BaF2 TOFPET Detector Simulation Status

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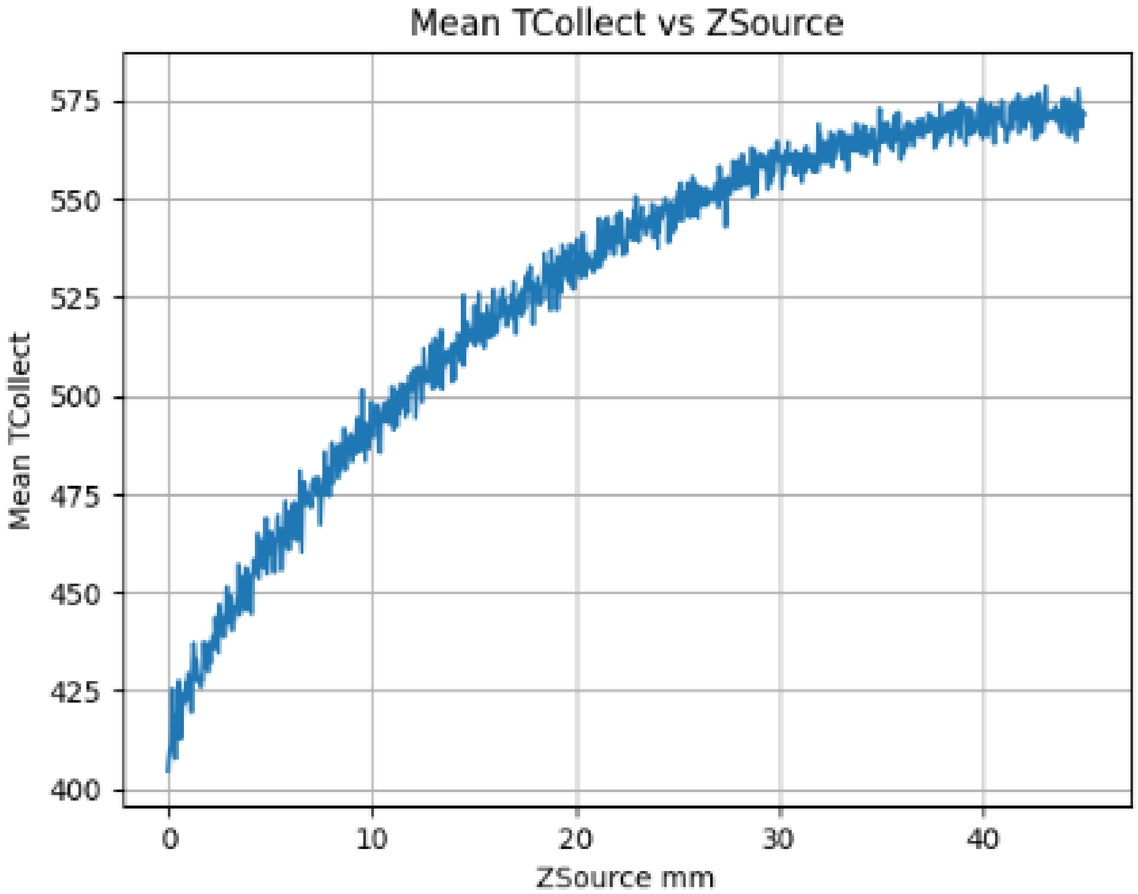
PicoRad Imaging -> MGH

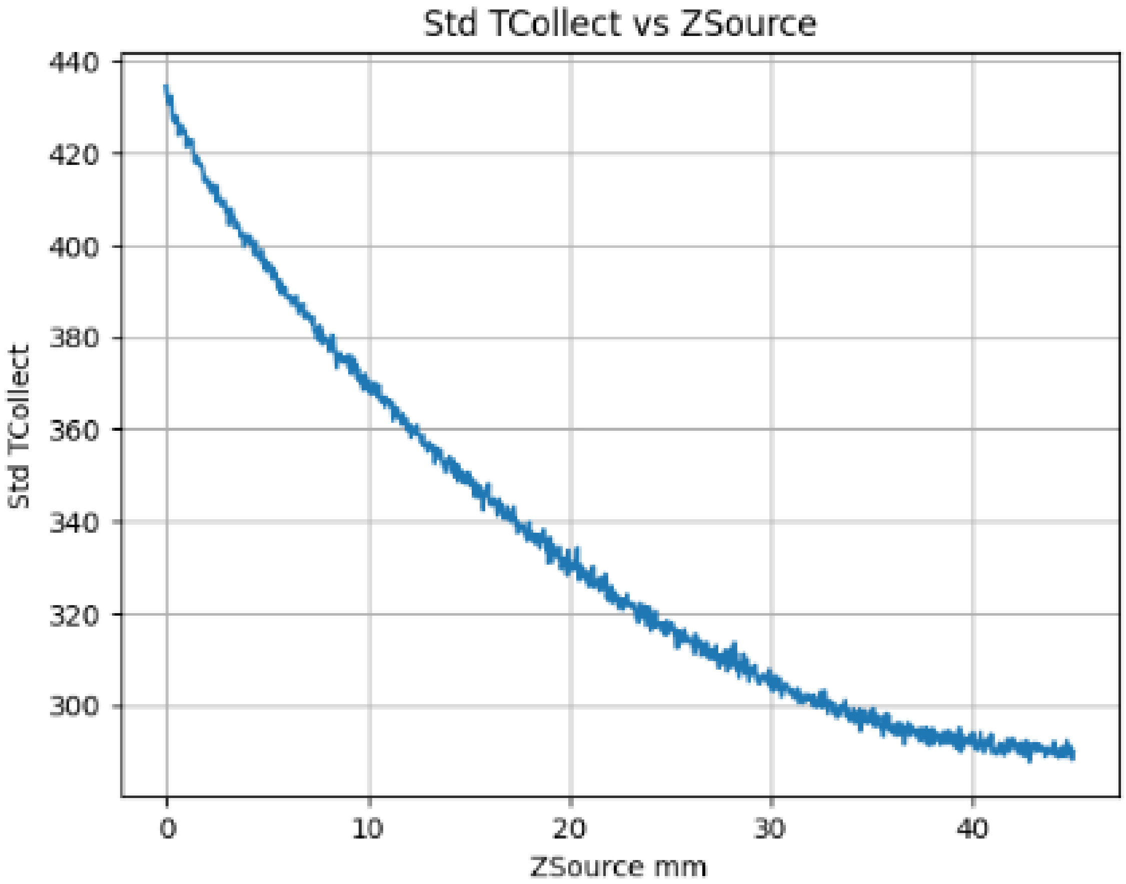
10/25/2023

SimpleOpticsZPencil.ipynb

Photon collection time statistics depend as expected with Depth of Interaction Z

```
NEvents: 1000
ic| SqrtNPhotons: 100
ic| XBounds: [1.5, 1.5]
ic| YBounds: [-3.0, -3.0]
ic| ZBounds: [0, 45.0]
ic| RegularZ: True
ic| XSource.size(): torch.Size([1000, 10000])
ic| YSource.size(): torch.Size([1000, 10000])
ic| ZSource.size(): torch.Size([1000, 10000])
```





