The **F**ocusing **DIRC** prototype, an innovative detector for charged **P**article **ID**entification

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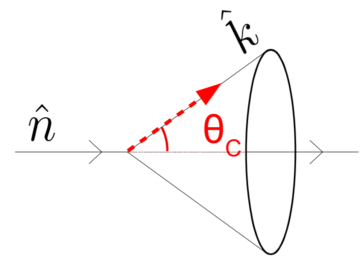
Outline

- From the BaBar DIRC to the Focusing DIRC
- Imaging photons with a complex folded optics
- Construction of the first FDIRC prototype
  - optics and electronics
- The FDIRC prototype at the SLAC Cosmic Ray Telescope (CRT)
- Data analysis method and preliminary results

DIRC detector concept

Detector for Internally Reflected Cherenkov light

$$\cos\theta_C = \frac{1}{n\beta}$$

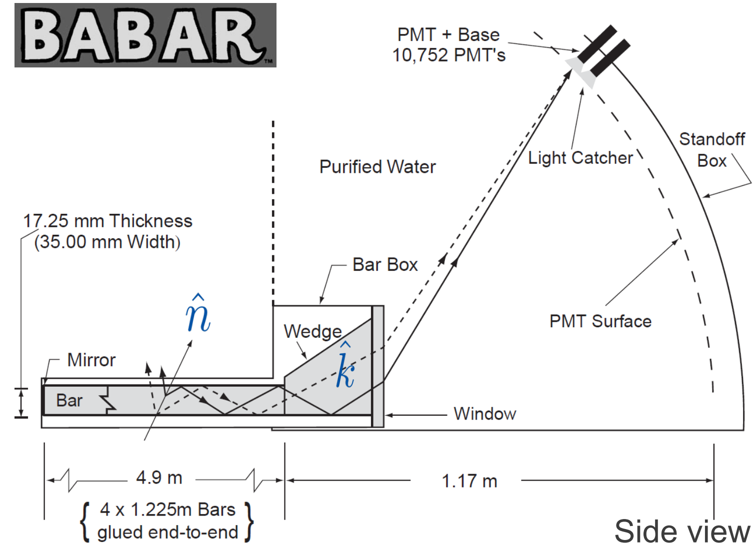


<u>Principle of measurement:</u>

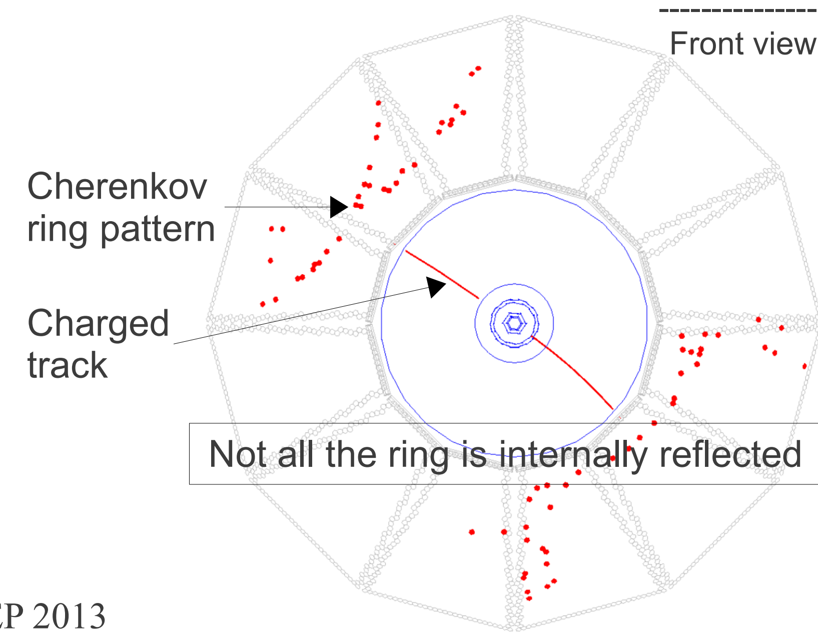
$$\cos\theta_C = \hat{n}\cdot\hat{k}$$

$\hat{n}$: given by tracking
$\hat{k}$: the main (F)DIRC challenge
→ photon paths unknown

BABAR



- 144 quartz bars forming a **barrel** around the IP
- A part of the Cherenkov photons produced inside the bar is carried out of the barrel via internal reflection
- There, an imaging camera filled of water measures $\hat{k}$



<u>BaBar Performance</u>:

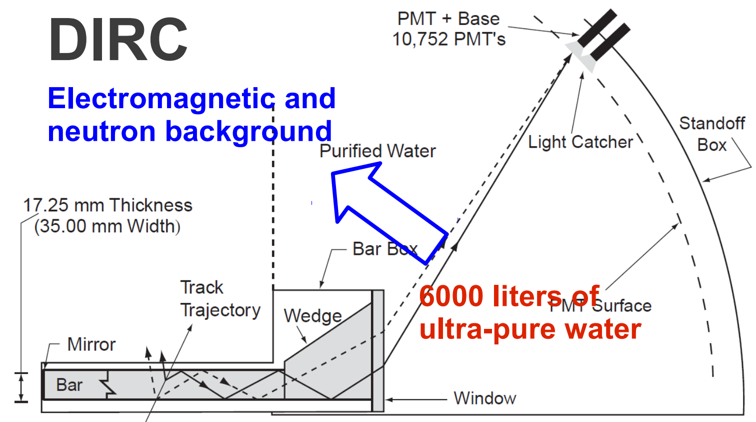
- Single photon θ_c resolution of 9.6 mrad
- Measured time resolution of 1.7 ns
- N_{pe}~23 for a 90° track of β=1
- Performed reliably for ~10 years

