Photon Detection at the LHCb RICH Upgrade I

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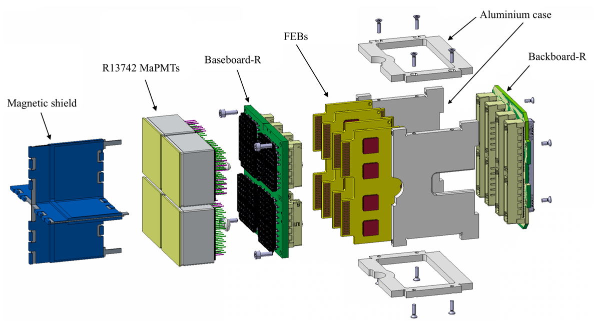
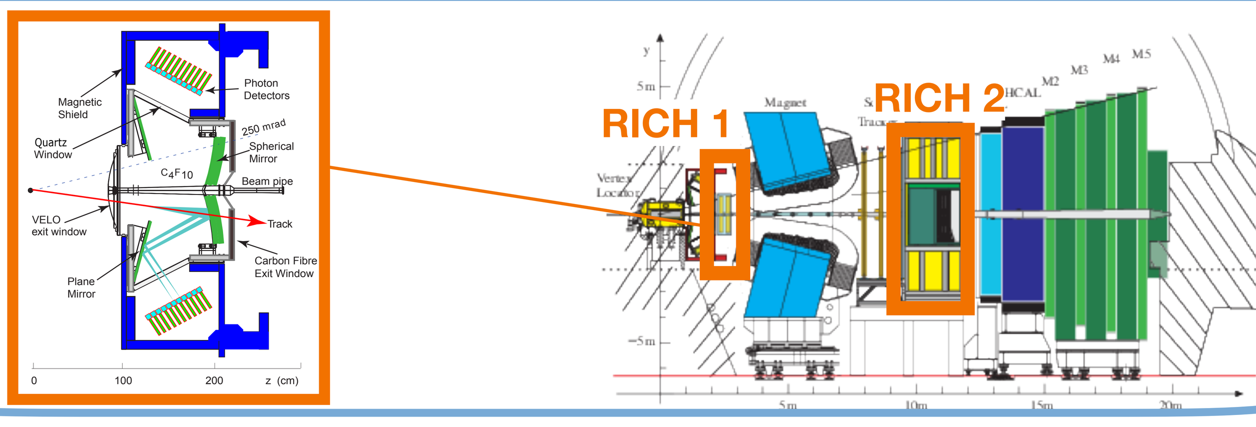
1 The LHCb RICH subsystem

Photon-Detection chain

- **MAPMT** : Hamamatsu R13742 MaPMTs for high occupancy region, R13743 MaPMTs for low occupancy region
- **CLARO chip:** 8-channel amplifier/discriminator ASIC, adjustable threshold and attenuation for each channel, radiation-hard by design





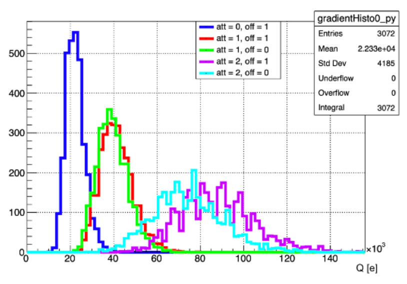
2 Studies on gain: the analysis method

Threshold scans analysis are a fundamental tool to **optimise the detector performance** since it allows to:

- **fine tune** the **HV**
- check the **aging** of the sensors

Before the columns installation a **full set of scans** was taken at the CERN Commissioning laboratory (Comlab). This means:

- One **integrated charge spectrum** for **each anode** (threshold scan)
- One **DAC scan for each anode** , to correlate threshold and charge