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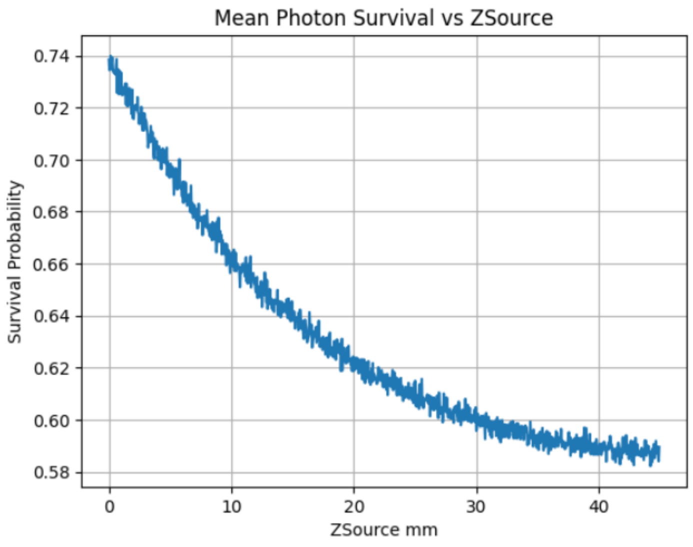
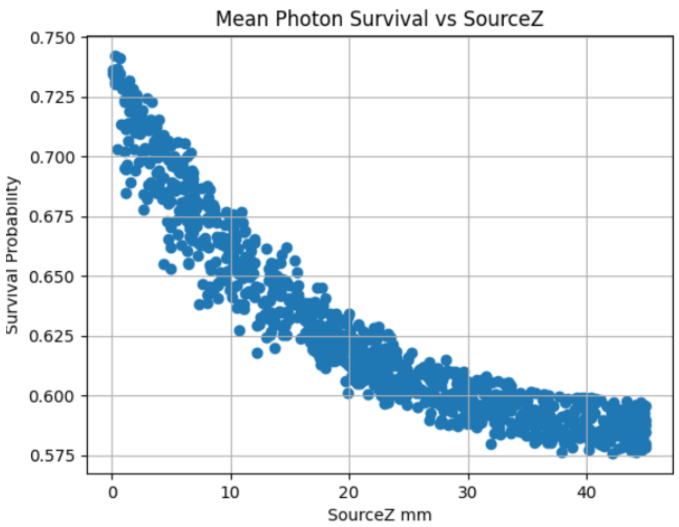
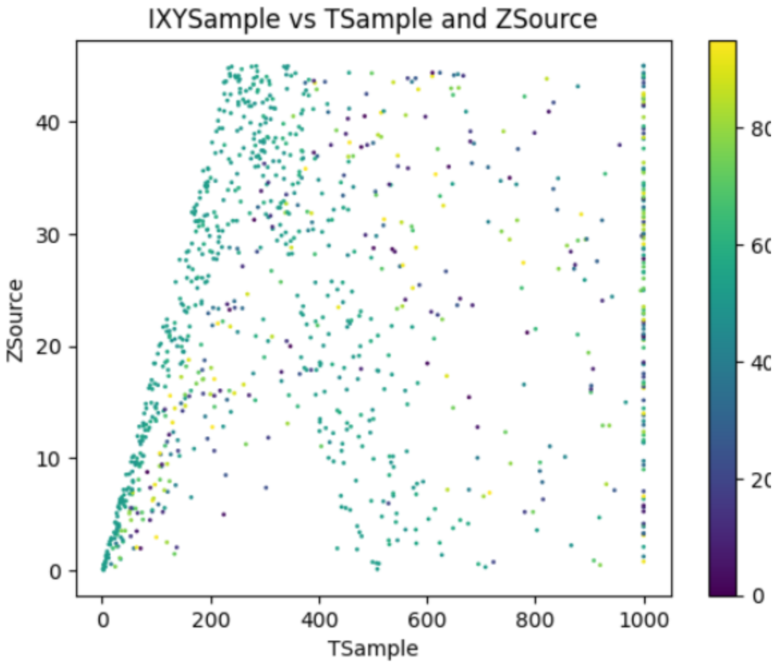
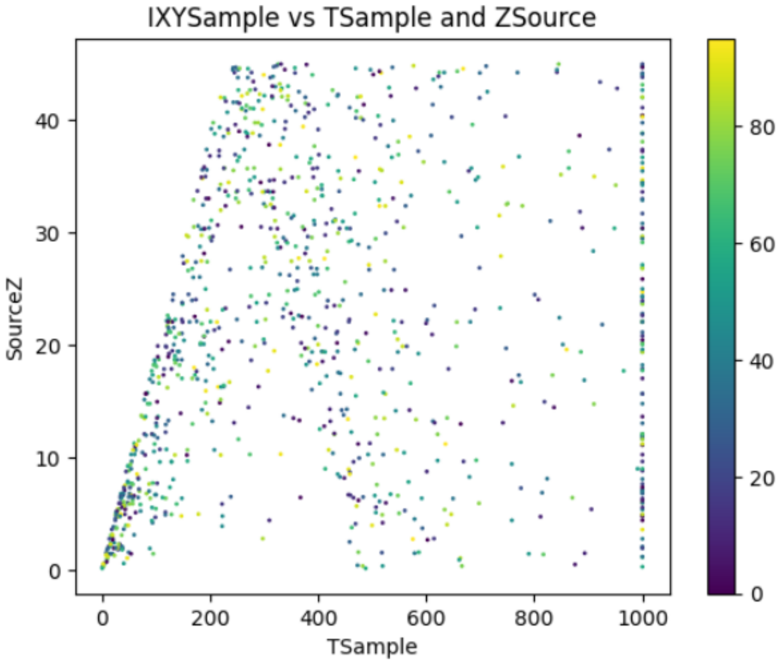
There is second-order broadening of Mean Photon Survival vs depth Z across different X,Y

