The RICH for the Upgraded LHCb

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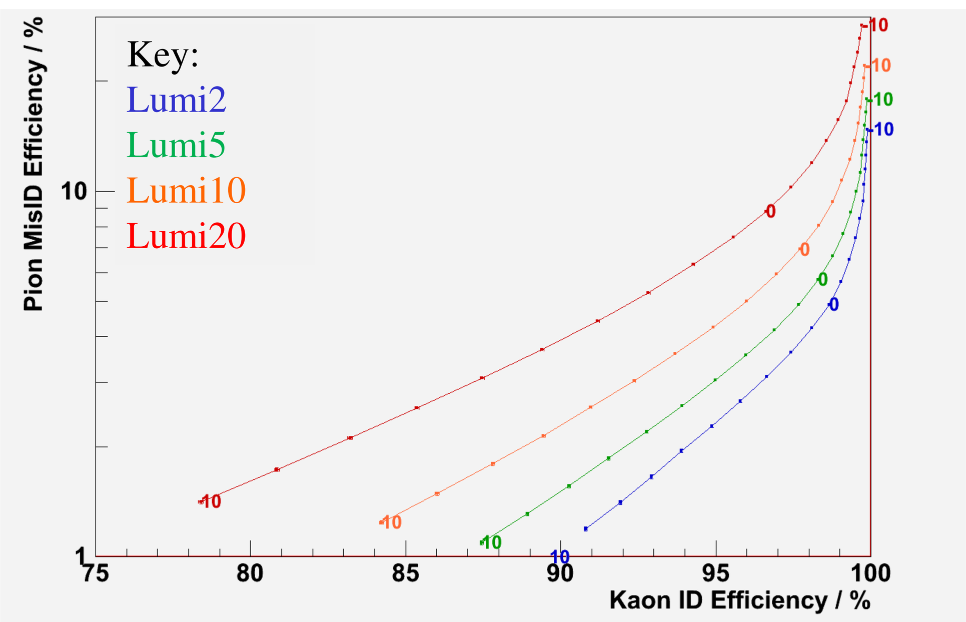
Motivation

The LHCb experiment plans to operate at an LHC luminosity of $2x10^{32}$ s^{-1} cm^{-2}. After about five years it will have recorded a data sample of about 10 fb^{-1}. At this time LHCb plans an upgrade to operate the detectors at a significantly increased luminosity that will extend greatly its potential for discovery and study of new phenomena. The key to get such an improvement is to read out the full detector at the LHC bunch crossing rate of 40MHz and to run the first level of the trigger in the data acquisition computer farm. Studies performed to optimise the design of the LHCb Upgrade are presented.

The RICH detector will require new photon detectors as the current HPDs have encapsulated electronics which only supports reading out up to 1MHz data rate. Two Photo Multiplier Tube (PMT) models are evaluated as photon detector candidates and their properties including pulse height and shape are measured. The particle identification performance is studied at luminosities ranging up to the luminosity of $20x10^{32}$ s^{-1} cm^{-2}, as foreseen for the LHCb upgrade. Finally, the performance of flavour tagging using Kaons, which strongly relies on RICH particle identification will also be presented.

