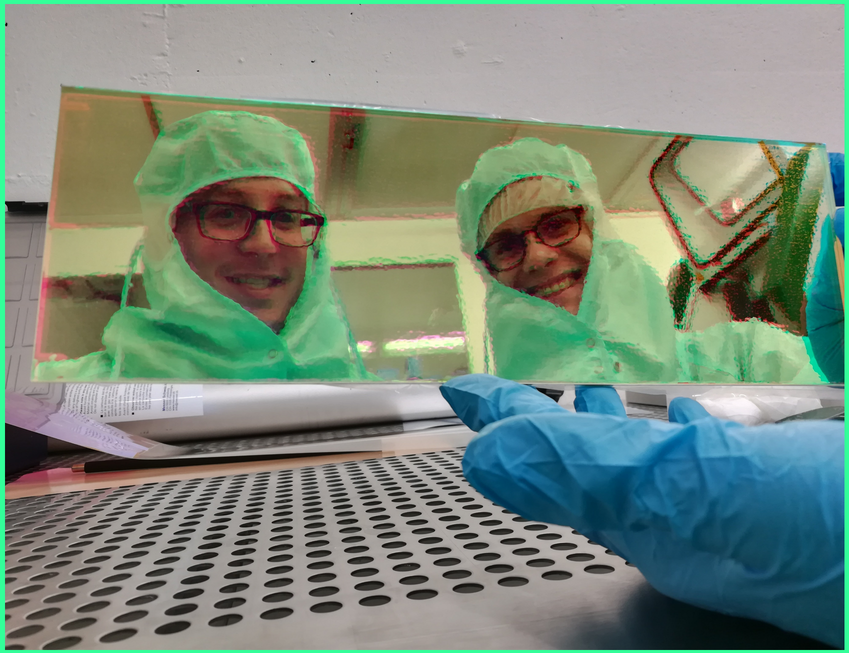
Photon readout with Pixels



Pixel LArTPC Autumn Workshop,
Fermilab, 29.09.18

Igor Kreslo
AEC/LHEP University of Bern

LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

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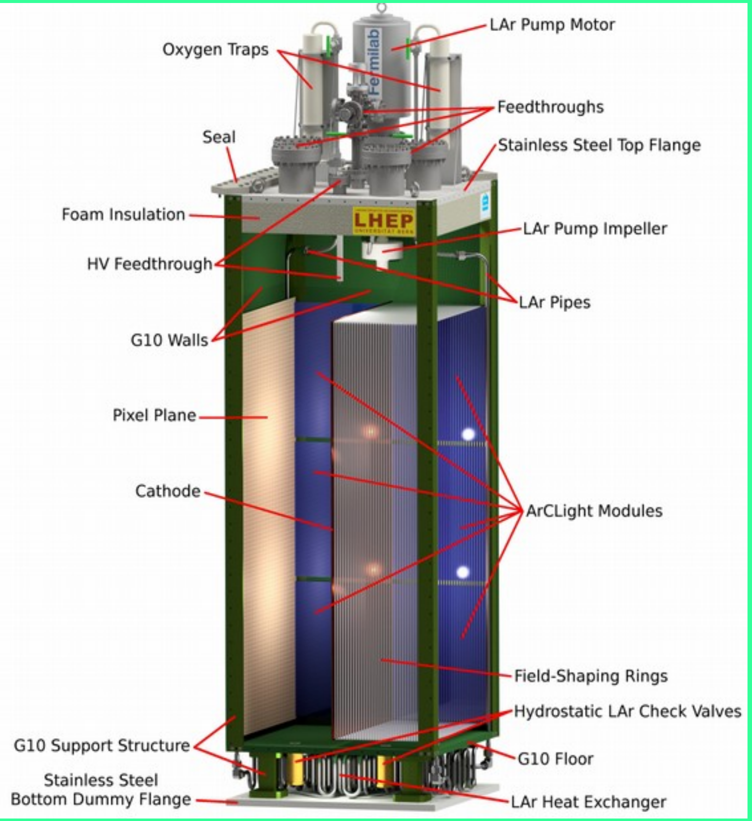
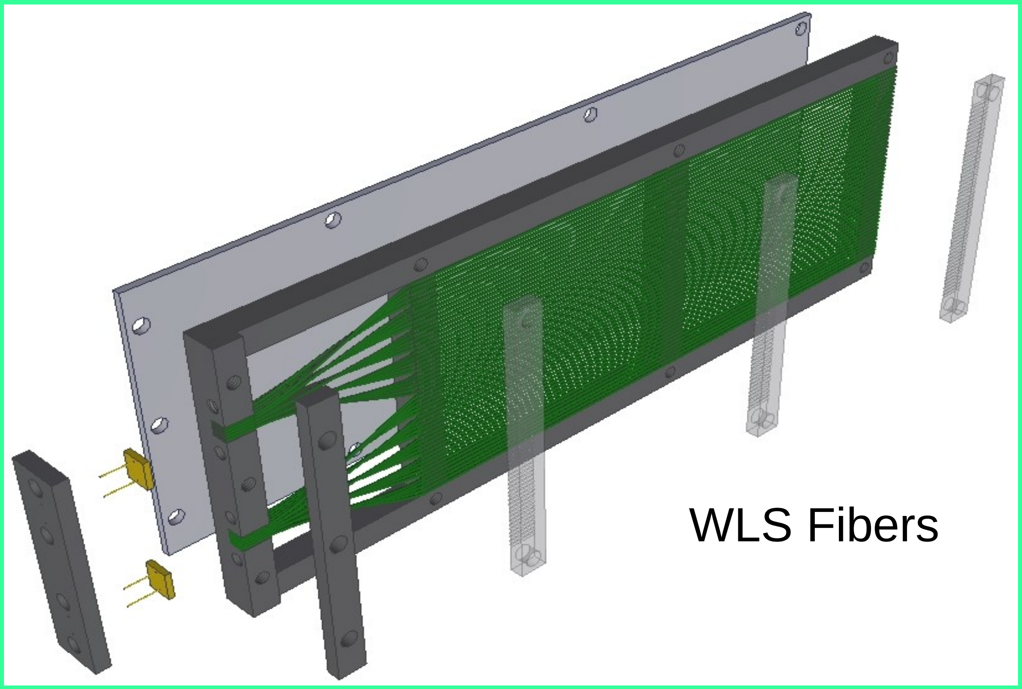
AEC
ALBERT EINSTEIN CENTER
FOR FUNDAMENTAL PHYSICS

