Progress Towards Completion of the MICE Demonstration of Muon Ionization Cooling

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ILLINOIS INSTITUTE OF TECHNOLOGY
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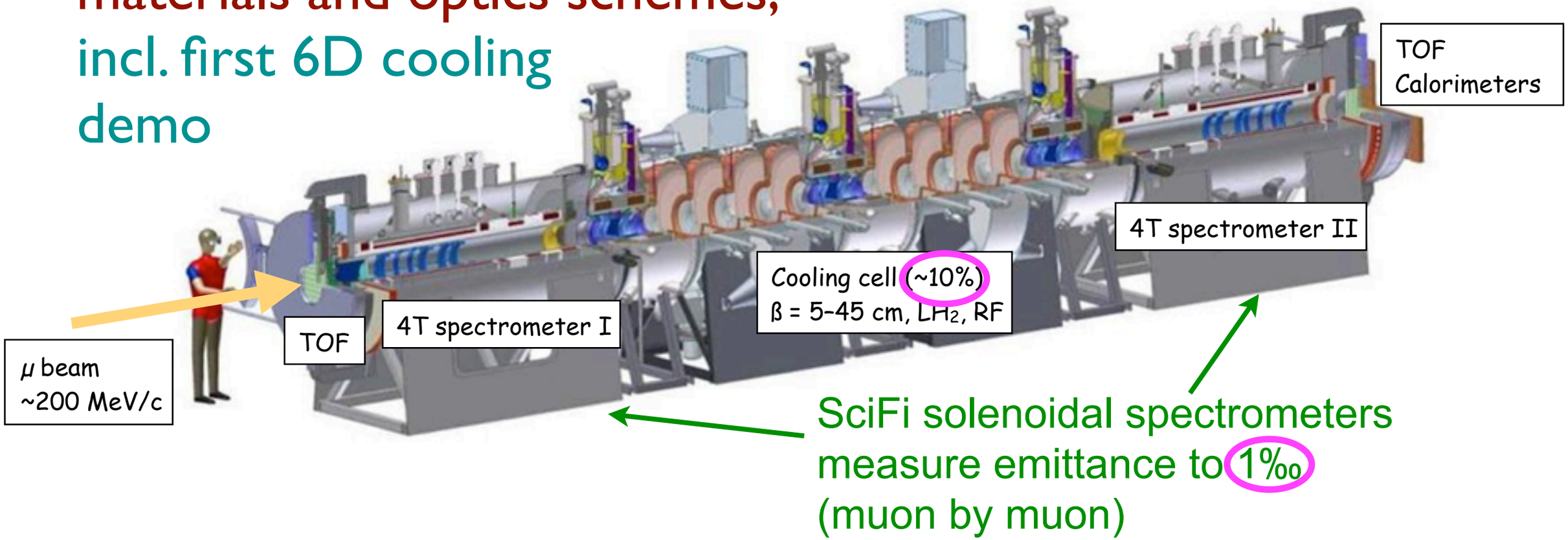
NuFact 2013
IHEP Beijing
21 August 2013

Outline

- Brief MICE overview
- Magnets & other equipment
- Software & results
- Conclusions

MICE

- International Muon Ionization Cooling Experiment at UK's Rutherford Appleton Laboratory (RAL)
- Has flexibility to test several absorber materials and optics schemes, incl. first 6D cooling demo



- Nutshell: under construction, program complete ~2020

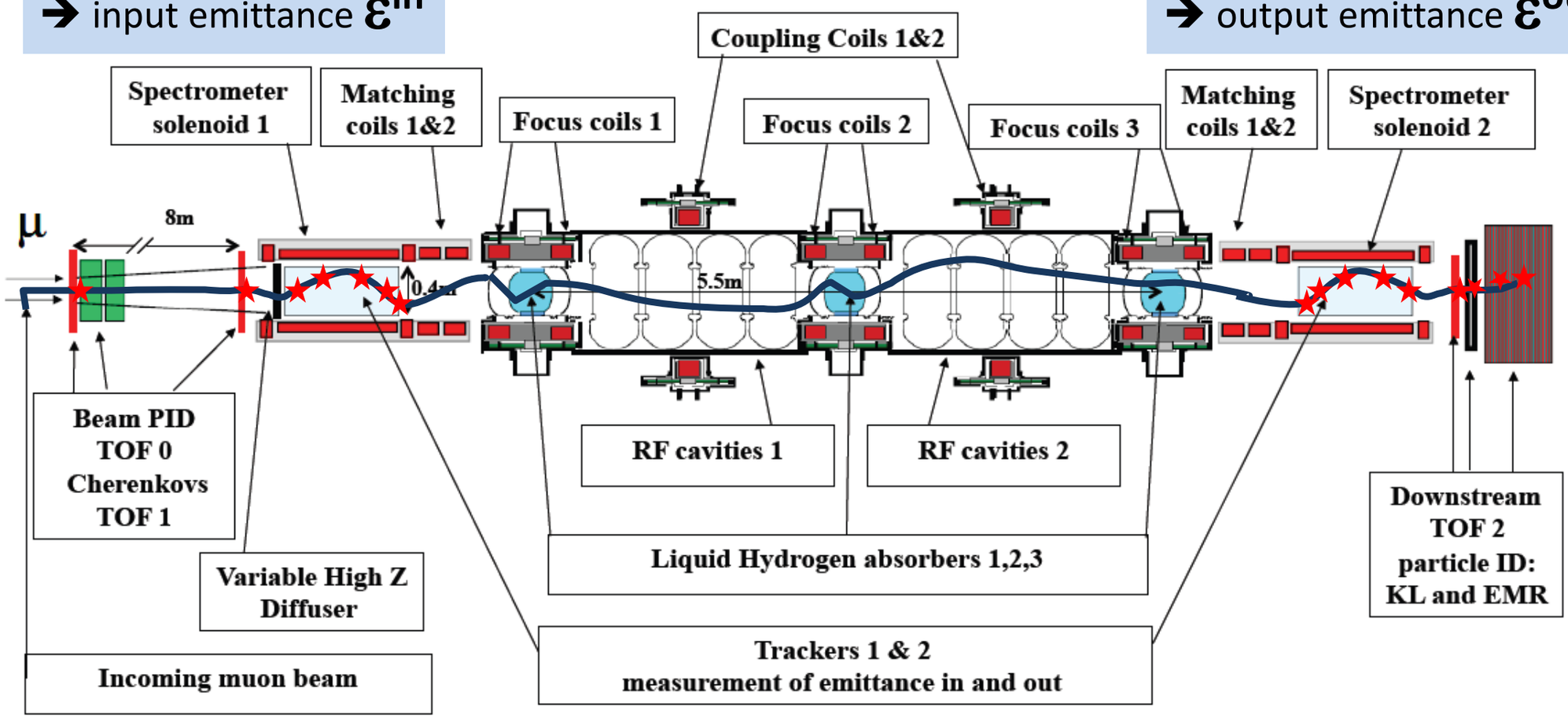
Principle of MICE

MICE the Muon Ionization Cooling Experiment

Measure input particle
x,x',y,y', t, t'=E/Pz
➔ input emittance ε^{in}

COOLING CHANNEL

Measure output particle
x,x',y,y', t, t'=E/Pz
➔ output emittance ε^{out}

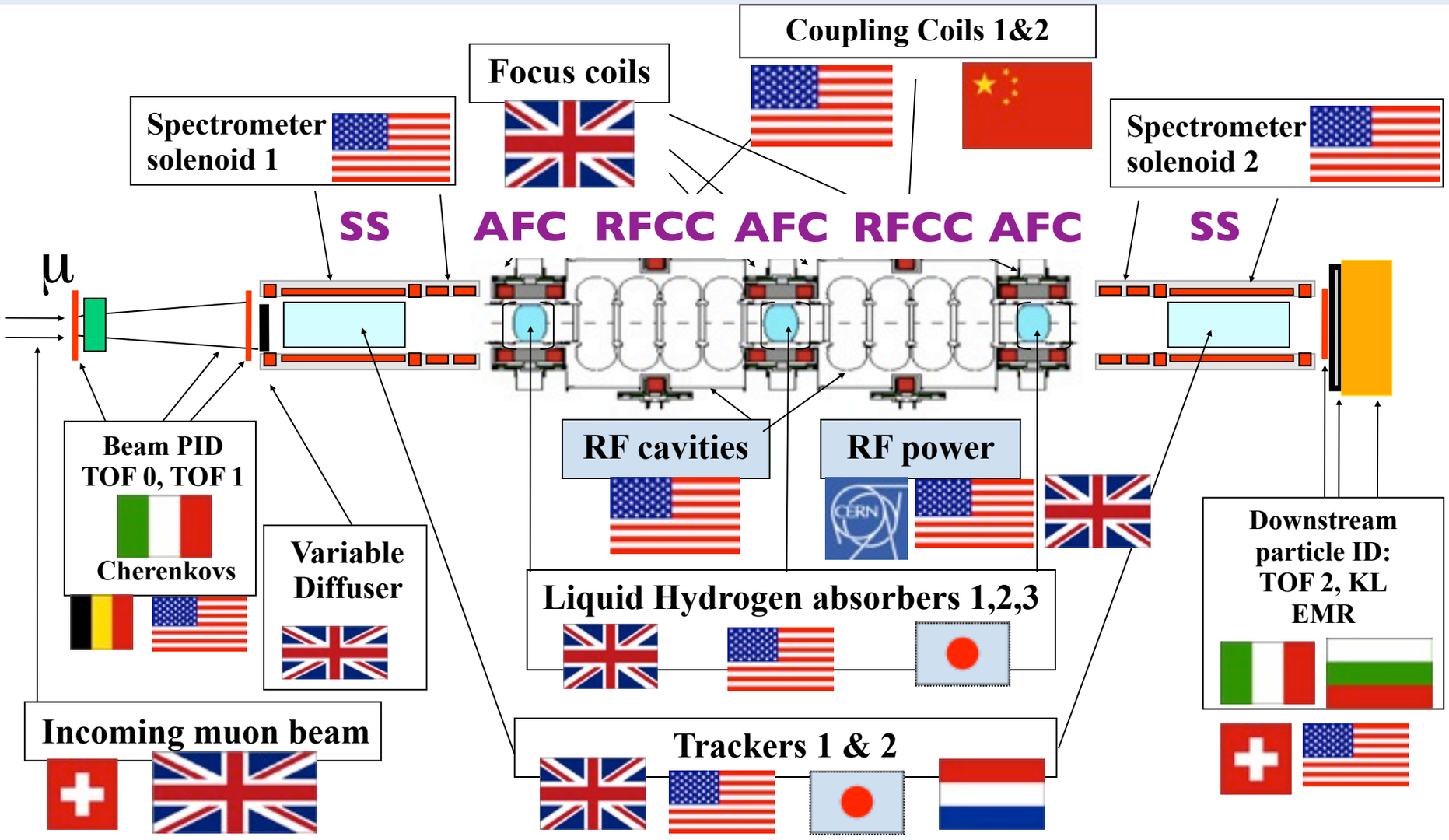


- Plus PID to achieve 99.9% muon purity

Particle by particle measurement, then accumulate few 10^5 muons
➔ $\Delta[(\varepsilon^{in} - \varepsilon^{out})/\varepsilon^{in}] = 10^{-3}$

5

MICE Collaboration



MICE Module Key:

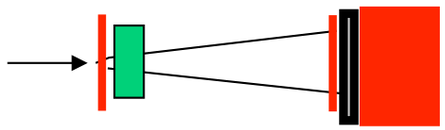
- **S**pectrometer **S**olenoid **(SS)**
- **A**bsorber–**F**ocus **C**oil **(AFC)**
- **RF**–**C**oupling **C**oil **(RFCC)**

