Proposed New Beam Instrumentation

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I. Introduction

The goal of the present upgrade in the upstream beam elements is to provide better kaon position measurements, and to completely cover the upstream region with efficient photon detectors.

One of the problems in the search of $K^+ \to \pi^+ \nu \overline{\nu}$ above the $K_{\pi 2}$ peak is to reliably find the kaon stopping fiber in the target when the kaon and pion tracks are parallel, or rather overlap. The ambiguity in the stopping fiber assignment causes a long (or short) range tail of the $K_{\pi 2}$ peak, resulting in a higher background level. Our solution to this problem is to get a better position resolution of a kaon at B4 that determines the entering position of the kaon into the target, so that the other end of the kaon track, the stopping end, can be unambiguously assigned.

In the search of the decay $K^+ \to \pi^+ \nu \overline{\nu}$ below the $K_{\pi 2}$ peak, the sensitivity is limited by the low energy tail of the $K_{\pi 2}$ peak due to pion-nuclear interaction in the target. A more efficient photon veto is required to compensate the loss of the background suppression capability in kinematics. At least a factor of ten improvement over the existing photon veto capability is needed to reduce the background to the signal level. The new barrel veto liner will provide an improvement factor of 2–3, but that will not be enough by itself. Since the inefficiency in the beam direction becomes the dominant cause of π^0 detection inefficiency at this level, an additional factor of five or more can be gained by plugging this region with efficient photon detector.

II. B4 Hodoscope

A. Existing B4 hodoscope

The B4 detector is intended to do the following:

- Signal the entry of a particle into the target, as part of the trigger

- Give the x and y coordinates of a particle as it enters the target so that this information can be correlated with the hit target fibers.
- Give information on the dE/dx of a particle as it enters the target, to identify the particle as a K and reject K-decays in flight.
- Signal the arrival of background particles, particularly pions, around the time of the K-decay.

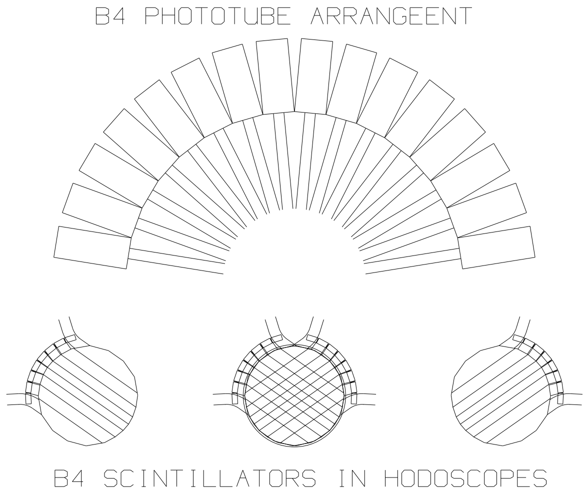

Figure 1: Existing B4

The present system consists of two 8-finger hodoscopes at 70 deg , arranged as in Figure 1. The scintillators are read out by 16 Lucite lightguides and Hamamatsu R1924 25 mm tubes. The size of the hodoscopes is such that they just cover the target, which is 119 mm in diameter. The thickness of each scintillator is 6.35 mm, which gives a resolution (FWHM) in dE/dx of about 28 percent for K's of energy greater than 110 MeV, whose energy loss in the 12.7 mm of B4 is 5 MeV. This resolution corresponds to about 12 photoelectrons per MeV of energy loss, or about 5 photoelectrons per mm of scintillator traversed by the K's. The spatial resolution in x and y is given by the width of the hodoscope elements, being 1 cm at the centre of the target and getting wider towards the edges of the target.

B. Proposed new B4

We propose to improve B4 by increasing the number of elements in the hodoscopes and change to wavelength-shifting-fiber (WLS) readout. The WLS readout is reported to give 20-30 photoelectrons/cm for MIP, which is about the same as we get with the lucite lightpipes, but is considerably more flexible. We aim to reduce the spatial resolution in x and y to less than 5mm, which corresponds to the size of the target elements, by both increasing in the number of hodoscope elements and overlapping them so that the energy sharing between the neighbouring fingers through which the particle passes can be used to further refine its location.

