New candidate polymeric wavelength shifters for noble liquid detectors

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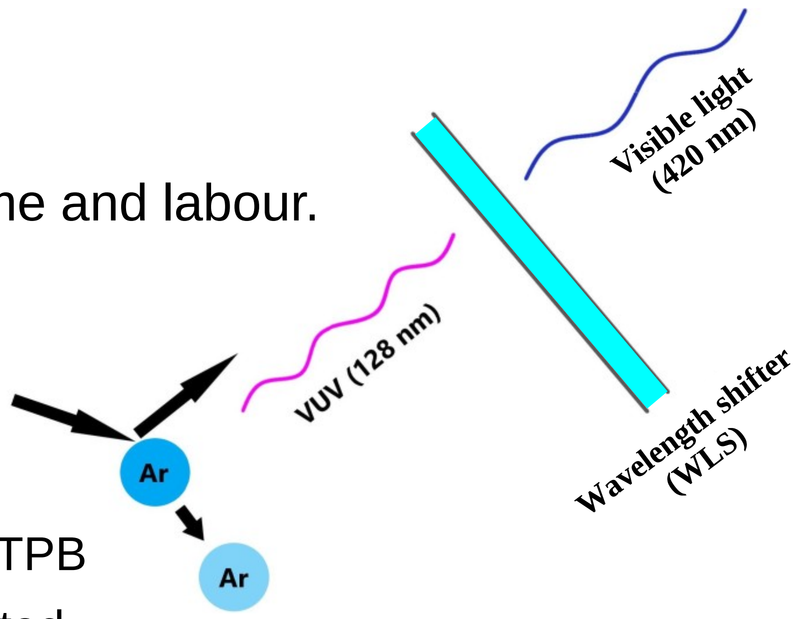
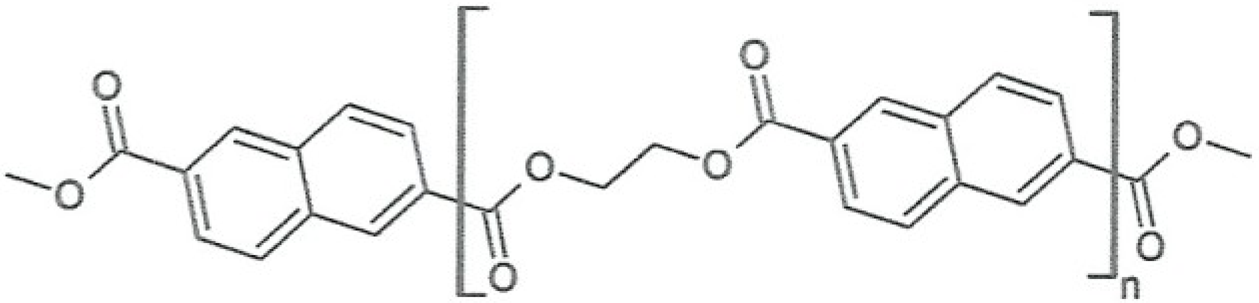
Wavelength shifters (WLS)

- Tetraphenyl butadiene (TPB) works fine*, but production of up to 1000m^2 using vacuum evaporation technique would be a challenge
  - Large vacuum chamber needed
  - Pumpdown and production cycle take much time and labour.



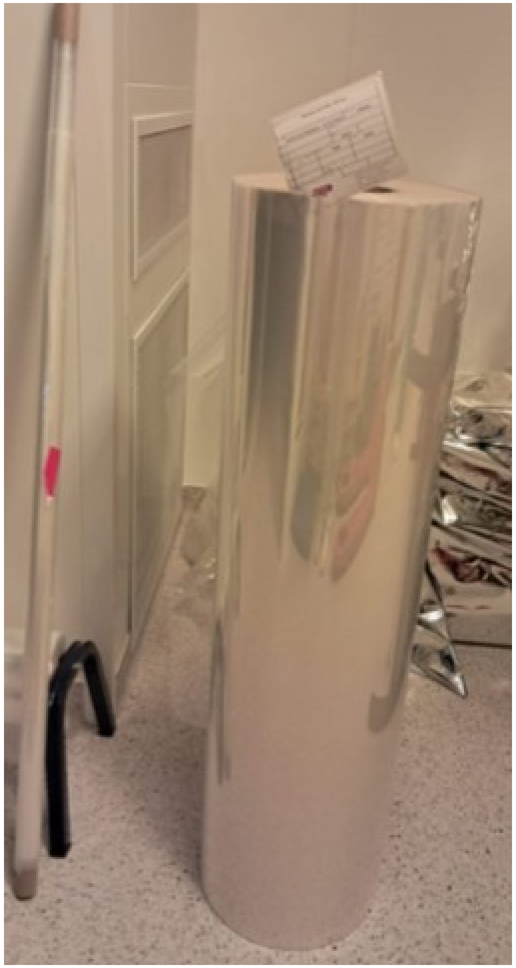
- Alternatives:
  - Solvent based methods
    - Efficiency between 0.33 and 0.5 of evaporated TPB
    - Much easier, but mass production still complicated
  - <u>PEN, or similar, polymeric materials</u>



