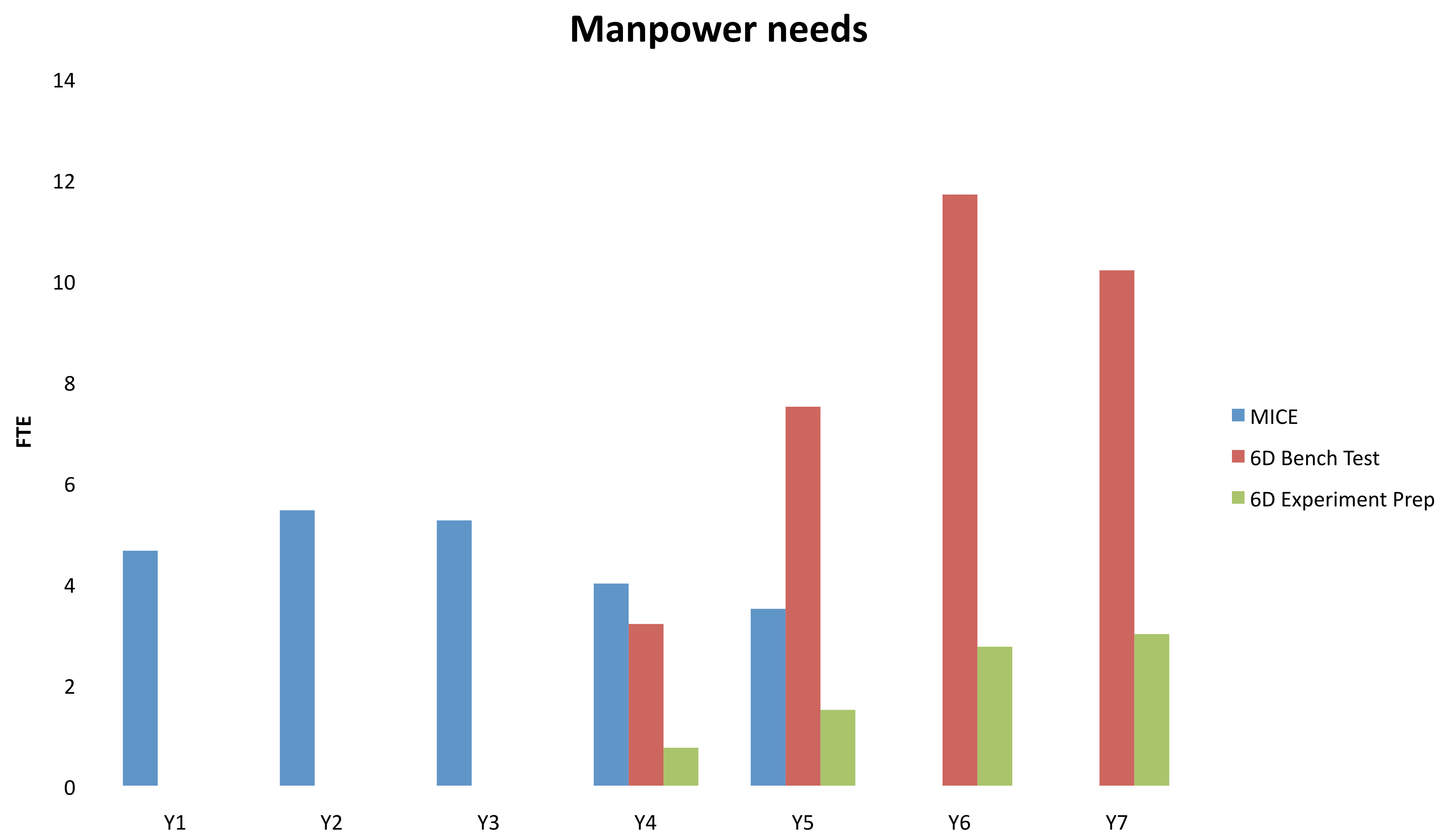
Date	Milestone	Designation	Deliverables[a)]
FY10	Study possible minor extensions to MICE	ST10.1	DR
FY11	Deliver Spectrometer Solenoids to RAL	ST11.1	DR
FY12	Deliver first RFCC module to RAL	ST12.1	DR, MR
FY13	Initial specification of 6D cooling bench test	ST13.1	DR, MR
FY14	Finalize 6D cooling bench test specification	ST14.1	DR, MR
FY15	Initial component specifications for 6D cooling experiment	ST15.1	MR
FY16	Install 6D cooling bench test section in MTA	ST16.1	MR
	Prepare proposal for 6D cooling experiment	ST16.2	FR, ER

a) DR: design report (MAP technical note); ER: external review; FR: formal report; MR: MAP (internal) review.

