Minicooling Absorber Design and Performance

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Outline:

1. Minicooling absorbers
2. Power dissipation and refrigeration cost
3. Heat transfer
4. Window design
5. Alternatives to LH_2
6. Conclusions

Minicooling:

- “Parameters version 2” calls for 2 minicooling absorbers preceded by beryllium plate (to absorb low-*E* protons):

Absorber	**Mat'l**	**Length (cm)**	**Radius (cm)**	**Power Diss. (kW)**
"0"	Be	1?	30	?
1	LH_2	175	30	≈5.5
2	LH_2	175	30	?

- H. Kirk simulation results (from 12/18/00 video meeting):

ICOOL Simulation Results

Induction Linac Phase Rotation

Power dissipated in 1st mini-cool LH cell

Positive muon collection

	Power, KW				
	e	μ	π	K	p
positives	0.42	2.02	0.14	0	0.86
negatives	0.43	1.29	0.24	0	-

Total Power dissipated = 5.4 KW

Negative muon collection

	Power, KW				
	e	μ	π	K	p
positives	0.42	1.45	0.19	0	0.94
negatives	0.45	1.90	0.14	0	-

Total Power dissipated = 5.5 KW

Refrigeration Costs:

- **15´ bubble chamber had 6.7-kW refrigerator (J. Kilmer)**
- **5.5-kW refrigerator:**
  - capital cost: >$1M (J. Kilmer, FNAL)
    ≈$1.7M (M. A. Green, LBNL)
    ≈$2.5M (B. Norris, FNAL)
  - operating cost:

    Green: 5.5 kW at 20 K $\longrightarrow$ ≈ 660 kW at room temp

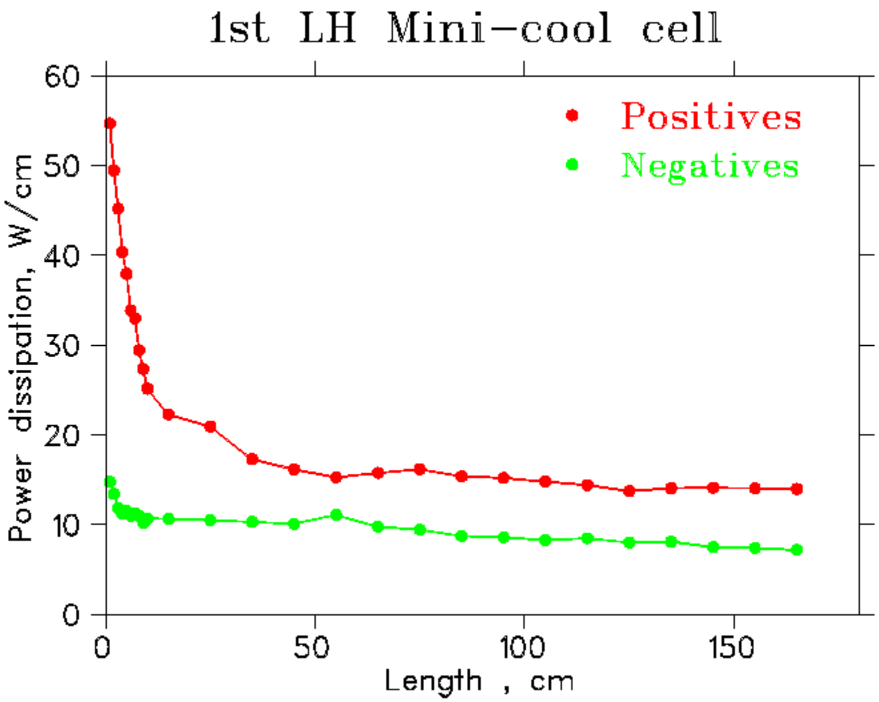
    [cf. Kilmer: 15´ bubble chamber required

