Review of relevant Cherenkov imaging devices in particle/nuclear experiments currently running, under construction and planned

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6th International Workshop on Ring Imaging Cherenkov Counters (RICH2007)
Stazione Marittima, Trieste, Italy
15 - 20 October 2007
Outline of this talk

Review of *relevant* Cherenkov imaging devices in particle/nuclear experiments currently running, under construction and planned

**What is included?**
Detectors of focused Cherenkov radiation in accelerator/collider experiments

**Why is the RICH needed?**
Physics motivation

**How is the RICH detector used?**
highlighting specific features of current/planned experimental devices

"Review" → "Preview"
a pointer to contributed papers presented here

Apologies for omissions
does not mean *irrelevant*!

Acknowledgements
to experiment websites for presentation material
Outline of this talk

What? Types of RICH detector in use/proposed

- Image focused by lens/mirror
  Classic RICH detector (Seguinot, Ypsilantis)

- Proximity focusing
  “thin” solid/liquid radiator

- Pin-hole focusing
  DIRC (Detector of Internally Reflected Cherenkov light)

- Imaging using timing
  Water Cherenkov
  TOP – time of propagation

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Why are RICH detectors used?

Physics motivation

• Flavour physics and CP violation
  Hadron ID: to identify quark flavours in decays
  LHCb, BELLE, BABAR, NA62

• Hadron (low $p_T$) physics
  Hadron ID: to identify final states, particle production, spectroscopy
  PANDA, MIPP, COMPASS

• Nucleon structure
  Hadron ID: charmed hadrons as probe of gluons in nucleons
  COMPASS, HERMES

• Heavy Ion physics and QGP
  Electron ID: nuclear matter transparent to leptons so probe interior
  ALICE, JLAB, CBM

• Neutrino physics
  Event reconstruction for oscillation studies
  T2K (MIPP)

Reported at RICH2007
Flavour physics – BABAR DIRC

Babar detector at PEPII electron-positron collider b\bar{b} factory – CP violation in decay of B_{u,d} mesons
Flavour physics – BABAR DIRC

11,000 PMTs: 29mm diameter
\( \pi / K \) separation: 0.5 - 4 GeV/c

N_photons detected > 30 / track
\( \sigma_\theta < 10 \) mrad
x 6 reduction in \( D^0 \rightarrow K\pi \) background
Flavour physics – BABAR DIRC

DIRC Upgrade – to handle x 100 luminosity

- Focusing DIRC
- Reduced photon detector pixel size → 5mm
- Reduced timing resolution → ~100ps
- Determine colour of photon and correct chromatic error on $\theta_C$

See talk by: J. Schwiening
Flavour physics – BELLE upgrade

BELLE detector at KEK electron-positron collider $b\bar{b}$ factory – CP violation in decay of $B_{u,d}$ mesons

Currently uses aerogel threshold

Upgrade proposed for super B factory $\times 100$ luminosity

$\pi / K$ separation: 0.5 - 4 GeV/c

Focusing / Time of Propagation (TOP) DIRC

Proximity focusing aerogel RICH
Flavour physics – BELLE upgrade

TOP barrel DIRC:
Multichannel Plate PMTs with time resolution ~ 40ps

End Cap proximity focused aerogel
20mm-thick Aerogel tiles to limit emission-point error
FlatPanel (H8500) PMTs → $\sigma_\theta \sim 14$ mrad
N_detected photons ~ 6

Increase N_ph by using graded-n aerogel tiles (FARICH)

See talks by:
K.Inami
T.Iijima
E.Kravchenko
P.Krizan
S.Nishida
Flavour physics – CLEOc

Beauty and Charm physics at CESR electron-positron collider

Proximity focused LiF RICH

$\pi/K$ separation up to 3 GeV/c

CH$_4$-TEA gas photo detector $20 m^2$ (biggest out there)

