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A compact positron annihilation lifetime spectrometer*

LI Dao-Wu(李道武)[1,2] LIU Jun-Hui(刘军辉)[1,2] ZHANG Zhi-Ming(章志明)[1]
WANG Bao-Yi(王宝义)[1] ZHANG Tian-Bao(张天保)[1] WEI Long(魏龙)[1;1)]

[1] Key-Laboratory of Nuclear Analysis Techniques, Institute of High Energy Physics,
Chinese Academy of Sciences, Beijing 100049, China
[2] Graduate University of Chinese Academy of Sciences, Beijing 100049, China

Abstract: Using LYSO scintillator coupled on HAMAMATSU R9800 (a fast photomultiplier) to form the small size γ-ray detectors, a compact lifetime spectrometer has been built for the positron annihilation experiments. The system time resolution FWHM=193 ps and the coincidence counting rate ~8 cps/μCi were achieved. A lifetime value of 219±1 ps of positron annihilation in well annealed Si was tested, which is in agreement with the typical values published in the previous lectures.

Key words: compact, PLS, LYSO, positron annihilation

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1 Introduction

It is well known that the plastic scintillator, which was used for the detectors of positron lifetime spectrometers (PLS) in the early years, has been widely replaced by the BaF_2 scintillation crystal, because the BaF_2 scintillator has higher stopping power and better timing property for 0.511 MeV γ-rays originating from the positron annihilation. Usually, two detectors and the ^{22}Na-sample are aligned and the source-sample is in the middle (180° arrangement) for a good counting efficiency of these PLSs. It was noticed that a sum-coincidence effect [1], which affects the short component analysis for a lifetime spectrum, exists considerably in BaF_2 PLS. One of two ways for suppressing the sum-coincidence effect should be adopted: to insert a radiation filter (~3 mm Pb or W) in between the start detector and the sample [1, 2] or to set the detector-sample-detector as right-angled (90° arrangement). On the other hand, it would not be good to use a higher intensity ^{22}Na source for precise positron lifetime measurements in BaF_2 PLS due to the pile-up effect in electronics which arises from the slow scintillation component (0.6 μs) of BaF_2 scintillator. Therefore in our experience, a volume >10 cm^3 of BaF_2 detector and a coincidence counting rate <300 cps would be limited in BaF_2 PLS due to the reasons mentioned above. Another method, full absorption of ^{22}Na γ-ray energy [3, 4] can be used, but the very low counting rate of the system should be improved.

In the past decade, a new type of scintillator, LSO (Lu_2SiO_5: Ce) or LYSO, with a stopping power about 2 times as large as that of BaF_2 for 0.511 MeV γ-rays, has been developed and used for the detectors of positron emission tomography (PET) [5]. In 2007，Haaks [6] tested the LSO scintillator for the detectors in PLS. With the scintillator volume (~13 cm^3) similar to that of BaF_2, the LSO spectrometer showed almost the same counting efficiency but a worse time resolution FWHM=372 ps.

In this work, small size LYSO detectors are employed for improving the time resolution of PLS and arranged in a refined pattern to avoid the degradation of counting efficiency.

2 Setup

The experimental setup (see Fig. 1) is a positron annihilation lifetime spectrometer. Two detectors and the source-sample in the figure are arranged as 90°, which can also be changed to 180° arrangement where a filter of 3 mm W-Cu in front of the start detector

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1) E-mail: weil@ihep.ac.cn

and 2 mm Sn-Fe in the stop one. Different sized LYSO detectors as well as BaF_2 detector were tested, where photomultiplier XP2020Q was used for bigger scintillators and R9800 for smaller ones. All of the scintillators used here were thoroughly polished, capped with Teflon tape and then optically coupled on PMTS.

