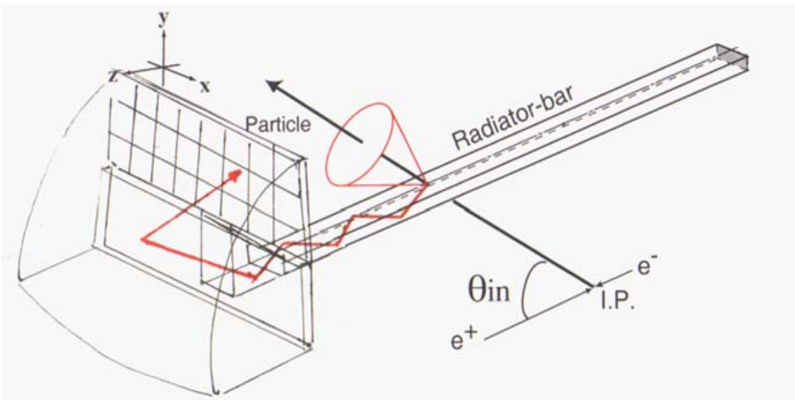
Progress on The Fast Focusing DIRC R&D



DIRC R&D group at SLAC:

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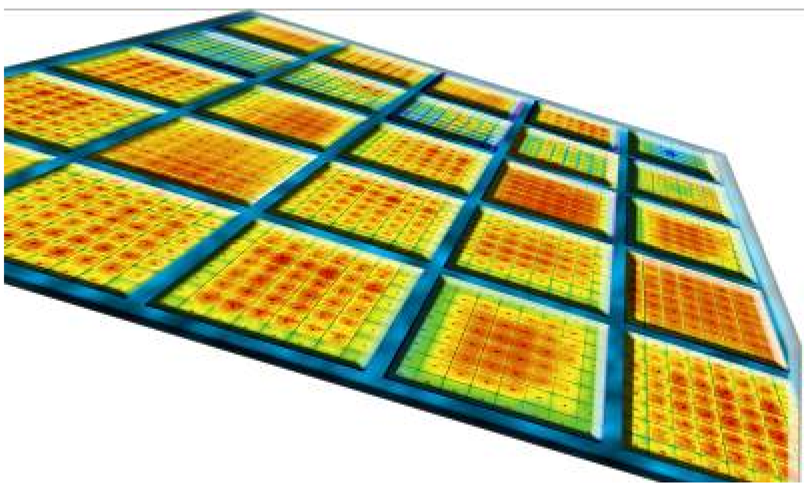


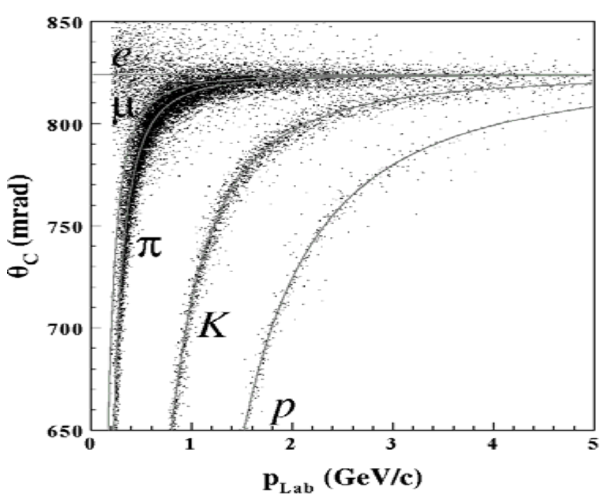
Outline

- Motivation
- Prototype
- Recent Beam Test
- Preliminary Results
- Conclusions

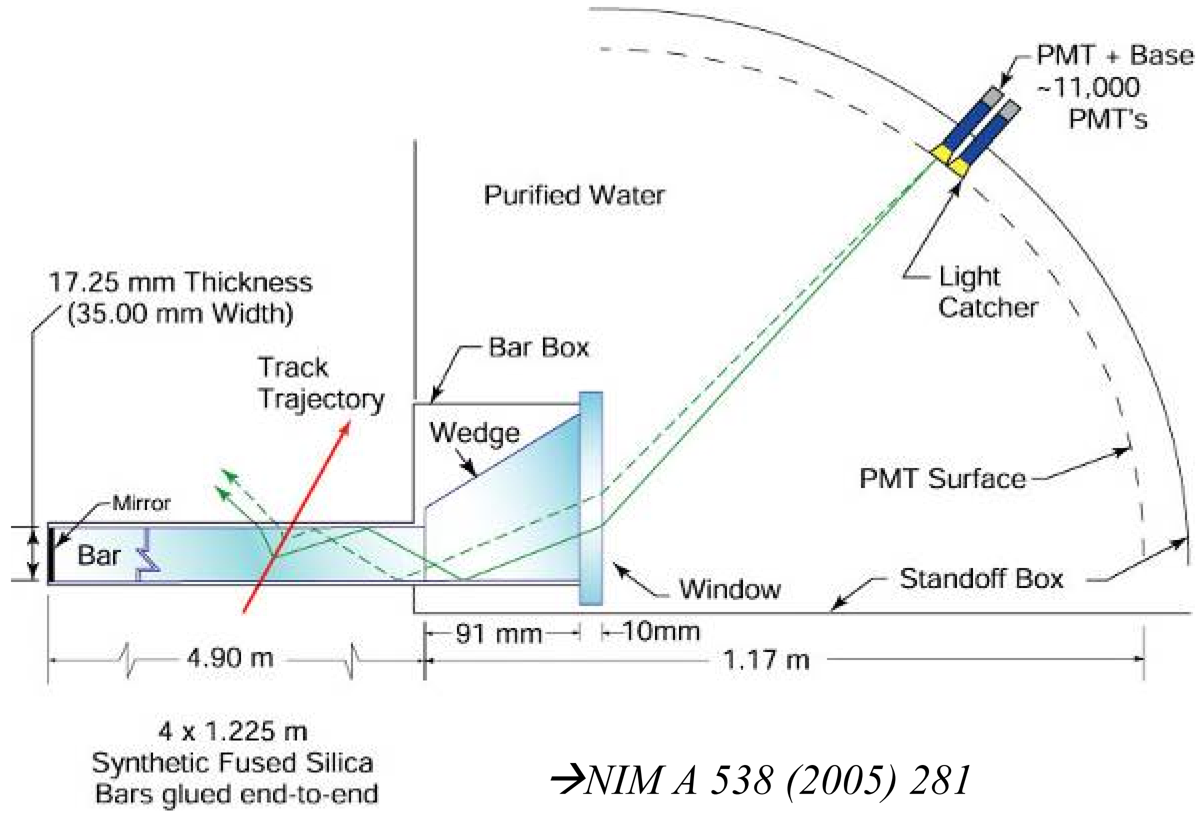
Motivation

DIRC - Detection of **I**nternally **R**eflected **C**herenkov light

- **R**ing **I**maging **CH**erenkov detector used for the first time in the BABAR Experiment (*operating since 1999)*.
- 3D imaging of photons: θ_c ,ϕ_c & time of propagation (TOP).
- θ_C resolution ~9.6 mrad.
- Very successful in hadronic particle identification (PID), with ~ 3σ π-K separation at 4 GeV/c.



