MICE

The International Muon Ionisation Cooling Experiment

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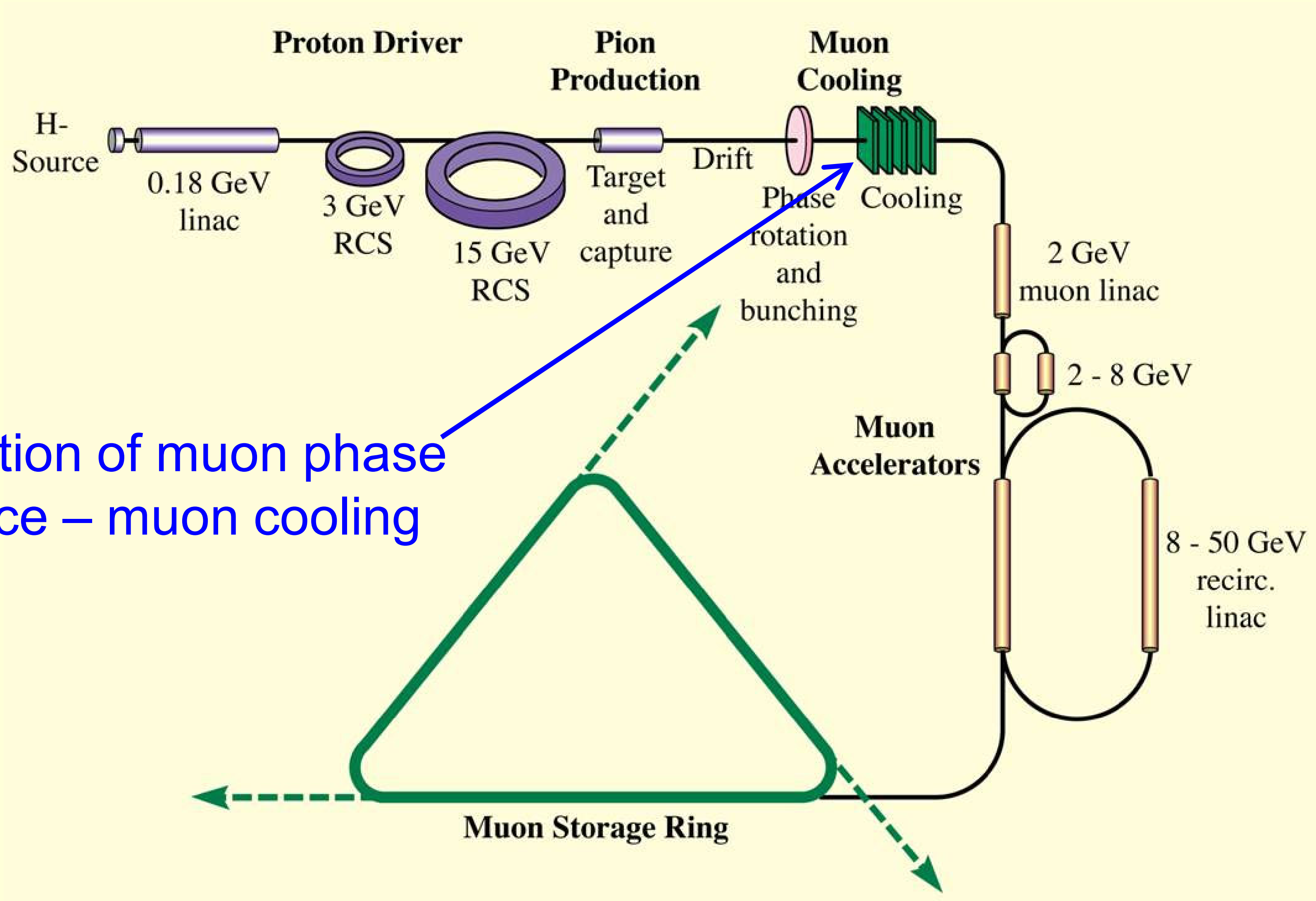
3rd July 2008

Outline

- Motivation: a Neutrino Factory
- Cooling
- Introduction to MICE
- Upstream beam-line
- Fibre tracker
- Cooling components
- Particle ID
- Schedule

A Neutrino Factory design

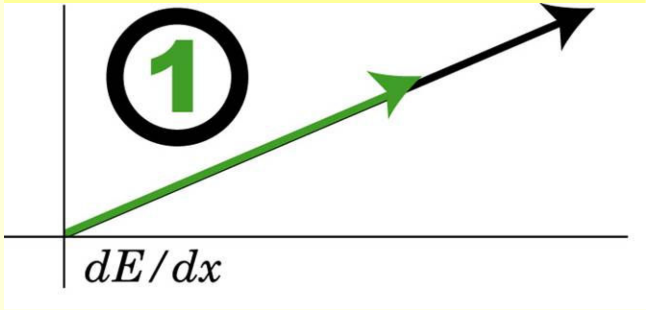


- Reduction of muon phase space – muon cooling

Muon Cooling

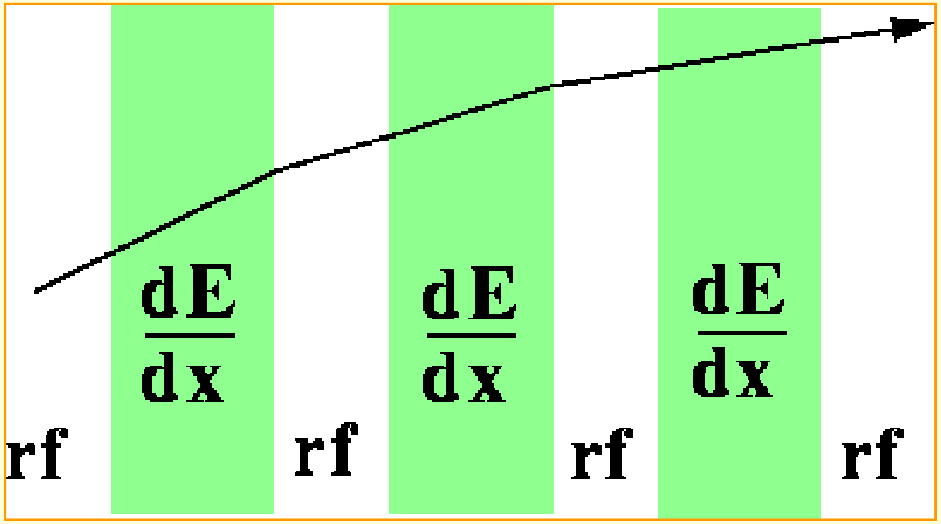
- Muons produced from decay have large phase space (emittance)
- Cannot efficiently inject into accelerator
- Must cool (reduce spread of angles and momenta)
- Short lifetime (τ=2μs) $\Rightarrow$ cannot use conventional (stochastic, electron) cooling
- Use ionisation cooling

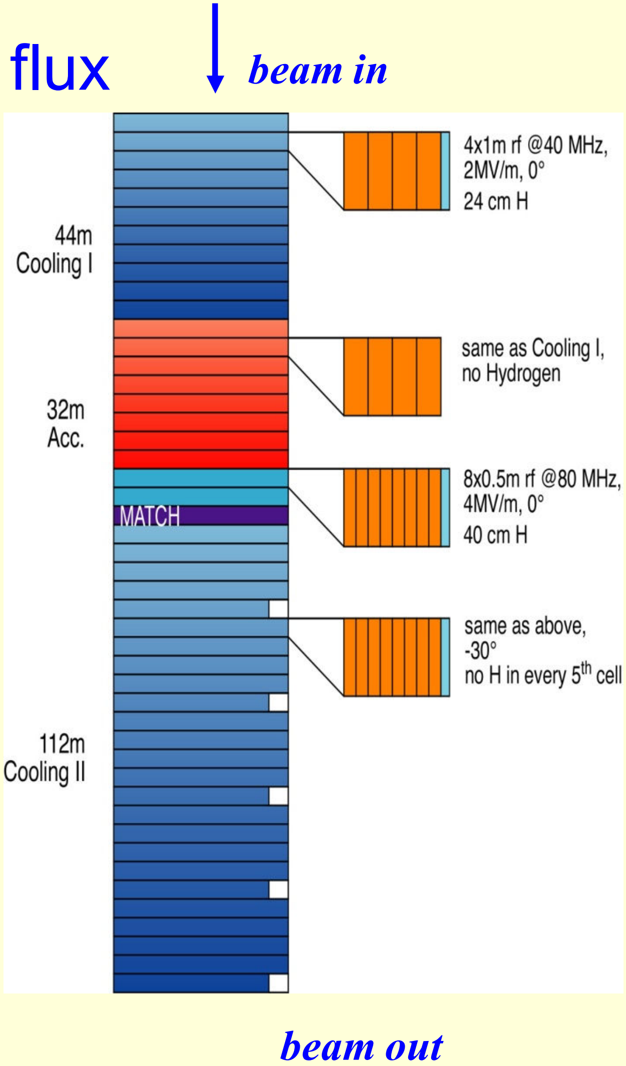
Principle



Muon Cooling

- Cooling aim: >4 – 10 increase in muon flux





- Cooling is delicate balance:

