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Studies of a Proton Phase Beam Monitor for Range Verification

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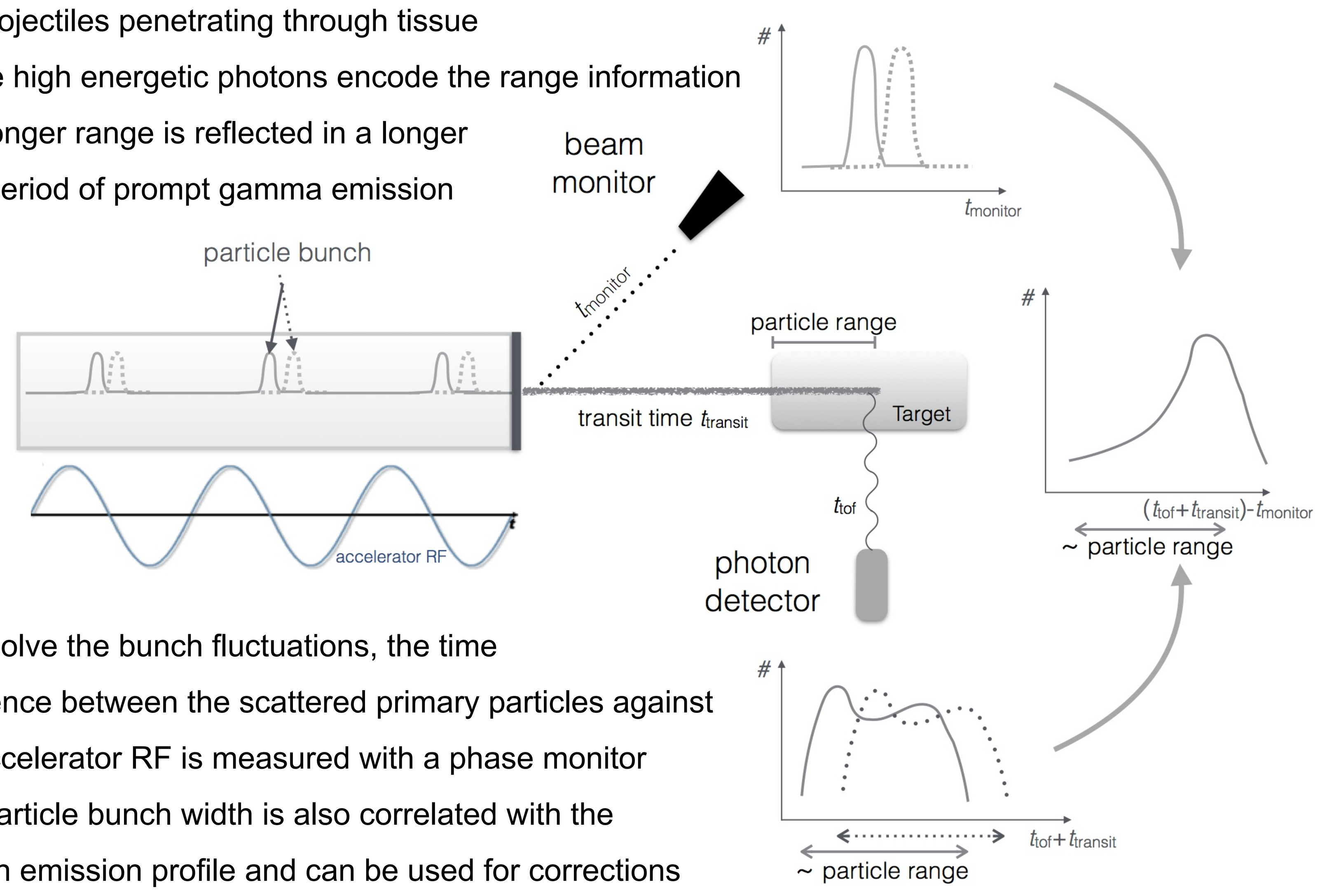
Background and Motivation

- Several components in the beam pipe and an unstable phase of the accelerator proton current
- Unknown inhomogeneities in tissue
  - → leads to a stretching and fluctuations of the primary particle bunch profile
- Consequence: Irradiation uncertainties while scanning the target volume
- This requires an in vivo localization of the incoming particles during the treatment

Phase Monitor coupled Prompt Gamma Timing (PGT)

