Performance and operational experience of ALICE FIT in LHC Run 3

Tatiana Karavicheva, on behalf of the ALICE Collaboration

Joint Institute for Nuclear Research, Dubna

Institute for Nuclear Research of the Russian Academy of Sciences, Moscow

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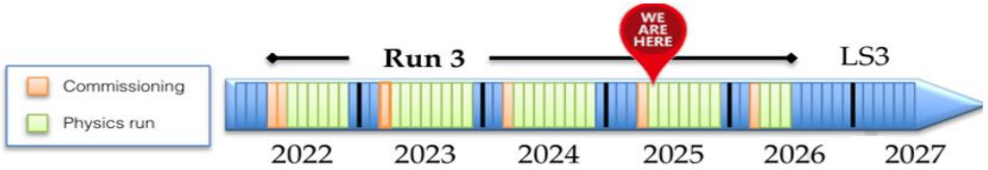
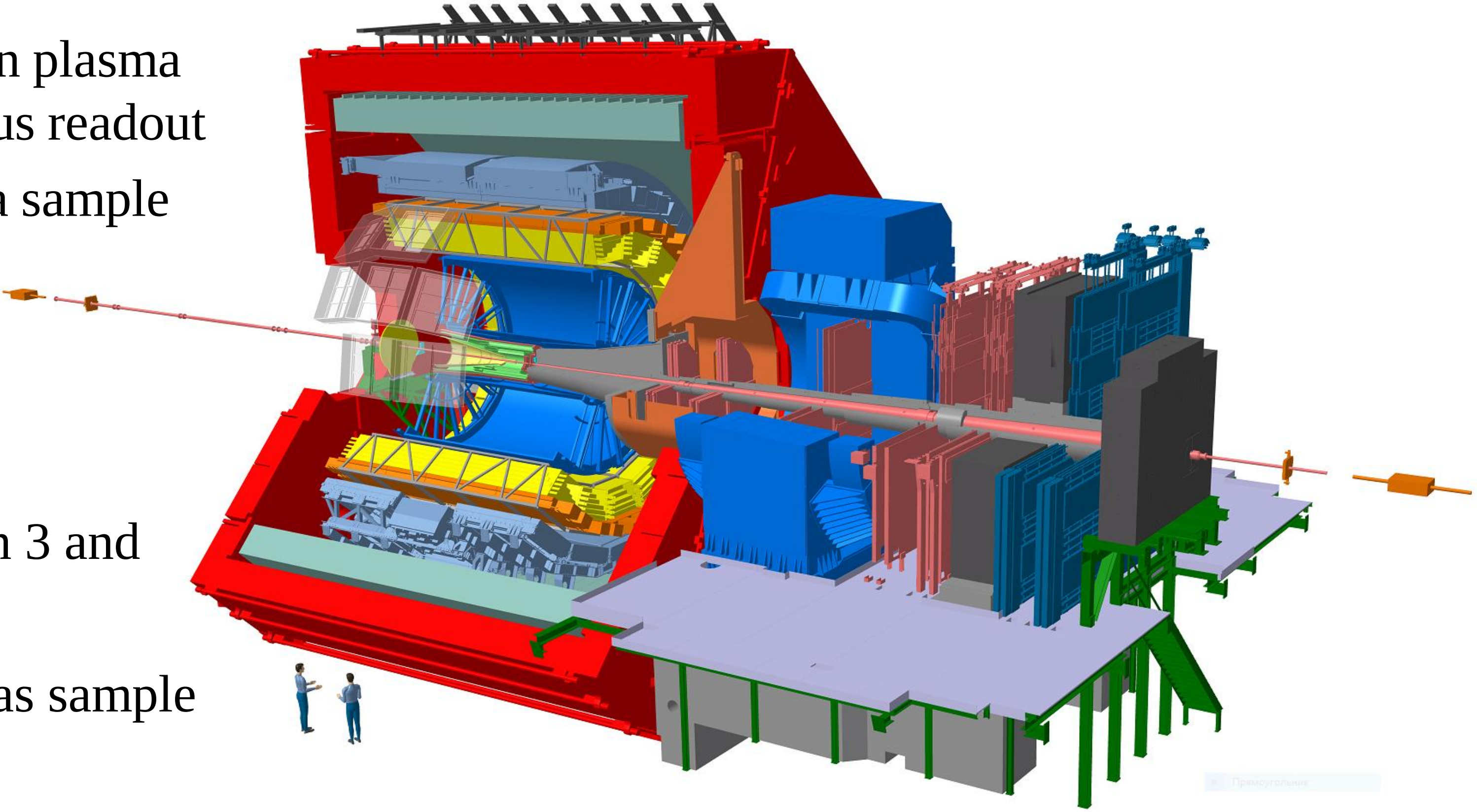
A Large Ion Collider Experiment: Run 3



ALICE → dedicated heavy-ion experiment at the LHC

Motivation

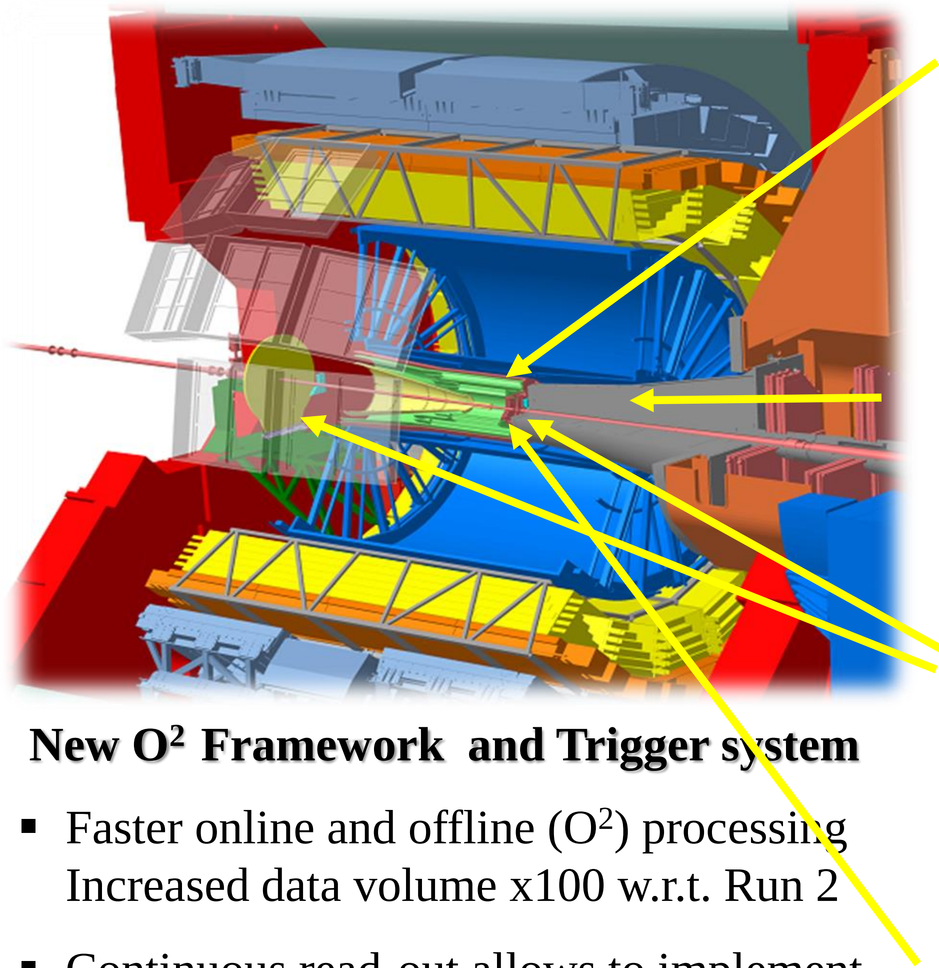
- High-precision measurements of quark-gluon plasma (QGP) properties and beyond with continuous readout
  - Need to record large minimum-bias data sample
  - Readout all Pb-Pb interactions up to the maximum collision rate of 50 kHz



Goal

- Pb-Pb integrated luminosity > 10 nb^{-1} in Run 3 and Run 4 (plus pp, p-O and O-O data)
- Gain factor 100 in statistics for minimum-bias sample with respect to Run 1 and Run 2
- Improved vertex reconstruction and tracking capabilities

ALICE upgrades in Long Shutdown 2 (LS2)

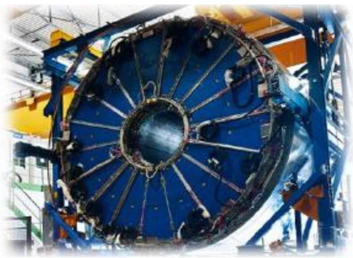


New Inner Tracking (ITS)

- 7 layers of silicon pixel detectors with reduced material budget
- First detection layer closer to IP + new beam pipe (ITS L0 at 22 mm)

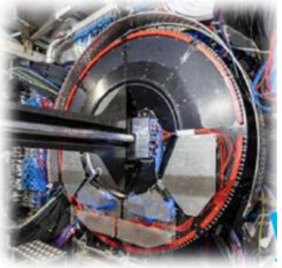
New Time Projection Chamber (TPC)

- Tracking, PID (dE/dX)
- MWPCs replaced with GEMs
- Continuous readout up to 50 kHz
- Pb-Pb interaction rate (x50 w.r.t. Run2)



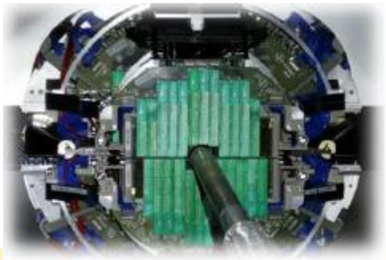
New Fast Interaction Trigger (FIT)

- Triggering
- Collision time
- Event plane, centrality



New Muon Forward Tracker(MFT)

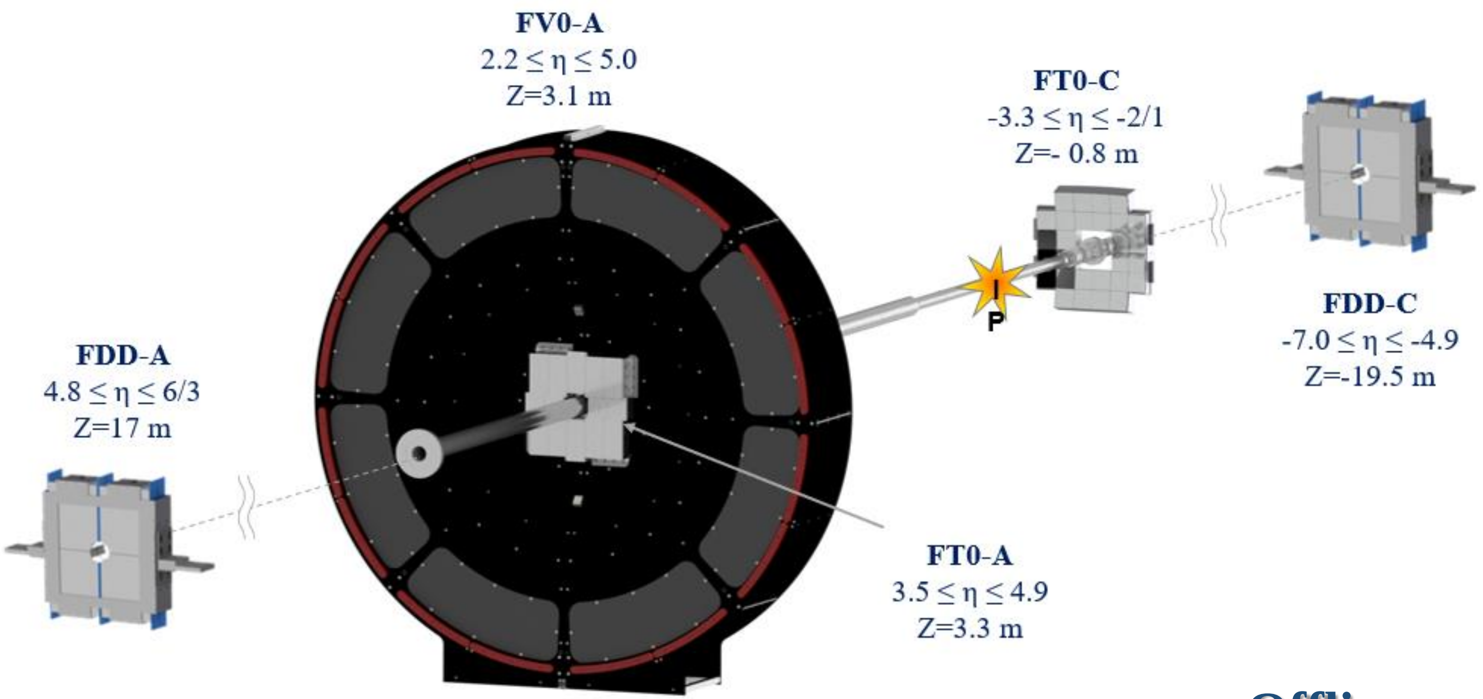
- Gives the muon system access to the vertex



New O^2 Framework and Trigger system

- Faster online and offline (O^2) processing
  Increased data volume x100 w.r.t. Run 2
- Continuous read-out allows to implement custom software triggers

Fast Interaction Trigger layout & purpose



Three different sub-detectors – FT0, FV0 and FDD with different particle detection technology, located on both opposite sides of the interaction point (IP)

See also M.Sukhanov 's talk

Online

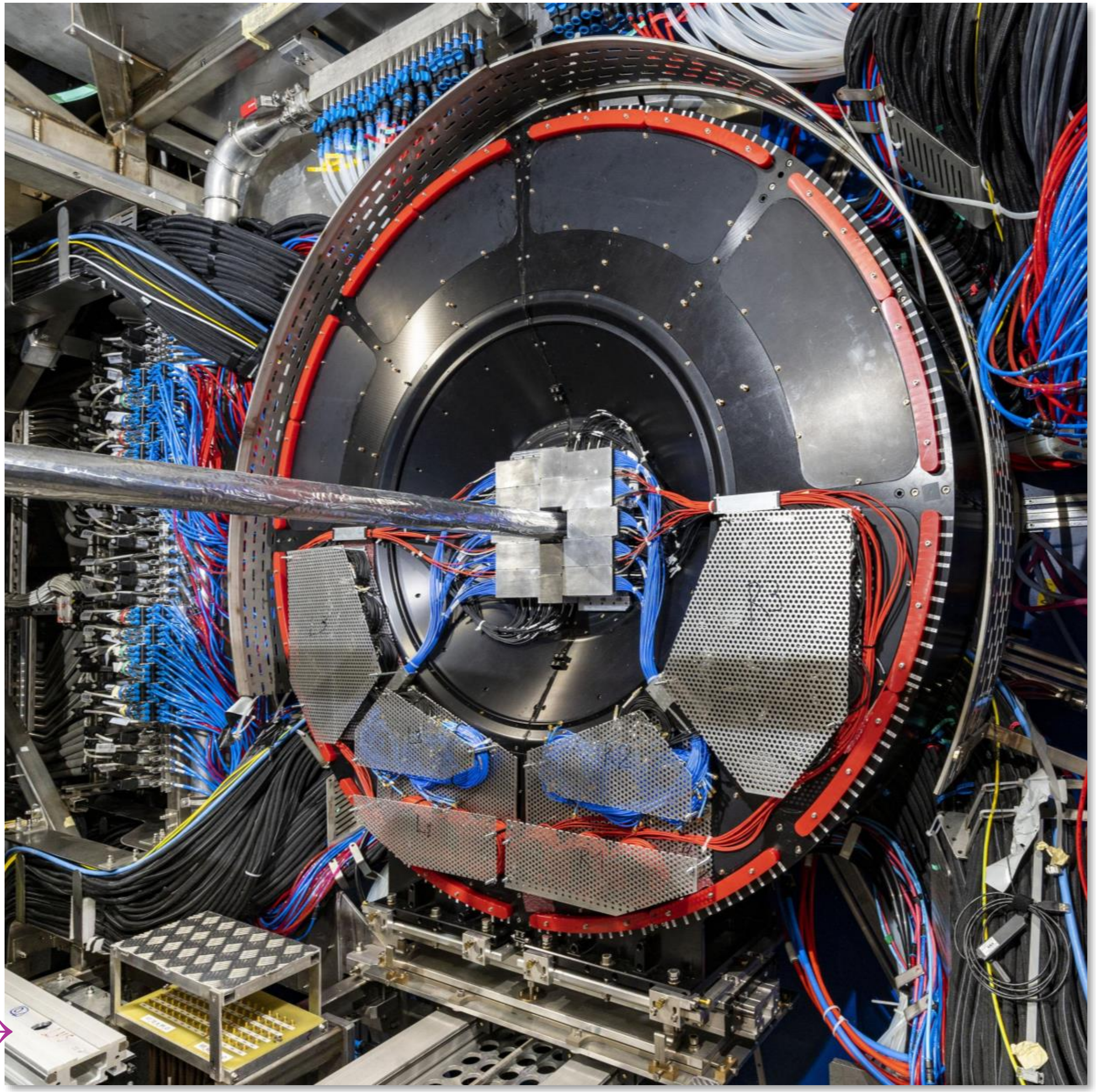
- ALICE luminometer and trigger detector (**FT0**,FDD,FV0)
- LHC background monitoring (FT0,FDD)
- Background rejection (FT0)

