Muon Collaboration

Perspective on Absorber R&D

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MuCool Meeting

IIT/Fermilab

2/6/02 (revised)

Absorber-Medium Options

- Cooling rate: $$\frac{d\varepsilon_{x,N}}{dz} \approx -\frac{1}{\beta^2}\frac{\varepsilon_{x,N}}{E}\left|\frac{dE}{dz}\right| + \beta_\perp \frac{(0.014\ \text{GeV})^2}{2\beta^3 E m_\mu L_R}$$

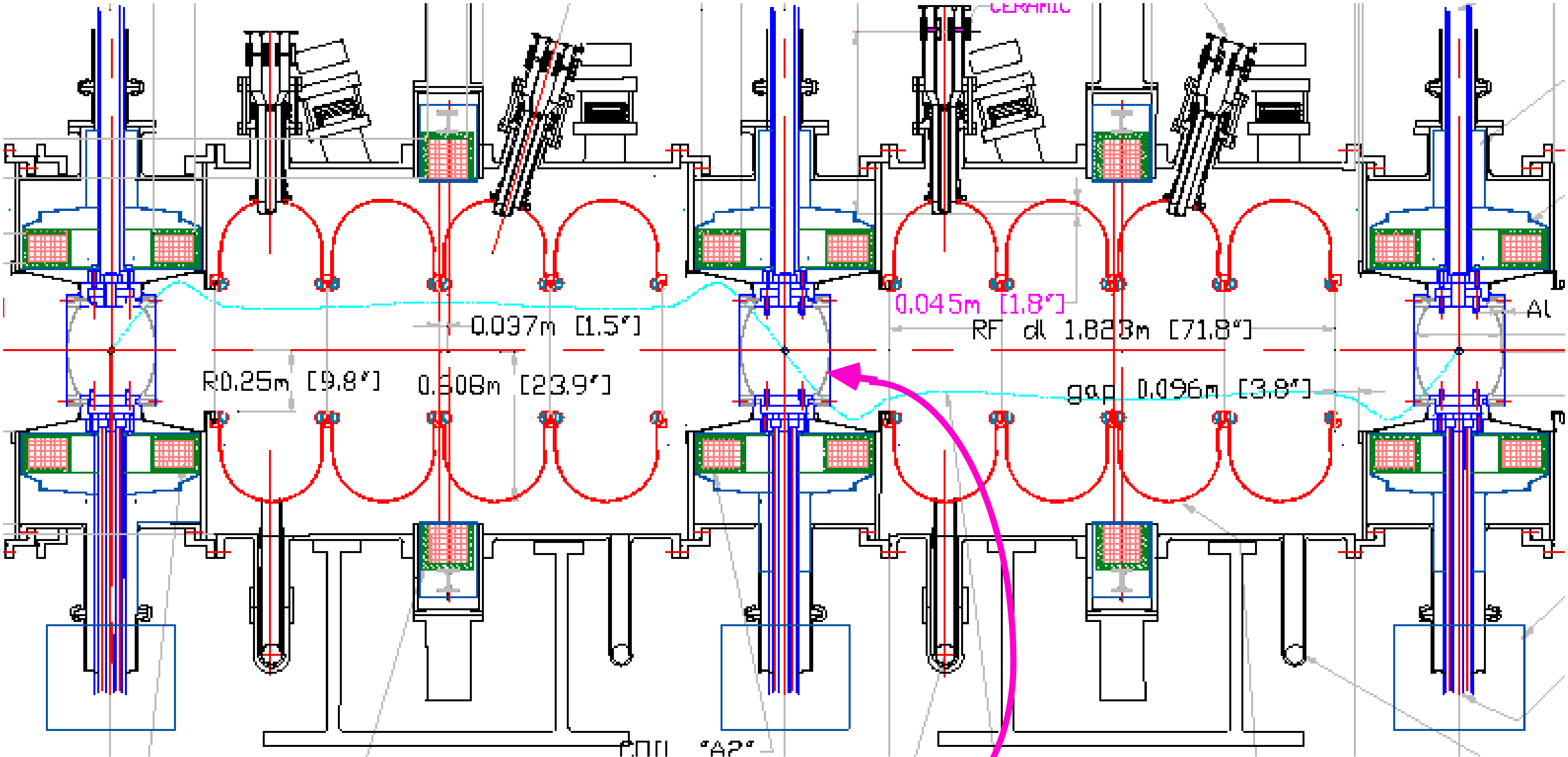
Mat'l	ρ	dE/dx	dE/dx/cm	L_R	**merit**
	(g/cm^3)	(MeV/g·cm^2)	(MeV/cm)	(cm)	$(L_R\, dE/dx)^{-2}$
LH_2	0.0708	4.05	0.29	866	1
LHe	0.125	1.94	0.24	755	1.95
LiH	0.82	1.94	1.59	106	2.28
Li	0.53	1.64	0.88	155	3.54
CH_4	0.42	2.42	1.03	46.5	5.15
Be	1.848	2.95	2.95	65	6.02

