PoWER: a new concept for DUNE Phase 2 FD PDS

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Introduction

- In a TPC operated at 500 V/cm, about half of the energy deposited by ionizing particles goes into photons;
- A Photon Detection System, with the levels of Light Yield expected for FD1 and FD2, can improve DUNE physics performance for both beam and low energy events;
- PDS of Phase 2 FDs should continue improving the LY and uniformity of light collection through an optimization process to help in achieving the main DUNE physics goals and open the possibility for additional, high impact, physics studies (solar neutrinos, BSM neutrino interactions, ...)

Principles

We propose some guiding principles on which PDS design should be based:

- High detection efficiency;
- Simplicity in the construction;
- Reduced R&D;
- Cost effective.

PoWER

Polymer Wavelength shifter and Enhanced Reflection - PoWER.

PoWER Concept

- Full coverage of the field cage with PEN WLS
- Large arrays of SiPMs mounted on the membrane.
- VUV sensitive SiPM as an active veto;
- ESR reflector (reflectivity 95% in the visible) installed on the membrane;
- Cathode (partially) covered with PEN and eventually reflector

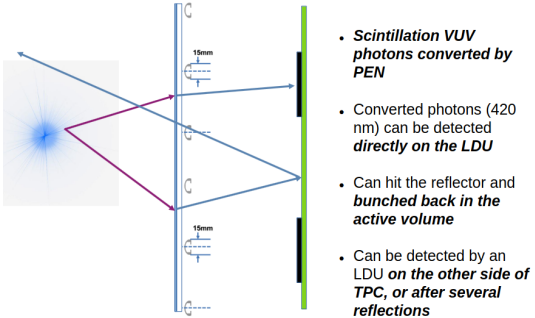


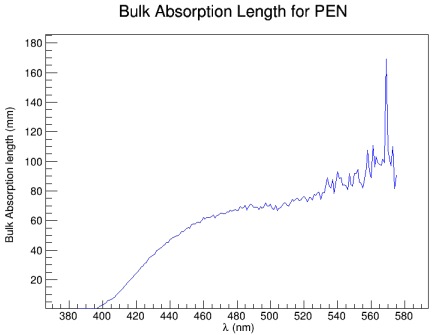
Figure. 1: Ettore's talk in DUNE CM Meeting, April 2024.

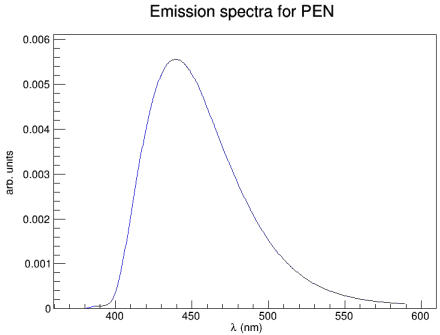
PolyEthylene Naphtalate - PEN

- PEN is a thermoplastic polyester that can be easily drawn into foils or extrusion molded and has wide applications in industry.
- Currently, PEN conversion efficiency is at the level of 50% compared to evaporated TetraPhenyl Butadiene (TPB) [1].
- The QE (quantum yield) is estimated to be about 57% [2].
- Intense effort is ongoing to improve conversion efficiency.
- Emission peaked at 420 nm.
- Transparent to its own emitted light.

[1] Eur. Phys. J. C (2021) 81:1099
[2] Eur. Phys. J. C (2022) 82:442

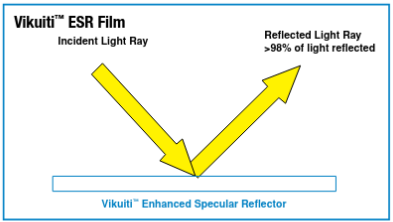
PolyEtylene Naphtalate - PEN





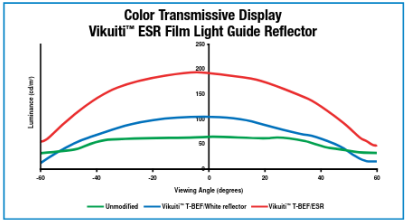
Refractive Index: 1.65
Data from Luis Manzanillas.

