Wavelength shifting and reflective foils using TPB or polyethylene naphthalate (PEN)

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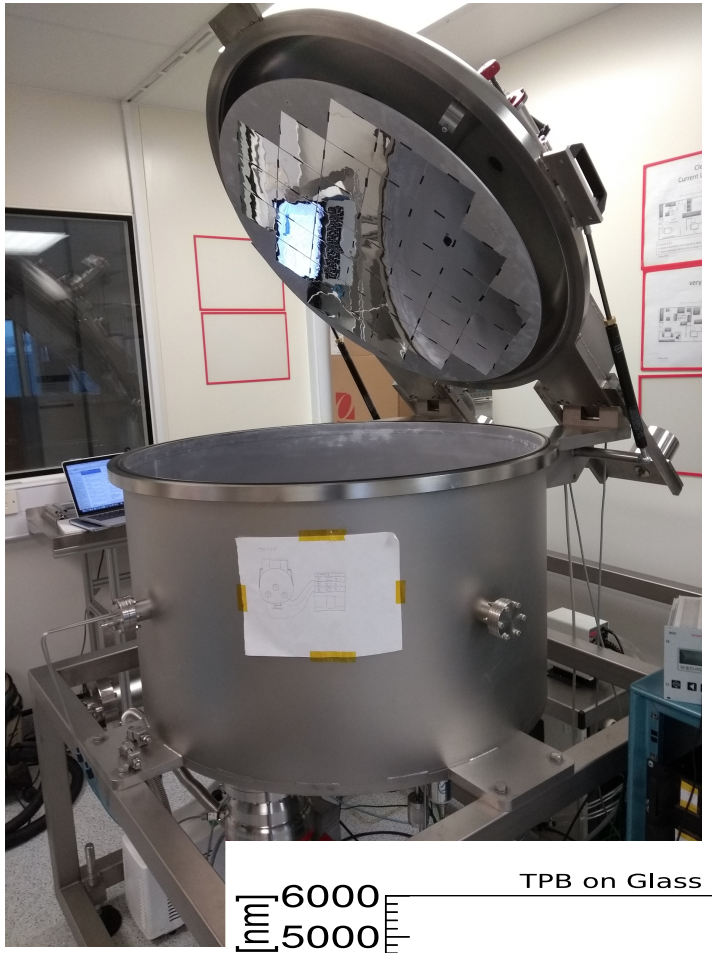
Outline

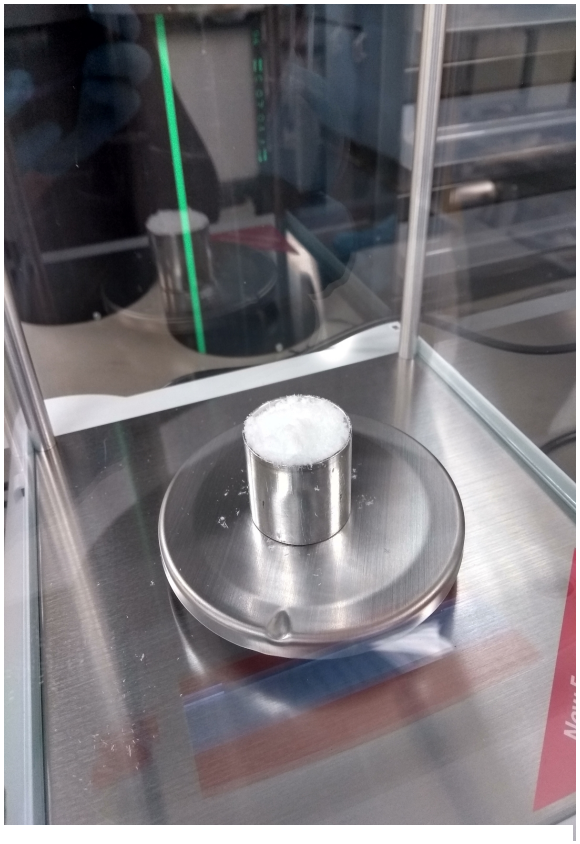
- For general rationale – see A. Szelc talk earlier today

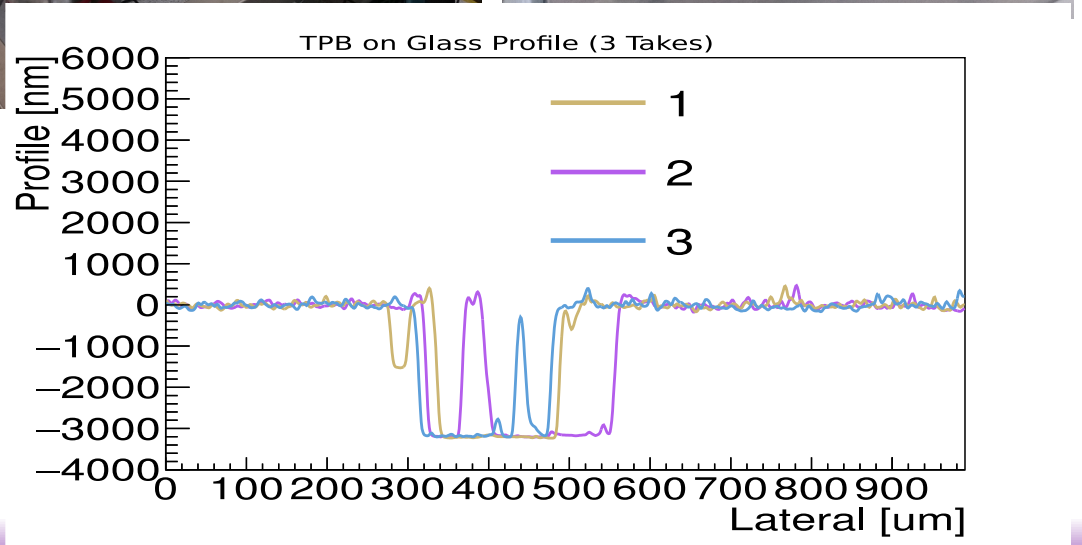
- TPB coated foils (slides from A. Szelc, Manchester)
- Motivation for alternative wavelength shifters
- Polyethylene napthalate (PEN)
- Measurements relative to TPB
- New developments
- Future work

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.



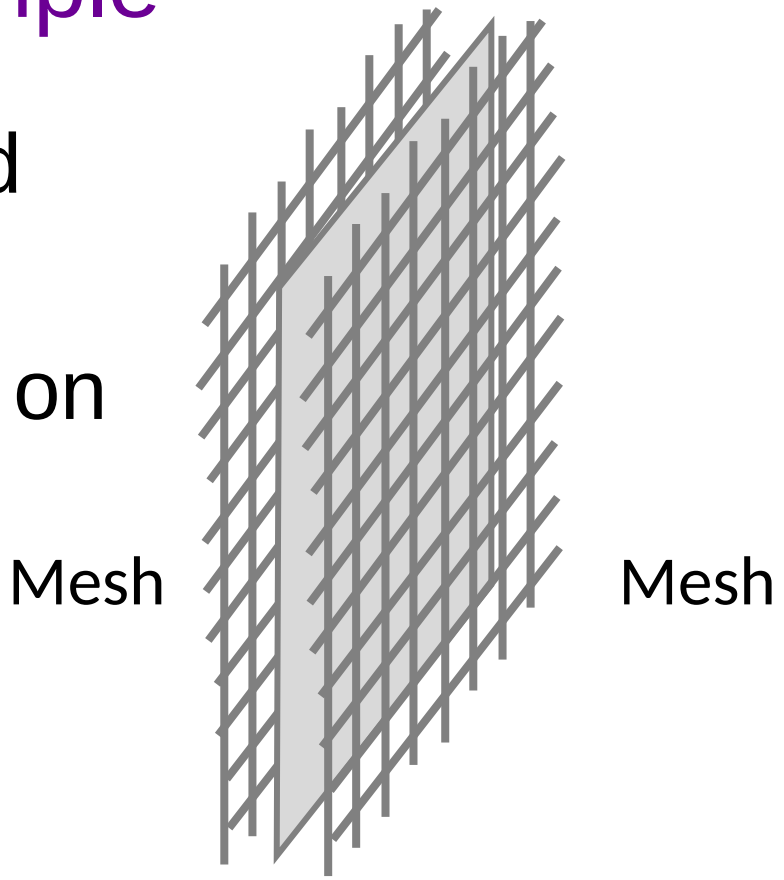


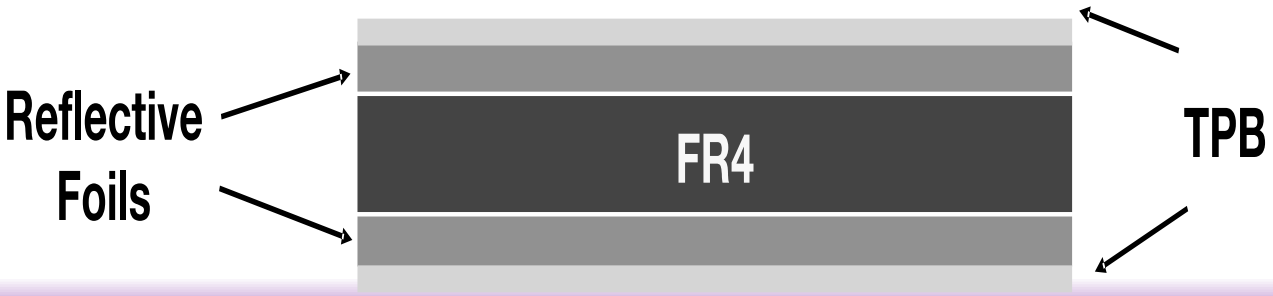


Slide courtesy A. Szelc

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.





SBND foil Production

- 64 FR4 plates needed (128 foils)
  - 128 laminations (performed by IIT, B. Littlejohn's group)
  - 128 evaporations – total area 38m^2
- Evaporations:
  - Evaporation took 2-2.5 hours, depending on experience of team.
  - 4 – 6 evaporations per day. Double sided pieces complicated things, so procedures could be streamlined.
- Production performed jointly by Manchester and UNICAMP.
- Stay tuned for first results from SBND.