Steps of MICE

Provisional MICE SCHEDULE
update: June 2013

Run date

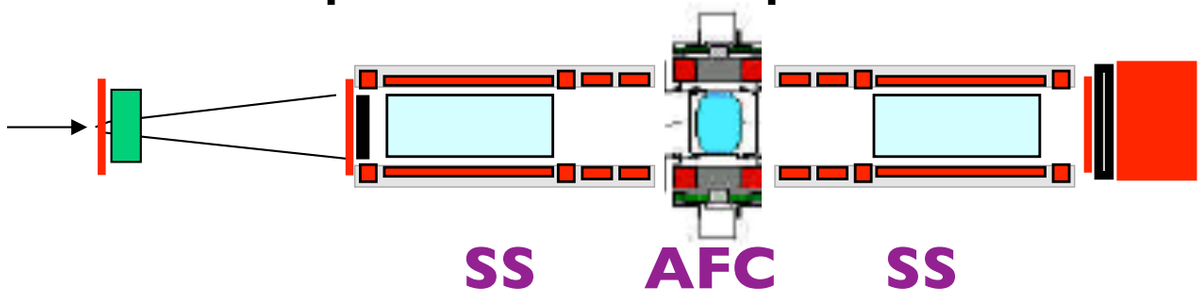
μ



STEP I

EMR run Oct 2013

- Needed for Step IV: EMR, 2 spectrometers & 1 AFC module



STEP IV

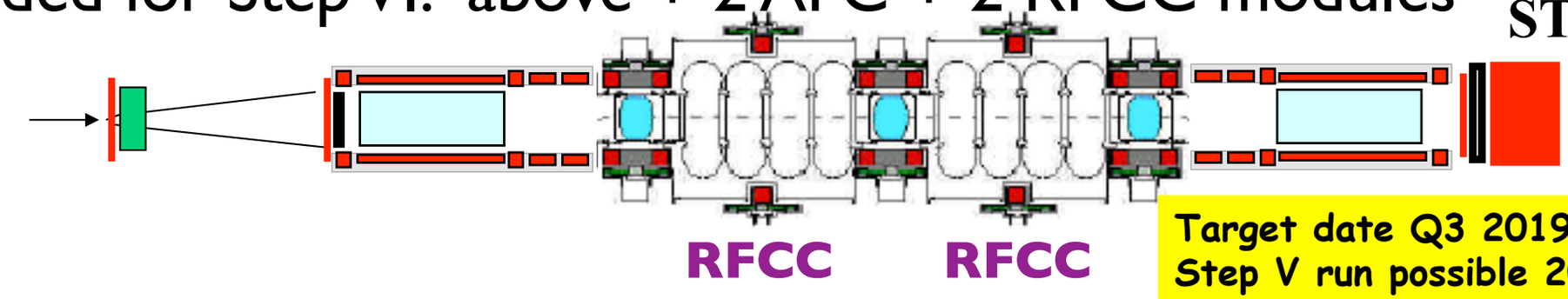
(possibly w/o field: Q2 2014)

Q1 2015 to Q1 2016

Under construction:

- Needed for Step VI: above + 2 AFC + 2 RFCC modules

STEP VI

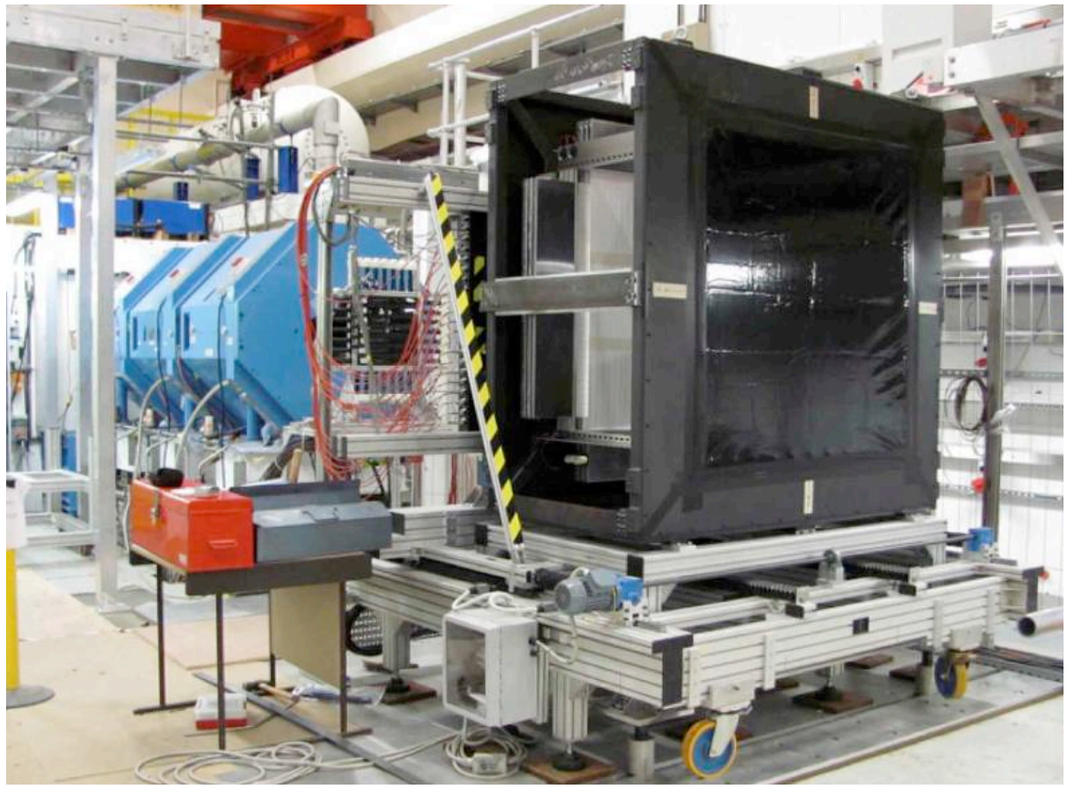


Target date Q3 2019
Step V run possible 2018

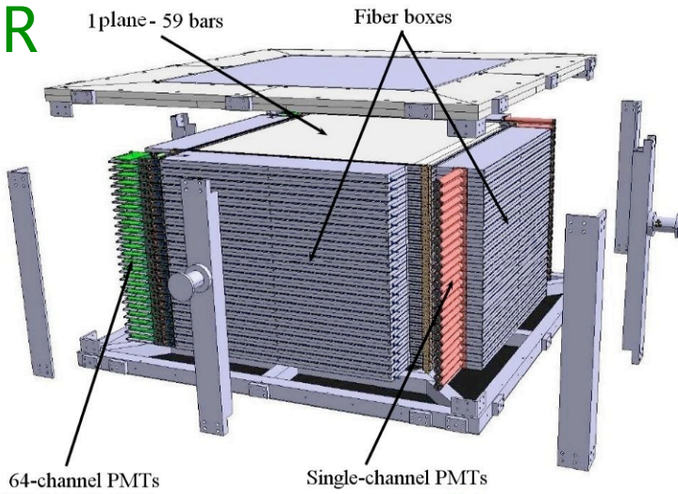
Electron–Muon Ranger

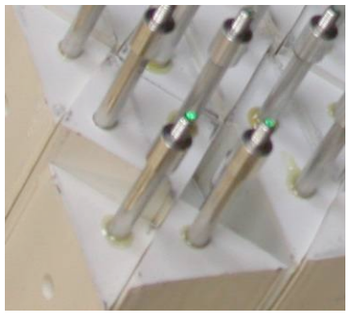
[Geneva, FNAL, Trieste/Como]

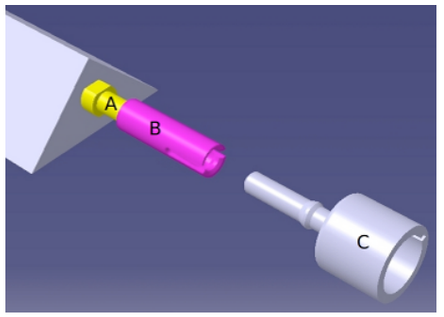
- Final MICE PID detector, under construction at U Geneva
  - totally active scintillator calorimeter in which muons range out
  - prototype already tested at MICE
  - to be installed in Sept., commissioned with beam in Oct.

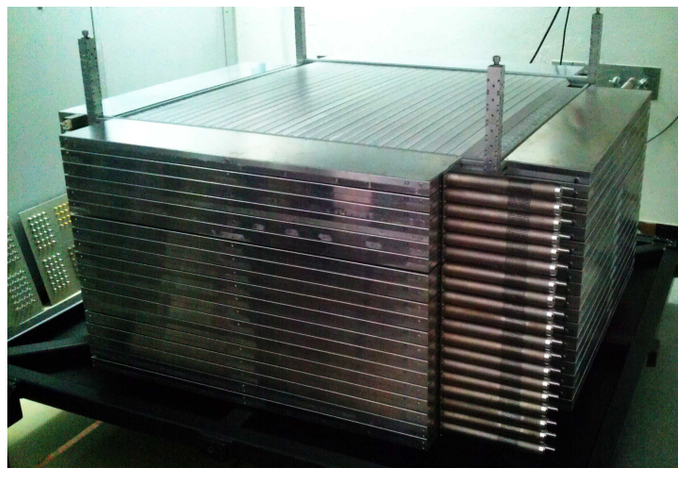


EMR





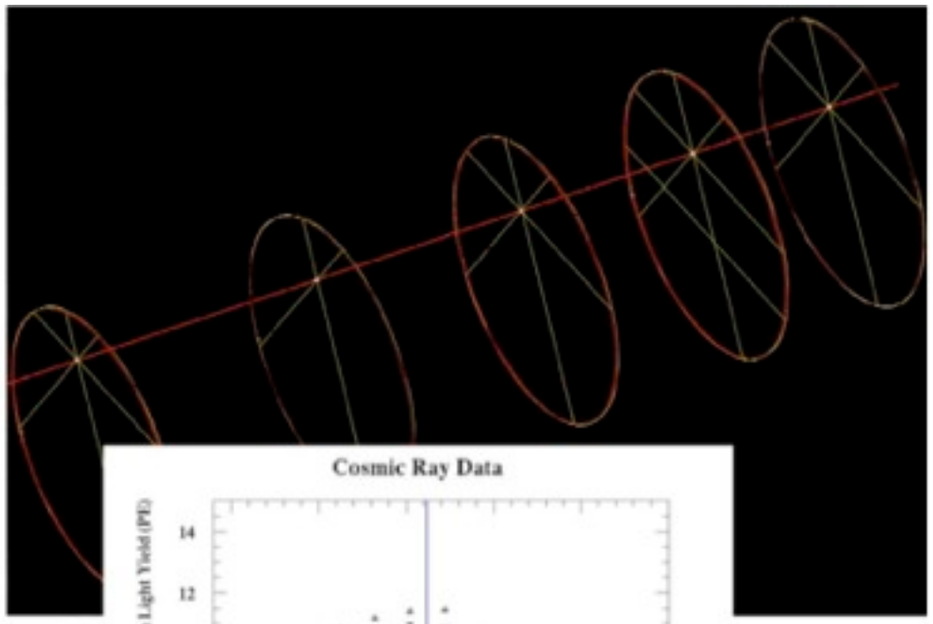




SciFi Spectrometers

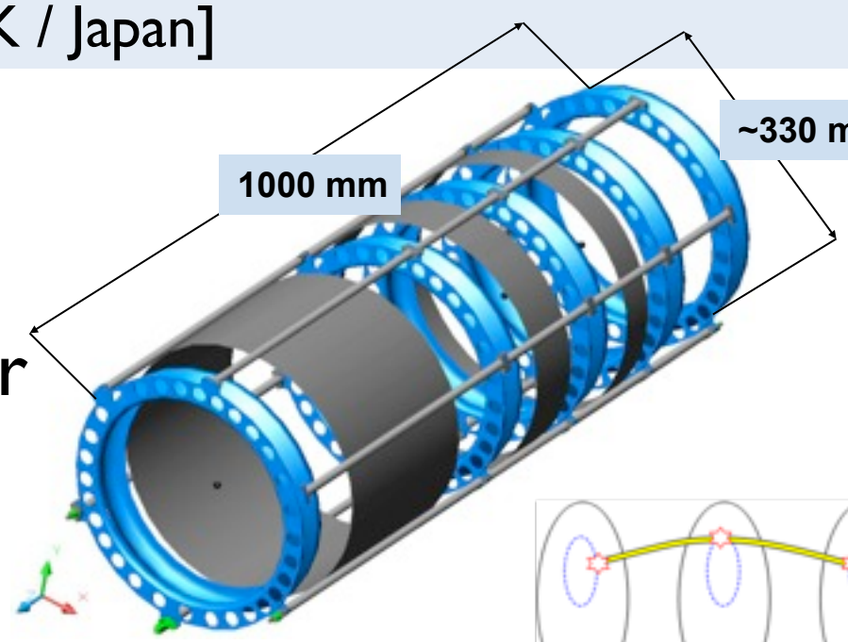
[US / UK / Japan]

- Trackers complete & tested with cosmic rays
  - installation awaiting Spectrometer Solenoid (SS) delivery

