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PROPOSAL FOR TEST BEAM RUNNING OF THE CLEO III RICH DETECTOR

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Abstract

Cherenkov ring imaging systems play an important role in many B physics experiments. The CLEO detector will undergo major improvements in conjunction with a high luminosity upgrade of the CESR e^+e^- collider, that should increase the luminosity of this machine by a factor of 10. The most innovative feature of the planned CLEO detector is the addition of a state of the art Ring Imaging Cherenkov detector featuring excellent hadron identification at all the momenta relevant to the study of decays of B mesons produced at the $\Upsilon(4S)$ resonance. This system is also being considered as part

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of the particle identification system for a dedicated B physics detector at the Fermilab collider. We request beam time to test our already constructed prototype and several of the fully constructed modules.

1 Introduction

A major upgrade of the CLEO detector is underway (CLEO III), which, together with the planned increase in luminosity of the CESR e^+e^-collider at Cornell University, should open exciting prospects for studying CP violation in charged B decays and mapping the phenomenology of rare B decays. The main innovation is the introduction of a high class particle identification system which will identify charged hadrons in the kinematic domain characteristic of B decays at the $\Upsilon(4S)$ with high efficiency and low fake rate. The approach chosen is a Ring Imaging Cherenkov Detector (RICH), where the position of the Cherenkov photons generated by relativistic particles crossing a dense medium is reconstructed at a detector plane.

The CLEO RICH is based on the 'proximity focusing' approach, in which the Cherenkov cone is simply let to expand in a volume filled with ultraviolet transparent gas (the expansion gap) as much as allowed by other spatial constraints, before intersecting the detector surface where the coordinates of the Cherenkov photons are reconstructed. The design is based on work of the College de France–Strasbourg group [1], who tested a system with a plane LiF radiator and a CH_4-TEA photon detector. We are considering a unique geometry for the LiF solid radiator [4], which has the light emitting surface cut in the shape of a sawtooth. It should provide a substantial increase in the number of reconstructed photons and in the angular resolution of this device. The photon detector is a thin gap multiwire proportional chamber (MWPC) with cathode pad readout. The photoconverter chosen is triethylamine (TEA), whose molecules are dispersed in CH_4 by means of a bubbler. A fine segmentation of the cathode pad is required in order to achieve the spatial resolution needed, which in turn implies a high density of readout electronics. Our design involves 230,000 processing channels.

The components of our system are illustrated in Fig. 1. It consists of a radiator, providing U.V. photons, an expansion region, and a photosensitive detector. The angle θ_p is the polar angle of the incident particle with respect to the radiator normal, the angle ϕ specifies the azimuthal angle of the Cherenkov photons. The figure also shows our choice of components, discussed below.

This system can also be used as part of the particle identification system for a dedicated B physics experiment at the Fermilab collider. By using sawtooth radiators oriented close