– "merit" ~ rate of increase of (4D) transverse phase-space density

⇒ Hydrogen is best by factor ≈2

FS II Cooling Channel

2.75-m SFOFO ("Lattice 1"):



- Performance simulations based on single set of windows per absorber at ≈1 atm operating pressure:

2.75-m SFOFO lattice: 360 μm Al

1.65-m SFOFOlattice: 220 μm Al

Safety Considerations

- Established FNAL LH_2 guidelines:

  1. Vacuum vessel enclosing LH_2 flask must contain neither oxygen nor ignition sources
  2. Although absorber can operate at ≈15 psi, vacuum vessel enclosing LH_2 flask must be rated for 30 psid (to handle pressure rise from evaporating LH_2 in case of flask rupture)

- RF cavity is ignition source!

  → Especially if cells closed by grids rather than windows

  (In any case, Be RF windows not rated for 30 psid so wouldn't satisfy guidelines)

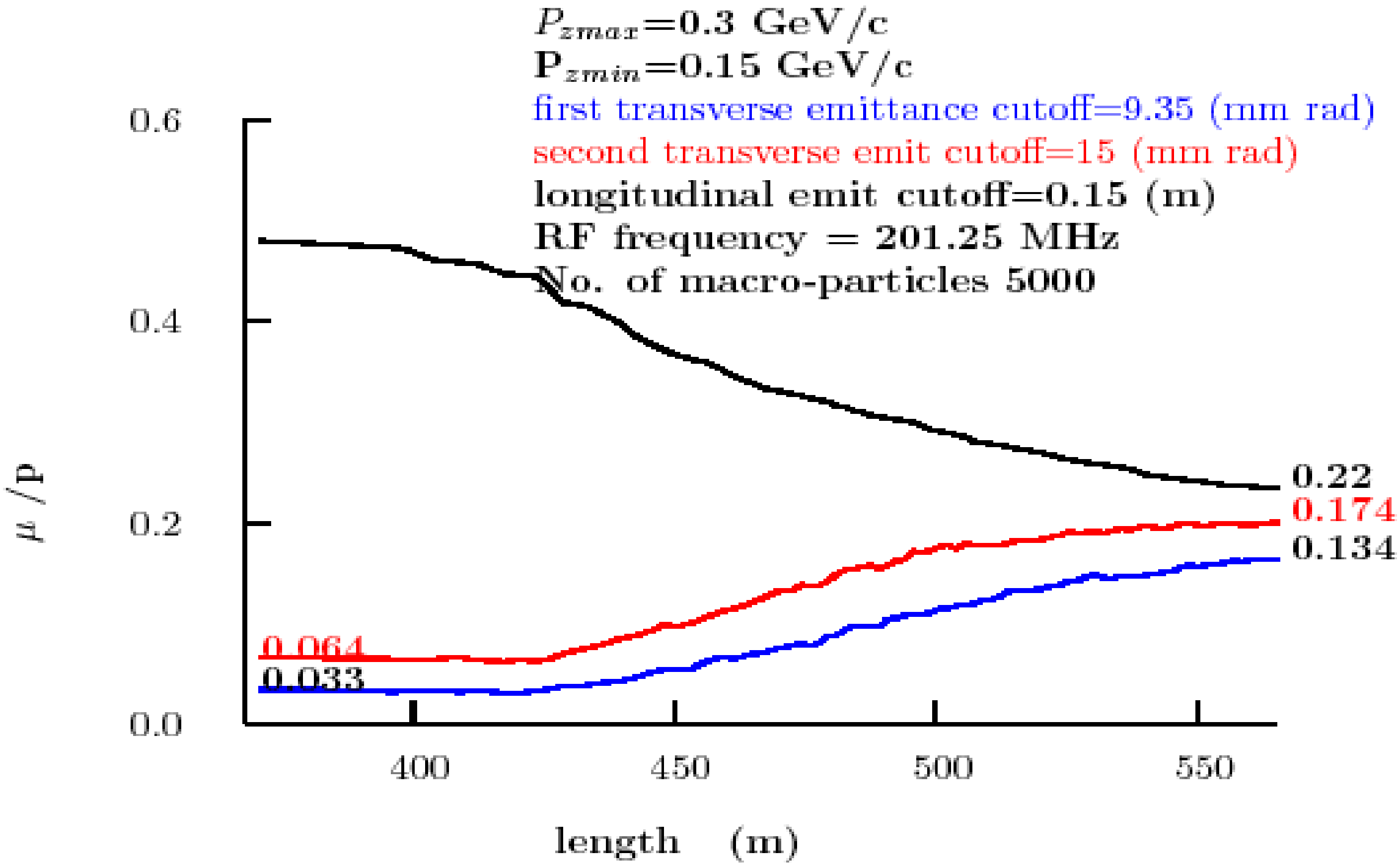
⇒ **Need vacuum vessel around absorber with additional set of windows that are twice as strong as absorber windows themselves**

