International MUON Collider Collaboration

MuCol

CERN

MuCol WP8 Cooling Cell Workshop

Absorbers

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- LiH & MICE
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- LH2 assembly at MICE
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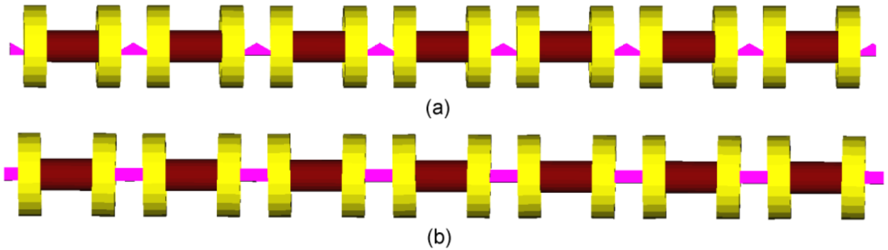
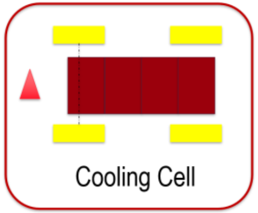
Muon Cooling and absorbers

- Initial **μ beam has large phase-space volume** → **needs to be compressed for low emittance and high-luminosity collisions** in short time (before muon decay 2.2μs)
- **Ionization cooling** → reduce beam momentum via **ionization loss in absorbers** and replenishing momentum loss in longitudinal RF cavities Reduce transverse phase-space, and only increase momentum longitudinally
- **Emittance exchange** → High energy particles pass via more absorber material than low energy particles (e.g. **wedge absorber**). Reduce longitudinal emittance, but increases transverse emittance





R. Losito

FIG. 2. Conceptual design of a rectilinear channel: (a) top view; (b) side view.

Rectilinear six-dimensional ionization cooling channel for a muon collider: A theoretical and numerical study, Diktys Stratakis and Robert B. Palmer, DOI: 10.1103/PhysRevSTAB.18.031003

Muon Cooling and absorbers

- Ideal cooling channel will produce the lowest equilibrium emittance
- → **material with high radiation length & high specific ionization**
- → materials w/ low atomic number have long radiation length relative to rate of energy loss, thus better cooling performance → **ideal absorbers**

Rate of change of normalised emittance due to ionization cooling in a medium of thickness X

$$\frac{d\varepsilon_N}{dX} \approx -\frac{\varepsilon_N}{\beta^2 E_\mu}\left\langle\frac{dE}{dX}\right\rangle + \frac{\beta_t (0.014\ \mathrm{GeV})^2}{2\beta^3 E_\mu m_\mu X_0}$$

Equilibrium emittance

$$\varepsilon_{eq} \approx \frac{\beta_t (0.014\ \mathrm{GeV})^2}{2\beta m_\mu X_0}\left\langle\frac{dE}{dX}\right\rangle^{-1}$$

The MICE Muon Beam on ISIS and the beam-line instrumentation of the Muon Ionization Cooling Experiment, arXiv:1203.4089v2 [physics.acc-ph] 23 Mar 2012

LiH & MICE

LiH & MICE

- → materials w/ low atomic number (**Li & H**)

Step IV Absorbers

	X_0 (gcm^{-2})	dE/dX (MeV g^{-1} cm^{-2})	ρ (gcm^{-3})	Δx
LH2	63.04	4.103	0.07	350 mm
LiH	79.62	1.897	0.82	63 mm
PolyE	44.77	2.079	0.89	52 mm
Be	65.19	1.595	1.848	34 mm
C	42.7	1.742	2.21	26 mm
Al	24.01	1.615	2.699	23 mm
Ti	16.16	1.477	4.54	15 mm
Cu	12.86	1.403	8.96	8 mm

