10 years of operation of the MRPC TOF detector of ALICE: results and perspectives

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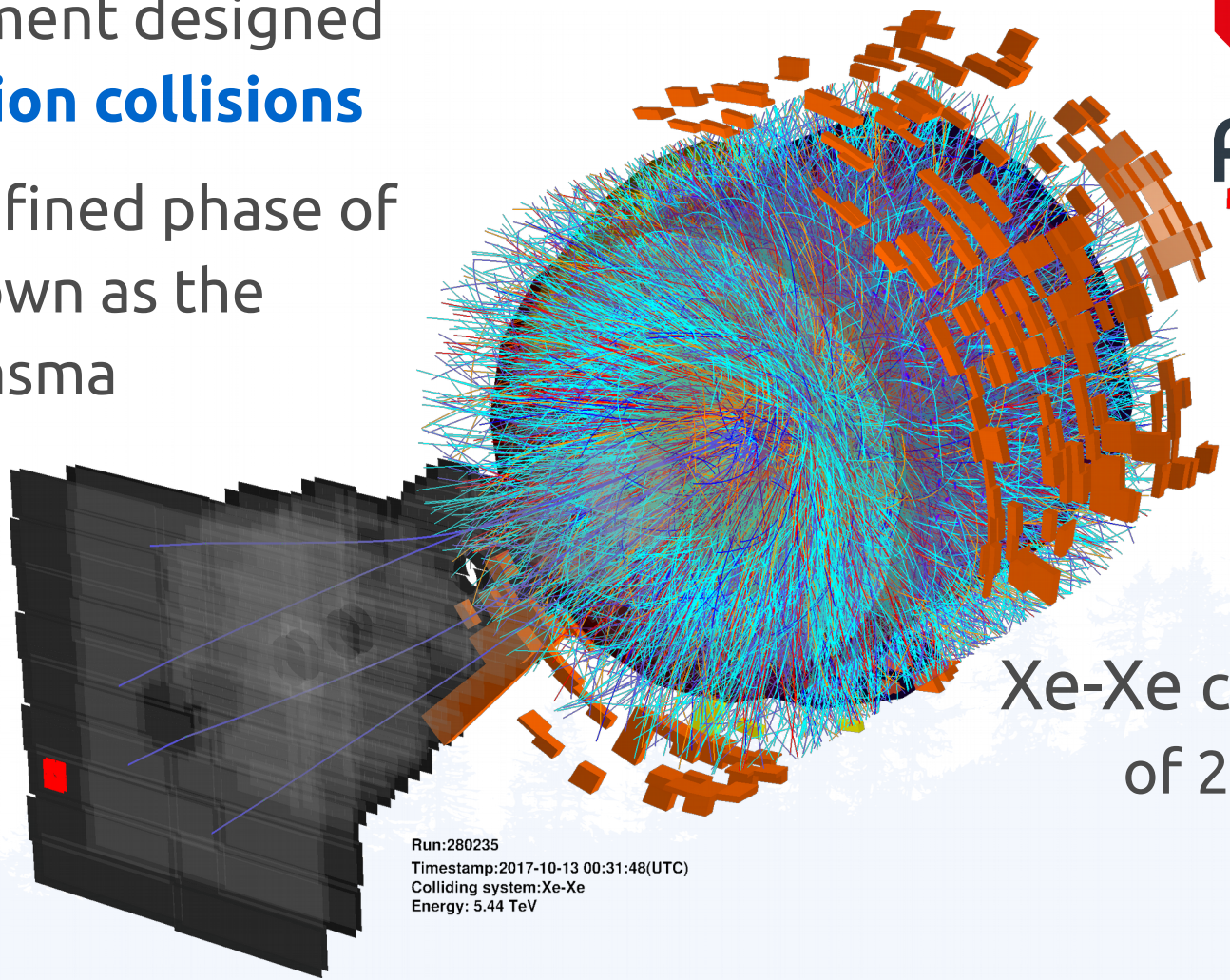
ALICE

The ALICE experiment

- The LHC experiment designed to study **heavy-ion collisions**
- Study the deconfined phase of QCD matter known as the **Q**uark **G**luon **P**lasma
- Large number of charged particles produced at mid-rapidity

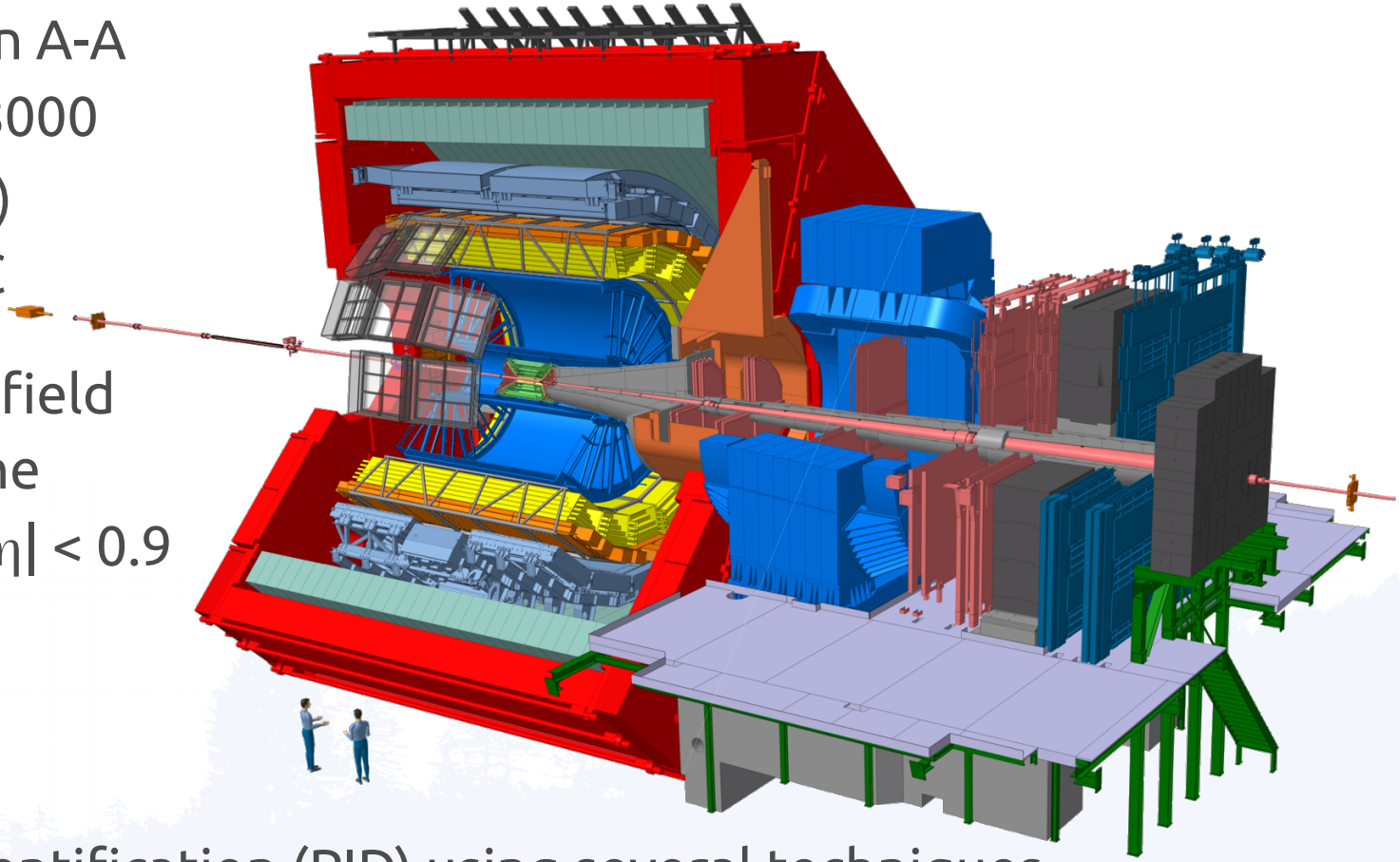


Xe-Xe collision of 2017

The detector

The ALICE experiment

- High granularity to cope with the high occupancy in A-A collisions $dN_{ch}/d\eta \leq 8000$ (design requirement)
- 3D tracking with TPC
- Moderate magnetic field (B = 0.5 T, 0.2 T) in the mid-rapidity region $|\eta| < 0.9$
- Low material budget
- Tracking down to $p_T \sim 100$ MeV/c
- Extensive particle identification (PID) using several techniques

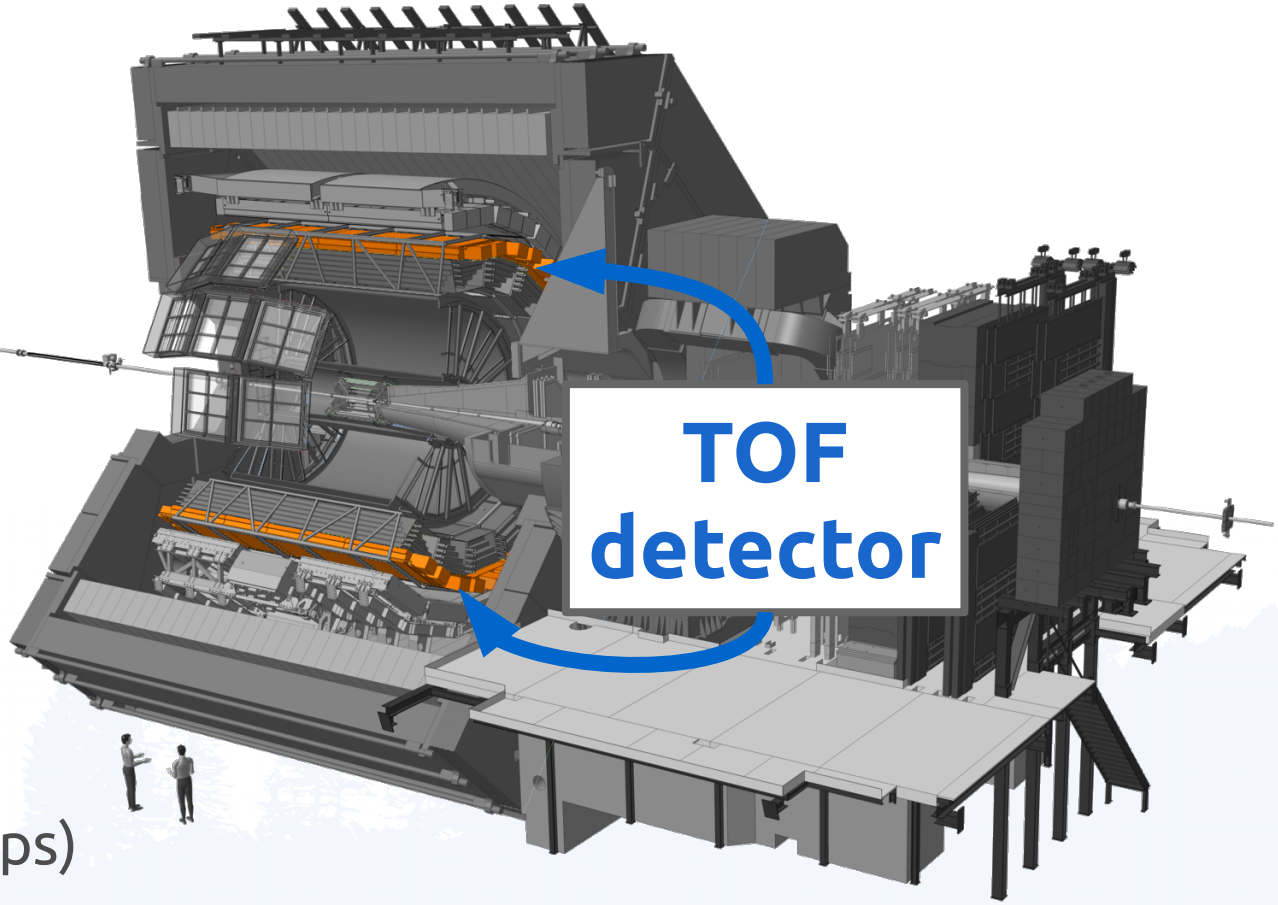


The ALICE TOF detector

- The *Time-Of-Flight* (**TOF**) detector is located in the central barrel ($|\eta| < 0.9$) with full azimuthal coverage
- Active area of **~ 141 m²**
- Inner radius from the interaction point **370 cm**

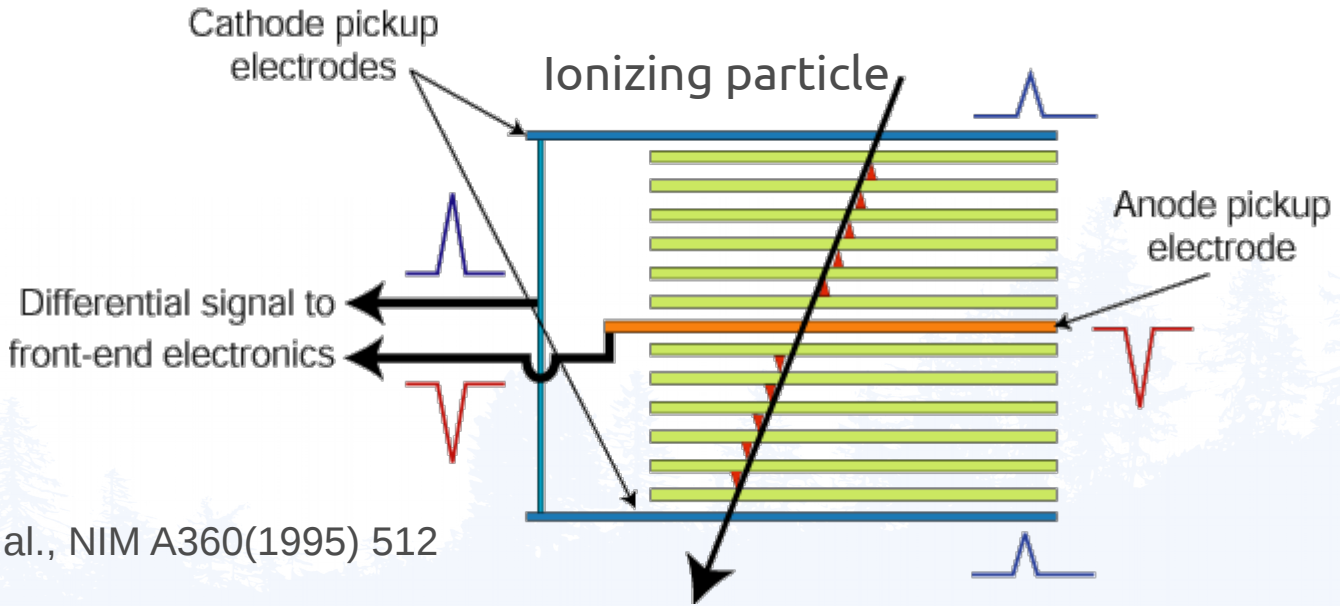
Requirements:

- High efficiency (> 95%)
- High granularity (~10^5 channels)
- Good time resolution (<100 ps)
- Low material budget



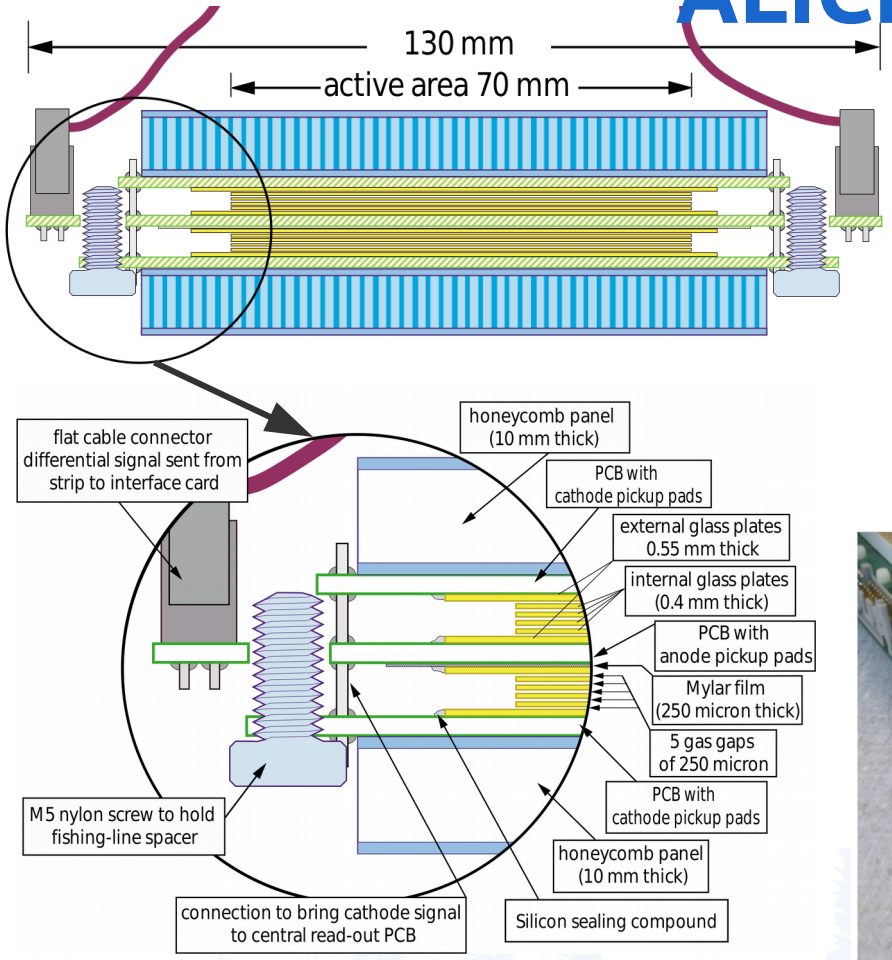
The ALICE Time-Of-Flight detector

- Designed for charged hadron identification in A-A collisions at intermediate p_T
- Gaseous detector
- Based on the **Multigap RPC** technology

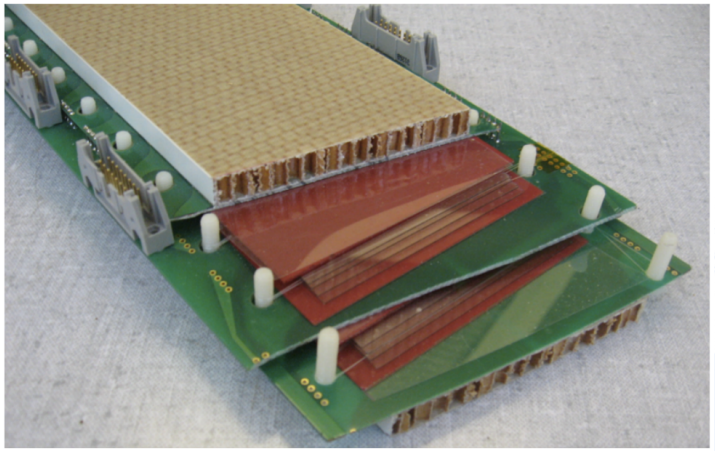


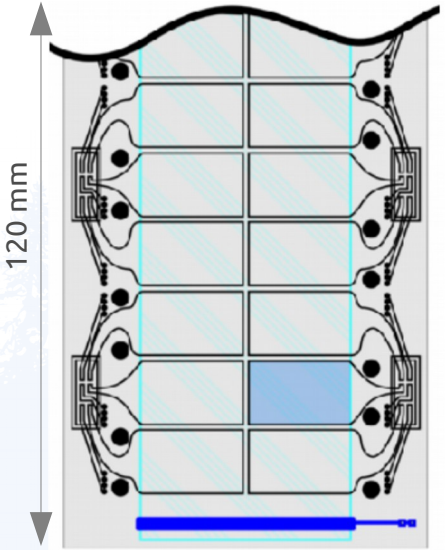
M.C.S. Williams et al., NIM A360(1995) 512

