OncoRay – National Center for
Radiation Research in Oncology, Dresden

Prompt γ-ray Timing during different modalities of proton beam delivery

18.02.16

T. Kormoll[1], J. Berthold[1], A. Duplicy[3], F. Hueso Gonzalez[2], W. Enghardt[1,2], R. Löschner[3], J. Petzoldt[1], T. Werner[1] and G. Pausch[1]

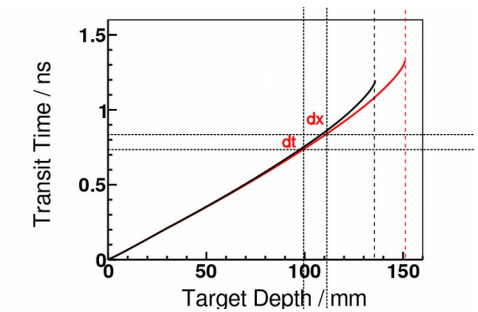
1 OncoRay, Dresden, Germany

2 Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

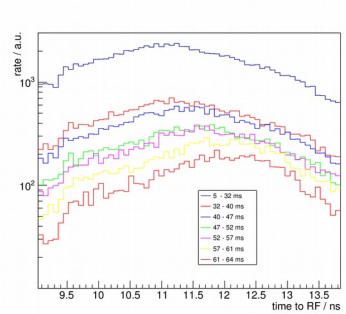
3 IBA Proton Therapy, Louvain-la-Neuve, Belgium

Outline

- Prompt γ-ray timing range verification

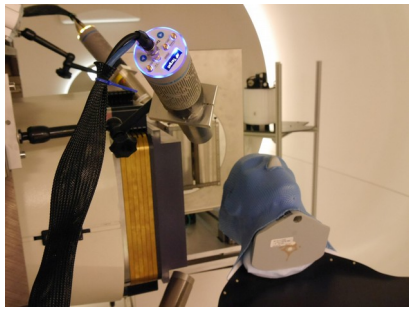


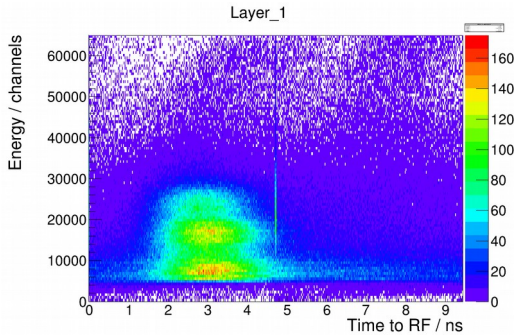
- Experiments in double scattering



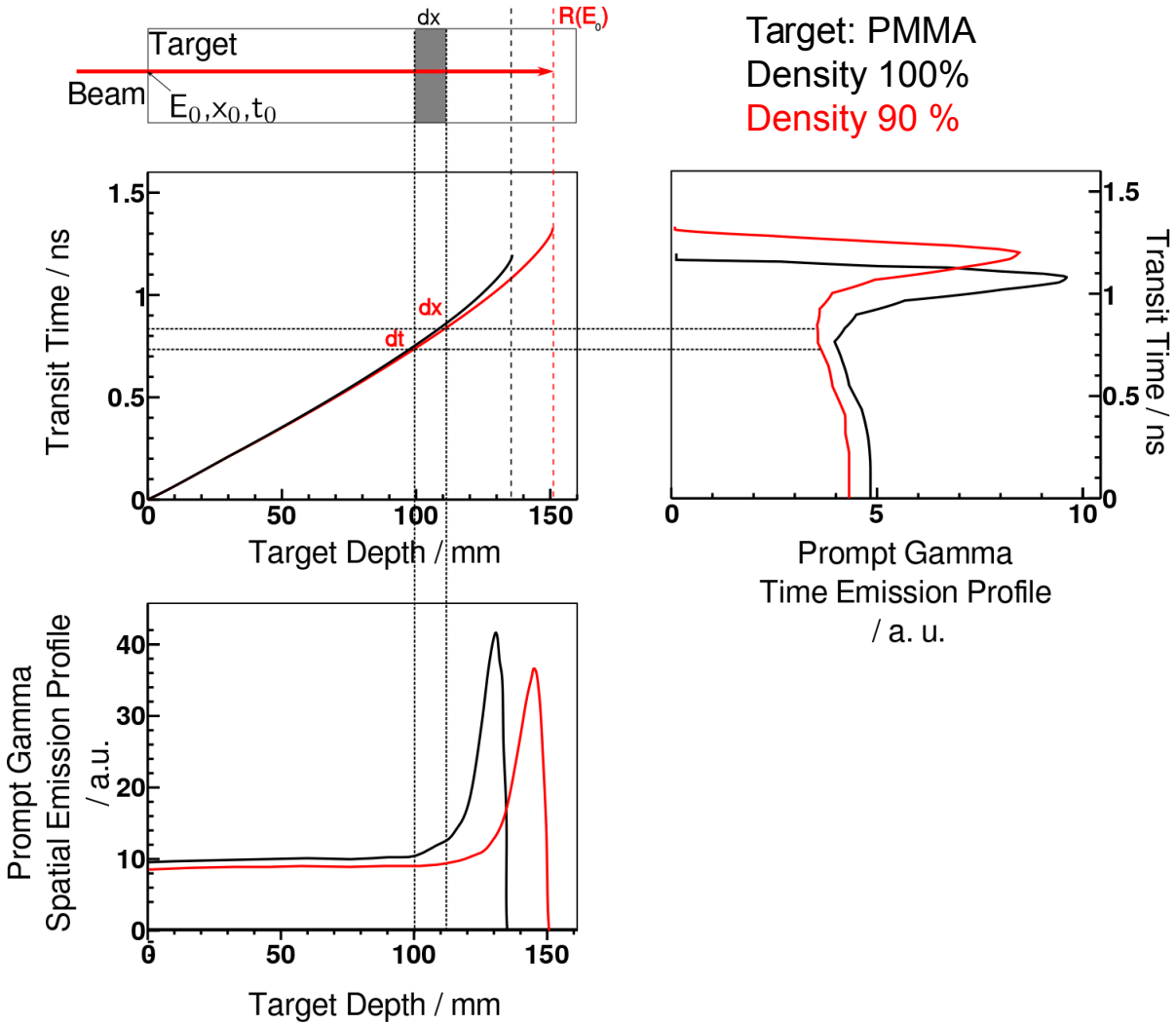
- Experiments in pencil beam scanning

- Summary of the current state and next steps





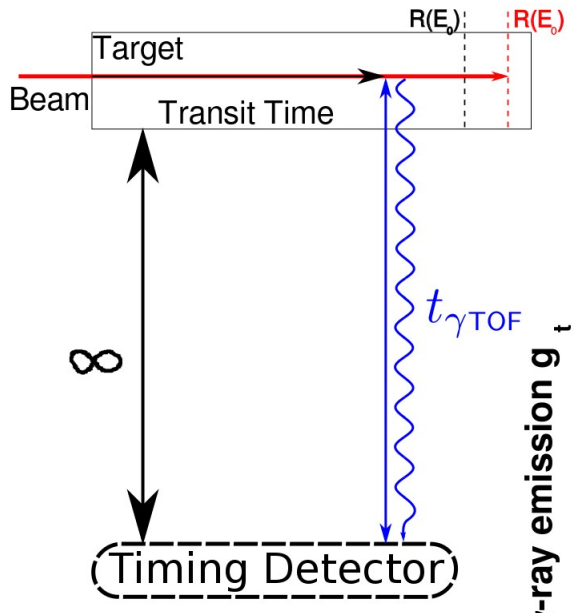
Prompt γ-ray timing (PGT): Idea



Density variation:

