

Absorber cryo and safety design

MUCOOL – MICE meeting

Del Allspach / PPD

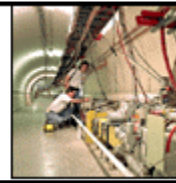
Christine Darve / BD

Arkadiy Klebaner / BD

Alexander Martinez / BD

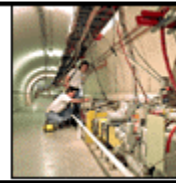
Barry Norris / BD





Absorber cryo and safety design

- ☾ Environment of the LH2 absorber test facility (cf Barry's talk)
- ☾ LH2 Absorber system and cryogenic loop @ test facility
- ☾ Safety and Cryo-design
- ☾ Conclusion and further works



Environment of the test (cf Barry's talk)

★ Helium refrigeration schematic

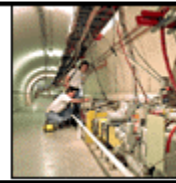
How can we provide the refrigeration power ?

=> Tevatron cooling system like

How much could be provided ?

=> Up to 500 W at 20 K

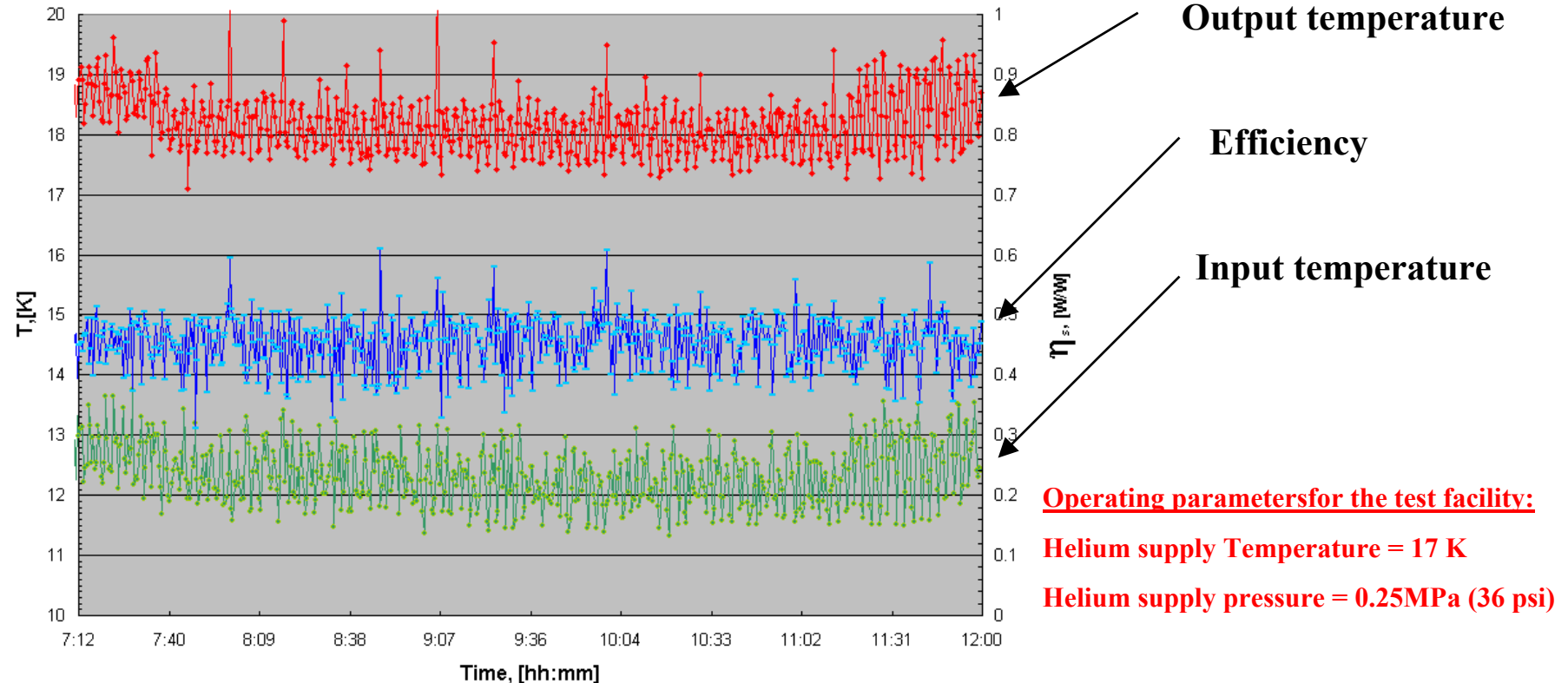
★ Hydrogen refrigeration loop schematic

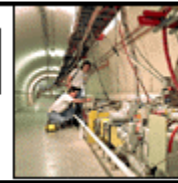


Cryo-test during a Tevatron shut-down period

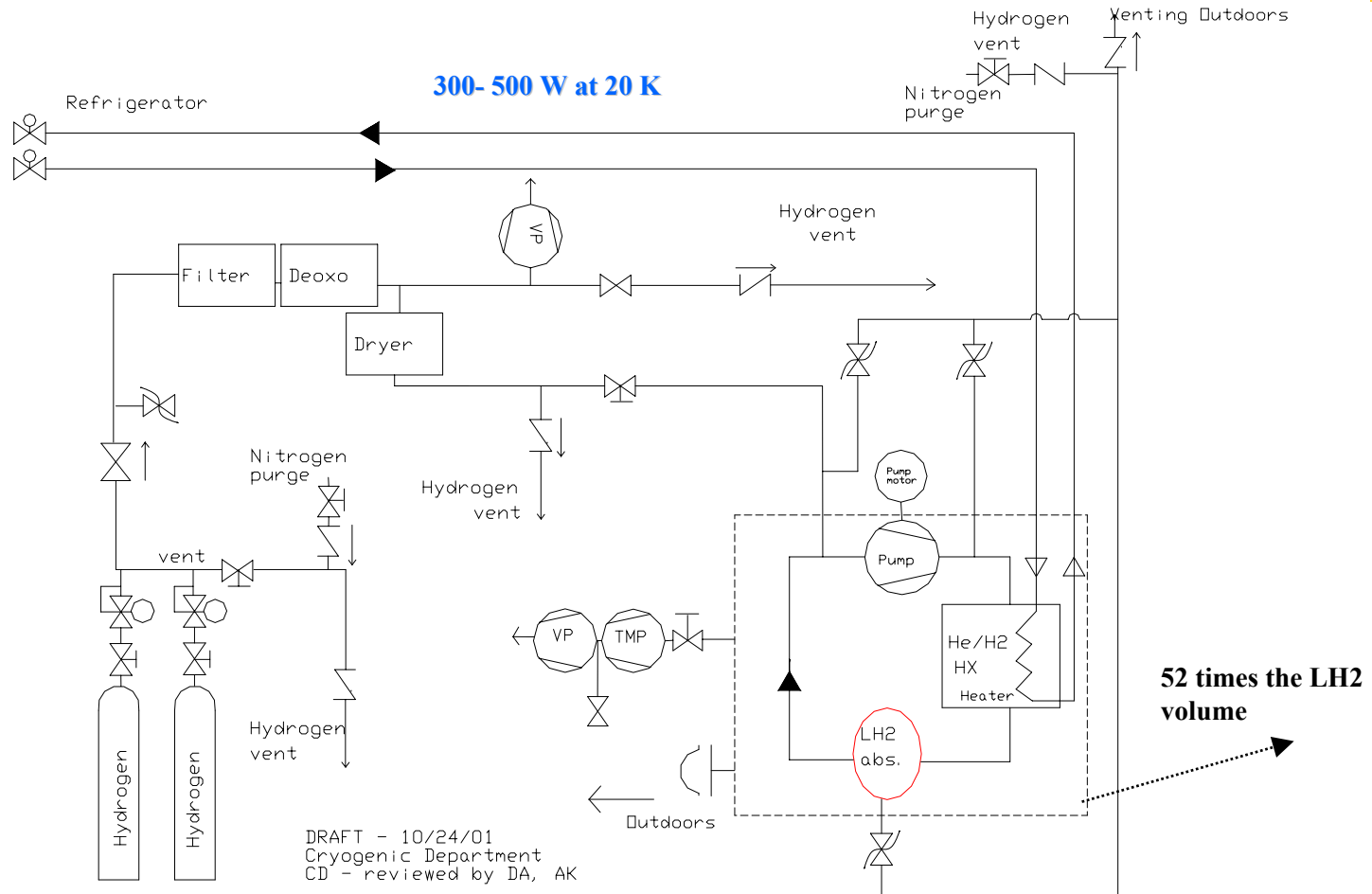
Goal of the test: stability measurement for running at 14 K instead of 5 K

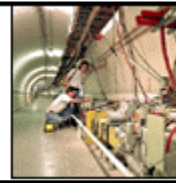
MuCool Test at F4





Hydrogen refrigeration loop schematic

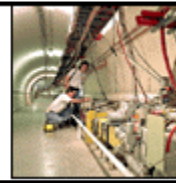




LH2 Absorber system and cryogenic loop @ test facility

Components:

- ☾ Cryostat
- ☾ LH2 Absorber
- ☾ LH2 pump
- ☾ Helium/Hydrogen heat exchanger
- ☾ Heat load to the cryostat
- ☾ Pressure drop



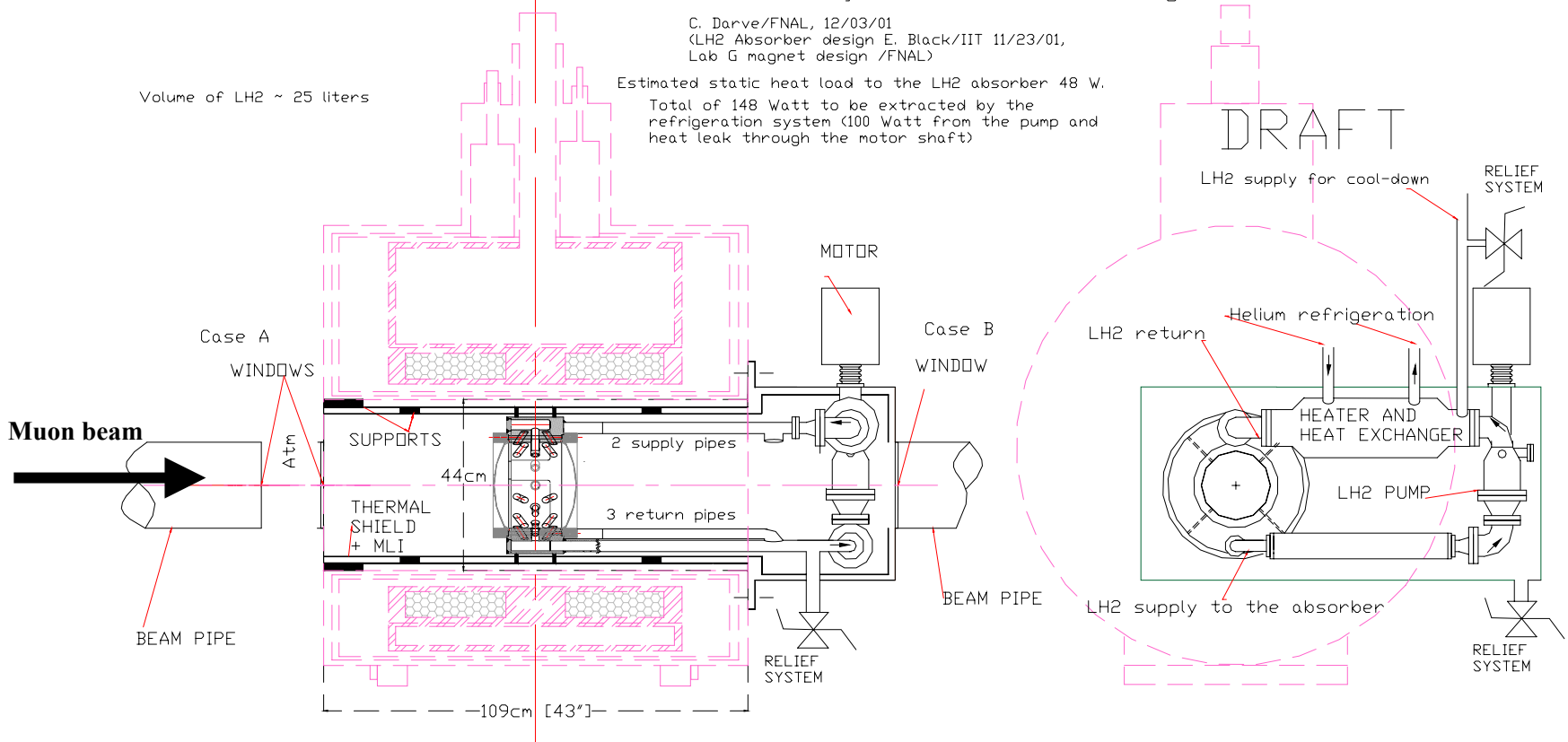
LH2 Absorber system and cryogenic loop @ test facility