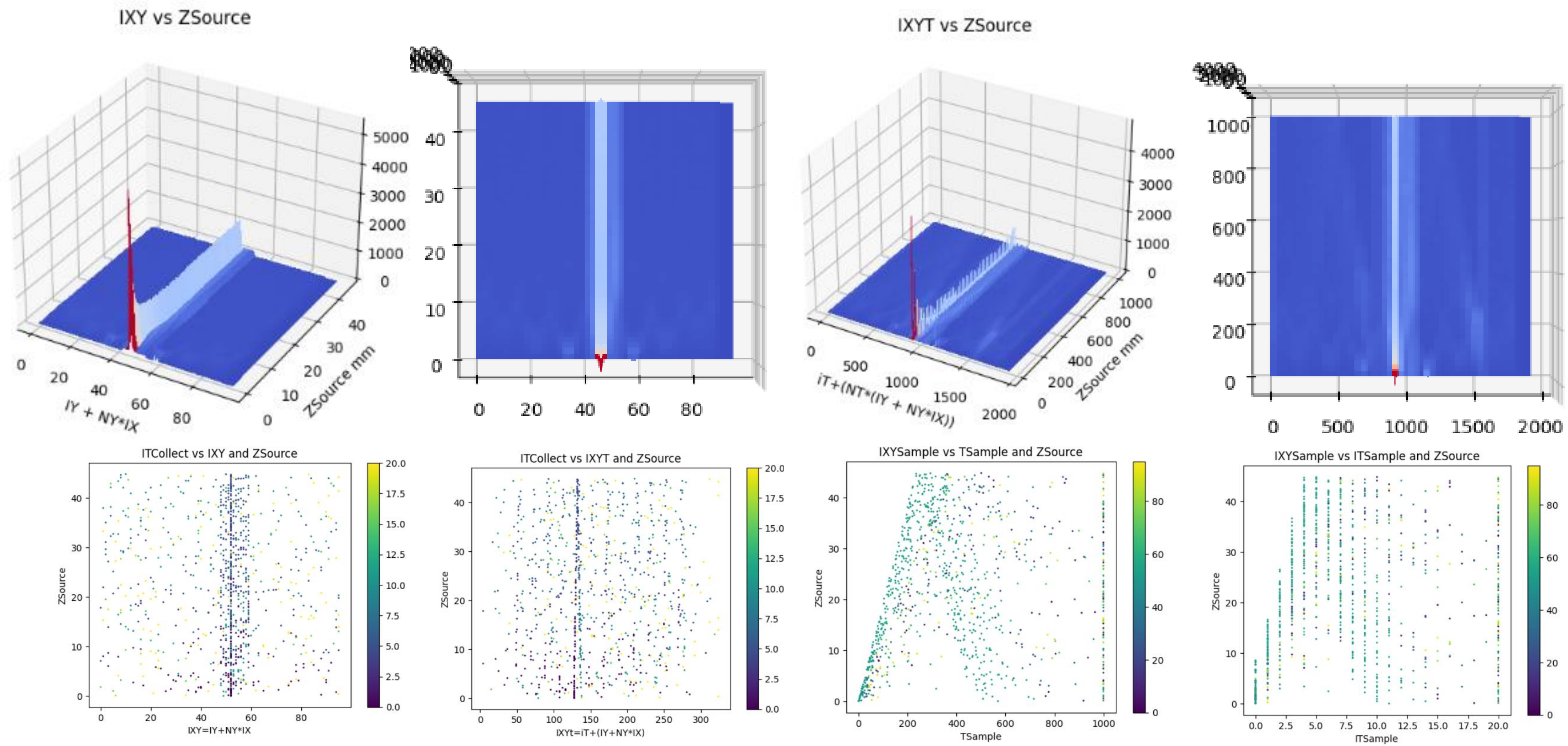




First event waveform encodes Depth of Interaction Z and Z reflection echo time peak





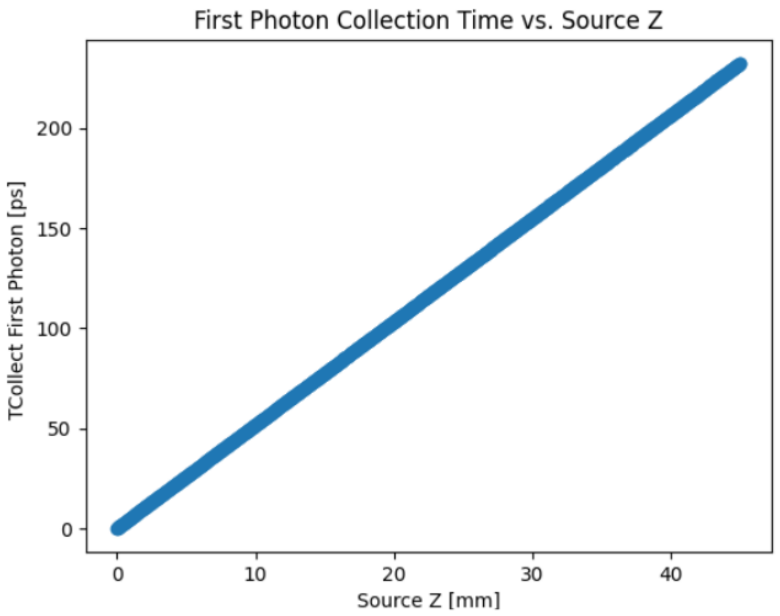


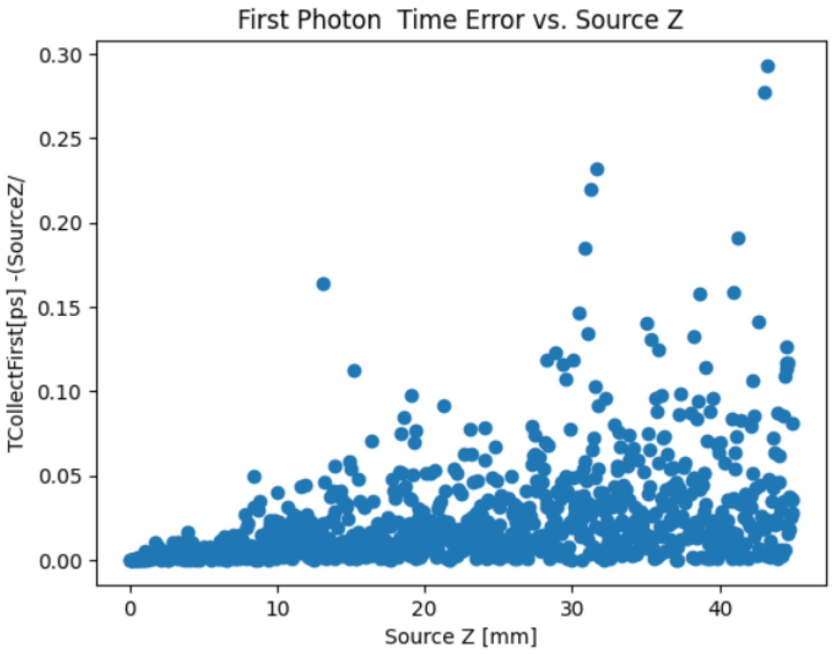
Detection X and Y coordinates are nearly Independent of Depth of Interaction Z. while T distribution varies with Z.

