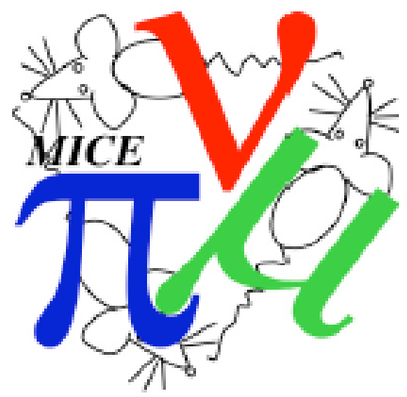
System Tests: Summary and Outlook

Daniel M. Kaplan



MAP Meeting
Fermilab
22 June 2013

Outline

- System Demonstrations overview
- MICE Status
- 6DICE Status
- Outlook

MICE & 6DICE

MICE & 6DICE

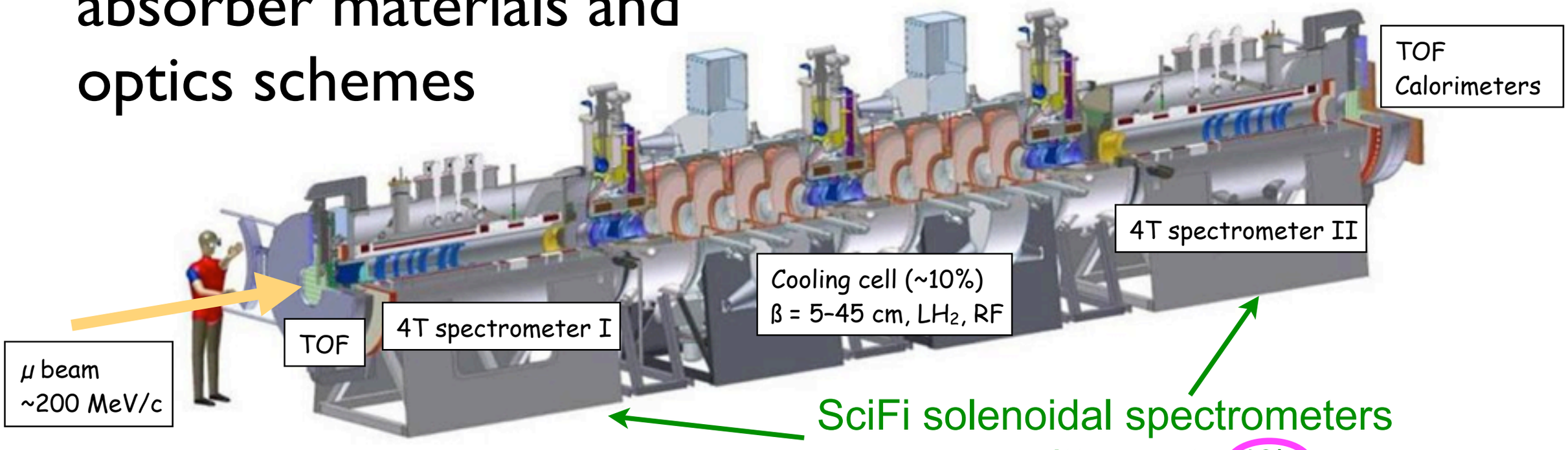
- MICE Goals:
  - Demonstrate feasibility & performance of muon ionization cooling by building & testing actual cooling channel section
    - validate Monte Carlo models
    - understand performance well enough to reliably extrapolate MC or NF cooling cost
    - measure ≈10% emittance reduction to 1% ⟹ need 10^{-3} emittance resolution

MICE & 6DICE

- MICE Goals:
  - Demonstrate feasibility & performance of muon ionization cooling by building & testing actual cooling channel section
    - validate Monte Carlo models
    - understand performance well enough to reliably extrapolate MC or NF cooling cost
    - measure ≈10% emittance reduction to 1% ⟹ need 10^{-3} emittance resolution
- 6DICE Goals:
  - Develop plan (FP-I) for, and bench-test (FP-II), components needed for 6D cooling
  - 1st emittance-exchange demonstration (in MICE Step IV)
  - Evaluate need for dedicated 6D cooling test & design if necessary
    - nuSTORM could provide a suitable beam
  - Evaluate need for collective-effects test & design if necessary (*p*-beam)

MICE

- International Muon Ionization Cooling Experiment at UK's Rutherford Appleton Laboratory (RAL)
- Flexibility to test several absorber materials and optics schemes



- Status: under construction, program complete by ~2020

MICE

- Located at STFC Rutherford Appleton Lab (Chilton, Oxfordshire, UK)

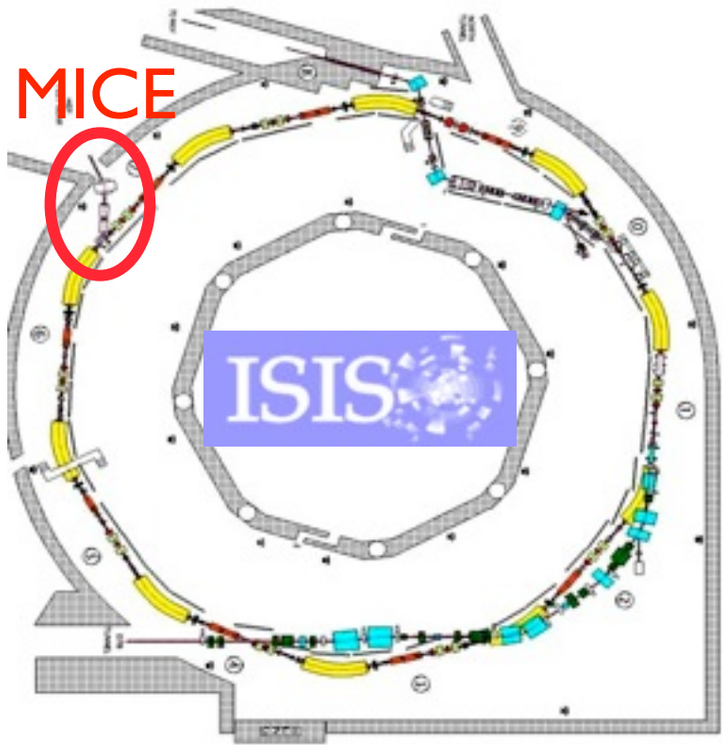
MICE

- Located at STFC Rutherford Appleton Lab (Chilton, Oxfordshire, UK)

Science & Technology Facilities Council

MICE

- Located at STFC Rutherford Appleton Lab (Chilton, Oxfordshire, UK)



- Uses dedicated, custom muon beamline off of ISIS 800-MeV proton synchrotron

MICE Collaboration

The MICE Collaboration

(listed alphabetically in country.town order)

- M. Bogomilov, Y. Karadzhov, D. Kolev, I. Russinov, R. Tsenov
  Department of Atomic Physics, St. Kliment Ohridski University of Sofia, 5 James Bourchier Boulevard, BG-1164 Sofia, Bulgaria
- R. Bertoni, M. Bonesini, S. Terzo
  INFN Milano, Dipartimento di Fisica G. Occhialini Piazza Scienza 3, 20126 Milano, Italy
- V. Palladino
  INFN Napoli e Università Federico II, Napoli, Italy
- G. Cecchet, A. de Bari
  INFN Pavia, Italy
- D. Orestano, L. Tortora
  INFN Roma III and Physics Department of ROMA TRE University, Via della Vasca Navale 84, I-00146 Roma, Italy
- P. Chimenti, G. Giannini
  University of Trieste and INFN Trieste, Italy
- S. Ishimoto, S. Suzuki, K. Yoshimura
  High Energy Accelerator Research Organization (KEK), Institute of Particle and Nuclear Studies, Tsukuba, Ibaraki, Japan
- Y. Mori
  Kyoto University Research Reactor Institute, Kumatori-cho Sennan-gun, Osaka 590-0494, Japan
- Y. Kuno, H. Sakamoto, A. Sato, T. Yano, M. Yoshida
  Osaka University, Graduate School of Science, Department of Physics, Toyonaka, Osaka, Japan
- L. Wang, F. Y. Xu, S. X. Zheng
  Institute of Cryogenics and Superconductivity Technology, Harbin Institute of Technology, Harbin, 150001, PR China
- F. Filthaut*
  NIKHEF, Amsterdam, The Netherlands
- N. Mezentsev, A. N. Skrinsky
  Budker Institute of Nuclear Physics, Novosibirsk, Russian Federation
- R. Garoby, H. Haseroth, F. Sauli
  CERN, Geneva, Switzerland
- A. Blondel, J.-S. Graulich, V. Verguilov
  DPNC, Section de Physique, Université de Genève, Switzerland
- C. Petitjean
  Paul Scherrer Institut, CH 5232 Villigen PSI, Switzerland
- R. Seviour
  The Cockcroft Institute, Daresbury Science and Innovation Centre, Daresbury, Warrington WA4 4AD, UK
- M. Ellis%, P. Kyberd, M. Littlefield, H. Nebrensky
  Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom
- D. Forrest, F. J. P. Soler
  Department of Physics and Astronomy, Kelvin Building, The University of Glasgow, Glasgow, G12 8QQ, UK
- P. Cooke, R. Gamet
  Department of Physics, University of Liverpool, Oxford St, Liverpool L69 7ZE, UK
- G. Barber, A. Dobbs, P. Dornan, A. Fish, R. Hare, A. Jamdagni, V. Kasey, M. Khaleeq, K. Long, H. Sakamoto, T. Sashalmi, K. Walaron
  Imperial College of Science, Technology and Medicine, Prince Consort Road, London SW7 2BW, UK
- W. W. M. Allison, M. Apollonio, G. Barr, J. Cobb, S. Cooper, S. Holmes, H. Jones, W. Lau, H. Witte, S. Yang
  Department of Physics, University of Oxford, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, UK
- J. Alexander, G. Charnley, S. Griffiths, B. Martlew, A. Moss, I. Mullacrane, A. Oats, S. York
  CCLRC Daresbury Laboratory, Daresbury, Warrington, Cheshire, WA4 4AD, UK
- R. Apsimon, P. Barclay, D. E. Baynham, T. W. Bradshaw, M. Courthold, R. Edgecock, P. Flower, T. Hayler, M. Hills, T. Jones, N. McNubbin, W. J. Murray, C. Nelson, A. Nicholls, P. R. Norton, C. Prior, J. H. Rochford, C. Rogers, W. Spensley, K. Tilley
  CCLRC Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire, OX11 0QX, UK
- C. N. Booth, P. Hodgson, R. Nicholson, E. Overton, M. Robinson, P. Smith
  Department of Physics and Astronomy, University of Sheffield, Sheffield S3 7RH, UK
- J. Norem
  Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439, USA
- A. D. Bross, S. Geer, D. Neuffer, A. Moretti, M. Popovic, R. Raja, R. Stefanski, Z. Qian
  Fermilab, P.O. Box 500, Batavia, IL 60510-0500, USA
- T. J. Roberts
  Muons Inc., Batavia, IL 60510, USA
- A. DeMello, M. A. Green, D. Li, A. M. Sessler, S. Virostek, M. S. Zisman
  Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
- B. Freemire, P. Hanlet, G. Kafka, D. M. Kaplan, P. Snopok, Y. Torun
  Illinois Institute of Technology, 3101 S. Dearborn St., Chicago, IL 60616, USA
- M. A. C. Cummings
  Northern Illinois University, DeKalb, IL 60115, USA
- U. Bravar
  University of New Hampshire, Durham, NH 03824, USA
- Y. Onel
  University of Iowa, Iowa City, IA52242, USA
- D. Cline, K. Lee, Y. Fukui, X. Yang
  UCLA Physics Department, Los Angeles, CA 90024, USA
- R. A. Rimmer
  Jefferson Lab, 12000 Jefferson Avenue, Newport News, VA 23606, USA
- L. M. Cremaldi, T. L. Hart, D. J. Summers
  University of Mississippi, Oxford, MS 38677, USA
- L. Coney, R. Fletcher, G. G. Hanson, C. Heidt
  University of California, Riverside, Riverside, CA 92521-0413 USA
- R. B. Palmer, S. Kahn, J. Gallardo, H. Kirk
  Brookhaven National Laboratory, Upton, NY 11973-5000, USA

