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INFN Istituto Nazionale di Fisica Nucleare

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

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Outlook

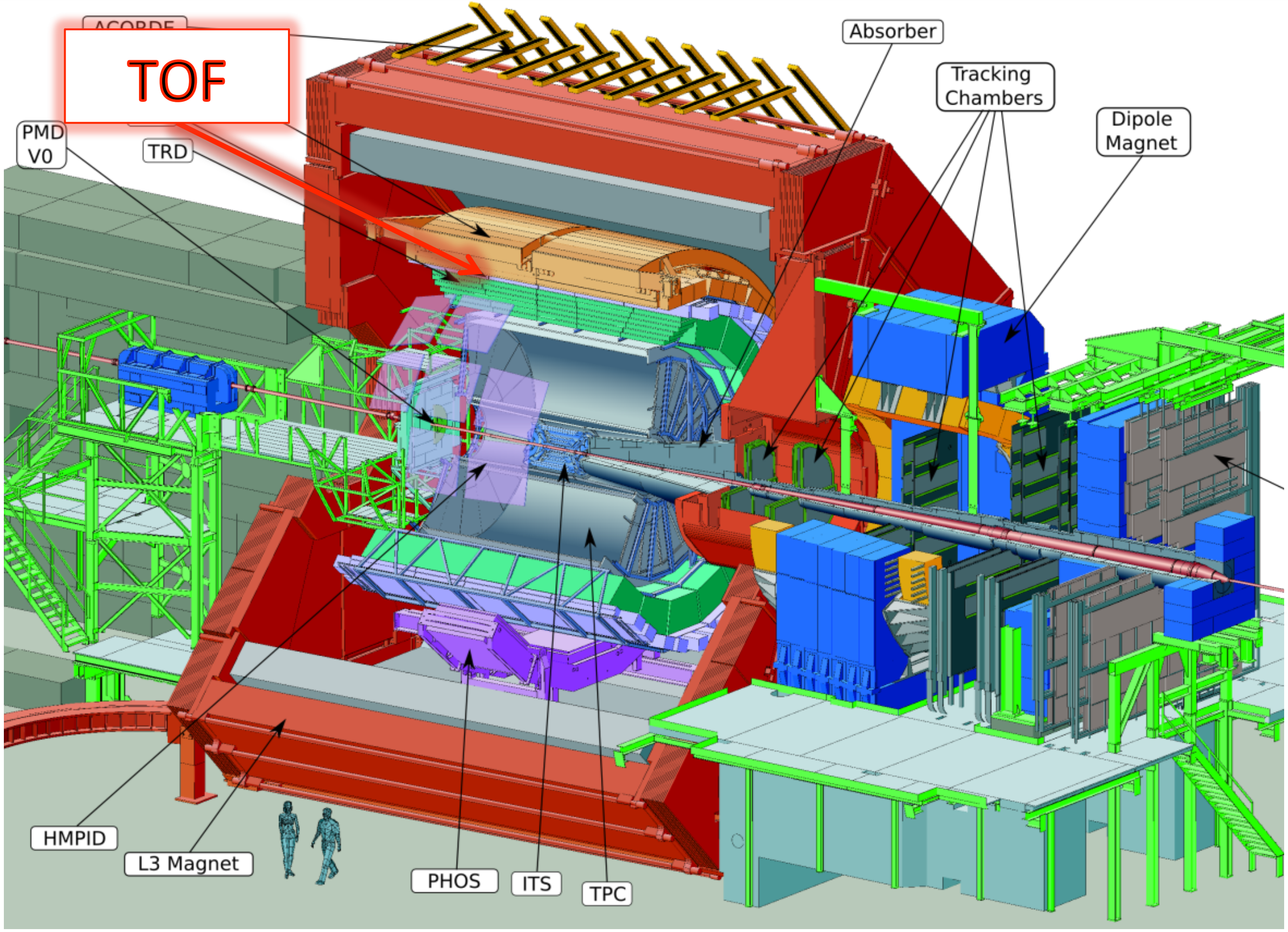
1. Overview of the TOF detector at the LHC ALICE experiment

2. The core of the ALICE TOF detector: the Multigap Resistive Plate Chambers (MRPCs)

3. Status and performance of the TOF detector

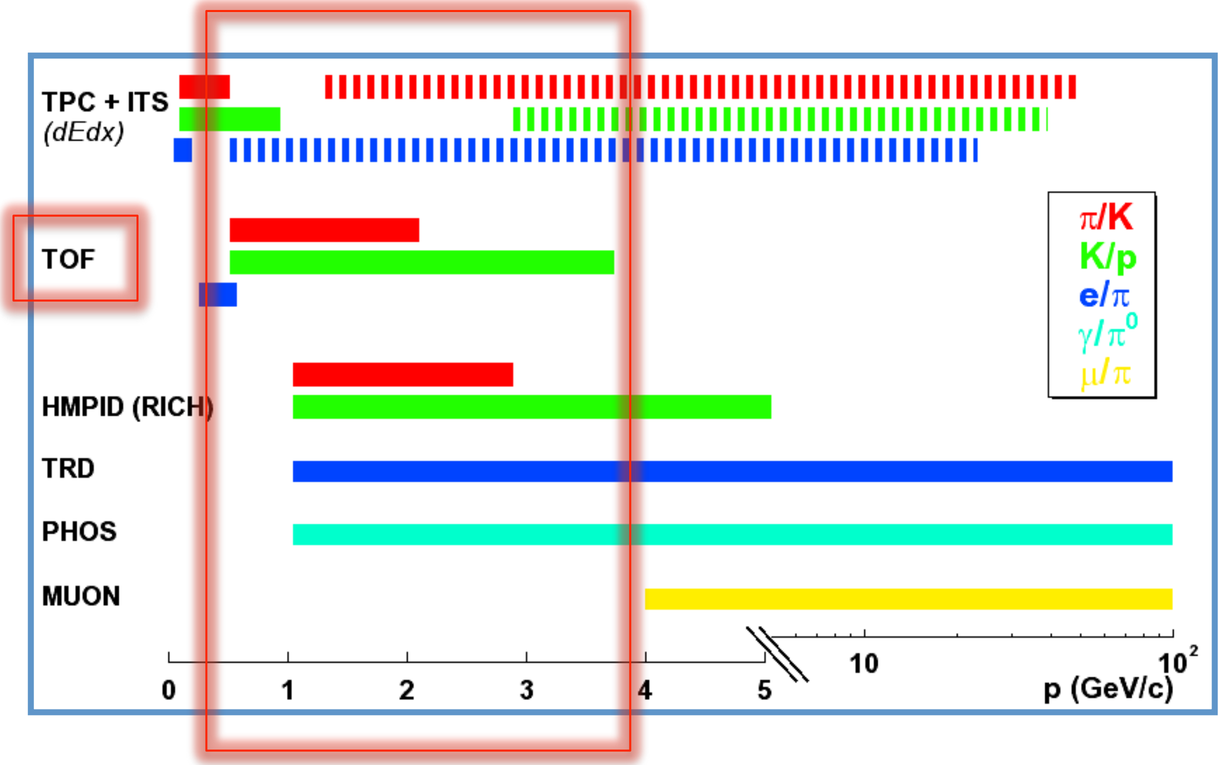
ALICE experiment

ALICE is the heavy-ion dedicated experiment at LHC, designed and optimized for Pb-Pb collisions @ 5.5 TeV/NN. A **large Time-Of-Flight array** is devoted to charged hadron identification in the mid-rapidity region.



The ALICE Time-Of-Flight detector

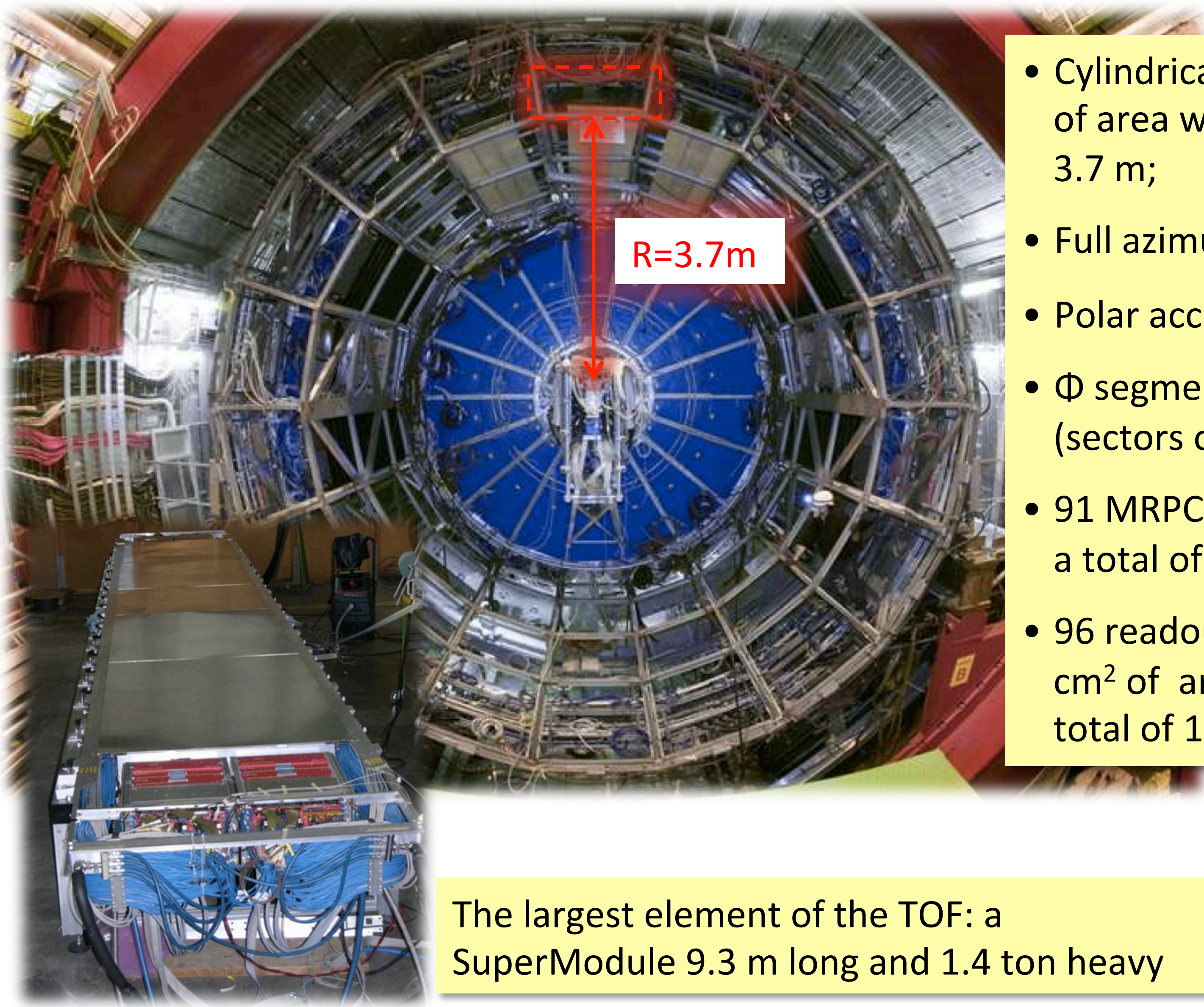
The ALICE TOF detector aims at charged hadron identification up to a few GeV/c (3σ π/*K* and *K*/*p* separation up to 2.5 GeV/c and 4 GeV/c respectively).



Design values assuming a TOF **global time resolution of 80 ps**

Separation: @ 3σ @ 2σ

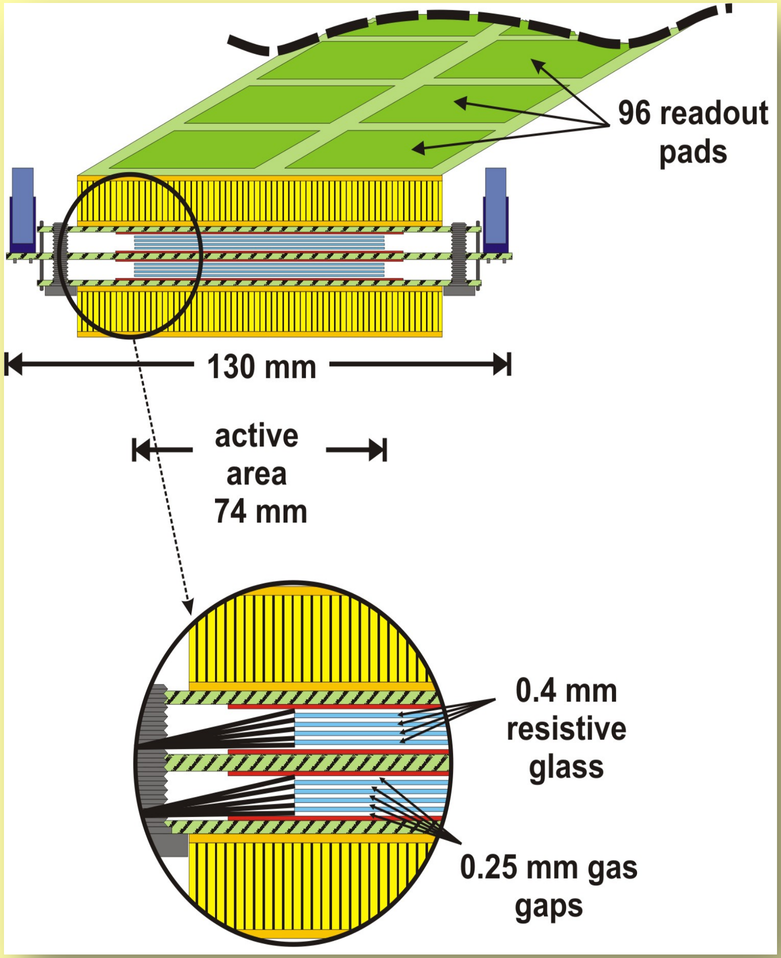
The ALICE Time-Of-Flight detector



- Cylindrical surface of ~ 150 m^2 of area with an inner radius of 3.7 m;
- Full azimuthal acceptance;
- Polar acceptance $|\eta| \leq 0.9$;
- Φ segmentation : 18 – fold (sectors or SuperModules);
- 91 MRPCs for SuperModule for a total of 1593 MRPCs;
- 96 readout channels of ~ 10 cm^2 of area for MRPC for a total of 152928 channels.

