Total Body PET Scanner & Novel Scanner Design Simulations

A cumulative slide deck of all my processes, studies, findings, and more related to PET simulations

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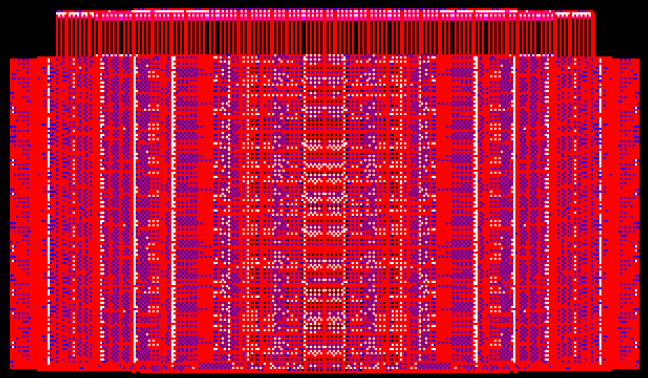
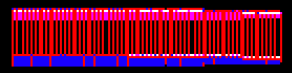
Original Simulations from our helmet paper





Geometry of the scanner in Geant4

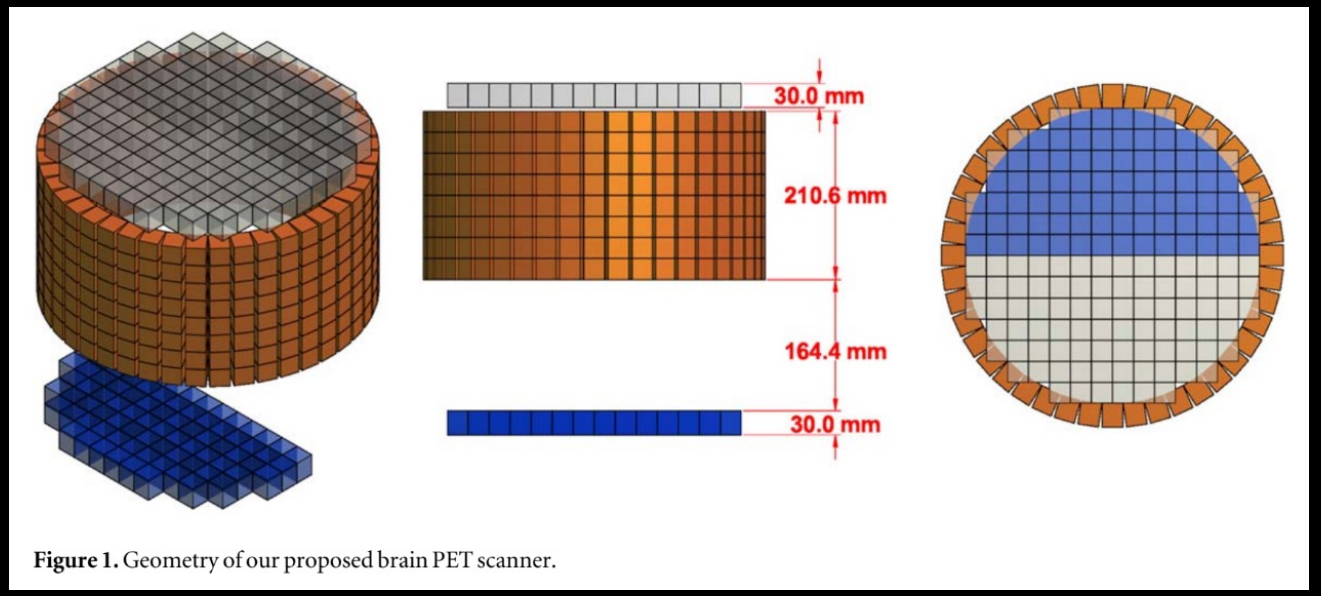


Figure 1. Geometry of our proposed brain PET scanner.

Figure 1 from our paper

Layden, C., Klein, K., Matava, W., Sadam, A., Abouzahr, F., Proga, M., ... & Lang, K. (2022). Design and modeling of a high resolution and high sensitivity PET brain scanner with double-ended readout. *Biomedical Physics & Engineering Express*, *8*(2), 025011.

BGO Material Definitions

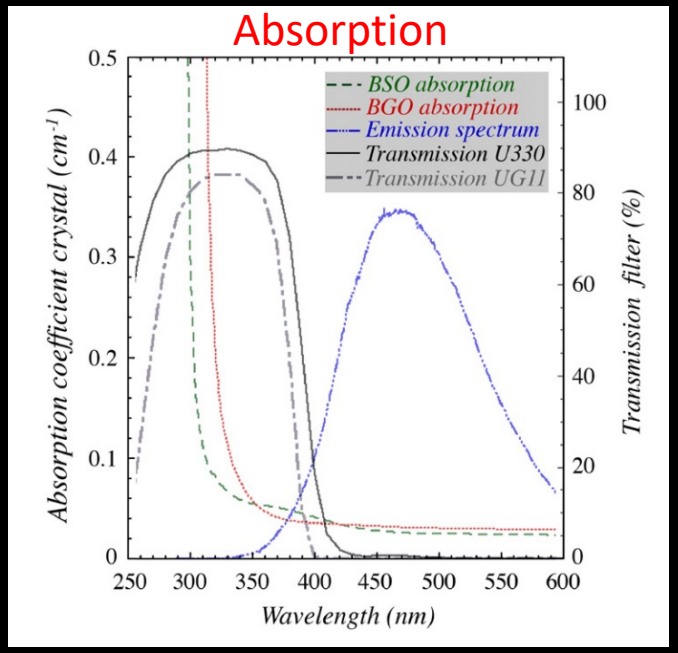
Updating and checking the accuracy of our BGO material in Geant4

