Lucite Detector Overview

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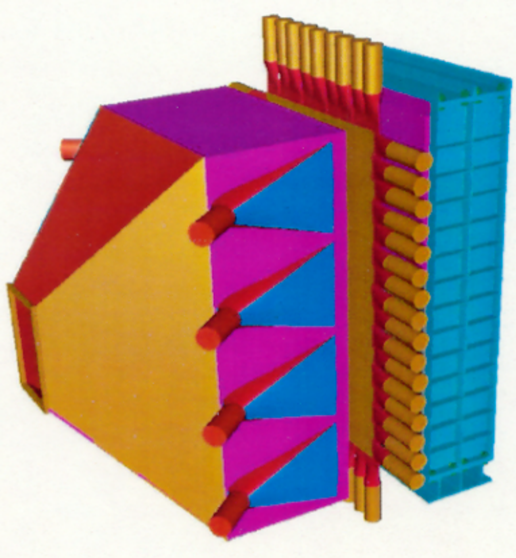
SANE collaboration meeting
March 26, 2004

- Requirements
- Specifications
- Reference Design
- Expected Performance
- Summary



List of Transparencies

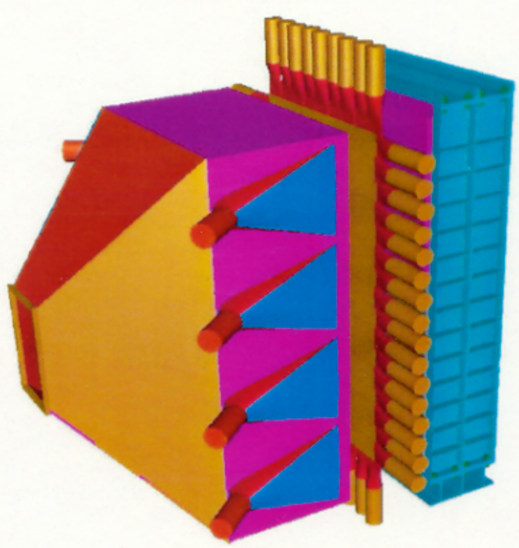
SANE Tracking Requirement

We must know whether a $GasCerenkov \bullet Calorimeter$ trigger tracks back to the target cell.

The high directionality of the Gas Cerenkov is almost sufficient for this task, but confounding factors are

- intrinsic Cerenkov PMT noise
- stray light in the Gas Cerenkov radiator
- Cerenkov noise induced by particles striking PMT's

Since the Gas Cerenkov performance, thresholds, and shielding are unknown, additional tracking would be a good idea. The high rate environment and the newness of the SANE concept also beg for added robustness.



As we will see, the right choice of tracking detector can benefit SANE in other important ways.

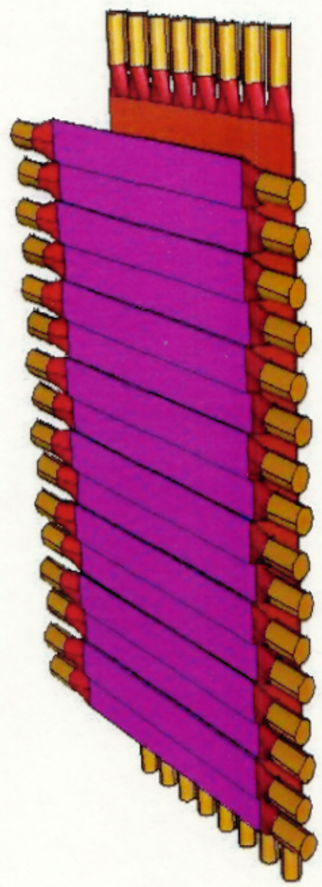
Tracking Detector Specifications

1. tracking resolution must be sufficient to distinguish between events from target cell and those from outside the scattering chamber
2. $> 99\%$ efficient for electrons
3. insensitive to backgrounds
4. low deadtime
5. minimal radiation damage
6. $< 10\%$ radiation length to avoid worsening calorimeter energy resolution
7. multiple scattering should not unduly affect the tracking resolution
8. $<$ \$100k cost unless external funding available

Magnetic Field!

