Study of the performance of the RICH system for the LHCb Upgrade II

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1. Introduction

The LHCb **RICH** system offers outstanding PID capabilities across a wide momentum spectrum, ranging from 3 to 100 GeV/c and uses a pattern recognition algorithm to compare observed photon detector hits with expected patterns for each particle type, based on trajectories from the tracking system. New challenges will be posed by the approximately ten times higher track and photon densities in Run5 that are addressed in the proposed **Upgrade II** of the detector.

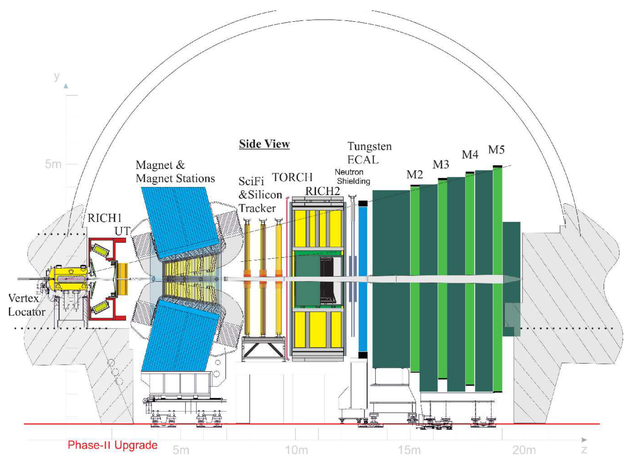

Figure 1: Scheme of Upgrade II LHCb [1].

3. Emulation procedure

Upgrade II emulation is achieved by applying scaling factors to Cherenkov angle resolution, pixel size and photon count.

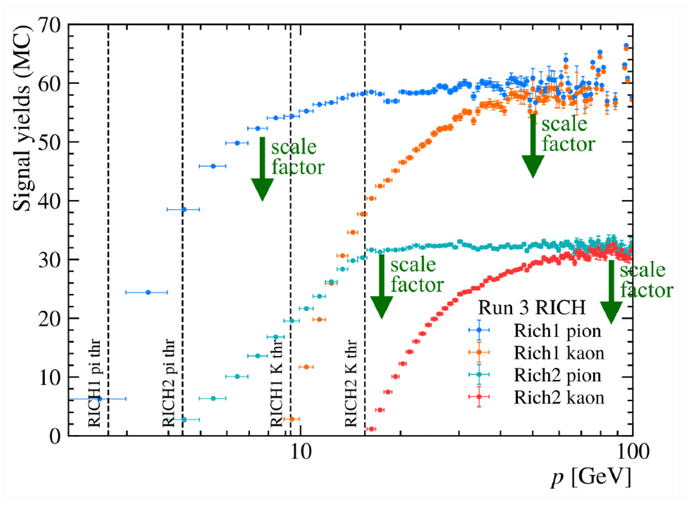

Figure 3: Emulated Run 3 signal yield as a function of momentum for π and K, with the 'scale factor' reducing these values according to the scenario considered.

Emulation based on the Run3 simulation, modified by a resolution function derived from comparisons between simulated and emulated data.

Cherenkov angle resolution is also used to emulate the effects of optics.

6. Conclusions

The **performance** studies demonstrate that:

- **Baseline** and **Middle** $\mapsto$ benefits of new RICH2 optics, particularly at high momenta;
- **Baseline** $\mapsto$ significant drop in performance at low momentum at $L = 1.5\times10^{34}$ cm^{-2}s^{-1}, mitigated at 150 ps.

The **occupancy** studies demonstrate that:

- **Baseline** $\mapsto$ occupancy remains well-controlled, with finer granularity in the innermost region;
- **Middle** and **Low** $\mapsto$ the occupancy exceeds 30% in parts of the RICH1 inner region.