BABAR-DIRC



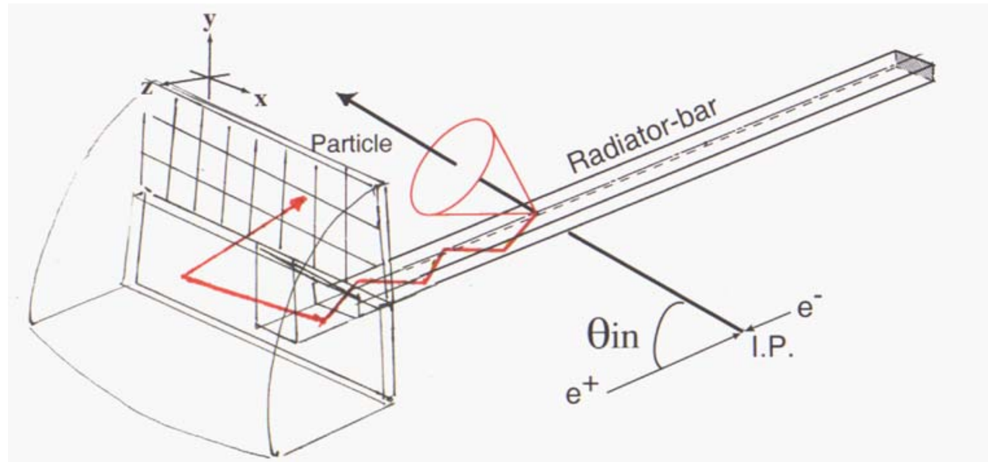
→*NIM A 538 (2005) 281*

Motivation

<u>Improvements in the Focusing DIRC</u>

- Smaller expansion region (25% of BABAR-DIRC)
  - less accelerator induced background.
- Faster PMTs: σ~100ps (BABAR-DIRC σ~1.7ns)
  - better background rejection
  - color of photons becomes measurable
    → better PID resolution
- Possibly operable in strong magnetic field. (BABAR-DIRC is not operable in magnetic field)

Ultimate DIRC Design



This detector could be used in a future experiment like a Super B-Factory, Panda, GlueX, ILC, …

A Prototype of the Focusing DIRC

Prototype

Radiator

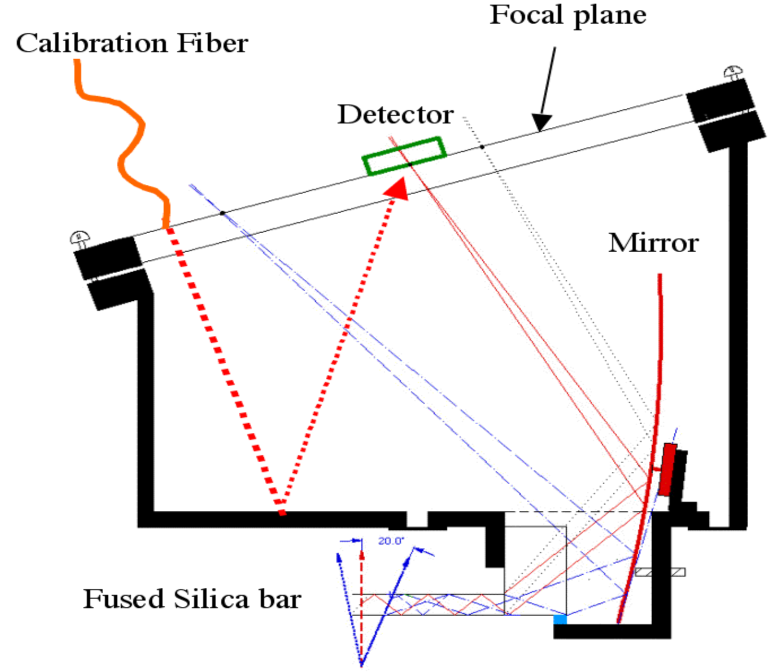
- a 3.7m-long bar (3/4 of BABAR-DIRC) made from three high-quality BABAR-DIRC bars
- use same glue as BABAR-DIRC (Epotek 301-2)

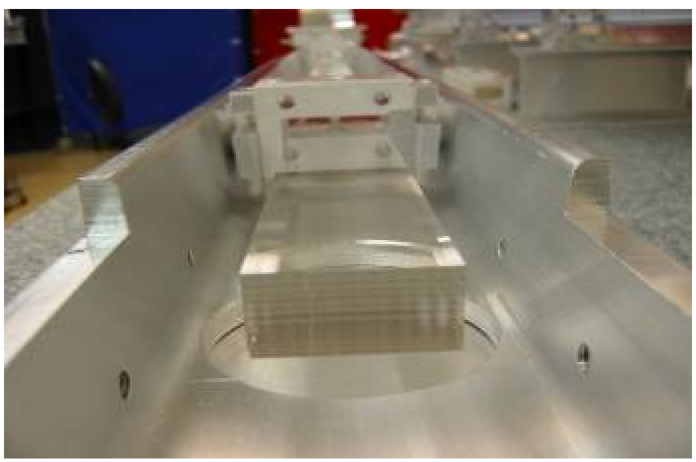
Expansion region

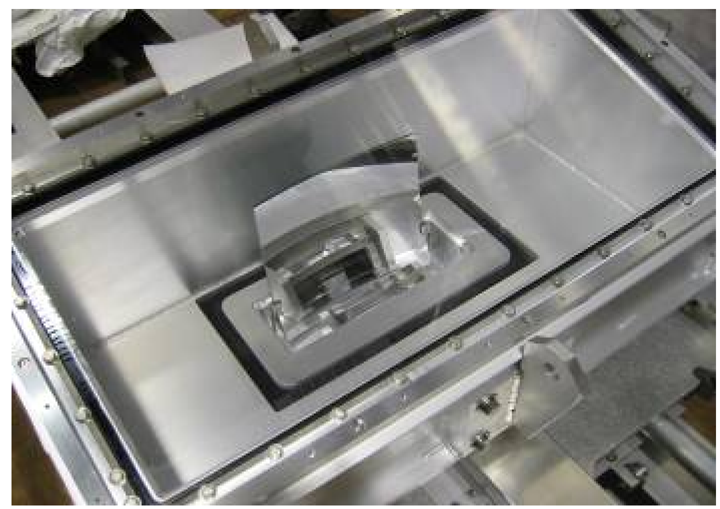
- coupled to radiator bar with small fused silica block
- filled with mineral oil (KamLand experiment) to match fused silica refractive index
- include optical fiber for electronics calibration

Focusing optics

- spherical mirror with 49.2 cm focal length focuses photons onto the detector plane.




Radiator bar


Expansion Region

Photon detectors

(→ NIM A 553 (2005) 96)

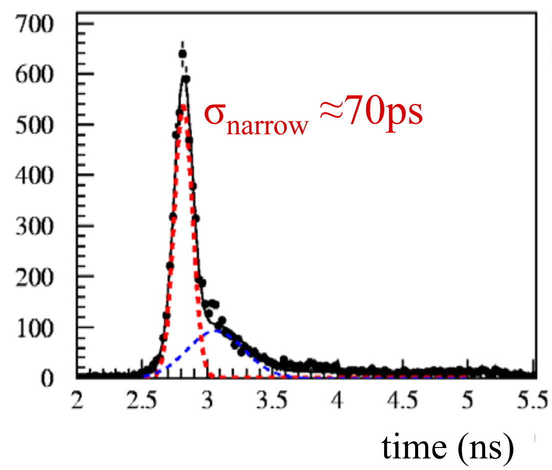
Our research has identified several detectors which have:

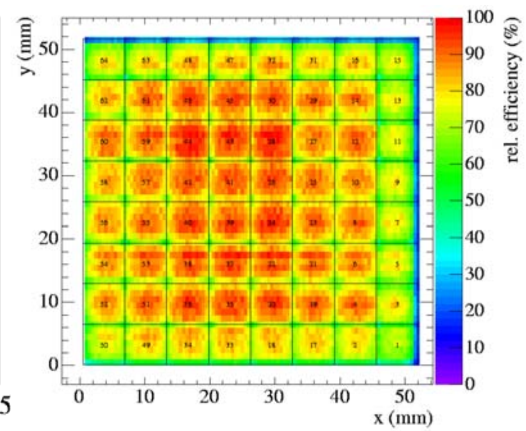
- Good timing resolution (transit time spread < ~200ps), about 10x better than BABAR-DIRC PMTs.
- Small pixel size (6x6mm and 12x3mm)
  →allow for smaller expansion region
- Good detection efficiency and uniformity.

