Particle Detection Techniques in HEP

Two Phase Noble Gas TPCs

Post-Graduate Lecture Series

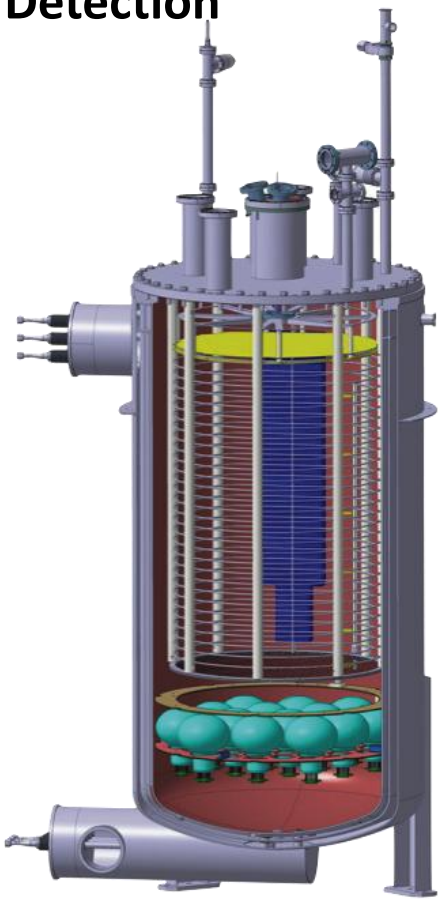
Kostas Mavrokoridis
k.mavrokoridis@liv.ac.uk
Room 207

Outline

- Two phase ionisation/scintillation detectors
  - Operation principle
- Putting together the Liverpool LAr TPC from scratch
- Visit to the Liverpool LAr lab
  - Collection of argon scintillation and ionisation signals

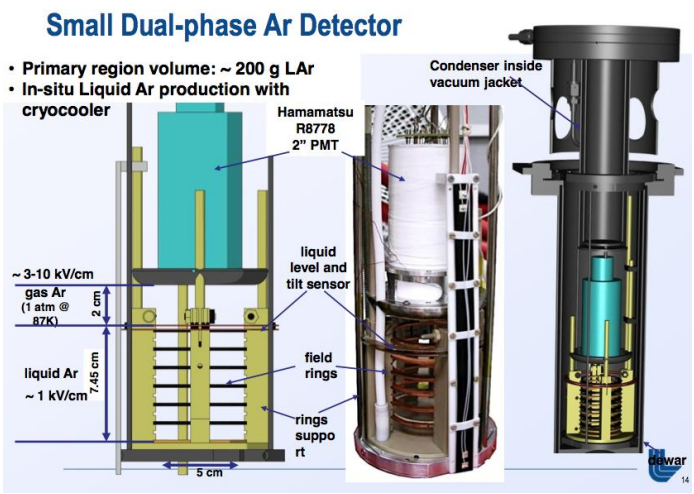
Main Applications of Two Phase Noble Gas Detectors