Blue = materials used in the Neutrino Factory;
material thickness corresponds to 10 MeV energy loss

$$\frac{d\varepsilon_n}{dz} = \frac{-\varepsilon_n}{\beta^2 E}\left\langle\frac{dE}{dX}\right\rangle + \frac{\beta_t (0.014\ \mathrm{GeV})^2}{2\beta^3 E m_\mu X_0}$$

courtesy Timothy Carlisle

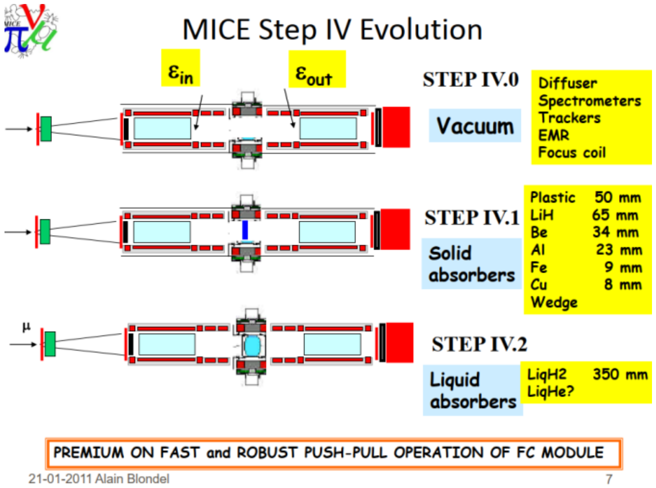
Solid Absorber Program for Step IV, Pavel Snopok, MICE Schedule Review, May 24, 2011

LiH & MICE

Purpose of the solid LiH absorbers:

- Transverse emittance reduction w/ flat solid absorber (reduce the beam momentum via ionization energy loss) + RF acc.
- Longitudinal emittance reduction w/ wedge absorbers

MICE IV -> study solid/liquid absorbers for cooling



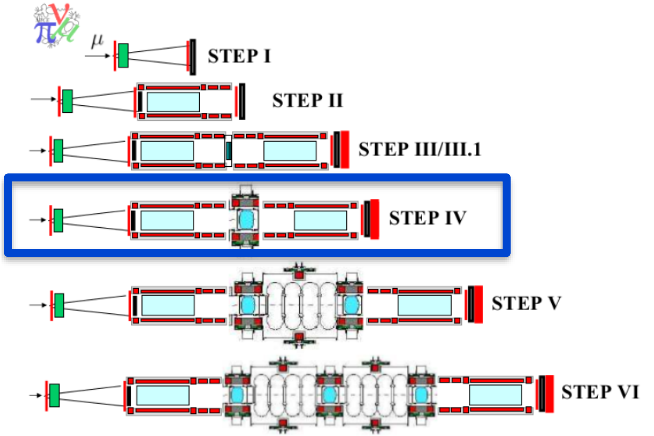


Figure 3.3: The original MICE staged plan. Step I would consist of a muon beamine, the first two TOF detectors and the Cherenkov detector to allow for PID. Step II and III introduce the trackers. Step IV introduces an absorber module, along with the focus coil. Step V and VI would finally add the RF cavities and additional absorbers to complete the demonstration.

LiH & MICE – feedback from Alan Bross

LiH Feedback from MICE

- LiH procured from Y12 (weapons facility), thus it was **6Li-enriched**, **which complicated transport** (considered nuclear material). But **natural Li would have been fine**
- LiH discs were **produced via HIP**
- **Coated with Parylene** (Commercial H2O vapor barrier)
- Always **kept disc in inert atmosphere** for safety reasons.
- But once **coated, is very stable**. E.g. disc left in air for 2 months w/o major damage besides hydrolyzation on the edges (coating was thin there).