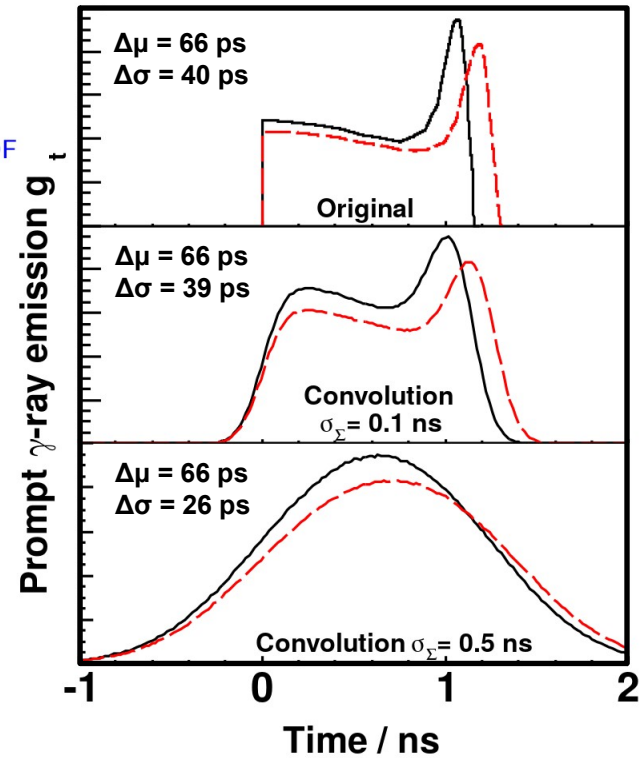
- 100% -> 90 %
- Range is increased
- Spatial and time emission profiles of prompt gamma-rays are streched as well

Prompt gamma timing (PGT)



Prompt gamma-ray TOF effects neglected due to infinite detector distance

Target: PMMA
Density 100%
Density 90 %



Measurement process:

- Uncertainties typically lead to convolution of the measured profile
- Spectral shape lost under convolution
- Spectral momenta (mean, std. deviation) still sensitive to range variation

→ Bunch monitoring
J. Petzoldt et al., PMB 2016

Error of the mean ~ σ/N1/2

Golnik et. al., PMB 59 (2014), 5399-5422

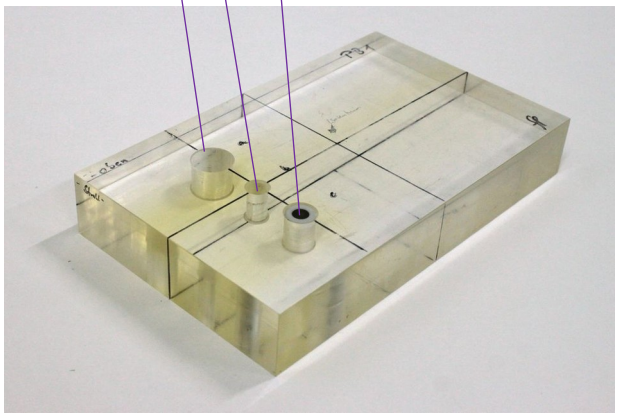
Does that really work?

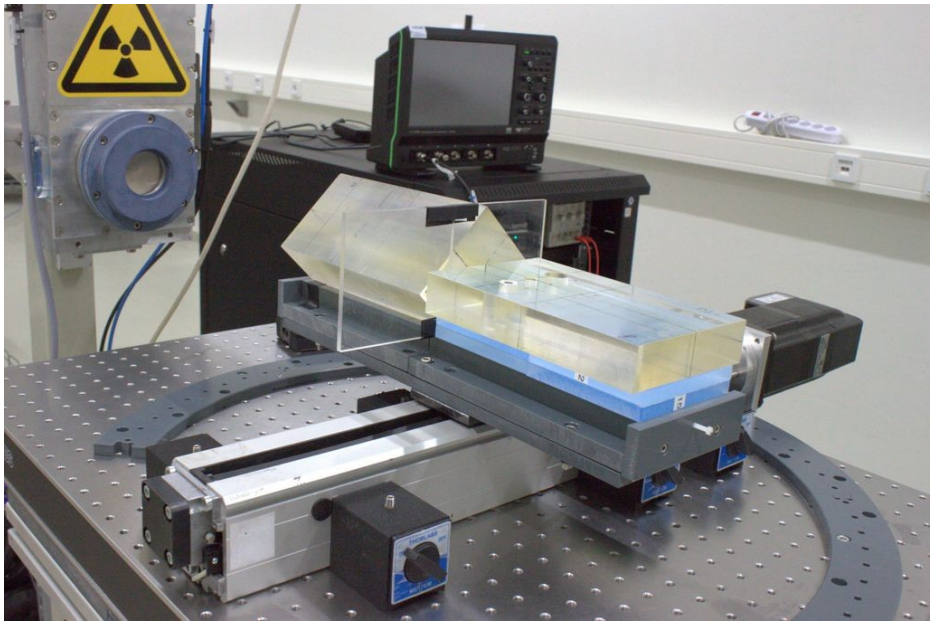
- Prompt gamma timaging *Petzoldt et al., submitted to PMB, 2015*
  - Proton beam scanning of a structured PMMA target at OncoRay to explore imaging capabilities of PGT

∅ 13mm filled cavity („marrowbone“)

∅ 9mm (small) cavity

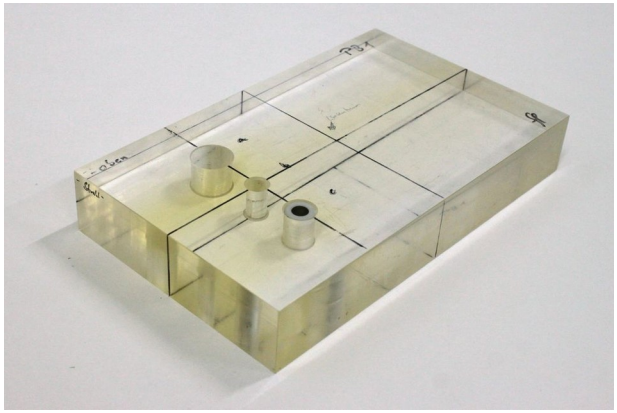
∅ 19mm (large) cavity

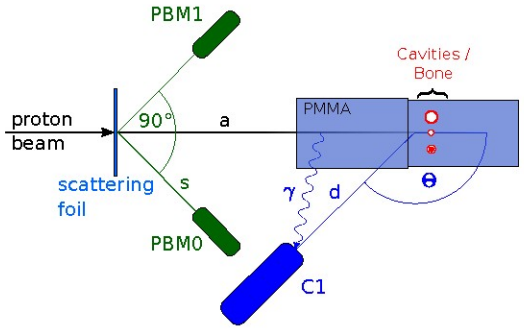


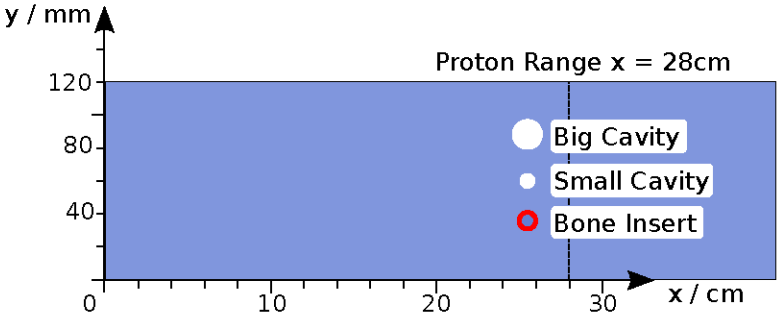


State of the art in PGT

- Prompt gamma timaging *Petzoldt et al., submitted to PMB, 2015*
  - Proton beam scanning of a structured PMMA target at OncoRay to explore imaging capabilities of PGT
  - PGT spectra measured and corrected for RF-bunch phase shifts, target absorption, and solid angle variation