Direct Dark Matter Detection



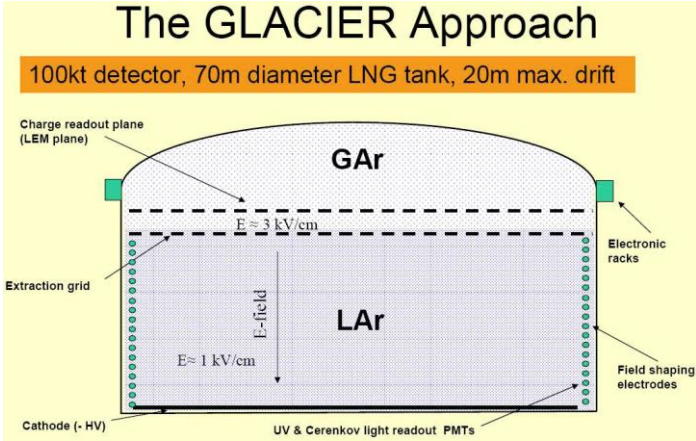
The ArDM detector

Coherent Neutrino Scattering Search



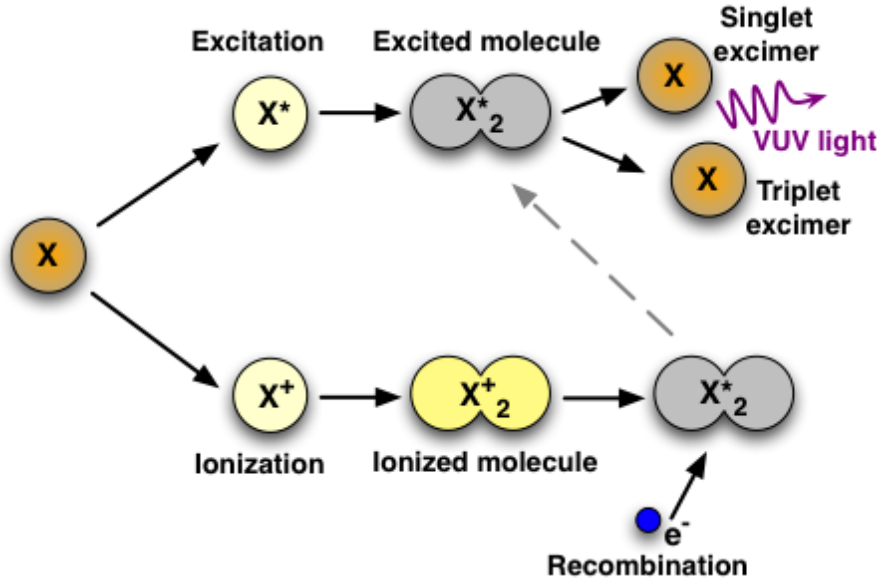
The Livermore detector

Neutrino Physics



LAGUNA design study

Noble Gas Scintillation Production Mechanism

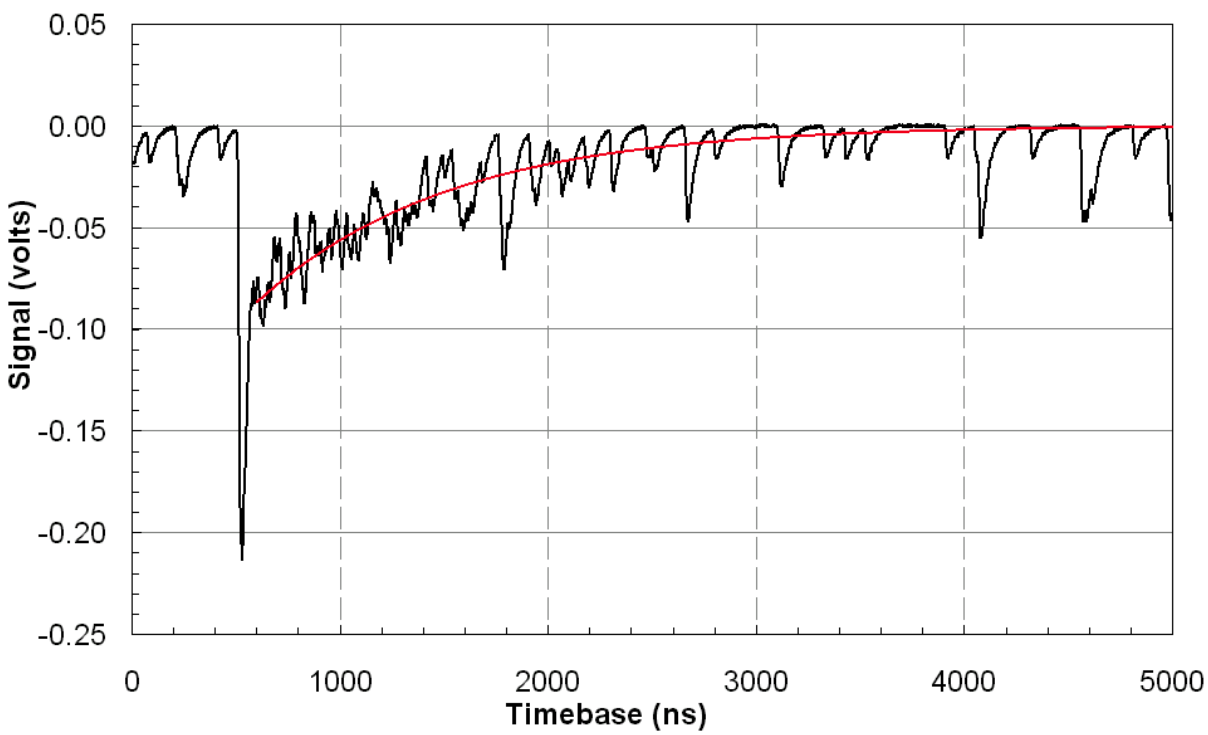


An interaction with a noble gas atom X (i.e. argon/xenon) causes excitation and ionization, producing electron-hole pairs (X^+, e^-) and excitons (X^*). Molecular ions form X^+_2 and attract free electrons (hot electrons can escape this attraction). In addition, the electrons can ionize and excite the medium, yielding extra electron-hole pairs and excitons. In due course the electrons thermalize and recombine with the neighbouring ions(X^+_2) forming more excitons. Self-trapping occurs producing excimers X^*_2. De-excitation of these states gives rise to a luminescence emission of approximately 128 nm for argon and 175 nm for xenon.

LAr Scintillation

LAr detection technology has the best performance in identifying the topology of interactions and decays of particles, thanks to excellent imaging performance.

Interactions in liquid noble gases lead to the formation of excimers in either singlet or triplet states, which decay to the ground state with characteristic fast (6 ns) and slow (1.6 µs) lifetimes in liquid argon with the photon emission spectrum peaked at 128 nm.



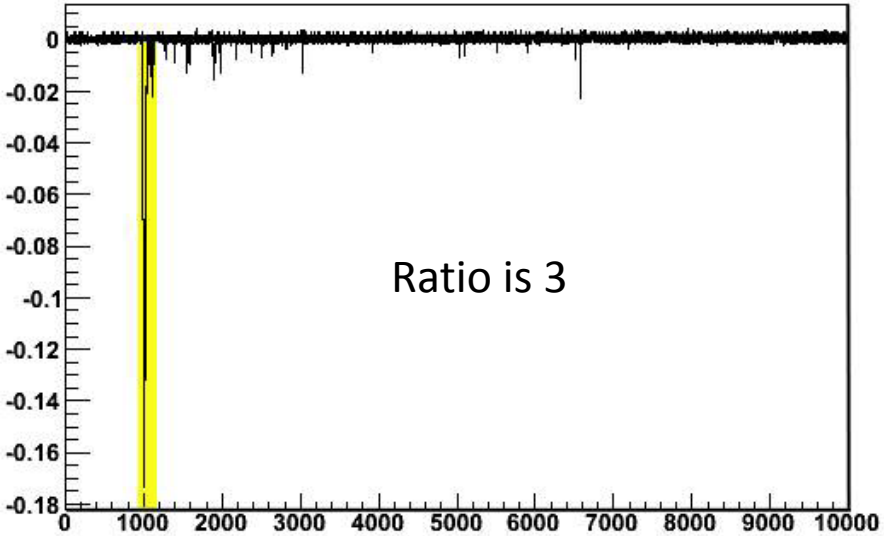
Discrimination Principle Between Particles

The fraction of dimers in singlet or triplet state depends on the incident particle type. A NR will produce more ionisation in comparison to an ER.

