PID performance of the ALICE-TOF detector

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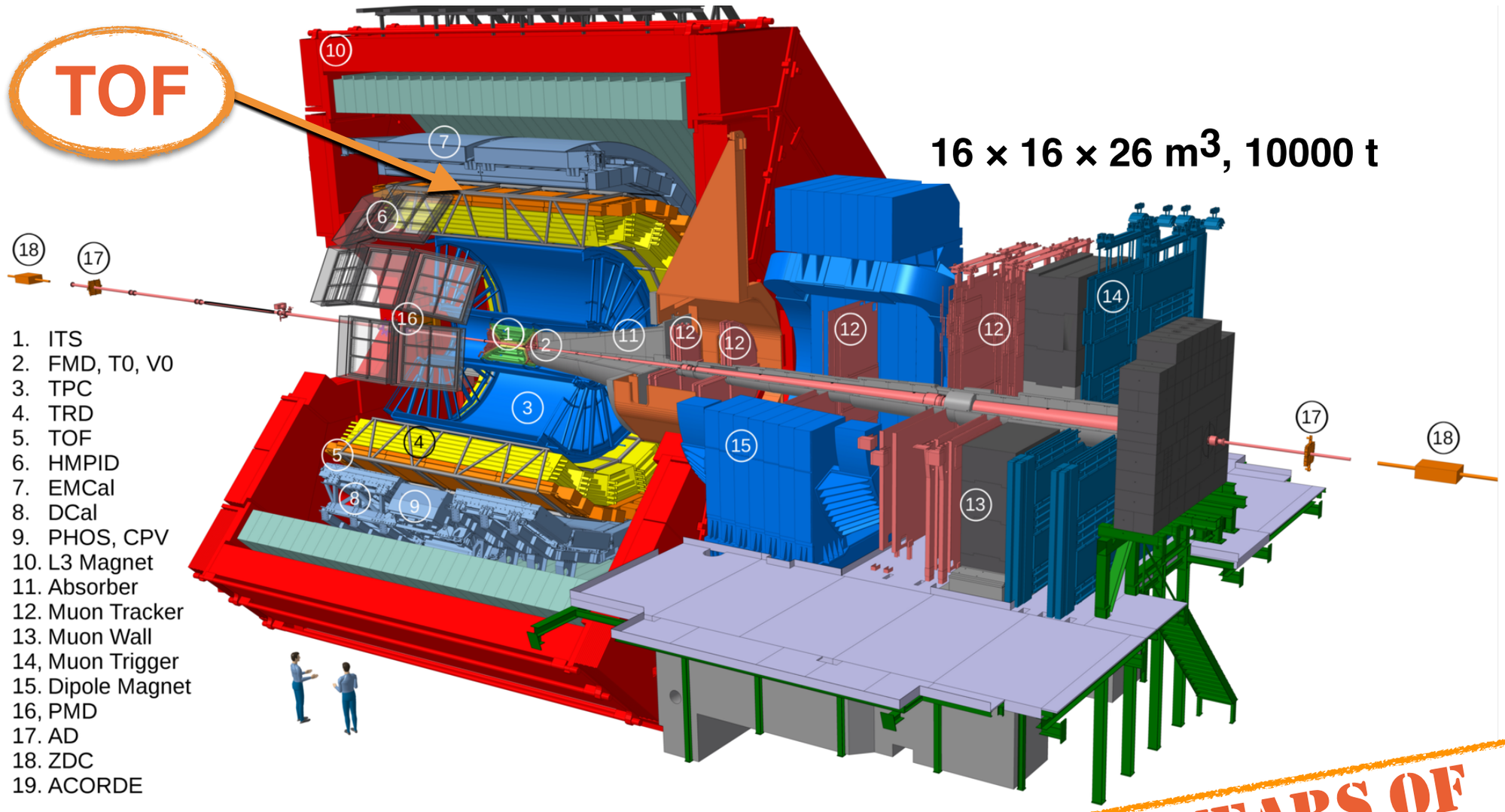
on behalf of the ALICE collaboration

INFN and University of Bologna, Centro Fermi Roma, Italy

ALICE-TOF

ALICE at LHC:

- The experiment devoted to the study of **Q**uak **G**luon **P**lasma
- (0.15 - 20) GeV/*c* • First pp: 2009



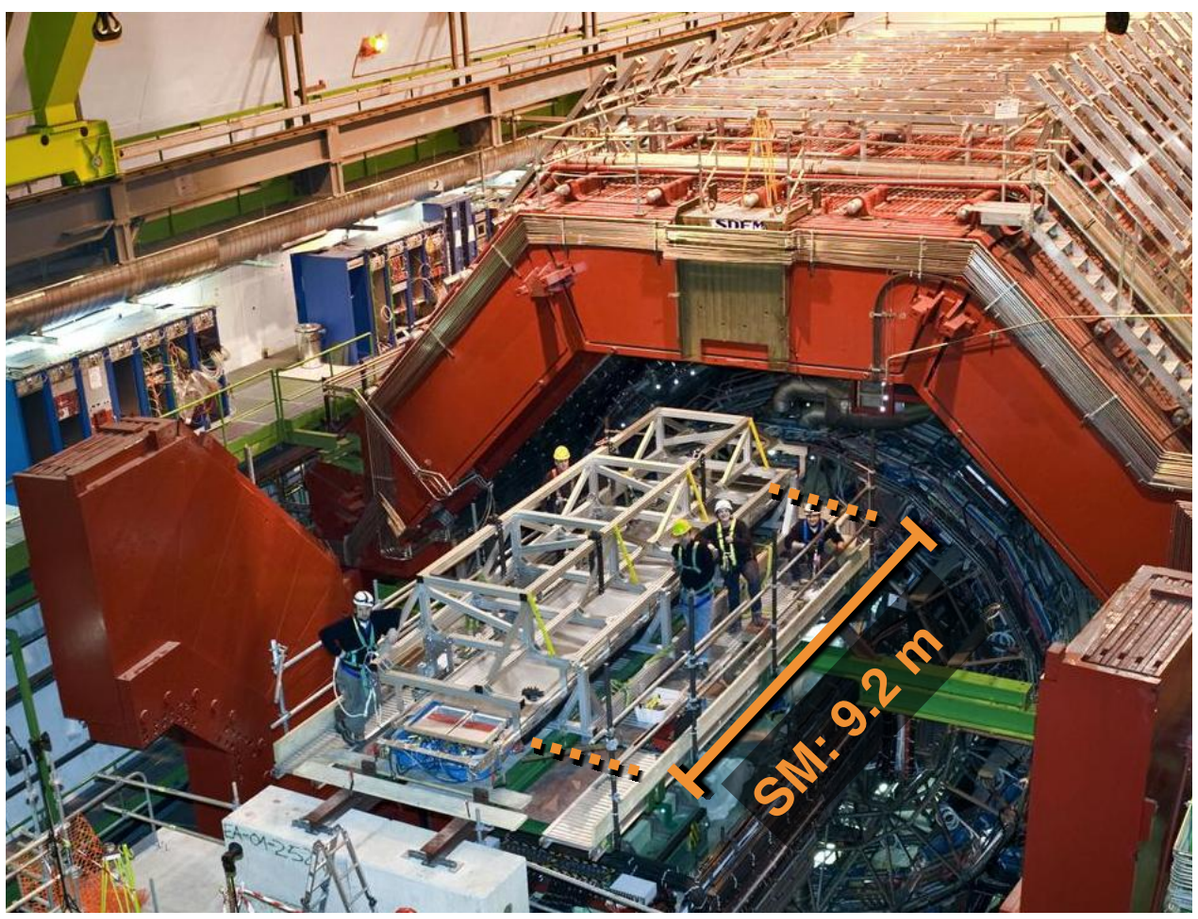
ALICE-TOF:

- Based on **MRPC** technology
- Installed in **2008**
- **PID** from 0.3 GeV/*c*; 3σ up to 2.5 GeV/*c* (π/K) , 4GeV/*c* (p/K)

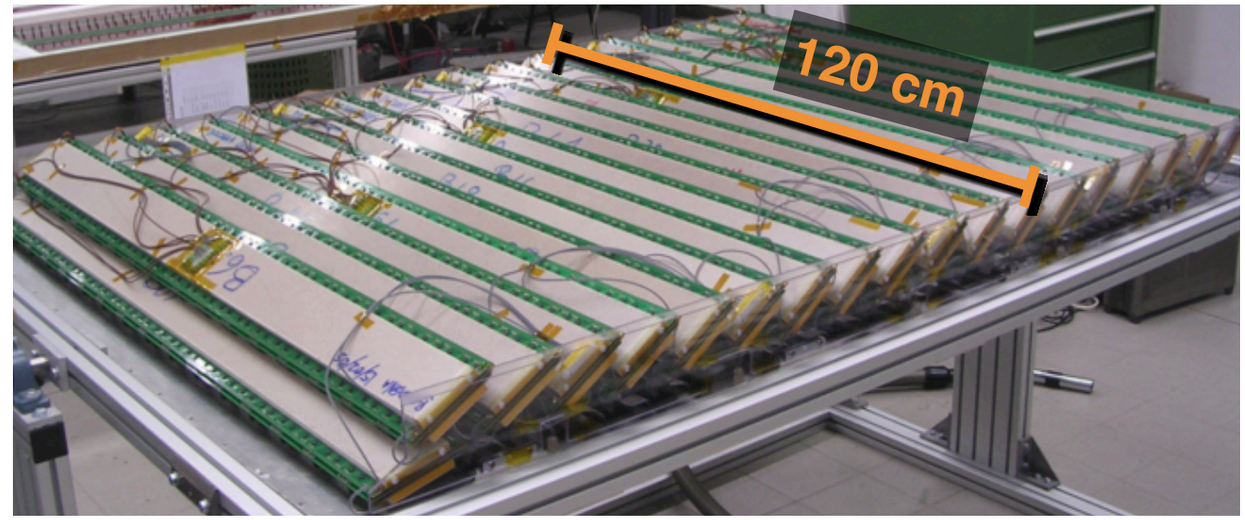
10 YEARS OF DATA TAKING

ALICE-TOF

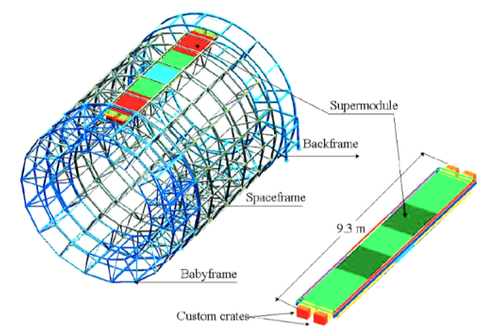
- inner/external radius: 3.7/3.99 m
- active area **141 m²**
- weight 26 tons
- $|\eta| < 0.9$
- full φ —> 18 SuperModules(SM)
- 5 Modules for each SM
- 19(15) MRPCs per Modules
- total of **1593 MRPCs**
- **152928** readout **channels**



- 120 × 7.4 cm² active area per MRPC



…**wide area** MRPC application!



In **2018**, total of **2253** hours:

- ~**98% total time availability**
- ~**93%** average active **channels**

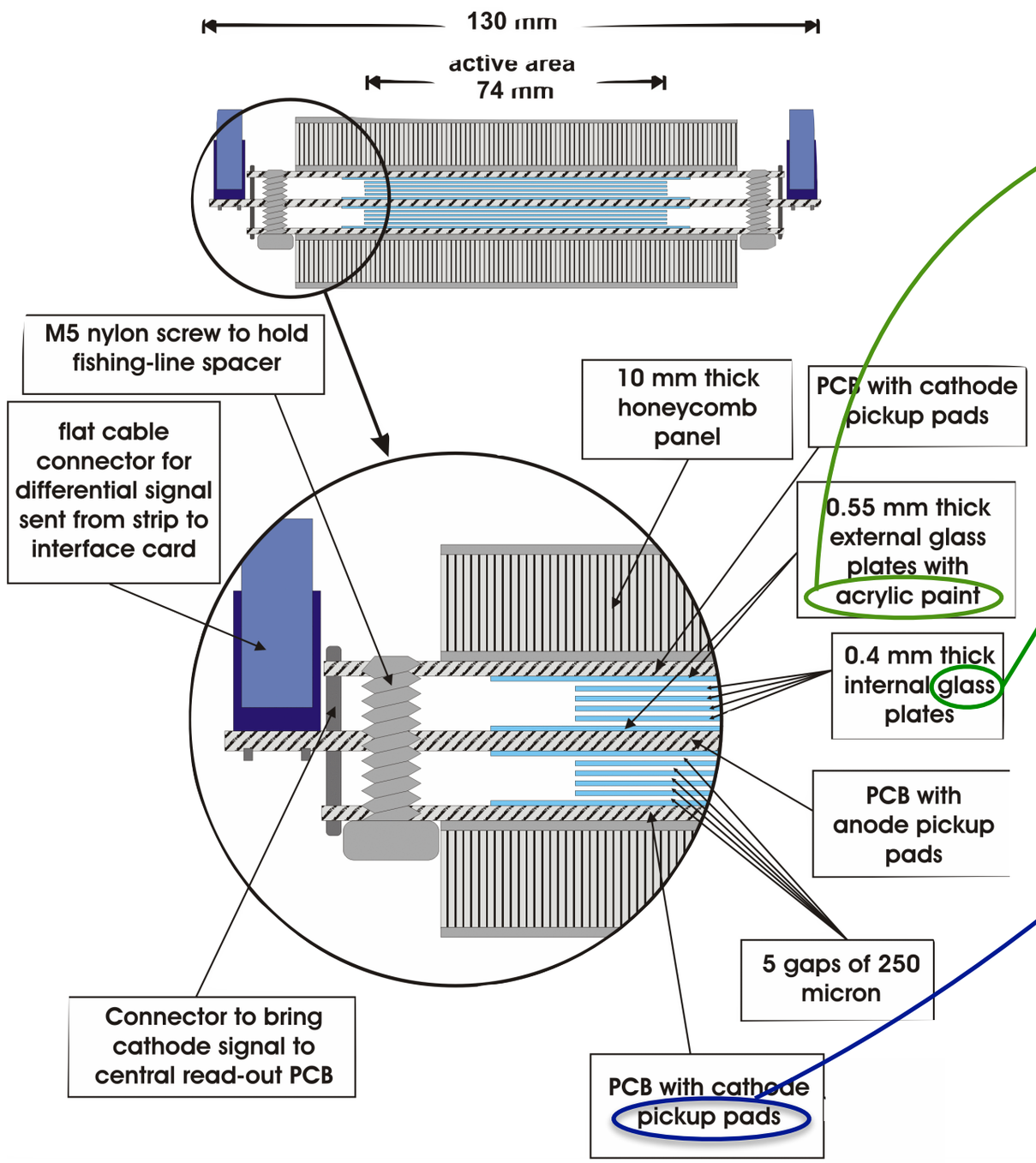
The missing **7%** —>due to **electronics** and **connectors** (**not** to MRPC!)

ALICE-TOF MRPC

10 gas gaps, **250 μm**, **double-stack** design

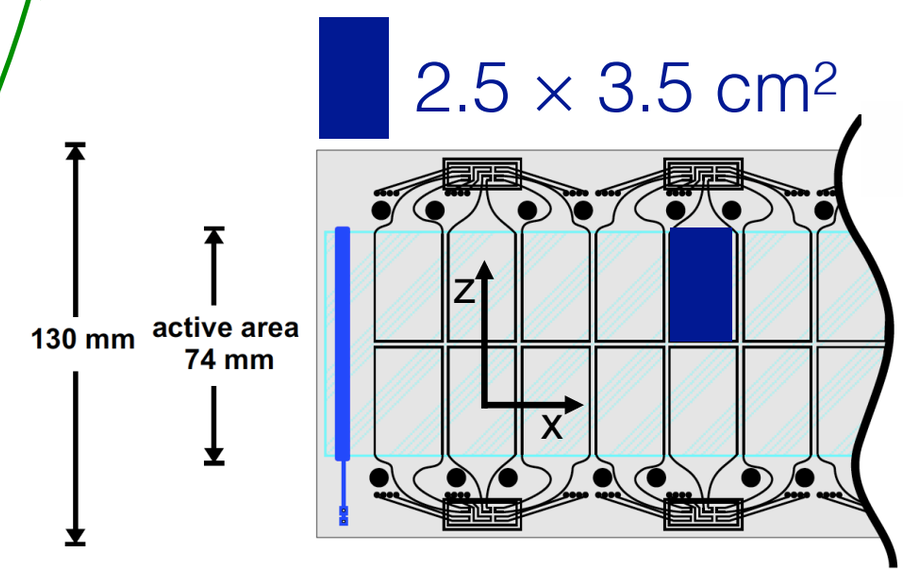
Gas mixture **recirculating**: **93% $C_2H_2F_2$ + 7% SF_6**

