Design Notes and Cost Breakdown for the BigBite Cerenkov Detector

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Contents

1 Design Goals

This document describes the Cerenkov detector that is to be constructed for the Hall A neutron d_2 experiment (E06-014). The inclusive nature of that experiment makes the addition of the Cerenkov counter for pion and proton rejection critical for the low energy bins. Monte Carlo and analysis of G_E^n suggest particle rates of (assuming a $500\,\mathrm{MeV}_{ee}$ threshold on the the BigBite shower detector):

- e^-: 2—5 kHz (signal)
- π^-: 90 kHz

- e^+: <1 kHz
- π^+: 90 kHz

- p: 50 kHz
- n: 50 kHz

The single-arm nature of E06-014 makes it necessary to remove the pion and proton backgrounds from the online trigger. This will be accomplished using the heavy gas Cerenkov detector described in this document.

The design goal for E06-014 is a conservative pion rejection factor of 500:1. When coupled with a 20:1 rejection ratio from the shower/preshower, a total rejection factor of 10^4 should be achievable.

It is understood that the Cerenkov detector will become part of the "standard" electron detector package for BigBite to the benefit of all subsequent experiments involving that spectrometer.

2 Mechanical Design

The Cerenkov detector will be installed into the gap between the front and back wire chambers in the BigBite electron detector stack. The current design has been developed to fit in this location with minimal changes to the existing frame. This fixes the maximum depth of the tank to 60 cm. The front profile has the dimensions of the sensitive region of the rear wire chamber in order to match the solid angle of the existing detector stack. Figure 1 shows a diagram with outer dimensions for the Cerenkov detector overlaid on an engineering drawing of the BigBite detector stack. Figure 2 shows an exploded CAD model of the Cerenkov design. Joints will be welded where possible to improve leak tightness. Each PMT will be inserted in its own cylinder until it butts up against the Winston cone (green). The base of the PMT will have a support ring (not shown) to increase its outer diameter to match the ID of the cylinder and to secure the PMT in place. Access to the PMTs (*i.e.* for replacement) may be accomplished though a circular flange at the rear of the cylinder. That flange will also provide feedthroughs for signal and HV. In this design the PMT would share the gas environment of the tank, protecting it from
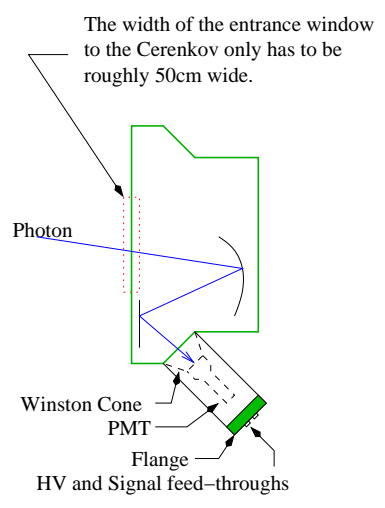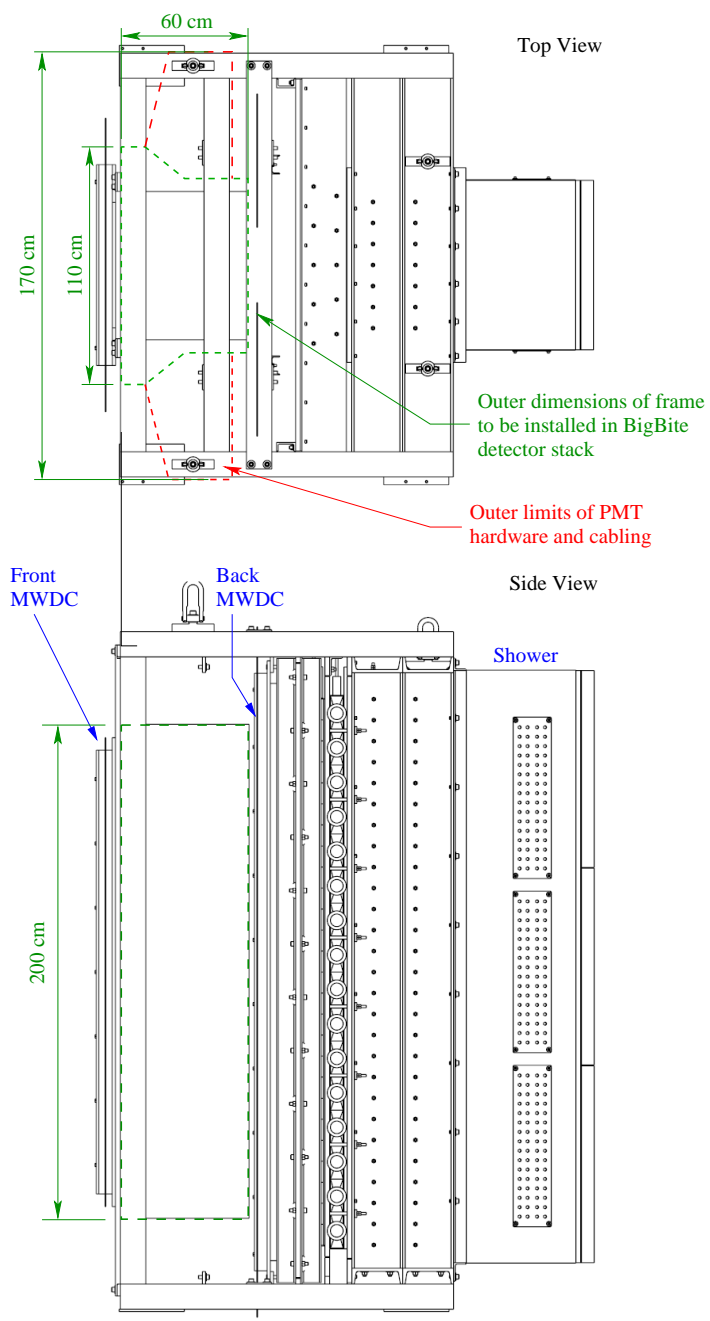
damage due to Helium exposure.

