SiPMs in Liquid Argon Experiments

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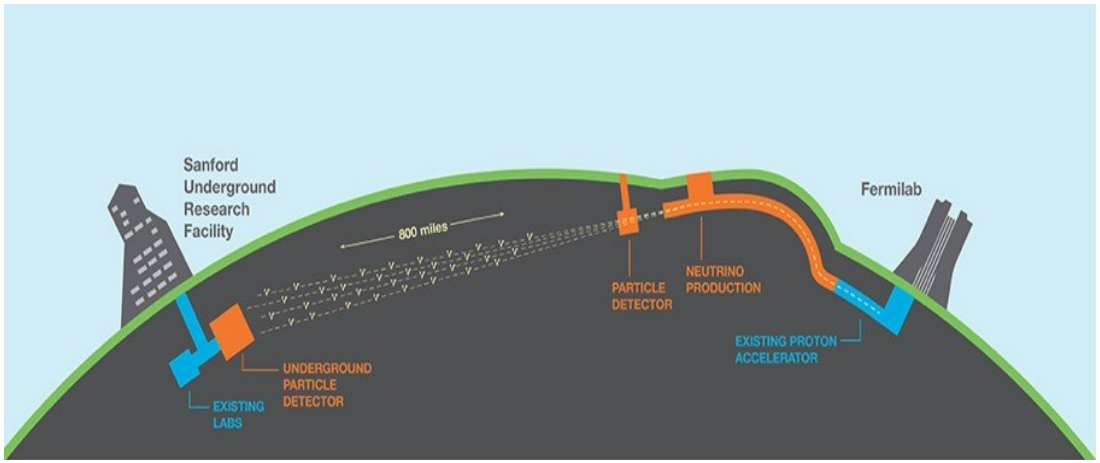
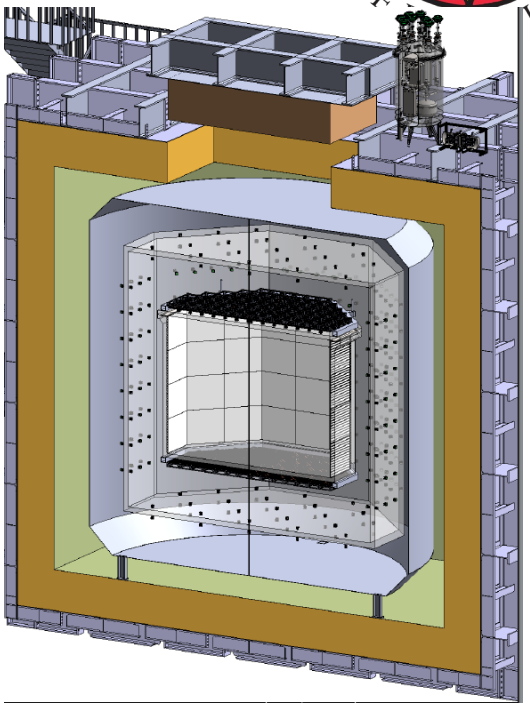
Introduction

- LAr detectors (DUNE & DarkSide-20k), and how they use scintillation light
- What we'd like light detectors to do, and how SiPMs do it.
- DarkSide-20k R&D:
  - Lowering backgrounds of SiPMs towards low-mass DM searches
  - Working towards VUV sensitive SiPMs.
- DUNE and DUNE-VD

LAr Detectors

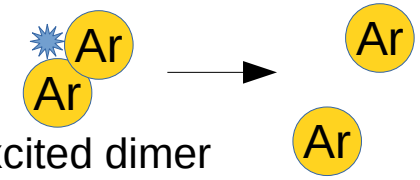




- Neutrinos / Dark Matter
- Very different energy scales
- Largest masses of noble liquids to date
- Both use SiPMs for scintillation read out.

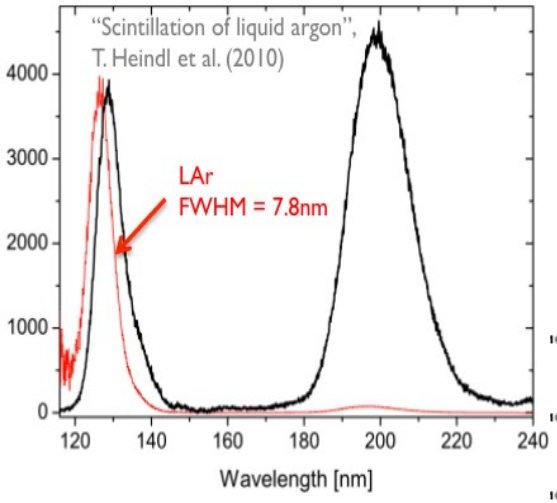
Scintillation Light in Argon

Emission:



Excited dimer state

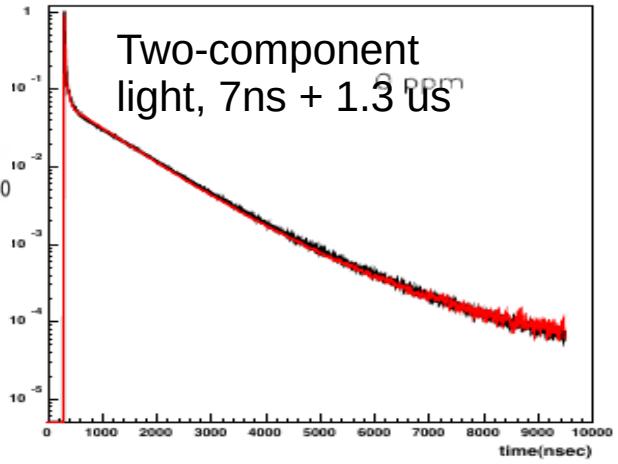
Photons are all ~128 nm – VUV



Transport:

Liquid argon is mostly transparent to its scintillation.