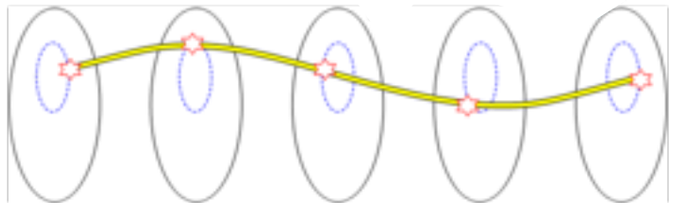


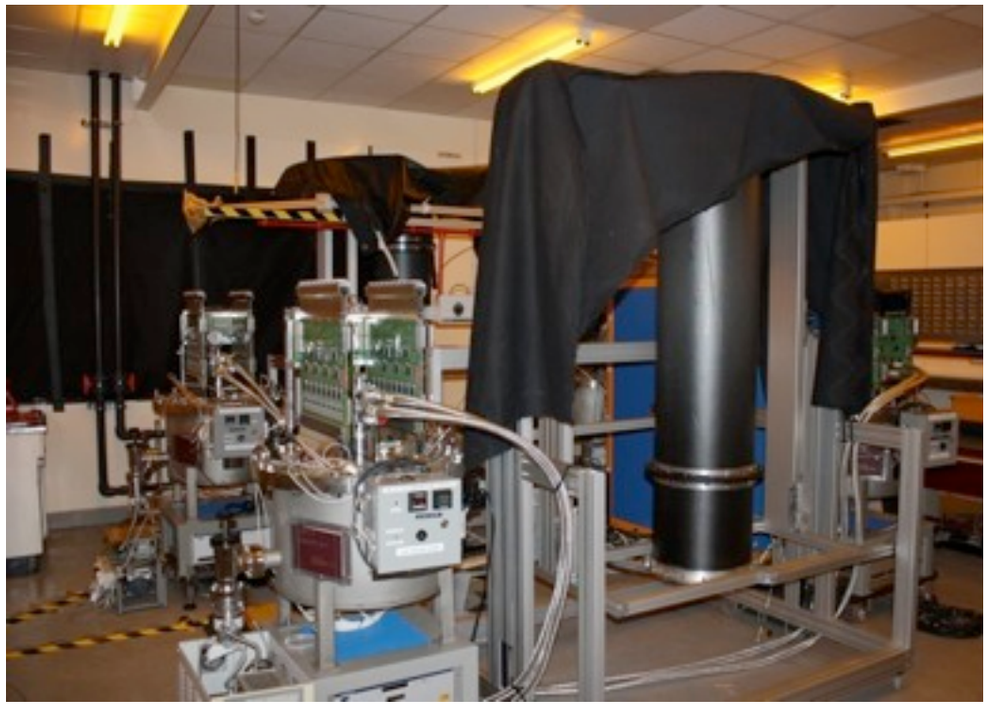
← Typical cosmic track

← Light yield ≈10 p.e.



5 stations of 350 μm SciFi



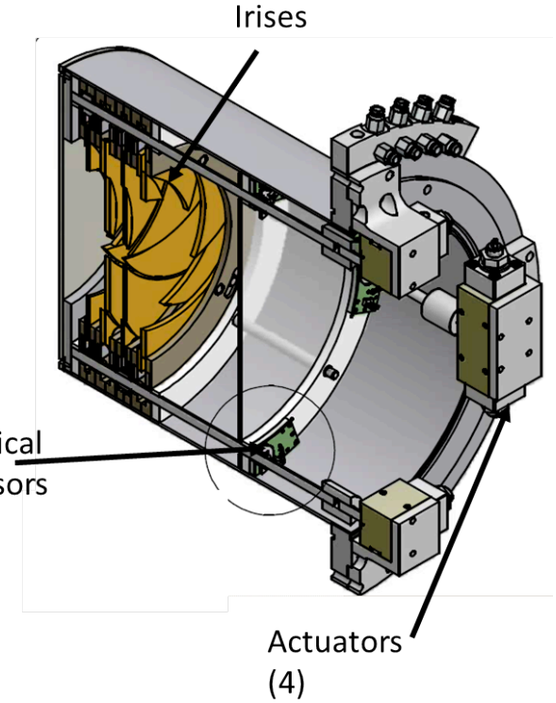


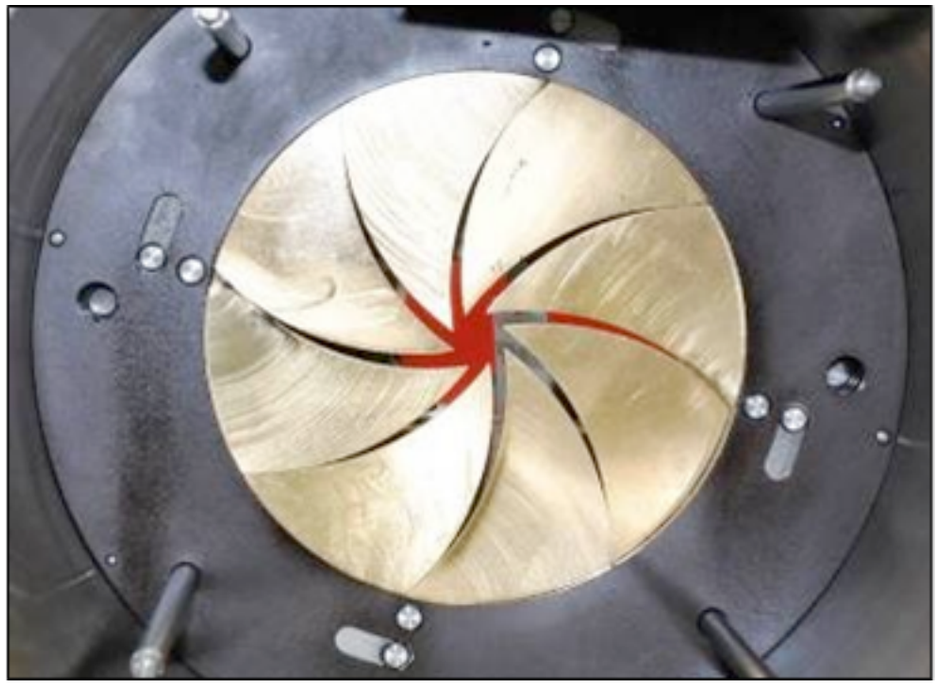
Cosmic test setup

Diffuser

[U Oxford]

- Need variable-thickness high-density material in 1st SS to generate required input emittances



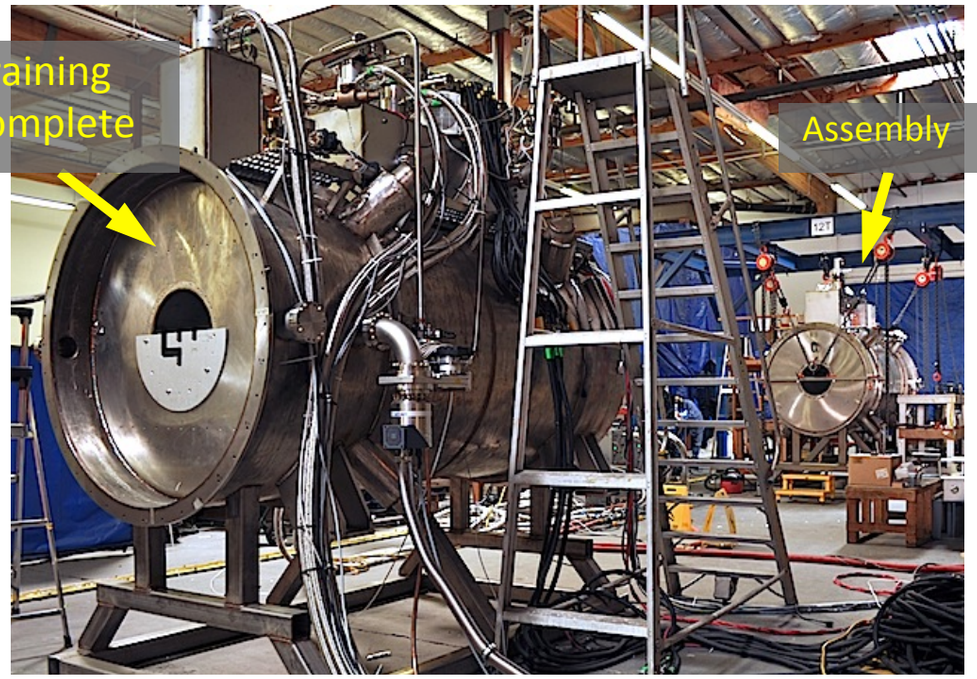


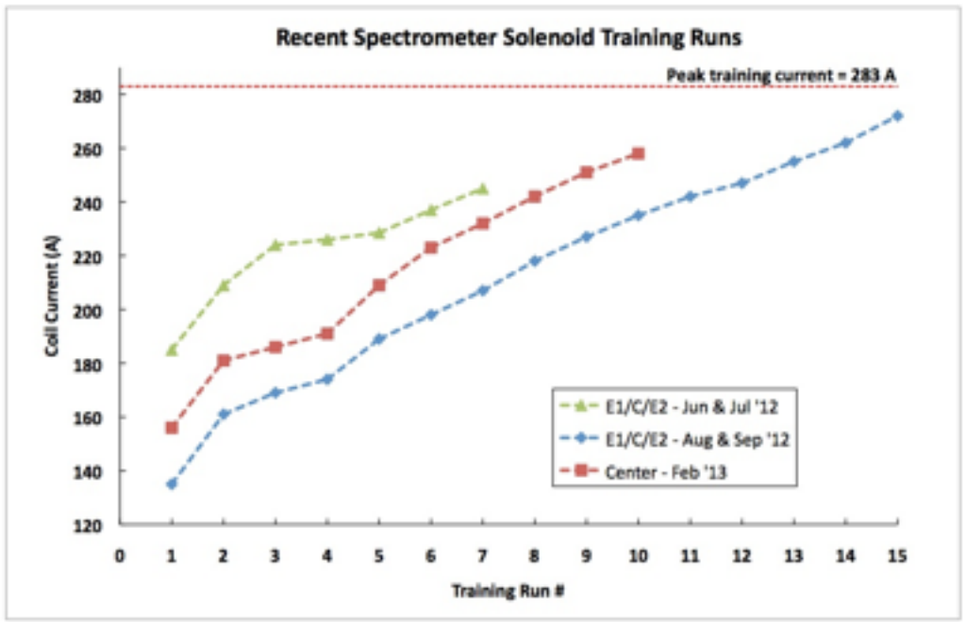
- 4 irises with W or brass petals
- W petals have brass backing plate
- ready for installation

Superconducting Magnets: SS

[LBNL, FNAL]

- Spectrometer Solenoids
  - two 4 T magnets with 0.1% field quality, each with 5 NbTi coils
  - specified by LBNL, built by Wang NMR (CA)
  - initial cryogenic and superconduncting-lead problems required significant repair and retrofit effort
  - 1st SS now trained & mapped (CERN), shipping soon