* except, not stable in LXe and evidence for ‘emanation’ in LAr

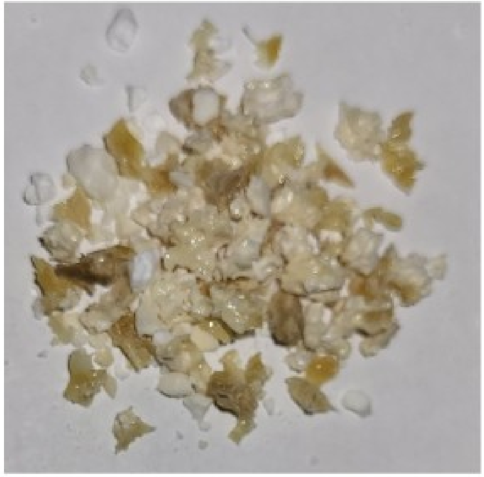
Status of work on PEN

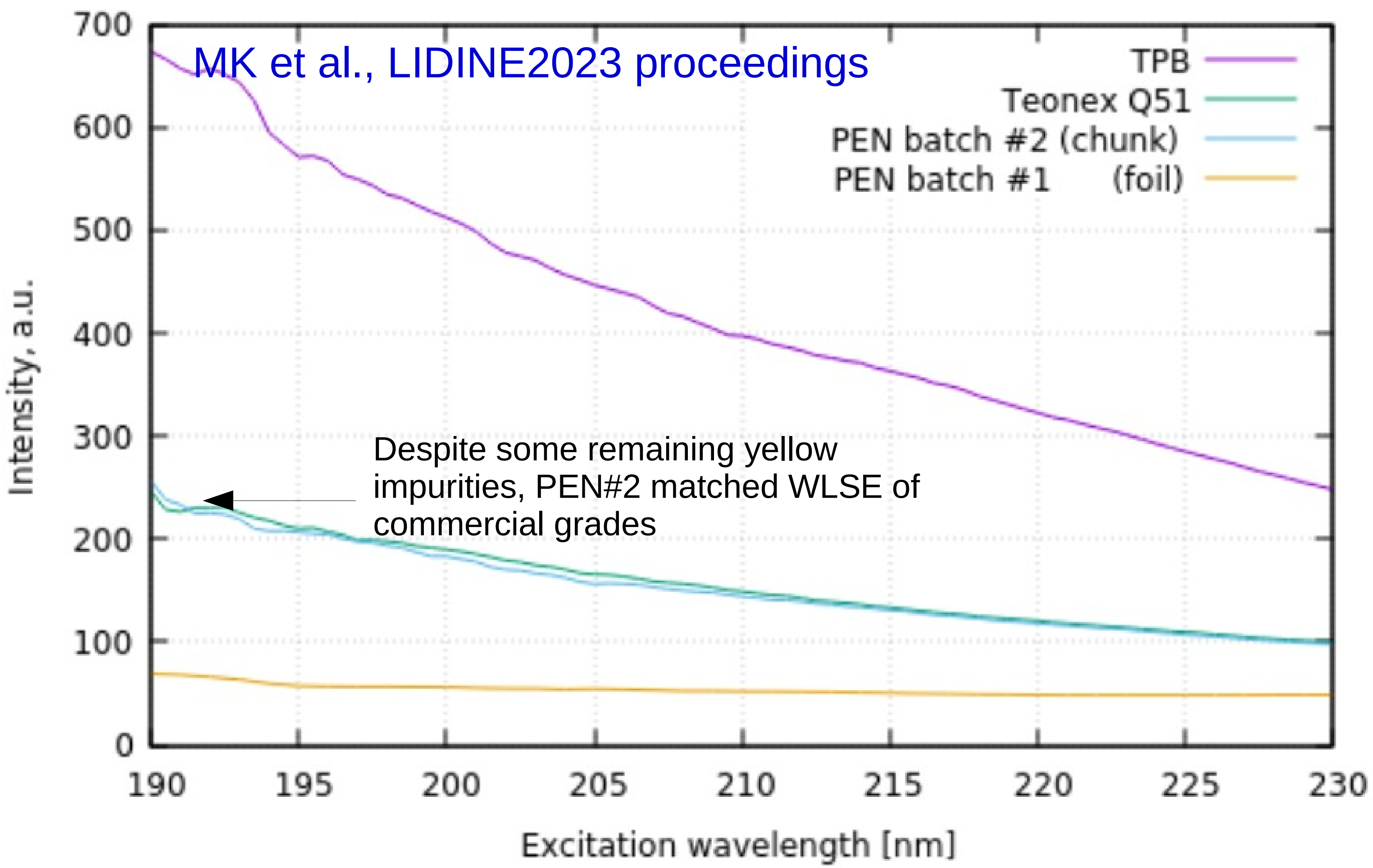
- Use of commercially available grades
  - To be used for the DarkSide-20k veto
    - See next talk by Sarthak Choudhary
  - Interest also from more experiments
  - Recently tested stability of 4 m^2 of PEN over ~2 weeks of taking data in LAr
    - See poster by Vikas Gupta et al. (joint effort of many researchers from DarkSide, DUNE, Neutrino Platform and LEGEND)
  - However, conversion efficiency in 0.4-0.7 range (relative to TPB)
    - Important to maximize LY for DM detectors
    - Can conversion efficiency of PEN be improved?



Status of work on PEN

- Hope to get there with custom synthesized PEN
  - Without additives (fillers, absorbers, colorants, anti-sticking agents), in controlled conditions
  - Optimized for WLS efficiency (WLSE)