Offline

- Vertex trigger for event selection (FT0)
- Collision-time and vertex measurement (FT0)
- Forward multiplicity/centrality (FV0,FT0)
- Event plane of heavy-ion collisions (FV0,FT0)
- Veto for ultra-peripheral collisions (FT0,FDD,FV0)
- Cross section determination in VdM scans (FT0,FDD,FV0)

FIT design constraints

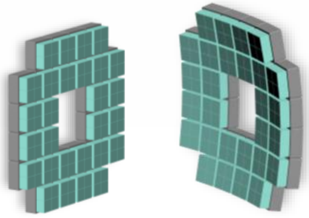
- Brand-new subsystem of the upgraded ALICE for the **LHC RUN 3 & 4** (2022 onwards);
- **BC-per-BC* readout capability** (dead time ~15 ns);
- **Minimal latency** – trigger decisions in less than 425 ns from the collision (150 ns cabling delay included);
- Efficient running at **full LHC Pb-Pb collision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



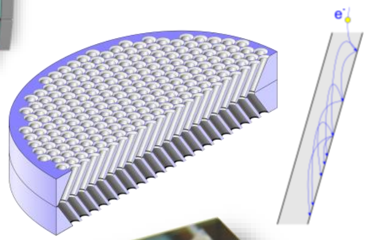
FT0+FV0 just after the installation in the cavern →

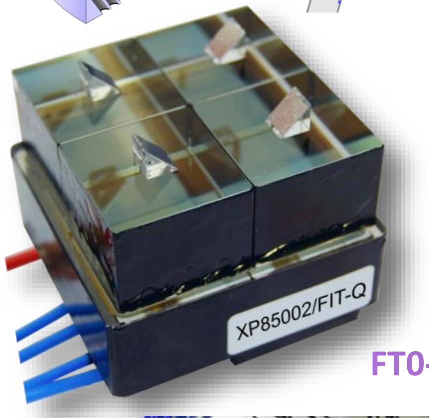
*BC – Bunch Crossing interval (25 ns)

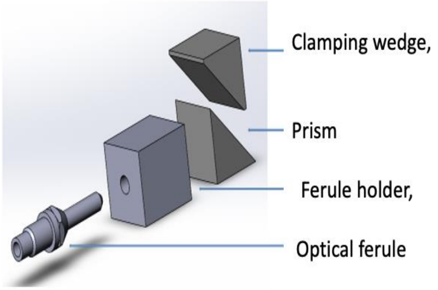
FT0 – the FIT Time-zero detector



- 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.



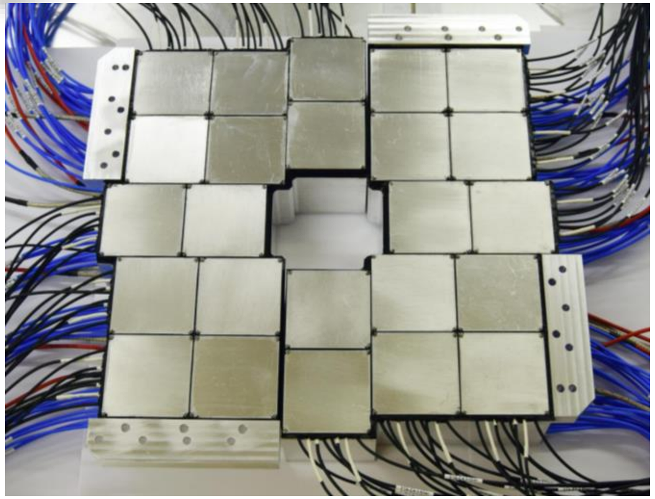




FT0-C half – back view

FT0-C half – front view

FT0-A assembled



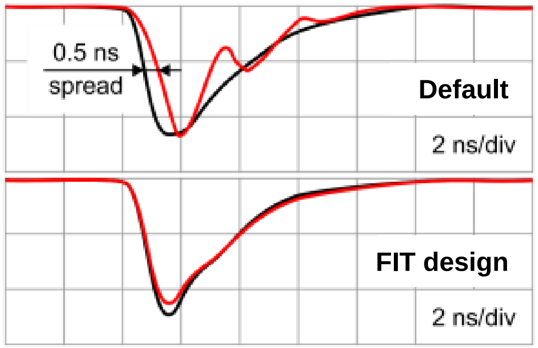
Planacon upgrade for ALICE FIT – [NIM A 952 (2020) 161689]

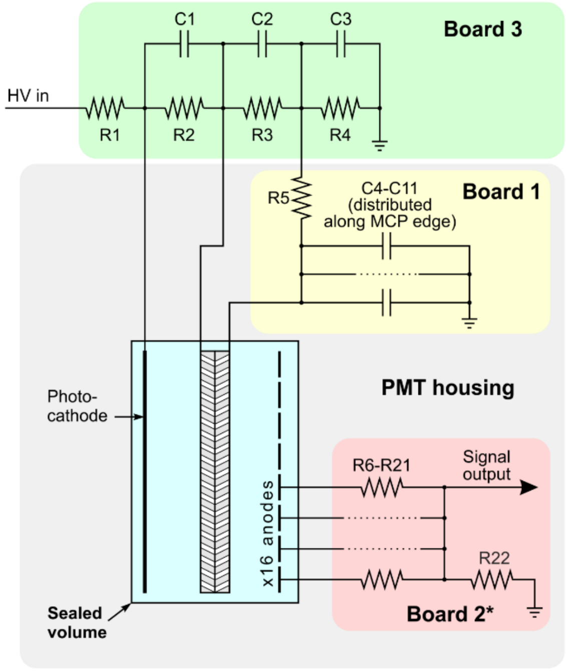
Bench testing of the ALICE FIT Planacons – [JINST 16 (2021) P12032]

FIT solution for Planacon modification

We have designed custom internal PCBs for Planacons – they were installed to FIT devices by the manufacturer:

- Common output and its load resistance are eliminated → no positive cross-talk → **rising edge is never distorted**;
- Signals from 16 individual outputs go directly to the MMCX jack for quadrant signal output → **no additional PCB for signal collection**;
- Equalized connection length → **better time resolution** when wide light spots are detected;
- Optimized traces length and ground plane location at the most inner PCB → twice smaller anode capacitance → **smaller cross-talks between anodes, higher amplitude-to-charge ratio**;
- No resistors inside HV port → **unit thickness reduced to 27 (23) mm**;
- In-line 75 Ω resistors to **reduce Q-factor of anodes LC-circuit.**

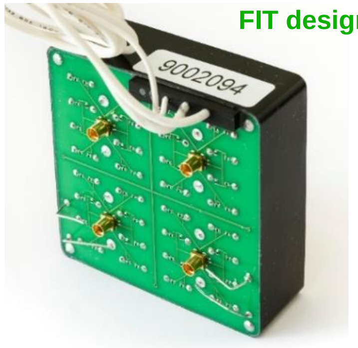




*only 16 out of 64 channels shown.

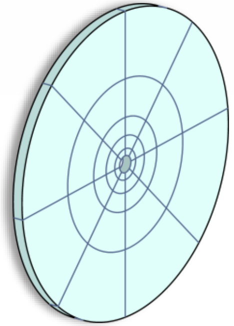
Default design

FIT design



FIT design with base

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;

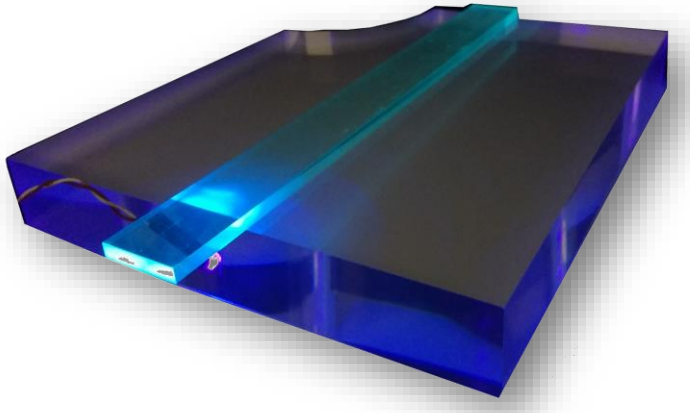
- Fine-mesh PMTs: H6614-70-Y001, B-field immunity;
- High signal rate capacity;
- Keep pulses width < 25 ns;
- Time resolution:

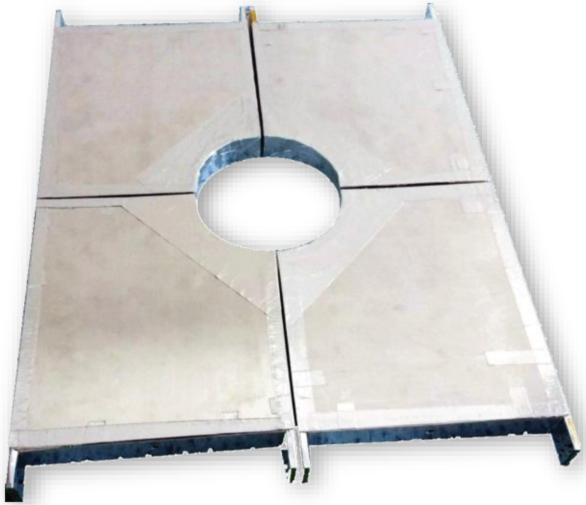
  200-250 ps @ 1 MIP.

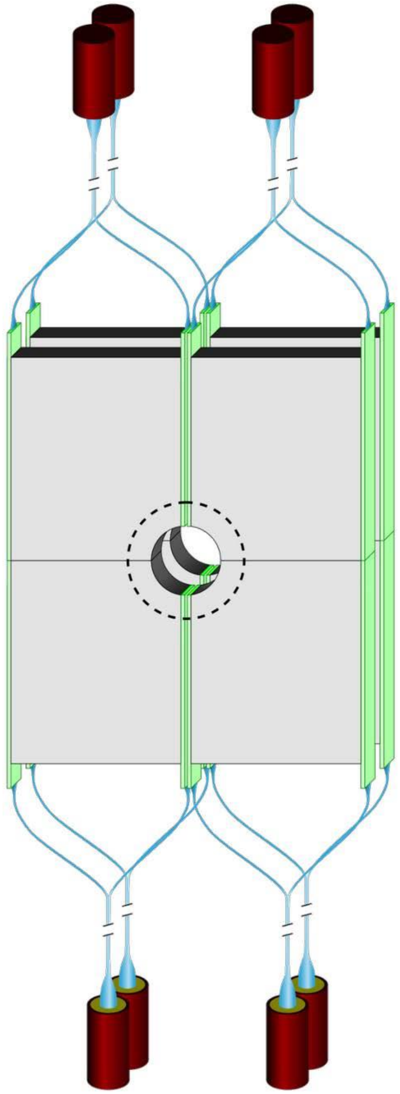
On the novel light collection technique – arXiv:1909.01184v1X

FDD – the FIT Forward Diffractive Detector

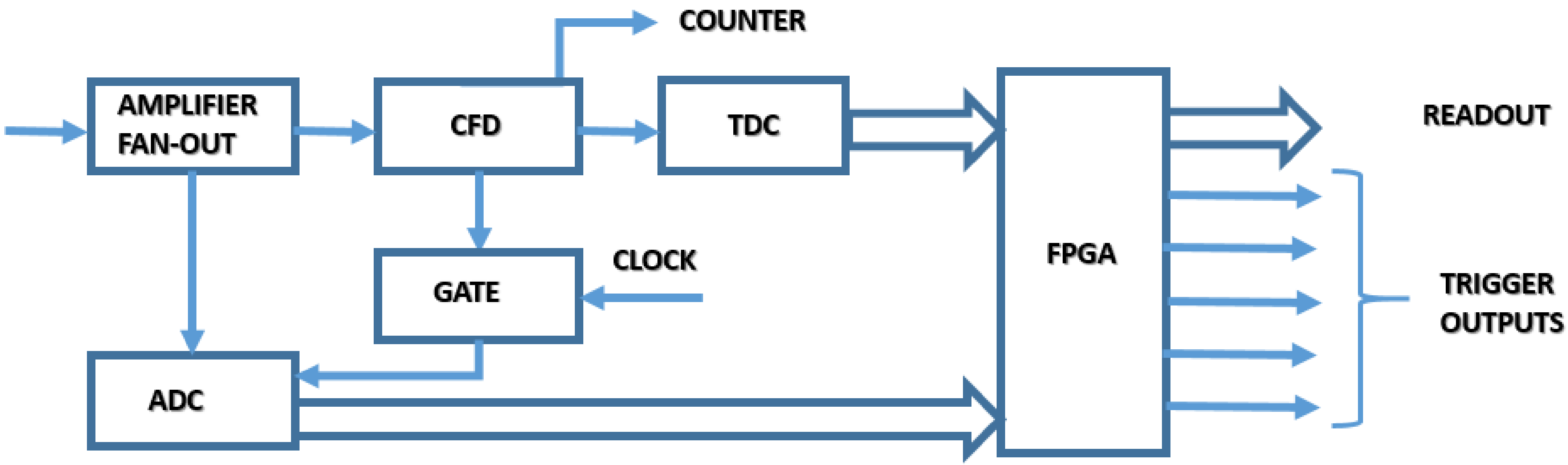
- Double-layered plastic scintillator read out by fine-mesh PMTs through WLS plastic bars and clear fibers (coincidence mode);
- Fine-mesh PMTsH8409-70: B-field immunity, good timing, high signal rate capacity;
- Fast wavelength-shifting bar: 1 ns re-emission time, NOL-38;
- Light transport by clear fiber bundles: Kuraray PSM-Clear.