BGO data for our Geant4 material properties…

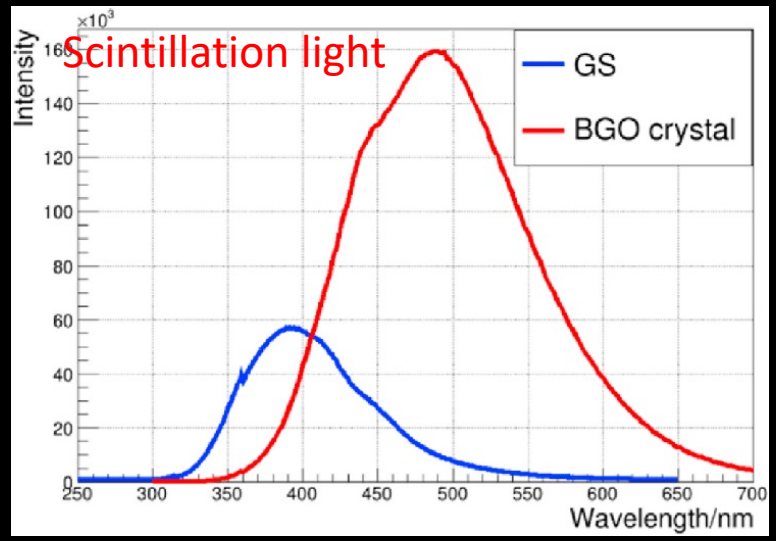
Optical properties we need:

- Scintillation spectrum with efficiency
- Fast and slow time constants (300/60 ns)
- Absorption/attenuation
- Stopping power of gammas
- Refractive index

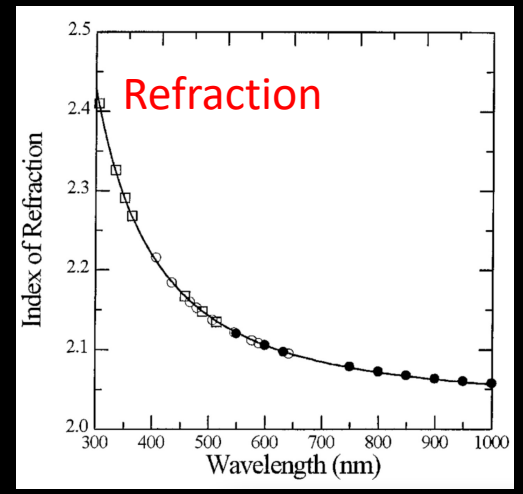
Need to be functions of energy where applicable



Akchurin, N., Bedeschi, F., Cardini, A., Cascella, M., Ciapetti, G., De Pedis, D., ... & Wigmans, R. (2011). A comparison of BGO and BSO crystals used in the dual-readout mode. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *640*(1), 91-98.



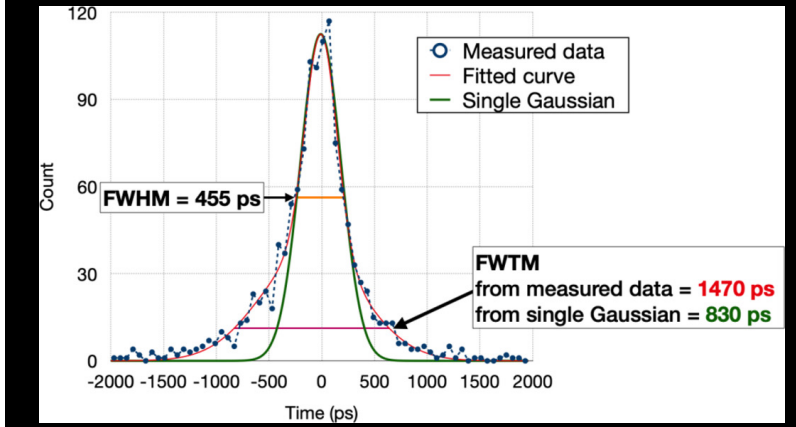
Tang, G., Hua, Z., Qian, S., Sun, X., Ban, H., Cai, H., ... & Zhang, L. (2022). Optical and scintillation properties of aluminoborosilicate glass. *Optical Materials*, *130*, 112585.



Williams, P. A., Rose, A. H., Lee, K. S., Conrad, D. C., Day, G. W., & Hale, P. D. (1996). Optical, thermo-optic, electro-optic, and photoelastic properties of bismuth germanate (Bi 4 Ge 3 O 12). *Applied Optics*, *35*(19), 3562-3569.

