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

\[ \cos \theta_C = \frac{1}{\beta n} \]

- 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:

\[ N = 370L \int \varepsilon \sin^2 \theta_C \, dE \]
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_

Bradley Wogsland

Cherenkov Detectors, August 2006
RICH Detectors

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

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


Bradley Wogsland

Cherenkov Detectors, August 2006
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

Bradley Wogsland
Cherenkov Detectors, August 2006
• The Aerogel Cherenkov Counter first used by the Belle Collaboration
  - Aerogel used has refractive index in the range 1.010-1.030
  - K/π separation up to 3.5 GeV/c
  - 1188 modules total
• Also used by PHENIX collaboration at RHIC
  - Replaced older PID system in 2004
  - K/πi 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
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


Bradley Wogsland
Cherenkov Detectors, August 2006
The DIRC Concept

- Particle traveling faster than light in a given medium emits Cherenkov radiation
  \[ \cos \theta = \frac{1}{\beta n} \]

- 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 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.
- $99.9 \pm 0.1\%$ transmission per meter at 442 nm
- $98.9 \pm 0.2\%$ transmission per meter at 325 nm

Recall now the Frank-Tamm equation:

$$ N = 370 L \varepsilon \sin^2 \theta_C \, dE $$
Nitrogen gas is circulated around the quartz bars to protect 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 Plant – Here the water from the SOB is degassed, irradiated and circulated
But we have humidity sensors in too, just in case!
Photomultipliers

ETL 9125FLB17 PMT
- Used in BaBar's DIRC
- 26 mm active photocathode diameter
- Gain $1.7 \times 10^7$
- Timing resolution $\sim 1.5$ ns
- Arrayed with hexagonal rhodium-plated light catchers

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

Bradley Wogsland

Cherenkov Detectors, August 2006
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.

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 $\theta_C$
  - 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.


Bradley Wogsland

Cherenkov Detectors, August 2006
Reconstruction

- Arrival time is used to reduce background

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

---

Bradley Wogsland

Cherenkov Detectors, August 2006
Reconstruction

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

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.
Background

• High luminosity $\sim 11 \times 10^{33}$ 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

• 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)

\[
\cos \theta = \frac{1}{\beta n(\lambda)}
\]

Joe Schwiening, SNIC 2006
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
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 ($\sigma < 140$ ps)
- t can be used for PID
- focusing removes bar size dependence

Joe Schwiening, SNIC 2006

Bradley Wogsland

Cherenkov Detectors, August 2006
Potential for use in Future experiments

others?

Bradley Wogsland

Cherenkov Detectors, August 2006
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