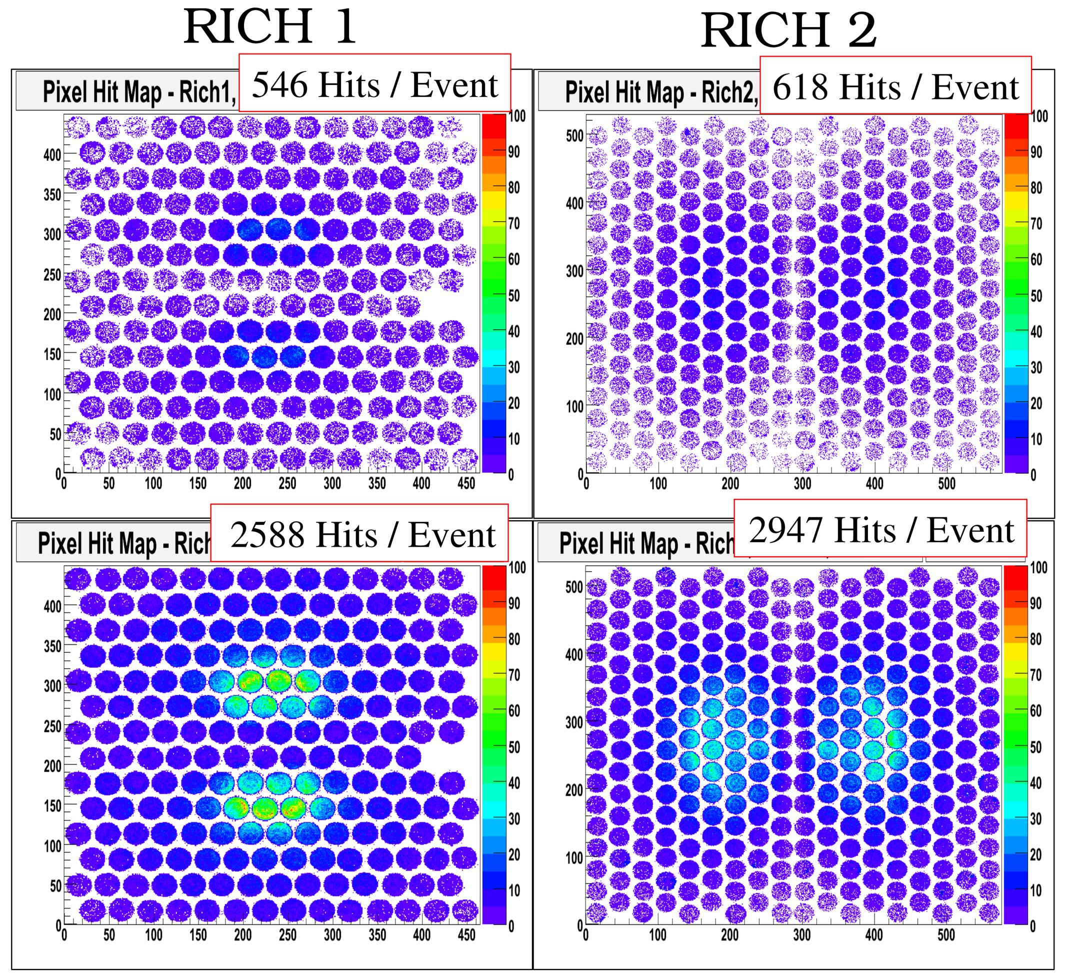
Challenges of Higher Luminosity

Going from 2 $x10^{32}$ s^{-1} cm^{-2} ("Lumi2") to 20 $x10^{32}$ s^{-1} cm^{-2} ("Lumi20"), the average of number of inelastic, 'hard' proton-proton collisions per event rises from 1 to 4.7.



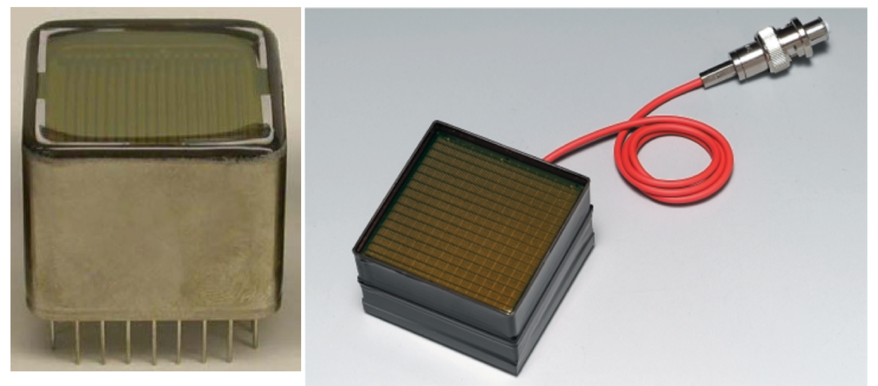
π misID rate vs Kaon ID rate. From blue to red, the curves show the simulated RICH Particle ID performance vs luminosity. Each data point corresponds to a different likelihood cut, affecting how certain the RICH is of a Kaon hypothesis for a track to be labelled as such.

Particle identification algorithms designed for Lumi2 function at Lumi20 but re-optimisation is necessary.



