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

Thomas Kraetzschmar

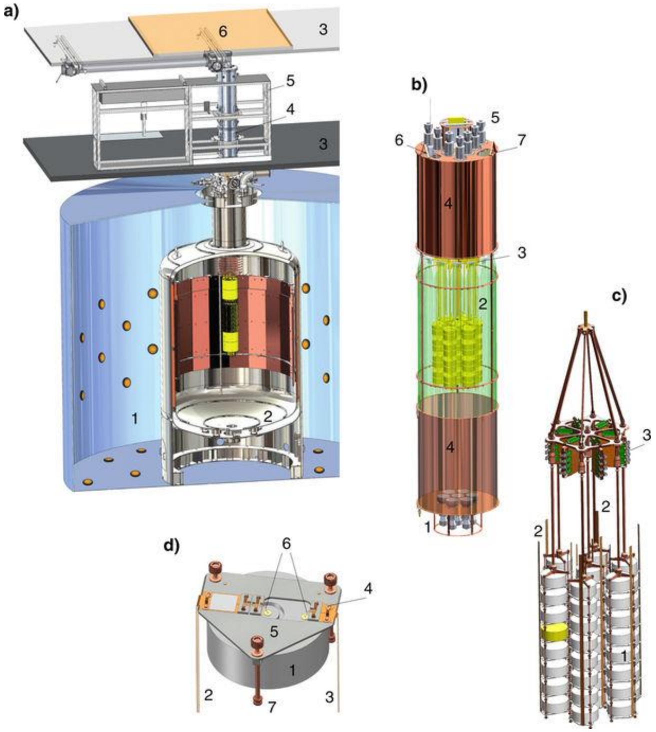
(S. Eck, F. Fischer, C. Gooch, C. Hayward, D. Heuchel, B. Majorovits, E. Sala, F. Simon, O. Schultz, H. Windel)

MPI für Physik, München

Context

- Low background experiments
  - Search for dark matter
  - Neutrinoless double beta decay
- Large Enriched Germanium Experiment for Neutrinoless ββ-Decay (LEGEND)
  - Successor to GERDA and Majorana Experiments

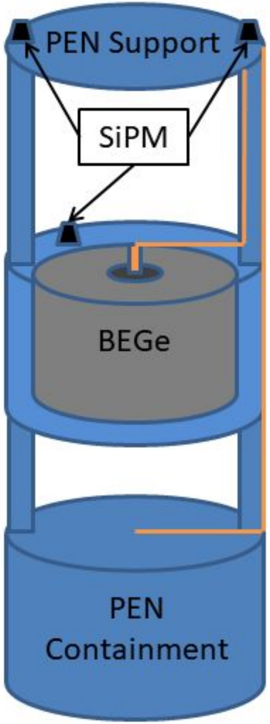
$$\tau_{0\nu\beta\beta} \propto \sqrt{\frac{MT}{b\Delta E}}$$



Thomas Kraetzschmar: kraetzsc@mpp.mpg.de

Motivation: a New Structural Material

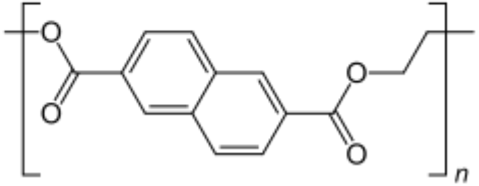
- Idea:
    - Use an ultrapure transparent active structural material in low background experiments
    - But ultrapure standard plastic scintillators are expensive and potentially not radio pure



Thomas Kraetzschmar: kraetzsc@mpp.mpg.de

Polyethylene Naphthalate (PEN)

