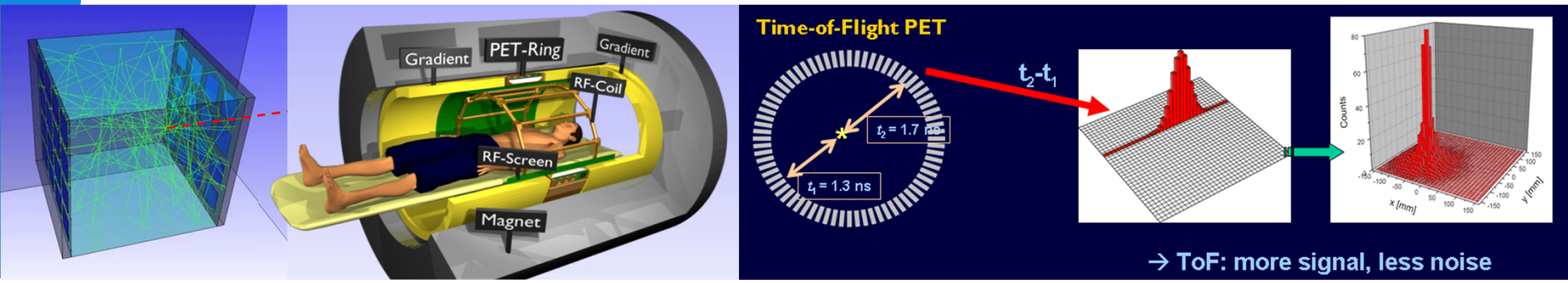


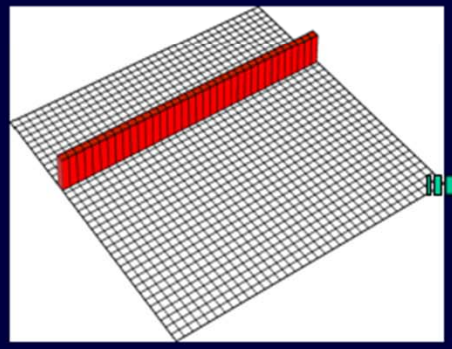
Ultrafast PET Detectors Based on Digital SiPMs and Their Use in In-Situ PET and Prompt Gamma Ray Imaging

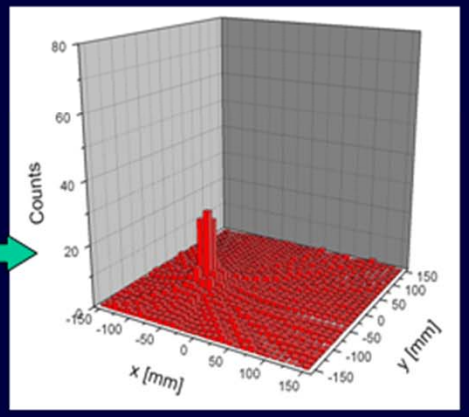
Dennis R. Schaart

ICTR-PHE 2014, Geneva, 13-Feb-2014

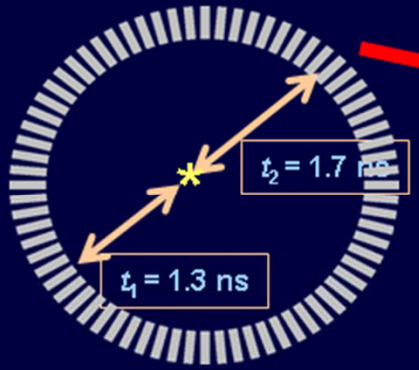
Time of Flight PET Systems

Conventional PET/ ToF off

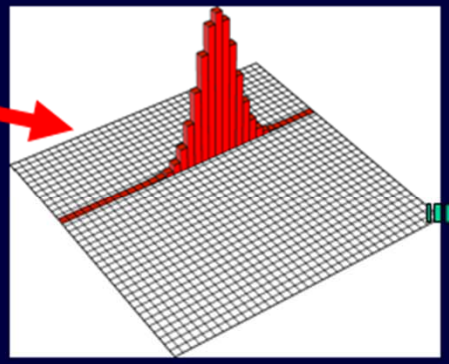


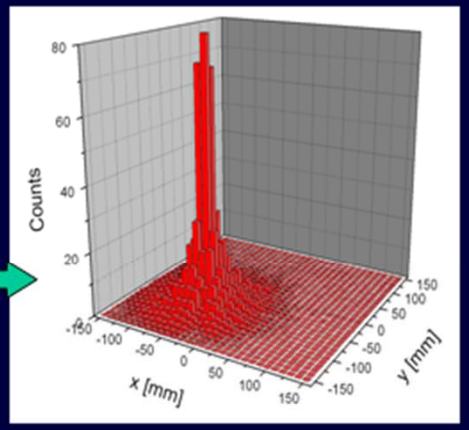


Time-of-Flight PET



t_2-t_1

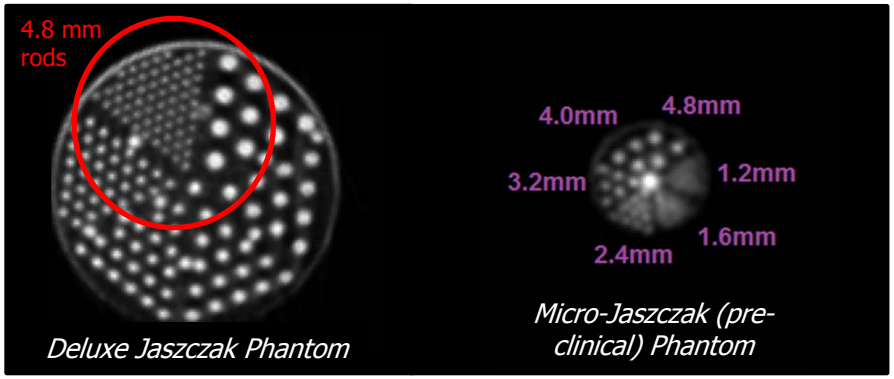


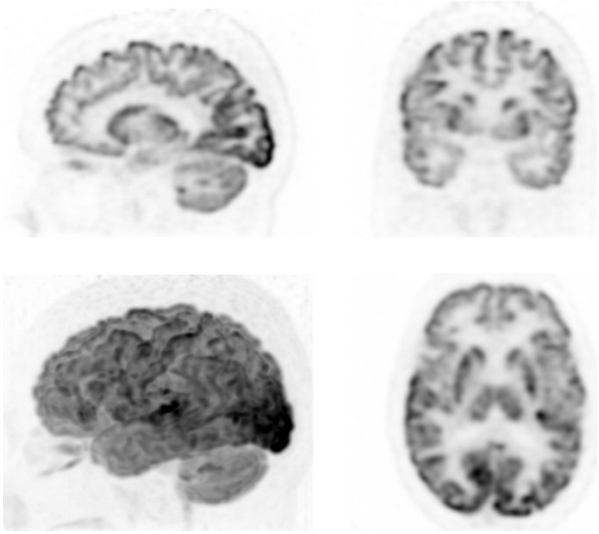


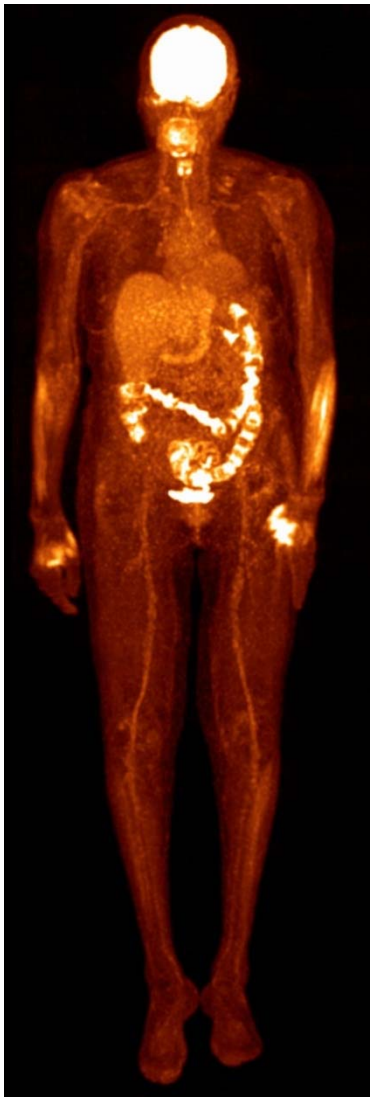
→ ToF: more signal, less noise

Vereos PET/CT system

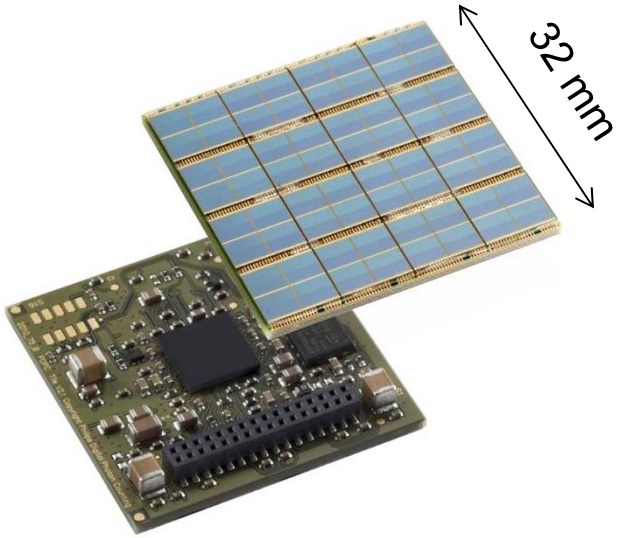
Coincidence resolving time (CRT) ~350 ps FWHM due to digital photon counting

