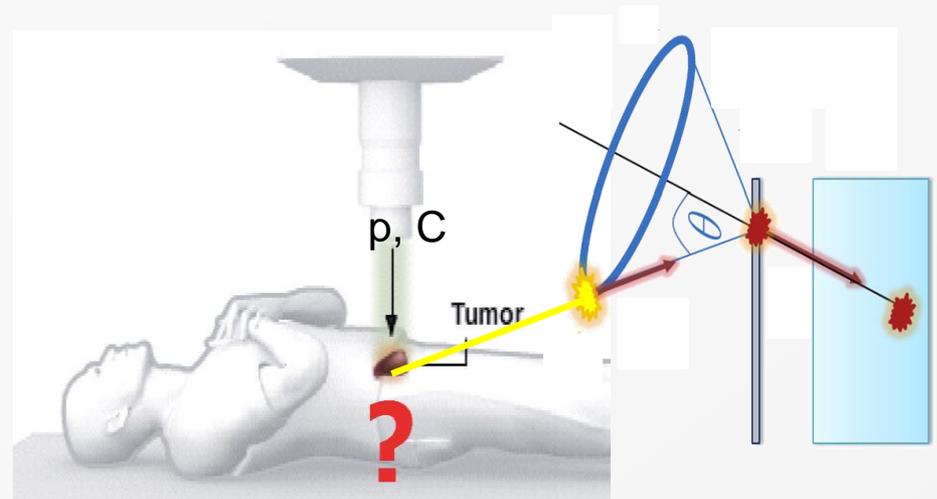


# Commissioning of a Compton camera for ion beam range verification via prompt $\gamma$ detection

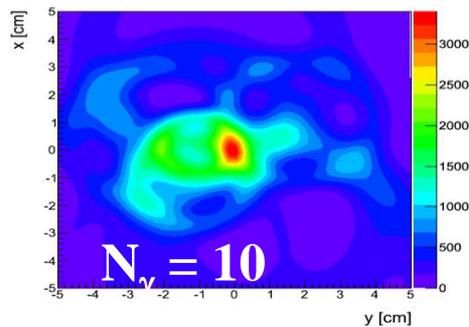
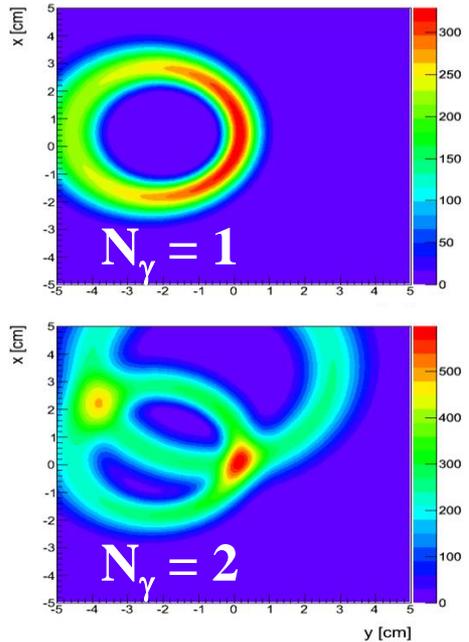
Saad Aldawood  
LMU/ Munich

## Outline:

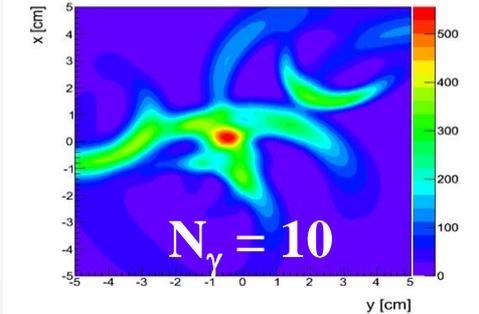
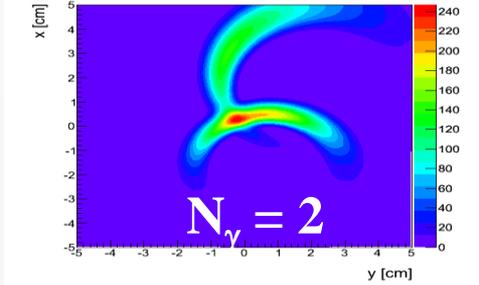
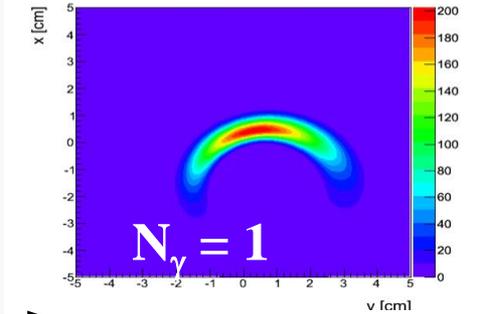
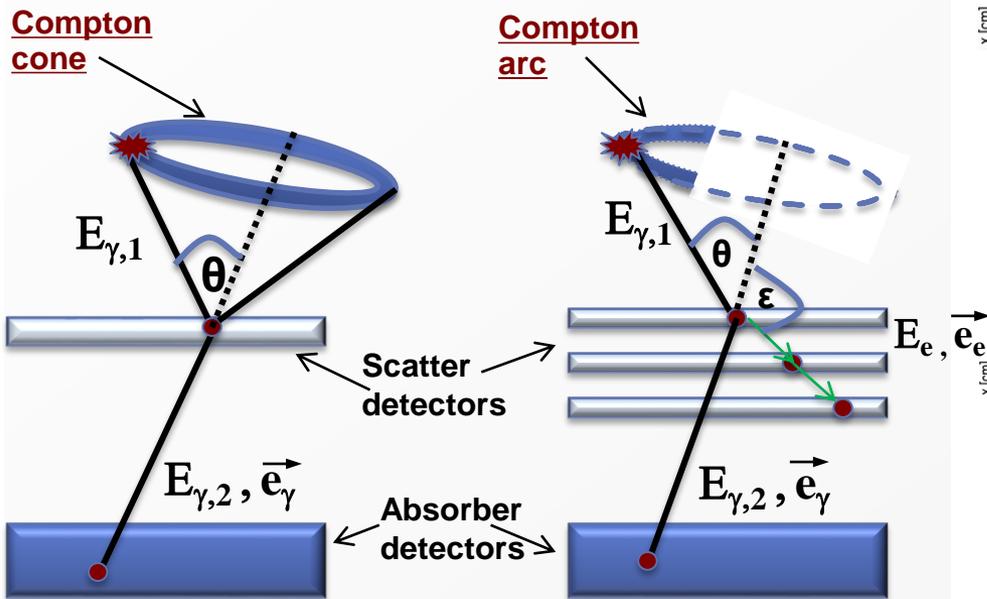
- ❖ Compton camera
  - principle
  - materials and setup
- ❖ Offline and online characterization of prototype detector system