GWP = 1430 **GWP = 23900**

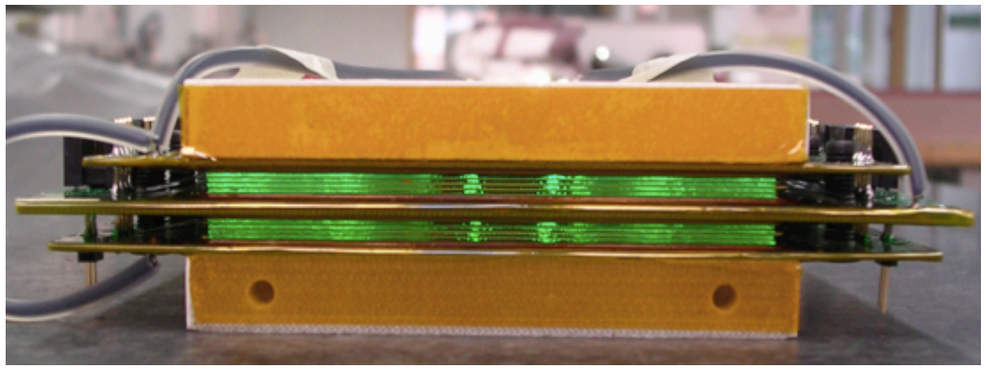


surface resistivity ~ MΩ/□

bulk resistivity ~ 5 10^{12} Ωcm

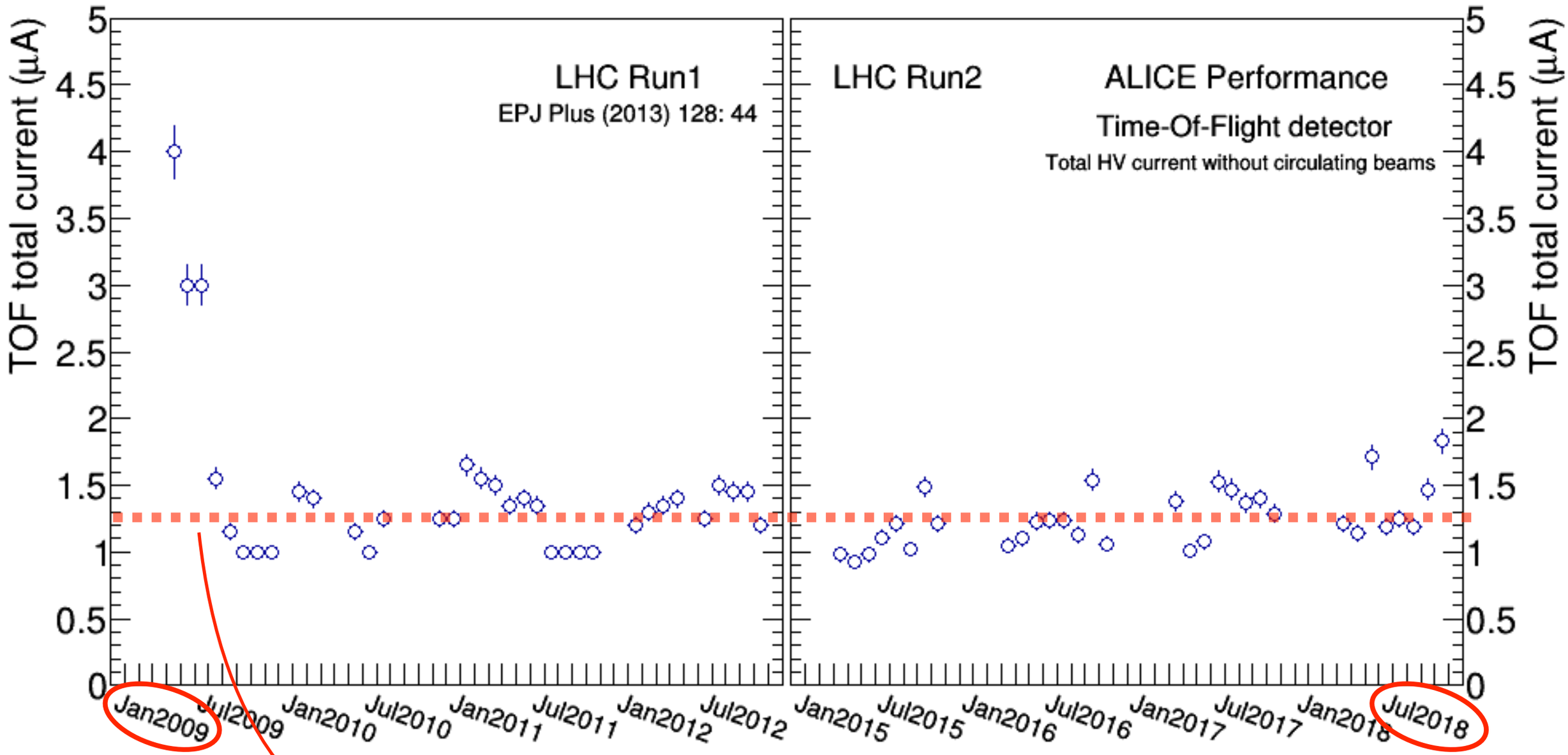


2 rows of **48** pickup **pads**



Operation - Current

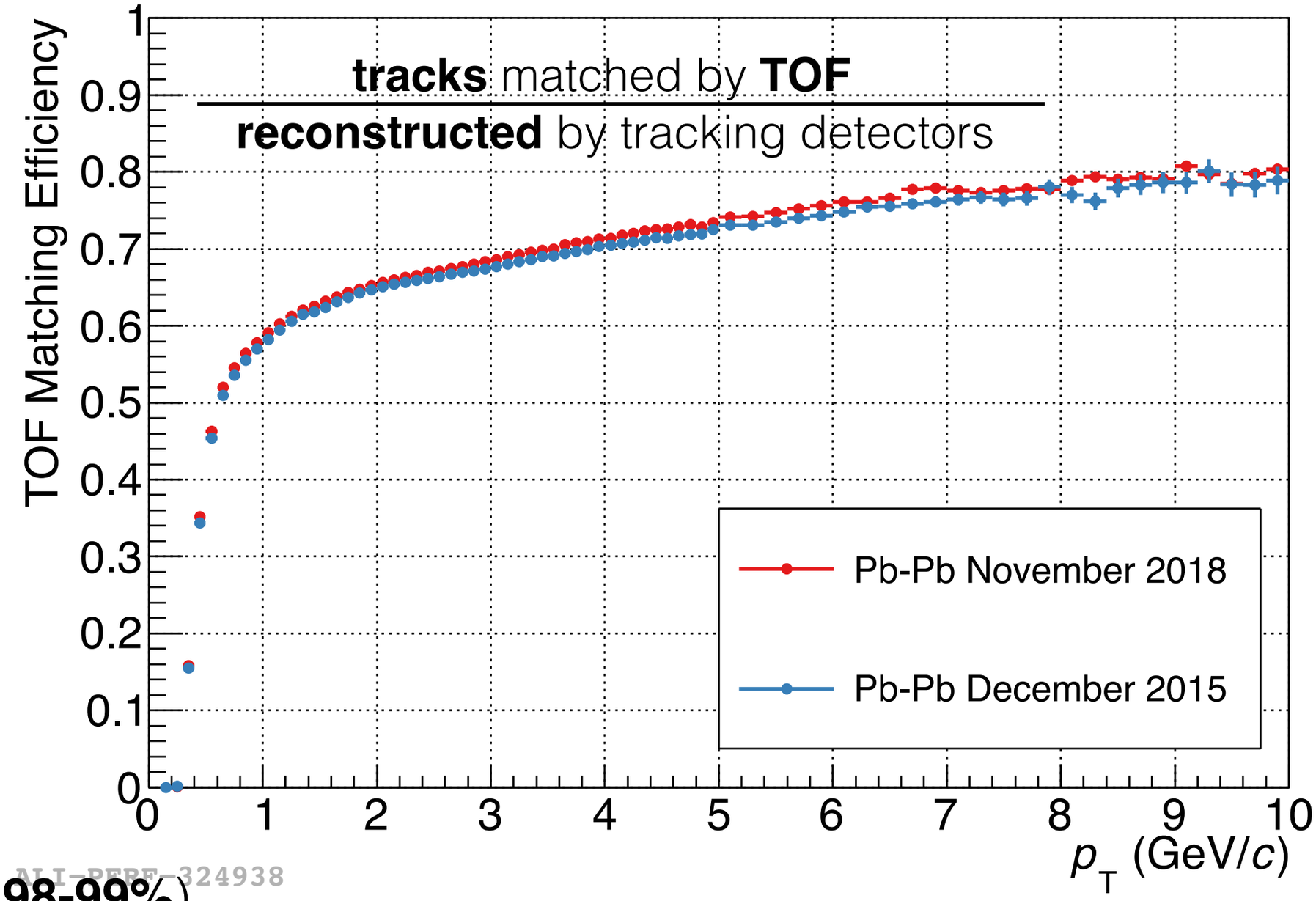
Total current: overall the 1593 MRPCs (without beam)



stable over the years!

Operation - Matching Efficiency

For p_T < 0.3 GeV/c particles do not reach TOF (B=0.5 T)

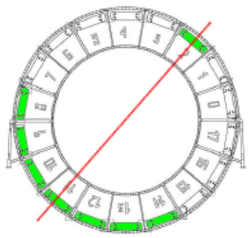


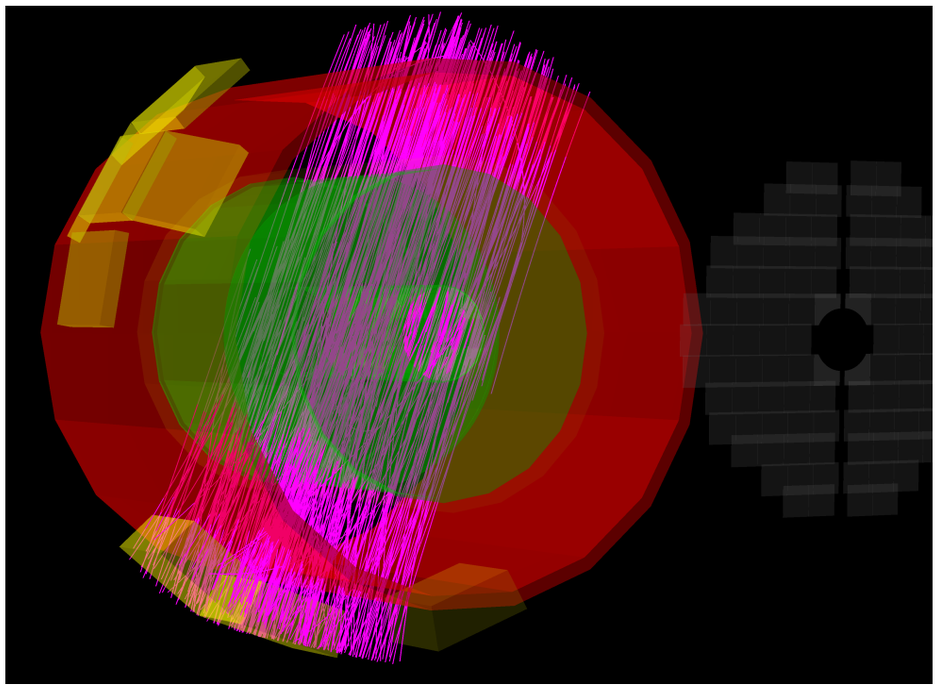
- **MRPC** efficiency (~**98-99%**)
- TOF algorithmic inefficiency
- TOF geometrical acceptance (dead space)
- **Material** budget (in front of TOF)
- **Hardware** data taking **conditions (extern.)**
- **Track extrapolation**

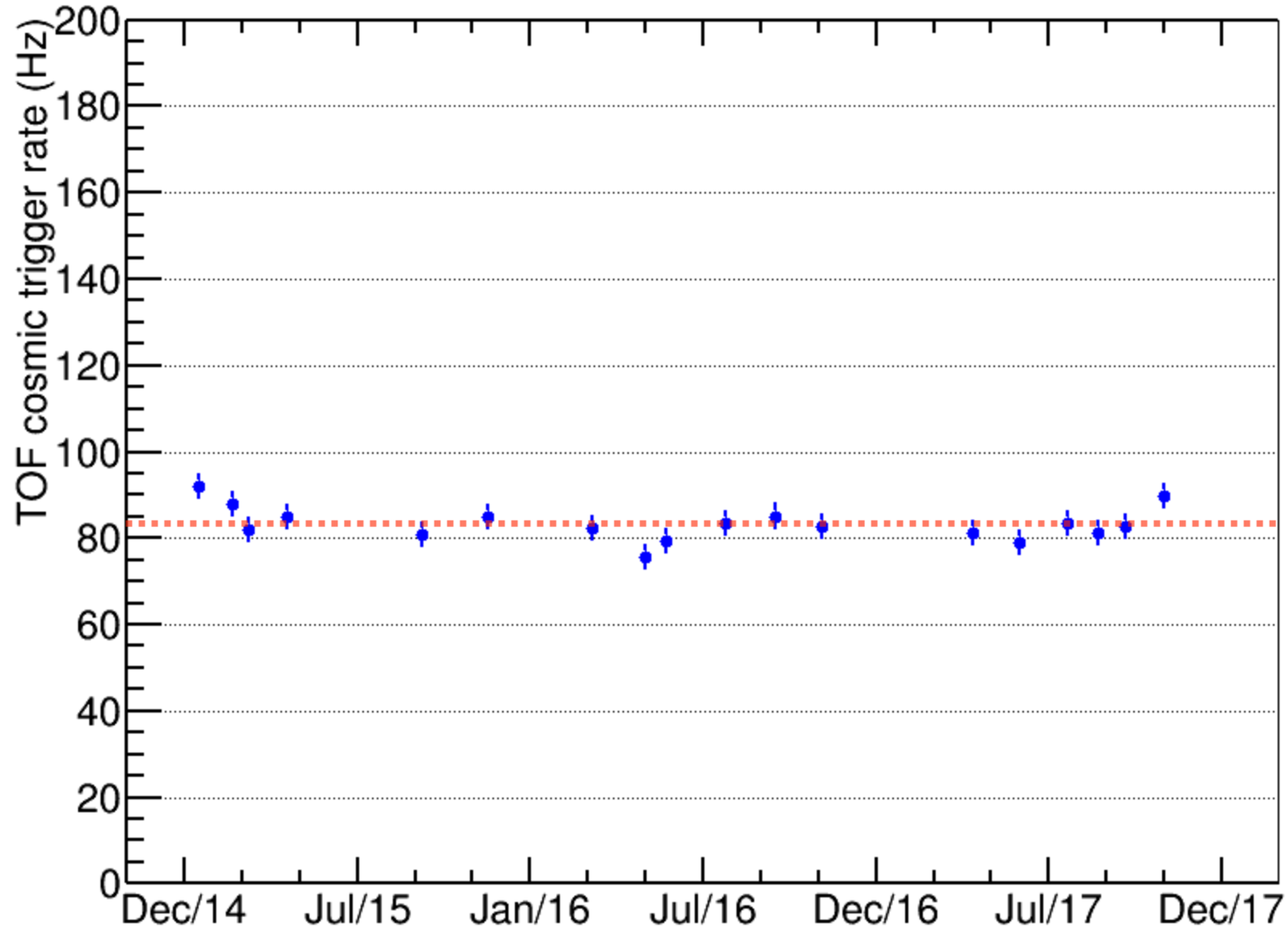
Performance stable

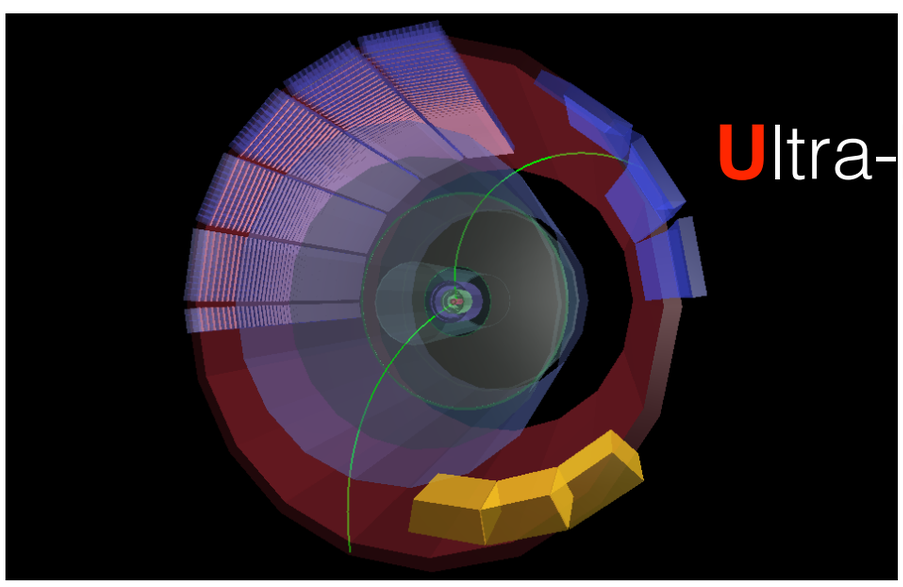
Operation - Trigger

Cosmic ray



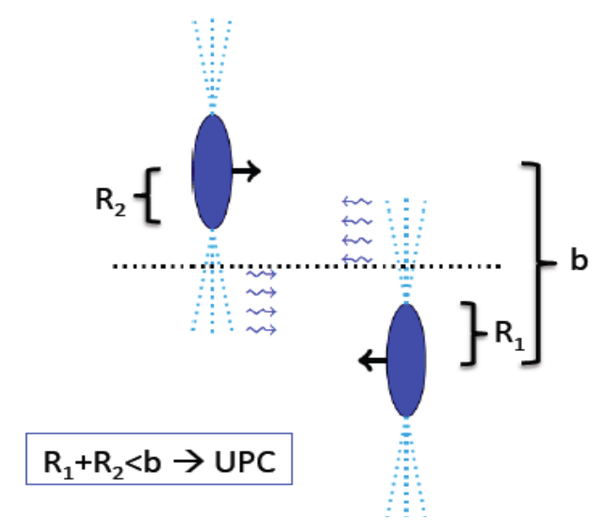






Ultra-**P**eripheral **C**ollisions

we expect two tracks in the central detectors with forward detectors showing no activity

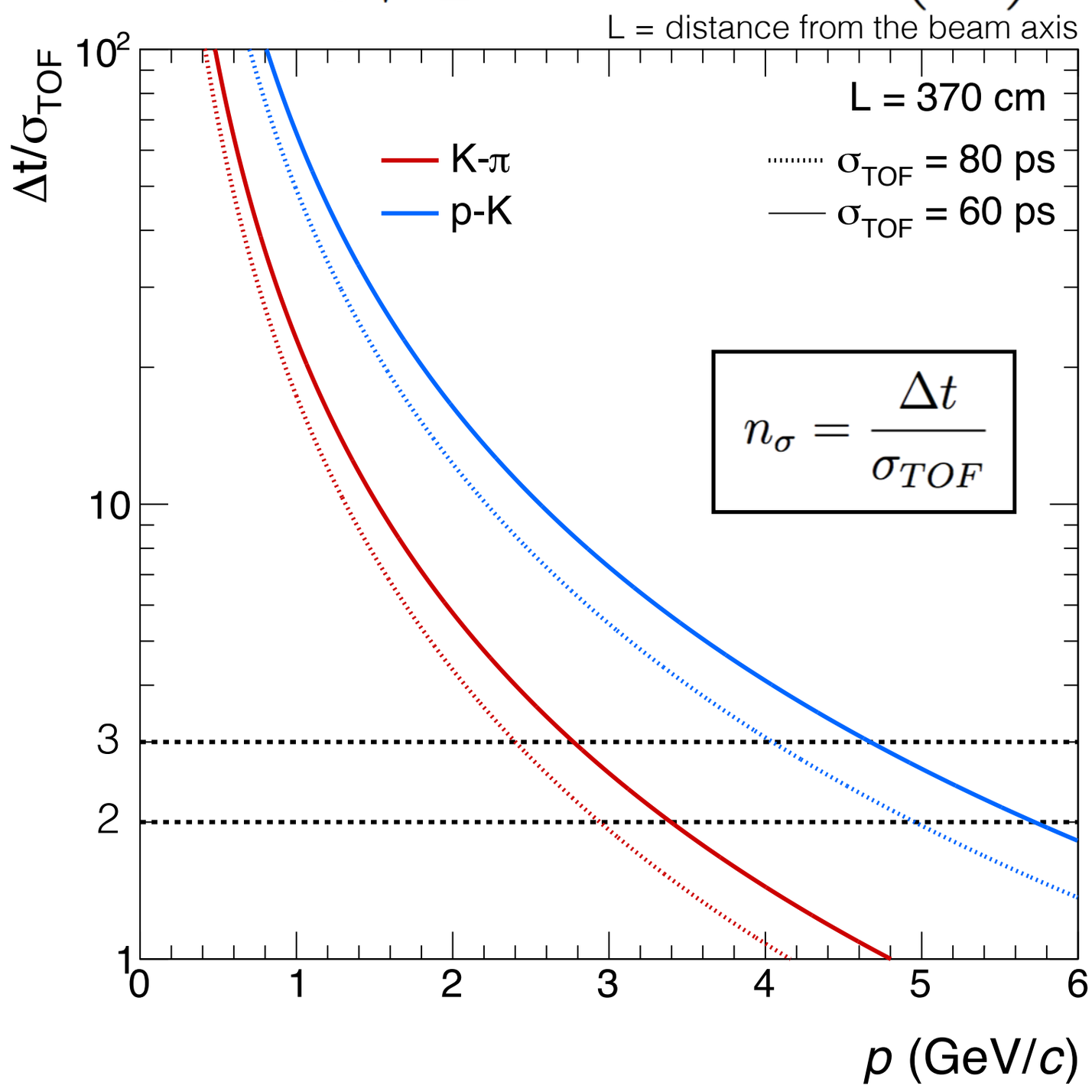


PID with a TOF detector

Dominant term for high momenta

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

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



$$n_\sigma = \frac{\Delta t}{\sigma_{TOF}}$$

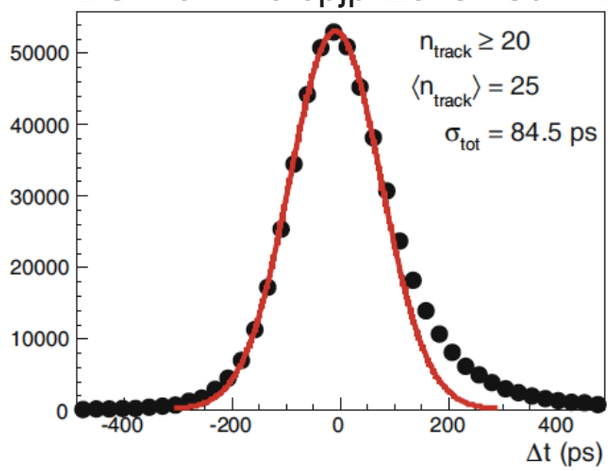
$$\Delta t = t_i - t_j \simeq \frac{Lc}{2p^2}(m_i^2 - m_j^2)$$

← PID capability of a TOF detector

→ **time resolution as low as possible**

Time resolution

DOI 10.1140/epjp/i2013-13044-x



$\sigma \sim 84$ ps

$$\sigma_{TOF}^2 = \sigma_{MRPC}^2 + \sigma_{TDC}^2 + \sigma_{FEE}^2 + \sigma_{Cal}^2$$

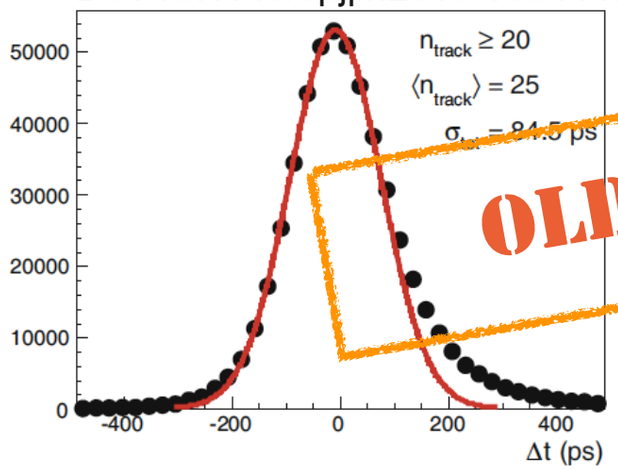
TOF-PID performed by the difference:

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

$$\sigma_{TOT}^2 = \sigma_{TOF}^2 + \sigma_{trk}^2 + \sigma_{event}^2$$

(negligible for p> 1 GeV/c)

