# 15 Years Young: the ALICE TOF detector in LHC RUN 3

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on behalf of the ALICE Collaboration
(University and INFN Bologna, Italy)

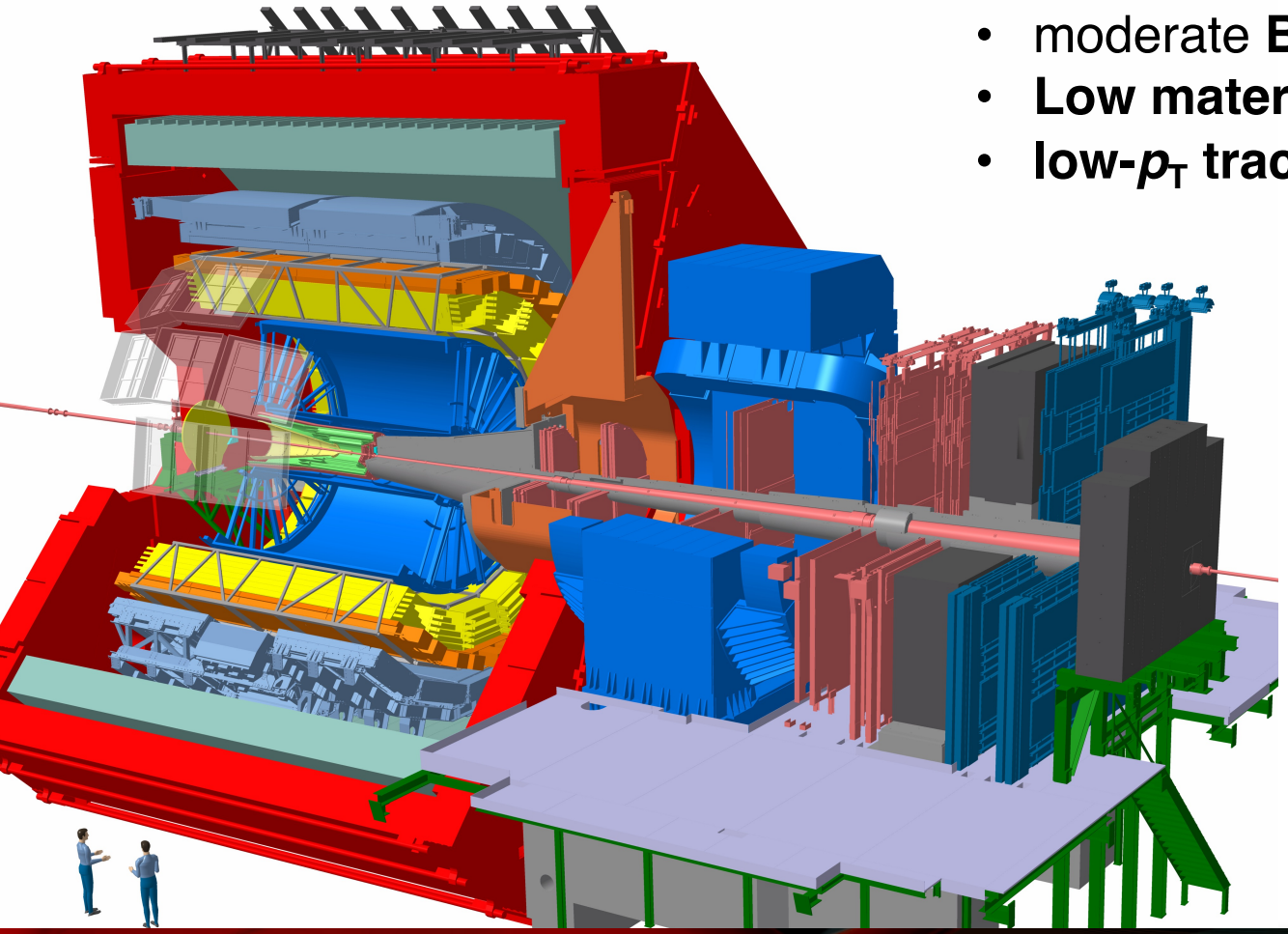
**XVII Conference on Resistive Plate Chambers and Related Detectors**

9-13 September 2024

- ALICE TOF MRPC
- Upgrade of LS2
- Performance in Run3
- Physics with TOF
- LS3 plans

# The ALICE Experiment a dedicated heavy-ion experiment at the LHC

Designed to cope with **very high multiplicities** ($dN_{ch}/d\eta \leq 8000$)



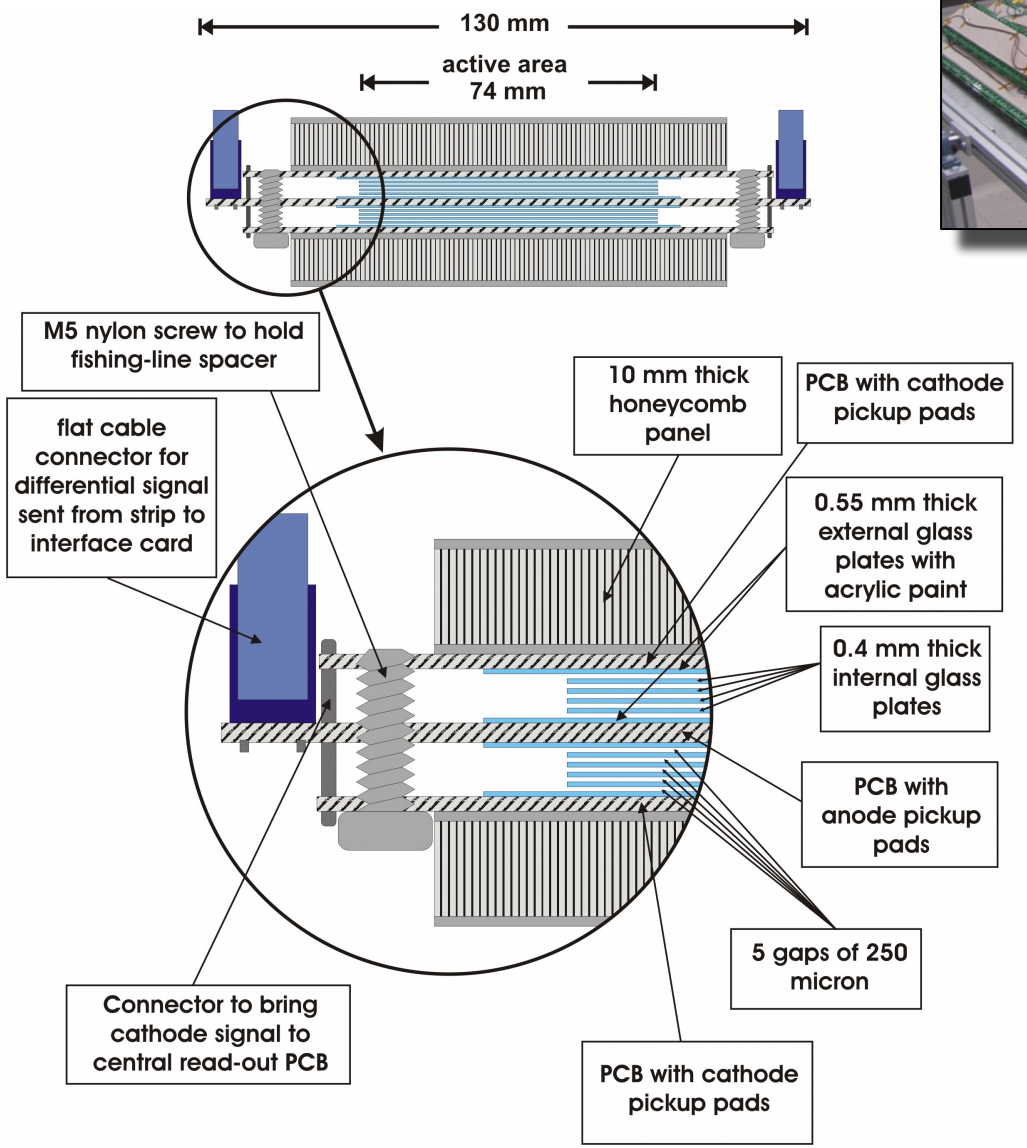
- **3D tracking** with TPC
- moderate **B = 0.5 T**
- **Low material budget**
- **low-$p_T$ tracking** down to $p_T \sim 100$ MeV/$c$

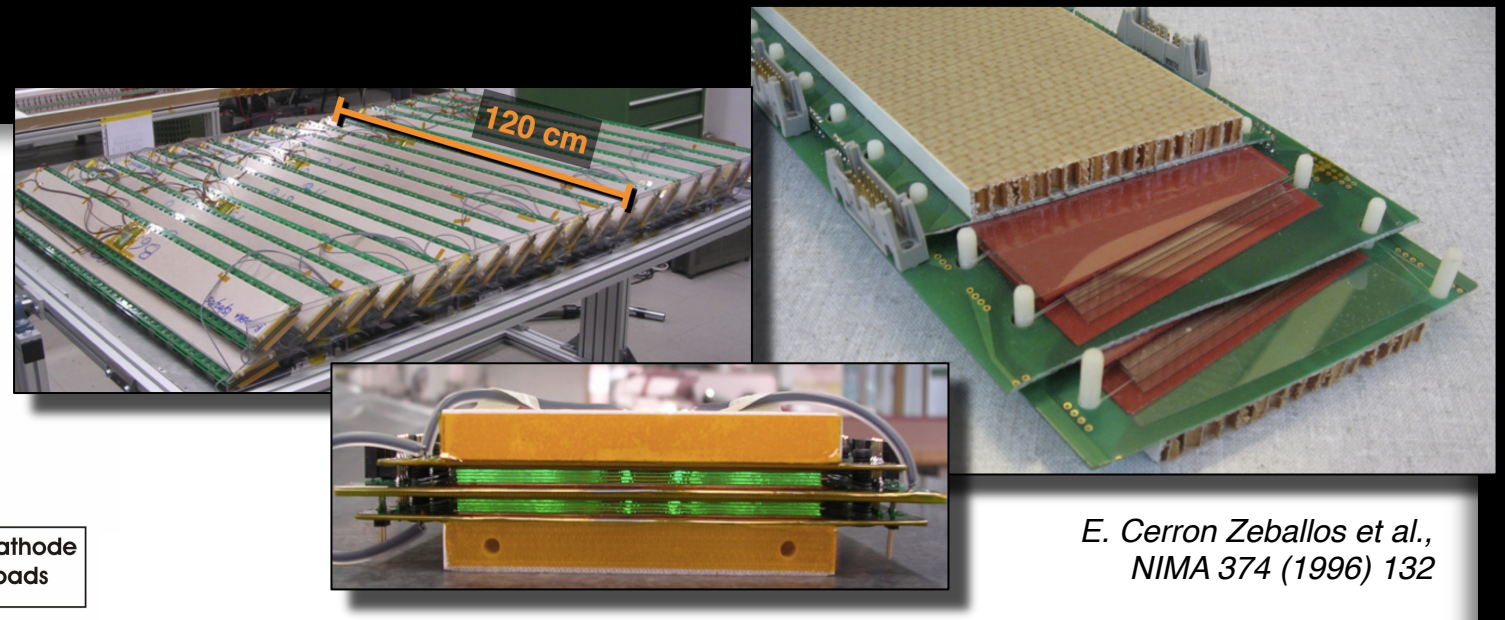
Uses all known **PID** techniques
among which a large area
**T**ime **O**f **F**light detector

L: 28 metres
H: 16 metres
W: 10kt

**15 years of data taking**

# ALICE TOF MRPC




*E. Cerron Zeballos et al., NIMA 374 (1996) 132*

## 1593 MRPCs double stack Multi-gap Resistive Plate Chamber

- Gas mixture: 93% $C_2H_2F_2$ + 7% $SF_6$
- **10**(2x5) **250 mm gaps** (double stack)
- **120x7.4 cm² strip active area**
- 2 rows of 48 pickup pads per strip (3.5x2.5 cm²)

