Warm electronics concept for VD PDS

David Cussans
On behalf of RAL, Bristol
27-July-2021

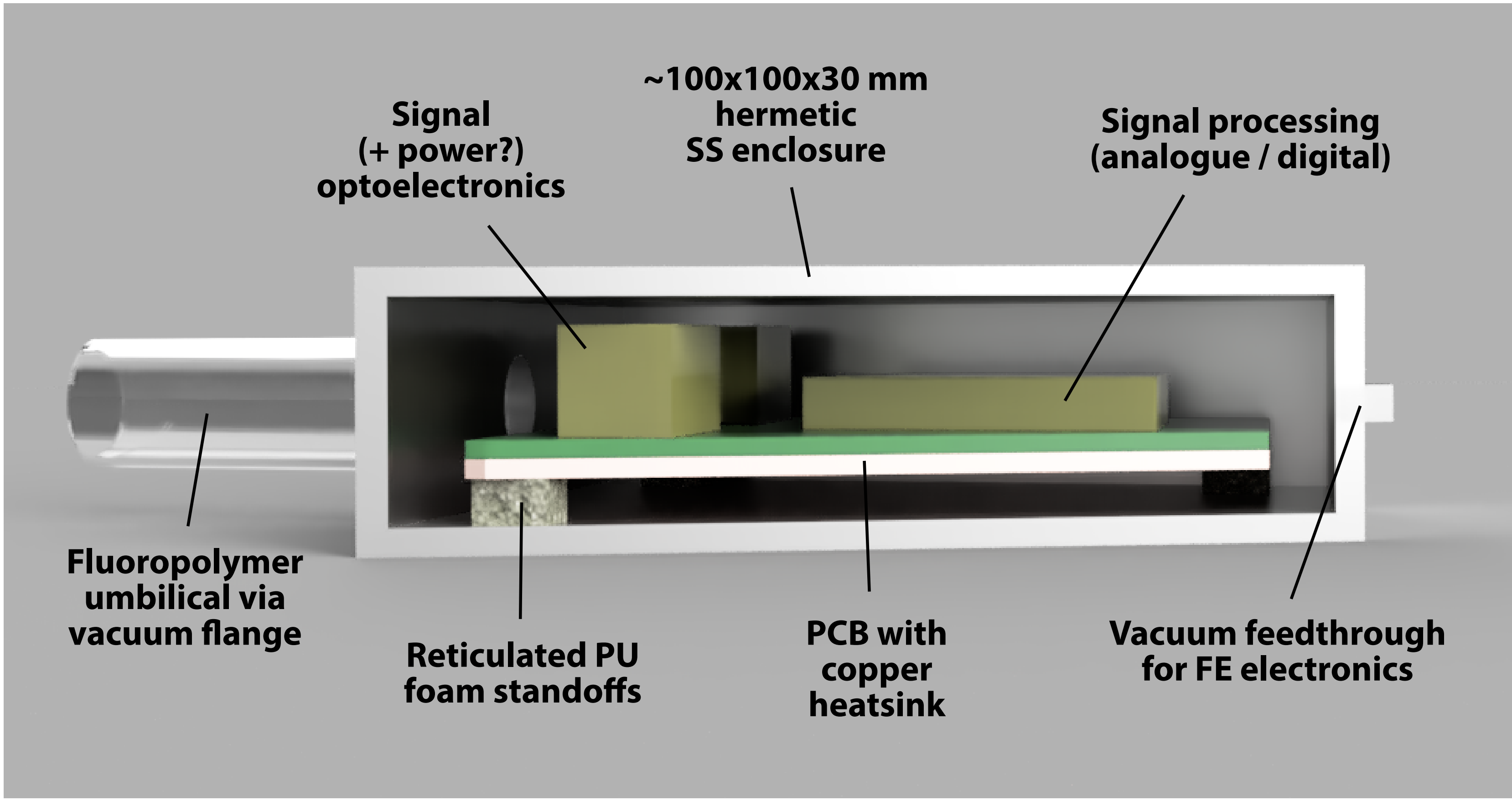
Basic Concept

- The concept
  - House electronics in a hermetic soft-vacuum-insulated enclosure
  - Electronics operates at “room temperature”
    - Although, has to be able to survive cryogenic temperatures during installation
  - Electronics self-heats to raise temperature to ~0C
    - Temperature is self-regulating due to constant optical power input
    - Or: active regulation of temperature by modulation of power consumption – will use for cold box tests
  - Pressure is maintained by pump via umbilical tube
    - Also acts as robust secondary containment for power and signal fibres

Basic Concept

- Investigated for cryogenic photon detector testing at RAL
  - Quick solution for ‘off the shelf’ readout electronics
  - Consulted with RAL Space / Cryogenics groups
    - Day job is making space-based instruments (JWST, Herschel, Planck…) and superconducting magnets
  - Input: nobody in space runs their electronics cold