$$\frac{d\varepsilon_{\perp,N}}{dz} = -\frac{\varepsilon_N}{\beta^2 E}\frac{dE}{dz} + \frac{\beta_x (13.6\mathrm{MeV/c})^2}{2\beta^3 E m_\mu X_0}$$

Cooling Scattering

MICE – Muon Ionisation Cooling Experiment

Aims

- Design, build, commission and operate a section of a real cooling channel
- Solve the engineering challenges
- Measure performance under a variety of beam conditions
- Test a variety of energy-absorbing media
  - Liquid H_2
  - LiH
  - Carbon, …
- Produce data required for optimised design of Neutrino Factory cooling channel

Principles

- Generate a diffuse (uncorrelated) muon beam
  - Produce pions at target
  - Select collimated momentum bite
  - After drift, select lower momentum muons (from π decay)
  - Pass through “diffuser” (scatterer)
  - Verify muons by particle id
- Measure muons’ position and momentum (vector)
- Pass through cooling channel (dE/dx & RF)
- Measure new position & momentum
- Verify particles are still undecayed muons
- Calculate change in emittance from selected “beam”
- Repeat for other momenta, energy absorbers, magnetic field configurations, etc.

MICE collaboration

Universite Catholique de Louvain **Belgium**

St.Kliment Ohridski Univ. of Sofia **Bulgaria**

INFN: Milano, Napoli, Pavia, Roma III **Italy**

KEK, Kyoto Univ., Osaka Univ. **Japan**

ICST Harbin **China**

NIKHEF **The Netherlands**

CERN

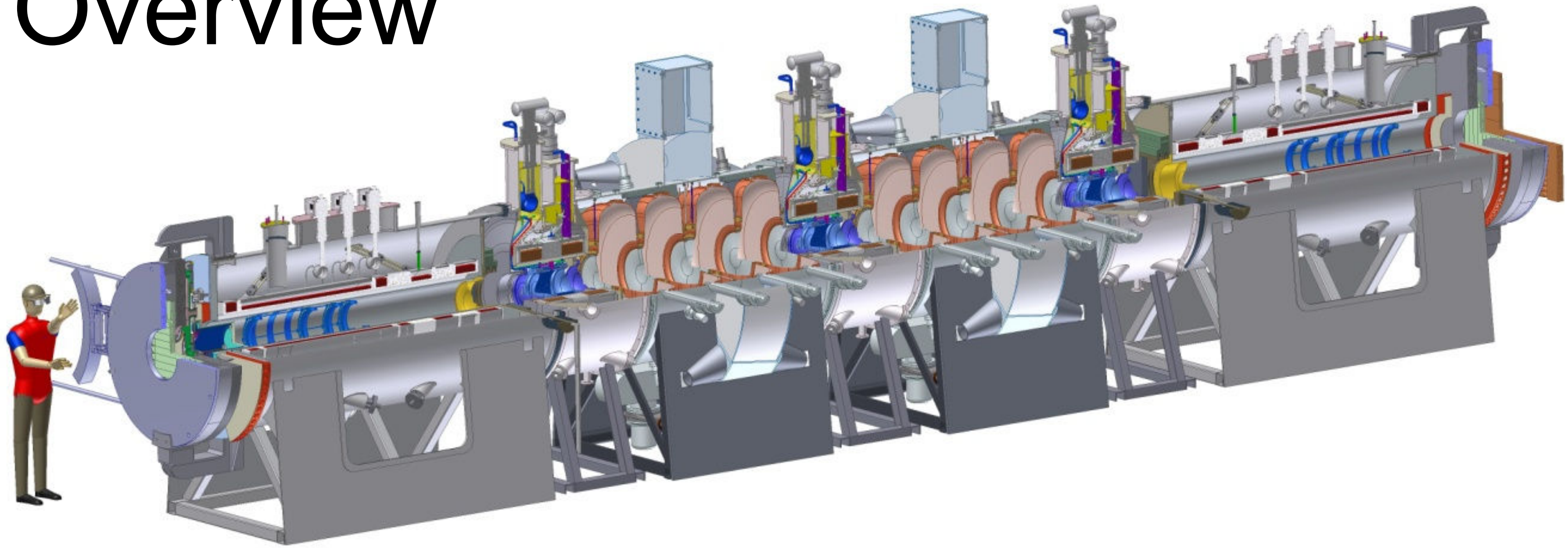
DPNC, PSI **Switzerland**

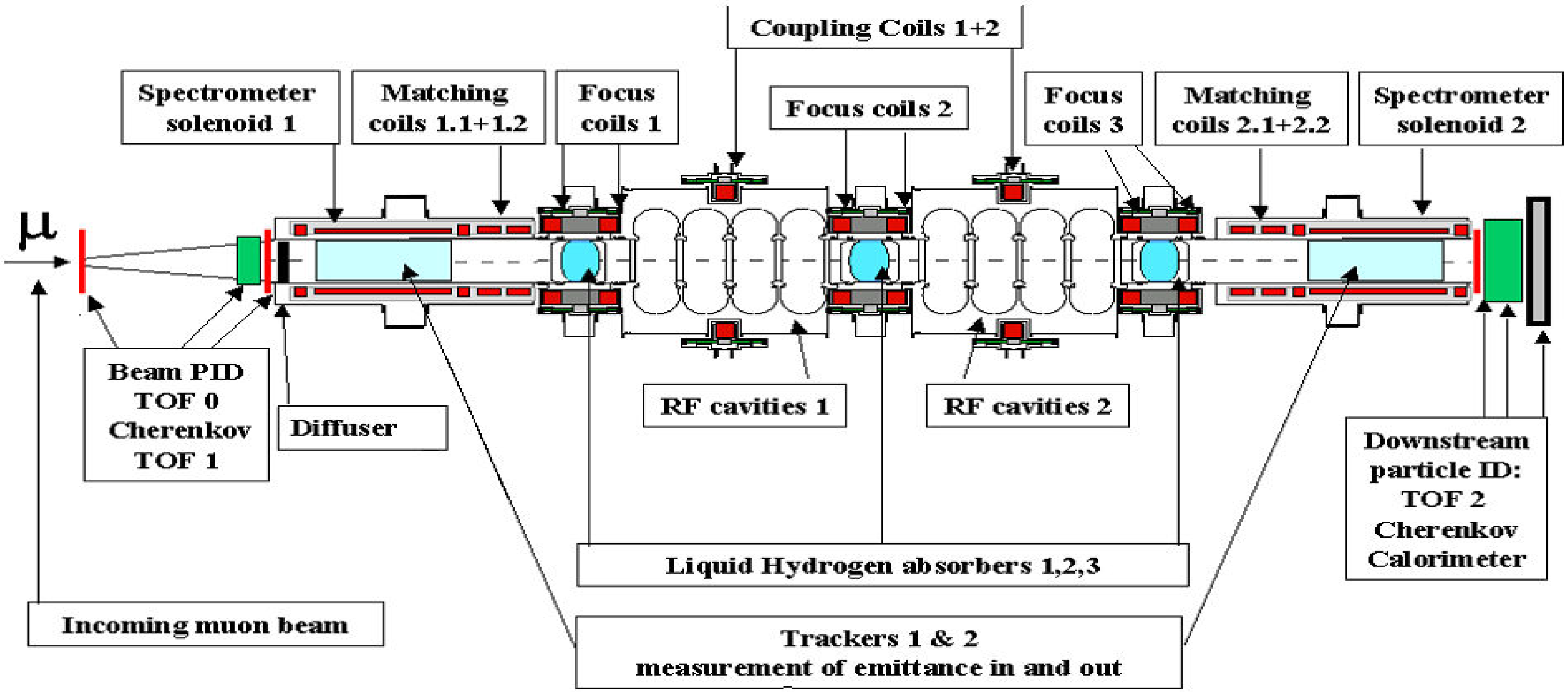
Cockcroft Lab, Daresbury Lab, Brunel, Glasgow, Liverpool, Imperial, Oxford, RAL, Sheffield, Warwick **UK**

ANL, BNL, Fermilab, LBNL, Muons Inc., IIT, New Hampshire, Iowa, UCLA, Jefferson Lab, Mississippi, Riverside **US**

3 continents
9 countries
34 institute members
140 individual members
- Engineers & physicists (part.& accel.)

