Investigation of time-of-flight PET detectors with depth encoding

Eric Berg, Jeffrey Schmall, Junwei Du, Emilie Roncali, Varsha Viswanath, Simon R. Cherry

Department of Biomedical Engineering

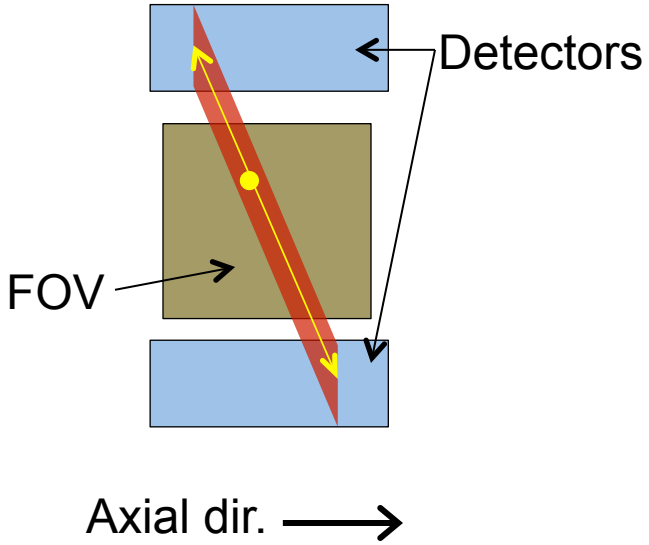
University of California, Davis

UCDAVIS

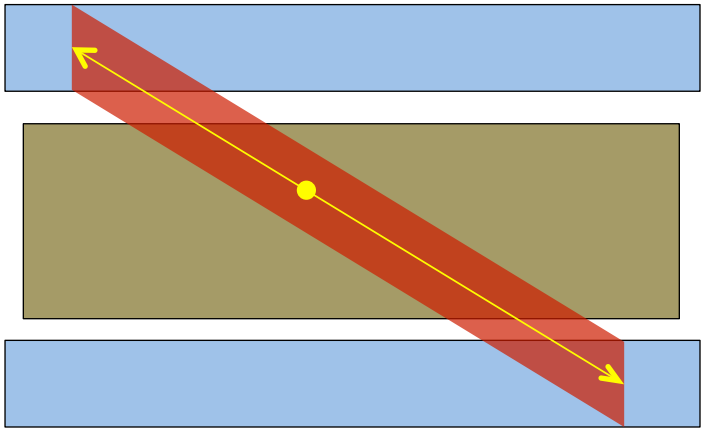
Background

- Combining time-of-flight (TOF) and depth-of-interaction (DOI) especially important for long axial field-of-view PET scanners.
- Long LORs have axial DOI blurring
- High attenuation introduces need for TOF

Typical PET scanner



Long axial FOV PET

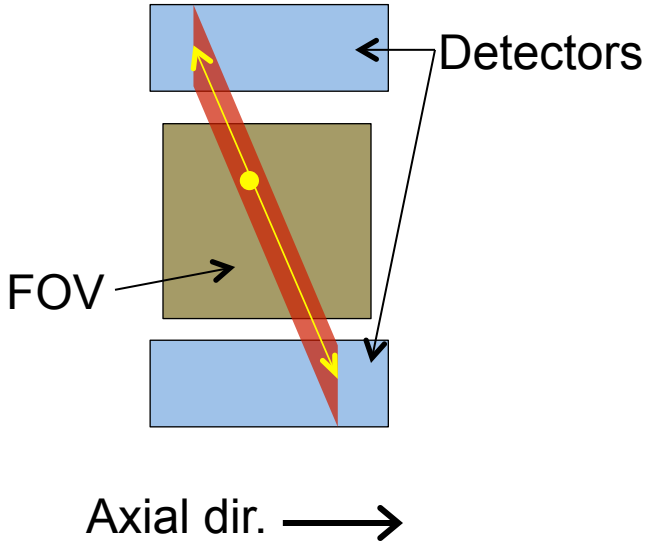


UCDAVIS

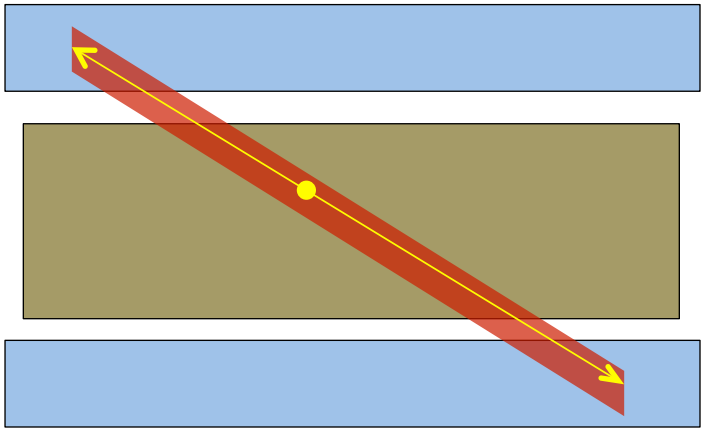
Background

- Combining time-of-flight (TOF) and depth-of-interaction (DOI) especially important for long axial field-of-view PET scanners.
- Long LORs have axial DOI blurring
- High attenuation introduces need for TOF