    - Concerns around availability, qualification, reliability, longevity, etc – same as us
    - Typical solution is ‘active thermal control’ to run the electronics ‘warm’ in vacuum
- Initial tests indicate that this is conceptually workable – now the details

Rough Sketch



- Small enclosure is optimal – aiming for 150x150 for cold box

Advantages

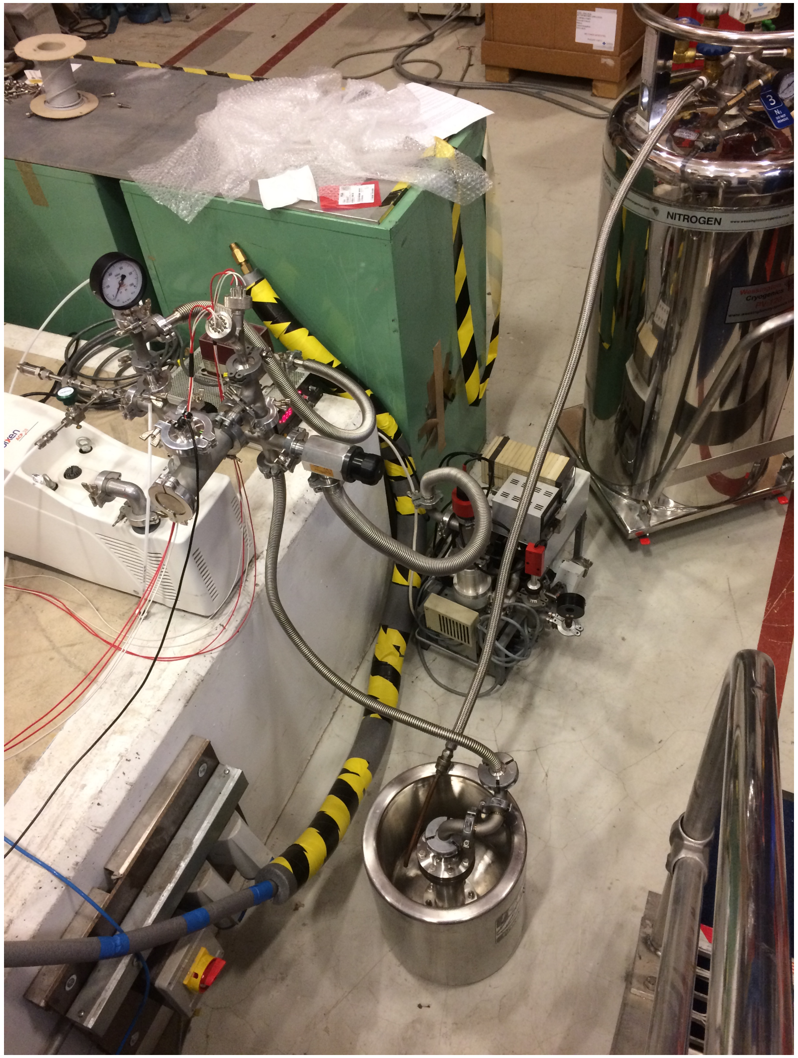
- Allows use of standard commercial electronics off the shelf
  - No problem with optoelectronics
  - No problem with semiconductors
  - Can use ‘standard’ accelerating ageing techniques to qualify system lifetime
- Only well-characterised materials in contact with LAr
  - Specifically: stainless steel enclosure, fluoropolymer umbilical and o-rings (inert even in LO2)
- Power dissipation over relatively large surface area
- Isolation of powering / signal light in case of fibre break
- ‘Very small self-contained module’ with backup inter-module fibres is doable
- Low cost
- Key advantage: can be delivered quickly and in time for extended testing and design iteration

