CalAliMon: in-situ Rayleigh-scattering-based Calibration Alignment and Monitoring system for the future LHCb RICH upgrades

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The concept

The LHCb-RICH detector at the LHC at CERN [1, 2, 3], requires a robust calibration, alignment and monitoring system to provide essential information for its proper operation, independent of the data-taking, while also ensuring redundancy. The LHCb UPGRADE II is an even greater challenge as previously small and neglected systematic effects can become critical in view of the targeted accuracies. A collimated laser beam running a few cm above the entrance window of the photo-sensors arranged in a column-like structure (see figure 1) provides a thin uniform source of Rayleigh scattered light with known kinematics which can be straightforwardly used for relative comparison of the $\approx 10^6$ pixels. A collimated laser beam in nitrogen in standard conditions scatters a fraction $\approx 10^{-6}$ of photons almost isotopically resulting, for average power of a tens of μW, in tens of kHz detected rate on a pixel of the MAPMT used in the LHCb-RICH at a few cm distance. The thin, linear and uniform source is a strong advantage. The setup is planned for relative gain, efficiency and time measurement for the LS3E of the LHCb-RICH. It will allow absolute efficiency measurements at the LS4 of the LHCb-RICH thanks to absolute laser beam measurements.

Scheme

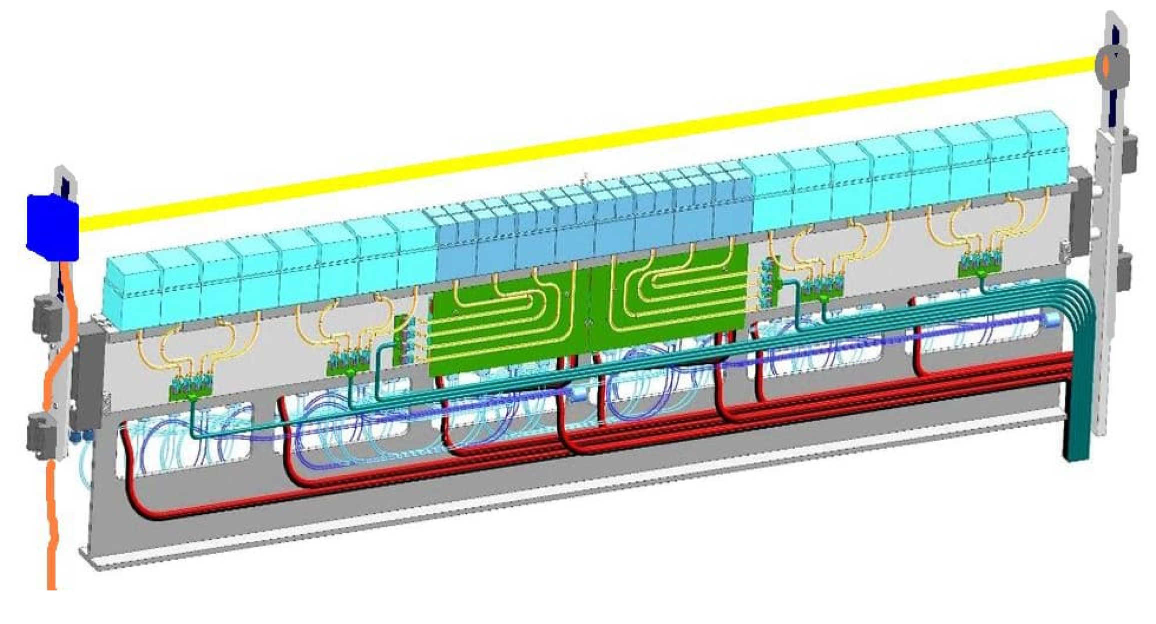


Fig. 1: Scheme: laser beam running in front of one column of RICH2

Concept validation: simulations

Toy simulations have been developed to study the intensity and time distribution of scattered photons.

- A collimated laser beam, taking into account its timing profile, while the Gaussian transverse profile is negligible,crosses a gas volume (air, will be pure nitrogen in the experiment).
- The scattering position is sampled uniformly along the laser path (equivalent to an exponential distribution with mean free path $\lambda \sim 25\,\mathrm{km} \gg L_{\mathrm{column}} \simeq 60\,\mathrm{cm}$ in lab).
- Scattered photons are generated according to the Rayleigh angular distribution: $\frac{d\sigma}{d\Omega}(\theta) \propto 1 + \cos^2\theta$ with uniform azimuthal angle
- The photon path length $\ell_1 + \ell_2$ from emission to detection and the corresponding time of arrival $t_{\mathrm{ToF}} = (\ell_1 + \ell_2)/c_{\mathrm{air}}$ is calculated.
- Photosensor TTS ($\sigma_{\mathrm{MCP}} = 17\,\mathrm{ps}$ and $\sigma_{\mathrm{MaPMT}} = 120\,\mathrm{ps}$) is included in the simulation.