# Principle of Compton Camera



C.Lang; PhD thesis; 2015



C.Lang; PhD thesis; 2015

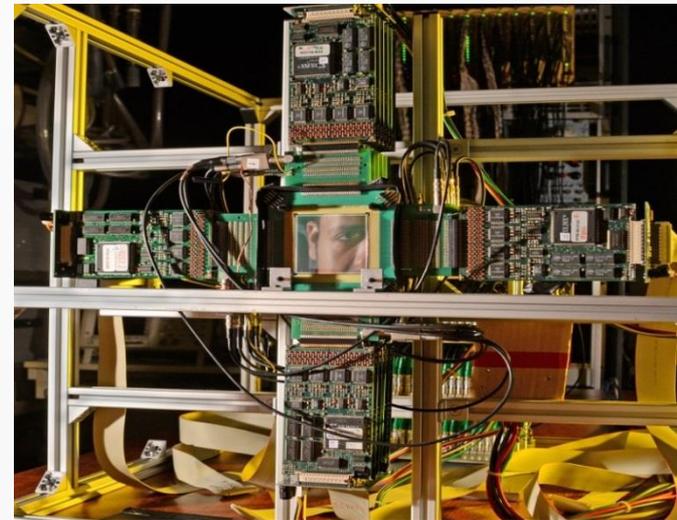
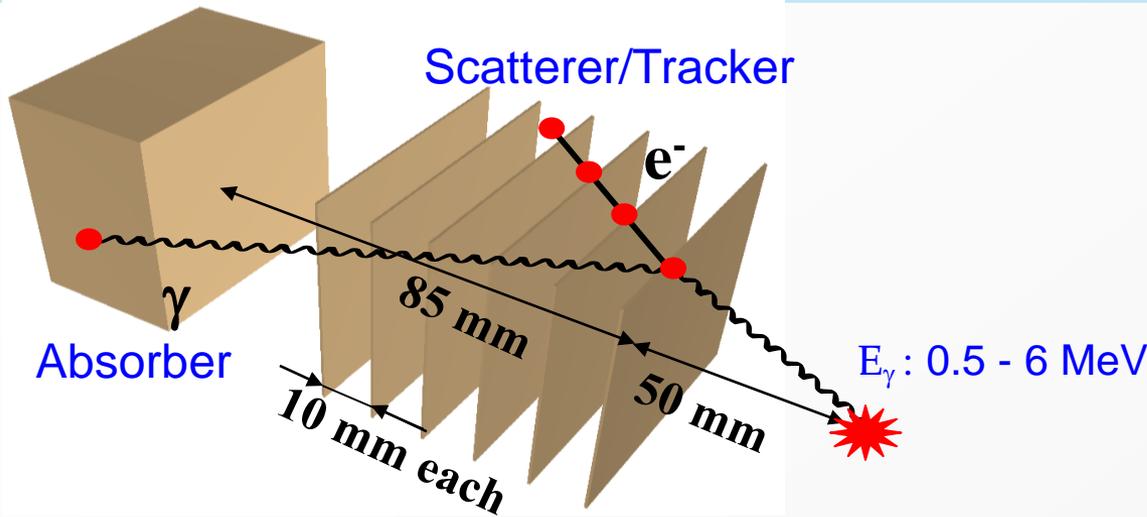
## ➤ $\gamma$ tracking

- incident and scattered photon
- Compton cone

## ➤ $\gamma$ and $e^-$ tracking

- Compton arc
- increase of reconstruction efficiency

# Compton Camera Layout



## ➤ Scatterer/Tracker:

6x double-sided silicon strip detectors (DSSSD)

- active area 50 x 50 mm<sup>2</sup>
- thickness : 500 μm
- 128 strips on each side
- pitch size 390 μm
- resistivity : > 10kΩcm

➔ ASIC-board: GASSIPLEX

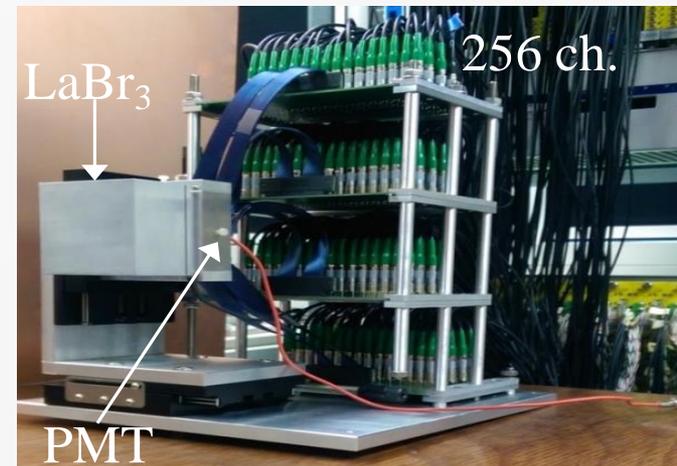
## ➤ Absorber:

LaBr<sub>3</sub> crystal:

- 50 x 50 x 30 mm<sup>3</sup>
- H9500 PMT(256 ch)

