PROSPECTS OF THE CARLETON CRYOGENIC FACILITY FOR NOBLE LIQUID DETECTOR DEVELOPMENT

Carleton UNIVERSITY

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September 24th, 2017

LIDINE 2017

OVERVIEW

- Early 2017, Canadian funding agencies approved a combined $9M (CAD) proposal for a new cryogenic facility at Carleton U., Ottawa, Canada.

- Collaboration between several institutions; Carleton U., U. British Columbia, TRIUMF, McGill & U. Sherbrooke.

- Applying multi-institutional hardware expertise, the facility will provide an ideal environment for a series of table-top sized argon (Ar) and xenon (Xe) measurements that will inform the design of a future dark matter (DM) and neuntrinoless double beta decay (NDBD) experiments.

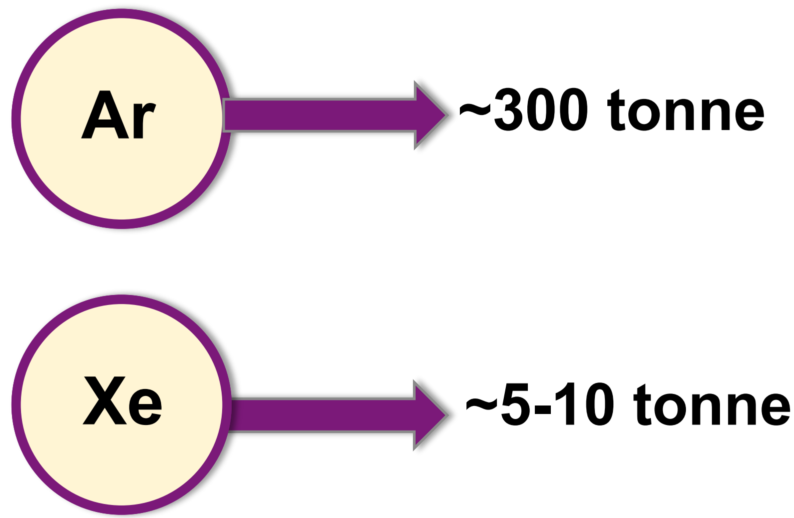
Cubehall Balcony
SNOLAB, 2016

AR & XE GOALS

Low background physics community aiming for larger volumes with optimal light collection for increased physics sensitivity. Facility will aim to address the following…

Argon

- Ion quenching
- Light yield (LY) of different wavelength shifters (WLS)
- Outgassing contaminants in LAr
- 3D Digital SiPMs operation
- Ar + X admixtures (e.g. Ar+Xe)
- Scattering of VUV/optical light
- Turbulent effects
- Surface/alpha backgrounds
- Quantifying fluorescence and Cherenkov yield in detector materials (acrylic, plastics, etc.)
- Background reduction techniques



Xenon

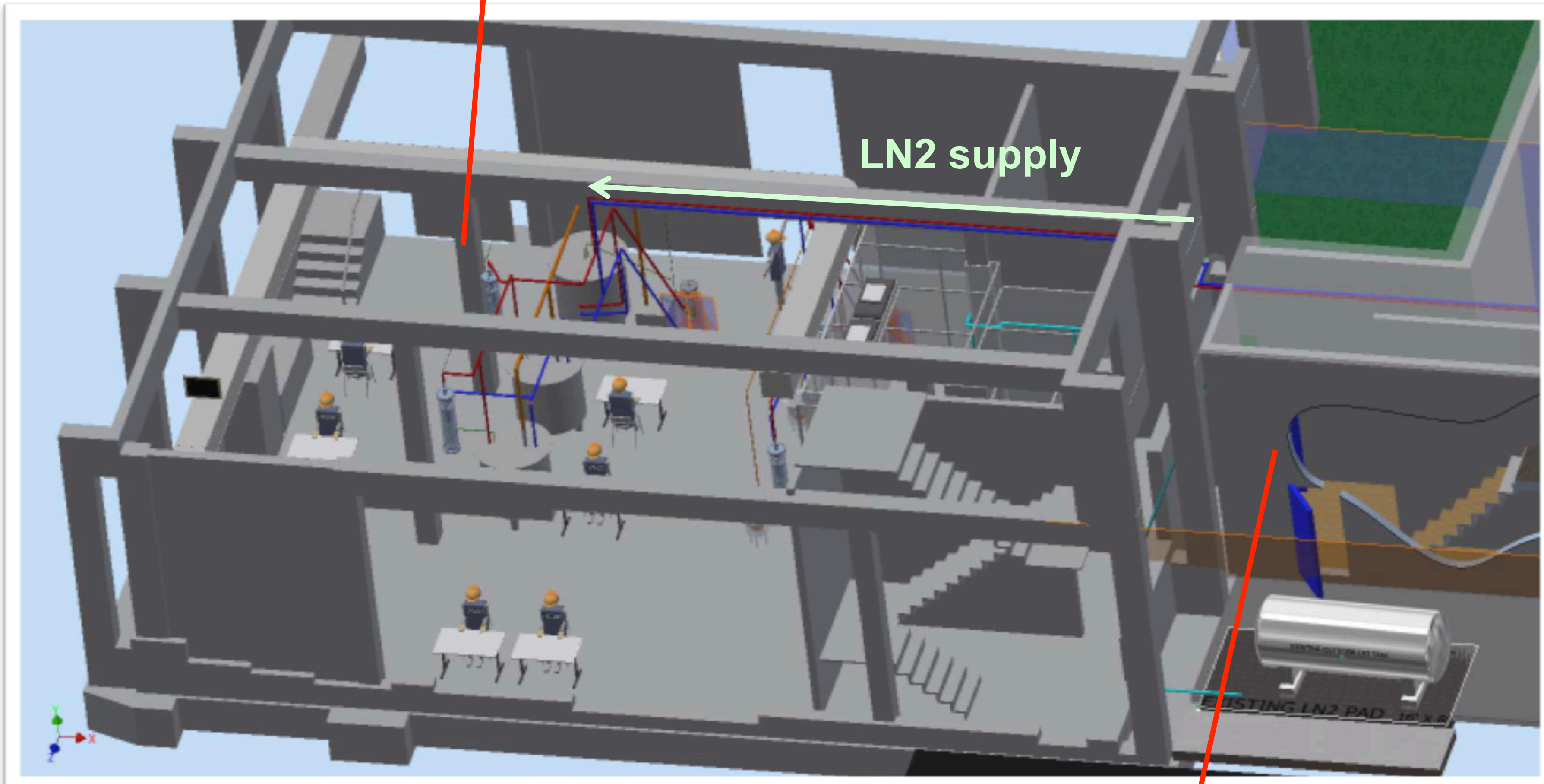
- 2-phase TPC
- Operation of SiPM in LXe
- Fast timing for Cherenkov detection in scint-only LXe
- Xe bubble chamber development
- Measurement of Xe properties
- Enrichment tower

* briefly discussed in this presentation

FACILITY LAYOUT *

*Design not final.