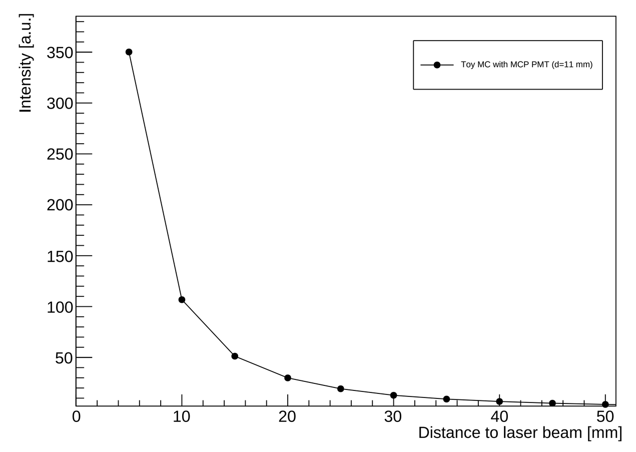


Fig. 2: Intensity vs distance to the beam.

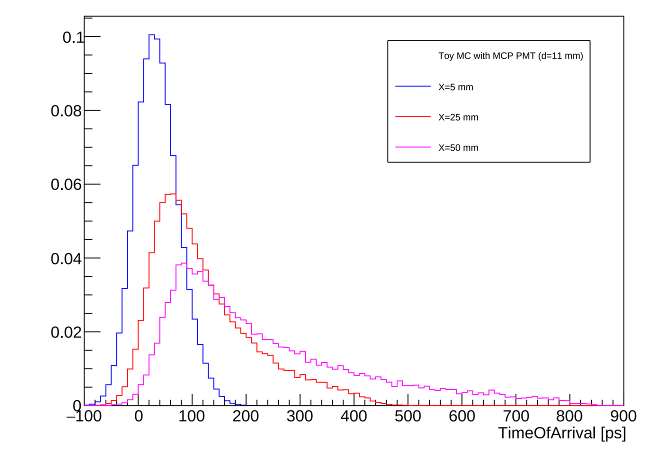


Fig. 3: Time of arrival at distance X to the beam.

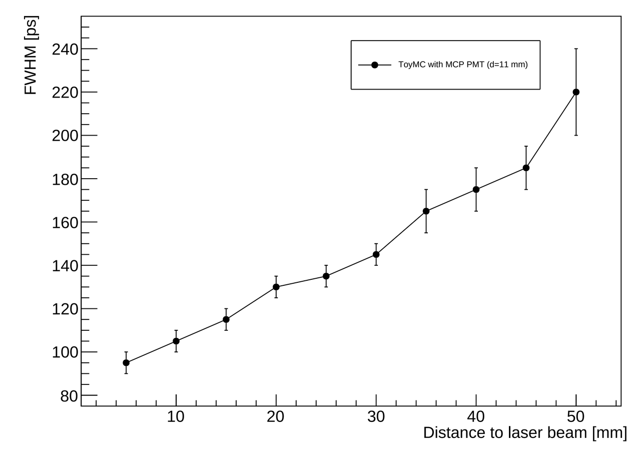


Fig. 4: Time spread vs distance to the beam.

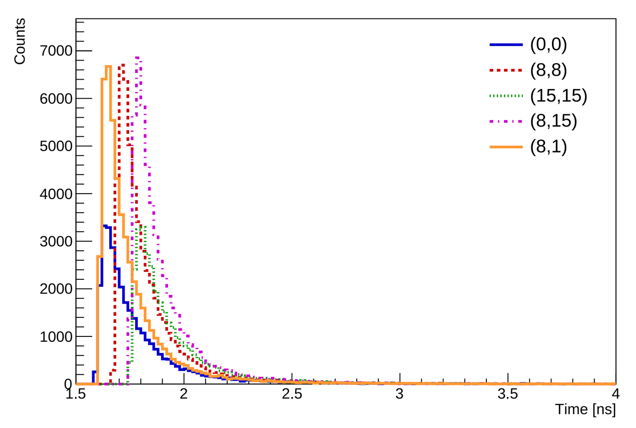


Fig. 5: Photon time of arrival on different pixels on the EC (no laser timing profile and MaPMT TTS).