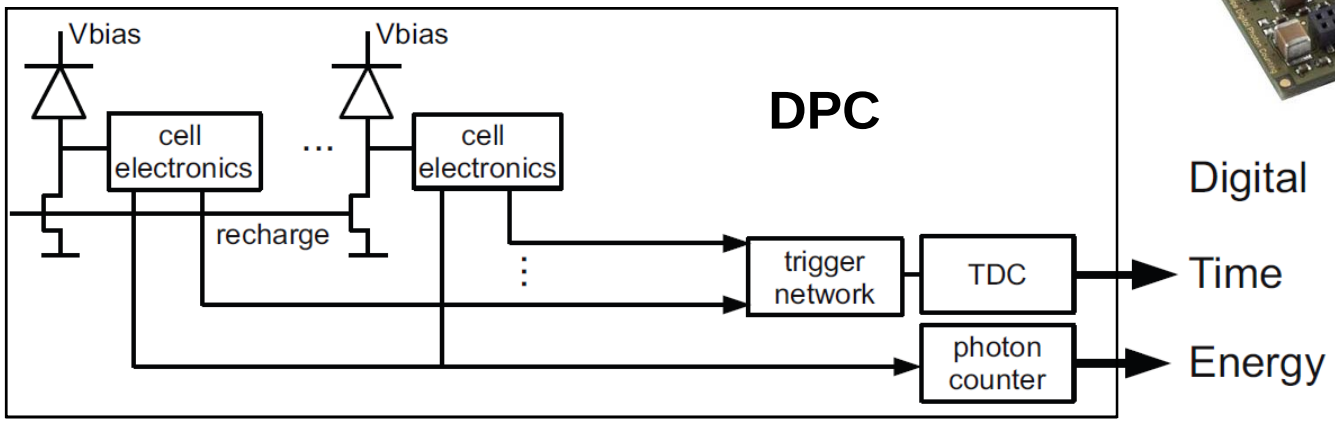






Digital Photon Counter



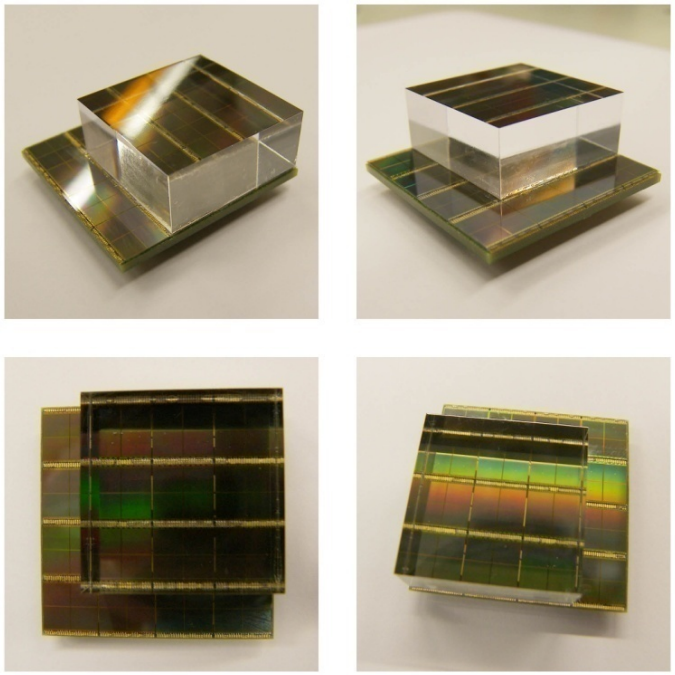


++ small single-photon time jitter
++ negligible noise at the single photon level
++ ~ 30% photon detection efficiency
+ MR-compatible

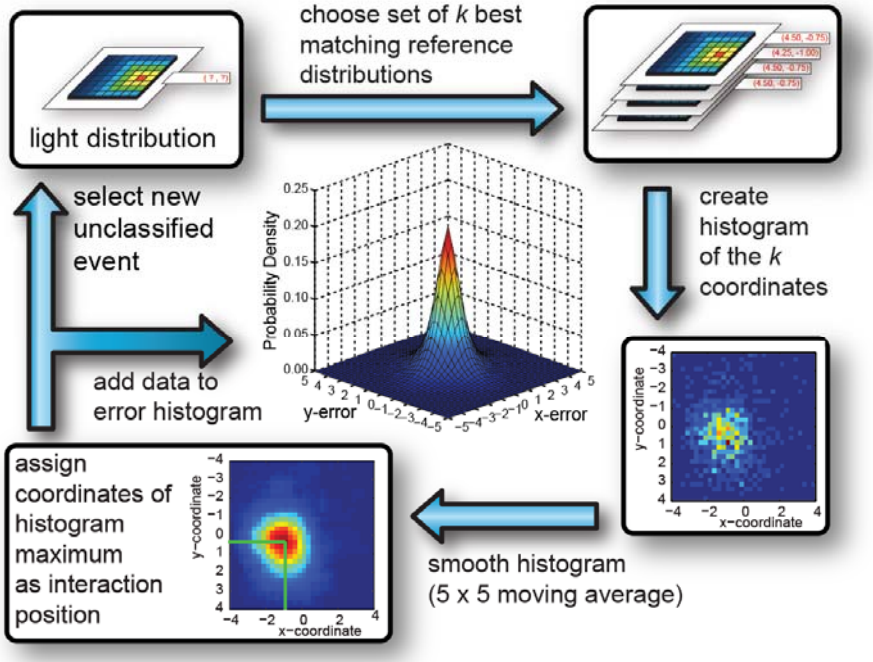
16 Si dies (4 x 4)
Each Si die:
→ 1 timestamp
→ 4 pixels values (no. of counts)

The monolithic scintillator detector

Monolithic TOF/DOI detector with improved performance due to Ca co-doped LSO scintillator, digital photon counters (DPCs), and optimized readout algorithms



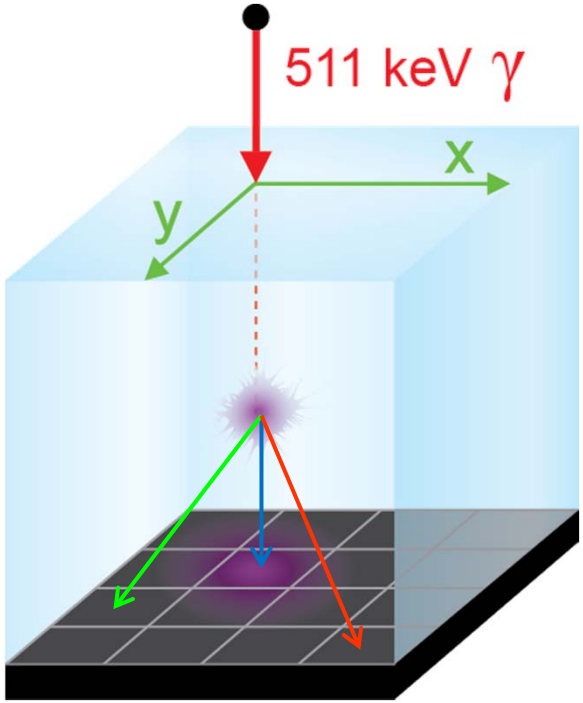
24 mm x 24 mm x 10 mm LSO:Ce,Ca scintillator on PDPC digital SiPM array