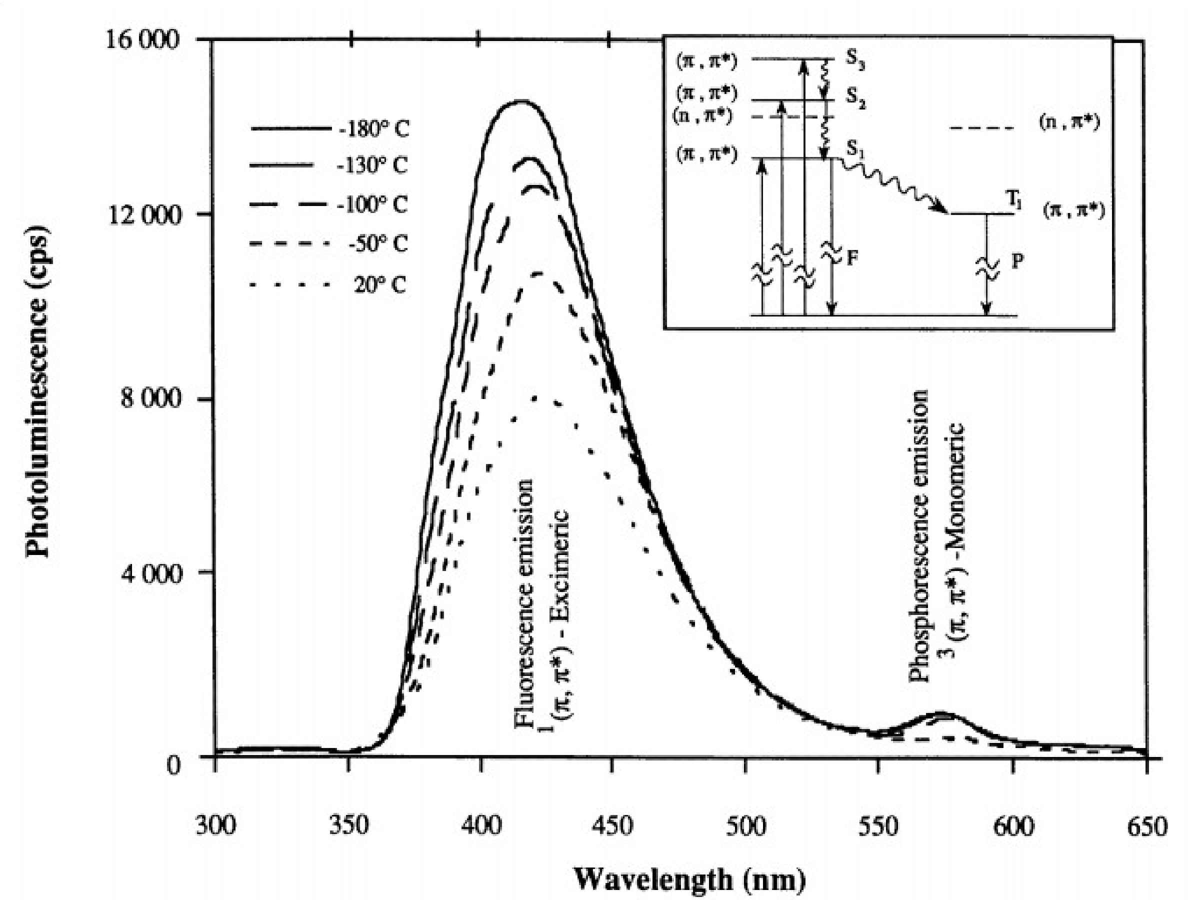




Significant investment needed for the next step. Looking into applied grants w/industrial partners

PEN fluorescence mechanism

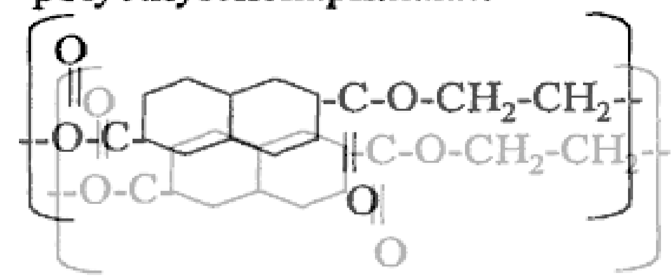
Is PEN the only option?



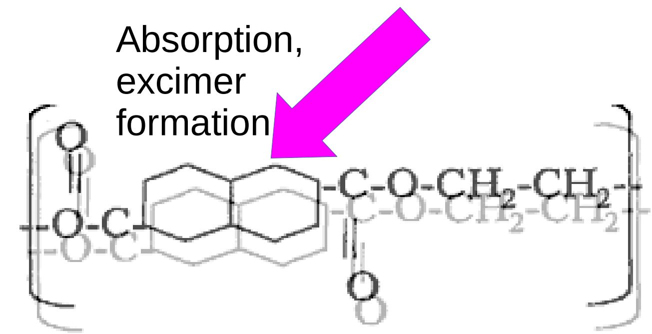
D. Mary et al., J. Phys. D: Appl. Phys. 30 (1997)

PEN

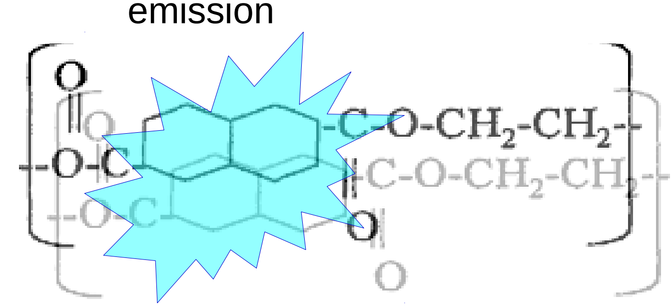
polyethylenenaphthalate



Absorption,
excimer
formation



de-excitation,
emission

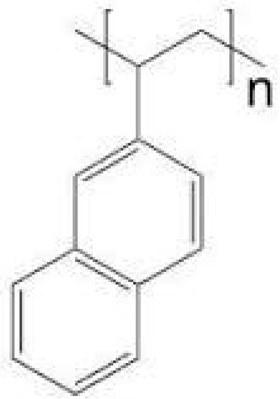


- Significant enhancement at low temperatures and at VUV excitation wavelengths
- **Excimer emission: need many close pairs of naphthalene groups**

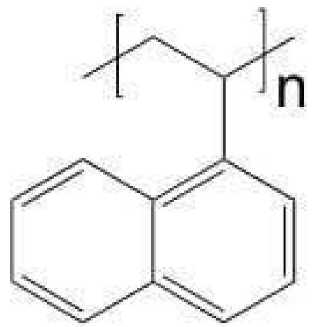
Other interesting polymers

- Colleagues from IChP suggested PVN: poly(vinyl naphthalene)

Poly(2-vinyl naphthalene)



