Photon Yield and Time Response of a Wavelength Shifter Coated Polystyrene Strip

A. Brignoli, C. Eckardt, H. Lacker, **C. Mullesch**, C. Scharf, B. Skodda

Institut für Physik
Humboldt-Universität zu Berlin

3rd High-D consortium meeting, 9th - 10th February 2023

Bundesministerium für Bildung und Forschung

HIGH-D

Goal and Previous Work

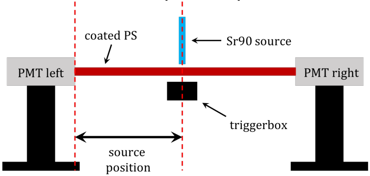
- Goal: Determine photon yield and time response of a low-cost and easy to build plastic scintillator
- Previous work: Wavelength shifter (WLS) coated polystyrene (PS) is suitable[1] (presented at the last High-D consortium meeting[2])
  - Findings from analyzing a 50 x 50 x 5 mm^3 piece of coated PS: Light output vs. cost motivates further studies
- In this work, we want to examine a larger PS strip with dimensions of order 400 x 50 x 5 mm^3 and analyze its photon yield and time response

[1] arxiv.org/abs/2210.10083
[2] indico.desy.de/event/35259/contributions/127483/attachments/76579/98837/HighD_Doramas_Jimeno.pdf

Setup - Concept

- Components:
  - Two calibrated[3] Hamamatsu R1924A photomultiplier tubes (PMTs) operating at 1 kV
  - ^{90}Sr β^- source
  - Triggerbox[3]
  - 398 x 50 x 5 mm^3 coated PS slide wrapped in Dupont™ Tyvek® 1073D
  - Silicone paste[4] for optical coupling between PS and PMT
- Whole setup located in a darkbox

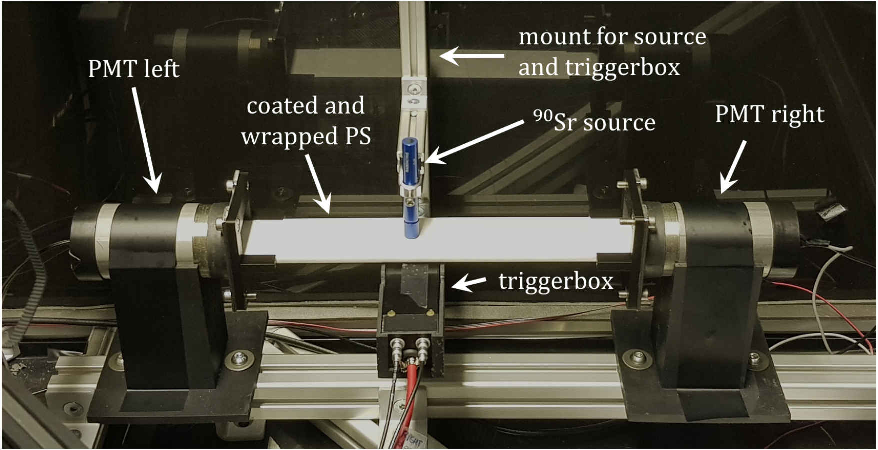
Setup concept



[3] The calibration procedure and the triggerbox are the same as used in the previous work

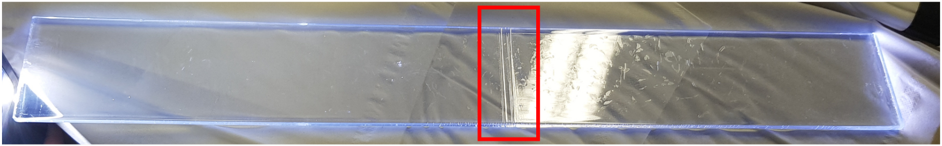
[4] KORASILONE® medium viscosity

Setup - Implementation



Setup - Coated PS

- Some trouble with dipcoating (non-uniform middle region, damaged paint due to machining after coating)
- Expect impact on overall performance, expecially in middle region