➡ **π/K separation above 2.5 σ up to a momentum of 4.2 GeV**

http://dx.doi.org/10.1016/j.nima.2013.05.107

The Focusing DIRC

Challenge for future experiments:
Retain DIRC PID performances while dealing with ~100×luminosity (~10^{36} $cm^{-2}s^{-1}$)



New Optical Camera

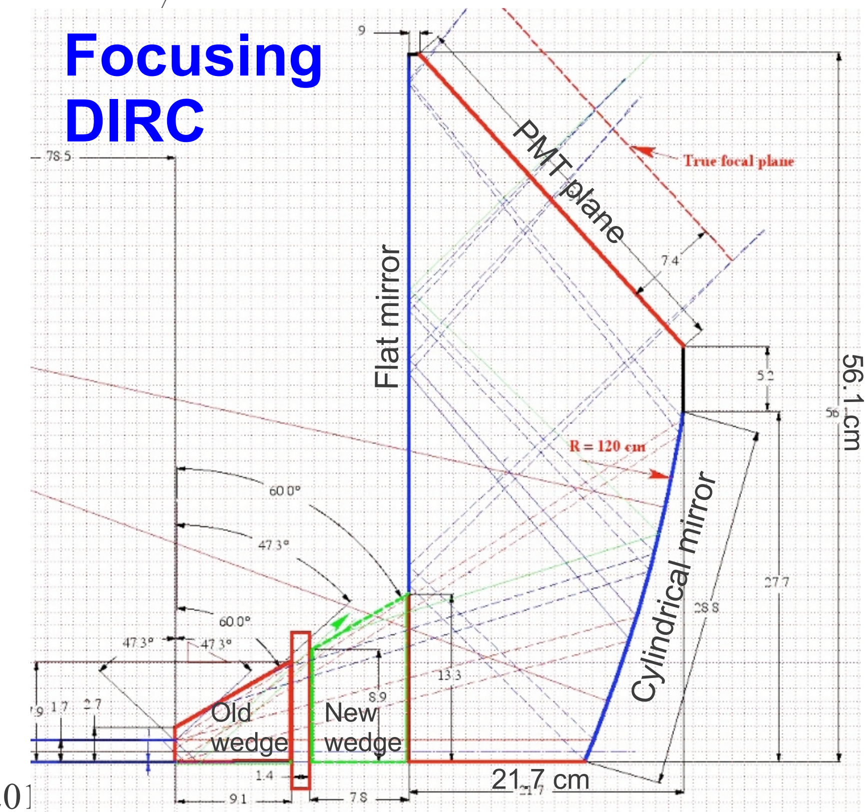
- 25 times smaller
- Radiation-resistant fused silica
- Modular cameras (with reflective sides)

BaBar quartz bars reused

- Still in perfect shape
- Reduce overall detector cost
- The design would have been different if the detector would have been built from scratch

New H-8500 MaPMTs

- 10 times faster (~200 ps) than in BaBar
- Highly pixelated
- Coupled to new fast digitizing electronics
- Should allow chromatic correction