ND Photon Detection System requirements

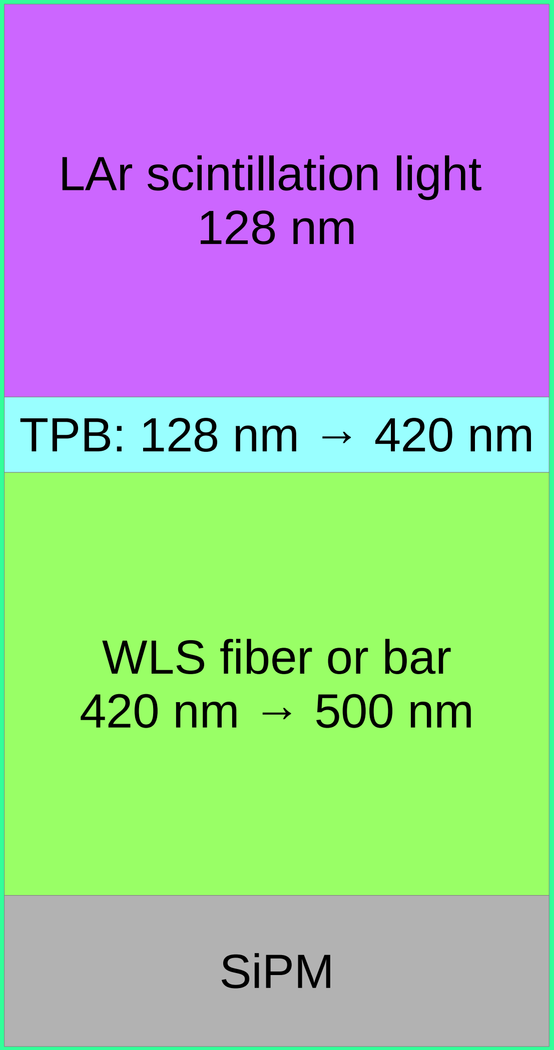
- Energy threshold ~ 100 keV
- Time resolution — several ns
- Coordinate resolution — several tens of cm
- Energy resolution of ~ 10% is very desired (can be then combined with charge)



Light Collection Module (LCM) by JINR, Dubna



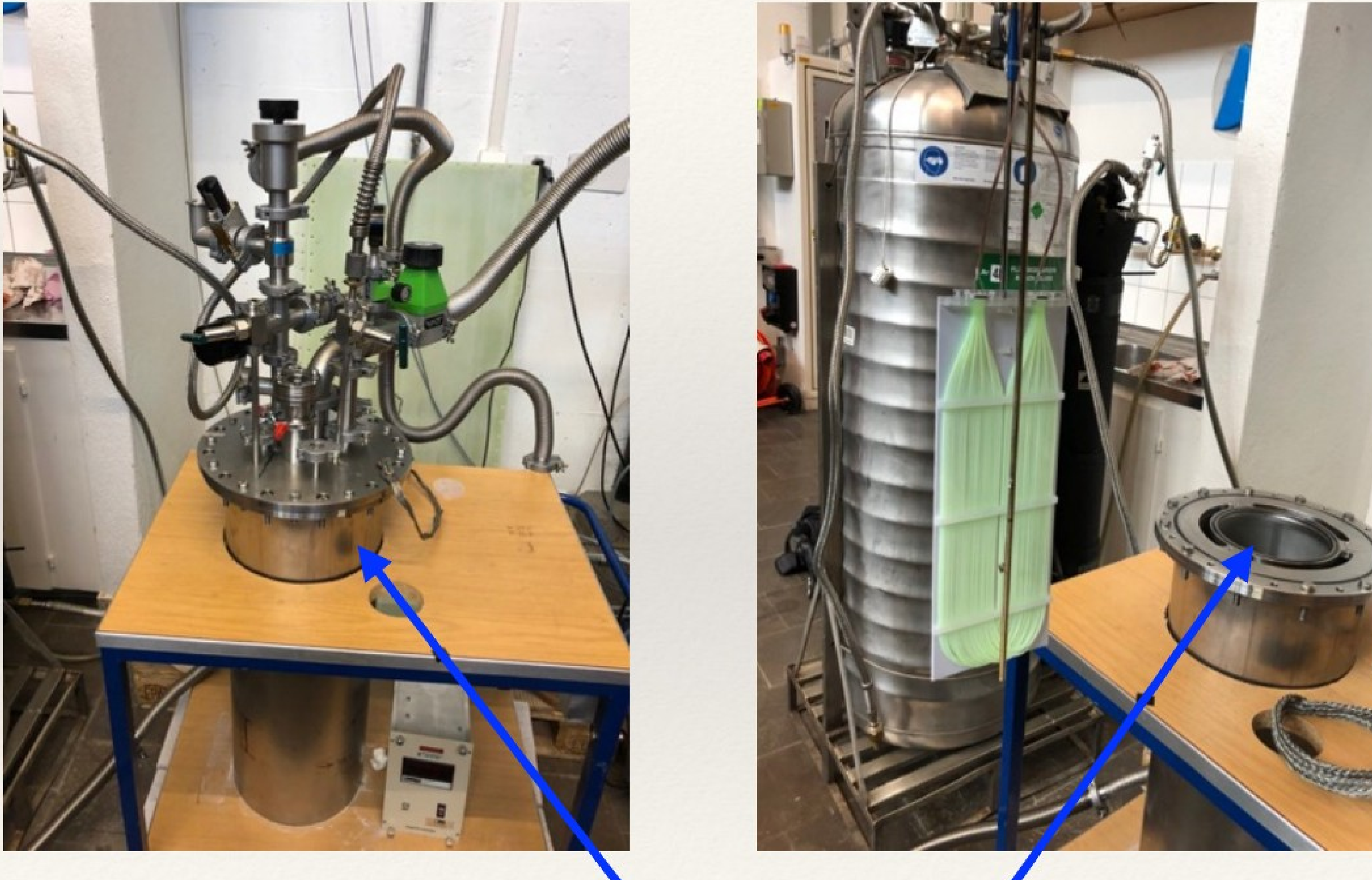
VUV scintillation light is double-shifted to green



