Cherenkov Detector Simulation

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http://www.jlab.org/~gen/gluex/gas_cher_geom.html

Outline

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Introduction

Purpose of this talk

- Discuss the impact of Cherenkov detector(s) on PID
- Revisit the optical design

PID goal: $\pi^{\pm}$ vs $K^{\pm}$ separation

Events with strangeness: $\sim$ 1-5% of all events
$\sim$ 10% of non-strange BG $\Rightarrow$ $R \sim 1 - 5 \cdot 10^{-3}$ rejection factor

Examples: multiplicity high vs low, kaons slow vs fast:

1. $\gamma p \rightarrow nX^{+}(2.2) \rightarrow nK^{\circ}(890)\overline{K}^{\circ}(890)pi^{+} \rightarrow nK^{+}\pi^{-}K^{-}\pi^{+}\pi^{+}$
2. $\gamma p \rightarrow nX^{+}(2.2) \rightarrow nK^{+}\overline{K}^{\circ}(890) \rightarrow nK^{+}K^{-}\pi^{+}$

Components of the PID system

- dE/dx[a] in CDC for $\theta > 15 - 20^{\circ}$ and $P < 0.6$ GeV/c;
- *TOF* in BCAL, resolution $\sigma \approx 0.25$ ns;
- *TOF* in FTOF, resolution $\sigma \approx 0.08$ ns;
- *Cherenkov* detector, with a gas and/or aerogel radiators.

[a] neglected for this analysis

TOF coverage: MC simulation

- TOF cut with an offset of $1.3 \cdot \sigma$ to lose 5% of kaons
- "hits" - fraction of kaons hitting the detector
- "R" - rejection factor, column → fraction of "hits" for given R

		K^+					
		BCAL			FTOF		
#	final state	hits	$\overline{P}$ GeV	R < 0.1	hits	$\overline{P}$ GeV	R < 0.1
1	$nK^+K^-\pi^+\pi^+\pi^-$	22%	1.9	24%	48%	2.4	74%
2	$nK^+K^-\pi^+$	52%	2.6	8%	32%	5.0	5%

- Losses due to decays and interactions
- Process #1 - 40% identified, #2 - 6%

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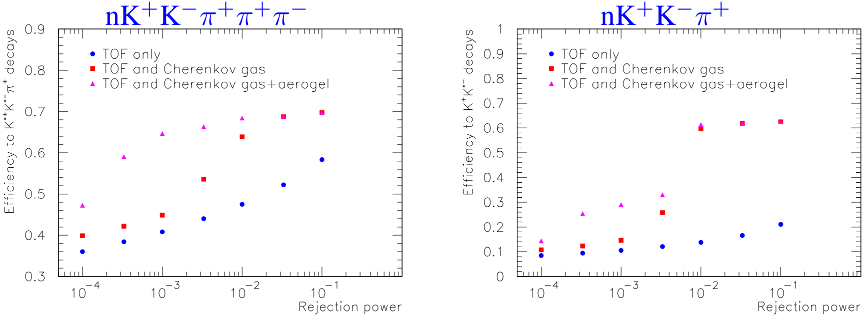
TOF and Cherenkov

- Gas Cherenkov with pion threshold ∼3 GeV/c
- Aerogel with kaon threshold ∼3 GeV/c
- Acceptance similar to FTOF



Conclusion:

- Gas Cherenkov is needed for processes like 2)
- Additional aerogel would help to achieve strong rejections

Initial design by RPI

- Some features inherited from the old LASS Cherenkov
- Location at the exit of the solenoid
- Gas radiator ∼2 m long: $C_4F_{10} \Rightarrow P_\pi > 2.65$ GeV/c
- Azimuthal segmentation
- PMT at $Z \sim 590$ cm, $R \sim 100 cm$, perpendicular to $\vec{B}$
- Two elliptical mirrors

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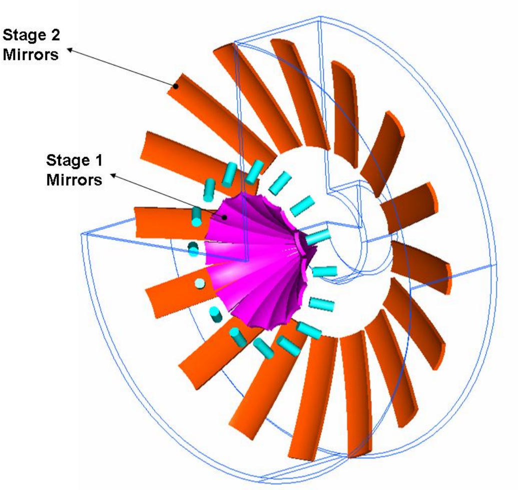
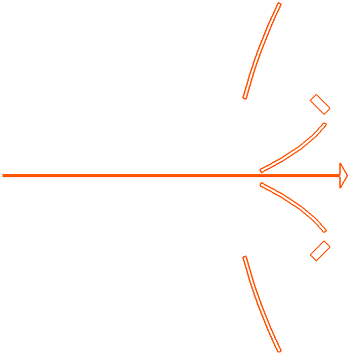
RPI Layout





