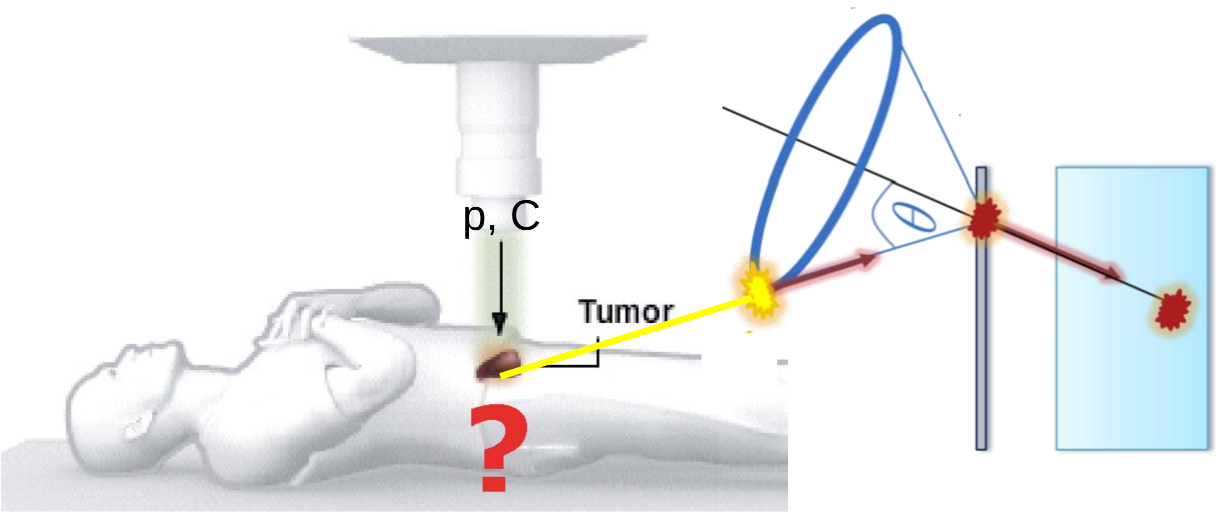
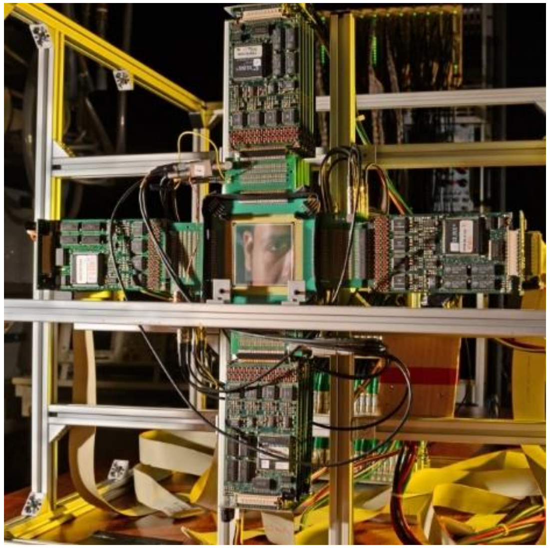
Status of the Garching Compton Camera Prototype

P.G. Thirolf, LMU Munich



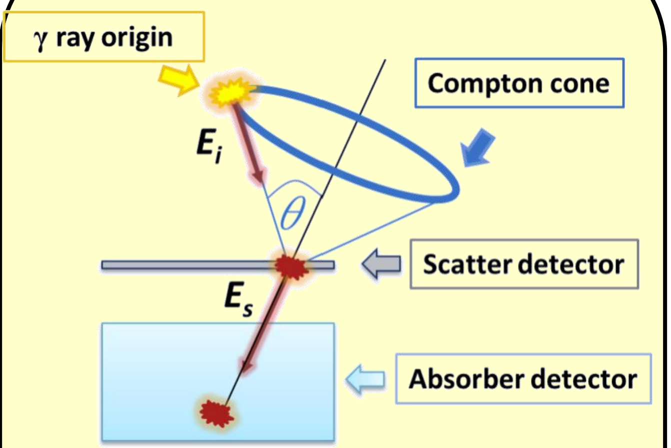


- monolithic absorber detector performance:
  - spatial resolution: k-NN algorithm vs. Convolutional Neural Network
  - influence of multi-hit interactions
- alternative component studies: $CeBr_3$ compared to $LaBr_3$(Ce)
  SiPM compared to MA-PMT
  pixelated GAGG scatter array
- optical alignment system

Compton-Imaging and Compton Camera

- **exploit kinematics of Compton scattering for medical imaging:**

γ tracking:

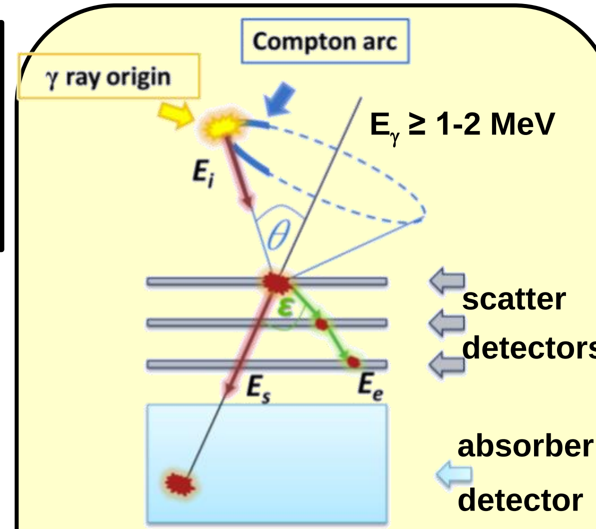


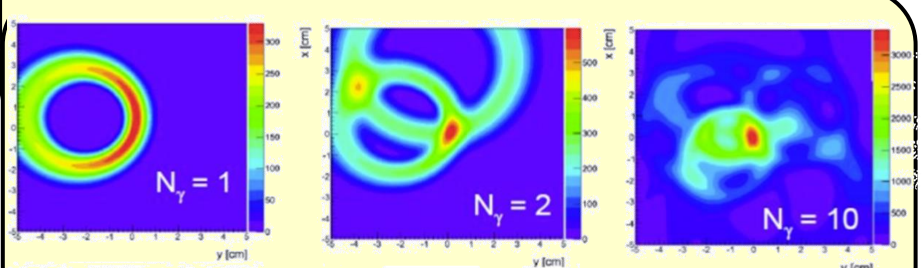
Idea already in 1974:

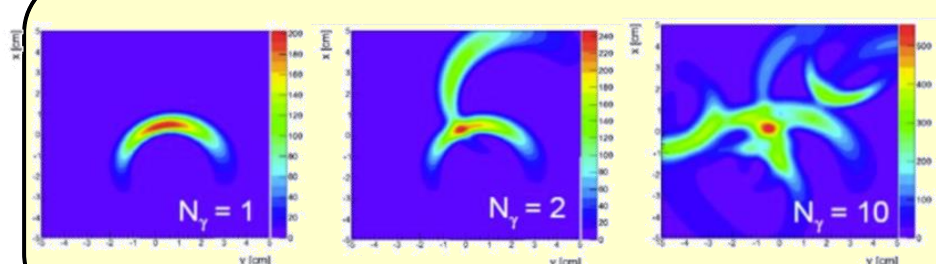
Todd, Nightingale, Everett:
(Nature 251, 132-134):
"A proposed gamma camera"

$$E_s = \frac{E_i}{1 + \frac{E_i}{m_0 c^2}\left(1 - \cos\theta\right)}$$

γ + electron tracking:







LMU Munich
Compton Camera Prototype

- **Garching Compton camera layout:**

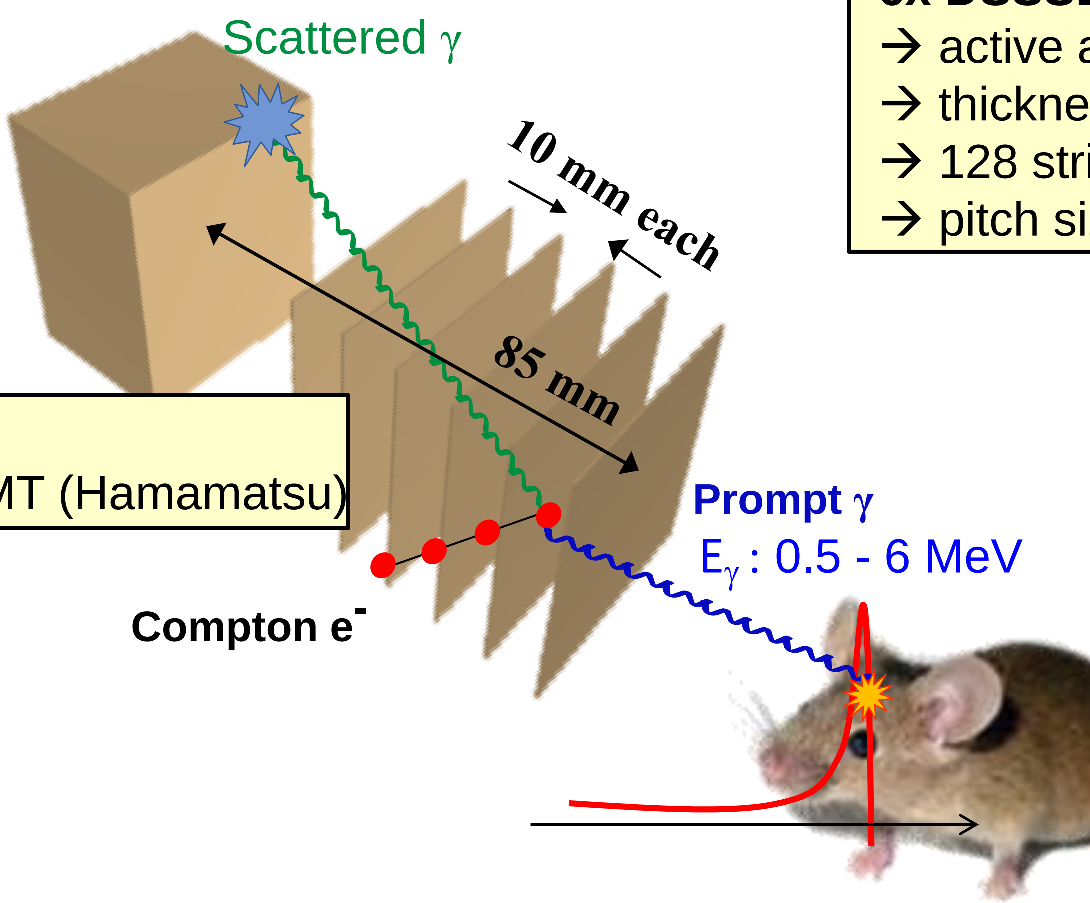
Scatterer/Tracker Array : (double-sided) Si-strip detector (DSSSD)

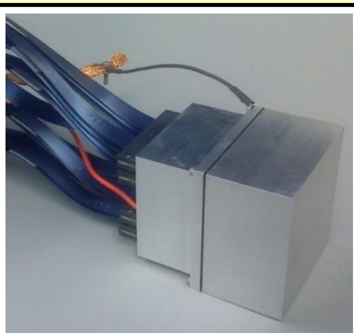
6x DSSSD
→ active area 50 x 50 mm^2
→ thickness : 500 μm
→ 128 strips on each side
→ pitch size 390 μm

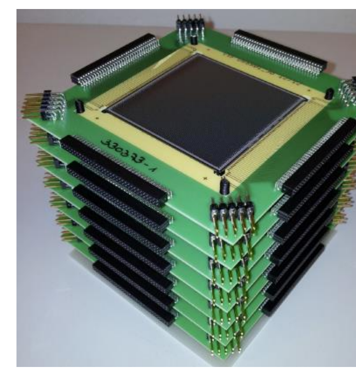
Absorber:

Scintillator crystal ($LaBr_3$:Ce + PMT, $CeBr_3$ + PMT)

50 x 50 x 30 mm^3
64/256-seg. MA-PMT (Hamamatsu)







P.G. Thirolf et al., EPJ Web of Conf. 117, 05005 (2016)

