RPC 2024
Santiago de Compostela (Spain)

ALICE

A new generation of RPCs for the ALICE Muon IDentifier

Sara Garetti[1,2] on behalf of the ALICE Collaboration

[1] INFN Istituto Nazionale di Fisica Nucleare

[2] Università di Torino

Outline

- **ALICE Muon IDentifier**
  - The ALICE experiment in Run 3
  - Muon IDentifier
- **New RPC production**
- **RPC characterization**
  - INFN Torino Laboratory **Test Setup**
  - **Test procedure**
    - Study of detector uniformity and working point
    - High statistics efficiency map
    - Dark rate
  - **Test results**
- **Performance** of the new **RPCs installed** in **ALICE**
- **Summary**

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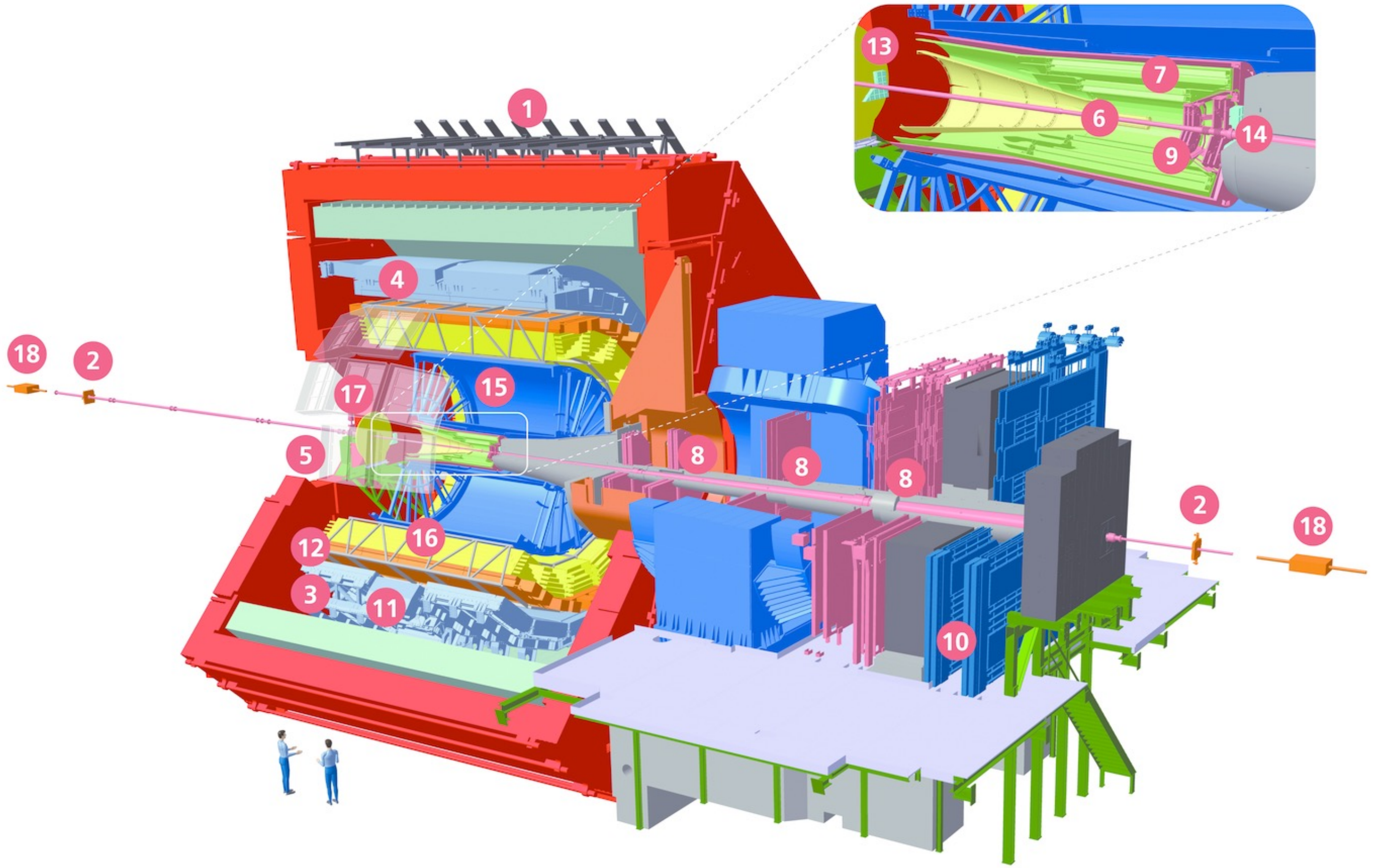
ALICE Muon IDentifier

ALICE experiment during the LHC RUN 3

- Study of the **Quark-Gluon Plasma** properties
- To detect **heavy quarkonia** muonic decays → **Muon Spectrometer**
- To **identify muons** → **Muon IDentifier**



Sketch of the ALICE detector @ CERN

1. **ACORDE** | ALICE Cosmic Rays Detector
2. **AD** | ALICE Diffractive Detector
3. **DCal** | Di-jet Calorimeter
4. **EMCal** | Electromagnetic Calorimeter
5. **HMPID** | High Momentum Particle Identification Detector
6. **ITS-IB** | Inner Tracking System - Inner Barrel
7. **ITS-OB** | Inner Tracking System - Outer Barrel
8. **MCH** | Muon Tracking Chambers
9. **MFT** | Muon Forward Tracker
10. **MID** | Muon Identifier
11. **PHOS / CPV** | Photon Spectrometer
12. **TOF** | Time Of Flight
13. **T0+A** | Tzero + A
14. **T0+C** | Tzero + C
15. **TPC** | Time Projection Chamber
16. **TRD** | Transition Radiation Detector
17. **V0+** | Vzero + Detector
18. **ZDC** | Zero Degree Calorimeter

Takes data in:

- **Pb-Pb** collisions
- **pp** collisions
- **p-Pb** collisions

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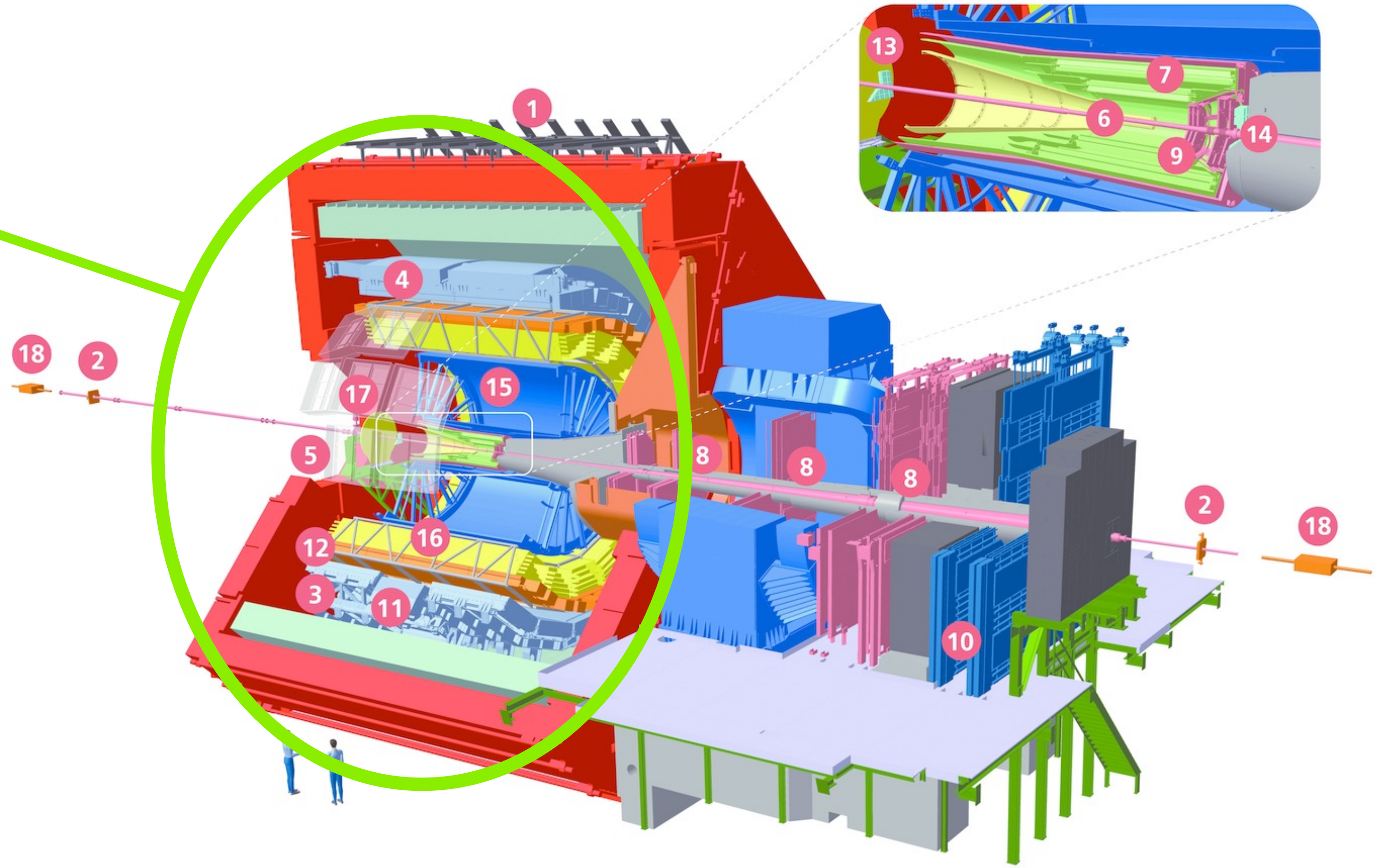

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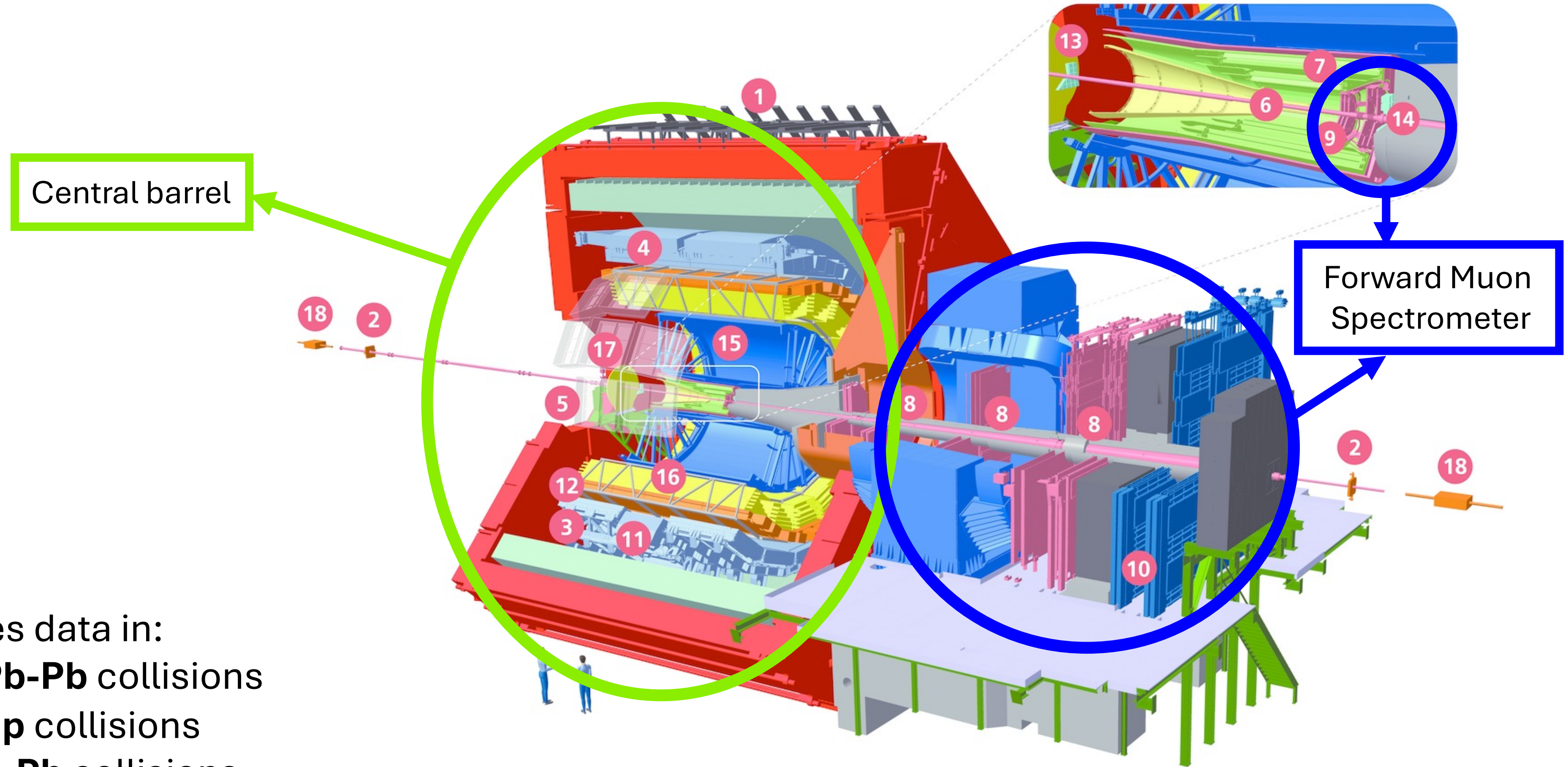

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Takes data in:
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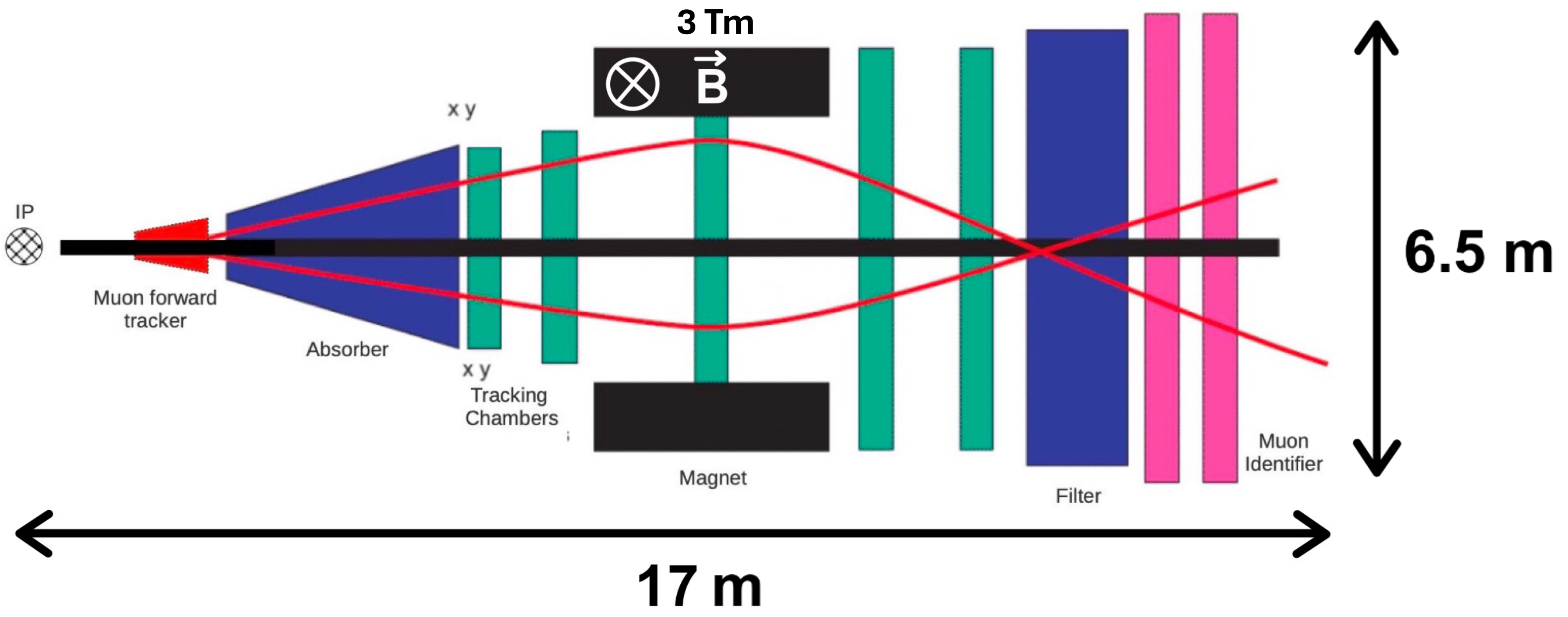
Muon Spectrometer

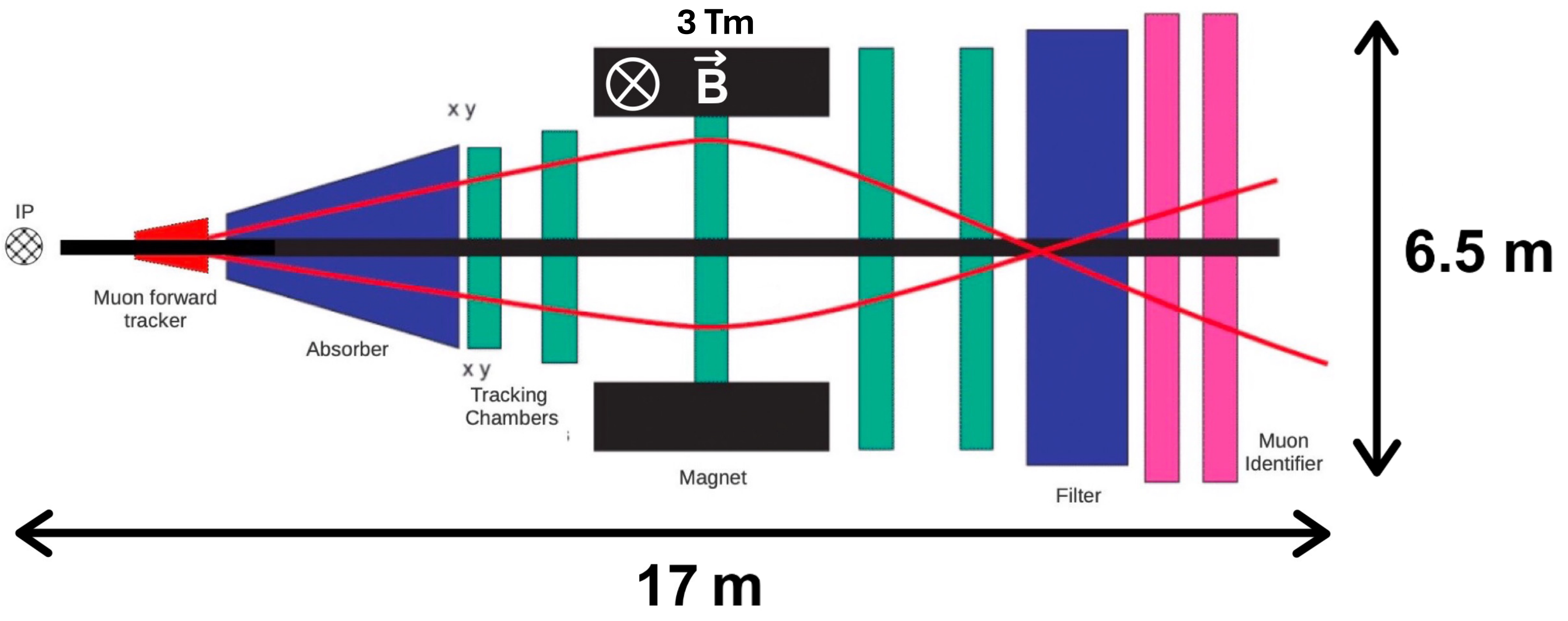


Muon Forward Tracker (MFT):
- **Silicon pixel detector**
- Improves tracking and vertex finding of the spectrometer
- Part of the Run 3 upgrades

Absorber:
- Cone composed of low Z materials
- Stops most hadrons and photons

Tracking chambers:
- **5 stations**/10 planes of **cathode pad/strip chambers**
- Provide muons and residual hadrons tracking

Muon Spectrometer



Dipole Magnet:
- Curves muon tracks
- 3 T·m

Filter:
- Iron wall
- Removes residual background of hadrons

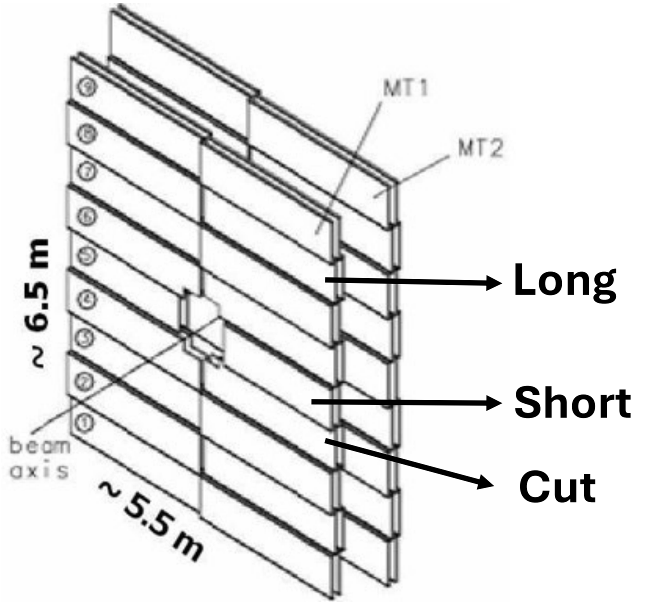
Muon IDentifier (MID):
- **2 stations**/4 planes of **RPCs**
- Provides muon identification

