A DIRC for Gluex ?

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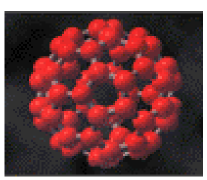
- *The BaBar DIRC*
- *Adaptation to Gluex*


The University of Tennessee
Department of
Physics & Astronomy

Why PID in the BaBar Experiment ?

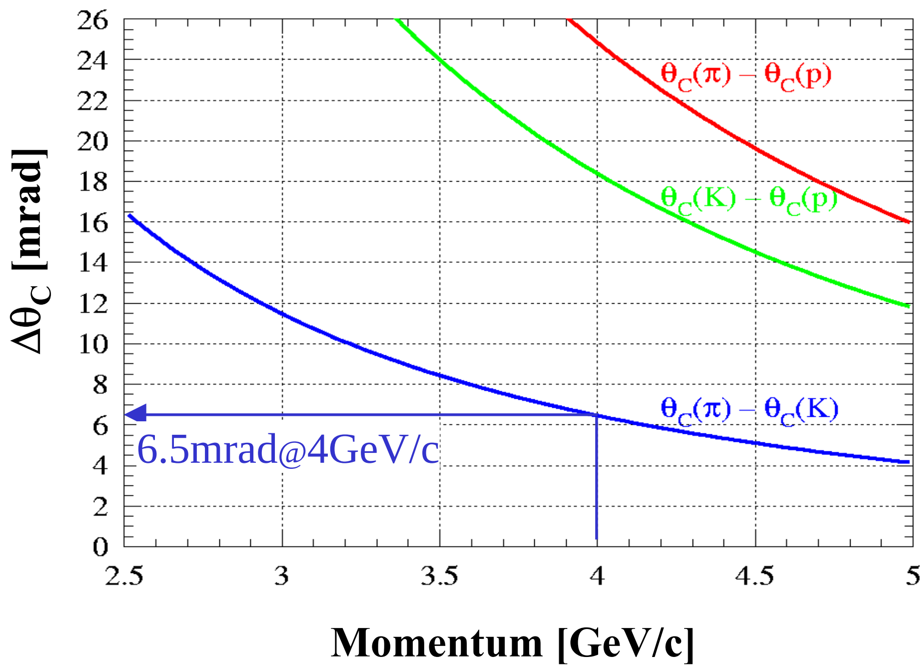
BaBar measures B-meson decays in the reaction:

$$e^+e^- \rightarrow \Upsilon(4s) \xrightarrow{>96\%} \{ B\,\bar{B} \} \rightarrow \pi,\ K,\ p,\ e,\ \mu$$

mass(B) ≈ 5.279 GeV/c^2,
lifetime ≈ 1.5 ps

E = 10.580 GeV

e.g. separate channels $B/\bar{B} \rightarrow \pi^+\pi^-$, $\pi^\pm K^\mp$ $O \approx 10^{-5}$, *momentum < 4.3 GeV/c*

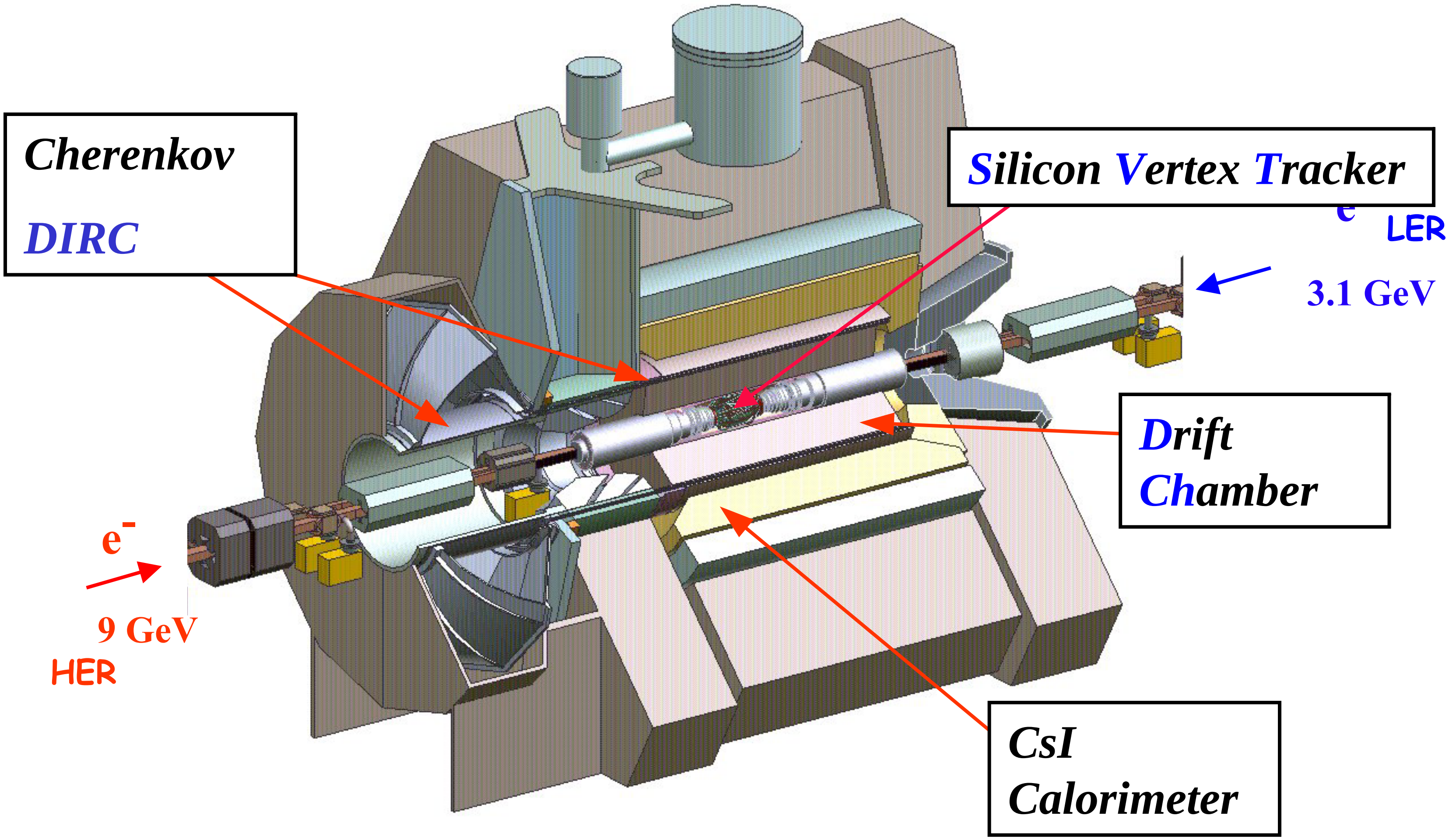


π/K Separation
in Cherenkov angle
in quartz
$\Delta\theta_C$ = 6.5mrad
at 4 GeV/c
⇒ 3σ need 2.2 mrad
resolution

$$\sigma(\theta_C) = \sqrt{\sigma(\theta_{track})^2 + \sigma(\theta_{C,\gamma})^2/N_\gamma}$$

BaBar

BaBar detector



Requirements for the DIRC

- continue π/K separation of SVT/DCH (p>700 MeV/c),
- small radial dimensions because of
  momentum cutoff of B-field (1.5 T),
  cost of calorimeter,
  distortion of photon detection down to 20 MeV.
- radiation robustness: expect 10 krad within 10 years,
- insensitive to background from accelerator/physics,
- fast device on BaBar scale (event duration <1 μs),
- easy access to components.

The Babar - DIRC Collaboration

D ETECTION OF
I NTERNALLY
R EFLECTED
C HERENKOV LIGHT

Novel **R**ing **I**maging **Ch**erenkov detector based on total internal reflection of Cherenkov light.

It is used for the first time in BABAR.

The BABAR-DIRC Collaboration

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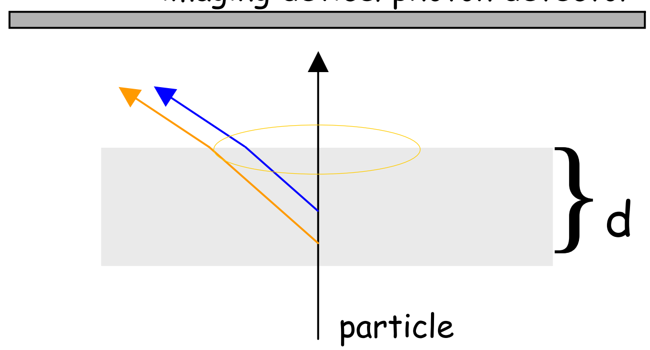
The Cherenkov Detector

$$\cos\theta_C(\lambda) = \frac{1}{\beta\, n(\lambda)}$$

RICH detector

Resolution:

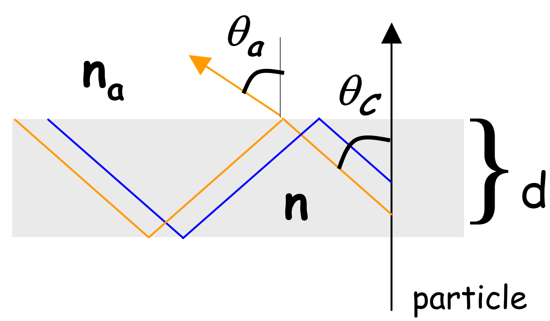
- geometrical (d) /imaging
- color smearing



Total internal reflection (DIRC)

$$\theta_a > 90^o$$

$$n \sin\theta_C = n_a \quad \text{[Snell]}$$



for $\beta \approx 1$ from Cherenkov cone:

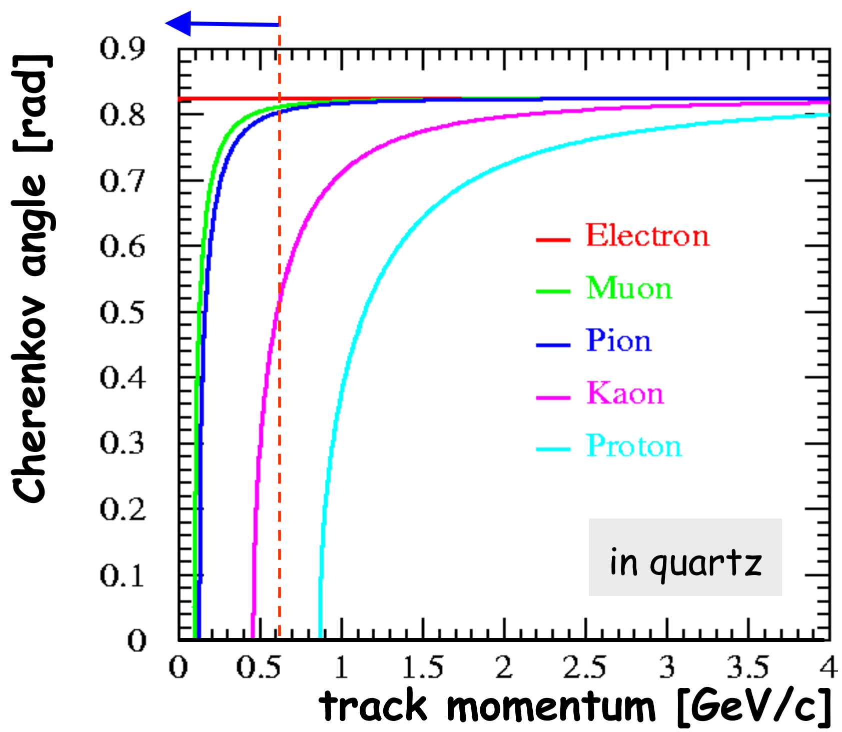
$$n = \sqrt{n_a^2 + 1}$$

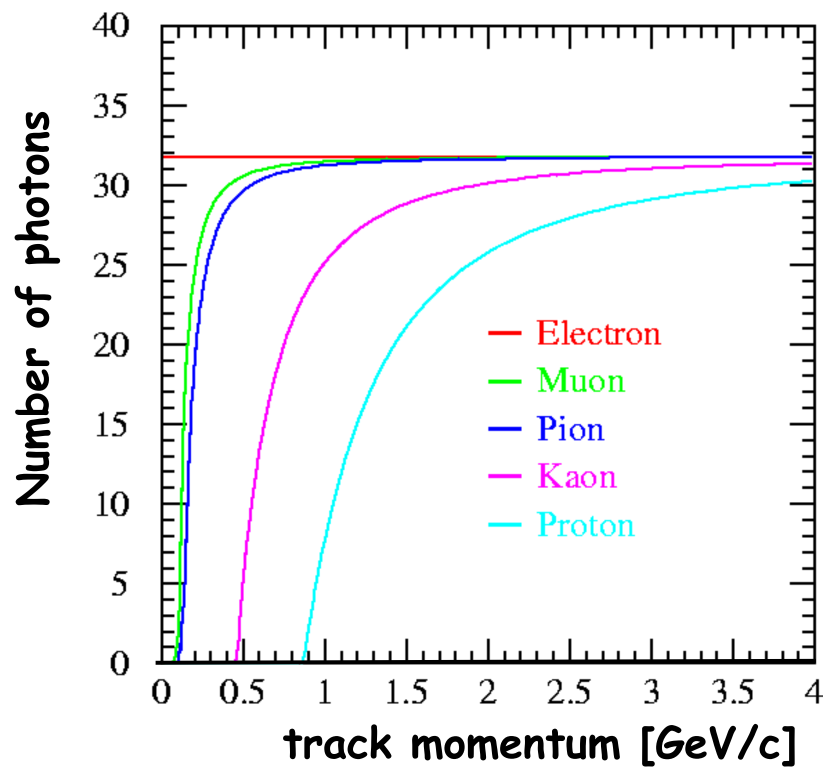
$$n_a = 1 \Rightarrow n = \sqrt{2} \equiv \text{quartz}$$