Typical PET scanner



Long axial FOV PET

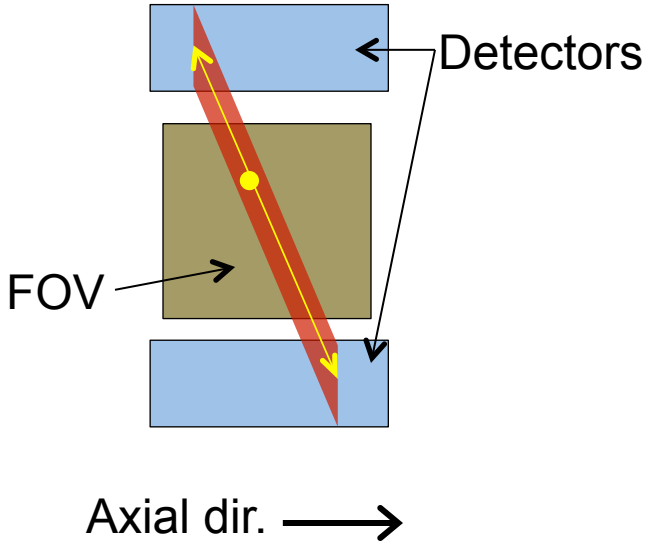


UCDAVIS

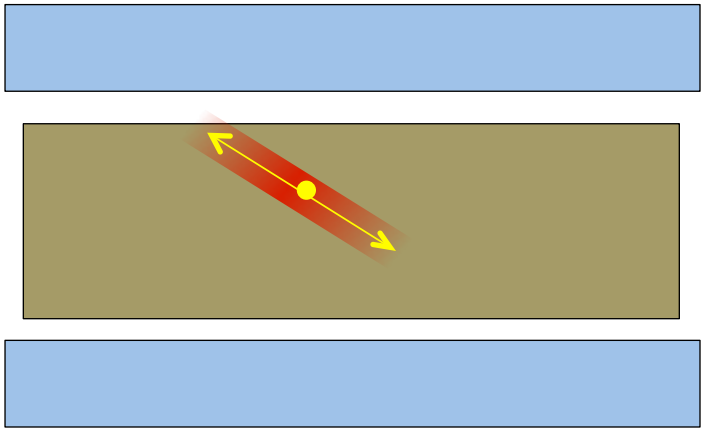
Background

- Combining time-of-flight (TOF) and depth-of-interaction (DOI) especially important for long axial field-of-view PET scanners.
- Long LORs have axial DOI blurring
- High attenuation introduces need for TOF

Typical PET scanner



Long axial FOV PET

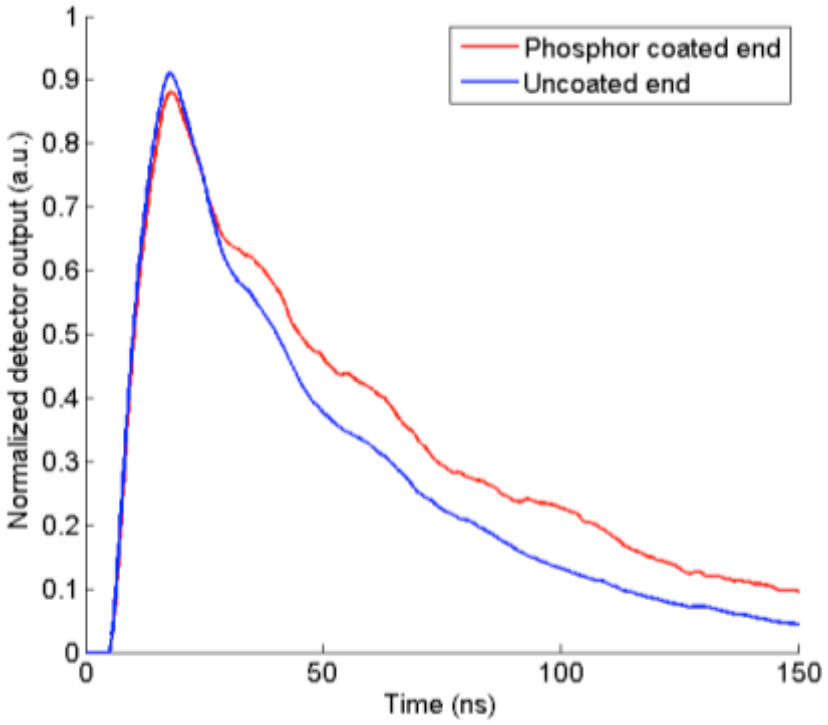


UCDAVIS

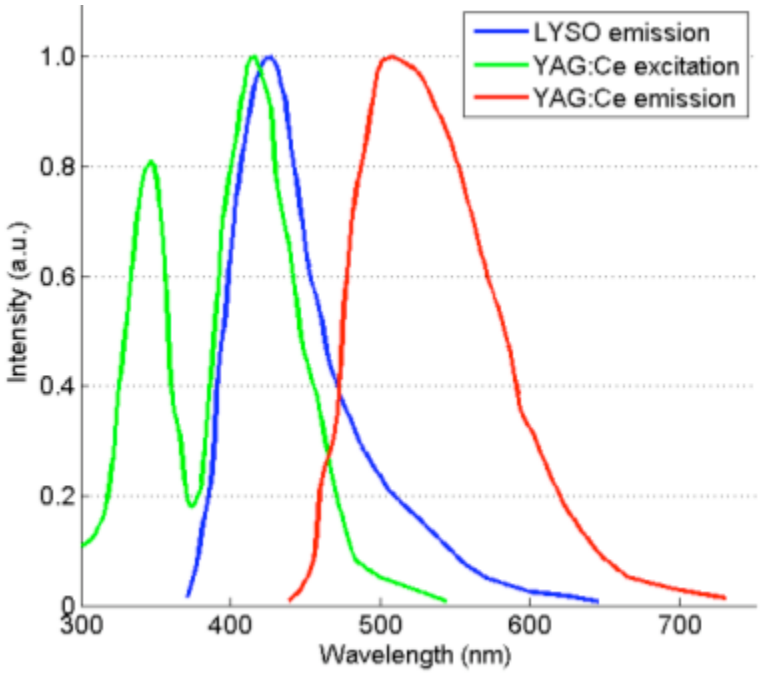
Background

- Use of phosphor coated crystals to determine DOI previously investigated (Du *et al.* 2009, Roncali *et al.* 2012).
- DOI determined by decay time changes.

