Operation and performance of the ALICE Muon IDentifier RPCs during LHC Run 3

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Outline

- A Large Ion Collider Experiment (ALICE)
  - Muon Spectrometer (MS)
  - Muon IDentifier (MID)
  - MID upgrades for Run 3
- MID Run 3 performance
  - MID status at CERN
  - HV scan
  - RPCs efficiency stability
  - RPCs dark current stability
  - Run quality statistics
- Conclusions

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A Large Ion Collider Experiment (ALICE)

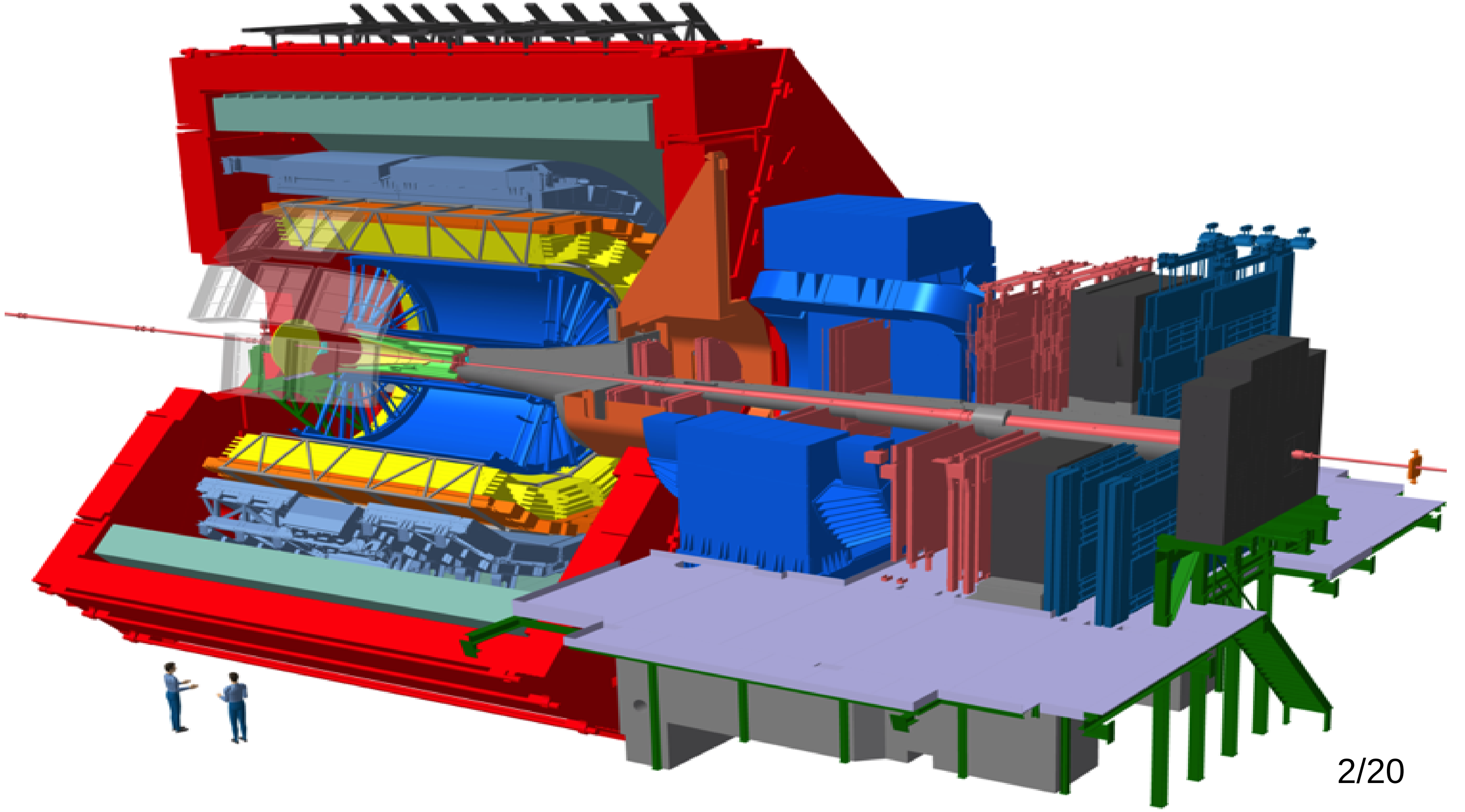
- A Large Ion Collider Experiment (ALICE) at the CERN Large Hadron Collider (LHC) is the experiment specifically designed to study the QGP in heavy-ion collisions

- During the Long Shutdown 2 of LHC, ALICE achieved a major upgrade of its apparatus:

→ to cope with the increased Pb-Pb collision rate foreseen for Run 3

Run 2	Run 3
10 kHz	50 kHz

→ to allow a new ambitious program of high-precision measurements



The ALICE Muon Spectrometer (MS)

- It detects muons in the polar angular range 2° - 9°, i.e. it covers the pseudorapidity range $2.5 < \eta < 4$

- It consists of:

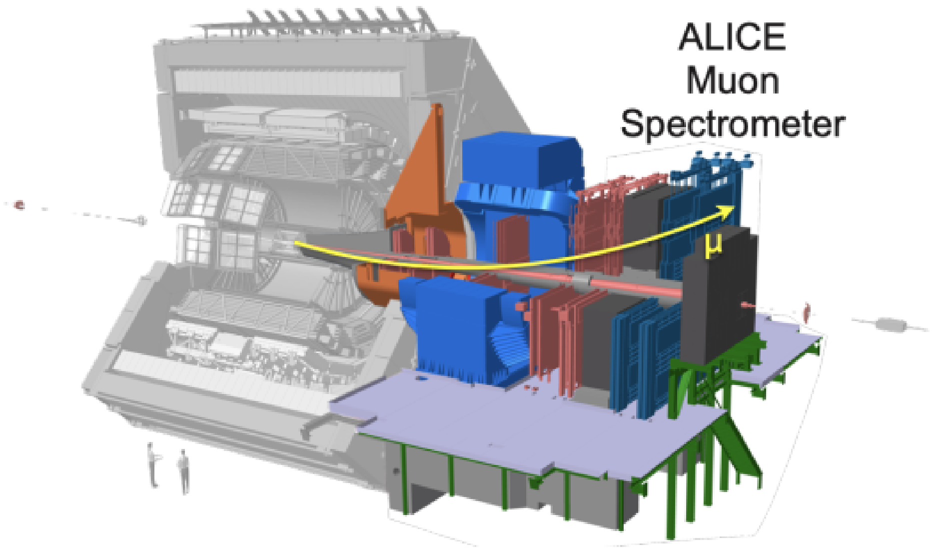
  1. **Absorbers**
     → front hadrons absorber
     → filter iron wall

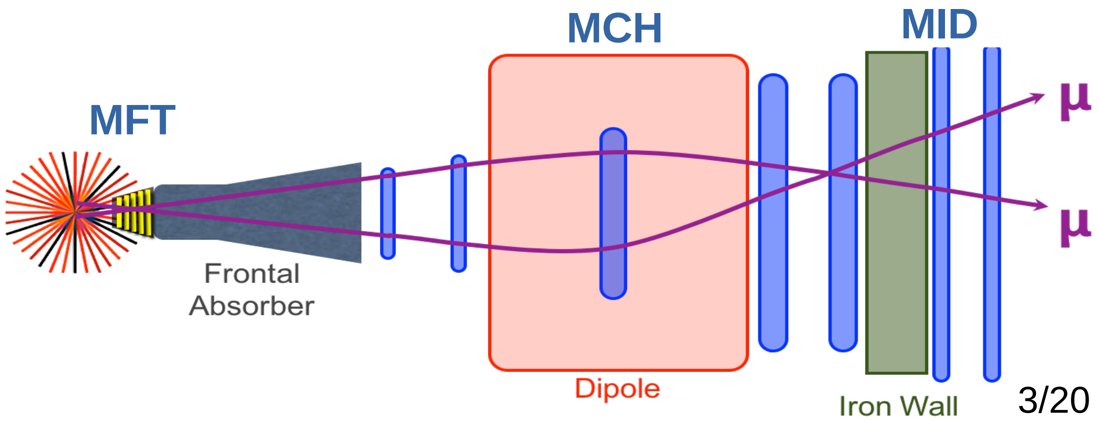
  2. **Dipole magnet**

  3. **Muon Forward Tracker (MFT)**
     → 2 half-cones containing 5 detection planes each of ALPIDE Silicon pixel sensors based on Monolithic Active Pixel Sensors

  4. **Muon Chambers (MCH)**
     → 5 stations of 2 planes of Cathode Pad Chambers and Cathode Strip Chambers

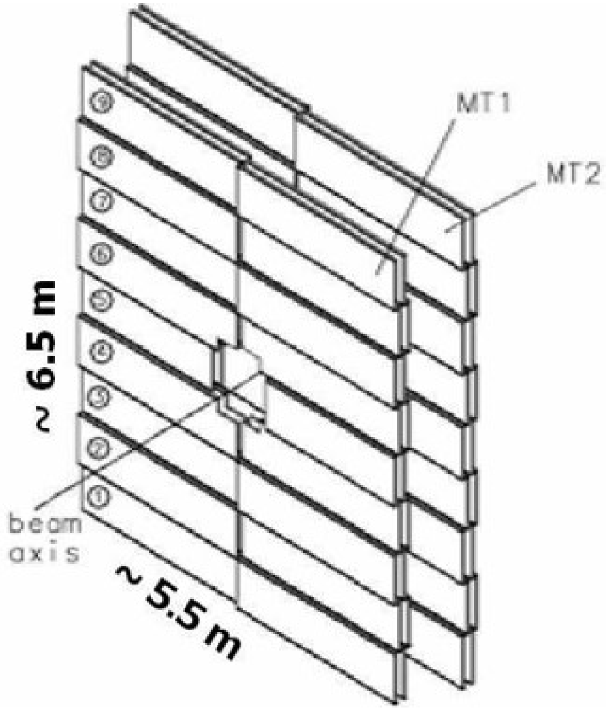
  5. **Muon IDentifier (MID)**
     → **2 stations of 2 planes of Resistive Plate Chambers (RPCs)**