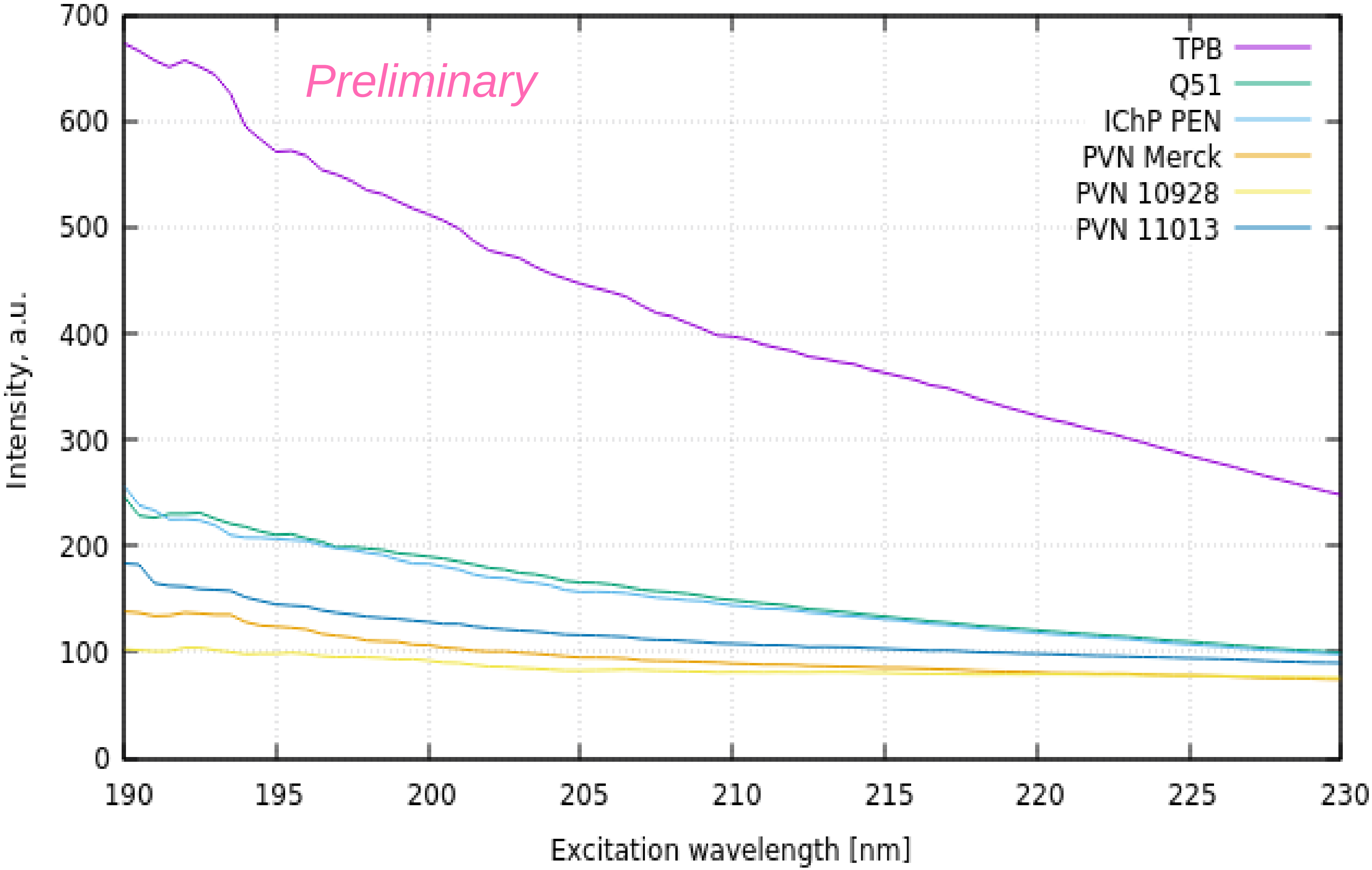
Poly(1-vinyl naphthalene)



- Analogue of polystyrene (PS), except with the naphthalene group
- Soluble in organic solvents, e.g. toluene
- Much less demanding polymerization / synthesis process than for PEN
- But no industrial application, so only available in small samples for research (and expensive)
- Sparse evidence for fluorescence in the literature:
  European Polymer Journal 8, 1019-1031 (1972), Macromolecules 14, 105-110 (1981)
- Relying on common sense... involvement from a quantum chemist would be very welcome!

Poly(2-vinyl naphthalene) fluorescence

At room temperature, using near UV excitation and a spectrophotometer with an integrating sphere



- Tried several grades, differing in the polymeric chain length
- PVN here is in the powder form – so not exactly apples to apples comparison with PEN & TPB
- **Clear signs of fluorescence!**

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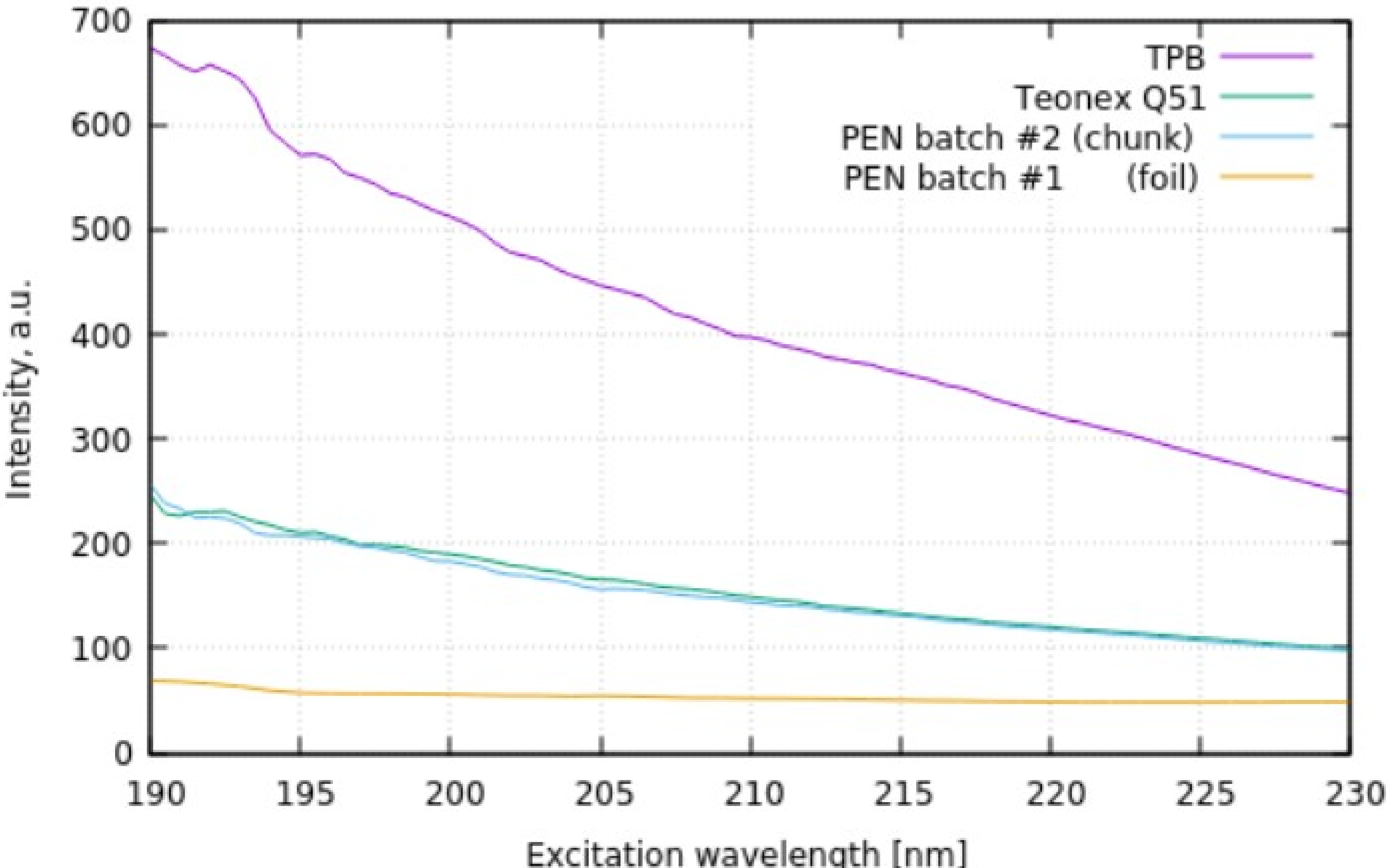