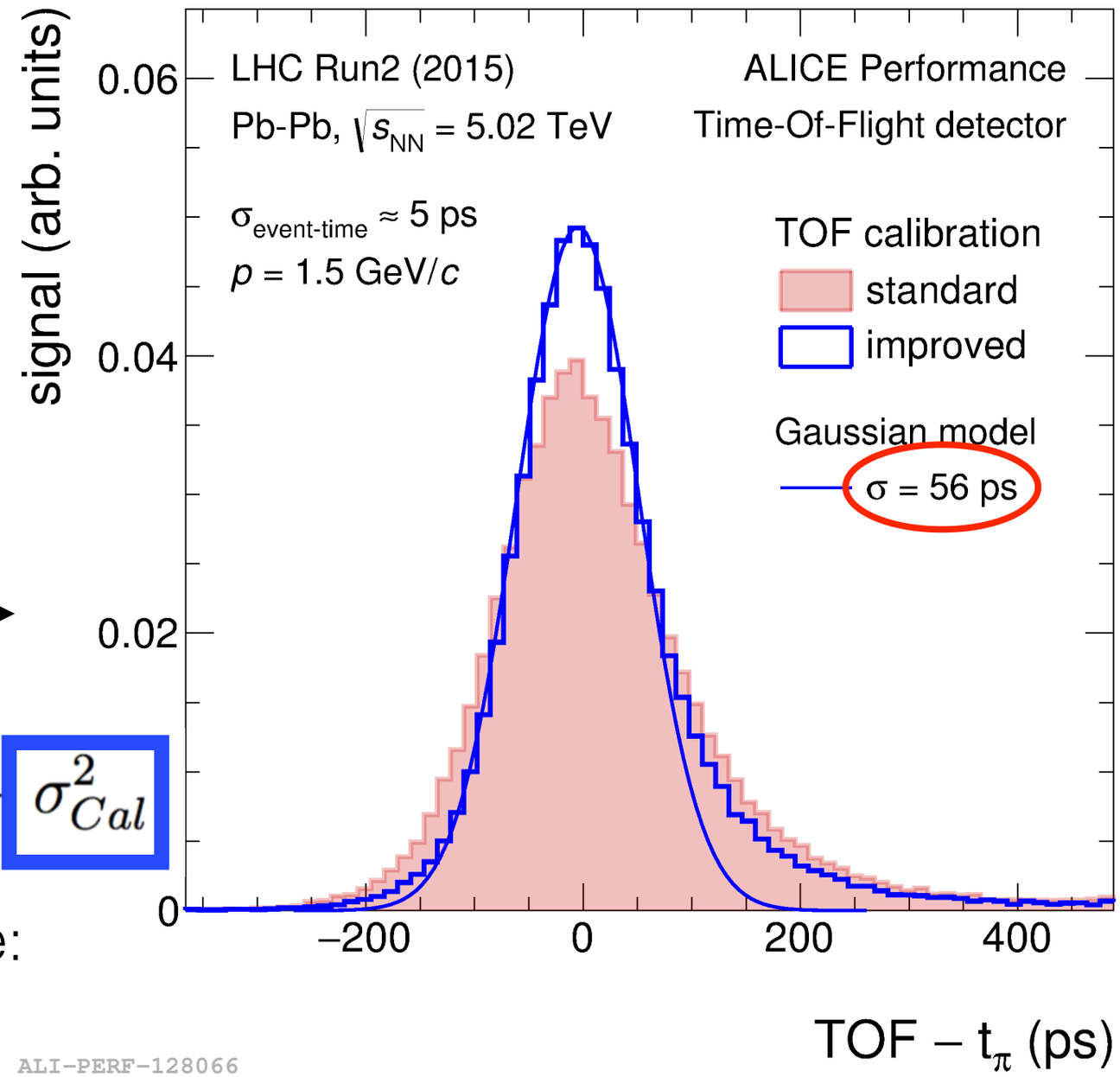
Time resolution



OLD! $\sigma \sim 84$ ps

…**improved!**

$\sigma \sim 56$ ps



$$\sigma^2_{TOF} = \sigma^2_{MRPC} + \sigma^2_{TDC} + \sigma^2_{FEE} + \sigma^2_{Cal}$$

TOF-PID performed by the difference:

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

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

(negligible for p> 1 GeV/c)

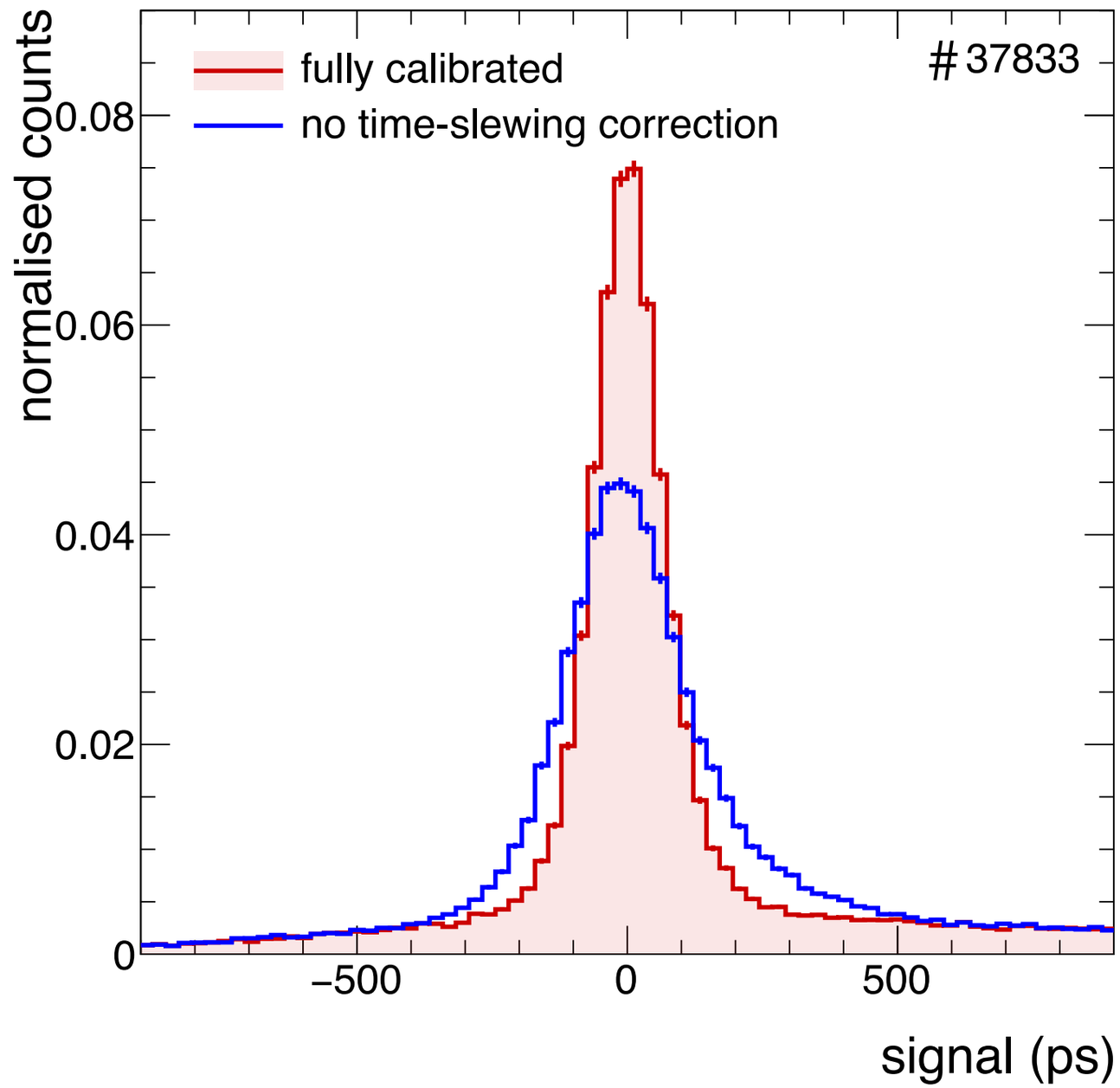
Other factors that can lead to a spoiling of the ALICE-TOF time resolution:

- hit multiplicity (cluster)
- time walk
- asymmetric tails

Time resolution - Time slewing

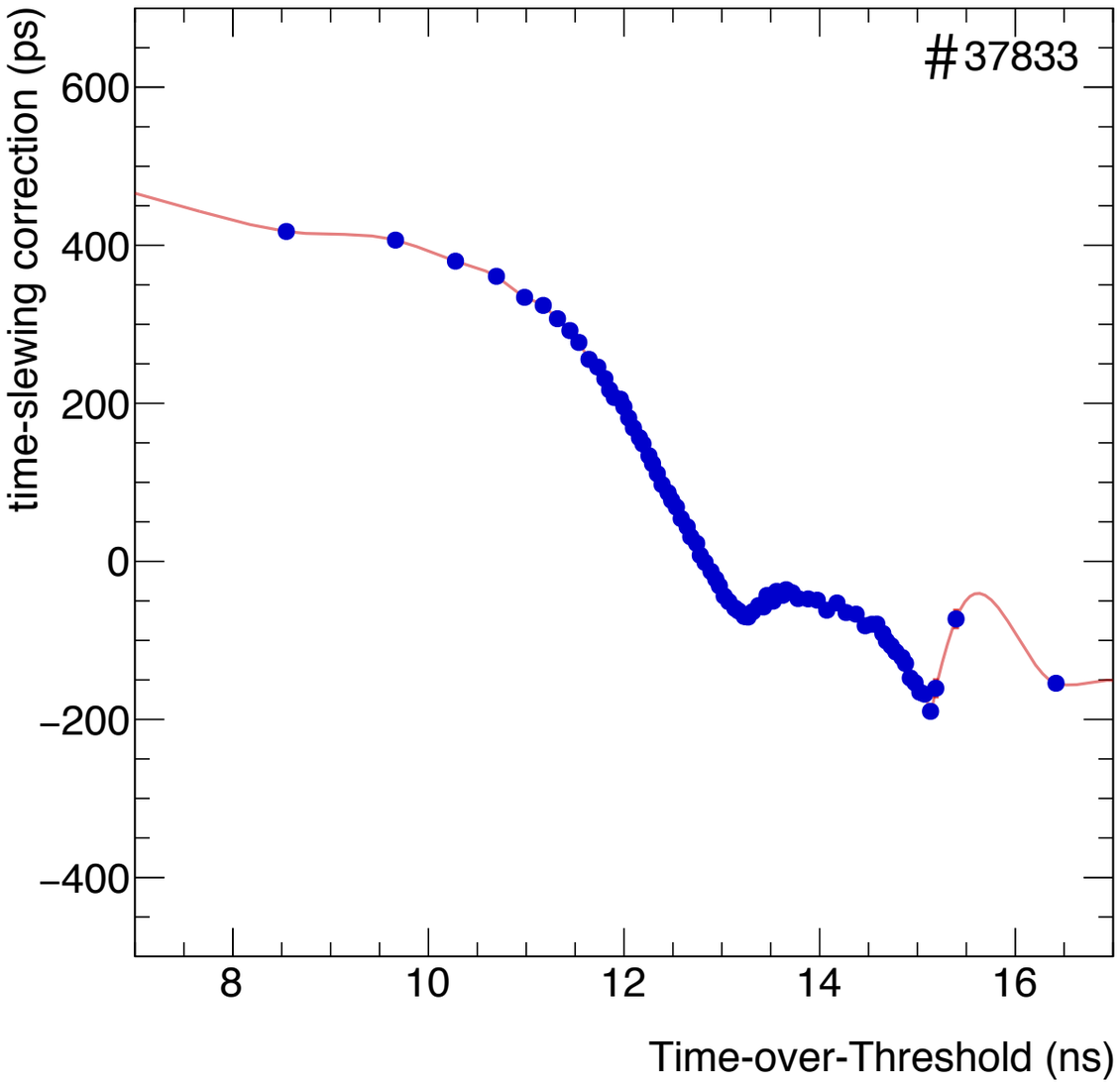
TOF time **calibration** is based on 3 components:

- global offset, common to all channels (clock)
- channel-by-channel offset (cables,…)
- **time-slewing** correction: correlation between the **time** and charge —> TOF system uses **T**ime **O**ver **T**hreshold, as a proxy for the charge



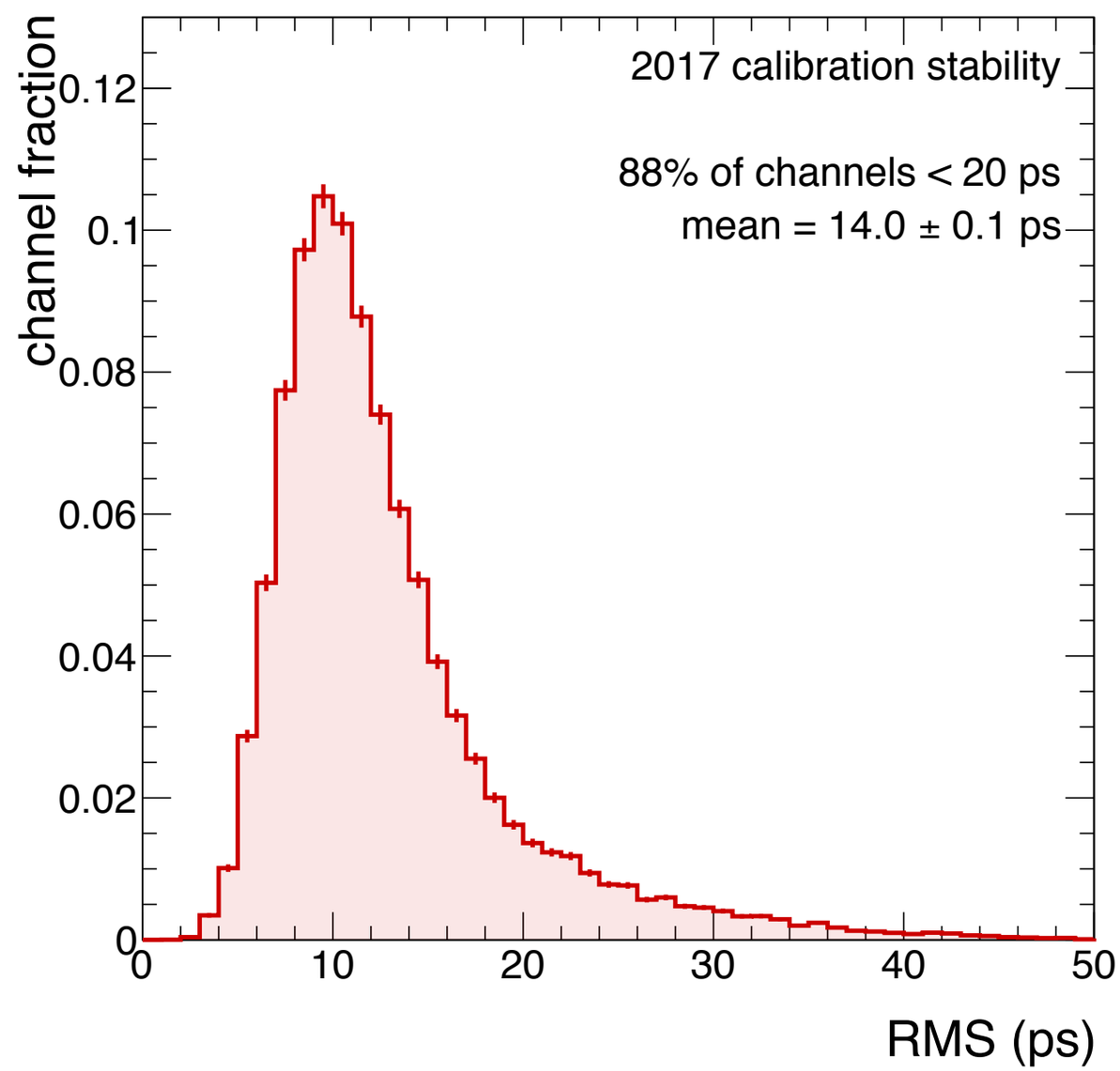
~ 50% improvement
(~110-130 ps in quadrature)

Time resolution - Time slewing



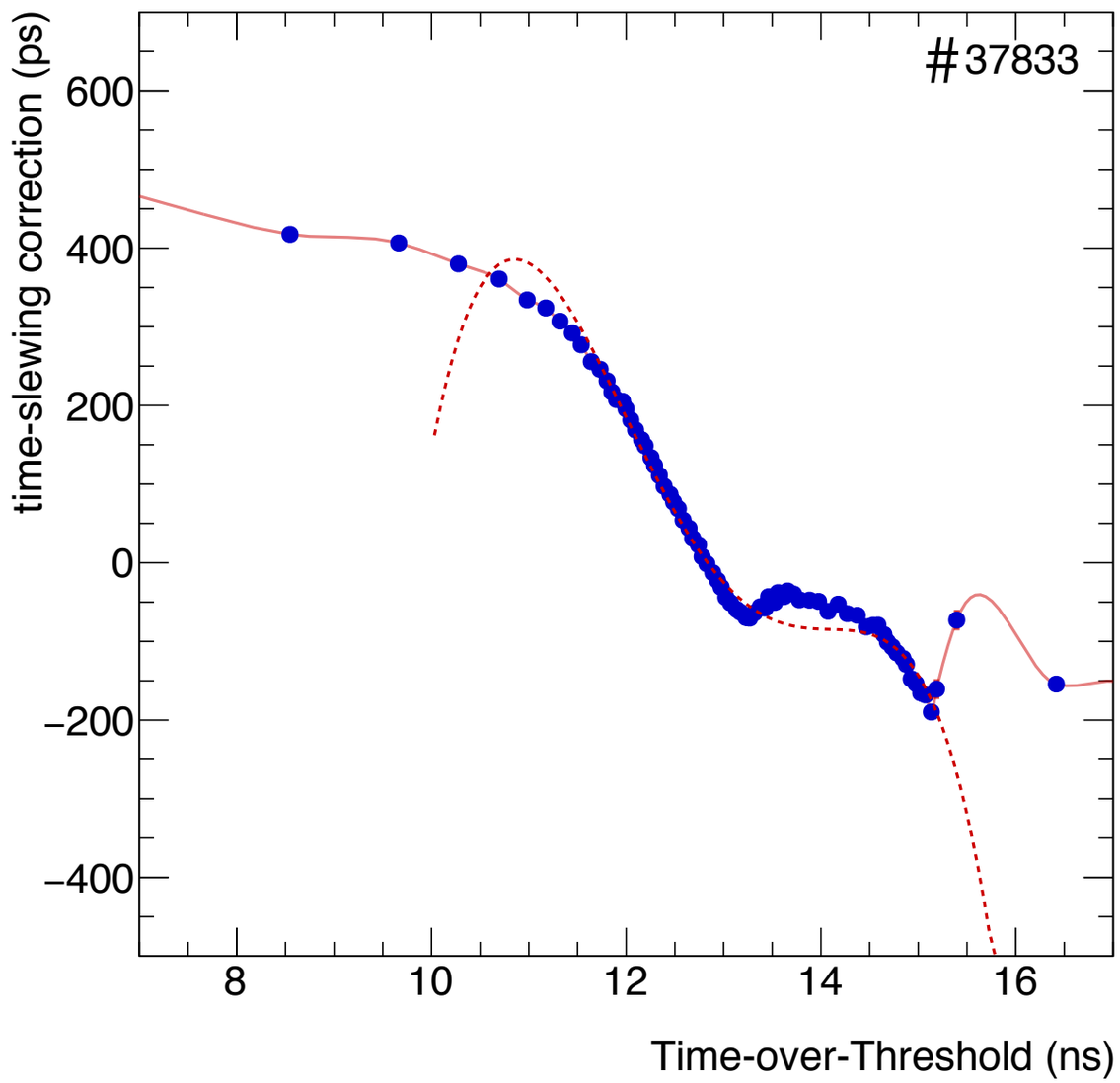
single channel upgraded calibration (2017)

~40000 channels



stable during the year…

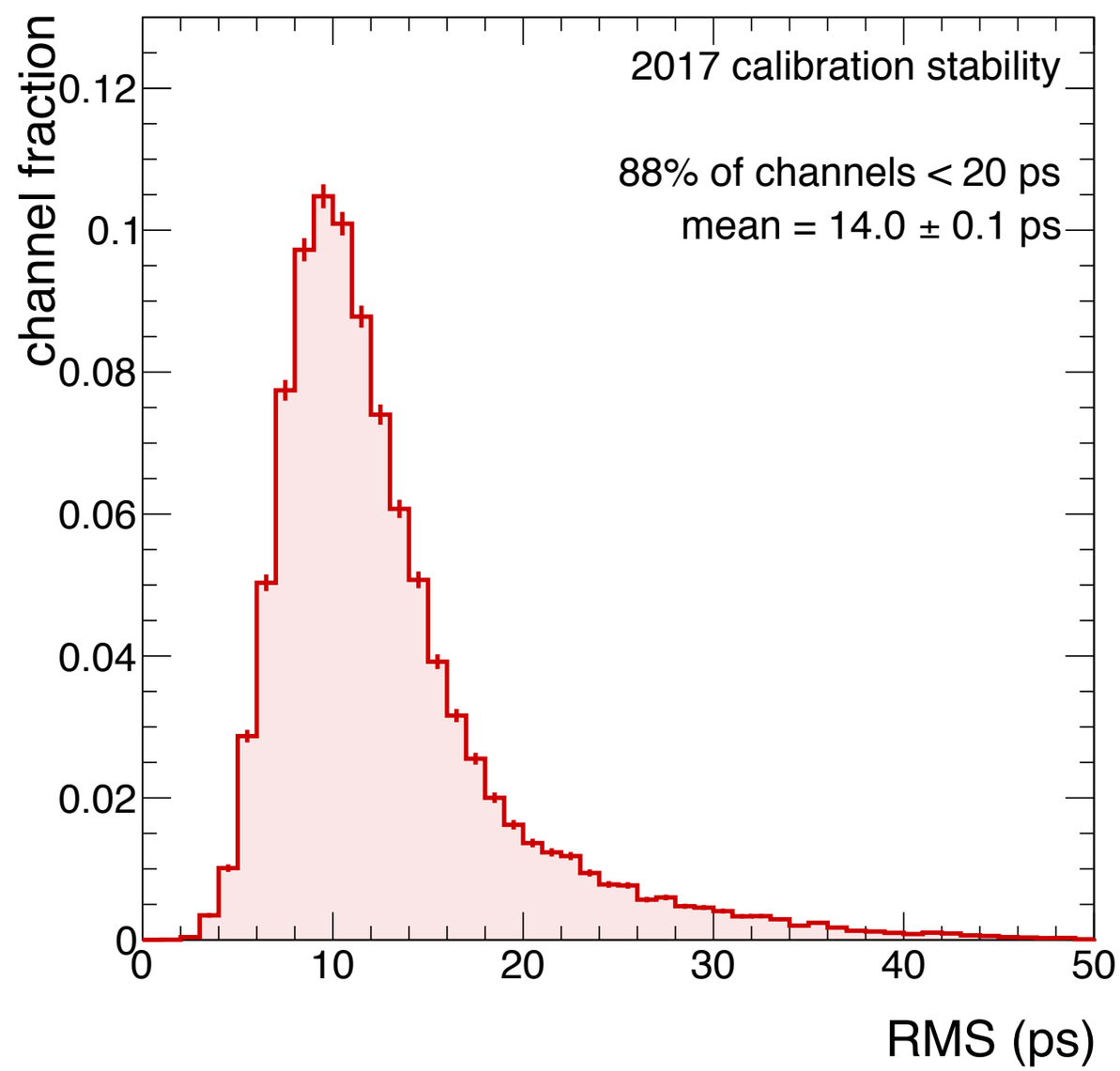
Time resolution - Time slewing



single channel upgraded calibration (2017)

