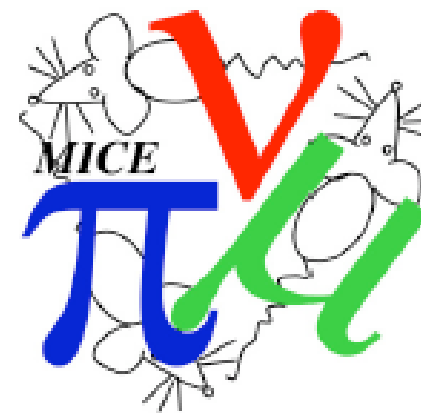


Level I Report: MICE Status & Prospects

Daniel M. Kaplan



MAP Meeting
SLAC
6 March 2012

Outline

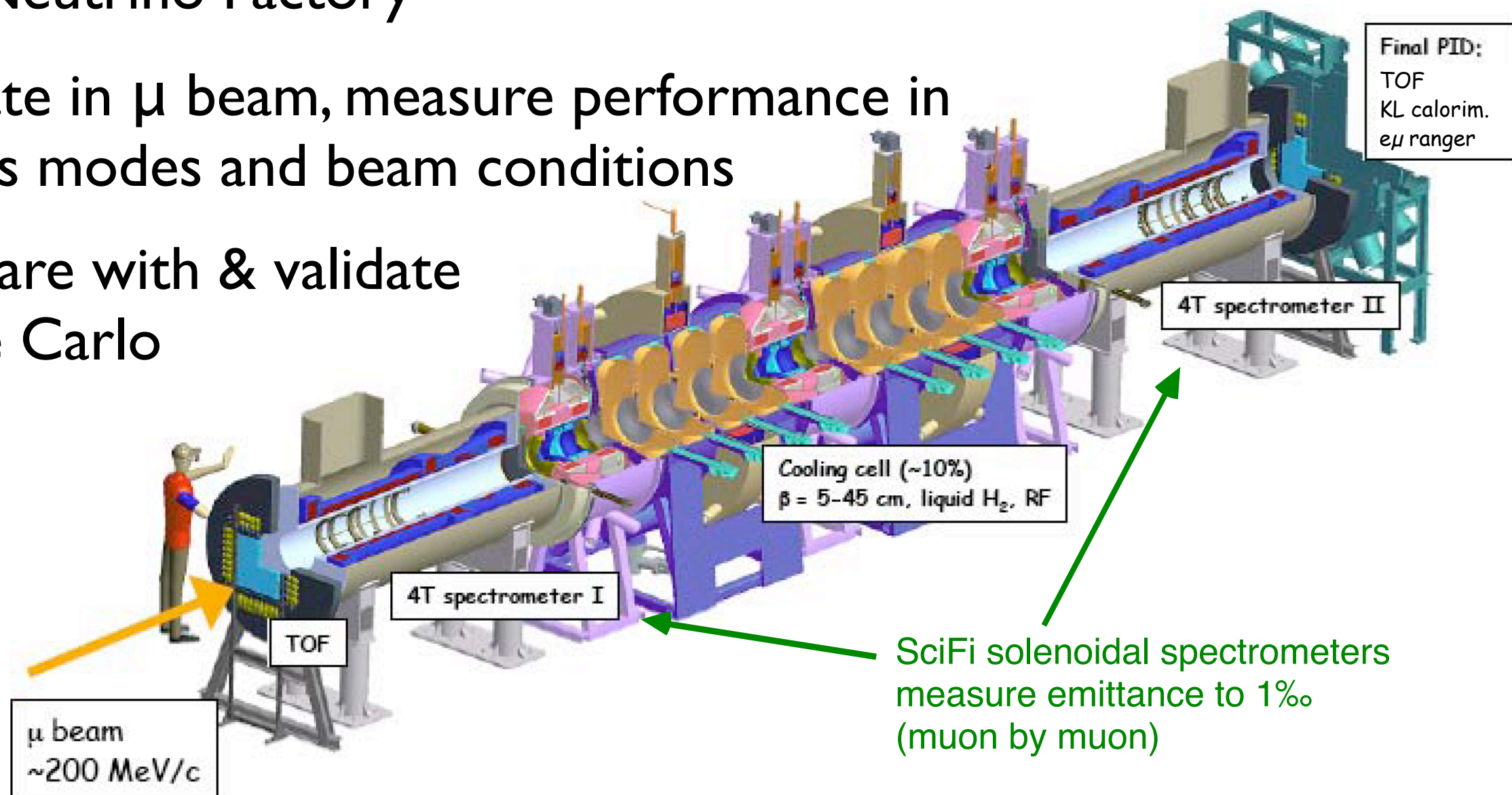


- MICE overview
- Beam & target
- Particle ID
- Emittance measurement
- Tracking
- Cooling cell & infrastructure
- Software
- Outlook

Muon Ionization Cooling Experiment

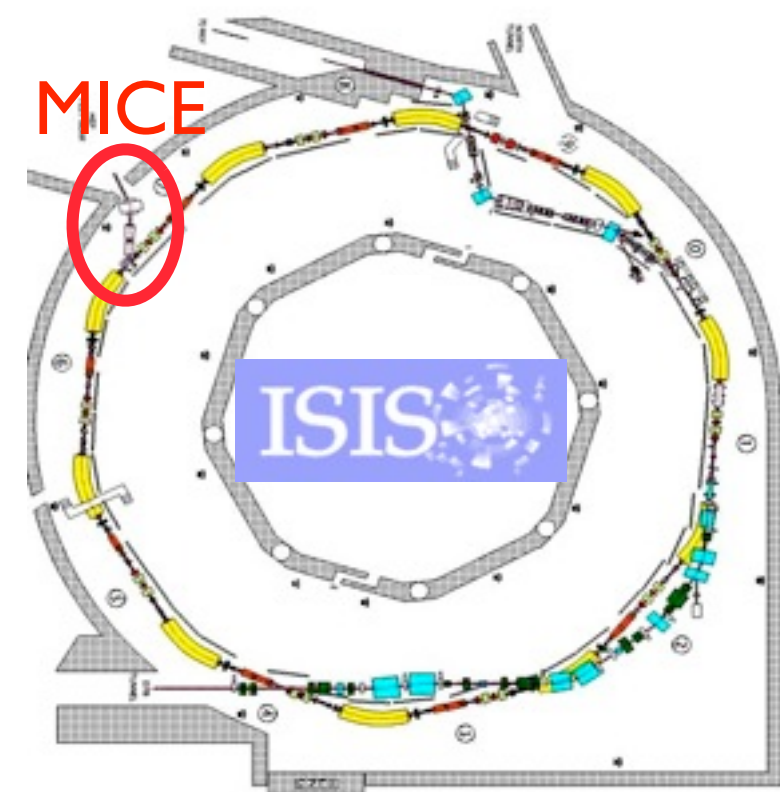
- Goals of MICE:

- Build section of cooling channel giving desired performance for a Neutrino Factory
- Operate in μ beam, measure performance in various modes and beam conditions
- Compare with & validate Monte Carlo



Muon Ionization Cooling Experiment

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



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

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 Bouchier Boulevard, BG-1164 Sofia, Bulgaria
- R. Berton, 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. Verguilo
[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. Mullacraane, 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 Collaboration

(listed alphabetically in course)

- M. Bogomilov, Y. Karacim, [Department of Atomic Physics](#), Sofia, Bulgaria
- R. Bertoni, M. Bonesini, [INFN Milano](#), Dipartimento di Fisica, Università di Milano, Italy
- V. Palladino, [INFN Napoli](#), Dipartimento di Fisica, Università di Napoli, Italy
- G. Cecchetti, A. de Bari, [INFN Pavia](#), Italy
- D. Orestano, L. Tortora, [INFN Roma III](#) and Physics Department, University of Rome, Italy
- P. Chimenti, G. Giannini, [University of Trieste](#) and [INFN Trieste](#), Italy
- S. Ishimoto, S. Suzuki, [High Energy Accelerator Research Organization](#), Japan



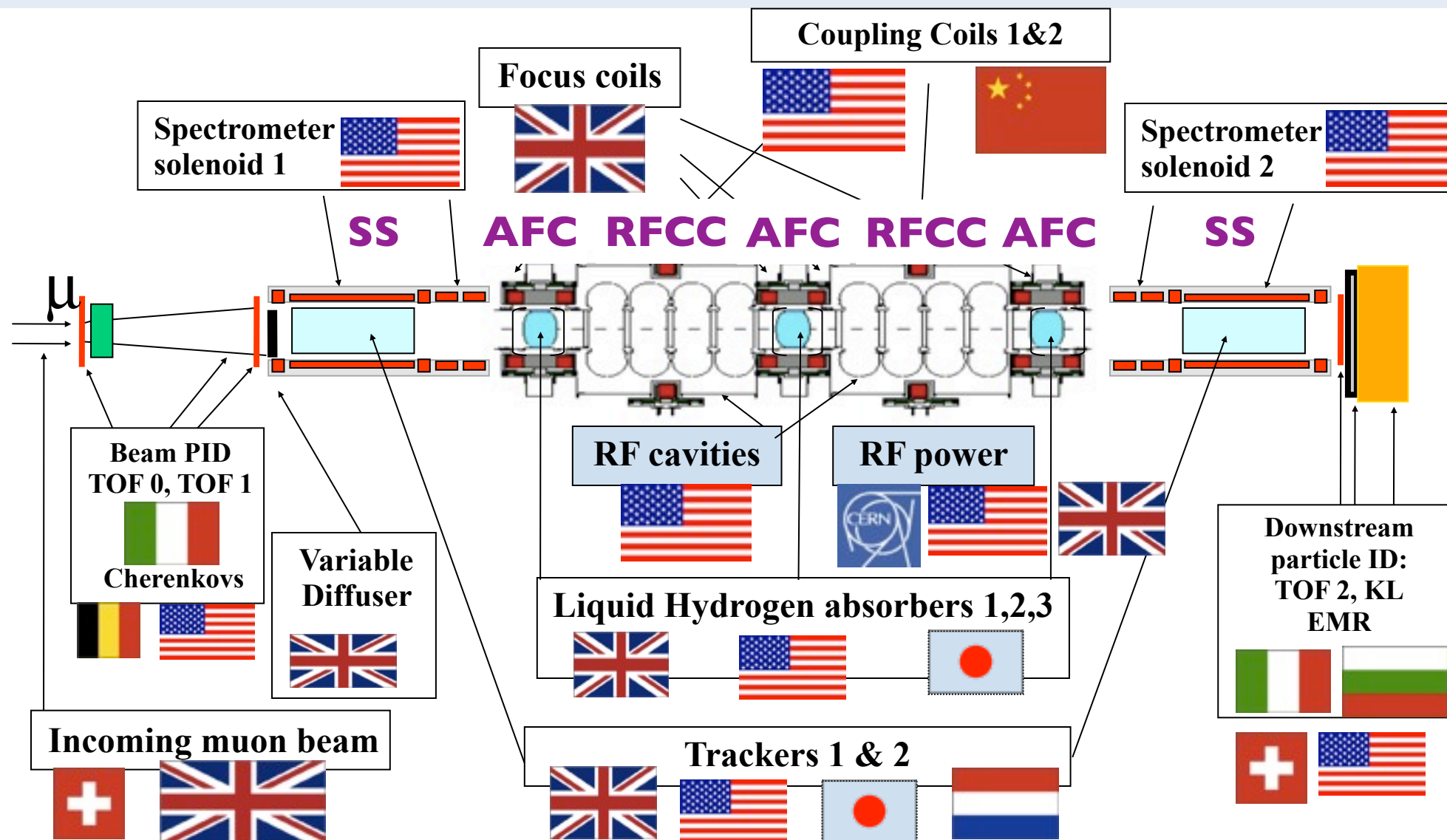
C. Long, H. Sakamoto, T.