  – "2ndary containment"

- These extra windows were not in the FS II simulations!

ICOOL Studies of Absorber Options

- Cooling performance (FS II report):



- Updated μ/p within 15-cm longitudinal cutoff (Gallardo email 1/29/02):

Case	Buncher start	Final
FS II	0.04	0.14
LH2 (Al x 3)	0.04	0.12
LHe	0.04	0.11
LiH	0.04	0.11

⇒ given add'l windows, LHe or LiH only ≈10% worse than LH2 (?)

somehow lost factor ≈2 w.r.t. theoretical performance?

LHe Issues

- FNAL cryo engineers believe LHe absorber would need to operate above He triple point to avoid boiling

$\Rightarrow$ $\geq$ 2.2 atm

$\Rightarrow$ windows twice as thick

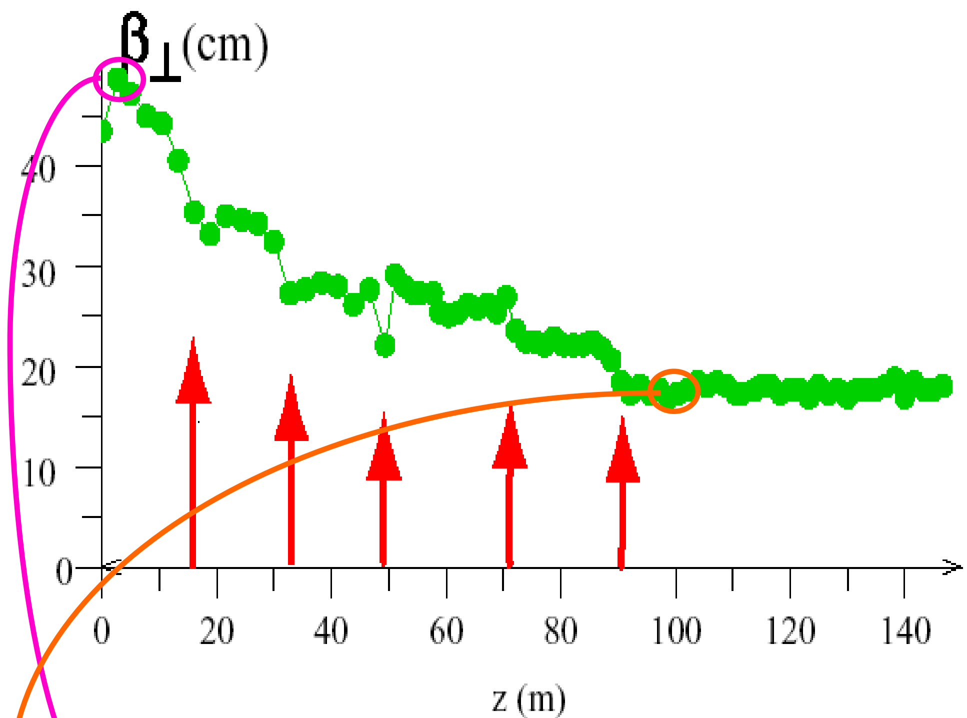
(≈1-atm operation mey be possible but only with internal heat exchange?)

