ST4 - Towards an Alternative Absorber Detector for the Garching Compton Camera Prototype

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Motivation: Beam Range Monitoring in Hadron Therapy

Hadron therapy : exploiting Bragg-peak properties for highly localized dose deposit in tumor tissues required

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Methods for **Bragg Peak** monitoring

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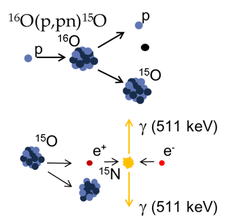	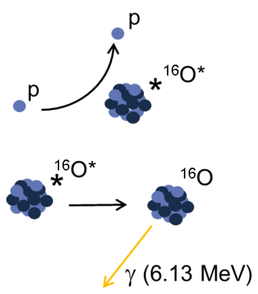	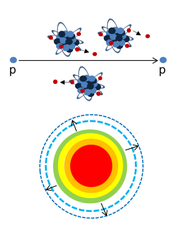
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β^+ emitters produced by nuclear fragmentation	**prompt-γ emission by excited nuclei**	Shock wave induced by proton pulse (ionoacoustic effect**)**
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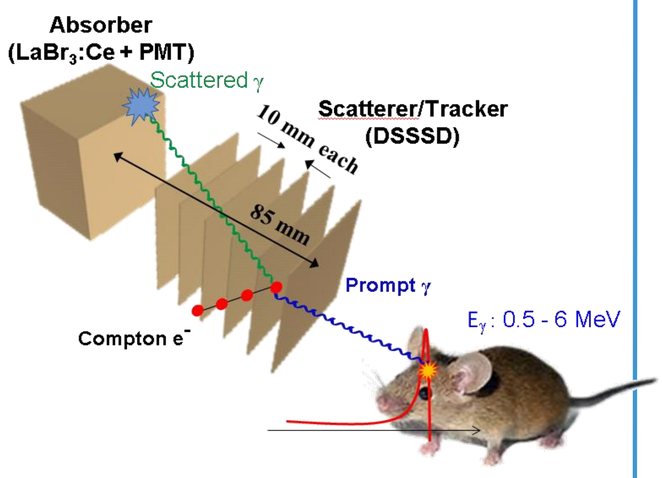
PET scanner	**Compton Camera (CC) System (for position resolved prompt-γ detection)**	Ultrasound detector

Schematic sketch of the Compton camera prototype



The Compton camera is designed to allow for tracking the Compton-scattered electron via an array of double-sided silicon strip detectors (DSSSD)

- **Present status:**
  - **$LaBr_3$ scintillator** with multi-anode PMT readout and NIM/VME based electronics
  - Complete system characterization and commissioning performed at conventional and medical accelerator facilities
  - Determination of **spatial information** from **monolithic $LaBr_3$:Ce** scintillator
- **Current restrictions:**
  - PMT not usable in environments with magnetic (stray) fields
  - Electronics **not** suitable for **identical readout of scatterer and absorber**
- **Aims:**
  - Usage of alternative scintillator with negligible internal radioactivity (**$CeBr_3$**)
  - Usage of new, improved photodetector (**SiPM**)
  - Evaluation of an alternative readout electronics (**ASIC/FPGA based**)
  - Alternative scatterer (one layer of **pixelated GAGG**) with SiPM readout

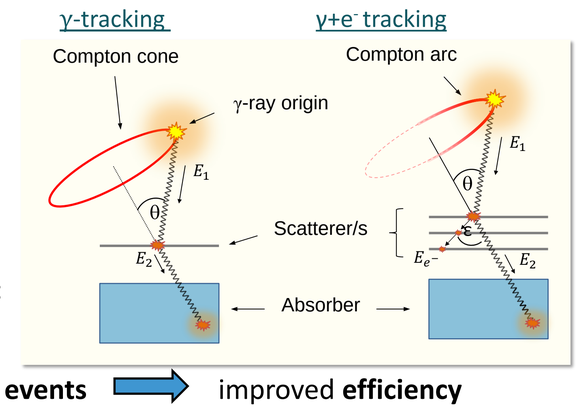
The (current) Compton Camera Prototype

Physical Principle:

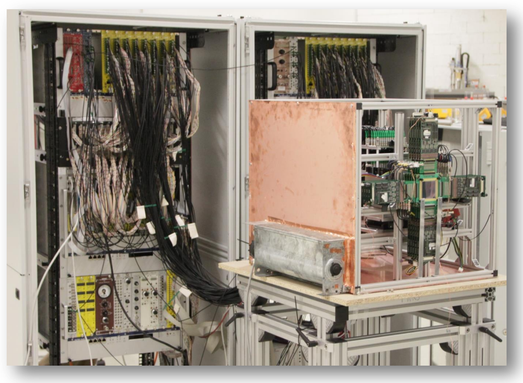
Compton kinematics { Momentum conservation / Energy conservation ⇒ $$cos\vartheta = 1 - m_e c^2 \left[\frac{1}{E_2} - \frac{1}{E_1}\right]$$

Modes of operation:

- **Thick scatter detector**:
  Compton e^- will be absorbed ⇒ cannot add information to the **Compton kinematics**
- Scatterer made of **layers of double-sided Si strip detectors (DSSSD)**:
  e^- tracking will become possible ⇒ will allow to:
  - restrict the Compton cone to an **arc segment**
  - reconstruct also **incompletely absorbed photon events** ⇒ improved **efficiency**



Compton Camera (prototype):



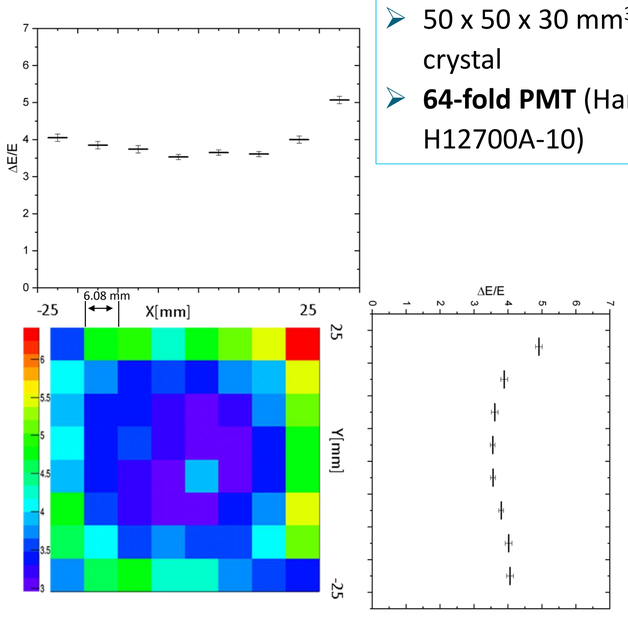
- Designed to allow for **e^- tracking**
- Scatterer: stack of **6 DSSSD** (0.5 mm thick, 50x50 mm^2, 128 strips/side)
- Absorber: **$LaBr_3$:Ce scintillator** (50x50x30 mm^3)
- Scintillator read out:
  - **256-fold multi-anode PMT** (Hamamatsu H9500)
  - **individual spectroscopy electronics** (NIM/VME) for each PMT channel, digitizing energy and time signals

New Components:

- **$CeBr_3$ absorber** with
  - 64-fold PMT readout
  - 256 SiPM readout w/ ASIC/FPGA based electronics
- Evaluation of (22 x 22) pixelated array of GAGG crystal (0.9 x 0.9 x 6 mm^3) for use in low-energy photon applications (γ-PET)

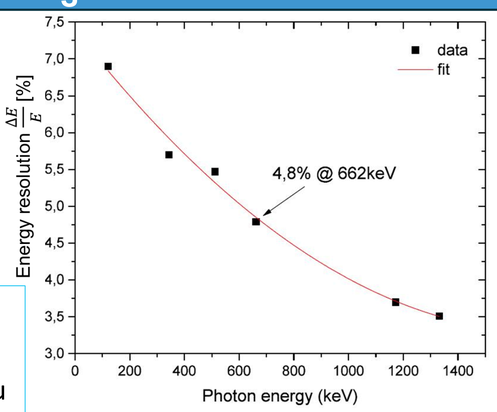
Energy Resolution of $CeBr_3$ scintillator

