SiPMs in DUNE ND complex

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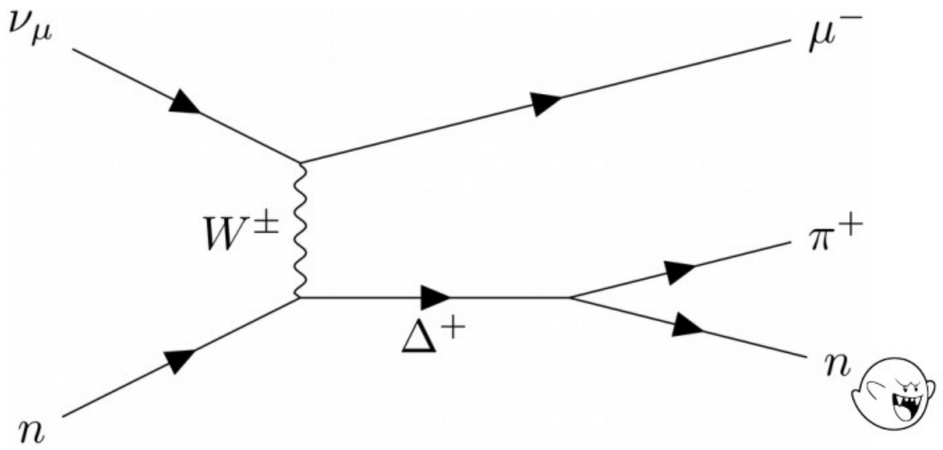
SiPMs in ND

- Used extensively in
  - ArgonCube
  - MPD ECAL
    - In all configurations discussed
  - MPD Muon tagger
    - If we use scintillator
  - 3DST
    - Active target
    - ECAL
  - KLOE
    - ECAL upgrade?

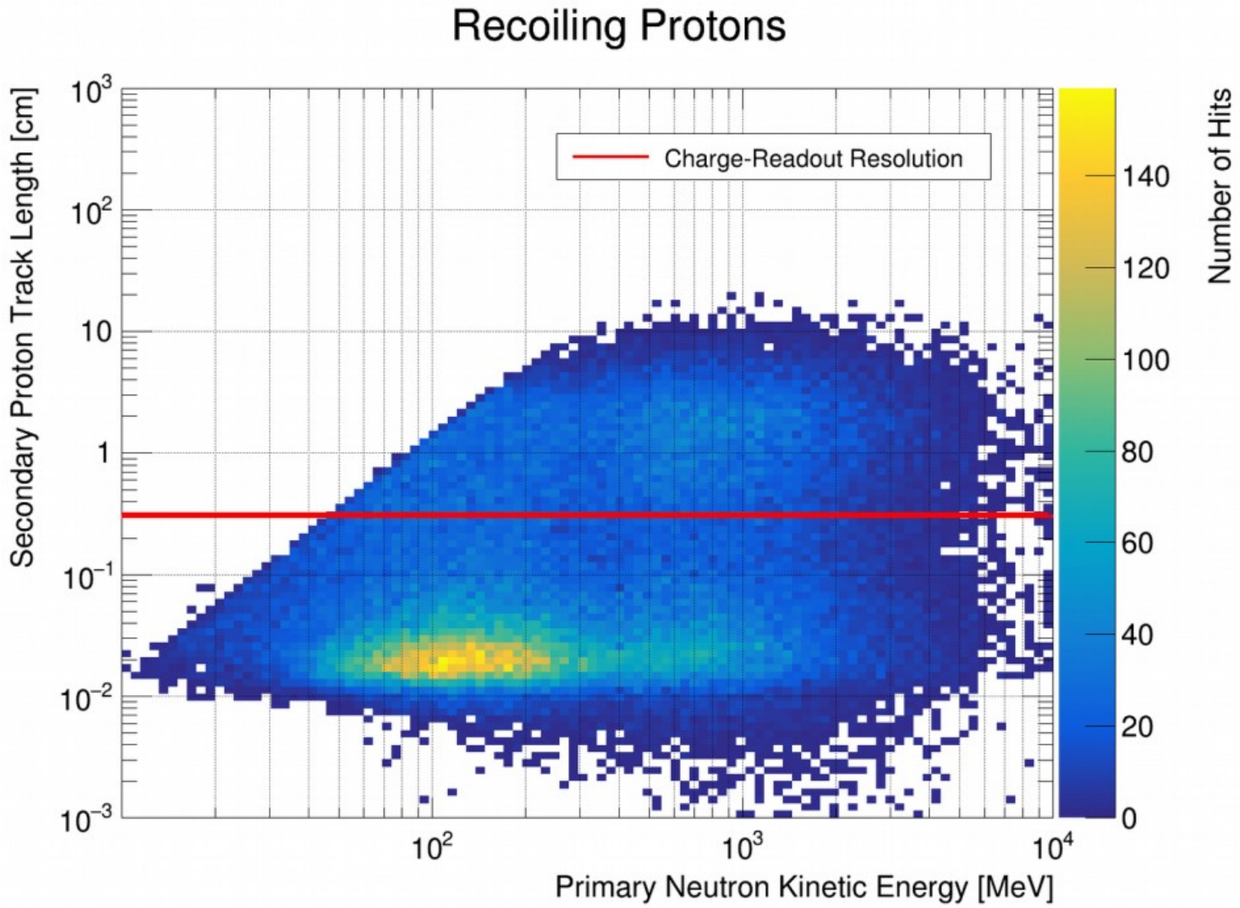
Why fast Light R/O in LAr? - Fast Neutron Tagging