S. Liprandi, PhD thesis (2018), S. Aldawood, PhD thesis (2017)

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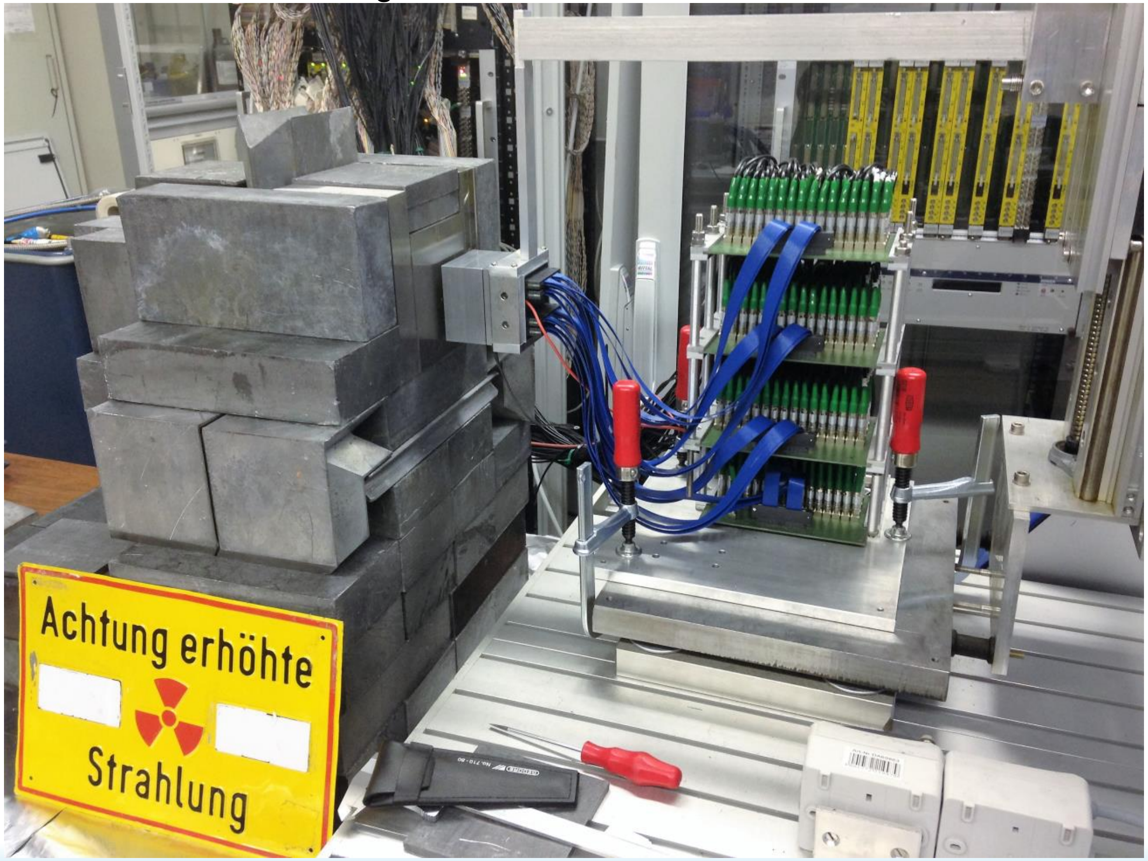
Experimental setup for collimated source scan

- spatial resolution: based on 2D detector response

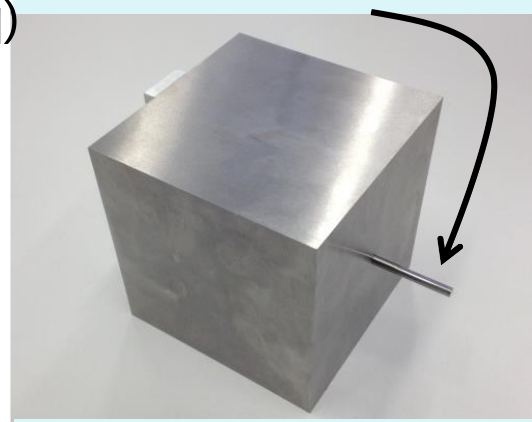
  - collimated γ source (Ø 1 mm): ^{137}Cs (662 keV, 72 MBq)

    ^{60}Co (1.17/1.33 MeV, 20 MBq)

  → 2D scan of $LaBr_3$ (mounted on translational stage)



Exchangeable WC collimator tube



100x100x100 mm³ DENSIMET®

1 mm opening

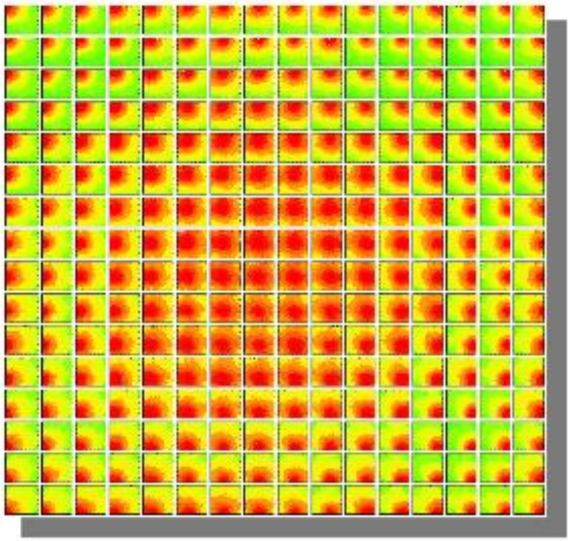
2D Light Amplitude Distributions

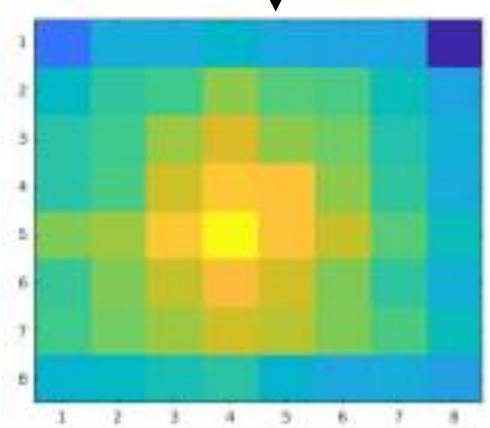
2D light amplitude reference library

^{60}Co (1.3 MeV)
here: 3 mm step size in (x,y)

8x8 ch. light distribution, single event

- 1 mm collimation
- 0.5 mm step size (x,y)
- 10^4 irradiation position
- 400 – 800 photopeak events/position





Interaction position reconstruction:

Conventional method: k-nearest neighbour (kNN) algorithm
variant: Categorical Averaged Pattern (CAP)

Machine learning approach: Convolutional Neural Network (CNN)

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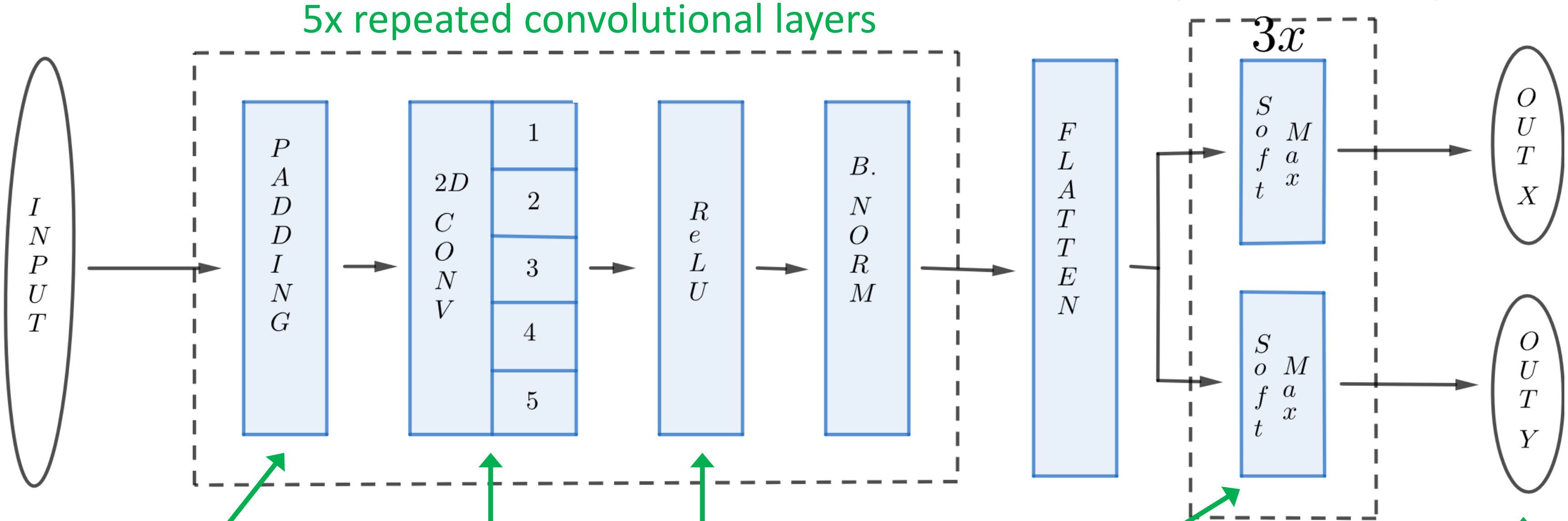
Convolutional Neural Network Architecture

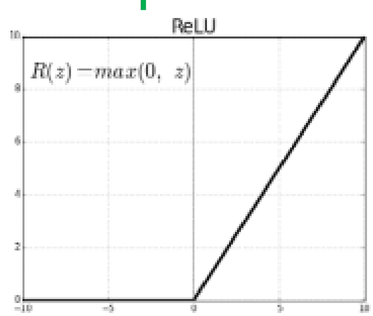
5x repeated convolutional layers

3 fully connected layers



Zero padding

5 kernels
3 x 3 size



- 2x FC, ReLU
- SoftMax output activation

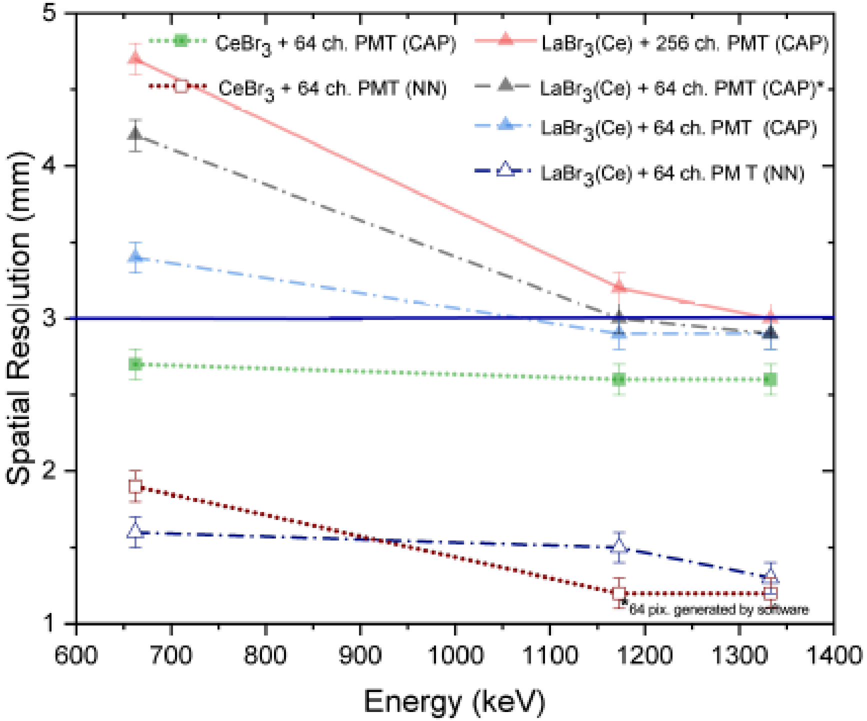
2 probability vectors reconstructed (x,y)

Much better explanations in **Poster Session by Maria Kawula**

M. Kawula, MSc thesis, LMU 2019 (in preparation)

Spatial Resolution from Monolithic Scintillator

spatial resolution reached physical limit for $CeBr_3$ @ 60Co energies:



Energy [MeV]	Spatial resol. CAP [mm]		Spatial resol. Neural Netw. [mm]	
	$LaBr_3$	$CeBr_3$	$LaBr_3$	$CeBr_3$
0.662	3.4(1)	2.7(1)	2.5(1)	2.1(1)
1.17	2.9(1)	2.6(1)	1.5(1)	1.2(1)
1.33	2.9(1)	2.6(1)	1.6(1)	1.2(1)
Memory	~GB		~MB	
Speed	~1ev/s		~10^4 ev/s	

→ CNN outperforms k-NN algorithm (CAP version)
→ CNN allows for drastic reduction of computional costs (prerequisite for in-vivo application)
→ sub- 1.5 mm resolution reached in large monolithic crystals

→ **Still open: behaviour at higher photon energies ?**

M. Kawula, MSc Thesis LMU 2019 (in preparation)

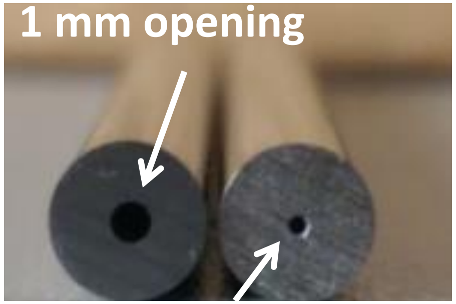
Ongoing Studies

- Can spatial resolution < 1 mm be reached ?