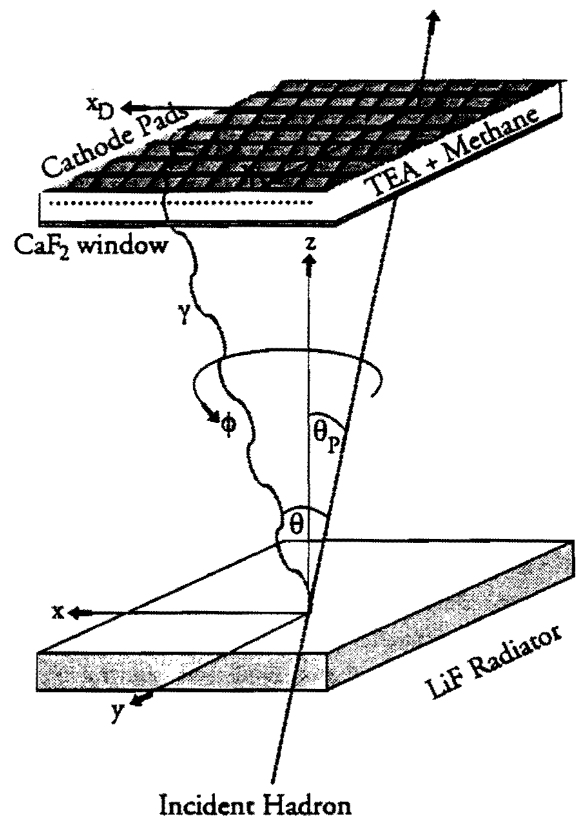


Figure 1: Schematic diagram of LiF-TEA RICH system.

to normal to the B decay products it may be possible to achieve 4σ K/π separation at 3.5 GeV/c momentum. We then would need to couple this system with a gaseous radiator to extend the coverage to higher momenta. It is important to realize that many tracks are below 3.5 GeV/c and this part of the detector is critical.

The author list of this proposal has both CLEO III physicists and those interested in particle identification for a dedicated B experiment.

2 Relevance to Collider B Physics at Fermilab

We have considered several possible particle identification schemes that would be relevant for forward or central detector geometries at the collider. The goal is to have at least 4σ

kaon/pion separation over the momentum range of interest. This is indicated in Fig. 2 for the decay process $B_s \to \psi K^*$, where the $K^* \to K^+\pi^-$ in both the forward and central geometries. This mode has been suggested as good way to measure B_s mixing [2]. The momenta are not particularly large especially in the case of the central detector. The pion momentum distributions for $B^o \to \pi^+\pi^-$ are shown for the forward detector in Fig. 3. Here the momenta are significantly larger as expected.

The only known devices providing a good chance of particle identication are Cherenkov counters. The most critical choice from the detector point of view is the choice of photon detectors. Although large systems have been built using TMAE gas as a photo-converter, it is well known that TMAE is very difficult to work with. Furthermore, small cell chambers such as those used in the Jetset experiment reduced the number of photoelectrons by about 40% [3]. Therefore, we have developed a system for a forward detector that uses TEA gas as the photo-converter. Although it appears at first glance that a central detector presents an easier problem, due to the lower momentum B decay products, in fact the rigorous radial spatial constraints of a central detector make the solution much more difficult.

A system of consisting of a sawtooth LiF radiator followed by a C_2F_6 gas radiator of 2.5 meter thickness has been investigated for a forward geometry. The LiF radiator provides separation between 0.5 GeV/c and 3.5-4.0 GeV/c depending on the radiator thickness (1cm - 2cm). This is followed by an expansion gap of 20 cm and then a proximity focussed photon detector or a mirror which sends the light to a more remotely located photon detector. An important point here is that the LiF radiators can be aligned within a few degrees of the normal to the incident particles, thereby insuring the best possible resolution.

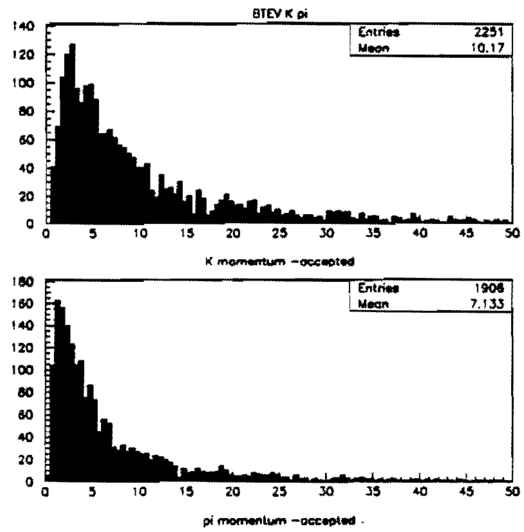
The C_2F_6 gas radiator which follows must be mirror focussed. The following calculation is based on assuming that the resolution is not degraded by poor mirror quality or poor charged particle tracking. The momentum at which pions radiate in the gas in the wavelength region of interest (135-165 nm) and produce 5 detectable photo-electrons is 3.3 GeV/c. The momentum at which 4σ separation is achieved in shown in Fig. 4 as a function of angle incident to the mirror. The plot covers the entire detector. We see that the useful separation extends out to about 70 GeV/c.