The largest element of the TOF: a SuperModule 9.3 m long and 1.4 ton heavy

The ALICE-TOF MRPCs

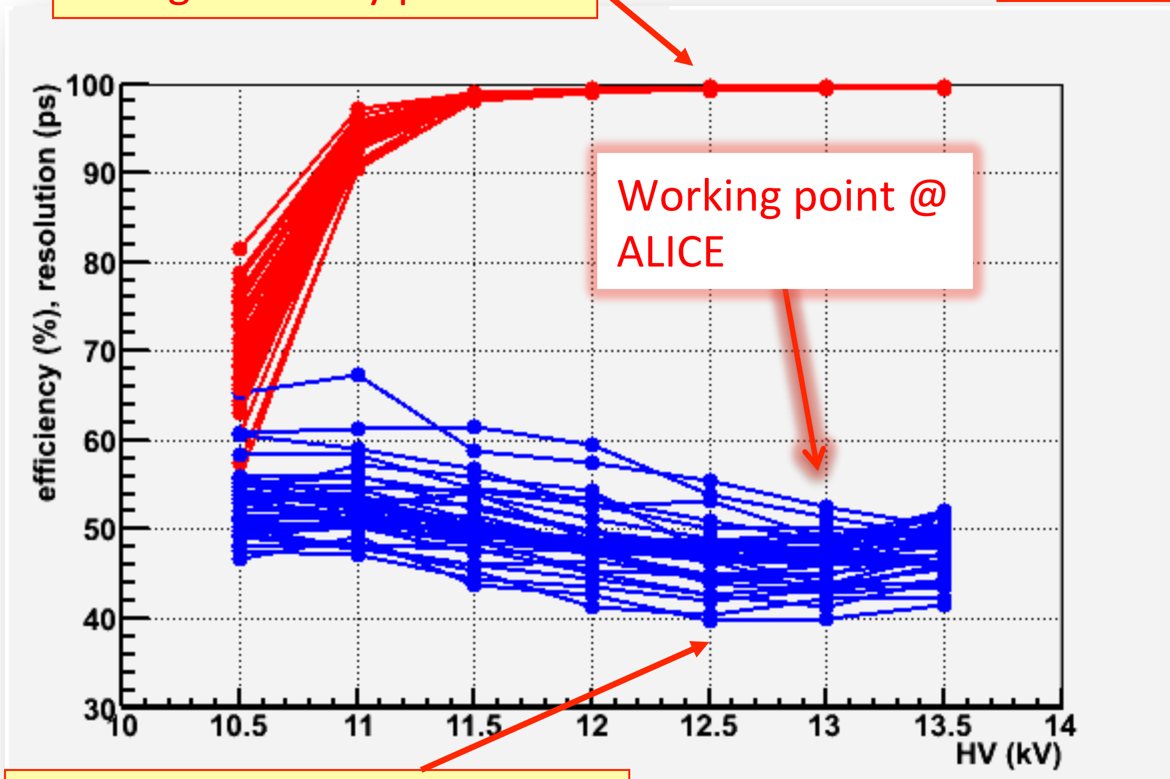


- The ALICE TOF MRPCs are designed as *strips* of 7.4 x 120 cm^2 active area.
- Ten **250 μm width gas gaps** grouped into two stacks placed on both sides around a central anode.
- Resistive plates are made of **400 μm tick *soda – lime* glass** with a bulk resistivity of ≈ 10^{13} Ωcm.
- External electrodes are obtained from 550 μm tick glasses with a specially developed acrylic paint loaded with metal oxydes giving an **average surface resistivity between 2 and 25 MΩ/☐**.

The MRPC: performance @ test beam

Results of a test with a **beam of charged particles @ CERN PS** during autumn 2006 over a MRPC **mass production sample**

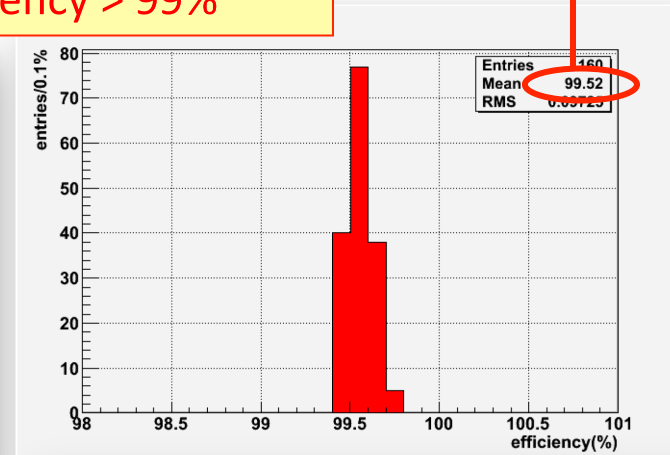
long efficiency plateau

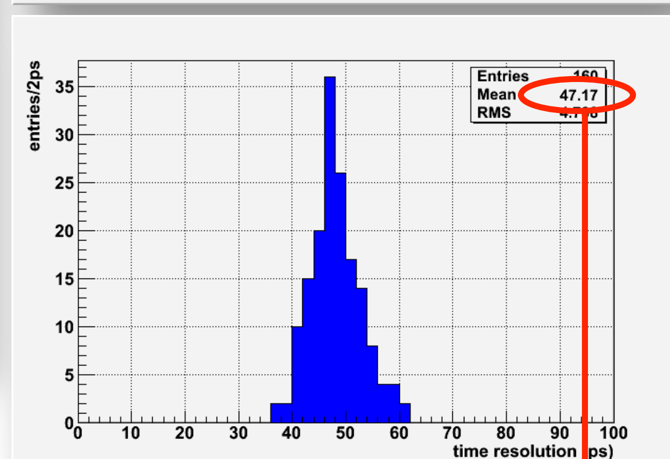


Working point @ ALICE

very uniform performance

efficiency > 99%





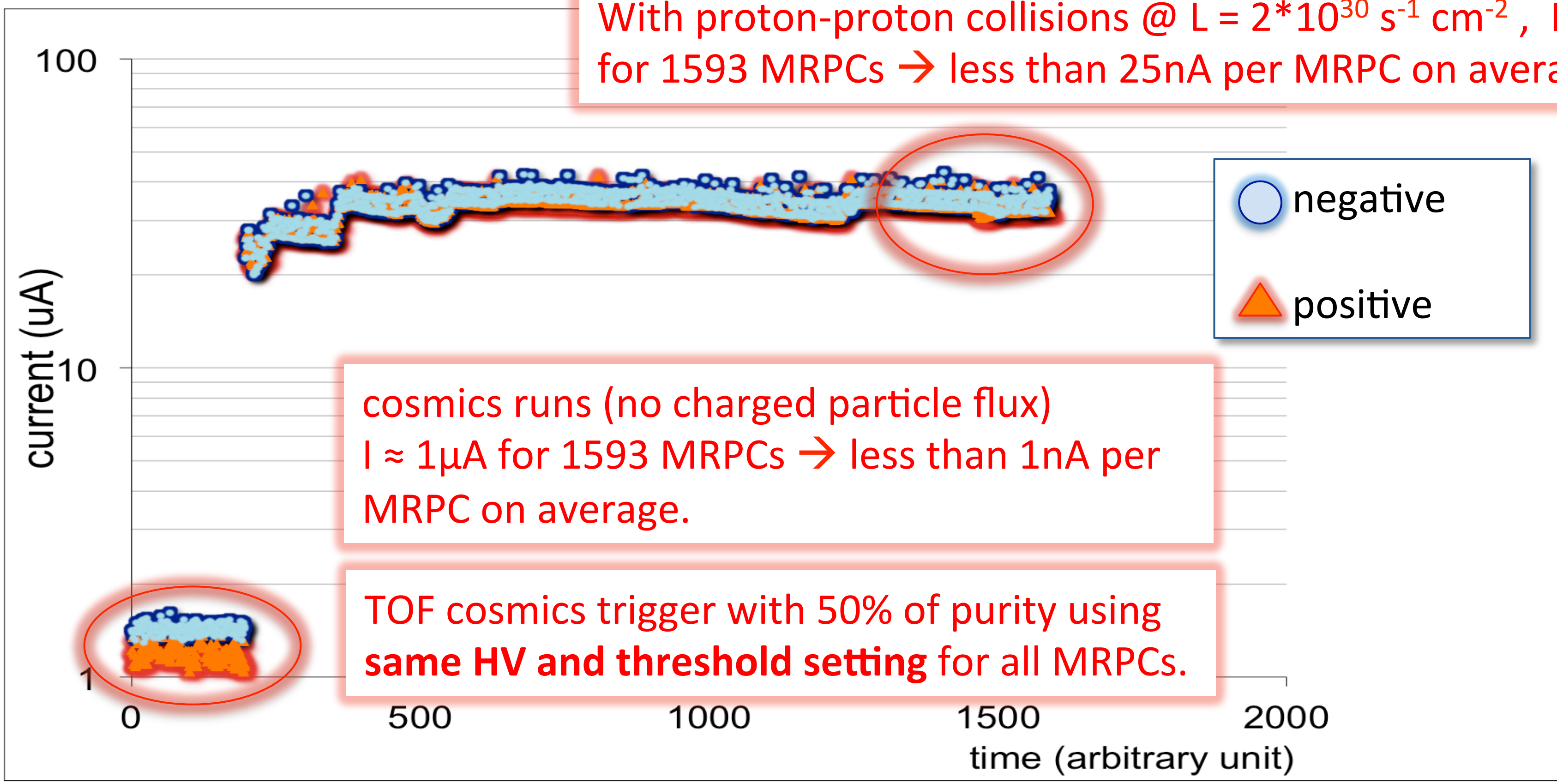
resolution < 50ps

gas mixture: 90% $C_2H_2F_4$ 5% C_4H_{10} 5% SF_6

TOF Performance in ALICE

The MRPC: dark current and ageing

Average current drawn by full TOF @ 13 kV during Summer 2011



With proton-proton collisions @ $L = 2*10^{30}\ s^{-1}\ cm^{-2}$, $I \approx 35\mu A$ for 1593 MRPCs → less than 25nA per MRPC on average

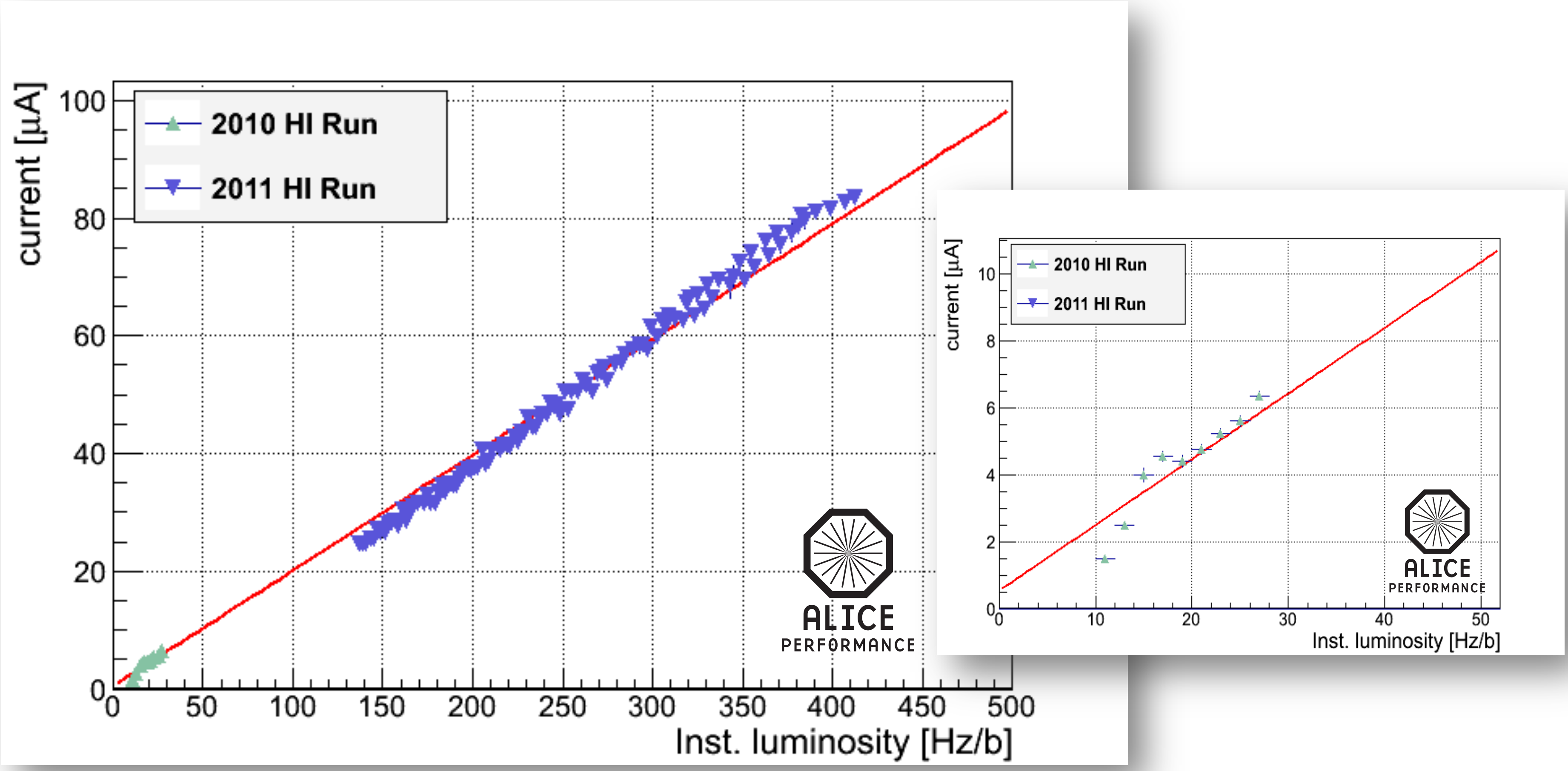
cosmics runs (no charged particle flux)
$I \approx 1\mu A$ for 1593 MRPCs → less than 1nA per MRPC on average.