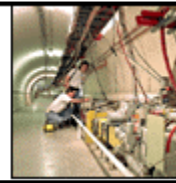
Draft for the Absorber assembly in the G-Lab magnet

C. Darve/FNAL, 12/03/01
(LH2 Absorber design E. Black/IIT 11/23/01,
Lab G magnet design /FNAL)

Volume of LH2 ~ 25 liters

Estimated static heat load to the LH2 absorber 48 W.
Total of 148 Watt to be extracted by the
refrigeration system (100 Watt from the pump and
heat leak through the motor shaft)





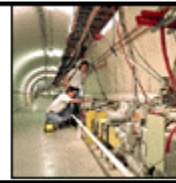
LH2 Absorber system and cryogenic loop @ test facility

☾★ Cryostat

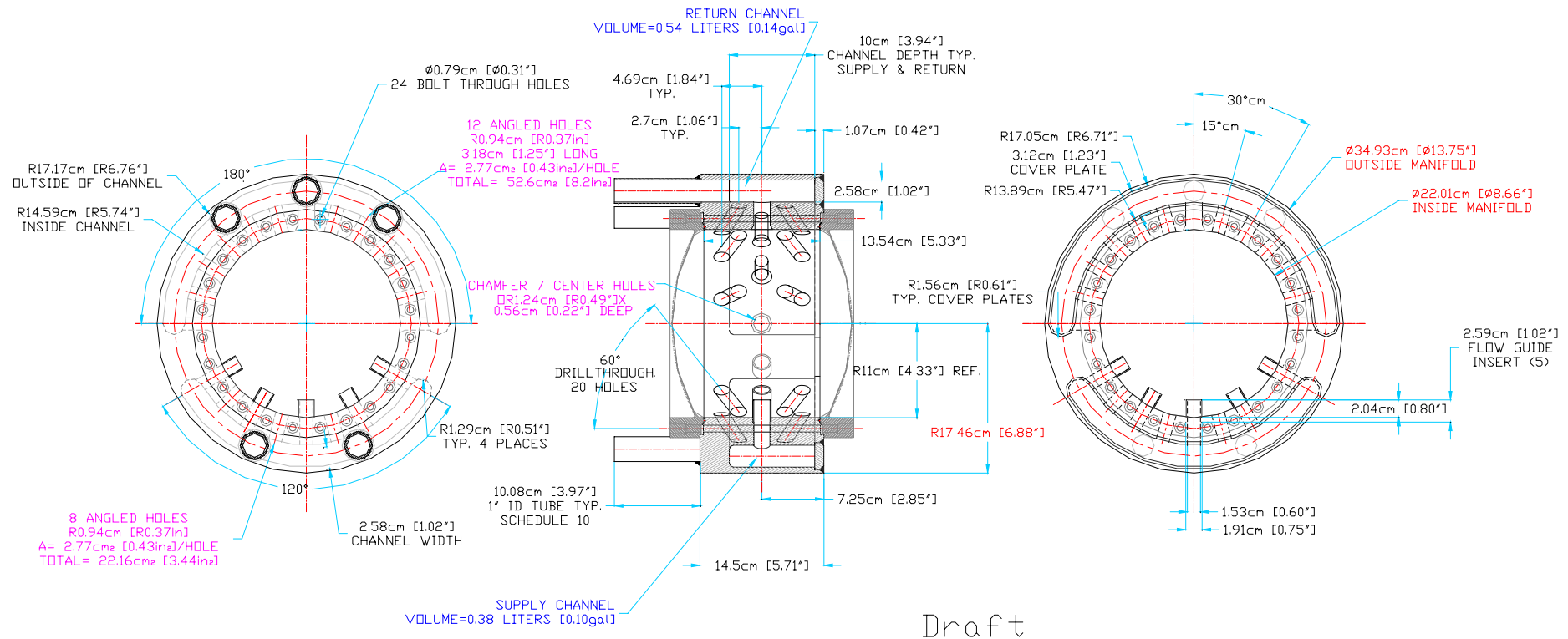
- ☾★ Stainless steel vacuum vessel
- ☾★ Thermal shield actively cooled by nitrogen
- ☾★ Super insulation (30 layers of MLI on the thermal shield)
- ☾★ G10 support spider
- ☾★ Pressure safety relief valves

☾★ Absorber (2 windows + manifold)

- ☾★ 6 liters of LH₂
- ☾★ Supporting system (mechanical support, insulation, alignment..)
- ☾★ Supply and return channels connections

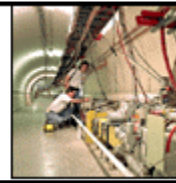


LH2 Absorber system and cryogenic loop @ test facility



R 11 CM WINDOW MANIFOLD DETAIL

E.L.Black/IIT 5/22/2001
GEN.REV. 11/23/2001



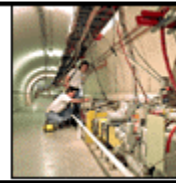
LH2 pump

Spare pump from SAMPLE

- ★ Reference: "Nuclear Instruments and methods in physics research", by E.J. Beise et al.