Open plan workspace for table-top sized measurements

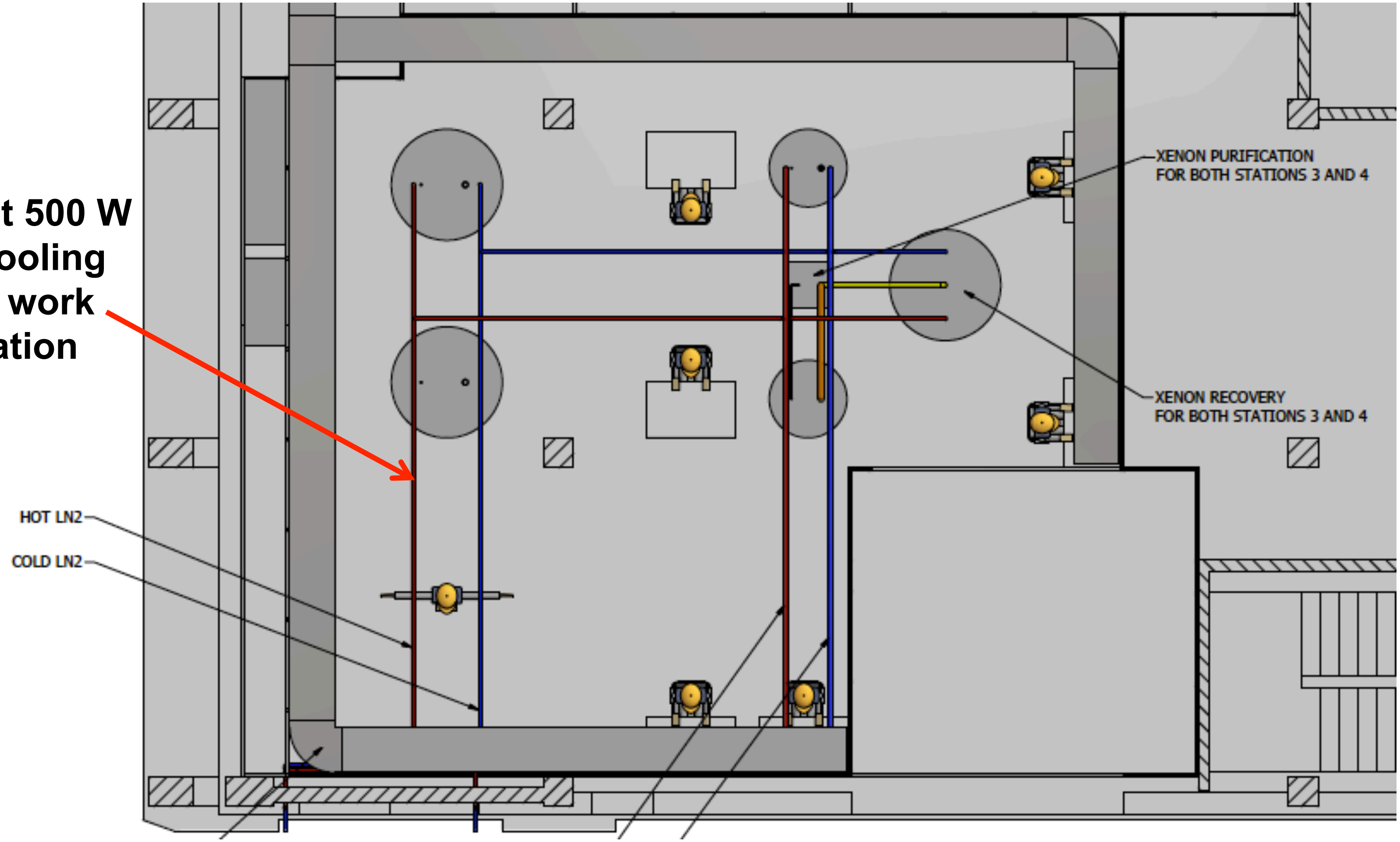


Separate storage area for cryogenics systems producing LN2.
Delivered through thermosyphons to provide
compatible cooling for both Ar & Xe.

*Design not final.

FACILITY LAYOUT *

Target 500 W of cooling per work station



Capacity: 4 workstations. 2 initially be assigned to an Ar scintillation detector and 2-phase Xe TPC