Muon IDentifier

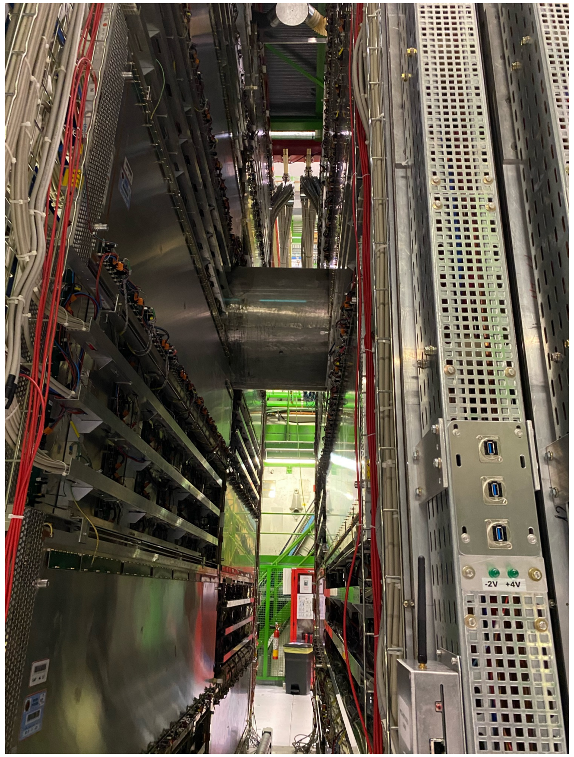
- **72 Resistive Plate Chambers (RPC)** in total
- **2 stations** (MT1 and MT2) at 16 and 17 m from the interaction point
- Each station has 2 planes of 18 RPCs each
- RPCs readout on **2 perpendicular strip planes** (X and Y)
- RPC operated in **avalanche mode**
  (89.7% $C_2H_2F_4$, 10% i-C_4H_{10}, 0.3% SF_6)
- Three different shapes: **Long**, **Cut** and **Short** covering a total area of ~ 144 m^2
- Arranged in **projective geometry** for track acceptance

Station	Detector type	Area (mm^2)
MT1	L,C	2740x720
MT1	S	2230x720
MT2	L,C	2920x765
MT2	S	2376x765

MID RPC dimensions per plane



Scheme of the MID RPCs



Beam pipe shielding crossing the MID

ALICE experiment Run 3 upgrade

New ALICE running conditions in Run 3 w.r.t. Run 2:

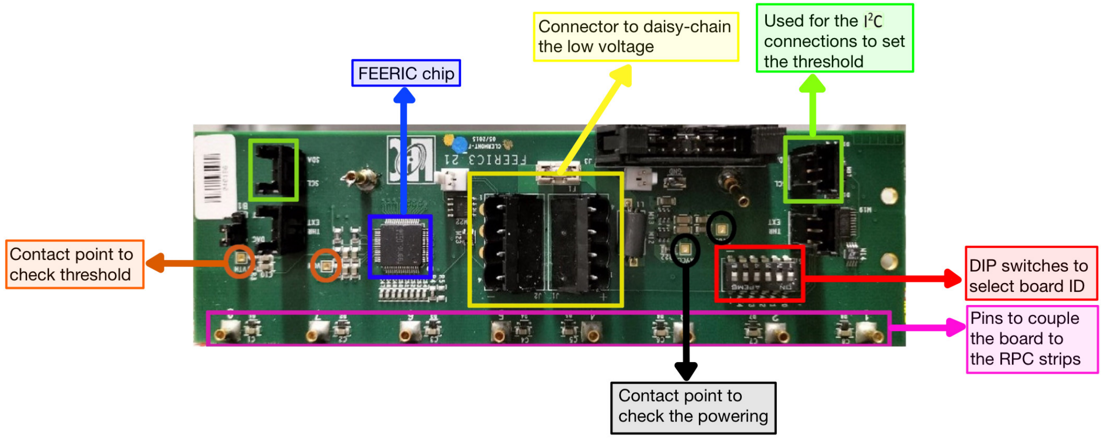
- Run 2 Pb–Pb interaction rate ~ 8 kHz
- Run 3 Pb–Pb interaction rate ~ 50 kHz
- Run 2 pp interaction rate ~ 100 kHz
- Run 3 pp interaction rate ~ 500 kHz

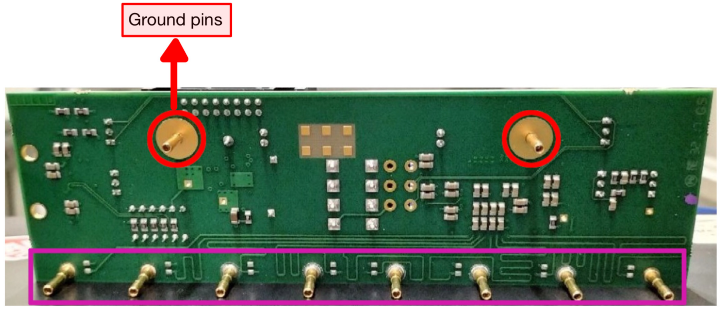
} To cope with the interaction rate → **Continuous readout mode**

See: https://cds.cern.ch/record/1603472

Muon IDentifier Run 3 upgrade w.r.t. Run 2:

- Upgrade of **readout electronics** → support continuous readout
- Upgrade of **front-end electronics** → FEE with pre-amplification, support low-gain RPC operation
- Production of **new RPCs** → replace up to ~ 25% of chambers





FEERIC (**Front End Electronics Rapid Integrated Circuit**), signal discriminator, **new Run 3 electronics**

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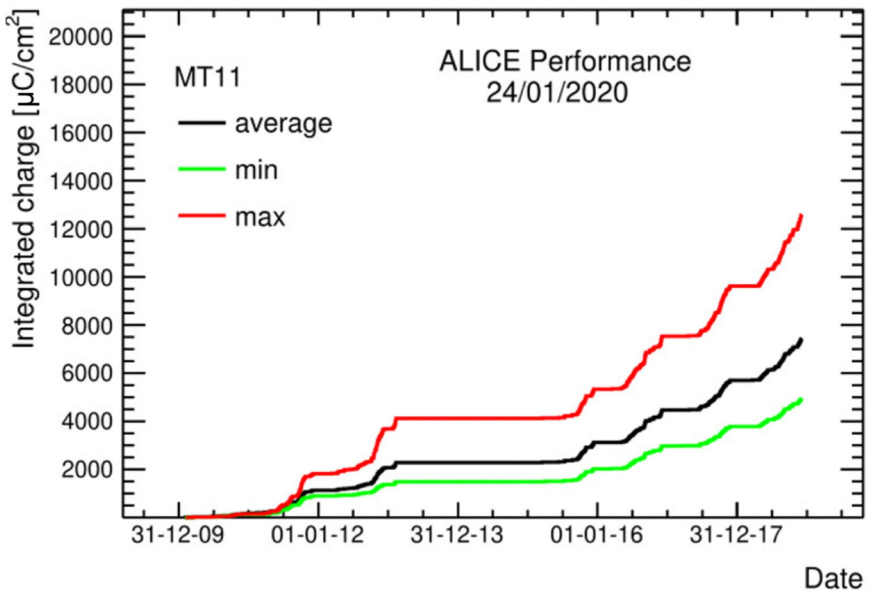
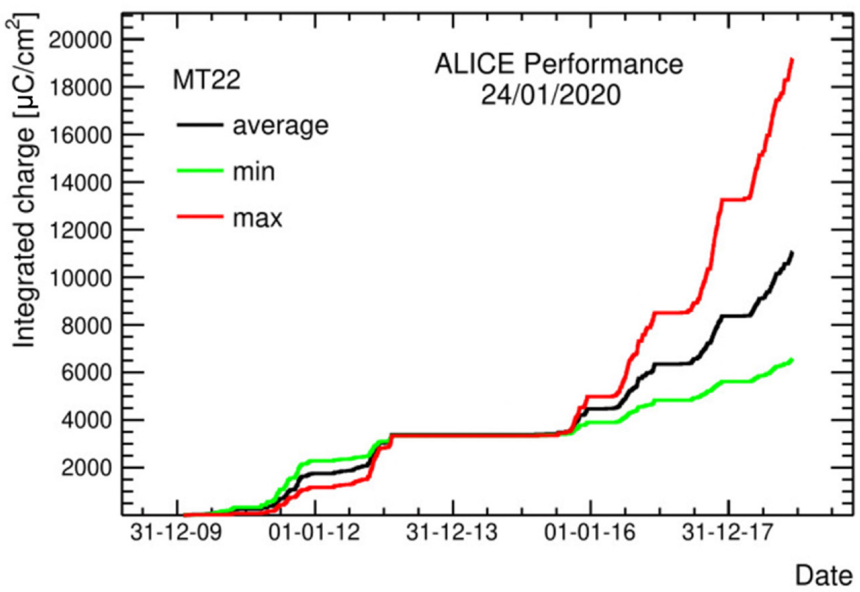
New RPC production

Why a new production?

- **Charge integrated** by the RPCs (mC/cm^2)
- Some of the RPCs currently installed in ALICE have integrated by the end of Run 2 a charge non negligible w.r.t. the certified lifetime from ageing tests (i.e. ~ 50 mC/cm^2)
- Expected integrated charge in Run 3+Run 4 is another ~ 50 mC/cm^2
- Decision to **build new RPCs** (about 25% of the system) to be kept as spares and installed as needed





RPC production

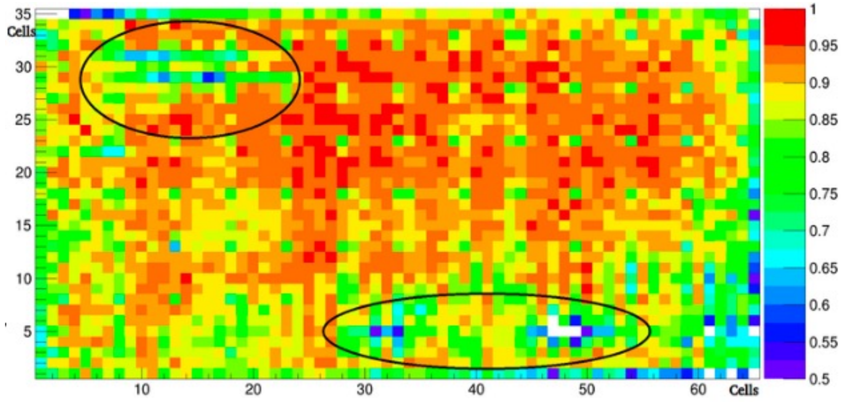
2018

New RPCs production launched in 2018: **unsatisfactory,** acceptance rate <50%:

- **Inefficiency holes** at HV working point
- **Higher HV working point** shifted up by 300-400 V w.r.t. the RPCs installed in ALICE
- **High currents** (tens of μA)
- Not possible to use them in ALICE

Due to:

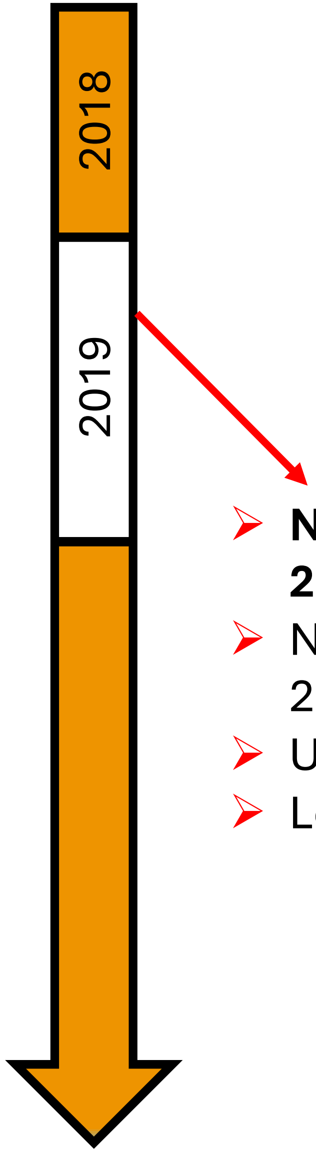
- Flaws in the production process (for example glueing problems)



Example of inefficient chamber


Issue with spacers glueing

RPC production



- **New glueing procedure** tested at the end of **2019**
- New pre-production of 3 RPCs at the end of 2019
- Uniform efficiency at the working point
- Lower currents

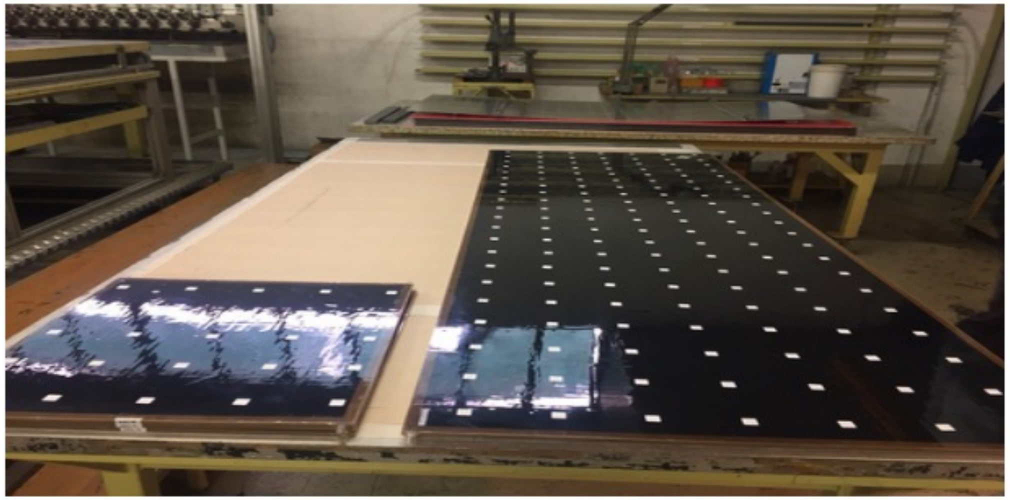
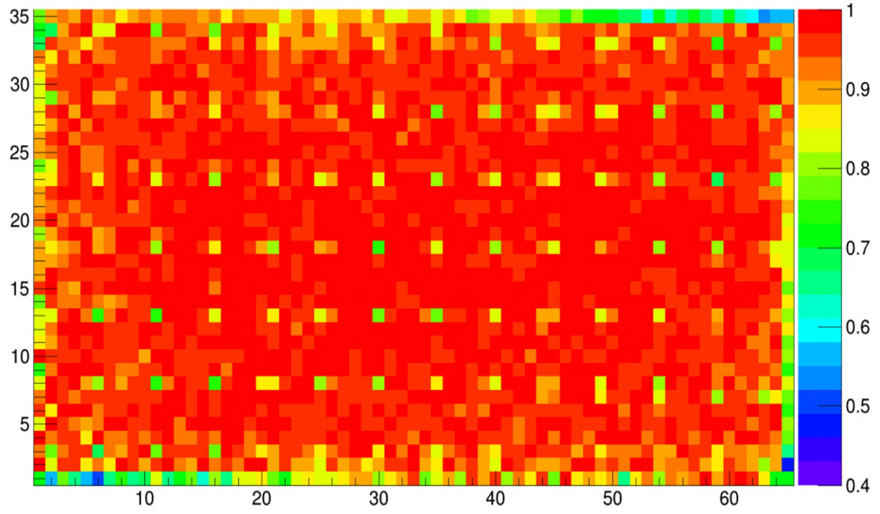


photo of RPCs produced at the end of 2019



efficiency map

RPC production

2018

2019

2021-2024

- New production of **18 RPCs in 2021**
- RPCs being tested in the INFN Torino Laboratory
- **Test results described in this presentation**

photo of RPCs produced in the 2021

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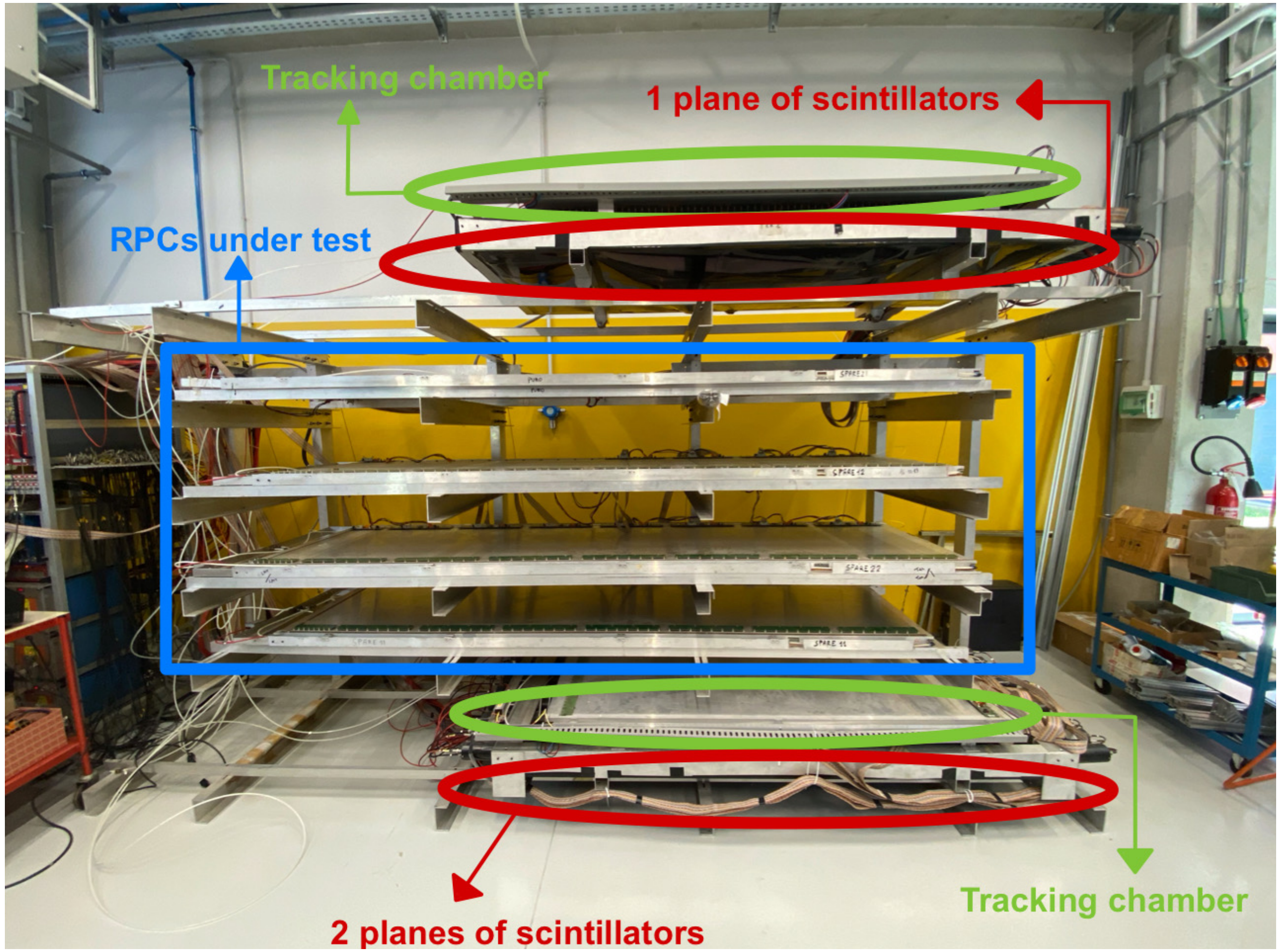
RPC characterization

Test setup

- ALICE RPCs tested in the Torino INFN laboratory
- Goal: full characterization of the chambers i.e. local measurement of efficiency, study of dark rate, dark current measurement.