Proposed Solution

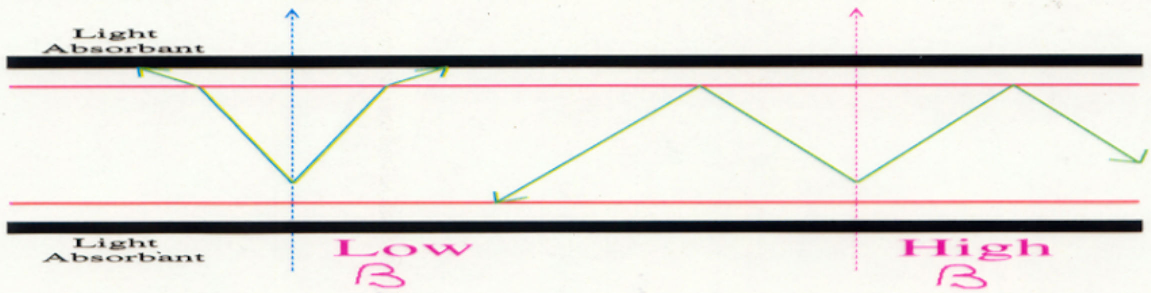
After rejecting most technologies as too sensitive to low energy backgrounds, we have chosen a high-index Cerenkov hodoscope operating in total internal reflection (TIR) mode.



But will there be enough photoelectrons?

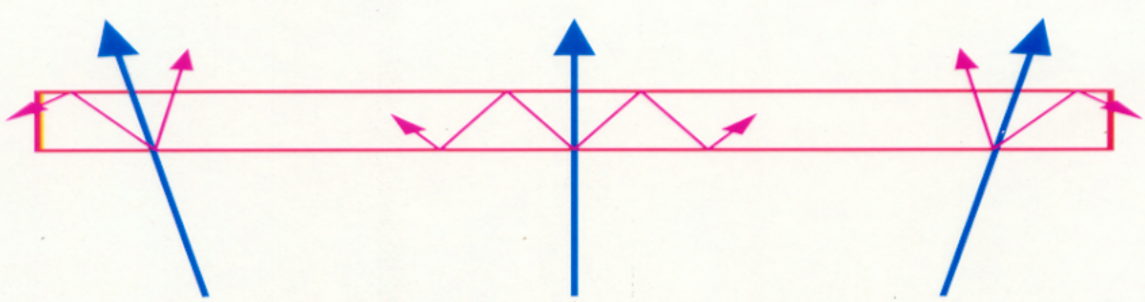
Cerenkov Light Trapping by TIR

For the special case of perpendicular incidence, Cèrenkov light can be trapped by Total Internal Reflection (TIR).



Refractive Index n	θ_{CER} (β=1) (deg)	θ_{TIR} (deg)	Non-Perpendicular Acceptance (deg)
1.35	42.2	47.7	
1.40	44.4	45.5	
1.45	46.3	43.6	2.8
1.50	48.1	41.8	6.4
1.55	49.8	40.1	9.6
1.60	51.3	38.6	12.6

For perpendicular incidence, Total internal reflection becomes possible near n = 1.425. With increasing n, light is more easily trapped.



Radiator Choice

Omitting materials with fatal flaws such as scintillation, too low an index, liquid phase, or inavailability in large sizes; and avoiding undesirable materials which are hygroscopic, or very brittle, here's most of what's left:

Material	Index of Refraction (nominal)	Maximum Alignment Tolerance
Calcium Fluoride	1.43	1.3°
Quartz (SiO_2)	1.47	4.3°
Pyrex	1.474	4.6°
Lucite	1.49	5.0°
Crown Glass	1.50-1.62	6.4-13.8°
Flint Glass	1.57-1.88	10.9-25.7°
Sapphire (Al_2O_3)	1.81	23.0°

The reference design assumed Lucite because of its low cost and straightforward procurement. The feasibility must be checked!