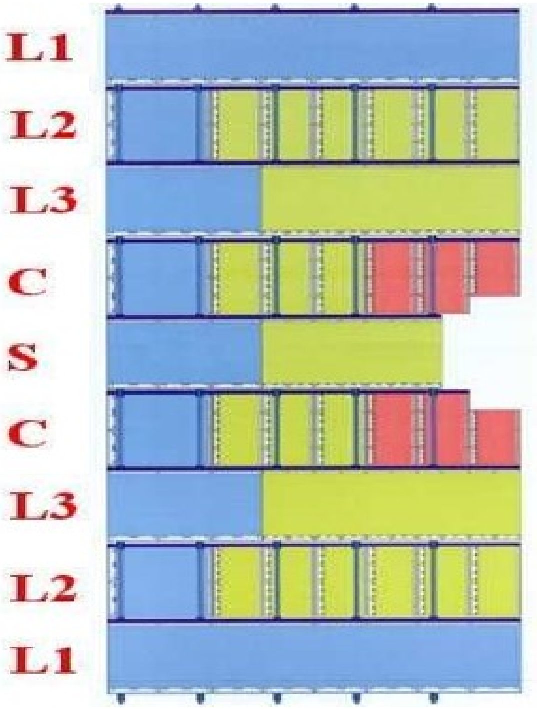




The Muon IDentifer (MID) RPCs (I)

- The MID consists of **72 Resistive Plate Chambers** arranged in 2 stations of 2 planes each
- each plane is 5.5 x 6.5 m^2 , with 1.2 x 1.2 m^2 central hole to allow the beam pipe and shielding
- the RPCs are equipped with **orthogonal strips** in order to provide the spatial information along the X and Y directions, for a total of 21k strips with 1, 2 and 4 cm pitch

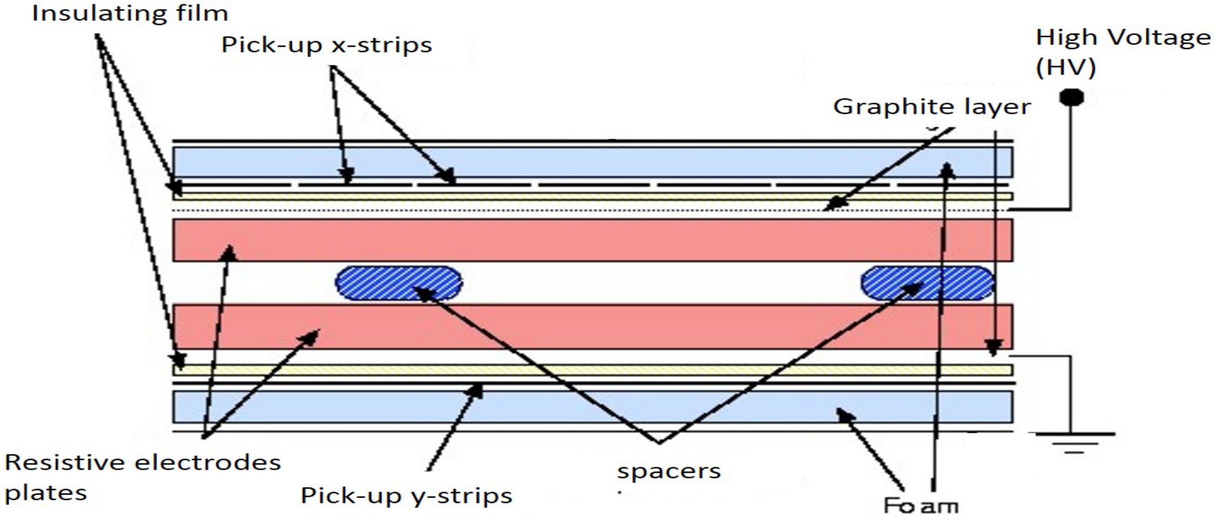




The Muon IDentifer (MID) RPCs (II)

- ALICE MID RPCs:
  - **2 mm single** gas gap detectors
  - resistive **bakelite** electrodes, 2mm thick, $\rho \simeq 3 \times 10^{9} - 1 \times 10^{10}\ \Omega$ cm
  - the signal is picked-up inductively by means of copper strips with 50 Ω impedance

- Operational parameters during Run 3:
  - gas mixture: 89.7% $C_2H_2F_4$, 0.3% SF_6, 10% i-C_4H_{10}, humidified at 35-40% (same as Run 2)
  - **lower effective applied HV** (thanks to the new FEE) w.r.t. Run 2
  - **avalanche mode** instead of maxi-avalanche of Run 2



MID upgrade for Run 3

- Starting from Run 3 the detector supports **continuous readout mode (i.e. without trigger)**
  - this required an **upgrade of the read-out electronics**

- to cope with the increased counting rate and to reduce aging effects, RPC are operated at lower gain thanks to a **new front-end electronics** **(FEERIC ASIC)** including a pre-amplification stage

- some RPCs have integrated a non-negligible charge during Run 1 and 2 and **aging effects** might lead to sub-optimal performance for some RPCs
  → new production of RPCs (*see S. Garetti's talk*)
  → **four new RPCs** installed so far, to replace detectors with high dark current or gas leaks

https://ieeexplore.ieee.org/document/6829539

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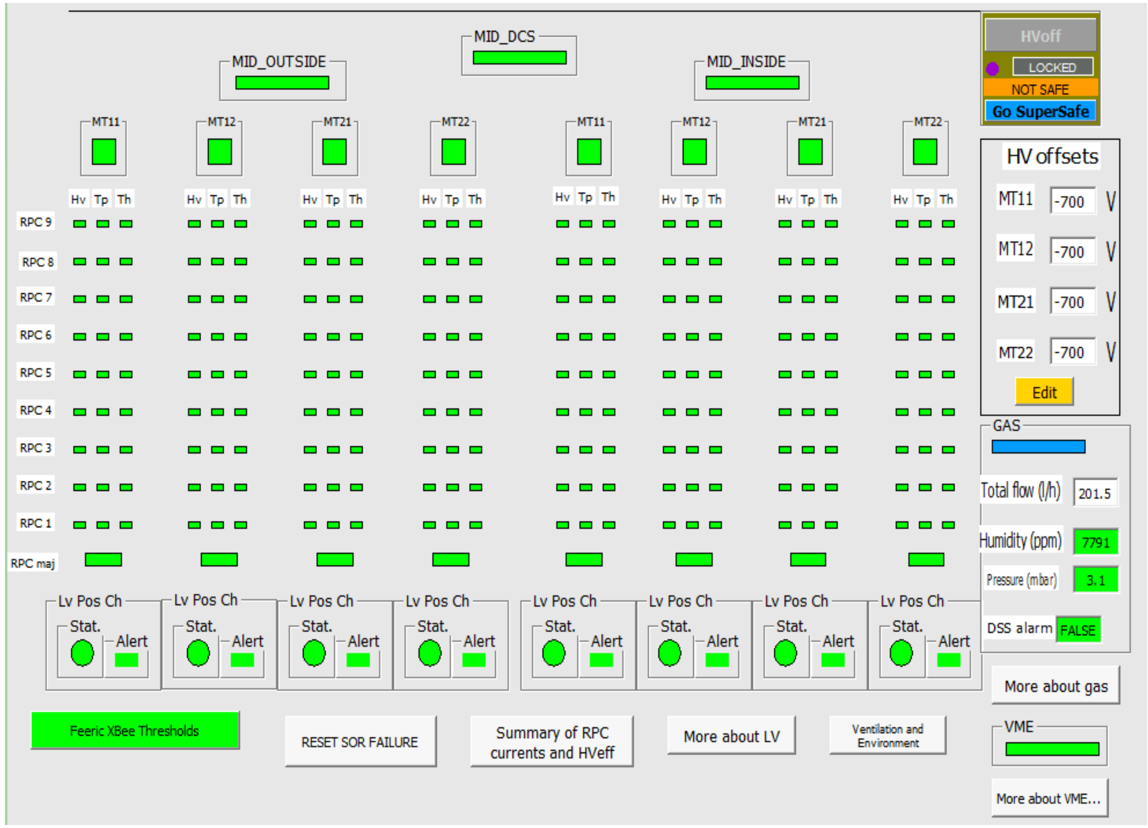
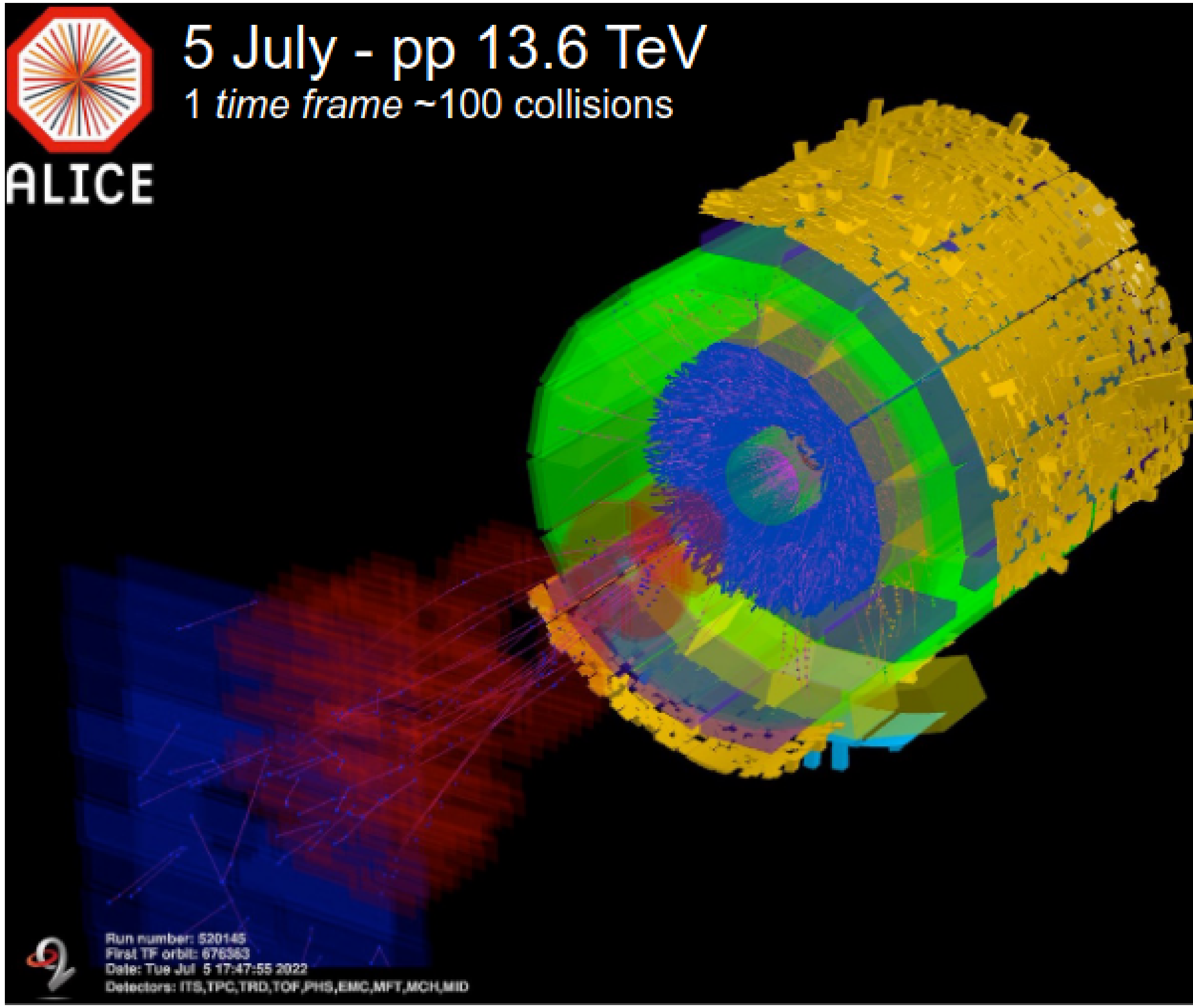
MID status at CERN

