Towards Reconstructionless 3D Imaging of Positron-Emitting Radiotracers using Cerenkov Radiation

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Biomedical Engineering and Radiology
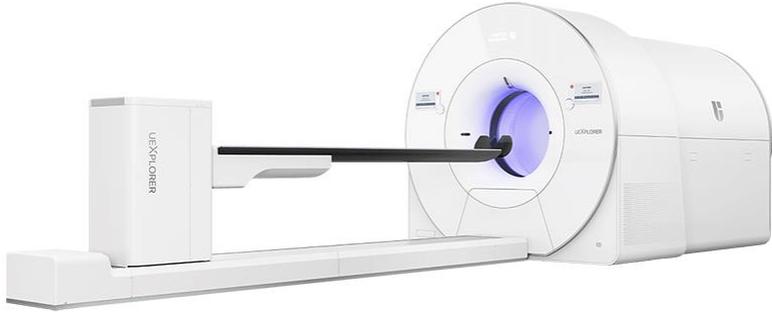
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Disclosures

Research Agreements
Canon Medical Research Unit
United Imaging Healthcare

UC Davis has a revenue sharing agreement with
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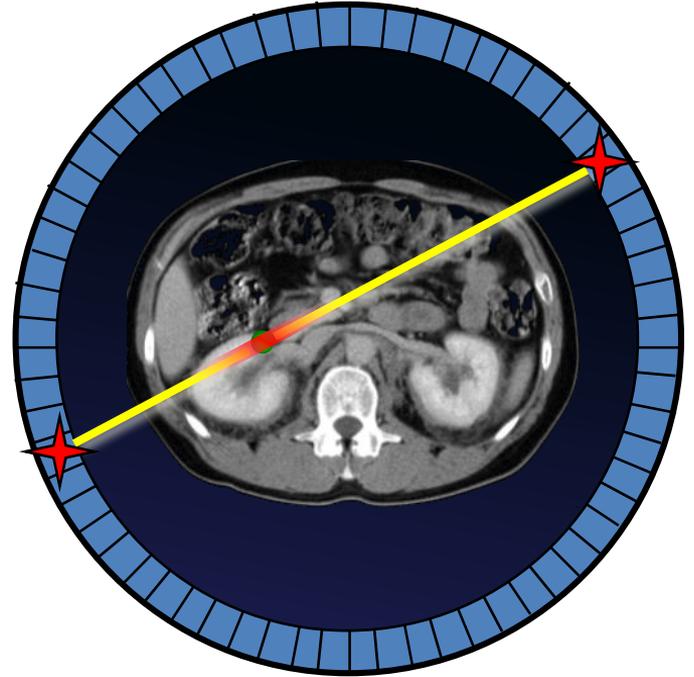
State-of-the-Art PET/CT

- 3-4 mm spatial resolution
- Detection sensitivity 5-10%
- Timing resolution: 200-500 ps
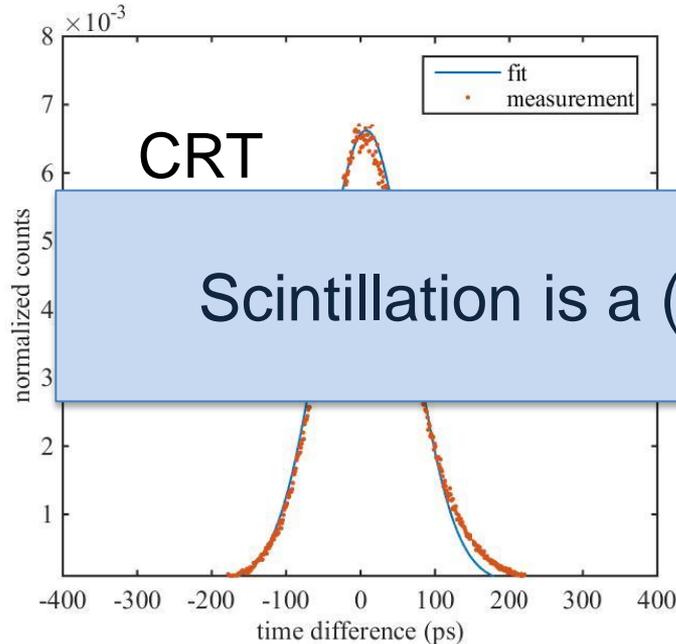
Time-of-Flight (TOF) PET

