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Design and Construction of the Barrel Shower Counter in the Beijing Spectrometer

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The design and construction of the Barrel Shower Counter (BSC) for the Beijing Spectrometer (BES) are described in detail. The BSC is a 3.85 m long cylinder with an inner diameter of 2.5 m and an outer diameter of 3.4 m, constructed on a 4.23 m long aluminum spool with a diameter of 2.5 m and a thickness of 3 cm. It is composed of 23 layers of lead (0.5 r.l. each as absorber) and 24 layers of self-quenching streamer (SQS) tubes, weighing 40 tons and with a solid angle coverage of 80% of 4π.

1. INTRODUCTION

The BSC is one of the major detectors in the BES. It uses the electro-magnetic shower method to measure the energy and position of the electrons and gamma-rays produced in electron-positron collision. In 1982, we started with the R & D of the SQS mode gas sampling shower counter, which went through single tube and prototype tests [1-8]. Starting from Sept. 1984 when the physical and mechanical design were finished [9], it took us four years to complete the BSC, including the fabrication, assembly, wire stringing, gas sealing, installation in the coil of the BES and cable connecting. In August, 1988, the BES was built up and tested with read-out circuits. Eventually the muon tracks of cosmic rays were observed.

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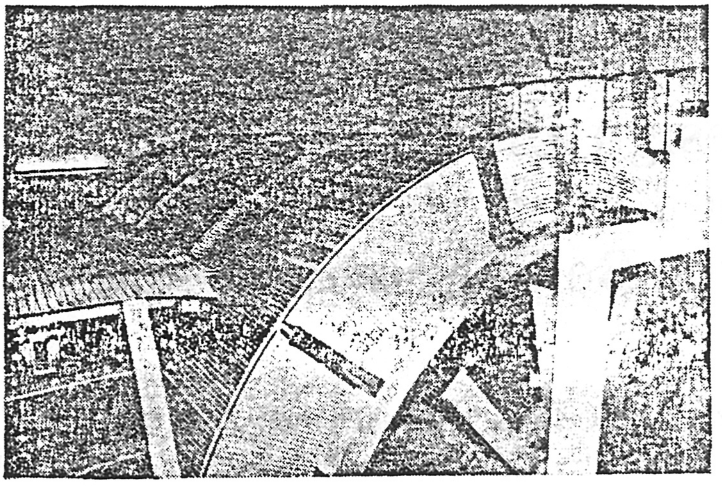

FIG.1
Structure of BSC.

2. DESIGN OF THE BARREL SHOWER COUNTER

For a general purpose spectrometer, the design of the shower counter must meet the following requirements: 1) High detection efficiency for photons (or electrons), particularly for low energy photons. 2) Good position resolution and good energy resolution. 3) Good lepton/hadron rejection ratio. 4) Large solid angle coverage. 5) A reasonable cost. The BES design was improved

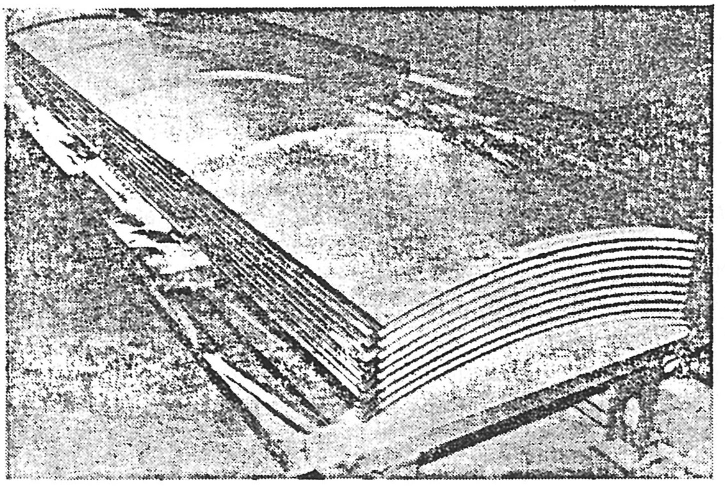

FIG.2
Panel of BSC.