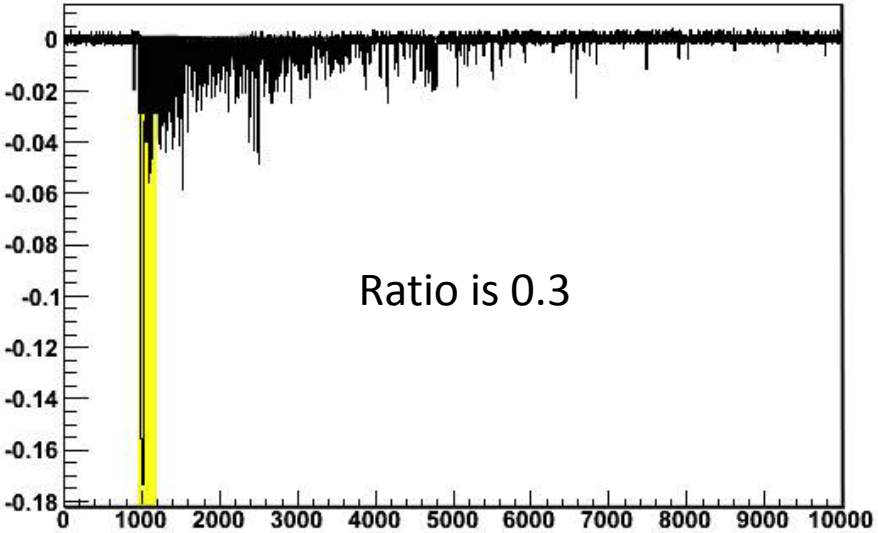
Yellow: Fast photon emission region due to singlet

Ratio: Fast (6 ns) light / Slow (1.6 µs) light

An event due to neutron interaction

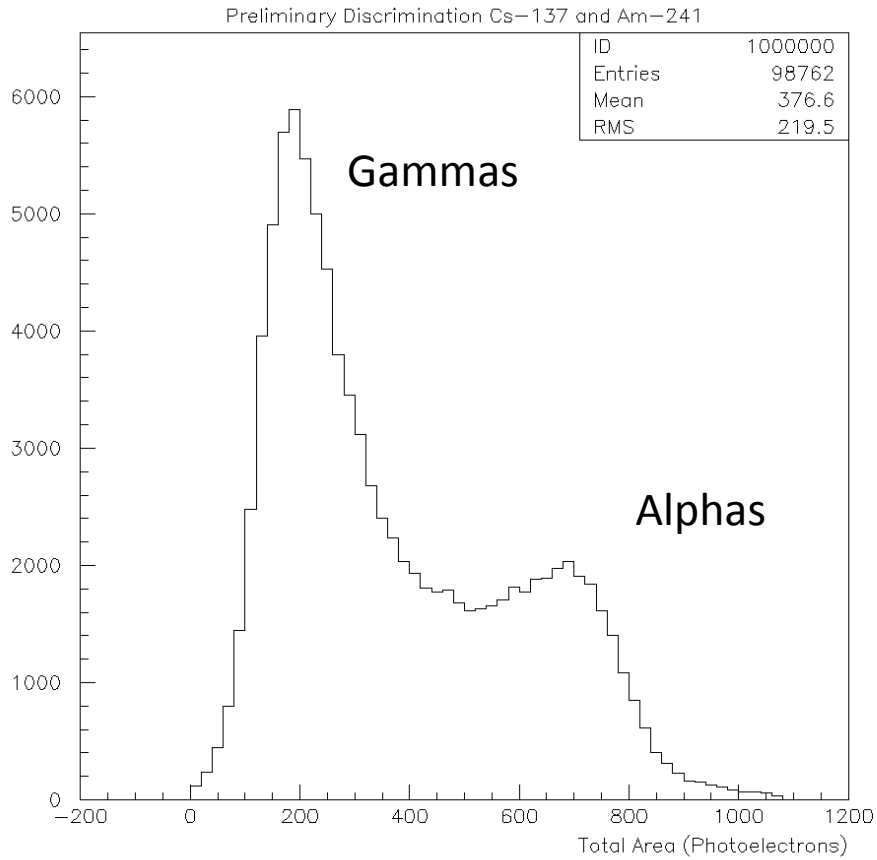


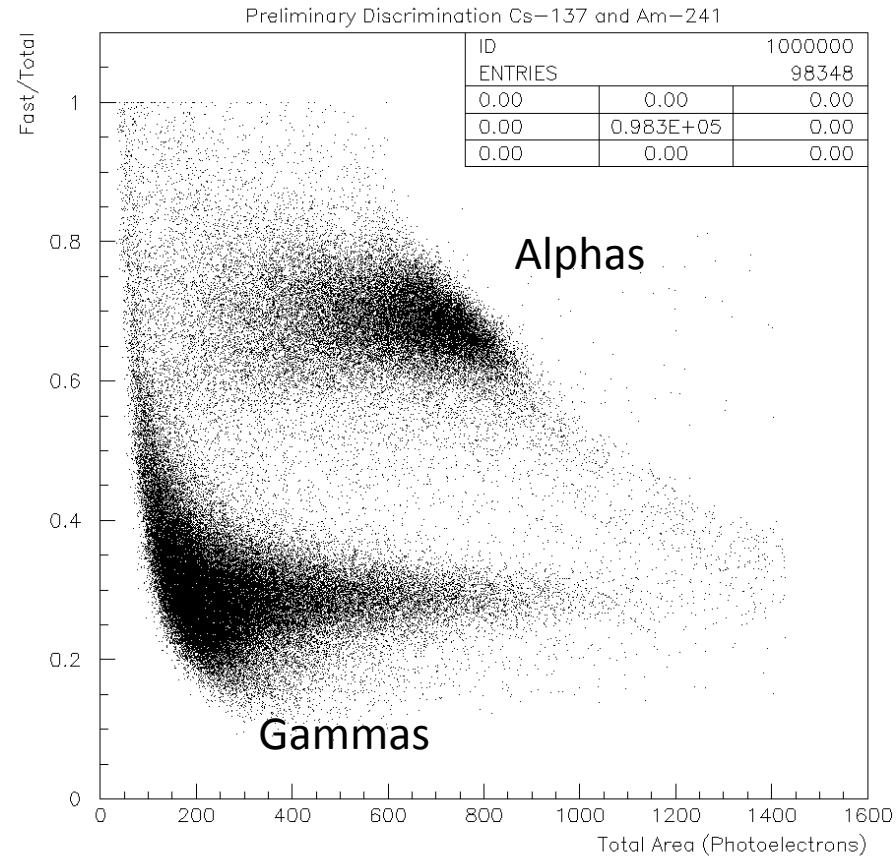
An event due to electron interaction



Discrimination between nuclear and electron recoils can be achieved by pulse shape discrimination.