- **MID was READY for physics when Run 3 started in July 2022, and up to now is always READY and taking data**
  - all 72 RPCs operational



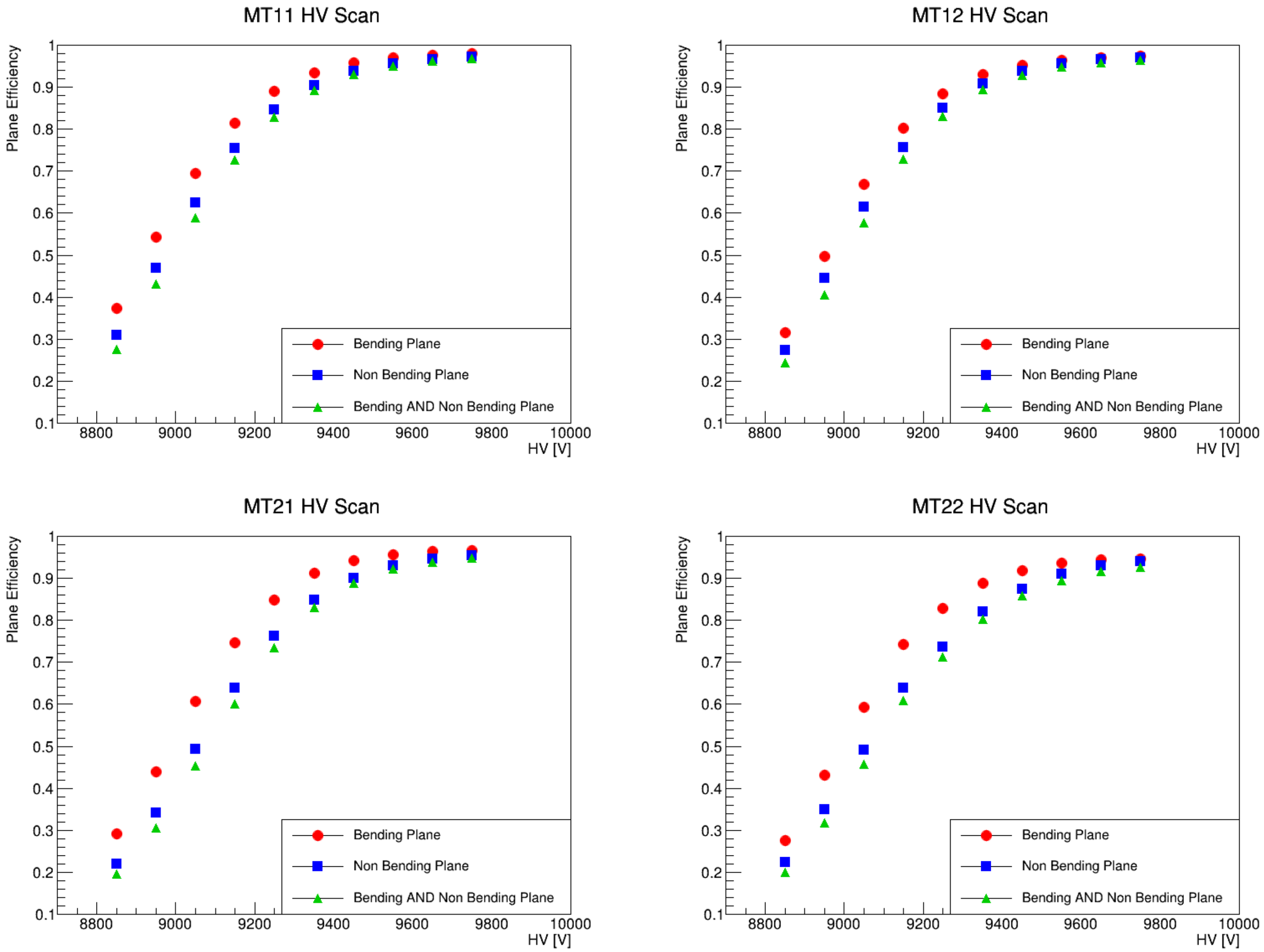


HV scan for efficiency measurement

- MID HV Scan to **set the correct HV working point** (w.p.) on all RPCs
- reminder: RPCs are working in avalanche mode in Run 3, w.r.t. the maxi-avalanche mode of Run 2
- one scan was done already during 2022, but:
  - with MID tracks only
  - some RPCs were replaced during YETS 2022-2023
- **New Scan done this year on April 10-11th with matched tracks MCH-MID**, using pp collisions at 500 kHz visibile interaction rate
- **Procedure:**
  - RPCs initially operated at the provisional w.p. of -700 V w.r.t. Run 2
  - HV was changed on one plane at the time, while the other 3 planes were kept at the provisional w.p.
  - 10 points taken per plane, with HV ranging from -1400 V to – 500 V w.r.t. Run 2 w.p., in steps of 100 V
- Efficiency evaluated per each **Plane**, per each **RPCs**, and per each Local Board (**LBs)**, in the three cases: Bending Plane (**BP)** only, Non Bending Plane (**NBP**) only and **Both** BP and NBP

HV scan results (I)

- Efficiency per plane
  - MT1 on the top
  - MT2 on the bottom
- in each plot 3 cases (BP, NBP and Both)
- for all 4 planes the plateau is reached at ~ 9700 V (- 600 V w.r.t. Run 2)



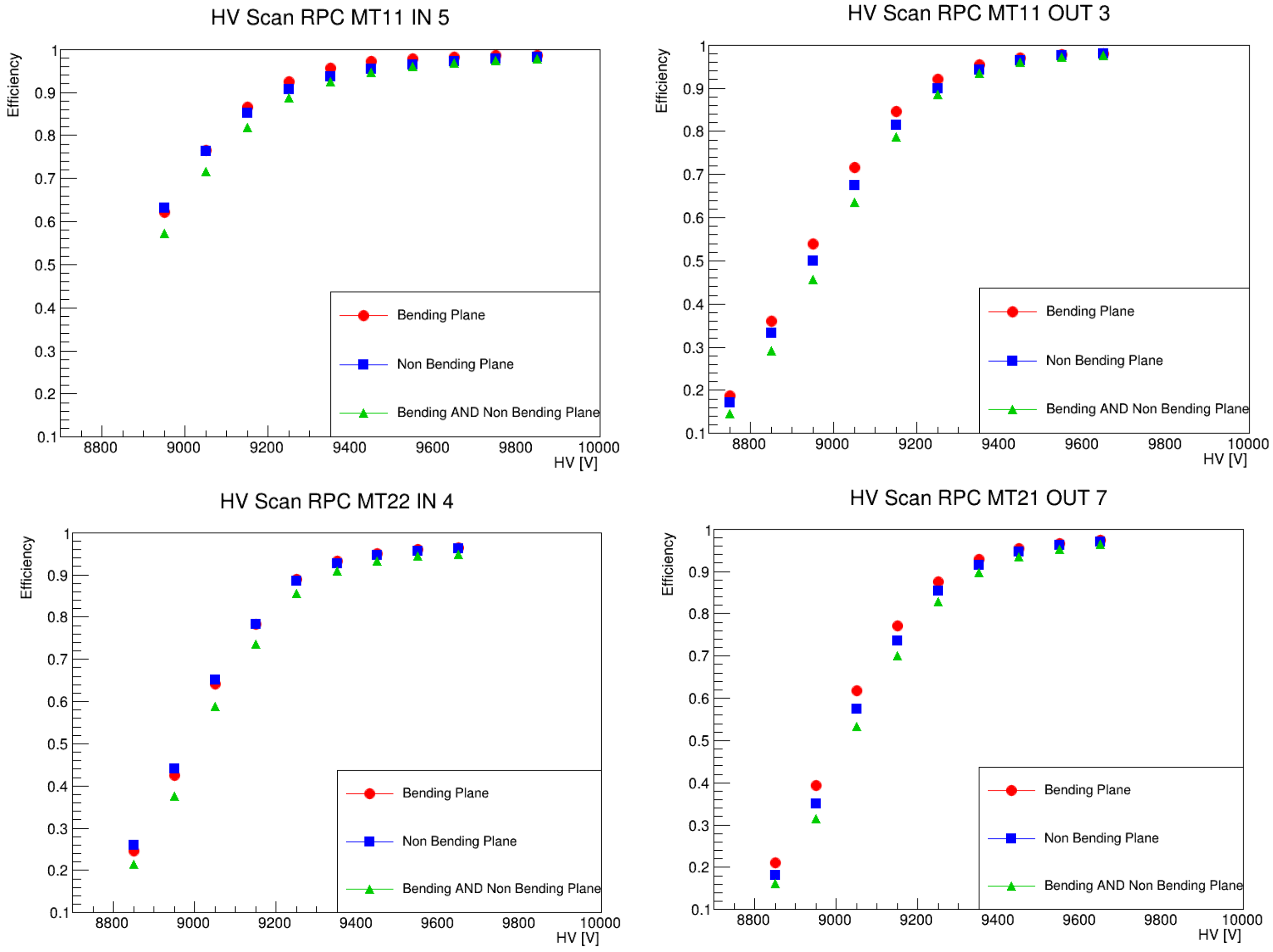
HV scan results (II)

- Efficiency per RPCs (few examples)

- All good for the majority of RPCs
  - few of them need further investigation on slightly lower efficiency