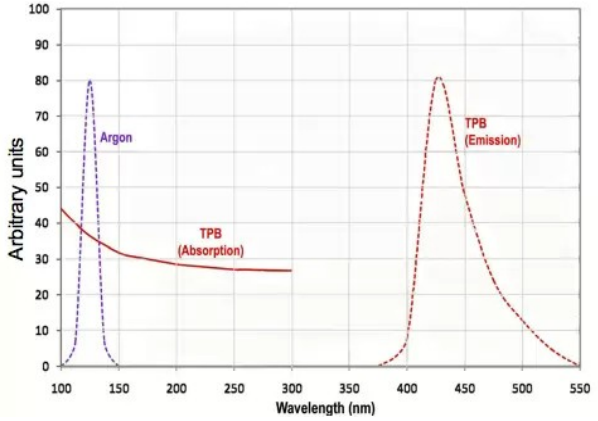
At longer distances Rayleigh scattering ~50-100cm f(λ) and absorption, e.g. on nitrogen ~30 m @2ppm N_2 begins to play a role. Note high refractive index ~1.5 for VUV.



Detection:

Liquid argon is almost the only thing transparent to its scintillation.

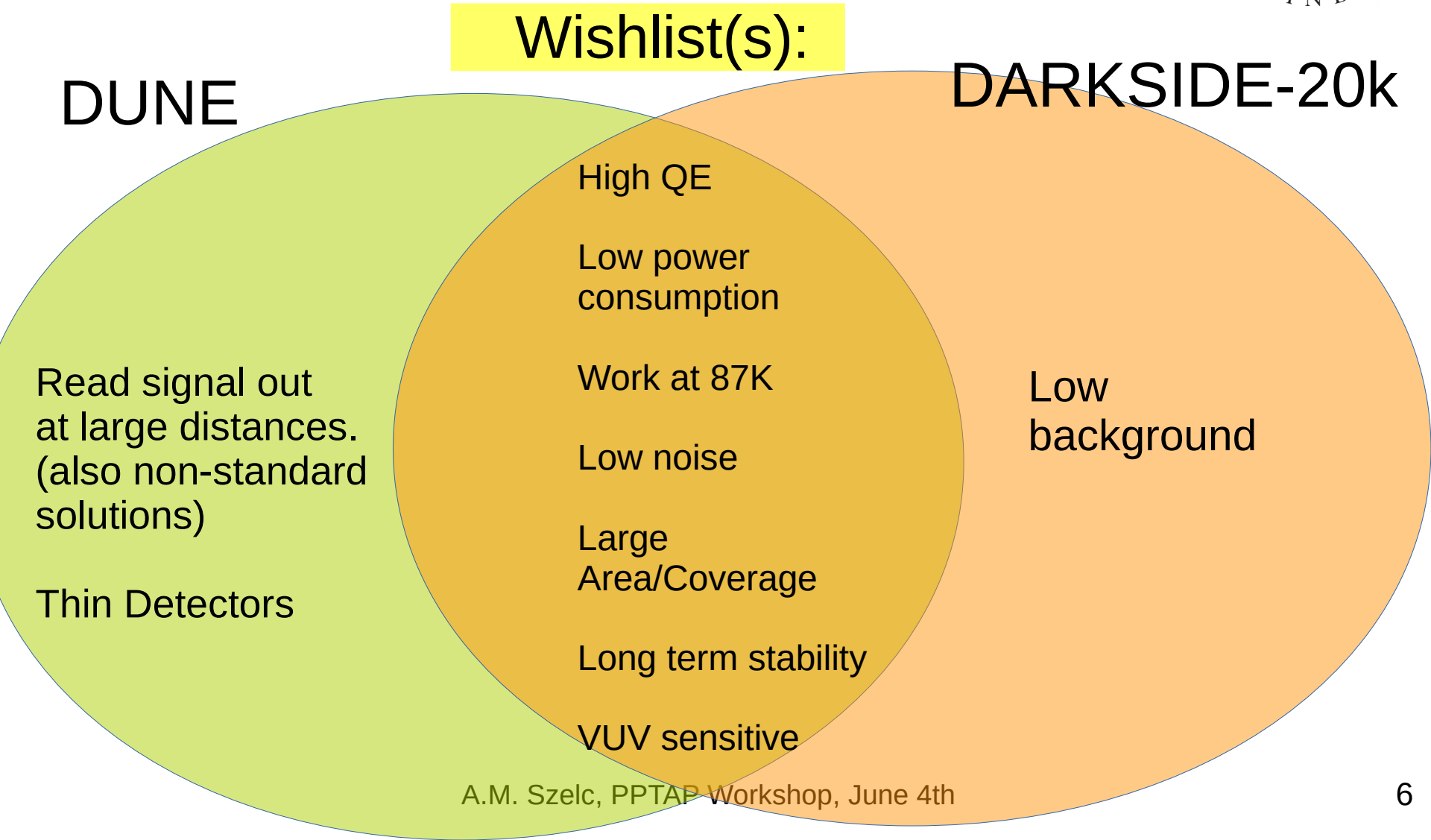
Detection is challenging – most often need to use Wavelength shifting compounds, like TPB/PEN



LAr Scintillation Light Applications

- Dark Matter:
  - Primary channel,
  - S1, S2 detection, used for calorimetry, position resolution, particle ID.
  - Need sensitivity to as low energies as possible – maximize LY (PDM coverage + Detector walls coated with TPB/PEN)
- Neutrino Detectors:
  - Supporting Channel
  - Non-beam trigger, timing, position reconstruction, calorimetry.
  - Interesting energy range above few MeV (usually)
  - Usually only PD coated in WLS. (SBND cathode coated in TPB)

SiPMs as light detectors (in large LAr experiments)



LAr SiPM R&D in the UK

PUBLISHED: *October 6, 2008*

Characterisation of a silicon photomultiplier device for applications in liquid argon based neutrino physics and dark matter searches