Two schemes have been considered. The first utilises hodoscope elements whose cross section is an isosceles triangle, as depicted in Figure 2.

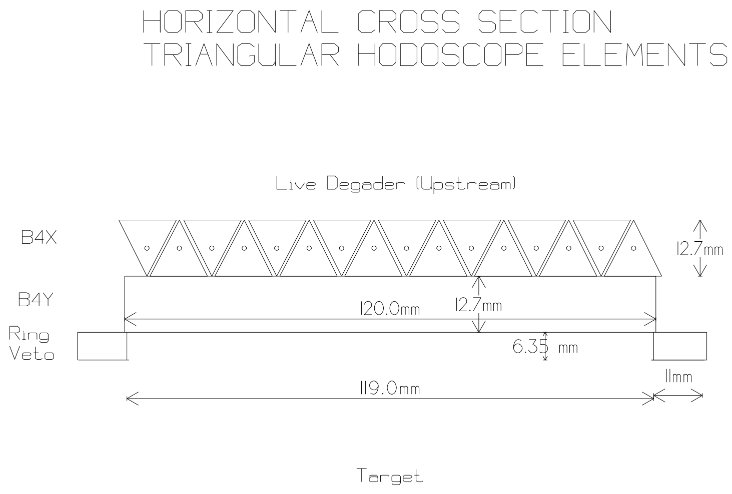

Figure 2: Triangular cross sectional hodoscope elements

If the height of the triangle is 12.7 mm,then 32 elements would be required to cover the target in two dimensions.The hodoscope array as seen by a beam particle is shown in Figure 3. The WLS fibers could either run through a 1 mm hole in the centre of the triangle (more difficult to make), or be glued into a groove inscribed in the surface, which is easier to make but may not be as efficient for light collection. (Tests will be carried out to determine which of these alternatives is best.) The total thickness of the B4 detector seen by particles would increase from 12.7 mm to 25.4 mm, so that the resolution in dE/dx should improve by a factor of 1.4. Each particle would pass through two elements in the x-hodoscope array and two in the y-hodoscope array. The spatial resolution would be 7.3 mm based on hit elements alone, and about 20-30 % of this or 1-2 mm, based on the energy sharing between hit elements.This resolution is probably better than we need, since the pixel resolution in the target is 5 mm, but the factor of two increase in segmentation should improve background rejection. This scheme has the disadvantage that twice as many phototubes must be installed in the congested region of the upstream endplug. The second scheme utilises hodoscope elements whose cross section is a trapezoid (see Figure 4). If the triangles in scheme 1 above are truncated at a height of 10 mm then 24 elements will cover the target in x and y. The spatial resolution will be about 3-4 mm, a factor of 3 improvement over the existing B4, but

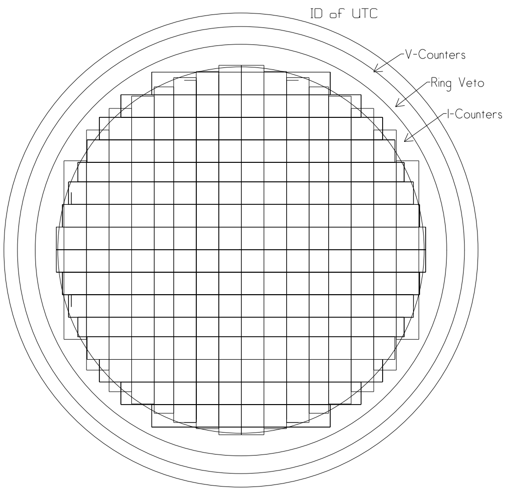

Figure 3: Triangular cross sectional hodoscope elements-beam's eye view

the resolution in dE/dx would only improve by 1.25.

C. Ring Veto Counters

In order to be able to veto events where the Kaon stops in the I-Counters, we propose to add a ring of 6 veto counters with individual segments read out by WLS fibers embedded in the scintillator. These counters would be located between B4 and the upstream face of the target, and would have an inner diameter of 119 mm and an outer diameter of 141 mm so as to completely cover the I-Counters and overlap with the V-Counters around the target (see Figure 5).