2.1 Optics

Cerenkov radiation emitted by relativistic particles will be collected in 20 spherical focusing mirrors tiled in a 10x2 arrangement at the back of the tank. Each of those primary mirrors focuses light into a 5" PMT by way of a flat secondary mirror located towards the front of the tank. This design allows the PMTs to be positioned away from the BigBite fringe field and provides a compact configuration that can be installed into the existing BigBite detector frame with minimal modifications. One of the challenges in designing the optics for this device was accommodating a side-effect of BigBite's exceptionally large momentum bite. The larger bend angle of low momentum particles results in their associated Cerenkov radiation being focused higher on the PMT surface than that of high-momentum particles.

When the ray-trace simulation was run using Monte Carlo'd trajectories for 0.6, 1.0, and 1.4 GeV/c electrons[1] produced in the target cell, tracked through the BigBite magnet (1.2 Tesla field), and into the detector stack we found the resulting Cerenkov light formed a vertical band roughly 7–8" tall in the plane of each PMT surface (Fig. 3). Simply increasing diameter of the PMT becomes untenable as background rates and PMT cost rise rapidly as the photocathode diameter increases. The simplest solution was to install a conical collar extending 3" out from the 5" PMT surface with a final diameter of 8". This simplified Winston cone improves the geometric ray collection efficiency of the associated PMT to > 95% and allows the Cerenkov sensitivity to remain relatively flat for particles with momentum >0.6 GeV/c. Note that length of the focal "band" at the PMT is largely driven by the low-energy (short-orbit) end of the momentum acceptance. For example, the separation between the mean focal point for the 1.0 and 1.4 GeV electrons is roughly 1/4–1/5 that of the separation between the 0.6 and 1.0 GeV focal points for a BigBite field of 1.2 T.

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[1]Those electron energies bound the kinematic region of interest to E06-014.

Top View

60 cm

170 cm

110 cm

Outer dimensions of frame
to be installed in BigBite
detector stack

Outer limits of PMT
hardware and cabling

Front
MWDC

Back
MWDC

Side View

Shower

200 cm

The width of the entrance window
to the Cerenkov only has to be
roughly 50cm wide.

Photon

Winston Cone
PMT
Flange
HV and Signal feed–throughs

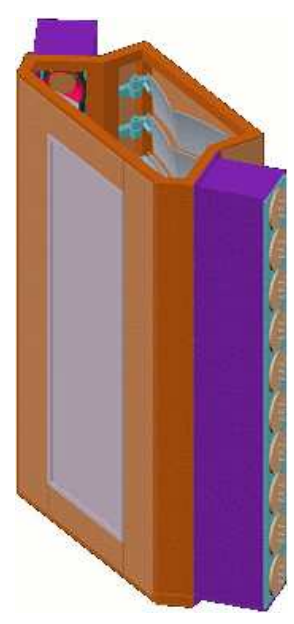NOTE: The drawings are not necessarily
to scale.

Figure 1: Conceptual diagram of the BigBite detector stack with an overlay of the Cerenkov detector's outer dimensions. The sketch on the upper right illustrates how the PMTs will be mounted to the tank. The rendering on the lower right is from a recent CAD model.
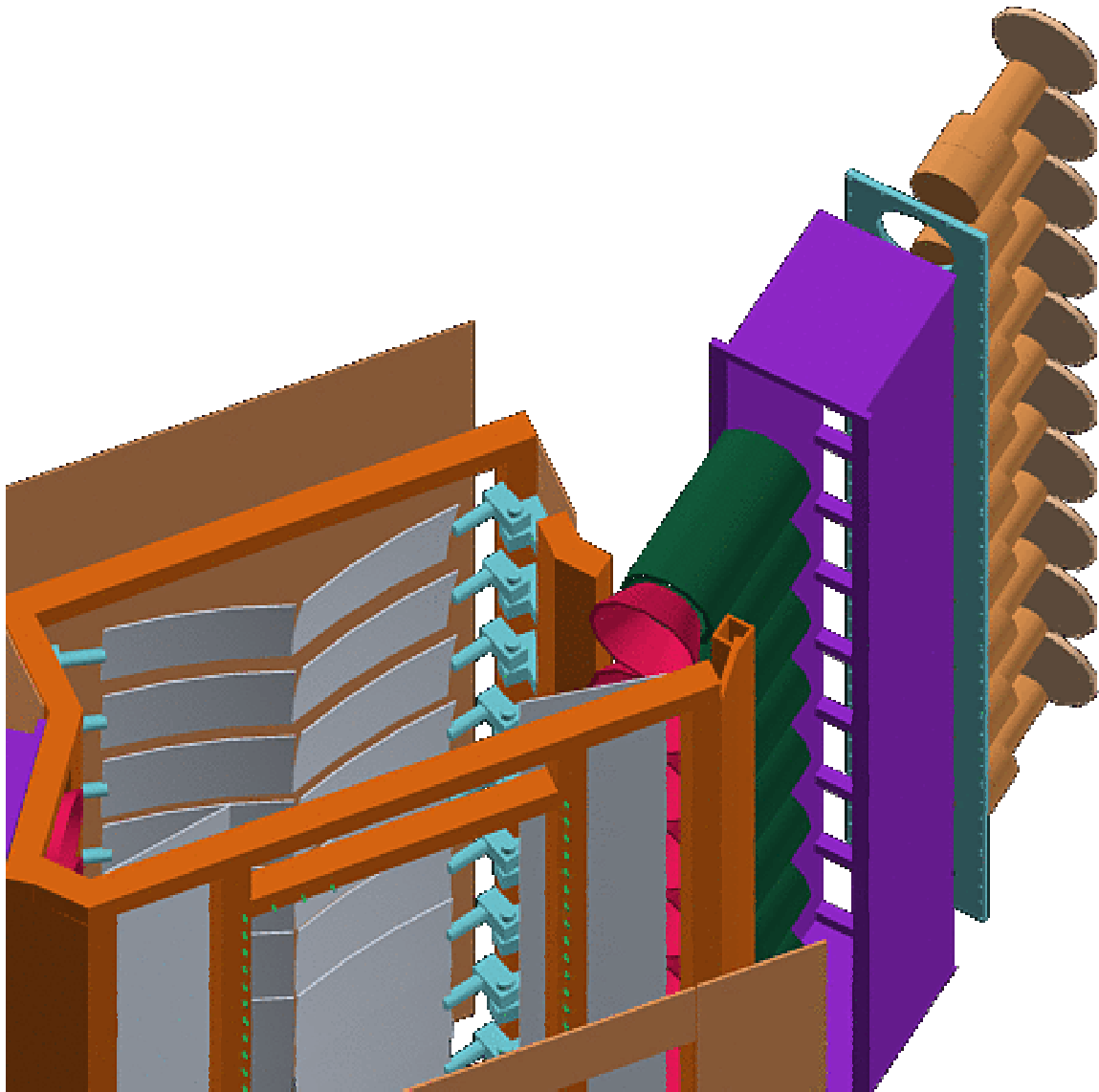
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Figure 2: Exploded diagram of the Cerenkov detector showing mirrors , PMTs, and simple Winston cones. The primary spherical mirrors are 31 cm wide by 21 cm tall with a radius of 116 cm (focal length: 58 cm). The flat secondary mirrors are 24 cm wide by 20 cm tall.
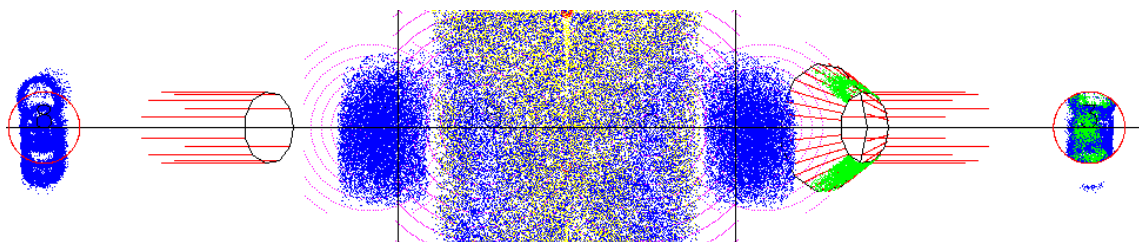
Figure 3: Front-view of the Cerenkov clipped to show two PMTs and their associated mirrors. Ray trace results showing the intersection points of the Cerenkov rays with the mirrors and PMTs are presented. The red circles on the right and left sides of the figure represent the PMTs. The imaged photons in the plane of the PMT face with (right side) and without (left side) the simplified Winston cones are shown in blue. The green dots on the right side indicate rays reflected off the Winston cone back onto the PMT. (Note: The curved 'banding' visible in the photon distribution on the main mirrors is purely an artifact of the rendering engine and is *not* present in the actual photon distribution.