**Built in 2005-2006**

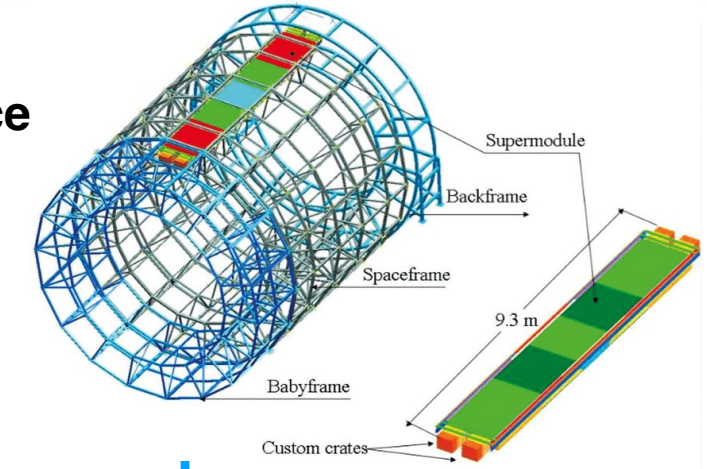
# ALICE Time-Of-Flight (TOF) detector

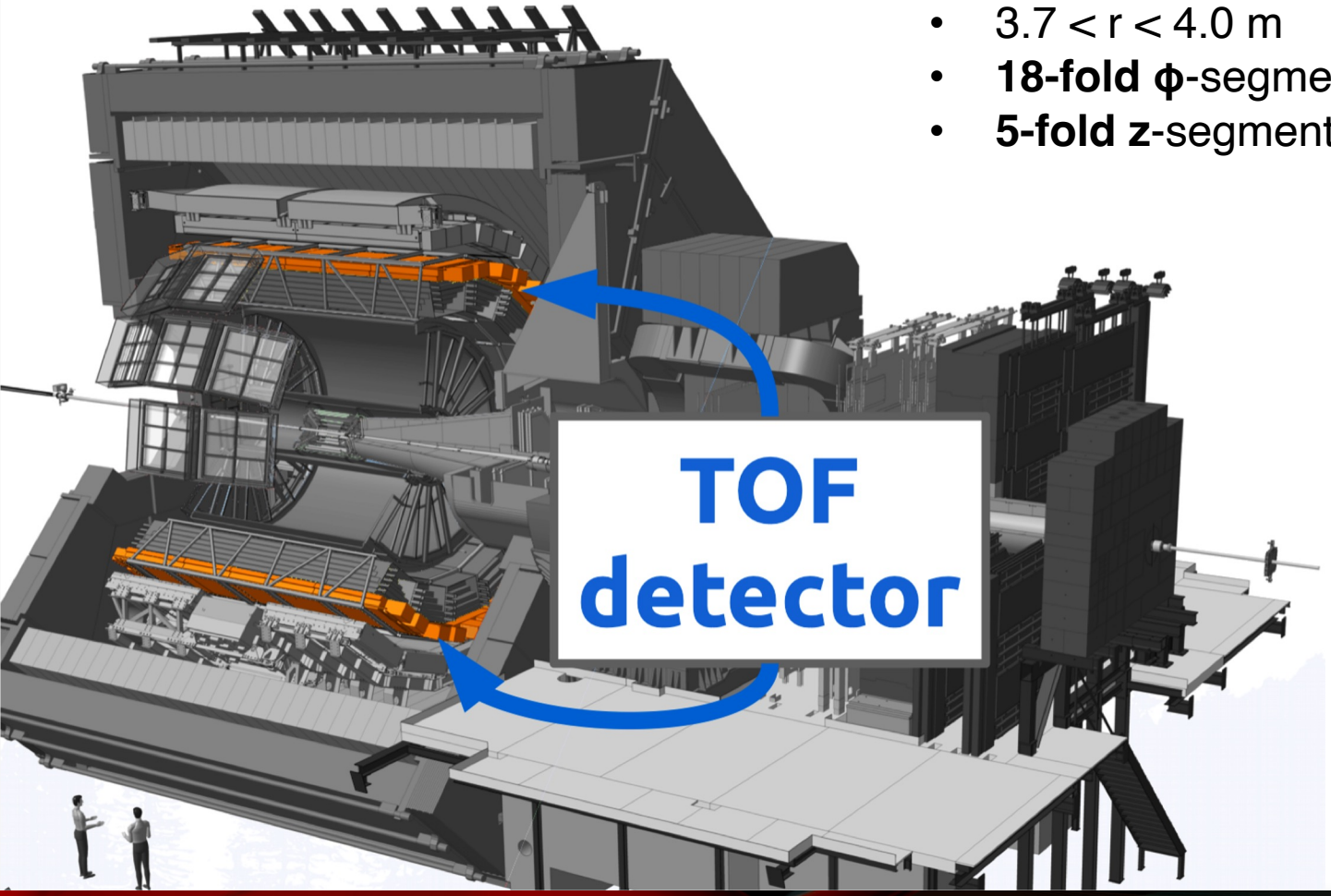
## Needs

**Hadron identification** in **Pb-Pb** collisions at **intermediate $p_T$**

## Design

- $|\eta| < 0.9$ polar acceptance
- **2π** full **azimuthal acceptance**
- **cylindrical surface**
- $3.7 < r < 4.0$ m
- **18-fold ϕ**-segmentation
- **5-fold z**-segmentation




## Requirements

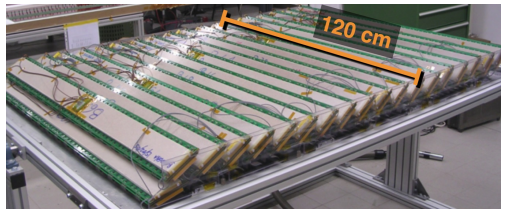
- large coverage **(~141 m²)**
- High PID efficiency **(> 95%)**
- excellent time resolution **(< 80 ps)**
- high granularity **(~10⁵ channels)**
- Noise without beam **(~1 Hz/pad)**

→ Based on the **multigap RPC** technology (**MRPC**)

→ Example of **wide area** MRPC application!

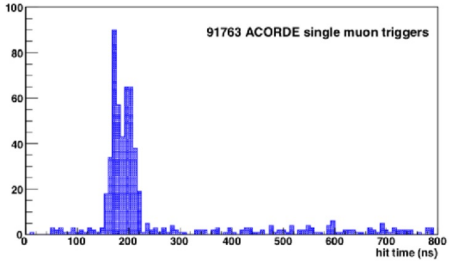
# ALICE TIMELINE

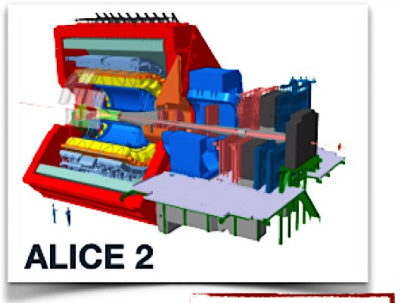
**2006**
End of MRPC production



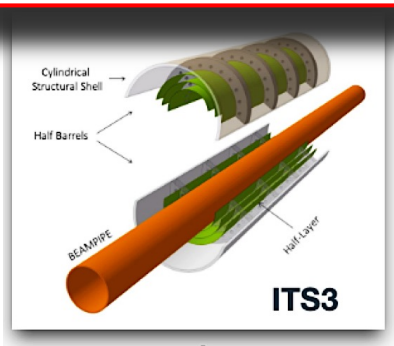

**2008**
End of installation

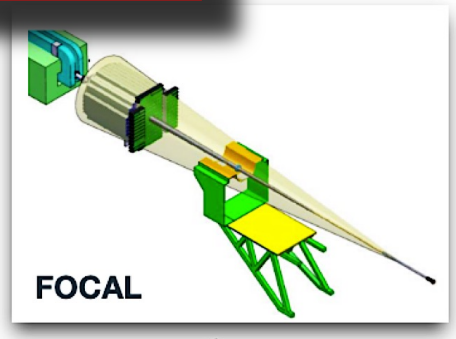
**mid-2008**
First data taking




Pb-Pb: 6.2 nb$^{-1}$
O-O: 500 μb$^{-1}$

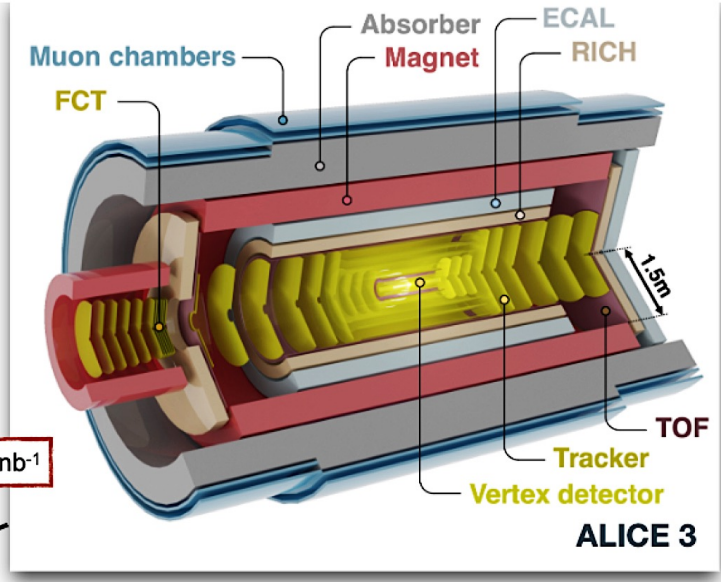



Pb-Pb: 6.8 nb$^{-1}$
p-Pb: 0.6 pb$^{-1}$

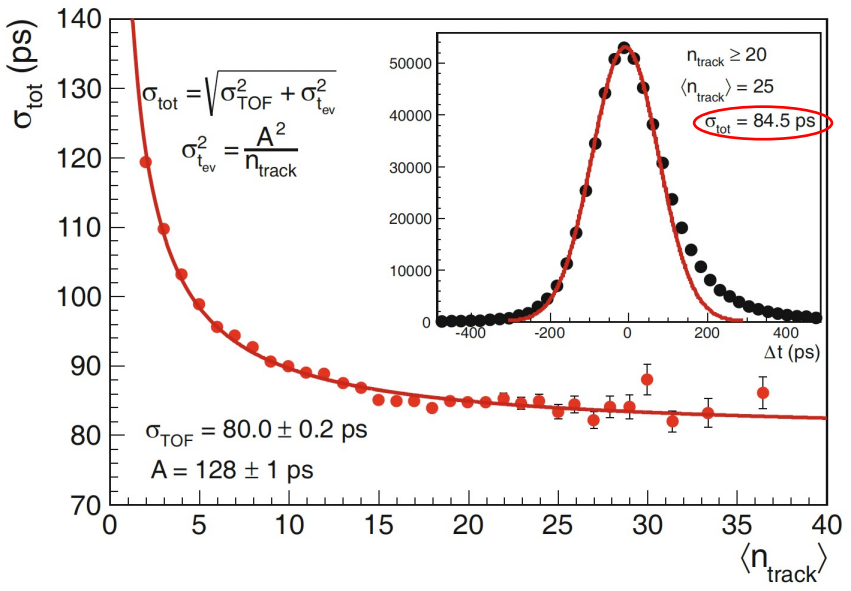
Pb-Pb: ~ 35 nb$^{-1}$

End of **ALICE**

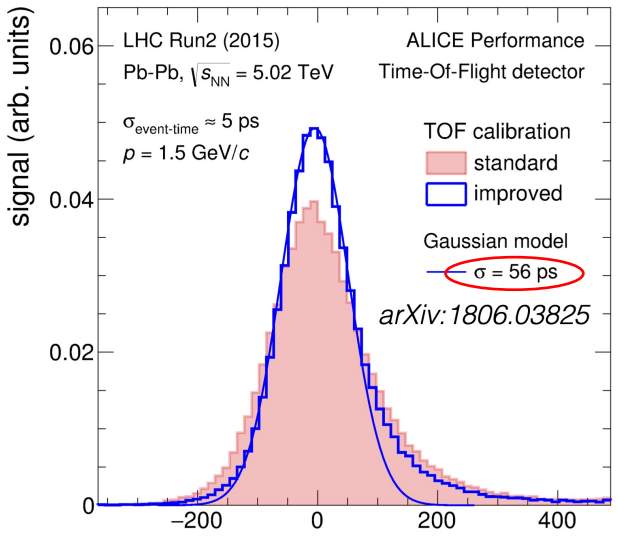


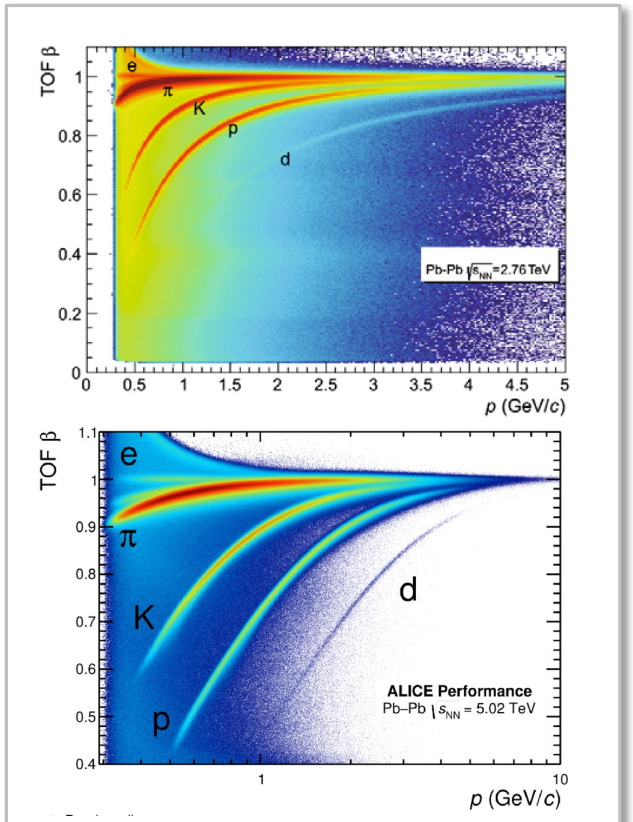

# Timing performance in old runs

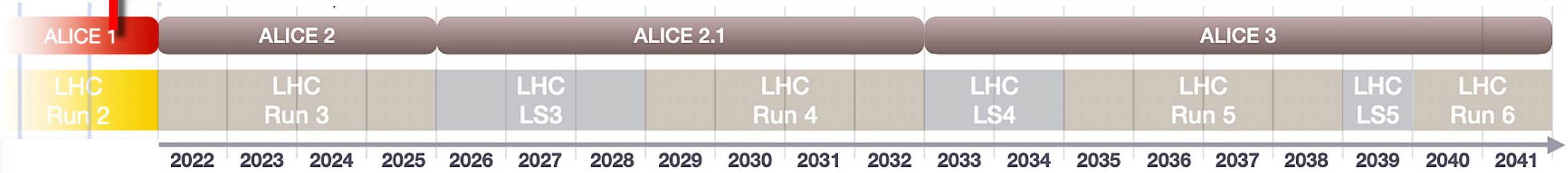
## Run 1



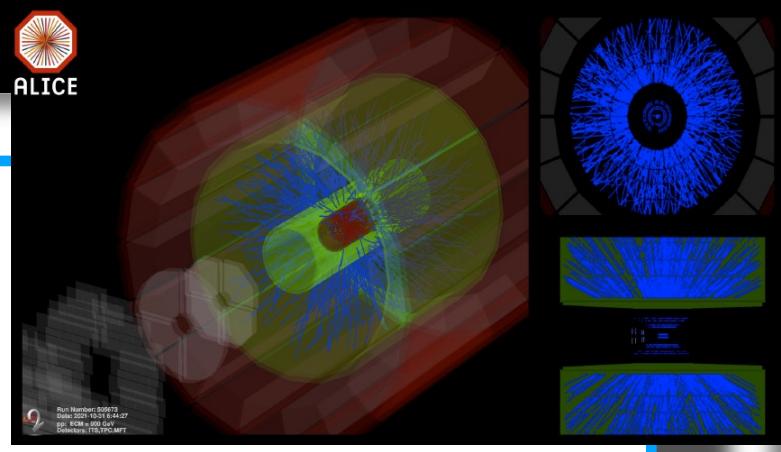

## Run 2 + calibrations



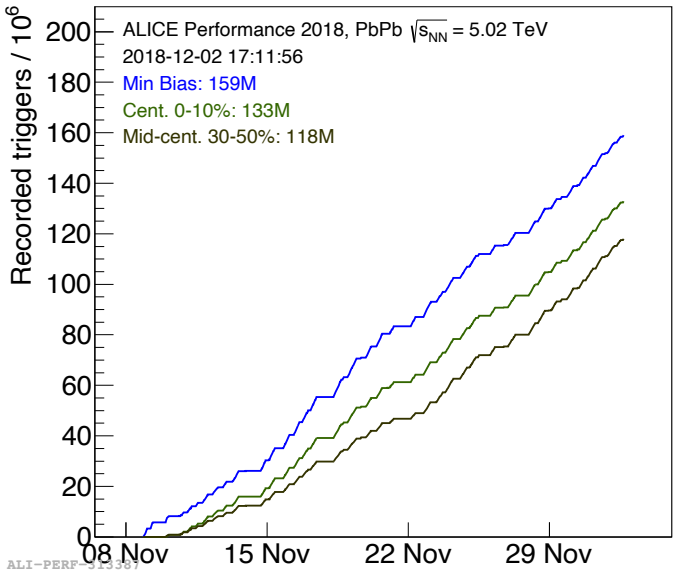



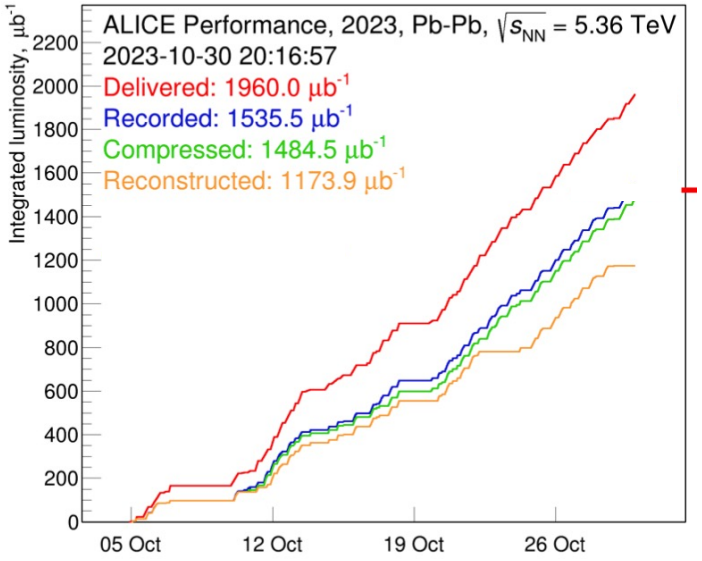
# Increase in luminosity from Run2 to Run3