  - use of 0.6 mm collimator:

    not feasible with $LaBr_3$:Ce
    (SNR reduction due to internal activity)

    but: promising results with $CeBr_3$

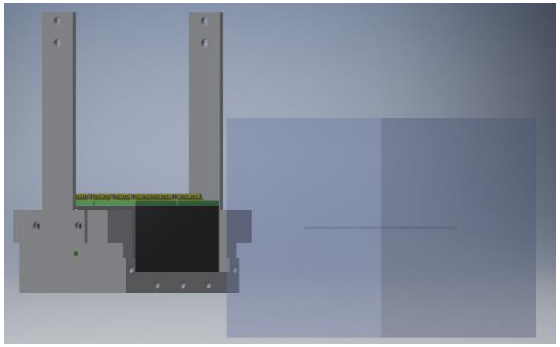


- Can DOI information be retrieved via Neural Network reconstruction ?

  - extend collimated crystal scan from 2D to 3D:

    sample light amplitude distributions from
    2 opposite side surfaces

  - libraries have been acquired, analysis is in progress



Multi-Hit Interactions in Absorber Crystal

- How do double-hit interactions affect the interaction position reconstruction ?

→ γ + γ (^{137}Cs, ^{60}Co) & γ + e (^{204}Tl: E_e = 764 keV)

- direct combined irradiations will not provide sufficient coincidence rate

→ combinatoric summation of γ-γ and γ-e events from individual collimated irradiations

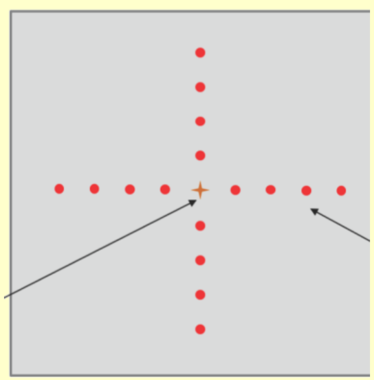
→ $CeBr_3$ crystal used (+ H12700 64-ch. PMT)

γ-γ

absorber crystal front face

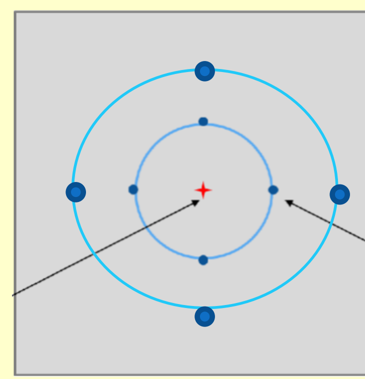
γ-e

^{60}Co or ^{137}Cs



^{60}Co or ^{137}Cs in distances of 5, 10, 15, 20 mm

^{137}Cs in center



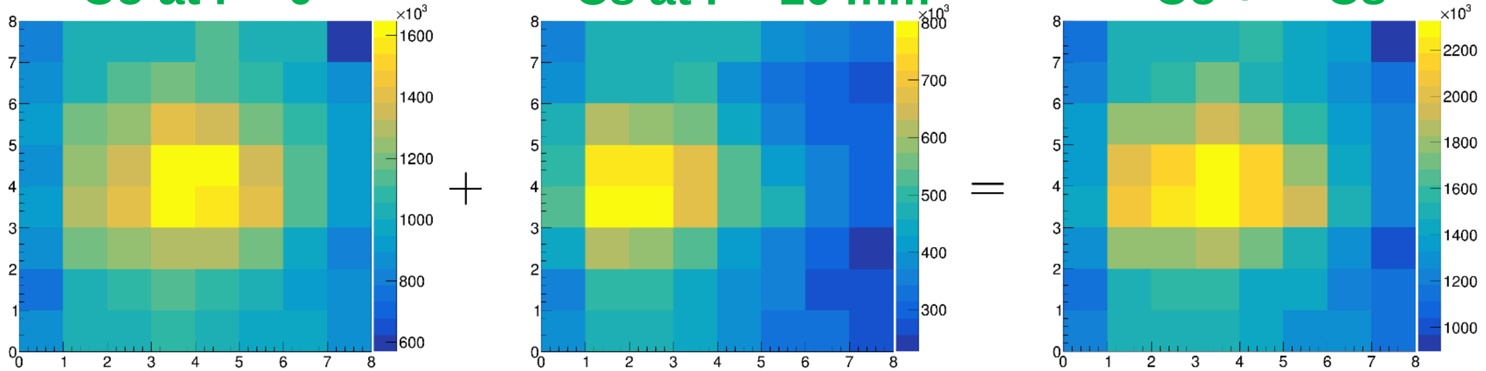
^{204}Tl in distance of 10, 20 mm

G. Vinci, MSc Thesis LMU 2019

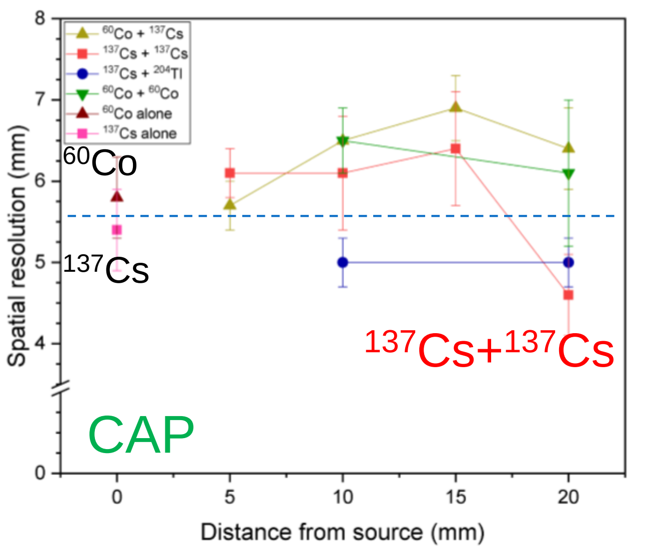
Multi-Hit Interactions in Absorber Crystal