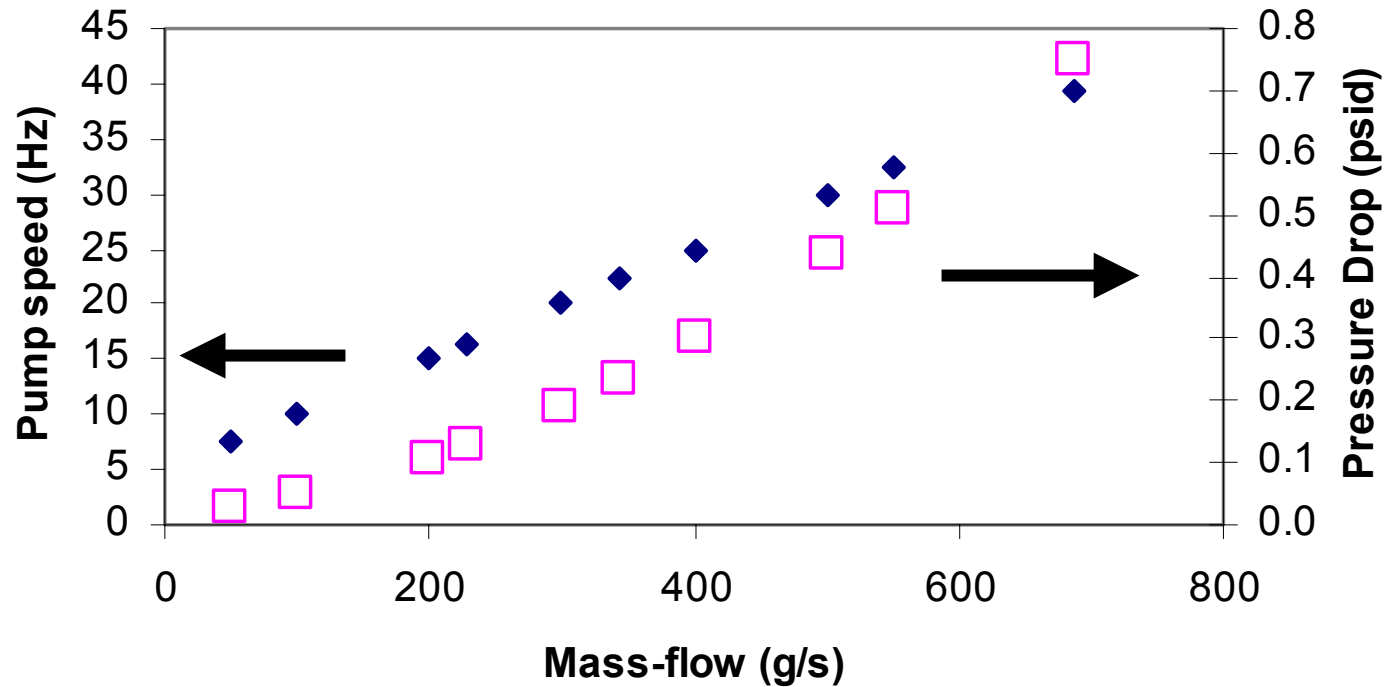
Characteristics:

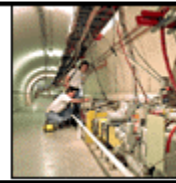
- ★ Controlled by AC motor @ RT (2 HP)
- ★ Circulating pump (up to 550 g/s)
- ★ Expected pump efficiency ~ 50% (cf. SAMPLE test)
- ★ Heat load \propto (fluid velocity)³ and Heat load \propto (pump speed)³
<100 Watt from the pump and heat leak through the motor shaft