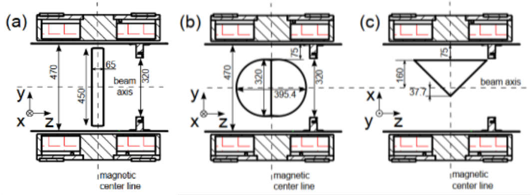
LiH & MICE

Parameter	Value
Material	LiH
Density	0.82 g/cm^3
Radiation length, X_0	79.62 g/cm^2
dE/dx (at 200 MeV)	1.92 MeV/(g/cm^2)
Flat absorber specific	
Thickness	65.0 mm
Disk radius	225 mm
Mass	8.4 kg
Norm. equilibrium emittance	2.9 mm
Wedge (half-wedge) absorber specific	
Thickness	75.4 mm
Wedge radius	160 mm
Wedge height	197.7 mm
Opening angle	90(45) deg
Mass	7.336 (3.668) kg

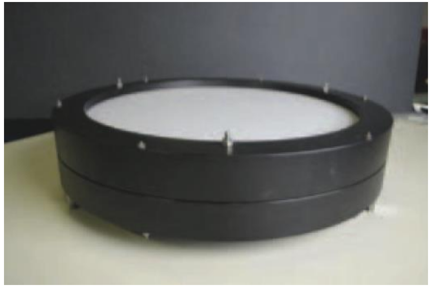
Table 1: LiH Disk and Wedge Absorber Parameters

Integration aspects (flat absorber)

- Absorber module was placed inside a superconducting "focus-coil" (FC) module, precisely at the magnetic center of the focusing coil (AFC)
- +/-2 mm tolerance wrt beam axis and magnetic centre
- Perpendicular within 0.5deg
- Allow easy insertion in the module bore
- No ferromagnetic nor good conductivity materials for the supports.
- Built in the US



SOLID ABSORBER PROGRAM STATUS FOR MICE STEP IV, P. Snopok et al, Proceedings of IPAC2011, San Sebastián, Spain



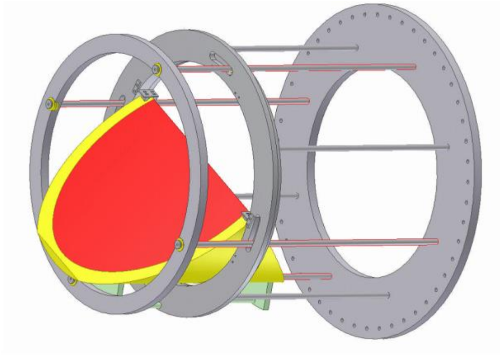


Figure 5: One of the preliminary wedge absorber support designs.

LiH considerations

LiH considerations

Lithium hydride (LiH) ?

- Alkali metal hydride with FCC atomic lattice
- **Low density solid** at RT
- **White/grayish** color
- **Melts at ~690 C**
- **Reactive!**
  - w/ H_2O produces Li hydroxide and H_2 gas
  - Can explode even with humid air or due to static electricity
  - Flammable, corrosive, toxic…
- **Usage:**
  - n moderator in (certain) nuclear reactors
  - To make other metallic hydrides
  - For hydrogen storage

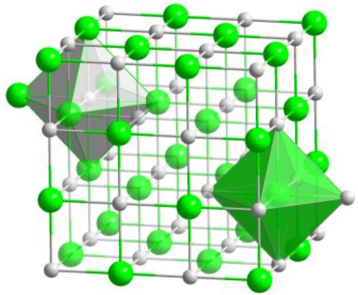
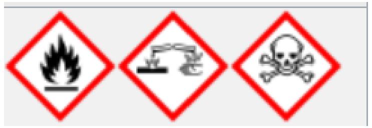


Table 1: LiH Disk and Wedge Absorber Parameters

Parameter	Value
Material	LiH
Density	0.82 g/cm^3
Radiation length, X_0	79.62 g/cm^2
dE/dx (at 200 MeV)	1.92 MeV/(g/cm^2)