First photon collection time varies linearly with Depth of Interaction Z

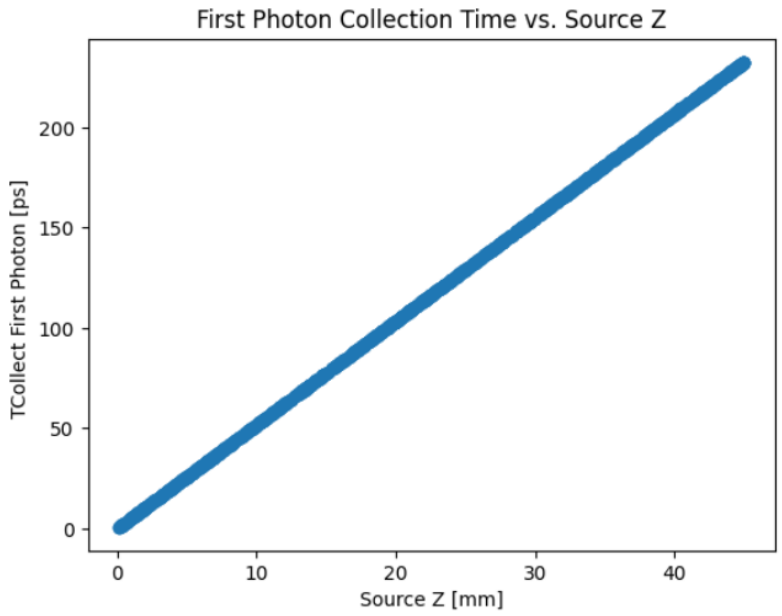
Timing errors are sub-picosecond for 10000 prompt photons with exact DOI correction

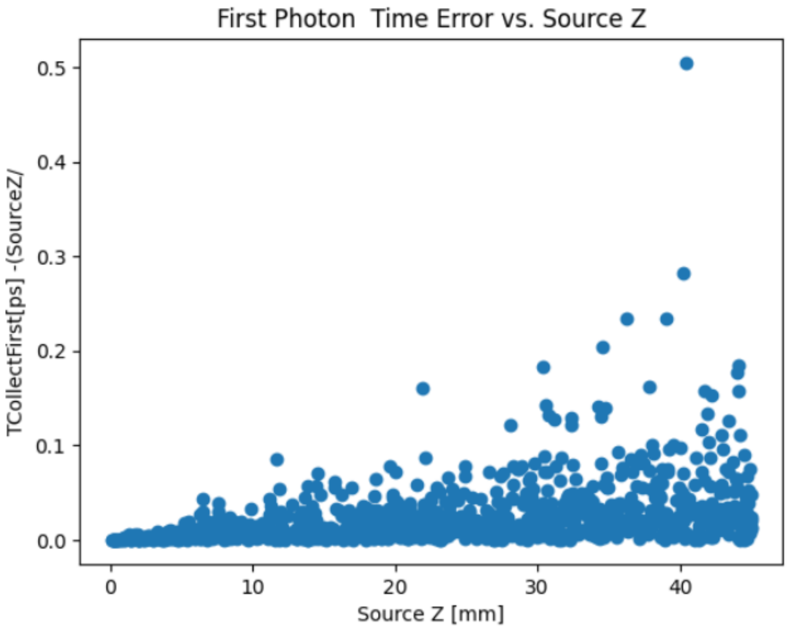
SimpleOpticsZPencil.ipynb





SimpleOpticsFlood.ipynb





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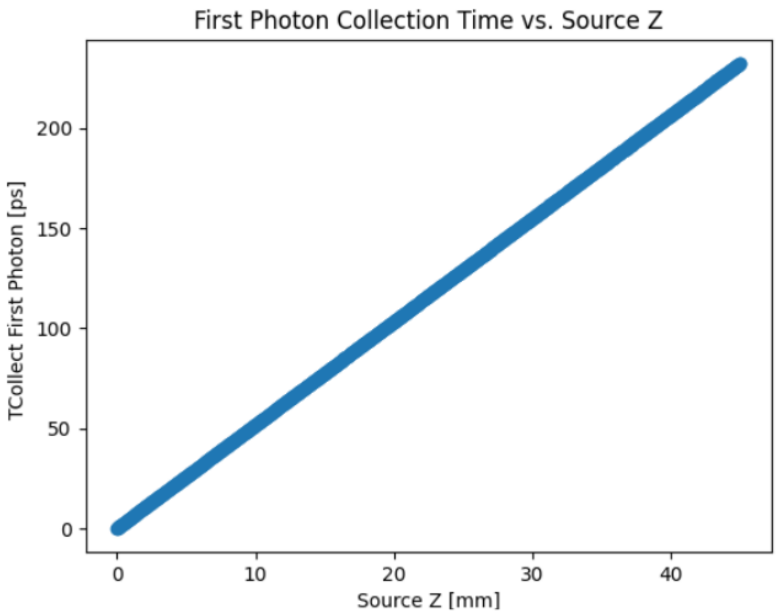