3   Ray trace simulations

Figure 4 shows a ray-trace with the current configuration. Colors map to ray/object classifications as follows:

- yellow $\rightarrow$ initial photon emitted by an relativistic electron,

- blue $\rightarrow$ reflected photon,

- the red cylinders with the flared ends represent PMTs with the attached Winston cone.

The blue dots on the back view indicate points where rays reflect off a mirror. The yellow dots indicate the projected impact points of photon rays on the back-plane (*i.e.* if the mirrors were not present). Photons hits on the PMT photo-cathode are shown in the 10 small circles to the right and left of the back-view projection. Rays that hit the Winston cone and get reflected onto the PMT are shown as green dots. Rays that only involve the primary and secondary mirrors are colored blue. The green "spray" evident in the upper- and lower portions of the Winston cone (back-view) respectively correlate to rays from the lowest (0.6 GeV/c) and highest (1.4 GeV/c) momentum electrons involved in this simulation.
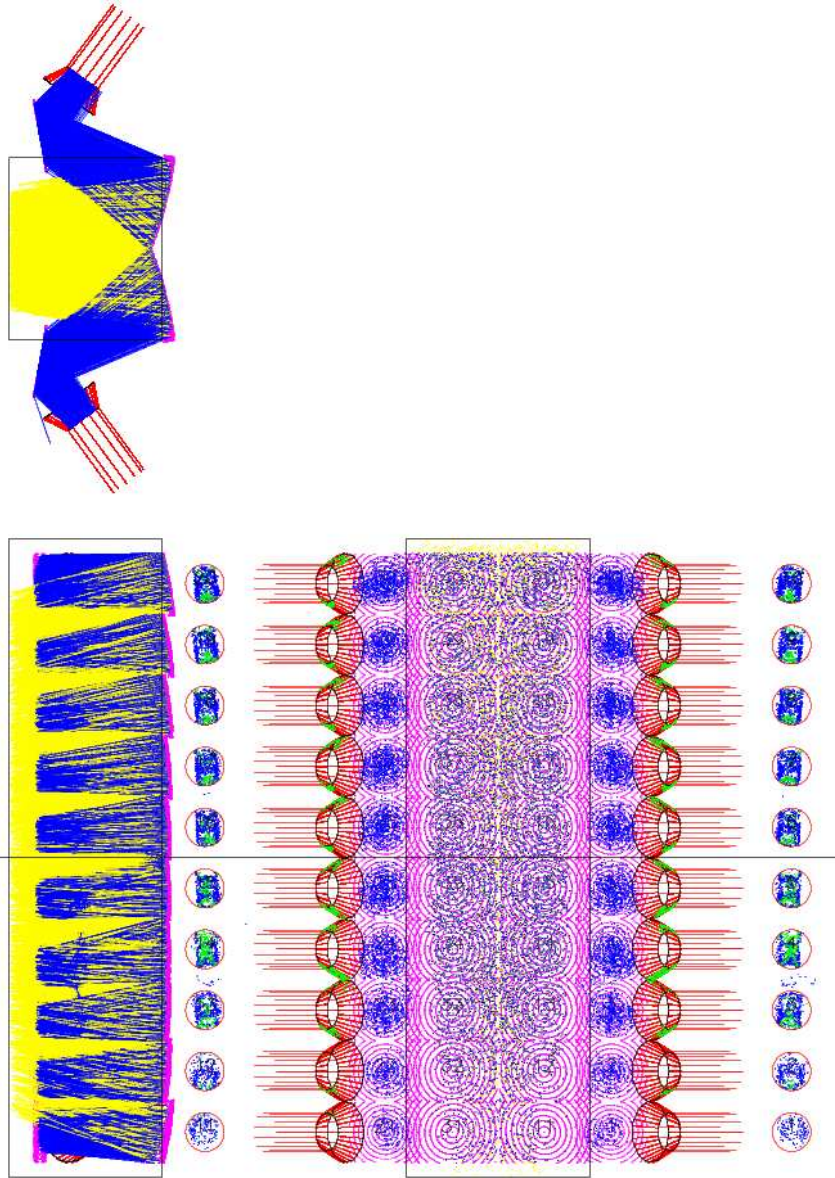
Figure 4: Ray trace of the Cerenkov optics for incident electrons with energies 0.6, 1.0, and 1.4 GeV. Incident electrons (not shown) emit Cerenkov photons (yellow) which are incident on the primary mirrors. The reflected rays are shown in blue. Photon hits on the PMT photo-cathode are shown in the 20 small circles to the right and left of the back-view projection. Rays that hit the Winston cone and get reflected onto the PMT are shown as green dots.