(..... **before**: groups of 8 channels, limited TOT range, polynomial parametrisation)

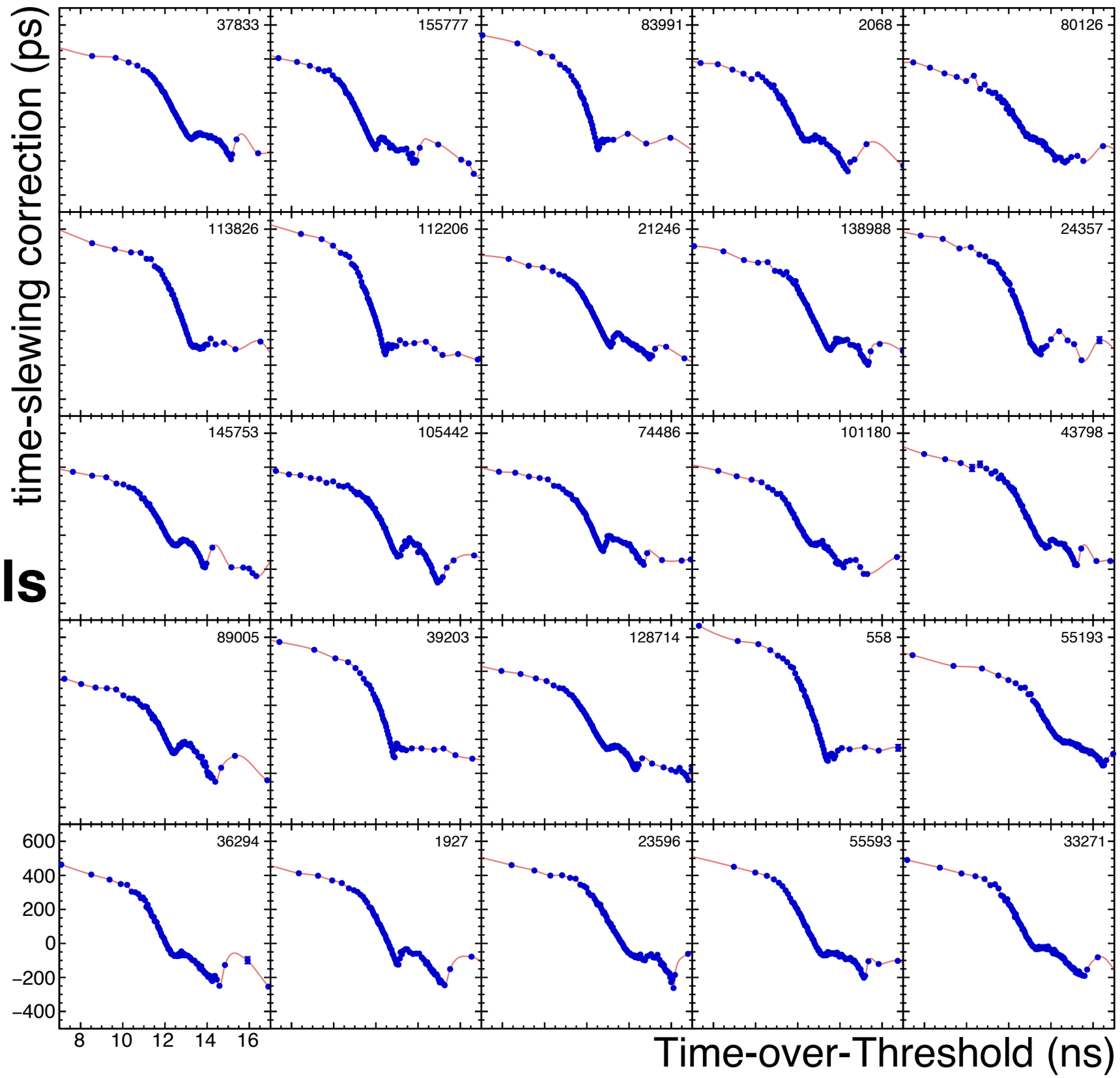
~40000 channels



stable during the year…

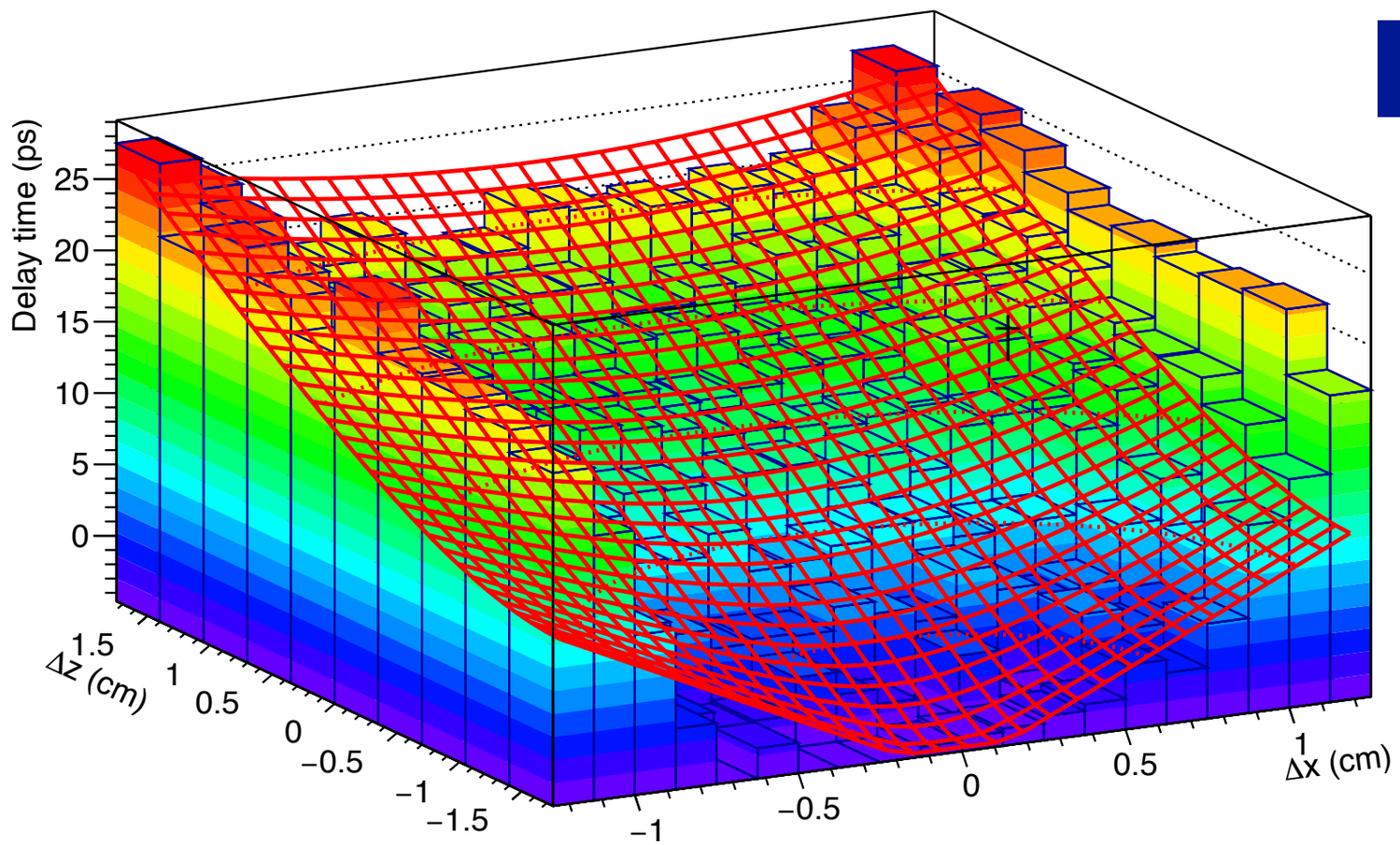
Time resolution - Time slewing

… and **uniform** between **channels**

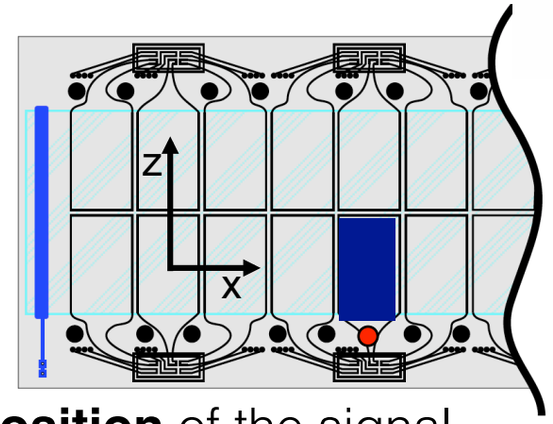


Time resolution - Time walk

Delay time due to the finite signal propagation time on the **pad**



2.5 × 3.5 cm²



- Defined **position** of the signal **collection** electrode on the pad

Ph.D. Thesis, F. Carnesecchi, 18th April 2018, http://www.infn.it/thesis/thesis_dettaglio.php?tid=11852

Time resolution - Time walk

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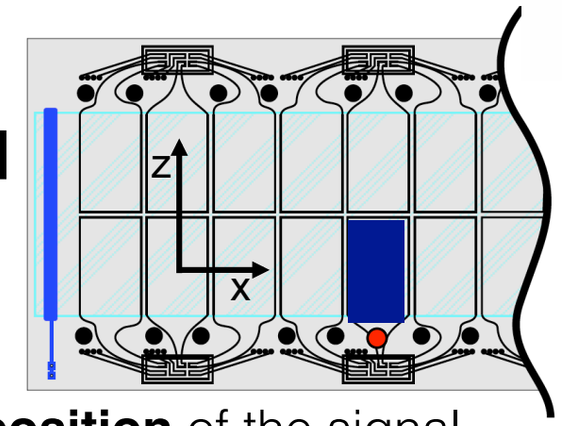

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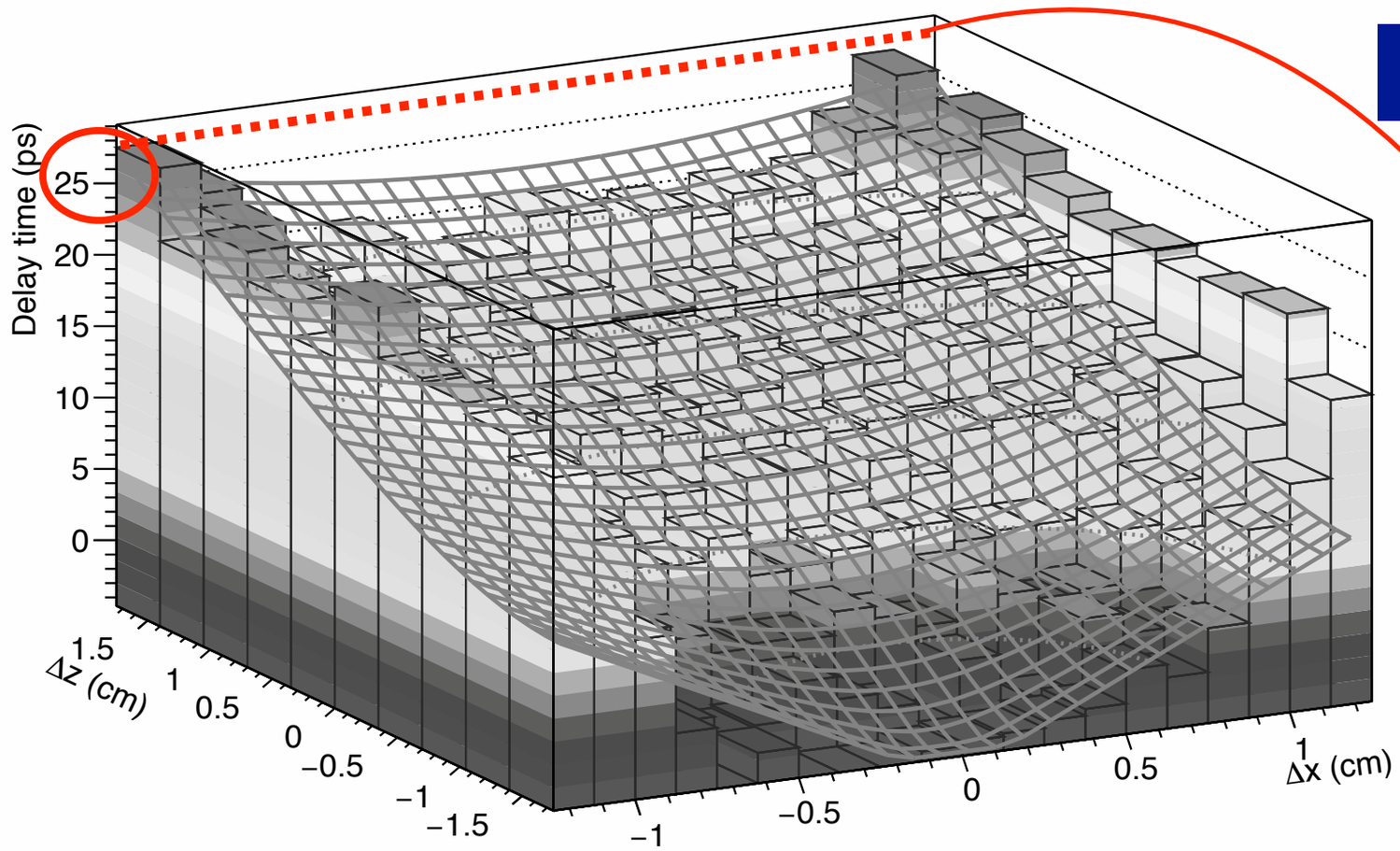


Ph.D. Thesis, F. Carnesecchi, 18th April 2018, http://www.infn.it/thesis/thesis_dettaglio.php?tid=11852

Maximum delay time **< 30ps**

↓

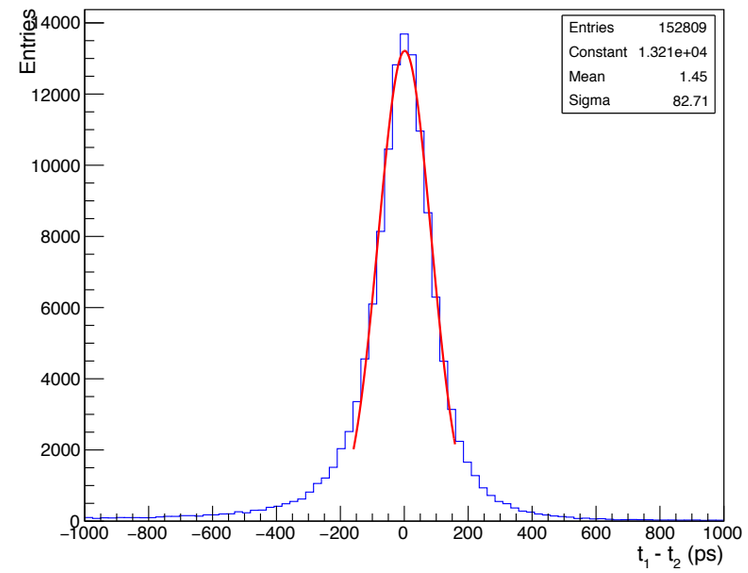
Time walk correction ($\sigma_{\text{time walk}}$) **negligible**

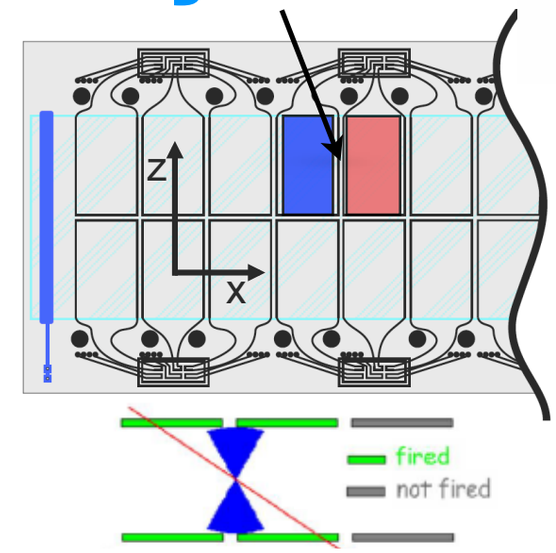
But in a **beam test**: **maximum** delay time **~140 ps —> $\sigma_{\text{time walk}}$~ 40 ps**

Difference due to worst spatial resolution and alignment wrt beam test —> **room for time resolution improvement**

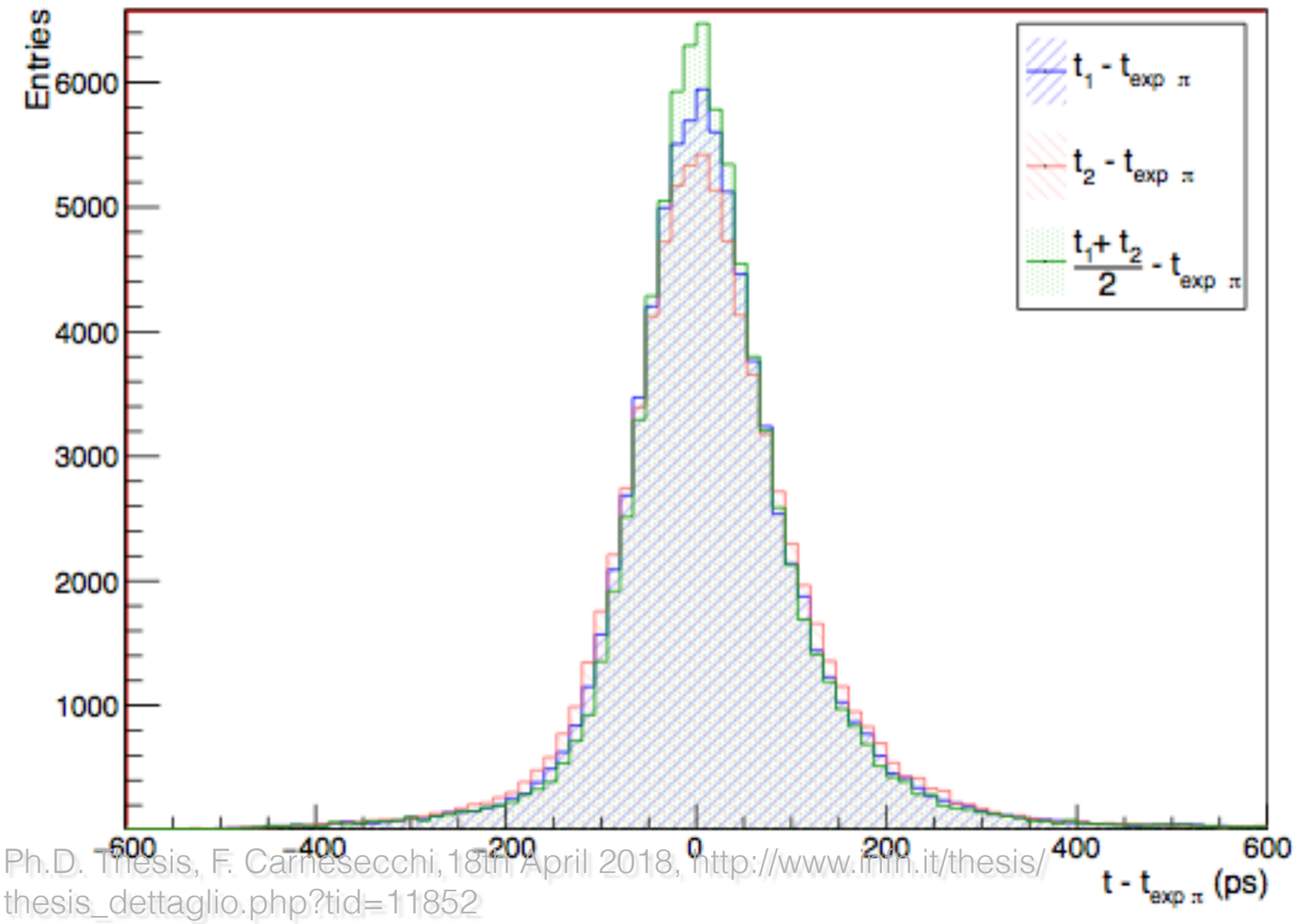
Time resolution - Hit multiplicity

Double pad case, corrected with **clusterization** (signal induced on more than one readout pad)





Goal: get a **single position** and single (**corrected**) **time**.