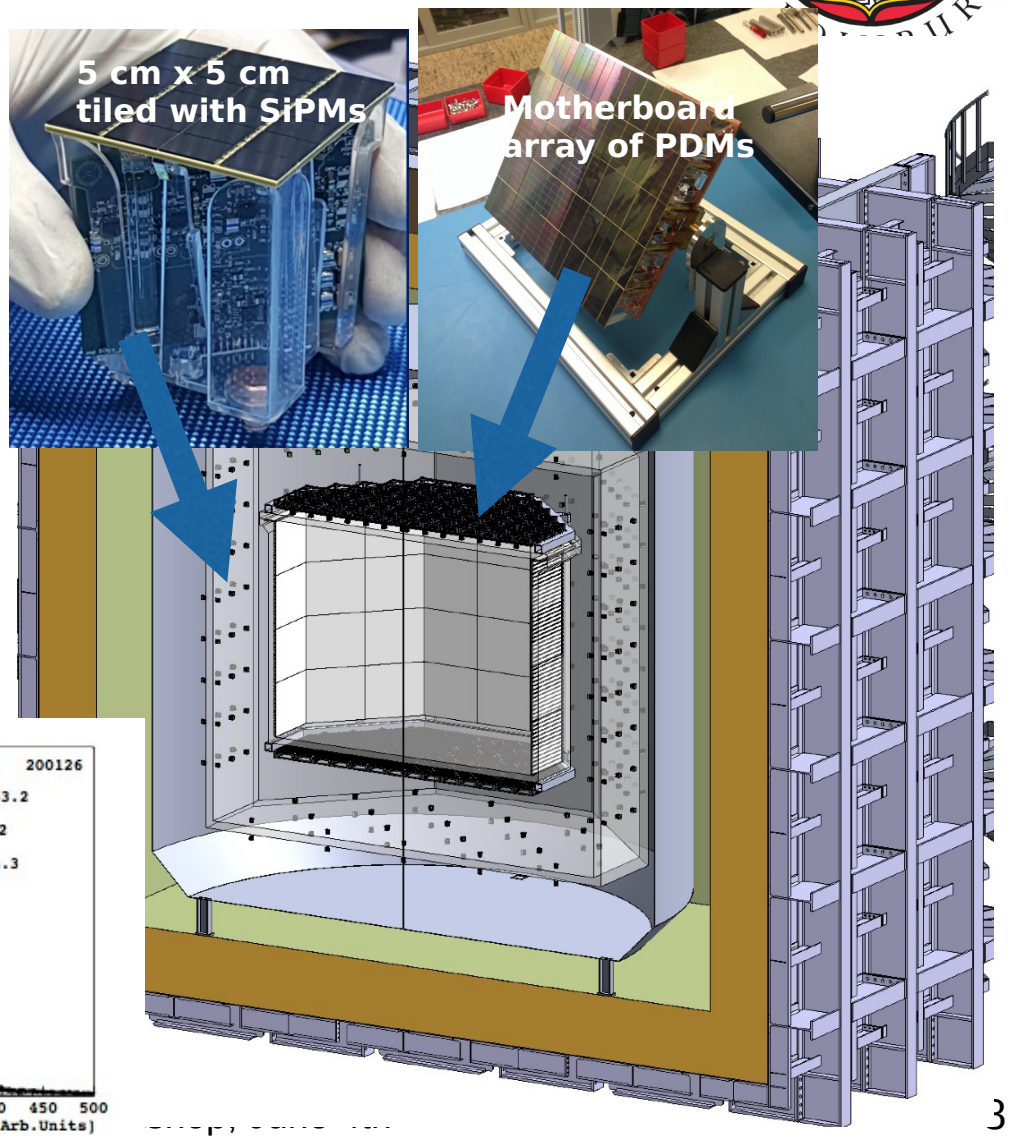
P.K. Lightfoot,[a*] G.J. Barker,[b] K. Mavrokoridis,[a] Y.A. Ramachers[b] and N.J.C. Spooner[a]

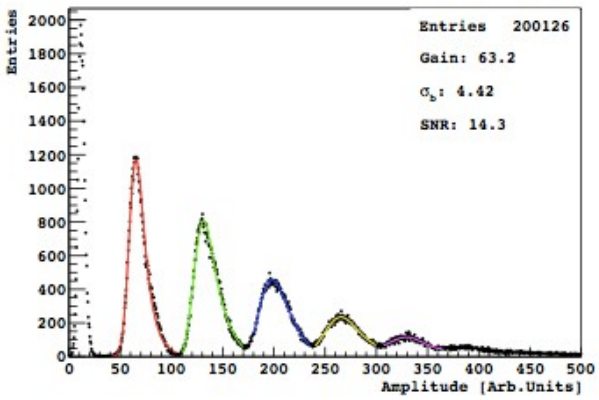
2019 STFC Dark Matter Strategic Review:

"The development of SiPMs for future large-scale direct-DM searches using noble gases provides the opportunity for the UK to invest in early R&D in order to achieve technological leadership in any future next generation experiment. R&D would focus on the design, production and testing of large SiPM tile arrays including electronics. The creation of a common R&D SiPM UK DM consortium with an integrated and coherent programme, would avoid duplication of effort. It is expected that this would result in cost savings and a more efficient use of resources for the two noble-gas technologies based on argon and xenon. A single entity would also likely boost collaboration with UK industry."

