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ARC implementation discussion
28 March 2023

RICH reconstruction

Gerri asked me to give a brief overview of the RICH reconstruction techniques used in LHCb, as I was responsible for originally developing them

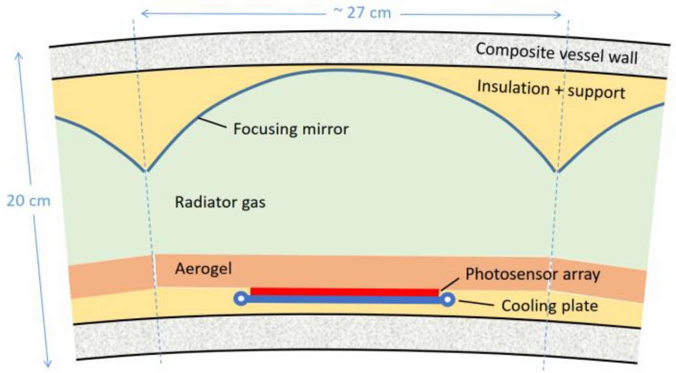
The relevant reference is a note I wrote with Olivier Schneider LHCB/98-040 (from 30 April 1998!)

The procedures have since been implemented in the software framework of LHCb and refined over the years, for details of which you should contact the experts such as Chris Jones (Cambridge Univ.)

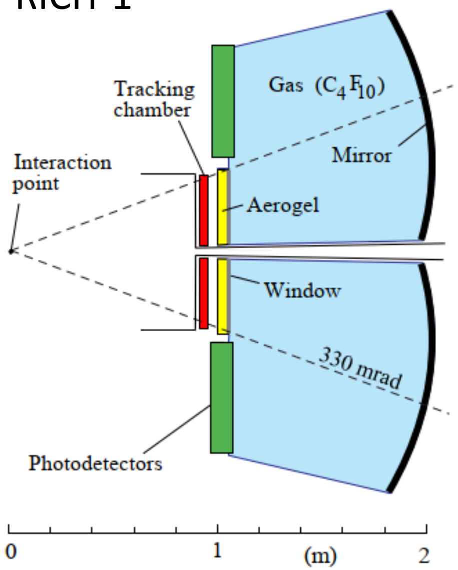
RICH environment

- The analysis in LHCb was developed for its RICH system, comprising **RICH-1** (low momentum 1-50 GeV, full acceptance, originally dual radiator) + **RICH-2** (high momentum 20-100 GeV, limited acceptance)
- RICH-1 looks similar to an individual ARC cell – however at the LHC the track multiplicity is high, so most of the complexity comes from background due to overlapping "signal" rings
- With the simpler e^+e^- collisions and the many cells of ARC, most events will have at most only a single track per cell, which will simplify the pattern recognition

