Monolithic scintillation crystals coupled to photosensor arrays for Time-of-Flight Positron Emission Tomography

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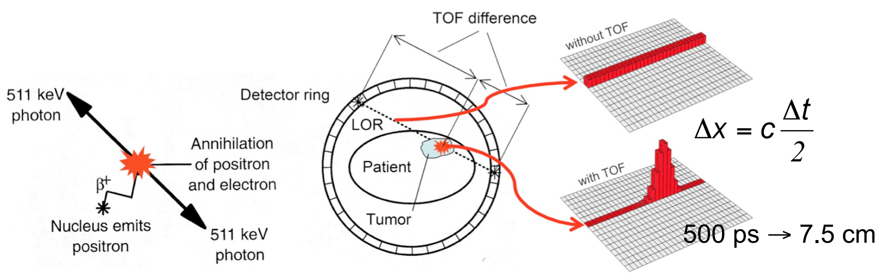
Supported by SenterNovem grant No. IS055019

Time-of-Flight Positron Emission Tomography



Time-of-Flight Positron Emission Tomography (TOF-PET) allows

- **better image**
- **shorter scan**
- **smaller radiation dose to patient**

Detector components for fast timing

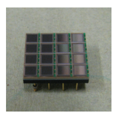
fast and bright crystals

	LYSO	$LaBr_3$
rise time (ns)	~0.3	≤ 1
decay time (ns)	~40	~15
light yield (ph/MeV)	~25 000	~65 000
energy resolution* (%)	11	3
attenuation length* (mm)	12	22
photofraction*	0.34	0.14

* for 511 keV photons

fast photosensor arrays

Silicon PhotoMultiplier (SiPM) 4×4 arrays:
Hamamatsu MPPC S11064-050P(X1)
SensL SPMArray 3035G16

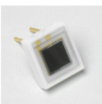


4×4 multi-anode PMT
Hamamatsu H8711-03

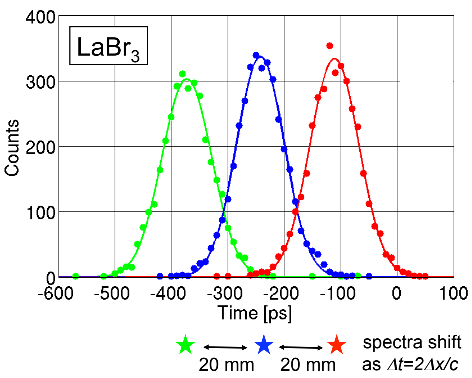
Results: Coincidence Resolving Time (CRT)

Small crystals

- crystal: 3×3×5 mm³
  - bare $LaBr_3$:Ce(5%)
  - LYSO
- sensor: 3×3 mm²
  Hamamatsu SiPM
  (MPPC S10362-33-050c)



511 keV CRT (FWHM)	
$LaBr_3$:Ce(5%)	95 ps
LYSO:Ce	138 ps



- **world record for 511 keV with scintillator**
- **limited by photon statistics**

S. Seifert et al., IEEE Trans. Nucl. Sci. (2011) accepted
D.R. Schaart et al., Phys. Med. Biol. 55 (2010) N179
R.Vinke et al., 2009 IEEE Nucl. Sci. Symp. Conf. Rec. M06-2
S.Seifert et al., 2009 IEEE Nucl. Sci. Symp. Conf. Rec. J01-4

Monolithic crystals

scanner CRT(*) (ps)	
$LaBr_3$:Ce(5%)	205(1)
LYSO:Ce	380(2)
commercial, L(Y)SO	≤ 600

(*) Calculated from CRT between monolithic and reference detector by removing contribution from reference detector and multiplying by √2.

(1) 16.2×18×10 mm³ $LaBr_3$:5%Ce on SiPM array Hamamatsu MPPC S11064-050P(X1)
- CRT for central 4 sensors of array

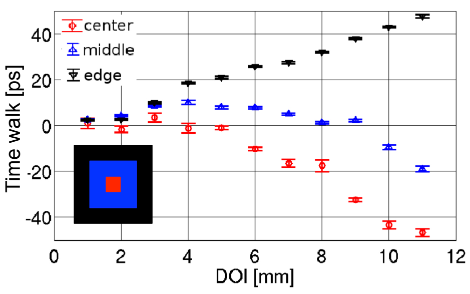
S. Seifert et al., IEEE NSS/MIC 2011

(2) 16.2×18×L mm³ (L=10, 15, 20) LYSO on Hamamatsu H8711-03 multi-anode PMT
- CRT is independent of crystal length L

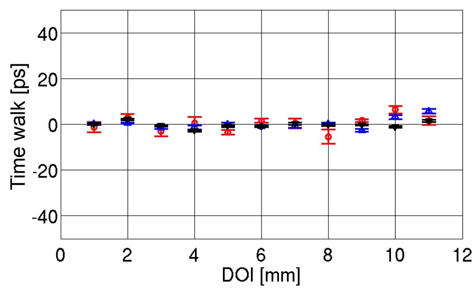
R. Vinke et al. IEEE NSS/MIC 2010 Conf. Rec. NM3-3

Results: Time walk correction

20×20×12 mm³ LYSO on Hamamatsu H8711-03 multi-anode PMT



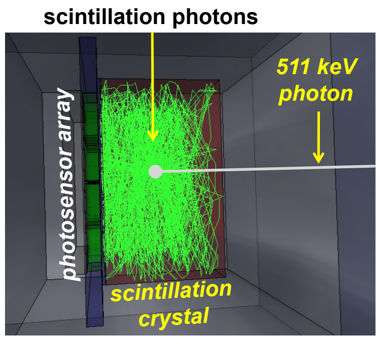
Time walk versus DOI for center, middle and edge regions (see insert) of the monolithic scintillation crystal.