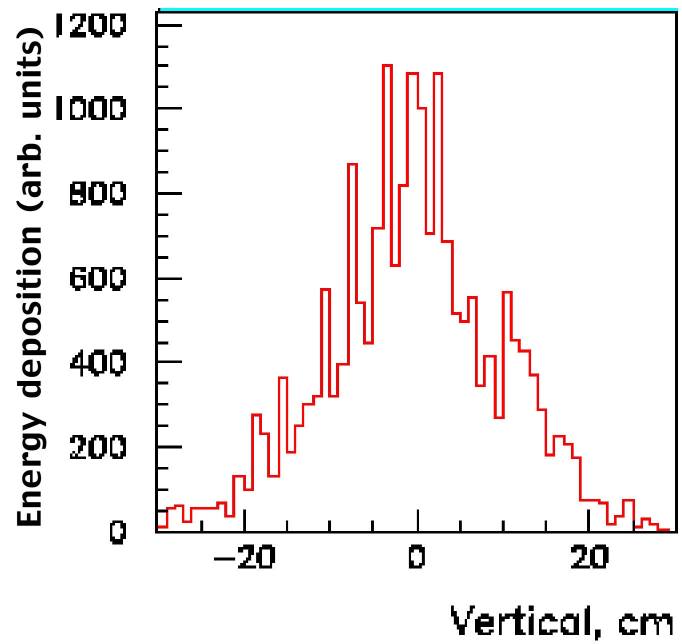
    400 hp (cooling)
    \+ 50 hp (vacuum)] } 336 kW

$\Rightarrow$ operating cost @10¢/kWh: ≈$130k/yr (Green)

Heat Transfer:

- Peak dissipation much higher than average:





⇒ Need to assure adequate heat transfer from core to periphery

Don’t know how to do this yet! Note that power/cm at upstream end is >10 × that proposed for SLAC E158, but power/cm^3 is <10^{-2} × E158

⇒ Probably feasible

Window Thickness:

- Assuming operation at 1.2 atm, hemispherical Al-alloy windows, and "canonical" safety factor of 4,

$$t \approx 2\,PR/S \approx 2 \times 0.12\text{ MPa} \times 0.3\text{ m} / 300\text{ MPa} \approx 240\ \mu\text{m}$$

(Determination of exact thickness awaits detailed design and finite-element analysis)

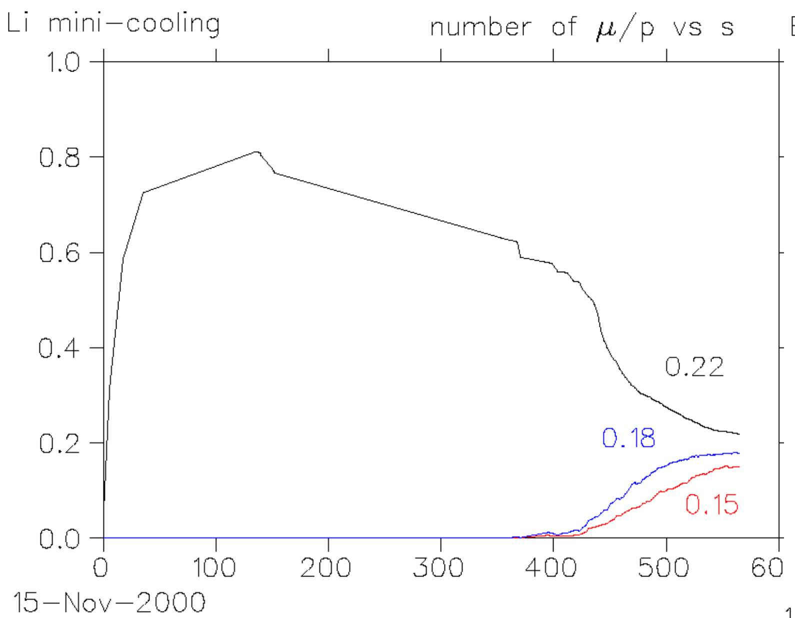
$\Rightarrow$Given 175 cm of LH_2 per absorber, this is unlikely to affect the beam significantly