- Tetraphenil-butadiene (TPB) as primary WLS
- Kuraray green fibers as secondary WLS
- SiPMs as photon detectors
- SiPM dark current at 87K is O(Hz) at 1 p.e.
- Estimated efficiency — 1%

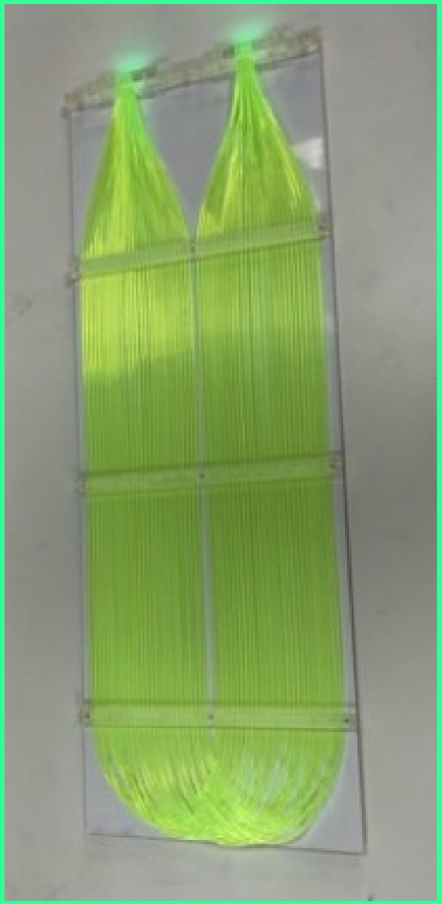
Efficient light collection from large area

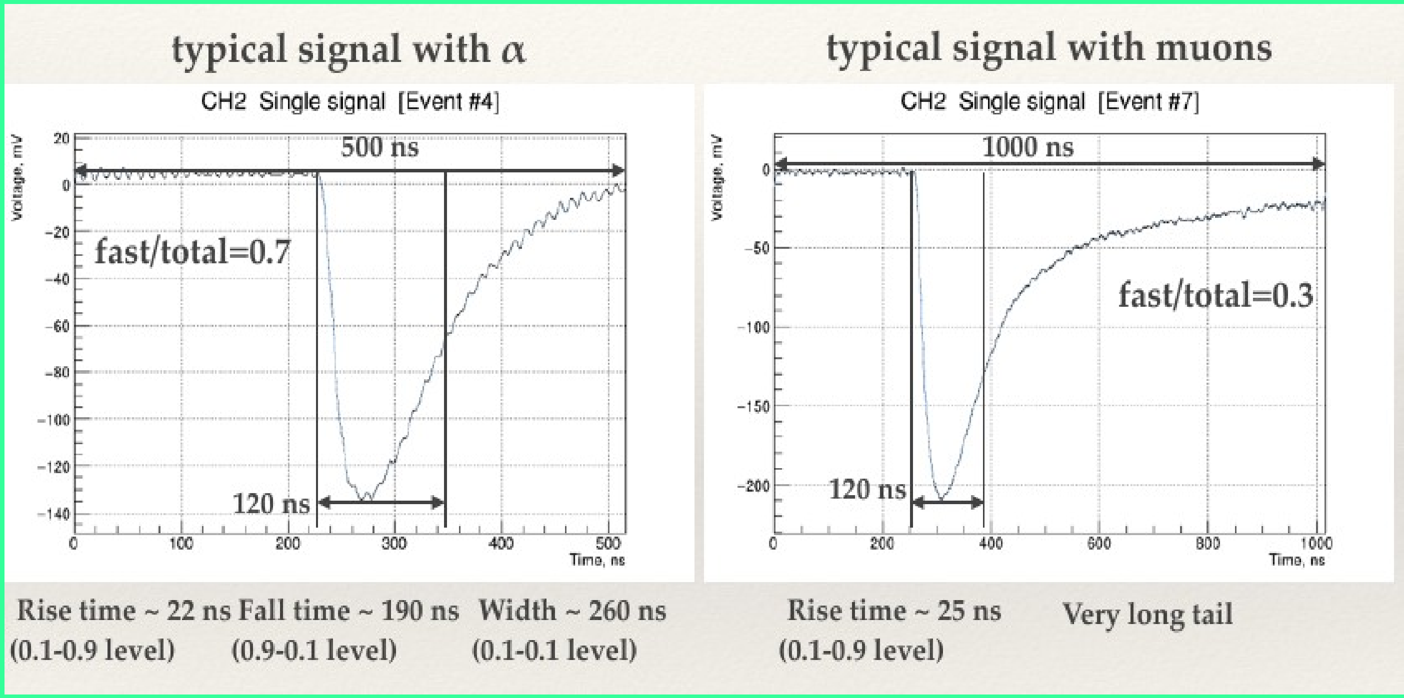
Light Collection Module (LCM) by JINR, Dubna
Tested in Bern, 2018



Cryostat inner volume - cylinder 60x15 cm

Light Collection Module (LCM) by JINR, Dubna
Tested in Bern, 2018





Expected 2%

Measured 0.9 %

Improvement possible...