Disadvantages

- Routing of vacuum umbilical harder than individual fibres
  - Though no worse than cables from charge readout
  - Almost certainly want to keep umbilicals separate all the way to cryostat roof for ease of installation
- Need for additional infrastructure (pumping plant)
  - Including the need for monitoring via SC

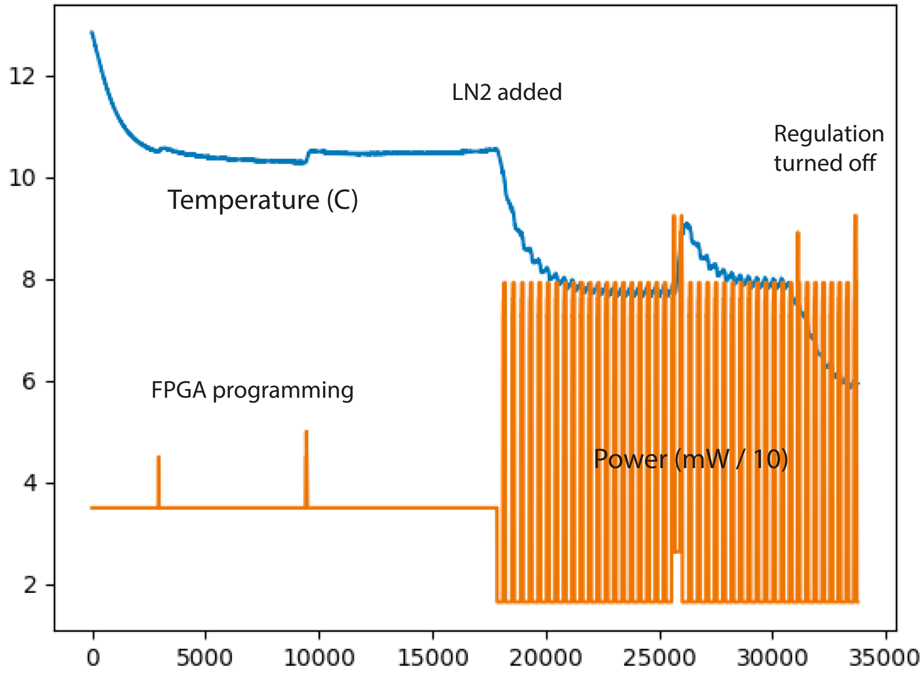
First Tests at RAL

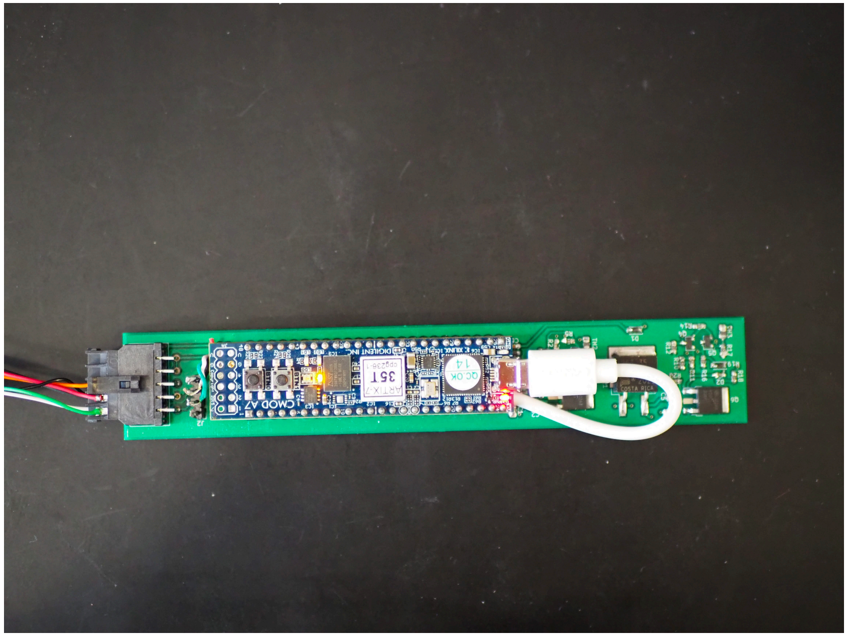
- Test setup
  - 1atm LN2
  - Running at ~0.1Pa pressure with simple roughing pump
  - Enclosure is standard 65mm vacuum tube with flanges
  - Metallic umbilical with copper powering / control
    - Heat leak ~20mW - not an issue
- Achieved so far
  - Thermal performance of enclosure and materials characterised