ALICE-TOF MRPC



- Double stack **M**ulti-gap **R**esistive **P**late **C**hamber
  - » Gas mixture: 93% $C_2H_2F_2$ + 7% SF_6
  - » 2x5 250 μm gaps (double stack)
  - » 120 x 7.4 cm² strip active area
- 2 rows of 48 pickup pads per strip (3.5 x 2.5 cm²)





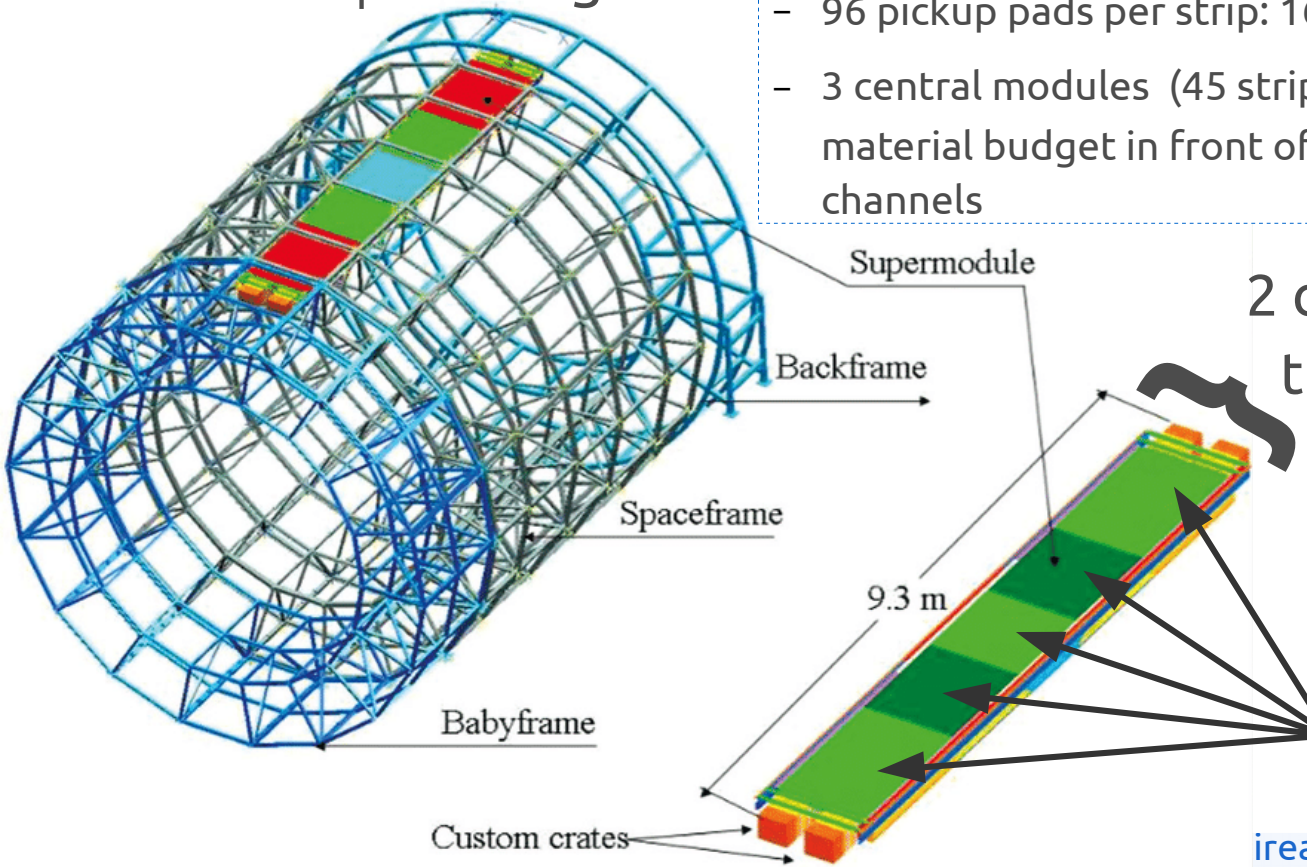
NIM A 532 (2004) 611
Nuovo Cim. B 124 (2009) 235

The ALICE Time-Of-Flight detector

18 SuperModules (SM)

with full φ coverage

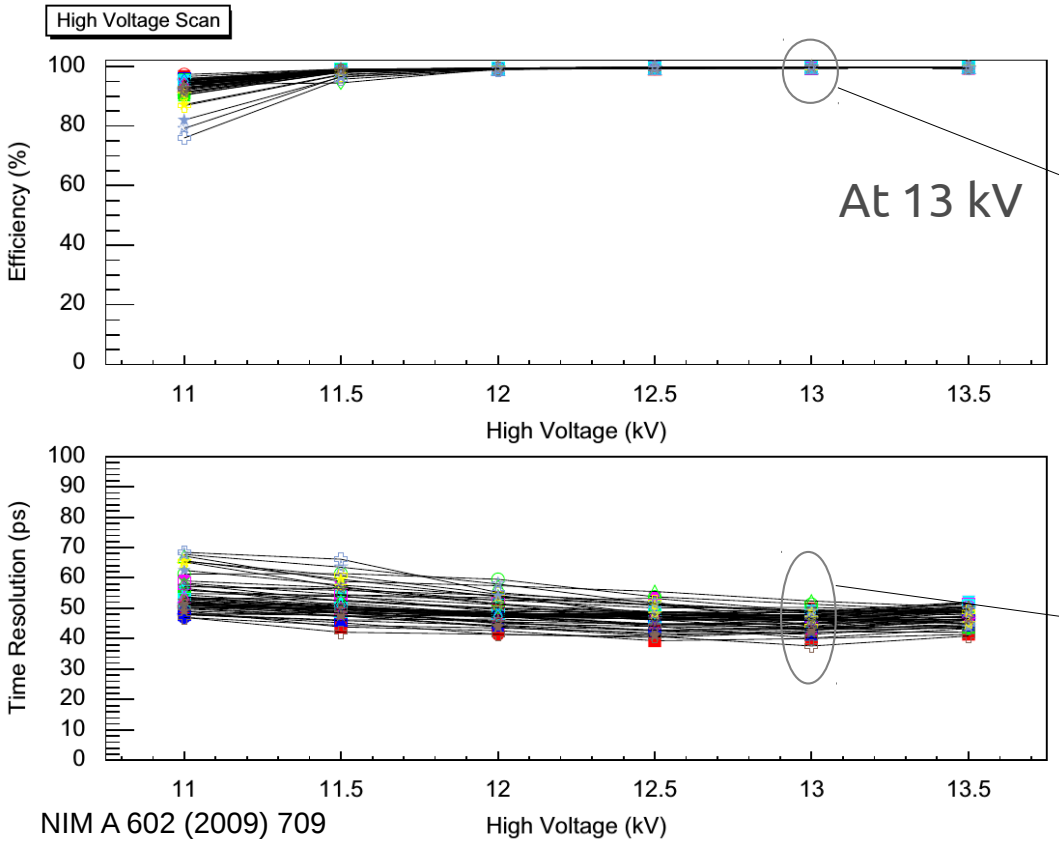
- 19 or 15 strips per module: 4 x 19 + 15 → **91 Strips per SM**
- 18 x 91 → **1638 Strips in total**
- 96 pickup pads per strip: 1638 x 96 → **157248 channels**
- 3 central modules (45 strips) are missing at φ ~ 0 to reduce the material budget in front of the **PHOS** detector: 152928 "real" channels

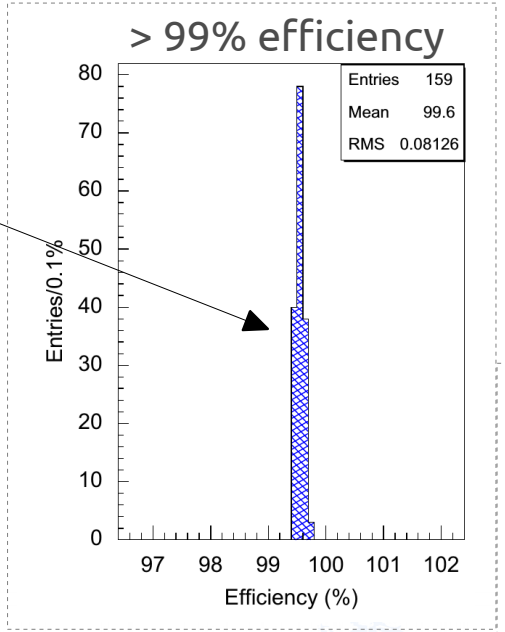


2 crates read half of the Supermodule

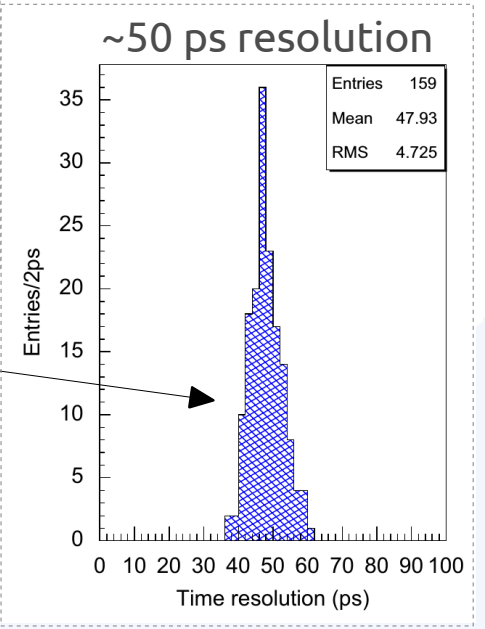
5 modules form each Supermodule

Results from the test beam





At 13 kV



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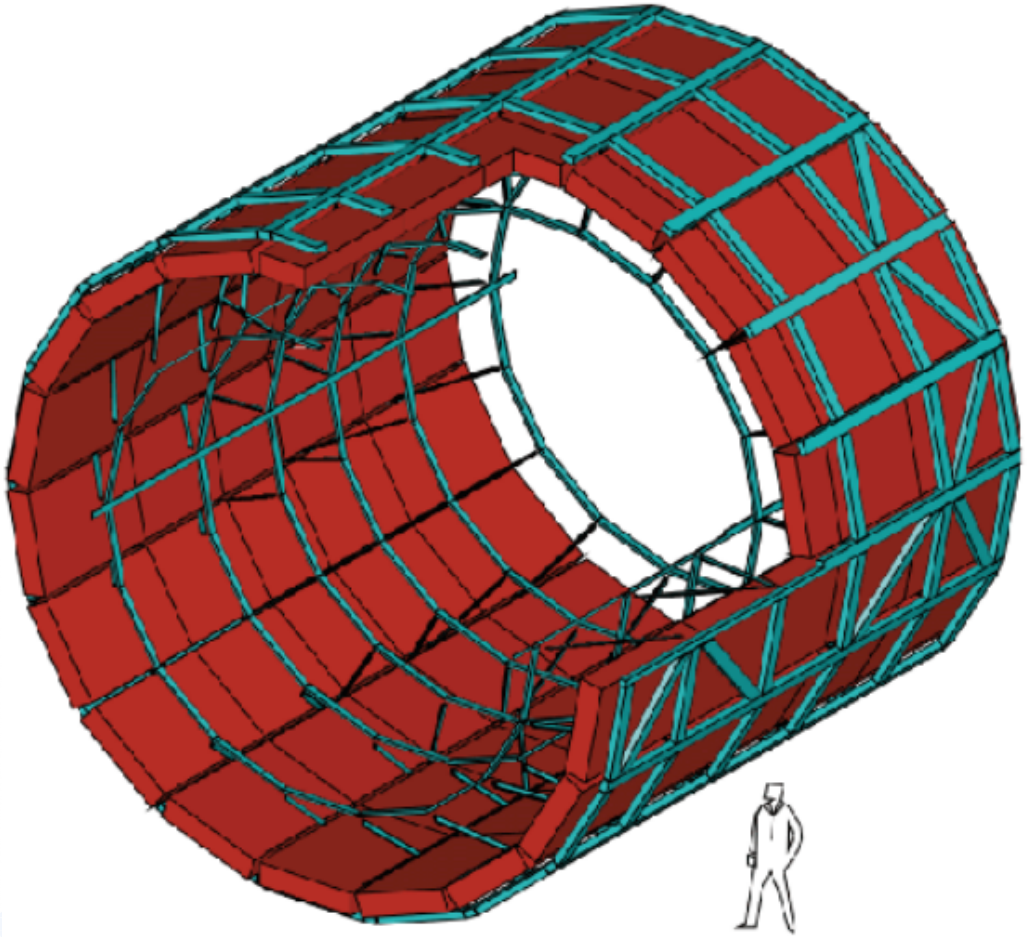
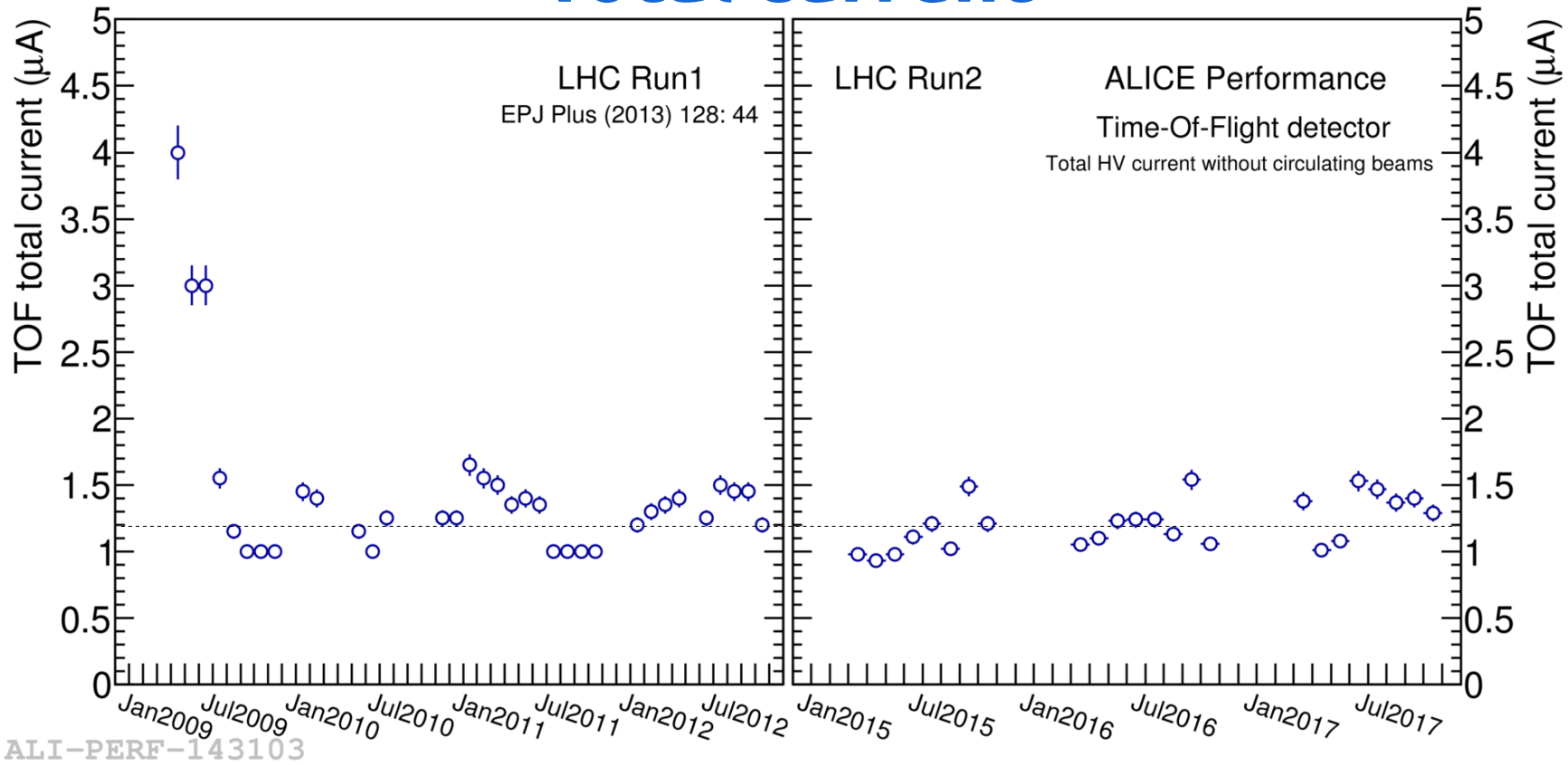
TOF operations and performance

Installation and start of operations



- TOF installation was completed in 2008
- 10 years later, in 2018, during a total of 2253 hours of data taking (enough to watch Titanic 693 times):
  - » total time availability **~98%**
  - » average active channels **~93%**
  - » due to electronics and connectors (not to MRPC!)

Total current



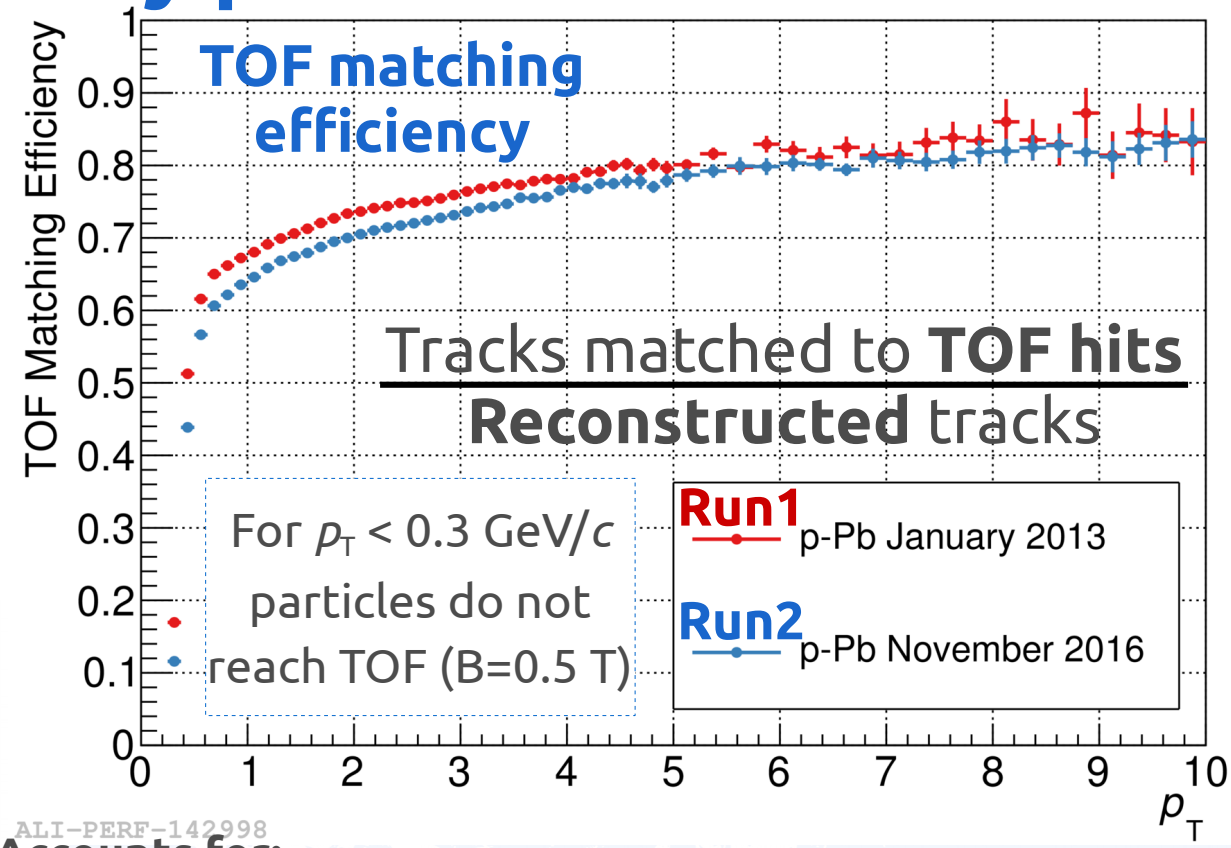
- Current measured with no beams circulating, **low** and **stable** over several years
- **No sign of aging!**

Efficiency performance

Stable performance during **Run1** and **Run2**

Differences are not TOF related!