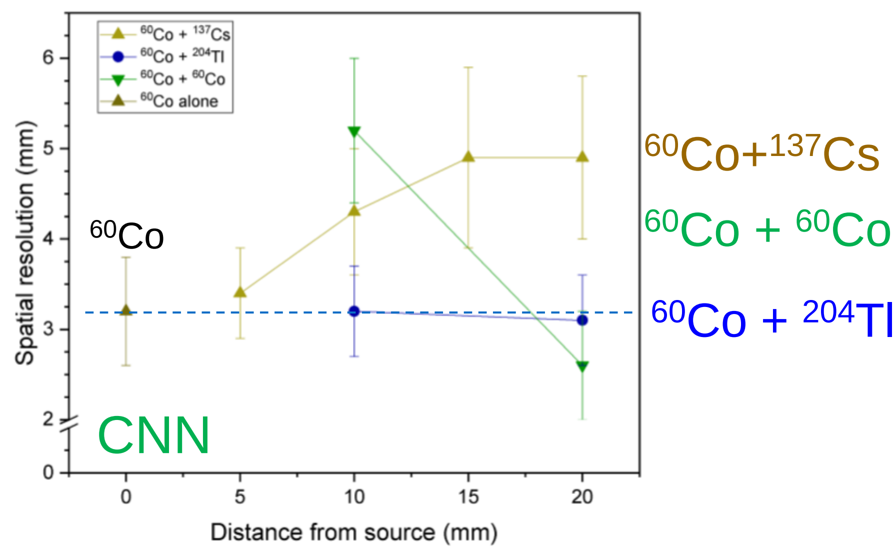
- Example: Photon + Photon (^{137}Cs, ^{60}Co):

^{60}Co at r = 0 | ^{137}Cs at r = 10 mm | ^{60}Co + ^{137}Cs



- Results:





G. Vinci, MSc Thesis LMU 2019

Comparative Scintillator SiPM Readout Studies

- Study any combination of:

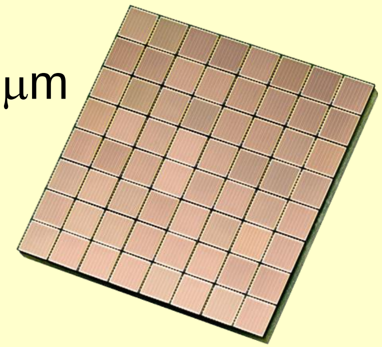
Detector: $LaBr_3$:Ce
$CeBr_3$

Photosensor:

KETEK SiPM array:
8x8 ch., 3x3 mm^2, cell size 15/25/50 μm

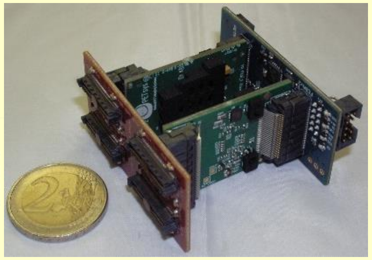
Hamamatsu SiPM array:
8x8 ch., 3x3 mm^2, cell size 50 μm

Hamamatsu MA-PMT:
8x8 ch., H8500, H12700



Readout/signal processing electronics:

PETsys (ASIC based)



Mesytec (individual components)

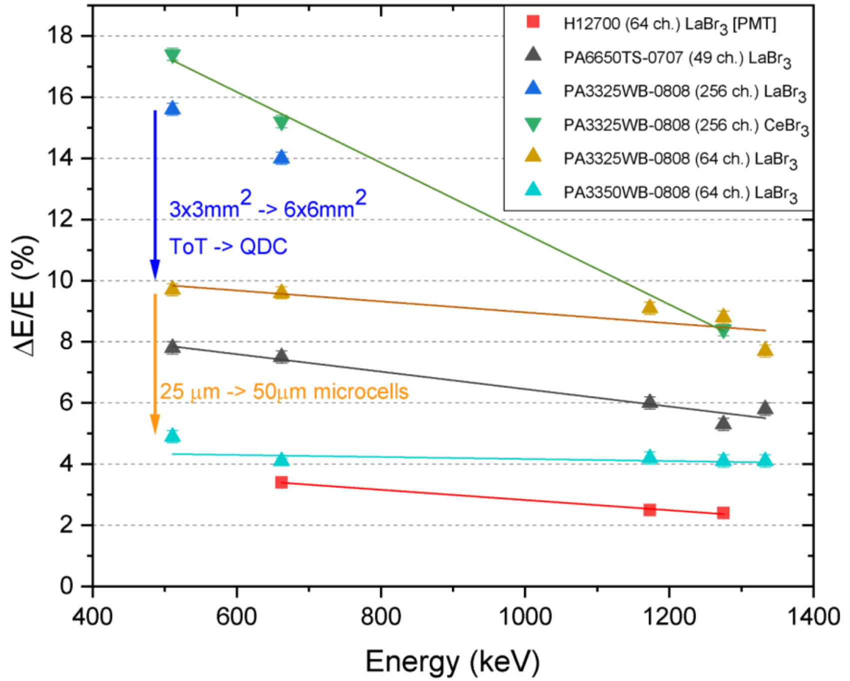
T. Binder, PhD thesis, LMU, in preparation

SIPM-based Scintillator Readout

- Energy resolution:

$LaBr_3$:Ce ($50x50x30\ mm^3$) crystal coupled to:

- **256-fold PMT** (Hamamatsu H9500)
- **64-fold PMT** (Hamamatsu H8500)
- **64-fold PMT** (Hamamatsu H12700)
- **256 ch. SiPM array:**
  4 x KETEK PA3325WB-0808 (cell: 25 μm)
- **64 ch. SiPM array**
  KETEK PA3325WB-0808/PA3350WB-0808 (25/50 μm)



