Summary of the LHCb Particle ID, and Implications for the EIC

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The LHCb particle ID system is very instructive for the particle ID challenge of the ion-side end-cap detectors of a future Electron Ion Collider (EIC). In particular, the LHCb design attempts to achieve full charged hadronic particle ID (π, K, p) from 1 to 100 GeV/c. This was initially implemented with a dual RICH (Aerogel plus C_4F_{10}) followed by a second CF_4 RICH. The LHCb upgrade plans call for a TORCH detector, based on time reconstruction of the DIRC concept. The Aerogel will be removed from RICH1, and the optics and photon sensors replaced to improve the high-multiplicity performance.

I. LHCB PARTICLE IDENTIFICATION DESIGN

The LHCb detector is summarized in Ref. [1]. The detector is illustrated in Fig. 1. Particle ID is achieved with two RICH detectors. RICH1 has dual Aerogel and C_4F_{10} radiators. The aerogel is 5 cm thick, with index $n = 1.03$ at $\lambda = 400$ nm. The gas volume has a 95 cm active depth. The properties of C_4F_{10} are described on the LHCb wiki [2]. In particular, the index of refraction (at STP) is parameterized as [3]:

$$n - 1 = 10^{-6} \left[\frac{(0.25324(nm^{-2}))}{(73.7 \text{ nm})^{-2} - \lambda^{-2}} \right] \tag{1}$$

At $\lambda = 400$ nm, and ambient temperature and pressure (NTP), $n(C_4F_{10}) = 1.0013$. The anticipated photoelectron yield ($\beta = 1$) was 6.5 from the Aerogel and 30 from the C_4F_{10}. This was expected to provide particle I.D. up to 60 GeV/c [1].

The LHCb RICH2 covers a smaller angular range downstream of the primary magnet, with a single radiator of CF_4 gas. The active gas depth is 1.8 m. The index of refraction (STP) of CF_4 in the visible range is [1]:

$$n - 1 = 10^{-6} \left[\frac{(0.12489(nm^{-2}))}{(61.8 \text{ nm})^{-2} - \lambda^{-2}} \right] \tag{2}$$