MICE Collaboration

The MICE C

(listed alphabetically in cour

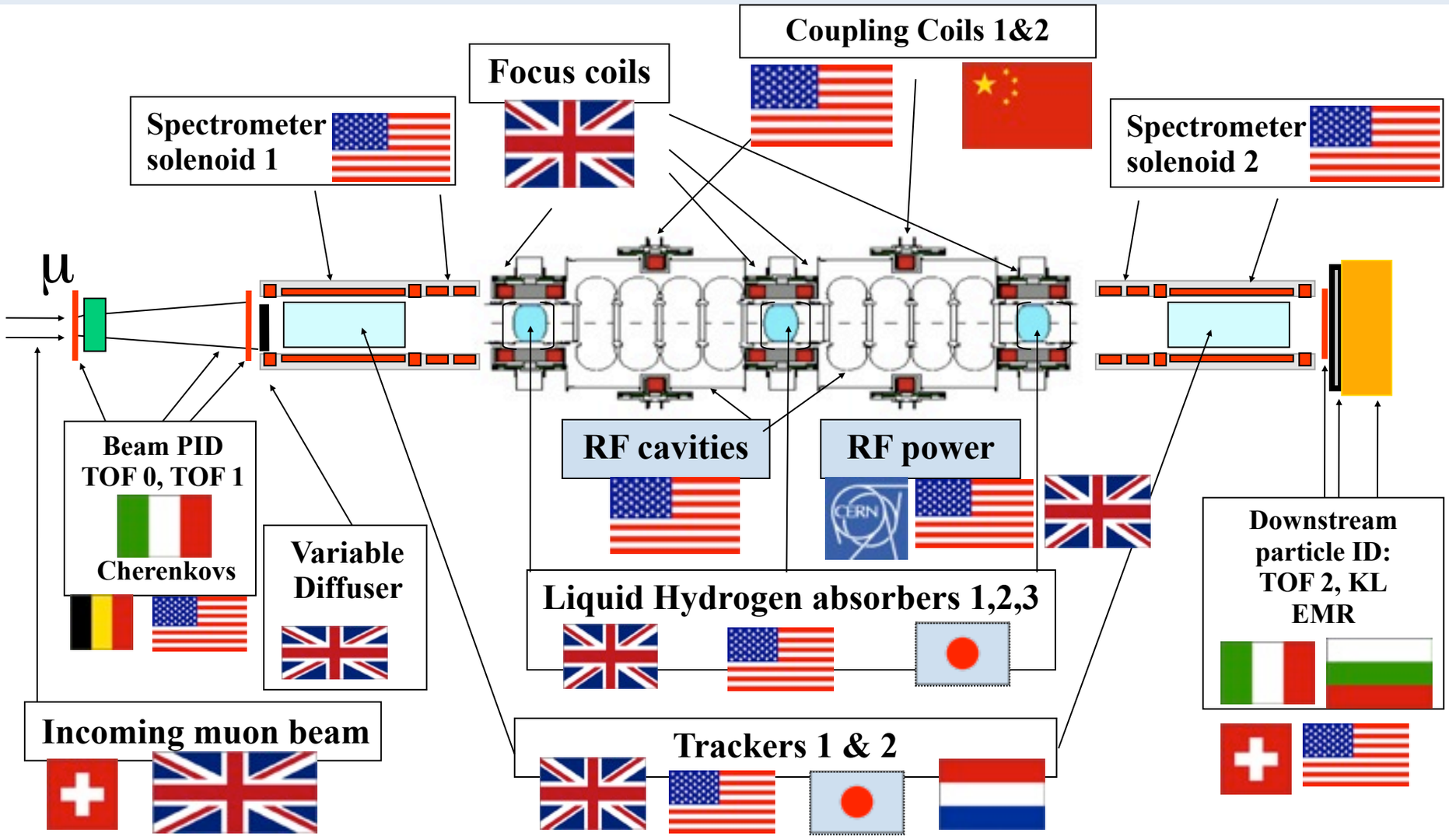
- M. Bogomilov, Y. Karac
  Department of Atomic P
  Sofia, Bulgaria
- R. Bertoni, M. Bonesini
  INFN Milano, Dipartim
- V. Palladino
  INFN Napoli e Universi
- G. Cecchet, A. de Bari
  INFN Pavia, Italy
- D. Orestano, L. Tortora
  INFN Roma III and Phy
- P. Chimenti, G. Giannin
  University of Trieste an
- S. Ishimoto, S. Suzuki, I
  High Energy Accelerato
  Japan
-
-
-
-
-
-
-
-
-
-
-

. Long, H. Sakamoto, T.

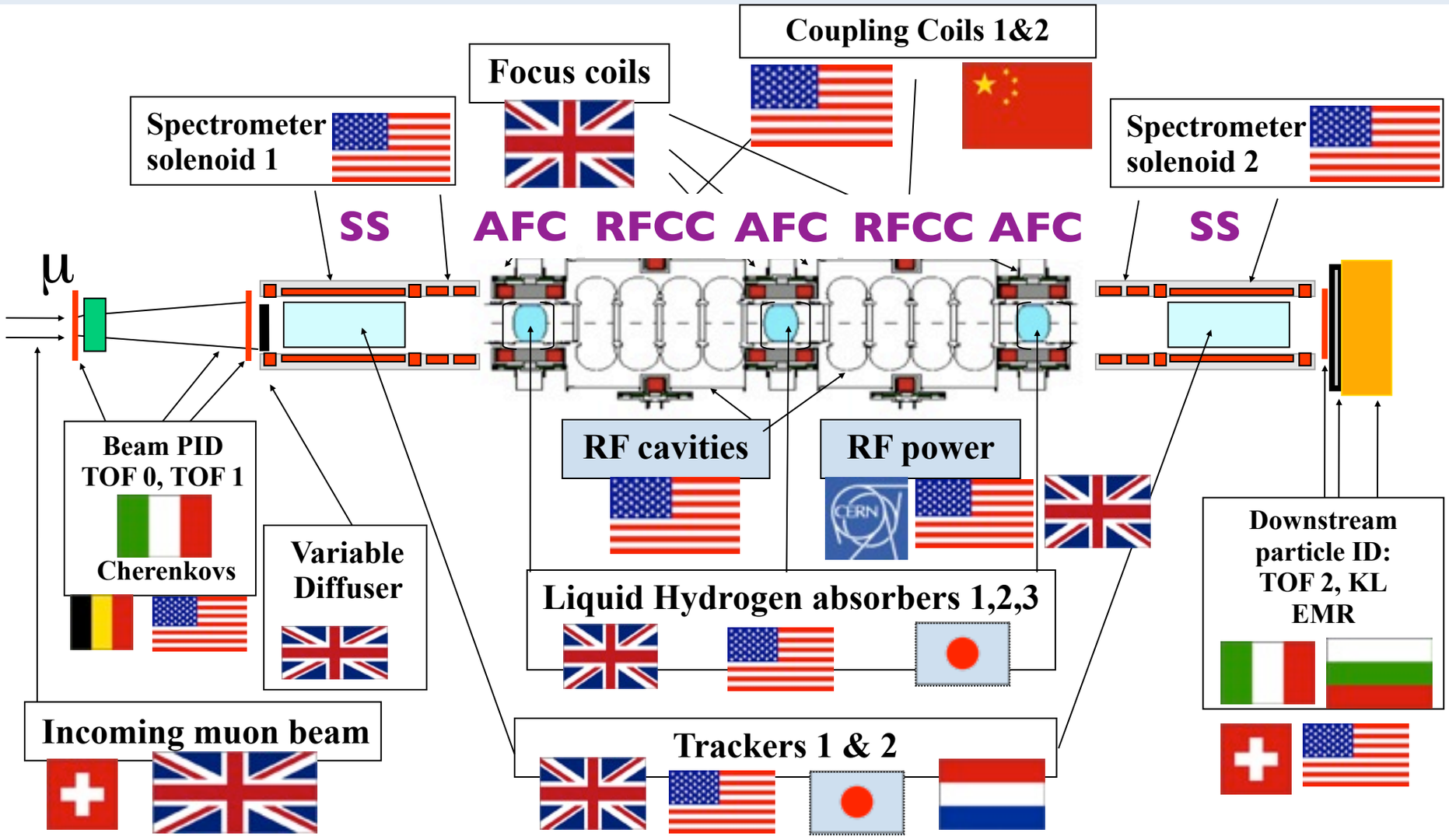
W7 2BW, UK
au, H. Witte, S. Yang
Oxford OX1 3RH, UK
York

Flower, T. Hayler, M. Hills,
I. Rochford, C. Rogers, W.

MICE Collaboration



MICE Collaboration



MICE Module Key:

- **S**pectrometer **S**olenoid **(SS)**
- **A**bsorber–**F**ocus **C**oil **(AFC)**
- **RF**–**C**oupling **C**oil **(RFCC)**

Steps of MICE

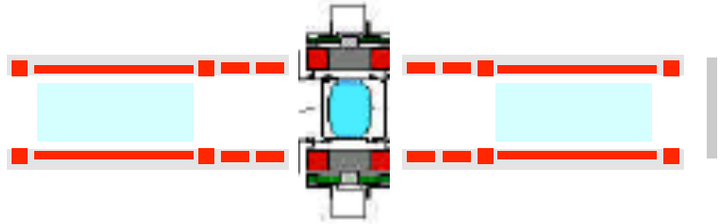
Provisional MICE SCHEDULE
update: June 2013

Run date:

μ

STEP I

EMR run Oct 2013



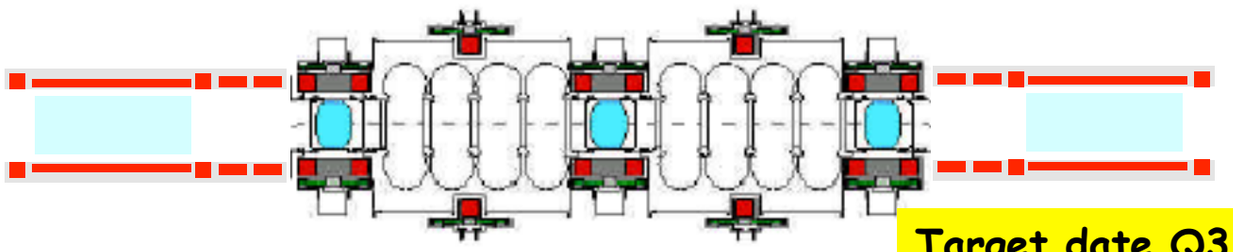
STEP IV

(possibly w/o field: Q2 2014)

Q1 2015 to Q1 2016

Under construction:

STEP VI



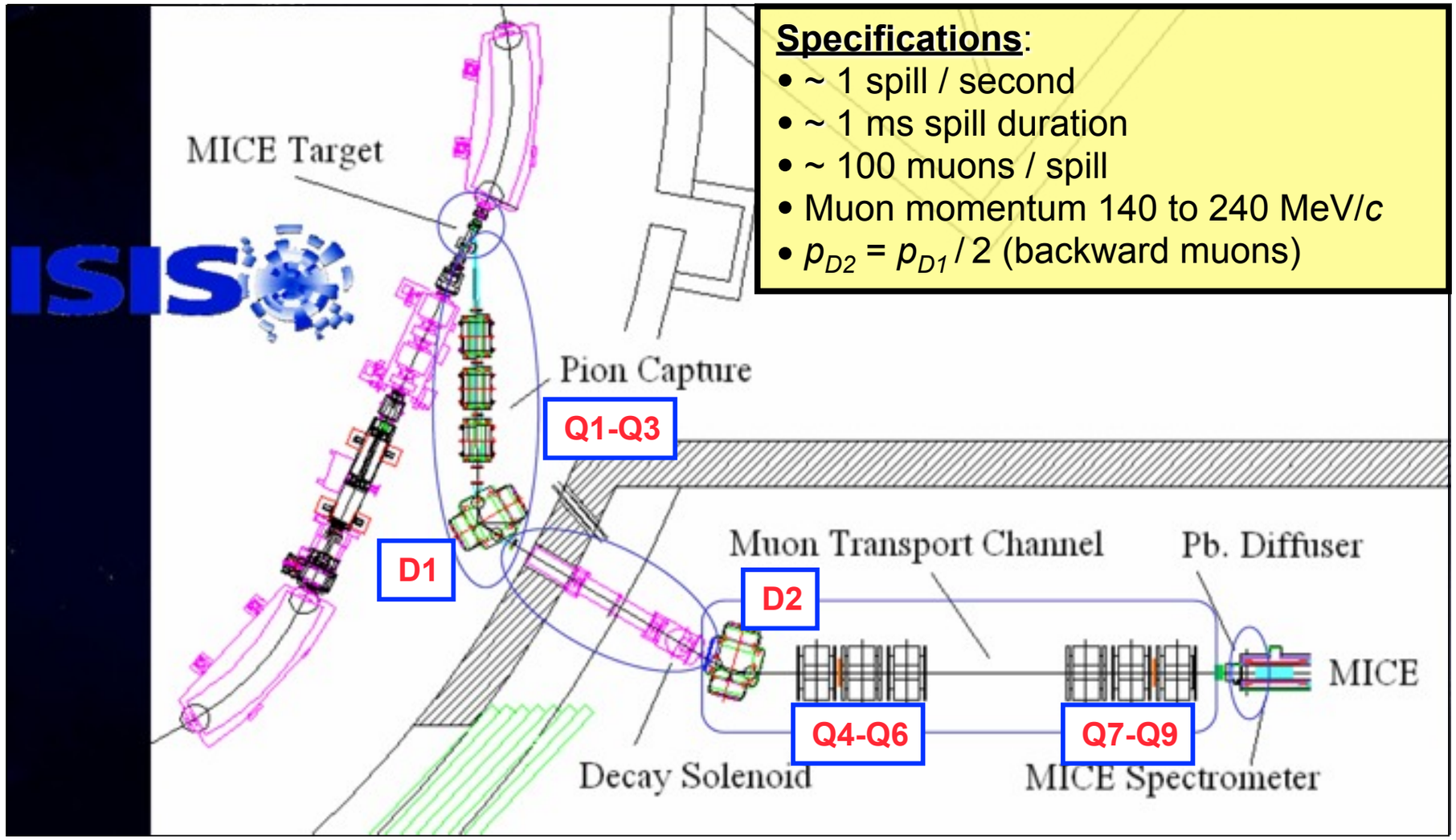
Target date Q3 2019
Step V run possible 2018

Resource Loaded Schedule -- MIPO's hard work!