The Cherenkov Detector

⇒ identify particle by measuring θ_c , if its momentum p is known :

identify particle also by measuring the number of photons





$\beta = p/E$, $E = \sqrt{p^2 + m^2}$

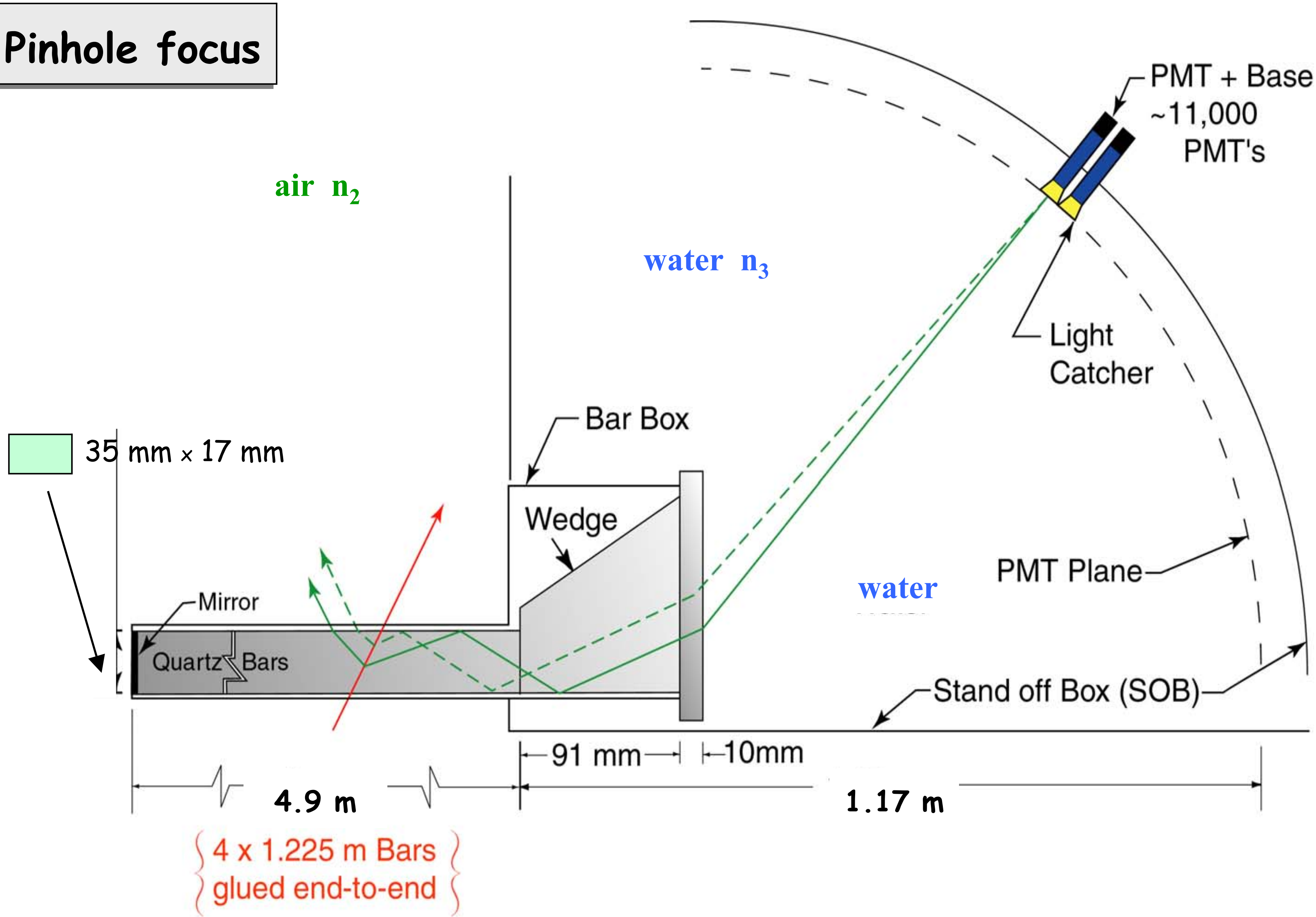
m = mass of particle

$N \propto L \sin^2 \theta_C$

L = pathlength in medium

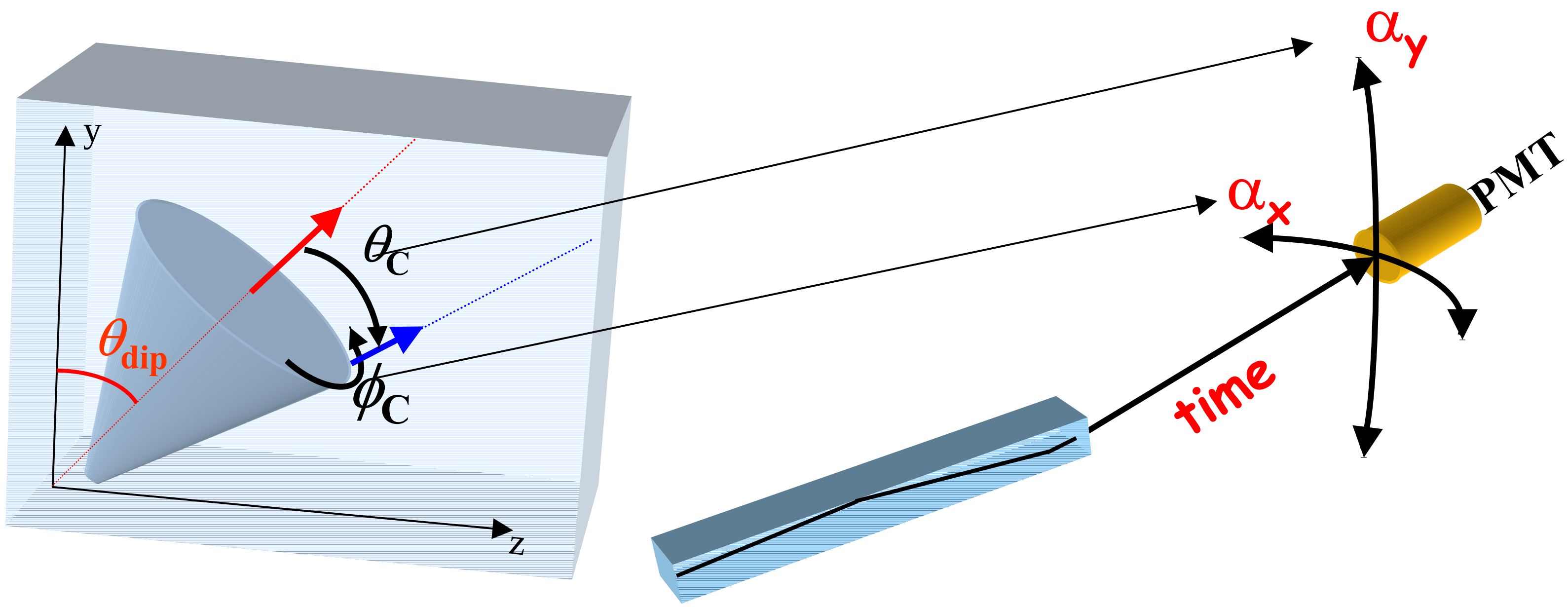
The Principle

Pinhole focus

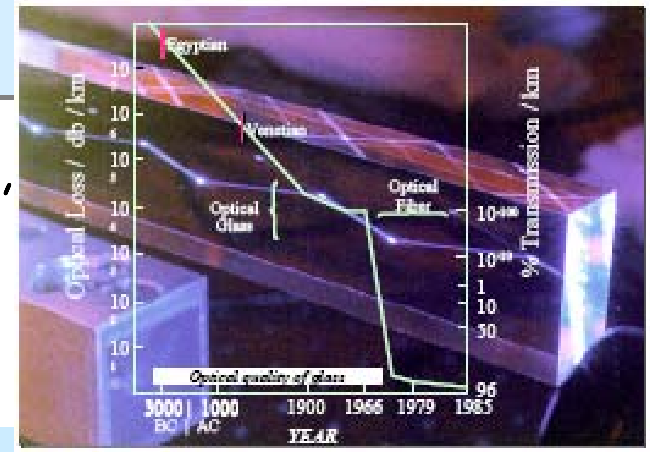


The Principle

3D - device



The Bar Quality



synthetic fused silica (amorphous silicon dioxide), cutting, grinding and polishing in several steps.

Efficiency loss per component less than 20%.

Typical photon: λ = 400 nm,
path length in quartz = 6 – 20 m,
bounces on surface: = ~ 200 – 300

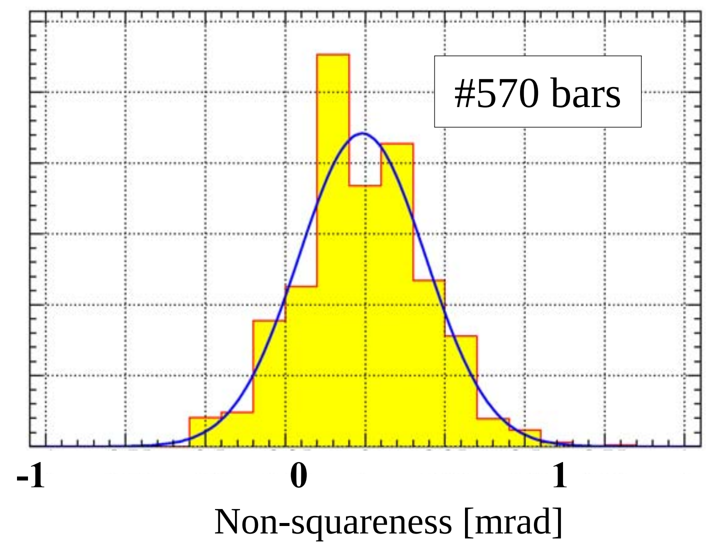
- bulk absorption (Raleigh scattering; attenuation length $\propto \lambda^4$)
  light transmission @ 442 nm : (99.9 ± 0.1)%/m
- surface scattering (attenuation length $\propto$ roughness r^{-2})
  reflection : (99.96 + 0.01)%/bounce
- Mirror
  reflection : ~ 92%
- Radiation hardness
  rated lifetime dose > 100krad (10 krad in 10 years)

The Bar Quality

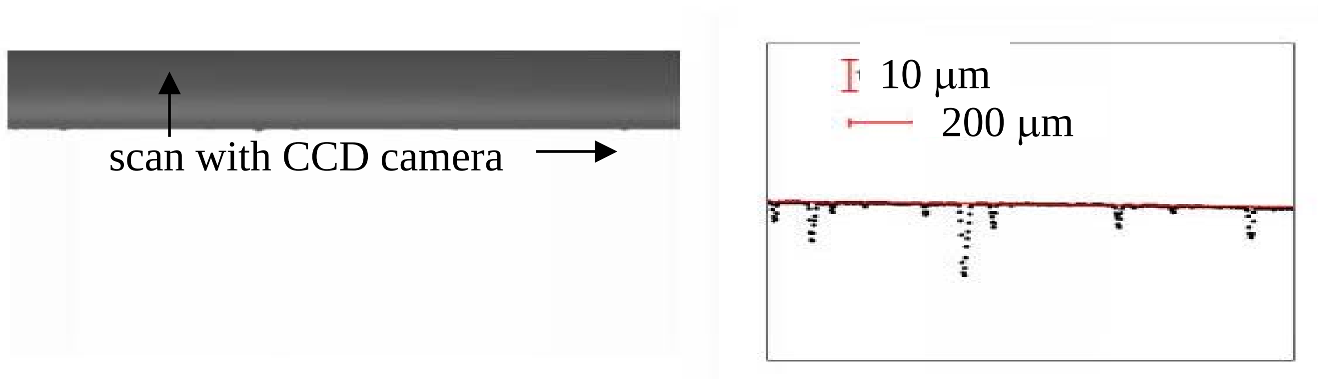
- Non-squareness on bar crosssection:

4 angle defining the bar cross section;

$\sigma \sim$ **0.2 mrad**

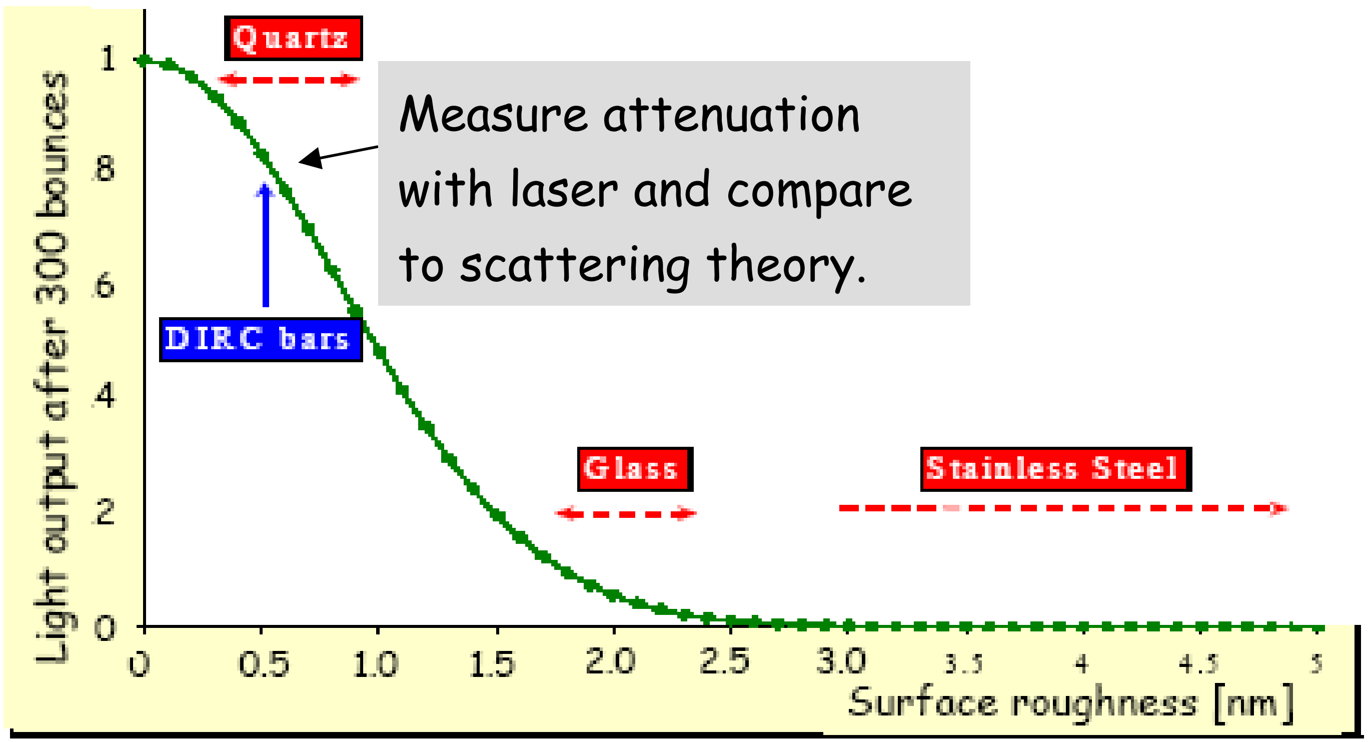


- Bar-edge precision:



The Bar Quality

- Super-polished surfaces:



Polished to roughness < 5Å

Internal reflection:

(99.96 ± 0.01)% / bounce

The Bar Assembly

Class 10 clean room at SLAC

Gluing of bars with capillary method.

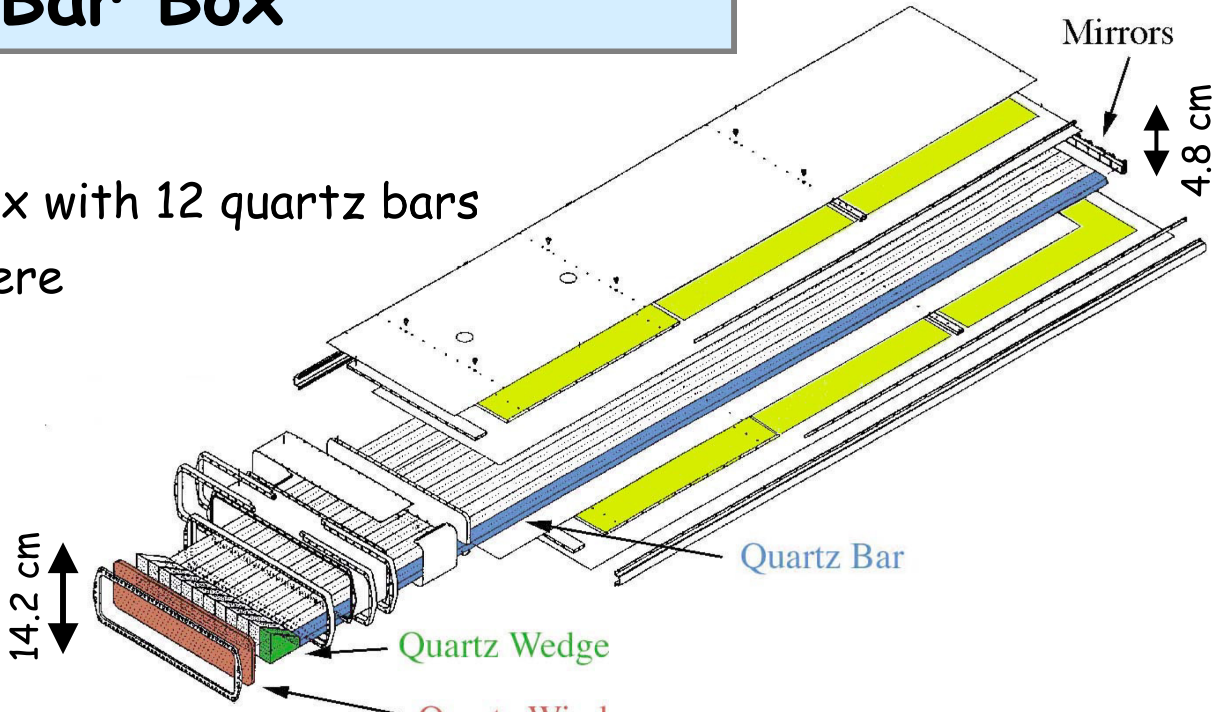
The Bar Box

- 12 DIRC sectors
- each has one aluminum box with 12 quartz bars
- kept in nitrogen atmosphere
- Coverage:

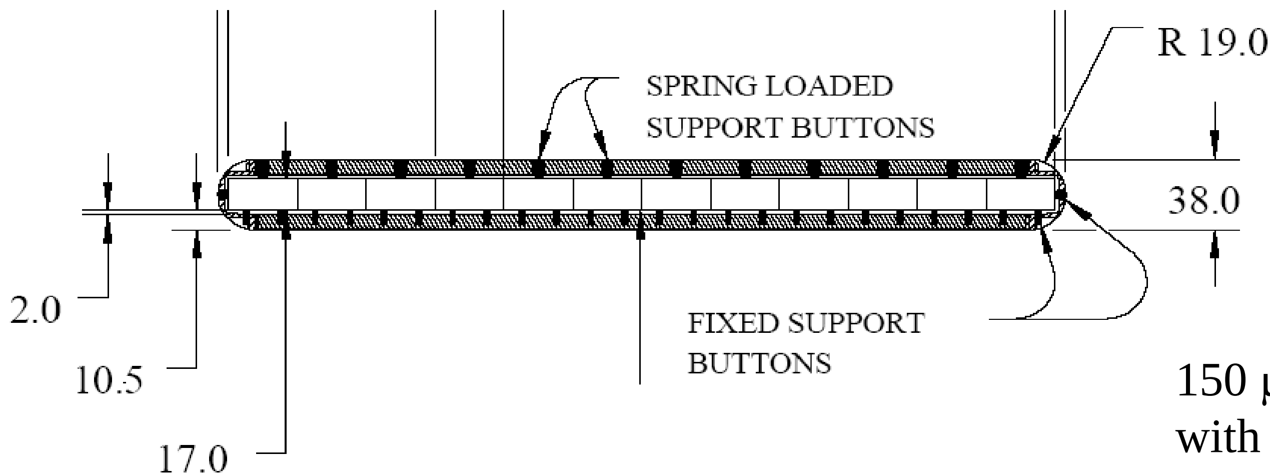
  87% C.M. polar angle,

  94% azimuthal angle

  19% radiation length
  incl. supports

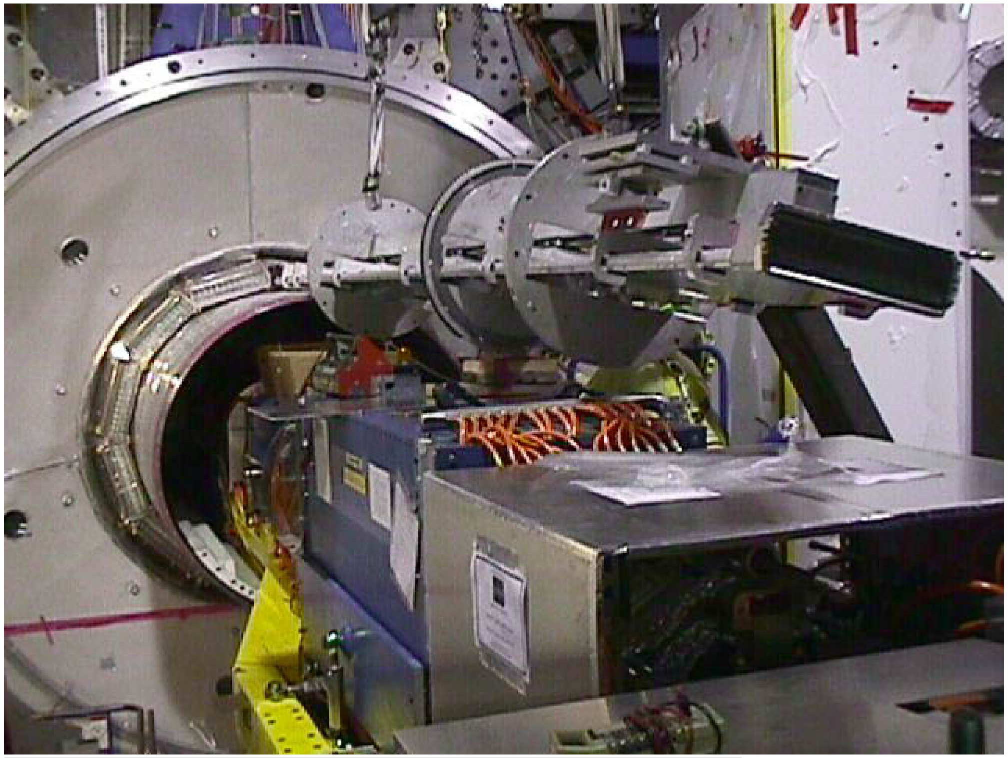


Cross section

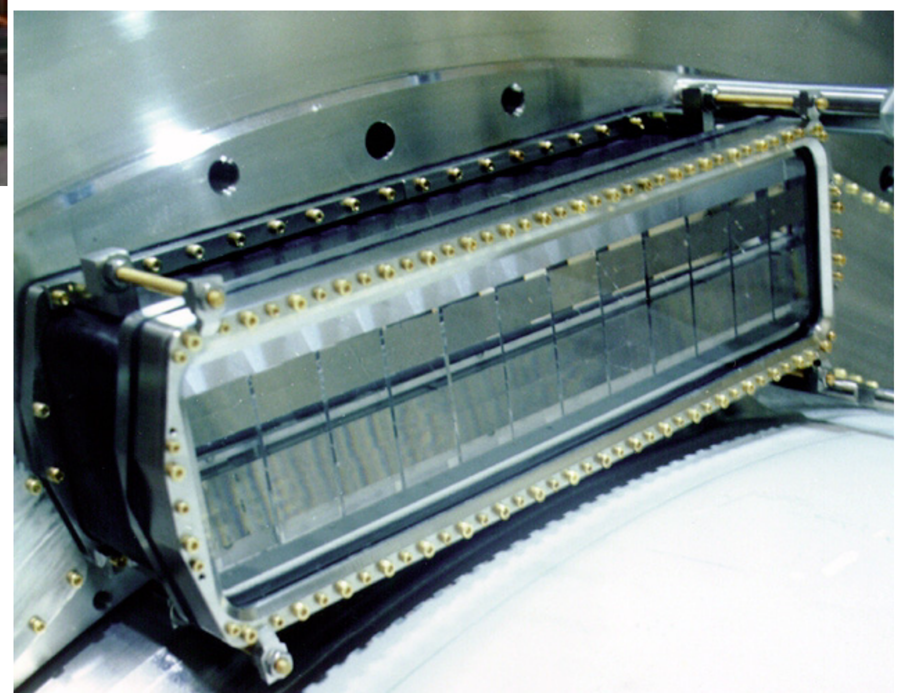


150 µm bar spacing
with Aluminum shims

The Bar Box



Installation of the last bar box

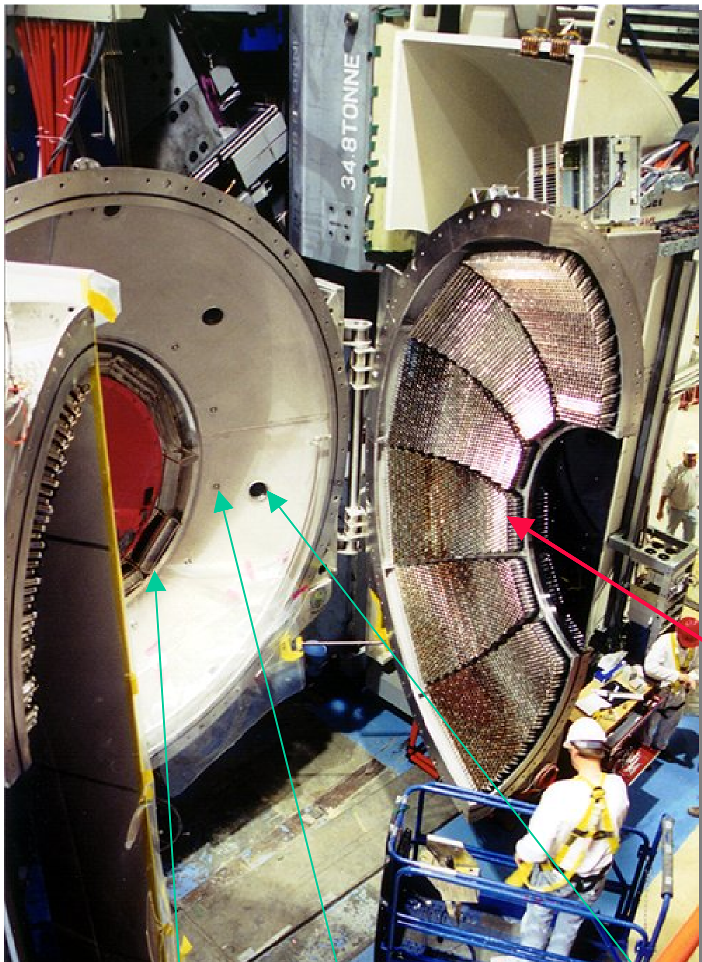


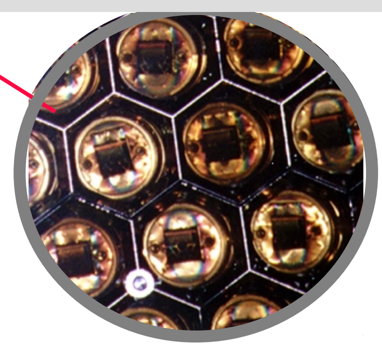
The Photon Detector

.. photons exit from wedge into expansion region filled with 6000 l pure, de-ionized water ($n \approx 1.346$).

10,752 conventional photo tubes

- *immersed directly in water,*
- *hexagonal light catchers*
- *time resolution : 1.5 ns rms*
- *max quantum efficiency@410 nm*



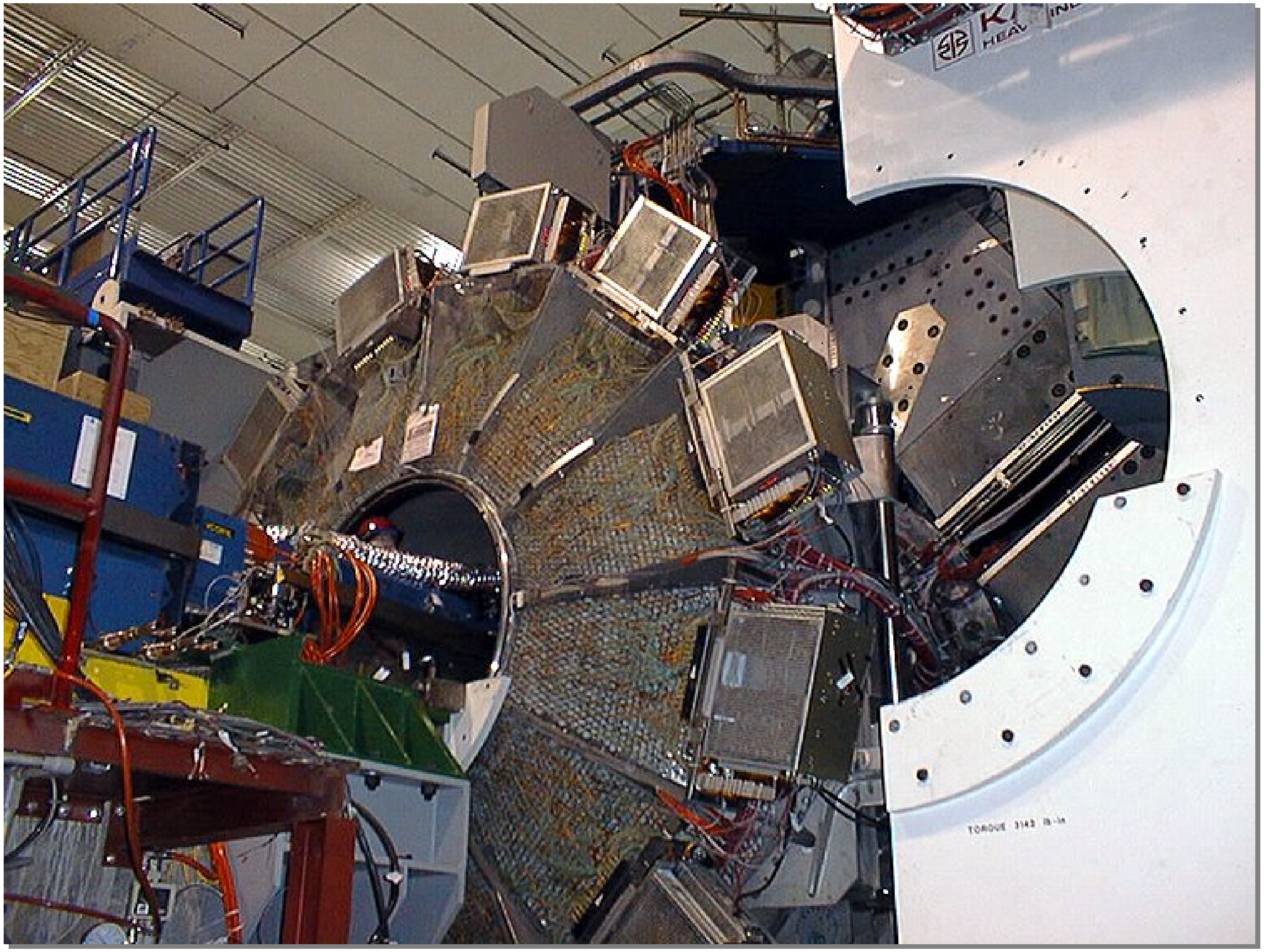


Calibration diode

window

Bar box (wedge)