- Speed of light is
  - 3×10^8 m/s
  - 30 cm/ns

- Current state of the art is ~250 psecs - localizes signal to ~3.75 cm

- 20 psecs timing would localize event to 3 mm
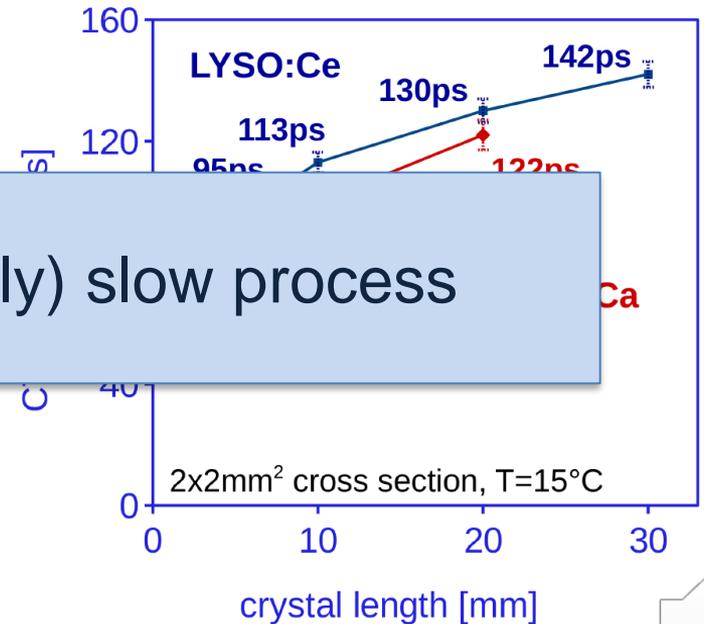

noise reduction ~ $\sqrt{\dfrac{2P}{c\,\Delta t}}$

Current work with Scintillators

Monolithic LYSO, double-sided dSiPM

L(Y)SO pixels, FBK NUV SiPM

CRT

Scintillation is a (relatively) slow process

Courtesy Dennis Schaart (TU Delft)

Courtesy Paul Lecoq (CERN)

Cerenkov Radiation in Scintillators
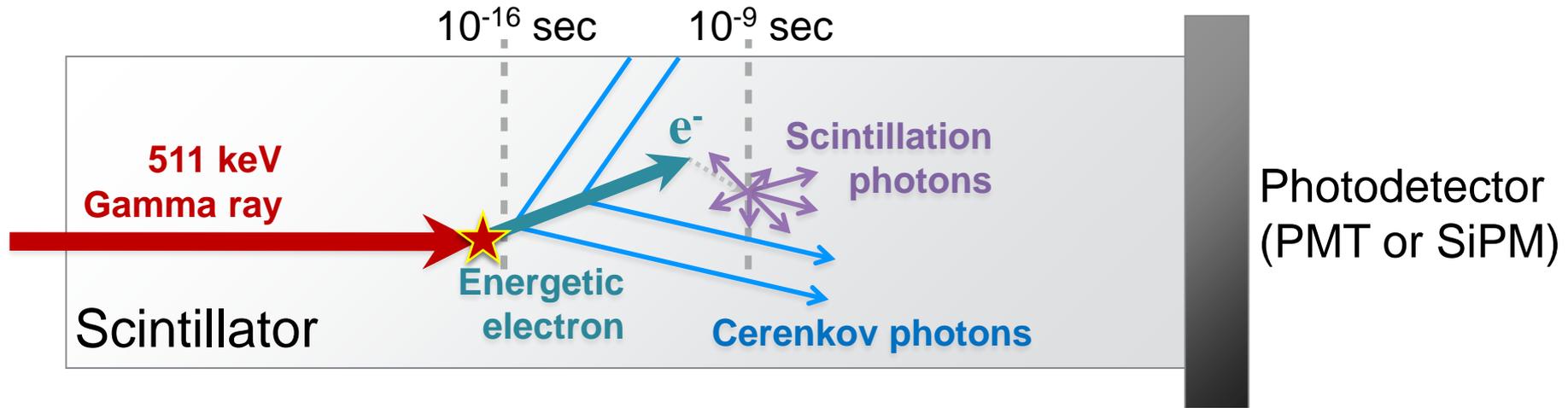
Using Cerenkov Radiation for Time-of-Flight PET

number of photons

timing
Cerenkov
photons

energy
scintillation
photons

time of 511 keV
photon interaction

time

$$\frac{dN}{dx} \propto \left(1 - \left(\frac{c}{\boldsymbol{n} \times v} \right)^2 \right) \int_{\lambda_1}^{\lambda_2} \frac{d\lambda}{\lambda^2}$$