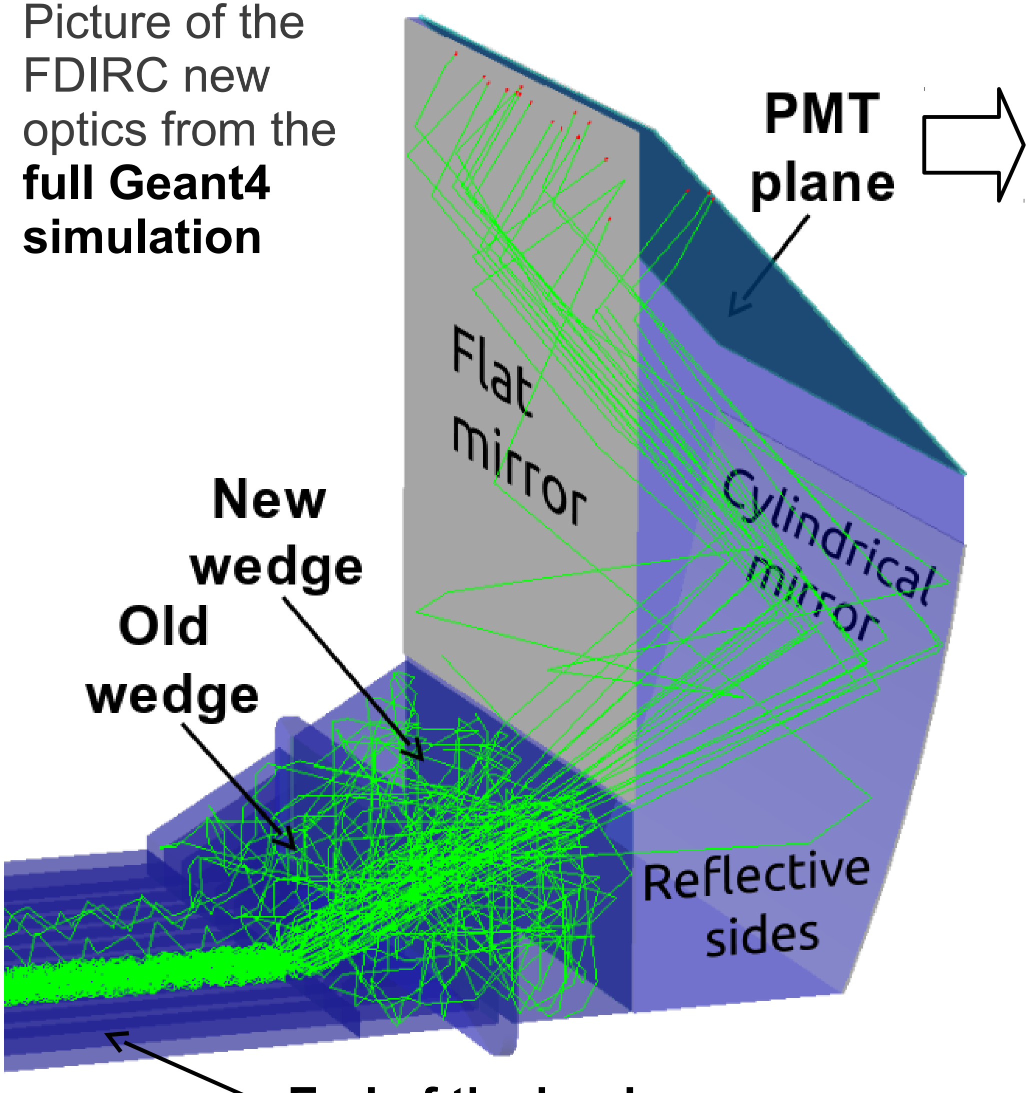


The FDIRC would have been the main PID detector in the barrel region of the SuperB experiment, a project which has been stopped in December 2012

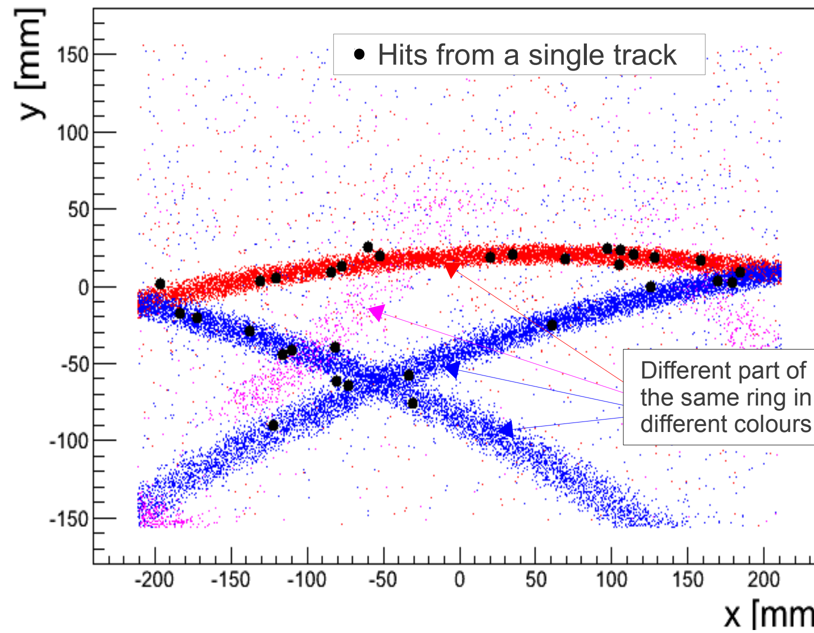
Detailed information about the design in the SuperB TDR published in arXiv: http://arxiv.org/abs/1306.5655

A compact focusing optics

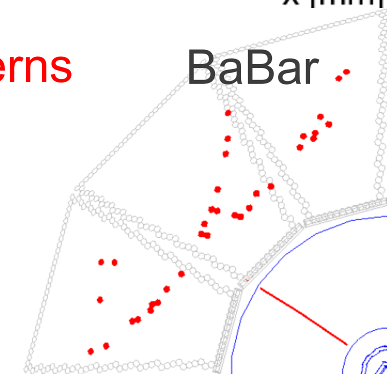
Picture of the FDIRC new optics from the **full Geant4 simulation**



Folded ring patterns



Folded ring patterns



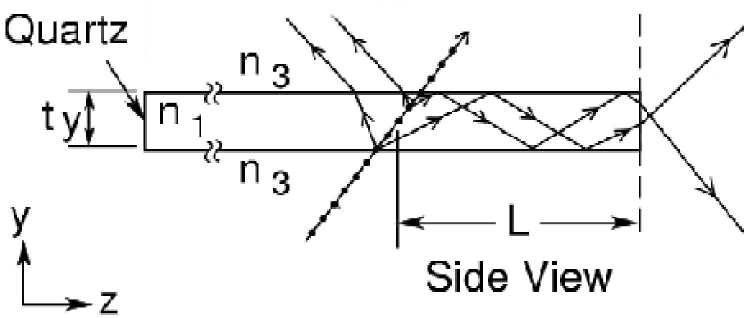
One more coordinate: **time** (thanks to better time resolution)

