The RICH Upgrades

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LHCb UK upgrade II meeting

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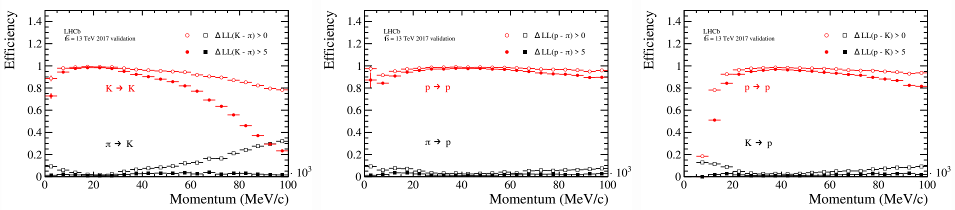
Request from LHCb physics case



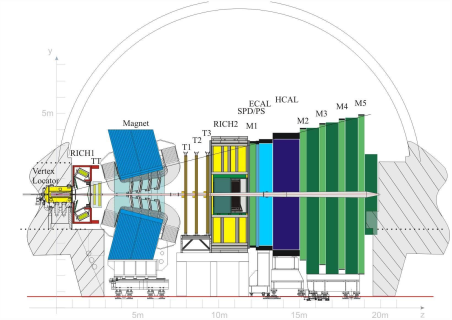
Charged hadron identification

- key ingredient of the physics programme of LHCb to distinguish final states with the same topology, to suppress combinatorial background
- excellent separation over a large momentum range: $2.6 - 100$GeV
  [Eur. Phys. J. C 73 (2013) 2431]
  [JINST 17 (2022) P07013]
- PID achieved with two gas-based RICH detectors: RICH1 and RICH2, with two different radiators (C_4F_{10} and CF_4 respectively)

Request for Upgrade II: improve (or at least maintain) PID performance in harsher and challenging conditions

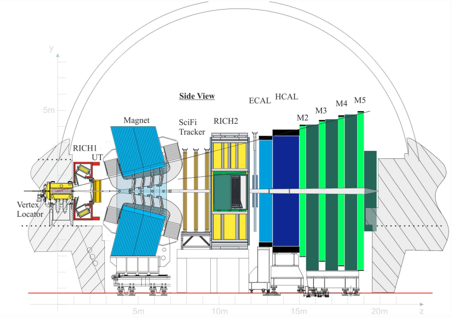
The RICH over the years

Run1&2



- $\sim 4 \times 10^{32} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- $\sim$1 visible interaction per bunch crossing
- collected $\sim$9 fb^{-1}

Run 3



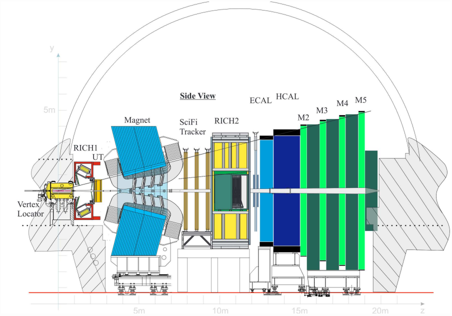
- $\sim 2 \times 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- $\sim$5 visible interactions per bunch crossing
- should collect $\sim$23 fb^{-1}

$\downarrow$

- new RICH1 detector
- new sensitive material in RICH2

The RICH over the years

Run4

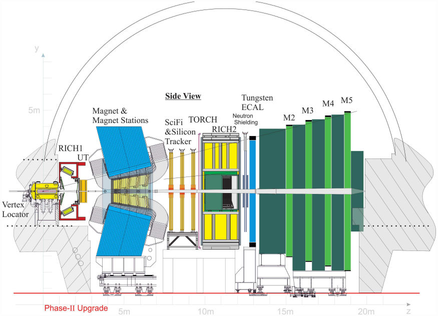


- $\sim 2 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$
- $\sim$5 visible interactions per bunch crossing
- should collect $\sim$50 fb^{-1}

$\downarrow$

- new front-end electronics

Run5&6



- $\sim 1.5(1.0) \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$
- $\sim$40 visible interactions per bunch crossing
- should collect $\sim$300 fb^{-1}

$\downarrow$

- new sensitive material
- new RICH1
- new RICH2?