Probability

$\frac{1}{\lambda^2}$

Wavelength (λ)
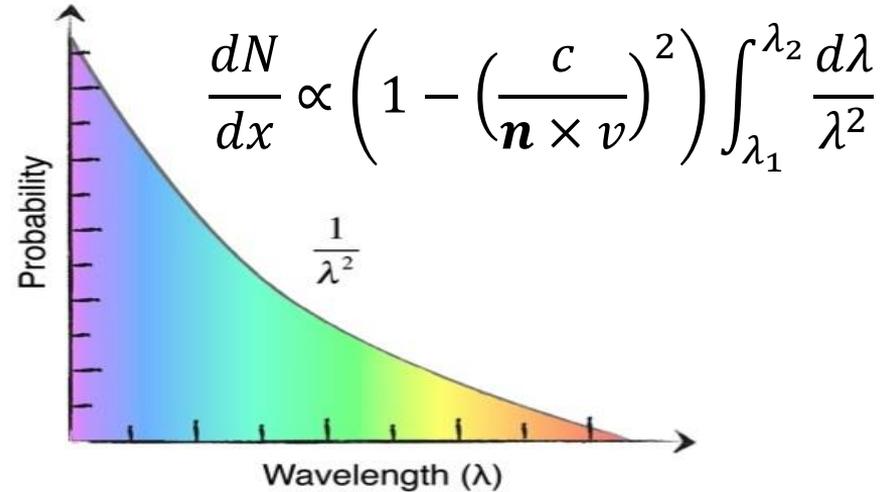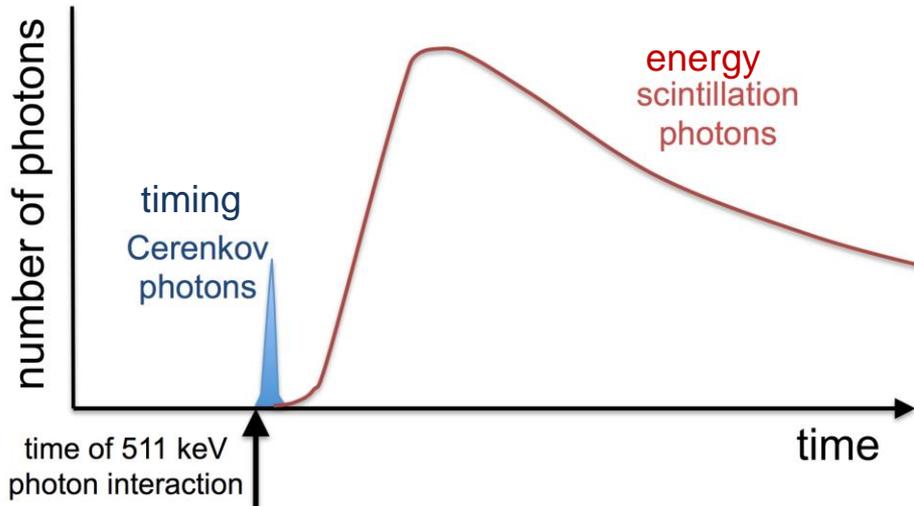
Korpar et al, *Nucl Instr Meth* A654; 532-8 (2011)
Brunner et al, *IEEE Trans Nucl Sci* 61; 443-7 (2014)
Lecoq et al, *IEEE Trans Nucl Sci* 61; 229-34 (2014)
Somlai-Schweiger et al, *Med Phys* 42; 1825-35 (2015)

Needs:

• Dense materials with high index of refraction and high transparency in blue/UV

• Photodetectors with high blue/UV sensitivity and low noise

Scintillators

Property	NaI(Tl)	BGO	LSO(Ce)	GSO(Ce)	CsI(Tl)	LuAP(Ce)	LaBr$_3$(Ce)	Plastic*
Density (g/cm^3)	3.67	7.13	7.40	6.71	4.51	8.34	5.3	1.03
Effective atomic number	50	73	66	59	54	65	46	12
Decay time (nsec)	230	300	40	60	1000	18	35	2
Photon yield (per keV)	38	8	20-30	12-15	52	12	61	10
Index of refraction	1.85	2.15	1.82	1.85	1.80	1.97	1.9	1.58
Hygroscopic	Yes	No	No	No	Slightly	No	Yes	No
Peak emission (nm)	415	480	420	430	540	365	358	Various

