

Investigation of PEN as a Scintillator for Low Background Experiments: Characterisation of Light Yield Properties

Thomas Kraetzschmar
MPI für Physik, München



Thomas Kraetzschmar: kraetzsc@mpp.mpg.de



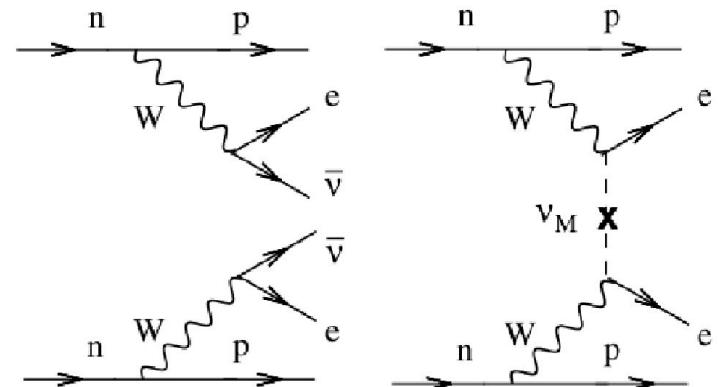
Motivation for Low Background Experiments

- Dark matter problem
- Baryogenesis not understood
 - Majorana nature of neutrinos



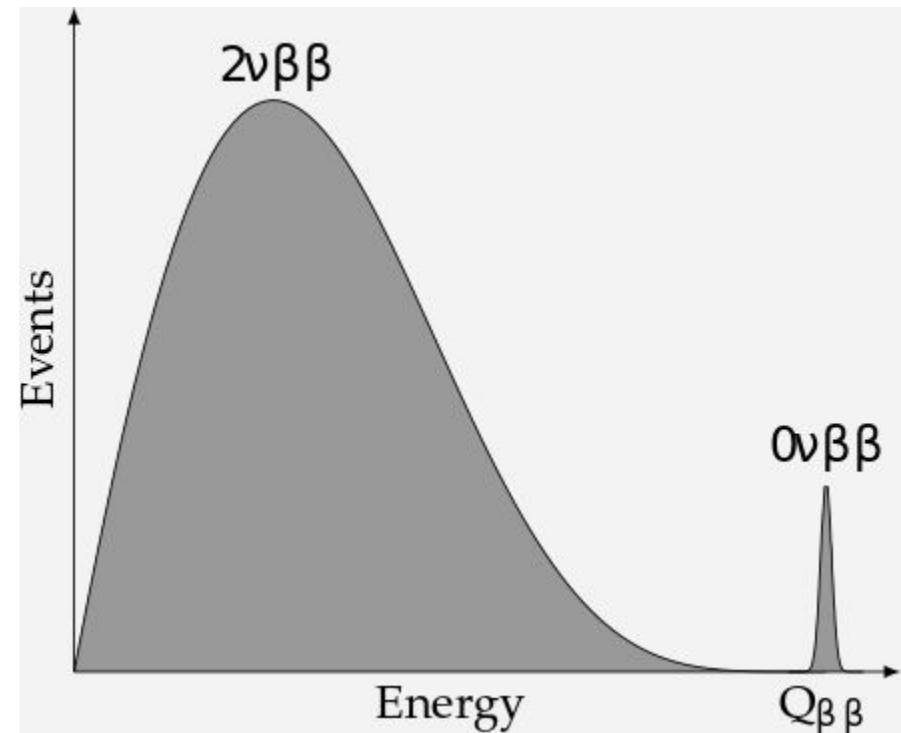
Neutrinoless Double Beta Decay

- Double beta decay occurs if:
 - $E(A, Z) < E(A, Z+1)$
 - $E(A, Z) > E(A, Z+2)$
- Neutrinoless double beta decay
 - Non-vanishing Majorana neutrino mass necessary
 - Allows for an exchange of the neutrino
⇒ no neutrinos in final state



Neutrinoless Double Beta Decay

- Double beta decay occurs if:
 - $E(A, Z) < E(A, Z+1)$
 - $E(A, Z) > E(A, Z+2)$
- Neutrinoless double beta decay
 - Non-vanishing Majorana neutrino mass necessary
 - Allows for an exchange of the neutrino
⇒ no neutrinos in final state



Sensitivity of Neutrinoless Double Beta Decay Experiments

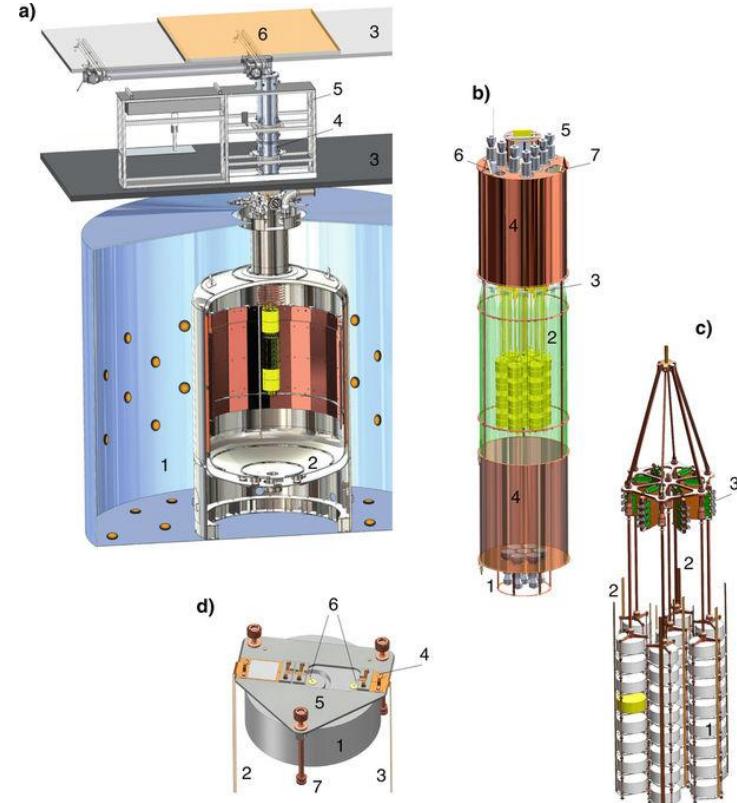
$$\tau_{0\nu\beta\beta} \propto \sqrt{\frac{MT}{b\Delta E}}$$

- M: mass in tons
- T: measurement time in years
- ΔE : energy resolution
- b: background
 - dependent on
 - radiopurity
 - vetoes
 - ...



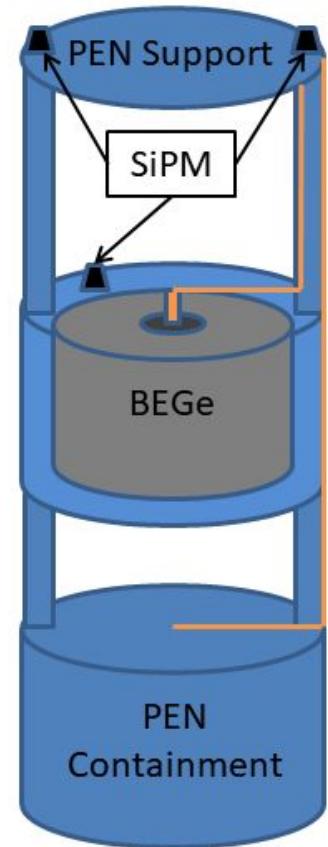
The LEGEND Experiment

- Large Enriched Germanium Experiment for Neutrinoless $\beta\beta$ -Decay
 - Aim to measure ${}^{76}\text{Ge}$ $\beta\beta$ -decay energy spectrum in a ton-scale experiment.
 - Successor to GERDA and Majorana experiments



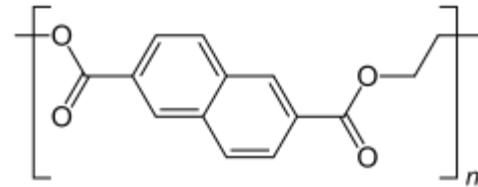
Motivation: a New Structural Material

- Idea:
 - Use an ultrapure transparent active structural material in low background experiments
 - But standard plastics scintillators are expensive and potentially not radiopure