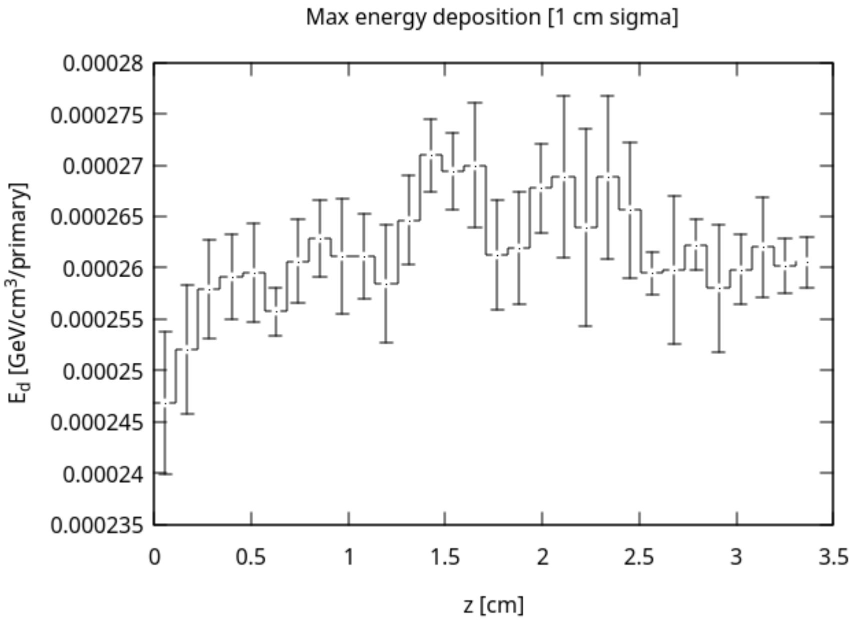
LiH considerations

- **Operation**
  - Collect thermal-mechanical-physical properties
  - Need to study what thermo-mechanical conditions LiH will experience in operation
  - Understand what LiH and surrounding equipment can tolerate (temperature, stresses, power dissipation)
  - Need for dedicated beam test?

LiH considerations

A quick look

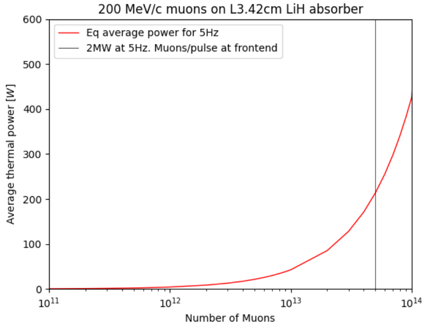
- Dummy LiH absorber with L34.2mm
- 200 MeV/c muons
- 100um, 300um, 600um, **1cm beam** sizes (1σ)

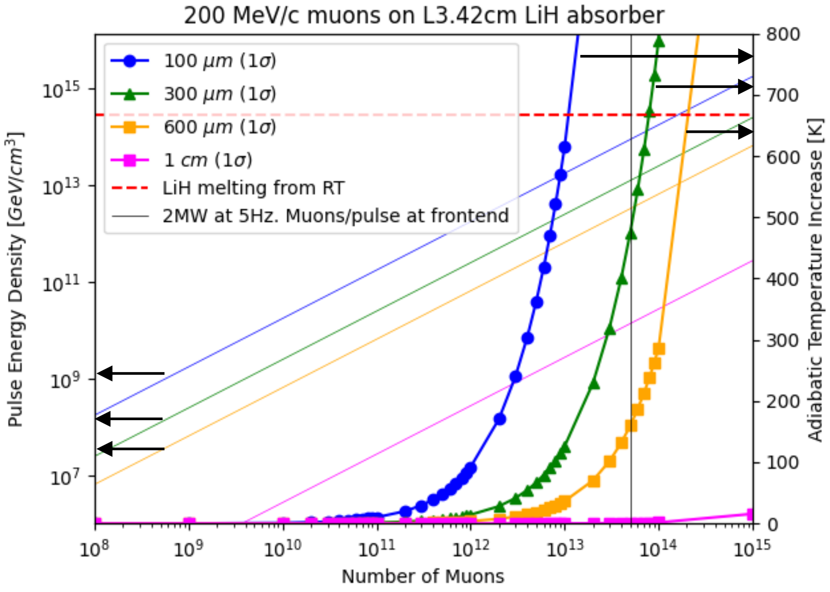


LiH considerations

A quick look

- Unless we go towards 100s μm range muon beam sizes, pulse temperature effects are small on a test facility
- Average thermal power in the absorber may be important





