pTP paper & planning

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LAr R&D Meeting

Brookhaven
National Laboratory

Paper Status

- draft went through 1st internal review: thanks to everyone who contributed!
- since the first circulation, we have made following notable changes
  - added Matteo as an author
  - removed post-deposition treatment subsection (more on this later)
  - updated old plots (thanks to Yichen)
- note: authors listed alphabetically for now


Preprint typeset in JINST style - HYPER VERSION

Industrial Deposition of Wavelength–Shifting Films for Liquid Argon Photon Detection Systems

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ABSTRACT: The Deep Underground Neutrino Experiment (DUNE) Phase-II Far Detector (FD3) will require an unprecedentedly large-area (~2000 m^2) photon detection system to achieve a target mean light yield of 180 PE/MeV. Meeting this requirement demands scalable, cost-effective, and high-quality wavelength-shifter (WLS) coatings capable of converting 127 nm liquid-argon scintillation light into visible photons with high efficiency. We report on the successful realization of an industrial *p*-terphenyl (pTP) coating process, adapted from vacuum thermal-deposition techniques developed for the display and optics industries, to produce uniform WLS layers on large-area substrates. The coating performance is characterized using UV–Vis spectrometry to measure the emission spectrum and optical transparency, together with stylus profilometry to quantify thickness and spatial uniformity at the sub-10% level. The industrial process demonstrates reproducibility, scalability, and significantly reduced production time compared to traditional laboratory-based methods, while maintaining the optical quality required for large-scale liquid-argon time-projection chamber (LArTPC) photon detection systems. These results establish a viable pathway for mass production of high-performance pTP coatings for DUNE FD3 and future neutrino experiments.

KEYWORDS: Liquid argon detectors, Photon detectors for VUV, Wavelength shifters, Thin film deposition, Vacuum technology.

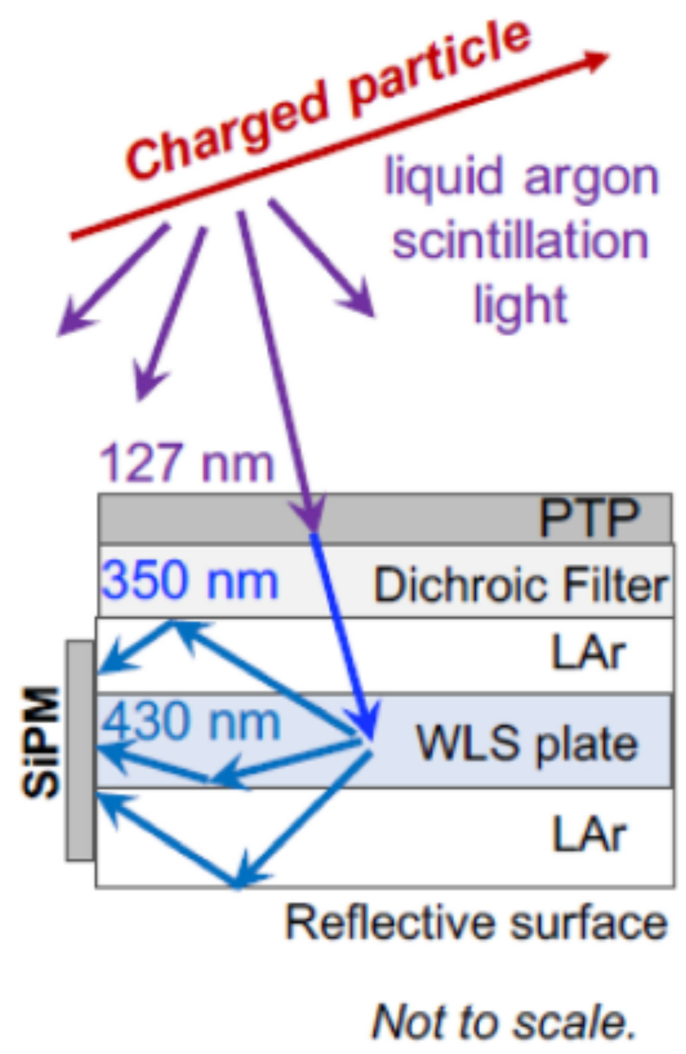
Outstanding items

- even though we do not have dichroic filter coated for this first WLS layer, the baseline X-Arapuca does have the filter

- as our sample is a variant of X-Arapuca, it does make sense to have the full figure of the baseline XA

- note, FD3 light trapper is still undergoing R&D so it's not fully decided if the filter will be included or not

- regardless it does make sense to write explicitly that we do not have the filter in our sample



(a) X-Arapuca

it converts the 127 nm VUV scintillation photons into near-UV photons suitable for subsequent trapping and detection.