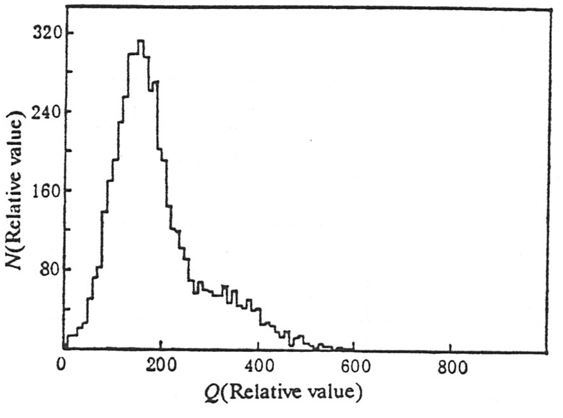

FIG.3
Typical SQS spectrum.

on the basis of the general purpose spectrometer MARK III at SLAC, in the hope that the BSC performance of the BES would be better than MARK III [10].

The BSC which chose the gas sampling mode has the advantages of simpler construction and lower cost compared with the uniform lead glass total absorption or lead-scintillator sampling shower counter, but has poorer energy resolution. The energy resolution is proportional to one over the square root of photon energy. For the BEPC 2.2 GeV electron-positron colliding beams, the energies of more than 90% photons are less than 400 MeV. Therefore, there can be no good energy resolution. If we chose a uniform mode counter, there would be a few-percent-higher energy resolution improvement, but no essential change in physical result. The gas sampling counter outputs

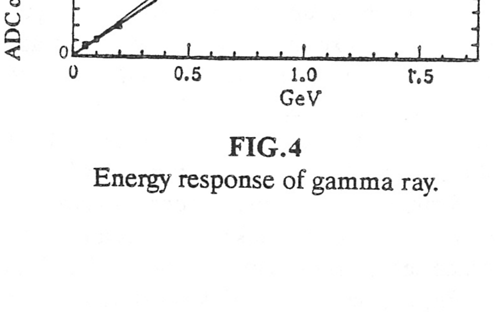

FIG.4
Energy response of gamma ray.

Table 1
Main parameters of BSC

	Length	4230mm	Diameter of wire	50μm(6J20 type)
Spool	Outer diameter	2532mm	Total absorption thickness	12r.l.
	Inner diameter	2470mm	Panel thickness	4.5mm
Width of cell	In the first layer	14.2mm	Length of BSC	3850mm
	In the last layer	18.7mm	Radial thickness of BSC	415.5mm
Thickness of sampling layer		13mm		

signals at both ends, the position in z directions is determined by the charge division method and the radial position resolution depends on the width of the cells. Therefore, it shows superiority in position resolution.

A BSC using the SQS mode has many advantages. The pulse amplitudes of the output signals are higher and more consistent compared with proportional signals. It can suppress the "Landau tail" effectively and improve the energy resolution. The signals can be sent out directly without preamplifier and the requirement of the ratio of signal and noise for the readout circuit can also be lowered. The accuracy of charge division depends directly on the quantities of charges, so it may be expected that the position resolution of the counter will apparently be improved. All of the above-mentioned results had been achieved in the R & D. In order to avoid the effect of double streamer, the SQS tubes were designed to keep nearly a square shape to make the electric field uniform in the counter, decrease the dead time and raise the detection efficiency.

The shower counter uses lead as an absorber. In the BEPC energy range, a full absorption thickness of 12 r.l. was chosen which is in turn divided into 24 layers. The first layer is approximately 0.5 r.l. which includes the thickness of the aluminum spool and the scintillator of TOF inside the BSC. Prototype beam test and Monte-Carlo calculation indicated that such a thickness was suitable for the absorber.

The BSC is put inside the solenoid coil to achieve good detective efficiency for low energy photons. To obtain the greatest solid angle coverage with a minimum gap between the barrel and endcap shower counters, the BSC was designed as a cylinder to utilize the space with optimum efficiency and avoid a dead region.

