Novel designs for photon collection/detection in a LAr detector

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Outline

- AstroCeNT group and expertise
- Basic considerations
- Reflectors
- Wavelength shifters
  - TPB
  - Polyethylene napthalate (PEN)
- Measurements relative to TPB
- WLS-FAT-GEM
- Future work

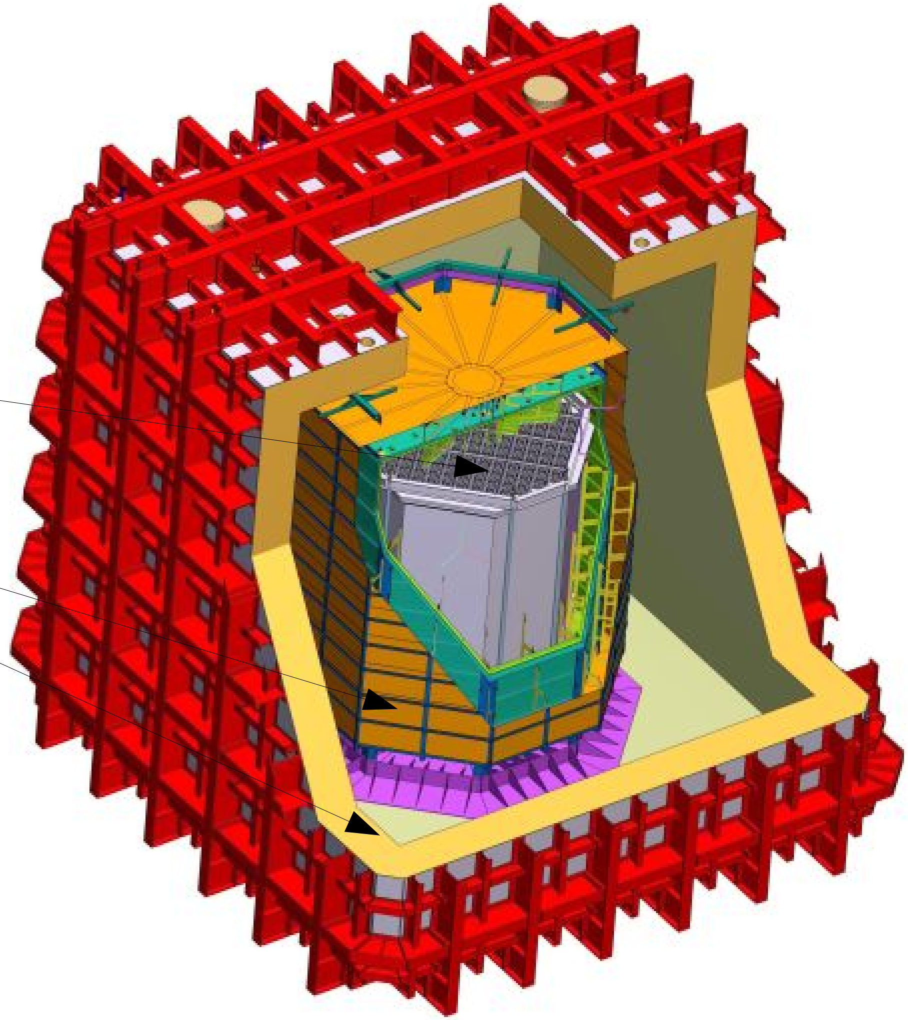
Group profile

- Group members:
  - Leader Marcin Kuźniak
  - 2 PhD students: Theo Hugues, Sarthak Choudhary
  - 3 Postdocs: Cenk Turkoglu, Marek Walczak
  - Support from technicians and an engineer
- Accesss to electronics, chemistry and cryogenic (cleanroom) lab
- Main projects:
  - Direct search for dark matter with liquid argon detectros:
    - **DEAP-3600** (currently running at SNOLAB in Canada)
    - **DarkSide-20k** (under construction in Italy)
    - **ARGO** (conceptual phase)

