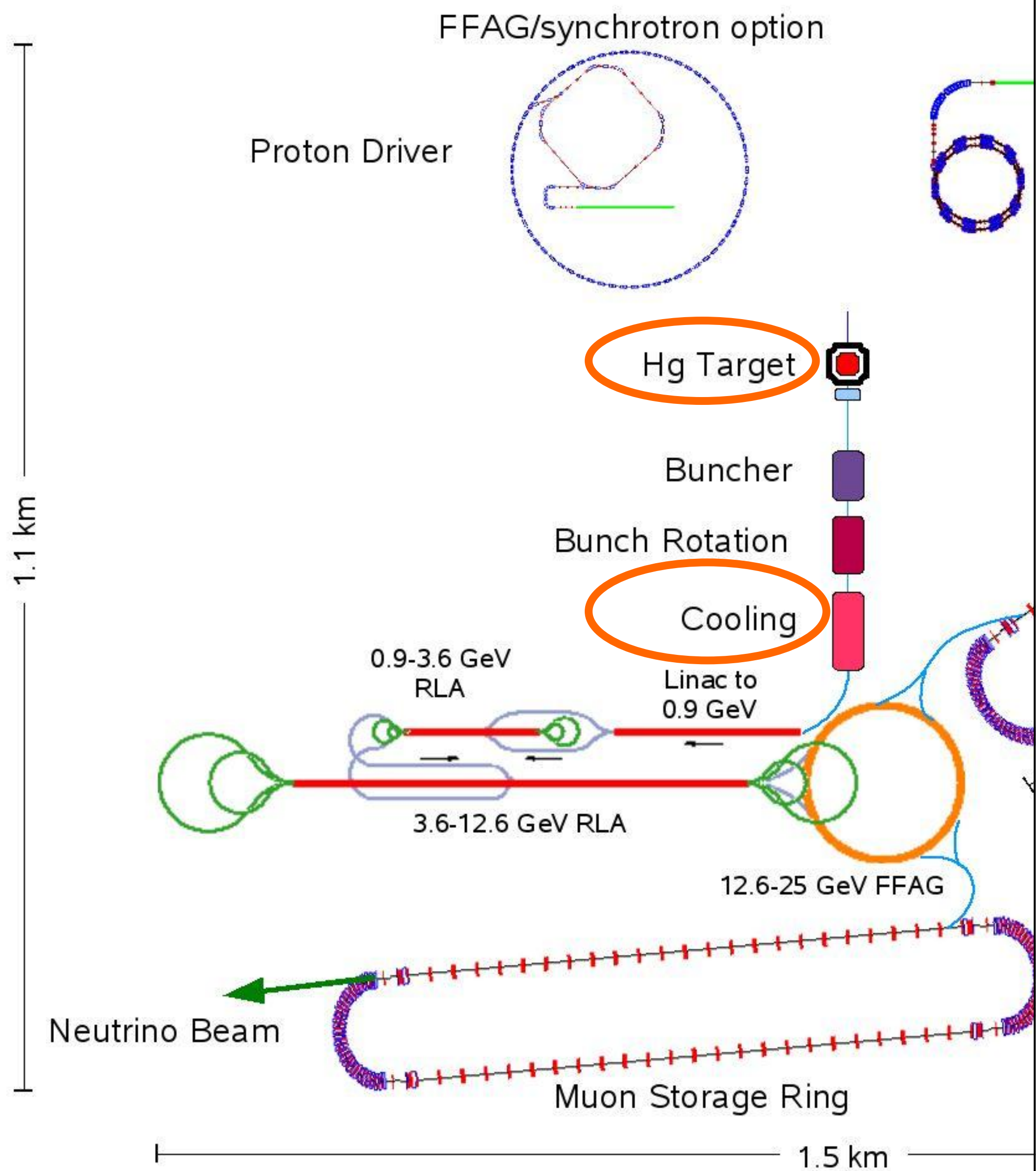
The International Muon Ionization Cooling Experiment

MICE = critical R&D for neutrino factory and muon collider



neutrino factory:
accelerate muons and store to produce neutrinos

$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$$

Or opposite charges (and anti-)

-- flux known to <±1%

-- high energy electron neutrinos

Golden channel:

long baseline oscillation manifests itself by wrong sign muons:

$$\nu_e \rightarrow \nu_\mu \; ; \quad \nu_\mu + N \rightarrow \mu^- + X$$

LARGE (100kton) magnetized iron detector

+ unique ability to test $\nu_e \rightarrow \nu_\tau$

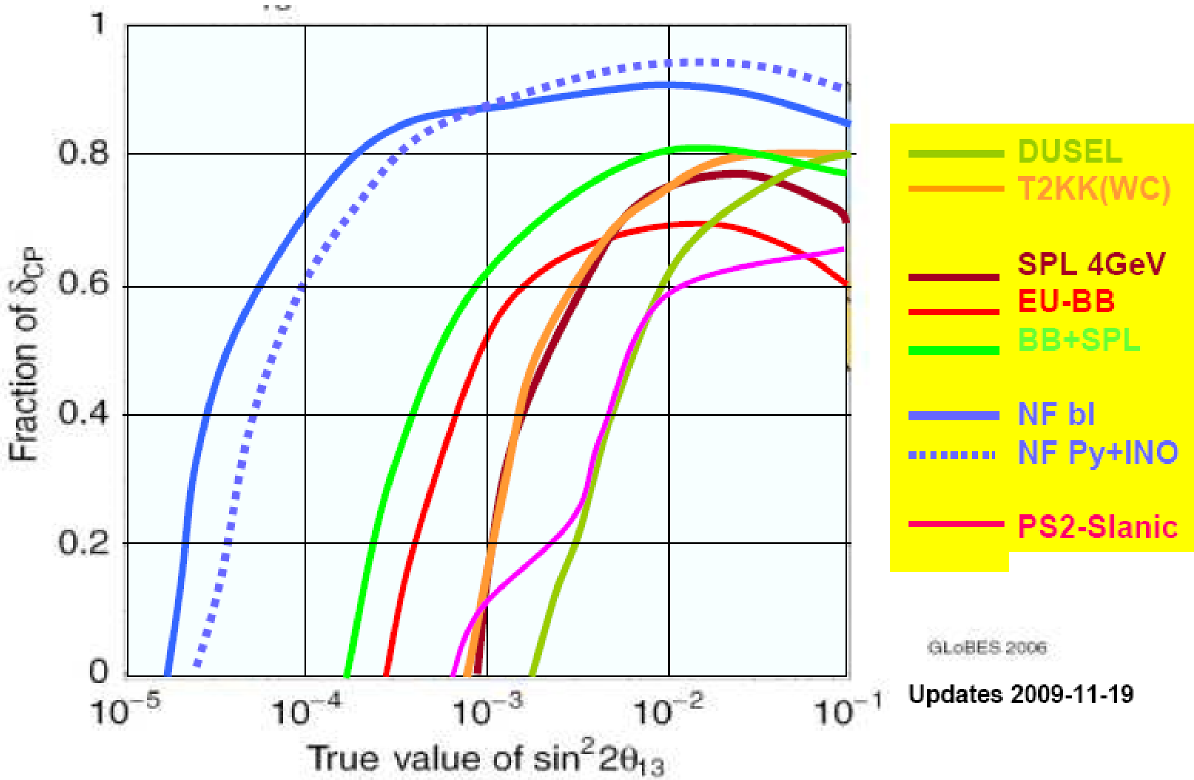


Figure 2 A representative compilation of sensitivities of some future long baseline projects. Here the fraction of δ_{CP} where CP violation can be observed at 3 standard deviations is plotted as a function of θ_{13}.

T2KK: *T2K 1.66 MW beam to 270 kton fid volume Water Cherenkov detectors in Japan (295km) and in Korea (1050 km);*
DUSEL*: a WBB from Fermilab to a 300 kton WC in Dusel (1300km);*
SPL 4 GeV, EU-BB and BB+SPL: *CERN to Fréjus (130km) project;*
NF bl *is the Neutrino Factory baseline (4000km and 7000km baselines) and*
NF Py+INO *represents the concrete baseline from CERN to Pyhasalmi mine in Finland (2285 km) and to INO in India (7152 km);*
PS2-Slanic *is a preliminary superbeam study at 1500km based on an upgrade of PS2 to 1.66MW and a 100kton Liquid Argon TPC*

CERN – SPC panel report , 16.03.2010

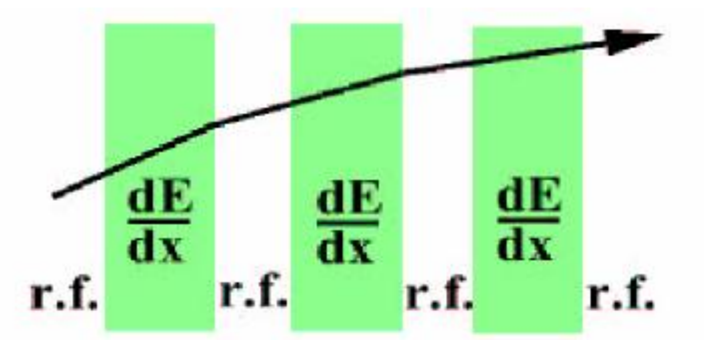
High Brilliance muon beams

Neutrino Factory and Muon Collider rest heavily on

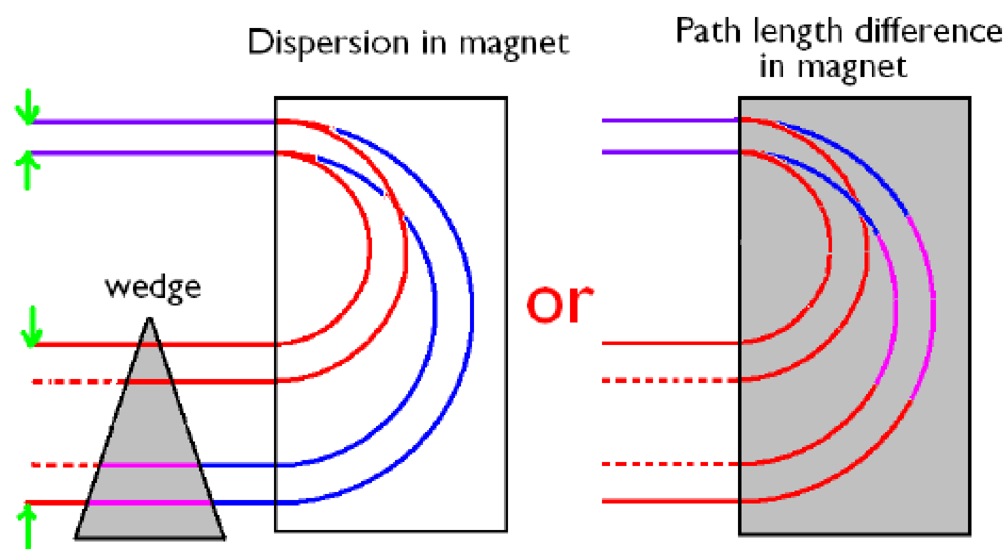
-- ionisation cooling
-- more generally manipulations of muon beams within solenoid magnetic fields
-- MANY VARIANTS!