While this proposal addresses only the LiF radiator, it is clearly possible to construct a gas radiator and mirror to be coupled with the existing photon detectors.

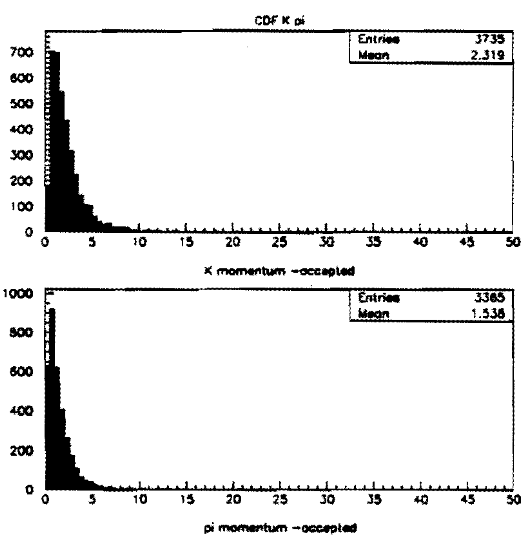
3 Mechanical Design

The mechanical design of this detector faces several challenges. One of the most severe constraints is dictated by the bandwidth of the photosensitive element, centered around

$B_s \rightarrow K^* J/\psi$



BTEV Kaon and Pion Momentum



CDF Kaon and Pion Momentum

Figure 2: The momentum distributions for kaons and pions resulting from $B_s \rightarrow \psi \overline{K^{o*}}$ for forward "BTEV" (top) and central "CDF" like detectors (bottom).

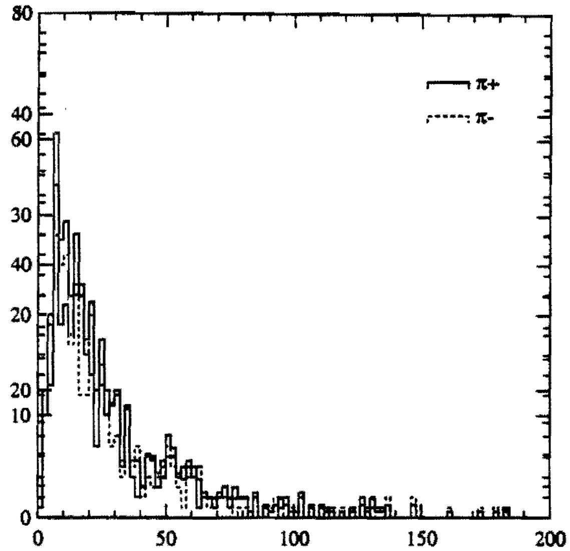


Figure 3: The pion momentum distributions from $B^o \rightarrow \pi^+\pi^-$.

150 nm. This implies a hermetic sealing of the expansion gap, the space between the LiF radiatiors and the CaF_2 windows, from the neighboring gas volumes, in order to prevent contamination from oxygen and water from the outside environment. In addition the TEA inside the photodetector must not leak into the expansion gap because this would also cause loss of photoelectrons. The other important goal is to keep the CaF_2 windows free of any kind of mechanical stress in order to prevent cracks from developing. This has been achieved by attaching these windows to their frames through hinges, as shown in Fig. 5, which provide a soft joint to relieve the stresses. The LiF radiators are held in place by an inner carbon fiber cylinder to which they are attached. The back of the cathode boards which constitute the outer side of the MWPC are strengthened by hollow G10 rods which also act as channels for the cooling gas (N_2). The strength has been achieved with great care to minimize the amount of material in the detector, in order to preserve the excellent performance of the electromagnetic CsI calorimeter. The average material thickness is 13% of a radiation length for tracks at normal incidence.