FACILITY LAYOUT *

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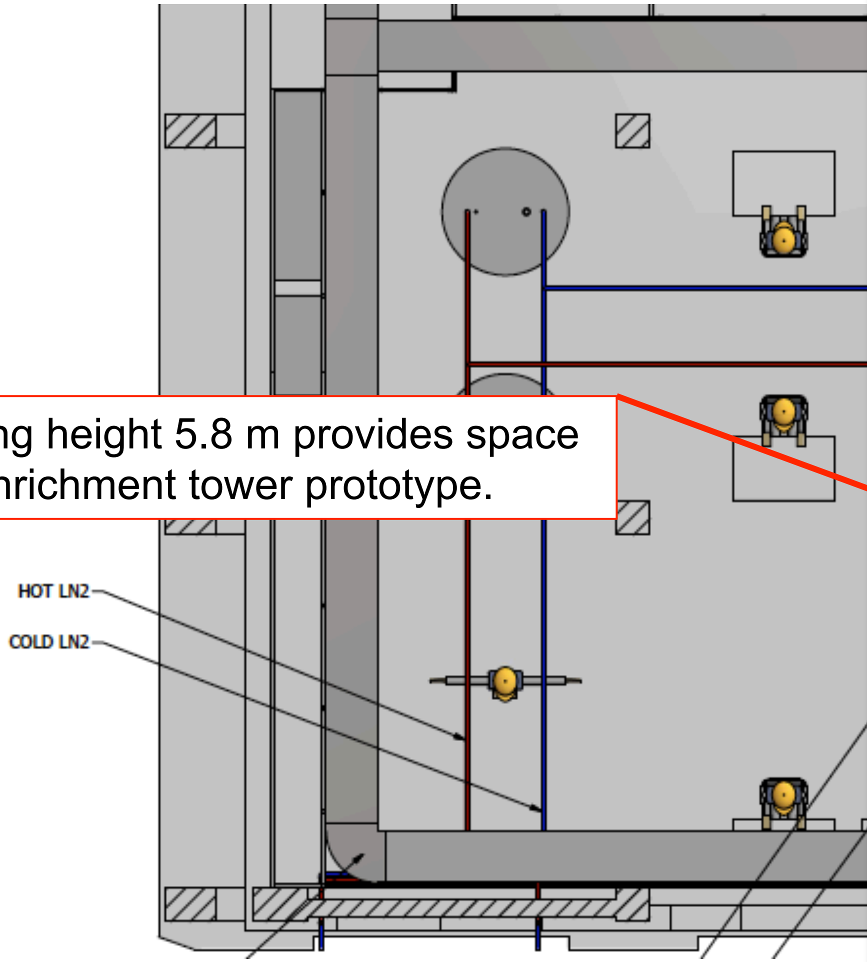
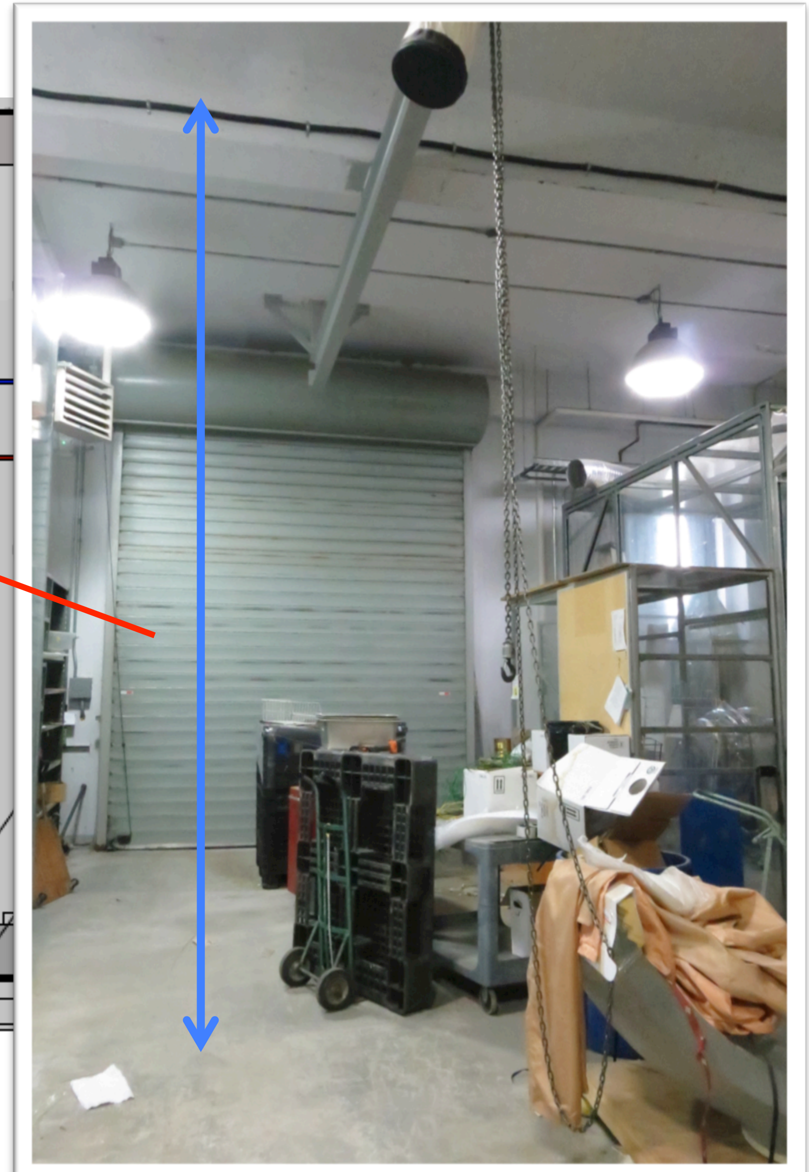


Ceiling height 5.8 m provides space for enrichment tower prototype.



September, 2017

SILICON PM DEVELOPMENT

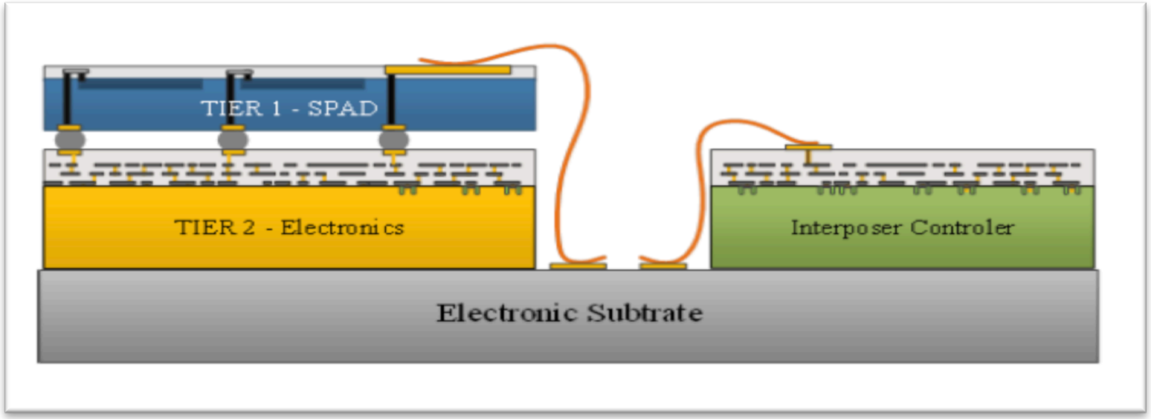
Interest in digital Silicon photomultipliers (SiPMs) as a replacement to conventional PMTs in a future NDBD or dark matter experiment.

- Advantages: compact, insensitive to magnetic fields, good timing resolution, single photon detection, low cost, high radiopurity, low power consumption and supply voltage, function at cooler temperatures.

Digital 3DSiPM design developed by U.Sherbrooke allows for better noise reduction over analog SiPMs:

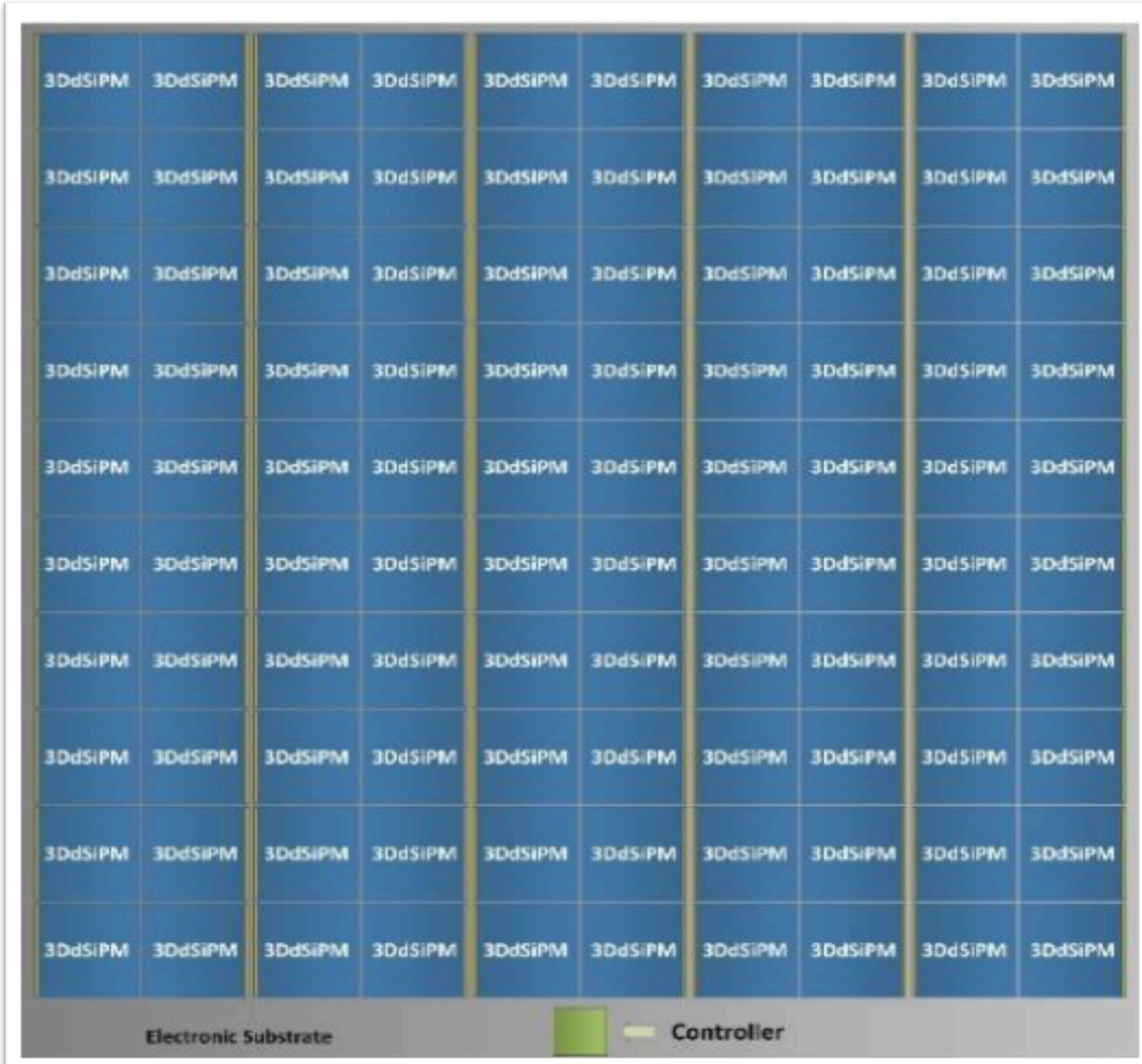
- **Analog:** Sum across all silicon photon avalanche diodes (SPADs) [photosensitive area]. Sum subject to gain non-uniformities from dark counts and temperature.
- **Digital**: Dedicated readout micro-electronics for each SPAD in a SiPM. Pixel-by-pixel control over each photosensitive area.

Increased complexity (fill factor) in readout electronics overcome By 3D-design. Readout located beneath SPAD.



More Info: F. Nolet et al., IEEE Trans.Nucl.Sci.63, 2293(2016)

SILICON PM DEVELOPMENT



Dimensions:
106 mm
x110 mm (W:H)

SURFACE BACKGROUNDS

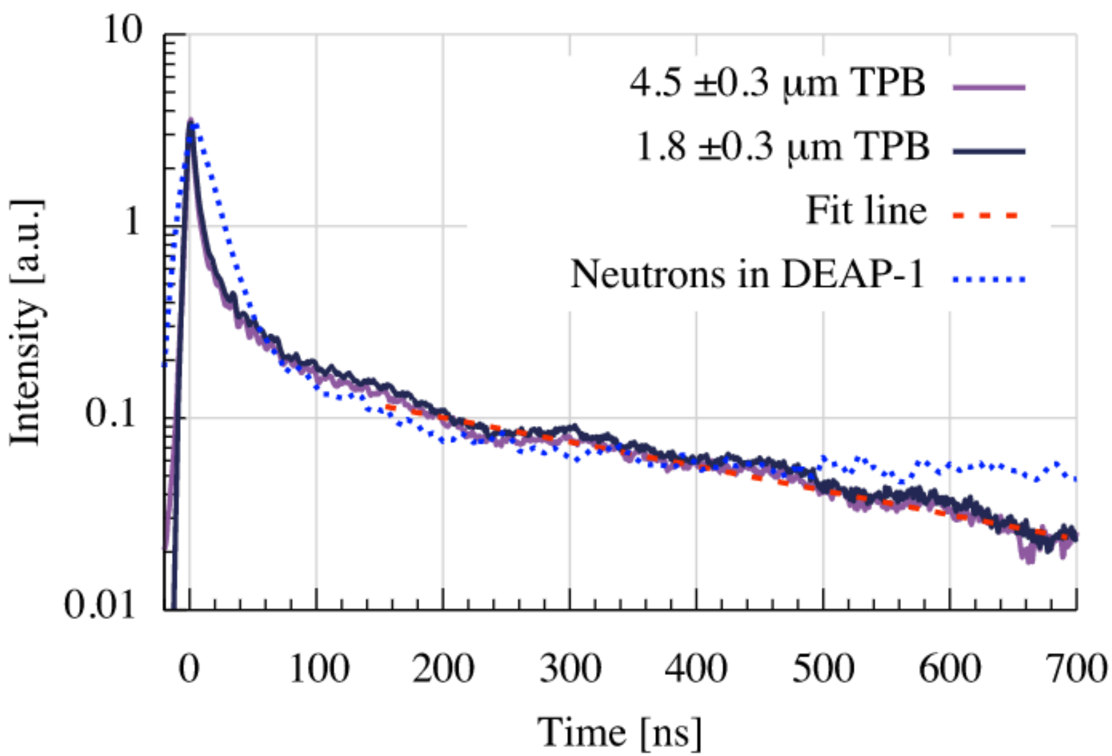
Concern for DM detectors are false signals coming from alpha emitters, usually 222Rn decay daughters embedded in detector walls.