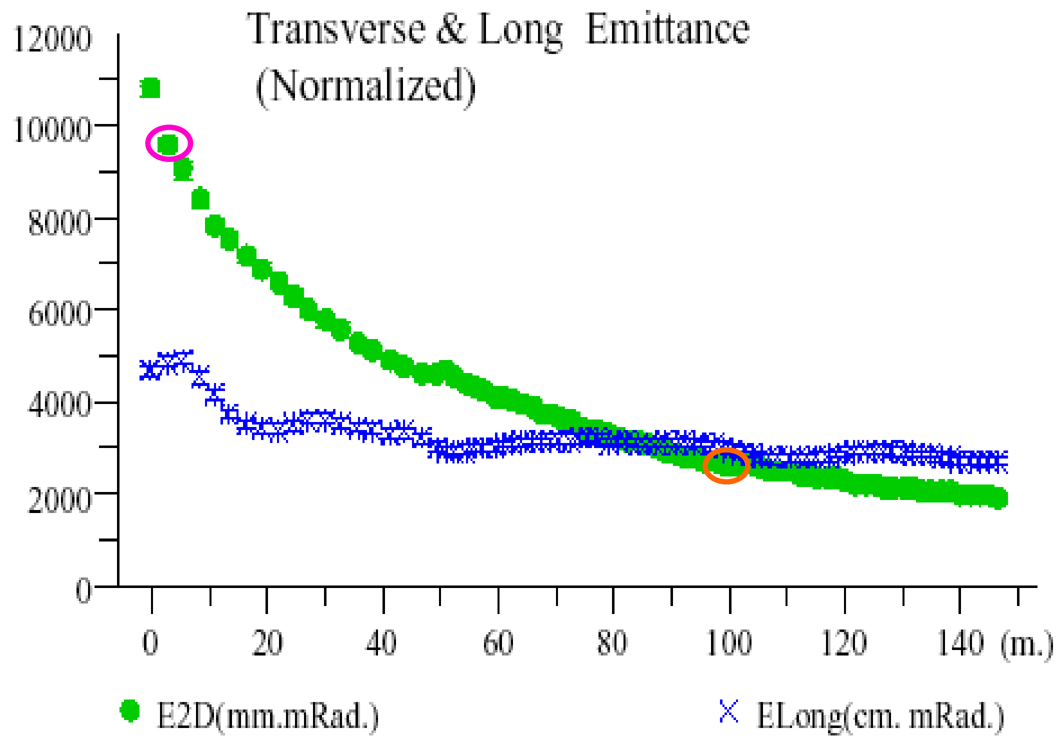
- Absorber cryoplant ≈ $10M in FS II
  - M. Green: refrigerator cost scaling ~ $(1/T)^{0.7}$ $\Rightarrow$ LHe cost ~ LH_2 cost × ≈2.5
    - not show stopper
  - BUT:
    - Neuffer bunched ϕR $\rightarrow\times$ 2 (keeps both signs)
    - Palmer: 4 MW *p* beam more cost effective than more cooling $\rightarrow\times$ 4

$\Rightarrow$ Power ×10, LHe cryoplant cost $\times 10^{0.7}$ ~ $130M?