Quartz or high-index glass would yield more photoelectrons (for different reasons), but would add 100K-200K dollars to the radiator cost.

Other Benefits

There are two other benefits of a Cerenkov hodoscope:

- Because Lucite is sensitive to both e's and $\pi^{\pm}$, we can make an ancillary trigger to acquire a clean $\pi^{\pm}$ sample to measure the asymmetry of this background[1]:

$$\overline{GasCerenkov} \bullet LuciteCerenkov \bullet Calorimeter$$

- Because Lucite is insensitive to γ's, we an make an ancillary trigger to acquire a clean γ sample:

$$\overline{GasCerenkov} \bullet \overline{LuciteCerenkov} \bullet Calorimeter$$

  The single γ events can be used to help calibrate the $e^{+}e^{-}$ source term in the Monte Carlo, and the two-γ events can be used for $\pi^{0} \rightarrow \gamma+\gamma$ energy calibrations.[2]

I suspect the ability to distinguish between $\pi^{\pm}$ and γ should be a requirement (for the sake of the energy calibration) although it is not yet listed as such.

[1] In fact, the expected $\pi^{\pm}$ contamination is only 0.1%, so our estimates would have to be low by an order of magnitude for this to matter.

[2] The calorimeter rate is dominated by the γ's from π^{0} decay, but without additional PID there will be significant contamination from $\pi^{\pm}$.

1. Tracking Resolution

$$\sigma_{Lucite} = width/\sqrt{12}$$

$$\sigma_{Vertex} = \sigma_{Lucite}\frac{Z_{Cal}}{Z_{Cal} - Z_{Lucite}}$$

where $Z_{Cal} = 345$ cm.

Version	Z_{Lucite} (cm)	Width (cm)	σ_{Lucite} (cm)	σ_{Vertex} (cm)
Ref. Design	240.	10.	2.9	9.5
Closer to Tgt	190.			6.5
5 cm Pitch		5.	1.4	3.2

The Lucite array could be made smaller if it could be moved closer to the target. For example,