Studies from Patrick Koller.



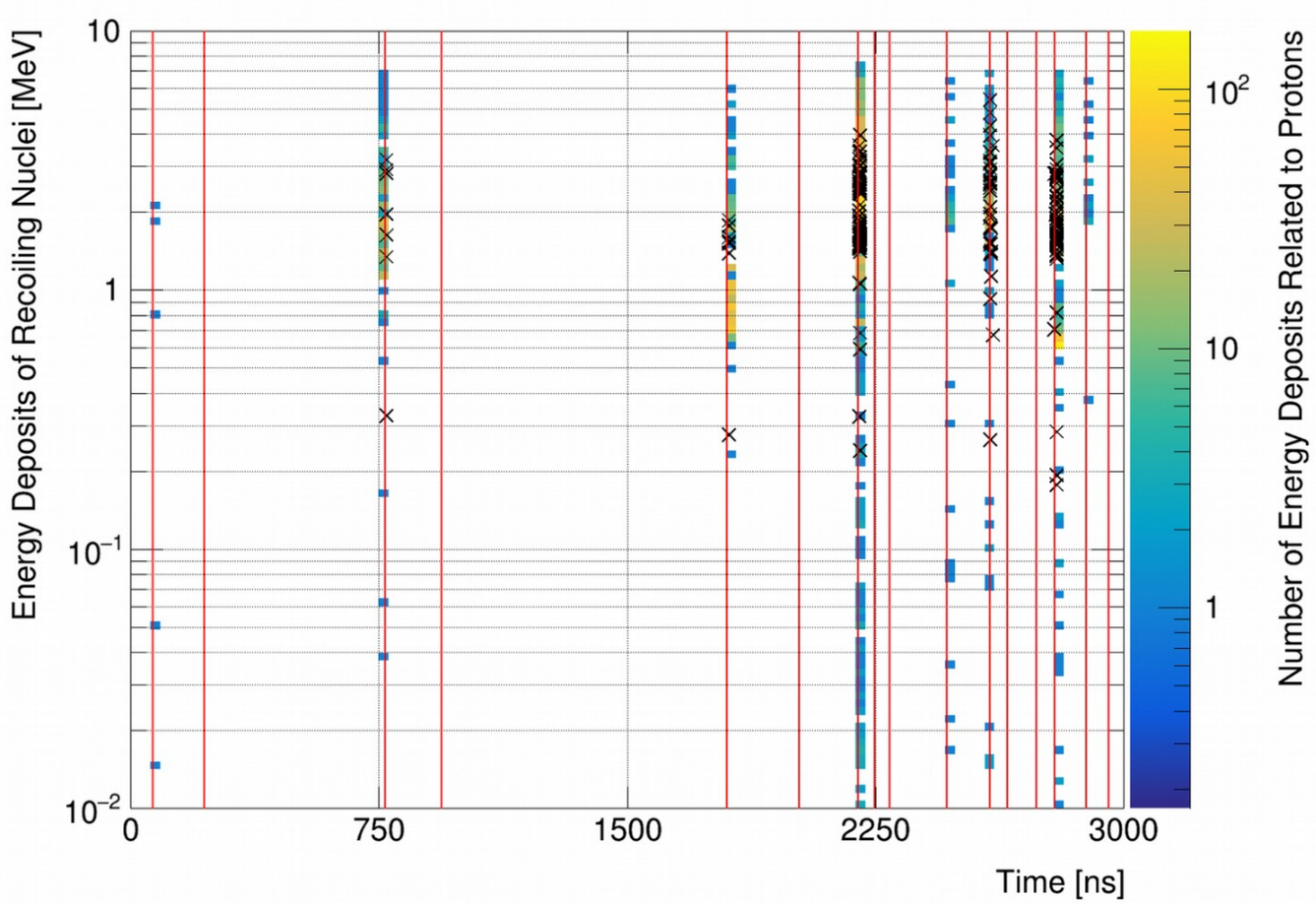
$$E_{\nu,reco} = \underbrace{E_\mu}_{leptonic} + \underbrace{\sum_{i=p,\pi^\pm} E_i}_{hadronic} + \underbrace{\sum_{i=\pi^0,e,\gamma} E_i}_{EM-showers} + \underbrace{\cancel{\sum E_n}}_{neutrons}$$