End-to-end signal comparison



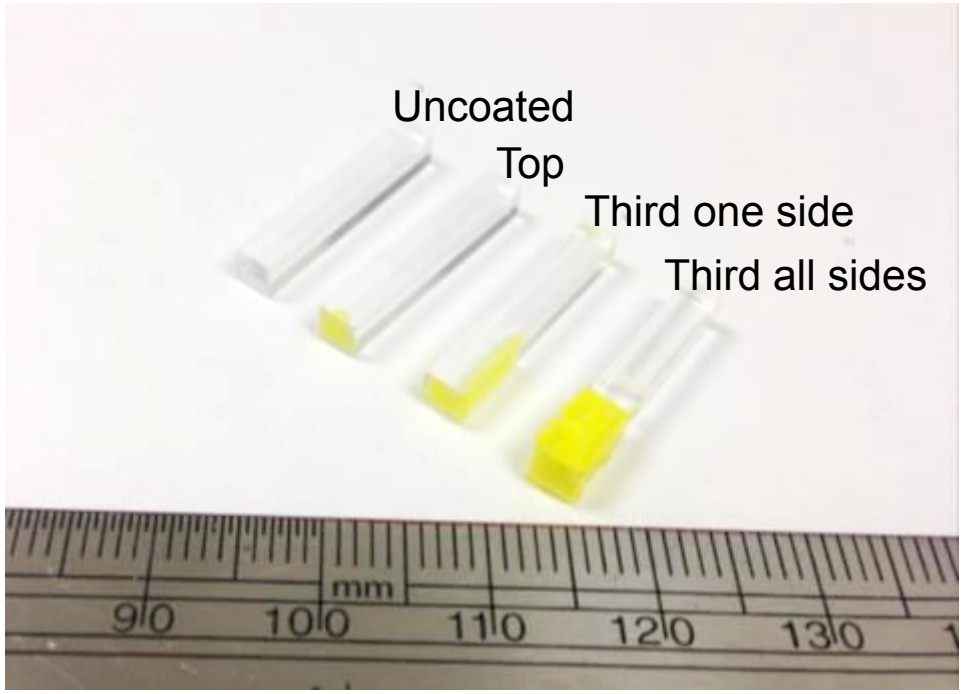
LYSO and YAG:Ce light intensities



UCDAVIS

Introduction

- Phosphor (YAG:Ce) coated LYSO polished crystals to be used for hybrid TOF and DOI encoding PET detector



Phosphor coated 3x3x20 mm^3 LYSO crystals

Objectives:

- Compare DOI resolution with PMTs and SiPMs
- Investigate timing properties of phosphor coated crystals

UCDAVIS

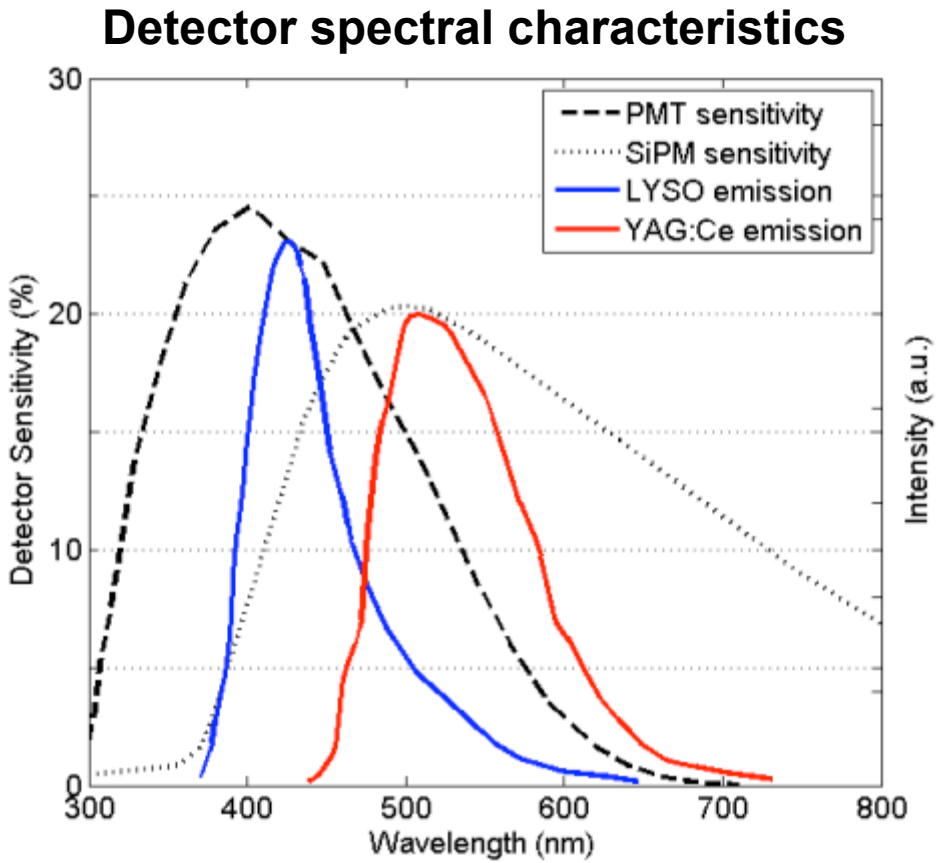
Spectral Characteristics

PMT:

- Hamamatsu R9800
- Fast output signal
- Peak sensitivity at LYSO emission peak
- Sensitivity poorly matched for YAG:Ce emission spectrum

SiPM:

- SensL MicroFM-30035
- Sensitivity profile matched with YAG:Ce emission
- Sub-optimal sensitivity for LYSO emission