III. Active Degrader

III-1. Present active degrader

The active degrader is located between the BeO degrader and the B4 counter to detect incoming pions and photons associated with a kaon decay. It consists of a 10-cm long, 11.2-cm diameter lead-glass cylinder operated as a Čerenkov-light radiator of 3.5 radiation length. The mean numbers of hit phototubes out of sixteen are one phototube/10 MeV for a photon shower, 8–9 phototubes for an incoming pion, and 1–2 phototubes for a kaon.

There are a few problems with the present active degrader. (1) It is not thick enough to efficiently detect photons. (2) Since the largest diameter of the target is 119 mm, photons

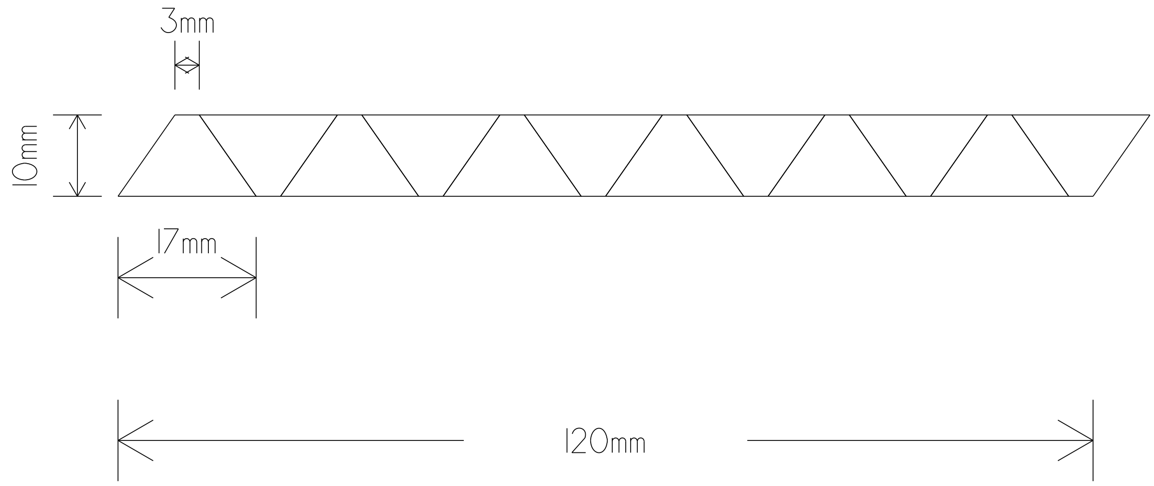

Figure 4: Trapezoid cross sectional hodoscope elements

emitted from the outer region of the target may not pass thought any active material. (3) The photon detection threshold (10 MeV) is too high.

III-2. New Active Degrader

The proposed new active degrader will consist of 40 layers of sandwiches of 1-mm thick lead and 2-mm thick plastic scintillator discs. This corresponds to the total thickness of 120 mm with 7 radiation lengths. Each disc having a diameter of 132 mm is segmented into 8 45^o-sectors to reduce a chance of getting a kaon and a photon shower in the same module—the presence of an early kaon hit in the same module may block detection of the subsequent photon, especially when the kaon pulse is significantly larger than the photon pulse. The scintillation light is converted and transmitted by a 1-mm diameter, 2-m long double-cladded WLS fiber attached at the circumference-arc of each sector (see Figure 6). A group of four scintillators at the same angle will be read by the same photo-tube to reduce the number of tubes, but will still maintain an acceptable range of kaon and γ pulse height ratios for effective second pulse detection. In order to avoid overlap of light guides (WLS fiber) between adjacent groups of four , neighbouring groups are shifted azimuthally by $\sim 4^o$.