- Different tracking algorithm
  - » Changed mass hypothesis in tracking
- Different material budget
  - » All TRD modules were installed after Run1

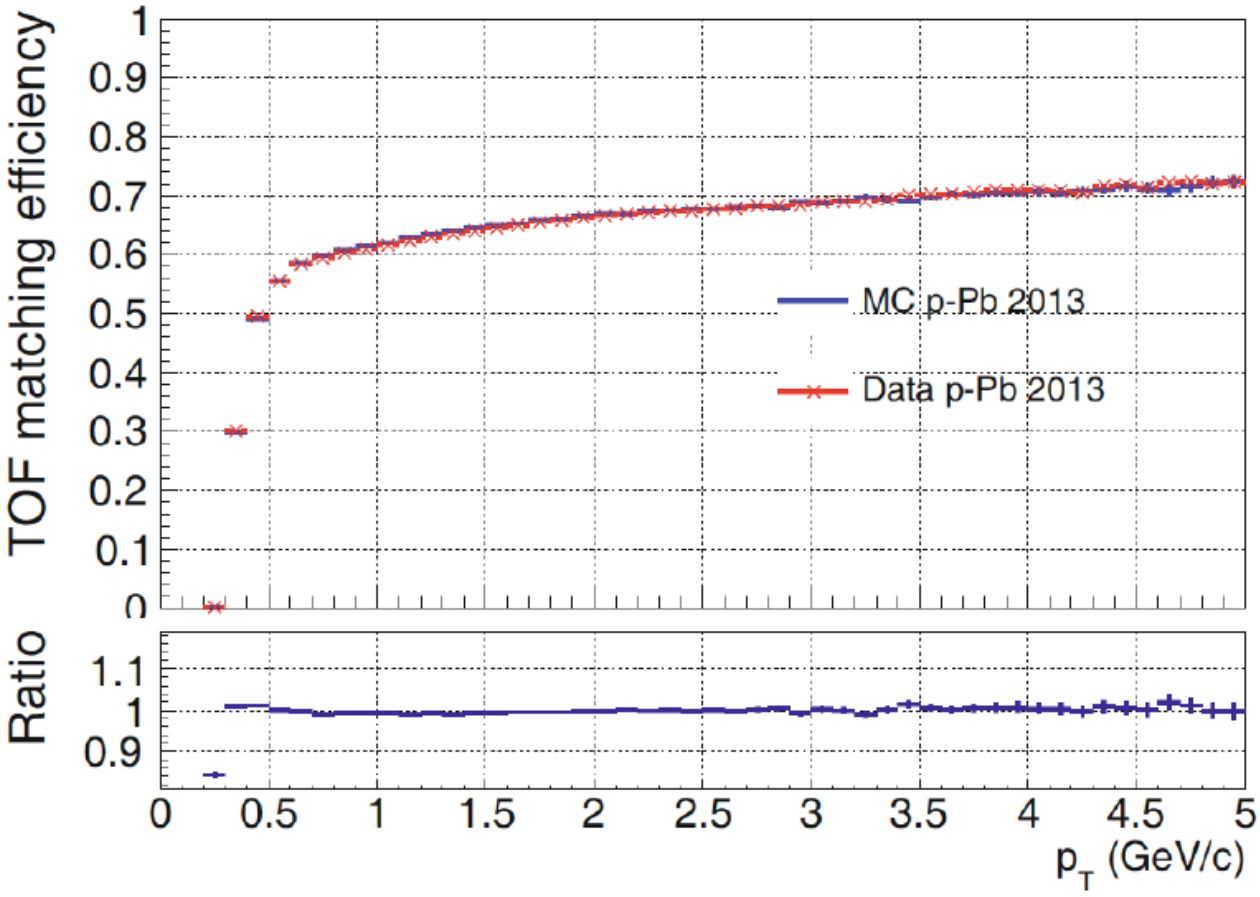


Accounts for:

- Algorithmic inefficiency of the track propagation to TOF
- TOF geometrical acceptance (dead space, inactive channels)

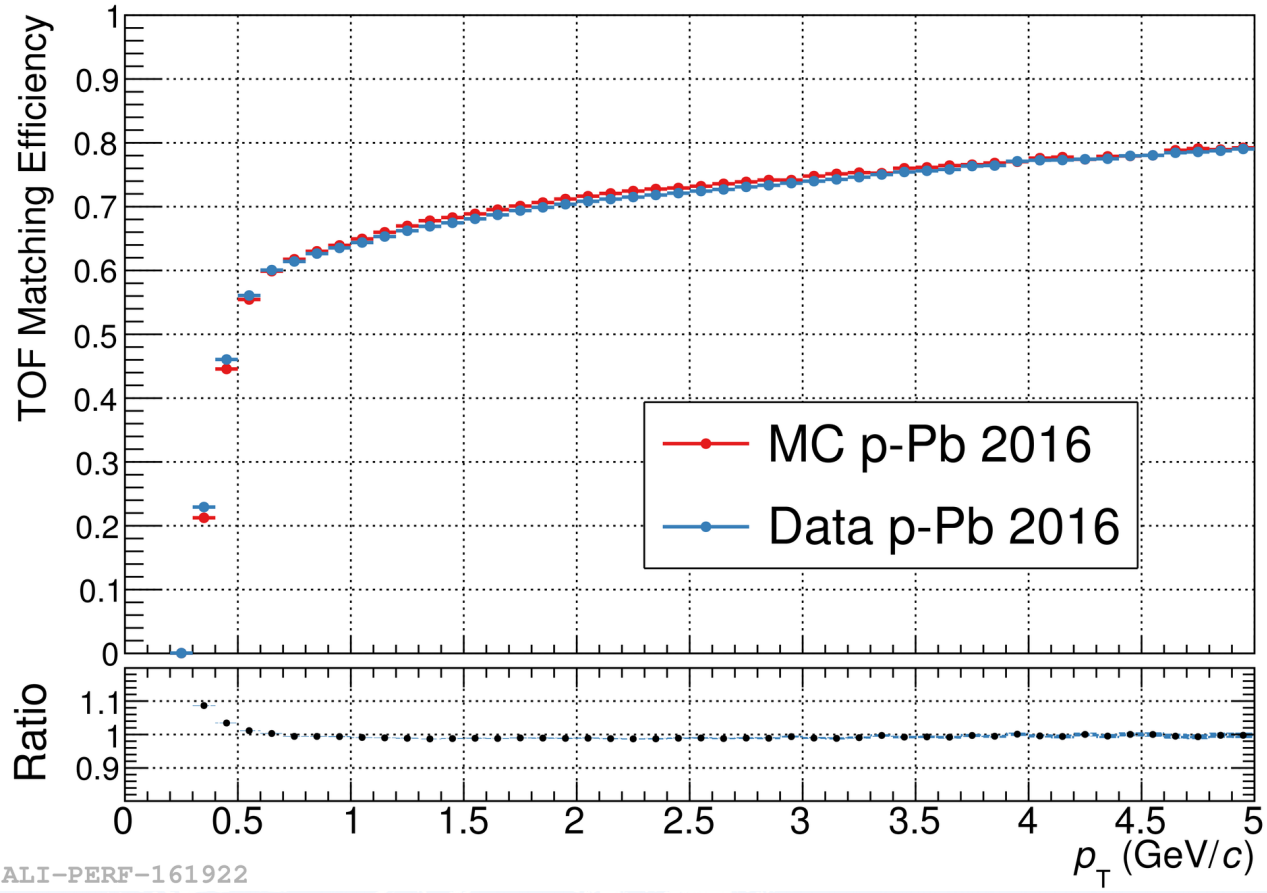
Efficiency performance

DOI 10.1140/epjp/i2013-13044-x



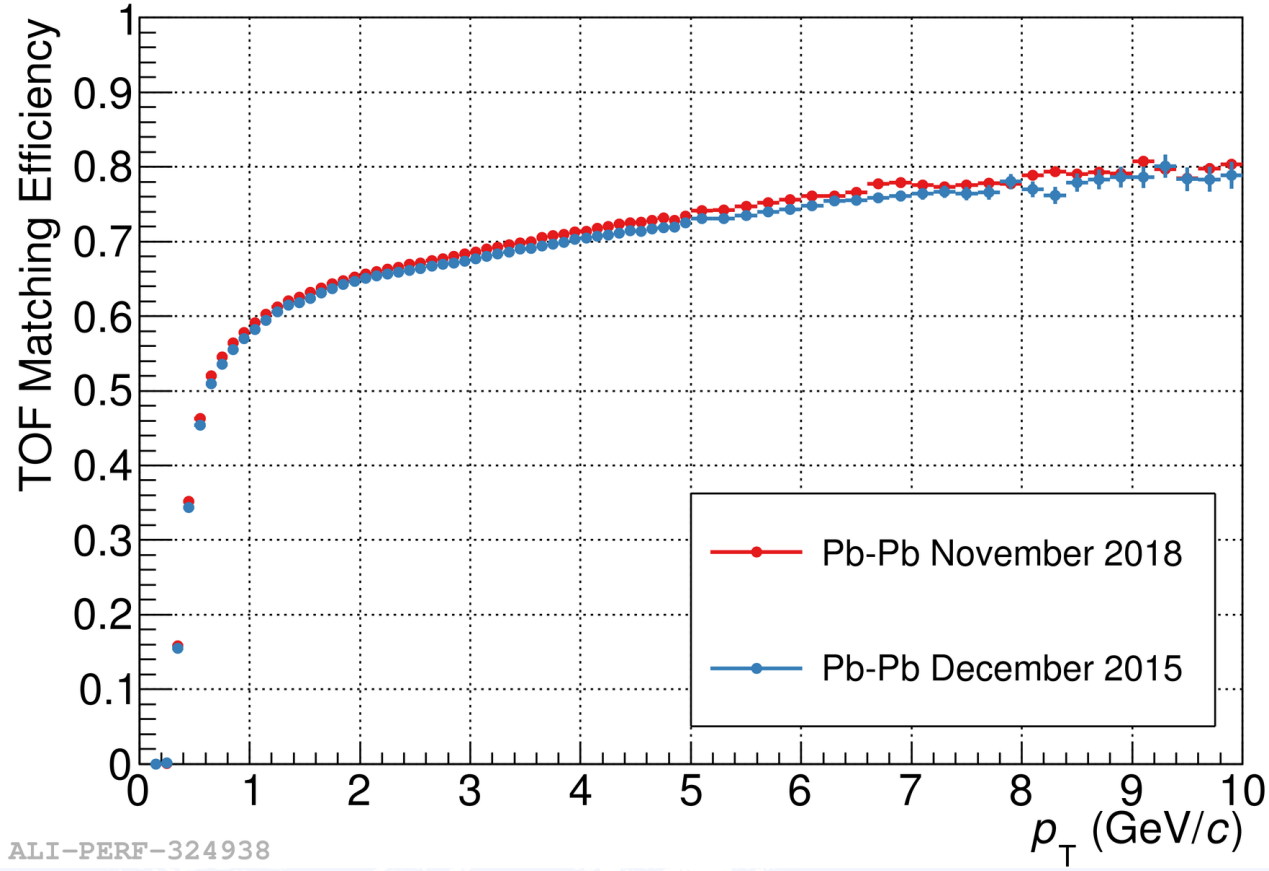
- MRPC efficiency 98.5% (in the center of a pad is ~ 99.5%)
- Good agreement of the data-MC efficiency

Efficiency performance



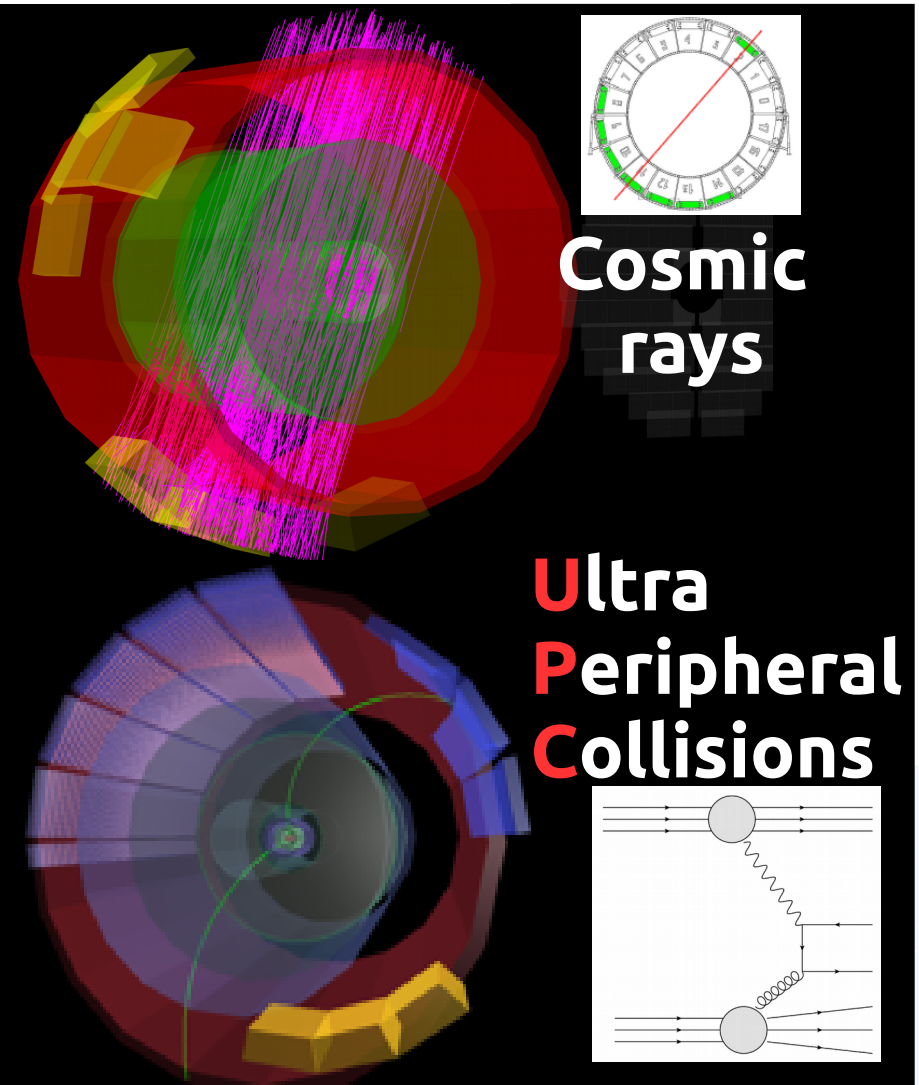
- MRPC efficiency 98.5% (in the center of a pad is ~ 99.5%)
- Good agreement of the data-MC efficiency
- Unchanged intrinsic module efficiency in simulation
  → No signs of efficiency degradation in 10 years!

Efficiency performance



- MRPC efficiency 98.5% (in the center of a pad is ~ 99.5%)
- Good agreement of the data-MC efficiency
- No significant change in the efficiency during Run2 (with similar running conditions)