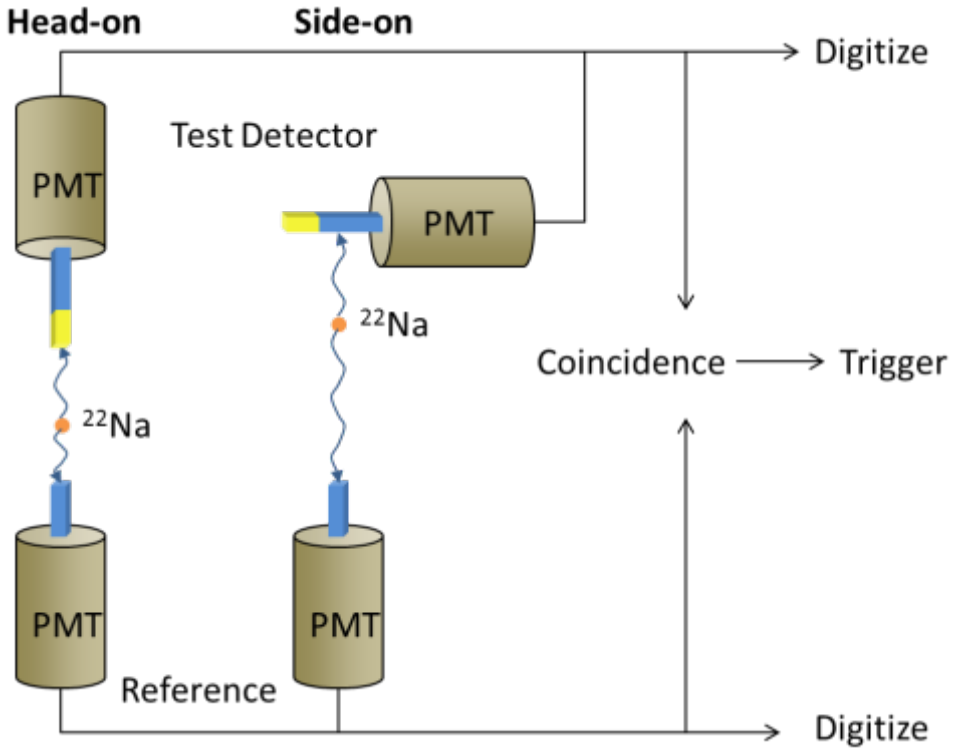


UCDAVIS

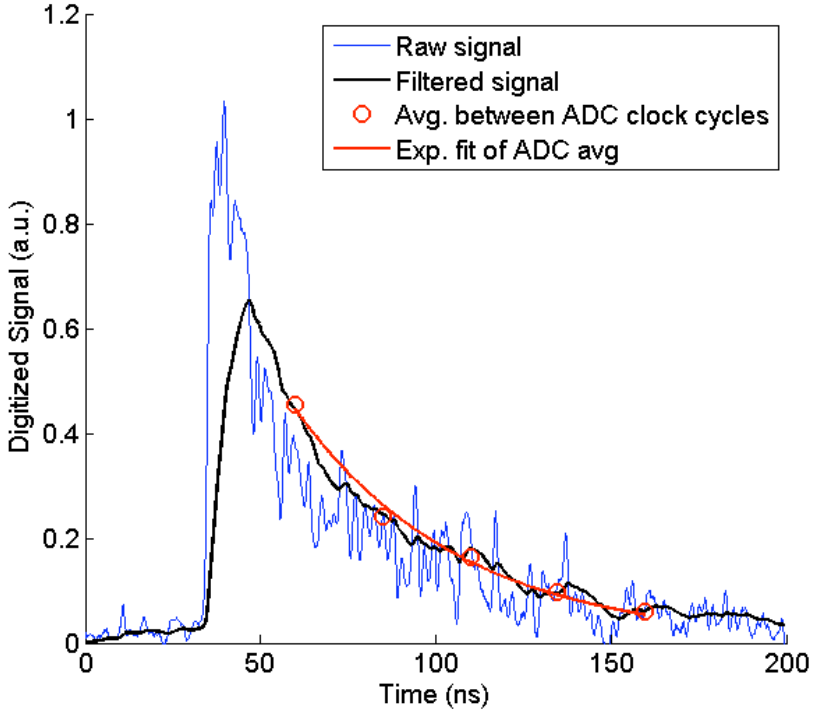
Method

- Detector signals are sampled at 5 GHz, filtered with 20 MHz low-pass filter and down-sampled to 40 MHz for decay time calculation.
- Timing resolution calculated using leading edge time pick-off