individual spectroscopy (NIM+VME-) electronics

- QDC
- TDC

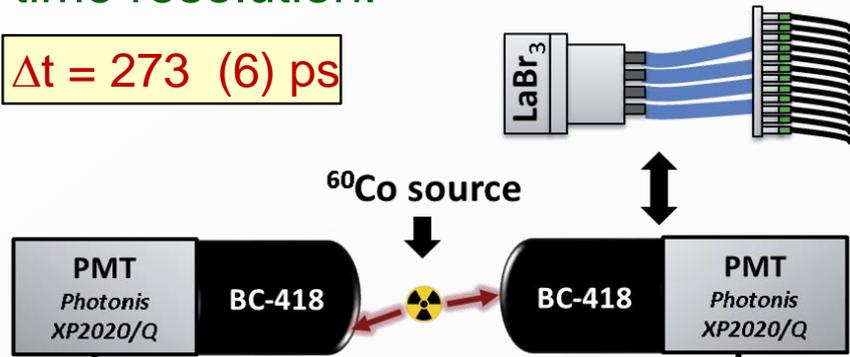


# LaBr<sub>3</sub> detector properties: offline characterization

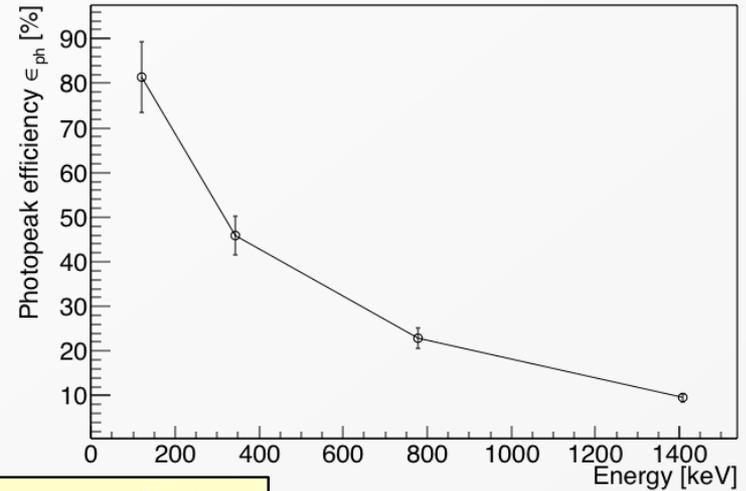


time resolution:

$\Delta t = 273 (6) \text{ ps}$

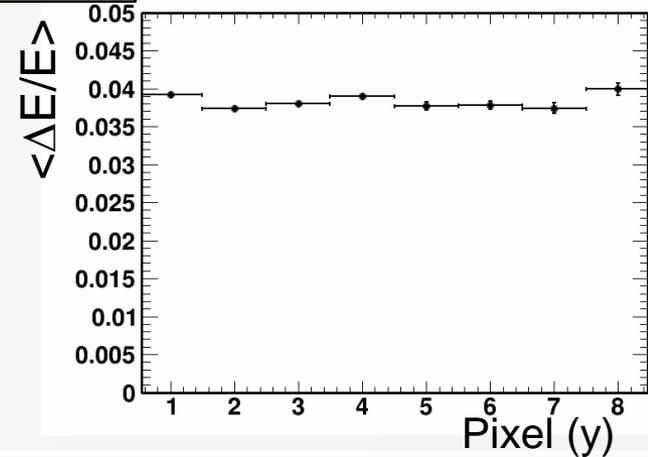
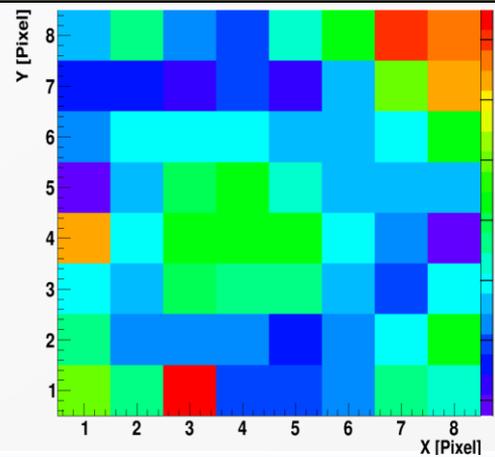
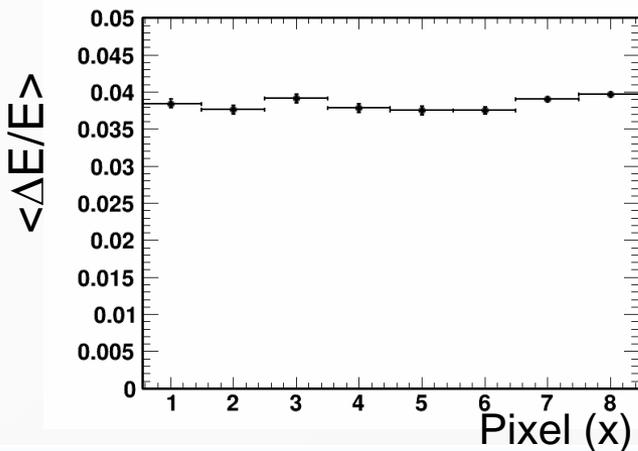


photopeak efficiency:



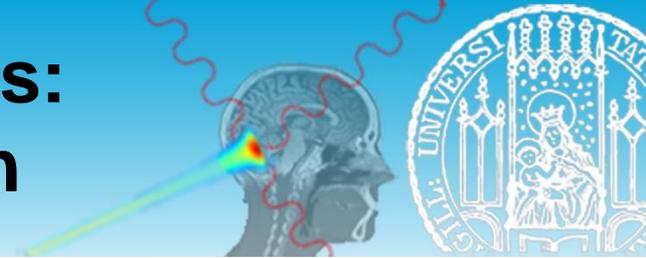
energy resolution:

$\langle \Delta E/E \rangle = 3.8\% \text{ @ } 662 \text{ keV } (^{137}\text{Cs})$

