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Chemical deposition of wavelength shifter for the next generation VUV light trap photodetectors

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CPAD 2025 at Penn

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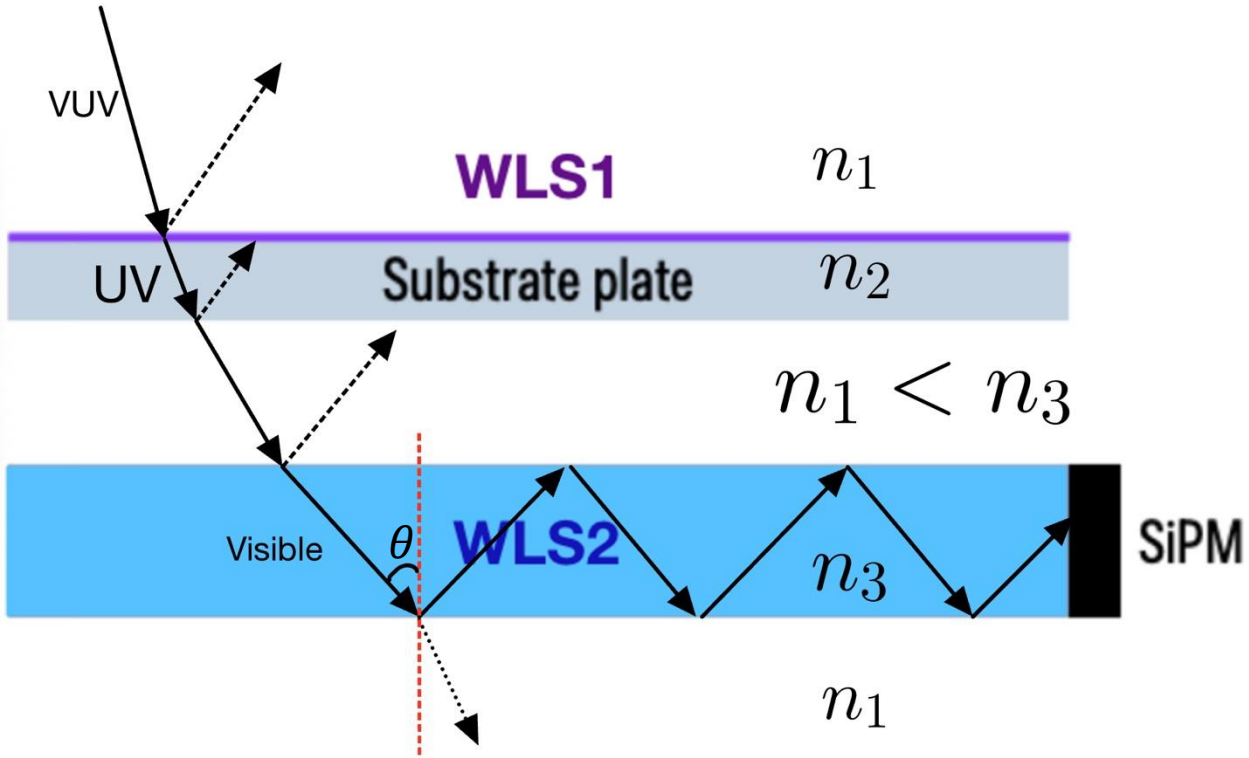
Background

- Investigation on a two-layer light trap to operate at cryogenic temperature.
- Critical angle for total internal reflection in WLS2 : given by θ_c
- Vacuum Ultraviolet (VUV) scintillation light of noble liquid.
- Need to wavelength shift the VUV to Visible and detect the light with Silicon Photomultiplier (SiPM).



$$\theta_c = \arcsin\left(\frac{n_1}{n_3}\right)$$

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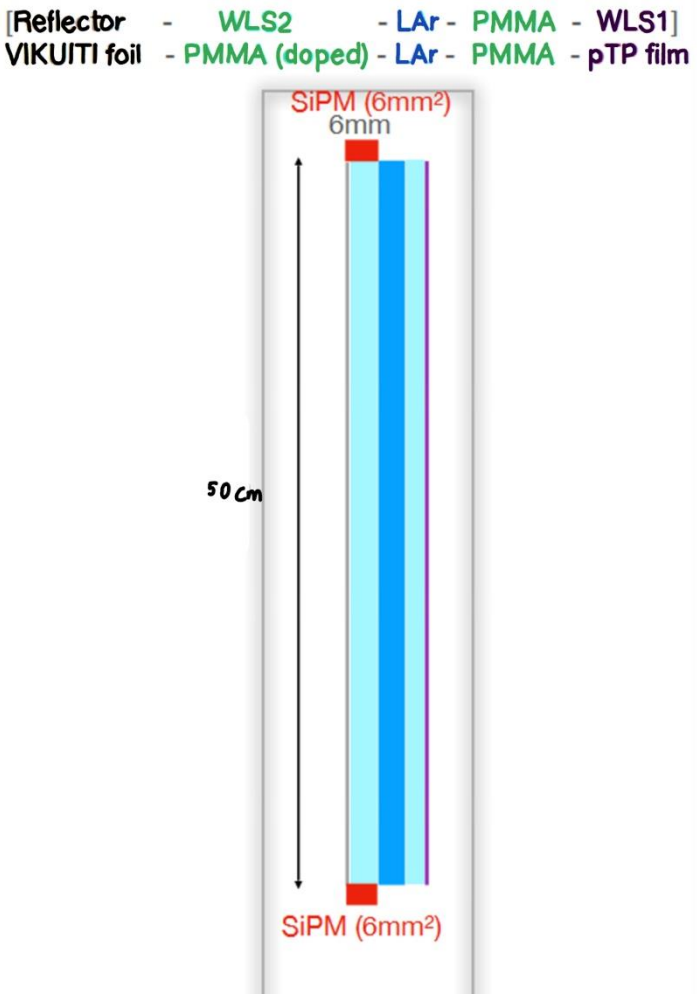
Photodetector module



Dimensions:

- Vary from 10cm x 10cm up to 50cm x 50cm depending on the physics requirements
- Prototype : 15cm x 15cm
- 1st layer: 3mm
- 2nd layer: 6mm

Components of the detector:

- 1st layer: UVT acrylic spray coated with WLS.
- 2nd layer: acrylic doped with Wavelength shifting material : ~350nm -> ~430nm.
- SiPMs mounted at two edges of the 2nd layer. Other edges without SiPMs will be covered with reflective foils.

The two layers are mechanically coupled.

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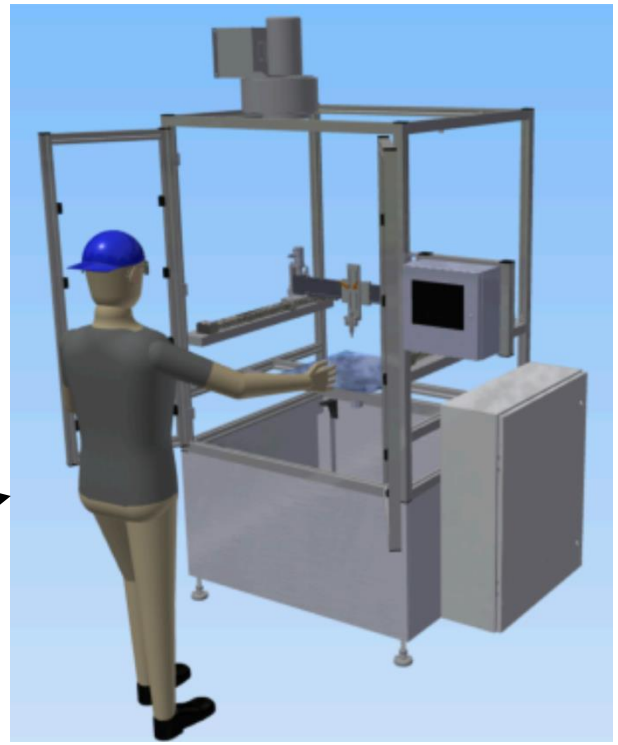
Motivation of the chemical deposition of WLS

- Vacuum deposition :
  - High vacuum
  - Low material efficiency
  - High cost
- This work investigates on the application of chemical deposition of an organic wavelength shifting material on an acrylic substrate:
  - Low cost
  - Can accelerate the coating process once automatized.
- Applications: Noble liquid-based dark matter and neutrino experiments, nuclear and particle physics, etc. (see Wei Shi's talk)



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Advantages of using an acrylic

- Low weight (<= half of SiO_2-based substrate), but similar refractive index.
- Easy to manufacture, mechanically/cryogenically more reliable.
- More radio pure than typical glass substrate.
- Potentially easier to bond with the wavelength shifter.