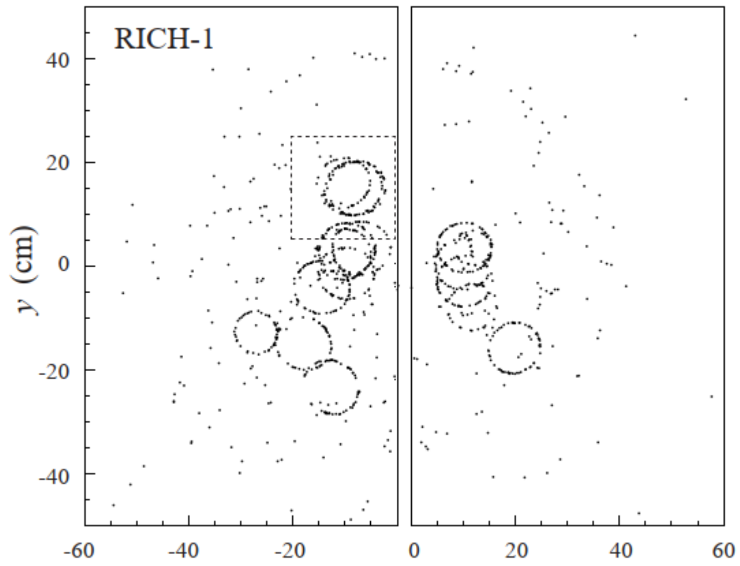
ARC cell



RICH-1

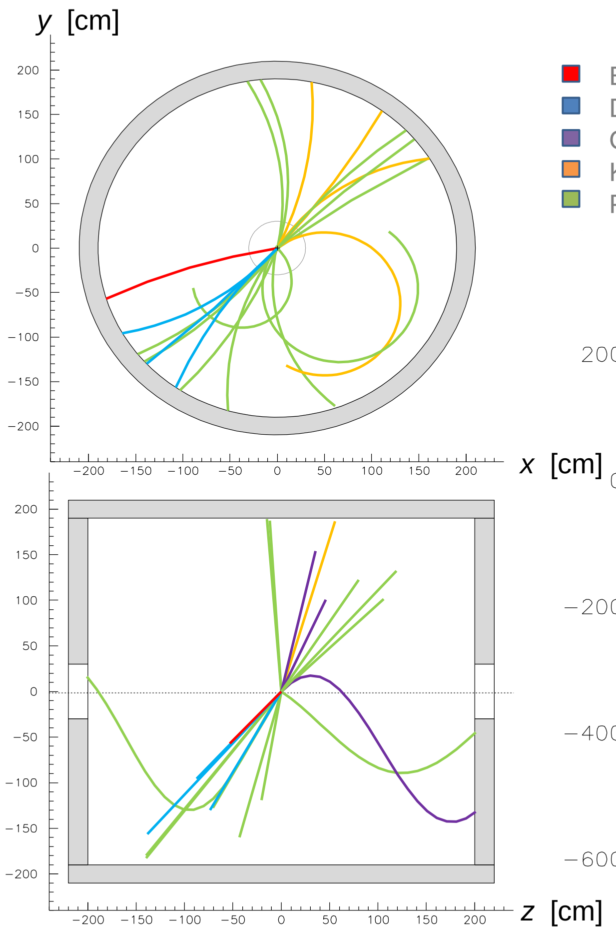


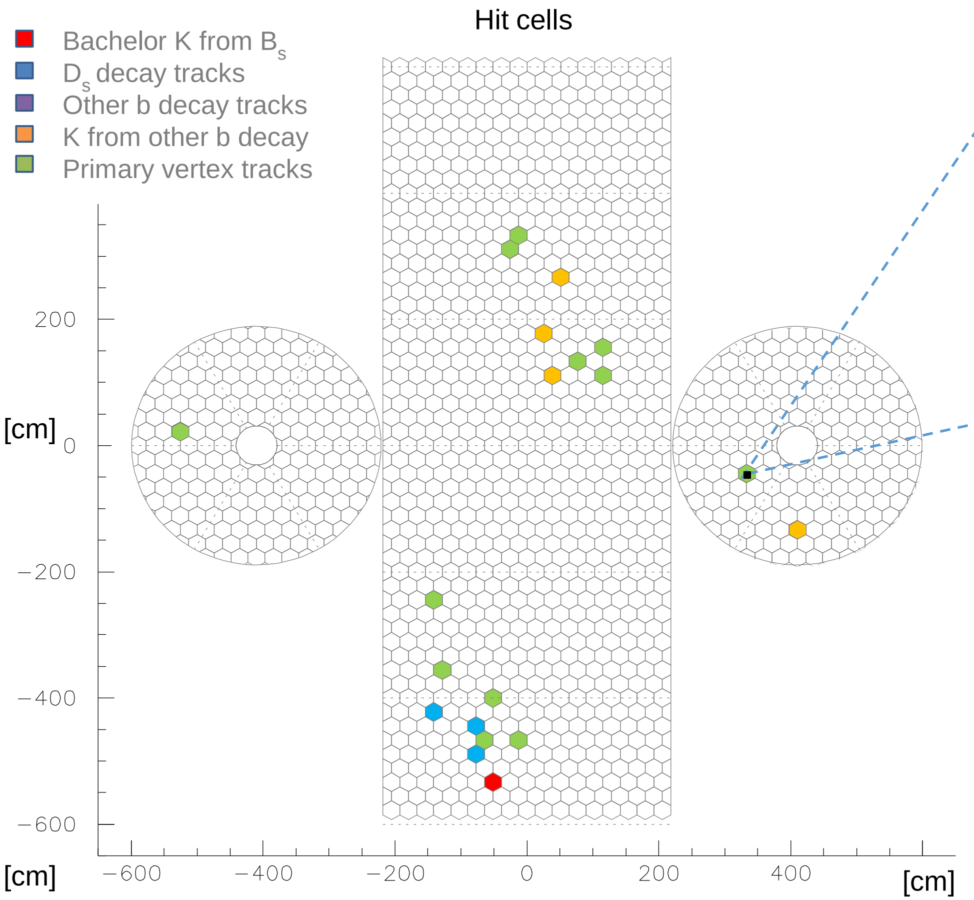
Single simulated event in LHCb



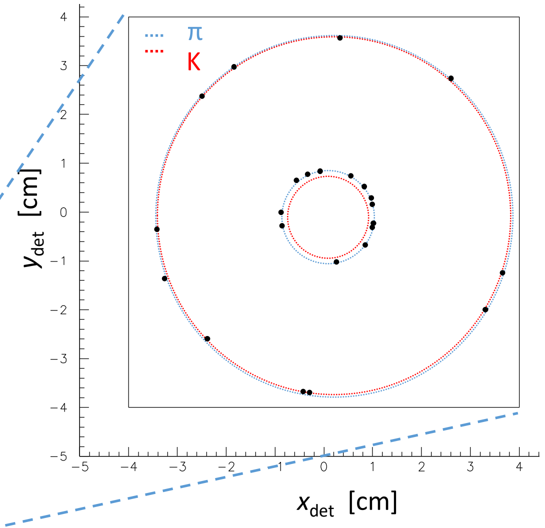
Event display in ARC

- Display of a simulated Z event containing a $B_s \rightarrow D_s K$ decay

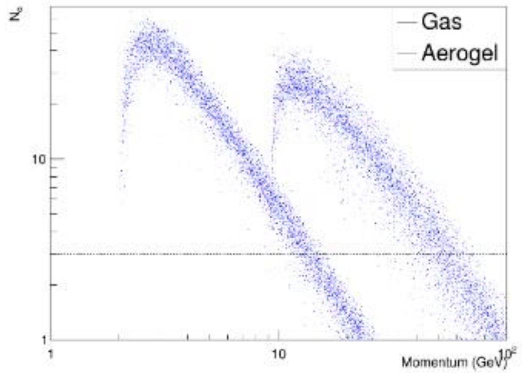




Zoom on hits in a single cell



K-π separation [Martin]



Cherenkov angle reconstruction

- First step is to reconstruct the Cherenkov angles (θ_C, ϕ_C) for each photon detector hit, calculated w.r.t. each track that passes through the cell
- *Tracks* could be taken from the simulation, or (better) after reconstruction in the tracker, e.g. of the CLD experiment
- *Emmission point* taken as the midpoint of the track's passage through each radiator
- *Photon hit* positions defined in the sensor of the photon detector, after pixellisation
- For reflection in a spherical mirror the Cherenkov angles can be determined analytically, by solving a quartic equation (or numerically by ray tracing, if preferred)