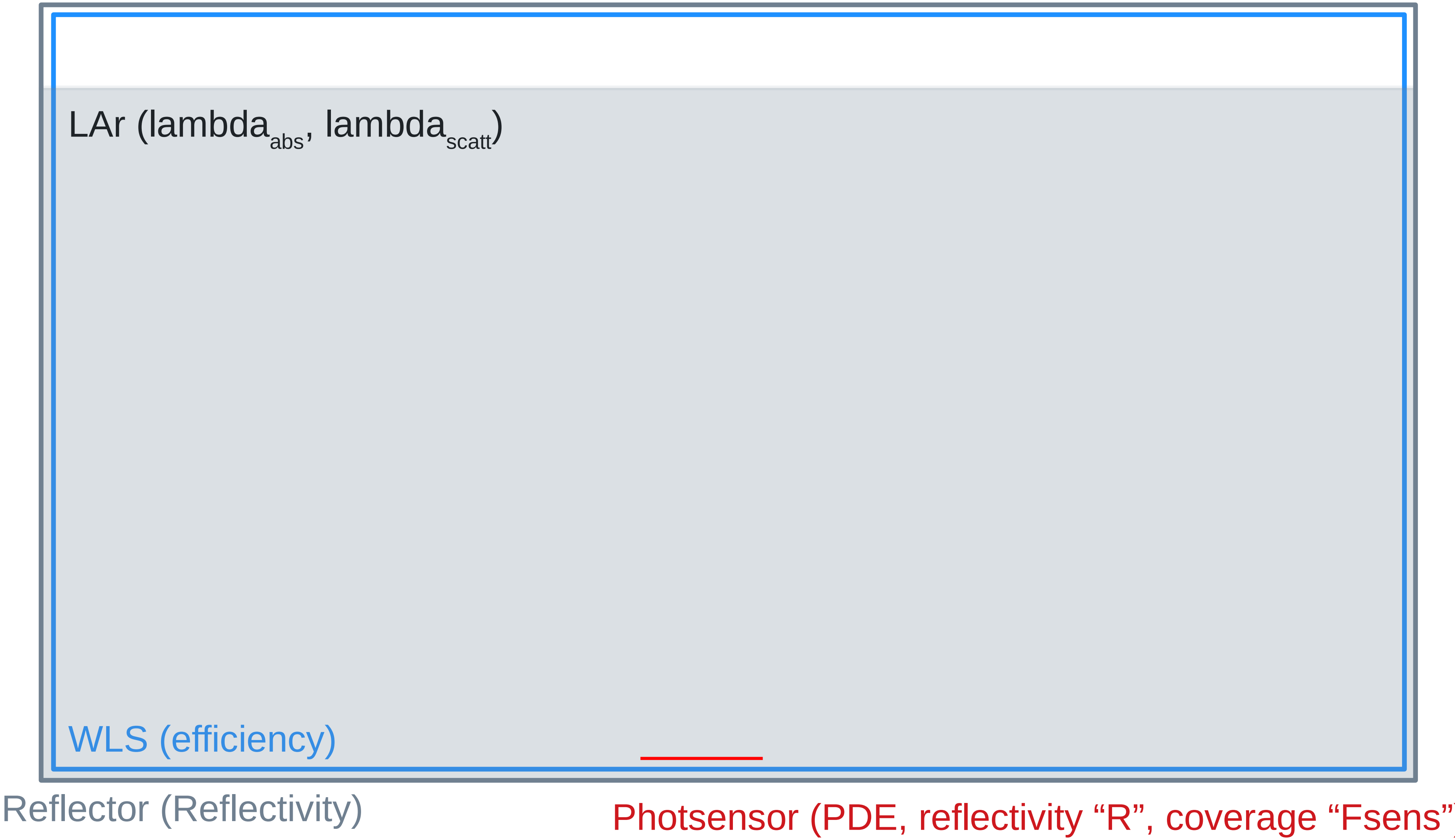
    } **G**lobal **A**rgon **D**ark **M**atter **C**ollaboration
  - Synergies with DUNE:
    - Recently joined CERN Neutrino Platform. Planning large scale WLS tests. (support from a Horizon 2020 grant)
- Joint projects with Dr. Wada's group at AstroCeNT
- Strong links with APC Paris, McDonald Institute (Canada), TUM (Munich) and Italian collaborators from DarkSide.