Disclaimer: no pattern recognition algorithm

$$\cos\theta_C = \hat{n} \cdot \hat{k}$$

A single pixel hit gives multiple k-vector solutions

Bar ambiguities

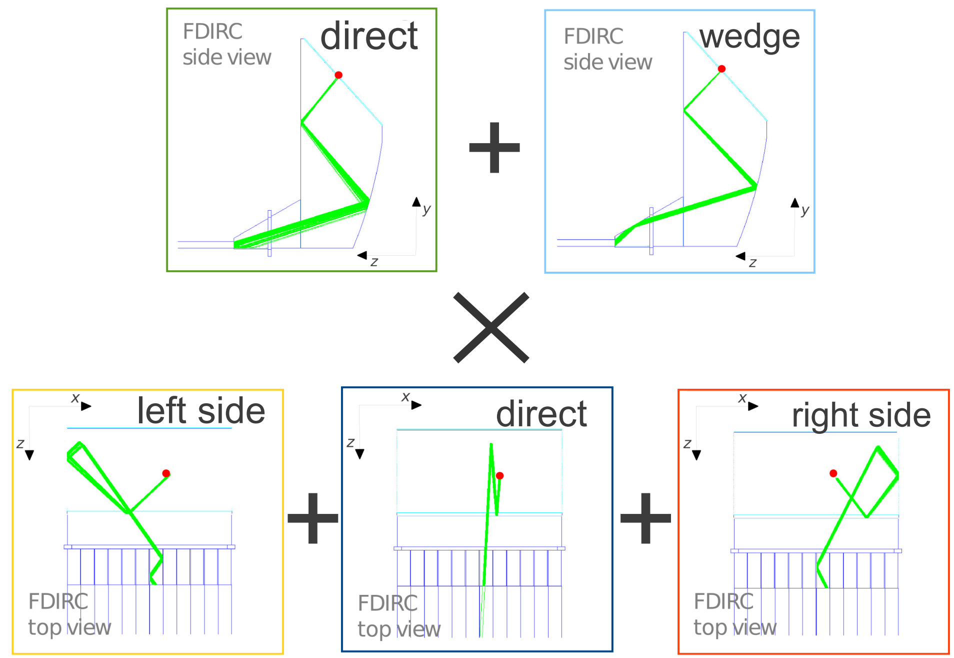


The number of reflections inside the bar is unknown → **sign ambiguity**

$$(\pm k_X, \pm k_Y, \pm k_Z)$$

= 8 ambiguities

New camera ambiguities



= 6 ambiguities

8×6=48 !!

two powerful methods to filter data

Physical Cherenkov angle

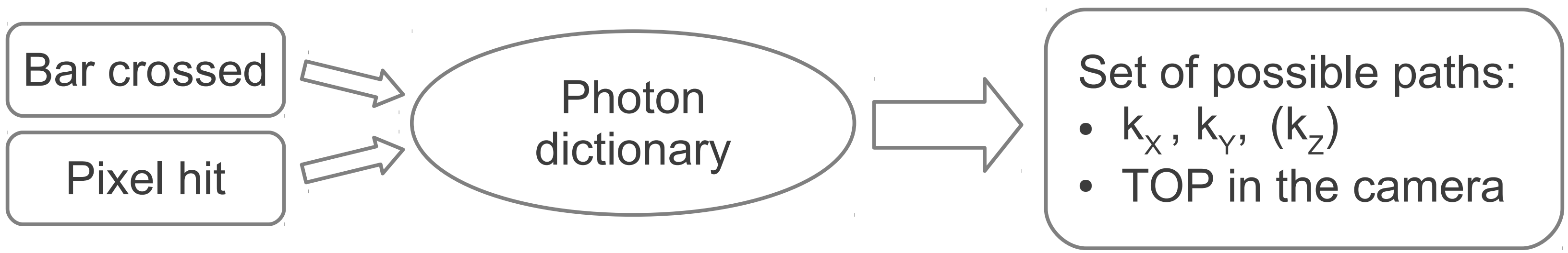
Many ambiguities give impossible values for the Cherenkov angle

$$\beta < 1 \;\Rightarrow\; \cos\theta_C > \frac{1}{n}$$

Time Of Propagation (TOP)

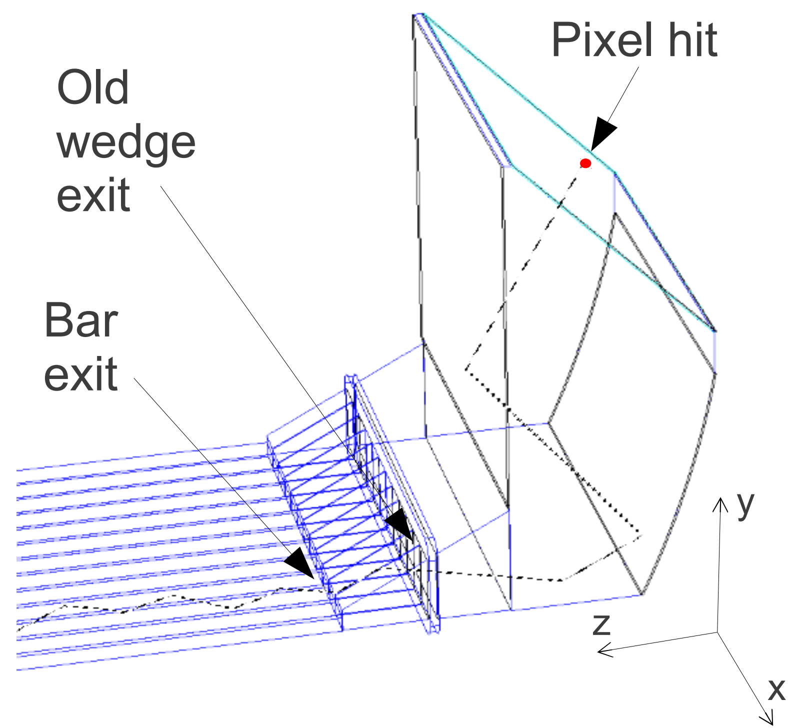
- Compute the expected TOP
  - TOP in the bar with a simple geometrical calculation
  - TOP in the camera from lookup table → *"Photon dictionary"*
- **Compare it to the recorded hit time**

The “photon dictionary” (1)