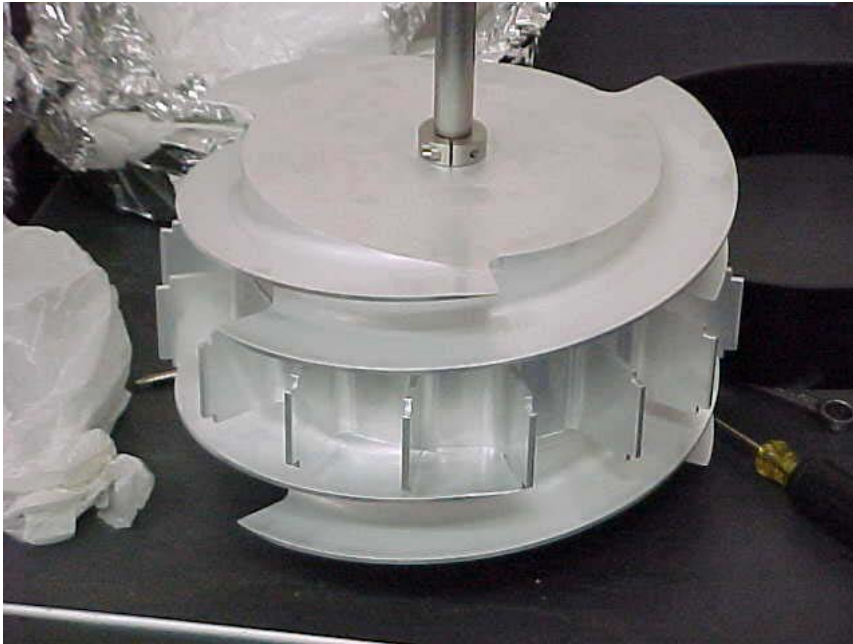
LH2 pump

Characteristics of the current LH2 pump



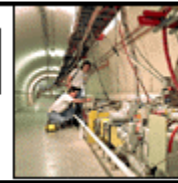


E158 LH2 pump



Note: Our pump is 1.5 time smaller than the E158 one



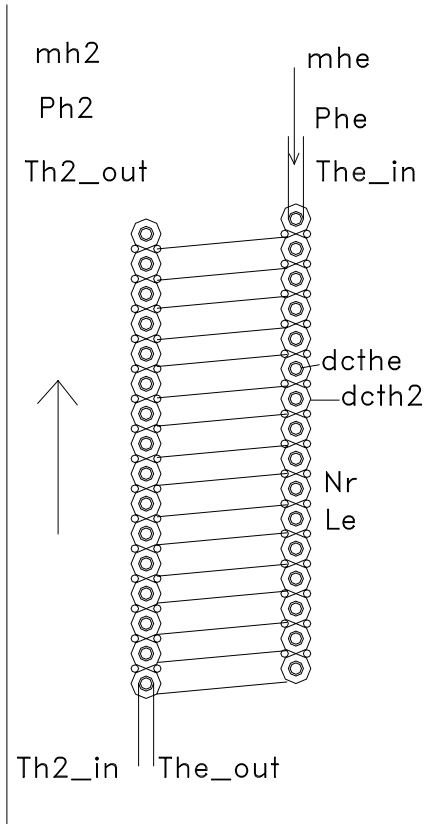


Heat Exchanger

The HX is sized to extract up to 1 kW
Helium/LH2 co-current flow

Helium properties:

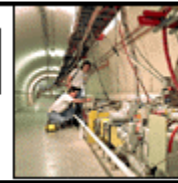
Thein = 14 K
Theout=16.5 K
Phe=0.135 MPa (19.6psi)
mhe=75 g/s



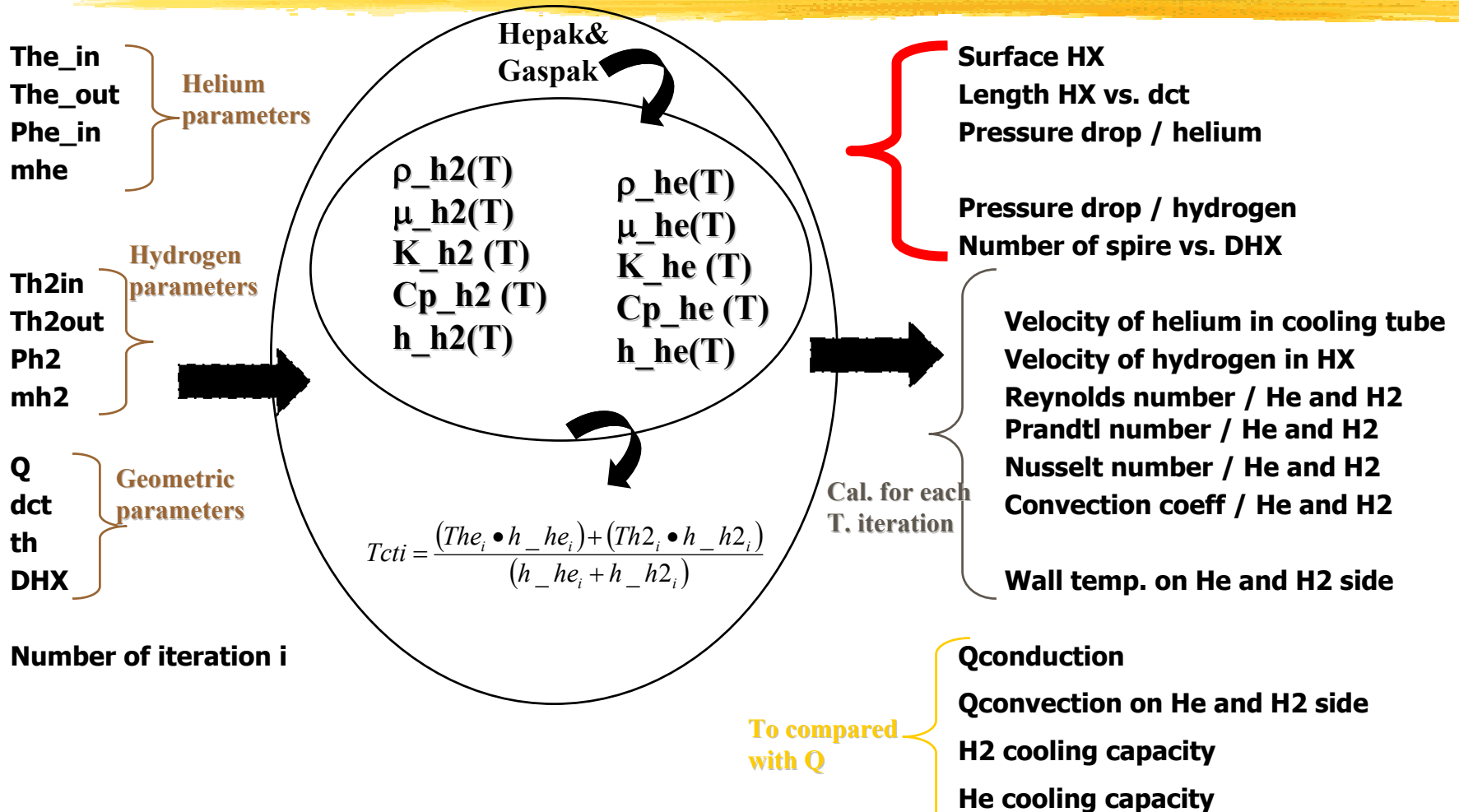
Hydrogen properties:

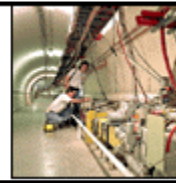
Th2in=17.3 K
Th2out=17 K
Ph2=0.121 MPa (17.5 psi)
mh2=420 g/s