Hadronic showers can also fluctuate to neutrons

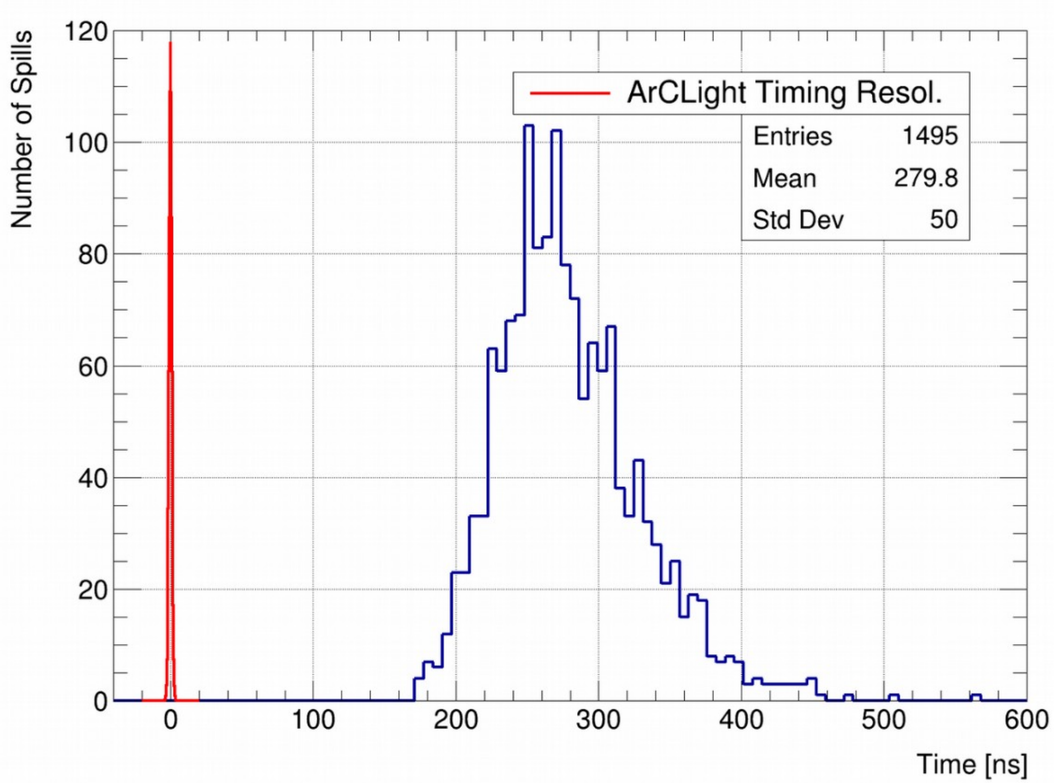


Tracks from recoiling protons at neutron energies > 50 MeV (~30% of all recoiling protons)

Neutrino Vertex Temporal Separation



1/3 of a 1 MW 3 horn optimised, FHC spill
Temporal separation of neutrino events (red), recoiling protons(coloured), and nuclear recoil (X)



The mean temporal separation of vertices in a spill

Use prompt light from protons and vertex to associate fast neutrons with correct neutrino.