230k pixels: 8mm x 8mm

$N_{\text{detected photons}} \sim 12$

$\sigma_0 \sim 14$ mrad
Flavour physics – HERA-B

Beauty and Charm physics with fixed target at HERA proton ring

“Classic” C4F10 gas RICH

5 yrs stable good performance

Pioneered use of MultiAnode PMTs
Hamamatsu M4, M16 equipped with lenses

$N_{\text{detected photons}} \sim 30$
$\sigma_\theta \sim 14 \text{ mrad}$
Flavour physics – LHCb

Single arm spectrometer for precise CP Violation measurements and rare decays in the B-meson system in the LHC

See talks by:
N.Harnew
C.D’Ambrosio
S.Eisenhardt
S.Brisbane
C.Buszello
T.Bellunato
A.Papanestis
F.Metlica
M.Sannino
D.Wiedner
F.Muheim
Flavour physics – LHCB

Hadron ID from 1-100GeV/c

3 radiators: Aerogel, C$_4$F$_{10}$, CF$_4$

484 HPDs: 2.8m$^2$ with 2.5 x 2.5mm$^2$ pixels

Allows rare B-decay to be cleanly identified
Hybrid Photon Detectors in LHCb RICH

LHCb has pioneered use of HPD (DEP-Photonis)

1000 pixels per tube: readout chip
bump-bonded to sensor and
encapsulated in vacuum tube

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Flavour physics – NA62 at CERN

Measure $K^+ \rightarrow \pi^+ \nu \nu$ branching fraction to extract $V_{td}$

SM prediction: $0.8 \times 10^{-11}$

$K^+ \rightarrow \mu^+ \nu$ background: $x 10^{12}$ rejection required (RICH x $\mu$-veto x kinematics)

18m Ne radiator “classic” RICH with 16mm PMTs will deliver $\sigma_\theta < 0.1$ mrad
e- $\mu$- $\pi$ separation over 10 – 70 GeV/c

See talk by: F.Bucci

CKM (kTeV2)
Similar expt planned for FNAL Main injector
Nucleon structure physics - HERMES

HERA electron beam on polarized gas-jet target
Probe spin structure of nucleon

$C_4F_{10}$ gas + Aerogel radiators (Pioneered Aerogel RICH)
Hadron ID in range 2 – 15 GeV/c

Completed in 2007 after 7 years stable running

2000 PMTs 23mm diameter
$N_{\text{photon hits}} \sim 12$
$\sigma_\theta \sim 7\text{mrad}$

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Nucleon structure physics - COMPASS

160 GeV polarized muons on polarized target at CERN SPS
Probe of gluon structure function and spin of nucleon
Charm is signature of gluon (no vertex detector so hadron ID is crucial)

RICH: $C_4F_{10}$ gas radiator, mirror (20m$^2$) focused RICH
5m$^2$ CsI photocathode + MWPC (1cm$^2$ pixel)

See talk by:
F.Tessarotto
F.Sozzi
M.Sulc
A.Teufel
Compass operation stable after 2 years running in 2006 upgrade: Replaced central CsI photon detectors by M16 MaPMTs

Big improvement

\[ N_\gamma \sim 60 \text{ (cf 14)} \]
\[ \sigma_{\text{ring}} \sim 0.3\text{mrad}(0.6) \]
PID up to 55 GeV (43)
\[ \Delta t \sim 1\text{ns (3\mu s)} \]
Hadron physics (low $p_T$) - PANDA

Anti-Proton ANihilation at Darmstadt (~2013)

**PANDA**: 100% acceptance fixed target spectrometer at FAIR (Facility for Antiproton and Ion Research at GSI)

Exotic hadron spectroscopy – glueballs, quark molecules, hybrids
Cherenkov Detectors in PANDA

- HERMES-style RICH
- BaBar-style DIRC
- Disc focussing DIRC

See talk by:
K. Föhl
C. Schwarz
P. Schönmeier

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side view

fused silica radiator

2-dimensional imaging type

one-dimensional imaging DIRC type

front view
Hadron physics (low $p_T$) – MIPP

100% acceptance spectrometer

$\pi, K, p$ beam from FNAL Main Injector

CO$_2$ classic RICH, 3000 PMTs

$3\sigma \pi / K$ separation up to 90 GeV

Planned upgrade for neutrino beam and ILC studies (verification of Hadron interaction simulation codes)

COMPASS also moves on to its hadron spectroscopy programme
ALICE studies the physics of strongly interacting matter and the quark-gluon plasma (QGP) in nucleus-nucleus collisions at the LHC.