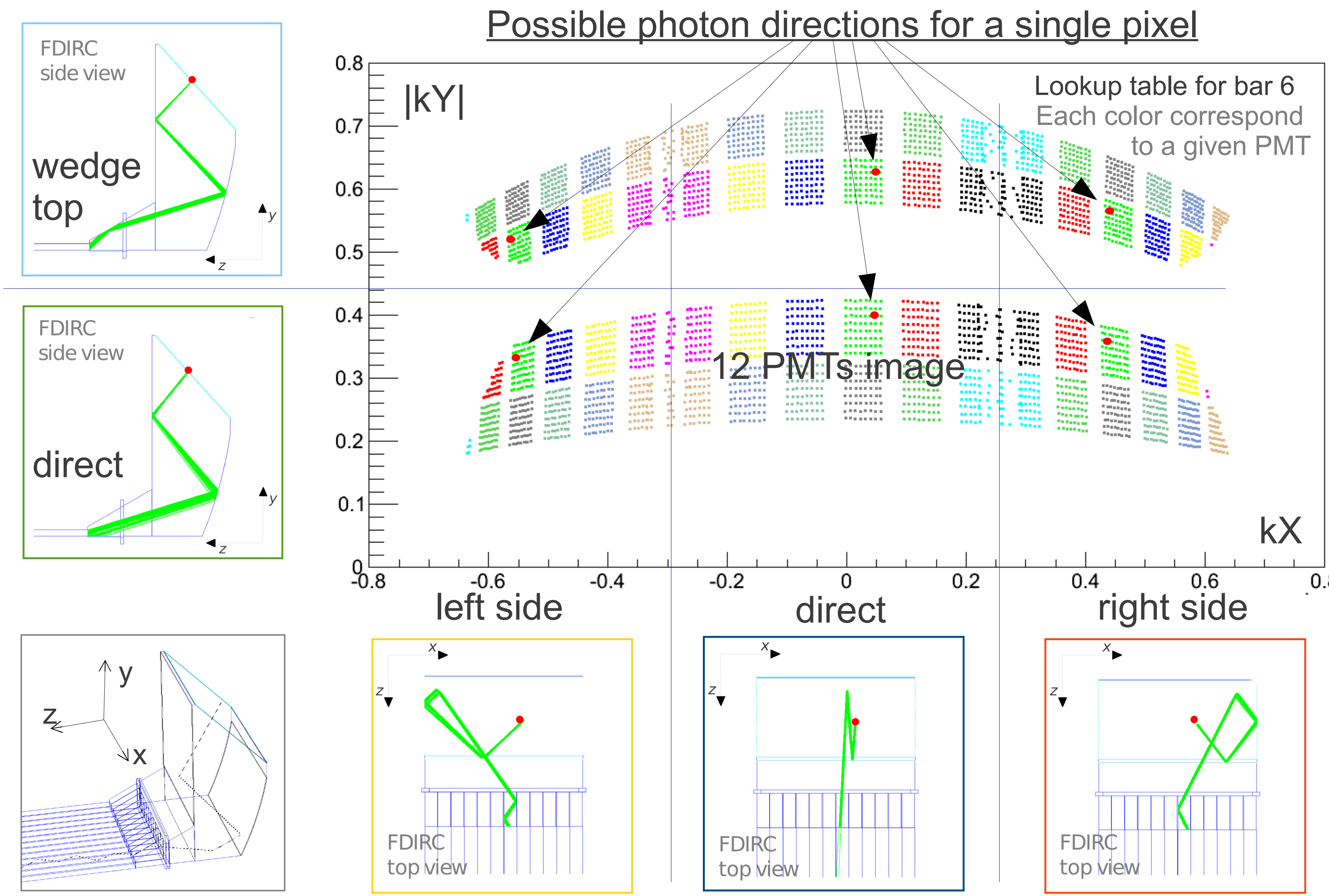


Lookup table built using the Geant4 MC

- Single photons generated in each bar (10^7 photons each)
- { k_X, k_Y, TOP } collected for each hit
- Definition of different paths by clustering single photons
- Best identification of paths using:
  - Absolute k_Y at bar exit
  - Signed k_X at old wedge exit
  - TOP in the camera

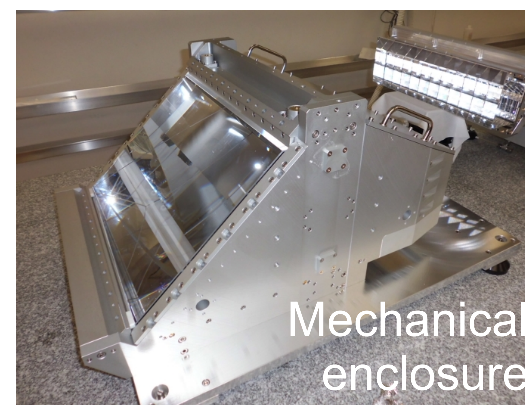


The “photon dictionary” (2)



First FDIRC sector built

- A complete sector has been assembled (12 bars out of 144)
- First radiation-hard fused silica optical block manufactured
    - Heigth ~56 cm, weight ~80 kg
    - Requested surface polishing of 30 Å RMS (8 Å in bars)
    - Mirrors coated with aluminium
    - Optical coupling to wedge with RTV glue (separation possible)
- Mechanical enclosure with all services (HV and LV distributions, data links, etc.)



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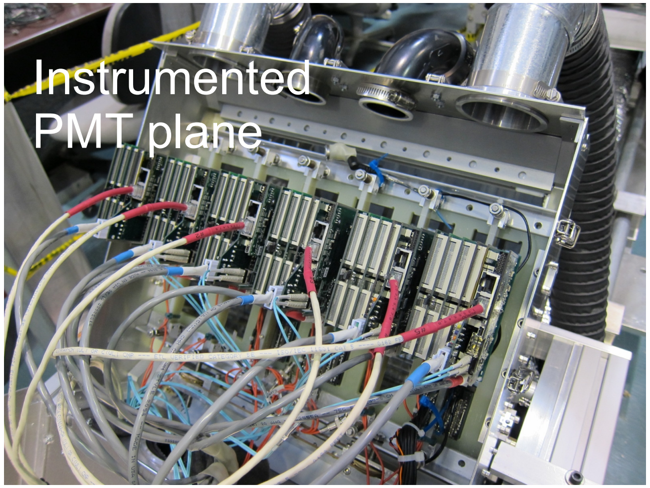
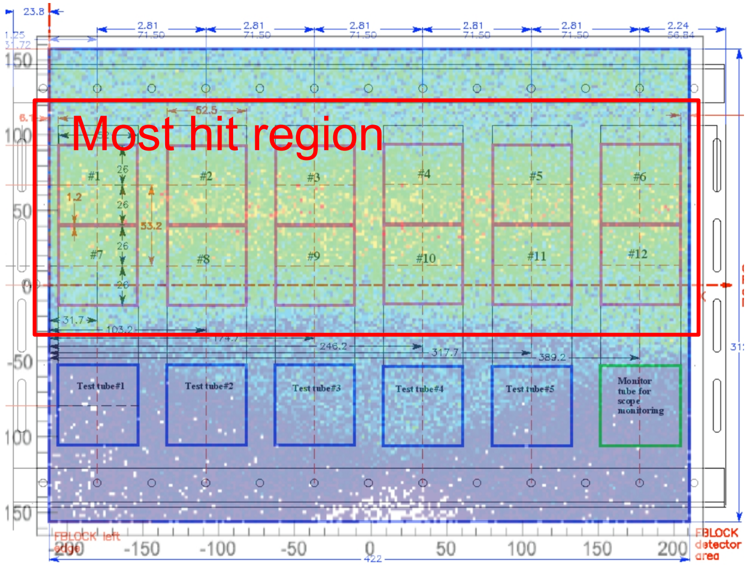
Photon detection