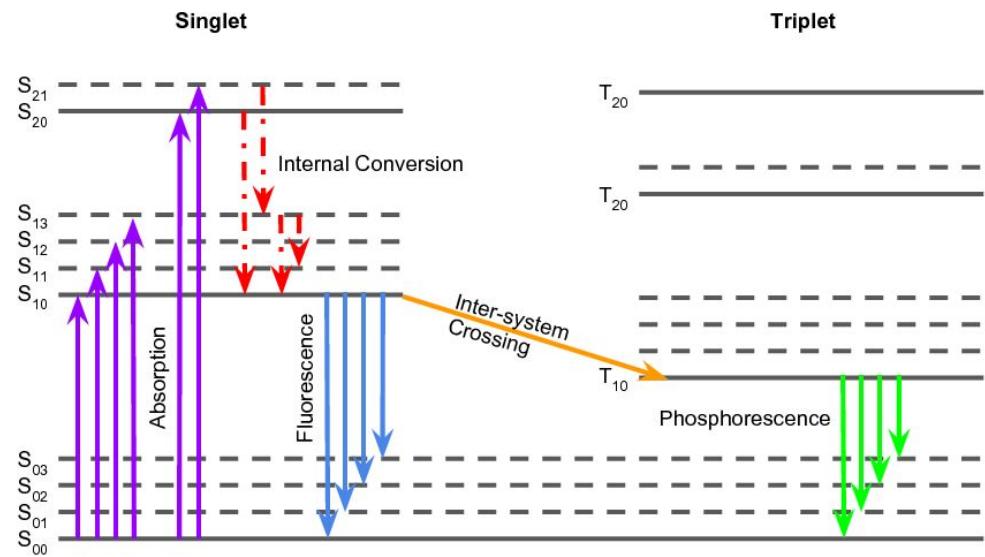
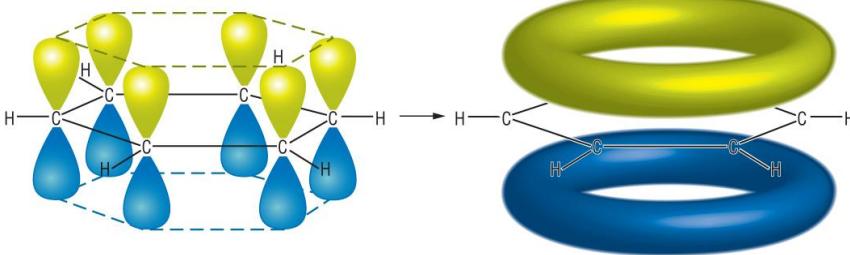
Polyethylene Naphthalate (PEN)

- What is PEN?
 - $C_{14}H_{10}O_4$
 - Used for everyday products
- Why is it interesting for us?
 - It scintillates
 - It is radiopure
 - It can be moulded into arbitrary shapes
 - It has high mechanical stability



Why is PEN Interesting as a Scintillator?

- How does PEN fit into this?
 - Binary scintillator
- What scintillates?
- Quantum mechanical model



PEN as a Scintillator

- Investigation of a new scintillator
 - Light spectra of custom-made PEN
 - Light output measurements with a PMT
 - Temperature dependence of the light output