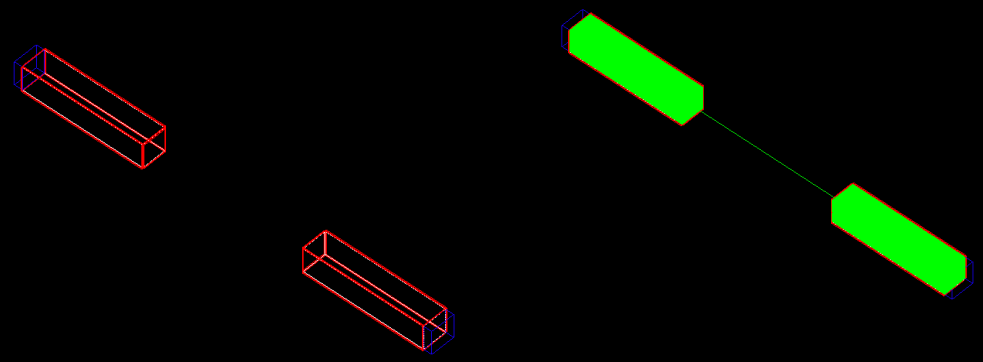
1.5.3 BGO Crystals

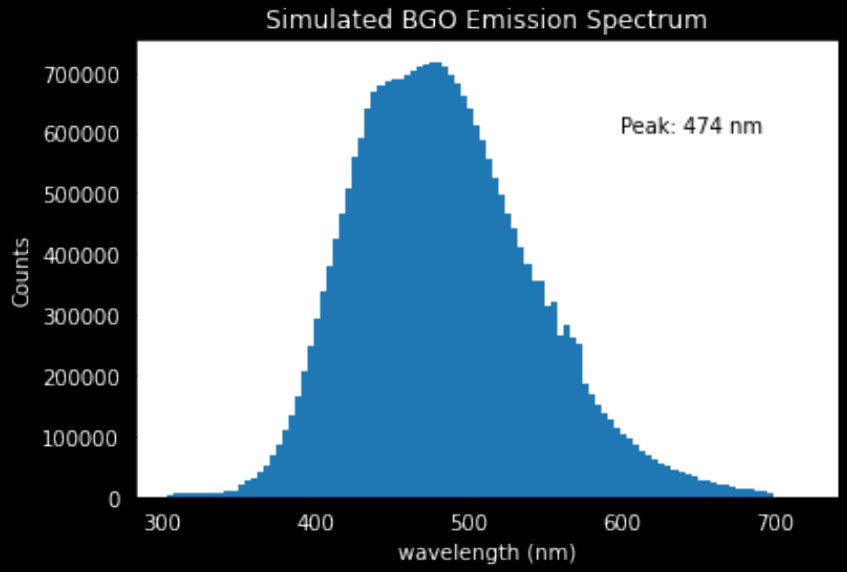
Bismuth germanate (BGO) is a very dense scintillator material (7.1 g/cm^3) with an effective atomic number of 73 [31]. Despite its poor light output and long decay time, this has made it the crystal of choice in PET scanners for 20 years. BGO is most often quoted with a decay time of 300 ns. Its scintillation pulse shape is actually bi-exponential. A small component with a decay time of 60 ns is also present in the pulse shape [32]. The small component contains about 10% of the total number of scintillation photons [20]. The small amount of scintillation photons in this component outrules its interest for PET applications, since even the main pulse of the BGO crystals contains very few scintillation photons compared to alternative crystals. The total light output of BGO crystals is about 12 000 photons per MeV. The energy resolution obtainable with BGO crystals is some places reported to be about 10%, while others state about 20% (see Table 1.2).