Slide courtesy A. Szelc

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!
- 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
  - PEN

Eur. Phys. J. C (2019) 79:291
https://doi.org/10.1140/epjc/s10052-019-6810-8

THE EUROPEAN PHYSICAL JOURNAL C

Check for updates

Letter

Polyethylene naphthalate film as a wavelength shifter in liquid argon detectors

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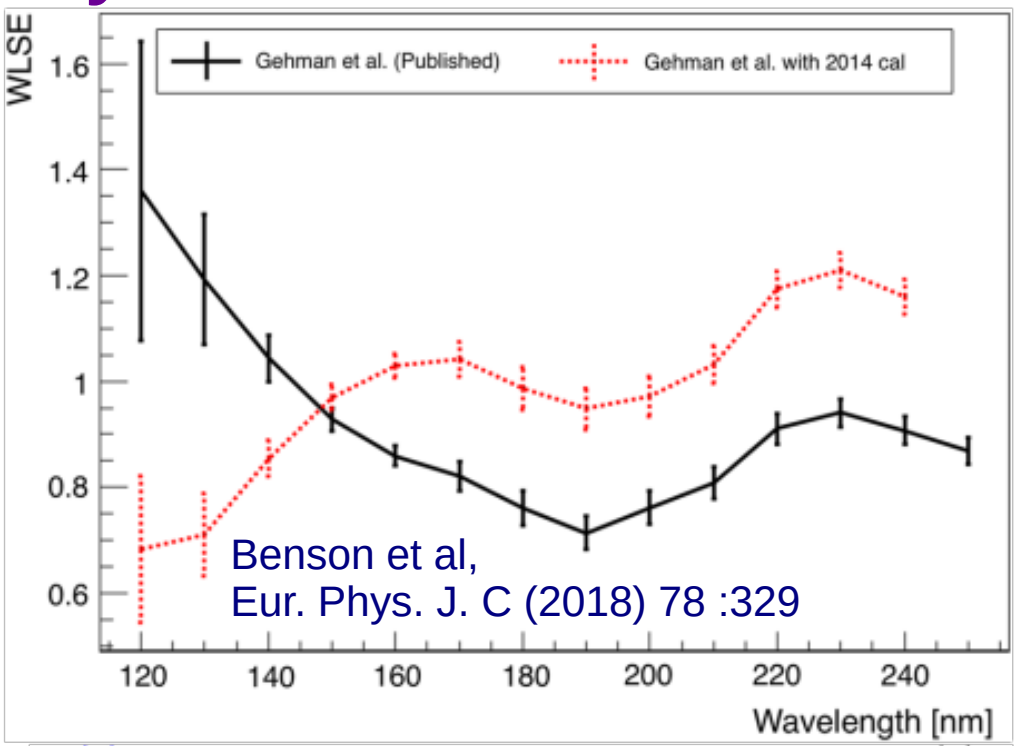
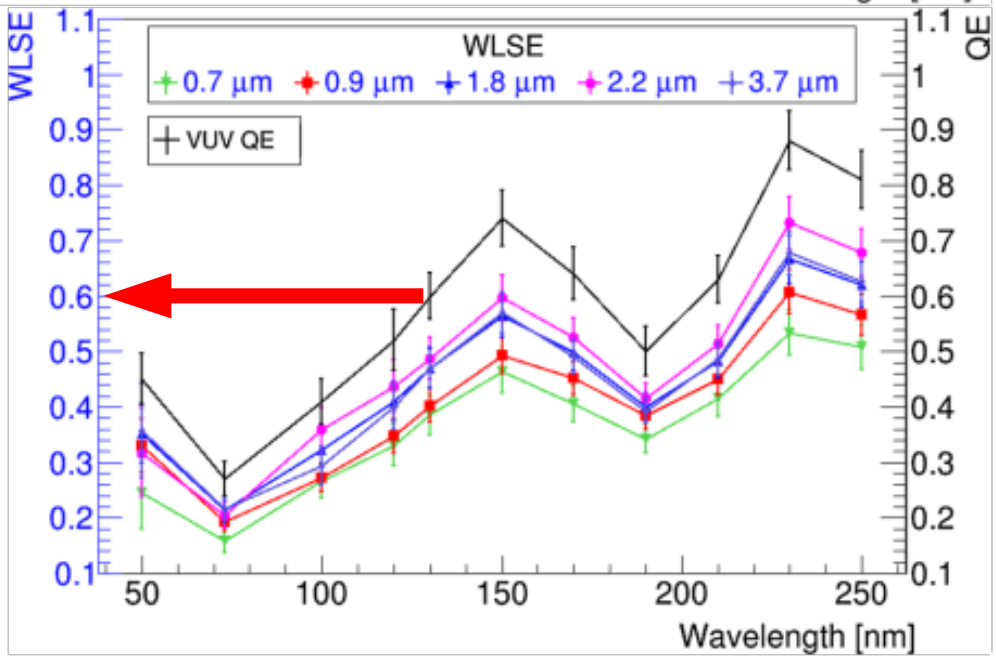
TPB: the industry standard

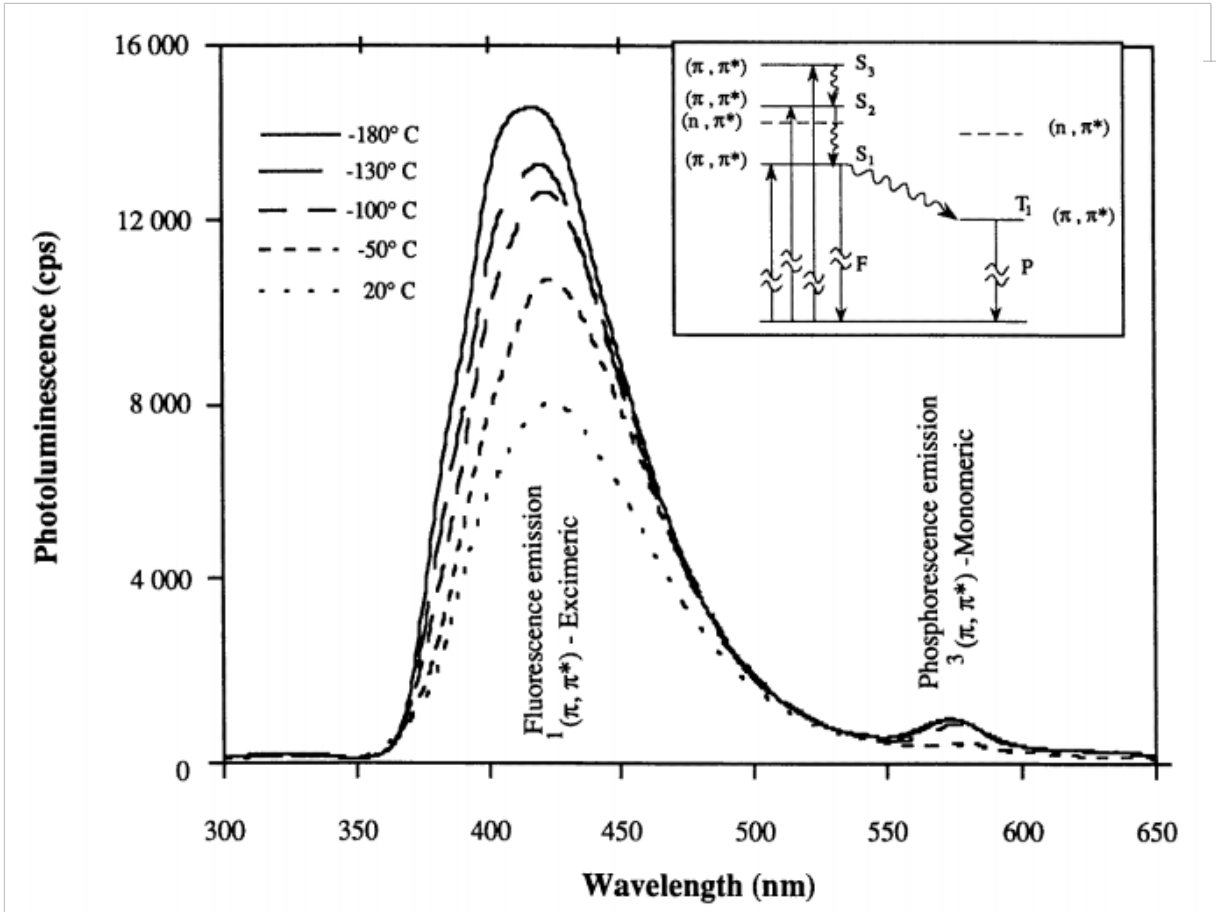
- Expensive, requires challenging vacuum evaporation
- “Painted” TPB-doped polymeric coatings yield 3x less light
- Intrinsic QE of TPB: ~60%@128 nm according to a recent paper
- More efficient / easier to use WLS in high demand for large future LAr detectors (Argo, DUNE ...)



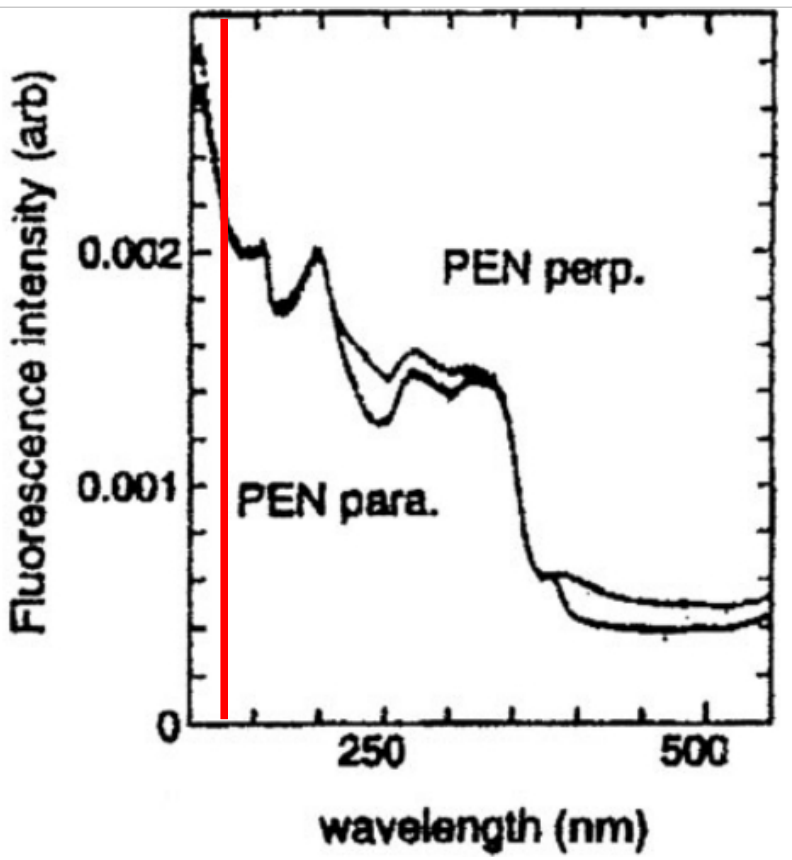


PEN evidence for fluorescence

D. Mary et al., J. Phys. D: Appl. Phys. 30 (1997)



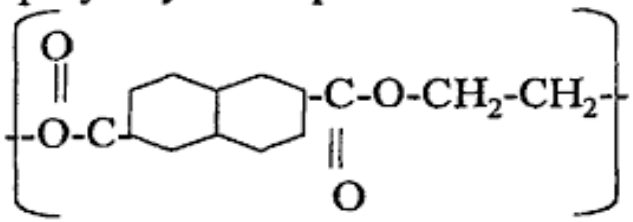
Ouchi et al., 10.1002/app.26085 (2006)