- Photo-detectors
  - 12 **Hamamatsu H-8500** MaPMTs placed in the region most hit by cosmic rays
    (48 needed to complete the sector)
  - PMTs have 64 channels each (6 mm × 6 mm pixels)
  - Transit Time Spread down to ~140 ps
- Electronics
  - **SLAC amplifiers** with a gain of ~40
  - **IRS2 digitizing electronics** (ASIC)
    - 2.7 GHz of sampling rate
    - Analog storage depth up to 12 μs (ring buffer)
    - On-ASIC Wilkinson ADC for digitization
    - Digitized waveforms analyzed offline

G. Varner, presentation at TIPP 2011

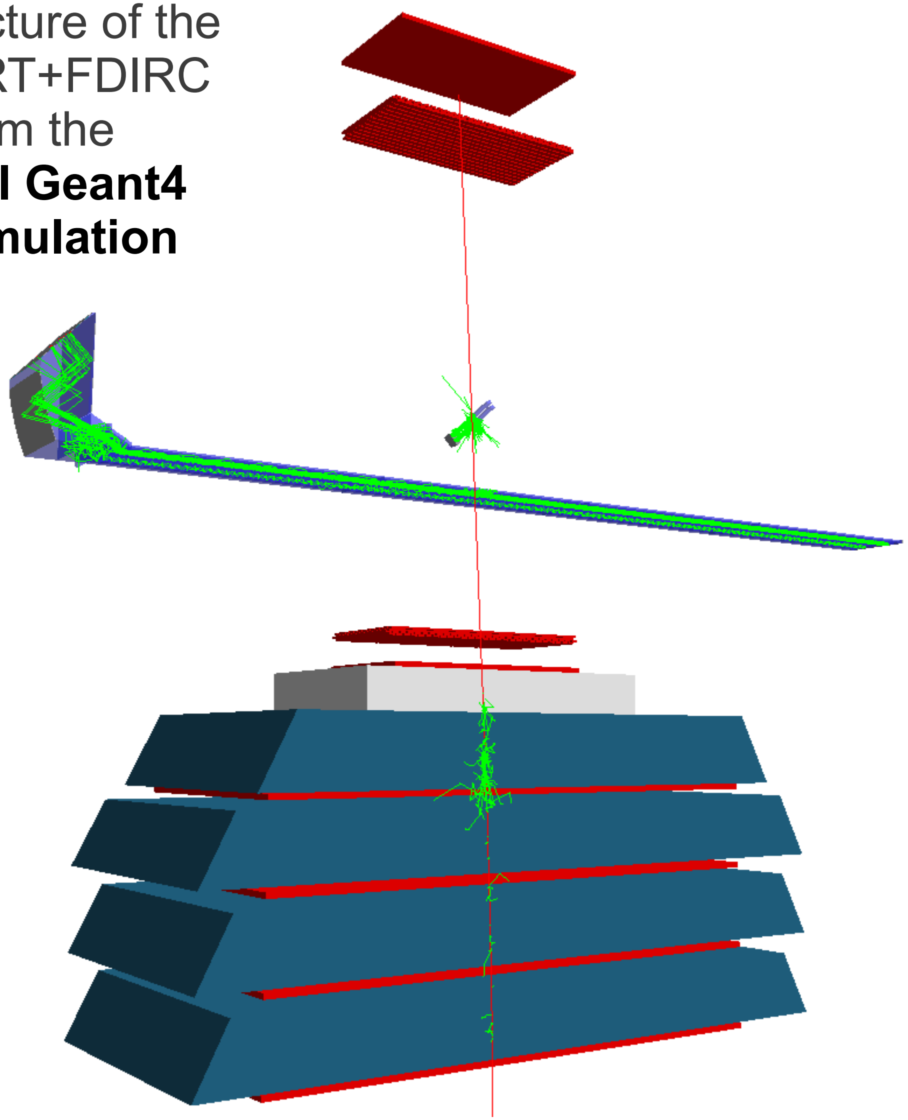
  - Other electronics to be tested after summer on two additional PMTs

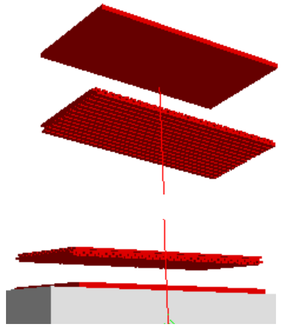




The Cosmic-Ray Telescope facility at SLAC

Picture of the CRT+FDIRC from the **full Geant4 simulation**

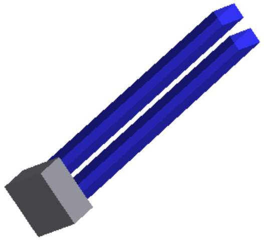




2 large hodoscopes

+ 2 trigger counters
- Angular precision of ~1.5 mrad
- Position resolution at bar level of ~5 mm

