Centre of Excellence in Quark Matter

HELSINKI INSTITUTE OF PHYSICS

ALICE

ALICE Fast Interaction Trigger

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Helsinki Institute of Physics

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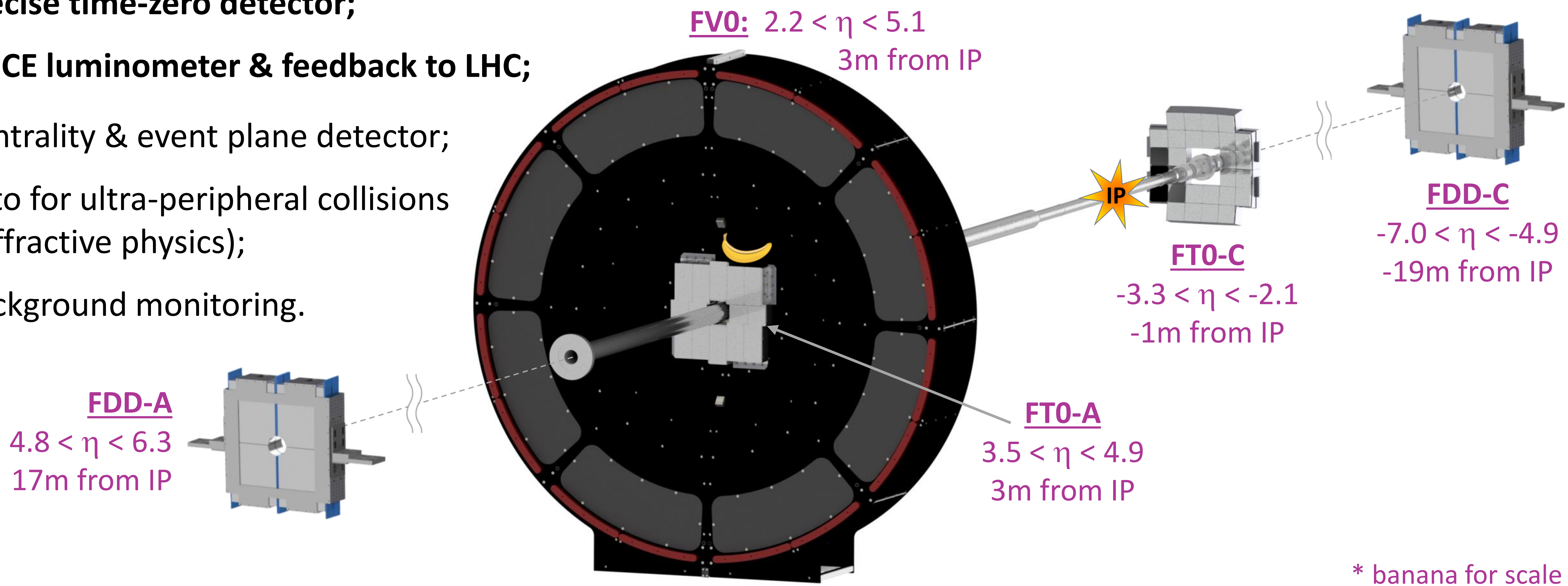
FIT layout & purpose

Three different sub-detectors – FT0, FV0 & FDD

arranged in five separate arrays on both sides of the Interaction Point (IP)

- **On-line trigger;**
- **Precise time-zero detector;**
- **ALICE luminometer & feedback to LHC;**
- Centrality & event plane detector;
- Veto for ultra-peripheral collisions (diffractive physics);
- Background monitoring.

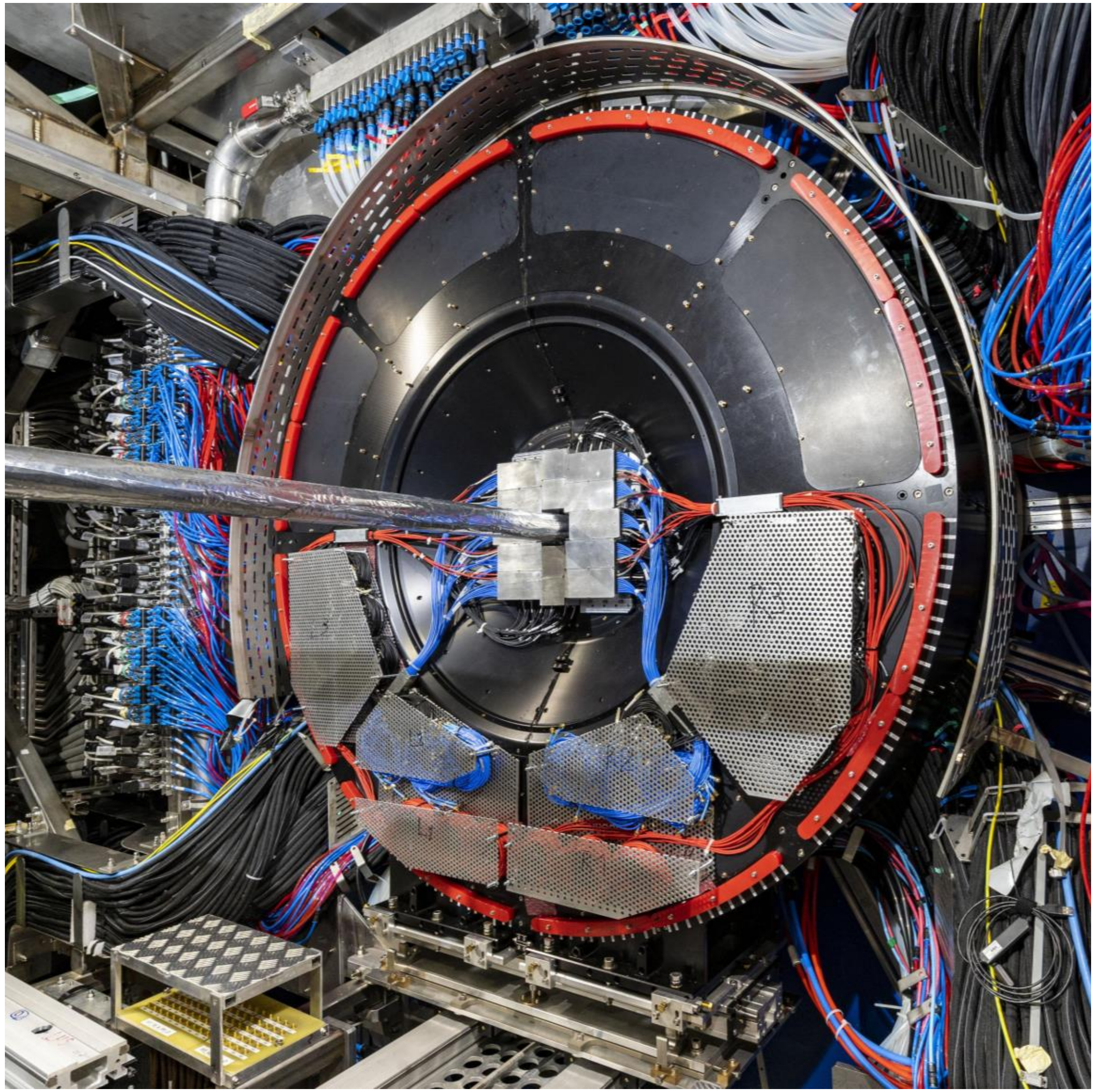


* banana for scale

FIT design constraints

- Brand-new subsystem of the upgraded ALICE for the **LHC RUN 3 & 4** (2022 onwards);
- **BC*-per-BC readout capability** (dead time ~15 ns);
- **Minimal latency** – trigger decisions in less than 425 ns from the collision (150 ns cabling delay included);

FT0+FV0 just after the installation in the cavern →

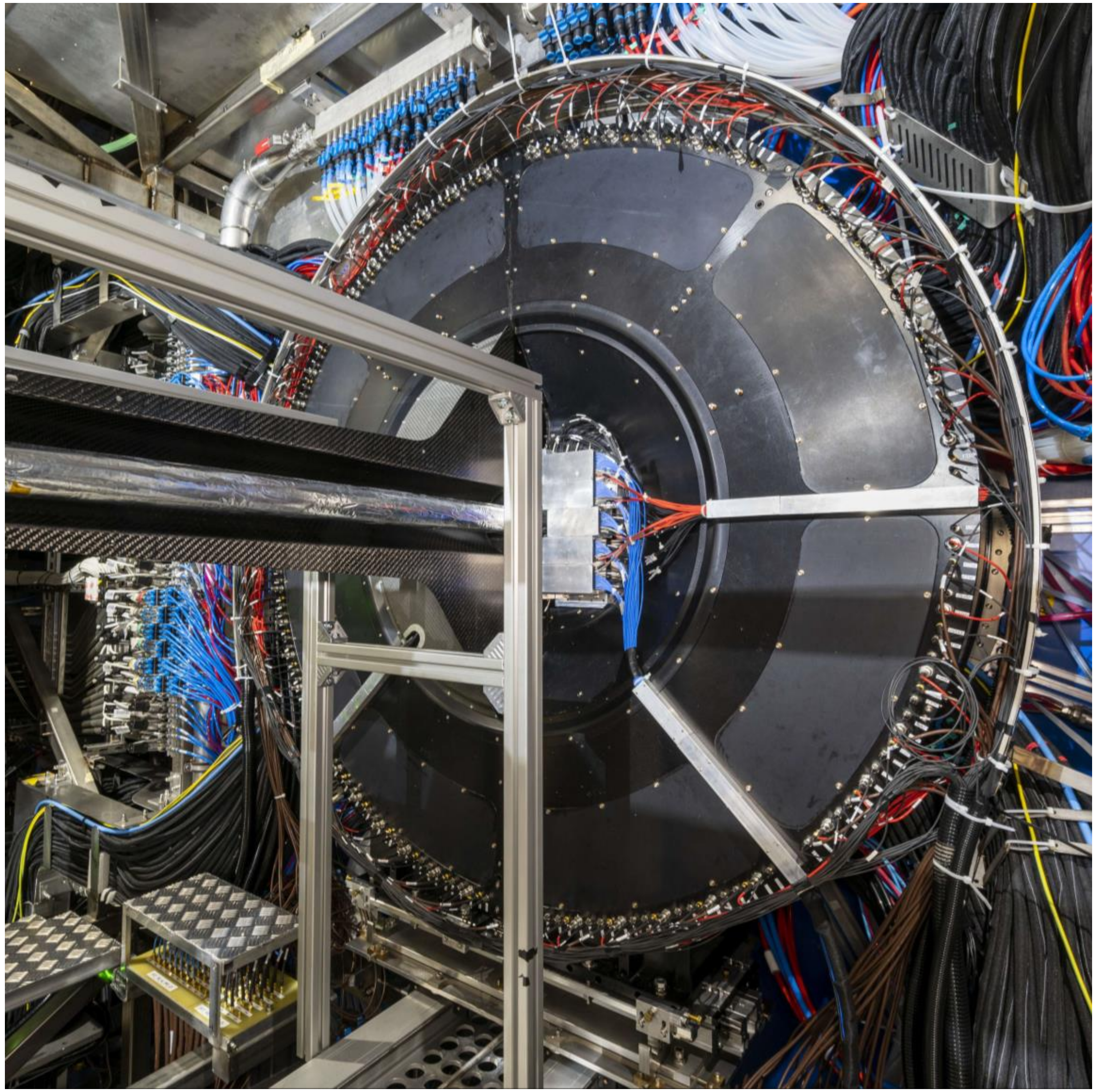


*BC – Bunch Crossing interval (25 ns)

FIT design constraints

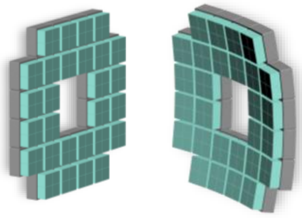
- Brand-new subsystem of the upgraded ALICE for the **LHC RUN 3 & 4** (2022 onwards);
- **BC*-per-BC readout capability** (dead time ~15 ns);
- **Minimal latency** – trigger decisions in less than 425 ns from the collision (150 ns cabling delay included);
- Efficient running at **full LHC Pb-Pb collision rate** (50 kHz);
- **Tolerance to the solenoid field** B = 0.5 T and **harsh radiation conditions** (~10^{13} 1-MeV-n_{eqv} / cm^2, ~0.5 Mrad);
- Operability outside the LHC's "stable beams" mode.

No make-up view of FT0+FV0 (all cables connected) →

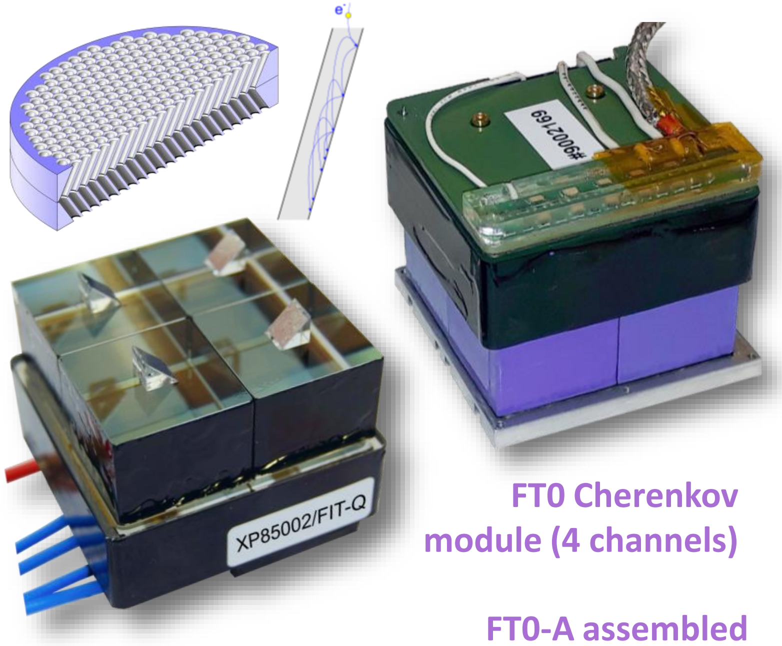


*BC – Bunch Crossing interval (25 ns)

FT0 – the FIT Time-zero detector

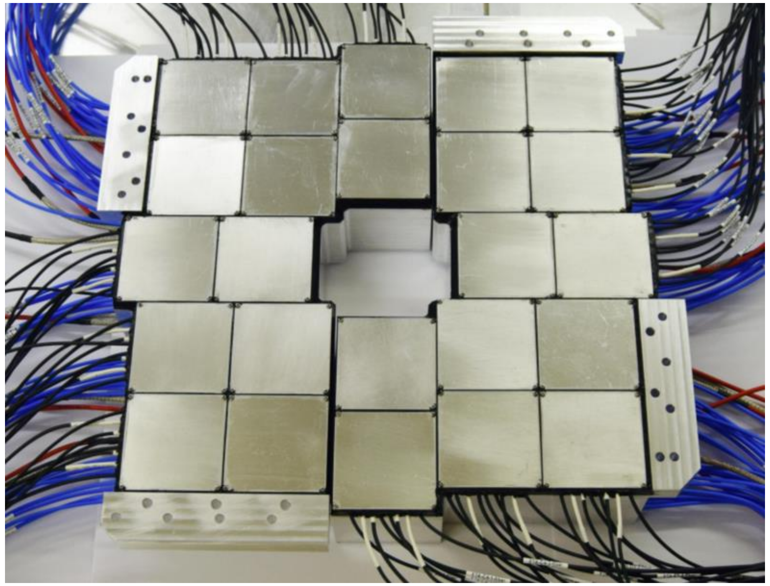


- Two arrays of Cherenkov counters;
- 96+112 quartz radiators coupled to 52 multianode microchannel plate-based PMTs (MCP-PMTs) for the best time resolution;
- First massive application of the Planacon® MCP-PMTs in HEP;
- Each channel equipped with individual inputs of the optical monitoring system based on a picosecond laser.