Position-dependent relative energy resolution



Relative energy resolution up to 1.33 MeV

- 50 x 50 x 30 mm^3 **$CeBr_3$** crystal
- **64-fold PMT** (Hamamatsu H12700A-10)

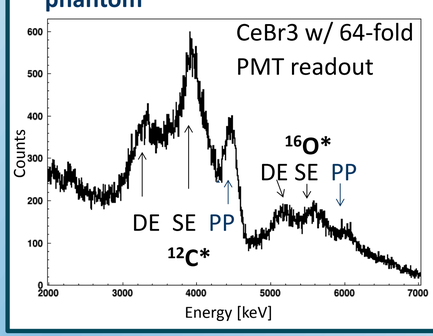


- Uncollimated γ-sources
- Central γ-source position
- 20 min. acquisition time with ^{152}Eu, ^{22}Na, ^{137}Cs
- 90 min. acquisition time with ^{60}Co (low activity)

- Measured **@ 1.33 MeV**
- flat distribution in central region
- Moderate degradation of ΔE/E at the crystal edges

$CeBr_3$ vs. $LaBr_3$(Ce)

Prompt-γ energy spectrum from 20 MeV protons hitting a PMMA phantom



- $CeBr_3$ w/ 64-fold PMT
- $LaBr_3$(Ce) w/ 256-fold PMT

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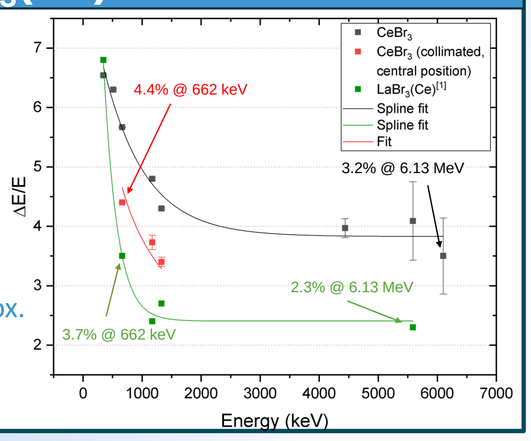
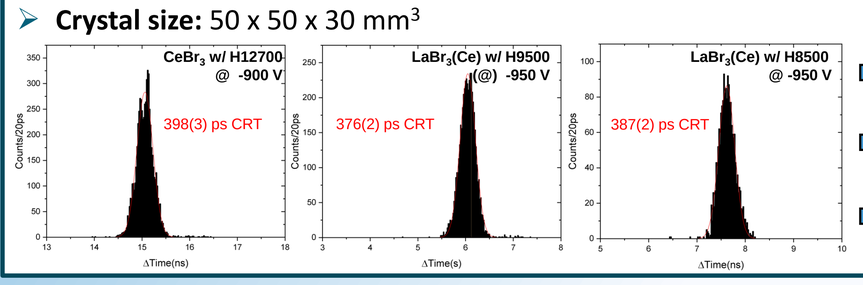
$LaBr_3$(Ce) shows approx. 1% reduced relative energy resolution



Coincidence Resolving Time

- Reference coincidence time resolution measured against plastic scintillator (**BC-418**) read out by **Photonis XP2020Q PMT**
- **Crystal size:** 50 x 50 x 30 mm^3
- Time resolution of an individual detector obtained by deconvolution of CRT:

$$\triangle T_{LaBr_3} = \sqrt{(\triangle T_{tot})^2 - (\triangle T_{plast.1})^2}$$



- **$CeBr_3$/H12700**: 281(3) ps
- **$LaBr_3$/H8500**: 266(3) ps
- **$LaBr_3$/H9500**: 250(2) ps

Outlook: next experimental steps

- **Spatial resolution** determination of $CeBr_3$ and $LaBr_3$(Ce) with 64-fold PMT
- **New electronics for SiPM** readout under investigation (PETsys)
- Investigation of pixelated **GAGG scatter array with SiPM** readout
- Investigation of simultaneous, but spatially disjunct **photon and electron** detection in monolithic absorber
- Study for **speeding up** the photon interaction point reconstruction in monolithic crystal
- Investigation of **multiple photon** detection in monolithic absorber
- **Depth-of-Interaction (DOI)** measurements in the absorber

References :
[1] S. Aldawood, PhD Thesis, LMU/ King Saud University, 2016

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