80 cm x 160 cm → 63 cm x 127 cm

Temple/Hampton Lucite Detector

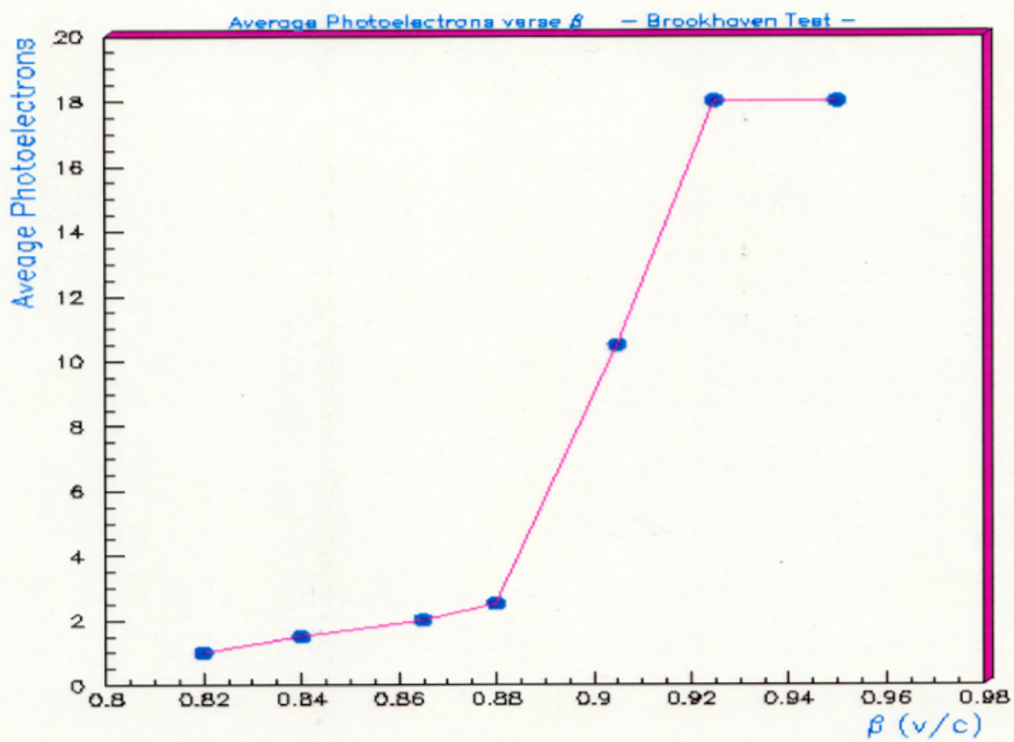
Material: UVT Lucite

Dimensions: 40 cm x 13.7 cm x 2.5 cm

Dark-wrapped to favor Total Internal Reflection

Tapered Lightguides and 3" PMT's

From an in-beam test at BNL, the number of photoelectrons was measured versus β for near-perpendicular incidence (Wendy Hinton's Ph.D. thesis, HU 2001):



summing the two ends, one finds about 18 pe's as $\beta \rightarrow 1$.

Louisian Tech Lucite Detector

Material: UVT??? Lucite

Dimensions: 65 cm x 15 cm x 1 cm

Reflectively wrapped to maximize light collection

Photoelectron yield is not yet available. However, important information on the attenuation length can be extracted from the LaTech measurements (Marija Novovic, ppt presentation, 7/25/03):

Using the central region (to minimize various biases),

x (cm)	Left Pulse Height (a.u.)	Right Pulse Height (a.u.)
-17	30.8	13.3
0	21.7	20.
+17	17.5	30.8

The function

$$PH = PH_0 e^{-x/\lambda}$$

is well fitted by $\lambda = 50$ cm, hence

we will use $\lambda = 50$ cm for our 1.25 cm sheet thickness.

Thicker sheets involve fewer reflections, so the attenuation length is longer (ie, better). For guidance, we use results from a glass Cerenkov detector of varying thicknesses[3],

suggesting $\lambda = 75$ cm for our 2.50 cm sheet thickness.

[3]C. Biino et al., NIM A295 (1990) 102-108.

A Normalized, Exponential Model

We assume the yield more than several diameters from the PMT's is given by an exponential model.

$$PE = PE_L + PE_R = N_0[e^{-(x+L/2)/\lambda} + e^{+(x-L/2)/\lambda}]$$

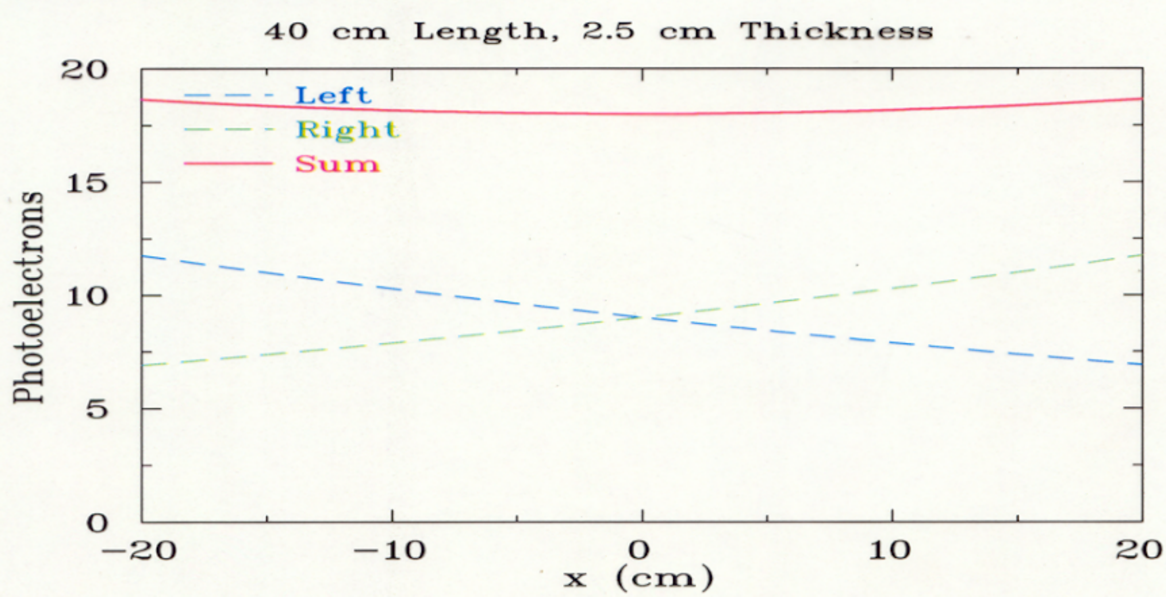
yielding a caternary (or cosh) distribution,