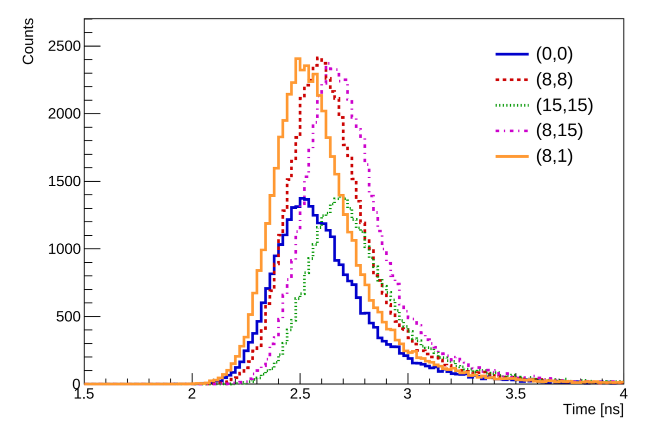


Fig. 6: Photon time of arrival on different pixels onto the EC taking into account laser timing profile and MaPMT TTS.

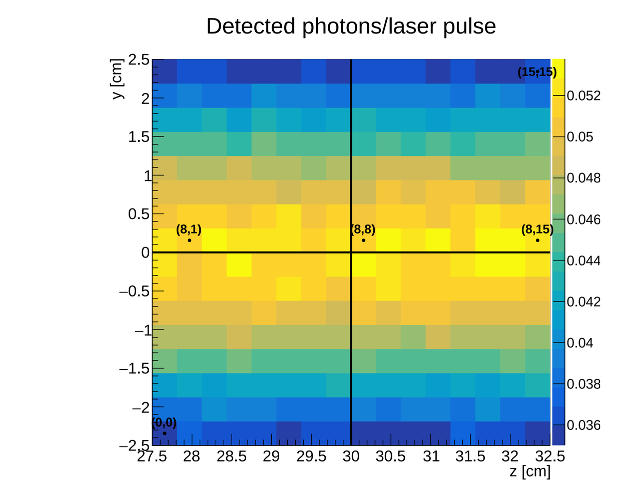


Fig. 7: Detected Raylegh Scattered photons per laser pulse $(40\,\mathrm{pJ})$ on the EC $(\epsilon_{\mathrm{tot}} = \epsilon_{\mathrm{geo}} \times \epsilon_{\mathrm{QE}} \times \epsilon_{\mathrm{transm}} = 0.36)$.

It is concluded that the beam should pass as close as possible to the photo-sensor, both to gain intensity and because at larger distances the time of arrival distribution becomes wider and asymmetric; distance $\lesssim$5 cm is needed for a time resolution O(100) ps. See figs 3 and 4.

Laboratory

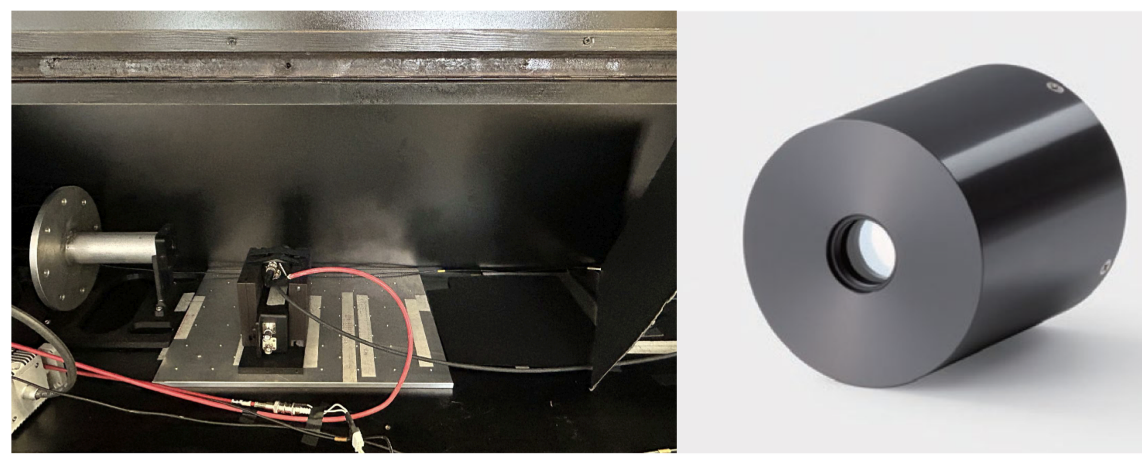


Fig. 8: Setup #1 with MCP PMT (Hamamatsu R3809U-052) used for time measurements.