Simulation with GEANT(3.21)

Goal : Optimize the optics and check various options

Standalone GEANT3.21 simulation

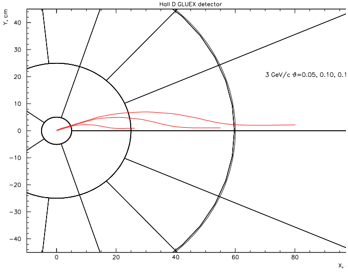
- Ellipsoidal shapes included
- General sizes, materials and the magnetic field - as in HDDS
- Geometry less detailed than in HDDS

Optics

Trajectories at $P > 3$ GeV/c in the Cherenkov

- Straight in R-projection
- Have very little azimuthal (φ) component
- Nearly point-like source

Threshold detector: minimize the size of the light spot



- Light spot size $D \approx \theta_{light} \times f$
- $\theta_{Cher} < 0.05 < \Delta\theta_{traj} \approx 0.08$
- Elliptical mirror - point-to-point
- Spherical mirror - Cherenkov-to-ring
- Elliptical mirror - sensible choice

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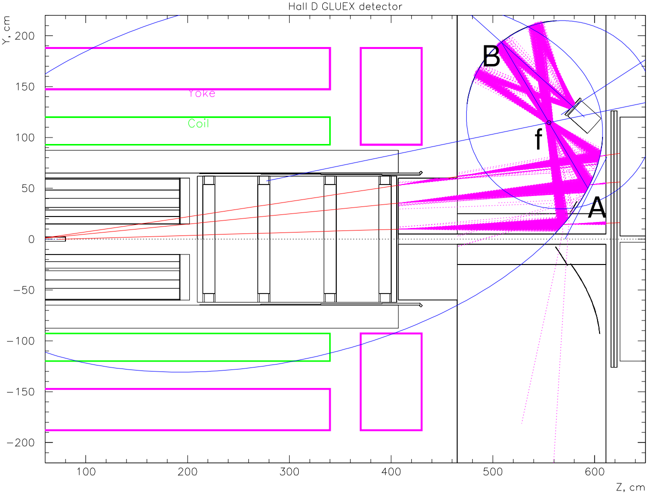
Optics Optimization



PMT $\perp \vec{B}$

$f1_a$ = target

$f1_b = f = f2_a$

$f2_b$ = PMT

$\theta = 0.1 \rightarrow$ A $\rightarrow$ B $\rightarrow$ PMT axis

spot size $\propto (f - A)$

A - fixed

B - nearly fixed

f - free, optimized

Small $f - A$ - small light spot, but large M2, crosstalks

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Results of Optimization

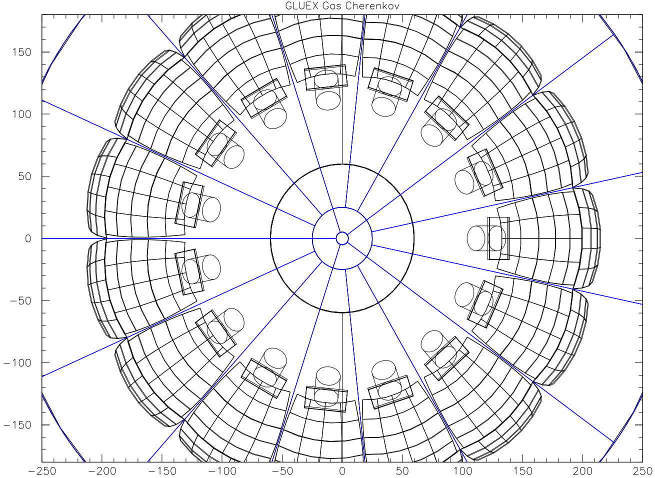
Two iterations have been done. The first one with small $f - A$ demonstrated a cross-talk between azimuthal sectors (M1→M2).