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

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



MICE Collaboration

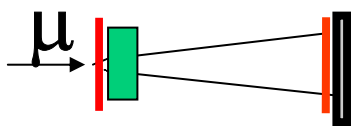


MICE Module Key:

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

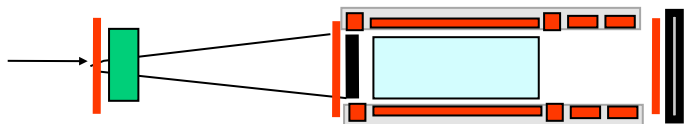
Steps of MICE

April '08 Plan:



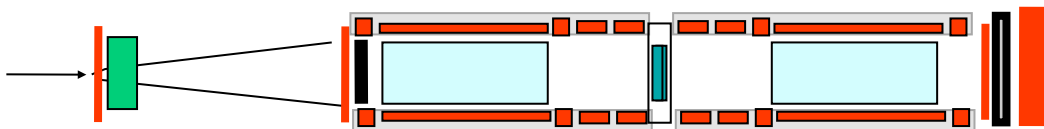
STEP I

2008-9



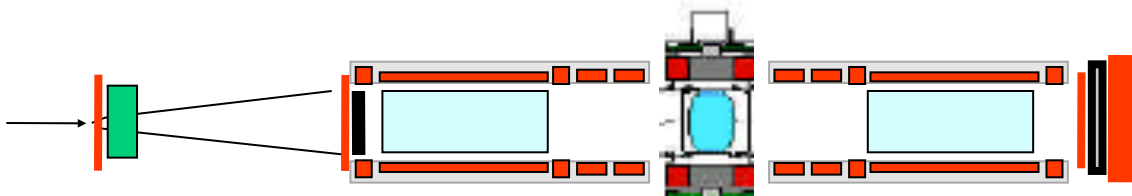
STEP II

Q2/Q3 2010



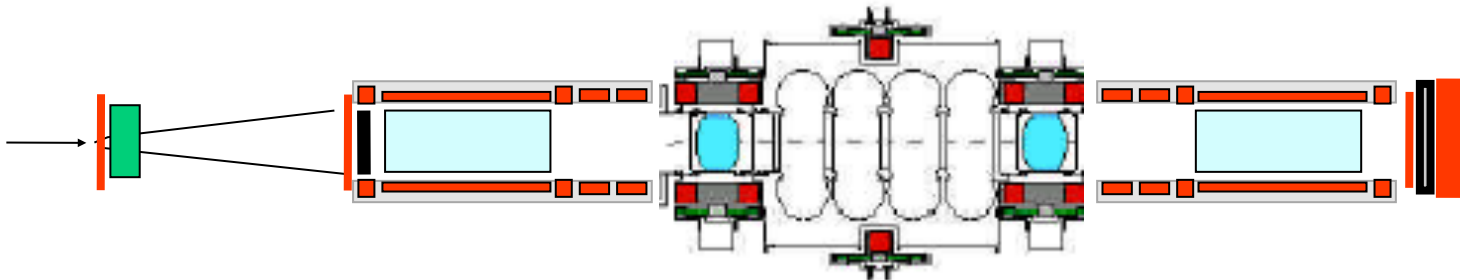
STEP III/III.1

Q4 2010 - 2011



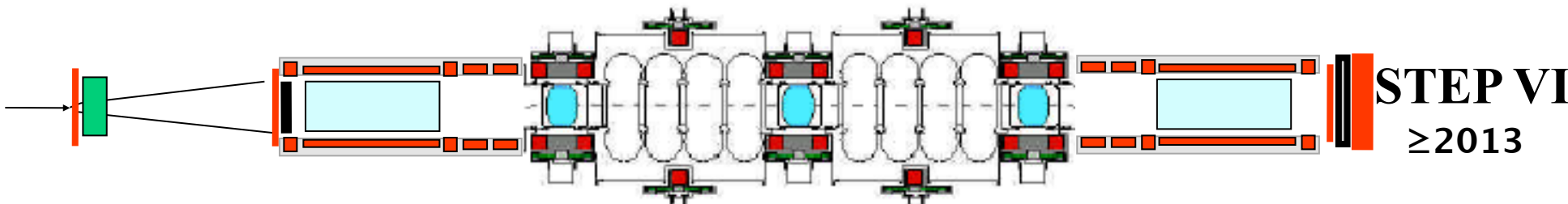
STEP IV

2011



STEP V

2012-13



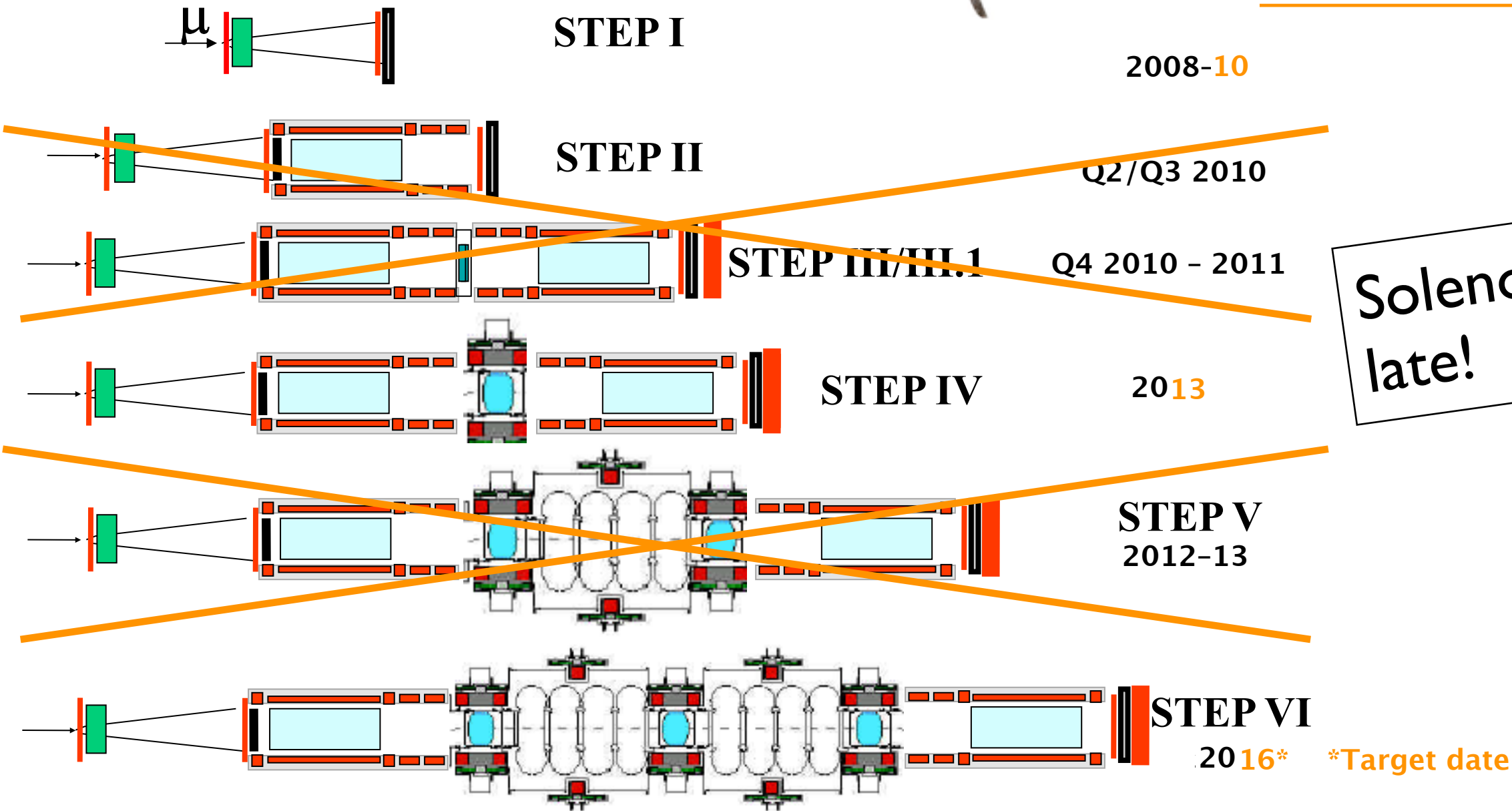
STEP VI

≥2013

Steps of MICE

April '08 Plan:

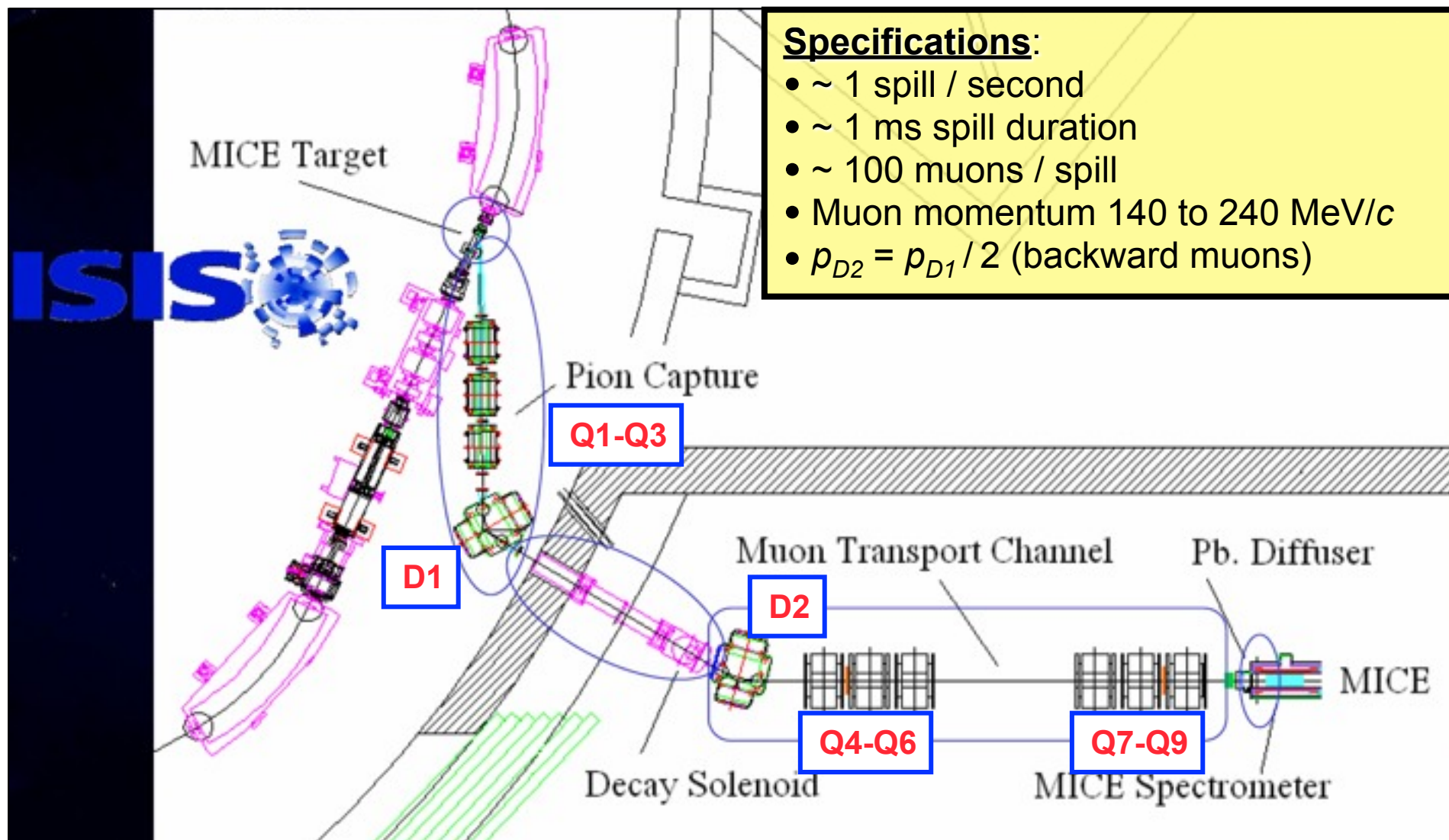
As of Feb. '12:



MICE Beamline

[RAL]

- Installed 2007–8

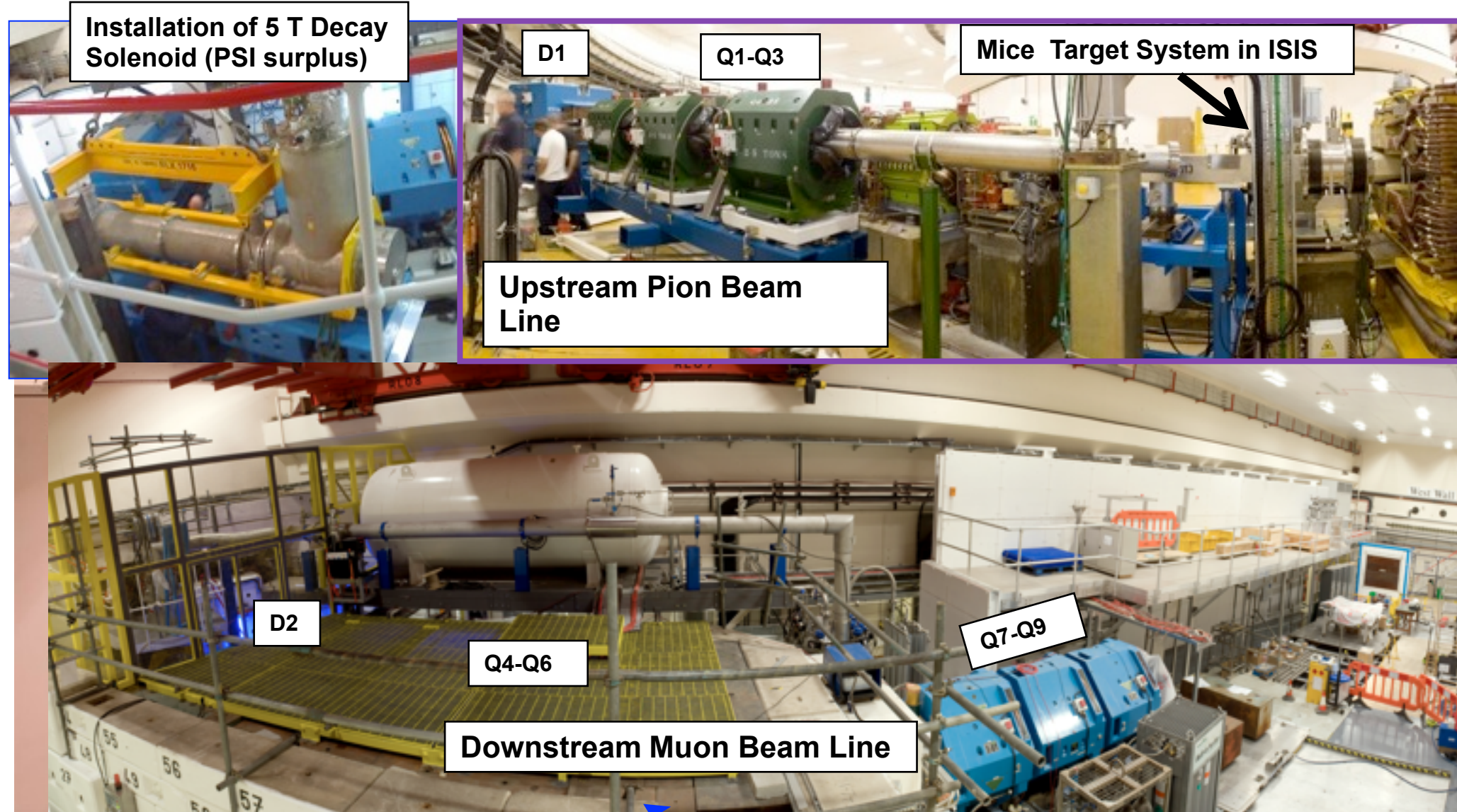


- Working well

MICE Beamline

[RAL]