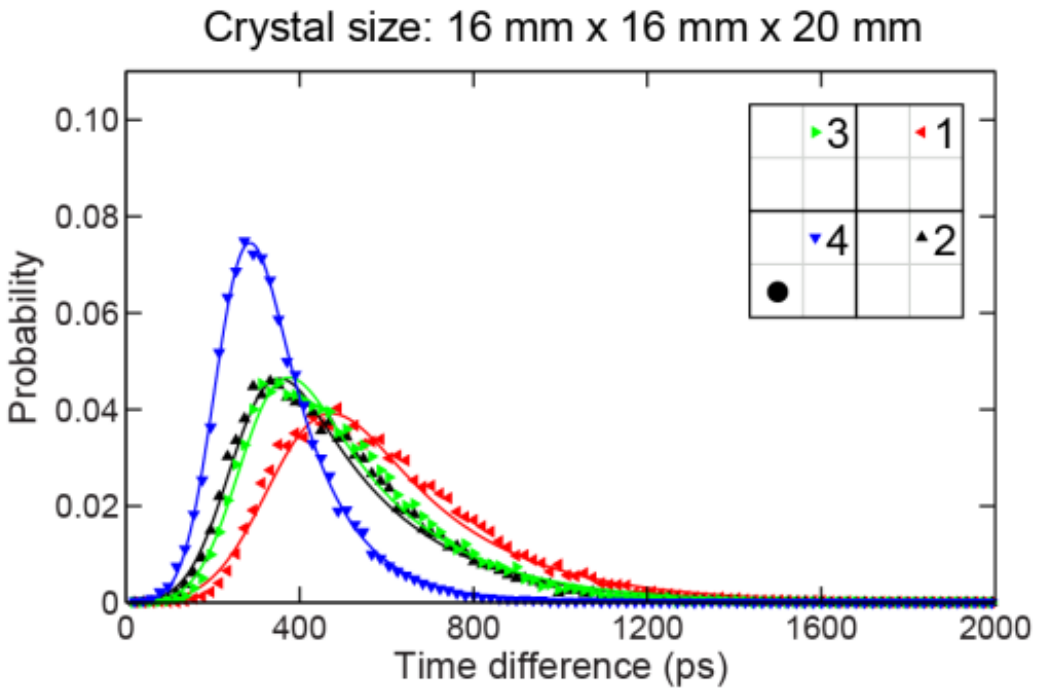


Fast & accurate nearest-neighbour algorithm, H.T. van Dam et al, IEEE Trans Nucl Sci 58, 2139-2147, 2011

Timing in monolithic scintillators

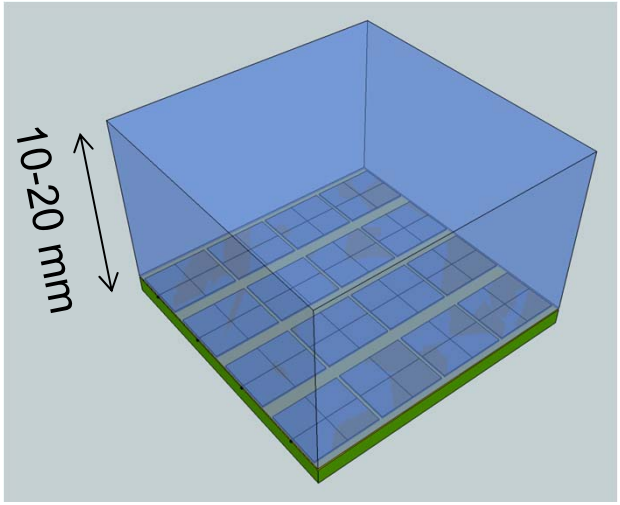
Maximum likelihood interaction time estimation (MLITE), using measured 1st photon arrival time probability distribution for each (x,y,z) position





H.T. van Dam et al "Sub-200 ps CRT in monolithic scintillator PET detectors using digital SiPM arrays and maximum likelihood interaction time estimation (MLITE)", *in preparation*

Performance summary



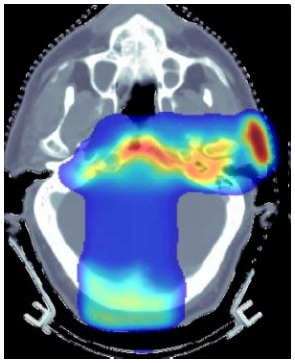
Current results with 10 mm and 20 mm thick L(Y)SO monolithic scintillators on DPC arrays:

Performance parameter		Monolithic	State of the art
Energy resolution	(% FWHM)	**11 - 12**	~12
Spatial resolution	(mm FWHM)	**1.0 - 1.6**	4 - 6
DOI resolution	(mm FWHM)	**3 - 5 mm**	None
CRT	(ps FWHM)	**160 - 185**	500 - 650

⇒ A highly promising detector for future PET/CT and PET/MRI systems

HollandPTC in Delft (2016)

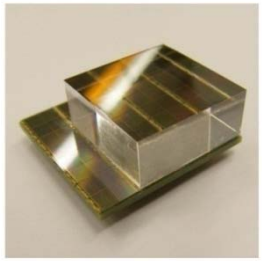
In-situ TOF-PET

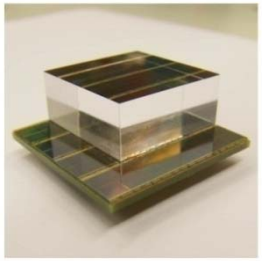


See also: P. Dendooven, this session, 11:50 AM

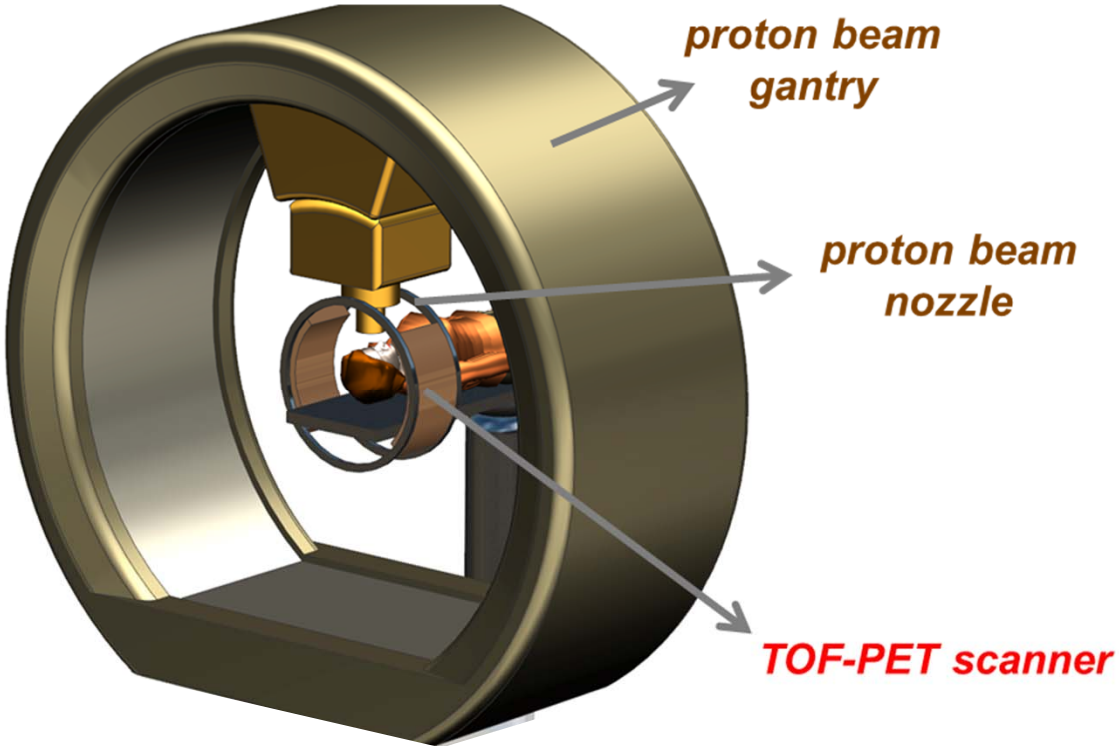
Incentive

Use novel PET detector technology under development at TU Delft to realize a clinically useful in-situ dose imaging device