Principle is straightforward…

transverse



longitudinal

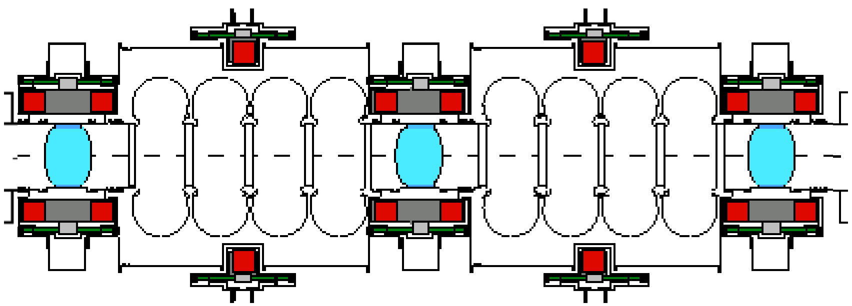


Empty magnet
+ wedge absorber

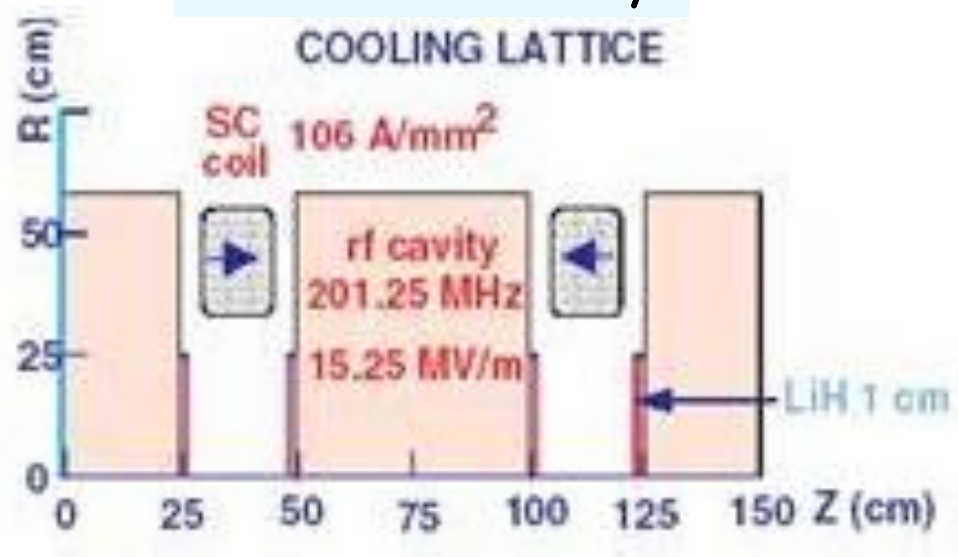
Magnet filled
with (gas) absorber

Practical realizations are more delicate…

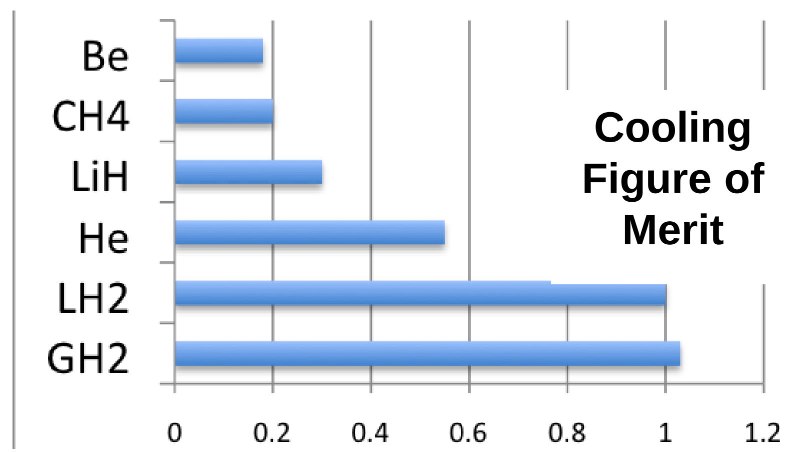
MICE (from Study II 2001)



IDS Neutrino Factory



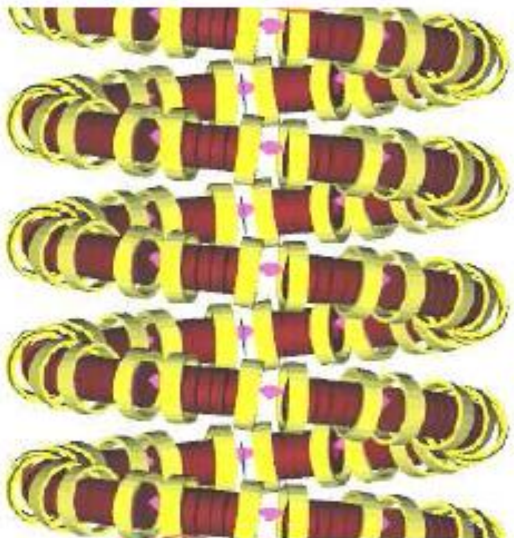
$$\epsilon_{N,\min} = \frac{\beta_\perp (14\ \mathrm{MeV})^2}{2\beta m_\mu \frac{dE_\mu}{ds} L_R}$$



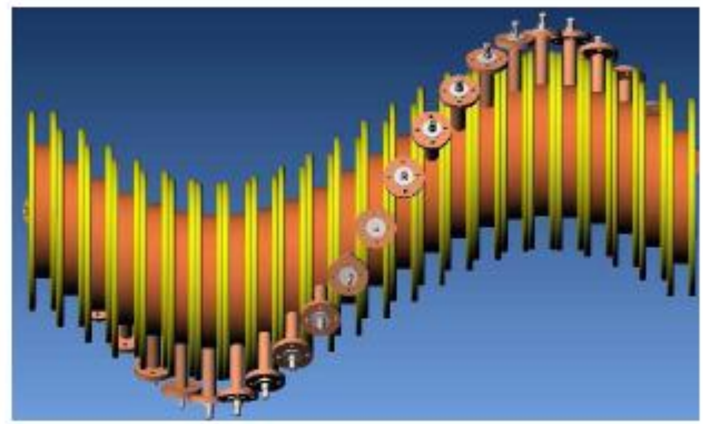
Practical realizations vary…

But all contain
solenoid magnets (for transport and focus)
RF cavities (for re-acceleration)
and absorbers (for cooling itself. Best is Liq H2)