Inspired by ARAPUCA

A.A. Machado and E. Segreto 2016 JINST 11 C02004

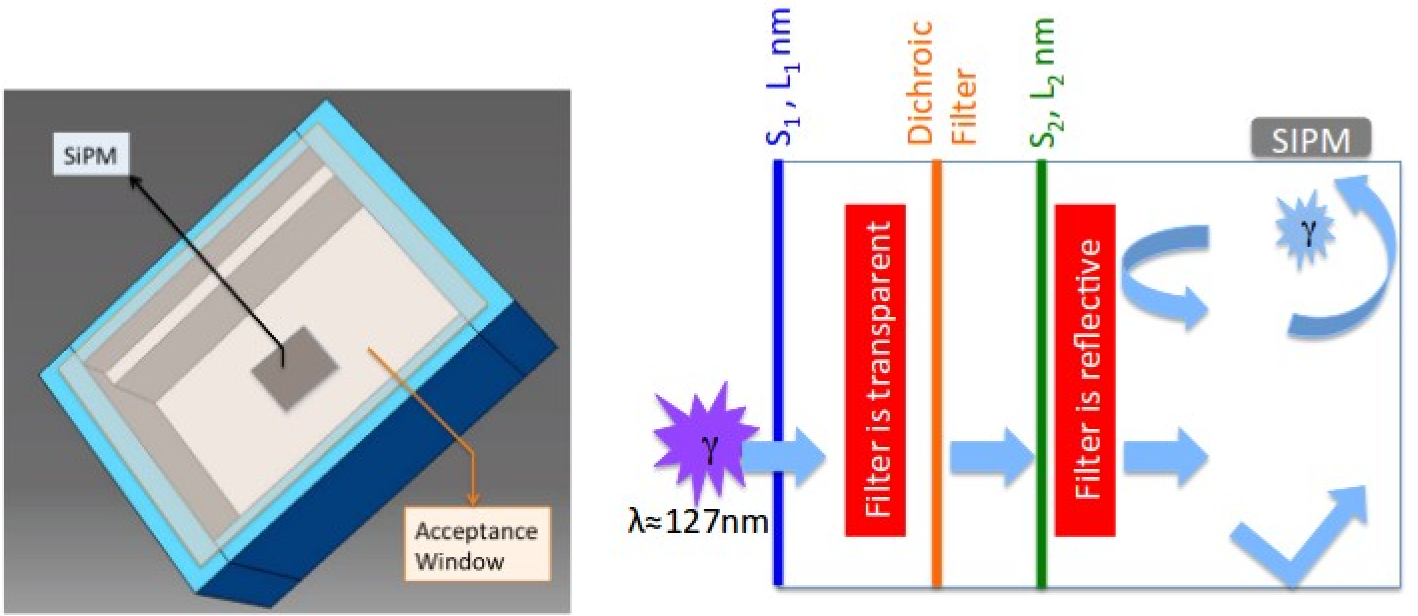
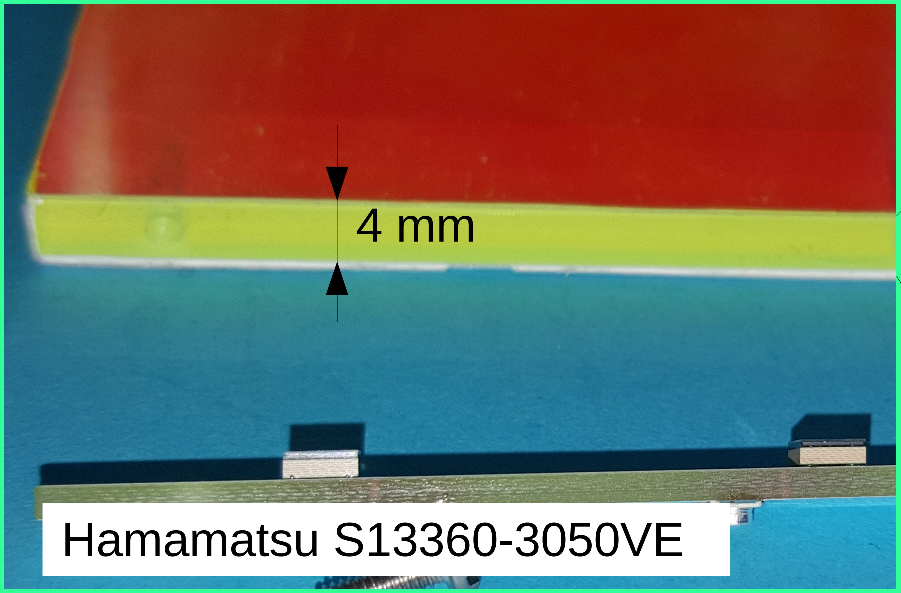


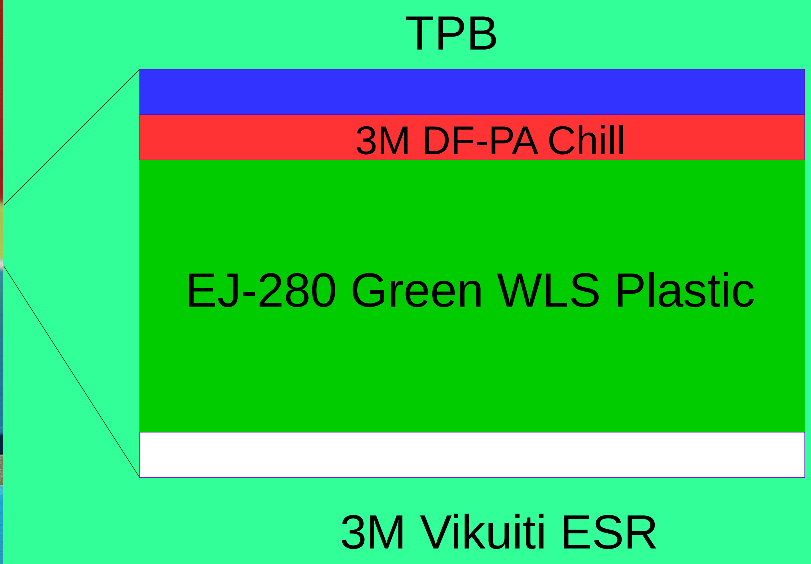
Figure 1. Left: pictorial representation of the ARAPUCA. Here are represented the box with internal reflective surfaces (in blue), the dichroic window and the photo-sensor (SiPM). Right: operating principle of ARAPUCA.