FT0 Cherenkov module (4 channels)

FT0-A assembled



FT0-C half – back view

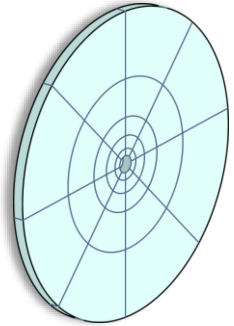
FT0-C half – front view

Planacon upgrade for ALICE FIT – [NIM A 952 (2020) 161689]

Bench testing of the ALICE FIT Planacons – [JINST 16 (2021) P12032]

FV0 – the FIT Vertex-zero detector

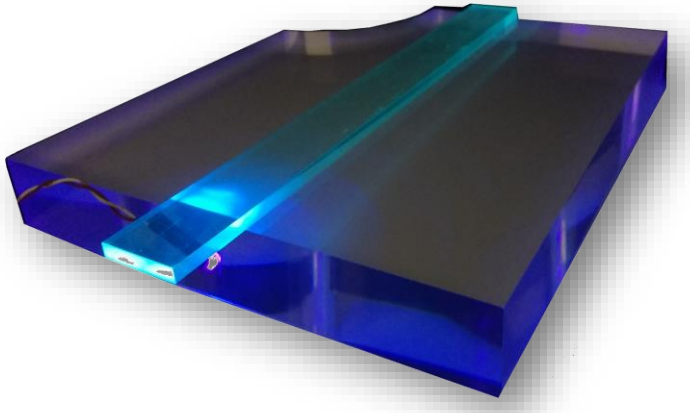
- Circular arrays of plastic scintillator tiles with novel light collection technique;
- Clear plastic fibers in direct optical contact with the scintillator back plane – non-WLS for the better timing;
- Fine-mesh PMTs: B-field immunity, good timing, high signal rate capacity.

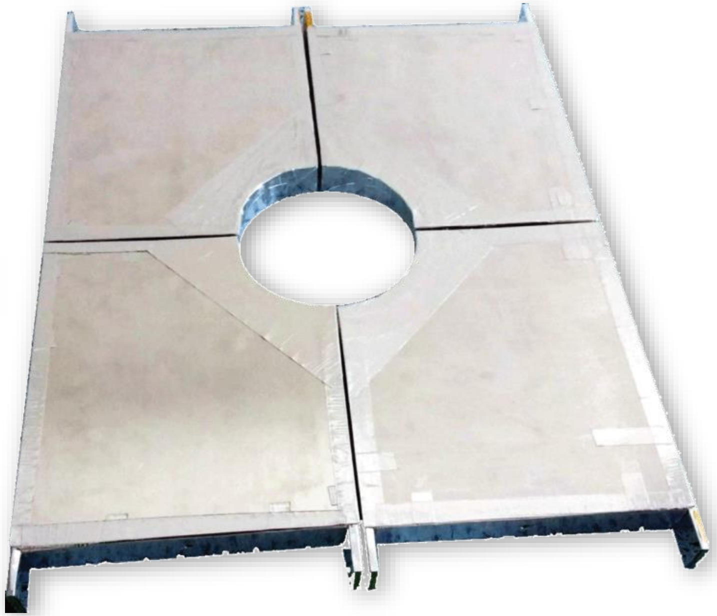


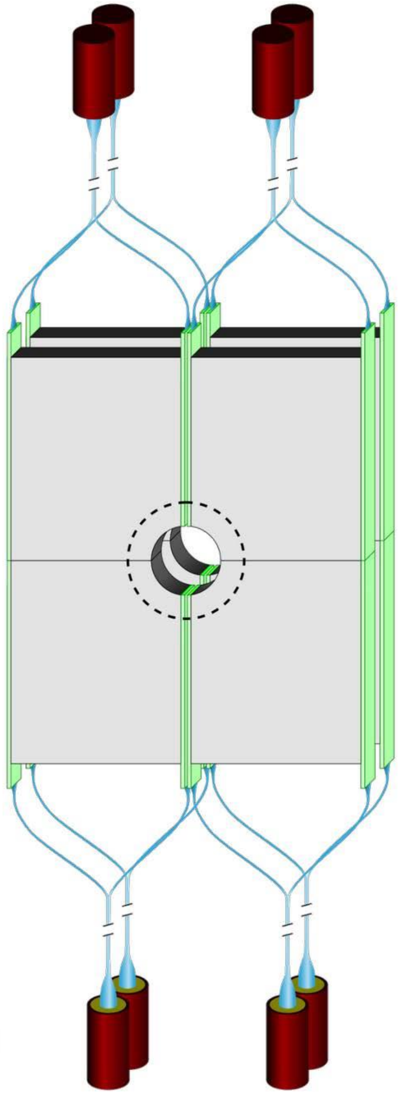
On the novel light collection technique – arXiv:1909.01184v1X

FDD – the FIT Forward Diffractive Detector

- Covering very large pseudorapidities ($5 < \eta < 7$) to study diffractive physics;
- Double-layered plastic scintillator read out by fine-mesh PMTs through WLS plastic bars and clear fibers (coincidence mode);
- Fine-mesh PMTs: B-field immunity, good timing, high signal rate capacity.

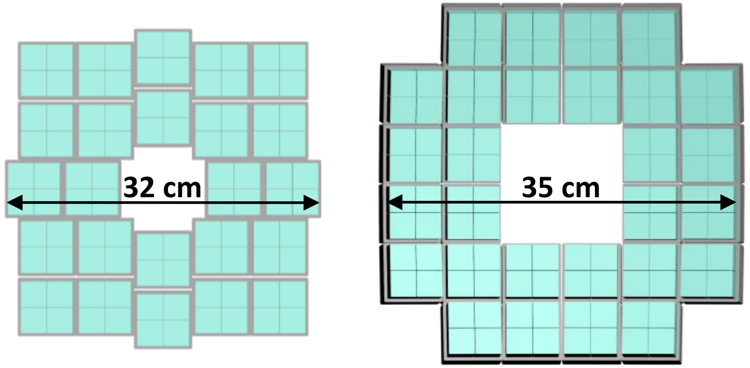




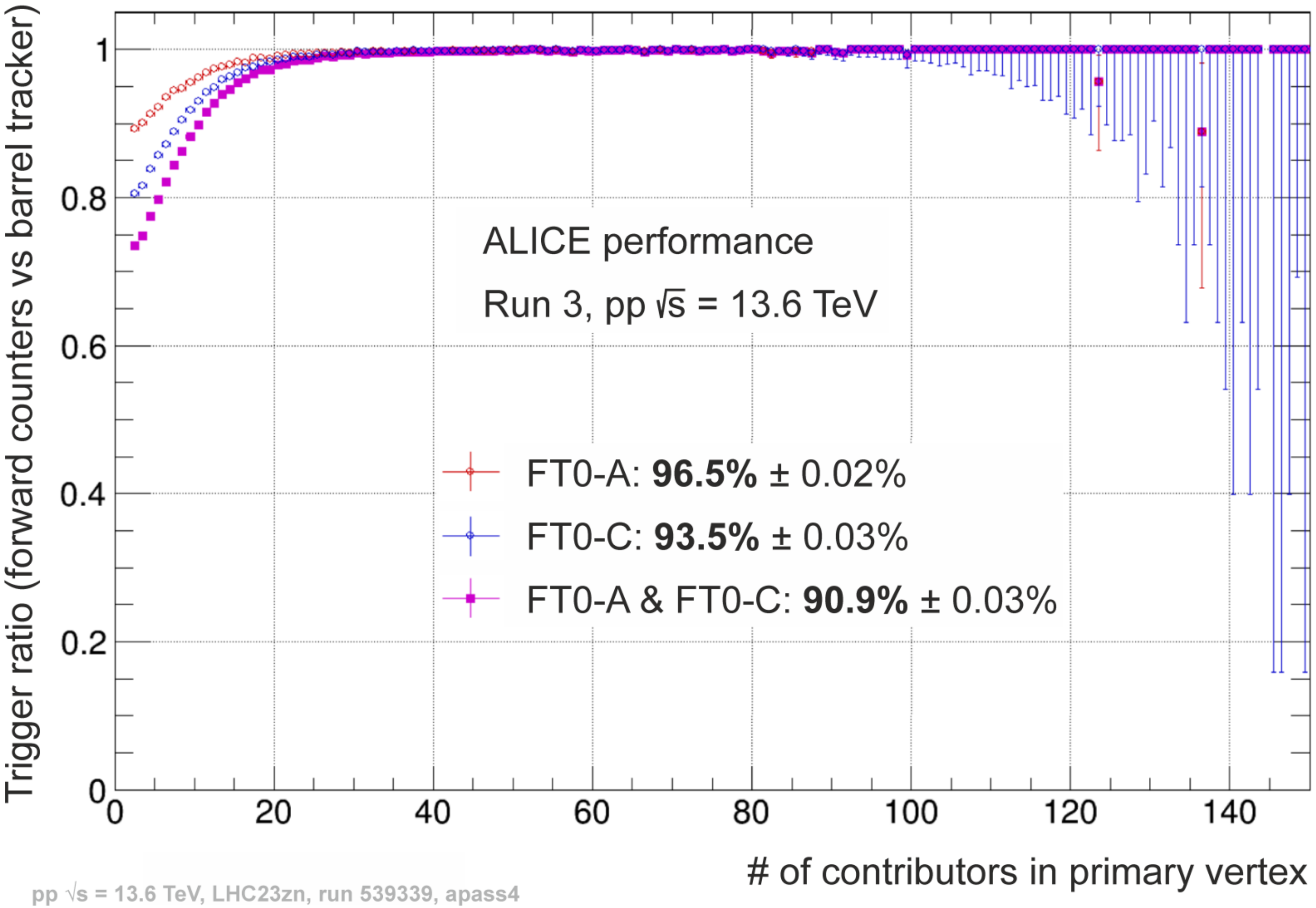


FT0 efficiency

- FT0 efficiency exceeds 90% in top-energy pp collisions;

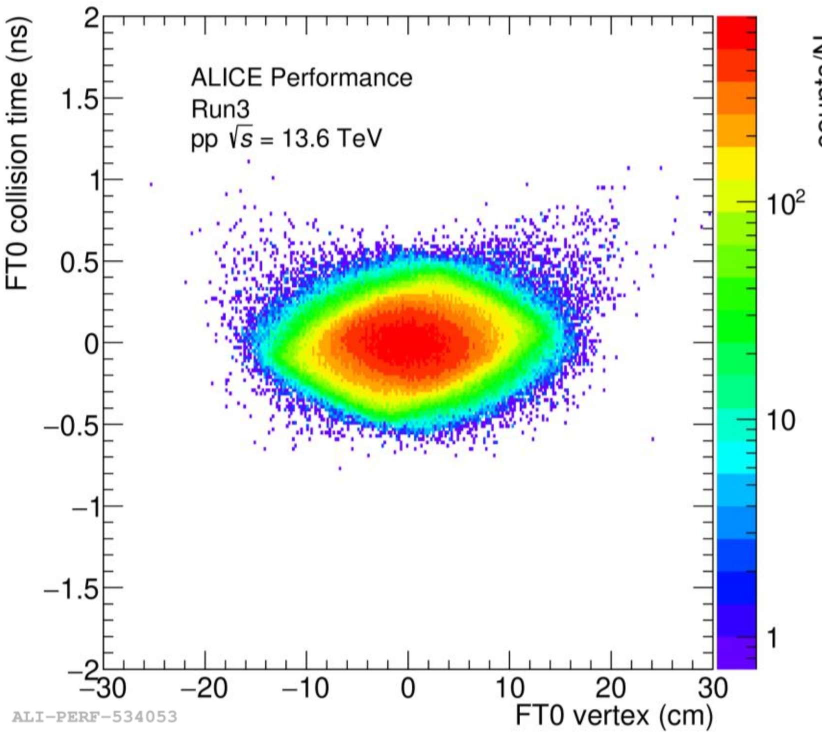


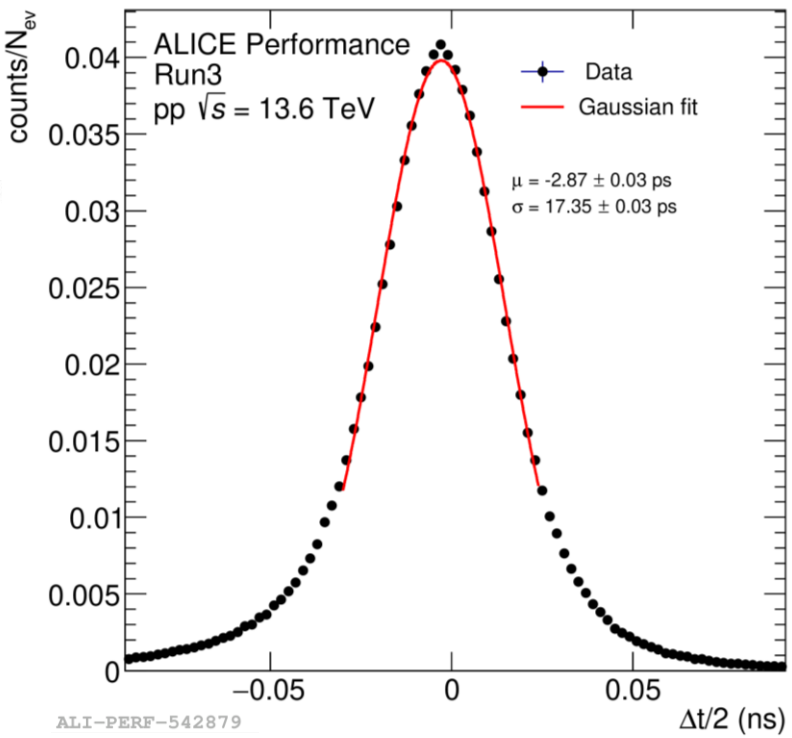
- Complemented with the larger & no-gaps FV0 detector.