- **Streamer mixture** used
  (50.5% Ar, 41.4% $C_2H_2F_4$, 7.2% i-C_4H_{10}, 1% SF_6):
  - practical reasons
  - compare results with those from first-generation RPCs
- **ADULT** front-end electronics (threshold: 80mV, no pre-amplification)

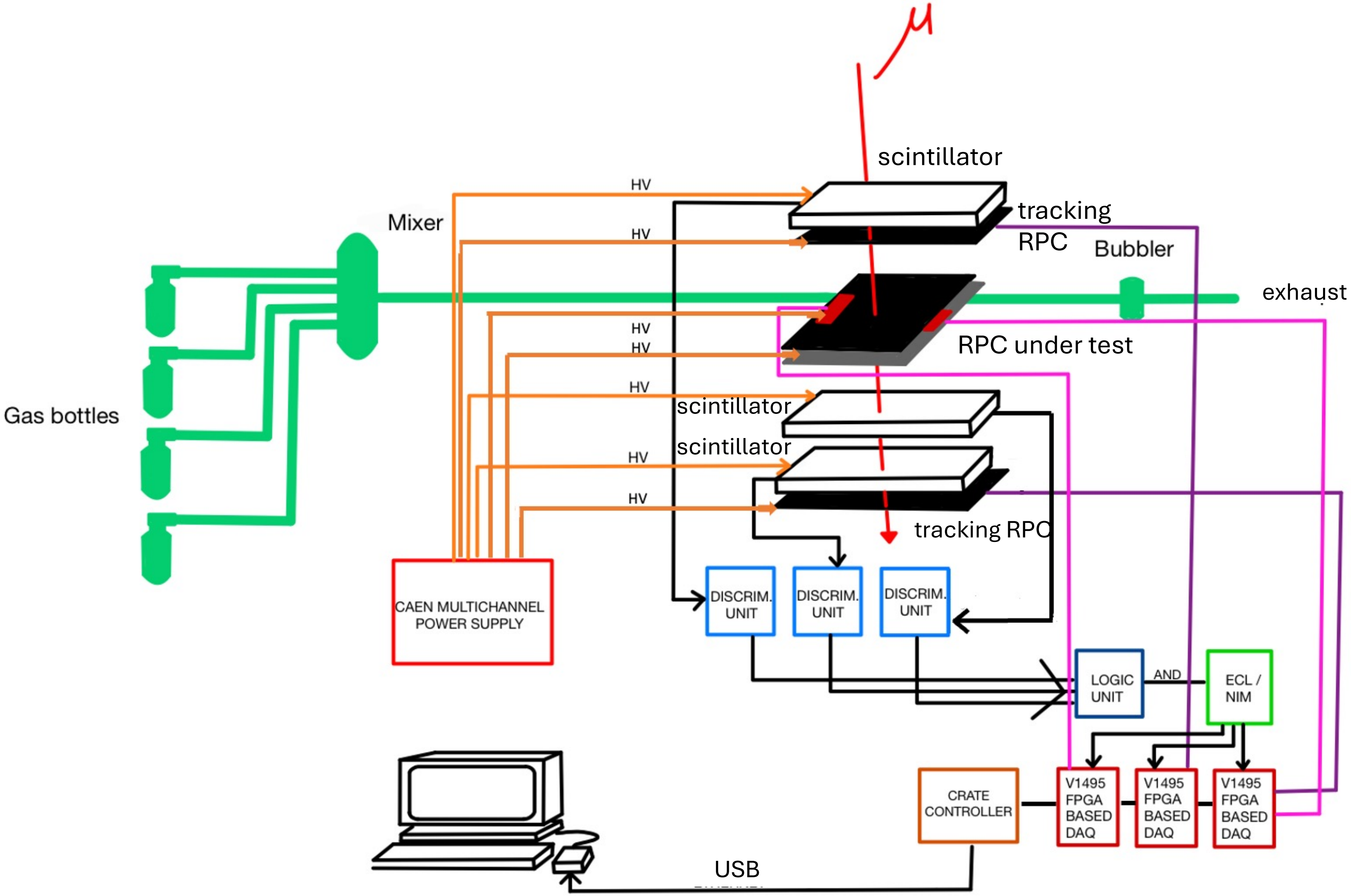
- 2 tracking RPCs (area of 172x87 cm^2 each)
- 3 planes of 9 scintillators each (arranged to cover an area of 90x150 cm^2)
- 4 test slots to place RPCs under test



Torino laboratory test setup

Test setup electronic chain

Scheme of the electronic chain of the INFN Torino laboratory



Test methodology

ALICE

1) **Gas tightness** test → we don't want leaks!

2) HV **ramp-up** → current monitoring

3) Study of the detector uniformity and **working point (wp)** → whole RPC area is efficient

4) **High statistic efficiency map** → to test the efficiency locally @ HV wp

5) **Dark rate** → to test intrinsic detector noise

Ramp-up

Ramp-up:

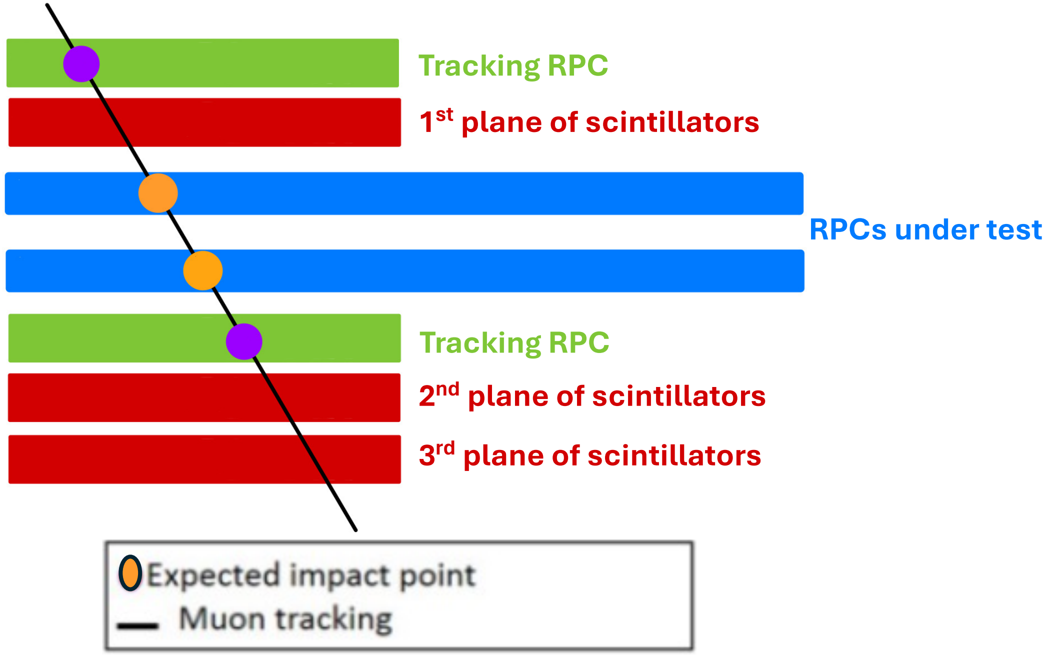
1) **RPC flushed ≃10 volume changes**
2) **HV <= 7 kV** → steps of 300/500 V
3) **HV > 7 kV** → **step variable**

Goal:

- **Measure** the **RPC current** as a function of the HV
- Check its stability over time

Tracking system

- Tracking chambers:
  - **->** **reconstruct** the cosmic rays **tracks**
  - **->** interpolate **impact points expected on RPCs** under test
- Cosmic ray trigger:
  - **->** coincidence between scintillators planes and tracking chambers is required
- Goal:
  - **->** RPC **local efficiency map**



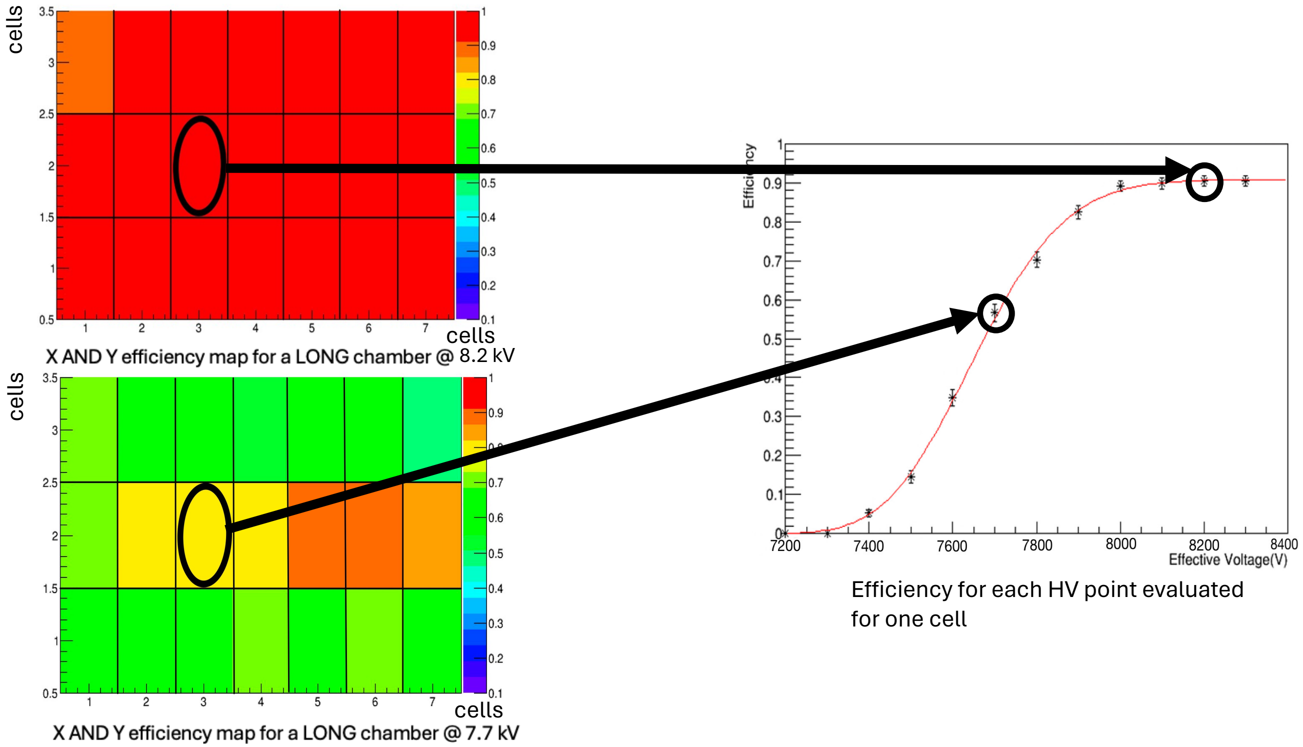
scheme of the tracking system

Study of detector uniformity and WP

Efficiency curve (vs HV):

1) 12 HV points (7.2 kV -> 8.3 kV) steps of 100 V

1) Detector surface divided in ~ **20x20 cm^2 virtual cells** → efficiency computed for each cell

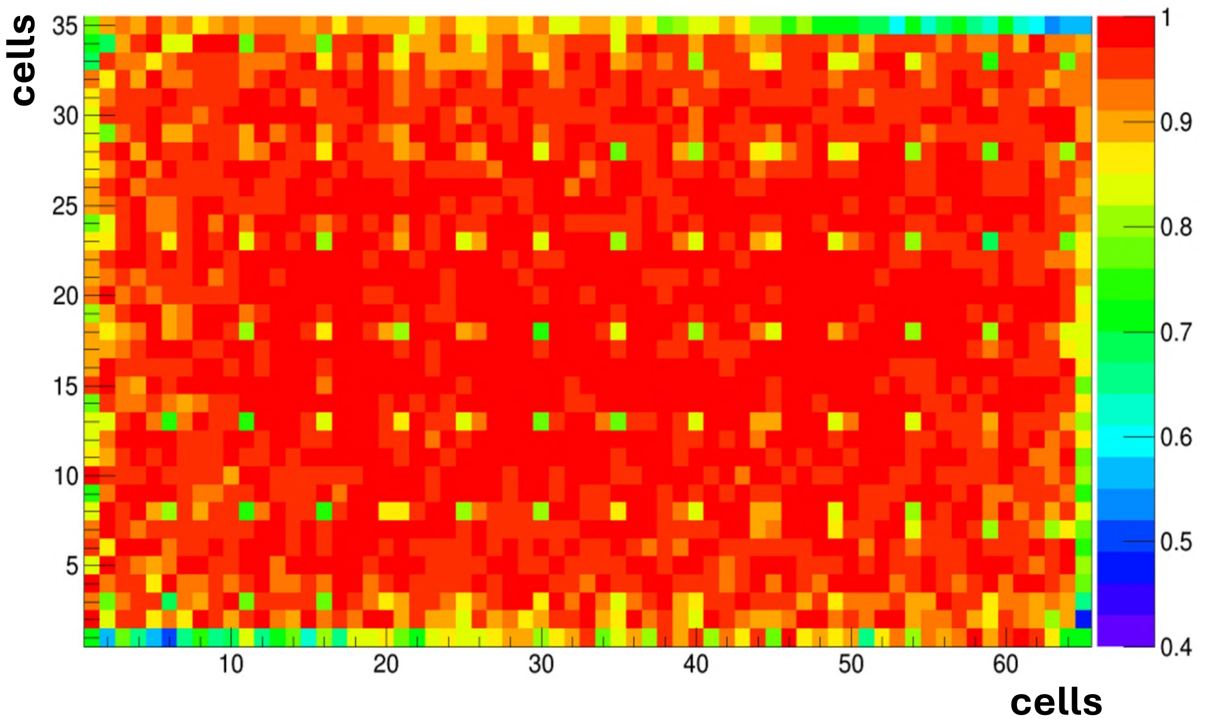


Goal:

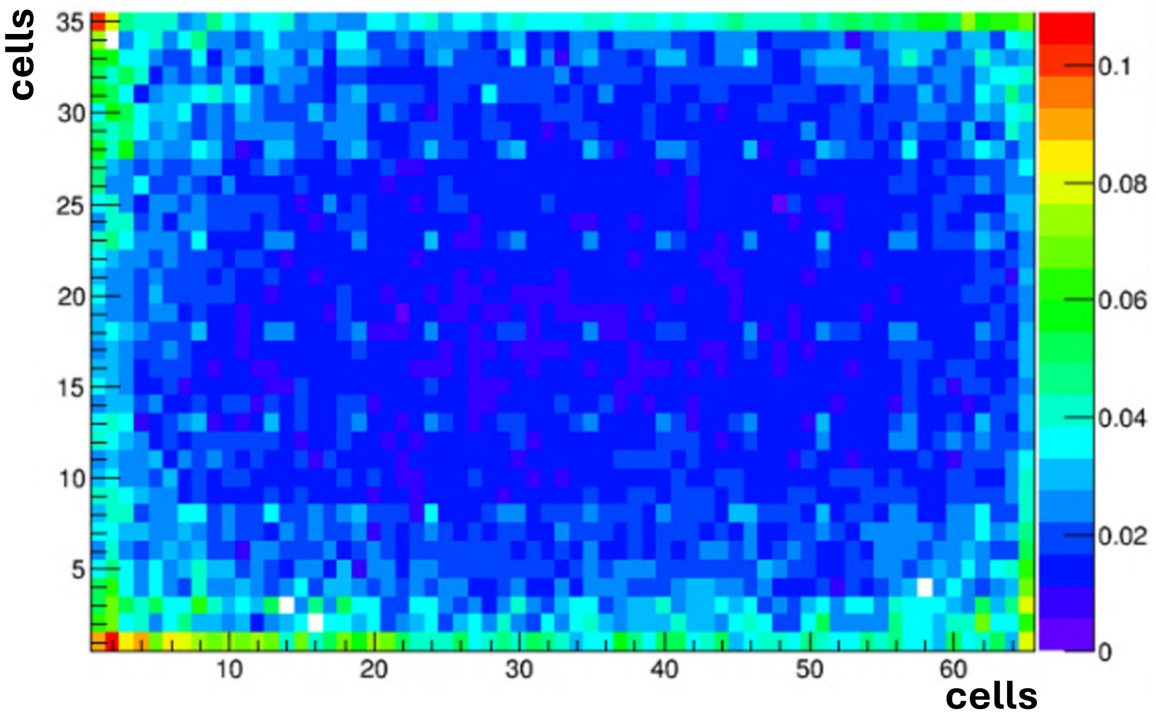
- Test of the **uniformity** of the detector
- Find the HV **working point** (**WP**) where each cell has reached the efficiency plateau

Local efficiency map

- **Fixed HV wp**
- Detailed efficiency map of RPC
- Virtually divided in ~ **2x2 cm^2 cells** (vs ~ 20x20 cm^2 cells in efficiency scan)
- Large number of events required (**750k events**) to **minimize statistical error**



X AND Y efficiency map



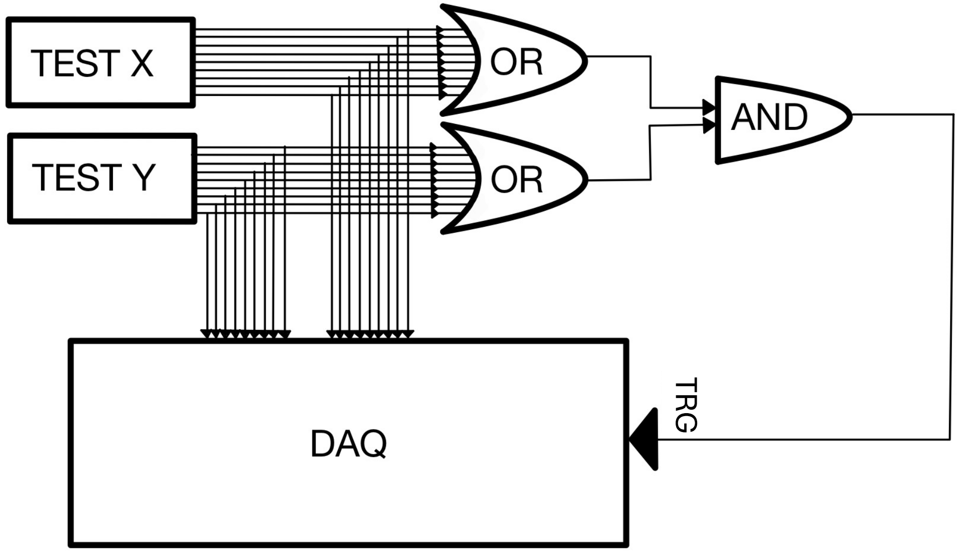
X AND Y error efficiency map

Study of the dark rate

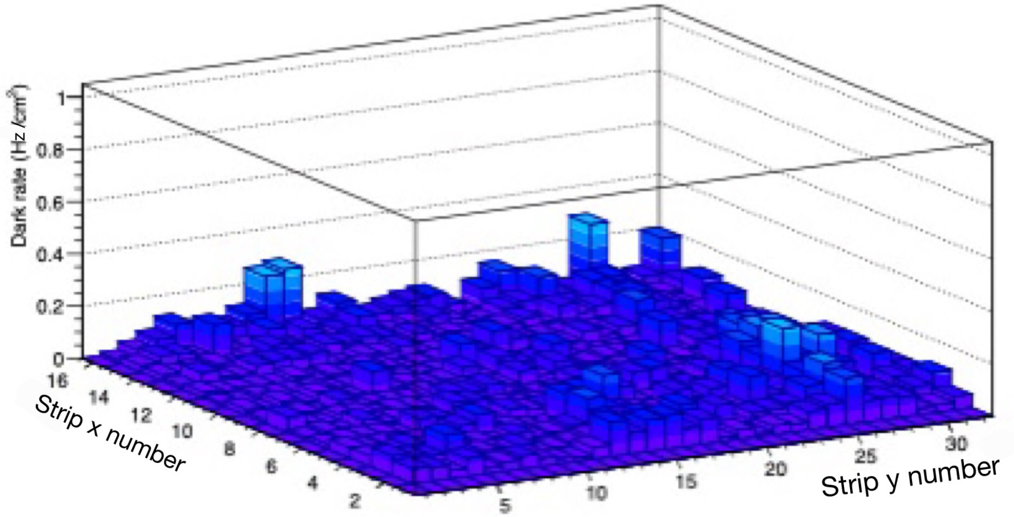
- Trigger signals if at least **one strip fired on each strip plane (x and y)**
- The noise rate measured for 12 HV points (7.2 kV -> 8.3 kV) with 20k triggers per point

- Rate R_{ij} (Hz/cm^2) of the i-th X strip and j-th Y strip: $R_{ij} = \frac{N_{ij}}{\Delta t\, A_{ij}}$

Where N_{ij} is the number of event registered by the cell itself, Δt is the time duration of the acquisition and A_{ij} is the area of the single cell.