## 2018, Run 2




## 2023, Run 3

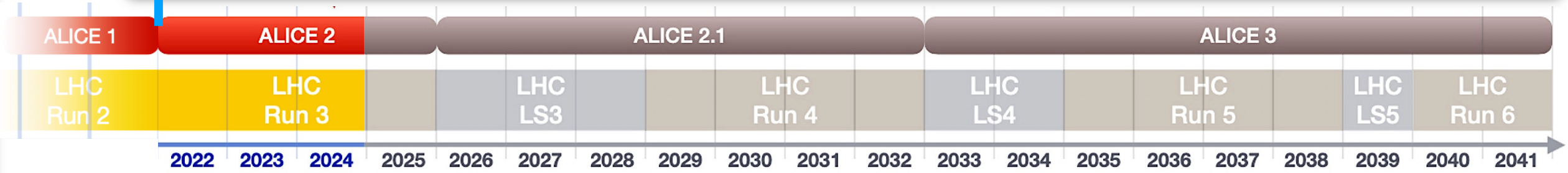



**pp:** 0.02 pb$^{-1}$ → 65 pb$^{-1}$ *(ongoing)

***3250 times higher*** *in Run 3 wrt Run2*

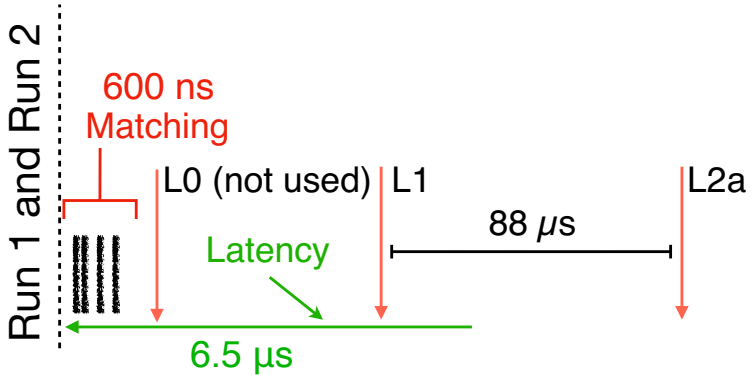
**PbPb:** 800 µb$^{-1}$ → 2.16 nb$^{-1}$

***3 times higher*** *in Run 3 wrt 2018*



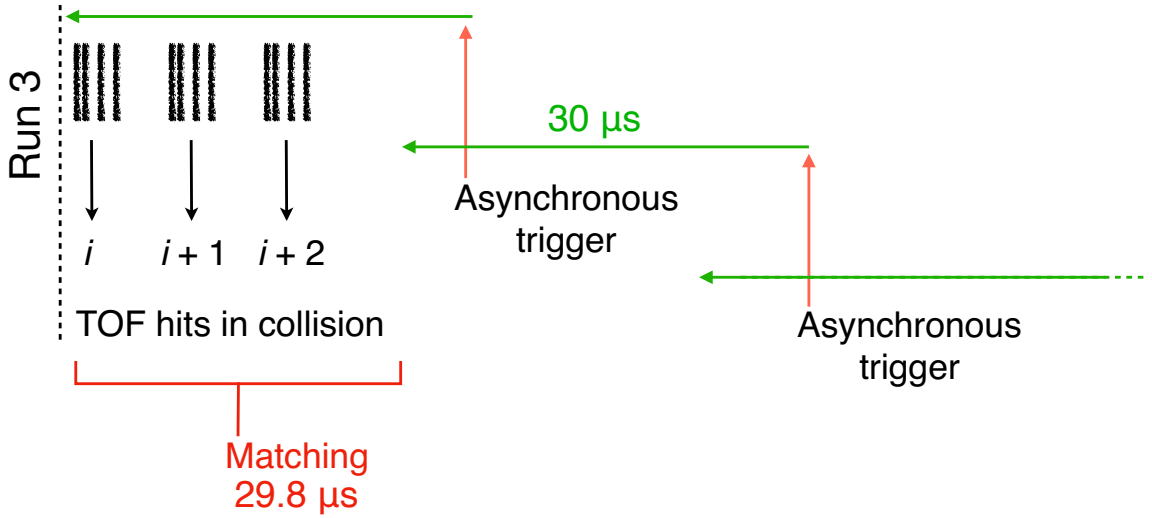
# TOF readout UPGRADE for Run 3

ALICE moved in Run3 to **continuous readout** **to cope with the enhanced luminosity**




→ **Run 1 and 2** (physics trigger received)

- trigger from Central Trigger Processor (CTP)
- TDC selected matching window of 600 ns
- only one collision event




→ **Run 3** periodic trigger (asynchronous with respect to physics events)

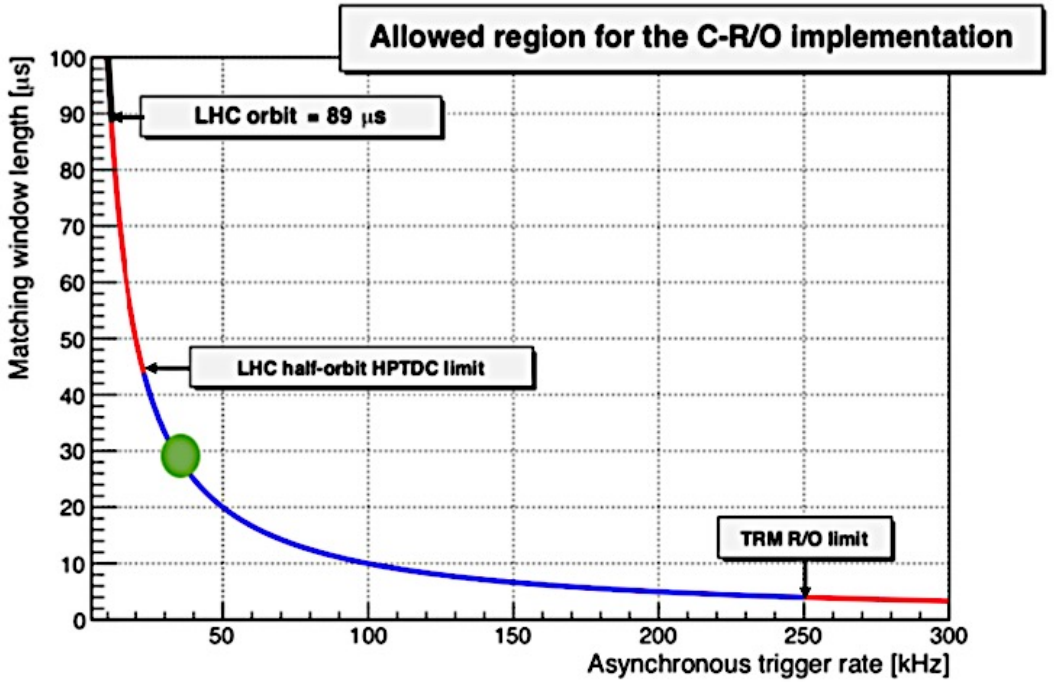
**Continuous readout** implemented in TOF with large (30 μs) **latency window**, and **periodic triggers** to cover all the orbit.

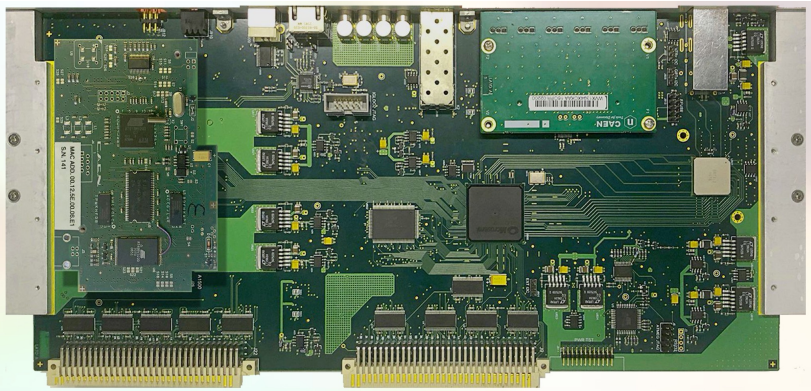
# TOF readout UPGRADE for Run 3

To achieve this condition the internal buffering capabilities of the HPTDC are fully exploited

→ using a **matching window** of ~ **30 µs** and a pseudo-**trigger** at a **fixed frequency**

$f_t = 3/t_{LHC-orbit}$ of **33 kHz**



In order to keep up with the increase of the interaction rate ~ 1 MHz in pp & 50 kHz in Pb–Pb

→ a new **Digital Readout Module 2 (DRM2)** was designed

# TOF calibrations in the continuous readout scheme

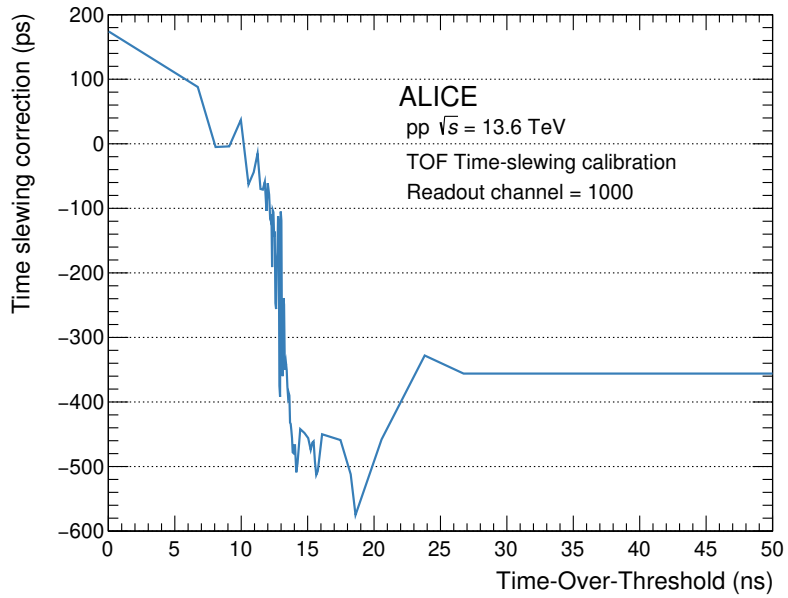
TOF calibrations are performed at different stages of data taking and reconstruction:

1) **Start of the run** → **from** the TOF **slow control system** storing the TOF active channel map at the beginning of the run (DCS calibrations)

2) **Sync calibration** → **During the data taking** on the EPN farm

3) **Offline reconstruction** (async calibration) → performed offline with a **better reconstruction quality** and updated with the final **time slewing correction**

Example of time slewing calibration for a single channel is reported

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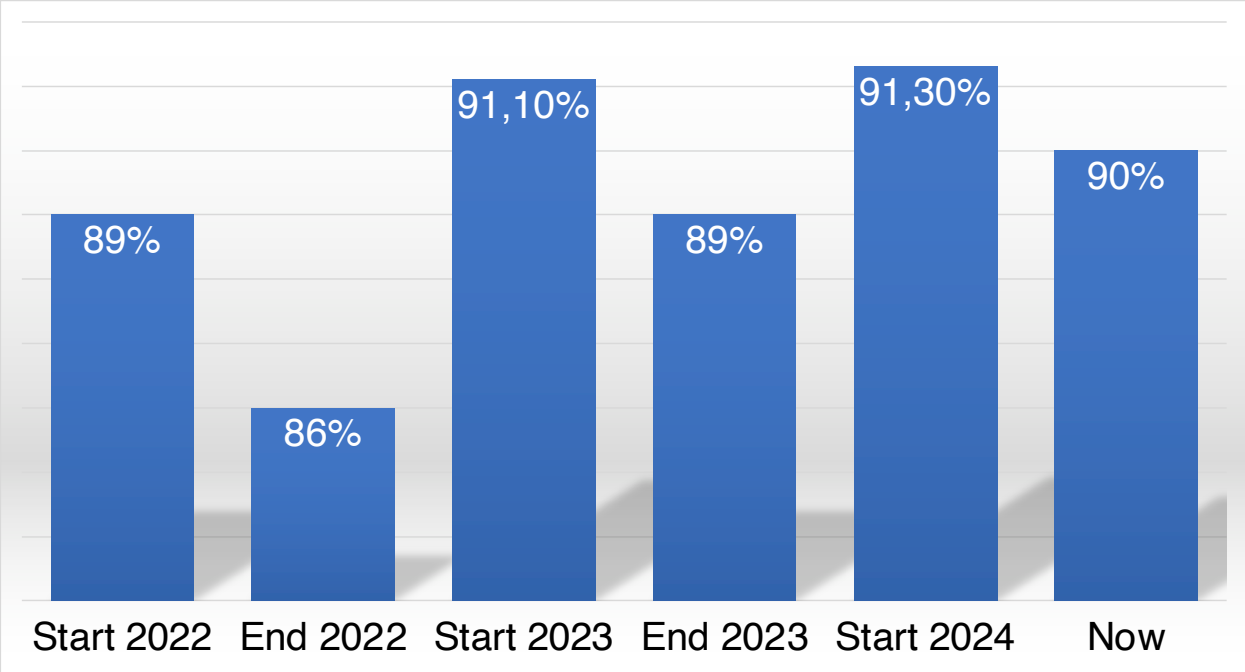
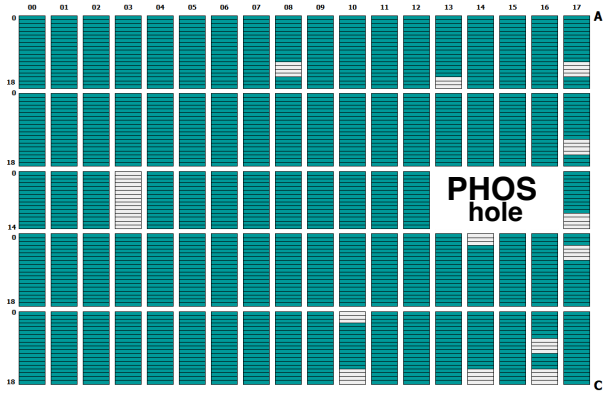
# TOF Operations – Stability

## PERCENTAGE OF ACTIVE CHANNELS DURING TIME




The missing **%** → due to **electronics (TDC cards)** and **HV connectors** (not to MRPC!)