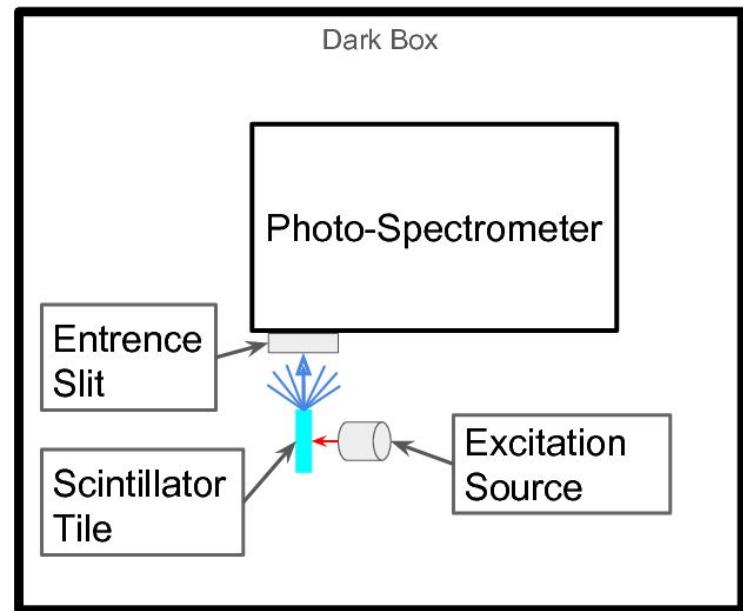
PEN without radiation



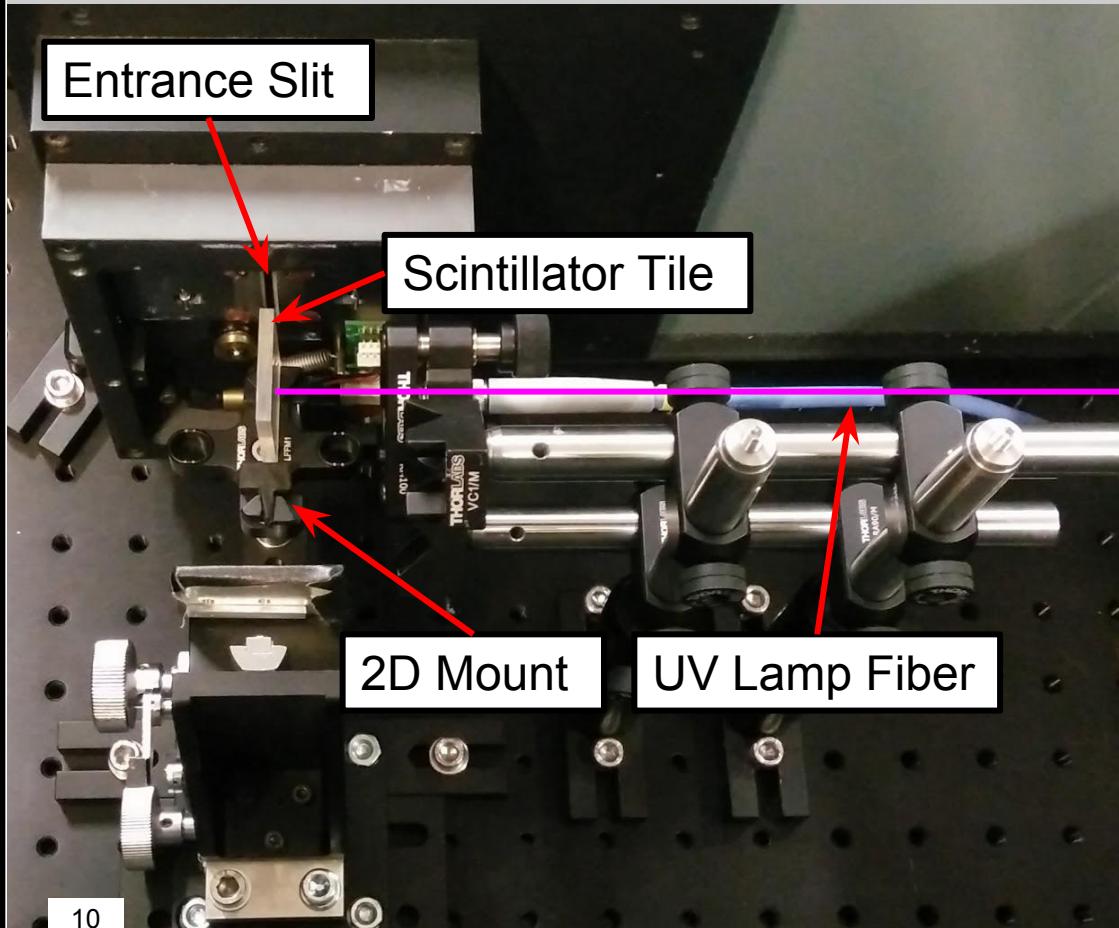
PEN with UV light

Spectrometer Setup

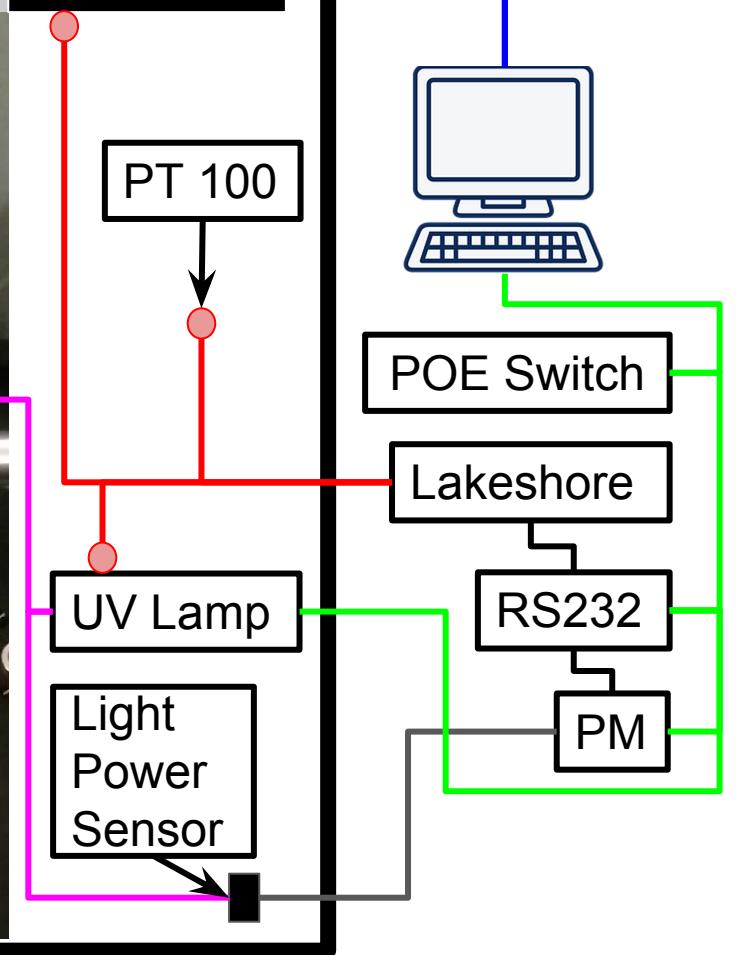
- Requirements
 - Spectra are comparable to those found in literature
 - Low noise
 - Stable source



Spectrometer

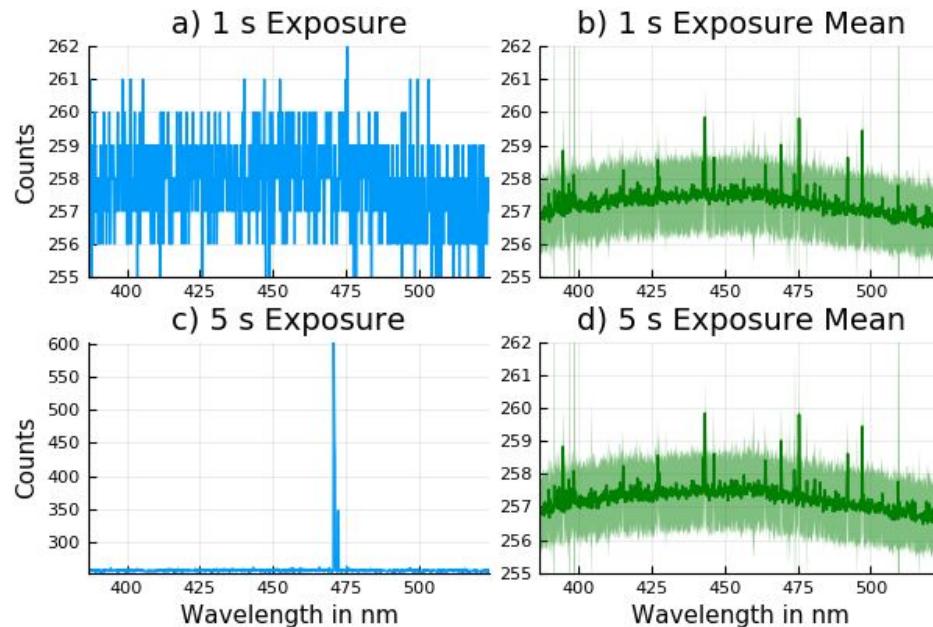


CCD-Camera

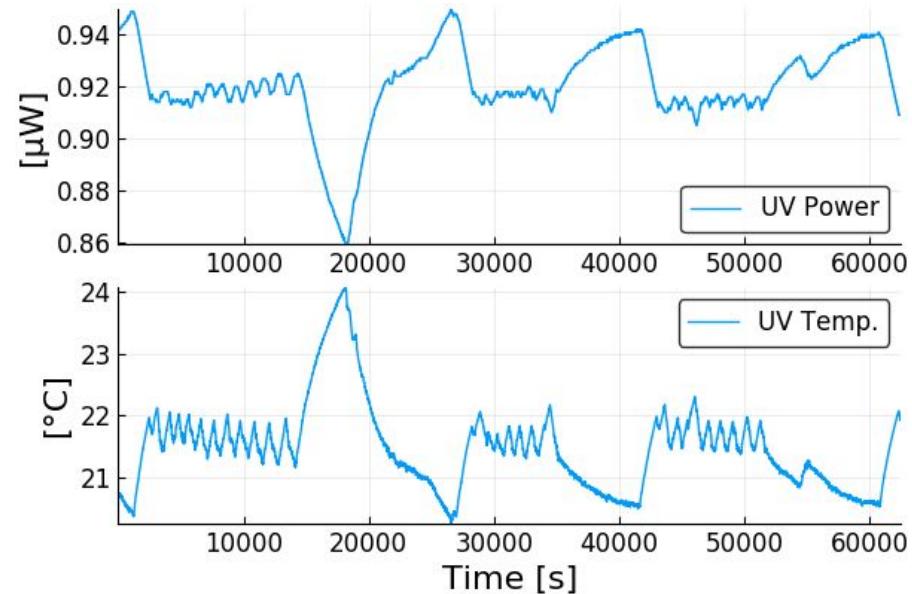


Influencing Parameters of Spectrometer Data

Background Measurements



UV Light Power Fluctuations



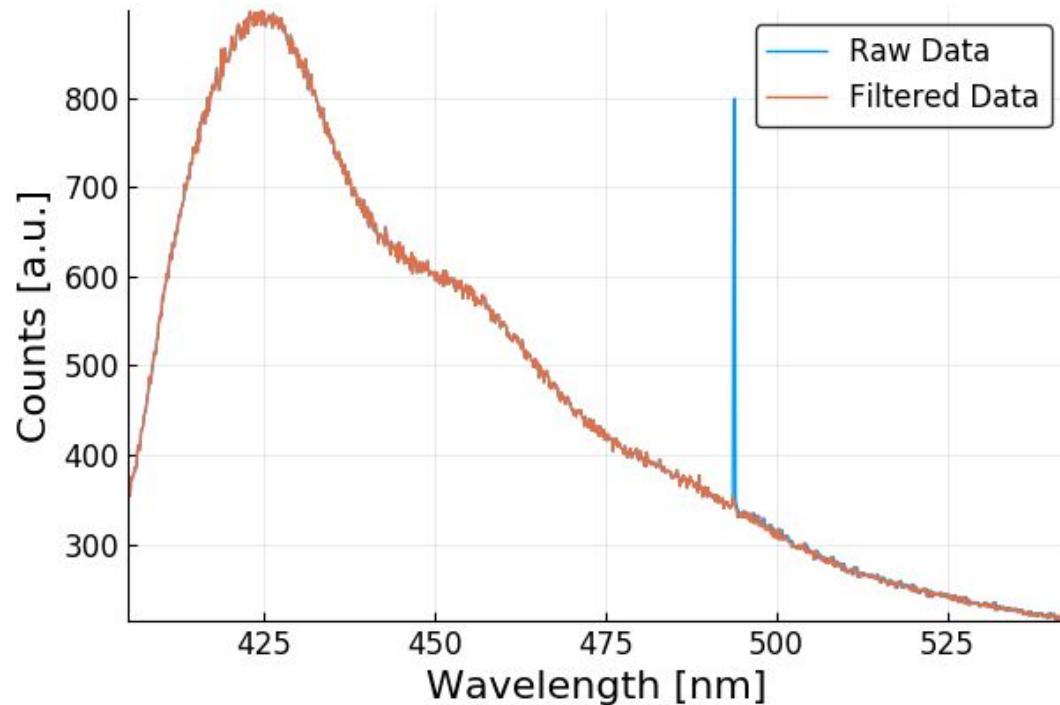
Analysis

Measure spectra and determine:

1. peak wavelength
2. light output

Three-step analysis:

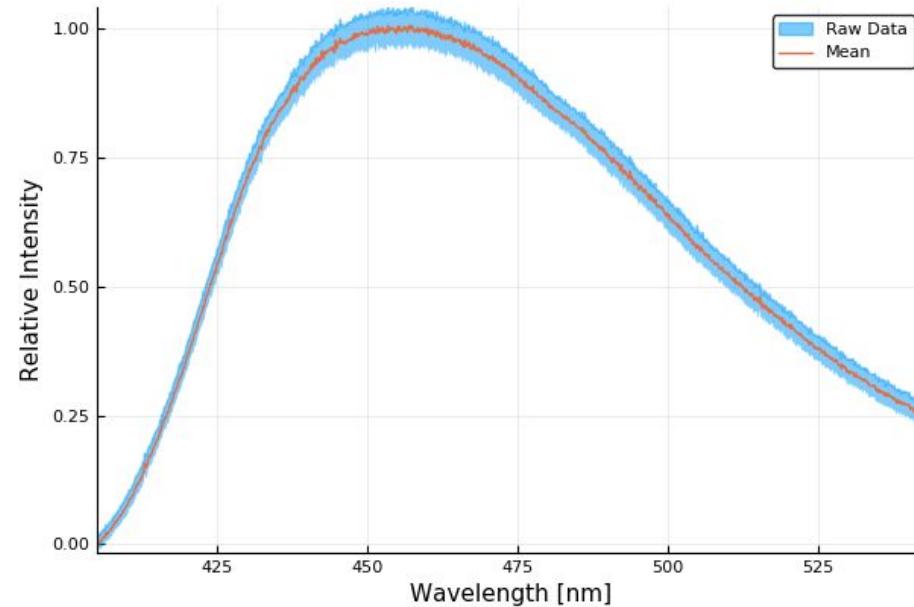
1. Data preparation
 - a. Filter muon events and clocking time issues
2. Parameter calculation
3. Uncertainty estimation



Analysis: Data Preparation

Three step analysis:

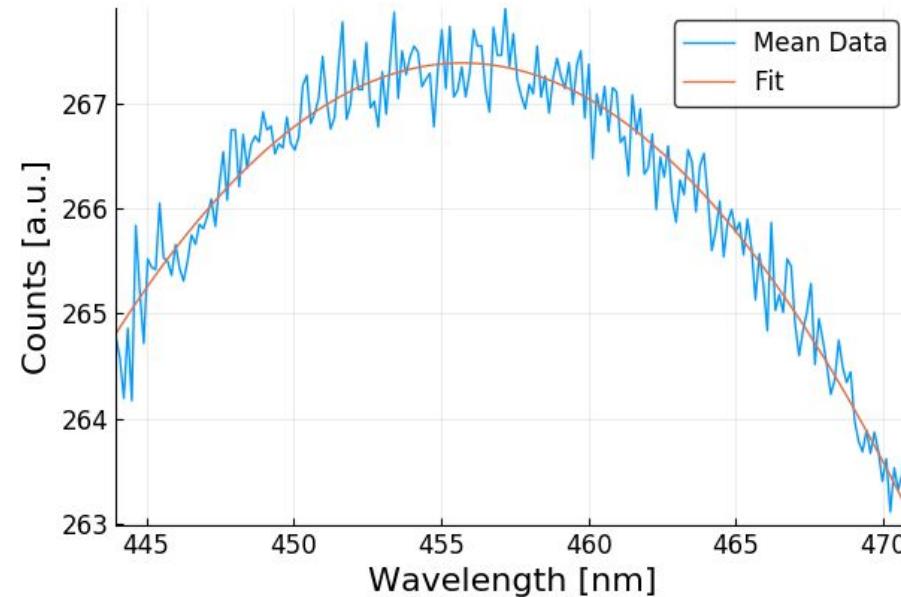
1. Data preparation
 - a. Filter muon events and clocking time issues
 - b. Calculate μ_n and σ_n for all bins, and light power p
 - c. Account for the background:
$$\mu_n' = \mu_n - \mu_n^{bg}$$
 - d. Account for the light power μ_p :
$$\mu_n'' = \mu_n' / \mu_p$$



Analysis: Parameter Calculation

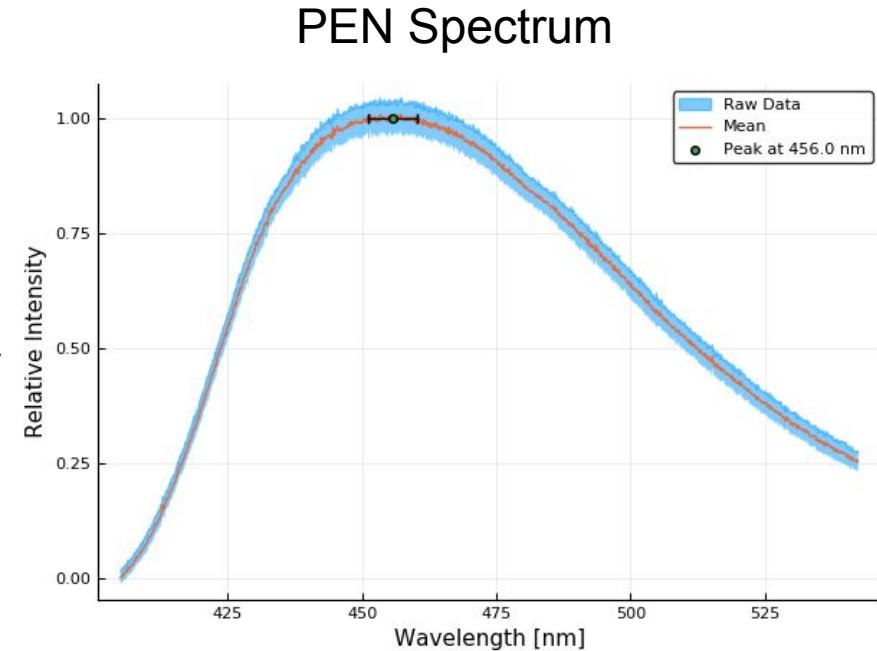
Three step analysis:

1. Data preparation
2. Parameter calculation
 - a. Fit peak with parabola
 - b. Obtain light output by integrating spectrum:
$$\sum_{i=1}^n \mu''_i$$
3. Uncertainty estimation
 - a. Error propagation
 - b. Mean of fit parameters for each spectrum