What's the fuss?

Literature

- review of RICH detector in particle and nuclear physics in 2022
- review of RICH detector in particle and nuclear physics in 2018
- review of RICH detector in particle and nuclear physics in 2016
- review of RICH detector in particle and nuclear physics in 2013

A RICH Detector is as simple as

- a box
- some mirrors
- and a few phototubes?

NO!

RICH – The Reality

- Center of ring depends on track angle
  $\Longrightarrow$ large detector surface (up to square meters)
- good resolution of photon position
  $\Longrightarrow$ large number of "pixels" (up to 100000 or more)
- Number of Cherenkov photons $\propto 1/\lambda^2 \Longrightarrow$ Ultraviolet
- refractive index $n = n(\lambda) \Longrightarrow$ Chromatic dispersion
- Mirrors
- Detection of UV-photons: convert photon in electron (photoeffect)
- Tracks passing through photon detector
- All pieces have to work together!

highly heterogeneous system! to improve the performance all the ingredients have to improve!

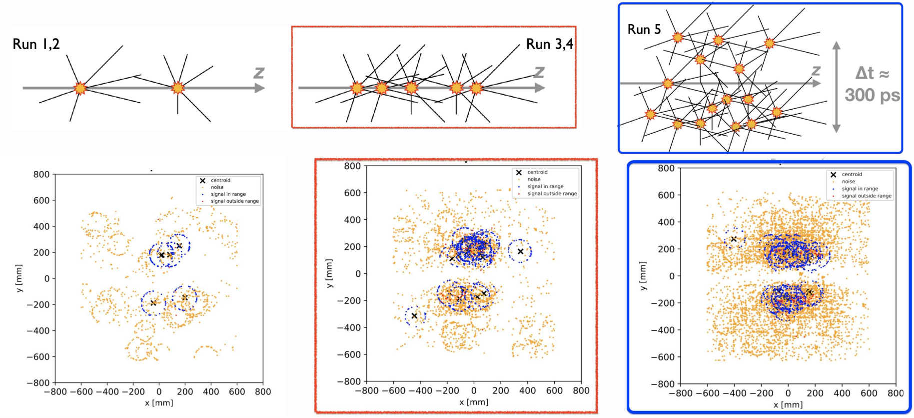
What's special about the LHCb RICH and upgrade II?

- $N_{photons} = L \frac{\alpha^2 z^2}{r_e m_e c^2} \int \sin^2 \theta_c(E) dE \Rightarrow$ low number of Cherenkov photons $\Rightarrow$ in general large radiator volume needed
  - upgrade II: envelopes largely constrained by initial design of LHCb
- optics design to magnify rings
  - upgrade II: envelopes largely constrained by initial design of LHCb
- single photon detection $\Rightarrow$ low noise photon detector with excellent granularity
  - upgrade II (LHCb): huge number of tracks $\Rightarrow$ reduce granularity $\Rightarrow$ huge number of channels $\Rightarrow$ for the first time the cost per channel of the electronics becomes a dominating factor
  - LHCb: huge number of tracks $\Rightarrow$ need of robust pattern recognition algorithm and reconstruction
- rate and radiation hardness:
  - upgrade II: detection rates up to $\mathcal{O}(1\ \mathrm{GHz/cm^2})$, corresponding to a neutron fluence (10y) of $6 \cdot 10^{13}\ \mathrm{n_{eq}\ cm^{-2}}$

we want as many photons as we can get but we have too many photons
$\Rightarrow$ let's add timing: separate in time different *pp* collisions in the same BXID

Requirements for the evolution of the LHCb RICH system

Keep the excellent Run 1 and 2 performance while increasing the instantaneous luminosity up to a pile-up of $\sim$ 40!

