LAr Purification Studies and a Novel Recirculation System

Konstantinos Mavrokoridis
k.mavrokoridis@liverpool.ac.uk

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Talk Outline

Why argon purity matters

Effects of various contaminations on gas argon scintillation light

Purification chemicals - How do they work?

Summary of a set of experiments performed to determine the efficiency of the purification chemicals

The 40L LAr Liverpool Cell

- **Construction**
- **A novel recirculation pump and LAr purification**
- **Effects of O_2 contamination on LAr scintillation light**

Why Purity Matters

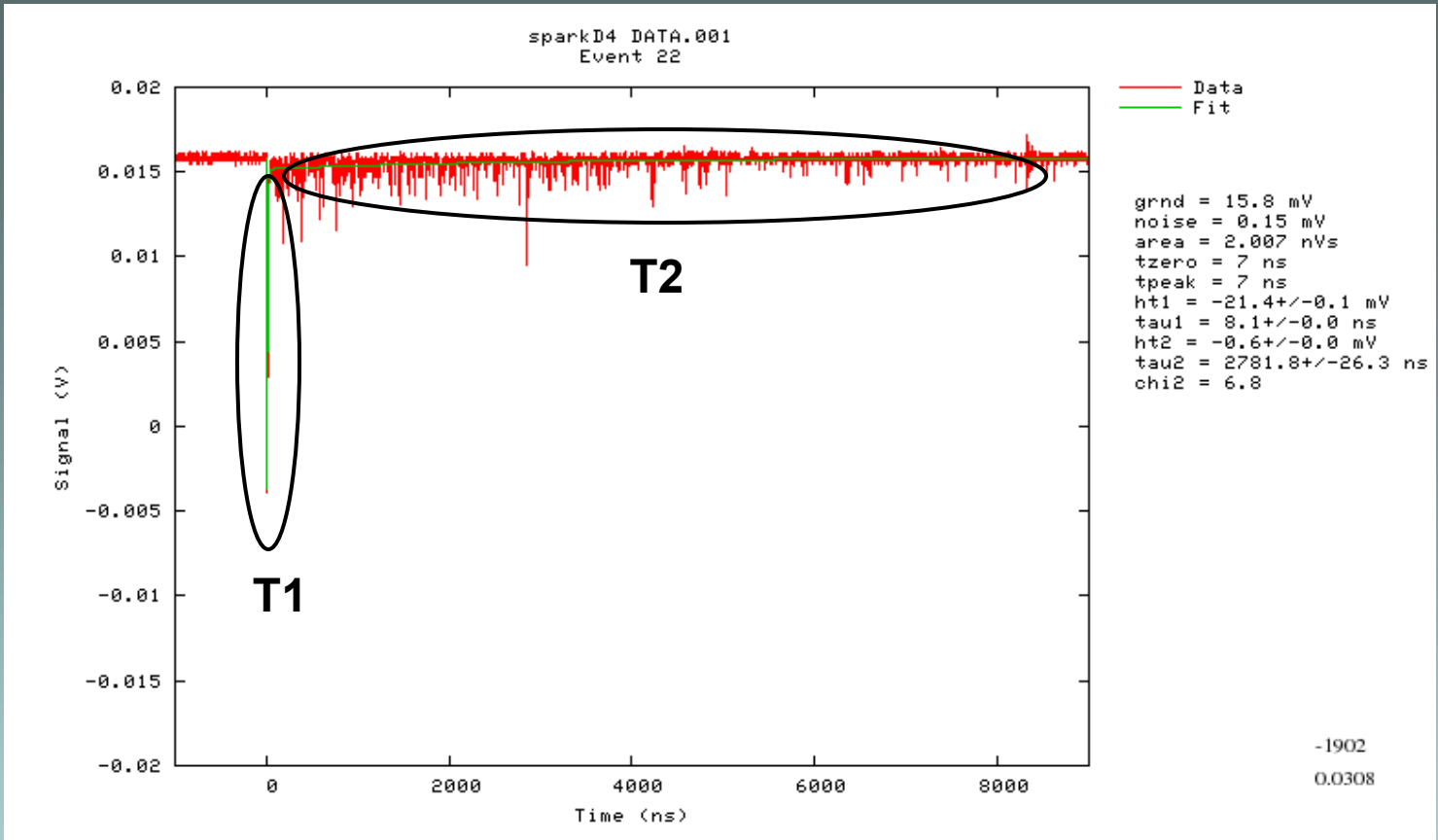
The ionised electrons produced in a liquid argon detector such as the ArDM must be able to drift over a distance longer than a metre, without substantial capture by electronegative impurities (i.e O_2,H_2O,CO_2,N_2)