Architecture of FIT electronics



- **Fully integrated system** based on an amplifier, a CFD, on-board TDC/ADCs and FPGA processors; digital trigger processing and GBT based read-out.
- **Trigger decision based on digitized data (after TDCs & ADCs)**
- **No active elements** near the sensor
  - Limited access, radiation hardness issues
- **Low-attenuation, double-shielded** signal cables
  - Shortest possible cable length

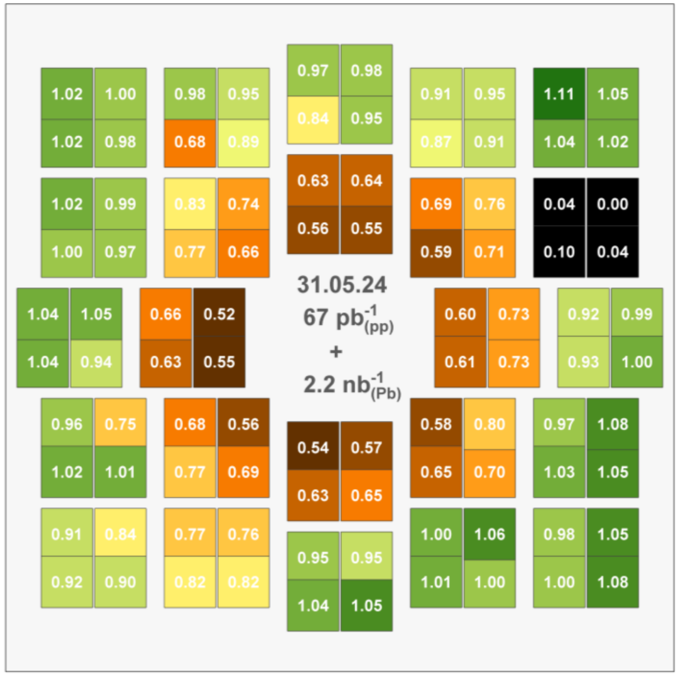
FIT trigger menu

FT0/FDD	FV0
Trigger mode: (A+C) or (A&C)	-
OrA (at least one fired channel on A side)	**OrA** (at least one fired channel on A side)
OrC (at least one fired channel on C side)	**Nchan** (# fired channels in event > nchan_threshold)
SCen (chargeA+chargeC > scen_threshold)	**Charge** (total charge > chrg_threshold)
Cen (chargeA+chargeC > cen_threshold)	**ChargeInnerRings** (charge in 3 inner rings > chrgin_threshold)
Vertex (-1.3 < (timeC-timeA) < 1.3 ns)	**ChargeOuterRings** (charge in 2 outer rings > chrgout_threshold)

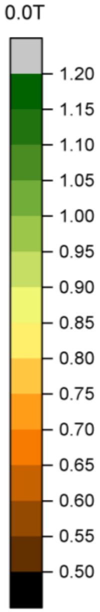
- ❑ FT0 Vertex - minimum bias trigger for luminosity monitoring in pp collisions
- ❑ FT0 (SCen || Cen) – minimum bias trigger in Pb-Pb collisions
- ❑ FT0 Cen and FV0 Charge – high multiplicity triggers in Pb-Pb collisions

MCP-PMT ageing after two full years of operation

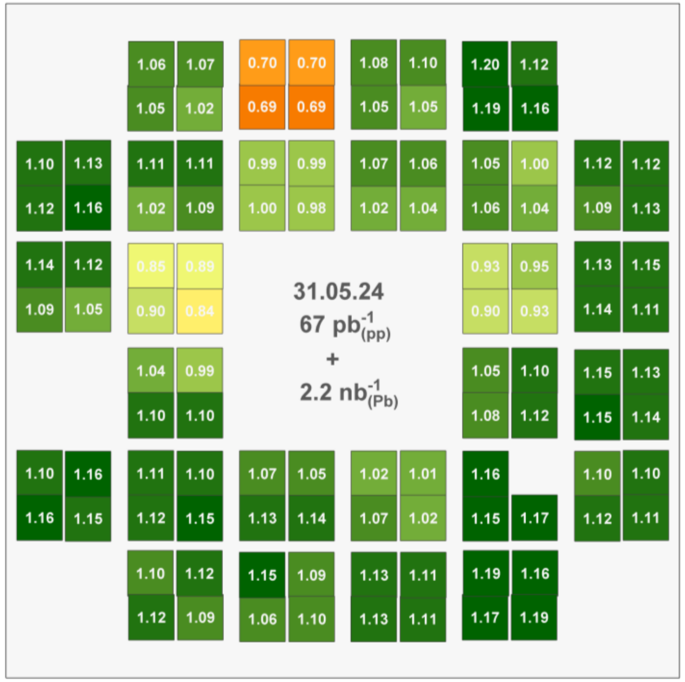
A-side



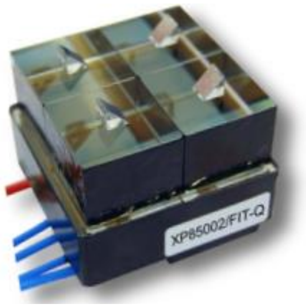
MCP-PMT response (June 2024 / start of RUN3)

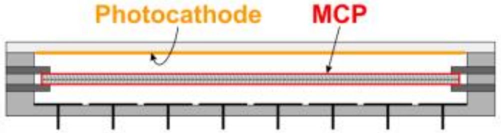


C-side



- The **innermost MCP-PMT quadrants'** gain & photocathode Q.E. dropped 50% after collecting 1 C/cm^2
- As expected, the **outer quadrants'** ageing is visible but considerably smaller
- To compensate for the gain loss, HV is increased
  - It is one of the benefits of low-gain MCP-PMT operation

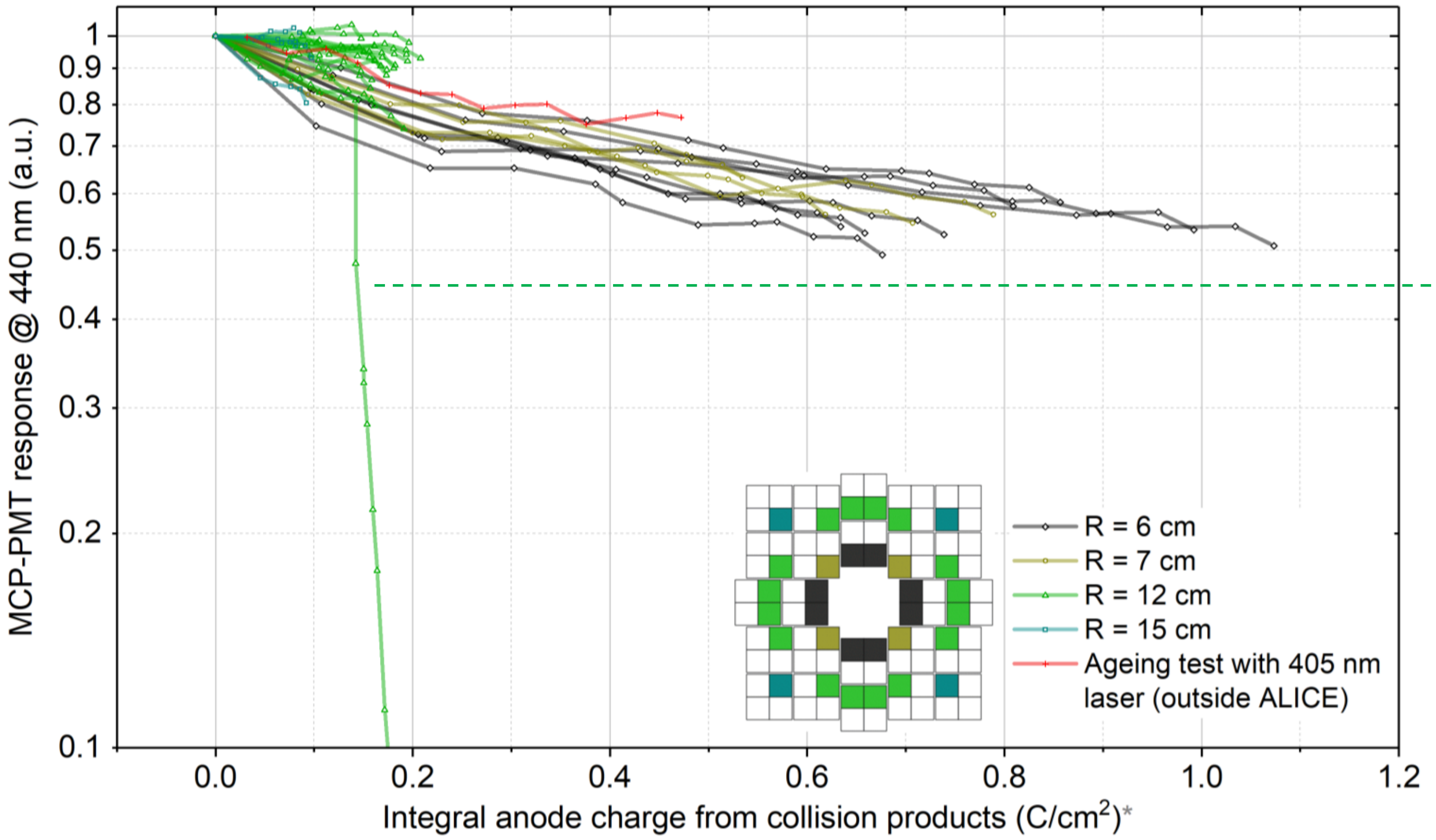




Detector ageing

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

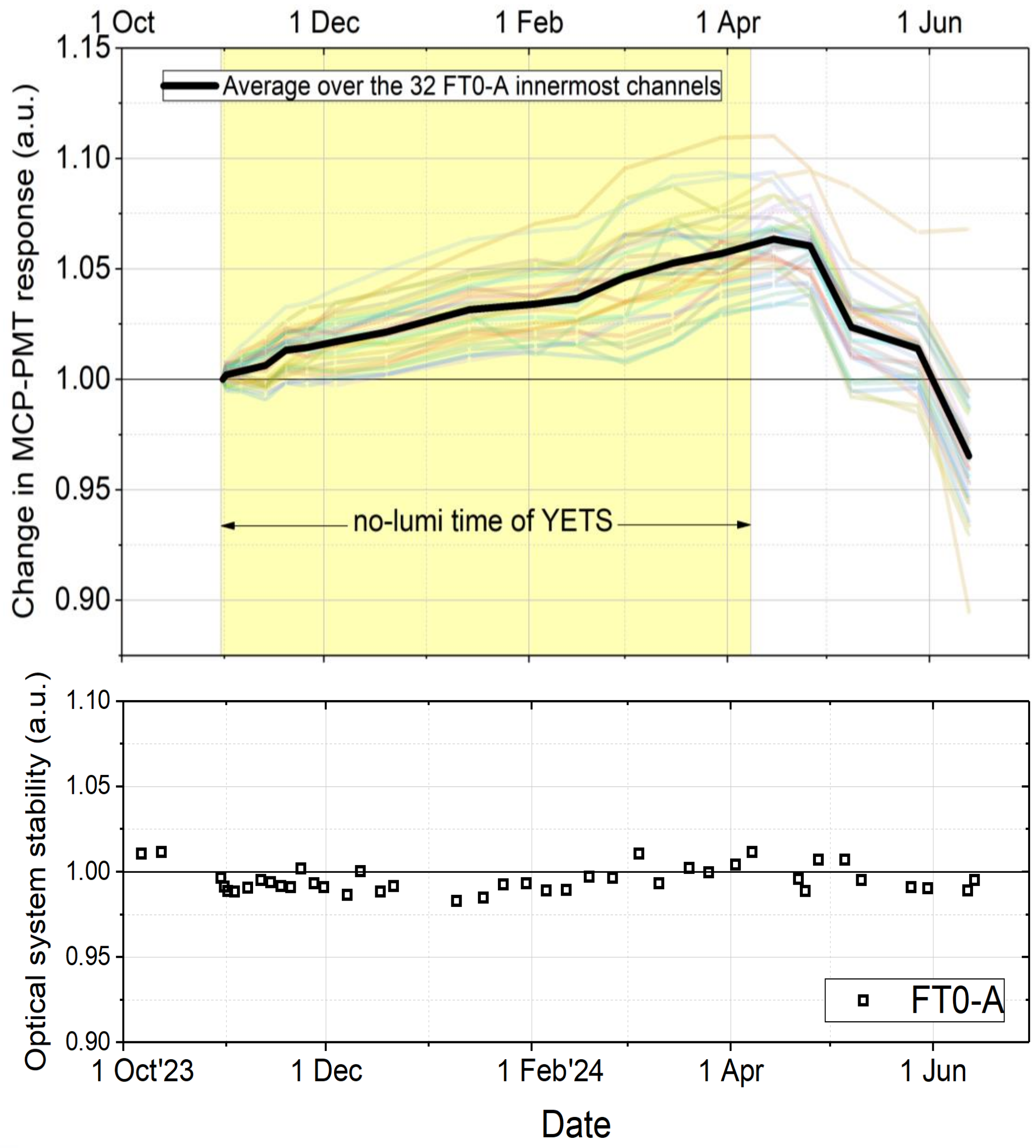
Smooth ageing trends versus IAC:



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

*background contribution unaccounted, but small.

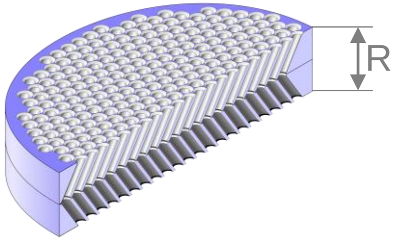
A-side annealing/recovery during the 2023 YETS



- The newly observed annealing effect occurred during the 2023 YETS
- After 160 days without a beam, aged MCP-PMTs self-recovered noticeably
- Response recovers monotonously and permanently (ageing of the recovered device is no faster than of a new one).

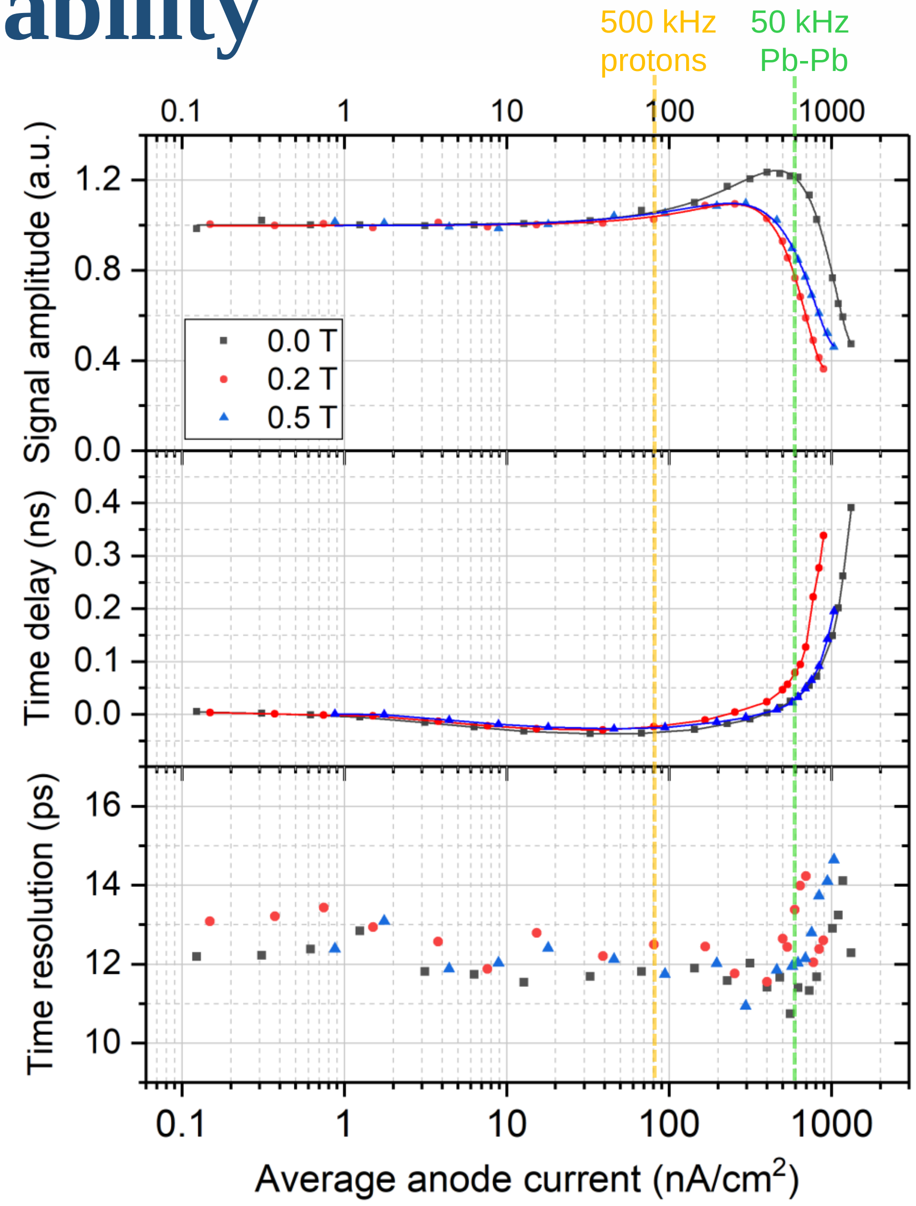
Detector technology limits – rate capability

- 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);
  - further **reduced x2** inside 0.5T B-field.

