Design and optimization of the KAPAE phase II detector for searching of positronium invisible decay

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1.ABSTRACT

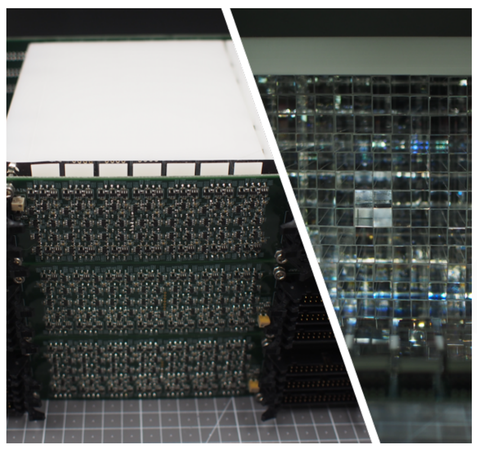
KNU Advanced Positronium Annihilation Experiment (KAPAE) aims to detect visible rare positronium decay, search for C, CP, and CPT violations as well as search for invisible decay. The KAPAE Phase II is designed to increase the sensitivity of the invisible decay of the positronium such as milli-charged particles, mirror world, new light X-boson, and extra dimensions. Compared to KAPAE phase I, the detector is less segmented, the trigger of the detector is changed to reduce the dead area, the size of the BGO scintillation crystal, and the size of the overall detector is increased. The KAPAE phase II detector consists of BGO scintillation crystals stacked in a 5 by 5 array coupled with SiPM arrays. We are presenting here the design of the KAPAE phase II detector and the sensitivity of the invisible decay of the detector using the Geant4 Monte-Carlo simulation. Furthermore, we will report the performance of the detector optimization.

2.MOTIVATION

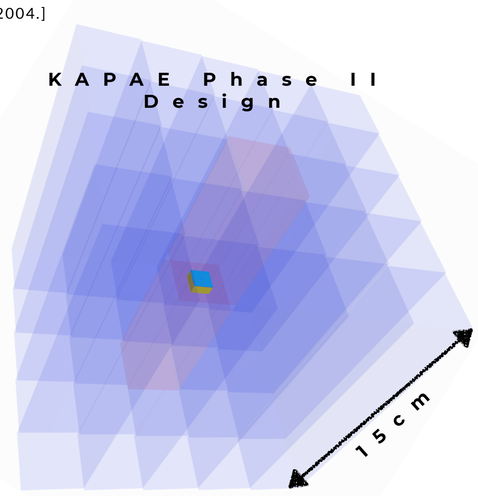
- The KAPAE phase I detector aims at positronium visible annihilation studies using high angular resolution.
- The detector in the previous experiment EHT Zurich group had an invisible detection sensitivity of **4.2×10^{-7} (90% C.L.)**.[Ref*]
- We intend to design a detector with the world's best positronium invisible annihilation detection sensitivity.
- A phoswich type trigger will be employed to reduce the dead area of the trigger part.
- The detector will be installed in the Underground Yemmi-Lab for low background environments.

*[A. Badertscher, P. Crivelli, W. Fetscher, U. Gendotti, S. N. Gninenko, V. Postoev, A. Rubbia, V. Samoylenko, D. Sillou, Improved limit on invisible decays of positronium, Phys. Rev. D 75 (2007) 032004.]