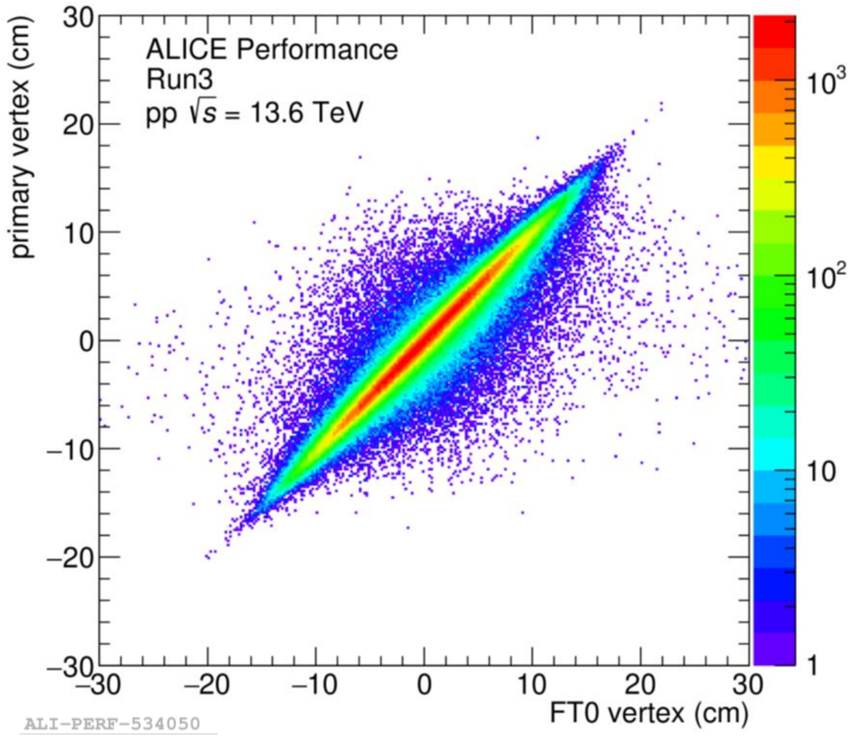


FT0 performance in proton-proton collisions

- Collision point of the LHC beams fluctuates within **±10 cm along the beam axis**;
- **σ = 17 ps ≡ ±5.1 mm** – precision of the offline time-of-flight determination of the collision point;
- Good correlation with the vertex reconstructed from the particle trajectories in the inner barrel tracker.

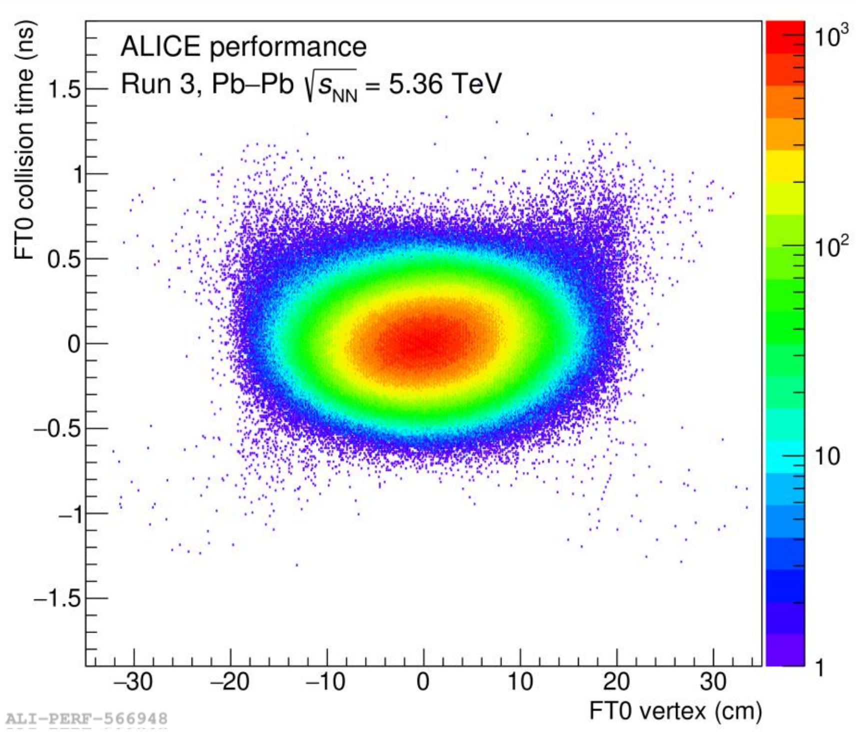


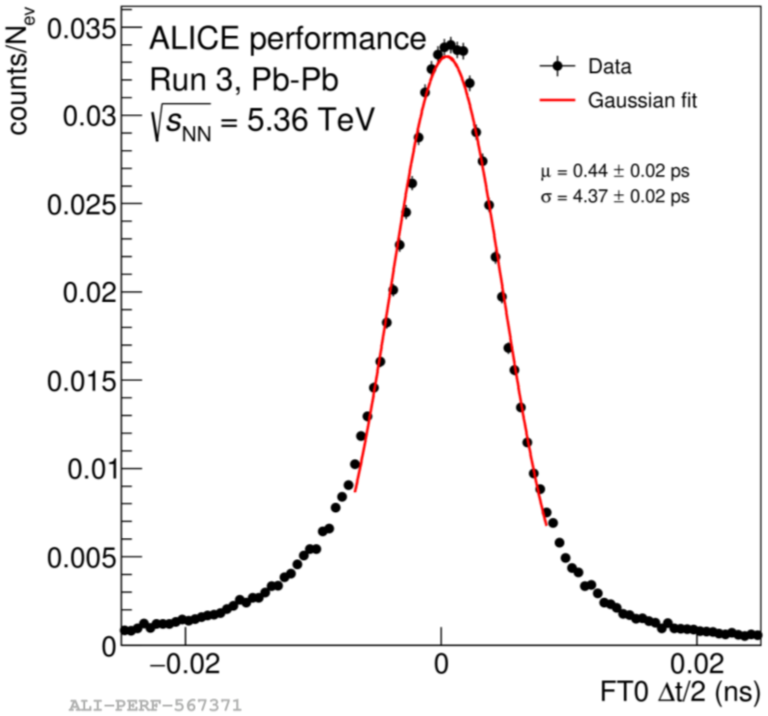


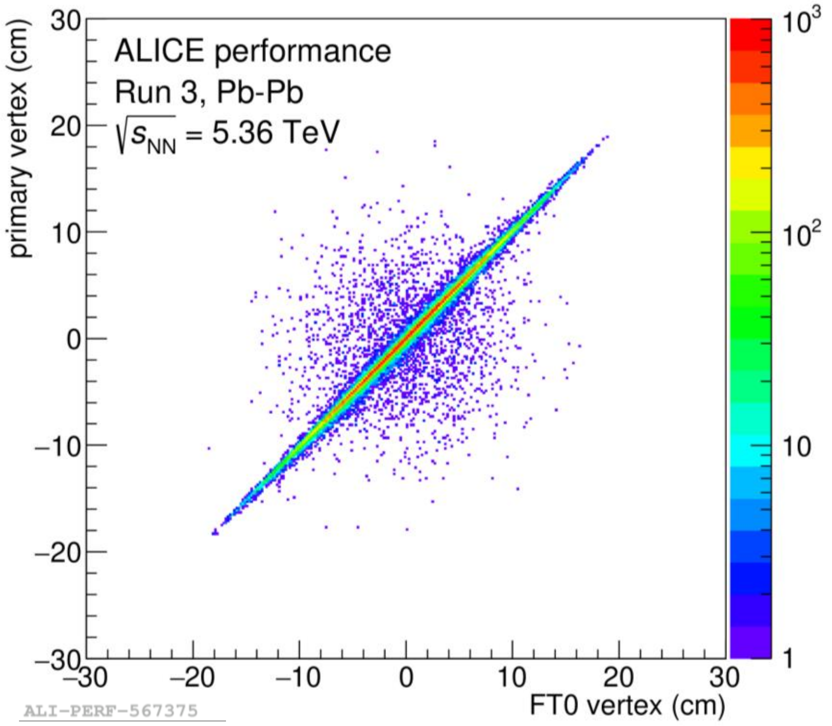


FT0 performance in Pb-Pb collisions

- Pb-Pb collisions result in much higher multiplicities **(x20)** as compared to pp $\rightarrow$ better timing precision;
- **σ = 4.4 ps ≡ ± 1.3 mm (!)** – FT0 timing precision for lead ion collisions at 5.36 TeV (with offline time-walk correction) .

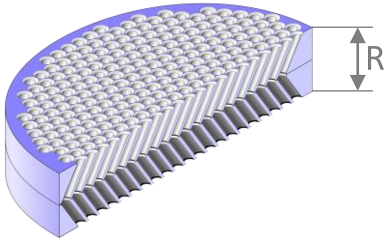






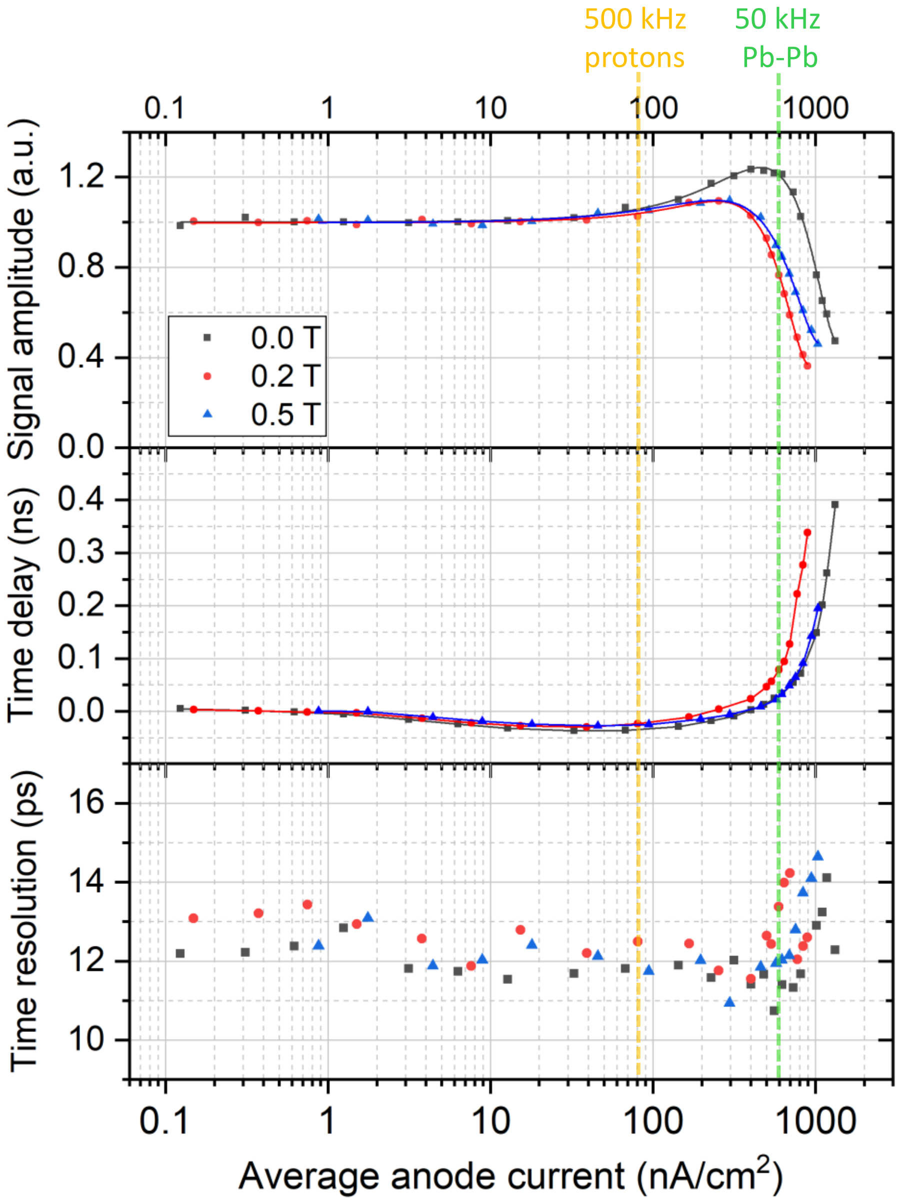
Detector technology limits – rate capability

- Rate capability of MCP-PMTs naturally limited by the MCP resistance:
  - **100 nA/cm²** for standard Planacons;
  - **800 nA/cm²** for XP85002/FIT-Q devices [(JINST 16 (2021) P12032)](JINST 16 (2021) P12032);
  - further **reduced x2** inside 0.5T B-field.



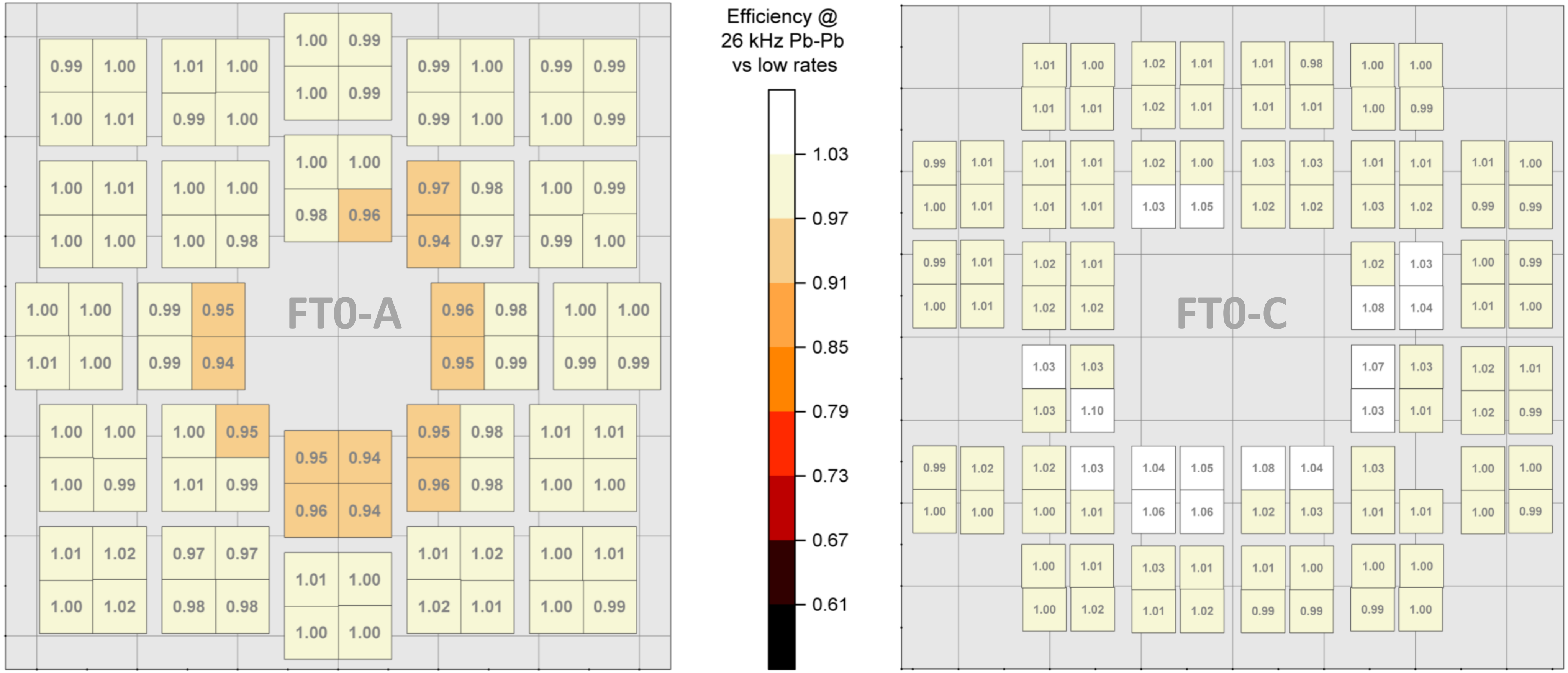
- 50 kHz Pb-Pb corresponds to ~7x10⁶ particle hits per second in each of the most occupied FT0 channels: 3x10⁸ photo-electrons/cm² → **600 nA/cm²**.

- Signal rate affects gain of the photosensors → efficiency of the "hottest" channels at highest Pb-Pb rates.