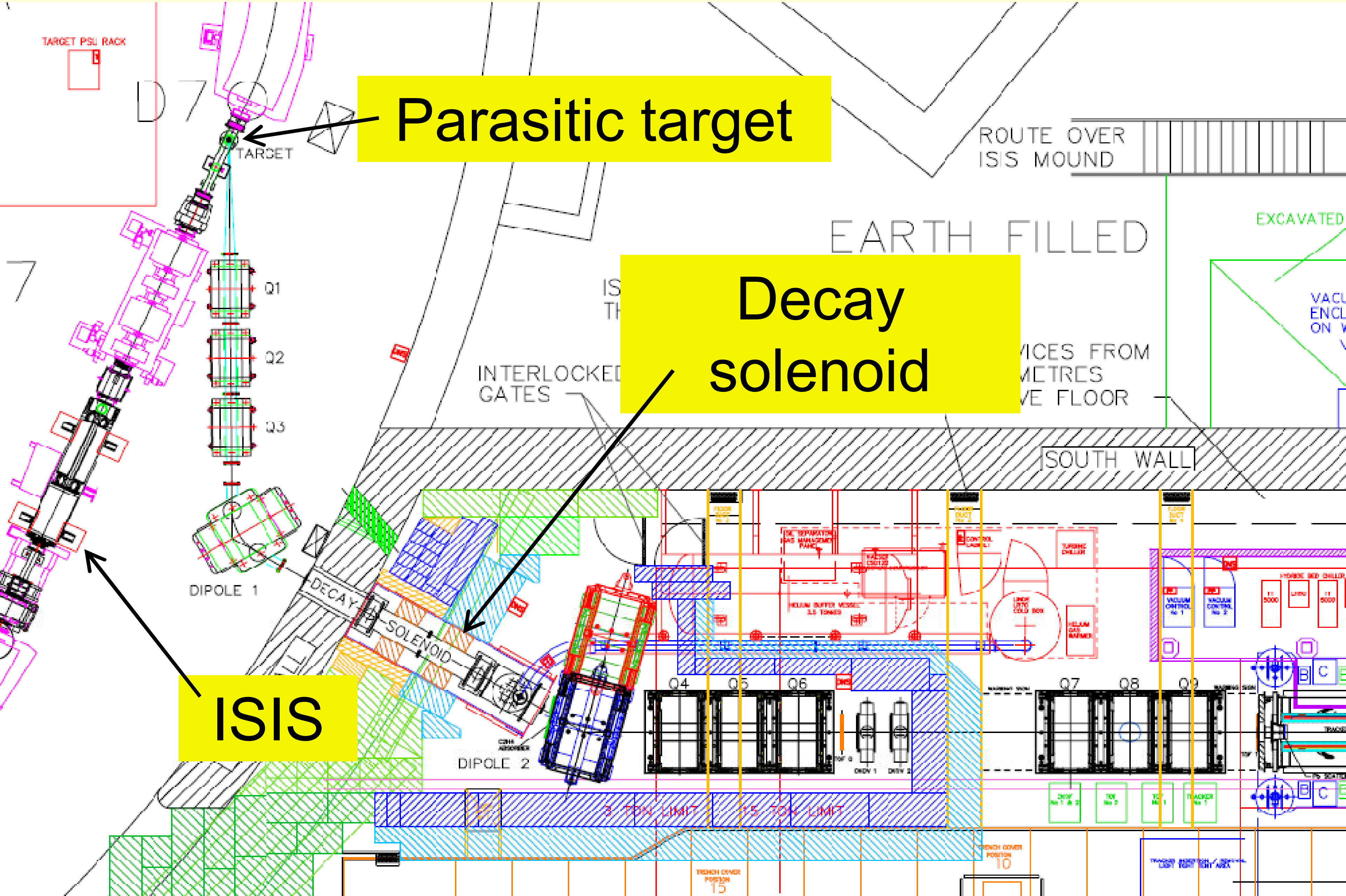
Overview





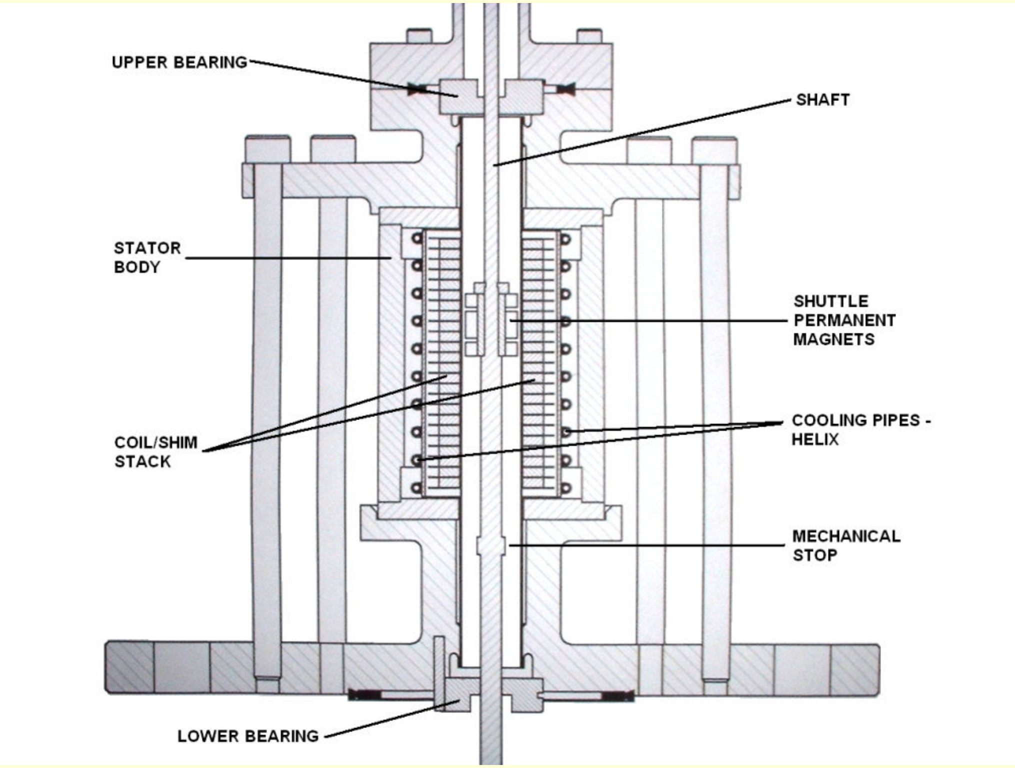
Coupling Coils 1+2
Spectrometer solenoid 1
Matching coils 1.1+1.2
Focus coils 1
Focus coils 2
Focus coils 3
Matching coils 2.1+2.2
Spectrometer solenoid 2
μ
Beam PID
TOF 0
Cherenkov
TOF 1
Diffuser
RF cavities 1
RF cavities 2
Downstream particle ID:
TOF 2
Cherenkov
Calorimeter
Liquid Hydrogen absorbers 1,2,3
Incoming muon beam
Trackers 1 & 2
measurement of emittance in and out