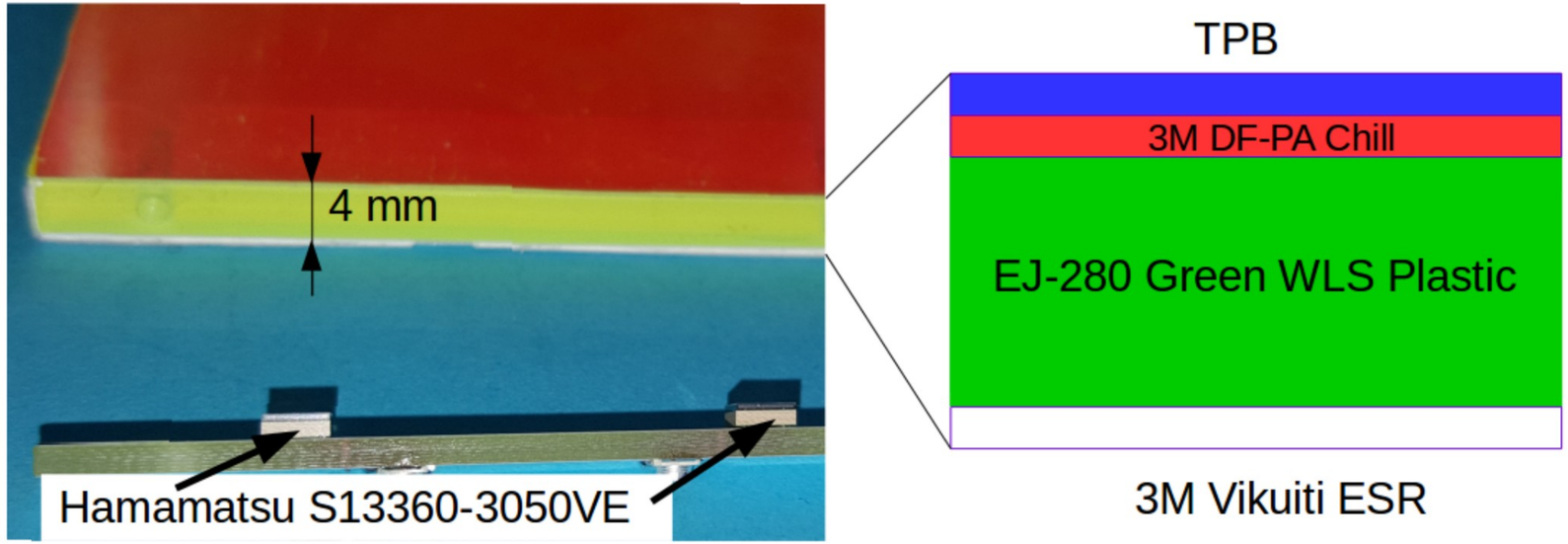
Light Readout - ArCLight

A compact dielectric light R/O: ArCLight(arXiv:1711.11409).

The dielectric bulk can be deployed within the TPC, covering a large area.

Successfully operation in test beam at FNAL. Further characterisation in progress.

Spatial resolution requirements of fast-neutron tagging will be used to optimise dimensions.