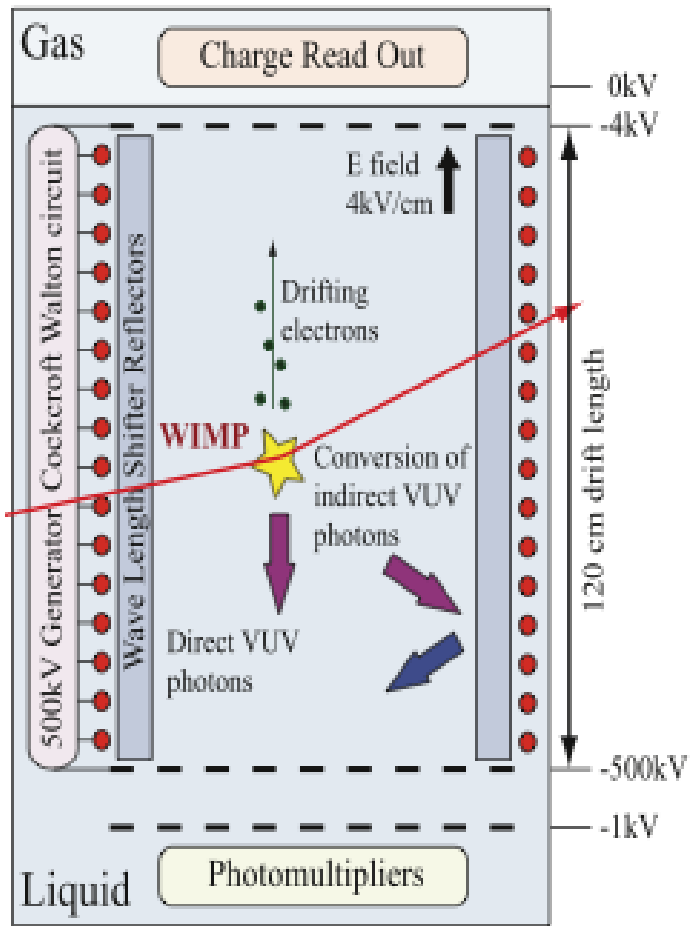
Pulse Shape Discrimination





Alphas and gammas discrimination by measuring the Fast/Total scintillation light components.

Detection Principle



Electrons and gammas interact with shell electrons creating light and charge.

Neutrons do the same but the charge quickly recombines.

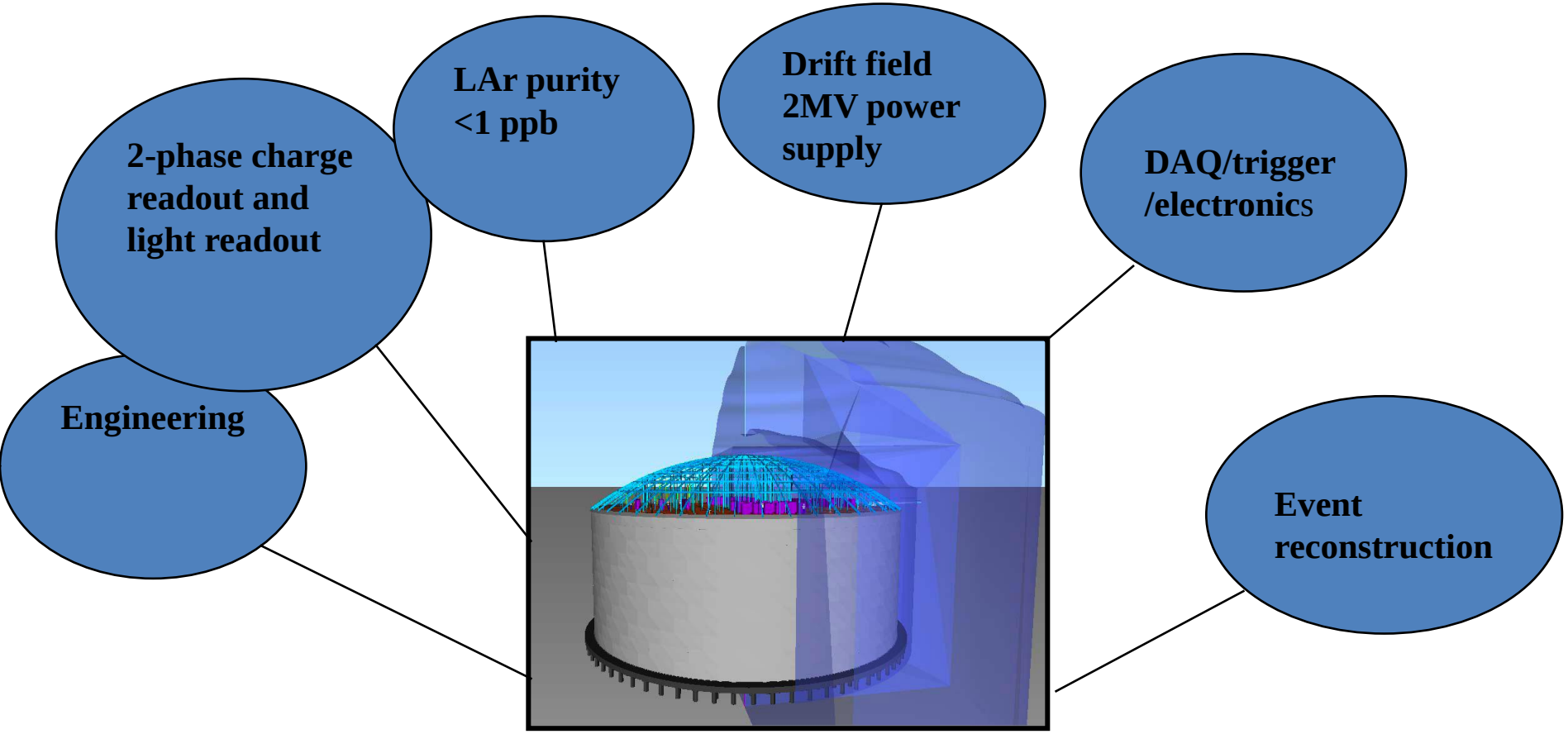
In both cases any charge produced is drifted upwards in the field to the charge readout where it is detected.

