Systematic Uncertainties in the lH2 Absorber

Craig Brown

Brunel University

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Aims

Determine the factors which can contribute to the systematic uncertainties of the lH2 absorber and to what extent, including:

- Change in lH2 density for varying temperatures/pressures
- Accuracy of temperature/pressure sensors
- Warm absorber bore contraction as it is cooled
- Deflection of absorber windows due to pressure
- Effect of lH2 weight on the absorber windows
- Smoothness of absorber windows (thickness variance)
- Ortho/Para Hydrogen

A lot of the information follows from MICE note 155 by Michael Green and Stephanie Yang who investigated similarly

Energy Loss in lH2 absorber

At standard temperature and pressure:

- dE/dx is 0.02856 MeV/mm for lH2
- dE/dx is 0.4358 MeV/mm for aluminium

- This is for a density of 70.8 kg/m3 and 1 atm of pressure for lH2

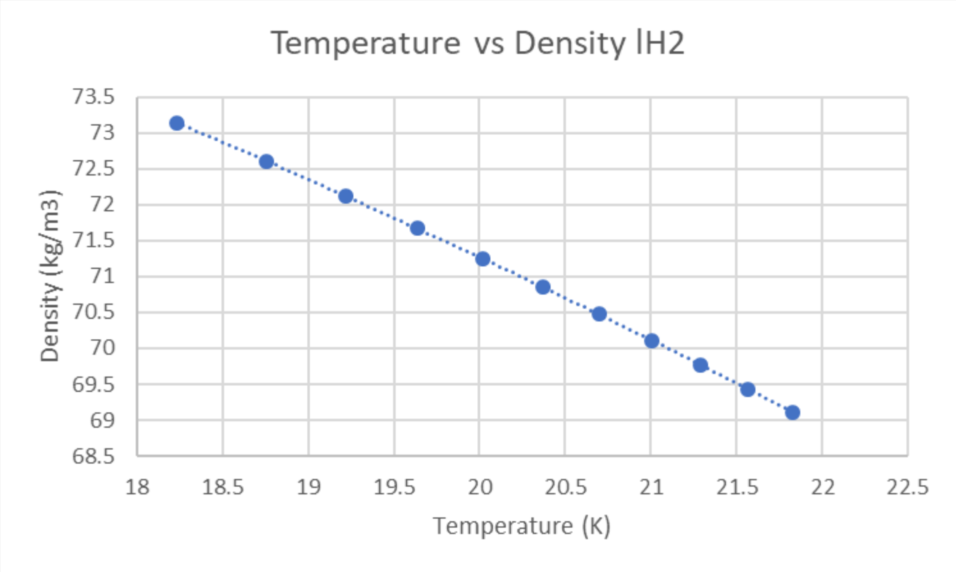
- Density of lH2 changes at varying temperatures and pressures

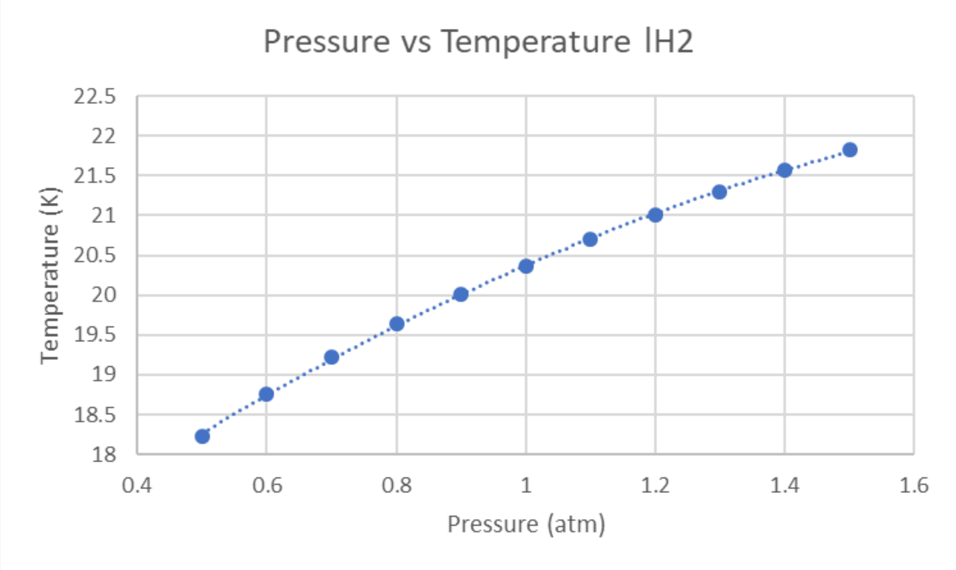
- This changes the energy lost by the muon travelling through the absorber

- Accuracy of temperature and pressure sensors determines the accuracy of the lH2 density and thus the energy loss

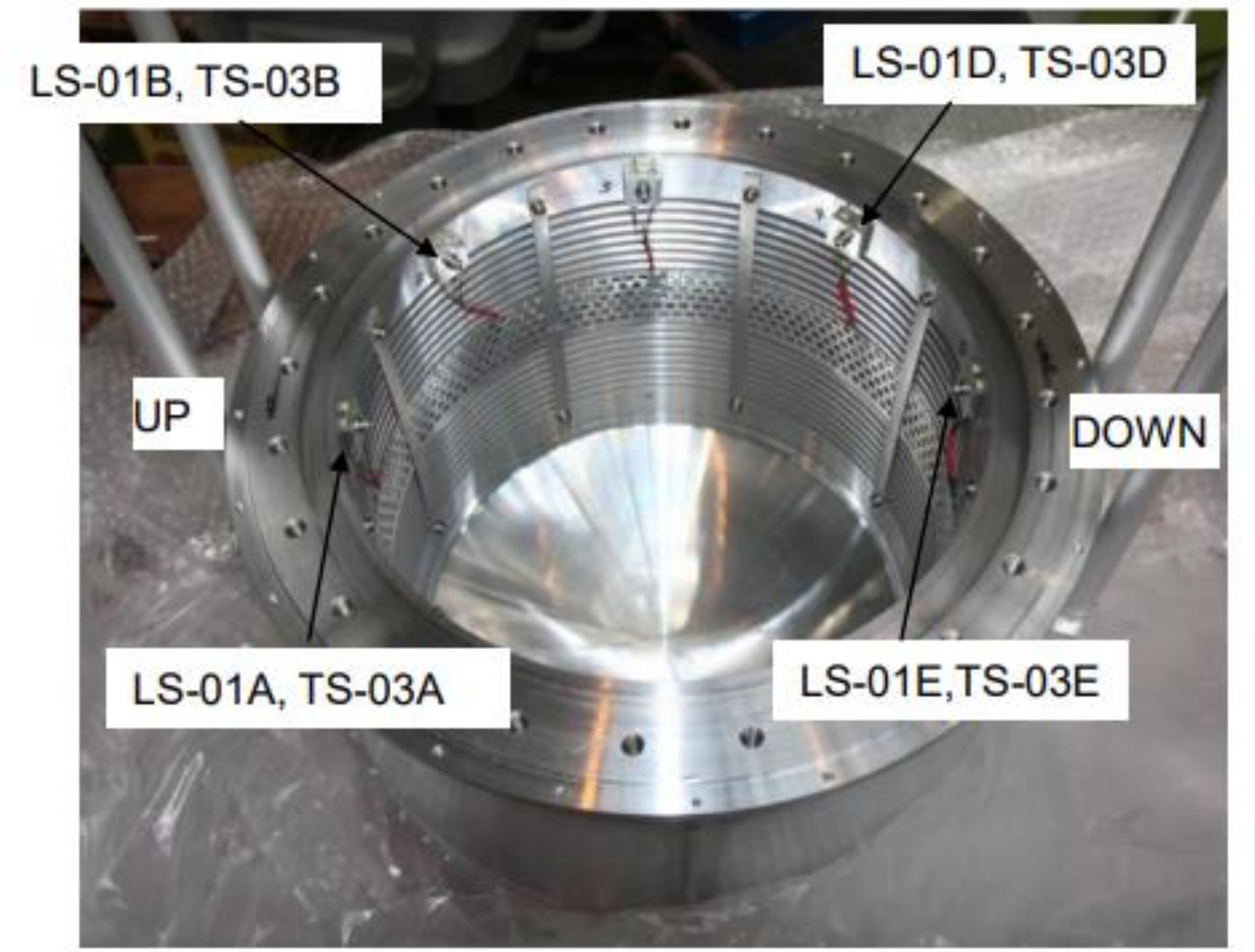
Saturation Properties for lH2

Temperature (K)	Pressure (atm)	Density (kg/m3)
18.232	0.5	73.145
18.755	0.6	72.608
19.219	0.7	72.12
19.636	0.8	71.669
20.017	0.9	71.248
20.369	1	70.85
20.696	1.1	70.473
21.003	1.2	70.114
21.291	1.3	69.769
21.565	1.4	69.436
21.824	1.5	69.115