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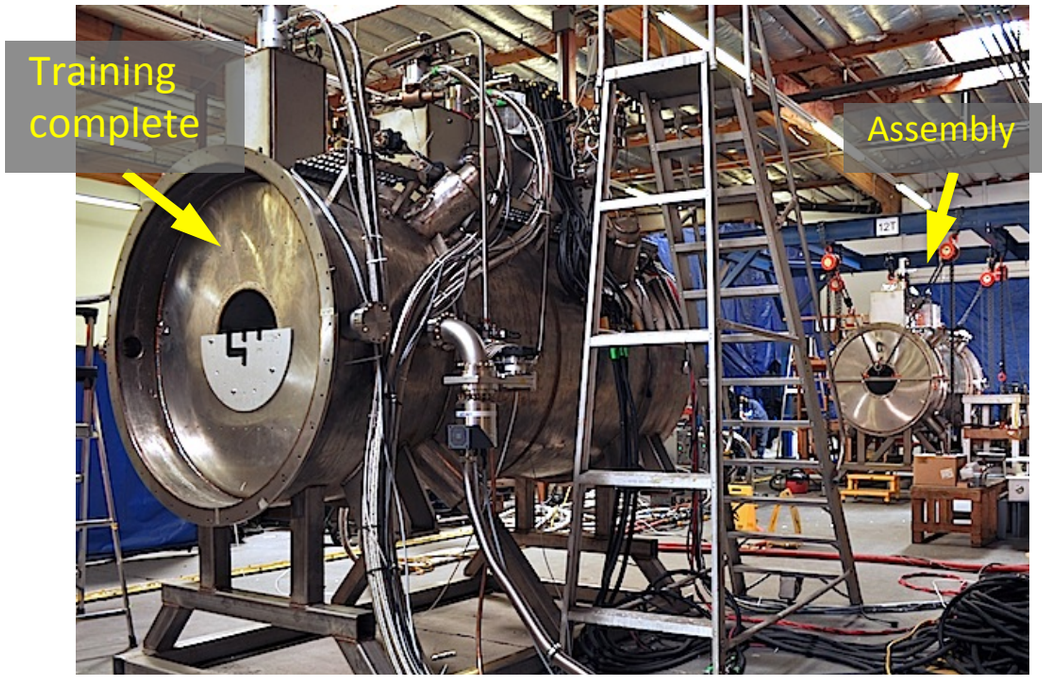
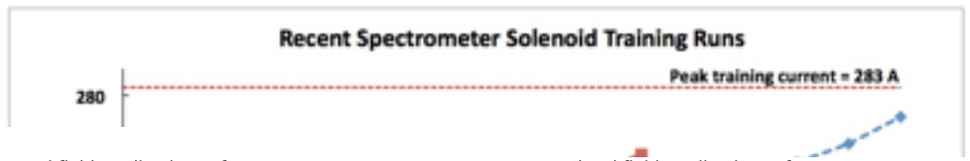
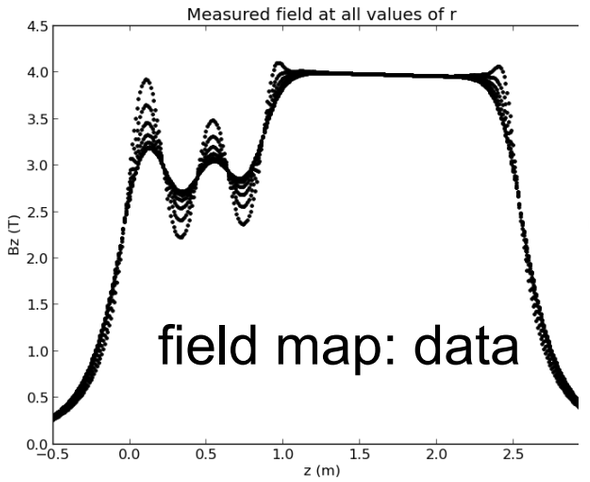
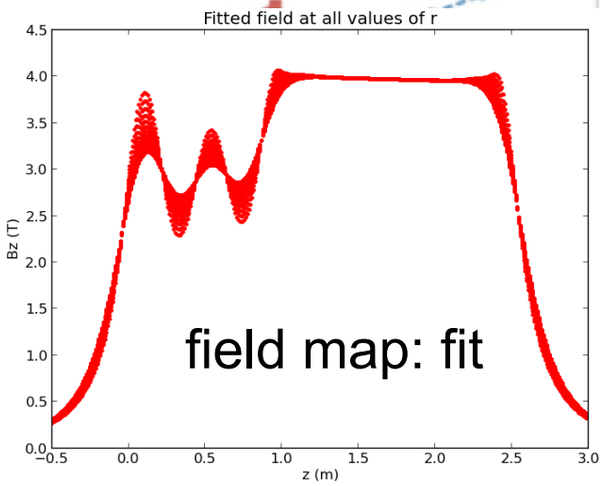
  - 1st SS now trained & mapped (CERN), shipping soon
  - 2nd SS reassembled but requires further repair before training





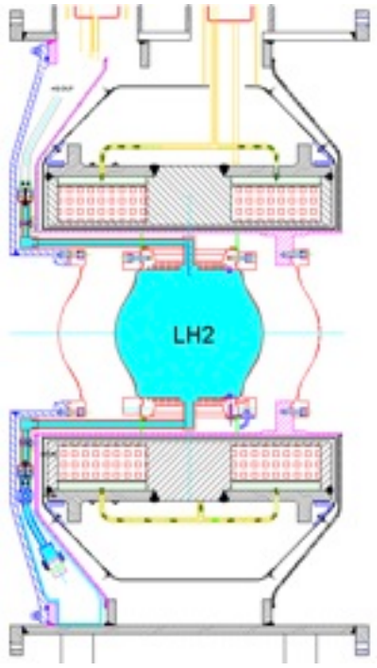


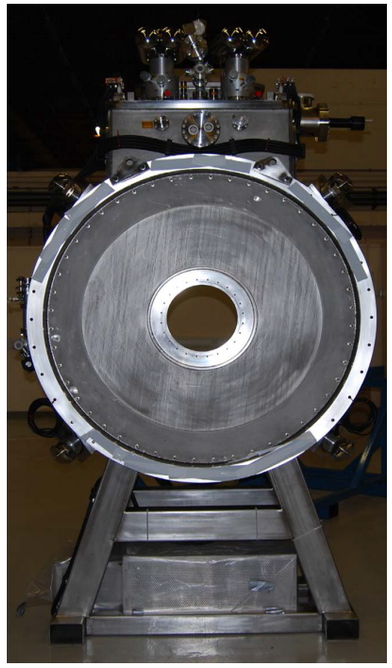


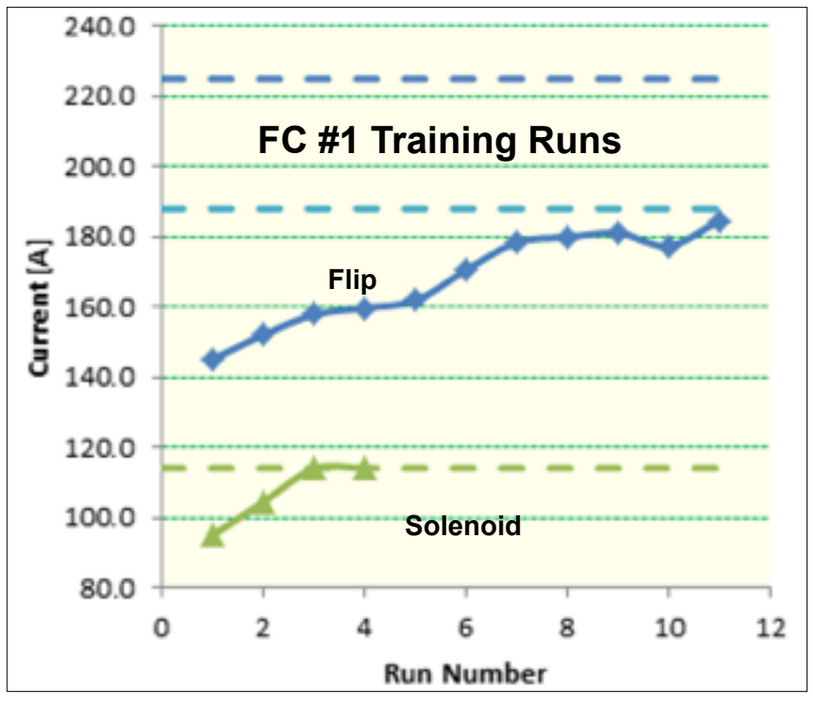
Superconducting Magnets: FC

[U Oxford, RAL]

- Focus Coils
  - three 3 T solenoid pairs operable in both gradient ("flip") and solenoid modes to provide low beta at absorbers
  - specified by U Oxford & RAL, build by Tesla Engineering (UK)
  - 1st two delivered
    - one needed for Step IV
  - 1st successfully trained in solenoid mode, flip-mode training going slowly
  - 2nd FC nearly ready for training



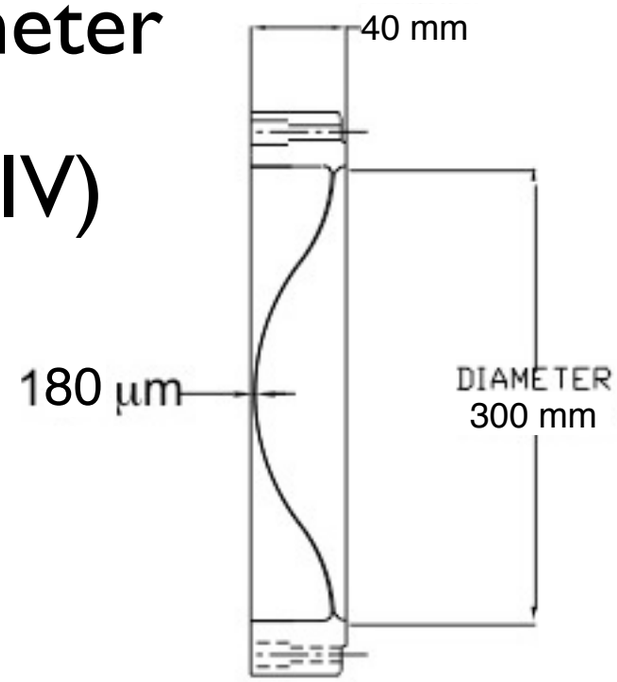


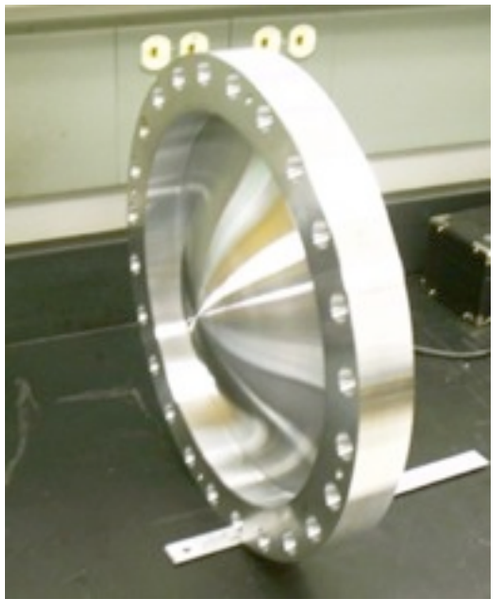


LH2 Absorbers

[KEK]

- 35 cm long x 30 cm diameter
- 3 required (one for step IV)
  - 2 built so far
- Thin, tapered Al-alloy windows
  - designed by IIT & U Oxford
  - fabricated by U Miss
- Can also use LHe

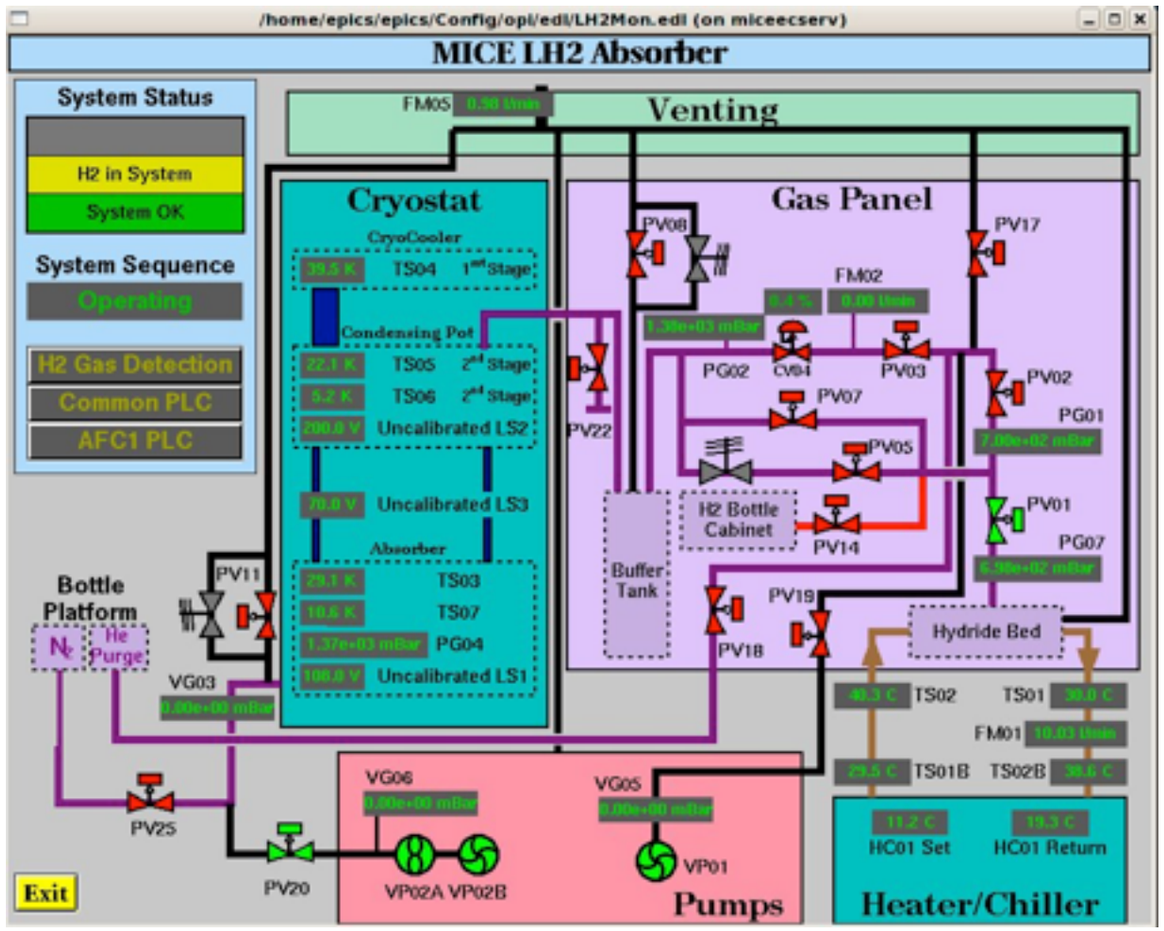




LH2 System

[RAL]