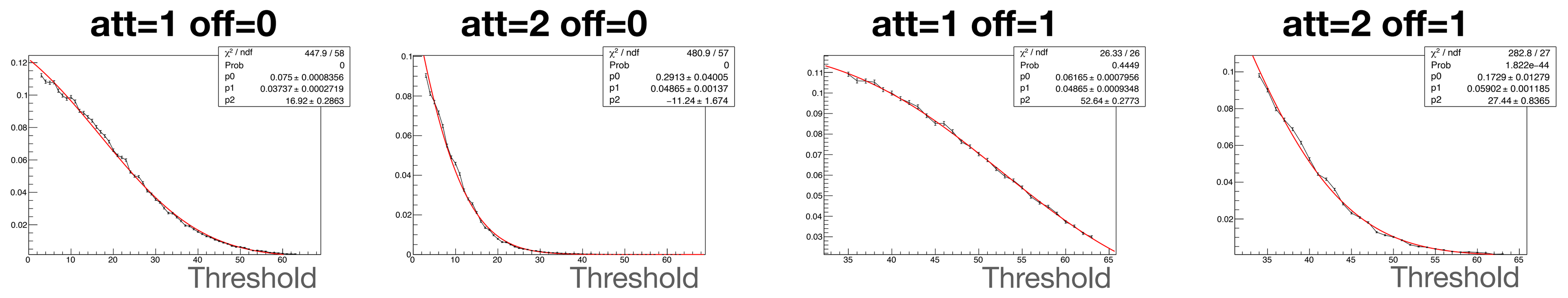


x4 ! **CLARO asic** has **two possible configuration parameters**:
- **Attenuation** (amount of charge for each threshold step)
- **Offset** (shift of CLARO, the front end ASIC, baseline)

RICH1 (22 columns)	RICH2 (24 columns)
5632 anodes each column x4 configurations	3072 anodes each column x4 configurations

A **fit to the integrated charge spectrum** with an erf function is performed to extract the flex for **different CLARO configurations.**
As an example for one anode of RICH2 column A01:

att=1 off=0 **att=2 off=0** **att=1 off=1** **att=2 off=1**

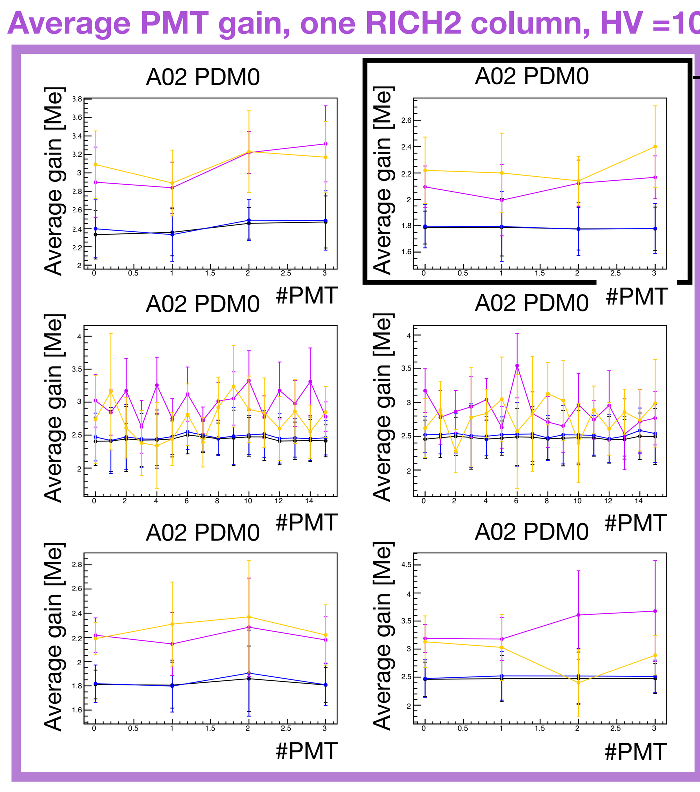


Once a **gain-threshold for all the configurations** is extracted, a **subset of the best configurations** is identified picking the ones where the **flex** has a **central threshold step position** in the available range.
Out of the best configuration chosen, if the gain at **attenuation equal to 1 is present** then this is **chosen as the reference one**, since it allows the **best precision** available, given the smaller charge step per threshold.