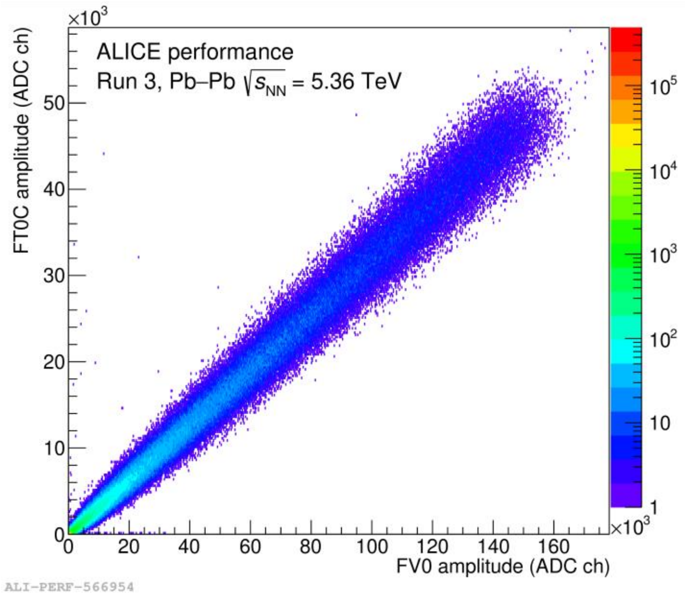
Detector technology limits – rate capability

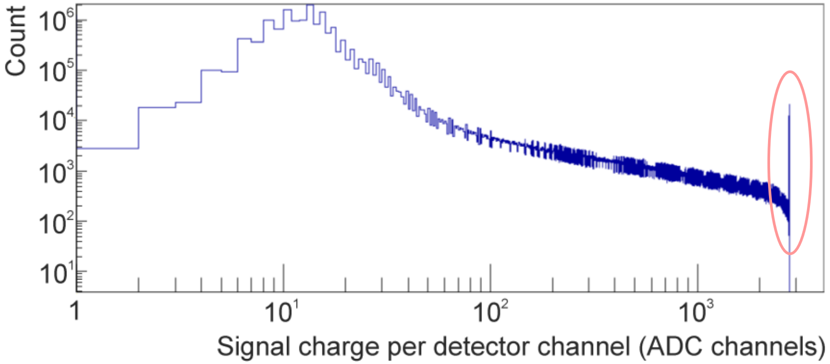
- LHC never reached 50 kHz Pb-Pb collision rate - majority of 2023 collected with 25 kHz levelling;
- Sufficient rate capability of all FT0 channels at 25 kHz.

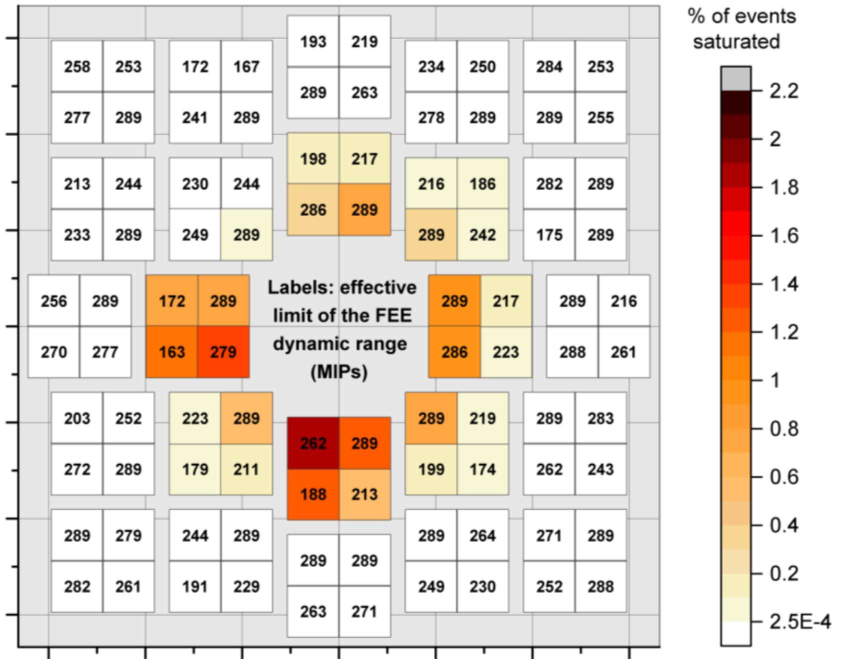


Detector technology limits – dynamic range

- **No limitation at the photosensor level (linearity range > 1:3000);**
- Effective dynamic range limited by:
  - ADCs resolution **(12 bits)**;
  - CFD threshold bottom limit (**~3 mV** → 0.5 MIP);
  - Inhomogeneous response across the MCP-PMTs (**≤1:1.5** at start);
- All limitations combined, effective FT0 dynamic range exceeds **1:500** for the majority of channels → good linearity of FT0-C vs FV0;
- Minor portion of signals fall outside the ADC range in the few central channels of FT0-A at R ≈ 6 cm;
- The full set of FT0-A channels is kept for the higher efficiency in proton collisions.



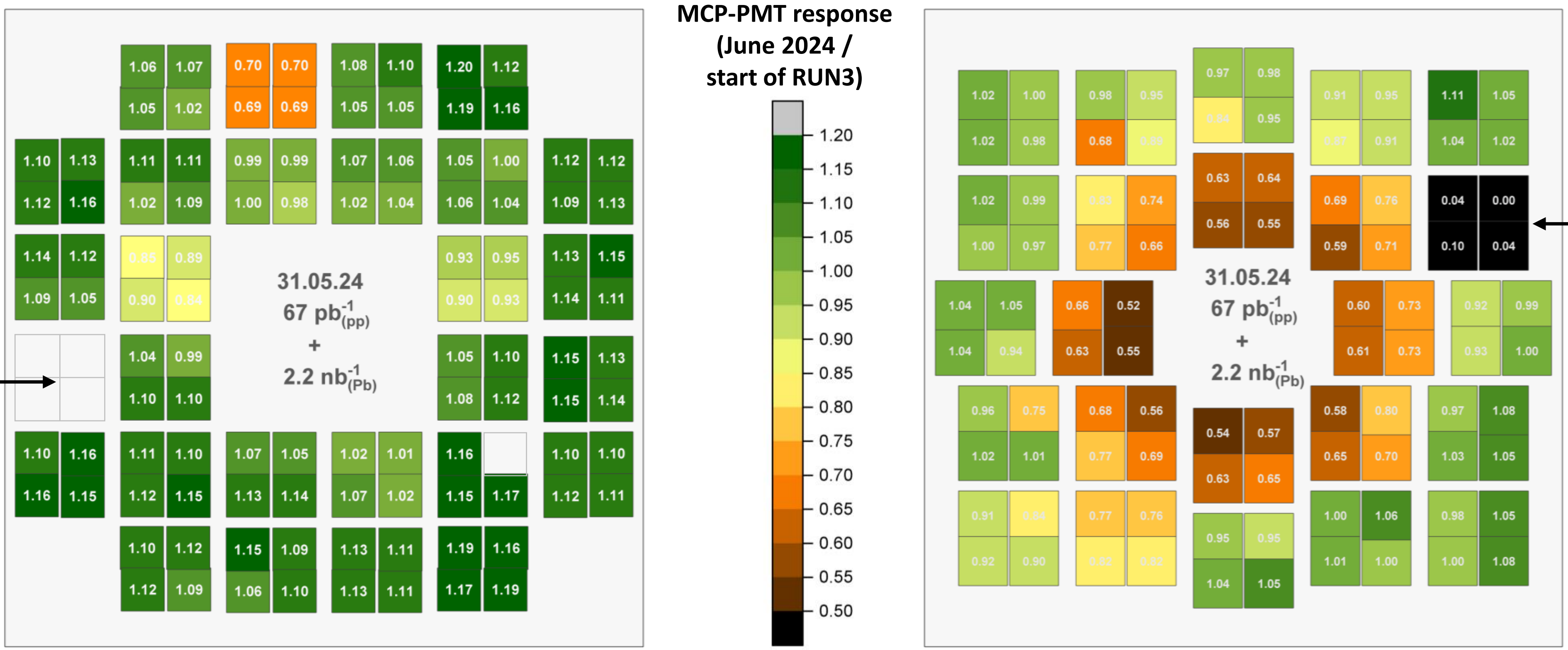




Detector technology limits – ageing

- Lifetime of MCP-PMTs without atomic layer deposition (ALD) is limited to a fraction of that for classical PMTs;
- ALD-MCP-PMTs have long lifetime, but unacceptably low rate capability [JINST 13 (2018) T09001, NIM A 949 (2020) 162854];
- FIT's choice was to go for non-ALD MCP-PMTs securing **orders-of-magnitude margin in photon statistics;**
- We are monitoring ageing evolution, compensating it by HV increase: **x2 drop seen so far (x10 looks acceptable).**

HV breakdown across the MCP



Proven vacuum microleak

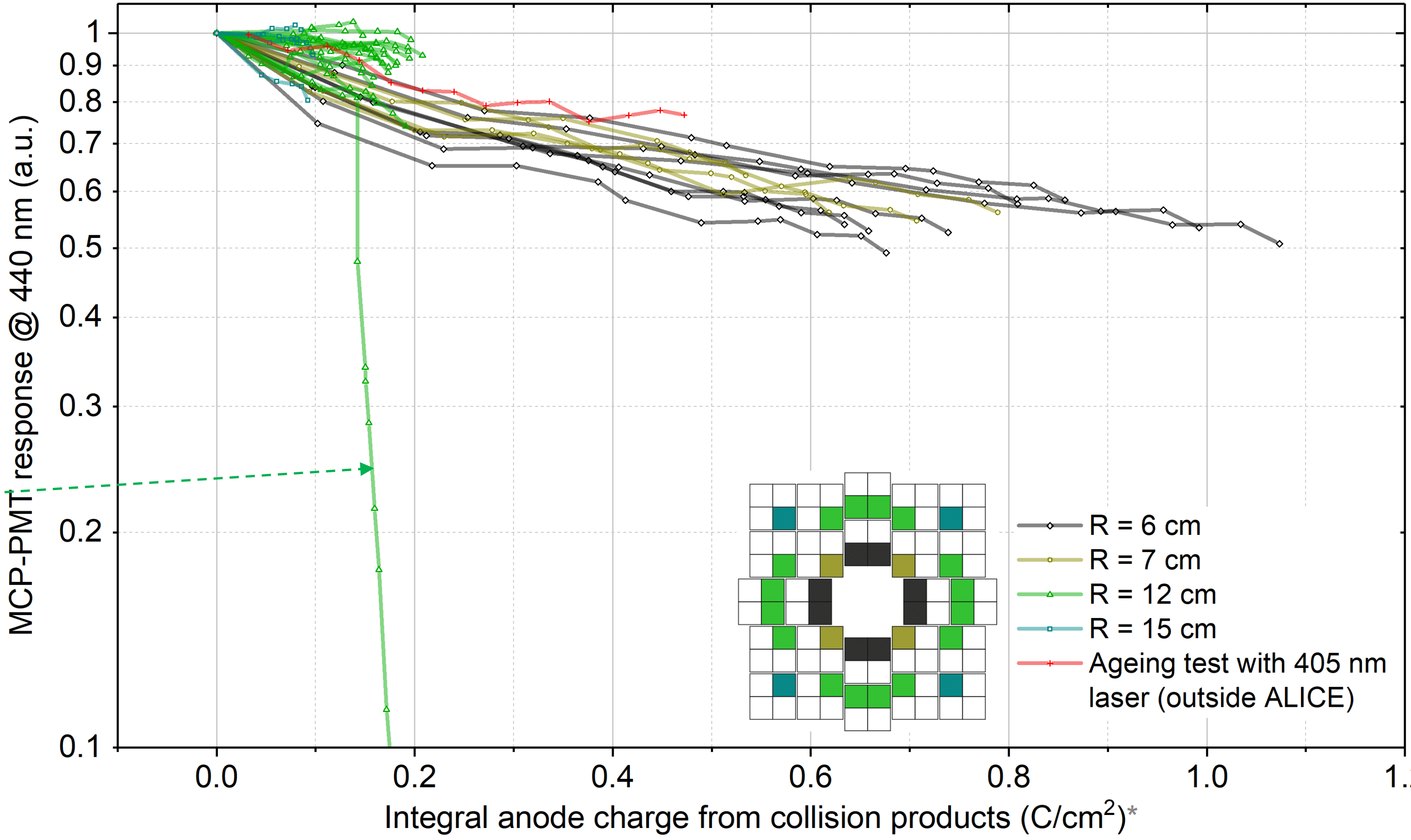
Detector technology limits – ageing

Ageing is proportional to the Integral Anode Charge (IAC) – **distinct from radiation damage;**

Smooth ageing trends versus IAC:

Unlike of those reported a decade ago [JINST 6 (2011) C10001], lifetime of modern non-ALD MCP-PMTs **exceeds 1 C/cm²** →

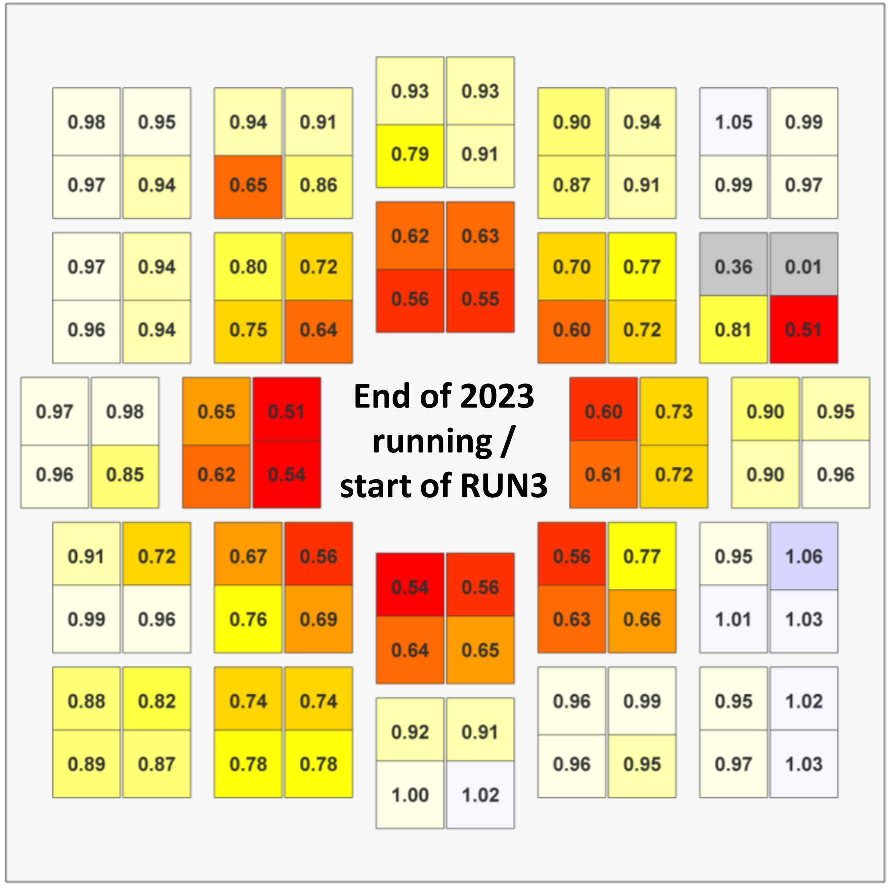
The only outlier here suffered from accelerated ageing caused by a vacuum microleak