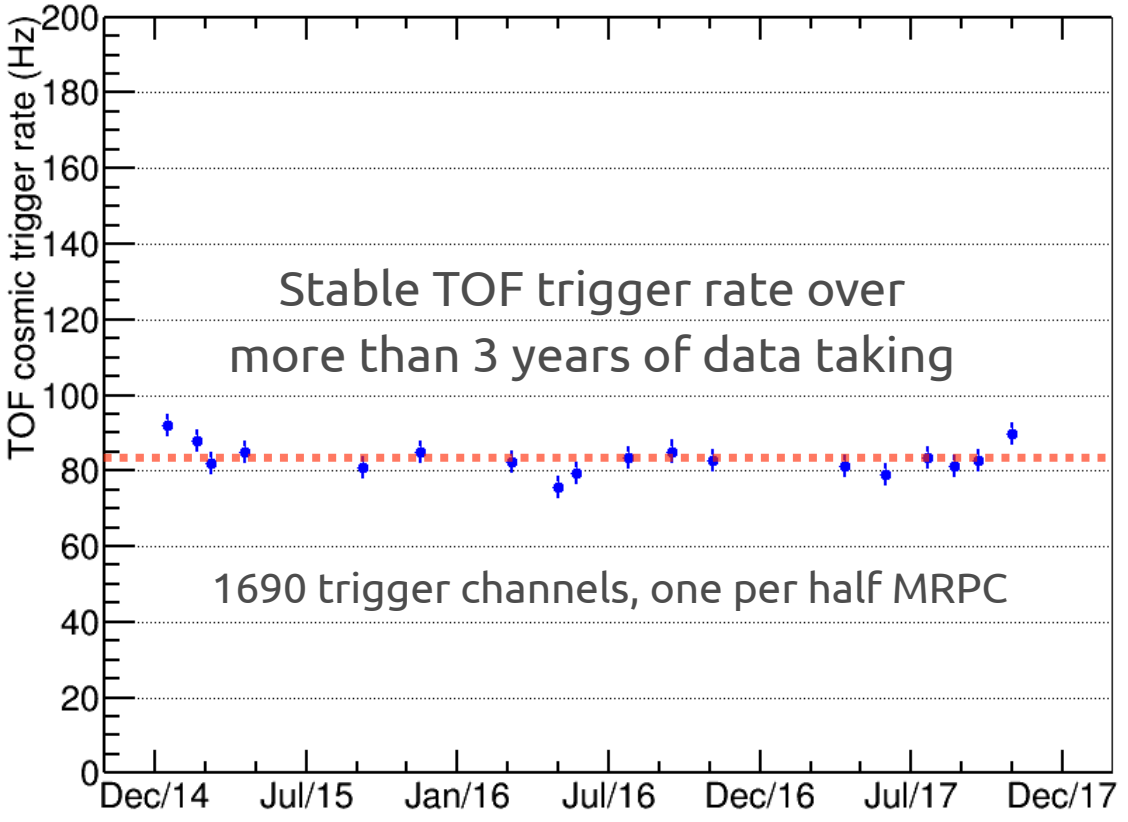
ALICE-TOF trigger Performance



Cosmic rays

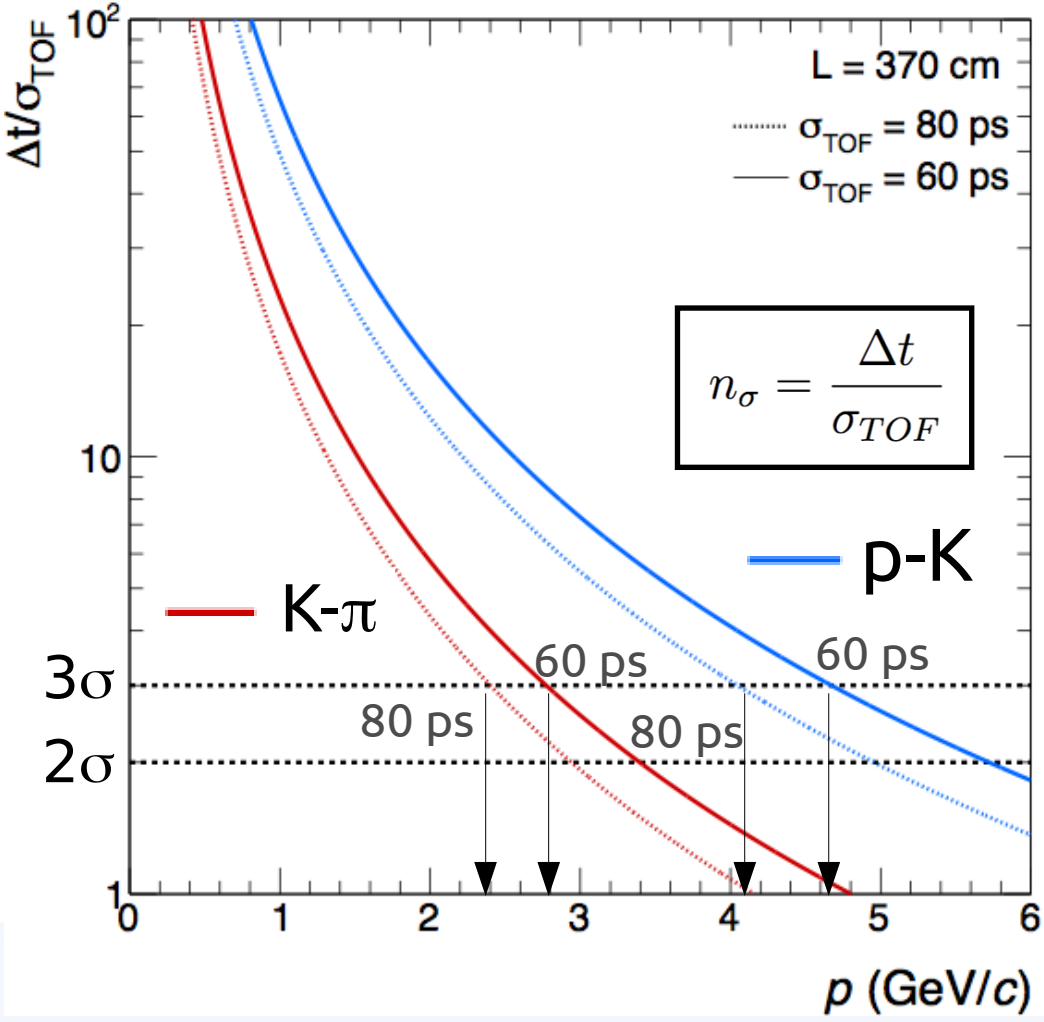
Ultra Peripheral Collisions

- TOF provides a dedicated trigger for **cosmic events** and **UPCs**



NIM A 602 (2009) 372

ALICE-TOF PID Performance



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

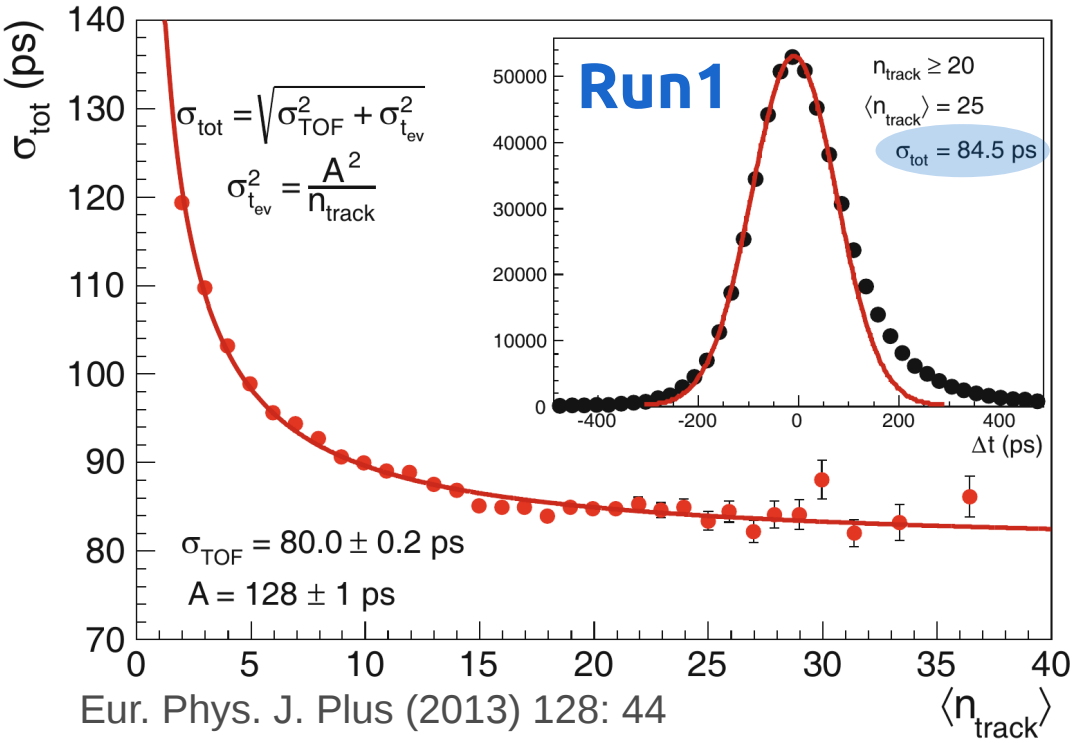
$$\left(\frac{\delta m_{TOF}}{m}\right)^2 = \left(\frac{\delta p}{p}\right)^2 + \gamma \cdot \left(\frac{\delta L}{L}\right)^2 + \gamma \cdot \left(\frac{\delta t}{t}\right)^2$$

Dominant term at high momentum

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

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

ALICE-TOF time resolution



Eur. Phys. J. Plus (2013) 128: 44

Time-Of-Flight

$$TOF = t_{TOF} - t_{event} - t_{\exp_i}$$

Time-Of-Flight resolution

$$\sigma_{TOF} = \sigma^2_{t_{TOF}} + \sigma^2_{trk} + \sigma^2_{event}$$

In Run1 = 84.5 ps

Intrinsic time resolution

$$\sigma^2_{t_{TOF}} = \sigma^2_{MRPC} + \sigma^2_{TDC} + \sigma^2_{FEE} + \sigma^2_{Calib.}$$

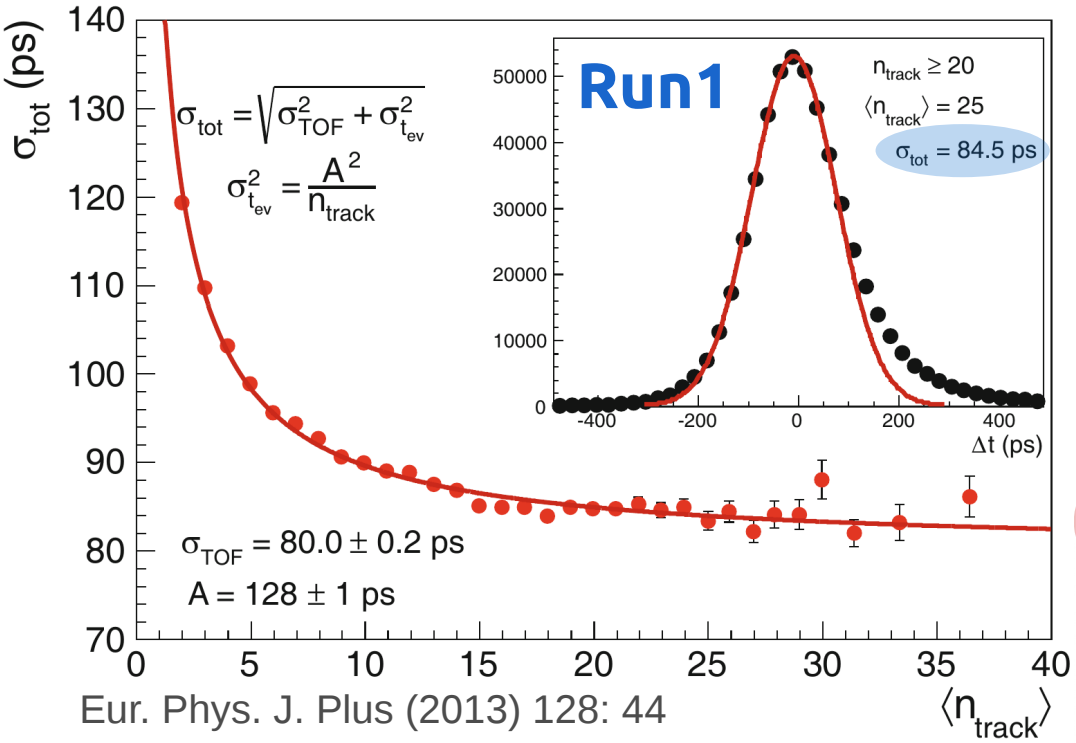
Event collision time resolution

$$\sigma_{event} \sim \sigma_{t_{TOF}} / \sqrt{TOF\ track\ multiplicity}$$

Eur.Phys.J.Plus 132 (2017) no.2, 99

Asymptotic value for large track multiplicities → best event collision time precision

ALICE-TOF time resolution



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Constant terms

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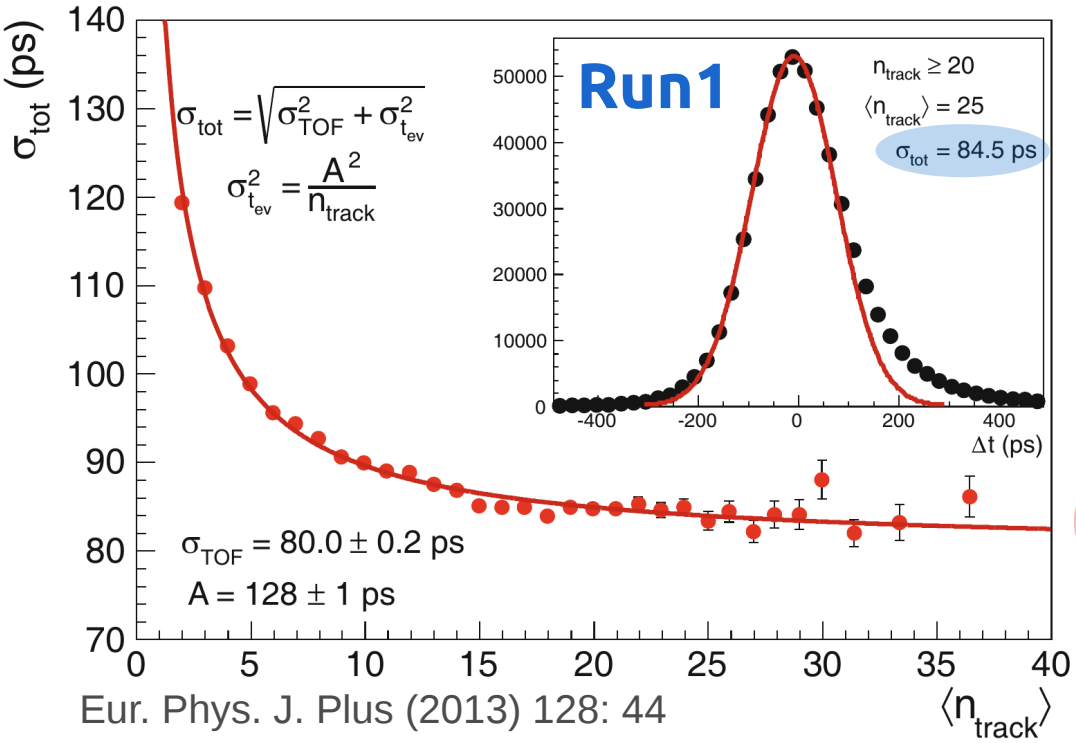

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Fixed by the calibration procedure

Event collision time resolution

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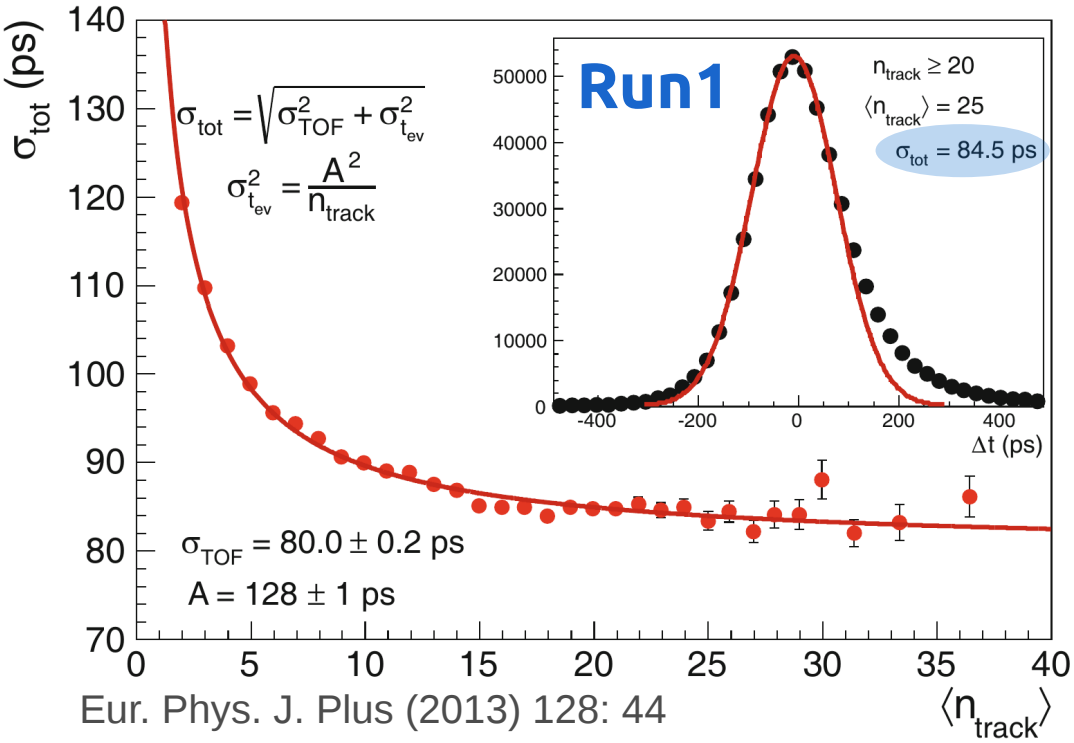
ALICE-TOF time resolution



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Time-Of-Flight resolution

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In Run1 = 84.5 ps

Negligible for p > 1 GeV/c

Intrinsic time resolution

$$\sigma^2_{t_{TOF}} = \sigma^2_{MRPC} + \sigma^2_{TDC} + \sigma^2_{FEE} + \sigma^2_{Calib.}$$

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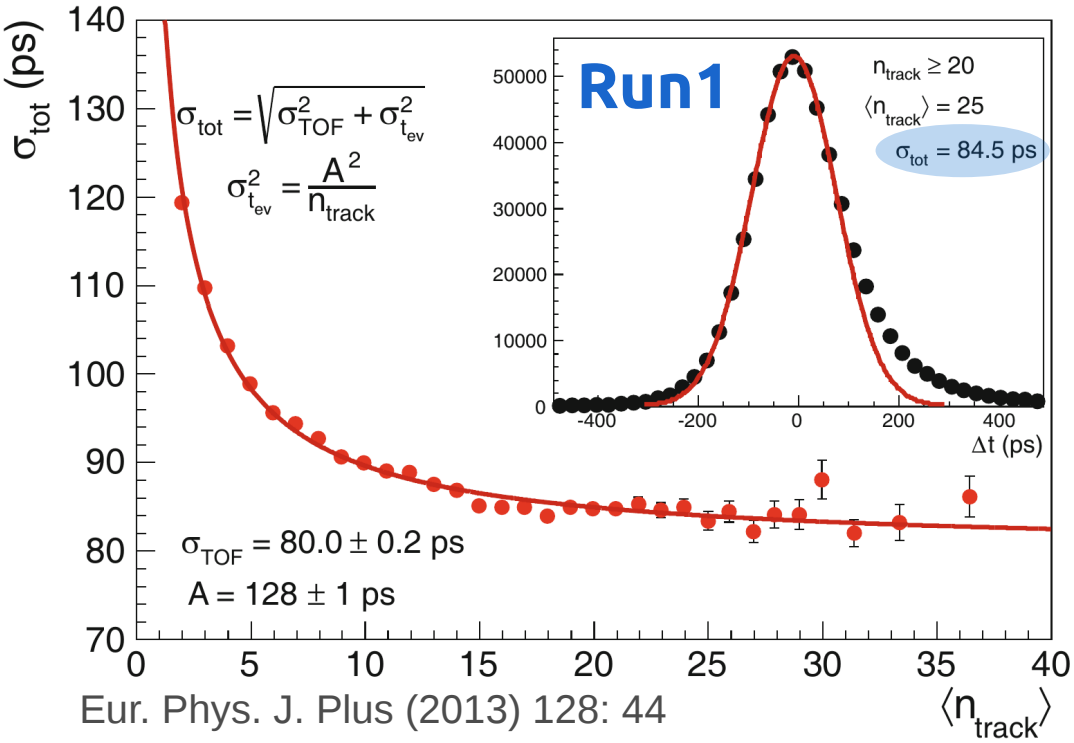

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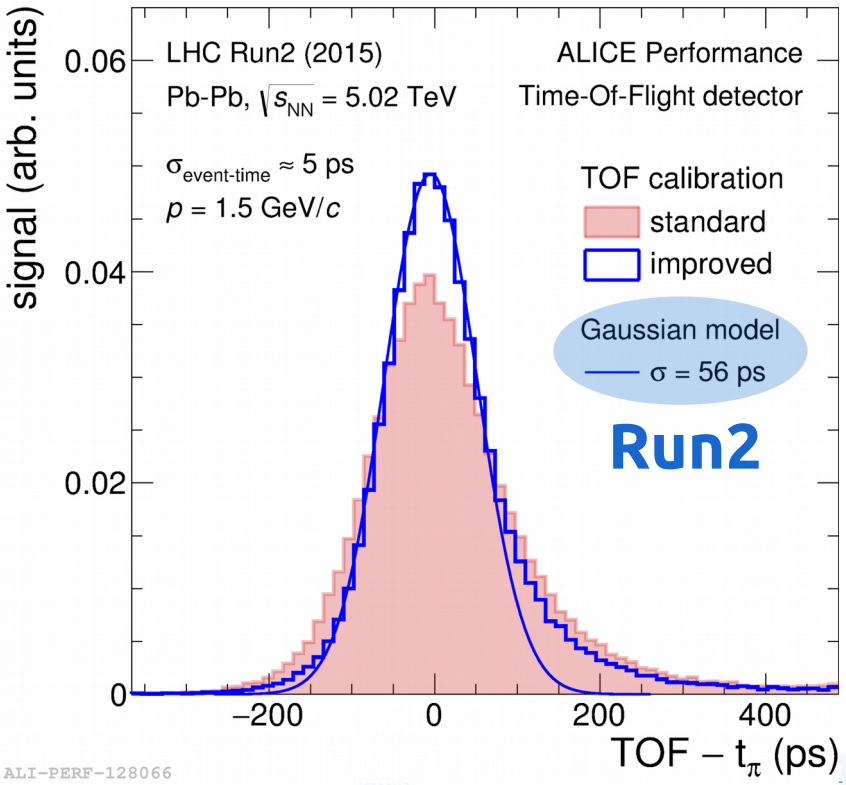