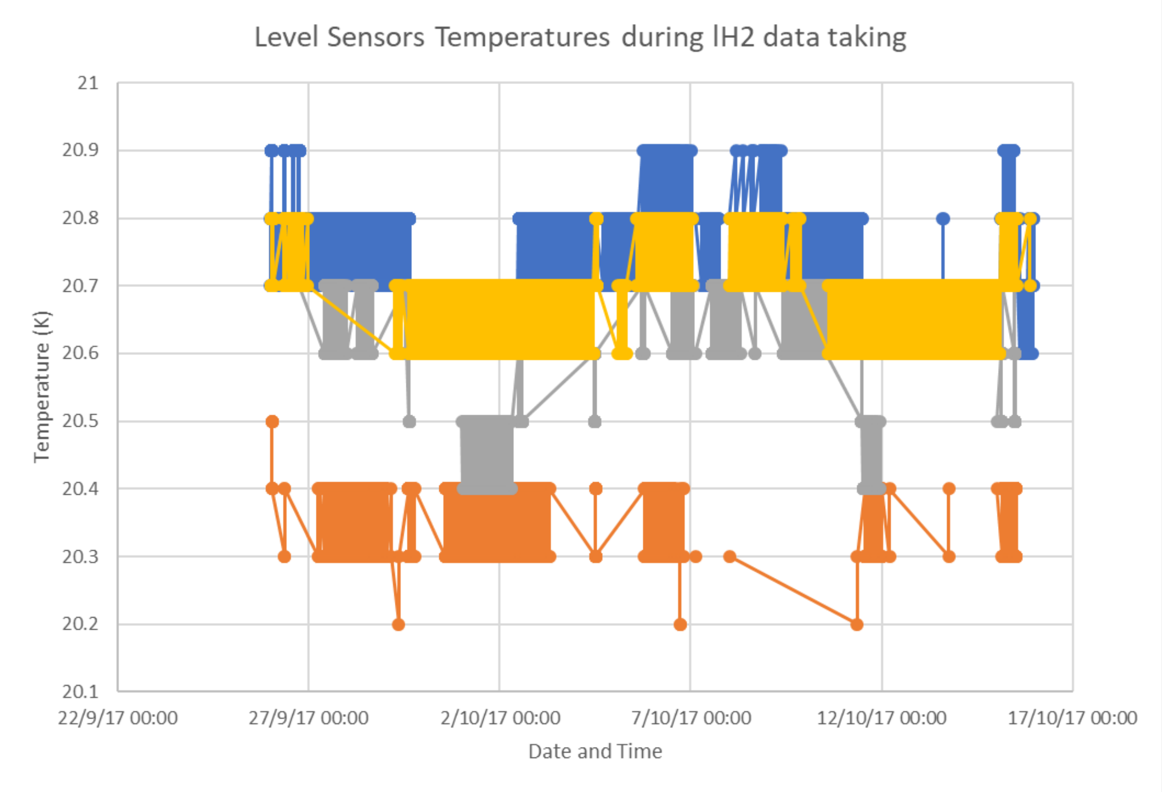


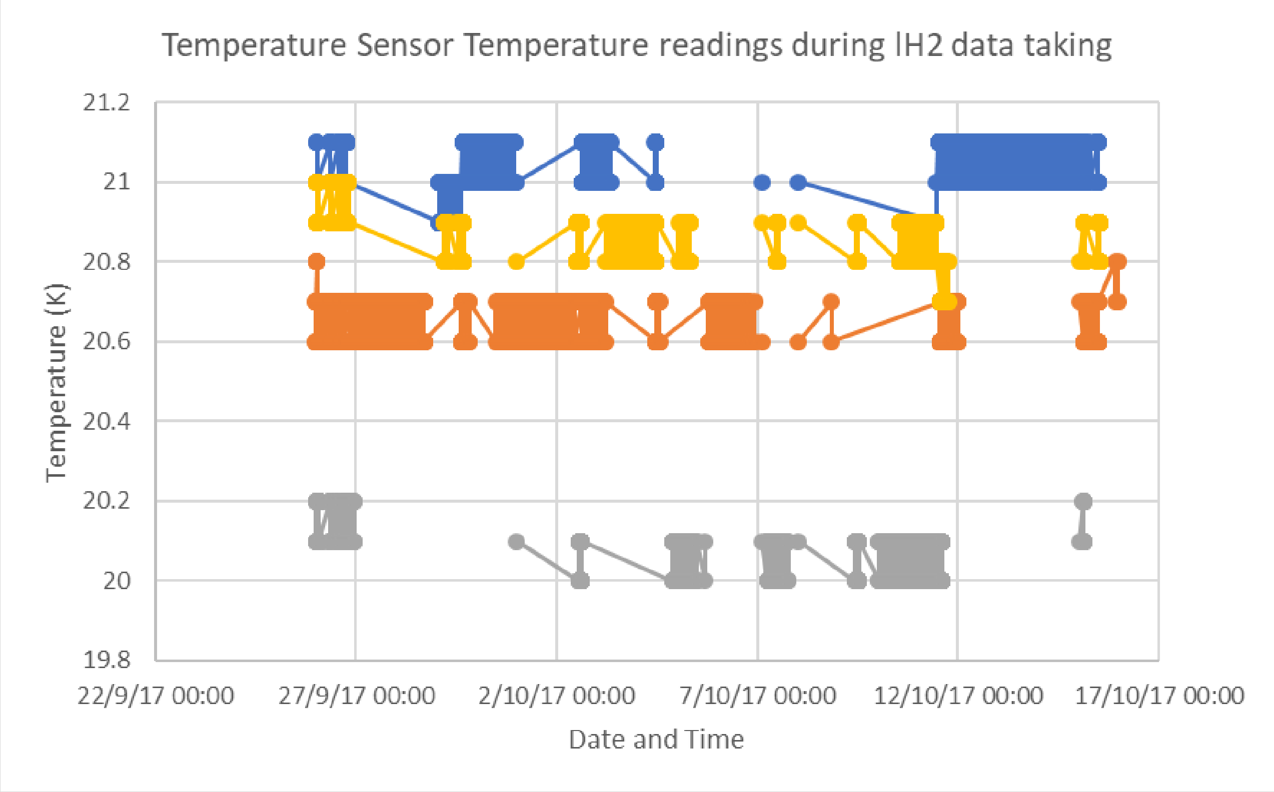


IH2 absorber body



Level Sensor and Temperature Sensor Raw Readings

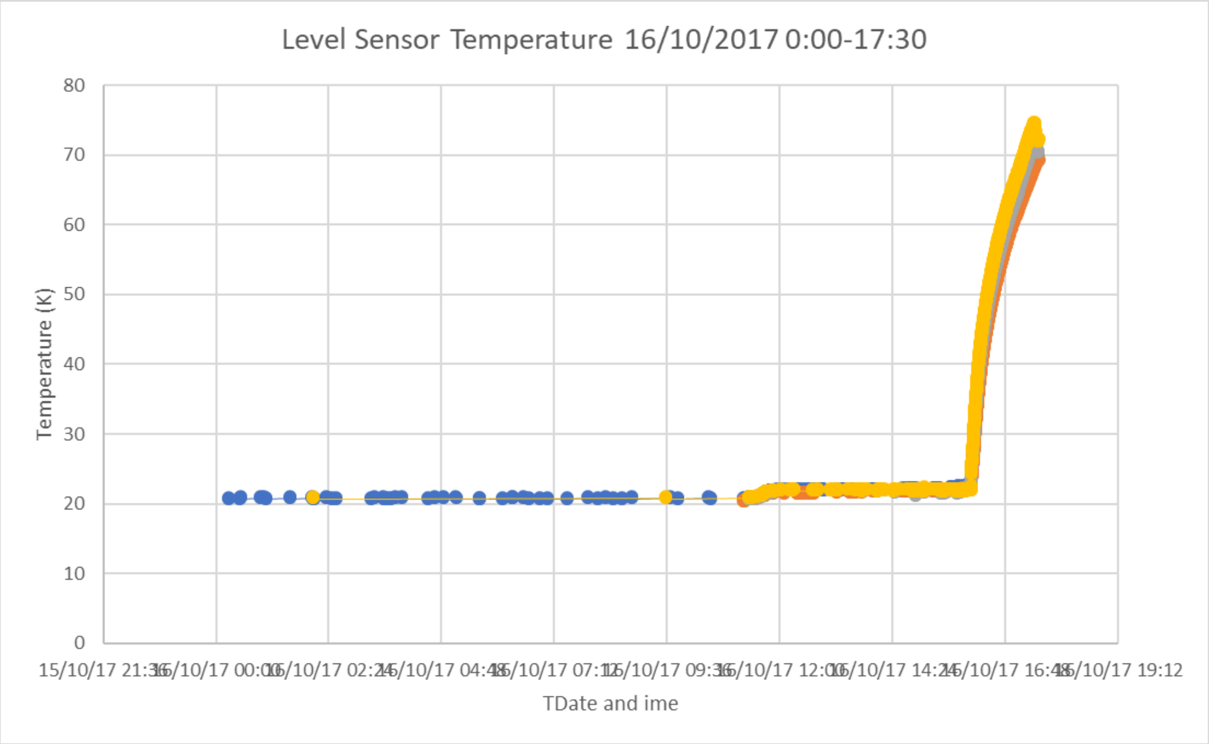




LSA: Blue
LSB: Red
LSD: Gray
LSE: Yellow

TSA: Blue
TSB: Red
TSD: Gray
TSE: Yellow

Temperature Readings during heating (at 50 Watt) on 16 Oct 2017



LSA: Blue
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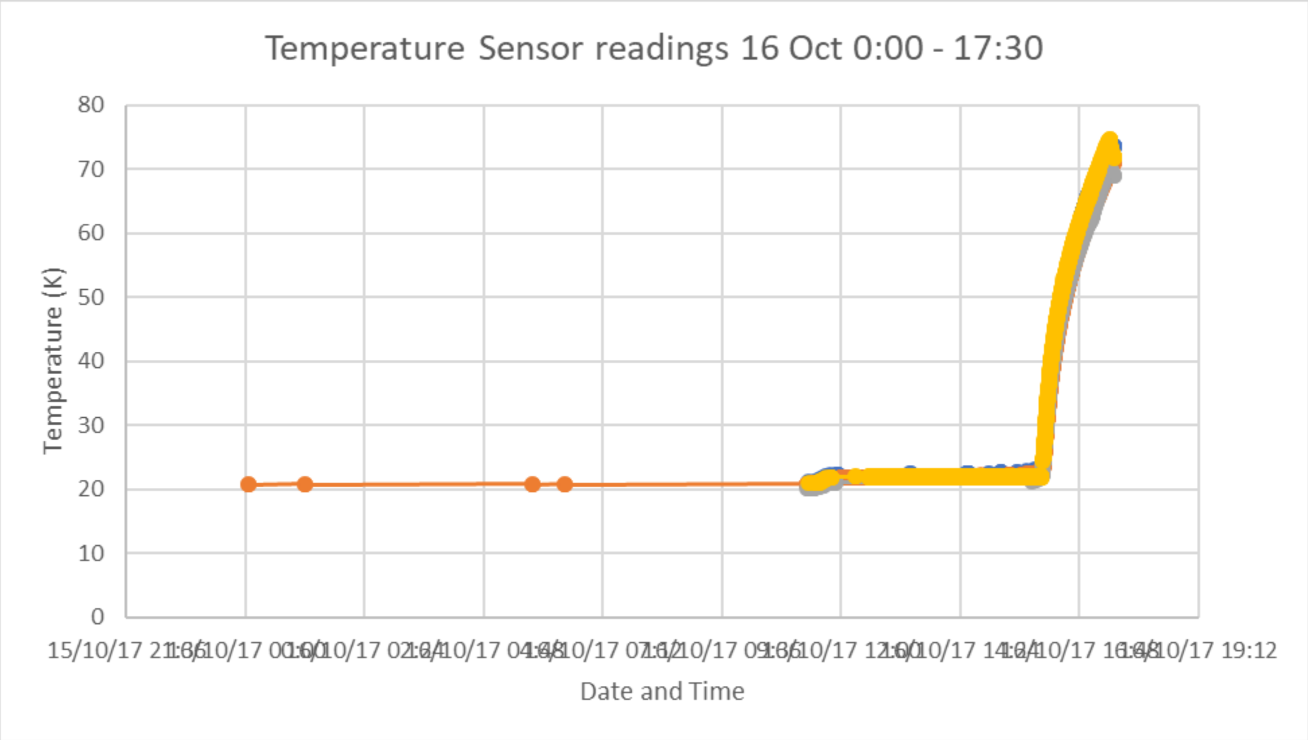
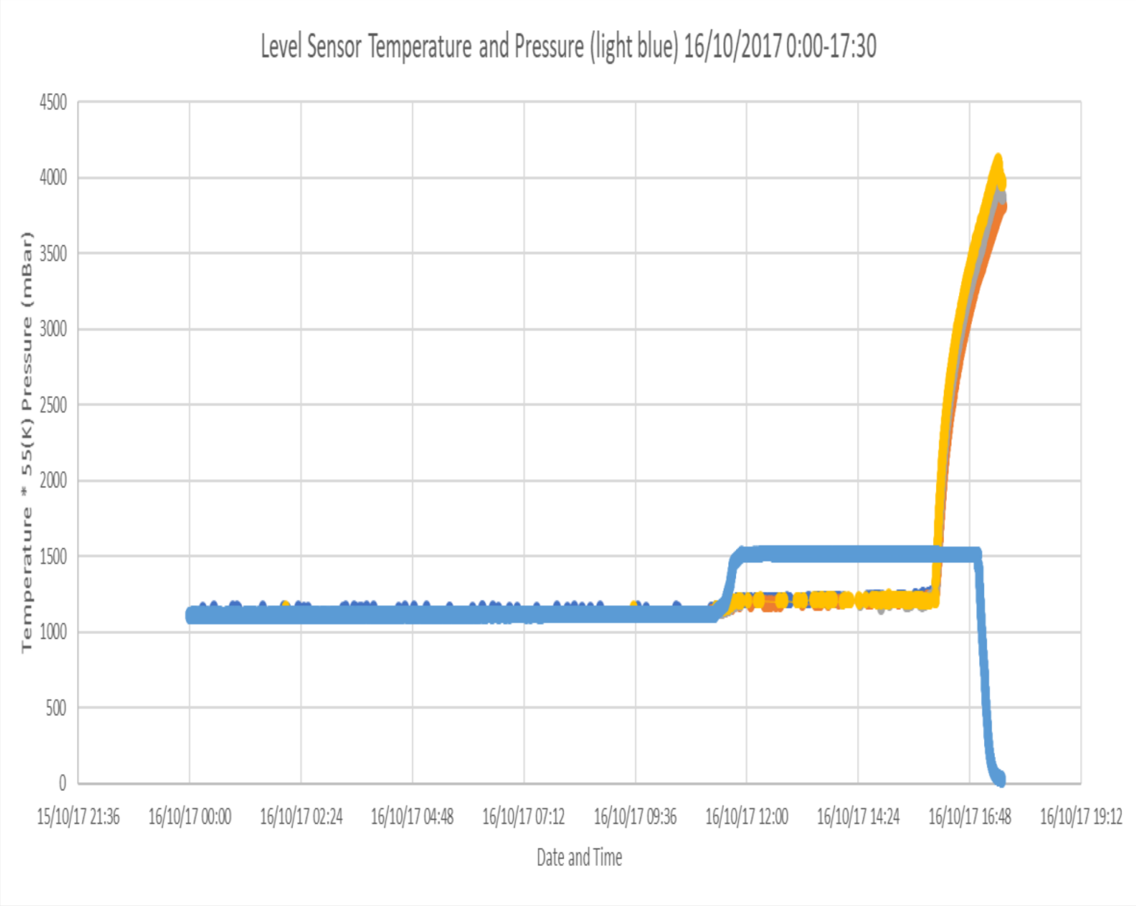
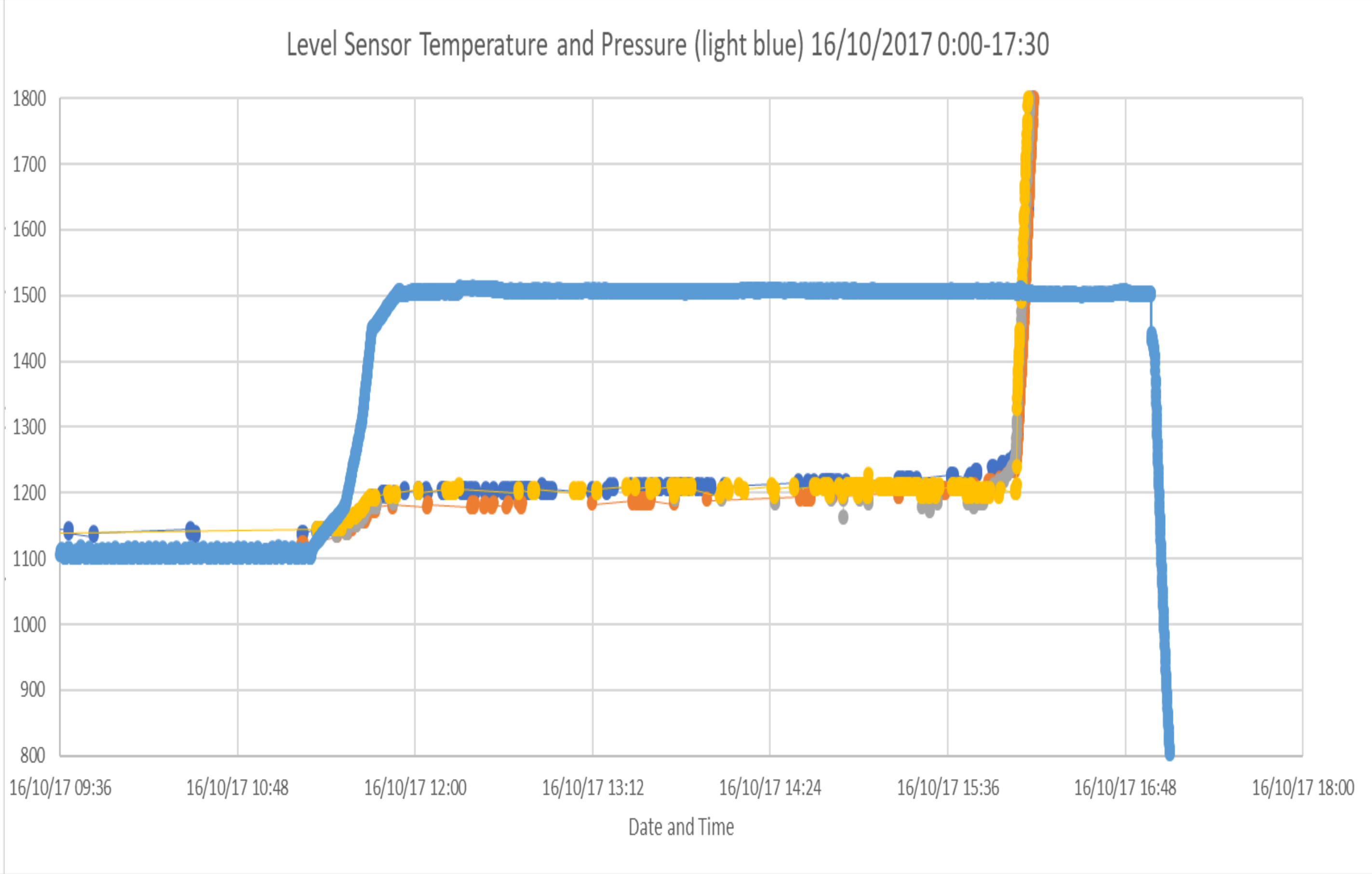