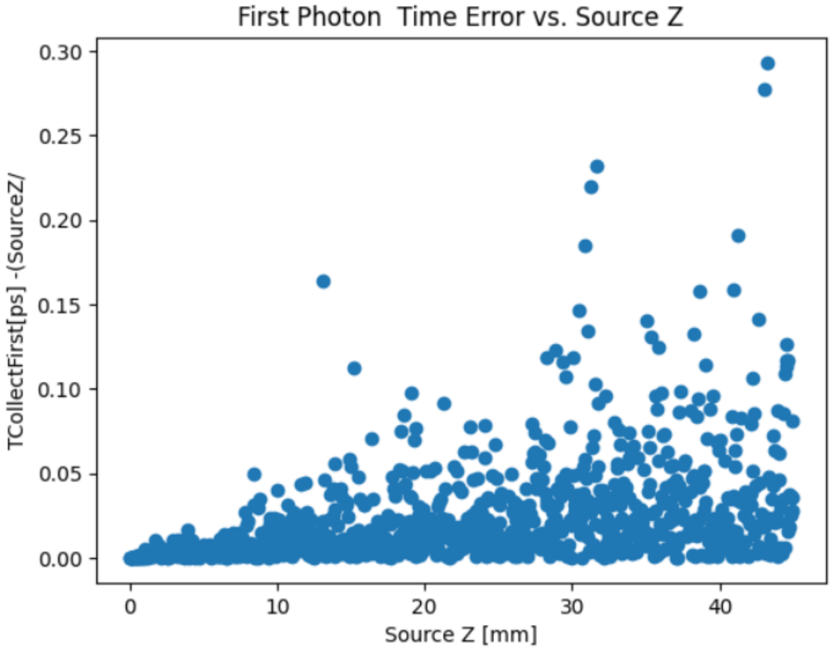

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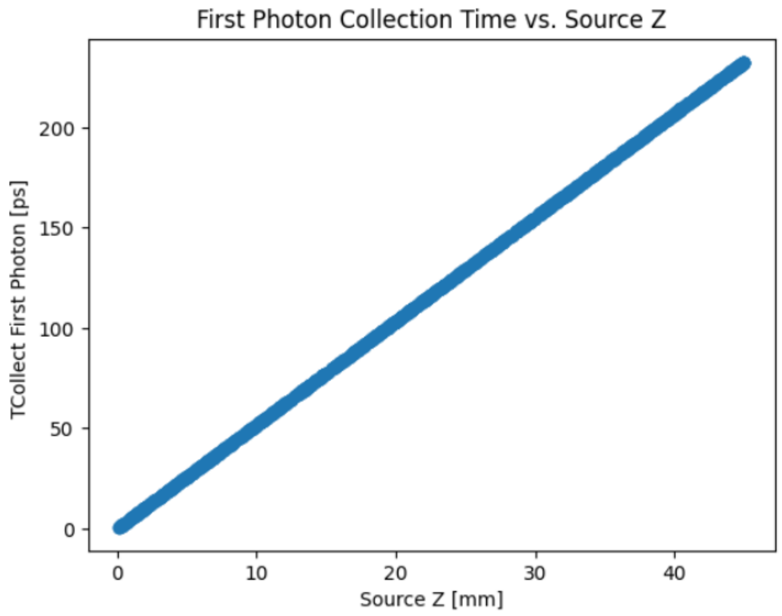
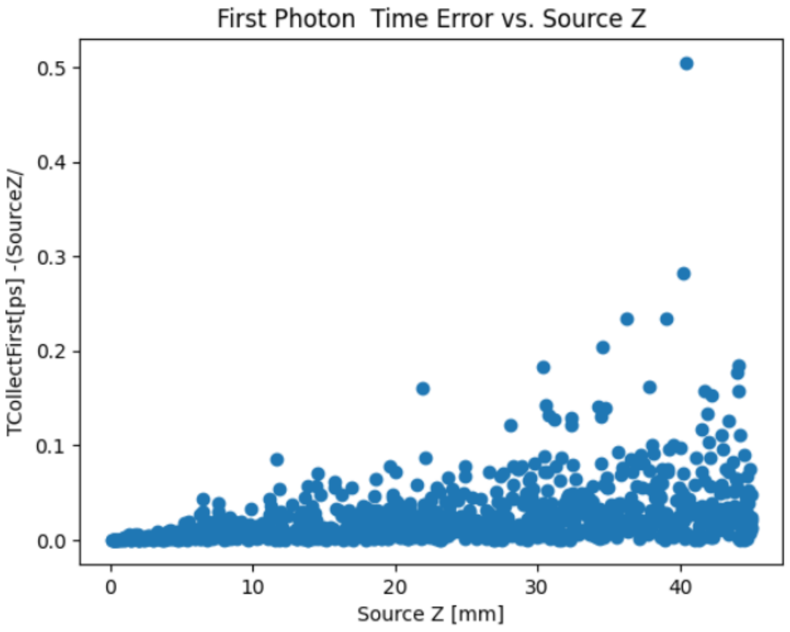
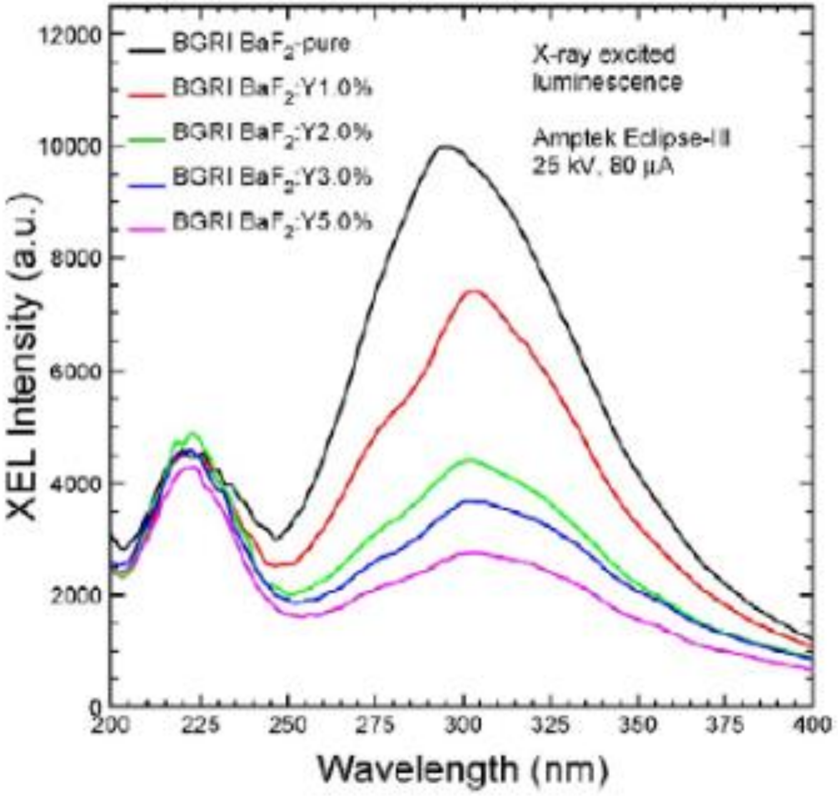