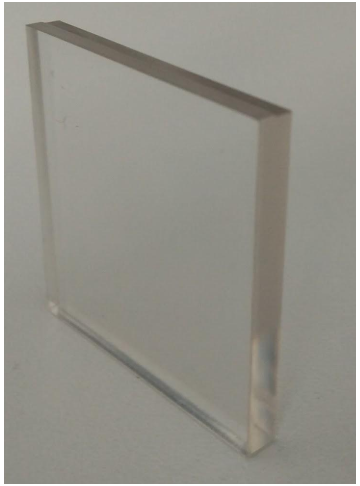
- What is PEN?
  - $C_{14}H_{10}O_4$
  - Used for everyday products
- Why is it interesting for us?
  - It scintillates
  - It is radiopure
  - It can be moulded into arbitrary shapes
  - It has high mechanical stability



Thomas Kraetzschmar: kraetzsc@mpp.mpg.de

PEN as a Scintillator

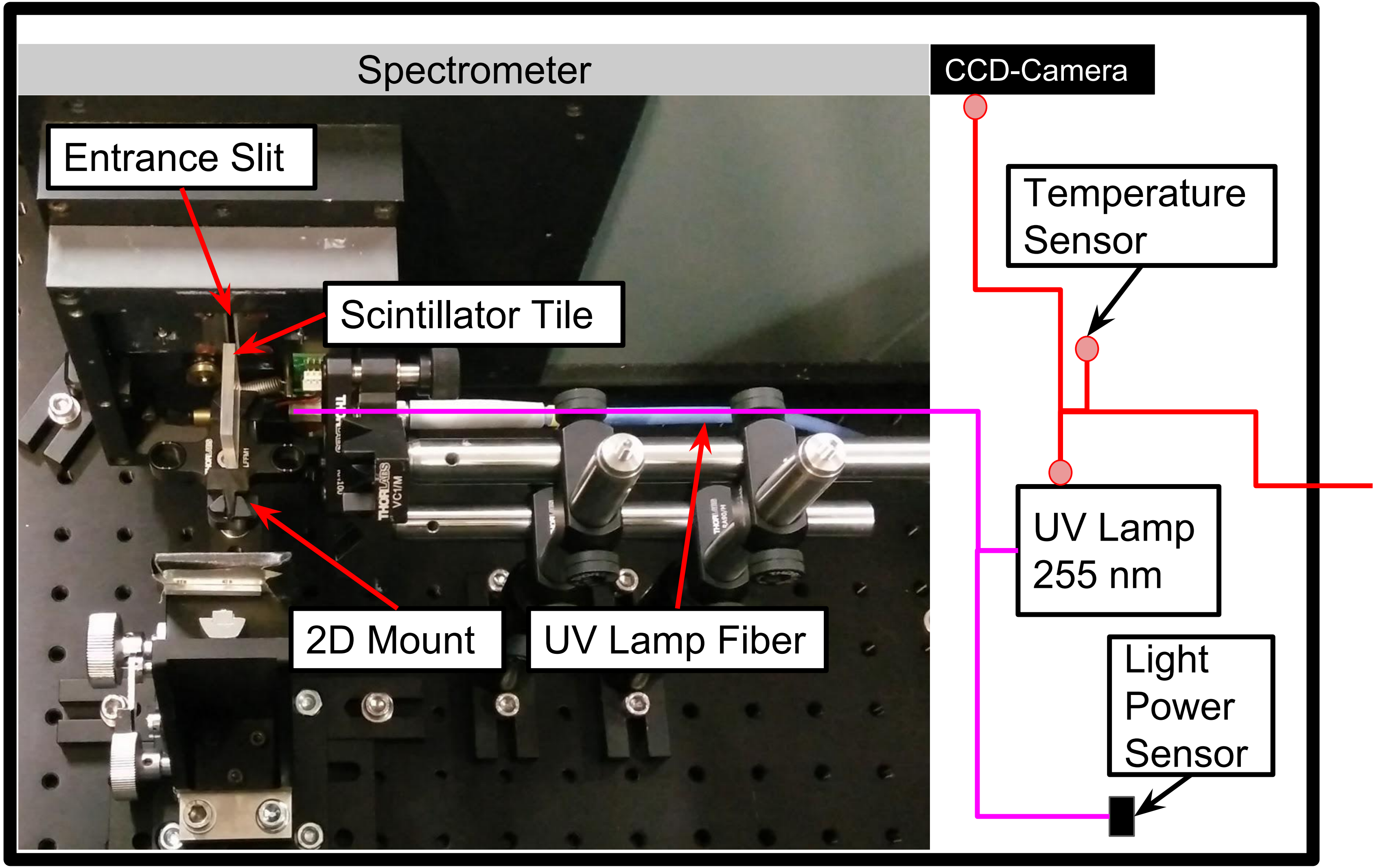
- Investigation of a new scintillator
  - Light spectra of custom-made PEN
  - Light output measurements with a PMT
  - Temperature dependence of the light output