- Significant enhancement at low temperatures and at VUV excitation wavelengths

PEN

polyethylenenaphthalate



PEN as a component of Vikuiti

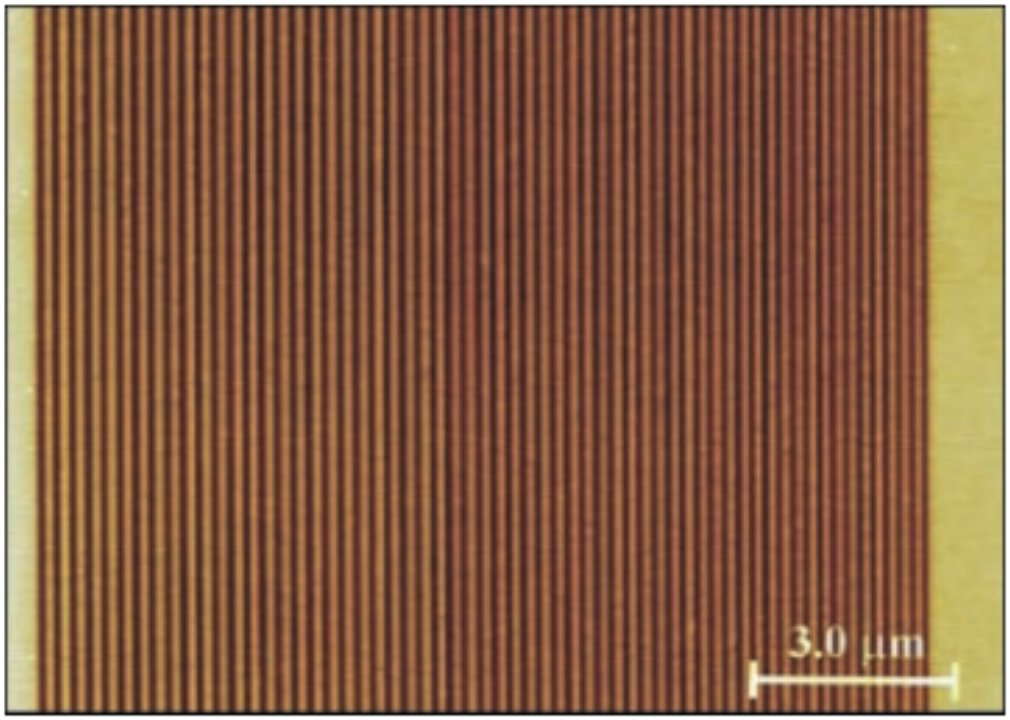
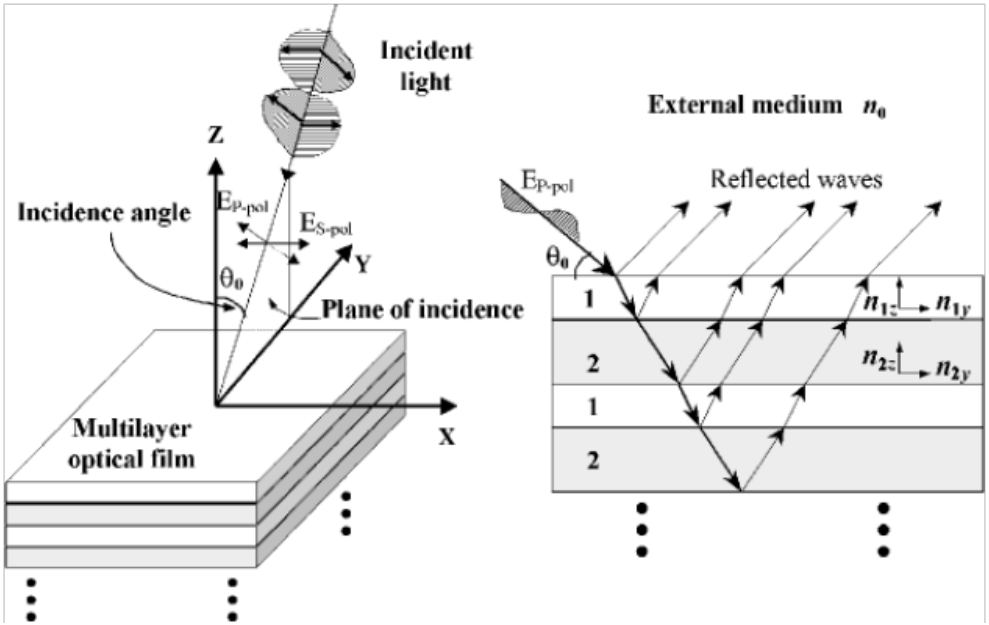


Fig. 4. An AFM image of a GBO stack (*31*); the dark-colored layers are PMMA and the light-colored layers are birefringent polyester (poly-ethylene naphthalate). Layers on the left side of the image are about 25% thicker than those on the right.

Giant Birefringent Optics in Multilayer Polymer Mirrors

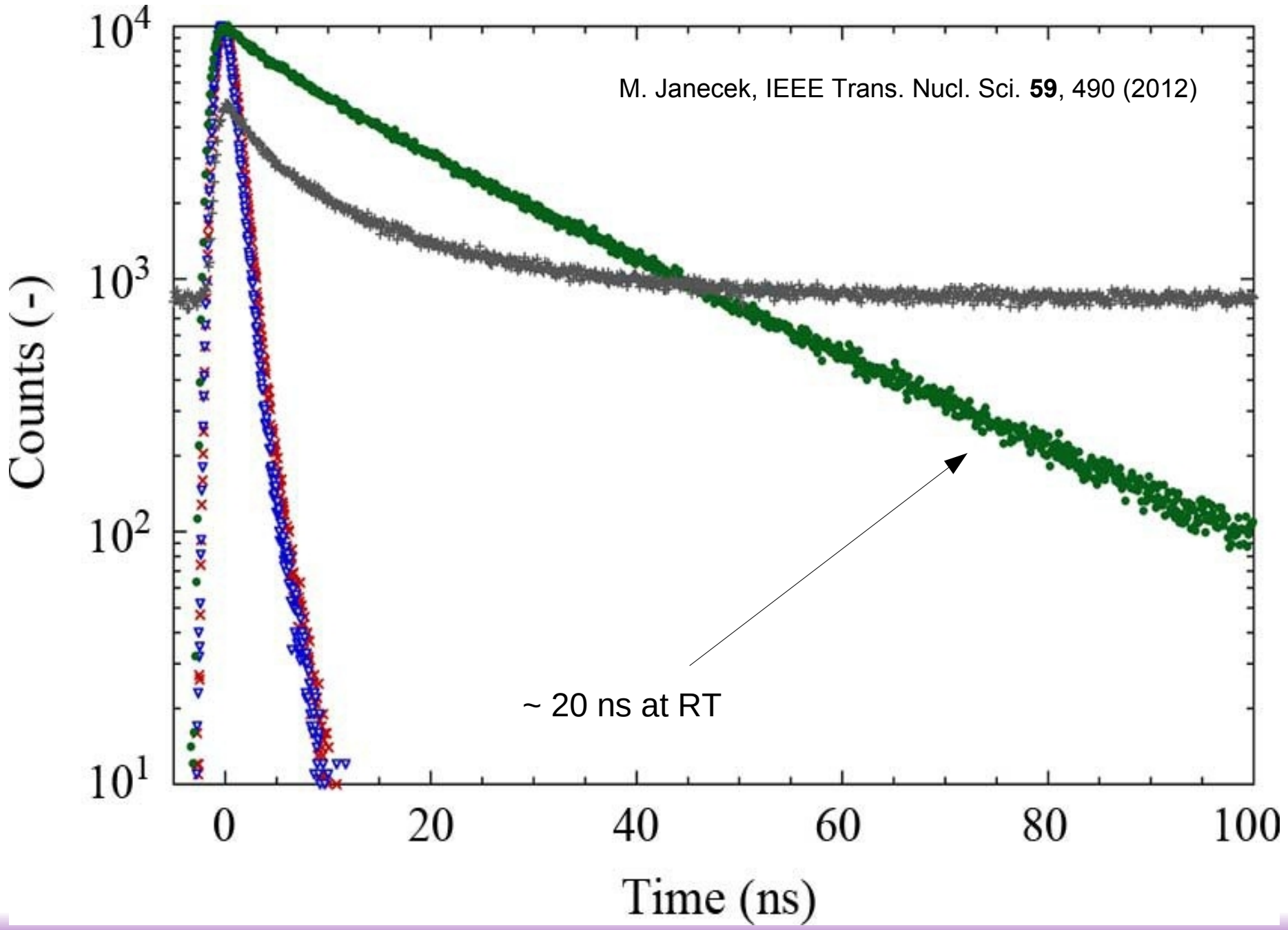
Michael F. Weber, Carl A. Stover, Larry R. Gilbert, Timothy J. Nevitt, Andrew J. Ouderkirk*



www.sciencemag.org SCIENCE VOL 287 (2000) 2451

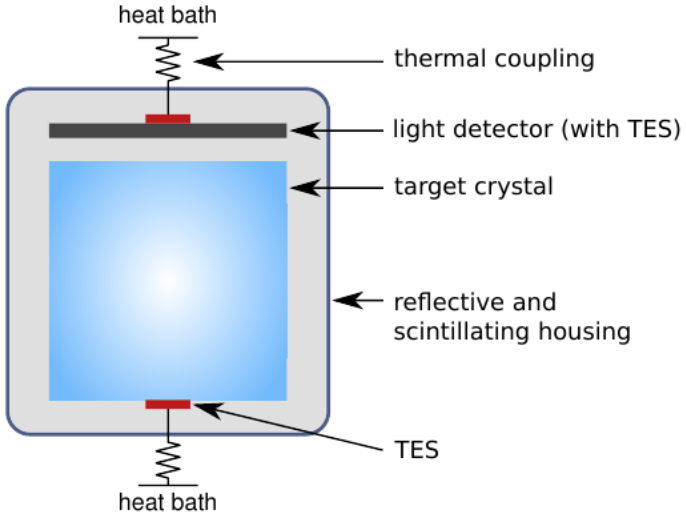
Also, anecdotal evidence of Vikuiti UV induced fluorescence from GERDA and others

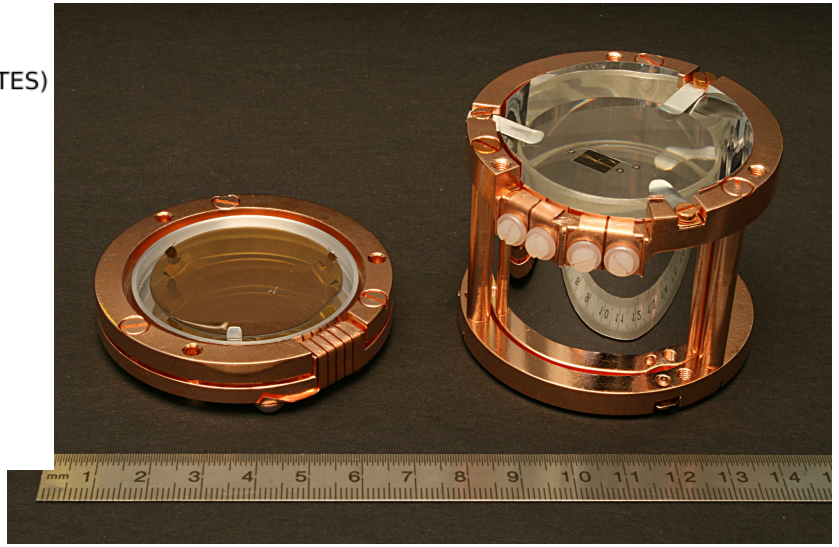
PEN (Vikuiti) timing



Uses as a scintillator in experimental physics

Vikuiti used as reflector and scintillating veto against surface alpha activity in CRESST