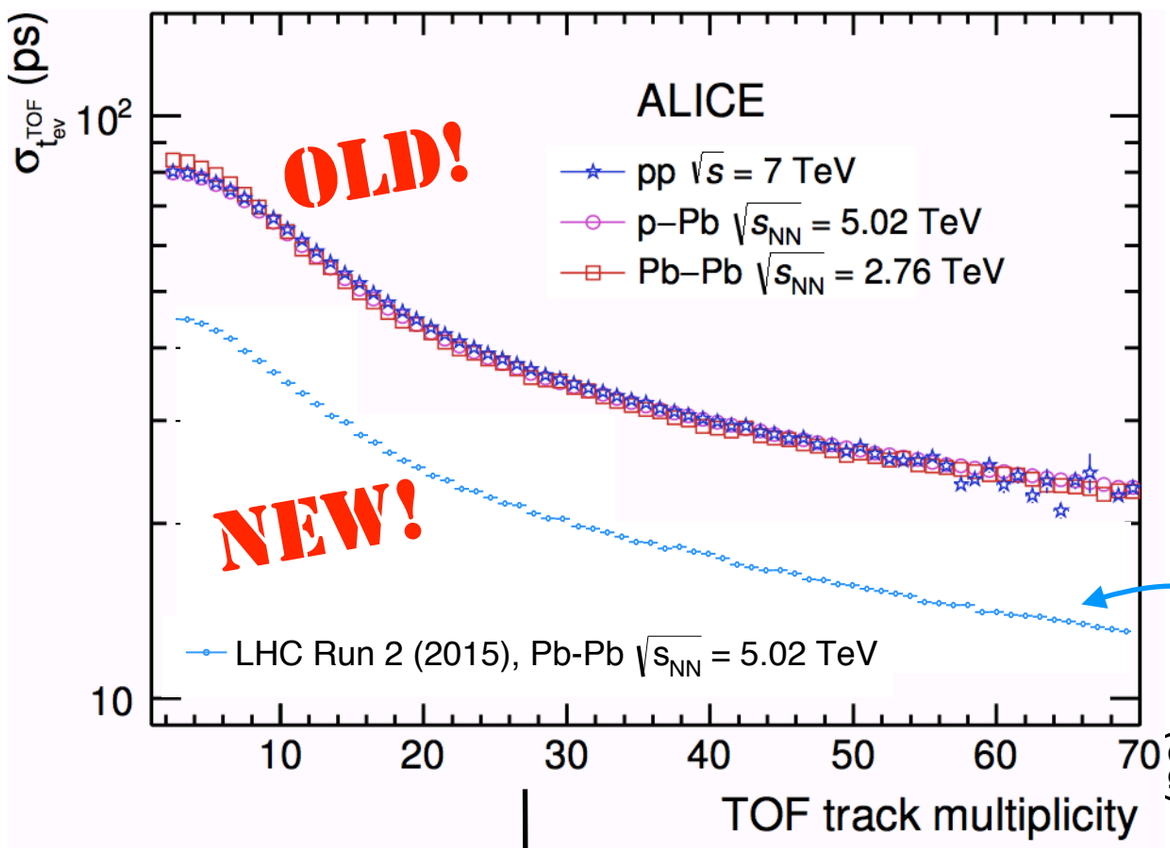


σ_1 = 65 ps
σ_2 = 69 ps
→ σ_{av} = 58 ps

Ph.D. Thesis, F. Carnesecchi, 18th April 2018, http://www.infn.it/thesis/thesis_dettaglio.php?tid=11852

Time resolution - t_{event}

Eur. Phys. J. Plus (2017) 132: 99



Time event is the event collision time:

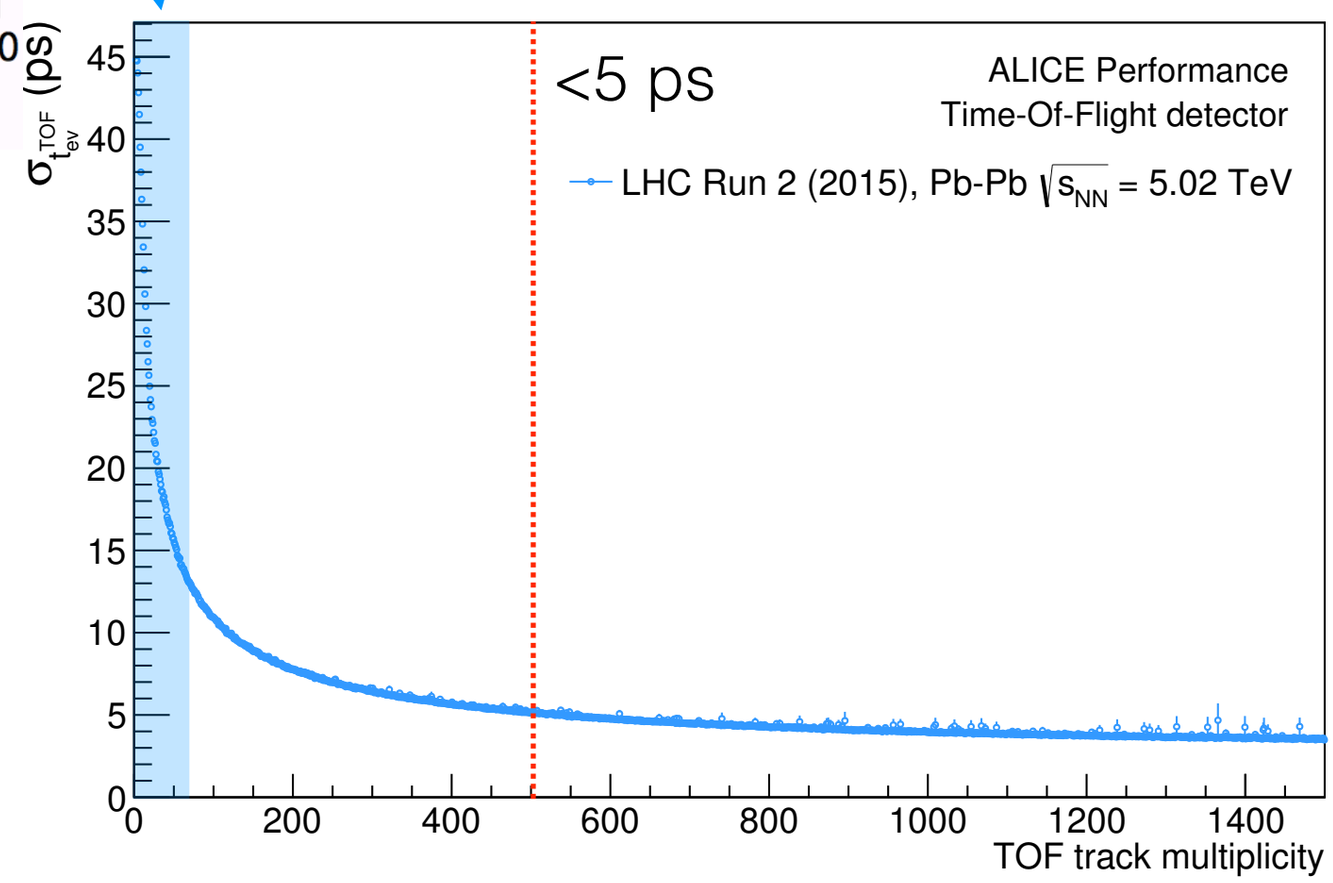
for $N_{track} \geq 2$ →

TOF can measure it independently

Same for different collision systems (**pp, p-Pb, Pb-Pb**) —> depends just on the track multiplicity

Improvement:

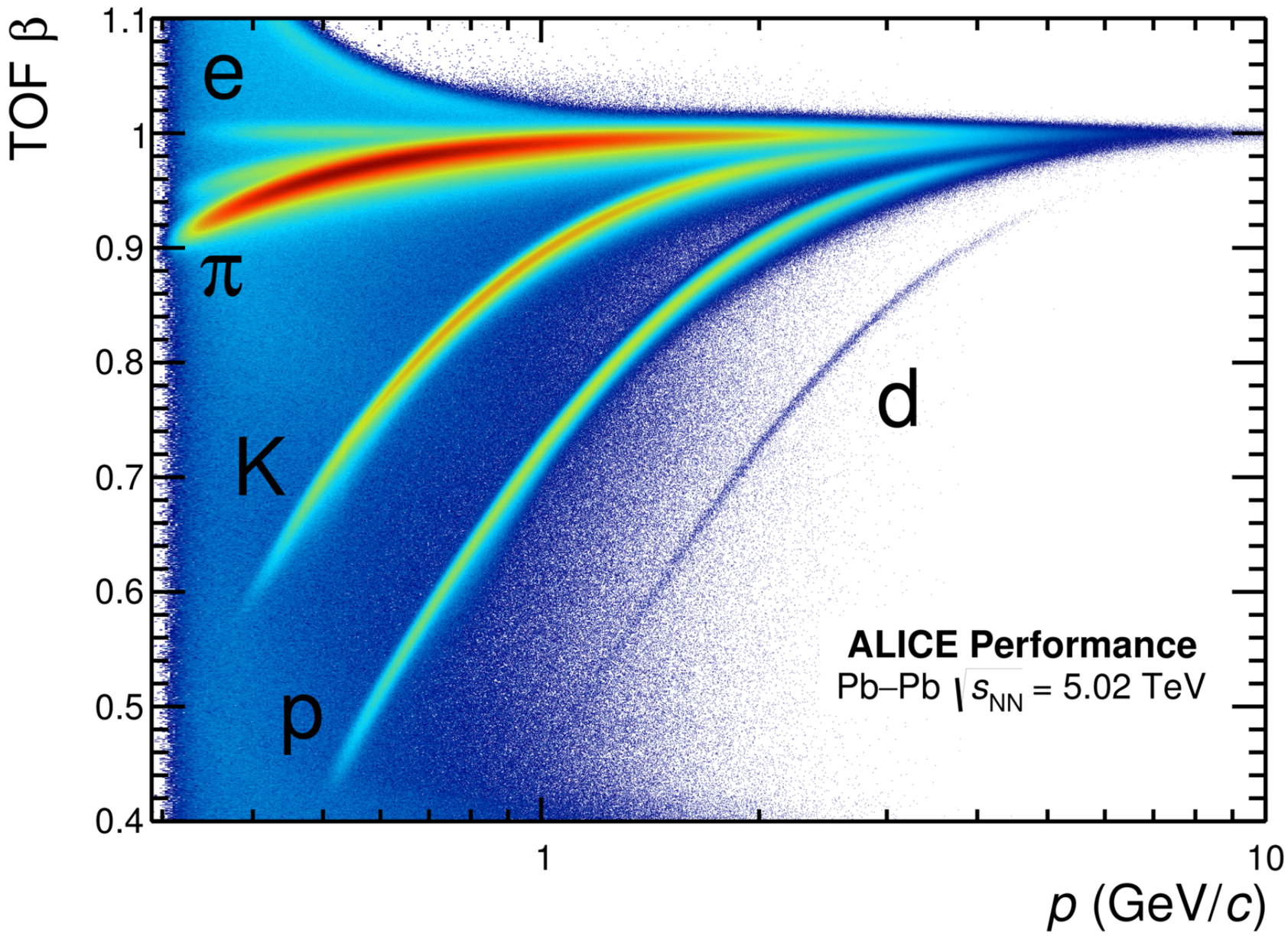
$$\sigma_{t_{ev}} \sim \frac{\sigma_{TOT}}{\sqrt{TOF\ \ track\ \ multiplicity}}$$



ALI-PERF-143047

PID performance

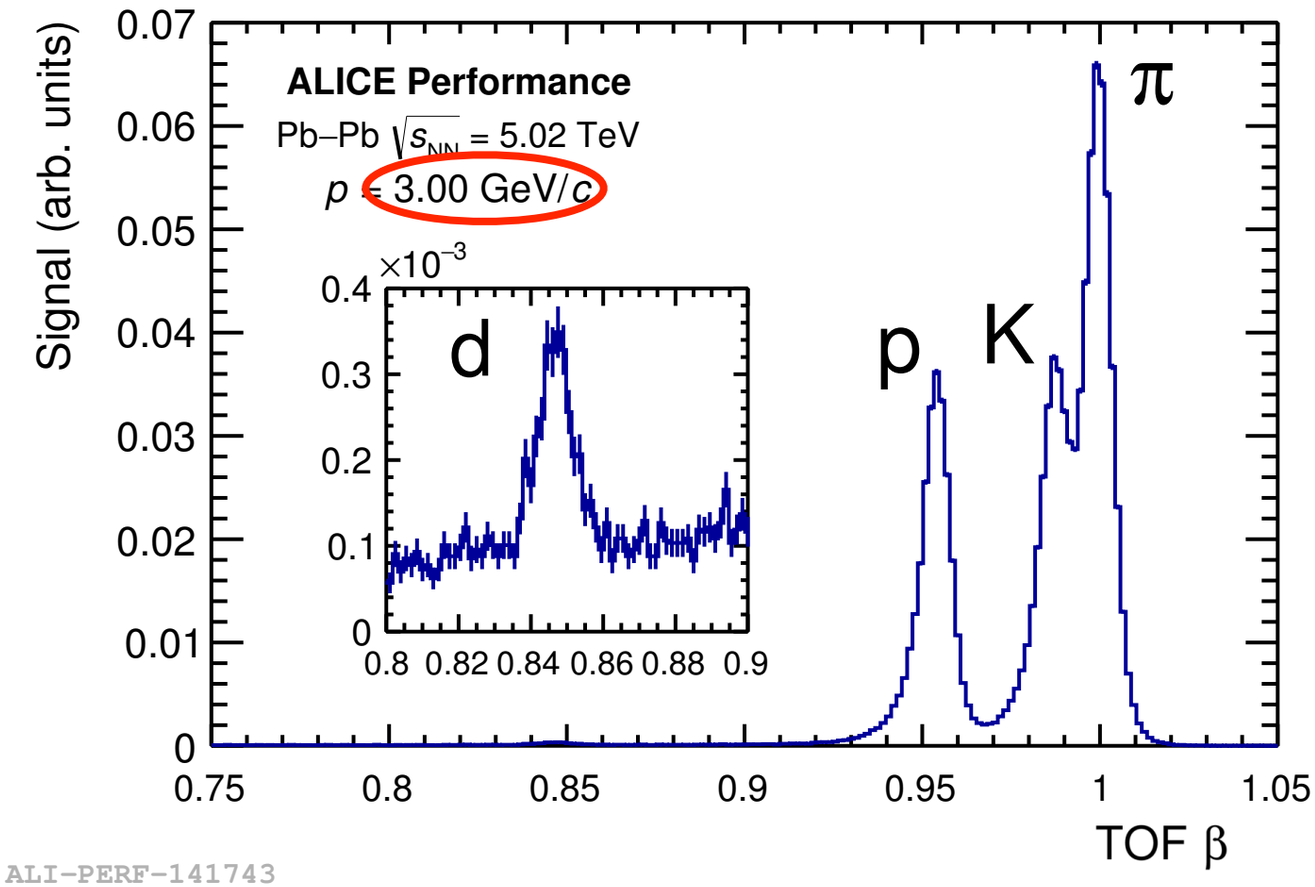
TOF β vs momentum (pseudorapidity region |η| < 0.5)



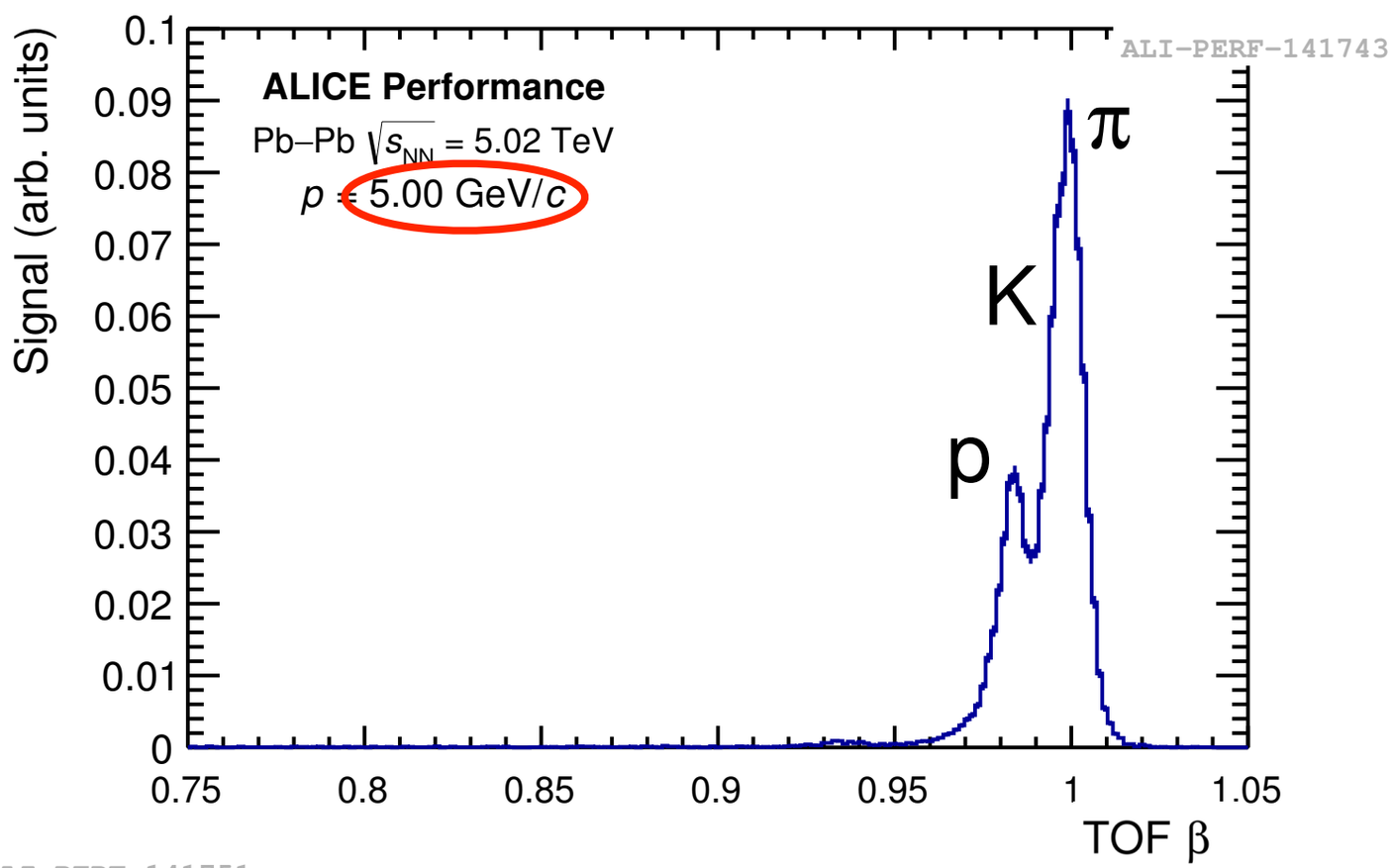
B=0.5 T

ALI-PERF-106336

PID performance



K/π still **separated** ⟵



⟶ **p/K** still **separated**

ALI-PERF-141751

Conclusions

- The **ALICE-TOF** detector is a high performance detector based on **MRPC** technology; is a **large** (active area 141 m^2) detector taking data for almost **10 years**

- Since its installation until today:
  - **no** degradation
  - very **stable** detector
  - **no** loss in performance

- The **time resolution** is improved thanks to calibrations (upgraded time slewing corrections) in 2017: **from ~ 80 ps** to **less** than **60 ps**

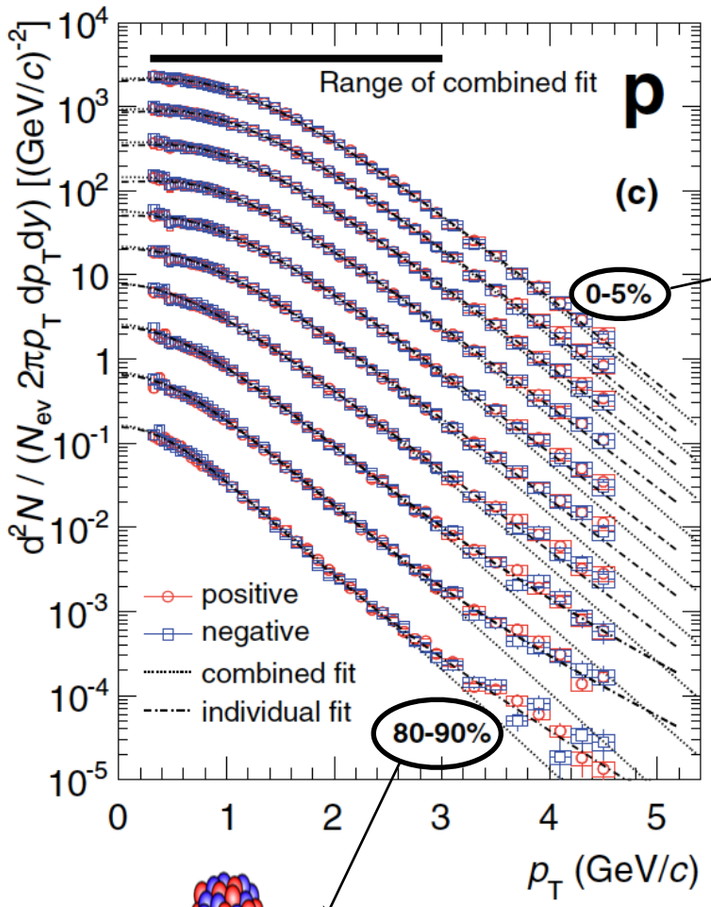
- With 2 tracks or more reaching the TOF, t_{event} can be determined by the TOF itself (resolution on $\mathbf{t_{event}}$ **below 30 ps** with 10 tracks)

- It provides a **K/π** separation up to **3 GeV/*c*** and a **p/K** separation up to **5 GeV/*c*** (PID)