TOF cosmics trigger with 50% of purity using **same HV and threshold setting** for all MRPCs.

Very small current draw by ALICE TOF MRPCs implies:
→ less ageing effects (no aging ever seen with prototypes tested for years)
→ very low noise (TOF trigger is the preferred choice for cosmics runs in ALICE)

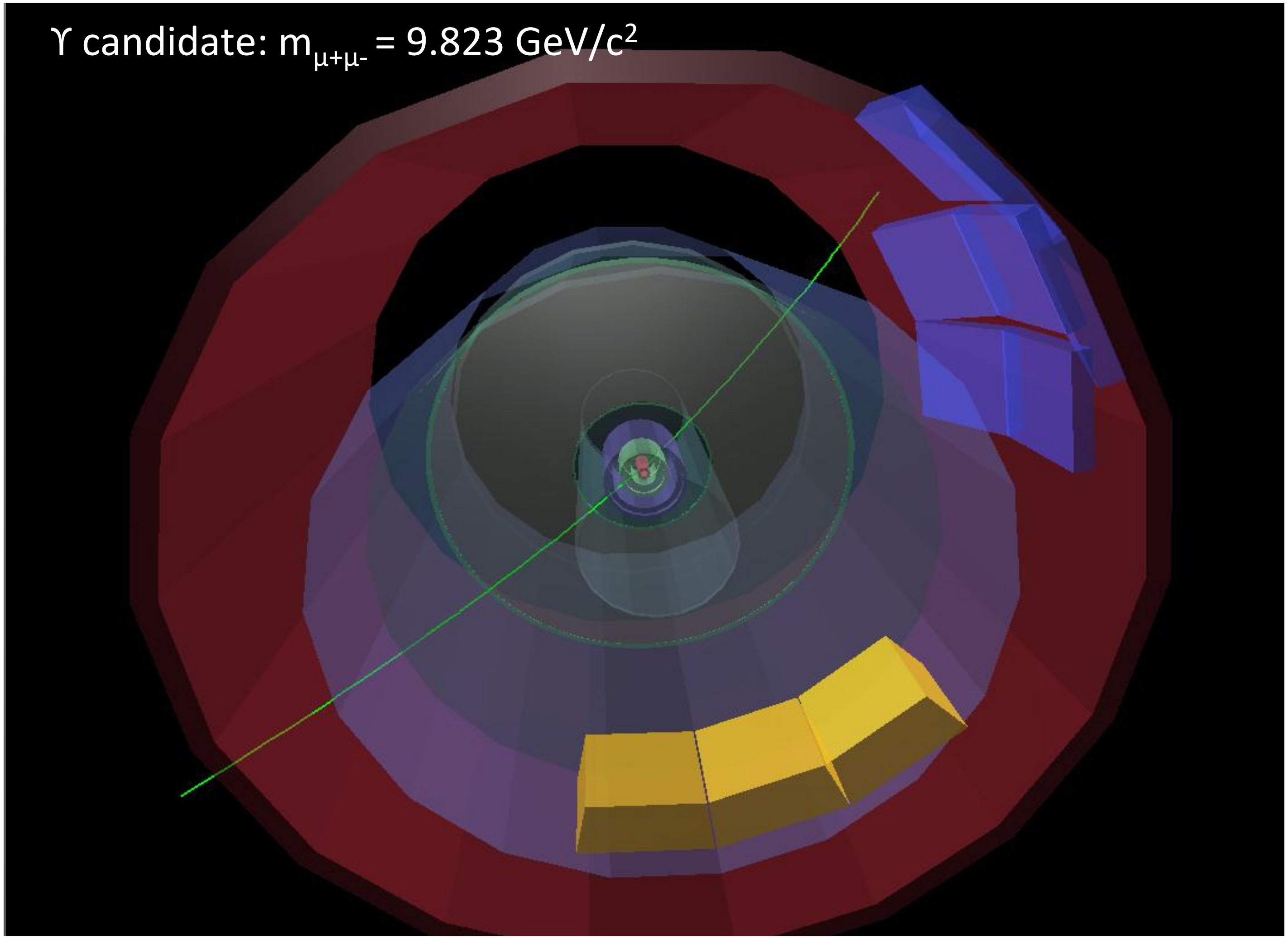
The MRPC: dark current and ageing

Average current drawn by full TOF @ 13 kV – comparison between 2010 and 2011 LHC heavy-ion run → the behaviuor of the MRPCs looks stable after one year of data taking.



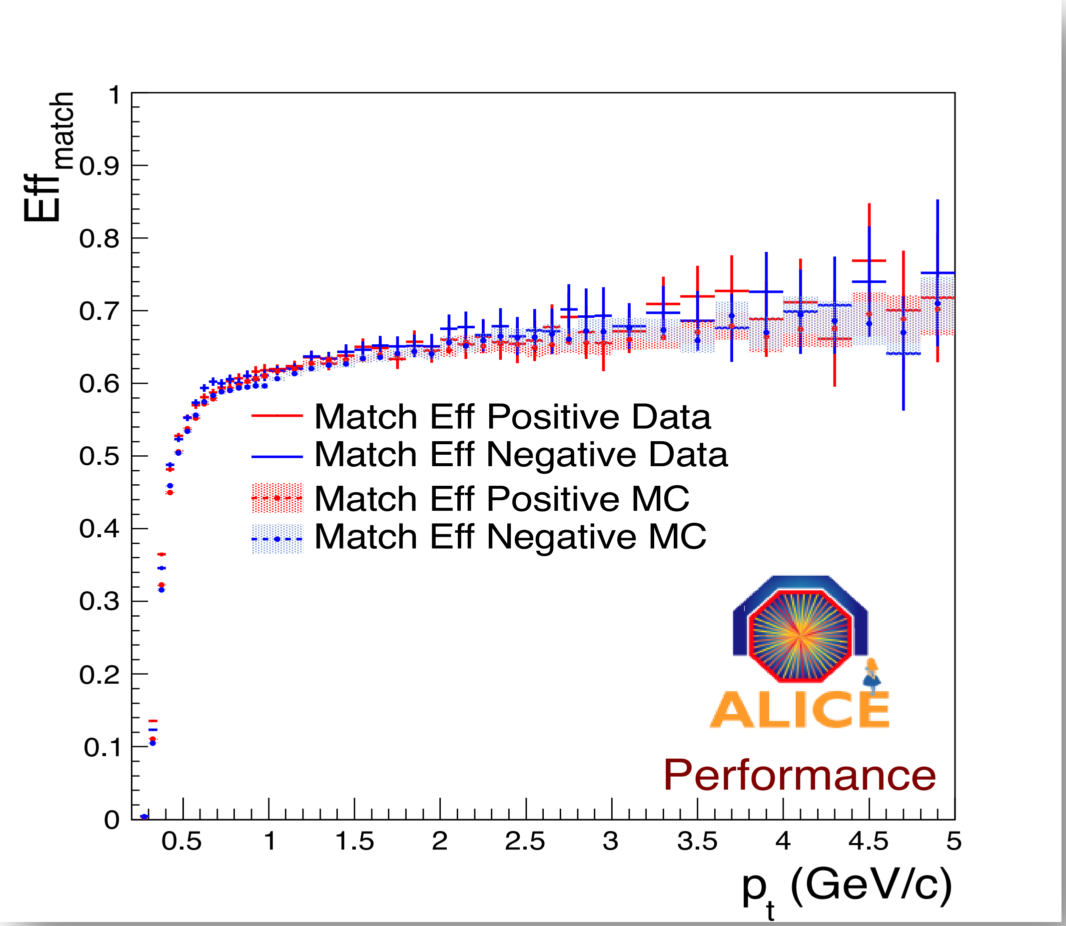
TOF as trigger detector during 2011 HI run: UPC

In Ultra Peripheral Collisions (UPC) we would expect two tracks in the central detectors with forward detectors showing no activity.



thanks to D. De Gruttola

TOF performance - efficiency



Matching efficiency includes:

- TOF efficiency
- Dead space
- Decays
- Interaction with materials
- Algorithmic inefficiency

Efficiency of the TOF matching ($\varepsilon = N_{TPC\_tracks\_with\_TOF\_signal} / N_{TPC\_tracks}$) is compared for positive and negative particles in MC sample and in data for different p_t values.

TOF detection efficiency is close to the ones declared in MC (98%)

TOF Performance – time resolution

A time-of-flight measurement always consist of two measurements: $time_{hit} - timeZero$.

the timeZero for the event (measured/estimated in different ways)

$$\widehat{PID}_{TOF} = \frac{(time_{hit} - timeZero) - time_{expected}(p, m, L)}{\sigma_{PID(TOF)}}$$

the time measurement made by the TOF detector

This is computed, during reconstruction by ALICE core central tracking ('integrated times')

$$\sigma_{PID(TOF)} = \sqrt{\sigma^2_{TOF} + \sigma^2_{timeZero} + \sigma^2_{tracking}}$$

timeZero is the time of the interaction, measured in ALICE by means of:

- dedicated Cherenkov detector (T0)
- TOF detector itself (if a certain amount of tracks is available)
- the average t_0 of LHC fill σ_Z/c (finite length of colliding bunches of particles)

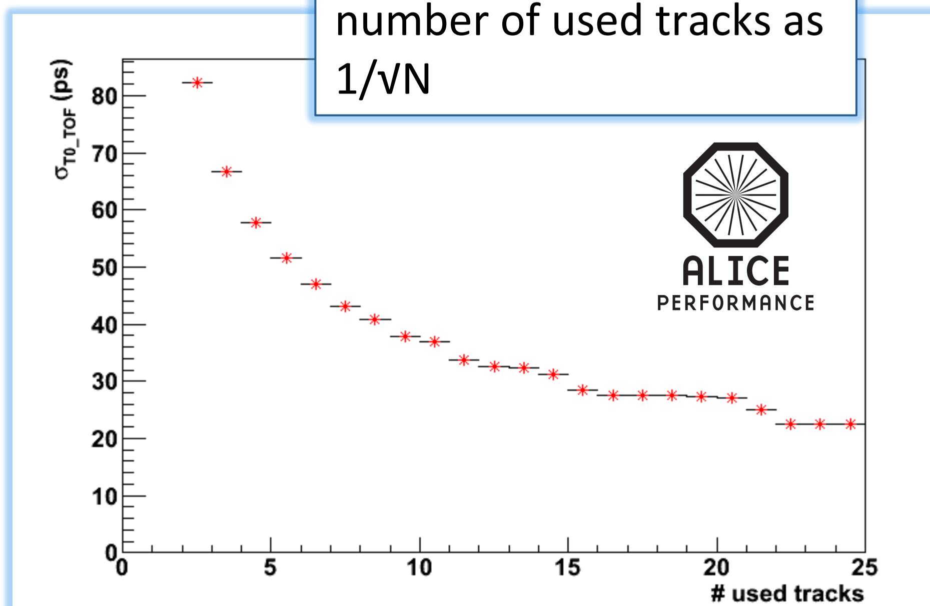
T0 with TOF detector

- we divide selected primary tracks matched with TOF in sets $C(m_1,\ldots m_N)$ (max N=10 tracks per set);
- for each track of the set we consider the 3^{N-1} possible mass configurations (track is assumed to be only π, *k* or proton) using the other N-1 tracks;
- for each mass configuration of the set we define the N-1 t^0_i and the ChiSquare using the weighted mean over all N-1 t^0_i.

$$\chi^2(C) = \sum_{i=1,\ldots N} \frac{\left[t_i^0(m_i) - \left\langle t^0(C)\right\rangle\right]^2}{\sigma_i^2}$$