MICE Beamline

[RAL]

- Installed 2007–8



Specifications:
- ~ 1 spill / second
- ~ 1 ms spill duration
- ~ 100 muons / spill
- Muon momentum 140 to 240 MeV/*c*
- $p_{D2} = p_{D1} / 2$ (backward muons)

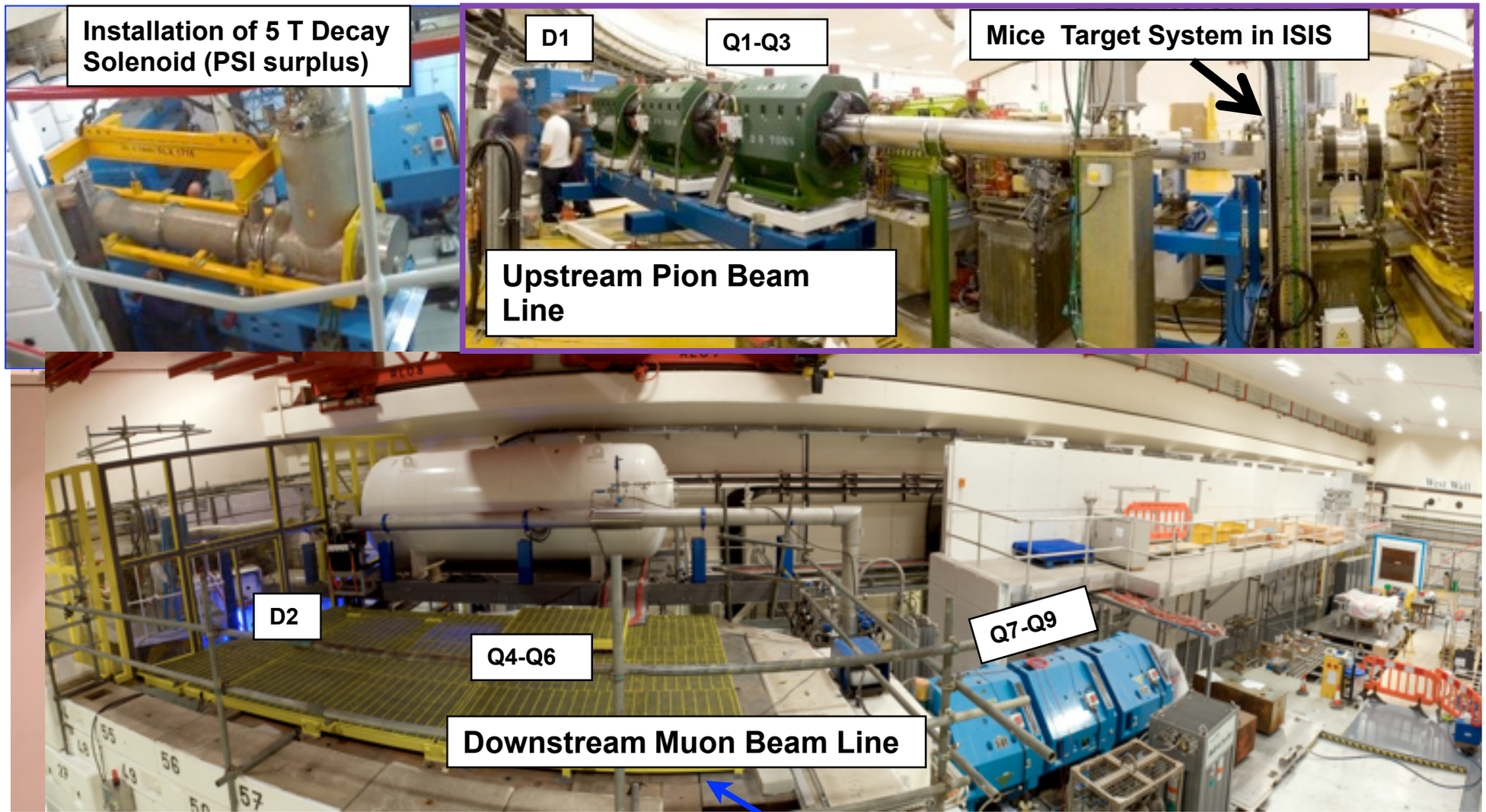
- Works well

  see Bogomilov *et al.*, JINST 7 (2012) P05009

MICE Beamline

[RAL]

- Installed 2007–8



- Works well

see Bogomilov *et al.*, JINST 7 (2012) P05009

MICE Particle ID

- Need to suppress (to < 10^{-3} level) undecayed π in beam & decay electrons

- Performed using
  - 3 sets of TOF counters (Milan/Pavia/Geneva/Sofia),
  - 2 Cherenkov counters (U Miss/IIT/U Iowa)
  - KL sampling EM Calorimeter (Rome III), and
  - Electron-Muon Ranger (Geneva/FNAL/Trieste/Como)

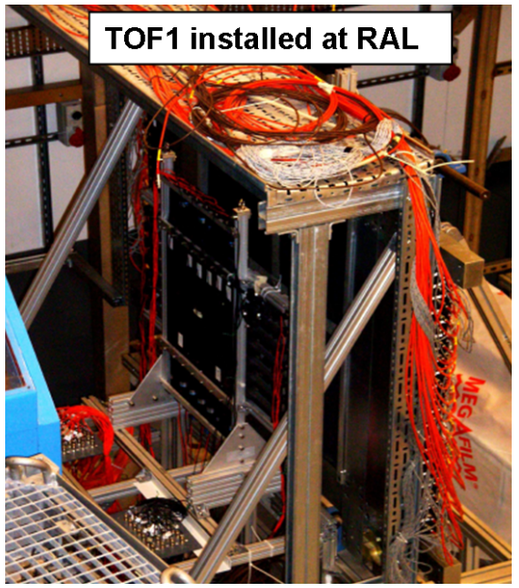
MICE Particle ID

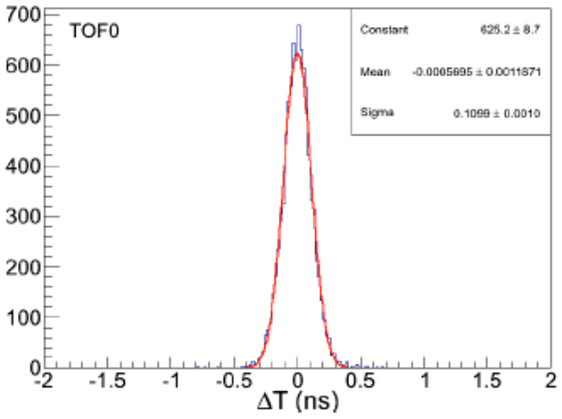
- Need to suppress (to < 10^{-3} level) undecayed π in beam & decay electrons

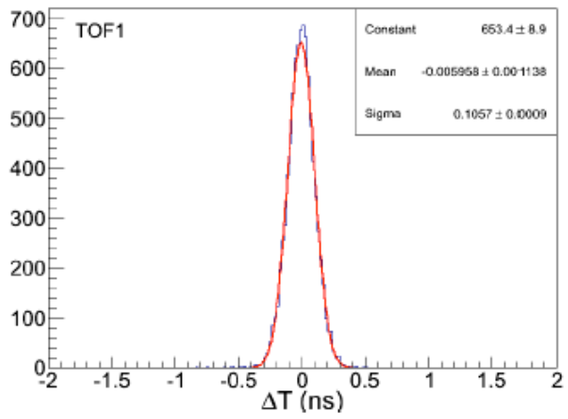
- Performed using — In and working?
  - 3 sets of TOF counters (Milan/Pavia/Geneva/Sofia), √
  - 2 Cherenkov counters (U Miss/IIT/U Iowa) √
  - KL sampling EM Calorimeter (Rome III), and √
  - Electron-Muon Ranger (Geneva/FNAL/Trieste/Como) due in Sept

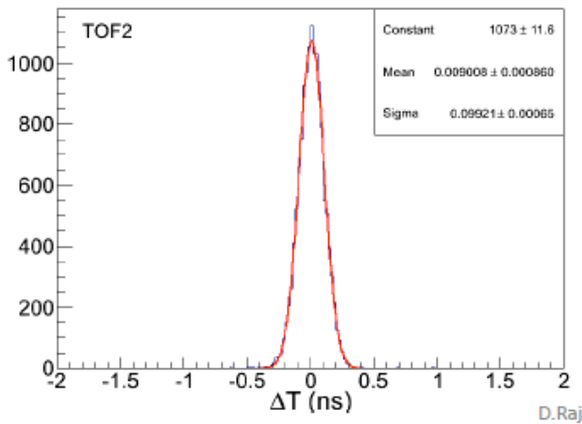
Time-of-Flight Counters

[Milan, Pavia, Geneva, Sofia]





