PHOTON DETECTION in a (SP) LAr TPC

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Physics Justification

- Implications on the physics program not fully understood
- What we do know:
  - precision determination of t_0 (especially relevant for non-beam events)
  - fiducialization and corrections
  - triggering
  - calorimetry
- Evolution in thinking as far as the PD system is concerned
- Proton decay → Supernova Neutrino → Solar Neutrino (?)
- Necessary evolution of requirements and performance
- Not clear what will be feasible for the first 10kT module

Not clearly established yet

Requirements

Table 5.1: PDS performance requirements to achieve the primary science objectives (under review).

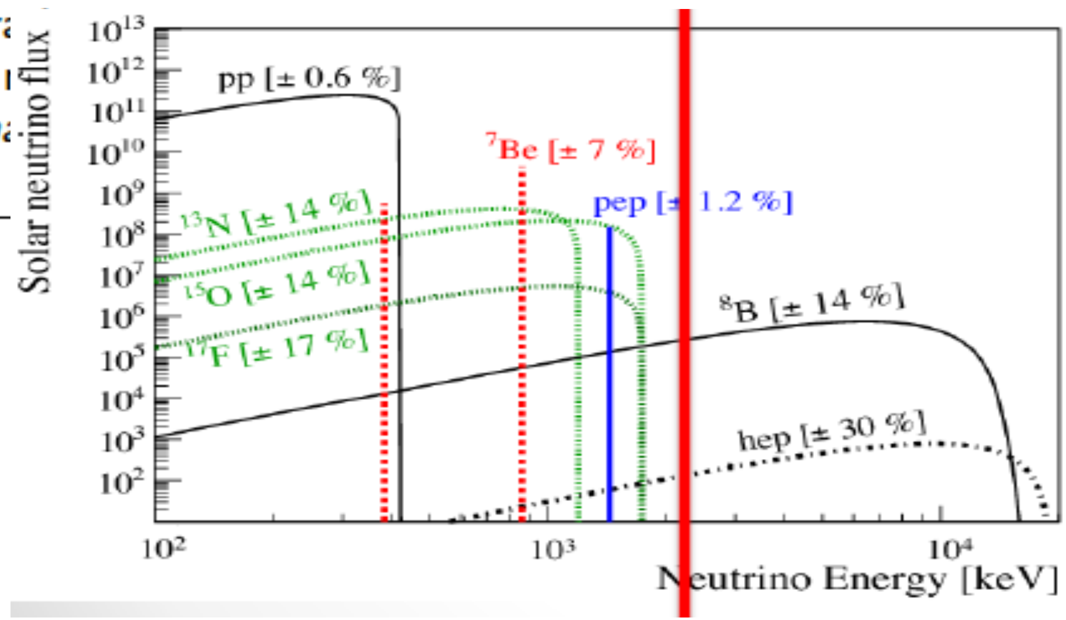
Requirement	Rationale
The far detector (FD) PDS shall detect sufficient light from events depositing visible energy >200 MeV to efficiently measure the time and total intensity.	This is the region for nucleon decay and atmospheric neutrinos. The time measurement is needed for event localization for optimal energy resolution and background rejection.
The FD PDS shall detect sufficient light from events depositing visible energy <200 MeV to provide a time measurement. The efficiency of this measurement shall be adequate for SNB events.	Enables low energy measurement of event localization for SNB events. The efficiency may vary significantly for visible energy in the range 5 MeV to 100 MeV.
(Proposed) The FD PDS shall detect sufficient light from events depositing visible energy of 10 MeV to provide an energy measurement with a resolution of 10%.	Enables energy measurement for SNB events with a precision similar to that from the TPC ionization measurement.
The FD PDS readout electronics shall record time and signal amplitude from the photosensors with sufficient precision and range to achieve the key physics parameters.	The resolution and dynamic range needs to be adjusted so that a few-photoelectron signal can be detected with low noise. The dynamic range needs to be sufficiently high to measure light from a muon traversing a TPC module.

Requirements

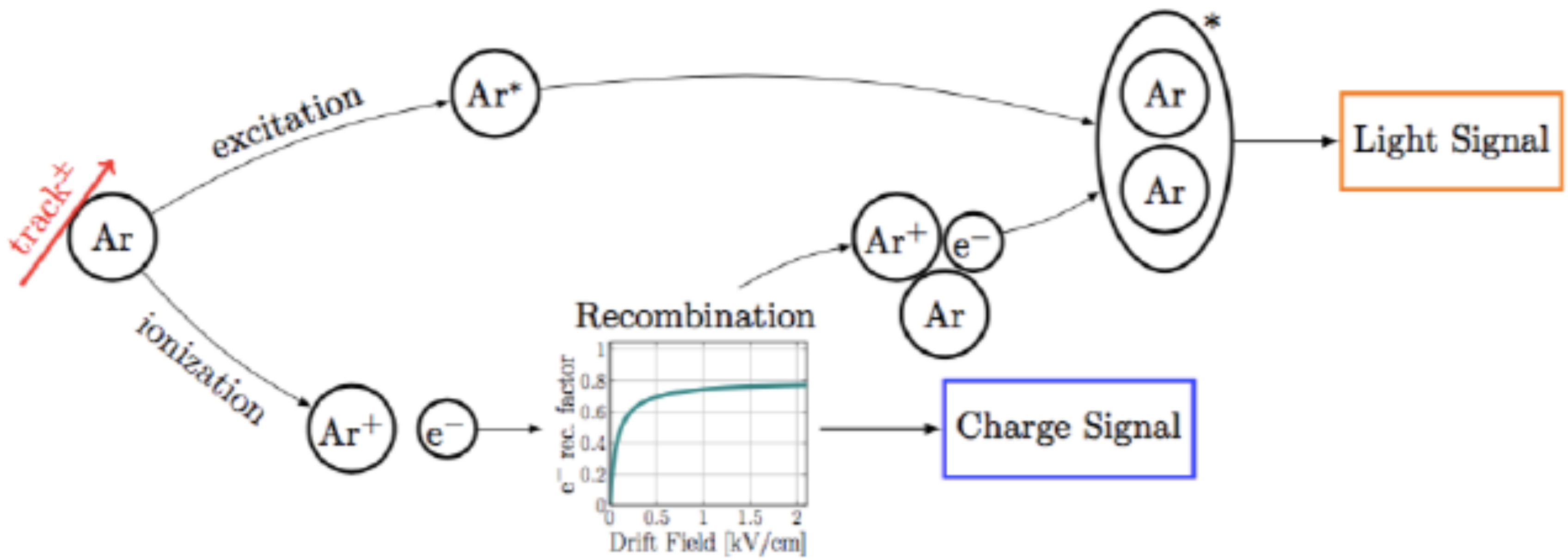
Table 5.2: PDS performance requirements (under review).