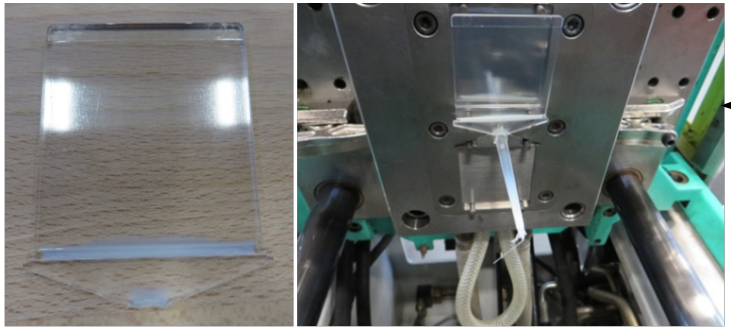
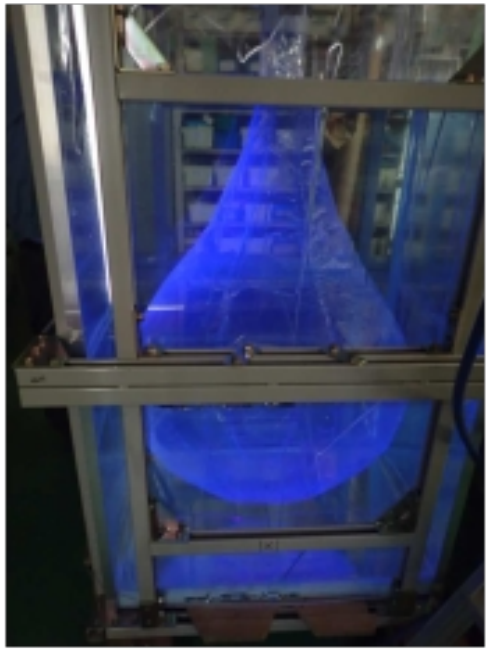


FIGURE 2: Tiles molded at Fraunhofer Institute ICT. Left: 170x170 mm^2 tile. Right: 55x50 mm^2 tile still inside the mold.

PEN as a self-vetoing structural material in GERDA,

AIP Conf. Proc. 1921 (2017)

PEN scintillating balloon for vetoing surface backgrounds in KamLAND-Zen



arXiv:1903.10736v3

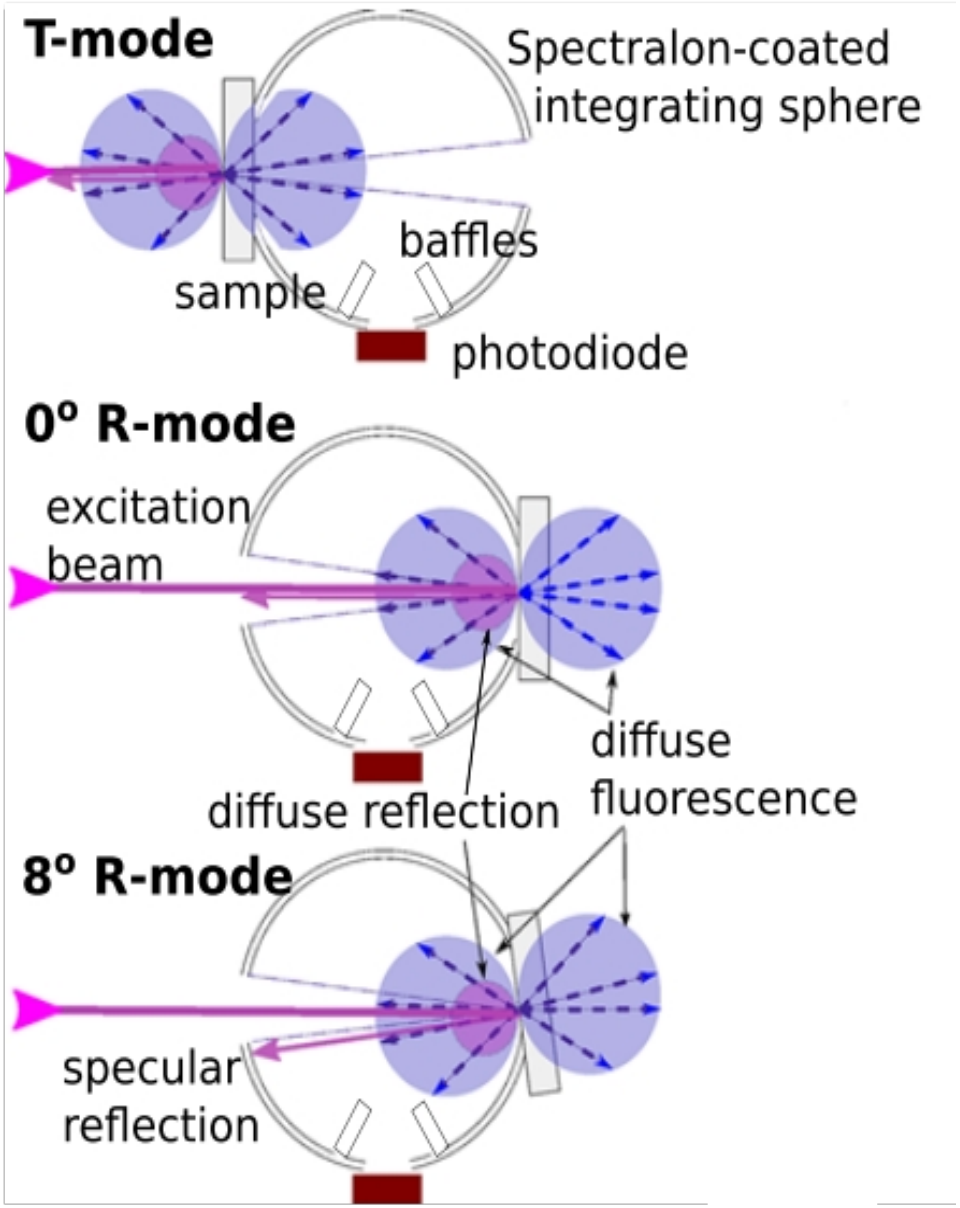
Our work: fluorescence measurement relative to TPB

TPB and PEN scatter light differently, which is a dangerous systematic in a fixed detection angle measurement.

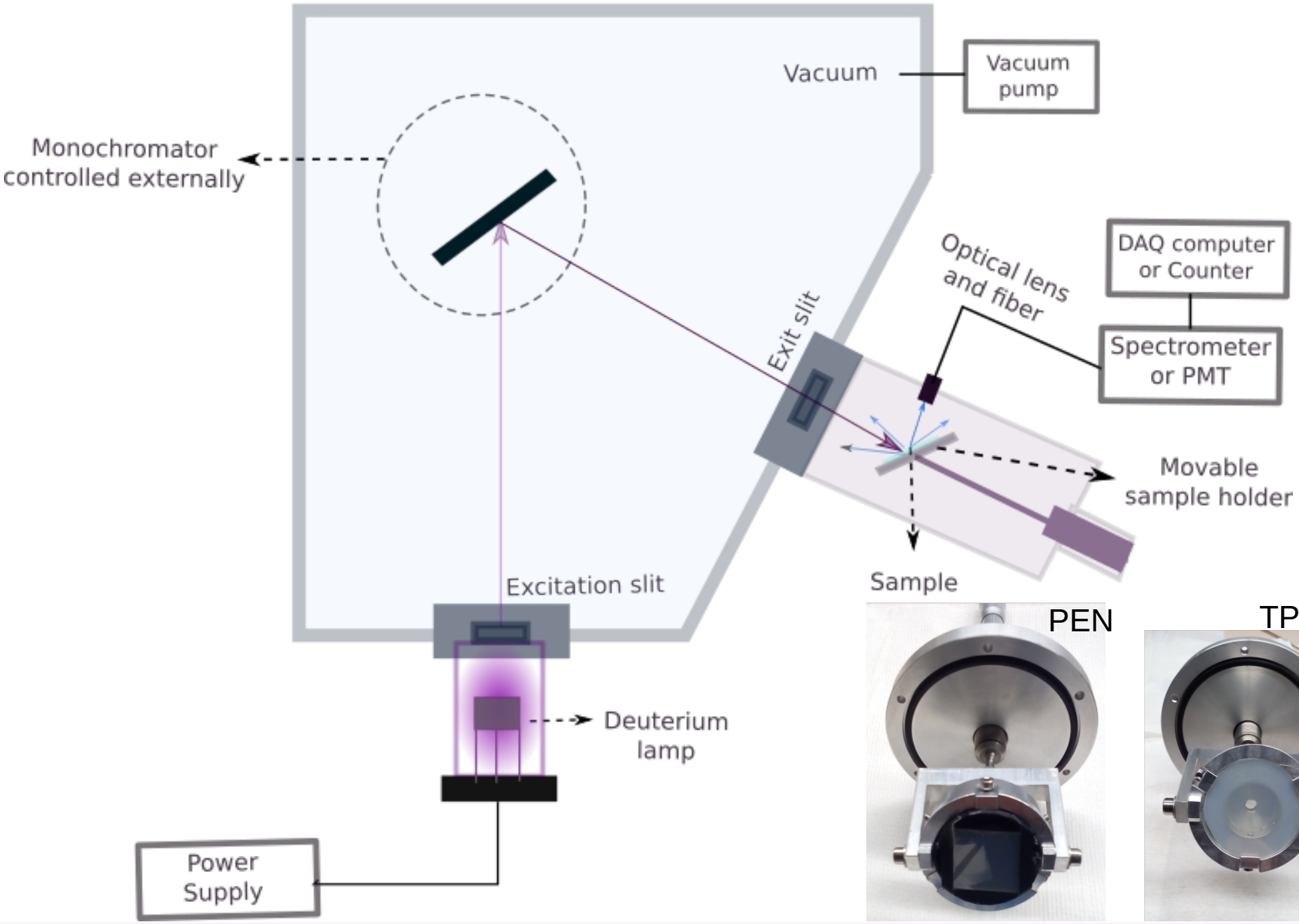
Strategy

- integrating sphere measurement (excitation >210 nm)
  - several configurations
  - provides syst. uncertainty
  - not available at VUV

- Fixed detection angle measurement at 128nm (vacuum monochromator)
  - Informs extrapolation to VUV



VUV setup

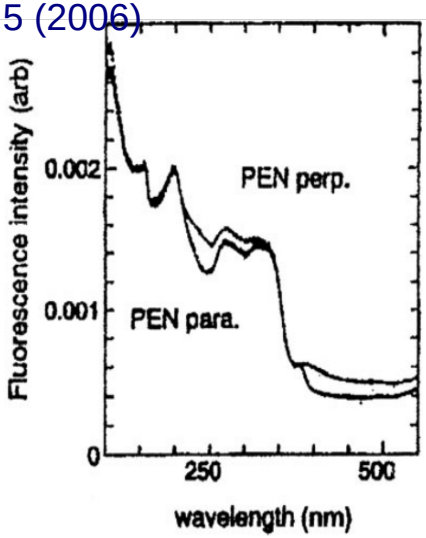

Vacuum
Vacuum pump
Monochromator controlled externally
Optical lens and fiber
DAQ computer or Counter
Spectrometer or PMT
Exit slit
Movable sample holder
Sample
Excitation slit
Deuterium lamp
Power Supply