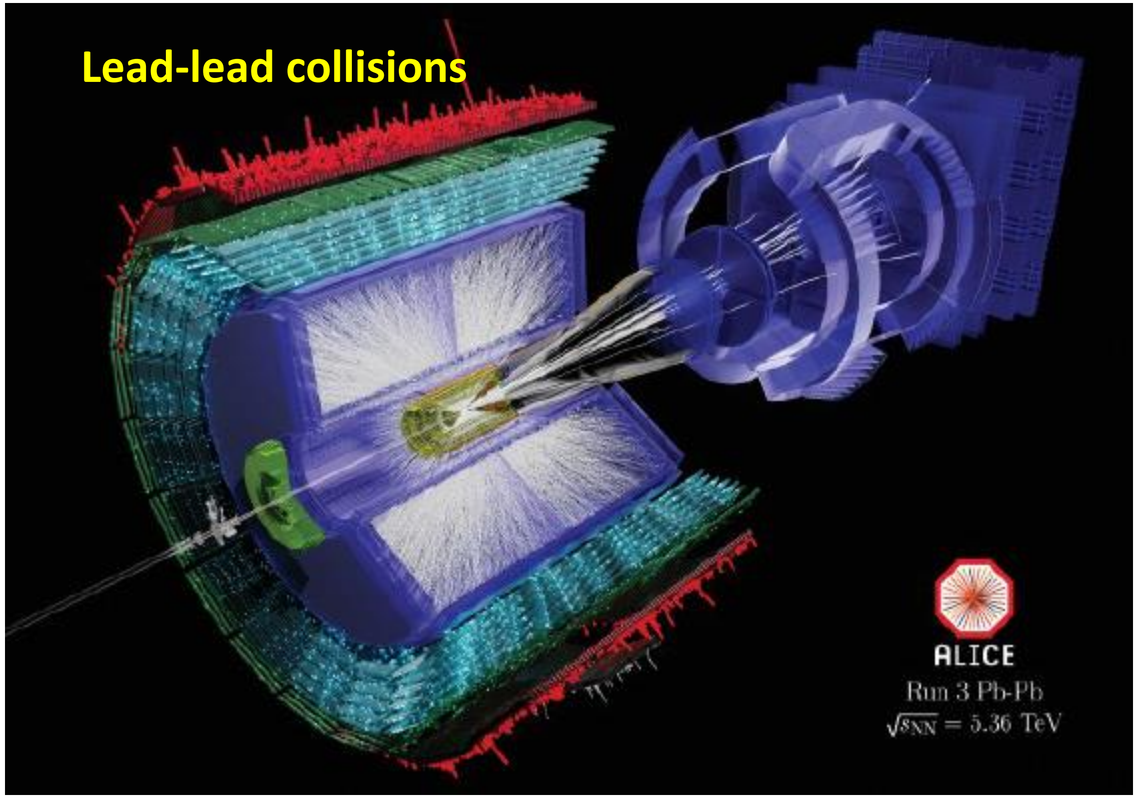


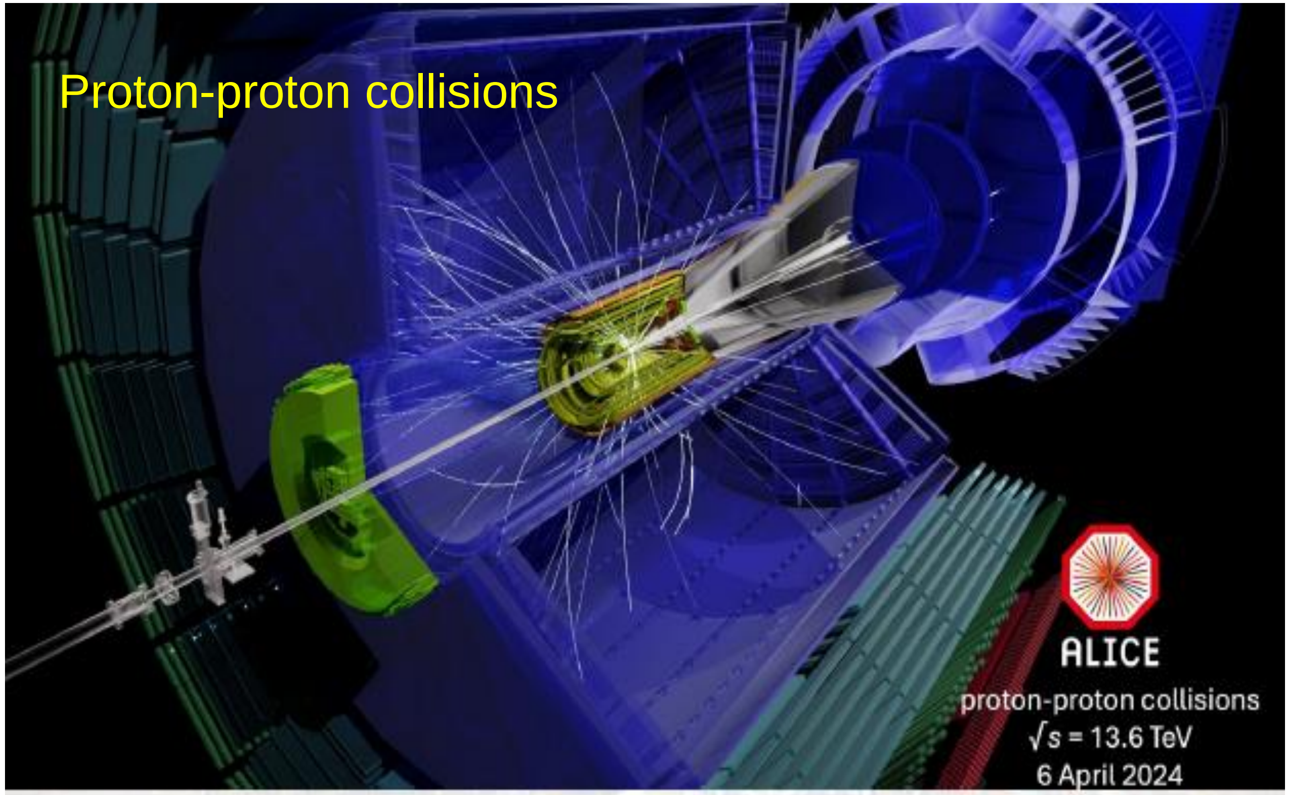
- 50 kHz Pb-Pb corresponds to ~7x10⁶ particle hits per second in each of the most occupied FT0 channels: 3x10⁸ photo-electrons/cm² → **600 nA/cm²**.

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



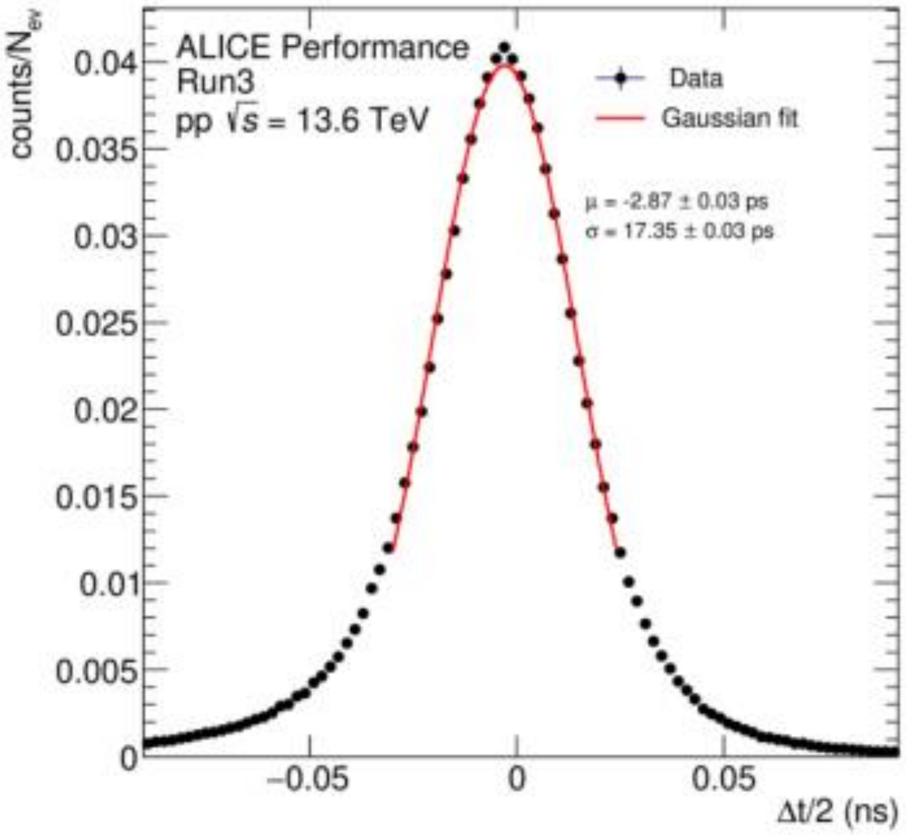
FIT performance in pp & Pb-Pb data taking



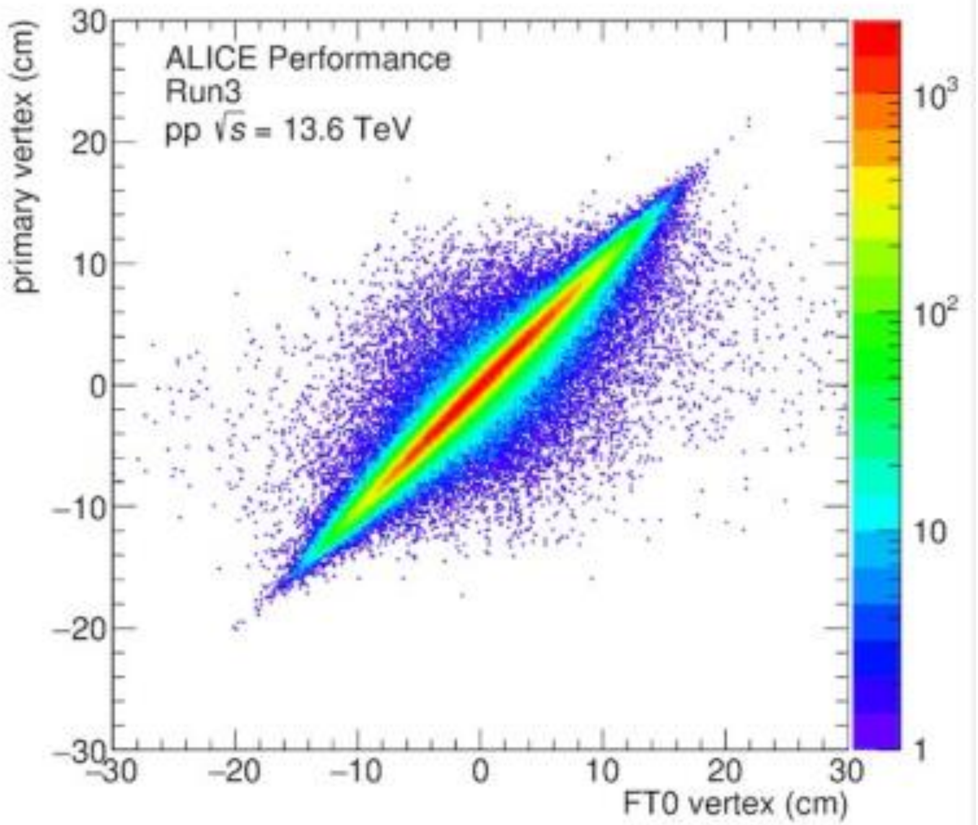


FIT performance in pp – FT0

FT0 time resolution in pp 13.6 TeV



Primary vertex vs. FT0 vertex

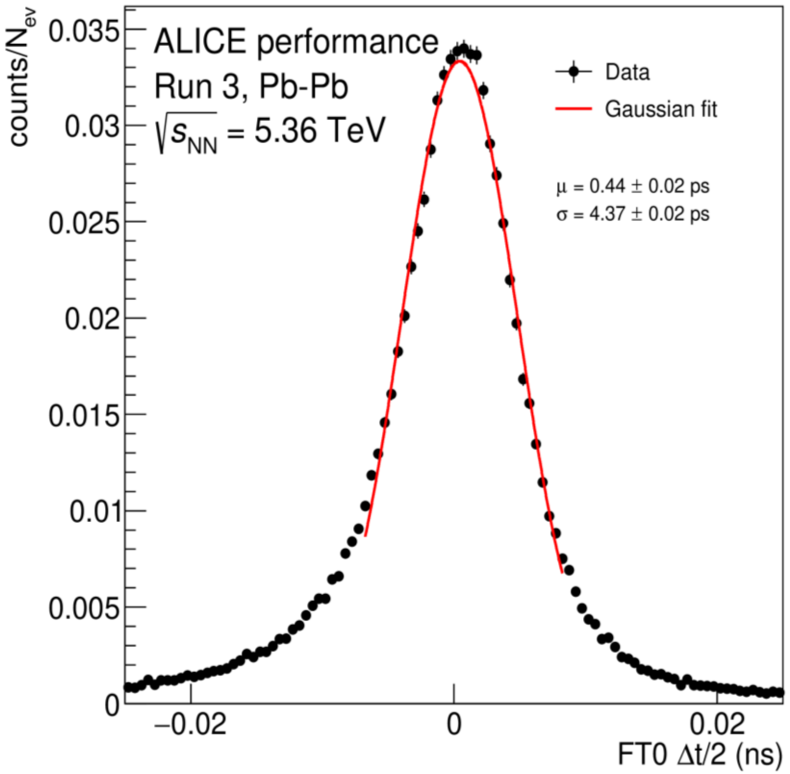


σ = 17 ps ≡ ±5.1 mm – precision of the determination of the collision point in pp collisions;

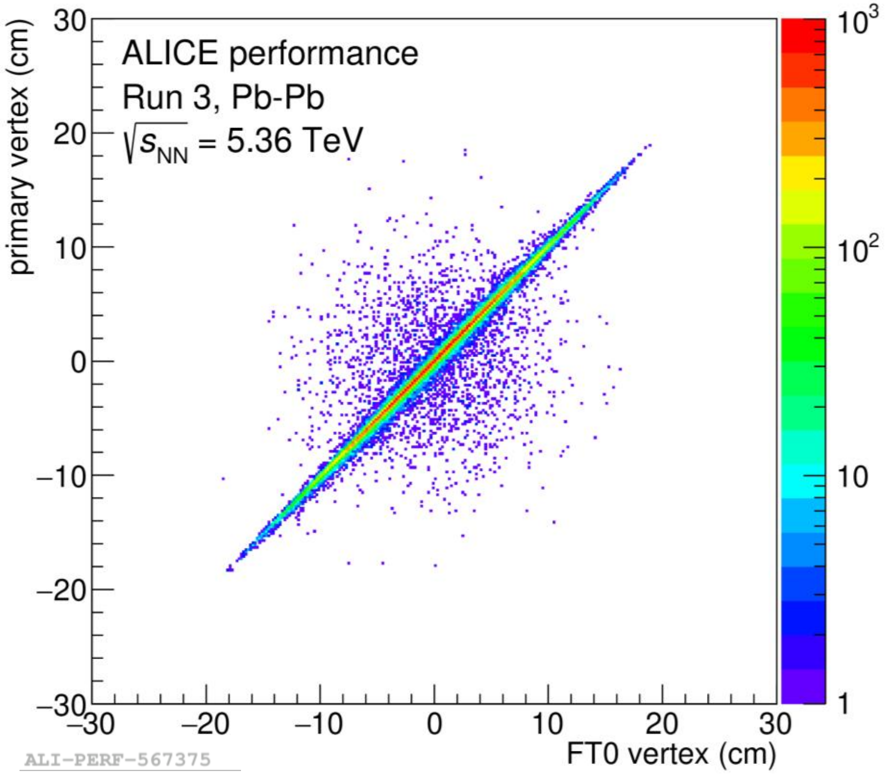
Good correlation with the primary vertex reconstructed from the inner barrel tracker.