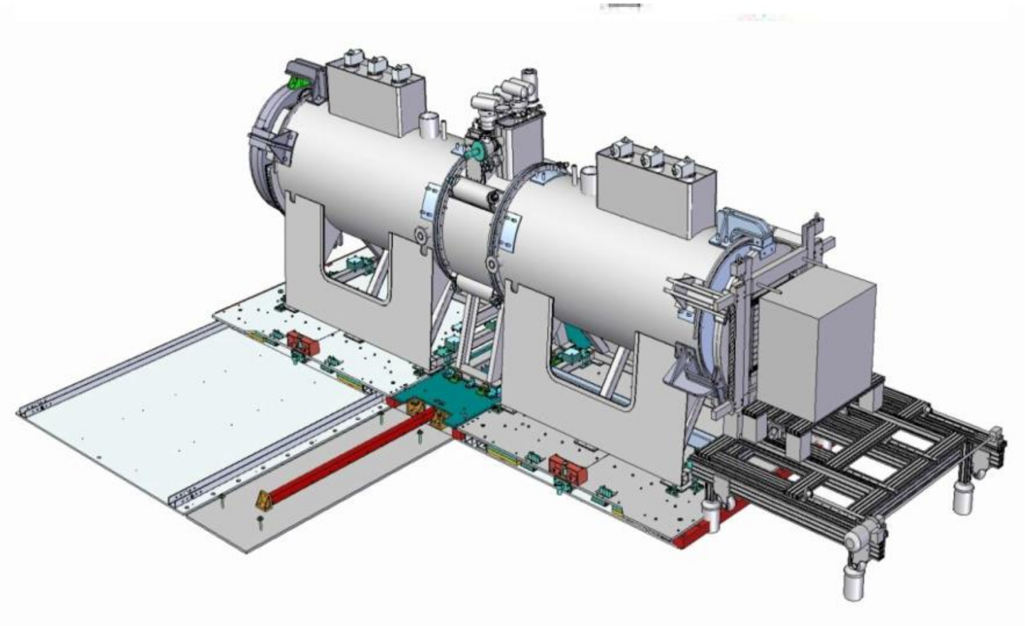
LiH considerations

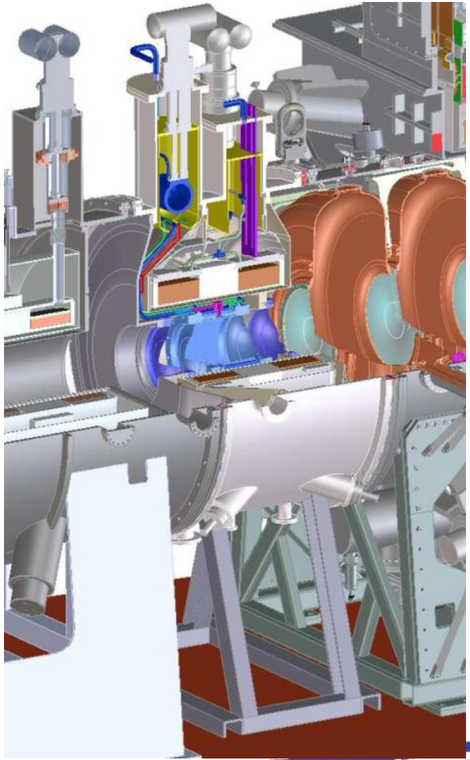
- **Operation**
  - Collect thermal-mechanical-physical properties
  - Need to study what thermo-mechanical conditions LiH will experience in operation
  - Understand what LiH and surrounding equipment can tolerate (temperature, stresses, power dissipation)
  - Need for dedicated beam test?
- **Integration/assembly**
  - Integration of the solid absorber should not be forgotten (taken from the early design stages, even if trivial compared to LH2 absorber or remaining equipment).
  - What tolerances do we want? What can we accept?
- **Procurement/manufacturing**
  - How to procure it ? powder raw form (500 EUR/kg) or final form (not as trivial)?
  - To what extent shall (or need) to develop an in-house manufacturing technique (e.g.HIPing, coating) ?
- **Safety**
  - Define the required safety handling and storage procedures.
  - Define the risks and hazards associated with its operation (and post irradiation)