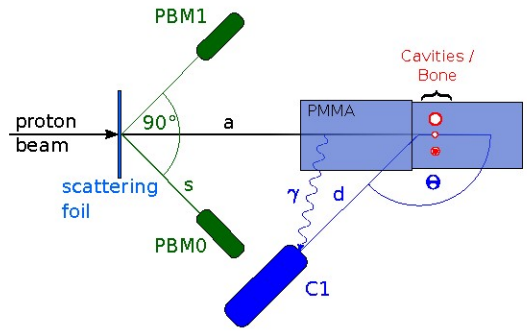


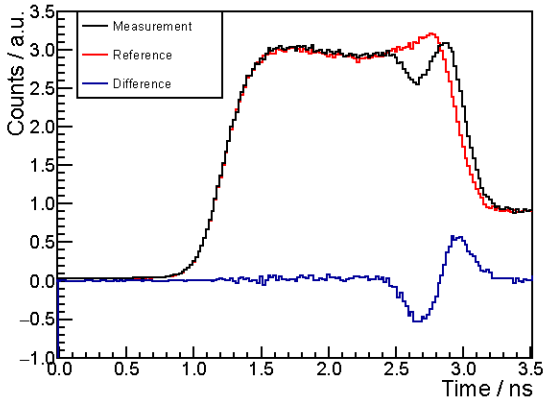


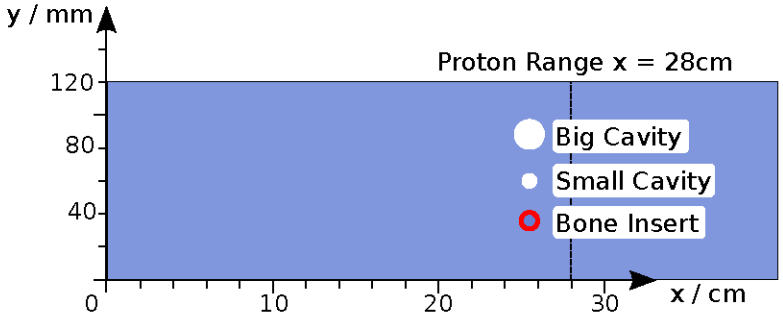


State of the art in PGT

- Prompt gamma timaging *Petzoldt et al., submitted to PMB, 2015*
  - Proton beam scanning of a structured PMMA target at OncoRay to explore imaging capabilities of PGT
  - PGT spectra measured and corrected for RF-bunch phase shifts, target absorption, and solid angle variation
  - Difference of the measured to a reference distribution is calculated

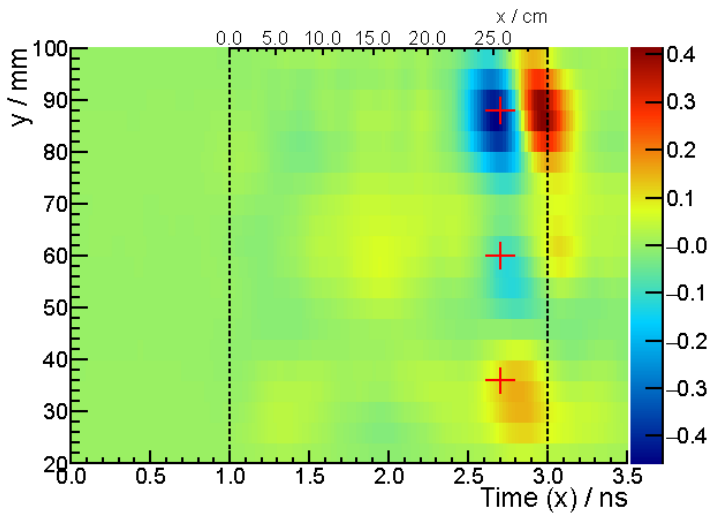


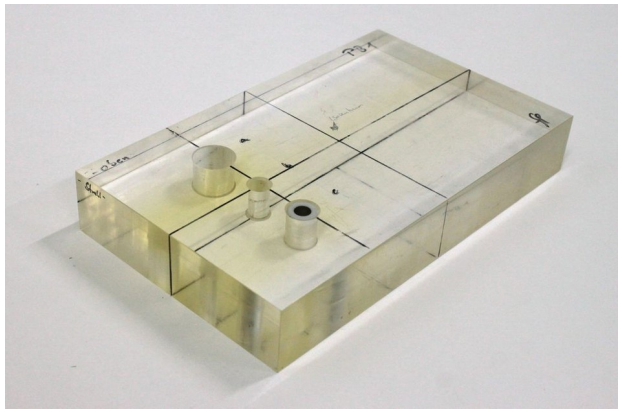




State of the art in PGT

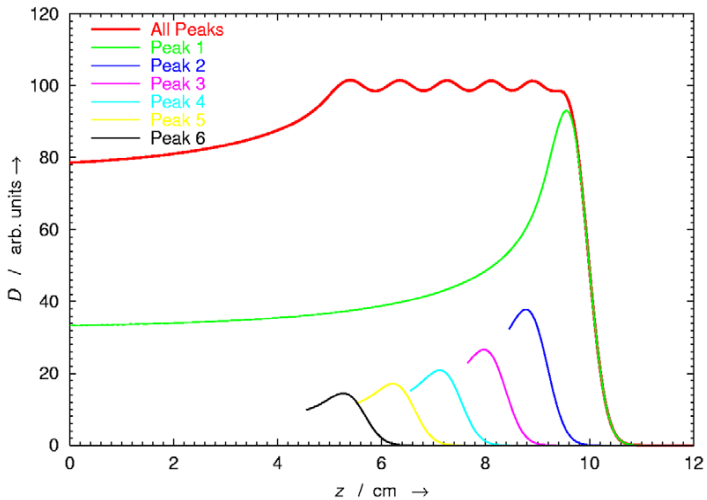
- Prompt gamma timaging *Petzoldt et al., submitted to PMB, 2015*
  - Proton beam scanning of a structured PMMA target at OncoRay to explore imaging capabilities of PGT
  - PGT spectra measured and corrected for RF-bunch phase shifts, target absorption, and solid angle variation
  - Difference of the measured to a reference distribution is calculated and visualized



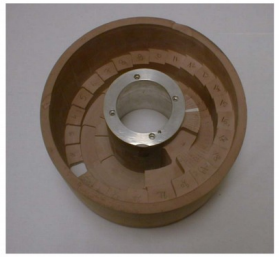


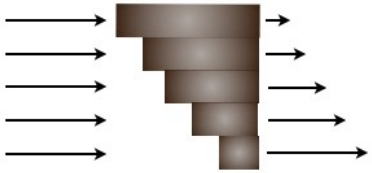
Scattered Beam Delivery

The spread out Bragg peak: Homogenous dose distribution in depth



Newhauser et al., PMB 60 (2015) R155





Modulator wheel: wheel with steps of different thickness

The wheel spins at 600 RPM while the beam current is switched on when the desired steps are in position

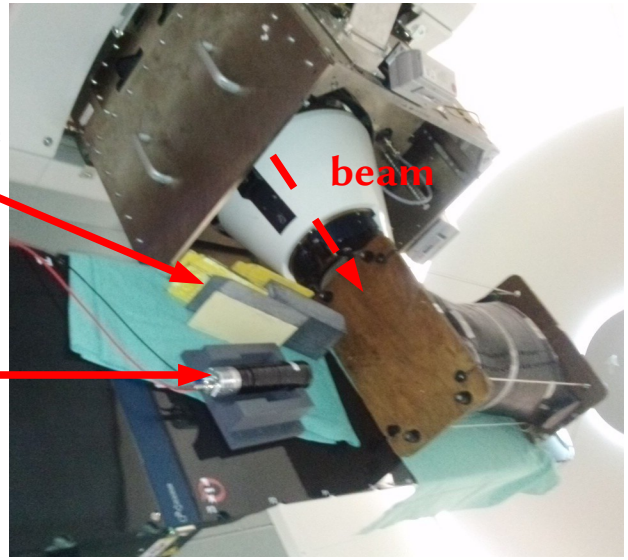
Experiments in the Gantry Room

CAEN DT5720 digitizer
Clocked with the **cyclotron RF** at
2×106 MHz ⟶ 212 MSamples/s

Parasitic experiment during workflow training
Irradiation time < 1 minute per field