- Installed 2007–8



- Working well

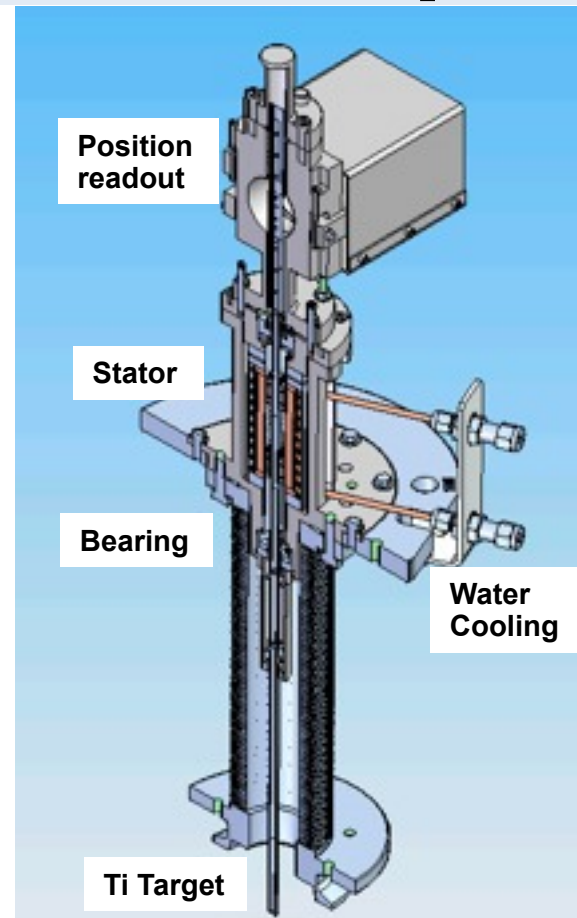
Decay Solenoid Area (DSA)
– shielded against possible neutron spray from ISIS

MICE Target

[Sheffield, RAL, ICL]

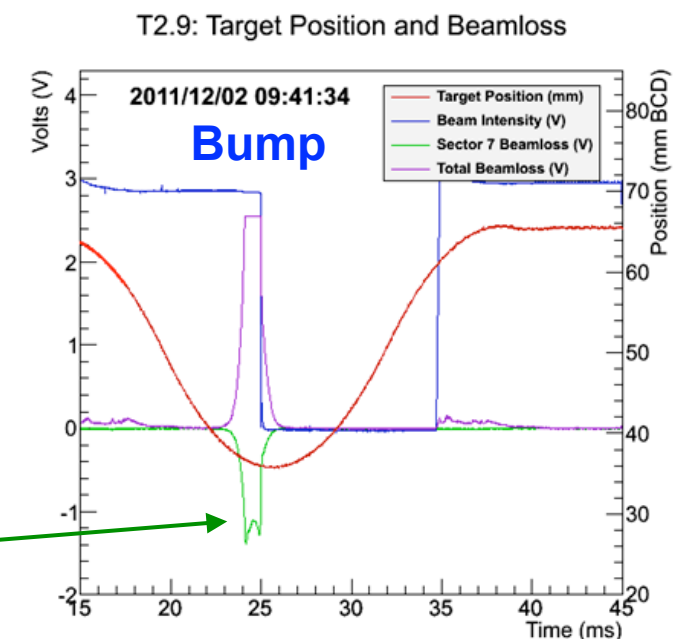
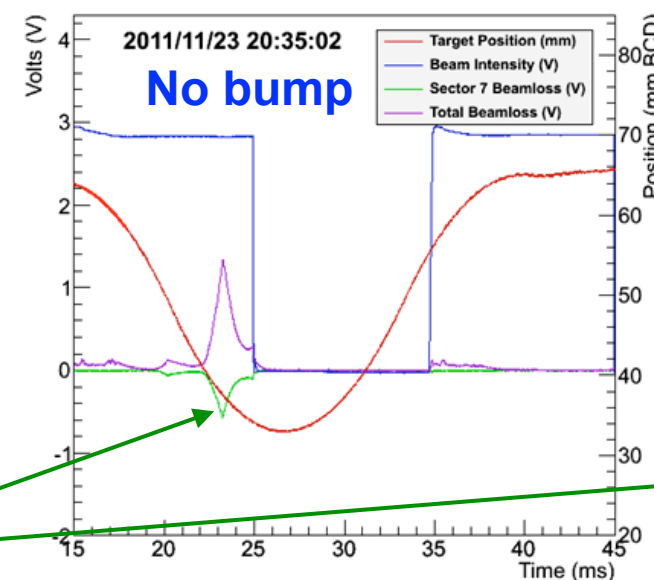
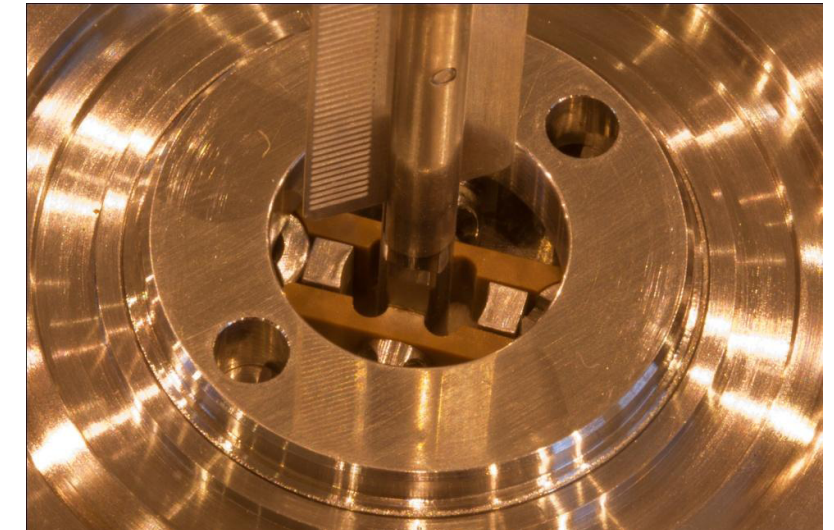
- Linear electric motor drives Ti tube down into ISIS beam at ≈ 1 Hz repetition rate
- Uses 80g acceleration to get in and out within one pulse (ISIS pulses at 50 Hz)
- Demonstrator with Tefzel/DLC bearings has run for 3M cycles without dust
- MICE beam intensity smoothed via “beam bump”:
 - steer ISIS beam down, then up to meet descending target

MICE beam intensity



T2.9: Target Position and Beamloss

Target bearing detail



Beam Bump
-8mm(5-7.5ms)
-6mm(7.5-8ms)
+2.2mm(8-9ms)
+4mm(9-10ms)

MICE Particle ID

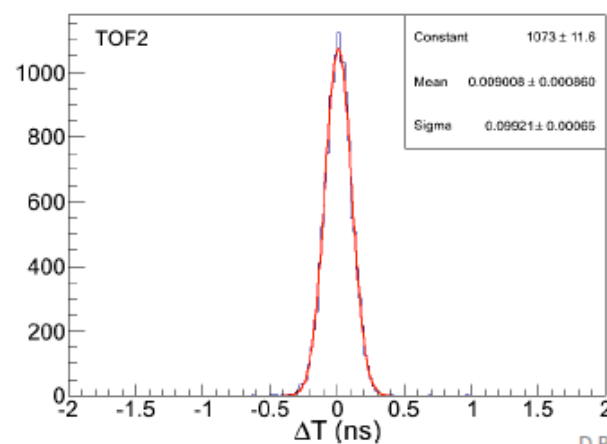
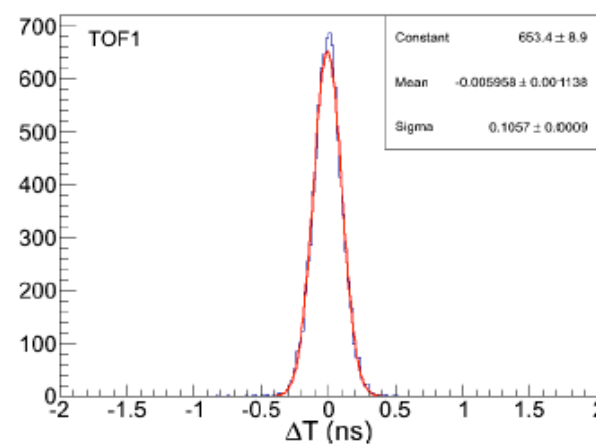
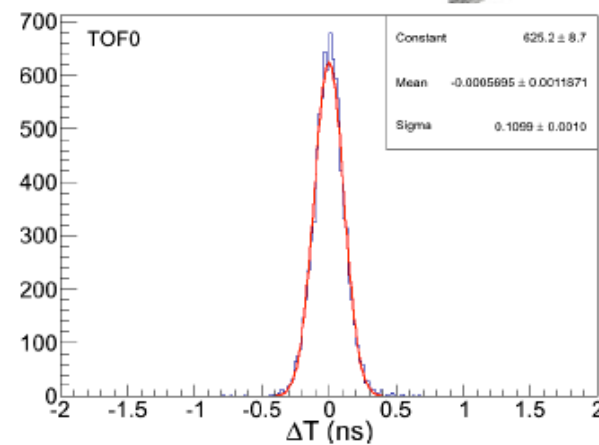
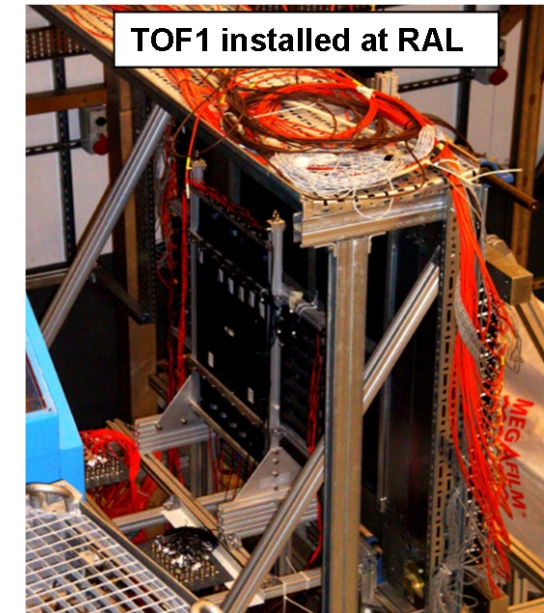
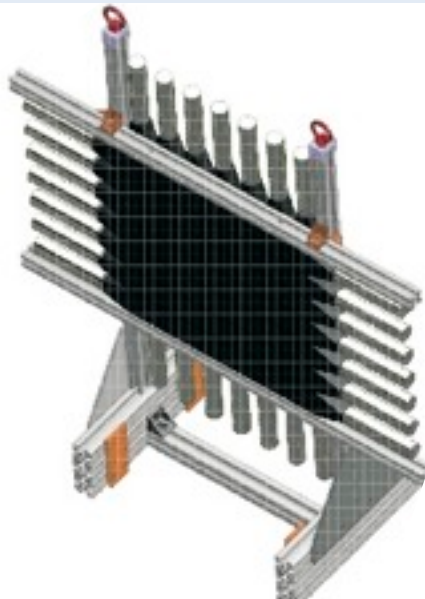
- Need to suppress (to $< 10^{-3}$ level) undecayed π in beam & decay electrons
- Performed using
 - 3 sets of TOF counters (Milan/Pavia/Geneva/Sofia),
 - 2 Cherenkov counters (U Miss/IIT/U Iowa)
 - KL sampling EM Calorimeter (Rome II), and
 - Electron-Muon Ranger (Geneva/FNAL/Trieste/Como)