RHX = variable
Did = 6"



Heat Exchanger





Heat Exchanger

⌘ Solution

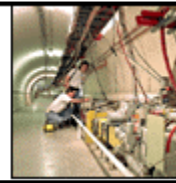
Inner diam. cooling tube = 0.623"=15.8 mm

Thickness = 0.032"=0.81 mm

Outer Shell diameter = 6"= 152.4 mm

Length including the heater = 20"= 508 mm

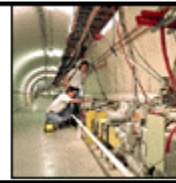
1. **Surface of the heat exchange** = 0.359 m²
2. **Length for d_{cthe} = 0.623 " (15.82 mm)**, Le= 7.22 m
3. **If DHX=4.5 " and d_{ct} = 0.623 " than**, Nr = 22 spires and Le₂=7.46 m
4. **Pressure drop on the LH2 side**, drop_{h2}= 2.1E-3 psi
5. **Pressure drop in Helium side**, drop_{he}= 3.9 psi



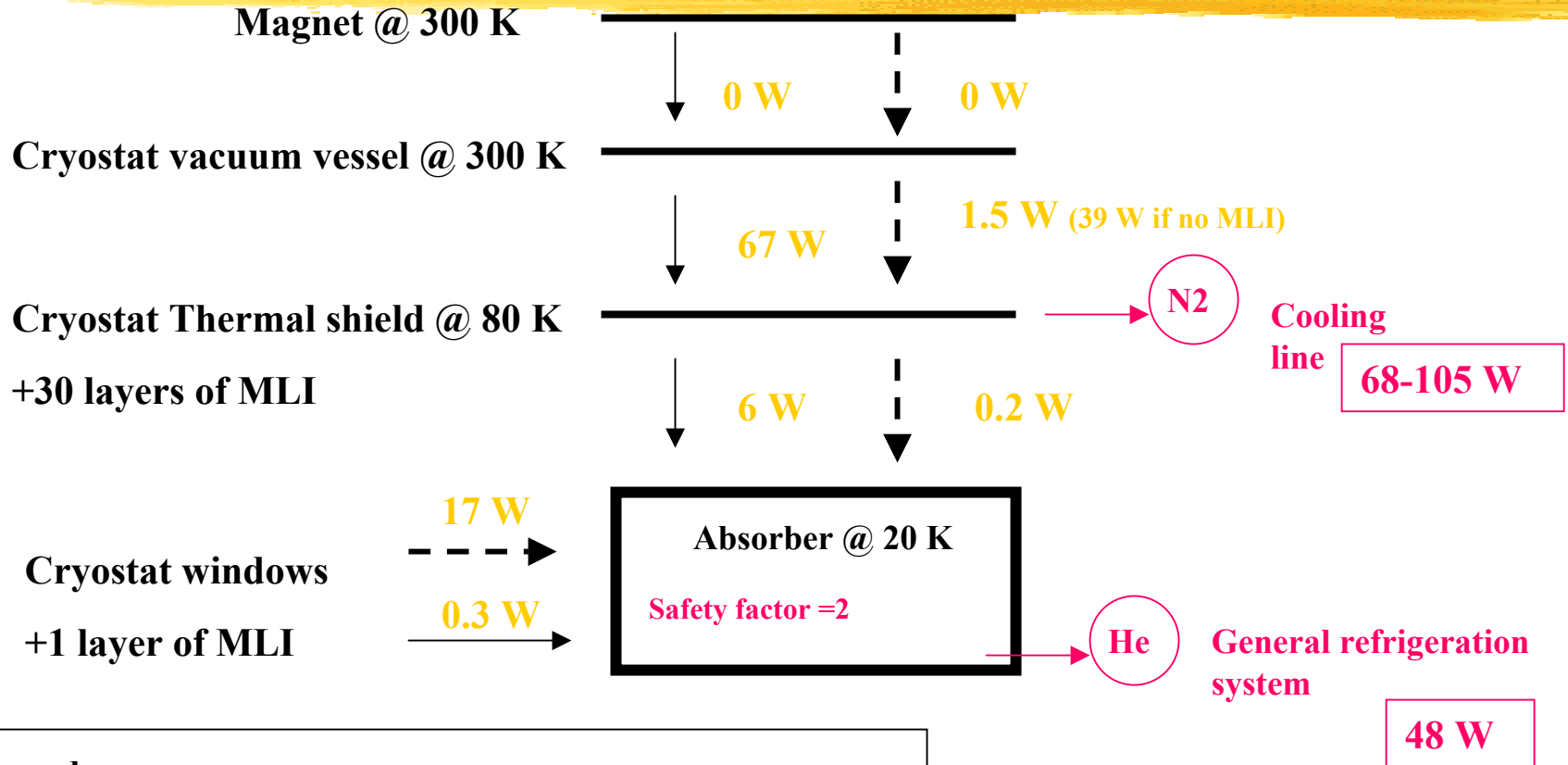
Heat load from ambient to absorber temperature level

The refrigeration power will be distributed between the beam load and the static heat load

- ⌘ Determination of the heat load to the Absorber
- ⌘ Conduction through the G10 support (VV → TS → Abs)
- ⌘ Radiation and Conduction in residual gas, MLI (VV → TS → Abs)
- ⌘ Radiation (windows → Abs)



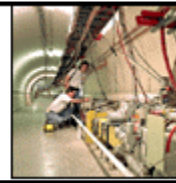
Heat load from ambient to absorber temperature level



Legend:

→ Heat transfer by conduction through the G10 support

--- → Heat transfer by radiation and through MLI



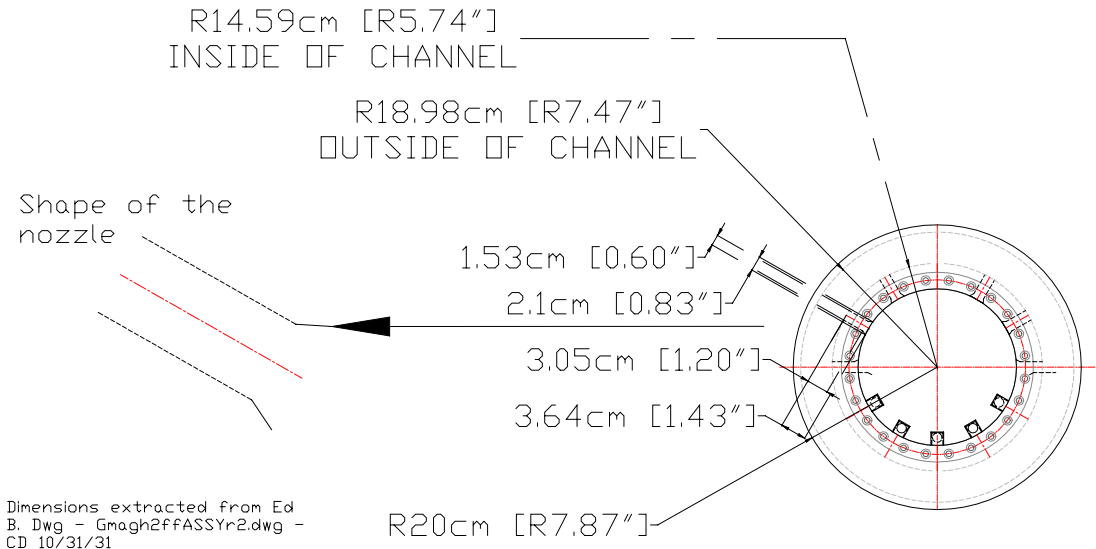
Pressure drop in the LH2 loop

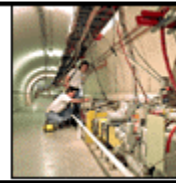
- ★ 1D analysis of the total pressure drop at the pump inlet and outlet
- ★ Hydrogen mass flow: 550 g/s
- ★ Pressure/temperature of Hydrogen: 1.7b/17K

Absorber flow circuit:

Supply: 13 nozzles

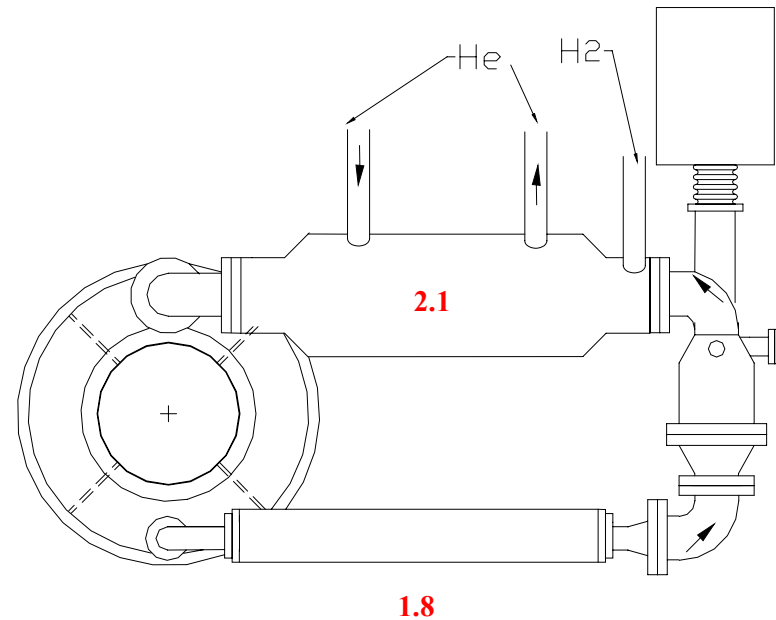
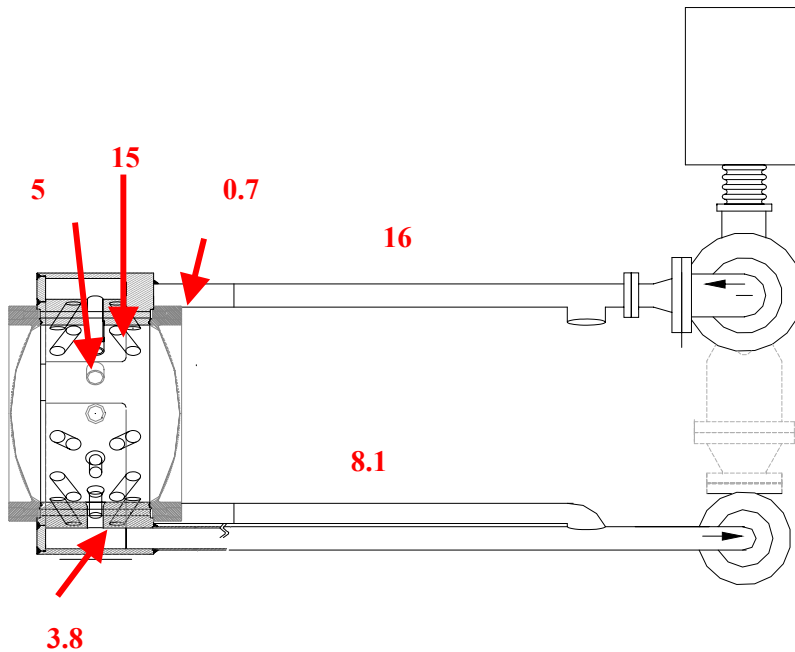
Return: 19 nozzles



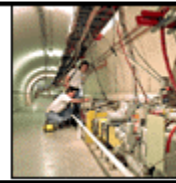


Pressure drop

Map of the pressure drop: Delta-P (10^{-3} psi)



C/C: The total Pressure drop through the system is $52.5 \cdot 10^{-3}$ psi (356 Pa)