Light is converted to 430 nm and detected by photomultipliers.

Background rejection possibilities:
– Different light/charge ratios
– Different shape of the scintillation light (ratio fast/slow components)

A segmented charge readout allows the XY coordinate to be determined and the time of flight following the scintillation pulse provides the Z coordinate.

Challenges Towards a Large LAr TPC



Liverpool activity focuses on LAr purification, light and charge readout methods

Heat Load Considerations for the Design

The formula that describes **conduction** is:

$$\frac{Q}{t} = \frac{-KA\Delta T}{L}$$

where Q is the energy (J), t is the time (seconds), K is the thermal conductivity (W/cm·K), A is the cross sectional area (cm2), L is the length (cm) and ΔT is the temperature difference (K).

The formula that describes **convection** for pressure values (P) between 10−3 torr and 10−5 torr is:

$$\frac{Q}{t} = 0.5A\left(\frac{\gamma+1}{\gamma-1}\right)\left(\frac{R}{8\pi\Gamma m}\right)^{0.5}(T_2 - T_1)P$$

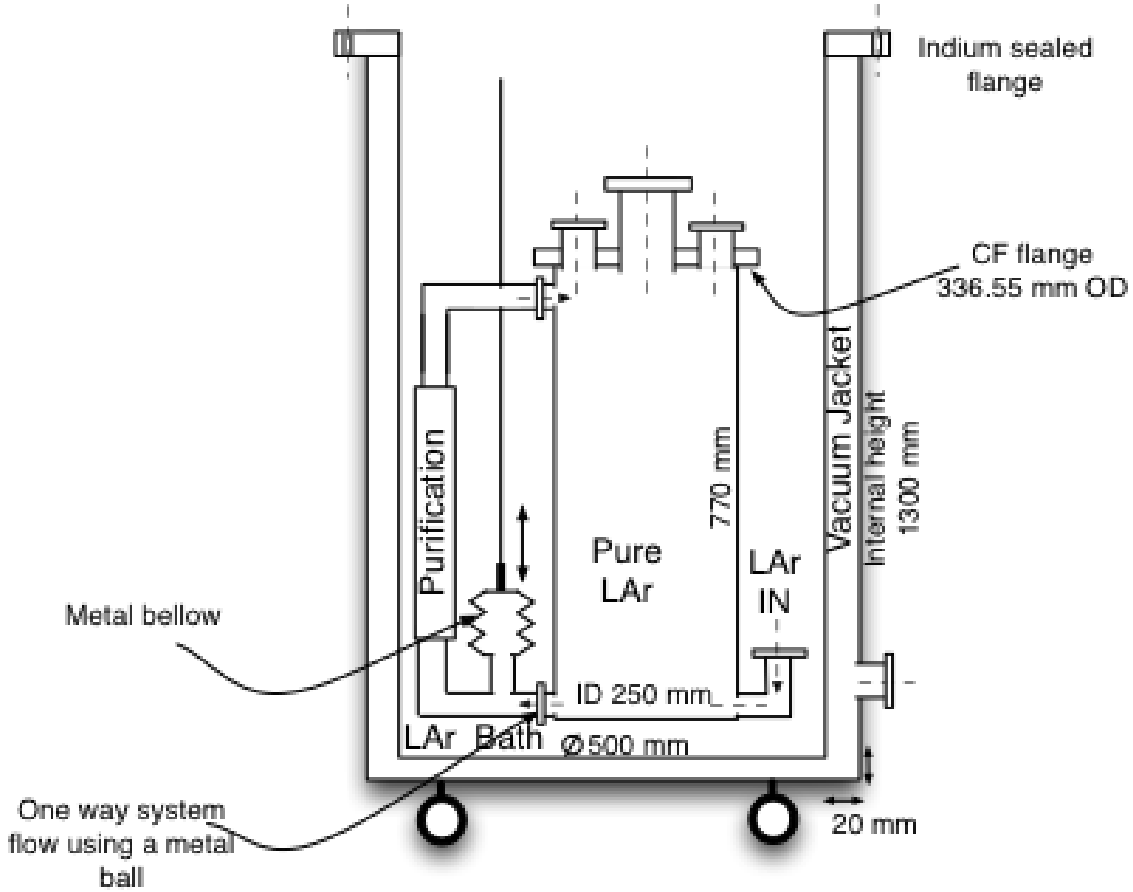
where R is the gas constant of 8.205×10^{-2} m^3·atm/kmol·K, γ is C_p/C_v of air, Γ is the temperature of the vacuum space gas (assumed to be halfway between the target and room temperature in K), m is the molecular weight in g/mole, P is the pressure of the vacuum space gas in atmospheres, and T_2 and T_1 are the temperatures of the hotter and colder bodies respectively (K).

The formula that describes **radiation** is:

$$\frac{Q}{t} = \frac{A\sigma\varepsilon(T_2^4 - T_1^4)}{n+1}$$

where $\sigma=5.67\times10^{-8}$ W/m^2·K^4, A is the area of the warmer body (m2), T_2 and T_1 are the temperatures of the hotter and colder bodies respectively (K), ε is the emissivity coefficient (0.05 for steel), and n is the number of layers of aluminised plastic placed between the hotter and colder objects.