In order to improve the coupling between cathode pads and anode wires and to reduce the mean number of pads corresponding to a single photoelectron avalanche, the chamber geometry is asymmetric, with the anode wire to cathode pad distance of 1 mm and a 3mm gap between the anode wires and the CaF_2 windows. The anode wires are run at positive high voltage, while the windows have metallic traces applied so they can be used with a negative high voltage. The wires run along the 2.5 meter detector length. In order to preserve a

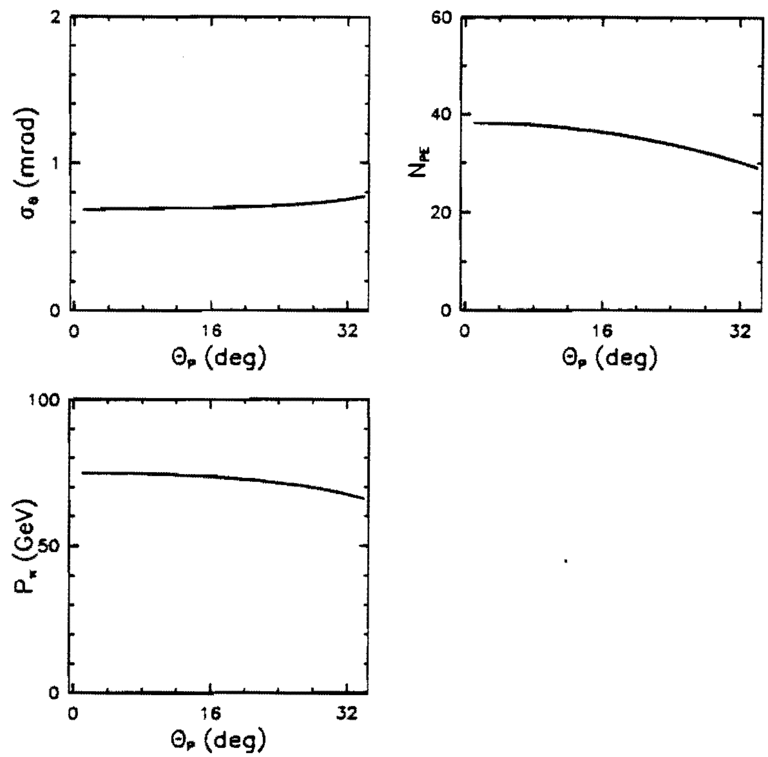


Figure 4: The properties of a 2.5 m long mirror focussed C_2F_6 gas radiator as a function of the angle of track incident to the mirror, Θ_P. Upper left is the Cherenkov angular resolution, upper right is the number of detected photoelectons and the lower figure shows the momentum for 4σ K/π separation.

high uniformity in the wire to cathode distance over such a length ceramic spacers are glued between the wires and the cathode pads along the azimuthal direction every 30 cm.

4 Readout Electronics

The 230,000 readout channels are distributed over the surface at the outer radius of the detector and are impossible to access routinely. Therefore the readout architecture must feature high parallelism, and extensive testing of active components and connection elements is required in order to insure their reliability. The MWPC detector surface is segmented into 30 modules, which will be divided into 12 subunits each with 640 readout channels. Each of