**TOF MRPC HV map**

**→ stable since LS2**

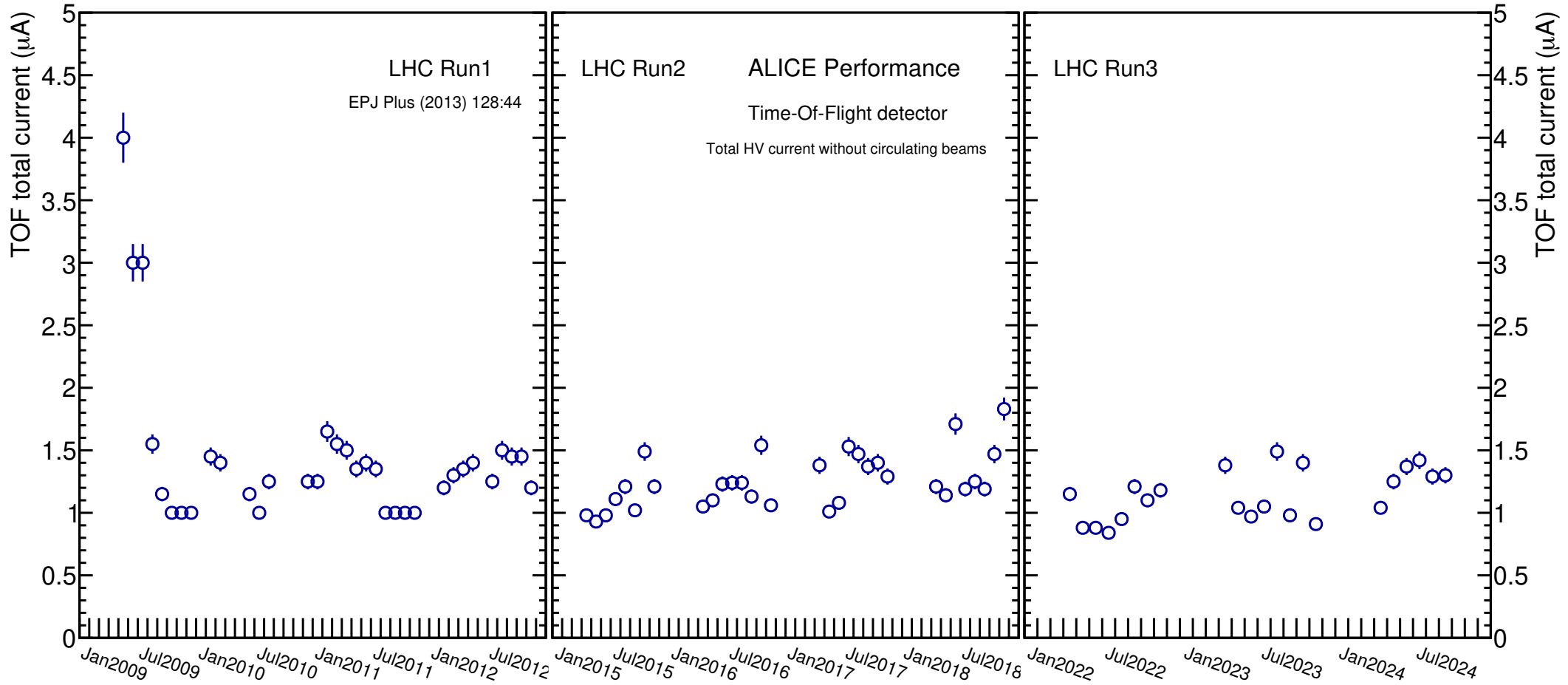
## BEAM TIME EFFICIENCY

**2018 → TOF has been in readout 98% of time**

**2024 → So far TOF has been in readout 99.1% of time**

**Stable efficiency during years**
→ now with **higher statistics** acquired thanks to the upgraded readout

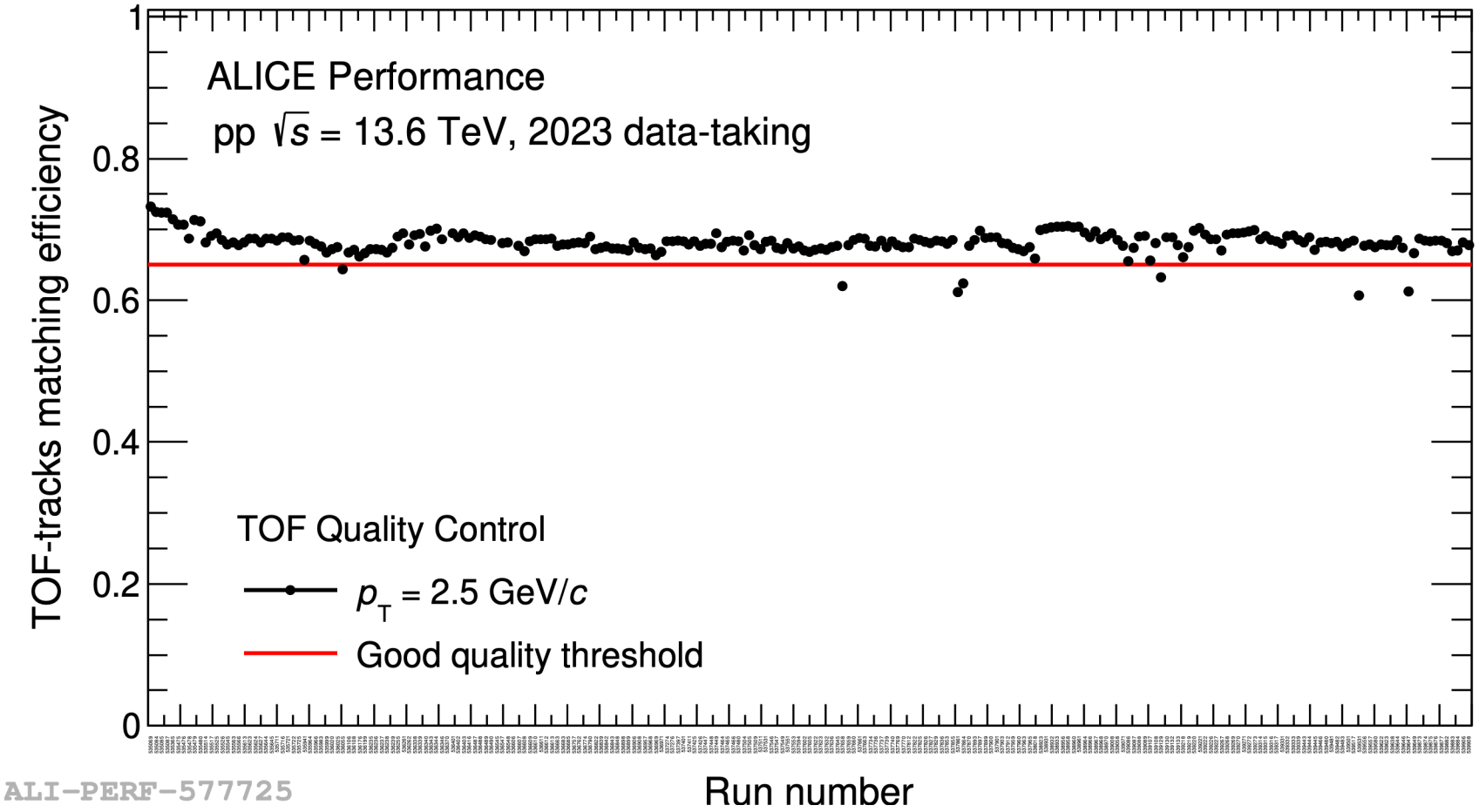
# TOF Operations – Stability

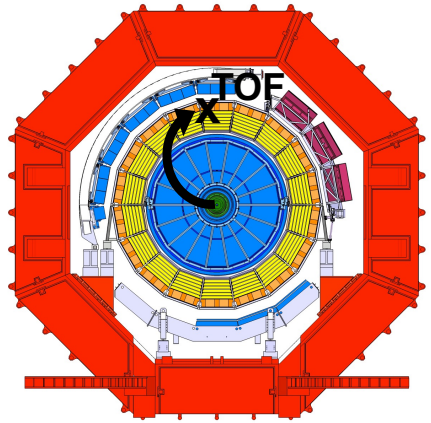



**Very stable operations** over the years { **average current** per MRPC of **few nA**
**no ageing** effects

# TOF Operations – Matching efficiency

TOF-track matching efficiency at 2.5 GeV using the 2023 dataset (pp, 13.6 TeV)



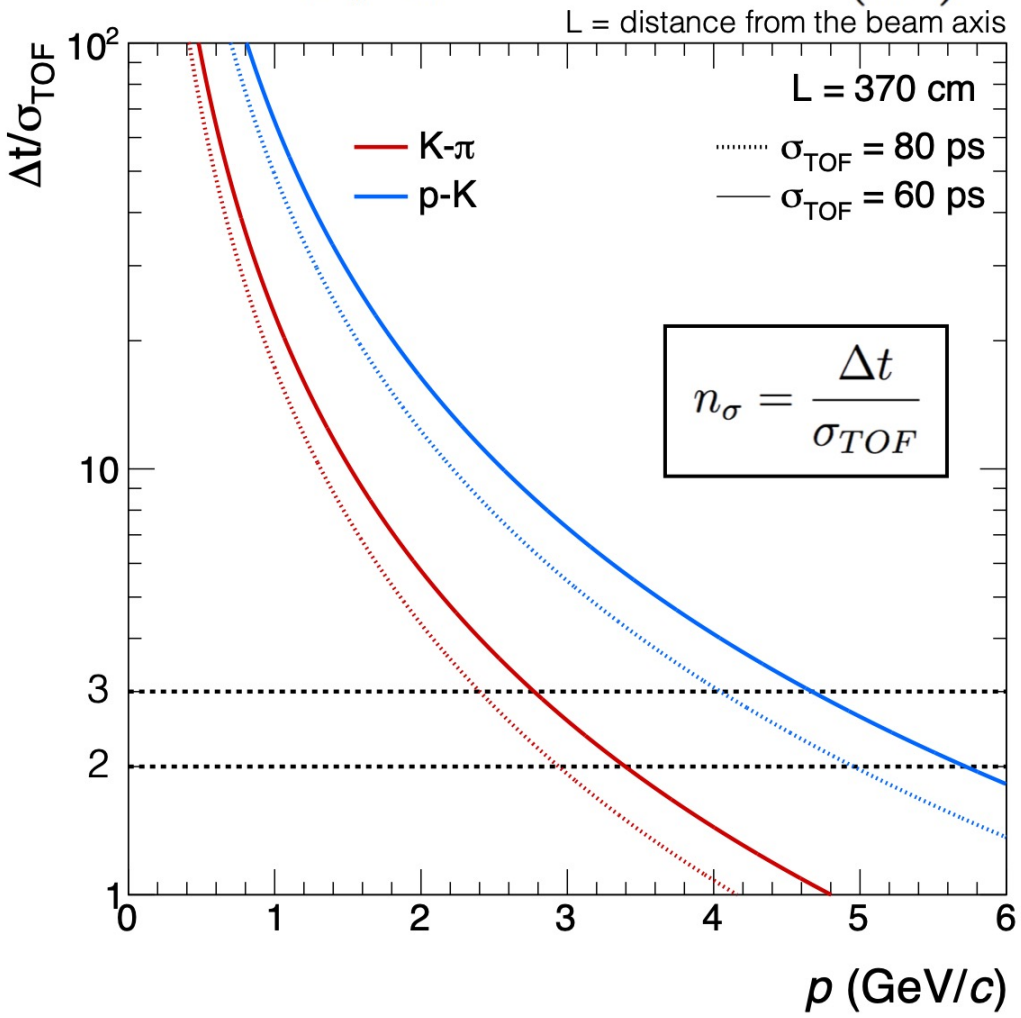

→ **Very good homogeneity of the TOF response**

# Particle IDentification (PID) with TOF

$$m = \frac{p}{c}\sqrt{\frac{c^2t^2}{L^2} - 1}$$

**Dominant term**

$$\left(\frac{\delta m}{m}\right)^2 = \left(\frac{\delta p}{p}\right)^2 + \left(\gamma^2\frac{\delta L}{L}\right)^2 + \left(\gamma^2\frac{\delta t}{t}\right)^2$$




$$\Delta t = t_i - t_j \simeq \frac{Lc}{2p^2}\left(m_i^2 - m_j^2\right)$$

**PID separation power of the TOF detector depends mainly on the intrinsic time resolution**

Goal → **time resolution as low as possible**

# Particle IDentification (PID) with TOF

$$m = \frac{p}{c}\sqrt{\frac{c^2t^2}{L^2} - 1}$$

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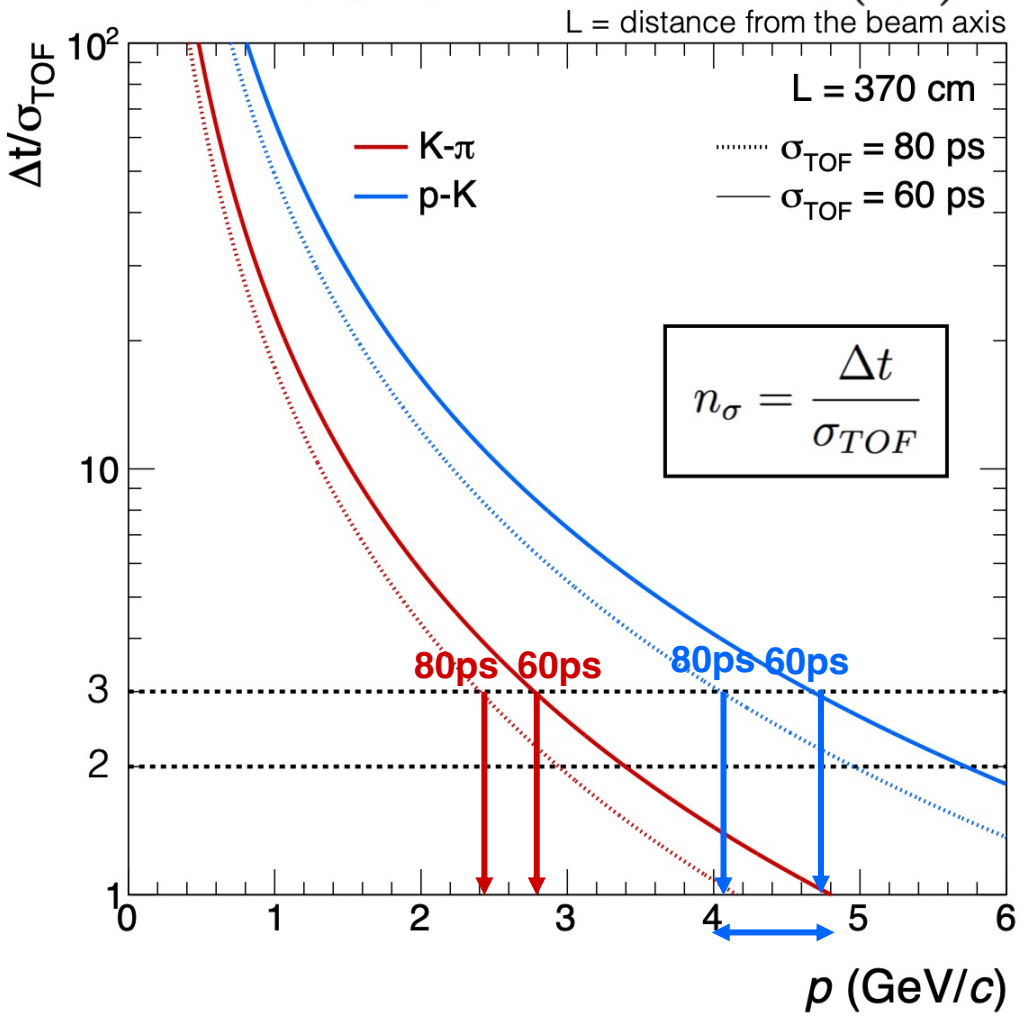
$$\left(\frac{\delta m}{m}\right)^2 = \left(\frac{\delta p}{p}\right)^2 + \left(\gamma^2\frac{\delta L}{L}\right)^2 + \left(\gamma^2\frac{\delta t}{t}\right)^2$$