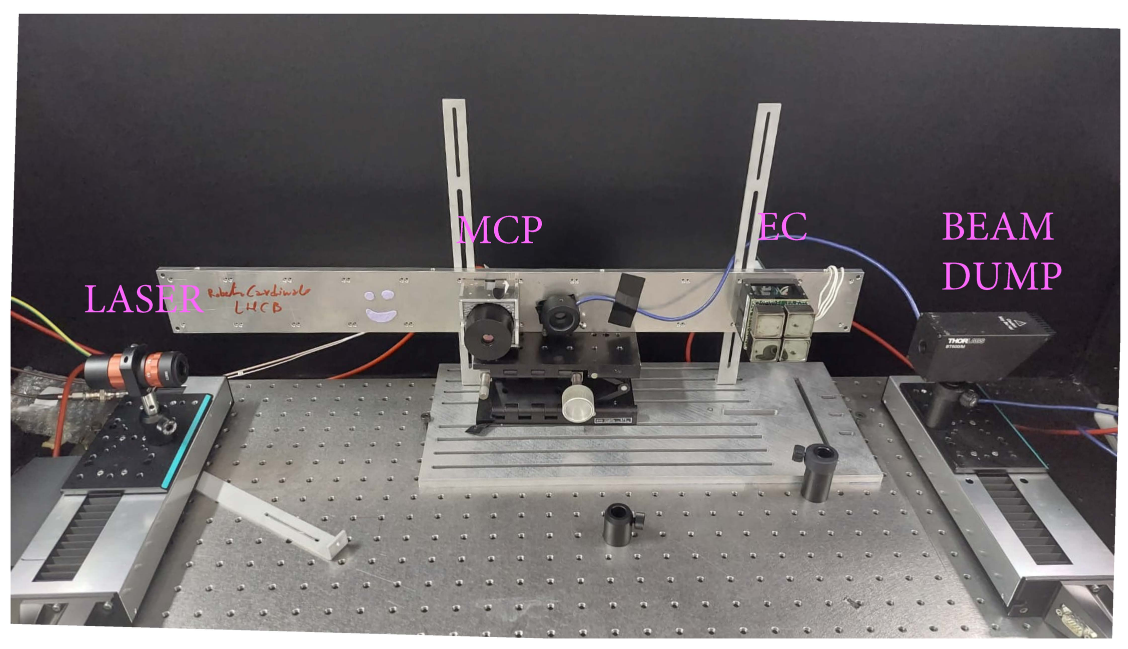


Fig. 9: Setup #2: MCP PMT and the LHCb-RICH Elementary cell (EC) equipped with 4 Multi-anode PMTs (MaPMTs) are visible.

Concept validation: measurements

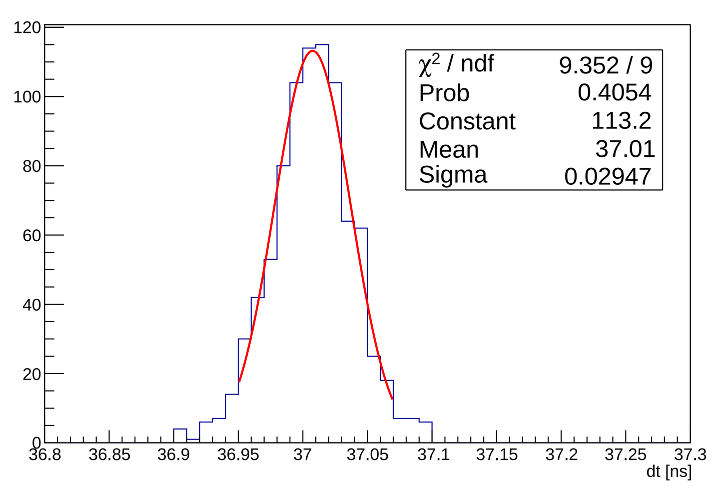


Fig. 10: $T_{MCP\ PMT}$ - T_{laser}. MCP PMT on the beam, low laser intensity.