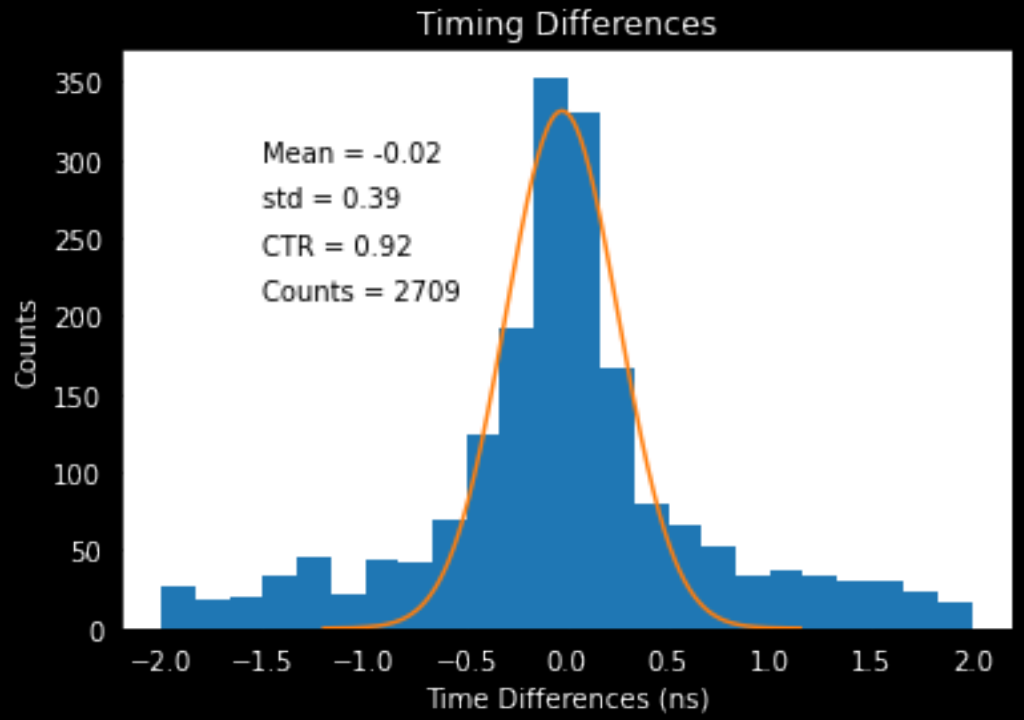


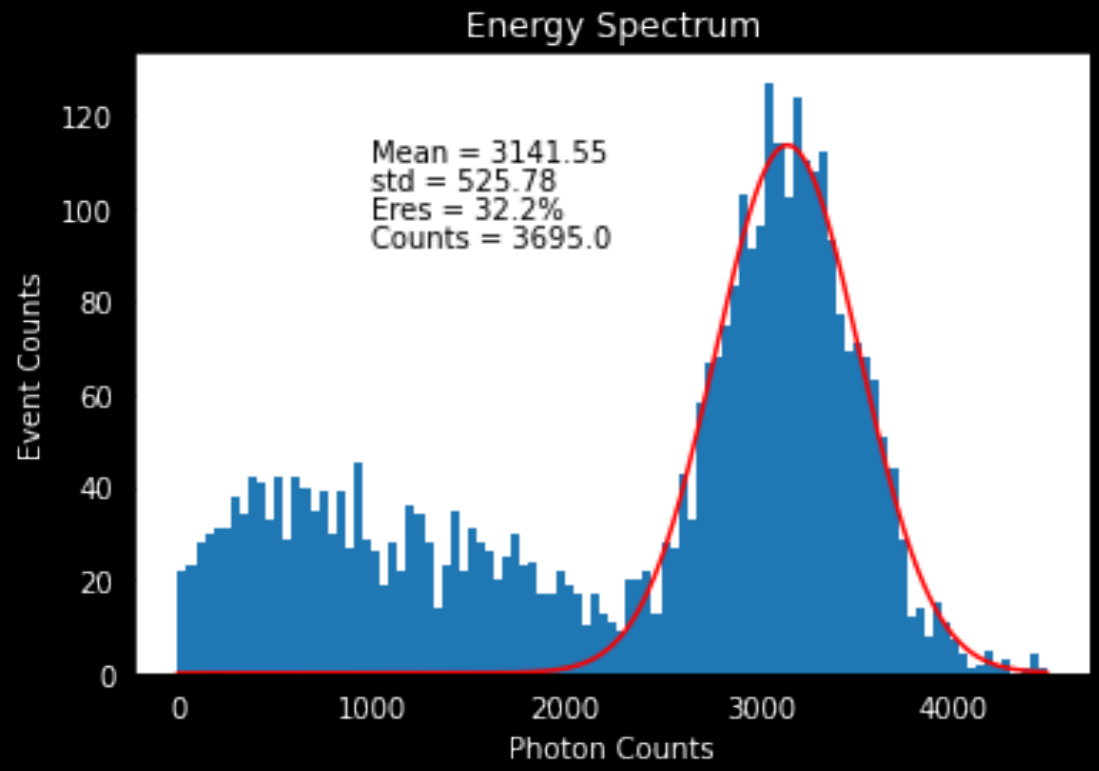
Simple tests of BGO accuracy

I tested the accuracy of our BGO material via a simple testing geometry of two coincident pixels.





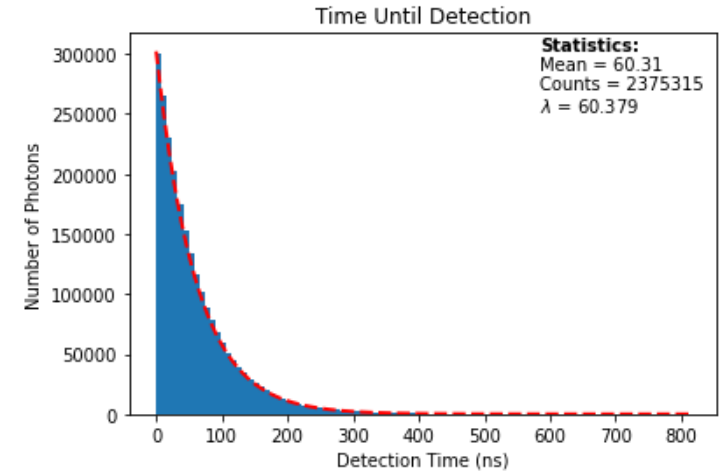


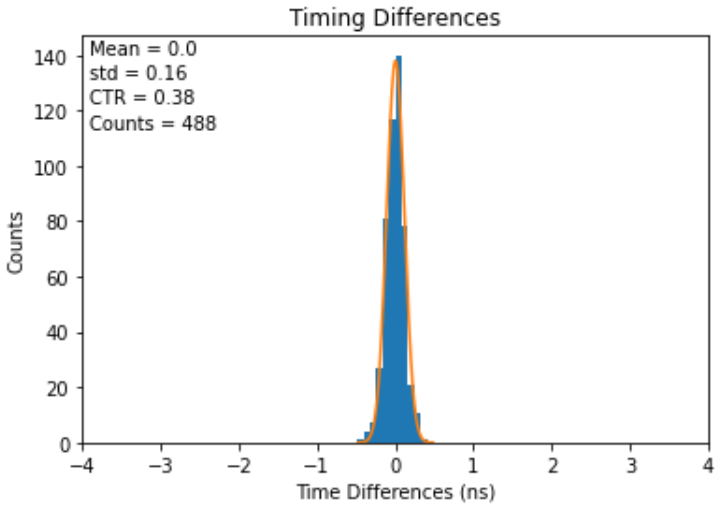


BGO Timing Results

- After a week of some issues, I have now defined BGO with both realistic and relatively good timing results (see next slides for literature review verification)
- All CTRs produced with 1.5σ photopeak cuts.

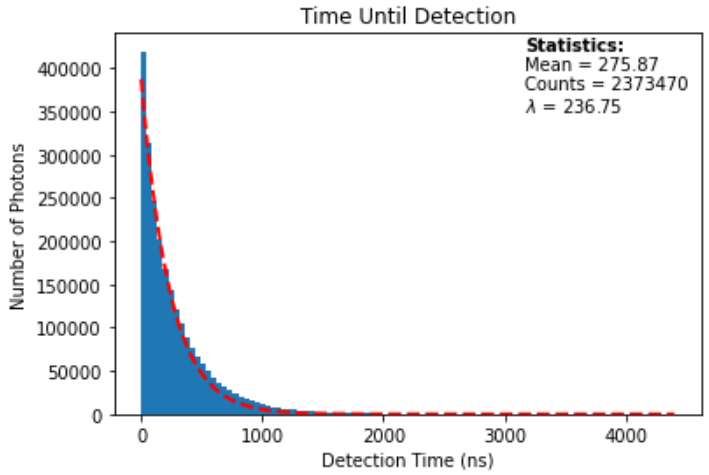
Fast Only (60 ns)