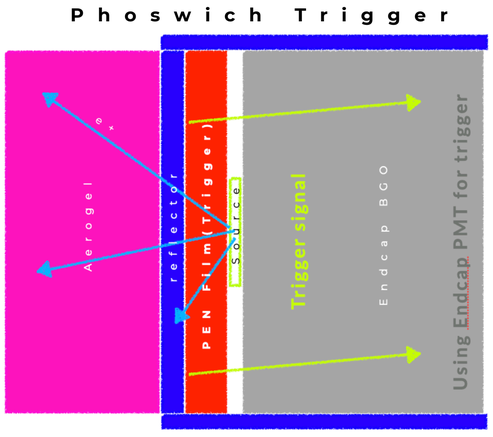
KAPAE Phase I

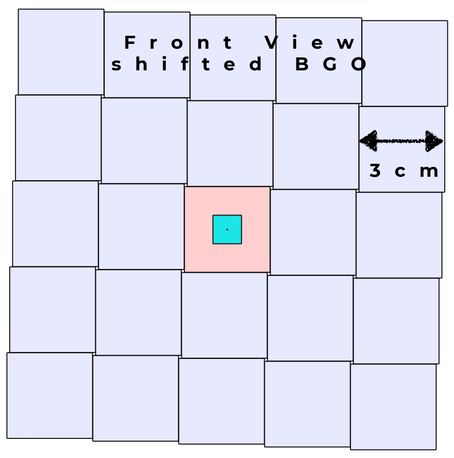


KAPAE Phase II Design



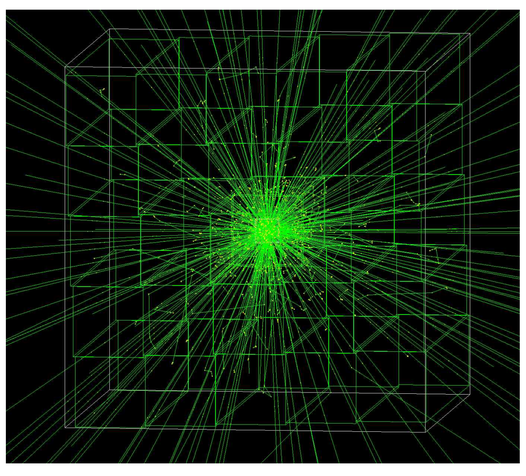
Phoswich Trigger

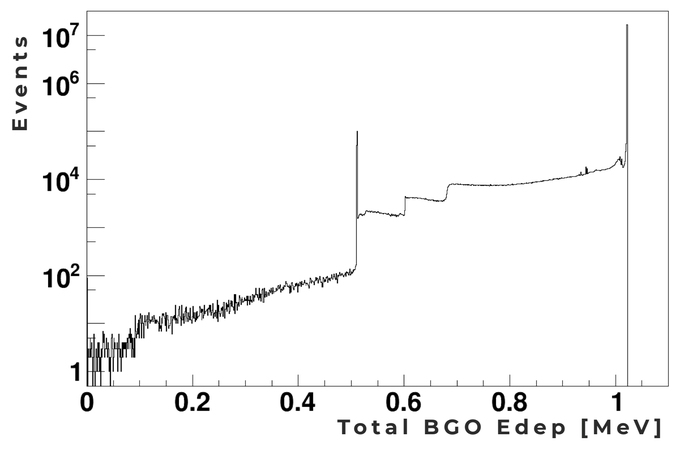




3.SIMULATION

- As a result of the total 100,000,000 event simulation, the number of zero energy deposition in BGO events are 154 (< 30 keV).
- The maximum number of events that the KAPAE detector can receive over three years is about 2.352×10^{12}.
- Calculated at 90% confidence level, the upper limit of invisible annihilation detection sensitivity of KAPAE phase II is **1.0×10^{-9}**.

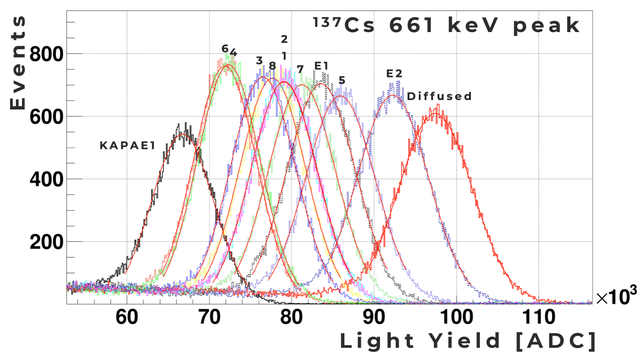




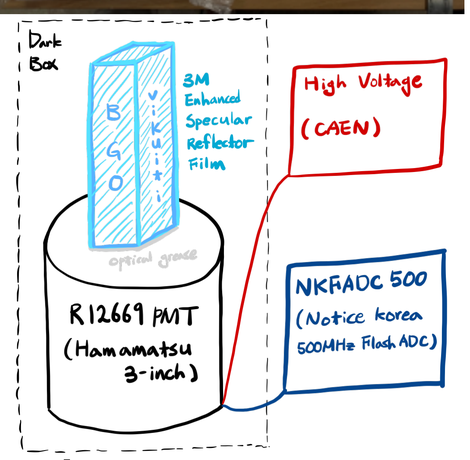
4.BGO CRYSTAL TEST

(1) Light Yield

- We tested 10 BGO crystals (NIIC SB RAS, Russia) which will be used in the KAPAE phase II detector.
- In comparison with Phase I BGO crystals the performance is satisfactory.
- The light yield of the diffuse BGO crystal was found to be about 25% higher than that of polished BGO.