3 Comparison with Quality Assurance results

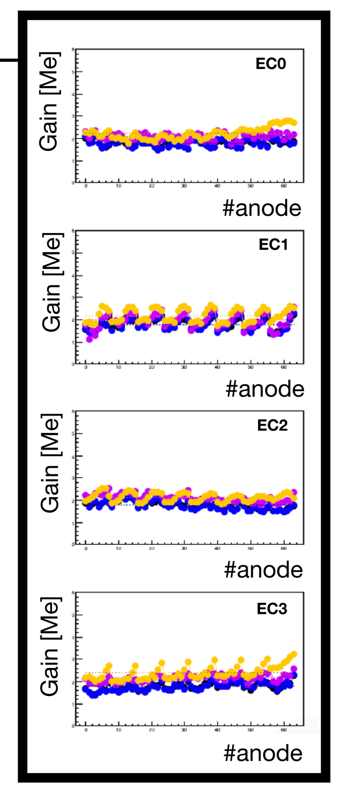
In oder to validate the analysis method, it is possible to **compare Quality Assurance and Comlab threshold scans anode gains,** both computing the **average gain for each PMT** and the **gain for the single anode**. These data were acquired with different electronics chain, so the gain measurements are completely independent.

Average PMT gain, one RICH2 column, HV =1000V



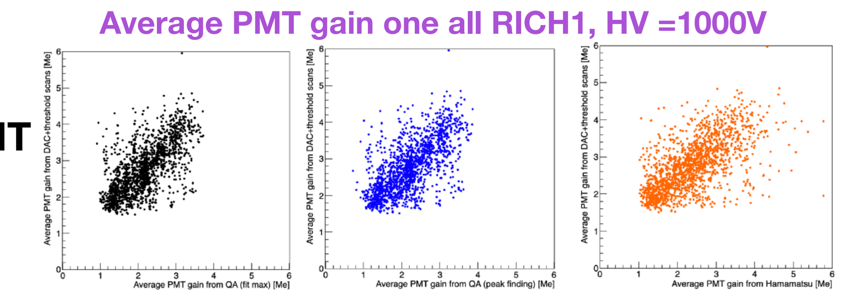
The **gains** obtained via the **Comlab threshold scan** data analysis are **consistent** with the ones obtained in the **Quality Assurance phase** with a completely different electronics and data acquisition system.

The **analysis method is validated** and thus I could proceed with the comparison of the Comb gains with the ones acquired with the P8 threshold scans.



Average PMT gain one all RICH1, HV =1000V

One can also look at the **correlation** in between the **Comlab average PMT gains** and the various **QA gains:**