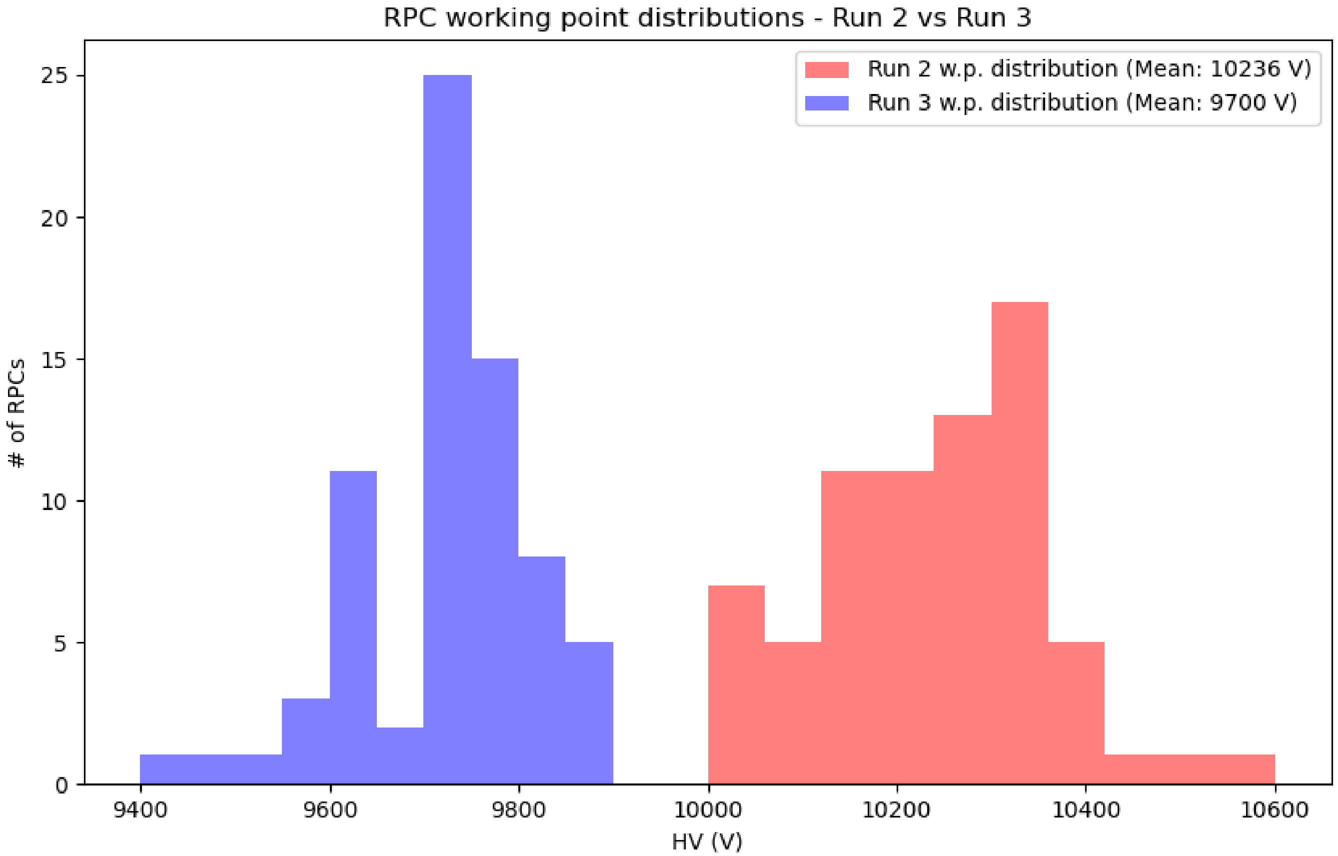
    → study of the efficiency on Local Board level

- As previously seen at plane-efficiency level, the plateau is reached around ~ 9700 V



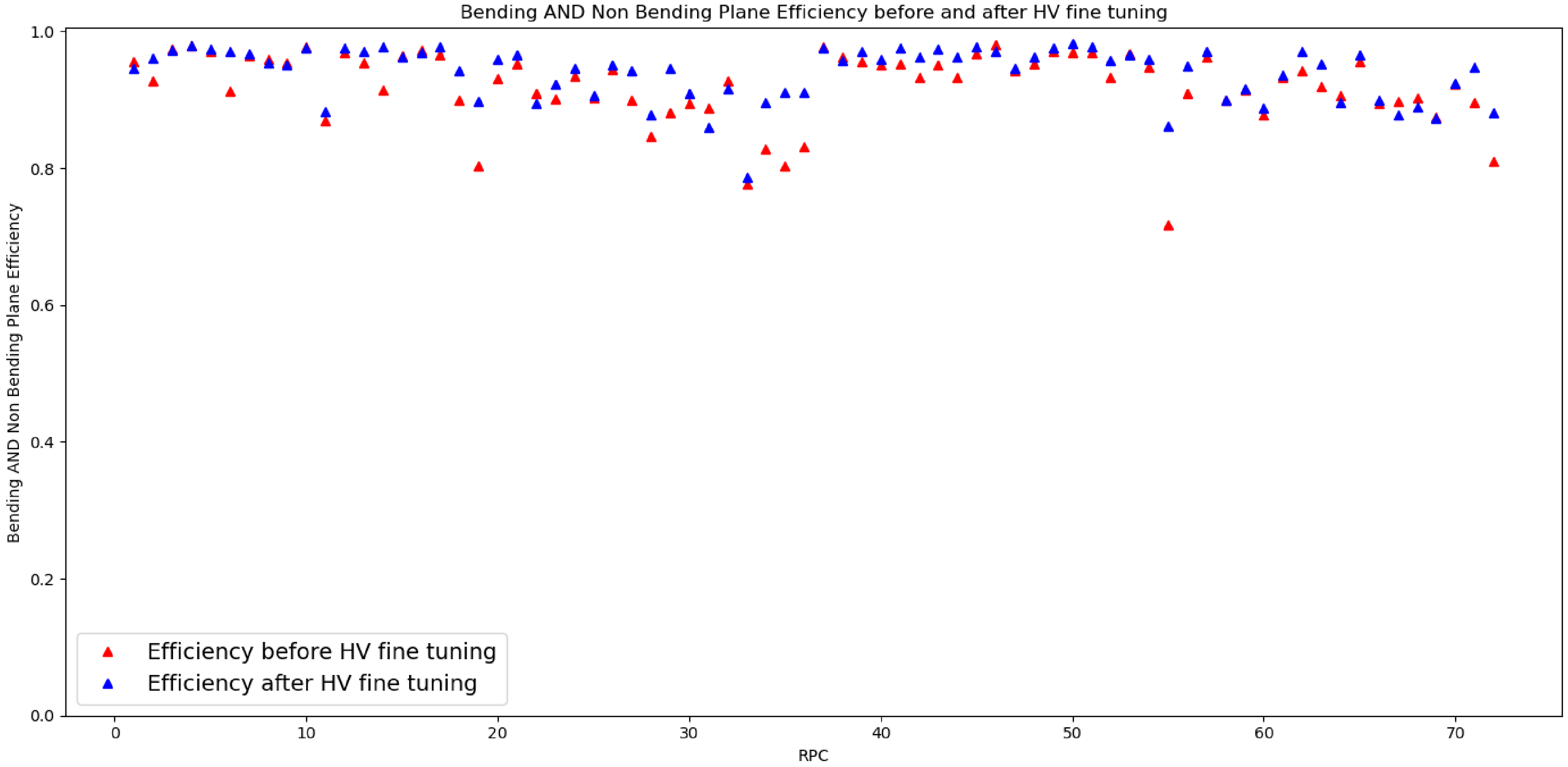
Working point distribution in Run 2 and Run 3

- From Run 2 to Run 3:
  - HV working point lower by about 600 V



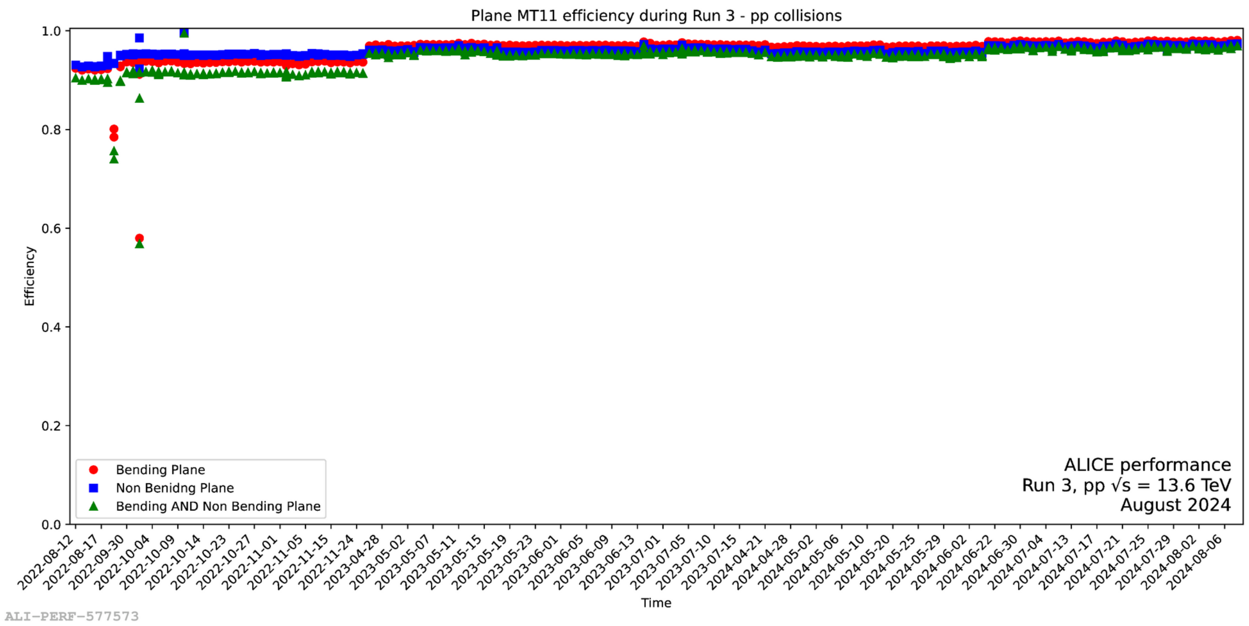
RPC efficiency before and after HV fine tuning