2. RICH Upgrade II scenarios

For comparative analysis across scenarios — referred to as **Baseline**, **Middle** and **Low** — at different values of instantaneous luminosity $L = 1.0\ (1.3) \times 10^{34}$ cm^{-2} s^{-1} an emulation has been used, as a full simulation framework was unavailable for new geometries. Different granularities and time resolutions have been considered for the RICH Upgrade II studies to compensate for the expected increase in luminosity.

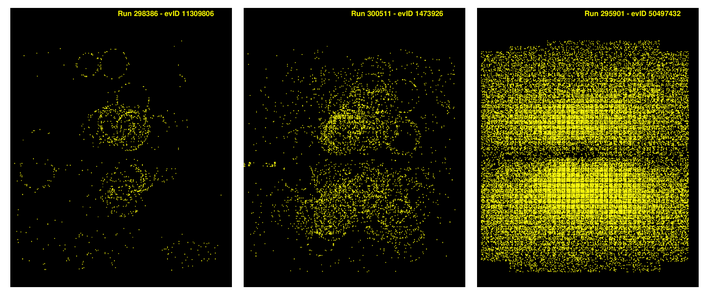

Figure 2 : Typical single event in RICH first generation, typical event in Upgrade I, expected occupancy in Upgrade II if we do not Upgrade the RICH system

4. Occupancy studies

A crucial aspect across these scenarios is managing the detector's occupancy. In each RICH two regions are defined, given particular attention to the high occupancy inner region:

Scenario	High occupancy area	Pixel size in high occupancy area	Pixel size in low occupancy area	Readout channels	New optical layout
Baseline	1/3	$1.4 \times 1.4\,\mathrm{mm}^2$	$2.8 \times 2.8\,\mathrm{mm}^2$	750,000	RICH1, RICH2
Middle	1/4	$2.0 \times 2.0\,\mathrm{mm}^2$	$2.8 \times 2.8\,\mathrm{mm}^2$	469,000	RICH1, RICH2
Low	1/4	$2.0 \times 2.0\,\mathrm{mm}^2$	$2.8 \times 2.8\,\mathrm{mm}^2$	445,000	RICH1

Table 1: Summary of the **Baseline**, **Middle** and **Low** scenarios for the RICH system [2].