The Liverpool LAr Vessel- Conceptual Design



250 L LAr bath
40 L LAr target

Heat load loses ~115 W

Boiling rate ~12 l/min

Loosing about 20 L in 24h- assumming 10cm thick polyethylene lid

Major Commercial Suppliers

- Kurt Lesker
- MDC
- Lew vac

Vacuum components

- Hamamatsu
- ETL enterprises

Photomultiplier tubes, SiPM, CCD chips

- CAEN
- Agilent
- LEMO

NIM electronics, Waveform digitisers, Connectors

Major Vacuum Components

Turbo molecular pump

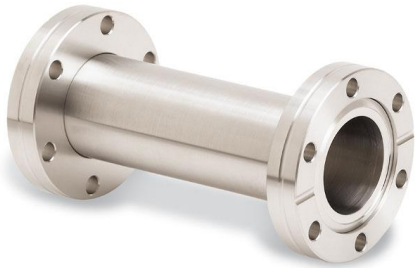
Scroll pump

Pirani/Piezo pressure gauge

Copper gasket

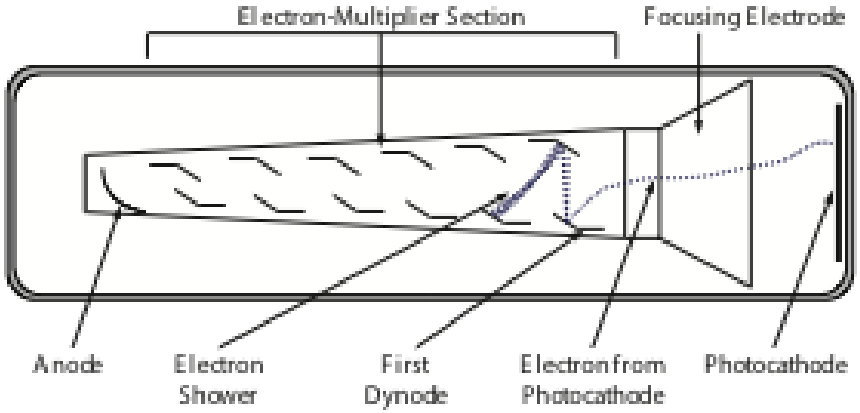
CF (ConFlat) flange

Cross

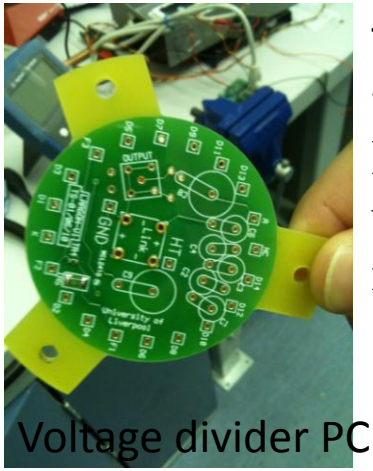


Full nipple

Cryogenic PMT

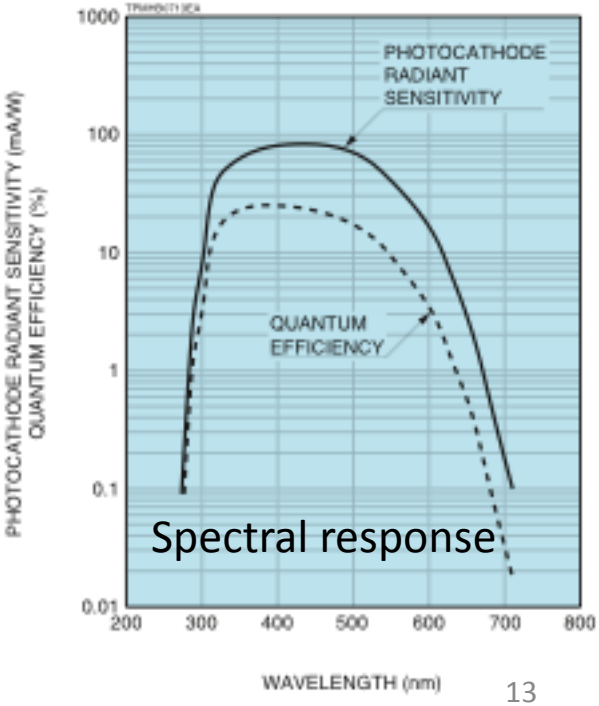


8-inch Hamamatsu R5912-02MOD PMT (~2500 GBP).
Bialkali photocathodes with Pt underlay (conductive material) for operation at cryogenic temperatures.