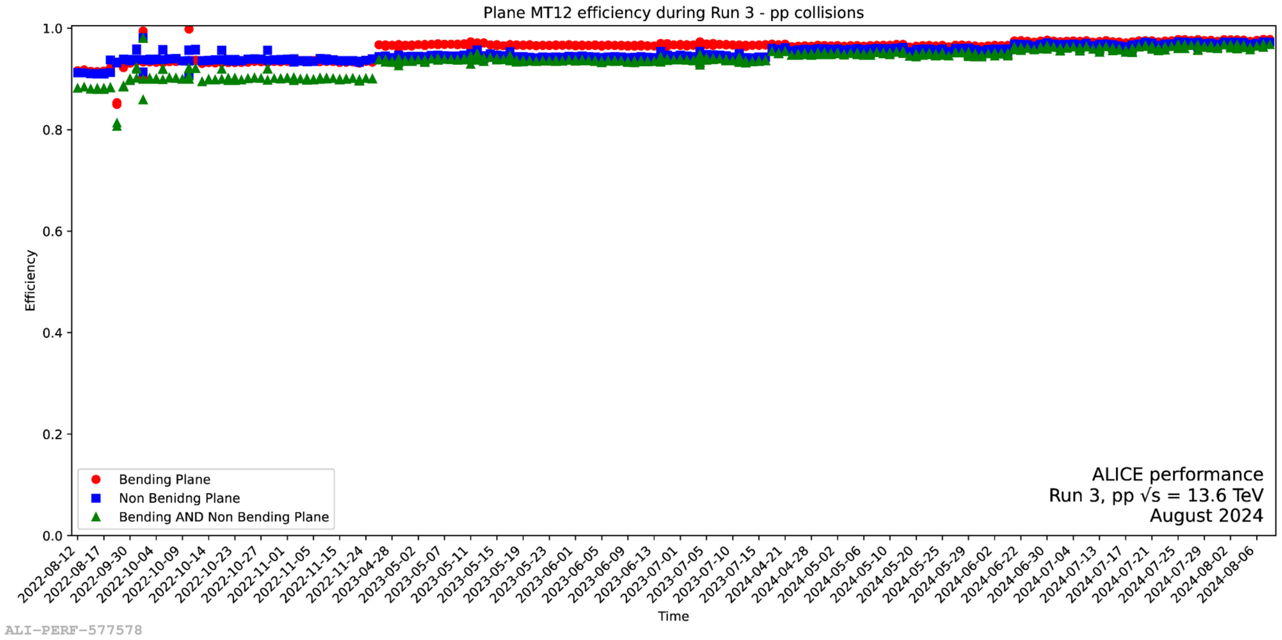
- Average efficiency of the 72 RPCs in 2024 before and after the HV fine tuning done in June 2024



Efficiency in Run3 – MT11 and MT12

- Average efficiency of the MT11 and MT12 planes as a function of time in the period July/2022-Aug/2024
- Bending plane, non-bending plane and the AND of the 2 are shown separately
- pp collisions only
  - still tuning the efficiency evaluation algorithm for Pb-Pb collisions

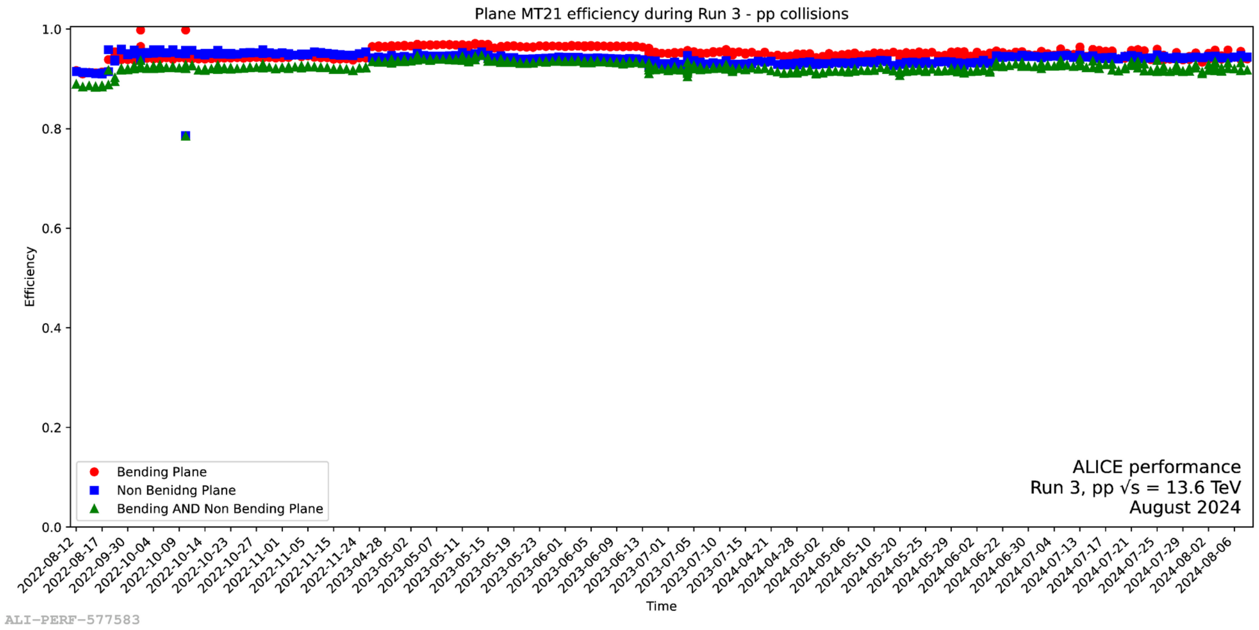


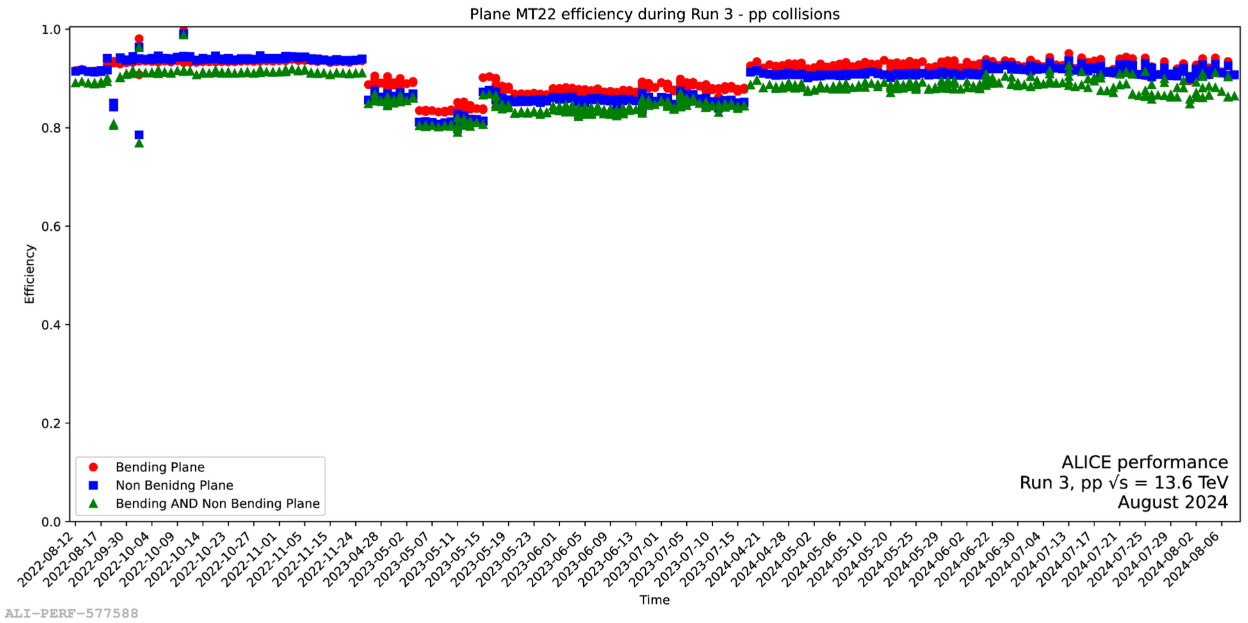


- **Efficiency is increasing each year from 2022 to 2024 thanks to hardware improvements**
- **Efficiency higher than 95%**

Efficiency in Run3 – MT21 and MT22

- Average efficiency of the MT21 and MT22 planes as a function of time in the period July/2022-Aug/2024
- Bending plane, non-bending plane and the AND of the 2 are shown separately
- pp collisions only
  - still tuning the efficiency evaluation algorithm for Pb-Pb collisions