Typically better than 1 ppb purity is required

Purest argon gas in the market (N6 cylinder) contains 1 ppm impurities

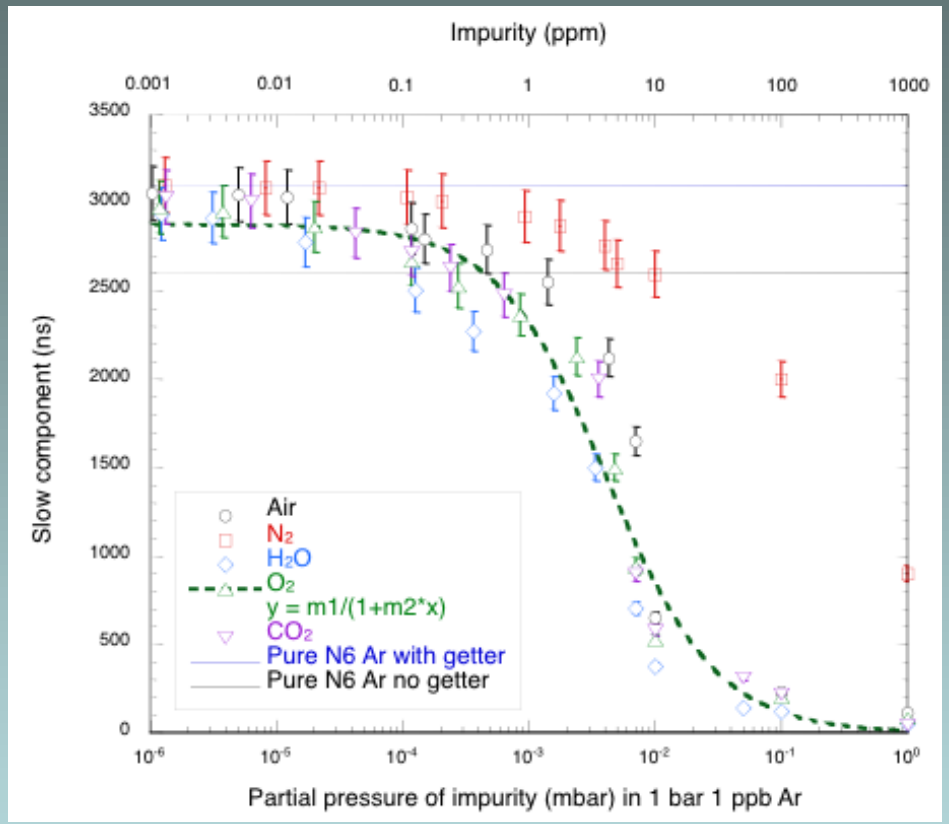
Therefore purification cartridges and recirculation systems have to be employed

Argon Gas Scintillation

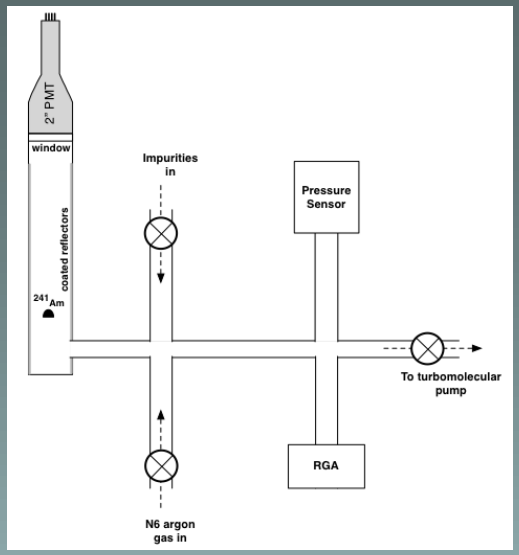


Scintillation light from argon has two distinct decay times - a slow component, T2 (triplet), and a fast component, T1 (singlet). The slow component, T2, can be used as a measure of Argon purity. The purest gas argon has a T2 of about 3200 ns (J. W. Keto *et al*, PRL, 1974).

Effect of various impurities on GAr scintillation light



K. Mavrokoridis, PhD Thesis



--H_2O was found to be very marginally the worst impurity followed by CO_2 and O_2.
--N_2 was found to be the most benign impurity within argon gas.

--Birks law type function fit y=m1/(1+m2*x); m1=2878ns, m2=0.24

Correlation of the slow component decay time to partial pressure of impurities within 1 bar ppb argon gas

The Argon Purification Chemicals (a)

Molecular Sieves

Size/Steric Exclusion

Molecules small enough to pass through the pores are adsorbed while larger molecules are not

Molecular sieves can be graded to capture molecules with sizes between 3 Å and 10 Å

Thermodynamic Selectivity

A measure of preferential absorption of certain molecules over others when all molecules can enter the pores.

Is achievable because the adsorption of a particular gas is favourable over another on the accessible cationic sites within the crystal.