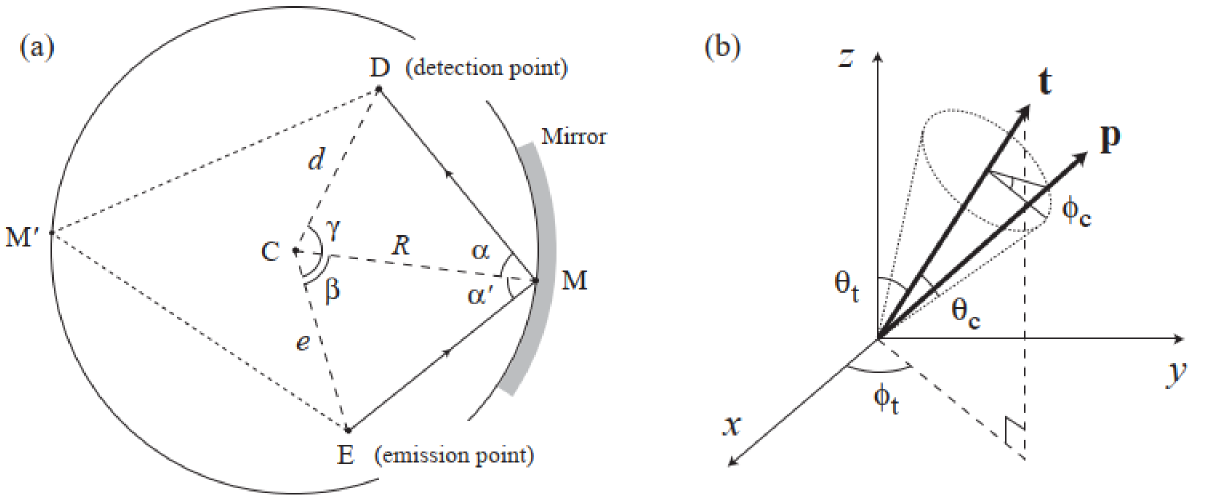


Figure 3: (a) Definition of parameters used in the reconstruction of the Cherenkov angles, for a photon emitted from point E, reflected in a spherical mirror at M and detected at D. (b) Definition of the angles describing the direction of a track **t** in the lab frame, and a photon **p** emitted by the track.

Local pattern recognition

- To perform simple-minded pattern recognition, can just plot the Cherenkov angles for all hits in the cell, for each track in turn
- Hits that come from the given track will line up at a given θ_C, while the hits from other tracks will be spread out as a background
- This "local method" involves searching for a peak in the θ_C distribution – which should be good enough for the simple ARC events
- With both aerogel and gas radiators, there will be up to two peaks at their respective θ_C – the fitted values of the peaks can be compared to the expectation from π or K hypothesis to perform particle identification
- $\cos\theta_C = 1/\beta n$ (β depends on mass-hypothesis)

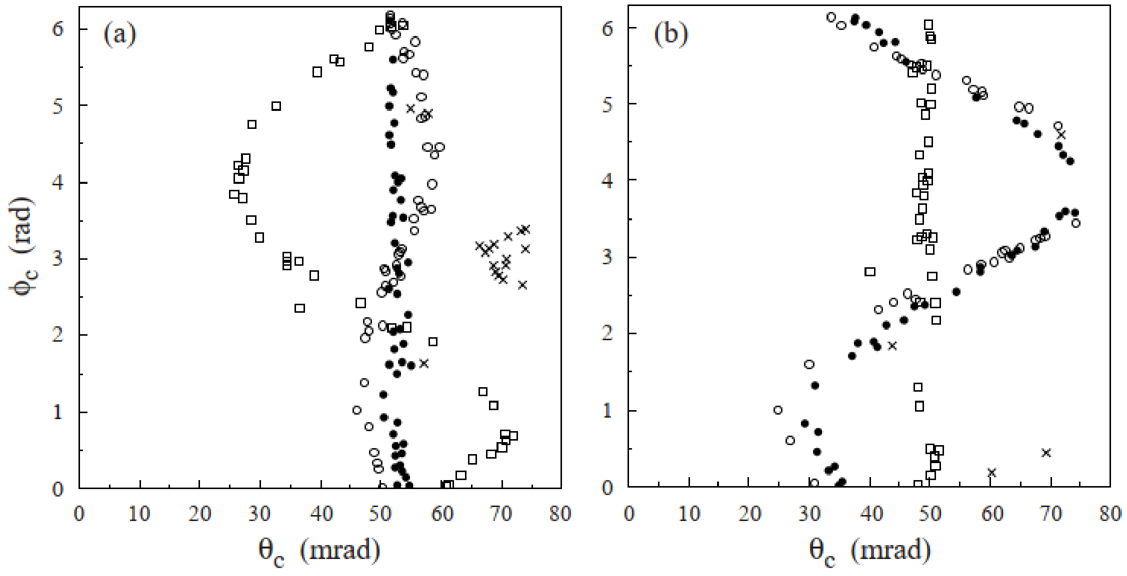


Figure 4: Reconstructed Cherenkov angles (θ_c, ϕ_c) for the hits in the event of Fig. 2, when calculated assuming that the photons were emitted from the gas radiator of RICH-1, from two tracks in turn: (a) from the track that gave the right-most ring in the dashed box of Fig. 2, and (b) from the track that gave the left-most ring in the same box. The symbol indicates which track the hit truly originated from: solid points for the track that gave the right-most ring, open points for the tracks that gave the other two rings, and crosses for hits from any other track.