An event-by-event time walk correction completely removes the time walk.

R. Vinke, et al., Nucl. Instr. Meth. A 621, 595 (2010)

Monolithic scintillation crystals on photosensor arrays

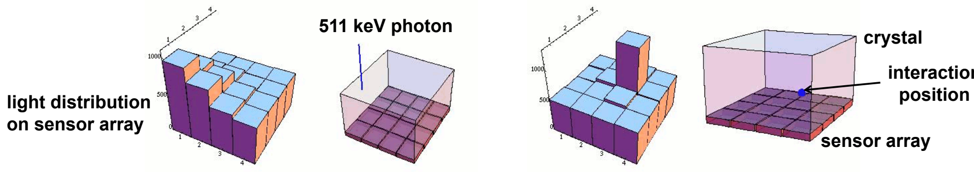


Advantages compared to segmented crystals commonly used in PET scanners:

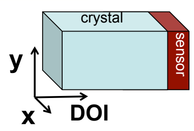
- depth-of-interaction can be determined
- smaller efficiency loss from inter-crystal dead space
- inter-crystal scatter is less of an issue
- lower cost

Figure: Scintillation photons generated by the absorption of a 511 keV photon are detected by a photosensor array

Determination of the interaction position



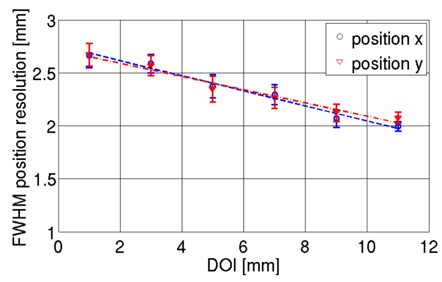
Principle: light distribution "centroid" → x,y position
light distribution "width" → depth-of-interaction (DOI)

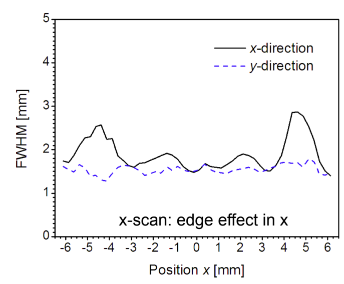


Method:
- calibration by scanning pencil beam
- position estimation by comparison with calibration data using maximum likelihood or nearest neighbors techniques

D.R. Schaart et al., Phys. Med. Biol. 54, 3501 (2009)
R. Vinke, et al., Nucl. Instr. Meth. A 621, 595 (2010)
H.T. van Dam et al., Phys. Med. Biol. 56, 4135 (2011)
H.T. van Dam et al., IEEE Trans. Nucl. Sci. 58, 2139 (2011)

Results: Thin monolithic crystals x, y resolution





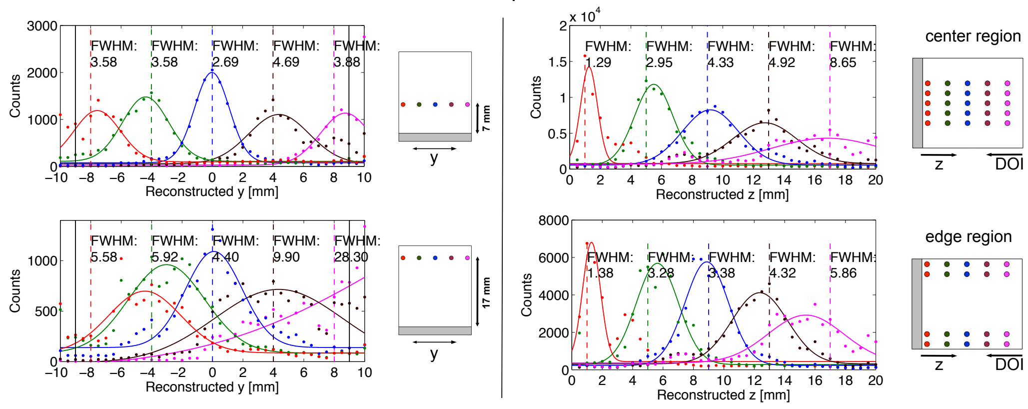
crystal:	20×20×12 mm³ LYSO:Ce	13.2×13.2×10 mm³ LYSO:Ce
sensor array:	Hamamatsu 8711-03 multi-anode PMT	SensL SPMArray 3035G16 SiPM array
calibration scans:	front, 1 side (~1 mm Ø spot)	front, different angles (~0.5 mm Ø spot)
algorithm:	maximum likelihood	nearest neighbor

slight DOI dependence

entry point is determined
(DOI not relevant)

Results: Thick monolithic crystals: x, y, DOI resolution

16.2×18×20 mm³ LYSO on Hamamatsu H8711-03 multi-anode PMT
maximum likelihood position reconstruction



interaction position reconstruction:
- **poorer away from the sensor**
- **shows edge effects**

Conclusions

- ***SiPM photosensors allow world-record timing performance***
- ***3D interaction position in monolithic crystals can be determined***
  - ***excellent spatial resolution close to sensor***
  - ***edge effects***
- ***time-walk across the crystal can be corrected***
- ***next to do: PET imaging performance of monolithic scintillation crystals***