Molecular sieves can be used to purify argon based on the size/steric exclusion and thermodynamic selectivity properties

The Argon Purification Chemicals (b)

Copper

Copper reacts strongly with oxygen forming copper oxide.

$$2Cu + O_2 \rightarrow 2CuO$$

Phosphorous pentoxide

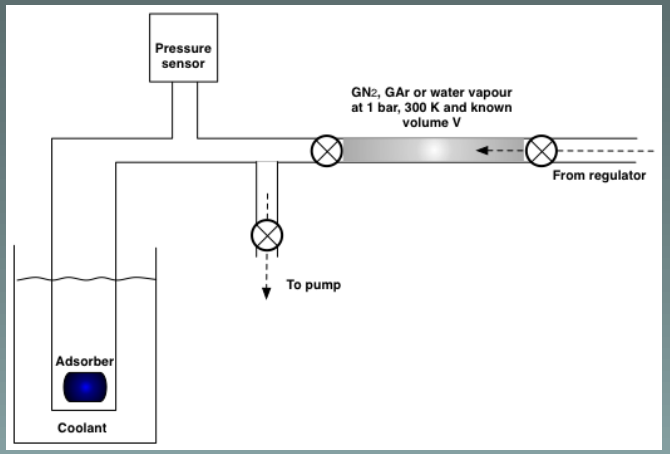
P_4O_{10} reacts exothermically very strongly with water producing orthophosphoric acid.

$$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$$

Hazardous upon skin contact and inhalation

Adsorption of H_2O, N_2, Ar

Measurements of the enthalpy of adsorption, total capacity, and effective surface area of interaction, for argon gas, nitrogen gas and water vapour on a range of molecular sieves and anhydrous complexes were performed.

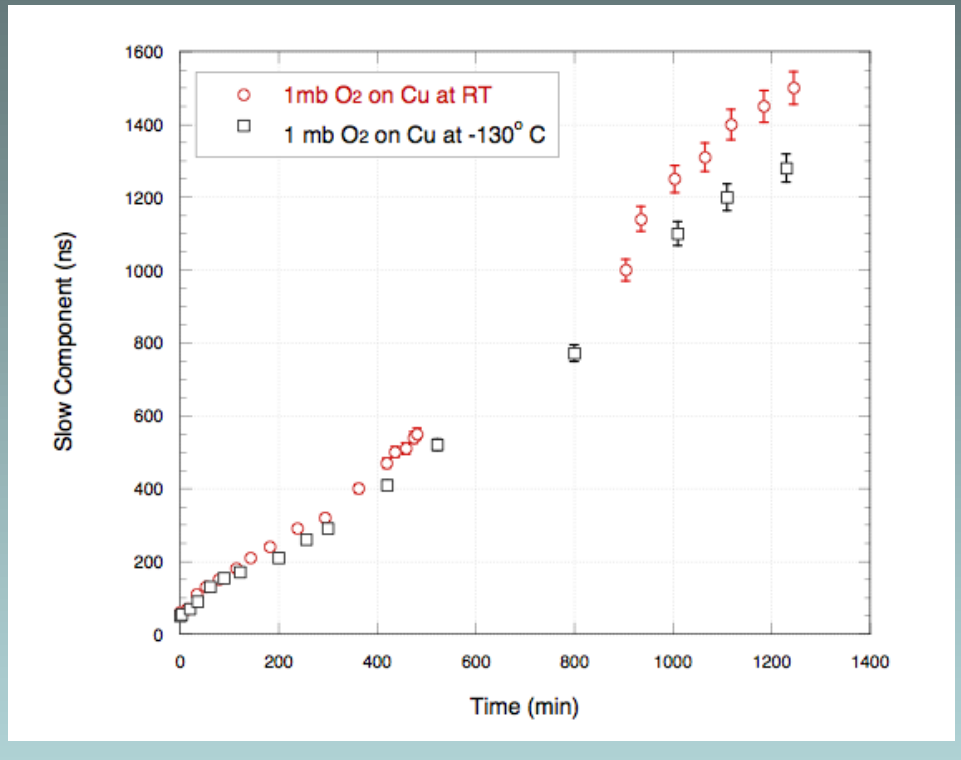


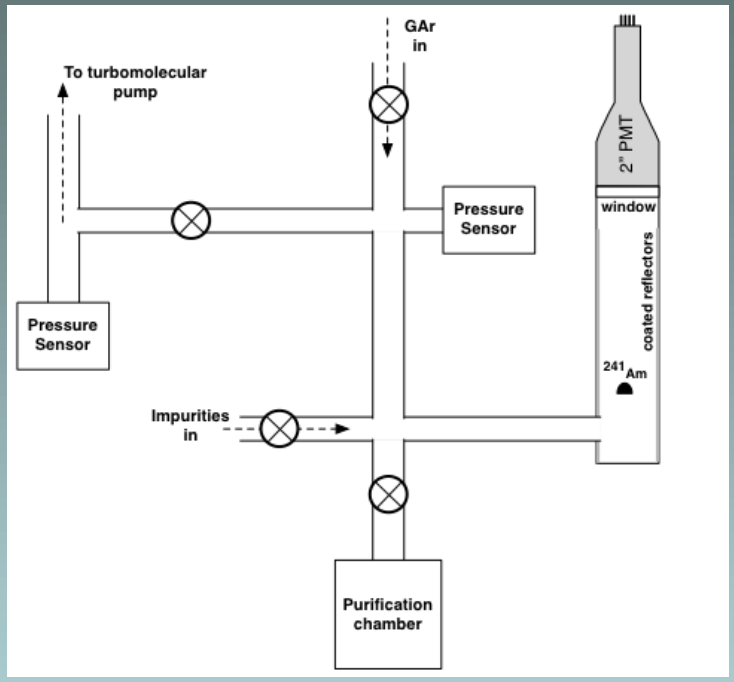
The BET (Brunauer, Emmett, Teller) isotherm describes adsorption and provides a route to measuring both the average enthalpy of adsorption and the effective surface area of the adsorber (e.g. activated charcoal)