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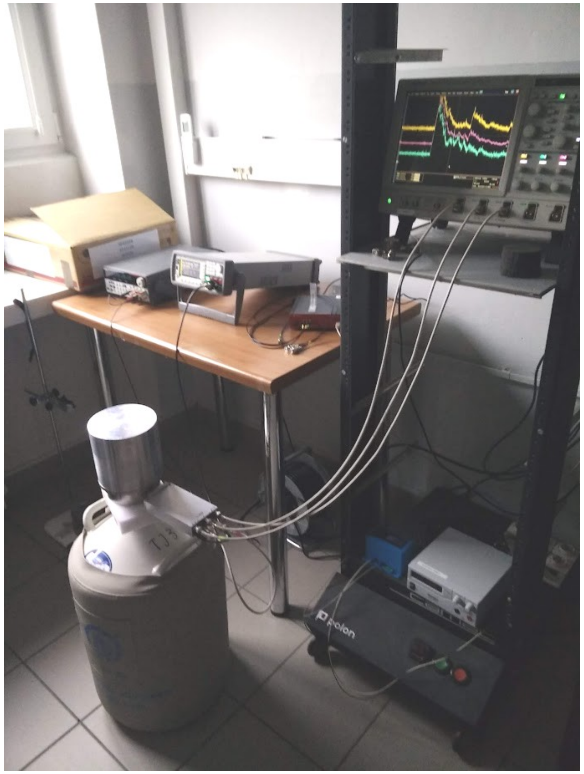
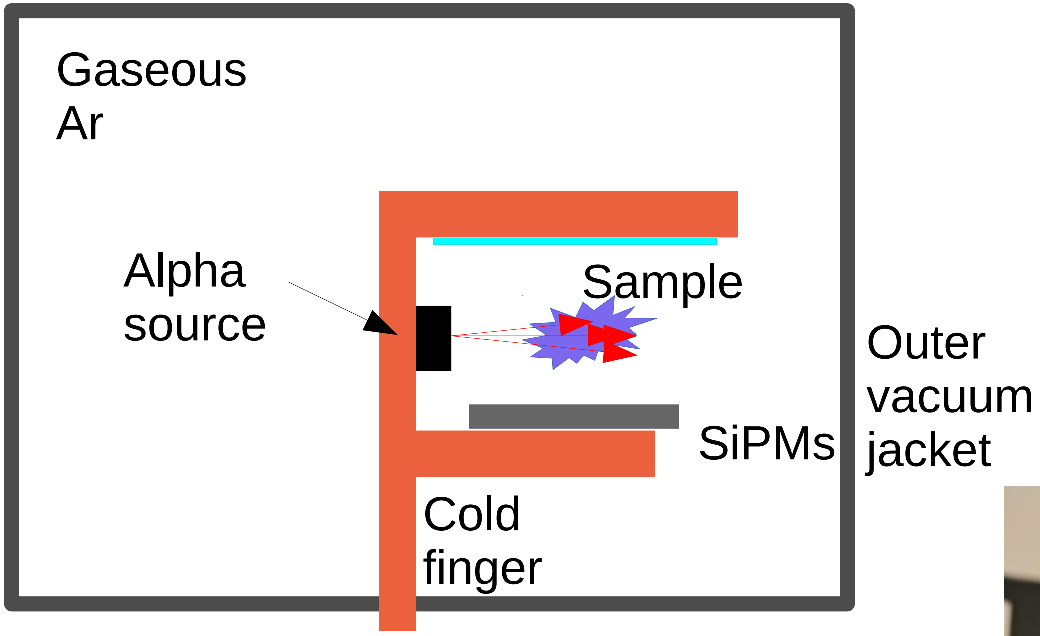
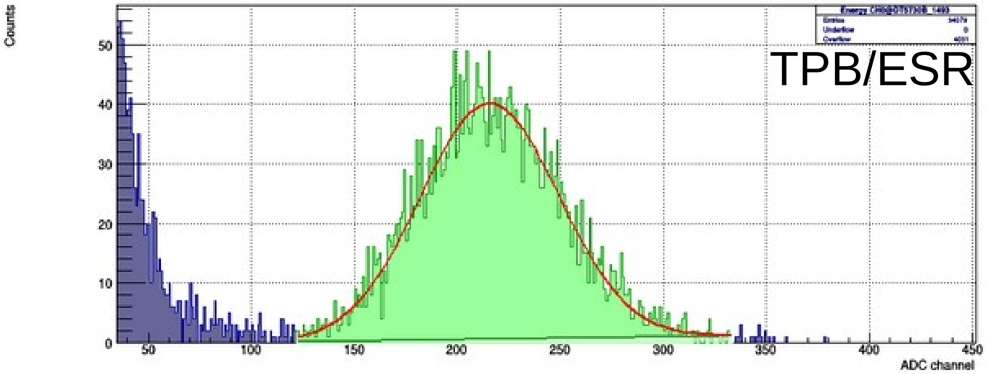
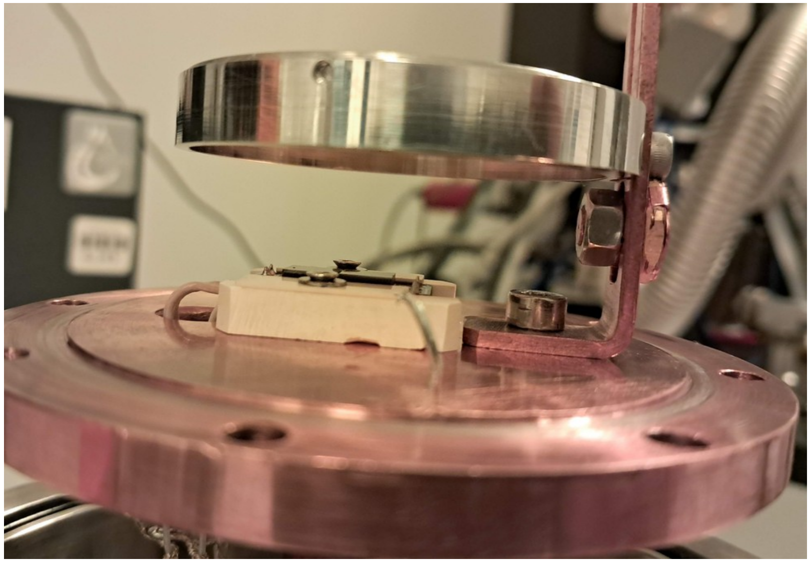
ArGSet: WLS test stand @ AstroCeNT