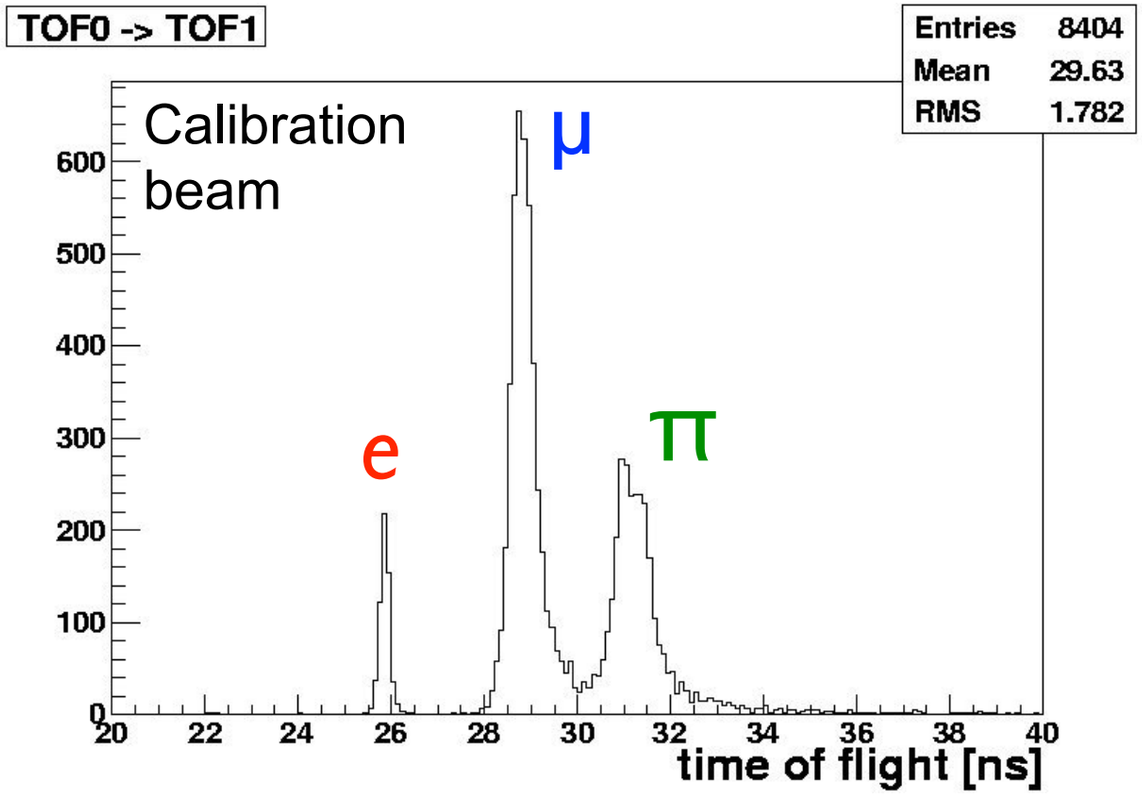




Resolutions

- TOF0: 55 ps
- TOF1: 53 ps (improved)
- TOF2: 50 ps

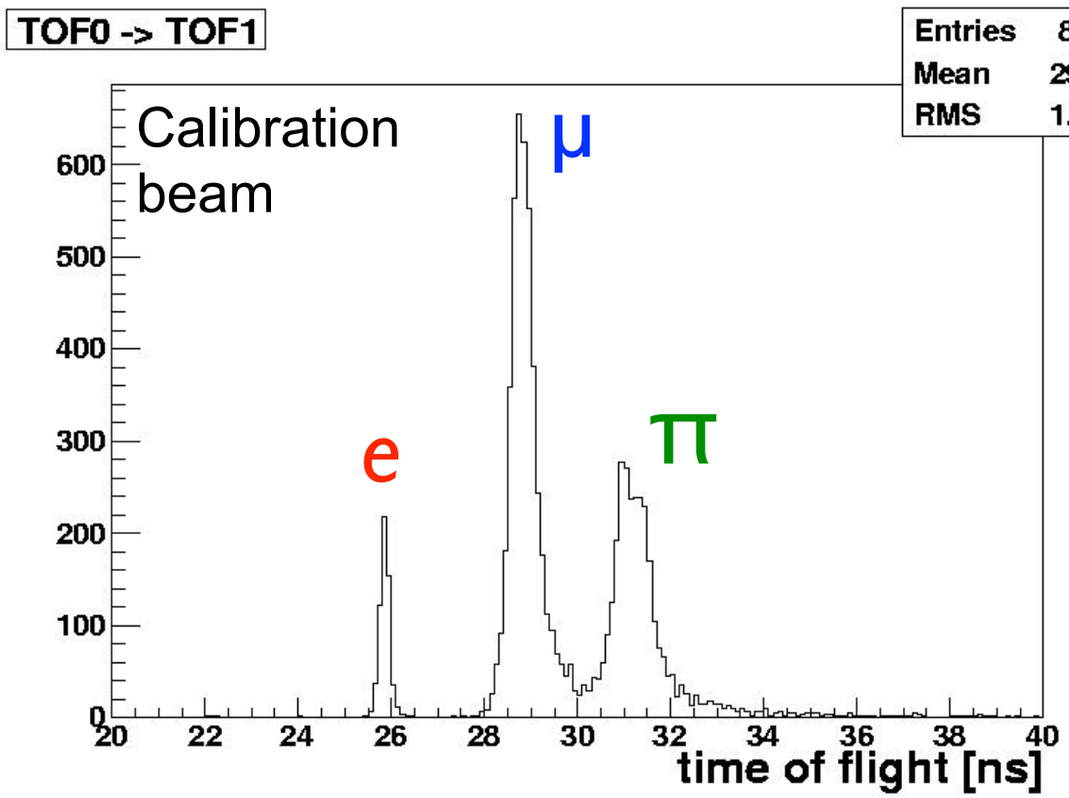
D.Rajaram, IIT, 2/9/12



Time-of-Flight Counters

[Milan, Pavia, Geneva, Sofia]

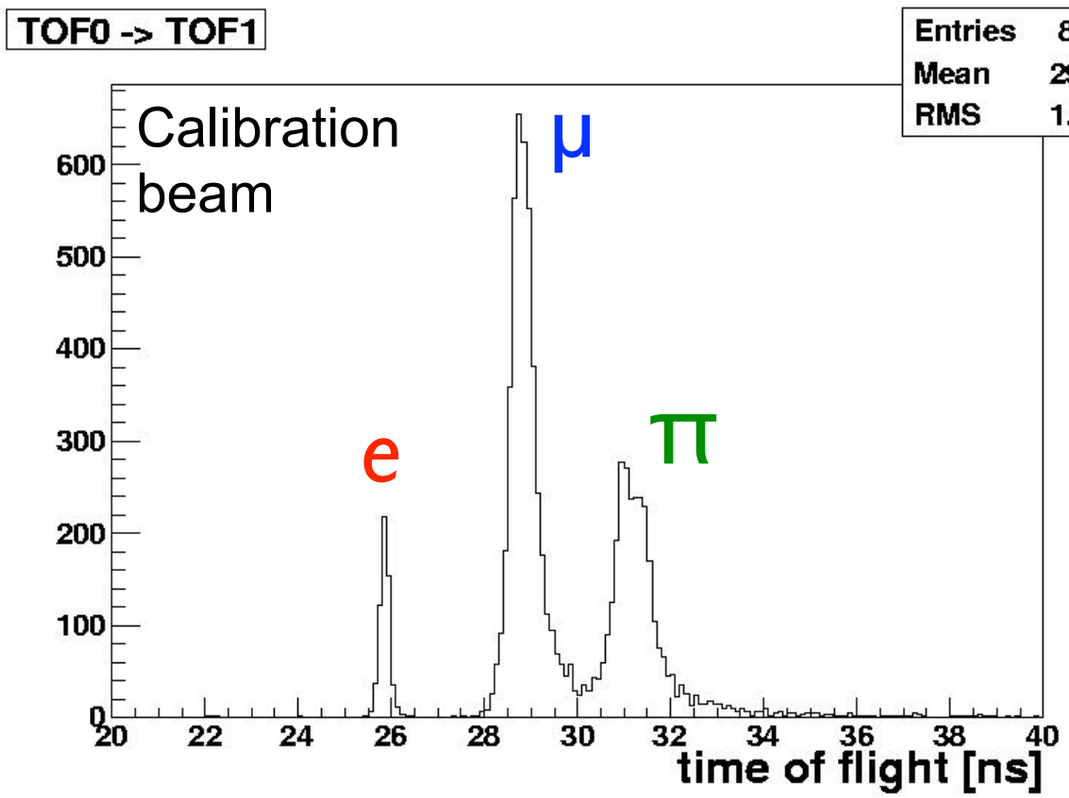
- Setting $p_{D2} = p_{D1}$ gives π/μ/e calibration beam:



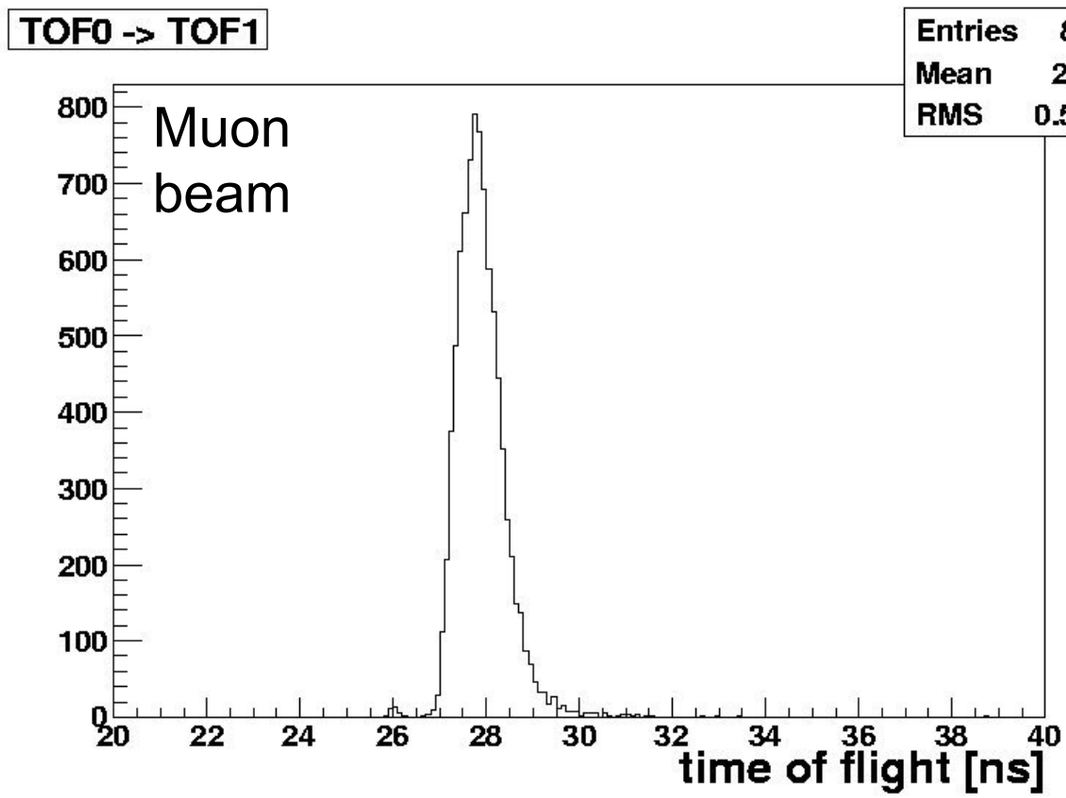
Time-of-Flight Counters

[Milan, Pavia, Geneva, Sofia]

- Setting $p_{D2} = p_{D1}$ gives π/μ/e calibration beam:



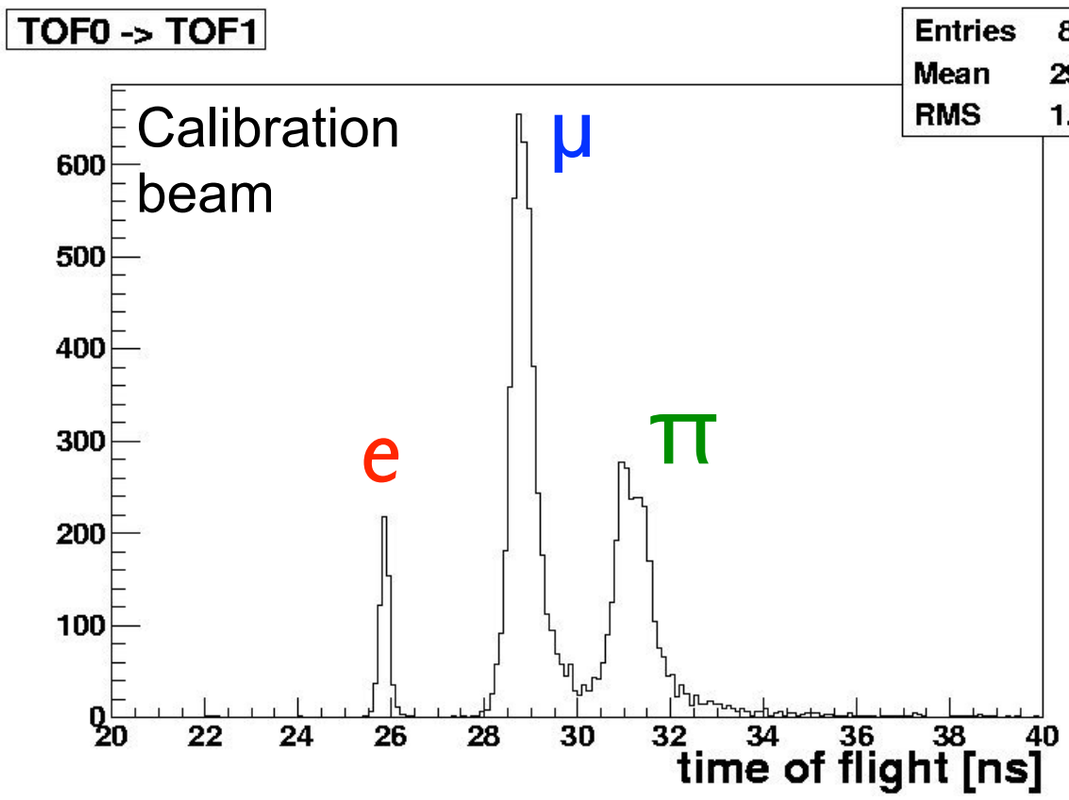
- Can select "pure" μ beam by $p_{D2} = 0.5\ p_{D1}$:



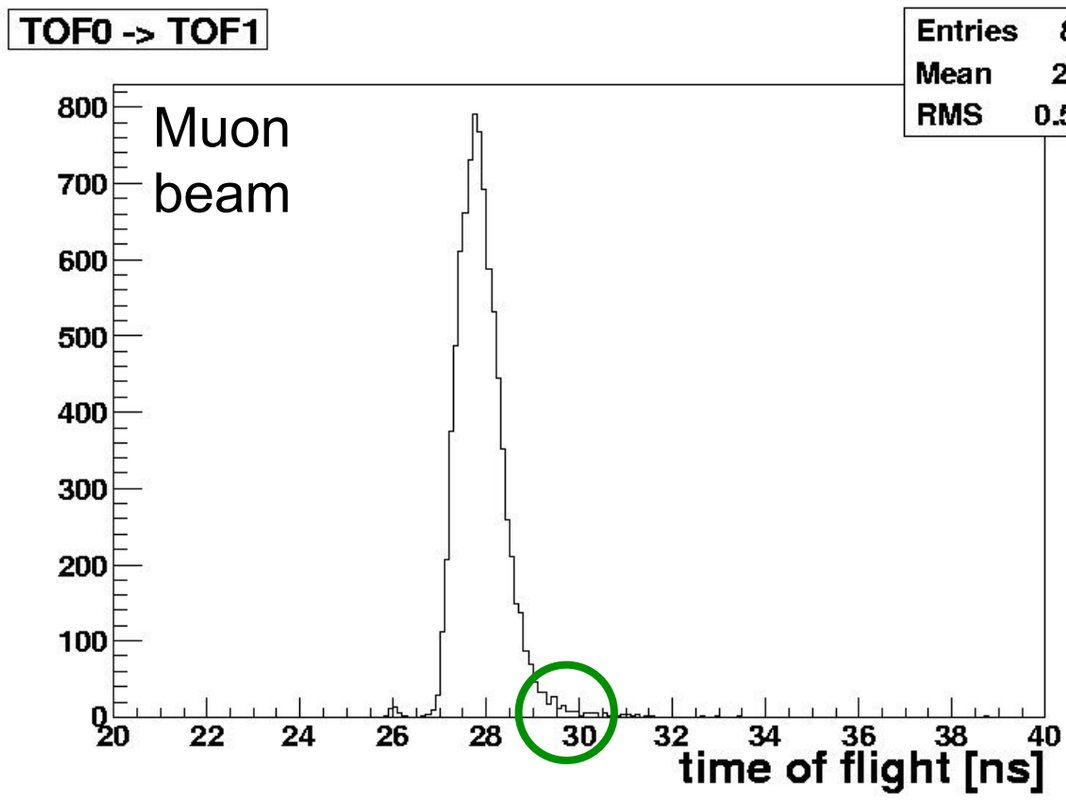
Time-of-Flight Counters

[Milan, Pavia, Geneva, Sofia]