Pixel Hit Occupancy Maps for both LHCb RICH counters from full detector simulations, at luminosities of 2 and 20 $x10^{32}$ s^{-1} cm^{-2}. Initial adaptations for the upgrade have been made to the detector geometry. The Z-scale shows how many hits each pixel received over ~500 simulated, minimum bias events.

Photodetector Candidates



Left: *MaPMT (R7600)* , **Right:** *Flat-Panel PMT (H9500) Two alternate PMTs from Hamamatsu for possible use in RICH. Samples of both are currently being tested.*

The Multi-Anode Photo Multiplier Tube (MaPMT) and the Flat-Panel PMT (FP-PMT) are 2 of the candidates being considered by LHCb for its upgraded RICH. Below are a selection of their technical specifications and their pulse shapes to single photon signal:

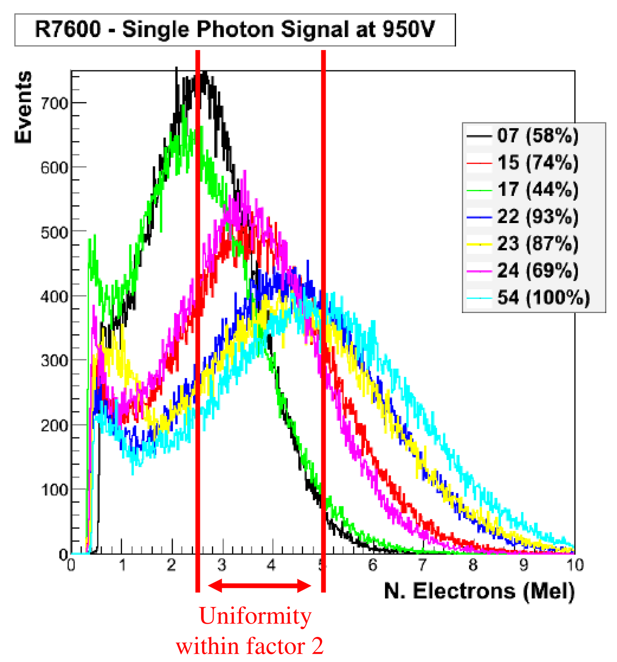
MaPMT Selected Properties

- •Pixel size: 2.0x2.0mm
- •Unit size: 25.7x25.7mm
- •Active area: 38.7% (with Quartz lens: 78.1%)

FP-PMT Selected Properties

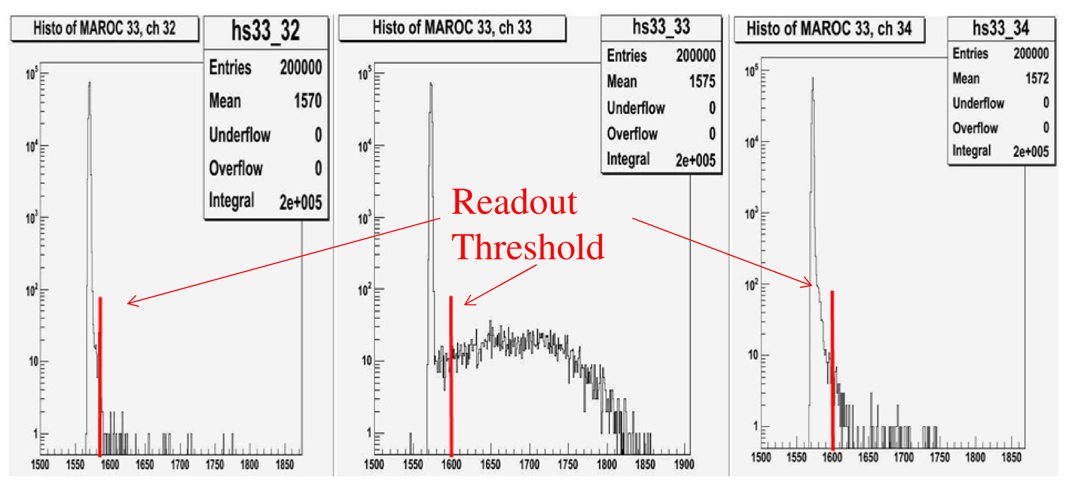
- •Pixel size: 3.04x3.04mm
- •Unit size: 52.0x52.0mm
- •Active area: 78.3%

Individual Pixel Response to Single Photon Signal



Multi-Anode PMT

MaPMT individual pixel response to single photon signal input. Pulses of 7 different pixels from the same unit are shown. The output has been fast-amplified with a gain of ~ -10. The response signal is uniform to within a factor of 2 between the maximum and minimum, agreeing with the manufacturer's data. Note how low the noise readout threshold is.