The HMPID RICH identifies hadrons $\pi/K/p$ in the range 1/3/5 GeV/c.
Heavy Ion physics - ALICE

Measurement of particle ratios over a wide momentum range
dE/dx, TOF, RICH, TRD are used

The HMPID RICH covers the range 1-5GeV/c
7 modules of 1.5m x 1.5m (5% of barrel)
C$_6$F$_{14}$ liquid radiator, proximity focused → CsI + MWPC (8mm x 8mm pixels)

VHMPID: upgrade planned to extend PID to 30 GeV/c.
C$_5$F$_{12}$ gas radiator (1m) mirror-focussed RICH
CsI photocathode + GEM photon detector

See talk by:
G.Volpi
Heavy Ion physics - JLAB

JLAB: fixed target High Resolution Spectrometer
RICH for K physics
Same technology as ALICE HMPID
Electron scatter form nuclei
(ee’K) reaction creates hypernuclei
important to physics of neutron stars
Pion rejection factor ~ 1000 (0.8 – 3 GeV/c)
Upgrade foreseen for 2008 running

See talk by:
E.Cisbani

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Heavy Ion physics - CBM

**CBM:** Compressed Baryonic Matter at FAIR, GSI (2013)
Fixed target: 15-35 AGeV, 10MHz rate
Detect low-mass vector mesons → leptons
PID up to 10GeV/c with excellent electron ID

**RICH:** “Classic” mirror-focussed RICH
2.2m gas radiator
Be-glass mirrors
PMT photon detectors

*See talk by: C.Höhne*

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Heavy Ion physics - RHIC

Relativistic Heavy Ion Collider: $E_{CM} = 200$ AGeV

Physics requirements

- Compare hadron ratios: e.g. meson/baryon in p-p vs A-A
- Identify electron pairs: nuclear matter is transparent so probe interior

Three of the experiments use RICH for PID

**BRAHMS**

$C_4F_{10}/C_5F_{14}$ gas: M4 MaPMTs: hadron ID up to 30GeV

**PHENIX**

$C_4F_{10}$ gas: CsI photocathode: hadron blind electron ID

**STAR (ALICE-like RICH)**

$C_6F_{14}$ liquid: proximity focused: π/K/p ID from 1/3/5GeV/c
Super Kamiokande

The largest Cherenkov in use at an accelerator-based experiment will soon be fully repaired, operational with upgraded DAQ 50ktonnes water viewed by 13,000 20” PMTs

Upgrade: deadtime-less acquisition and enhanced DAQ allow refined trigger and lower (~2MeV) threshold
Aim is to measure mixing angle $\theta_{13}$
Summary - 1

Many accelerator/collider experiments use or plan to use RICH detectors

Flavour physics and CP violation
- BELLE, BABAR, HERA-B, LHCb, NA62
- HERMES, COMPASS
- PANDA, MIPP, COMPASS
- ALICE, JLAB, CBM, STAR, BRAHMS, PHENIX
- T2K (MIPP)

Nucleon structure

Hadron (low p_T) physics

Heavy Ion physics, QGP

Neutrino oscillations

NB: Not in high p_T collider detectors – Tevatron, LHC GPDs

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Summary - 2

Personal observations and interpretations

Ubiquity of the RICH detector

Diversity of RICH detector types – choice informed by:
  physics requirements
  space constraints
  cost

Current trends
  Classic mirror-focused gas RICH for high energies
  Use of vacuum tube photon detectors where feasible
  Proximity focused + CsI/MWPC photon detectors for large areas
  Emergence of DIRC as favoured technique for barrel configuration

Future trends
  Exploring benefits of precise timing (TOP)
  Development of solid state photon detectors