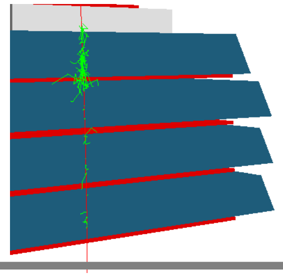
3-D muon tracks



Cherenkov Start-Counter

- Double quartz bar
- 4-pixel MCP-PMT
- Rotated by ~47 deg (direct Cherenkov light)

Time resolution ~90 ps



Absorbers + scintillators

- 4 iron + 1 lead absorbers
- 4 large stack counters

E_μ > 2 GeV

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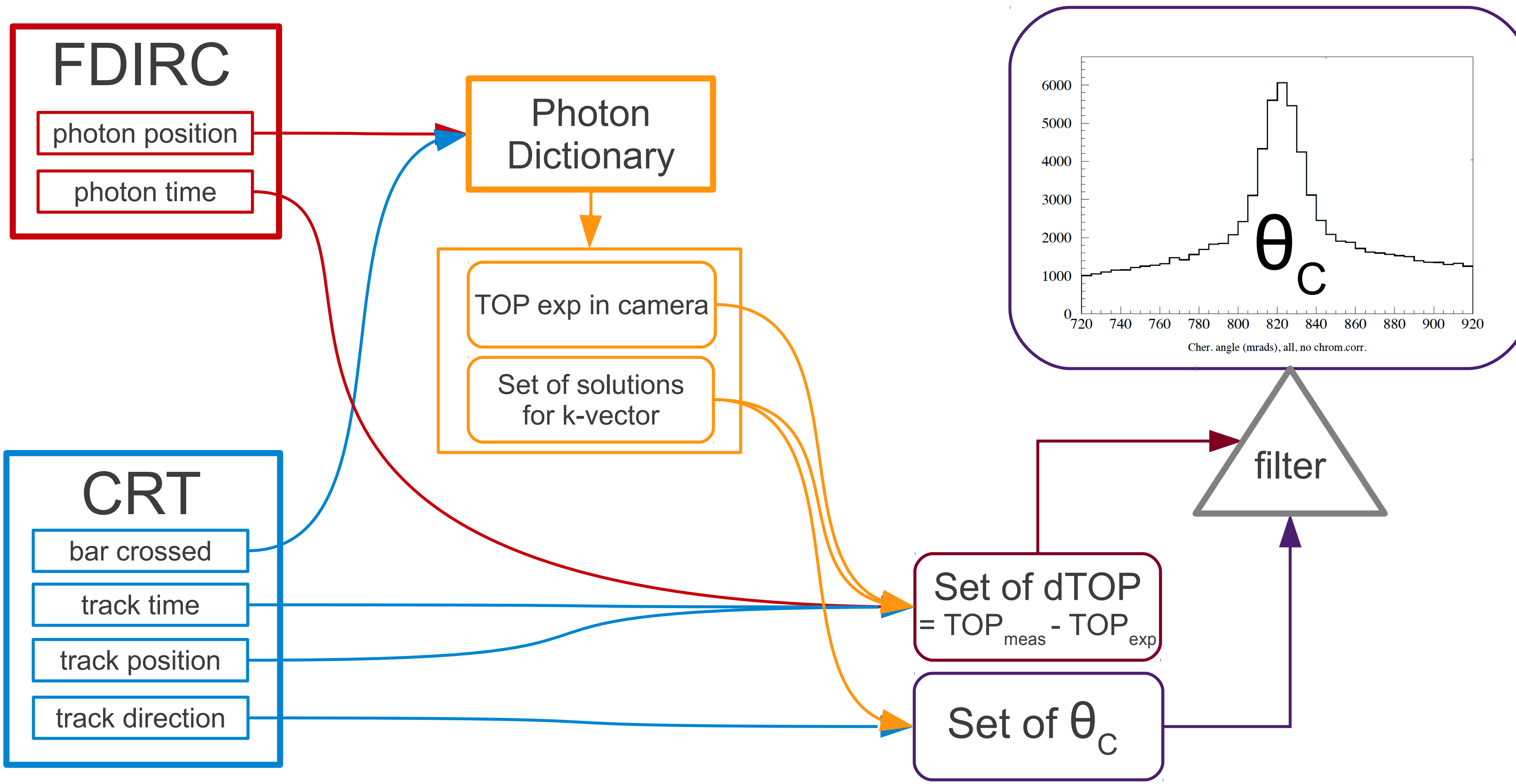
Data analysis