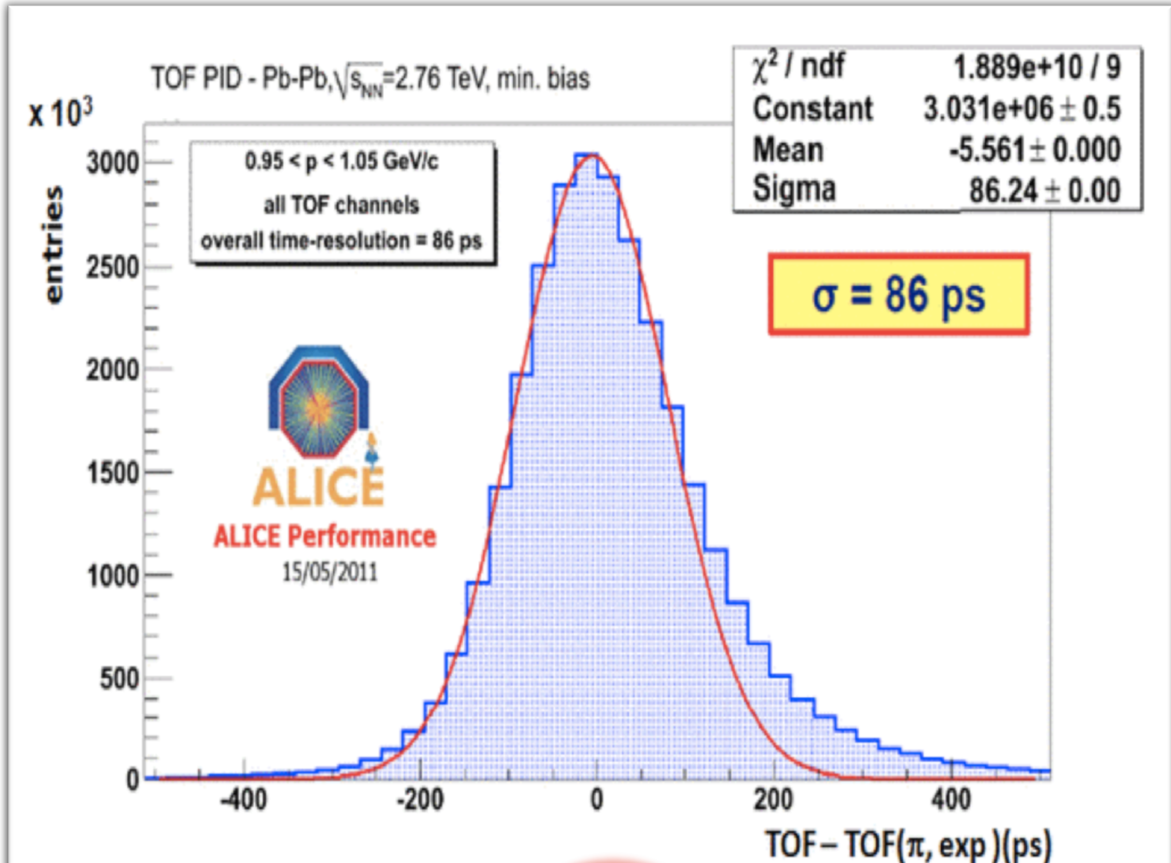
- We define the best $t^0(C)$ as the one with minimum ChiSquare.

resolution scales with number of used tracks as 1/√N



thanks to B. Guerzoni

TOF Performance – time resolution



$$\sigma_{TOF}^2 = \sigma_{Intr}^2 + \sigma_{el}^2 + \sigma_{clk}^2 + \sigma_{cal}^2$$

$$\sigma_{tot} = \sqrt{\sigma_{TOF}^2 + \sigma_{t-Zero}^2 + \sigma_{t-Track}^2}$$

In Pb+Pb:

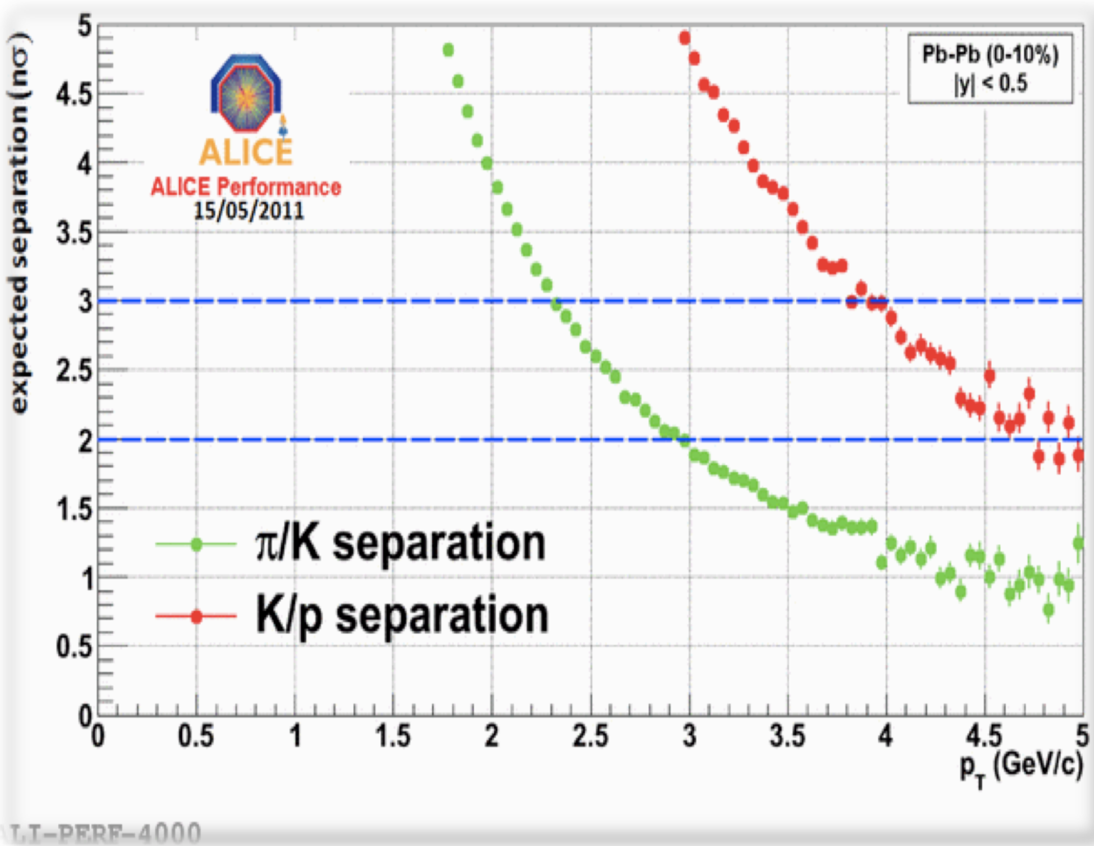
1. $\sigma_{t\text{-}Zero} \approx 10$ ps (obtained with TOF itself)
2. $\sigma_{t\text{-}Track} \approx 20$ ps

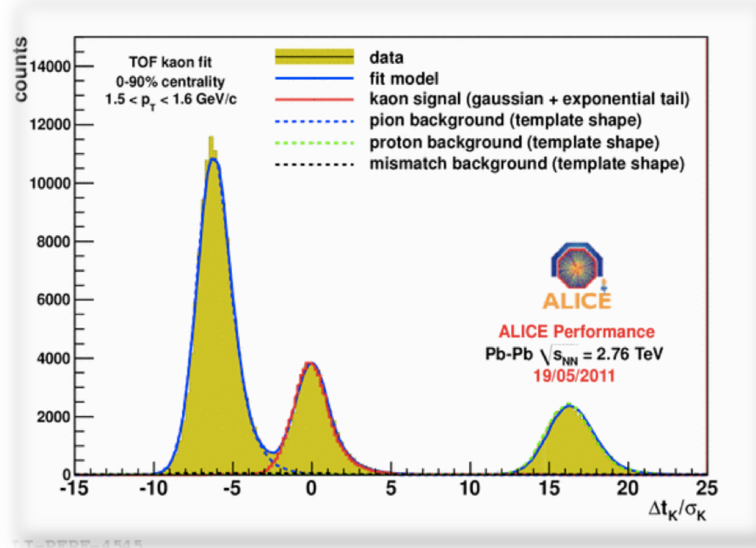
$\sigma_{TOF} \approx 80$ ps, as from Design Value

Calibration can be still improved by:

- single channel *time-slewing* corrections (finite rise time of the amplifying electronics)
- *time-walk* corrections (signal propagation delays on the pick-up pad)

TOF Performance – separation power





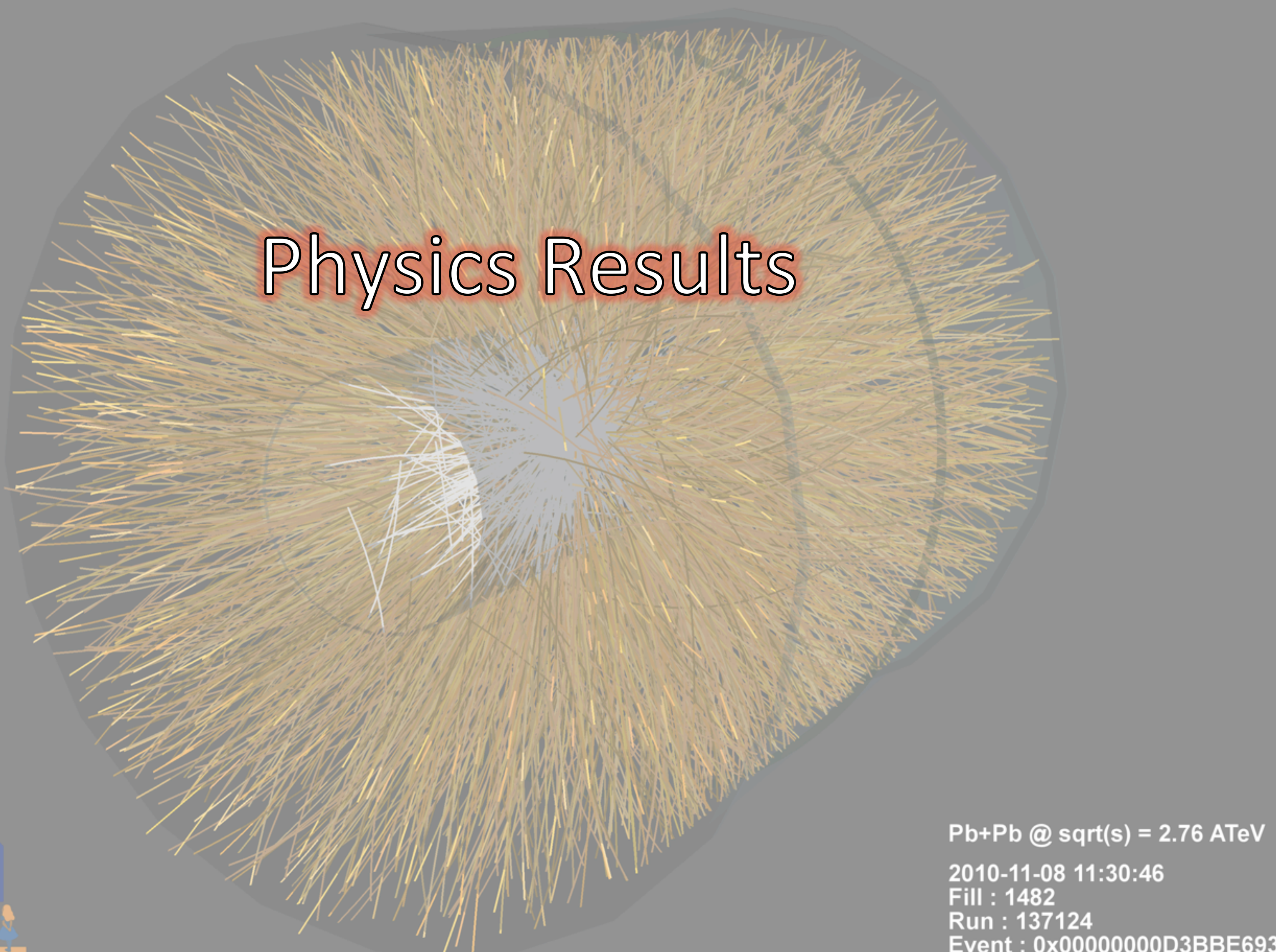
$$\frac{t_{K,\exp} - t_{\pi,\exp}}{\sigma(K)}$$

$$\frac{t_{p,\exp} - t_{K,\exp}}{\sigma(p)}$$

Expected separation for π/K and p vs transverse momentum; the plot is based on expected integrated times at TOF smeared according experimental resolution achieved in PbPb central collisions.