DarkSide PDMs

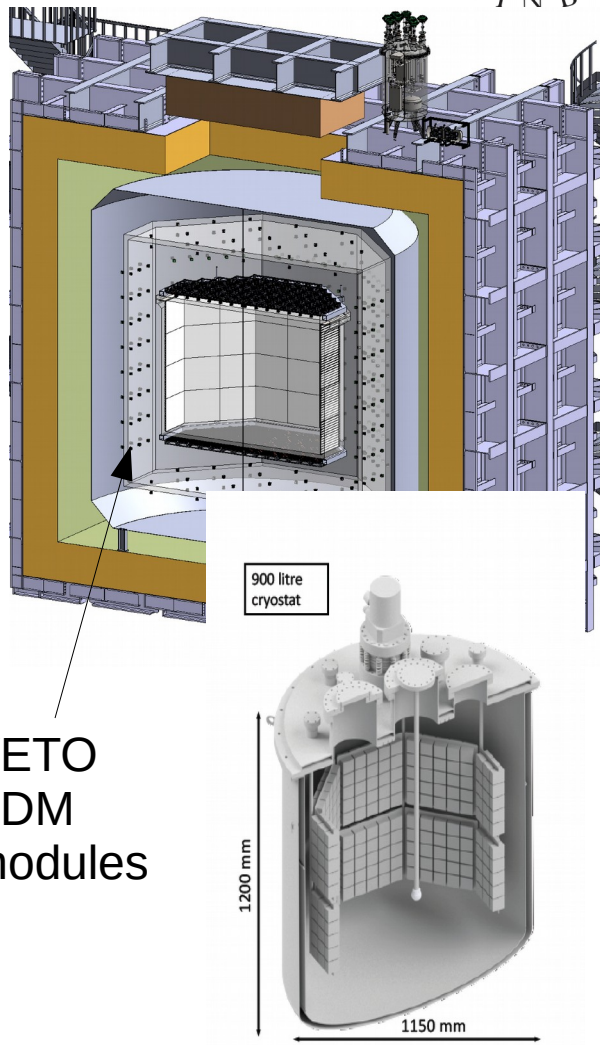
- PDM size 25cm^2 comparable to 3” PMT.
- High efficiency, less material (less radioactive backgrounds)
- developed in collaboration with FBK
- Current state of the art in terms of Cryogenic SiPM detectors.





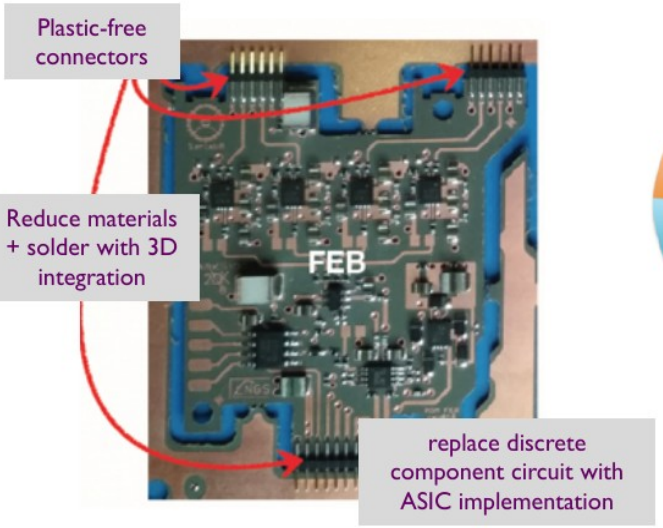
UK DarkSide SiPM R&D

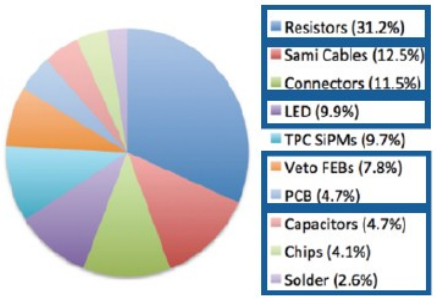
- Building up capability for large scale production by constructing and testing a large fraction of the DS VETO PDMs:
  - 25 sensors packed into a PDM.
  - UK will produce ~3k PDMs.
- R&D on lowering the radioactivity of the PDMs towards next generation experiments.
- R&D on various methods to increase SiPM VUV sensitivity.