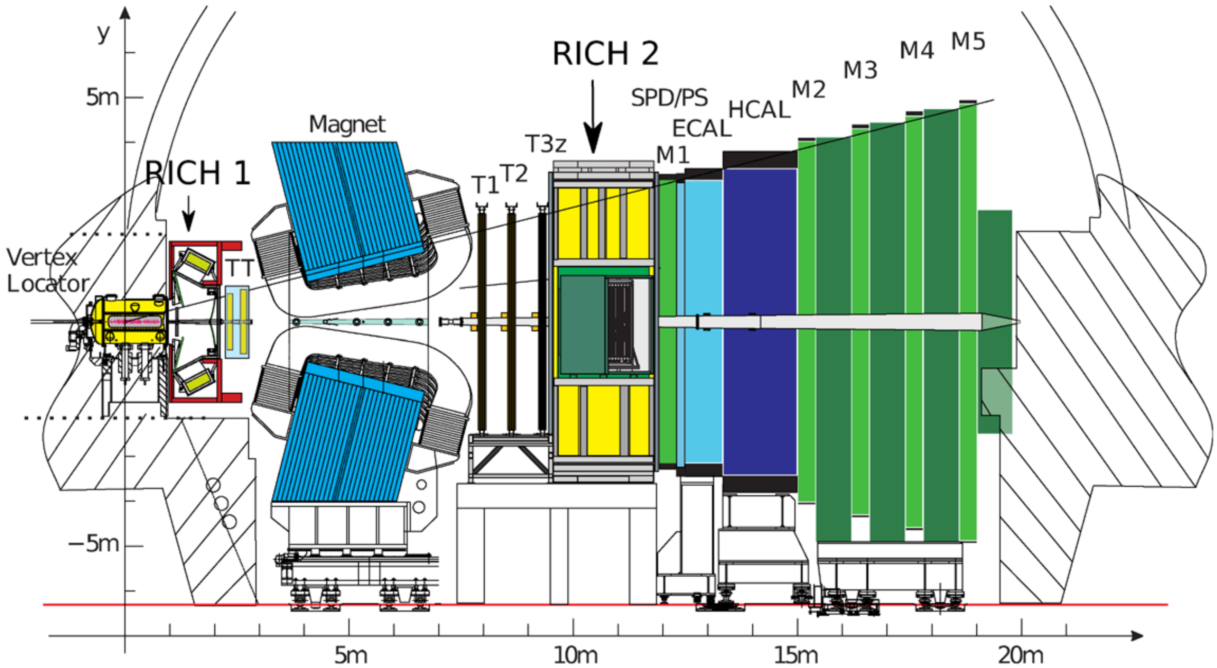

Figure 1. The LHCb Detector, highlighting the two RICH detectors (Fig. 1 from [5]).

Almost identical parameters are found in the far UV range [4]. At NTP and $\lambda = 400$ nm, $n(CF_4) = 1.00044$. The anticipated photoelectron yield was 22 from RICH2. This detector was expected to provide particle I.D. up to 100 GeV/c.

II. PERFORMANCE

The LHCb RICH performance, as of 2013, is summarized in [5]. The Cerenkov angle reconstruction achieved in the gas is 1.62 mrad in RICH1 and 0.68 mrad in RICH2. Fig. 2 illustrates the particle ID separation achieved in the C_4F_{10}. The overall PID performance is summarized in Fig. 3.

III. LHCB UPGRADE

The LHCb Collaboration plans a major upgrade of the detector for the 2018–2019 Long Shutdown (LS2) of the LHC [6]. The main purpose of the upgrade is to enable primary digitization and read-out at the 40 MHz LHC bunch crossing frequency. For PID, the

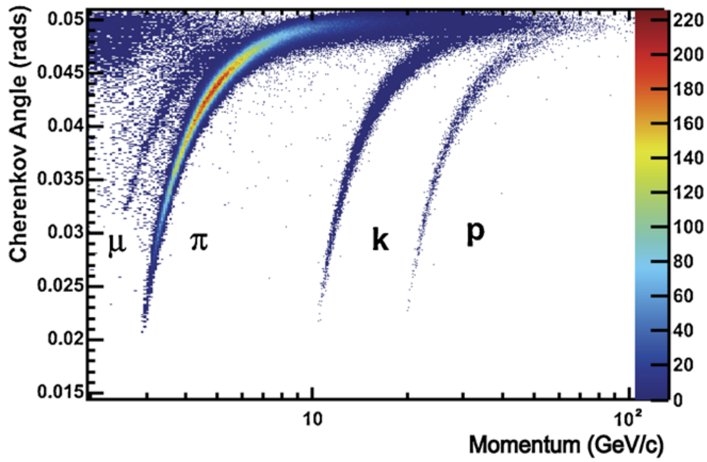

Figure 2. Reconstructed Cherenkov angle as a function of track momentum in the C_4F_{10} radiator (Fig 14 from [5]).

aerogel will be removed from RICH1. The RICH1 mirrors will be replaced with longer focal length mirrors, and the photosensors will be replaced and repositioned. The photosensors must be replaced because the Front End Electronics (FEE) is inside the vacuum enclosure of the Hybrid Photomultiplier Detectors (HPD) from Photonis. These upgrades to RICH1 will improve data throughput and decrease pixel pile-up from the very high multiplicity (both true and random coincidence) of the events. To replace the aerogel, and improve the PID below 10 GeV/c (the kaon threshold of C_4F_{10}), a new Time Of internally Reflected CHerenkov Light (TORCH) detector will be installed behind RICH2 [7]. The TORCH design goal is to achieve 15 ps TOF track resolution of the 12 m flight path. The design requires focussing DIRC optics to measure individual photo-electron timing to 70 ps rms per photo-electron, with a yield of 30 photo-electrons per track.