- Prompt Gamma Timing involves the detection of promptly emitted photons, which are a byproduct of the projectiles penetrating through tissue
- These high energetic photons encode the range information
  → longer range is reflected in a longer period of prompt gamma emission



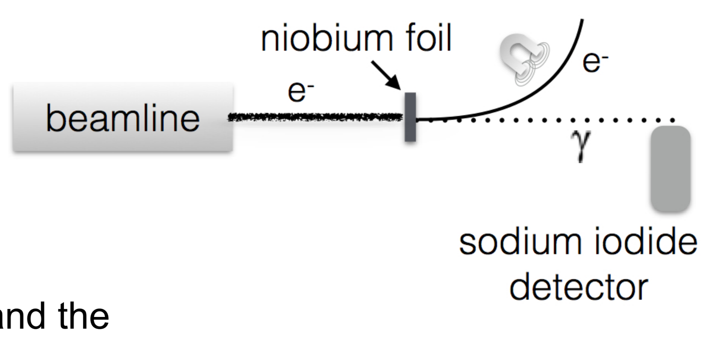
- To resolve the bunch fluctuations, the time difference between the scattered primary particles against the accelerator RF is measured with a phase monitor
- The particle bunch width is also correlated with the photon emission profile and can be used for corrections
- Without phase monitor, PGT spectrum is smeared out and method would not be robust

Monitoring the primary particle bunch profile with the help of a beam monitor could allow for better quality assurance in proton therapy

Preparatory Experiments at ELBE (HZDR) and GSI Darmstadt

ELBE

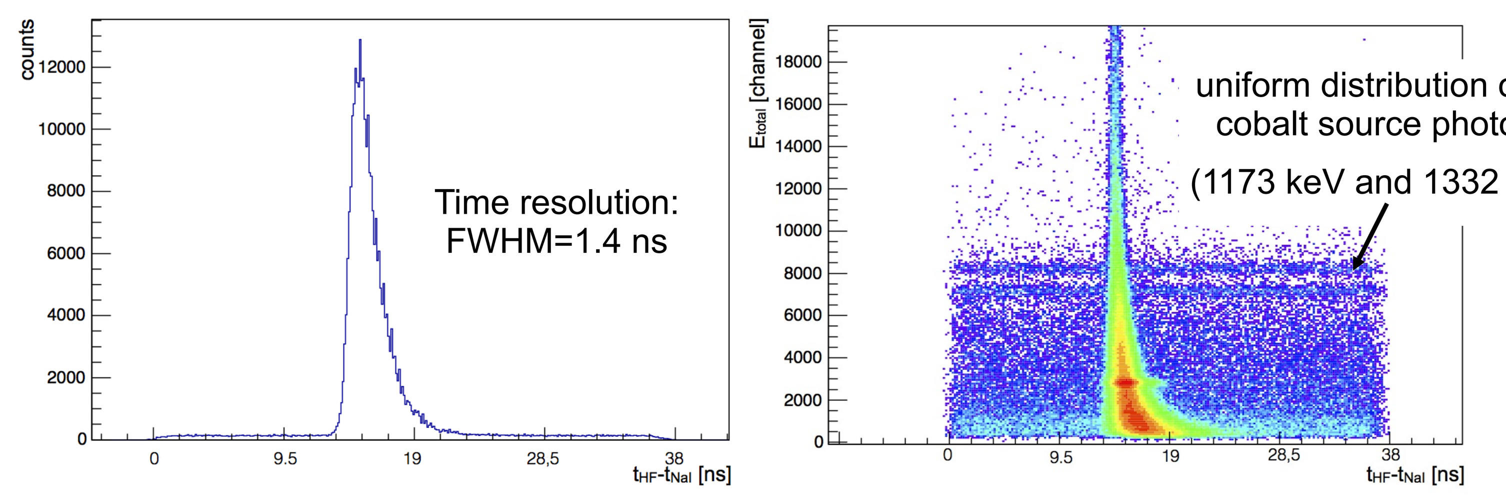
Bremsstrahlung (13 MeV) is produced by the electron beam hitting a niobium foil in the accelerator hall



» Accelerator RF: 13 MHz (<50 ps jitter)

» Recording the time difference between the accelerator RF and the incoming photons

» Cobalt source – RF uncorrelated photon distribution (uniform across the time axis)