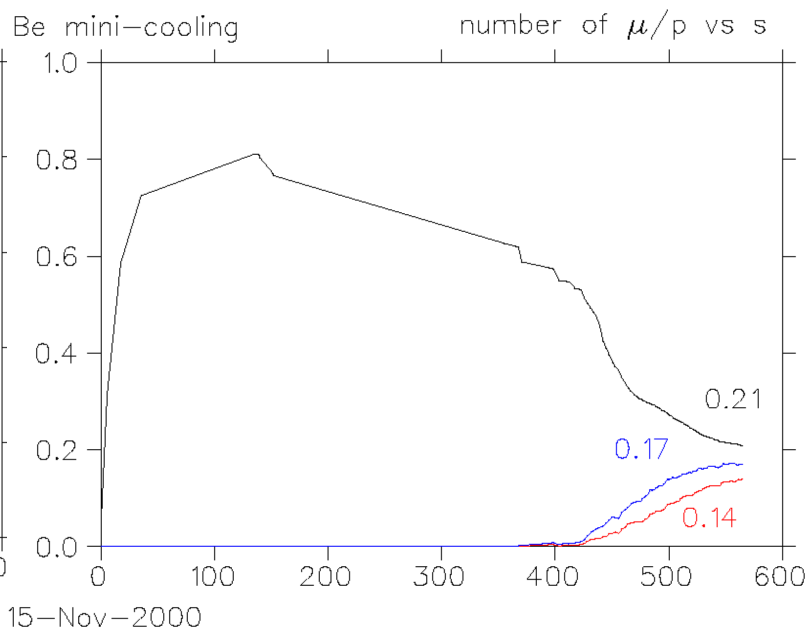
Simpler Alternatives?

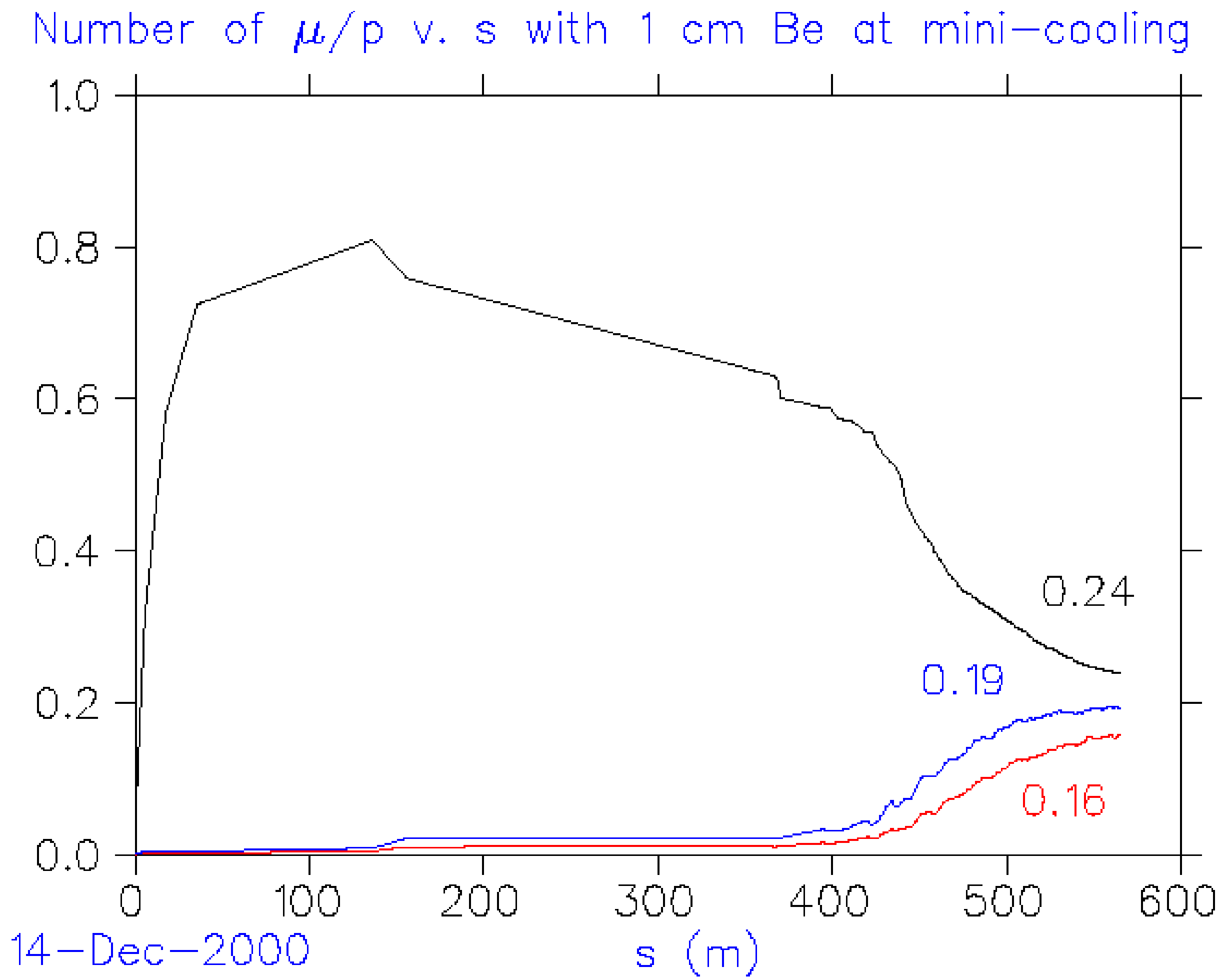
- Does it make sense to operate two “15´ bubble chamber equivalents” for this purpose?