- Setting $p_{D2} = p_{D1}$ gives π/μ/e calibration beam:



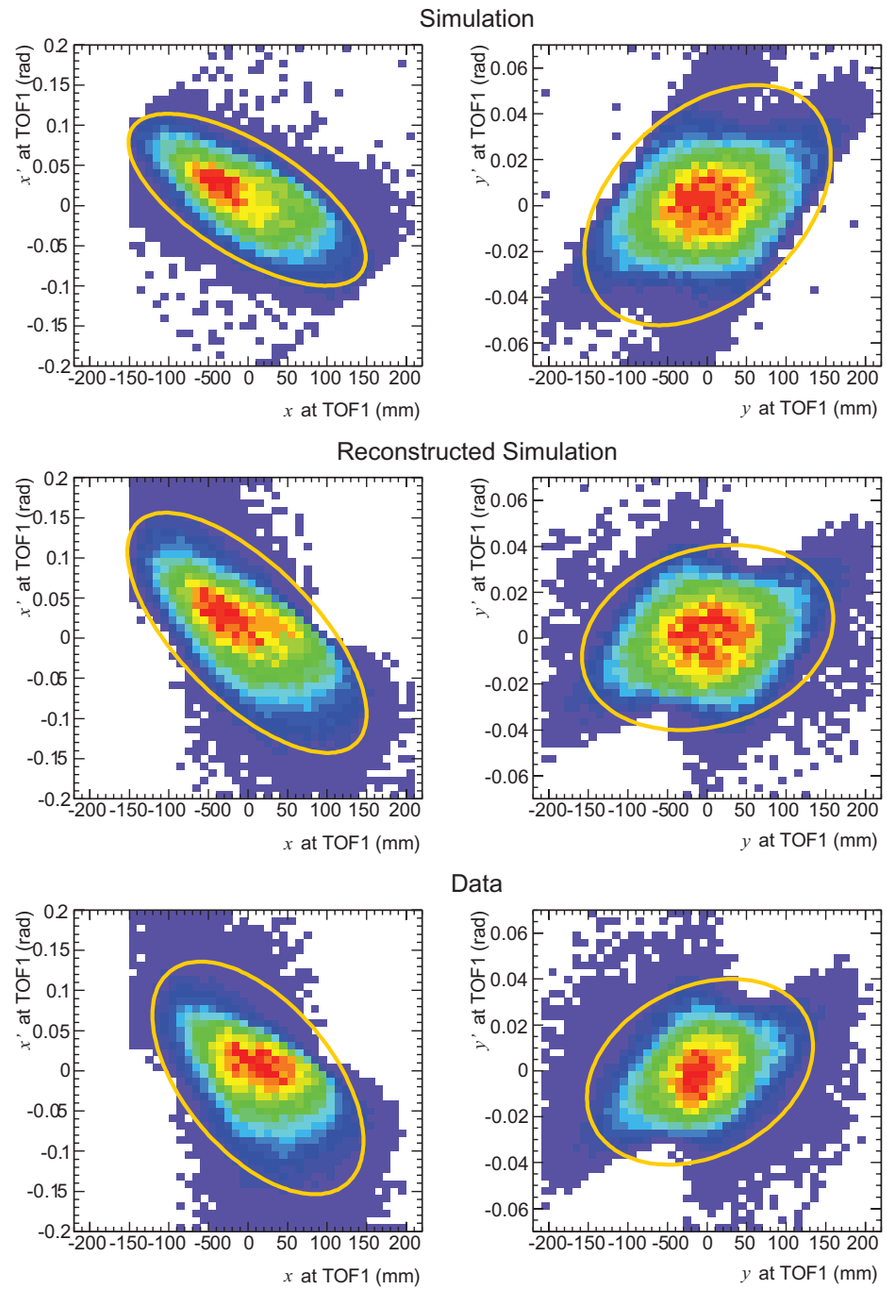
- Can select "pure" μ beam by $p_{D2} = 0.5\ p_{D1}$:



- $\mathcal{O}(\%)$ residual pions in MICE muon beam, to be suppressed via Cherenkov counters

TOF Emittance Analysis

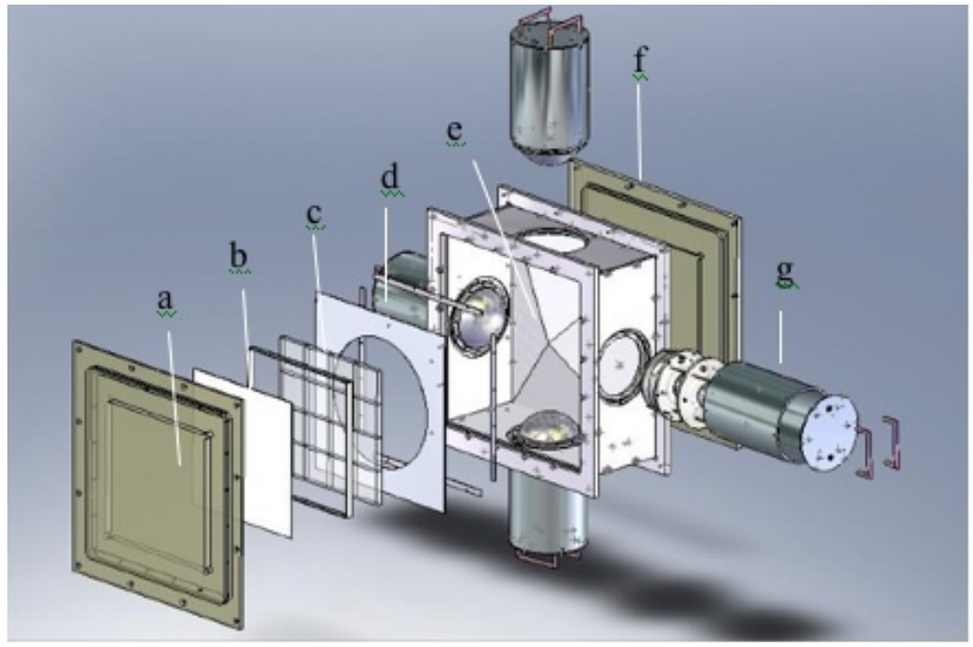
- Emittance analysis *without* spectrometers (done because SS delayed):
  - PMTs at each end allow interpolation to ≈1 cm
  - TOFs measure x' to 18 mrad, y' to 5 mrad, p to ≈ 2%
  - see Adams *et al.*, arXiv:1306.1509
- Conclusion:
  beam is well understood and suitable for MICE program

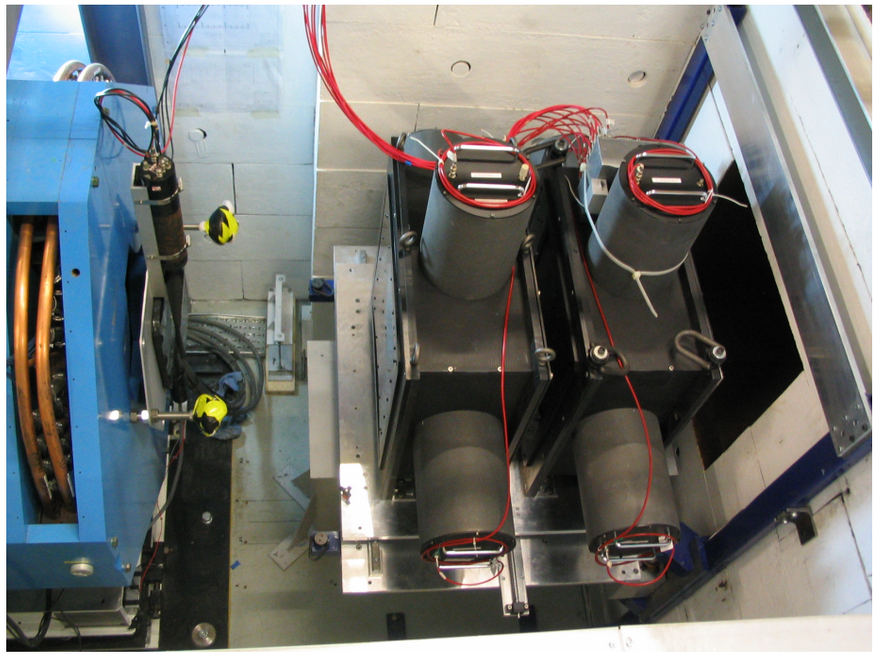


Cherenkov Counters

[U Miss, IIT, U Iowa]

- 2 Cherenkov counters with aerogel radiators:



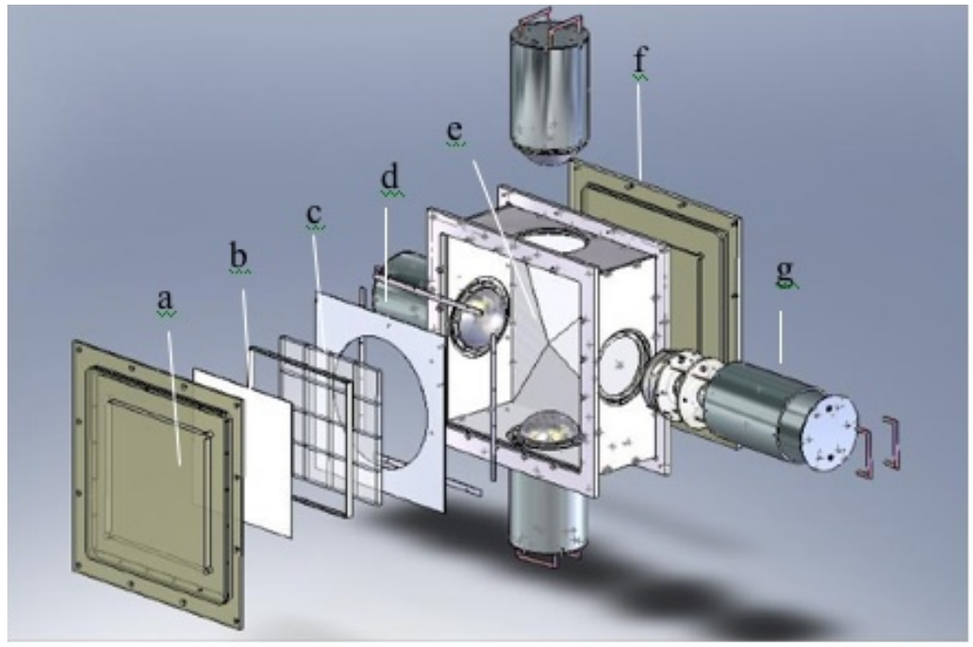


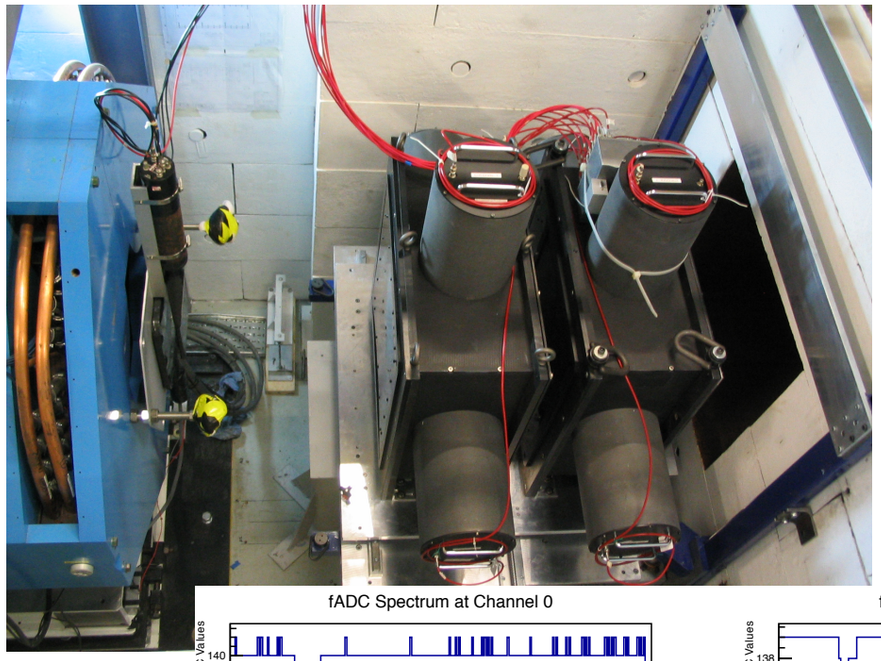
- Located in DSA, downstream of Q9 & TOF0
- 1 GS/s FADC readout
- Working well