Great idea!!! but...

Fragile membrane, void inside, heavy frame, thermal deformations...

ArCLight concept





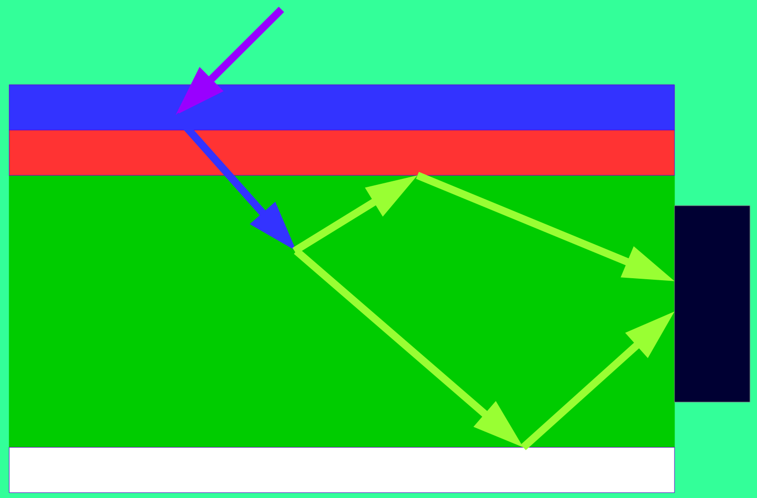
Self-supporting

SiPM can be placed at one edge only

No frame — no deformations in cold

Can be placed in high field region (parallel to the the drift)

PDE : theoretical view



10x10 cm

TPB conv. efficiency ε_{tpb}= 1.3/2

Dichroic transparency for blue T_{430}= 0.87

EJ-280 conv. efficiency ε_{WLS}= 0.86

Dichroic reflectance for green R_{490}= 0.98

ESR reflectance for green R_{490}= 0.98

Total surface area S_{tot}= 216 cm^2

SiPM covered S_{det}=0.36 cm^2

$f = S_{det} / S_{tot}$= 0.0017

Absorbtion is neglected! (λ ~ meters)

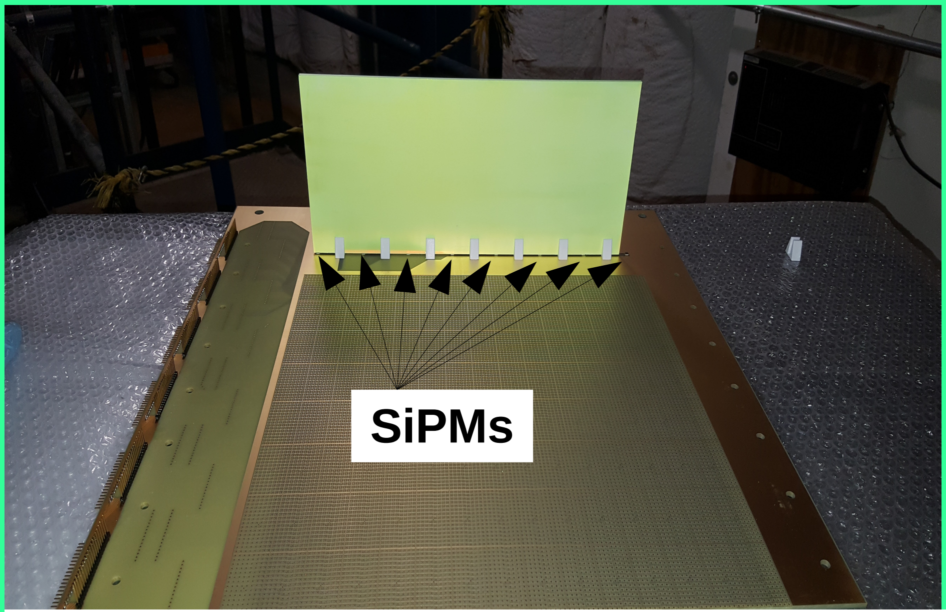
E. Segreto 2012 JINST 7 P05008 :

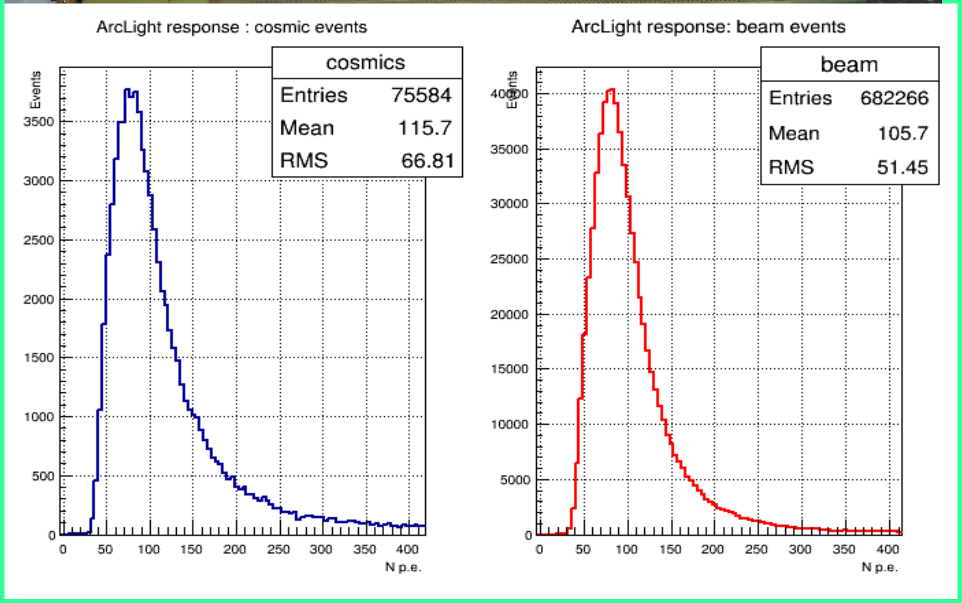
$$\epsilon_{coll}=\frac{f}{1-\langle R_{490}\rangle(1-f)}=0.077$$