Parameter	Value
(Current) Minimum detector response per MeV energy deposition (Light Yield).	1 pe/MeV for events at the center of the TPC and no less than 0.5 pe/MeV at all points in the fiducial volume.
(Proposed) Minimum detector response per MeV energy deposition (Light Yield).	10 pe/MeV for events at the center of the TPC and no less than 5 pe/MeV at all points in the fiducial volume.
Minimum requirements on energy deposition, spatial separation, and temporal separa from other events, for which the system m associate a unique event time (*flash ma-ing*).	10 MeV, 1 m, 1 ms respectively.

DUNE IDR



Scintillation in LAr

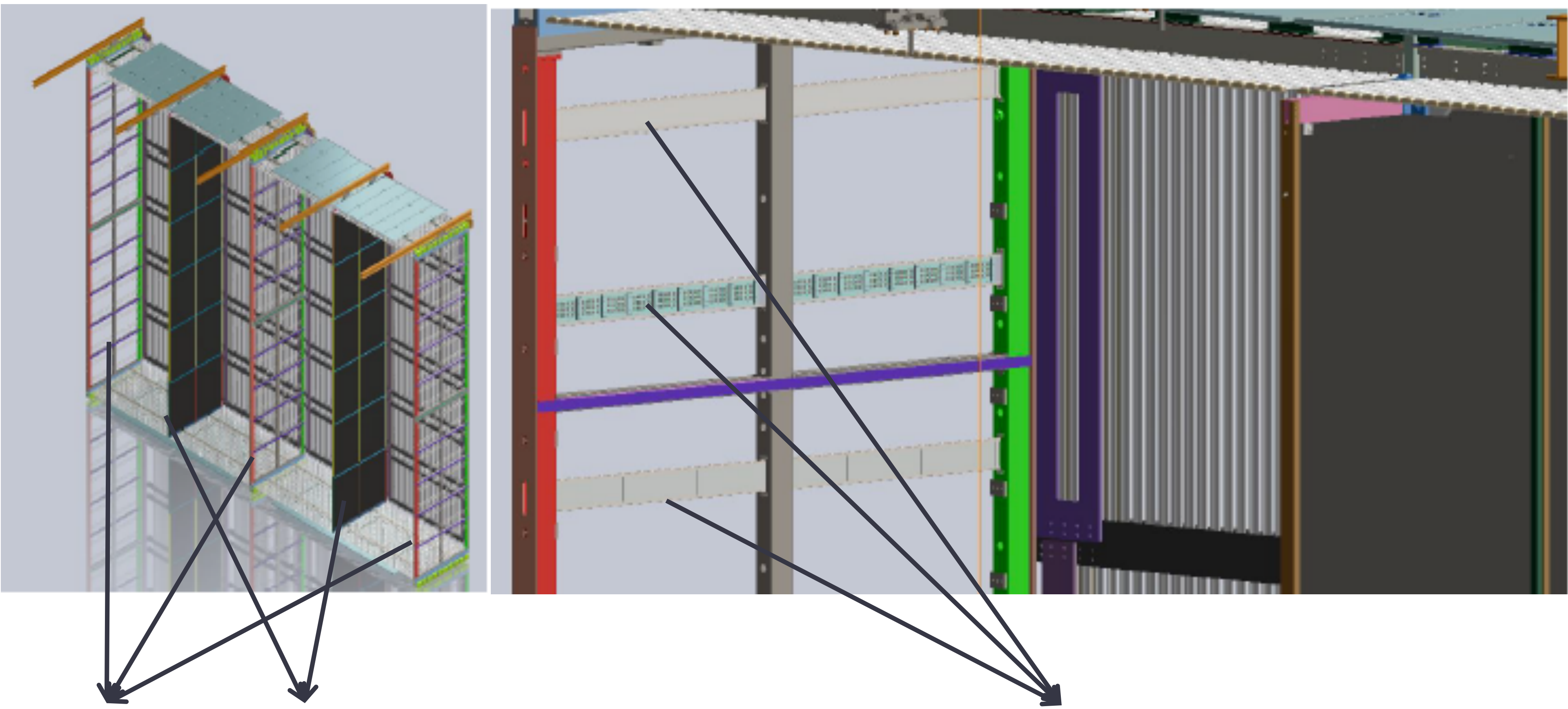


Emission through de-excitation of singlet (τ ~ 6 nsec) and triplet (τ ~ 1.3 μsec).
In nominal DUNE E field ~ 24 ϒ/keV within a 10 nm band around 127 nm.
Particle-dependent fast/slow fraction: 0.3 (electron), 1.3 (alpha) and 3 (neutron)
Attenuation length of ~20m and Rayleigh scattering length of ~ 55 cm.

General Considerations

- LAr TPC size
  - large catchment area
  - direct to much smaller photosensors
- Scintillation light wavelength
  - wavelength shifting offers some advantages w.r.t. photosensor options
  - TPB widely used (but there may be issues)
- The ubiquitous ^{39}Ar background
- Physical constraints from TPC structure and drift volumes
- Signal ganging (active or passive)

