07 - Cherenkov and transition radiation detectors

Jaroslav Adam

Czech Technical University in Prague

Version 2
Cherenkov radiation

- Emitted by passage of charged particle in dielectricum at velocity greater than speed of light in respective material
- $\beta > \frac{1}{n}$ where $n$ is refractive index
- Dipole moment of polarized electrons, emission of electromagnetic field
Angle of Cherenkov radiation emission

- Light emitted into forward cone of aperture

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

- Threshold of Cherenkov light emission given by \( \beta_{thr} \geq \frac{1}{n} \)
Yield of Cherenkov photons

- Yield per unit length of track proportional to $\lambda^{-2}$
- Smaller than scintillation light
Threshold Cherenkov detectors

- Separation of particles with different masses at the same momentum
- Set of Cherenkov radiators of different $n$, different threshold for each particle
- Radiators of material of desired $n$ or gaseous radiator at a given pressure
Differential Cherenkov detectors

- Tagging of particles in selected range of velocities
- Light reflected by spherical mirror, aperture in front of PM provides velocity window
- Particles parallel to optical axis (fixed-target experiments)
Fitch-type differential Cherenkov detector

- Upper limit on velocity by internal reflection
- Light at higher angle does not escape into the light guide
Ring imaging Cherenkov (RICH) detector

- Particle identification by angle of Cherenkov radiation
- Photons reflected by spherical mirror (SM) and focused onto spherical detector SD
- Measured circle of Cherenkov photons to get particle velocity, together with particle momentum provides the identification
Detection of Cherenkov photons in RICH

- Position sensitive detector of large surface
- MWPC with photosensitive vapor in counter gas
- Quartz entrance window for vapor of low ionization energy, UV transparent crystal otherwise
- More intense rings by fast heavy ions (number of photons proportional to square of particle charge)
Cherenkov ring of relativistic heavy ion in RICH

- Early measurement of heavy ion with RICH
- Center of ring visible due to ionization loss in photon detector
- Spurious signals by $\delta$-rays of heavy ion
Cherenkov rings by monoenergetic beam

- 100 events of collinear monoenergetic beam
- Entrance windows by calcium-fluoride crystals
Solid-state detectors in RICH

- CsI photocathode as photoconverter
- Single or multi-anode conventional photomultiplier or hybrid photomultiplier
- Micropattern gaseous detector with CsI photocathode
Cherenkov angle dependence on particle momentum

- Cherenkov rings detected by system of multichannel photomultipliers
Cherenkov rings in electromagnetic cascades

- Secondary particles in cascade follows direction of initiating electron or photon
- Also relativistic, emit overlapping Cherenkov rings, concentric with equal radii
- Distortion of the ring (elliptic for inclined angle) gives direction of incidence - gamma-ray astronomy
Detection of neutrino induced muons and electrons

- Muon produced in interaction of atmospheric neutrino, detected by Cherenkov ring in heavy water
Detection of neutrino induced muons and electrons

- Cherenkov ring of electron from decay of muon which was produced by neutrino interaction
Detector of Internally Reflected Cherenkov light (DIRC)

- Based on internal reflection of Cherenkov radiation in quartz bars of rectangular cross section
- Readout by system of PM tubes
RICH of LHCb experiment

- Detectors RICH1 and RICH2
Cherenkov radiators of RICH in LHCb

- Different particle momenta covered by RICH1 (lower) and RICH2 (higher momentum)
- Identification among several particle species
Layout of RICH1 in LHCb

- Cherenkov light emitted by Aerogel and gaseous radiators
- Light reflected by flat and spherical mirrors outside the LHCb acceptance
Layout of RICH1 in LHCb

- Reflected Cherenkov light detected by the photon detectors
Layout of RICH2 in LHCb

- Second Cherenkov detector with different radiator
Photon detector in RICH of LHCb

- Hybrid photon detector HPD
- Photon conversion at photocathode, photoelectron accelerated and detected by segmented silicon detector
- Image of photocathode de-magnified onto the detector by the electrodes
Transition radiation detectors (TRD)

- Charged particle moving towards boundary of materials of different dielectric properties
- Time-dependent electromagnetic field of electric dipole of charged particle and its mirror at boundary
- Emission of electromagnetic radiation
Energy of transition-radiation photons

- Average energy of TRD photons vs. electron momentum

![Graph showing the average energy of transition-radiation photons vs. electron momentum. The x-axis represents electron momentum in [GeV/c] and the y-axis represents the average energy of photons in [keV]. The graph shows a curve increasing with electron momentum.]
Arrangement of transition-radiation detector

- Angle of emission of transition-radiation photons inversely proportional to Lorentz factor of the particle
- System of periodic foils and gaps as radiator
- Photons detected by MWPC filled by Kr or Xe
Energy loss distribution in TRD

- Energy loss by relativistic electrons
- (a) - radiator with gaps, (b) - radiator without gaps, no transition radiation in this case

![Graph showing energy loss distribution with and without radiator gaps.](image)
TRD of ALICE experiment

- TRD located in the central barrel above TPC, provides electron identification.
Detector element of TRD in ALICE experiment

- Radiator for transition radiation, gas drift volume of Xe/CO₂ and MWPC
- X-ray photons of transition radiation converted at the beginning of drift volume
Electron identification by TRD in ALICE

- Discrimination between electrons and pions
- Increased specific energy loss by electrons at the same momentum
- Signal at large drift times for electrons by conversion of transition radiation at the beginning of drift sector