Putting it all together:

$$PDE = \epsilon_{tpb}\cdot 1/2\cdot T_{430}\cdot\epsilon_{WLS}\cdot\epsilon_{SA}\cdot\epsilon_{SiPM} = 0.01$$

ArCLight 43x15 cm with TPB coating
Installed in PixLAr detector (Fermilab)





PDE :

Calculated 0.34%

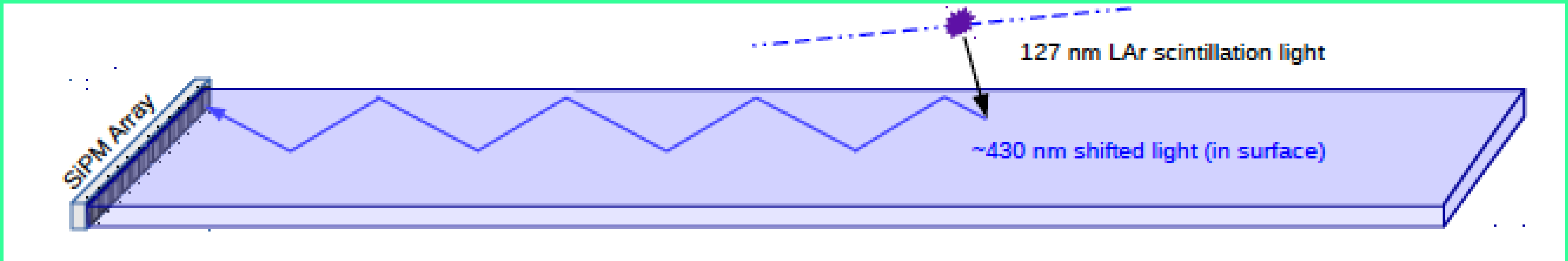
Measured 0.24%

Expected for ND: 0.2%,
(100 SiPMs / m2)

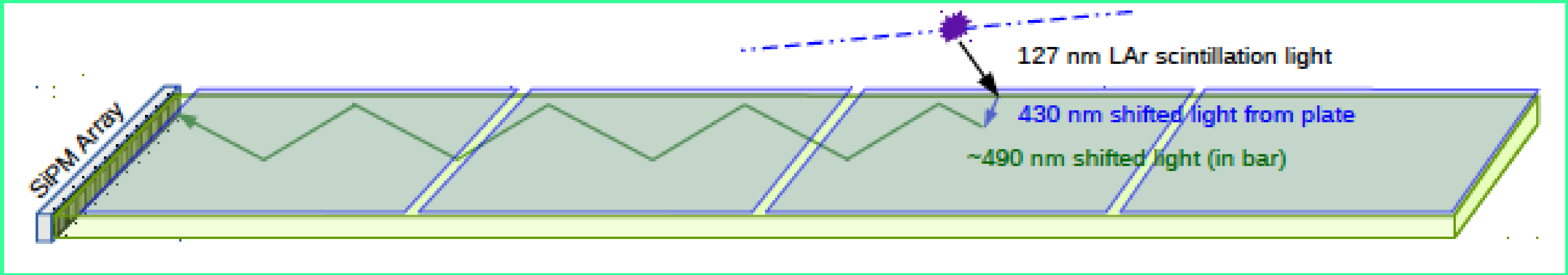
Can be increased for the cost of SiPMs

Ultimate test is ongoing in TallBo..

Light guide system (ProtoDUNE type)



Dip-coated bar



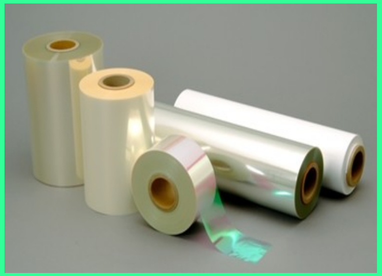
Double-shift bar

Detection efficiency of ~ 0.1 – 0.25%

Novel ideas for PDS: Get rid of TPB !

New material for primary WLS is found: PEN (TEONEX) !

arXiv:1806.04020 [physics.ins-det]
Polyethylene naphthalate film as a wavelength shifter in liquid argon detectors
Marcin Kuźniak, Benjamin Broerman
(Submitted on 11 Jun 2018)



Available as 12 to 250 microns films

Adhesive or not

Large quantities available

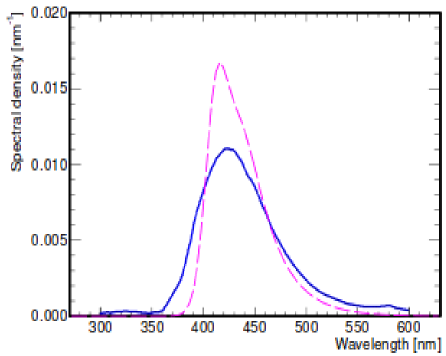


Fig. 1 Comparison of emission spectra at room temperature for PEN [12] (solid line) and TPB [27] (dashed).