In 2017 the detector calibration was refined

→ significant improvement in the performance

Time-Of-Flight

$$TOF = t_{TOF} - t_{event} - t_{\exp_i}$$

Time-Of-Flight resolution

$$\sigma_{TOF} = \sigma^2_{t_{TOF}} + \sigma^2_{trk} + \sigma^2_{event}$$

In Run1 = 84.5 ps

In Run2 56 ps

Intrinsic time resolution

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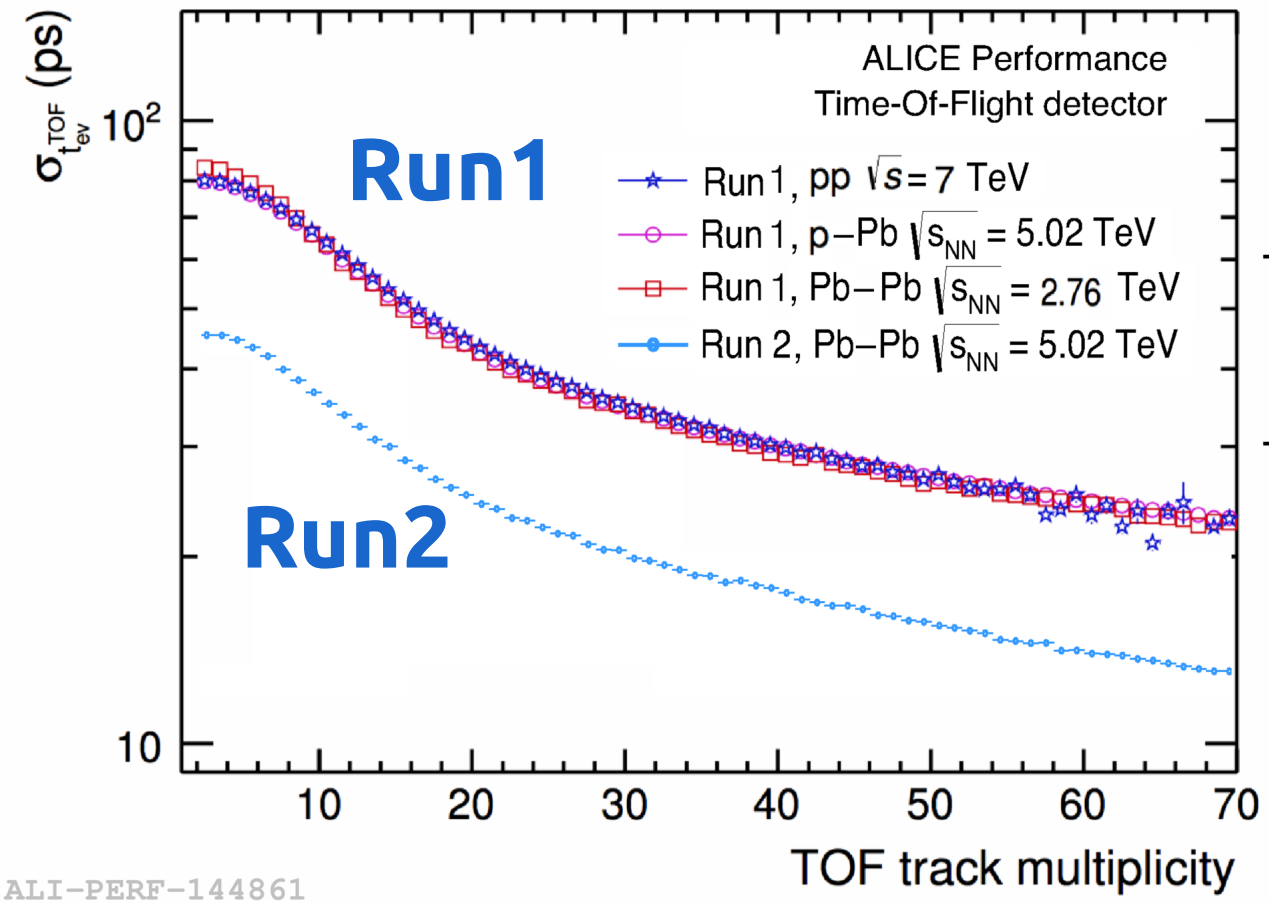
ALICE-TOF event time resolution

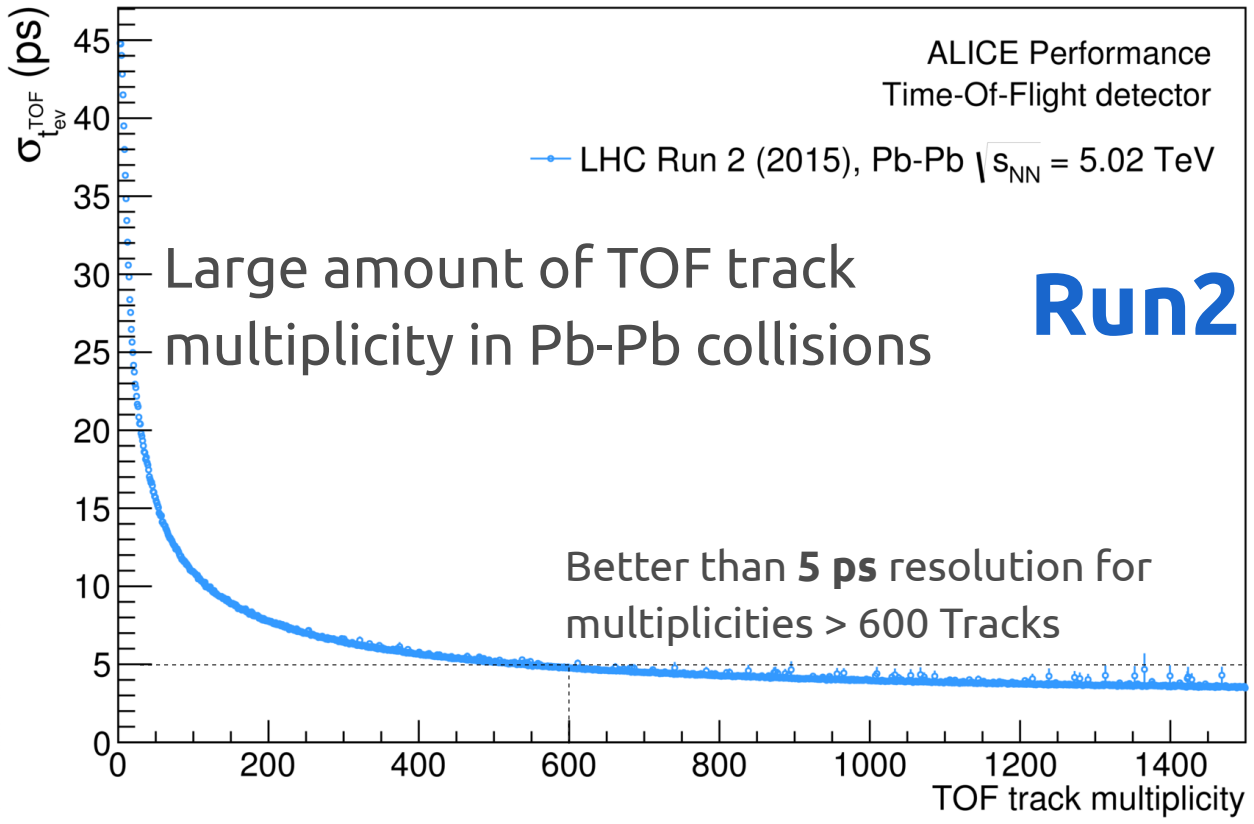


- If TOF track multiplicity > 2 the event time can be measured directly by TOF
- TOF can measure it independently
- Independent of the collision systems (pp, p-Pb, Pb-Pb)

→ depends just on the TOF track multiplicity

$$\sigma_{event} \sim \frac{\sigma_{t_{TOF}}}{\sqrt{TOF\ track\ multiplicity}}$$

ALICE-TOF event time resolution



ALI-PERF-143047

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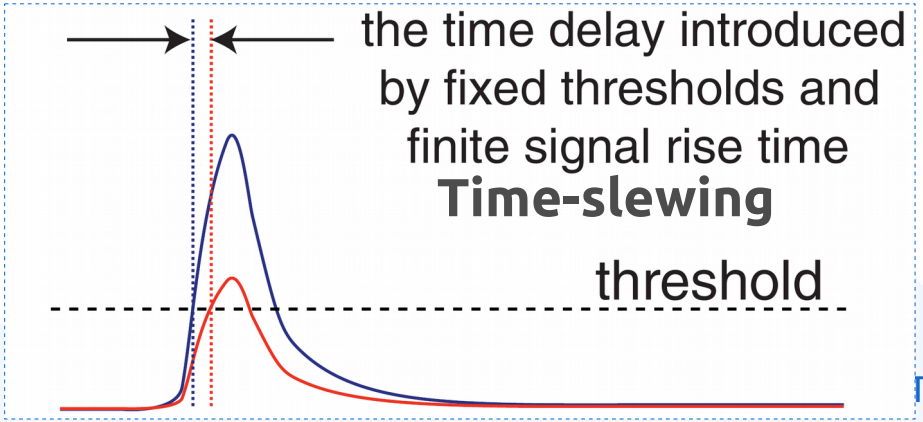
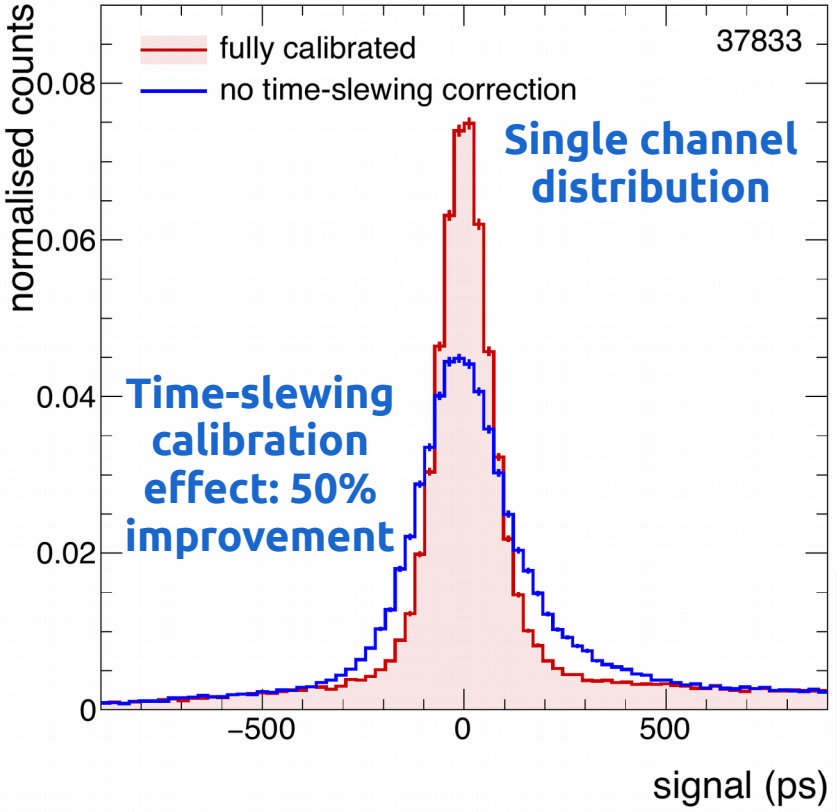
ALICE-TOF calibration

TOF time calibration is based on **3 components**:

1) Global offset, common to all channels (clock)
2) Channel-by-channel offset (cables lengths,…)
3) Time-slewing correction:
   correlation between the time and charge
   → TOF system uses *Time-Over-Threshold* (**ToT**) as a proxy for the charge





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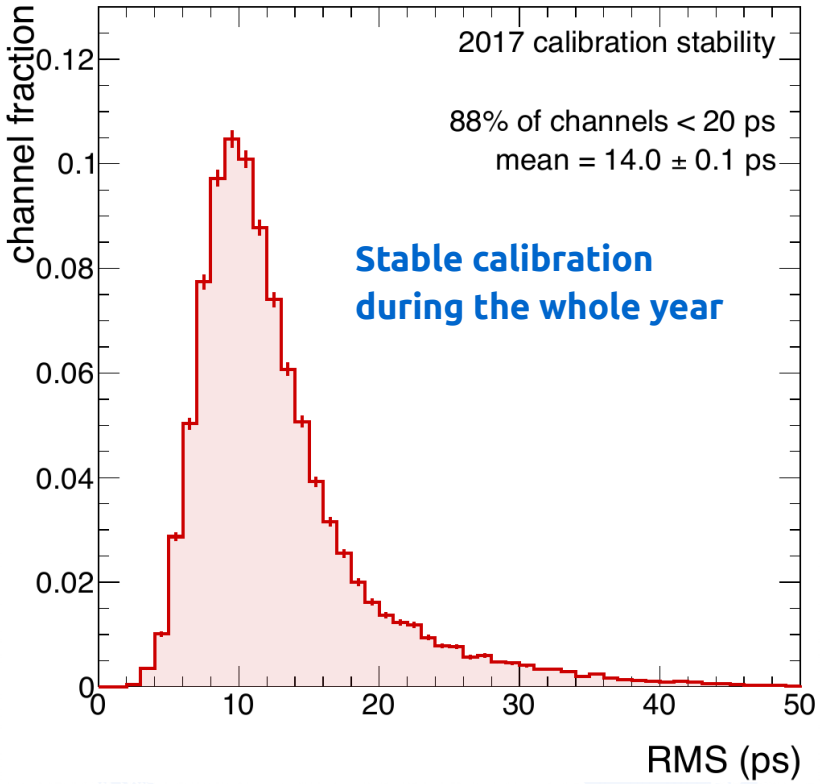
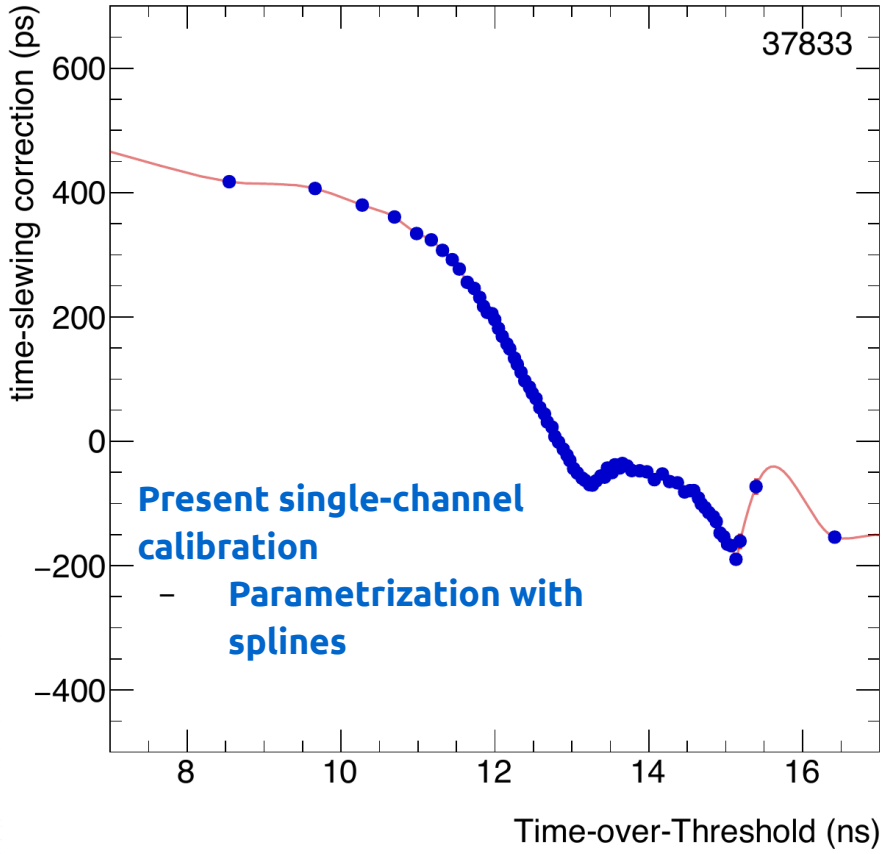
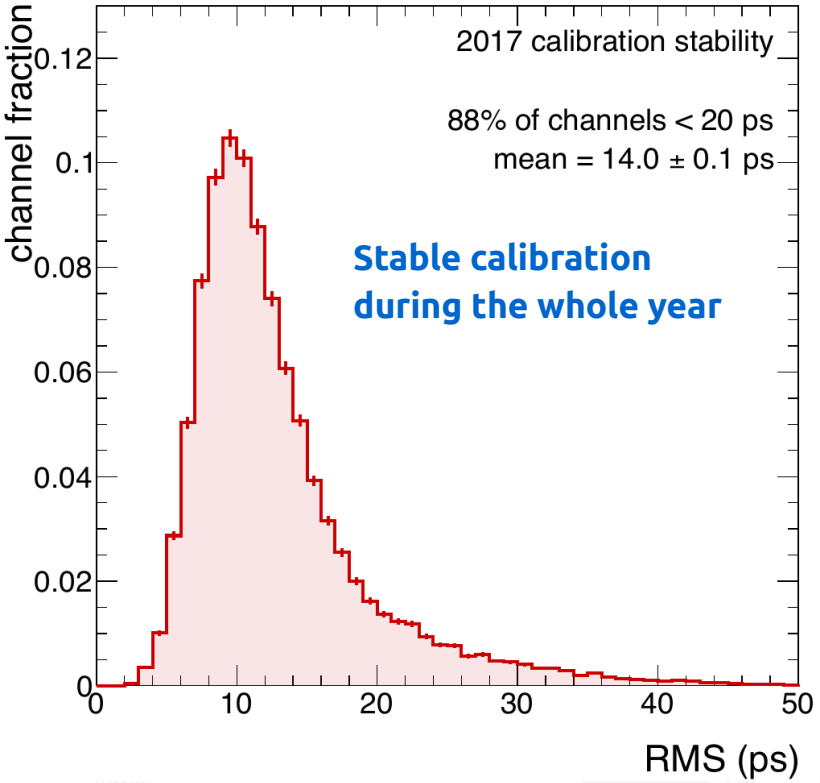
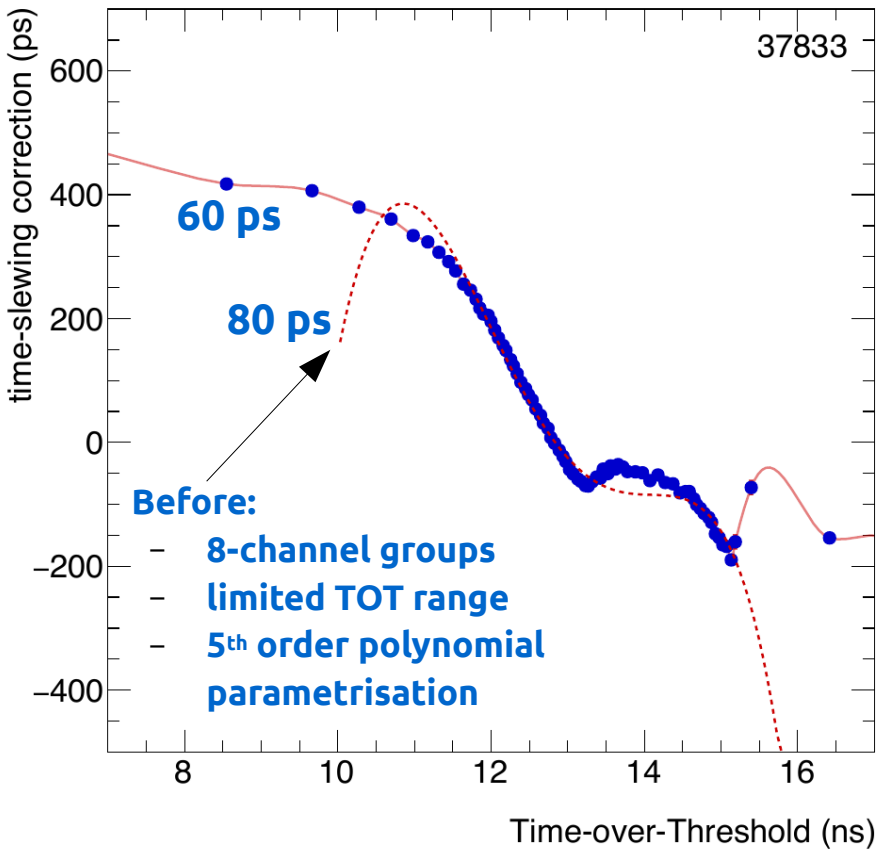