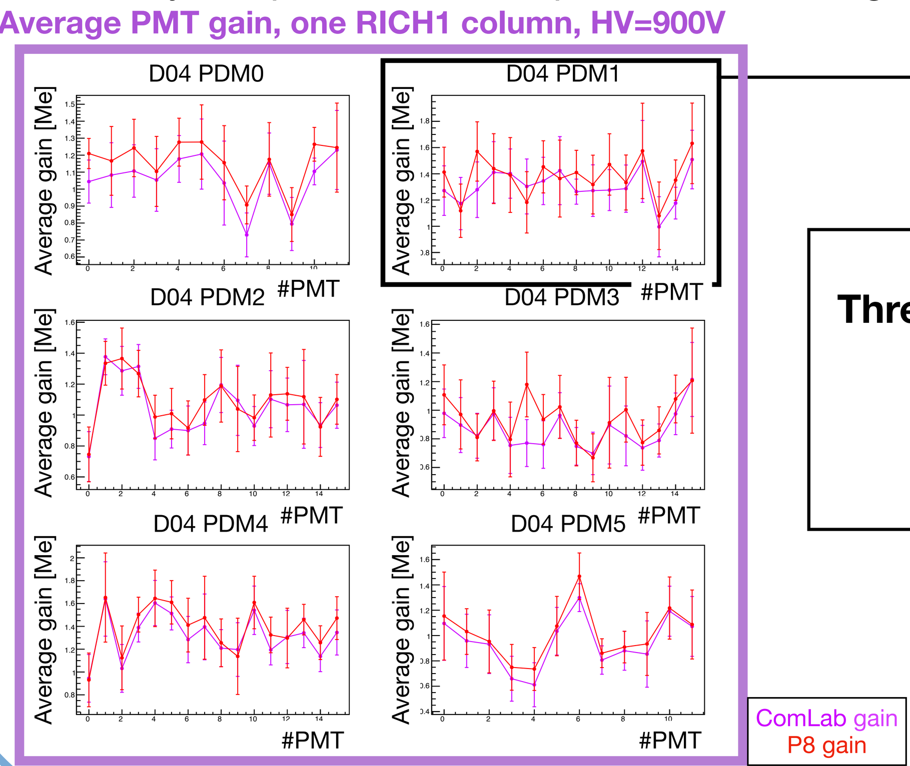


Analysis method validated

4 Comparison with P8 results

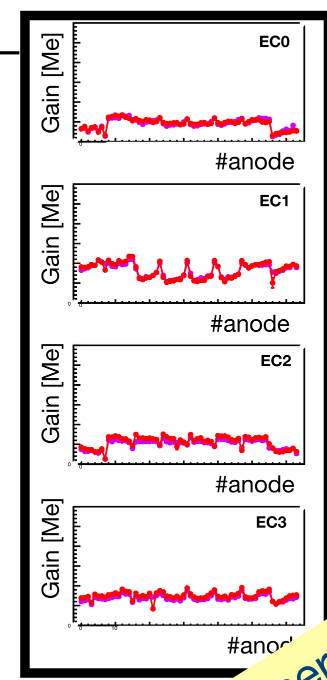
Finally it is possible to compare the MAPMT gains measured in the Comlab and at the P8.

Average PMT gain, one RICH1 column, HV=900V



Threshold scan procedure fully **validated**

No aging observed



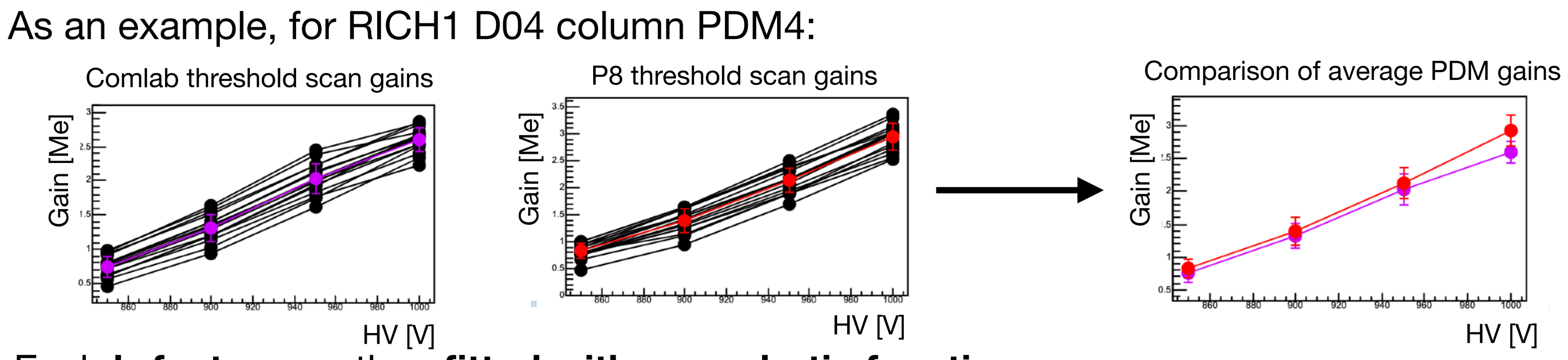
No aging observed!

5 K-factor studies

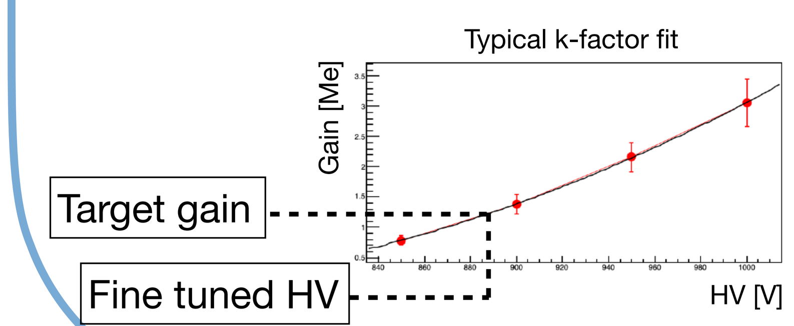
In order to **fine tune the High Voltage** (HV), it is necessary to **study the gain variations as a function of the applied HV**, namely the study of the **k-factors**.