ArCLight cross-section

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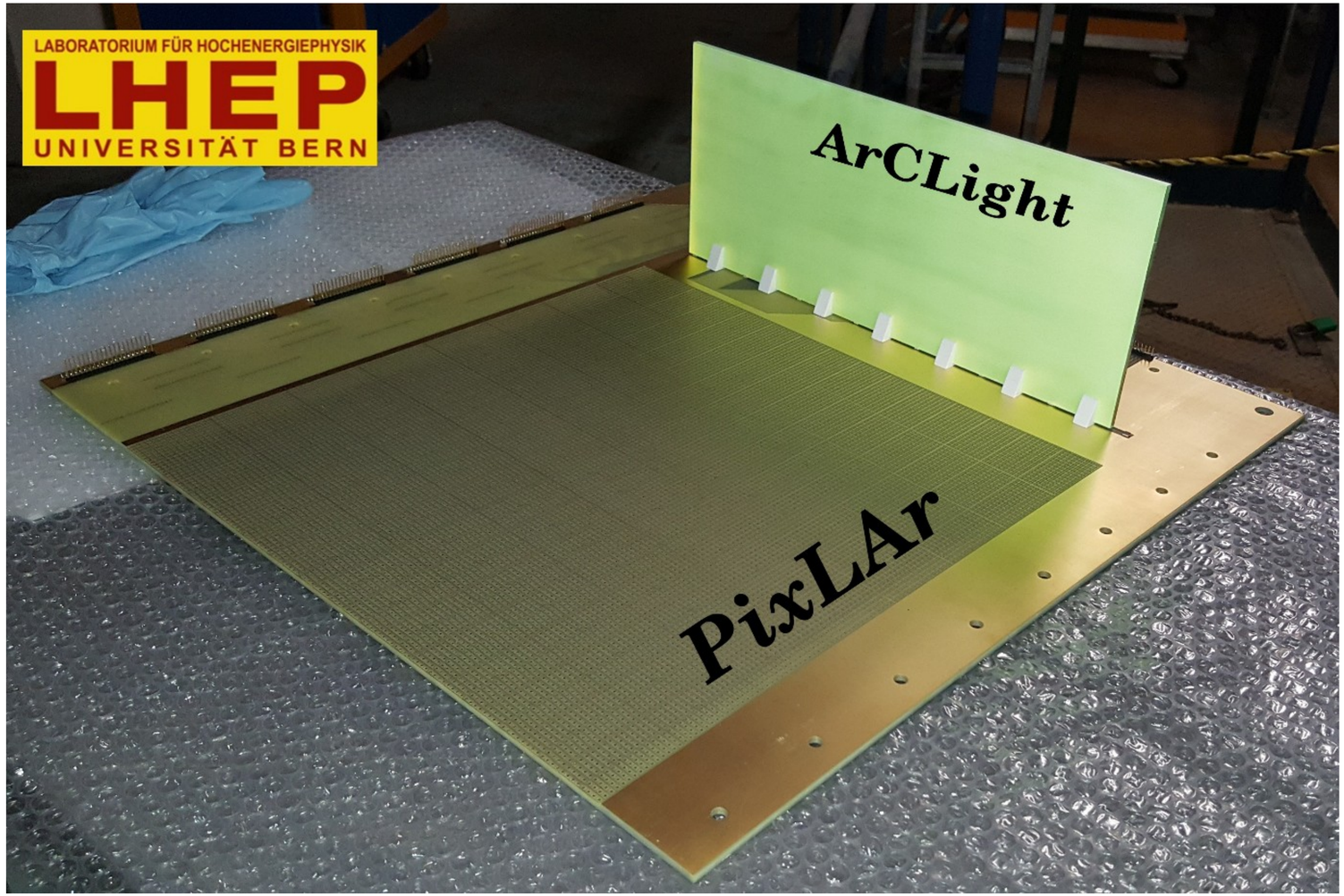
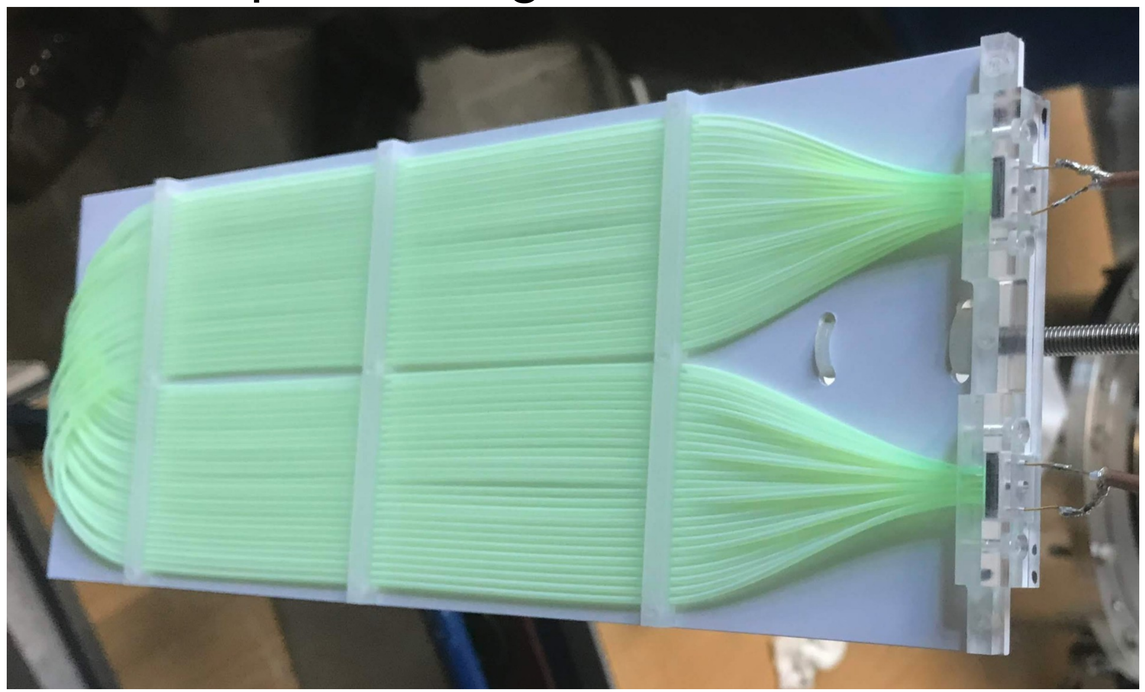