The following three detectors are currently in the prototype:

Burle 85011-501 MCP-PMT (6x6mm pixels)

1)

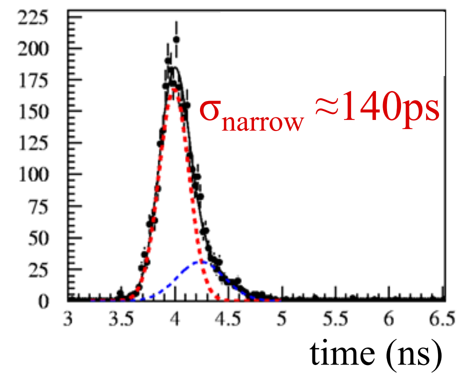


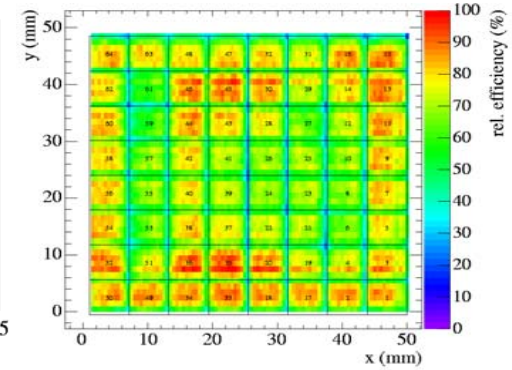


PHOTON DETECTORS

Hamamatsu H-8500 Multianode PMT (6x6mm pixels)

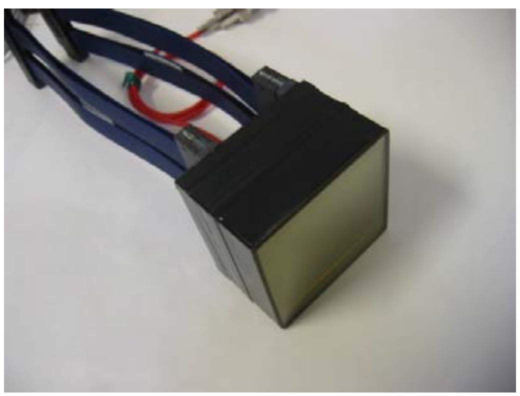
2)

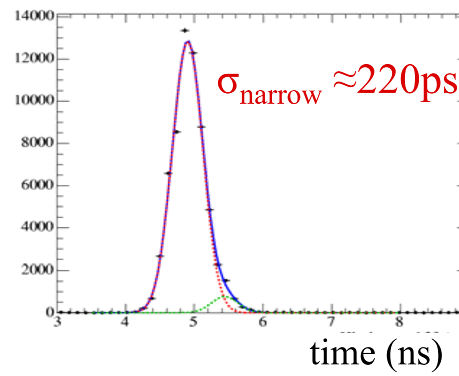


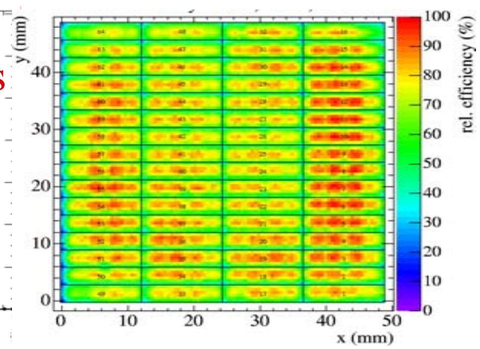


Hamamatsu H-9500 Flat Panel Multianode PMT (12x3mm pixels)

3)







➢These timing resolutions were obtained using a fast laser diode in bench tests with **single photons** on pad center.

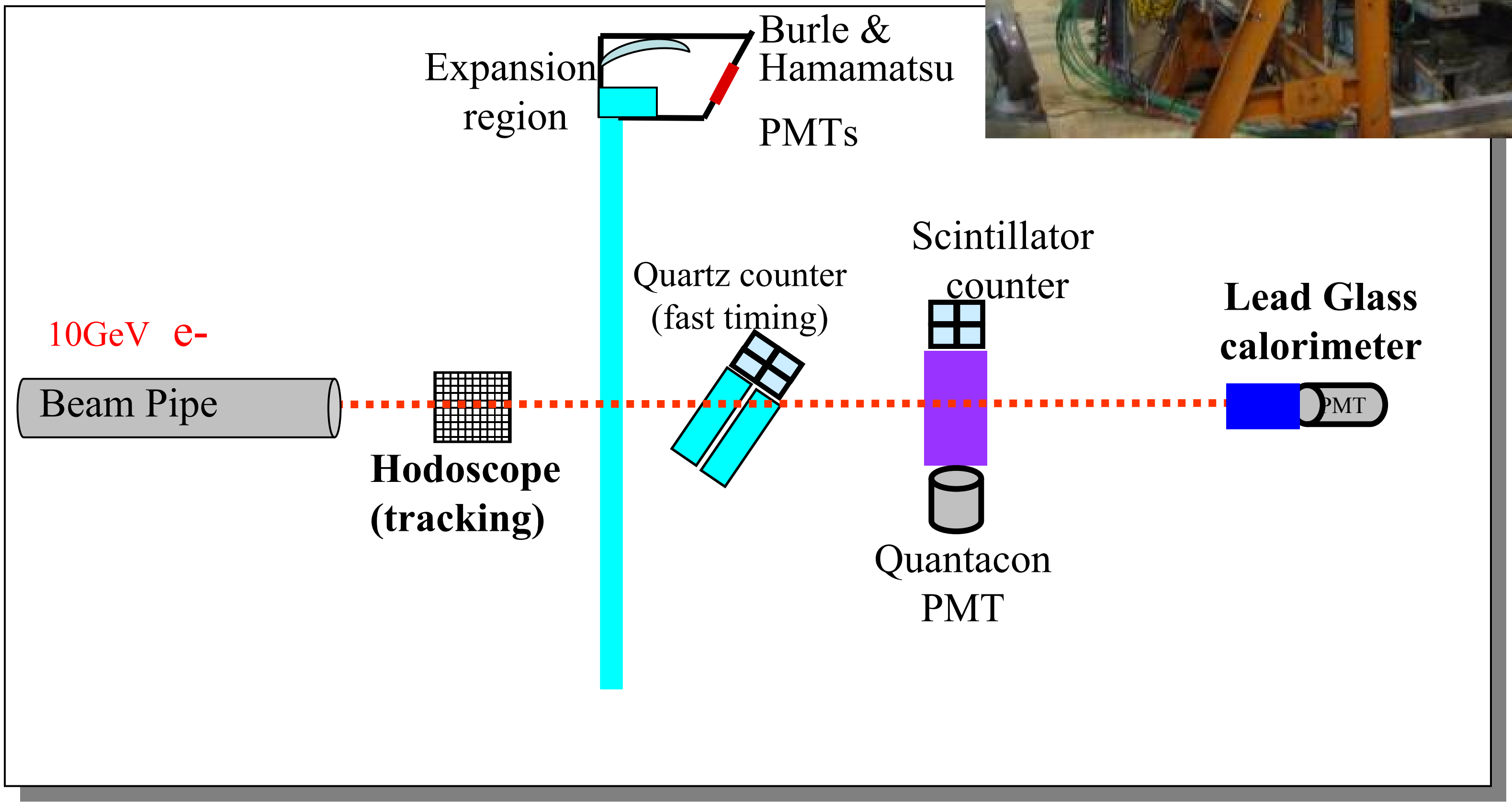
Beam Test of the Prototype

Beam Test

Experimental Setup:

- Prototype is located in the beam line in End Station A at SLAC, third beam test conducted this past July.
- Accelerator delivers low intensity 10 GeV/c electron beam (e^-)
- Beam enters bar at 90º angle.
- Prototype is movable to 7 beam positions along bar.

End Station A

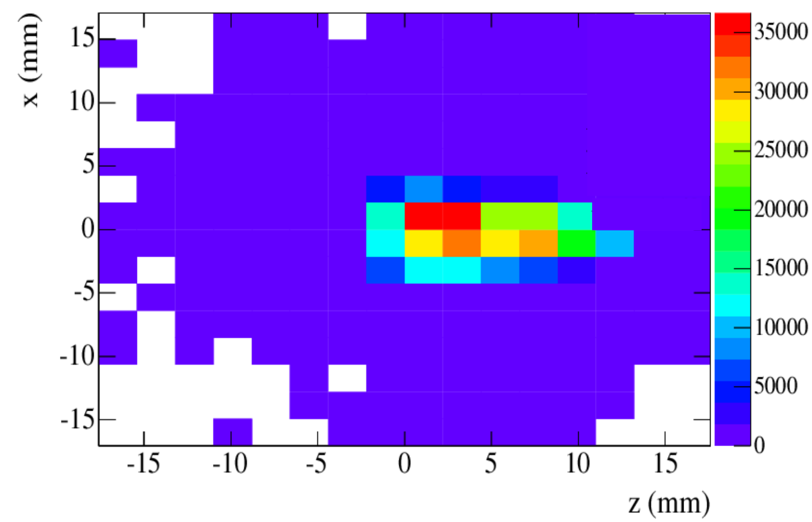


Beam Detectors

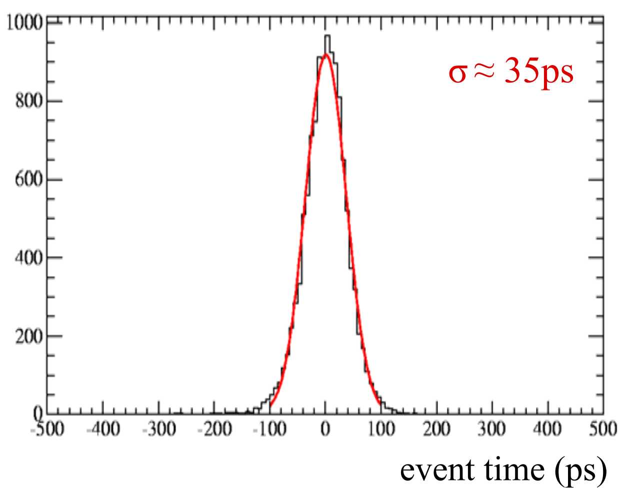
Event analysis:

- ➢ require single track signal in hodoscope.
- ➢ require charge in lead glass to be consistent with single electron.
- ➢The trigger is obtained from the linac RF signal.