  - Active control of temperature by digital board demonstrated



University of BRISTOL Science & Technology Facilities Council Rutherford Appleton Laboratory DUNE

Results with First Digital Board



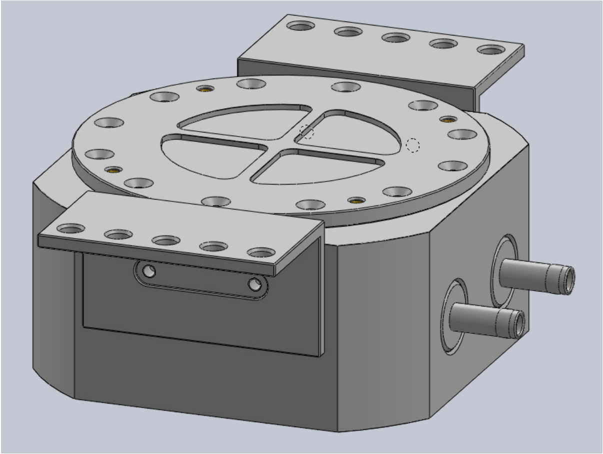


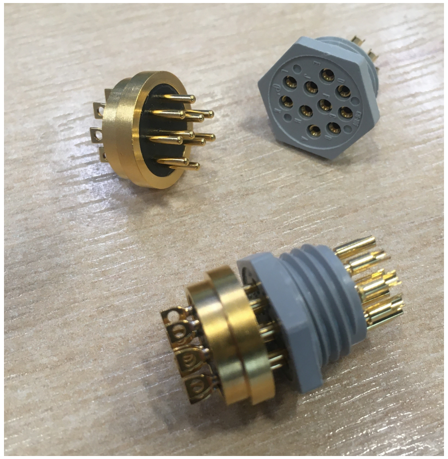
- System operates at ~8C with ~50mW input power
  - This is considerably better performance than needed for DUNE (>250mW)
  - Clearly one can always make the insulation worse (control emissivity)
- NB: active control is probably not needed for DUNE (power converter integrated with electronics?)
  - Optical input power, and therefore total dissipation is *independent* of electronics activity

University of BRISTOL
Science & Technology Facilities Council Rutherford Appleton Laboratory
DUNE