DarkSide-20k

- ~300 physicists, 60 institutions, 11 countries
- Under costruction at Gran Sasso (Italy)
- Concept:
  - Inner LAr chamber (~50 tons) instrumented with **SiPMs**
  - Enclosed in an active LAr veto
  - Enclosed in a passive LAr shield tank
- Our resonsibilities:
  - **Relectors and wavelength shifter (WLS) for the active LAr veto (~600 m^2 surface)**
  - **Veto SiPM system: analysis, testing and development**
- After DarkSide-20k:
  - In 10 years?
  - ARGO: 400 tonnes of LAr



Basic scheme



$$LY = 40\ [\mathrm{ph/keV}] \cdot PDE\ [\mathrm{pe/ph}] \cdot WLSE \cdot \frac{F_{sens} \cdot FF \cdot (1 - R_{sens})}{1 - (F_{sens} \cdot R_{sens} + (1 - F_{sens}) \cdot R_{wall})}$$

To first order light yield can be modelled analytically with high accuracy. For large detectors, Fsens tends to be small -> this makes the system very sensitive to average wall reflectivity.

Light yield prediction

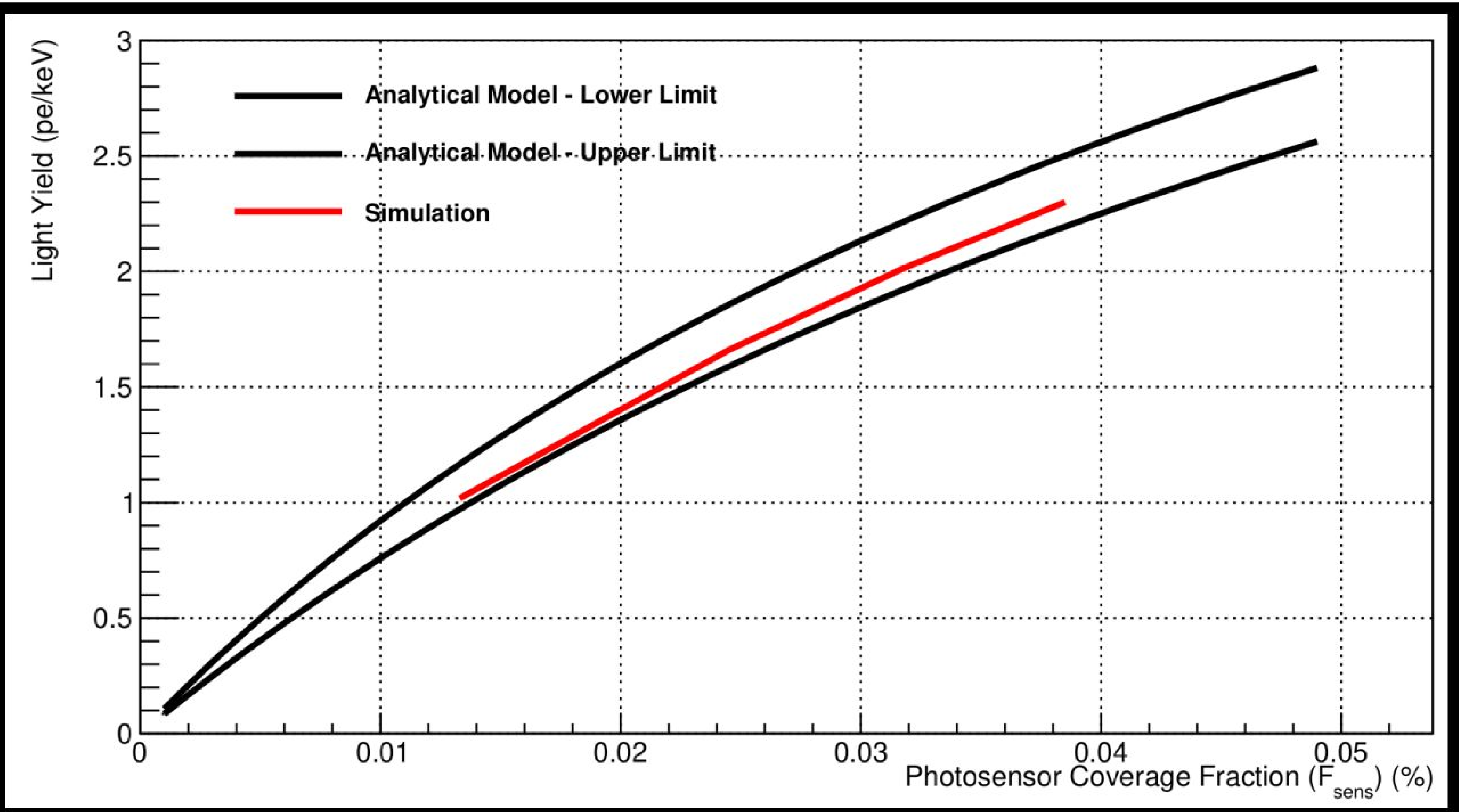


Figure 3: Light yield output of the veto simulations (red) with respect to different configurations of the photosensor (SiPM) coverage fraction compared to the analytical model (black) according to [5]