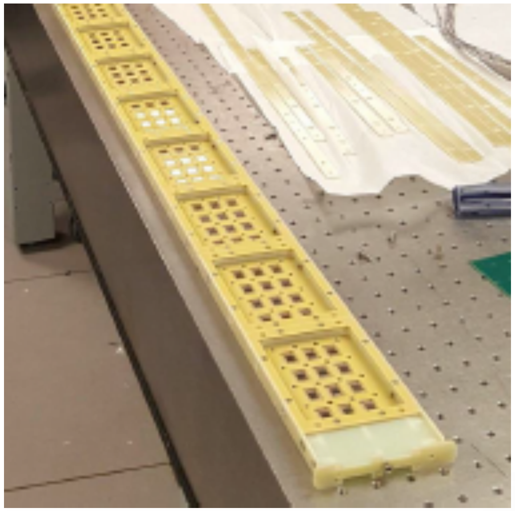
DUNE SP LAr TPC



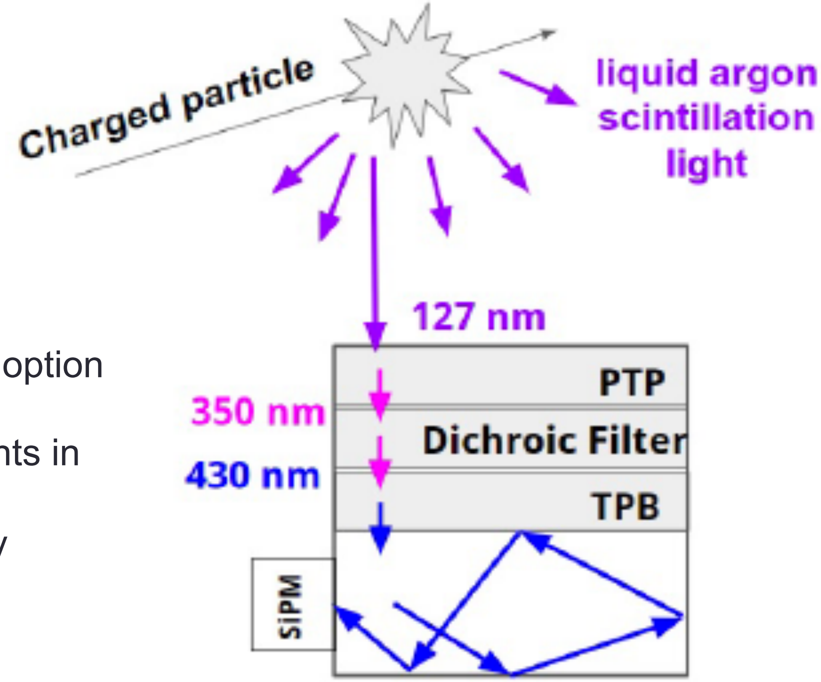
APA CPA PD Modules inside an APA

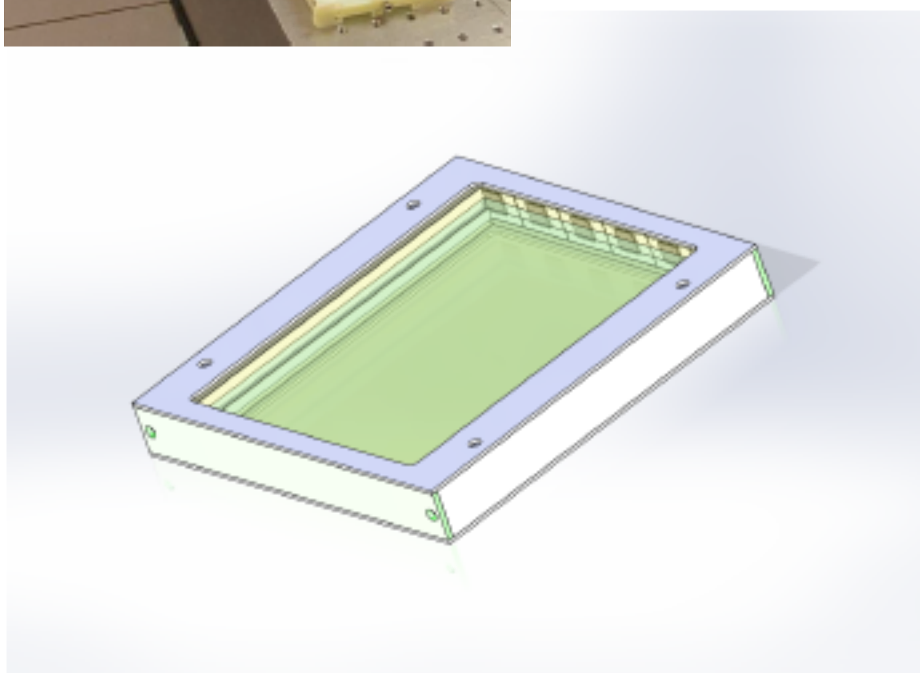
A total of 1500 such modules

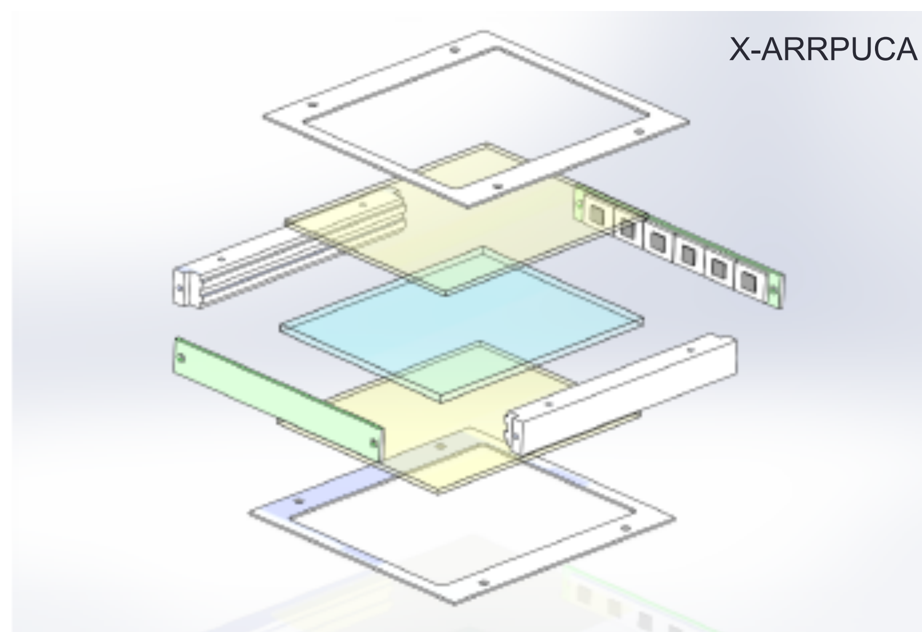
ARRAPUCA(s)



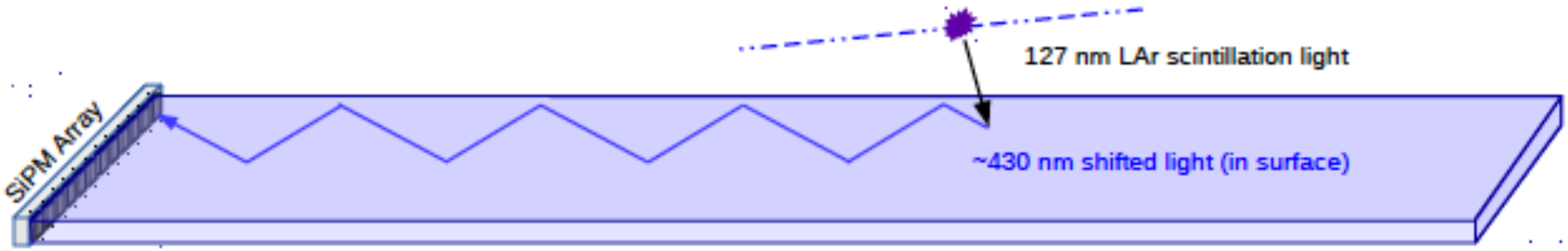
Currently the baseline option
Prototype detection efficiency measurements in the 0.4 – 1.8% range
Offers better scalability