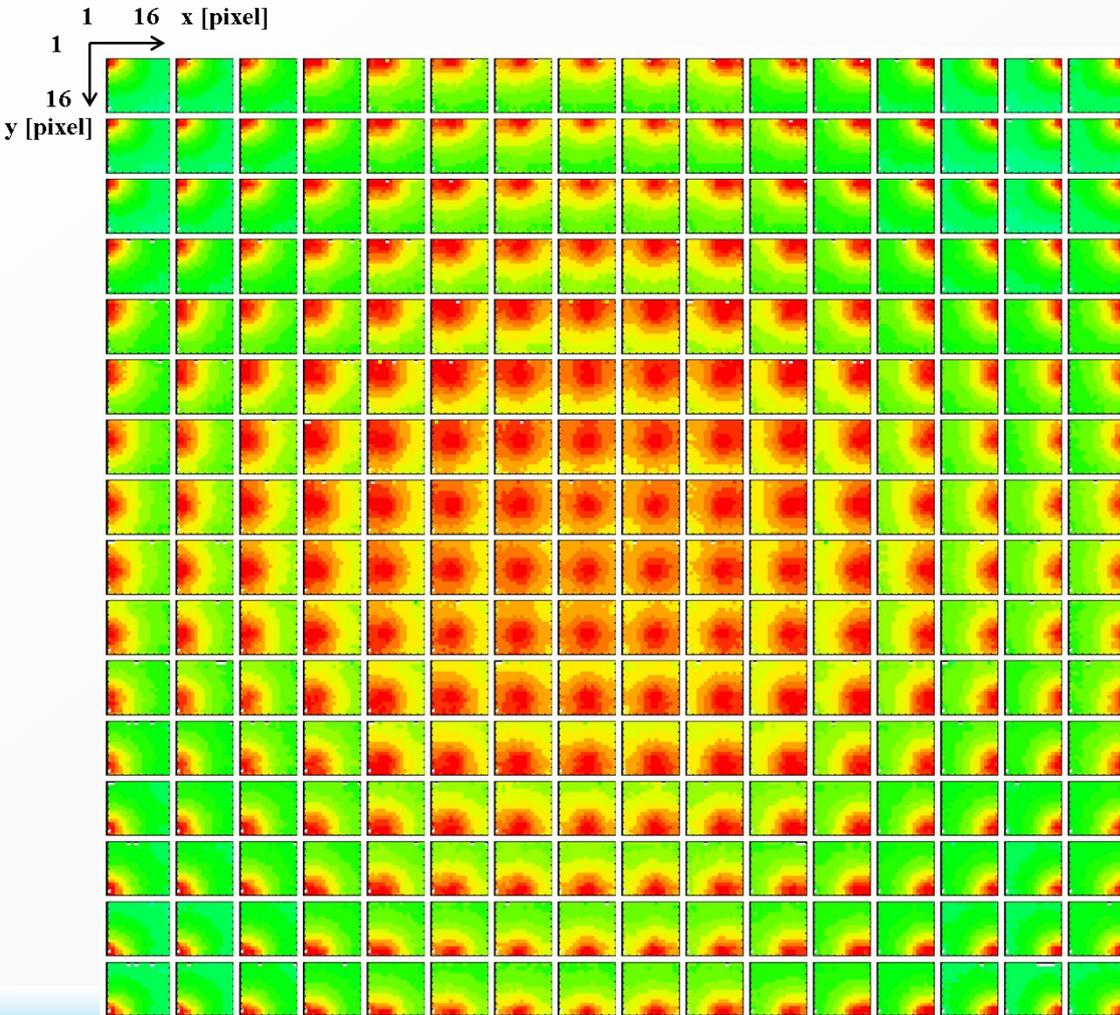


S. Aldawood et al, Frontiers in Oncology 5, 270 (2015).

# LaBr<sub>3</sub> detector properties: offline characterization



## ■ spatial resolution:

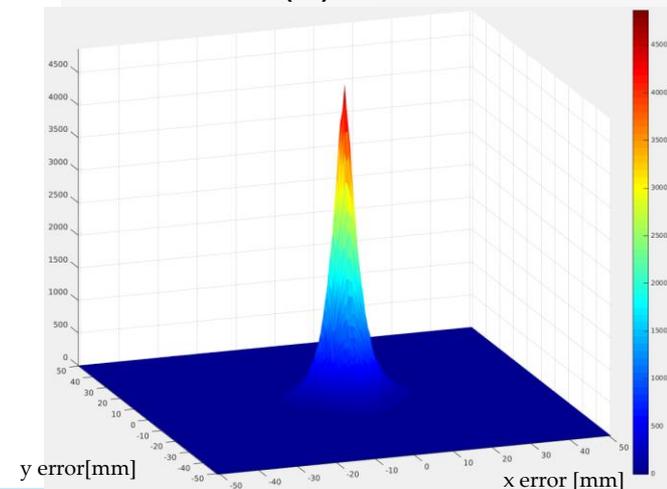


## ➤ k-Nearest Neighbor algorithm (k-NN, developed at TU Delft)

→ Full 2D scan of the crystal:  
step size 3 mm (in x,y)

- Source position moving from top left to bottom right
- positions
- In reality use position scan (step size 0.5 mm)