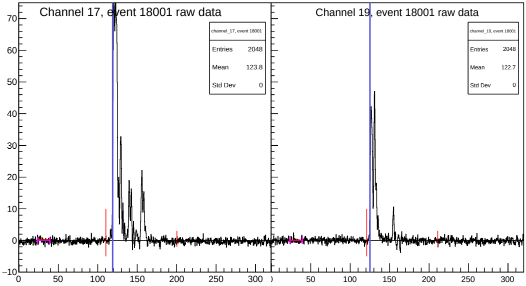
Measurements - Outline

- β^- penetration → Cherenkov & scintillation in PS → voltage signal in PMTs
- Readout: WaveCatcher digitizer[5] and WaveCatcher Data Analysis Software ReadRun[6] based on ROOT Cern C++ framework[7]
- From PMT signal, extract as a function of source position:
  - Photon yield expressed in number of photoelectrons (#PE) from distribution of area under the signal (time integrated spectrum)
  - Timing information using constant fraction discrimination (CFD)[8]

[5] WaveCatcher Family User's Manual
[6] ReadRun GitHub
[7] ROOT Data Analysis Framework
[8] Troughout the analysis, a constant fraction value of 0.15 was used

Waveforms and Integration Window

- Integration window: [-10 ns, 80 ns] relative to maximum
- Example waveform:[9,10]



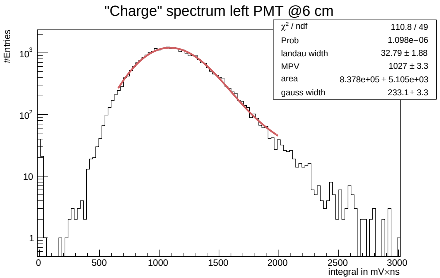
[9] Channel 17 corresponds to the left PMT, channel 19 is the right PMT

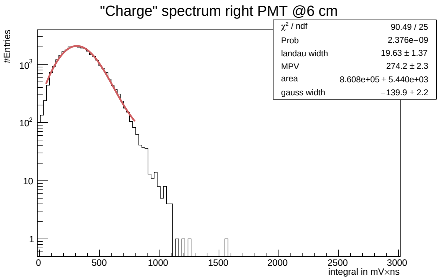
[10] Waveform at a source position of 6 cm

Time Integrated Spectra

- Thin-layer energy loss of charged particles $\rightarrow$ Landau distribution
- Electronic noise in the readout setup $\rightarrow$ Gaussian distribution

  $\Rightarrow$ Landau $*$ Gauß convolution to fit time-integrated spectra
- MPV of fit translated into #PE using calibration value (PMT gain)

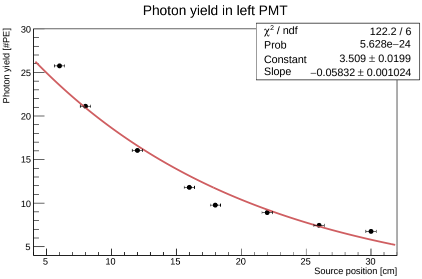




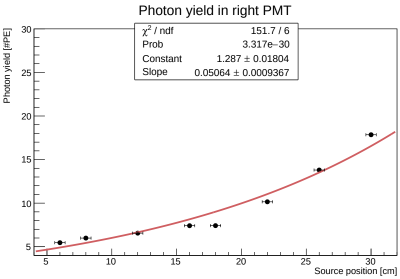
Photon Yields and Effective Attenuation Length

- Expect exponential relation between #PE and distance traveled (Beer-Lambert-Law)

  $\Rightarrow$ Exponential fit $\rightarrow$ effective attenuation length[11] λ_{att}