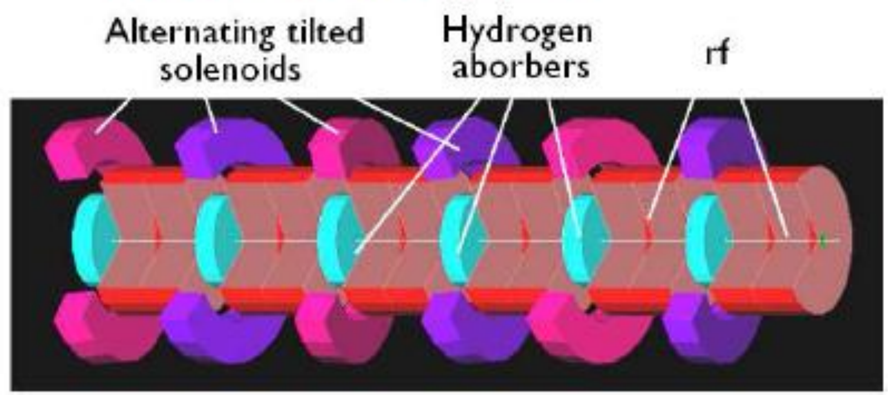
3 candidate 6D cooling lattices



Guggenheim



Helical Cooling Channel



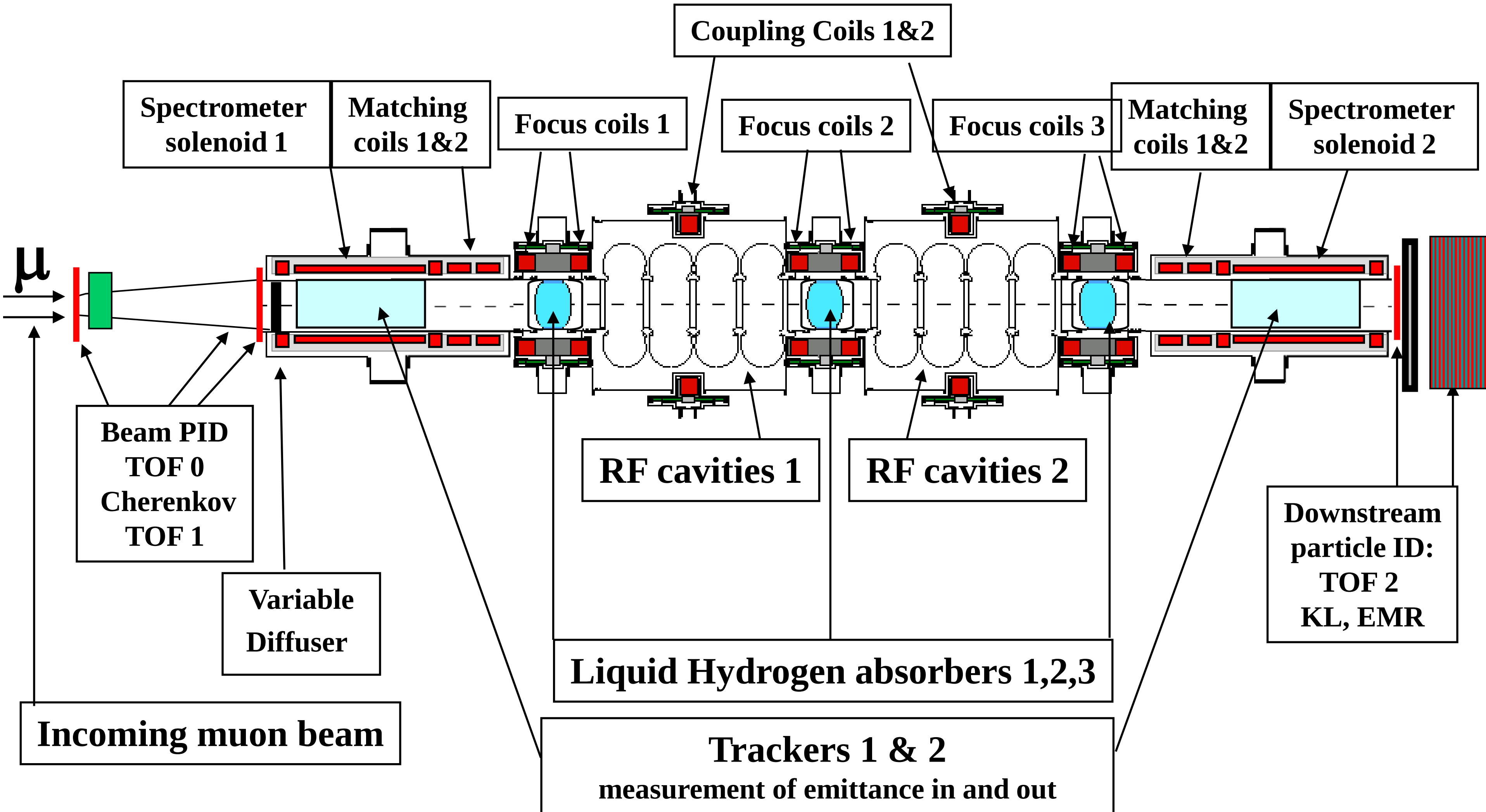
Snake

10% cooling of 200 MeV/c muons requires ~ 20 MV of RF

single particle measurements =>

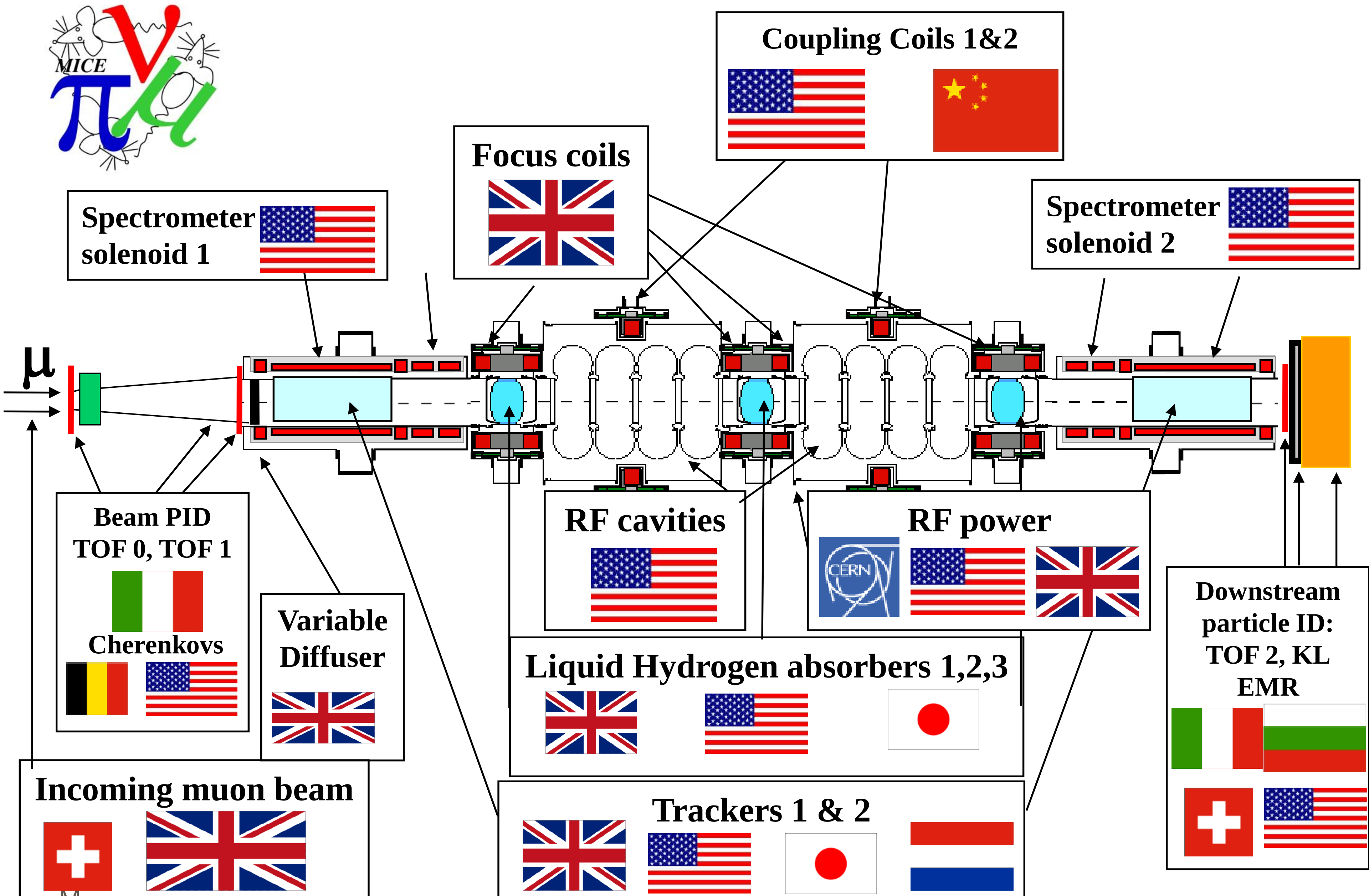
measurement precision can be as good as $\Delta (\varepsilon_{out}/\varepsilon_{in}) = 10^{-3}$