TSA: Blue
TSB: Red
TSD: Gray
TSE: Yellow

Pressure increase as Temperature increases



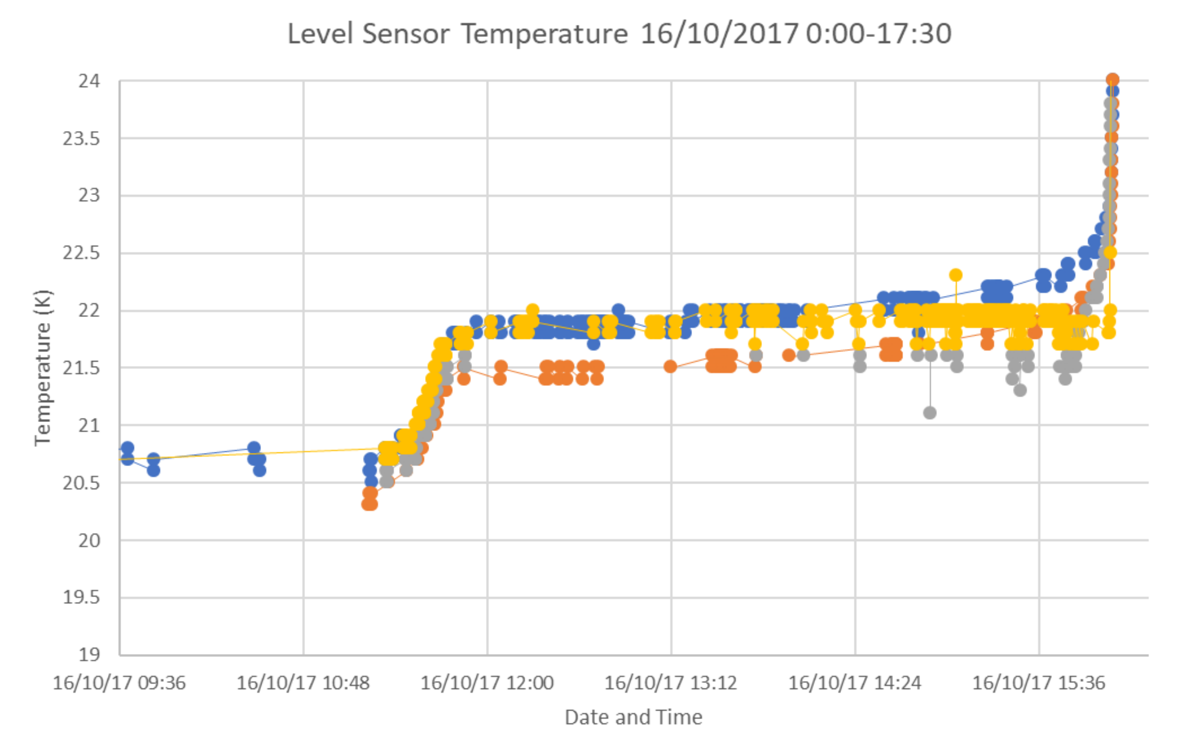


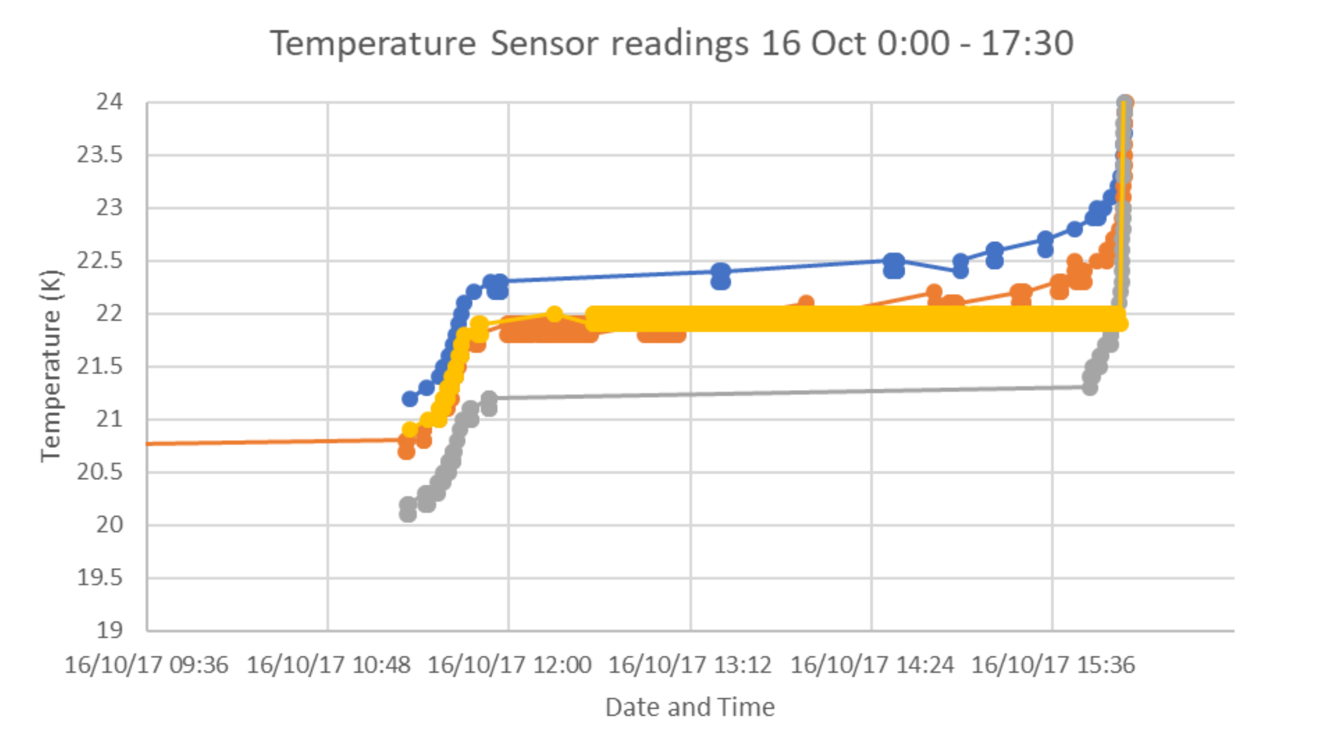
Is that the Vaporisation Point?