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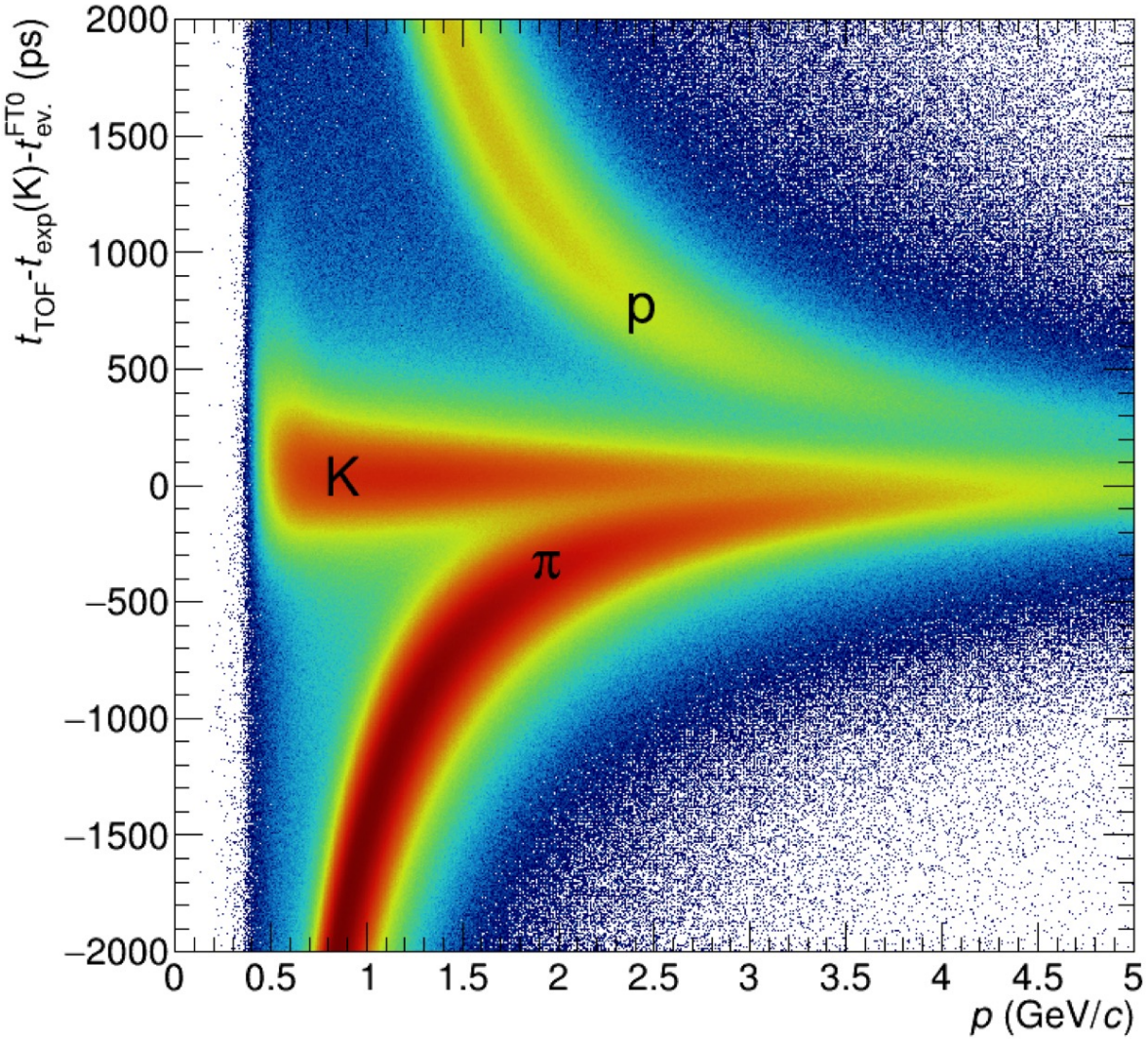
**PID separation power of the TOF detector depends mainly on the intrinsic time resolution**

Goal → **time resolution as low as possible**

*1 GeV of difference in p-K separation going from 80 to 60 ps resolution*

# PID performances in the commissioning of RUN 3




**Separation of the different particle species achieved with the TOF** as a function of p computed under the mass hypothesis of the kaon

→ The pion and proton bands are clearly visible and separated at low momenta

# TOF time resolution in Run 3

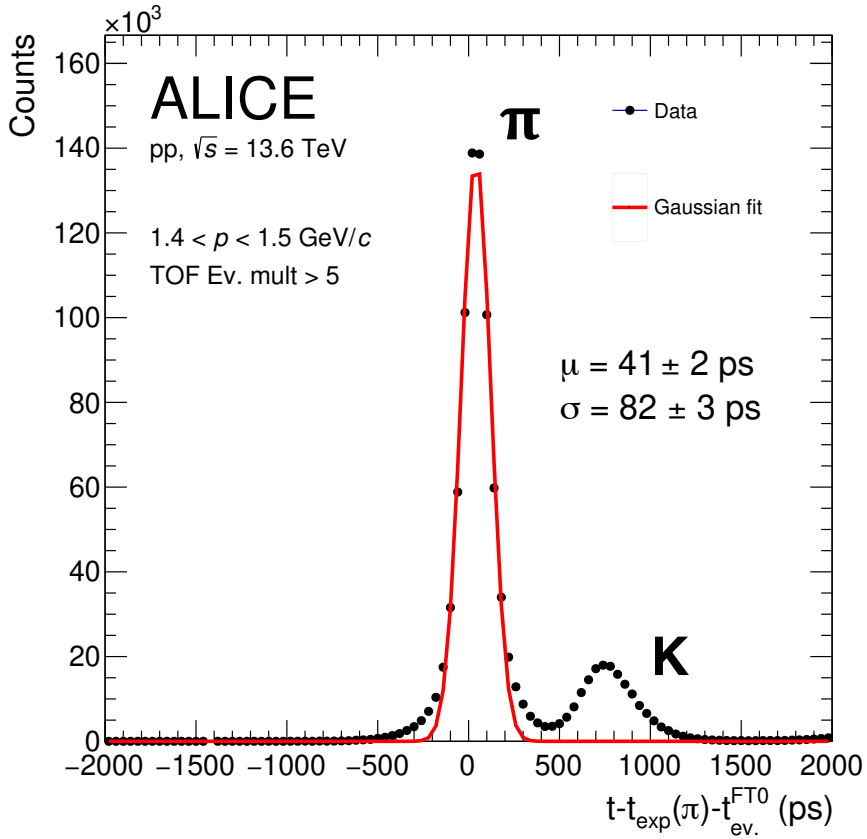
**A measurement of the separation between particle species** ($t_{TOF} - t_{exp} - t_{ev}$) generated by using the event times acquired from the TOF and FT0 detectors

Resolution extracted in the range
**$1.4 < p < 1.5$ GeV/$c$**

- Negligible tracking contribution
- Well separated pions and kaons peaks

**$\sigma_{TOF} = (81.7 \pm 2.7)$ ps**

The contribution of FT0 detector (~17 ps) was subtracted




ALI-PERF-577680

# TOF time resolution in Run 3

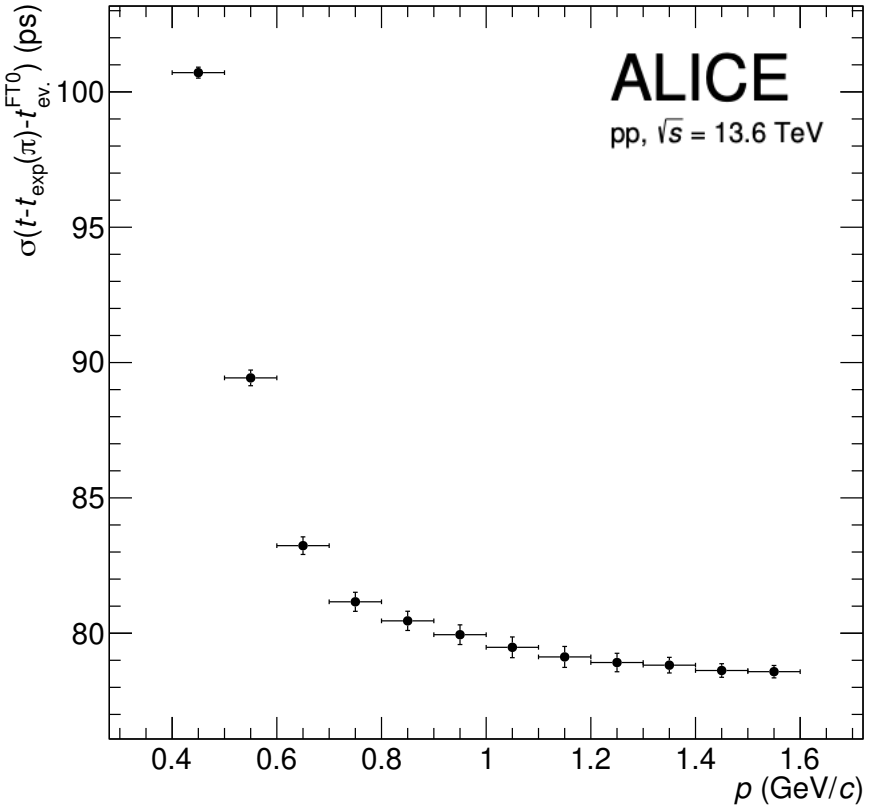
**A measurement of the separation between particle species** ($t_{TOF} - t_{exp} - t_{ev}$) generated by using the event times acquired from the TOF and FT0 detectors

Resolution extracted in the range
**1.4 < *p* < 1.5 GeV/*c***

- Negligible tracking contribution
- Well separated pions and kaons peaks

**$\sigma_{TOF}$ = (81.7±2.7) ps**

The contribution of FT0 detector (~17 ps) was subtracted




ALI-PERF-577665

# New approach to extract time resolution in a standalone way

A **self-consistent measurement** by employing

$$\Delta\Delta t_{TOF} = (t_{TOF}\text{-}t_{exp}^{\pi})_2\text{-}(t_{TOF}\text{-}t_{exp}^{\pi})_{1=ref}$$

by **correlating two tracks matched to TOF in the same event** (independent of the definition of collision) → using **tracks in a specific kinematic region (reference) to provide the "event time"** information

$$\sigma^{PID}_{TOF} = \sigma_{TOF} \oplus \sigma_{trk,expTime} \oplus \sigma_{ref}$$

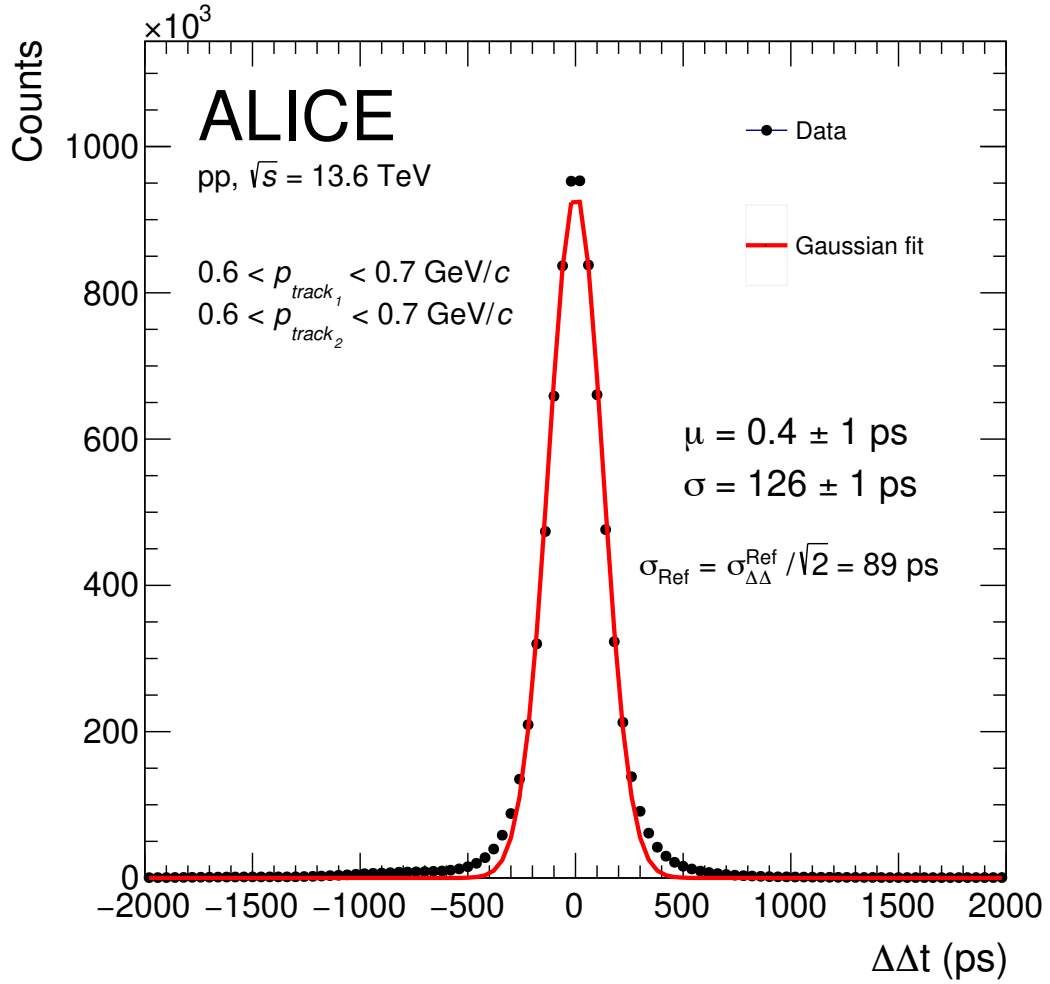
**0 for large $p_T$**

$$\sigma_{TOF} = \sqrt{(\sigma^{PID}_{TOF}{}^2 - \sigma_{ref}{}^2)}$$

Obtained by fitting the signal

Measured with high precision (only tracks in the reference kinematic region, 1=ref)