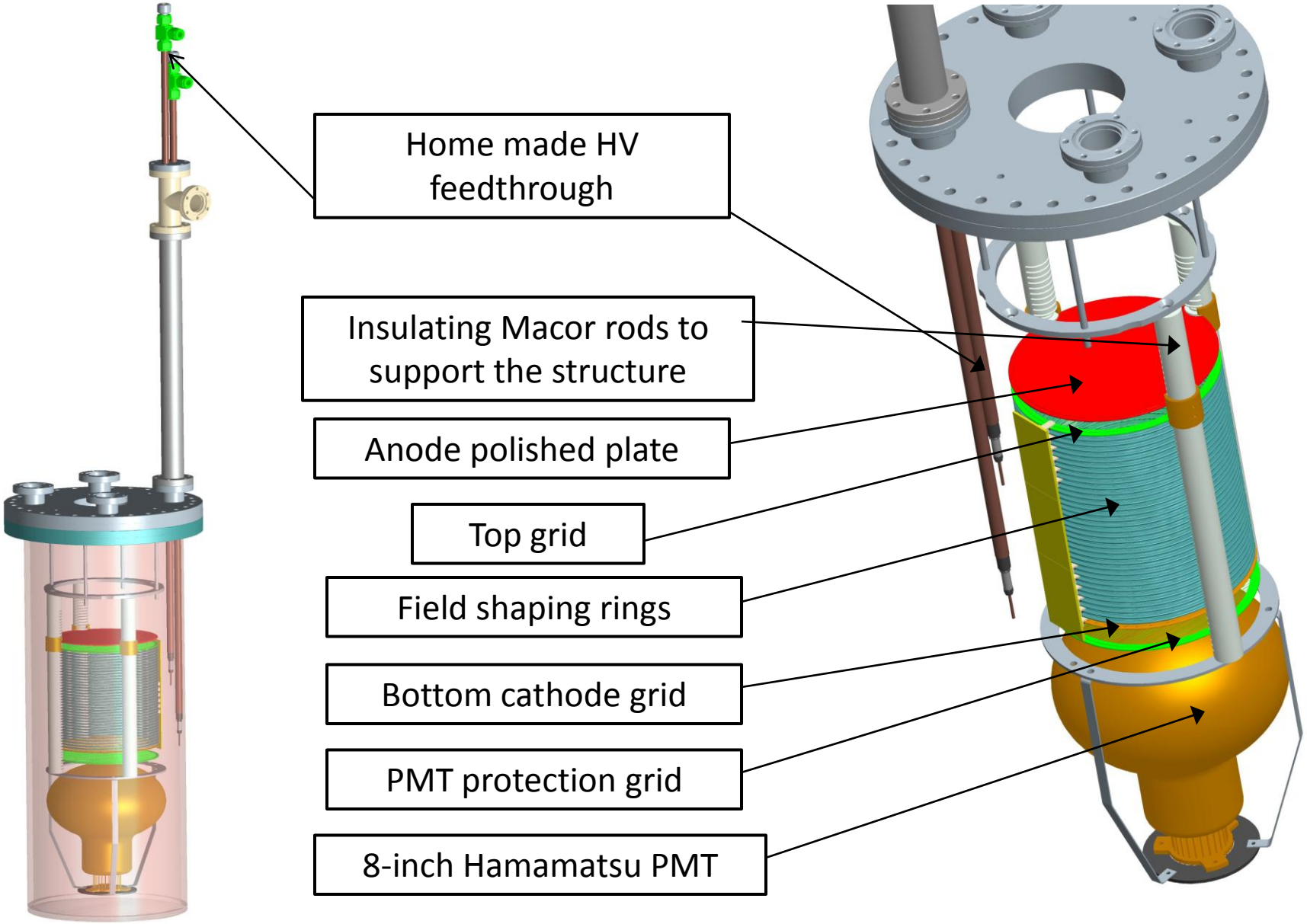


Voltage divider PCB

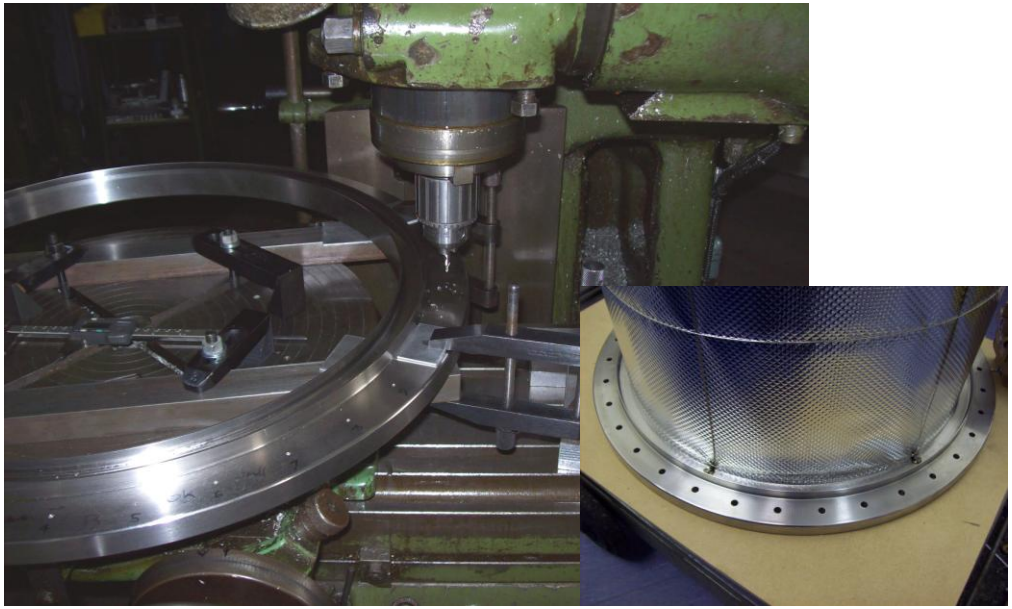
The PMT face is coated with TPB wavelength shifter. TPB absorbs 128 nm light and reemits ~430 nm which is within the high quantum efficiency region of the PMT



Modeling the Detector with Pro/Eng



Construction of the LAr Cell in the Workshop



Left: Rolling the stainless steel sheet

Right: Machining the top flange

Construction by Kevin McCormick

Construction of the LAr Cell in the Workshop

Wrapped with Mylar reflector to minimize radiation losses

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

The Target Vessel and Recirculation System

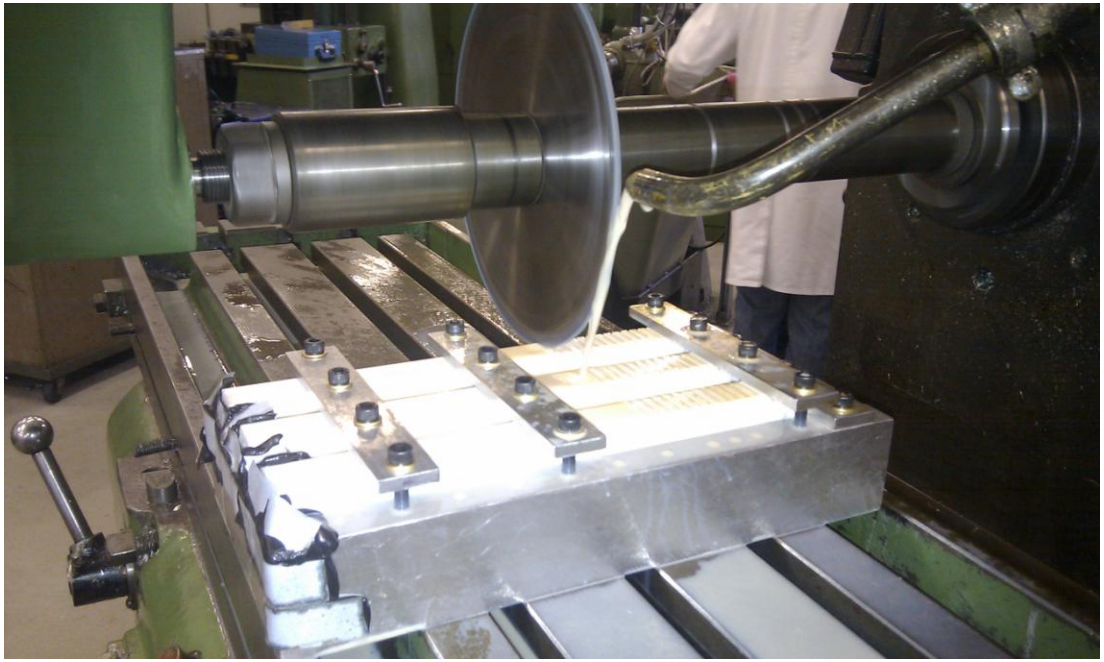
Development of a novel one way recirculation system using metal balls and a bellows