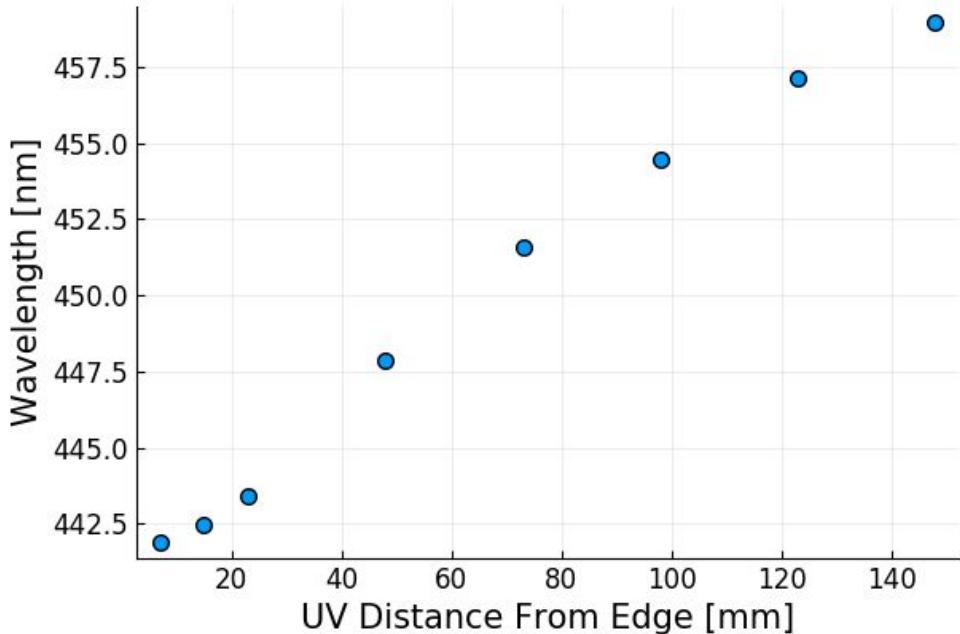
Method for Measuring Light Spectra

- Measure 100 spectra and light power of UV light
 - Calculate mean and uncertainty for spectra and light power
- Account for background and light power in spectra data
 - calculate uncertainty
- Determine parameters of spectra

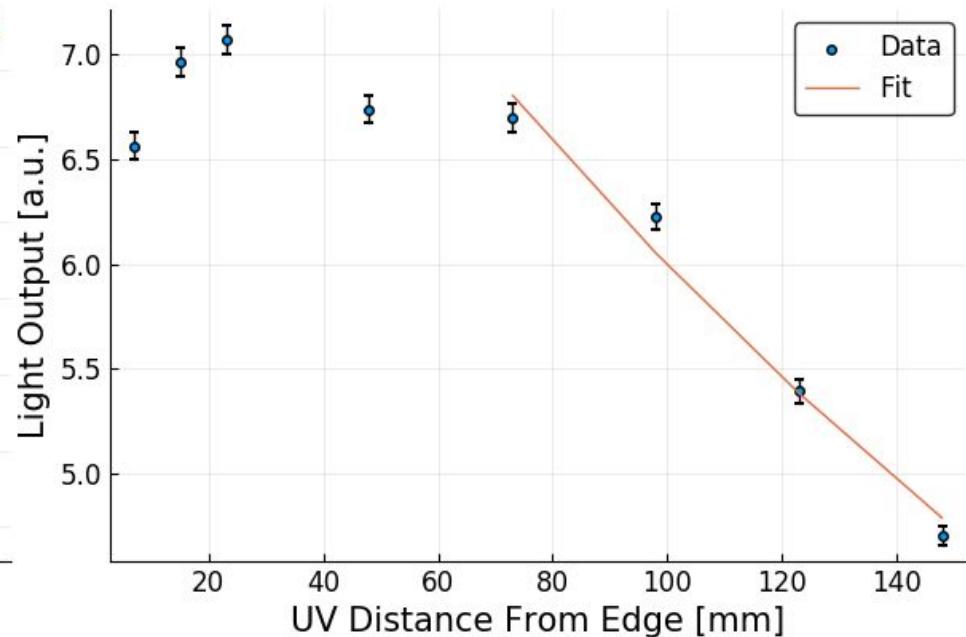


Attenuation Length Study

Peak Wavelength

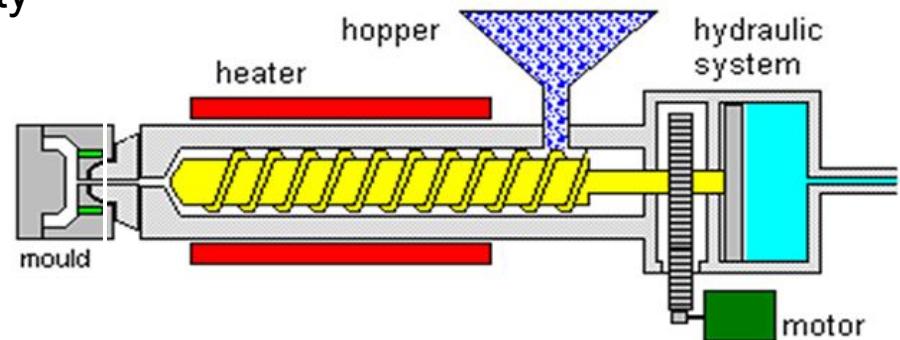


Light Output



Injection Moulding of PEN

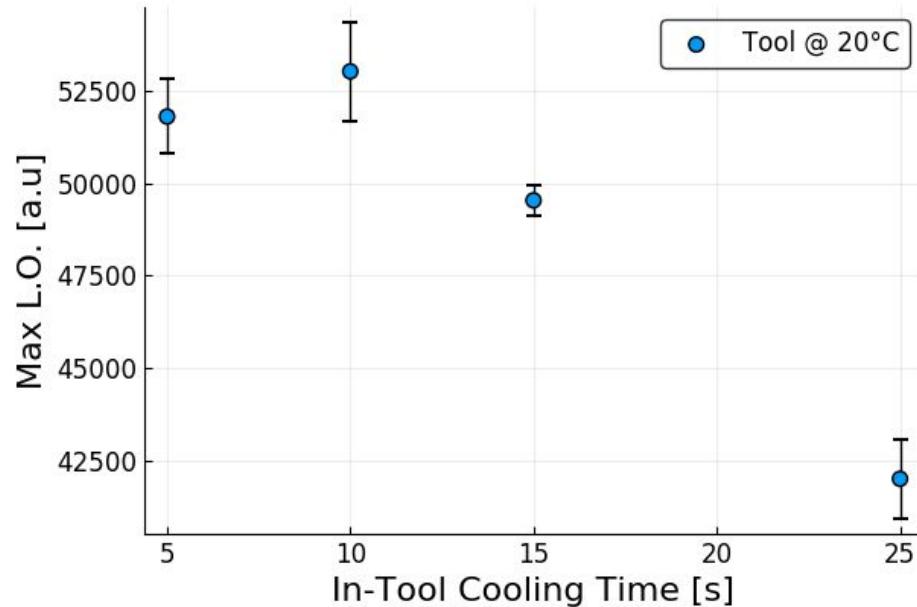
- How can PEN be shaped?
- Crystallinity is determined by injection moulding process
 - multiple parameters to be considered
- Light output is dependent on crystallinity
- Important to understand which parameters influence the light output and how



Results of Moulding Parameter Investigation

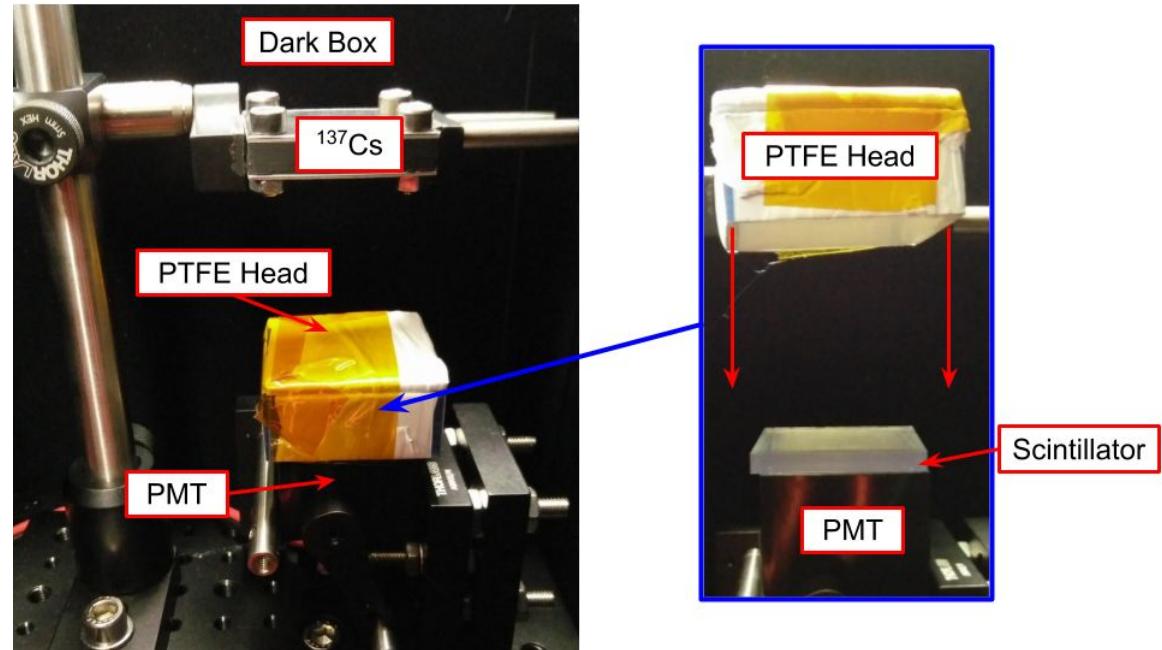
- Moulding process does have an influence in the light output of PEN