Physics in Nuclear Medicine, 4th Edition
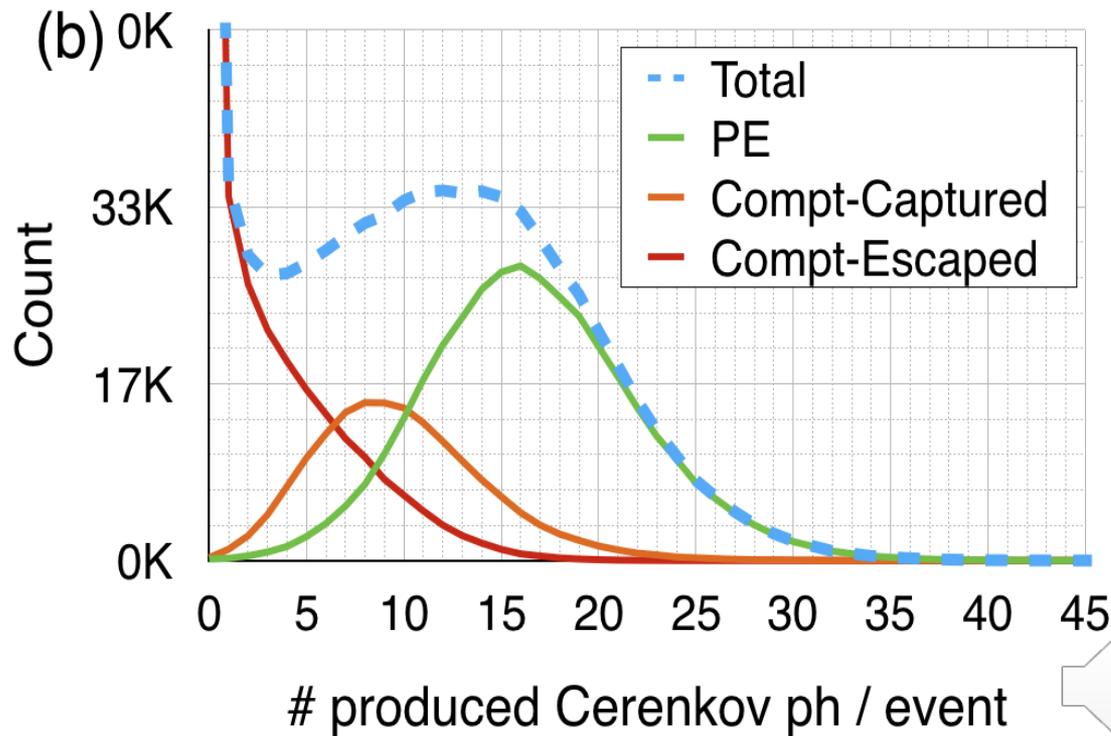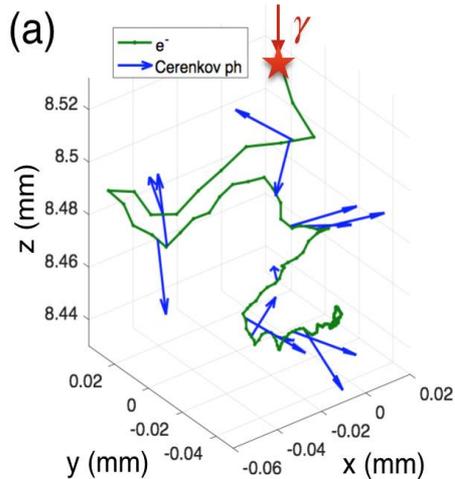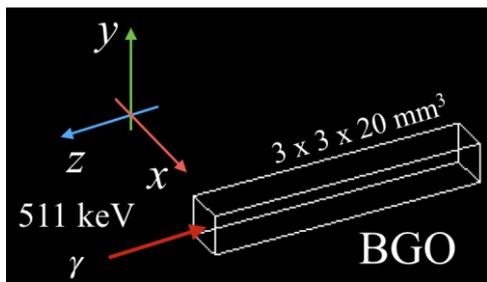
ToF PET with Bismuth Germanate?