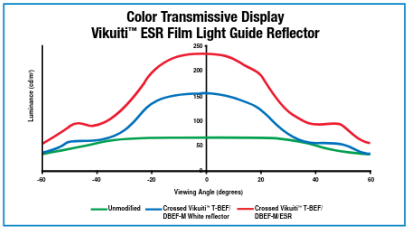
Enhanced Specular Reflector - ESR



Nominal film properties

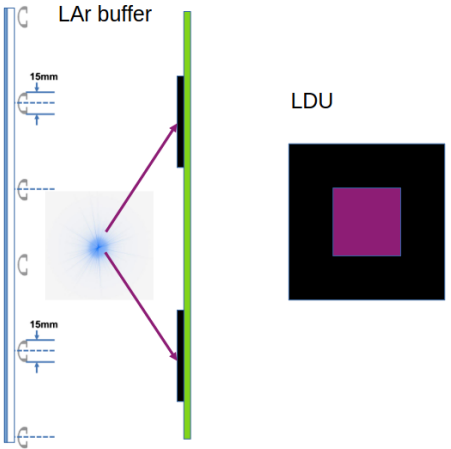
Film properties	Vikuiti™ ESR Film
Reflectance	>98%
Physical Characteristics	
• Thickness (microns)	65µm (2.6 mils)
• Shrinkage (15 minutes @ 150°C)	<1%
• Specific Gravity	1.29





Active Veto

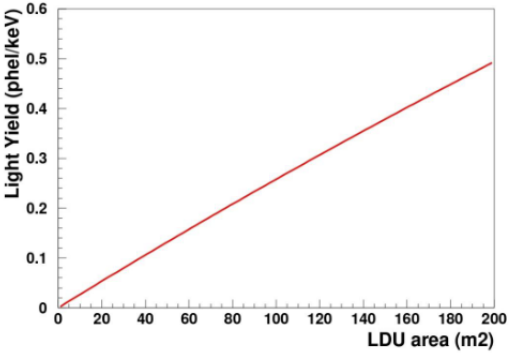
- LDU can be a combination of standard and VUV sensitive SiPMs;
- Photons produced in the LAr buffer are not shifted, being directly detected by the VUV active fraction of the LDU;
- Events inside the active volume produces signals on both Standard and VUV sensitive SiPM
- Unbalance of the signals between the two channels allows using the LAr buffer as an active veto.

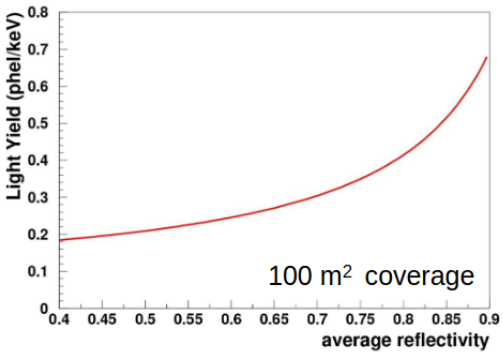


PoWER Configurations

Optical Parameter	Symbol	Value
Photon yield @ 500 V/cm	N_γ	20 photons/keV
Xenon doping		10 ppm
Fraction light 128 nm	Enters in Q	30%
Fraction light 175 nm	Enters in Q	70%
PEN conversion @ 128nm	ε_{ws}	50%
PEN conversion @ 175nm	ε_{ws}	50%
Field cage transparency	T_w	70%
PEN coverage		FC + 80% of cathode
Rayleigh scattering @ 128nm	Enters in Q	1 m
Rayleigh scattering @ 174nm	Enters in Q	6 m
Absorption length		50 m
Reflectivity of anode	Enters in R	30%
Reflectivity of ESR planes	Enters in R	90%
LDU photon detection eff.	ε_{LDU}	50%

Estimated performances



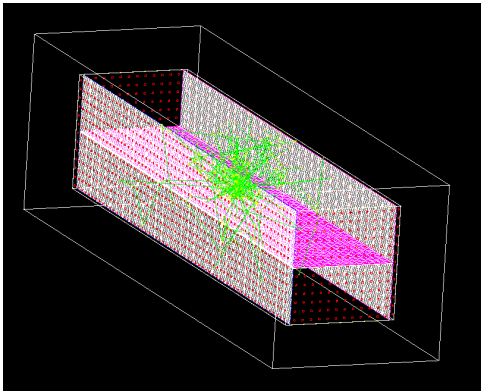


The most relevant parameters for the LY are the ***active coverage with SiPM*** and the ***reflectivity of internal surfaces***. For R>70% there is a rapid increase in the LY.