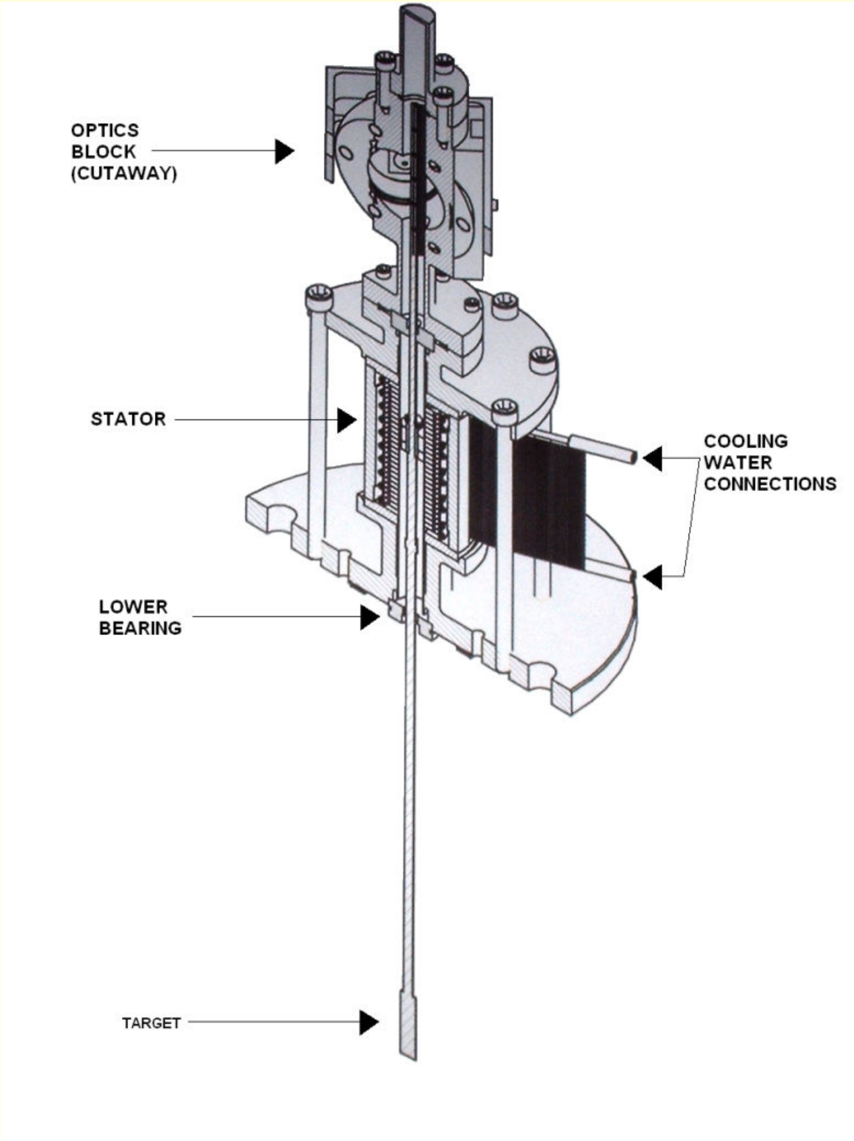
Upstream Beam-line



Target Mechanism

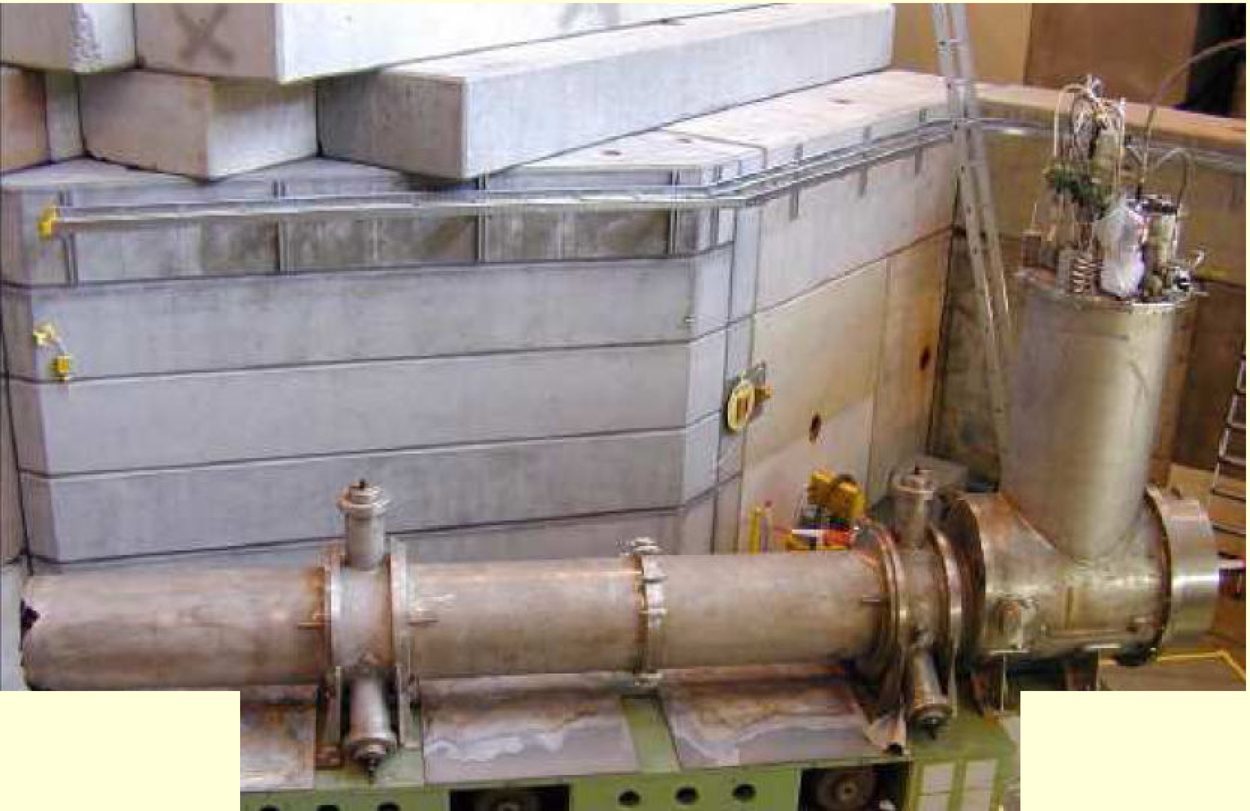
- Titanium target dips into accelerated proton beam.
- Dip rate ~1 Hz, on demand
- EM linear motor: acceleration ~850 ms^{-2} to sample correct time.
- Installed January 2008. >190K pulses used for beam & detector commissioning.
- Reliability problems with parallel “demonstrator” system led to mechanical redesign.
- New target will be installed in August


UPPER BEARING
SHAFT
STATOR BODY
SHUTTLE PERMANENT MAGNETS
COIL/SHIM STACK
COOLING PIPES - HELIX
MECHANICAL STOP
LOWER BEARING


OPTICS BLOCK (CUTAWAY)
STATOR
COOLING WATER CONNECTIONS
LOWER BEARING
TARGET

Upstream quad triplet and dipole

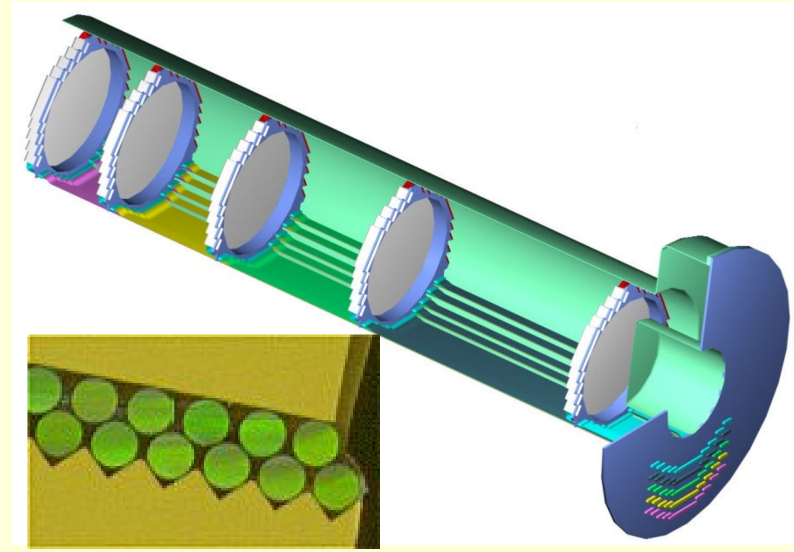
Superconducting decay solenoid (5 m long, 5 T) – PSI