IV. IMPLICATIONS FOR EIC PARTICLE ID

The LHCb particle ID design and performance is a good match to the requirements of the Ion-side End-Cap detectors. The EIC will probably not have as high an event multiplicity as the LHC, which is a simplification. On the other hand, whereas LHCb dedicates $\Delta z \sim 3$ m to PID detectors, EIC designs can probably only allocate 1.5–2 m of longitudinal space.

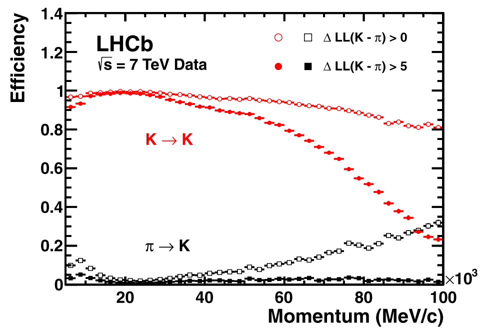

Fig. 17 Kaon identification efficiency and pion misidentification rate measured on data as a function of track momentum. Two different $\Delta \log \mathcal{L}(\mathrm{K}-\pi)$ requirements have been imposed on the samples, resulting in the open and filled marker distributions, respectively

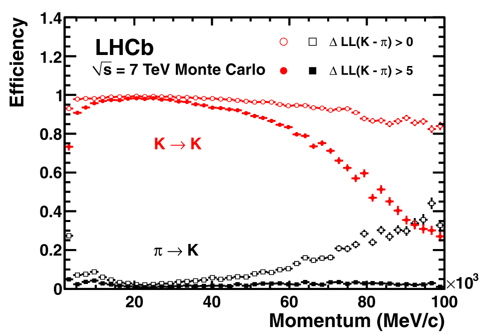

Fig. 18 Kaon identification efficiency and pion misidentification rate measured using simulated events as a function of track momentum. Two different $\Delta \log \mathcal{L}(\mathrm{K}-\pi)$ requirements have been imposed on the samples, resulting in the open and filled marker distributions, respectively

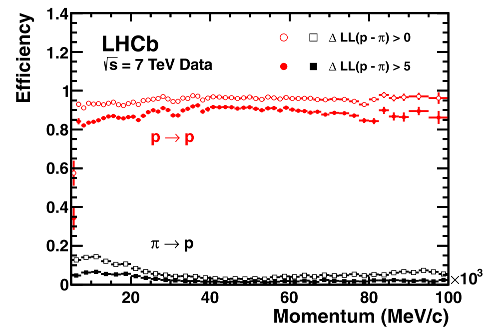

Fig. 19 Proton identification efficiency and pion misidentification rate measured on data as a function of track momentum. Two different $\Delta \log \mathcal{L}(\mathrm{p}-\pi)$ requirements have been imposed on the samples, resulting in the open and filled marker distributions, respectively

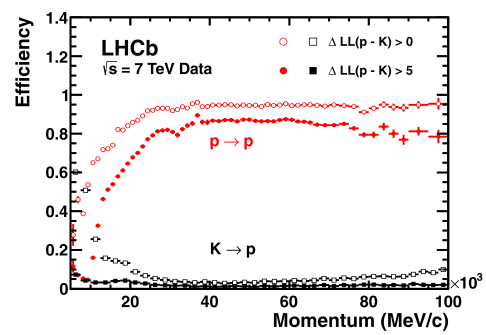

Fig. 20 Proton identification efficiency and kaon misidentification rate measured on data as a function of track momentum. Two different $\Delta \log \mathcal{L}(\mathrm{p}-\mathrm{K})$ requirements have been imposed on the samples, resulting in the open and filled marker distributions, respectively

Figure 3. Overall Run-1 LHCb particle-ID performance (Figs. 17-20 from [5]). The p/K separation/misidentification is excellent over the range 20–100 GeV/c. For π/K, depending upon the LogLikelihood (LL) cut imposed, either: $\pi \to K$ misidentification can be kept below 5% at the price of a kaon ID efficiency of only 20% at 100 GeV/c (Fig. 17 solid markers); or kaon ID efficientcy can be maintained at $\geq 80\%$ over the entire momentum range at the price of the $\pi \to K$ misidentification rising to 30% at 100 GeV/c.