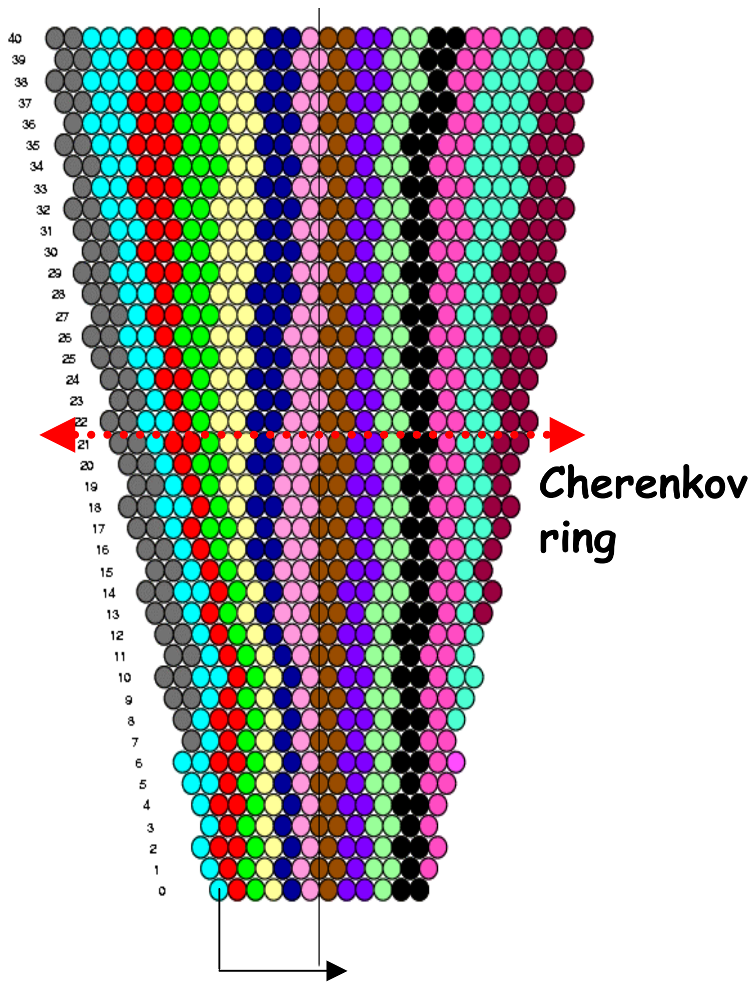
The Photon Detector



Magnetic shielding: passive and active
B_T at the PMT < 0.2 Gauss

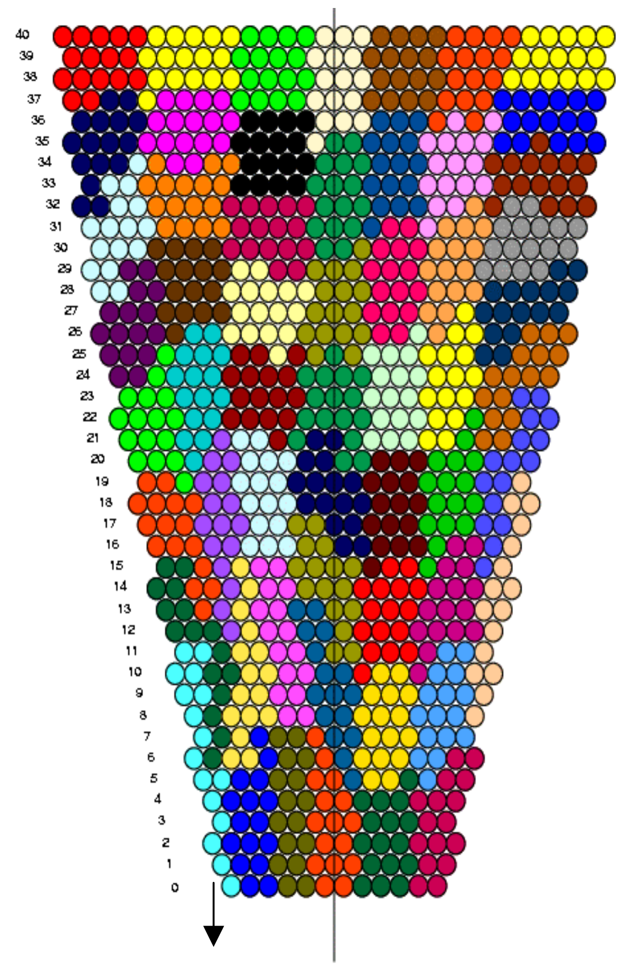
The Photon Detector

Readout structure



- each 64 PMT are read into
  4 TDC (0.525 ns binning) + 1 ADC
- 1.2 Gbits optical fibers to ROM

HV cabling



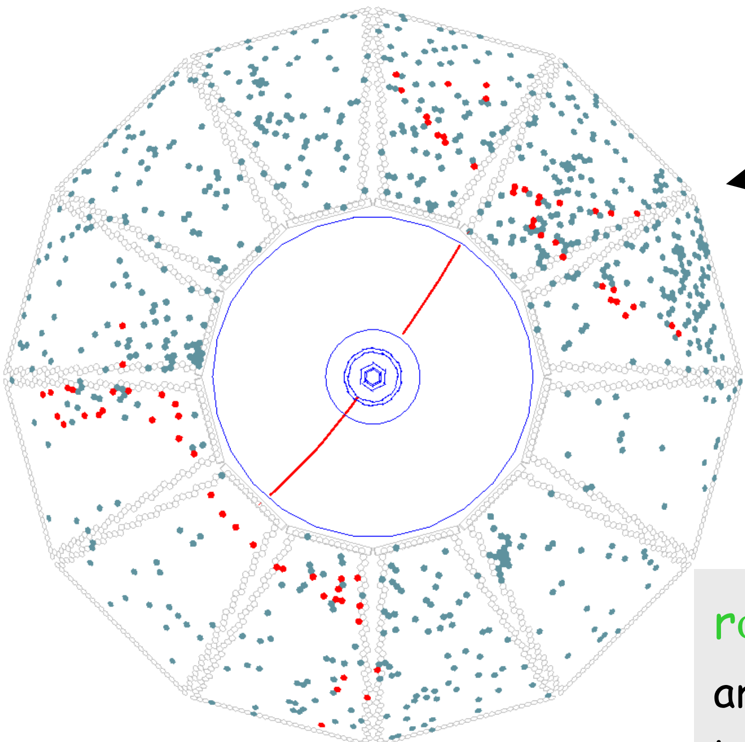
- 900-1400 V per tube
- correlation HV%time
  -> calibration

Timing

L1 trigger rate ≈ 2 kHz ⇒ time T

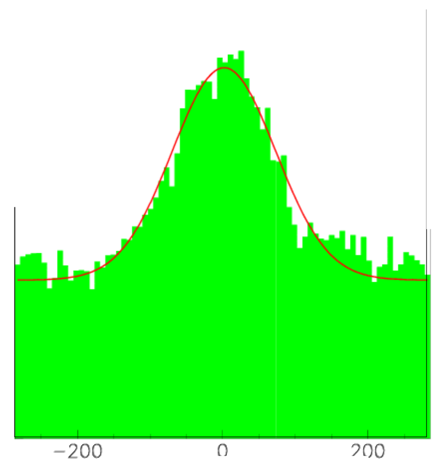
- derived from fast pattern recognition in DCH ($\sigma(T) \approx 60$ ns)
- latency = 12 μs (-> buffering in FE-electronics)

o.k. with DIRC event duration ≤ 100 ns

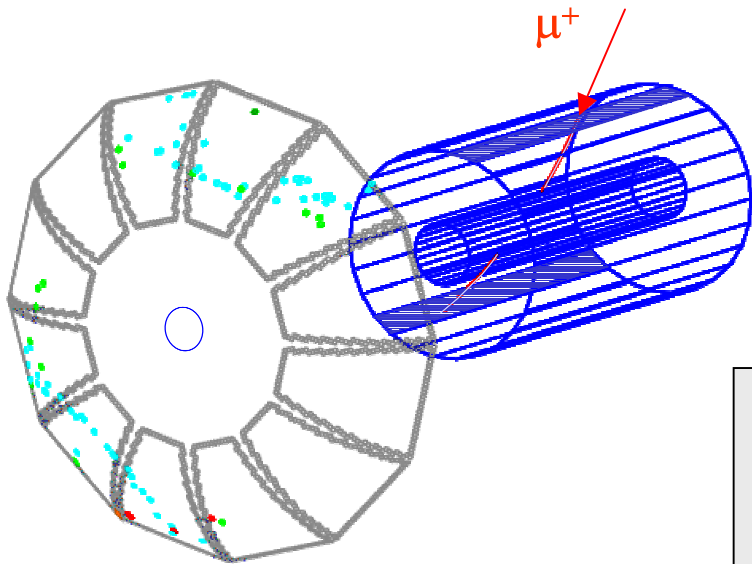


raw PMT time $t = t_{hit} - T$;
use interval of ±300 ns

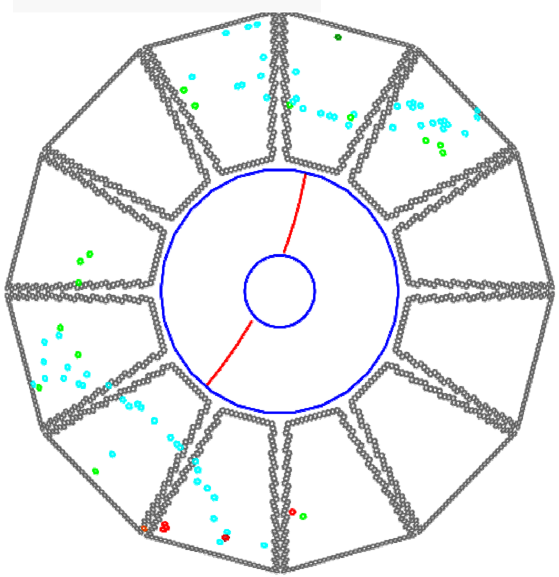
rφ projection of the PMT array showing the phototubes hit within the ±300 ns raw time interval; the hit rate/PMT is kept below 200 kHz.



Timing



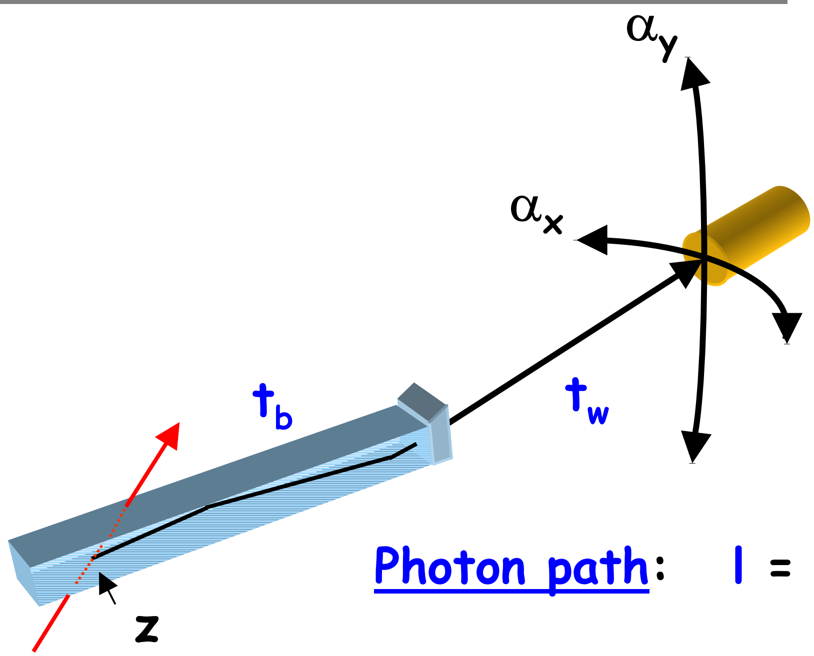
cosmic event



- Correction of the measured time $t \rightarrow t'$ for
  - bunch crossing (from track reconstruction),
  - electronic delays and
  - calibration
  (PMT time, FEE delays with LED source)

- Expected arrival time t_e of Cherenkov photons
  - track time-of-flight
  - photon propagation in quartz and water.
  It depends on photon angle in the bar:
  3D - device !

Timing



<u>Photon path</u>: $l = \dfrac{z}{\cos(\alpha_x, \alpha_y)} = \dfrac{\text{coordinate along bar}}{\text{photon direction in bar}}$

$\Rightarrow$ propagation time $t_b = l/v = t(\alpha_x, \alpha_y) \sim t(\theta_C, \phi_C)$

(a) correct for attenuation along photon path:

- $\theta_C = \theta_C(\lambda)$ -> shift of the mean (~0.5 mrad)
- $t = t(\alpha_x, \alpha_y)$ -> shift negligible for time (~20 ps)

(b) in future faster timing ($\sigma \ll$ 1ns):

- measure θ_C via $t(\alpha_x, \alpha_y)$
- distinguish colours: $v = v(\lambda) \Rightarrow t(\lambda) = l/v(\lambda)$

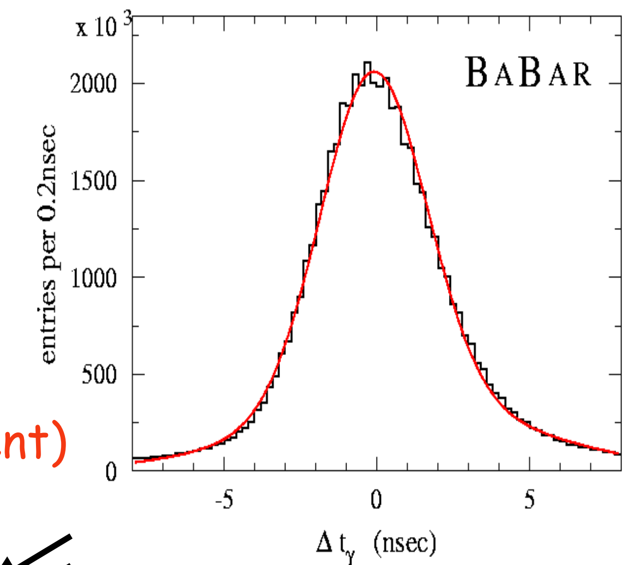
Timing

Cut on the difference Δt between measured t' and expected arrival time t_e:

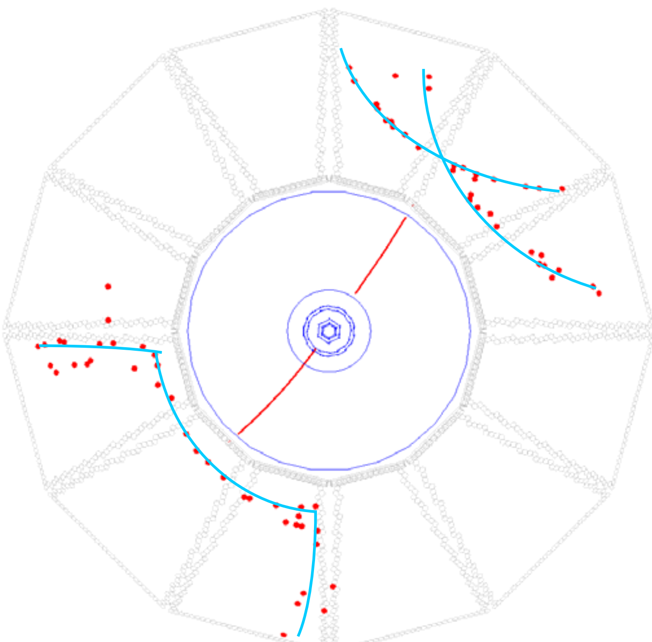
$\sigma(\Delta t) = 1.5\text{ns}$

compare to ~1.5 ns
intrinsic time resolution
of PMTs

$\pm$ 8 ns Δt window
(1 background hit/sector/event)



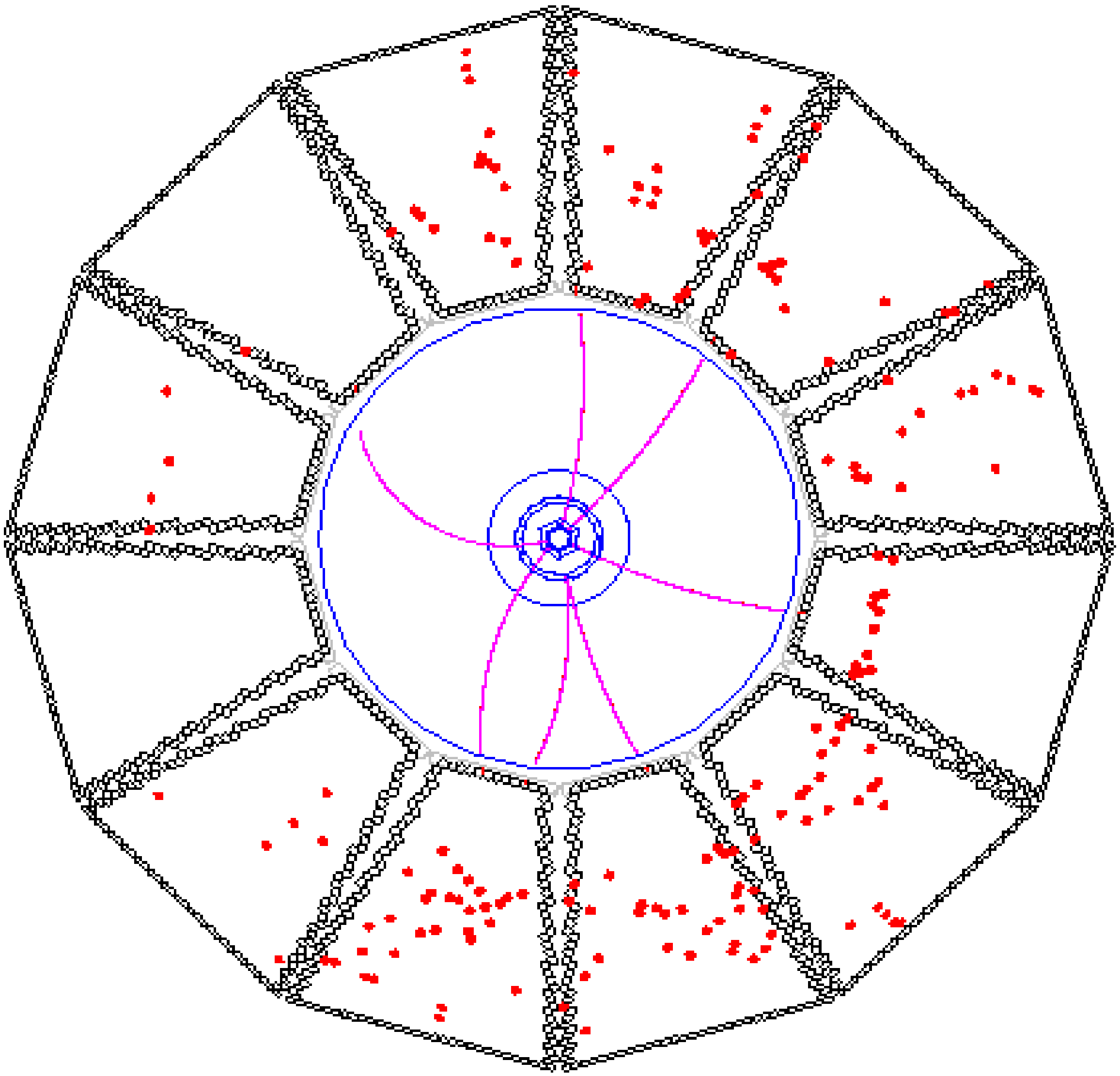
In a typical multi-hadron event 11 randomly distributed photons and ~240 signal photons