- Foil samples at -185 C, illuminated with 128 nm alpha scinitllation light from gaseous Ar

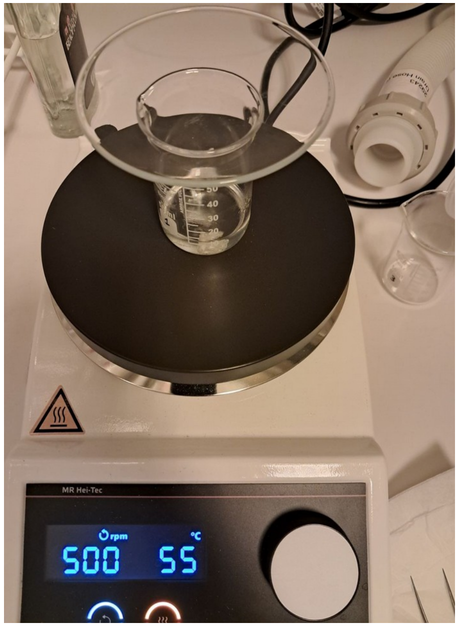




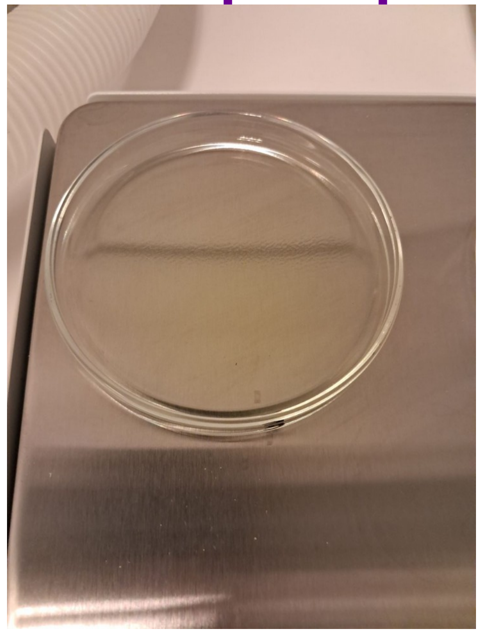




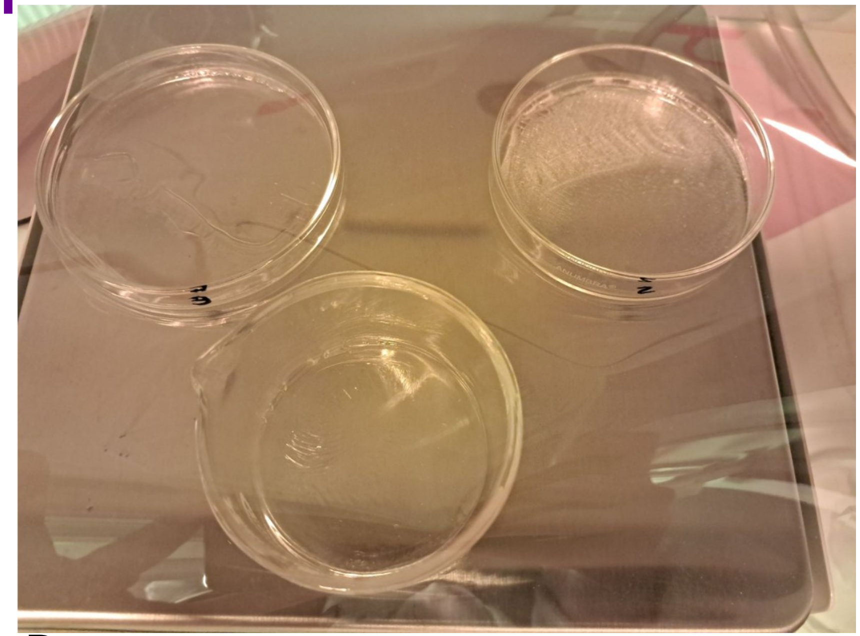
Sample preparation



Dissolve in toluene

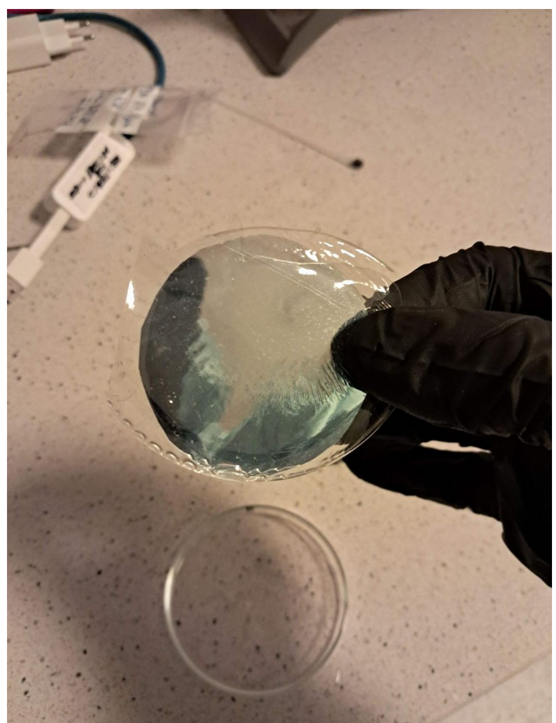


Cast

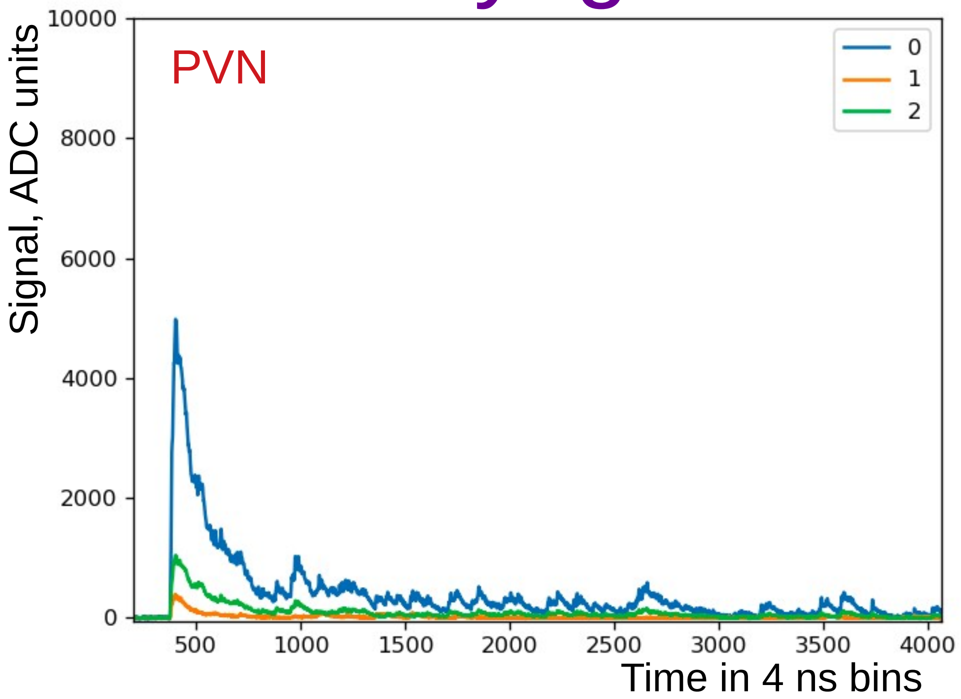


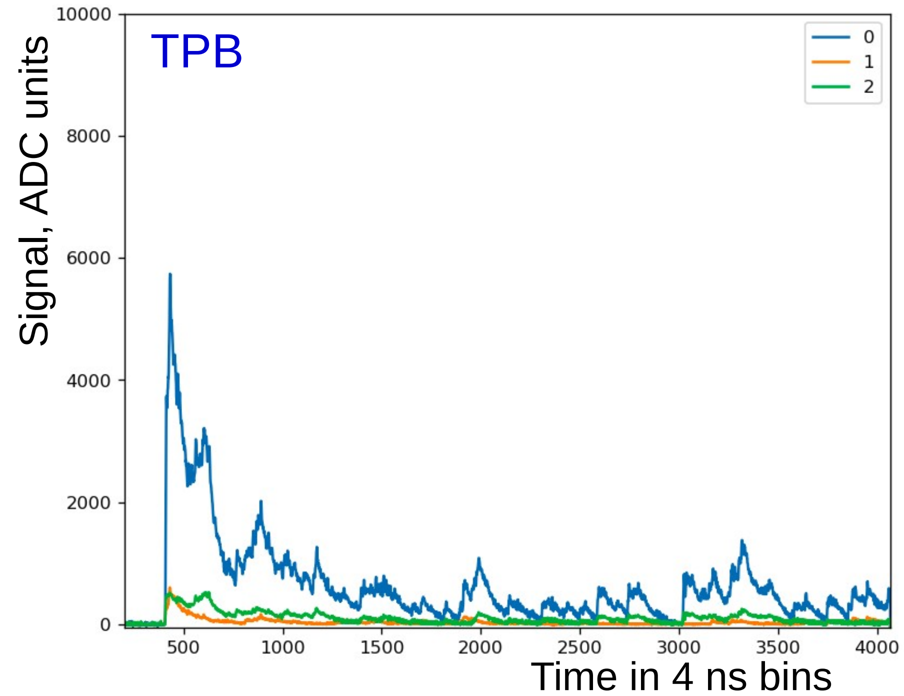
Dry

Install in the sample holder, coupled to reflector



Cryogenic fluorescence of PVN



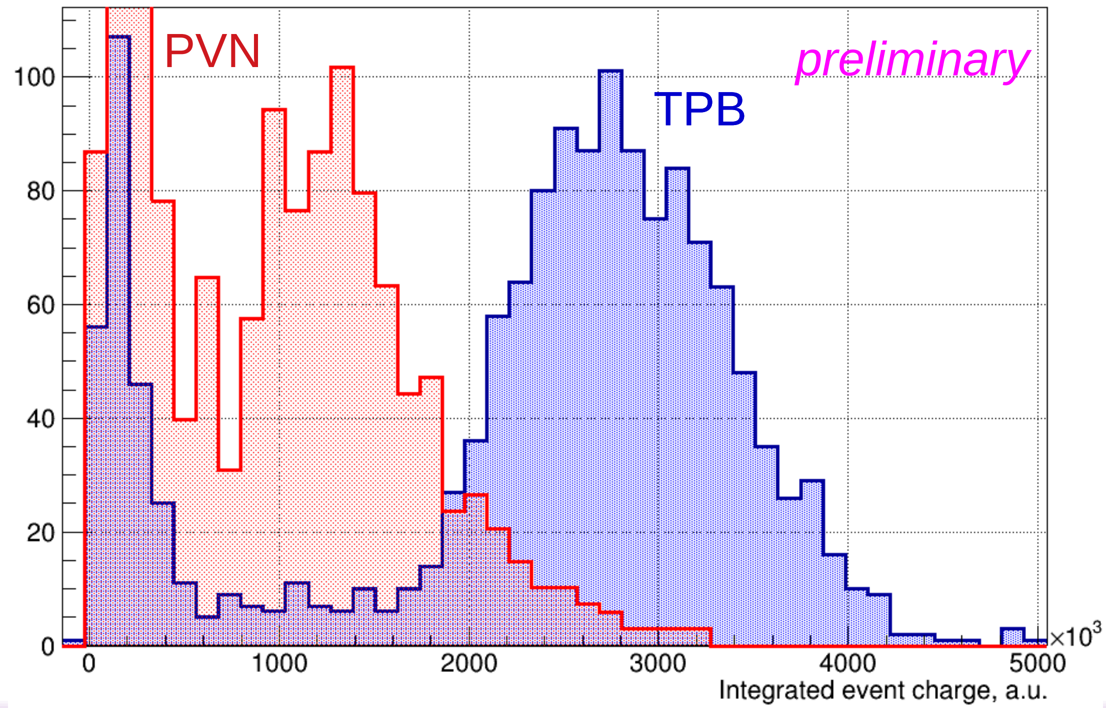


Highly preliminary raw data, not corrected yet for triplet lifetime, geometrical shits, temperature dependence etc.

Nevertheless, clear signal.

Comparable to PEN in terms of WLS efficiency, i.e. approx. 40-50% (rel. to TPB).

Detailed analysis in progress...



PEN foil scintillation @ RT

PVN foil scintillation @ RT

Results