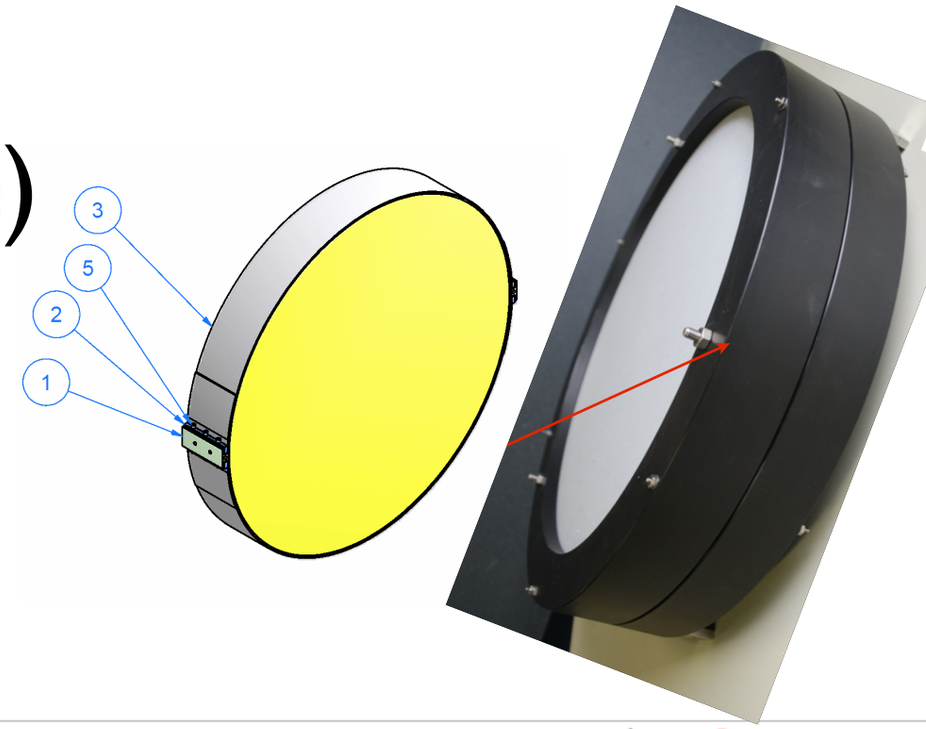
- Liquid-hydrogen system successfully tested
  - uses hydride-bed H_2 storage

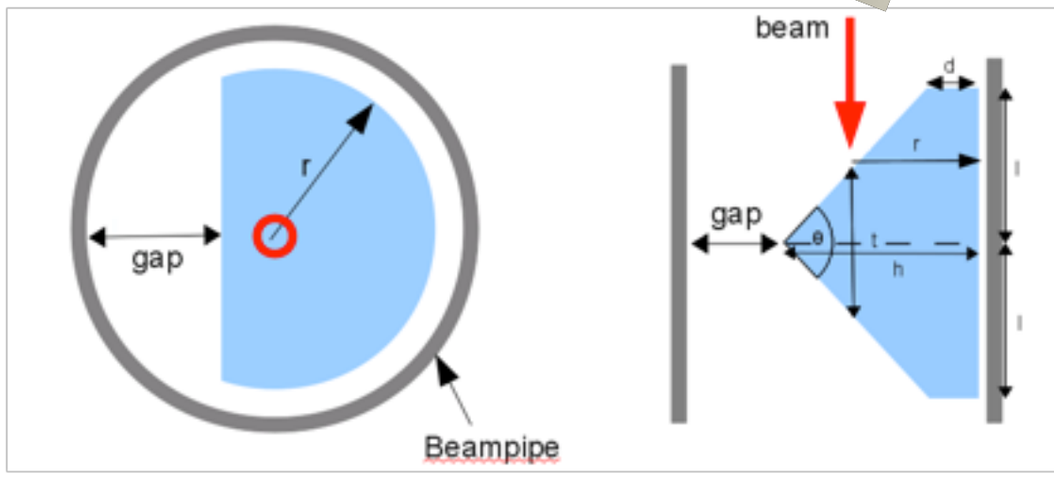


LiH Absorbers

[FNAL]

- Fabrication at Y12 (Oak Ridge)
  - both disks and wedges (6D test) ordered
  - disks done, awaiting approvals for delivery to RAL (CRADA with STFC)
- Other solid absorbers also under consideration:
  - C, Al, polyethylene,...

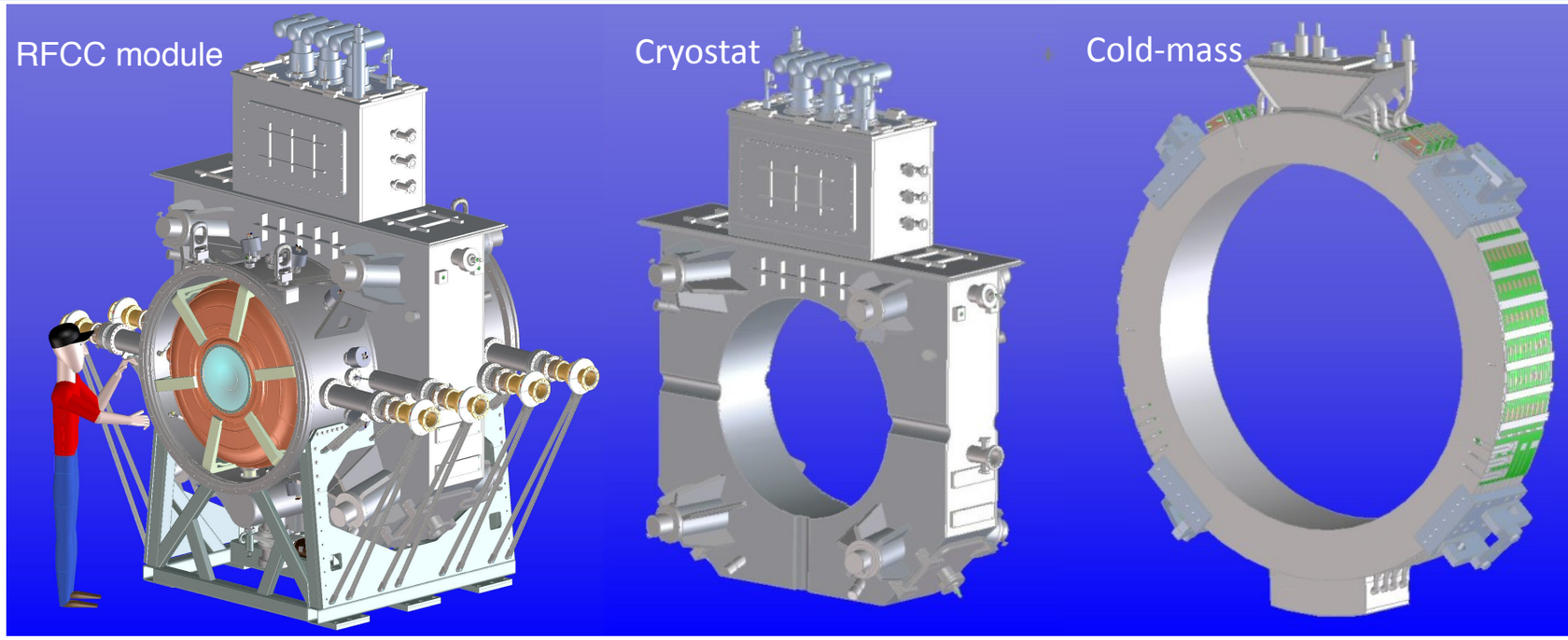




RFCC Modules

[LBNL, HIT, U Miss]

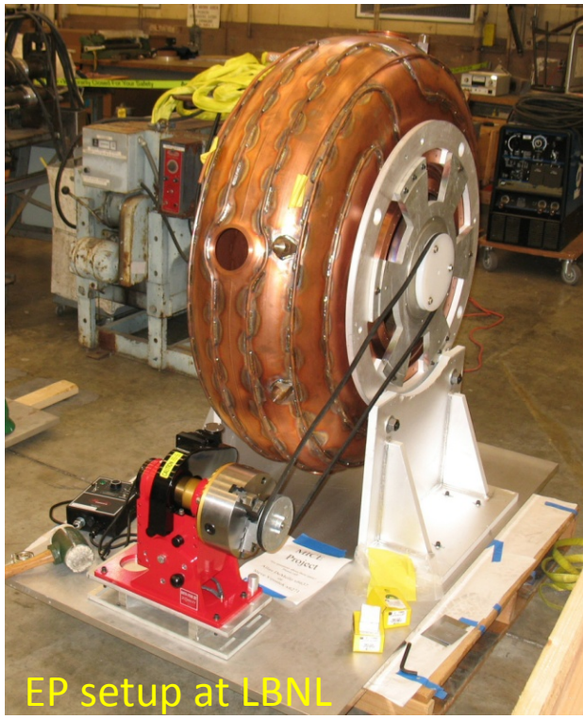
- One (2) needed for MICE Step V (VI)
- Modules designed, RF cavities built
  - 1st cavity at FNAL for tests
  - much work in progress on RF couplers, tuners & assembly procedure
- Coupling Coil fab in China (HIT, Qi Huan, SINAP) led by LBNL
  - 1st CC cold mass delivered, test in progress at FNAL STF
    - working on cryogenics issues

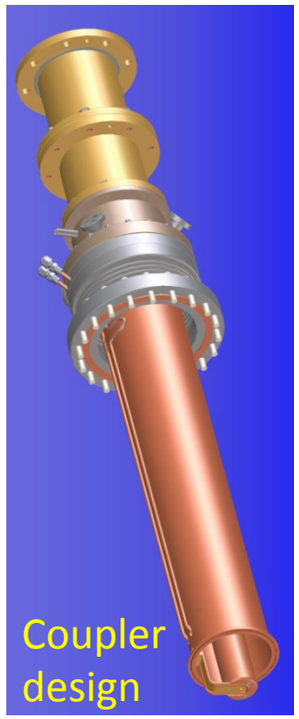


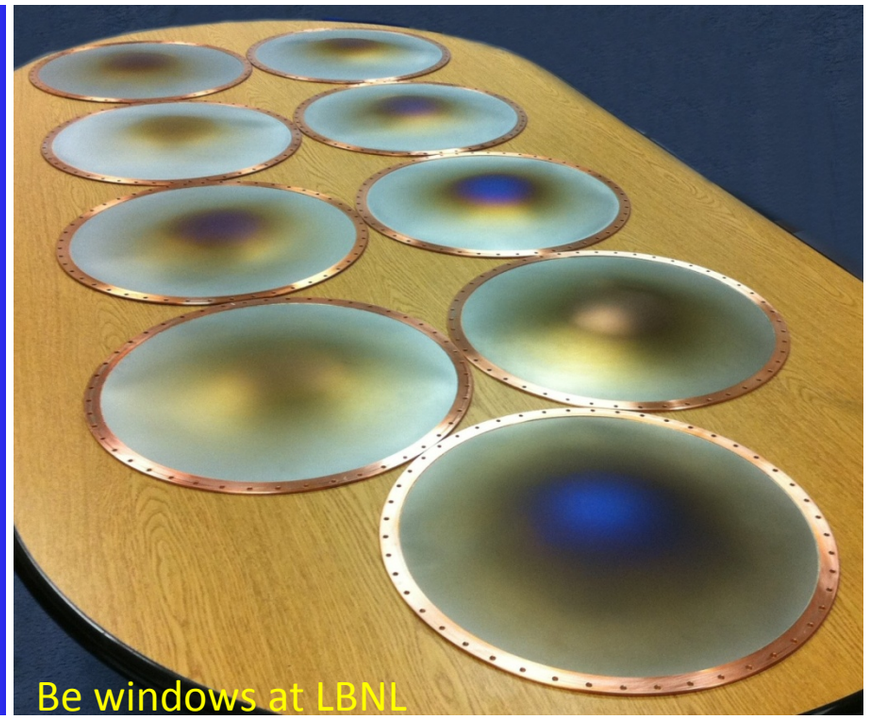
RFCC Modules

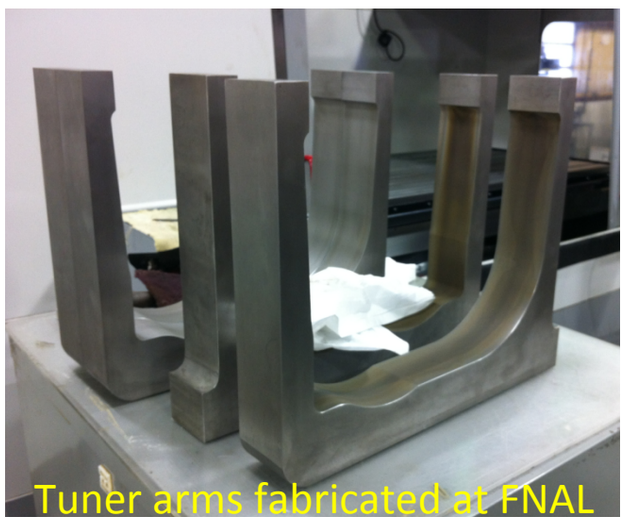
[LBNL, HIT, U Miss]

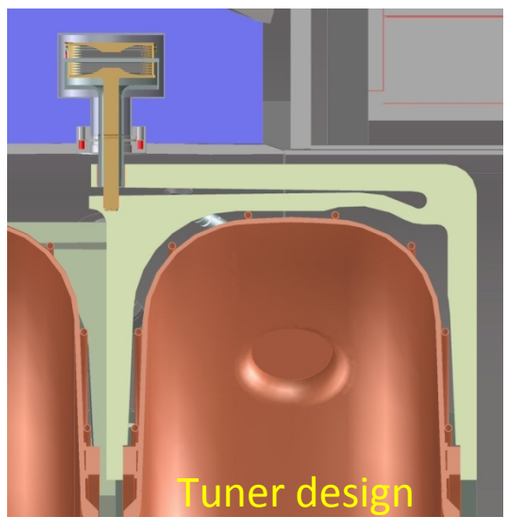
- More on cavities...