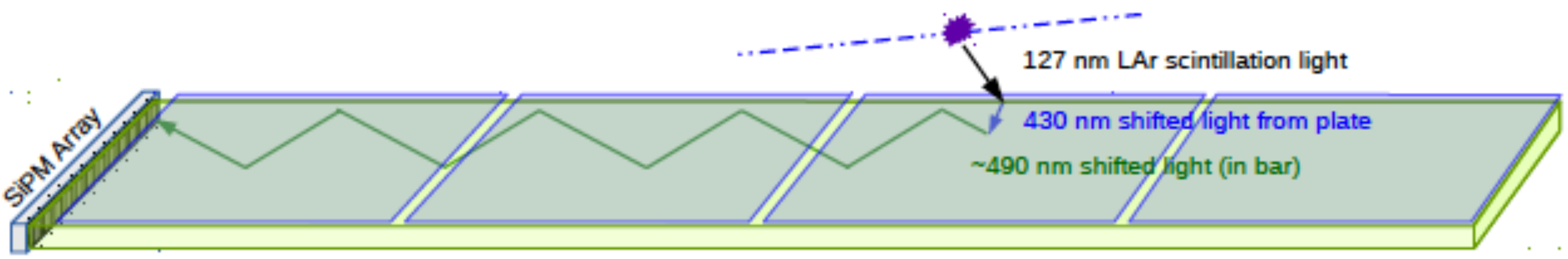




Light Guide Options



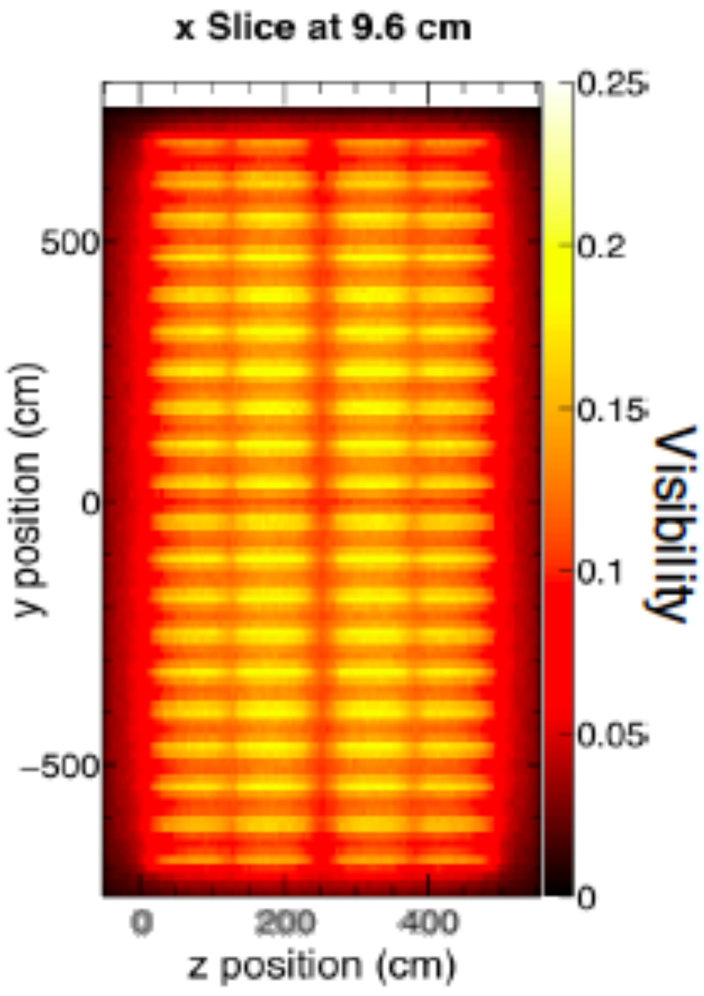
Dip-coated bar