III-3. Ring photon Veto

The ring photon veto counter is a cylinder with inner diameter of 132 mm and outer diameter of 188 mm to provide a coverage at the perimeter of the active degrader. The physical length will depend on the material but it should have more than 7 radiation lengths. The

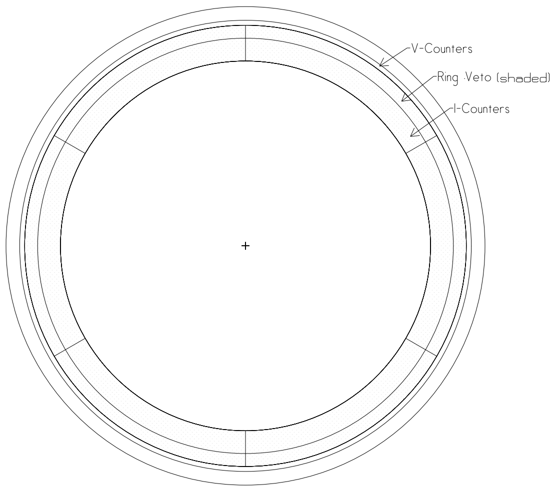

Figure 5: Cross-section at entrance to target, showing B4 hodoscopes and Ring veto counters

material can be CeF_3 or GSO crystals with 1-mm double cladded WLS fibers located in grooves at the edge of sectors (as in the Shashlik type read-out). Alternative material can be sandwiches of 1-mm thick lead and 2-mm thick plastic scintillator discs.

IV. Upstream Photon Veto (UPV)

Presently, there is a hole counter between the Princeton Cerenkov counter and BWC1.The old hole counter has been heavily used in double-beam background study and rejection. However, because of its shape (L) it may not have a good efficiency in some regions, and since the pion beam location is different from kaon's it is desirable to have the hole counter aperture somewhat larger to accommodate it. So, the existing hole counter requires some improvement.

The photon vetoing capability in the upstream direction can be further strengthened by converting the hole counter into a combined hole/photon veto counter, to be installed just upstream of the Princeton Cerenkov . A conceptual design for this new detector consists of a lead/scintillator sandwich with 1mm-thick layers of lead interspersed with 2mm -thick layers of scintillator. With 40 such layers, we would have a total thickness of 120mm and 7.32 Radiation lengths. The diameter should be about 250 mm, so that the 200 mm diameter hole in the endplug is covered. In order to allow the beam to pass through, the detector is split in the horizontal plane and the two halves separated vertically by about 30 mm (Figure 7). At the upstream end of the Princeton Cerenkov counter, where the UPV is located, the beam is very wide horizontally and small vertically. The scintillators are read out by WLS

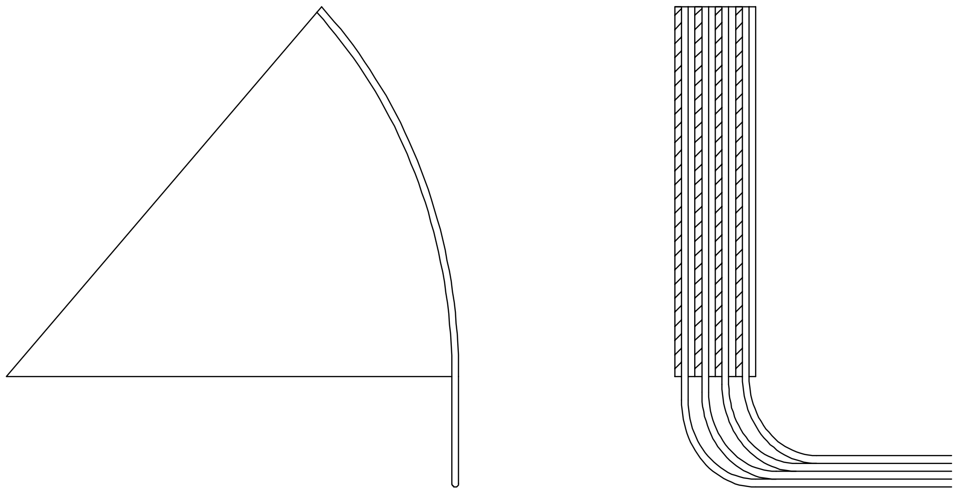

Figure 6: Front and side views of a 4-sector group of the active degrader

fibers running in grooves cut into the scintillator pieces at their outer radii. All the fibers in the upper half go to one tube, and all the scintillators in the lower half to another.