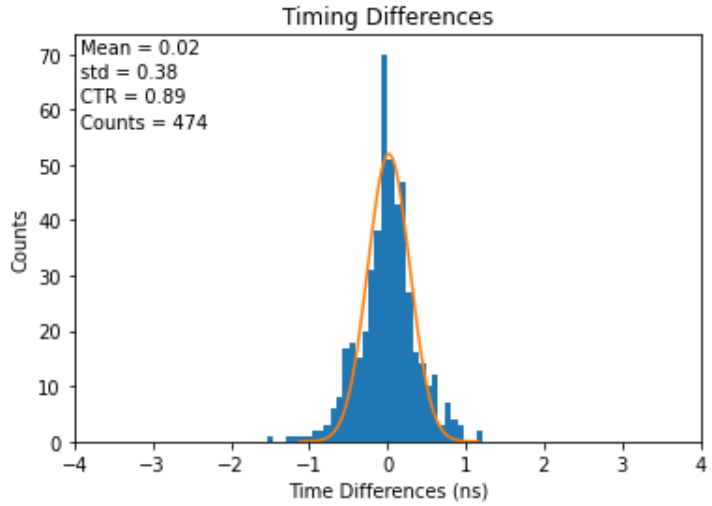




CTR: 380 ps

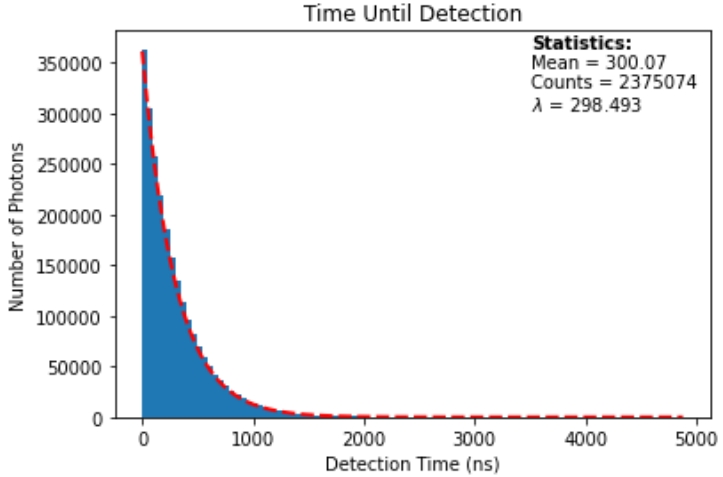
BGO (300 ns & 60 ns)

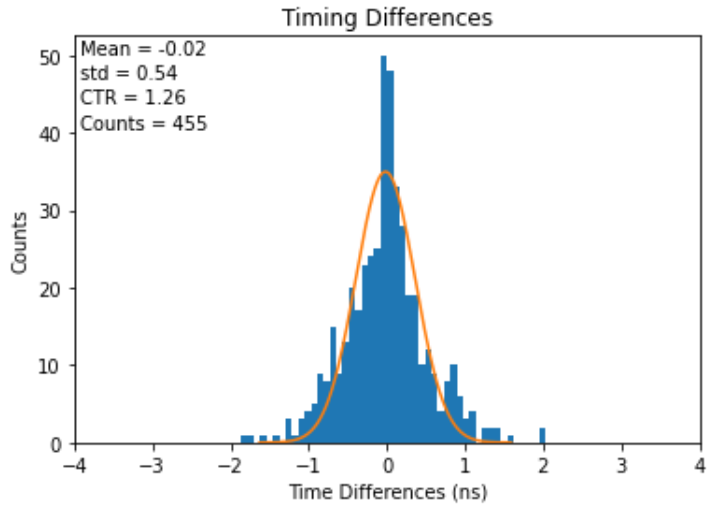




CTR: 890 ps

Slow only (300 ns)