→ FWHM = 5.0 (1) mm



# LaBr<sub>3</sub> detector properties: (online) high-energy calibration

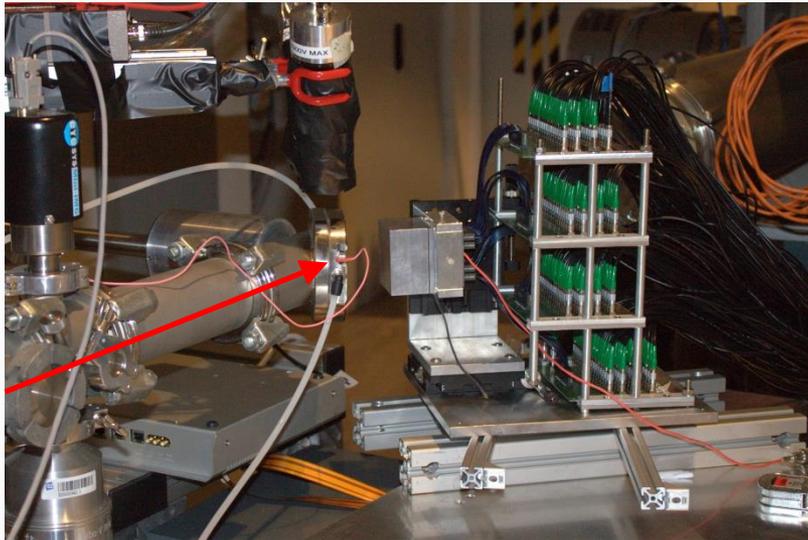


## ➤ simulation: GEANT4

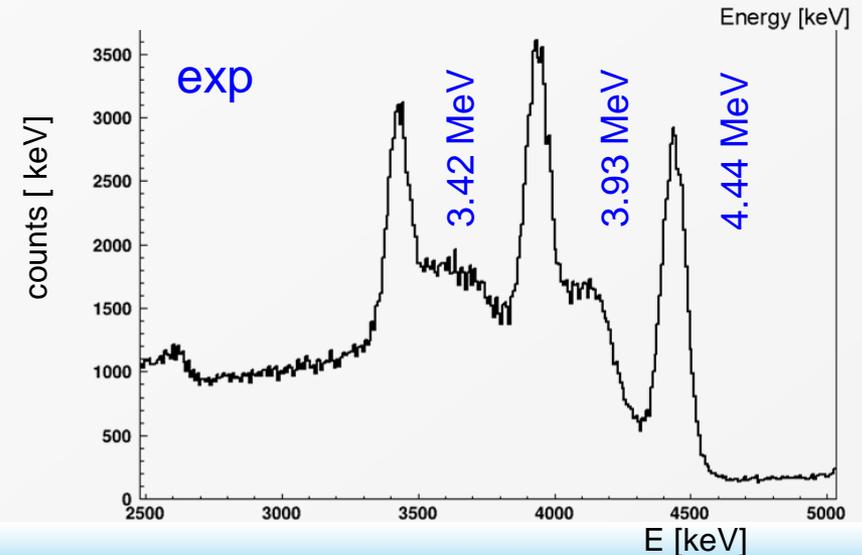
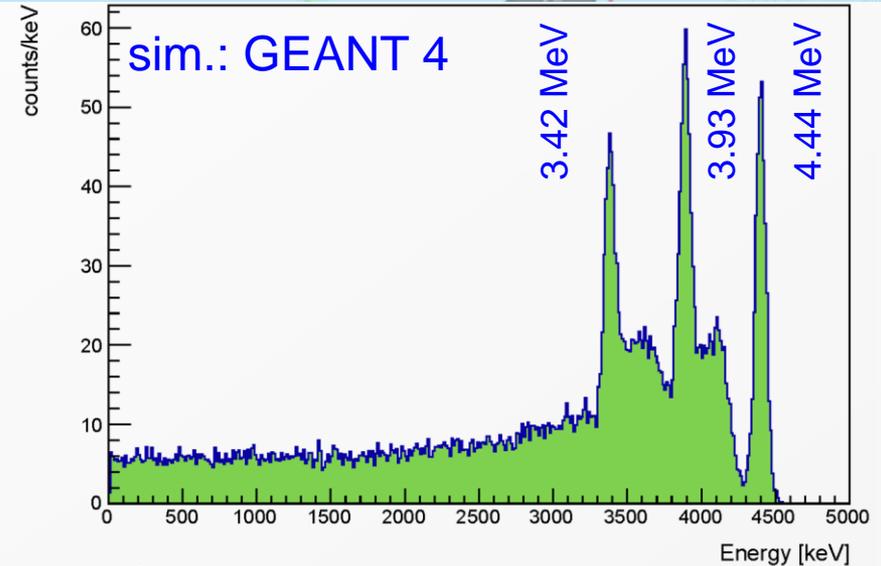
- $E_\gamma = 4.44$  MeV

## ➤ experiment at Tandetron (HZDR, Dresden/Rossendorf):

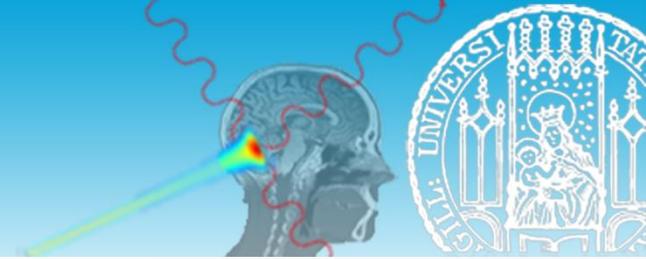
- low energy ( $\sim 1$  MeV) protons
- $E_\gamma = 4.44$  MeV via  $^{15}\text{N}(p, \alpha\gamma)^{12}\text{C}$



➔ validation of MC simulations

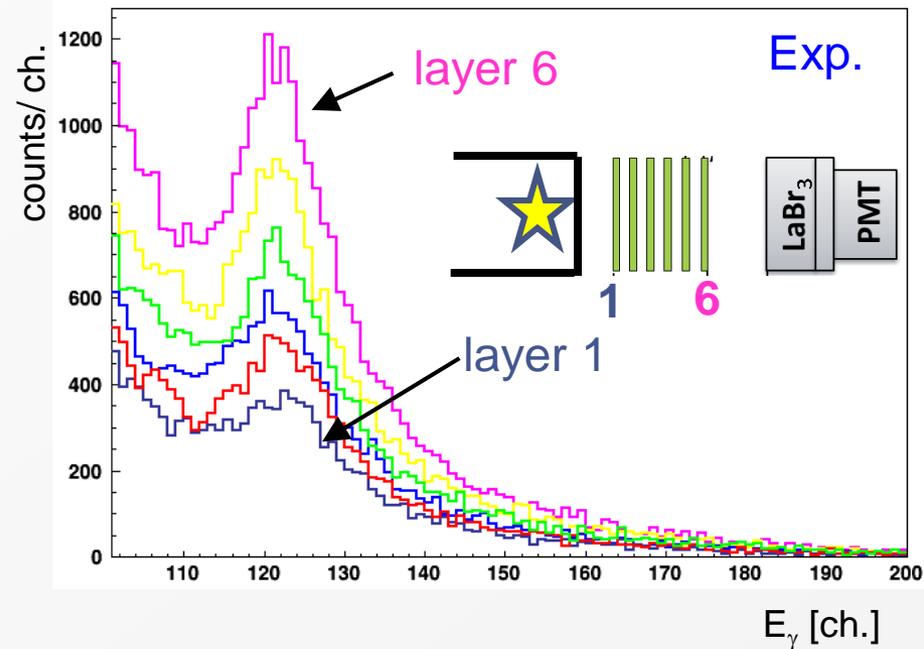
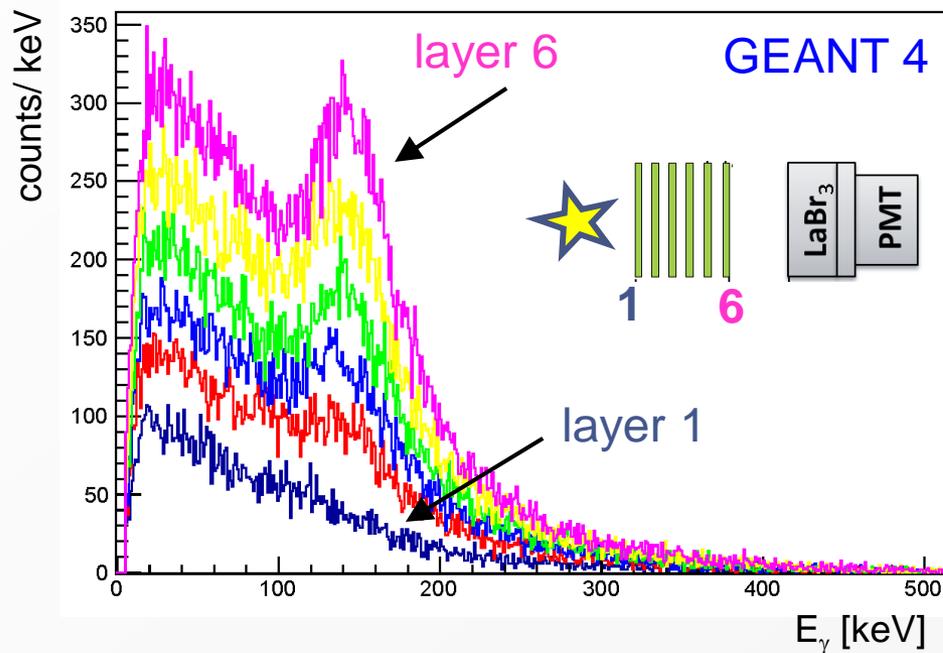


