From a single to a multi-channel array Prompt Gamma detection system based on PETsys Electronics

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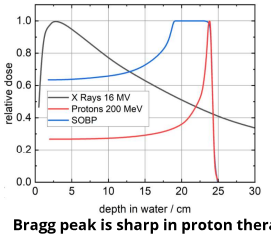
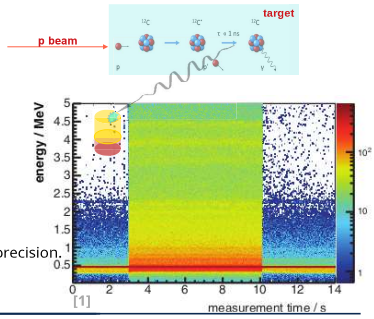
Abstract

Prompt Gammas (PG) in proton therapy are one of the developing techniques for non-invasive measurement of the in-vino proton range. For the prompt gamma timing (PGT) application, we have successfully characterized a single channel system of a $CeBr_3$ crystal read out by a SiPM based on PETsys Electronics. Both time and spectral characteristics achieved the required resolution. Measurements at the OncoRay TU Dresden facility with protons of energies between 100 MeV and 162 MeV protons suffered from very low statistics for a single channel. We investigated several multi-channel arrays that were read out by Hamamatsu SiPMs with 3x3 mm² dimensions and 50 μm microcells, as well as by SensL SiPMs with 6x6 mm² dimensions and 35 μm microcells, and Hamamatsu SiPMs with 6x6 mm² dimensions and 25 and 50μm microcells. We present our investigation of system characteristics, including crosstalk and homogeneity, as well as energy and time spectra using multi-channel $CeBr_3$ crystal array.

Motivation



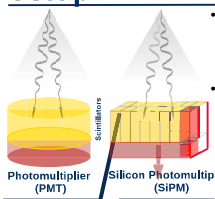


[1]

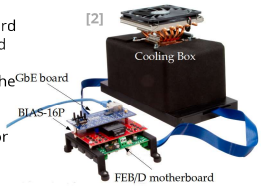
Bragg peak is sharp in proton therapy

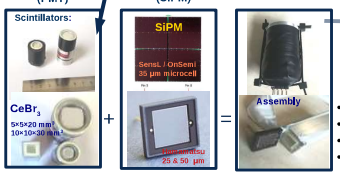
→ Range must be controlled within 2-3mm precision.
For PG, energy-time spectra are collected.
The energy is used for selection of PGs.

Setup

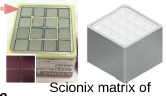


- High volume scintillators suffer from high load, but allow to record more events with fully absorbed PGs.
- Segmented scintillators reduce the load, but full energy cannot be absorbed any more. Single and double escape peaks are used for the analysis.





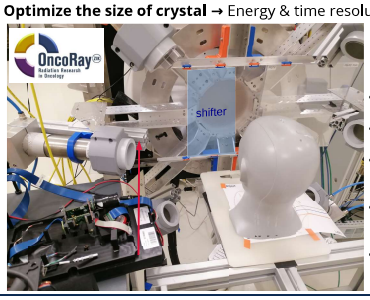
- **Cost effective, fast, scalable**
- from PET to PG energies of 3-8 MeV
- Energy Resolution 8-9% at 3.4 MeV
- Time resolution below 100 ps

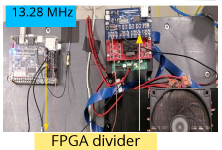


Scionix matrix of 4x4 5x5x20 mm³ $CeBr_3$ scintillators coupled with SensL 2x2 array

Methods

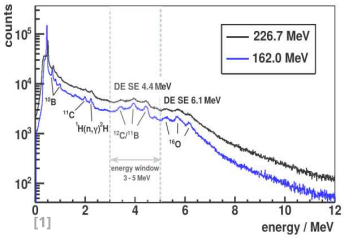
High statistics with full acceptance - Extreme load tolerance 10^6 ... 10^8 p⁺ /pencil beam spot (PBS), (~ 2 x 10^9 PG/s)
Reduce size of one channel → Reduce number of events
Optimize the size of crystal → Energy & time resolution, high rates





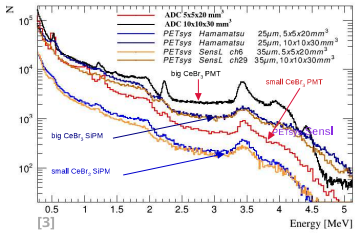
- Initial haracterisation with 4.4 MeV line of AmBe source.
- Tested at ELBE for time resolution and at OncoRay for energy spectra.
- For energy-time spectra – first tests at OncoRay were succsessfully performed in 2023.
- To synchronize with beam clock, FPGA (LVDS/PLL) clock divider is used for the PETsys triggering (divided up to 103.75 kHz)
- Jitter measured in the lab (93 ps - 103 ps) and at OncoRay (80 ps - 130 ps).

