INVESTIGATION OF PEN AS STRUCTURAL SELF VETOING MATERIAL FOR CRYOGENIC LOW BACKGROUND EXPERIMENTS

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LEGEND
Large Enriched Germanium Experiment for Neutrinoless ββ Decay

Motivation

Rare event search ($0\nu\beta\beta$, $\beta\beta$, Dark Matter ...)

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- ○ New generation of experiments approaches
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$\Rightarrow$ PEN as structural self vetoing material

WHAT IS PEN?

Polyethylene naphthalate (PEN)

The common plastic PEN has been shown to scintillate.[1]

[1] H. Nakamura et al. In: Europhysics Letters 95.2 (June 2011)
[2] B. Majorovits et al., arXiv:1708.09265v1

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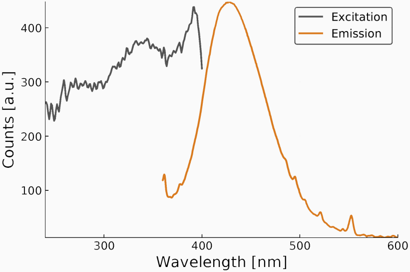
Excitation and emission spectrum of PEN. The sample was moulded at TU Dortmund.[2]



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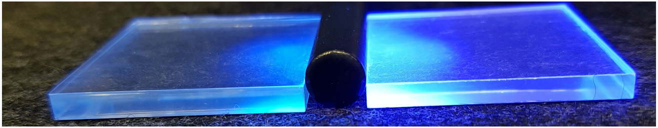
Why PEN?



PEN as scintillator	vs.	Common plastic scintillator

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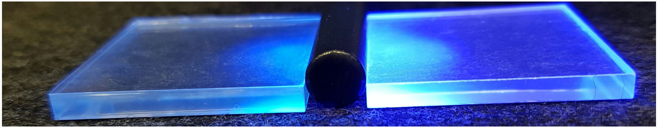

PEN as scintillator	vs.	Common plastic scintillator
Emits in favourable region	$=$	Emits in favourable region
Fast enough signal	$\rightarrow$	Fast signal
(Reported) High light yield[3]	$=$	High light yield
Wavelength shifting	$=$	Wavelength Shifting

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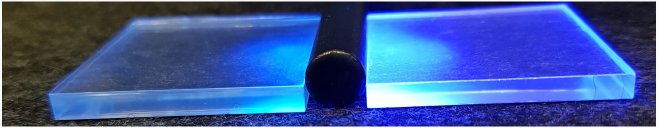

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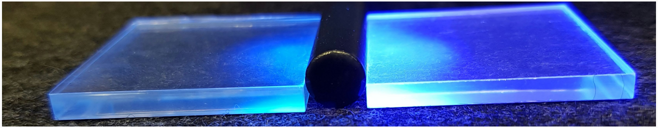

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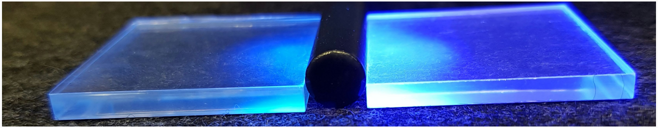

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Pure material is already a scintillator	←	Mixture of plastic and organic scintillator
Can be purified	←	Expensive to purify
Low costs	←	Relative expensive

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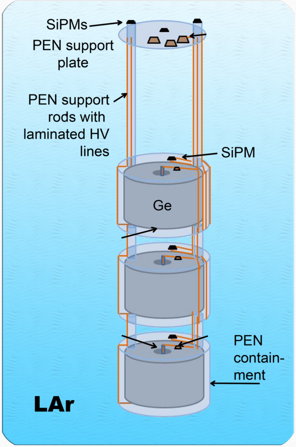
Application



- Replacement for inactive structural materials like copper in low background experiments [4]

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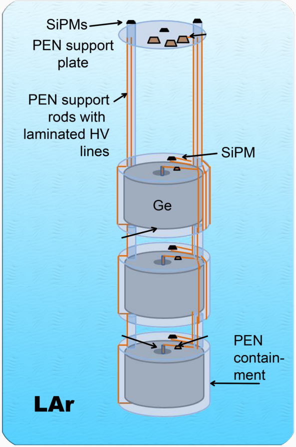
[5] F. Simon, CALICE AHCAL, *Alternative Scintillator Option*, Dec. 2015