Such a counter would detect photons passing between the active degrader and the collar. Because of the vertical separation for the beam, coverage would not be complete, but with a vertical separation of 30 mm, coverage would be about 90 percent. The vertical separation between the two halves should be made adjustable, so that photon coverage can be optimised.

V. Mounting scheme and construction

V-1. The present scheme

The stainless steel (ss) cylinder is mounted onto the iron plug to provide a support for the beam counter system and protection to the endcap and collar calorimeters. The B4 assembly is mounted at the end of a semi-circular ss tray that slides into the upper half of the support cylinder. The tray extends from the target region to the outside of the support cylinder. The light guides of the B4 hodoscope are attached to the tray anf fanned out at the supporting flange where they are read by photo-tubes.

V-2. New Scheme

The new ss cylinder is similar to the existing one that provides a mechanical support to the beam counter system. Figure 8 shows the whole mounting scheme. The major difference is a smaller diameter cylindrical carbon fiber extension at the target end, which serves as an

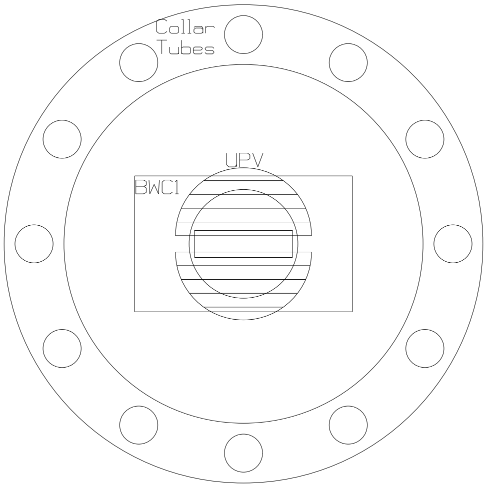

Figure 7: Upstream Photon Veto (UPV)- beams-eye view

alignment guide and a protector for the UTC.

The removable part of the beam counter assembly (the new ring counter, B4, active degrader and ring photon veto counter) is contained in a thin Al cylinder, which can be inserted into the ss-carbon fiber support cylinder as one body on Teflon slides.

One problem is that the inner diameter of the ring photon veto counter is smaller than the outer diameter of the active degrader. Further complication is due to interleaving of the WLS fibers from the B4 and the active degrader to minimize the waste space. These considerations require a unified construction of the B4, the active degrader and the ring counter.

V. Phototubes

The phototubes which have been considered for the B4 hodoscopes and the active degrader are shown below.

Tube	Size(inc base)	Ext Green	Cost/ch	# anodes	Gain Var	Crosstalk
H3164-10	12x95 mm	No	628US	1	NA	NA
H3165-10	15x116 mm	No	339US	1	NA	NA
H3165-10	15x116 mm	Yes	418US	1	NA	NA
R580-17	48x220 mm	Yes	Free	1	NA	NA
H6568-10	40x100 mm	No	89US	16	1.3:1	< 1 %
H7546	40x100 mm	No	32US	64	3:1	<2 %