Although the baseline X-Arapuca design (Fig. 1a) employs a dichroic filter as part of its primary WLS layer to achieve photon trapping, our current development samples do not include such a filter. The photon detection system design for DUNE FD3 is still under active optimization, with several alternative light-trapper geometries under evaluation. Recent optical simulations and small-scale prototype studies suggest that comparable photon collection efficiency may be attainable without the dichroic interface, motivating the simplified single-layer pTP coating approach adopted in this study.

p-Terphenyl (pTP) is selected as the primary WLS material for its high quantum efficiency, fast

Outstanding items

2. Methods

The coating procedure developed in this work was established through collaboration between Brookhaven National Laboratory (BNL) and LaserFiberOptics LLC, adapting industrial physical vapor deposition (PVD) processes commonly used in the optical and display industries for the production of high-uniformity organic thin films. The goal was to demonstrate that such an industrial approach can be directly applied to the deposition of p-terphenyl (pTP) wavelength-shifting layers for large-area photon detection systems in liquid-argon detectors. Compared to traditional laboratory-based techniques, this process offers improved reproducibility, precise thickness control, and the throughput necessary for scaling to square-meter–level production. The following sections describe the deposition setup, characterization methods, and substrate studies carried out to establish the process parameters and verify coating performance.

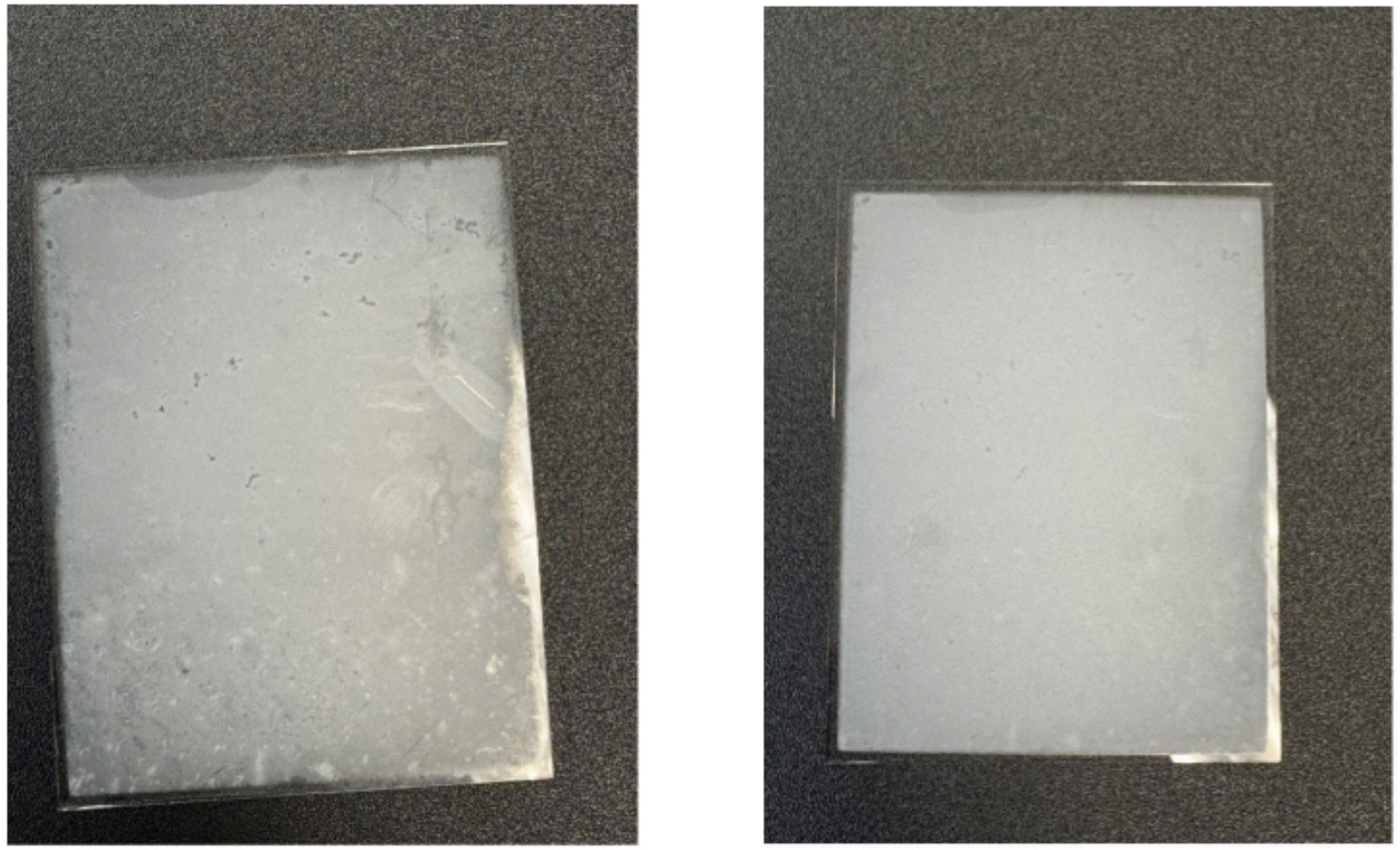
Plasma surface treatment Plasma surface treatment was employed to enhance the adhesion and surface cleanliness of the substrates prior to pTP deposition. In this process, the substrate surfaces were exposed to a low-pressure plasma environment that removes residual organic contaminants and activates the surface by introducing reactive functional groups, thereby improving bonding with the evaporated pTP film. The plasma was generated from a mixture of N_2, O_2, and CF_2 gases in a ratio of 2:10:1 for approximately 15 minutes (Fig. 2). The substrates were placed on metal meshes inside the plasma chamber to ensure uniform exposure.