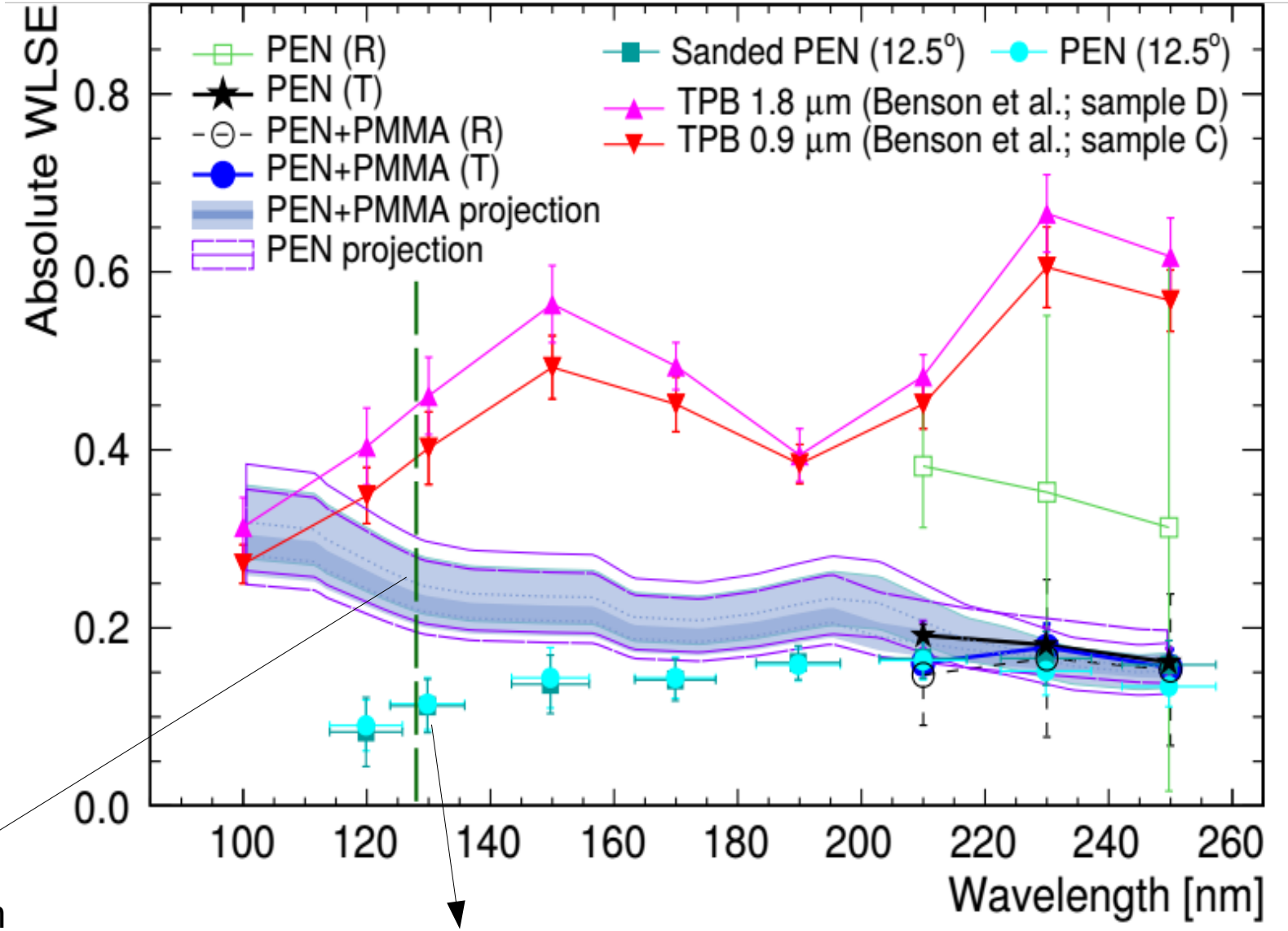
PEN

TPB

RT results summary

Ouchi et al., 10.1002/app.26085 (2006)





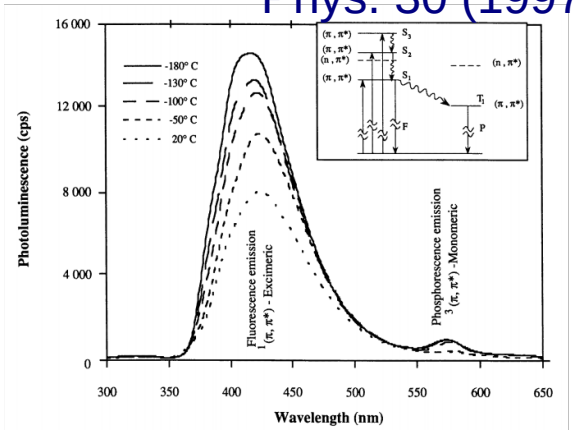
Projection based on Ouchi et al.

Projection based on our VUV measurement

Yield relative to TPB @87K

Sample	293 K		87–93 K
	250 nm	128 nm	128 nm
TPB+PMMA	0.59(7)	0.43(7)	0.52(10)
PEN+PMMA	0.15(2)	0.24(4)	0.40(7)
PEN	0.16(4)	0.25(5)	0.42(8)
PEN (glass)	0.15(3)	0.12(3)	0.20(6)
$\frac{\text{PEN+PMMA}}{\text{TPB+PMMA}}$	0.25(5)*	0.56(13)	**0.77(20)**
$\frac{\text{PEN}}{\text{TPB+PMMA}}$	0.27(8)*	0.58(15)	**0.80(23)**
$\frac{\text{PEN(glass)}}{\text{TPB+glass}}$	0.26(4)*	0.28(4)*	**0.38(7)**
$\frac{\text{VM2000}}{\text{TPB+TTX}}$	0.09		0.317(16)

D. Mary et al., J. Phys. D: Appl. Phys. 30 (1997)



Extrapolation based on literature data at 128 nm

Extrapolation based on our sample measured at 128 nm.

UV exposure (sunlight, possibly fluorescent lighting) is known to degrade PEN yield.
Significant difference between Ouchi et al based and our projection

UV ageing

- Exposure to ambient light and history of the samples was not controlled
- UV exposure from sunlight or fluorescent lighting can lead to
  - up to an order of magnitude reduction in intensity
  - broadening and shift of the emission peak towards higher wavelengths

D. Mary et al., 2001 Annual Report Conference on Electrical Insulation and Dielectric Phenomena, p. 165 (2001). https://doi.org/10.1109/CEIDP.2001.963512

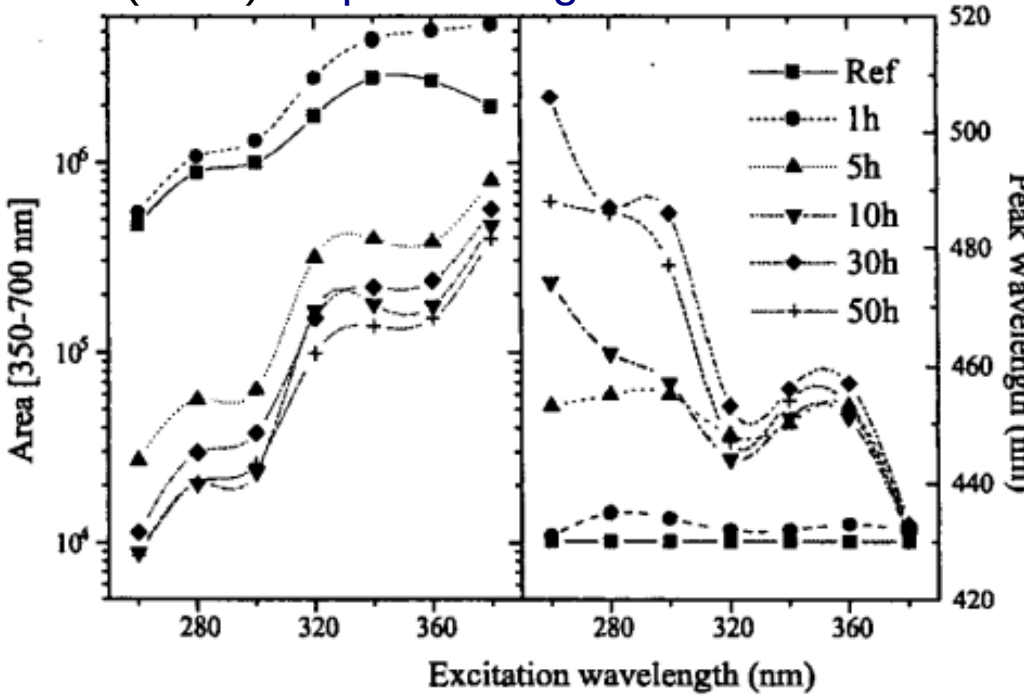


Figure 3: Area (left) and peak wavelength (right) of photoluminescence spectrum as a function of excitation wavelen for different irradiation times. The area is given in counts for an integration time of 10s of the CCD camera.