Safety and Cryo-design

The design of the LH2 absorber cryo system must meet the requirements of the report "Guidelines for the Design, Fabrication, Testing, Installation and Operation of LH2 Targets – 20 May 1997" by Del Allspach

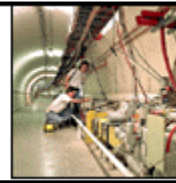
Test facility

LH2 Absorber

- ☼ Aluminum 6061 T6 and series 300 Stainless-steel
- ☼ Design for a MAWP of 25 psid..
- ☼ PSRV sized to relieve at 10 psig (25 psid)

Vacuum vessel

- ☼ Aluminum 6061 T6 and series 300 Stainless-steel
- ☼ Stress analysis for mechanical and thermal loads
- ☼ Design for a MAWP of at least 15 psig internal
- ☼ PSRV sized to relieve less than 15 psig (30 psia)



Safety and Cryo-design

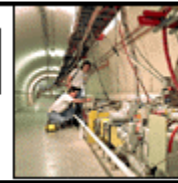
The Pressure safety valves

Sized for the cases of Hydrogen boil-off in vacuum failure (no fire consideration)

- ⌘ LH2 loop => Two pressure relieve valves (Anderson Greenwood type) located before and after the LH2 pump
- ⌘ Vacuum vessel => two parallel plates and a check valve in series with a safety controlled valve

Comments

- ☉ Electrical risk– Follow guidelines – NEC Requirements for H2
- ☉ Second containment vessel avoided if possible.
- ☉ Hydrogen vent



Vacuum vessel - Cryostat window thickness

⌘ Parameters that influence the mechanical choice of the window:

- ☒ Pressure (value, direction) => 2 Configurations
- ☒ Shape
- ☒ Material
- ☒ Diameter

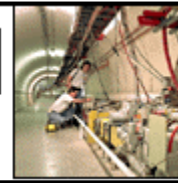
⌘ Pressure configurations

Case A) two windows to be separated by the atmosphere

Beam pipe vacuum----wind#1----atm----wind#2----Cryostat vacuum => P=15 psid
twice the thickness

Case B) one window in between both vacuums

Beam pipe vacuum----wind#1----Cryostat vacuum => P=30 psid



Vacuum vessel - Cryostat window thickness

⌘ Shape

The maximum allowable stress in the window should be the smaller of:

$S_u \times 0.4$ or $S_y \times 2/3$

Flat plate

$$f(y) := K1 \cdot \frac{y}{tk} + K2 \left(\frac{y}{tk} \right)^3 - q \cdot \frac{a^4}{E \cdot tk^4}$$

$$K1 := \frac{5.33}{(1 - \nu^2)}$$

$$K2 := \frac{2.6}{(1 - \nu^2)}$$

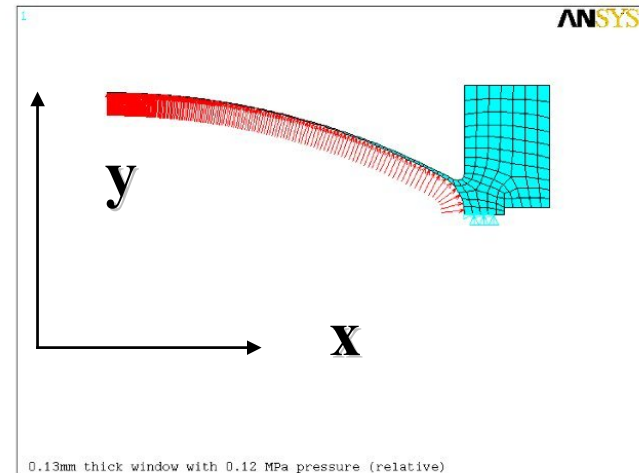
$$\text{Sigma} = E \cdot \frac{tk^2}{a^2} \left[K3 \cdot \frac{y}{tk} + K4 \left(\frac{y}{tk} \right)^2 \right]$$

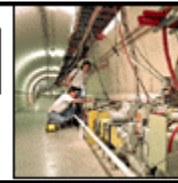
K3= 4.286

K4:= 0.976

Torispherical

Finite element analysis =>





Vacuum vessel - Cryostat window thickness

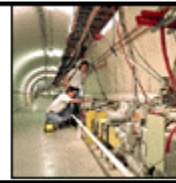
⌘ Materials (need exact material physical properties)

Materials	E (GPa/10 ⁶ psi)	Ultimate stress (MPa/ksi)	Yield stress (MPa/ksi)
Titanium – Ti 15-3-3	92.4/13.40	835.0/121.10	737.7/107.0
Aluminum – 6061 T6	68.0/9.86	312.0/45.25	282.0/40.9
Beryllium – S-200E	251.0/36.41	485.4/70.40	297.9/43.2

⌘ Diameter

Even if the muon beam diameter can vary along the cooling channel, the first containment window should keep the same diameter

→ D= 22 cm (8.66")



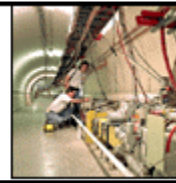
Cryostat window thickness – Potential solutions 22-cm window

Flat plate thickness (mm)

Materials	W/ Atmosphere interface 2 windows, 15 psid	W/o Atmosphere interface 1 window, 30 psid
Titanium – Ti 15-3-3	0.489	0.775
Aluminum – 6061 T6	5.280	3.887
Beryllium – S-200E	4.360	3.080

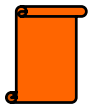
Torispherical thickness (mm)

Materials	W/ Atmosphere interface 2 windows, 15 psid	W/o Atmosphere interface 1 window, 30 psid
Aluminum – 6061 T6	0.304	0.260



Conclusions

The feasibility of the LH2 Absorber cryo. system has been studied, conceptual designs are proposed. Safety issues still need to be finalized.



- ✓ Preparation of the safety documentation / Safety Hazard Analysis
- ✓ Committee and review

More results can be found at:

http://www-bdcryo.fnal.gov/darve/mu_cool/mu_cool_HP.htm