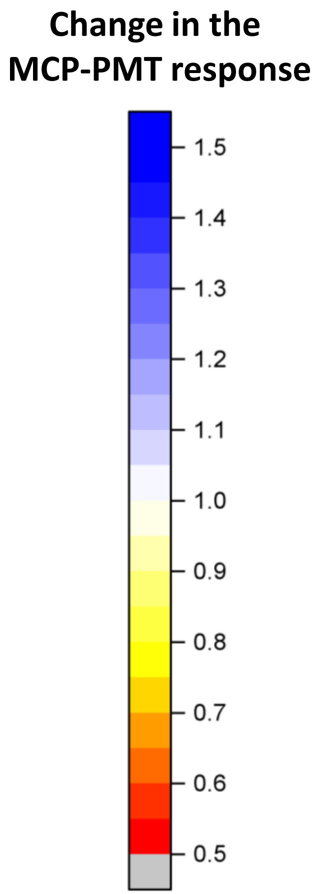


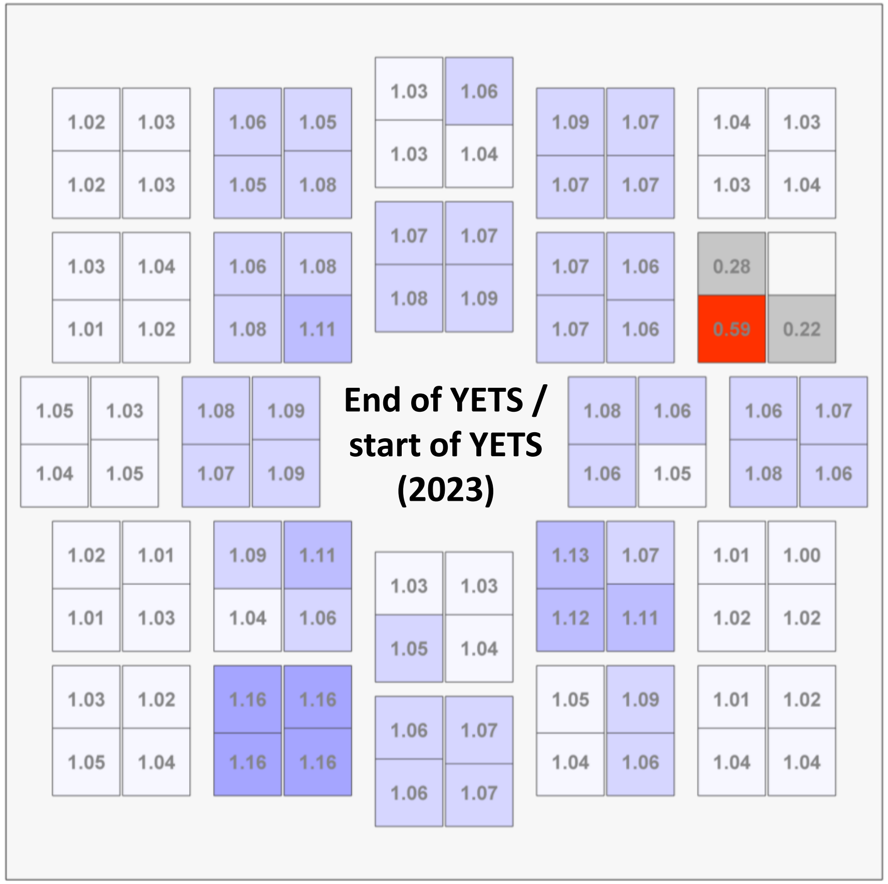
*background contribution unaccounted, but small.

Detector technology surprises – MCP-PMT “self-annealing”

- A newly-observed effect taking place during the Year-end technical stops (YETS) of the LHC;
- YETS 2023-2024 secured 160 days of no-lumi, causing notable self-recovery of the aged MCP-PMTs.

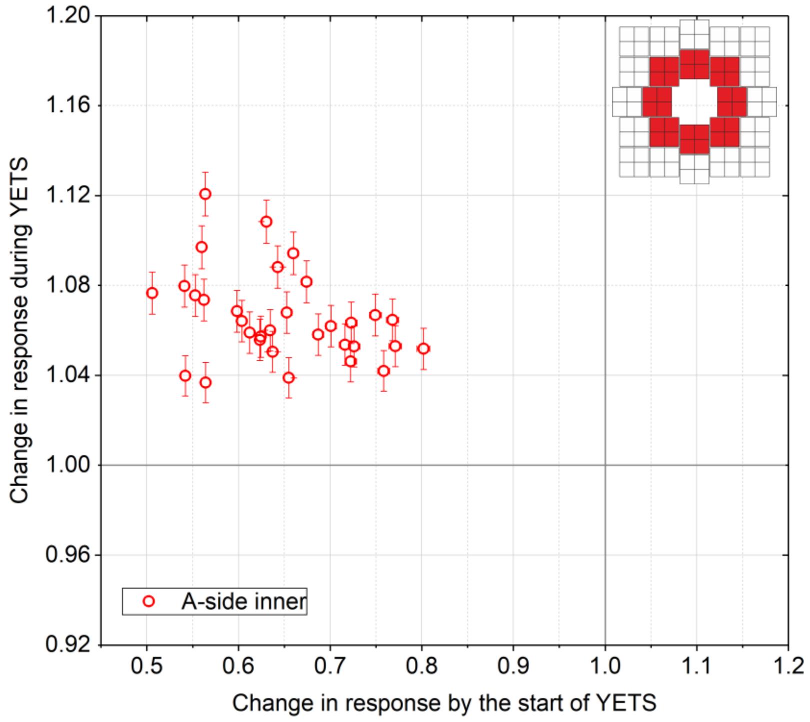


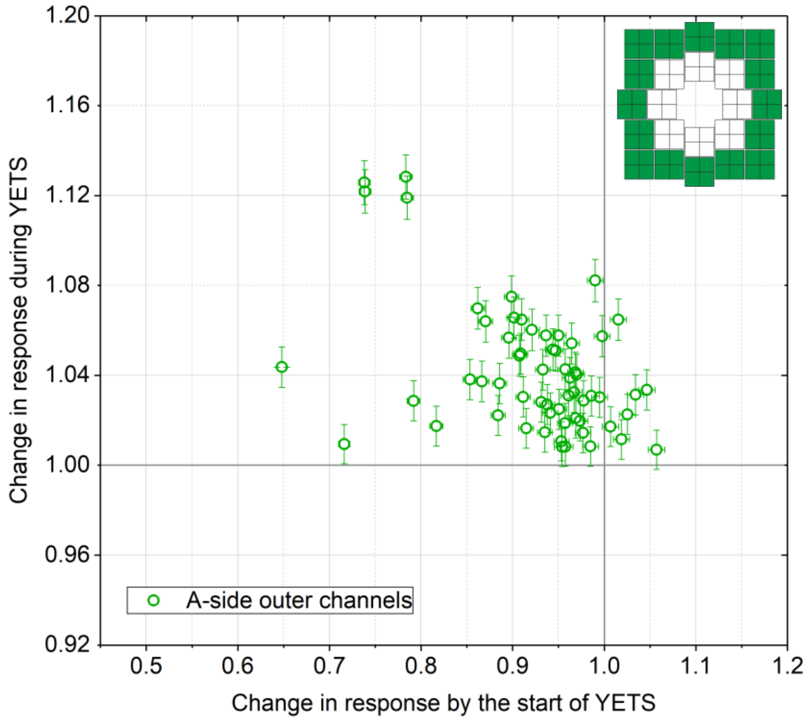


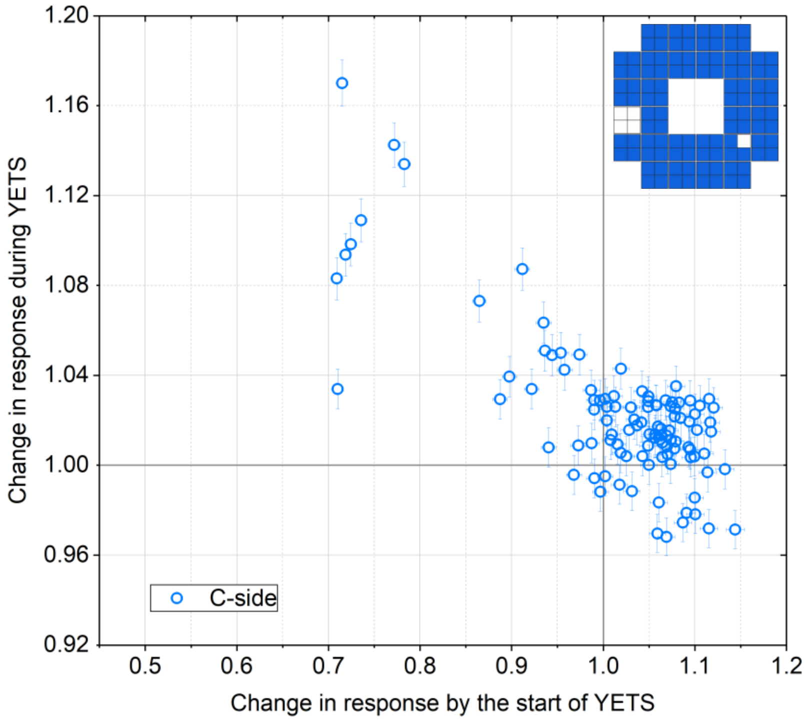


Detector technology surprises – MCP-PMT “self-annealing”

- No ageing → no annealing;
- More ageing → more annealing (true at moderate ageing);
- Strong ageing → notable annealing.

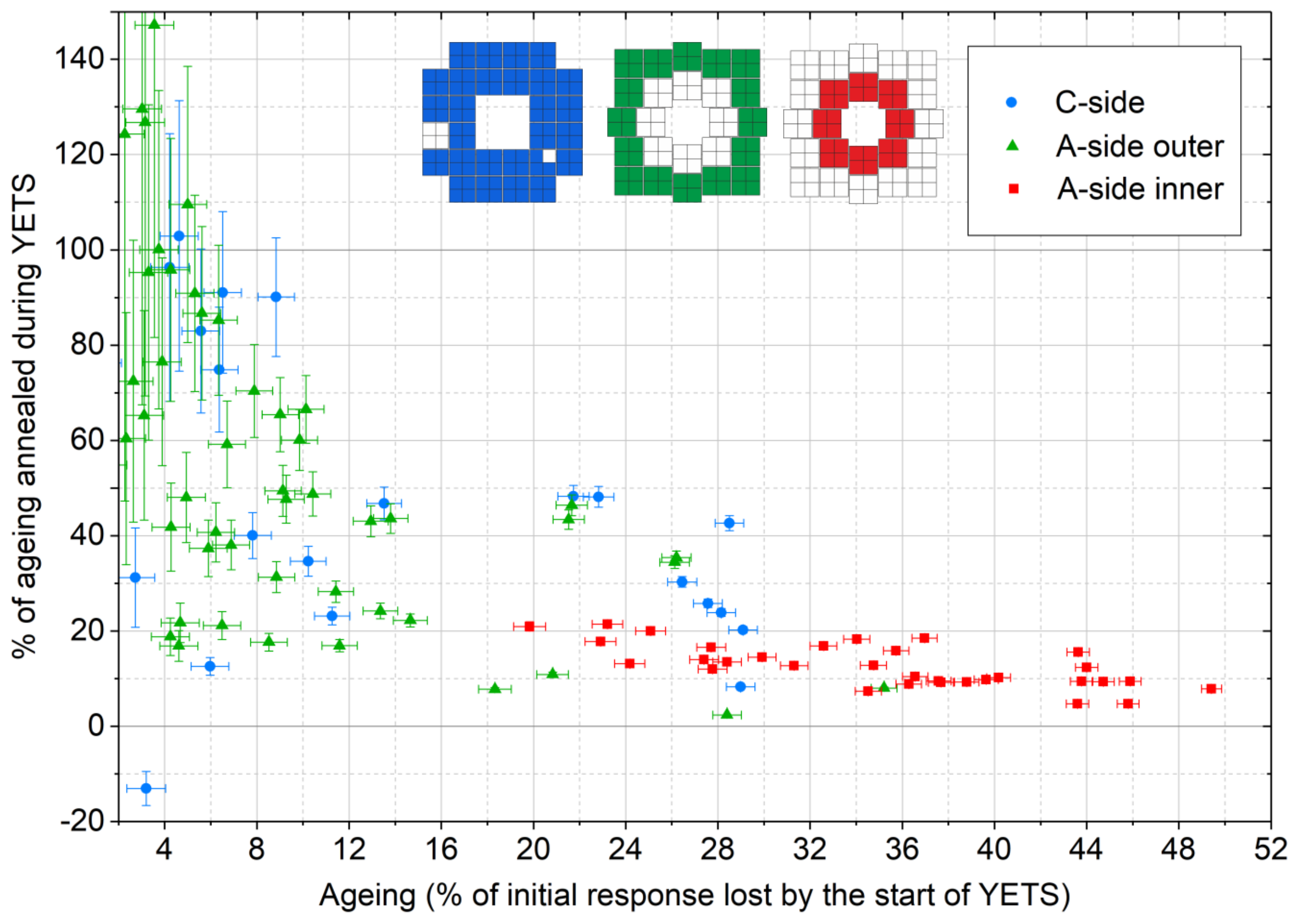


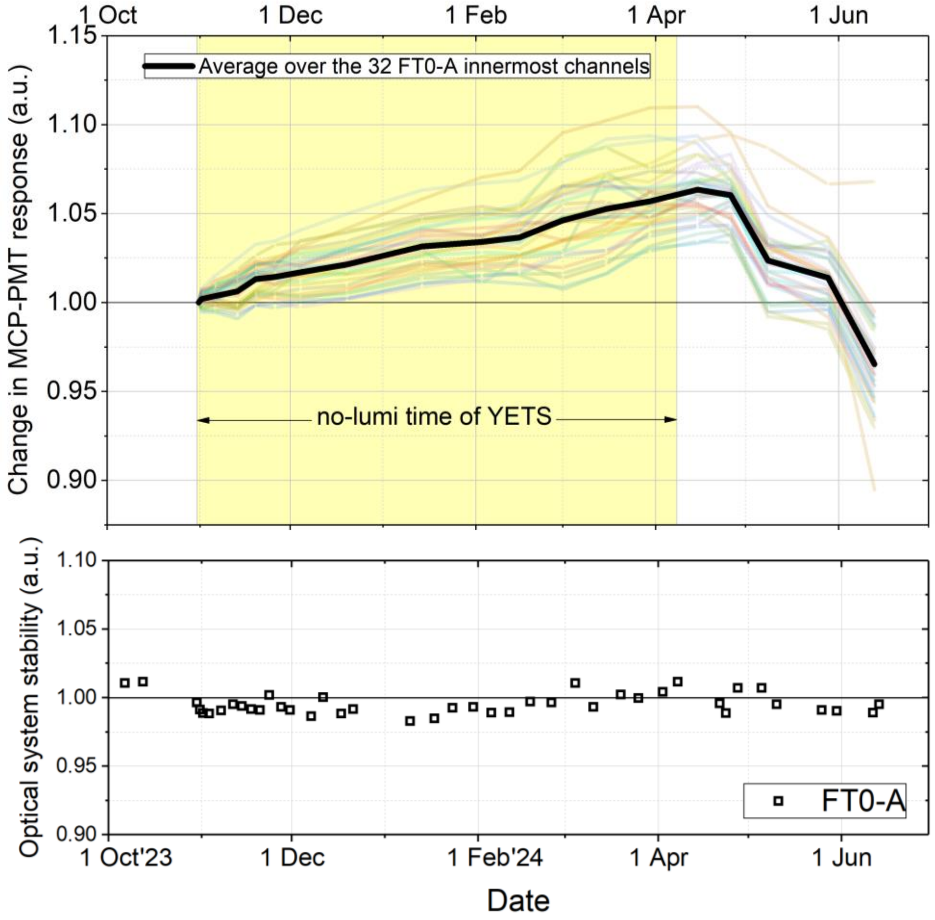




Detector technology surprises – MCP-PMT “self-annealing”

- In 160 days of no-lumi, 5…100% of ageing recovers in all affected channels;
- Response recovers monotonously and permanently (ageing of the recovered device is no faster than of a new one).