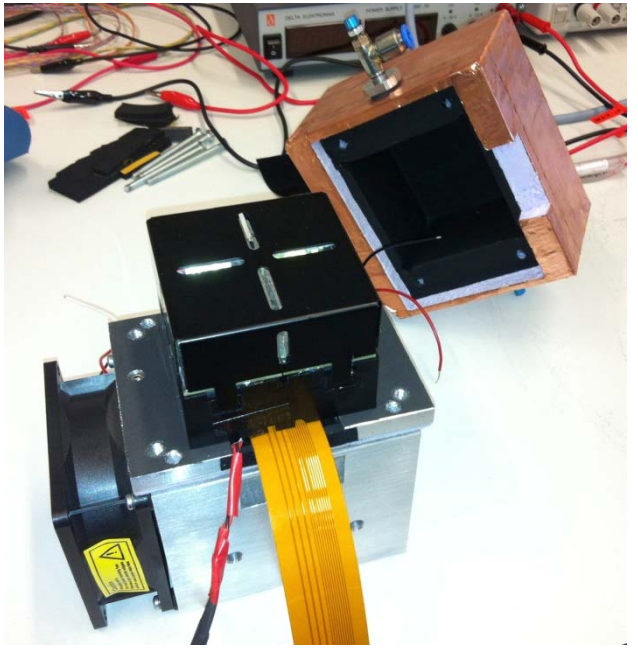


www.sublima-pet-mr.eu

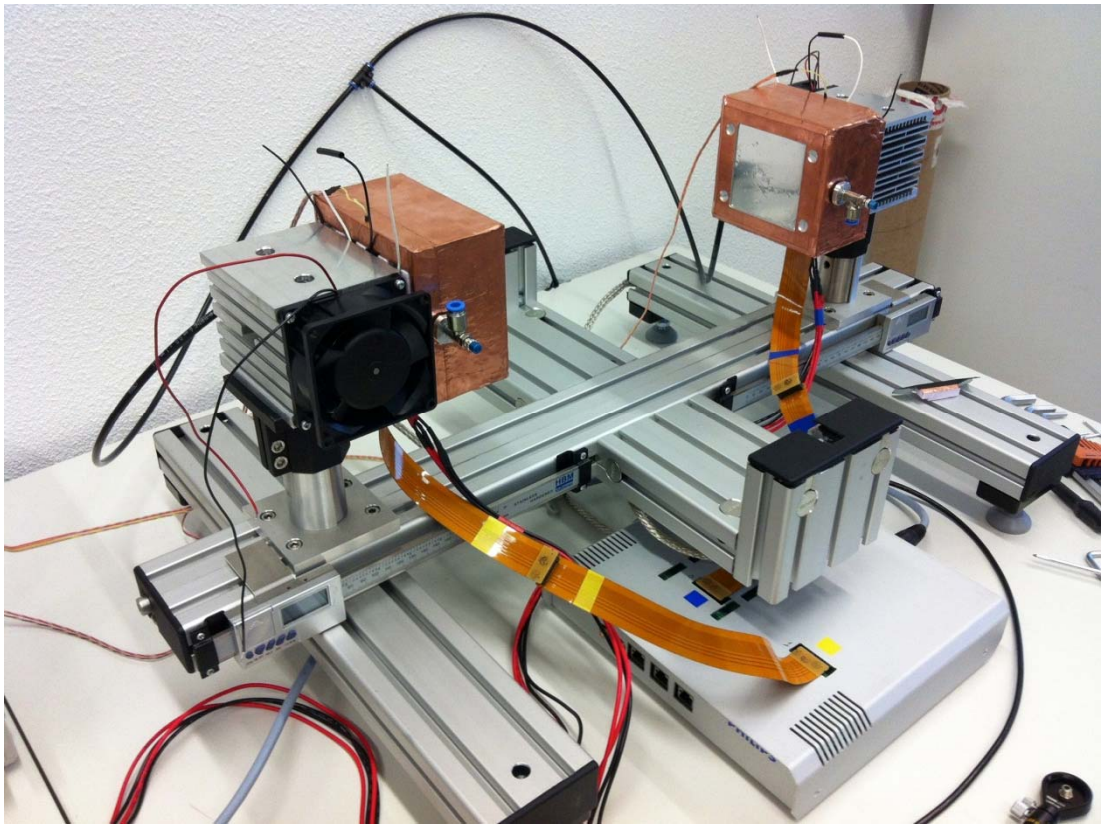


ISoToPE project (Delft-Groningen)
In-situ PET gantry, conceptual view, by P. Dendooven (KVI-CART)

TOF-PET setup



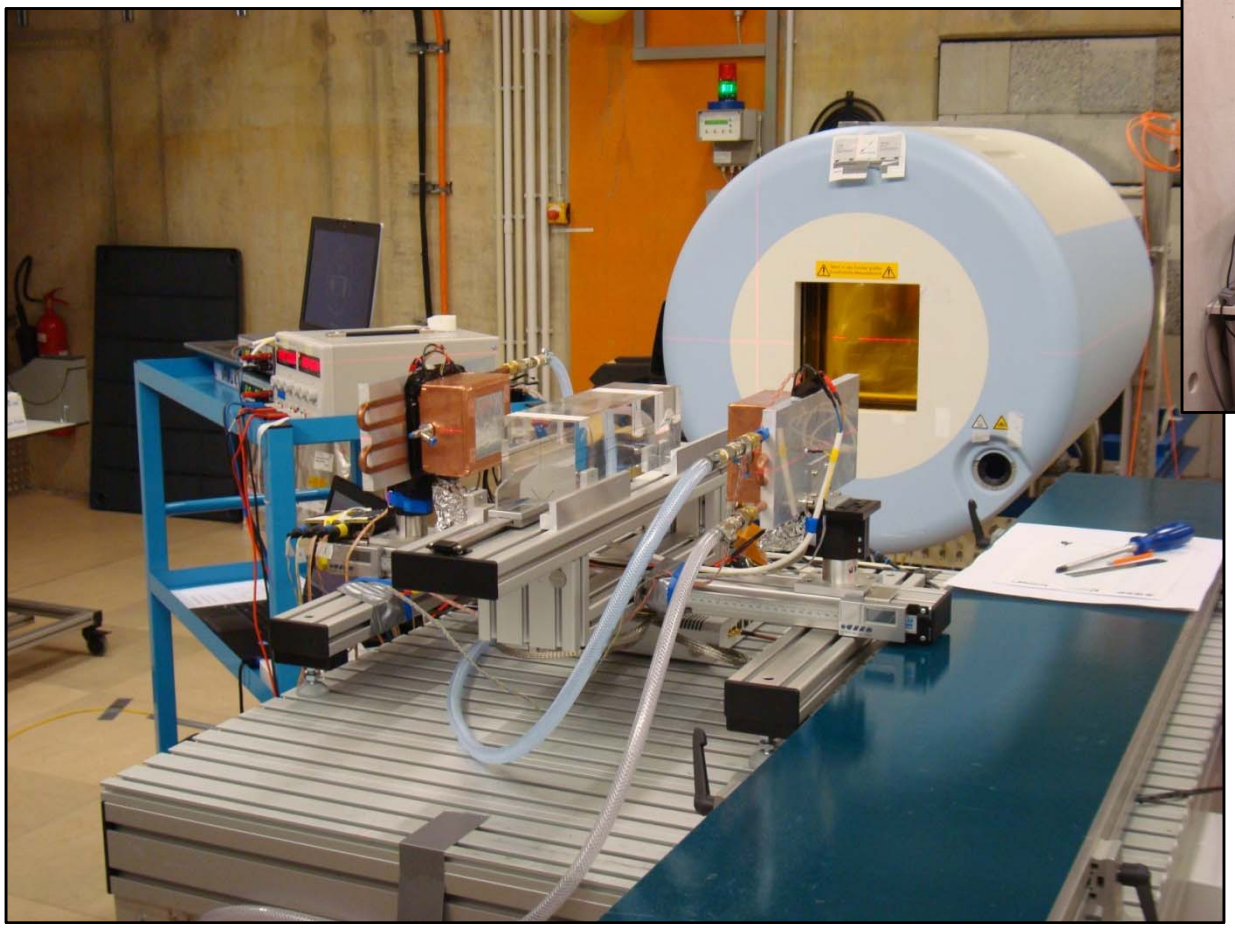
dSiPM-based TOF-PET setup for in-beam tests



TOF-PET module:

- 4 digital SiPM arrays from Philips Digital Photon Counting
- 4 LYSO:Ce crystal matrices 16 x 16 crystals 4 x 4 x 22 mm^3