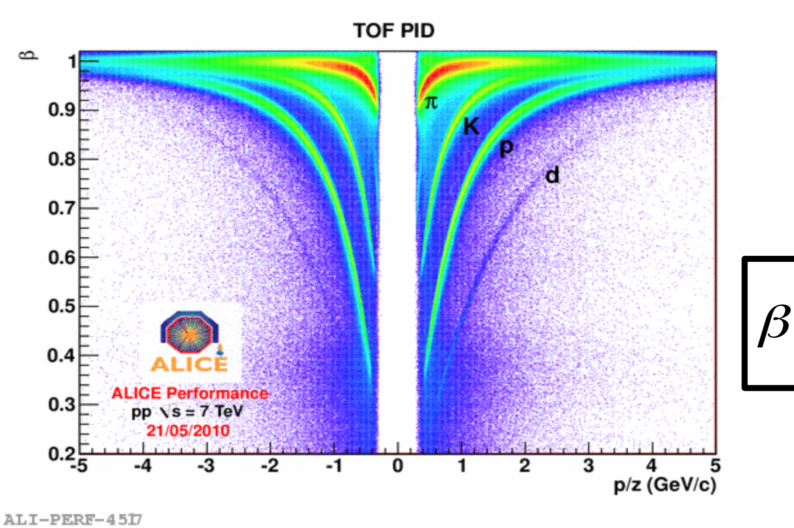
A 2σ separation is achieved up to 3 GeV for π/K and up to 5 GeV for K/p

Physics Results



TOF Performance - PID

pp collisions



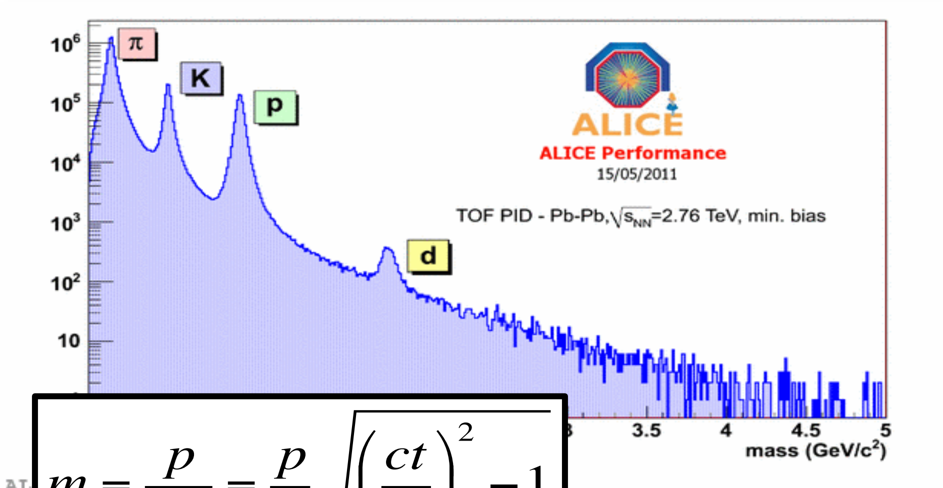
$$\beta = \frac{L}{tc}$$

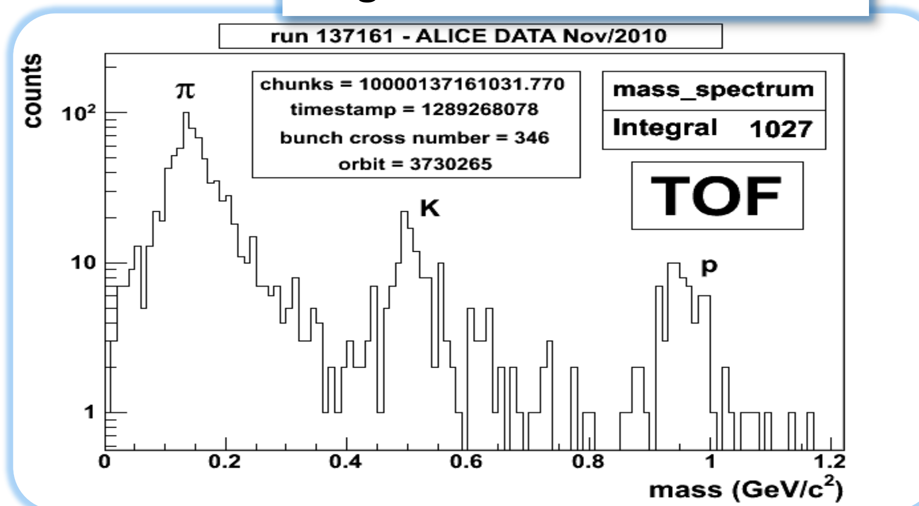
TOF measured particle β vs. signed momentum in pp collisions @ 7TeV

Different species are clearly visible

PbPb collisions

Mass distribution in one single PbPb collision!



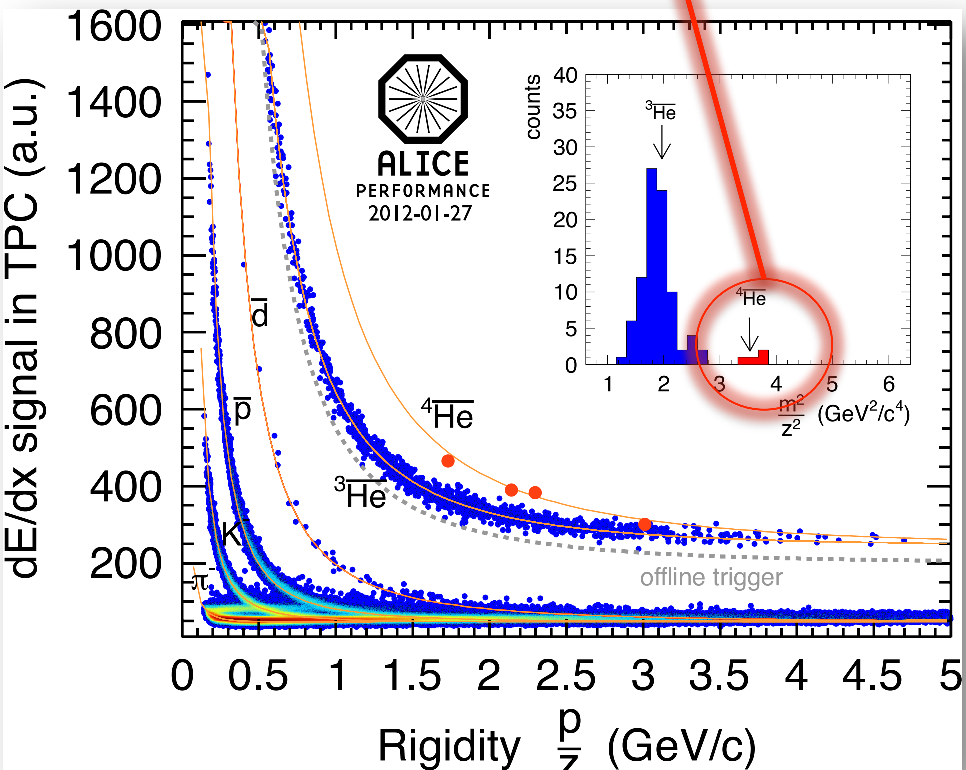


$$m = \frac{p}{\beta\gamma} = \frac{p}{c}\sqrt{\left(\frac{ct}{L}\right)^2 - 1}$$

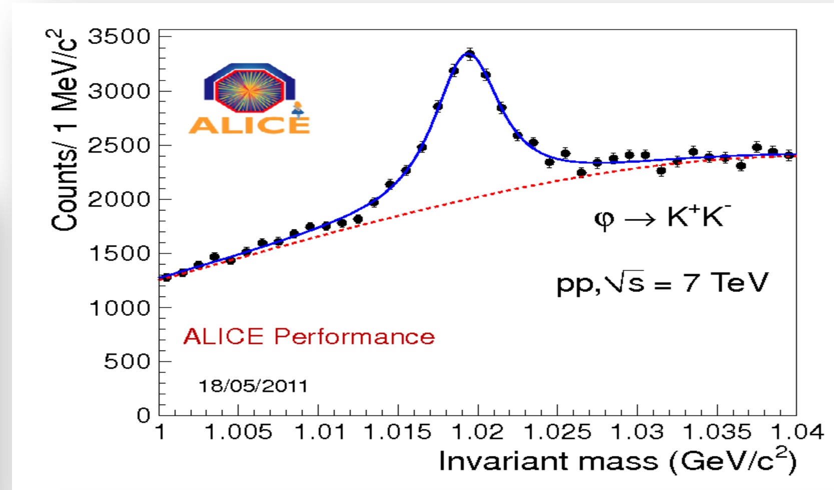
Mass spectra from TOF in Pb-Pb collisions @ 2.76 TeV

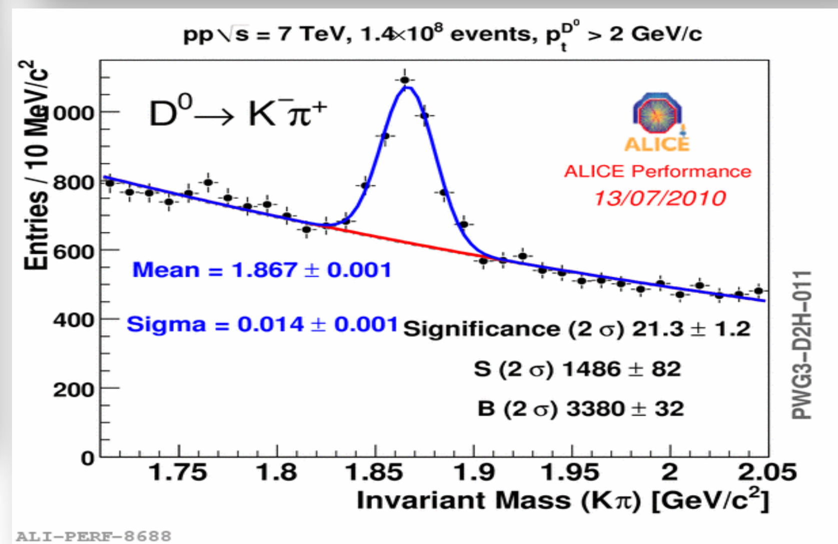
TOF Performance – combined PID

Anti matter search in ALICE: anti-alpha candidates confirmed by TOF



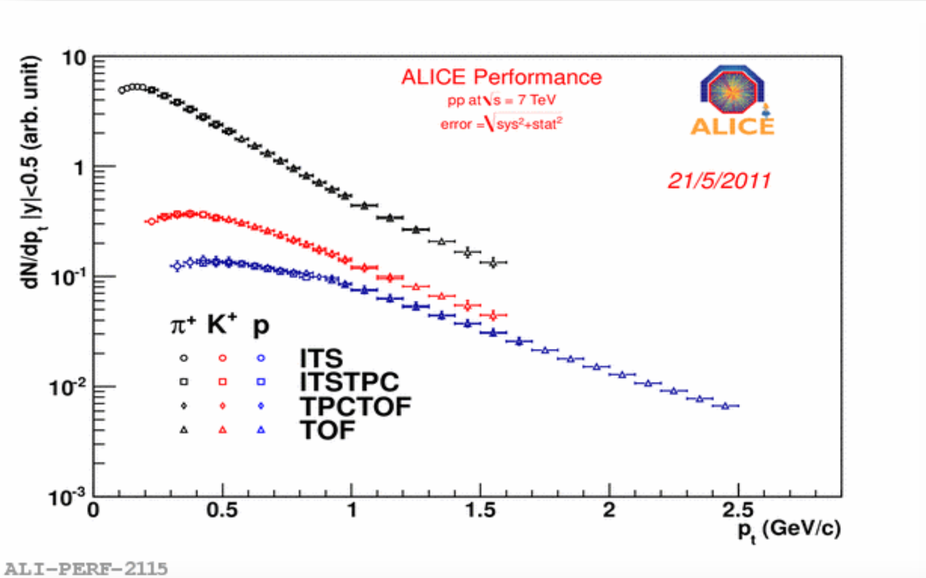
Above R=2.3GeV/c the <dE/dx> bands from (anti)^{3}He and (anti)^{4}He are overlapping and the mass calculated with the TOF is needed to separate these two species.