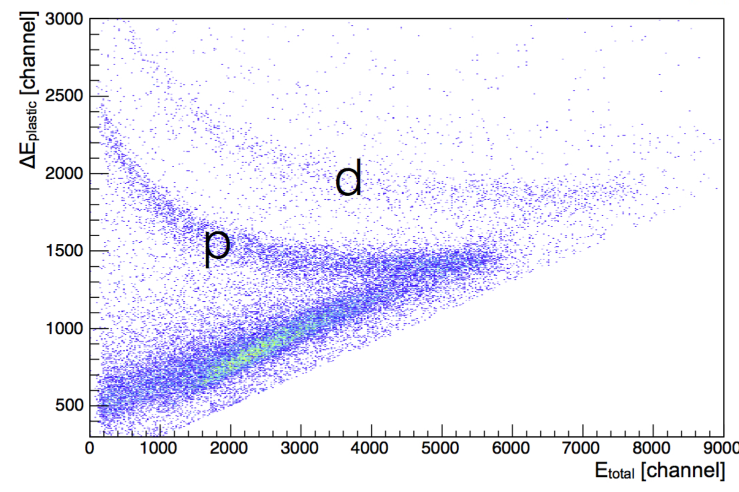
GSI

Carbon ions (~ 200 AMeV) scattered on PMMA

» Correlation of energy loss and residual energy measured with a phoswich detector

» Separation of hydrogen and helium isotopes

» Accelerator RF: 20 MHz

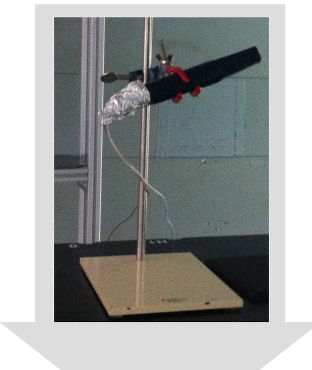


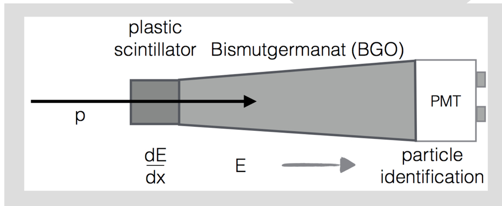
Technical Equipment

- For clinical applications, a compact design with high readout rate must be provided
  - → digital sampling and pulse shape discrimination

Experimental setup consists of:

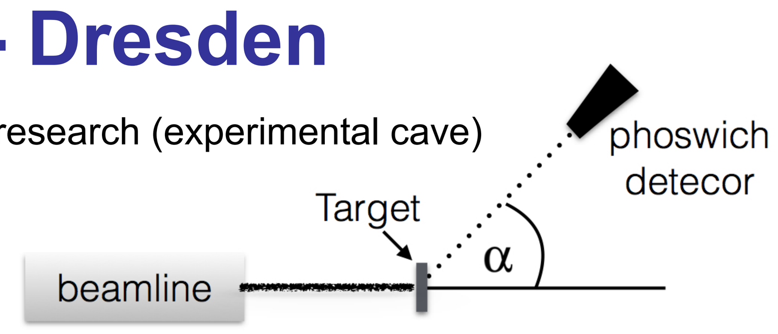
- Digitizer: recoding the waveform with a 4 Channel 12 bit 250 MS/s CAEN Digitizer
- Custom firmware: ADC synchronized to cyclotron HF (212 MHz = 2x106 MHz)
- HV Power Supply : 4 independently controllable High Voltage channels in a compact desktop module
- Computer: control and setup of the Digitizer and HV module, Data storage
- Phoswich detector: consisting of a plastic scintillator for timing information and a $Bi_4Ge_3O_{12}$ (BGO) crystal for energy absorption
  → combination enables particle identification