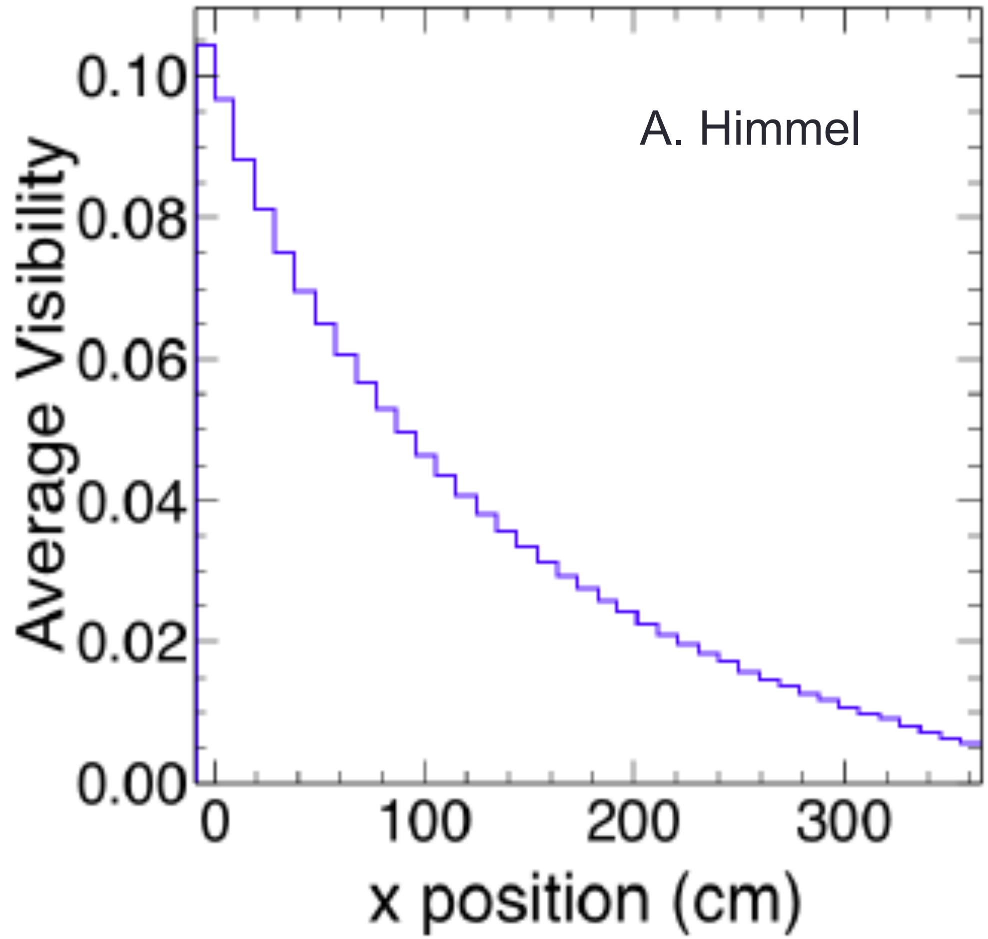


Double-shift bar

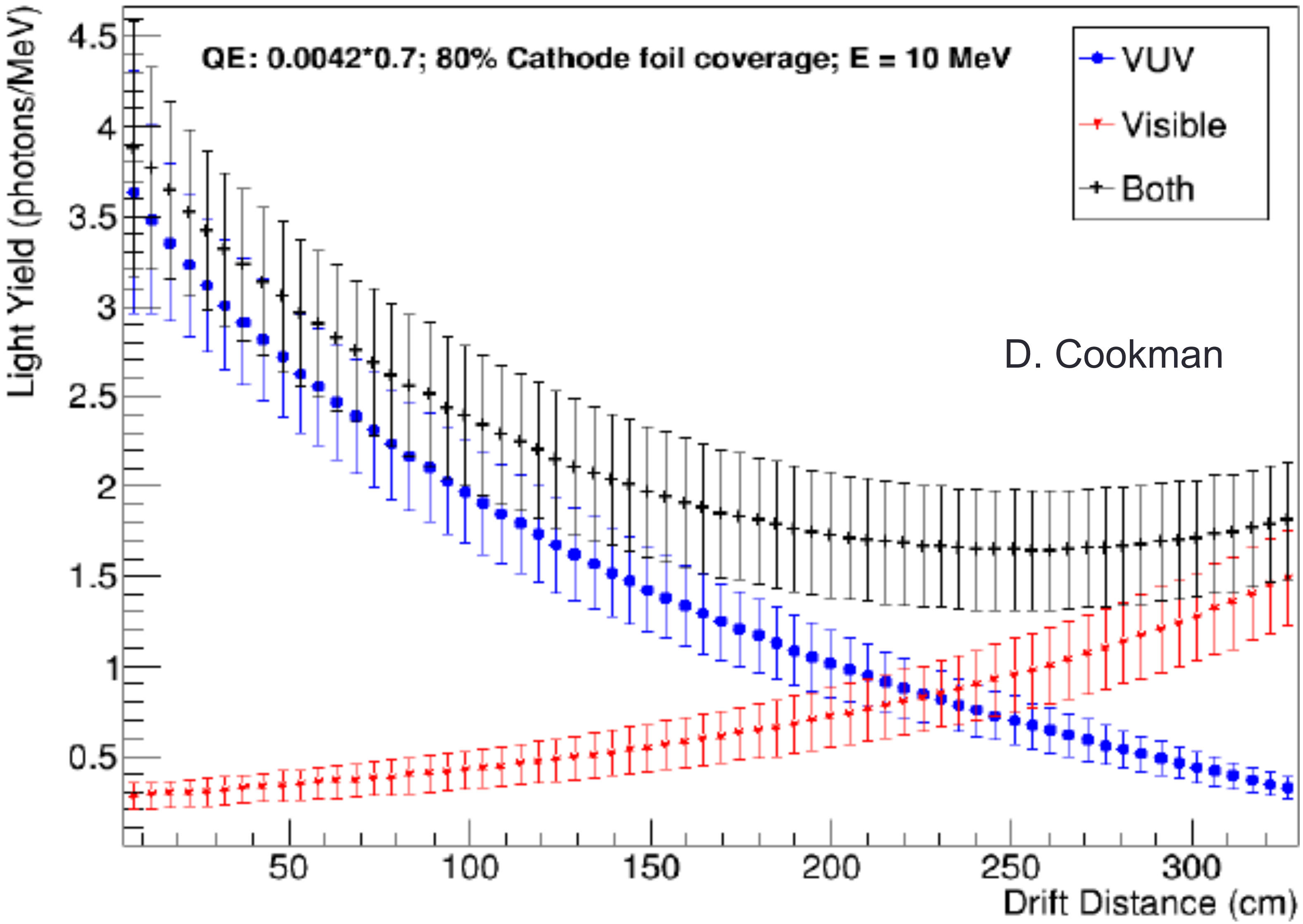
Detection efficiency of ~ 0.1 – 0.25% (single-sided readout)