Assumptions: walls fully lined with Vikuiti ESR reflector (R=~98%) and polyethylene naphthalate (PEN) wavelength shifter => To be installed in the DarkSide-20k veto. Small reduction in R results in a major drop in LY.

What is the target LY?

3M reflectors

- The usual candidate: Vikuiti Enhanced Specular Reflector (ESR) – from the line of VM2000 and VM3000 reflectors

Nominal film properties

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

The technical data for the products are typical, based on information accumulated during their life, and are not to be used in the generation of purchase specifications which define property limits rather than typical performance.

Product Size Offering

- Custom Sizes—Converted to Customer Sizes
- Product Kits—30 Sheets 11″ x 11″

Pricing:

- hundred 17x17" sheets (0.19 m^2) = 5.2 kEUR
- **~281 EUR per m^2**
- Will buy a large amount for us in DarkSide
- Cheaper products exist

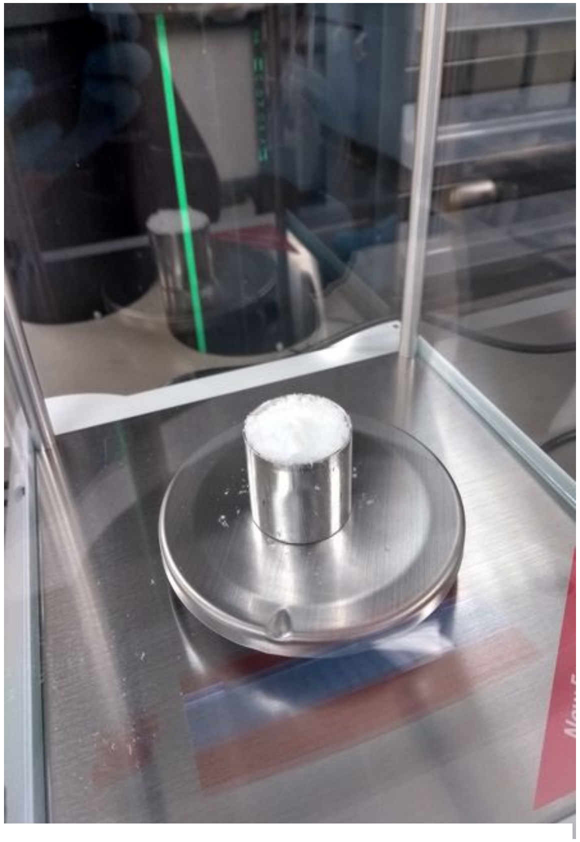
https://www.digikey.ca/product-detail/en/3m/98-0440-2750-0/3M162763-ND/4021339