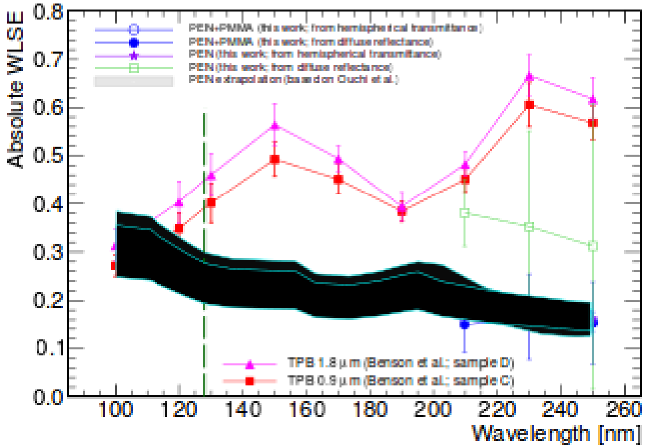
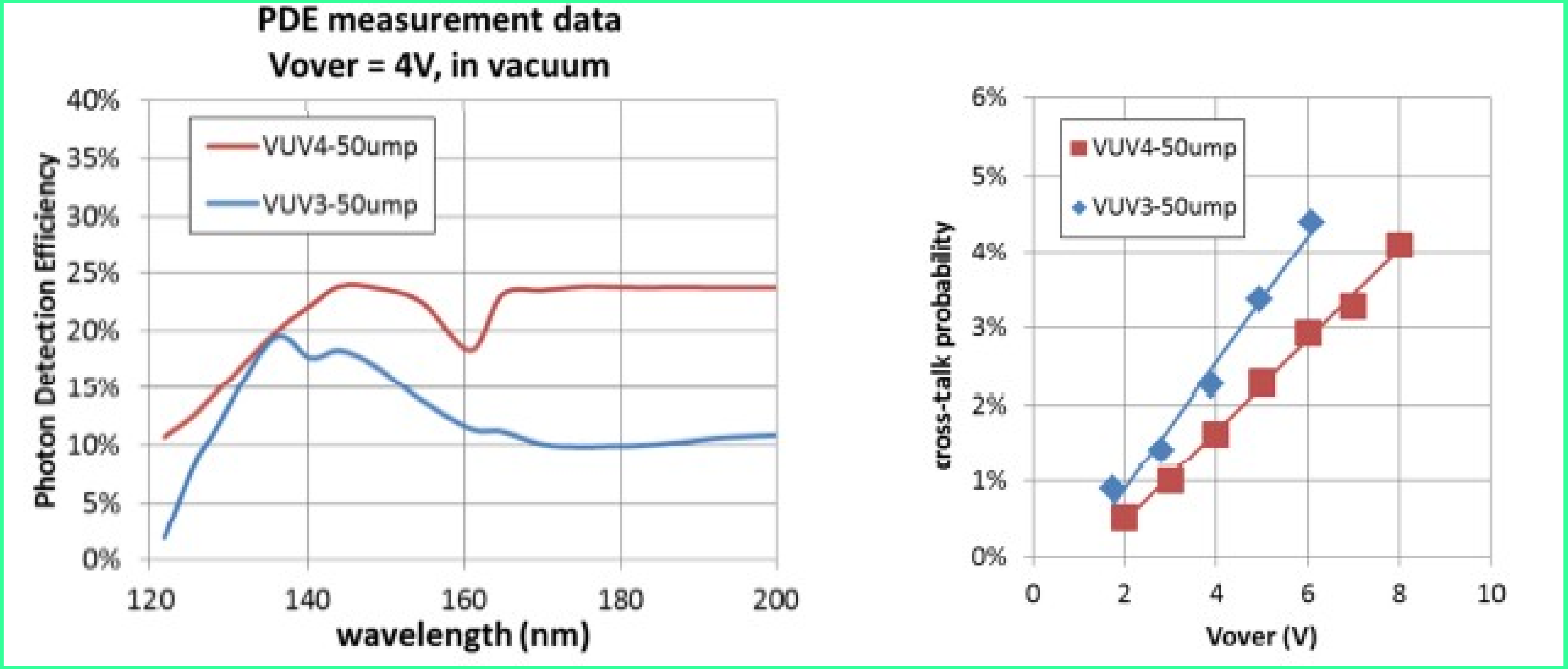


Fig. 4 Comparison of measured and extrapolated absolute WLSE of PEN with TPB data [27] (lines drawn to guide the eye). The vertical dashed line marks the 128 nm LAr scintillation wavelength. See text and legend for more details.