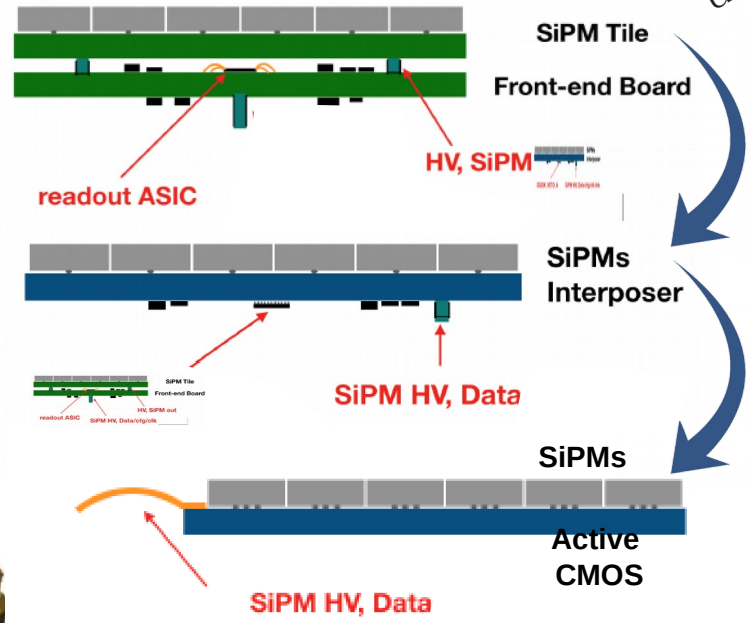


VETO PDM modules

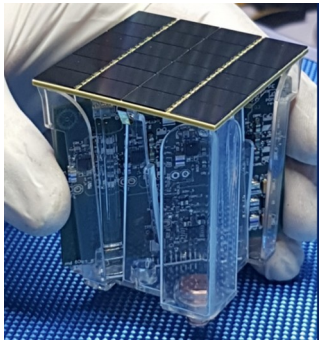
Lowering Radioactivity



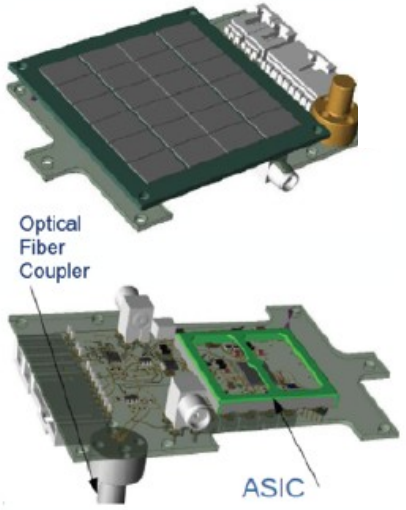




Current DarkSide PDM

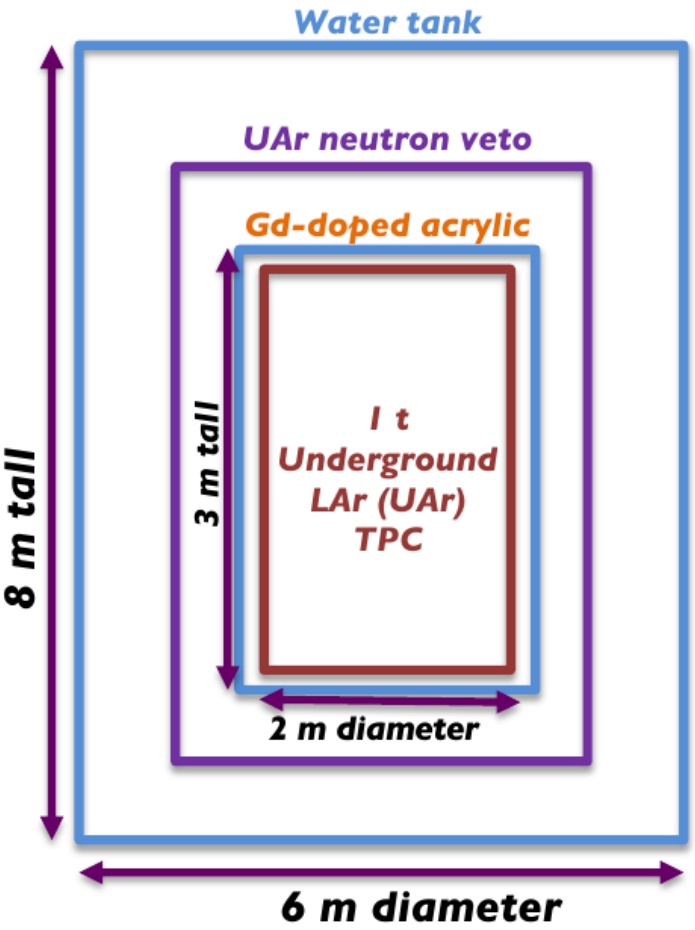


Front-End Board (FEB)