Heidelberg experiments



HIT
Heidelberger Ionenstrahl-Therapiezentrum

TU Delft Delft University of Technology

HIT Heidelberger Ionenstrahl-Therapiezentrum

LIP Laboratório de Instrumentação e Física Experimental de Partículas

UniversitätsKlinikum Heidelberg

university of groningen

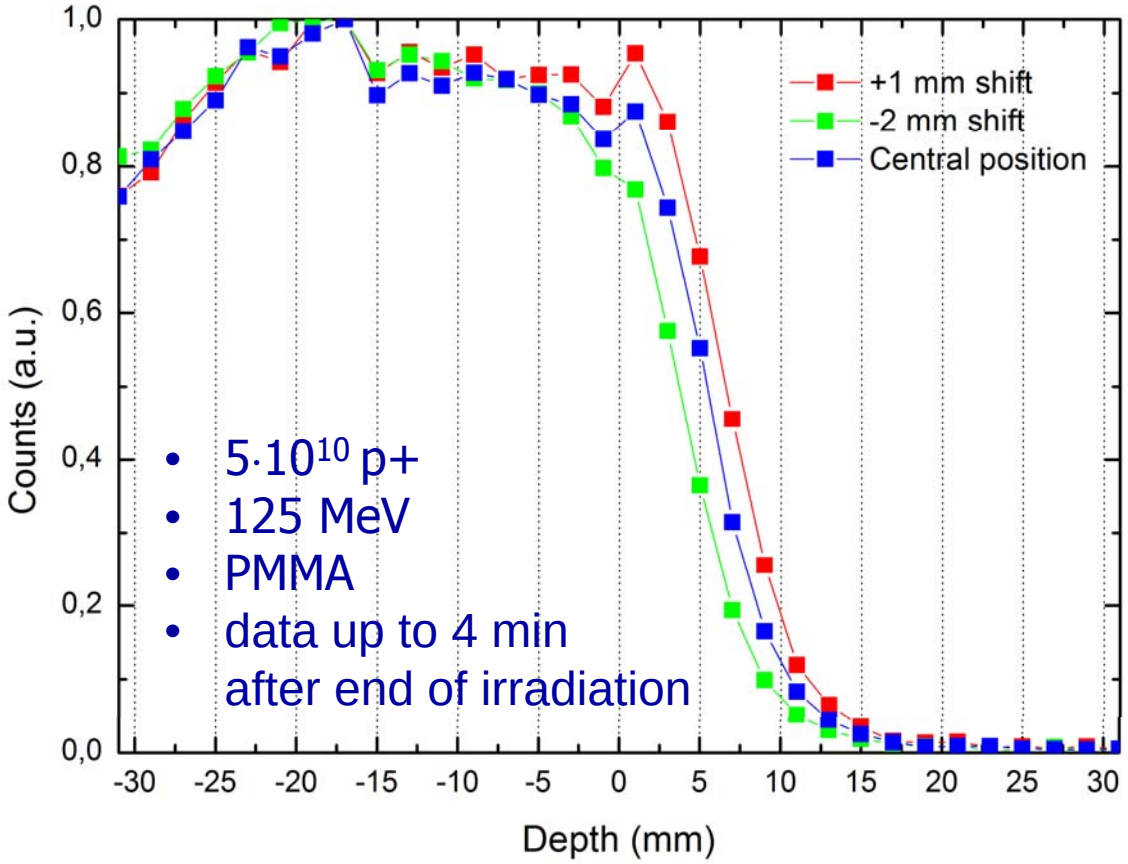
U C

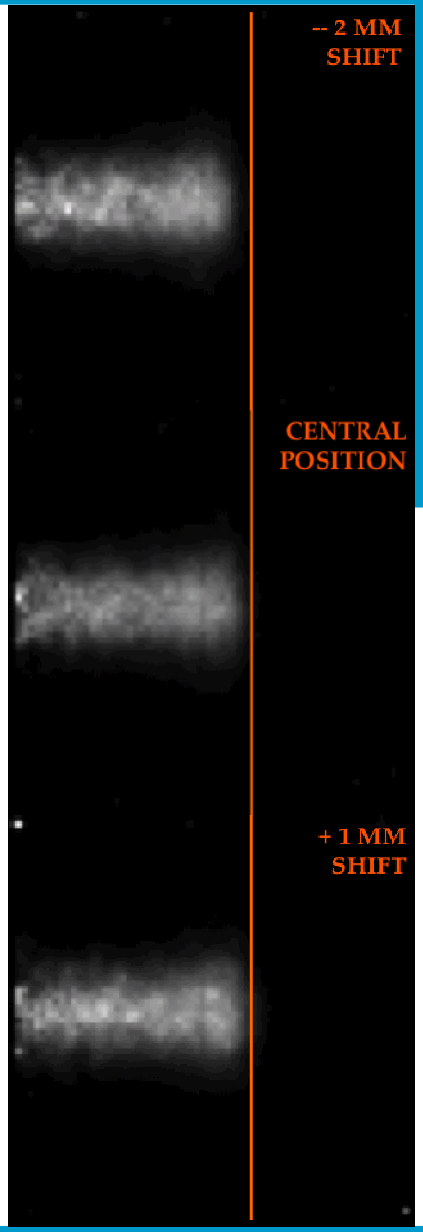
Physics Department
Universidade de Coimbra

LMU Ludwig-Maximilians-Universität München

In-situ PET measurements

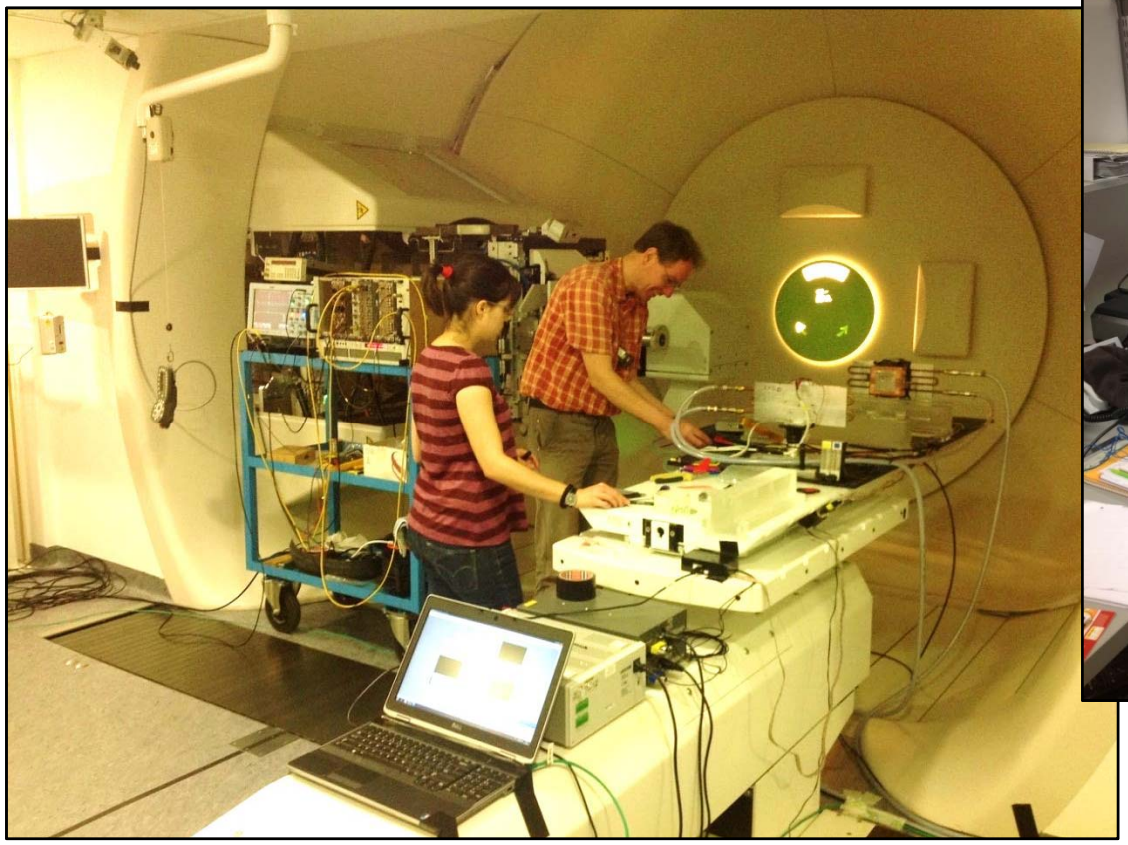
Preliminary reconstructed images,
ML-EM, 11 it., scatt. & att. corr.