Lead shielding towards the nozzle

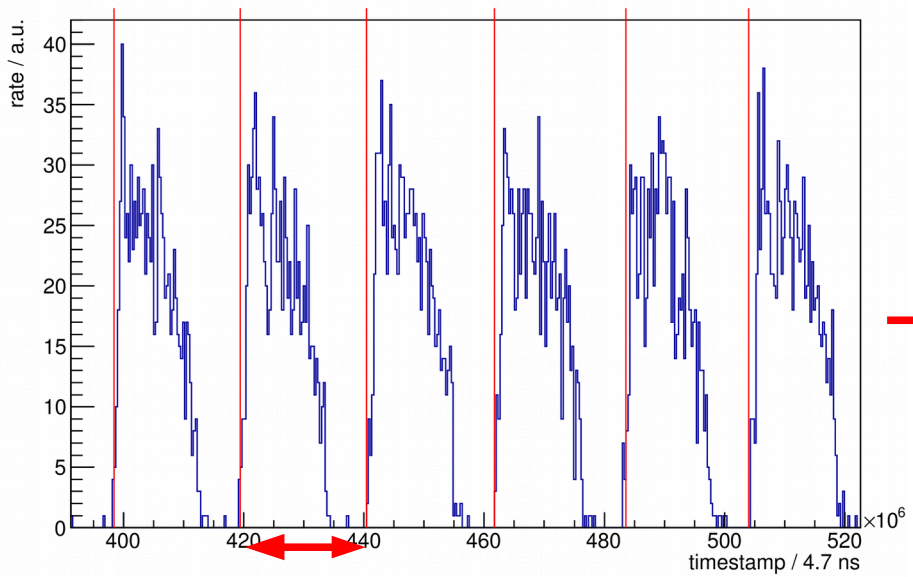
$CeBr_3$ photon detector

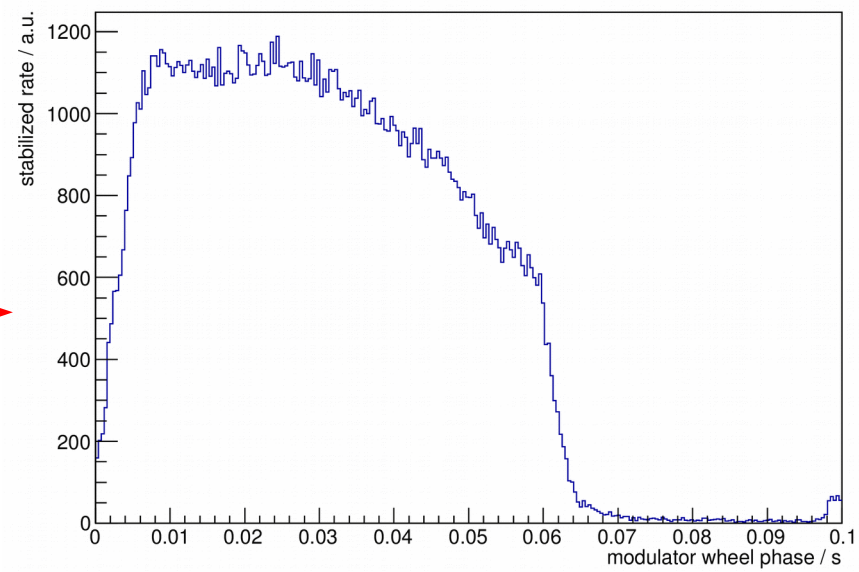


T. Kormoll. ANIMMA 2015

Results

Count rate over time – beam macrostructure





100 ms ⟶ 600 RPM

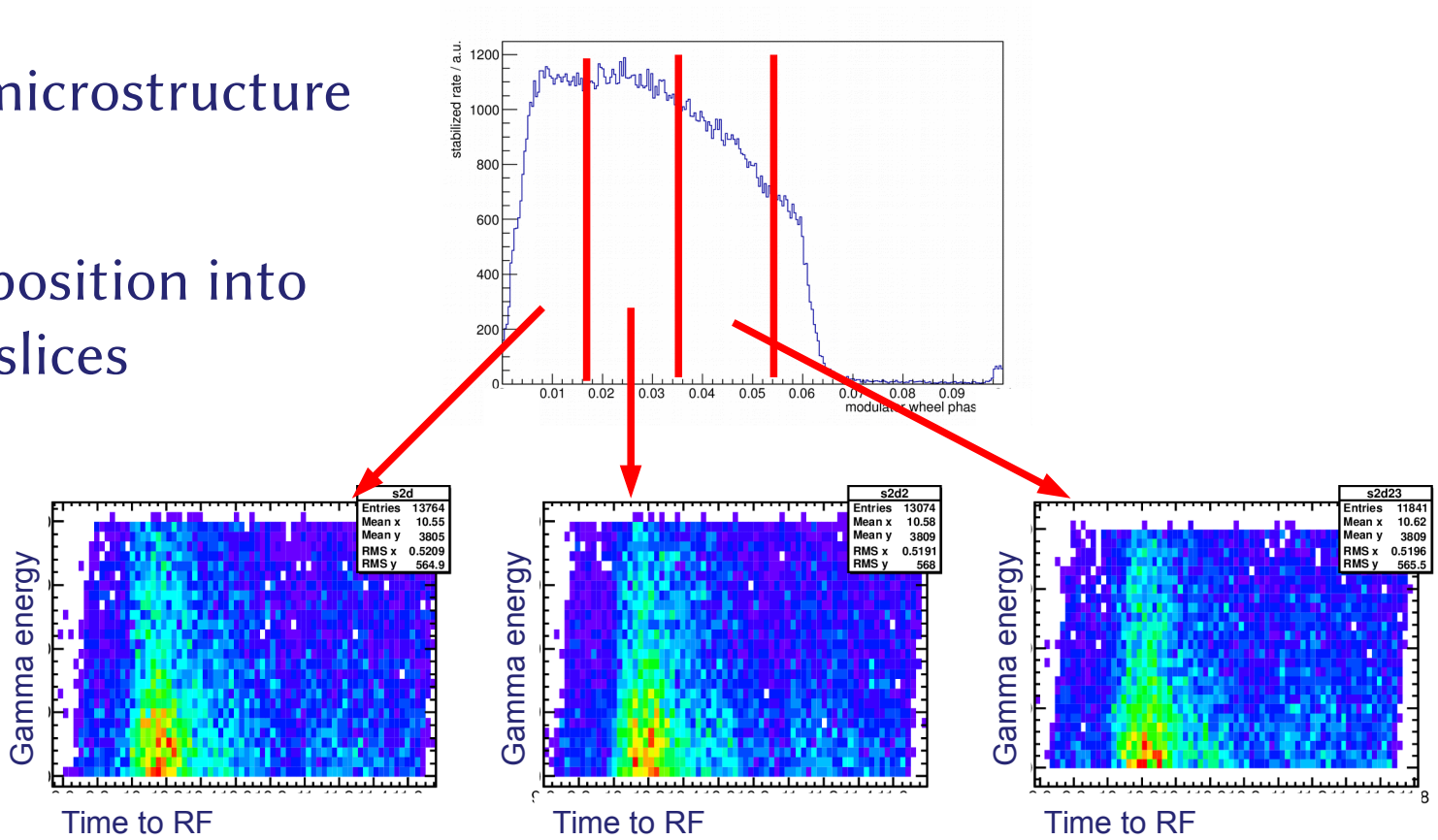
Wheel speed is electronically stabilized via a feedback loop
⟶ **Edge detection**

Each event can be assigned to a wheel pase

Results

Beam microstructure

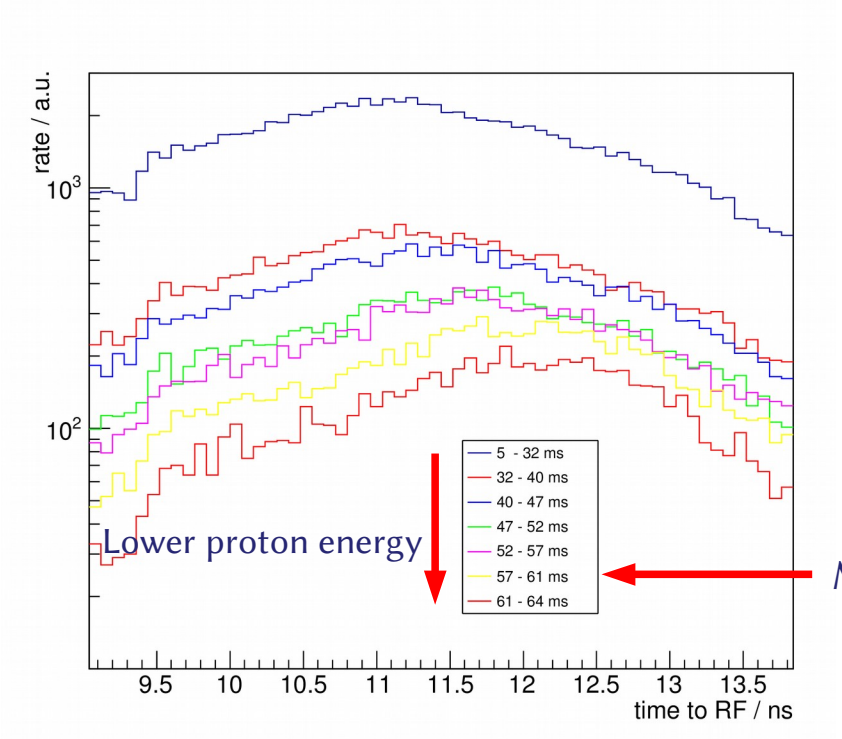
Decomposition into energy slices



Results

A closer look at the time profiles:

Range 18.2 cm
Modulation 7.5 cm



Modulator wheel steps

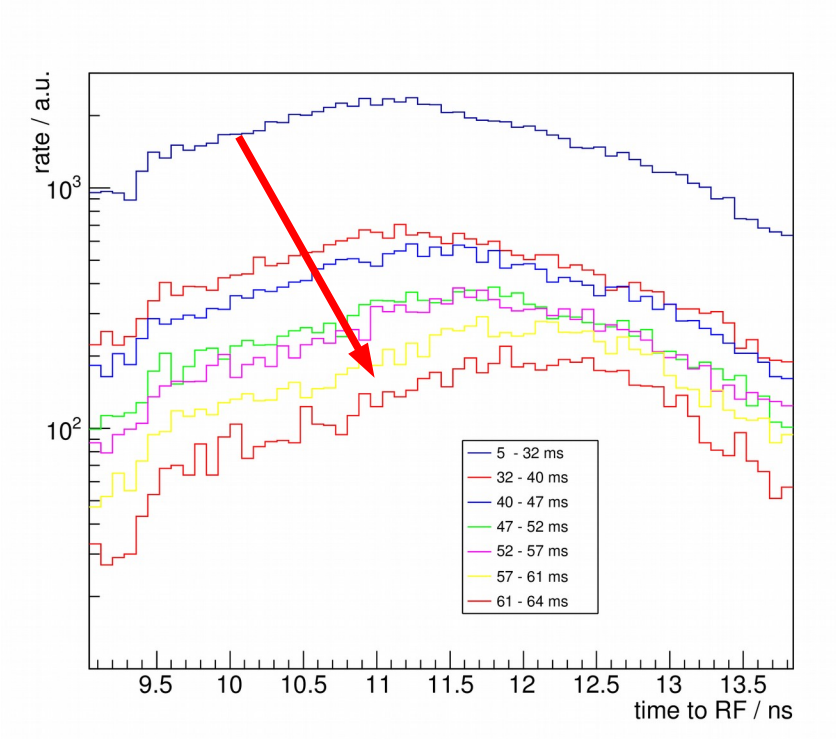
Results

A closer look at the time profiles:

Range 18.2 cm
Modulation 7.5 cm

1. The lower energy profiles start later

→ longer time of flight **to** the target



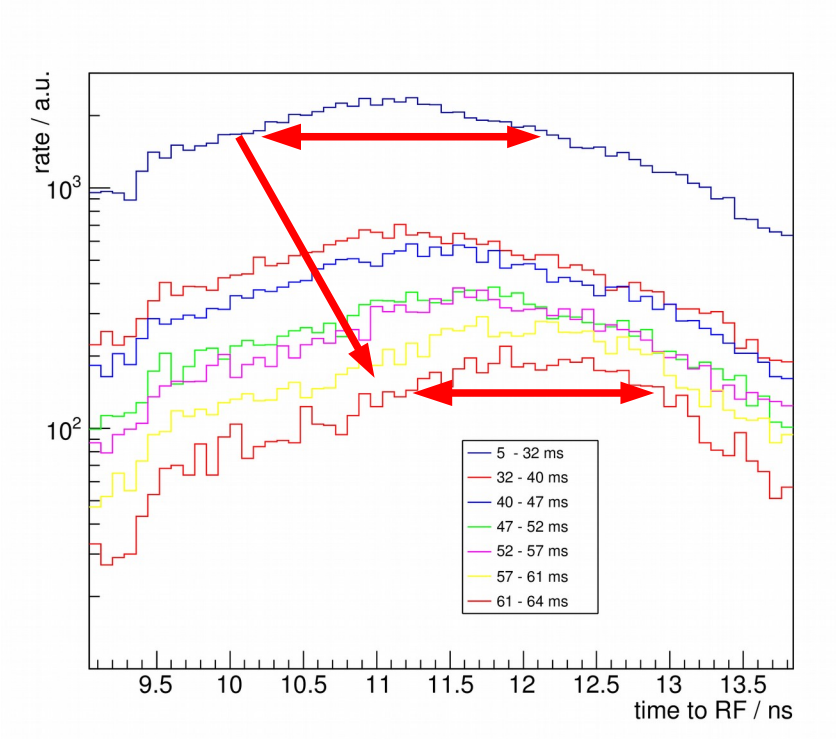
Results

A closer look at the time profiles:

Range 18.2 cm
Modulation 7.5 cm

1. The lower energy profiles start later

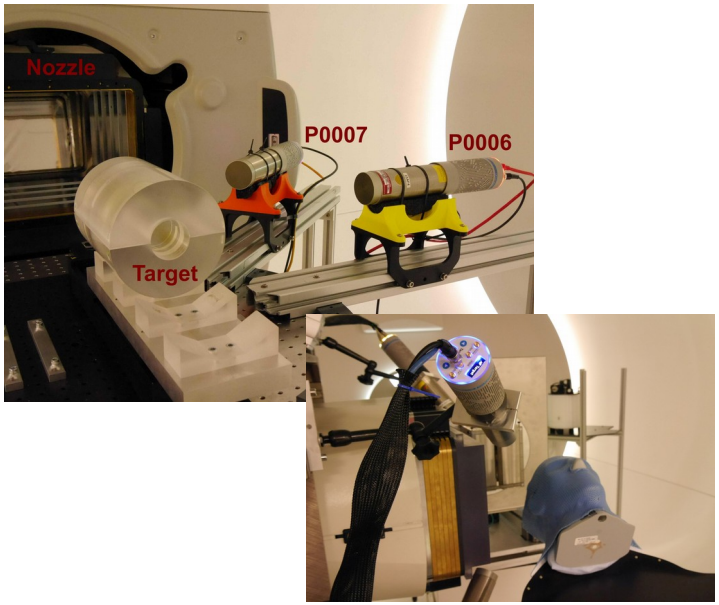
⟶ longer time of flight **to** the target