[6] E, Tiras et al., arXiv:1611.05228v1

[7] D, Flühs et al., Ocul Oncol Pathol 2016; 2:5–12



- Replacement for inactive structural materials like copper in low background experiments [4]
- Low cost alternative when needing a lot of scintillating tiles[5]
- Radiation hard scintillation detectors for high energy physics[6]
- Replacement for polyvinyltoluene-based scintillators in eye plaque dosimetry[7]

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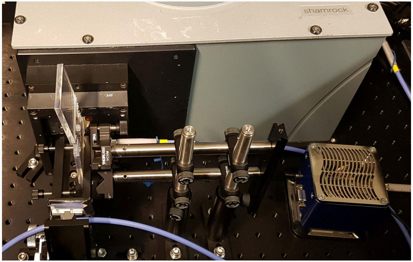
PEN CHARACTERISATION

PEN Characterisation

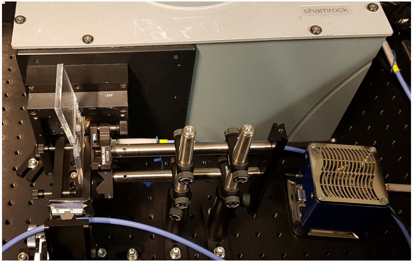
- Light yield properties
- Spectral response
- Temperature dependence
- Environmental influences
- Dependence of the light output on mechanical stress
- Attenuation length
- Radiopurity
- Moulding of scintillator tiles

Spectroscopy Based Investigation



- Andor spectrometer and CCD camera[8]
- UV-LED: 255 nm, $P_{\text{max,UV}} = 2\ \mu\text{W}$

[8] *Shamrock-SR-303I-A* spectrograph, *iDus DV420A* CCD camera



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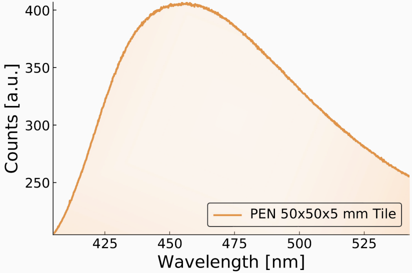
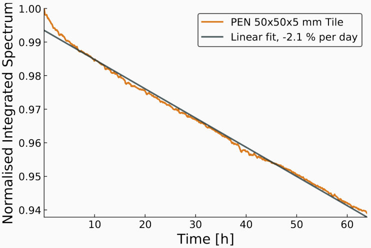


- Resulting spectrum for PEN
- Integrated spectrum is treated as *light output*

→ Integrated range: 405 to 542 nm

[8] *Shamrock-SR-303I-A* spectrograph, *iDus DV420A* CCD camera

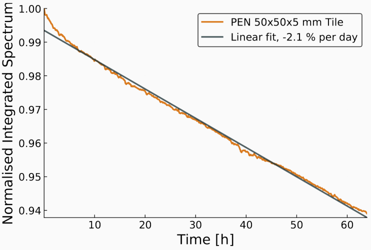
Radiation Damage and Reproducibility



- Constantly decreasing light output when exposed to UV (255 nm, 1.36 μW)

→ In accordance with other plastic scintillators[9]

[9] C. Zorn, https://doi.org/10.1016/0969-806X(93)90040-2



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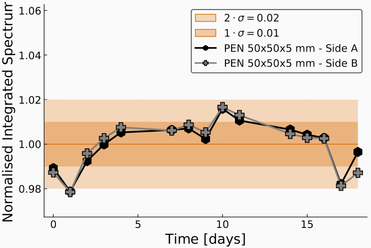

- Three-week reproducibility measurement:

→ Standard deviation: 1.0 %

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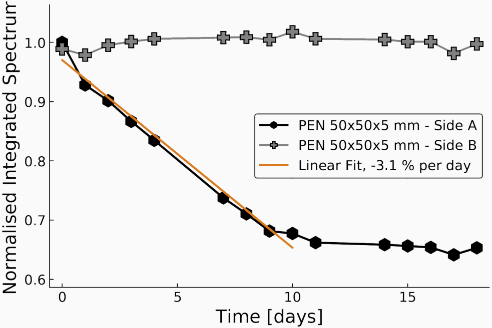
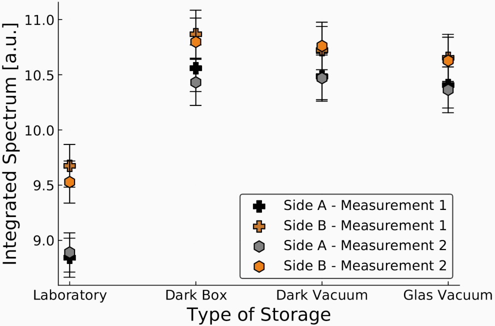
Deterioration of the Light Output



- One self-moulded tile was constantly exposed to UV light ($1,36 \pm 0.01\ \mu$W) for 10 days
- $\approx$ 30 % decrease due to photon induced damage (surface effect)
- Afterwards, no recovery detected

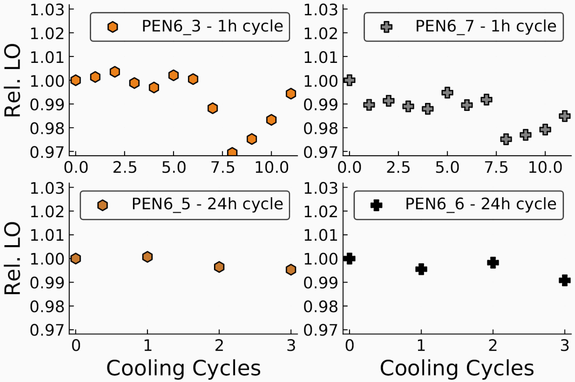
Environmental Influences on the Light Output



- 32 self-moulded tiles, randomly chosen from one batch were set under different conditions for one month:

→ Dark vacuum, vacuum, dark box, laboratory

Cryogenic Environment - Liquid Nitrogen

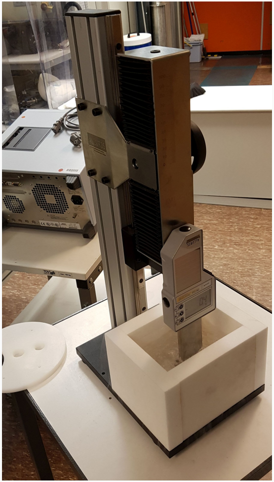


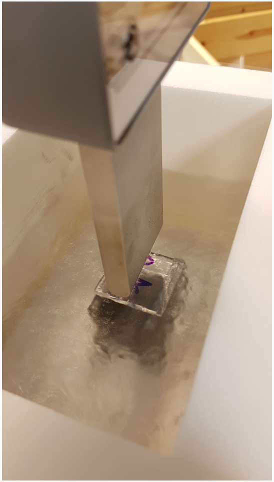
PEN tiles were stored in liquid nitrogen for different time spans. After each cycle, the light output was measured again

→ Cooling procedures do not influence the light output of PEN

Stress Tests

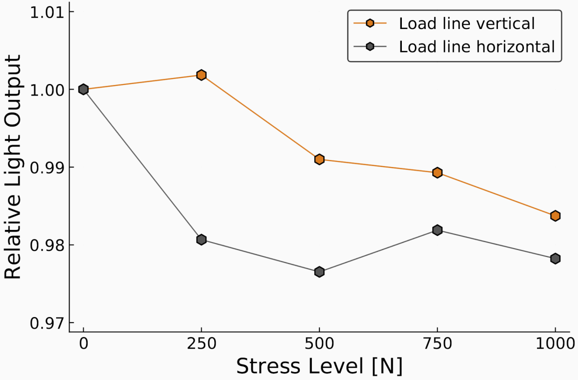
Experimental set-up[10] to expose PEN tiles to stress in a cryogenic environment.