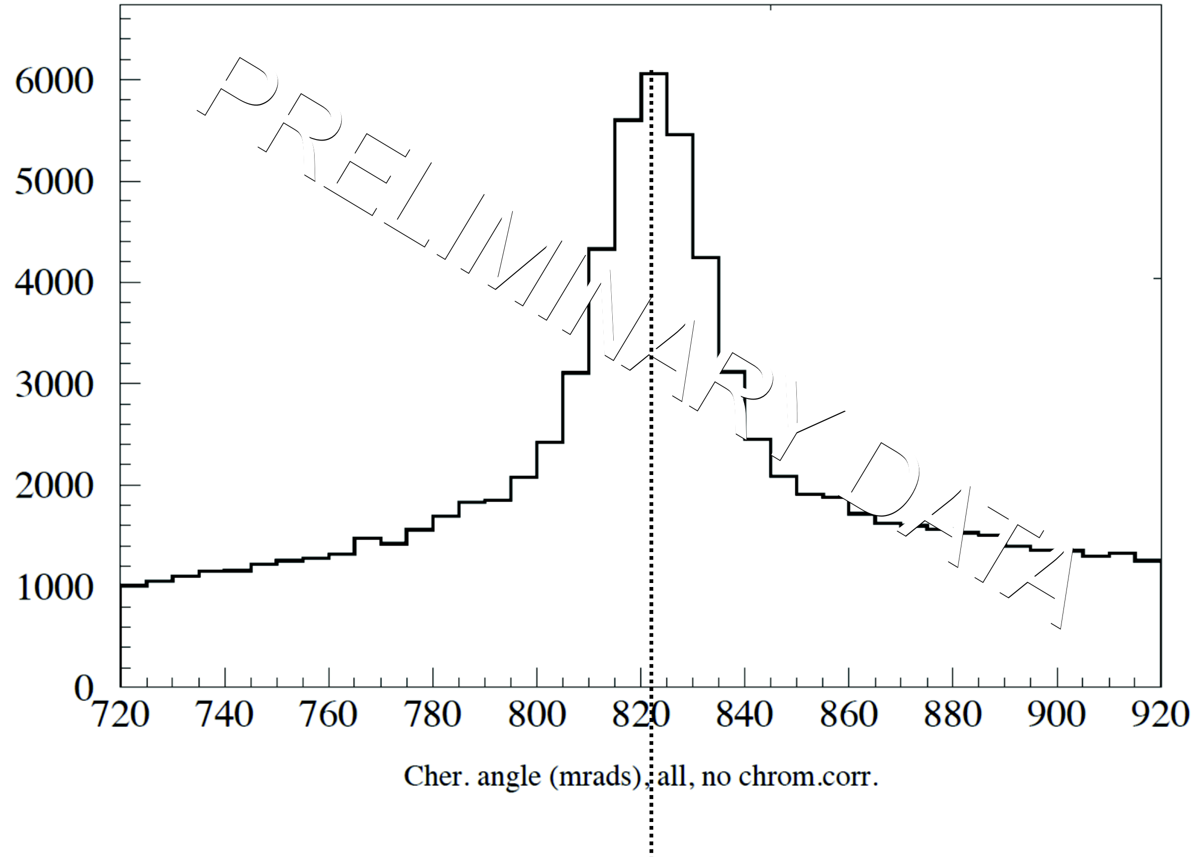
$\cos\theta_C = \hat{n} \cdot \hat{k}$ for each photon detected



Preliminary results

- Preliminary data validate the optical design with 3D tracks
- No quantitative performance results yet but they are very encouraging and close to expectations from MC

- S/N ratio is good, but can be improved by better timing alignment
- Tails are mainly due to ambiguities
- Chromatic correction is possible



A muon with E_μ > 2.0 GeV in quartz gives a Cherenkov angle of ~822 mrad

Conclusions

- The FDIRC construction has been successful despite the technical challenges
- Data taking is ongoing at the SLAC CRT
  - About one week allows to gather enough statistics to evaluate the FDIRC performance thanks to the large CRT acceptance
- Preliminary results show that the optical design is working
- Various improvements are still in progress
  - Digitizing electronics firmware
  - data analysis method
  - time alignment of PMTs
- Final results will be available later this year
  - single photon Cherenkov angle resolution
  - Number of detected photons per ring
  - S/N ratio between the Cherenkov peak and the background (composed mainly of ambiguities)
  - Effect of the chromatic correction

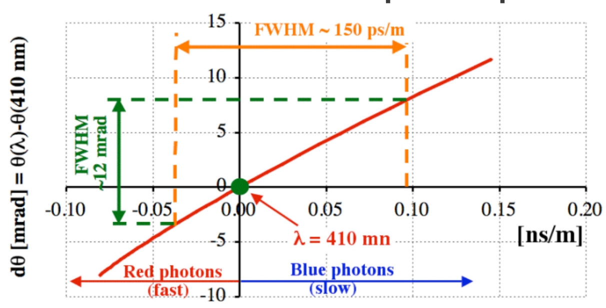
BACKUP

Chromatic correction with timing

Principle: The chromatic contribution to the θ_C resolution is reducible

$$\cos\theta_C = \frac{1}{n_{\rm ph}(\lambda)\beta} \qquad \frac{\rm TOP}{L_{\rm path}} \propto v_{\rm gr} = \frac{c}{n_{\rm gr}(\lambda)} \qquad n_{\rm ph} \simeq n_{\rm gr} + \lambda\frac{\partial n_{\rm ph}}{\partial\lambda}$$

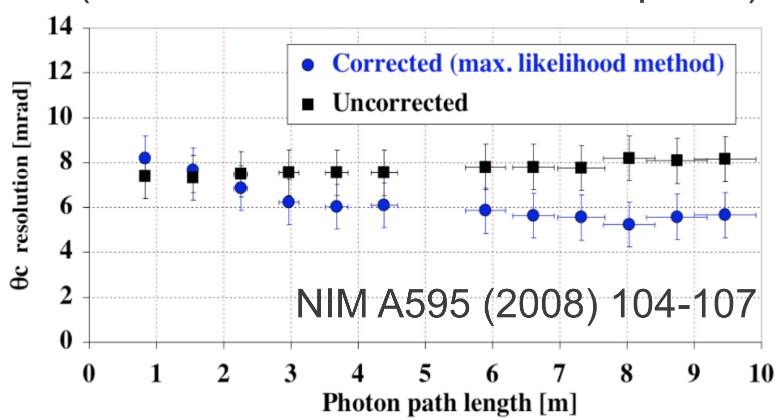
Sketch of the principle



Ingredients needed:

- Long path-length in the quartz
- Good timing (~200 ps)

Results from previous prototype
(oil-filled camera with smaller pixels)



- Previous FDIRC prototype has shown that the chromatic correction with timing is doable with perpendicular tracks
- Data for 3D tracks show chromatic broadening and we are already able to correct it with timing gaining ~0.5 mrad
- Results are too preliminary to be shown
- First RICH detector which will correct chromatic broadening for 3D tracks