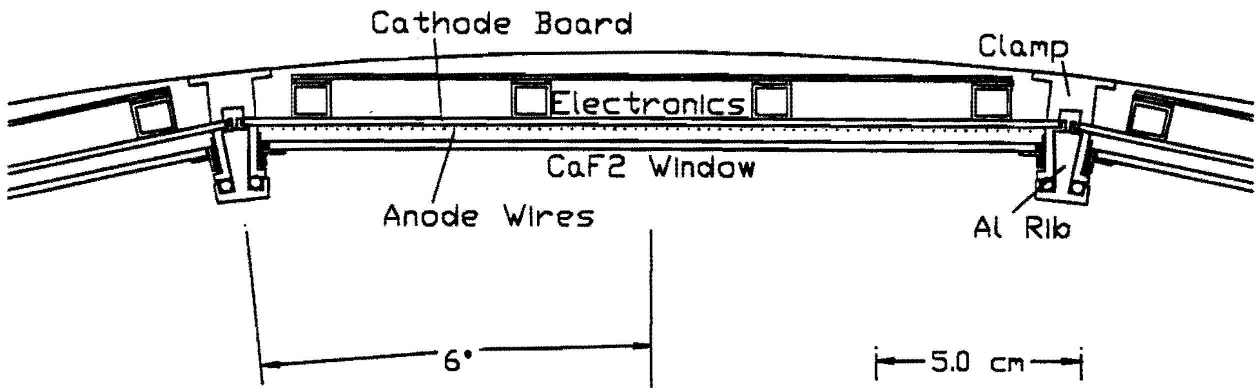


Figure 5: A detail of a section of the CLEO RICH showing the mechanical design of individual detector modules showing the attachment method for the CaF_2 window and the method to strengthen the cathode plane.

these subunits will communicate via a low mass cable connection with VME cards providing the control signals and receiving the analog or digitized signals as discussed below.

Several considerations affect the design of the individual channel processor. Low noise is an essential feature because the charge distribution for the avalanche produced by a single photon is exponential at moderate gains. It should be stressed that it is beneficial to run at low gains to improve the stability of chamber operation. Therefore in order to achieve high efficiency, the noise threshold should be as low as possible. An equivalent noise charge of about 200 electrons is adequate for our purposes. On the other hand, an exponential distribution implies that a high dynamic range is desirable in order to preserve the spatial resolution allowed by charge weighting. Note that charged particles are expected to generate pulses at least 20 times higher than the single photon mean pulse height. In order to improve the robustness of the readout electronics against sparking, a protection circuit constituted by a series resistor and two reverse biased diodes is required in the input stage. Finally it is important to sparsify the information as soon as possible in the processing chain, as the occupancy of this detector is very low and therefore only a small fraction of the readout channels contain useful signals.

There is a preamplifier/shaper VLSI chip developed for solid state detector applications which incorporates many of the features discussed above [2]. A dedicated version of this chip, called VA_RICH, has been developed and will be tested shortly. Its predicted equivalent noise charge is given by:

$$ENC = \sqrt{(73e^- + 12.1 * Ce^-/pF)^2 + (50e^-)^2} \quad (1)$$

The first term corresponds to the noise contribution from the input transistor and the (80 Ω) series resistor used for the input protection where C is the input capacitance (typically < 10 pf) and the second term to the noise from subsequent stages, small but non negligible because of the lower gain chosen to increase the dynamic range. This device is expected to maintain linear response up to an input charge of 700,000 e^-.

The choice of digitization and sparsification technique has not yet been finalized. Under consideration is the digitization and sparsification at the front end level, using the zero suppression scheme and the ADC included in the SVX II readout chip [4]. Alternatively we will digitize all the analog output signal and perform the zero suppression afterwards.

5 Performance of the CLEO RICH Prototype

We have constructed a prototype of an individual detector module about 1/3 the length of an actual detector module and about the same width. The prototype system is enclosed in a leak tight aluminum box. The expansion gap is 15.7 cm. In this prototype we have used plane 1 cm thick LiF radiators. The chamber geometry is approximately the same as the final design in terms of gap size, wire to cathodes distance and pad sizes. The total number of pads read out is 2016. Pad signals are processed by VA2 preamplifier and shapers [5]. The detector plane is divided into 4 quadrants each of which has 8 VA2 daisy–chained for serial readout.