Table 1: Options for the radiator gas at 1 atm. The number of detected photo-electrons (p.e.'s) assumes a 40 cm track through the gas and includes the effects of PMT quantum efficiency, absorption losses in the radiator, and has been scaled by a factor of 0.7 to accommodate losses at the mirrors and PMT surface.

Gas	n	e^- thr. (MeV/c)	π thr. (MeV/c)	Detected p.e.'s	
				Burle 8854	Quartz PMT
N_2	1.0003	21	5926	3.2	5.4
CO_2	1.0004	17	4671	5.4	9
Freon12	1.0011	11	2984	11	16^1
C_4F_{10}	1.0015	9	2522	14	25^2
PMT Cost				$4–6k[3]	$2.5k[4]

[1]Freon12 absorbs UV light with $\lambda < 230$ nm reducing the advantage of the UV transparent quartz PMT.

[2]A fill is estimated to be 1800 liters priced at US$195/kg (1 kg liquid = 100 liters gas at STP) (Synquest Labs: Nov 20, 2006).

[3]Informal estimate from Photonis/Burle rep (Aug 2006). The 8854 model is undergoing a (re-)design phase.

[4]Quote for Photonis XP4508B (Aug 2006). A performance-equivalent Electron Tubes model 9823B was quoted at $5460. (Quartz window), and $3534. (UV glass model).

4 Anticipated Performance

Our preferred choice of Cerenkov radiator is C_4F_{10} at 1 atm. This material is non-flammable, non-toxic, odorless, and does not require special handling to remain a gas at room temperature. It is currently in use in Cerenkov devices in both Hall B and Hall C at Jefferson Lab. Its index of refraction is 1.0015 giving a pion threshold of 2.5 GeV/c. Assuming a 40 cm track length in the radiator, our calculations predicts a mean PMT response of 25 measured photo-electrons (p.e.'s) per electron with a Photonis XP4508 5" PMT (quartz-window). This estimate includes the PMT quantum efficiency, PMT window transparency, and is multiplied by a factor of 0.7 to accommodate a cumulative 10% loss at each mirror interface (Fig. 5).

When the same mathematical model was used to simulate the current Hall A short Cerenkov (similar design, Burle 8854 UV-glass PMTs, CO_2 radiator) we found the calculation agreed with the measured number of p.e.'s to within 20%.

Table 1 lists the characteristics of several gases along with an estimated p.e. yields for the commonly used 5" Burle 8854 PMT and for a Photonis XP4508 quartz-window PMT. Due to the heavy UV weighting of the Cerenkov spectrum, a quartz-window PMT has a significant advantage over a "UV glass" PMT like the Burle.

The high number of registered p.e.'s will allow an aggressive online threshold (3–4
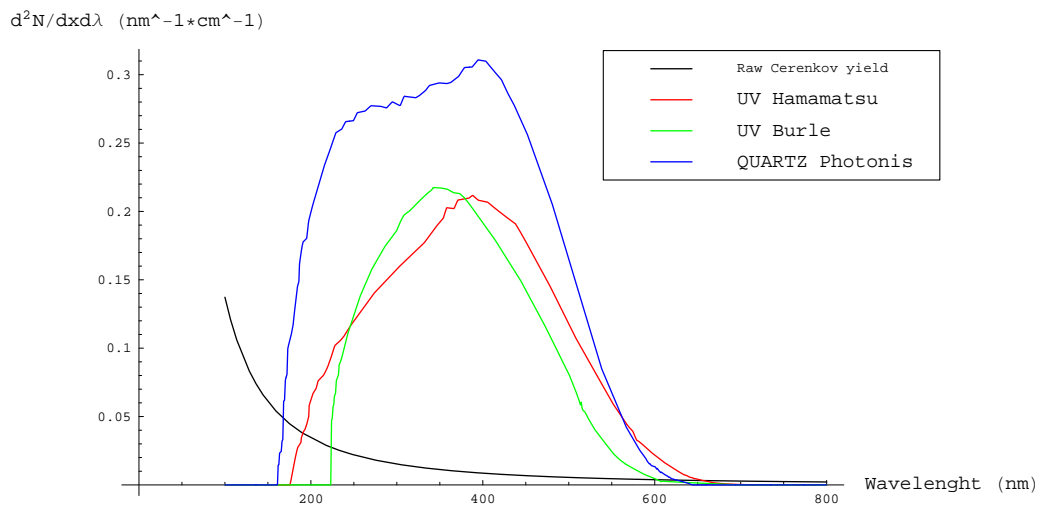
Figure 5: Differential photo-electron (p.e.) yield per wavelength (in nm) per unit distance in radiator (in cm). The three colored curves represent the quantum efficiencies (q.e.) of three characteristic 5" PMTs ((i.e.) p.e.'s per photon). The black curve is the raw Cerenkov differential photon yield. Integrating the product of the Cerenkov yield and the q.e. gives a first-order estimate of the PMT response to an electron track in the radiator.

p.e.'s) to be applied which should remove virtually all of the 1–2 p.e. background noise while triggering on $> 98\%$ of the electron tracks (with a healthy margin of error).