Cherenkov 'ring' image is complex, because of
- limited acceptance for total internal reflection in quartz bar
- reflection ambiguities (up/down, left/right, forward/backward, wedge)
  $\Rightarrow$ 16 ambiguities per hit;
  average 2.5 (pattern recognition), max 4
- toroidal detection surface

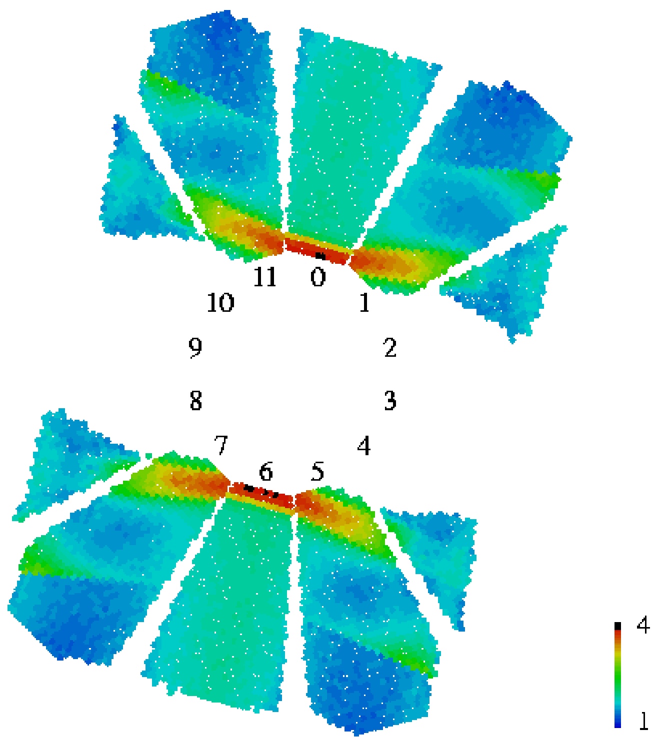
Multi-Hadron Event

Stefan Spanier 9/10/2004



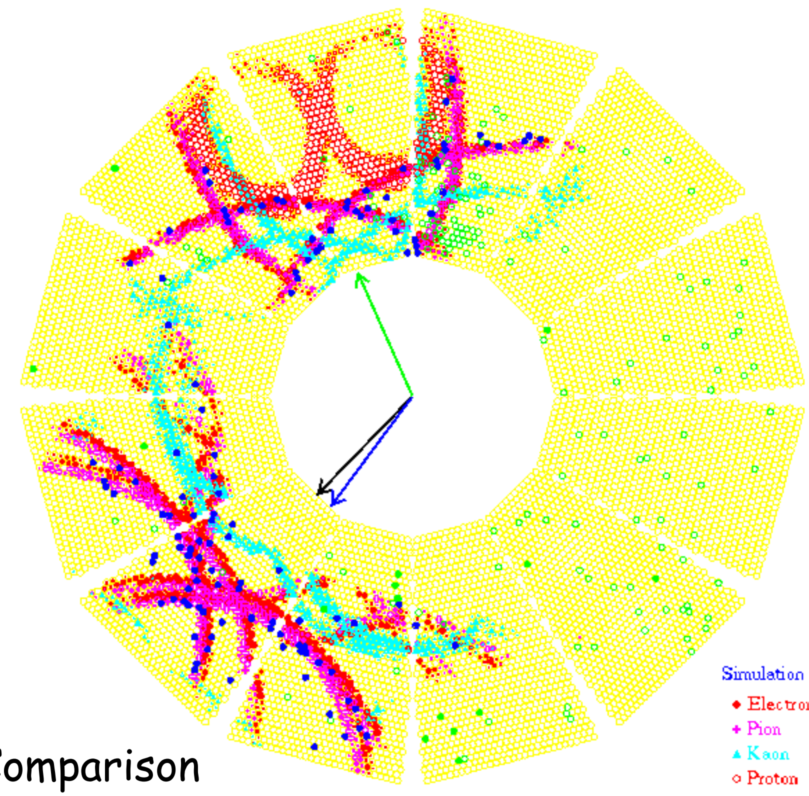
Reconstruction

Most of the ambiguities are solved by the correlation between α_x,α_y and t (physical solutions) using a lookup table or ray-tracing.



Ambiguity map:

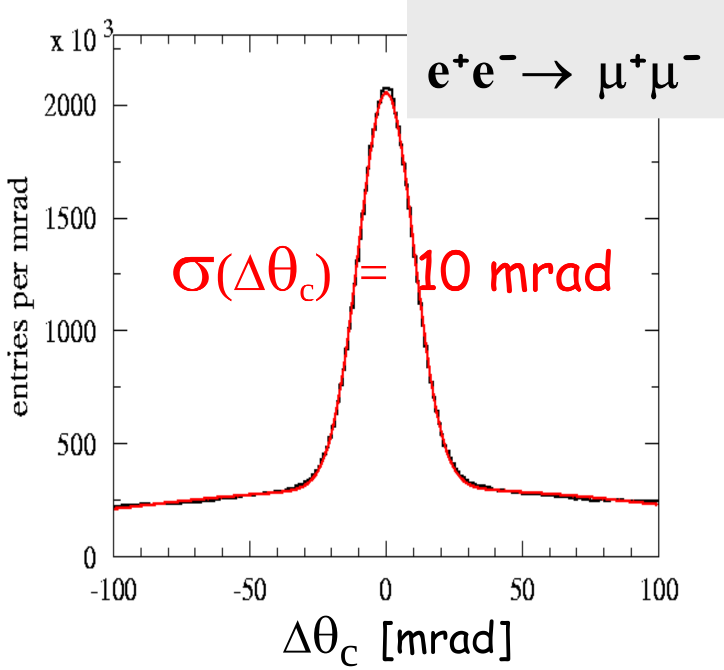
Particle identification uses the Combination of photon solutions probing the hypotheses e,μ,π,K,p



Example: Comparison of a real event to simulated response of the DIRC for different particle types.

Single Photon Resolution

$\Delta\theta_c$: difference between measured $\theta_{c,\gamma}$ per photon solution and θ_c of fit:



Background contributions:

- combinatorics, overlap between tracks,
- knock-on electrons in quartz
- reflections down the bar/mirror
- beam background (small effect)

$$\sigma_\theta{}^2{}_{tot} = \sigma_\theta{}^2{}_{chromatic} + \sigma_\theta{}^2{}_{transport} + \sigma_\theta{}^2{}_{imaging} + \sigma_\theta{}^2{}_{detection}$$

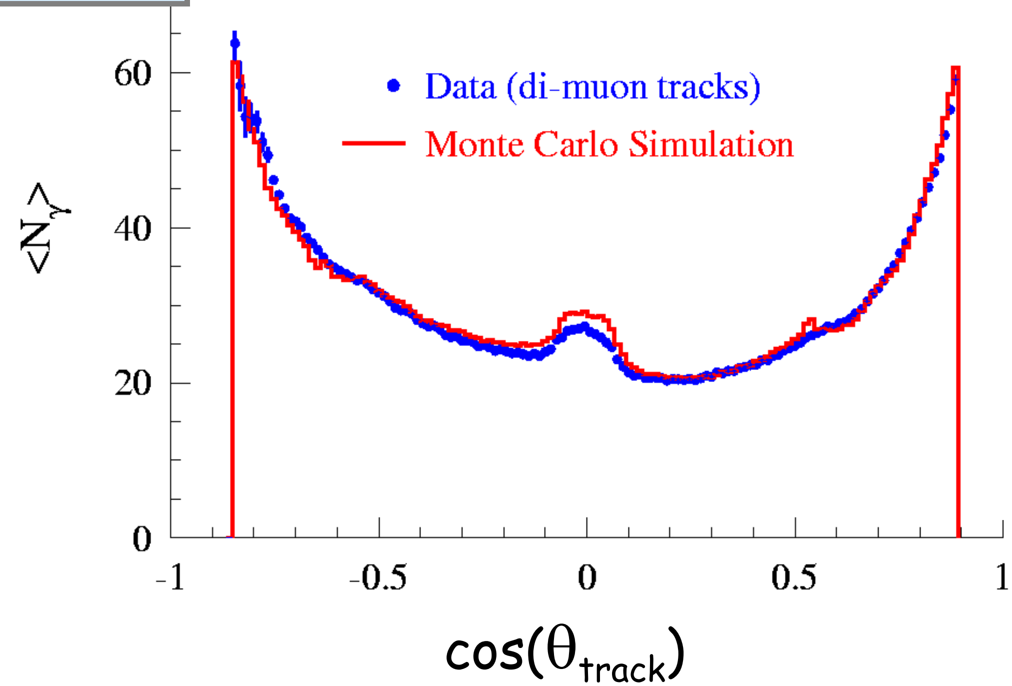
$\sigma_\theta{}^2{}_{chromatic}$: $n = n(\lambda)$: 5.4 mrad

$\sigma_\theta{}^2{}_{imaging+detection}$: ~ 7.3 mrad bar size and imaging granularity

$\sigma_\theta{}^2{}_{transport}$: smearing down the bar (sides/faces; $\leq$1 mrad)

Resolution

Number of Cherenkov photons per track *versus* polar angle for di-muon events. Observe between 20 and 60 photons

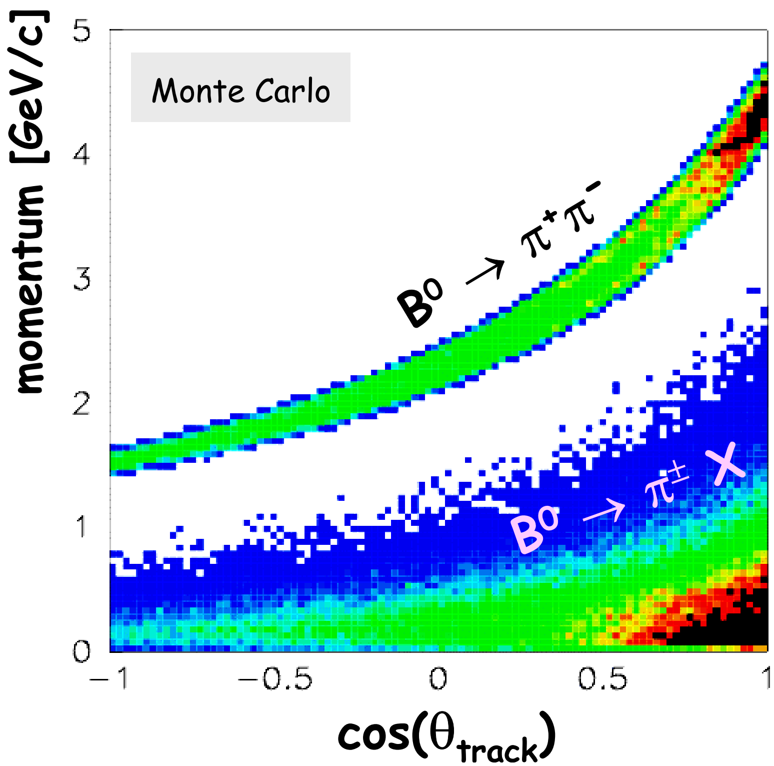


Photon efficiency: - geometry / sensitive area

- mirror reflection ~ 92 %
- transmission/ internal reflection ~ 80 %
- water transmission ~ 98 %
- photo tube efficiency ≤ 25 %

- **glue joint cutoff @ 280nm**
- **transition quartz/water**
- **photo tube window in water**

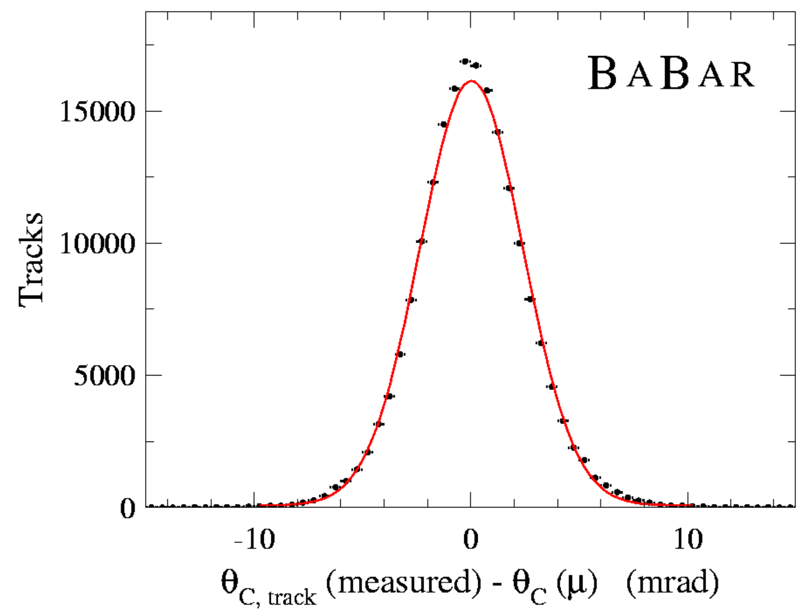
Resolution



Correlation between momentum and polar angle for B->π π and B->π X.

Resolution of Cherenkov angle per track:

$$\sigma_\theta = \sqrt{\sigma_{track}^2 + \sigma_{\theta\gamma}^2 / N_\gamma}$$



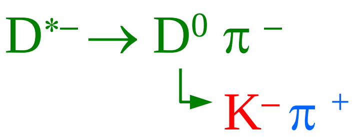
$\sigma(\Delta\theta_{c,}) = 2.4$ mrad

Track Cherenkov angle resolution is within ~10% of design.