Geometric Efficiency

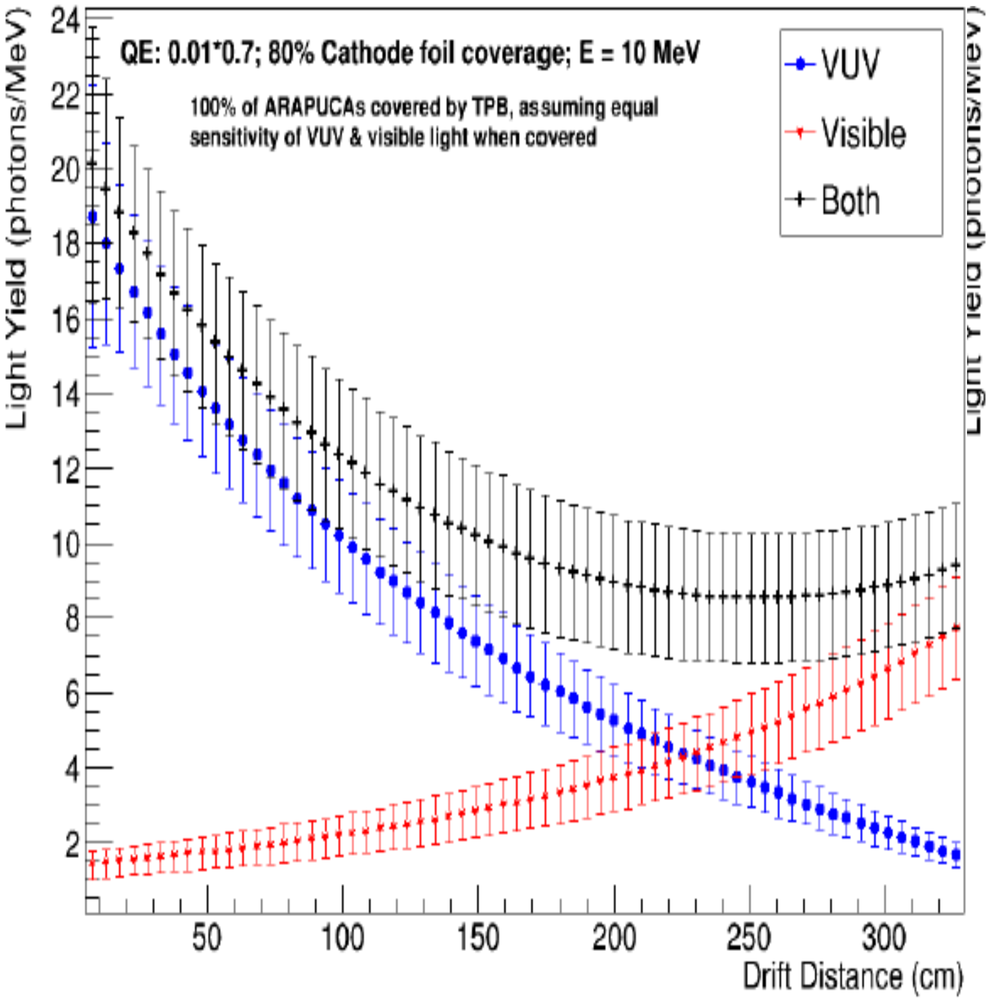


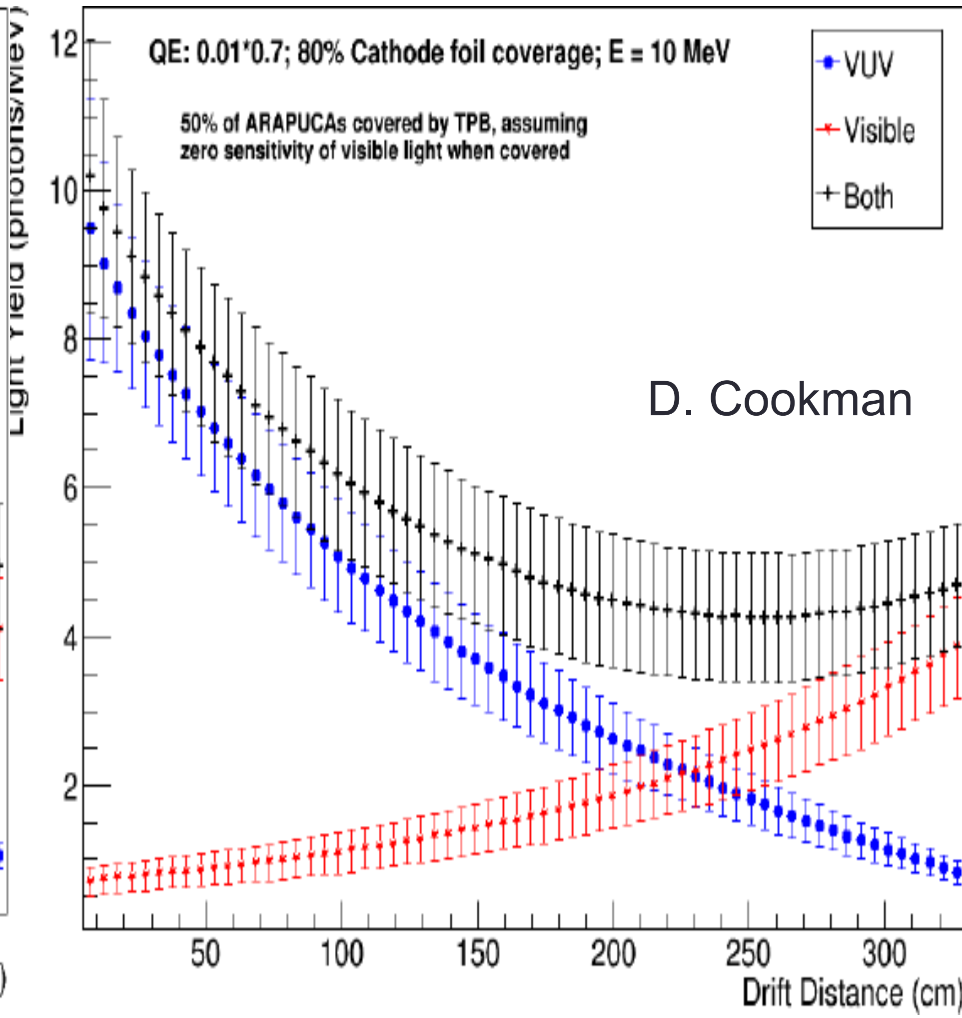


PE/MeV (light guide like)



PE/MeV (ARRAPUCA like)