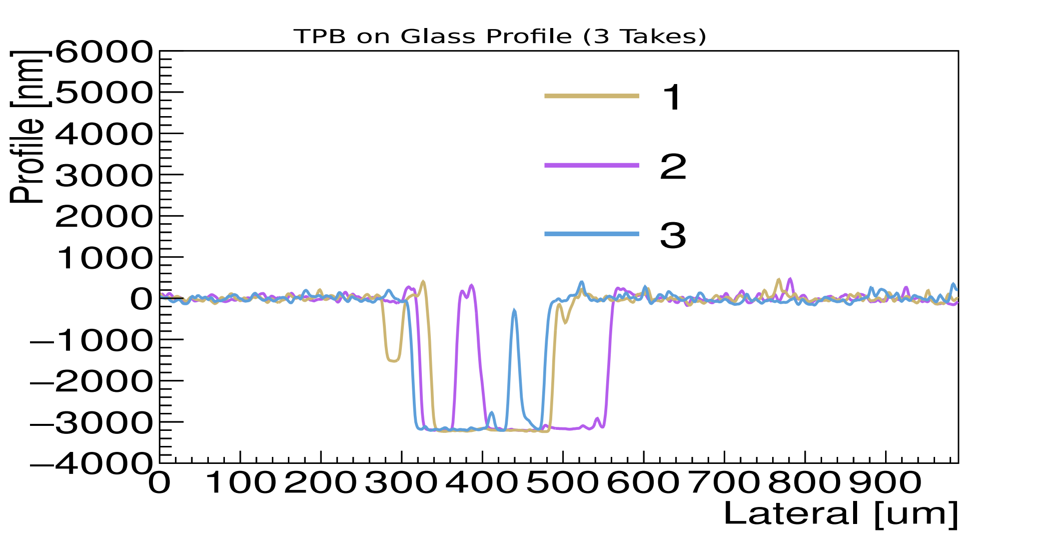
Wavelength shifter

- Tetraphenyl butadiene (TPB) works fine, but production of up to 1000m^2 using vacuum evaporation technique is a challenge
  - Large vacuum chamber needed
  - Pumpdown and production takes time. For DEAP deposited 10 m^2 area at once. But this takes a few days!
- PEN
- Alternatives:
  - Solvent based methods (similar to GERDA approach or dip-coated bars)
  - Light yield between 0.33 and 0.5 of evaporated TPB
  - Much easier, but mass production still complicated

TPB Deposition

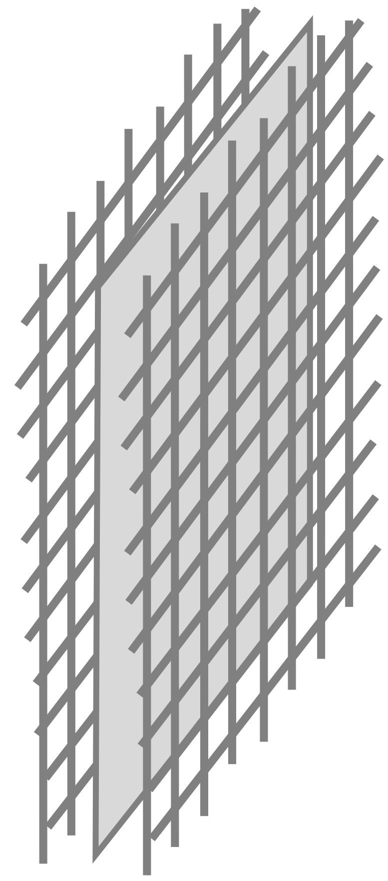
- Usually done via Low Temperature Evaporation.
- Use Knudsen Cell to heat TPB up to 220°C
- Sample rotating above gives uniform deposition.
- Evaporators capable of evaporating 50x50cm are foils exist in Manchester and Campinas
- Amount of TPB defines the thickness of deposition.