# New approach to extract time resolution in a standalone way




## REFERENCE

The range for the **reference** is

**0.6 < *p*< 0.7 GeV/*c***

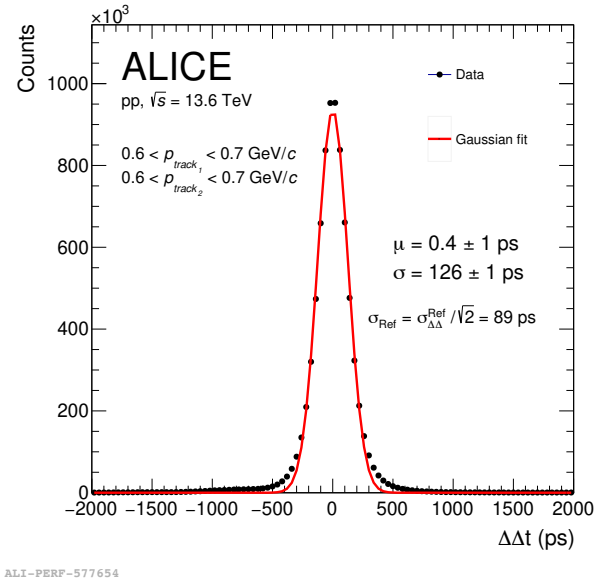
In order to:

- Avoid the effects related to tracks' reconstruction
- Have good statistics

$$\sigma_{\text{Ref}} = \sigma^{\text{Reference}}_{\Delta\Delta t_{\text{TOF}}} / \sqrt{2}$$

$$= (89 \pm 1)\ \text{ps}$$

# New approach to extract time resolution in a standalone way

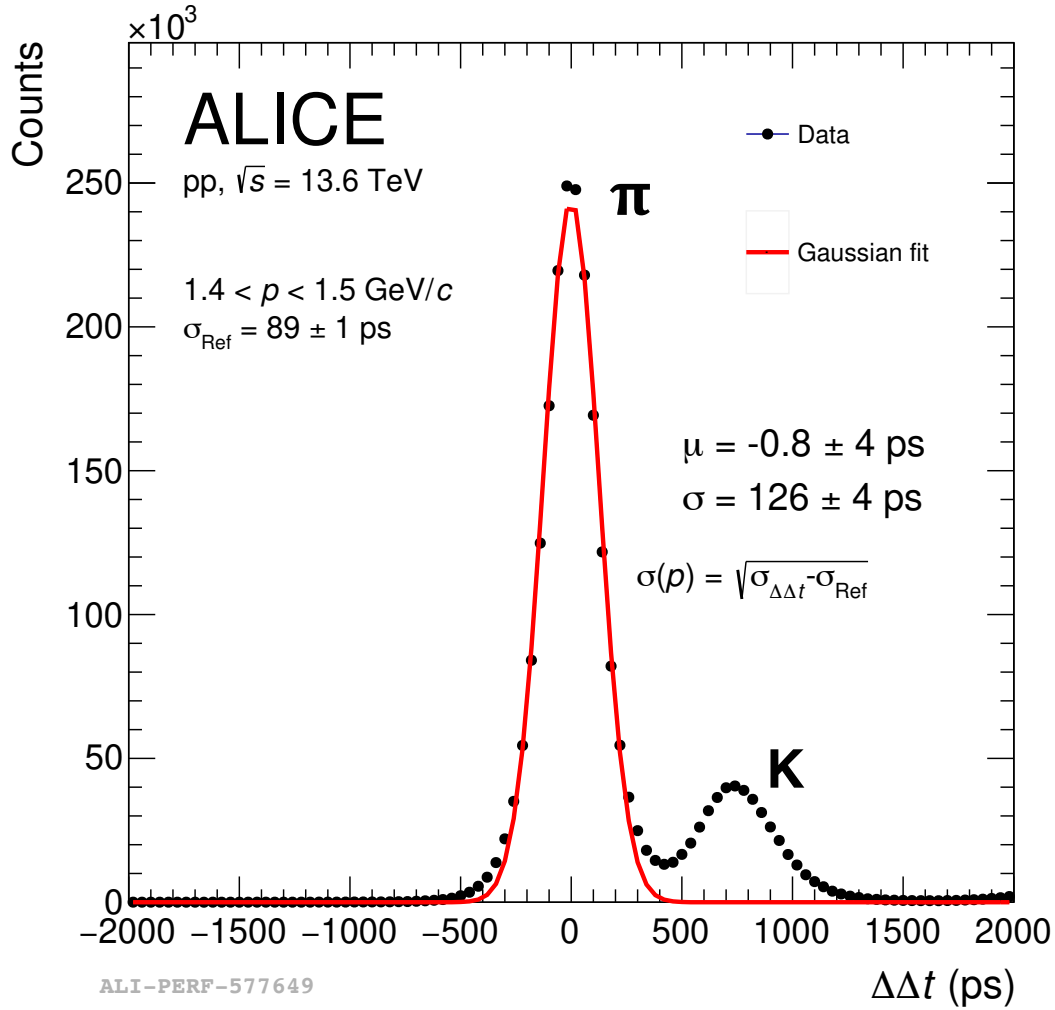



⇨ $\sigma_{Ref} = \sigma / \sqrt{2} = (89 \pm 1)$ ps

$$\sigma_{Reference} = \sigma_{TOF} \oplus \sigma_{Tracking}$$

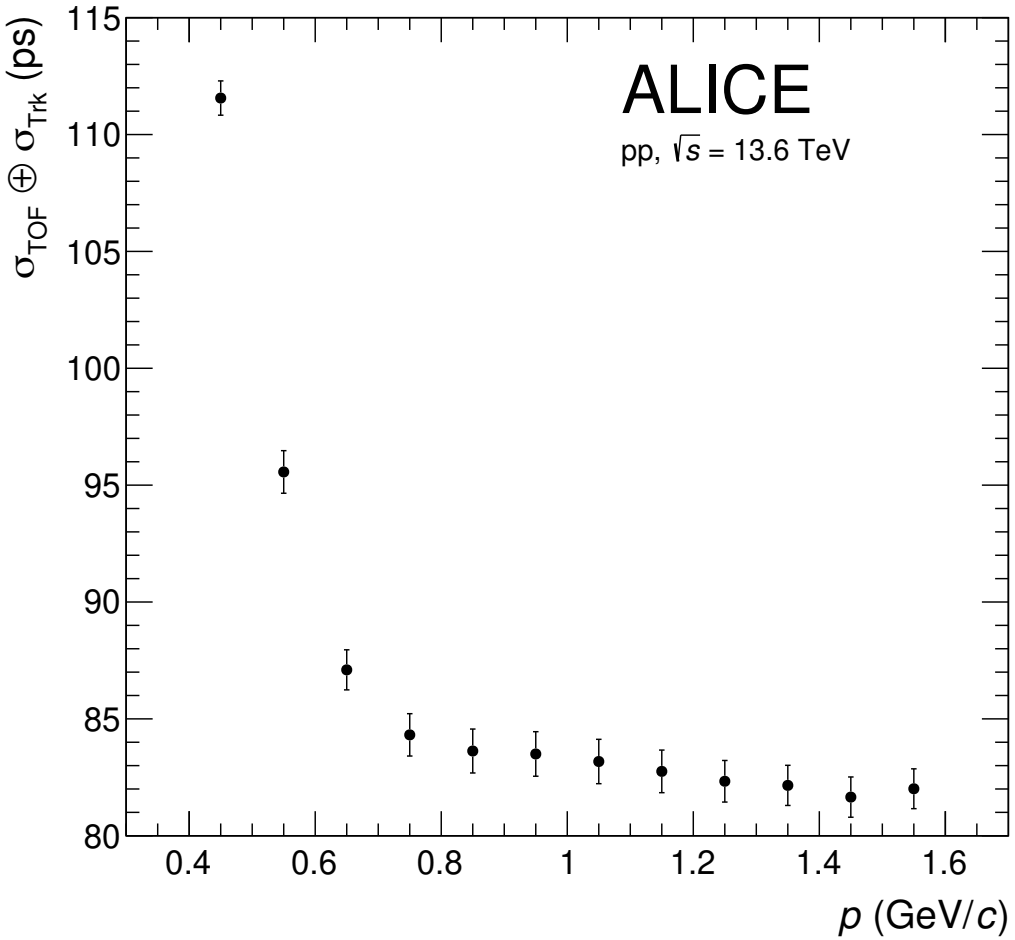
⇩

$\sigma_{TOF} = (84.2 \pm 2.7)$ ps




**Consistent results with the two methods!**

# Tracking contribution




ALI-PERF-577671

When particle momentum is high enough (pions $p > 1$ GeV/$c$)

→ the **contribution from $\sigma_{Tracking}$** becomes **negligible**

→ **only** the **TOF** component **contributes to the resolution**

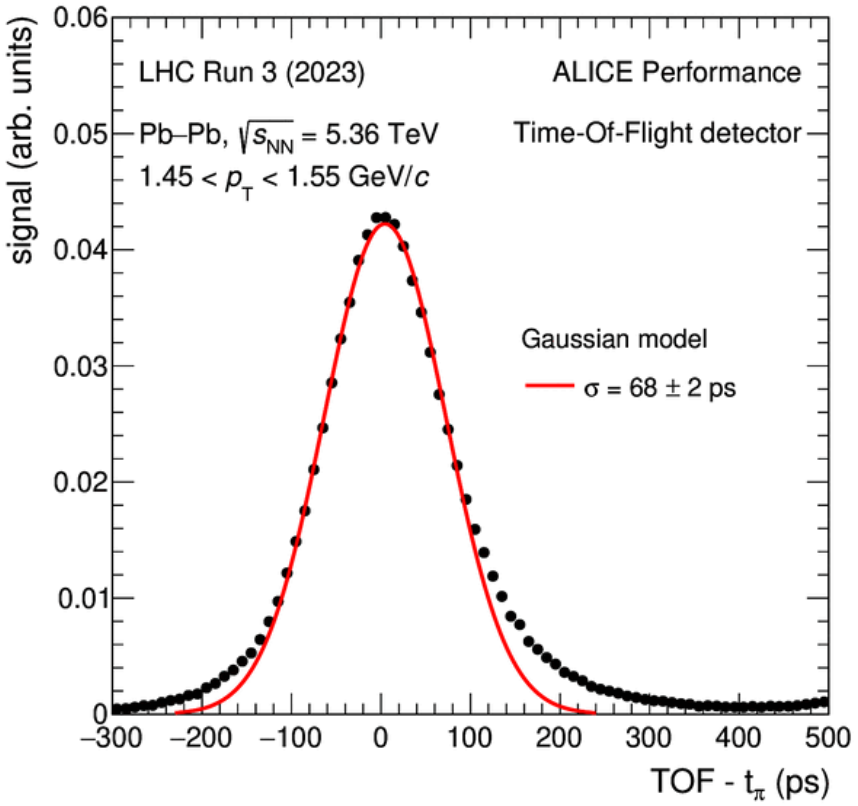
↘ **p**: Higher contribution from tracking

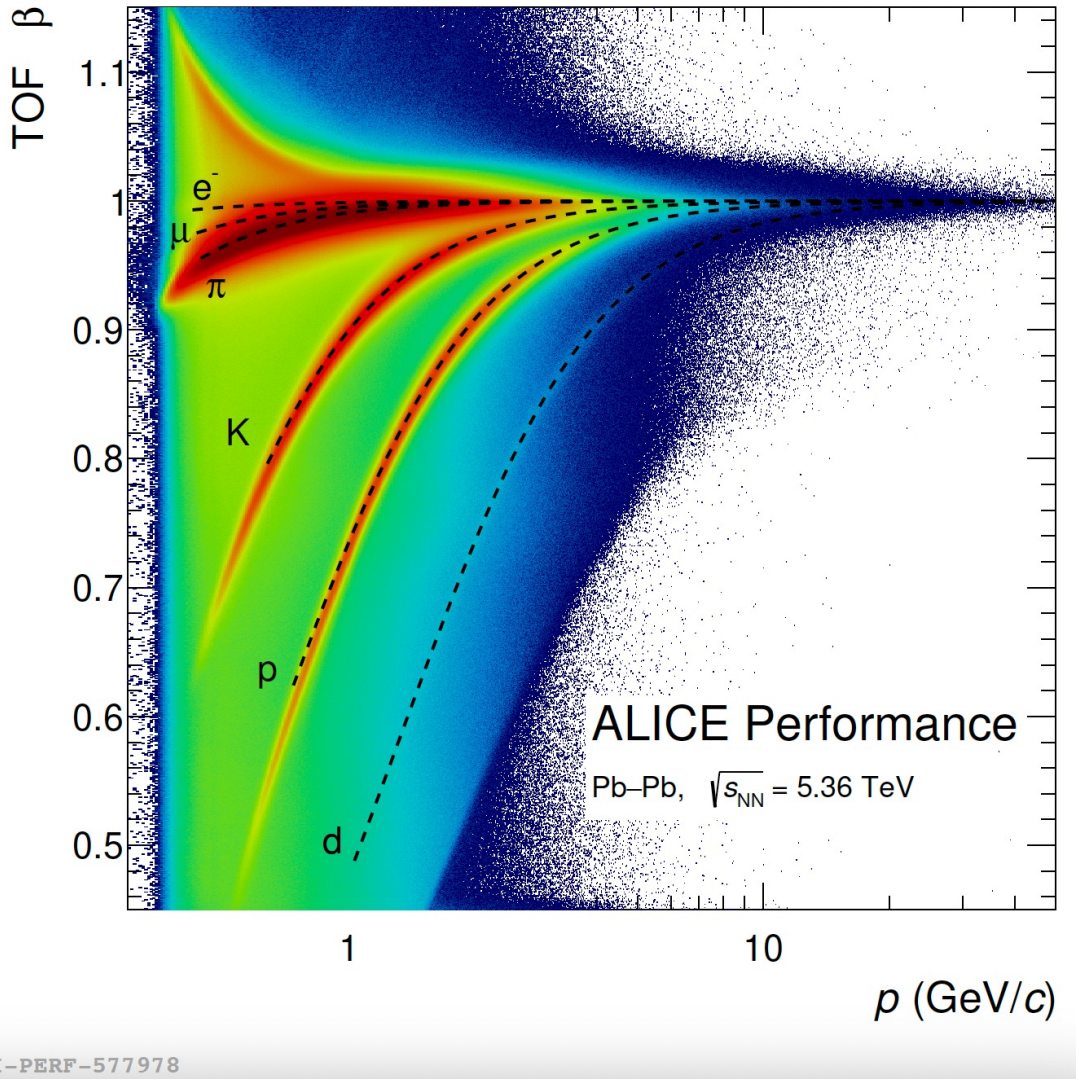
↗ **p**: Negligible tracking contribution, we expect to reach a plateau