Energy spectra



[1]

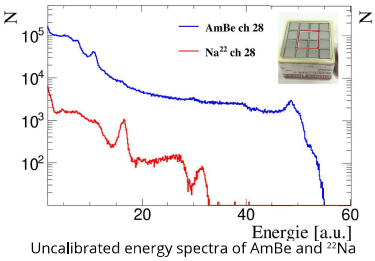
The calibrated PG energy spectra of a reference measurement for 226.7 MeV (black) and 162.0 MeV (blue) proton beam energies. Clearly visible is the response to the PG rays arising from the ground state transition in ^{16}O, ^{11}B and ^{12}C. The peaks are accompanied by single (SE) and double escape peaks (DE).



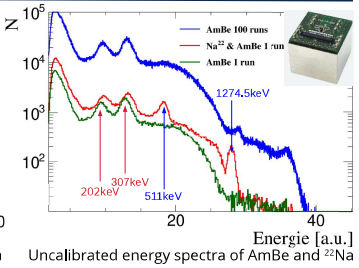
[3]

Calibrated energy spectra of two different $CeBr_3$ crystal sizes acquired with different SiPMs and the PETsys setup and with a conventional photomultiplier, and a CAEN ADC v1730B digitizer.

Results



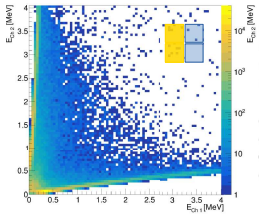
Uncalibrated energy spectra of AmBe and ^{22}Na sources measured with 5x5x20 mm³ $CeBr_3$ array and a SensL 2x2 channel matrix (ARRAYJ-60035-4P-PCB)



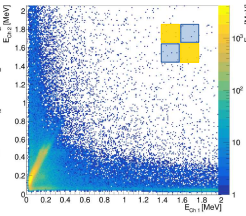
Uncalibrated energy spectra of AmBe and ^{22}Na sources measured with 3.2x3.2.20 mm³ LFS crystal array, read out by Hamamatsu S13900-3220LR-08 (8x8 channels).

Absence of additional peaks in the AmBe/^{22}Na spectra shows that crosstalk between channels is small

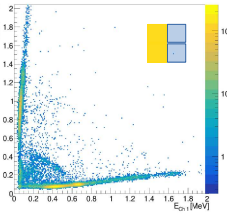
Cross-talk



Correlation plot for calibrated energies (AmBe) for two direct neighbor $CeBr_3$ channels.
Crosstalk 5% to 12%



Correlation plot for calibrated energies (AmBe) for two diagonal $CeBr_3$ channels.
Crosstalk < 2%



Correlation plot for calibrated energies (^{22}Na) for two direct neighbor $CeBr_3$ channels.
Crosstalk 7% to 13%.

Discussion

The proposed setup of a single channel $CeBr_3$ coupled to SiPMs and read out by PETsys appeared to be sufficient for further PGT measurements. We investigated the available multichannel systems for crosstalk effects. Tests with a $CeBr_3$ matrix and a SensL array (ARRAYJ-60035-4P-PCB) showed crosstalk for neighboring channels of 5% to 13%. Energy spectra are thus not influenced much by cross-talk over the energy selection region. This will allow a calibration of all available channels.
A second test was performed with a commercial PET crystal array, constructed out of 3x3 mm² LFS scintillators and read out by a multi-channel array of Hamamatsu SiPMs with 50 μm microcells. Here, the size of scintillating crystals did not allow to resolve 3.4 MeV peak.
This work showed that $CeBr_3$ matrices are good candidates for further PG measurements at OncoRay.

References:

1 T. Werner, "Processing of prompt gamma-ray timing data for proton range measurements at a clinical beam delivery", 2018
2 A. Di Francesco et al., "TOFPET2: a high-performance ASIC for time and amplitude measurements of SiPM signals in time-of-flight applications", JINST 11 C03042, 2016
3 O. Novgorodova, A. Glatte, R. Hentges, T. Kögler, B. Lutz, K. Roemer, T. Teichmann, D. Weinberger and A. Straessner, "Characterisation of a high granularity multi-channel prompt γ-ray detection system prototype for proton range verification based on the PETsys TOFPET2 ASIC", JINST 19 P02030, 2024

We would like to thank the HZDR and OncoRay research groups for their support.

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