Cerenkov luminescence

BGO transmittance

BGO emission

$$\frac{dN}{dx} \propto \left(1 - \left(\frac{c}{\boldsymbol{n} \times v}\right)^2\right) \int_{\lambda_1}^{\lambda_2} \frac{d\lambda}{\lambda^2}$$
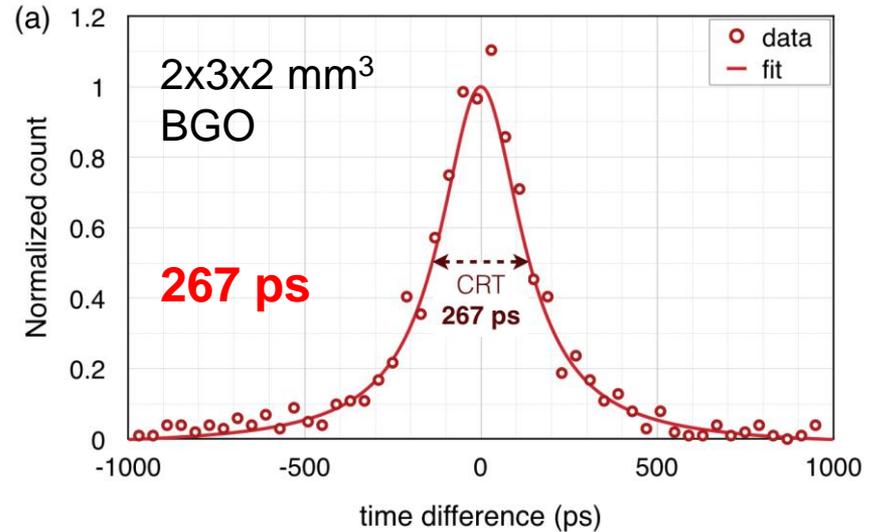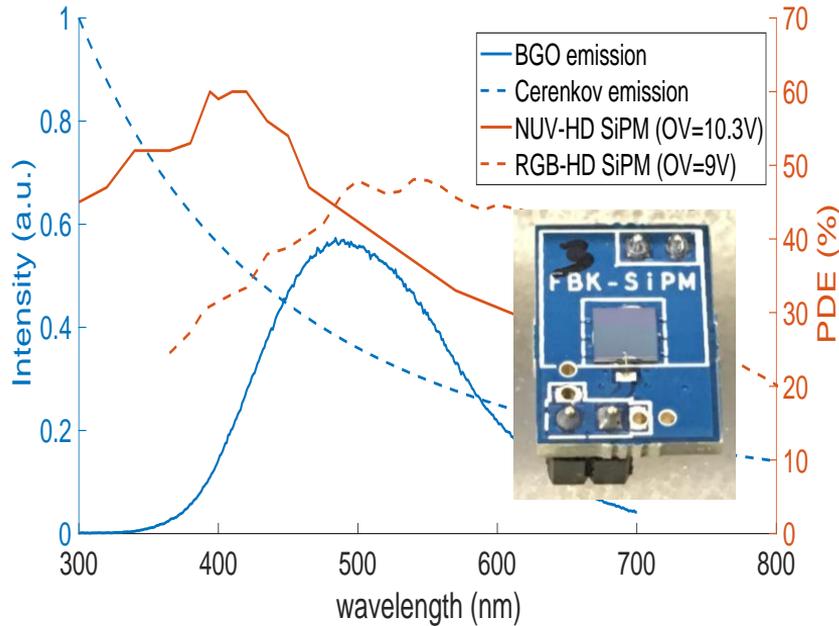
For BGO, *n*=2.15
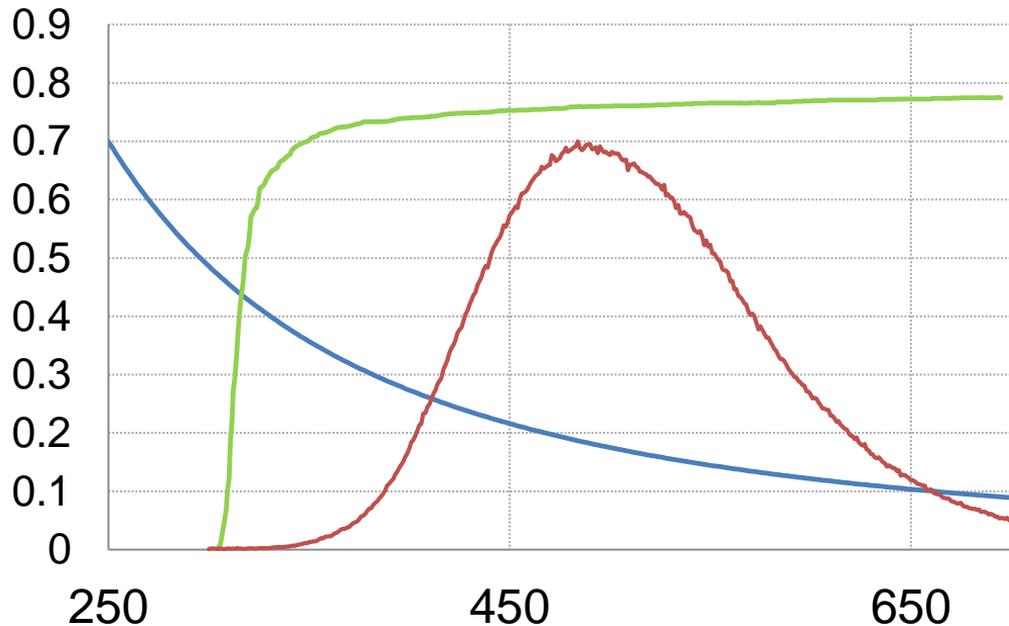
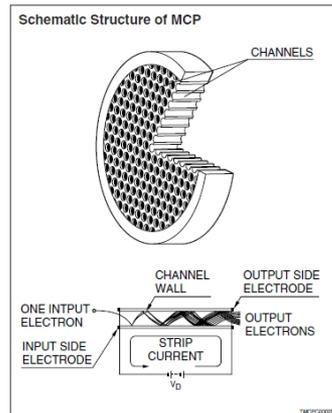# Generation of Cerenkov Photons in BGO