The configuration of the BSC is shown in Fig.1. An aluminum cylindrical spool called the inner spool supports the entire weight of the counter. It is 4230 mm long and 30 mm thick with the outer diameter of 2532 mm. In order to make the spool stronger and assembly easier, there is a flange at each end of the spool. It is 90 mm long and its radial thickness is 80 mm. The shower counter consists of absorption layers and sampling layers. The former is made of Al-Pb-Al curved panels whereas the latter is composed of aluminum ribs and I-beams. The Al-Pb-Al sandwich panel is made by stacking the sheets of a 0.6 mm thick Al, a 0.25 mm thick SL-4 glue, a 2.8 mm thick Pb, a 0.25 mm thick SL-4 glue and a 0.6 mm thick Al formed under pressure in 180°C. The length of the panel is 3850 mm. Ten panels with the same radius make up a circular layer. Between two absorption layers there is a 13 mm gas gap which serves as the sampling layer. Five ribs are evenly spaced apart, axially, on each panel as shown in Fig.2. Such an assembly is called support panel. Each rib has 56

Table 2
Compromise of the BSC

Designation	Number of kinds	Quanitity
Spool	1	1
Al-Pb-Al Panel	23	230
Rib	24	1200
Inner feed-through	24	40320
Outer feed-through	24	26880
Clip	24	40320
Fix-flake	24	53760
I-beam	1	53760
Pin	1	26880

holes of 6 mm diameter precisely drilled. In each hole there is inserted a plastic inner or outer feed-through which facilitates the stringing of the wire and the fixing of the I-beams. The circumference of one layer is divided into 560 cells by the 13 mm high I-beams. Because the radii of the sampling layers are different, the widths of the cells vary from 14 mm for the first layer to 18 mm for the 24th layer. As known from electric field calculation in a rectangular tube, in order to maintain the same electric field on the wire (ϕ50 μm) surface, the high voltage should increase 100 V (when H. V. is approximately 3600 V) from the first layer to the 24th layer. Thus, it will be inconvenient to design the signal output board with each layer having a different high voltage. Inversely, if all of the 24 layers have the same high voltage, the charges of the readout signals will be different for each layer. We have done Monte-Carlo calculation to estimate the influence of these differences. It was assumed that the charge spectrum of the SQS tube is the same as that shown in Fig.3, that the signal charge of every layer is decreased one by one, and that the signal charge of the first layer is 1.5 times that of the 24th layer. Without correction, the data of the energy response of the BSC will deviate from linearity at 1 GeV photon energy as shown in Fig.4. If the corrections are made respectively for the output signals, the energy response will resume linearity over 1 GeV and there will be no influence on the energy resolution. Therefore, we have adopted the same high voltage for all the layers and corrected the output values from different layers in off-line analysis.

Beam test of the prototype, which was done with a T1 beam at KEK, showed that the linear region of the energy response reached 1 GeV; the best energy resolution was $16\%/\sqrt{E}$ and the angular resolution in ϕ direction was 4.5 mrad. With charge division we have obtained the position resolution in z direction better than that of the proportional tube, and the experimental result was 0.7%. For SQS mode, the accuracy of the gas mixture component and high voltage stability are not rigorous. It is suitable for a big detector system.

The BSC has 13440 cells in all. Due to the limited number of readout electronics channels, it is impossible for one tube to use one channel readout electronics. According to the shower distributions of different energy photons in each layer obtained from Monte-Carlo stimulation, we arranged anode wires of 24 layers into 6 groups to make uniform the output amplitudes from all

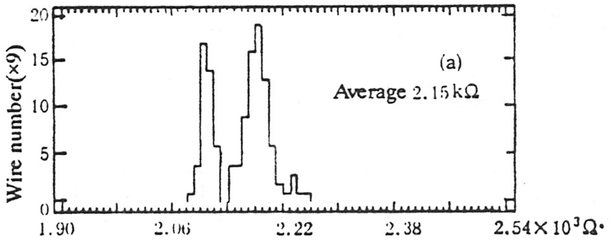

FIG.5

(a) Distribution of wire resistances.

groups. For the first six layers every two wires were arranged in a group, from the seventh to the twelfth layers every three wires were grouped. For the last twelve layers, all wires were grouped together. The signals from both ends of the grouped wires were used for charge division. The BSC has 6720 channels of readout circuits in all.