-- never done before either…



M

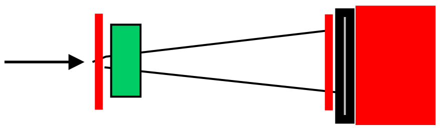
MICE Collaboration across the planet



μ

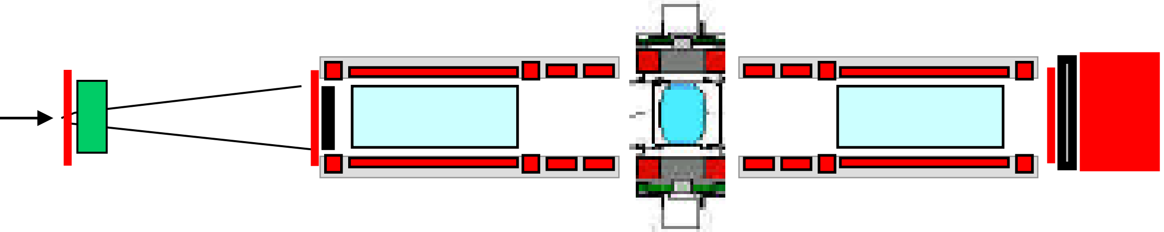
MICE SCHEDULE
update October 2011

Run date:



STEP I

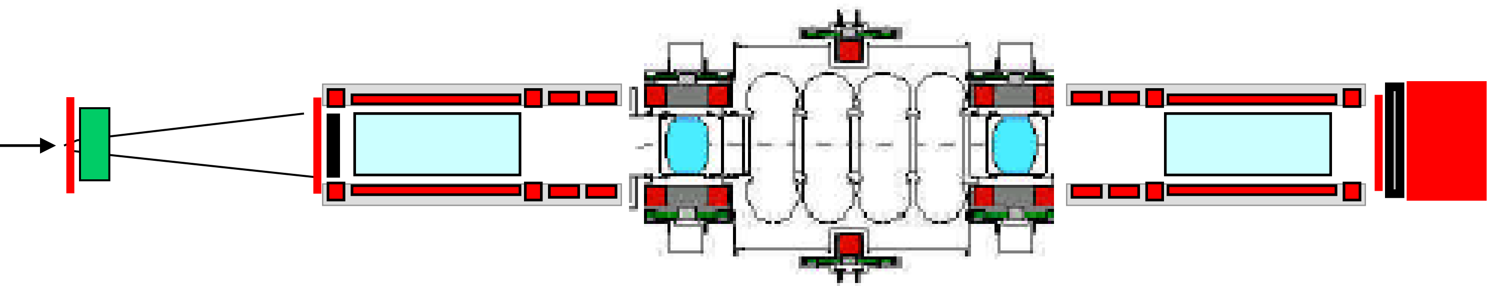
Completed
EMR run Q2 2012



STEP IV

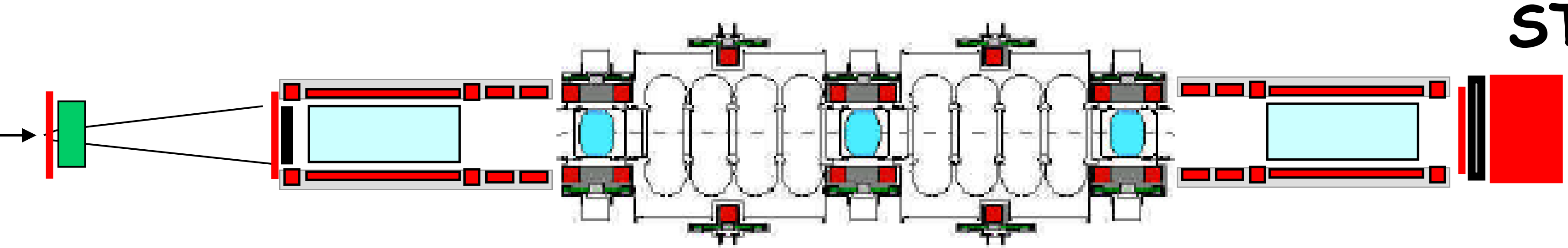
Q4 2012
and 2013

Under construction:



STEP V

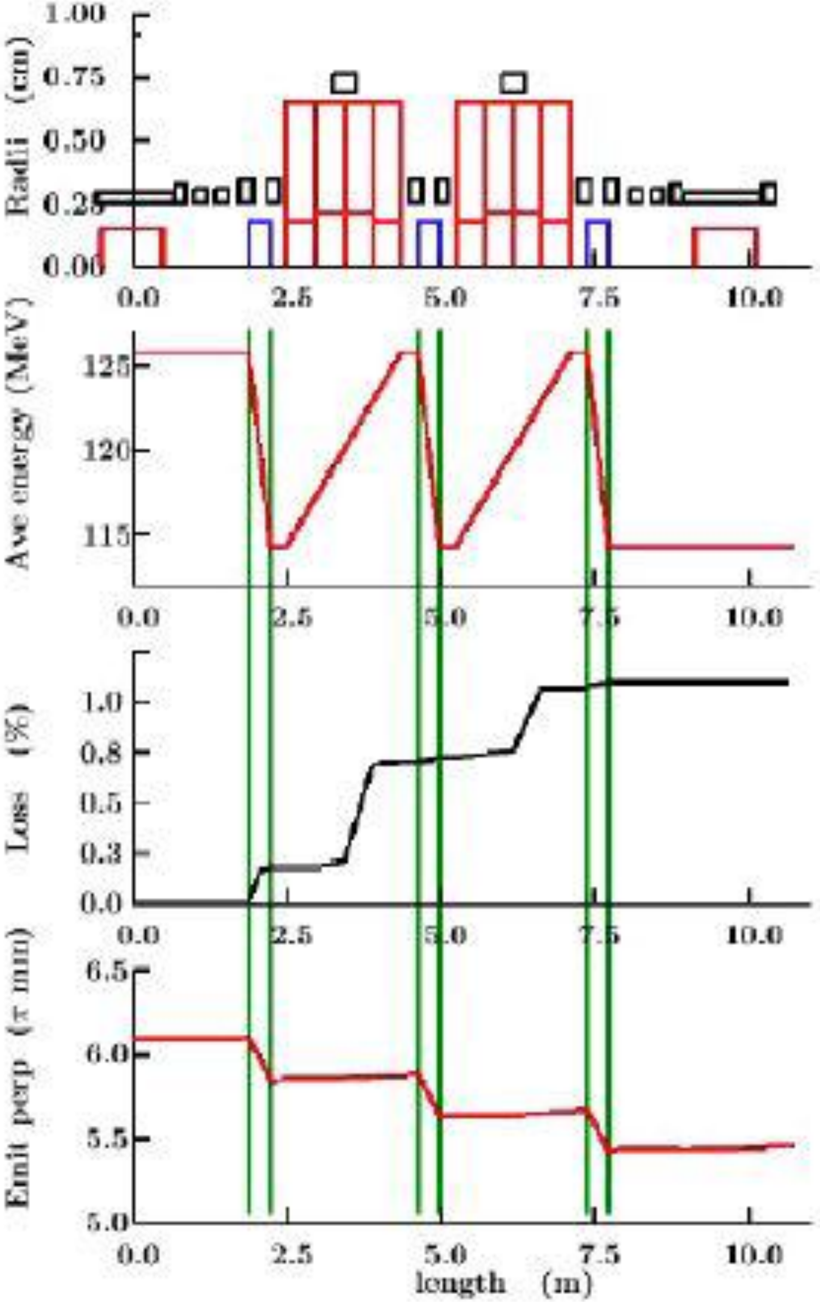
STEP VI




MICE construction:
world-wide team effort!
Diffuser (Oxford)
EMR (Geneva)
Trackers
(JP-UK-US)
RF Amplifier
(Daresbury)
LiqH2
absorber
(KEK)
Aim for completion in 2016
AFC Magnet
(RAL/Oxford)
Coupling coil
(Harbin China)
absorber
windows
(Mississippi)
RF cavities
(Berkeley)

RF requirements:

1. **Baseline mode, step V and step VI**
2. **Beyond the baseline**



Energy variation

Particle loss

2D ε reduction

MICE should cool by 10%. For 200 MeV particles this requires 23 MV of RF voltage.

This could be reached with 4 RF cavities operating at 16MV/m, 201MHz

However:

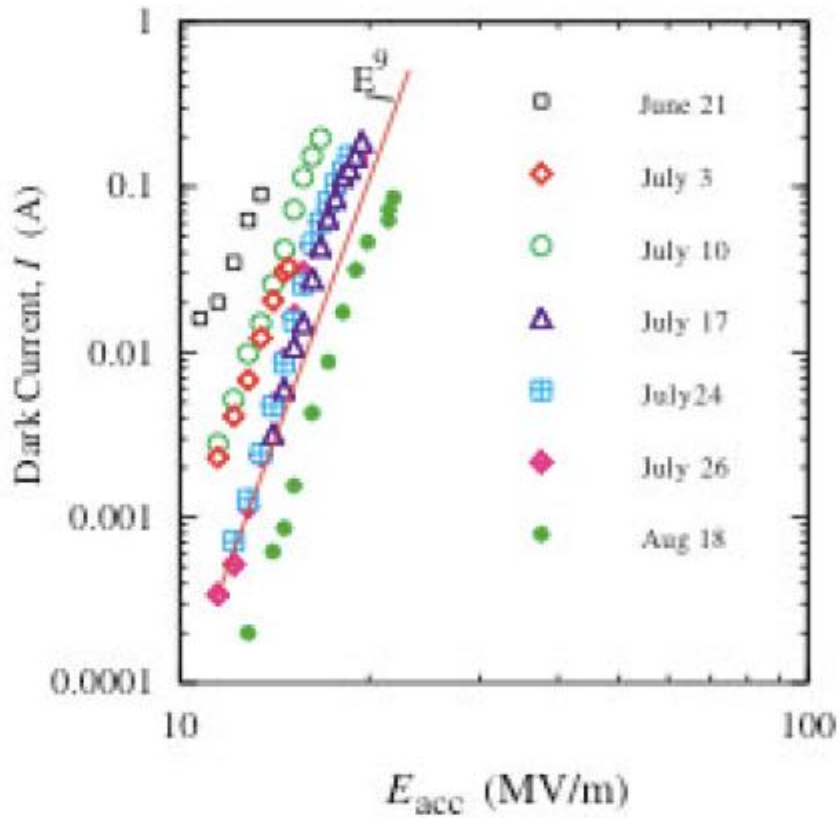
1. It is not clear that RF cavities could operate stably at this voltage in magnetic field