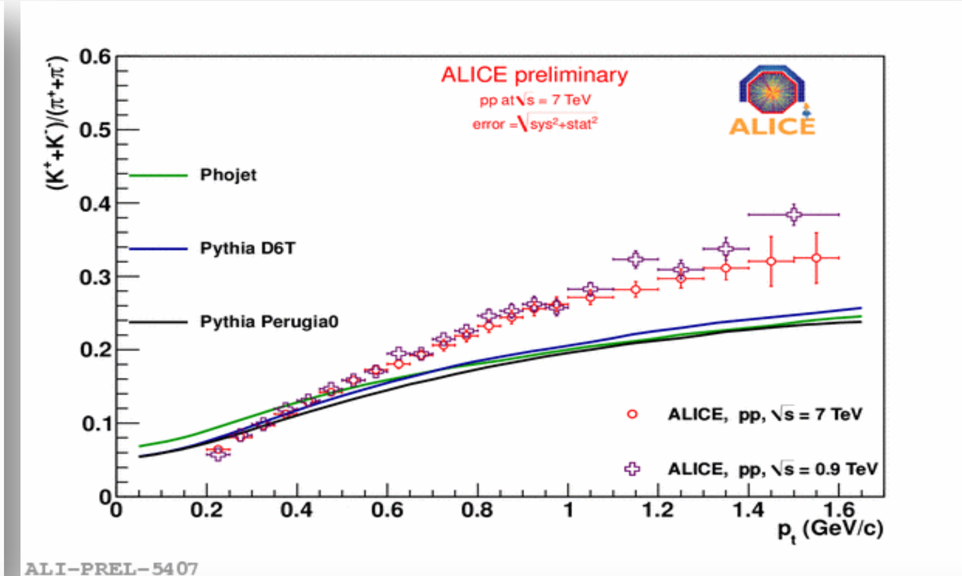


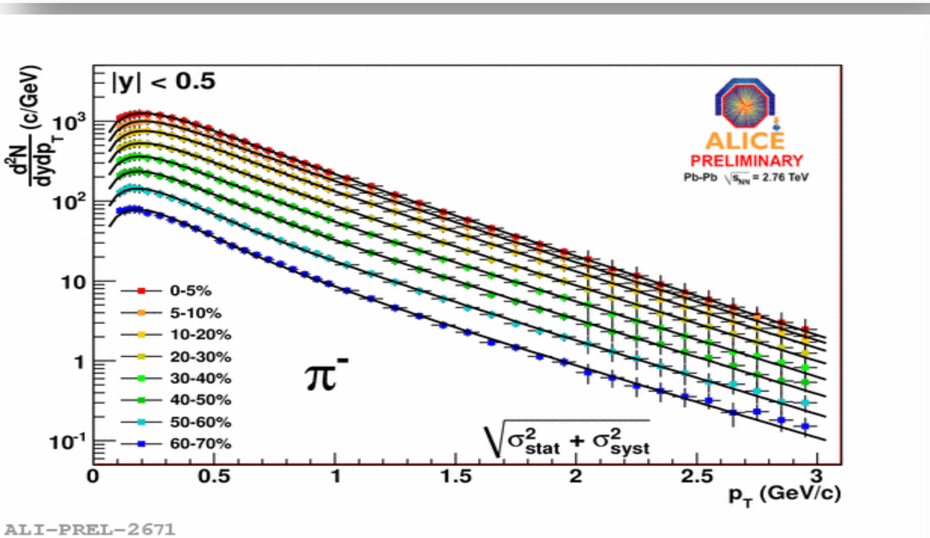


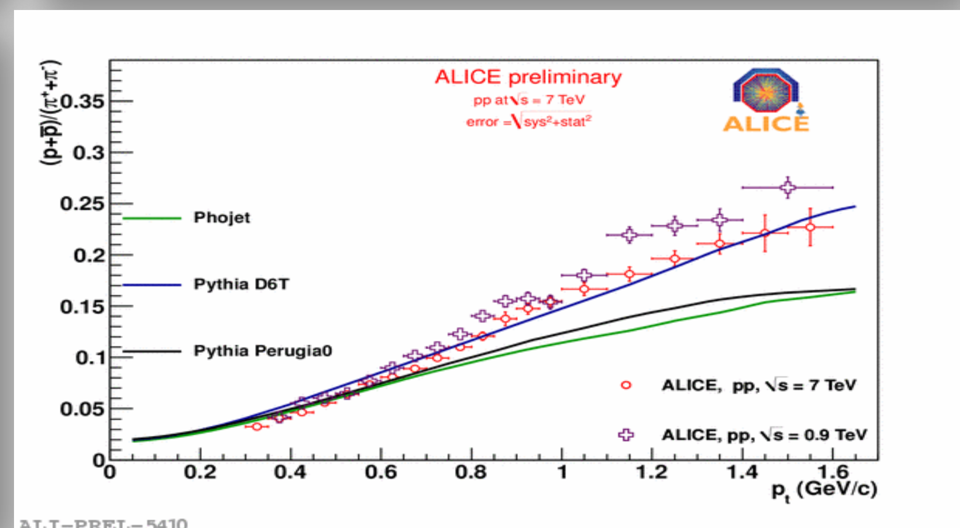
Example of resonance studies with TOF and TPC PID

TOF Performance – spectra









Spectra of identified hadrons from combined analysis.

particle ratio as a function of p_t plus MC models.

Conclusions

1. The ALICE TOF detector has been taking data since the first pp collisions recorder in ALICE in December 2009, with high performance in terms of dark current, noise, efficiency and time resolution.

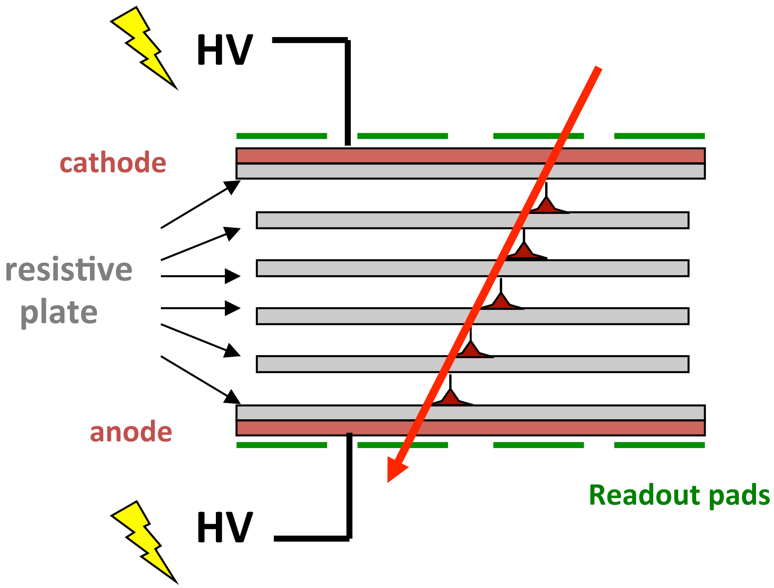
2. The performance are getting closer to the ones obtained so far at the test beam; the TOF is already able to extend the PID capabilities of the other central full-acceptance detectors (ITS and TPC) toward higher momenta.

3. During the 2010 and 2011 data taking the TOF successfully provided particle identification for both pp and Pb-Pb collisions; many analysis carried out by the ALICE Collaboration are widely using information provided by the TOF detector.

backups

The MRPC

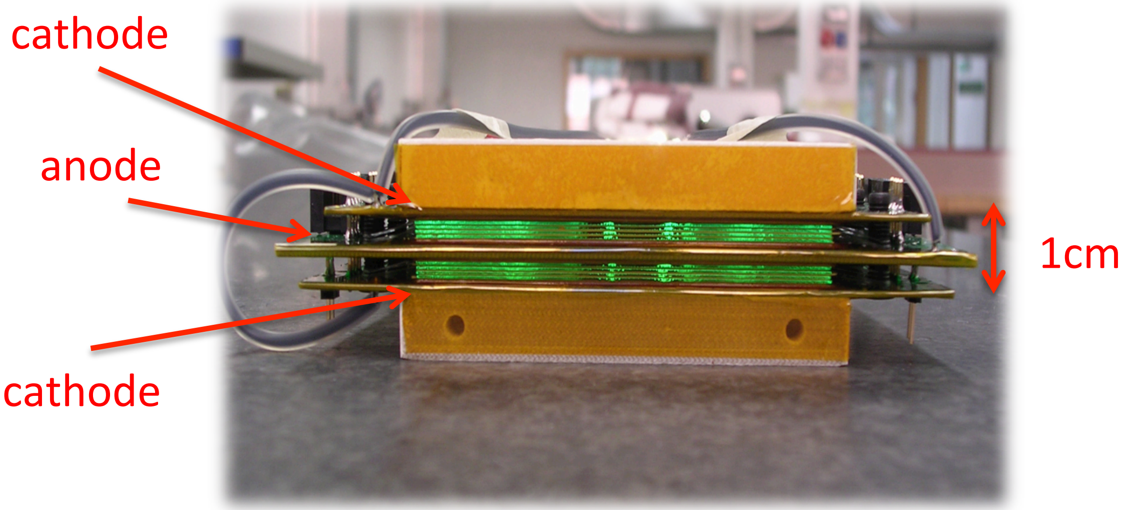
NIM A374 (1996) 132



Resistive plates are physics barriers to stop the avalanche growing too big, but they are *invisible* for fast signals; the readout signal is the sum of the signals induced in each gap.

- **High resistive electrodes** allow to apply very intensive electric fields avoiding sparks inside the gas gap.
- Dead time depends on the relaxation time $\tau=\rho\varepsilon_0\varepsilon_r$ and on the amount of charge in the avalanche; since this charge depends on the distance travelled by the avalanche as $n(x+d) =n(x)*\exp(\alpha_{eff}d)$, to ensure a good rate capability small gaps are needed.
- A serie of many gas gaps guarantees a high efficiency.

The MRPC as timing detector



Typical parameter for ALICE MRPCs are, assuming $\Delta V \approx$ 13kV and standard gas mixture →

$E \approx 100$ kV/cm

$\alpha_{eff} \approx 100\ mm^{-1}$

$v_D \approx 200\ \mu m/ns$

The key to obtain MRPCs with time resolution of few tens of ps is to have gas gaps with submillimetric size.

- **Time resolution** is determined mainly by the avalanche statistic $\sigma \approx 1/(\alpha_{eff}\, v_D)$.
- In this regime ($E \approx 100$kV/cm, very high Townsend coefficient $\alpha_{eff} \approx 100\ mm^{-1}$) the development of the avalanche is strongly dominated by space-charge effect. Space-charge field inside the avalanche reaches the same magnitude as the applied electric field, stopping the exponential develop of the avalanche → **avalanche mode** even at very high fields.

Time-of-Flight technique

Time-of-Flight measurements yield the velocity of a charged particle by measuring the particle *flight time t* over a given distance along the *track trajectory L*.

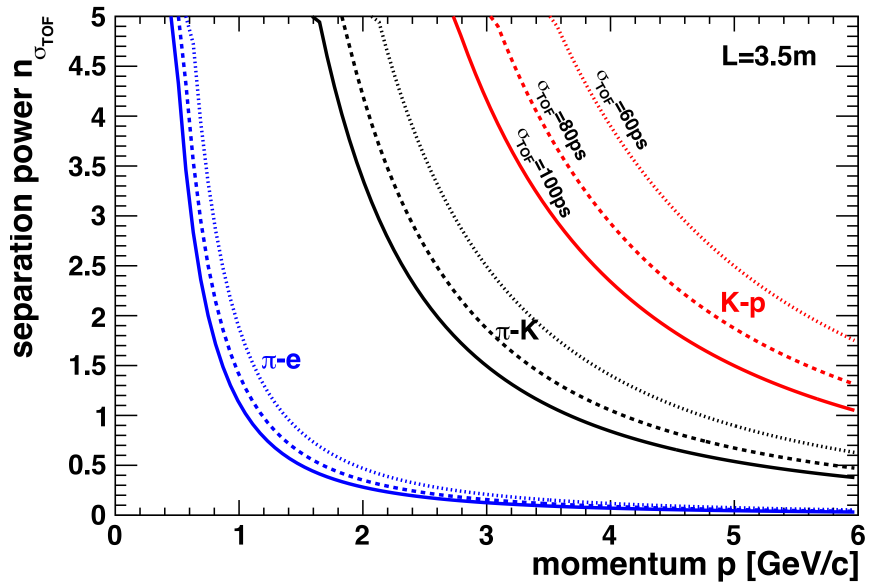
$$t_2 - t_1 = \frac{Lc}{2} \cdot \frac{(m_2^2 - m_1^2)}{p^2}$$

Error affecting the mass resolution:

$$\frac{dm}{m} = \frac{dp}{p} + \gamma^2 \left(\frac{dt}{t} + \frac{dL}{L} \right)$$

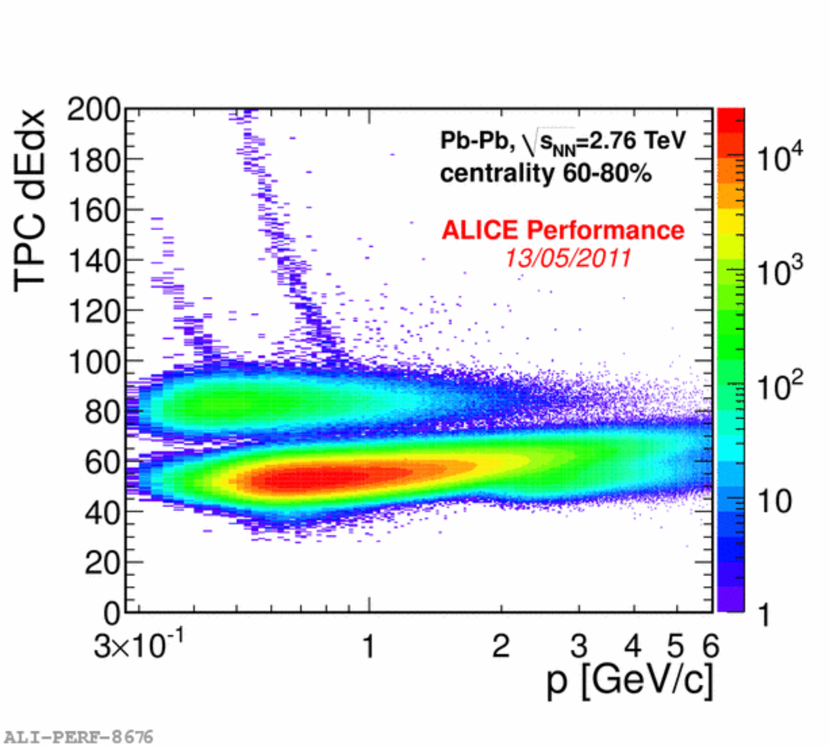
$$\sigma_{TOF}^2 = \sigma_{t_0}^2 + \sigma_{t_1}^2$$

Since in most cases γ>>1, the mass resolution is predominantly affected by the accuracies in time and length measurements.