- Single channel improved calibration in 2017
- Calibration was stable for single channels during 2017

ALICE-TOF calibration





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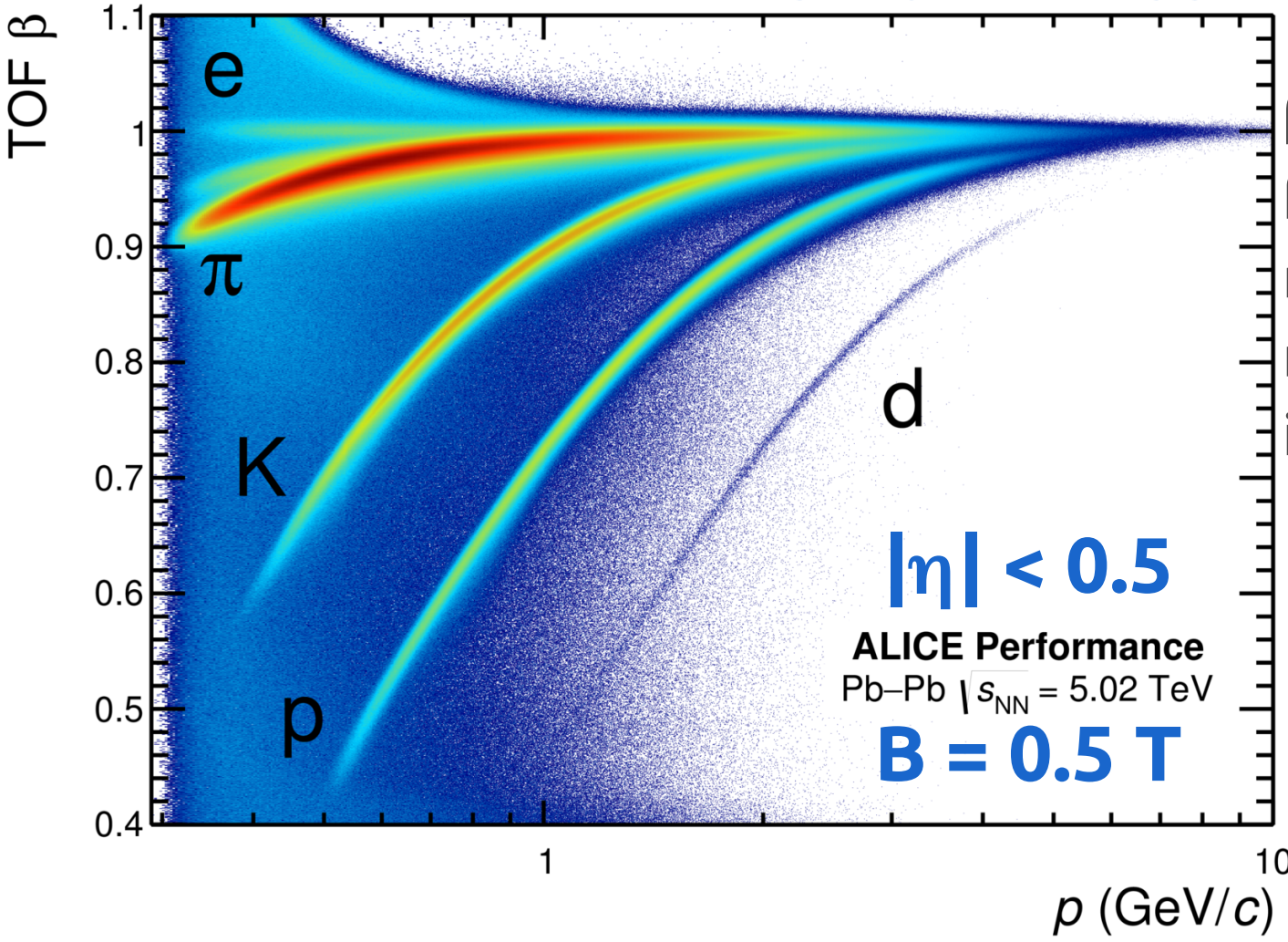
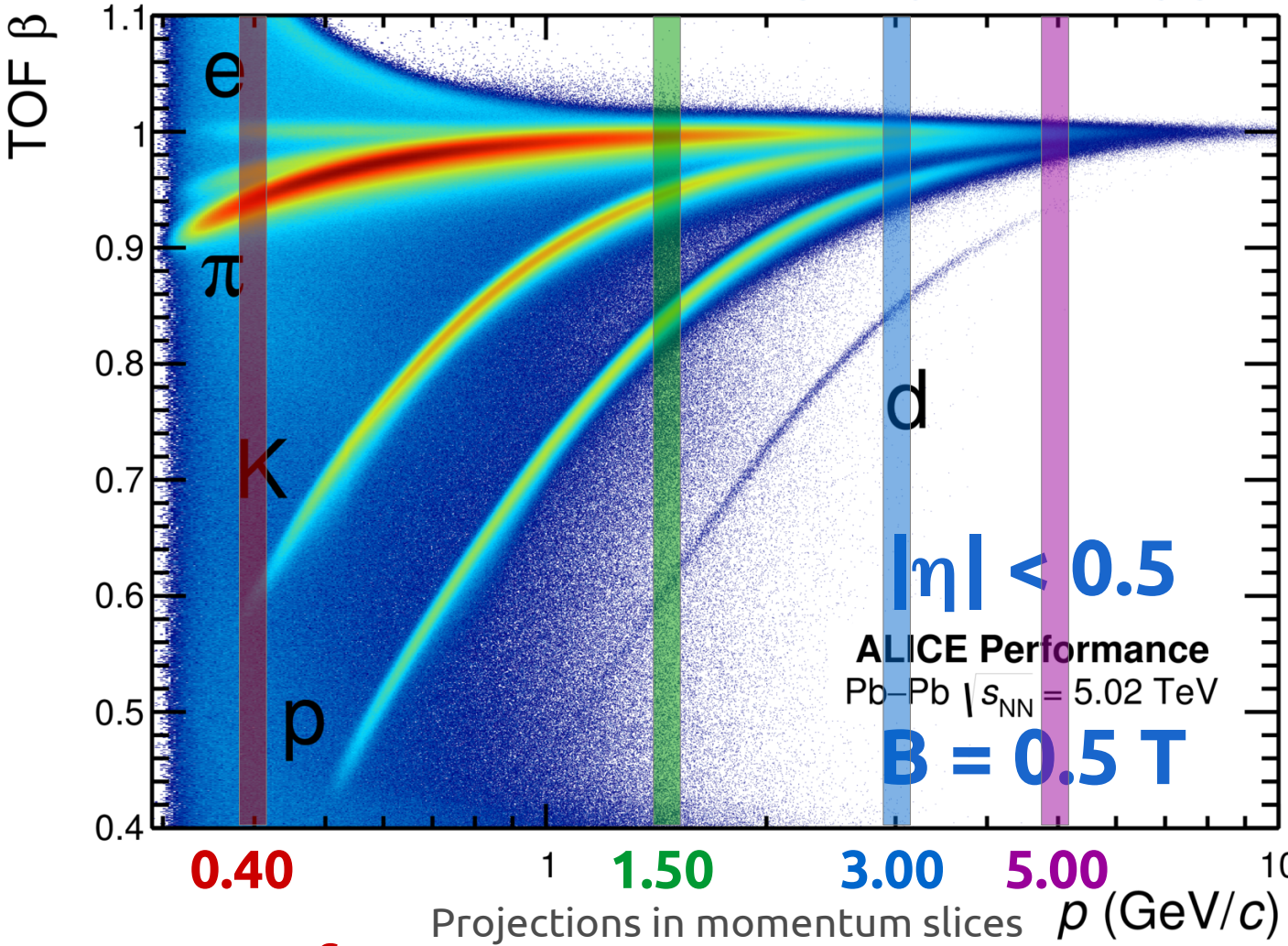
PID Performance



β distribution as a function of momentum measured with TOF in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

- Quantifies the separation of different particle species

PID Performance



β distribution as a function of momentum measured with TOF in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

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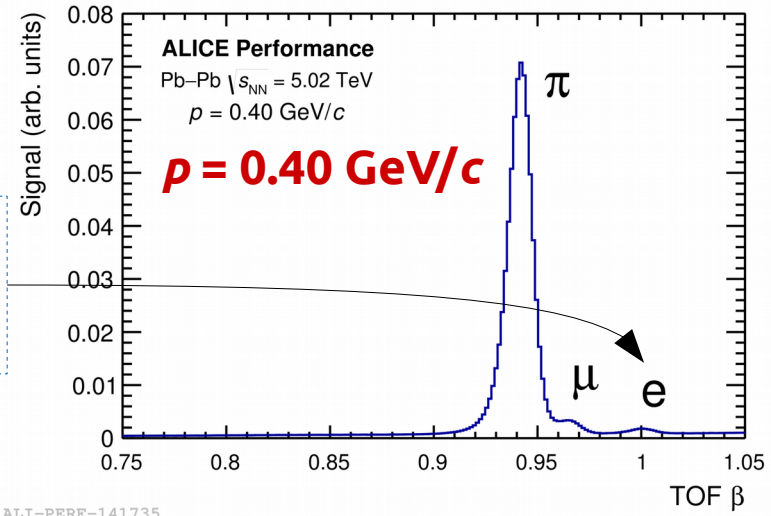
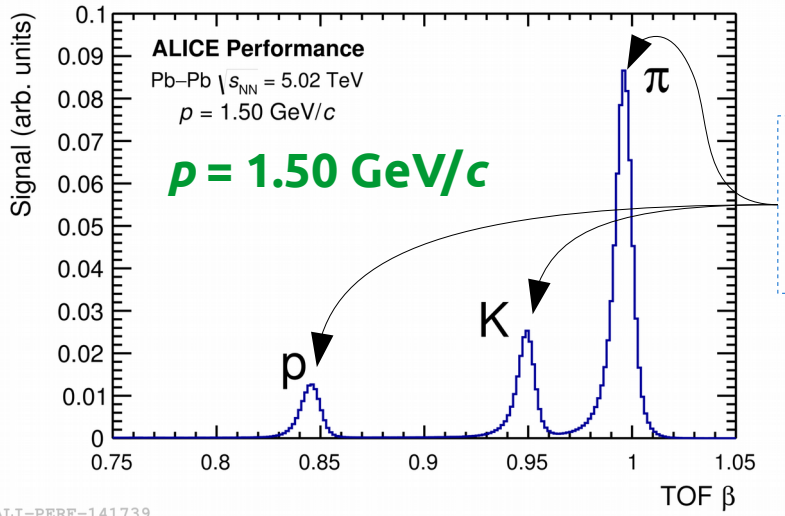
PID Performance

Electron separation at low p_T

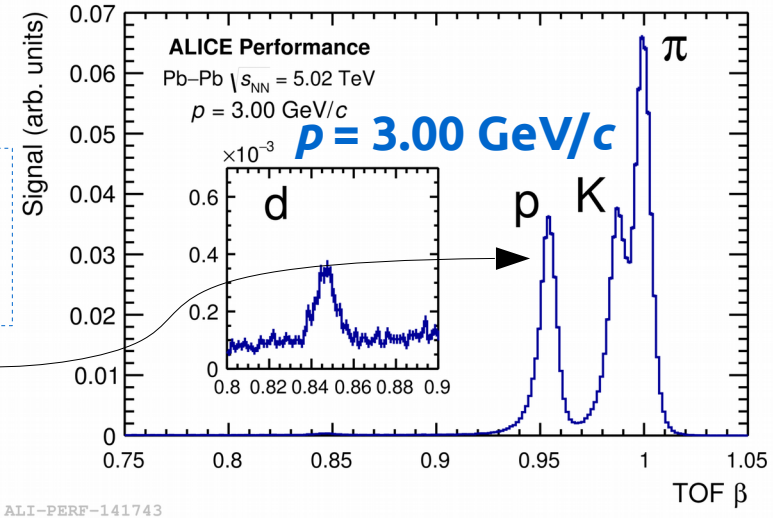


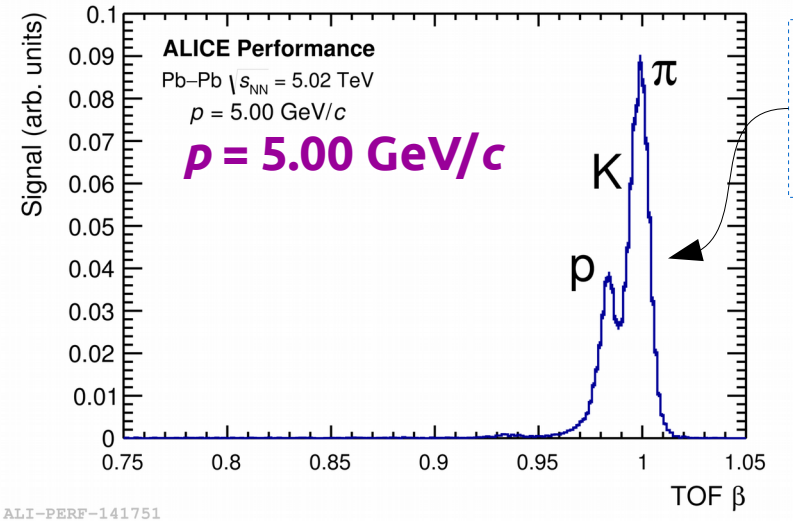


π-K-p well visible at intermediate momentum

Softest → **Hardest**

K/π are still separated at 3 GeV/c





p/K are still separated at 5 GeV/c

Eur. Phys. J. Plus (2013) **128**: 44
DOI 10.1140/epjp/i2013-13044-x

THE EUROPEAN PHYSICAL JOURNAL PLUS

Regular Article

Performance of the ALICE Time-Of-Flight detector at the LHC

From performance to physics

nature physics

LETTERS

PUBLISHED ONLINE: 17 AUGUST 2015 | DOI: 10.1038/NPHYS3432

OPEN

Precision measurement of the mass difference between light nuclei and anti-nuclei

ALICE Collaboration†

Physics with the TOF detector

nature physics

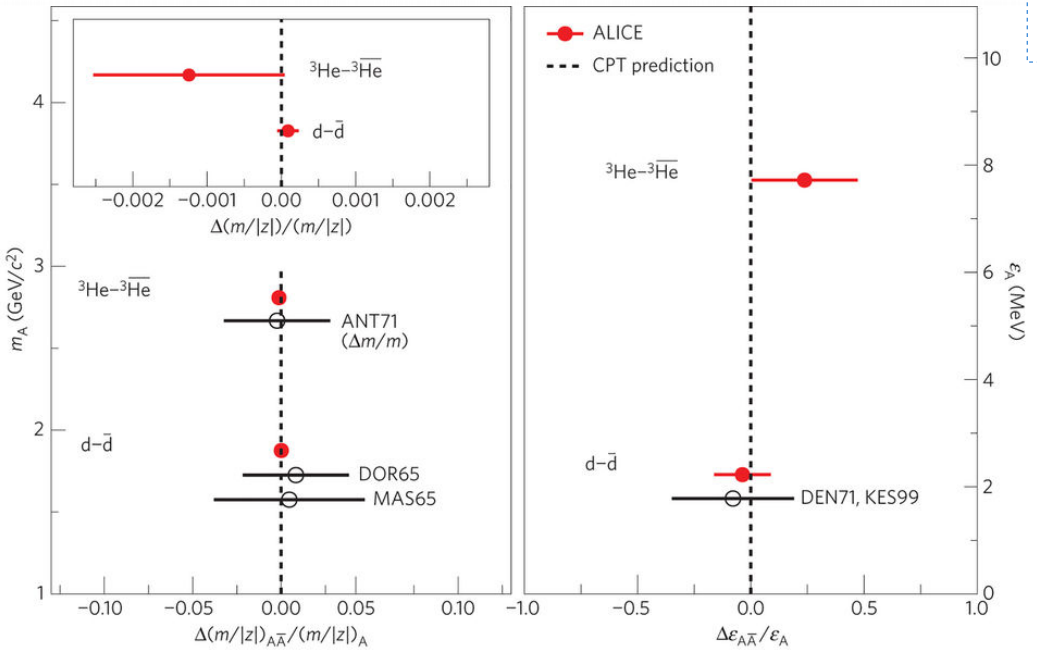
LETTERS

PUBLISHED ONLINE: 17 AUGUST 2015 | DOI: 10.1038/NPHYS3432

OPEN

Precision measurement of the mass difference between light nuclei and anti-nuclei

ALICE Collaboration†



The **TOF** detector is crucial for ALICE and contributes to many physics topics

Nuclei production and precision measurements

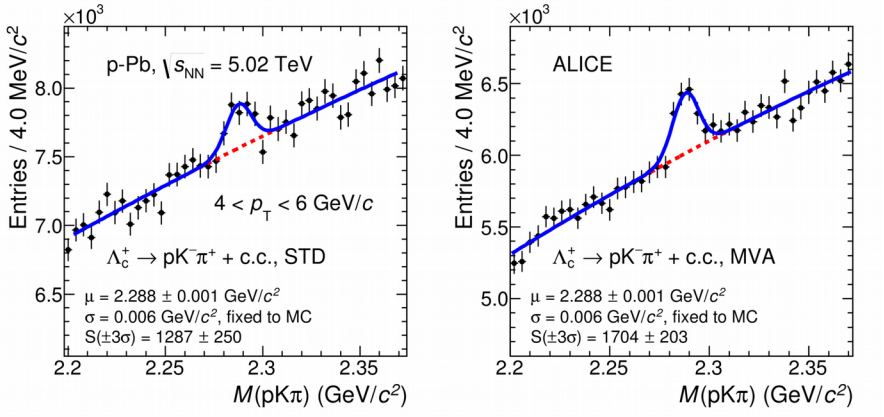
Physics with the TOF detector

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP-2017-339
22 December 2017

Λ_c^+ production in pp collisions at $\sqrt{s}$ = 7 TeV and in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