PEN without radiation

PEN with UV light

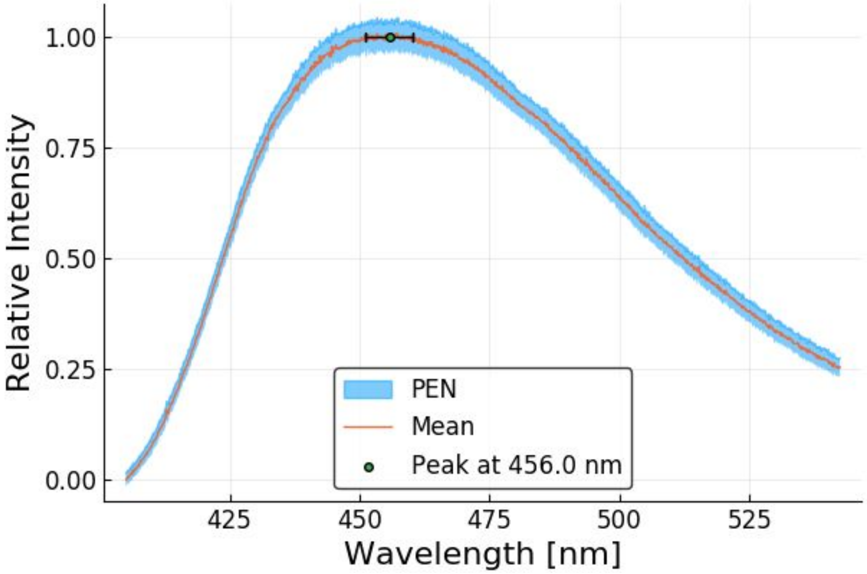
Thomas Kraetzschmar: kraetzsc@mpp.mpg.de


Spectrometer
CCD-Camera
Entrance Slit
Temperature Sensor
Scintillator Tile
UV Lamp 255 nm
2D Mount
UV Lamp Fiber
Light Power Sensor

Method for Measuring Light Spectra

- Measure spectra and determine:
  - peak wavelength
  - light output
- Measure 100 spectra
  monitor power of UV light
  - Calculate mean and uncertainty
    for spectra and light power
- Account for background and
  light power variations in spectra-data
- Determine parameters of spectra