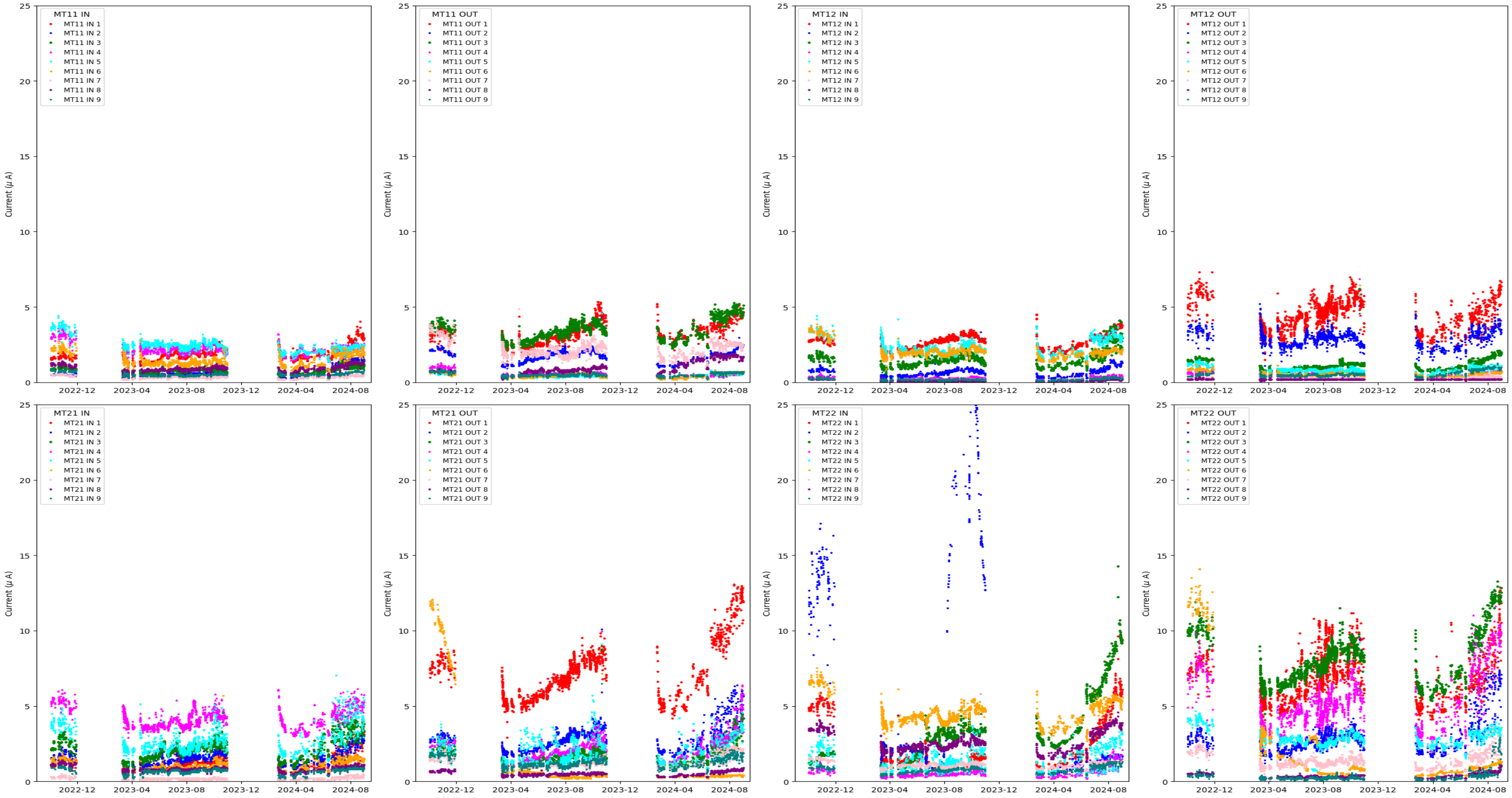




- **Efficiency is increasing each year from 2022 to 2024 thanks to hardware improvements**
- **Efficiency higher than 95%**
- **Some problems with the electronics of few RPCs of plane MT22, leading to a decrease of the average efficiency of the plane**
  - **partially solved at the end of 2023. Other improvements still ongoing**

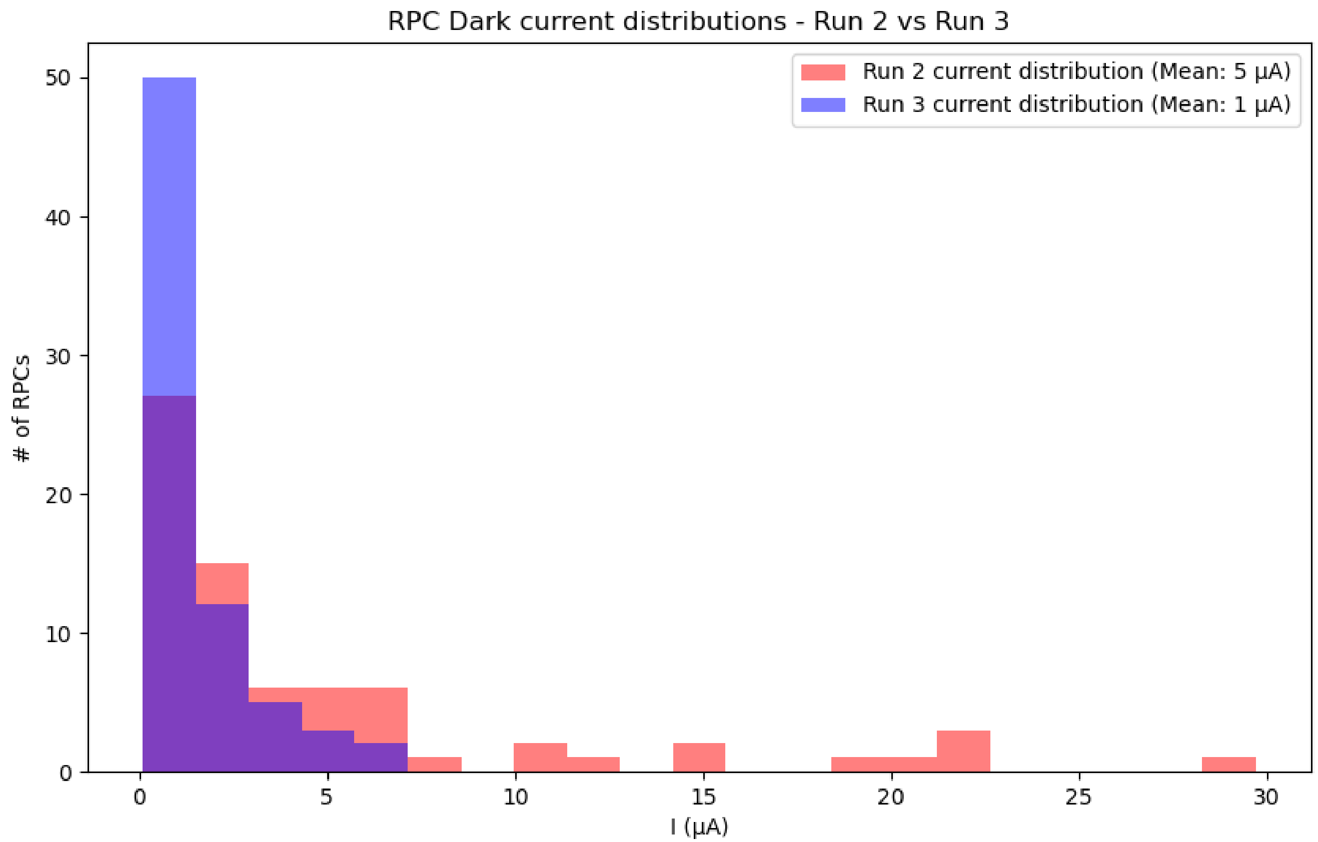
Dark currents in Run 3

- In each plot the dark current since the start of run 3 for 1 half-plane, i.e. 9 RPCs, is shown



Dark current distribution in Run 2 and Run 3

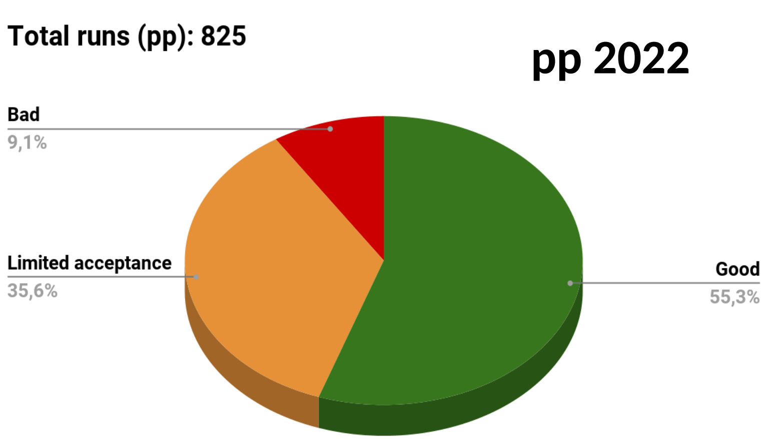
- From Run 2 to Run 3:
  - Dark current down by a factor 5



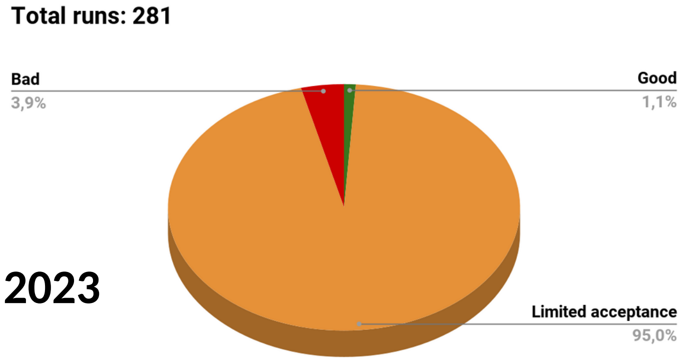
Run quality in Run 3 – 2022 and 2023

- Runs in pp 2022 have been flagged as "Bad" mainly because:
  - 1 end point of 1 common readout unit (CRU) lost (i.e. ¼ of the MID)
    - due to high noise from a few FEE cards
  - gas system stop due to faulty sensors

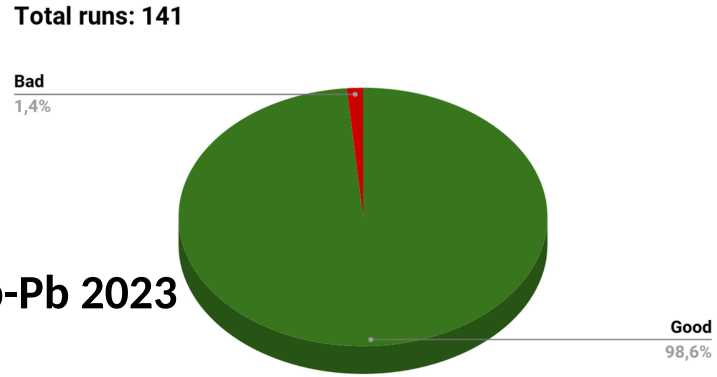
pp 2022



pp 2023



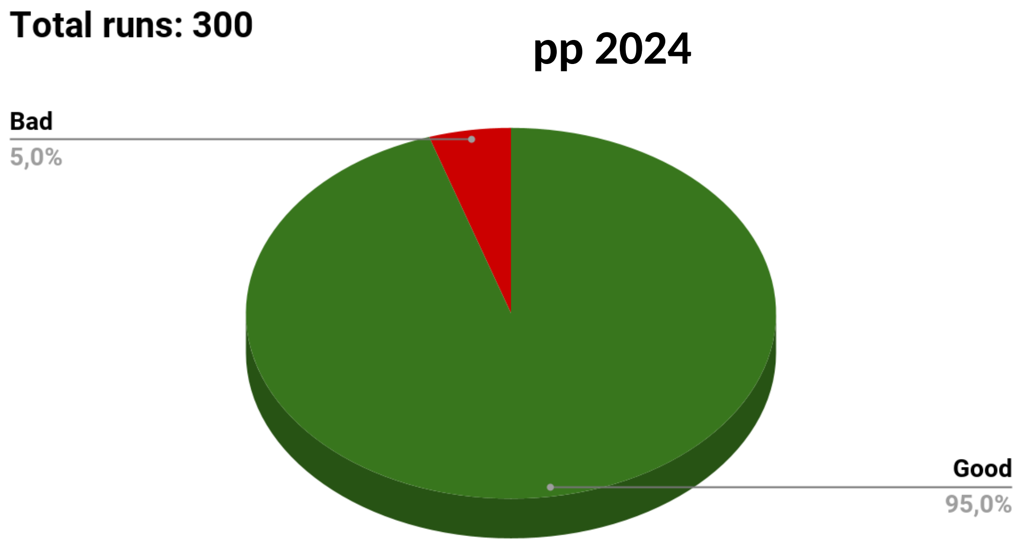
Pb-Pb 2023



- all runs in pp 2023 that have been flagged as **"Limited acceptance (MC reproducible)"**
  - 2 RPCs, MT22IN1 and MT22IN2 with an inverted HV polarity → very low efficiency
    - fixed at the end of 2023 before Pb-Pb run