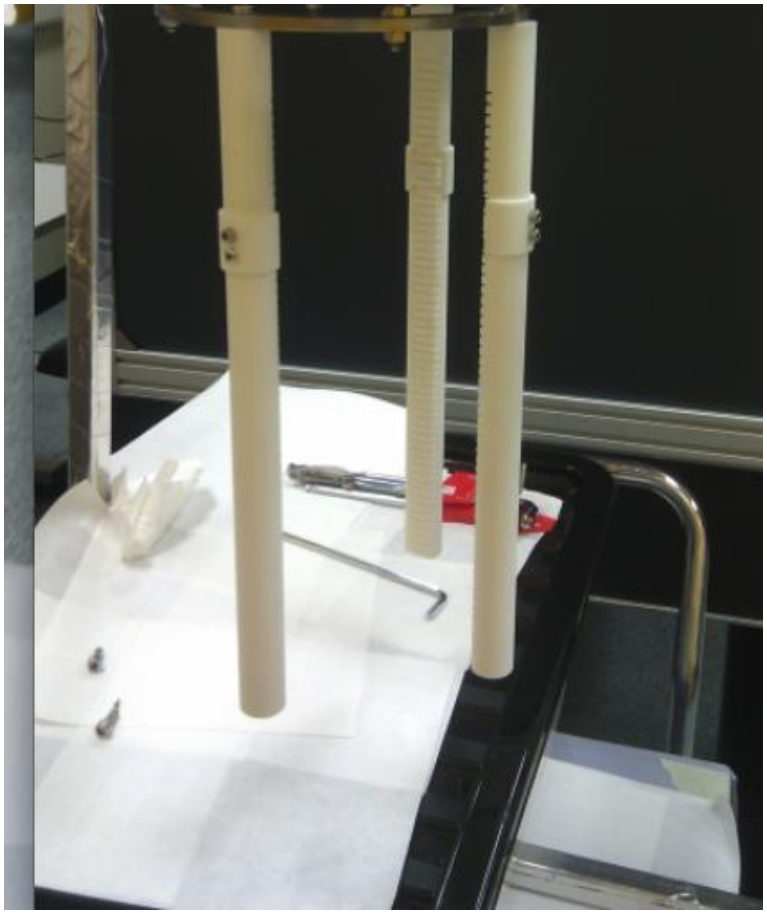
The Liverpool LAr Vessel – The Purification Cartridge

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

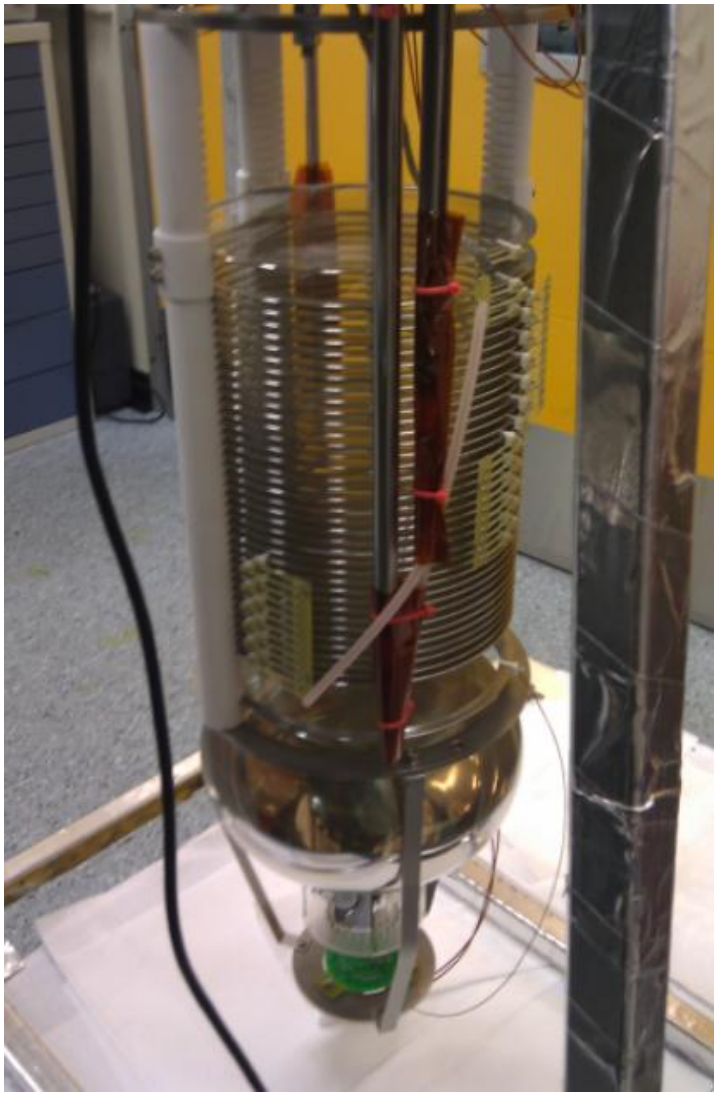
Filling the purification cartridge within an argon bag in order to avoid reaction with air molecules

Machining the Macor rods





The Liverpool Field Cage Completed



The Liverpool LAr Lab