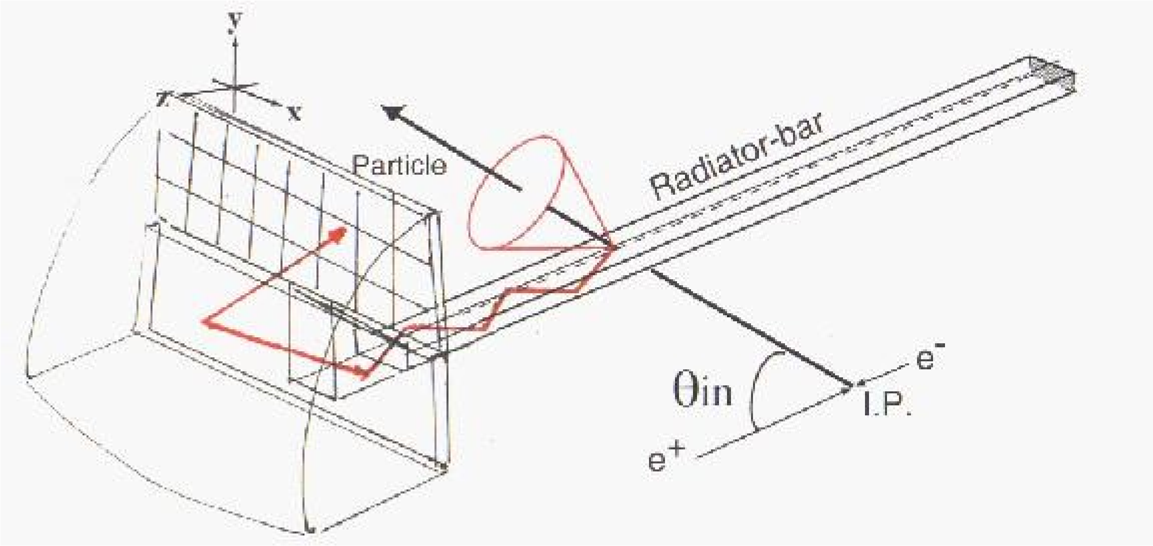
Cherenkov Detectors in Particle Physics



Brad Wogsland
University of Tennessee

Outline

- Cherenkov light
- RICH detectors
- CRID detectors
- The DIRC
  - Design & performance
- Potential for use in Future experiments

Cherenkov Light

- Particle traveling faster than light in a given medium emits Cherenkov radiation

$$\cos\theta_C = 1/\beta n$$

- However, the index of refraction is also a function of the light's wavelength in a non-trivial way depending on the medium

$$n = n(\lambda)$$

- The number of observed photoelectrons is given by the Frank-Tamm equation:

$$N = 370L\int\varepsilon \sin^2\theta_C \, dE$$

From the Physics to the Detector

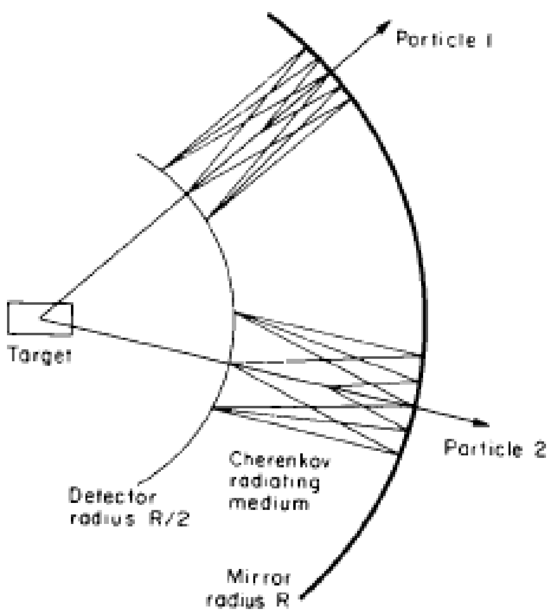
PHOTO-IONIZATION AND CHERENKOV RING IMAGING

J. SEGUINOT* and T. YPSILANTIS†

CERN, Geneva, Switzerland

Received 17 December 1976

We have investigated the photo-ionization process in gases and shown that single photon pulse counting in multiwire proportional chambers (MWPC) is possible with about 50% quantum efficiency for photons above 9.5 eV. An application of this technique in imaging the Cherenkov ultra-violet (UV) radiation is presented.



RICH Detectors

- Ring Imaging CHerenkov detector
- First used by DELPHI experiment at LEP
- Liquid and gas fluorocarbon radiators
- Actually 2 detectors working in parallel
- Optimized for K/π/p separation up to 30 Gev/c

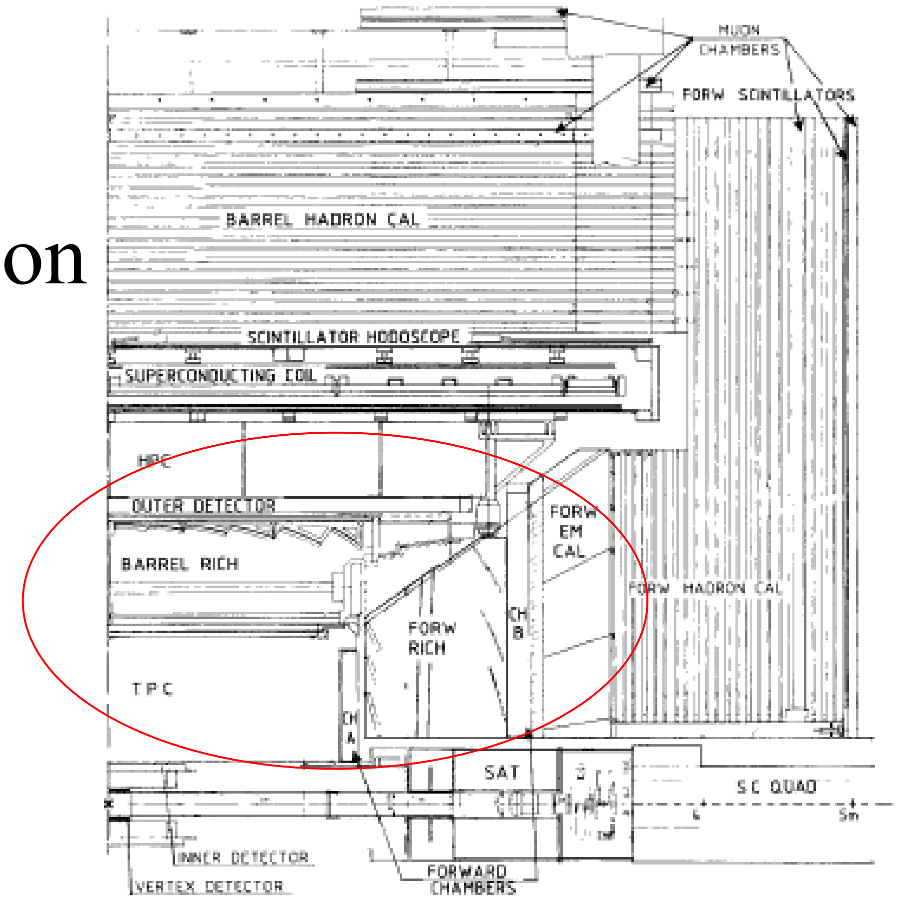


Fig. 1. The DELPHI detector at LEP

W. Adam et al. / Nucl. Instr. and Meth. in Phys. Res. A 343 (1994) 68–73

RICH Detectors

- First large scale realization of Seguinot & Ypsilantis' idea was fairly successful

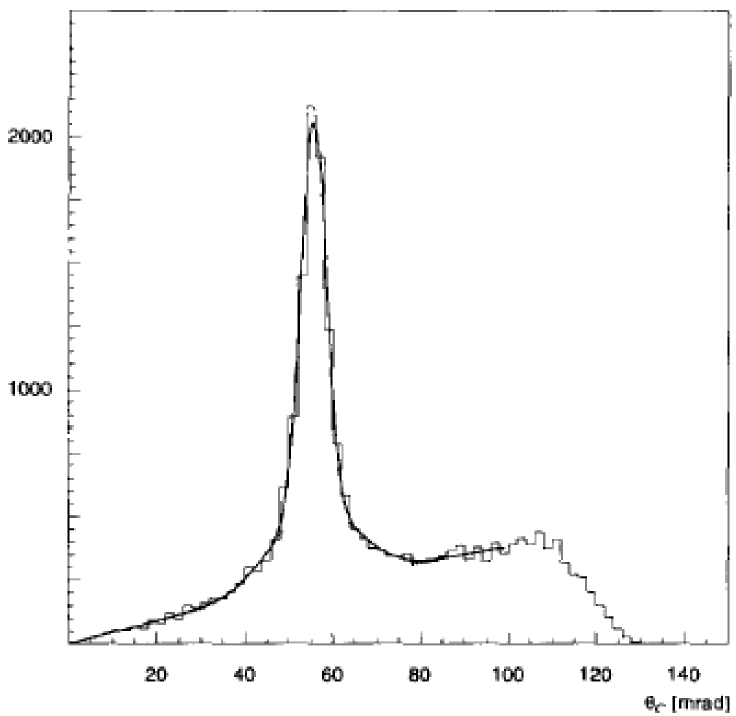


Fig. 3. Cherenkov angle resolution for individual photons from $Z^0 \to \mu^+\mu^-$ events in the gas radiator of the Forward RICH. There are 10 photoelectrons/track. The mean of the Gaussian fit is 55.6 mrad with a σ of 2.85 mrad.

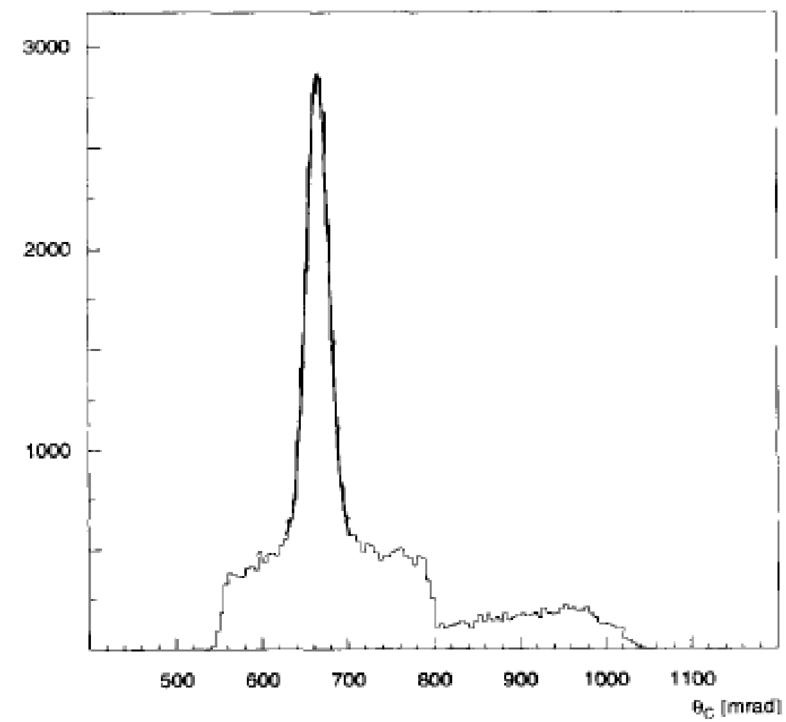


Fig. 4. Cherenkov angle resolution for individual photons from $Z^0 \to \mu^+\mu^-$ events in the liquid radiators of the Barrel RICH. There are 15 photoelectrons/track. The mean of the Gaussian fit is 666 mrad with a σ of 13 mrad.