- $f - A$ as large as needed to avoid the cross-talk
- Angles of the mirrors defined by the box size and the median particle trajectory.
- Results: mirror M1 is strongly elliptical, M2 - nearly spherical
- Rotational symmetry of the ellipsoids

object	R_Z, cm	R_R, cm	Z_{cent}, cm	R_{cent}, cm	angle
mirror M1	335.2	179.1	277.5	57.3	11.6°
mirror M2	93.3	92.2	567.0	112.3	33.1°
PMT window			590.	120.	138.0°

Azimuthal segmentation

Avoid the light splitting between more than 2 M1.



sectors:

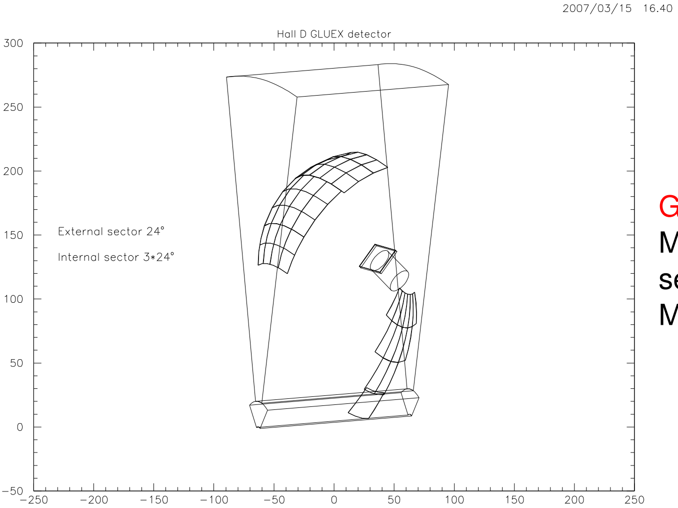
$R < 25$ cm - 5 $\times$ 72°

$R > 25$ cm - 15 $\times$ 24°

15 PMT: - 2-nd M1 ring

Every 3-rd PMT - 1-st M1 ring

One sector view



GEANT:
M1 larger than the sector, 'MANY' used
M2 - fits

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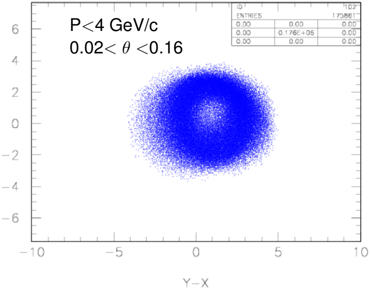
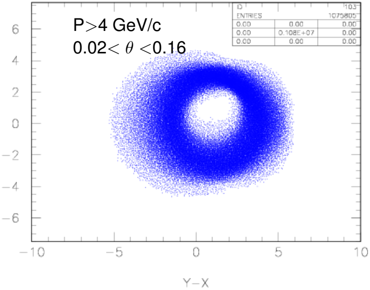
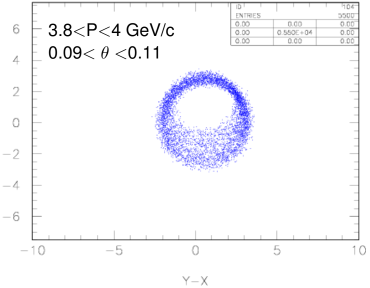
Light spot on the PMT







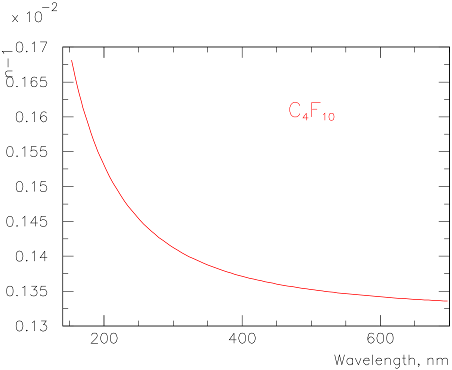
- Simulated for C_4F_{10}.
- PMT needed $D = 4 - 5$”
- No need for cones
- Rings are distorted by the elliptical mirrors

Choice of the Gas

We need as high refractive index as reasonable.