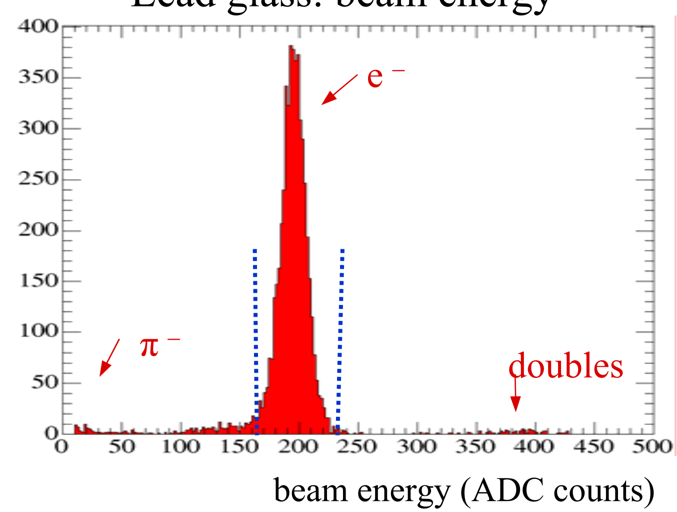
Hodoscope: Beam Position



Start counters: event time

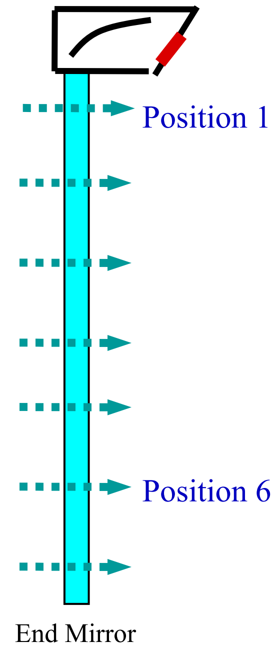


Lead glass: beam energy

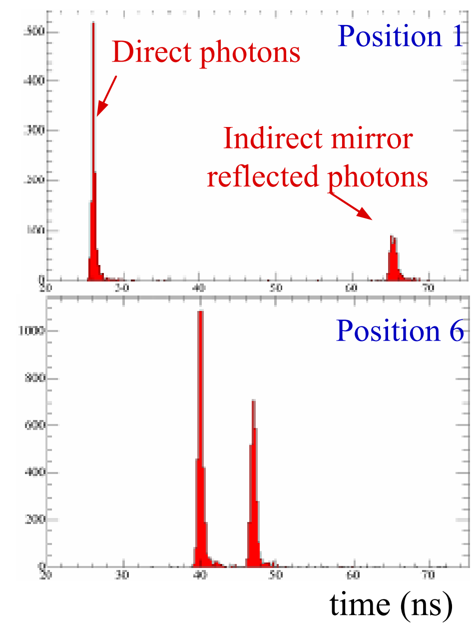


Cherenkov Photons

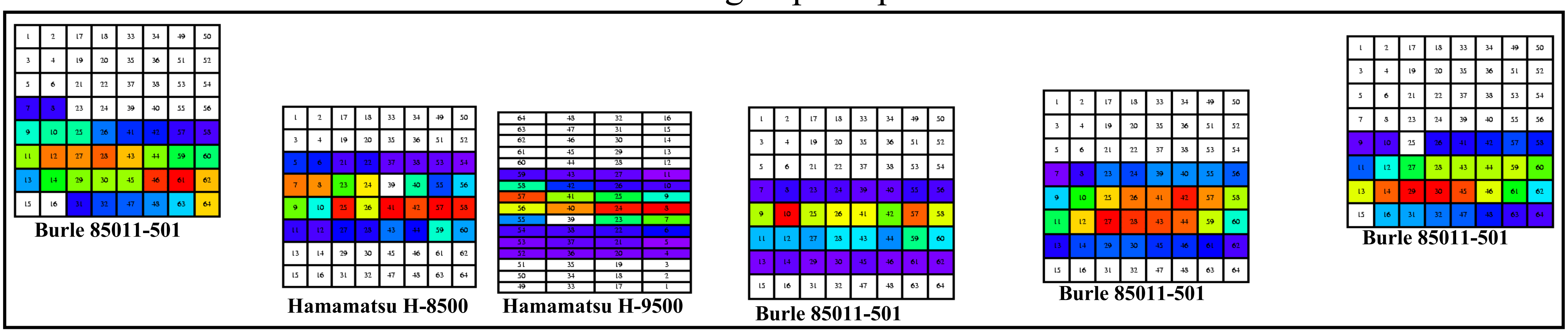
- Almost 200 pixels are instrumented around the expected ring image.
- Time of propagation measurement allows one to determine if the photon is direct or indirect (end mirror reflected).
- As a function of path length the time distribution spreads out due to chromatic dispersion and the number of photons decreases due to absorption.
- Ring image is most narrow in the 12x3mm pixel detector.



Propagation time



Cherenkov ring in pixel plane



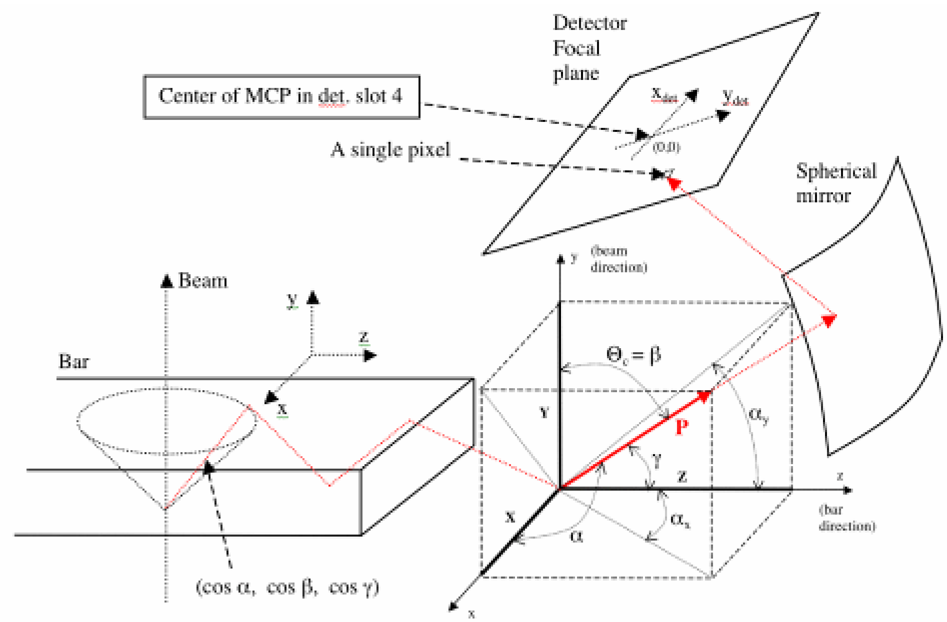
DIRC Reconstruction

➢DIRC detectors have the property that they can be simply ray-traced into the bar or track coordinate system.