Do absorber windows degrade the cooling?

- FS II report:





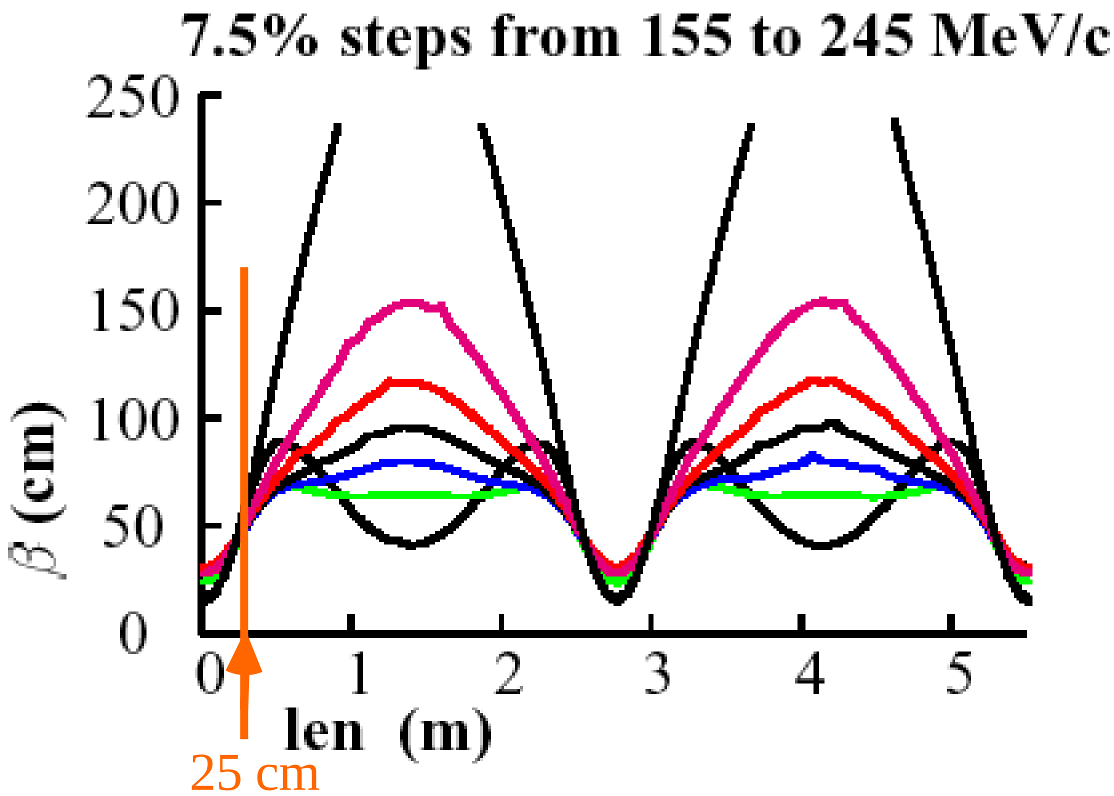
$$\beta = 48\text{ cm}, \varepsilon_{x,N} = 9.6\text{ cm} \Rightarrow \frac{d\varepsilon_{x,N}}{\varepsilon_{x,N}} \approx \begin{cases} 5.62\%/\text{cell} & 35\text{ cm LH}_2 \\ 5.60\%/\text{cell} & 35\text{ cm LH}_2 + 2\times 360\ \mu\text{m Al} \\ 5.55\%/\text{cell} & 35\text{ cm LH}_2 + 6\times 360\ \mu\text{m Al} \end{cases}$$

$$\beta = 17\text{ cm}, \varepsilon_{x,N} = 2.6\text{ cm} \Rightarrow \frac{d\varepsilon_{x,N}}{\varepsilon_{x,N}} \approx \begin{cases} 3.35\%/\text{cell} & 21\text{ cm LH}_2 \\ 3.33\%/\text{cell} & 21\text{ cm LH}_2 + 2\times 220\ \mu\text{m Al} \\ 3.29\%/\text{cell} & 21\text{ cm LH}_2 + 6\times 220\ \mu\text{m Al} \end{cases}$$