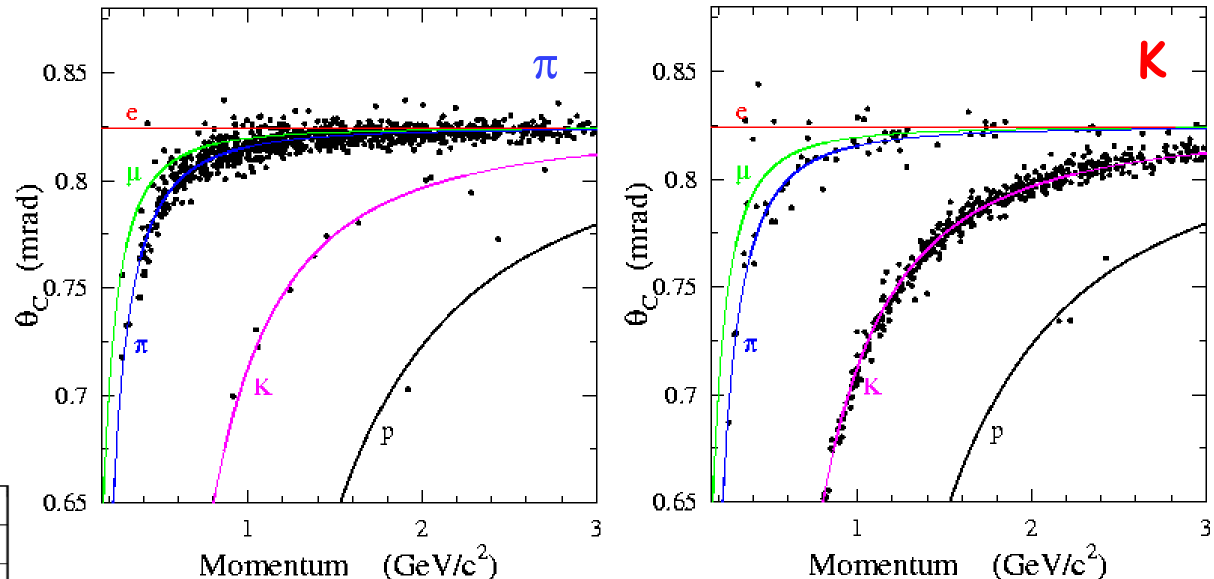
Particle Identification

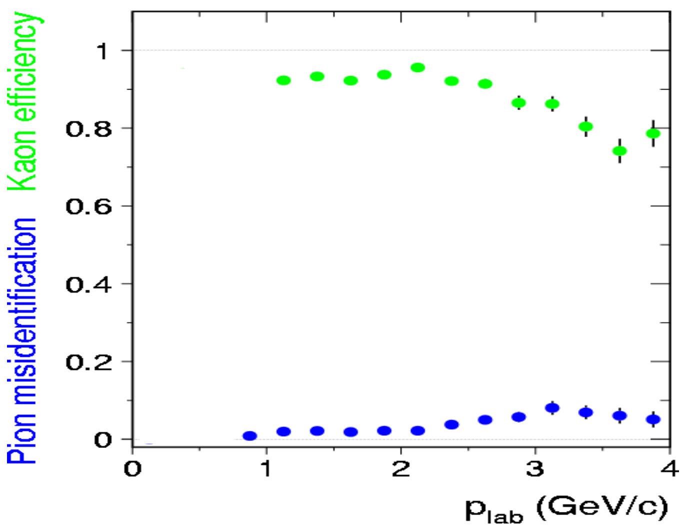
- For selection combine the Gaussian $G(\theta,\theta_C)$ with Poissonian $P(N_\gamma, N_{expected} + N_{bck})$ for photon counting.

- For selection tuning select the decay



identify the π and K from the D^0 kinematically. Correct for combinatorial background (~10%).





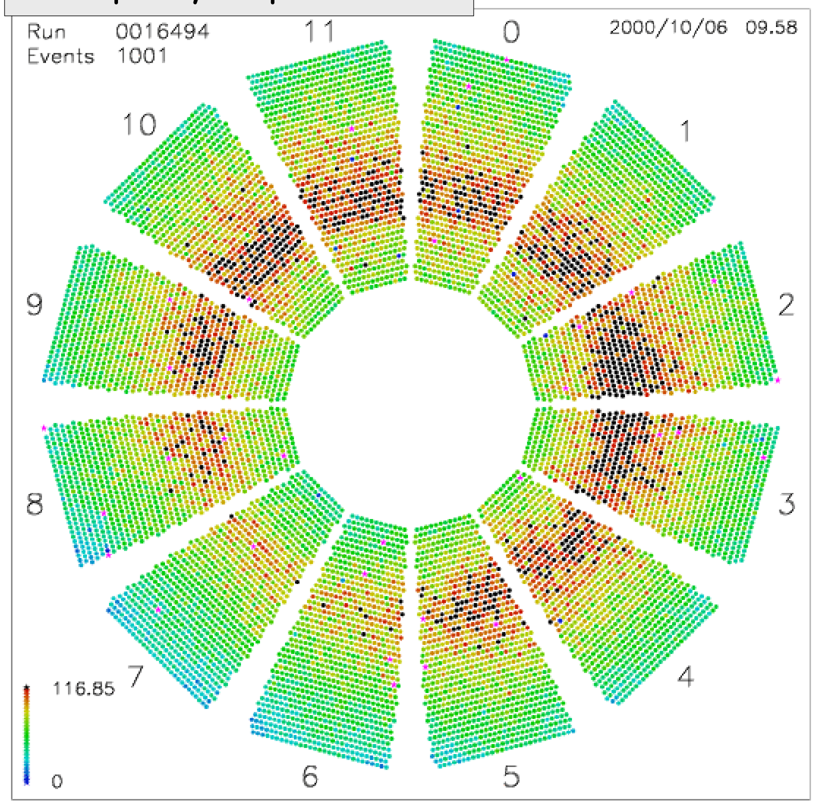
e.g. selection of $D^0 \rightarrow K^-\pi^+$

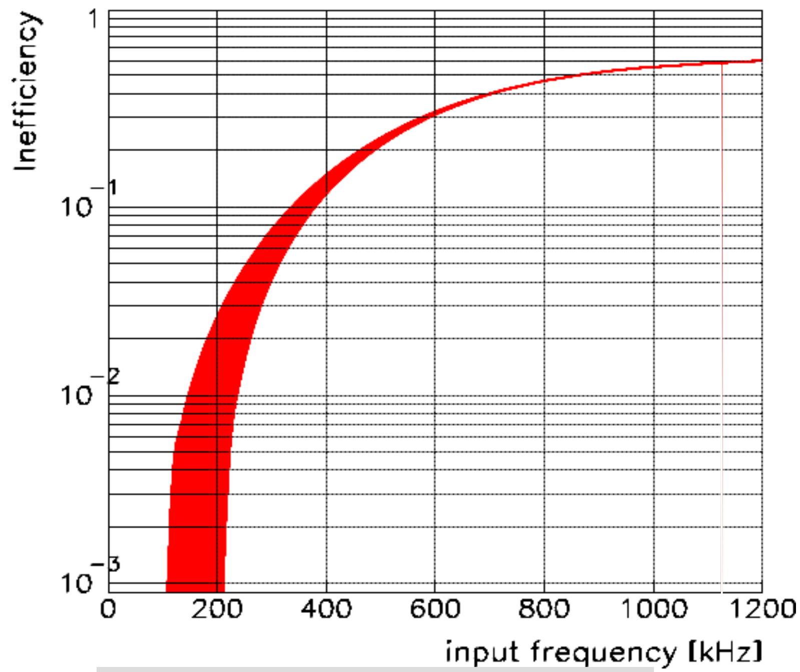
average K selection efficiency:	88%
average p mis-id:	2%
average rejection factor:	44

Beam Background

- Currently the rate is kept below 200kHz ≡ 1300 hits in ±300ns ≡ 12% occupancy

Occupancy map for a run





Readout inefficiency
for coherent/random hits

Generate headroom for accelerator:

- introduce local shielding
- speed up readout electronics

Operation

- 99.7% of all tubes are fully operational

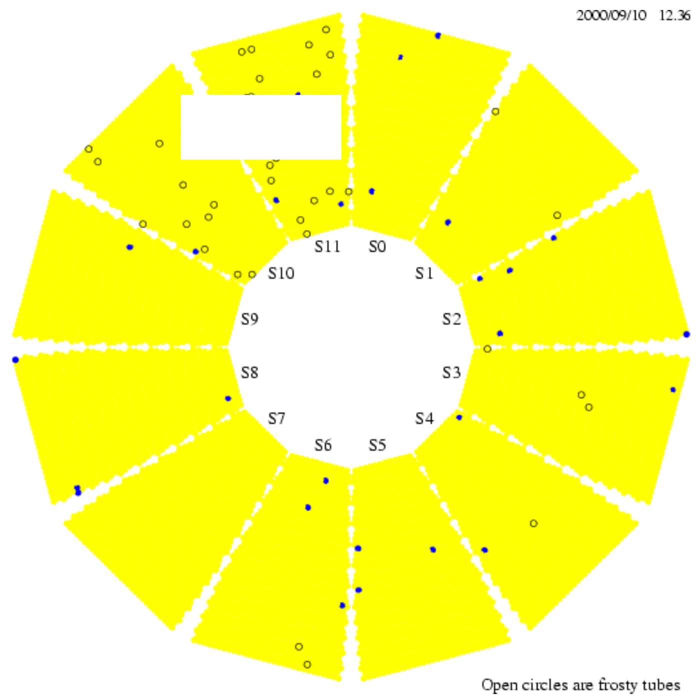
- failures so far due to
  - vacuum breakdown
  - light emitting tubes

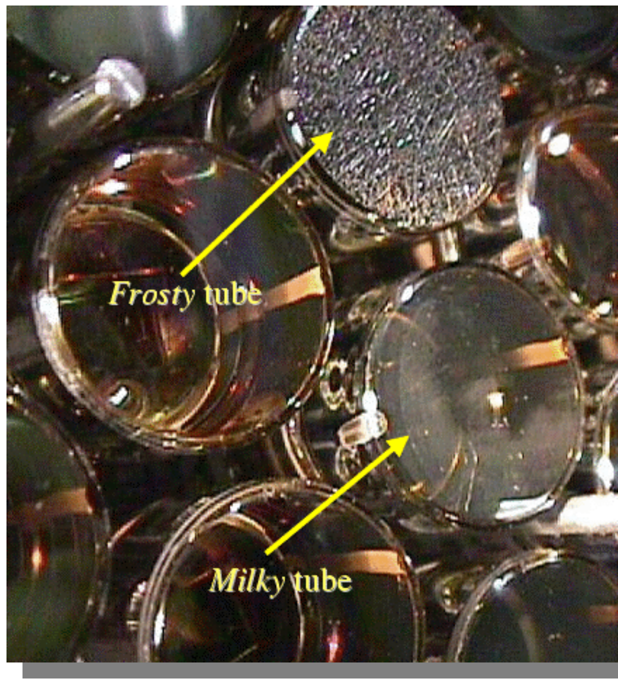
- glass degradation

  PMT front glass corrosion due to sodium depletion in ultra-pure water. In ≈ 50 tubes of one incorrectly manufactured batch (zinc-less glass) frosty. Same effect in all tubes (milkiness), which is not a long term problem.

- lifetime of phototubes

  ≈8 Cb/year ≈2% loss in efficiency compatible with observation (gain loss, worse transmission ?)





Gluex Adaptation

- Physics particle momenta and angle of incidence
  and their resolutions
  occupancy / correlations
- Background from beam
  occupancy
  photon / electron rates
- Geometry spacing
  magnetic field conditions
- Construction

Gluex Physics

preliminary

Ryan Mitchel simulated a variety of final states and inspect at plane behind hole of magnet z = 450 cm ; the straight forward segmentation is in y-direction. *Thanks to Richard and Ryan.*