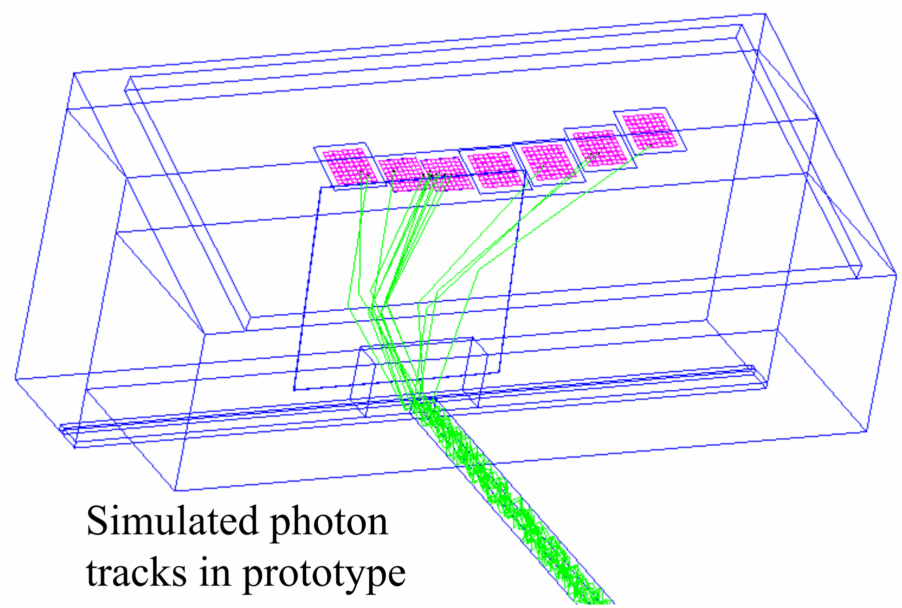
→Each detector pixel defines the photon track parameters:

θ_c, ϕ_c, path length L, # of bounces, cos α, cos β, cos γ,

➢We use GEANT4 simulation and stand-alone ray-tracing software to obtain photon track parameters for each pixel.



Prototype coordinate systems.



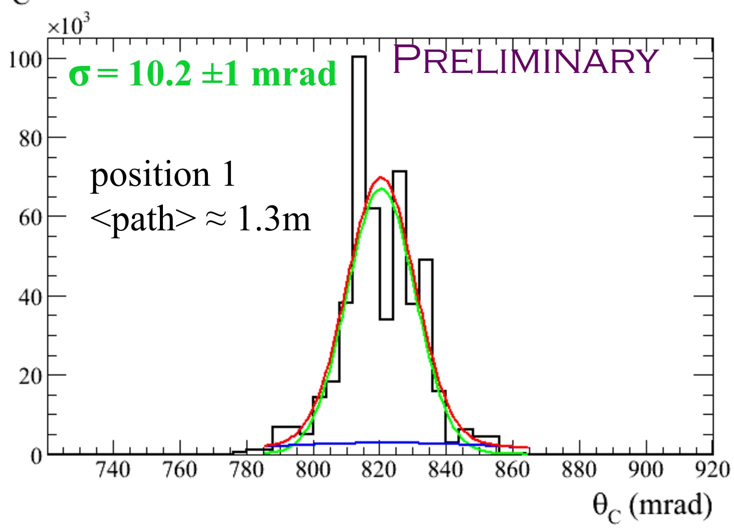
Simulated photon tracks in prototype

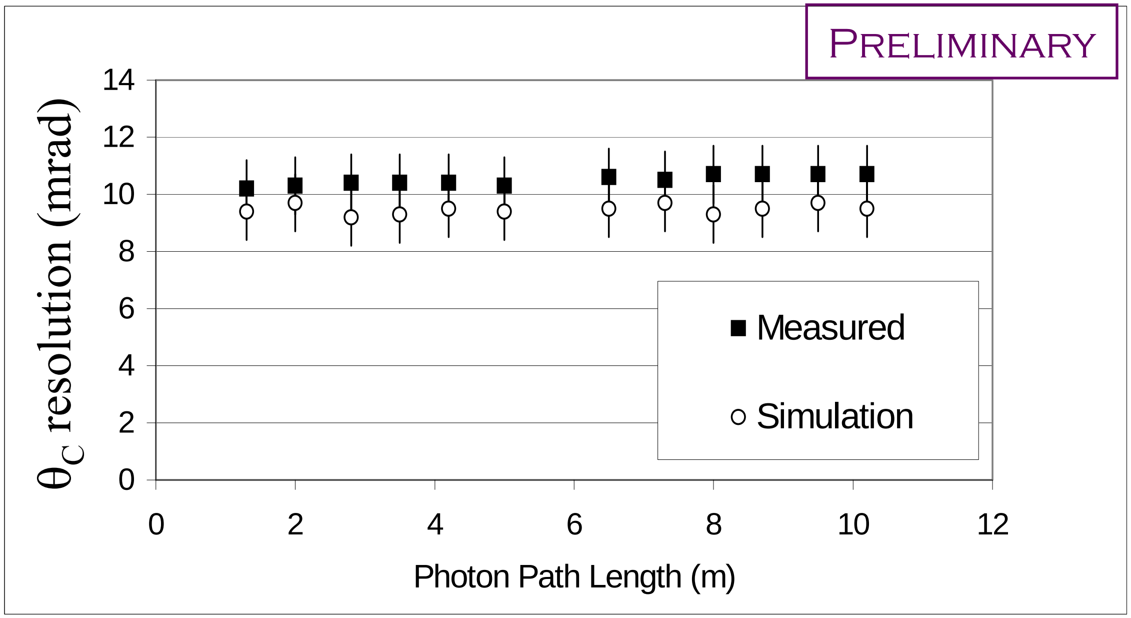
Preliminary Results: Single photon θ_c resolutions

ThetaC Resolution (Geometric)

Take the θ_c angle assigned geometrically to each pixel and combine all pixels to determine the width of the Cherenkov ring.

θ_C Distribution





➢Pixelated distribution due to relatively large pixel size.

➢Contributions to this resolution include:

1)chromatic smearing : ~ 3.5mrad,

2)pixel size : ~5.5mrad ,

3)optical aberrations : grows from 0 mrad at ring center to 9 mrad in outer wings of Cherenkov ring. (due to focusing mirror)

ThetaC Resolutions (using TOP)

Cherenkov angle from time of propagation (TOP)

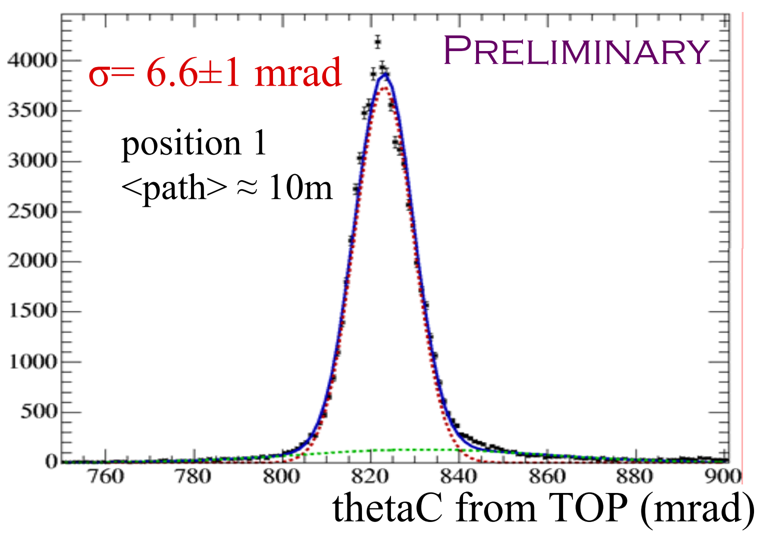
- Use measured TOP for each pixel and combine with the associated path length L to get group velocity