- PVN is a decent scintillator at room temperature (similar to PEN, with a slightly longer time constant)

Material	**Relative intensity**	**photons/MeV (rough estimate based on the litrature) ***
PEN foil	100%	10500 [EPL 95, 22001 (2011)] *
PVN foil	73%	7665 *

* could be an overestimate by up to a factor of 3

- PVN fluoresces at both room temperature and -185 C
  - WLS efficiency and time constant comparable to PEN
- Are PVN foils a better alternative to PEN as WLS in liquid argon?
  - Most likely not, as the material is brittle. (While PEN maintains flexibility even in liquid argon).
  - But there may be other modes of use (paint?) or more suitable applications
  - *No breakthrough in terms of reaching ~100% WLSE...*

Summary and outlook

- Work on “enhanced” PEN is continuing, but securing funds for the next step needs more time
- More polymers share WLS potential of PEN
  - Poly(2-vinyl naphthalene) has comparable performance
  - Poly(1-vinyl naphthalene) yet to be tested
- ... however, their brittleness possibly problematic for large area applications
- Detailed analysis and paper in progress

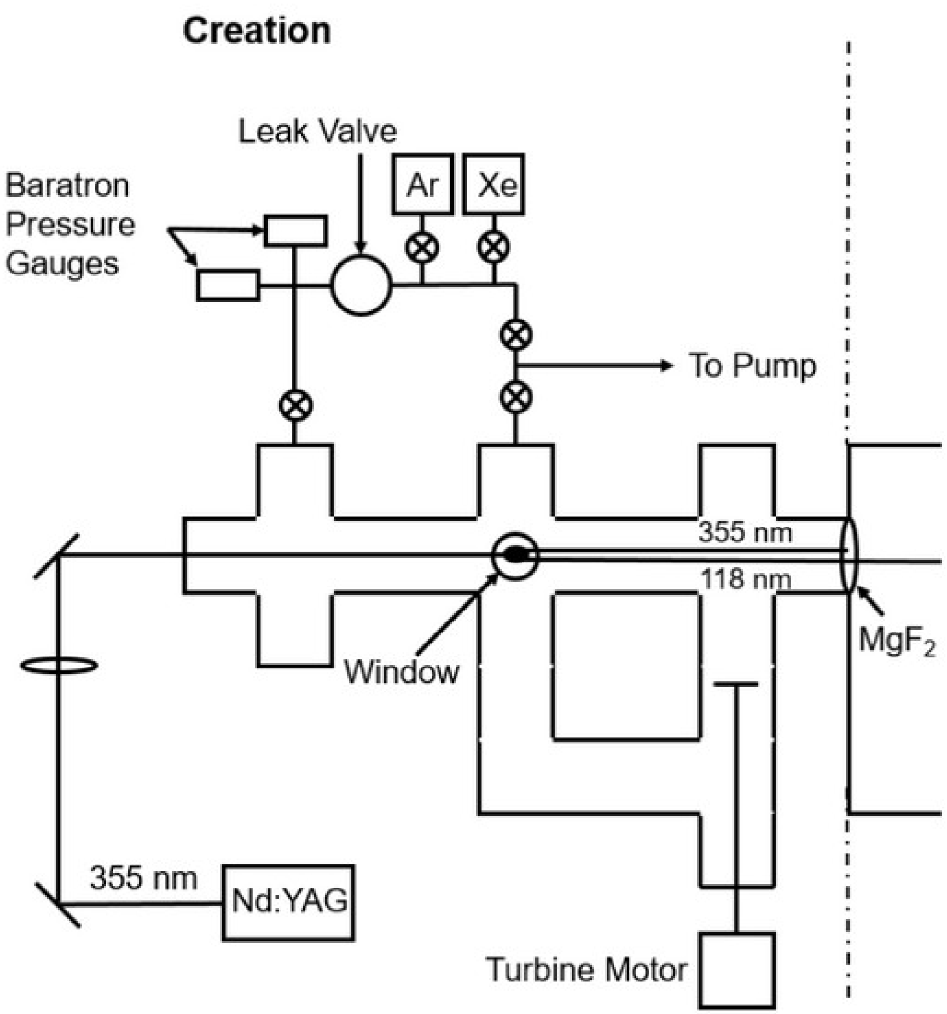
- ArGSet to be upgraded with a nanosecond-pulsed VUV light source, for improved studies of WLS time constants and better control of systematics
- My group will grow in the coming year, new openings planned – reach out if interested

Backup

Planned ArGSet upgrade

Next steps:
- Quality control for DarkSide-20k PEN
- New materials
- Add a nanosecond-pulsed VUV source
- Gaseous TPC configuration

- Funding in place to replace alpha/Ar source with a nanosecond pulsed VUV source
- Plan to procure and commission this year



J.M. Gray et al., J. Chem. Phys. 154, 024201 (2021)

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