Xenon Doped Liquid Argon

- 10 ppm of Xe Doping in Ar
- Refractive index: 1.228 (same as lAr)
- Bulk absorption length:
  - 20m for 128nm
  - 80m for 175nm
- Rayleigh scattering length:
  - 1m for 128nm
  - 8.5m for 175nm

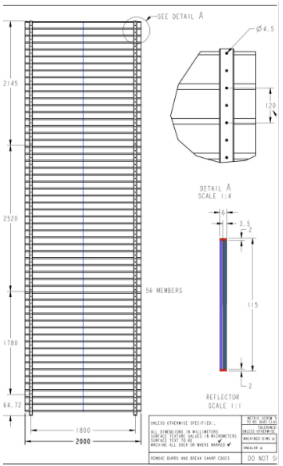
General view

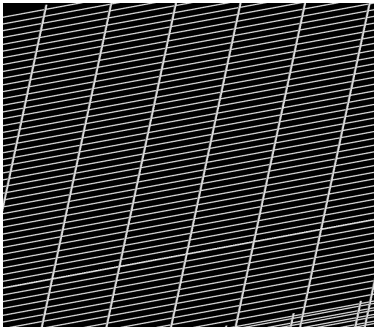


- Dimensions: 60m $\times$ 13m $\times$ 13m.

- Lateral membranes and field cage covered with enhanced reflectors (98%).
- Field cage covered with a wall made of acrylic and a layer of PEN (thickness 100 μm).
- Anodes covered by 30% reflectance material.
- Cathode in the middle covered by the enhanced reflector and PEN.
- 1872 LDUs on the membranes (75m^2).

Field Cage

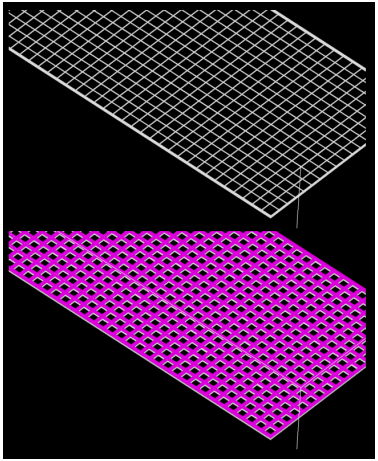




- Horizontal bars: $2\text{m} \times 15\text{mm} \times 8\text{mm}$;
- Distance between two horizontal bars: 120mm;
- Vertical bars: $13\text{m} \times 45\text{mm} \times 8\text{mm}$;
- Distance between two vertical bars: 1.8m.

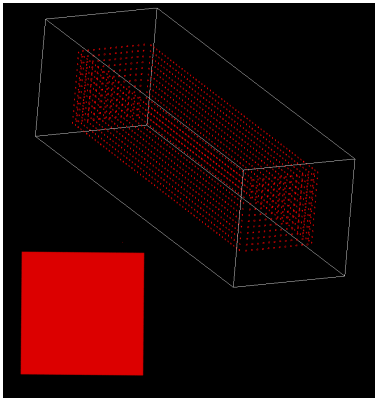
- Transparency: $\sim 85\%$.