[10] FMT-220 force test stand and FMI-S30K1 force gauge by *ALLURIS*

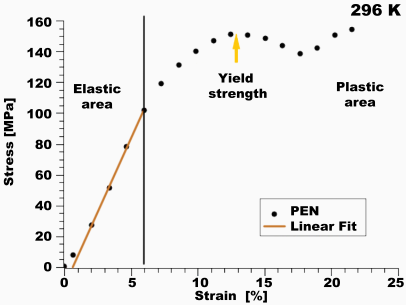
Stress Tests - Results

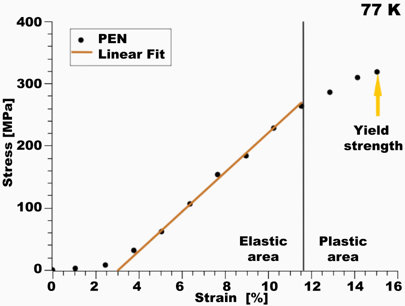


PEN tiles were measured regarding their light output before and after exerting them to different stress levels

→ No significant effect could be observed

Stress Tests - Youngs's Modulus





Young's modulus $\left(\frac{Stress}{Strain}\right)$ for PEN increases from 1.9 to 3.5 GPa when cooled down from room temperature to 77 K.[11]

Maximum yield strength: 150 MPa $\xrightarrow{Cooling}$ 300 MPa

[11] S. Eck, Bachelor Thesis

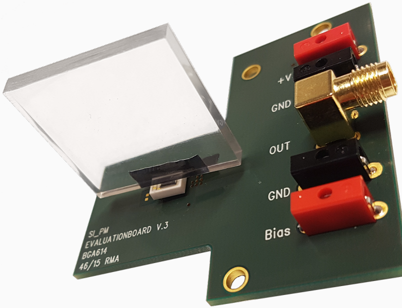
Conclusion

- The scintillation spectrum of PEN claimed by Nakamura could be reproduced.
- UV light deteriorates light output.
- Mechanical stress and cryogenic temperatures do not deteriorate light output.
- Light output not optimum yet, probably due to short attenuation length.

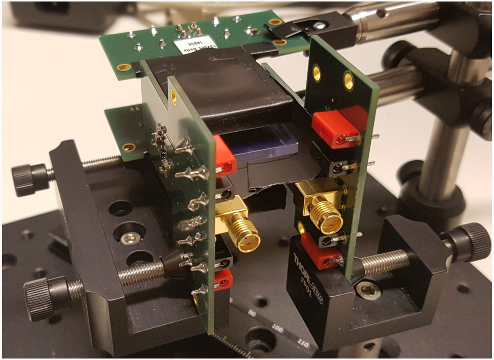
→ Work in progress

SiPM Based Investigation For cryogenic experiments, silicon photomultipliers (SiPM) are more favourable than a spectrometer.

- Evaluation-board including pre-amplifier from the *Future Detectors* group (MPP)
- 3×3 mm SiPM[12] with 3600 pixels (50 μm pitch)

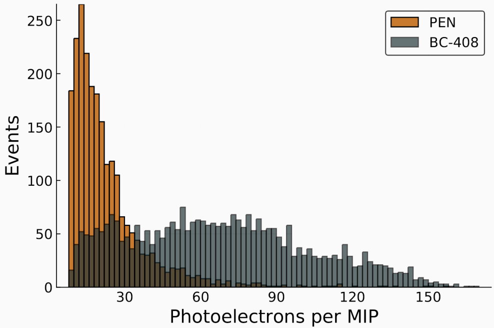


Muon Telescope



- Two triggers
- PEN and common plastic scintillator (BC-408) samples in between

Muon Telescope - Results



Preliminary!

Results:

- PEN: clear peak at 14 photoelectrons per MIP.
- BC-408: higher average light output (due to attenuation length?)

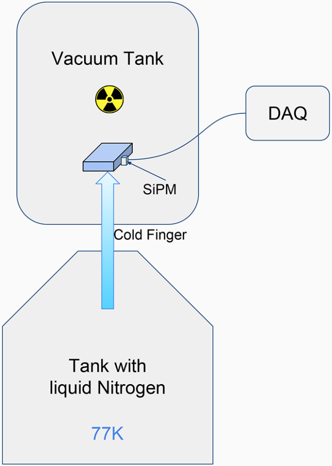
Detection efficiency:

- PEN: ≈ 60 %
- BC-408: ≈ 80 %

→ PENNI - **PEN** at liquid **N**itrogen temperature **I**nvestigation

Some scintillators provide a higher light yield at low temperatures.[13]