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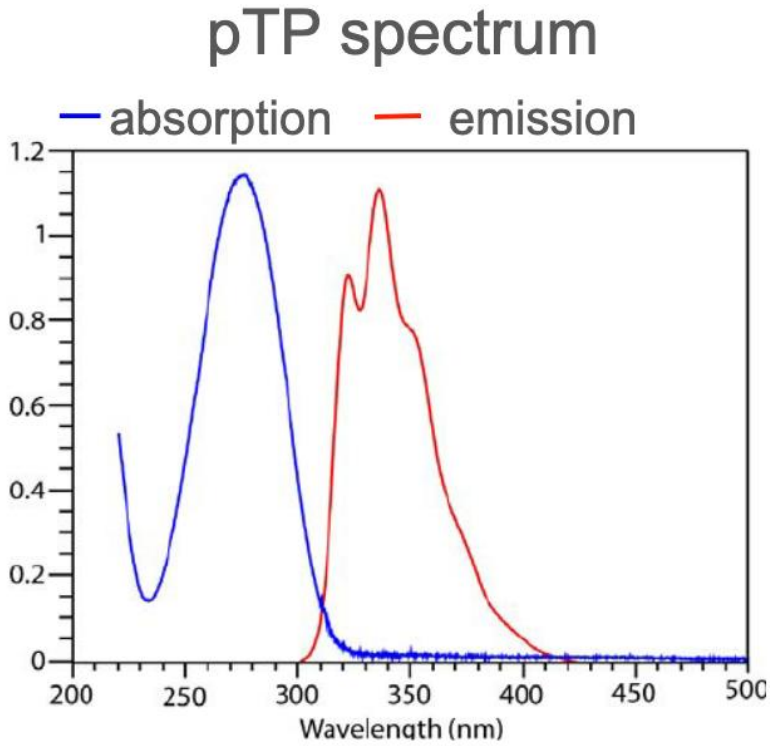
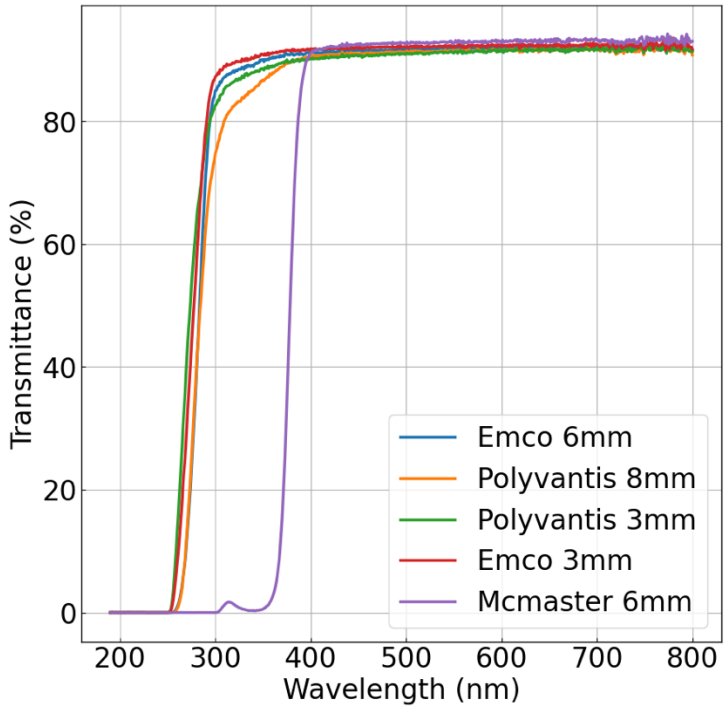
Choice of the acrylic substrate

- p-terphenyl (pTP) emission light peaking at 350 nm
  - Needs a UV transparent acrylic: transmitting wavelengths > 300 nm
  - ⇒ Choice of a UVT acrylic with a cutoff at 260 nm





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A. Ugur et al., P-Terphenyl deposited quartz plate calorimeter prototype, DOI: 10.1109/NSSMIC.2008.4774796, November 2008

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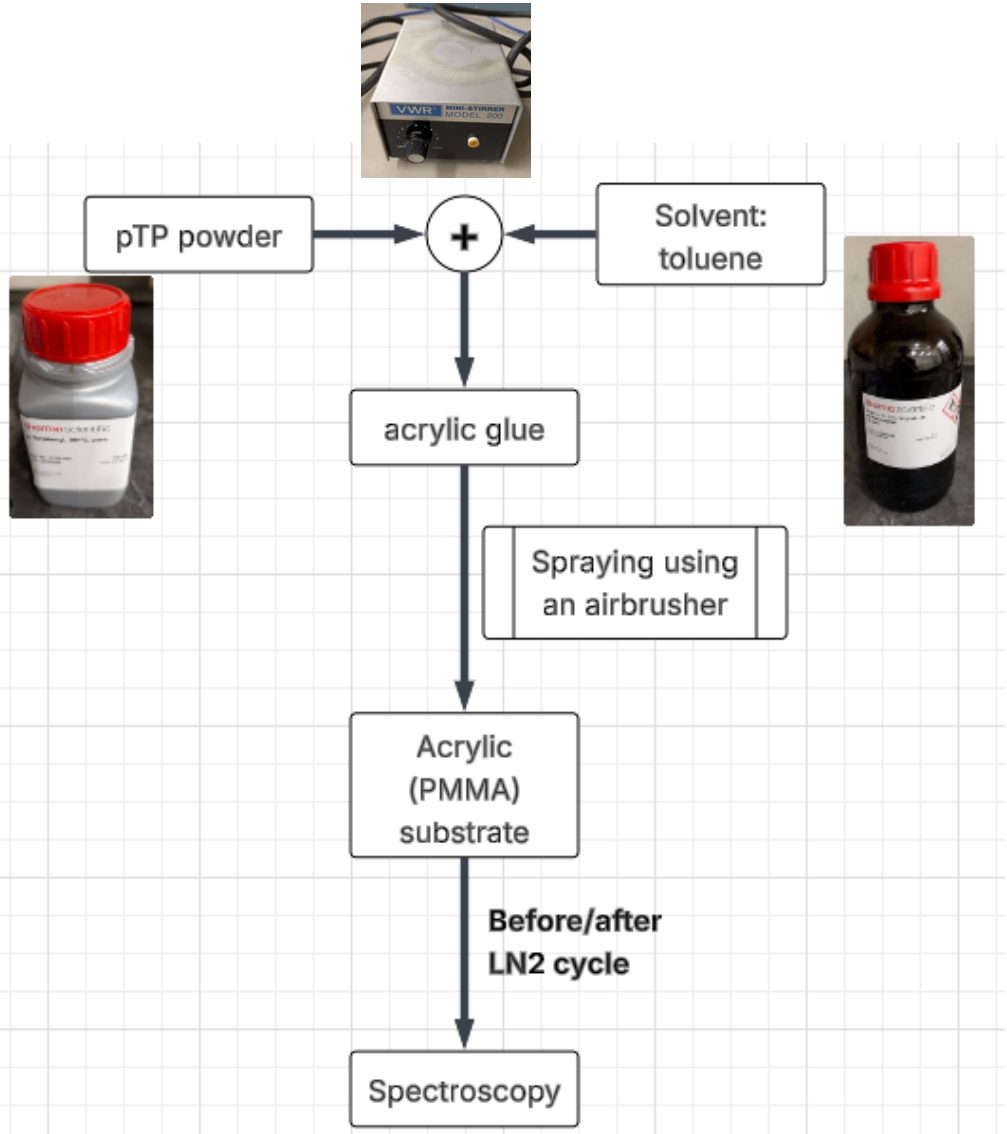
Coating method

- Acrylic glue:
  - binder of the pTP coating.
- PMMA substrate:
  - UV transparent acrylic with a cutoff at ~260 nm.
- Spectroscopy:
  - measurement of the pTP-shifted and transmitted light.