- Alphas scintillate in tetraphenyl butadiene (TPB), unique TPB scintillation timing provides means for surface event PSD

- Non-trivial temperature dependence of alpha scintillation

[L. Veloce, M. Kuzniak et al.,2016 JINST 11 P06003]

T. Pollmann, M. Boulay, M. Kuzniak, NIM A 635 (2011) 127–130



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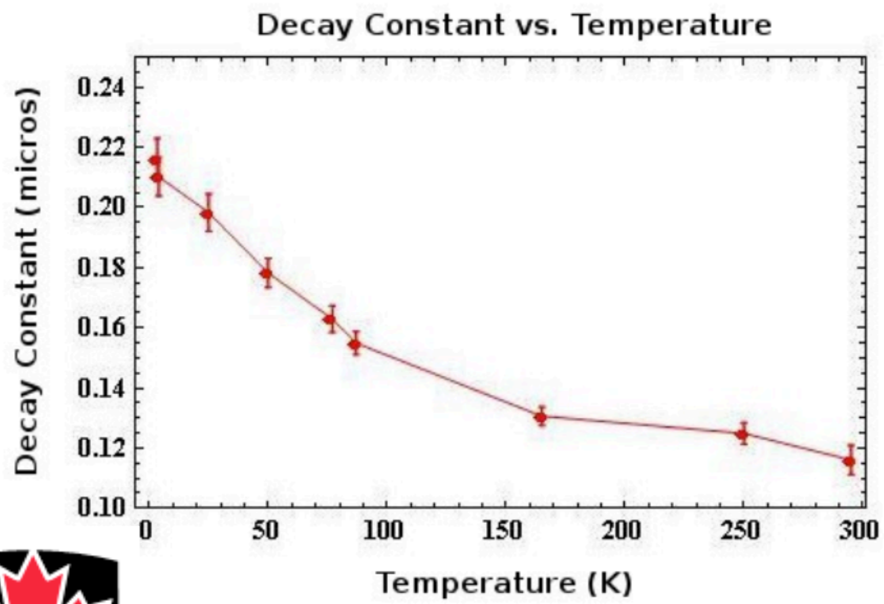


- Due to high vapour pressure evaporated pyrene coatings unstable
- Good stability using thin acrylic films with 5-10% dissolved pyrene concentration
- Measured light yield, emission spectrum and fluorescence lifetime vs temperature
- Promising: ~150 ns time constant at 87K

More here: CAP 2016 Conference
https://indico.cern.ch/event/472838/contributions/1150228/

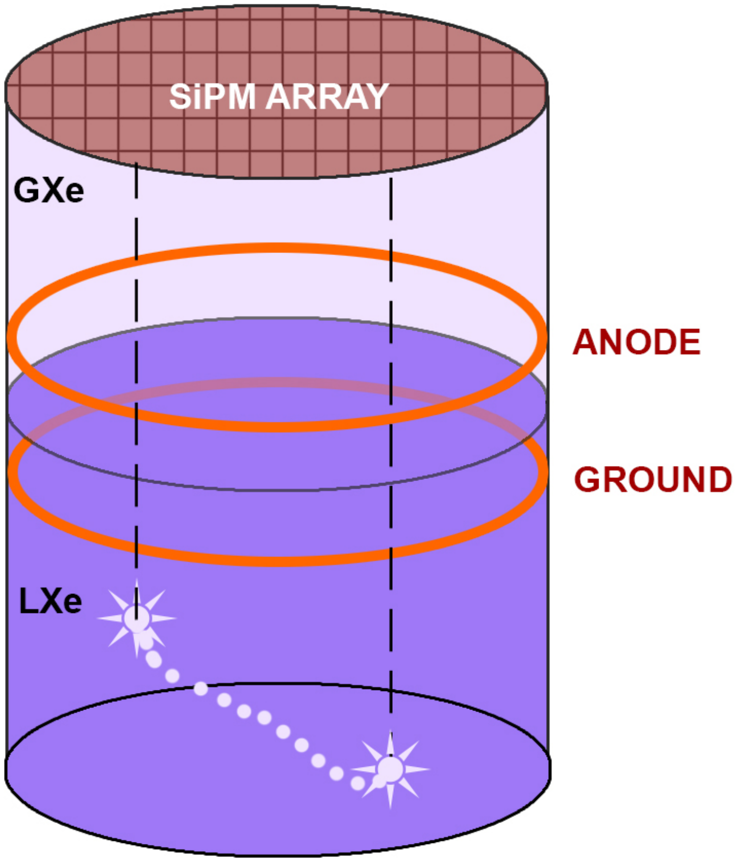
TWO-PHASE XE TPC

Application of SiPMs to two-phase Xe-TPC design of DM experiments for future NDBD experiment.

Prototype already underway at Carleton.

Benefits

- Signals are large and close to noise free with SiPMs.
- MeV scale physics naturally reduces threshold for single/multi site discrimination
- SiPMs enable better spatial resolution (particularly along z-axis). Reduced SiPM noise assists in better (x,y)-plane reconstruction
- Possibility to discriminate one/two-electron events.



Illustrative Figure

Challenges

- Electroluminescence signal is large, need to quantify SiPM saturation.
- Full design mechanically complex, additional anode and grid structures.