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 II), and ✓
 - Electron-Muon Ranger (Geneva/FNAL/Trieste/Como) due in May

Time-of-Flight Counters

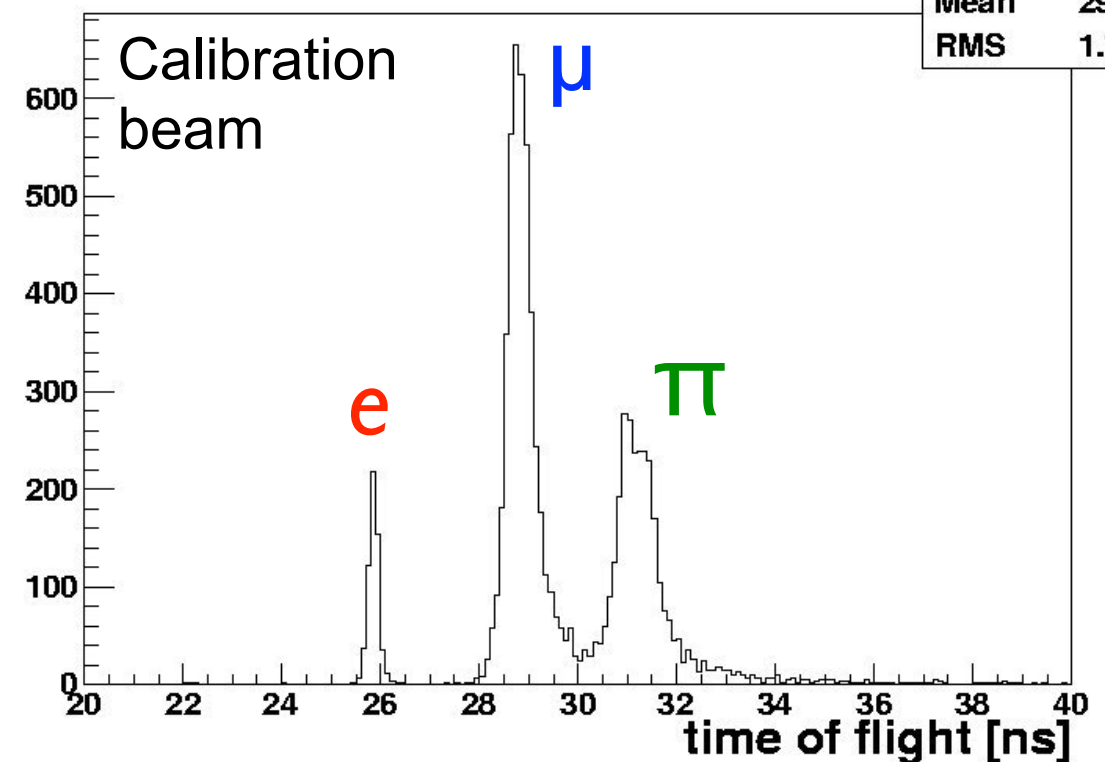
[Milan, Pavia, Geneva, Sofia]



Resolutions

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

TOF0 -> TOF1

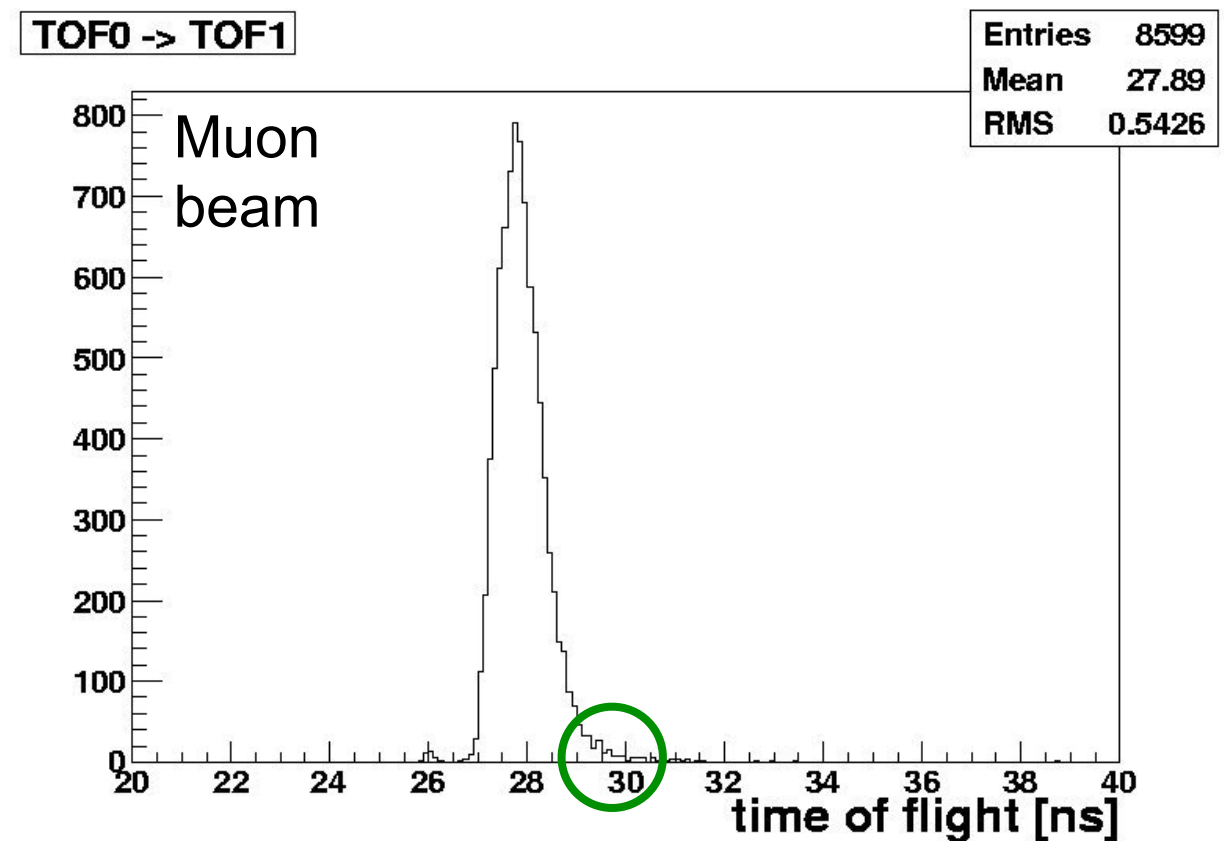
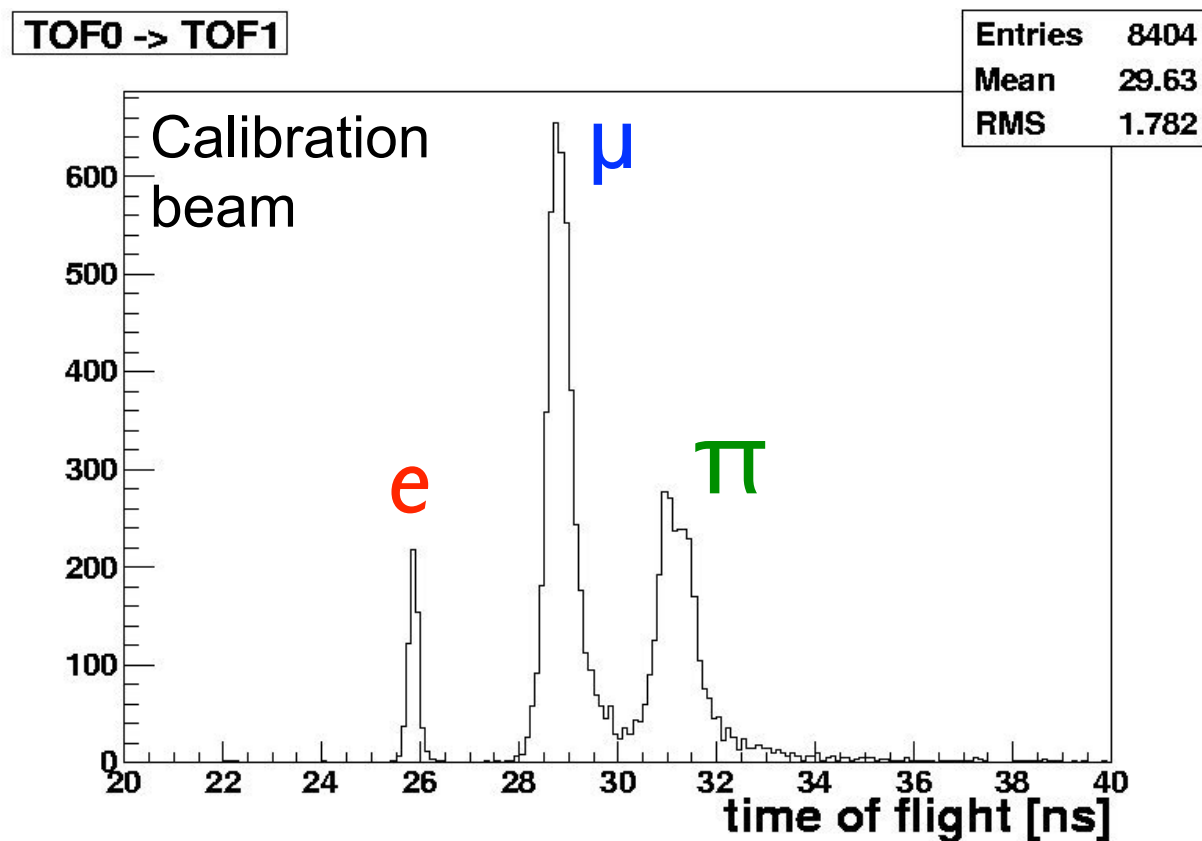


D.Rajaram, IIT, 2/9/12

Time-of-Flight Counters

[Milan, Pavia, Geneva, Sofia]

- Setting $p_{D2} = p_{D1}$ gives $\pi/\mu/e$ calibration beam:
- Can select “pure” μ beam by $p_{D2} = 0.5 p_{D1}$:



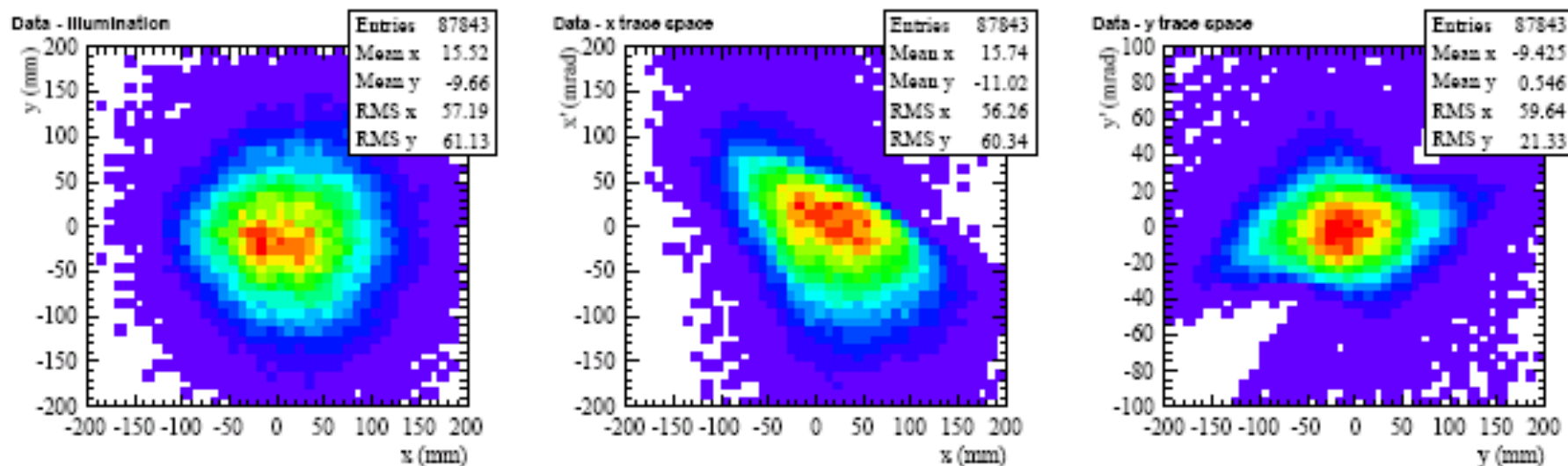
- $\mathcal{O}(\%)$ residual pions in MICE muon beam, to be suppressed via Cherenkov counters