→ investigate the scintillation properties of PEN at cryogenic temperatures



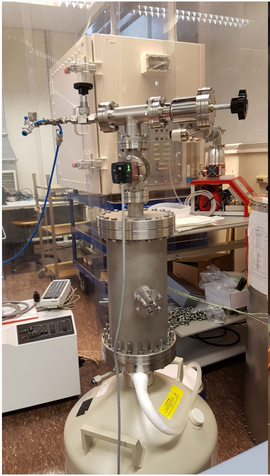
Outlook - PENNI

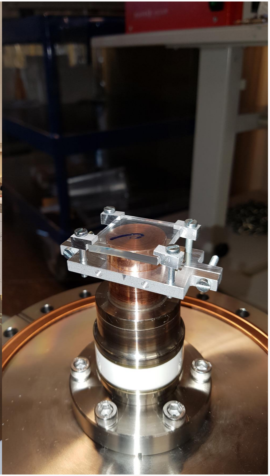
Achieved so far:

- Vacuum of: $\approx 10^{-6}$ mbar.
- Temperature at the inner part of the cold finger: $\approx -140°$C.

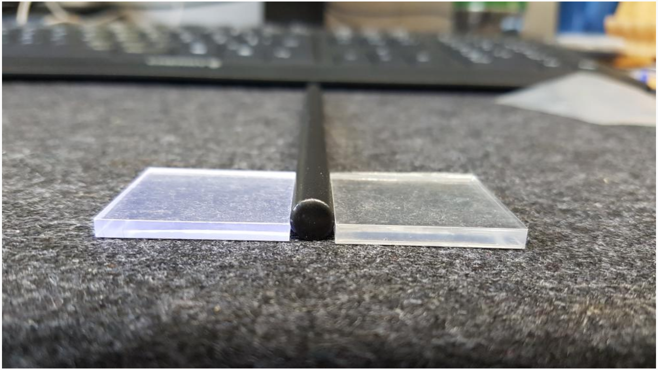
What has to be done:

- Better thermal insulation during the transition from the dewar into the vacuum.
- Construct a thermal insulated holding structure for radioactive sources.