This prototype has been installed in a cosmic ray set up composed of a telescope of scintillators whose geometrical arrangement can be varied. We either trigger on energetic cosmic rays having their Cherenkov image within the acceptance of the photodetector but not the charged track, or we trigger on charged tracks going through the detector.

Fig. 6 shows the charge distribution of reconstructed photon clusters as a function of the anode wire voltage U_a for several different voltages. Note that the pulse height distribution is consistent with an exponential profile and its mean value increases with U_a, as expected. Fig. 7 shows the excitation curve for hits which are more than six standard deviations above noise. It can be seen that the plateau corresponds to $N_{pe} \approx 13$. This number has to be corrected for possible background hits, which we estimate to be about 1 per event. This performance is in close agreement with our expectations based on the performance of a similar prototype built and tested by the College de France–Strasbourg group [1]. A

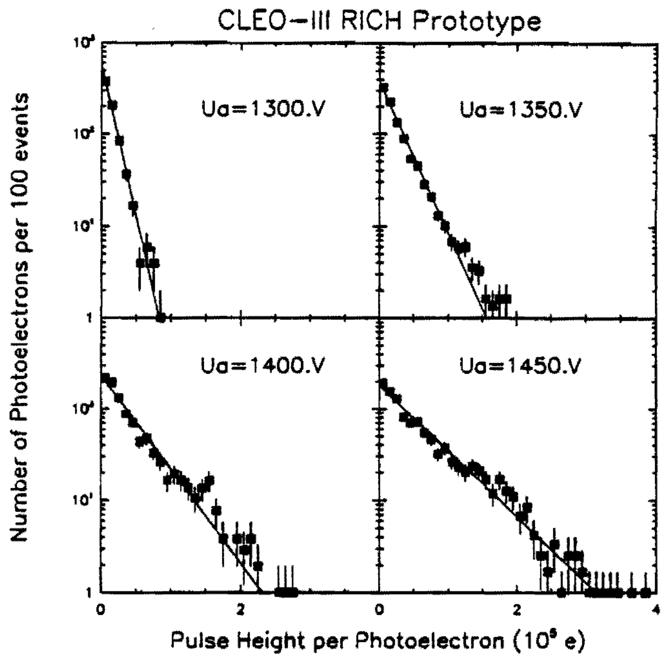


Figure 6: Photon induced avalanche charge distribution at different anode voltages. The voltage on the metallization of the CaF_2 windows is kept at -1350V.

tracking system is being added to this set-up to allow us to start measuring Cherenkov angular resolutions.

6 Beam Time Requests

We would like to measure the Cherenkov angular resolution using high momentum charged tracks. We are working on a novel radiator design where the light emitting surface is grooved [7]. These radiators should be available soon and we need to measure the light yield and resolution. We can use either our existing prototype detector which is approximately the same width as a full size module but only 1/3 the length or a set of 1-3 fully constructed CLEO modules. Testing the latter will also give us important information on the performance of the actual modules. Any beam with momentum greater than 20 GeV/c would be suitable for our needs. The rate could be as low as a few/second. Having a beam spot approximately 15x15 cm^2 would be optimal, but we could work around a larger size. We also want to measure the response to charged tracks directly. The RICH test detector geometry is shown