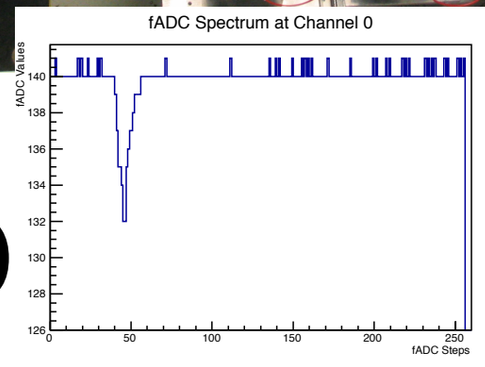
Cherenkov Counters

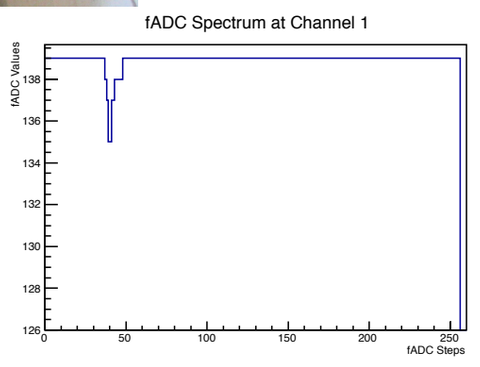
[U Miss, IIT, U Iowa]

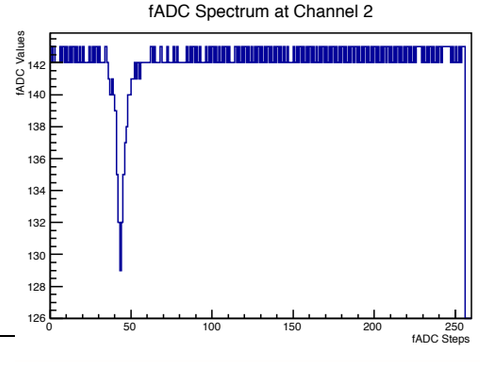
- 2 Cherenkov counters with aerogel radiators:

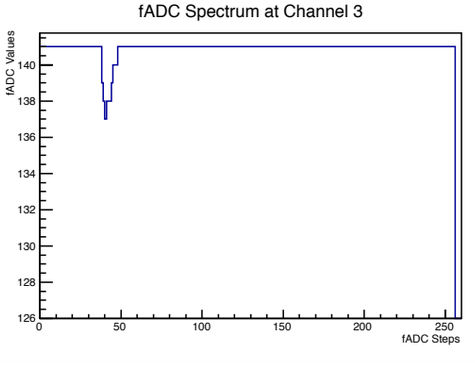










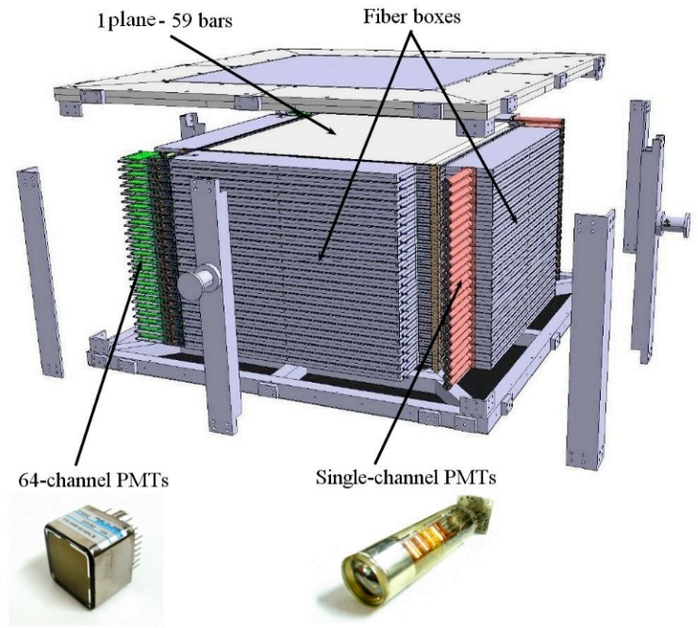


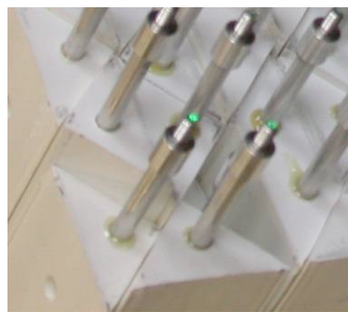
- Located in DSA, downstream of Q9 & TOF0
- 1 GS/s FADC readout
- Working well

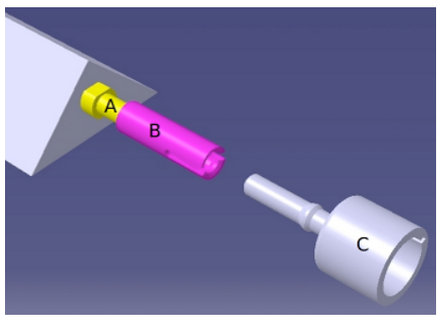
EMR

[Geneva, FNAL, Trieste/Como]

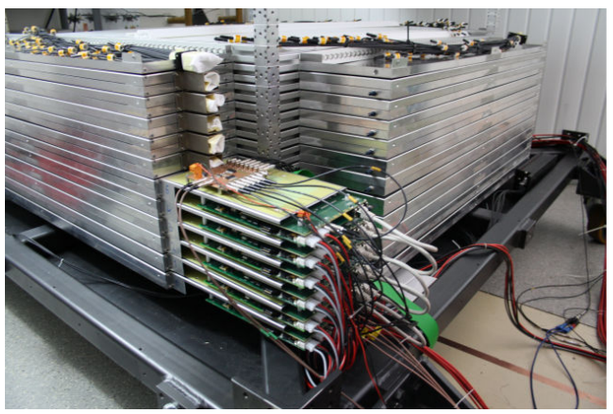
- Under construction at U Geneva







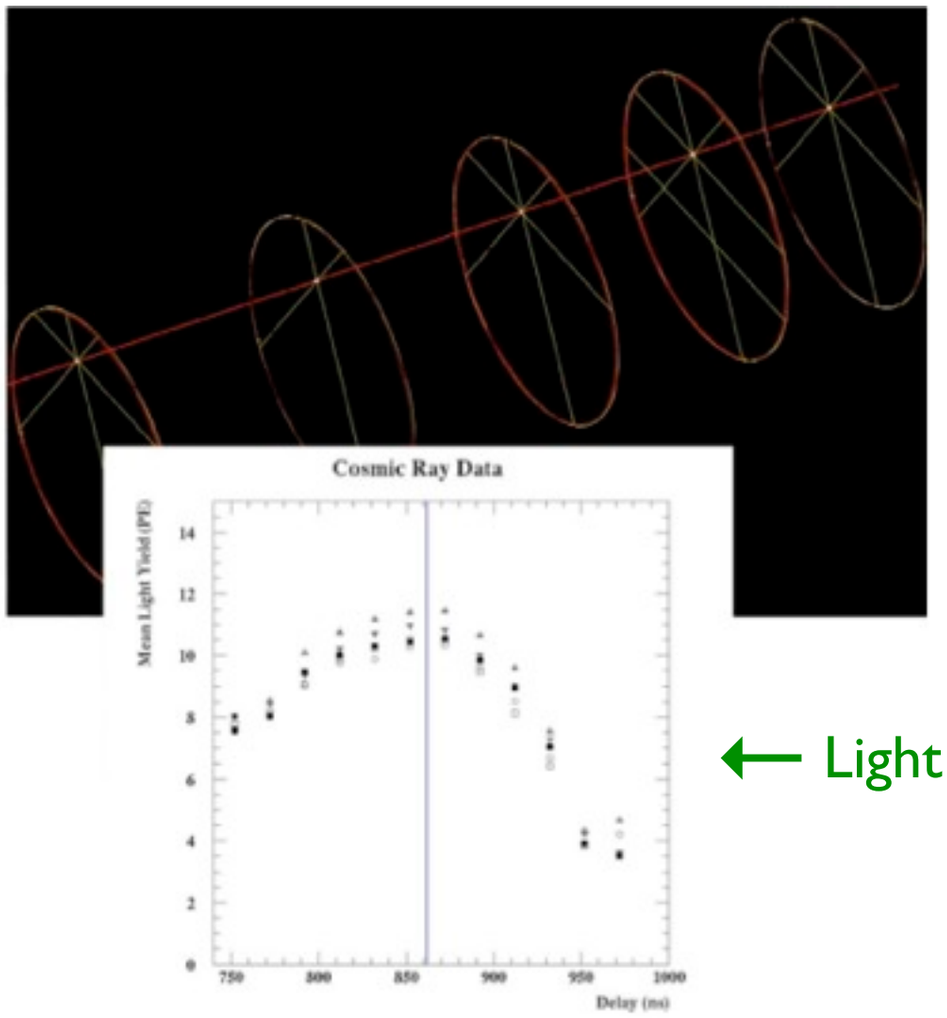
- Prototype already tested at MICE
- To be delivered & installed in Sept.



SciFi Spectrometers

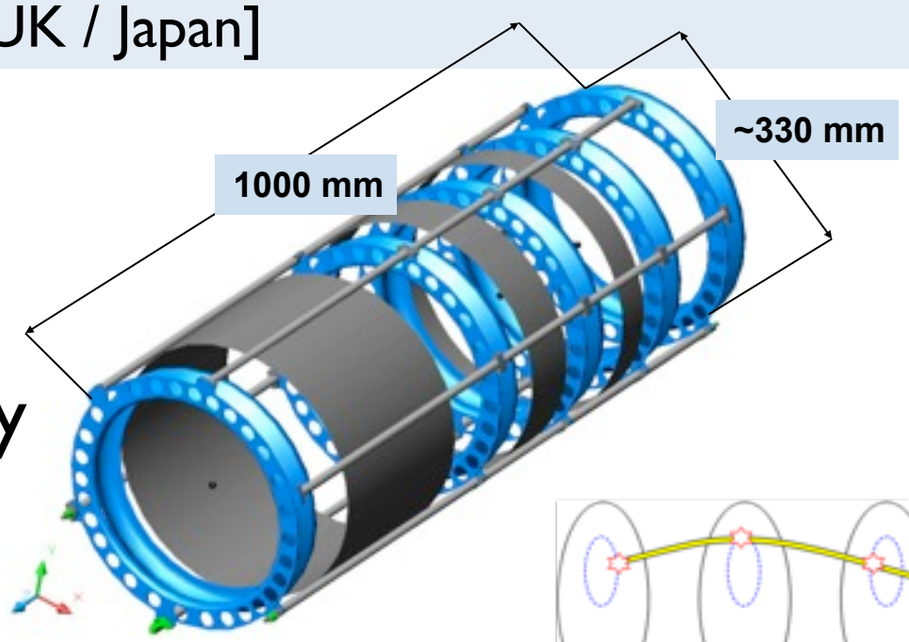
[US / UK / Japan]

- Trackers complete & tested with cosmic rays
  - installation awaiting SS delivery