- 1–2% in cooling rate in 1 coord ⇒ ≈ 2–4% decrease in μ yield, not ×2

(assuming naïvely that all windows are at β_{min})

Effect of β variation



- If 2ndary-containment windows at ≈±25 cm, looks like $\beta \approx 2\beta_{min}$ (dep. on *p*)

  → still hard to understand ×2 degradation in μ yield Gallardo implies

- Points up advantage of LiH: 5.5 × thinner than LH_2 ⇒ essentially all at β_{min}

More tricks up our sleeve:

Al alloy name	**Composition**	**Density**	**Yield strength @300K**	**Tensile strength @300K**	**Tensile strength @20K**	**Rad. Length**
	% by weight	(g/cc)	(ksi)	(ksi)	(ksi)	(cm)
6061-T6	1.0Mg 0.6Si 0.3Cu 0.2Cr	2.70	40	45	68	8.86
2090-T81	2.7Cu 2.2Li .12Zr	2.59	74	82	120	9.18

- “Aircraft alloys” (e.g. 2090-T81) ≈80% stronger than 6061-T6

  ⇒ Absorber window thickness might be reduced by ≈ 45%

- 2ndary-containment vacuum vessel can have Be or Ti windows & may only need safety of factor of 2 (*vs.* 4 for LH_2 flasks)

  – For same strength, in rad. lengths, Be is ≈5× thinner than Al & Ti about 2×

  ⇒ In rad. lengths, 2ndary-enclosure windows may be ≈half as thin as absorber window

  ⇒ All windows combined might be thinner in rad. lengths than FS II absorber windows alone

- But 2ndary-containment windows at larger β than absorber windows

  ⇒ may need to be larger diameter (but how fit?) & therefore thicker
  & cooling degradation will be worse even for same thickness

⇒ Need detailed simulation study and more detailed engineering

Conclusions:

- Effort to prototype and beam-test an absorber is teaching us valuable lessons about real-world safety engineering
- LH_2 may still be best material (especially in potential applications with longer absorbers $\Rightarrow$ relatively less window thickness)
- Need to explore stronger window materials
- Need realistic design including 2ndary containment & need to simulate its performance
- Detailed engineering may still find show-stopper, but none so far
- Need to begin to engineer LiH, for emittance exchange if not transverse cooling

Postscript:

- Clearer thinking about cooling-rate calculations:

$$\beta = 48\ \text{cm}, \varepsilon_{x,N} = 9.6\ \text{cm} \Rightarrow \frac{d\varepsilon_{x,N}}{\varepsilon_{x,N}} \approx \begin{cases} 5.74\%/\text{cell} & 35\ \text{cm LH}_2\ \text{(no scattering)} \\ 5.62\%/\text{cell} & 35\ \text{cm LH}_2 \\ 5.55\%/\text{cell} & 35\ \text{cm LH}_2 + 6 \times 360\ \mu\text{m Al} \\ 5.52\%/\text{cell} & 6.4\ \text{cm LiH} \end{cases}$$

$$\beta = 17\ \text{cm}, \varepsilon_{x,N} = 2.6\ \text{cm} \Rightarrow \frac{d\varepsilon_{x,N}}{\varepsilon_{x,N}} \approx \begin{cases} 3.44\%/\text{cell} & 21\ \text{cm LH}_2\ \text{(no scattering)} \\ 3.35\%/\text{cell} & 21\ \text{cm LH}_2 \\ 3.29\%/\text{cell} & 21\ \text{cm LH}_2 + 6 \times 220\ \mu\text{m Al} \\ 3.28\%/\text{cell} & 3.8\ \text{cm LiH} \end{cases}$$

$\Rightarrow$FS II cooling channel always stays far from equilibrium emittance

$\Rightarrow$ among lowest-Z materials, choice nearly immaterial!

LiH costs only

- o 1% in cooling rate near start of Lattice 1
- o 5% near end of Lattice 2

...w.r.t. pure, uncontained LH_2