Outlook

FIT will operate till the end of LHC RUN4 (2032).

Foreseen LS3 interventions (2026-2028):

- Replacement/rearrangement of degraded MCP-PMTs;
- Scrutiny of the MCP-PMT annealing signs once the devices are extracted from ALICE;
- FV0 & FDD FEE upgrade to improve the running efficiency at high rates & high loads
    - *New front-end cards with digitalized discriminator and time reference;*
    - *Even wider dynamic range;*
    - *Online tagging of pileup and background events.*

Conclusions

- **Smooth FIT running as an essential ALICE's subsystem since 2022;**

- **Success story of using the cost-effective* MCP-PMTs in the ALICE's forward region:**
  - Key contributor to the remarkable timing precision of **σ = 4.4 ps;**
  - Handling photon fluxes of up to **$3*10^8$ p.e./cm^2/s**;
  - Ageing balanced by HV increase **without timing deterioration beyond 1 C/cm^2 IAC;** the two degraded sensors suffered from a vacuum microleak and a HV breakdown;
  - **Self-annealing of aged channels** – newly observed effect;
  - Operable in non-axial 0.5T B-field; HV still below **1.5 kV** – far away from the rated maximum (2.0 kV).

(*25 µm pore size, non-ALD)

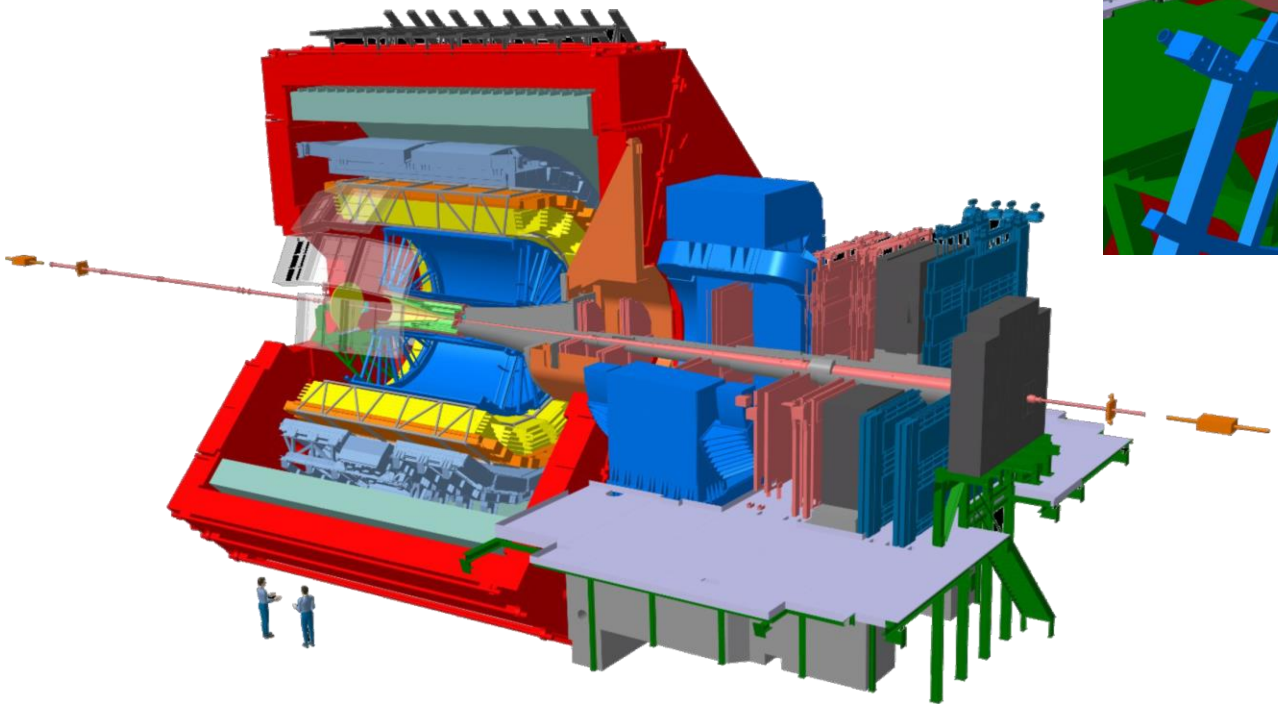
Thanks a lot for your attention!

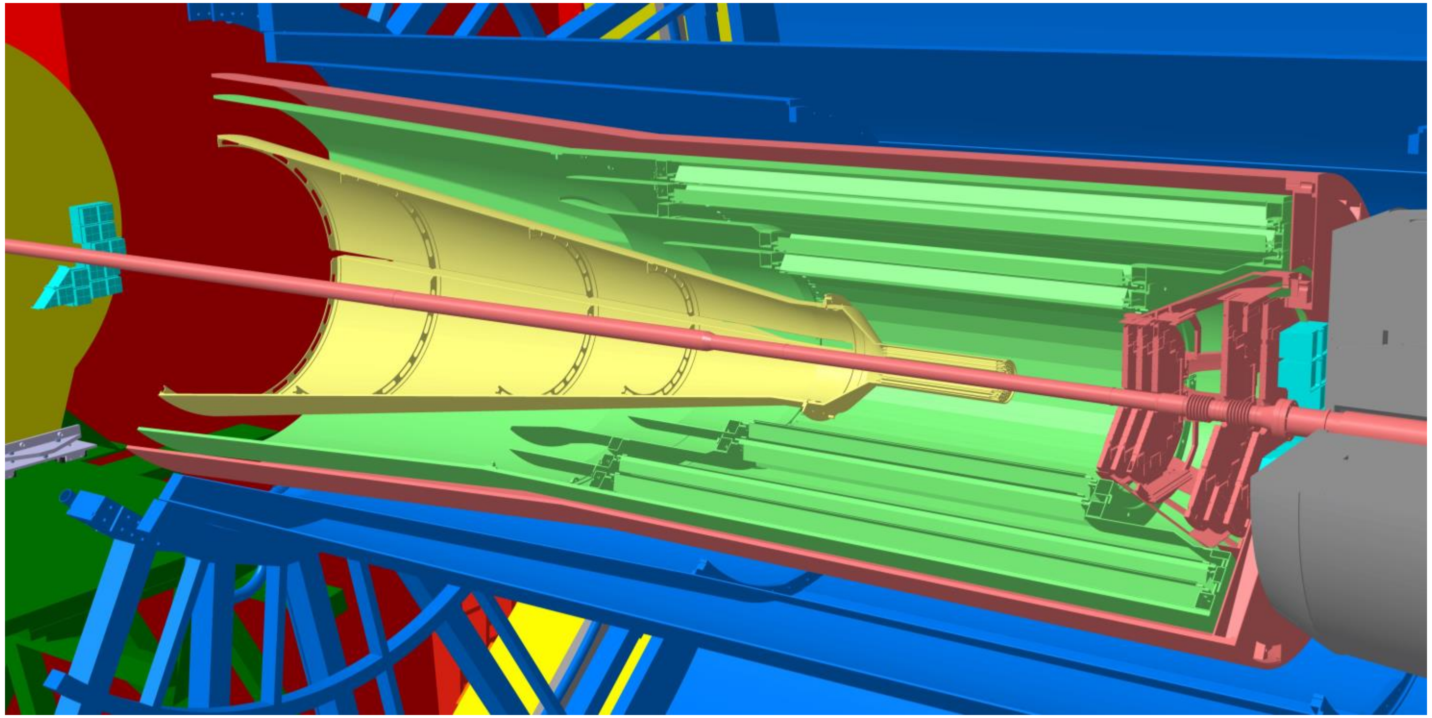
FIT outreach videos on YouTube:

- EN: https://youtu.be/PjsBIbKsuO0
- ESP: https://youtu.be/qR_lG7K3pfs
- PO: https://youtu.be/31s8jix2omo
- RU: https://youtu.be/phN0AohEDKI

Back-up slides

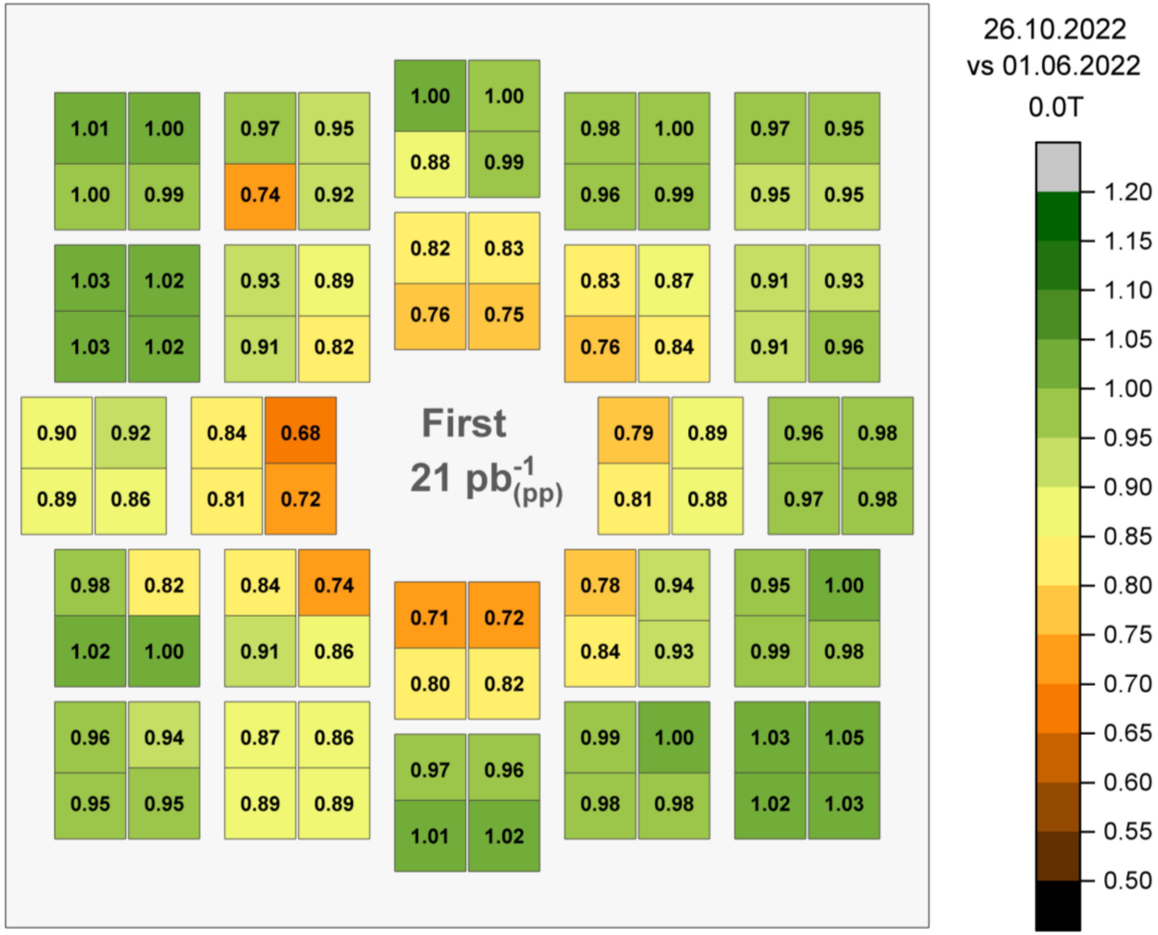
FIT within ALICE





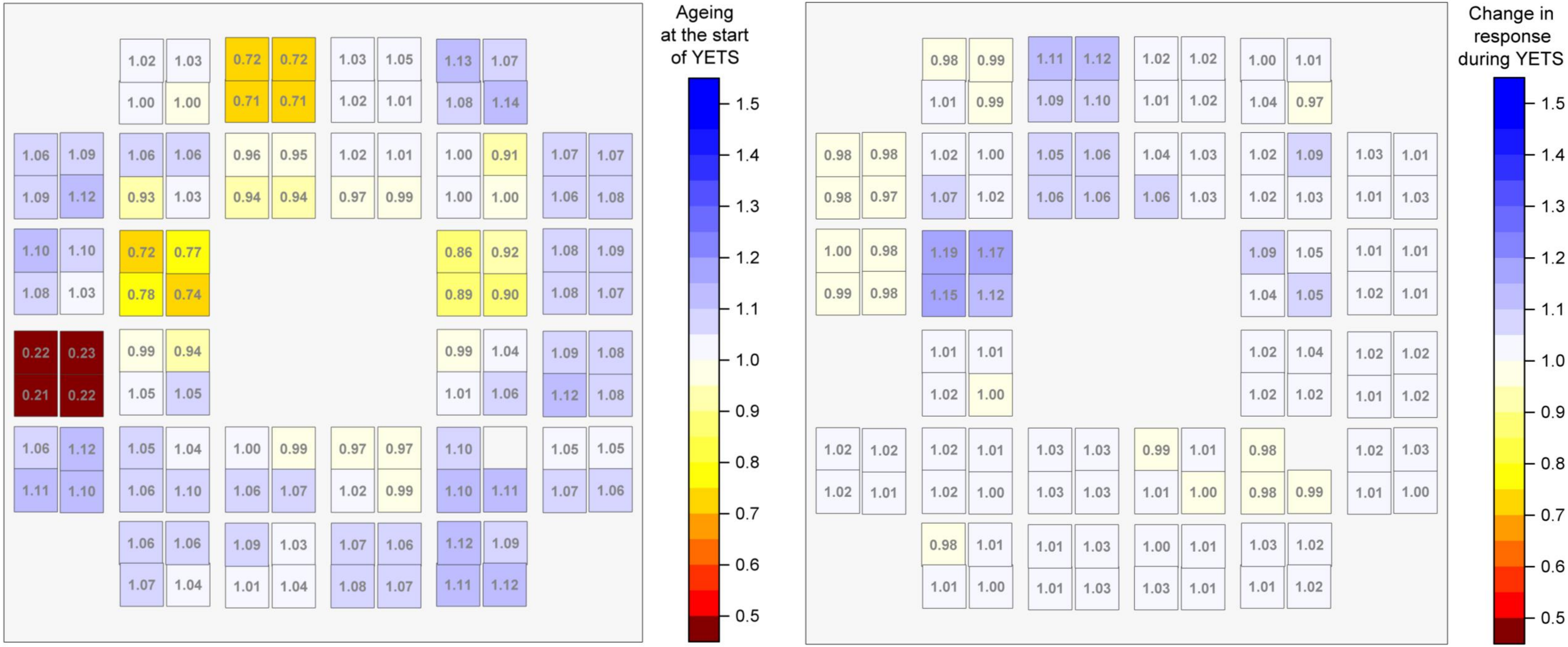
Ageing of the annealed MCP-PMTs

"Ageing speed" of the annealed MCP-PMTs is lower than that of the brand new ones.
(= this is a permanent effect)