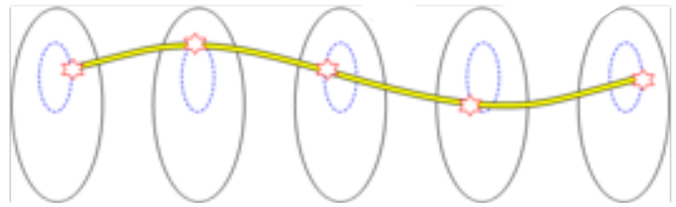


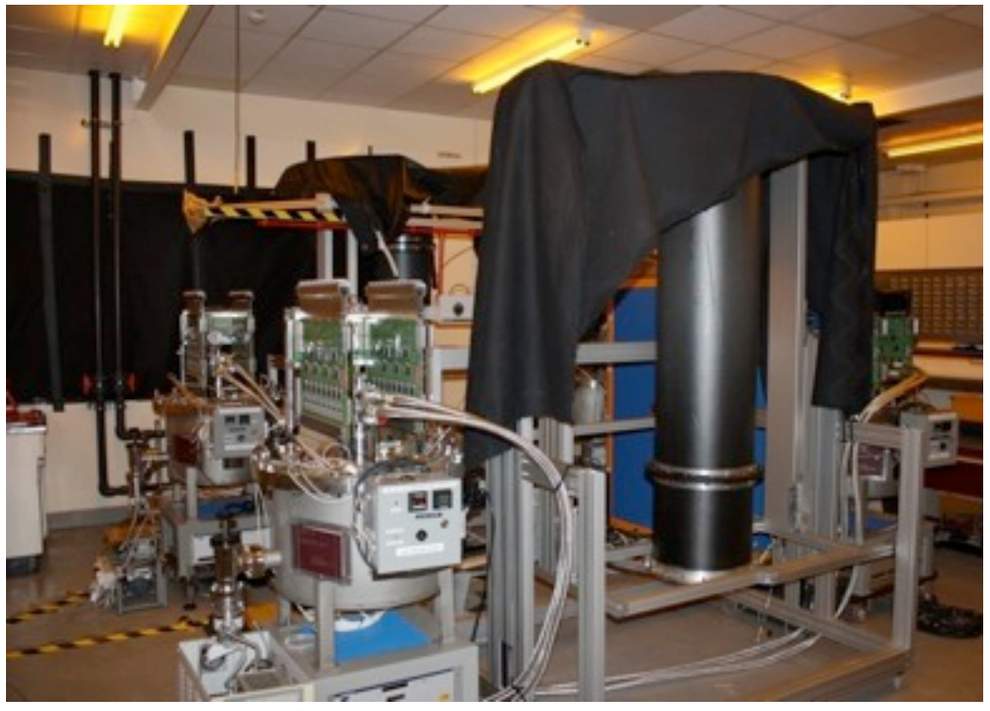
← Typical cosmic track

← Light yield ≈10 p.e.



5 stations of 350 μm SciFi





Cosmic test setup

MICE Magnets

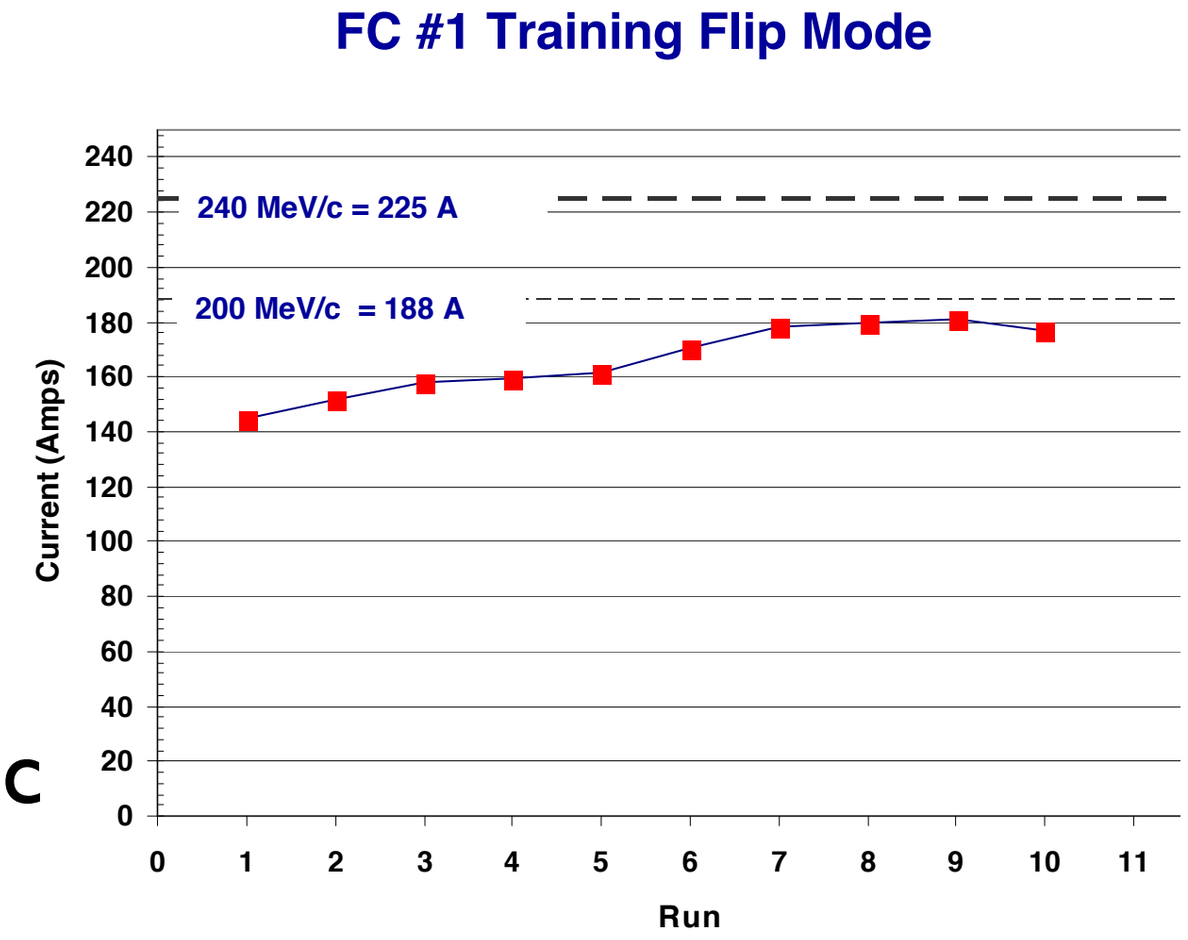
[LBNL, FNAL, U Oxford, RAL]

- US providing SS & CC (see talks this morning)
  - 1st SS trained & mapped, 2nd ready soon
- UK providing FC – status:
  - 1st FC completed, successful training in solenoid mode
  - flip-mode training problematic
    - now negotiating with vendor
  - 2nd FC nearly ready

MICE Magnets

[LBNL, FNAL, U Oxford, RAL]

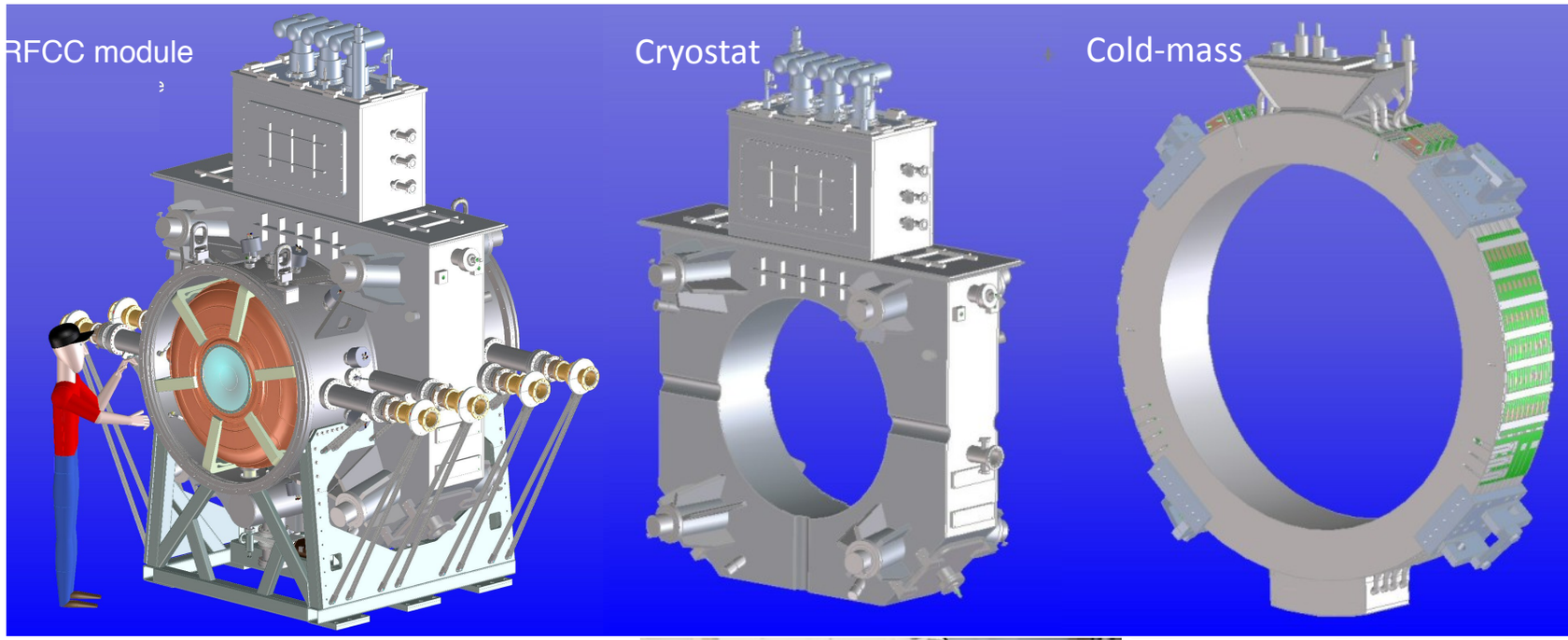
- US providing SS & CC (see talks this morning)
  - 1st SS trained & mapped, 2nd ready soon
- UK providing FC – status:
  - 1st FC completed, successful training in solenoid mode
  - flip-mode training problematic
    - now negotiating with vendor
  - 2nd FC nearly ready



RFCC Modules

[LBNL, HIT, U Miss]

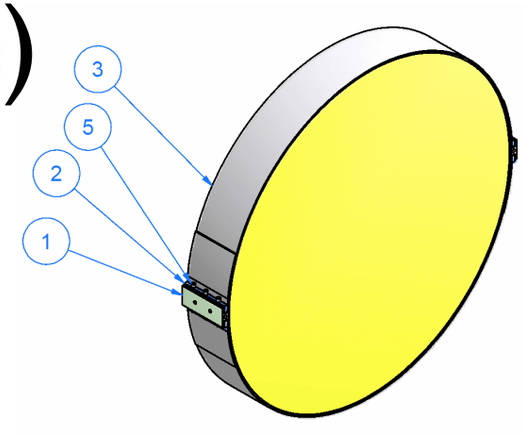
- Design ≈ done
- RF cavities built
  - 1st at FNAL for MTA tests
  - much work on couplers, tuners & assembly procedure
- Coupling Coil fab in China (HIT, Qi Huan, SINAP) led by LBNL
  - 1st CC cold mass delivered, under test at FNAL STF



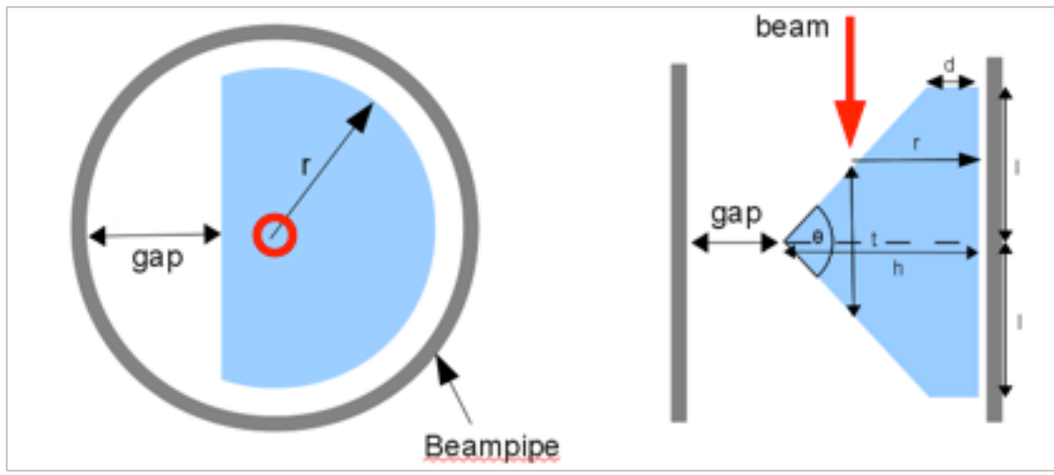
LiH Absorbers

[FNAL]

- Fabrication at Y12 (Oak Ridge)
  - both disks and wedges ordered
  - disks done, awaiting approvals for delivery to RAL (CRADA with STFC)



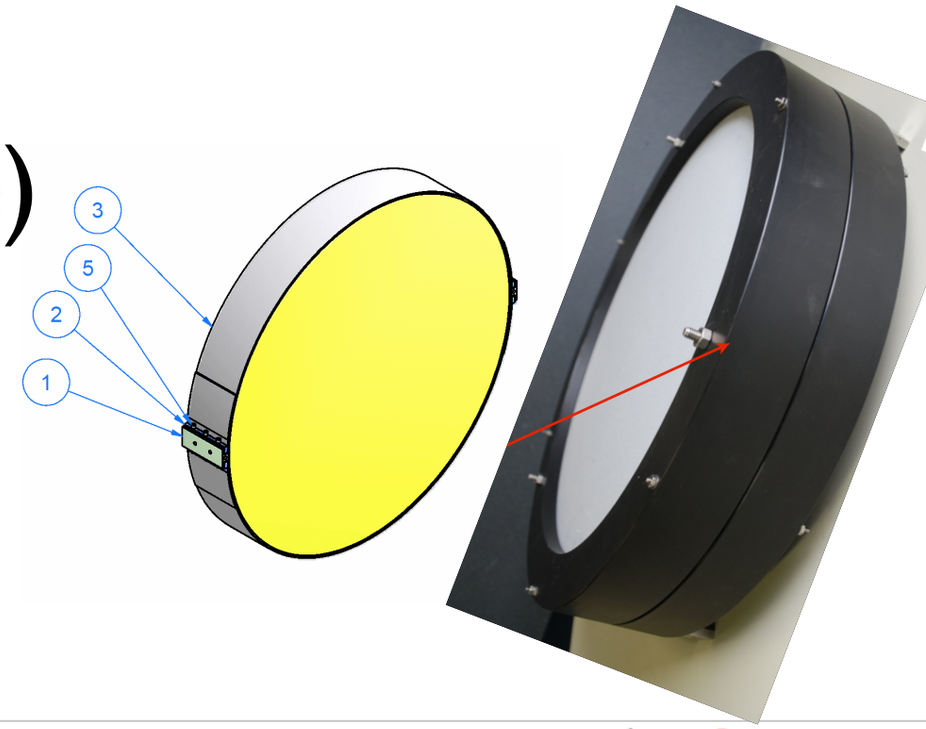
- Other solid absorbers also under consideration:
  - C, Al, polyethylene,...