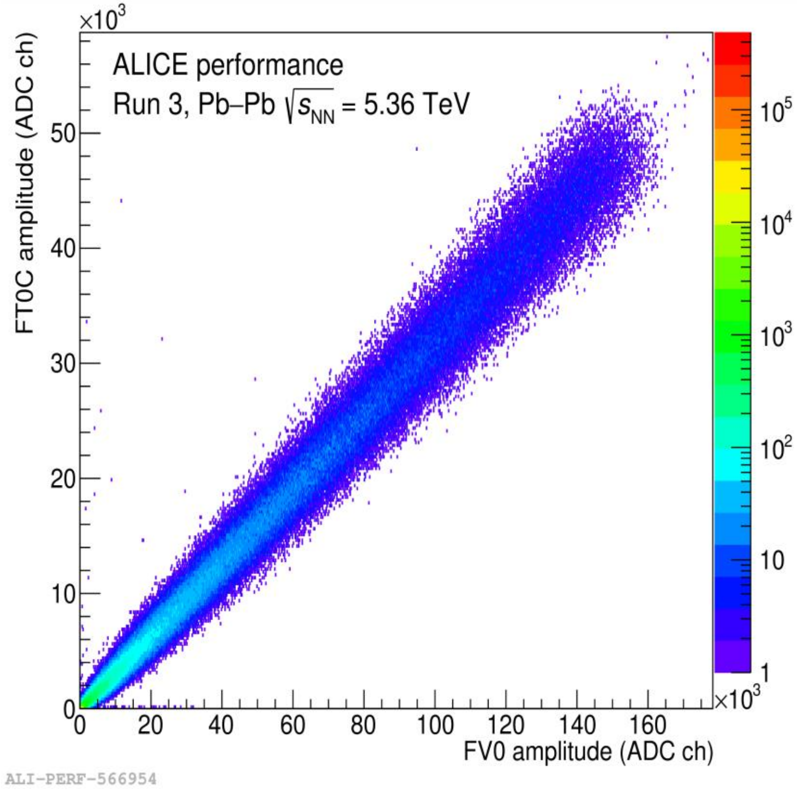
FIT performance in Pb-Pb – FT0, FV0

FT0 time resolution



Primary vertex vs. FT0 vertex





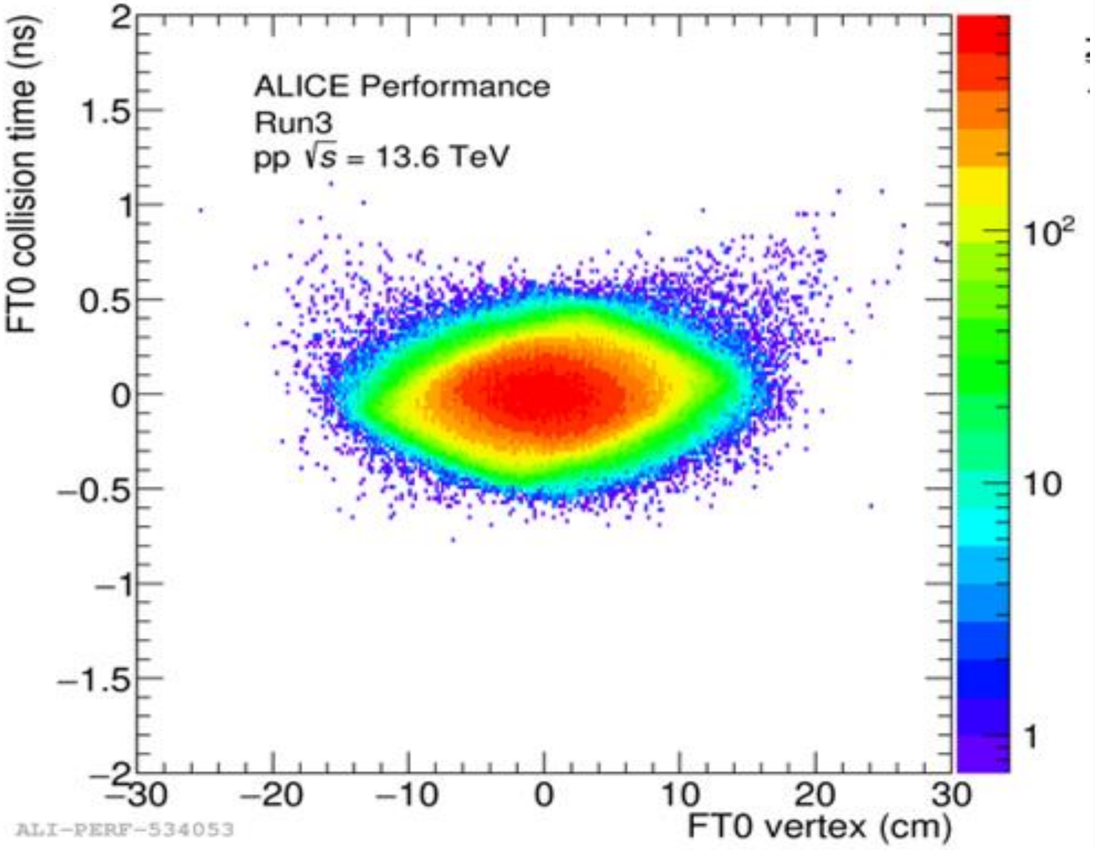
σ = 4.4 ps – precision of the determination of the collision point in Pb-Pb collisions;

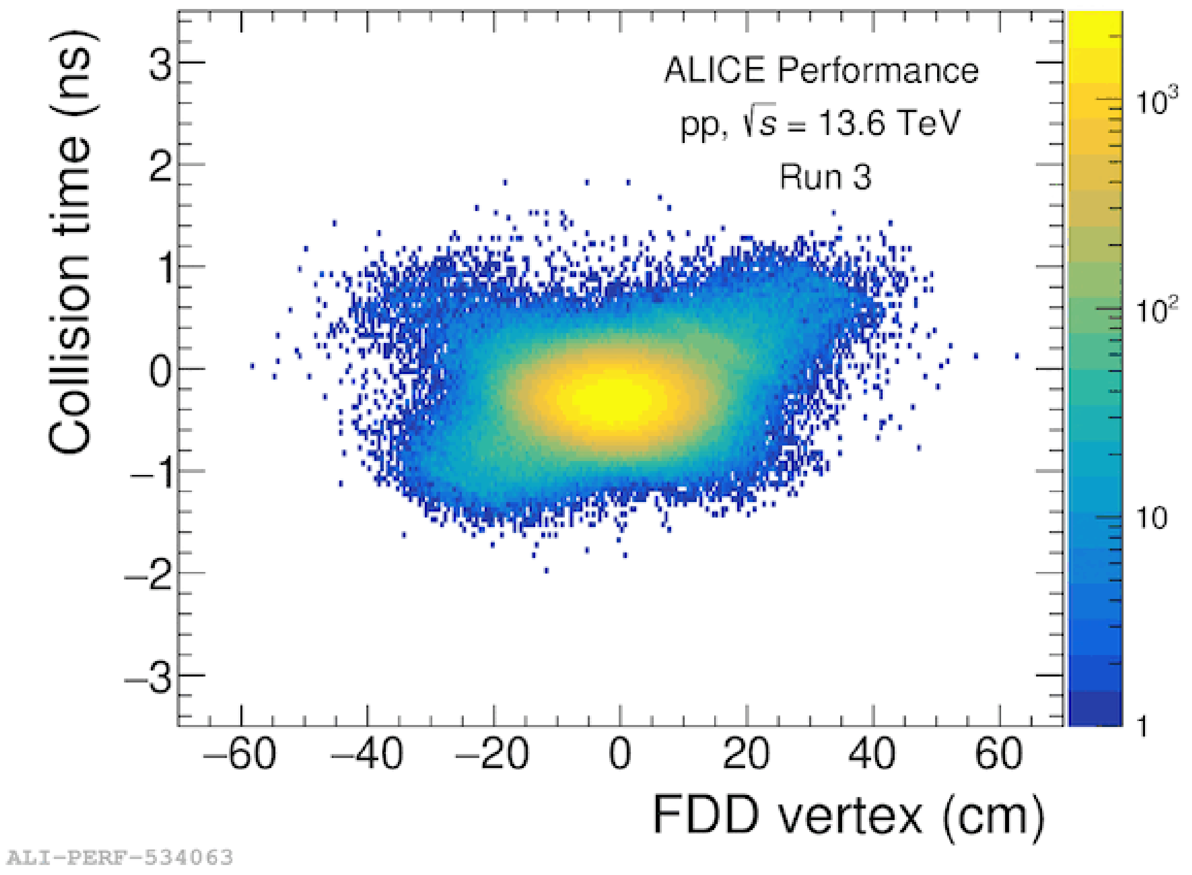
Good correlation with the primary vertex reconstructed from the inner barrel tracker.

Good correlation вetween FIT detectors measuring the multiplicity of events

FIT performance in pp – FT0,FDD

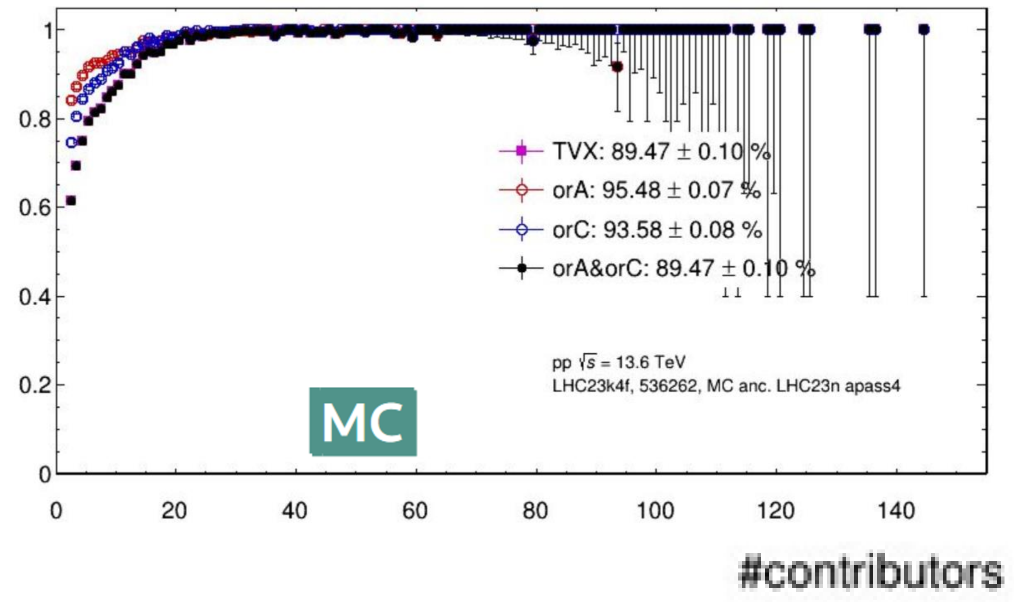
FT0/FDD vertex vs FT0/FDD collision time correlation in pp at 13.6 TeV



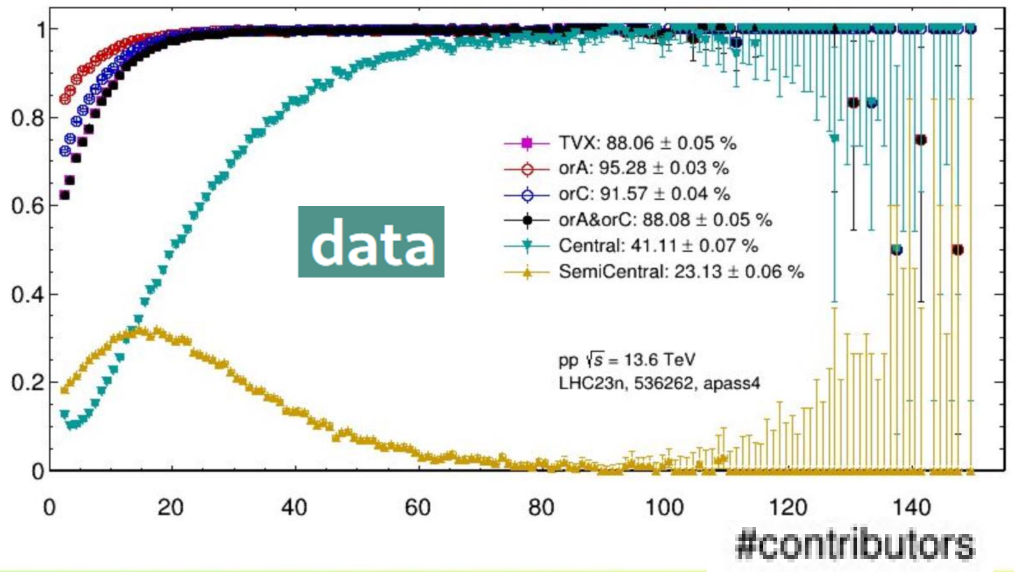


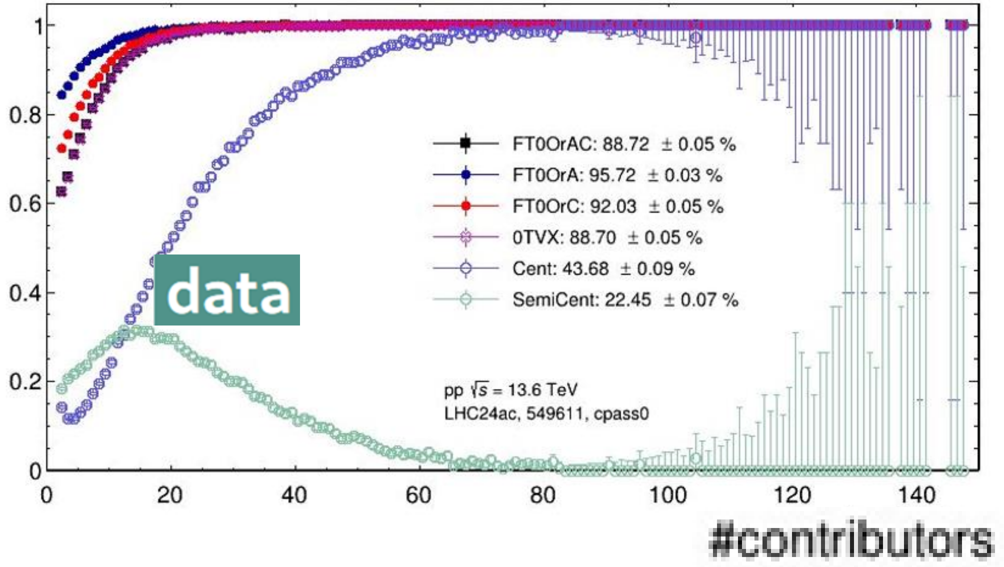
Good vertex and collision time calculation at forward and very forward pseudorapidity regions.