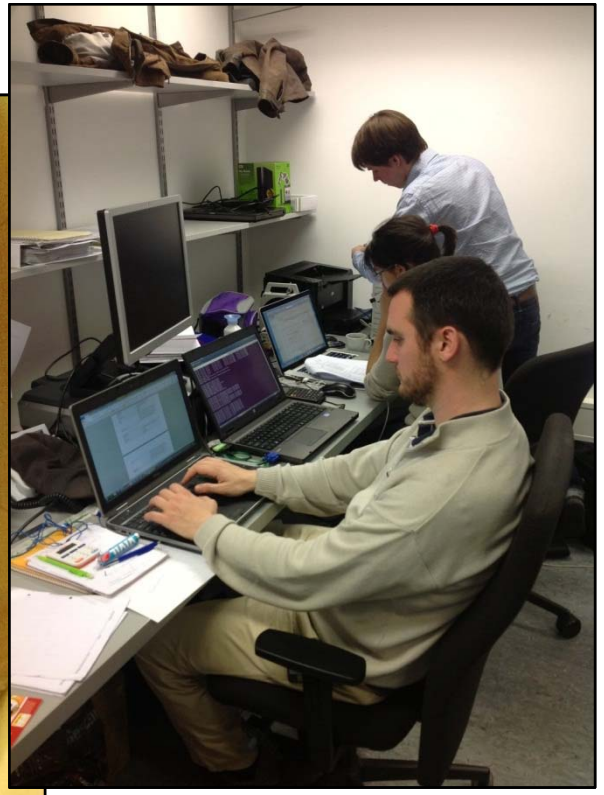




Prompt gamma experiments

Set-up @ West German Proton Therapy Center, Essen

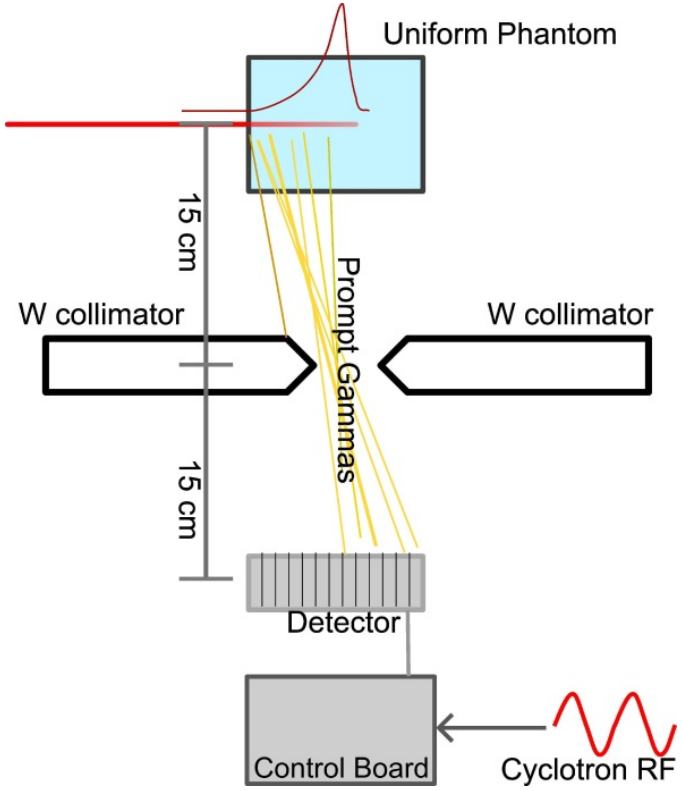


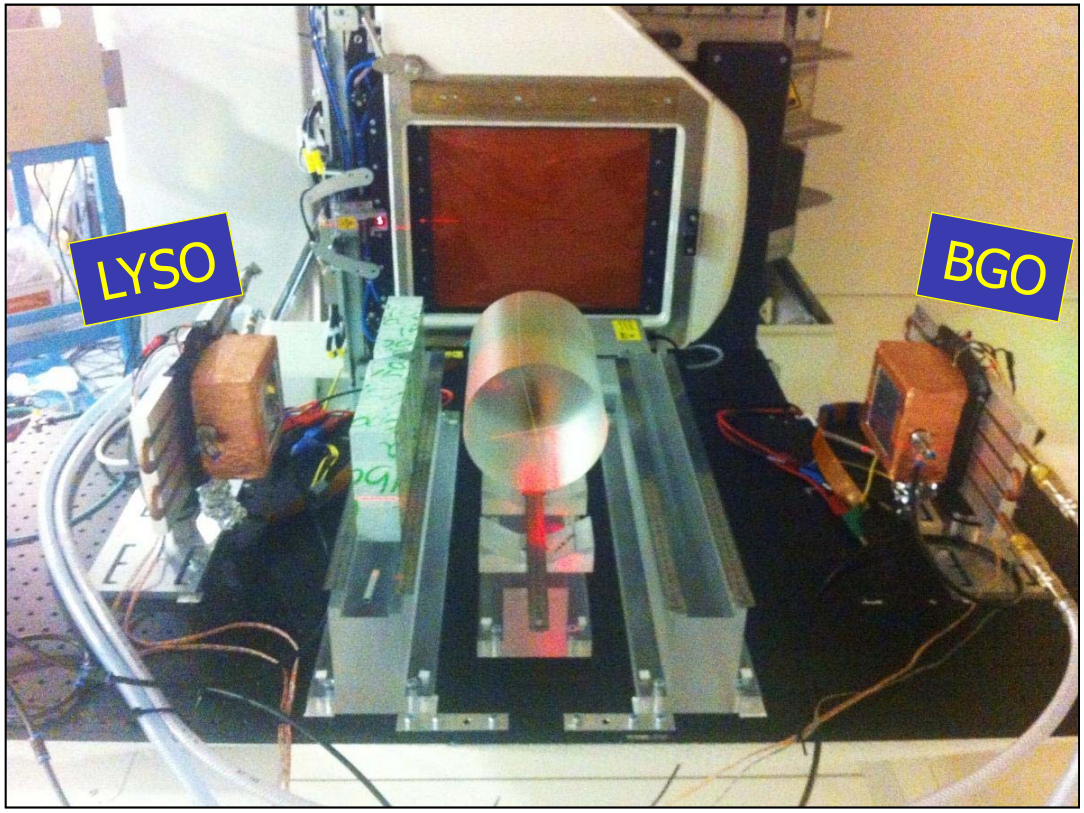


Experimental set-up

Set-up @ West German Proton Therapy Center, Essen

- Prompt gamma detection through a knife-edge slit collimator[1]