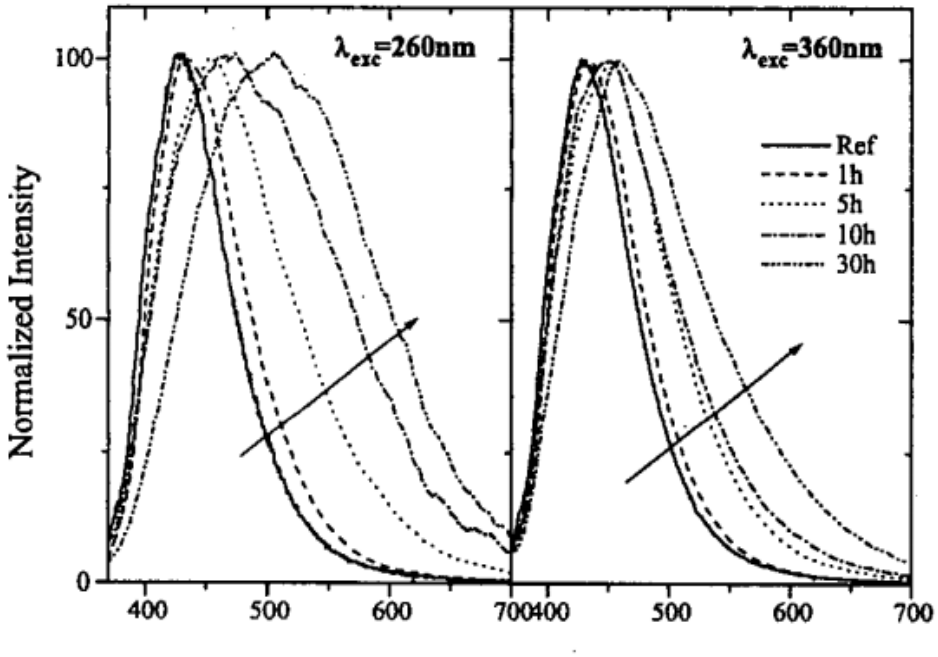
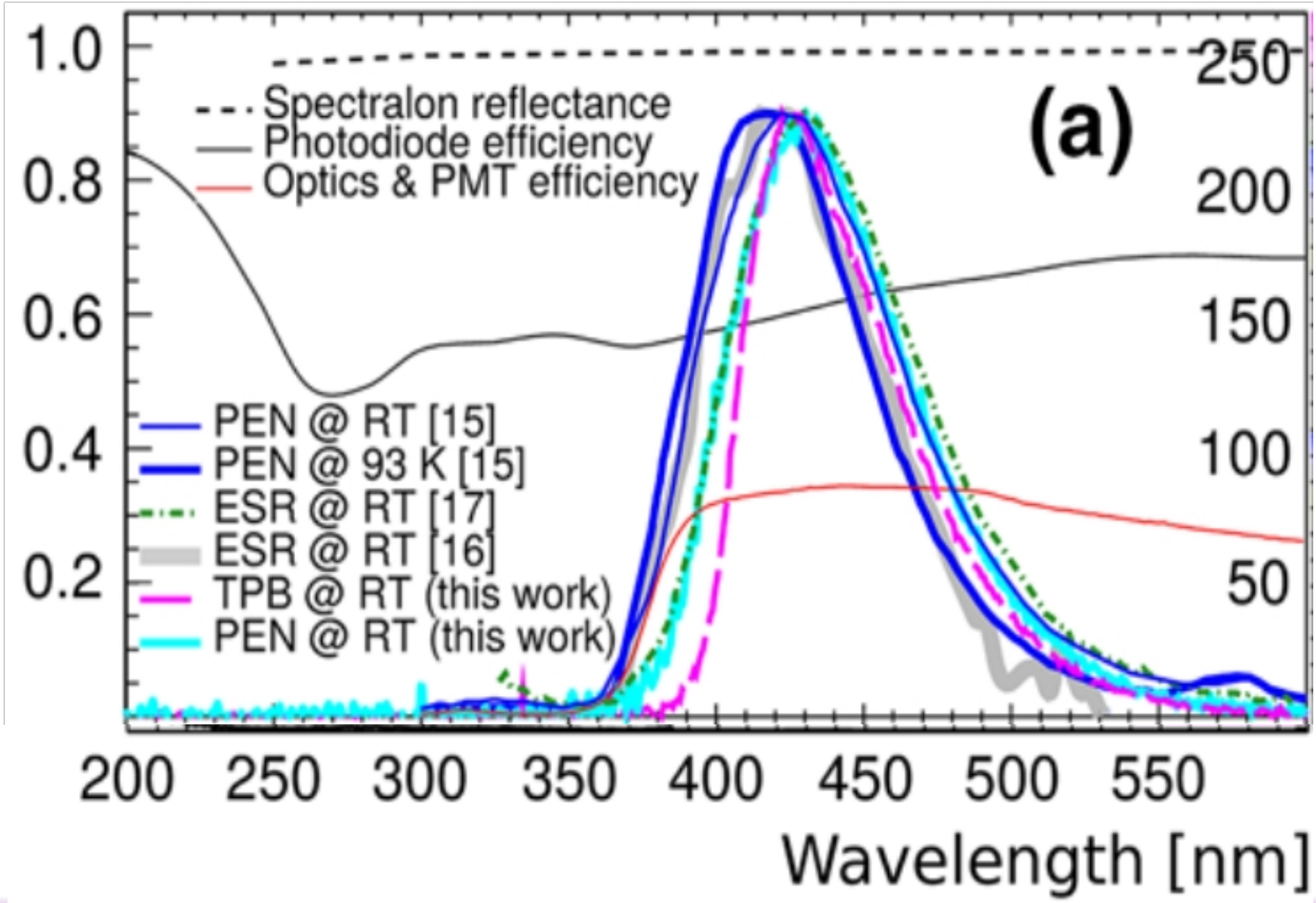


Figure 2: Normalized photoluminescence emission, spectra of PEN as a function of UV exposure time, for two excitation wavelengths.

Illumination with a 30 W broadband UVA lamp

UV ageing


1.0
0.8
0.6
0.4
0.2
250
200
150
100
50
Spectralon reflectance
Photodiode efficiency
Optics & PMT efficiency
(a)
PEN @ RT [15]
PEN @ 93 K [15]
ESR @ RT [17]
ESR @ RT [16]
TPB @ RT (this work)
PEN @ RT (this work)
200 250 300 350 400 450 500 550
Wavelength [nm]

Can the efficiency be higher?

L. Baudis et al., 2015 JINST 10 P09009

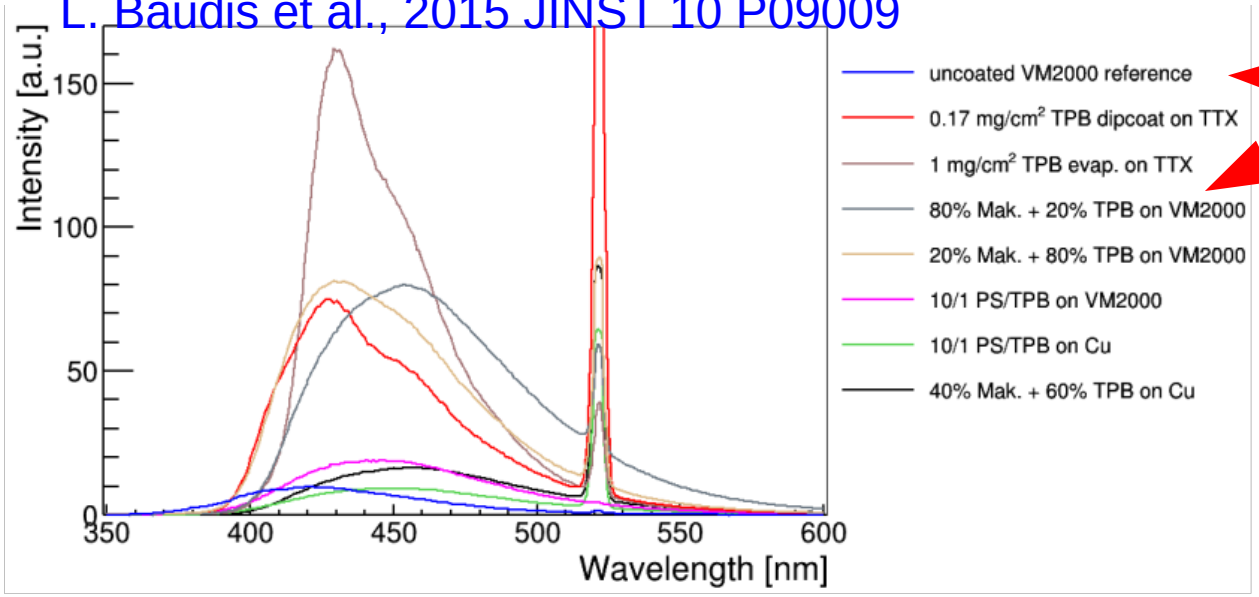


Figure 4. Typical fluorescence spectra of coated reflector foils using an excitation wavelength of 260 nm. The peak at 520 nm originates from diffuse reflected light at twice the excitation wavelength and is not related to fluorescence. TTX stands for Tetratex®.

- Ratio of emission intensities at @260 nm excitation of VM2000 and evaporated TPB coating is published
- Ratio measured in LAr using alpha scintillation light
- ~3.5(2) fold increase in LAr

- Similar scaling applied to our RT 260 nm result would translate to efficiency in LAr consistent with TPB

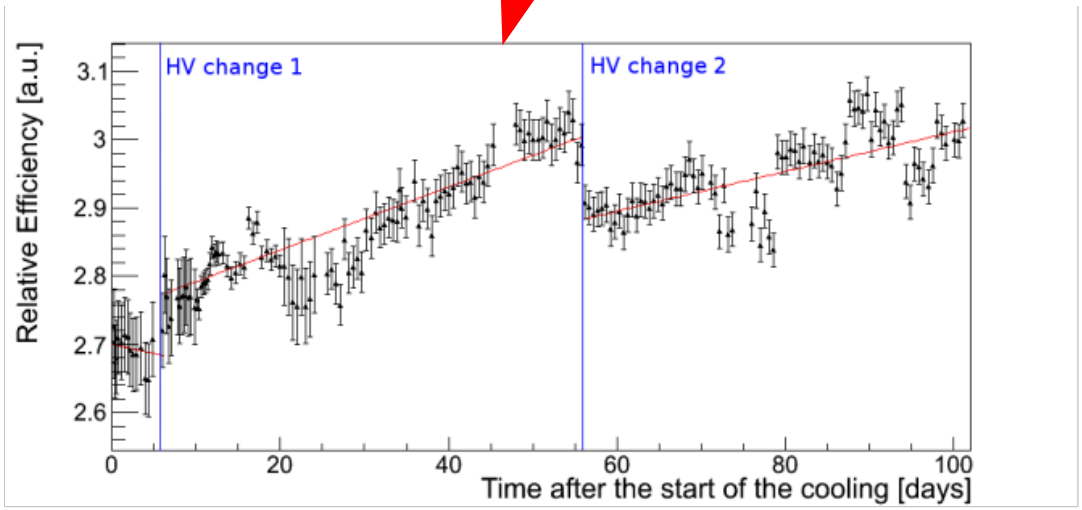


Figure 11. Relative light yield of Tetratex® dip-coated with TPB as a function of time in liquid argon, measured relative to uncoated VM2000. Time periods with 1500 V, 1475 V, 1490 V PMT voltages were fitted separately with a linear function. Error bars as described in section 5.4.