Flat Panel PMT

FP-PMT individual pixel response to single photon signal input, together with cross-talk in 2 of the neighbouring pixels. Across all 8 neighbours, the crosstalk above the noise threshold is 4.7%, matching the 5% specification in the manufacturer's datasheet.

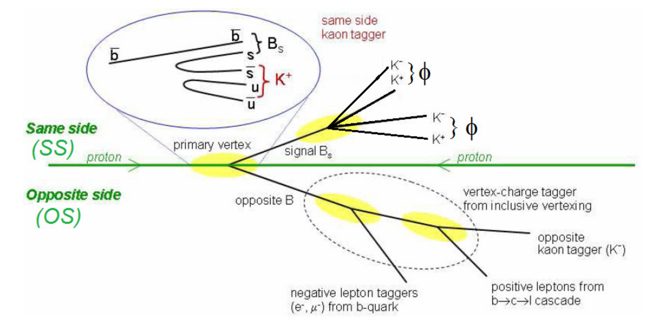
Evaluations

Besides the MaPMT and the FlatPanel PMT, the LHCb RICH collaboration is also looking into Micro Channel Plate PMTs (MCPs) and Hybrid Photon Detectors (HPDs) as candidates for its upgraded RICH detectors. Further characterisation of all candidates are required before a decision is made on which to use in the LHCb RICH.

Flavour Tagging

What is Flavour Tagging?

The LHCb experiment will study CP Violation in B-mesons. These are produced in b and anti-b pairs. One of them is the signal decay of interest. Flavour tagging is the process of identifying whether this signal decay was produced as a B or an anti-B meson. There are different methods - taggers - for deducing this.

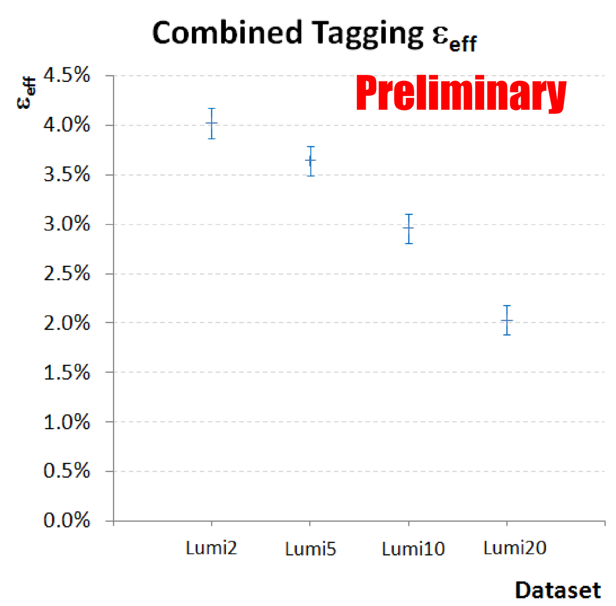


An example $B_s \to \phi\phi$ decay event with various possible methods to deduce the initial flavour of the signal B-meson. The RICH particle identification provides the Opposite Side (OS) and Same Side (SS) Kaon taggers.

Flavour tagging performance is characterised with the tagging efficiency, ε_{tag}, and the mistag rate, ω. The fraction of events where a tagging decision was made is ε_{tag} and ω is the fraction of such events where the tagging decision was correct. These two quantities are combined into an effective efficiency, ε_{eff} :