W. Adam et al. / Nucl. Instr. and Meth. in Phys. Res. A 343 (1994) 68–73

RICH Detectors

- Used by PHENIX at RHIC as well as many others since DELPHI
- Now subdivided into three subclasses:

I) The first group concerns a class of Multi-Step Avalanche Chambers (MSACs) with a Pre-Amplification (PA) gap followed either by a MWPC with fast readout of wires or a PA gap with slow (optical/CCD) readout of visible light from the avalanches.

II) The second group concerns Slow-RICH detectors using the TPC drift technique for 2D imaging with MWPC or Proportional Tube detectors, quartz windows and TMAE as the photosensor.

III) The third group concerns the most recently developed Fast-RICH detectors with fast solid or gas photosensors, MWPC or MSAC gas amplification and fast cathode pad readout using VLSI electronics.

J. Seguinot, T. Ypsilantis / Nucl. Instr. and Meth. in Phys. Res. A 343 (1994) 1–29

- Will also be used in ALICE and LHCb experiments at the LHC

The CRID

- Cherenkov Ring Imaging Detector
- Used by SLD in the 1990s
  - Liquid & gas fluorocarbon radiators
  - K/π/p separation up to 30 Gev/c
  - e/π separation up to 6 GeV/c
- Modified RICH design by using spherical mirrors

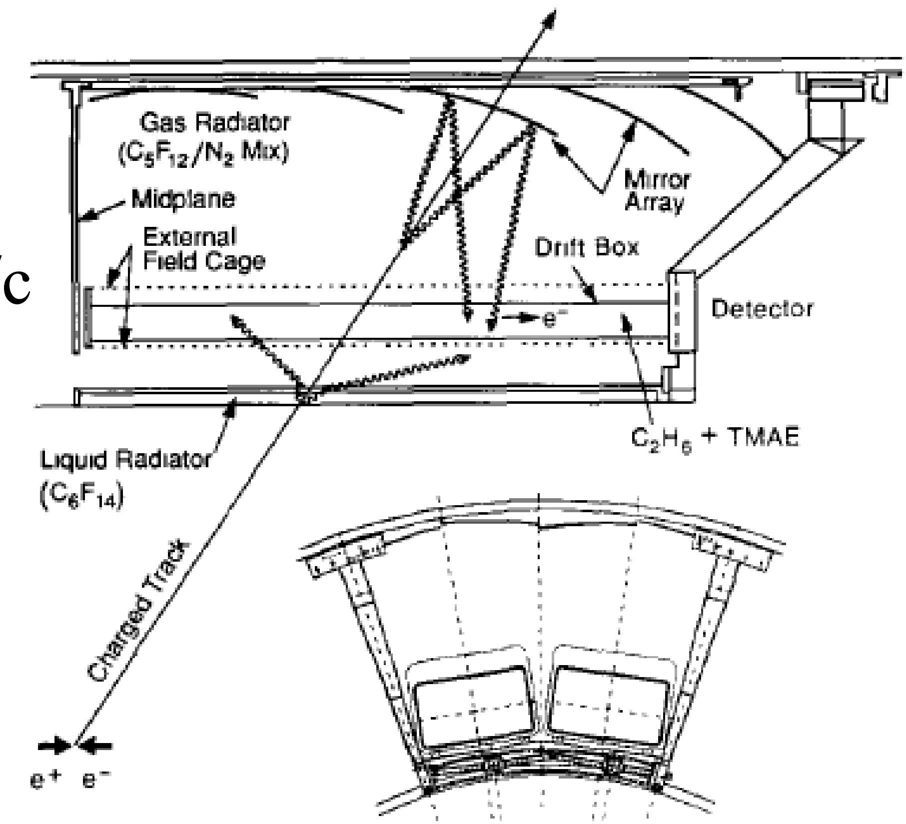
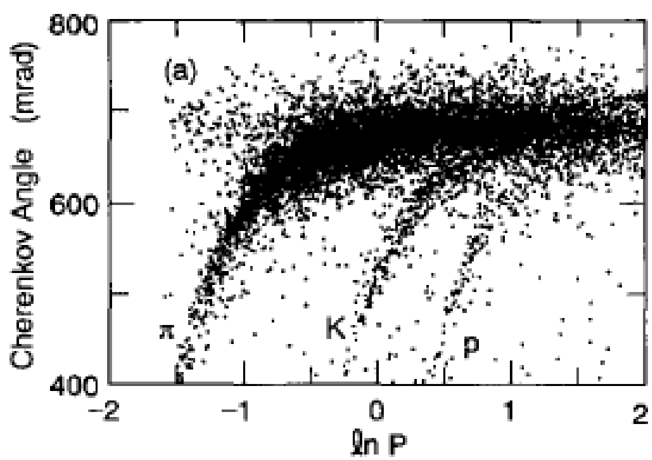


Fig. 1. Schematic of the SLD barrel CRID.

K. Abe et al. / Nucl. Instr. and Meth. in Phys. Res. A 343 (1994) 74–86



ACC

- The Aerogel Cherenkov Counter first used by the Belle Collaboration
  - Aerogel used has refractive index in the range 1.010-1.030
  - K/pi separation up to 3.5 GeV/c
  - 1188 modules total

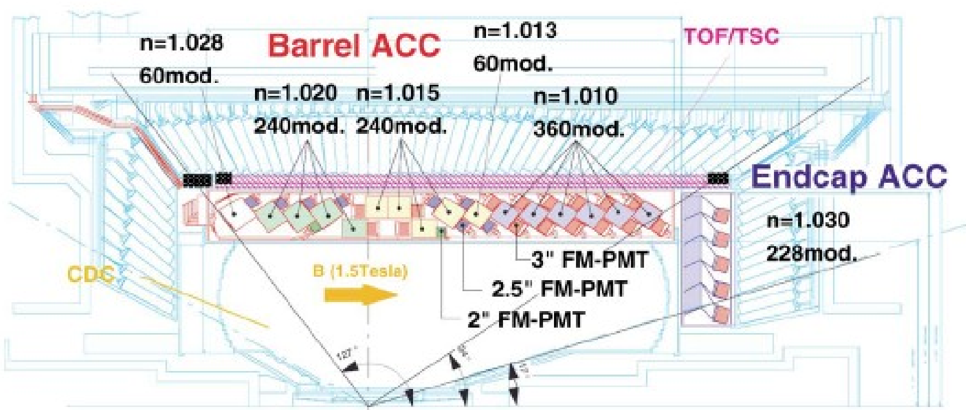
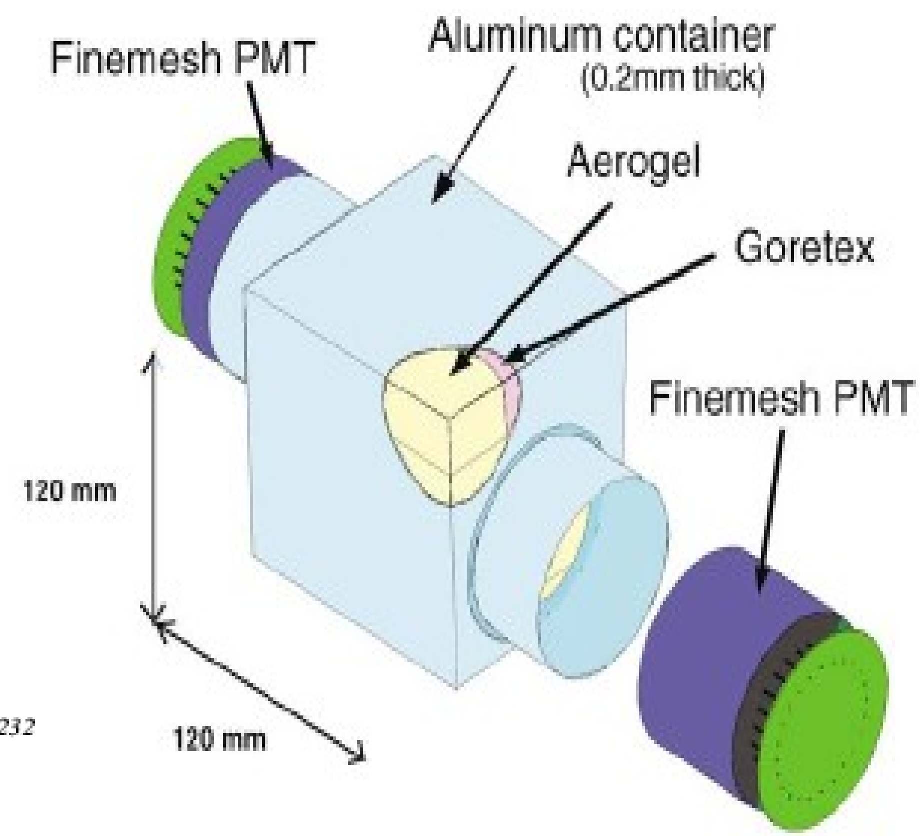


Fig. 40. The arrangement of ACC at the central part of the Belle detector.