$CeBr_3$: coupled to a **64-fold PMT** (H12700) and **256 ch. SiPM array** (4 x KETEK PA3325WB-0808)

Energy resolution (@ 662 keV):	**PMT**	**SiPM**
	3.4%	**4.1%**

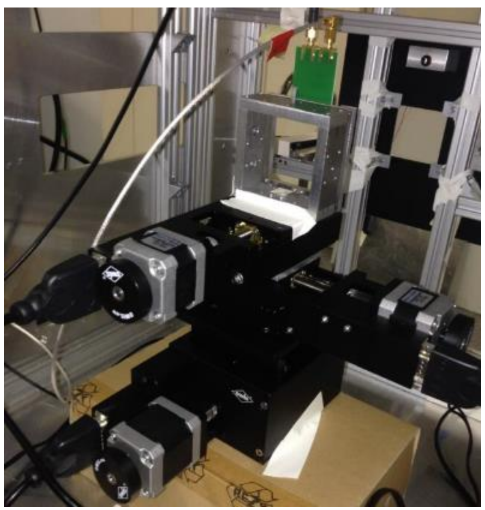
- Low light amplitude levels per channel deteriorate the energy resolution
- SiPM with high gain/ PDE and large active areas, provides comparable energy resolution as PMT (H12700 in red)

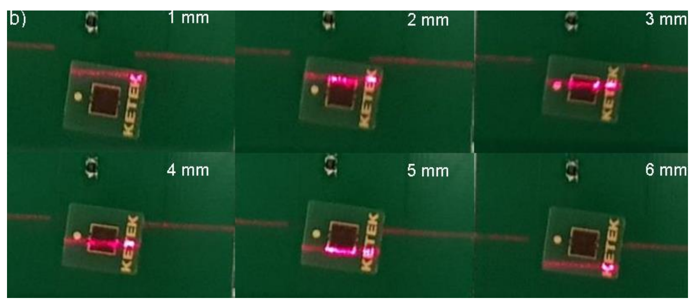
Much more information in **Poster Session by Tim Binder**

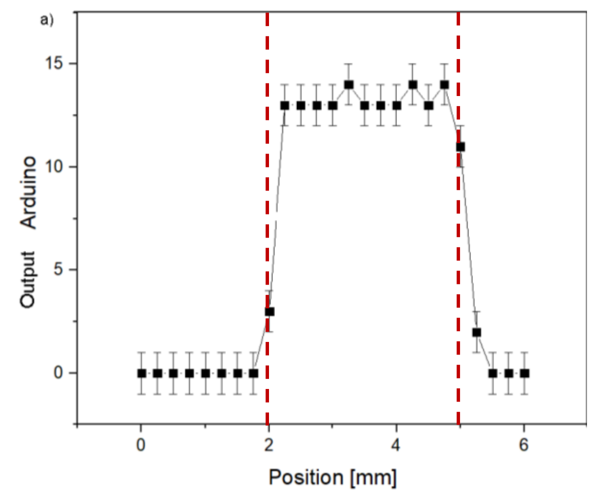
T. Binder, PhD thesis, LMU, in preparation

Optical Alignment System

- alignment of absorber relative to scatter component:
  - motorized (x,y,z) translation stages
  - laser diode attached to scatter detector frame
  - photosensor: SiPM pixel (final: 0.5x0.5 mm^{2}, tests with 3x3 mm^{2}) attached to absorber detector frame
  - control/readout via Arduino micro-processor



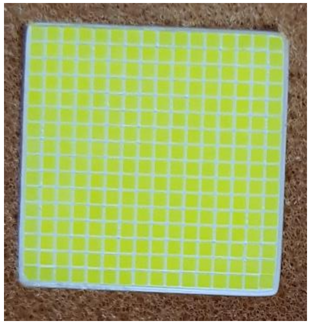




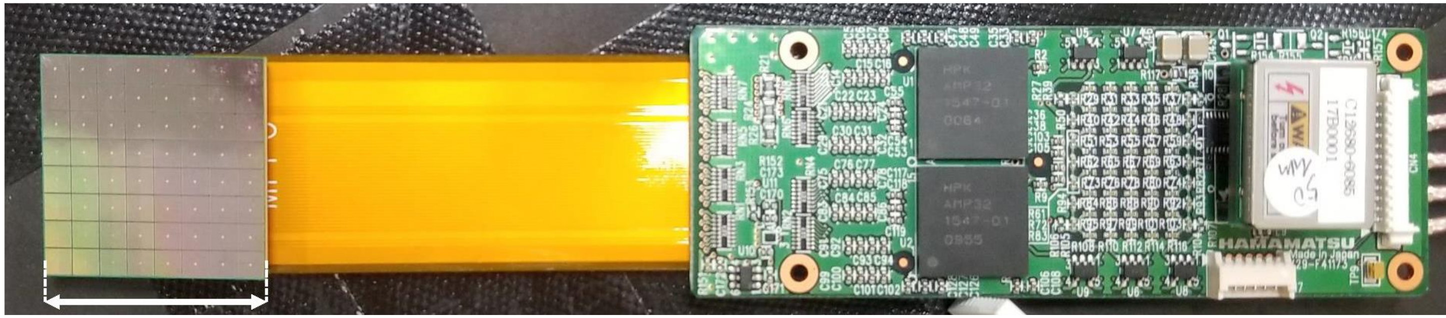
→ allows for relative alignment to ≤ 0.5 mm
→ allows for variation of distance between scatterer and absorber

A. Weinzierl, BSc thesis, LMU (2019)

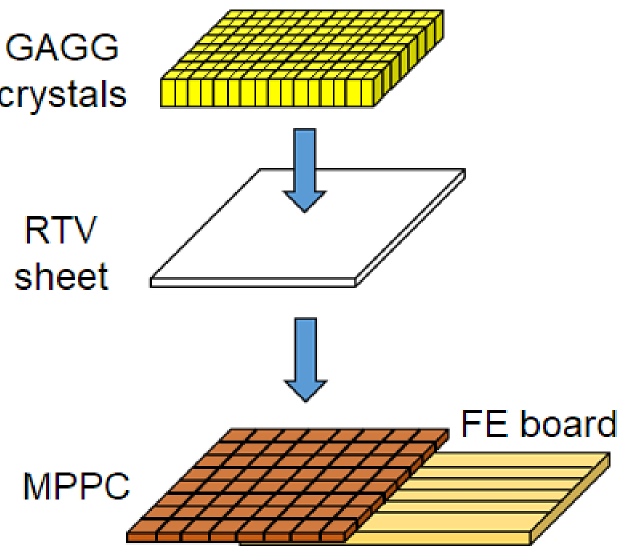
Pixelated (GAGG) Scintillation Scatterer