# TOF Performance in RUN 3 Pb-Pb

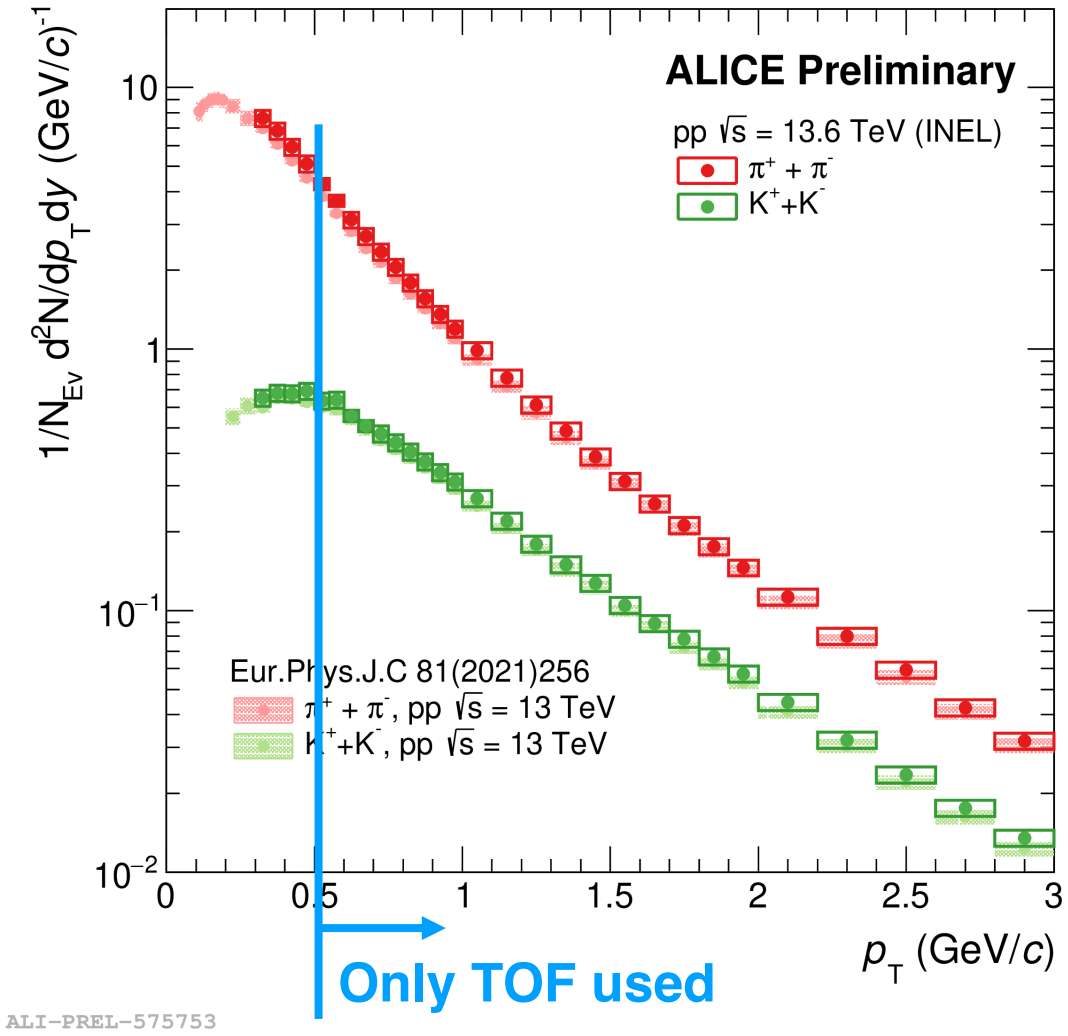
**TOF timing performance** in **Pb-Pb** with refined time-slewing calibration

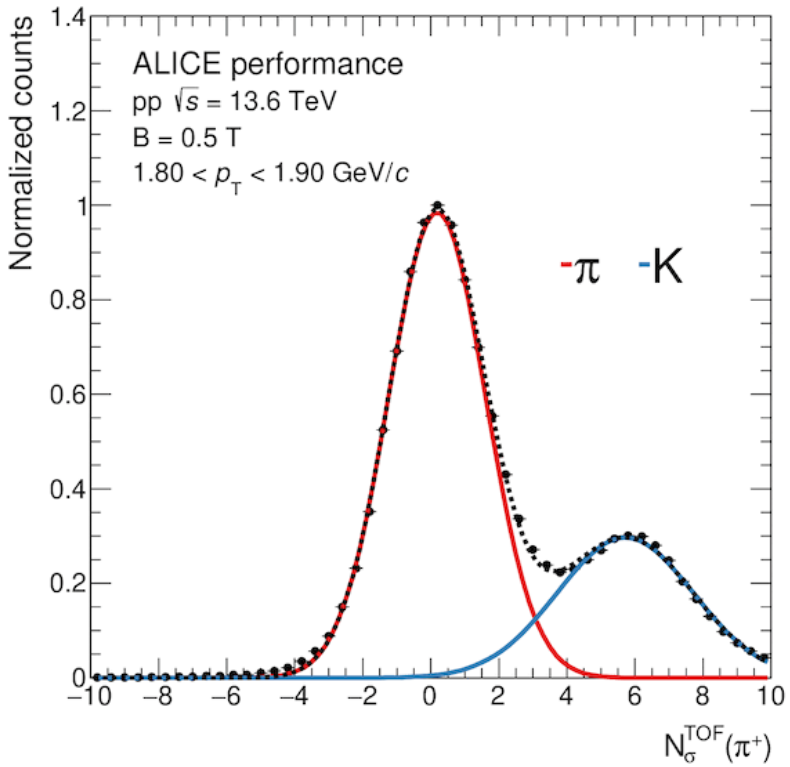
$\sigma_{TOF} \sim 68$ ps



# RUN 3 Physics with TOF (pp): spectra

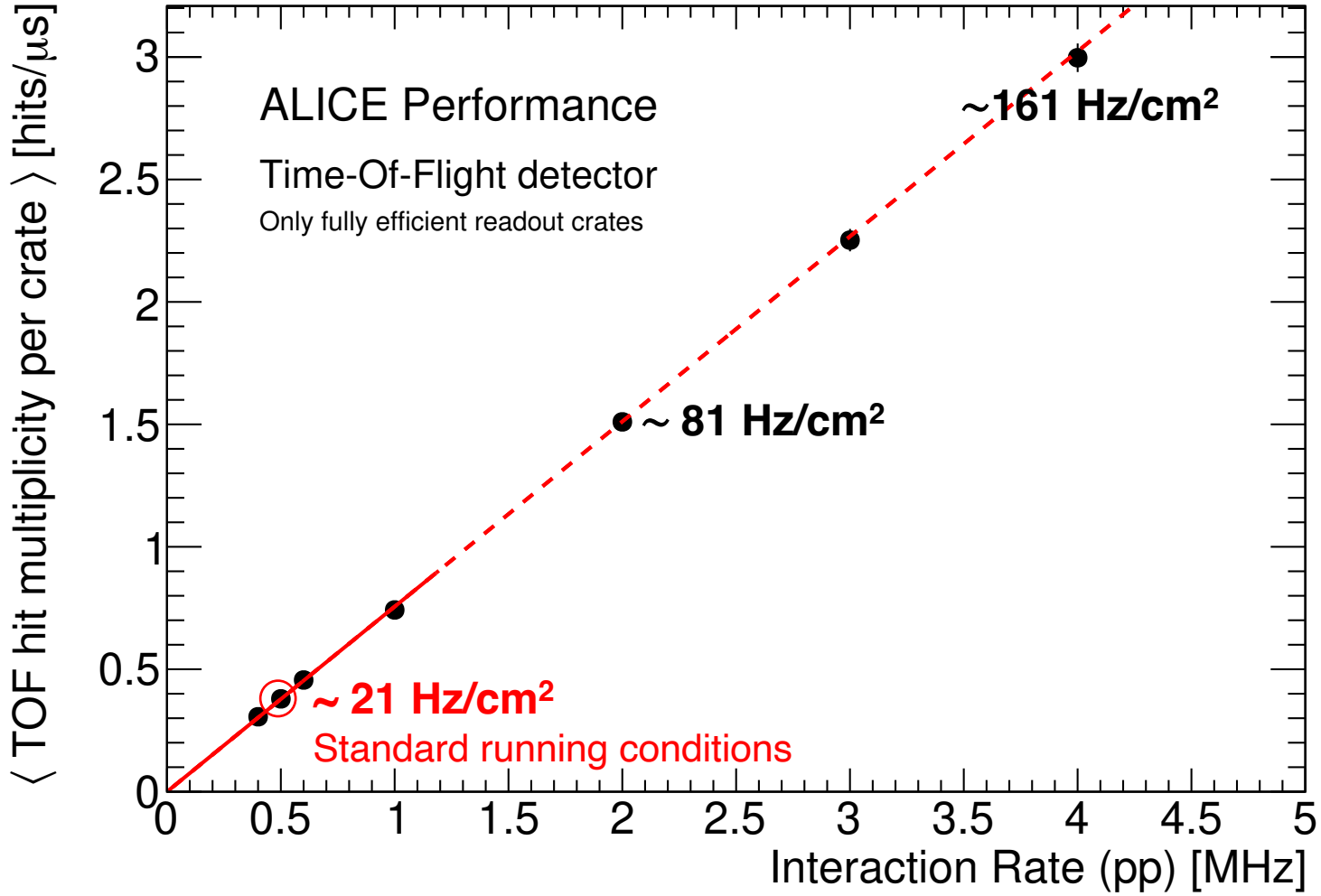



- Spectra in **Run 2 and 3 in agreement**
- Also extracted **VS multiplicity**

# Scan in luminosity – pp

June 2024




ALI-PERF-577695

Average **TOF hit multiplicity** (per readout crate) in 1 μs as a function of the **interaction rate** in pp

MRPC **hit rate increases linearly with** the LHC **luminosity** with **no sign of deviation** (no ageing effect after many years of operation)

# TRM2 project status

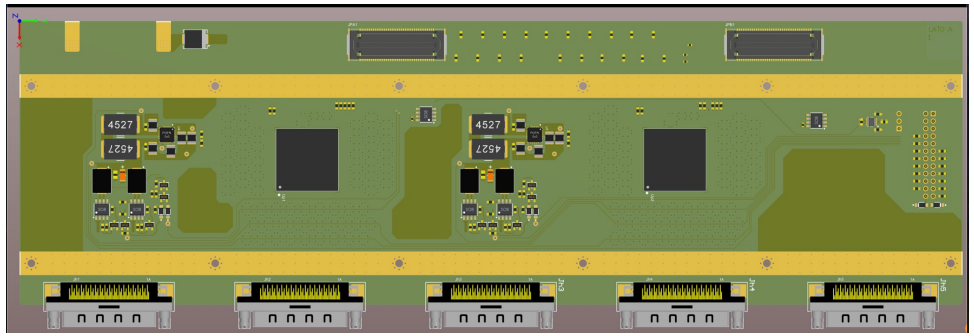
LS3 planning

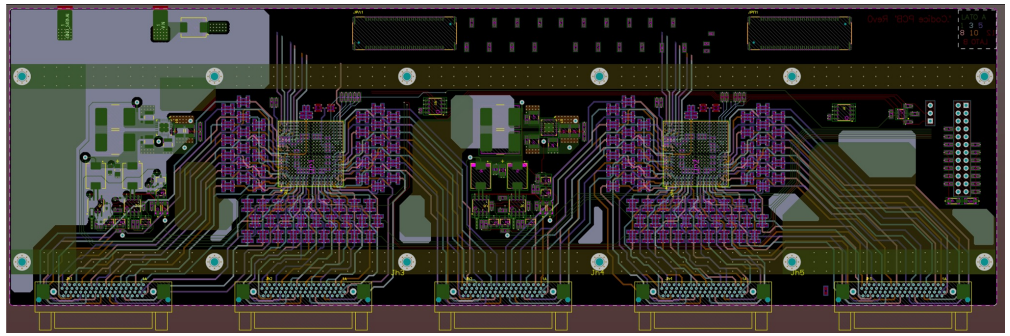
Long term project to **replace part of TRM damaged with a new TDC card** based on **PicoTDC** (instead of HPTDC) no longer spares available need to guarantee high efficiency up to end of Run4

→ **Plan:** produce **100 new TRM2**, **replace** during LS3 **up to 50** broken **TRM**

**Status**

- **picoTDC test board** (produced in 2023) **fully tested** coupled to PolarFire FPGA
- advanced status of schematics (INFN-BO) and layout (CAEN) for prototypes**: first prototypes expected by end of 2024**





# CONCLUSIONS

- The ALICE-TOF detector is a **large** (active area 141 $m^2$) **high-performance** detector based on **MRPC technology** taking data for **15 years.**
- Since its installation until today:
  - **no loss in performance:** time performance in Run 3 already equal or very close to Run 2!
  - **no degradation of MRPC**
  - very **stable** detector

**Stable for 15 years of data taking**

- **Readout upgrade for Run 3**
  - TOF is now operating in **continuous readout** due to increase of luminosity and interaction rate in LHC Run 3
  - Calibrations performed are working well

**Continuous readout** from Run 3

- **Performance** shows a time res. of **80 ps** in pp (new standalone method consistent with classical one) and **68 ps** in Pb-Pb