C_4F_{10} seems to be the best choice:

- The highest index for gases which do not need heating
- Second only to nitrogen in transparency in the UV region
- Needs recycling (cost), but widely used (CLAS, Hall C)



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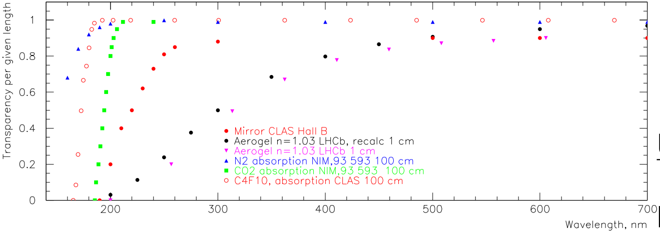
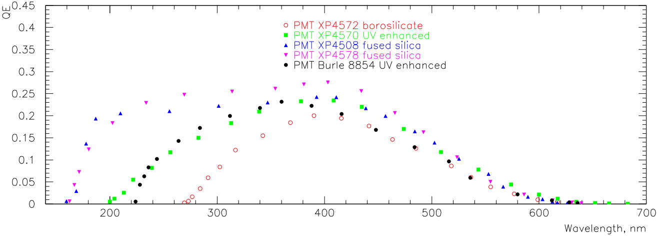
Light absorption in various elements





Used in simulation:

C_4F_{10} - $n(\lambda)$, $T(\lambda)$

Mirrors - $R(\lambda)$ CLAS

PMT - $QE(\lambda)$

Photonis data

norm/UV/quartz

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Cherenkov yield and its calibration

Conventional parametrization: $N_{pe} = N_{\circ} \cdot L(cm) \cdot sin^2\theta_{Cher}$
World experience for 1-reflection detectors:

- $N_{\circ} \sim$ 50 glass PMTs
- $N_{\circ} \sim$ 100 quartz PMTs

MC gives $N_{\circ}$ 90/160/240 for glass/UV-enhanced/quartz PMTs.

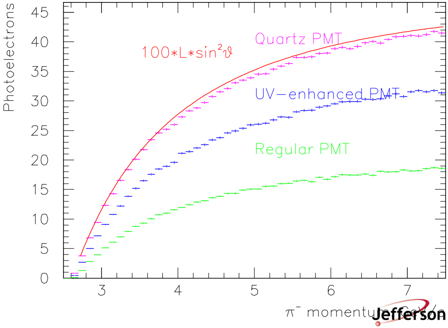
Calibration

MC: $N_{photons}$ $\times 0.5$
Quartz PMT: $N_{\circ} \approx 100$ - OK

Expected for GLUEX

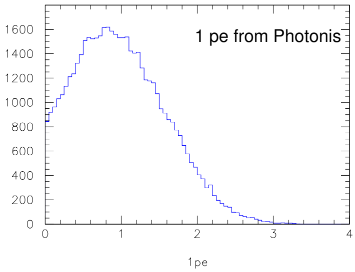
Quartz PMT: $N_{pe} \approx 50$ at $\gamma = 1$

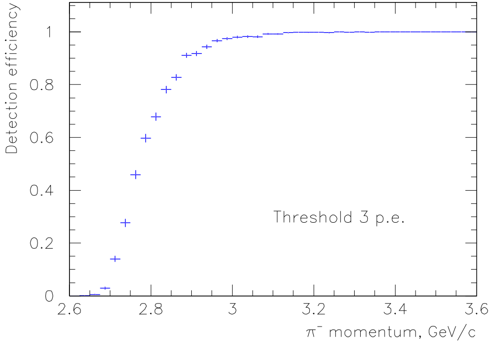
Comparable with CLAS results



Pion detection efficiency vs momentum

Light splitting : a pion gives light on average to 1.3 PMTs.
Assumption: no losses due to wrong assignment of signals
1-pe spectrum taken from Photonis
Threshold $\sim$ 3.pe





Backgrounds

There are various possible sources of background:

1. e^+e^- pairs from the photon beam: 50 kHz for 100 MHz beam, from the central ring of mirrors
2. Other accidentals: pion photoproduction - ?
3. Same event: $\pi^\circ \to \gamma\gamma$ conversion and showers: ?
4. Other ....

Summary

Gas Cherenkov Design

- The initial design has been studied and extended
- The mirrors have been optimized (35 in total)
- The choice of C_4F_{10} for the radiator is reasonable
- We may expect $N_{pe} \sim 50$ from 180 cm radiator, at γ=1
- We would need 15 quartz 4-5” PMTs
- Magnetic shielding of PMTs should be revisited

Gas Cherenkov Impact on PID

- Essential for PID of small multiplicity events with kaons
- An extension to a momentum range 2-3 GeV/c would help

Outlook

Further Studies

- Magnetic shielding issues
- Optics for PMTs parallel to $\vec{B}$ in a lower field area
- Optics for a RICH similar to HERMES
- Consider a standalone aerogel $n = 1.02$ diffusive detector
- Consider a combined gas+aerogel detector (HERMES)