- Heat of Vaporisation = 0.44936 kJ/mol
- 50 Watt of heat delivered (0.05kJ/s)
- One mole of H2 = 2.016 grams/mol
- Density = 70.85 grams/litre

- 22 l of H2 = 1558.7 grams = 773.16 mol
- => 773.16 * 0.44936 = 347.429 kJ of energy required
- => 347.429/0.05 = 6948.585 seconds = 115.8 min
- If all the energy goes into turning liquid into gas, it will take about 2 hours

Temperature readings focused on 9:30-15:30





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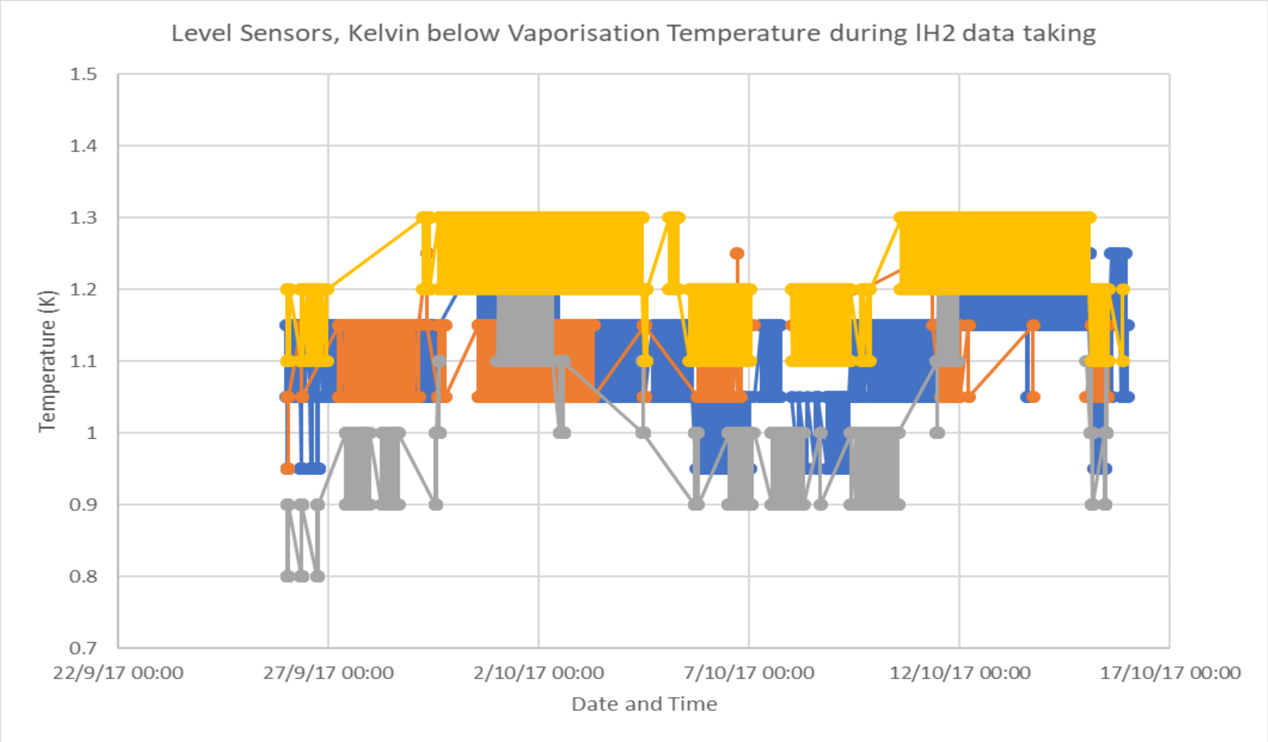
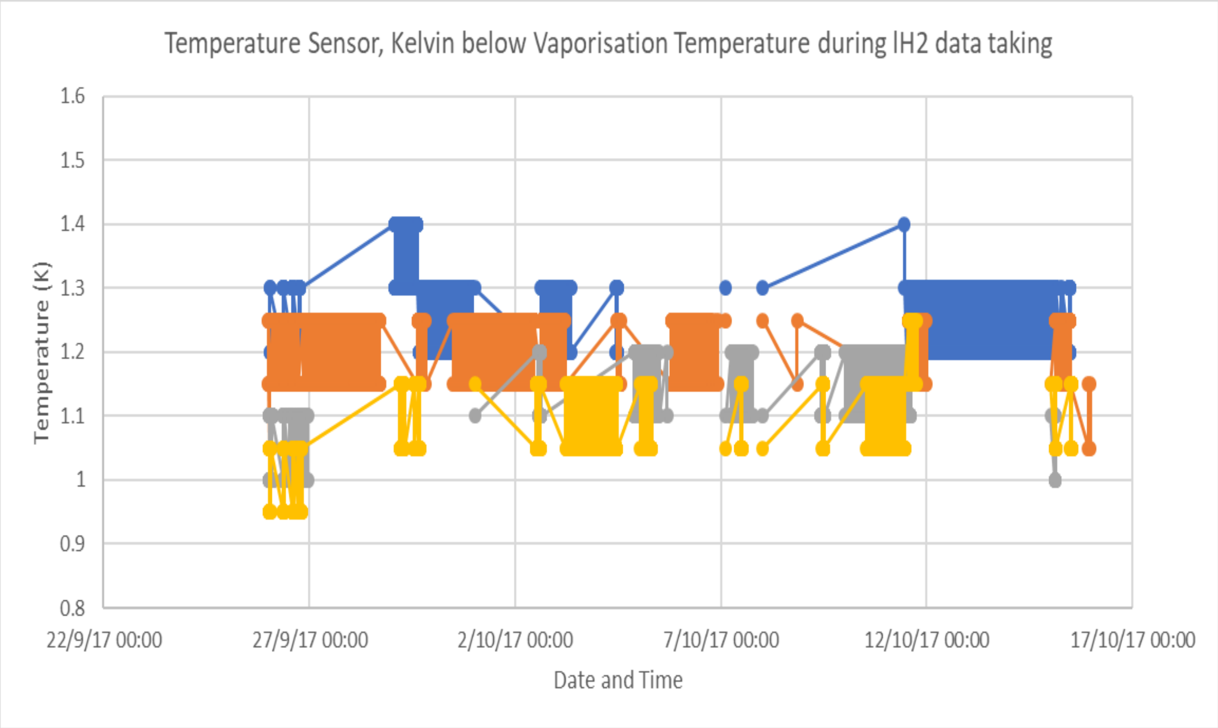
Temperature readings adjusted by Vaporisation Point at 1.5 Bar





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Adjusting Temperature according to Vaporisation Point at 1.5 Bar

- Before Adjustment:
- Level Sensors varied from 20.2K – 20.9K (variance 0.7K)
- Temperature Sensors from 20K -21.1K (variance 1.1K)

- After Adjustement:
- Level Sensors varied from 0.8K – 1.3K below Vap T (1.5Bar)(variance 0.5K)
- Temperature Sensors from 0.95 – 1.4K below Vap T (1.5Bar)(variance 0.45K)

- Sensors can read to accuracy of 30mK to 1K depending on calibration
- Resolution of readings is 0.1K

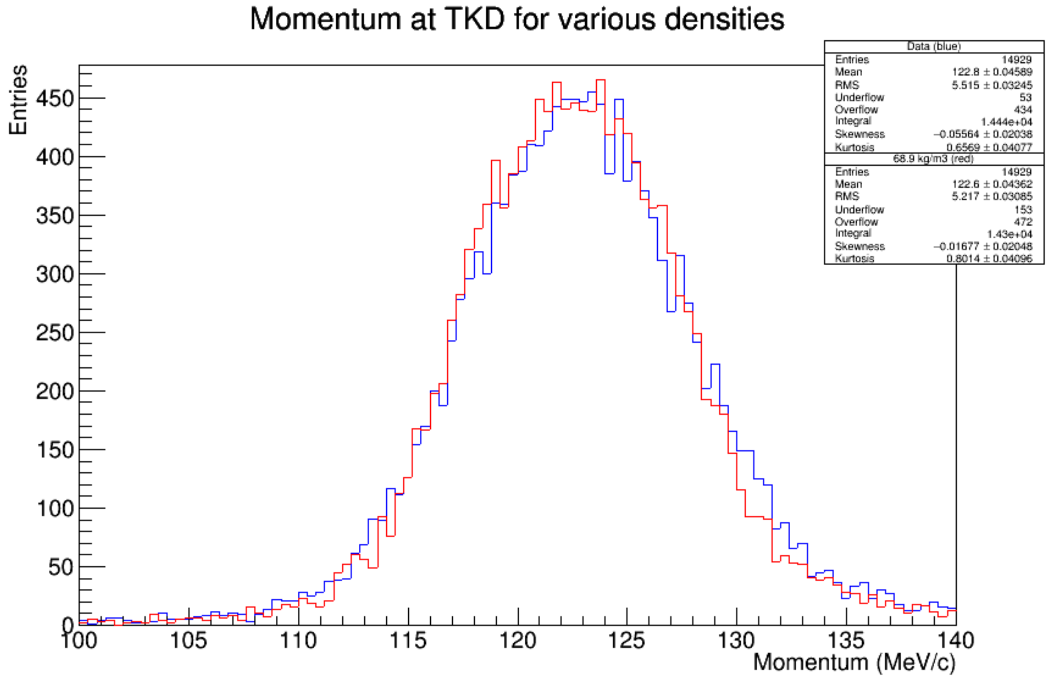
But what is the temperature?

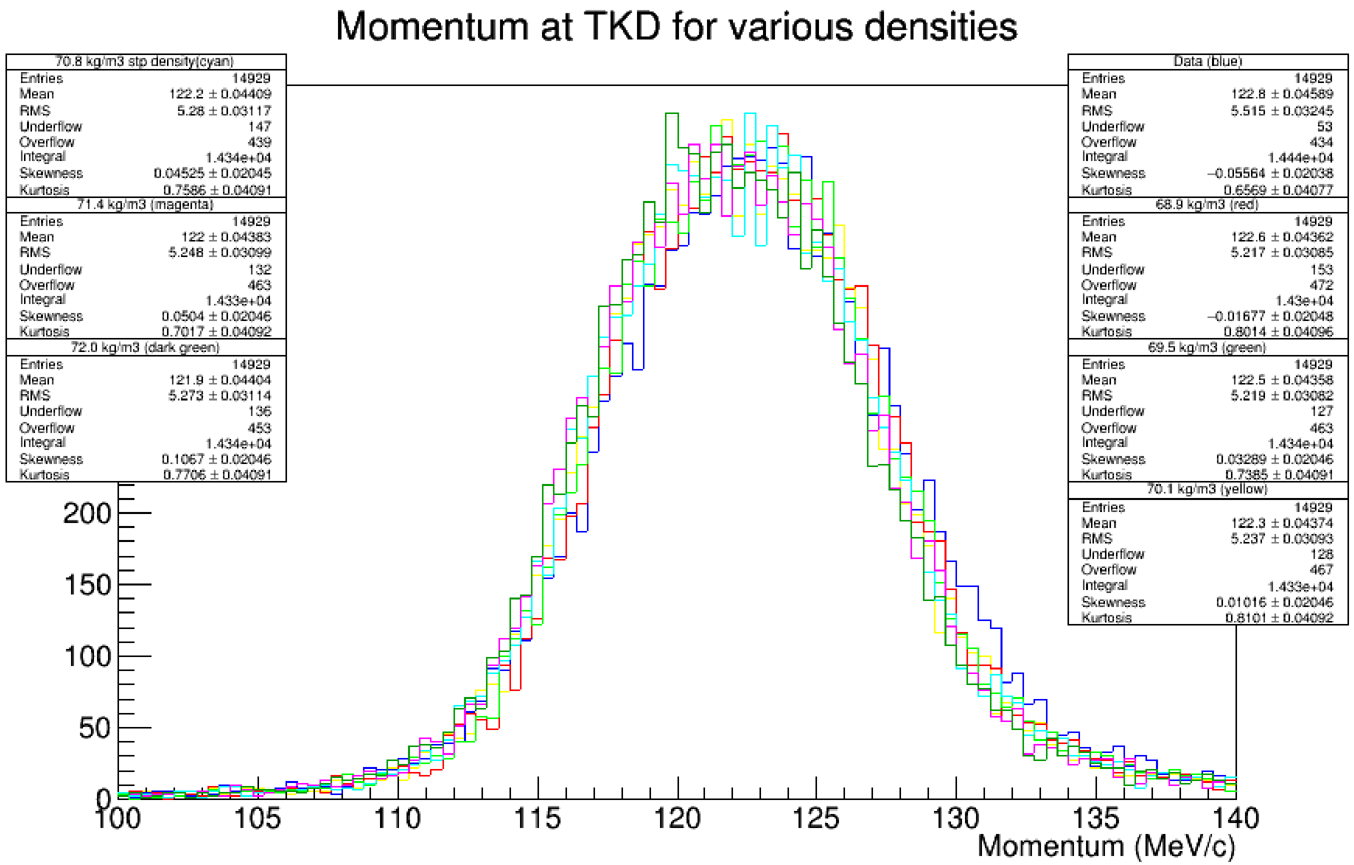
- Vaporisation Temperature at 1.5 Bar = 21.824K
- Vaporisation Temperature at 1.08 Bar = 20.63K