Novel ideas for PDS: SiPMs alone
Courtesy of Vishnu Zutshi, NIU/NICADD

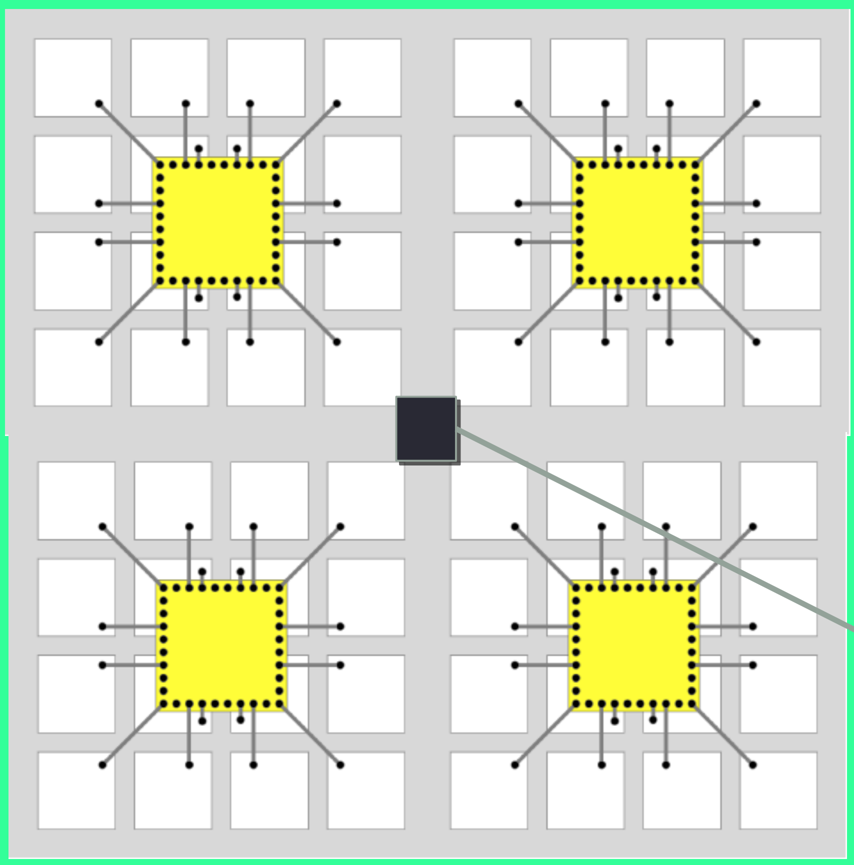


A double-sided bar can basically be replaced by ~125 6mm x 6mm SiPMs
Similar conclusion for SiPMs sensitive to shifted light

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

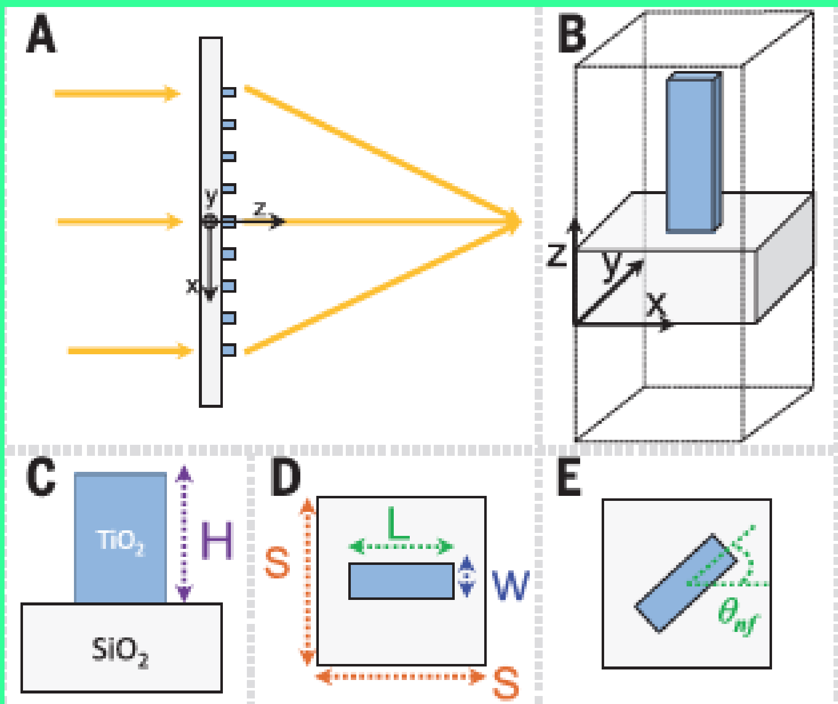
Is there a sensible way to optically segment the dielectric wall?

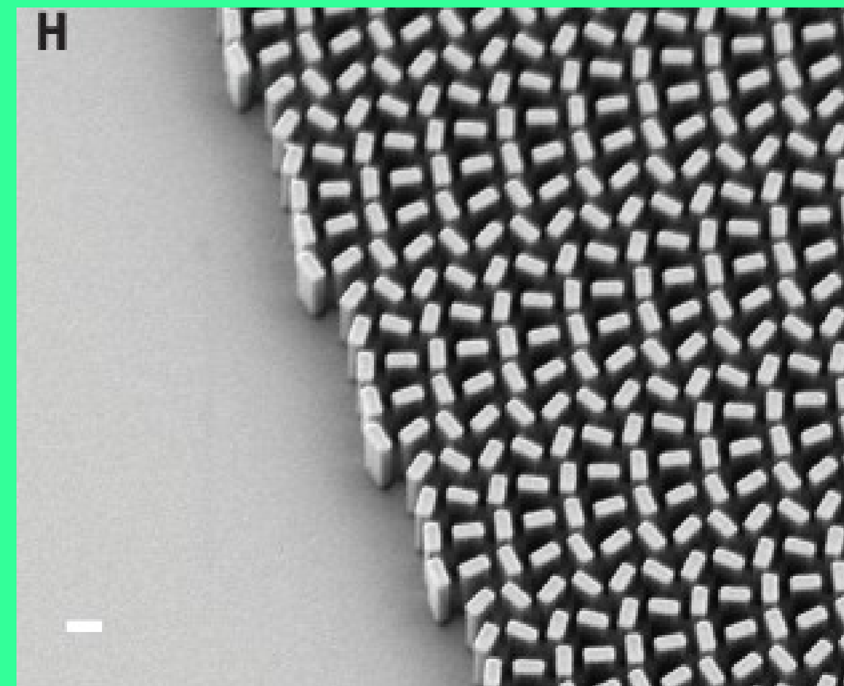
The ASIC/SiPM PCB could silk-screened or have a reflective foil glued to it

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

Novel ideas for PDS: Focusing light
Courtesy of Vishnu Zutshi, NIU/NICADD

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??

Novel ideas for PDS: SiPMs alone
Courtesy of Vishnu Zutshi, NIU/NICADD

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

Conclusions

- Two PDS technologies identified as a baseline: ArCLight and LCM
- Backup available: ProtoDUNE-like light guides
- New very interesting ideas ! Can be tested in AC 2x2 modules.
- Fast evolving R&D!