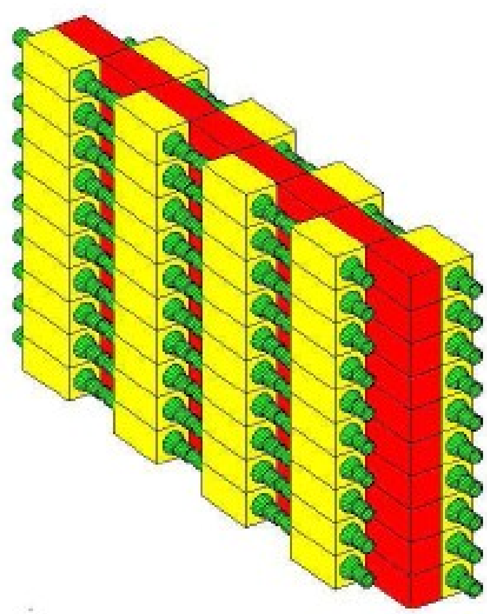
T. Iijima et al. / Nuclear Instruments and Methods in Physics Research A 453 (2000) 321–325

A. Abashian et al. / Nuclear Instruments and Methods in Physics Research A 479 (2002) 117–232



ACC

- Also used by PHENIX collaboration at RHIC
  - Replaced older PID system in 2004
  - K/pi separation 0.8 to 3.0 GeV/c
  - RICH detector used for higher momentum particles



The DIRC Idea

- Why not use a solid radiator which can also internally reflect the Cherenkov light to shrink the size of the detector?
- Pinhole focusing of the quartz bars into a stand-off box
- Cherenkov ring expands in SOB and is read out on the far side by PMTs

SLAC-PUB-6047
January 1993
(T/E)

**THE DIRC COUNTER:
A NEW TYPE OF PARTICLE IDENTIFICATION DEVICE FOR
B FACTORIES***

BLAIR RATCLIFF

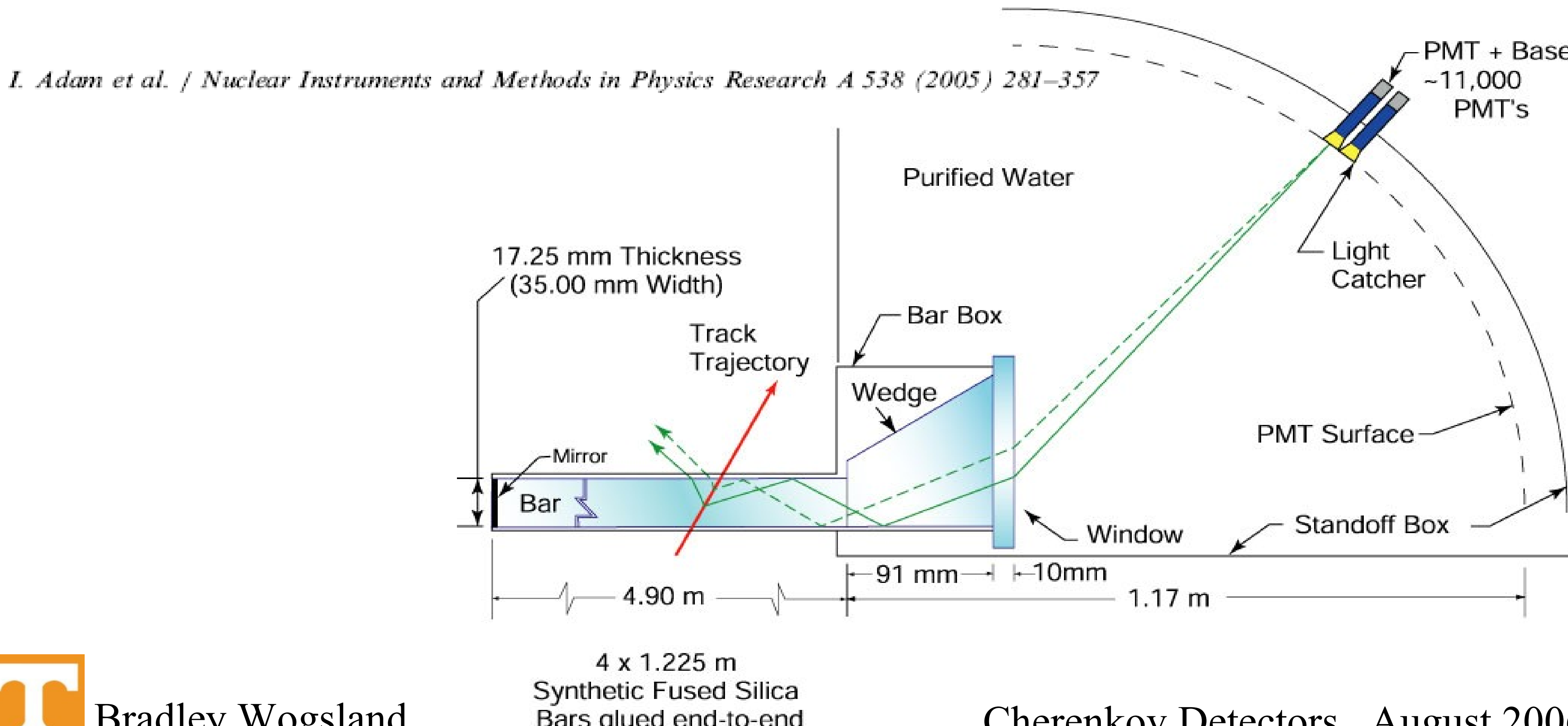
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309 USA

ABSTRACT

A very thin, solid radiator, totally internally reflecting, imaging Cherenkov counter (DIRC) is described. This device is well matched to the hadronic charged particle identification requirements at an asymmetric e^+e^- B Factory.

The DIRC

- Detector of Internally Reflected Cherenkov light
- DIRC first used for Particle ID at BaBar (1999 – present)
  - Very successful, robust system for K-π separation

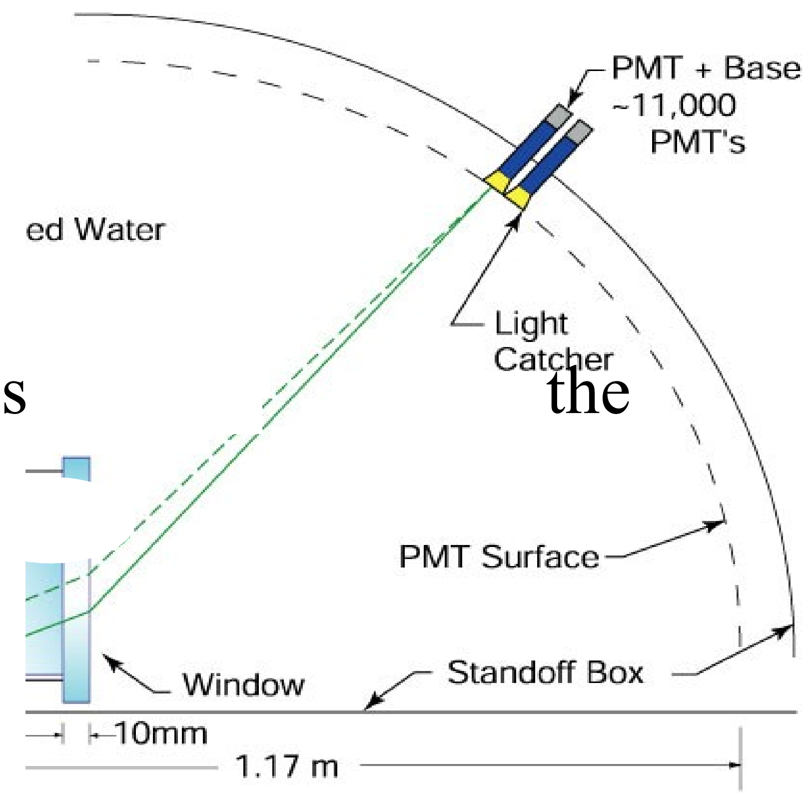


The DIRC Concept

- Particle traveling faster than light in a given medium emits Cherenkov radiation

$$\cos\theta = 1/\beta n$$

- The DIRC uses quartz bars both as Cherenkov radiators and to transmit the light to the detectors.
- In BaBar's DIRC the quartz bars are coupled to a tank of water which houses the PMTs on one side.
- Pinhole focusing still dependent on bar size however.



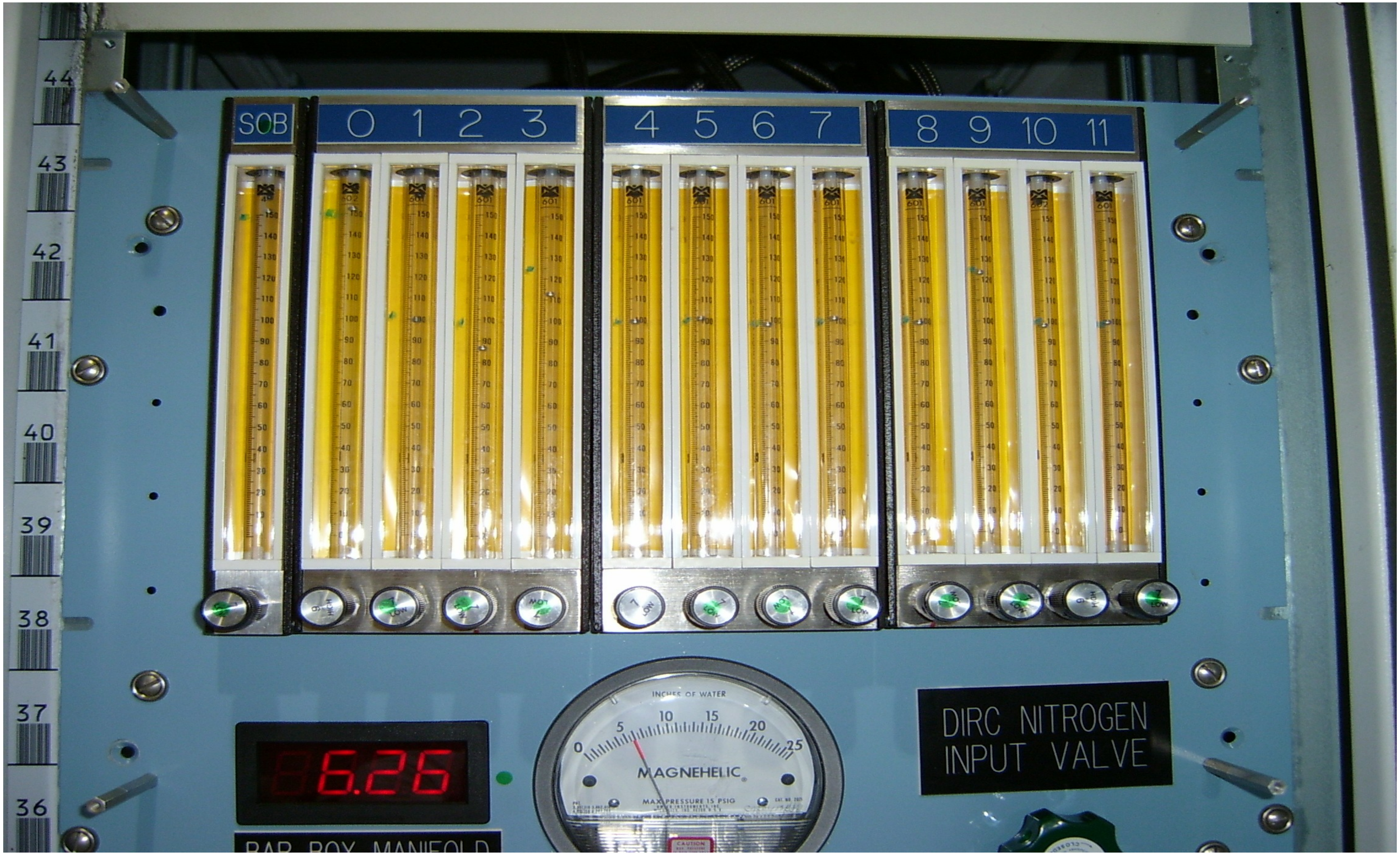
The "Quartz" Bars

- Material is actually synthetic fused silica (Spectrosil)
- Cross section 17.25 mm x 35.0 mm.
- Four 1.225 m long bars glued together with Epotek 301-2 optical epoxy to make one 4.9 m long DIRC bar.
- 99.9±.0.1% transmission per meter at 442 nm
- 98.9±.0.2% transmission per meter at 325 nm