D. Cookman

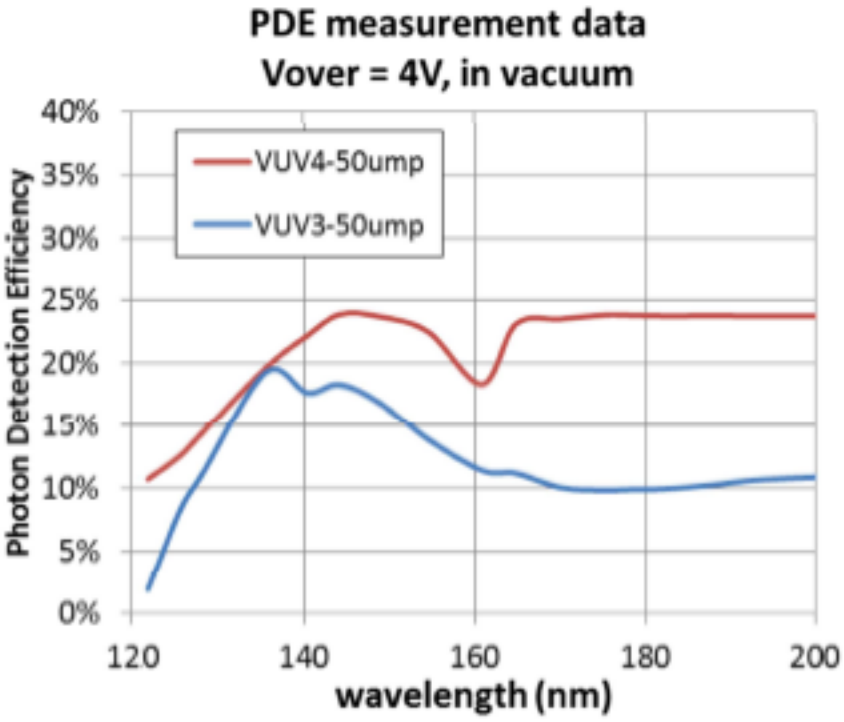
However…

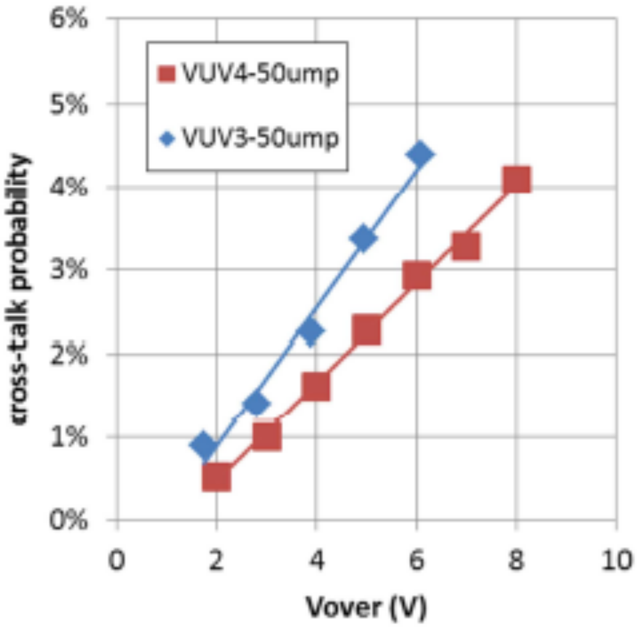
- Foil coverage of the CPA is not trivial given the HV
- Numerous issues that require R&D:
  - modification of field
  - possible discharges
  - handling and installation
  - impact on direct light and timing
- Alternative options would be to either decrease Rayleigh scattering (LXe doping), increase geometric coverage or detection efficiency or both

LXe Doping

- Potential to enhance enhance photon collection efficiency
- Significant R&D issues still to be addressed
  - scaling of doping technique to very large detectors
  - non-uniformity/freeze-out
  - impact on ionization yields
  - impact on early/late light
  - material and infrastructure cost

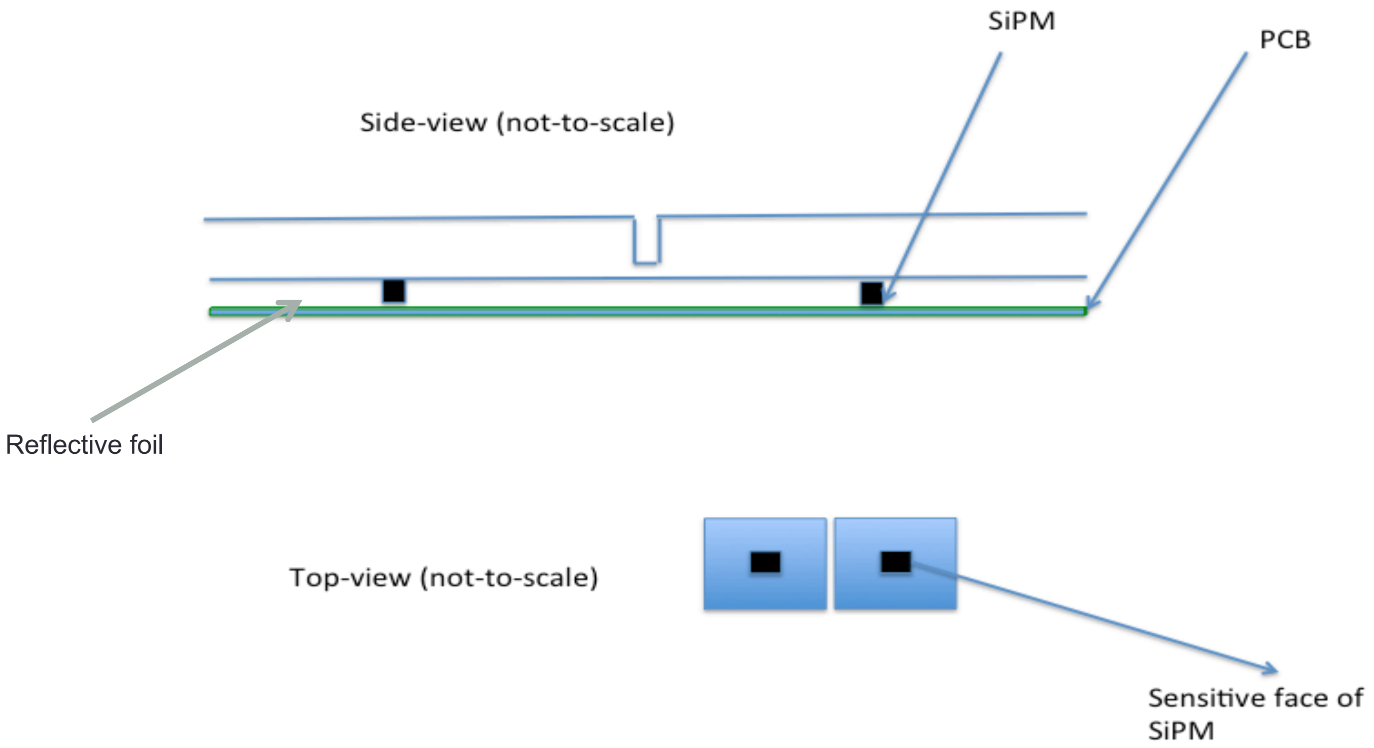
SiPMs Alone?