Experimental setup



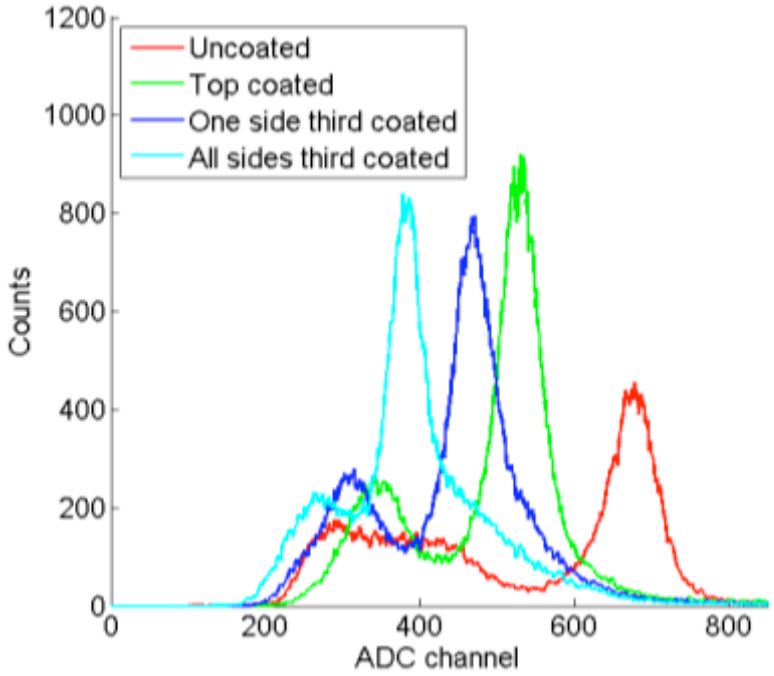
Signal processing



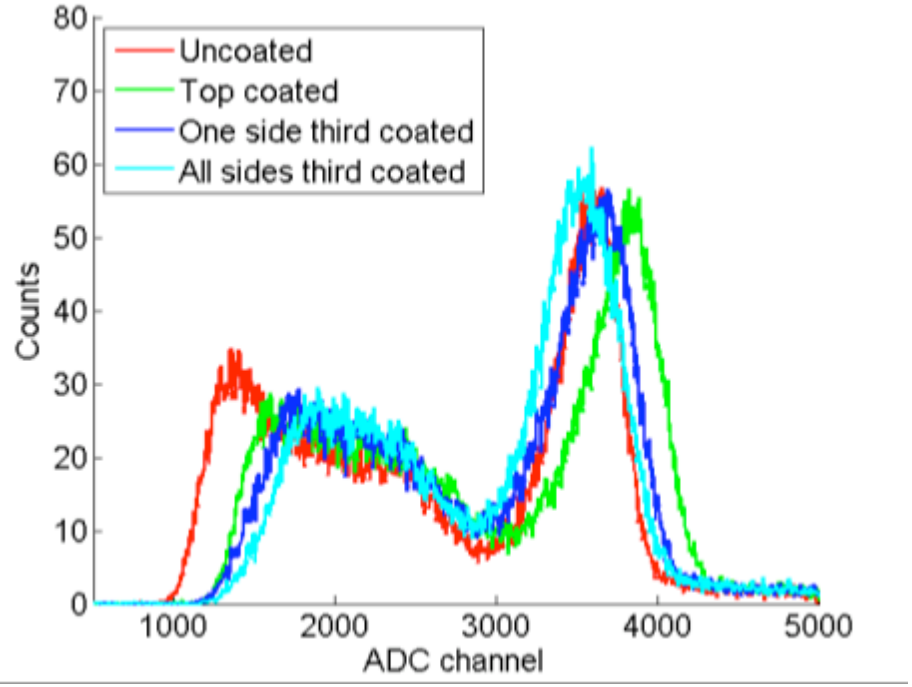
UCDAVIS

Energy Spectra

PMT



SiPM



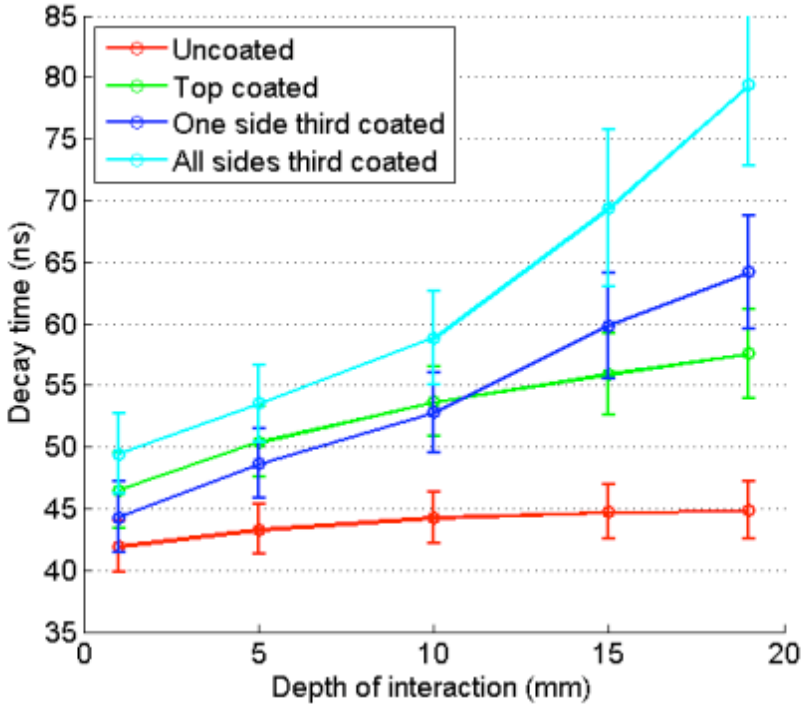
Head-on Energy Resolution (%)

	PMT	SiPM
Uncoated	12.0	12.9
Top coated	13.8	14.2
One side third coated	17.9	15.1
All sides third coated	19.9	14.5

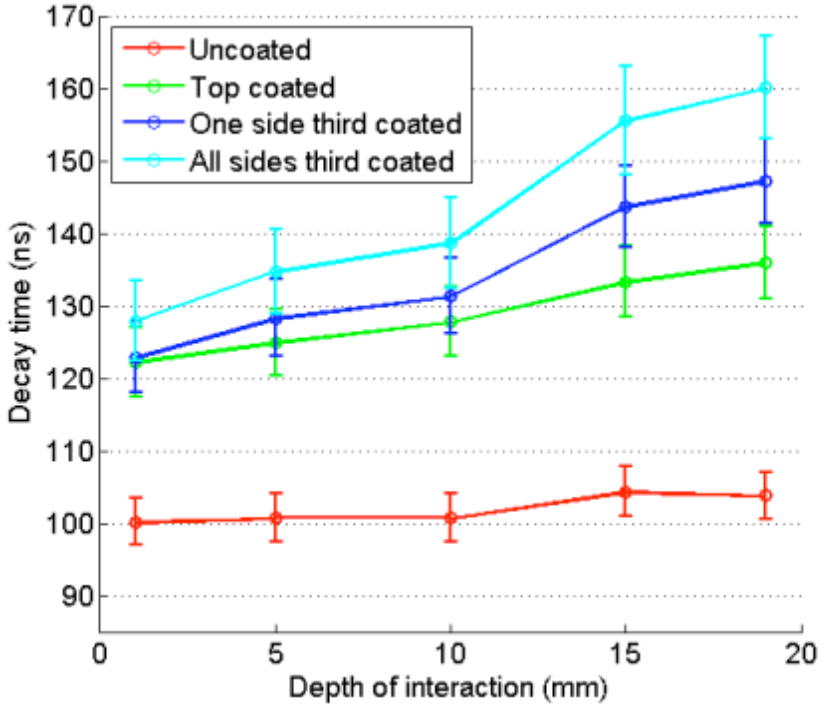
UCDAVIS

Decay Time vs. Depth-of-Interaction

PMT



SiPM



DOI Resolution (mm)

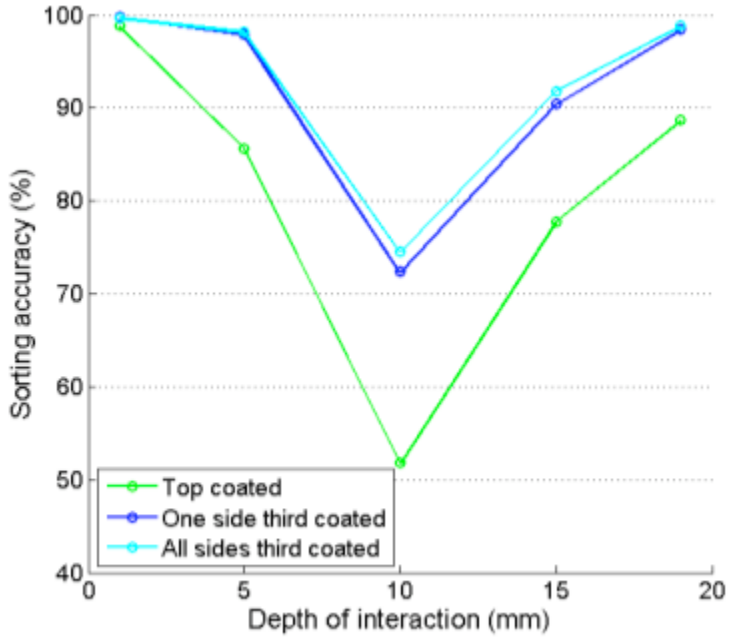
	PMT	SiPM
Top coated	12.3	14.5
One side third coated	7.5	9.1
All sides third coated	6.6	8.2