EP setup at LBNL


Coupler design


Be windows at LBNL


Tuner arms fabricated at FNAL


Tuner design

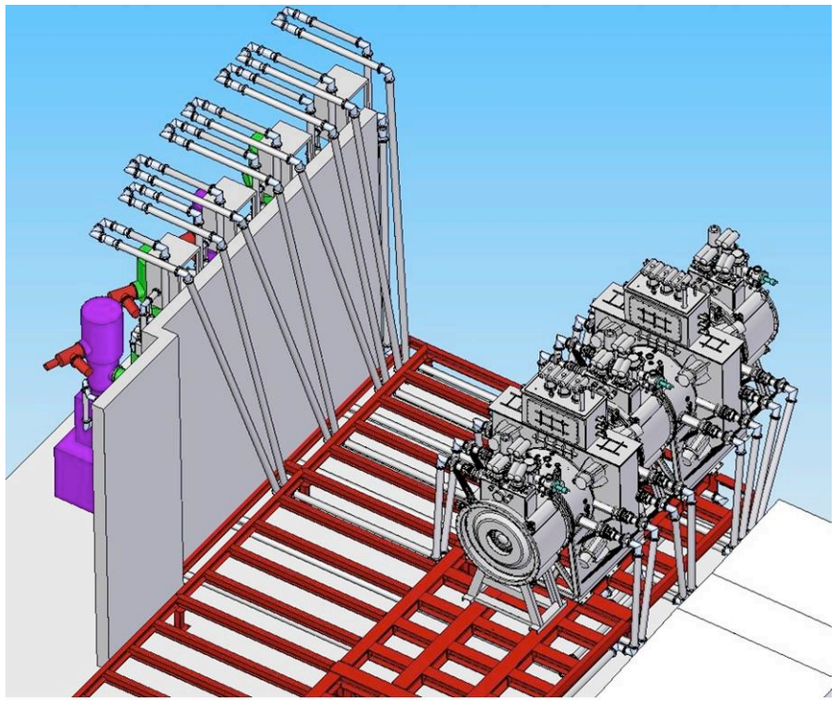

Wire EDM at FNAL

- novel Be cavity windows double the accelerating gradient for a given power level
- shown to work by MuCool

RF Power

[DL, LBNL, U Miss, U Strathclyde]

- 4 recycled 2 MW triode supplies
  - 2 from LBNL, 2 from CERN
  - refurbishment in progress at DL
  - 1st has been successfully tested at full power
- Installation plan devised
- LLRF design in progress
- "TIARA" test this year



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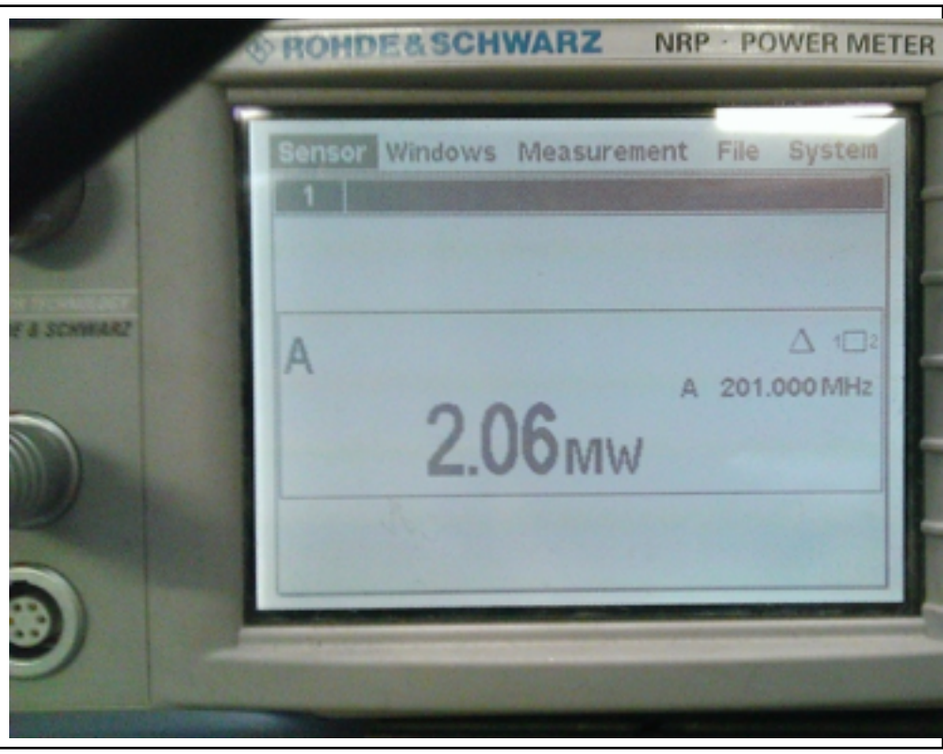
! N E W S F L A S H !

Begin forwarded message:
From: Andrew Moss <andrew.moss@STFC.AC.UK>
Subject: **Re: Fwd: 1.5 Megawatt**
Date: July 5, 2013 5:03:24 PM CDT
To: MICE-RF-POWER@JISCMAIL.AC.UK
Reply-To: MICE RF power distribution system <MICE-RF-POWER@JISCMAIL.AC.UK>

2MW from mice amplifier

Andy

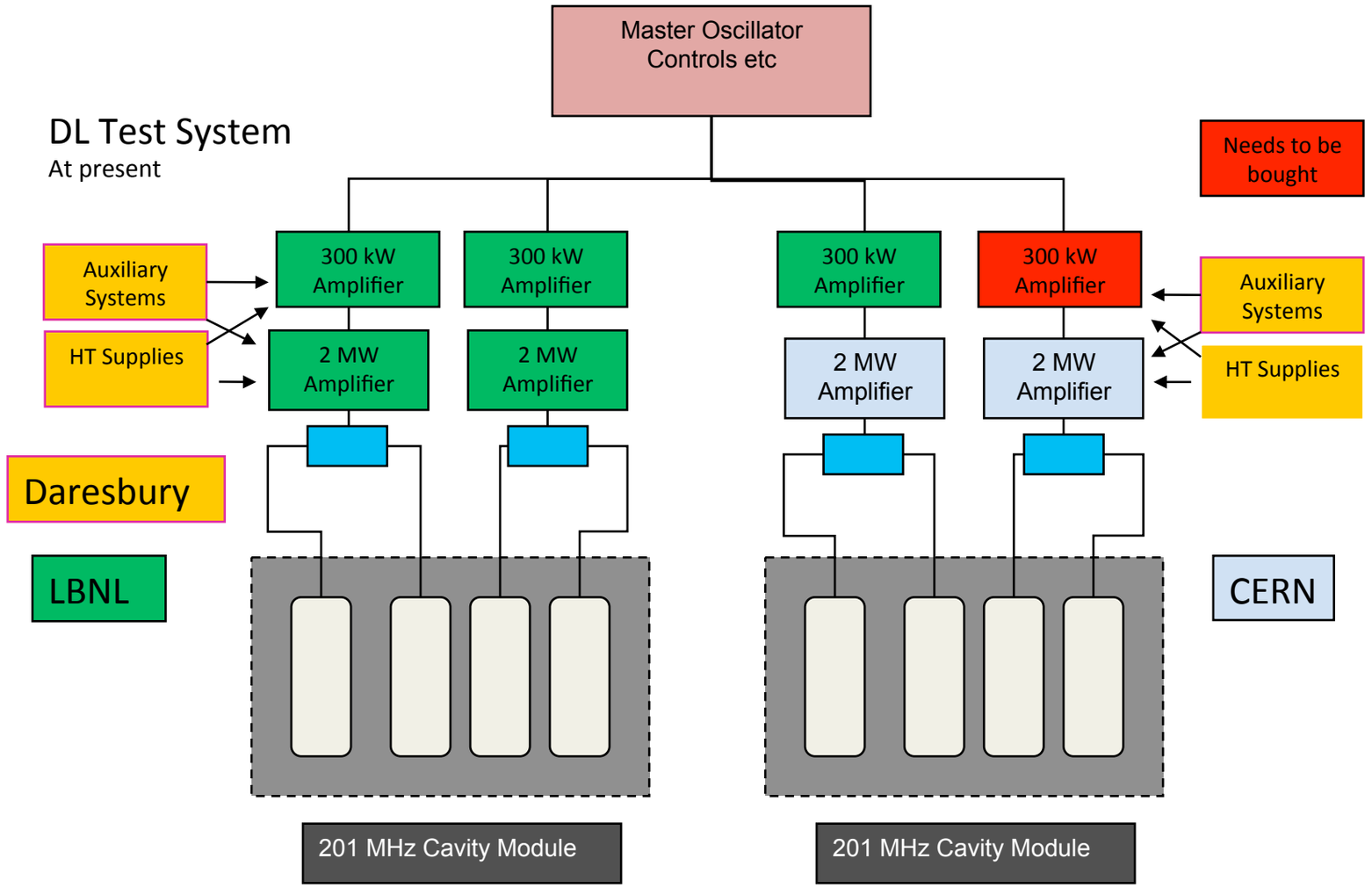
Sent from my Windows Phone



RF Power

[DL, LBNL, U Miss, U Strathclyde]

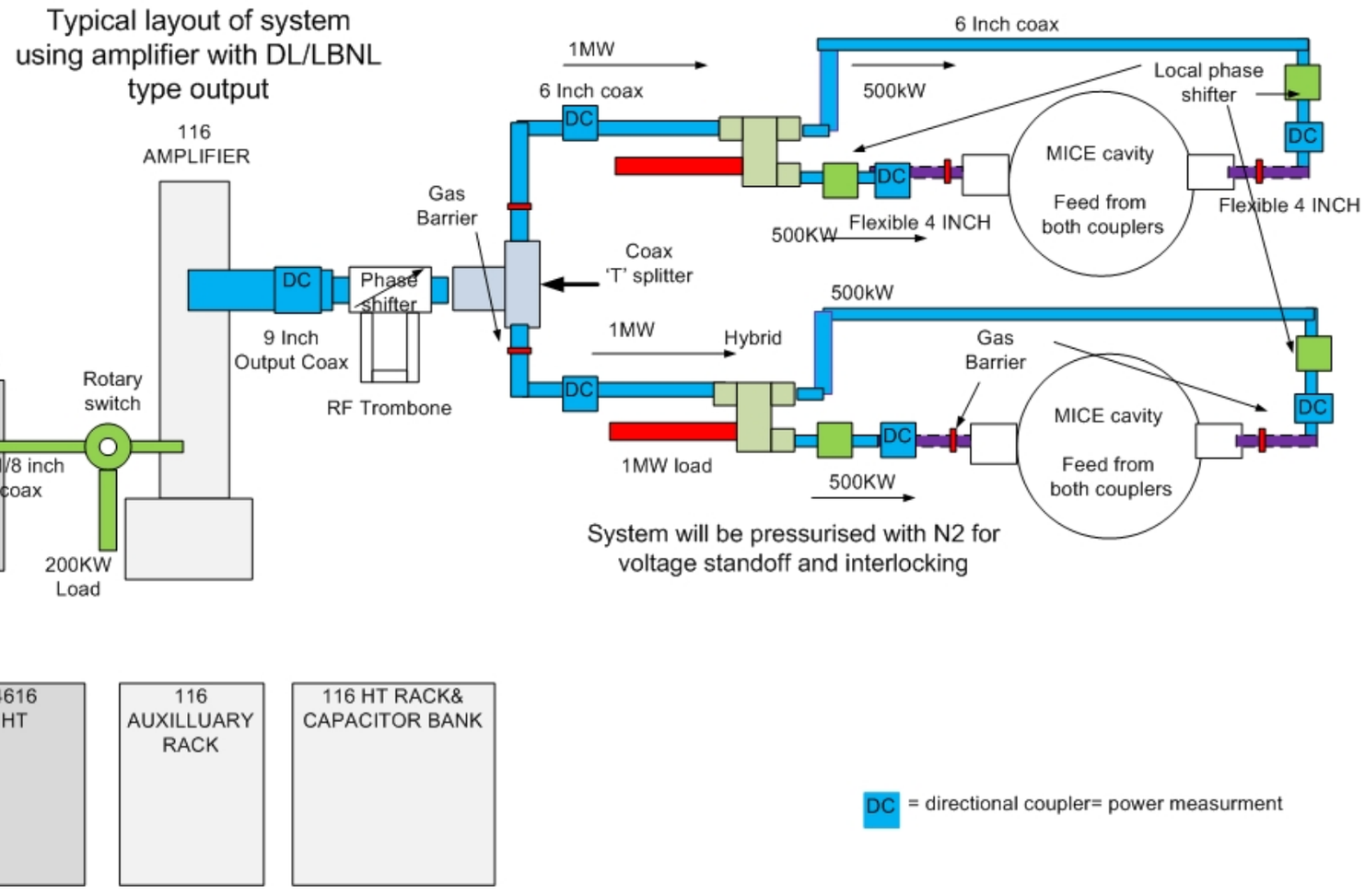
- Conceptual layout:



RF Power

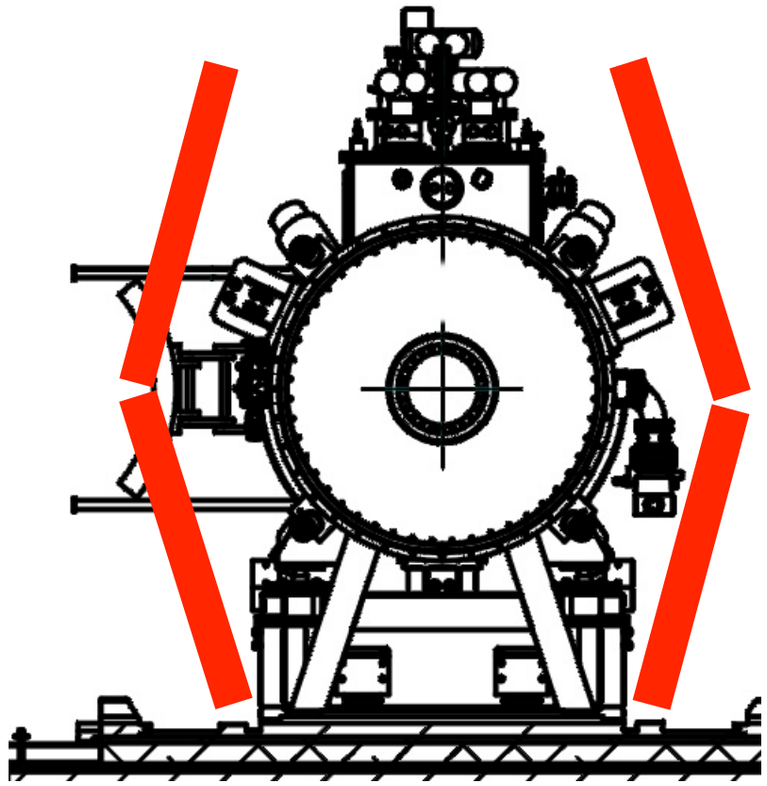
[DL, LBNL, U Miss, U Strathclyde]

- Some details:



B-Field Mitigation

- 2 concepts:
  - partial return yoke (PRY)
    - suppress the fringe field at its source
  - "local" shielding
    - shield (or move) each sensitive component



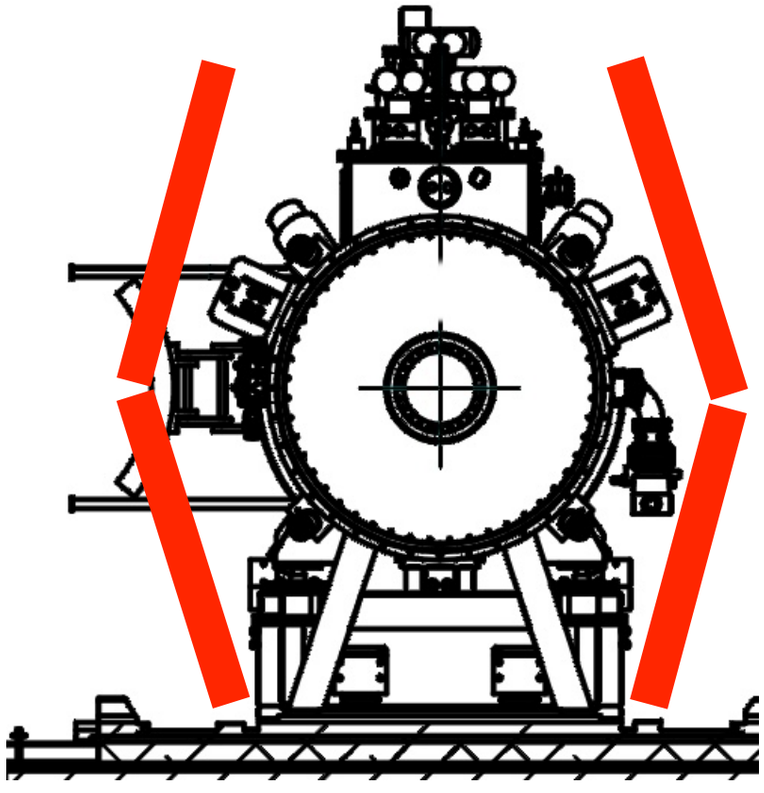
- PRY currently seems favored
  - local solution may be riskier: hard to identify all sensitive devices & assess their degree of sensitivity
  - SS delay leaves more time for PRY implementation
  - decision to be taken this fall

B-Field Mitigation

Concept

BROOKHAVEN NATIONAL LABORATORY

- Partial Return Yoke (a.k.a. “shield”, PRY?)
- Concept presented at MICE CM 2012
- Shielding plates
  - wall thickness >10 cm
  - weight: 35t
- Performance
  - Reduces stray field outside of shield to 5-10 Gauss



H Witte. Step IV & VI: Local Flux Return. MICE CM 34, October 2012.

(Note: not to scale)

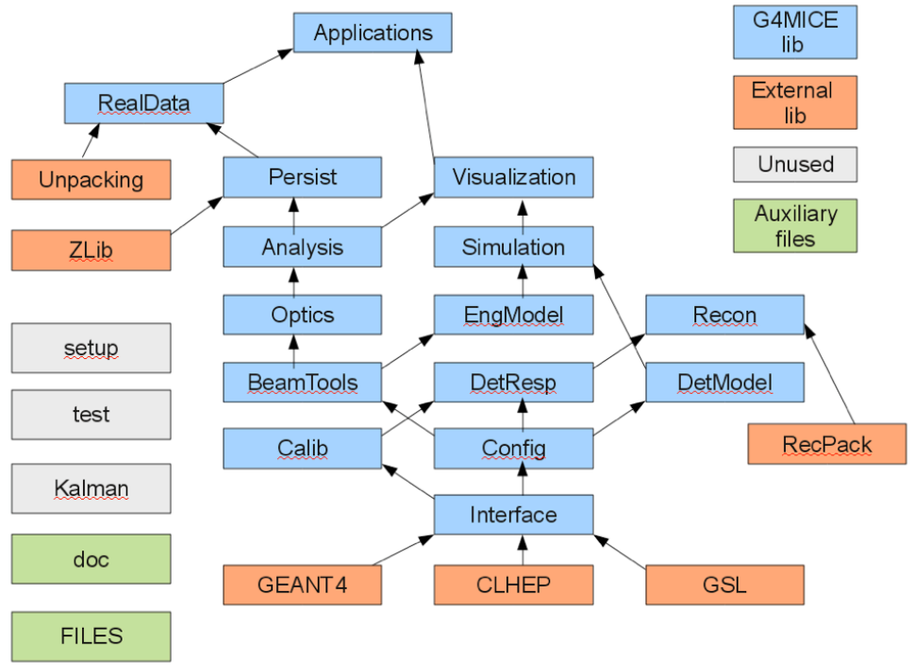
July 25, 13 3

- Engineering continues; review & decide in Sept.

MICE Software

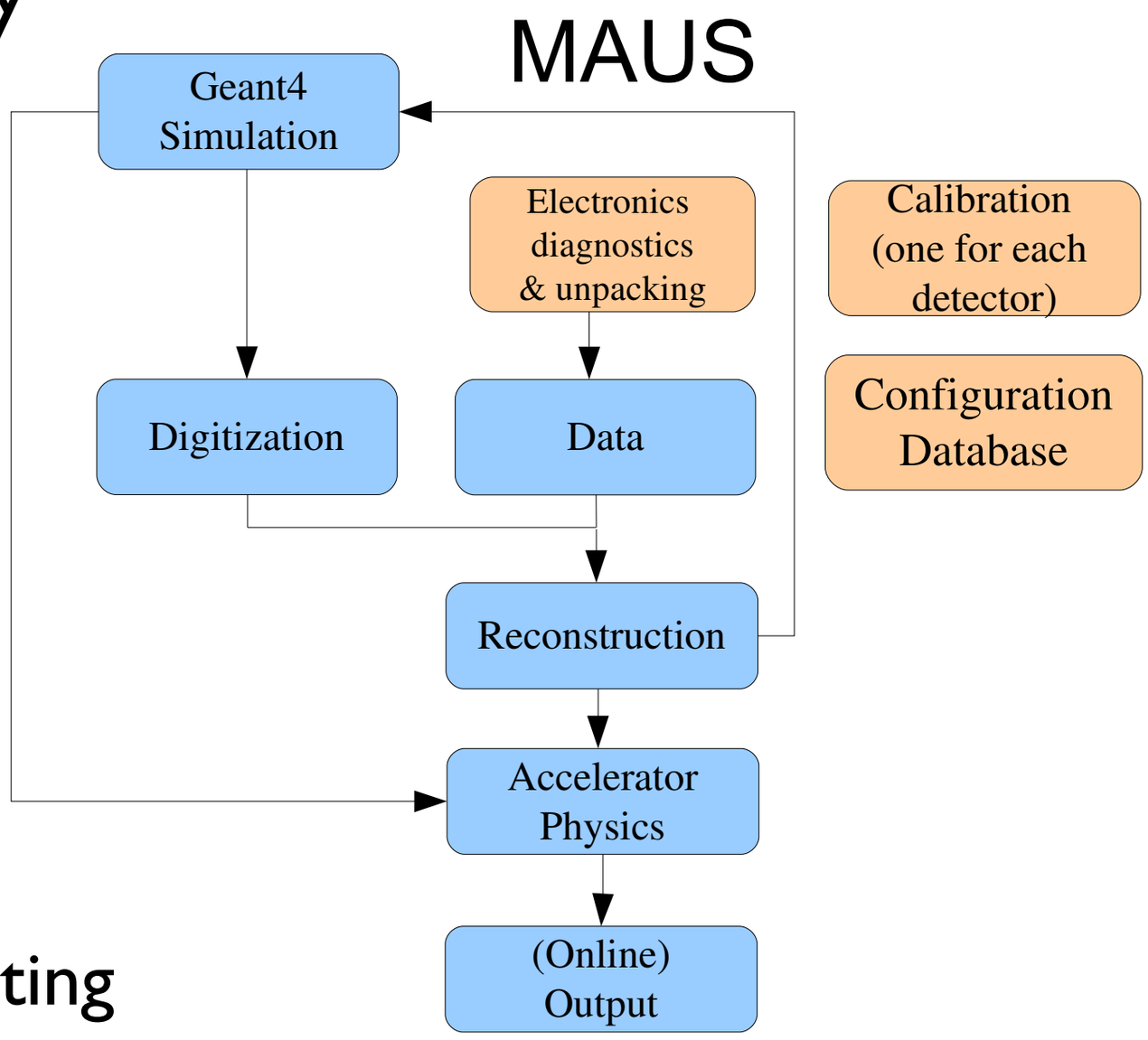
- G4MICE developed initially by Y. Torun (IIT)
  - used for Step I analysis