During R & D many experiments have been done for the gas mixture in the SQS tube. The results showed that if the gas mixture was 33%Ar + 67%CO_2 bubbling through n-pentane at 0°C, the performance of the tube would be satisfactory. But as n-pentane is an inflammable gas, it is necessary to take safety measures. For the first step, Ar and CO_2 bubbling through alcohol at 0°C will be used. We shall continue to test with different gas mixtures to select a gas mixture which is safer and has an excellent performance.

Expected performances:
Solid angle coverage: $4\pi \times 80\%$
Energy resolution: ~ $18\%/\sqrt{E}$ (E in GeV)
Position resolution: ~ 20 mm.
The main parameters of the BSC are shown in Table 1.

3. CONSTRUCTION OF THE BARREL SHOWER COUNTER

After we completed the mechanical design and raised the technical requirements for assembly, the Shanghai Aircraft Manufacturer attached to the Ministry of Aviation Industry undertook the fabrication of the BSC. But it was jointly assembled by the factory and us.

1). Inner Spool: The inner spool is made of LF6 type pure aluminum plates made in China, which were curled and Argon-Arc welded together to a cylinder. The whole welding seam was detected by X-ray and coloring. It was put aside for two months in order to relax its strain before processing. As the cathode of the first sampling layer, only the outer surface of the spool was machined. There were 24 non-magnetic stainless steel rods, each with a diameter of 36 mm, installed on the flanges of both ends equidistantly to support the BSC inside the magnet of the BES. During the construction the spool was fixed to a special assembling frame which allowed the spool to be rotated around its axis with one cycle per 10 minutes. In order to fix the support panels successfully,

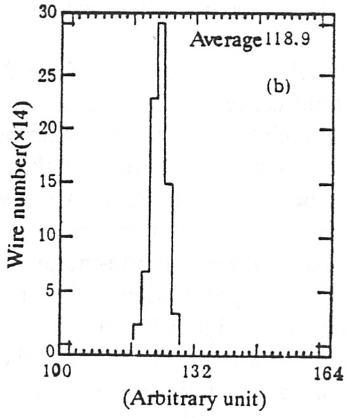

FIG.5
(b) Distribution of wire tensions.

it can also be rotated by hand for fine adjustment. The spool can support the entire weight (4000 kg) of the detector.

2). Support panel: It consists of two parts: the Al-Pb-Al sandwich panel, and five ribs which were evenly spaced apart axially. The sandwich panels were curved with a coverage angle of 36°. Ten panels with the same radius were put together as one layer. The arc lengths of the curved panels have 23 sizes and vary from 0.78 m to 1.05 m. It is required that no gas-gap should exist between two adhesive surfaces and that there be no peeling off around the panel. Since the panels are the cathodes of the Self-Quenching-Stream tubes, they should be smooth, with no serious scratch and residual glueon the surface. And the aluminum surface should be anodized to keep its good conductance.

The ribs are specially designed extruded sectional aluminum. Through forming and drilling, every 50 ribs must have the same curvature. The accuracies of the 56 holes of 6 mm diameter on each rib determine the positions of the anode wires and then the distribution of the electric field in each cell. Our design requires that when the support panel is pressed tightly, the non-axiality should be less than R 0.5. They were put into production after the quality of the sample was accepted.

3). I-beam: Because the aluminum I-beam extruded in China could not satisfy our requirement, the I-beams (13 mm high) were made of LY12 type hard aluminum with a thickness of 0.4 mm, which was pressed into 'ㄇ' shape and welded every two pieces back to back. The I-beams thus made have satisfied the requirement of our physical design.

4). Feed-Through, pin, clip, etc.: The feed-throughs were molded from polyformaldehyde. The pin was a small cylindrical tin-and-cerium-plating copper tube (produced in the Shanghai No.2 Copper Processing Factory), with an outer diameter of 1.6 mm and an inner diameter of 0.4 mm. The 0.2 mm thick phosphor-bronze clip was stamped in a special die.