# DSSSD: response to 4.44 MeV photons



## Energy deposition in 6 DSSSD layers: $E_\gamma = 4.4$ MeV

from simulation: increasing yield from front- to backside layers  
(accumulating contributions from Compton electrons)



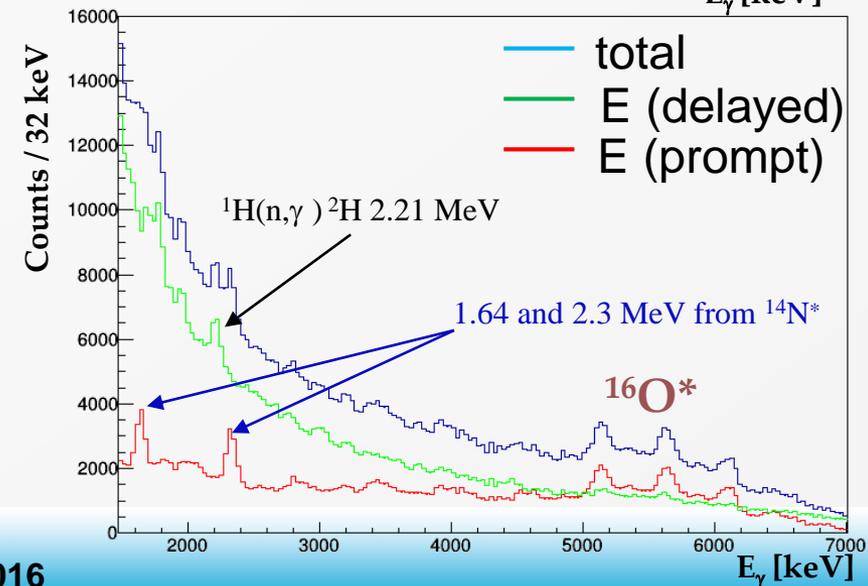
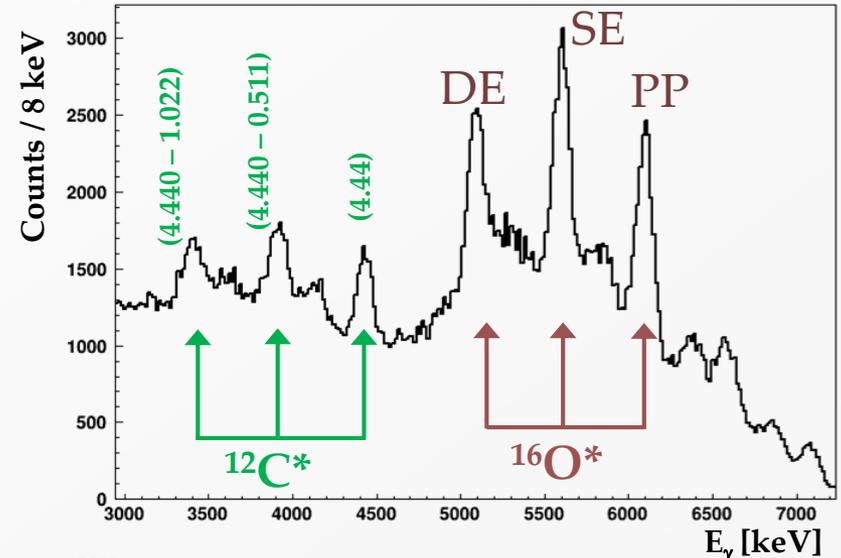
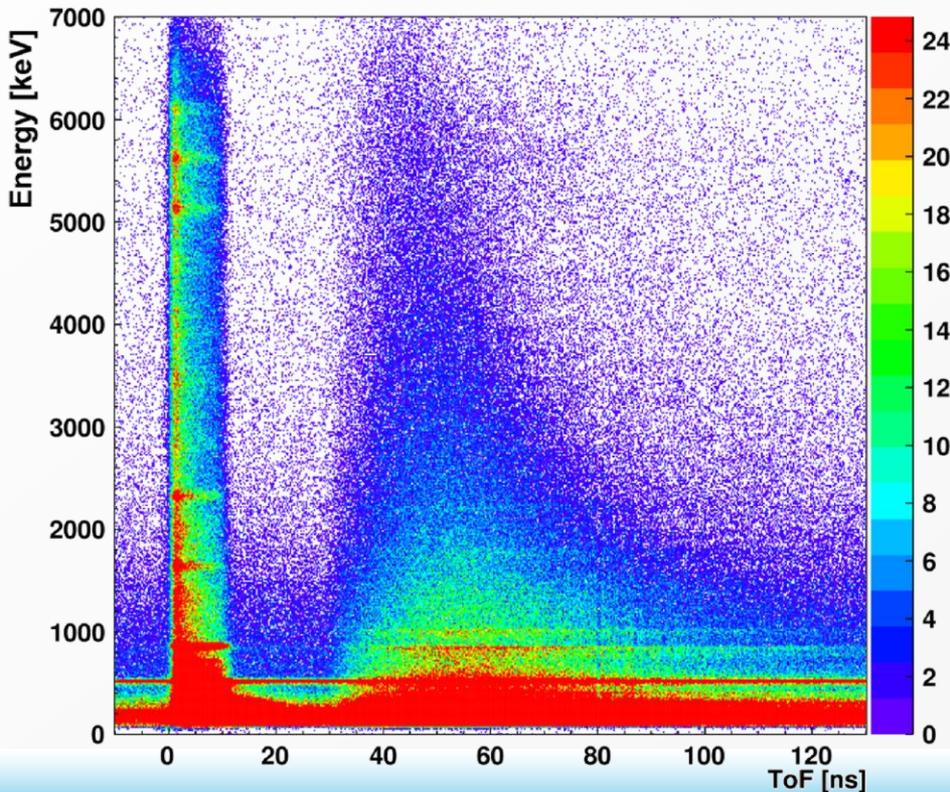
→ simulations verified