FT0 trigger performance in pp

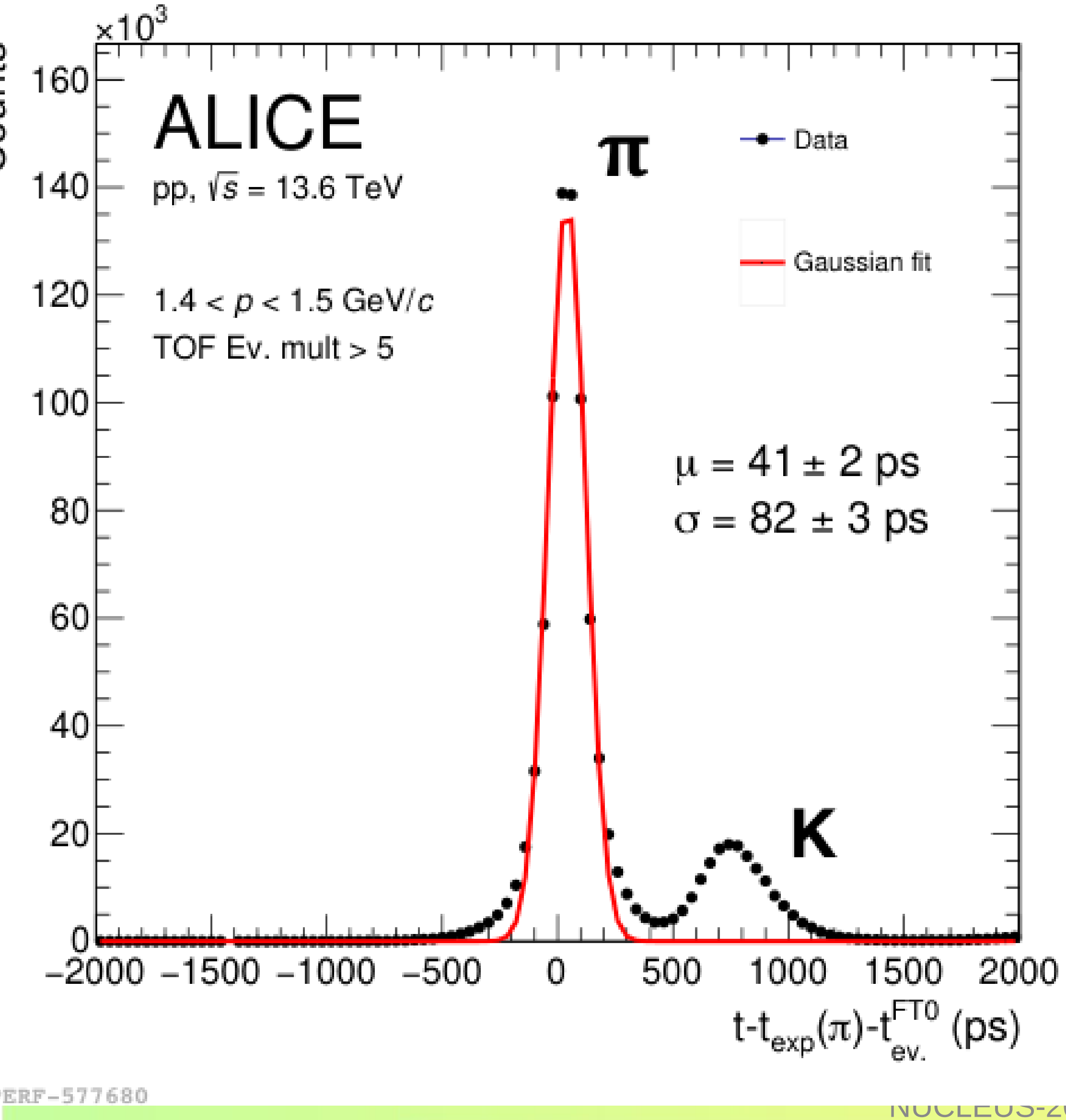


- Good agreement between MC and data
- Centrality triggers not yet included in MC
- FT0 performed well in 2023 and 2024





FT0 performance – collision time



A measurement of the separation between particle species ($t_{TOF} - t_{exp} - t_{ev}$) generated by using the event times acquired from the **TOF** and **FT0** detectors:

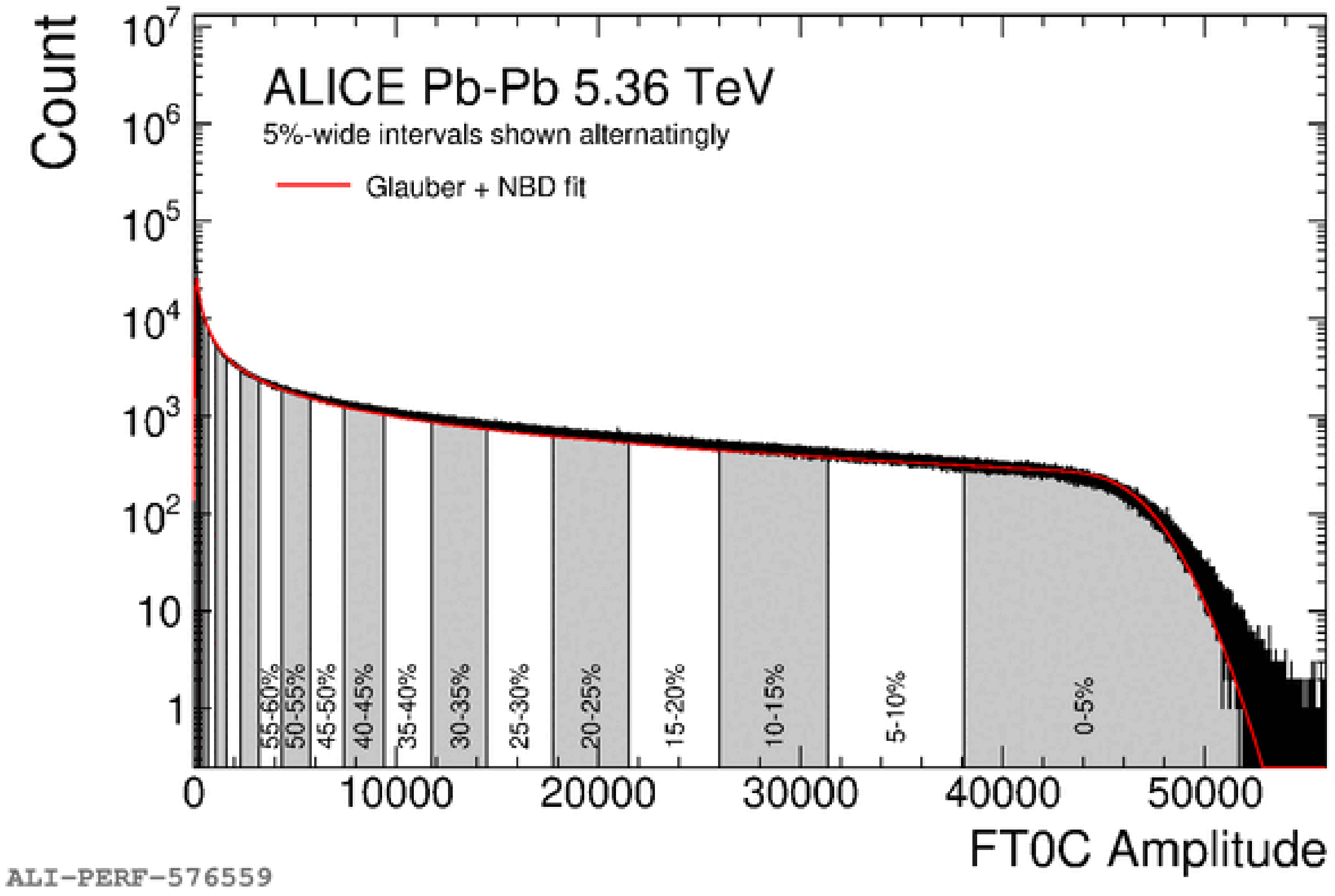
- Well separated pions and kaons peaks;
- TOF time resolution σ_{TOF} = (81.7±2.7) ps;
- FT0 time resolution σ_{FT0} = (17.35±0.03) ps.

FT0 - Estimation of centrality/multiplicity class

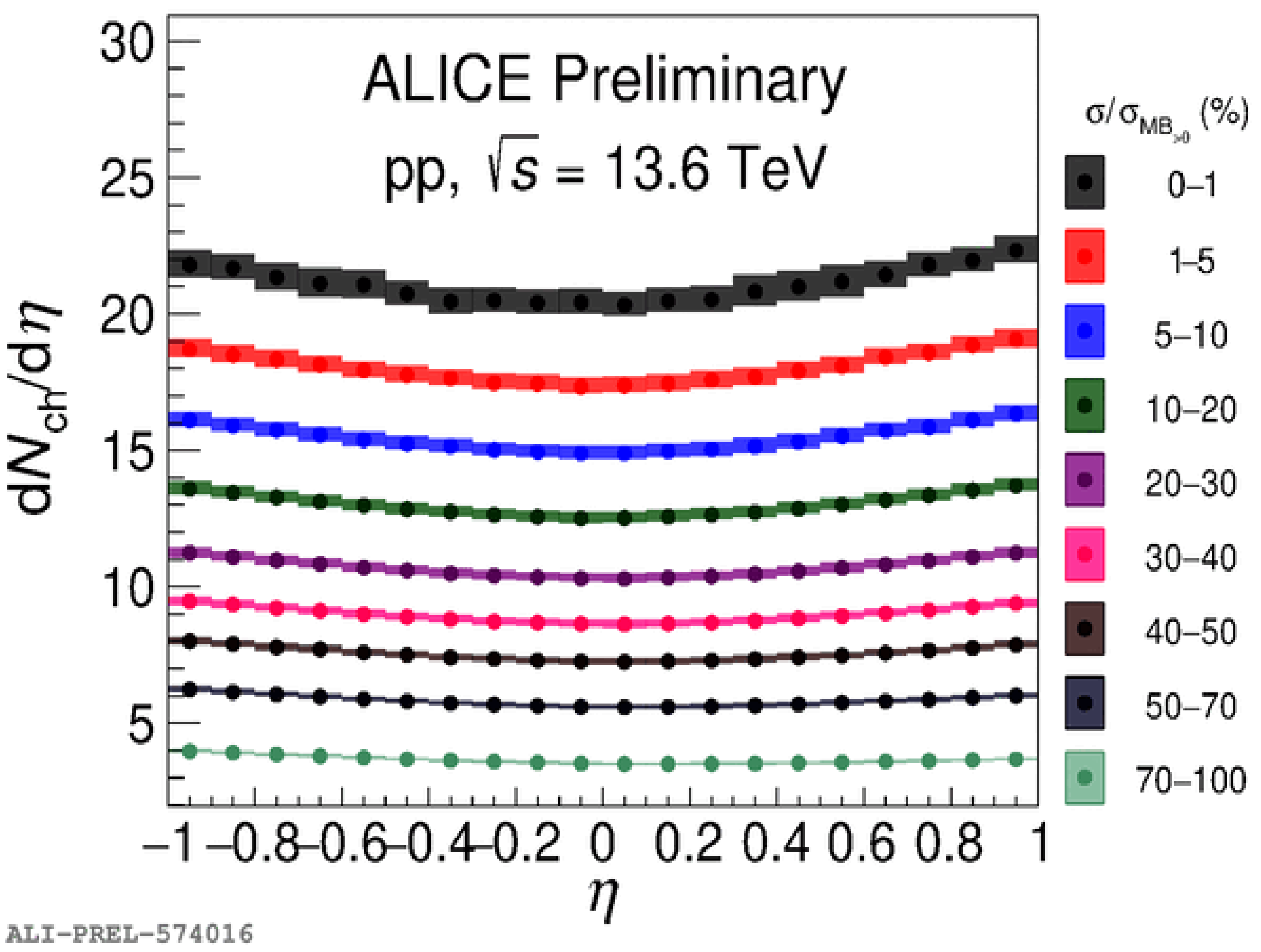
Centrality classification

Pb-Pb: Performing NBD Glauber fit to measured FT0C amplitude

pp: Multiplicity classes are determined by the signal sum of FT0A and FT0C



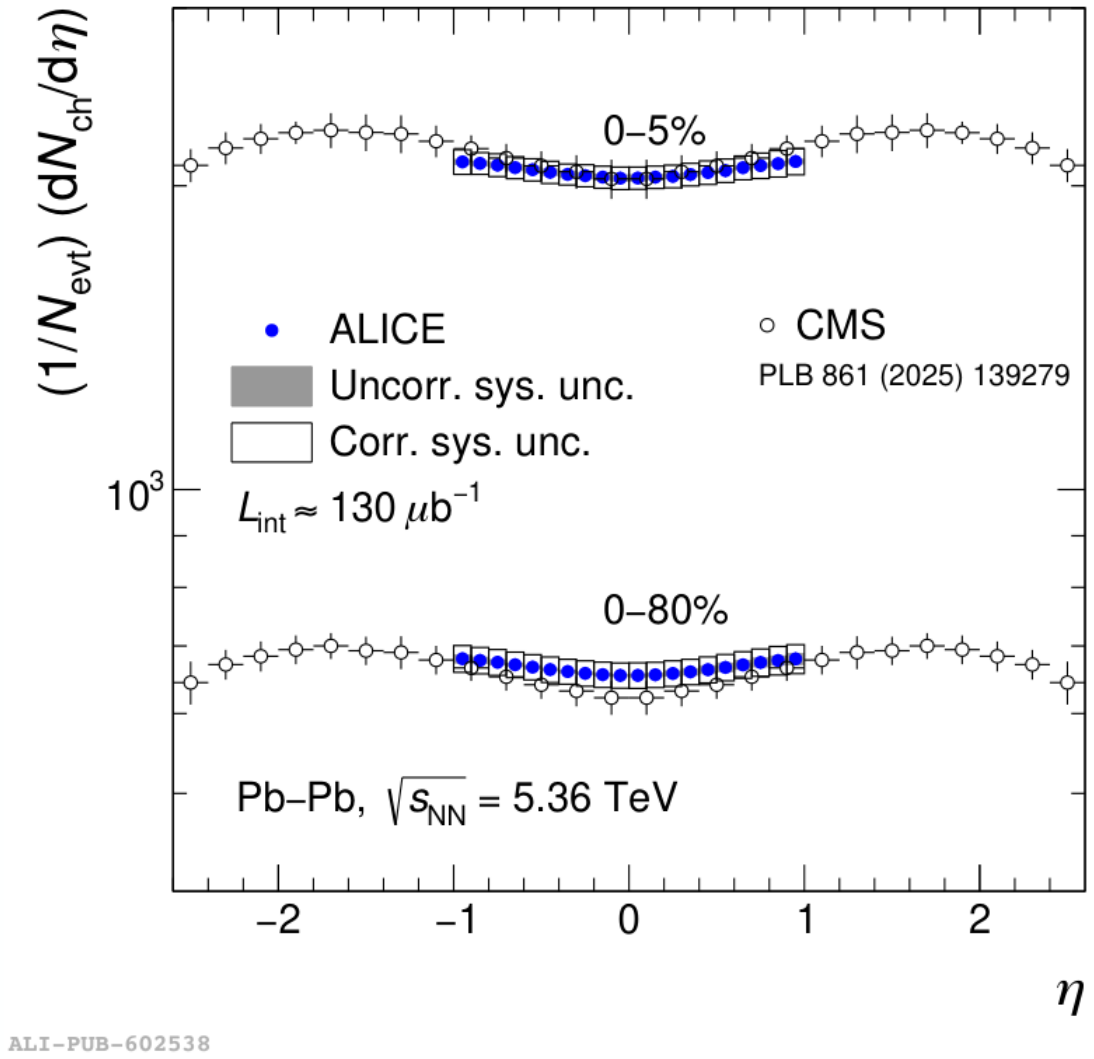
FT0 - Estimation of multiplicity class



The multiplicity-dependent results (preliminary) for all multiplicity classes:

- Multiplicity classes determined by sum of FT0-A and C signals (FT0M percentiles)
- Good input for various particle production models

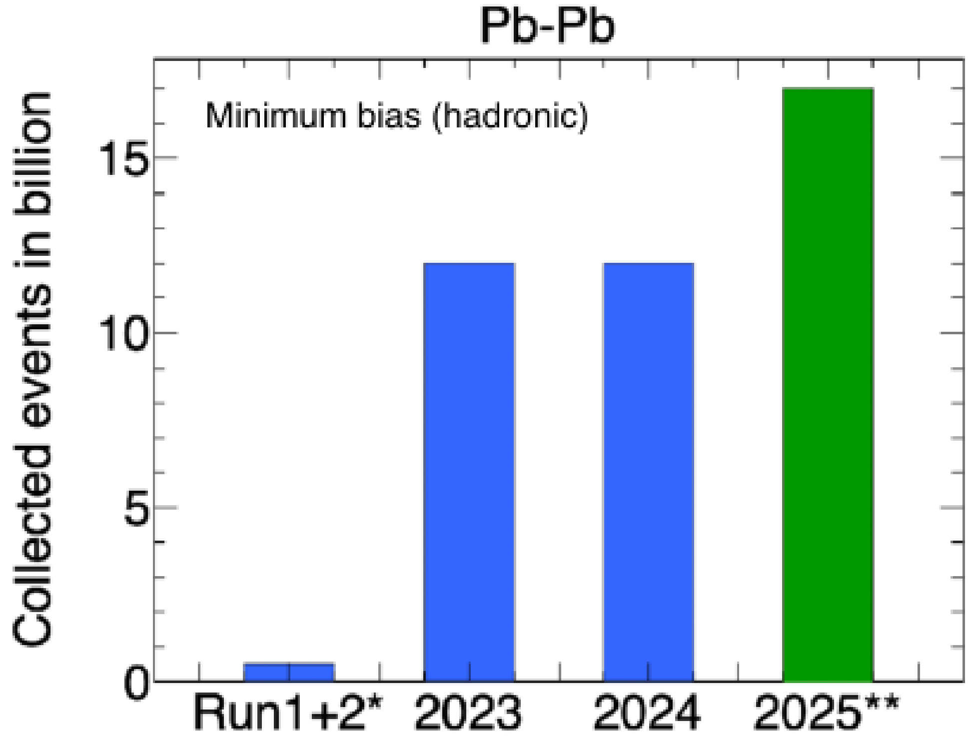
FT0 - Estimation of centrality class



New result of dNch/dη in different centrality classes:

- Centrality classes determined by sum of FT0-C signals (FT0C percentiles)
- New result of $dN_{ch}/d\eta$ agrees well with the measurements of CMS for both 0-80 % and 0-5% centrality classes within $|\eta| < 1$

Run 3 statistics and 2025/2026 schedule



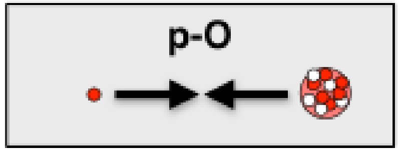
*for central barrel only (MB)
**expected in 2025

pp:
- 2 billion (Run1+2)
- 5700 billion (2022-2024)

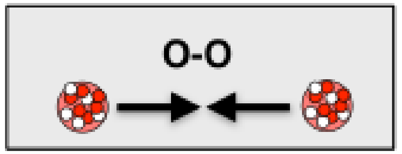
Goals for 2025-2026

- 47 pb^{-1} expected
- 3 pb^{-1} low field

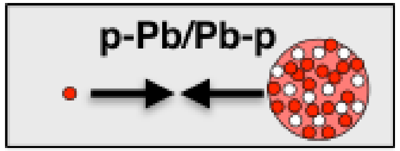
- 2.6 nb^{-1} expected



- ~2.5 nb^{-1} expected



- 1 day + maybe one day of Ne-Ne



- ~150 nb^{-1} expected

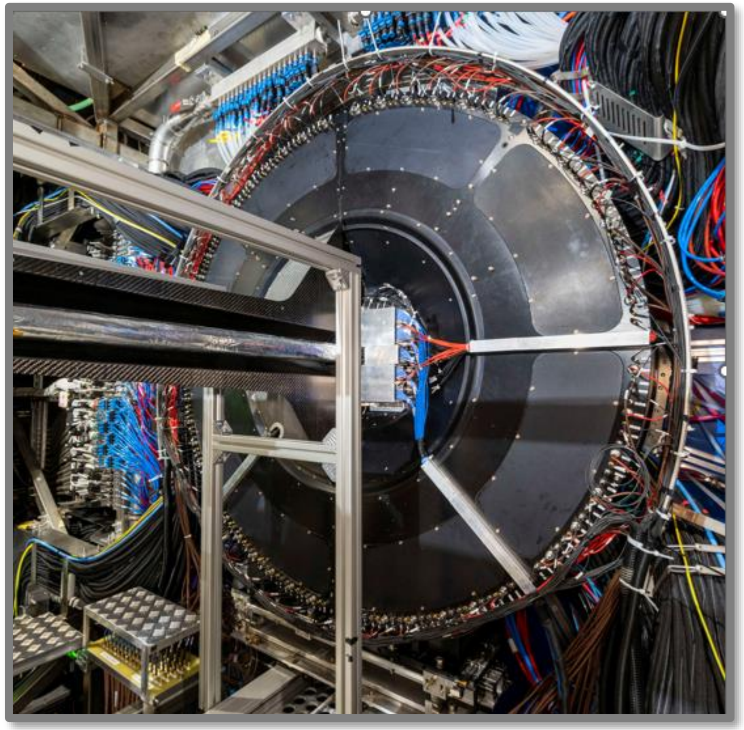
Conclusions

- New FIT detector was installed in ALICE during the LS2
- FIT is operational since the first day of Run 3
- The use of a modified MCP-PMT has made it possible to ensure:
  - Remarkable timing precision of σ = 17.4 ps in pp collisions and σ = 4.4 ps in Pb-Pb collisions;
  - Ageing balanced by HV increase without timing deterioration beyond 1 C/cm^2 IAC;
  - Handling photon fluxes of up to $3*10^8$ p.e./cm^2/s;
  - Self-annealing of aged channels – newly observed effect.
- First massive application of the Planacon® MCP-PMTs in HEP
- Excellent performance observed in both pp and Pb-Pb collisions:
  - As luminometer FIT provides important trigger counts of physics events
  - Multiplicity measured by FIT in forward region is used for centrality/ multiplicity determination in Run 3
  - Collision time is important measurable value for PID analysis via TOF detector

Thanks a lot for your attention!

FIT Movies

Russian



English

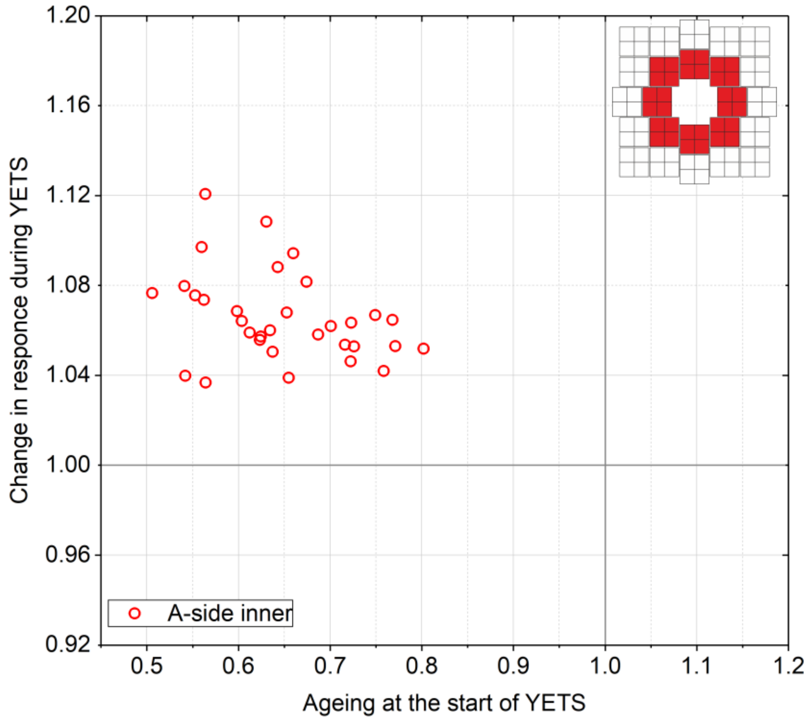
https://rutube.ru/video/7fd5631466ad0b38c22cd860cd65c4db/

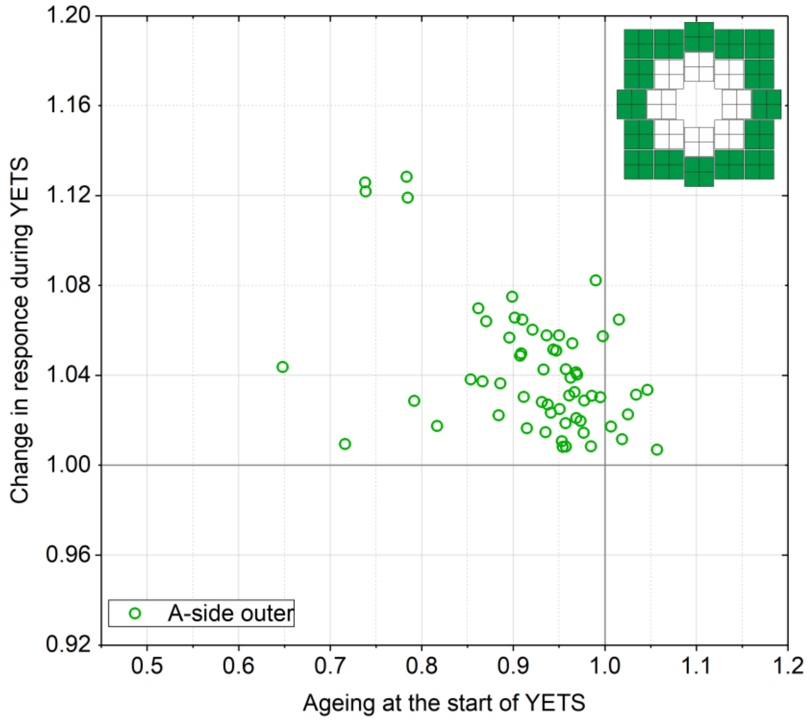
https://rutube.ru/video/8a60c49f24912e4219f5b2734a04d0a7/

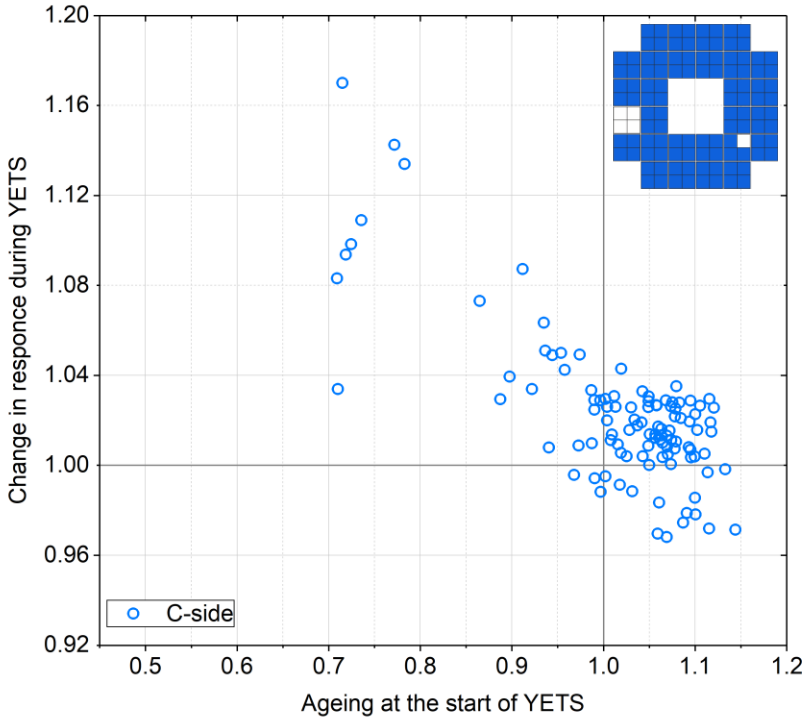
Back-up slides

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

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

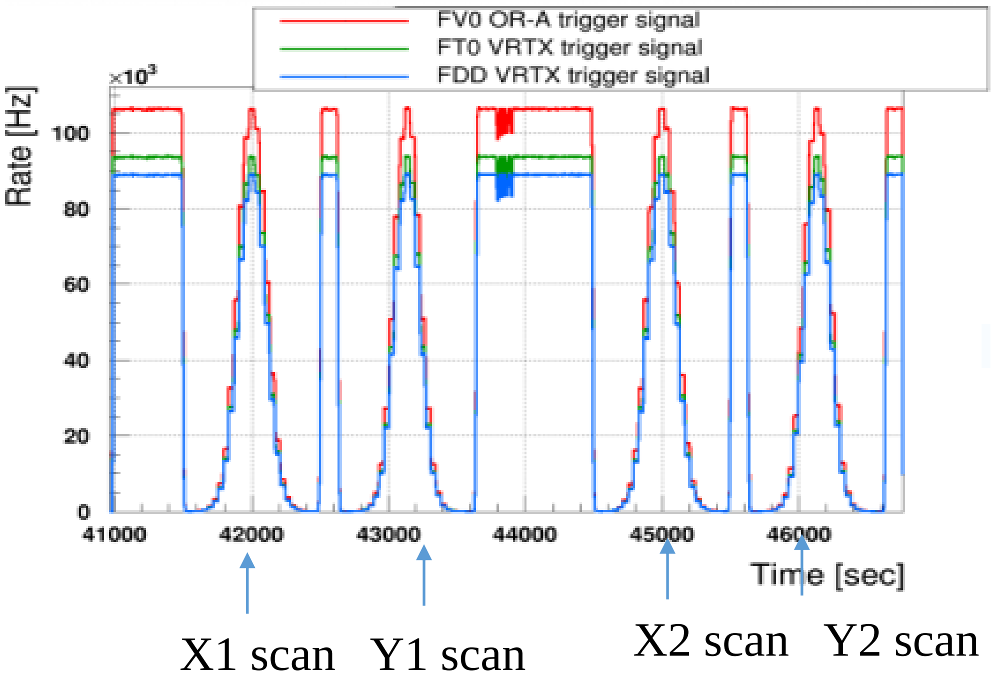






Luminosity determination

- **Luminosity determination in ALICE** is based on the measurement of visible cross sections in van derMeer (vdM) scans
  - In vdM scans, the two beams are moved across each other in the x (horizontal) and y (vertical) directions
  - The rate of the reference (visible) process is measured as a function of the transverse beam separations
  - vdM scan -based luminosity calibration requires a detailed data-taking and analysis procedure to have good control of several subtle effects
- **New ALICE luminometers :**
  - **Fast Interaction Trigger** system;
  - Upgraded ZN read-out.
- **Run 3 luminosity signals:**
  - **FT0 Vertex** - minimum bias trigger for luminosity monitoring in **pp** collisions :
    - Trigger purity;
    - Not sensitive to particles coming from backward direction;
    - Not triggered by satellites.
  - **FT0 (SCen || Cen)** – minimum bias trigger in **Pb-Pb** collisions
  - **FT0 Cen and FV0 Charge** – high multiplicity triggers in **Pb-Pb** collisions
  - Neutron emission at beam rapidity: **ZNA, ZNC**
- **Background monitoring:**
  - **FT0** uses non-colliding bunches (non Beam-Beam bunch mask)