$\gamma p \rightarrow \pi^+ \pi^- p$

$K^+ K^- p$

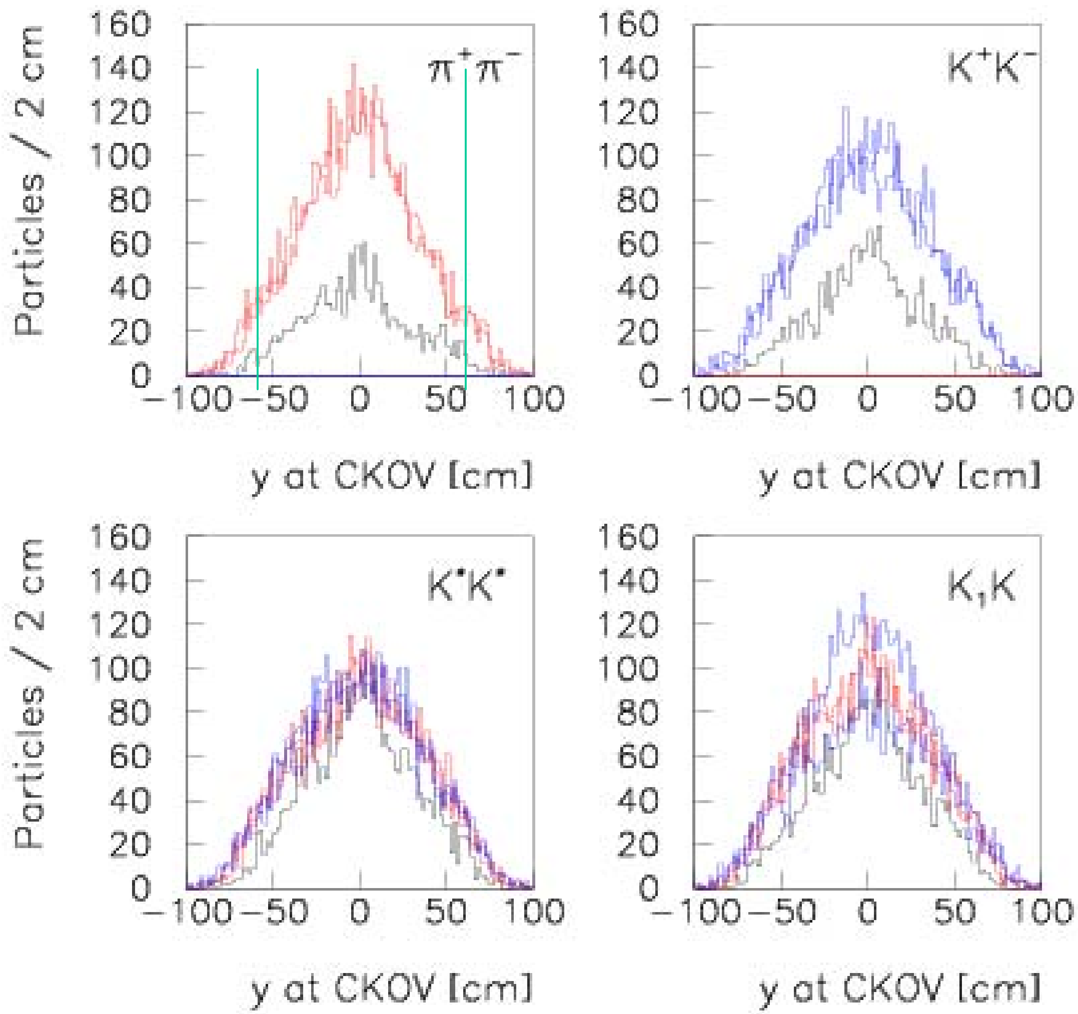
$K^* K^* p$

$\hookrightarrow K^+\pi^- K^-\pi^+ \pi^-$

$K_1(1270)K^- p$

$\hookrightarrow K^*\pi^+ K^- p$

— pion
— kaon
— proton

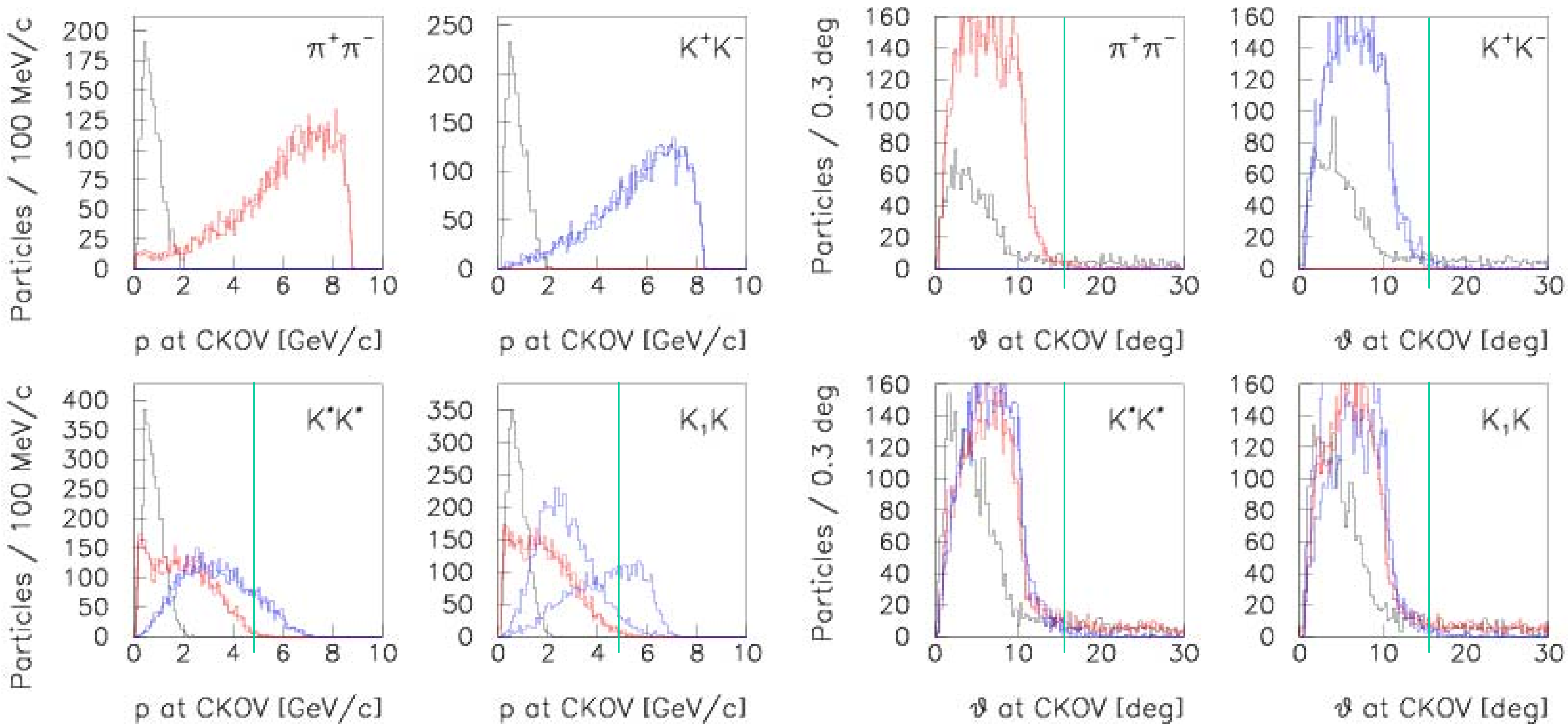


Gluex Physics

preliminary

Momentum : 1 ... 4.5 GeV/c
resolution @ 4.5 GeV/c:

Polar angle : < 15°
resolution @ 4.5 GV/c: < 2 mr



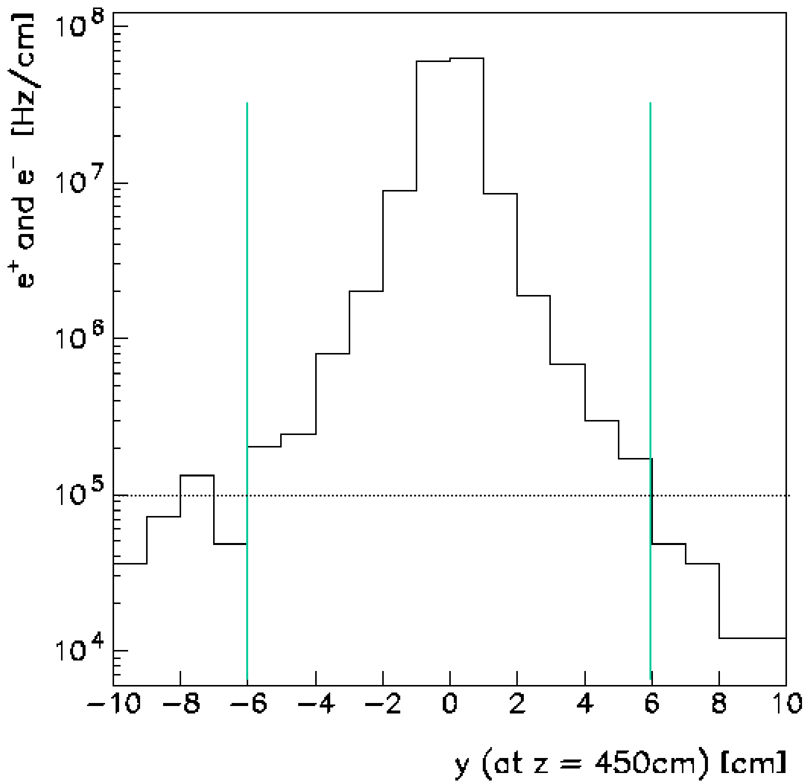
• Correlations: particles with polar angle > 15° are pions with momenta < 1 GeV/c

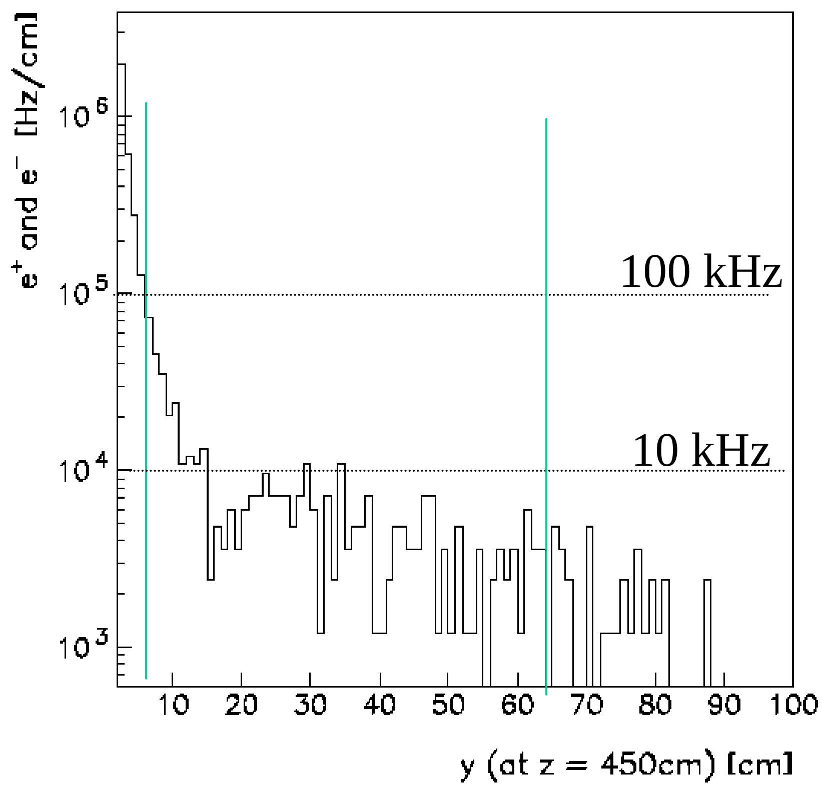
Beam Background

preliminary

Consists primarily of electrons/positrons and conversions from photons in the Cherenkov detector

e+, e- rate versus distance in y-direction





- Rate < 100 kHz / cm above/below 6cm and 200 kHz/2cm bar inner most,
- total rate |y| > 6cm : ~ 900 kHz
  |y| > 10 cm: ~ 580 kHz

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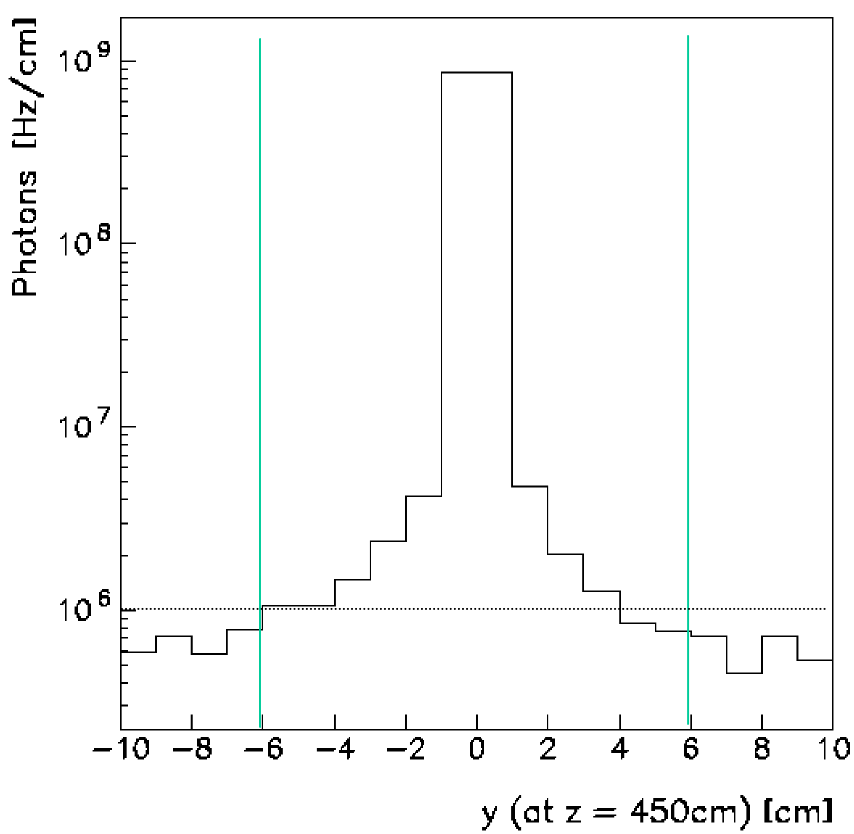
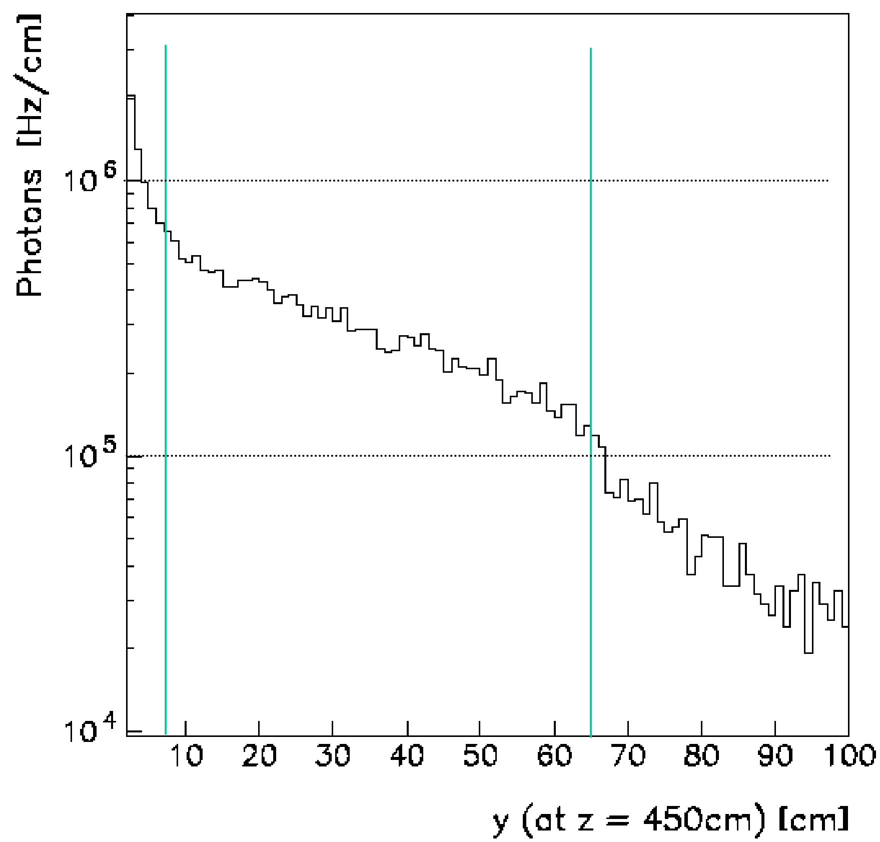
Beam Background

preliminary

γ rate versus distance in y-direction





- Rate ~ 600 kHz / cm above/below 6cm
- total rate |y| > 6cm : 29.6 MHz
  |y| > 10cm : 24.0 MHz

Beam Background

preliminary

Photon rate out of bars into photon detector

- Cherenkov light from e+,e- = 30 photons/lepton
- Cherenkov light from photons = 0.15/photon x 2e x 20 photons/e

➔ |y| > 6cm : 27 MHz + 180 MHz ~ 210 MHz

|y|> 10cm : 17 MHz + 144 MHz ~ 160 MHz

The event time (trigger window) is less than 100 ns

➔We expect 21/16 background photons from beam

The window for reconstructed photons is less than 10 ns

➔We expect 2 background photons

But: the single tube occupancy depends on optics and cutoff (??);

for 1000 phototubes randomly hit: rate ~ 210 kHz / tube

Gluex Adaptation

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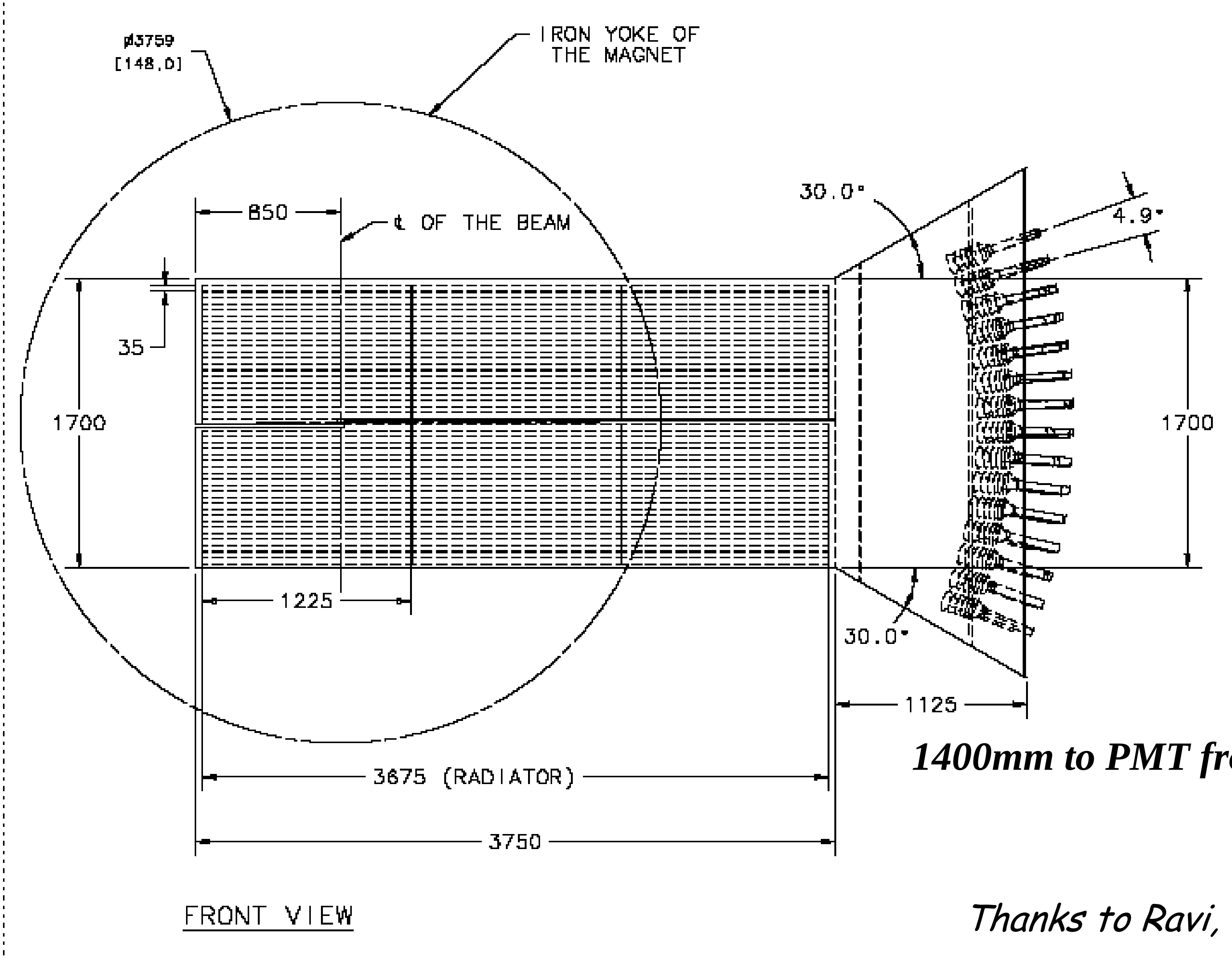
preliminary