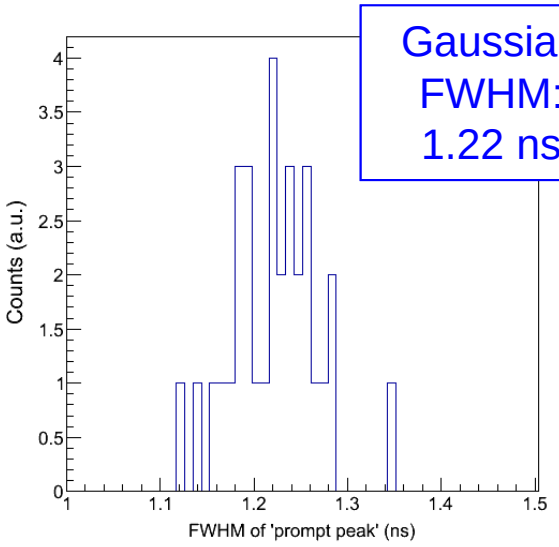


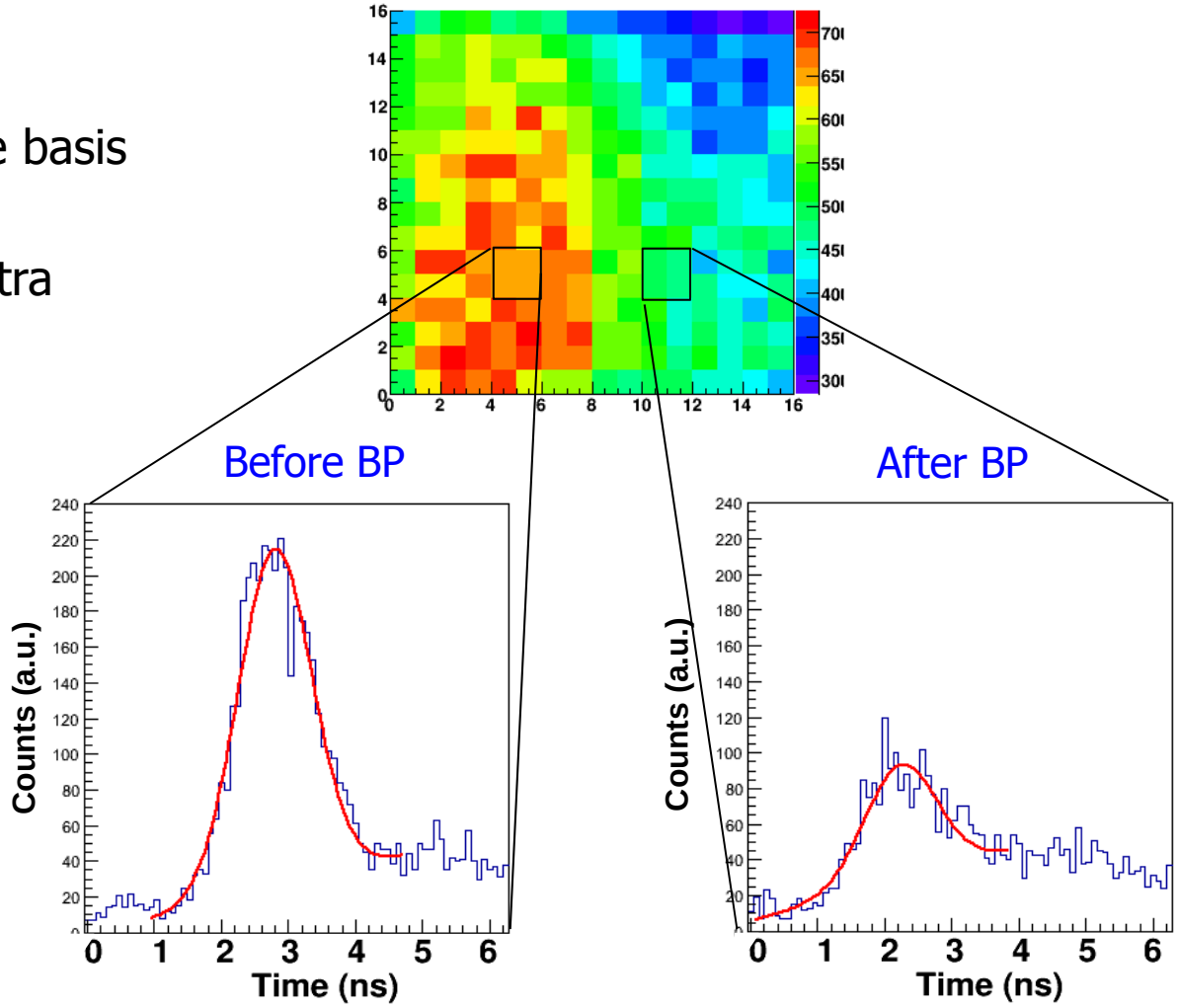
Methods & data acquisition

- 160 MeV proton beam
  - 15.2 cm range in PMMA
- A total of $6.5 \cdot 10^9$ protons delivered
  - 10 pA or $6.24 \cdot 10^7$ protons/s
  - Total dose: 10 Gy
- Knife-edge slit collimator[1]
  - 1:1 projection
  - 4 cm thick, 6 mm slit opening
- 4 LYSO:Ce or BGO matrices
  - 16x16 crystals 4x4x22 mm^3
- Operating voltage:
  - LYSO: - 1.1 V (below reference bias voltage, to reduce saturation)
  - BGO: - 0.4 V
- Cyclotron-RF synchronization (LYSO)
  - External 106 MHz clock
  - TOF discrimination

TOF analysis (LYSO:Ce)

- Calibration on per-die basis
- Gaussian fit (linear baseline)to TOF spectra from die TDC





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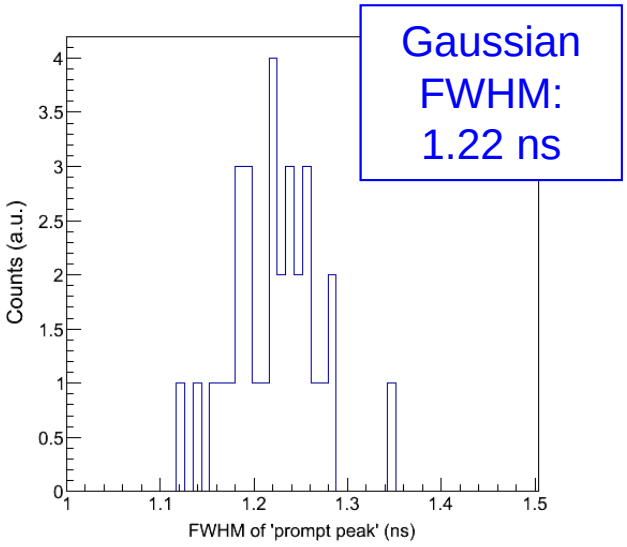
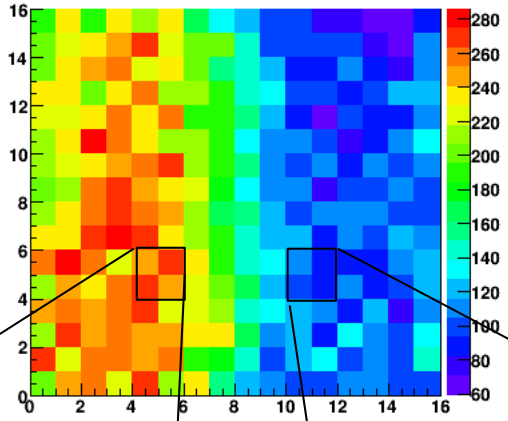
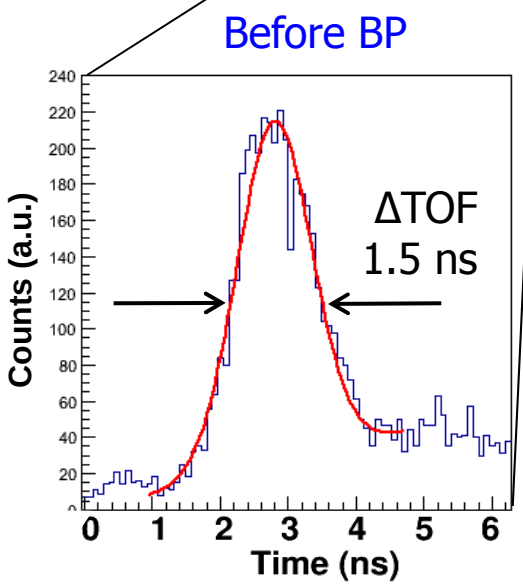
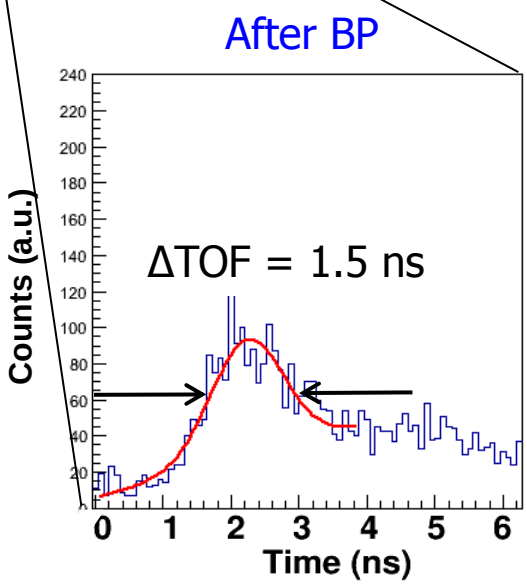
TOF analysis (LYSO:Ce)

- Time-of-flight (TOF) window of 1.5 ns
- Improved contrast !