For a MAPMT, the gain(G)-HV dependence can be modeled as: $G = A \cdot HV^{kn}$, where n is the number of dynodes.
The **HV** can be **tuned at the level of the Photo Detection Modules (PDM)**, so the **relevant quantity** to study is the **PDM average gain**.

To do so, for the **k-factors study** the **average gain of all the PMTs in a PDM** is considered, with **uncertainty** coming from the **standard deviation of the different PMTs gains.**
As an example, for RICH1 D04 column PDM4:



Each **k-factor** was then **fitted with a quadratic function.**



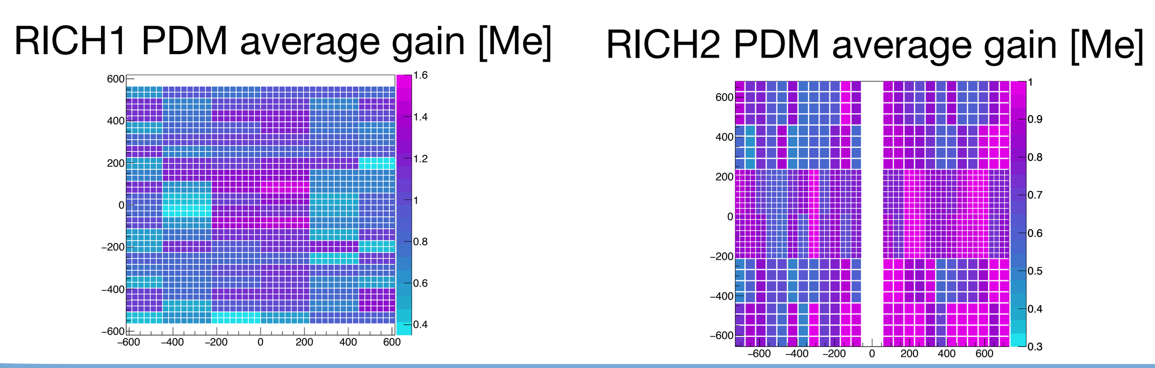
The HV fine tuning strategy

The **k-factors** are exploited to find the optimal HVs for a certain target gain.
As an example, if the target gain is 1.2 Me, by means of the k-factors fit function it is possible to tune the HV at the tens level. In particular, if the 1.2 Me gain is within the error bars of one of the. k-factor curve points, that particular voltage is chosen.