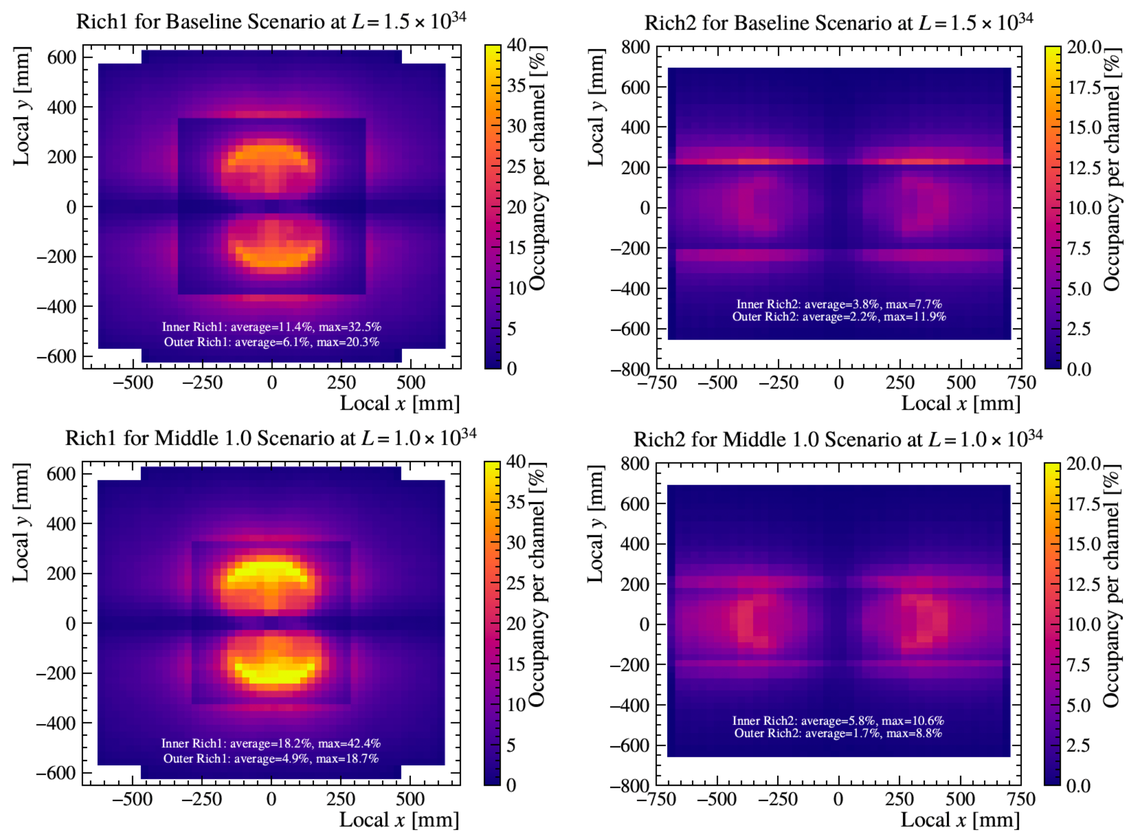

Figure 4: Occupancy plots for RICH1 (left) and RICH2 (right) for the Baseline (top) and Middle [2].

5. Performance studies

A strategy to reduce pile up will introduce timing windows to separate photons corresponding to different PVs. The performance is evaluated with two-time windows of $\pm2\sigma$ (time resolution).

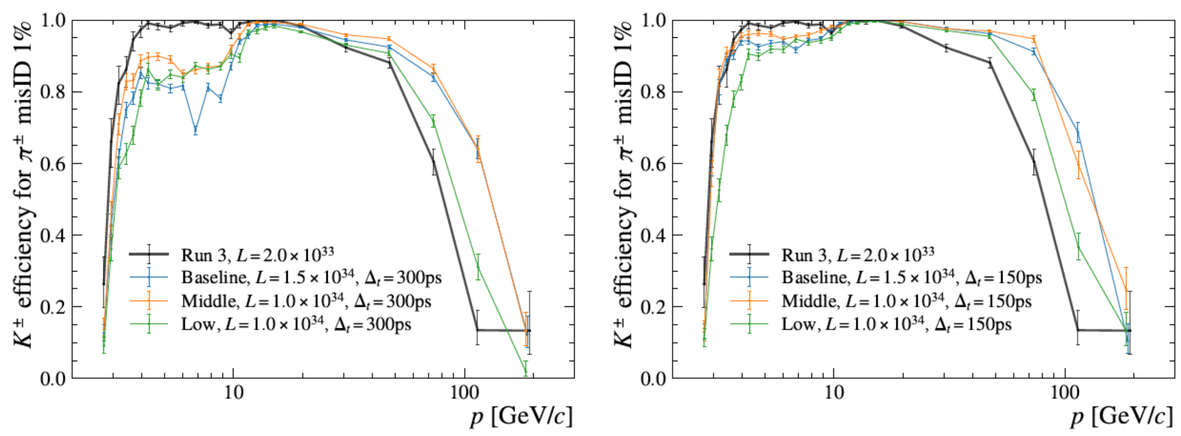

Figure 5: Performance comparison vs momentum p for the scenarios at different luminosities for two-time windows: (right) 150 ps and (left) 300 ps. The Run 3 performance is also shown for comparison [2].

7. References

[1] Framework TDR for the LHCb Upgrade II: Opportunities in flavour physics, and beyond, in the HL-LHC era. Technical report, CERN, Geneva, 2021.

[2] LHCb collaboration. LHCb Upgrade II Scoping Document. Technical report, CERN, Geneva, 2024.