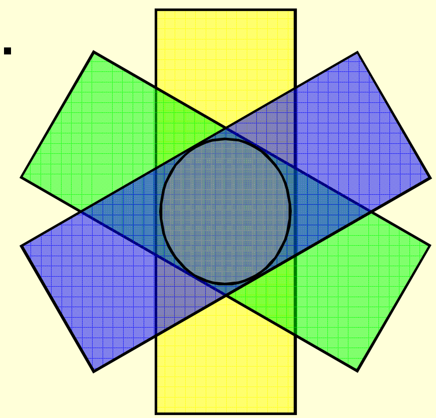


- Mechanical repairs completed
- Multi-layer insulation renewed
- Commissioned at full field successfully

Fibre Tracker

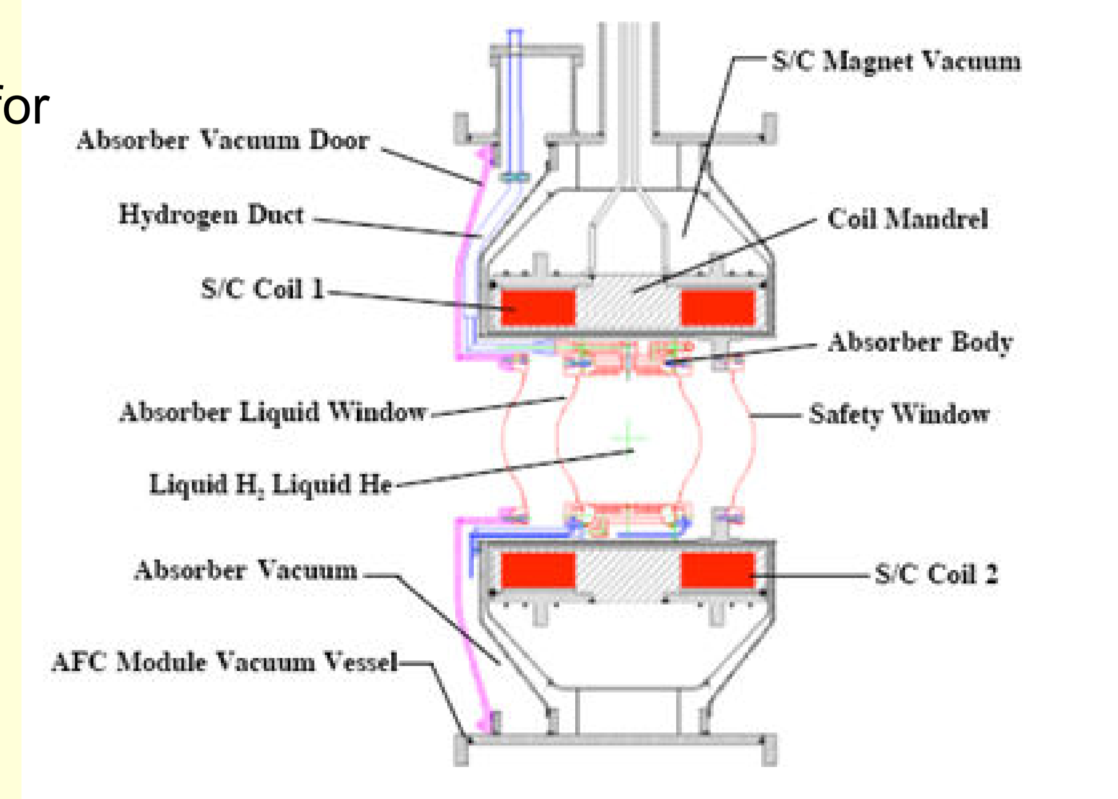
- 5 Scintillating fibre stations
- Double fibre layers (0.35mm diameter).
- Triplet of layers (120°) per station.
- VLPC readout.
- 8-10 photo-electrons per layer.
- ~0.6 mm resolution per plane (verified with cosmics).
- 4T superconducting solenoid.





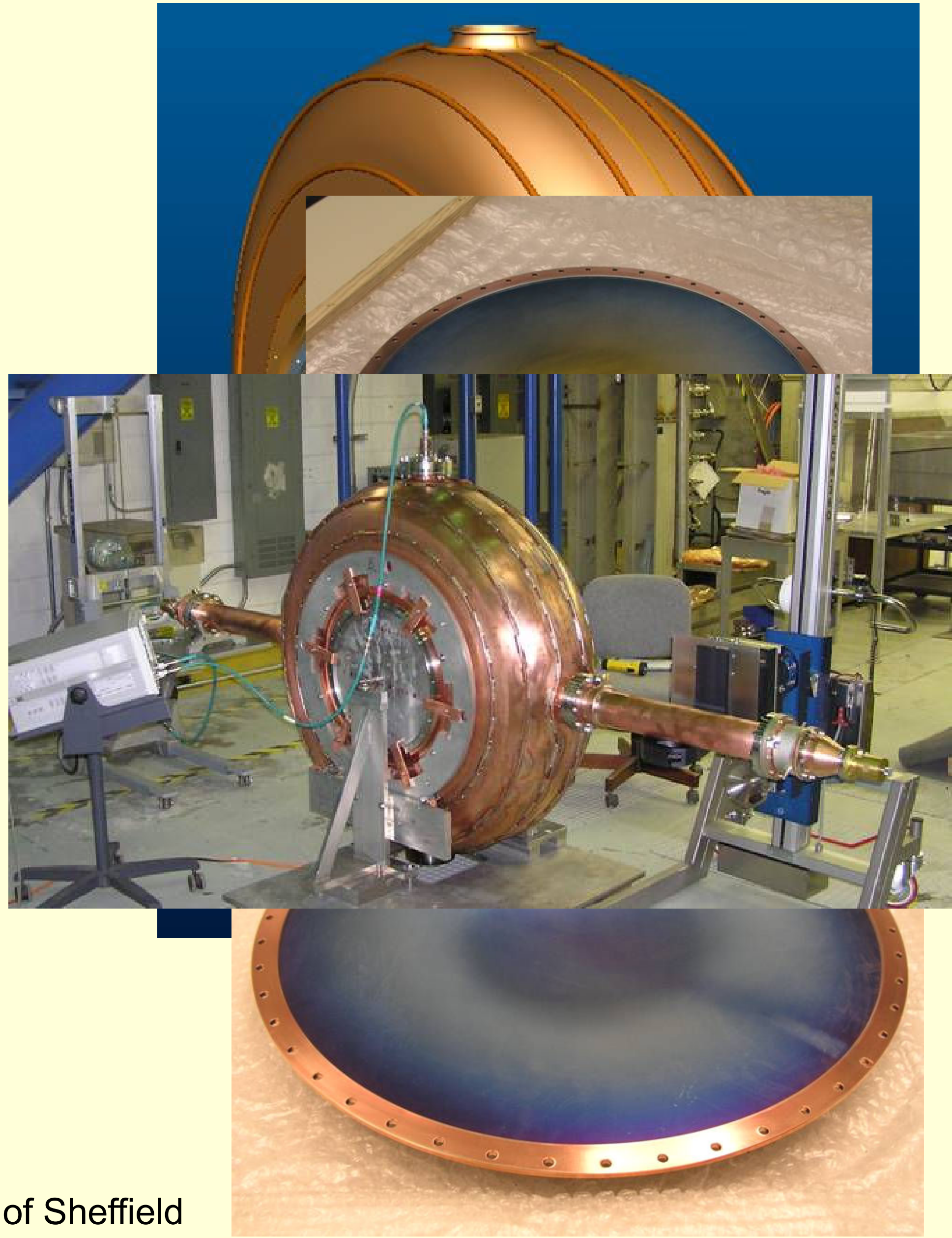
Liquid Hydrogen Absorbers

- Novel H_2 system based on metal hydride beds
  - Produce H_2 when warmed, absorb it when cooled
  - Technology developed for H_2 automobile industry
  - Intrinsically (relatively) safe.
- Cryo-coolers
  - Compact, closed-circuit refrigeration units
- Superconducting magnets
  - Low β environment