Combination	Enthalpy of adsorption (kJ/mol)	Surface area (m^2)	Maximum capacity (%wt)
N_2 and activated carbon	9.1	65836	37
Ar and activated carbon	11.1	62451	42
N_2 and 3A Mol. sieve	10.9	26264	23
Ar and 3A Mol. sieve	11.4	29477	27
N_2 and activated alumina	10.2	17330	13
Ar and activated alumina	11.1	16309	16
H_2O and calcium sulphate	48.4	4520	6
H_2O and 3A Mol. sieve	46.3	22785	14
H_2O and cobalt chloride	45.0	3275	3
H_2O and magnesium sulphate	45.1	3799	4

Adsorption results for the BET isothermal experiment

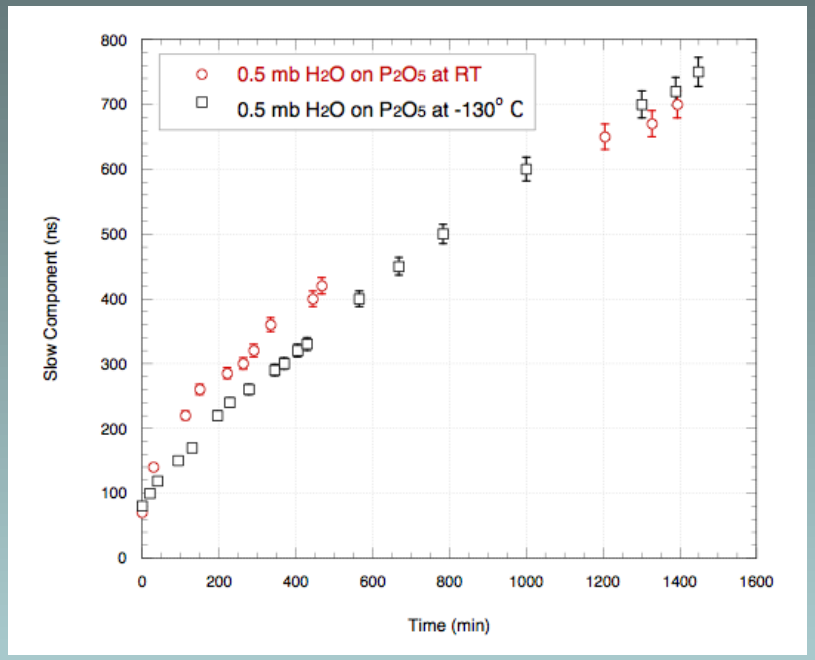
Efficiency of Cu and P_4O_{10} at removing O_2 and H_2O



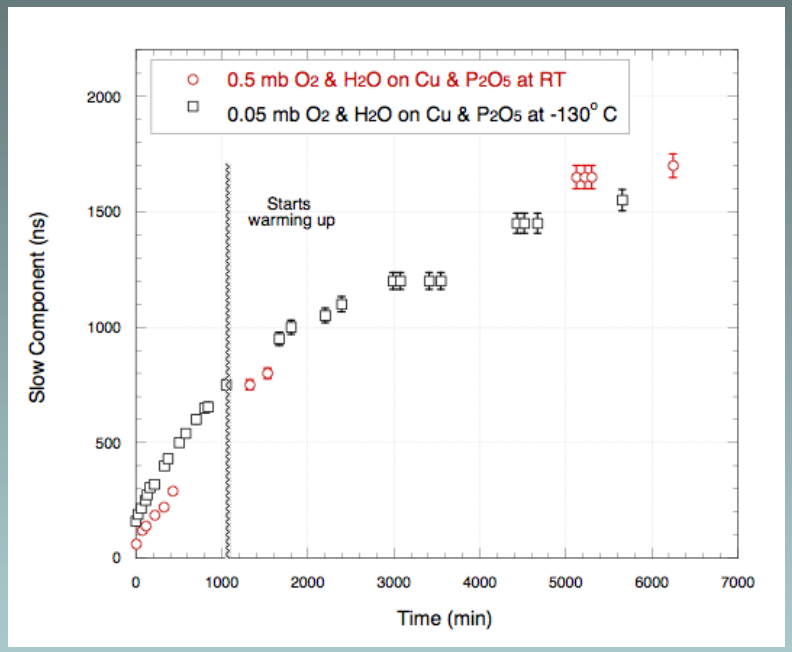


Efficiency of copper at room temperature and -130 ^{O}C at removing 1 mbar O_2 partial pressure impurity in 1 bar N6 argon gas