4.1 Magnetic Shielding for the PMTs

During G_E^n (E02-013) a bare (no scintillator) Photonis XP4318 3" PMT (quartz-window) was made light-tight and mounted on the sided of the BigBite detector stack at a location approximating the position of the PMTs in the current design (Fig. 6).

The BigBite fringe field at that location was measured to be ≈ 11 Gauss along the PMT axis. However, the remnant field inside the mu-metal shield (which happened to be for a Burle 8854) was < 0.02 Gauss. We also observed that the shielded PMT performance was independent of its alignment to the fringe field, confirming that a conventional mu-metal magnetic shield will be sufficient.

4.2 Background rates

Several measures of background rates in the 3" PMT were taken under production conditions with the pol. ^{3}He target during the latter portion of the G_E^n experiment. When the PMT was mounted on the upstream side of the BigBite detector stack (with no shielding from background radiation), single p.e. rates were observed to be on the order of $14 \, \text{kHz}/\mu\text{A}$. Shielding the PMT from the room with 1" of aluminum reduced the rate to roughly $7 \, \text{kHz}/\mu\text{A}$. Increasing the threshold to the 3 p.e. level dropped the rate to $1.8 \, \text{kHz}/\mu\text{A}$.

These data were used to estimate the rates for the d_2^n/Transversity experiments by

- scaling up by a geometric factor of $(5/3)^2$ to account for the additional "active area" of the 5" PMT,

- scaling up by an additional factor of two to account for the different kinematic conditions between the G_E^n test and the $\theta = 30°$ Transversity setup (which will have the highest backgrounds).[2]

This suggests we should anticipate background rates of roughly $10 \, \text{kHz}/\mu\text{A}$ ($40 \, \text{kHz}/\mu\text{A}$) for a threshold of ≥ 3 p.e. (≥ 1 p.e.). For a $10 \, \mu\text{A}$ beam this means a Cerenkov trigger rate of $\approx 100 \, kHz$ per PMT.

For a simple single-arm trigger consisting of the Cerenkov ANDed with a 10 kHz shower/preshower trigger (this rate was < 3 kHz for G_E^n) , this would imply a random

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[2]The factor of two is based on GEANT simulations of low-energy charged particle flux through the MWDCs for the Transversity configuration then normalized to the G_E^n data.
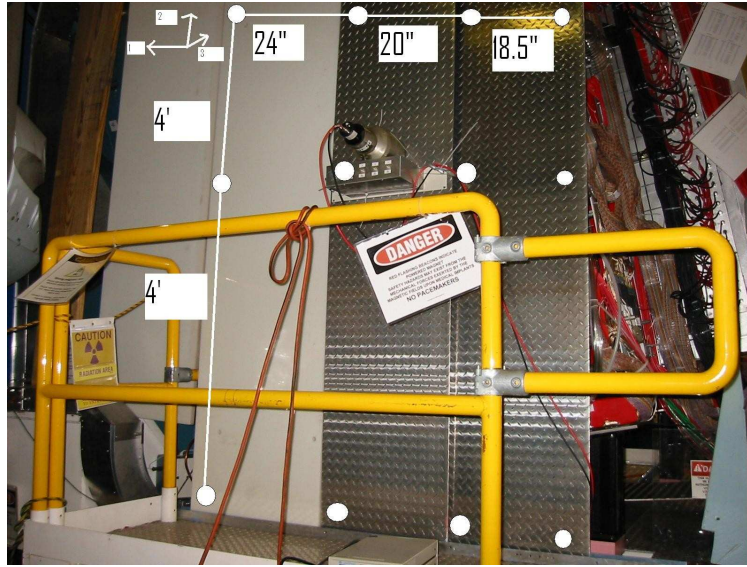
Units: Gs(Gauss)

1	2	3.7	2.5	1.3
2	0.04	10.3	2.8	1.75
3	21	9.4	2.68	1.4

1	-25	1.2	2.2	0.9
2	45	11	3.9	1.76
3	41	11.6	4.1	1.86

1	0.98	1.24	0.8	1.1
2	2.3	2.1	1.3	0.89
3	-2.4	0.9	1.2	0.8

Probe axis is indicated by (1,2,3) which reference a RH coord system with '1' pointing towards the target, parallel to the floor (see upper-left in photo).

Field INSIDE mu-metal shield for PMT strapped to shield plate was < 0.02 G for all directions. Probe was located 2" inside shield (see figure on lower-left).

5" mu-metal shield (originally for Burle 8854 PMT)

2"

3" Photonis PMT
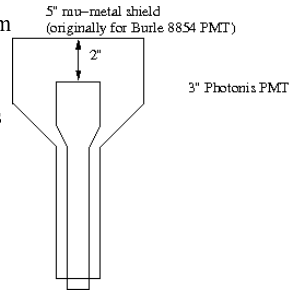
Figure 6: Photograph showing the location of the bare (no scintillator) PMT mounted on the upstream side of the BigBite detector stack during G_E^n. Magnetic field measurements were taken up against the shielding at the indicated points. The plastic (white) and Al panels were leaned up against the BigBite frame to shield the wire chambers from low energy background. The PMT being tested is tied to the make-shift shelf clamped to the Al plate in the center of the frame.

background trigger rate contribution of roughly 1000 Hz for a 100 ns coincidence window. This is a manageable worst-case scenario. We anticipate using a more sophisticated trigger that takes advantage of the geometric segmentation of the Cerenkov and the shower detectors. Such a segmented trigger would reduce the randoms rate by a factor of 5–10. These rates have been computed using conservative values and should be an upper bound. In any case, if the backgrounds are worse than are estimated here, then the rates in the MWDCs should be the limiting factor.