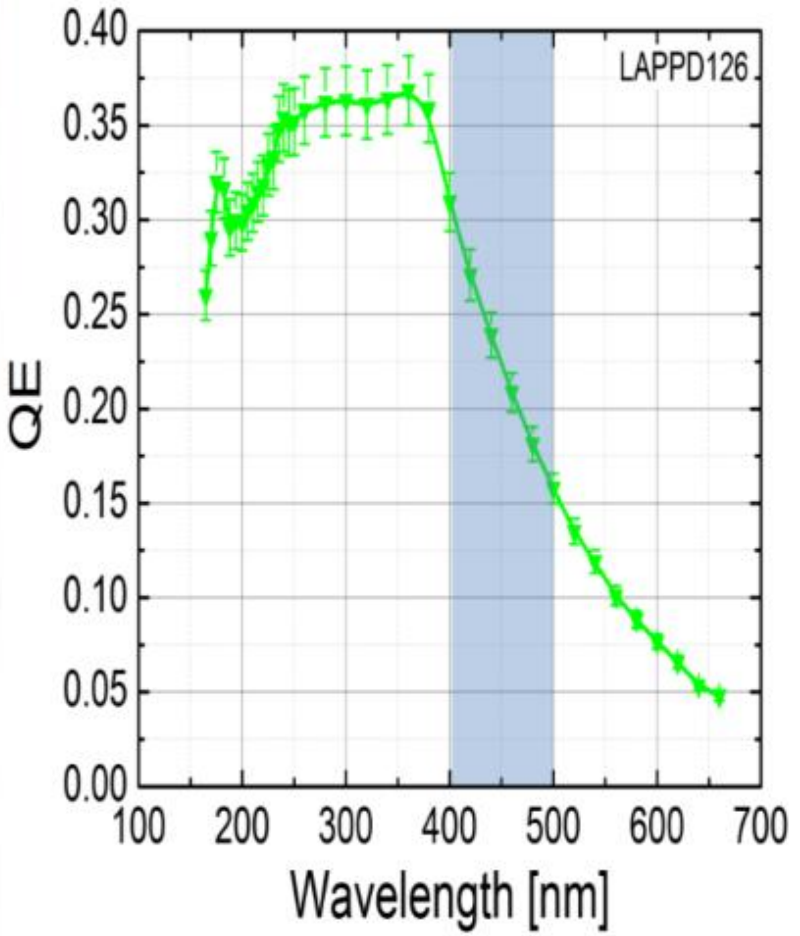


Intrinsic light yield, LY_{intr} (ph/MeV) $1400^{a\,b\,h}$–$7000^{b\,i}$



BaF2	Fast	Slow
Decay Time	700ps	600ns
Wavelength	220nm	310 nm
Photons /511keV	715	3577
Collection Fraction	0.8	0.8
Photons Collected	572	2862
QE	0.30	0.37
N = PEs/511keV	172	1059
1/sqrt(N)	8%	3%

LAPPD QE



Photoelectron Statistics

Gundacker, S., Pots, R.H., Nepomnyashchikh, A., Radzhabov, E., Shendrik, R., Omelkov, S., Kirm, M., Acerbi, F., Capasso, M., Paternoster, G. and Mazzi, A., 2021. Vacuum ultraviolet silicon photomultipliers applied to BaF2 cross-luminescence detection for high-rate ultrafast timing applications. *Physics in Medicine & Biology*, *66*(11), p.114002.

Pots, R.H., Auffray, E. and Gundacker, S., 2020. Exploiting Cross-Luminescence in Ba F 2 for Ultrafast Timing Applications Using Deep-Ultraviolet Sensitive HPK Silicon Photomultipliers. *Frontiers in Physics*, *8*, p.592875.

Table 1. Overview of the general characteristics of BaF_2, LSO:Ce and BGO. Values are taken from Lecoq *et al* (2017)
indicated.

Property	BaF2	LSO:Ce
Density ρ (g cm^{-3})	4.88	7.4
Effective atomic number, Z_{eff}	53	66
Photon absorption α @511 KeV (cm^{-1})	0.085	0.28
Radiation length X_0 (cm)	2	1.1
Intrinsic light yield, LY_{intr} (ph/MeV)	1400[a b h]–7000[b i]	40 000[b]
Decay time τ (ns)	0.6–0.8[h]/620[i]	22/44[b]
Photon fraction @ 0.5 MeV	0.19[c])	0.34[c]
Emission peak(s) λ_{max} (nm)	195[i] 220[i] 310[h]	420[b]
Refractive index (RI) @ λ_{max}	1.56[d]1.55[d] 1.50[d]	1.82[b]
Melting point (°C)	1280[e]	2150[f]
Cost ($ cm^{-3})	15[g]	60[g]

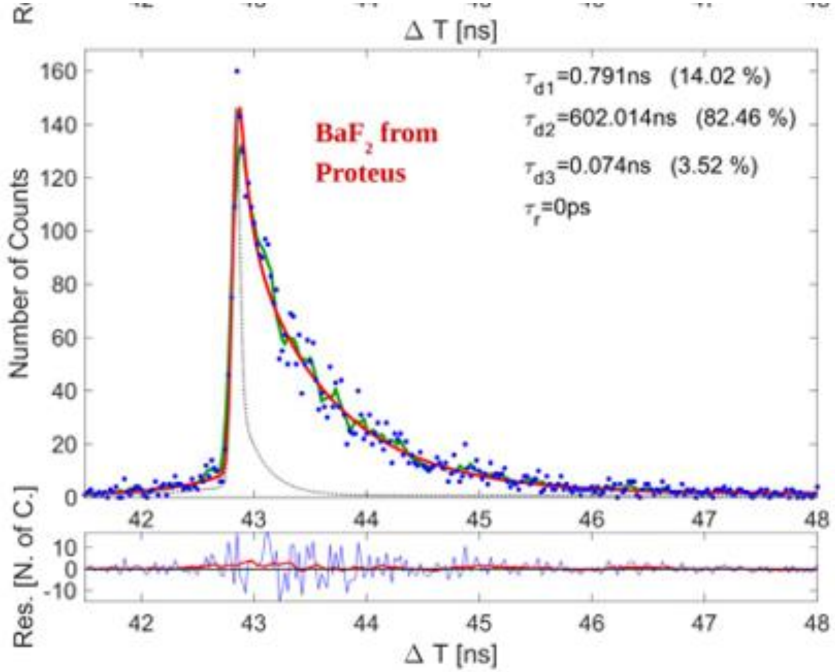


Table 4. Scintillation rise and decay times measured for BaF_2 crystals from the producer Epic Crystal (Ep.) and Proteus (Pr.). Two exponential decay fits are compared with three exponential decay fits and when the crystals are wrapped in Teflon (Tef.) or left unwrapped. Errors are given in $\pm$ 1σ, meaning a confidence interval of 68%.