**TOF PID** used in plenty of analyses: nuclei, id-spectra, HF

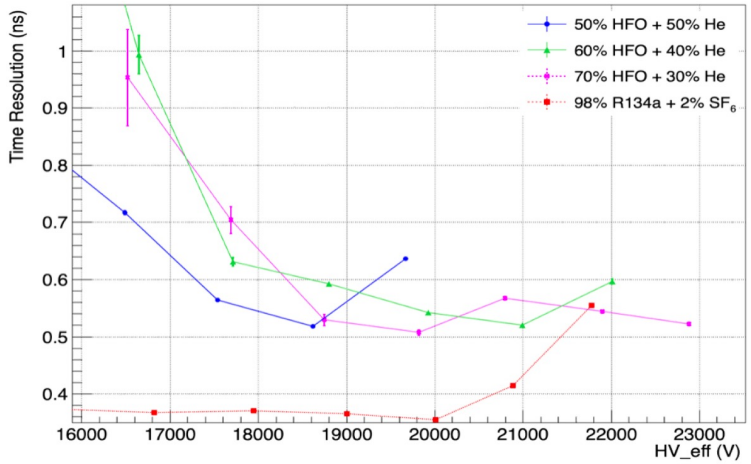
- Working for **LS3 "upgrade"**

# BACKUP SLIDES

1593 MRPCs with a **gas mixture** of **93% $C_2H_2F_2$ + 7% $SF_6$**

- Allowed for **scientific usage**
- **Gas volume** of ALICE-TOF is **small** compared to other experiments
- **Closed loop circulation system** with minimal losses

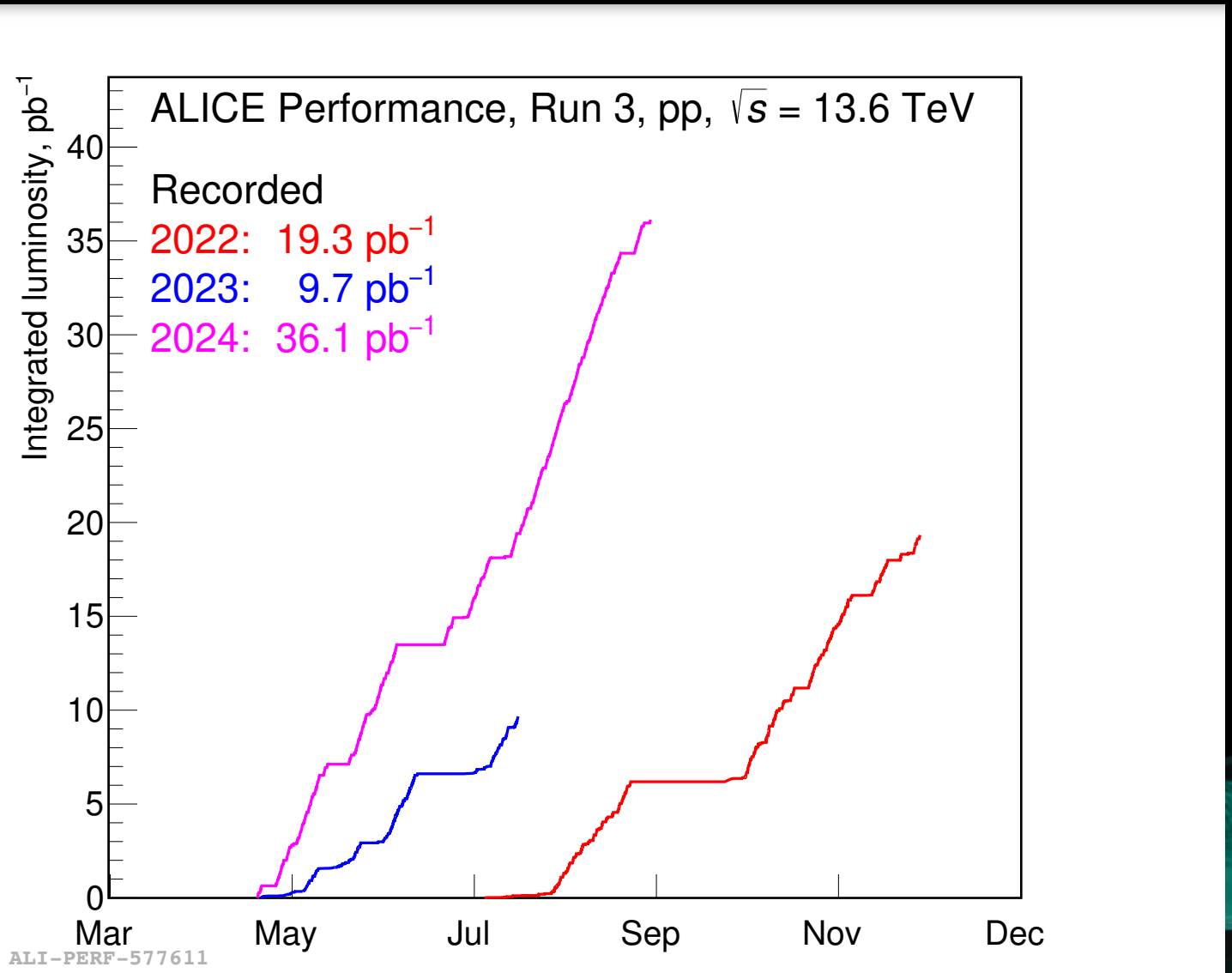
→ **The actual** mixture will remain **until Run 4** (end of life of TOF)



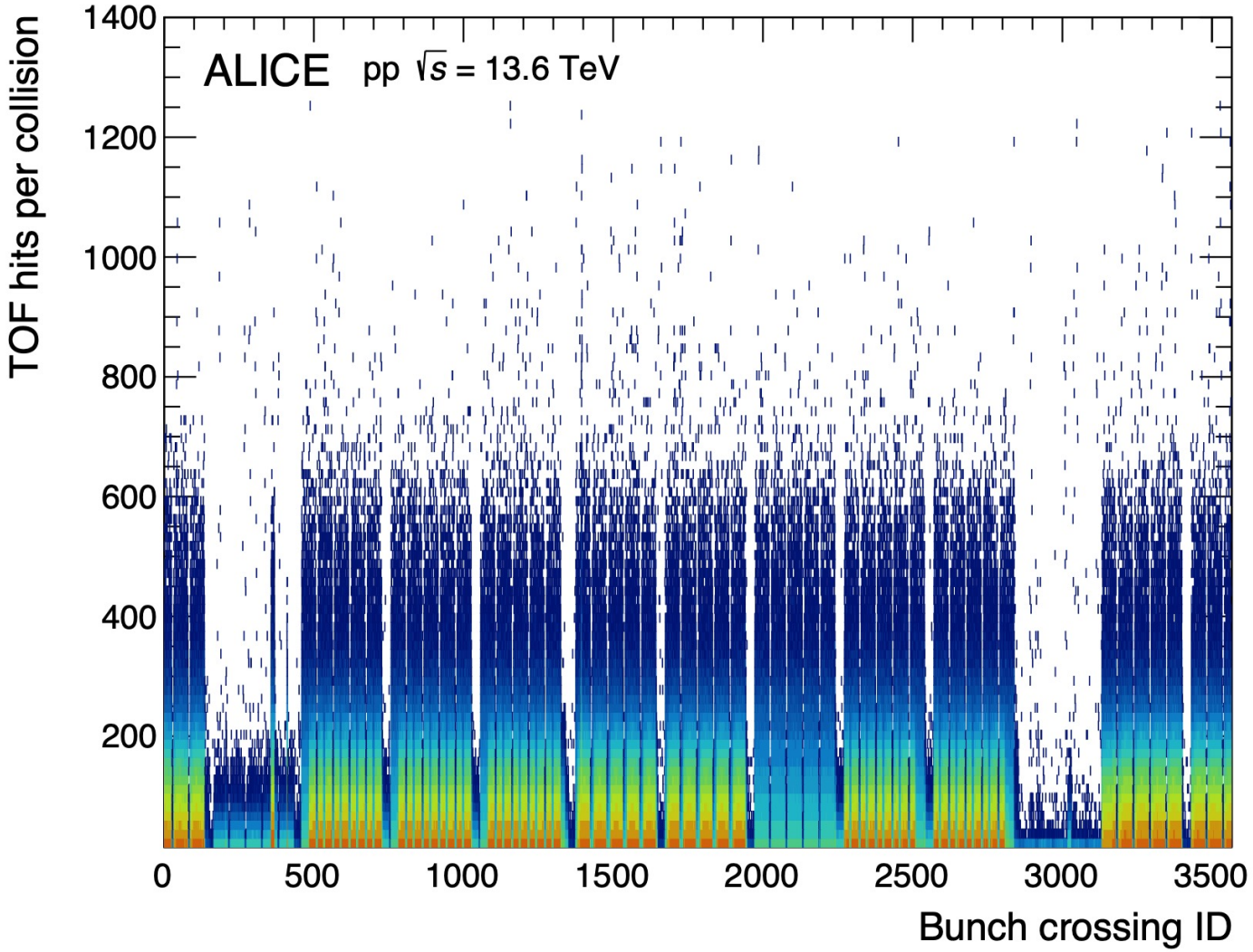

**R&D ongoing:**
**The EEE Collaboration** is testing **alternative green mixtures** based on **$C_3H_2F_4$** with the addition of **He or $CO_2$** to be used in RPC.

- Significant reduction of Global Warming Potential (GWP)
- Good performance ~ standard ones at moderate voltages
- **Does not allow ALICE-TOF time resolution** requirements

# Integrated luminosity in Run 3, pp



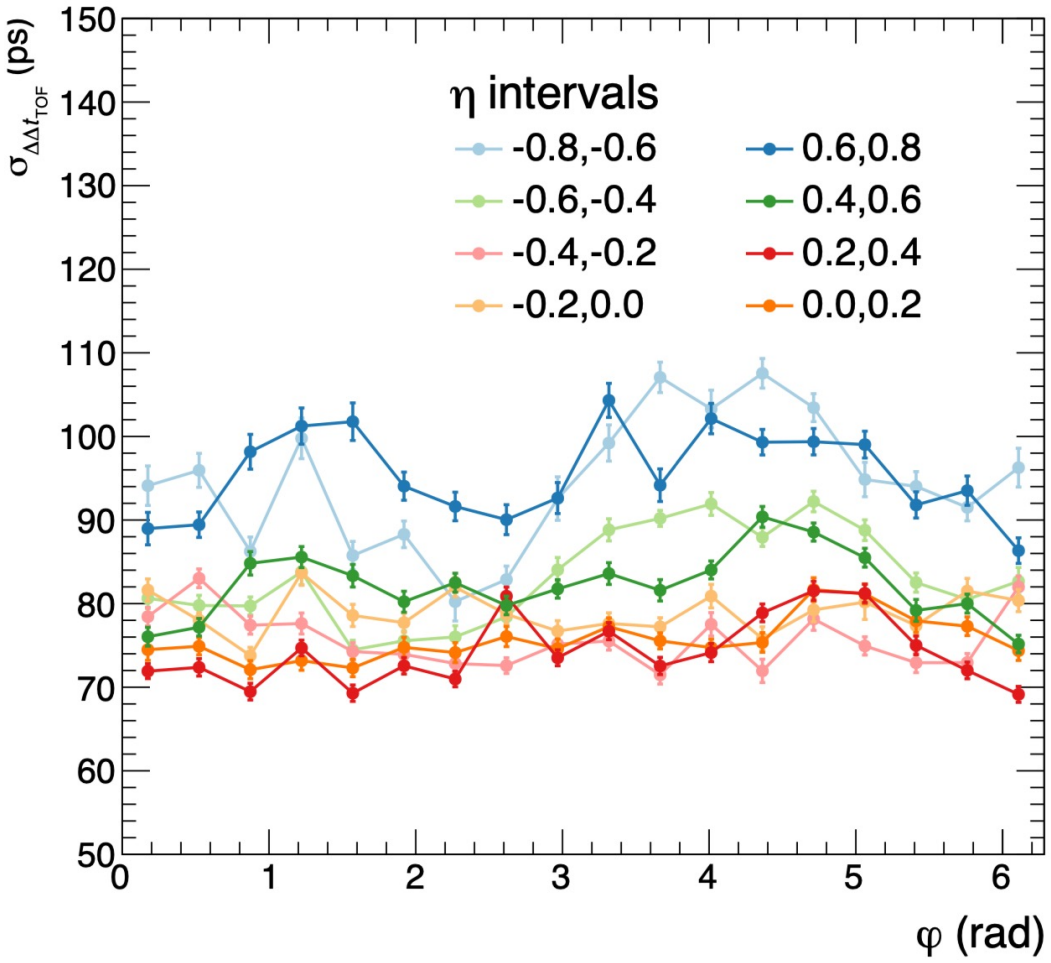
# TOF calibrations in the continuous readout scheme



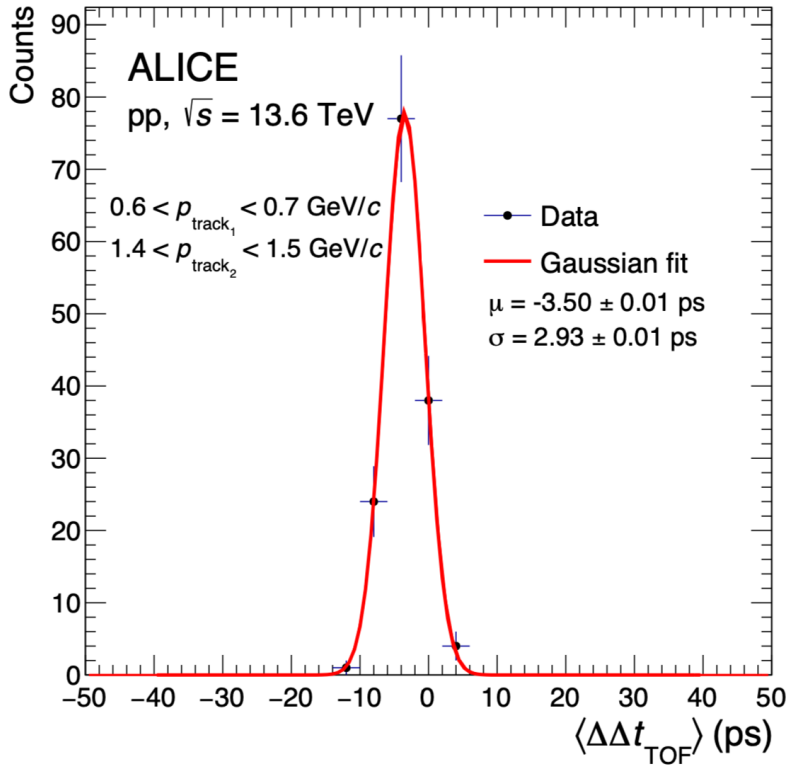

The present TOF acquisition and calibration chain allows to follow the event activity at the level of a **single Bunch Crossing**

Hit multiplicity as a function of the Bunch Crossing ID, the **structure of the LHC filling scheme is visible** in the TOF hit multiplicity

# TOF Time Resolution vs ϕ, η




The **effect of the calibration** can be seen from the **very narrow distribution** of the the $\langle \Delta\Delta t_{TOF} \rangle$ spread of the $\Delta\Delta t_{TOF}$ split per η intervals




The resolution **decreases at larger pseudorapidity**
→ **extra smearing** of the distribution when integrating over the full η acceptance