  → While capital and operating costs not show-stoppers, may want to minimize operational effort/safety concerns & maximize reliability

  ⇒ Why not minicool with water, liquid methane, solid lithium, or beryllium?







→ Li costs ≈ 5% in μ/*p*, Be ≈ 10%

– could raise *B* field to compensate?

Material Comparison:

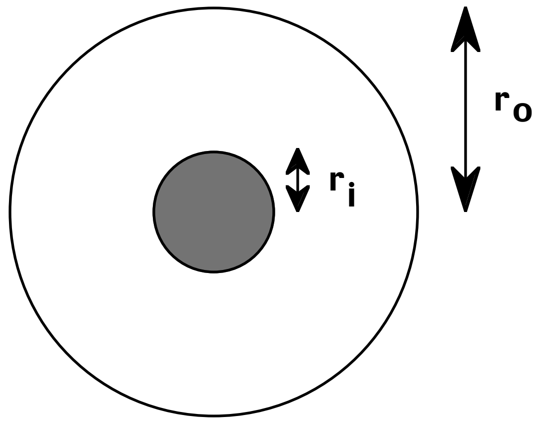
Mat'l	**ΔE_min (MeV)**	**Length (cm)**	**$\%X_0$**
LH_2	50	175	20
LiH	50	38	35
Li	50	57	37
CH_4	50	49	45
Be	50	17	48
H_2O	50	25	70

- Comments:

1. Liquid methane somewhat better than beryllium?
2. Liquids should give easier power handling by circulation
3. Solids require liquid-cooling $\rightarrow$ perimeter cooling sufficient, or some water needed in beam region?

Heat Transfer Guestimate:

- Approximate as 2D problem with heat applied in small inner core:



$$\Delta T \approx P/(2\pi k L) \ln(r_o/r_i)$$

(Neglect T dependence of k)

$k \approx 70$ W/m·K (Li) 200 W/m·K (Be)

say $P/L \approx 55$ W/cm (conservative)

$r_o/r_i \approx 5$ (conservative?)

$\rightarrow \Delta T \approx 20$ K (Li) ≈ 7 K (Be)

$\Rightarrow$ Water-cooling around perimeter probably sufficient

Conclusions:

1. LH_2 minicooling appears feasible and affordable
2. LH_2 minicooling complicated and hazardous
   - will probably diminish facility reliability
3. Understanding heat transfer in LH_2 requires more study
4. Should consider alternatives (in future study?):

   Li, LiH, CH_4, Be