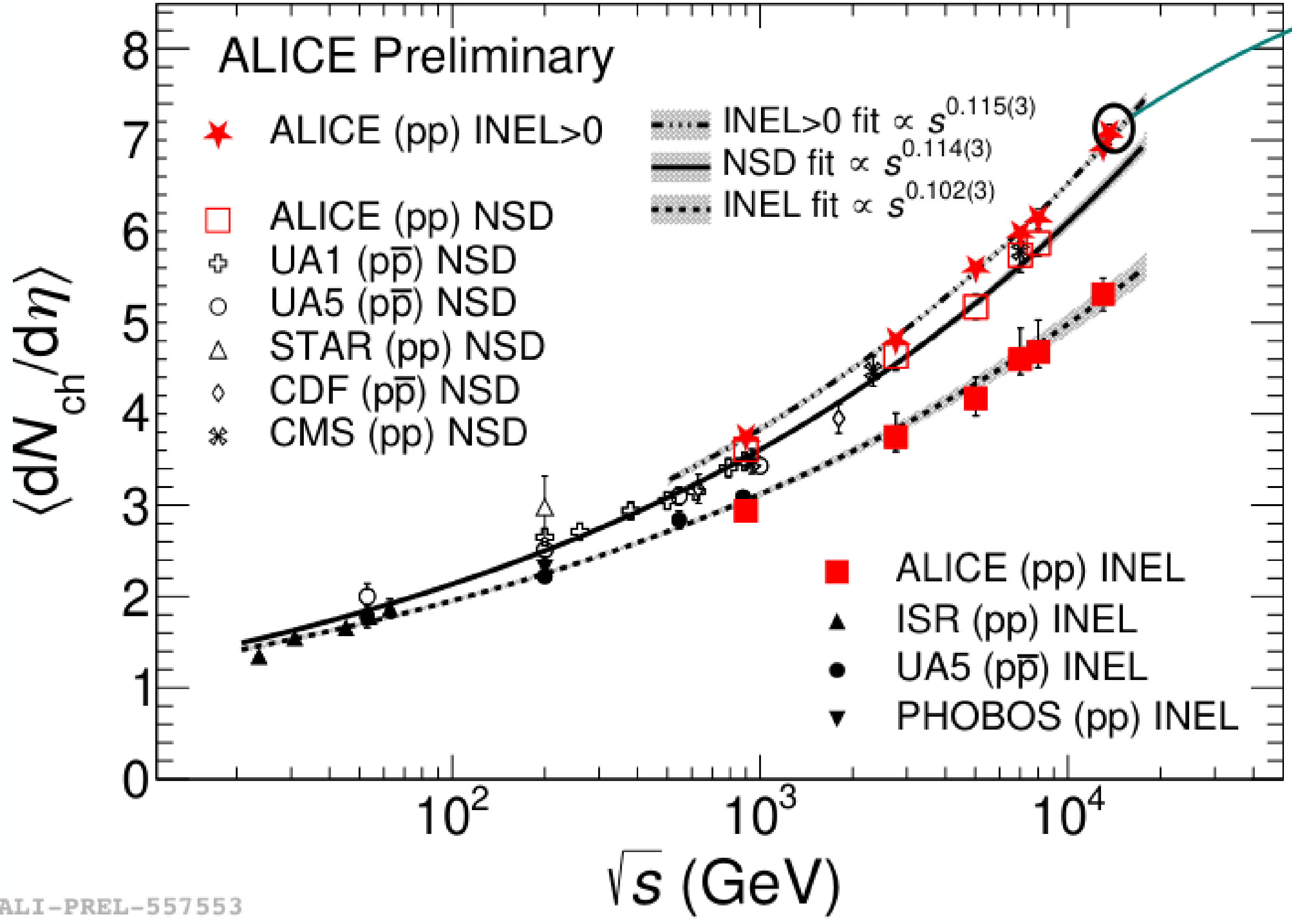
VdM scan analysis for Run-3 is currently ongoing

FT0 BC selection

- In **Run 2** converted data BCs and collisions have one-to-one correspondence, but there is no such feature in **Run 3**
- Collision time is not known precisely (up to ~100 bc uncertainties)
- Event selection tries to find closest bc with FT0 Vertex trigger (FT0-vertex activity) to account for the ambiguity of the BC collision:
  - Works well at low IR (typical TVX efficiency ~ 90%)

ALICE

☆ $dN_{ch}/d\eta$ as a function of collision energy

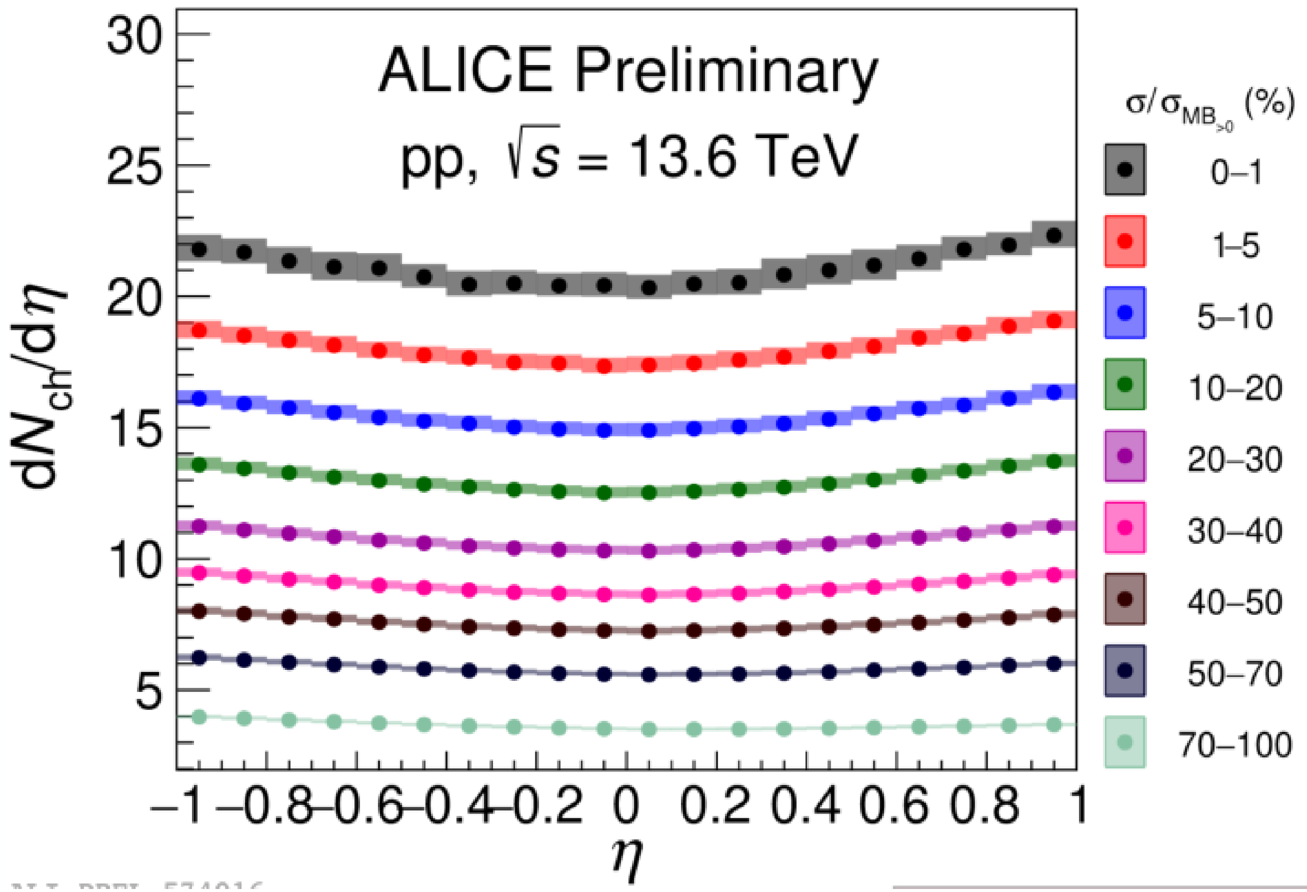


13.6 TeV

- New pp results in 13.6 TeV, follows the power law trend
- $\langle dN_{ch}/d\eta \rangle \propto s^{a}$ expected at LHC energy

ALICE

Multiplicity dependent $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$



multiplicity classes determined by sum of FT0-A and C signals (FT0M percentiles)

	Rapidity coverage
FT0-A	$3.5 \leq \eta \leq 4.9$
FT0-C	$-3.3 \leq \eta \leq -2.1$

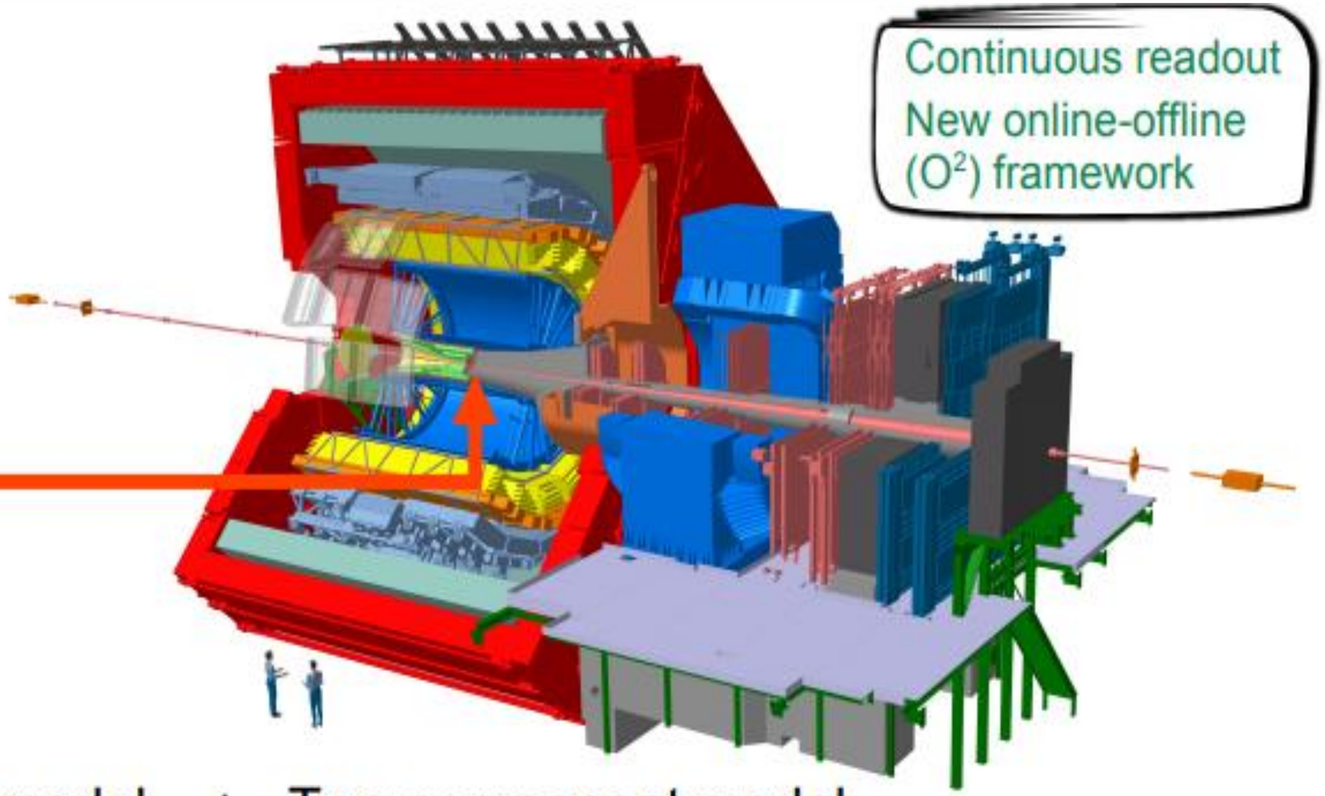
- $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$ increases with decreasing FT0M percentile.
- $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$ is ~5 times larger for 0-1% than for 70-100%
- Input for vs multiplicity studies using other per-event observables (particle yield, $\langle p_{\mathrm{T}} \rangle$)

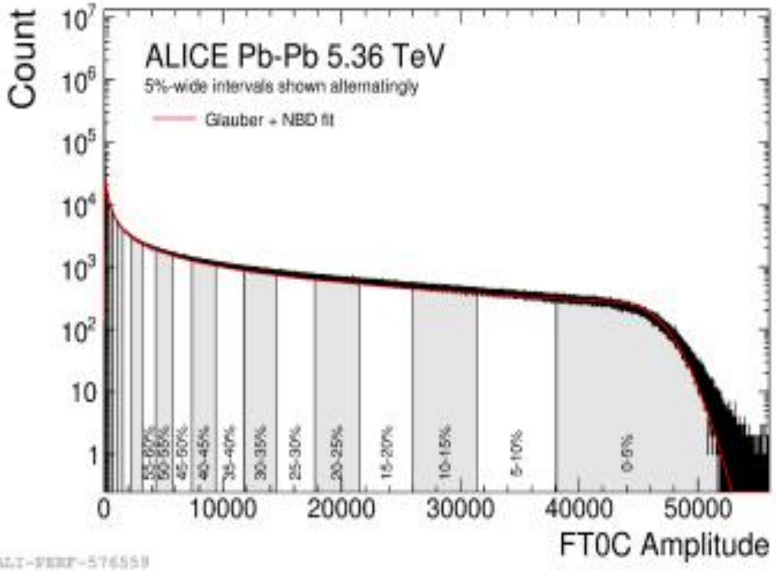
Centrality determination

Fast Interaction Trigger

- Cherenkov (FT0) detector
- Used for collision time, event selection and centrality estimation
- FT0C ($-3.3 < \eta < -2.1$)

Continuous readout
New online-offline (O^2) framework





Glauber model + **Two-component model**

$$\rho(r) = \rho_0 \frac{1 + w(r/R)^2}{1 + \exp(\frac{r-R}{a})}.$$

Nuclear radius $\boldsymbol{R}$ = 6.62 ± 0.06 fm
Skin thickness $\boldsymbol{a}$ = 0.546 ± 0.010 fm
σ_{INEL} = 68.2 ± 0.6 mb

$$N_{\mathrm{sources}} = f \times N_{\mathrm{part}} + (1 - f) \times N_{\mathrm{coll}}$$

Particle produced by each source is parameterised by NBD

The NBD-Glauber fit provides a good description of data