Recall now the Frank-Tamm equation:

$$N = 370L\int \varepsilon \sin^2\theta_C \, dE$$

Protecting the Quartz Bars

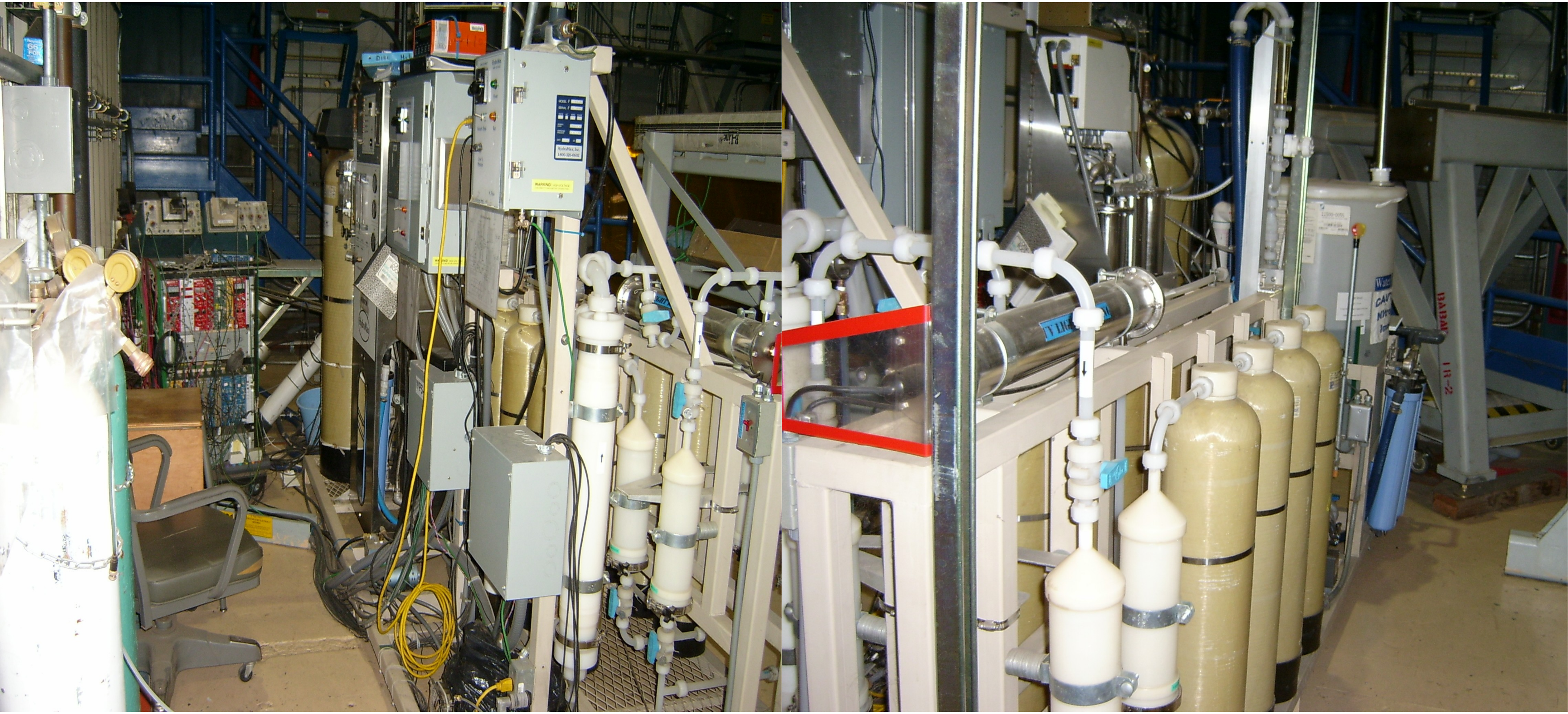


Nitrogen gas is circulated around the quartz bars to protected them from water condensation which would break the total internal reflection.

The SOB

- The stand off box (SOB) is filled with ultra-pure water coupling to a quartz wedge which is attached directly to bars.
- PMTs on the far side of the stand-off box.
- At high luminosities interactions with the water in the stand off box represents the main source of background.
- Ultra pure water also an environmental hazard if the SOB is dumped.

The DIRC Water System

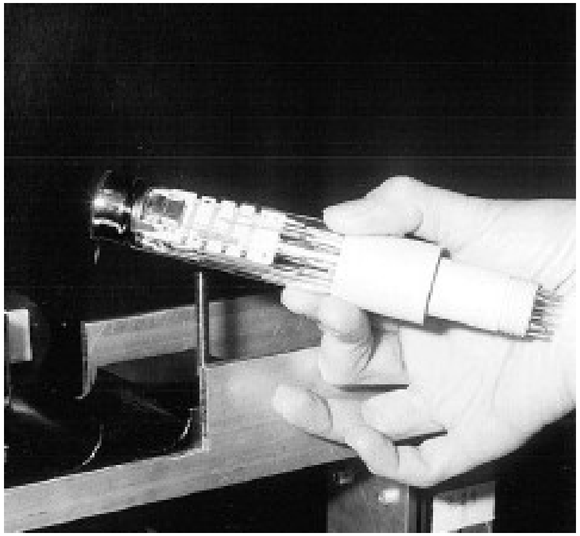


The DIRC Water Plant – Here the water from the SOB is degassed, irradiated and circulated

The DIRC Water System

But we have humidity sensors in too, just in case!

Photomultiplyers



ETL 9125FLB17 PMT

- used in BaBar's DIRC
- 26 mm active photocathode diameter
- gain 1.7×10^7
- timing resolution ~1.5ns
- arrayed with hexagonal rhodium-plated light catchers

→ SLAC-PUB-10516

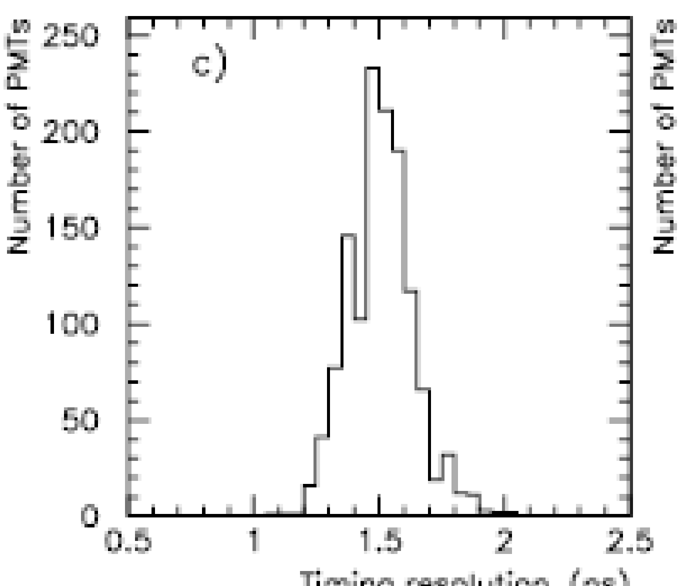
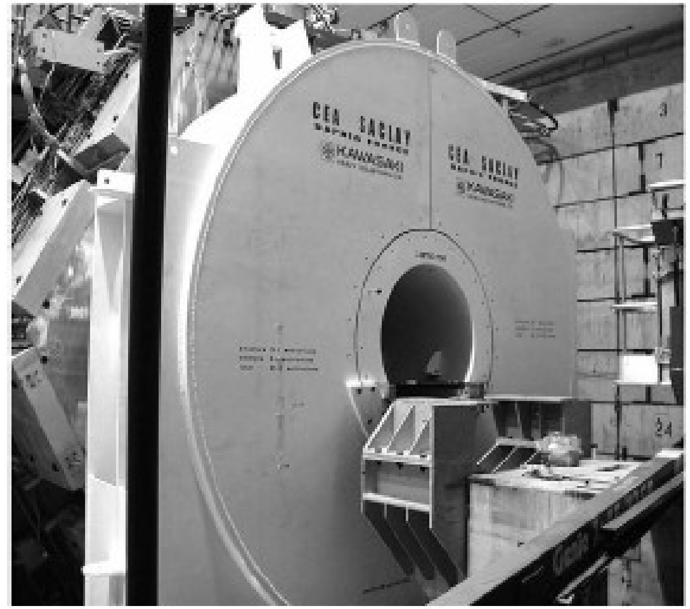


Figure 39. PMTs and rhodium-plated light-catchers in the SOB.