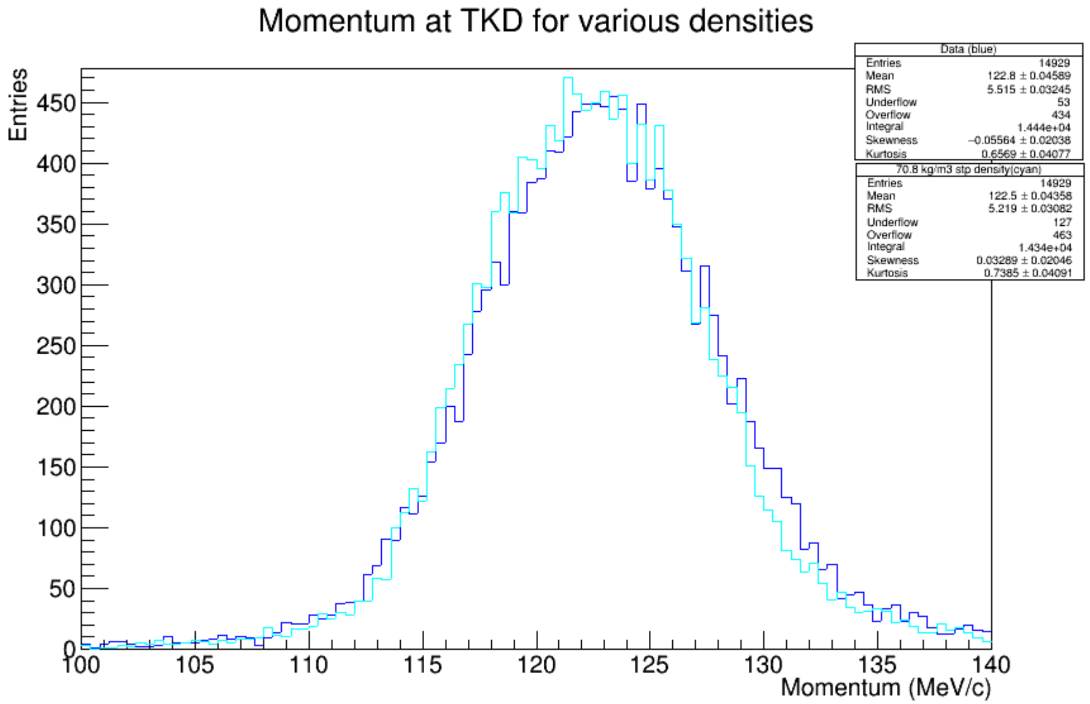
- Need to distinguish the temperature increase from pressure increase
- Need to look further into archiver temperature data, many missing points, bad points are ranges of no readings
- This will give a better average to adjust temperatures by
- Can then determine temperature to ± 0.3K
- Or the density to an approximation of ± 0.4kg/m3
- Needs more work

Monte Carlo for differing lH2 densities compared to data

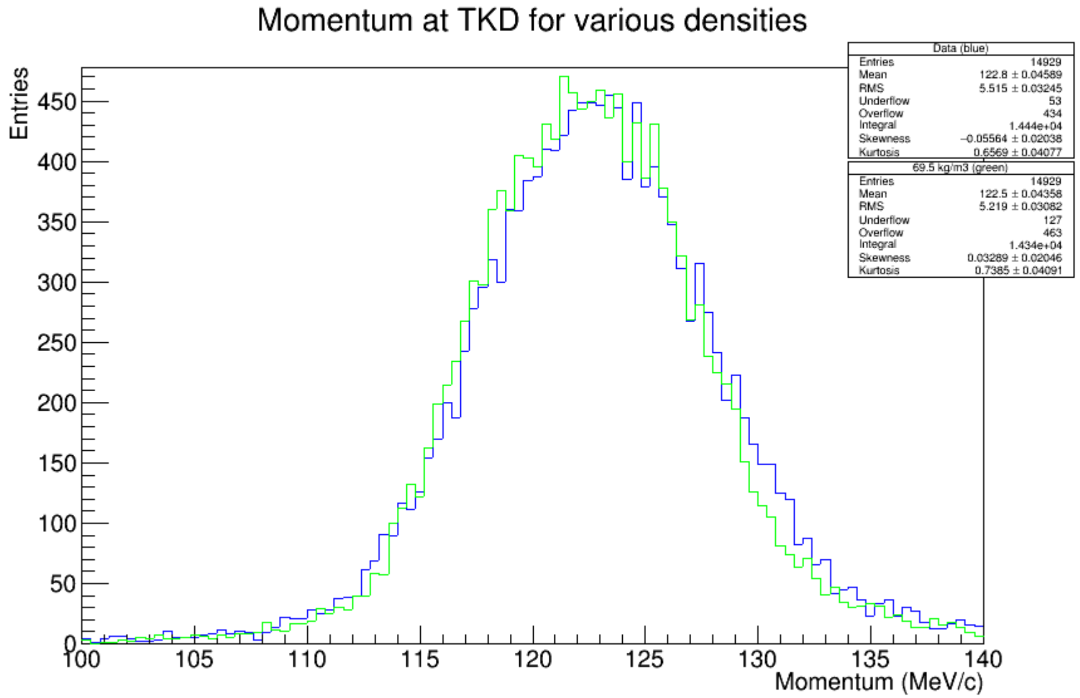
Below: Momentum at TKD for various densities
Top Right: For density of 68.9kg/m3
Bottom Right: Density of 70.8kg/m3 (STP)

