



PhD Thesis

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Abstract

Zusammenfassung

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Chapter 1

Detector Design and Construction

Two different scintillation-based detector-concepts were developed to measure the depth dose distribution of protons in real-time. Both detectors consist of scintillator-layers measuring the energy deposition.

The first detector concept uses PbWO_4 sheets with two thicknesses 2 mm and 3 mm. Here the thicker 3 mm are used in the front to provide more stopping power and the thinner 2 mm are used in the Bragg-Peak region to give the optimal spatial resolution whilst still only utilizing 32 channels. The thicknesses were chosen to fully cover the 66 mm range of 220 MeV protons in PbWO_4 , yet still being thick enough not to break as PbWO_4 is a very fragile material.

The second detector concept uses EJ-212 plastic scintillators with a thickness of 4 mm allowing for a better spatial resolution. However, since the 32 available channels with 4 mm EJ-212 only cover ≈ 12.8 cm of the 30.4 cm proton range, a passive absorber has to be included to fully stop the protons inside the detector. This 20 cm passive absorber consists of PMMA resulting in enough stopping power to stop the beam inside the detector. The passive absorber is placed between the first and second plastic scintillator such that the first works as a trigger channel which is used for the normalization in the analysis.

1.1 Readout

The scintillators of both designs are read out via SiPMs. Light yield measurements were conducted, to decide which SiPM types are suitable. With these the amount of incident photons can be estimated and compared with the number of pixel. From this, a balance can be struck between high resolution and a large enough dynamic range.

1.1.1 Light Yield Measurement

The measurements were conducted using the process described in Section ?? and the setup shown in Figure ?. The PMT used is an R2059 from Hamamatsu (serial number BA3200) with a quantum efficiency of 23.16 % [1] (cf. Appendix ??) at the luminescence peak of 420 nm of PbWO_4 [2] and EJ212.

1.1.1.1 Light Yield: PbWO_4

The PbWO_4 measurement were done in a flat and vertical position as shown in Figure ?, where all non PMT-facing scintillator sides were enveloped in highly reflective PTFE foil in order to not lose any photons. Two additional measurements were performed, where one 3 mm- and 2 mm crystal were fully wrapped with an SiPM sized window cutout in the center of one side as shown in Figure ?. The PbWO_4 crystals were mounted onto the PMT's optical window next to a ^{22}Na γ -source inside a climate chamber. The optical coupling was done using glycerol ($n = 1.4722$), as shown in Figure 1.1. Glycerin was used as a substitute for the commonly used Baysilone[®] Fluid M optical grease ($n \approx 1.404$, $\eta = 300000 \text{ mm}^2/\text{s}$ [3]), due to its less-adhesive characteristic. The Baysilone[®] Fluid M with its high adhesion might have lead to damaging the fragile crystals during removal. The refractive index of PbWO_4 and the SiO_2 glass window of the PhotoMultiplier Tube (PMT) are $n_{\text{PbWO}_4} \approx 2.3$ [2] and $n_{\text{SiO}_2} \approx 1.459$ [4], respectively. Additionally to the climate chamber's light-tightness, the setup is enclosed in PTFE foil, ensuring perfect light tightness, as shown in Figure ?.

The measurements were conducted at 20 °C for 5 min after an acclimation time of 5 min each. The acclimation time was chosen small because the crystals were kept inside the

Figure 1.1: Open light yield measurement setup for PbWO_4 crystals using a ^{22}Na γ -source.

Figure 1.2: Encased light yield measurement setup for PbWO_4 crystals using a ^{22}Na γ -source.

climate chamber for 24 h before the measurements were started, thereby only the short time frame inbetween measurements, where the chamber was opened, had to be accounted for. An exemplary light yield measurement of crystal number 0 in the flat position is shown in Figure ???. The measured light yield values of all crystals for the different setups are shown in Figure ??. The 3 mm thick crystals average approximately 164.73 ph/MeV and 129.44 ph/MeV in the flat and vertical positions, respectively. The 2 mm thick crystals average approximately 131.00 ph/MeV and 94.32 ph/MeV in the flat and vertical positions, respectively. With the SiPM-sized window cutout the light yield of a 3 mm and 2 mm crystal was (75.25 ± 33.09) ph/MeV and (59.70 ± 19.22) ph/MeV, respectively.

1.1.1.2 Light Yield: EJ-200

The light yield of a $50 \times 50 \times 10 \text{ mm}^3$ EJ-200 sample was measured to estimate the amount of incident photons on an SiPM by a plastic scintillator to decide which SiPM type is needed for the readout.

Bibliography

- [1] Hamamatsu Photonics. *R1828-01, R2059 Photomultiplier Tubes Datasheet*. Accessed: 2024-10-28. Hamamatsu Photonics K.K. 2019. URL: https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99%5C_SALES%5C_LIBRARY/etd/R1828-01%5C_R2059%5C_TPMH1259E.pdf.
- [2] *The CMS electromagnetic calorimeter project: Technical Design Report*. Technical design report. CMS. Geneva: CERN, 1997. URL: <https://cds.cern.ch/record/349375>.
- [3] Bayer AG. *Baysilone® Fluids Brochure*. Accessed: 2024-10-30. 2020. URL: <https://dcproducts.com.au/wp-content/uploads/2020/12/BayerBaysiloneFluidsBrochure.pdf>.
- [4] I. H. Malitson. “Interspecimen Comparison of the Refractive Index of Fused Silica”. In: *J. Opt. Soc. Am.* 55 (Oct. 1965). DOI: 10.1364/JOSA.55.001205.

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Selbstständigkeitserklärung

Hiermit versichere ich, die vorgelegte Thesis selbstständig und ohne unerlaubte fremde Hilfe und nur mit den Hilfen angefertigt zu haben, die ich in der Thesis angegeben habe. Alle Textstellen, die wörtlich oder sinngemäß aus veröffentlichten Schriften entnommen sind, und alle Angaben die auf mündlichen Auskünften beruhen, sind als solche kenntlich gemacht. Bei den von mir durchgeführten und in der Thesis erwähnten Untersuchungen habe ich die Grundsätze guter wissenschaftlicher Praxis, wie sie in der ‚Satzung der Justus-Liebig-Universität zur Sicherung guter wissenschaftlicher Praxis‘ niedergelegt sind, eingehalten. Entsprechend § 22 Abs. 2 der Allgemeinen Bestimmungen für modularisierte Studiengänge dulde ich eine Überprüfung der Thesis mittels Anti-Plagiatssoftware.

Datum

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