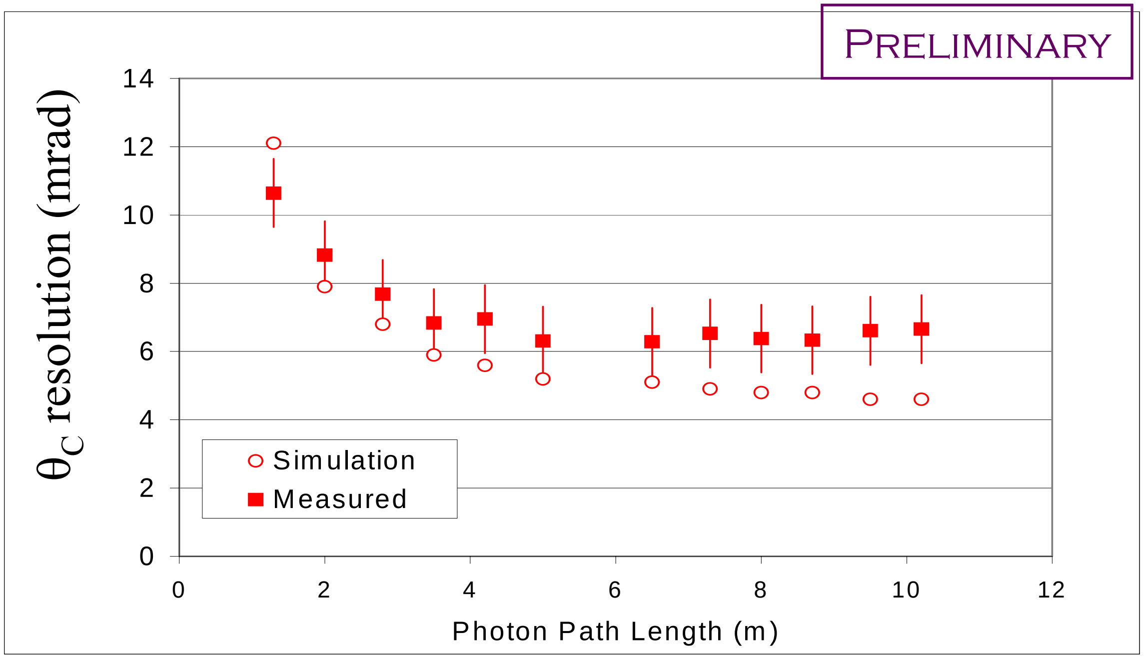
  v_g=L/TOP → $n_g=c_0/v_g$ → $n=n(n_g)$ → $\theta_c=\cos^{-1}(1/\beta n(\lambda))$ (Assume β=1 for 10GeV e-)

  where n_g is the group index of refraction and n is the (phase) index of refraction.

- Resolution of θ_c from TOP is quite good (6-7mrad for photon path length above ~4m).

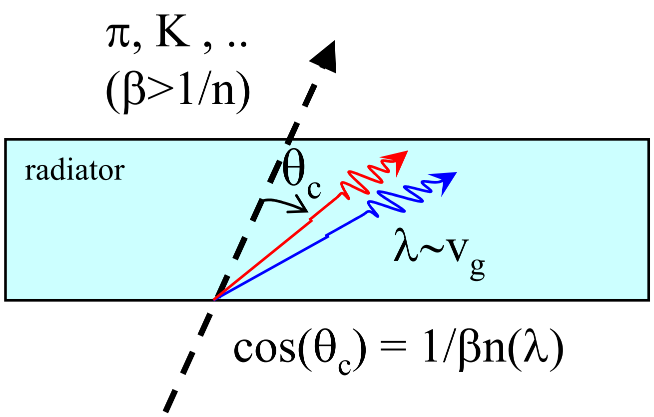
- This measurement is useful for checking the effect of timing resolution on θ_C, however it cannot be used for PID purposes because it assumes the particle ID (β=1).



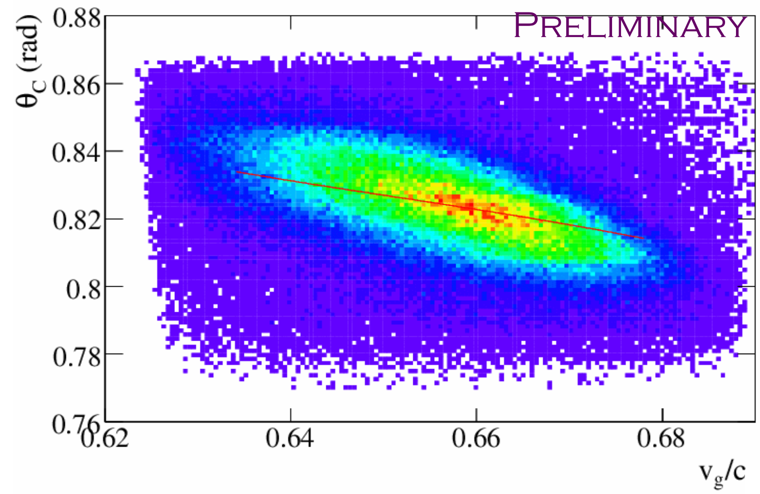


Chromatic Correction

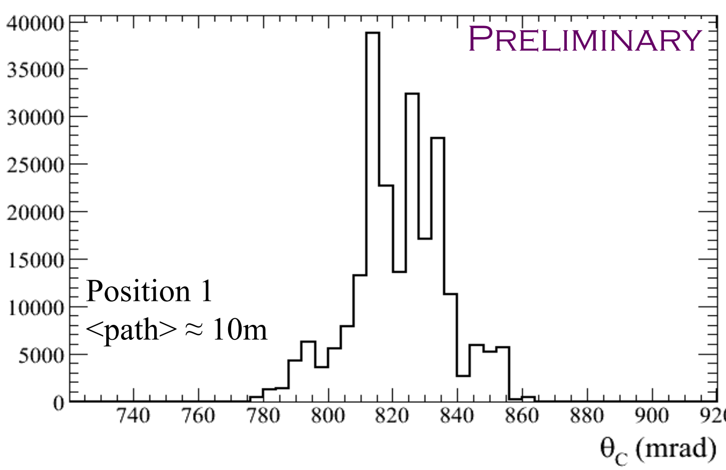
The theory of Cherenkov radiation predicts a smearing of θ_c due to different wavelengths produced, however there is correlation between θ_c and the wavelength λ of the photons. If we can measure this correlation we can correct θ_c. In practice we use the group velocity $v_g(\lambda)$=L/TOP instead of λ because it is easily measurable; v_g is equivalent to λ since there is a one-to-one map between them .