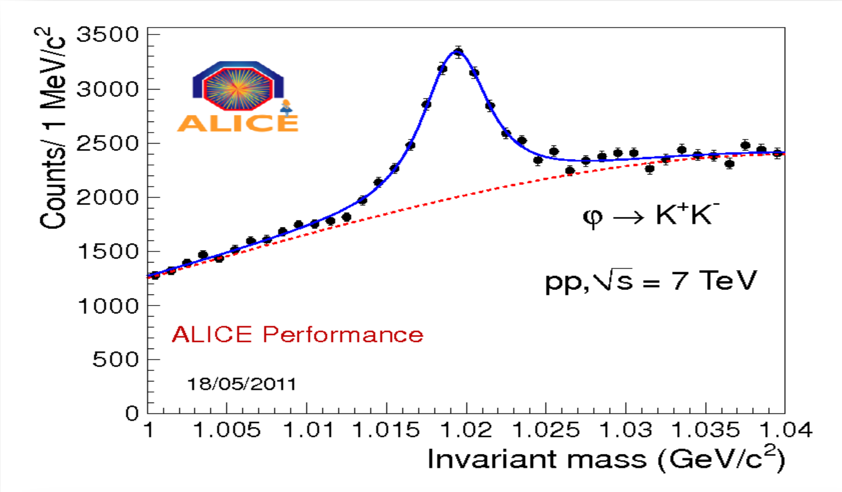


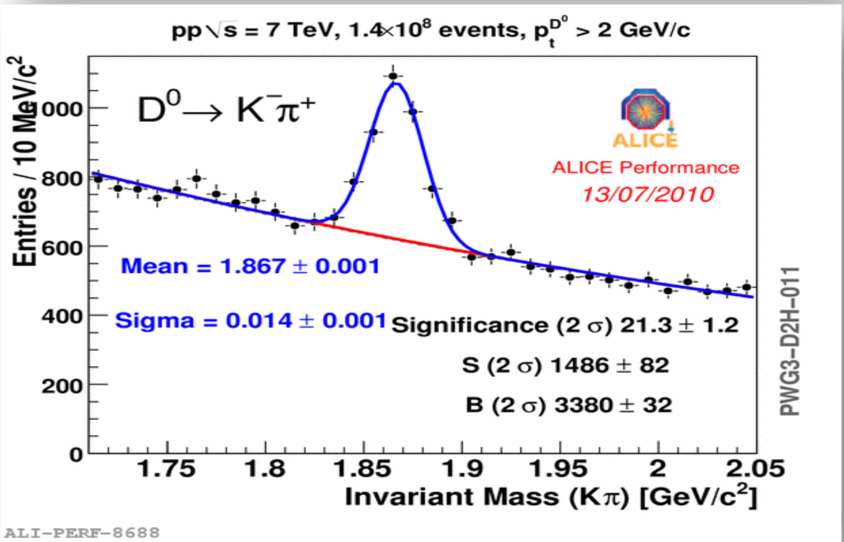
For L=3.5m, a 3σ separation for π/*K* up to 2.5 GeV/c requires a **global time resolution of 80 ps**.

TOF Performance – combined PID



TPC dE/dx vs. momentum after **TOF electron hypothesis 3σ cut** → the slower hadrons (for a given momentum) can be eliminated with a cut on the particle velocity.

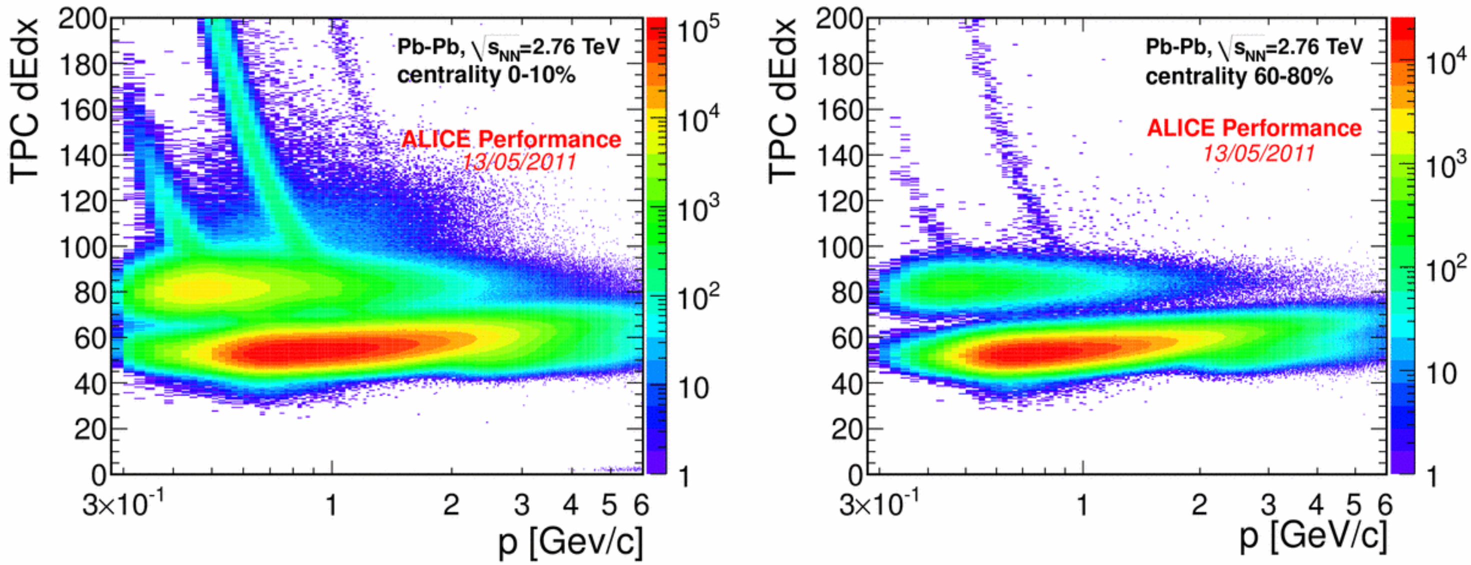




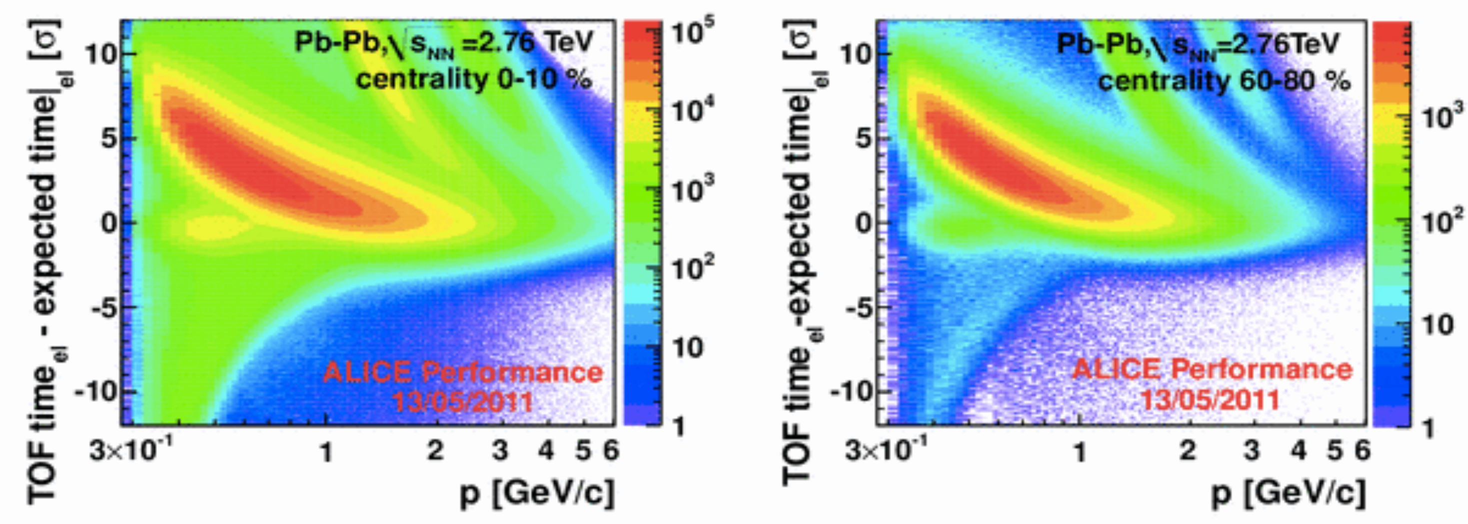
Example of resonance studies with TOF and TPC PID

TOF Performance – combined PID

TPC dE/dx as a function of momentum in central and peripheral collisions after TOF **electron** hypothesis cut (3sigma).

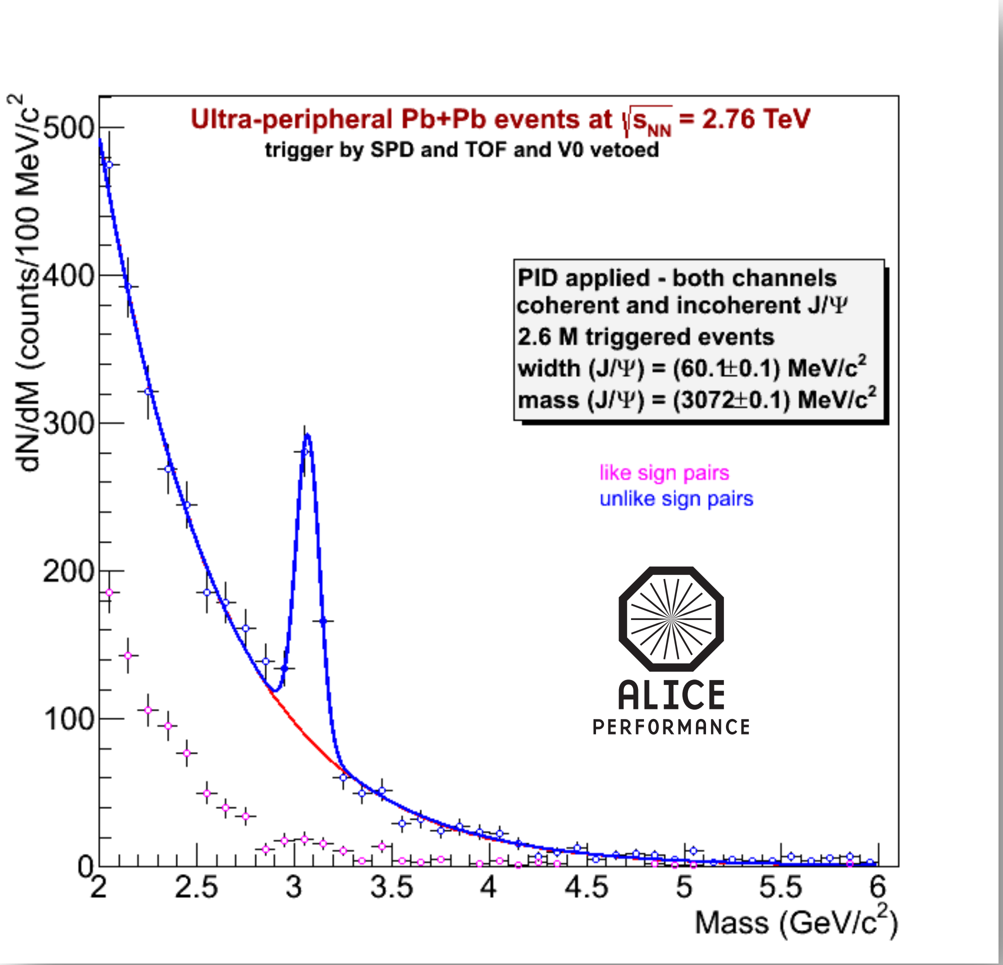


Electrons: TOF nsigma for central and peripheral events



TOF as trigger detector during 2011 HI run: UPC

In Ultra-Peripherical Collisions (UPC) two relativistic nuclei collide with impact parameter larger than twice their radius. They provide a powerful tool to study the gluon distribution function in the nuclei without hadronic background.



The UPC trigger in the ALICE barrel requires signals coming from the central detectors (ITS and TOF) while forward detectors not showing any activity.