$\lambda_{\text{att,L}} = (17.2 \pm 0.4)$ cm

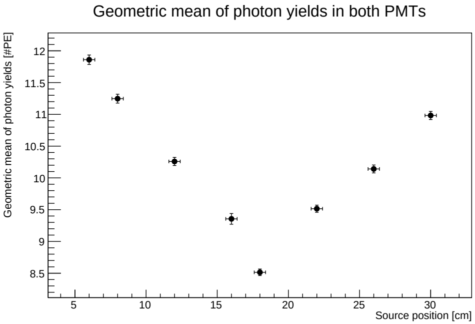


$\lambda_{\text{att,R}} = (19.8 \pm 0.4)$ cm

[11] Transmission measurements in previous work yield $\lambda_{\text{att}} = \mathcal{O}(30\text{ cm})$

Uniformity of Photon Yield

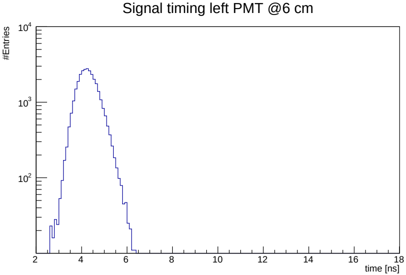
- Exponential relation between #PE and distance traveled
  → expect geometric mean of photon yields of both PMTs to be constant for every source position[12]

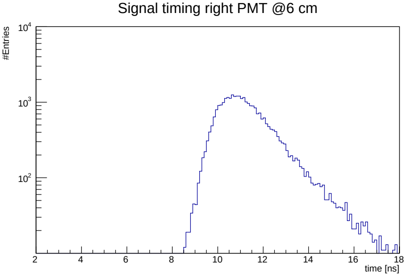


[12] The non-uniformity observed is likely due to the overall quality of the coated PS strip

Time Response - Signal Arrival Time

- Distribution of signal timing $t_i := t_{\mathrm{CFD},i} - \frac{1}{2}(t_{\mathrm{lower\ Trigger}} + t_{\mathrm{upper\ Trigger}})$ where $i \in \{\mathrm{L,R}\}$ and $t_{\mathrm{CFD},i}$ is the timing acquired from the waveform of the PMT signal
- For long travel distances, this distribution shows exponential decay-like tail





Time Response - Signal Arrival Time

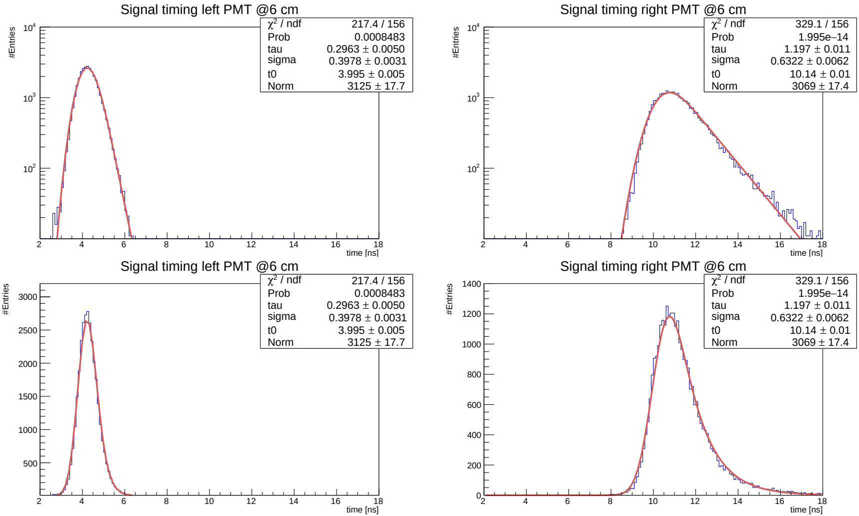
- From literature:[13] Shape is affected by both light collection process and self-absorption & re-emission in the WLS layer
- Good fit results achieved by using a Gauß $*$ Exp convolution $f * g$ where

$$f(x) \propto \exp\left(-\frac{(x-t_0)^2}{2\sigma^2}\right), \qquad g(x) \propto \exp\left(-\frac{x}{\tau}\right)$$