Circuit scheme for dark rate measurements



Example of dark rate map @ 7.9 kV

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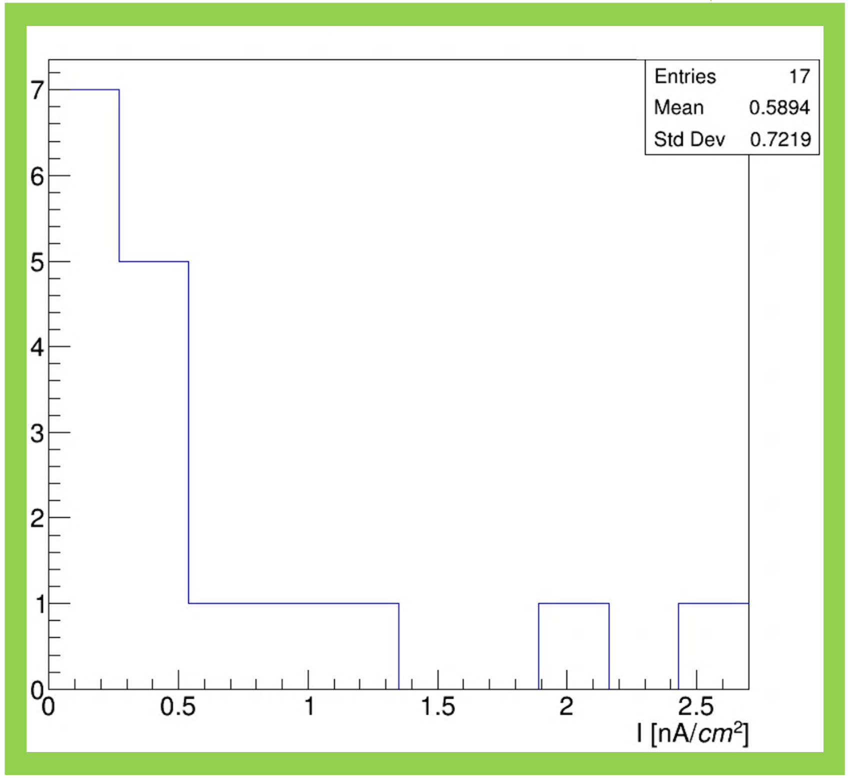
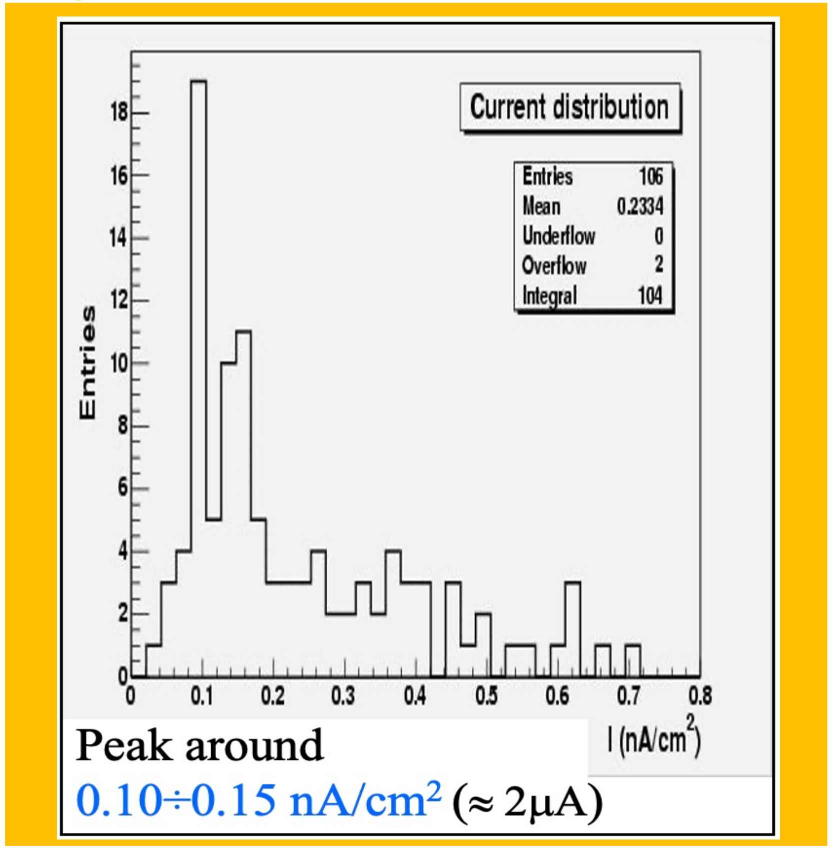
Test results

Test results: dark current

- Comparison between the **new production** and the **first-generation production**





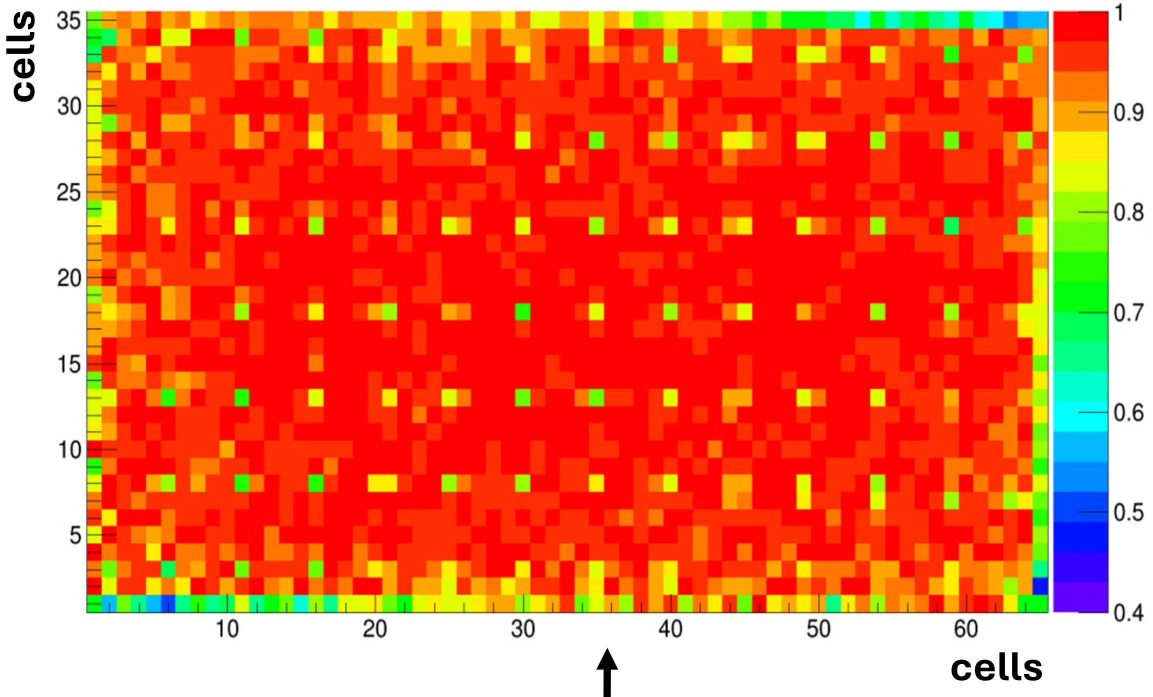
- Mean dark current: 0.39 nA/cm^2 (if not considering outliers)

See Martino Gagliardi's talk @ RPC 2008 and his thesis: *http://personalpages.to.infn.it/~gagliard/tesi.pdf*

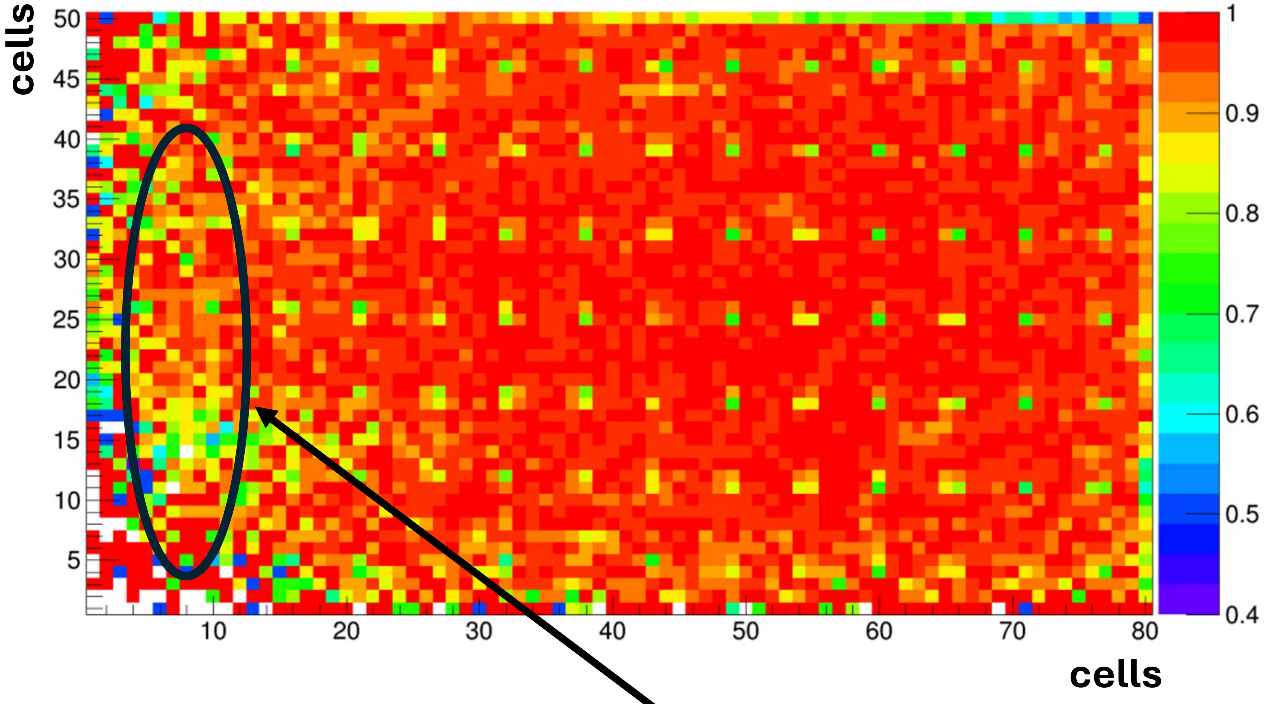
Dark current on average larger w.r.t. first-generation production

Test results: efficiency

- For each tested chamber the **efficiency maps** were **inspected** to **detect imperfections**



We want this

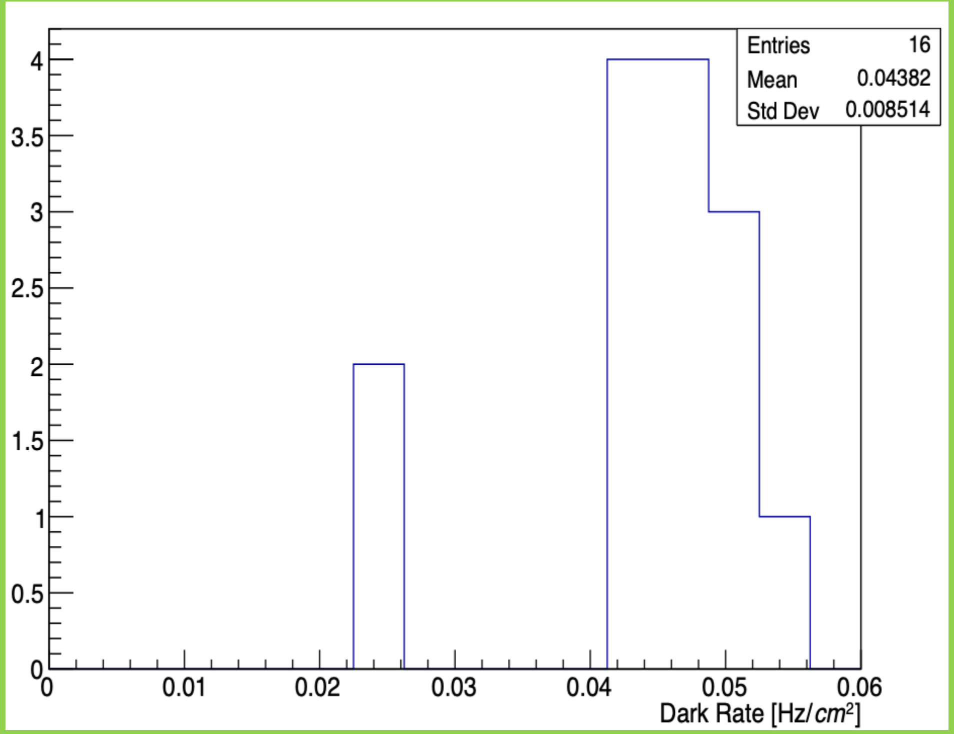


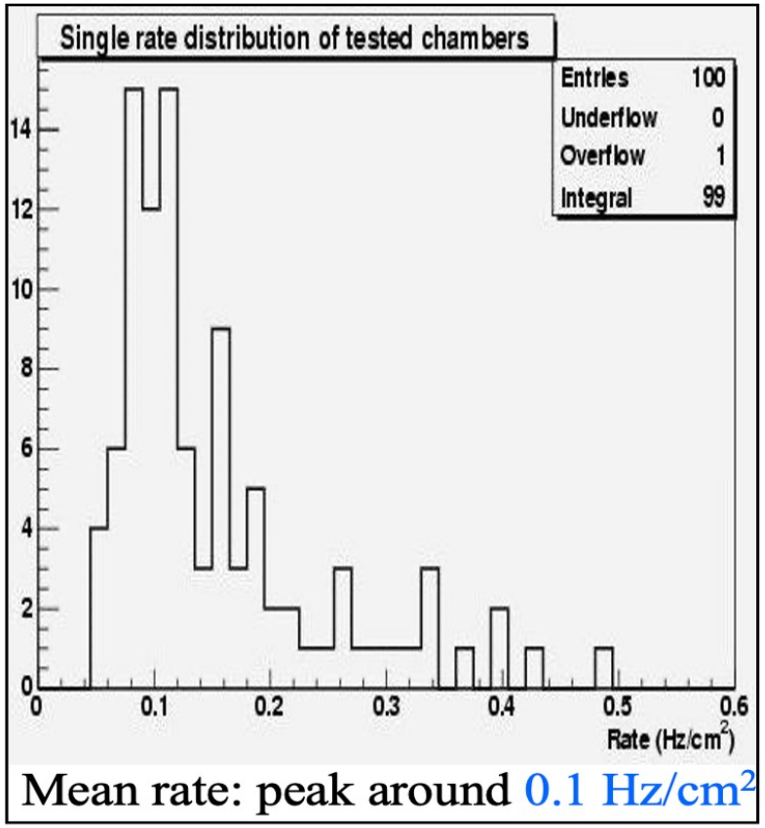
Not this!!

Test results: dark rate

ALICE

- Comparison between the **new production** and the **first-generation production**





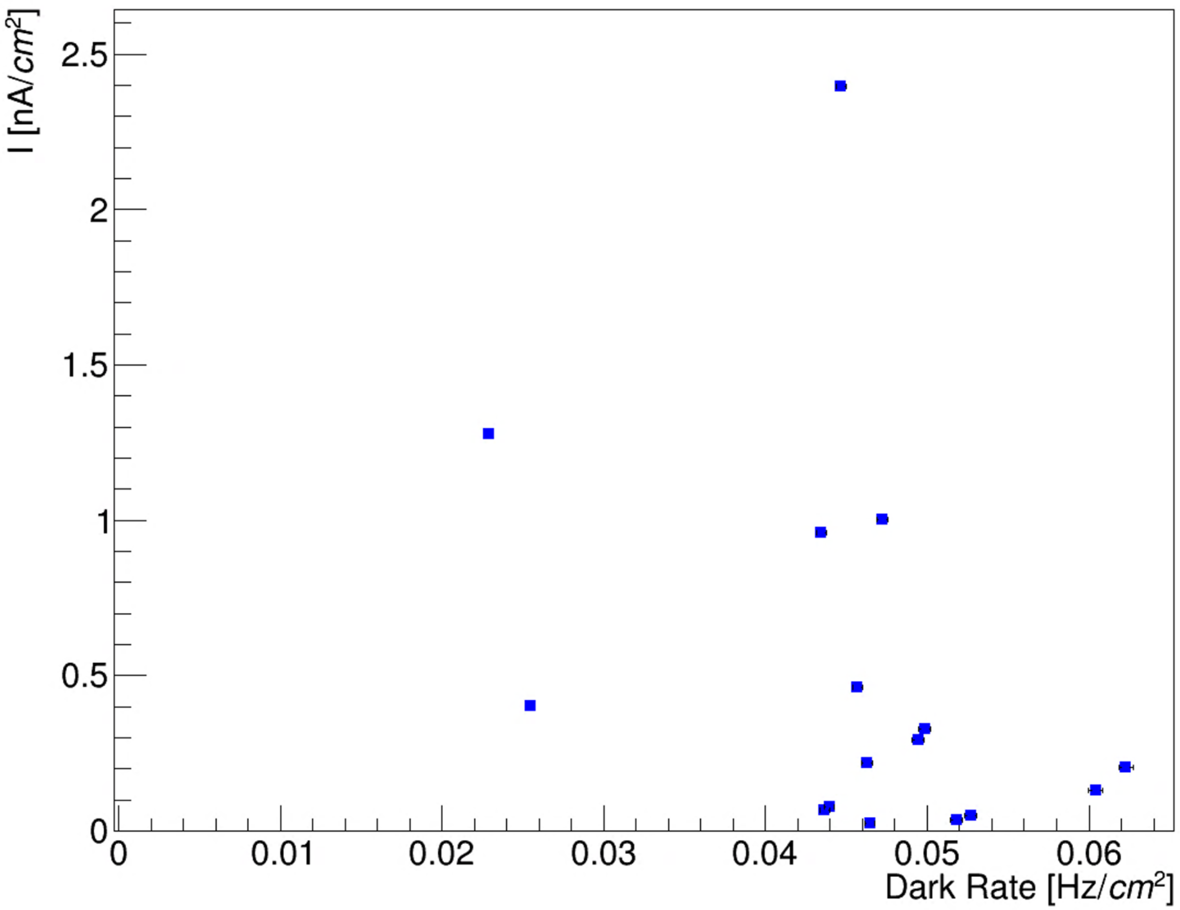
Mean rate: 0.04 Hz/cm^2

2 times lower w.r.t. first-generation production → different types of bakelite with different resistivity ($\rho_{old} \sim 10^{10}\ \Omega \cdot$cm, $\rho_{new} \sim 10^{11}\ \Omega \cdot$cm)

See Martino Gagliardi's talk @ RPC 2008 and his thesis: http://personalpages.to.infn.it/~gagliard/tesi.pdf

Test results: dark current vs dark rate

- The dark current of tested chambers is plotted as a function of the average dark rate
- Goal: investigate origin of the dark current



- No correlation between current and dark rate
- Current mainly due to ohmic effects?

Test results

RPC	Working Point [V]	Type	Efficiency	I [nA/cm^2]	Dark Rate [Hz/cm^2]	Status
706-21	8200	L2	ok	1.3	0.05	2
713-21	/	C2	/	2.6	/	0
717-21	8200	C1	ok	0.5	0.06	2
709-21	8300	L2	not ok	2.1	0.04	0
680-19	8300	S1	not ok	0.3	0.02	0
681-19	8300	S1	ok	0.1	0.05	1
712-21	8300	C2	ok	0.7	0.04	2
710-21	8200	C1	ok	0.3	0.04	2
721-21	8200	L2	ok	0.5	0.04	2
718-21	8100	C1	ok	0.3	0.06	2
705-21	8100	L2	ok	0.9	0.05	2
711-21	8200	C2	ok	0.1	0.04	2
720-21	8200	L1	ok	0.1	0.05	2
715-21	8100	C2	ok	0.1	0.05	2
714-21	8100	C2	ok	0.2	0.05	2
716-21	8100	C1	ok	0.04	0.06	2
707-21	8100	L2	ok	0.02	0.06	2
682-19	/	S1	/	/	/	0

- **18 spare RPCs** have been tested
- **4 spare RPCs** currently installed **in** the **ALICE cavern** to replace old chambers with large dark current or gas leaks

Status legend:
0 not ok
1 in case of need
2 all ok

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709-21	8300	L2	not ok	2.1	0.04	0
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681-19	8300	S1	ok	0.1	0.05	1
712-21	8300	C2	ok	0.7	0.04	2
710-21	8200	C1	ok	0.3	0.04	2
721-21	8200	L2	ok	0.5	0.04	2
718-21	8100	C1	ok	0.3	0.06	2
705-21	8100	L2	ok	0.9	0.05	2
711-21	8200	C2	ok	0.1	0.04	2
720-21	8200	L1	ok	0.1	0.05	2
715-21	8100	C2	ok	0.1	0.05	2
714-21	8100	C2	ok	0.2	0.05	2
716-21	8100	C1	ok	0.04	0.06	2
707-21	8100	L2	ok	0.02	0.06	2
682-19	/	S1	/	/	/	0

- **18 spare RPCs** have been tested
- **4 spare RPCs** currently installed **in** the **ALICE cavern** to replace old chambers with large dark current or gas leaks