UCDAVIS

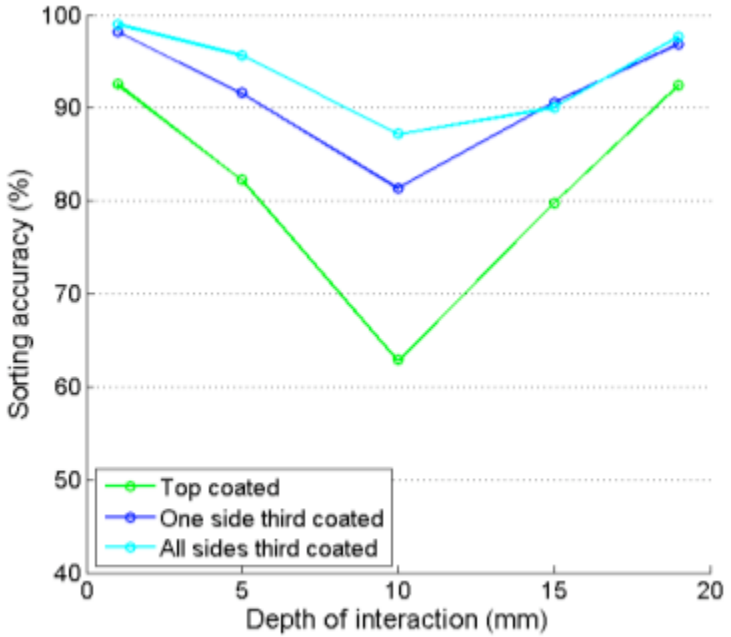
Two Bin DOI Sorting Accuracy

- Pulses are sorted into two DOI bins with cut-off at ~12 mm depth

PMT



SiPM



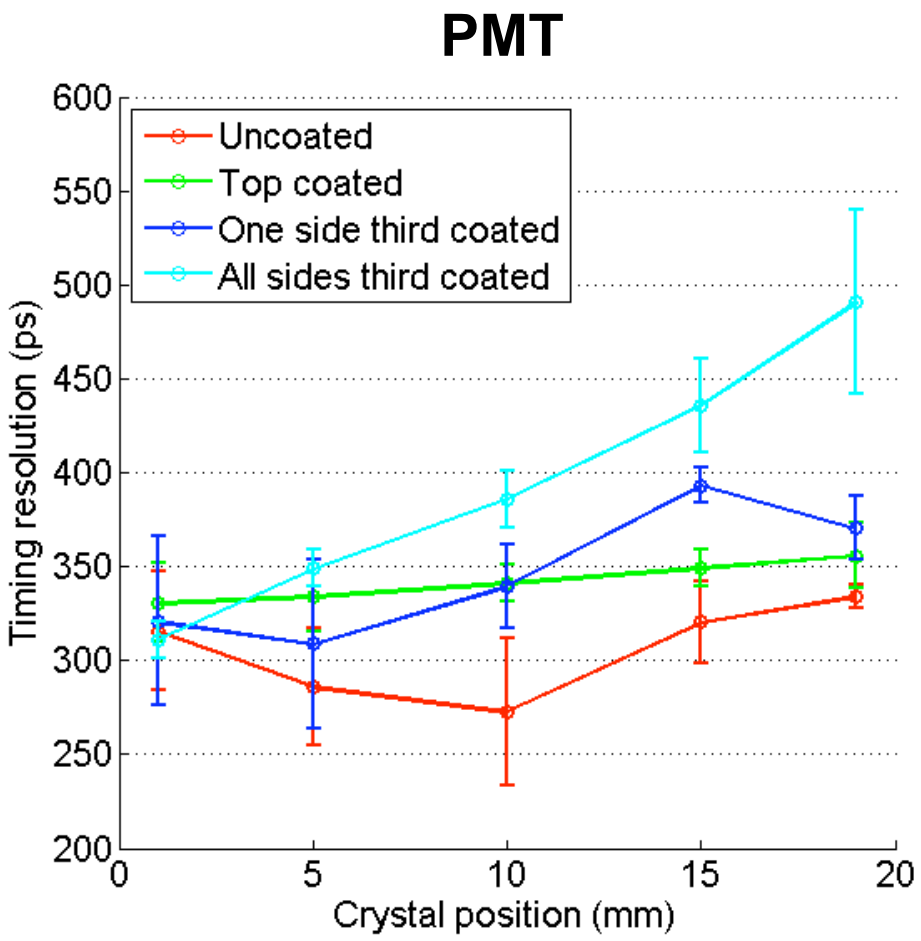
Two-bin DOI Sorting Accuracy (%)

	PMT	SiPM
Top coated	80.6	82.0
One side third coated	91.8	91.7
All sides third coated	92.6	93.9

UCDAVIS

Timing Resolution vs. Depth of Interaction

- Timing resolution measured at 5 irradiation depths for each crystal.



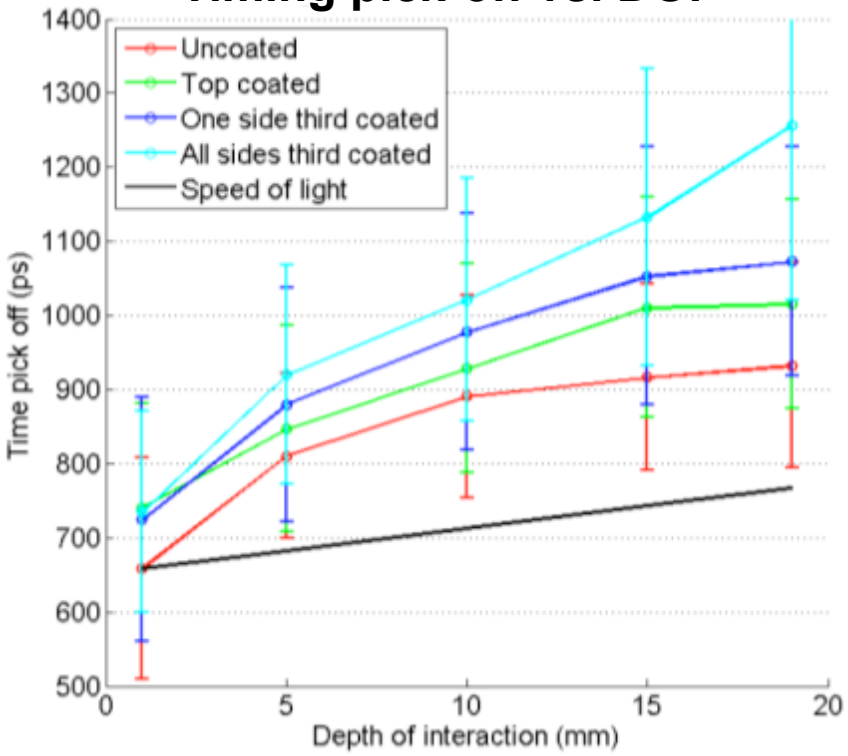
Degraded timing resolution due to low detection efficiency and delayed phosphor emission.