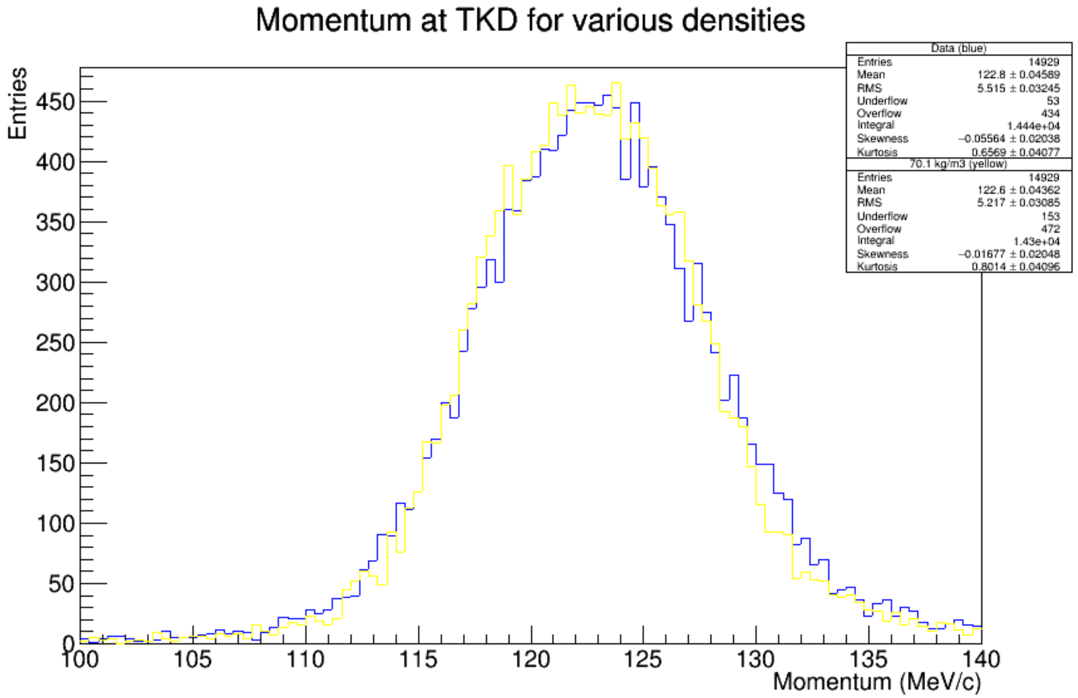


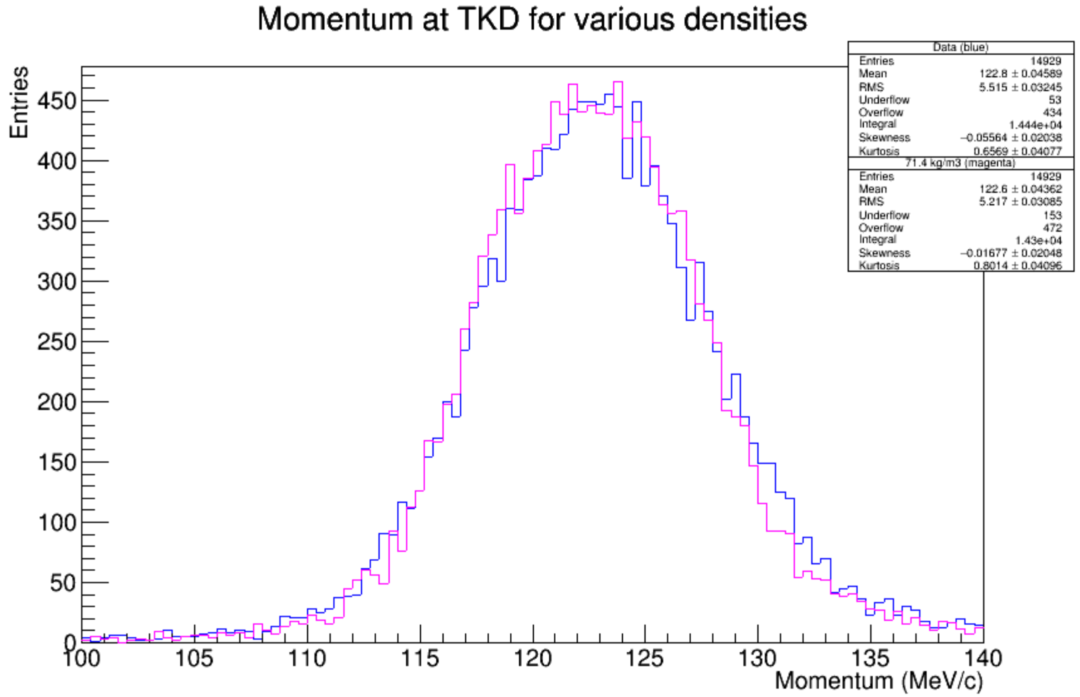


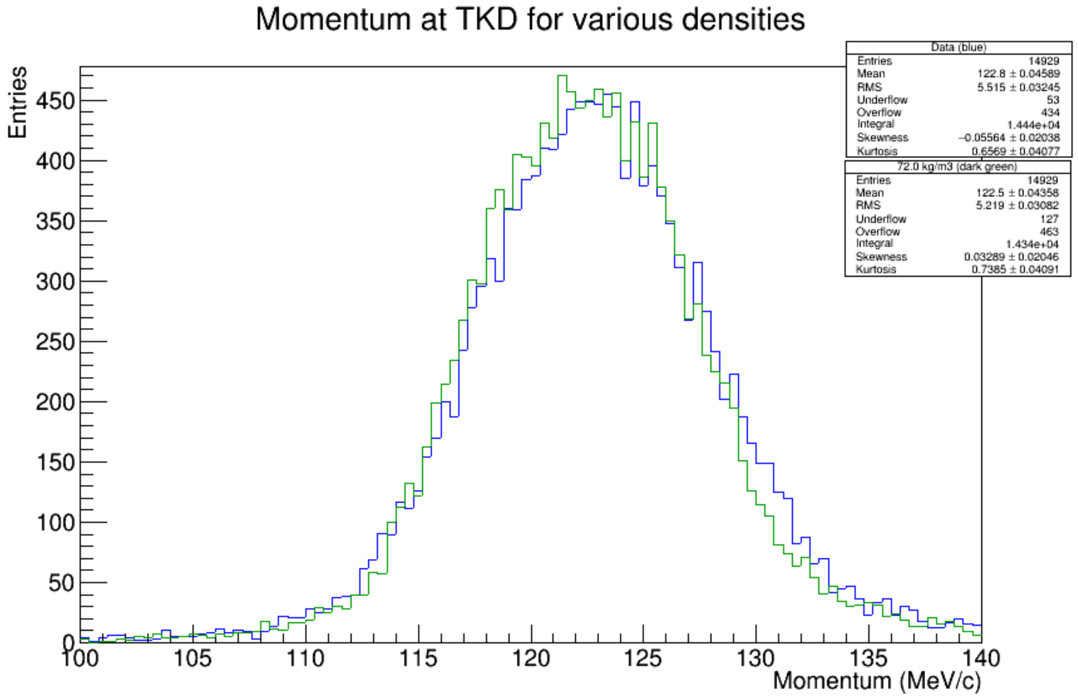


Density
TL: 69.5
TR: 70.1
BL: 71.4
BR: 72.0

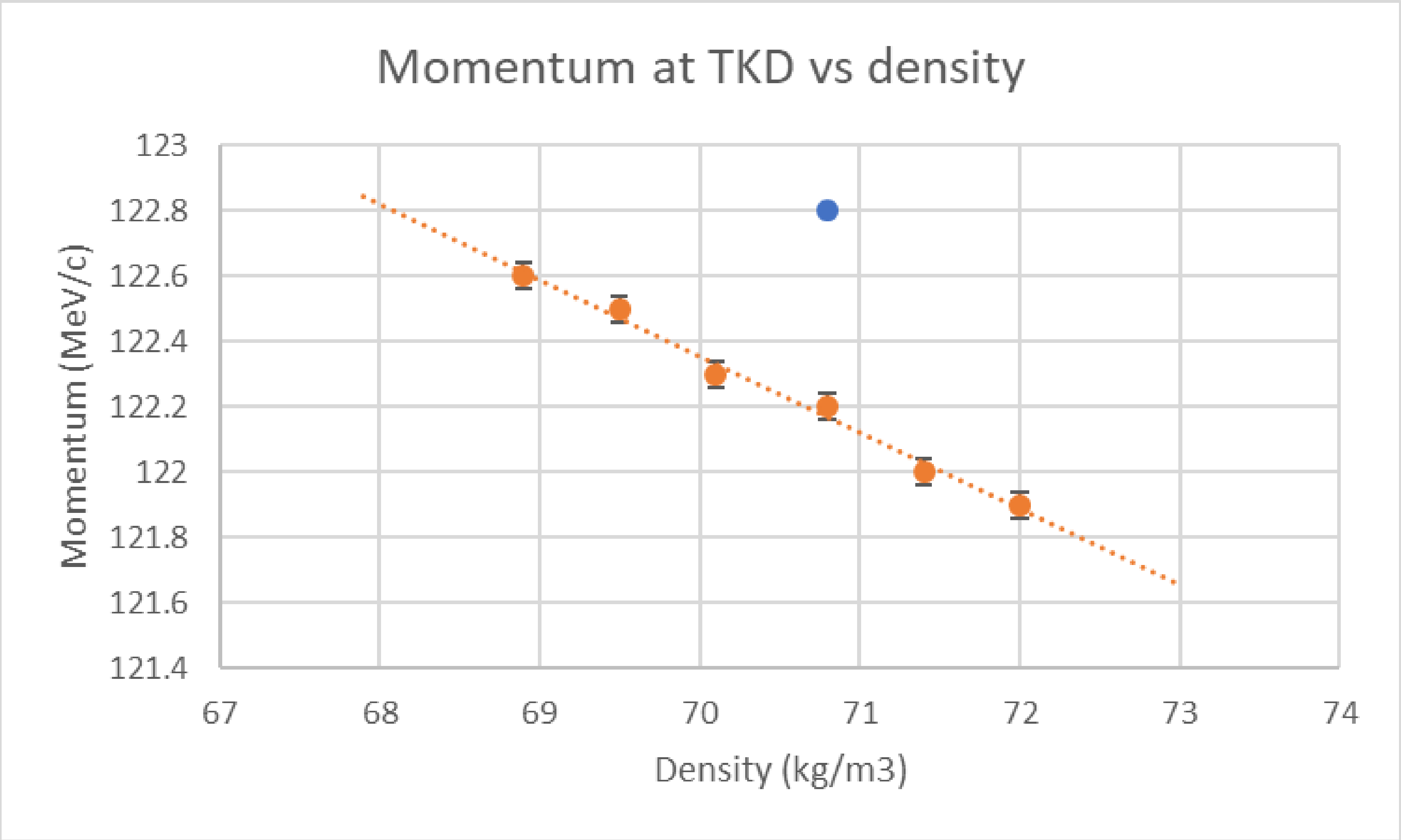








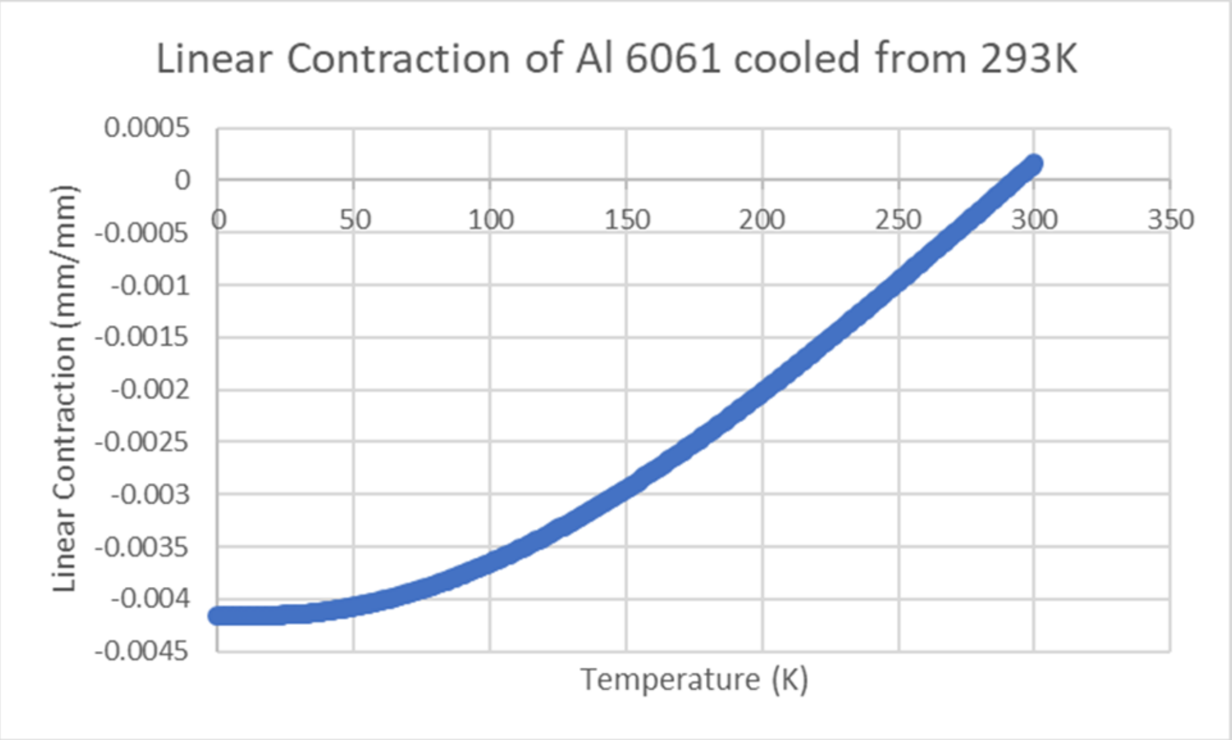
MC Momentum at TKD for various densities (orange) and data (blue)



Absorber Contraction

As the absorber is cooled from room temperature the linear contraction is:

- $y = a + bT + cT^2 + dT^3 + eT^4$
- Where
- a = -4.1277E-3
- b= -3.0389E-6
- c = 8.7696E-8
- d = -9.9821E-11
- e = 0
- T = Operating Temperature



Al 6061 absorber contraction

- When the Aluminium is cooled from 293K to the operating temperatures MICE runs at it shrinks by 0.415% along each plane (4% curve fit error)
- If the warm bore shrinks uniformly then