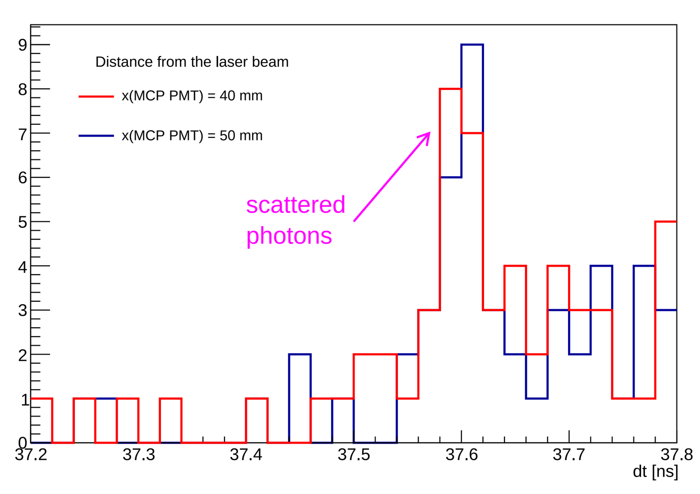


Fig. 11: $T_{MCP\ PMT}$ - T_{laser}. MCP PMT off the beam, low laser intensity.

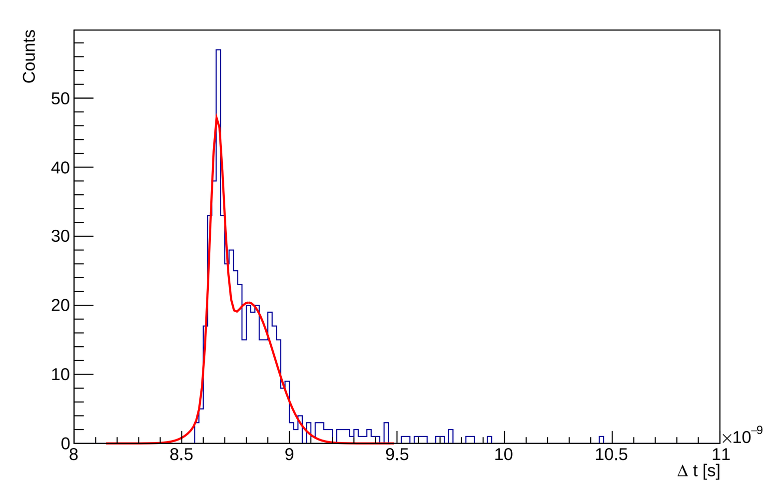
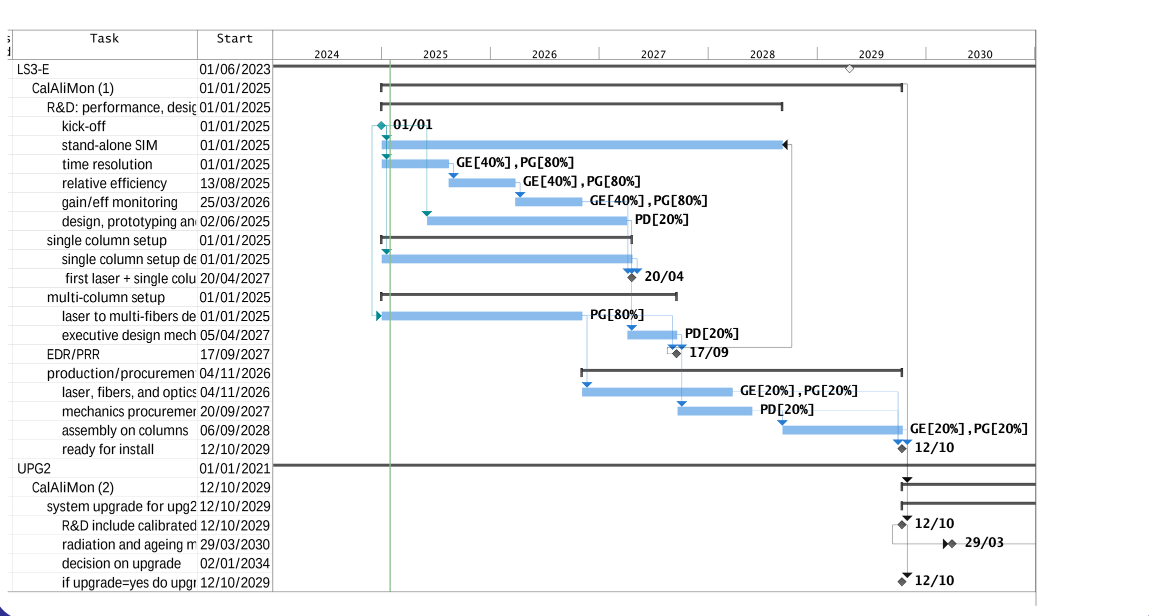