2. This would require 16 MW of peak RF power at room temperature → which we do not have

3. This would likely cause so much dark current that operation of detectors would be impossible.

   Dark current (electrons) grow as E^9

4. It was preferred to operate MICE with 8 cavities at 8MV/m



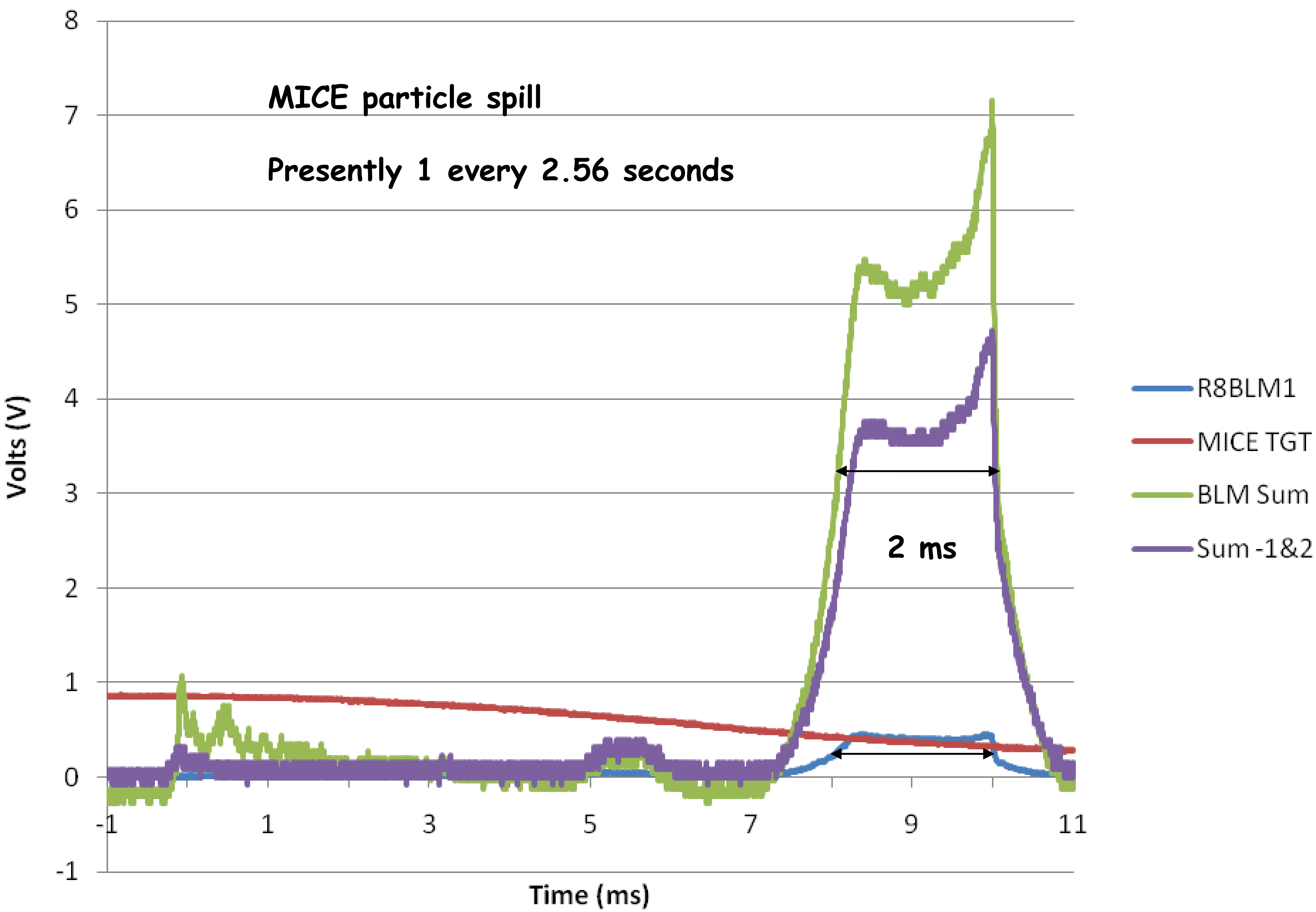
Nominal MICE step VI

➔ will operate with 8 RF cavities at 8MV/m.
This requires 1MW of peak RF power per cavity, shared among two RF couplers

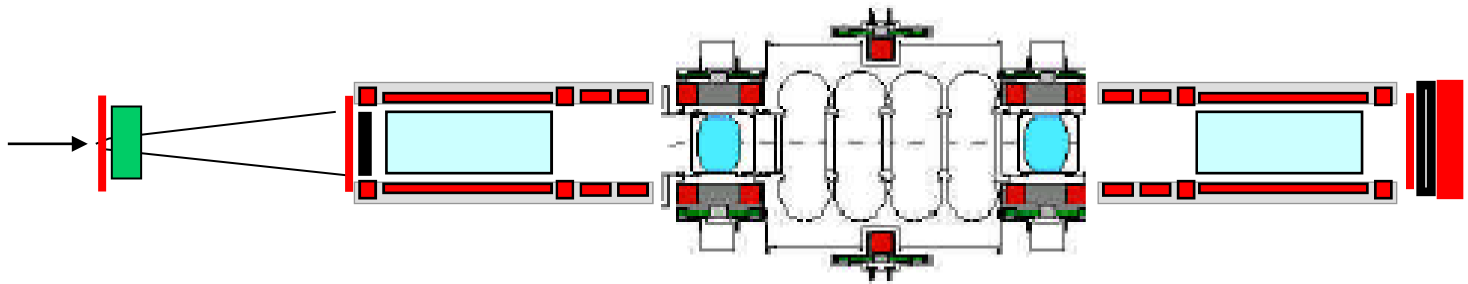
➔ Frequency 201 MHz.
Value is not critical within ~1MHz
RF cavities themselves are equipped with tuners
Should be tuned to maximize RF cavities performance and then fixed and stable

➔ Duty factor about 10^{-3}
e.g. 1ms RF pulse every second
or 2ms every 2s if this is preferred
are compatible with MICE beam operations (target dips in ISIS beam for 2ms)

pulse longer than 2ms is not useful for MICE beam
pulse shorter than 0.5 ms becomes inefficient

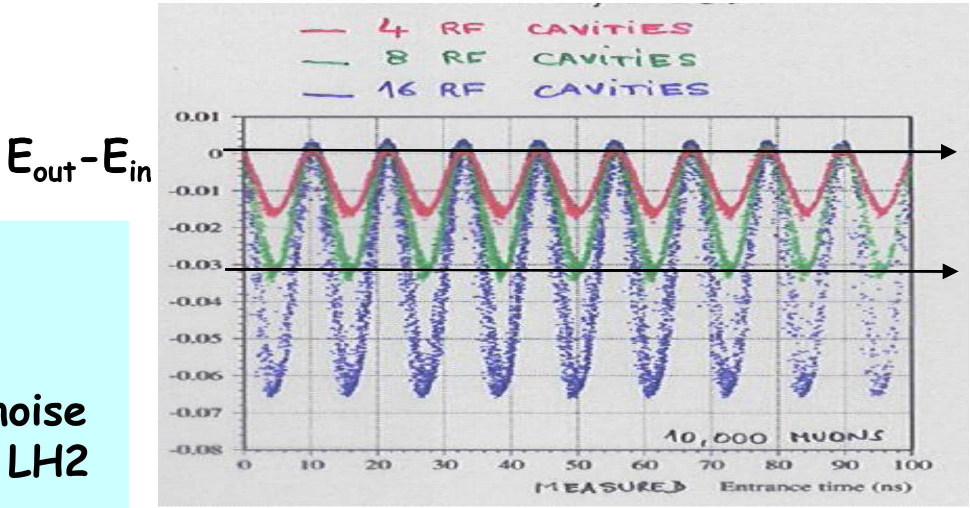

MICE particle spill
Presently 1 every 2.56 seconds
2 ms
Volts (V)
Time (ms)
8
7
6
5
4
3
2
1
0
-1
-1
1
3
5
7
9
11
R8BLM1
MICE TGT
BLM Sum
Sum -1&2

Step V



"sustainable" cooling:
cooling happens in the absorbers but production of cool beam requires acceleration with RF cavities

old simulation (at 88MHz)



RF phase

-1- running with shutters to commission RF cavities (no beam needed)
-1'- running with LH2 and RF first with no beam to check RF noise
-2- running with beam with no RF and no LH2 to check optics
-3- running with beam with LH2 no RF
-4- running with beam with LH2 and RF
-5- or running 2-3-4- with solid absorbers?

limited in optics and performance → step VI!