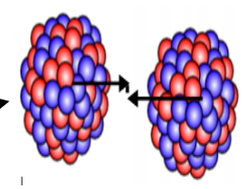
Backup

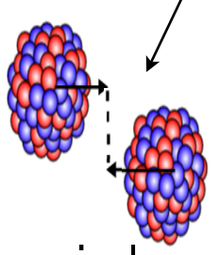
Physics with TOF PID

http://dx.doi.org/10.1103/PhysRevC.88.044910



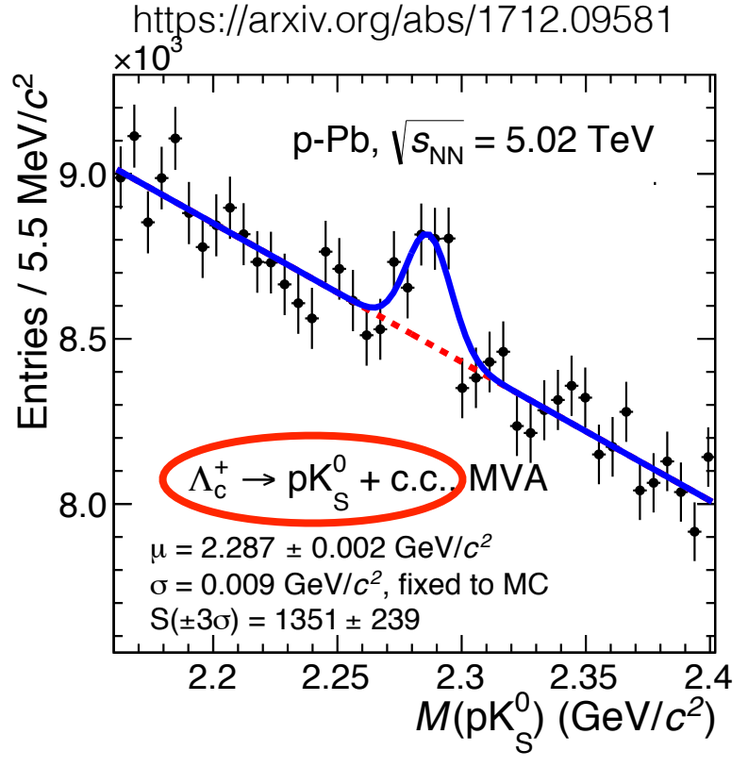
central





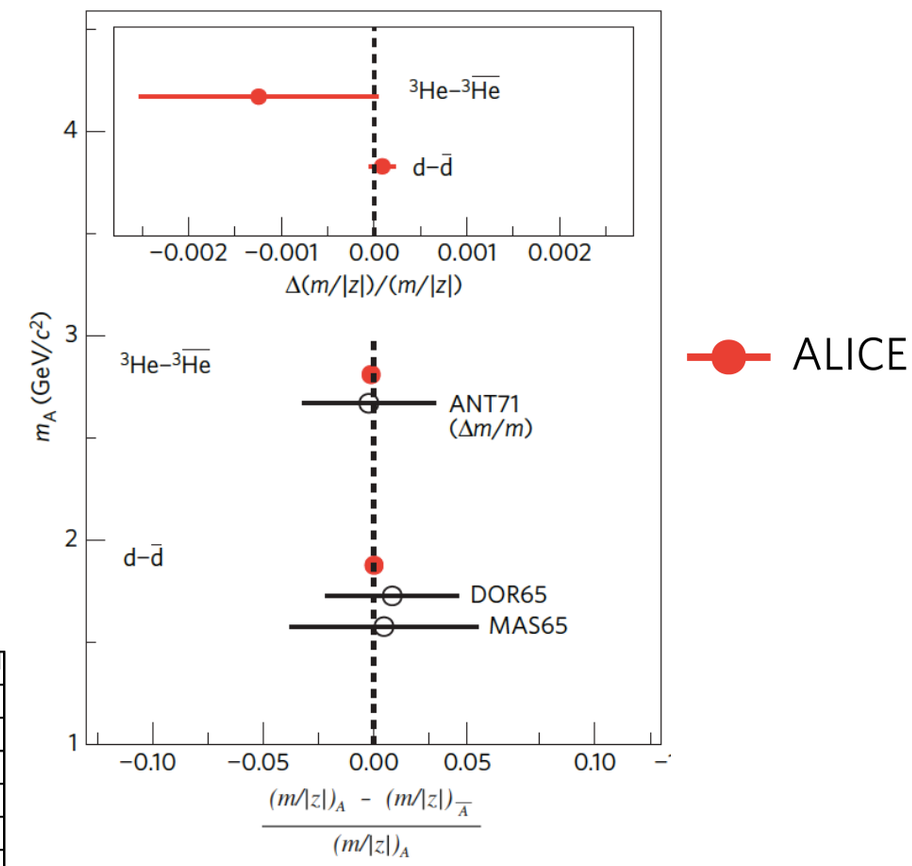
peripheral

https://arxiv.org/abs/1712.09581

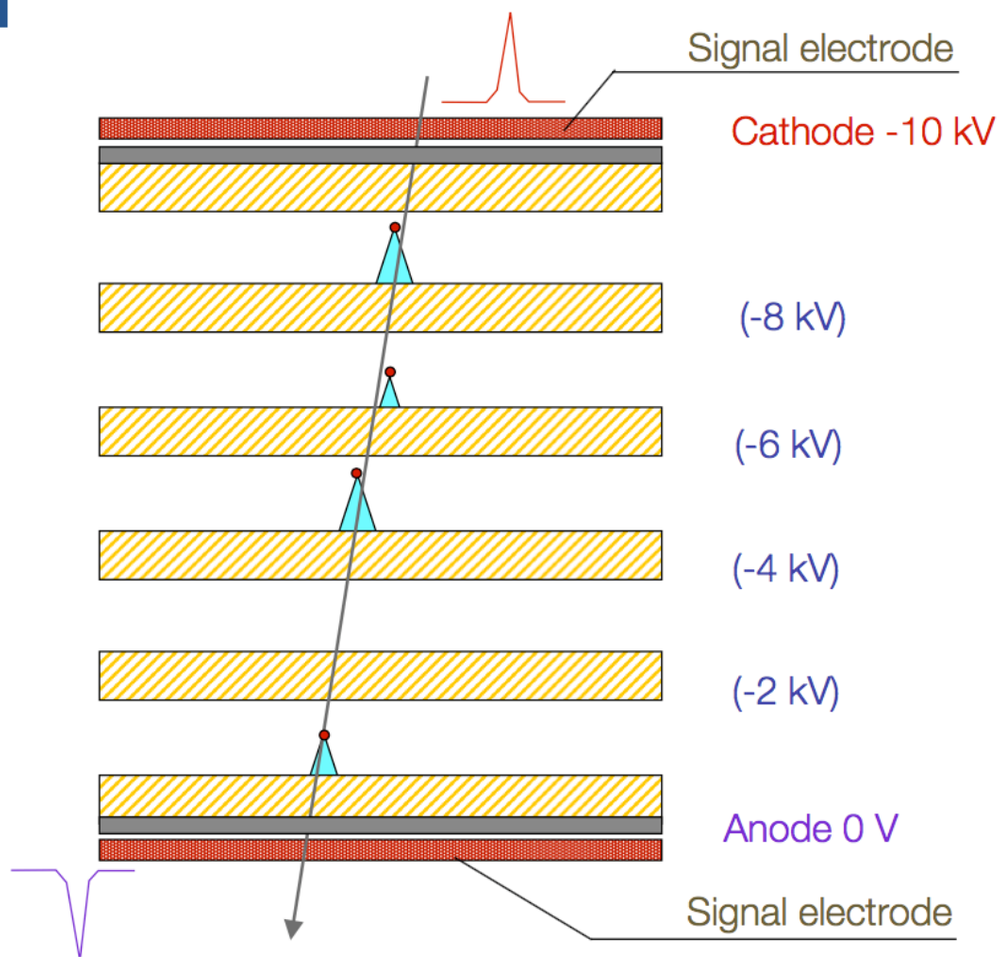


nature physics LETTERS
PUBLISHED ONLINE: 17 AUGUST 2015 | DOI: 10.1038/NPHYS3432
OPEN

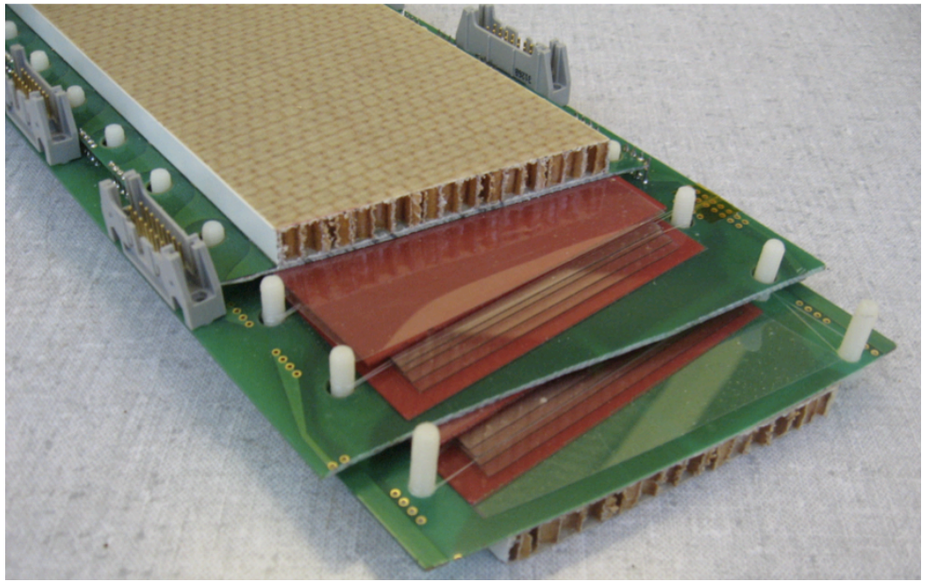
Precision measurement of the mass difference between light nuclei and anti-nucl



ALICE-TOF 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



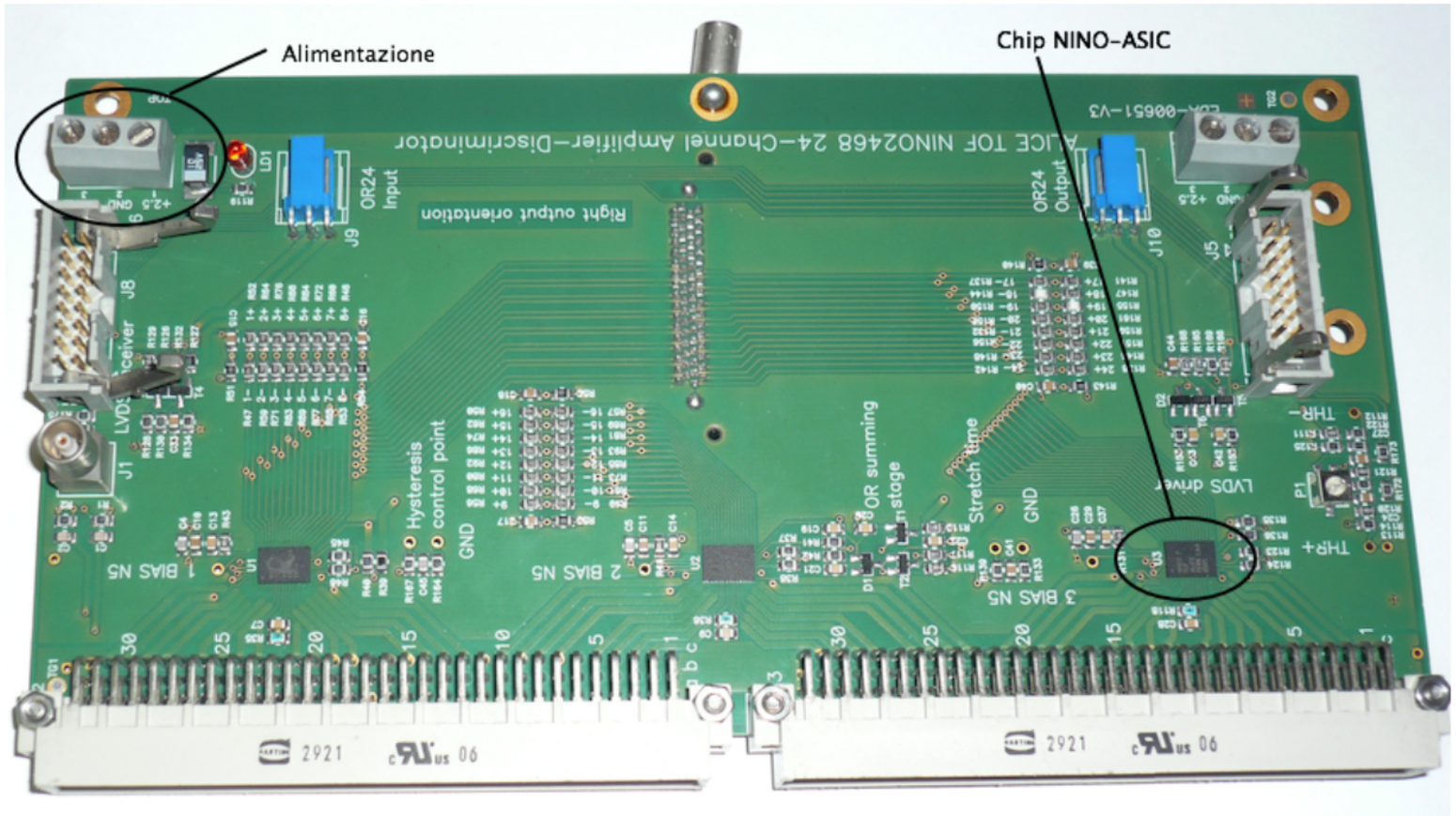
- Exhaust time $\tau = \varepsilon_0 \varepsilon_r \rho = 3.5$ s
- $\rho = 5 \cdot 10^{12}\ \Omega$cm,
- $\varepsilon_r = 8$,
- $\varepsilon_0 = 8.854 \cdot 10^{-12}$ C/V m.

acrylic paint loaded with metal oxydes~ MΩ/□

- E = 100 kV/cm,
- $\eta = 8.2$ mm^{-1}

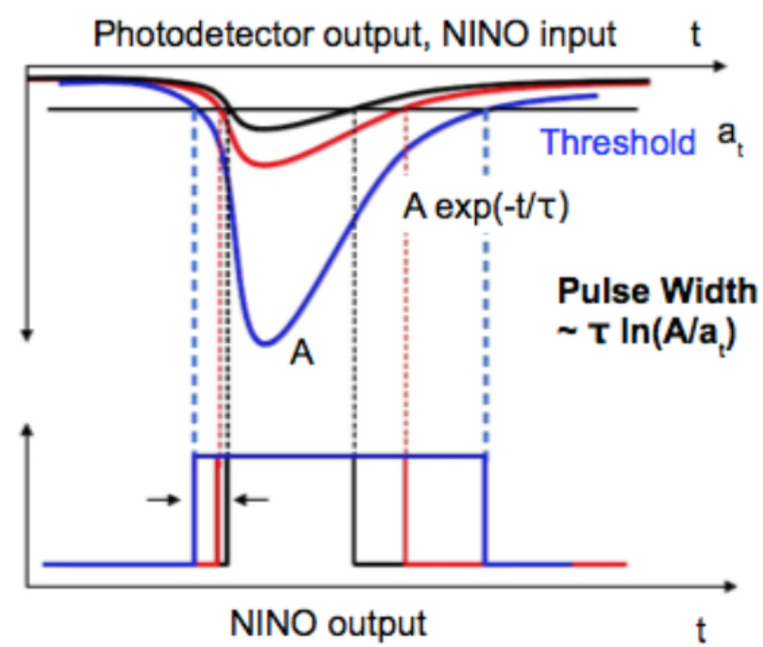
- $\alpha = 126.8$ mm^{-1}
- v = 21.62 cm/μs
- maximum avalanche ~ $1.6\ 10^7$

NINO



The NINO chip is an ultrafast low power Amplifier/Discriminator:

- IBM 0.25μm Si CMOS Technology
- 8 channel / chip (chip: 2x4 mm^2)
- Differential input and at all stage
- Low power (~ 40mW/chip)
- Intrinsic time jitter: 15-20 ps
- V= +2.5 V
- Output LVDS



Operation during LHC Run2

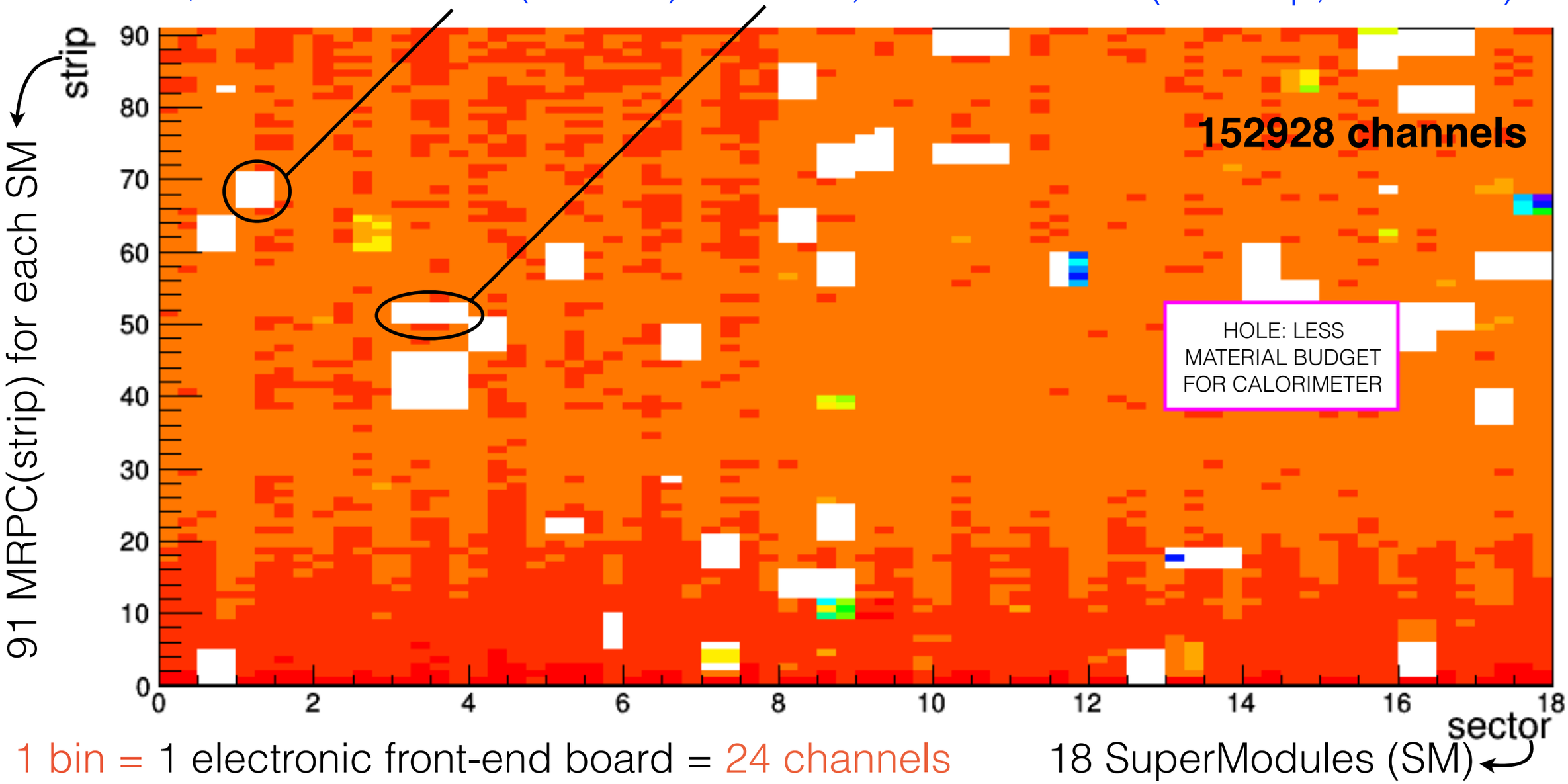
n **2018**, total of **2253** hours:

- ~**98% total time availability**
- ~**93%** average active **channels** ⟶

The missing **7%** —> due to electronics and connectors (**not** to MRPC!)