2. Profiles become Shorter

⟶ shorter transit time **in** the target

Experiments in Pencil Beam Scanning

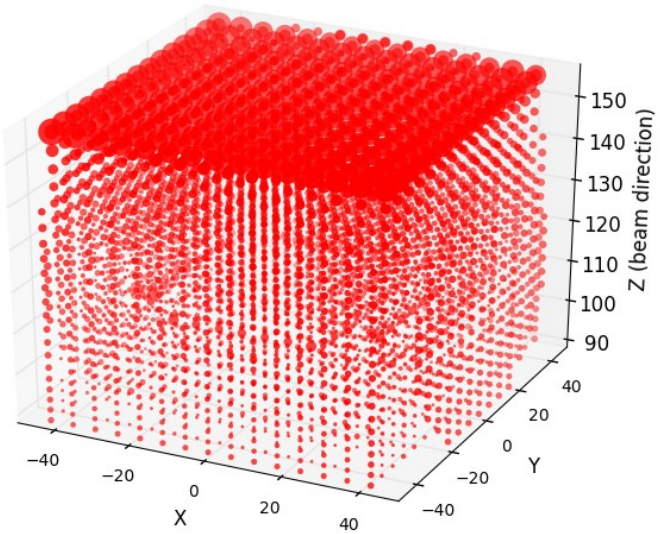


∅2“ x 2“ $CeBr_3$ detector on PMT

Target U100 readout electronics

PMMA target and head phantom

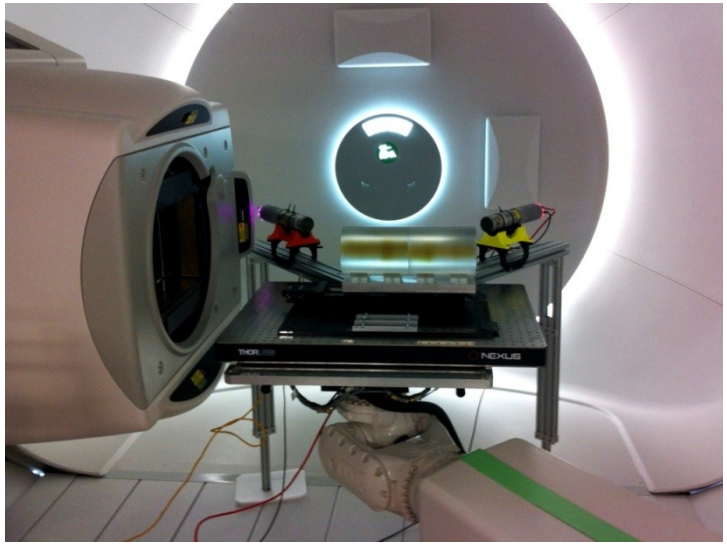
Layer and spot sequence has to be retrieved from machine log files to synchronize the PGT date with the delivery of the treatment plan

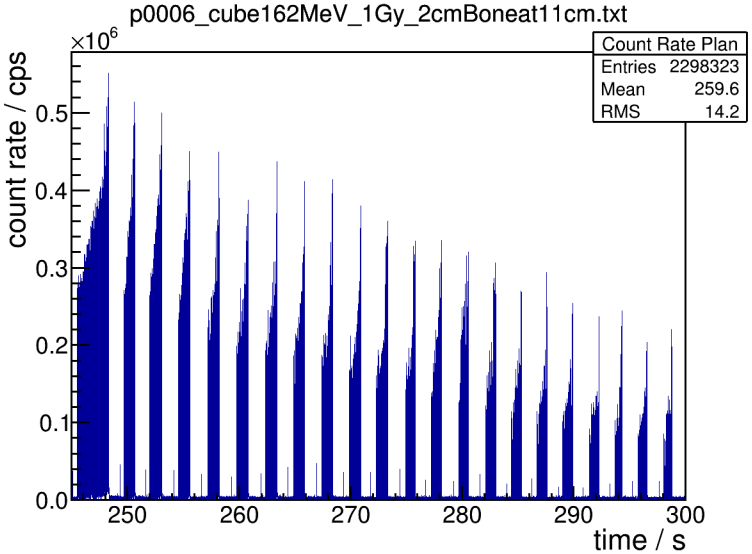


J. Berthold, Bachelor thesis

Experiments in Pencil Beam Scanning

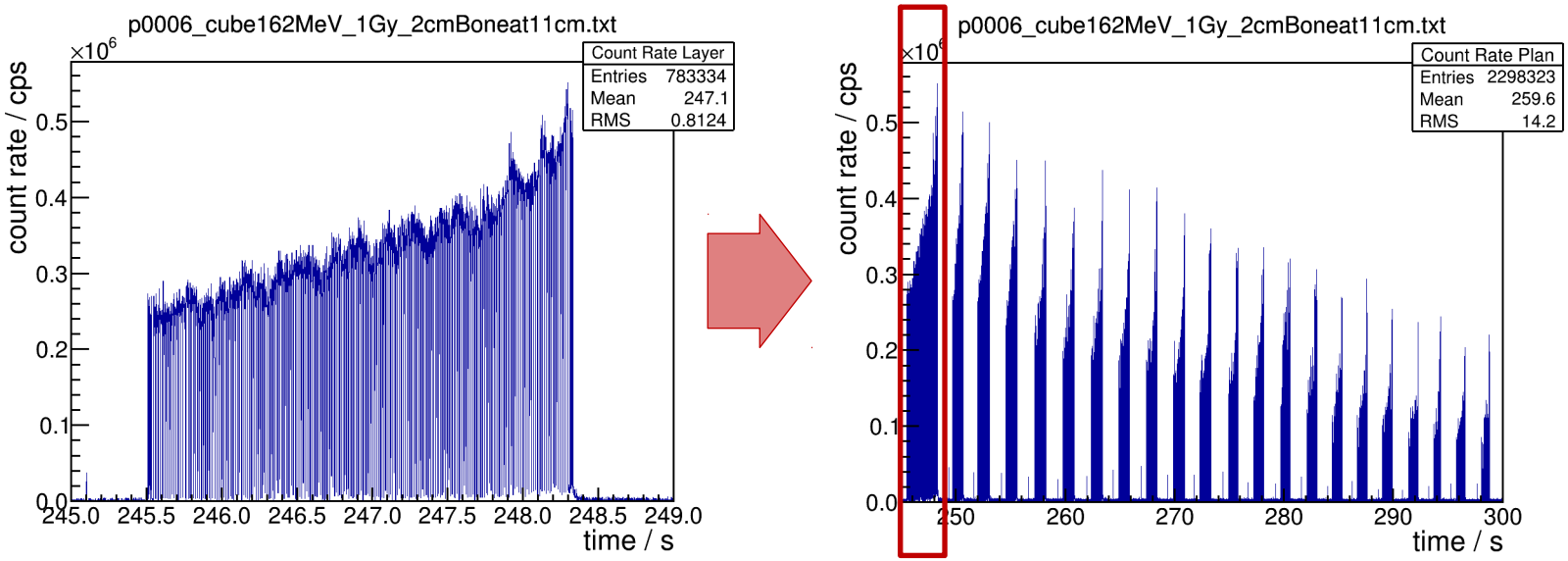
- Prompt gamma timaging *Petzoldt et al., submitted to PMB, 2015*
- PGT hardware *Pausch et al., paper accepted for publication in IEEE TNS, 2015*
  - Detection of ≤ 5 mm range deviations in single pencil beam spots
  - Maximum throughput to collect the statistics needed with few (2-4) detectors
  - Test at OncoRay, “dose cube” PBS plan (1 Gy)





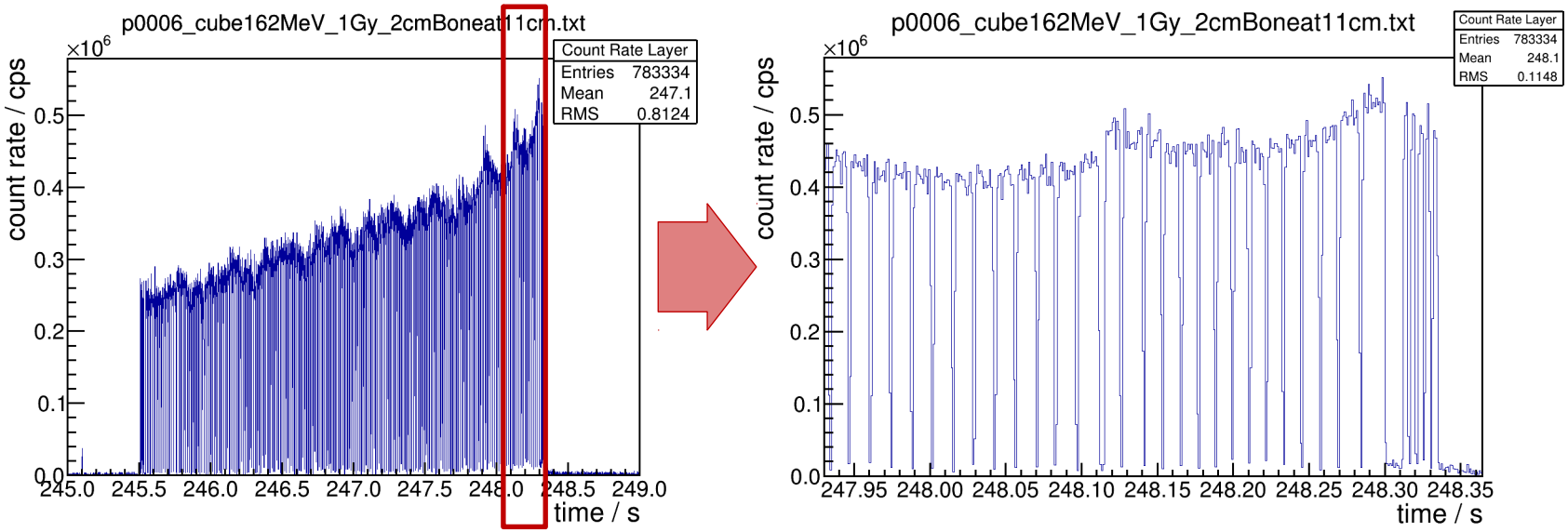
Experiments in Pencil Beam Scanning

- Prompt gamma timaging *Petzoldt et al., submitted to PMB, 2015*
- PGT hardware *Pausch et al., paper accepted for publication in IEEE TNS, 2015*
  - Detection of ≤ 5 mm range deviations in single pencil beam spots
  - Maximum throughput to collect the statistics needed with few (2-4) detectors
  - Test at OncoRay, “dose cube” PBS plan (1 Gy)