- Interpreting t_0 as the signal arrival time allows to extract effective signal speed in the detector

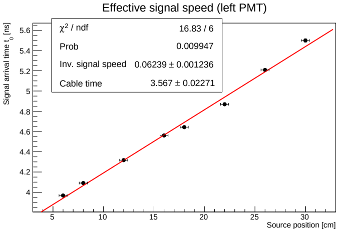
[13] M. Moszyński, B. Bengtson, "Status of timing with plastic scintillation detectors", Nucl. Instr. and Meth. **158**, 1979

Time Response - Signal Arrival Time

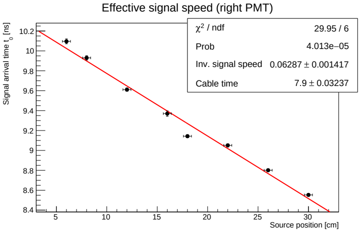


Time Response - Effective Signal Speed

- Linear fit[14] $ax + b$ to signal arrival time t_0 as function of source position $\rightarrow$ effective signal speed
- Effective signal speeds agree for both PMTs, **and** difference in offset parameter agrees with known cable length difference[15] $\rightarrow$ consistency



$$v_{\mathrm{eff,L}} = (16.0 \pm 0.4)\ \frac{\mathrm{cm}}{\mathrm{ns}}$$



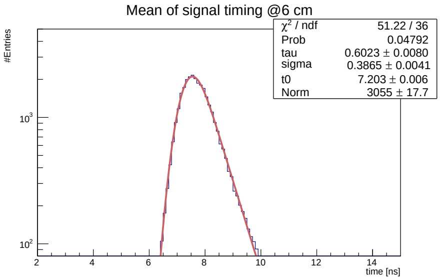
$$v_{\mathrm{eff,R}} = (15.9 \pm 0.4)\ \frac{\mathrm{cm}}{\mathrm{ns}}$$

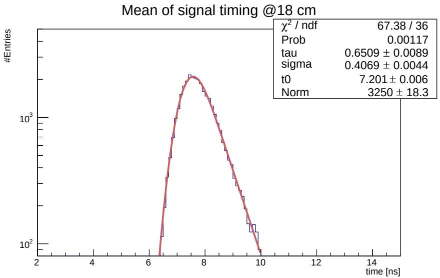
14 We expect the signal arrival time to be proportional to the inverse signal speed, including an offset to account for different cable lengths of the PMTs

15 Assuming $v = \frac{2}{3}c$ in coax-cable for a length difference of 85 cm

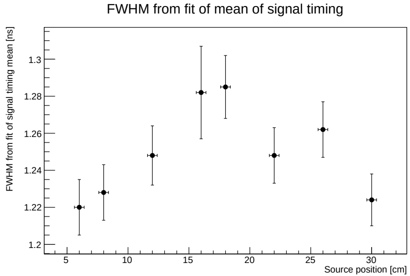
Time Response - Time Resolution

- For each source position, plot distribution of $t_{\text{mean}} := \frac{1}{2}(t_{\text{L}} + t_{\text{R}})$ with $t_{\text{L,R}}$ as defined on slide 10 and use Gauß $*$ Exp fit-function
- Quantify time resolution of the strip as FWHM of the fit





Time Resolution



Preliminary definition of time resolution as arithmetic mean of FWHM values:

$$\Rightarrow \text{FWHM}_{\text{Strip}} = (1.250 \pm 0.006)\ \text{ns}$$

If one naively assumes a Gaussian distibution[16] where $\sigma \approx \text{FWHM}/2.355$:

$$\Rightarrow \sigma_{\text{Strip}} = (0.535 \pm 0.003)\ \text{ns}$$

[16] To be taken with caution, distributions are cleary non-Gaussian

Conclusions and Outlook

- Uniformity of light yield heavily influenced by quality of coated PS strip
- Despite showing quite some defects from production, we were able to give an estimate of its time resolution
- Consistency checks for effective signal speed show that the choice of fit-function and interpretation of t_0 as signal arrival time are resonable
- Improvements to come:
  - Better coating procedure to remove necessity of machining after coating $\rightarrow$ higher photon yield
  - More careful analysis of t_{mean} distribution to improve on time resolution
  - Take more source positions to improve on statistics