TOF multiplicity trigger with

$2 \leq TOF_{trigger\_hit} \leq 6$

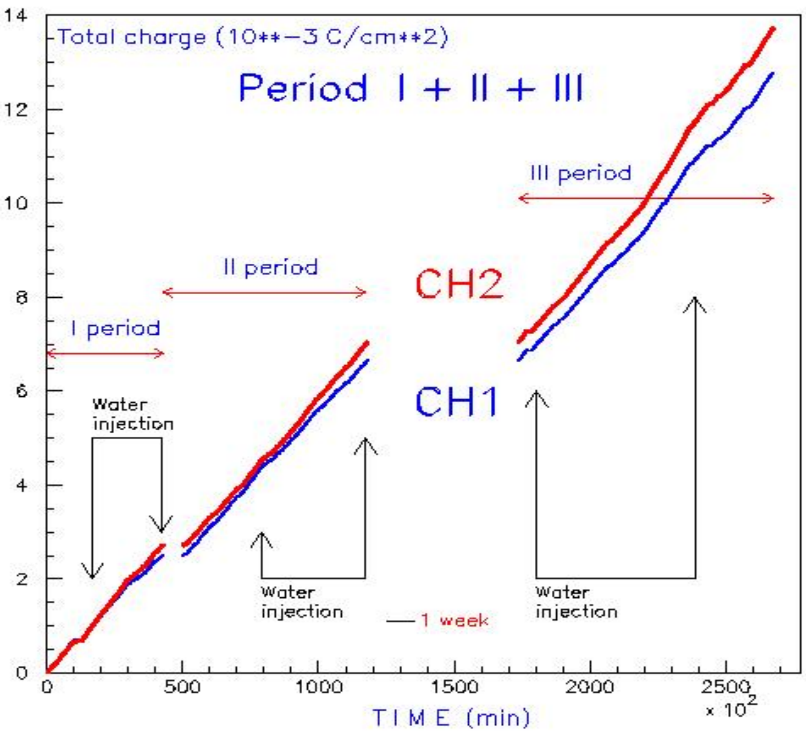
and at least two triggered tracks with

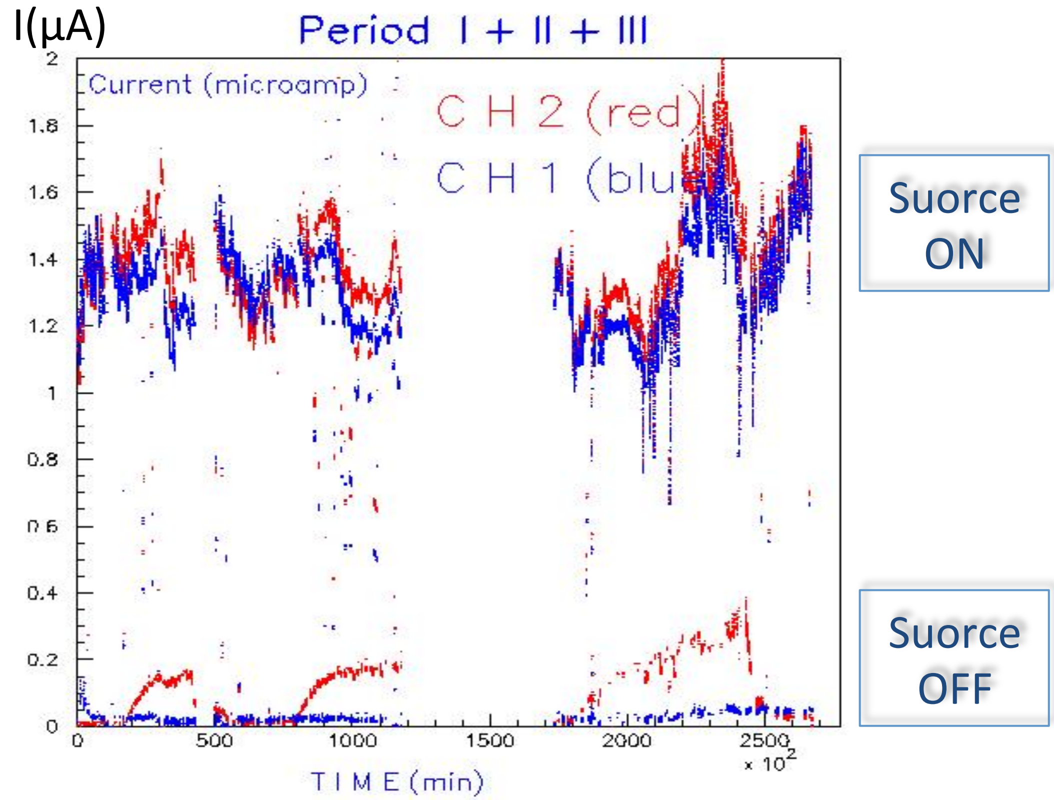
$150° < \Delta\varphi < 180°$

Trigger rate of 70-80 Hz @ luminosity L ≈ 400 Hz/b,
1000 – 1200 J/ψ founded in 8.3M triggered events.

Ageing

Two RMPCs irradiated @ GIF



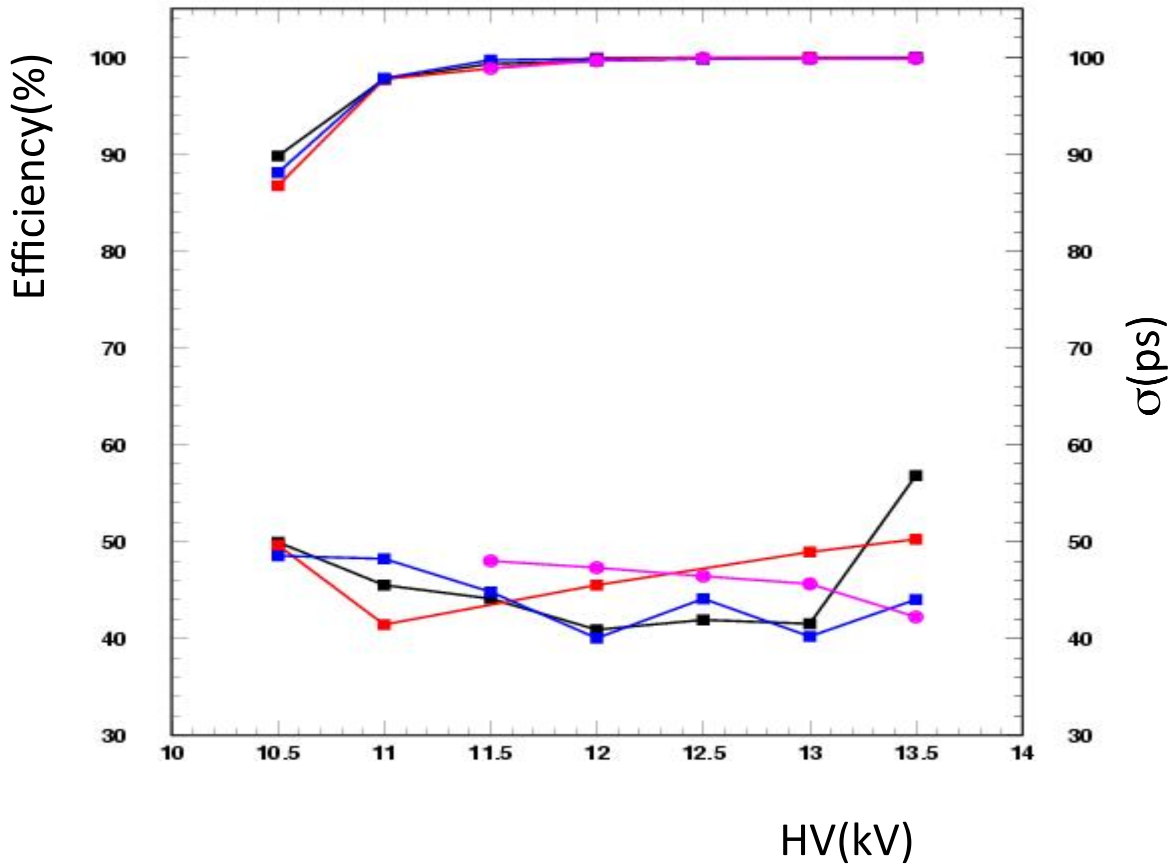


Total charge = 0.014 C/cm^2.
Average total charge per particles = 2pC
→ 7 10^9 particles/cm^2. If one assume a rate of 50 Hz/cm^2 → time = 1.4 10^8 sec = 1620 days (54 years, running ALICE at 30 days/year at full luminosity).

1. No current increase

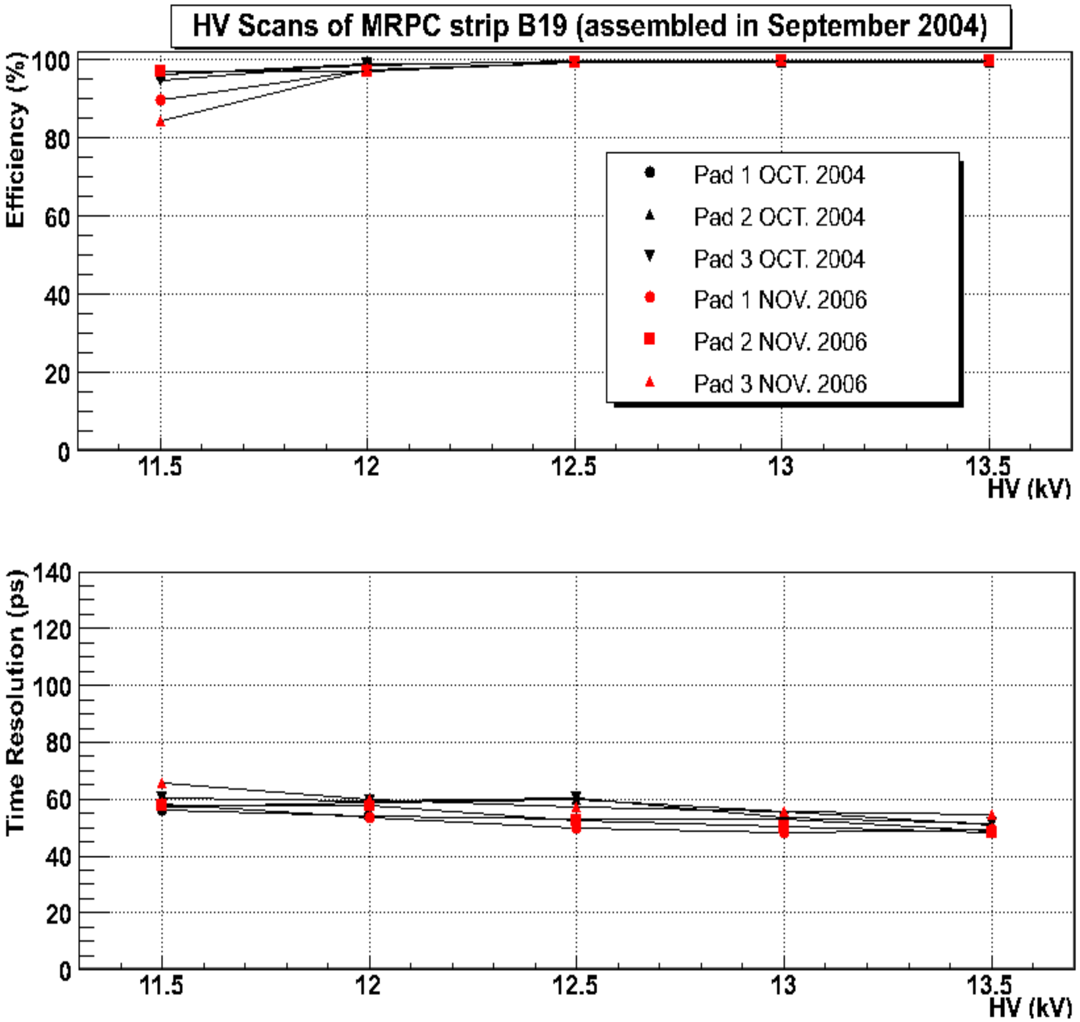
Ageing

Other 2 strips now exposed at GIF: already 0.01 C/cm^2 collected and exposed to PS-T10 beam.



2. No spoiling of efficiency and time resolution.

Ageing



MRPC strip running for 2 years in a cosmics telescope in Bologna and tested at the PS test beam facility at CERN.

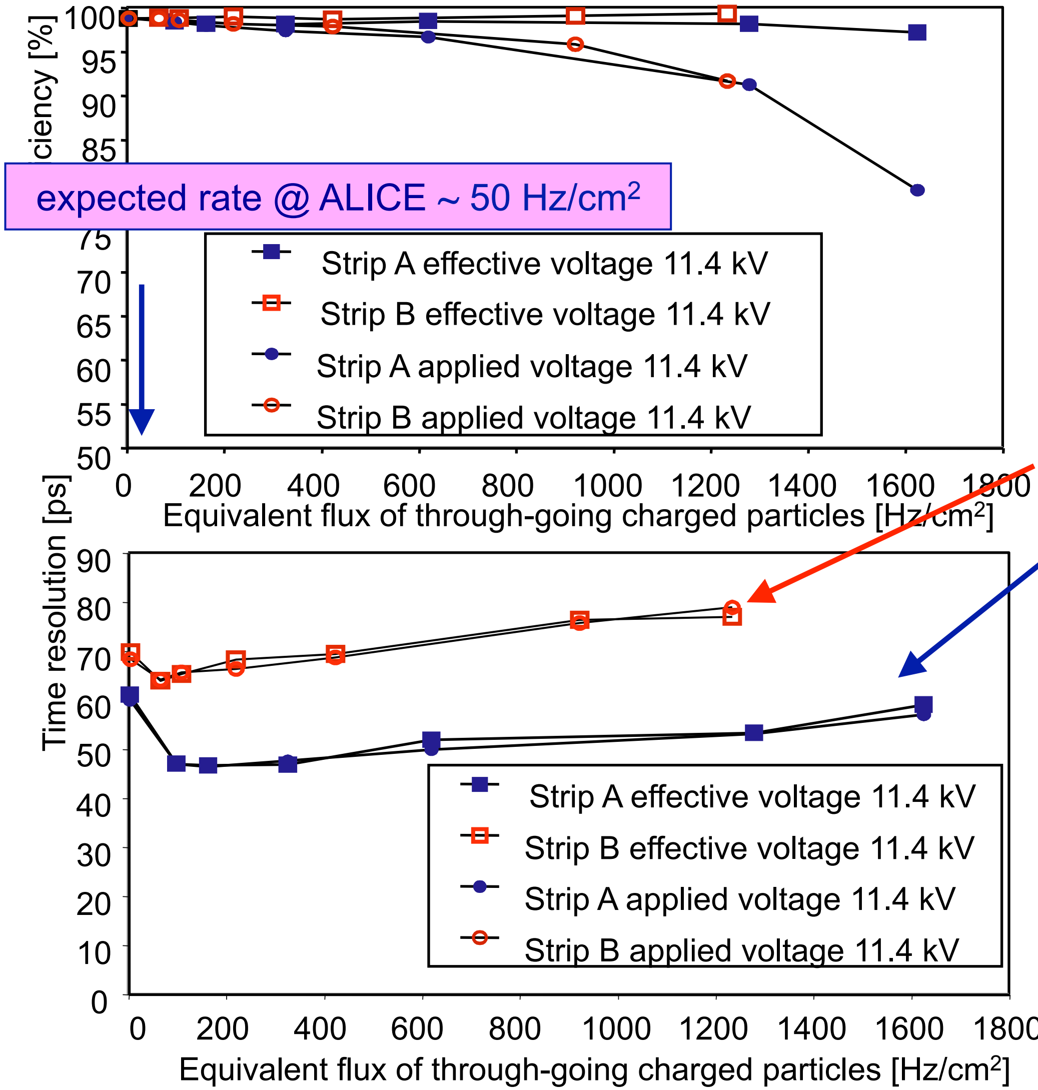
2. No spoiling of efficiency and time resolution.

Ageing

Chemical analysis (Chromatography) of the outgoing gas from both MRPCs (CH1, CH2) by CERN EST/SM-CP: measured concentration of Fluorine under the limit of detection (0.02 ppm), i.e**. no trace of HF in the sample**.

3. No HF formation

Ageing



NIM A490(2002) 58

strip B coating ~ 200 kΩ/□

strip A coating ~ 5 MΩ/□