LH2 at MICE

AFC module with LH2 at MICE

Integration aspects (AFC module w/ LH2)



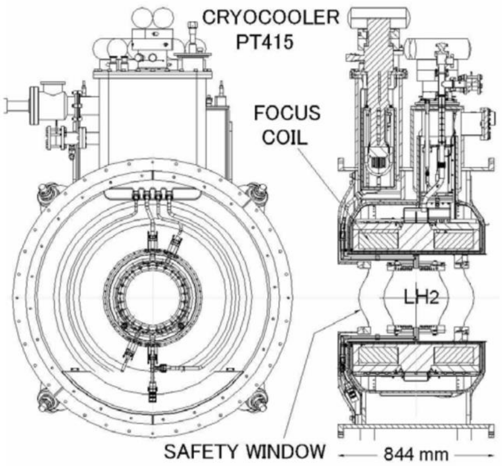


The status of the construction of MICE Step IV, K. Long, Nuclear and Particle Physics Proceedings 273–275 (2016) 162–169

AFC module with LH2 at MICE

Integration aspects (AFC module w/ LH2)

- 23 l & 350 mm long LH2 container
- 120-200um double Al curved windows
- Built and tested at KEK



PROGRESS ON THE MICE LIQUID ABSORBER COOLING ANDCRYOGENIC DISTRIBUTION SYSTEM, M.A. Green et al, Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee

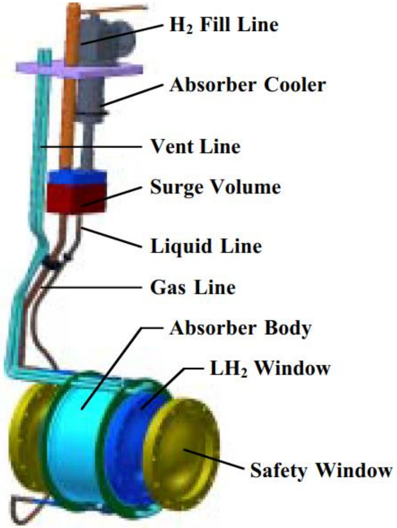
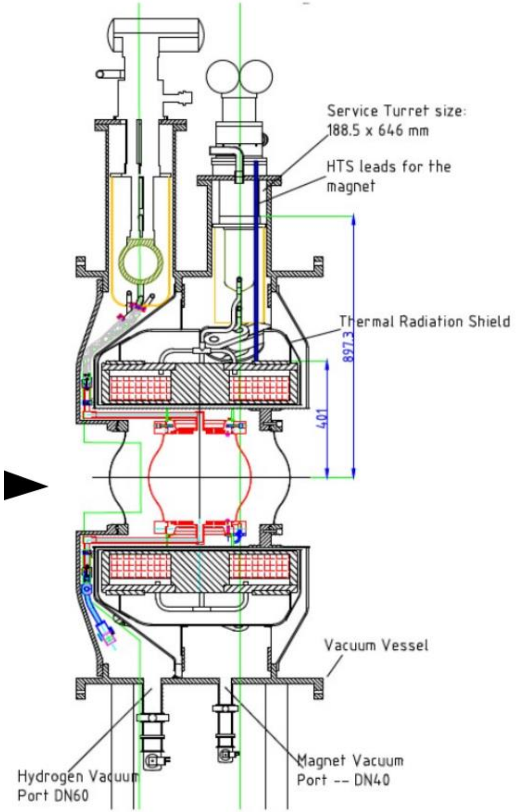
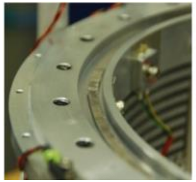
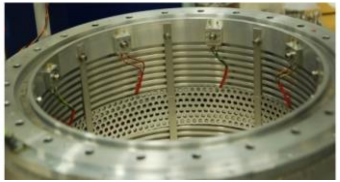


Figure 3: Three-dimensional view of the liquid absorber, its cooling system, and hydrogen (helium) supply system.