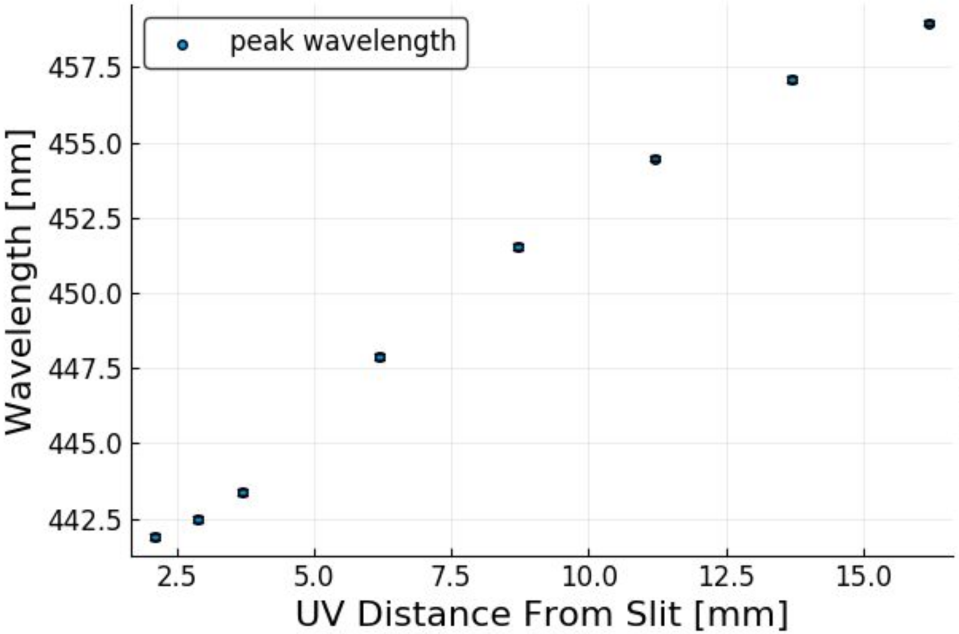
PEN Spectrum



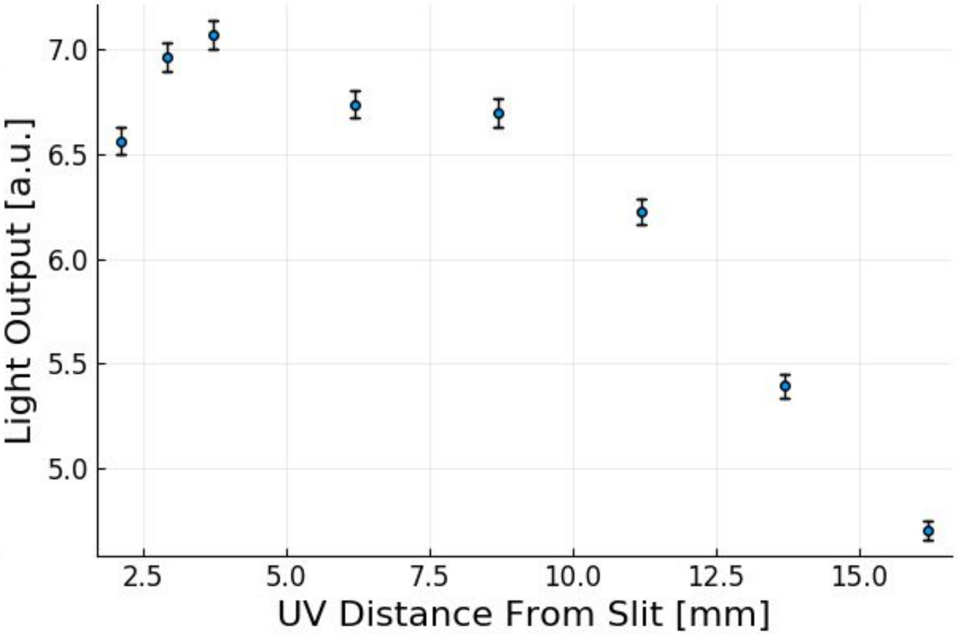
Thomas Kraetzschmar: kraetzsc@mpp.mpg.de