PEN Mould Cooling Time Study



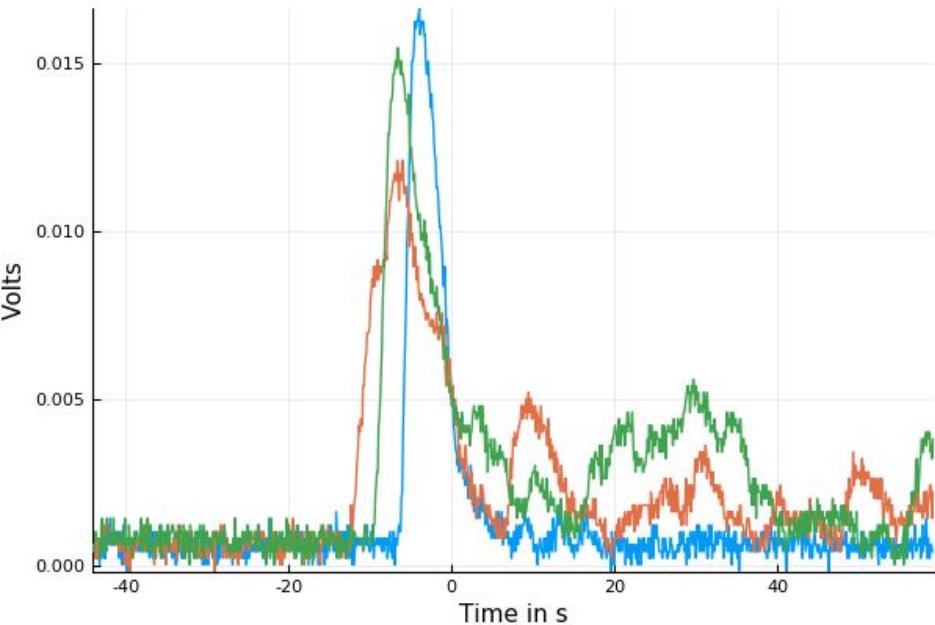
PMT Setup

- Goal:
Determine light yield
- Need for well-known
setup with all
independent variables
under control