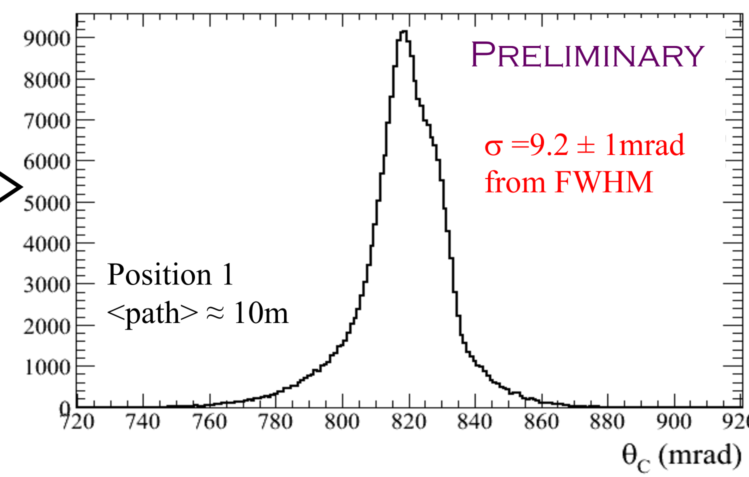
θ_C vs. v_g



θ_C Geometric Uncorrected



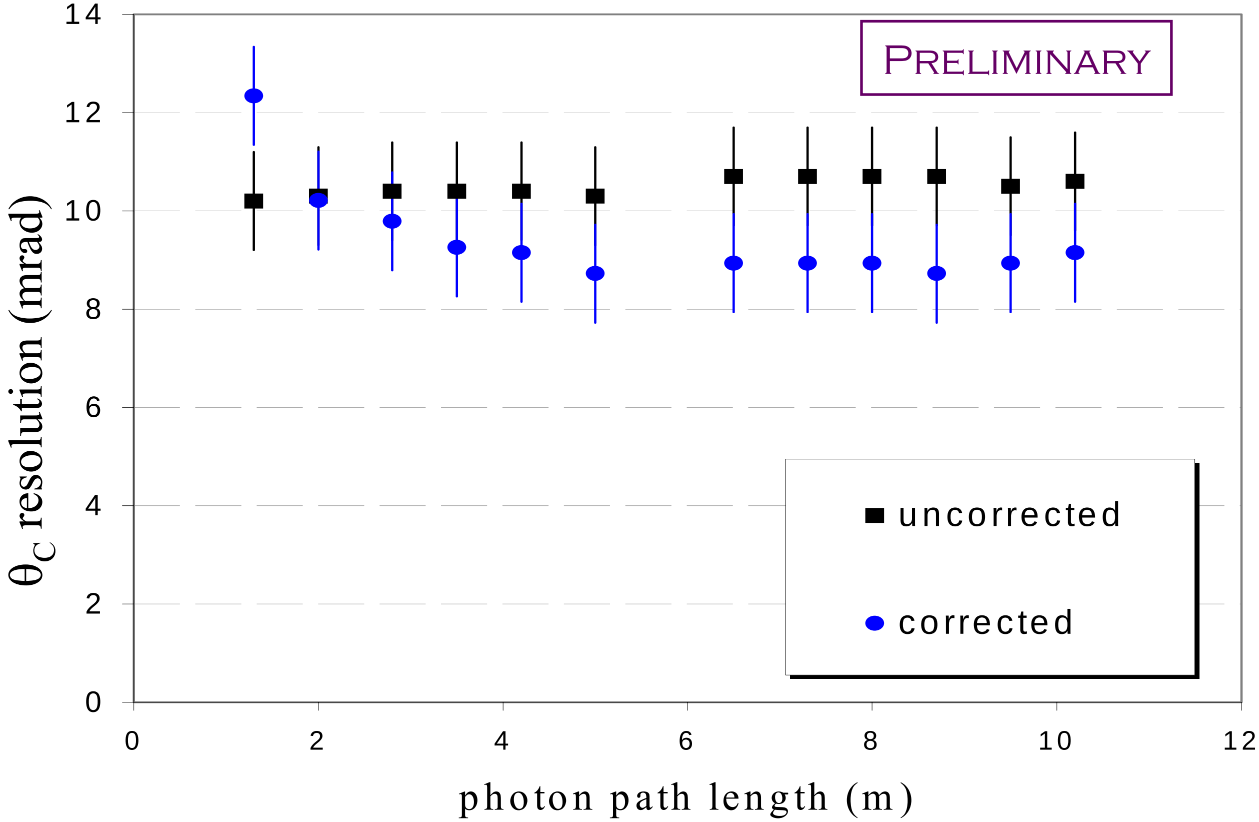
θ_C Corrected



Corrected thetaC vs. Path Length

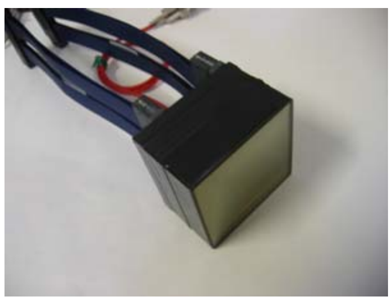
➢Chromatic correction improves the geometric θ_C resolution by about 2 mrad for the long paths.

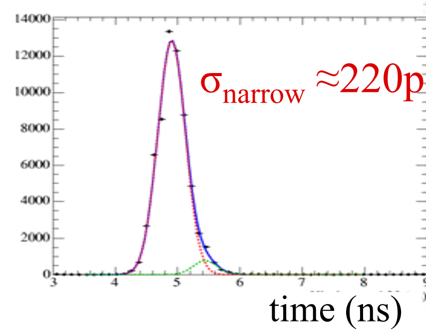
➢This correction starts to work after about 2 m, below this path length the group velocity resolution is not good enough.

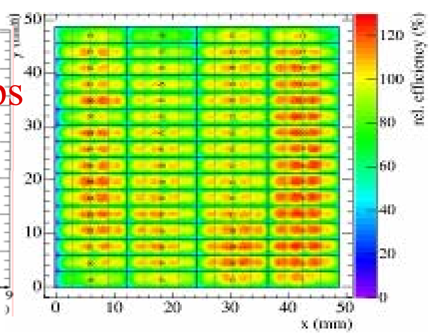


Performance of the 12x3 mm pixels

Hamamatsu H-9500 Flat Panel Multianode PMT

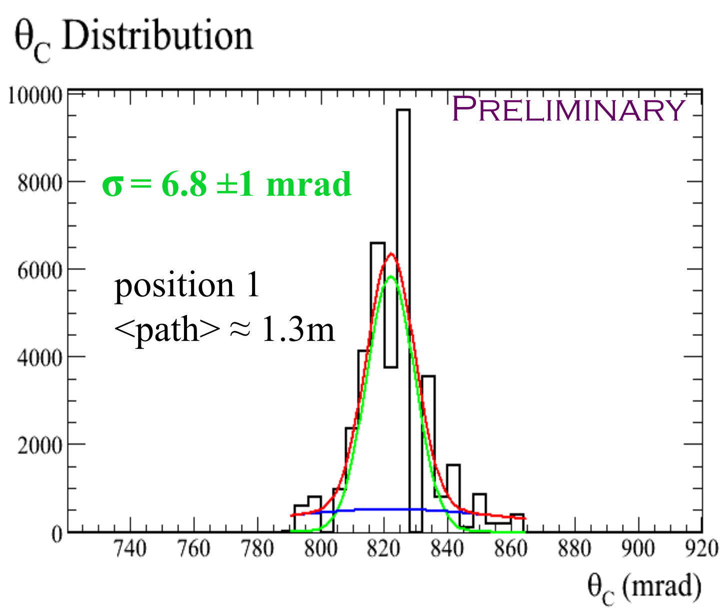


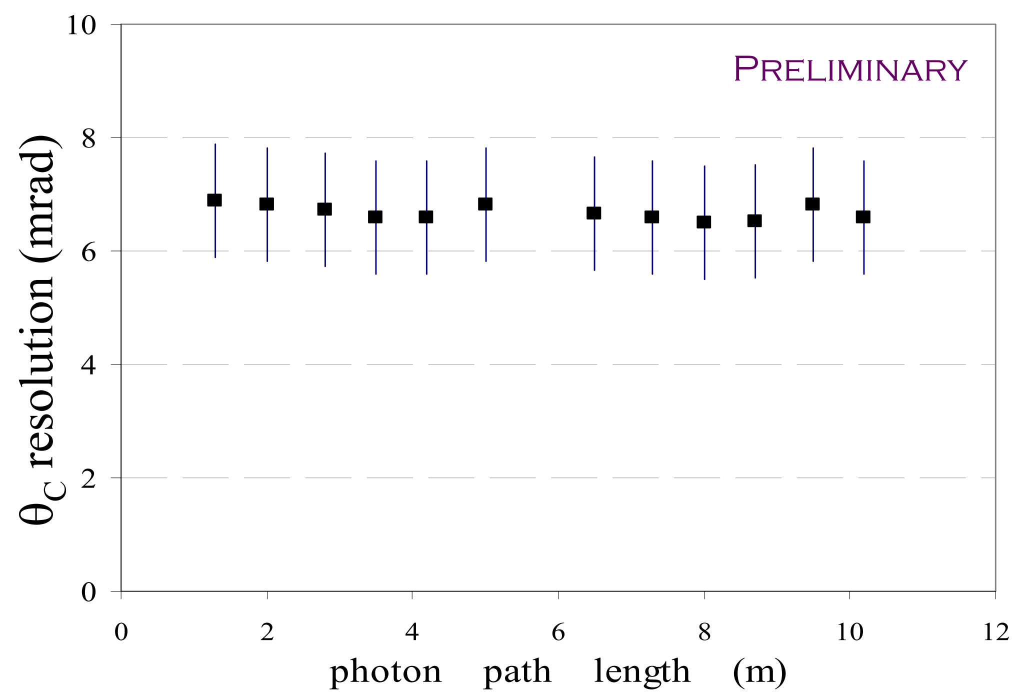




θ_C Resolutions (12x3mm pixels)

- Due to smaller size of pixel in the y direction we have better θ_C resolution with this detector (< 7 mrad).
- Pixelization effects are less visible.