Efficiency of Cu and P_4O_{10} at removing O_2 and H_2O



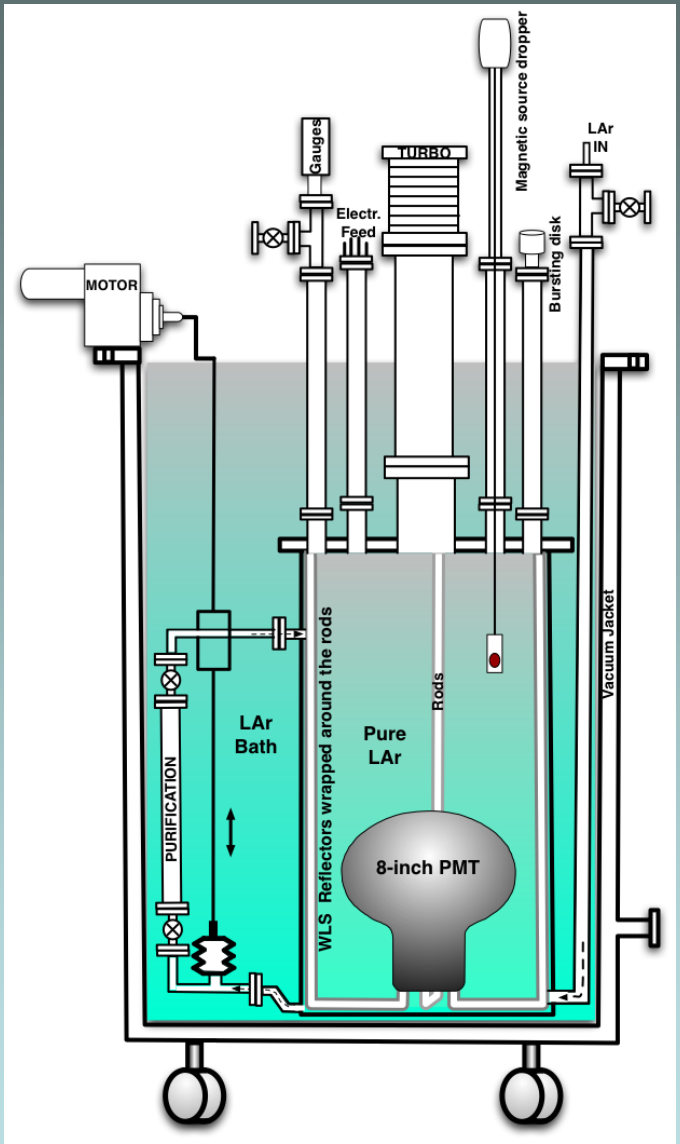
P_4O_{10} at RT and -130 °C removing 0.5 mbar H_2O partial pressure impurity in 1bar N6 argon gas



Cu and P_4O_{10} mixture at RT and -130 °C removing 0.5 mbar and 0.05 mbar respectively O_2/H_2O partial pressure impurity in 1bar N6 argon gas

Within 30 hours the slow component decay time increased from 70 to 1650ns corresponding to ~3 ppm O_2 equivalent impurity

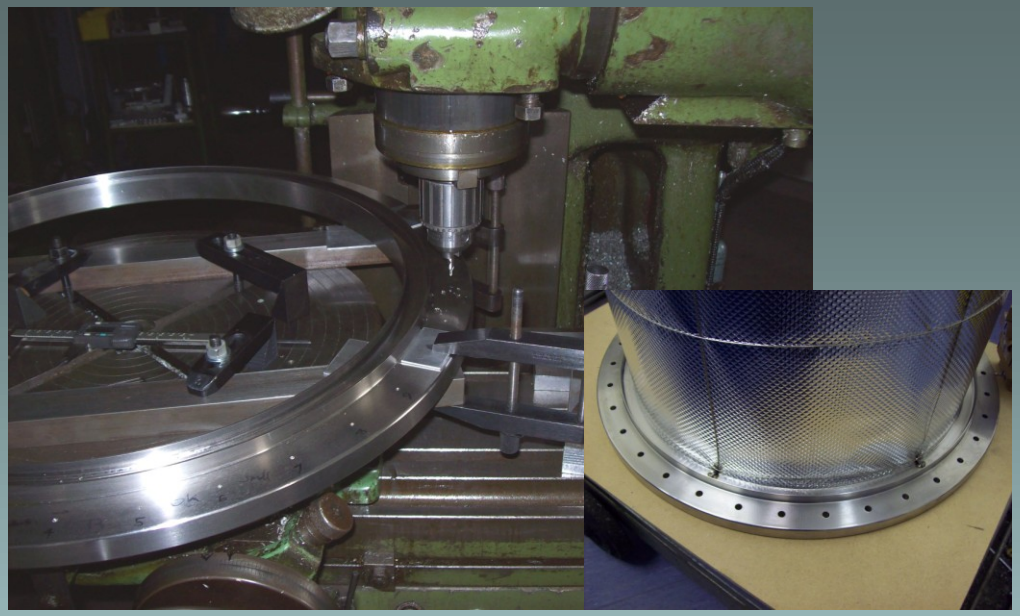
The Liverpool LAr Cell -Schematic



250 L LAr bath
40 L LAr target

- Bellow pump powered by an external geared motor
- Heat load loses ~115 W
- Boiling rate ~12 l/min
- Loosing about 20 L in 24h- assumming 10cm thick polyethylene lid