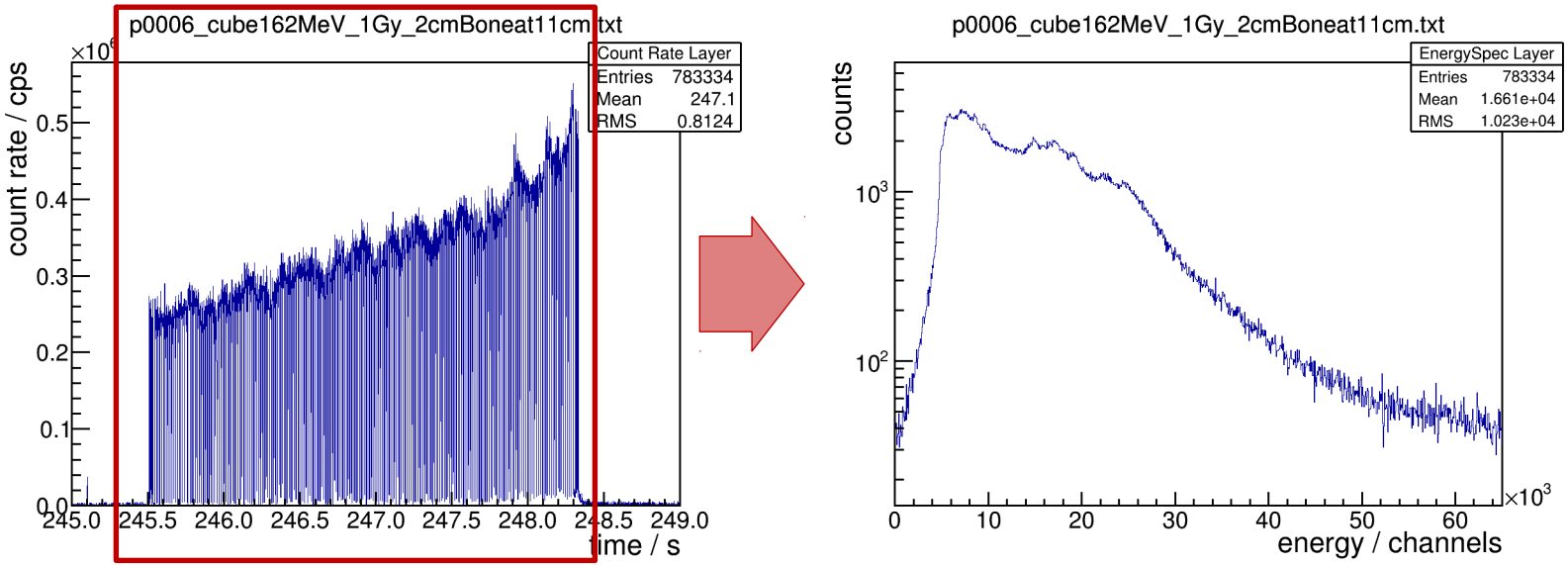
Experiments in Pencil Beam Scanning

- Prompt gamma timaging *Petzoldt et al., submitted to PMB, 2015*
- PGT hardware *Pausch et al., paper accepted for publication in IEEE TNS, 2015*
  - Detection of ≤ 5 mm range deviations in single pencil beam spots
  - Maximum throughput to collect the statistics needed with few (2-4) detectors
  - Test at OncoRay, “dose cube” PBS plan (1 Gy)



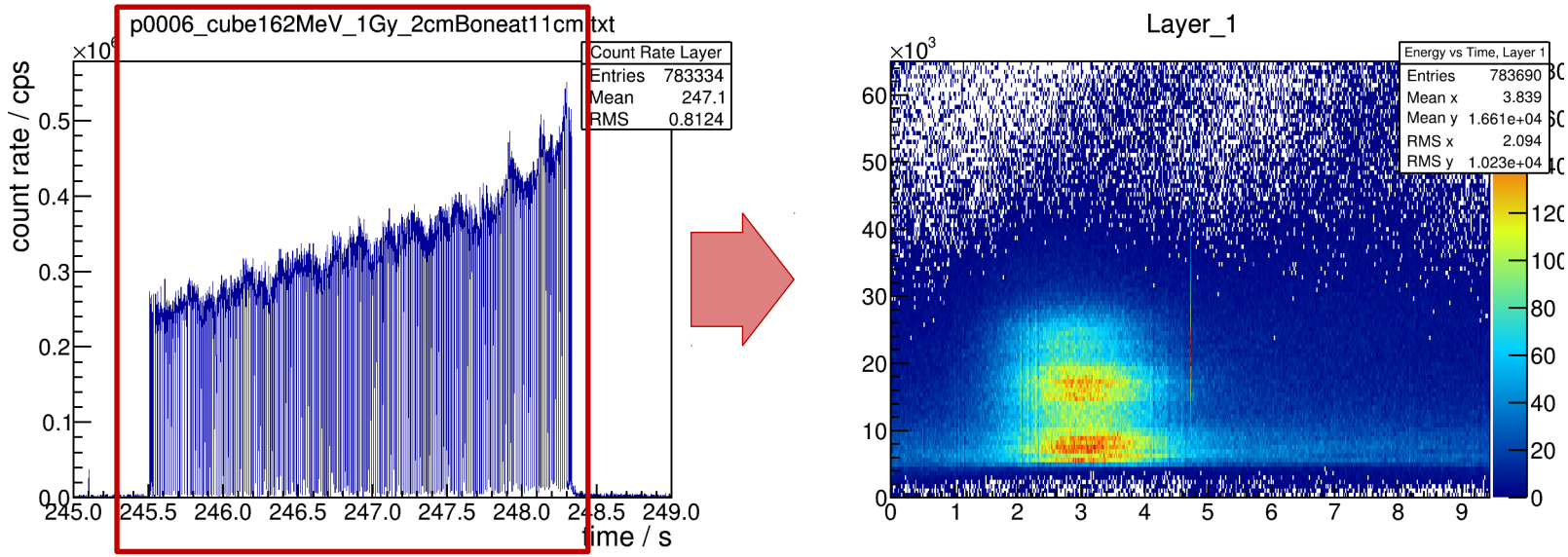
Experiments in Pencil Beam Scanning

- Prompt gamma timaging *Petzoldt et al., submitted to PMB, 2015*
- PGT hardware *Pausch et al., paper accepted for publication in IEEE TNS, 2015*
  - Detection of ≤ 5 mm range deviations in single pencil beam spots
  - Maximum throughput to collect the statistics needed with few (2-4) detectors
  - Test at OncoRay, “dose cube” PBS plan (1 Gy)