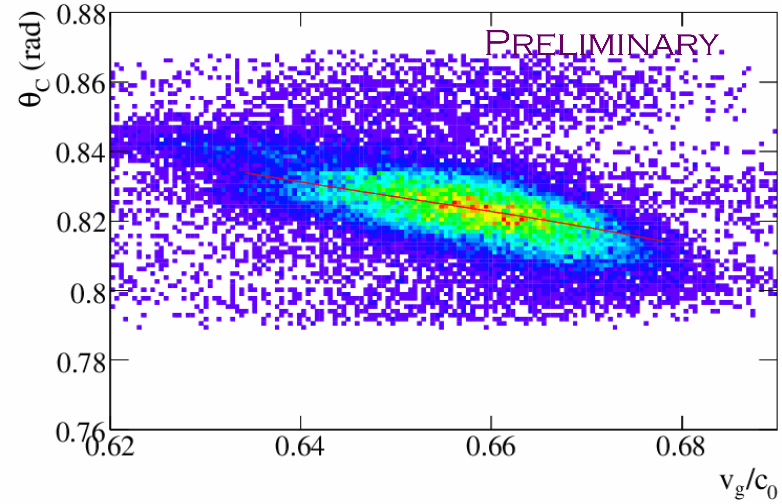




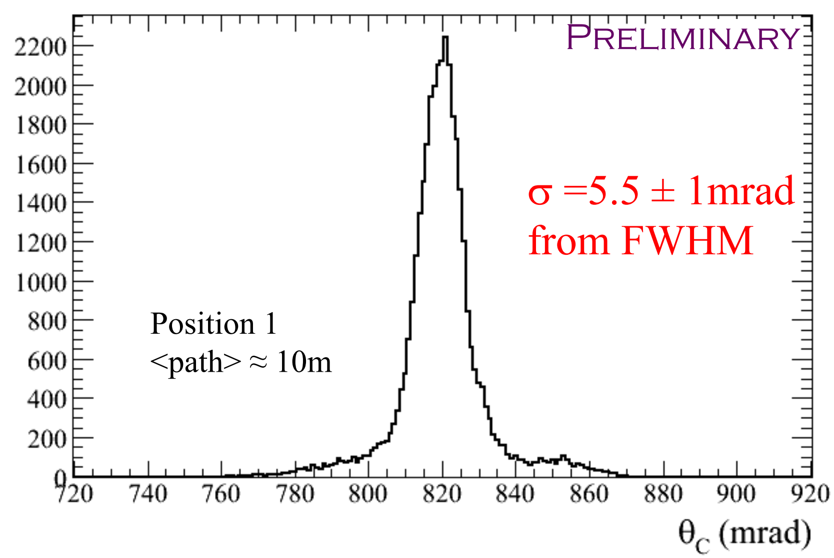
Corrected θ_C Resolutions (12x3mm pixels)

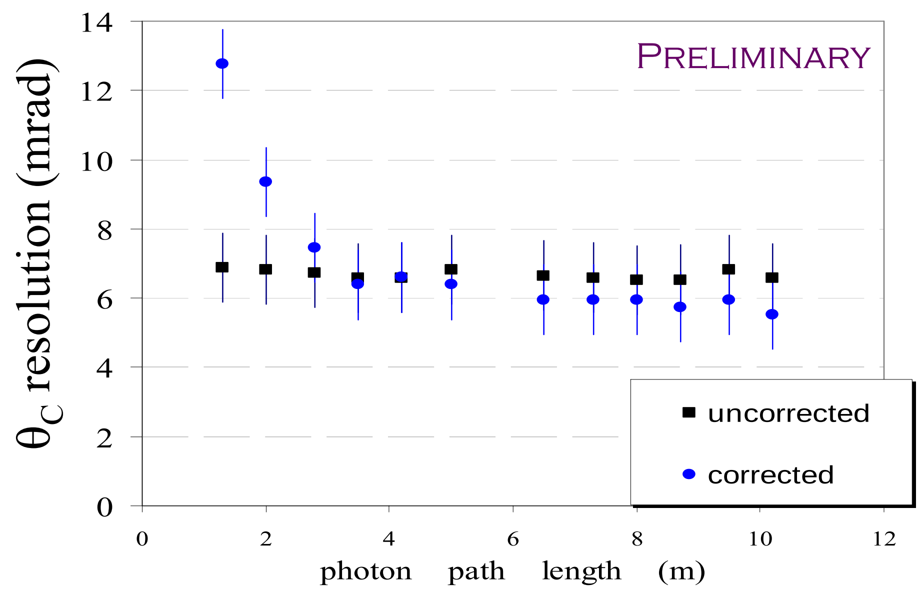
- The correlation of θ_C with v_g follows the expected curve.
- The amount of correction is about 1 mrad for the longest path lengths.
- Quadratic difference is 3-4 mrad consistent with the expected chromatic smearing.
- The chromatic correction starts to work at about 3m.

θ_C vs. v_g



θ_C Corrected





Conclusions & Outlook

- We have demonstrated that we can measure the correlation of θ_C with v_g and thereby correct for chromatic smearing of θ_C. This is the first RICH detector which has been able to do this.

- Focusing DIRC R&D has identified several PMTs capable of delivering single photon timing resolution on the order of ~100ps, with good uniformity and efficiency.

- 3D (θ,ϕ,t) readout makes the system more robust and helps with backgrounds and calibrations.

- For the case of 6x6mm pixels, our θ_C resolutions measured in the beam test are quite competitive with BABAR-DIRC implying this detector is capable of obtaining comparable PID resolutions.

- In the case of 12x3mm pixels the θ_C resolution is considerably better than BABAR-DIRC.

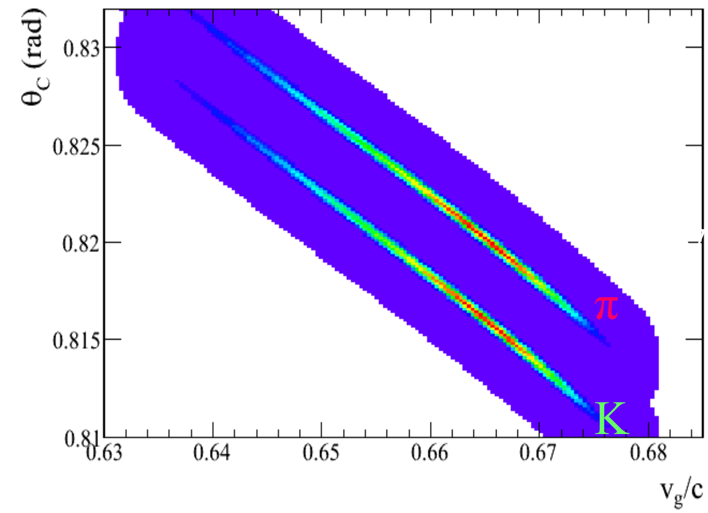
- Remaining questions include: behavior in magnetic fields, aging, rate capability.

- Next beam test of prototype is scheduled for 2007:
  - 12x3mm pixel detectors in all slots
  - Improved readout (add ADC information)

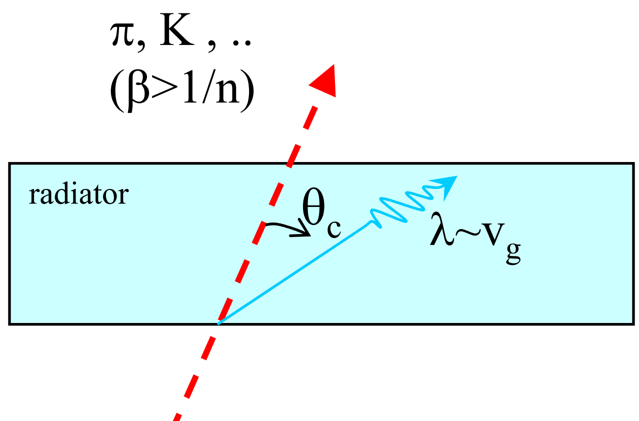
Backup Slides

Principle of Chromatic Correction

The theory of Cherenkov radiation predicts a correlation between θ_c and the λ of the photon. In practice we use the group velocity (v_g) since there is a 1-1 map between v_g and λ.



Consider π's and K's of p=5GeV traversing a radiator and assume we can measure both θ_c and v_g precisely.

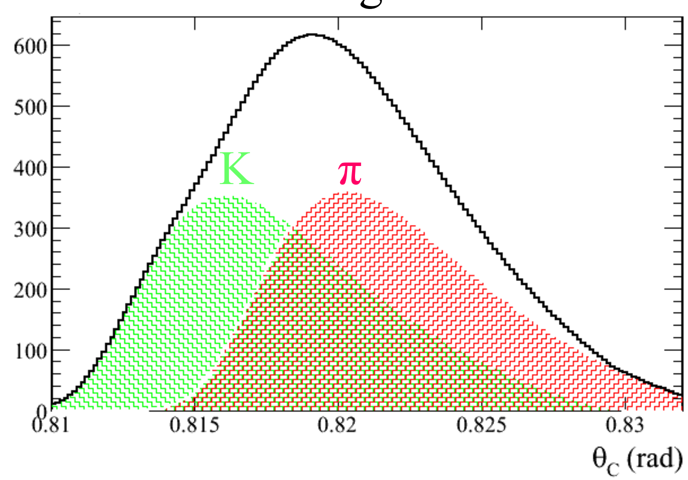


$$\cos(\theta_c) = \frac{1}{\beta n(\lambda)}$$

$$N(\lambda) \propto \left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right)\frac{1}{\lambda^2}\varepsilon(\lambda)$$

$$v_g = \frac{c}{n_g(\lambda)} \qquad n_g \equiv \frac{1}{1 + \frac{\lambda}{n}\frac{dn}{d\lambda}}$$

Simple projection on θ axis: Particles are merged.



Projection after Rotation: Particles are separated