Attenuation Length Study

Effect of Attenuation Length on Peak



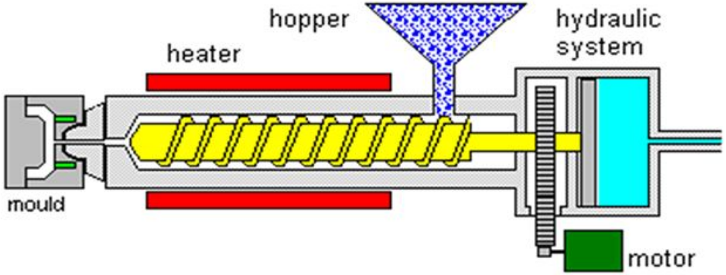
Light Output



Thomas Kraetzschmar: kraetzsc@mpp.mpg.de

Injection Moulding of PEN

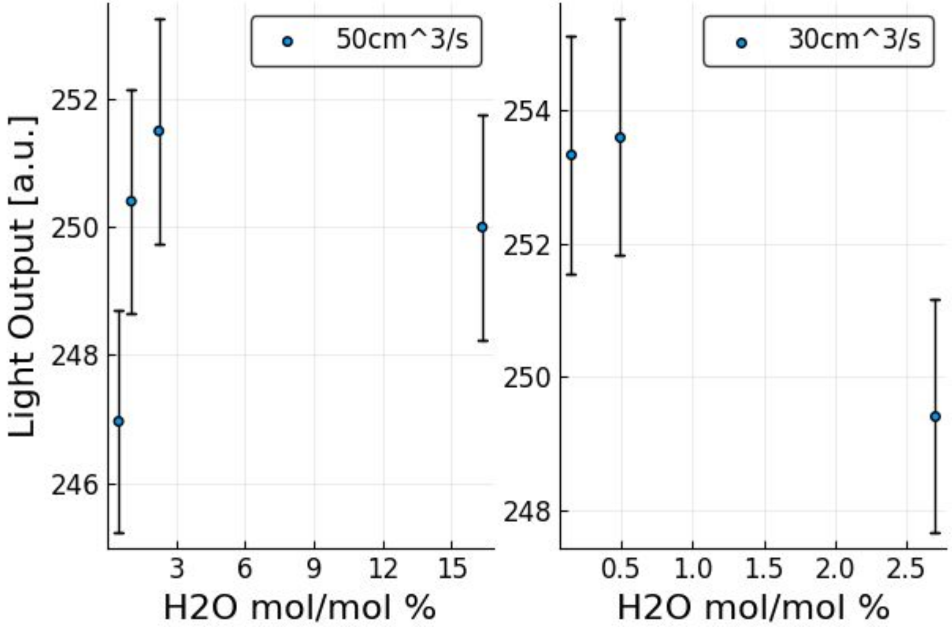
- Light output is dependent on crystallinity
- Crystallinity is determined by injection moulding process
  - 8 parameters to be considered
    - Humidity
    - In tool cooling time
- Important to understand which parameters influence the light output and how



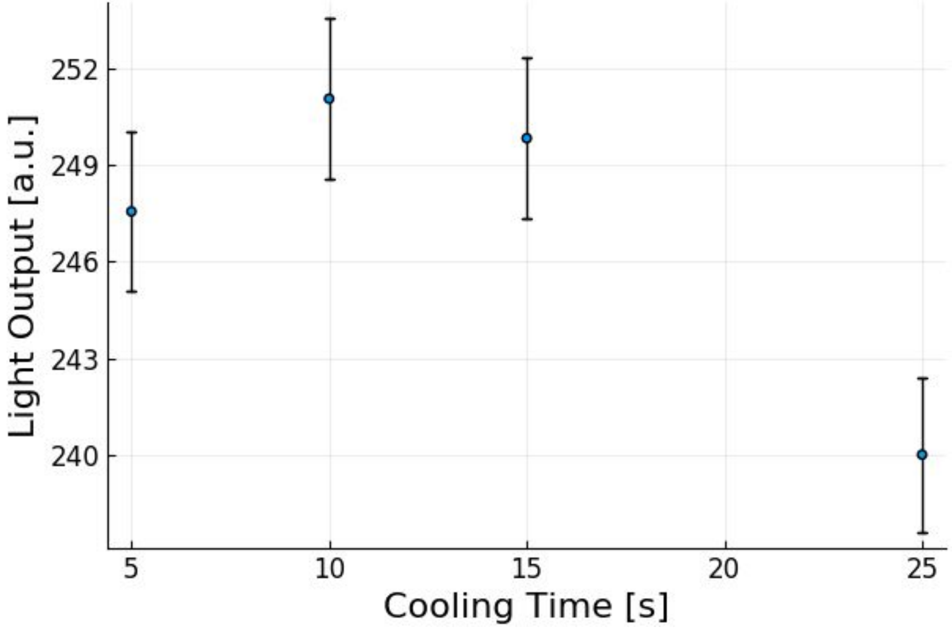
Thomas Kraetzschmar: kraetzsc@mpp.mpg.de