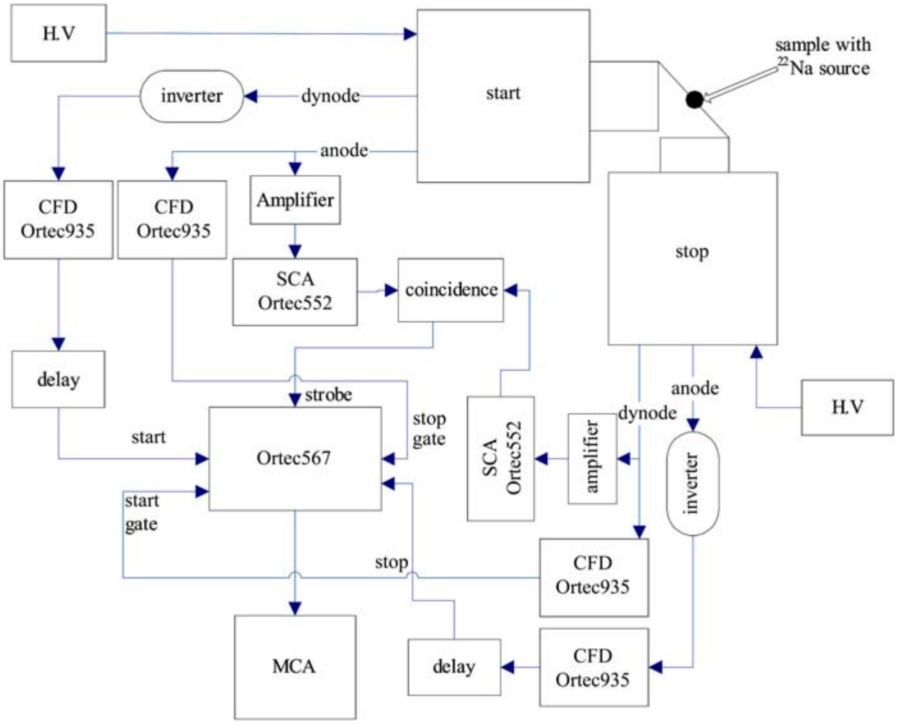

Fig. 1. Diagram of the spectrometer system.

Table 1. Test of time resolution and counting efficiency of PLS with different scintillators.

	scintillator size	arrangement of detector	start channel energy window	stop channel energy window	coincidence counting efficiency/(cps/μCi)	time resolution FWHM/ps
1	BaF_2, Ø30×20 mm^3	180°	> 0.8 MeV	0.511 MeV peak	65	198
		90°	> 0.8 MeV	0.511 MeV peak	10	198
2	LYSO, Ø27×20 mm^3	180°	1.28 MeV peak	0.511 MeV peak	222	361
		90°	1.28 MeV peak	0.511 MeV peak	37	361
3	LYSO, 10 mm×10 mm×10 mm	180°	1.28 MeV peak	0.511 MeV peak	10	227
		90°	1.28 MeV peak	0.511 MeV peak	8	227
4	start: LYSO, 10 mm×10 mm×10 mm stop: LYSO, 4 mm×8 mm×11 mm	180°	1.28 MeV peak	0.511 MeV peak	5	193
		90°	1.28 MeV peak	0.511 MeV peak	8	193

The electronics of the spectrometer is typical fast-slow coincidence equipment. The timing signal is picked up from the last dynode and the energy signal is delivered from the anode of the PMTs. The fast electronics consists of two home-made signal inverters, a quad constant-fraction discriminator Ortec935, a time to amplitude converter Ortec567 and a MCA, which acquires the time spectrum of the positron annihilation events. The slow part includes two home-made amplifiers, two timing SCA Ortec552 and a home-made coincidence circuit, which are used to define the energy windows for 0.511 MeV and 1.28 MeV γ-ray peaks of ^{22}Na (viz. Na-energy window) respectively and then to strobe Ortec567. On the other hand, the coincidence gates of both the start and stop channels on Ortec567 are used to suppress the random interferences.

3 Experiment

The coincidence counting efficiency (coincidence rate per μCi of ^{22}Na) and the time resolution, measured with ^{60}Co source at Na windows, of PLS with different LYSOs and BaF_2 were measured and listed in Table 1. Comparing the rows of No. 1 and No. 2, we see that the system coincidence efficiency with bigger LYSO is ~3.5 times that of BaF_2 with almost the same volume under both 90° and 180° arrangements. For example, efficiency 222 cps/μCi of Ø27×20 mm^3 LYSO is much better than 65 cps/μCi of Ø30×20 mm^3 BaF_2 at 180° arrangement, which means that the system counting rate can be >2000 cps for LYSO spectrometer if 10 μCi ^{22}Na is used. We expect that there is less pileup interference here because of the only mono component (40 ns) of LYSO scintillation which permits to use a higher intensity ^{22}Na source. But the time resolution (FWHM=361 ps) seems poor. It can be seen from rows of No. 3 and No. 4 that the time resolution gets better with the small size of LYSO scintillators. Based on the conditions of our lab, the LYSO scintillators listed on the row of No. 4 and the detector arrangement in 90° were selected to build the compact spectrometer (see Fig. 2) due to the better time resolution and the higher counting efficiency(8 cps/μCi). Two LYSO scintillators were optically coupled on two HAMAMATSU R9800 (Ø25×75 mm) PMTs and then installed in an 11 cm×11 cm×5 cm box.

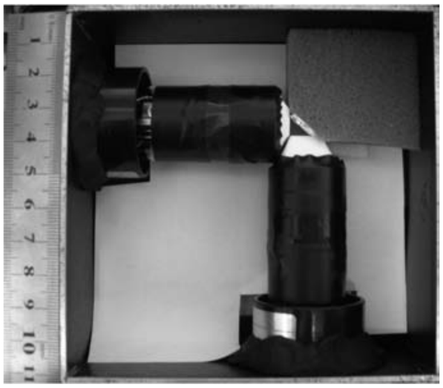

Fig. 2. The spectrometer detector arrangement.