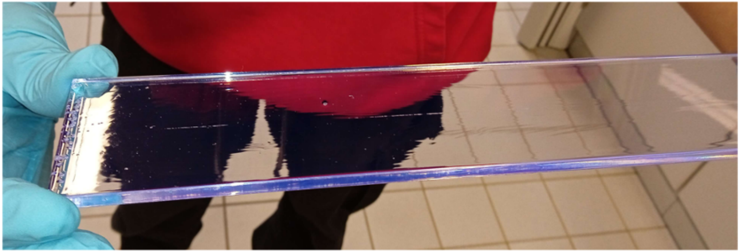
Thank you for your attention!

Bundesministerium
für Bildung
und Forschung

HUMBOLDT-UNIVERSITÄT ZU BERLIN

HIGH-D

Backup - New Strip



Backup - Triggerbox Smearing

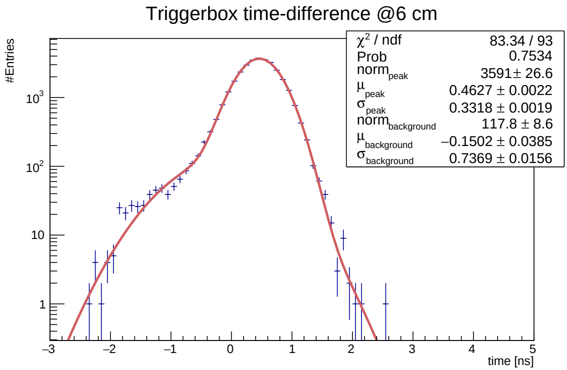
- Finite time resolution of triggerbox results in smearing of signal times
- From distribution of $\Delta t_{\text{Trigger}} := t_{\text{lower Trigger}} - t_{\text{upper Trigger}}$, extract standard deviation $\sigma(\Delta t_{\text{Trigger}})$ from a Gaussian fit
- Assume both trigger scintillators have same resolution

$$\Rightarrow \sigma_{\text{lower Trigger}} = \sigma_{\text{upper Trigger}} = \frac{\sigma(\Delta t_{\text{Trigger}})}{\sqrt{2}} =: \sigma_{\text{Trigger}}$$

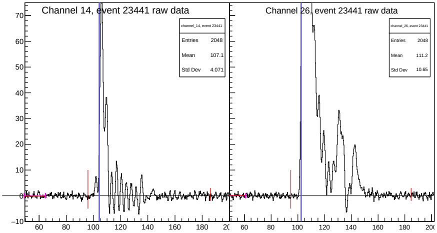
- We find $\sigma(\Delta t_{\text{Trigger}}) = \mathcal{O}(0.3 \text{ ns})$
- Since we have FWHM of order 1.2 ns, correcting for smearing only results in about 10% correction and is neglected in this presentation

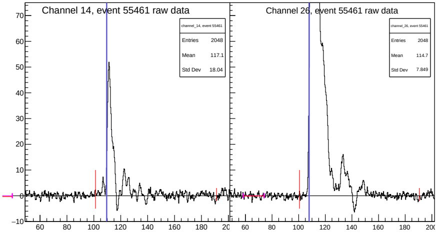
Backup - Triggerbox Smearing

- Fit-function used: Sum of two independant Gaussians to account for unfiltered background events without having to maually adjust fit-range



Backup - Unfiltered Background





Backup - Source Position

Time Resolution