Time of Flight PET with BGO

Kwon et al, *Phys Med Biol* 2017; 61: L38-47

Microchannel Plate Photomultipliers

Single photon time resolution (SPTR) is critical for very fast timing

Photosensor	SPTR (ps)
PMT (R9800)	270
FBK NUV-HD SiPM	91
MCP-PMT (R3809)	25

Schematic Structure of MCP

BGO coupled to MCP-PMT

FWHM 2066 ps
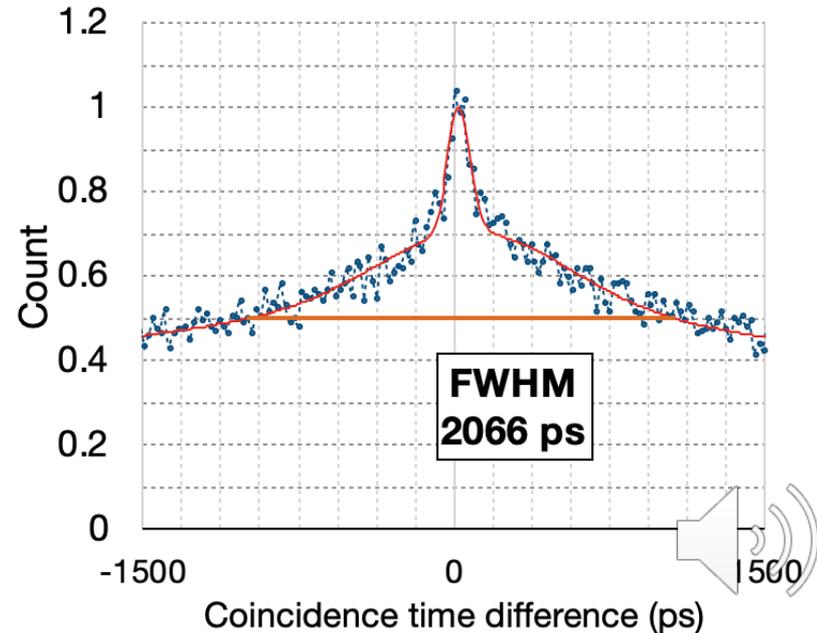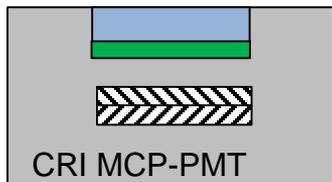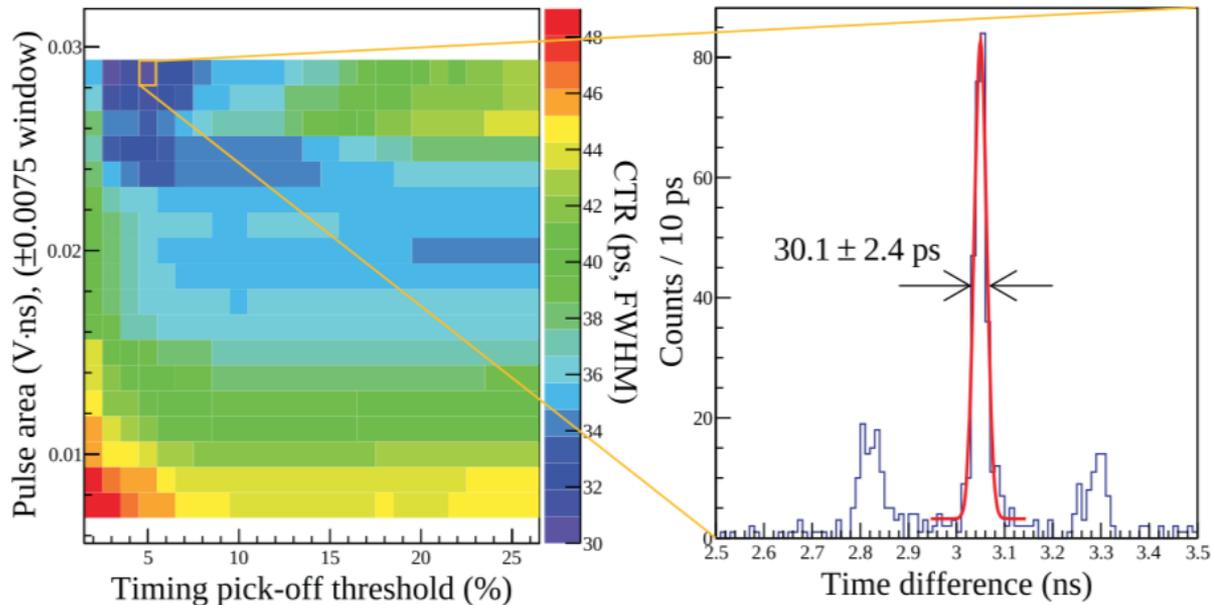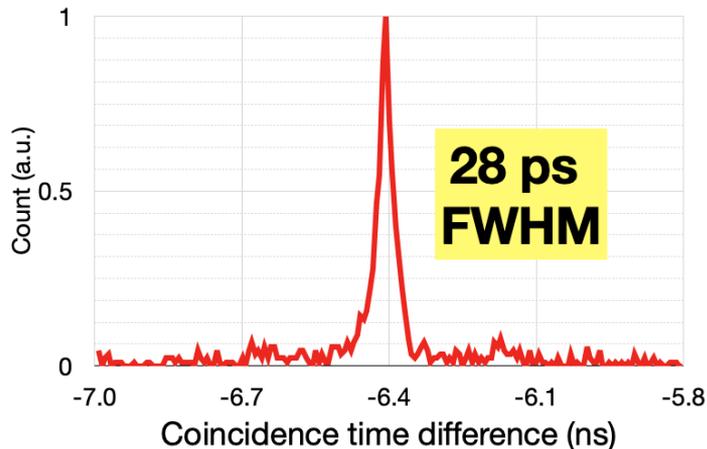
Dual-Ended Readout
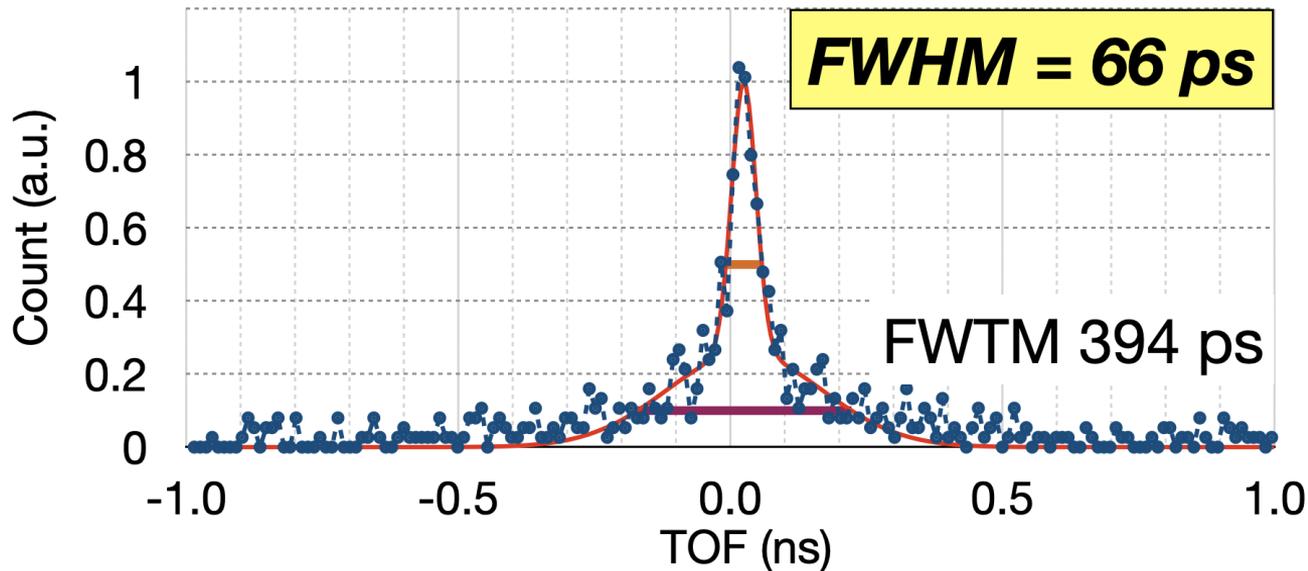
MCP-PMTs with Integrated Cerenkov Radiator