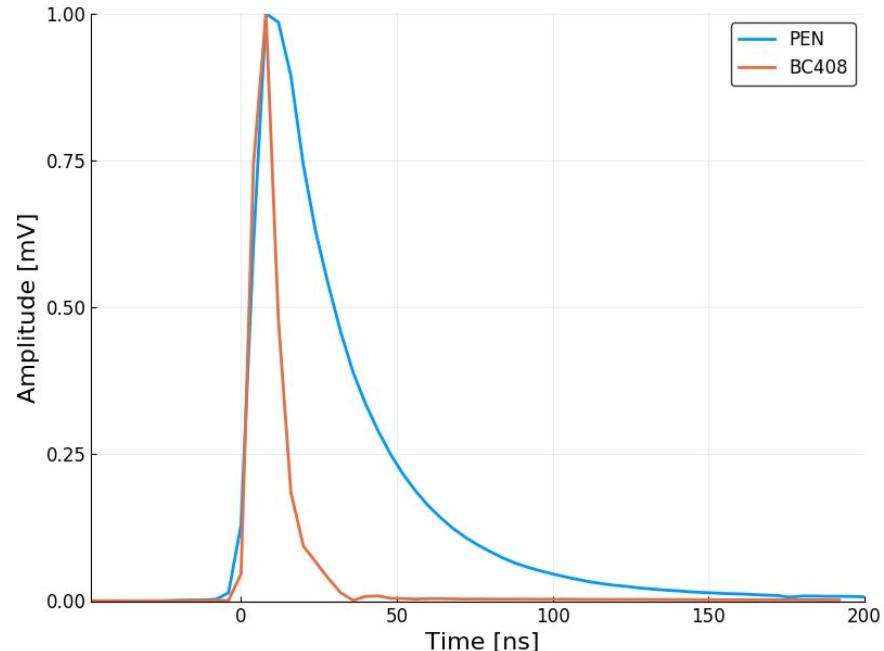


PEN Pulses

Typical PEN Pulses

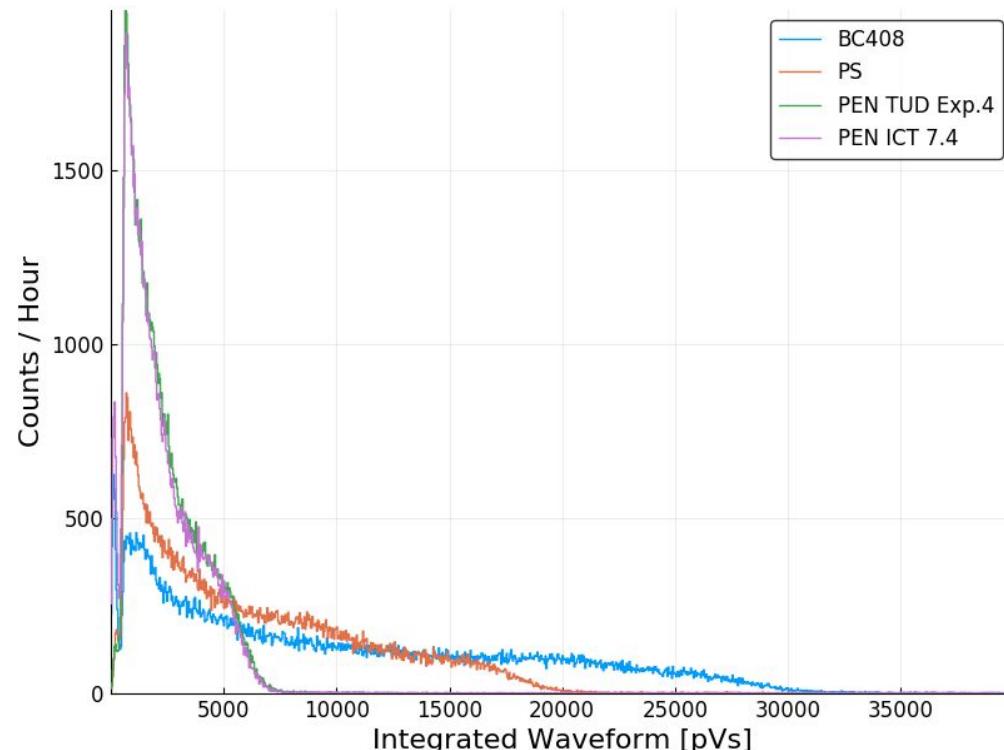


Average PEN Pulses



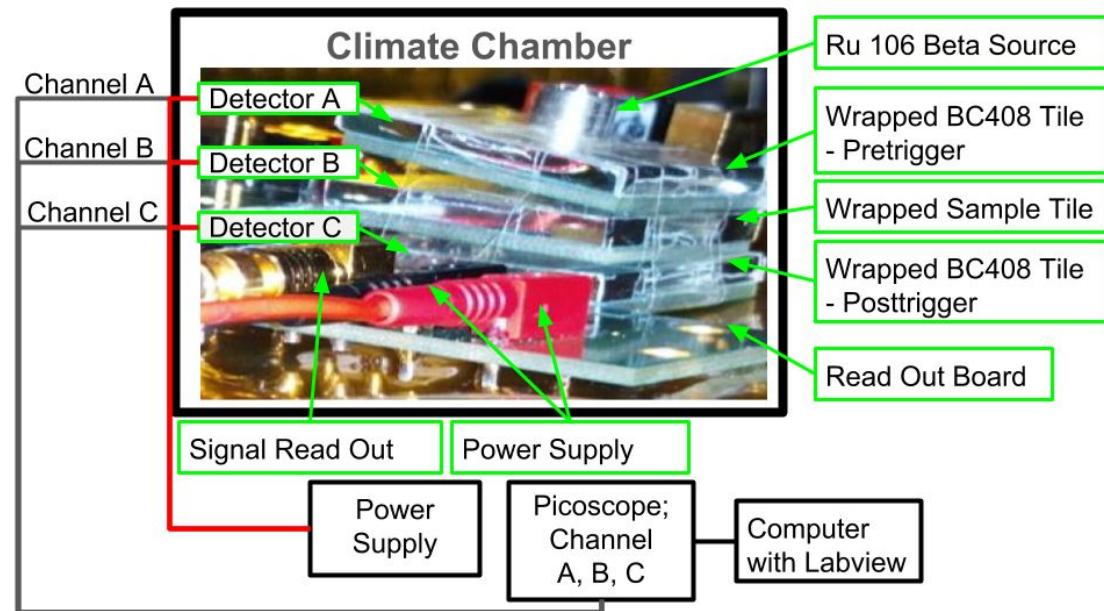
Scintillator Comparison with the PMT Setup

Material	# 1k Events in 1h	Mean Output [nVs]
PMMA	7.31 ± 0.09	$0.9^{+0.5}_{-0.2}$
BC408	95.6 ± 0.3	10^{+8}_{-10}
PS	98.1 ± 0.3	6^{+5}_{-6}
PEN TUD Exp. 4	97.8 ± 0.3	2^{+2}_{-2}
PEN ICT 7.4	93.1 ± 0.3	2^{+2}_{-2}



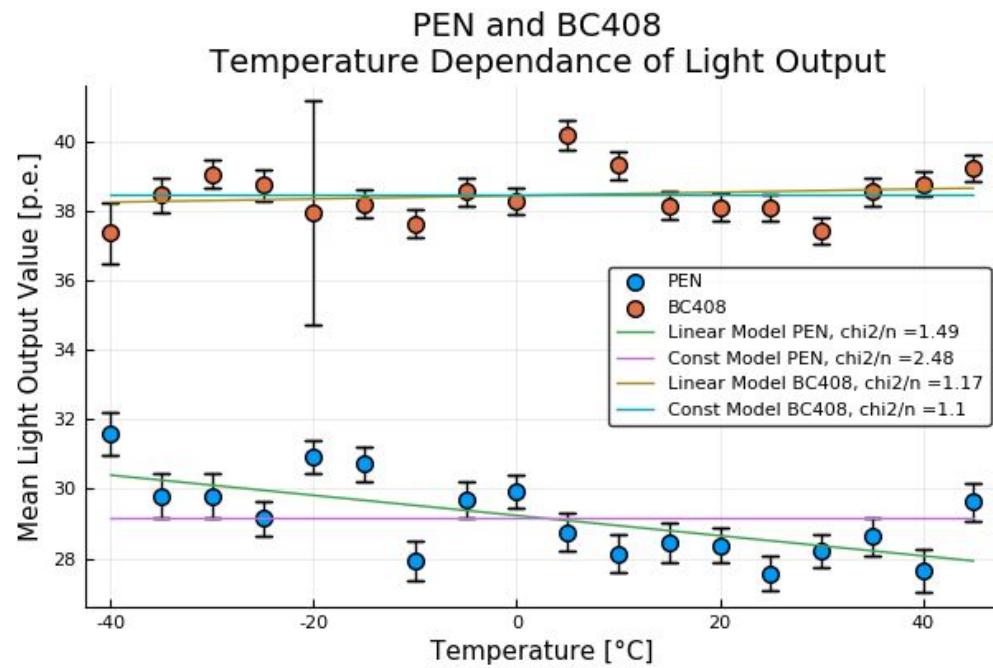
Investigation of Temperature Dependence of Light Output

- Motivated by temperature-dependent fluorescing paints
- Use climate chamber
 - Range: -40 to 45°C
 - Accuracy: 0.5 °C
- Sandwich configuration of scintillating tiles
 - Top/bottom is BC408 as pre- and post-trigger
- Signal of each tile read out by a SiPM



Results of Temperature Test Measurements

- Slope of linear model
 - BC408: slope = 0.001 ± 0.001
 - PEN: slope = 0.0294 ± 0.005

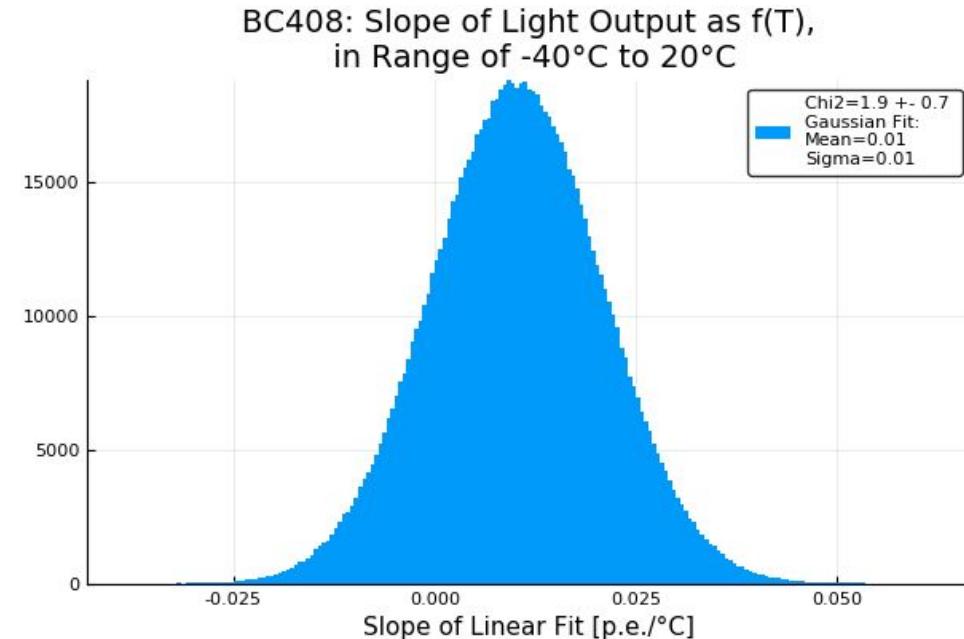


Results of Toy Monte Carlo Analysis

- Toy Monte Carlo:
 - Draw new data points r_i using $P(T, I_{out} | Data)$
 - Fit linear model to new data set
 - Repeat 1 million times
- Calculate Bayes factor:

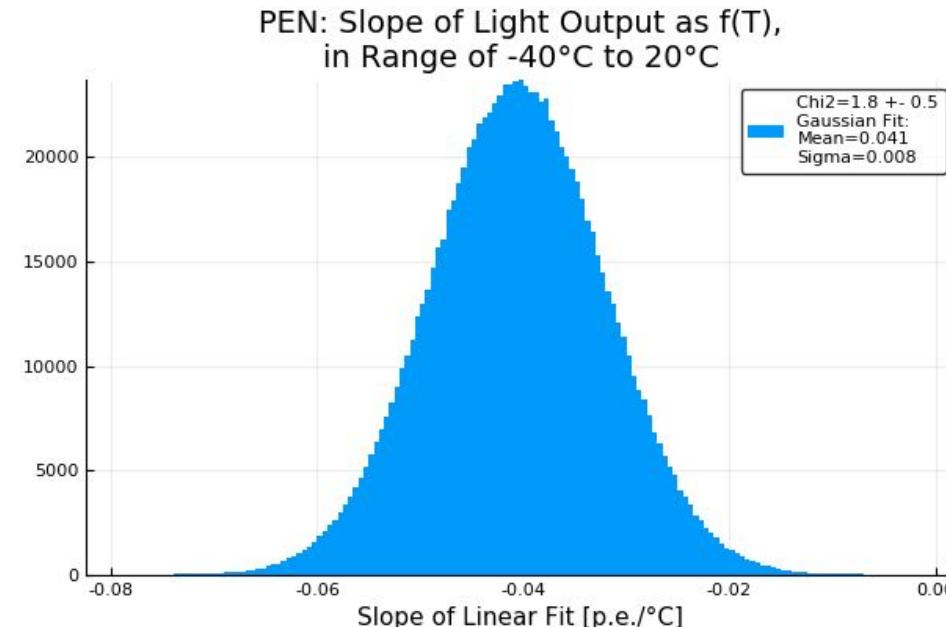
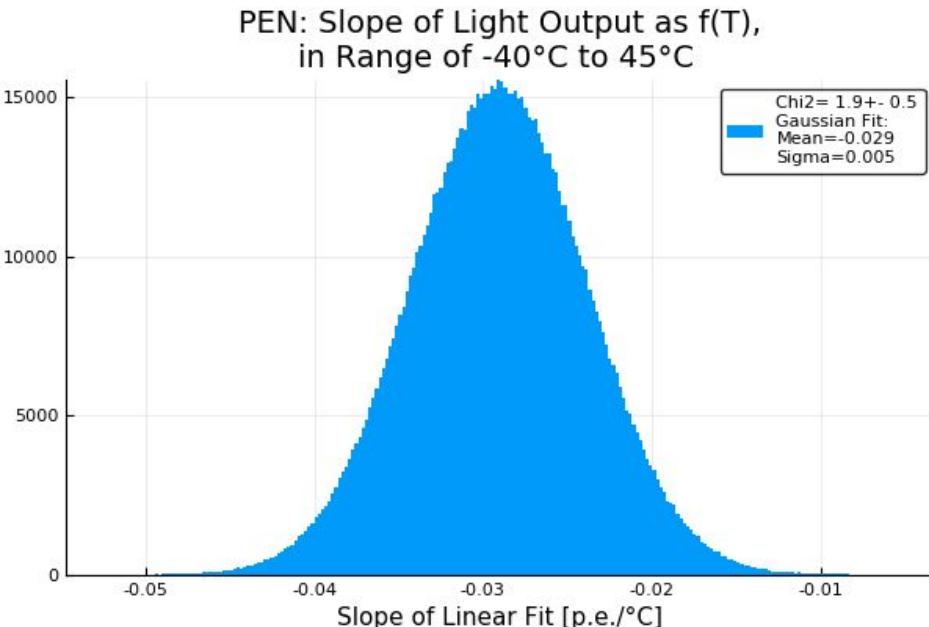
$$K = \frac{P(data|M_{lin})}{P(data|M_{const})}$$

- For BC408: $\ln(K)=0$



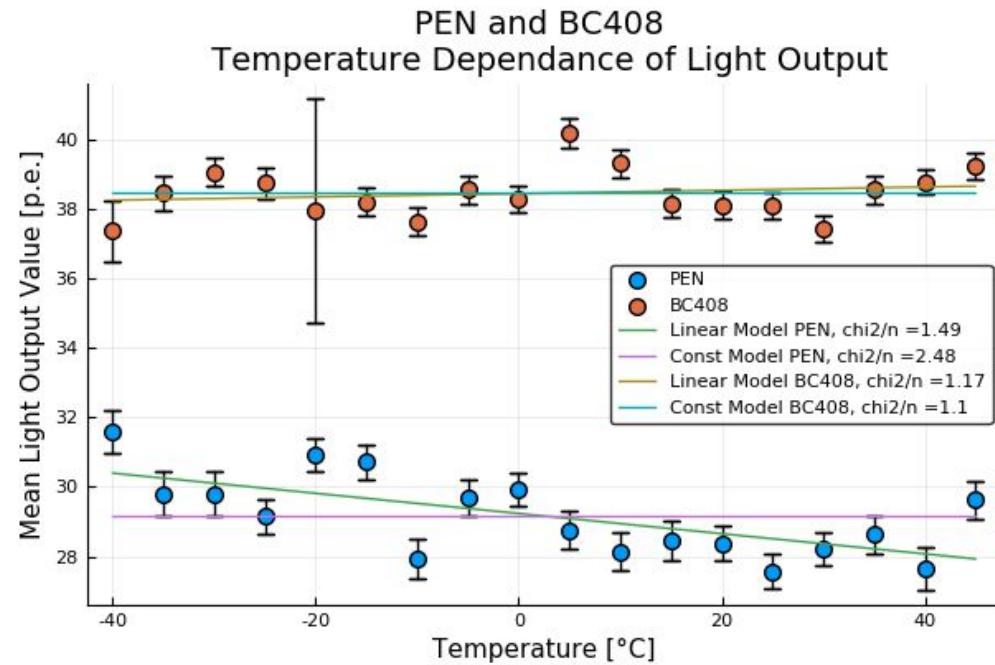
Results of Toy Monte Carlo Analysis

- Slope deviates $\sim 6 \sigma$ from 0
- Bayes factor: $\ln(K)=16.5$
- Slope deviates $\sim 5 \sigma$ from 0
- Bayes factor: $\ln(K)=11.8$



Results of Temperature Test Measurements

- PEN to BC408 light output ratio
 - In the spectrometer setup
 ≈ 0.1
 - In the temperature dependence experiment
 ≈ 0.75
- ⇒ Strong geometry dependence of light output



Conclusion

- Interesting material for low background experiments
- Can be shaped by moulding
 - Light output dependent on moulding parameters
- Indication of a temperature-dependent light output
- Further studies needed!





Thomas Kraetzschmar: kraetzsc@mpp.mpg.de



Climate Chamber

Channel A

Channel B

Channel C

Detector A

Detector B

Detector C

Signal Read Out

Power Supply

Power Supply

Picoscope;
Channel
A, B, C

Ru 106 Beta Source

Wrapped BC408 Tile
- Pretrigger

Wrapped Sample Tile

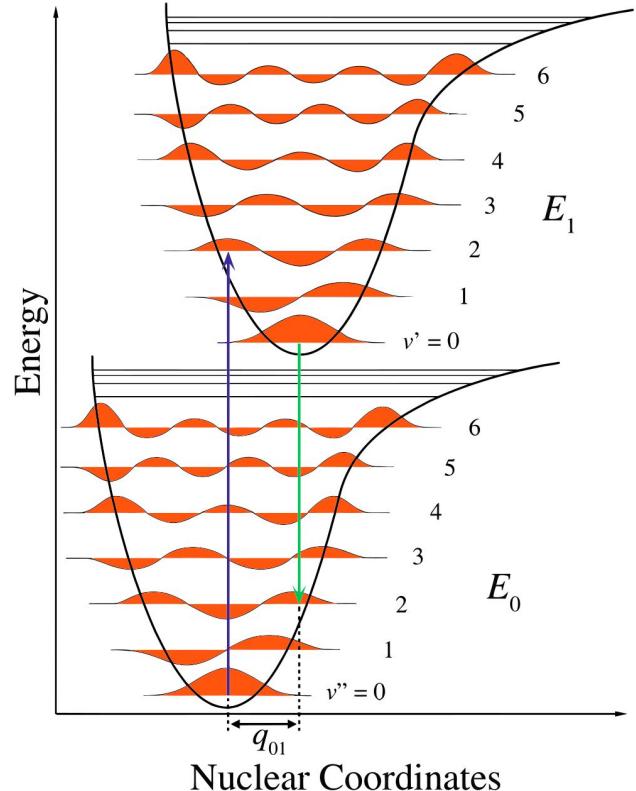
Wrapped BC408 Tile
- Posttrigger

Read Out Board

Computer
with Labview

PEN as a Scintillator

- Franck Condon Principle



Radio Purity

Isotope	PEN TN-8065S	PEN TN-8050SC
Ra-226	0.25 0.05 mBq/kg	< 0.11 mBq/kg
Th-228	0.23 ± 0.05 mBq/kg	< 0.13 mBq/kg
K-40	1.6 ± 0.4 Bq/kg	1.0 ± 0.4 Bq/kg
U-235	< 0.057 mBq/kg	< 0.066 mBq/kg



Moulding Parameter Investigation

1. Injection Speed
2. Cooling with and w.o. water
3. Granulate humidity
4. Tool temperature