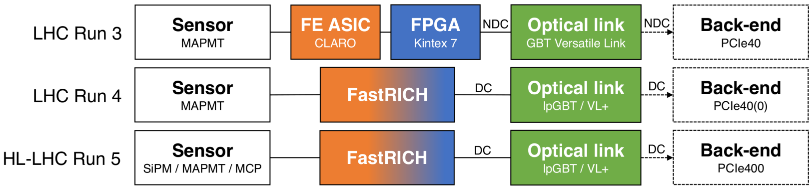


Introduction of timing concept more and more relevant!
(rings in blue matching search window for the input tracks)

[https://doi.org/10.17863/CAM.78867]

The plan for timing: LS3 enhancement

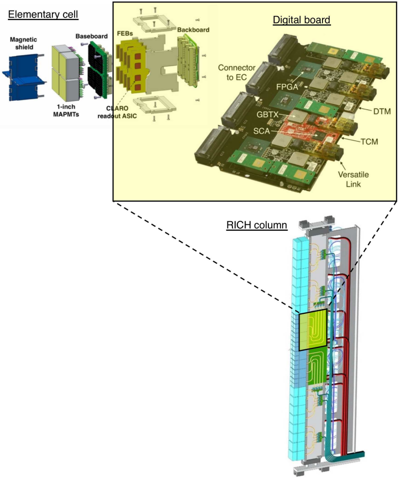
- timing concept new to LHCb but common amongst many systems for LHCb upgrade II
- anticipate ASIC development to LS3: introduce time stamp of photons
- ASIC fast enough to be used in upgrade II $\Rightarrow$ timing in Run4 limited by photon detectors



	Sensor [σ]	ASIC time walk	FE time gate	TDC time bin
LHC Run 3	150 ps	< 4 ns	6.25 ns	None
LHC Run 4	150 ps	CFD correction	2 ns	25 ps
HL-LHC Run 5	~ 50 ps	CFD correction	2 ns	25 ps

LS3 enhancement plan in a nutshell

- develop FastRICH before LS3
- develop new Elementary Cell (EC): FE boards, backboards, cooling
- develop new digital electronics with lpGBT and VTRX+
- extract all the columns at the start of LS3
- dismount all the ECs and digital electronics
- assemble new ECs
- modify services on the column (optical fibres)
- mount electronics
- columns commissioning in the lab
- install the detectors
- commissioning with no beam
- commissioning with beam at the start of Run4
- enhanced PID performance in Run4!



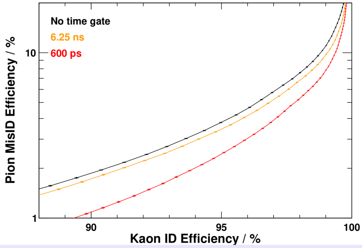
LS3 enhancement

anticipation of ASIC design for upgrade II:

- **pro** ASIC design is often one of the most critical aspects of an upgrade programme ⇒ largely simplifies the RICH upgrade II programme
- **con** very tight schedule to design the ASIC ⇒ mitigation: large team at work! (see Steve's slides)
- **con** design an ASIC without knowing the sensor used in upgrade II ⇒ mitigation: complex programme of validation including tests on beam (see Federica's talk)

full upgrade of RICH1 and RICH2:

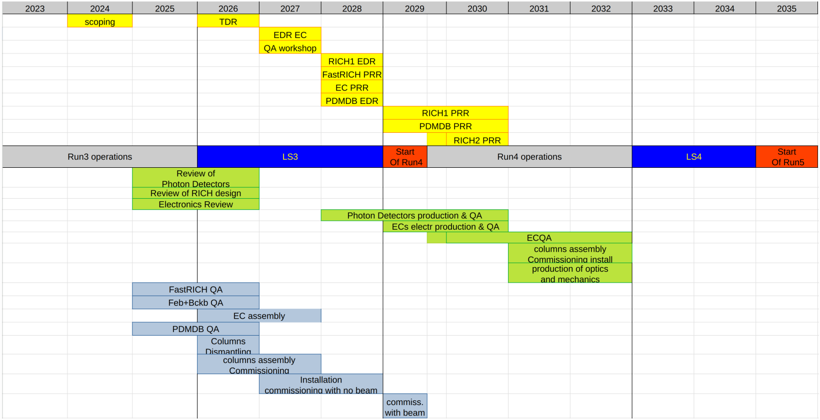
- **pro** overall improvement in the PID performance of LHCb
- **pro** provide T0 to LHCb
- **con** very intense assembly/commissioning programme during LS3 ⇒ mitigation: minimise modifications and anticipate the development of the commissioning facility
- **con** schedule for commissioning with beam as short as possible in Run4 ⇒ mitigation: anticipate integration with Online system, commissioning time with beam will still be needed



LS3 latest

- LS3 TDR approve in March 2024: CERN-LHCC-2023-005
- FastRICH review in May 2024, submission in September 2024
- lbGBT and VTRX+ already tested in testbeam campaign
- electronics in development
- strong interplay with Online developments in the coming years for Sol40/400:
  - clock and timing distribution of the Online system currently not compatible with LS3 programme
  - schedule of the PCie400 critical to the success of the programme: major development and work still to be done yo reach timing performance in PCie400
  - PCie40 not adequate for requirements for timing: major effort needed from the Online (success not guaranteed)

Overview of the RICH timeline



overview of the main events of the coming years: rough schedule, indicative dates

Overview of upgrade II strategy

Design criteria: keep the peak occupancy below $\sim 30\%$ and achieve a Cherenkov angle resolution < 0.5 mrad

- reduce photon detectors pixel size and employ fast photon detectors
- redesign and optimise the optics of the RICH system

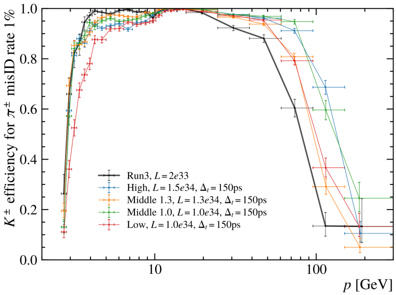
Options presented in the scoping document

Scenario	High occupancy area	Pixel size in high occupancy area	Pixel size in low occupancy area	Readout channels	New optical layout
Baseline	1/3	$1.4 \times 1.4\text{mm}^2$	$2.8 \times 2.8\text{mm}^2$	750000	RICH1&RICH2
Middle (1.3)	1/4	$1.4 \times 1.4\text{mm}^2$	$2.8 \times 2.8\text{mm}^2$	656000	RICH1
Middle (1.0)	1/4	$2.0 \times 2.0\text{mm}^2$	$2.8 \times 2.8\text{mm}^2$	469000	RICH1&RICH2
Low	1/4	$2.0 \times 2.0\text{mm}^2$	$2.8 \times 2.8\text{mm}^2$	469000	RICH1

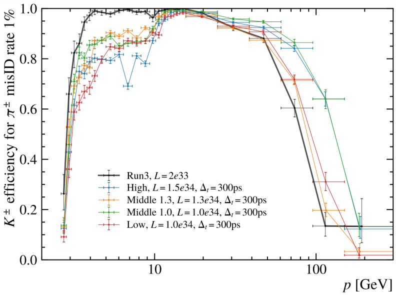
- general strategy: cost reduction coming from number of channels $\rightarrow$ cost of the electronics plays an important role in Upgrade II
- Middle (1.0) prepared by U2PG: descoping in RICH1 granularity to carve cost for the RICH2 vessel/optics