TOF Emittance Analysis

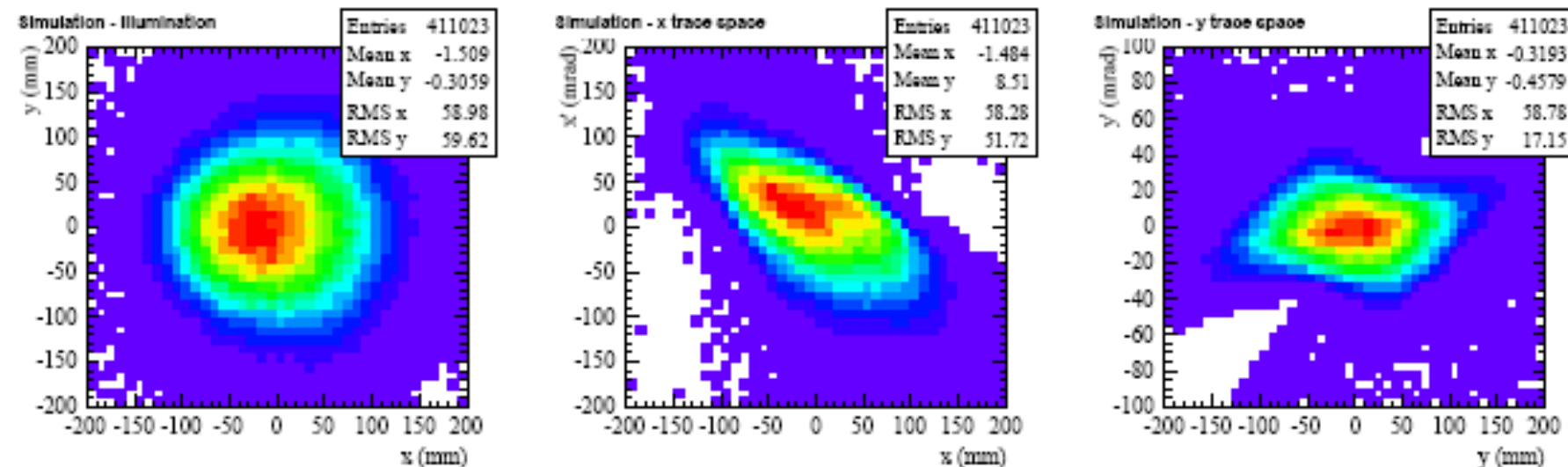
[M Rayner, U Oxford]

- Emittance analysis *without* spectrometers:

Data:



MC:

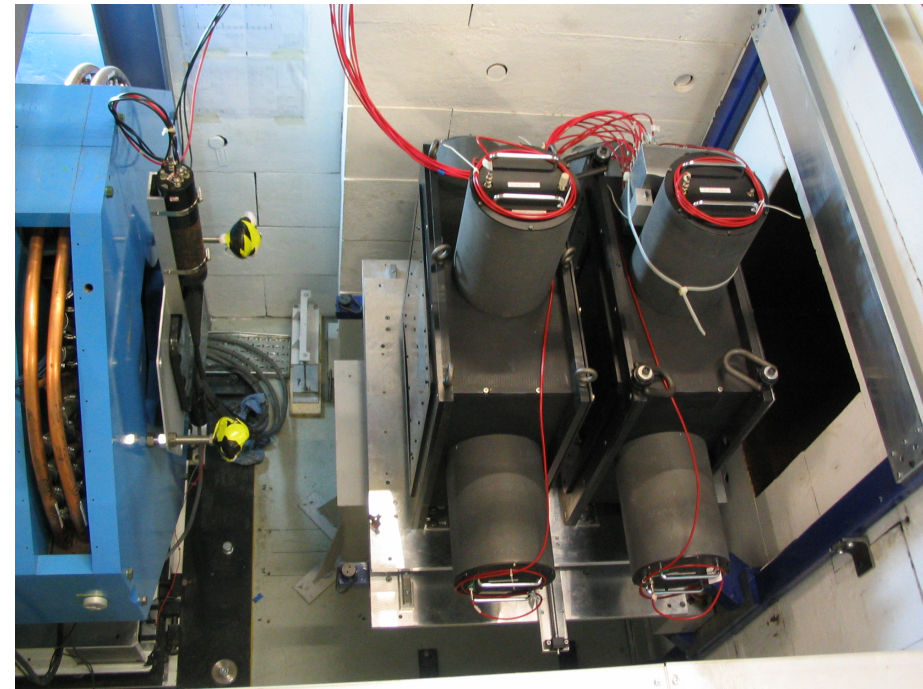
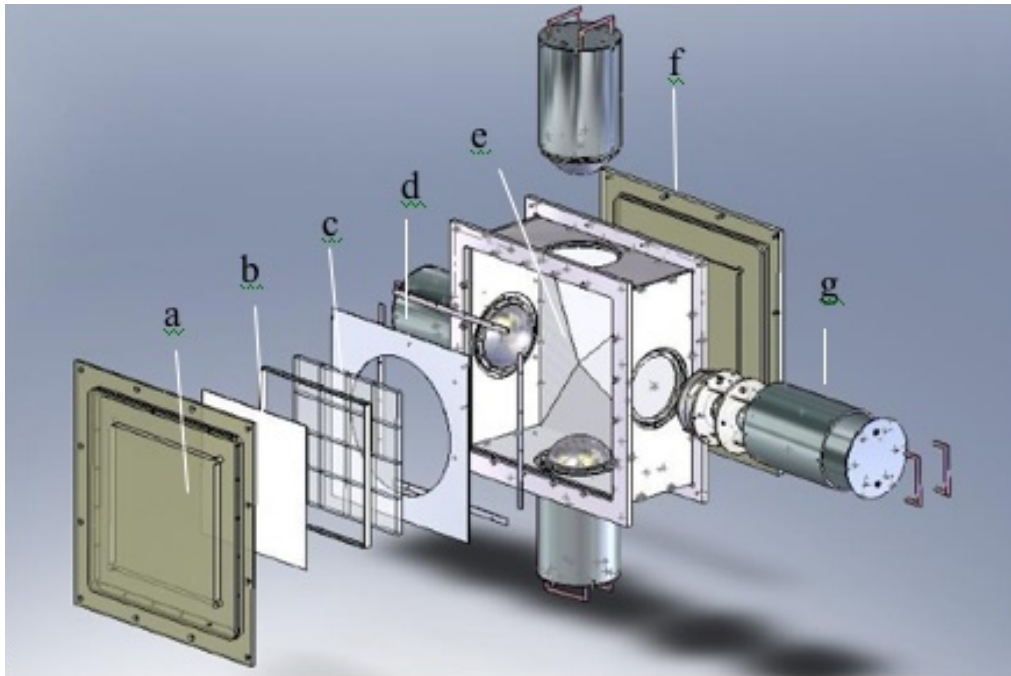


- PMTs at each end allow interpolation to ≈ 1 cm
- TOFs measure x' to 18 mrad, y' to 5 mrad, momentum to $\approx 2\%$
- paper in preparation

Cherenkov Counters

[U Miss, IIT, U Iowa]

- 2 Cherenkov counters with aerogel radiators:

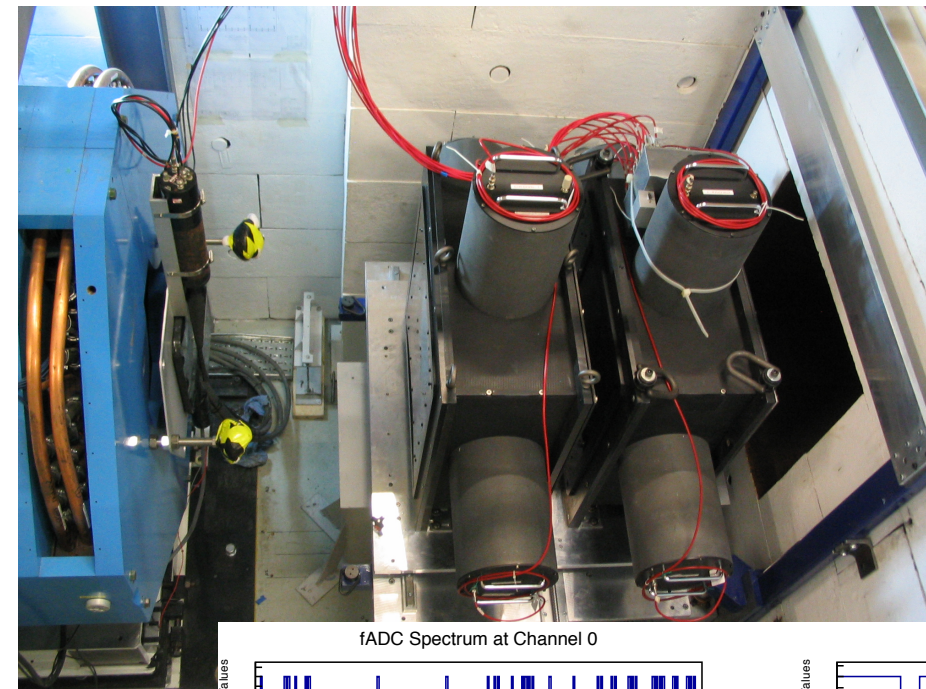
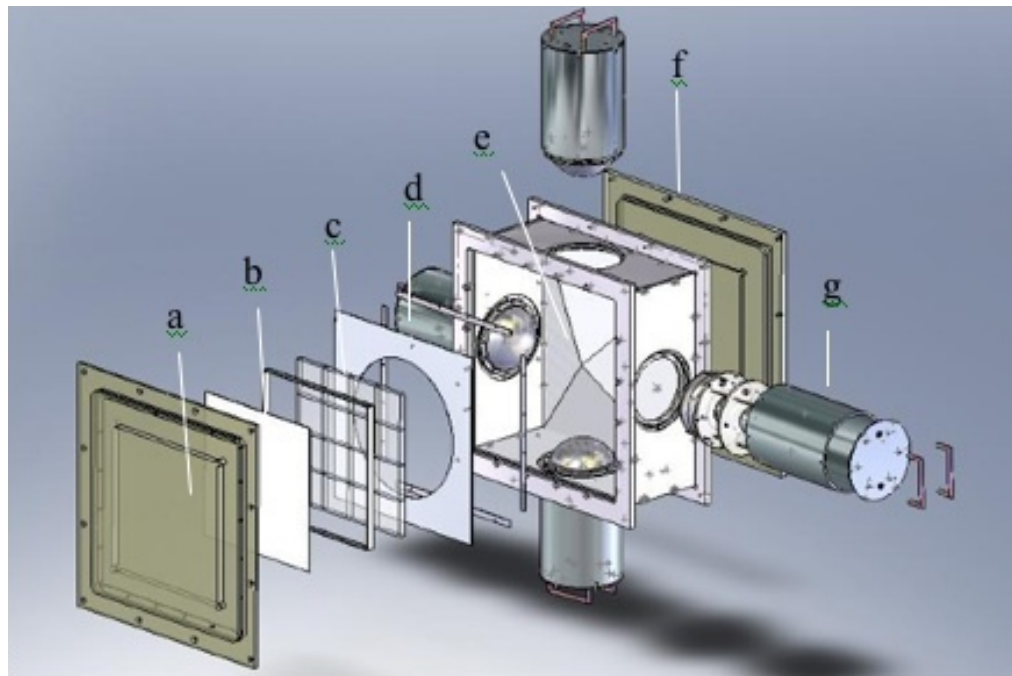


- Located in DSA,
downstream of Q9 & TOF0
- 1 GS/s FADC readout
- Performance under study

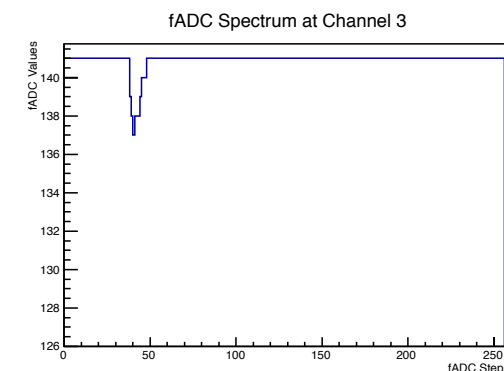
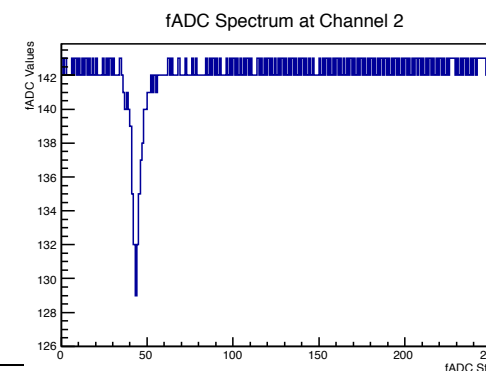
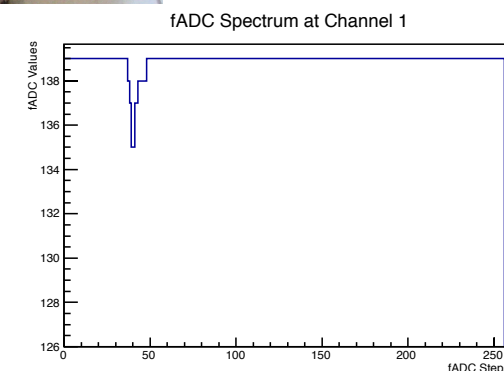
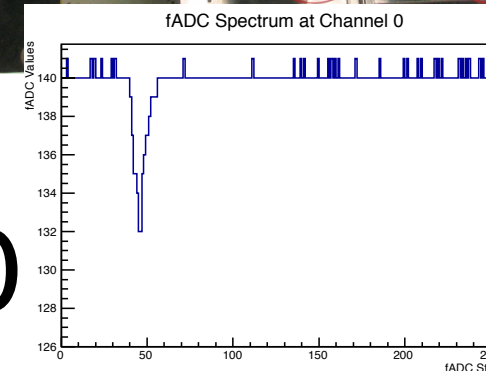
Cherenkov Counters