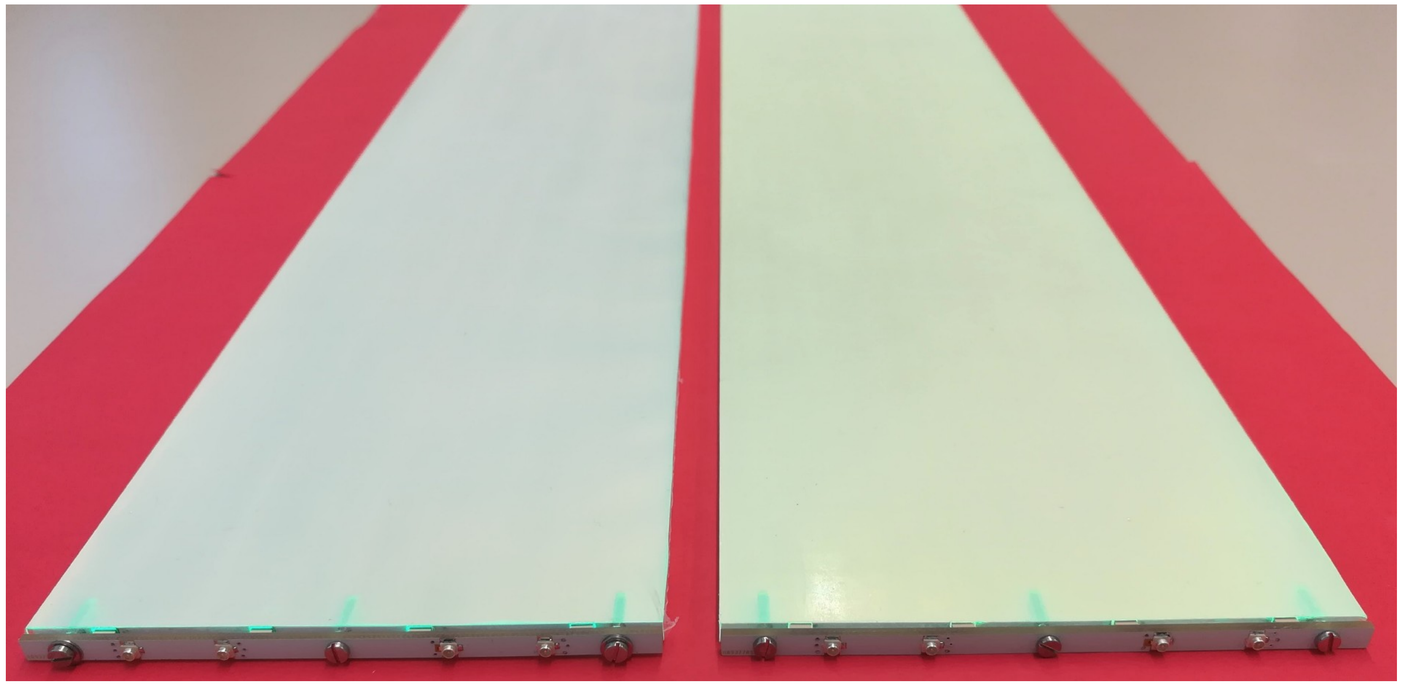
ArCLight mounted on one half of the PixLAr pixel plane

Light Readout

Two complimentary, functionally identical, SiPM-based systems currently being developed for ArgonCube:



Dubna's Light Collection Module,
TPB coated annealed WLS fibres.
120 SiPMs per ArgonCube ND TPC



Bern's ArCLight, TPB coated dichroic film on WLS plastic.
120 SiPMs per ArgonCube ND TPC

A Possible Alternative

As suggested by Nygren & Mei (arXiv:1809.10213): SiPMs mounted on the anode plane, facing the LAr directly.