Results of Parameter Investigation

PEN Humidity Study



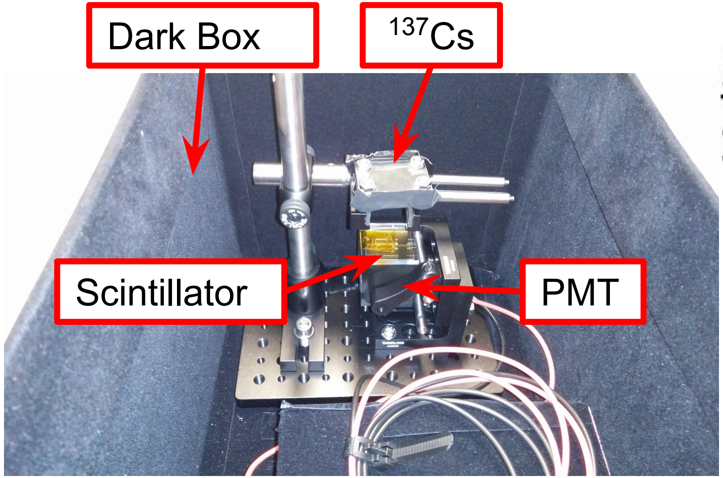
PEN Mould Cooling Time Study

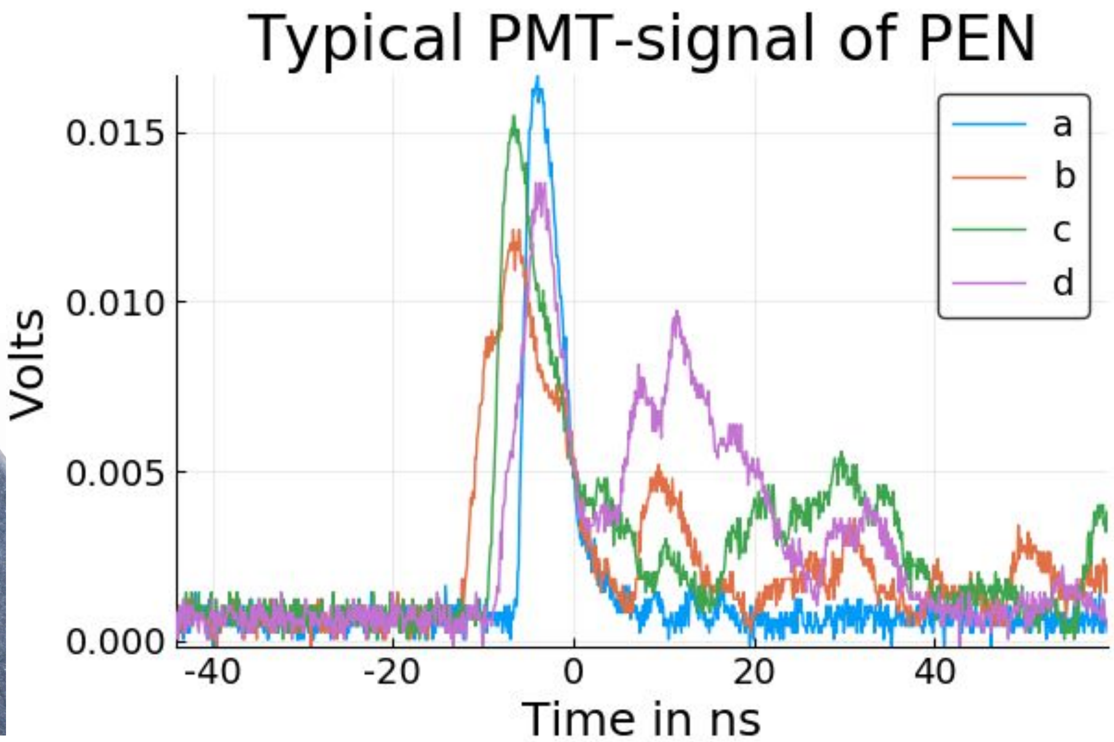


Thomas Kraetzschmar: kraetzsc@mpp.mpg.de

PMT Setup

- Determine light yield with a standard detector and simulations