[U Miss, IIT, U Iowa]

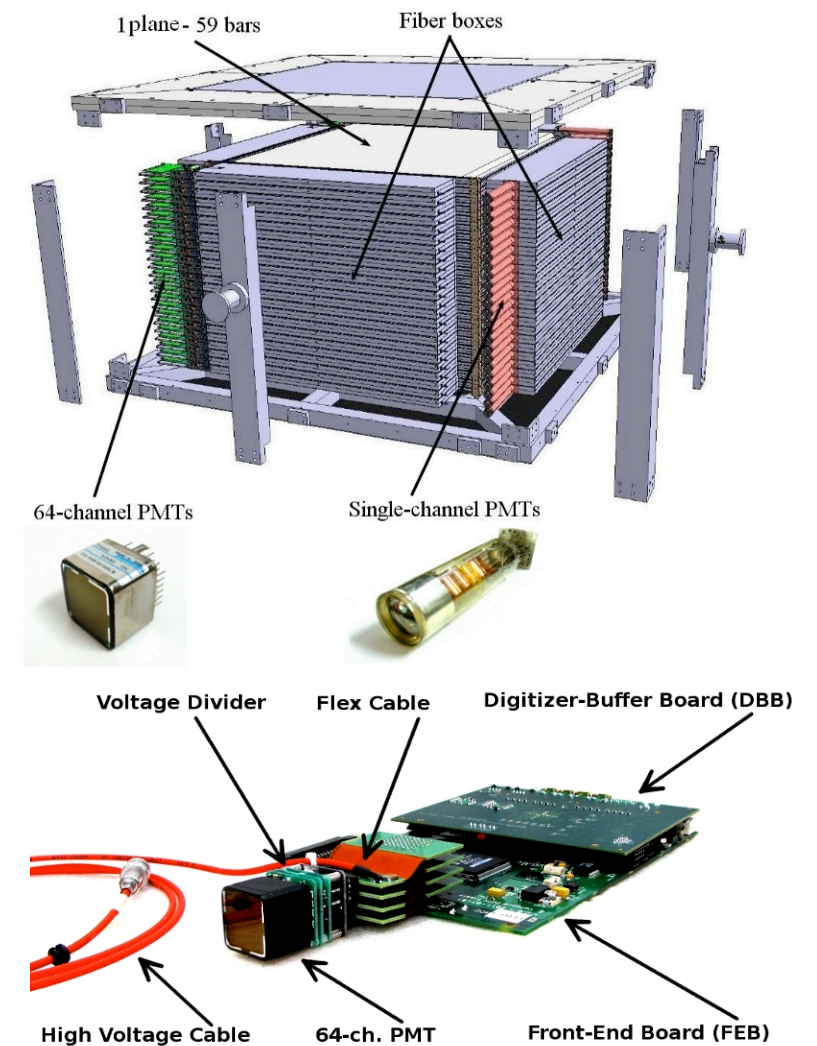
- 2 Cherenkov counters with aerogel radiators:



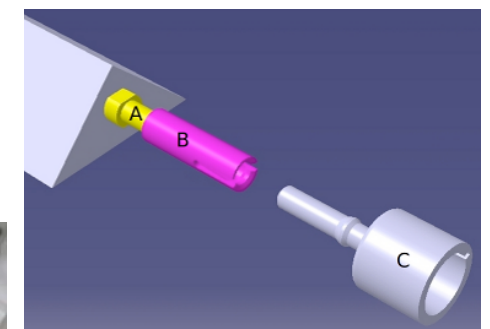
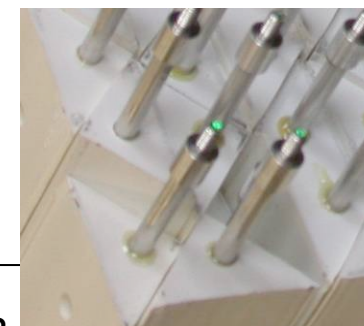
- Located in DSA, downstream of Q9 & TOF0
- 1 GS/s FADC readout
- Performance under study



- Under construction at U Geneva



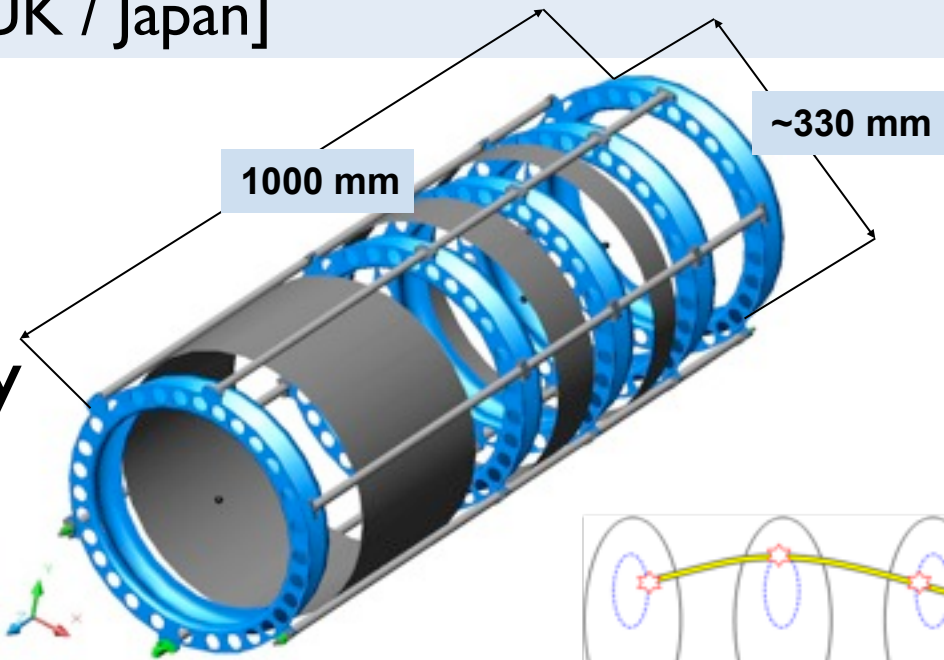
- Prototype tested at MICE last summer
- To be delivered & installed in May



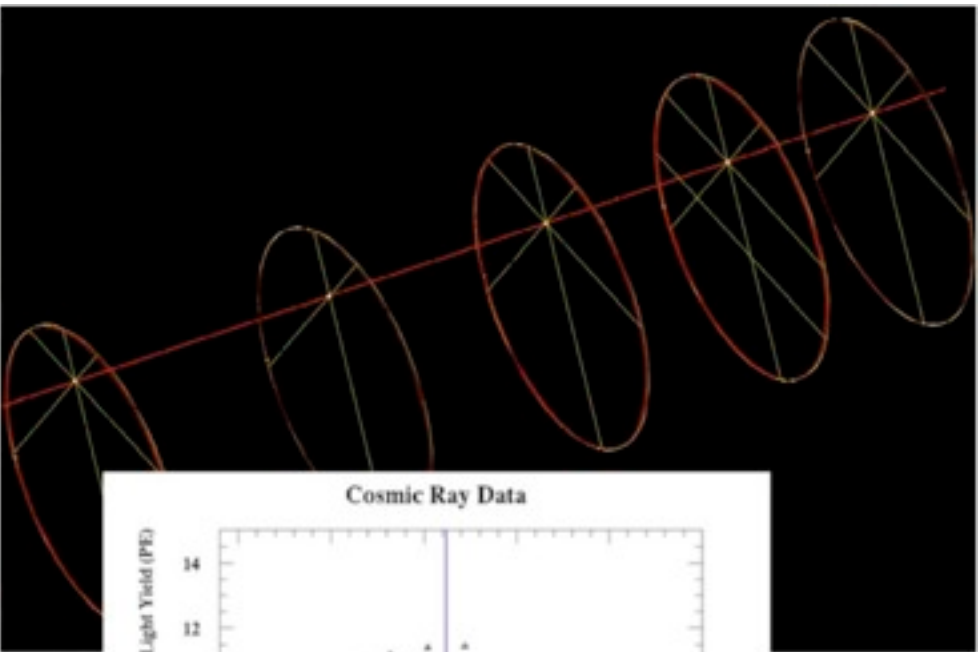
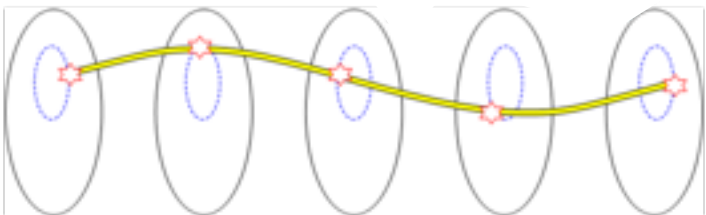
SciFi Spectrometers

[US / UK / Japan]

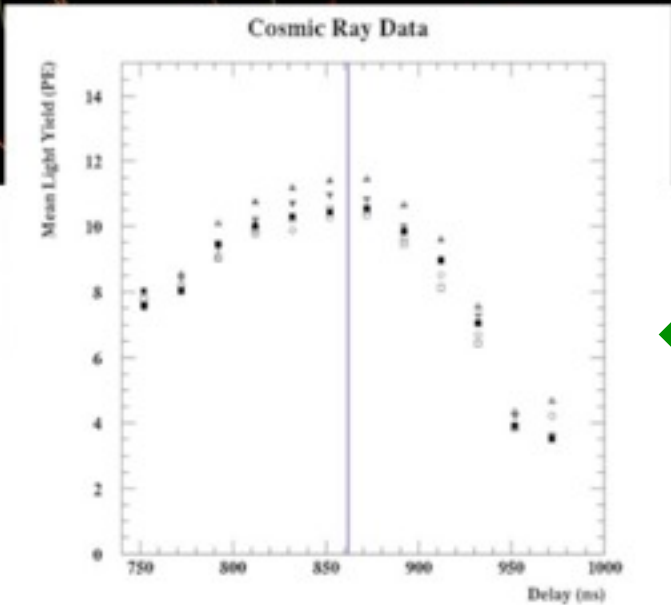
- Trackers complete & tested with cosmic rays
 - installation awaiting SS delivery (SS1 June, SS2 Sept.)



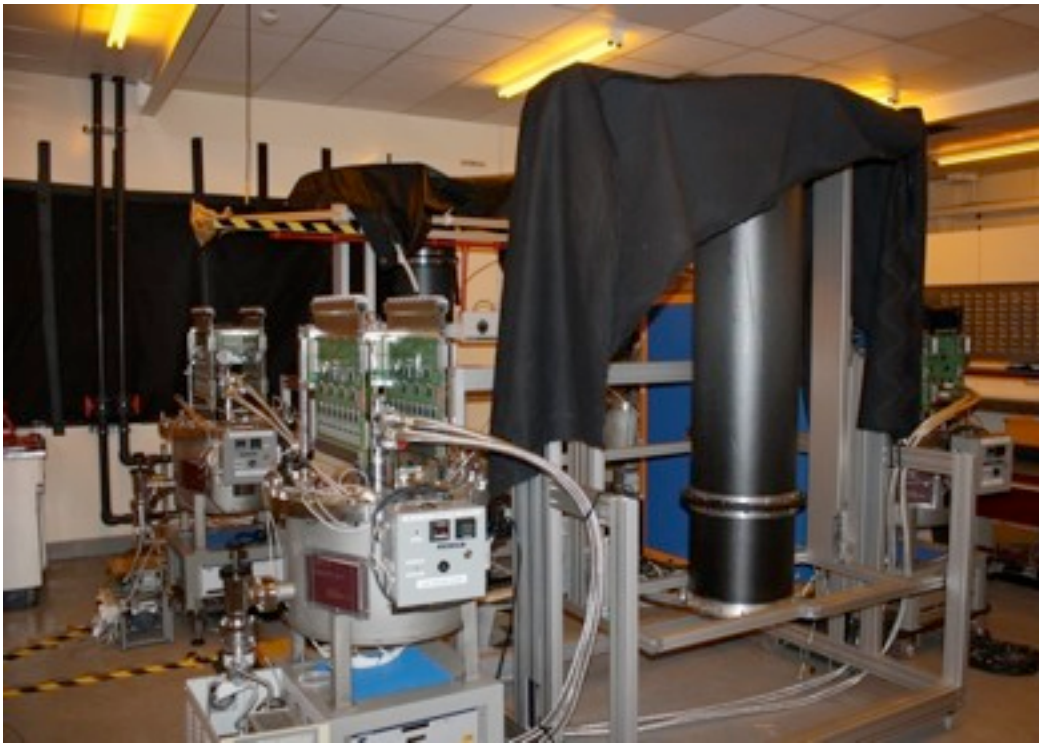
5 stations of
350 μm SciFi



← Typical
cosmic
track



← Light yield ≈ 10 p.e.