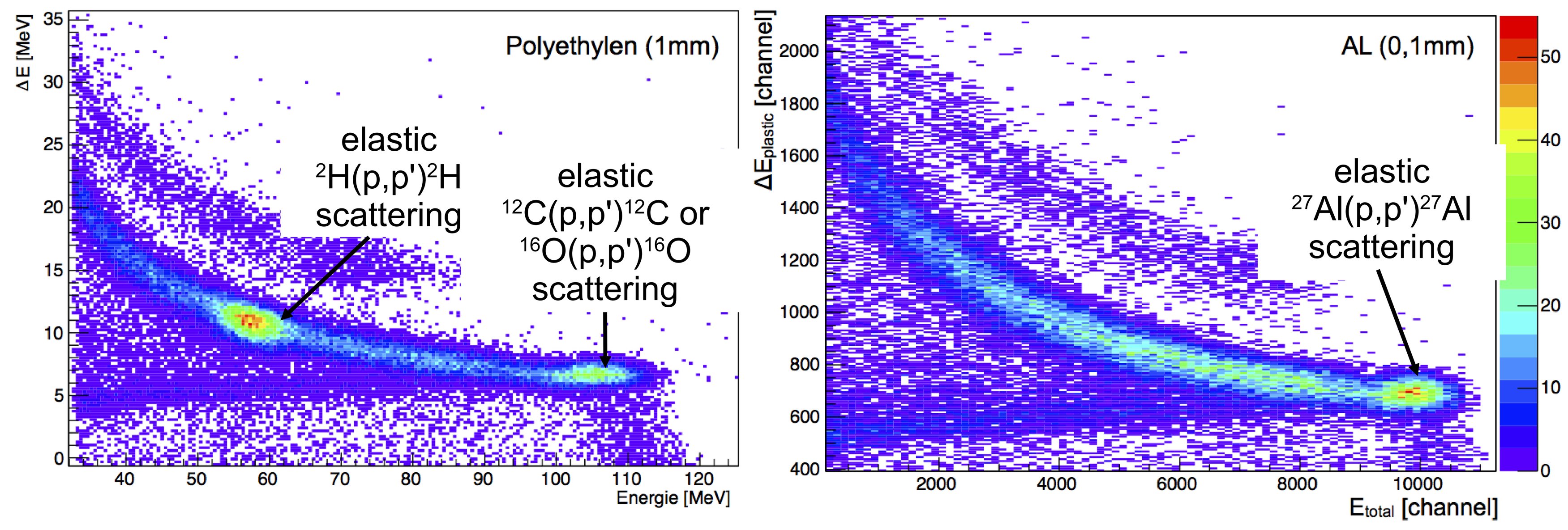


Experiments at OncoRay - Dresden

- Proton cyclotron (C230 IBA) for therapy (Gantry) and research (experimental cave)
- Proton energy area 70 MeV – 230 MeV
- Accelerator RF: f = 106 MHz (T = 9.4 ns)
- Detector: Phoswich
- Energy spectra of scattered protons with different scattering angles and scattering bodies (Al, Cu, PE) are recorded to determine the efficiency