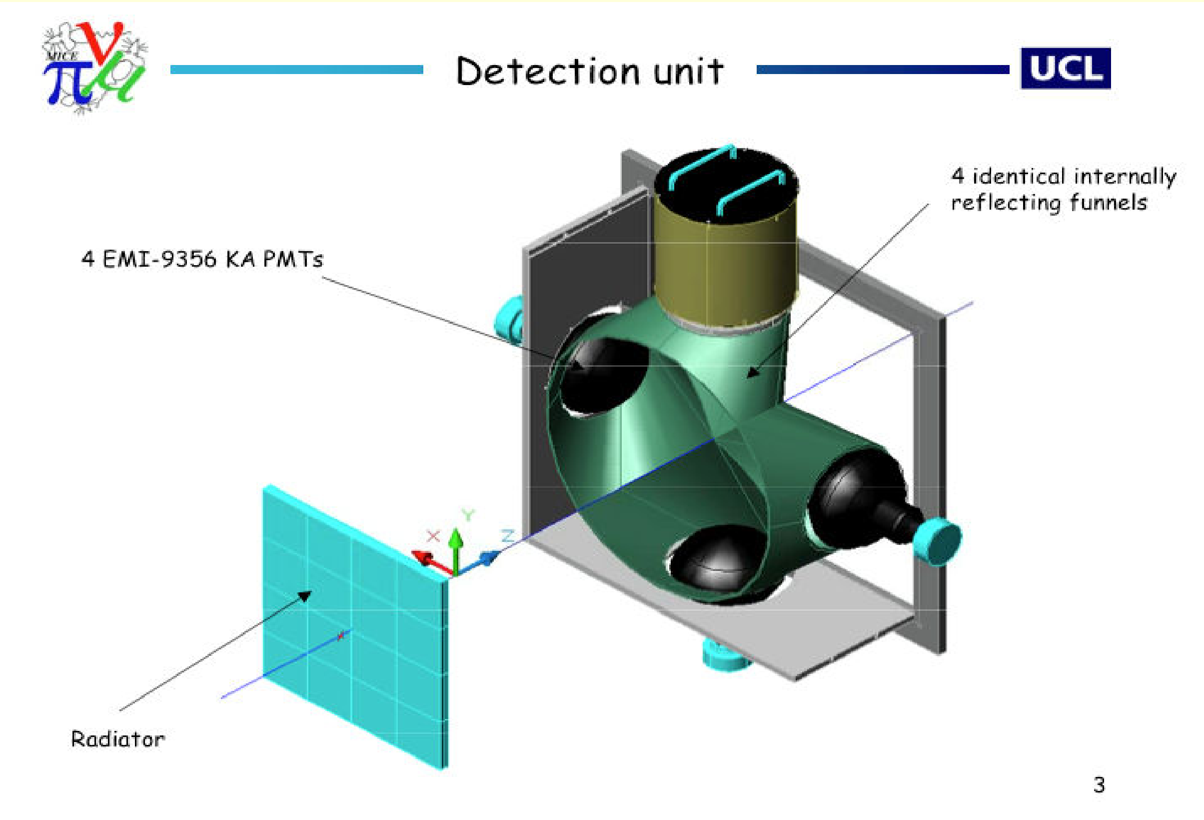


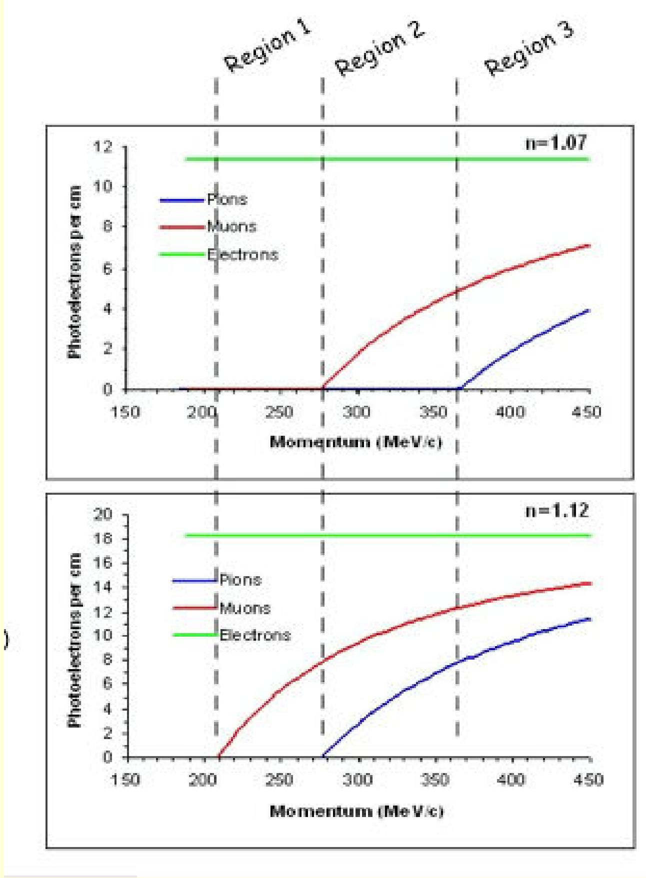
201 MHz RF Cavities

- Large aperture
  - for uncooled muon beam)
- High Q & high accelerating gradient
- Thin curved beryllium windows
  - Minimise multiple scattering
  - Double-curved shape prevents buckling caused by thermal expansion due to RF heating
- Tests underway at FNAL
  - Operation in large magnetic fields



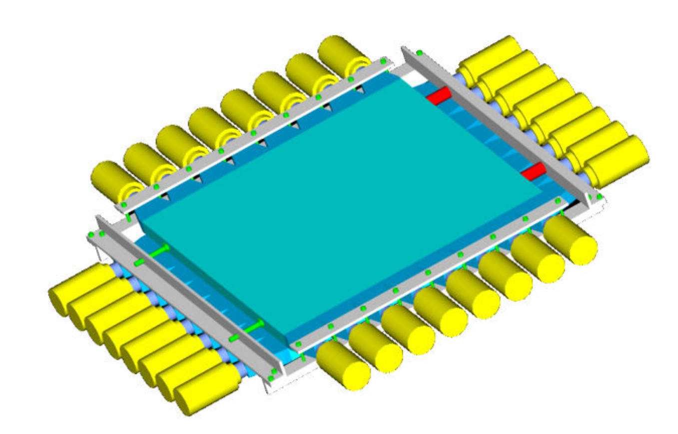
Cherenkov

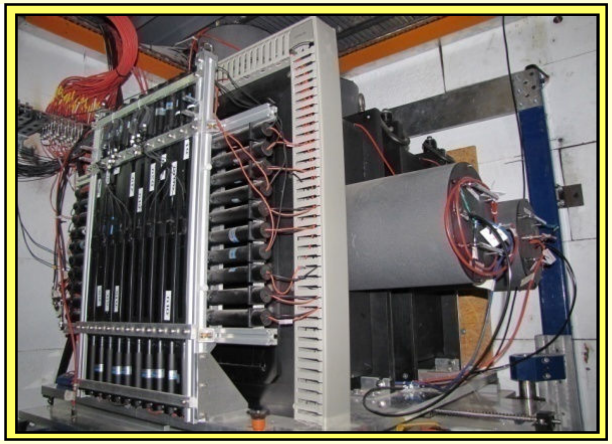


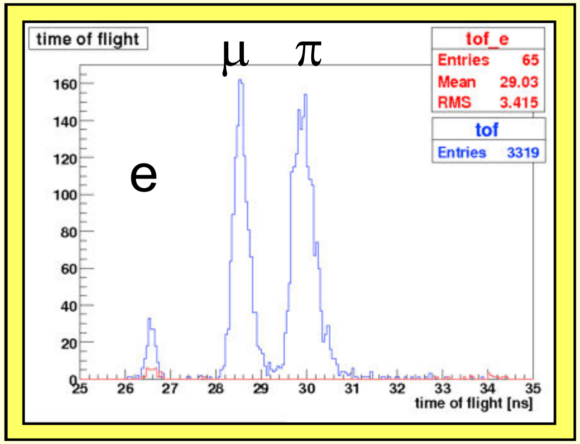


- 2 modules give π, μ, e separation
- Aerogel radiator sheets
- Low mass, reflecting funnels
- 8” photomultipliers