Cathode



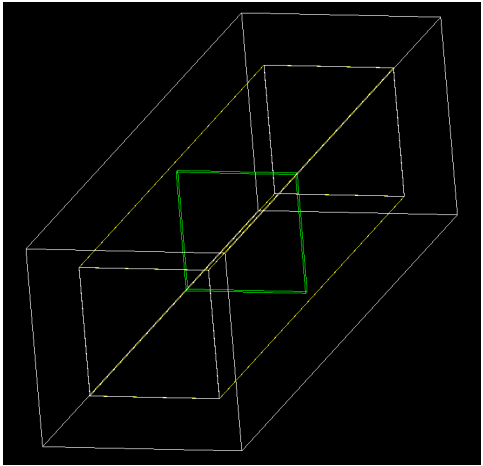
- Cathode dimensions: $60\text{cm} \times 60\text{cm}$.
- Cathode covered both sides with reflector and PEN.
- These layers have $42\text{cm} \times 42\text{cm}$ holes permitting lAr circulation.

Light Detection Units (LDUs)



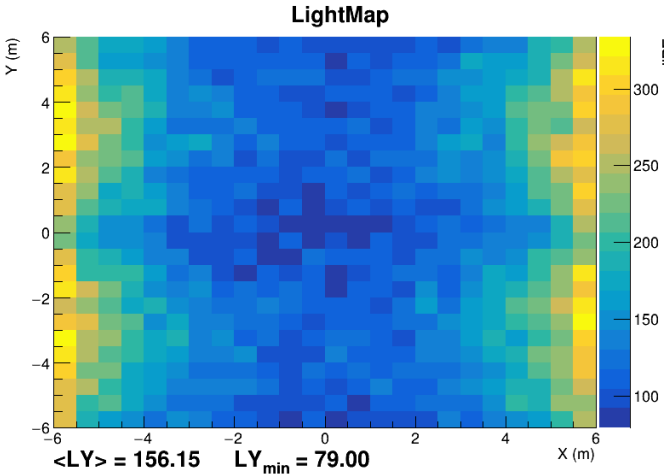
- Dimensions: $20\text{cm} \times 20\text{cm}$.
- Efficiency: 50%
- 1872 detectors, distributed as 780 on the lateral walls and 156 on the front/back walls.
- No LDUs on the cathode or anodes.
- Total of 75 m^2 active area.

Photons

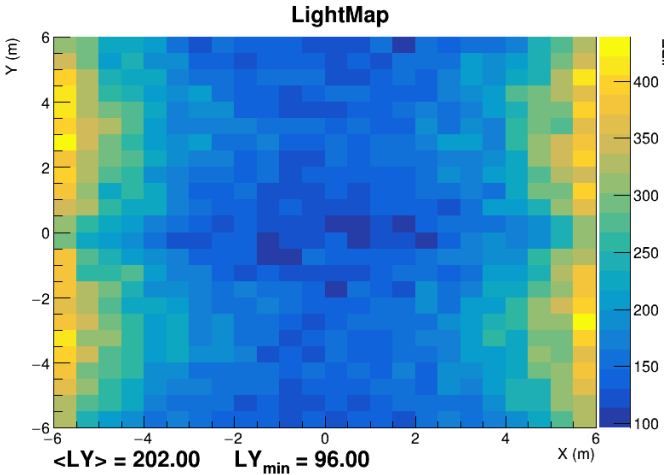


- Instead of using point sources, we use a "photon wall".
- The photons are produced randomly over different positions inside a parallelepiped of dimensions $6\text{m} \times 6\text{m} \times 0.5\text{m}$. The directions and polarizations are random.
- We produce a total of 14.4 million photons, resulting in approximately 25,000 photons/MeV per voxel of dimensions $0.5\text{m} \times 0.5\text{m} \times 0.5\text{m}$.

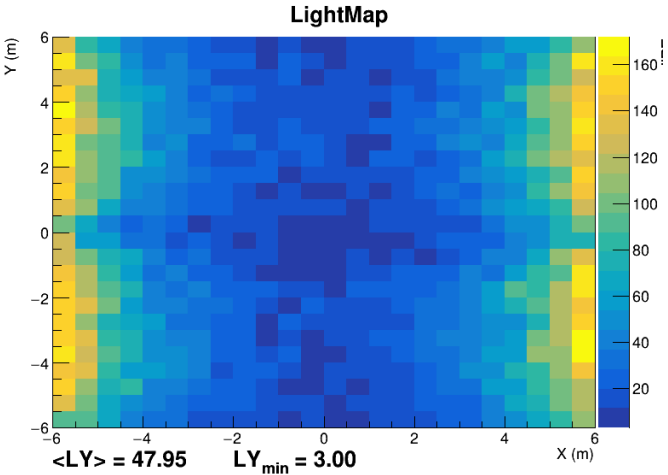
Xenon Doping lAr (50% PEN efficiency)