- Investigate pulse shapes

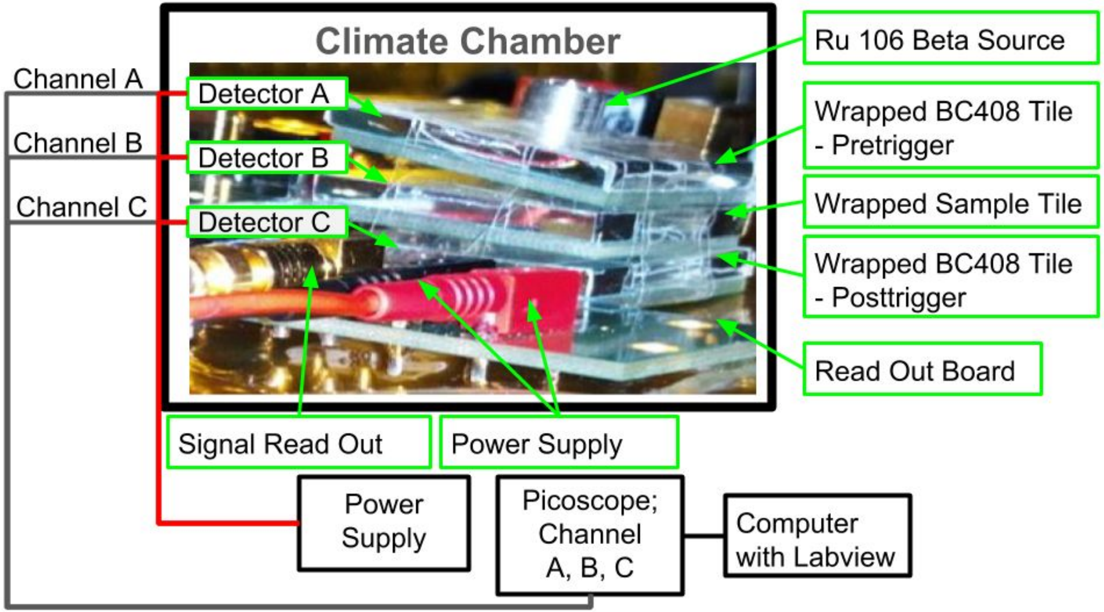




Thomas Kraetzschmar: kraetzsc@mpp.mpg.de

Investigation of Temperature Dependence of Light Output

- Motivated by temperature-dependent fluorescencing 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