Scenarios

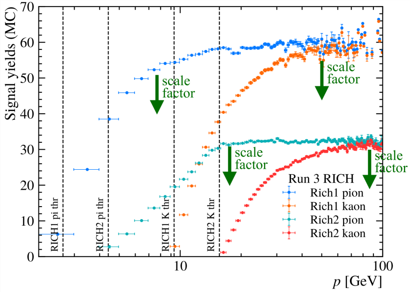
150 ps ↓



300 ps ↓

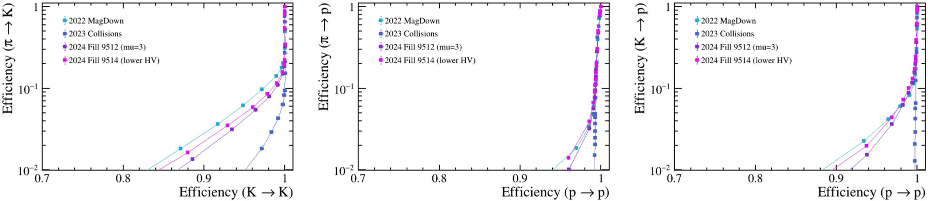


- curves obtained with emulation (not full simulation): useful studies for relative trends, not absolute value
- timing plays a crucial role
- improvement of Cherenkov angle resolution in RICH2 leads to improvement in PID at high momentum
- reduction of photon yield in RICH2 plays a role in PID in the momentum region where tracks in RICH1 are not saturated

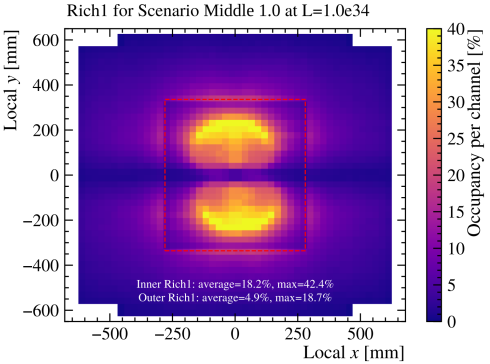


The challenges of Middle 1.0

Effect of Photon Yield tested in Run3 data taking

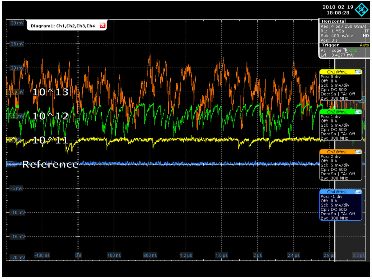


- photon yield reduction can have critical impact on PID performance: optimisation for both RICH1 and RICH2 needed
- RICH2 optics plus vessel size reduction are a critical parameter (see Adam's talk)
- descoped granularity in RICH1 leads to high peak occupancy ($\sim 40\%$) $\Rightarrow$ impact on photon detection efficiency
- construction of two detectors at the moment is a concern for the size of the project



Possible candidates: SiPM

- SiPMs have several advantages: extremely fine granularity, resilience to magnetic fields, high photon detection efficiency, green-enhanced quantum efficiency, good timing
- but important drawbacks: dark count rates after irradiation at 10^{13} n_{eq} cm^{-2} ($\sim$ 1y $= 6 \cdot 10^6$ s of data taking) are larger than expected signal rate
- R&D on cryogenic operations: very challenging from the operational point of view and requiring R&D on a possible interface between the photon detectors environment and the gas radiator envelope to avoid turbulence in the gas
- R&D on local cooling of SiPM with design of dedicated housing
- R&D on implementing annealing to compensate for irradiation effects