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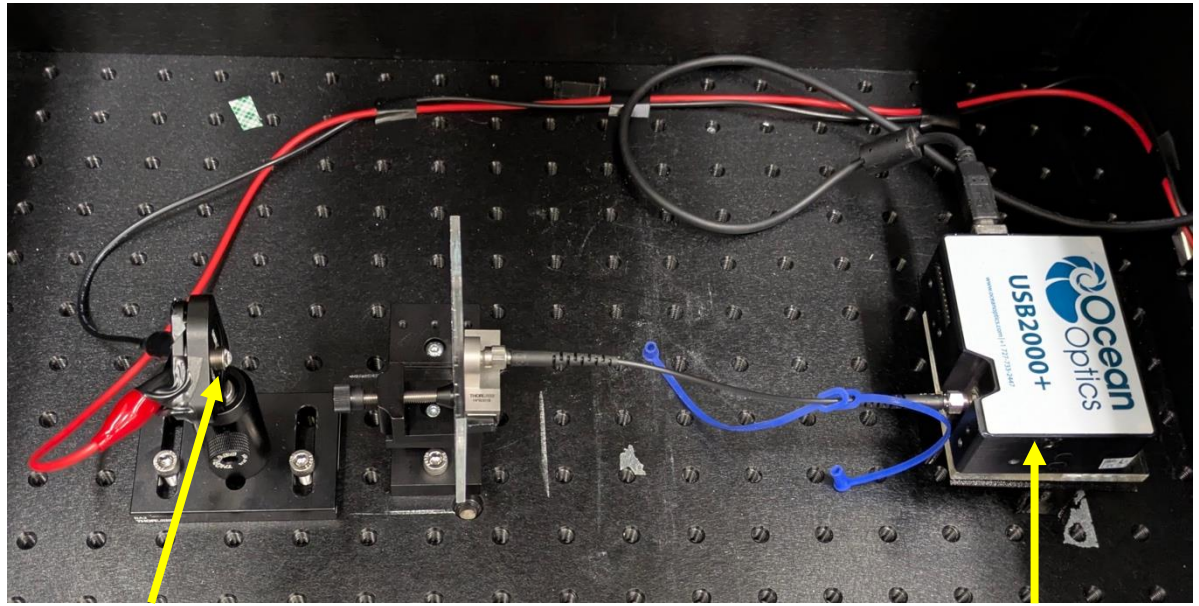
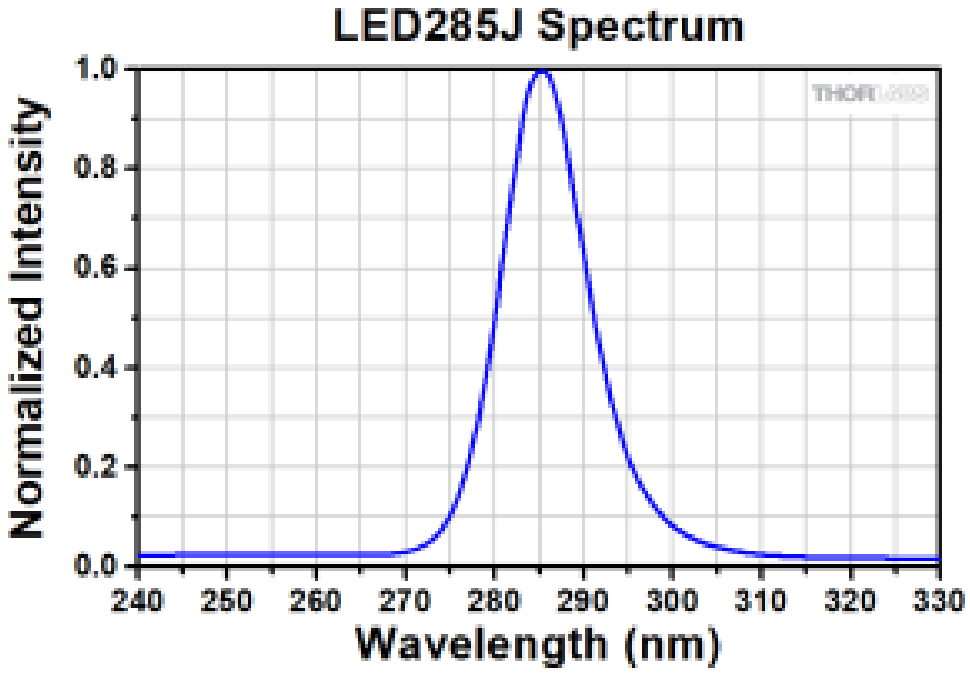
Setup of the spectroscopy

- Distance between the source, sample and the fiber optics connected to the spectrometer: fixed on the optical table.
- Measurements done in an optical black box.
- Spectrometer: OceanOptics USB2000+ with range of wavelengths 200 nm to 1000 nm.



UV source

Spectrometer



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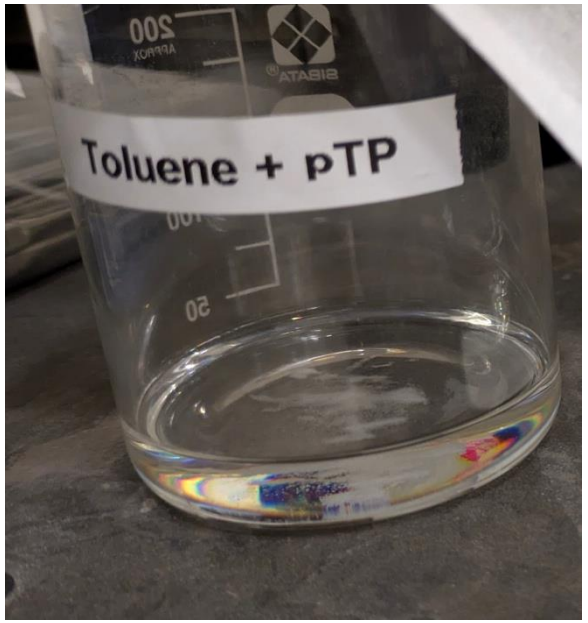
Test of solvents for the WLS

- Toluene : 9 mL of toluene can dissolve ~54mg of pTP.
- Acetone: 21 mL of acetone can dissolve ~54mg of pTP.
- THF : 9 mL of THF can dissolve ~86.4 mg of pTP
- Dicholoromethane : doesn't dissolve the pTP -> The powder floats in the solution.



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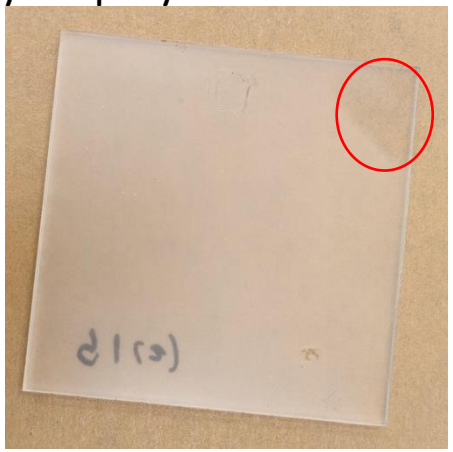
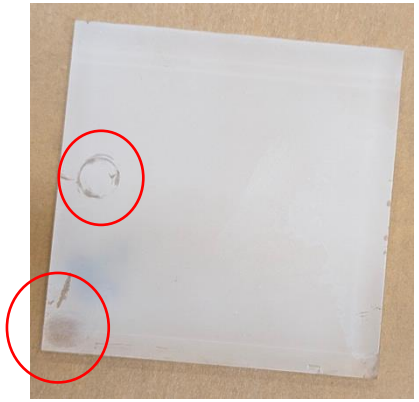
Sample prepared with toluene + pTP, and with acetone + pTP