Cosmic test setup

Spectrometer Solenoids

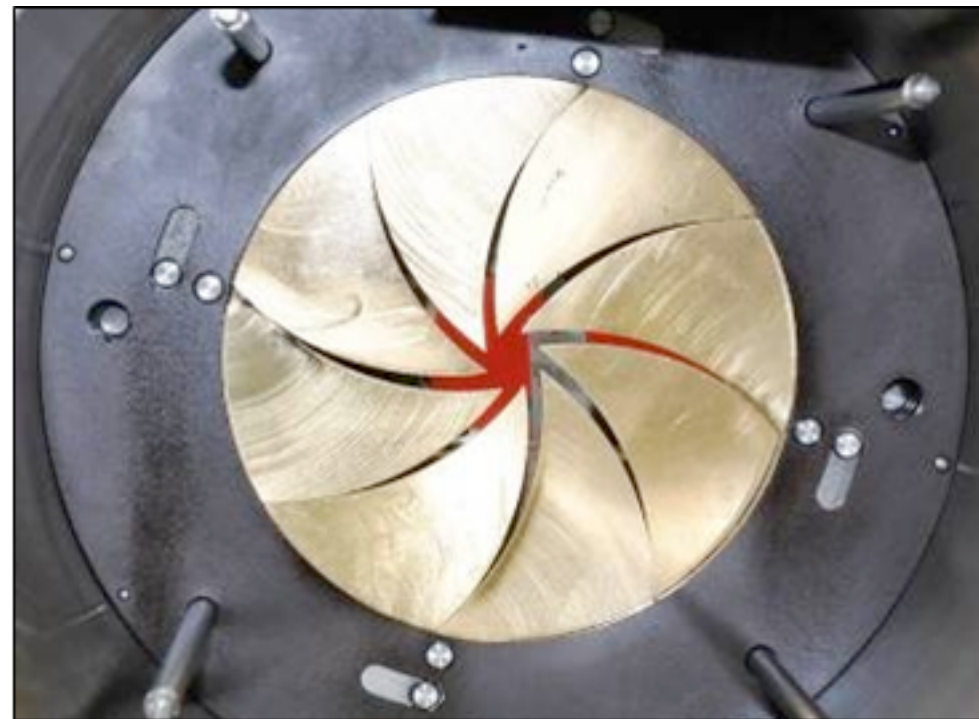
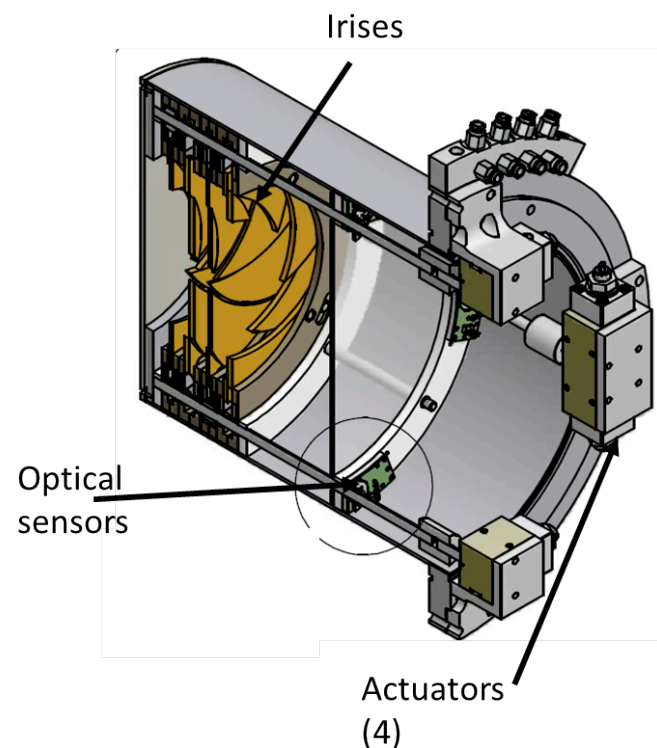
[LBNL]

- Build at Wang NMR in Livermore to LBNL spec
- Design field = 4 T
- Design flaws revealed during training (excessive boil-off, HTS, LTS lead burnouts)



- Repairs to SS1 done, SS2 nearly done

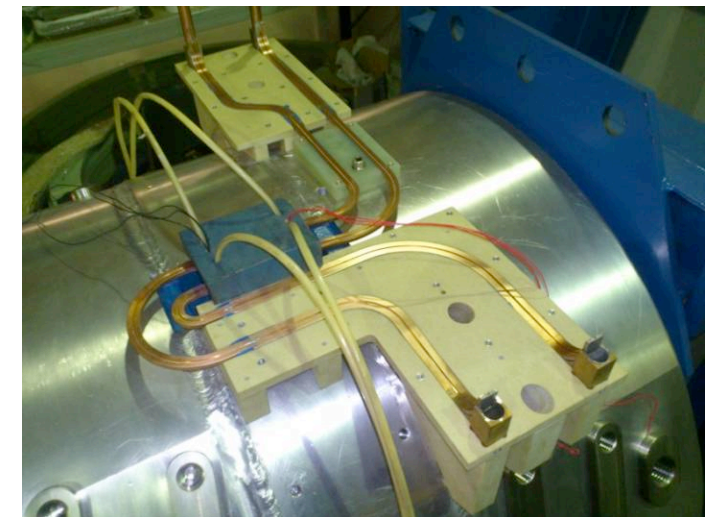
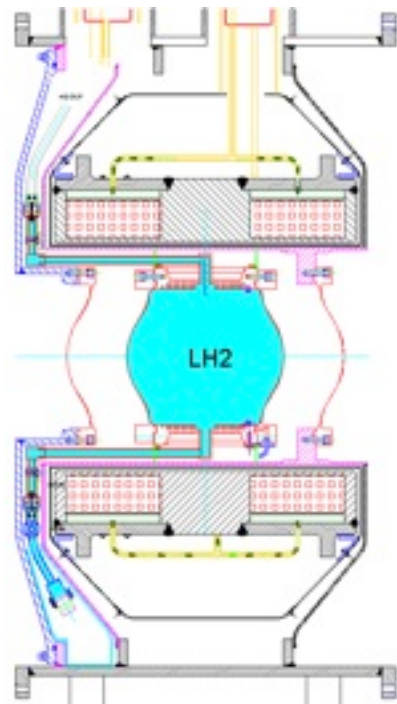
- Need variable-thickness high-density material in SSI to generate required input emittances



- 4 irises with W or brass petals
- W petals have brass backing plate
- delivery planned for August

AFC Modules

[U Oxford, RAL]

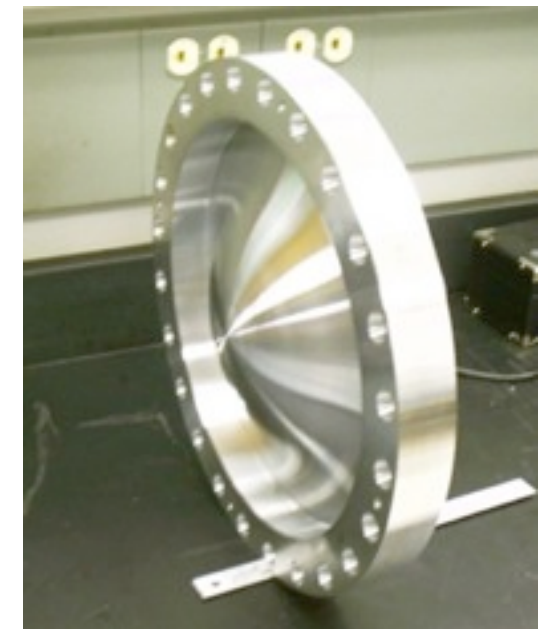
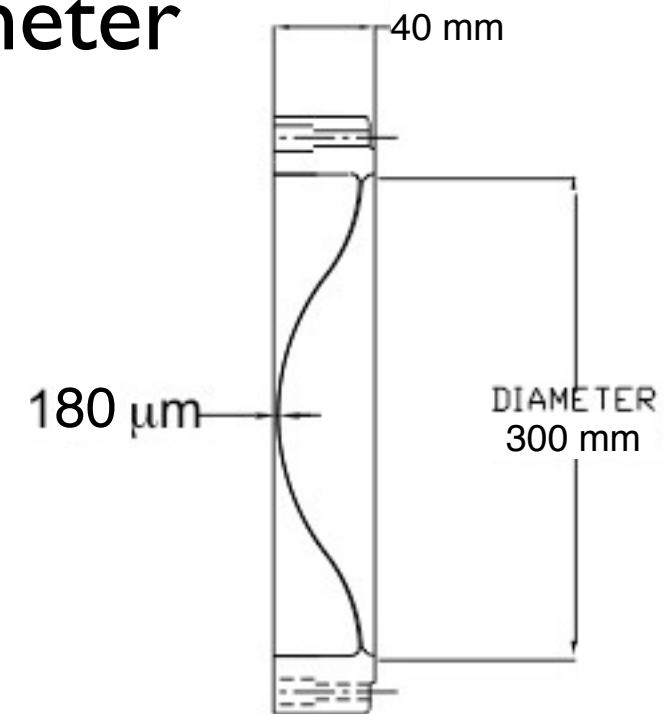


- Fabrication in progress at Tesla Eng. Ltd. (UK)
- Delivery of 1st FC expected in April
- Absorber (KEK) already on hand at RAL

LH2 Absorbers

[KEK]

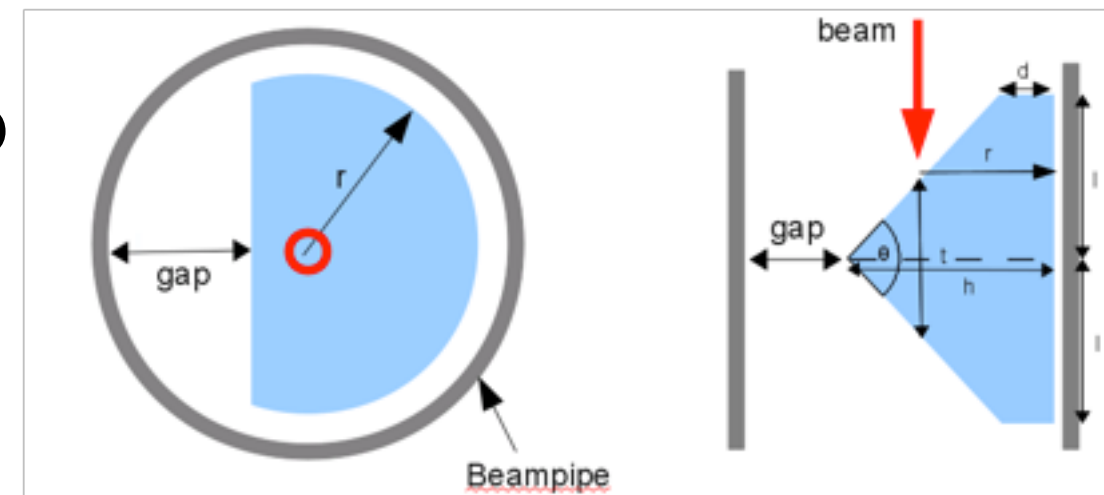
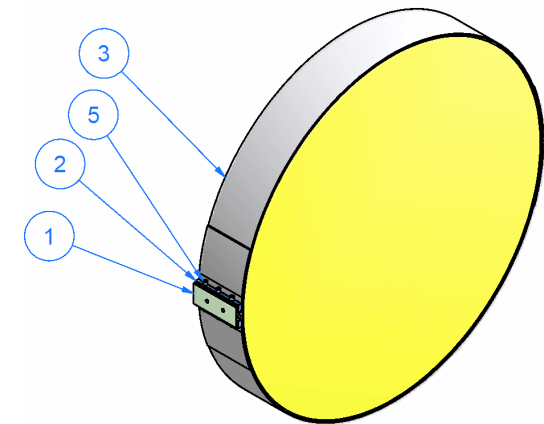
- 35 cm long x 30 cm diameter
- 3 required
 - 1 delivered so far, 2nd built
- Thin, tapered Al-alloy windows
 - designed by IIT & U Oxford
 - fabricated by U Miss
- Can also use LHe



LiH Absorbers

[FNAL]