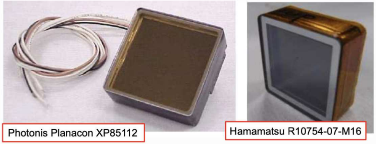


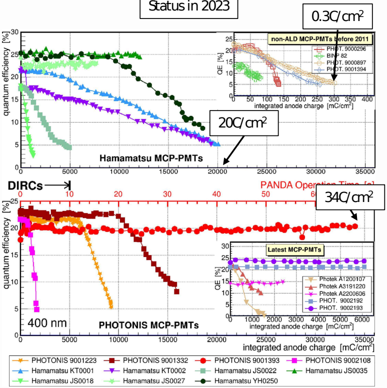
NIM A 922, 243-249, 2019

Possible candidates: MCP

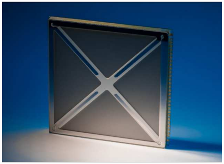
Extremely good time resolution < 70 ps, custom pixelisation tailored for individual applications, but important drawbacks related to lifetime and rate capability: R&D ongoing

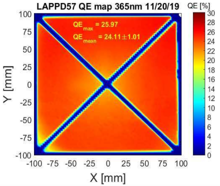
Conventional MCPs

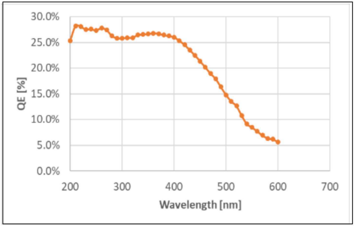




Large Area Picosecond PhotoDetector







Fused Silica 3.8mm Window (LAPPD #63)

R&D to investigate possible options of low-gain MCPs: MCP-HPD [JINST 13 C12005 2018]

Possible candidate MaPMT

- very reliable photon detector: state of the art currently installed in the RICH detectors
- limitations coming from pixels size: 2.8×2.8 mm^2 for R11265
- limitations coming from TTS$\sim$ 300 ps
- limitations coming form magnetic field tolerance
- limitations coming from maximum anodic current

HAMAMATSU

TENTATIVE DATA SHEET

Dec. 2015

MULTIANODE PHOTOMULTIPLIER TUBE

R13742

Exclusive for HPF-BS/ CERN and HPI/ INFN MILANO (for LHCb/RICH)

Super Bialkali Photocathode (SBA), UV Window, 1 Inch Square
8 x 8 Multianode and Fast Time Response

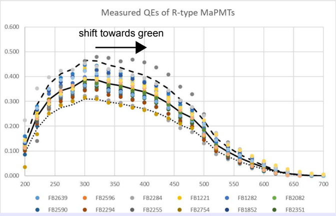
General

Parameter		Description	Unit
Spectral Response Range		185 to 650	nm
Peak Wavelength		350	nm
Photocathode Material		Bialkali	-
Window	Material	UV Glass	-
	Thickness	0.8	mm
Dynode	Structure	Metal Channel Dynode	-
	Number of Stage	12	-
Anode	Number of Pixels	64 (8 x 8 Matrix)	-
	Pixel Size	2.88 x 2.88	mm
Effective Area		23 x 23	mm
Dimensional Outline (W x D x H)		26.2 x 26.2 x 17.4	mm
Packing Density (Effective Area / External Size)		77	%
Weight		27	g
Operating Ambient Temperature		-30 to +50	deg C
Storage Temperature		-80 to +50	deg C

Maximum Ratings (Absolute Maximum Values)

Parameter	Value	Unit
Supply Voltage (Between Anode and Cathode)	1100	V
Average Anode Output Current in Total	0.1	mA

- very low noise
- excellent quantum efficiency: new version with green shifted spectrum produced and tested
- very good active area
- employable in low occupancy regions



Road forward

- R&D in close collaboration with industry is ongoing on SiPMs and MCPs
- strong involvement of the community in DRD4 ⇒ profit from synergies with collaborators within the PID community
- testing facilities in multiple institutes: complementary approach (see Constantinos' and Federica's talk)
- simulation with various candidate (see Lais's talk)
- evaluate both performance and operability

main challenge:
LHCb RICH upgrade II is quite unique: combination of high rate, radiation hardness and single photon detection not found in other PID detectors!

design & optimisation of the optics of RICH1&2 play a central role in the success of upgrade II! (dedicated talks later today)