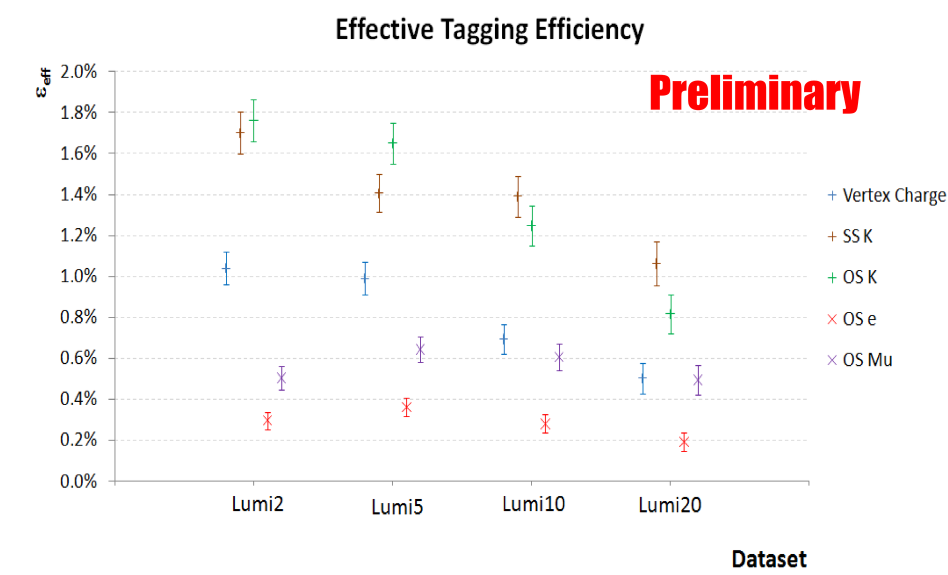
$$\varepsilon_{eff} = \varepsilon_{tag} (1 - 2\omega)^2$$

The following preliminary studies used full-detector simulations with initial upgrade adaptations to detector geometry.



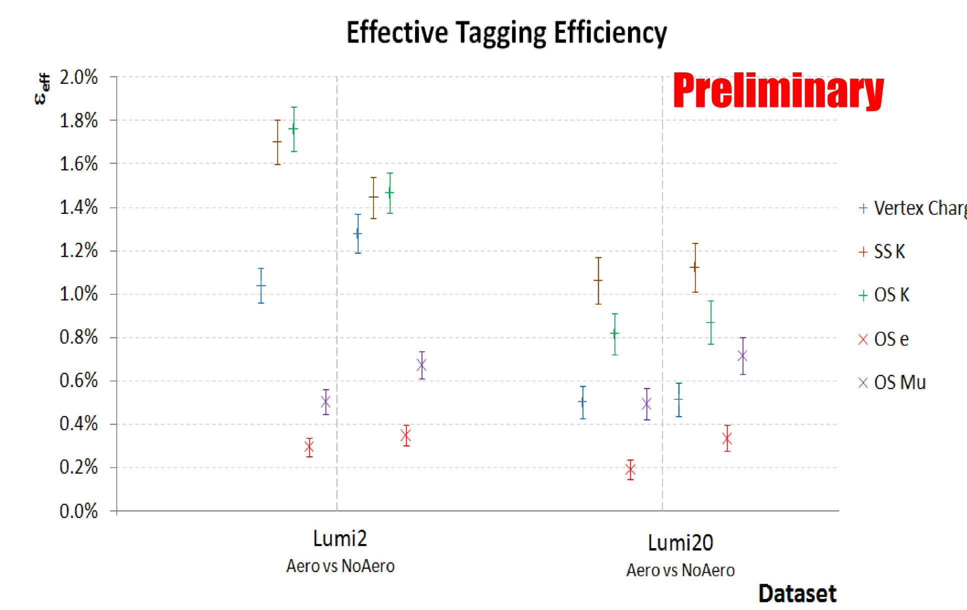
Effect of Luminosity

ε_{eff} vs luminosity from 2 and 20 $x10^{32}$ s^{-1} cm^{-2}. While the current tagging algorithms function at higher luminosities, the increase in track multiplicity degrades their performance. They must be re-optimised to cope with the additional noise.



Luminosity & Individual Taggers

ε_{eff} of individual taggers vs luminosity. The two Kaon taggers are the most efficient out of the 5 taggers but they are most affected by the increased track multiplicity at higher luminosities.



Effect of Aerogel

ε_{eff} of individual taggers at Lumi2 and Lumi20, with (left) and without Aerogel (right of vertical lines). The two Kaon taggers seem to be slightly affected by removing Aerogel at the current luminosity but unchanged at the upgrade but the errors are too large to draw solid conclusions. The effect of the Aerogel on the performance of the RICH detectors at upgrade luminosities is a subject of ongoing studies.