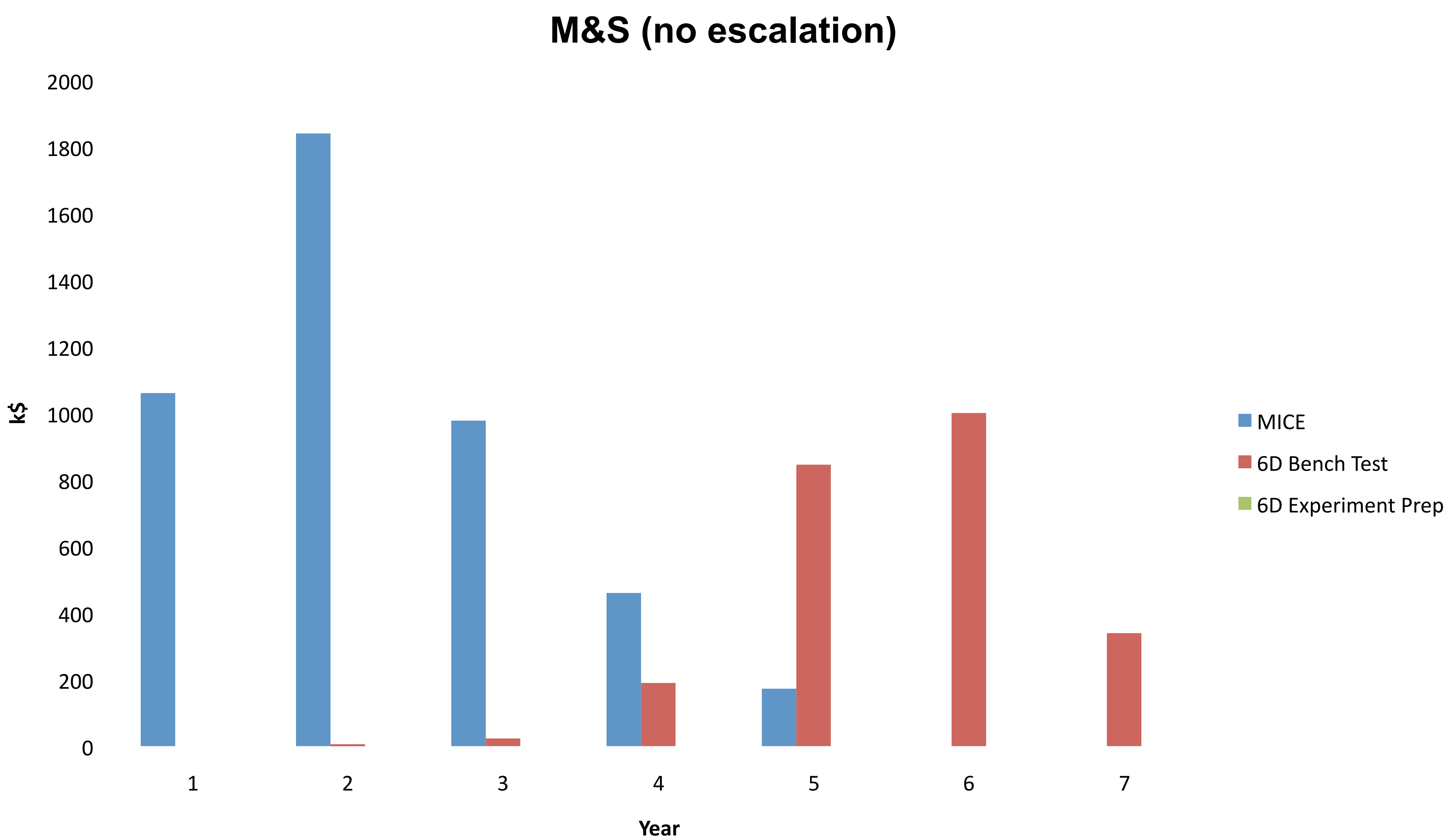
Resource Distribution



Manpower Needs



M&S Budget Profile



Conclusions

- The goal of the Systems Test activity is to test relevant hardware at the system level
  - Builds on results from both Technology Development and Design and Simulations
- Focus is on muon cooling channels, which are crucial for MC/NF
  - Complete MICE
  - Bench test of 6D cooling channel

  } Critical to show feasibility

  - Preparations for 6D cooling demo experiment (execution would be post-plan)