To achieve similar efficiency as typical WLS(0.1%PDE), a sufficient area of anode must be covered with SiPMs.

Hamamatsu VUV4 show 10% PDE at 128 nm (arXiv:1903.03663, ICHEP2016 ID450), therefore 10% of the charge readout has to be covered with SiPMs.

For single ArgonCube ND TPC readout plane is 3 m^2.
→ 0.3 m^2 of SiPMs, at 3 mm x 3 mm package gives 33.3k SiPMs

Total detector has 70 TPCs → 2.3M SiPMs (at cost per unit ???)
Mu2e $5/each 2X2

**SiPMs on anode require digitisation at anode, to avoid cross talk with charge R/O
→ new cold ASICs

A Possible Alternative

It is also possible to dope LAr with Xe, which shifts florescence to 174 nm (Citation??)

At 174 nm, Hamamatsu VUV4 show ~25% PDE (ICHEP2016 ID450), therefore only 4% of the charge readout has to be covered with SiPMs.

A single ArgonCube ND TPC readout plane is 3 m^2.

→ 0.12 m^2 of SiPMs, at 3 mm x 3 mm package gives 13.3k SiPMs

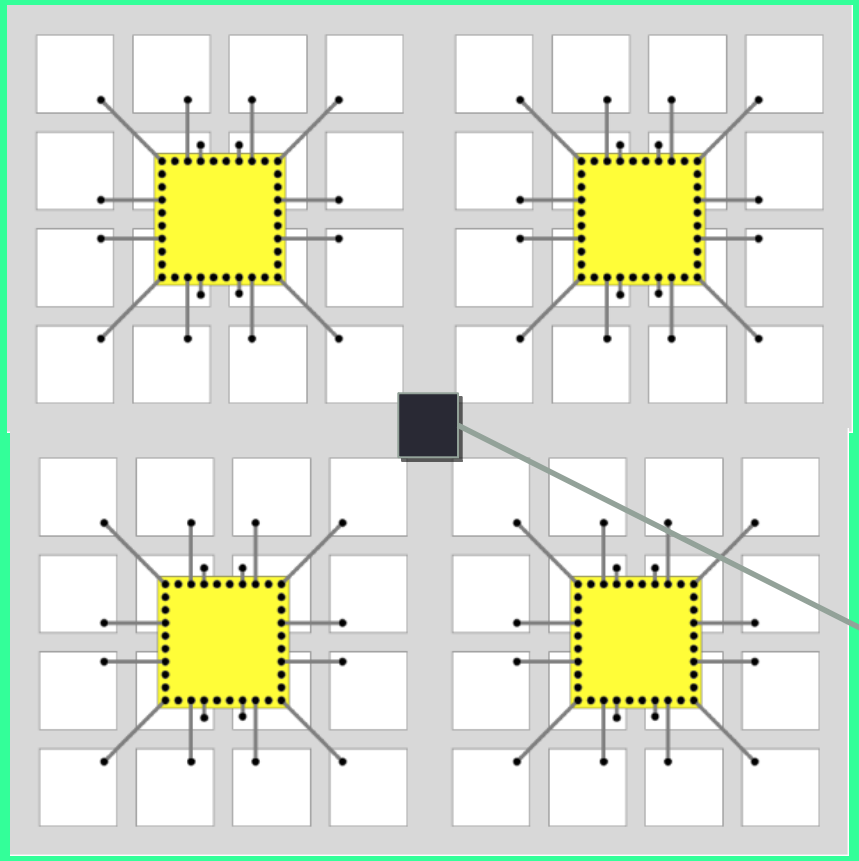
Total detector is 70 TPCs → 933.3k SiPMs

**Xe doping reduces the slow component of scintillation, but also degrades the prompt (Citation?)
→ Useful for nucleon decay in the FD, but could limit fast neutron tagging in the ND

Novel ideas for PDS: SiPMs alone

Courtesy of Vishnu Zutshi, NIU/NICADD

Minimizing Shifting & Maximizing Coverage?