MICE is an R&D experiment

Phases of individual cavities should be tunable
to match changes in muon momentum from 140 to 240 MeV/c

this should be routine operation and not require a specialist
(presently done several times a day)

Phase and Volts should be recorded in real time
to match with muon measured arrival time

Possibility to run higher gradients should be preserved
-- by feeding more RF power to fewer cavities
-- by cooling cavities at LN2 rather than water

This is *not* routine operation (change over a shut down)

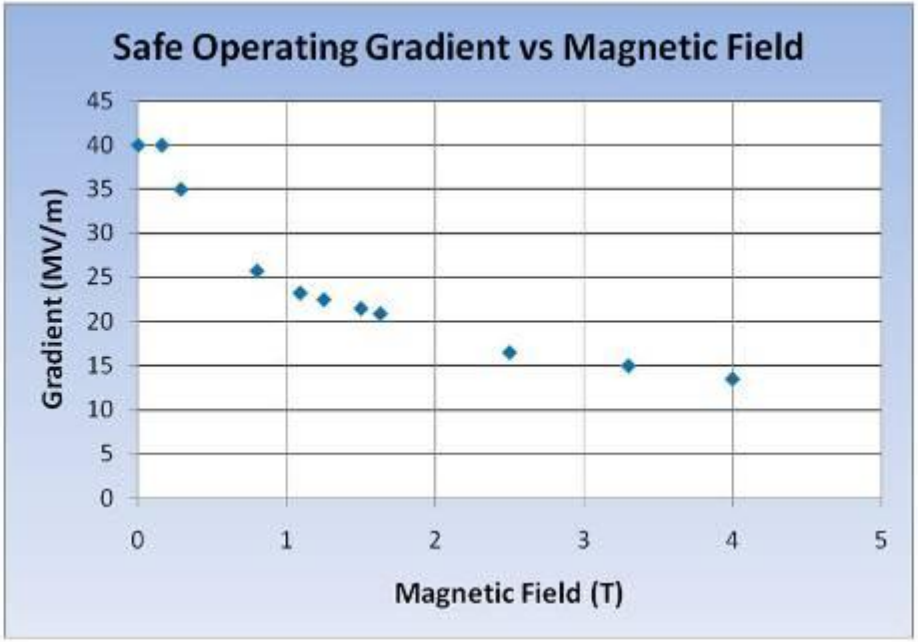
The main MICE issue

What about RF in Magnetic Field?

The RF *Challenge*

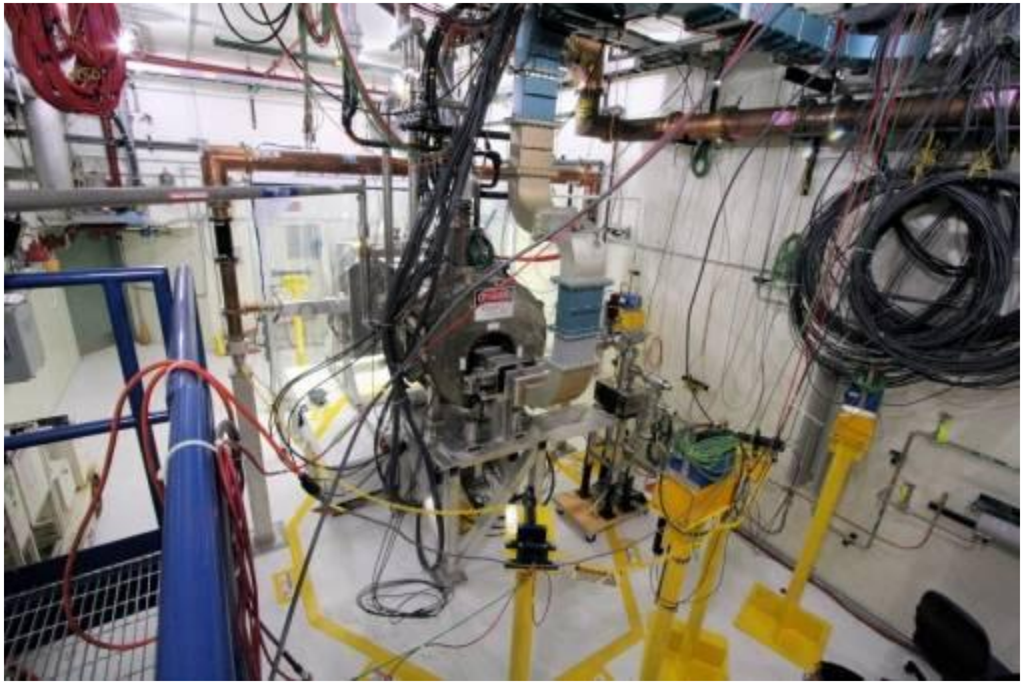
- **Significant degradation in maximum stable operating gradient with applied B field**

- 805 MHz RF Pillbox data
  - Curved Be windows
  - E parallel B
  - Electron current/arcs focused by B
- Degradation also observed with 201 MHz cavity
  - Qualitatively, quite different



RF Test Facility

- **MuCool Test Area (MTA)**
  - RF power
    - 201 MHz (5MW)
    - 805 MHz (12 MW)
  - Class 100 clean room
  - 4T SC solenoid
    - 250W LHe cryo-plant
  - Instrumentation
    - Ion counters, scintillation counters, optical signal, spectrophotometer
  - 400 MeV p beam line



201 MHz Cavity Test

Treating NCRF cavities with SCRF processes

- The 201 MHz Cavity – ***Achieved 21 MV/m***
  - **Design gradient – 16MV/m**
  - **At 0.75T reached 10-12 MV/m**

However, No observed damage!