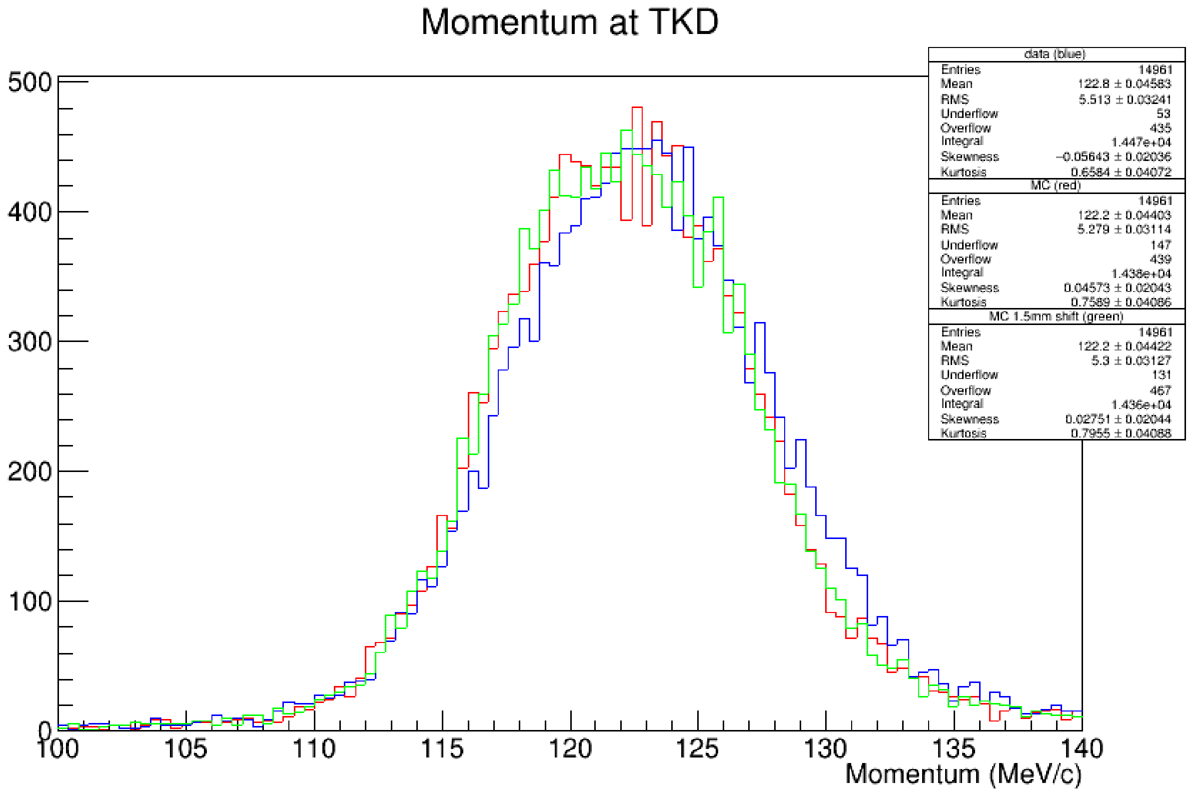
  350mm * 0.00415 = 1.4525mm

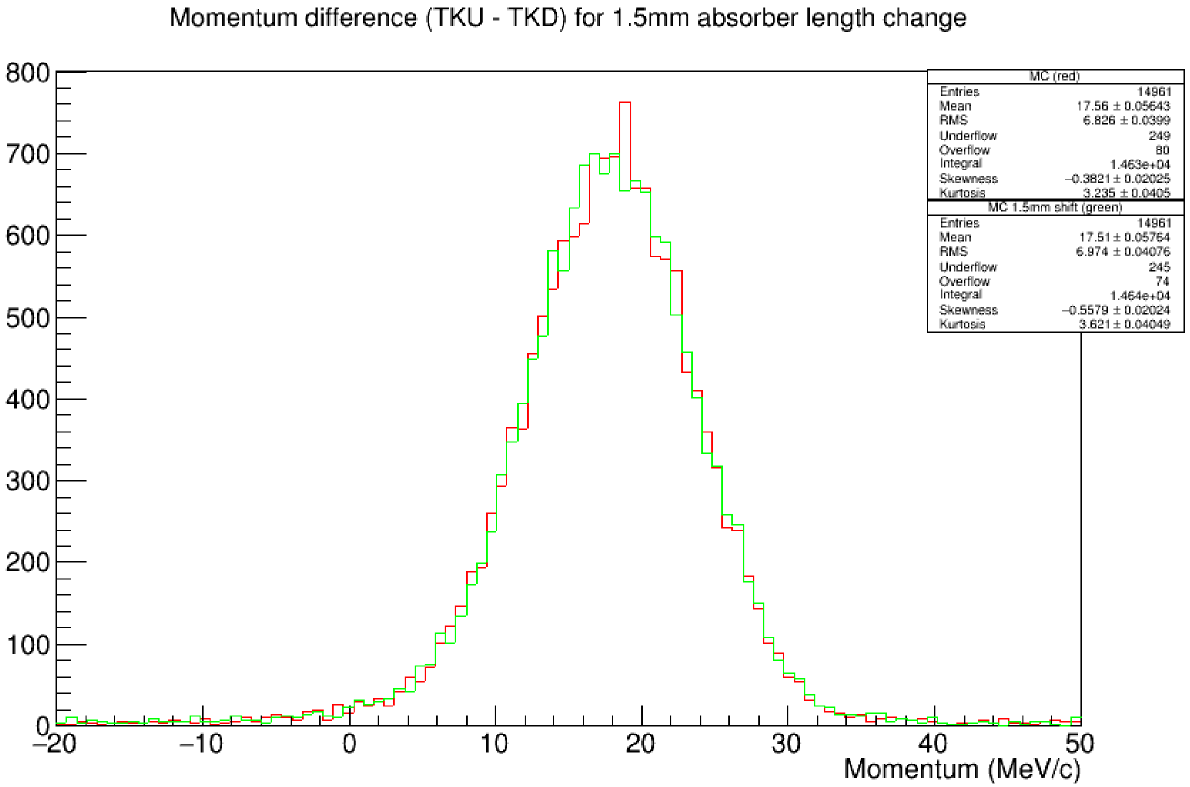
  The warm bore shrinks by 1.4525mm, however the central section is not free (attached to the rest of the apparatus and may not be free to contract uniformly, creating an extra strain on the absorber windows

  The windows may in fact deflect more, further reducing the central bore length
- Note however dE/dx for 1.4525mm of lH2 is

  1.4525mm * 0.02856 MeV/mm = 0.04148MeV (+/-4%)

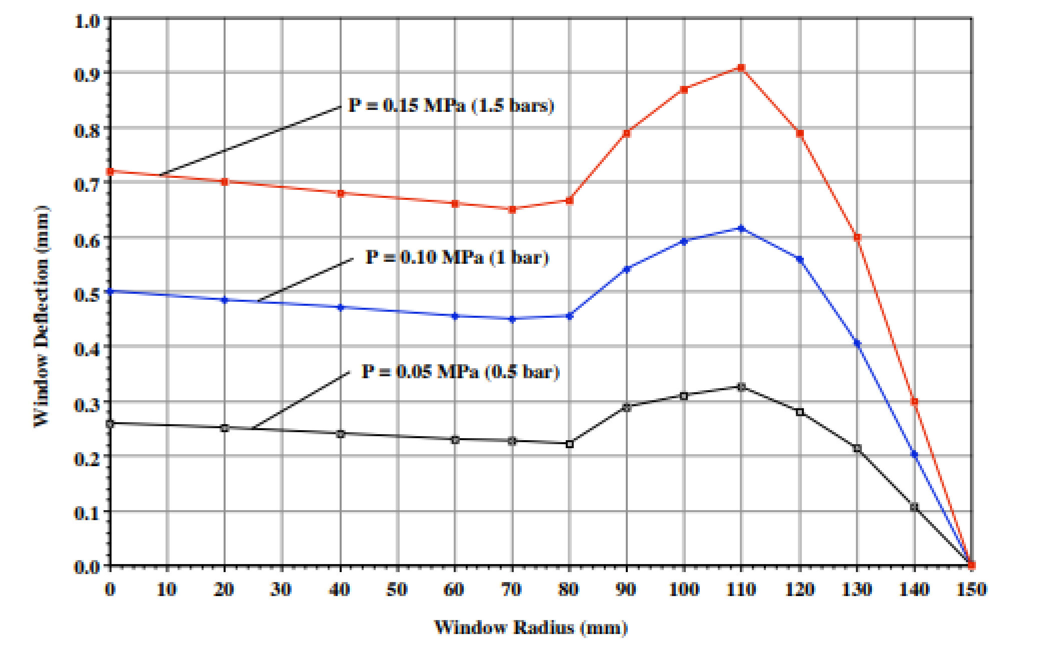
Monte Carlo for a central bore length section reduced by 1.5mm



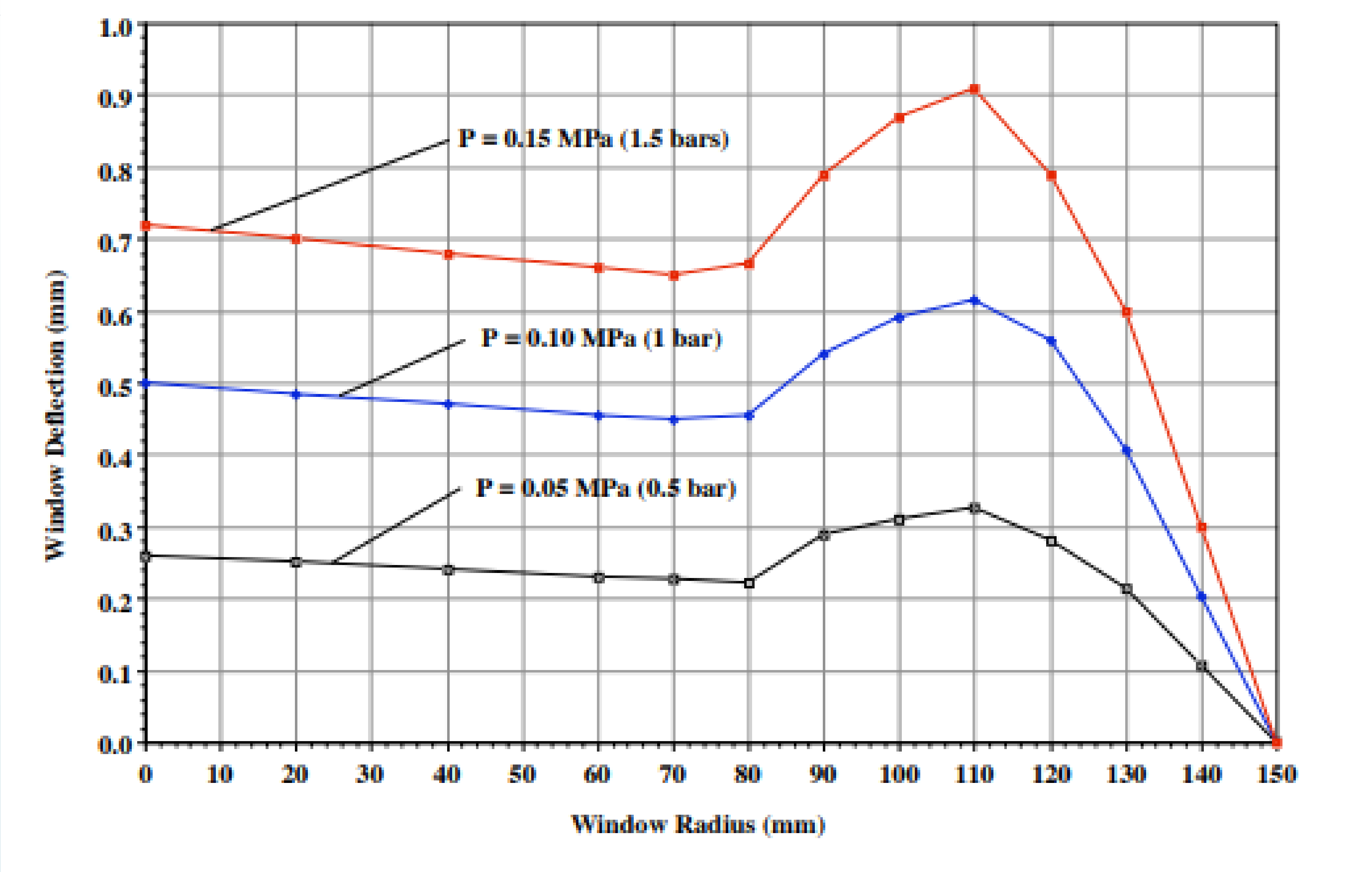


Deflection of Absorber Windows due to pressure

- ANSYS model from Green and Yang
- Error of up to 20%, although they believe far smaller
- Linear expansion with pressure
- Mice operating pressure 1.080 Bar
- Deflection at center of absorber window:
- For 1.08 Bar is 0.54mm(+/- 20%)



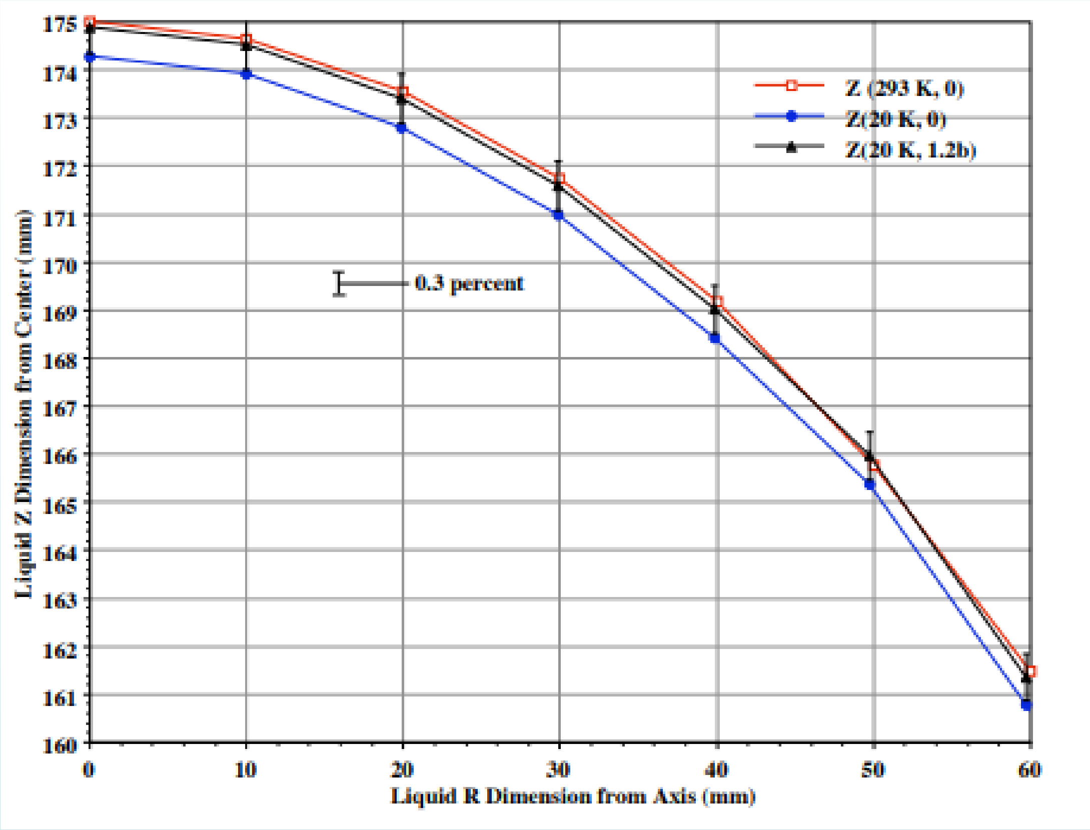
Deflection of absorber windows due to pressure