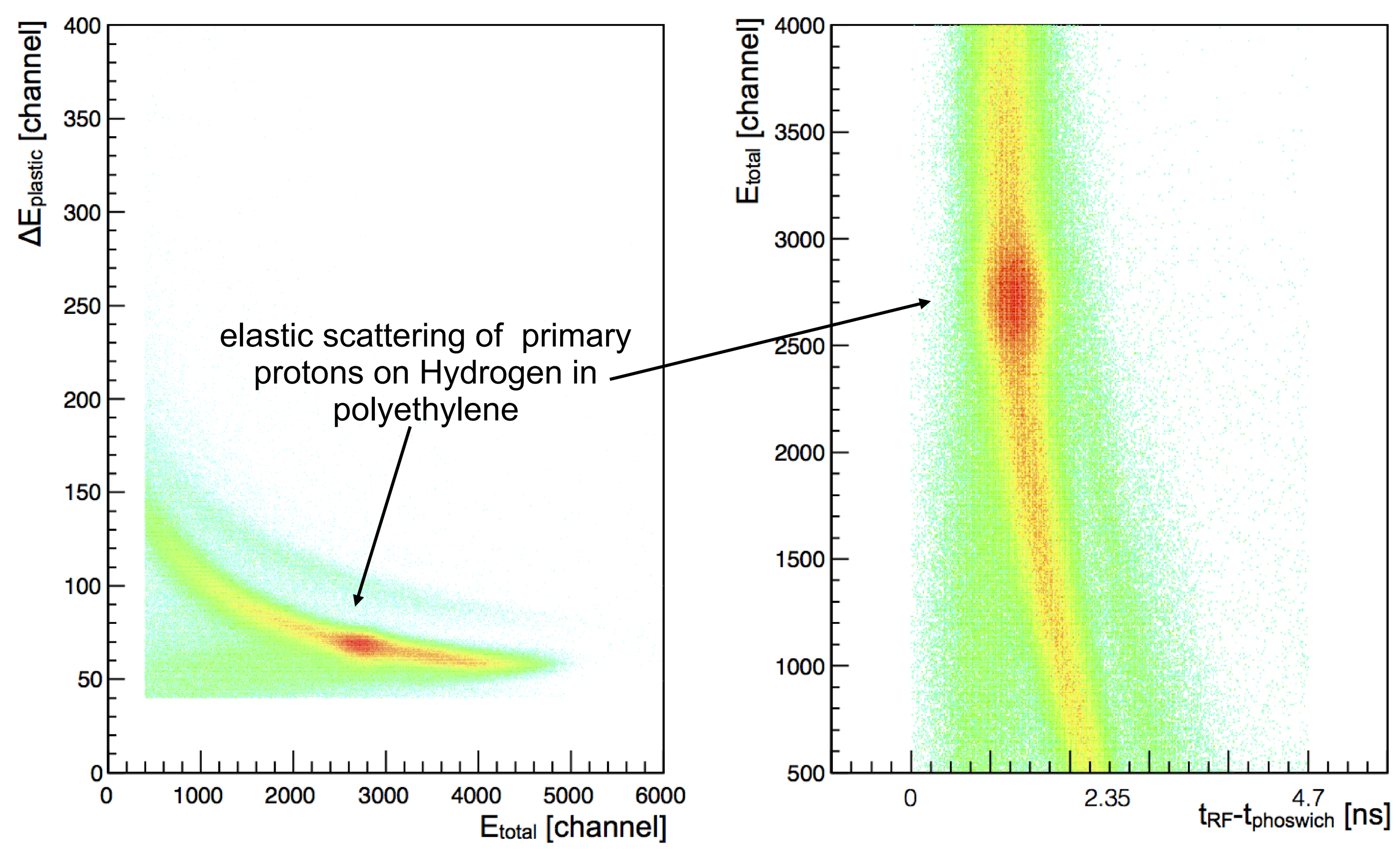


spectra of scattered 101 MeV protons



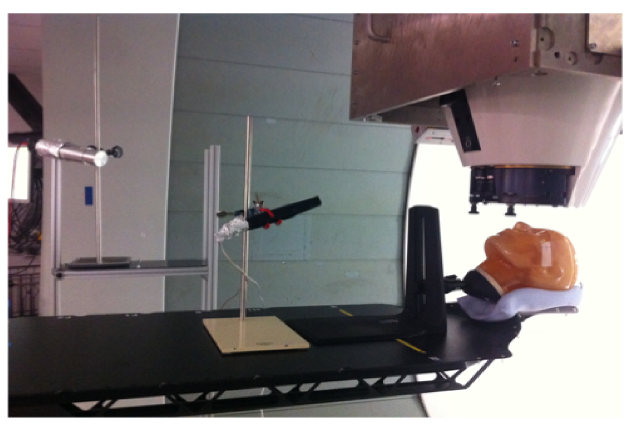
Coincidence time measurements

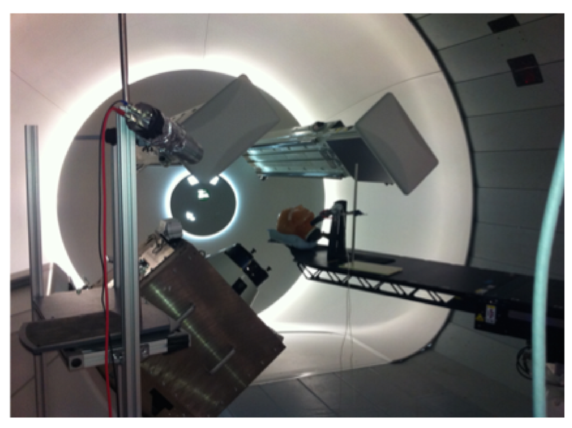
- Energy of primary protons: 217 MeV – scattered on Polyethylene
- Range: 30 cm (water)
- Measure the coincidence time spectrum between the accelerator RF and the proton bunch
- Constant fraction timing: trigger a signal at a constant fraction of the input amplitude
  → waveform signal from the fast plastic scintillator component
- Timing of the accelerator RF
- Difference ($t_{RF} - t_{phoswich}$) leads to a time resolution of FWHM = 0,6 ns



Conclusion and Outlook

- Bunch monitoring with proton detector at the clinical cyclotron is feasible
- The experimental setup is easy to handle and delivers an uncomplicated experimental construction under flexible circumstances
  → Experiments in the treatment room with different Targets and different types of beam delivery in the Gantry are in progress
- Further integration of integrating the beam monitor in the clinical beam delivery system is under evalutation





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