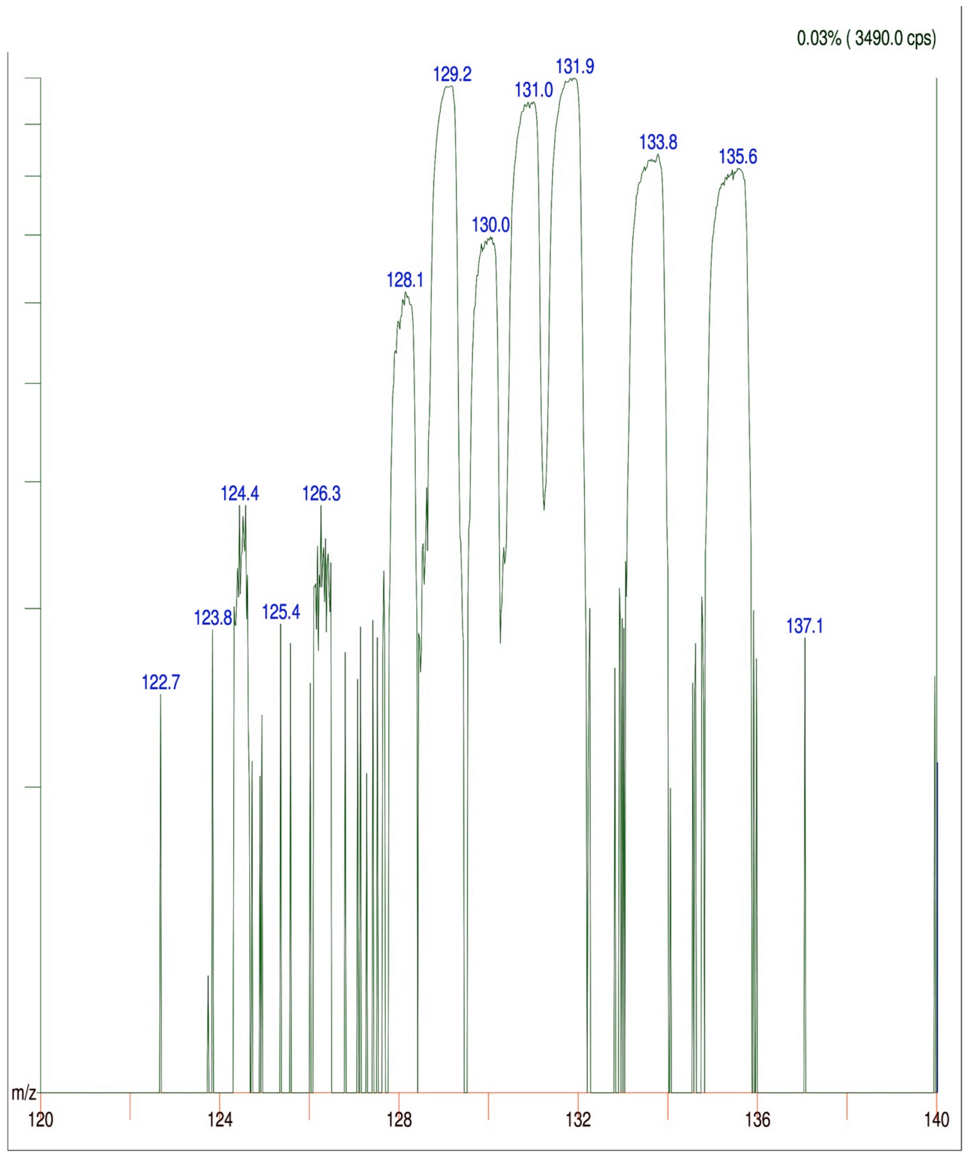
XE ENRICHMENT

Future Xe experiment will require several tonnes of enriched Xe-136. Very expensive.

- Carleton group interested in developing infrastructure to distil and separate noble gases e.g. Ar, Kr & Xe.

Separation relies on the small difference in vapour pressure of different isotopes, most pronounced near the triple value. Known for the lighter noble gases but little data exist for xenon.

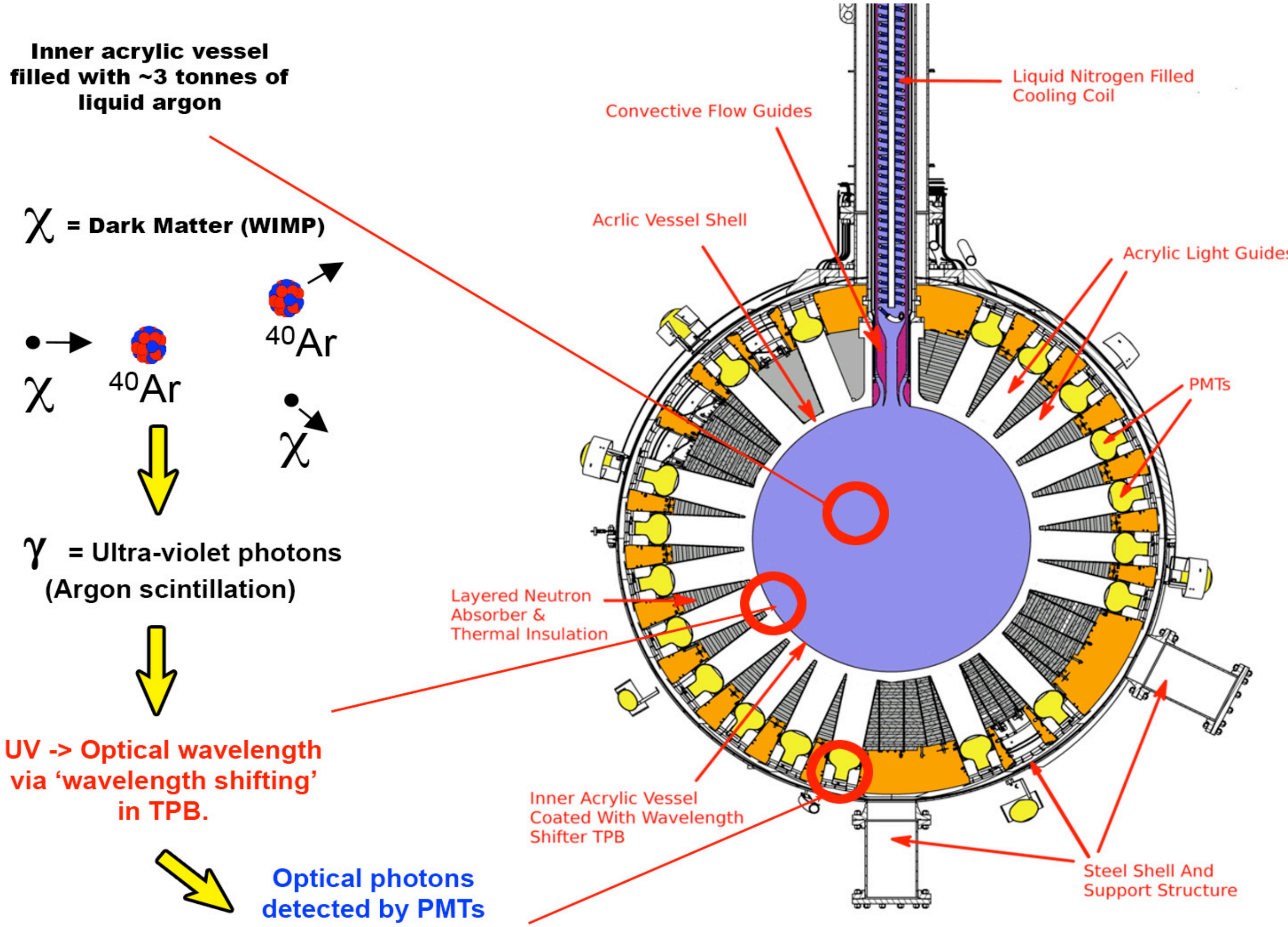
The plan for the current project is to measure the difference in vapour pressures for xenon isotopes. Develop several prototypes with a final target of a ~12m distillation column located at SNOLAB.



Extrel quadrupole system will be used to measure the isotopic abundances. Example readout above.

LIGHT DETECTION IN DEAP-3600

In DEAP-3600, 45 cm long acrylic light-guides coupled to each of the 255 PMTs shield the inner detector from PMT neutron backgrounds and transport TPB scintillation.



ACRYLIC ATTENUATION IN DEAP-3600

When selecting light guide materials, multiple samples of acrylic from different suppliers were tested for attenuation of wavelengths based on the TPB emission spectra.