ALICE Collaboration*



Heavy-flavor production

Physics with the TOF detector

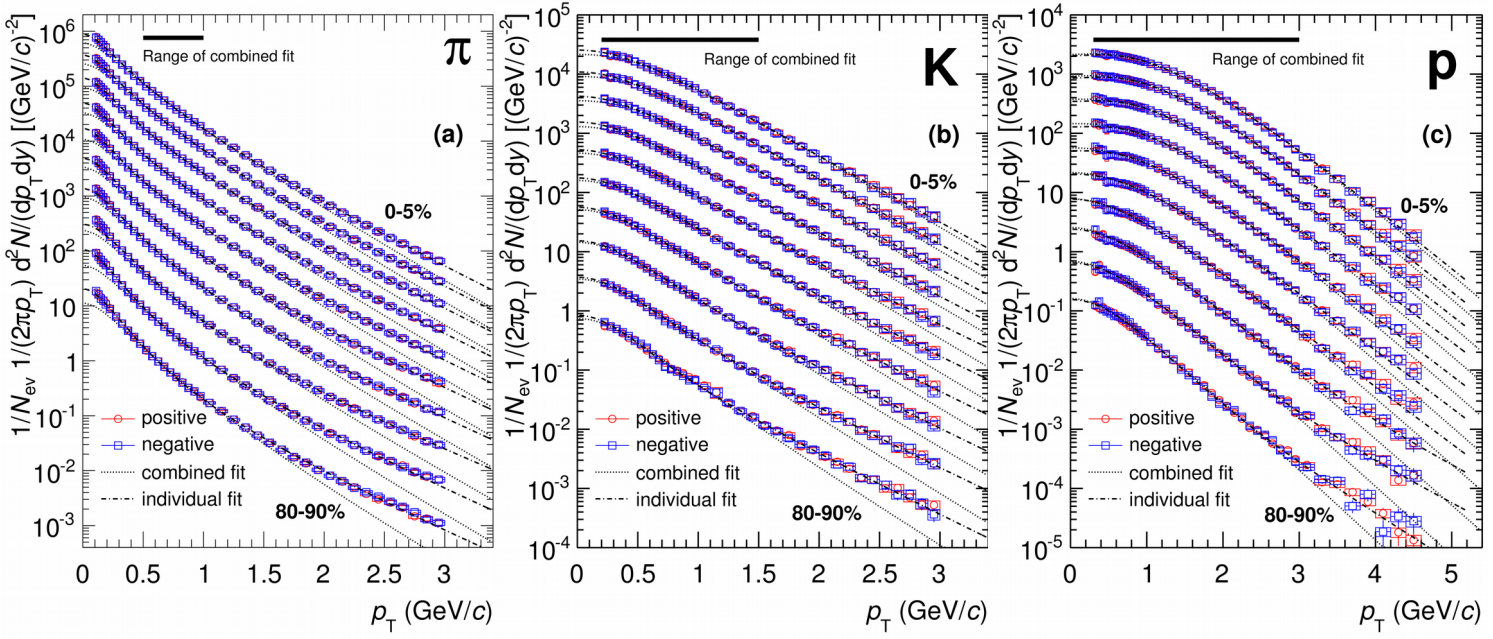
Light-flavor production

PHYSICAL REVIEW C **88**, 044910 (2013)

Centrality dependence of π, K, and p production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

B. Abelev *et al.*[*]
(ALICE Collaboration)

(Received 7 March 2013; revised manuscript received 2 September 2013; published 15 October 2013)

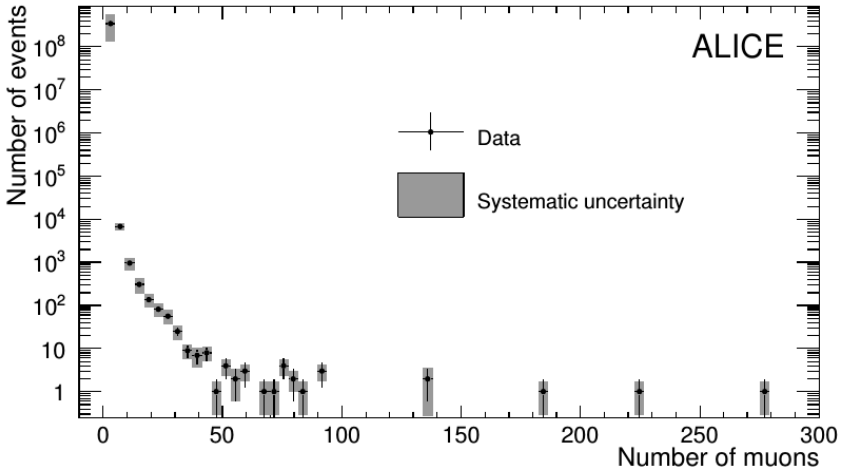


Physics with the TOF detector

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Study of cosmic ray events with high muon multiplicity using the ALICE detector at the CERN Large Hadron Collider

ALICE
The ALICE collaboration
E-mail: ALICE-publications@cern.ch



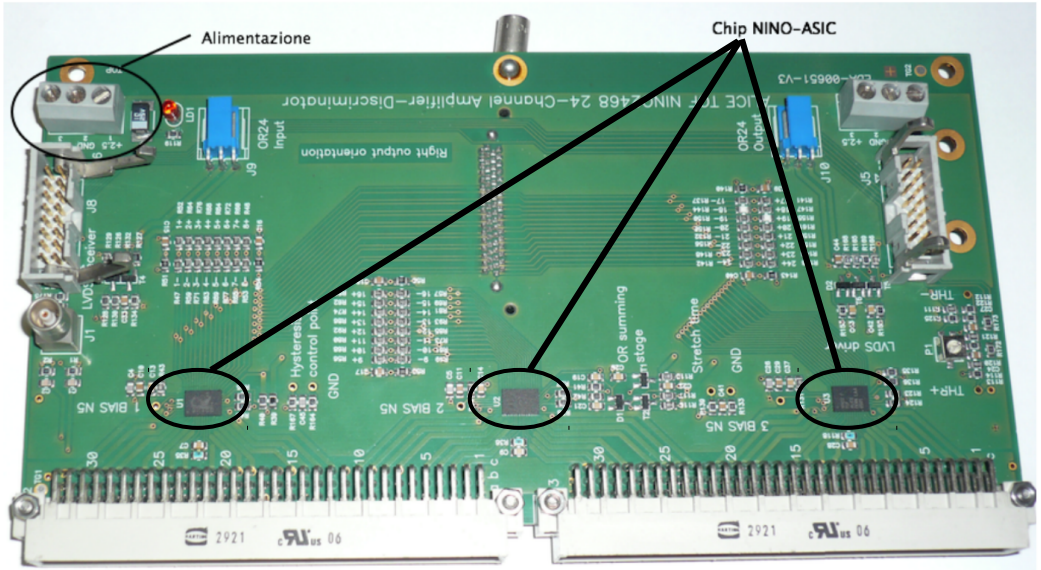
Muons from cosmic rays

Conclusions and outlook

- ALICE TOF proved to be a very **stable detector** since the start of data taking
- TOF detector shows **no sign of degradation nor loss in performance**
- The time resolution is improved thanks to 2017 calibration
  → Upgraded time-slewing calibration:
  - » Net improvement in TOF resolution from **~ 80 ps** to better than **60 ps**
- It provides a **K/π separation up to 3 GeV/*c*** and a **p/K separation up to 5 GeV/*c***
- The TOF-PID is extensively and successfully exploited in many analyses in ALICE
- Upgrade of the readout chain are ongoing but **no changes in operation** are expected during **Run3**
- Promising for the future with new technological developments in the field

Backup

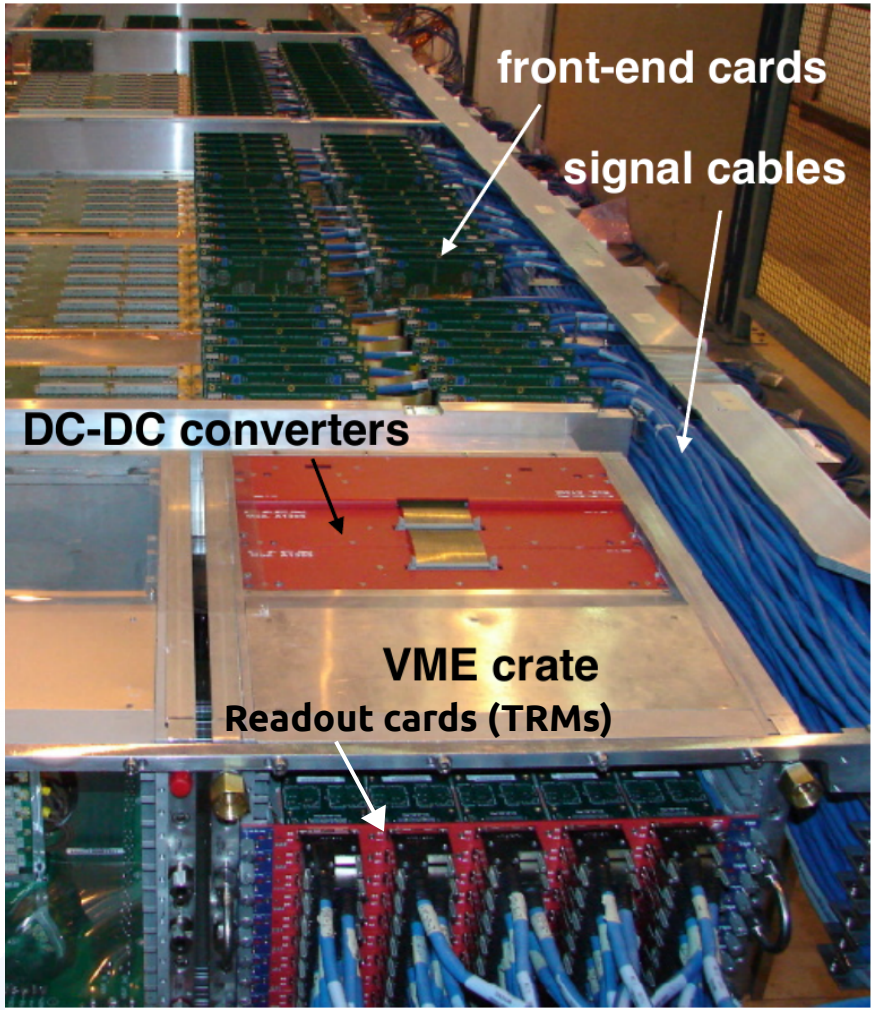
Front-end electronics



F. Anghinolfi et al. IEEE Trans. On Nucl. Science 51 (2004) 5

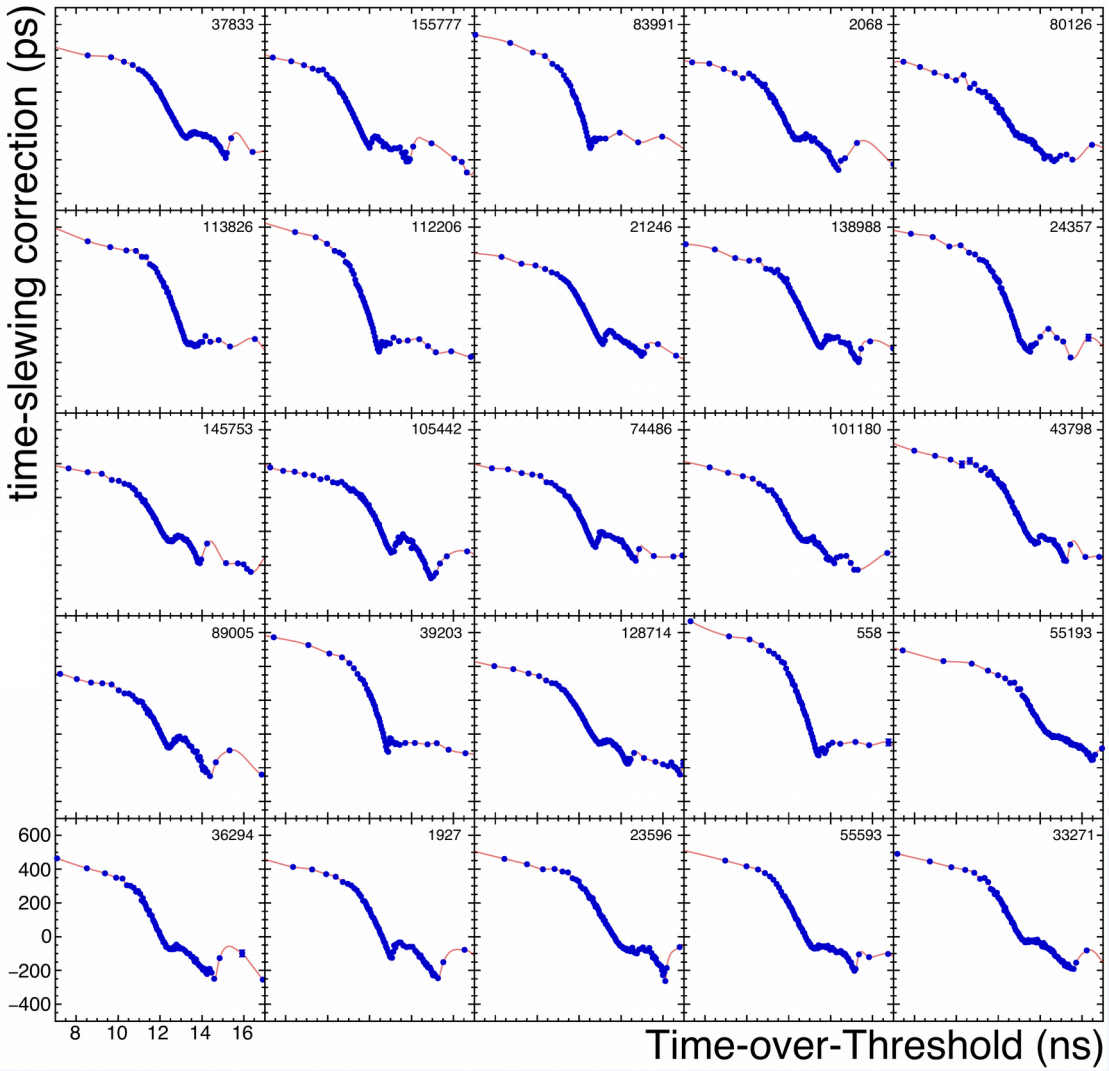
- Based on the **NINO ASIC** chip
- Ultrafast low power differential Amplifier and Discriminator
- IBM 0.25μm Si CMOS Technology
- Less than 1 ns peaking time
- 8 channel / chip (chip: 2x4 mm^2)
- Low power consumption (40 mW/chan)
- Input charge measurement via Time-over-Threshold (ToT)
- A front end card (FEA) hosts 3 NINO chips (24 channels)
- 4 FEAs read out a full MRPC strip

Readout electronics



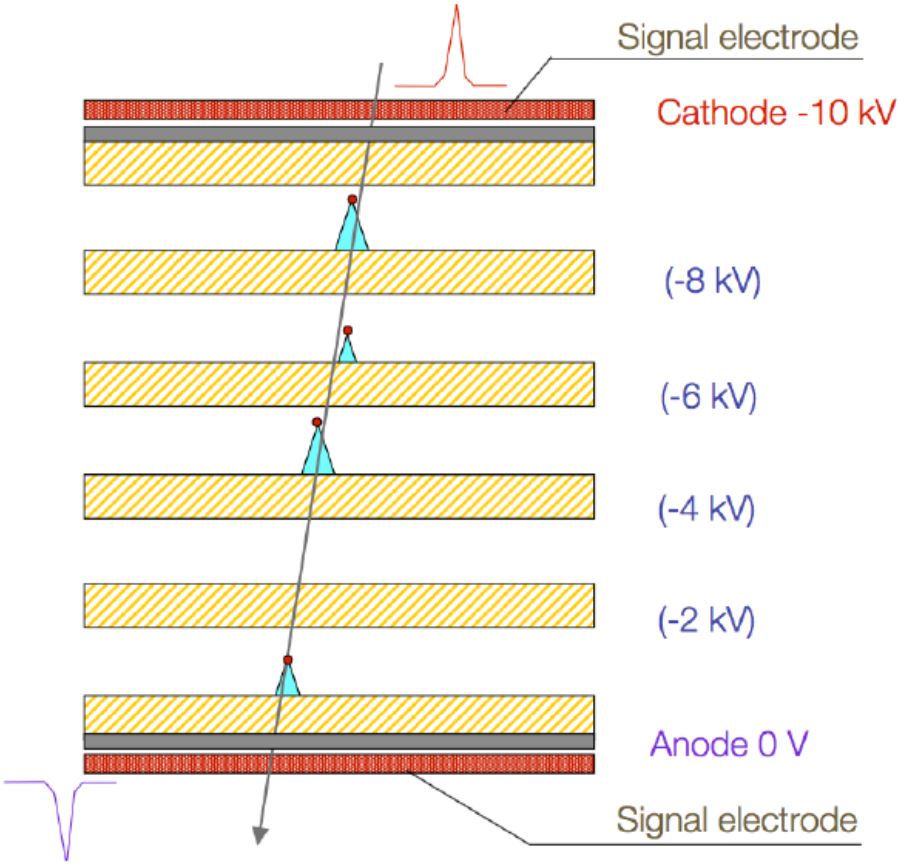
- Housed in water-cooled **custom VME crates**
- **DC-DC converter** power supply designed to work in B = 0.5 T
- **TDC Readout Module (TRM)**
  - » multi-hit / multi-event design
  - » based on HPTDC ASIC chip (VHRM)
  - » 8-channel TDC with 24.4 LSB
  - » leading/trailing edge detection capability
- **Data Readout Module (DRM)**
  - » interface to DAQ/trigger
- **Local Trigger Module (LTM)**
  - » local trigger + FEE monitor/setup
- **Clock Distribution Module (CPDM)**
  - » high-quality clock distribution to TRMs