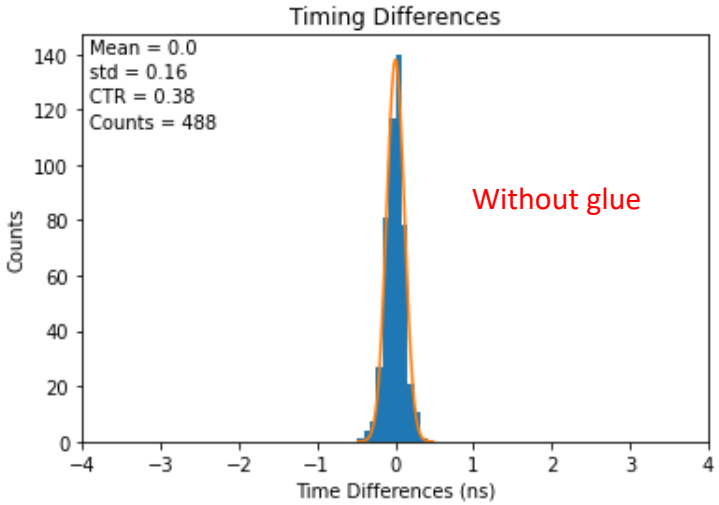


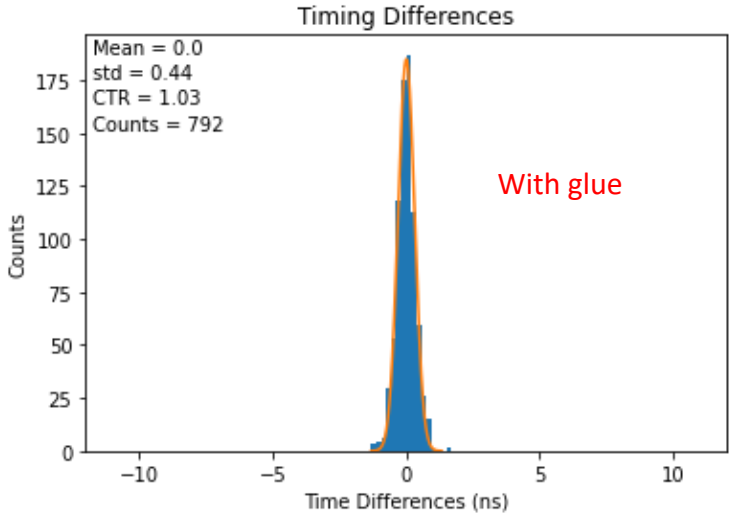
CTR: 1260 ps

Trouble in PETadise

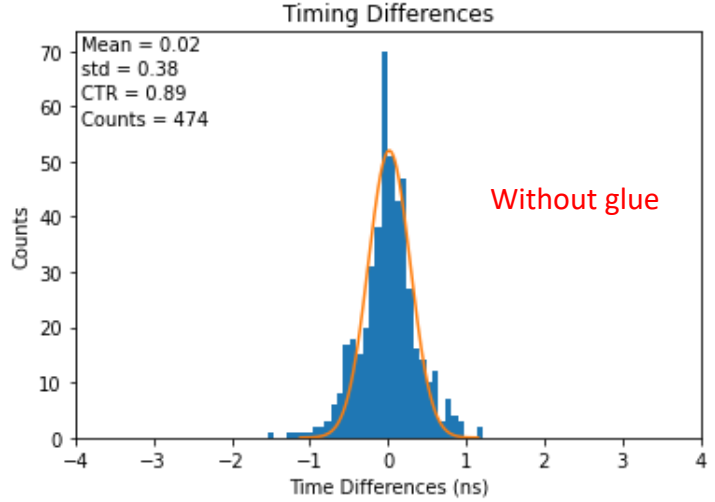
All my simulations have been updated to be more realistic including adding glue between SiPMs and crystals and adding SiPM jitter. However, we can see there is a problem with the added glue.

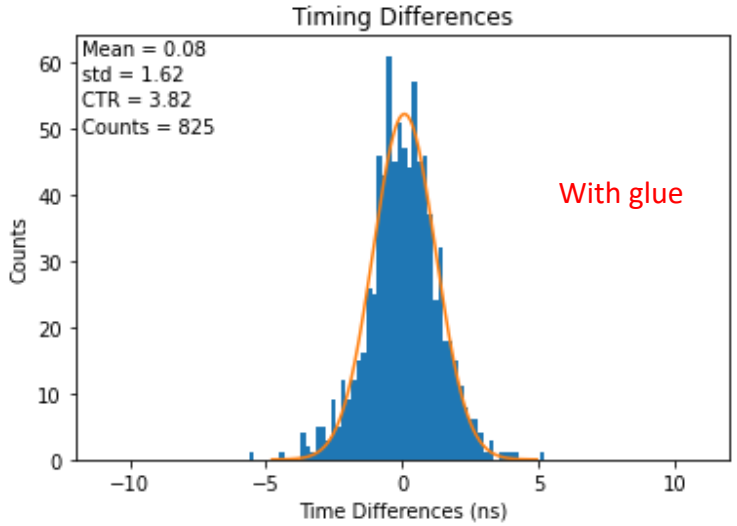
Fast Only (60 ns)



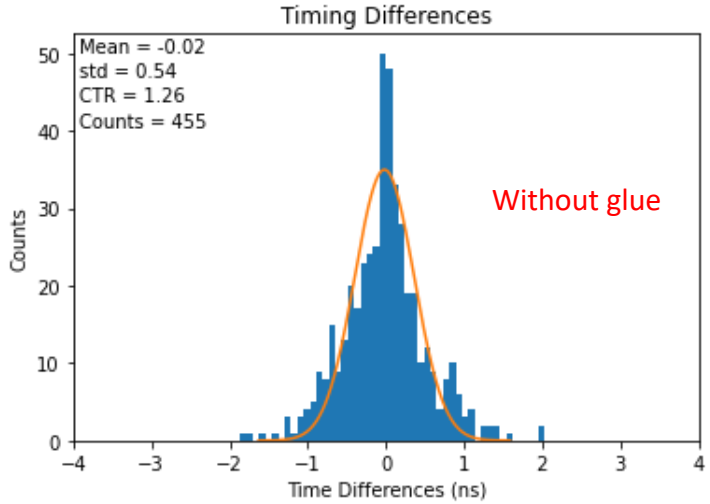


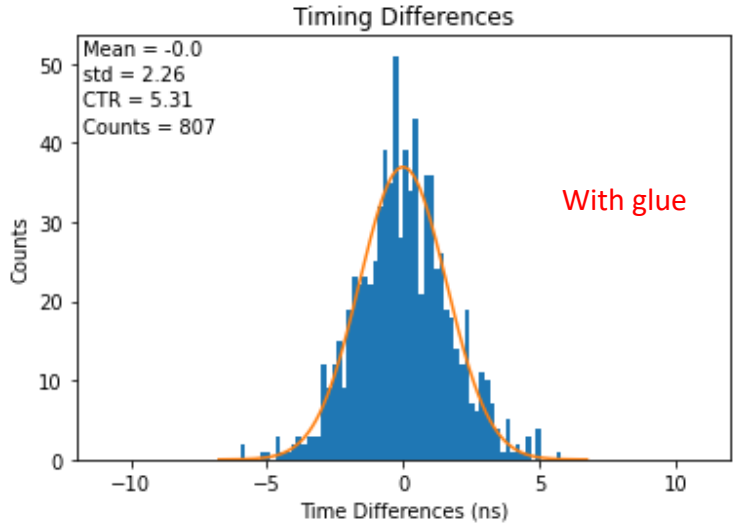
BGO (300 ns & 60 ns)





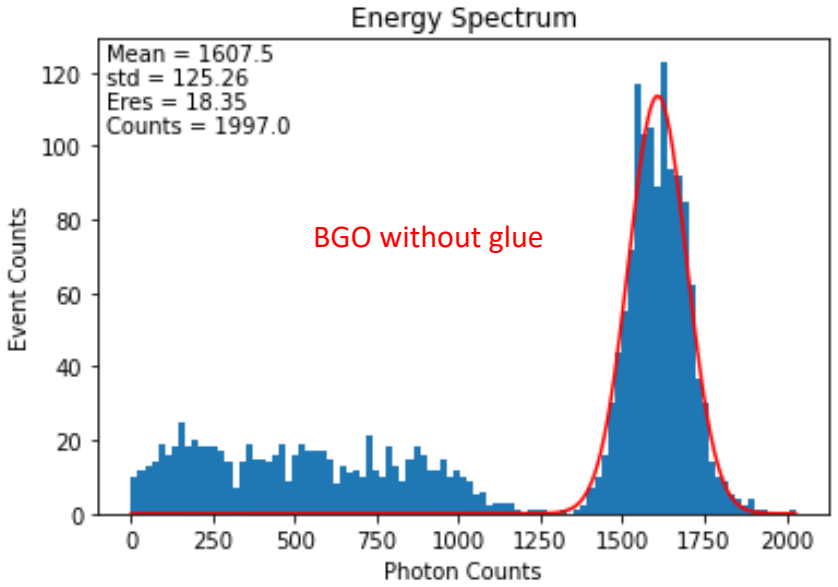
Slow only (300 ns)