Origin	τ_r (ps)	τ_{d1} (ns)	R_1 (%)	τ_{d2} (ns)	R_2 (%)	τ_{d3} (ns)	R_3 (%)	τ_{deff} (ns)[a]
Ep. Tef.	<4	0.207 ± 0.087	3.0 ± 1	0.842 ± 0.059	10.6 ± 1.1	692 ± 28	86.4 ± 0.7	3.676
Ep.	<4	0.136 ± 0.052	3.7 ± 0.7	0.855 ± 0.055	12.2 ± 1.0	805 ± 56	84.0 ± 1.1	2.405
Pr. Tef.	<4	0.118 ± 0.050	2.0 ± 0.5	0.814 ± 0.040	9.1 ± 0.5	648 ± 21	88.9 ± 0.7	3.538
Pr.	<4	0.074 ± 0.035	3.5 ± 0.7	0.791 ± 0.034	14.0 ± 1.1	602 ± 48	82.5 ± 1.4	1.535
Ep. Tef.	<4	—	—	0.656 ± 0.011	13.6 ± 0.6	678 ± 27	86.4 ± 0.6	4.794
Ep.	<4	—	—	0.616 ± 0.021	16.0 ± 1.0	771 ± 53	84.0 ± 1.0	3.834
Pr. Tef.	<4	—	—	0.639 ± 0.018	10.9 ± 0.4	637 ± 21	89.1 ± 0.4	5.815
Pr.	<4	—	—	0.557 ± 0.020	18.1 ± 1.0	577 ± 48	81.9 ± 1.3	3.064

[a] $\tau_{deff} = (R_1/\tau_{d1} + R_2/\tau_{d2} + R_3/\tau_{d3})^{-1}$.

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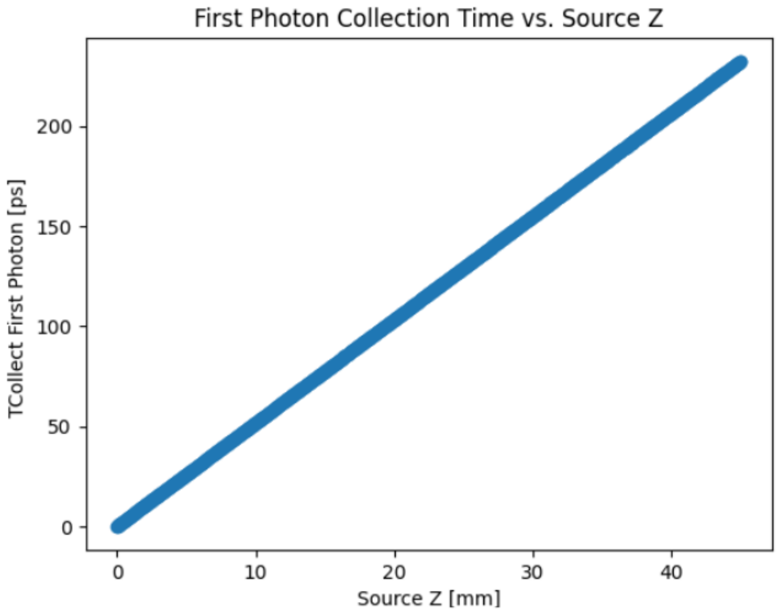
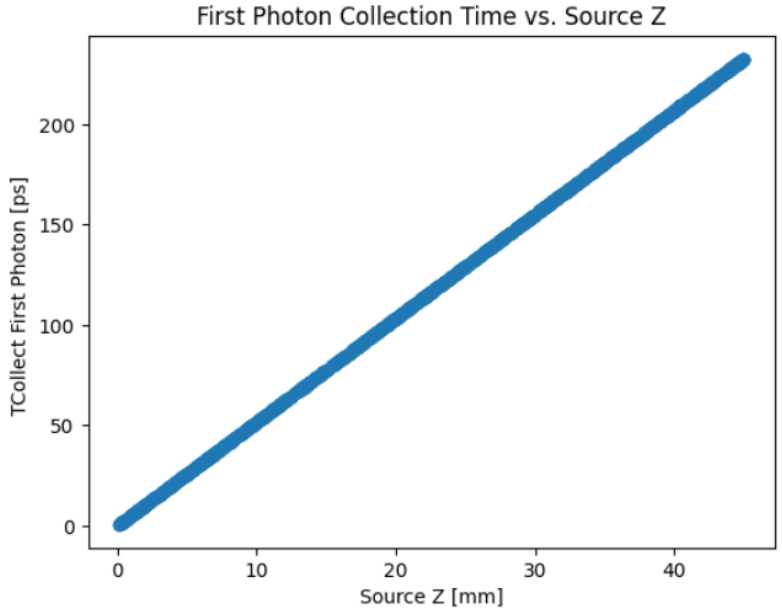
First photon collection time varies linearly with Depth of Interaction Z





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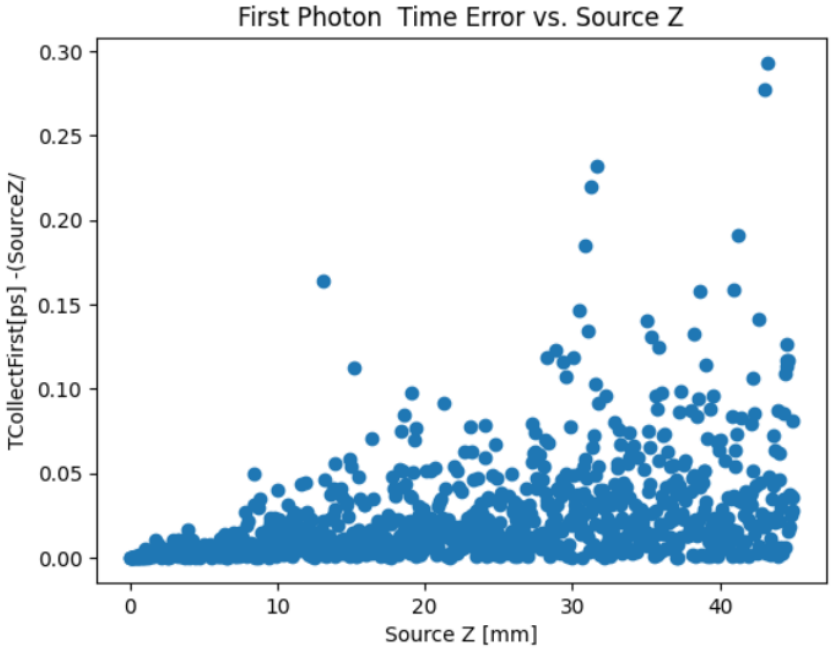