1400mm to PMT front

Thanks to Ravi, JLAB

Gluex Adaptation

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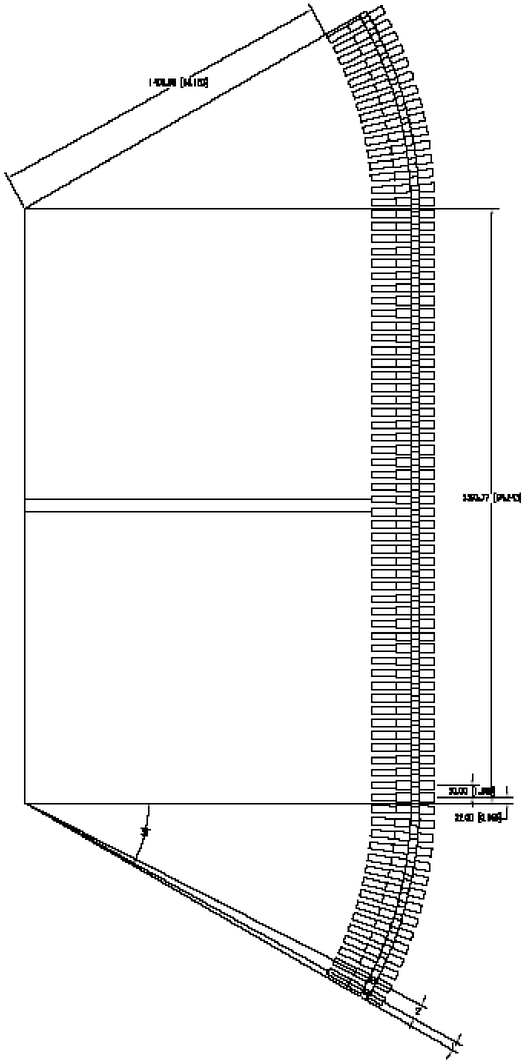
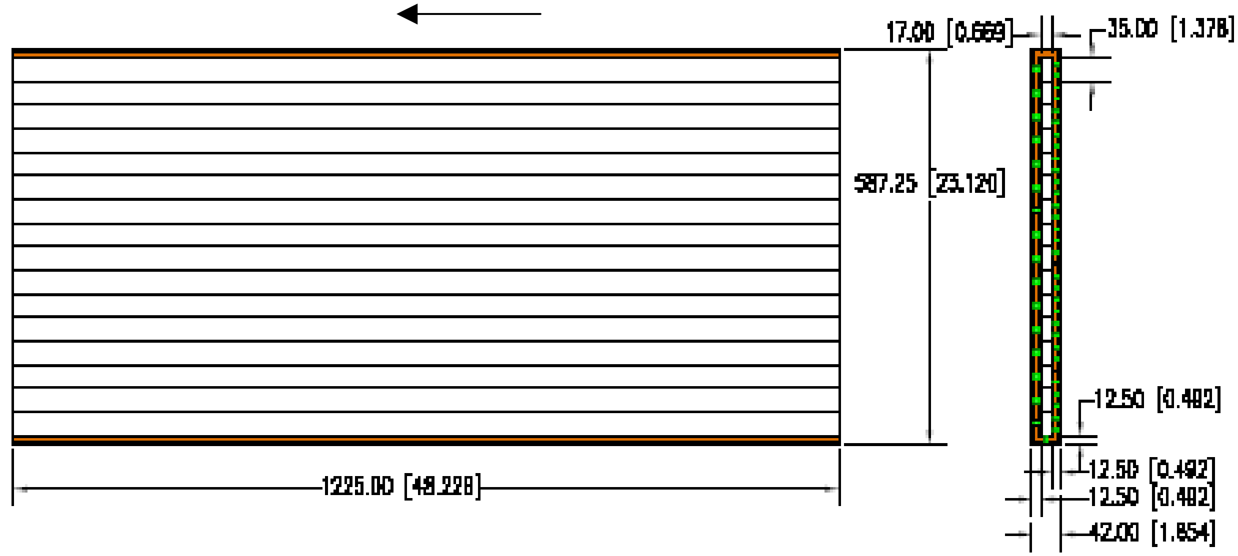
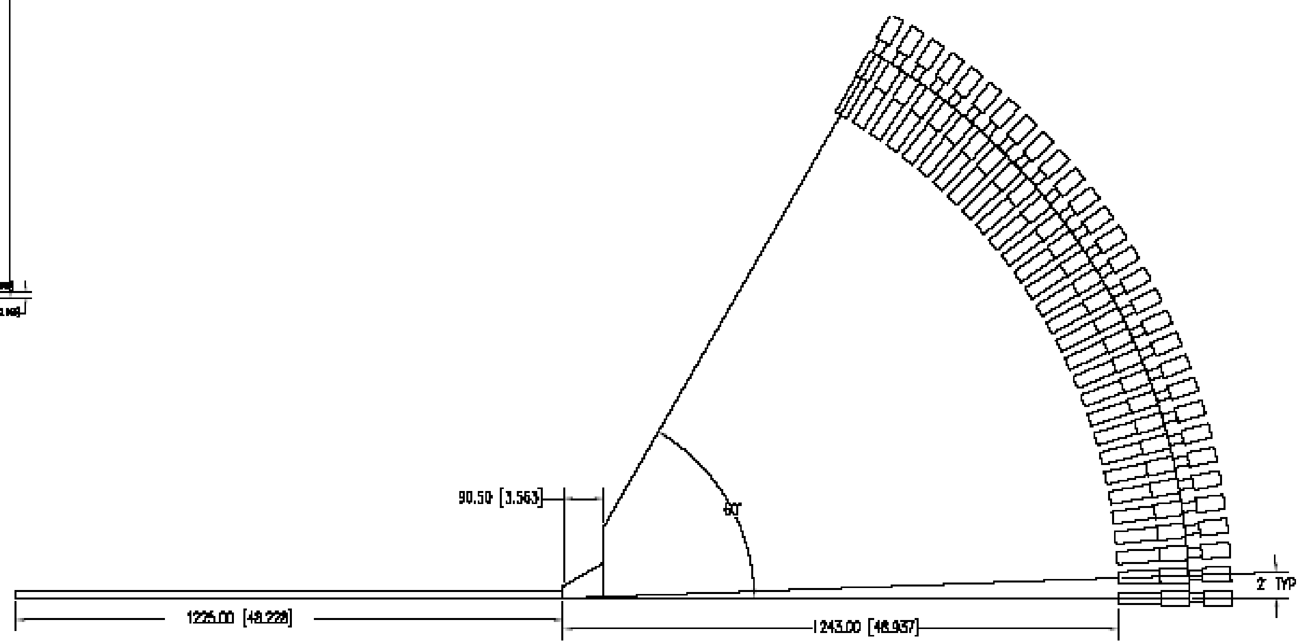
Thanks to Paul Mueller and Charles Reed, ORNL



×3

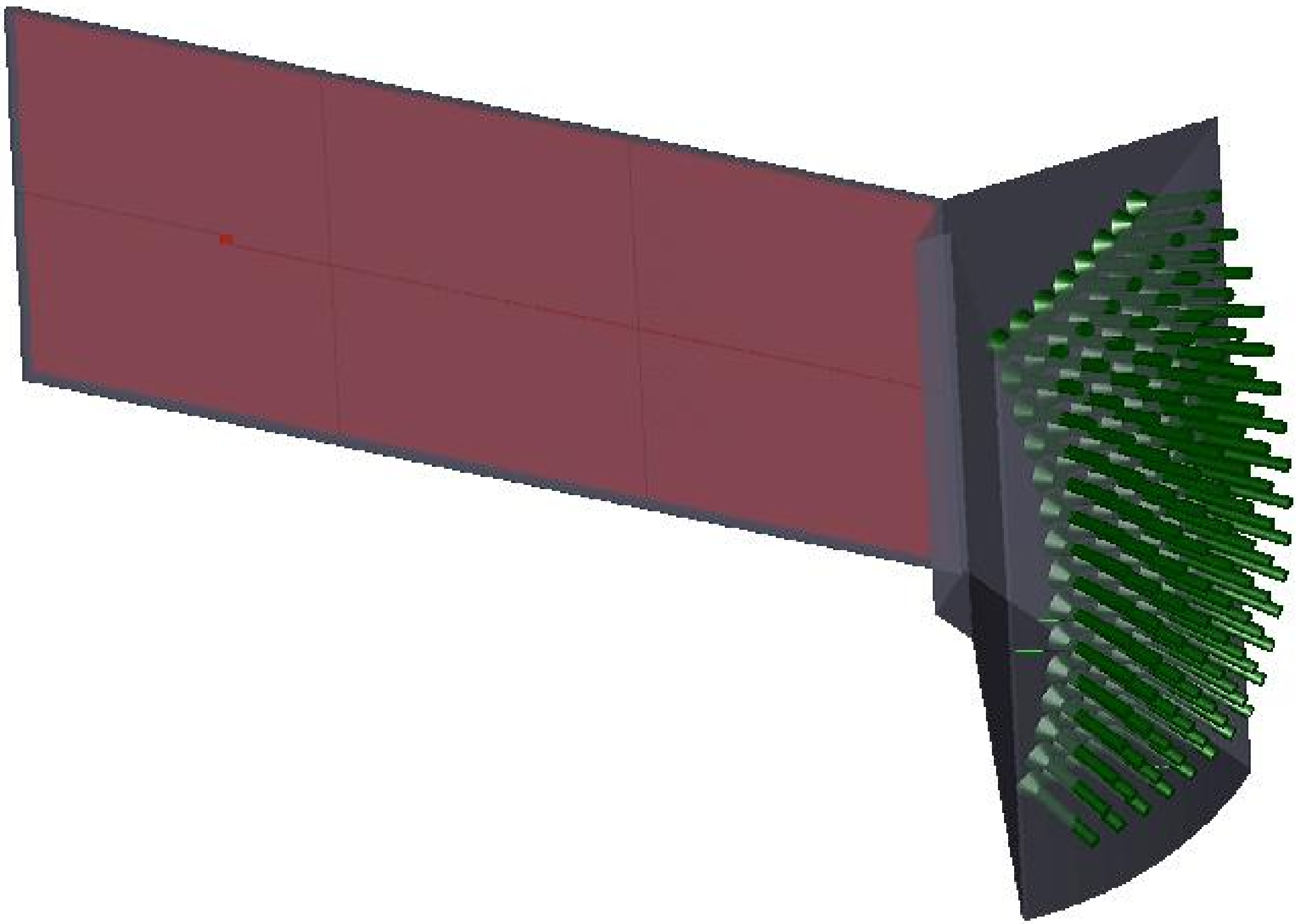




#2340 PMTs

Gluex Adaptation

preliminary



Ravi

Stefan Spanier 9/10/2004

Magnetic Field

preliminary

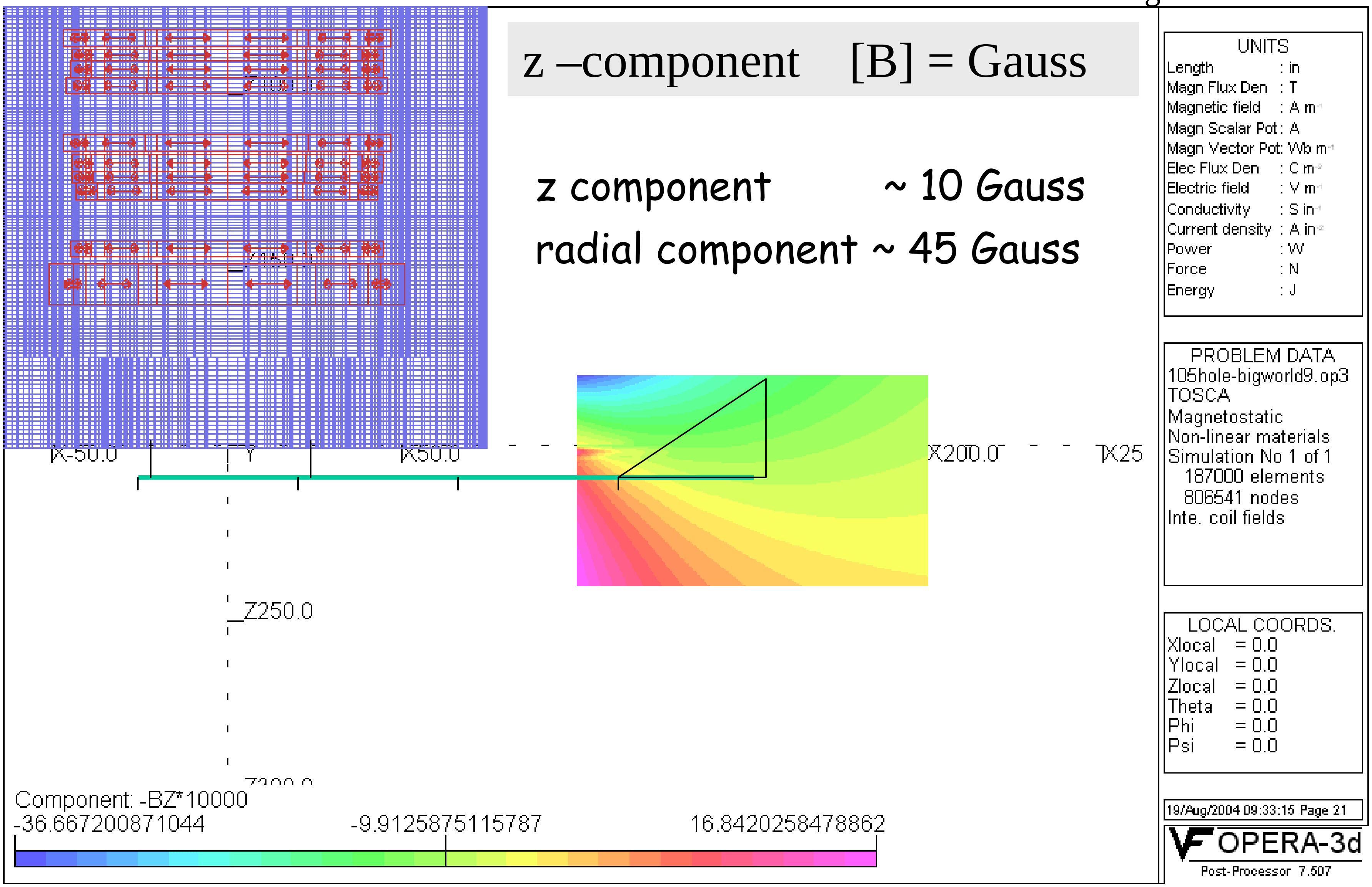
Thanks to Paul Brindza

Nodal mesh integral coil method

z –component [B] = Gauss

z component ~ 10 Gauss

radial component ~ 45 Gauss



Construction

preliminary

The Gluex RICH Cherenkov is about $\frac{1}{4}$ of the BaBar DIRC size.

Tasks: The detector naturally splits into radiator and photon detector
- the radiators should be assembled close to the final destination (clean-room at JLAB ?)
- the photon detector can be assembled at UT jointly by UT/ORNL
- …

Time : One wants to reserve 2 – 3 years
A lot of experience can be transferred from BaBar DIRC and if early enough even assistance.

People: **~ 12 physicists and engineers**
- 2 JLAB staff
- 1 (2) physicist (ORNL)
- 2 physicists (UT)
- 2 mechanical engineers
- 1 electrical engineer (UT)
- …

Outlook

- No Conceptional Design yet
- Looks feasible
- Cost estimate has to be based on former