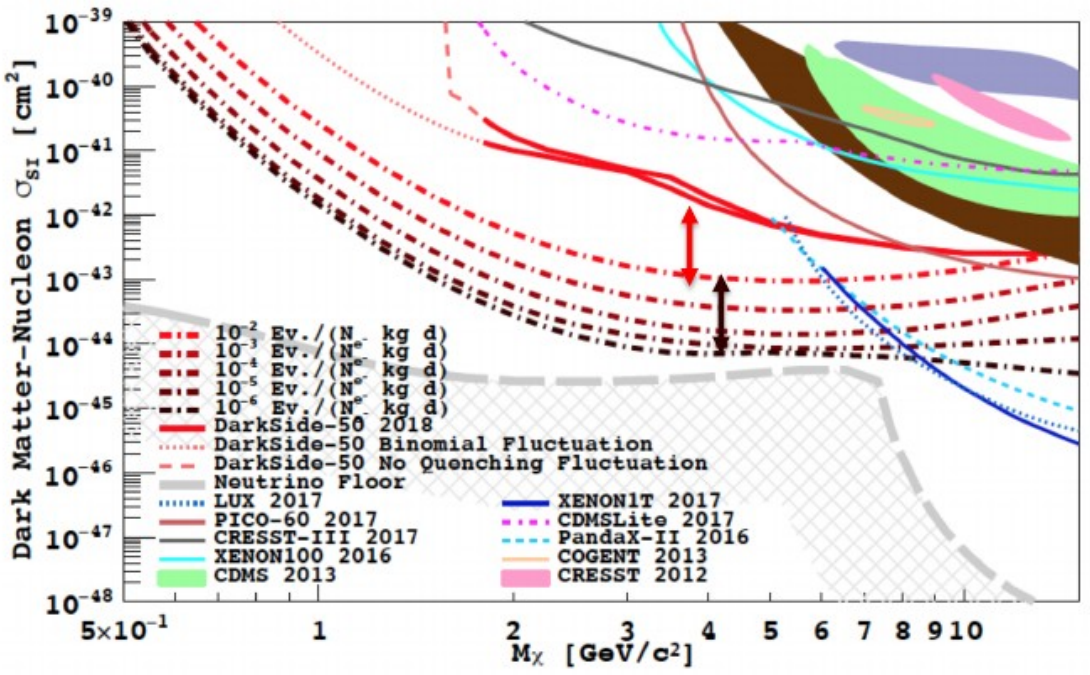


Goal next generation PDM with much better radio purity

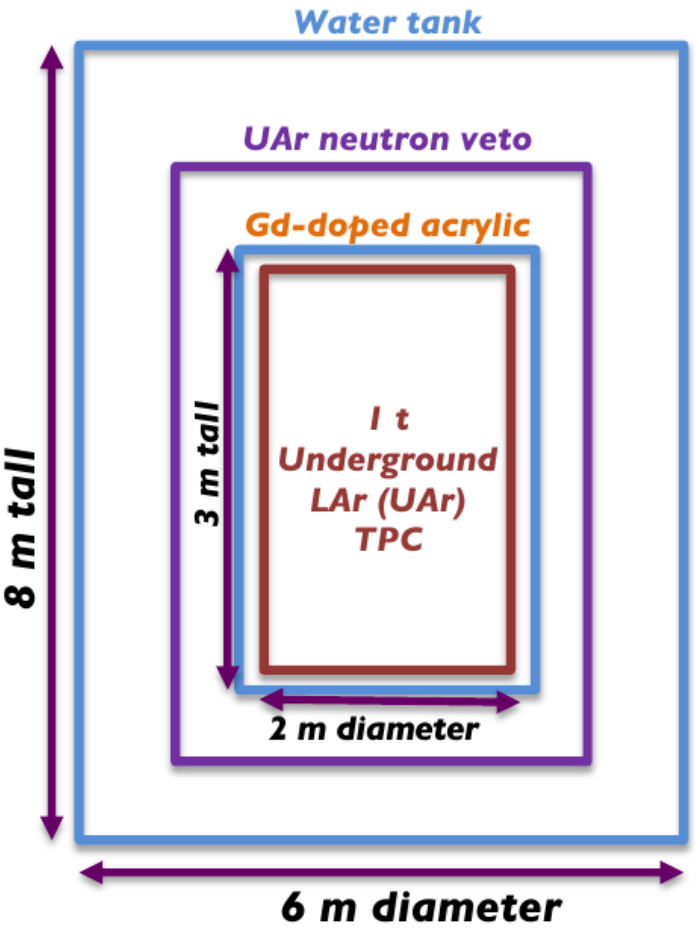
Benefits of radio-purity: DarkSide-LM



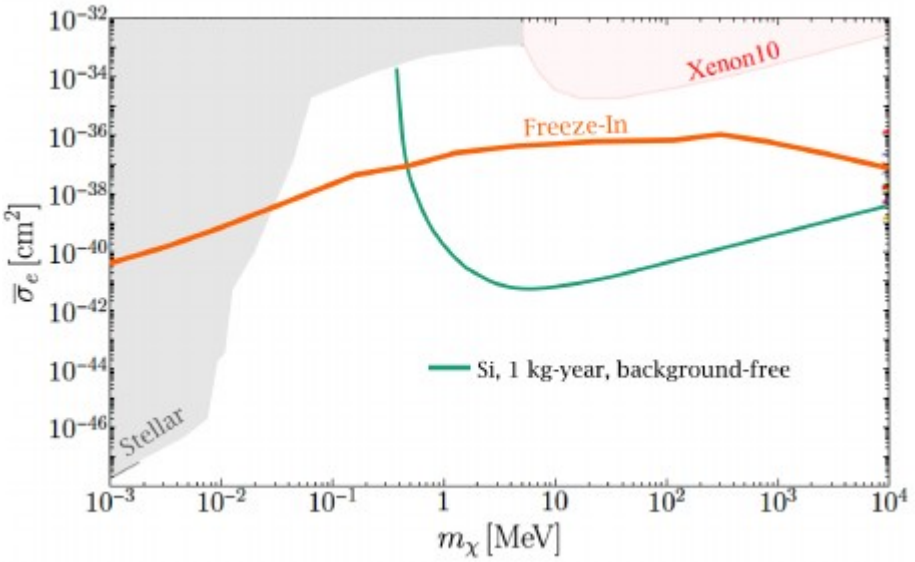
- Ultra-pure SiPMs enable S2-only searches for low mass WIMPs.
- World leading limit after 2 years of running.
- Boulby a possible site.



Benefits of radio-purity: DarkSide-LM



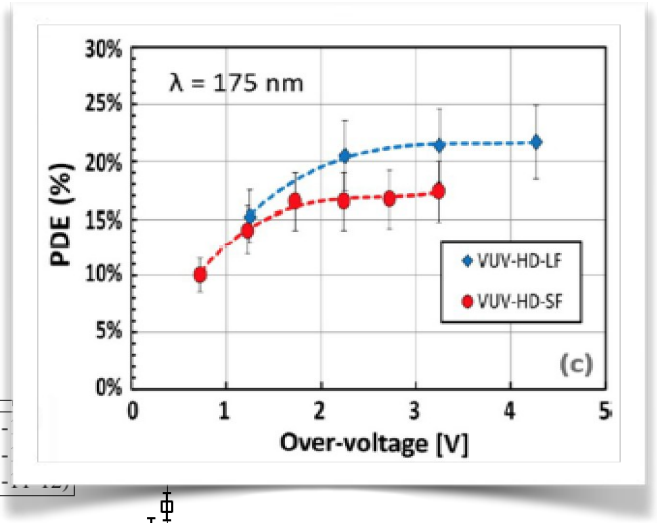
- Ultra-pure SiPMs enable S2-only searches for low mass WIMPs.
- Can use SiPMs themselves as target mass.
- 1kg of Si mass in the readout system gives sensitivity to low mass dark photons.