5   Gas Handling

Care will be taken in the design and construction of the Cerenkov frame to make sure that it is hermetically sealed. Prior to an experiment the tank will be purged with nitrogen to remove water vapor and oxygen. Then a C_4F_{10} bottle will be connected and the tank will be slowly filled with the upper vent open until C_4F_{10} can be visually observed spilling from the vent on the top of the tank. A single fill will require roughly 1800 liters of gas.

FermiLab experiment E907 used a C_4F_{10} gas Cerenkov with a similar design (3400 liter volume, PMTs located inside the gas tank). They used a pressure compensating gas system (Fig. 7) that maintained a slight overpressure in their tank. Excessive overpressure in the tank was relieved by venting into the atmosphere. Underpressures were dynamically corrected using an automated control valve coupled with a differential pressure meter monitoring the gauge pressure at the top of the tank. A separate differential pressure transducer was used to measure the weight of the C_4F_{10} column between the top and bottom of the tank. Their average gas consumption rate was roughly 28 liters/day (1 ft^3/day). This rate is consistent with calculations using average daily atmospheric pressure variation and the ideal gas law.

Managing the gas pressure in the BigBite tank will be accomplished using a similar design. If we assume an average 1 kPa daily fluctuation in atmospheric pressure then the associated gas consumption for an 1800 liter volume may be estimated to be roughly 18 liters/day. At US$1.95/liter that corresponds to $35/day.

A common storm can result in a pressure change at a rate of 2.5 kPa/hour while a 100 year storm can result in a drop of 8 kPa/hour. The associated flow rates of 900 to 2400 cm^3/minute need to be taken into account (assuming an STP volume of 1800 liters). Table 2 lists atmospheric pressure variations for the Newport News area.

The gas system described in Figure 7 has been reviewed by Jack Segal (Hall A) and George Jacobs (Hall B) and both agreed it looked reasonable. George Jacobs is the Hall B expert in charge of the CLAS C_4F_{10} Cerenkov system. Each agreed that the necessary components could be purchased for $3–5k, but felt that we could probably save 20–30%
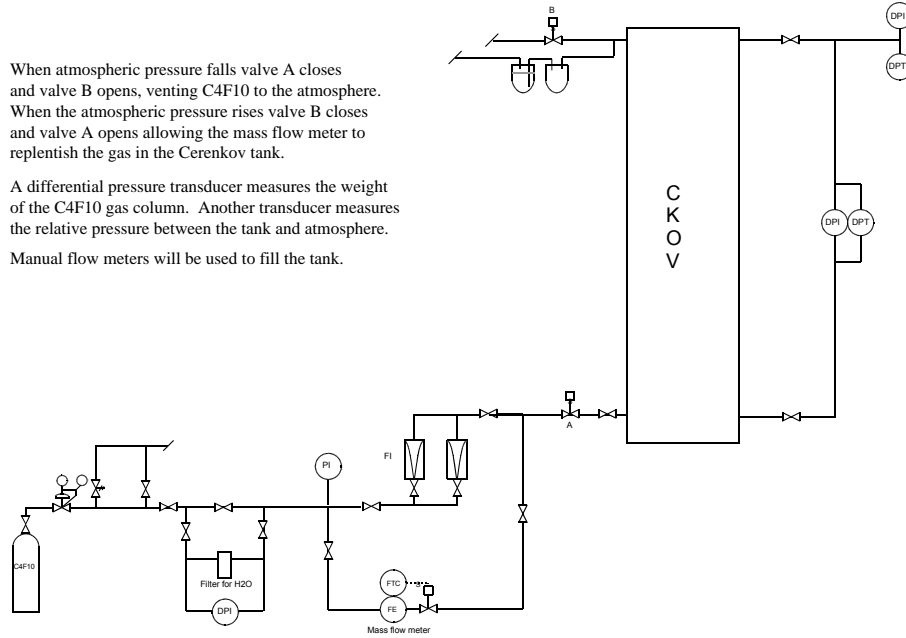
When atmospheric pressure falls valve A closes
and valve B opens, venting C4F10 to the atmosphere.
When the atmospheric pressure rises valve B closes
and valve A opens allowing the mass flow meter to
replentish the gas in the Cerenkov tank.

A differential pressure transducer measures the weight
of the C4F10 gas column. Another transducer measures
the relative pressure between the tank and atmosphere.

Manual flow meters will be used to fill the tank.

Figure 7: Gas system used for the FNAL E907 C_4F_{10} Cerenkov. An equivalent system is proposed for the BigBite Cerenkov.

Table 2: Atmospheric pressure variations for the Newport News area. The pressure load (if left uncompensated) is in units of kg-force per meter^2.

Period	Pressure variation	Pressure load
Average Daily	1 kPa (0.6 kPa typical)	102 kgf/m^2
Yearly (2005–6, peak-peak monthly scale)	3 kPa	306 kgf/m^2
Yearly (2005–6, maximum)	8 kPa	816 kgf/m^2

by reusing some equipment already on site. The gas system will be finalized (itemized parts list, prices, etc.) by the May 7 purchasing milestone.

Hall B relies on low-cost molecular sieves (13X) to remove water and oxygen contaminants from their C_4F_{10} and has not had a problem with gas purity or transparency. We've been warned that the 'very cheap' recycled C_4F_{10} supplies are commonly contaminated with pump oil. Synquest Labs (preferred vendor option) manufactures the gas in-house and measures 98.44% C_4F_{10} with impurities of 0.69% perfluoropropane, 0.02% Tetrafluoromethane, 0.03% perfluorocyclobutane, and 0.06% air. Following Hall B's example, we will run our gas through an equivalent sieve system to be safe.