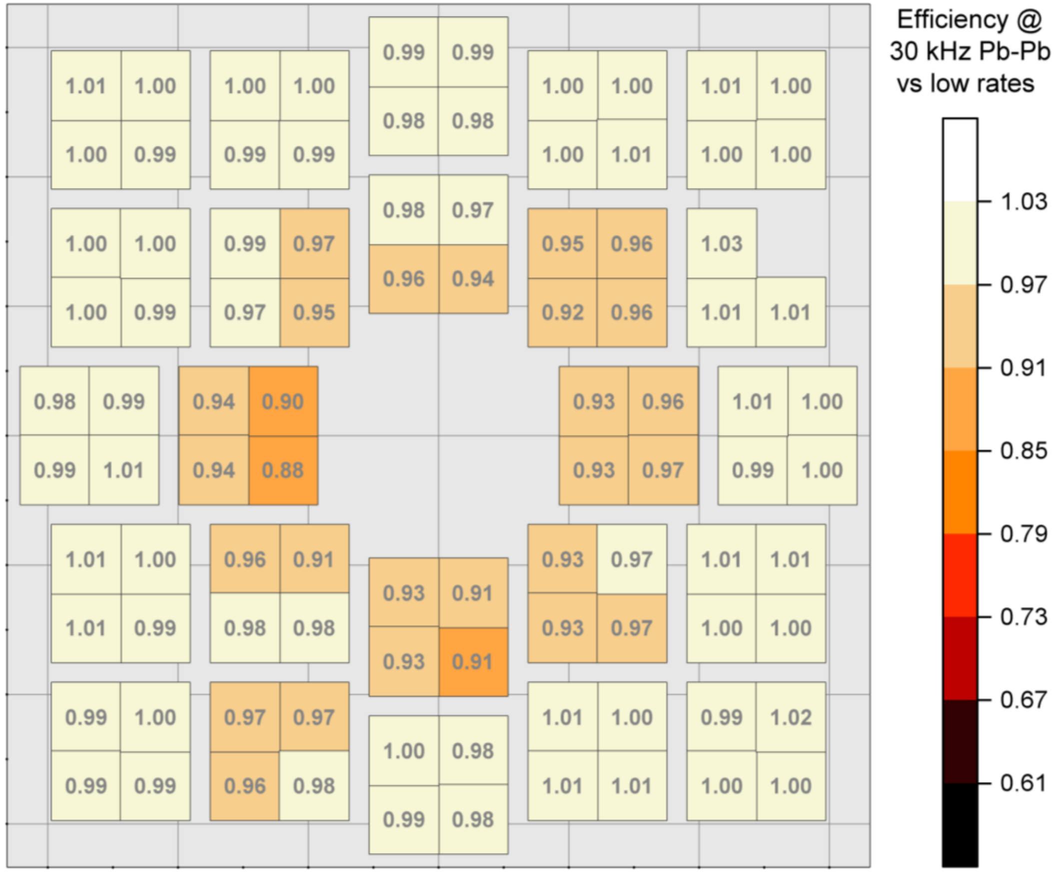
C-side ageing & annealing maps

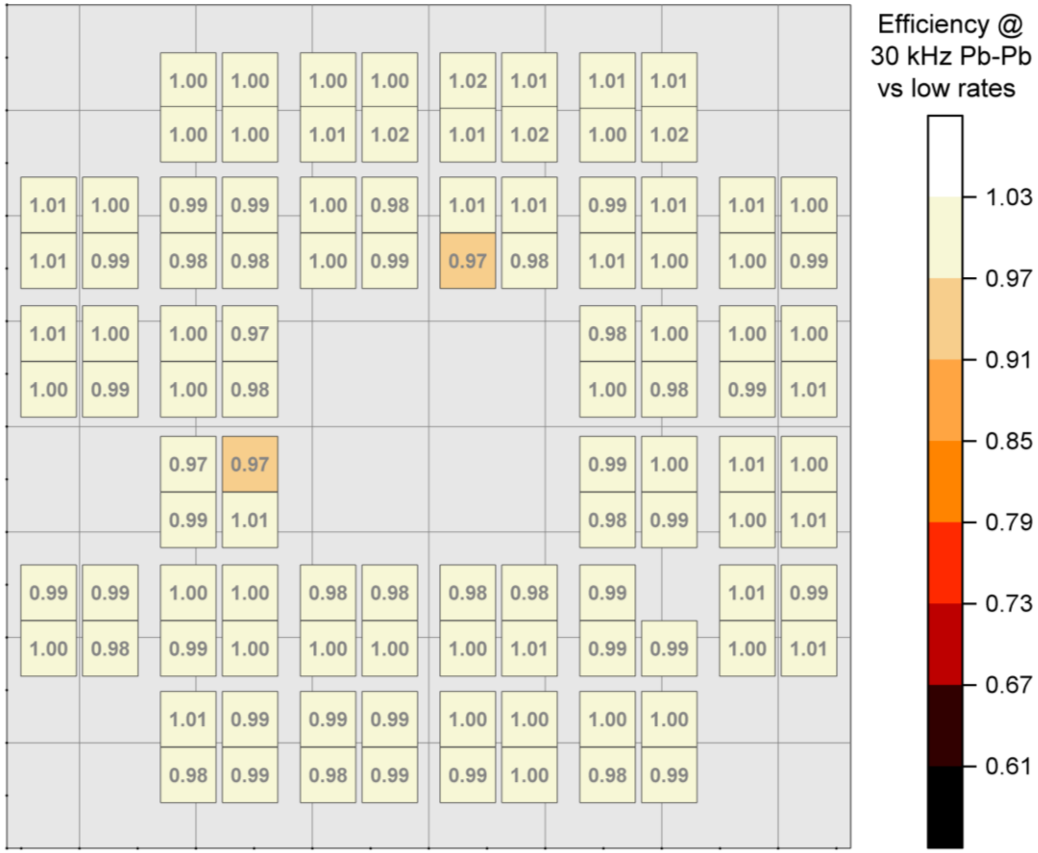
- Partial ageing recovery during the year-end technical stops (160 days of no-lumi);



Rate capability (30 kHz Pb-Pb)

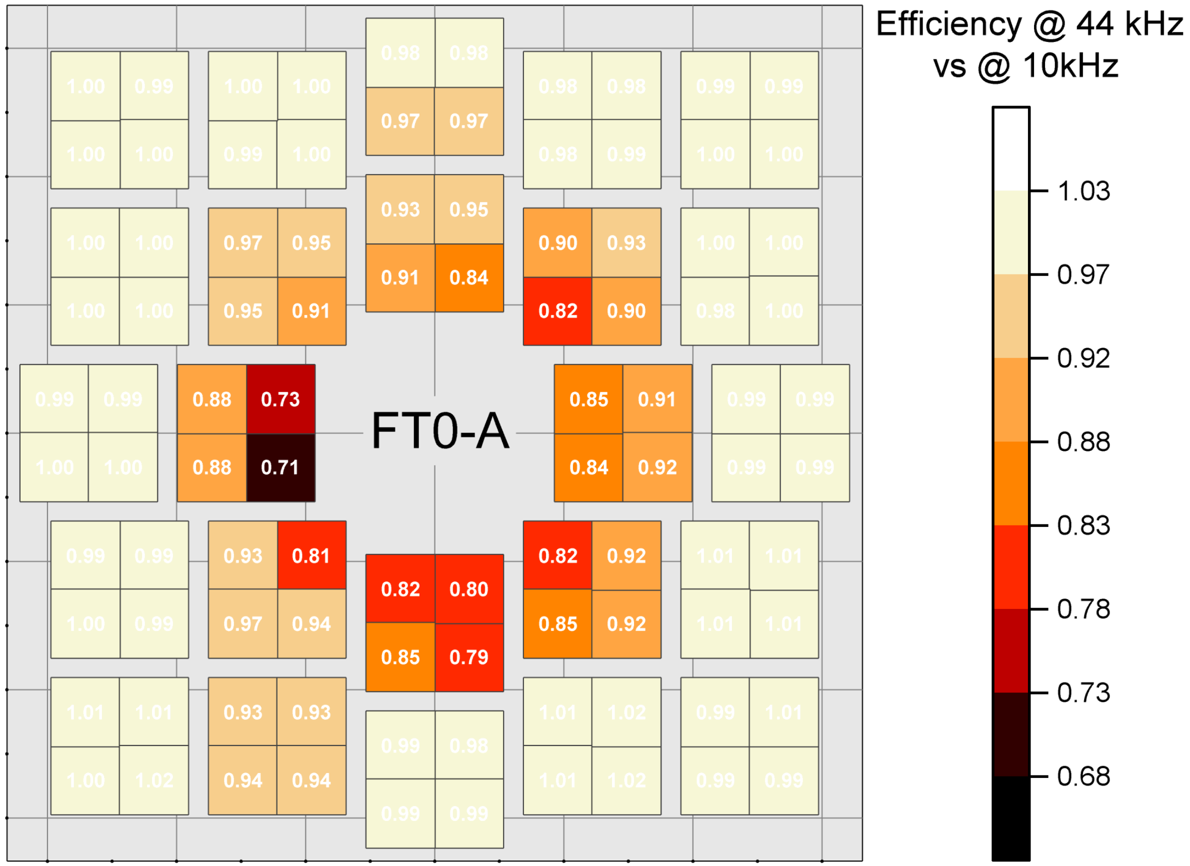
- LHC never reached 50 kHz Pb-Pb collision rate - majority of 2023 collected with 25 kHz levelling;

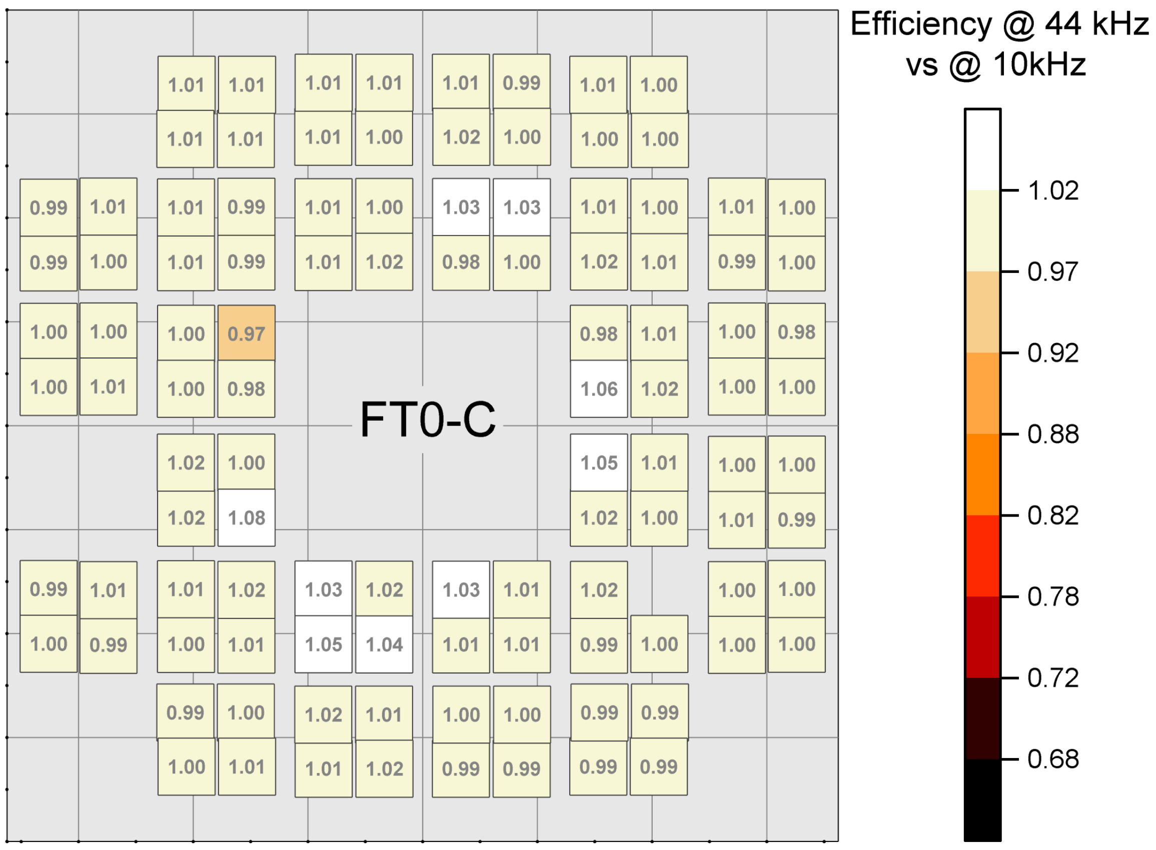




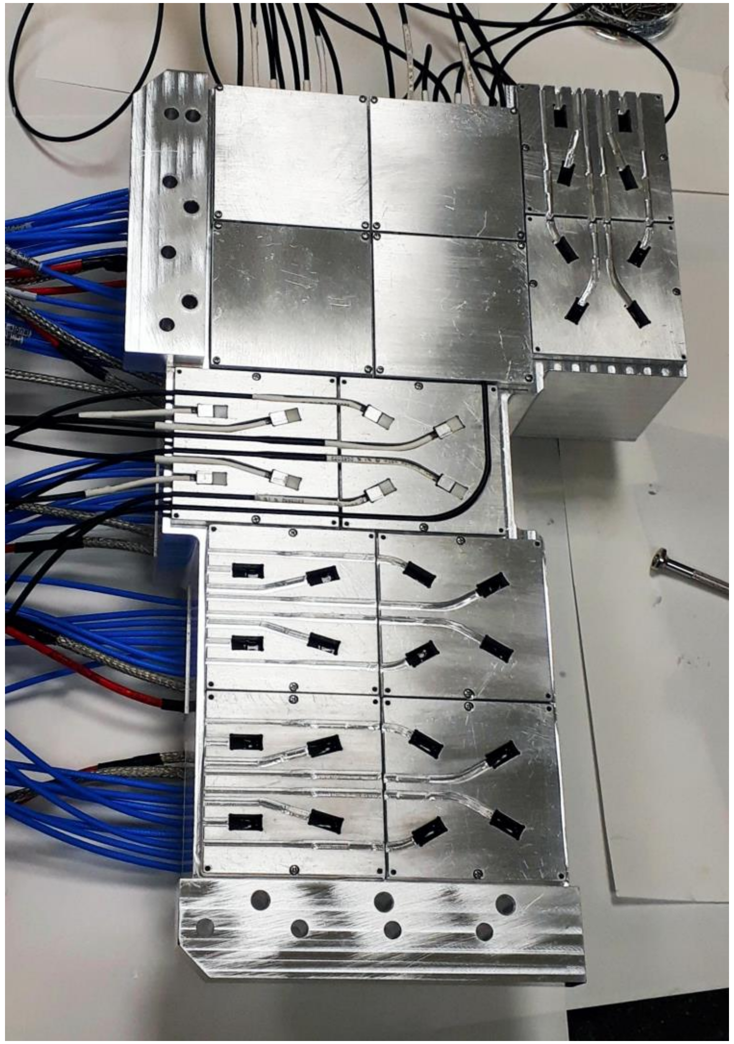
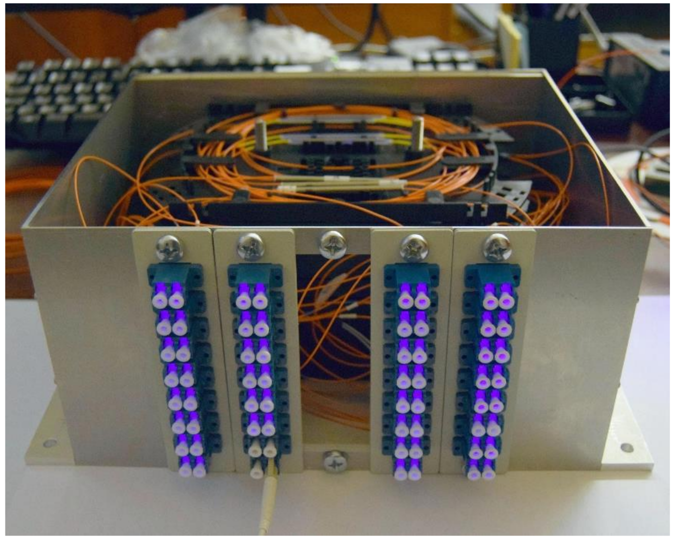
Rate capability (44 kHz Pb-Pb)