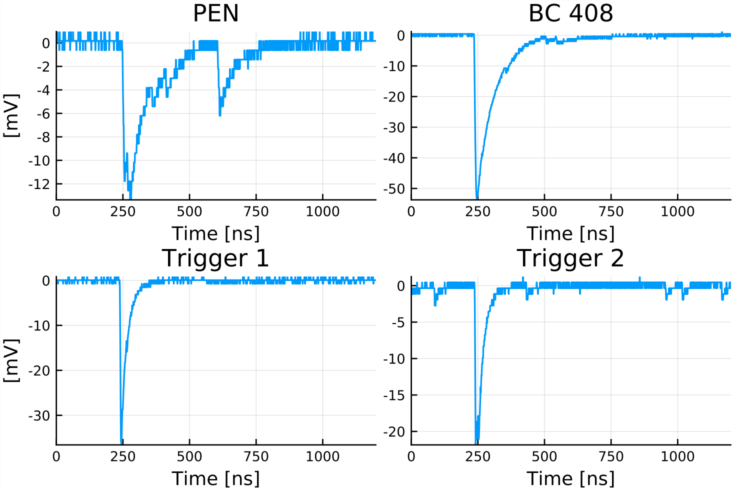




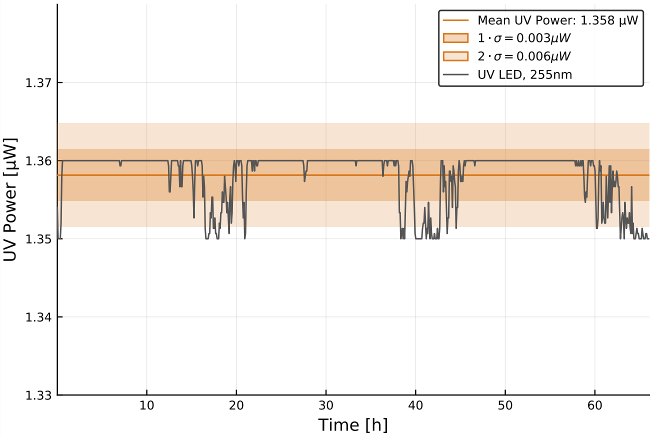
Backup - PEN vs. BC-408 without UV lamp



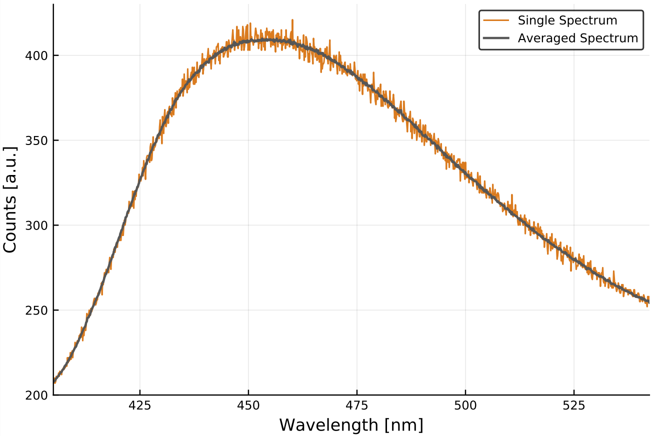
Backup - PEN and BC-408 Pulse from SiPM



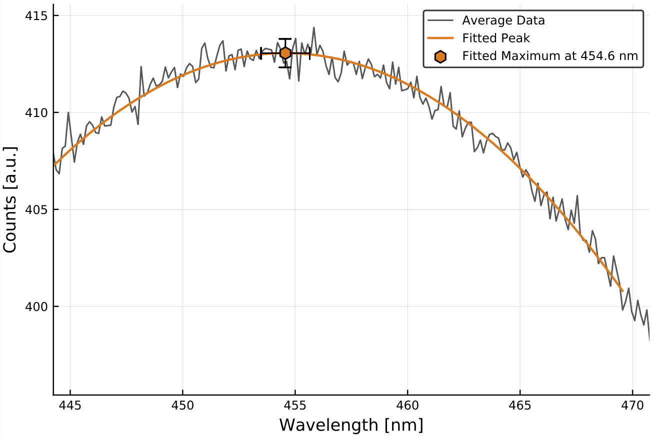
Backup - UV lamp stability



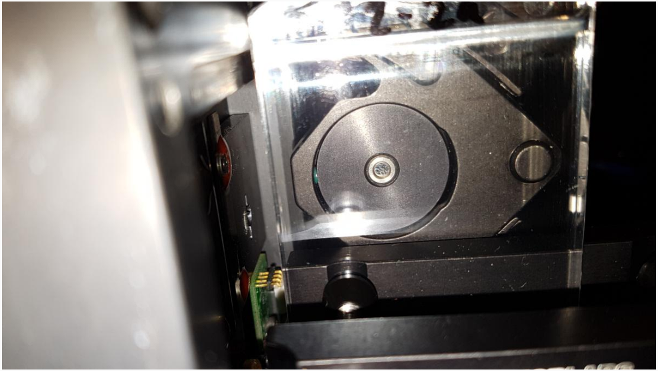
Backup - Average spectrum



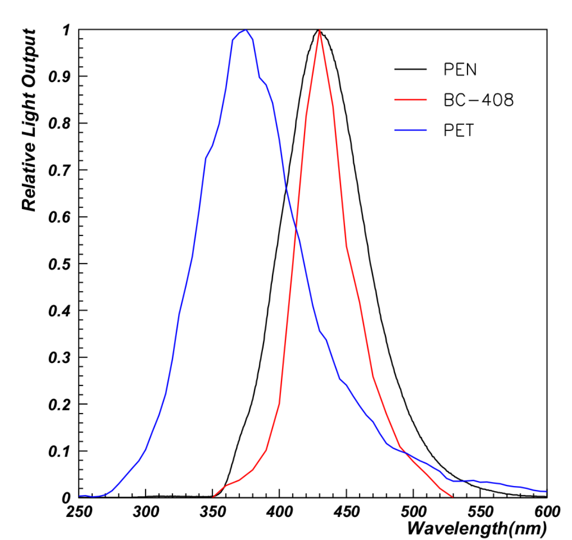
Backup - Fitted emission maximum



Backup - Exposure position



Backup - Claimed PEN spectrum



Backup - Spectra of reproducibility measurements