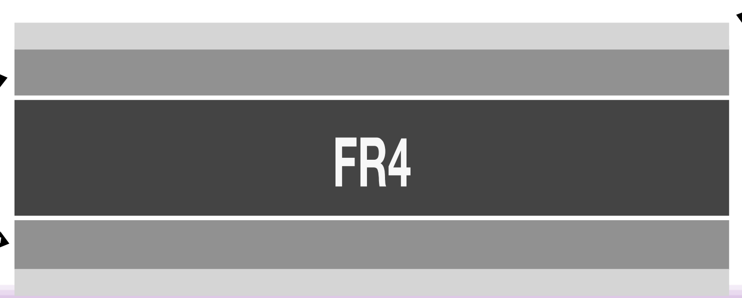




SBND Example

- SBND will run with TPB-coated reflector foils on the cathode.
- Required coating $38m^2$ of area on double sided plates.
- Will be sandwiched inside of metal mesh in the detector to avoid any effects on drift field.





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THE EUROPEAN PHYSICAL JOURNAL C

Letter

Polyethylene naphthalate film as a wavelength shifter in liquid argon detectors

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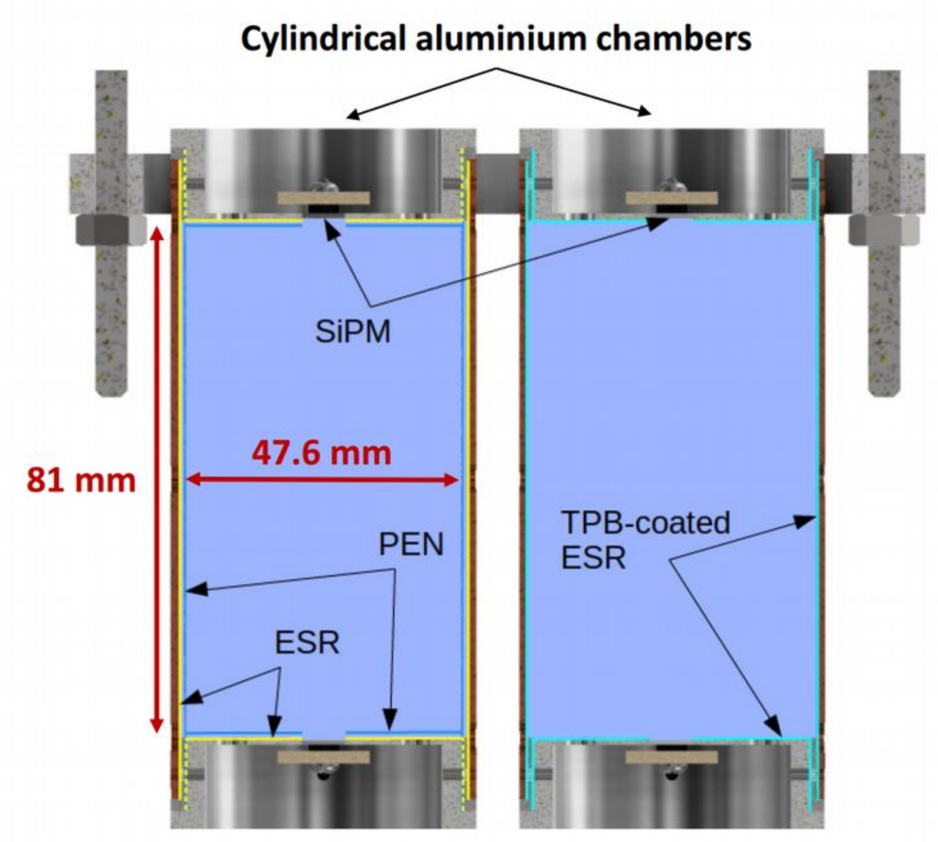
Direct comparison of PEN and TPB wavelength shifters in a liquid argon detector

M. G. Boulay, V. Camillo, N. Canci, S. Choudhary, L. Consiglio, A. Flammini, C. Galbiati, C. Ghiano, A. Gola, S. Horikawa, P. Kachru, I. Kochanek, K. Kondo, G. Korga, M. Kuźniak, M. Kuźwa, A. Leonhardt, T. Łęcki, A. Mazzi, A. Moharana, G. Nieradka, G. Paternoster, T. R. Pollmann, A. Razeto, D. Sablone, T. Sworobowicz, A. M. Szelc, C. Türkoğlu, H. Wang