G4MICE



MICE Software

- G4MICE developed initially by Y. Torun (IIT)
  - used for Step I analysis
- Succeeded by MAUS (MICE Analysis User Software) framework
  - simplifies maintenance & use
  - strong emphasis on good documentation & thorough testing
  - making good progress, but much remains to be done



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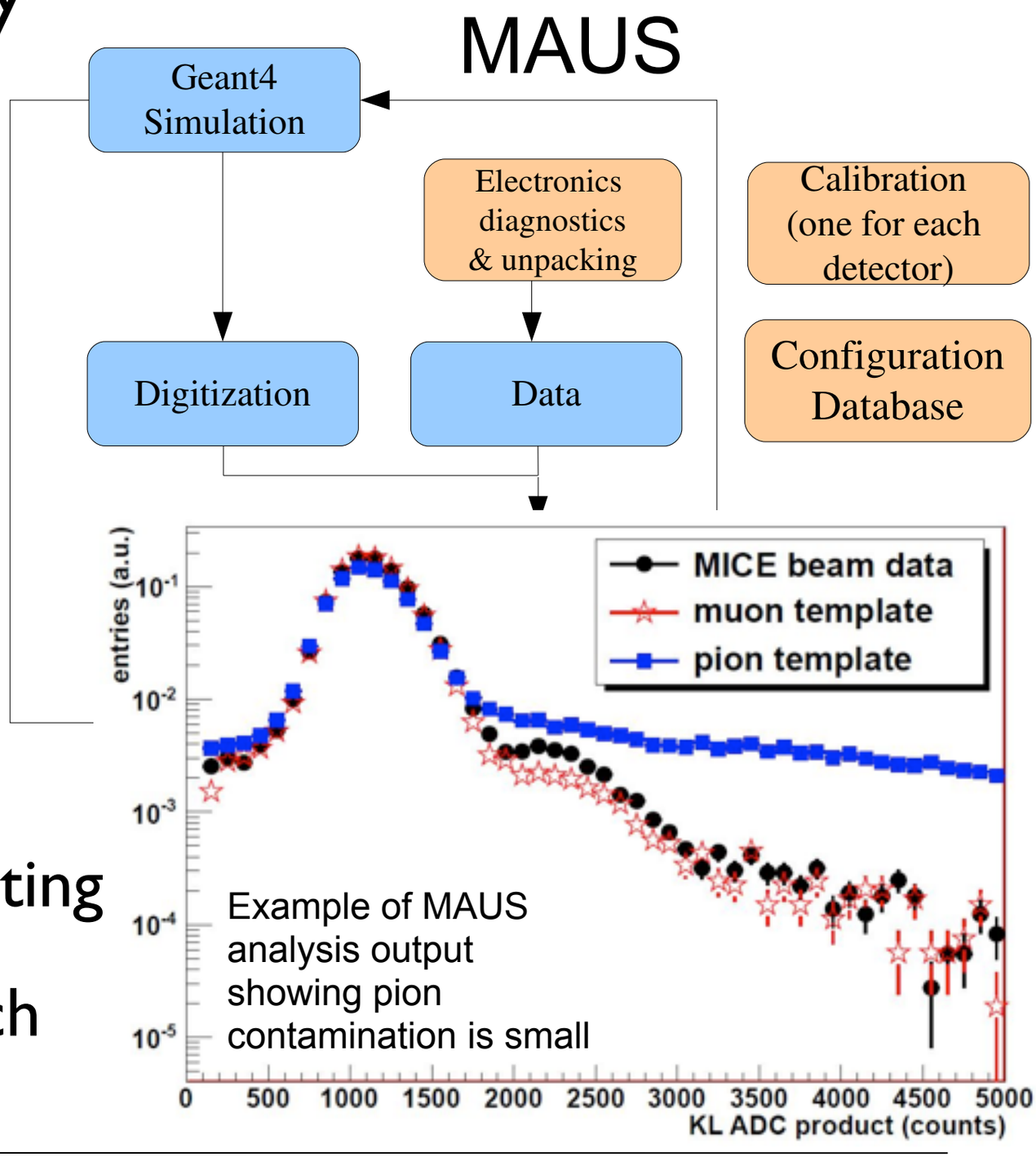
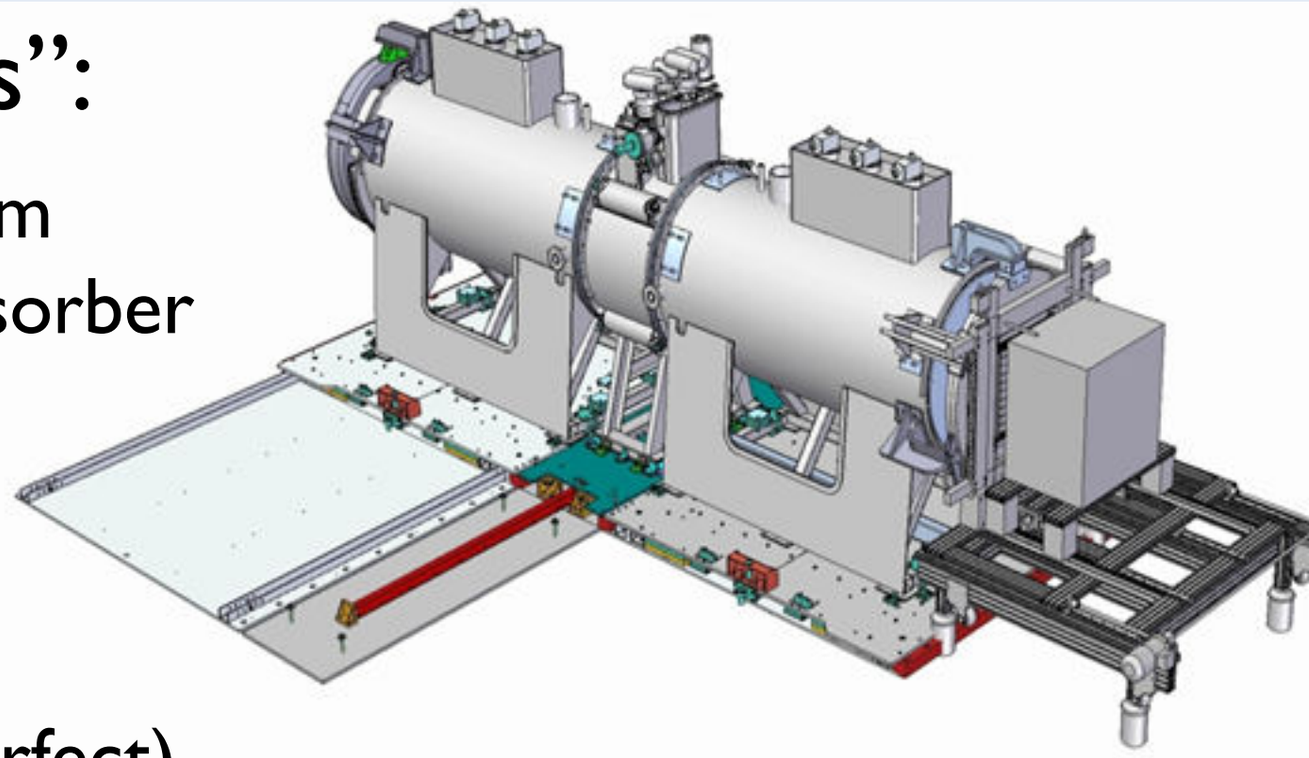
  - strong emphasis on good documentation & thorough testing
  - making good progress, but much remains to be done



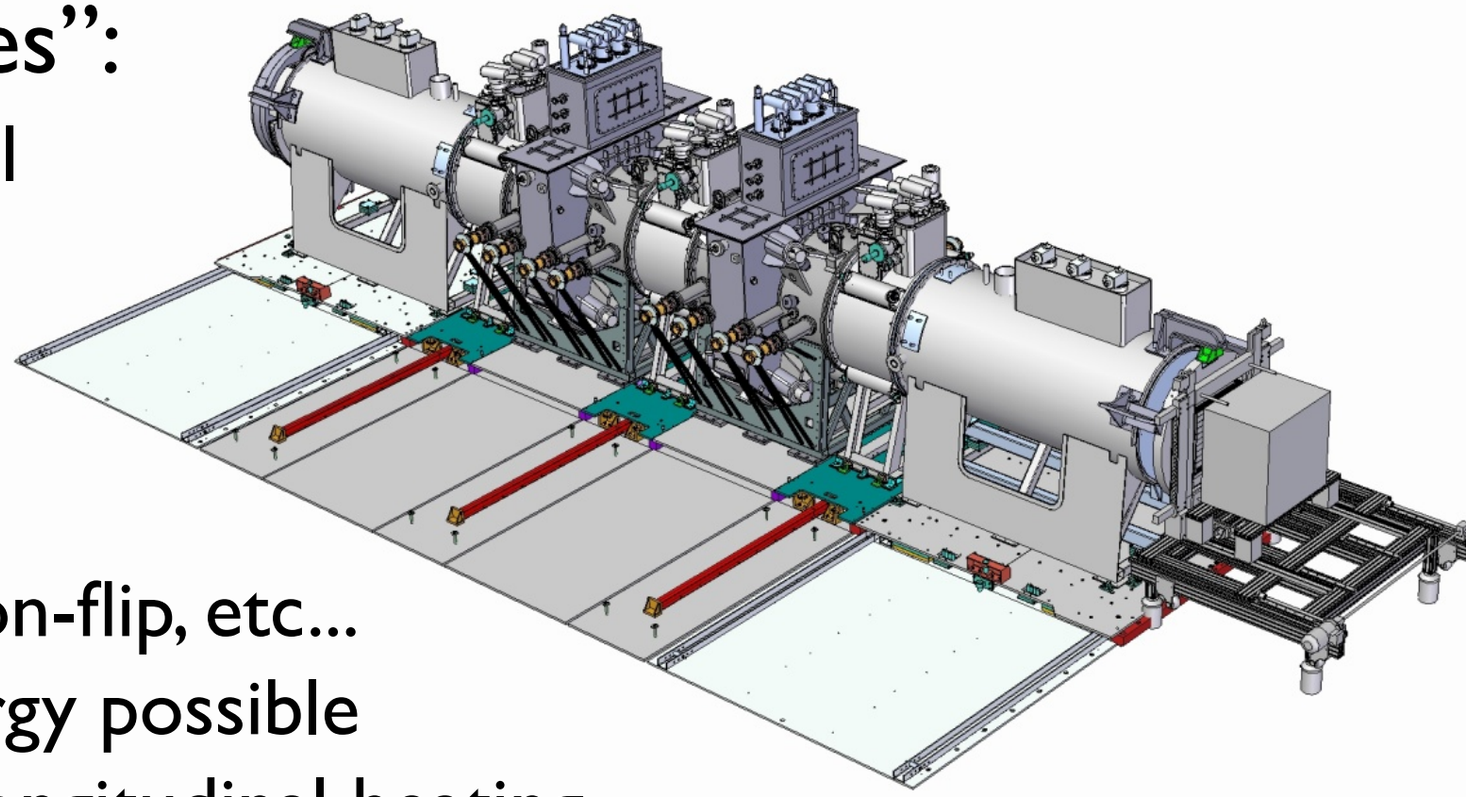
Step IV Plans

- MICE Step IV "deliverables":
  - complete particle detector system
  - establish safe and routine LH_2 absorber operation
  - engineering test of beamline made of several magnetically coupled components
  - understand propagation of (imperfect) beam through the "magnetic bottle"
  - calibration of emittance measurement to 10^{-3}
  - measurement of 6D emittance change (normalized-emittance cooling)
  - first test of longitudinal cooling (with wedge absorbers)
  - precision validation of simulation codes and physics models
  - precision measurements of correlated multiple scattering and energy-loss straggling



Step VI Plans

- MICE Step VI "deliverables":
  - operation of channel with all magnetic couplings in place
  - routine and safe operation of RF in *B* field near LH_2
  - full cooling cell allowing all optics configurations: flip, non-flip, etc...
  - exact replenishment of energy possible
  - significant and measurable longitudinal heating
  - precise measurement of equilibrium emittance of various optical and absorber configurations
  - detailed and precise verification of simulation codes
  - benchmark for many future cooling-channel options



- (Step V, with 1/2 lattice cell, possible as intermediate step, but not the current baseline)

Conclusions

- MICE is a major undertaking:
  - thorough demonstration that ionization cooling works as expected and is well understood
  - calibration and validation of Monte Carlo models used to design and characterize ionization cooling channels
- A major step on the way to Neutrino Factories and Muon Colliders
- Given adequate support we will accomplish this by 2020