Areas partially shielded by the supporting mesh exhibited reduced plasma exposure, resulting in lower pTP adhesion and thinner coating in those regions. To avoid such grid-pattern artifacts in the final coatings, all subsequent samples were positioned so that the active deposition surface was fully exposed to the plasma. This configuration provided consistent surface activation and significantly improved coating uniformity across the entire substrate area.

- added “glue text” at the beginning of Methods section
- better wordings for the plasma surface treatment subsection

Others

- thanks to Matteo's comments, many rewordings and addition of extra description for clarity applied
- still need some more updates for plots/ description: please see red texts and update accordingly
- post-deposition heat treatment section is removed, per Yimin's comments
  - Yichen will try to reproduce the treatment with CO's heating devices



(a) Before heat treatment (b) After heat treatment

Figure 4. Representative samples before and after post-deposition thermal treatment.

Post-deposition thermal treatment. As-deposited films were explored with a brief post-anneal. Uncovered films partially desorbed above $\sim$150 °C. Covering the coated surface with a clean B33 plate and heating to $\gtrsim$170 °C for $\sim$1 minute followed by a controlled cooldown preserved and further leveled the film (see Fig. 4). The cover plate did not adhere to the pTP layer and was easily removed, leaving the underlying film intact. Conversely, uncovered films were cleanly removed by the same bake, providing a practical route to rework. Given that high-quality films are achieved by PVD alone, this post-treatment may be optional; its value may be greater for solvent-processed coatings.

Plans for the paper

- new & improved B33 samples from LFO will be delivered to us, hopefully soon
  - check with Yimin on the new samples readiness
- unless the delivery does not happen in next ~2 weeks, I think it makes sense to swap the B33 result with the new samples (provided the measurements on the new samples will be superior/comparable to the current ones)
- we may also add back in the post-deposition heat treatment subsection, if Yichen can reproduce the result in time
  - this procedure will provide a certain “novelty” to the paper
- **rough timeline**
  - 10/28 - 11/7: new sample delivery
  - 11/7 - 11/14: new sample measurements (emission spectrum & profilometer)
  - 10/28 - 11/14: post-dep heat treatment testing
  - 11/14 - 11/21 update the paper draft, 2nd internal review
  - 11/24: send out the draft to Tech Pub Coordinator

DUNE Technical Paper

- Xin (APB chair) suggested we go with **DUNE Technical Paper** route for this paper
- we can still keep our guest authors to the author list
- we need **Technical Paper Coordinator**, who's not among the authors but has knowledge of the work in the paper, who will be overseeing the collaboration review procedure
- I suggest we talk to Ciro (SBU), once we have a draft ready

few words on CIEMAT travel

- per our discussion with CIEMAT group, they will only have a window sometime early next year (Feb?) to measure our sample's photon collection efficiency with XA setup
- in order to provide some help in exchange, we offered to help out with *their* own measurement that's currently ongoing (exact dates not too clear yet)
  - this will also help us to get familiar with their setup
  - probably 1-2 weeks by the end of the year
  - note that government shutdown is currently prohibiting use to travel internationally…
  - *(do/can we use group account for this travel?)*
- I now have an availability for three members (Yichen/Matteo/myself) for this year, so will coordinate with CIEMAT team as soon as the shutdown lifts

few words on CIEMAT travel

- Matteo:
  - Full availability: Nov 3-7, Nov 10-14, Dec 8-12
  - Can't make full week: Nov 17-21, Dec 1-5
- Yichen:
  - Full availability: Nov. 17-23, Nov. 24-30, Dec. 15-19, Dec. 22-26
  - Can't make full week: Nov. 10-16, Dec. 1-7
- Jay:
  - Full availability: Nov. 10- 14, Nov. 24-28, Dec. 15-19
  - Can't make full week: Nov. 17-21, Dec. 1-5, Dec. 22-26