Details: Capsule

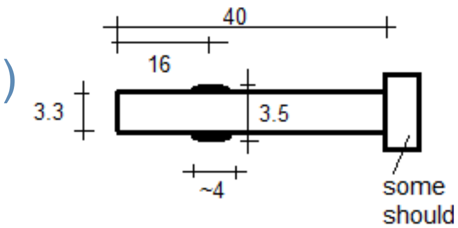
- Capsule
  - Design for Stainless Steel box to resist 300kPa differential pressure ready for manufacture
    - For the prototype, we will use a Helicoflex seal to allow for a ‘lid’ – good down to < 1K
    - https://technetics.com/products/helicoflex-delta-resilient-metal-seal/
  - Mechanical interface for CB tests understood – aim for ~ 100x250x80
  - Standard feedthroughs for signals and power

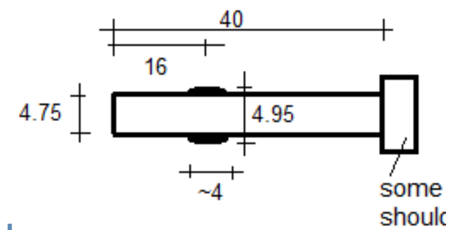




Details: Umbilical

- Issues
  - Sealing at ends (including assembly to top flange in situ)
  - Routing and flexibility
  - LAr compatibility (chemical and collapse pressure resistance)



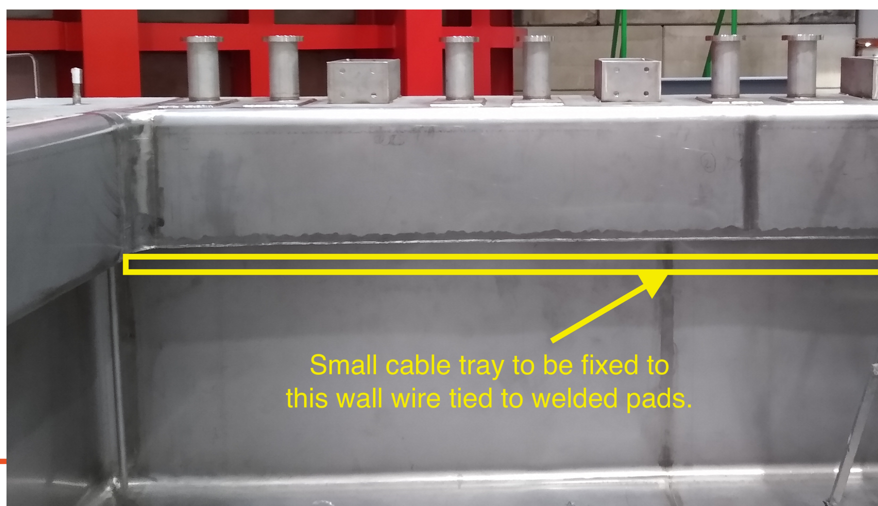


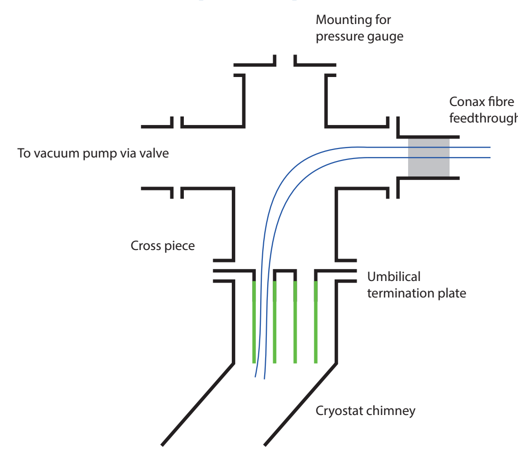
- First tests carried out with PTFE , PFA , FEP tubing
  - Using a very simple 'self-sealing' internal spigot approach
  - The spigot works! FEP, PFA OK (PTFE is porous)
  - Custom assemblies at reasonable prices available local to RAL
    - https://adtech.co.uk/bespoke-fabrications/thermoforming-fluoropolymers