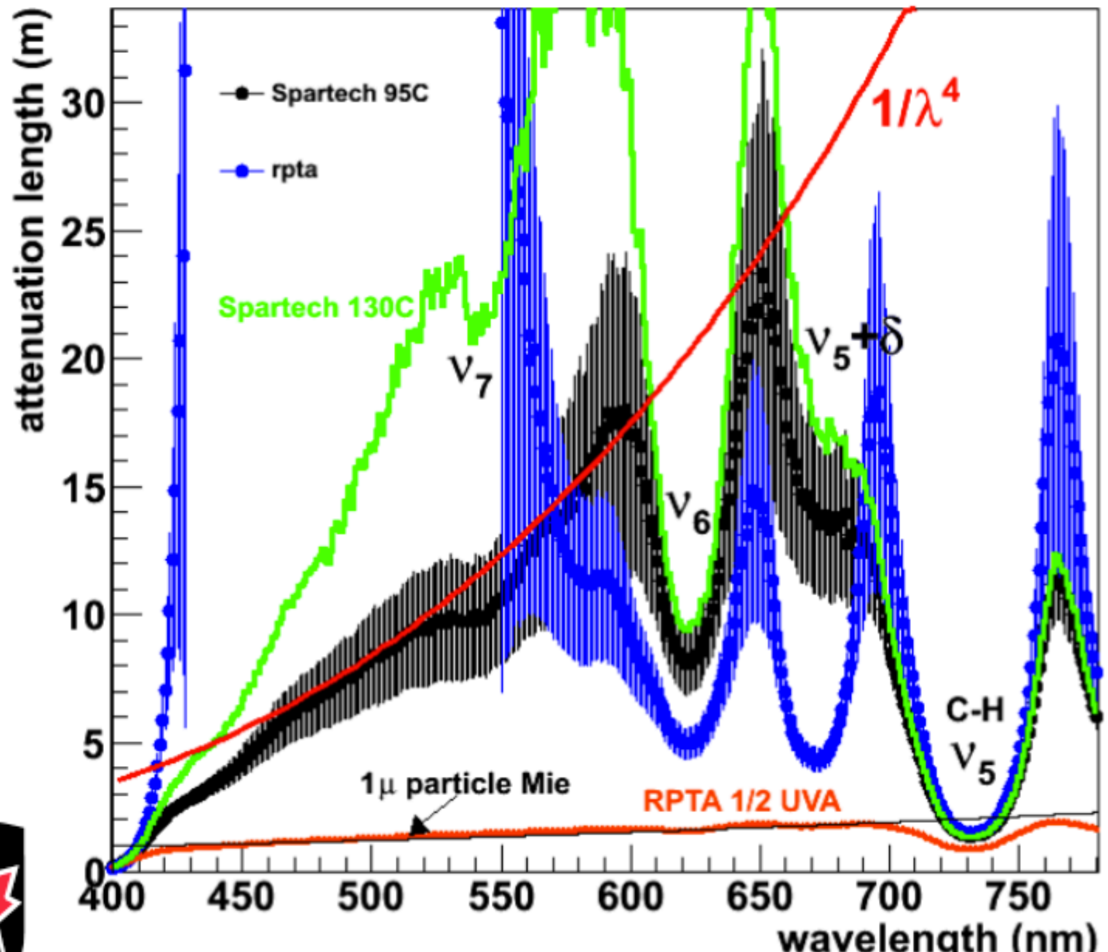
After a lot of investigation, found that polymerization of acrylic below glass transition temperature (105C) can lead to excess Rayleigh scattering from small scale inhomogeneous strains

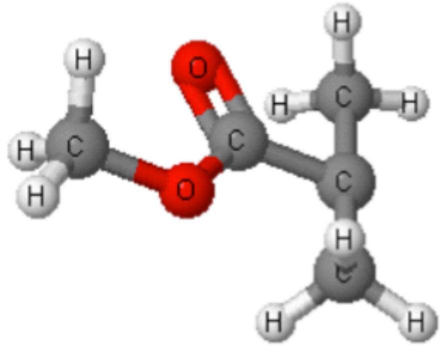
Supplier	Attenuation length (m)	Relative Transmission (%)	Origin	
RPT-UVA	3.7	77		1" slab
RPTA-UVA M&Ch	6.5	87	Thailand	1" slab
RPTA-UVA Standard	2.4	67	Thailand	1" slab
RPTA-UVA 0.5 UVA	0.9	33	Thailand	1" slab
Spartech UVA	5.4	84	USA	
Spartech UVA co-cast (short)	5.0	83	USA	6.5" slab
Spartech UVA co-cast (long)	5.0	83	USA	6.5" slab
Spartech UVA	5.6	85	USA	1" slab
DEAP PRODUCTION ACRYLIC				
RPTAsia	Almost no attenuation!	~100%	Thailand	4.5" sheet
Spartech	3.3 m	74%	USA	4" sheet

Weighted attenuation lengths of different acrylic samples from two suppliers

ACRYLIC ATTENUATION IN DEAP-3600

DEAP able to achieve longer attenuation lengths by annealing above glass transition temperature.