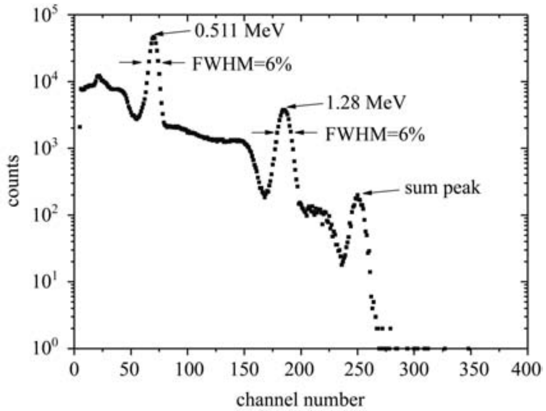

Fig. 3. The ^{22}Na γ-ray energy spectrum of start detector.

The ^{22}Na γ-ray energy spectrum for the start detector is shown in Fig. 3, from which the energy resolution FWHM=9% and 6% for 0.511 MeV and 1.28 MeV peaks are obtained respectively.

The prompt coincidence time spectrum measured with ^{60}Co source at Na-energy window is shown in Fig. 4, from which, the time resolution of the system FWHM=193 ps is calculated (see also in Row 4 of Table 1).

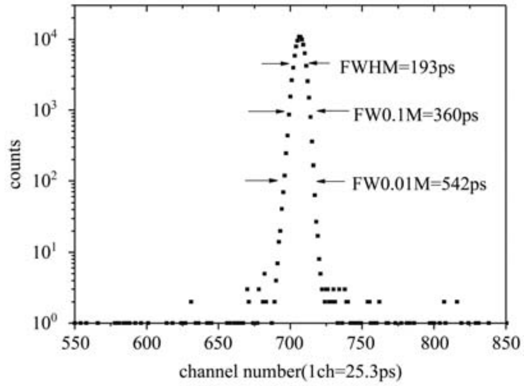

Fig. 4. The prompt coincidence spectrum of ^{60}Co at Na-energy window.

We measured the lifetime spectra of positron annihilation in a well annealed Si sample with 7, 14 and 22 μCi ^{22}Na sources. As an example, the spectrum measured with 22 μCi ^{22}Na (the counting rate ~180 cps) is shown in Fig. 5. All of the spectra were analyzed as 3 components (the main component I_1, τ_1 is attributed to the positron annihilation in Si) with the routine software, LifeTime, Version 9.0 (LT9). The results are presented in Table 2. It is noticed from Table 2 that no apparent effect of ^{22}Na intensity on the lifetime value has been found, so the mean value (219±1) ps is regarded as our measured result of positron annihilation in Si. Moreover a mean value

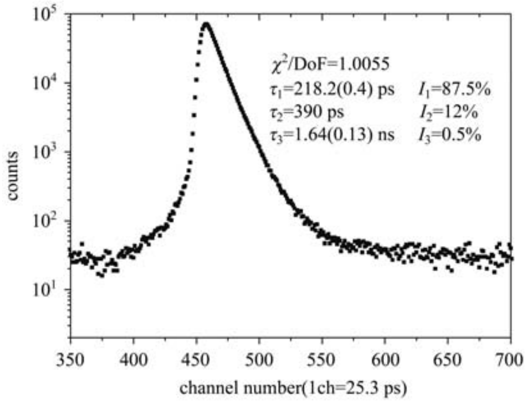

Fig. 5. The lifetime spectrum of positron annihilation in well annealed Si with 22 μCi ^{22}Na.

186 ps of the system time resolution is also obtained, which is quite close to that measured with ^{60}Co source (see Fig. 4). The lifetime spectra at 180° arrangement were also measured and analyzed, where the mean lifetime value 213 ps±2 ps is obtained, which is ∼3% smaller than that measured at 90° arrangement.

Table 2. The lifetime in Si with diffrient active intensity ^{22}Na Source.

source intensity/μCi	7	14	22	mean value
lifetime τ_1/ps	218.1	220.2	218.2	219±1
time resolution/ps	187.5	186.4	183.4	∼186

4 Discussion

Performance, including the time resolution FWHM=193 ps, the counting efficiency ∼8 cps/μCi, the permission of a ^{22}Na source >20 μCi, and a reasonable lifetime value (219±1) ps of positron annihilation in Si, shows that the compact spectrometer is applicable.

If the detectors in the compact PLS is changed to 180° arrangement, we recommend the size Ø16× 10 mm^3 for the start detector and Ø16×5 mm^3 for the stop one be used. We expect that the efficiency would be improved to ∼20 cps/μCi and the time resolution would not have a more degradation.

The spectrometer can be made more portable if the NIM modules used here are replaced by a specialized or dedicated electronics. The advancing capability will be studied in the near future.

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