# Commissioning of the camera at low energy particle beam



→ experiments at MLL Tandem

- proton beam,  $E_p=20$  MeV
- deuteron beam,  $E_d=20$  MeV
- $\Delta t = 400$  ns (width:  $\sim 6$  ns)
- water phantom

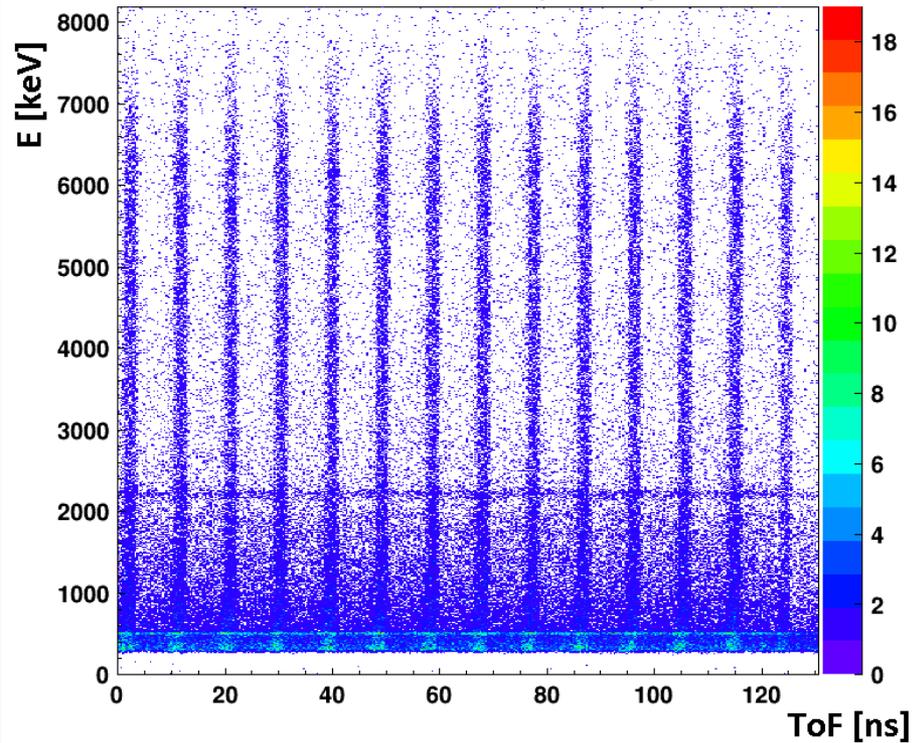


# Commissioning of the camera at therapeutic proton beam

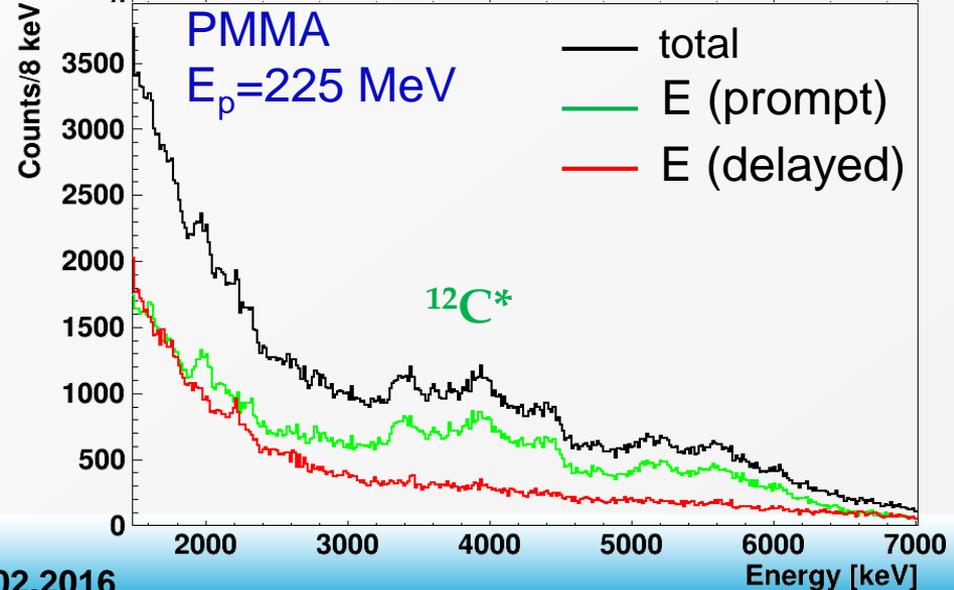
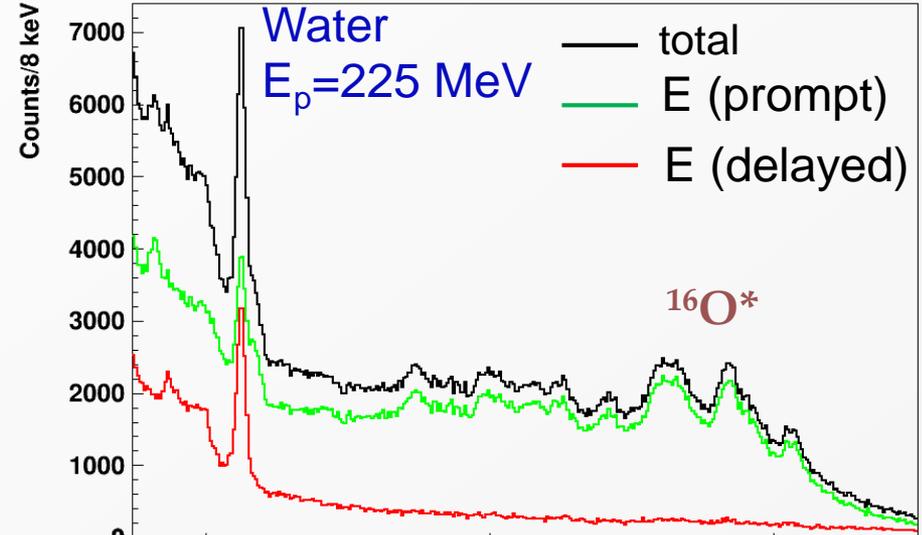


## Experiment at OncoRay (Dresden)

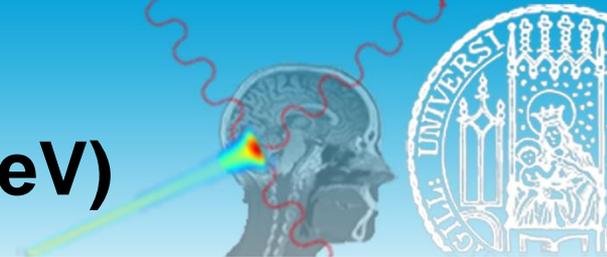
- $E_p = 100, 160$  and  $225$  MeV
- cyclotron RF:  $106$  MHz ( $\Delta t = 9.4$  ns)
- water phantom
- PMMA phantom ( $C_5O_2H_8$ )