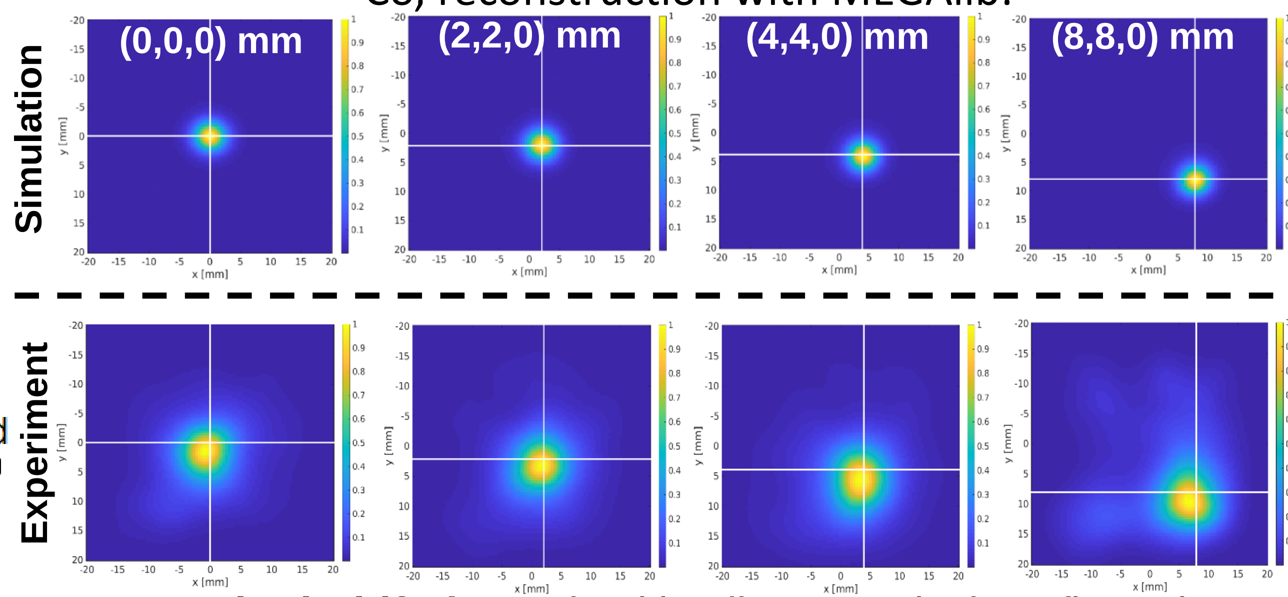
16x16: 1.45 x 1.45 x 6 mm³



25.8 mm, 8x8 ch., 3x3 mm²



^{60}Co, reconstruction with MEGAlib:



collaboration with QST-NIRS (Chiba/Japan)

- **2 mm (x,y) shift →** resolved in all geometrical configurations
- **σ_x, σ_y:** simulation: < 3 mm, experiment: < 6 mm

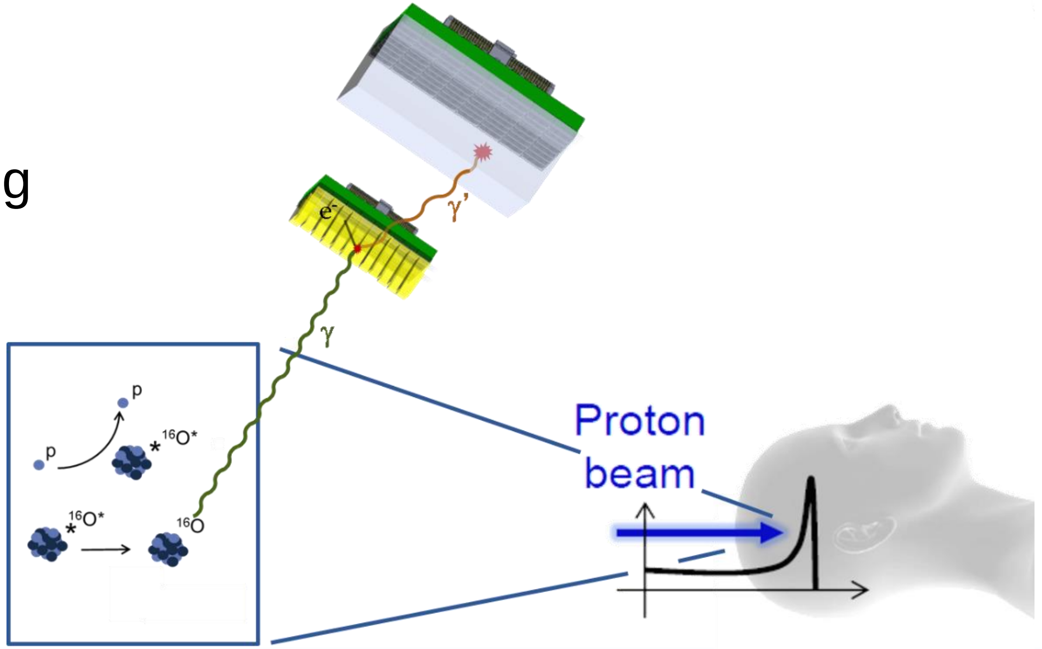
S. Liprandi, PhD thesis, LMU (2018)

Summary

- Spatial resolution:
  - drastic improvement (resolution & computational) by neural network
  - further improvement possible (0.6 mm collimation) ?
  - 3D extension for DOI ?
  - influence of double hits (γ+γ, γ+e): g-g has the larger impact

- Study alternative components:
  - SiPM readout vs PMT readout
    cross-comparison of crystals,
    photosensors, signal processing
  - $CeBr_3$ vs $LaBr_3$:Ce
  - pixelated GAGG scatter array

- Technical progress:
  - optical alignment system



Thanks to …

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Bayerische Forschungsstiftung

Thank you for your attention !