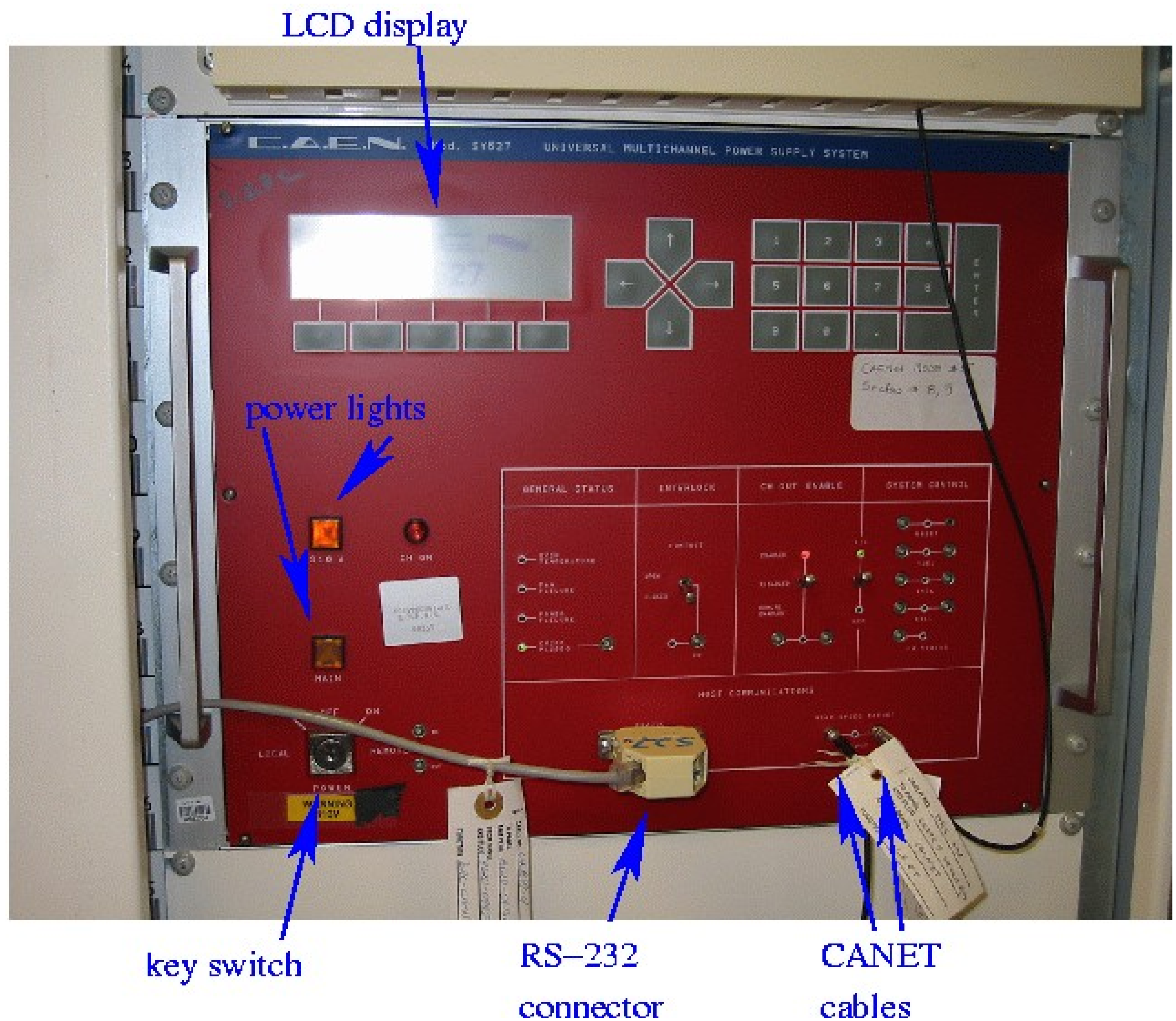
Shielding the PMTs



- BaBar solenoid runs at 1.5 tesla.
- PMTs don't work well in magnetic field.
- Active shielding cancels BaBar solenoid to levels < 1 gauss.

Powering the DIRC

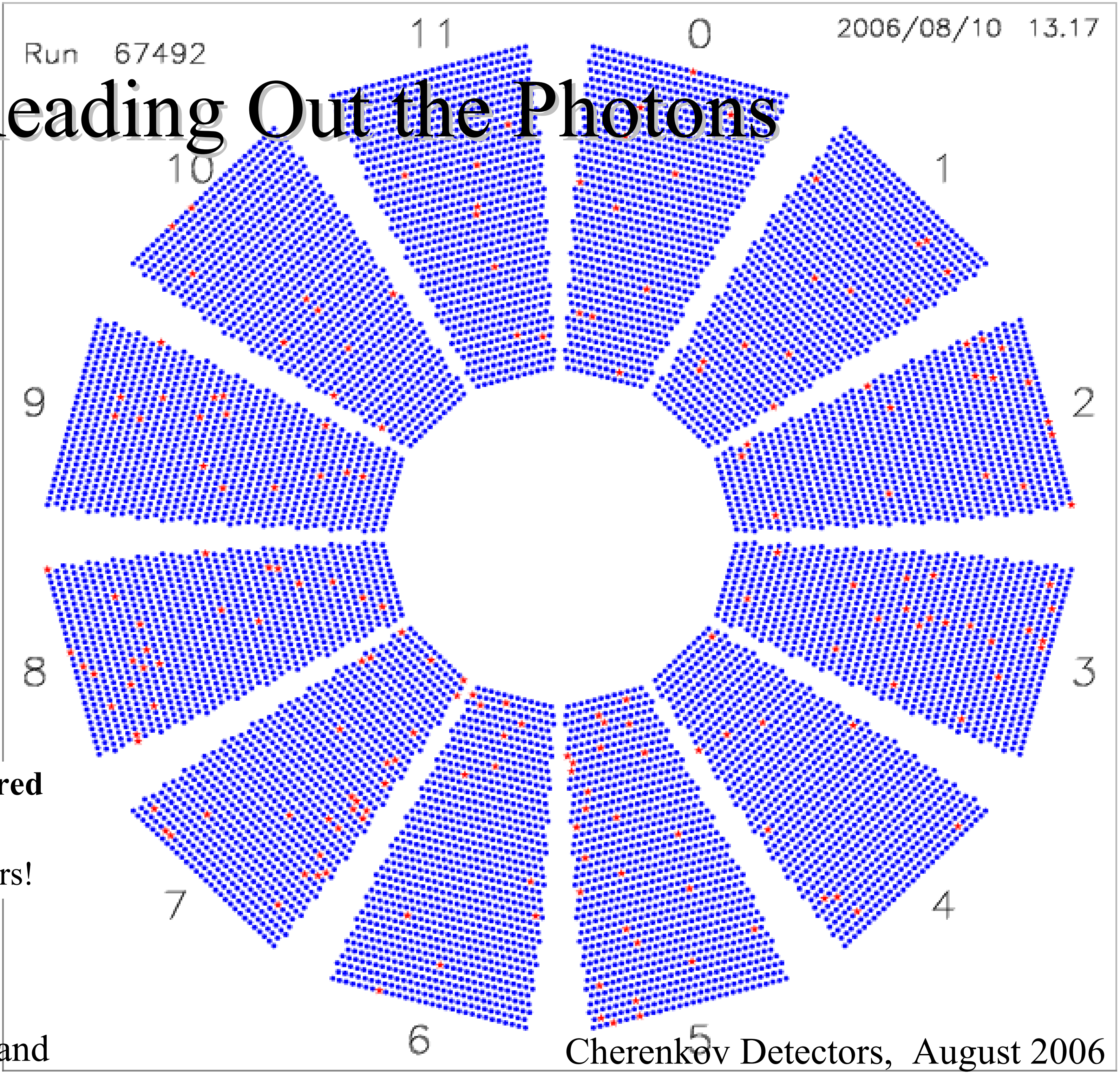
- PMTs need high voltage to for electron multiplication
- 6 CAEN HV power supplies
- 8 HV boards per supply
- 16 channels per board



Reading Out the Photons

- Accomplished in the front-end electronics (FEE) chain
  - 6 read out modules (ROMs) perform the data acquisition
  - 28 DIRC front-end boards (DFBs) per ROM
  - 4 time-to-digital conversion chips (TDCs) per DFB
  - 2 analog chips per TDC
  - 16 PMTs per TDC
  - This means a total of 10752 channels!
- 10562 of these PMTs are still functioning after 7 years

Reading Out the Photons



Dead PMTs shown in red

190 as of yesterday

<2% loss over ~7 years!

Electronics

- DIRC control carte (DDC) controls the flow of information in the FEE
- Each Wiener crate holds 14 DFBs and a DCC

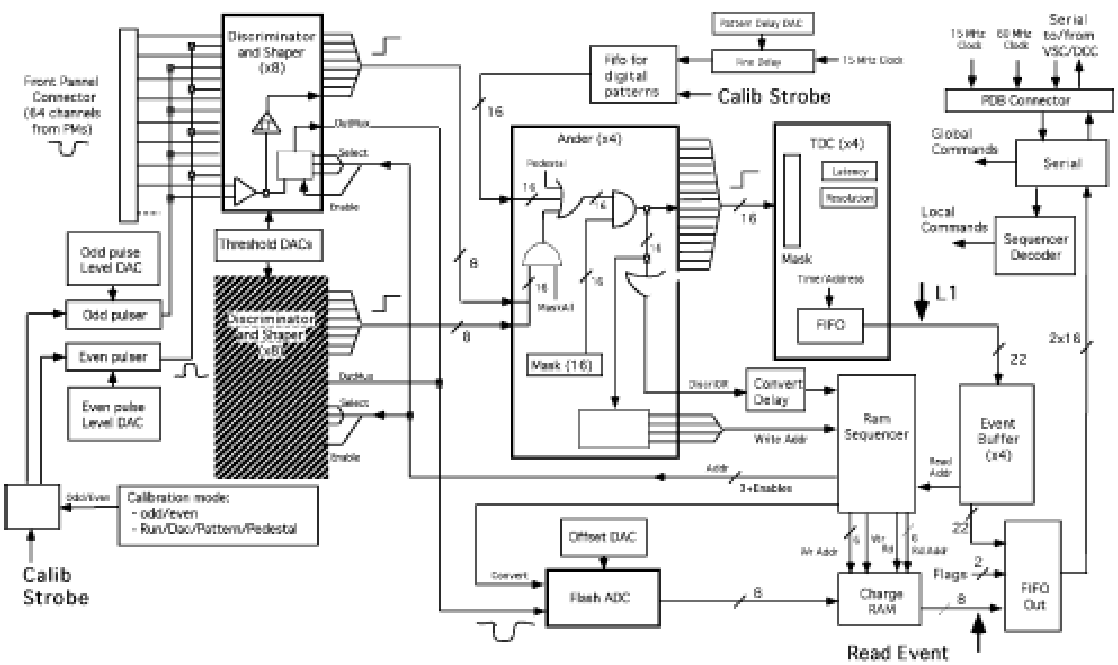


Fig. 43. Schematic diagram of the DIRC Front-end Board.

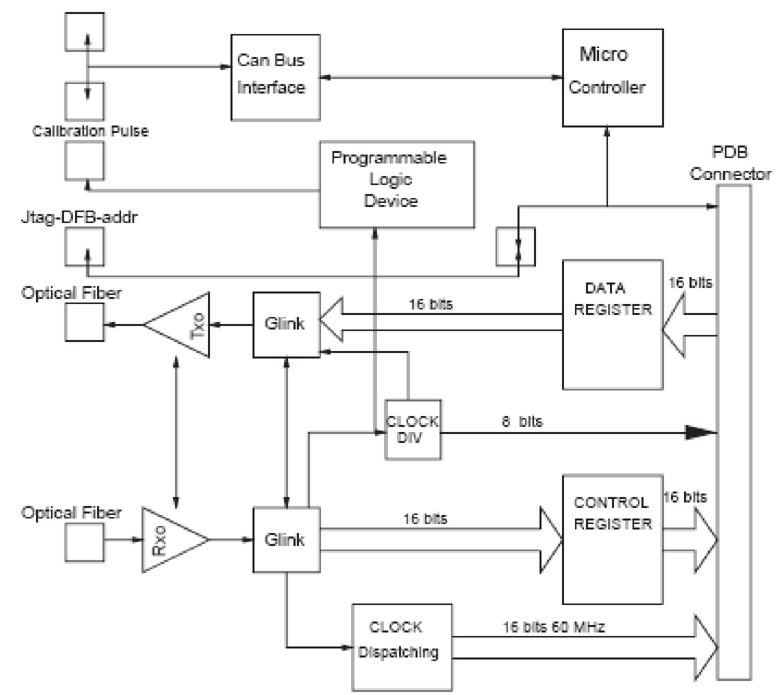


Fig. 44. Block diagram of the DIRC Crate Controller.