Depth-averaged coincidence timing resolution (ps)	
Uncoated	306
Top coated	342
One side third coated	347
All sides third coated	394

UCDAVIS

Decay Time and Timing Pick-Off Correlation

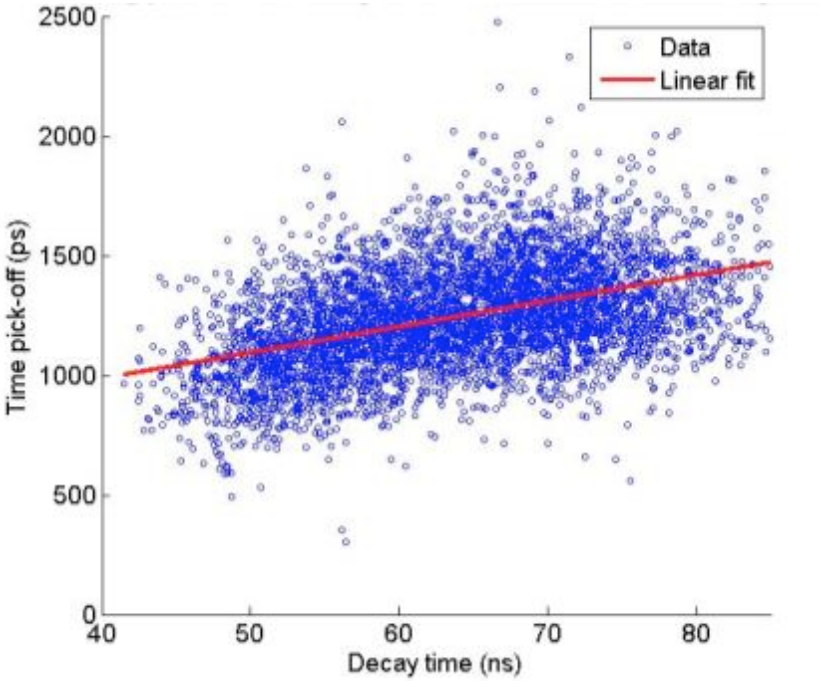
Timing pick-off vs. DOI



- Linear correlation found between timing pick-off and decay time.
- Used to correct head-on timing data for time pick-off dispersion

- Time pick-off dispersion increases for coated crystals
- Introduces systematic error in head-on timing resolution

Timing pick-off vs. decay time



UCDAVIS

Head-on Timing Resolution

- The timing resolution is calculated before and after the decay time – timing pick-off correlation factor is applied

Head-on Coincidence Timing Resolution (ps)

	Before correction	After correction
Uncoated	373 +/- 24	373 +/- 24
Top coated	391 +/- 15	388 +/- 11
One side third coated	433 +/- 25	394 +/- 29
All sides third coated	592 +/- 26	448 +/- 39

Minimal timing degradation when decay time – depth relation is used to correct timing pick-off.

UCDAVIS

Discussion and Conclusion

Phosphor coated LYSO crystals can achieve 2 bin DOI with sub-400 ps timing resolution.

Future Work:

- Construct TOF – DOI detector using an array of phosphor coated LYSO crystals.
- Further investigate the use of fast, enhanced blue sensitivity SiPMs for phosphor coated DOI method.

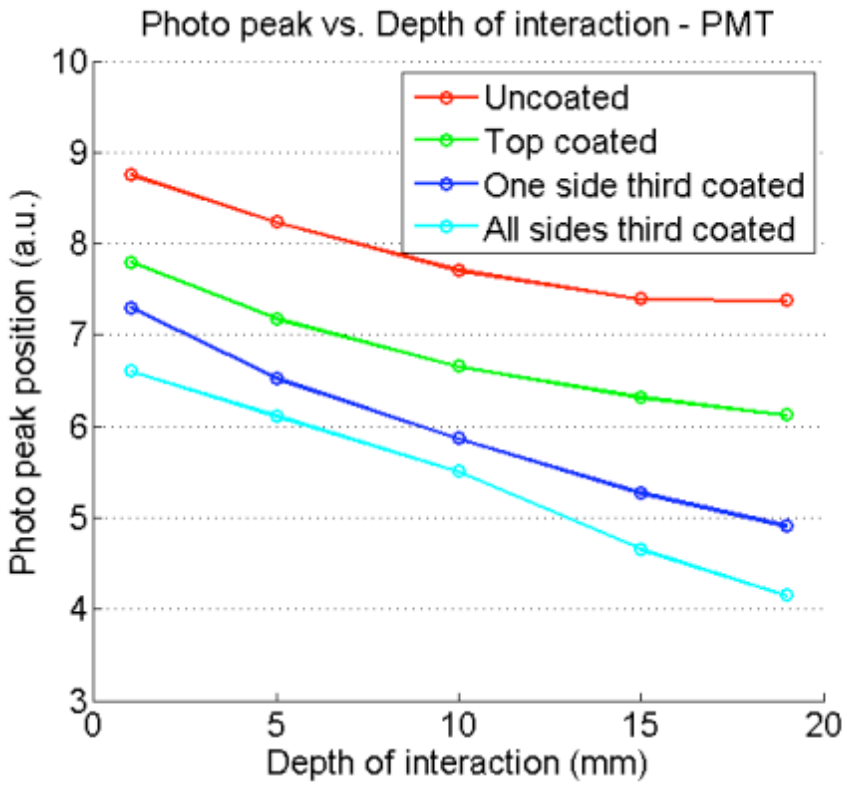
Acknowledgements:

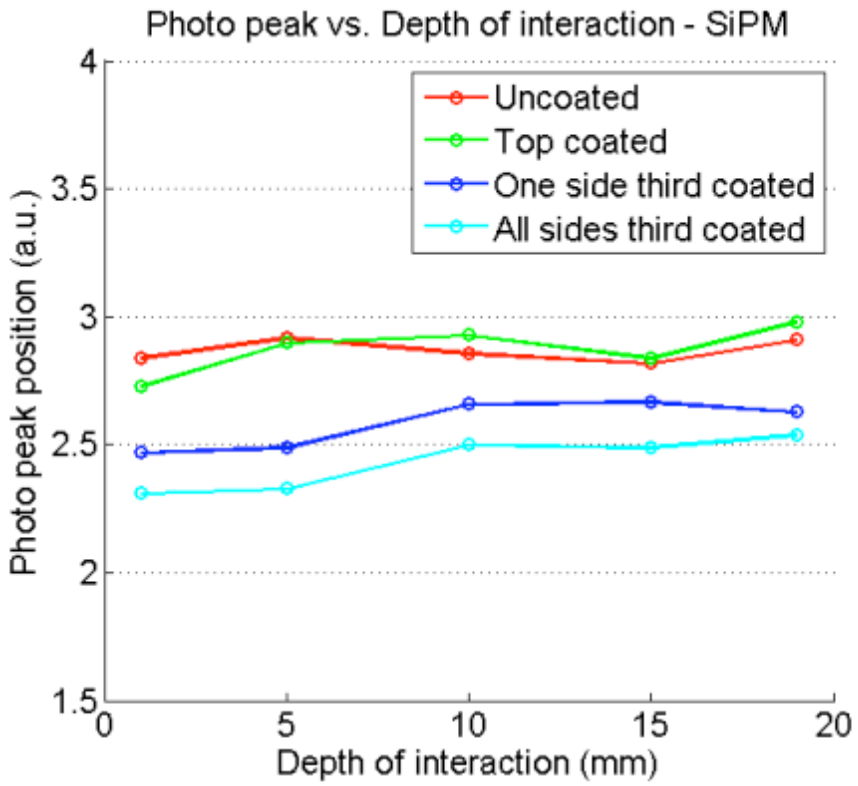
This work was conducted as part of the EXPLORER consortium and funded by a UC Davis RISE award.

EXPLORER

UCDAVIS

Side-on Photopeak Position

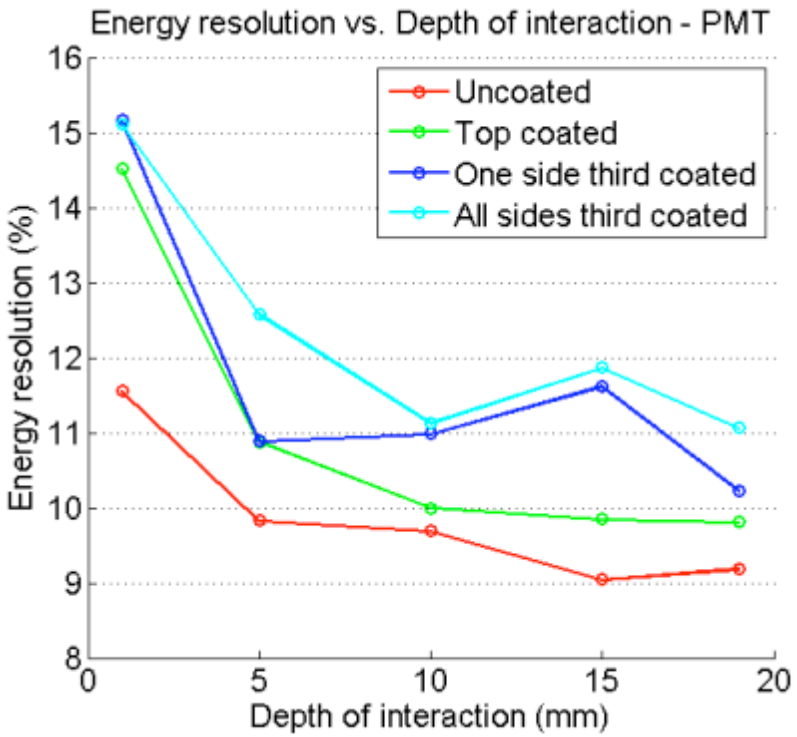


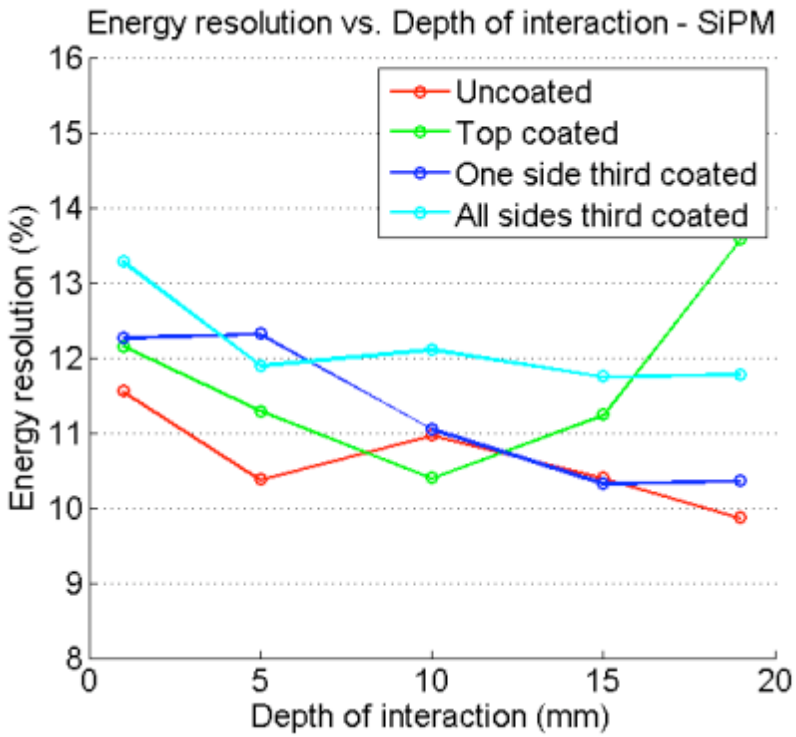


- SiPM shows little change in photopeak position along the crystal length and between crystals.
- Indicates insignificant light loss from phosphor but poor PMT detection efficiency to explain photopeak shift for PMT data.

UCDAVIS

Side-on Energy Resolution





Fixed Depth Average Energy Resolution (%)

	PMT	SiPM
Uncoated	9.9 +/- 0.9	11.0 +/- 0.8
Top coated	11.0 +/- 1.8	11.7 +/- 1.1
One side third coated	11.8 +/- 1.7	11.3 +/- 0.8
All sides third coated	12.8 +/- 1.6	12.2 +/- 0.6

UCDAVIS