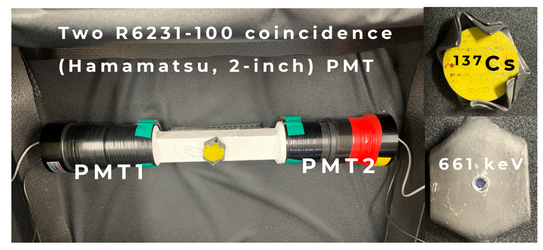


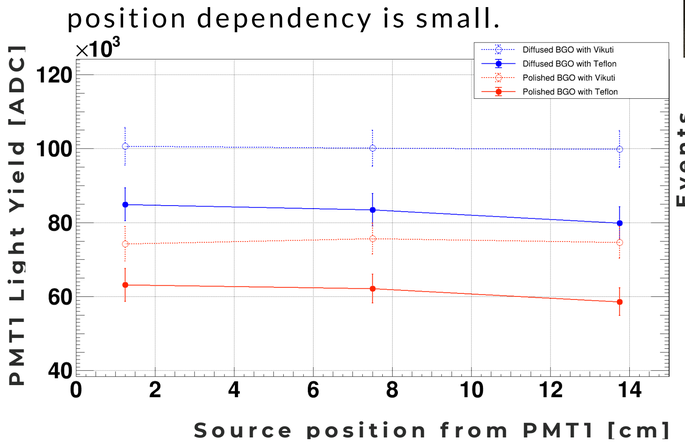
	Mean (Light Yield)			Sigma	Energy Resolution
	[ADC]	Average [ADC]	Relative [%]	[ACD]	(FWHM) [%]
KAPAE1 BGO	66720.7	85.6		3819.04	13.5
BGO 1	79040.1	Average 77965.6	101.4	4005.00	11.9
BGO 2	79073.7		101.4	4011.82	11.9
BGO 3	76535.9		98.2	3902.94	12.0
BGO 4	72309.3		92.7	3834.25	12.5
BGO 5	85919.9	Sigma 4286.8	110.2	4167.59	11.4
BGO 6	71907.6		92.2	3782.20	12.4
BGO 7	81216.1		104.2	4131.42	12.0
BGO 8	77722.3		99.7	3902.04	11.8
BGO Diffuse	97447.3	125.0		4473.15	10.8
BGO Endcap 1	83581.5	107.2		4138.95	11.6
BGO Endcap 2	92264.2	118.3		4351.98	11.1

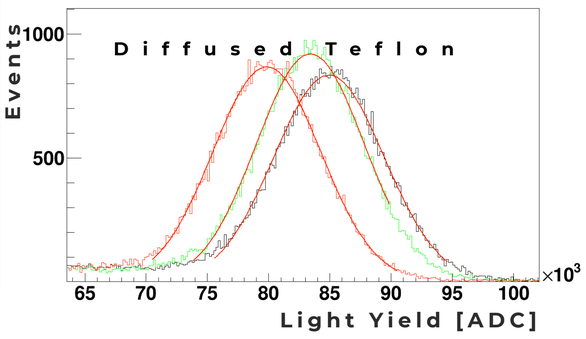


(2) Source Position Dependency

- Diffuse BGO crystals and polished BGO crystals were wrapped in one Teflon sheet(~100 μm) and one Vikuiti (75 μm).
- In the case of Vikuti, the source position dependency is small.



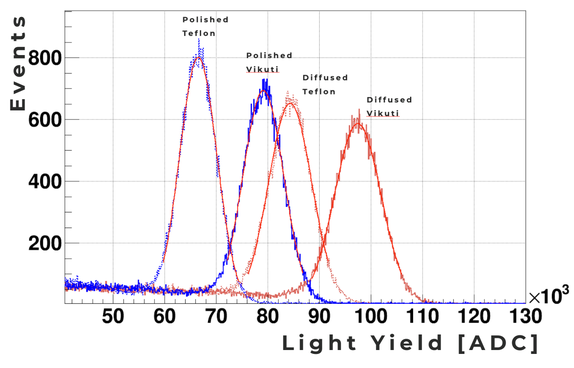




(3) Reflector and Polishing Dependency

- Same experimental setup with (1)
- Diffuse BGO crystal's light yield is about 23% more than polished BGO.

	Light Yield [ADC]	Relative [%]	Sigam [ADC]	Energy Resolution [%]
Polished with Teflon	66495.2	100.0	3618.23	12.79
Polished with Vikuti	79108.5	119.0 (100.0)	3944.81	11.72
Diffused with Teflon	84315.3	126.8	4201.73	11.71
Diffused with Vikuti	97435.0	146.5 (123.1)	4510.68	10.88



5.CONCLUSION

Simulation results showed that the sensitivity was improved from **4.2×10^{-7}** to **1.0×10^{-9}**. It is about 420 times more sensitive than previous experiments. The diffuse crystals with vikuti have shown a 23% higher light yield and good energy resolution but source position dependency is small. This year, we will construct a KAPAE phase II detector. To determine the design, we will further verify the characteristics of diffuse BGO crystal and compare the 2-channel coincidence design with the 1-channel design.