Installed in ALICE

Status legend:
0 not ok
1 in case of need
2 all ok

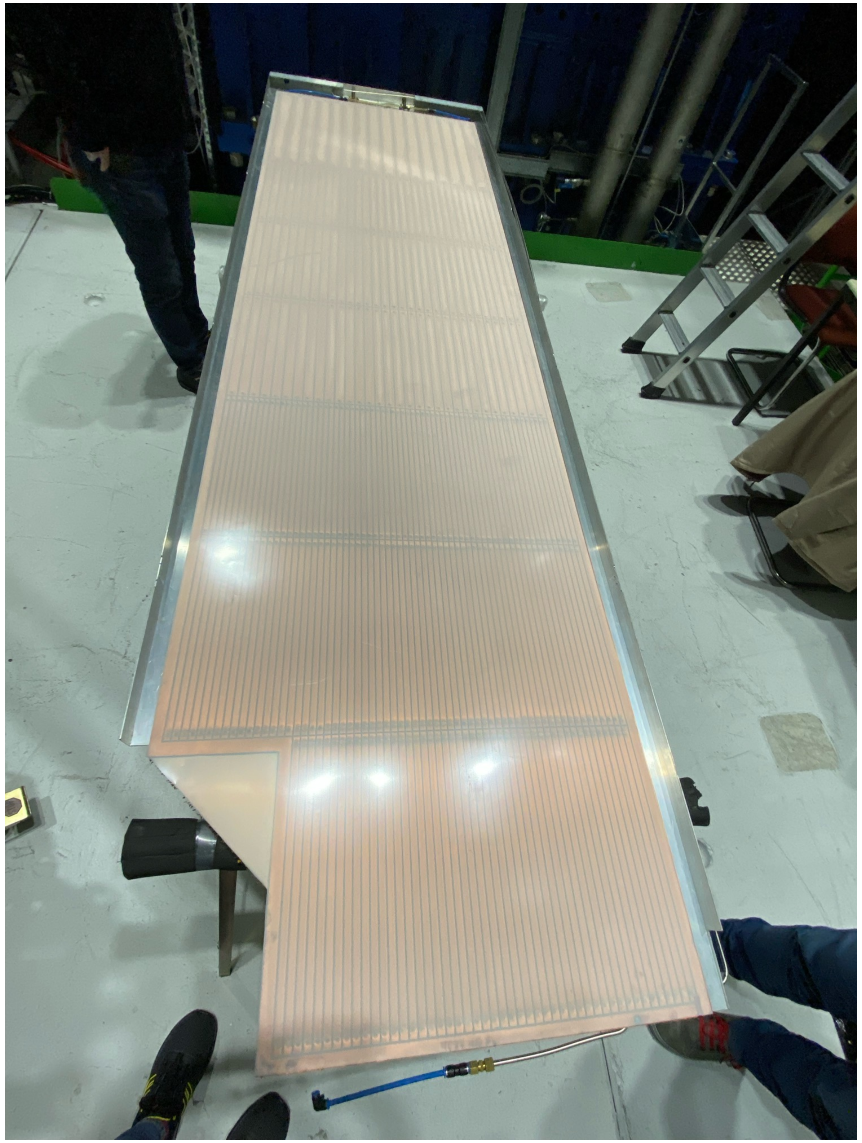
Outline

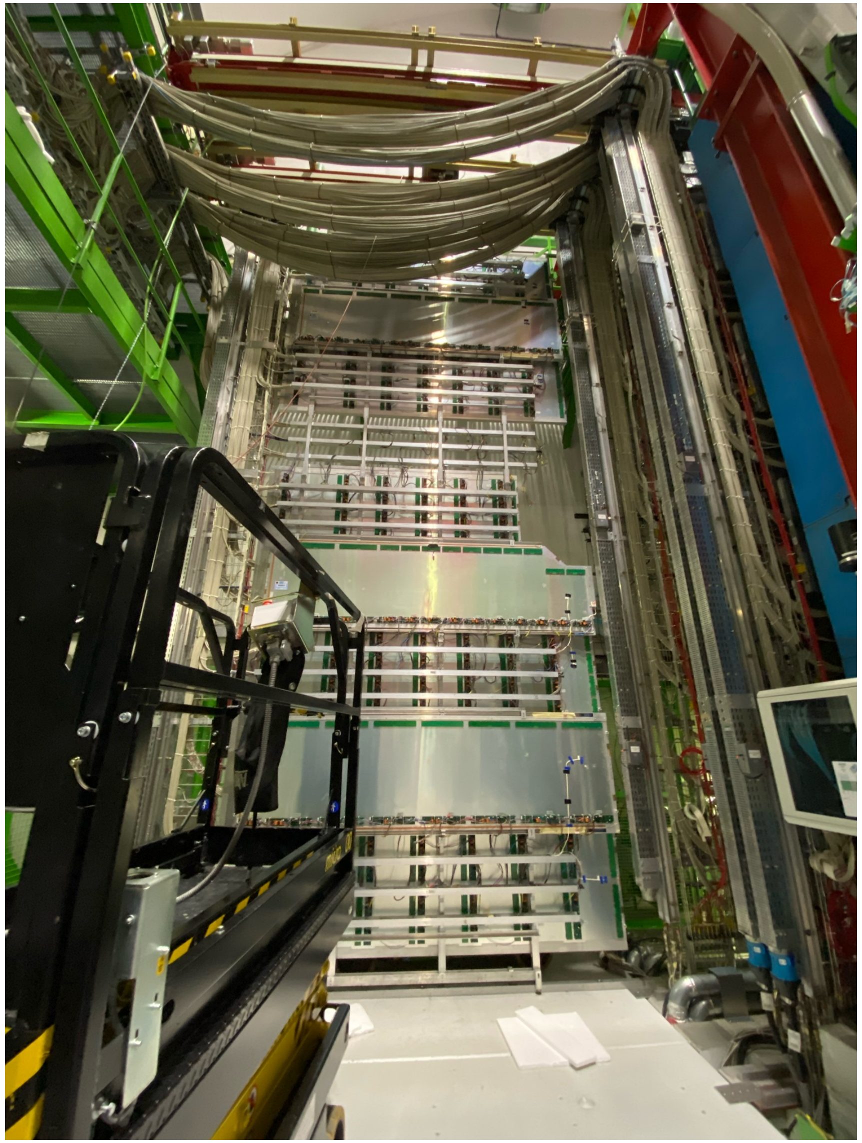
- **ALICE Muon IDentifier**
  - The ALICE experiment in Run 3
  - Muon IDentifier
- **New RPC production**
- **RPC characterization**
  - INFN Torino Laboratory **Test Setup**
  - **Test procedure**
    - Study of detector uniformity and working point
    - High statistics efficiency map
    - Dark rate
  - **Test results**
- **Performance** of the new **RPCs installed** in **ALICE**
- **Summary**

Performance of the new RPCs installed in ALICE

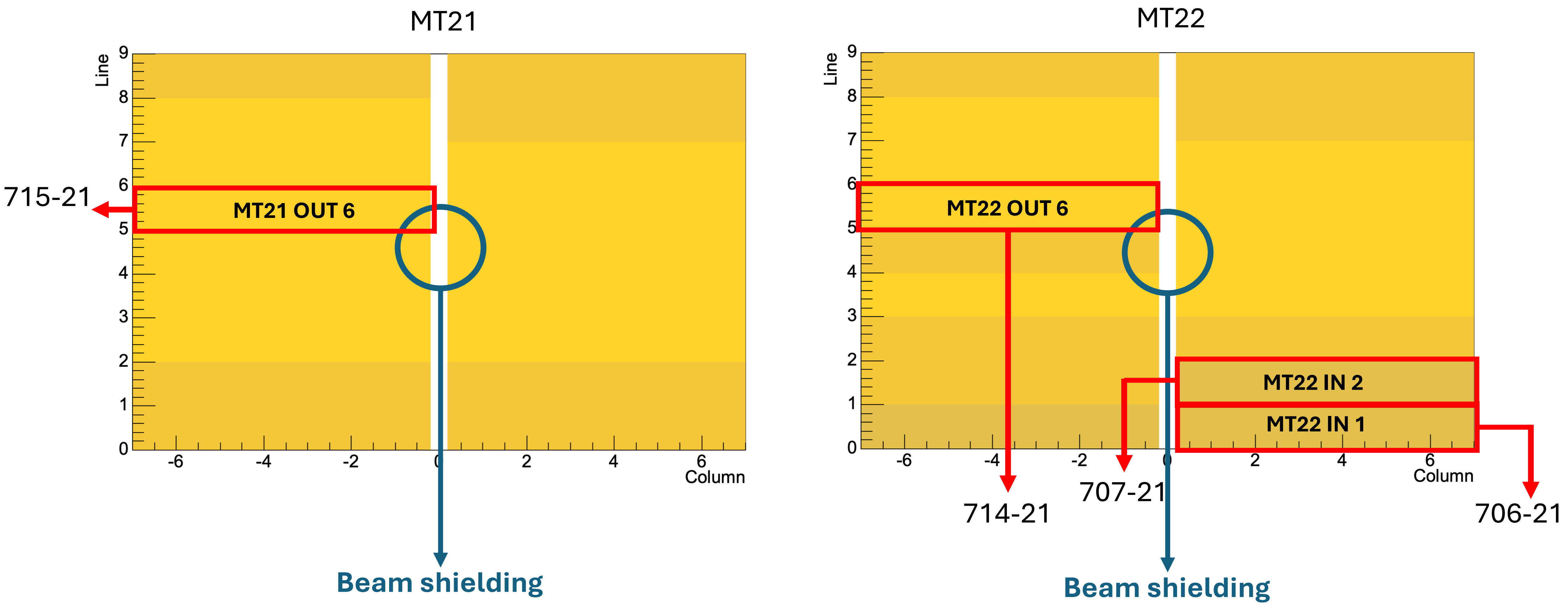
New RPCs installed at CERN

4 spare RPCs currently installed **in** the **ALICE cavern** to replace old chambers with large dark current or gas leaks

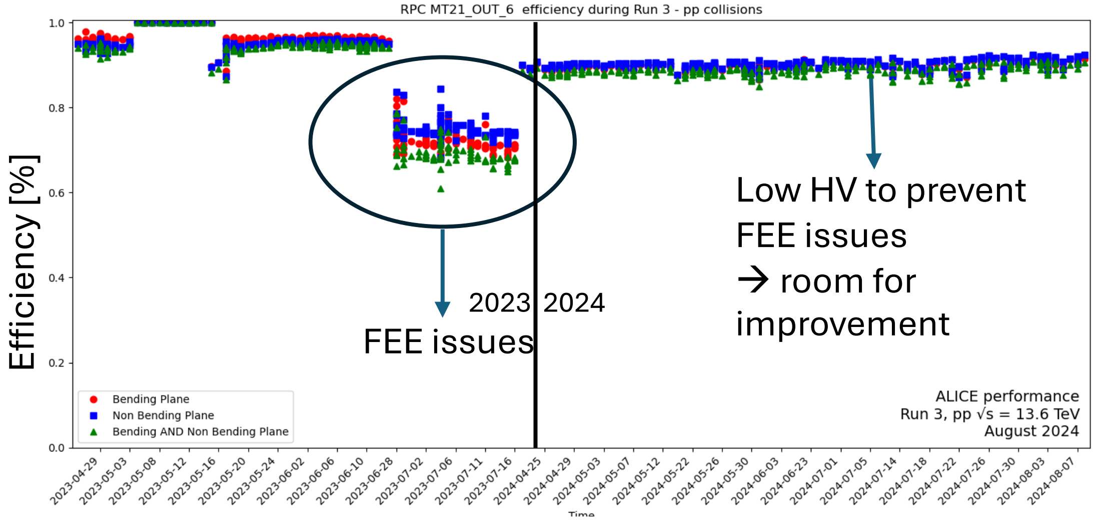


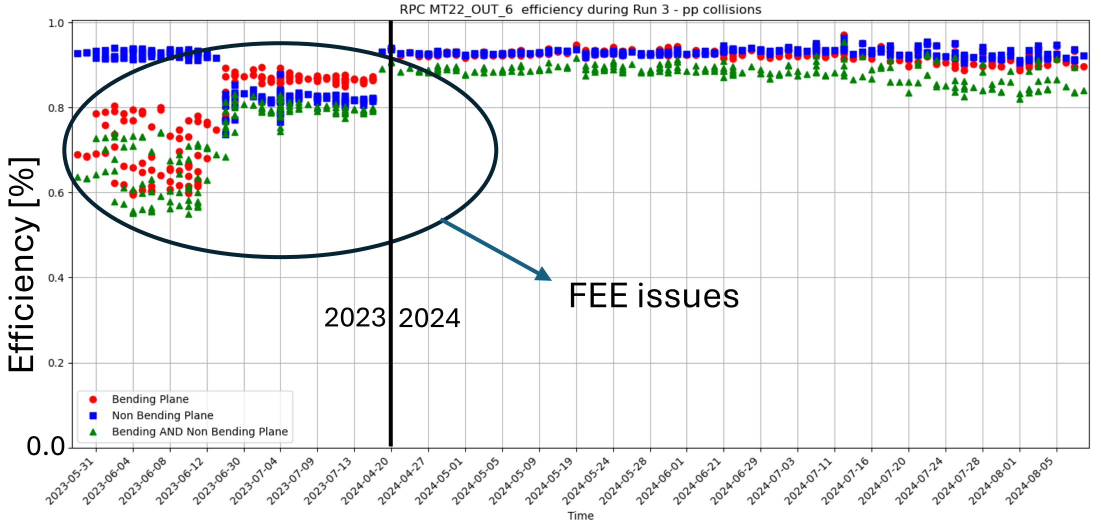


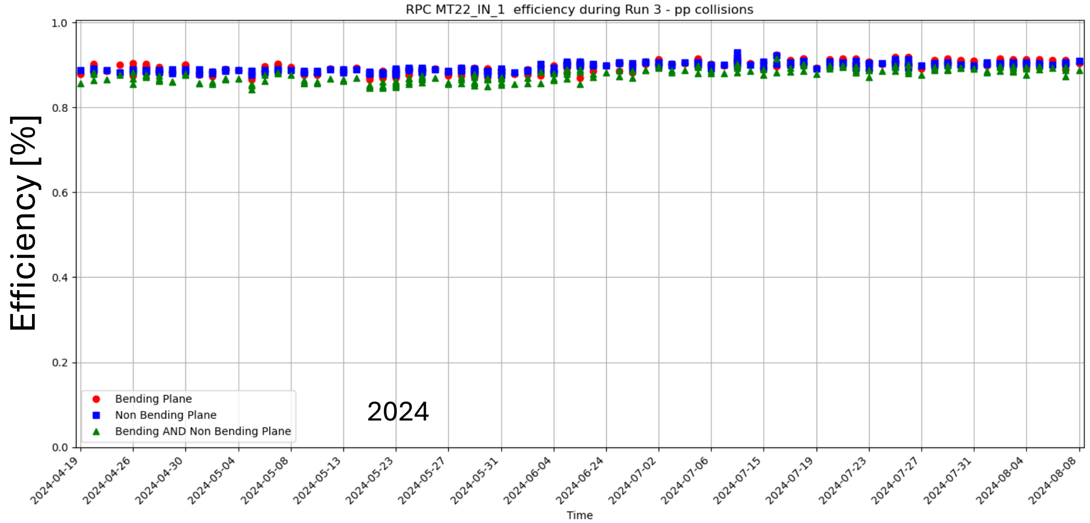
New RPCs installed at CERN: Performaces

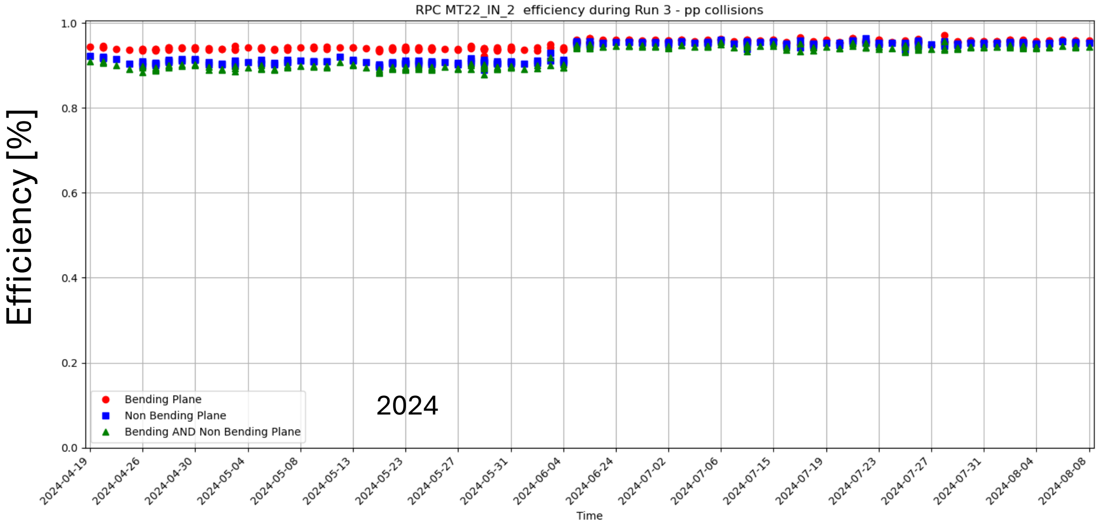


RPCs replaced @ CERN Performaces



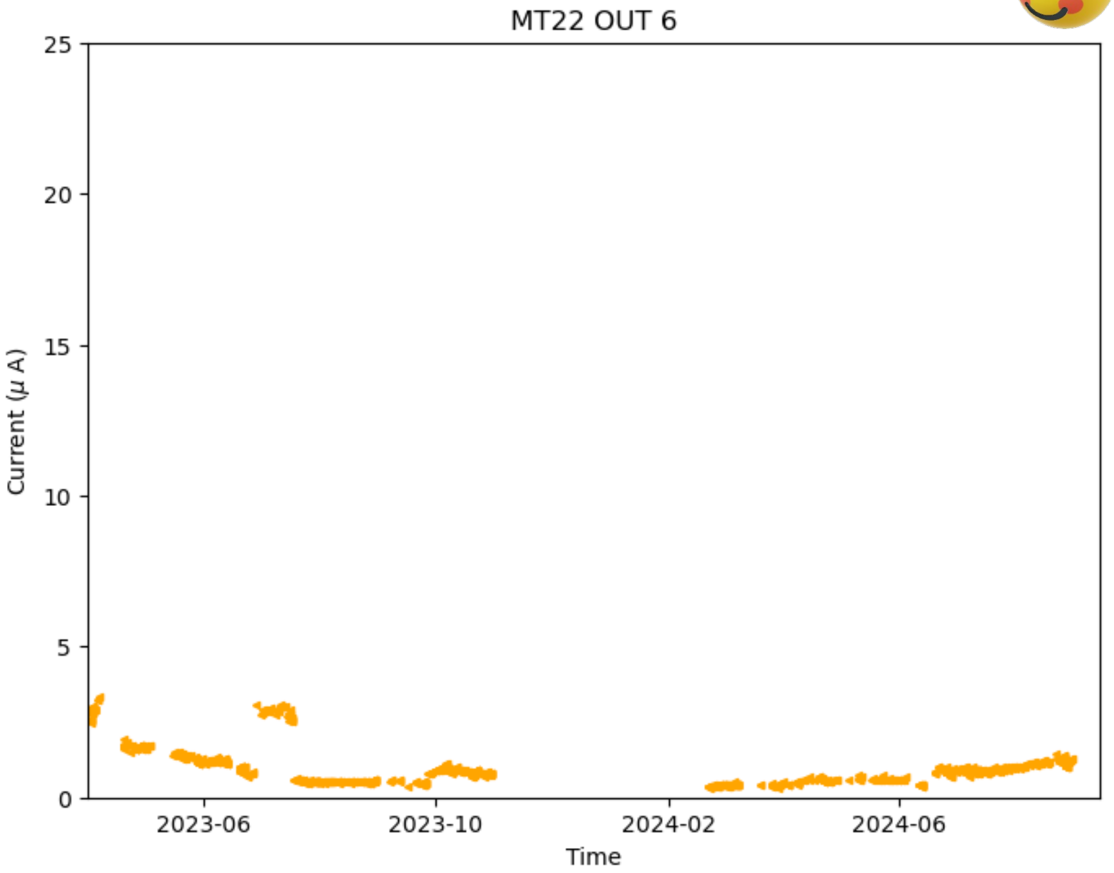




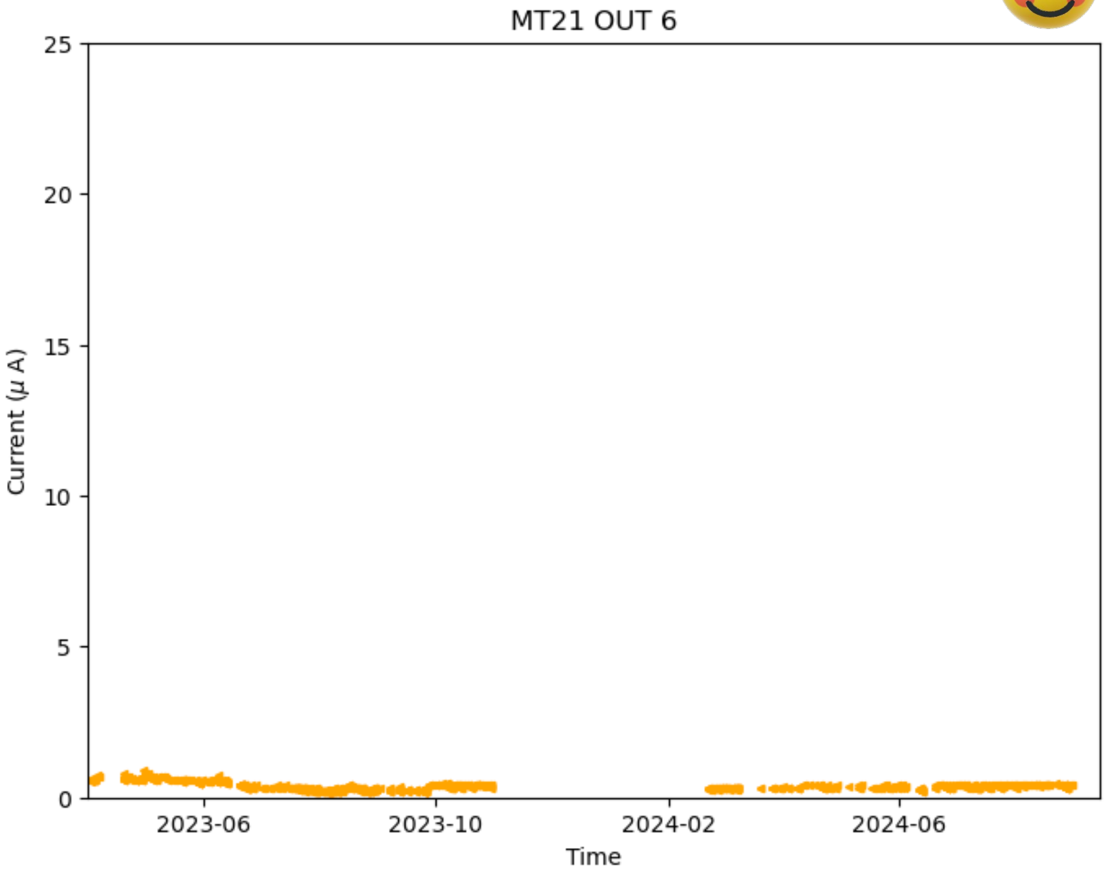


- Efficiency >= 90% and stable (but MT22_OUT6 needs monitoring)
- Dark currents at nominal voltage range from <1 μA to ~6 μA → room for increasing HV