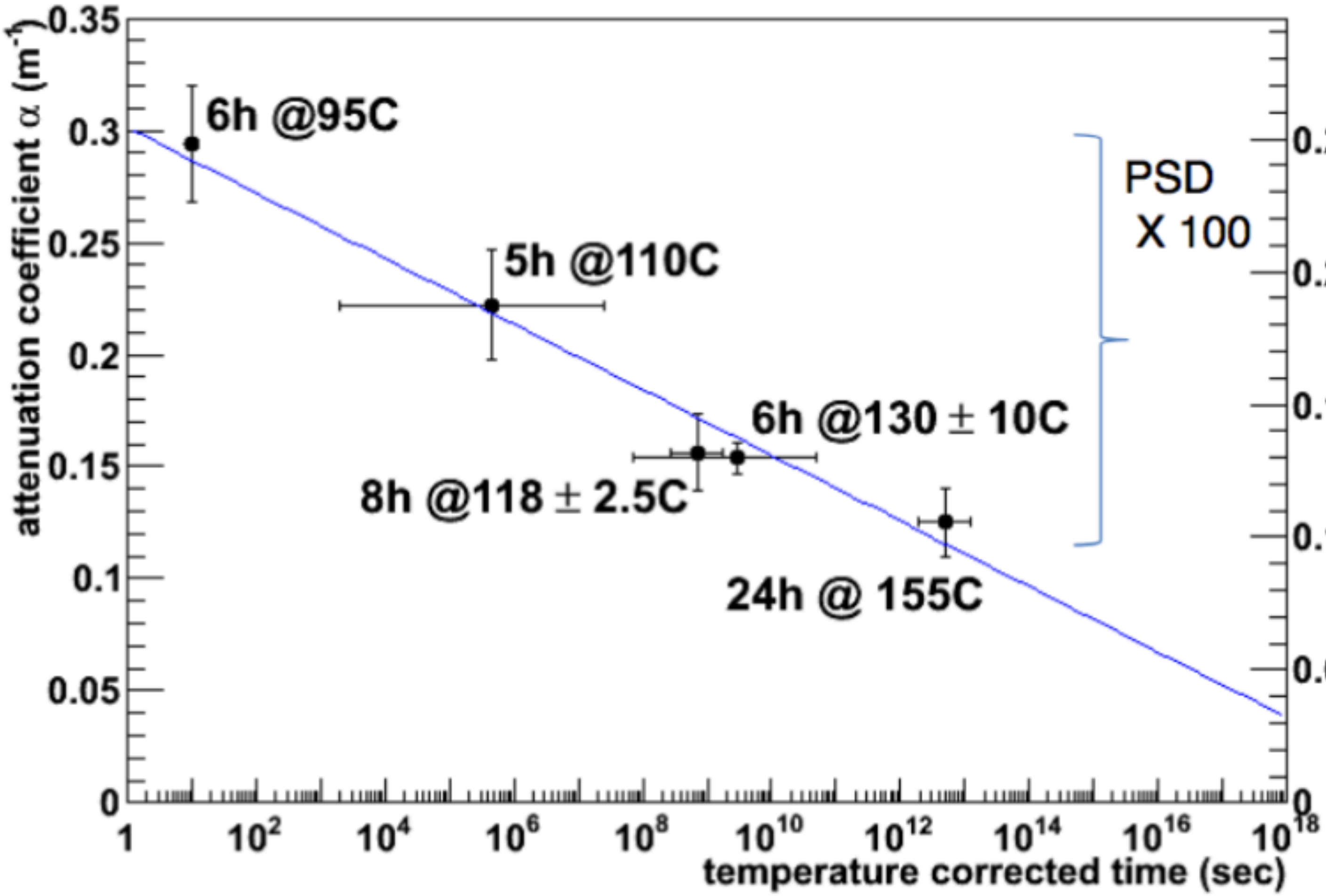


PMMA chain segment

Mean wavelength in DEAP: 440 nm

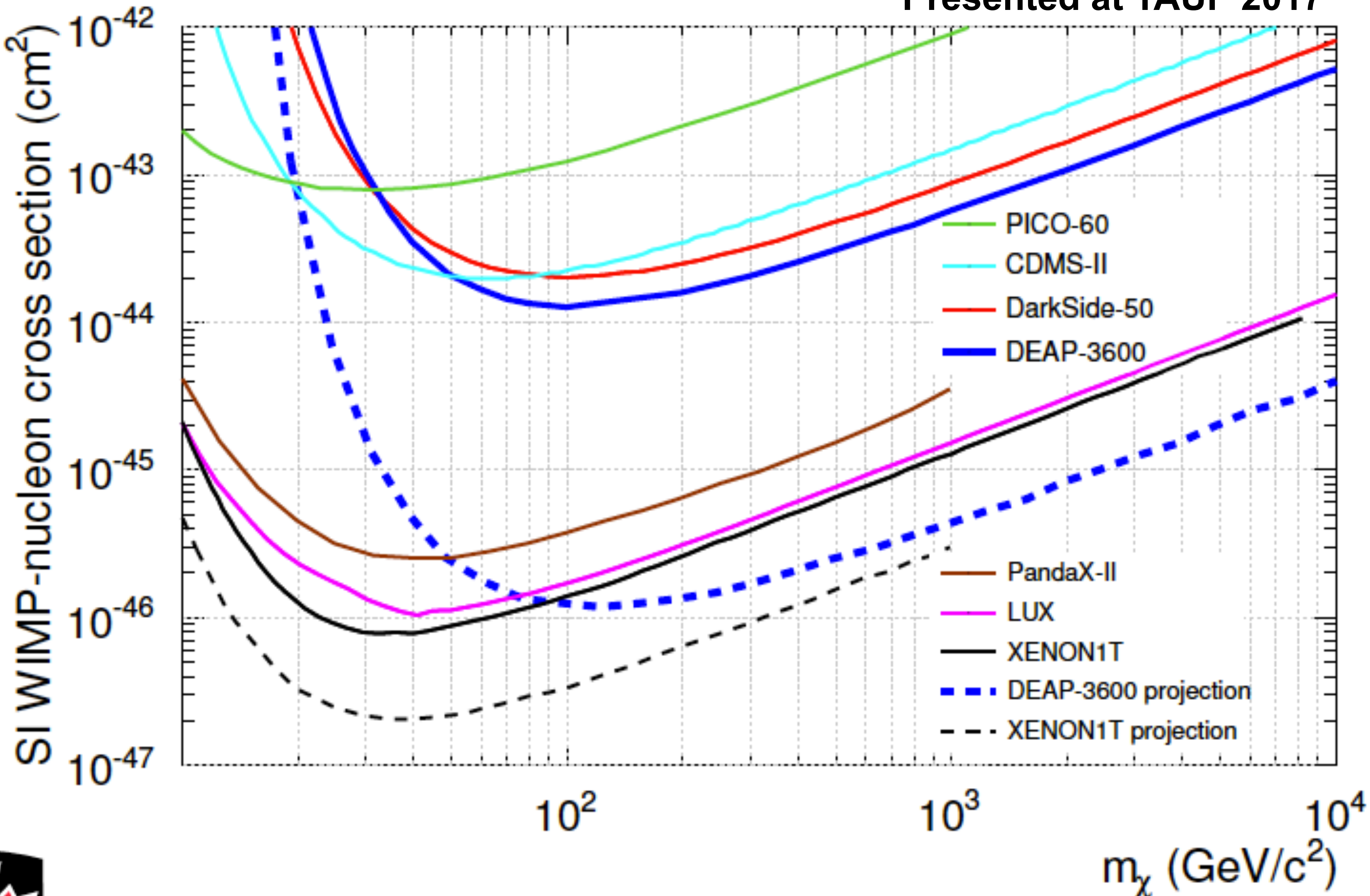
ACRYLIC ATTENUATION IN DEAP-3600

DEAP able to achieve longer attenuation lengths by annealing acrylic at high temperatures.



DEAP-3600 - RECENT RESULTS

Presented at TAUP 2017



First DEAP-3600 results submitted to PRL, arXiv:1707.08042 [astro-ph.CO]. Light yield of 7.36 PE / KeVee. Stay tuned, more results to follow!

SUMMARY

- Facility to provide ideal environment to prototype and develop the requirements needed in a future DM and NDBD experiment.

- Multi-work station design facilitates parallel development of both argon and xenon, single and multi-phase.

- Key focus on background mitigation and light collection through both direct VUV and wavelength shifters.

- Encourages collaborations of expertise from a wide range of fields both in and outside of particle physics. Please get in touch if you are interested!

Thank you for listening

Visit us at: physics.carleton.ca/apex