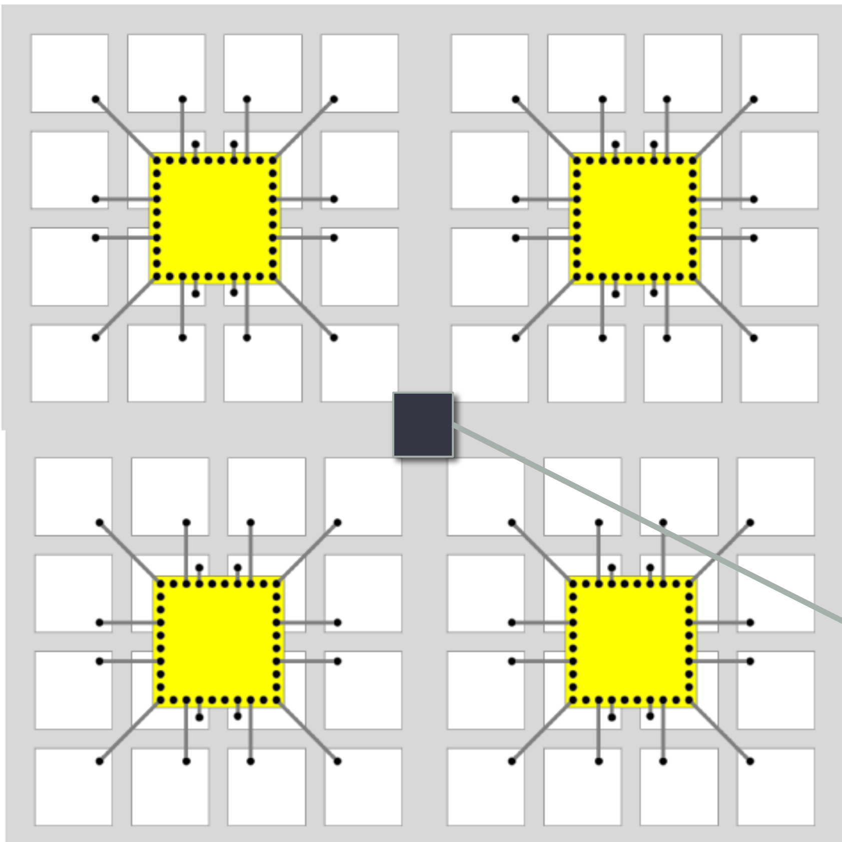
A double-sided bar can basically be replaced by ~125 6mm x 6mm SiPMs
Similar conclusion for SiPMs sensitive to shifted light

Minimize Shifting



TPB-coated acrylic “tiles” directly-coupled to SiPMs
Either rely on total internal reflection or foil between tiles
Could this be adopted for the pixel LAr TPC?

Minimizing Shifting & Maximizing Coverage?



~ 3.2 cm

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

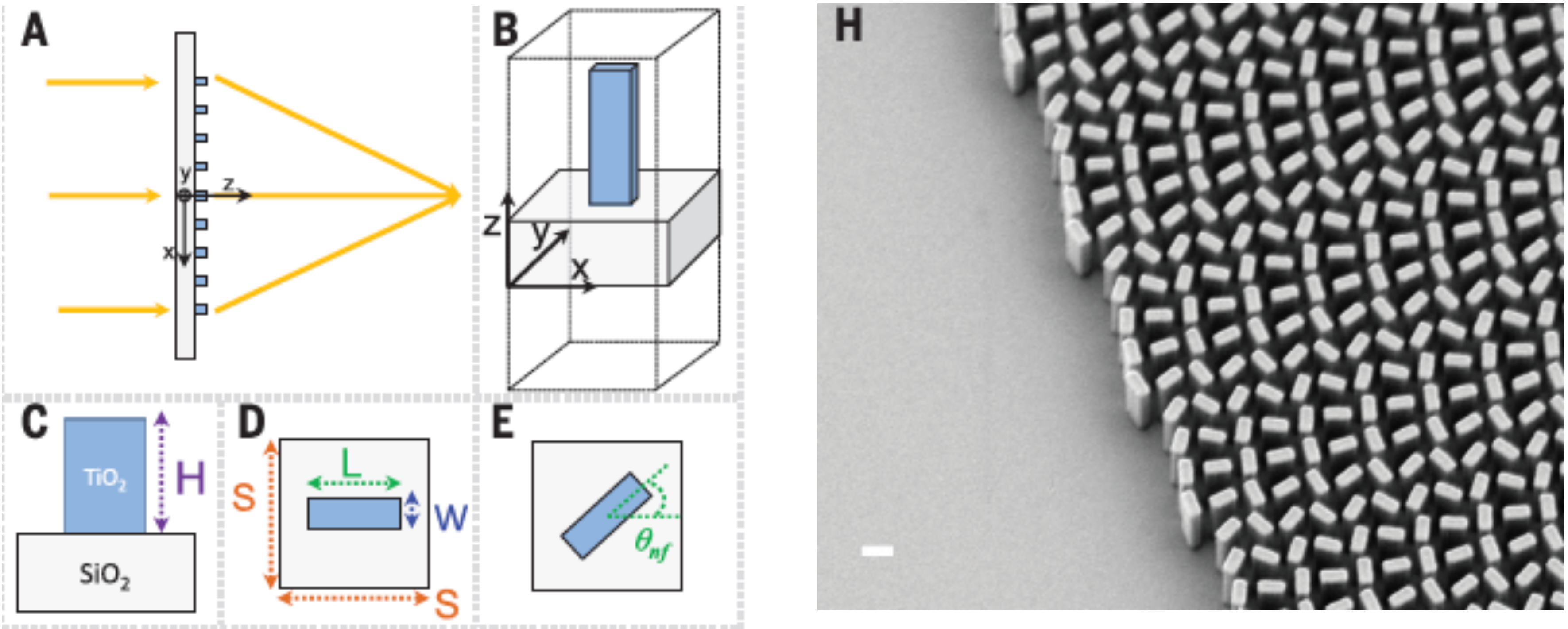
Could then, in principle, have a 3.2 cm x 3.2 cm “tile” readout with a SiPM

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)

Metalenses



Meta-surfaces: composed of sub-wavelength spaced phase shifters
Example: TiO_2 metasurfaces have been designed as lenses with high numerical aperture and efficiencies (~86% at 405 nm)
Sizes were 250 μm with a focal length of 100 μm. Scalability??

Pixel Readout of Scintillation Photons

- Idea is to coat the dielectric plane with photoconductive medium such as amorphous Selenium
- Elevation of an electron to conduction band by the incident photon in the vicinity of the pixel “button” may give rise to an avalanche
- The correlated firing (in time) of multiple pixels would be your photo-detection scheme

D. Nygren

Summary

- A high-performance photon detection system may offer enhanced physics opportunities for LAr-based TPCs
- The physics needs to detector requirements specification needs further clarification
- May still be interesting to think of ideas to improve PD performance
- Not a trivial problem
- Many interesting R&D avenues may exist (just scratching the surface)
- Some of them may be combined