Time of Flight/Trigger

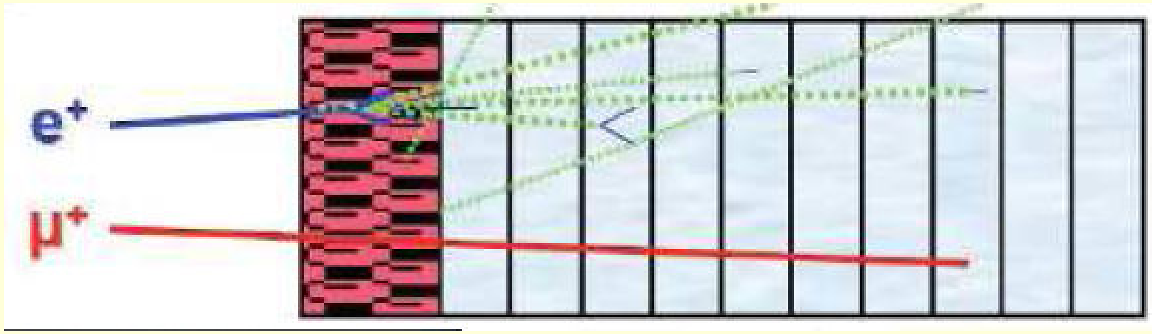




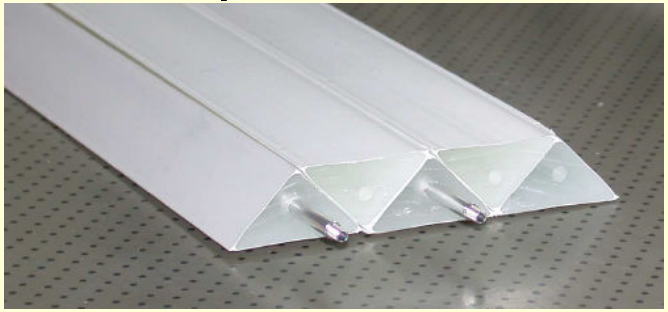


- 2 stations upstream + 1 downstream
- 2.5 MHz rate (for 1 ms) at TOF0
  - Modular (12×12) design
  - Fast scintillator BC404 or 420
  - 2.5 cm thick (compromise timing vs. scattering!)
  - Fine-mesh PMTs
    (e.g. Hamamatsu R4996) + magnetic shielding + modified base
- TOF 0/1 commissioned in 2008 using 300 MeV/*c* π^+
  - ~52 ps resolution achieved. $\pi/\mu/e$ separation.

Electromagnetic calorimeter/ranger

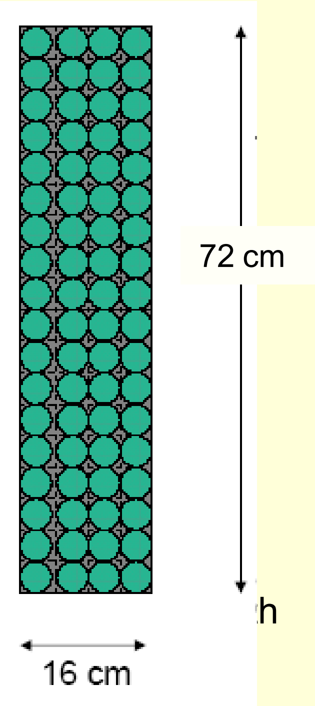


- Kloe-like lead/scintillating fibre calorimeter followed by scintillator electron/muon-ranger (EMR).



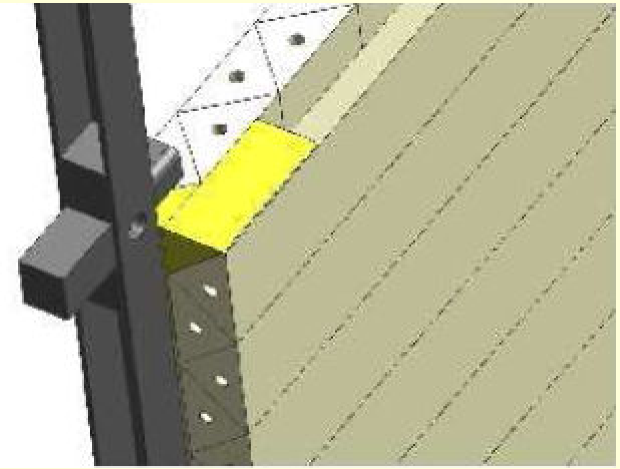
FRONT

- 1 mm scintillating fibres in 0.3 mm grooved lead foils.
- 4×4 cm^2 blocks, pm at each end.
- Muons punch through as mips; electrons produce shower.