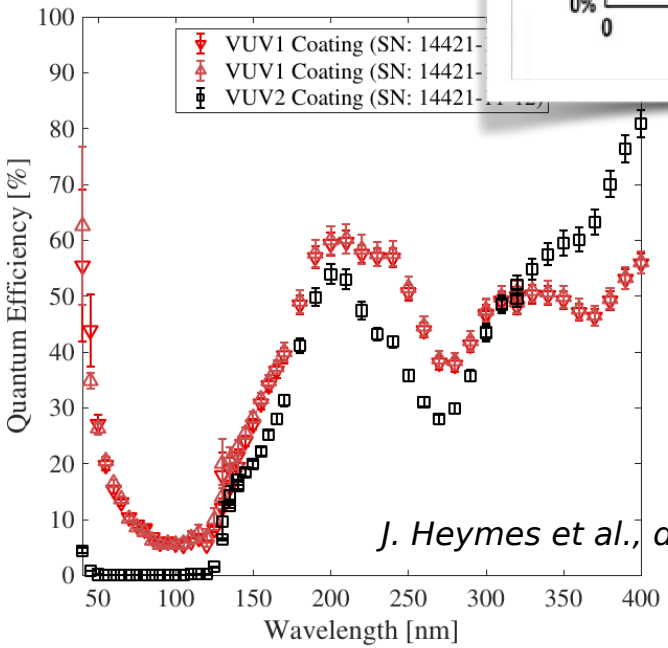
R&D towards VUV sensitivity

- Reflectivity and absorption length are the main culprits of low QE.
- Two main avenues of approach: passivation: and anti-reflective coatings (wavelength optimized)
- Backside-illumination as a solution
- High QE demonstrated for CCD devices.

A. Gola, Instruments 2019, 3, 15



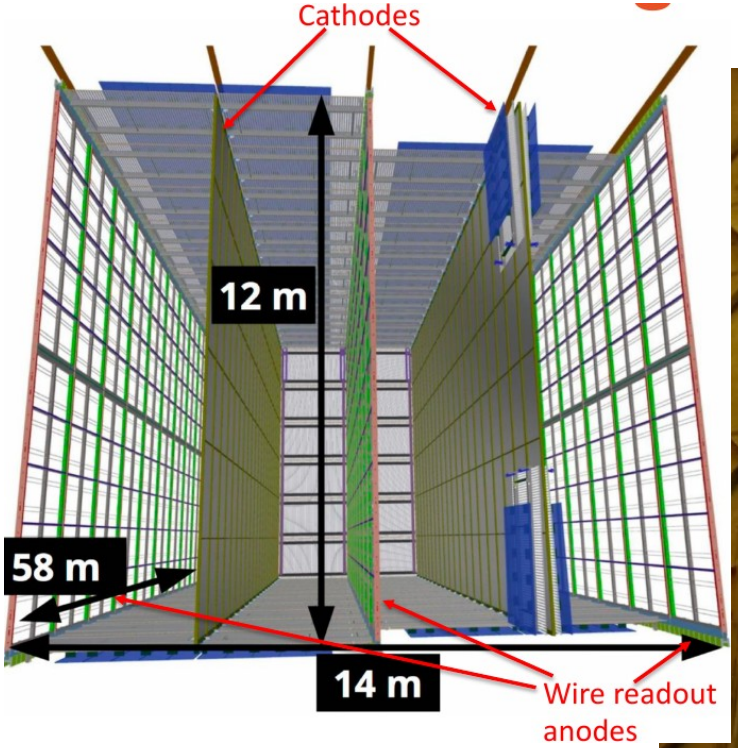
- Implementing in SiPMs is a big R&D item – too big to be done by one project. Needs international cooperation and across projects.
- Talks started with Canadian groups, e2v-Teledyne and FBK.

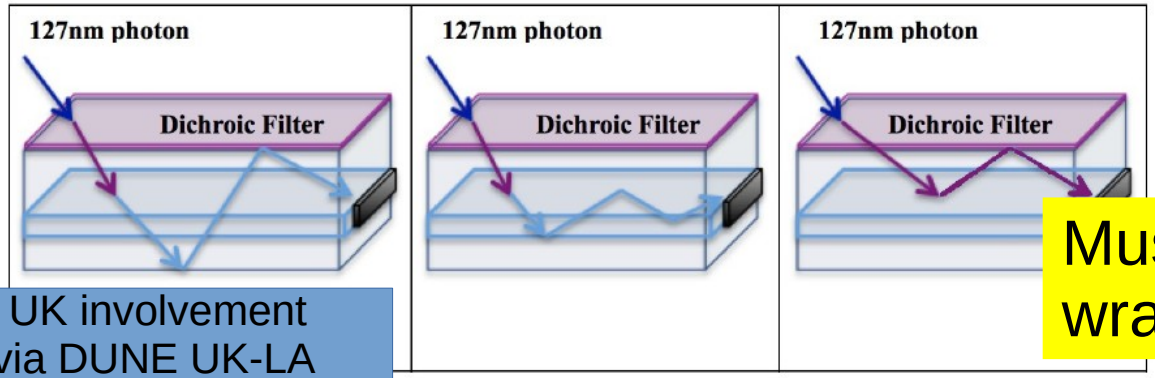


J. Heymes et al., doi.org/10.1117/12.2559711

DUNE SP Light Detectors

- X-ARAPUCA design:
  - Enable detection of VUV light.
  - increase photocathodic coverage, without increasing number of channels.