5.1   Gas Recovery Issues

It would be possible to recover much of the C_4F_{10} vented during daily operation or in the event of a re-fill situation (*i.e.* opening the tank to work on a mirror or PMT). A basic system would include a one-way valves from the exhaust port connected to a compressor/refrigeration system to reduce the storage volume. Care would have to be taken to keep the back-pressure seen by the tank the same as the local atmosphere to avoid imposing over/underpressures on the Cerenkov tank.

The gas exhausted due to the system "breathing" under atmospheric pressure fluctuations should remain relatively pure and could be fed back into the system with minimal (no?) filtering. However, the total amount of gas involved in that mode of operation is relatively small, estimated at 18 liters/day (or $35/day based on the Nov. 06 quotation). It is the refill scenario (involving 1800 liters) that would benefit most from a recovery system. Unfortunately, since it is not feasible to design the Cerenkov tank to support vacuum, the gas recovered from a refill situation would be contaminated with the gas used to flush the C_4F_{10} (air or nitrogen).

The added complexity and associated costs make it unclear if this is will be a net gain for the Hall A system. Our anticipated daily loss rate if we just vent to atmosphere is on the same order as the leakage rate of the (much larger) Hall B system. The low boiling point of C_4F_{10} requires the use of specialty pumps with heated heads to prevent liquefaction on the compression stroke. Pump cycling can generate pressure spikes that can also induce short time scale liquefaction/boiling cycles that can confuse feedback loops.

The best option may be to develop a simpler manual system that could capture the gas if we had to empty the tank (1800 liters). The recaptured gas could then be delivered to Hall B for distillation and later reuse. This possibility will be investigated further.

5.2 Monitoring

Leakage of the C_4F_{10} during a run will readily show itself as a drop in the mean number of p.e.'s per electron from the (estimated) 25 to down to something approaching the 3–5 p.e.'s for nitrogen. Such a reduction in amplitude should appear in the upper PMTs first as the dense C_4F_{10}[3] will naturally concentrate at the bottom of the tank. The combination should provide a clear online signal of gas leakage before it becomes a problem. The weight of the gas column measured by a differential pressure transducer can be used as a rough measure of the gas content in the tank that does not require monitoring Cerenkov detection efficiencies. Alternate/additional methods of monitoring the gas purity in the tank are being investigated. In particular, a cheap ultrasonic sound velocity system could be used as a density monitor at the top of the tank.

6 Installation and Alignment

6.1 Alignment and Testing in Test-Lab

Accessibility issues strongly favor installing the mirrors and completing the alignment while the Cerenkov is on the floor. Mirror alignment will be accomplished by placing a small laser source (*i.e.* laser pointer) at an effective target position, and adjusting the primary and secondary mirrors to reflect the ray to the appropriate PMT. The alignment of each pair of primary and secondary mirrors will involve several iterations of this procedure. At least two effective target positions will be used, one associated with each end of the momentum range of interest (0.6—1.4,GeV/c) due to the different mean bend angles induced by the BigBite magnet. The existing GEANT Monte Carlo will be used to locate the effective target positions relative to the BigBite detector stack.

It would be wise to do a "shake-test" of the Cerenkov tank with (a subset of) the mirrors installed. The mirrors would be aligned, the tank would then be subjected to the level of vibration/shake that the final detector will experience during transport from Test Lab to the Hall and the craning of the detector stack into place on the magnet frame. The mirrors would then be checked for shifts in alignment. Care will be taken to minimize any risk to the equipment during this test. We do *not* want to damage any mirrors!

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[3]$C_4F_{10}$is roughly $8\times$ denser than air.

6.2 Installation

6.2.1 Test Lab

After alignment and testing the Cerenkov tank will be installed into the BigBite detector stack frame. At this point the BigBite detector stack frame will also be sitting on the floor with good access from all sides. I anticipate installing the Cerenkov tank through the front of the frame where it will be bolted to a horizontal support structure welded to the BigBite frame. If we believe that the Cerenkov mirror alignment is stable then the front wire chamber assembly may be mounted at this point.

Once the Cerenkov is installed in the stack and sealed it will be made leak tight by filling with CO_2 and using a gas sniffer (*i.e.* Matheson Leak Hunter 8065 or equiv.) to check fittings and joints. Leaks will be sealed with a removable sealing compound such as Apiezon Q (or equivalent). This procedure was used with good success with the FNAL E907 Cerenkov detector.

6.2.2 In the Hall

The completed BigBite detector stack would be transported to the Hall and then be craned into place on the BigBite magnet stand. The $10°$ change in the direction of the load when the detector stack is mounted on the magnet frame has been communicated to the engineer developing the Cerenkov drawings. When the detector stack is on the magnet frame we will have reasonable access on the sides (there is room for a stepladder, for example), and limited access from the front if the front MWDC package is removed. For example, it would be possible for someone to squeeze an arm between the magnet and frame to access the interior of the Cerenkov from the front side to adjust mirror alignment.

As mentioned earlier, it would be reassuring to double-check the mirror alignment with the detector package in its final location relative to the target. Time constraints may make this re-check impossible, amplifying the importance of "getting it right" in Test Lab.
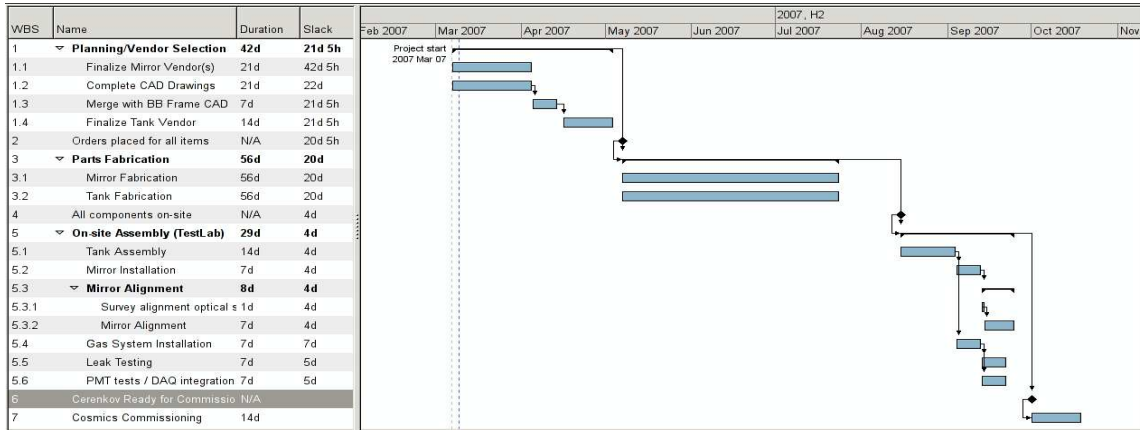
7 Timeline and Milestones