ALICE-TOF calibration



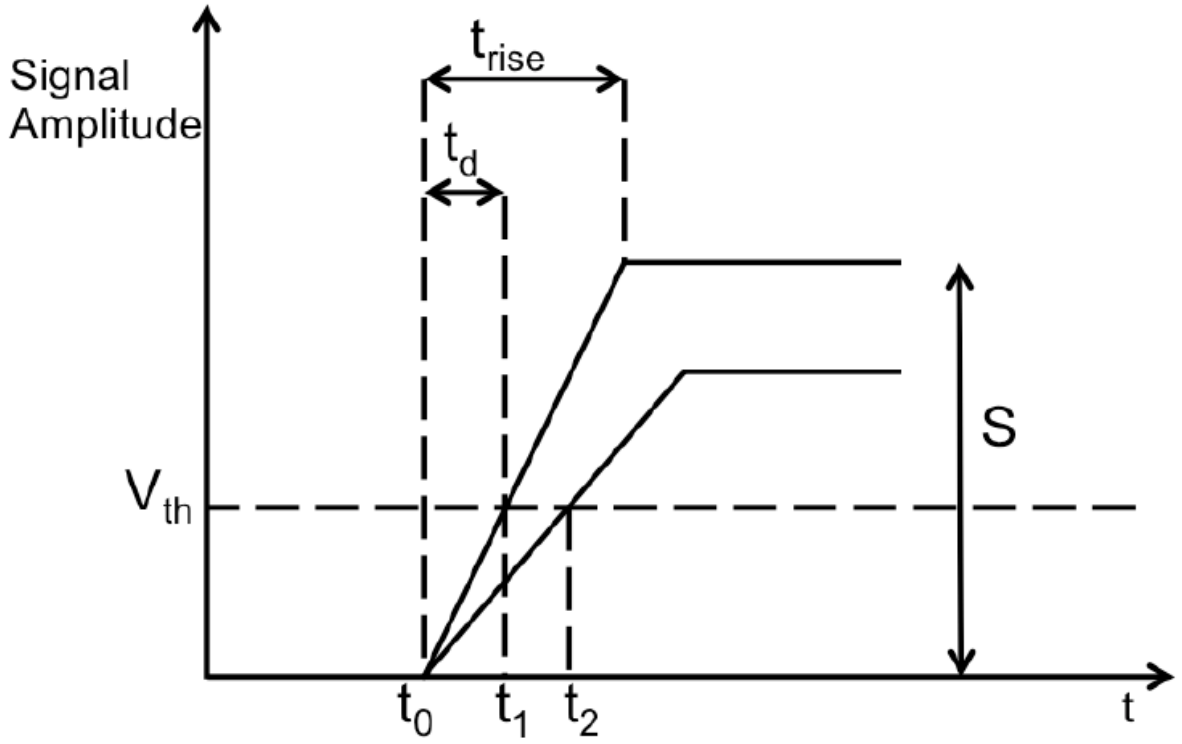
Uniform time-slewing calibration across different channels

The ALICE Time-Of-Flight MRPC



- Stack of equally-spaced resistive plates with voltage applied to external surfaces
- Internal plates left floating - equal gain in all gas gaps
- Working in avalanche mode
- Readout electrodes on external surfaces (resistive plates transparent to fast signal)
- Signal starts immediately and is the sum of many avalanches

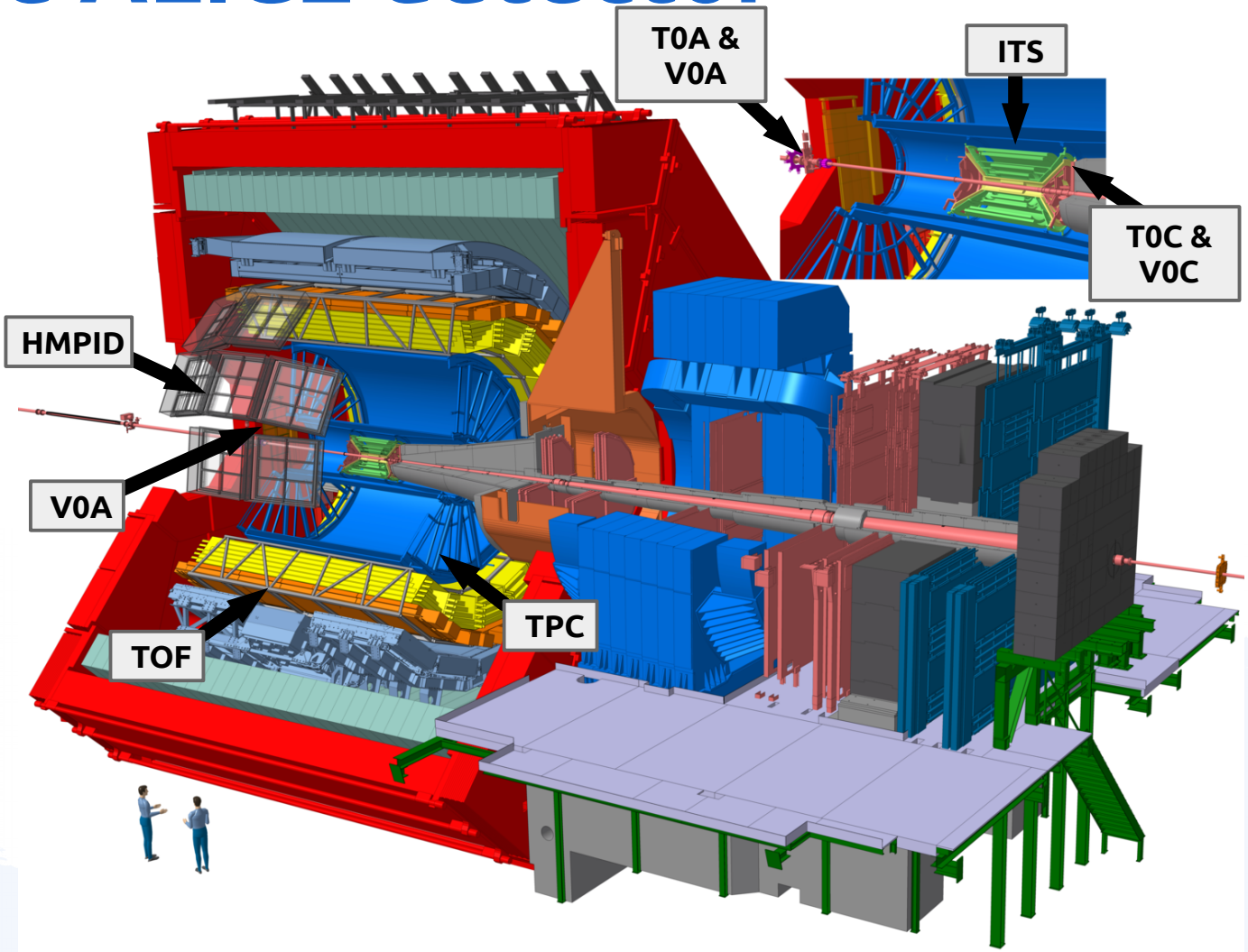
ALICE-TOF calibration



The time slewing effect is due to the comparison of the signal with a **fixed threshold voltage** Vth, usually related to the nature of the analog to digital conversion of the signals.

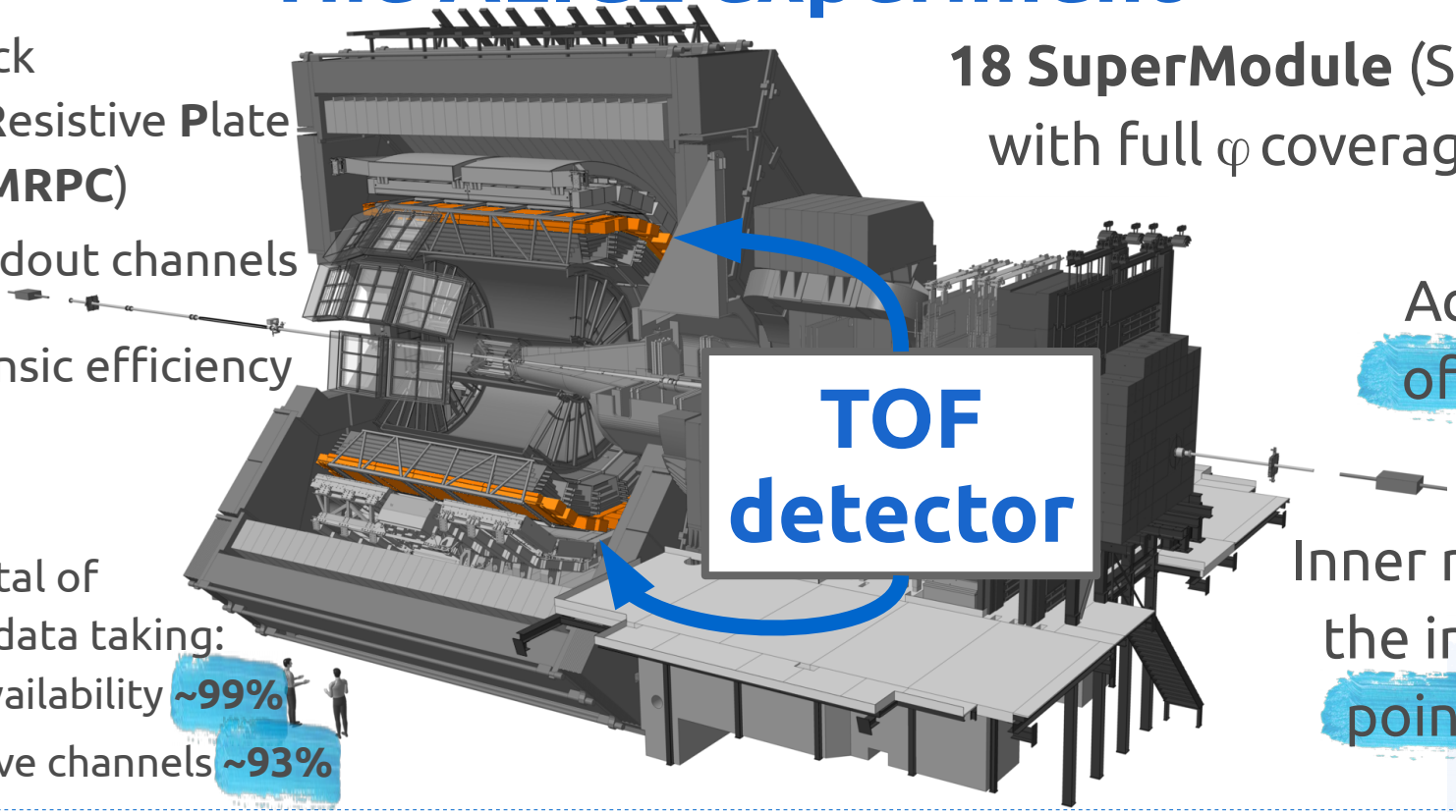
The ALICE detector

- Moderate magnetic field (B = 0.5 T, 0.2 T) in the mid-rapidity region $|\eta| < 0.9$
- Tracking down to $p_T \sim 100$ MeV/c
- High granularity to cope with the high occupancy present in Pb-Pb collisions
- Extensive particle identification (PID) by several techniques



The ALICE experiment

- Double stack **M**ulti-gap **R**esistive **P**late **C**hamber (**MRPC**)
- **152928** readout channels
- **MRPC** intrinsic efficiency **~ 98-99%**



18 SuperModule (SM) with full φ coverage

Active area of ~ **141 m²**

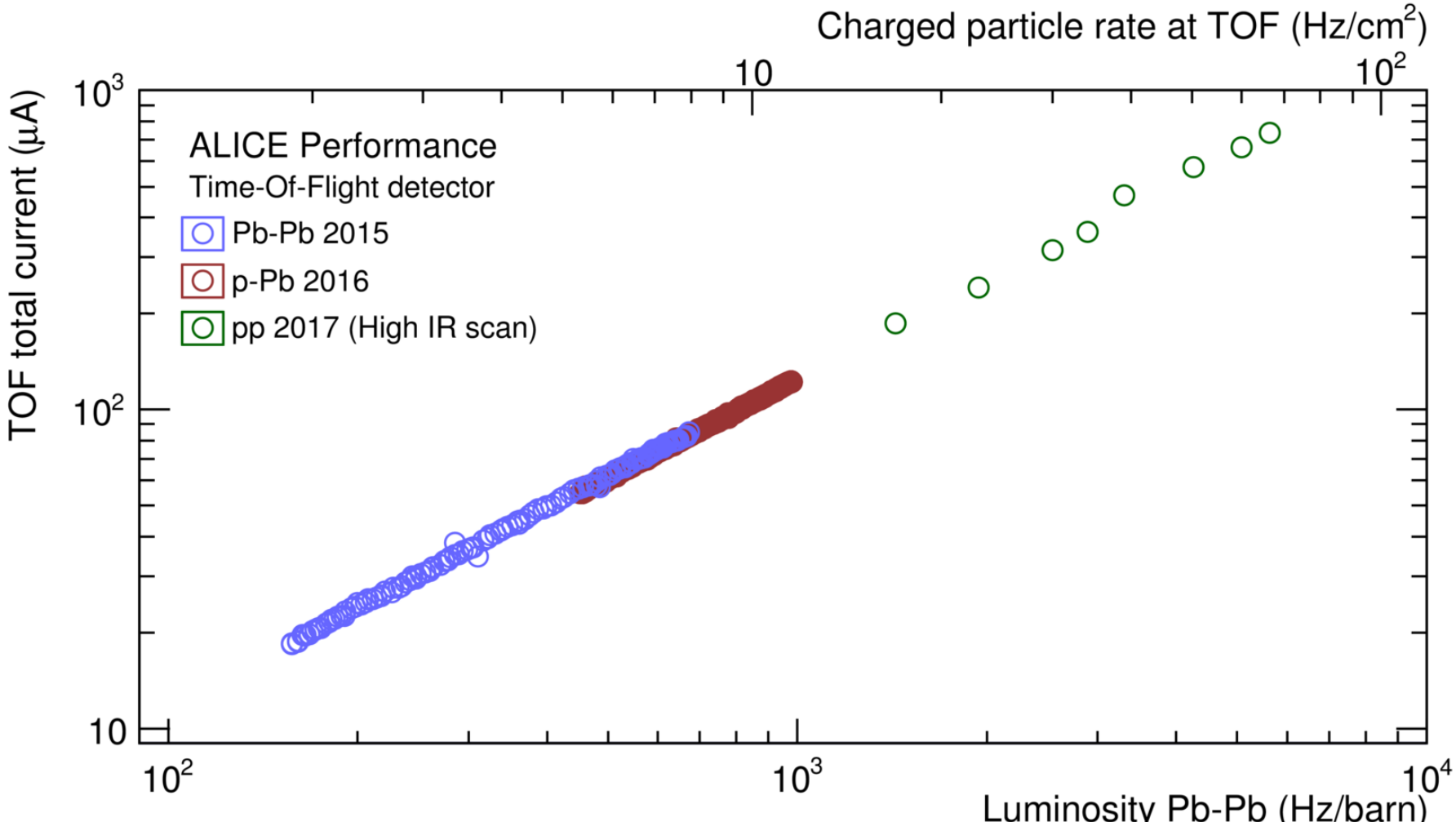
Inner radius from the interaction point **370 cm**

In 2017, in a total of **2116** hours of data taking:

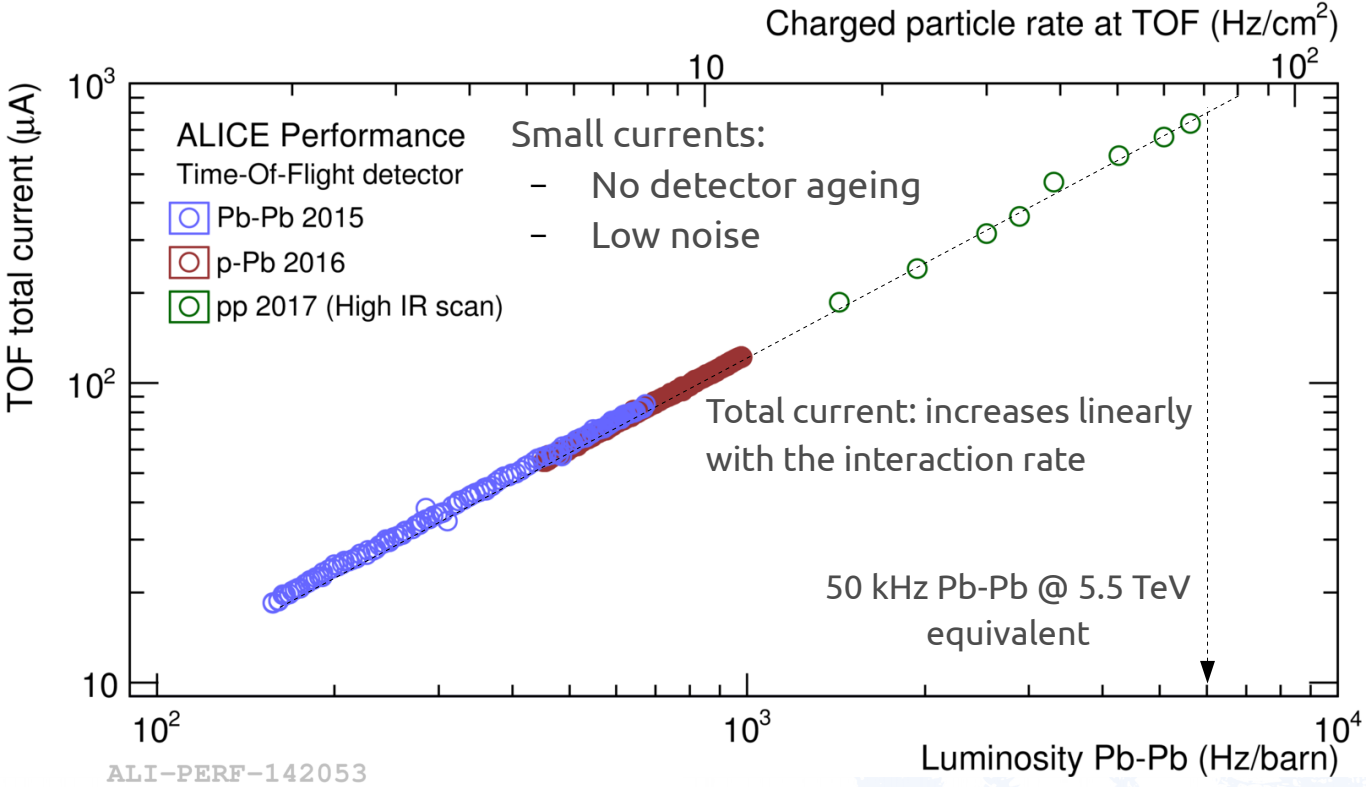
- total time availability **~99%**
- average active channels **~93%**

- Extensive particle identification (PID) using several techniques and multiple detectors
- The *Time-Of-Flight* (**TOF**) detector covers intermediate p_T range in the central barrel ($|\eta|< 0.9$) with full azimuthal coverage

ALICE-TOF Performance



TOF detector upgrade: brace for Run3

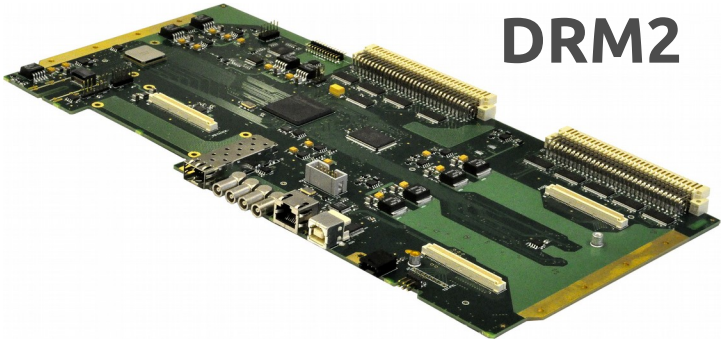


- Tests with pp collisions at higher interaction rates (Run3 equivalent) gave positive response
  - » No concerns with current hardware at Run3 equivalent interaction rates

- **TOF will record hits at 50 kHz interaction rate with 60 ps resolution in Run3**

TOF detector upgrade: brace for Run3

- TOF upgrade for Run3 will regard exclusively the readout electronics and software
- The only upgraded component is the **DRM2** (72 boards)
  - » Complies with the new data communication standards in the upgraded ALICE detector
  - » Enables full exploitation of rate/bandwidth capability
- Latest irradiation tests completed in 2018
- Boards are ready to be installed in october 2019



PoS(TWEPP2018)025