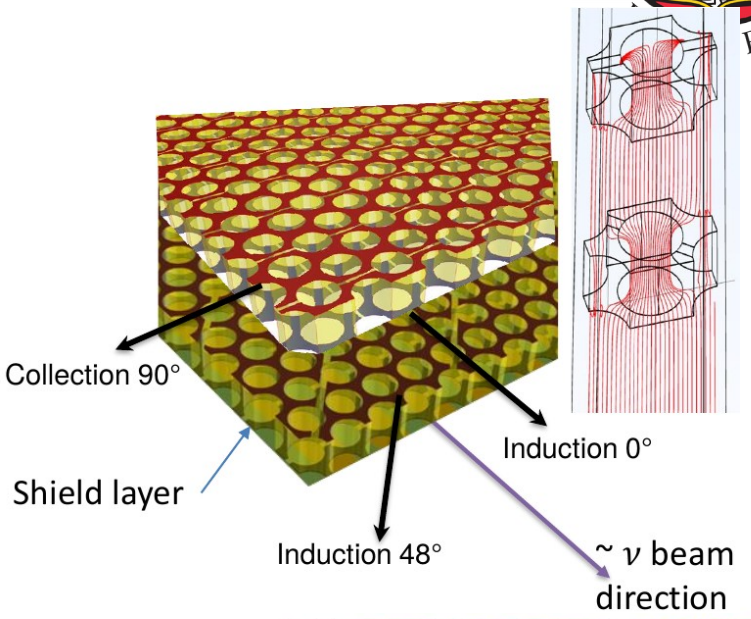


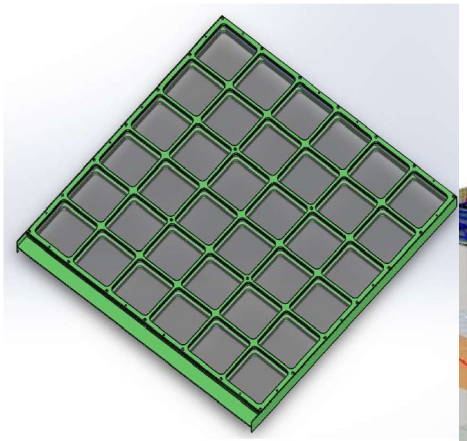
Must fit inside wrapped wires.

UK involvement via DUNE UK-LA initiative

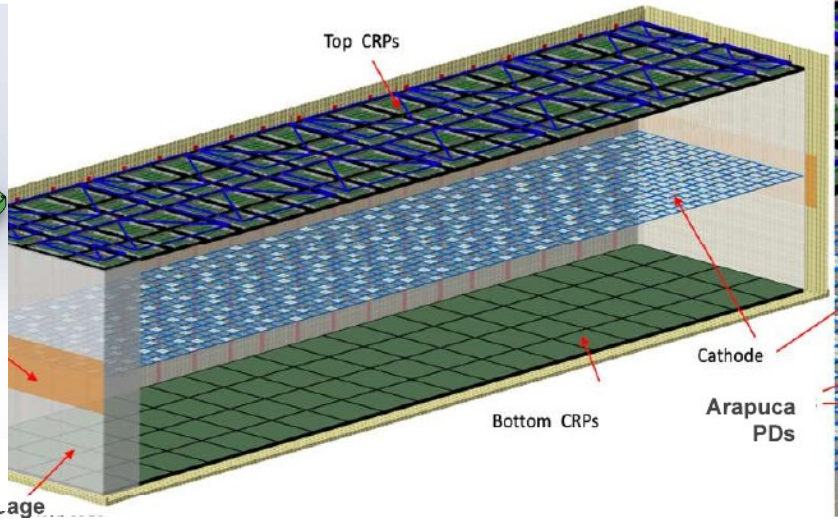
DUNE-VD

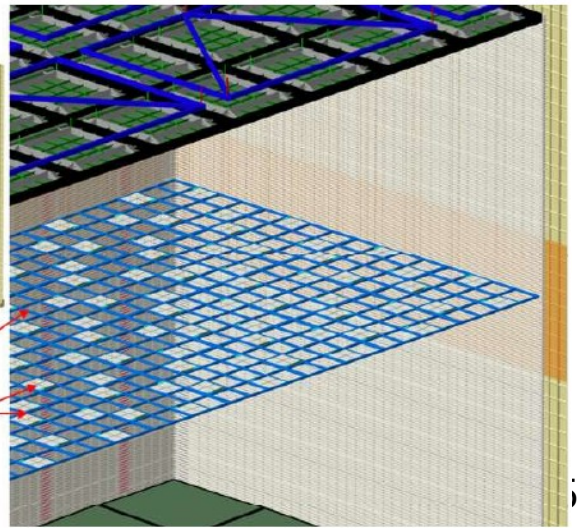
- New design of charge readout. Non-transparent anode.
- Proposed readout via large ARAPUCA's on the cathode – need to be clever with power and signal readout.
- UK R&D effort to develop sealed warm electronics for SiPM readout.





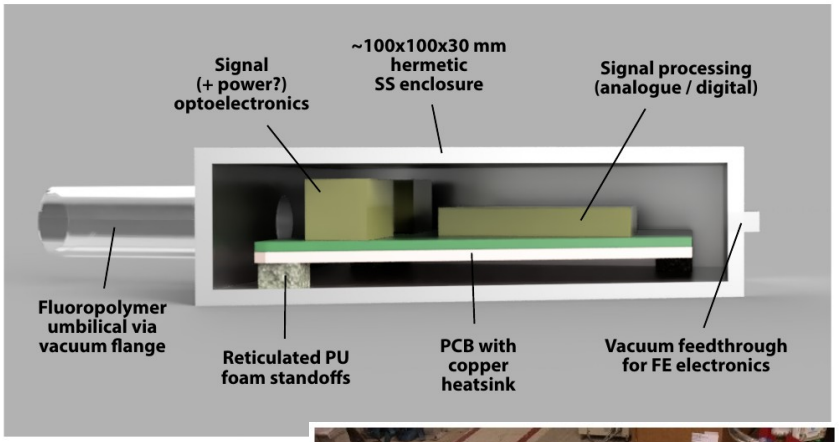
- Total active area ~3600mm^2 (X2 sides)
- 160 SiPMs (40 per side)





DUNE VD electronics

- Concept based on space -missions
- Electronics sealed inside vessel. Temperature self-regulating via heat dissipation.
- Don’t need to worry about cryo performance of electronics.
- Promising results already (RAL + Bristol)



Summary

- SiPMs are already the detectors of choice in liquid argon experiments currently being built (DUNE, DarkSide-20k).
- UK has an opportunity to build up infrastructure to ensure leadership in the next generation of experiments (ARGO, DUNE MoOD, also VD).
- R&D ongoing to improve the performance of SiPMs in terms of radioactive contamination and VUV sensitivity.

Thanks to Jocelyn Monroe, Dave Newbold, Darren Price, Julian Heymes for providing material.