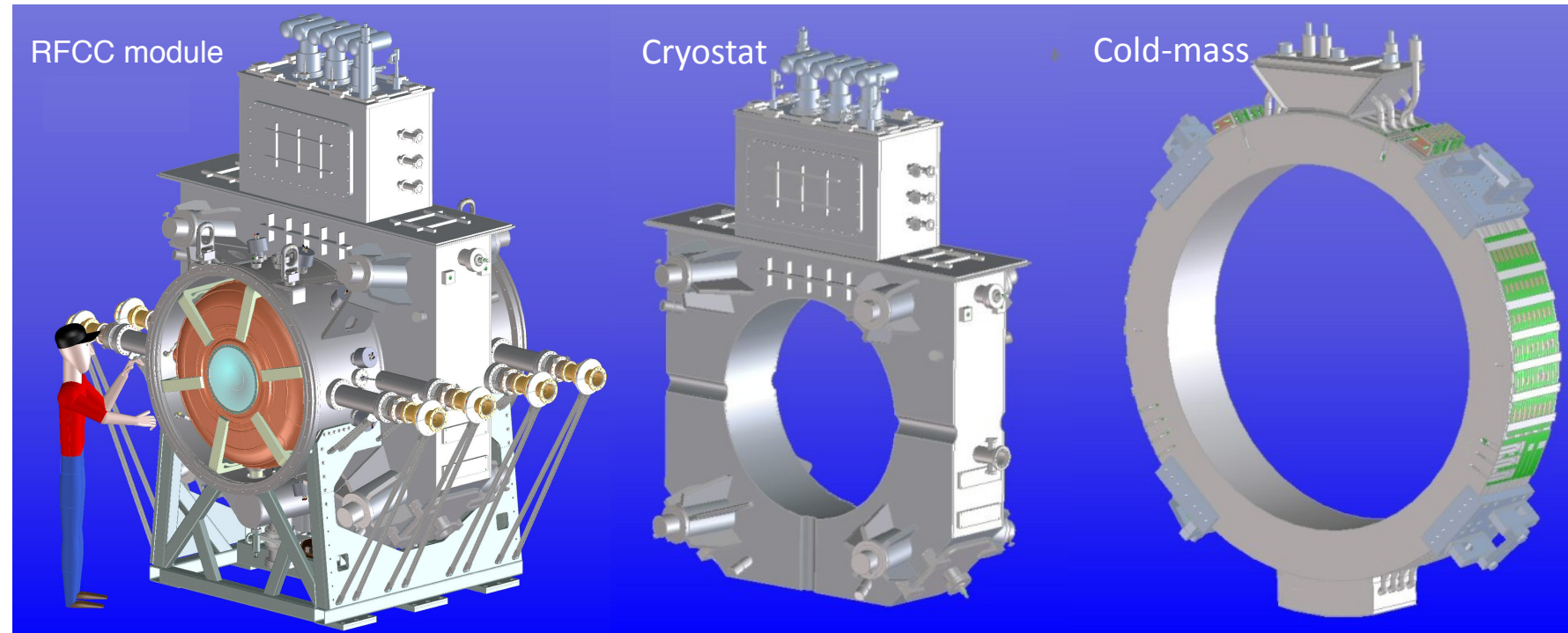
- In fab at Y12 (Oak Ridge)
 - both disks and wedges ordered
 - disks done, awaiting delivery-procedure approvals
- Other solid absorbers also under consideration:
 - C, Al, polyethylene,...



RFCC Modules

[LBNL, HIT, U Miss]

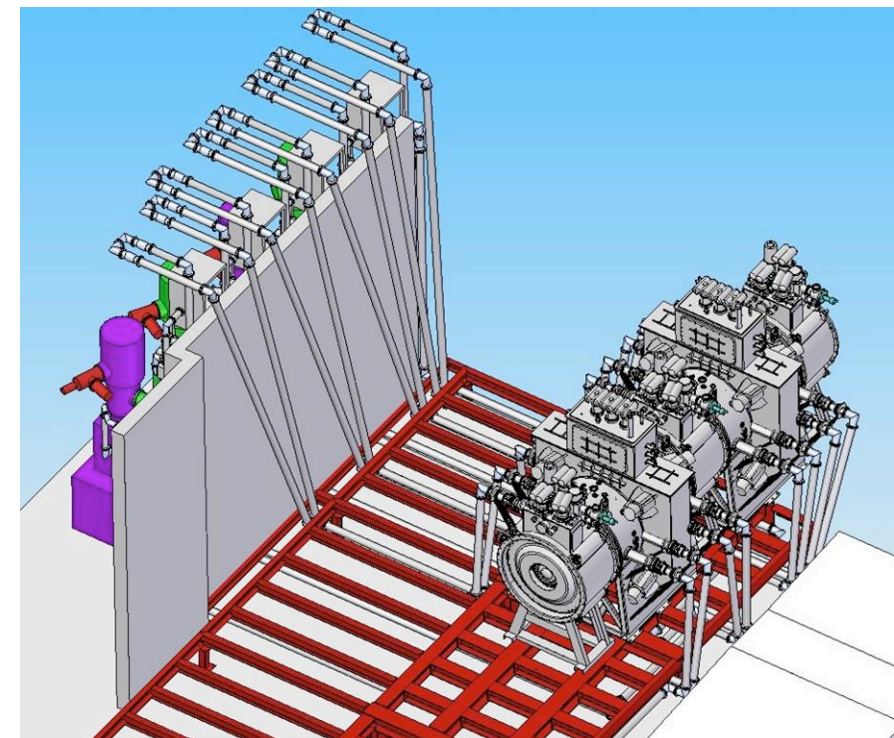
- Design done
- RF cavities built
 - electropolishing awaits LBNL EH&S approval
- Coupling Coil fab in China (HIT, Qi Huan, SINAP) led by LBNL
 - 1st CC delivered
 - test plan in development
 - seeking assembly partner



RF Power

[DL, LBNL, U Miss]

- 4 used 2 MW triode supplies
 - 2 from LBNL, 2 from CERN
 - refurbishment in progress at DL
 - 1st complete & tested at 1 MW
- Fitting it all in MICE Hall will be a feat!
- Workshop 16–17 April at DL to plan low-level system integration



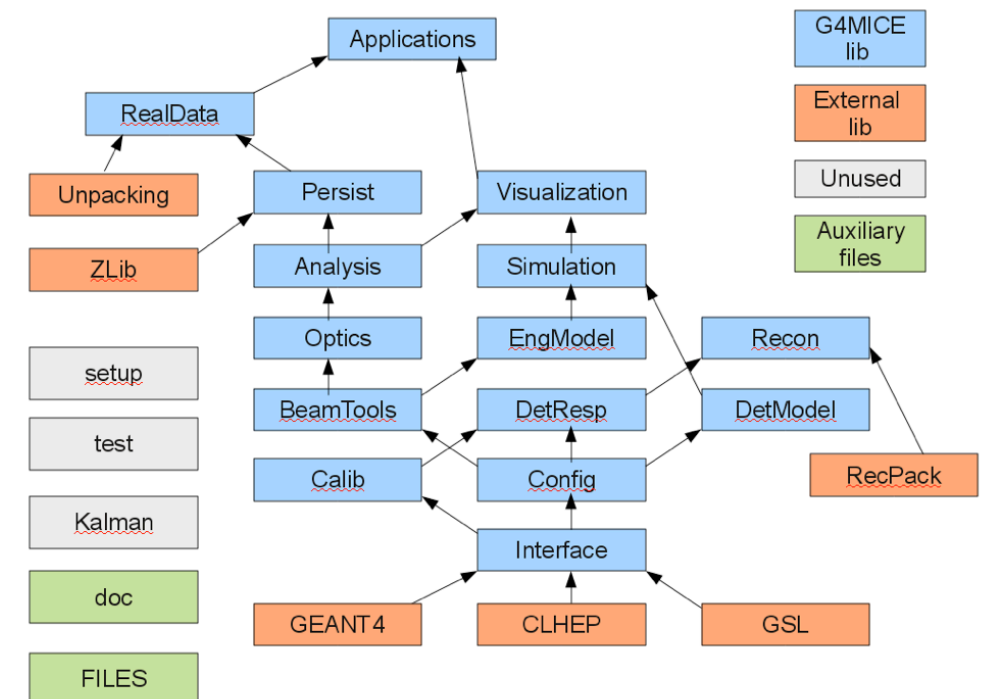
LH2 System

- RAL engineers have made good use of lull in MICE equipment delivery to assemble and begin tests of liquid-hydrogen system
 - uses hydride-bed H_2 storage
 - now doing helium leak-checking
 - 1st test with liquid hydrogen planned for 4 weeks TBD during April–May



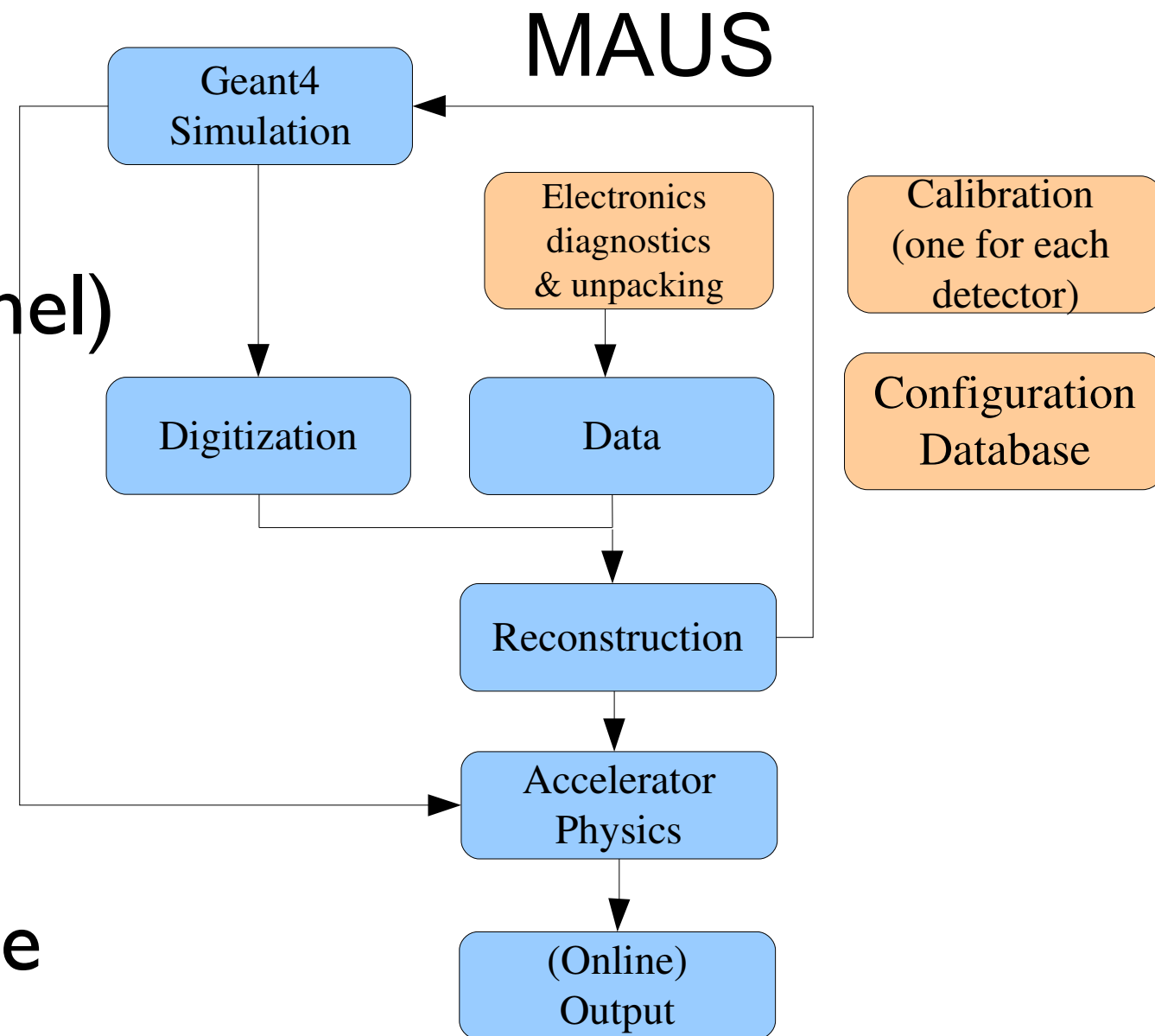
G4MICE

- G4MICE developed initially by Y.Torun (IIT)
- Since expanded under leadership of M. Ellis (ex-Brunel) and C. Rogers (RAL)



MICE Software

- G4MICE developed initially by Y.Torun (IIT)
- Since expanded under leadership of M. Ellis (ex-Brunel) and C. Rogers (RAL)
- New MAUS (MICE Analysis User Software) framework by C.Tunnell (Oxford)
 - simplifies maintenance & use



MICE Outlook

- Aim at complete (Step VI) study of transverse cooling by 2016
 - with 1st cooling demo (Step IV) in 2013
 - as well as demo of emittance exchange
- PhD theses for $\approx 1/2$ -dozen students so far, with several more to come
- For more, see upcoming talks
 - and <http://mice.iit.edu/>