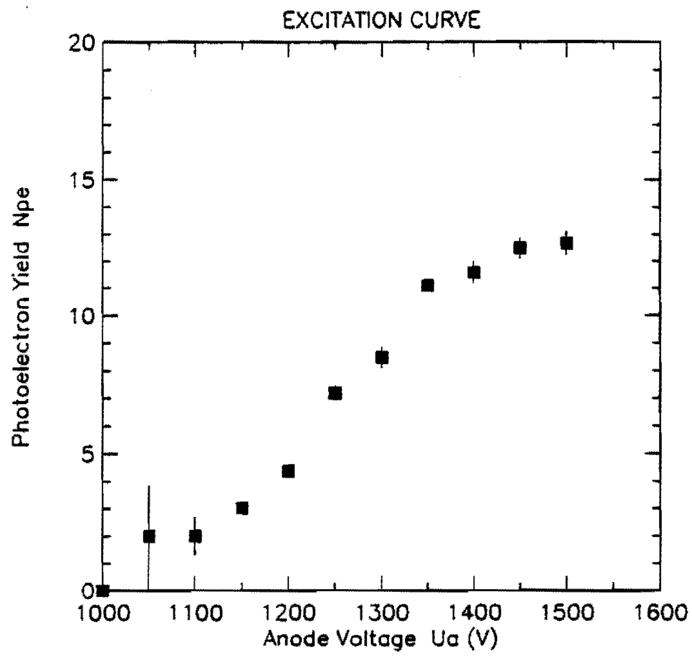


Figure 7: Excitation curve for $CH_4 - TEA$. The voltage on the metallization of the CaF_2 windows is kept at -1350V.

in Fig. 8. We would also have drift chambers in front of the device to define the charged particle angle. We need to have about 10 feet of space along the beam line and about 14 feet transverse to the beam line to place our equipment. We would need to supply the chambers with a mixture of TEA and CH_4. The volume of the chambers is quite small being only 1/4 m^3 for each chamber. We plan to use as many as three simultaneously. We also need to fill the expansion gap with pure N_2, and need to flush the drift chambers with a 50-50 Argon-Ethane. We will provide all of the gas systems, the electronics and the online computing. We request network connections to a UNIX computer such as fnalu and modest disk space and computer time on that system. We would like to have the beam time in July or August of 1996. We would also appreciate some help in surveying the final setup.

Hopefully, we could complete all of our tests with 3 weeks of beam time.

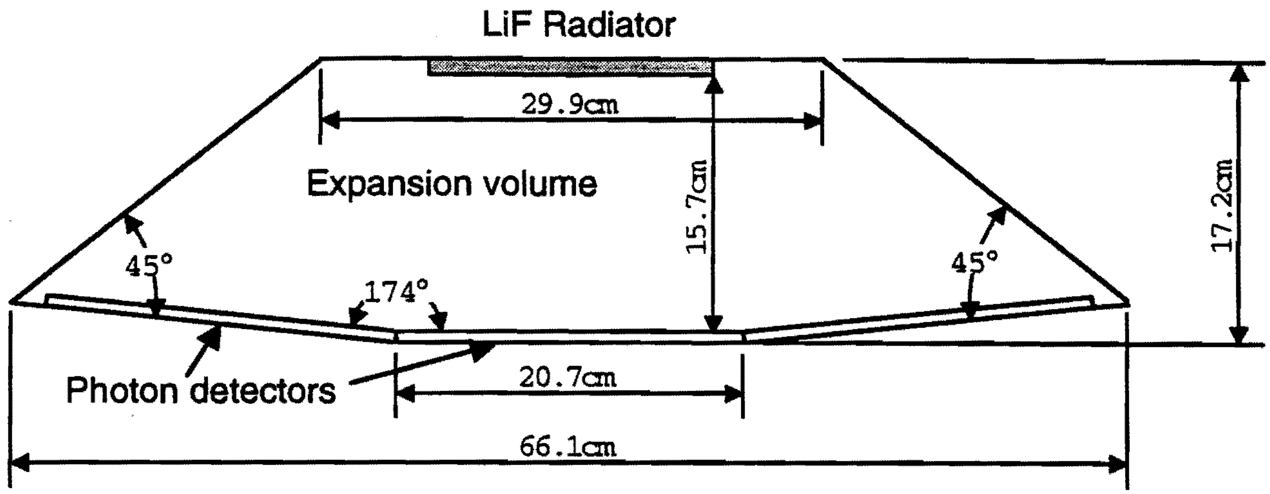


Figure 8: Schematic of 3 module test structure.

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