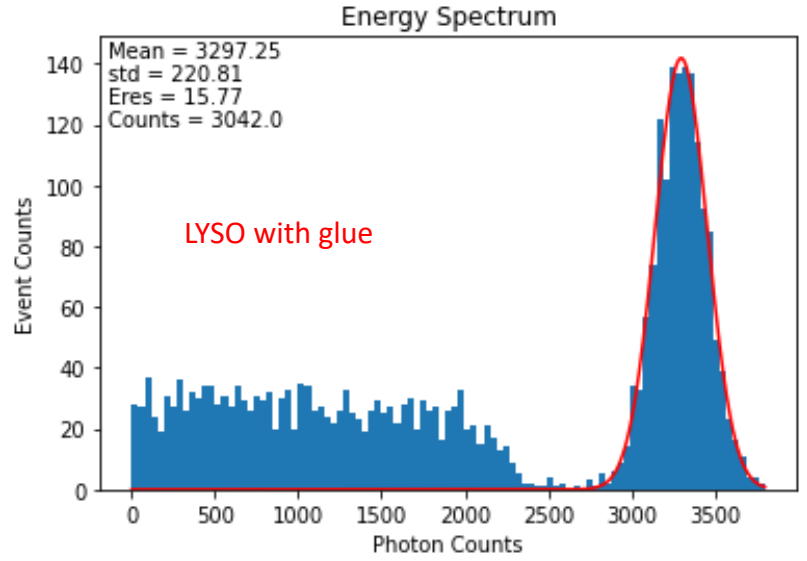


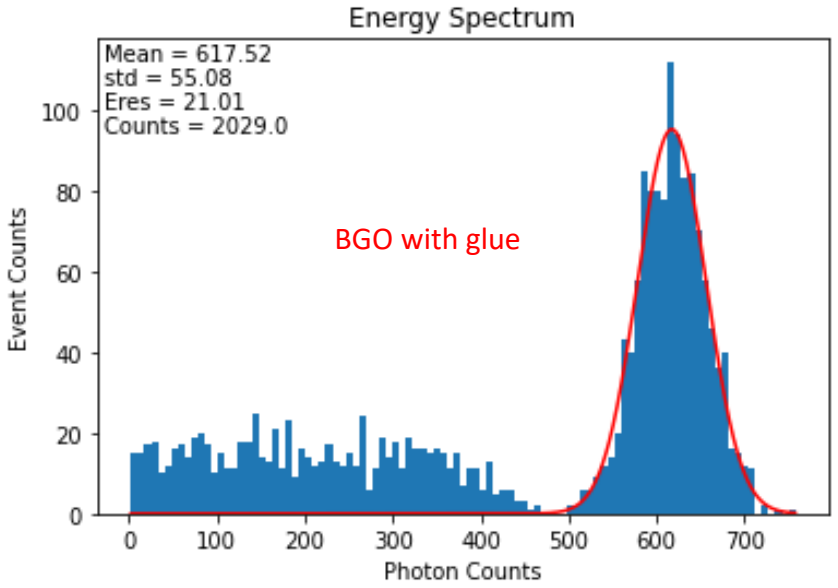


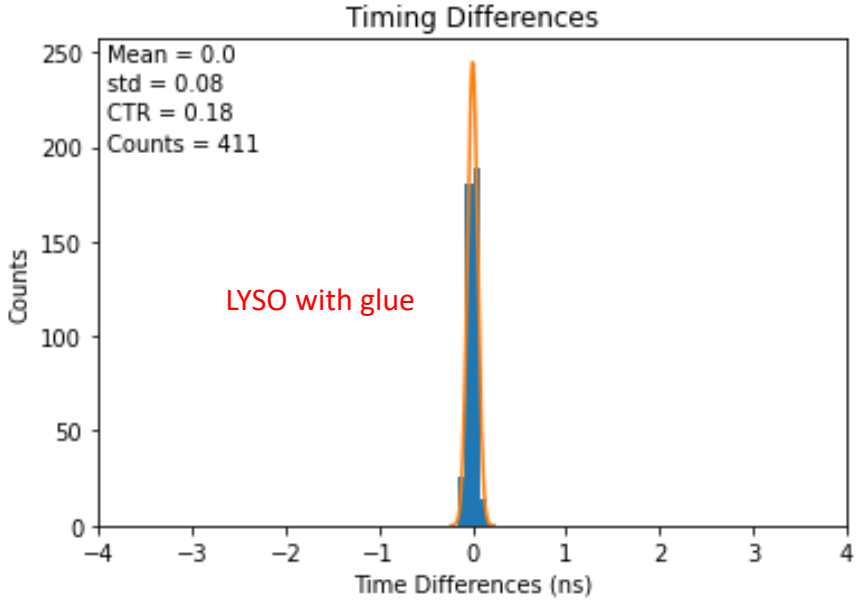
Considering the impact of glue:

Perhaps the problem we are seeing with glue is due to total internal reflection.









Refractive Indices:

$n_{LYSO} = 1.82$

$n_{BGO} = 2.15$

$n_{glue} = 1.519$

Critical Angles:

LYSO to Glue: $\theta_c = 56.6^{\circ}$

BGO to Glue: $\theta_c = 44.9^{\circ}$

I initially did all simulations with the same glue used for our LYSO simulations. However, it is now clear I need to simulate a glue suitable for BGO.