- In Pb-Pb 2 BAD runs due to 1 end point lost
  - entire columns in the hitmaps have low occupancy

Run quality in Run 3 – 2024

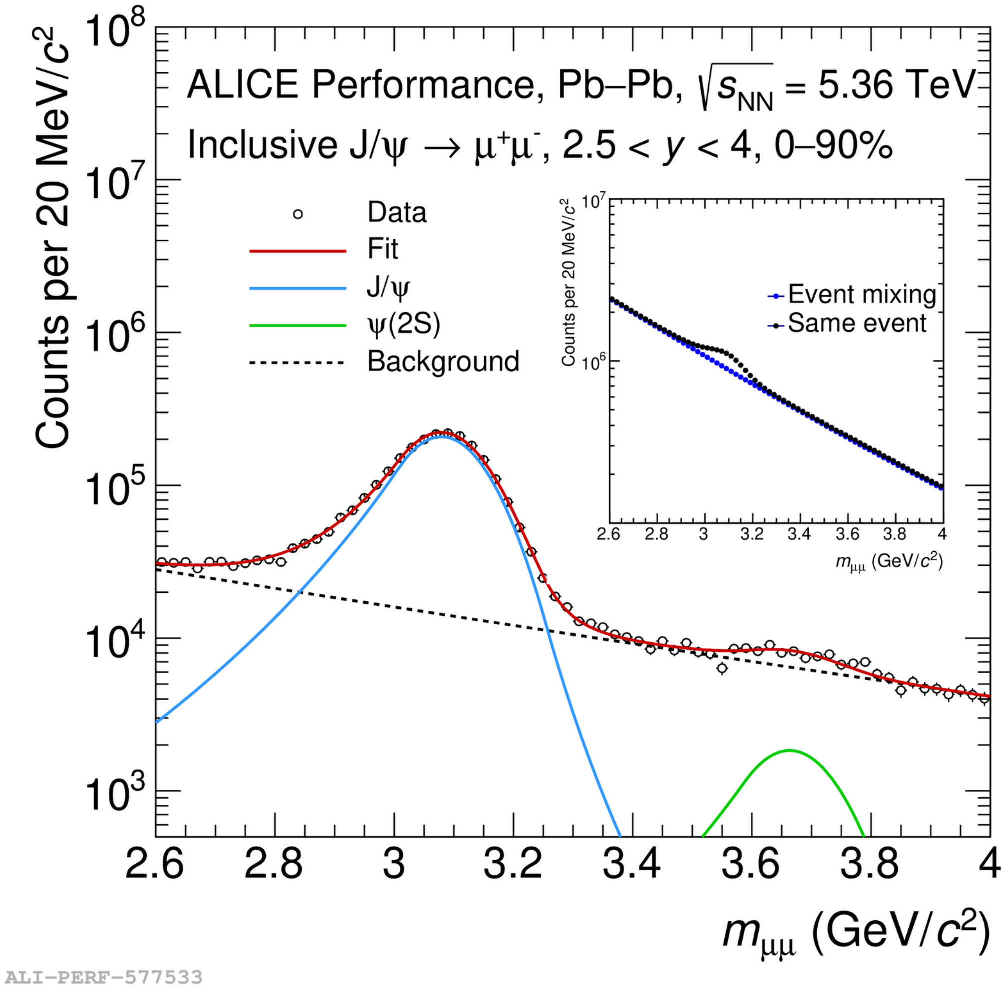


- Few BAD runs come from various readout problems that were translated into a bad quality of the run

- Sum-up:
  - Issues observed in 2022 and 2023 have been **fixed**
  - **pp** collisions:
    - 101/1406, i.e. only **~7% BAD runs**
      - **BAD runs fraction dominated by year 2022 and it is improving every year**
  - **Pb–Pb** collisions:
    - 2/146, i.e. only **~1.4% BAD runs** → very small fraction

First performance for quarkonium physics

- J/ψ and ψ(2S) invariant mass Run 3 in dimuon channel at forward rapidity 0 – 90%
  - matched MCH-**MID** tracks
  - 0 < pT < 30 GeV/c
  - mixed-event background
- The insert plot presents the invariant mass spectrum of J/ψ along with the mixed-event background for Pb-Pb collisions at 5.36 TeV
- The main plot displays the invariant mass and corresponding fits for J/ψ and ψ(2S) based on the invariant mass spectrum shown in the smaller plot, after subtracting the mixed-event background



Conclusions

- MID has been **successfully upgraded** for Run 3 to cope with the higher interaction rates
- MID is **running smoothly since the start of Run 3**, both in pp and Pb-Pb collisions with a low percentage of BAD runs, mostly due to readout failures
- The new FEE allow us to run with **lower HV** (-600 V w.r.t. to Run 2)
  - average dark current is lower too by about a factor 5
- HV scan successfully performed to allow the fine tuning of the new HV working points
- Both hw and sw improvements lead to a **constant increase of the average efficiency every year** from 2022 to 2024
  - **efficiency higher than 95% for the majority of RPCs**
  - still some margin for improvements
  - work ongoing on Local Boards efficiency studies
- Promising performance for both J/ψ and ψ(2S)

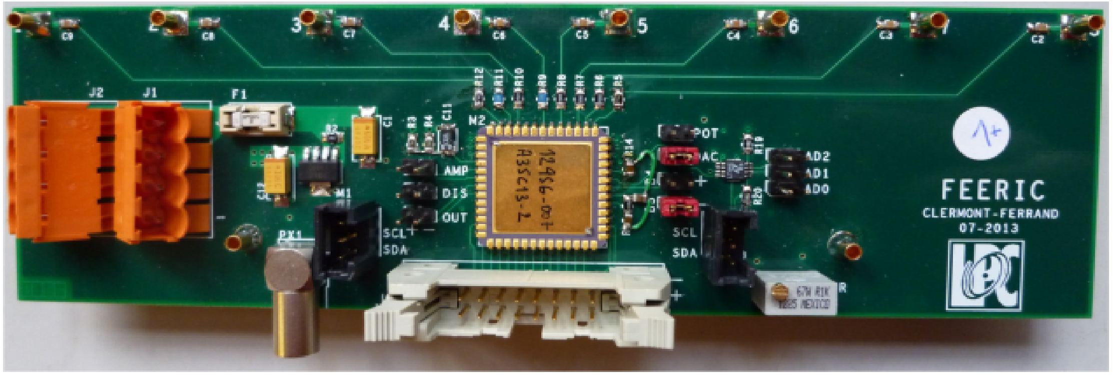
Thank you for the kind attention!

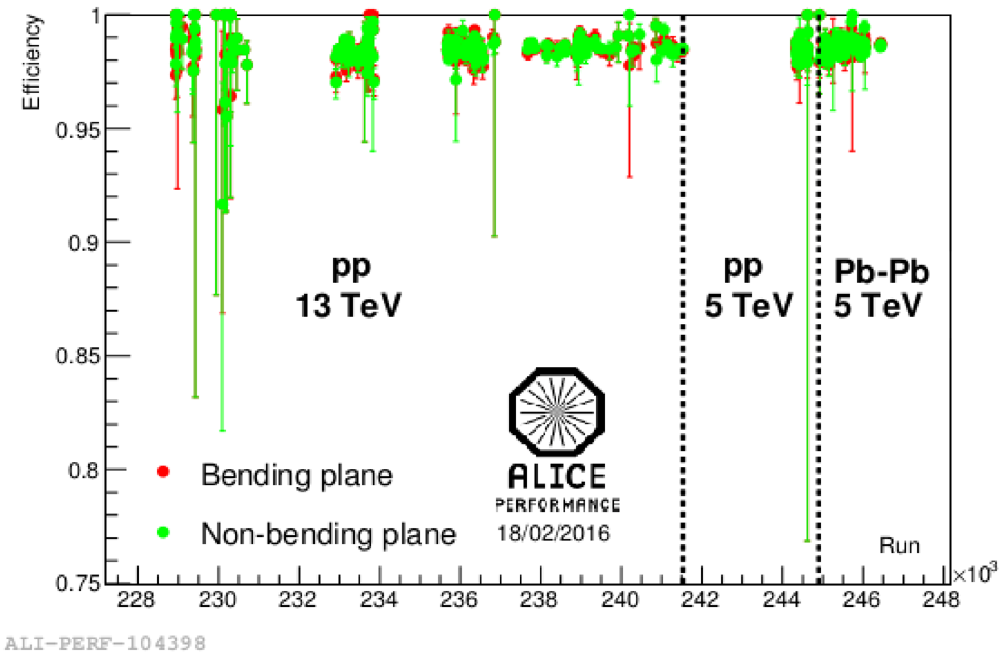
Back up slides

The new front-end electronics: FEERIC

Goal: **slow down RPC aging** after LS2 and **improve rate capability**

→ FEERIC has a pre-amplification stage for RPCs
→ 20992 channels, 2384 FEERIC cards (2720 spare included)
→ installation completed in July ‘19





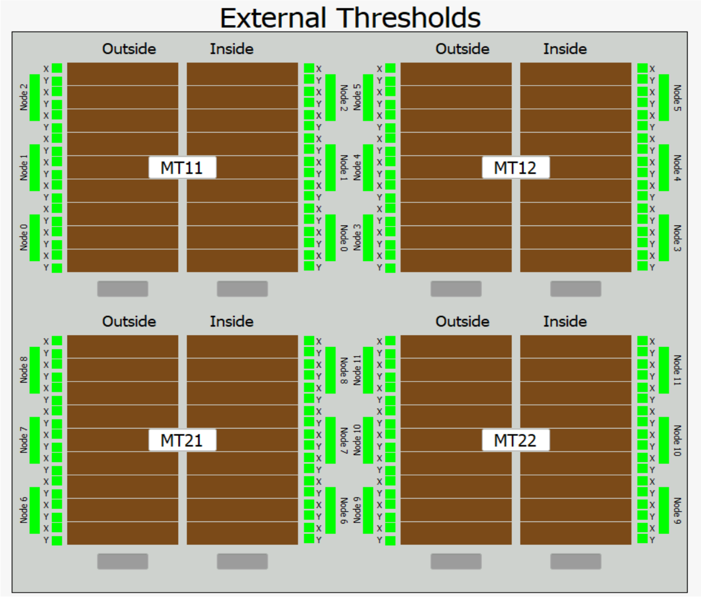
- One RPC was equipped with FEERIC during Run 2