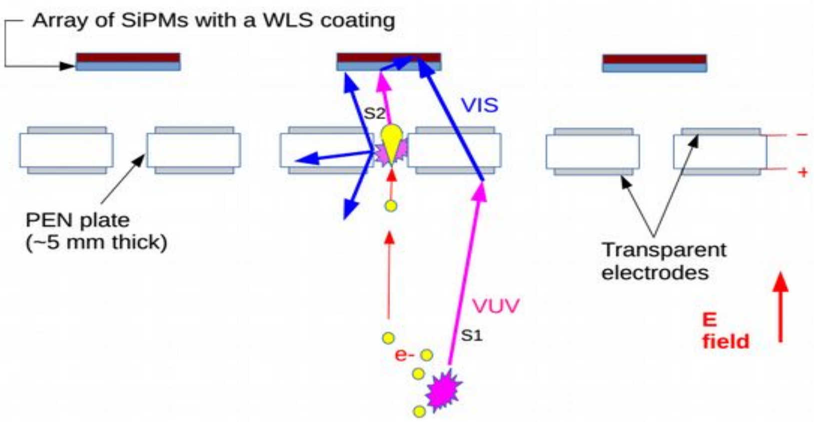
A large number of particle detectors employ liquid argon as their target material owing to its high scintillation yield and its ability to drift ionization charge for large distances. Scintillation light from argon is peaked at 128 nm and a wavelength shifter is required for its efficient detection. In this work we directly compare the light yield achieved in two identical liquid argon chambers, one of which is equipped with PolyEthylene Naphthalate (PEN) and the other with TetraPhenyl Butadiene (TPB) wavelength shifter. Both chambers are lined with enhanced specular reflectors and instrumented with SiPMs with a coverage fraction of approximately 1%, which represents a geometry comparable to the future large scale detectors. We measured the light yield of the PEN chamber to be 39.4±0.4(stat)±1.9(syst)% of the yield of the TPB chamber. Using a Monte Carlo simulation this result is used to extract the wavelength shifting efficiency of PEN relative to TPB equal to 47.2±5.7%. This result paves the way for the use of easily available PEN foils as a wavelength shifter, which can substantially simplify the construction of the future liquid argon detectors.

PEN: recent tests in LAr

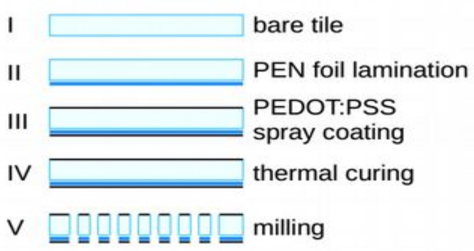


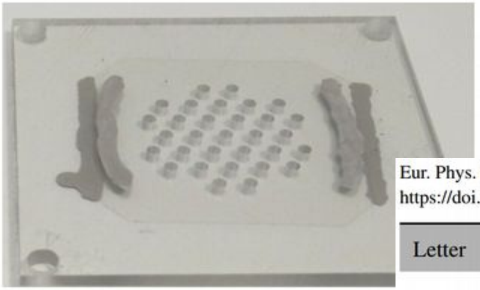
- Non-trivial excitation wavelength and temperature dependence
- Performed a relative measurement in LAr (against TPB) at LNGS
- WLSEpen / WLSEtpb = (47.2 +/- 5.7) %
- Identified an inexpensive technical off-the shelf grade of PEN, which is suitable for LAr detectors

Another idea: WLS-FAT-GEM



- Relevant for dual-phase TPCs
- Boosted collection of S2-light
- Advantages for scalability





- Optimized the technology of production of large area transpanent (polymeric) PEDOT:PSS electrodes

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THE EUROPEAN PHYSICAL JOURNAL C

Letter

Development of very-thick transparent GEMs with wavelength-shifting capability for noble element TPCs

M. Kuźniak[1,a], D. González-Díaz[2,b], P. Amedo[2], C. D. R. Azevedo[3], D. J. Fernández-Posada[2], M. Kuźwa[1], S. Leardini[2], A. Leonhardt[8], T. Łęcki[5], L. Manzanillas[6], D. Muenstermann[7], G. Nieradka[1], R. de Oliveira[4], T. R. Pollmann[8,9], A. Saá Hernández[2], T. Sworobowicz[1], C. Türkoğlu[1], S. Williams[4]