Fig. 12: $T_{MCP\ PMT}$ - T_{laser}. Rayleigh photons MCP PMT time distribution, high laser intensity.

Time measurements have been performed in the laboratory. The MCP PMT (Hamamatsu R3809U-52) was used as a photo-sensor (circular active area with d=11 mm). First, the sensor was placed on the beam axis and its time resolution was measured to be 30 ps (laser contribution included, fig. 10). Then the sensor was placed at a distance of few cm of the beam and a peak corresponding to scattered photons has been observed for low (fig. 11) and high (fig. 12) laser intensity. The double peak structure on the right plot is related to laser properties at high intensity. A resolution of $\sigma \sim 30\,\mathrm{ps}$ is obtained also for the sensor for Rayleigh scattered photons.

Planning



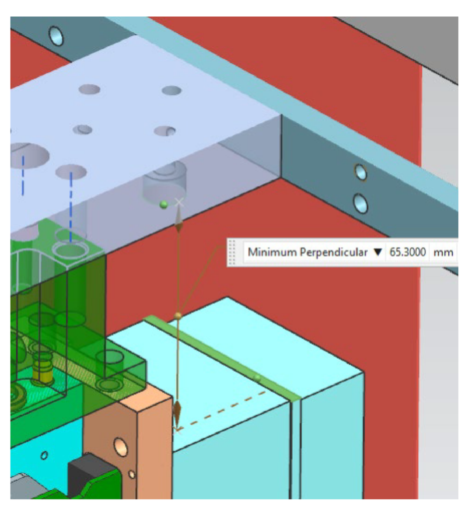
Validation of the technologies

Part of the system will be installed in the proximity of the RICH sensors, in a place highly irradiated (integrated dose at the end of Run-5 up to $\approx 3 \times 10^{13}$ neutrons/cm^2, in absence of shielding). In order to validate the technological solutions of the proposed calibration system irradiation campaigns are foreseen for the elements that will be placed inside the detector boxes (fibers, mirrors, collimators, beam-dumps, calibrated sensors and other possible opto-mechanical components). Two activities are considered:

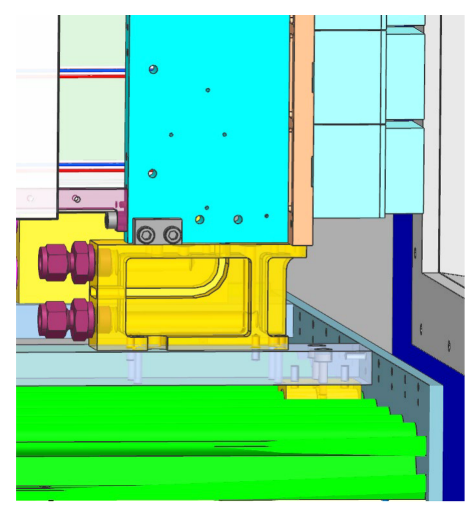
1. Place some samples in the LHCb environment during Run-3 data taking (in 2026) in positions were the irradiation is known/measured.
2. Send samples to irradiation facilities where doses can be evaluated; the planning is being finalized.

The relevant performance will be measured to assess the compliance.

The environment



Drawing of one end of the column



Drawing of the other end of the column

References

[1] LHCb collaboration, LHCb collaboration, *LHCb Particle Identification Enhancement Technical Design Report* , CERN, Geneva, 2023. doi: 10.17181/CERN.LAZM.F5OH.
[2] A. Schopper, *The LHCb Upgrade II*, in *Proceedings of 16th Pisa Meeting on Advanced Detectors, La Biodola, Isola D'elba, It, 26 May - 1 Jun 2024*, 2024.
[3] LHCb collaboration, LHCb Collaboration, *LHCb Upgrade II Scoping Document* , CERN, Geneva, 2024. doi: 10.17181/CERN.2RXP.HDK0.