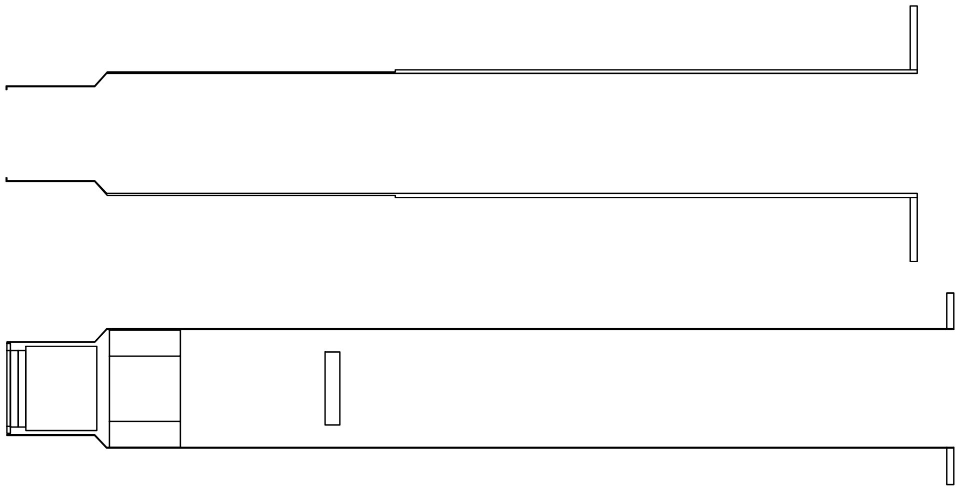

Figure 8: Support cylinder and the beam counter system

The primary considerations affecting the choice of tube are:

- For B4 we need to control the gain of individual elements since B4 is in the trigger. This consideration eliminates the multi-anode tubes for B4. For veto counters or the active degrader the principal concern is efficiency rather than resolution or cross-talk and multi-anode tubes are an option.

- Cost and the fact that we prefer extended-green tubes for the WLS fiber readout suggest the use of the R580-17 for B4.

- Space is very restricted at the upstream endplug: in fact it does not seem possible to fit 32 of the R580-17 tubes (as needed for the scheme with the triangular hodoscope elements) into the available space. This implies that if we want to increase the segmentation of B4 into 32 channels, for example to improve background rejection, then we must purchase a smaller tube.The green-selected H3165 would probably be best, at a cost of $13.5K for 32 channels. The layout could be as shown in Figure 9 and 10.

  Alternatively, we could go for scheme 2 with trapezoidal hodoscope elements and 24 tubes, in which case the R580-17 might just fit (Figures 11,12) if we move the Princeton Cerenkov counter upstream about 30 mm.

  Space considerations as well as cost suggest that the multi-anode tubes might be the best solution for the Ring veto counters, with 8 channels, and for the active degrader, which is expected to have more than 100 channels. Here the issues of crosstalk and the ability to adjust the gains of individual channels are of less concern. We have asked Hamamatsu for samples of the H6588 and H7546 for evaluation.

- If it is possible to efficiently connect WLS fiber to clear fiber at a bulkhead at the upstream endplug, then the phototubes could be removed from upstream region of the detector thus removing the space restriction. This possibility should be explored.

VI. Cost Estimate

Costs are in US $ and are estimated to the nearest one thousand dollars. Labour is costed at $40per hour. The total number of channels is assumed to be about 144. Two scenarios are considered:

A)The "cheap" scenario where we use the 24 tubes from Belle obtained via Princeton for B4, and the H6568 segmented anode (16 channels/tube) for the active degrader.

B)The "expensive" scenario where we buy H3164 (0.5", extended green) tubes for B4 and the active degrader. We would need 128 tubes plus spares. Because each tube needs HV supply and HV cable, these items are also more expensive.

These two scenarios pretty well bracket the range in cost for a meaningful upgrade to the existing beam instrumentation, and the cost of our reference design falls between them.

	Scenario A		Scenario B	
Item	Materials	Labour	Materials	Labour
Detector Construction	15K	20K	15K	20K
Phototubes	10K		57K	
HV supplies	3K		26K	
Cables	5K	2K	13K	4K
TDC (96 ch) x 1	8K		8K	
B4 Disc(16 ch) x 1	2K		2K	
B4 linear FI/FO (4 ch) x4	4K		4K	
Pulse shaping ($30 x 100)	3K		3K	
Total	50K	22K	128K	24K
Total(Can $)	72K	32K	186K	35K

VII. Reference design and work to be done

We could take scheme 1 i.e. 32 triangular elements read out by WLS fiber located at the centres of the fibers and 32 H3165 tubes, as the reference design. The layout would be as in Figure 6. The veto counters and active degrader would go to H6568-10 tubes and the UPV to two R580-17 tubes, one for the upper and one for the lower halves. The cost of this design would be about US$20K more than scenario A, i.e. a total of about US$92K