University of BRISTOL
Science & Technology Facilities Council Rutherford Appleton Laboratory
DUNE

Details: Umbilical

- Routing in cold box
  - This looks ‘tricky’ - but following visit by UK engineer to cold box we think we have a plan
  - Details of routing through cathode support seem OK for 12mm tube size and bend radius
  - Appears that the top flanges do *not* move with the cryostat insert
  - Need to find appropriate location / coupling for vacuum pump – do not intend to operate during run





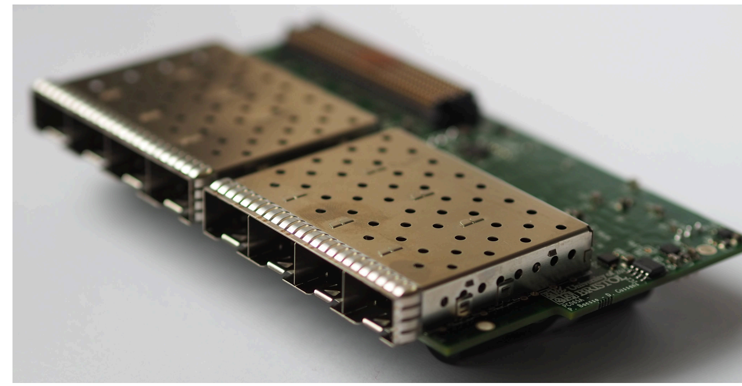
University of BRISTOL
Science & Technology Facilities Council Rutherford Appleton Laboratory

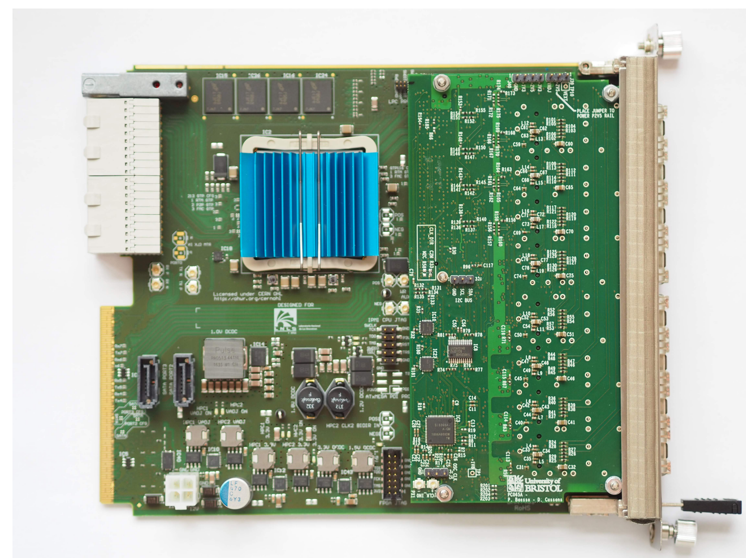
Details: Optical Link

- Fibre optic interface
  - Data for CB: 2mm plastic fibre via Firecomms 250Mb/s transceiver
    - https://www.firecomms.com/contentFiles/technicalDocuments/FB2M5KVR%20Datasheet_Revision_E.pdf
  - Tx is ~100mW, but assume we are using at low duty cycle
  - At least 50m distance available, more with superior fibre
  - Need to test for survival at LAs temperatures.
  - For prototype will be mounted on daughter board
    - Can be swapped if lower power solution found or problems with cryogenic survival

Details: Readout

- Use spare components from timing system for cold-box readout
  - “Fibre Interface Board” with POF SFP
    - Mounted on COTS uTCA AMC
  - MicroTCA based system
  - Synchronised to DUNE Timing System