→ neutron suppression using ToF

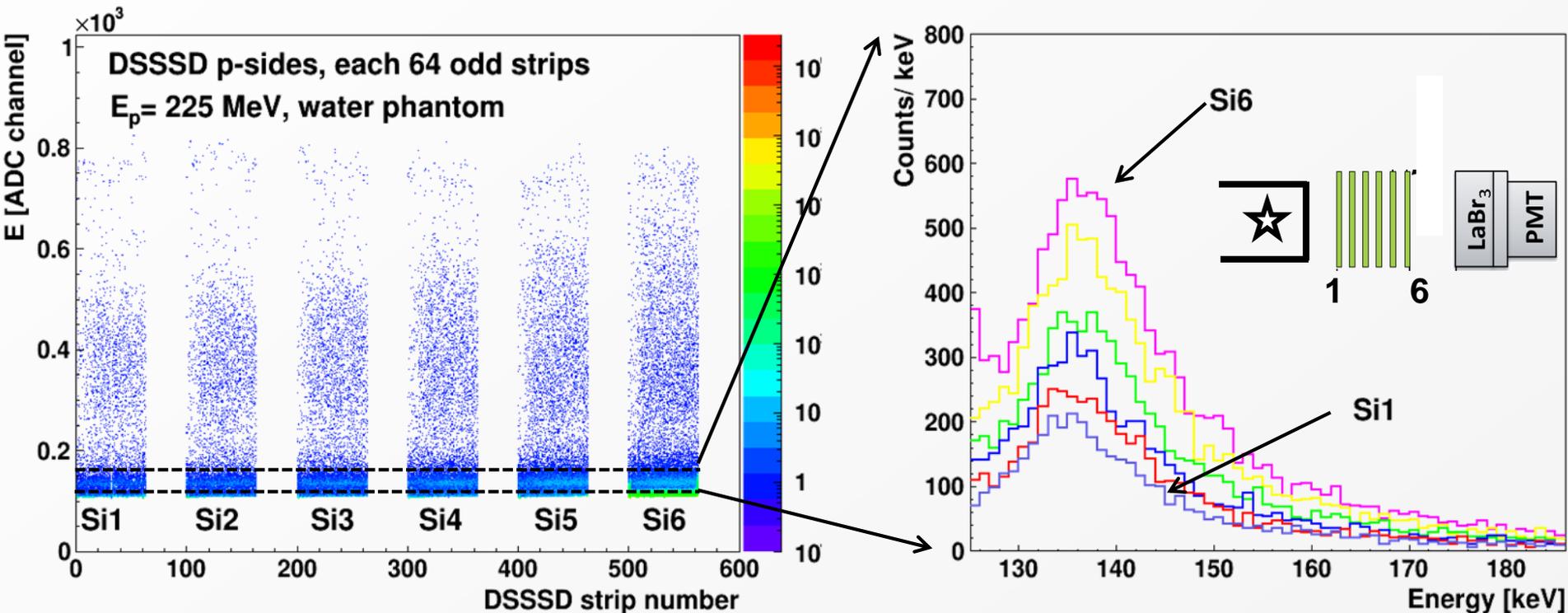


# DSSSD: response to prompt $\gamma$ ray (4.4 – 6.1 MeV)



## ➤ Energy deposition in 6 DSSSD layers due to prompt gamma ray

→ Compton electron energy deposition increases sequentially from layer 1 to layer 6



- one port of p-side
- 64 odd strips for each layer
- gain matching correction applied

$E_p = 225$  MeV, water target

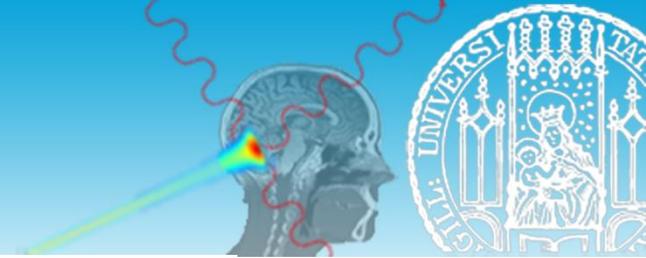
# Conclusion and Outlook



- Compton camera prototype for online ion beam range monitoring in hadron therapy under development:
  - Absorbing detector ( $\text{LaBr}_3$ ) characterization accomplished:
    - $\langle \Delta E/E \rangle = 3.8\% @ 662 \text{ keV}$
    - $\Delta t = 273(6) \text{ ps}$
    - Spatial resolution using kNN method:  $5.0(1) \text{ mm}$ , at 662 keV
    - Energy dependence: in progress ( $^{60}\text{Co}$ : 1.3 MeV)
  - Prompt  $\gamma$  energy measurement with therapeutic proton beam:
    - data analysis in progress
  - Upgrade of ASIC-based electronic readout system:  
modern GET ASIC chip,  $\mu$ -TCA standard  
applicable to full camera ?
  - Test the  $\text{LaBr}_3$  scintillator with SiPM sensor readout



# Thanks to:



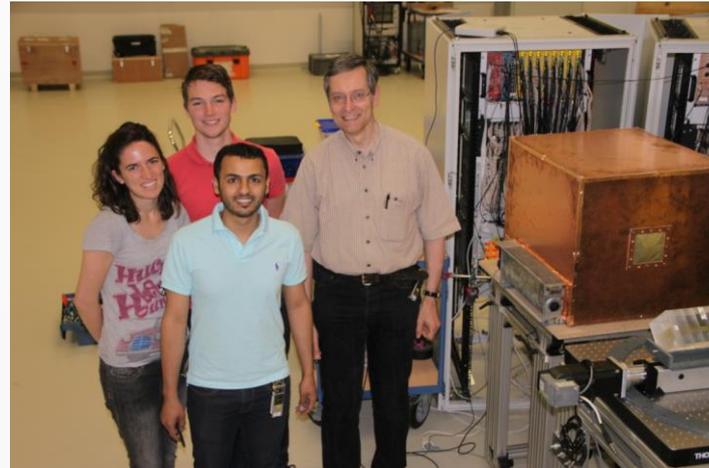
P. G. Thirolf  
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 A. Miani  
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