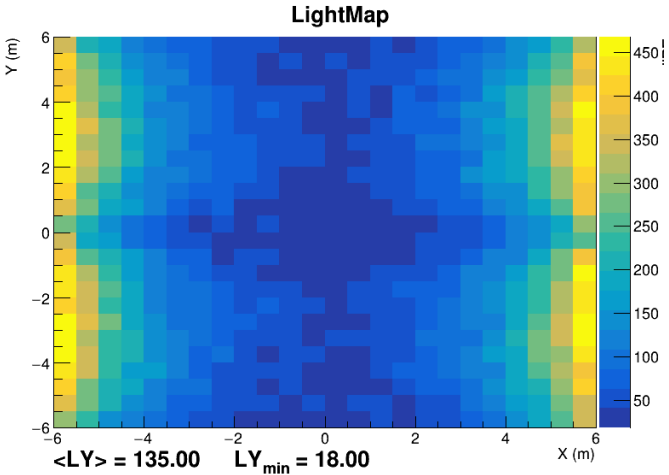
Xenon Doping lAr (100% PEN efficiency)



Pure Ar (50% PEN efficiency)



Pure Ar (100% PEN efficiency)



Conclusions

- PoWER design meets the criteria for simplicity, reduced R&D, and cost-effective criteria.
- The efficiency of this design is demonstrated using MC simulations.
- Although similar designs are to be tested in different experiments, it is necessary to perform experimental tests for its utilization in DUNE Phase 2 FDs.
- More simulations studies for full characterization and optimization of this setup and to study the active veto.
- More studies are needed to increase PEN QE and other WLS candidates for use in this setup.

[1] Manzanillas L. et al. *Optical properties of low background PEN structural components for the Legend-200 experiment*, **JINST**, 17 P09007 (2022).

[2] Abraham Y. et al., *Wavelength-Shifting Performance of Polyethylene Naphthalate Films in a Liquid Argon Environment*, 2103.03232.

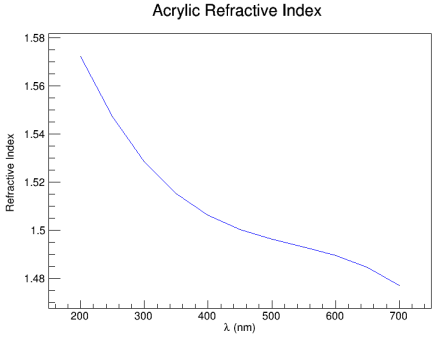
[3] Araujo G. R. et al., *R&D of Wavelength-Shifting Reflectors and Characterization of the Quantum Efficiency of Tetraphenyl Butadiene and Polyethylene Naphthalate in Liquid Argon*, **Eur. Phys. J. C** 82, 442 (2022).

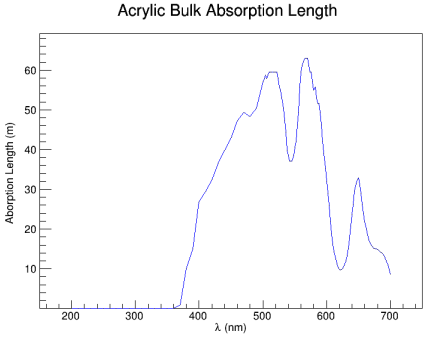
[4] Boulay, M.G. et al. *Direct comparison of PEN and TPB wavelength shifters in a liquid argon detector*. **Eur. Phys. J. C** 81, 1099 (2021).

Thanks!

Backup slides

Poly(methyl methacrylate) - PMMA





Common acrylic.
Data from Luis Manzanillas.

Reflectors

- 98% reflectance on the cathode, field cage, and membrane.
- 30% reflectance on anodes.
- Average reflectivity: 74%.