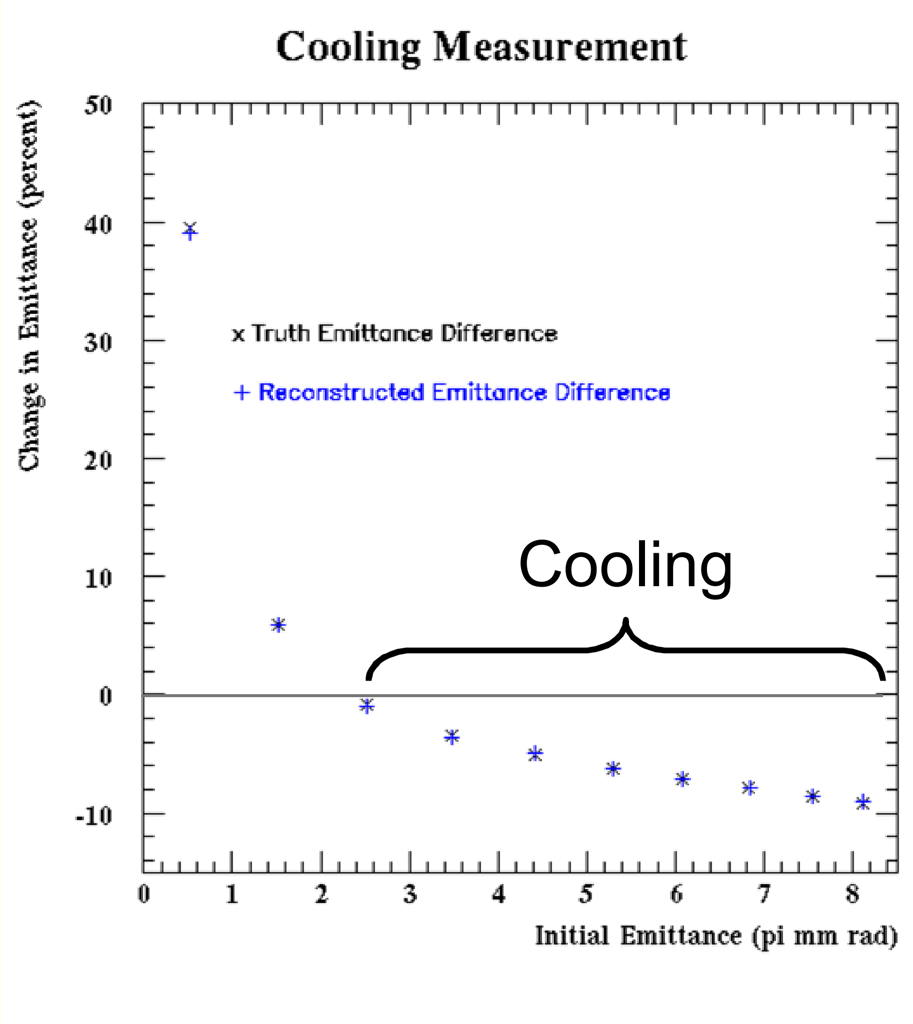


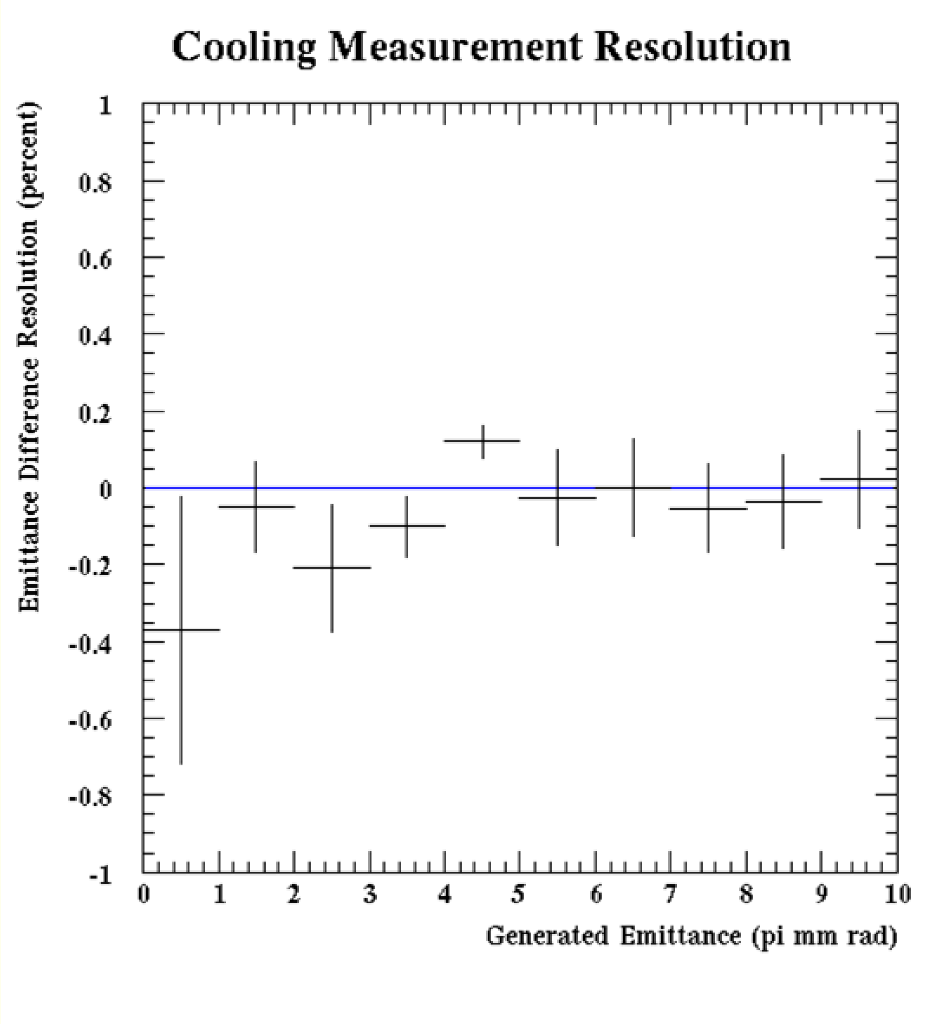
BACK

- 49 layers of 59 triangular bars.
- WLS fibre light-guides
- 64-pixel PMT



Projected Measurement of Cooling

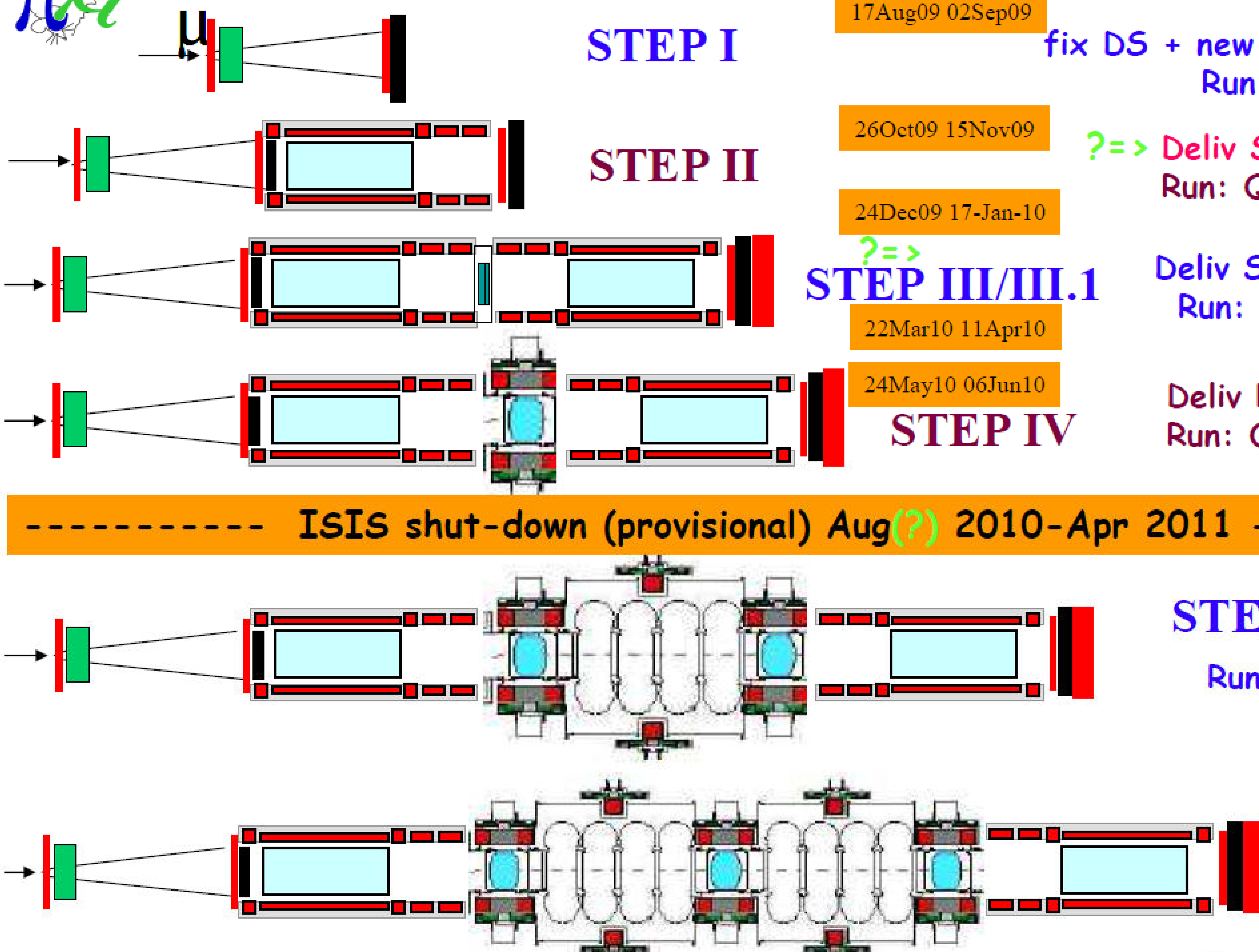




Target: “Measure 10% cooling to 1%” - i.e. 0.1% absolute

MICE schedule (April 2009).

ISIS shut downs



17Aug09 02Sep09

STEP I — fix DS + new target
Run: Sep09

26Oct09 15Nov09

STEP II — ?=> Deliv SS-1 Jun09
Run: Q4 2009

24Dec09 17-Jan-10

?=>

STEP III/III.1 — Deliv SS-2 Sep09
Run: Q1 2010

22Mar10 11Apr10

24May10 06Jun10

STEP IV — Deliv FC-1 Feb10
Run: Q2-3 2010

----------- ISIS shut-down (provisional) Aug(?) 2010-Apr 2011 ----------

STEP V

Run: 2011

STEP VI

Run 2011-2012

Conclusion

- MICE will make a detailed study of cooling under a wide variety of conditions.
- Construction is well underway.
- Beam characterisation started last year.
- Step 1 will start this summer; Step 2 in Autumn.
- Cooling measurements will occur (with increasingly sophisticated/realistic setups) over next three years.
- We should provide valuable input for design studies, to enable construction of a Neutrino Factory from the middle of the next decade.