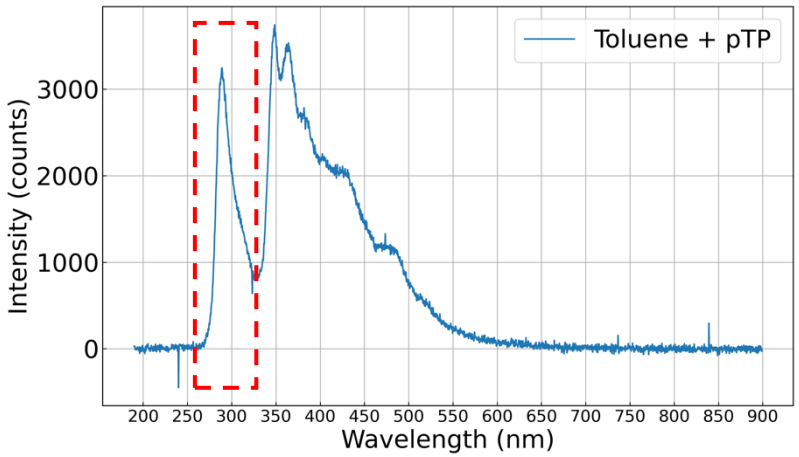
UVT acrylic sprayed with toluene + pTP

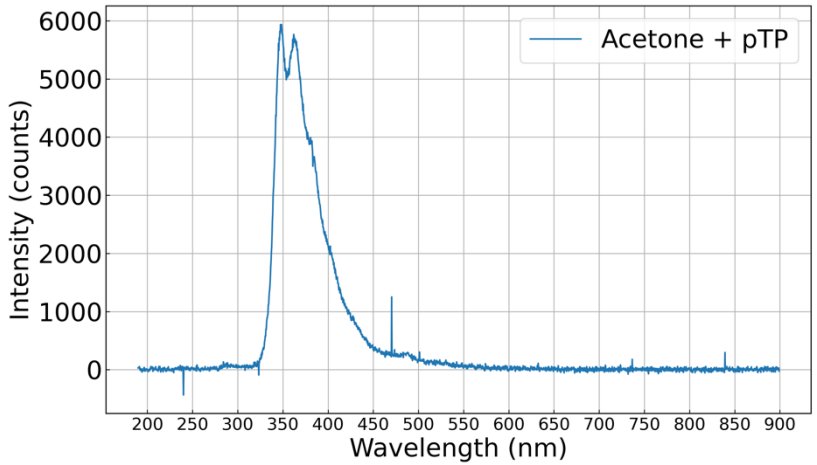


Coating is fragile without any binding material

UVT acrylic sprayed with acetone + pTP







- pTP target densities of both samples : 1mg/cm^2
- The source peaking at 285 nm is successfully shifted by the sample to ~350 nm.
- The two peaks of the spectrum is under investigation.
- Sample with toluene + pTP: part of the source is transmitted.
- The coatings are fragile.

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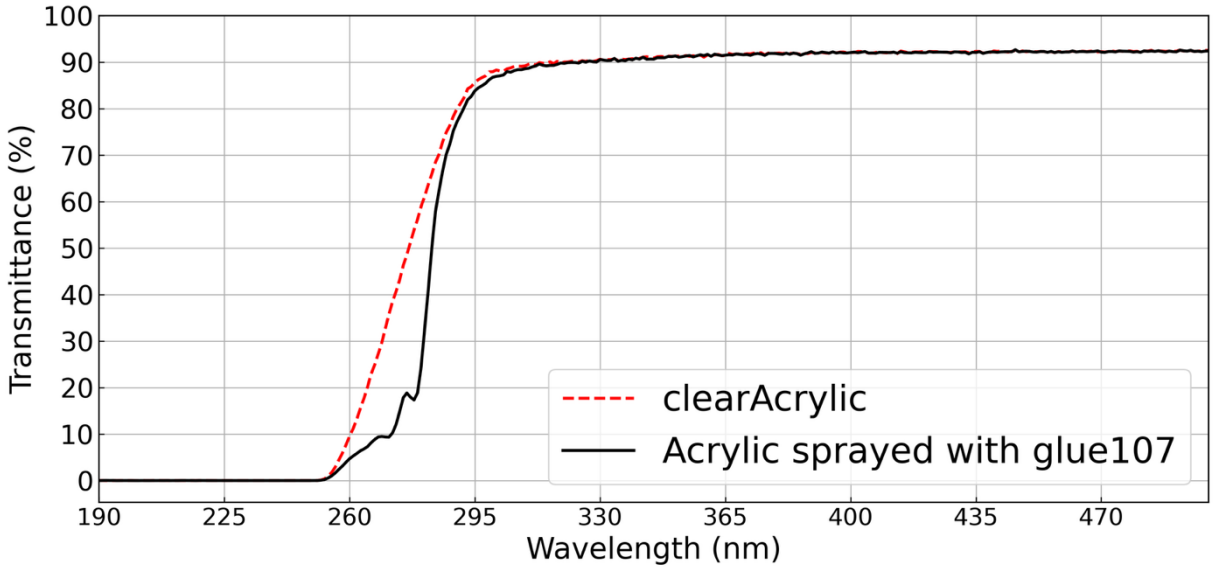
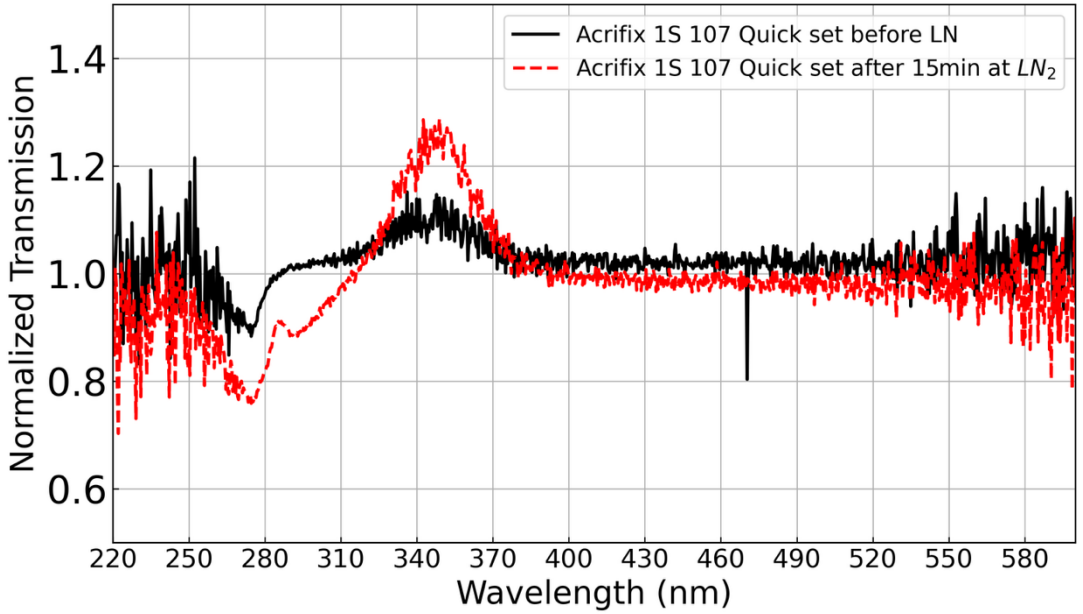
Test of acrylic glue as binder

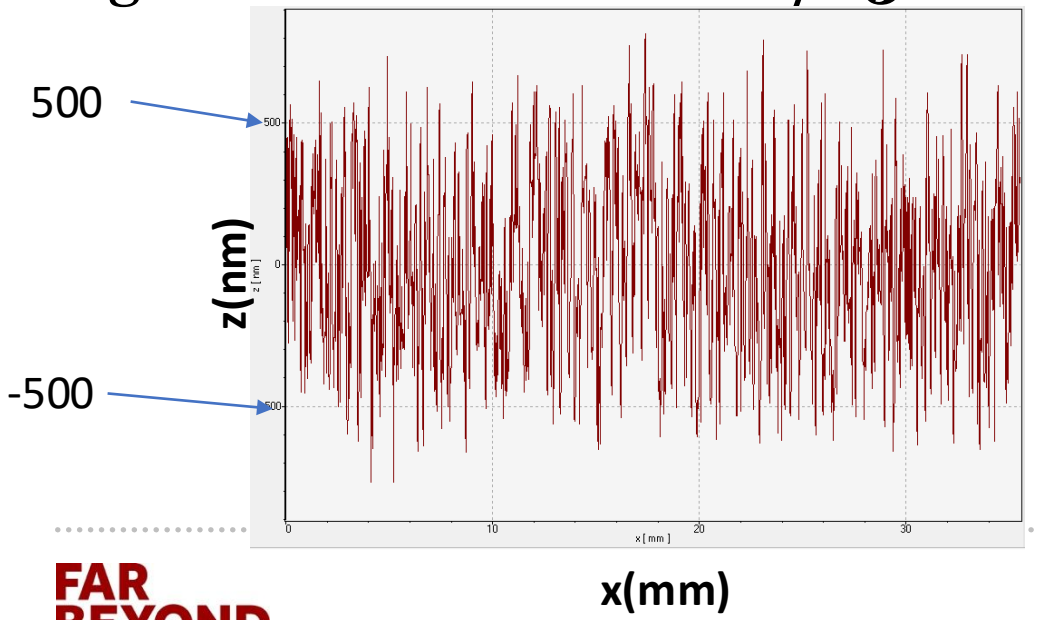
- The acrylic blocks light < ~260 nm, and with the glue it blocks some fraction between ~260 nm and ~280 nm.
- $Normalized\ transmission = \frac{Transmission\ of\ the\ sample}{Transmission\ of\ the\ susbtrate\ only}$
- The acrylic glue (Acrifix 1S 107 Quick Set) blocks light around 280 nm and emits at ~350 nm.