~3%, Readout module(10 bins)

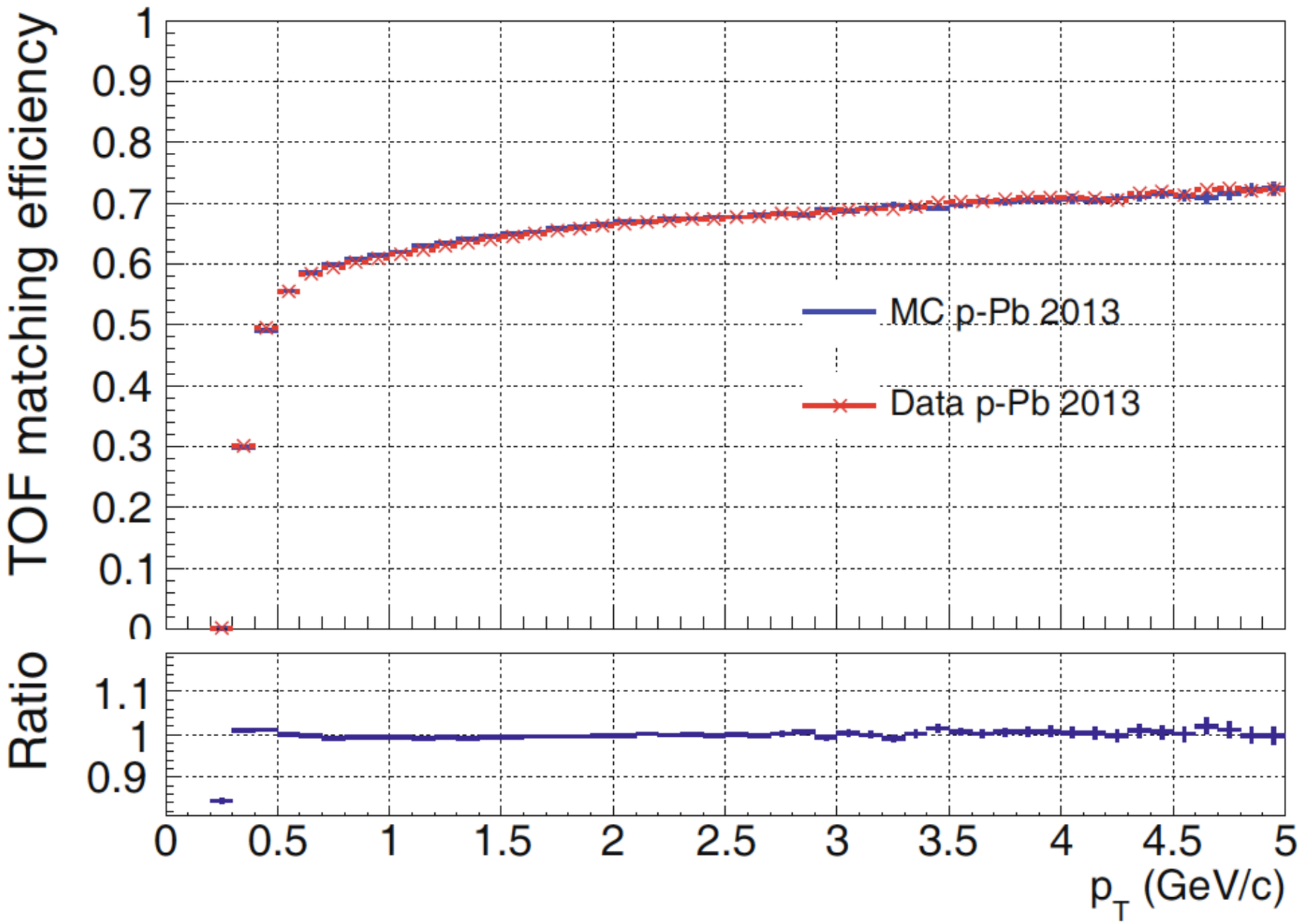
~4%, HV connectors(3-4 strip,12-16 bin)



1 bin = 1 electronic front-end board = 24 channels

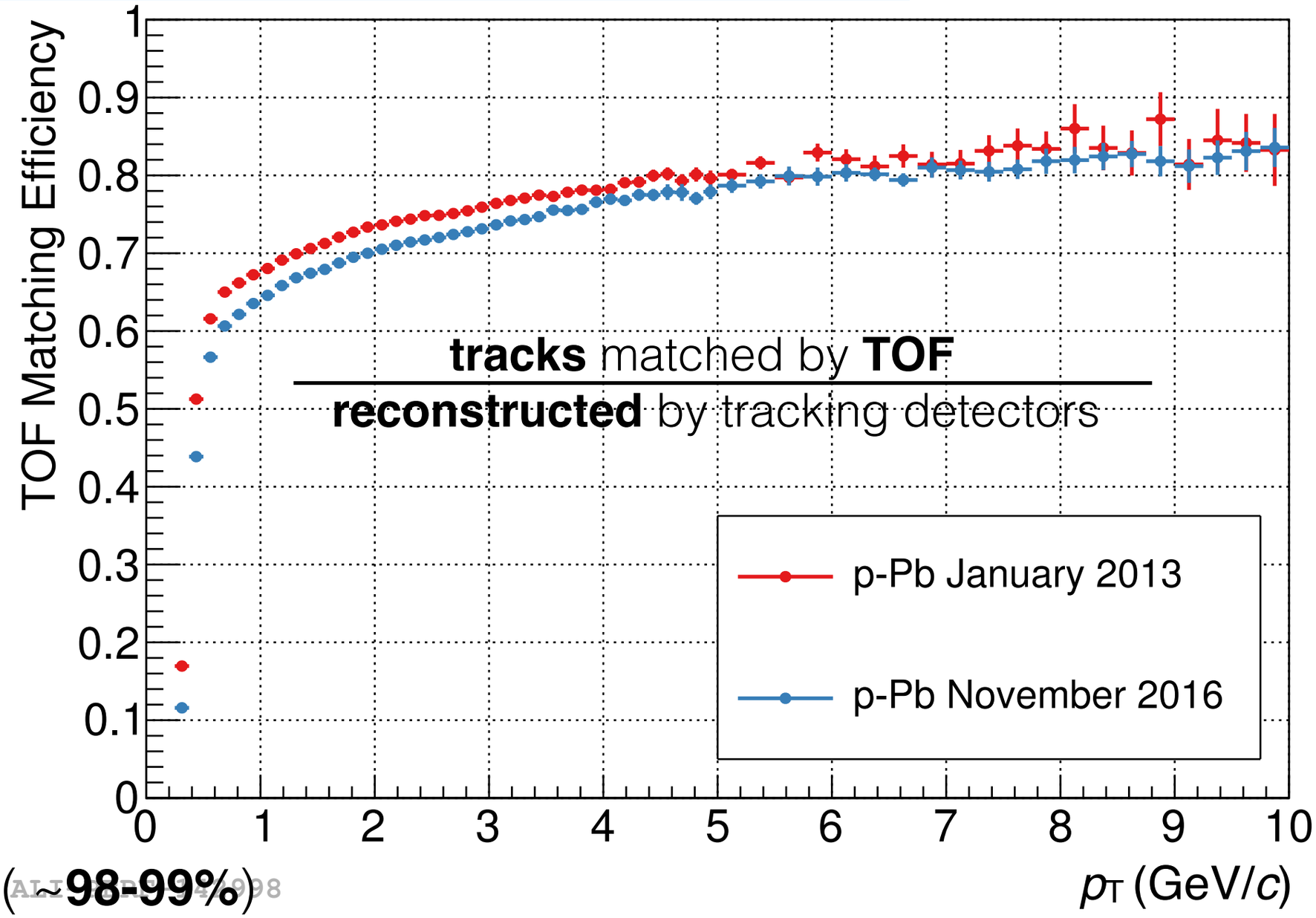
Operation - Matching Efficiency

DOI 10.1140/epjp/i2013-13044-x



MRPC efficiency 98.5% (in the **centre** of a pad is ~ **99.5%**)

Operation - Matching Efficiency



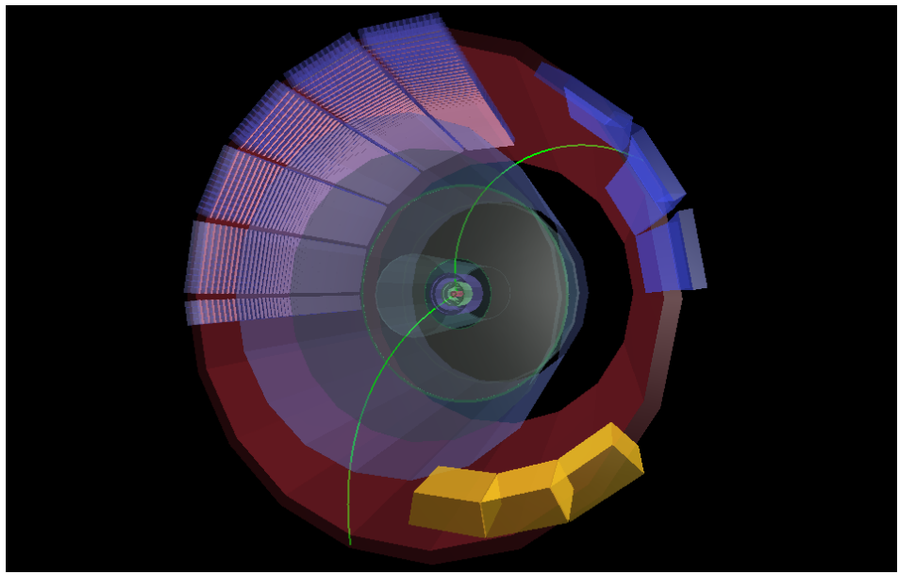
For p_T < 0.3 GeV/c particles do not reach TOF (B=0.5 T)

- **MRPC** efficiency (~**98-99%**)
- TOF algorithmic inefficiency
- TOF geometrical acceptance (dead space)
- Budget **material** (in front of TOF)
- **Hardware** data taking **conditions (extern.)**
- **Track extrapolation**

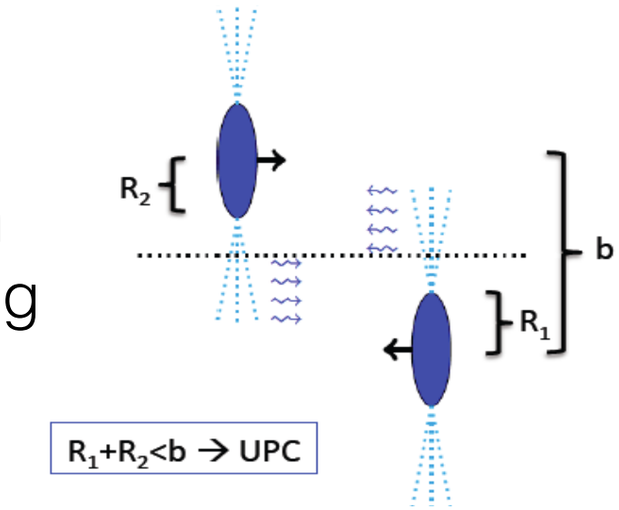
Performance stable during **Run1** and **Run2** (deviations due to)

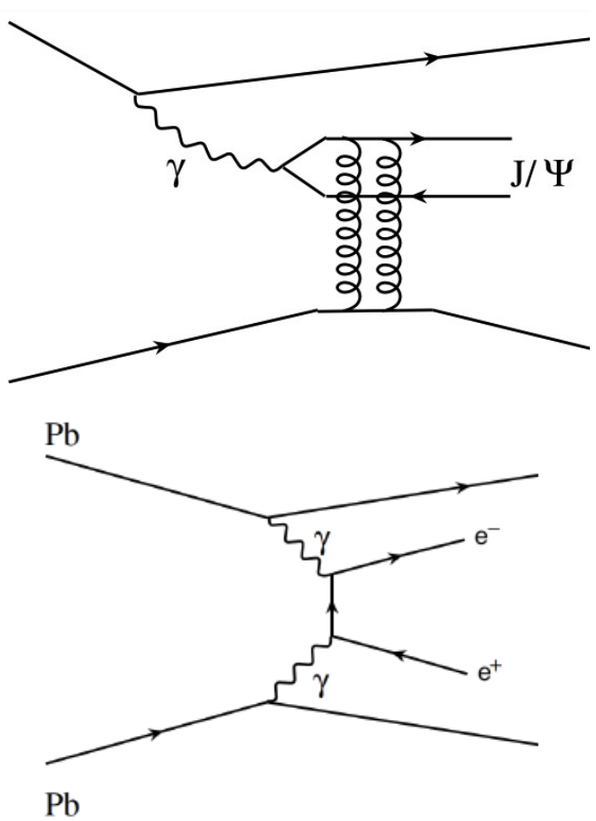
Operation - Trigger

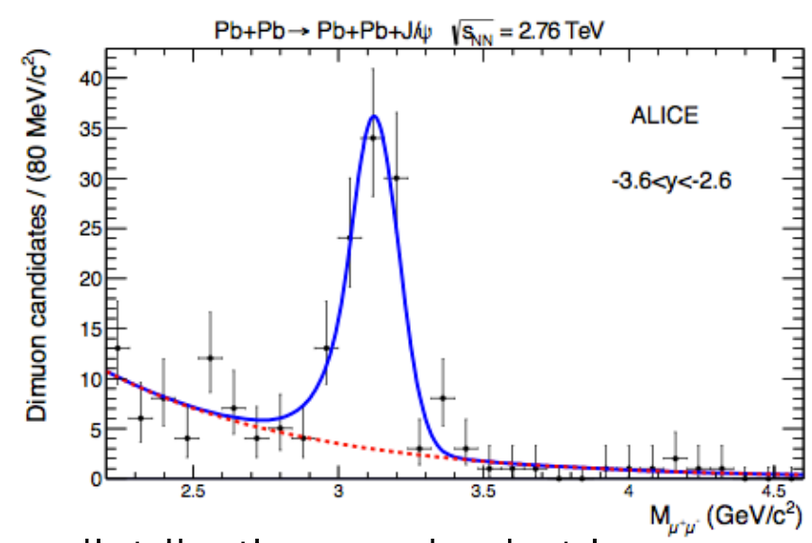
Ultra **P**eripheral **C**ollisions



we expect two tracks in the central detectors with forward detectors showing no activity





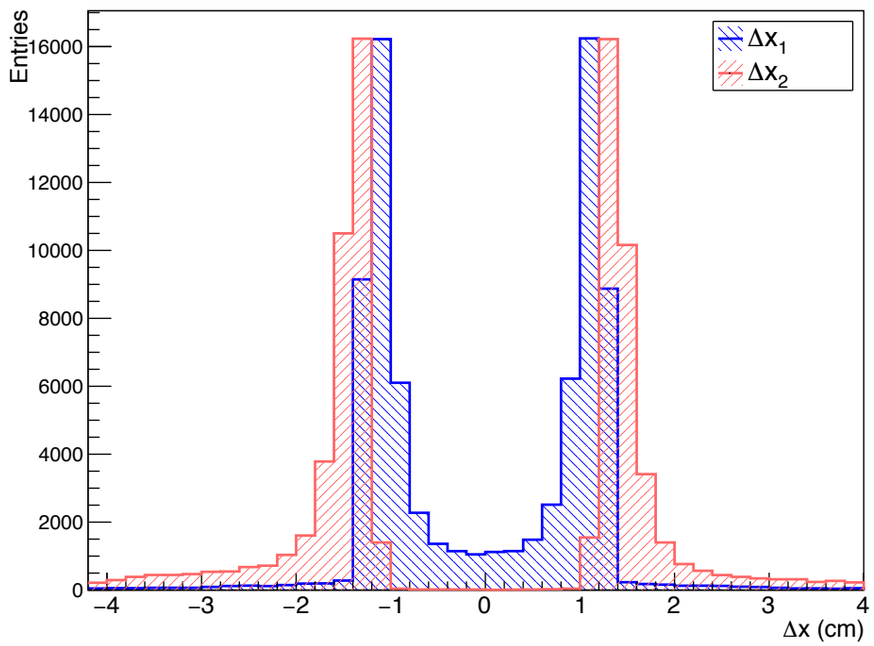


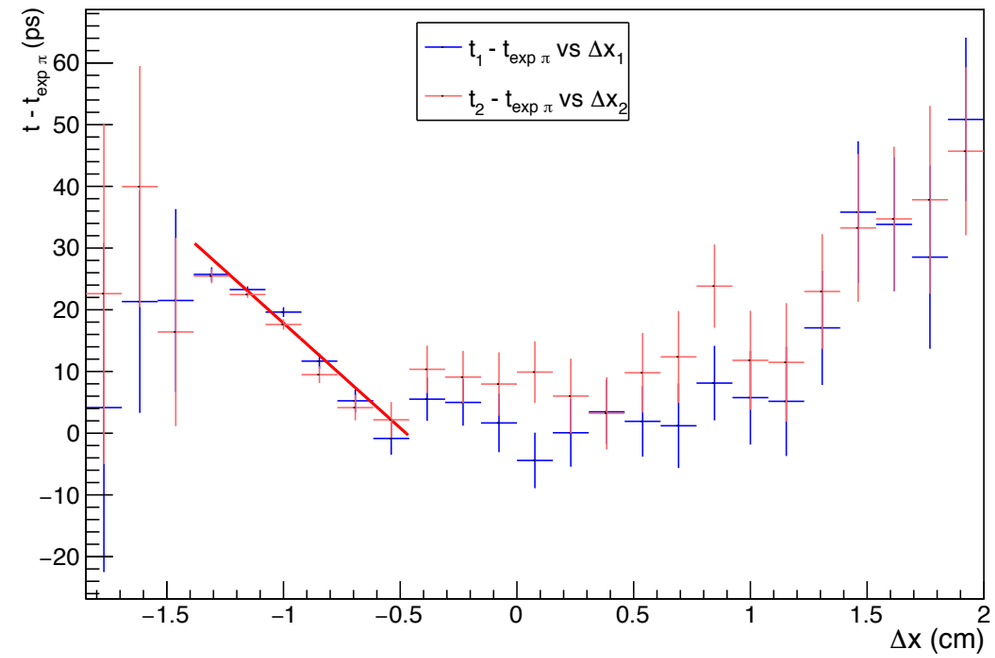
distribution peaked at low momentum as expected from **coherent** production

Time resolution - Clusterization

Double hit cases:

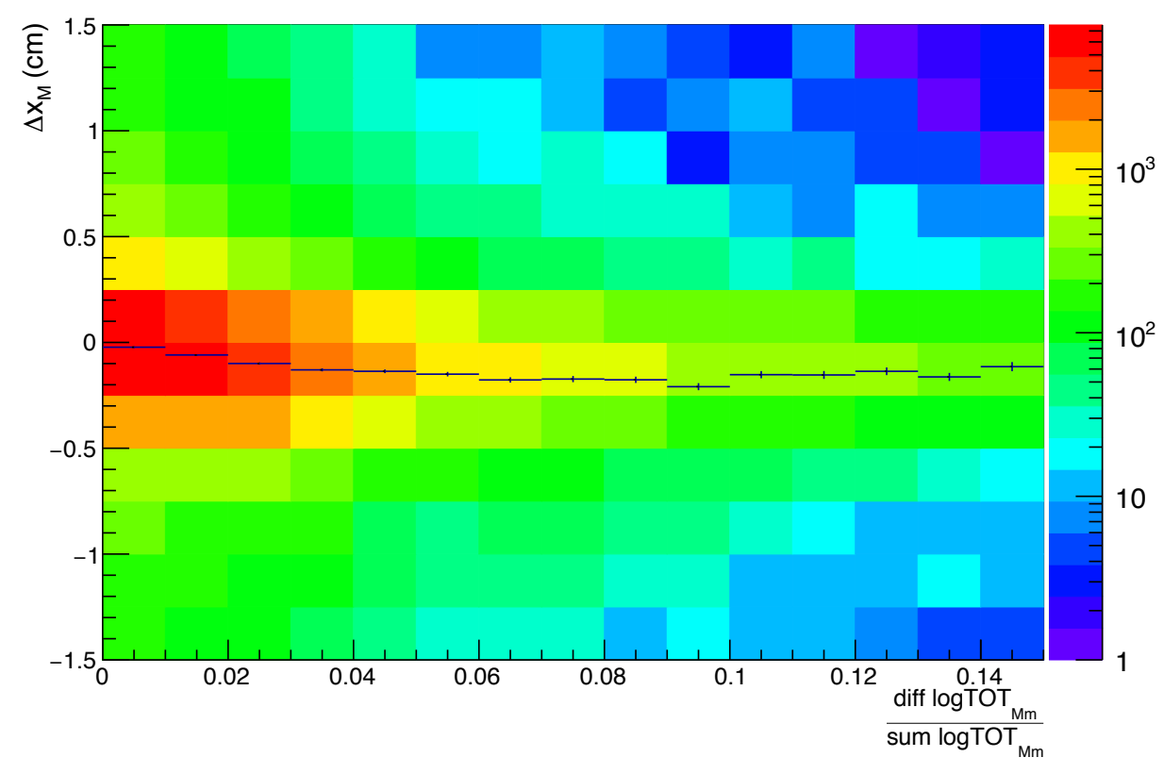
To optimise the TOF **time** resolution—> searched for possible edge effects (correlations between position on the pad and time —> negligible (time walk only)