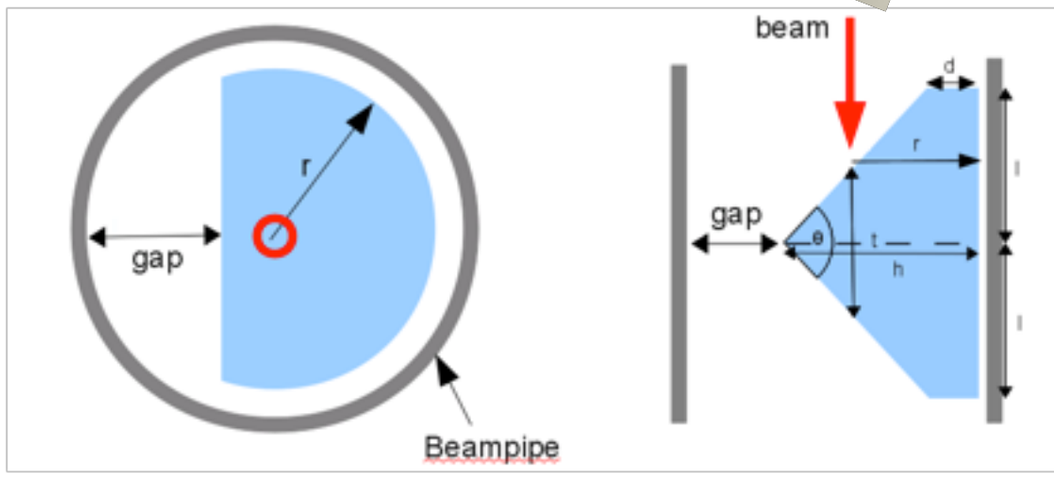


LiH Absorbers

[FNAL]

- Fabrication at Y12 (Oak Ridge)
  - both disks and wedges ordered
  - disks done, awaiting approvals for delivery to RAL (CRADA with STFC)
- Other solid absorbers also under consideration:
  - C, Al, polyethylene,...



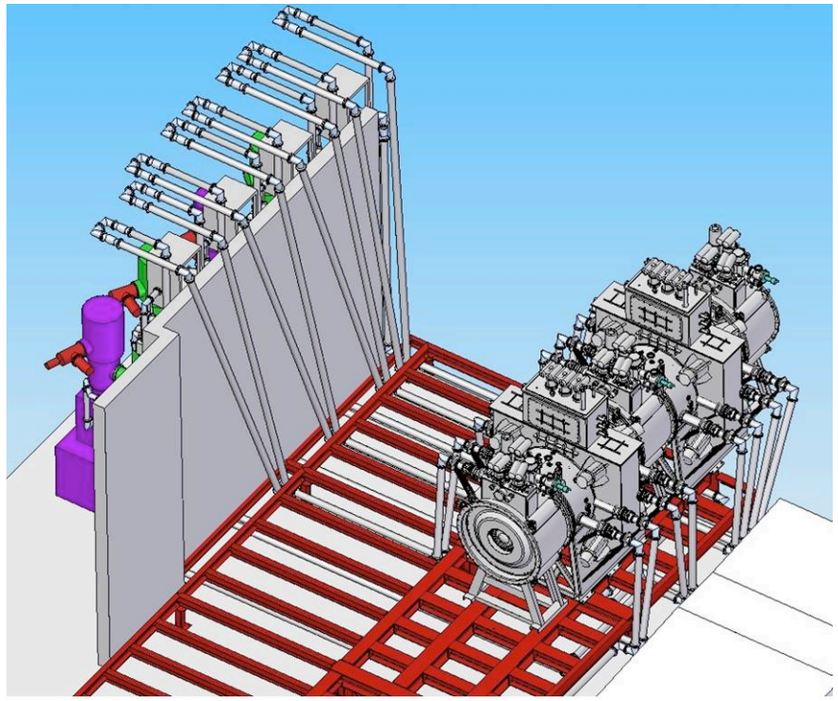


RF Power

[DL, LBNL, U Miss, U Strathclyde]

- 4 used 2 MW triode supplies
  - 2 from LBNL, 2 from CERN
  - refurbishment in progress at DL
  - 1st complete & tested at 1 MW
    - crowbar circuit improvements in progress for 2 MW test

- Installation plan devised
- LLRF design in progress
- TIARA test this year



LH2 System

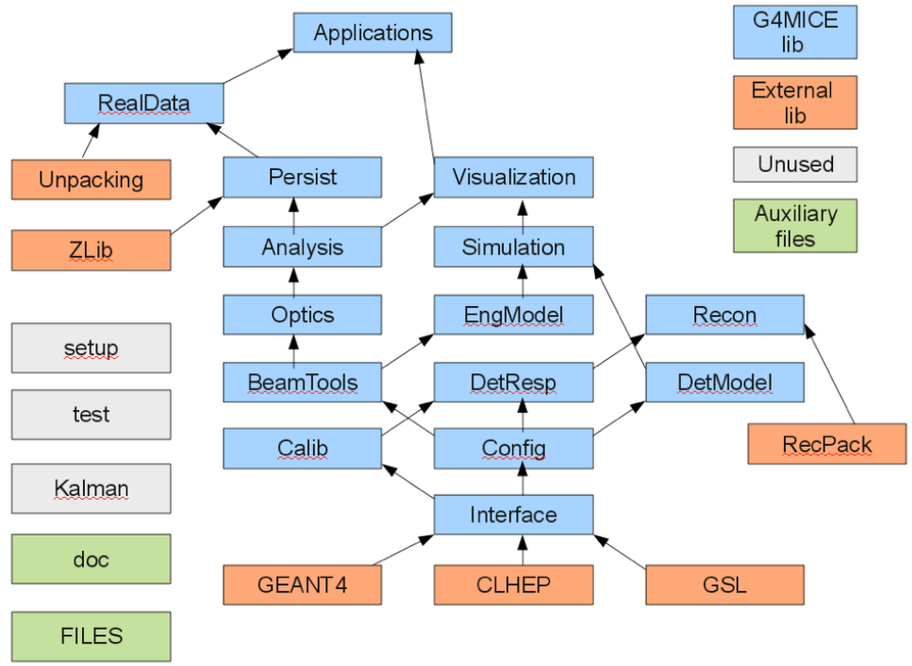
[RAL]

- Liquid-hydrogen system successfully tested
  - uses hydride-bed H_2 storage

MICE Software

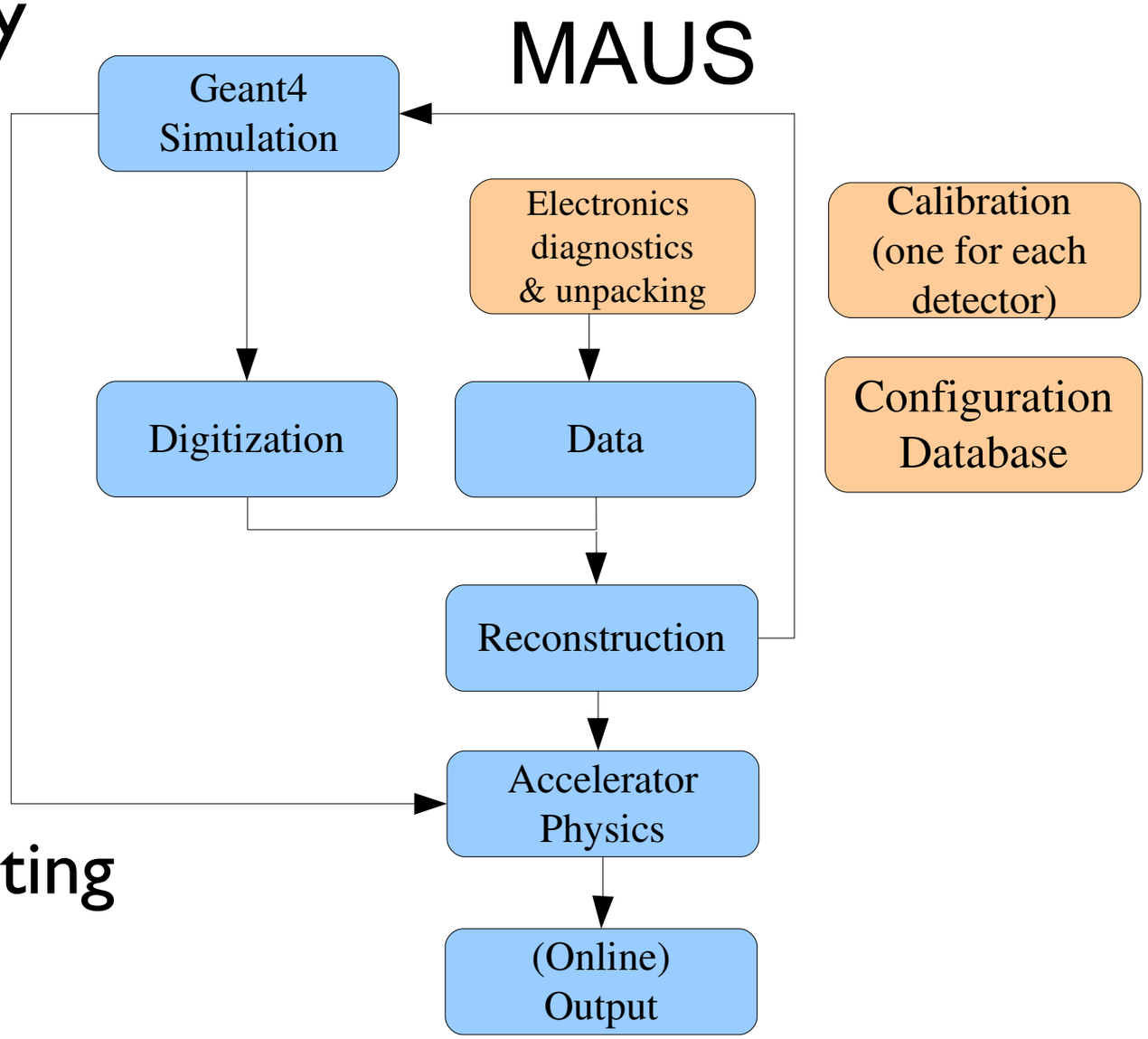
- G4MICE developed initially by Y. Torun (IIT)

G4MICE



MICE Software

- G4MICE developed initially by Y. Torun (IIT)
- Succeeded by MAUS (MICE Analysis User Software) framework
  - simplifies maintenance & use
  - strong emphasis on good documentation & thorough testing
  - making good progress but not all there yet
    - much to be done to be ready for Step IV!



MICE Outlook

- Complete (Step VI) study of transverse cooling by 2020
  - with 1st cooling demo (Step IV) in 2015
  - as well as demo of emittance exchange
  - and possibly Step V in 2018
- PhD theses for ≈ a dozen students so far, with several more to come
- For more, see http://mice.iit.edu/

6DICE Outlook

- Plenty of issues to work through
  - bi-weekly discussion meetings ongoing
  - you're welcome to join the fun!