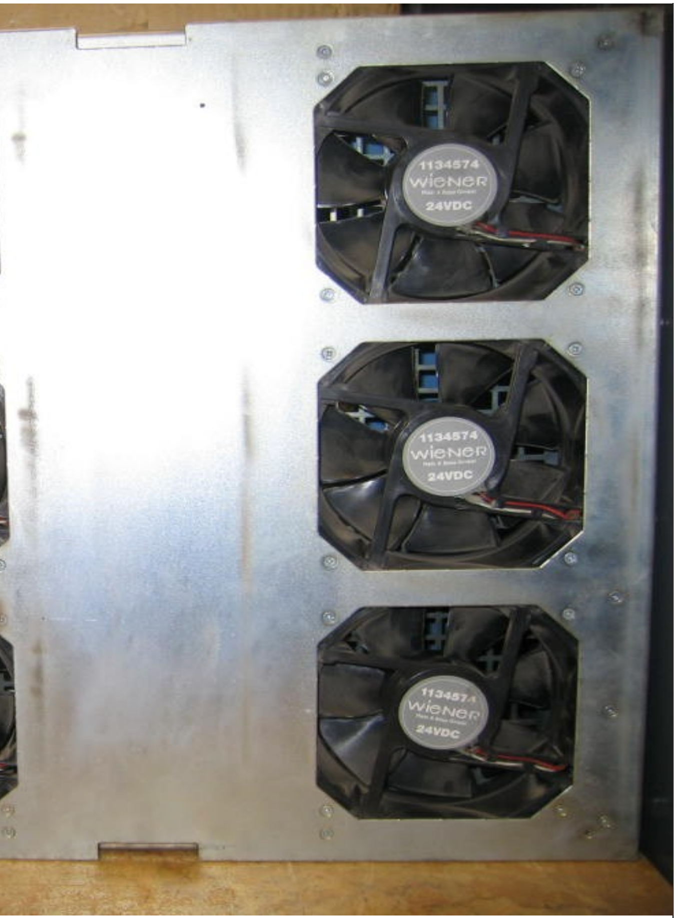
I. Adam et al. / Nuclear Instruments and Methods in Physics Research A 538 (2005) 281–357

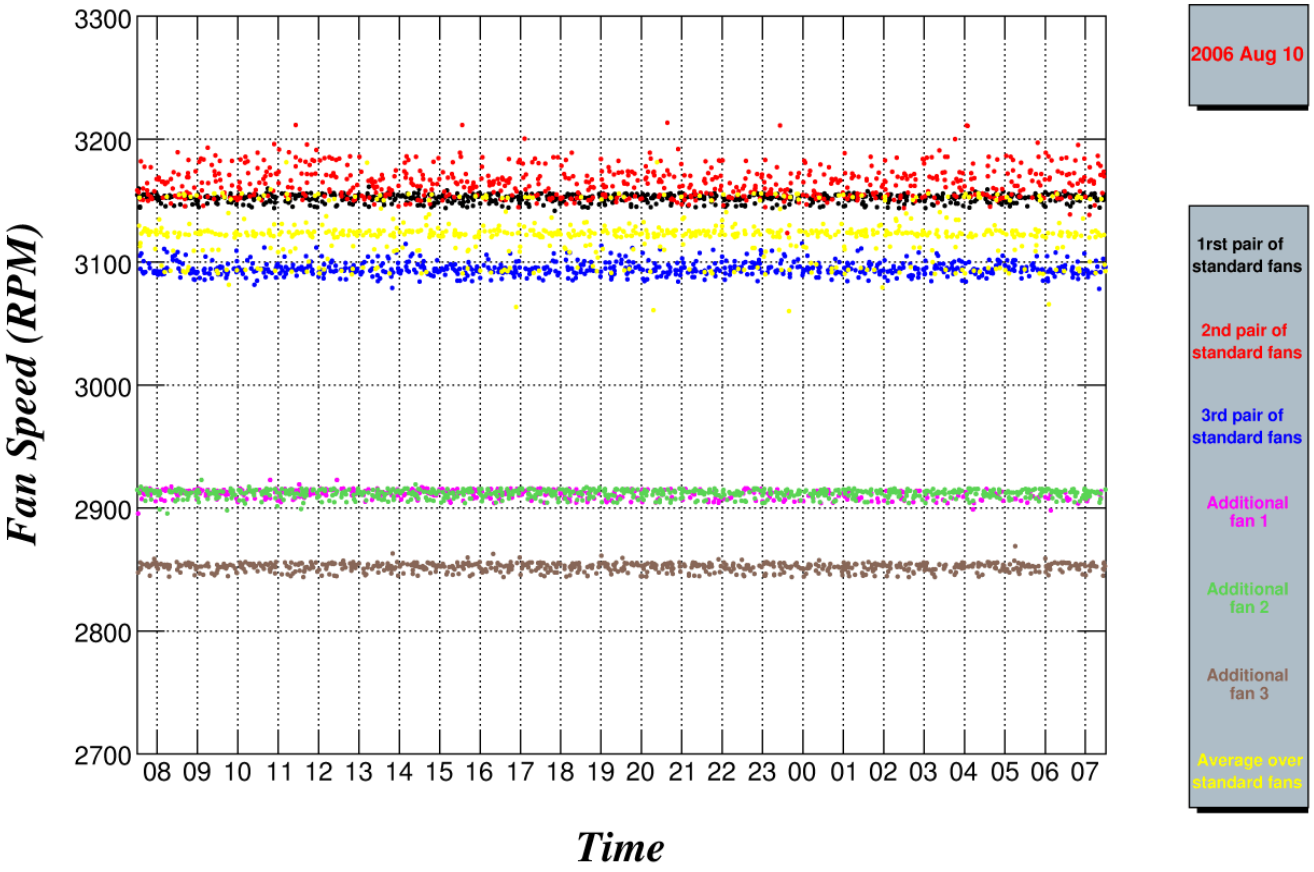
Keeping the Electronics Cool

This is the main chiller for the DIRC front-end electronics, but there is also a backup.

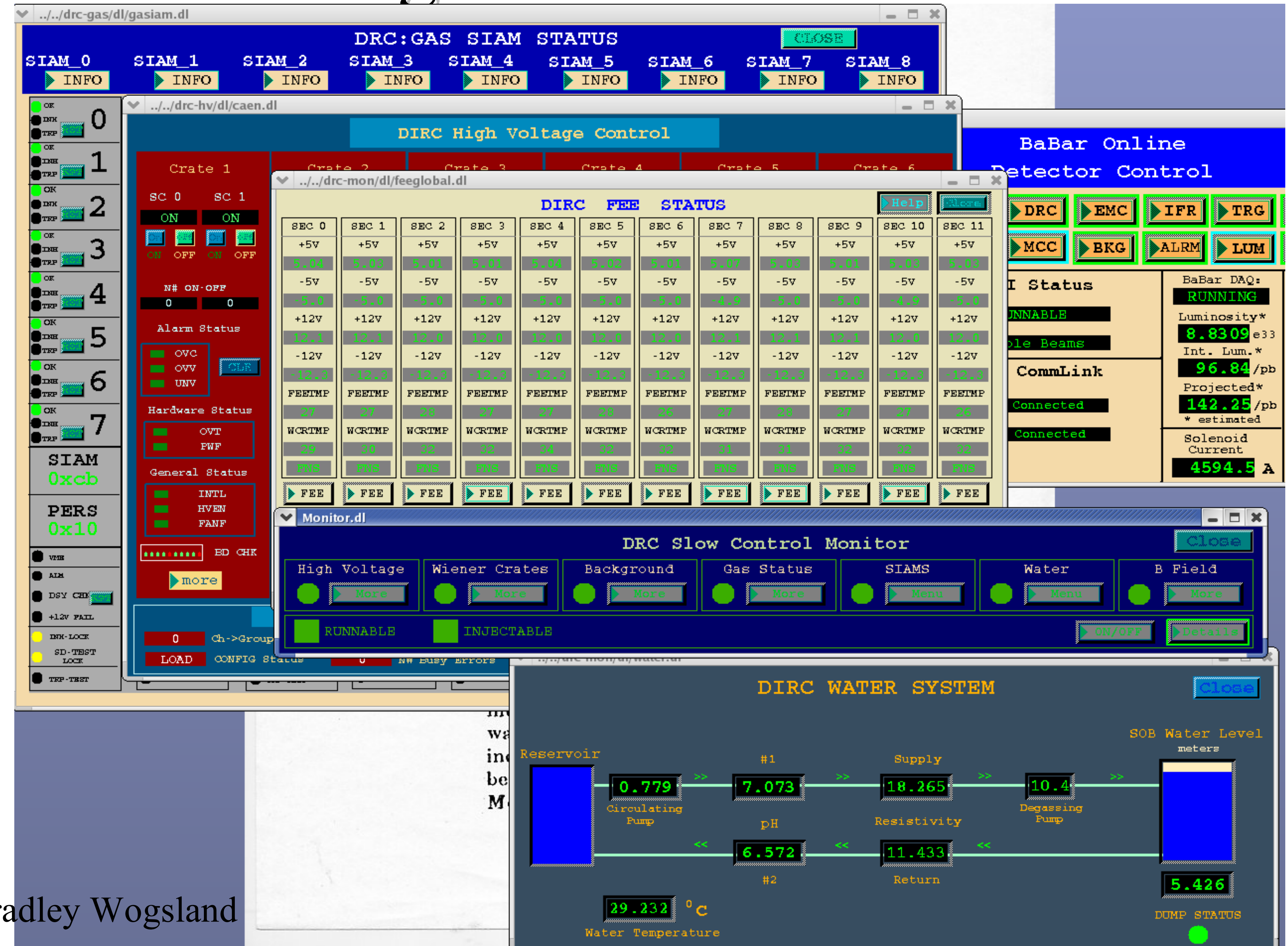
Keeping the Electronics Cool

- Fans also keep the front-end crates from overheating





Monitoring DIRC with EPICS



Bradley Wogsland

Reconstruction

- DIRC is not a stand-alone PID system, but instead relies on charged track information from the tracking detectors
- Position measurement yields the Cherenkov angle θ_C
  - resolution 9.6 mrad
- Arrival time also measured
  - Resolution 1.5 ns
- DIRC is a 3 dimensional measuring detector