RPCs replaced @ CERN Performaces

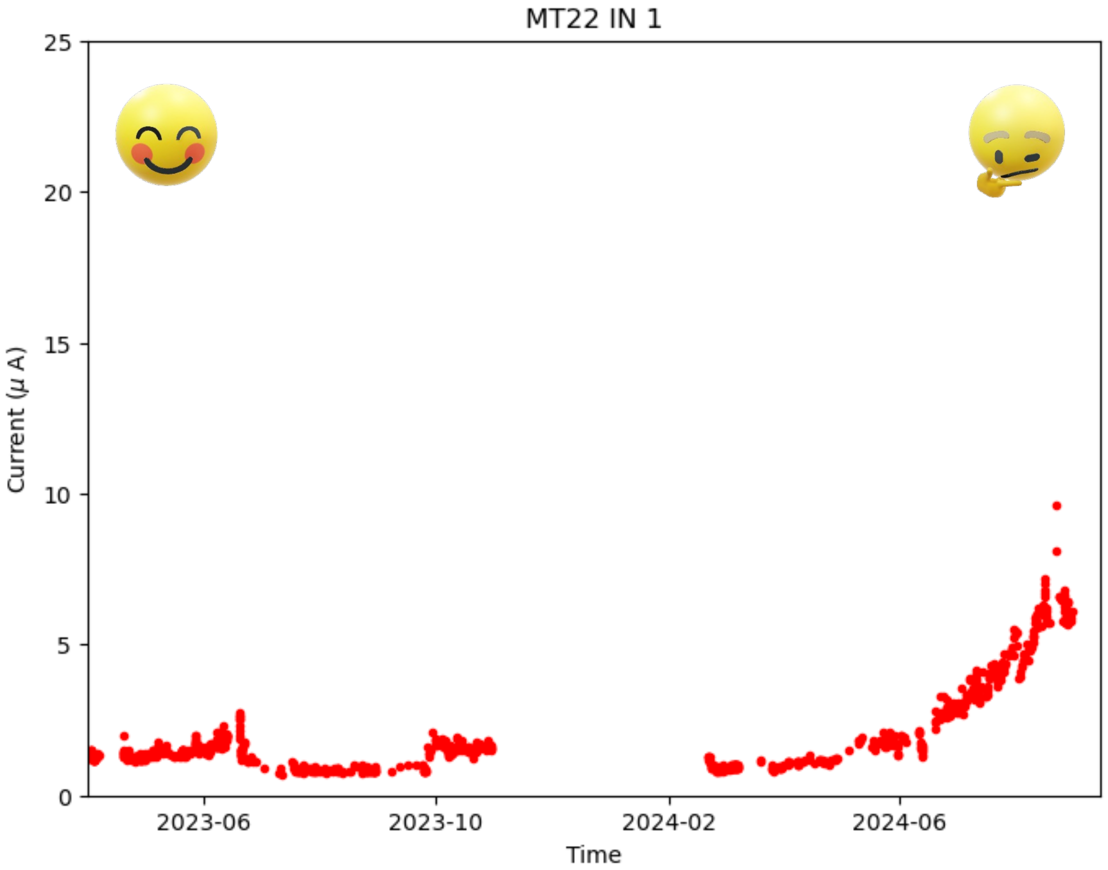


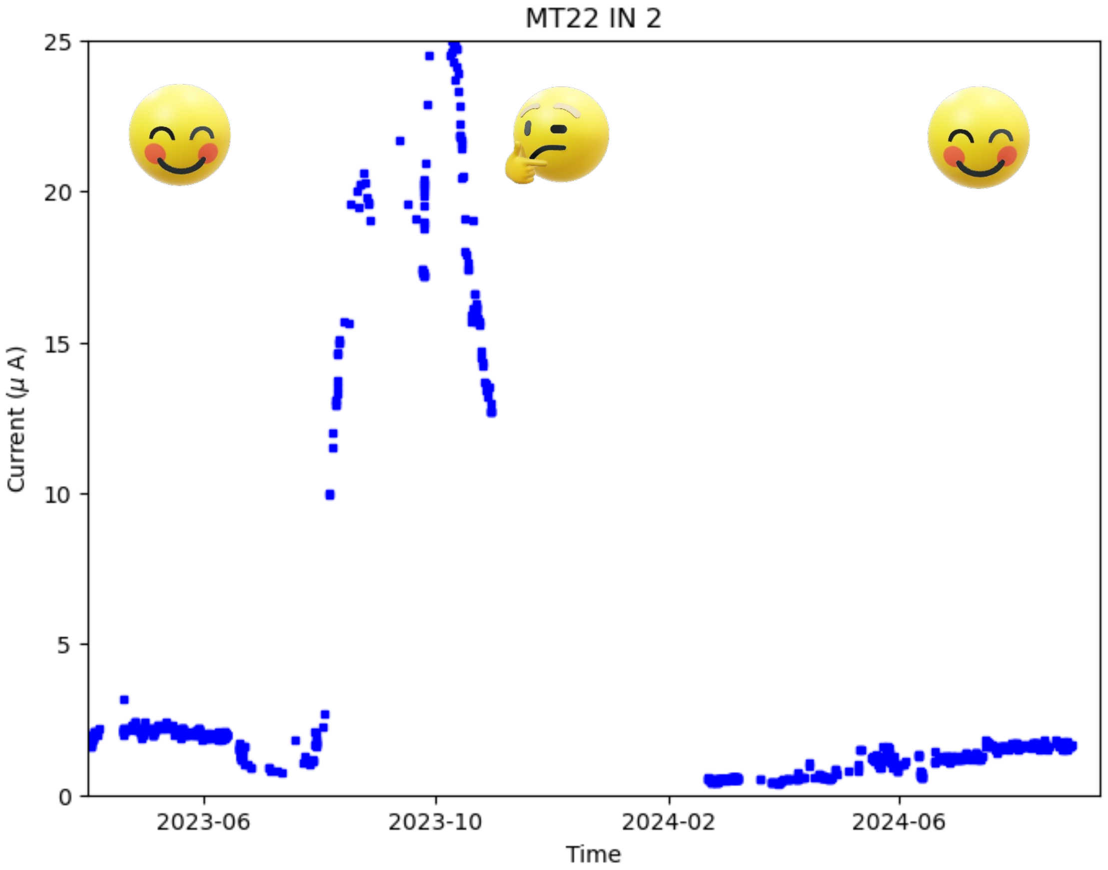
- Dark current low and stable over the time



- Dark current low and stable over the time

RPCs replaced @ CERN Performaces





- The current is increasing in the last months → under investigation

- Huge increase of current leading to a HV trip
- Fixed during winter → current again low in 2024

Outline

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  - **Test procedure**
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    - Dark rate
  - **Test results**
- **Performance** of the new **RPCs installed** in **ALICE**
- **Summary**

Summary

Done during this work:

- detailed **characterization** of **new RPCs**
- **18 RPCs tested**
- **72%** are **OK**, **6%** can be used **in case of need**, **22% discarded**
- **4 new RPCs already installed** in the **ALICE** cavern, with **satisfactory** and **stable performance**

Thank you for your attention!

BACKUP SLIDES

Tracking

For and event to be considered “valid” by the tracking algorithm, only one cluster (smaller than 3 strips) for each tracking RPC strip plane is required. Naming (x_1,y_1) and (x_2,y_2) the coordinates of the impact points on the tracking RPCs, placed at heights z_1 and z_2 respectively, (x_{test1}, y_{test1}) and (x_{test2}, y_{test2}) the coordinates of the RPCs under test, placed at heights z_{test1} and z_{test2} respectively, it is possible to calculate expected impact point coordinates as:

$$x_{test_{1,2}} = x_1 \frac{z_{test_{1,2}} - z_1}{z_2 - z_1}(x_2 - x_1)$$

$$y_{test_{1,2}} = y_1 \frac{z_{test_{1,2}} - z_1}{z_2 - z_1}(y_2 - y_1)$$

Efficiency

Efficiency of each cell:

$$\varepsilon = \frac{N_E}{N_C} \qquad \sigma_\varepsilon = \sqrt{\frac{\varepsilon(1-\varepsilon)}{N_C}}$$

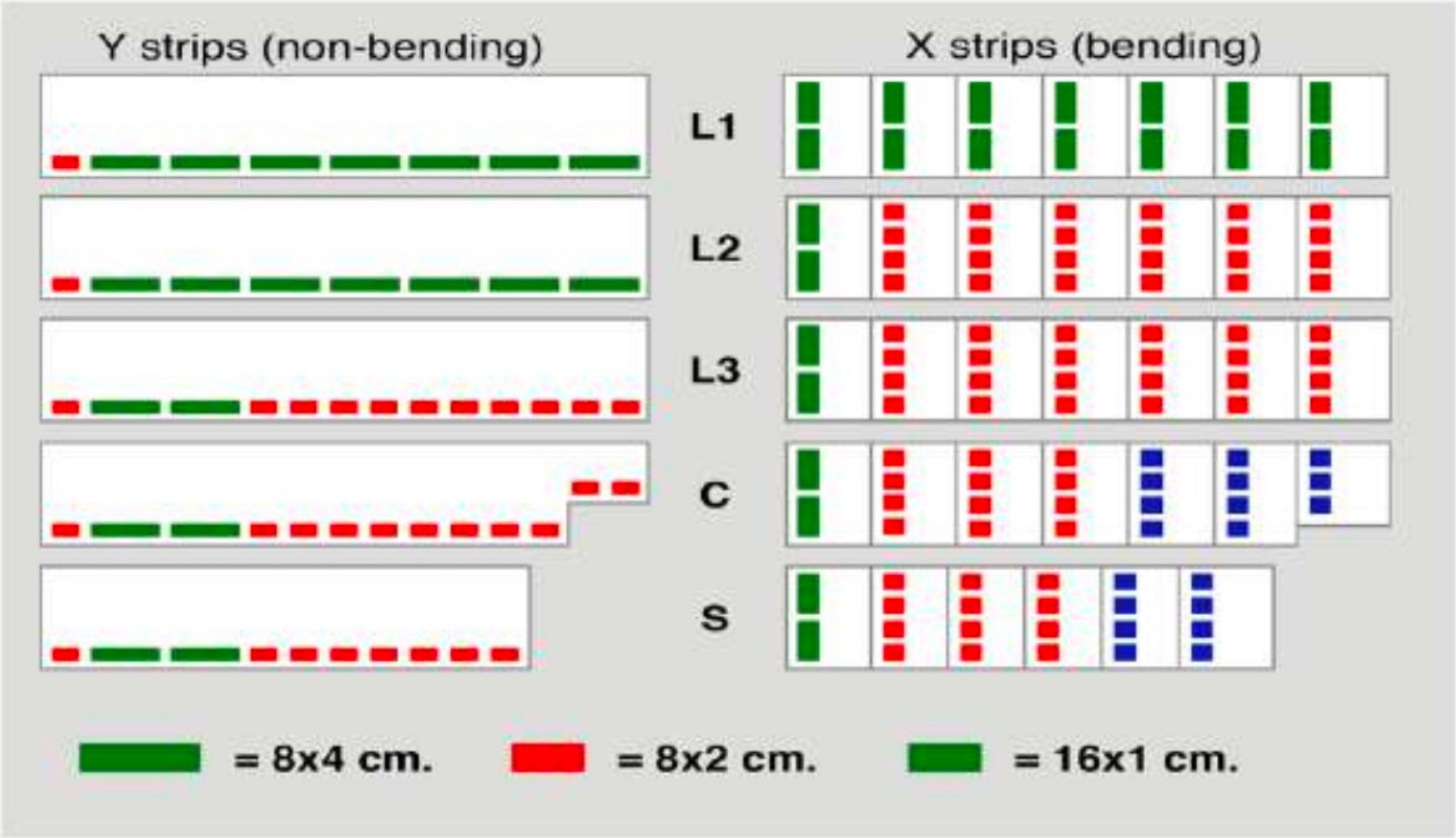
Where N_C is the number of cosmic rays crossing the same cell and N_E is the number of cosmic rays detected by the RPC under test

P-T correction

$$HV_{eff} = HV_{app} \frac{T}{T_0} \frac{p_0}{p}$$

where T_0 and p_0 are reference values (usually set to T_0= 293.15 °K and p_0 = 970 mbar), p and T are the actual values of temperature and pressure (which are monitored during data taking) and HV_{app} is the high voltage applied to the detector

MID



Scheme of the layout of the front-end electronics with different strips pitches

Dark current

For each signal the charge released in the gap in streamer mode ~ 500 pC

Average cosmic rate ~ 100 #/m^2s

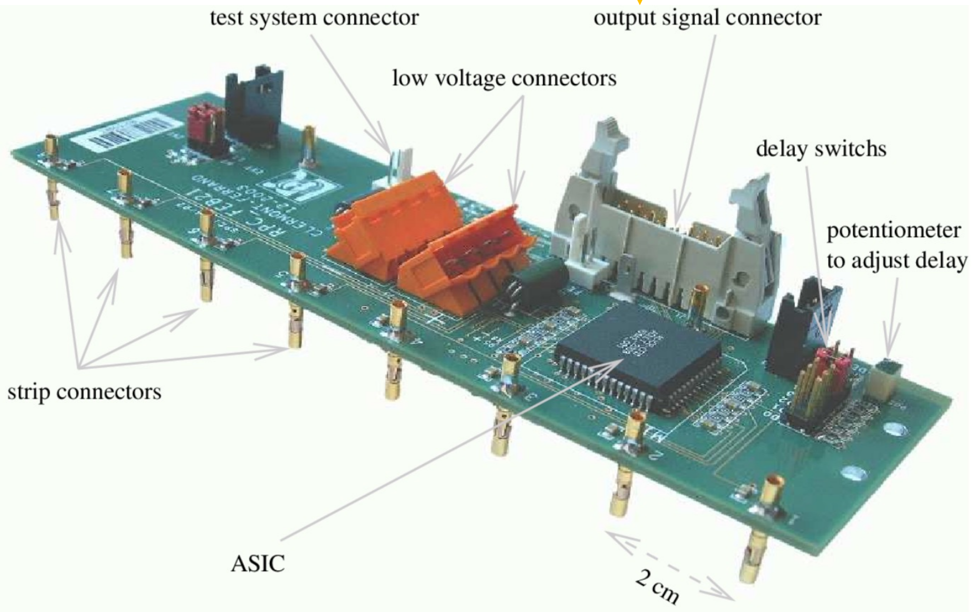
So the average current $\frac{I_{cosmic}}{A}$ ~ 50 nA/m^2

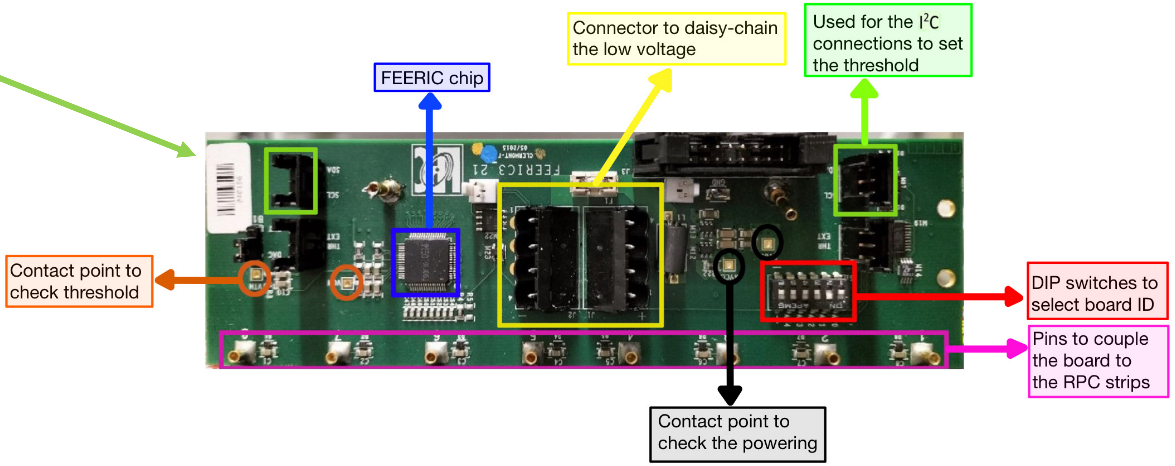
If we consider 100% efficiency and we multiply for the area

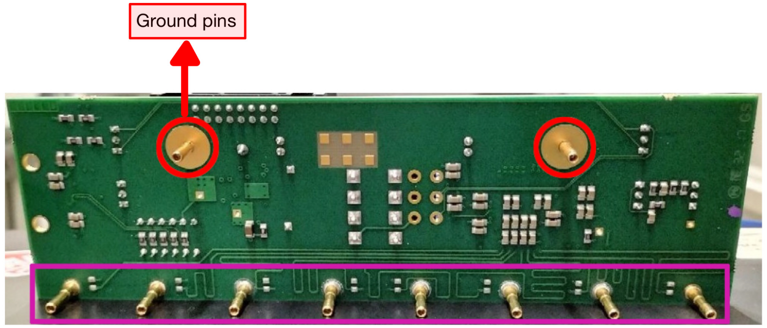
I_{cosmic} = 50*2.7 ~ 100 nA = 0.1 μA

Front-end electronics

❖ Differences between the old electronics and the new one







- Old electronics
- Signal discriminator
- **Threshold**: internal (~ **80 mV**)
- No preamplification stage is present

- **FEERIC** (**Front End Electronics Rapid Integrated Circuit**), signal discriminator, new electronics
- Has a **preamplification stage** of the analogue signal to work with lower gain signal -> slow down RPC ageing and improve rate capability
- The requested dynamic range is from 20 fC to 3 pC, while the expected mean charge at the working point is rather 100 fC

RPC current

Due to the exposure of the detector to high hit rates, the charge released in the gas gap during irradiation at nominal voltage can induce the generation of **chemically active gas molecules fragments** (i.e. fluorine, which is very reactive and can damage the bakelite electrodes surface by combining with the water vapor leading to the formation of **HF** hydrofluoric acid). The compounds released can create irregularities which can increase the RPC noise and then affect its efficiency.

A proxy for the detector "age" is the **integrated charge per unit surface** (measured in mC/cm^2), which can be estimated by the **integral of** the **absorbed current over time**.

$$I_{RPC} = I_{Ohmic} + I_{cosmic} + I_{dark}$$

I_{Ohmic} → non-perfect insulation of the HV electrodes from the rest of the system, so it depends linearly on the applied HV.

I_{cosmic} → cosmic irradiation

I_{dark} → discharges in the gap cause by electrons extraction from the cathodes that can cause the development of avalanche or streamer.

For what regards **ageing effects**, the **cosmic** and of the **dark currents** are relevant, while the Ohmic current is not expected to have an effect on the detector ageing since it is not associated to the liberation of charges in the gas gap.

Gas mixture history

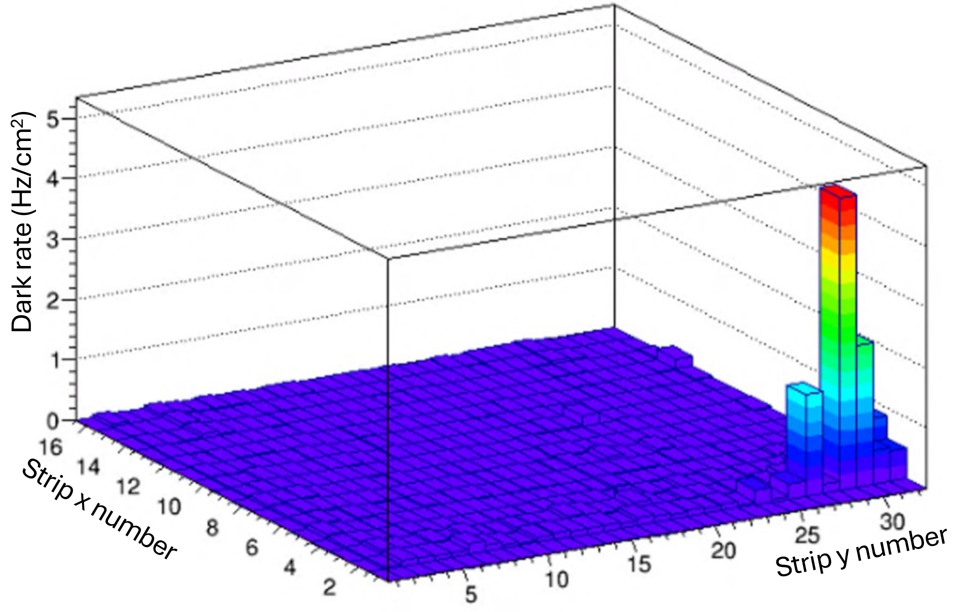
The original streamer mixture was selected to fulfill the spatial resolution requirements for Pb-Pb collisions

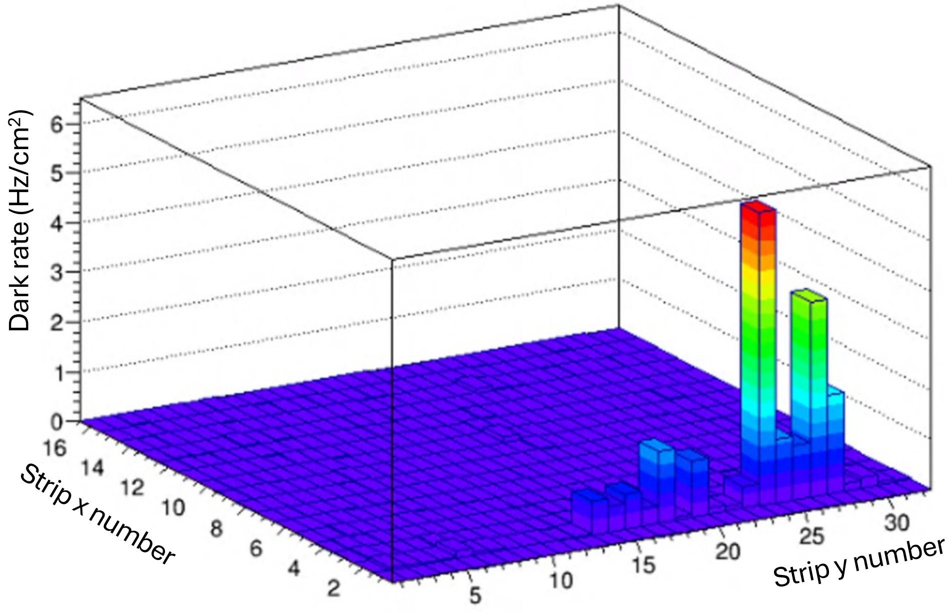
However the constraints for the pp data taking were different with respect to Pb–Pb:

- the **multiplicity** is **smaller**
- requirements on **the spatial resolution** are less stringent
- **longer data taking periods** (detector lifetime important issue)

Total charge per hit in **maxi-avalanche** mode is ~**100-150 pC**
Total charge per hit in of **pure avalanche** mode ~**30 pC**

Test results





Rates Run 3 and Run 4

During RUN 3 (2022-2025) and RUN 4 (2030-2032) peak **Pb-Pb** collisions ~ **50 kHz**

pp average	pp Most exposed RPC	Pb-Pb average	Pb-Pb Most exposed RPC
5 Hz/cm^2	13 Hz/cm^2	48 Hz/cm^2	90 Hz/cm^2

90 Hz/cm^2 maximum hit rate on the most exposed RPCs, with a safety factor 2

Avalanche/streamers: pros and cons

RPCs can be operated in streamer or avalanche mode

Streamer mode:

- smaller **cluster size**
- smaller **noise background**
- simpler discrimination
- worse **time resolution**
- larger amount of charge released in the gas -> **fast ageing, smaller rate capability**

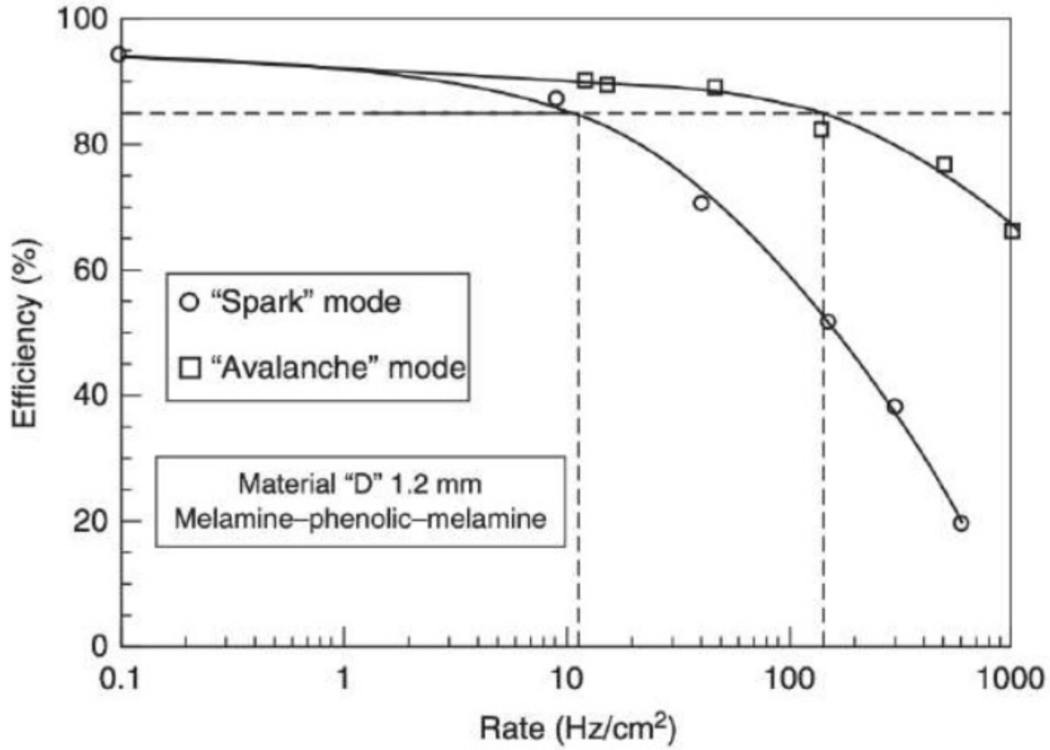
Avalanche mode:

- larger **cluster size**
- larger **noise background**
- preamplification stage needed
- better **time resolution**
- smaller amount of charge released in the gas -> **slower ageing, greater rate capability**

- **ALICE RPCs** have been designed in streamer mode, but operated in **avalanche**
- Streamer mode is still used for testing purposes

Rate capability

In avalanche mode, the charge released inside the gap is lower w.r.t. the one released when operating the RPC in streamer mode. As a consequence, the local drop of the electric field is smaller when working in avalanche mode and, in this case, the detector **rate capability** (i.e. the **maximum rate of particle** impinging on the detector **that can be detected** by the RPC) is improved. The **efficiency** of the **RPC operating** in **streamer** mode and in **avalanche mode** for **different particle rates** is reported.



Streamer signal

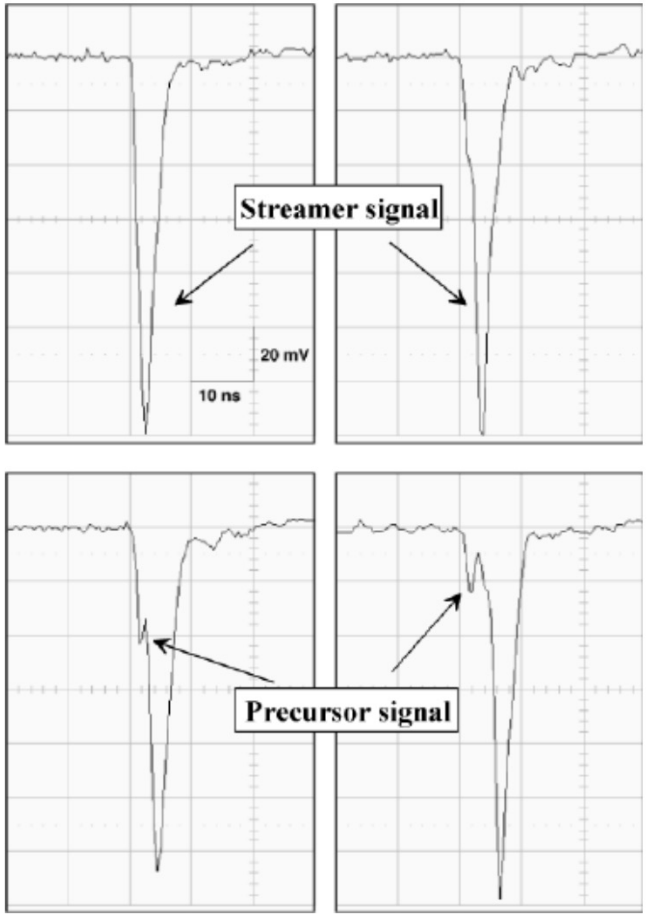


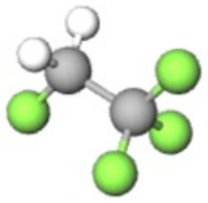
Figure 49: Typical pulses picked-up with an oscilloscope from a RPC operating in streamer mode [73]

The **streamer** signal has a typical amplitude of **hundreds of mV**, while the **avalanche** one of **few mV**.
The **better discrimination** between **signal** and **noise** w.r.t. the avalanche mode leads to a lower cluster size.
The disadvantage of this working mode is that a larger amount of charge is released in the gas (about few hundreds pC) and this leads to a faster ageing of the detector and a lower rate capability

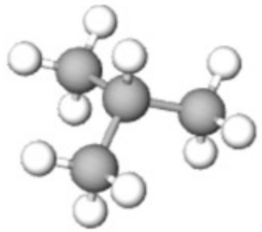
RPC characterization gas mixture

Streamer gas mixture

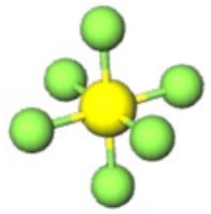
50.5% Ar



41.3 % $C_2H_2F_4$



7.2 % i-C_4H_{10}



1 % SF_6

Ar :
- **Noble gas**: primary electrons can ionize it and multiplicate ($\simeq$ 3 ion pairs per mm)

$C_2H_2F_4$ (R-134a):
- **Electronegative:** absorbs free electrons and limits the current
- Provides electrons from **primary ionization** ($\simeq$ 7 ion pairs per mm)

i – C_4H_{10}:
- **Quencher**: absorbs UV photons (**roto-vibrational degrees of freedom**)
- **Flammable**

SF_6 :
- **Highly electronegative**: captures free electrons

ALICE physics

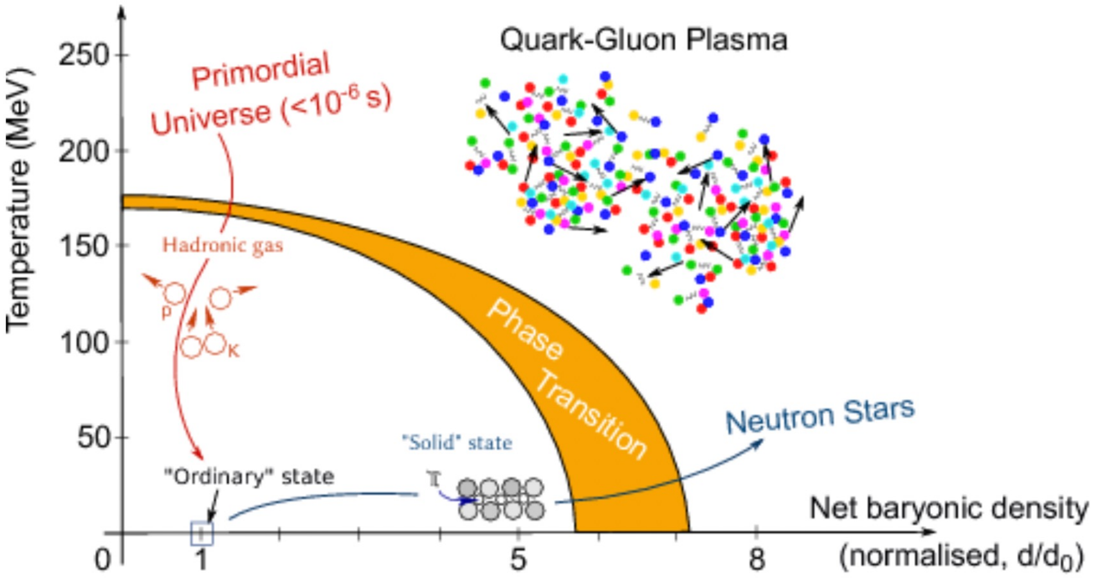
QCD (Quantum ChromoDynamics): theory that describes strong interactions among quarks and gluons -> **confinement**

T ~ 160 MeV, **ε ~ 1 GeV/fm³** → phase transition: Quark Gluon Plasma (**QGP**) → quarks and gluons **deconfined** → **few μs after Big Bang**

Experimentally → **ultrarelativistic heavy-ion collisions**

QGP observables:

- **Soft probes** (low p_T hadrons, collective motion...)
- **Hard probes** (high p_T hadrons, jets, open heavy flavor, **heavy quarkonia**)

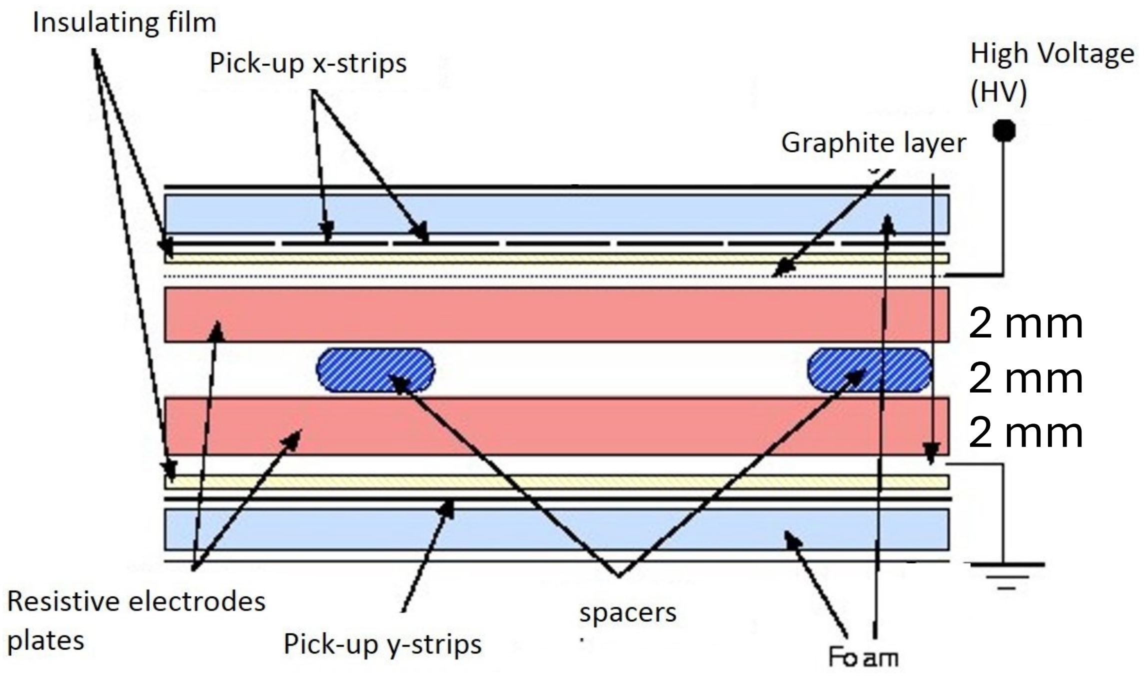


Allow to:

- Study of hadronization after **Big Bang**
- Study key issues of the **QCD**
- Study link to extreme matter → **neutron stars**

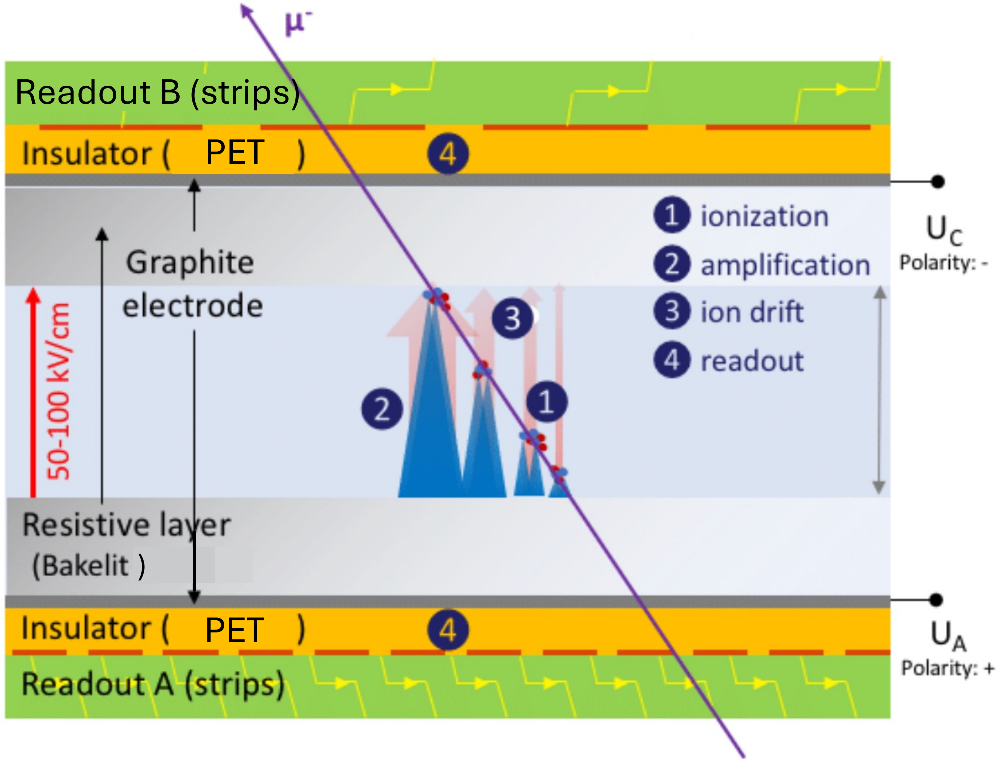
RPC layout

- **Resistive electrodes** made of bakelite (**$\rho \simeq 10^{10}\ \Omega$ cm**)
- **Conductive graphite layer** to apply HV
- **Uniform electric field** (50 kV/cm)
- **Polycarbonate spacers**
- Copper **readout strips**



RPC signal formation

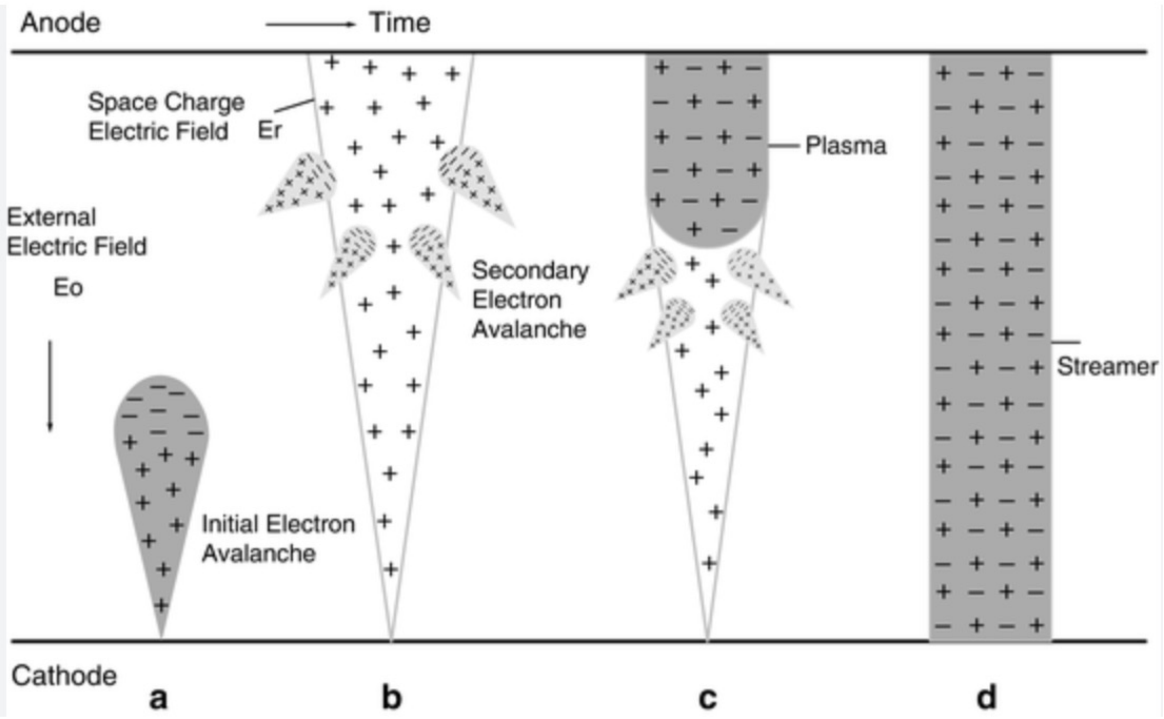
- A **crossing particle** produces **ion-electron pairs**
- **Electrons accelerate** towards the anode
- If electric field is enough: electron **multiplication**
- **Electrons drift** induces a **signal** on readout strips



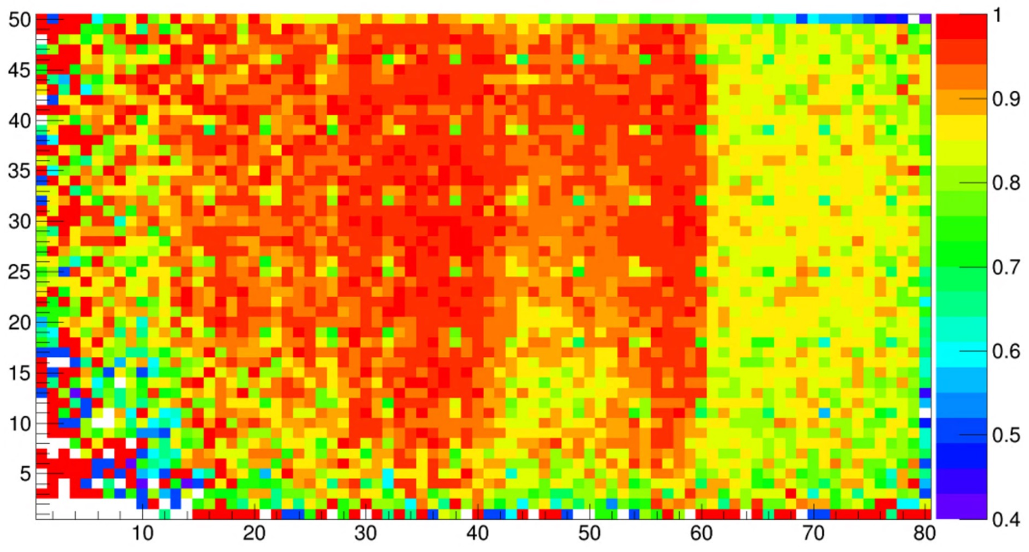
Avalanches and streamers

- **Multiplication stops** when internal electric field equals external one
- **Ion and electron can recombine** and emit UV photons
- **Photons and ions can extract electrons** from the cathode giving rise to new avalanches