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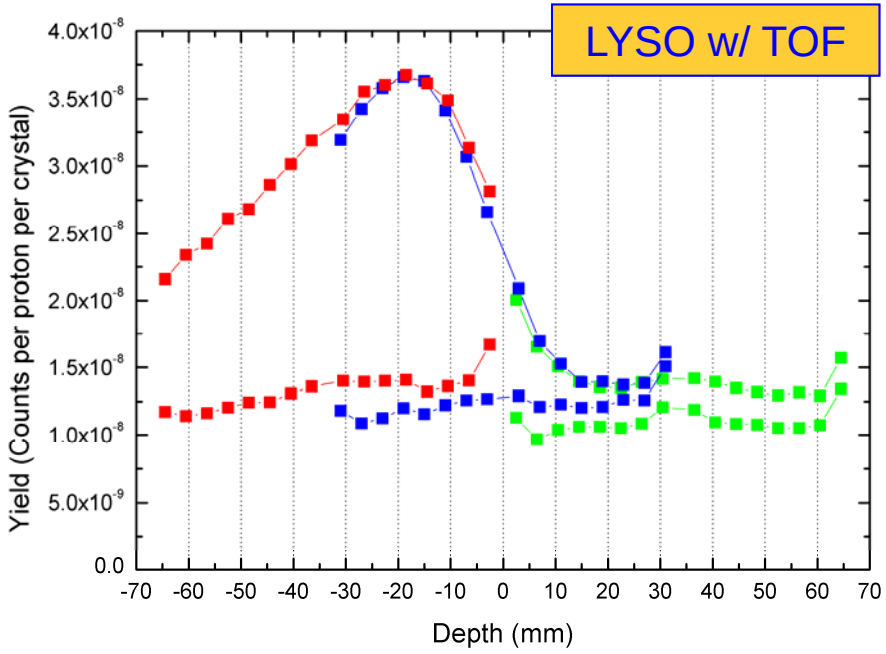
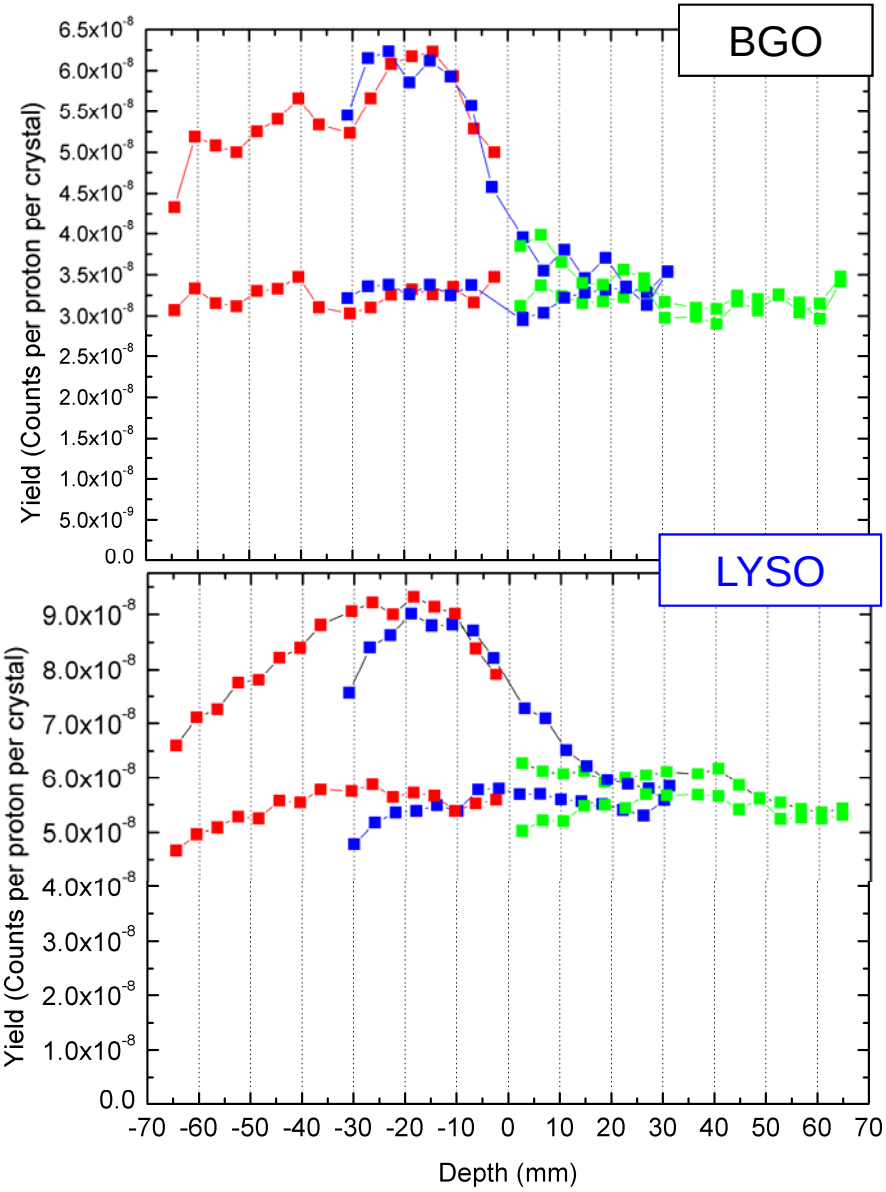
PG profiles

- Open/Closed collimator;
- 3 detector positions
- Energy > 3 MeV

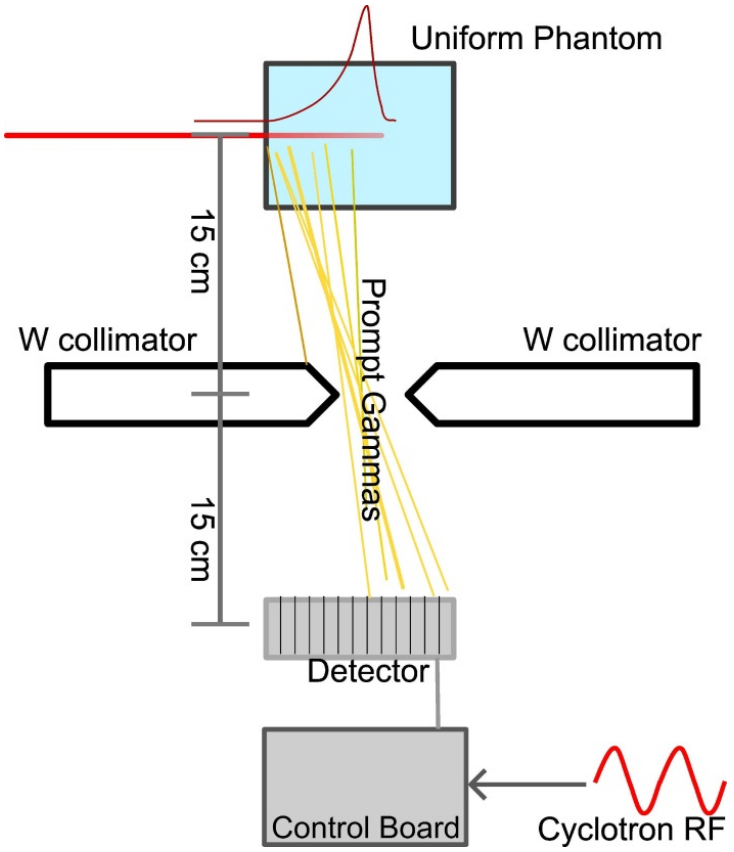


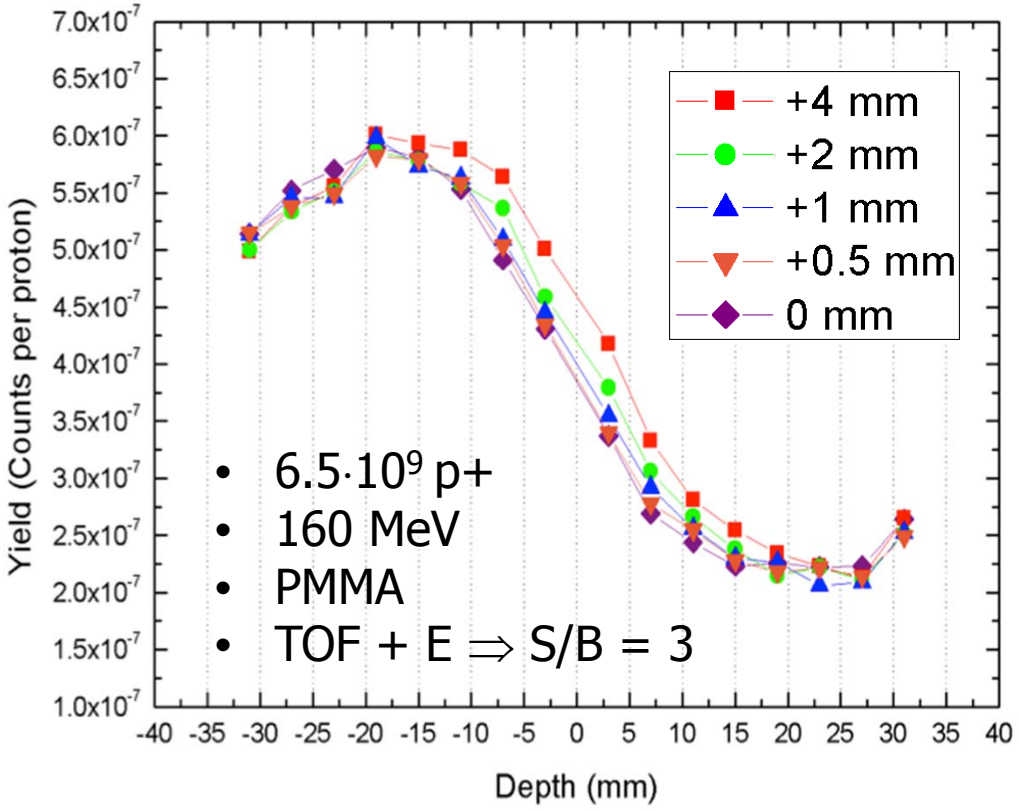


P.C. Lopes et al, IEEE NSS-MIC 2013

Prompt gamma results

P. Cambraia Lopes et al, First Performance Tests of Digital SiPMs in Prompt Gamma Imaging with a Knife-Edge Slit Camera
2013 IEEE NSS-MIC Student Competition





Prompt gamma experiments

P. Cambraia Lopes et al, First Performance Tests of Digital SiPMs in Prompt Gamma Imaging with a Knife-Edge Slit Camera

2013 IEEE NSS-MIC Student Competition ⇒ **First Prize!!!**