Hence, we define our new glue via the conception of the most efficient antireflection effect:

$n_{glue} = \sqrt{n_{BGO} n_{air}} = 1.46$

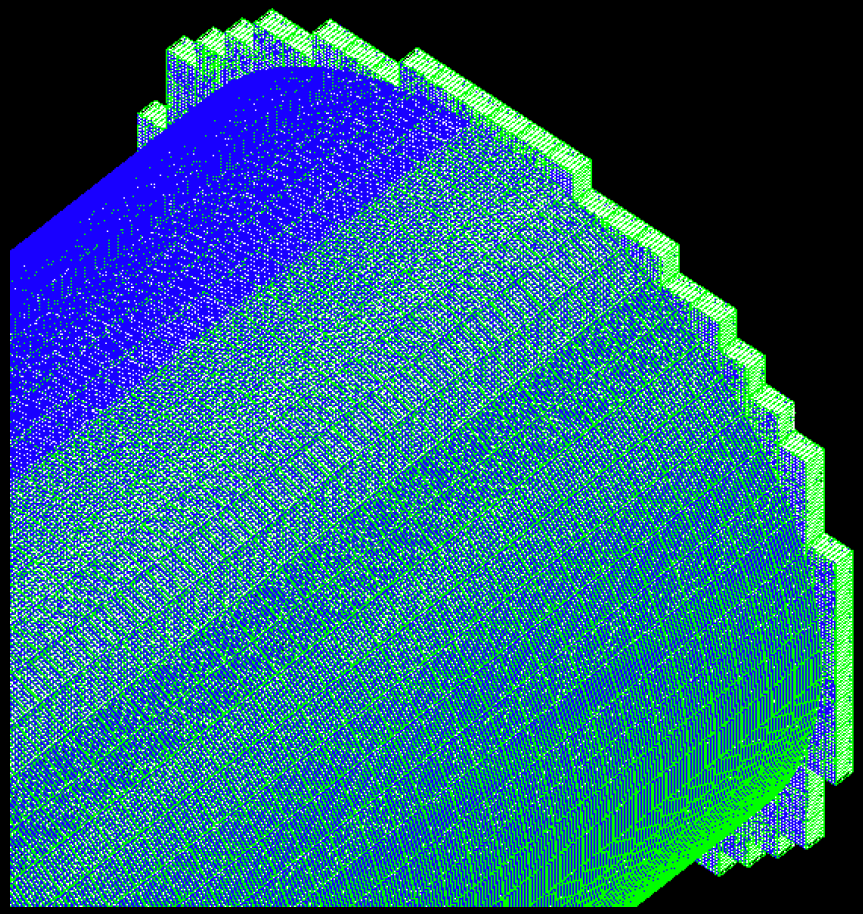
Good reference papers other than those already cited …

Zhang, H., Vu, N. T., Bao, Q., Silverman, R. W., Berry-Pusey, B. N., Douraghy, A., ... & Chatziioannou, A. F. (2010). Performance characteristics of BGO detectors for a low cost preclinical PET scanner. *IEEE transactions on nuclear science*, *57*(3), 1038-1044.

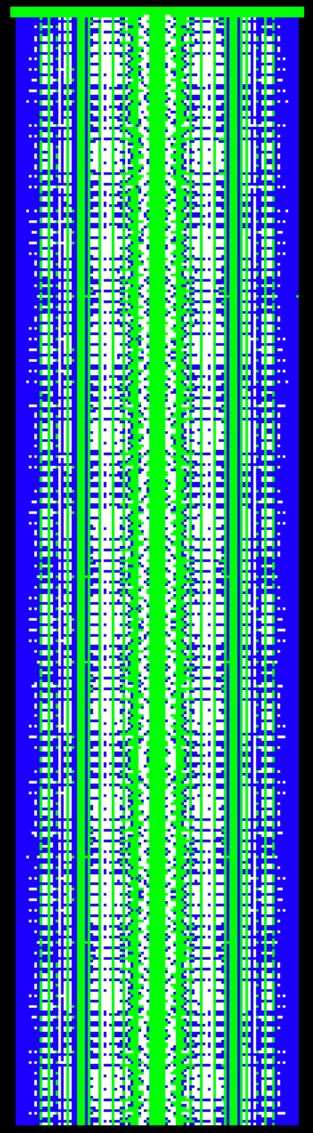
Total Body Scanner Preliminary Geometry

First looks at possible geometries and technical designs

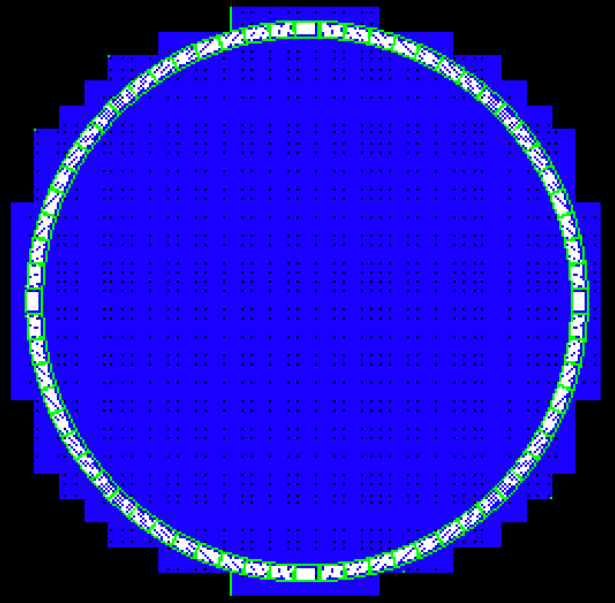
A Preliminary Geometry



Close up on the crystals and at the top of the barrel



Side view of entire geometry



Top View down the Corona

Height: 2078.6 mm ≈ 6.8 ft
Diameter: 604.56 mm ≈ 1.98 ft

Updated dimensions?
Height: the same
Diameter: ≈ 3 ft