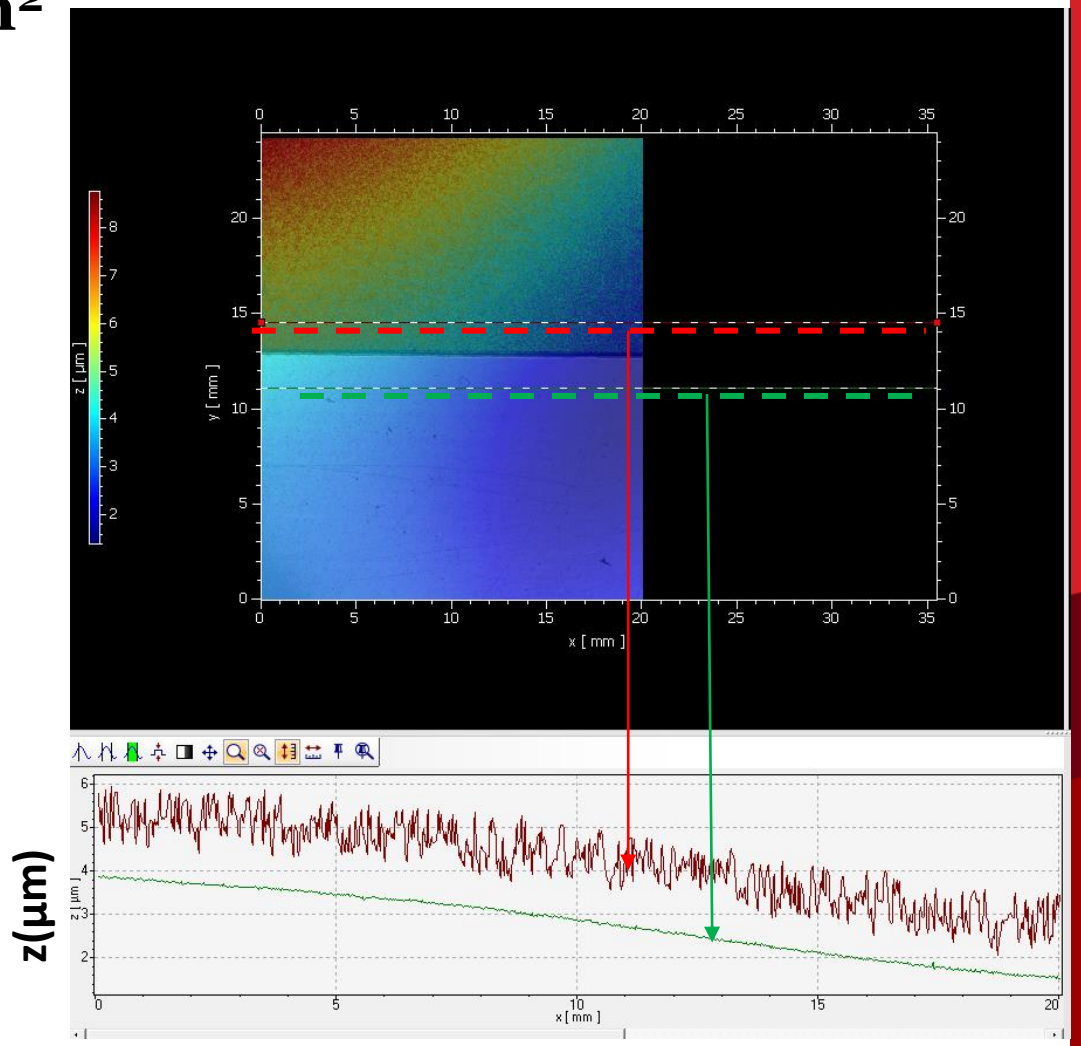




Thickness and roughness of the coated surface

- Target density of the pTP deposited: **1mg/cm²**
- 1μm < Thickness of the pTP layer < 2μm.
  - Expected thickness: 8μm.
- Loss of pTP: ~80%
- A glove box is prepared for the coating to reduce this loss.
- Roughness of the surface : **+/- 500nm**





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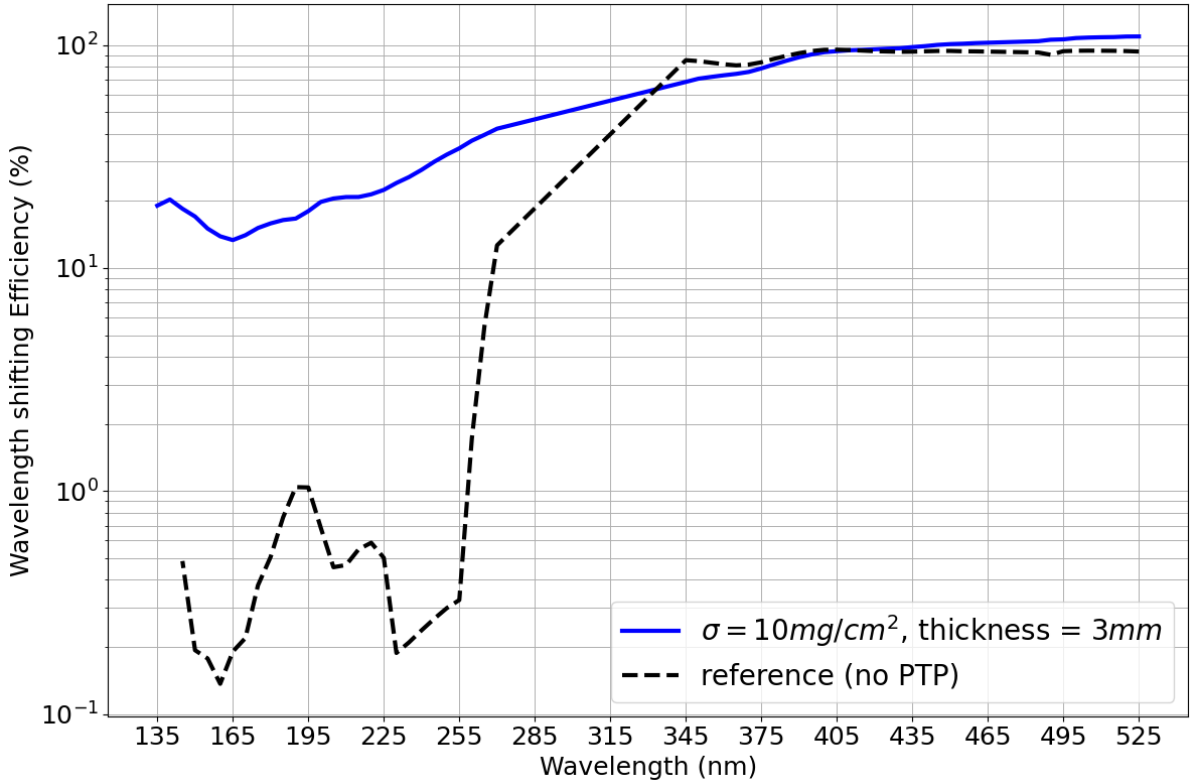
Wavelength shifting efficiency measurement