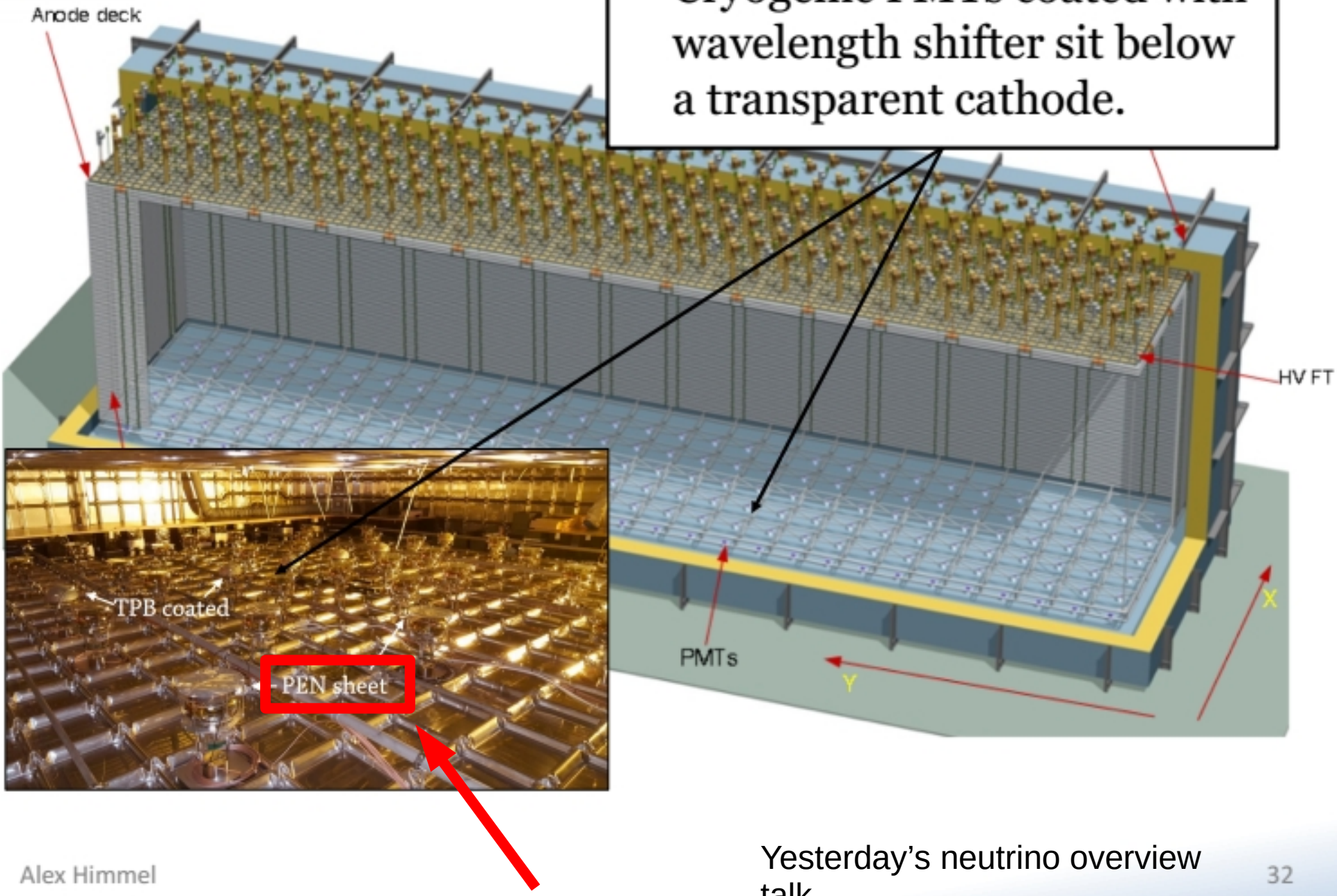
Applications

The range of potential applications of PEN-based WLS is very broad. In particular, it appears feasible to replace TPB-coated ESR foils, which are under consideration for large LAr TPCs such as SBND [5], with a laminate of PEN and ESR.[1] In addition to long baseline neutrino and, if WLSE consistent with TPB is confirmed, dark matter projects, PEN could also find use in other LAr-based detectors: (1) CENNS-10 [38] measuring coherent elastic neutrino-nucleus scattering, (2) neutrinoless double β decay searches employing LAr veto such as GERDA [24][2] or the future LEGEND [40], (3) medical physics, (4) nuclear or homeland security.

Most importantly, PEN could directly replace TPB in the planned large ktonne-scale LAr experiments and dramatically simplify the WLS deposition step, which is currently one of the main technological bottlenecks.

Dual Phase Far Detector

- Cryogenic PMTs coated with wavelength shifter sit below a transparent cathode.



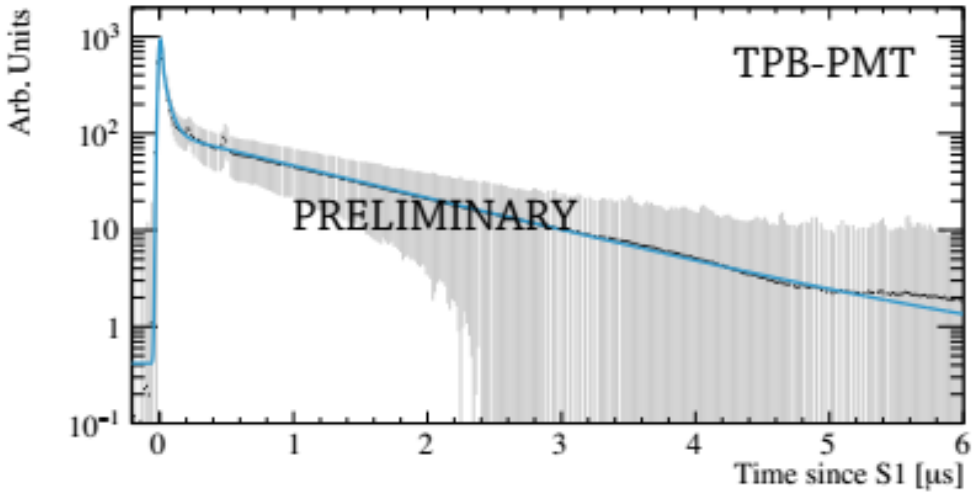
Alex Himmel

Yesterday's neutrino overview talk.

32

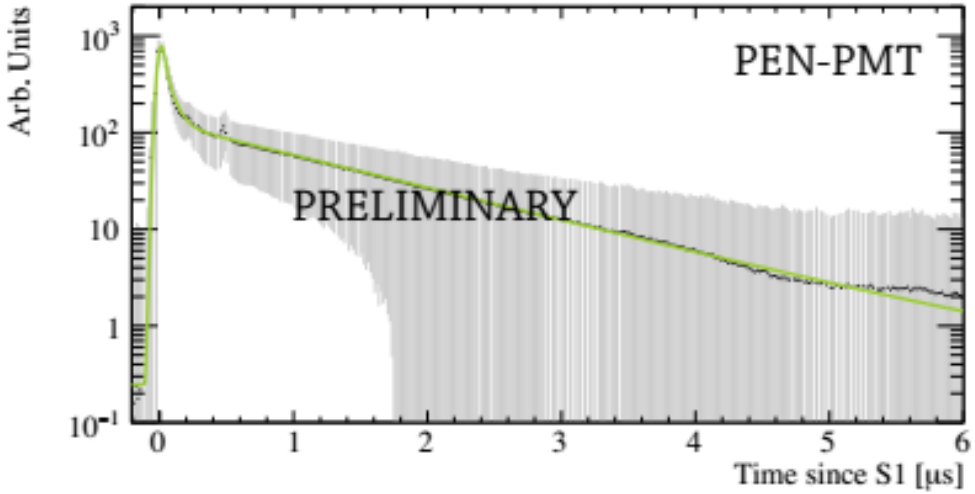
Preliminary averaged waveforms

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

DS-Proto-0

F. Carnesecchi - LIDINE 2019 University of Manchester, United Kingdom 28-30 August 2019

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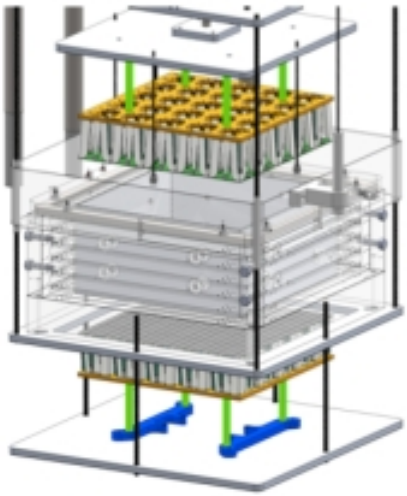
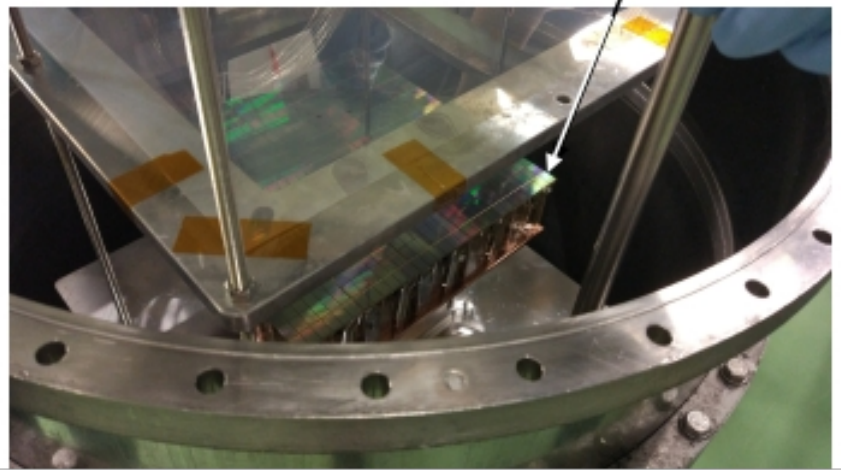
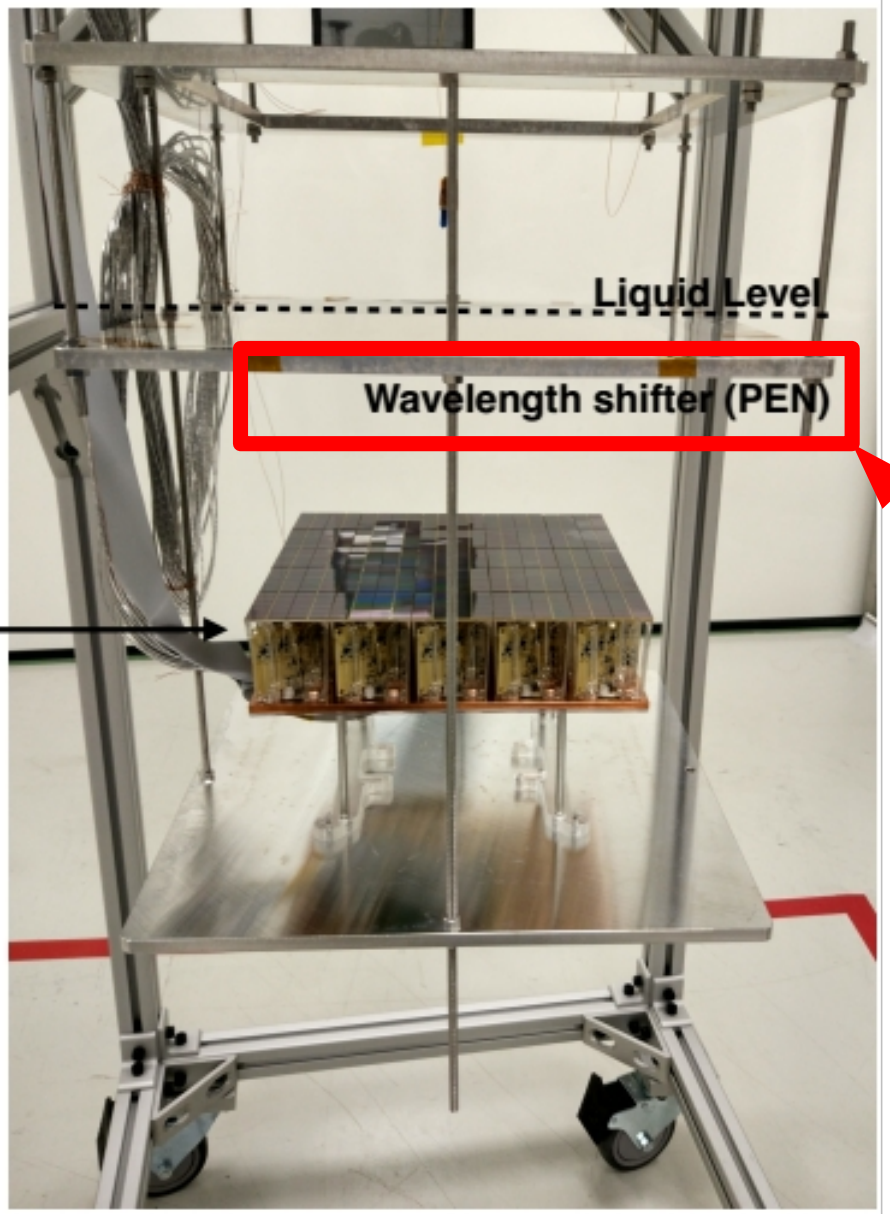
2 MB, 50 PDM, 1200 SiPM