Cerenkov radiator
Photocathode

CRI MCP-PMT

30.1 ± 2.4 ps

Ota et al, *Phys Med Biol* 2019; 64: LT01

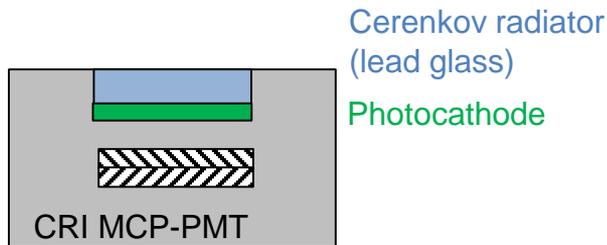HAMAMATSU

MCP-PMTs with Integrated Cerenkov Radiator

In collaboration with Ryosuke Ota and Tomohide Omura **HAMAMATSU**

Acknowledgements

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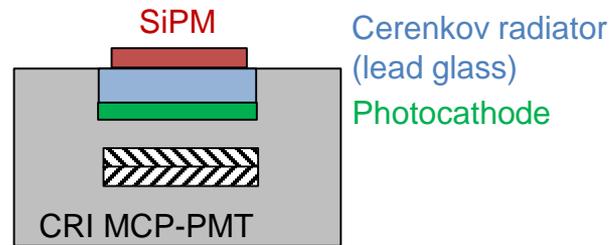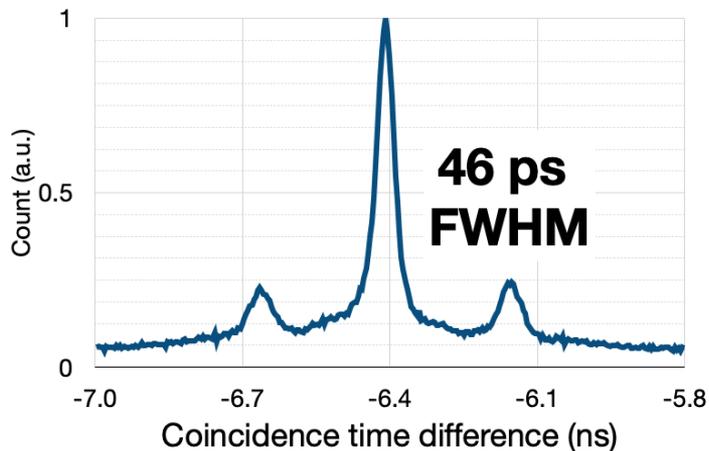
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