Construction of the Liverpool LAr Cell



Left: Rolling the stainless steel sheet

Right: Machining the top flange

Construction by Kevin McCormick

The Liverpool LAr Cell -Construction

Wrapped with Mylar reflector to minimize radiation losses

All the welding performed using argon gas to avoid oxidation and achieve UHV

The 40 L Target Vessel and Recirculation System

Development of a novel one way recirculation system using metal balls and a bellow

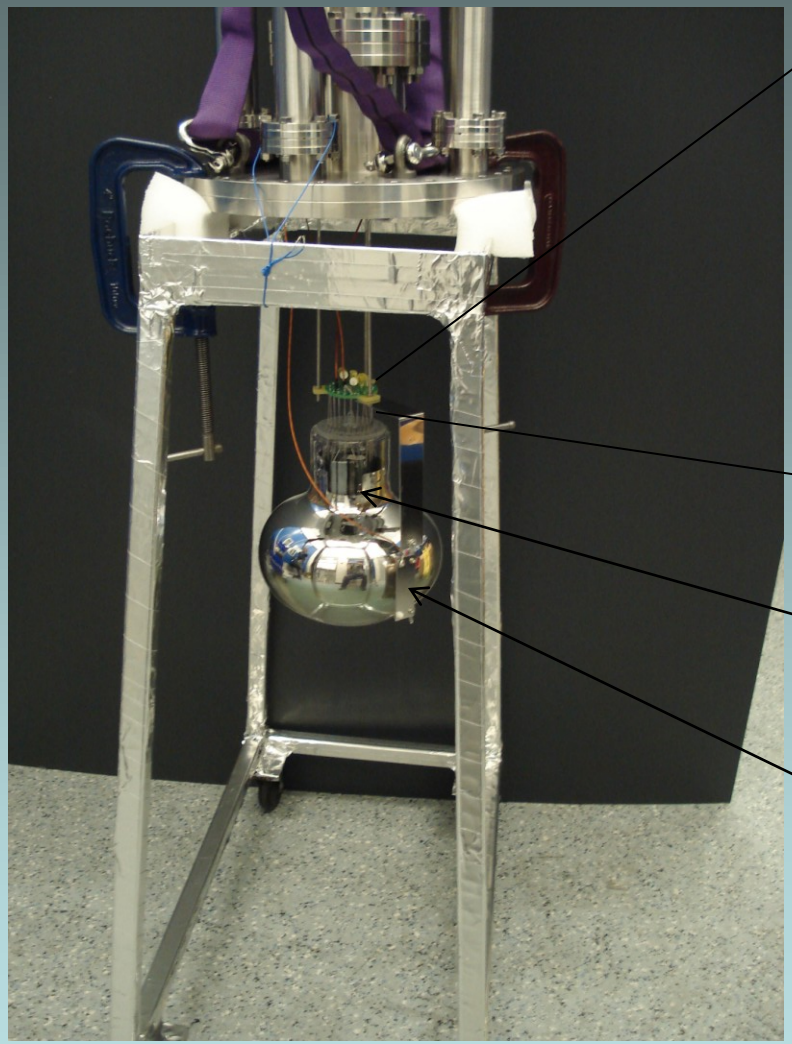
Scalable design

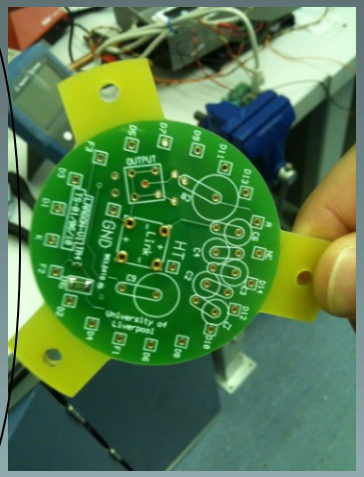
The Liverpool LAr Cell– The Purification Cartridge

- 3A,4A,13X Molecular Sieves for removing, N_2,H_2O,CO_2
- Copper for removing O_2 ($2Cu+O_2 \rightarrow 2CuO$)

Filling the purification cartridge within an argon bag in order to avoid reaction with air molecules