Contraction and absorber window deflection combined

- Green and Yang data from 2006, based on 1.2 Bar operating pressure
- Actually ~1.08 Bar
- Contraction was 1.4525mm
- Deflection is 0.54mm
- Combined :
- 1.4525 – 2(0.54) = 0.3725mm
- Large error from ANSYS model:
- Combined 0.37mm +/- 0.27mm

- dE/dx = 0.37 * 0.02856 = 0.01MeV
- dE/dx = 0.0106 +/- 0.0077MeV



Deflection of absorber windows due to weight of lH2

- Is it worthwhile to model?
- lH2 is not very dense => very light
- Approximate absorber vessel by a cylinder
- Maximum pressure exerted on walls of cylinder at base
- $W = \rho g V = 70.8 * 9.81 * 0.022 = 15.28N$
- $P = F/A = 15.28 / (\pi * 0.15 * 0.15) = 216.17$ Pa
- A pressure of only 0.002 Bar at base of absorber where window is thickest
- At center of absorber the pressure is only 0.001 Bar which corresponds to a deflection of 0.005mm
- Weight is so small that the effect is negilible

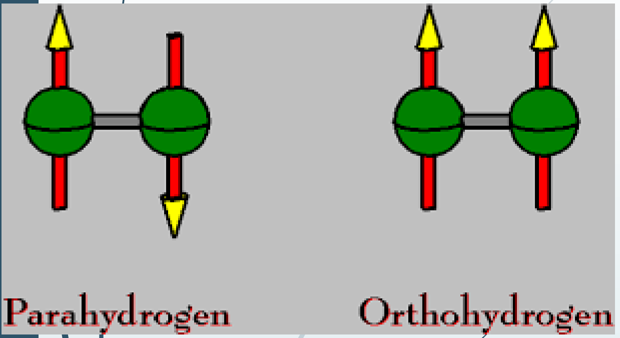
Absorber window thickness variation

- At centre of Absorber:
- Safety Window 1: 197 ± 8 Design: 210
- Absorber Window: 174 ± 5 Design: 180
- Absorber Window: 184 ± 2 Design: 180
- Safety Window 2: 230 ± 9 Design: 210

- Total 785 ± 24 Design: 780

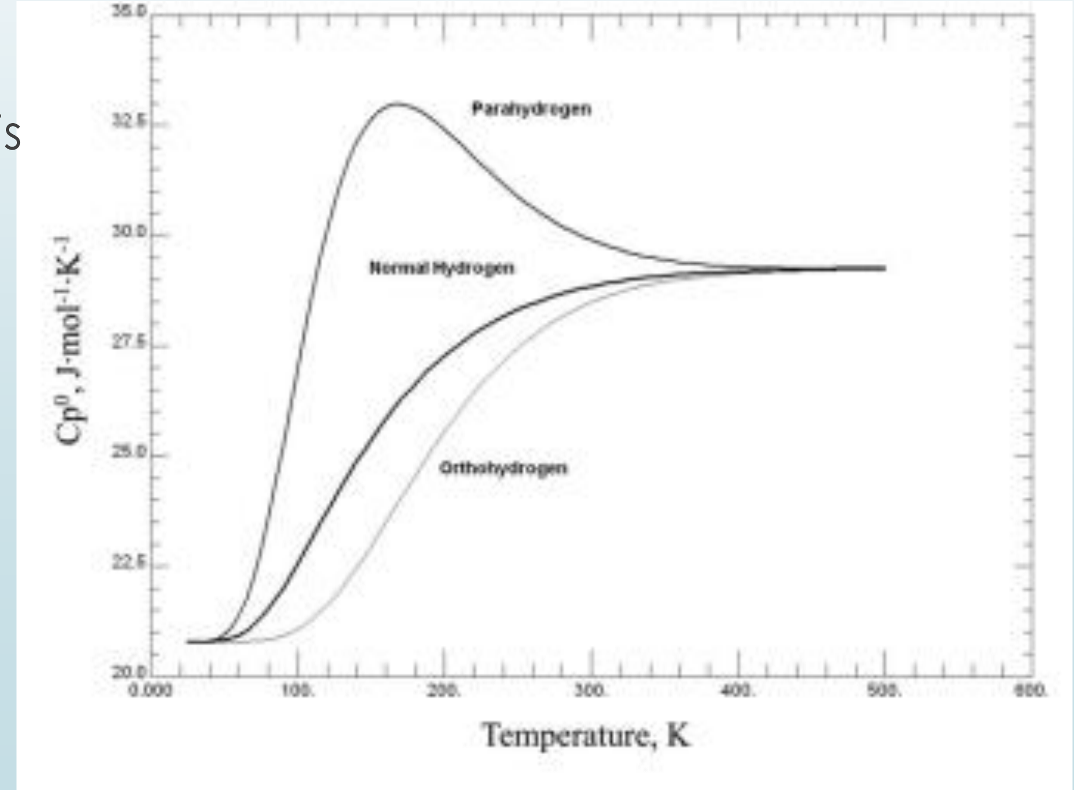
- dE/dx = 0.785 * 0.4358 = 0.342 MeV Design: 0.34 MeV
- dE/dx = 0.342 ± 0.01MeV
- At center of Absorber the variation due to the change in thickness of the Absorber window is 0.01MeV

Is Ortho/Para Hydrogen a consideration?



- In short, no
- Hydrogen experiments can show some variance as its properties are shifted due to its composition, e.g. specific heat capacity
- At room temperature the ratio of parahydrogen to orthohydrogen is 3:1
- At the operating temperature of MICE (and thus lower thermal energy) it populates the lowest energy states and is 99.75% Parahydrogen
- Any effects due composition variation will be minute

	T (K)	p (MPa)	ρ (mol dm^{-3})
		Parahydrogen	
Critical point	32.938	1.283 77	15.556
Triple point	13.8033	0.007 042	38.215
		Normal hydrogen	
Critical point	33.19	1.315	14.94
Triple point	13.952	0.007 7	38.3

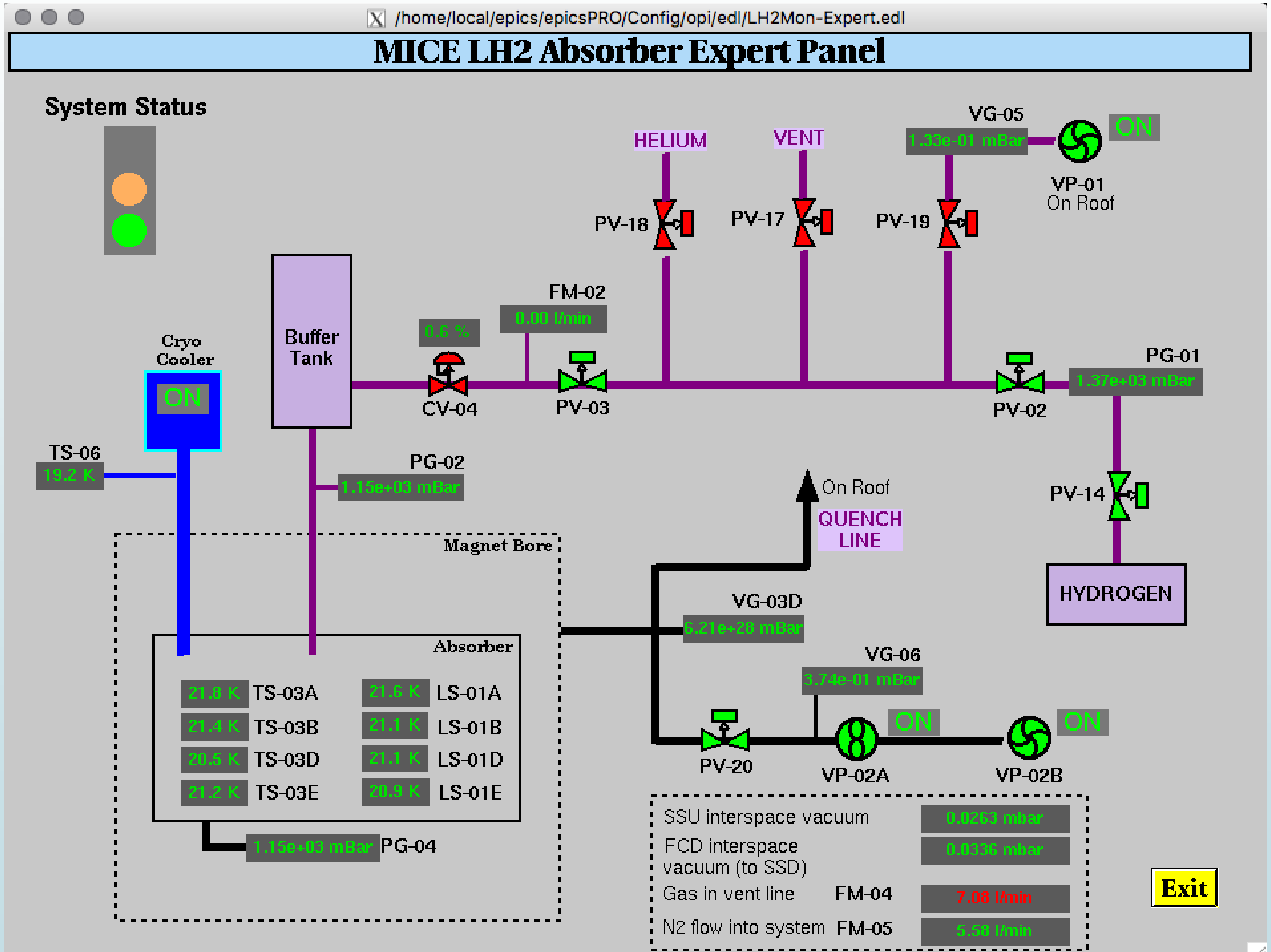


Summary of effects

	Error	dE/dx
lH2 Density (estimate)	± 0.4kg/m3	up to 0.1MeV
Contraction of absorber	0.37mm ± 0.27mm	
With deflection due to pressure	i.e. up to 0.64mm	up to 0.018MeV
lH2 weight	negligible	
Smoothness of windows	± 24 microns	up to 0.01MeV
Ortho/Parahydrogen	negligible	

- Total Energy Loss variance in the absorber ± 0.12 MeV
- Need to understand Temperature and Pressure readings better

Extra Slide


/home/local/epics/epicsPRO/Config/opi/edl/LH2Mon-Expert.edl
MICE LH2 Absorber Expert Panel
System Status
HELIUM
VENT
VG-05
1.33e-01 mBar
ON
VP-01
On Roof
PV-18
PV-17
PV-19
FM-02
0.00 l/min
0.6 %
Buffer Tank
Cryo Cooler
ON
CV-04
PV-03
PV-02
PG-01
1.37e+03 mBar
TS-06
19.2 K
PG-02
1.15e+03 mBar
On Roof
QUENCH LINE
PV-14
HYDROGEN
Magnet Bore
Absorber
VG-03D
6.21e+28 mBar
VG-06
3.74e-01 mBar
21.8 K TS-03A
21.4 K TS-03B
20.5 K TS-03D
21.2 K TS-03E
21.6 K LS-01A
21.1 K LS-01B
21.1 K LS-01D
20.9 K LS-01E
ON
ON
PV-20
VP-02A
VP-02B
1.15e+03 mBar PG-04
SSU interspace vacuum 0.0263 mbar
FCD interspace vacuum (to SSD) 0.0336 mbar
Gas in vent line FM-04 7.08 l/min
N2 flow into system FM-05 5.58 l/min
Exit