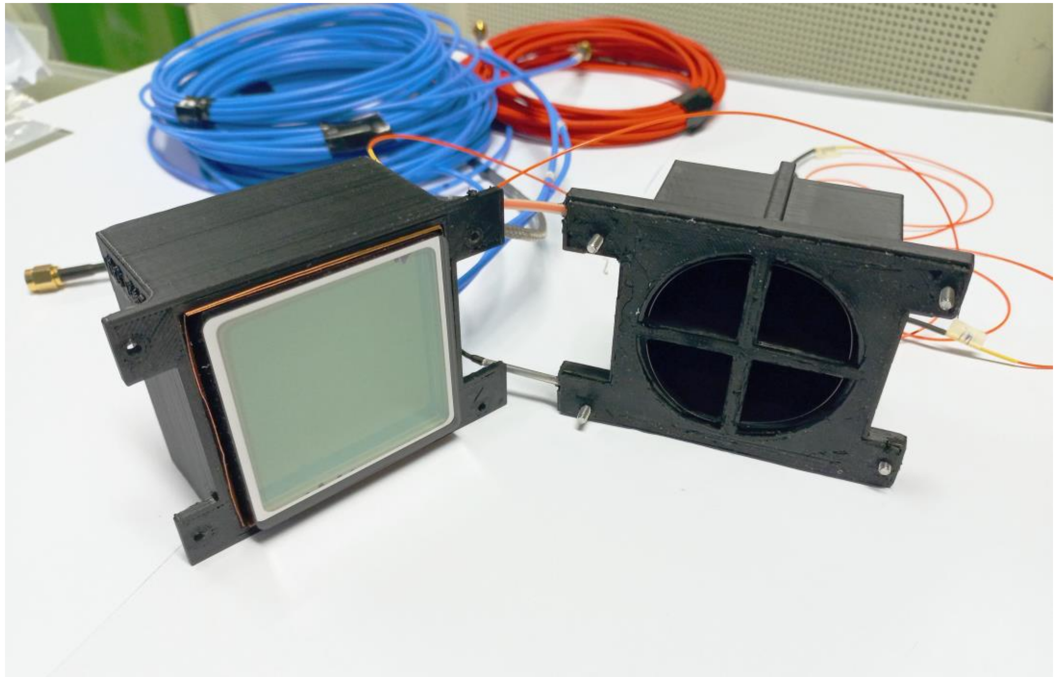
- LHC never reached 50 kHz Pb-Pb collision rate - majority of 2023 collected with 25 kHz levelling;





FIT laser monitoring components

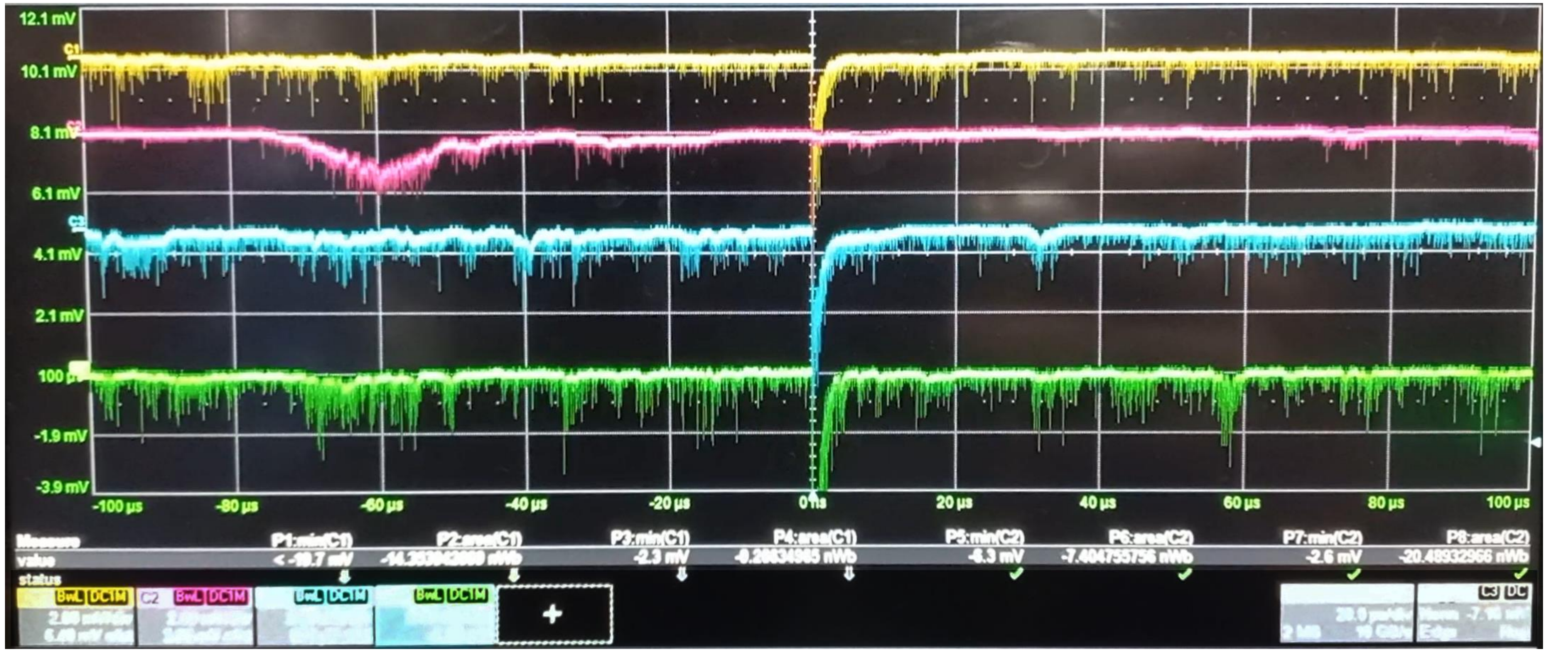






The vacuum microleak signatures

Going from the operational voltage (~1.2 kV) to ~1.6 kV, a clear patter of a vacuum leak is seen on a wider time scale:

1) SPE noise in live channels increased x10^6;
2) µs-wide “hills” of noise signals in the dead channel – those are local ion backflow avalanches;
3) no laser signal detected by the dead channel;
4) 0.1 – 3 µs-long tail of the ion backflow “beard” after the laser pulse in live channels;



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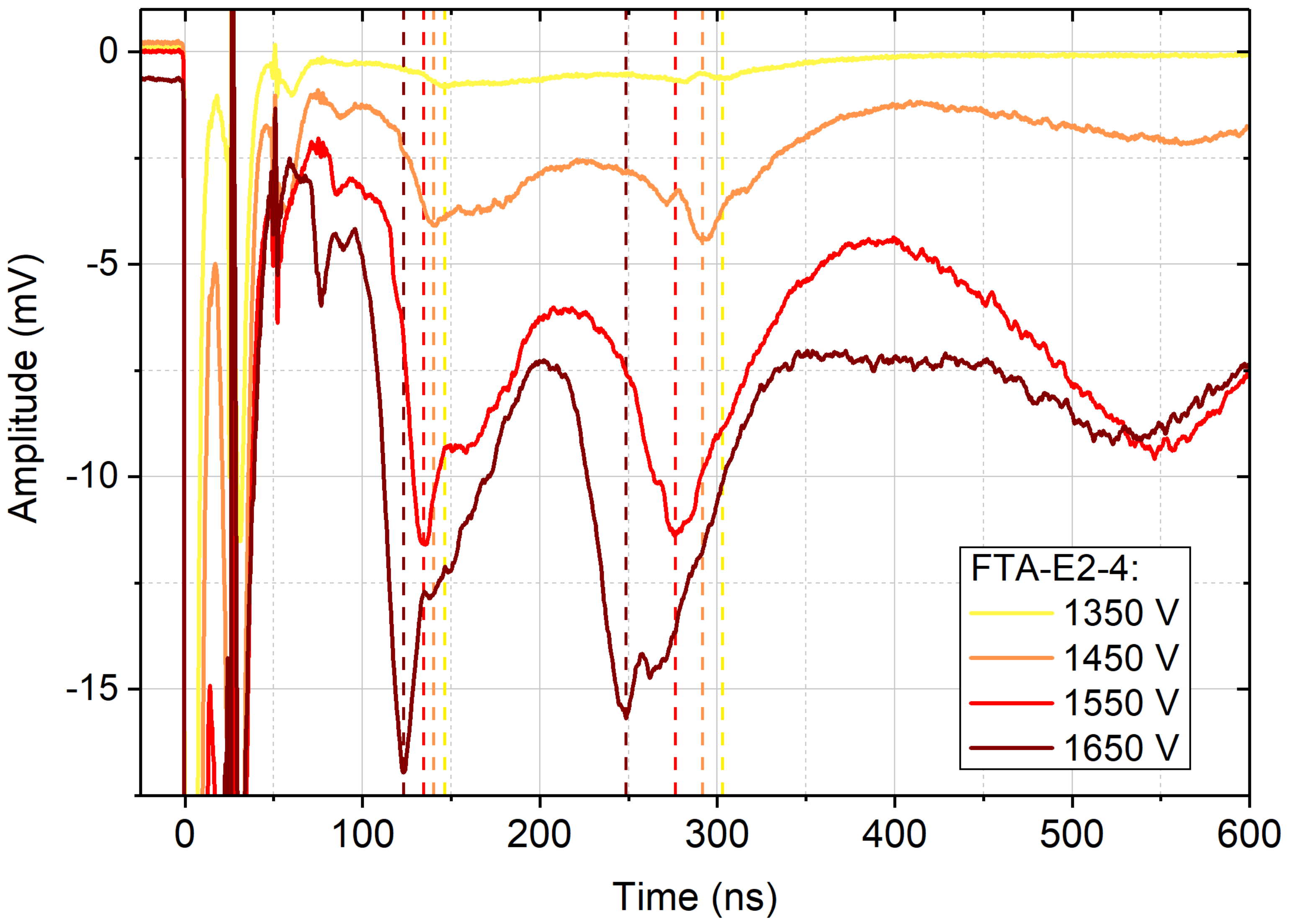
3) no laser signal detected by the dead channel;

4) 0.1 – 3 µs-long tail of the ion backflow "beard" after the laser pulse in live channels;

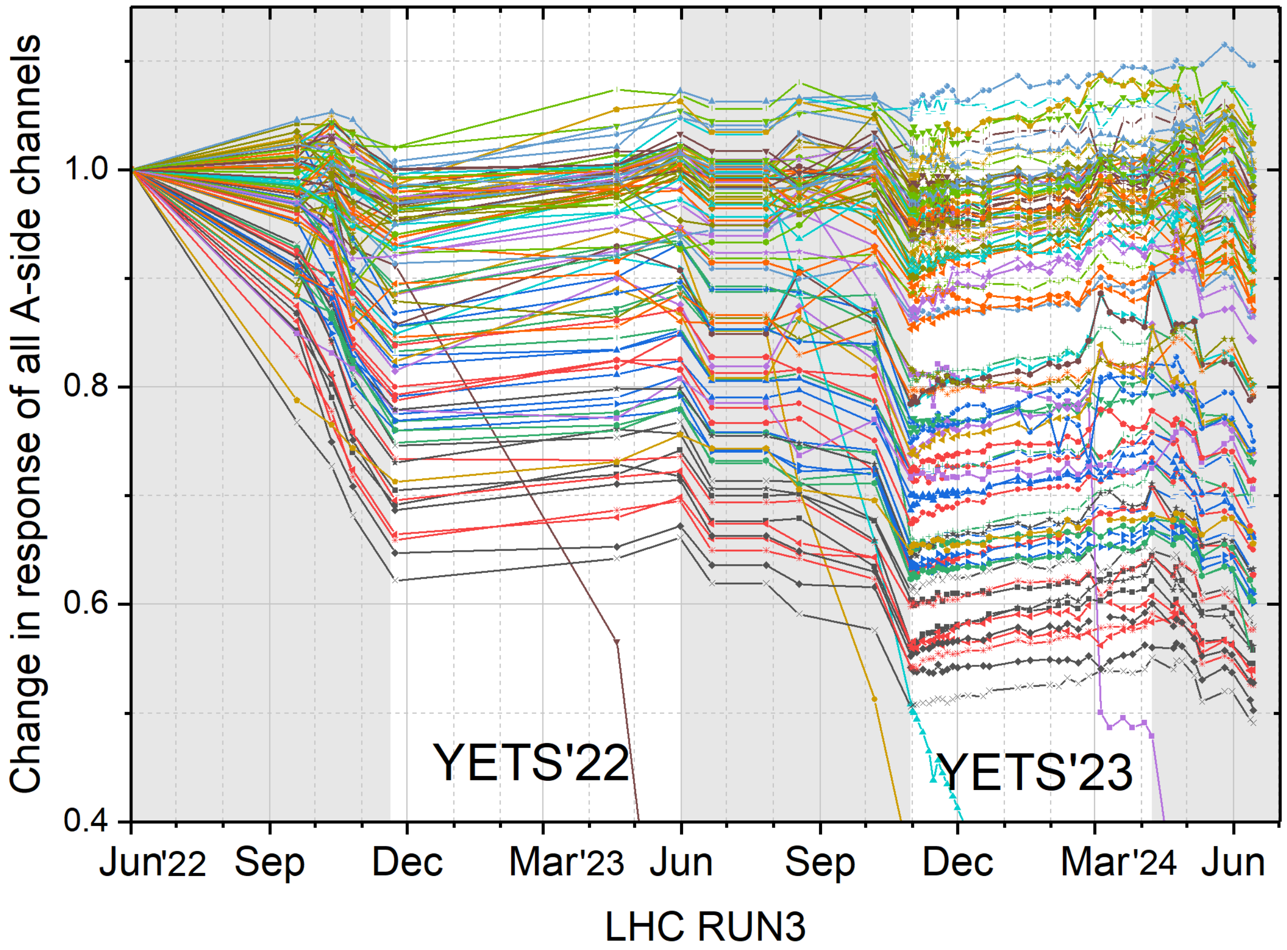
5) Peaked structure of the "beard" dependent on the bias voltage - typical for the ion backflow caused by a vacuum leak (and not helium leak).



Report from PANDA on similar case - [PHOSE2023]

Ageing maps over time

0T monitoring data




IP
FTC
FTA