More sophisticated approach

- The remainder of the note describes in detail a more sophisticated "global" approach to pattern recognition
- A likelihood is calculated by comparing the expected hit distribution (PDF) on the detector plane for all tracks, under a given set of mass hypotheses, to the observed set of hits
- Some numerical tricks allow this to be calculated quickly
- The mass-hypotheses (e, μ, π, K, p) are then adjusted for all tracks, to find the best fit – starting with taking all as π, then changing the track hypothesis that gives the largest improvement, and iterating: it converges fast
- The particle ID estimators are simply calculated from the difference in log-likelihood between different mass-hypotheses for a given track, e.g. $DLL_{K\text{-}\pi} = \ln L_K - \ln L_\pi$

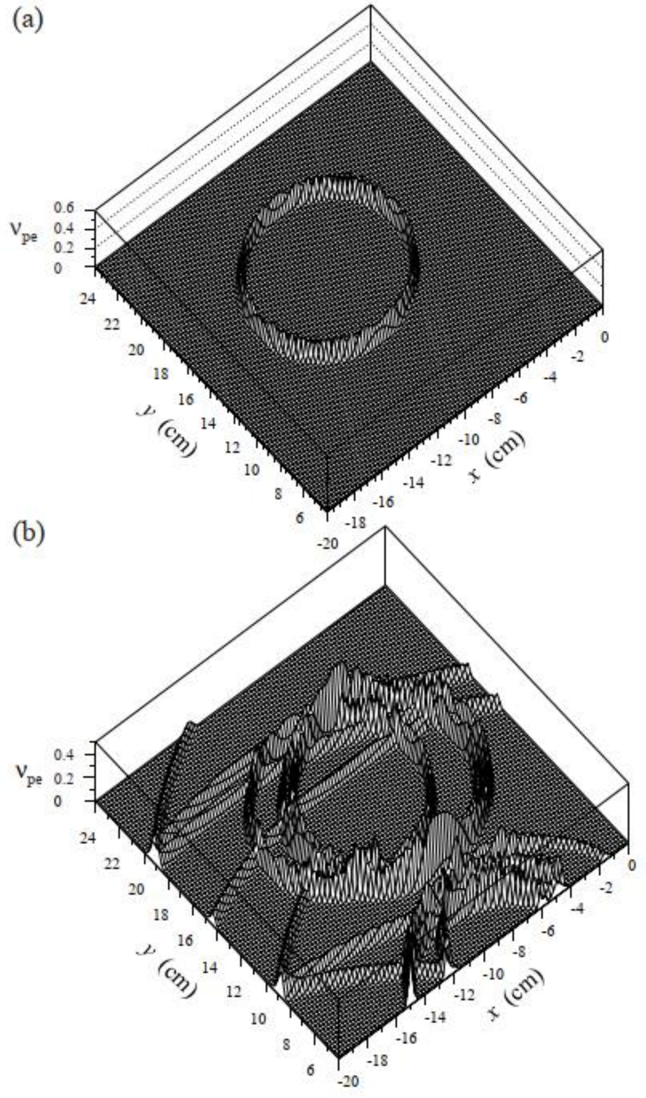


Figure 8: Expected number of photoelectrons in each pixel, for the region of the RICH-1 detector that is surrounded by a dashed box in Fig. 2: (a) for the Cherenkov ring from a single track in the gas radiator; (b) from all tracks in the event, using their true particle types, in both gas and aerogel radiators (×10 for the aerogel rings, to make them clearly visible).

Conclusion

- RICH reconstruction + pattern recognition + particle identification software has been developed in LHCb
- It works well in the complicated LHC environment
- For the simpler events expected for ARC at an e^+e^- Higgs Factory experiment, a simplified reconstruction should be enough – at least at this stage of the project
- Calculate the Cherenkov angle for each photon hit-track combination in a given cell, and make a simple peak search to determine the preferred particle type
- A more sophisticated global method for pattern recognition is available if needed, for use when there are multiple tracks per event passing though a cell, or if there are other significant backgrounds to be handled