Figure 8: Timeline for Cerenkov construction and commissioning.

The engineering work and shop drawings are being produced by Ed Kaczanowicz (Temple University). Ed was the principle engineer and draftsman for the Hall C SANE Cerenkov. We will recycle the design of some of the smaller, more complicated components (such as the gimballed mirror mounts) in the BigBite design to reduce overhead where possible. The initial design work is complete and shop drawings are now being developed (Feb/2007).

We envision three major milestones for this project:

- **May 7, 2007** All long-lead items ordered.

- **Aug. 15, 2007** Parts delivered on-site for assembly.

- **Oct. 1, 2007** Cerenkov assembled, prelim. tests complete, full check-out with cosmics begins.

Figure 8 presents a Gantt chart with additional detail. The eight week construction windows for the mirrors and tank are based on existing quotes (mirrors) and experience with the SANE Cerenkov (tank), using the longer ETA if a range was offered. The schedule also incorporates several weeks of slack into the milestones to buffer delays.

Also note that the Fabrication and Assembly start times are keyed on the milestone dates introducing additional slack. For example, orders for the mirrors should go out ASAP (end of March/early April). The tank fabrication will also be parallelized where possible (*i.e.* fabrication of mirror mounts can begin early, even if work on integrating the tank into the BigBite CAD drawing is still underway).

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8 Cost Estimate

Table 3: Cost estimate for the BigBite gas Cerenkov.

Component	Units	Cost/unit	Sub-total	$ Source
Cerenkov frame/mounting hw/fittings			$30.0k	Temple+JLab
Primary Mirrors (spherical)[1]	20+2	$915	$20.1k	Temple
Secondary Mirrors (flat)[1]	20+2	$166	$ 3.7k	+ Rutgers
Pseudo-Winston Cones[2]	20+2	$750	$16.5k	+ JLab
PMT, base, μ-metal shield (**UV glass**)	20+2	$3000	—[3]	
Gas Handling System:			$3–5k	JLab
C_4F_{10} gas: (cost/fill[4])		$3500	—	Temple
Daily consumption		$35/day	—	JLab

[1]Feb. 2007 quote from Cosmo Optics, Middletown, NY, 845-343-9831.

[2]Feb. 2007 quote from Model Optics, Woodstock, NY, 845-679-7386. A quote on this part from Cosmo Optics is pending. See Section 8.2 for more detail.

[3]12 XP4508 PMTs + base were purchased by Hall A for use with the BigBite Cerenkov. Arrangements have been made to acquire 12–15 of the 5" quartz-face PMTs purchased for the G0 Cerenkov.

[4]A fill is estimated to be 1800 liters priced at US$195/kg (1 kg liquid = 100 liters gas at STP) (Synquest Labs: Nov 20, 2006).

There are three primary expenses: the PMTs, mirrors, and the tank.

8.1 PMTs

Twelve 5" XP4508 PMTs (w/ base) have already been purchased explicitly for use in the BigBite Cerenkov. We have an agreement with Hall C that 12–15 of the 5" quartz-window XP4572 PMTs from the G0 Cerenkov will be available for our use. As a result the PMTs (including bases and mu-metal shields) are covered.

8.2 Mirrors

The vendor with the best prices to-date has been Cosmo Optics. They have the additional advantage of having been the mirror vendor for a large Cerenkov at FermiLab some years ago. As of March 9, 2007 they have delivered quotes for the spherical and flat mirrors but were still working on identifying a subcontractor for the conical mirror blanks. I've been told to expect a quote on the remaining component by the end of March, 2007.

We have a second quote from Model Optics for all three mirror components. However, their prices for the spherical and flat mirrors have been considerably higher[4] than those of Cosmo Optics. For the purposes of the Cost breakdown in Table 3 I am using the Model Optics price for the conical mirrors. Based on history I anticipate saving several $k if Cosmo can provide the conical part.

If we ordered today (Mar. 9, 2007; and using both vendors) the mirrors would total $41k. By waiting 2 more weeks to allow the remaining vendors to finalize their quotes we should be able to save an additional $10k.

8.3 Tank

The engineering work and dimensioned shop drawings are being produced by Ed Kaczanow-icz (Temple University). Ed has already completed the equivalent work for the SANE Cerenkov for use in Hall C. Based on the experience with the recently completed SANE tank we have budgeted $30k for the BigBite Cerenkov tank.

8.4 Remaining Items

There are two remaining "low cost" items. The gas handling system and an initial capitol expense purchase of C_4F_{10} (at least one "fill"). These items should run roughly $10k.

8.5 Funding Sources

The biggest single funding source is Jefferson Lab, Hall A. They have generously committed $60k to the BigBite Cerenkov. Temple University and Rutgers University will cover the balance (roughly $20k, using the current estimate). The University of Kentucky (W. Korsch) has also expressed interest in contributing UK shop time to the project—this would save the collaboration an additional several $k. Purchase orders will be going out ASAP (within a few weeks for several items). Our milestone for having all long-lead items ordered is May 7, 2007.

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[4]$1.5\times$ higher for the spherical mirrors; $6\times$ higher for the flat mirrors!