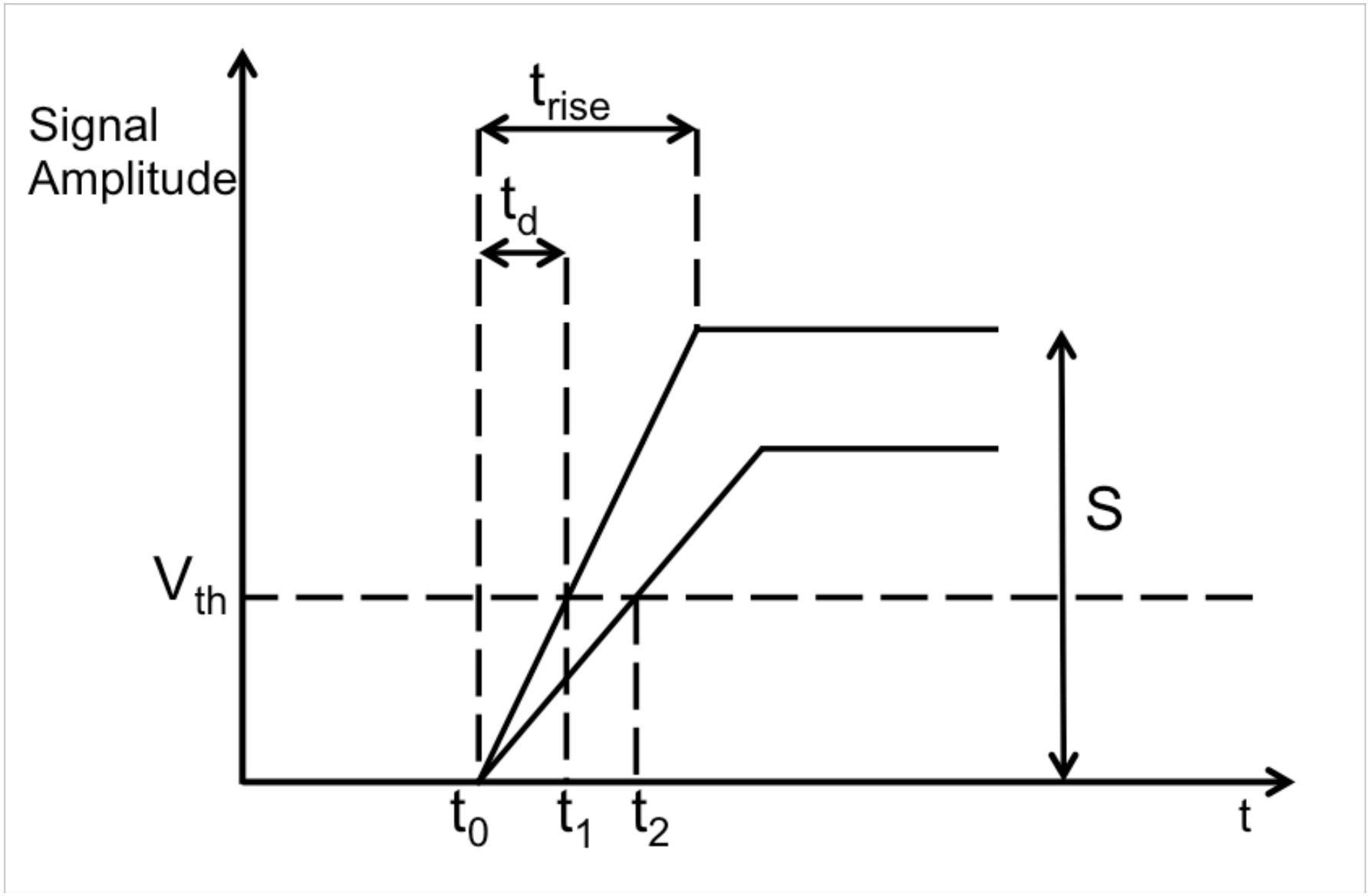


Position recentered and expressed as a function of *f(charge):*

- independent from TPC tracking and resolution
- f(charge)=Time Over Threshold

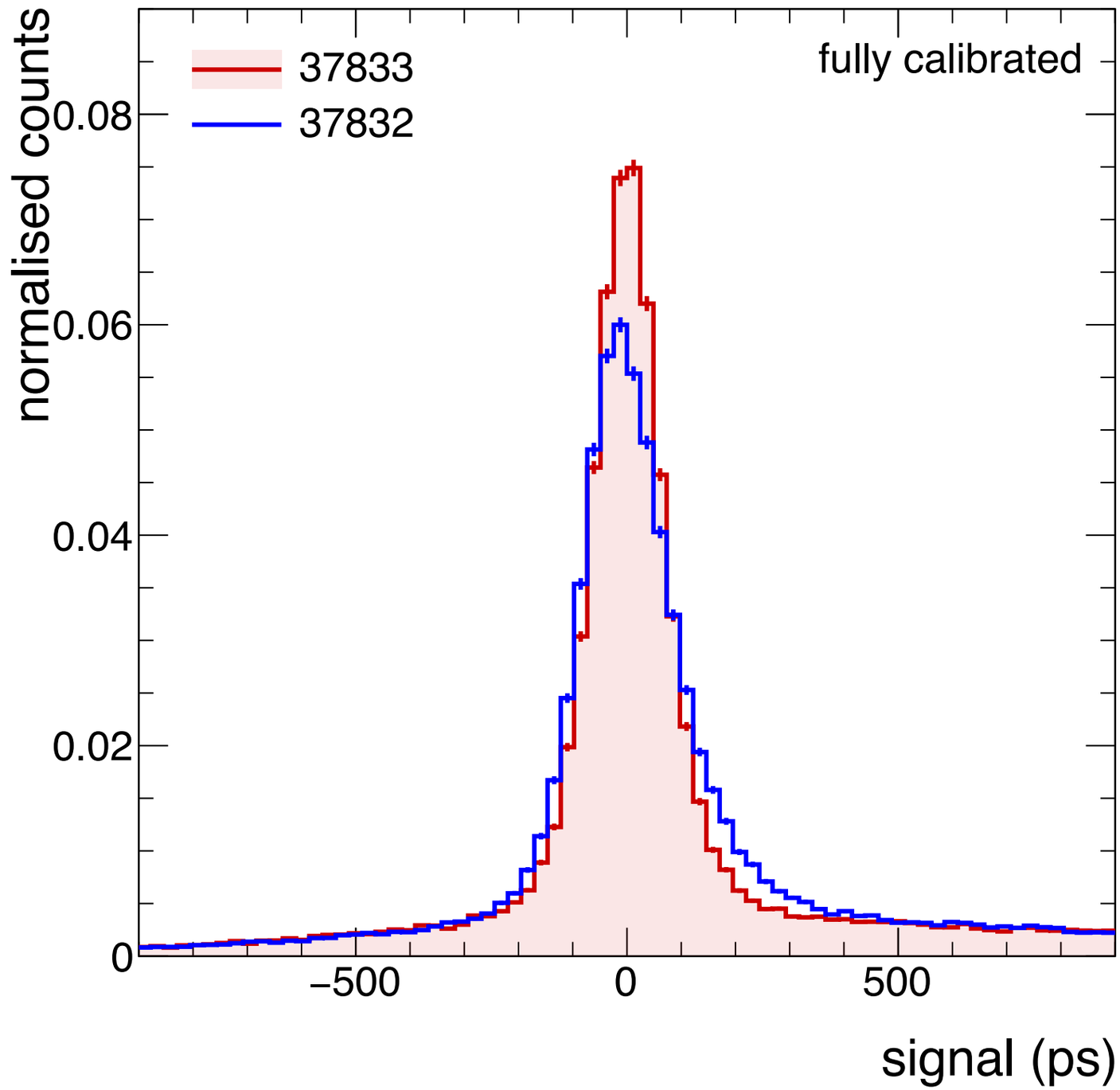


Time resolution - Time slewing



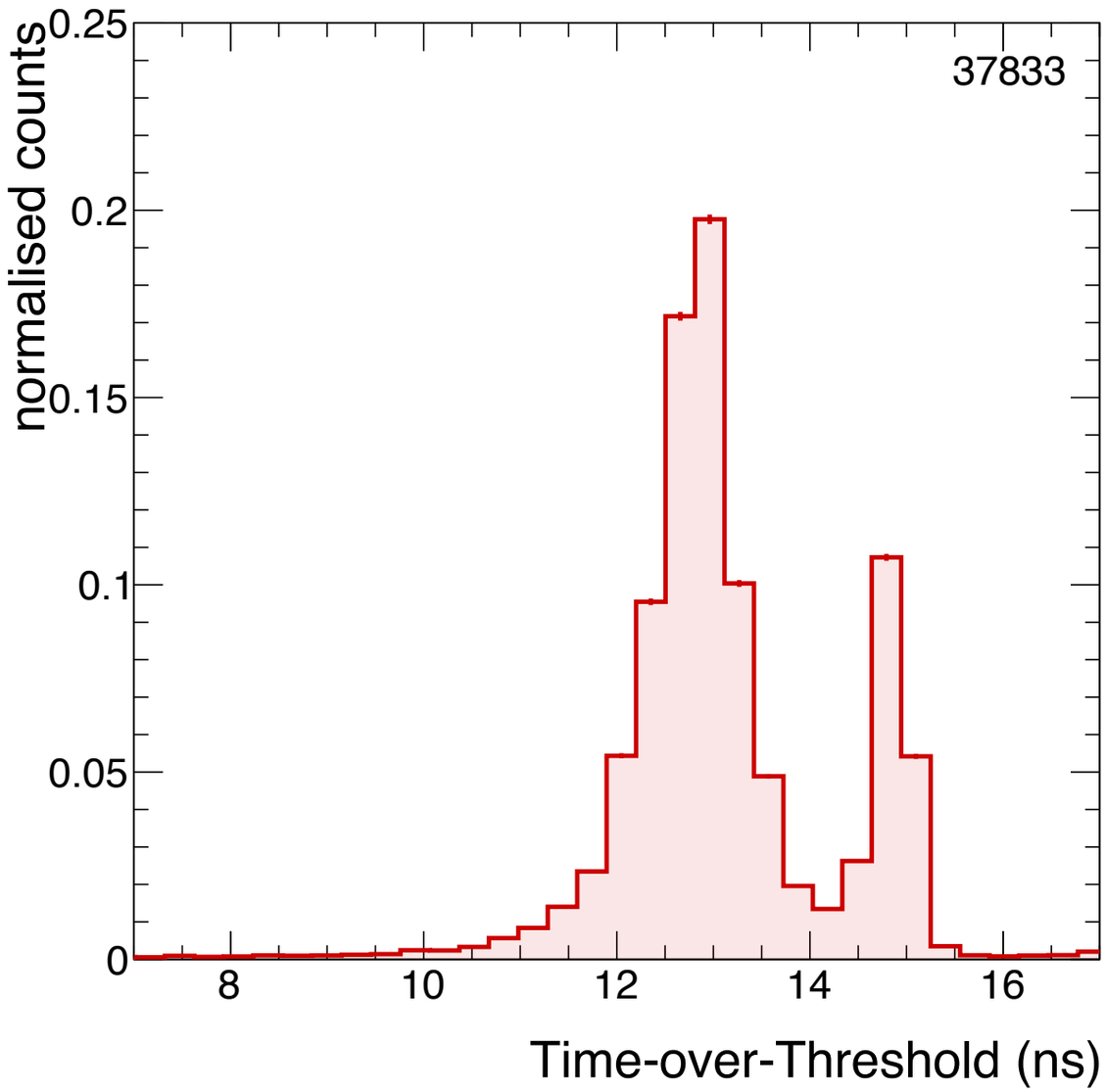
The time slewing effect is due to the comparison of the signal with a **fixed threshold voltage** Vth, usually related to the nature of the analog to digital conversion of the signals.

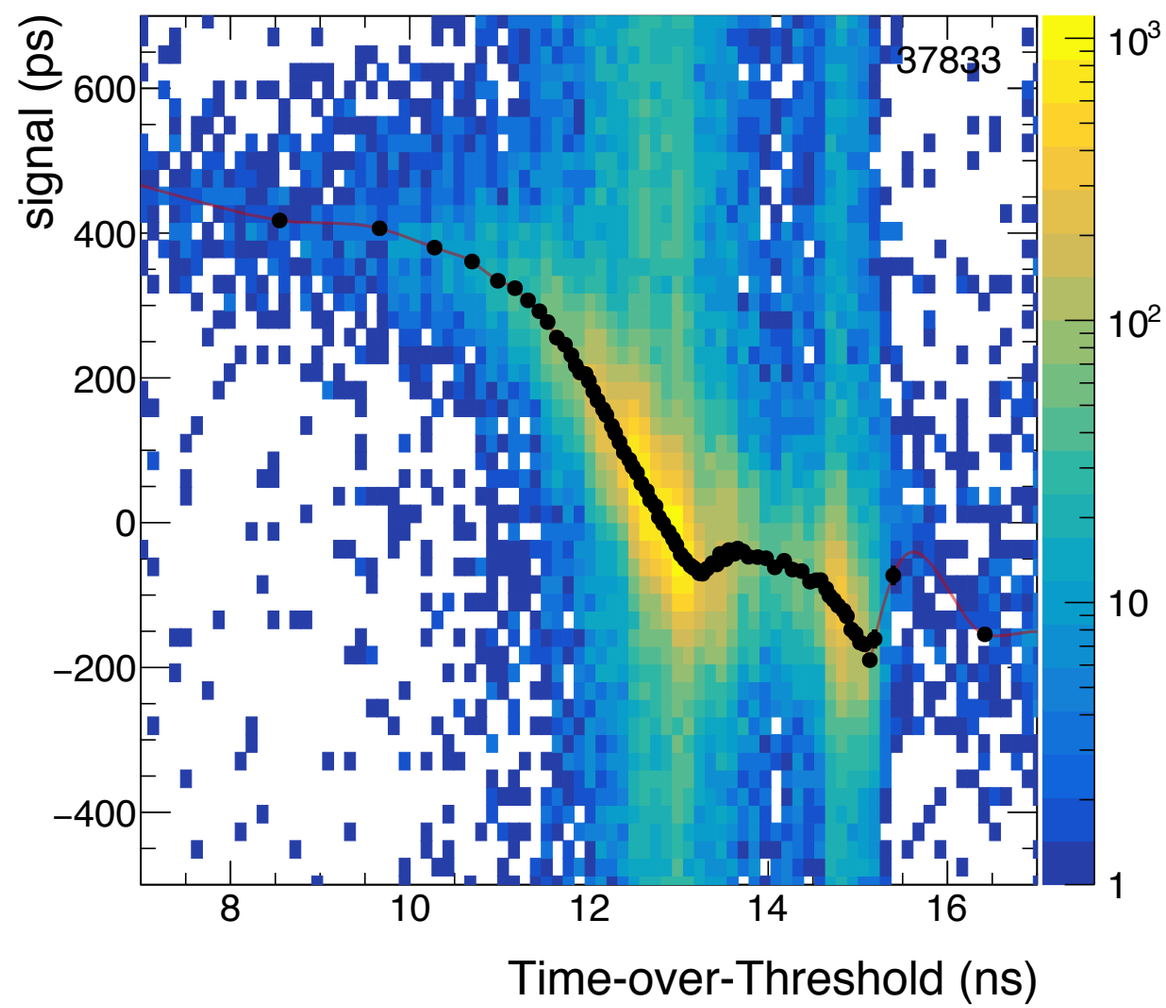
Time resolution - Time slewing



Tails (residual calib., electronics, …) —> …we can do even better

Time resolution - Time slewing





Time resolution - t_{event}

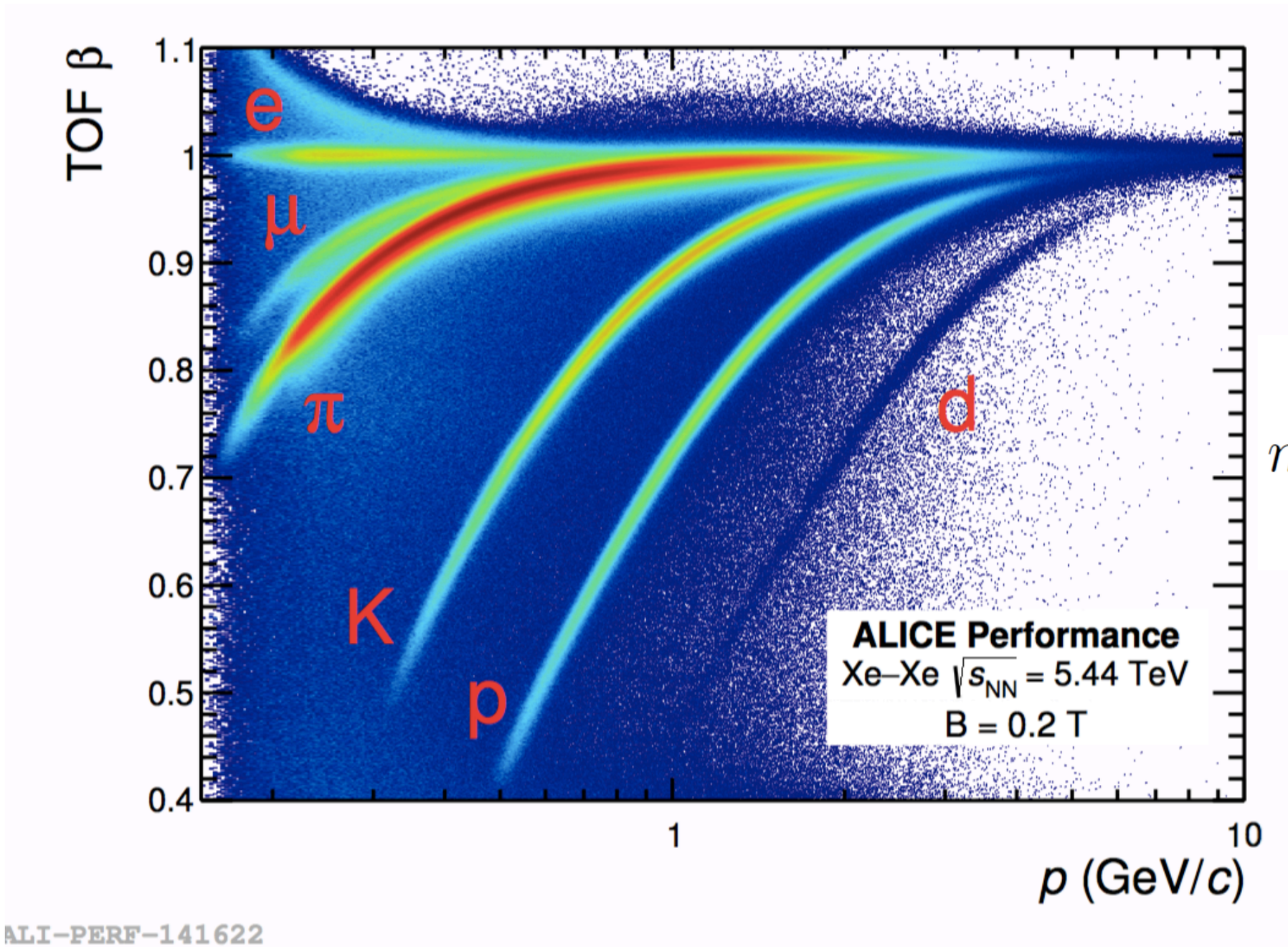
TOF event time—> when N_{track} >2 have an associated TOF signal:

- combinatorial algorithm —> compares the measured TOF times to the expected times of the tracks, assuming a common event time t_{ev}
- t_{ev} is obtained from a $\chi 2$ minimization

$$\chi^2(\vec{m}_i) = \sum_{n_{\text{tracks}}} \frac{\left(\left(t_{\text{TOF}} - t_{\text{ev}}^{\text{TOF}}(\vec{m}_i)\right) - t_{\text{exp,i}}\right)^2}{\sigma_{\text{TOF}}^2 + \sigma_{t_{\text{exp,i}}}^2}$$

TOF PID performance

The magnetic field —> prevent low- momentum particles to reach the TOF



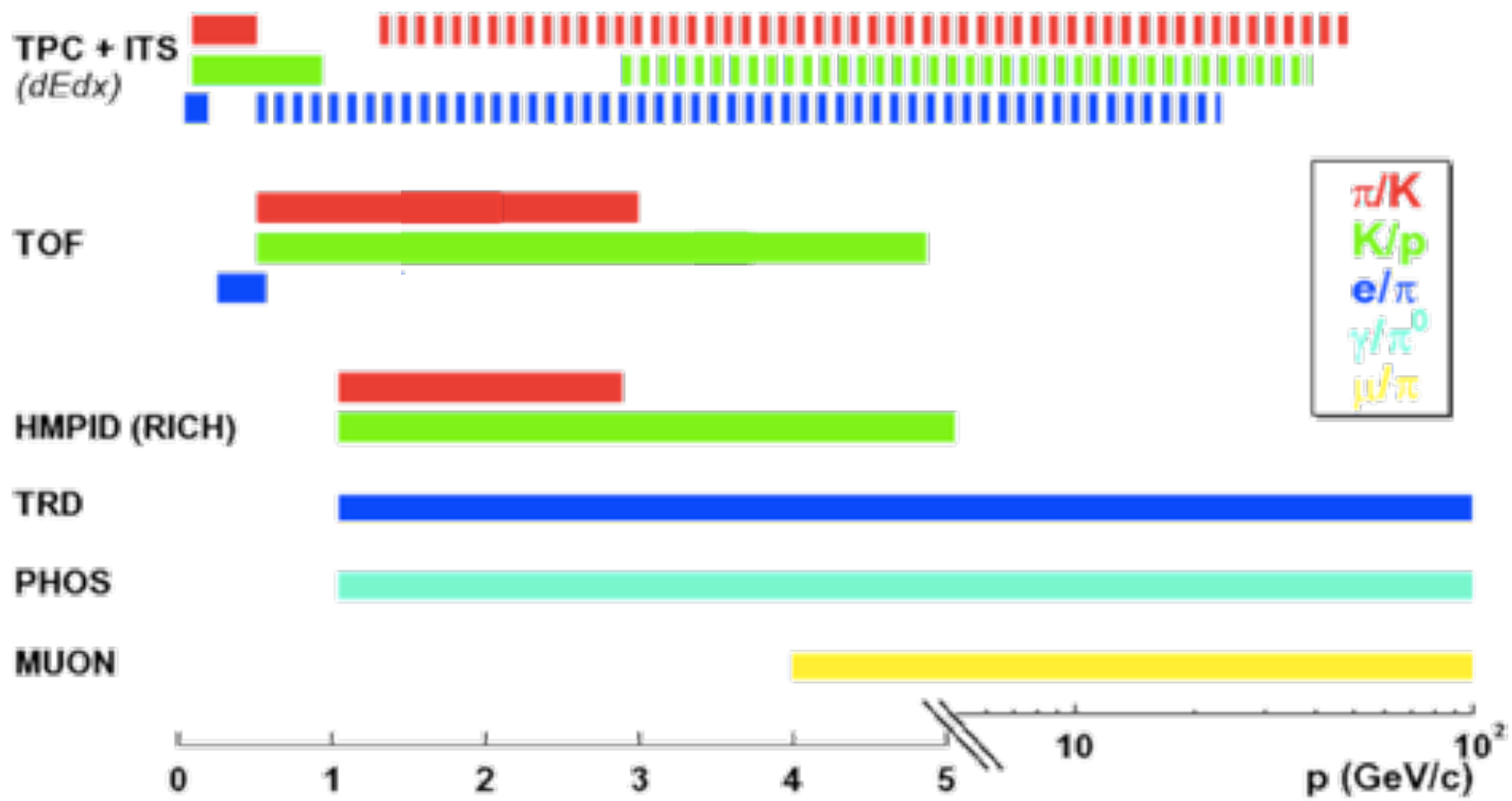
$$m = \frac{p}{c}\sqrt{\frac{c^2t^2}{L^2} - 1}$$

$$n_\sigma = \frac{\Delta t}{\sigma_{TOF}}$$

$$P\hat{I}D_{\mathrm{TOF},i} = \frac{t_{\mathrm{TOF}} - t_{ev} - t_{\mathrm{exp}}(m_i, p, L)}{\sigma_{\mathrm{tot}}(p, m_i, t_{ev})}$$

ALICE - PID

- Energy Loss — central barrel
  - ITS, TPC — single arm
- Transition radiation
  - TRD
- Time Of Flight
  - TOF
- Cherenkov Radiation
  - HMPID
- Calorimetry
  - EMCAL, PHOS, ZDC
- Preshower
  - PMD
- Muon Spectrometry
  - MUON
- Topological Decay
  - ITS



Separation: track-by-track statistical