Similarly, a TOF detector can be at most ~ 5 m from the EIC IP, in contrast to the 12 m for the proposed LHCb TORCH detector.

A dual RICH detector with a transparent membrane separating C_4F_{10} and CF_4 gas volumes is an attractive option. Based on photon statistics, the length of the two radiators should be in a 1:2 ratio, respectively. The HPD have a quantum efficiency $\geq 20\%$ for $\lambda = 240 - 400$ nm. To compensate for the shorter radiator depth at the EIC, it may be possible to use photo-sensors with a higher quantum efficiency. For example, Hamamatsu is listing a new S12571 series of Multi Pixel Photon Counters (MPPC) with 35% photon detection probability (including fill factor) at 450 nm (and $\geq$ 20% from 350 to 650 nm). A triple RICH, with an aerogel radiator is also an option, as the main difficulty for the LHCb aerogel was the very high multiplicity, which made it difficult to identify rings of ≤ 6 photo-electrons from the aerogel [5, 6]. A concept for a gas RICH detector in the MEIC full acceptance detector is illustrated in Fig. 4.

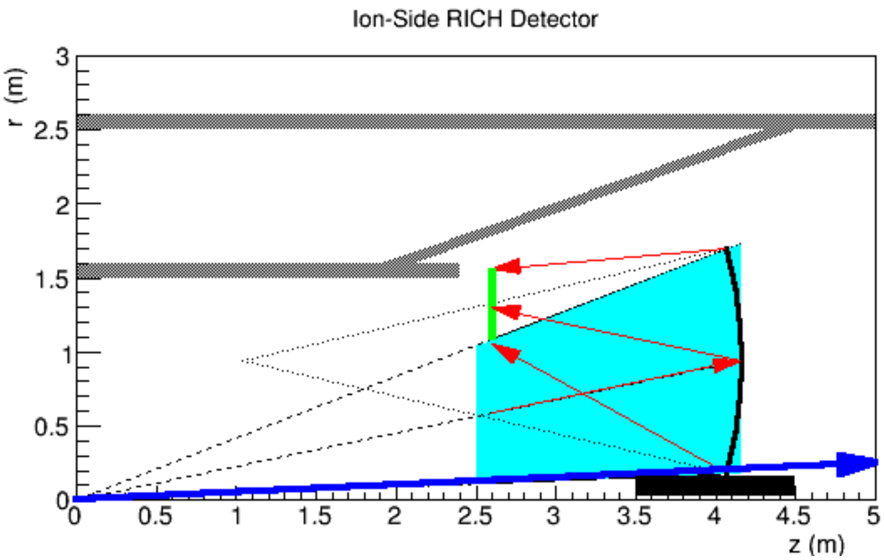

Figure 4. Concept for EIC Ion-Side RICH optics. The grey bands represent the cryostat of the proposal dual solenoid. In the central region, DIRC, TOF, and EMCal detectors occupy the radial space from 1.0 to 1.5 m. Thus the photosensors for the RICH are positioned in the shadow of the central detectors. The blue arrow represents the downstream ion beam (50 mrad crossing angle). The IP is at $r = z = 0$. The mirror focal length is 1.6 m, with its center of curvature indicated by the dotted lines.

The Cherenkov angle from an aerogel with $n = 1.03$ is $\theta = \cos^{-1}(1/n) = 242$ mrad. Thus over the 1.6 m gas depth of the RICH counter in Fig. 4, the aerogel cone would expand to 39 cm radius, causing many photons to be lost on the sides of the detector. The RD11 collaboration is studying the use of fresnel lens to image the Cherenkov rings from aerogel. Their primary concept is to use very short focal length sheets to create a compact imaging detector. If Fresnel sheets can be obtained with a focal length of 80 cm (half the distance from the aerogel to the mirror in Fig. 4), then the aerogel Cherenkov light can be contained to a smaller volume, while still focussing the light onto the photocathode surface.

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