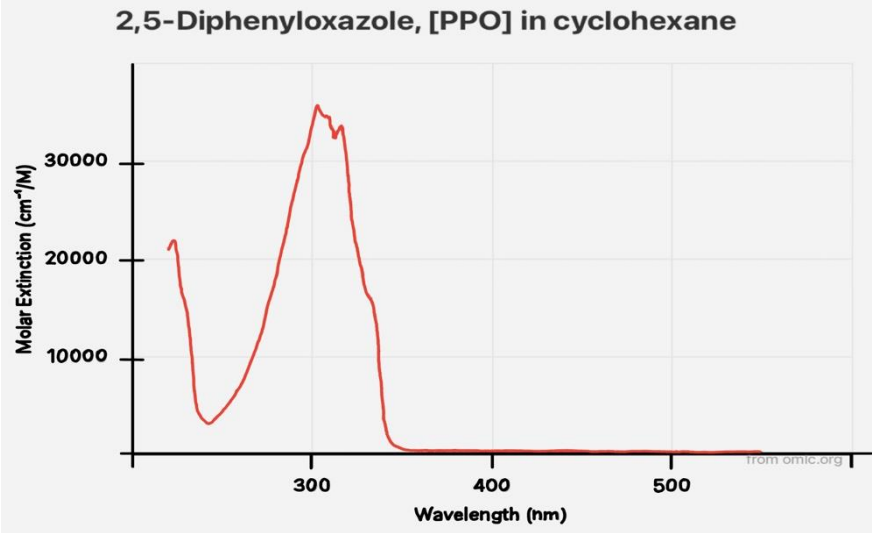


Alex Kish, Fermilab

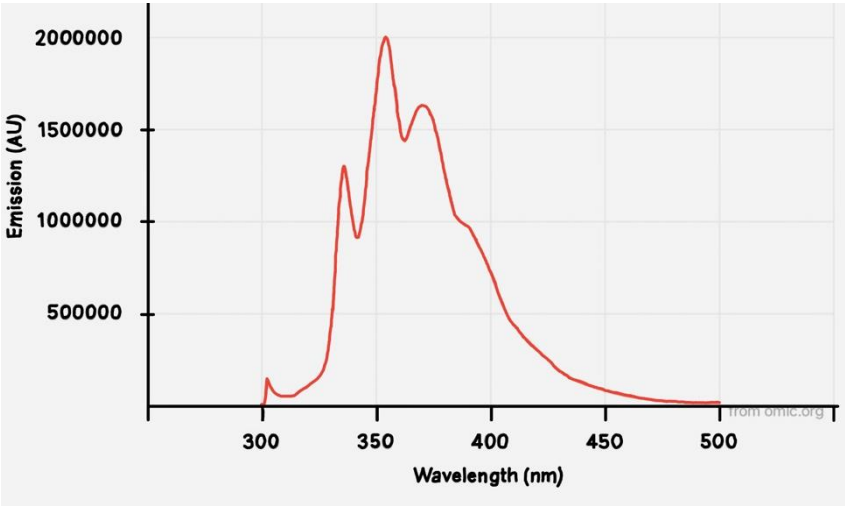
- Measurement done at the Noble Liquid Test Facility (NLTF) at Fermilab.
  - Using a monochromator : 135nm to 530nm
  - Measurement: light transmitted by the sample and collected at the back.
  - At wavelength < 260nm, only the pTP-shifted light is collected
- Black dashed line: clear UVT acrlic
  - The cutoff at ~260nm is observed
- Wavelength shifting efficiency at 135nm: ~20%

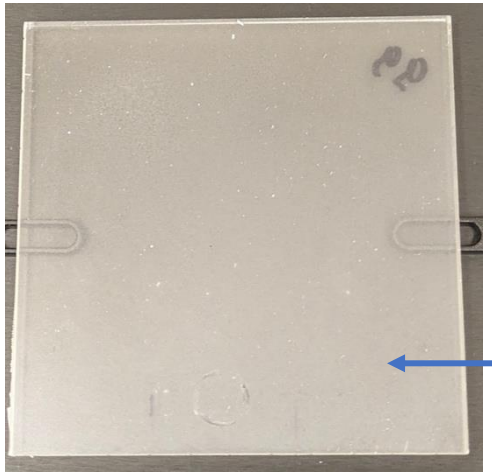
Trying the 2,5-Diphenyloxazole (known as PPO) as a WLS

Absorption

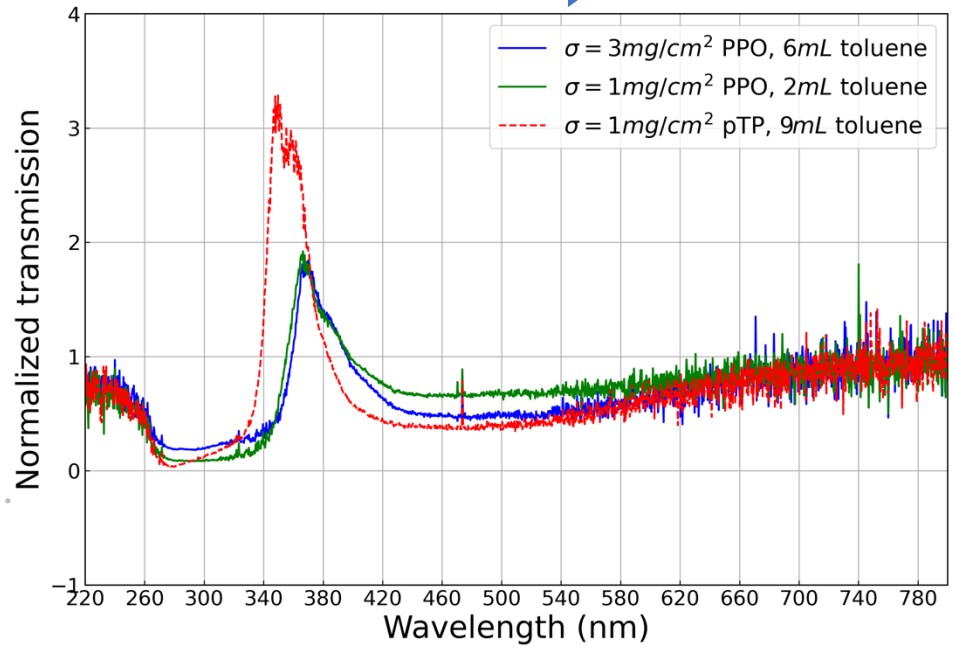


Emission





- The emission spectrum of PPO peaks at ~370 nm.
- Toluene is an excellent solvent for PPO.
- The spray coating can also be used to deposit the PPO on the substrate.