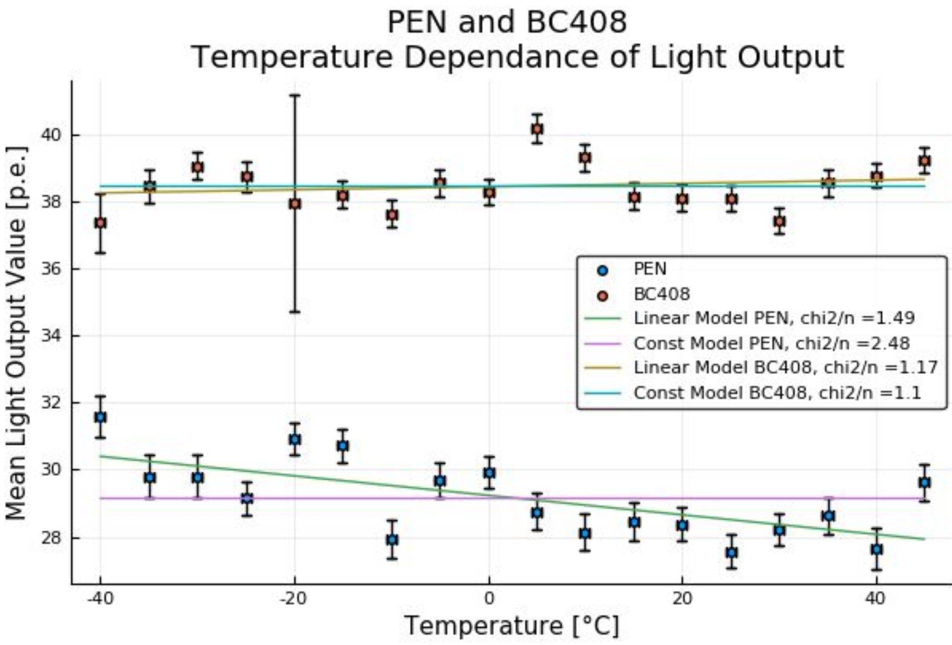


Thomas Kraetzschmar: kraetzs@mpp.mpg.de

Temperature Dependence Results

- Slope of linear model
  - BC408: slope = 0.001±0.001
  - PEN: slope = 0.0294±0.005
- Bayes factor
  - For BC408: ln(K)=0
  - For PEN : ln(K)=16.5
- 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



Thomas Kraetzschmar: kraetzsc@mpp.mpg.de

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!

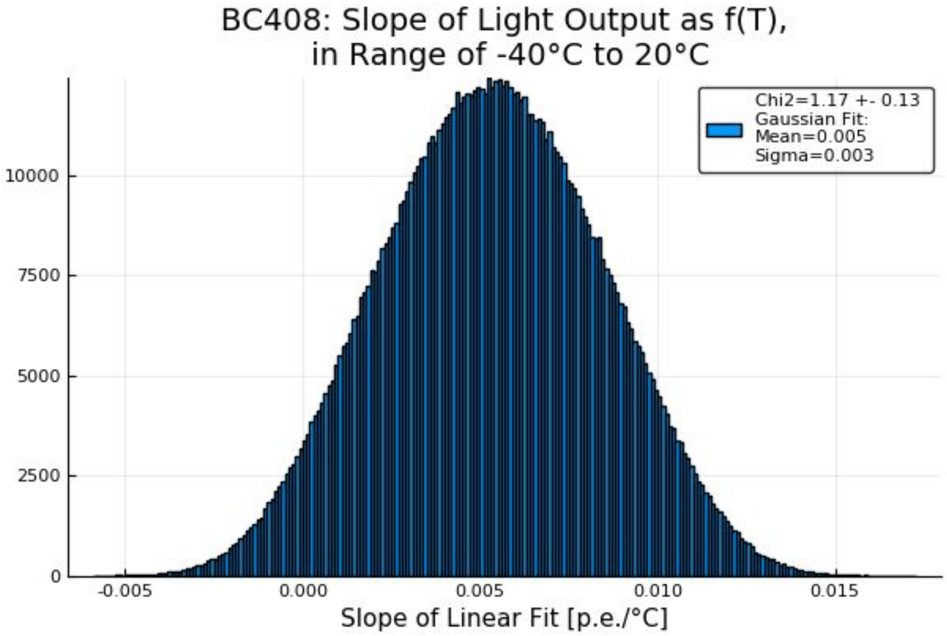
Thomas Kraetzschmar: kraetzsc@mpp.mpg.de

Results of Toy Monte Carlo Analysis

- Toy Monte Carlo:
  - Draw new data points r_i using P(T, L.O. | 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: K=0



Results of Toy Monte Carlo Analysis

- Slope deviates ~19.6 σ from 0
- Bayes factor: K=16.5

- Slope deviates ~16.9 σ from 0
- Bayes factor: K=11.8