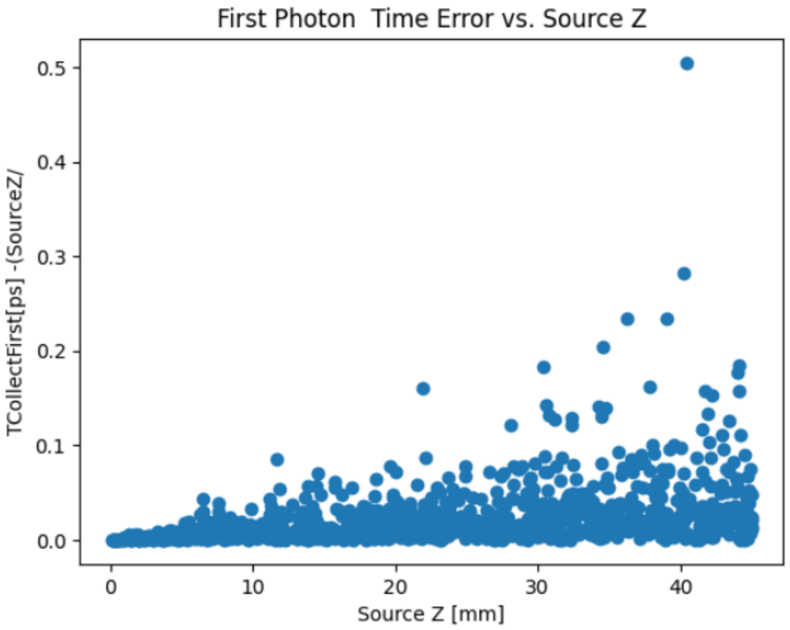

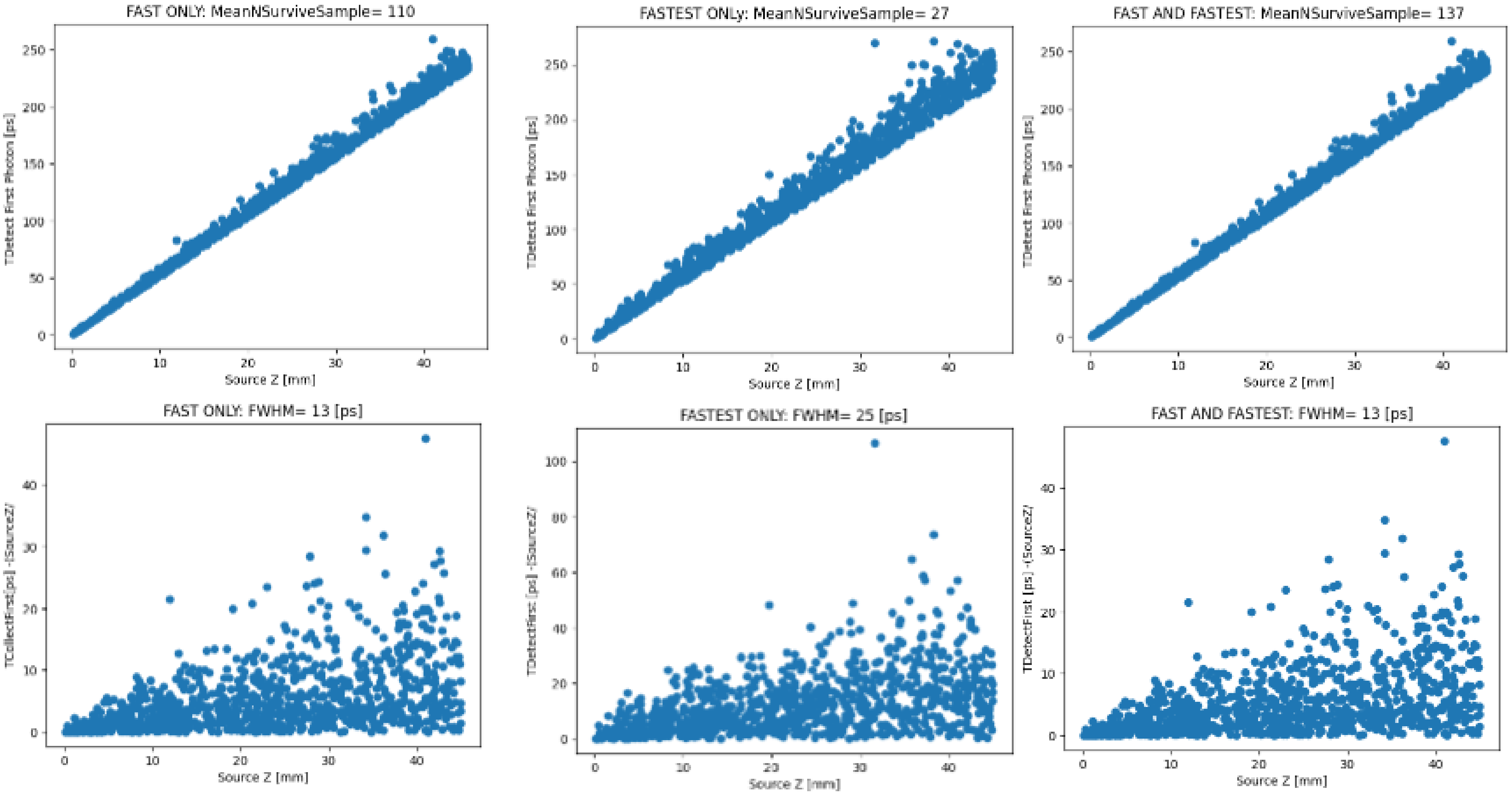

FAST ONLY: MeanNSurviveSample= 110
FASTEST ONLy: MeanNSurviveSample= 27
FAST AND FASTEST: MeanNSurviveSample= 137
TDetect First Photon [ps]
Source Z [mm]
FAST ONLY: FWHM= 13 [ps]
FASTEST ONLY: FWHM= 25 [ps]
FAST AND FASTEST: FWHM= 13 [ps]
TCollectFirst[ps] -(SourceZ/
TDetectFirst [ps] -(SourceZ/