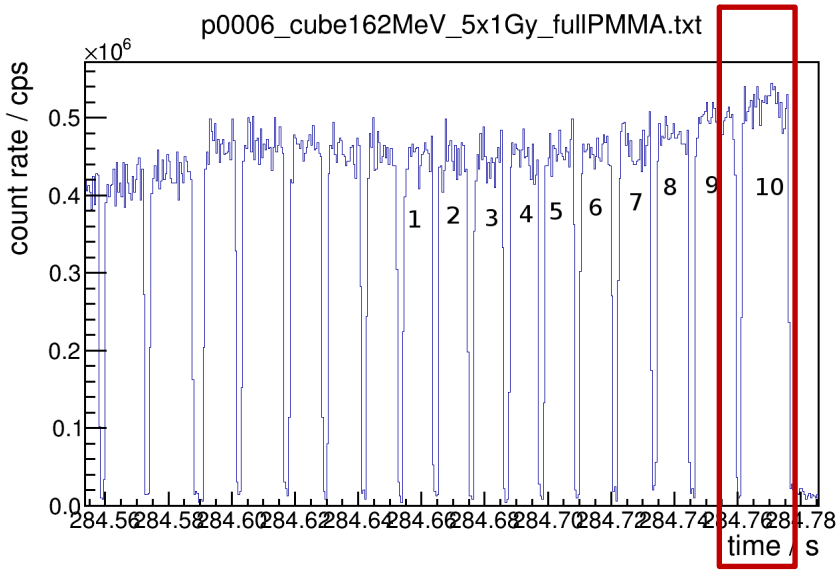
Experiments in Pencil Beam Scanning

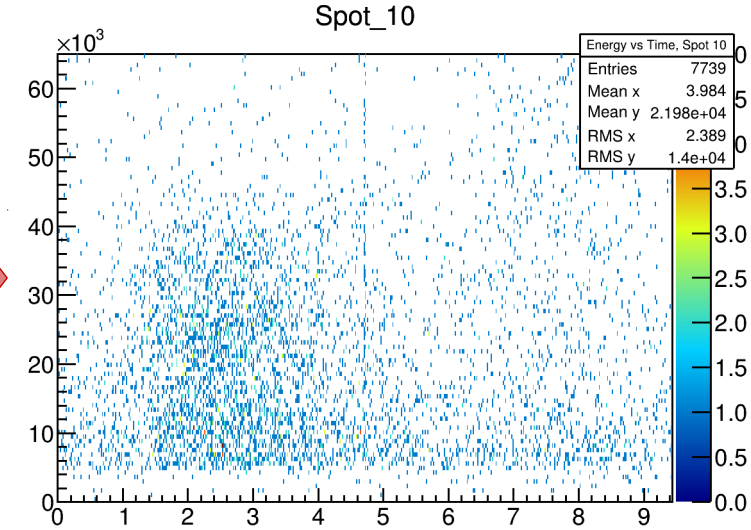
- Prompt gamma timaging *Petzoldt et al., submitted to PMB, 2015*
- PGT hardware *Pausch et al., paper accepted for publication in IEEE TNS, 2015*
  - Detection of ≤ 5 mm range deviations in single pencil beam spots
  - Maximum throughput to collect the statistics needed with few (2-4) detectors
  - Test at OncoRay, “dose cube” PBS plan (1 Gy)



Experiments in Pencil Beam Scanning

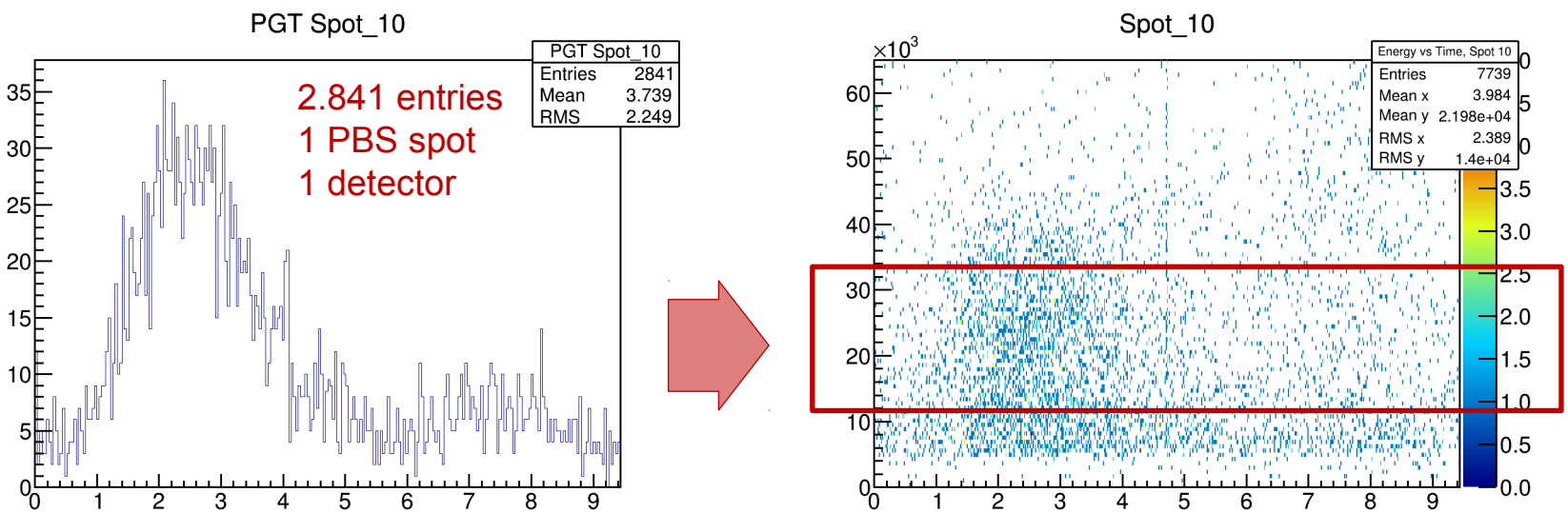
- Prompt gamma timaging *Petzoldt et al., submitted to PMB, 2015*
- PGT hardware *Pausch et al., paper accepted for publication in IEEE TNS, 2015*
  - Detection of ≤ 5 mm range deviations in single pencil beam spots
  - Maximum throughput to collect the statistics needed with few (2-4) detectors
  - Test at OncoRay, “dose cube” PBS plan (1 Gy)





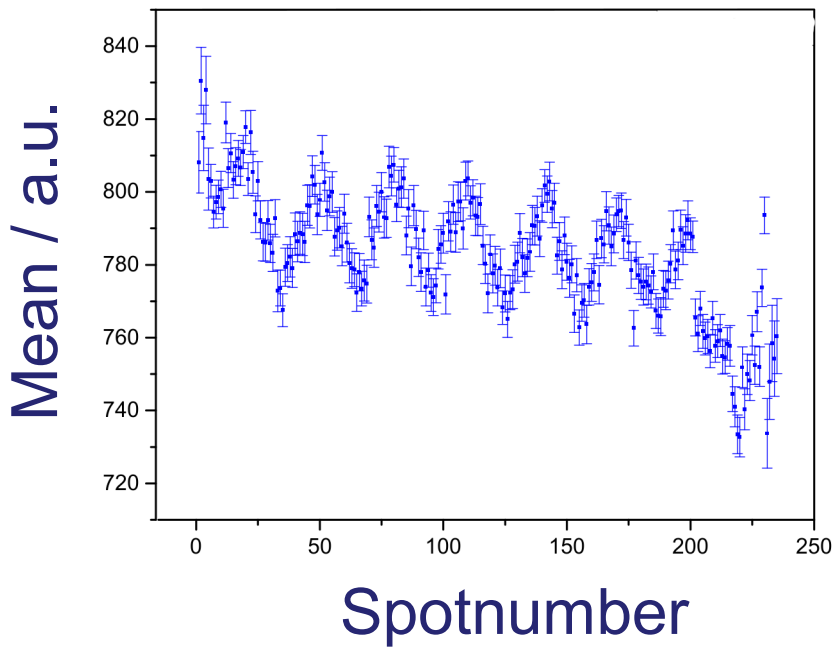
Experiments in Pencil Beam Scanning

- Prompt gamma timaging *Petzoldt et al., submitted to PMB, 2015*
- PGT hardware *Pausch et al., paper accepted for publication in IEEE TNS, 2015*
  - Detection of ≤ 5 mm range deviations in single pencil beam spots
  - Maximum throughput to collect the statistics needed with few (2-4) detectors
  - Test at OncoRay, “dose cube” PBS plan (1 Gy)



Experiments in Pencil Beam Scanning

The mean of the time distribution of all spots in one layer:



The spot position is reflected in the position of the mean.

Conclusions

- PGT in double scattering requires heavy shielding
- PGT in pencil beam scanning delivers cleaner data without shielding – analysis is ongoing
- The data of more than one detector has to be combined to allow to extract range information on a per spot basis
- We need a reference profile (simulation)