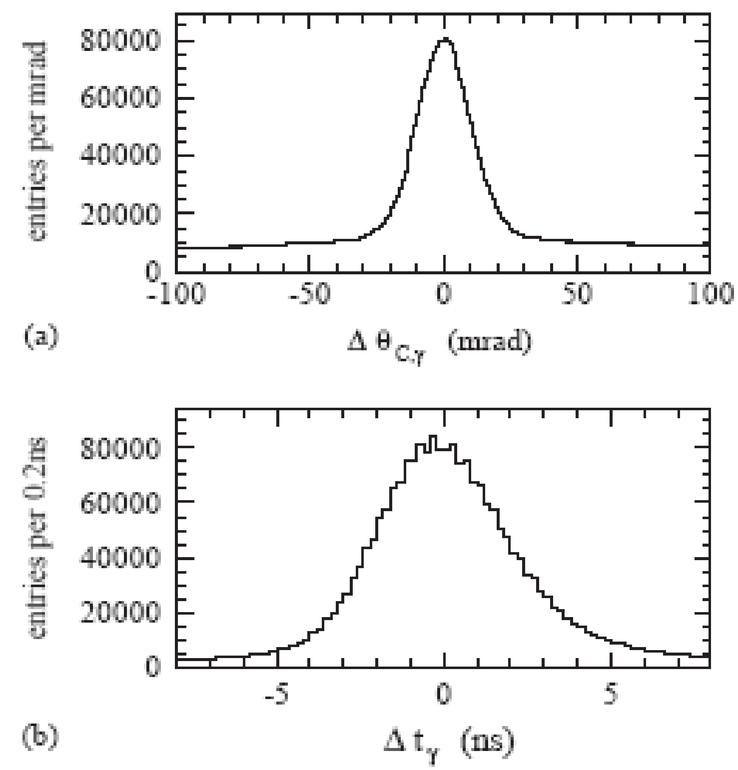
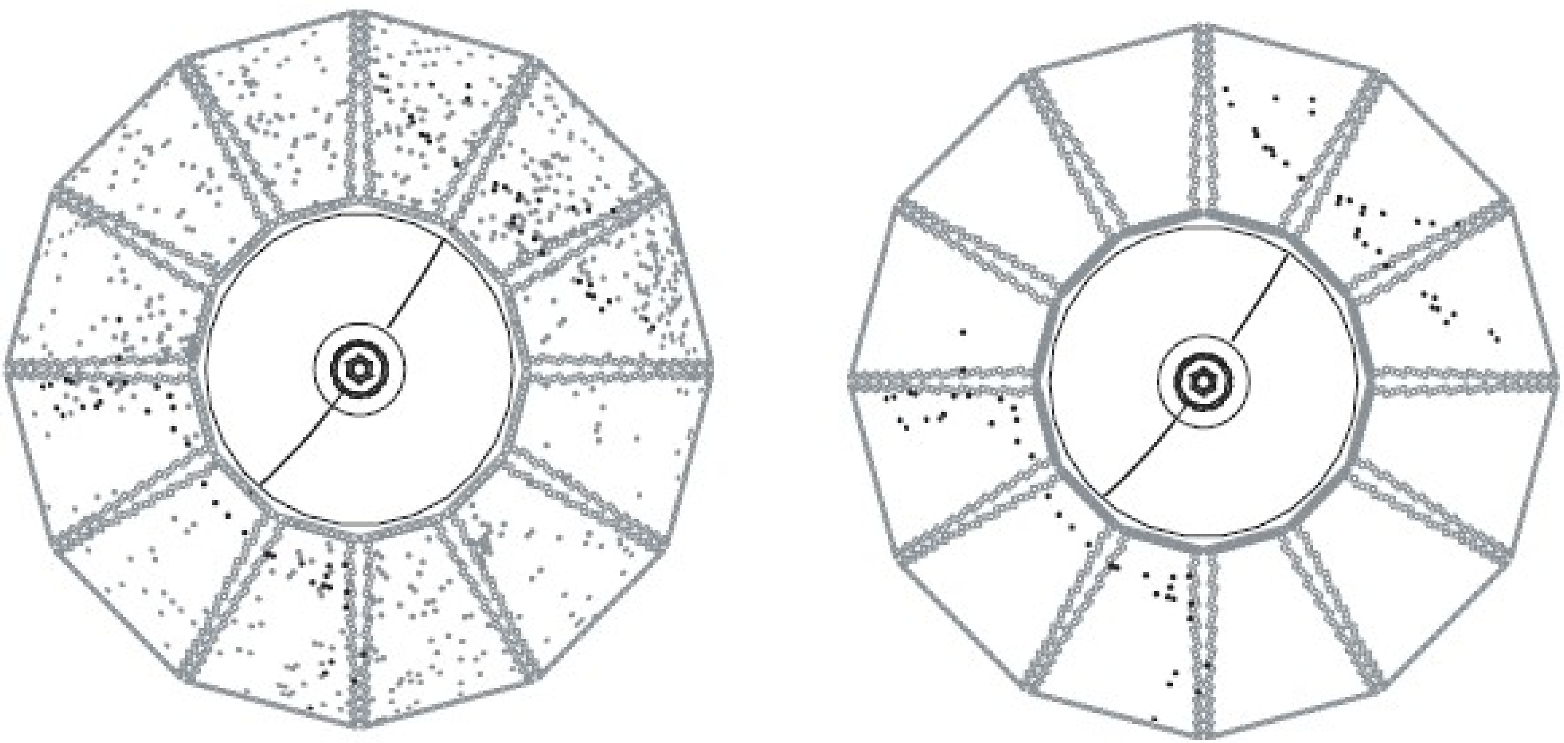


Fig. 47. The difference between (a) the measured and expected Cherenkov angle for single photons, $\Delta\theta_{C,\gamma}$, and (b) the measured and expected photon arrival time, for single muons in $\mu^+\mu^-$ events.

I. Adam et al. / Nuclear Instruments and Methods in Physics Research A 538 (2005) 281–357

Reconstruction

- Arrival time is used to reduce background



- Eliminating the photons outside of a ±300 ns window around the trigger time yields a very clean signal

I. Adam et al. / Nuclear Instruments and Methods in Physics Research A 538 (2005) 281–357

Reconstruction

- Complex global likelihood algorithm used
- An example where this would be used is $B^+ \rightarrow J/\psi\pi^0\pi^0K^+$

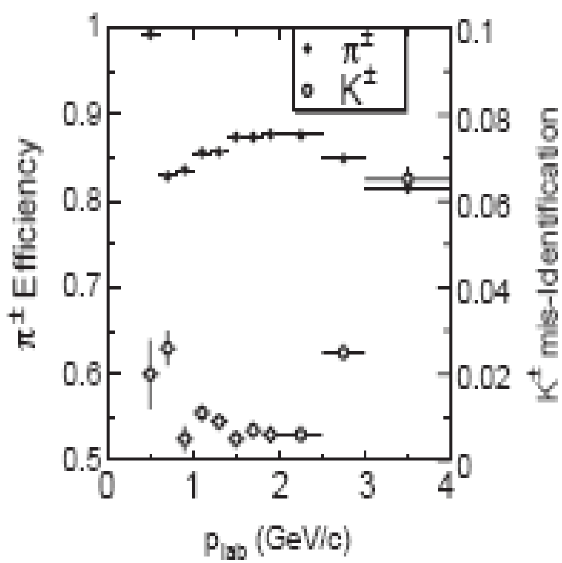


Fig. 58. The pion efficiency and kaon misidentification rate, as a function of momentum in the laboratory frame, for the charged pion selection used in the search for $B \rightarrow \rho\gamma$ and $B \rightarrow \omega\gamma$.

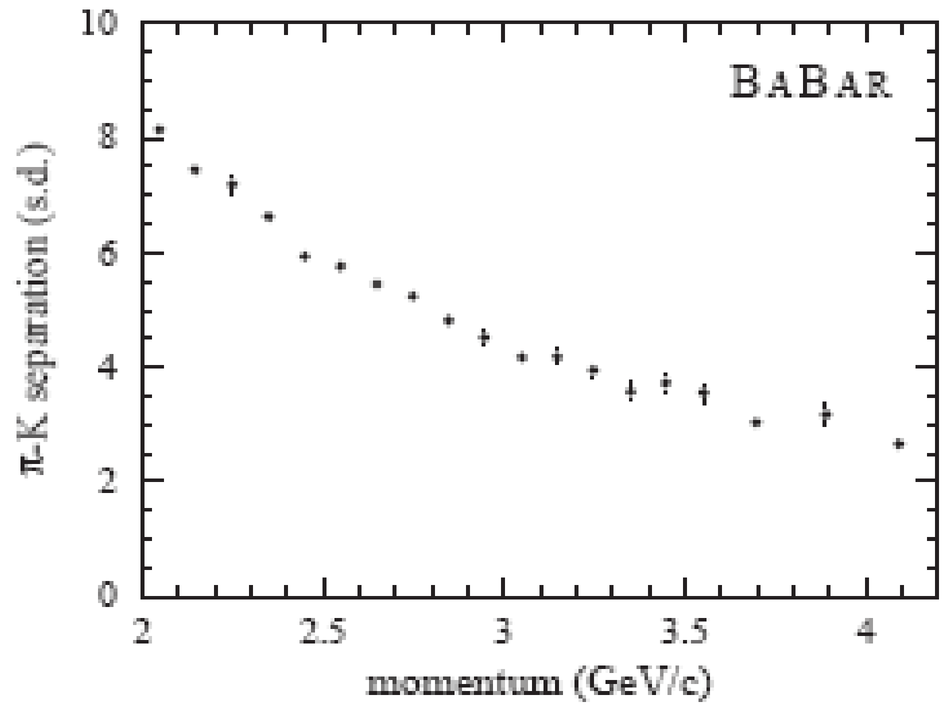
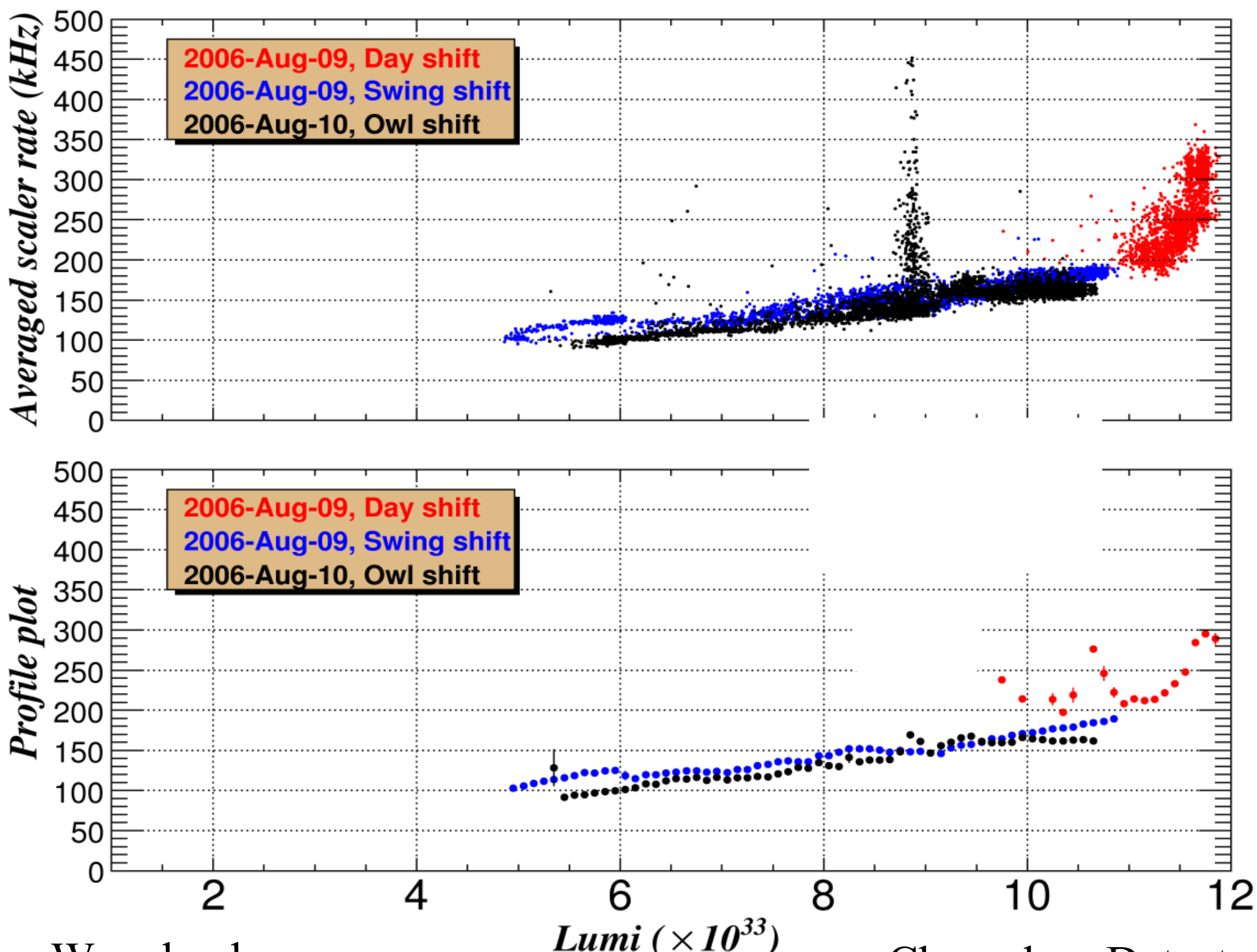