First test: July 2019
Test of **1 M**other**B**oard
in **LAr**

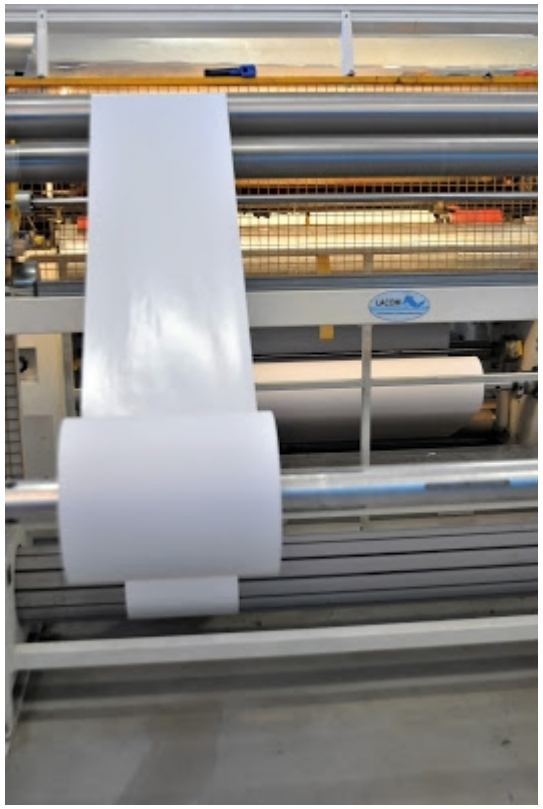
MB1
NUV-HD-LF





Towards scale-up

- Prototype sheets of PEN laminated with ESR fabricated at the CERN workshop (one sheet at a time)
- At Astrocent we're investigating large area lamination capabilities
  - ESR and PEN are available in 1.2 m wide, 3000 m long rolls
  - These could be laminated in one go (1 day) with hot roller laminating machines
  - Working with a local industrial company on developing such process.
  - First tests are ongoing, definitive results expected within the next few months

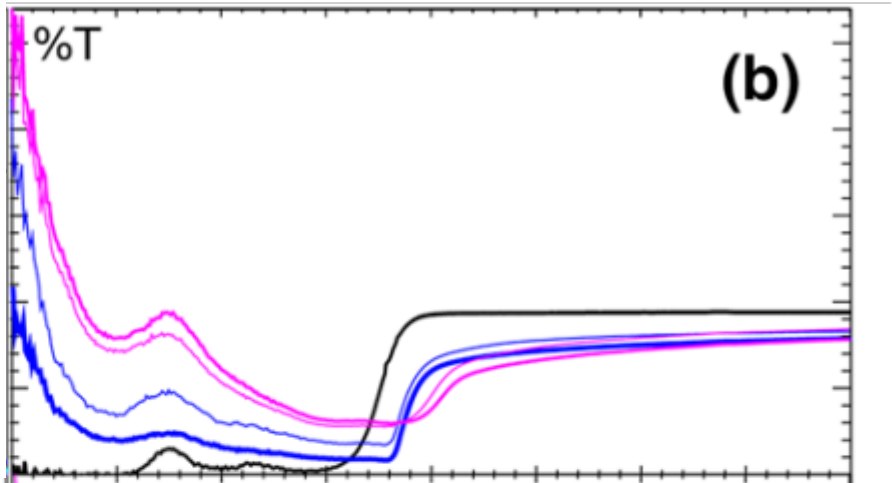


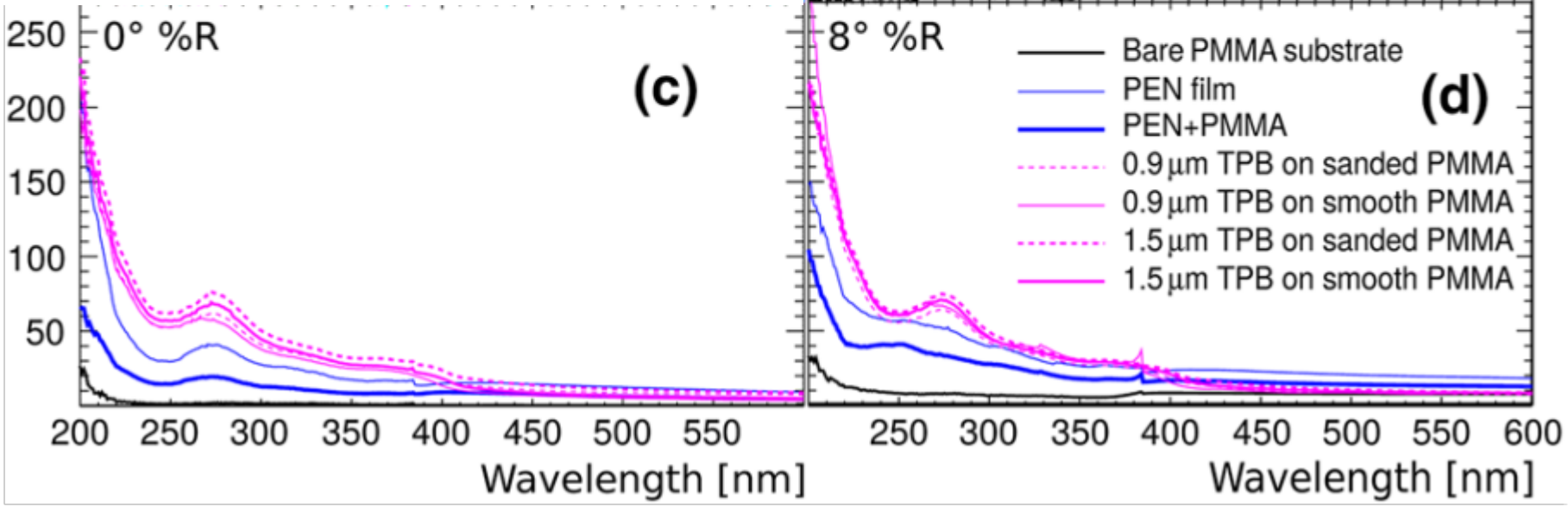
Summary

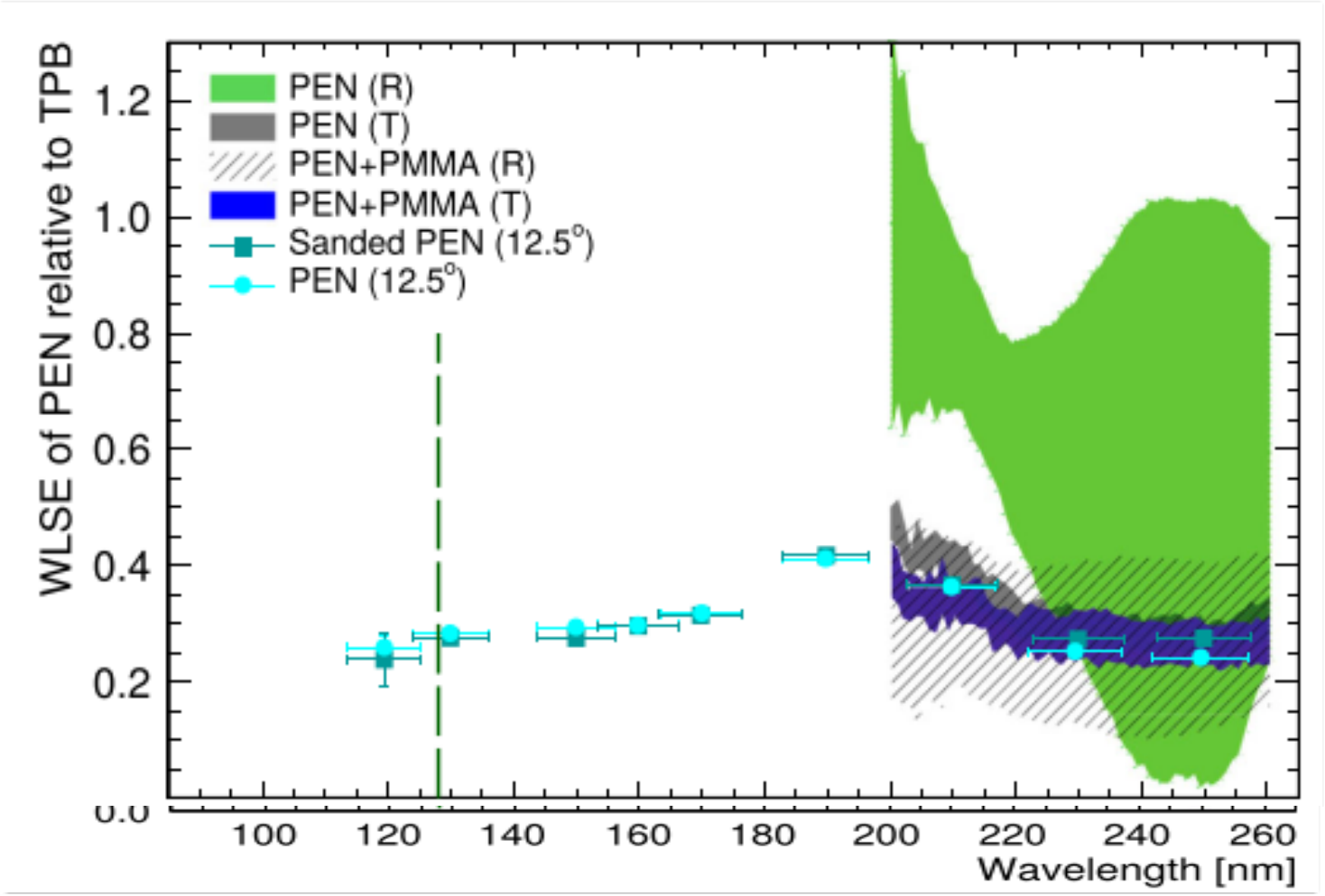
- Efficiency of PEN relative to TPB: 0.4 – 0.8
- Large systematic uncertainties from relative optical measurement and projections, to be fixed with future direct comparisons in LAr
- Suspect UV degradation affecting some results, hints of efficiency consistent with TPB, need for better control in the future
- Broad applications and significant interest from the community
- Discussions with industrial partners about large scale lamination are underway
- Contact me if interested in sharing ideas and R&D

Backup

UV-Vis spectrometer data






PEN (R)
PEN (T)
PEN+PMMA (R)
PEN+PMMA (T)
Sanded PEN (12.5°)
PEN (12.5°)
WLSE of PEN relative to TPB
0.0
0.2
0.4
0.6
0.8
1.0
1.2
100
120
140
160
180
200
220
240
260
Wavelength [nm]