$$PE = N_0 e^{-L/2/\lambda}[e^{-x/\lambda} + e^{+x/\lambda}]$$

Using the Temple/HU data for the photoelectron number and and LaTech/Biini data for the attenuation length, N_0 = 11.8, hence

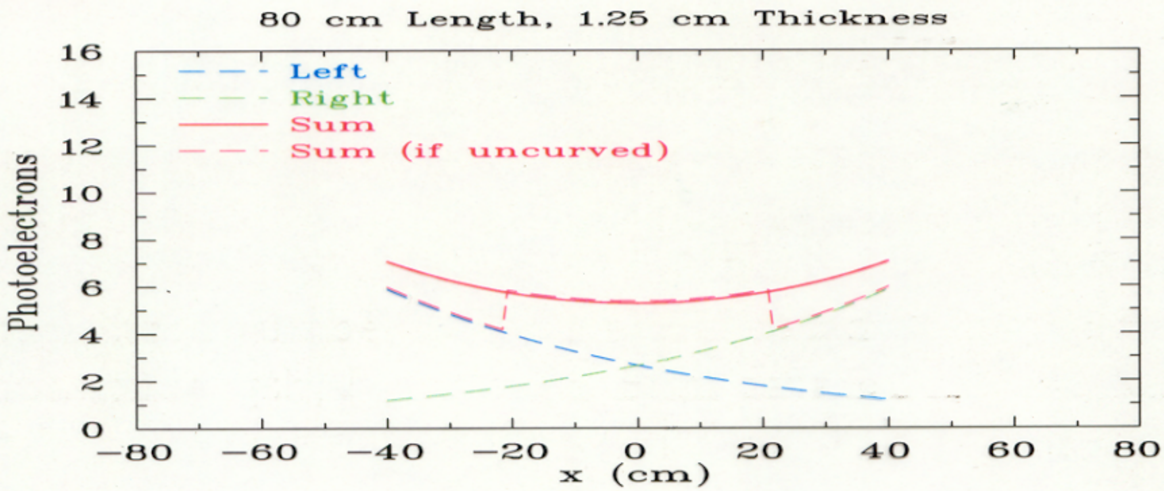
$$PE = 11.8(thickness/2.5cm)e^{-L/2/\lambda}[e^{-x/\lambda} + e^{+x/\lambda}]$$

which suggests that collection in the Temple/HU lucite detector was rather uniform