Fig. 54. DIRC π-K separation vs. track momentum measured in $D^0 \rightarrow K^-\pi^+$ decays selected kinematically from inclusive D^* production.

I. Adam et al. / Nuclear Instruments and Methods in Physics Research A 538 (2005) 281–357

Background

- High luminosity ~ 11x10^{33} makes it worse



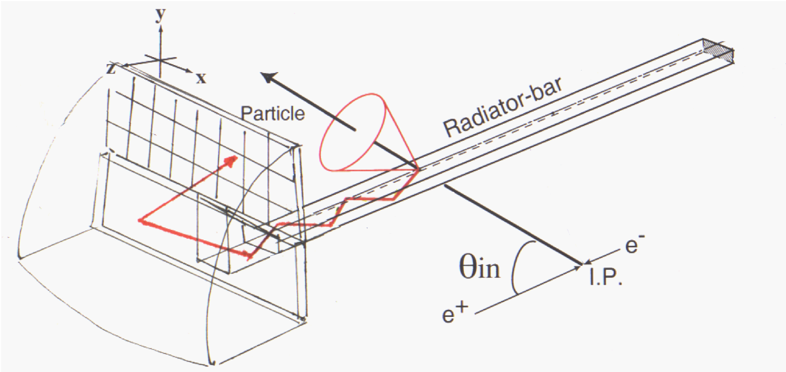
Limitations of the BaBar's DIRC

- SOB background limits luminosity
- Timing not good enough to yield PID info
- Resolution could be better

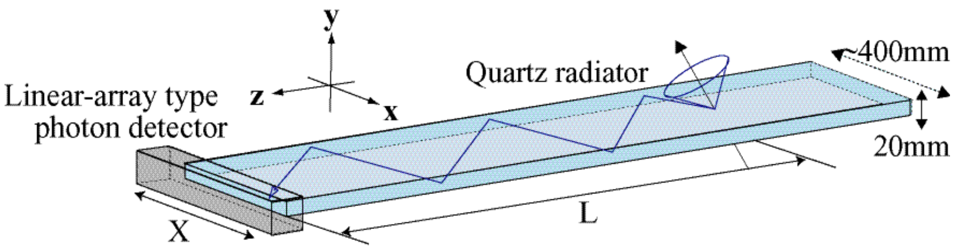
- So what's next?

Scenarios for a future DIRC

- SLAC focusing DIRC



- Nayoga's TOP counter proposed for Belle



- others?

Focusing the Cherenkov light

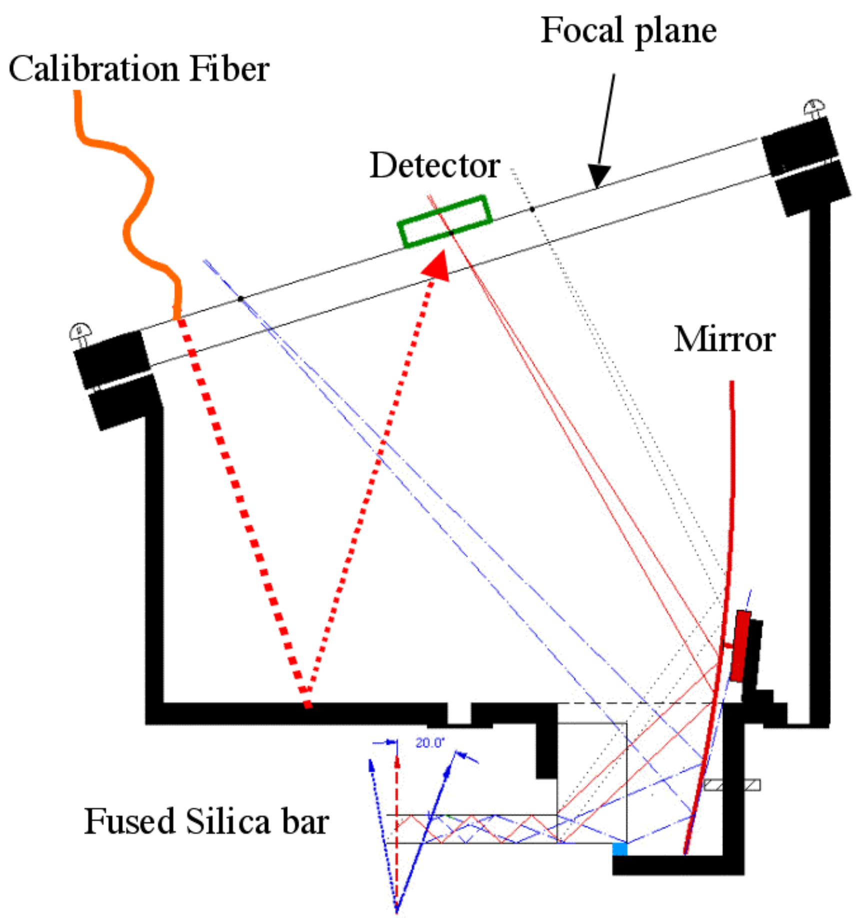
Joe Schwiening, SNIC 2006

- This is a second generation improvement to the DIRC design:
  - Focusing removes the effects of bar size in the uncertainties
  - Smaller, faster PMTs allow for a smaller standoff region with the same geometric resolution
  - ~100 ps timing allows photon color to be measured by timing differences due to chromatic dispersion (work in progress)

$$\cos \theta = 1/\beta n(\lambda)$$

Focusing Optics

- Radiator - 3.7m-long bar made from three spare high-quality BaBar DIRC fused silica bars glued together with the same glue (Epotek 301-2)
- Expansion region - mineral oil (KamLand experiment) to match fused silica refractive index
- Focusing optics - spherical mirror from SLD-CRID detector (focal length 49.2cm)
- Photon detector - use array of flat panel PMTs focal plane readout to CAMAC/VME electronics

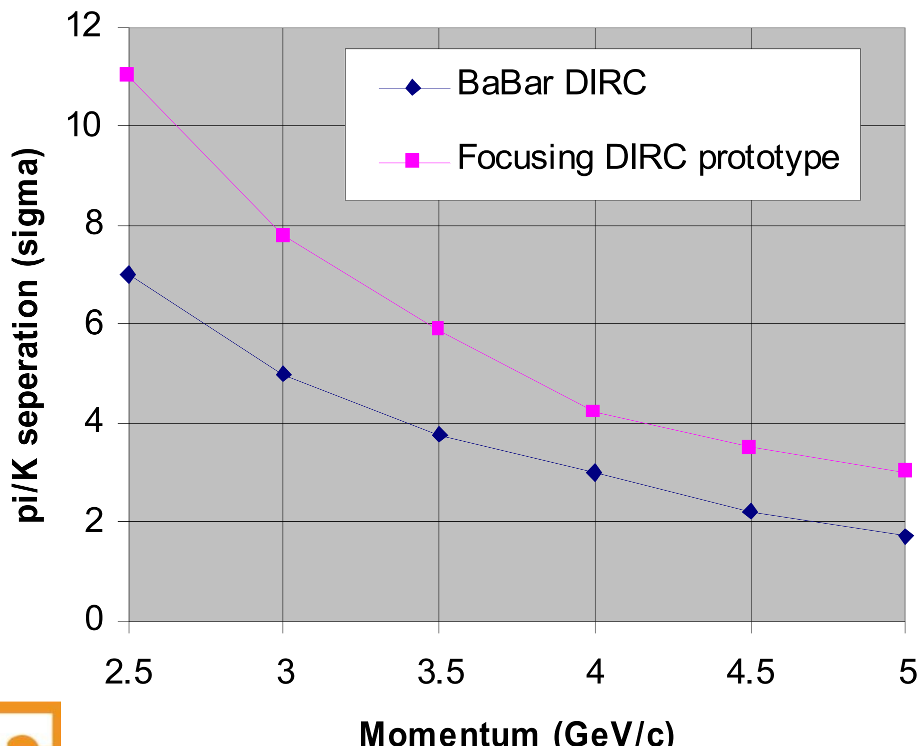


Joe Schwiening, SNIC 2006

Comparing DIRCs

BaBar

- x, y position measurements
- Time measurement ($\sigma = 1.7$ ns)
- t used to eliminate background



Prototype

- x, y position measurements
- **time measurement (σ < 140 ps)**
- **t can be used for PID**
- **focusing removes bar size dependence**

Joe Schwiening, SNIC 2006

Potential for use in Future experiments

others?

Acknowledgementation

Thanx to Joe Schwiening and Stefan Spanier for help in preparing this talk.

Questions?

More information available at

http://Wogsland.org/physics/hep/cherenkov_detectors.html