~ 3.2 cm

Would need a transparent or semi –transparent (to shifted light) dielectric “wall” which contains the pixel buttons

Could then, in principle, have a 3.2 cm x 3.2 cm “tile” readout with a SiPM

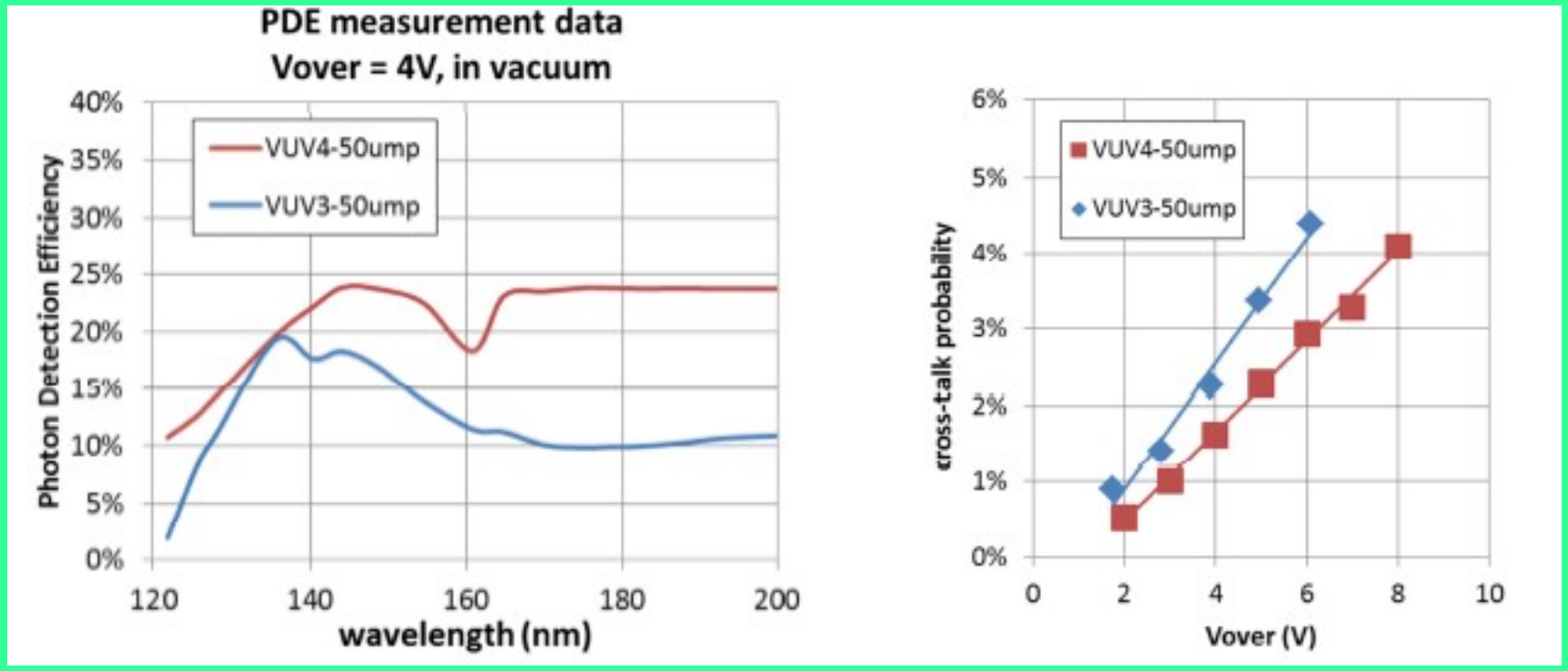
Is there a sensible way to optically segment the dielectric wall?

The ASIC/SiPM PCB could silk-screened or have a reflective foil glued to it

SiPM (6mm x 6mm or 3mm x 3mm)

Novel ideas for PDS: SiPMs alone

Courtesy of Vishnu Zutshi, NIU/NICADD



A double-sided bar can basically be replaced by ~125 6mm x 6mm SiPMs

Similar conclusion for SiPMs sensitive to shifted light