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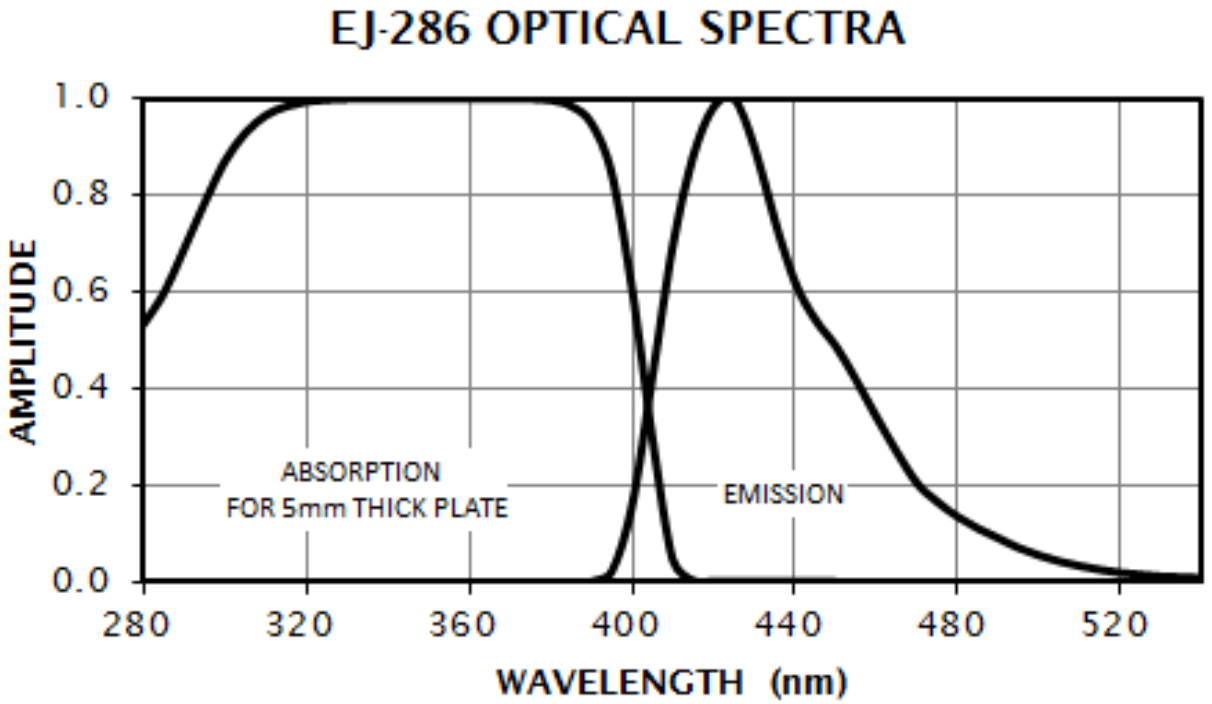
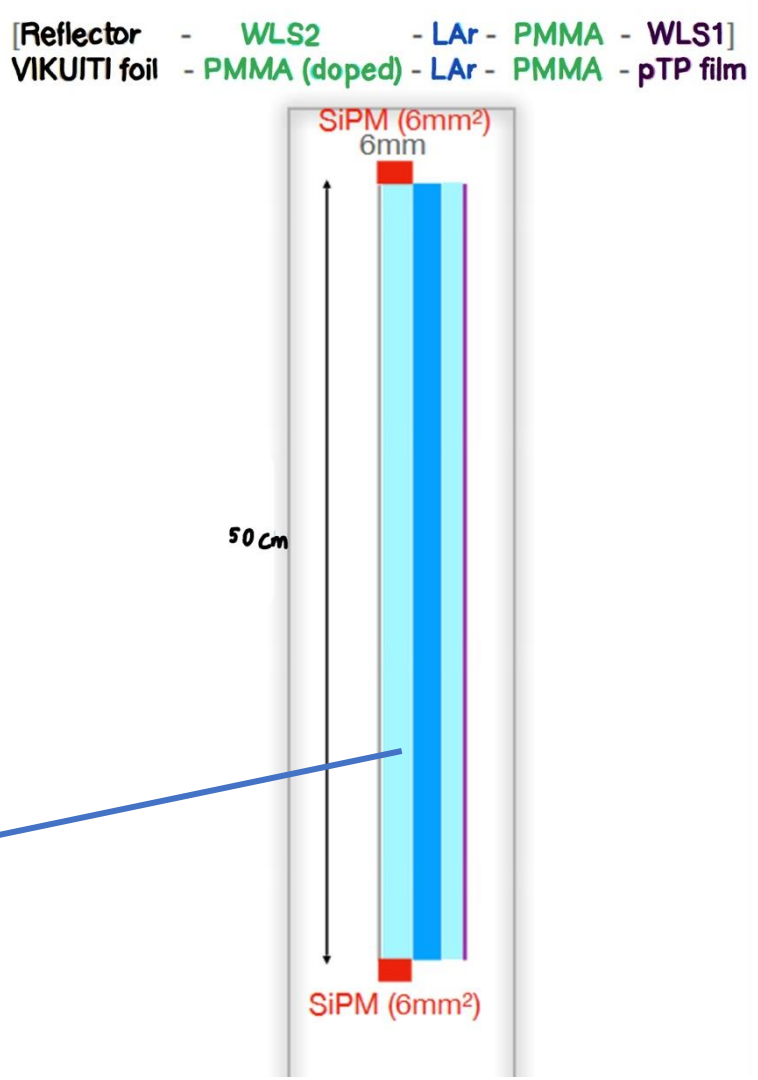
Source of PPO spectra:
https://omlc.org/spectra/PhotochemCAD/html/020.html

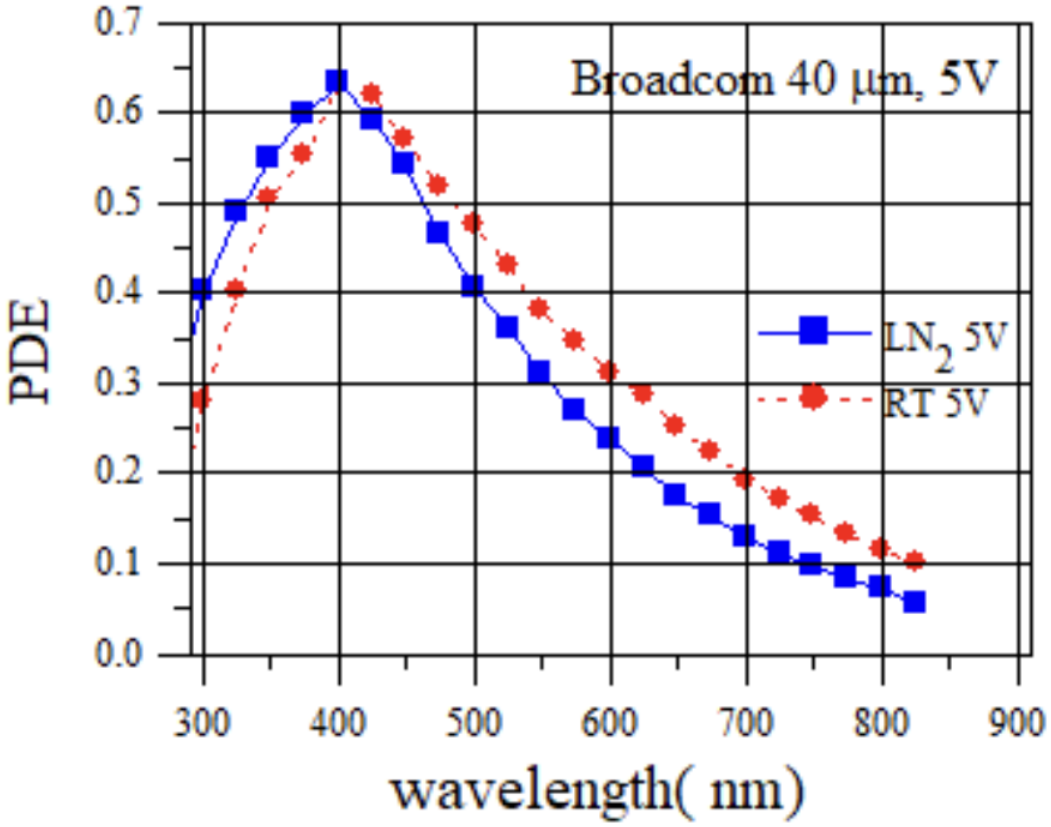
Absorption and emission spectra of ELJEN EJ286

- EJ286: second layer of the light trap
- Shift the ~350 nm emitted by the first wavelength shifter to ~430 nm.





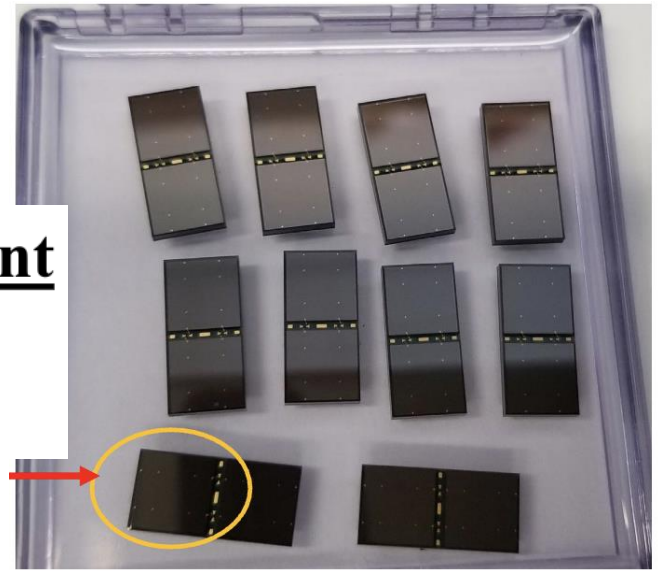
SiPM candidate for the light detection



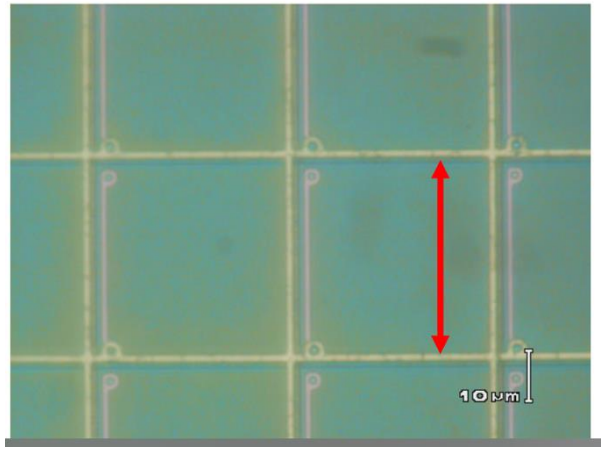
one single element

6x6 mm^2/each

Total: 0.36 cm^2



Pixel size : 40 µm



The Broadcom SiPMs are being favored due the their high absolute PDE.