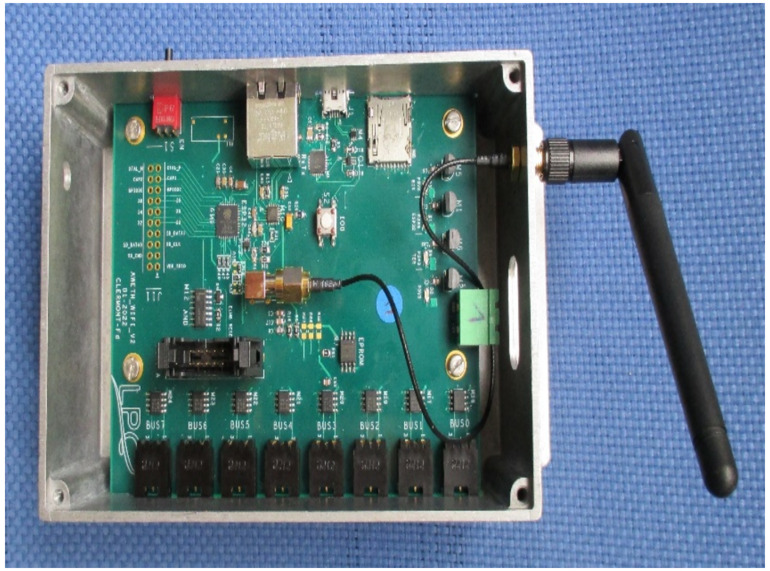
→ **factor 3-5 less charge** released in the RPC gas volume with FEERIC
→ lower HV working point w.r.t. to Run 2
→ **efficiency higher than 97%** in both bending and non bending plane, for different collision system
→ **very satisfactory performance and stability**

Wireless FEERIC threshold distribution

- New **wireless threshold distribution**:

  → **thresholds adjustable for each single FEERIC card** instead per RPC side like in Run 1 and Run 2
  → old Xbee system slow and unstable
  → agreement from TC+CERN-IT in June 2021 to upgrade to WiFi (band 2.4 GHz)



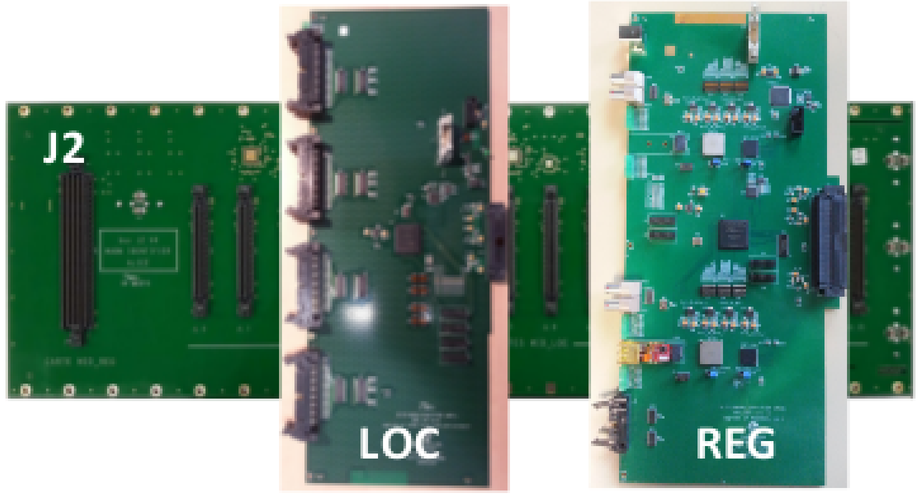


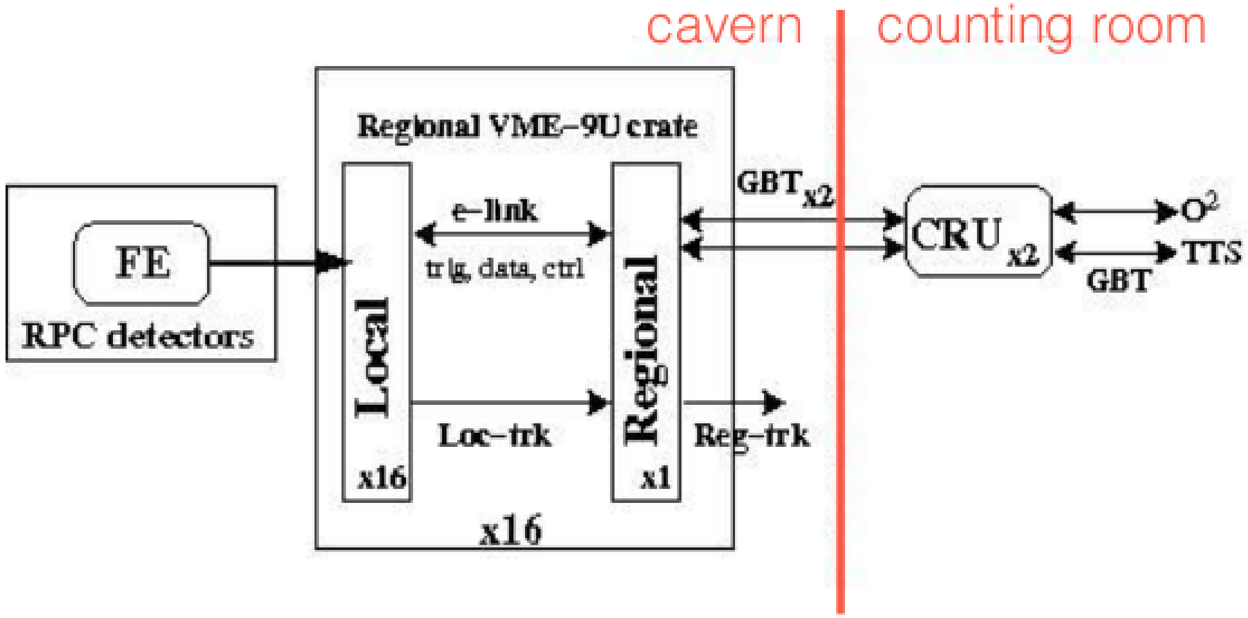
- **26 cards + spares**
  → 1 wifi router per side, connected to DCS via ethernet
  → 12 wifi stations per side, connected to FEERIC via I^2C
- Installation done during winter shutdown (December 2022 – January 2023)

Readout architecture

- **New readout electronics for continuous mode**

- Replacement of all the cards in operation during Run 2
  - → 234 Local cards, up to 16 per VME crate
  - → 16 Regional cards, interfaced with the new CRU via 2 GBTx links
  - → 16 J2-bus between the Local and Regional card





- One full crate: up to 16 Local, 1 Regional, 1 J2-bus

- **In total: 16 similar crates for the full project**

MID status at CERN

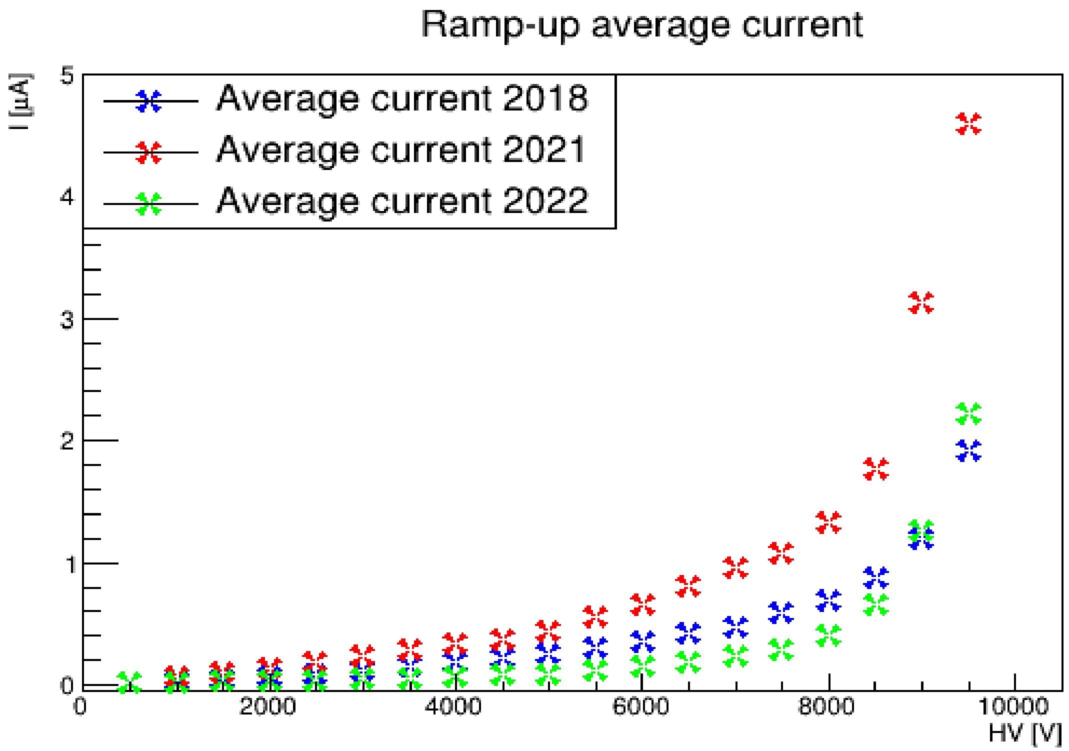
- Several **hardware interventions** during the commissioning without BEAMS:

  → **gas leakage**, **solved** after recovery on RPCs side

  → **HV trips**, **solved** after replacement of several faulty cables and connector on chamber side

  → **1 HV board** (for 6 RPCs) replaced

- Average current value at 9500 V:
  → **1.92 μA in 2018**
  → **4.59 μA in 2021**
  → **2.23 μA in 2022** (**after the intervention in cavern**)



HV scan analysis

- Efficiency has been evaluated per each **Plane**, per each **RPCs**, and per each **LBs**, in the three cases: **BP** only, **NBP** only and **Both** BP and NBP
  - in the formula N_D is, in the different cases, N_{BP}, N_{NBP} or N_{Both}
  - the error on the reconstructed efficiency follows a binomial distribution

$$\epsilon = \frac{N_D}{N_{tot}}$$

$$\sigma_\epsilon = \frac{\sigma_{N_{BP}}}{N_{tot}} = \sqrt{\frac{\epsilon(1-\epsilon)}{N_{tot}}}$$