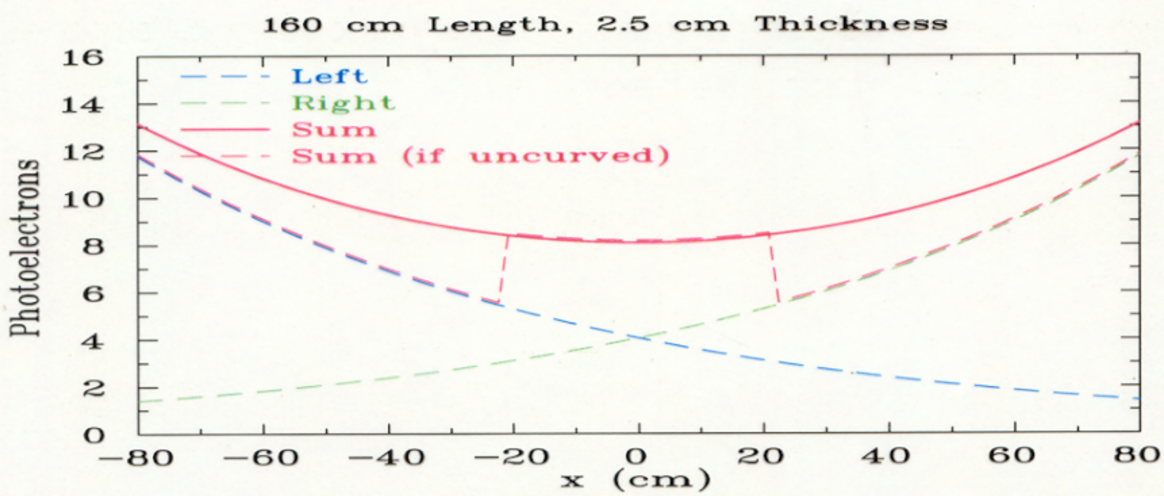


2. Projected Efficiency

Using the normalized, exponential model, and $\lambda = 50$ cm for 1 cm thickness



and $\lambda = 75$ cm for 2.5 cm thickness:



The expected efficiency for a mean of 7 pe's and a threshold of 0.5 pe's is about 99%. We're close. This could be achieved with a small increase in thickness.

3. Insensitivity to Backgrounds

Cerenkov $\beta_{threshold} = 1/\mathrm{n} = .671$
$\rightarrow$ can't see non-relativistic particles

Negligible scintillation
$\rightarrow$ can't see x-rays

$\rho t/\lambda_{nuclear} = (4.4g/cm^2)/(83g/cm^2) = 5.3\%$
$\rightarrow$ rarely sees relativistic neutrons

$\rho t/\lambda_{\gamma abs}\ (> 100\ \mathrm{MeV}) = (4.4g/cm^2)/(80g/cm^2) = 5.5\%$
$\rightarrow$ rarely sees high energy gammas

$\rho t/\lambda_{\gamma abs}\ (1\ \mathrm{MeV}) = (4.4g/cm^2)/(20g/cm^2) = 22\%$
$\rightarrow$ Watch! Needs more study.

4. Anticipated Rates and Deadtime

Total Lucite Rate $\simeq$ 250 KHz (proposal Table 5)

Table 5: List of predicted particle rates passing through the gas Čerenkov and in the calorimeter, as well as the overall BETA rates. All rates are in kHz. "Trig" indicates trigger rates for that detector and includes the online sensitivity of the detector in question. See text for further description.

		Gas Čerenkov			Calorimeter				BETA	
E	θ_N	e^-+e^+	$\pi^++\pi^-$	Trig	e^-+e^+	$\pi^++\pi^-$	π^0+p+n	Trig	True	Accd
4.8	-180	0.6	242	3.0	0.3	9.6	72.1	82.1	0.39	0.05
4.8	-80	1.0	223	3.2	0.3	10.4	70.6	81.3	0.39	0.05
6	-180	0.8	255	3.4	0.3	10.7	81.4	92.4	0.41	0.06
6	-80	1.2	236	3.6	0.3	11.5	79.8	91.6	0.39	0.07

Assuming a conservative 100 nsec timing window,

$$< N_{window} >= 250KHz * 100nsec = 0.025$$

Poisson statistics gives the expected occupancies as

0's	97.53%
1's	2.44%
2's	0.03%
3's	0.0003%

From this, I find that only $\simeq 1.2\%$ of events have multiple hits in the array, most of which are recoverable. Multiple hits per paddle are negligible.

The number of paddles is driven by tracking resolution requirements rather than the need to have a reasonable rate/paddle.