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Summary

- The spray coating of wavelength shifting materials on an acrylic substrate is under development.
- UV transparent acrylics, good at cryogenic temperature, have been identified.
- The incident light of ~285 nm has been successfully shifted by WLS-coated sample.
- A wavelength shifting efficiency of ~20% is achieved at ~135 nm for the samples coated with pTP and acrylic glue.
- The samples coated with PPO are under investigation.

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Acknowledgments

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- Stony Brook University: Chang Kee Jung, Ciro Riccio, Wei Shi, Vlada Yevarouskaya, Alex Heindel, Stone Chou
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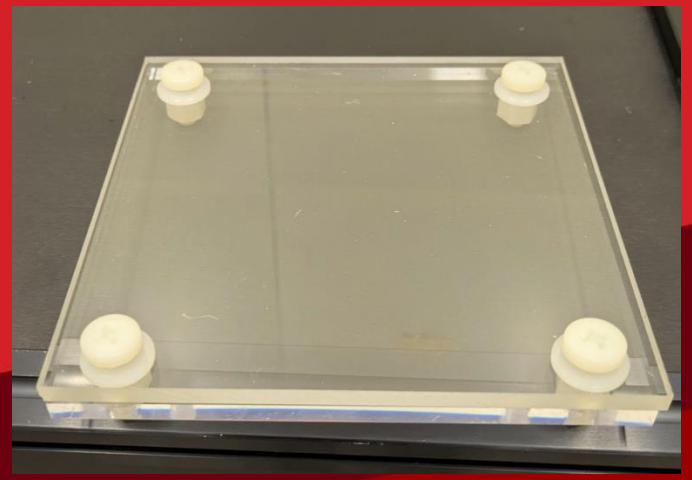
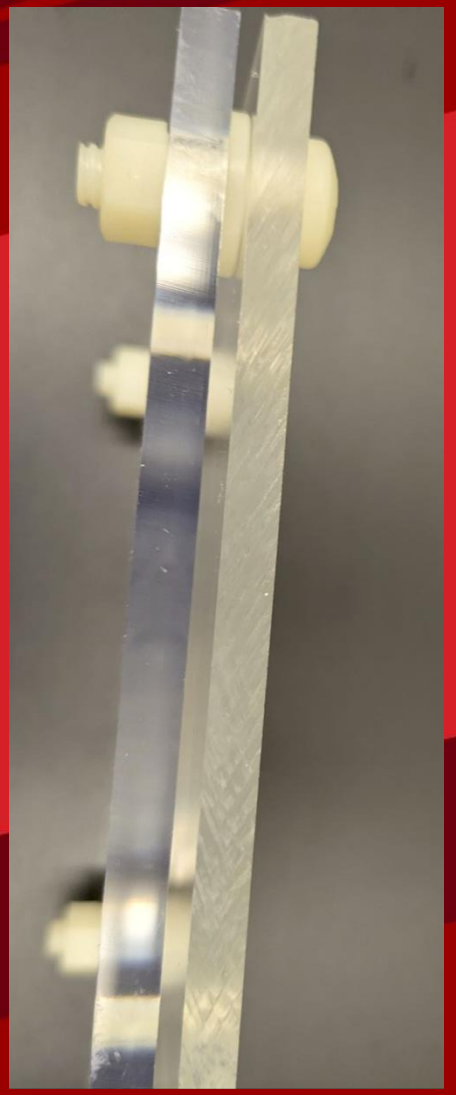
- IFIC: Anselmo Cervera, Julio Urena, Jordi Capo, Justo Martin Albo
- MiB: Carla Cattadori
- INFN: Gian Luca Raselli , Massimo Rossella, Simone Copello
- INFN Pavia: Luca Malinverni
- APC Paris: ITA: Franciole Marinho, Laura Paulucci

Mechanical coupling of the two layers of the prototype





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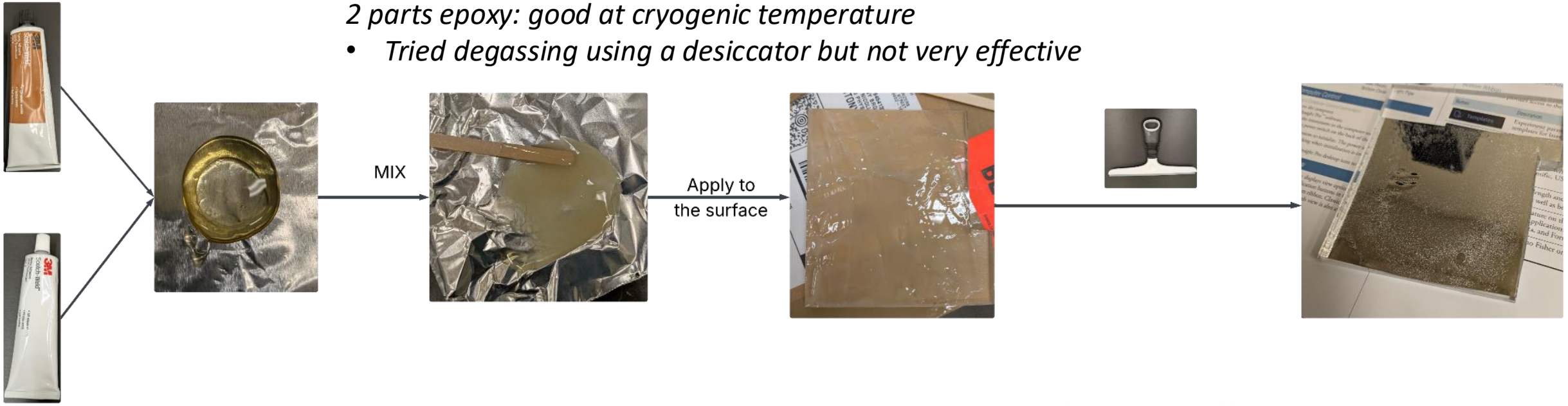
Thank you !

BACKUP

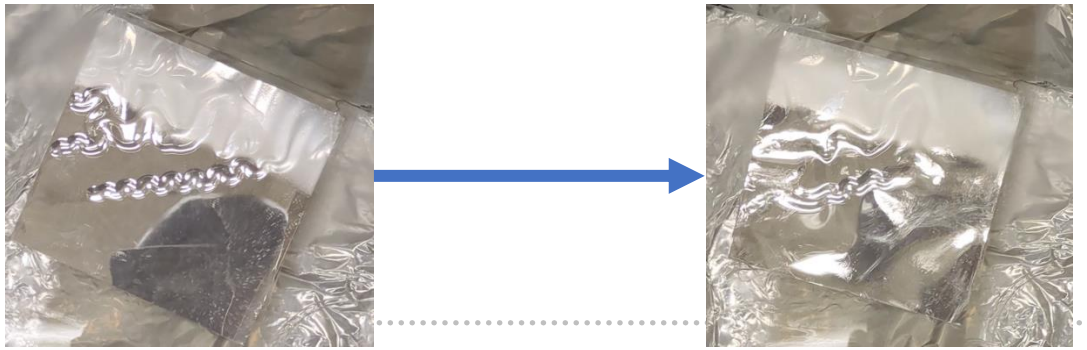
Backplane foil

2 parts epoxy: good at cryogenic temperature

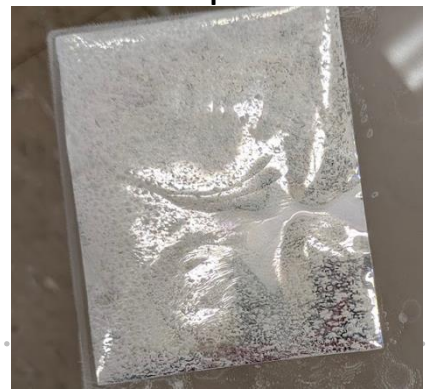
- *Tried degassing using a desiccator but not very effective*



UV cured resin : cracks at cryogenic temperature



Acrylic glue: The 3M foil peeled off in liquid nitrogen.



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