AFC module with LH2 at MICE





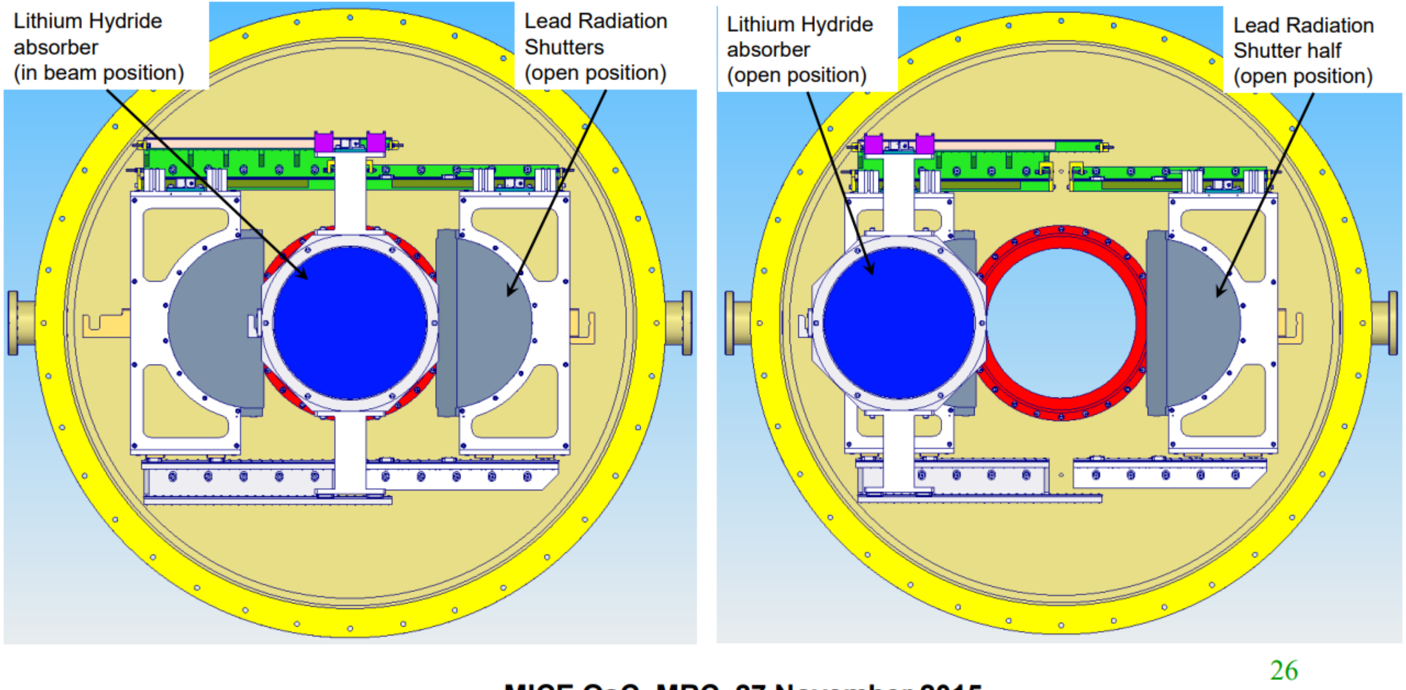
Final remarks

- Good experience from MICE with LiH absorber
- Need to understand operation, integration/assembly, procurement/manufacturing and safety aspects with LiH. Particularly when scaling up to demonstrator & final collider conditions
- LH2, still a possibility for a prototype cooling cell? And for the demonstrator?

Thank you

AFC module with LH2 at MICE

- Secondary LiH absorbers and opening closing mechanism defined – paid by UK but procured at Fermilab from Y12



MICE OsC, MRC, 27 November 2015