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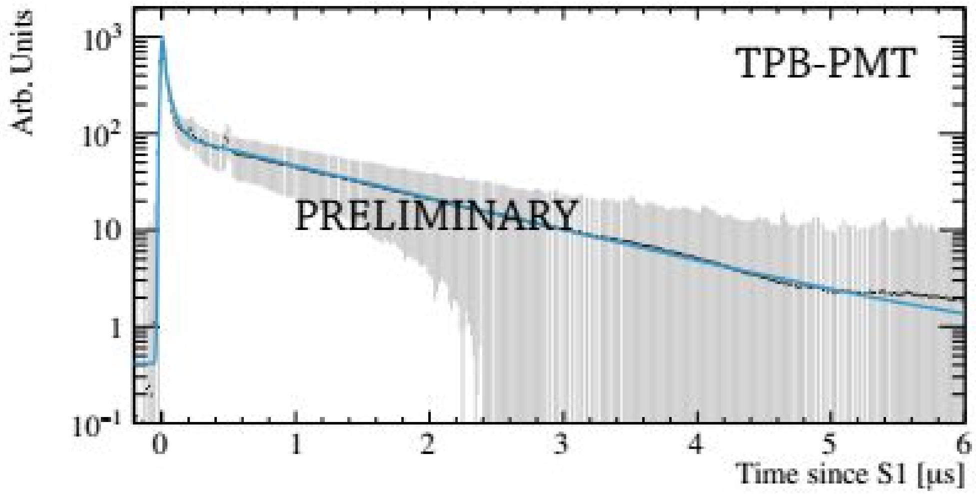
Summary

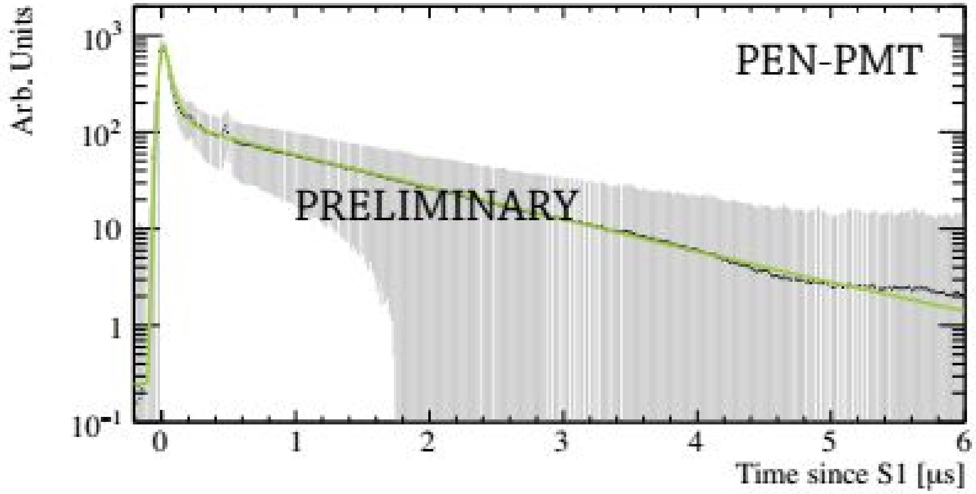
- Efficiency of PEN relative to TPB: ~0.47
- Discussions with industrial partners about custom synthesis of pure PEN with WLSE > 0.5
- Happy to contribute to FPF program with light collection scheme ideas and R&D
- For a start need the specification for minimum light yield and approximate geometry

Backup

Preliminary averaged waveforms

No drift field applied





- First average waveform in LAr from PMT self trigger events - LAr purification system not yet activated
- Fitted with a gaussian convoluted with 3 exponentials [fast, intermediate and slow components]
- Preliminary fit results suggest:
  - τ_{int} ~ 50-60 ns
  - τ_{slow} ~ 1280 ns

  for both WLS technology

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L. Zambelli - LIDINE 2019 - LDS in protoDUNE-DP