6 Gain distributions before HV fine tuning

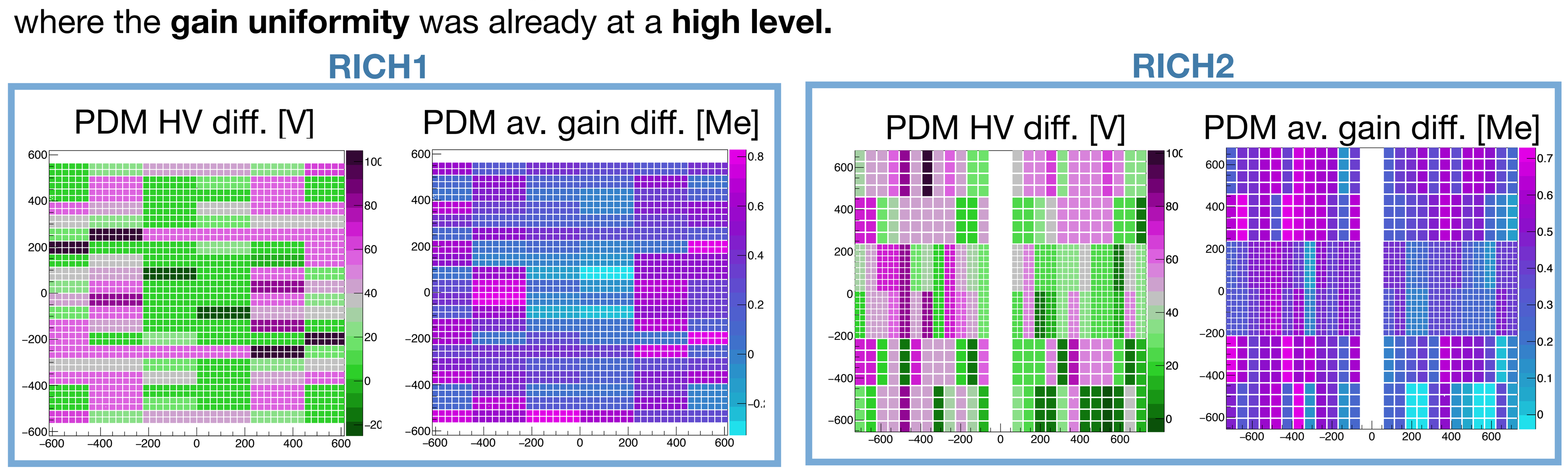
It is possible to visualise the **PDM average gain** across the **RICH1 and RICH2 detector plane.** In this way one can assess the **gain uniformity** throughout all the PDMs.

The goal is to **fine tune the HV** in order to get a **uniform gain as in the RICH1 high occupancy region**, so of about ≈1.2 Me .

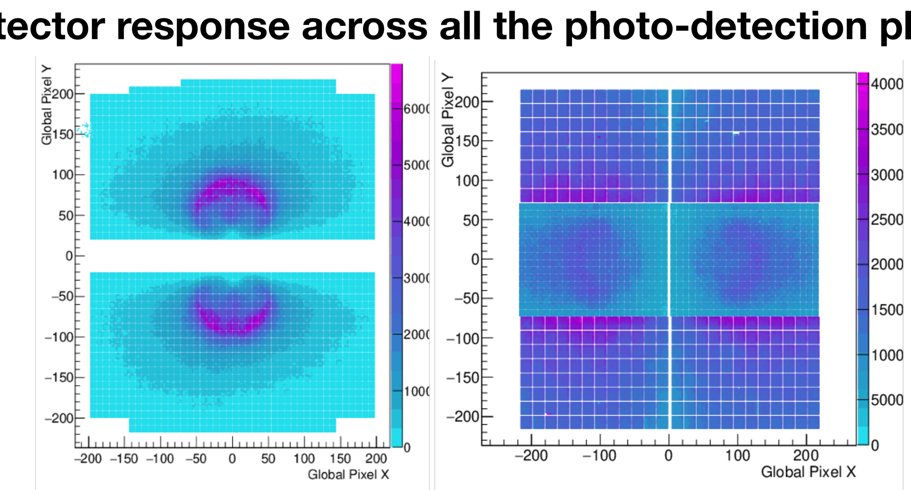


7 HV fine tuning results

Once chosen as **uniform goal gain 1.2 Me**, it was possible to **estimate the variation in gains and HV** with respect to the **operations ones**.
In **RICH2** one can observe that in general an i**ncrease of the HV is needed more often** than in **RICH1**, where the **gain uniformity** was already at a **high level.**



During the **pp reference** run it was possible to **test the new fine-tuned HV recipes**, resulting in a nicely **uniformed detector response across all the photo-detection planes**:



A **new time alignment** has been consequently **performed** and during the 2024 beam fills the PID performances will be evaluated with this optimised calibration.
The fine tuned HV recipes have also been used to study the Signal Induced Noise in the MAPMTs and **no increase** in such **background** has been **observed with respect to the operation HV** applied so far.

Conclusions

In order to make **the response uniform for the Run 3 RICH subsystem** and to **maximise the efficiency**, the **calibration data** acquired in the experiment has been used to **equalise the single photon gain over approximately 200k channels.** It is possible to conclude that:

- **No aging** was observed in RICH1 and RICH2
- **P8 k-factors** have been extracted and **HV fine tuning** has been performed to make the **gains uniform** at 1.2 Me across the detectors.