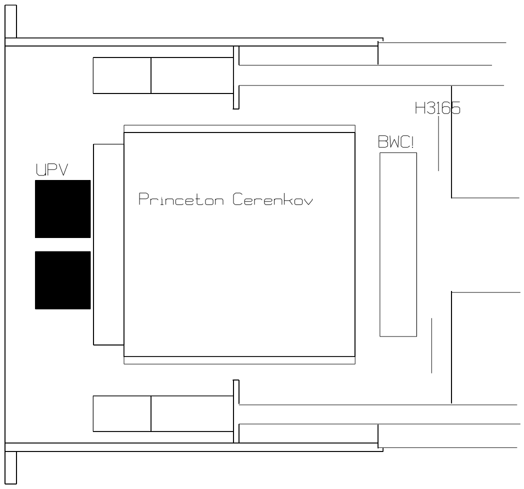

Figure 9: Possible layout with 32 H3165-10 tubes-side view

The job list for the immediate future is as follows:

- Determine whether WLS fiber readout is acceptable (should be at least as good as existing lucite lightguides, i.e. about 12 pe/MeV)
- Determine whether locating fiber in surface groove on scintillator instead of in centre is acceptable.
- Determine x-y position resolution obtainable.
- Decide whether B4 should be segmented into 32 channels or some smaller number (eg 24).
- Evaluate phototubes for suitability for WLS readout.
- Investigate fiber connection technology.
- Compare the number of photoelectrons in different options for the active degrader.

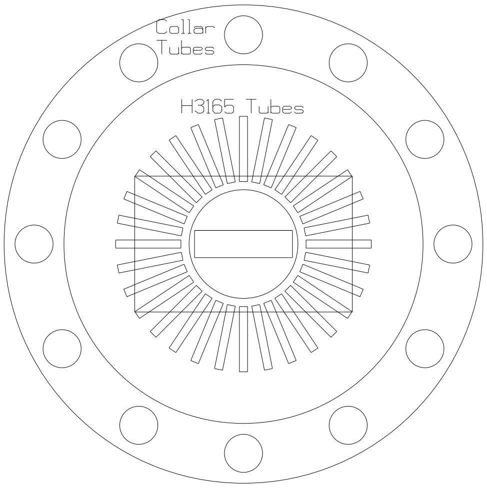

Figure 10: Possible layout with 32 H3165-10 tubes-beams-eye view

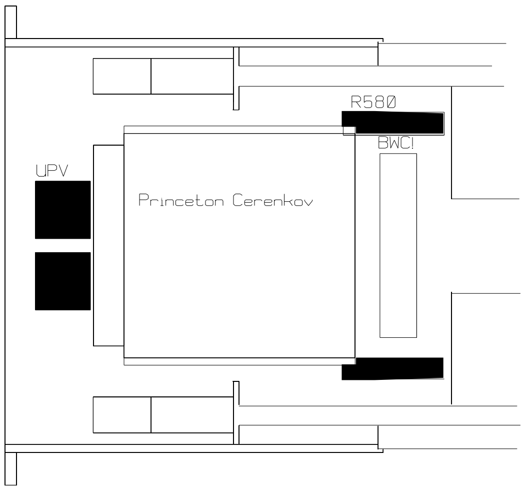

Figure 11: Possible layout with 24 R580-17 tubes-side view

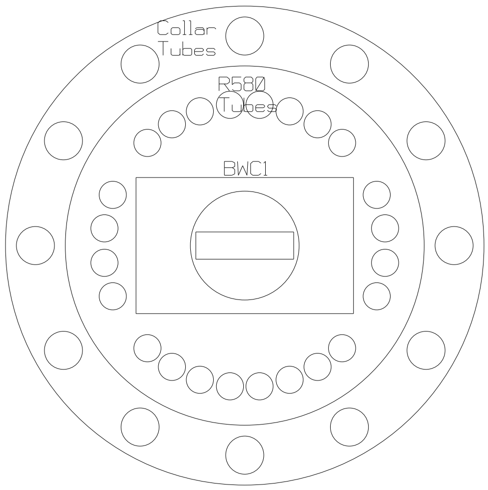

Figure 12: Possible layout with 24 R580-17 tubes-beams-eye view