5. Radiation Damage

Assumptions

Thin radiator approximation (1" lucite → $0.07X_0$)
Energetic charged particle rates from proposal, Table 5
All charged particles are minimum ionizing
1000 hours beam on target

Calculations

$$Dose[MeV/g] = \frac{N_e * dE/dx}{A}$$

where

$$N_e = 250 \text{ KHz} * 1000 \text{ hours} * 3600 \text{ seconds/hour} = 9 \cdot 10^{11} \text{ electrons}$$

$$\text{A} \simeq 80 \text{ cm x } 160 \text{ cm} = 12{,}800 \text{ cm}^2$$

$$dE/dx = 2.4 \text{ MeV/(g/cm}^2)$$

hence

$$\text{Dose} = 1.7 \cdot 10^8 [MeV/g] * 1000g/kg * 100rads/(6.24 \cdot 10^{12} MeV/kg)$$

$$= 2.7 \text{ Rads}$$

This is a very small total dose, with a rate only about 80 times sea-level background. Oxygen diffusion and room temperature annealing will repair some of this damage in real time.

I don't believe there will be any visible effects for $\lambda > 400$ nm, but this can be checked by leaving a bar in Hall C for a few days.

6. Radiation Length and
7. Multiple Scattering

Radiation Length

Assuming a Lucite radiator with (nonoverlapping) thicknesses of 1.25 cm and 2.5 cm, then

$$X/X_0 = (1.25cm + 2.50cm)/34.4cm = 10.9\%$$

which is a bit larger than our specification of $< 10\%$.

+ paper lucite + $\frac{1}{2}$" Alum.

Multiple Scattering

$$\theta_{MS} = \frac{0.0136GeV}{\beta cP}\sqrt{X/X_0} = 4.5msr$$

for electrons of 1 GeV/c. This worsens vertex reconstruction by only 1 cm (rms). Added in quadrature, this becomes a negligible contribution.

8. Materials and "Visible" Costs

Item	Reference Design	5 cm Pitch
PMT's	48×$ 0.5k = $24k	96×$ 0.5k =$ 48k
Bars	24×$ 0.1k = $2.4k	48×$ 0.1k = $4.8k
Lightguides	48×$ 0.1k = $4.8k	96×$ 0.1k =$ 9.6k
Misc. (Glue, etc.)	Hall C Ops	Hall C Ops
X,Y Frames	$ 5k	$ 5k
Designer Time	Hall C Ops	Hall C Ops
Summer Students	$ 10k	$ 10k
Electronics	Borrow	Borrow
Total	$ 46.2k	$ 77.4k

The price looks too low, but that's because Lucite is cheap, we assumed the electronics are borrowed, and designer time is a hidden cost.

Summary

The Good News:

- A Cerenkov with a Lucite radiator appears close to meeting all our specifications for a tracking detector.
- It would allow us to obtain clean $\pi^{\pm}$ samples for use in background subtraction (if needed) or as a backup gain monitor using punch-throughs.
- It would allow us to acquire a clean γ sample for energy calibration or to determine an important source term for pair production.
- Cost and effort are reasonable.

The Bad News:

- Photoelectron estimates still need to be demonstrated in a prototype.

Comments:

- I'm not advocating the 5 cm pitch. However, I do advocate moving the Lucite detector closer to the target if the Gas Cerenkov shrinks wrt the proposal.
- Other radiator options require perhaps 100k Dollars additional funding (presumably non-Hall C).

What's Next?

- Get Lucite photoelectron yields from cosmic or in-beam tests.
- Verify that radiation damage to transmission in long bars is negligible for 1-10 Rads.
- Check with Gas Cerenkov group to see if Lucite can be moved closer to target. probably
- Simulate: Background from photons in 1-10 MeV range.
- Think: do bars need to be curved?
  Dinko mentioned slumping lucite was easy.
- Get cost estimate for non-curved, natural quartz bars from Scionix.

collaboration encouraged exploring quartz options:

straight bars - x,y hodoscopes

(Glen) curved bars - x hodoscopes w/ [redacted]
y info from TDC difference