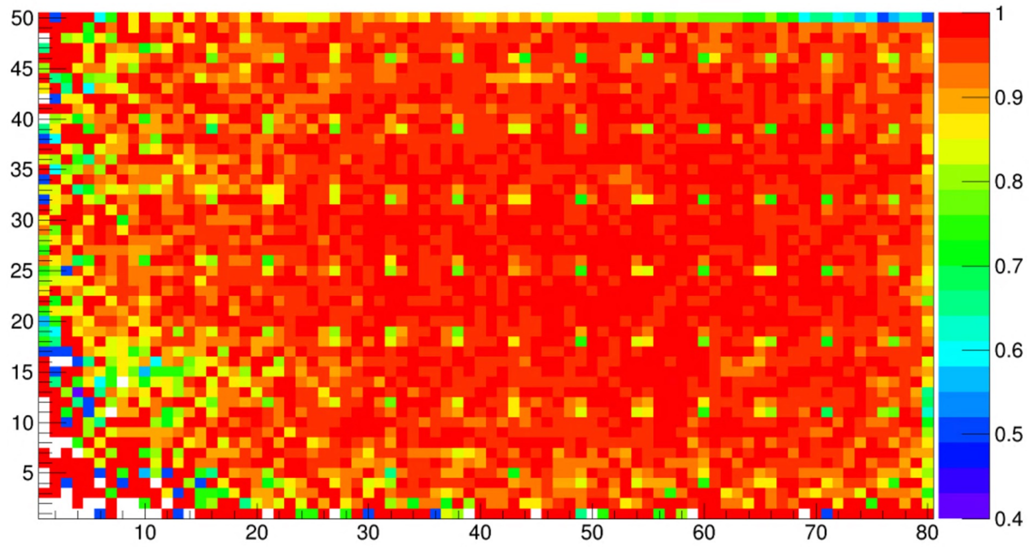
The combination of these effects can generate a streamer



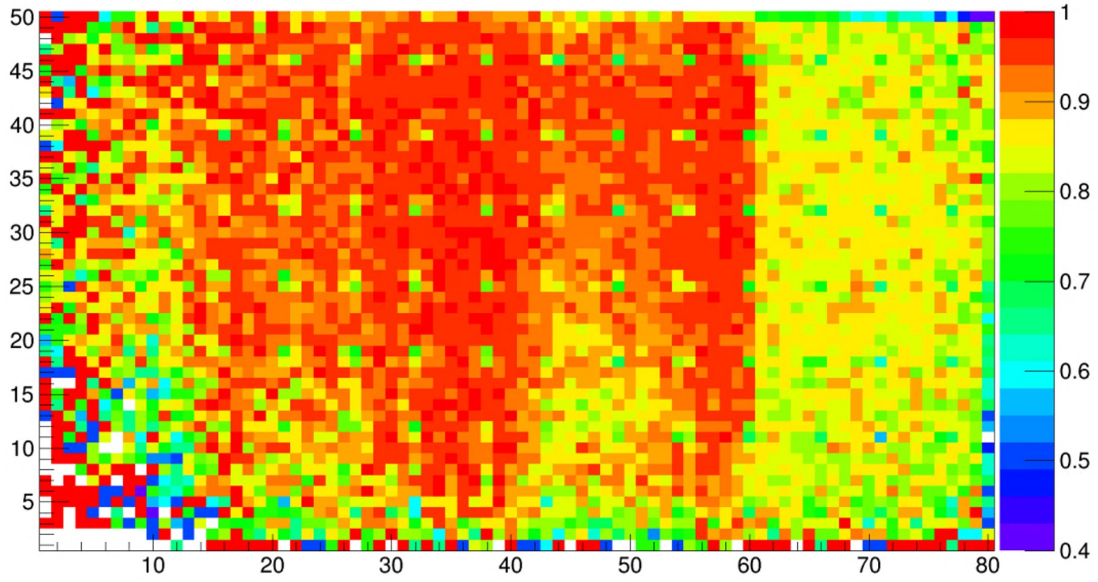
709-21 efficiency right half



Efficiency X AND Y

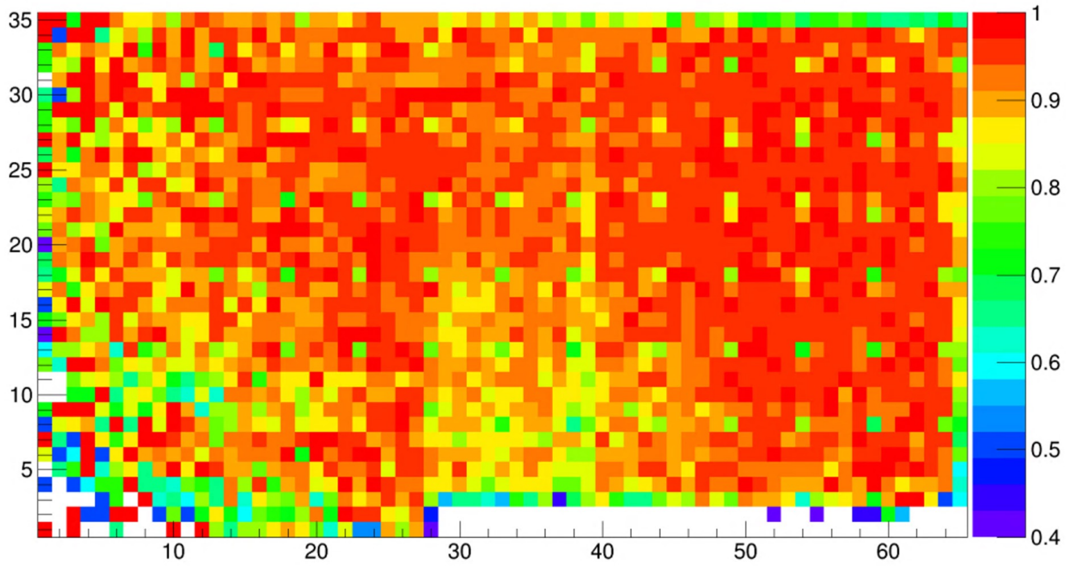


Efficiency X strips

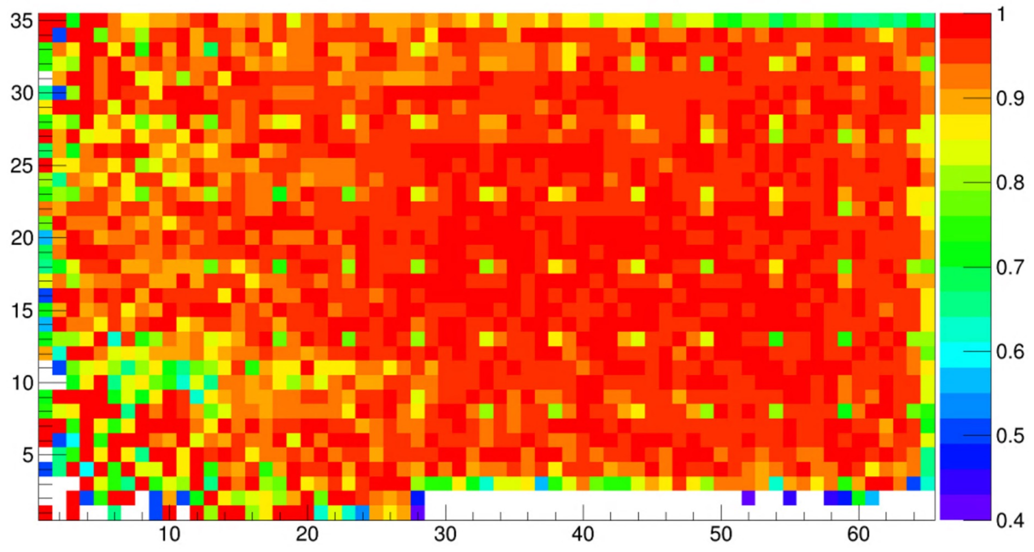


Efficiency Y strips

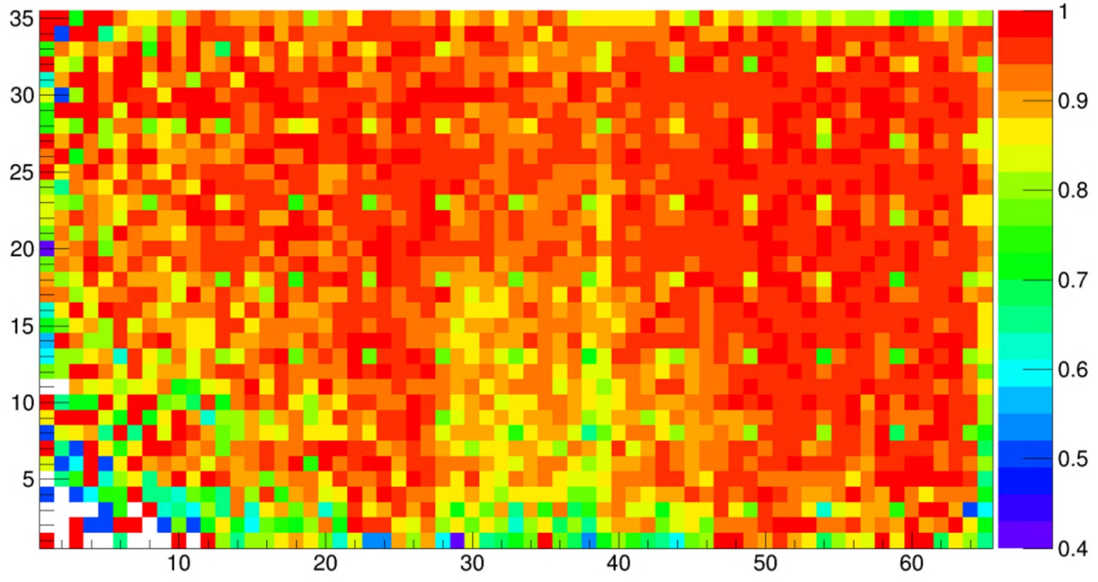
709-21 efficiency left half



Efficiency X AND Y

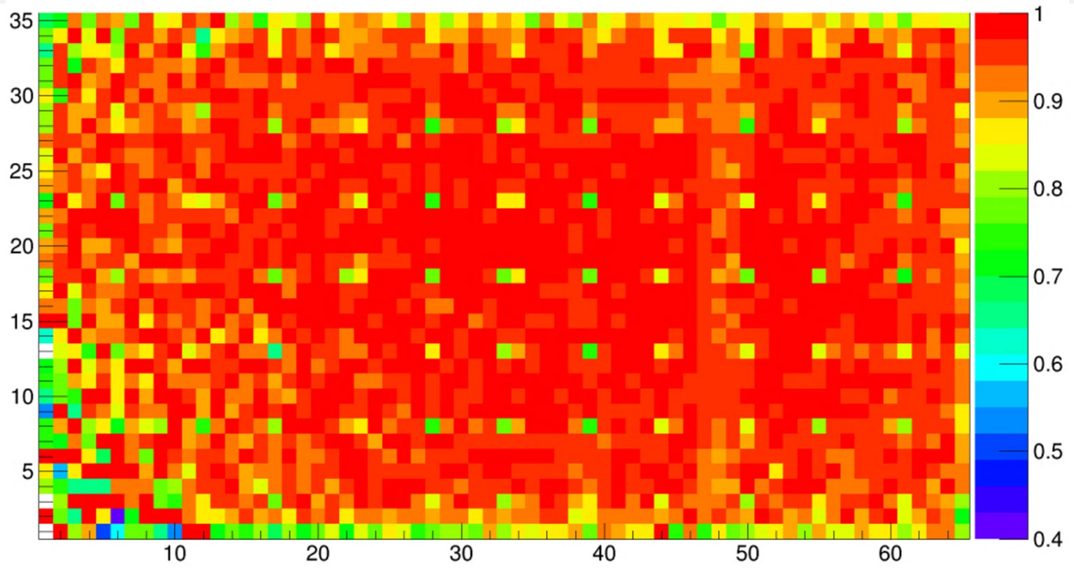


Efficiency X strips

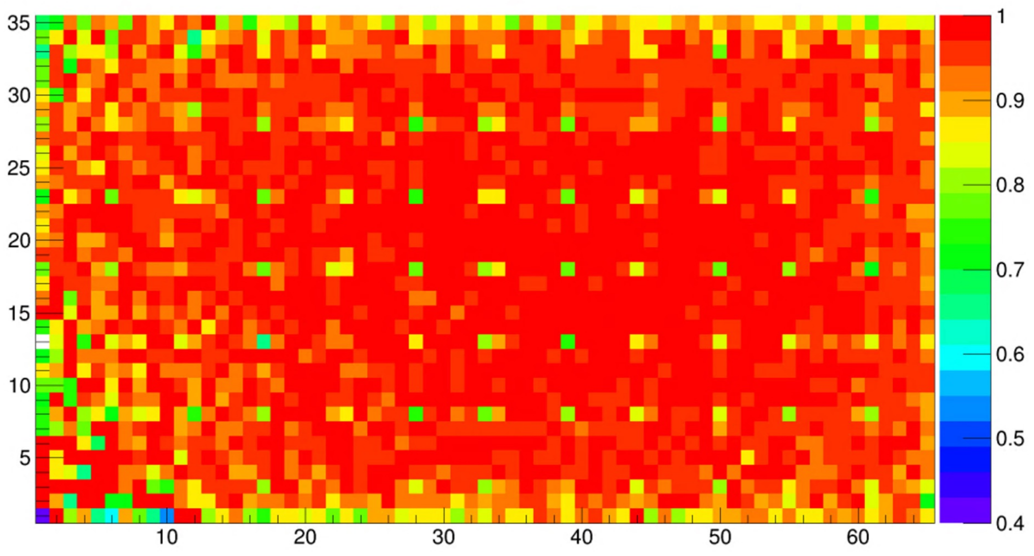


Efficiency Y strips

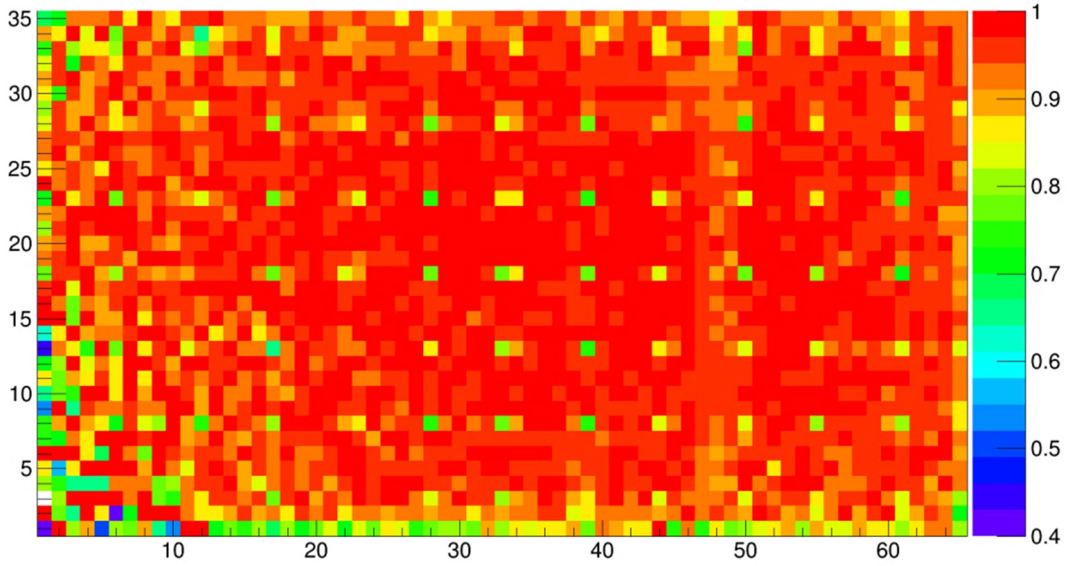
680-19 efficiency left half



Efficiency X AND Y

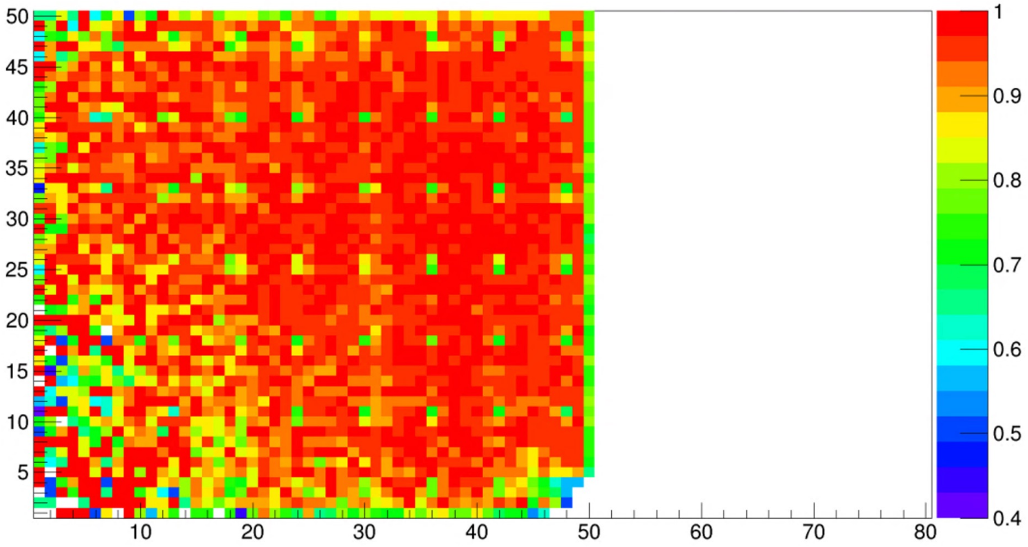


Efficiency X strips

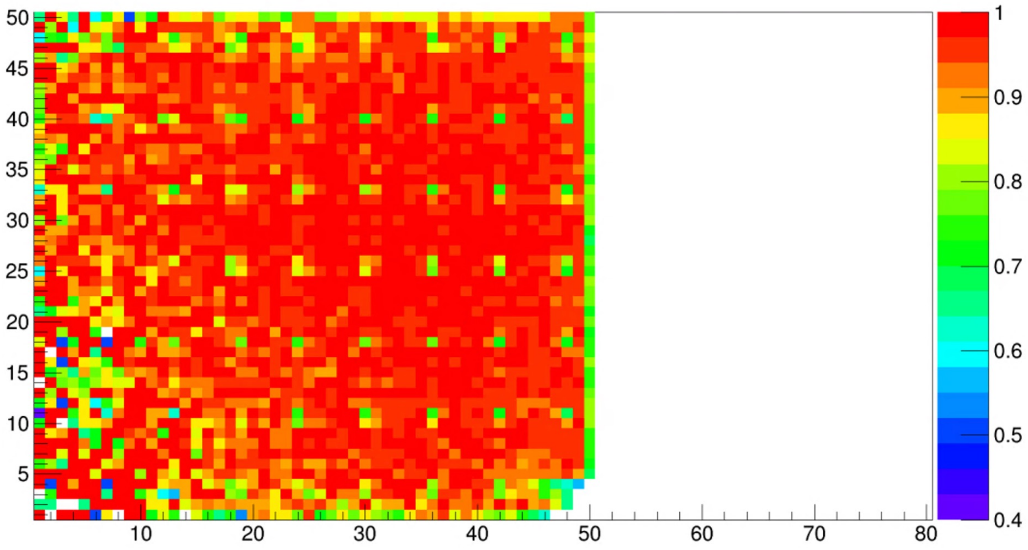


Efficiency Y strips

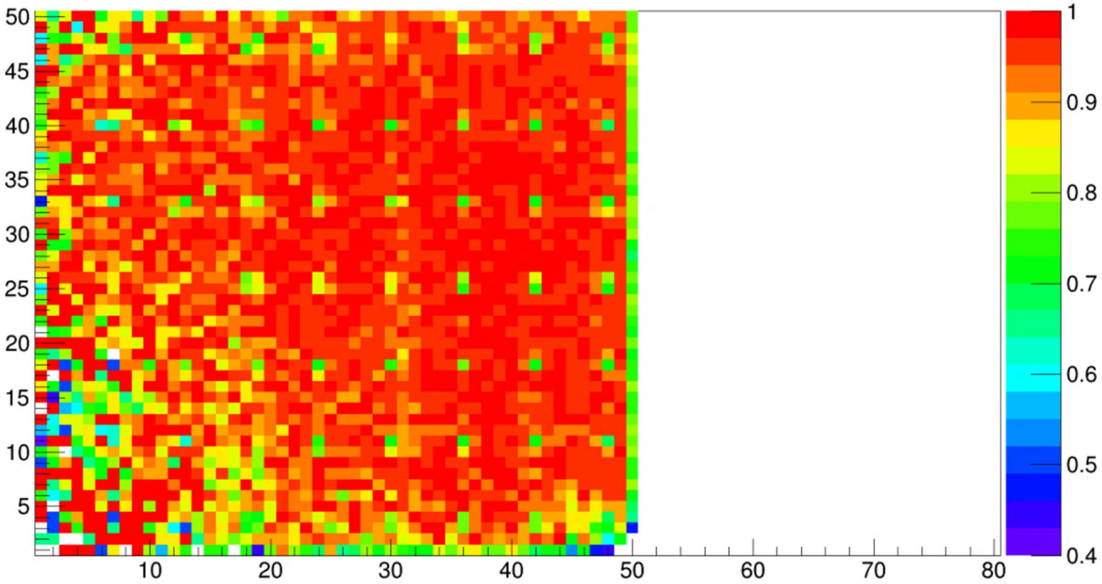
680-19 efficiency right half



Efficiency X AND Y



Efficiency X strips



Efficiency Y strips

Read-out

- FEE output -> local cards i.e. local boards (group 16 strips with a 1 cm pitch or 8 strips with a 2 cm and 4 cm pitch).
- Each local board receives the signal from the same area coming from all the 4 different MID planes for each bunch crossing.
- The regional card assembles the raw events in their final format and sends to the CRU
- Each CRU processes one half of the MID and then forwards the MID data on one DAQ First Level Processor, link to the O^2 system