Details: Electronics

- 2-channel 62.5MHz @ 14b digitiser board, buffer in FPGA, 250Mb/s uplink
    - Targeting XC7S15 device – slow static power, up to ~200us buffering, should be plenty
- Self-clocked or synchronised sampling – very low power external PLL
    - Will leave provision for ‘simple’ and ‘advanced’ (tunable VCXO) clocking approaches
- Active heater control on the separate board
- Target power consumption 250mW – i.e. one fibre, but provide for 500mW
    - Current power budget is <180mW average, ~50mW for FPGA (Vivado prediction)
    - Peak power is somewhat higher, dominated by FPGA configuration
    - Need an energy reserve via ~1mF capacitors during configuration
    - Single 5V power supply.
- Components in hand, schematic almost complete (missing temp sensor)
    - PCB layout end of month
    - External review of schematic would be very welcome
- Note that the “warm electronics” concept does not depend on digital readout
    - Will work with analogue readout + self-stabilisation with power-over-fibre

Questions

- Specific to warm concept:
  - Are we confirmed on the 'external power' for cold box?
    - We could include a power module in the warm box if needed (at expense of delay in manufacture)
  - Are we OK with 250Mb/s as the link data rate?
    - This is basically a power question – and we need to know the power to design the box
  - Can we source a roughing pump and manifold at CERN? (surely yes…)
    - Will also need leak testing capability if terminating in situ
  - Are we sharing the top flange?
  - Will we need to operate in the warm, and for how long?
  - Is any other output from the electronics needed (e.g. calibration pulse?)
- General
  - What are other groups doing about control and readout?
  - What is the schedule for 'integration on the support structure'?
  - Will there be people at CERN to take care of practicalities? Do we need to send someone?
  - What are we doing about interlock / mechanical protection for power fibres?
    - Is the umbilical satisfactory for this (guess: no), or do we need secondary protection also?

Frequently Asked Questions

- Will it implode / explode?
  - No. Enclosure can be arbitrarily robust - no constraints on mass
  - (Current enclosure would be OK for ~30atm external pressure)
- What level of vacuum is needed?
  - Very soft, performance is fine at 1Pa (probably at 1mbar…)
  - We simply do not care about slow outgassing from electronics
- Will it contaminate the LAr?
  - No. Encapsulating fibres in the umbilical helps here.
  - Fluoropolymers routinely used for transport of chemically aggressive materials (LO2)
- Does this require digital electronics?
  - No, a warm analogue solution would also be viable (perhaps preferred)
- Are the fibres cryo-compatible?
  - Acrylic POF appears to work well if used with connectionless terminations
  - Up to 250Mb/s optoelectronics (‘optolock’) is available with low power consumption

Frequently Asked Questions

- Doesn't this increase power consumption?
  - No. We are literally using the waste power from the electronics.
  - System simulation indicates that we could operate at <50mW if needed
  - Note that 75% of power comes from the efficiency of electro-optical conversion
- Can you use non-vacuum insulation?
  - Aerogel may have the required performance
  - However: operation of a sealed vessel in the LAr is NOT possible
    - Any inward diffusion or leak could result in explosion on warming the system
    - This implies the need for a vacuum connection in any case?
- Can you just evacuate it once?
  - Yes (we will not continuously pump). But you still need the umbilical.
- Does this take a large amount of flange space?
  - No. Half-inch umbilical probably adequate, equivalent to ~one charge electronics cable
  - In practice, the umbilicals combine at the flange, only fibres go through

Frequently Asked Questions

- Can you run it warm for commissioning / testing?
  - Yes. Will dissipate heat by convection if no vacuum – confirmed in testing
  - Can run for ~minutes even in vacuum due to heatsink
  - Cold front-end electronics may not operate though…
- What are the key remaining problems?
  - #1 problem: umbilical
  - Need robust (~5atm rated) polymer tubing, permanent seal to metal
  - The technology exists (cryogenic bulk transfer lines), but most hoses are metal braided to resist high internal pressures
  - RAL cryo group now looking at solutions
  - Availability of metal-backed polymer o-rings rated down to 4K is confirmed