The Liverpool LAr Cell – Light Readout



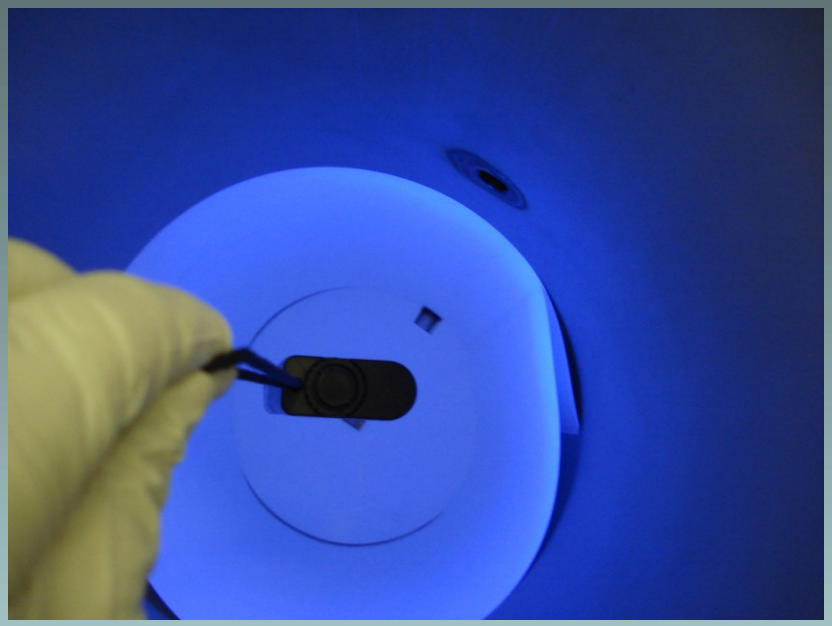


Development of cryogenic voltage divider

Cryogenic 8-inch Hamamatsu R5912-02MOD PMT (~2500 GBP)