The panel (planar), I-beam, feed-through, pin and stainless steel wire were tested and improved during the prototype beam test. Since the processing of the aluminum spool and the glueing of the large-sized Al-Pb-Al sandwich curved panels were done for the first time in China, they had to pass various tests before they were put into production. So they were all up to the design values.

The BSC was assembled at the Institute of High Energy Physics. The inner spool and assembling frame were laid in a clean room specially designed for the BSC. Before the support panels were glued and riveted the surfaces had been anodized. Every hole on the support panels and ribs were cleaned with alcohol and all other components were soaked in soap water and alcohol, cleaned with ultrasonic waves, packed separately according to their different layers and then sent to the clean room for assembling.

The outer surface of the spool is the first sampling layer of the BSC. 50 ribs were riveted on it. Efforts had been made to ensure the hole centers of every 5 ribs were in a straight line. The altitudes of the 50 ribs were examined after each layer had been assembled. Their differences were kept within ±0.5 mm. Then the feed-through, I-beams, clips and fix-flakes were installed in successive order. To prevent the flanges from affecting the wire stringing, the wires were strung when each layer was assembled for the first 4 layers. For other layers the wires were strung after the BSC body was built up. After every ten panels were installed, two layers of non-magnetic stainless steel straps were wrapped along the groove on top of each rib and spot welded with a tension of 160 kg. The height of the BSC is (3369 + 6) mm which has met the design value of (3369 ± 12) mm.

The test of the BSC prototype has proved that the quality of the stainless steel wire with a diameter of 50 μm produced by the Shanghai Institute of Steel has satisfied our demand. The wires passing through the inner and outer feed-throughs and the pins were firmly plunged into the hole of outer feed-through with glue at both ends and then clipped with a tension of 90 g. For every wire we measured the insulation between the wire and the ground, the wire resistance and the wire tension. Fig.5 shows the distributions of the tensions and resistances of the wires in layers 3 and 4. There were two peak values for the wire resistance in Fig.5(a). This was due to the use of two different batches of wires. When 24th layers had been assembled, the outermost layer was covered by a sandwich glued with two 1 mm Al plates and then wrapped with 5 layers of fiberglass epoxy. Table 2 shows the number of components of the BSC totalling 23351. All of them were made in China.

230 support panels were put together to form the BSC's 23 layers. There were many gaps at both ends which needed to be sealed airtight with Silicon Rubber. The BSC was filled with argon and checked with a gas leak detector. When the over-pressure in the BSC was 5 cm-water, its rate of leak was 0.2%/h. (The BSC actually works at 1.3 cm-water over-pressure.) The gas path in the BSC was formed by 10 inlets at one end of the first layer and 10 outlets at the other end of the 24th layer. In other words, one outer feed-through was replaced by a gas-hole and there was no wire in this cell. Corresponding to the gas-hole there were 3 holes, each with a diameter of 6 mm, on the panels of each layer, enabling the gas to spread quickly to all layers. There was one small hole with a diameter of 1.5 mm on one side of every outer feed-through, allowing the gas to spread laterally. In a cell the gas could flow through the hole of the inner feed-through. Prototype test showed that the gas resistance of each cell was the same and there was no dead region in this gas path arrangement. The gas-holes (10 inlets and 10 outlets) were connected with two big gas circles. These big gas circles were connected with the gas system and exhaust pipe respectively.

After the BSC had been assembled in the clean room, it had to be moved into the experimental hall of the BES and installed in the magnetic yoke. Because the BSC and its assembling frame were about 50 tons, it was very difficult to move them. When it was being moved, the lean of the BSC body was less then 3 degrees. It took one week to push the BSC into the yoke and locate it in the correct position.

The BSC contained 13440 cells and had to be connected with 26880 readout lines at both ends. The cell's resistance to voltage, the right order and good contact after the readout boards were inserted had to be individually checked. The leakage current for every four boards (including 192 cells) was required to be less than 5--6 μA at 3400 V. All the readout boards were connected in July 1988. After the BES was assembled in Oct. 1988, the test-run began with cosmic rays.

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