Capacitor LAr level meter

The Liverpool LAr Cell – The WLS Coated Reflectors



TPB coated 3M foil under a UV lamp

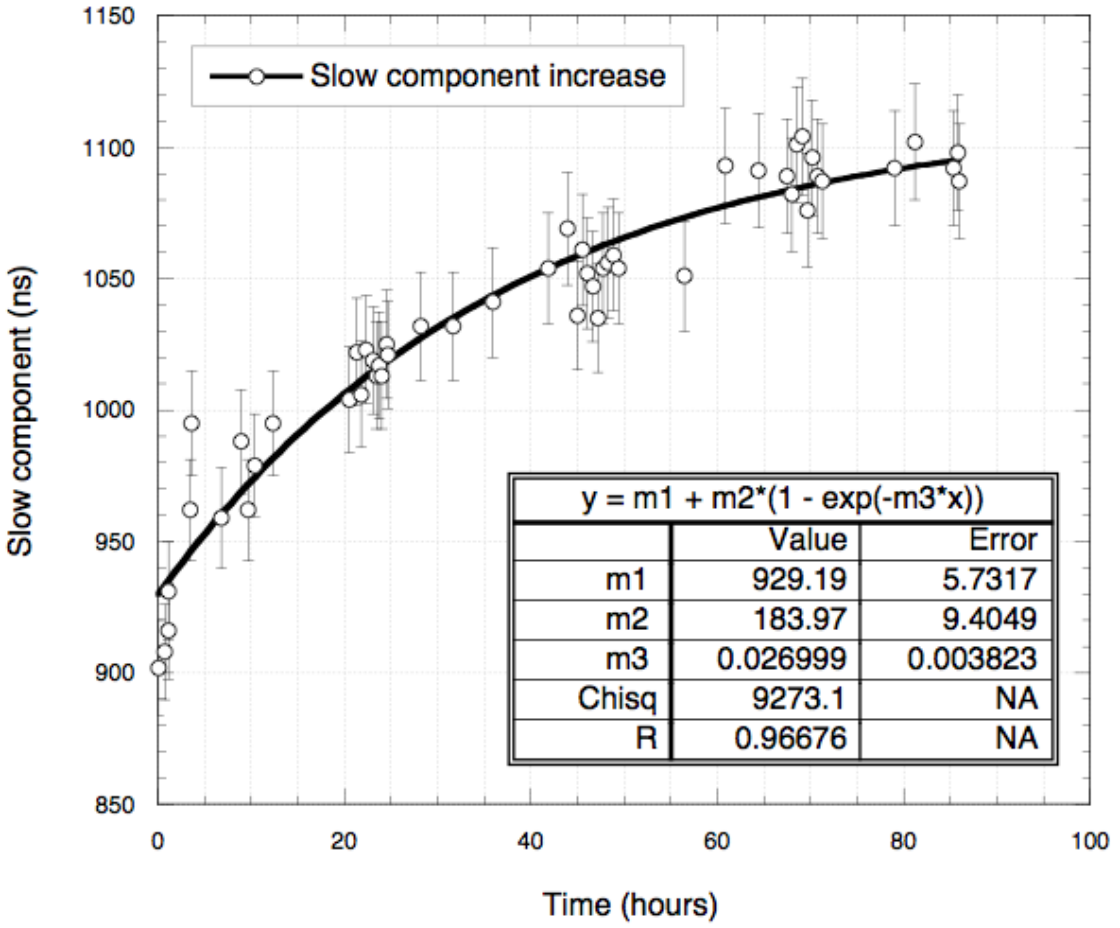
Shifts 128 nm → 430 nm

TPB coated PMT under a UV lamp

The Liverpool LAr Cell- Assembled

Closing the detector

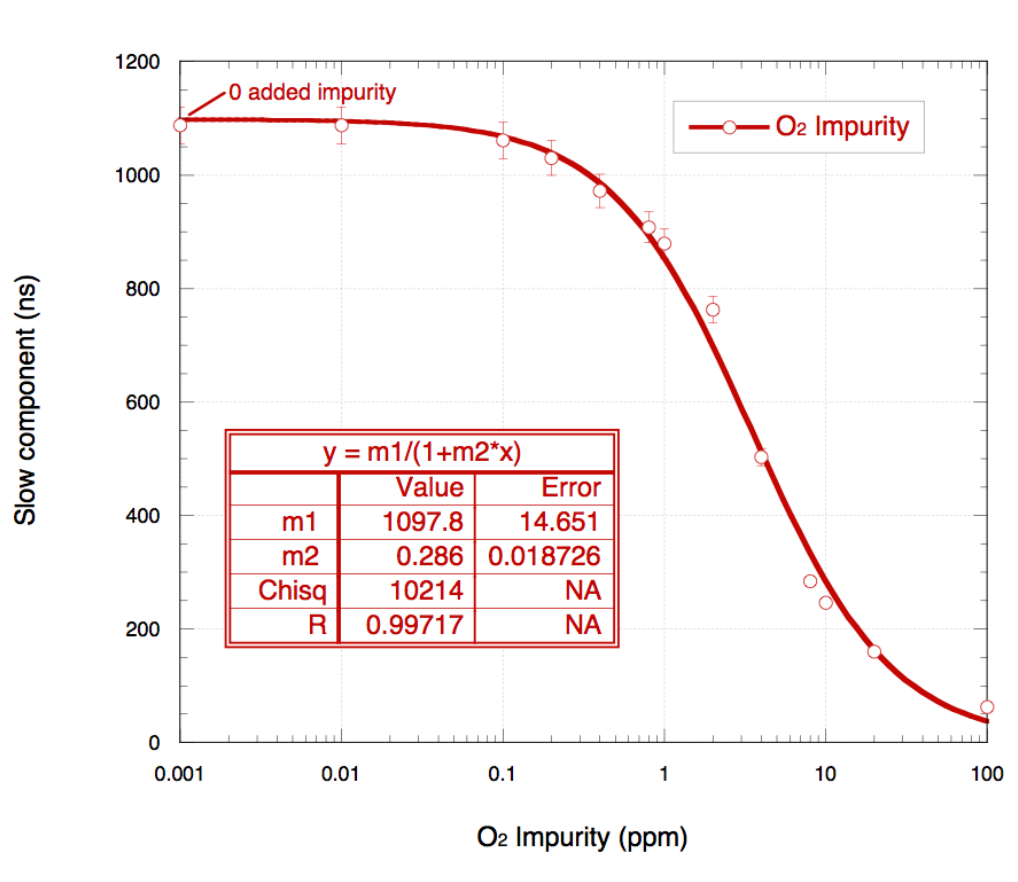
LAr Recirculation and Purification Test

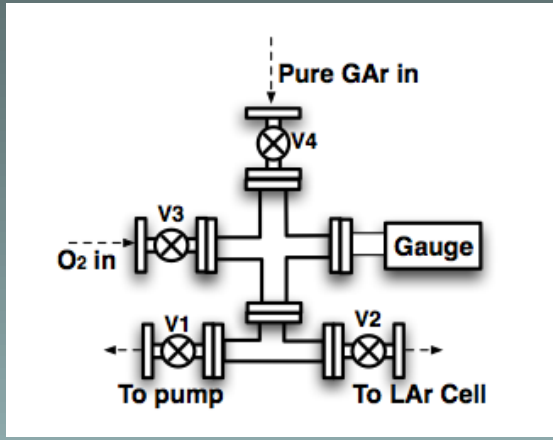


y = m1 + m2*(1 - exp(-m3*x))		
	Value	Error
m1	929.19	5.7317
m2	183.97	9.4049
m3	0.026999	0.003823
Chisq	9273.1	NA
R	0.96676	NA

Within 4 days continuous re-circulation at rate of 27 litres/hour, the slow component decay time was increased by 200 ns reaching ~1100 ns

Effect of 0.01 ppm to 100 ppm O_2 impurity on LAr scintillation light





Data collected using an Am-241 alpha source

Birks law type function fit y=m1/(1+m2*x); m1=1097ns, m2=0.28

Correlation of the LAr slow component decay time with part per million O_2 impurity

Summary & Conclusions

Effect of various impurities on the GAr scintillation –correlation of slow component decay time to ppm equivalent impurity level

Purification Chemicals -How they work

-Molecular Sieves, Cu and P_4O_{10}

Efficiency of the chemicals at removing O_2 , H_2O and N_2 found to be high

The Liverpool LAr Cell:

--Construction of a novel cryogenic recirculation pump,

--Successful operation of the pump with a recirculation rate of 27L/hour over four days

--Successful purification of LAr over 4 days recirculation -slow component of LAr increased by 200 ns reaching ~1100 ns

--Slow component decay time of LAr scintillation light was correlated to ppm O_2 equivalent contamination

Thank You