Performance of a resistive plate chamber equipped with a new prototype of amplified front-end electronics

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XIII workshop on Resistive Plate Chambers and Related Detectors
Gent, 25/02/2016

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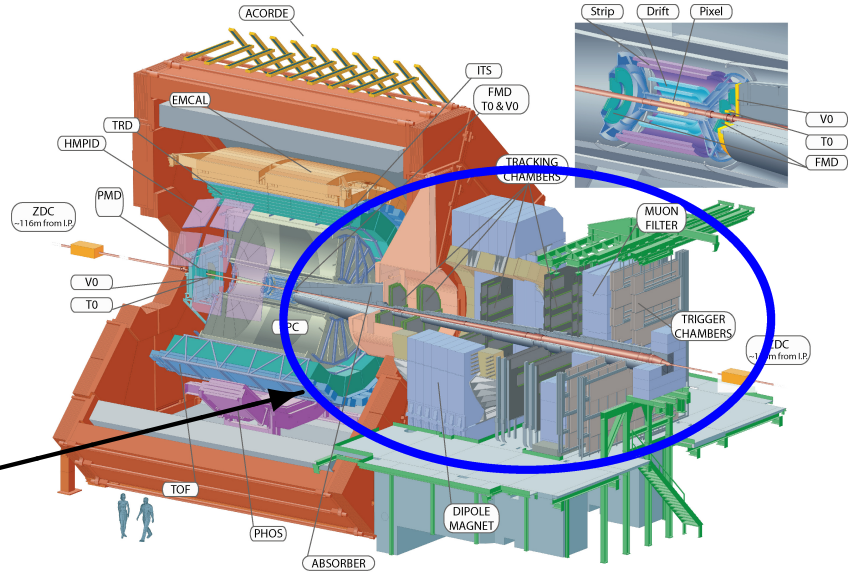
ALICE and the muon spectrometer

- ALICE is a multitasking experiment at the CERN–LHC, mainly designed to study the hot and dense matter produced in heavy-ion collisions.

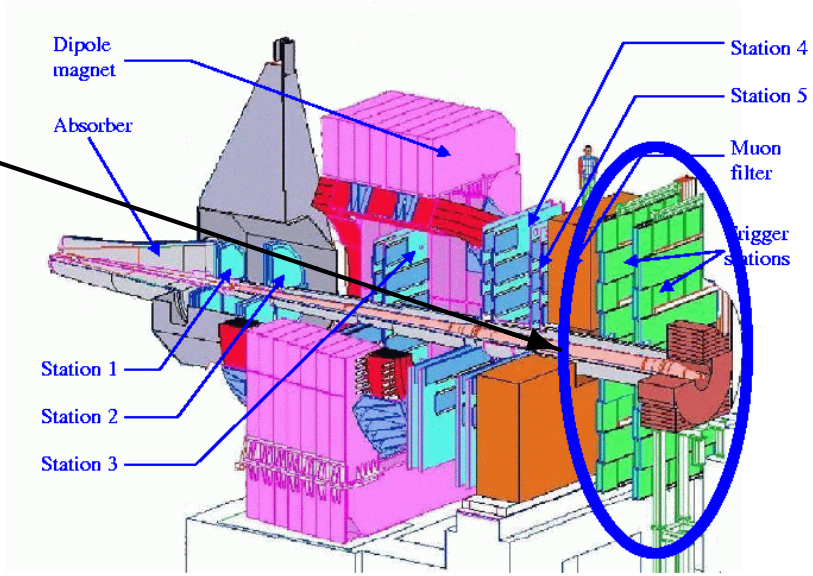
- At forward rapidity ($2.5 < y < 4$) muons are detected and reconstructed with a **muon spectrometer**.



ALICE and the muon spectrometer

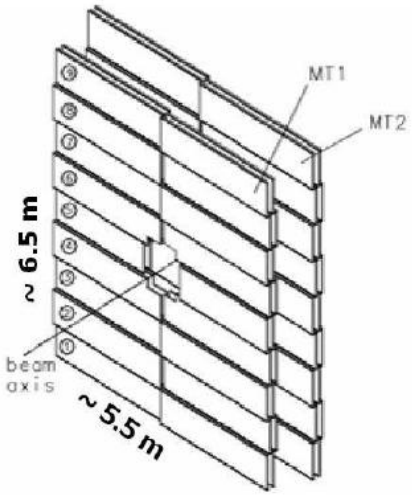
- ALICE is a multitasking experiment at the CERN–LHC, mainly designed to study the hot and dense matter produced in heavy-ion collisions.

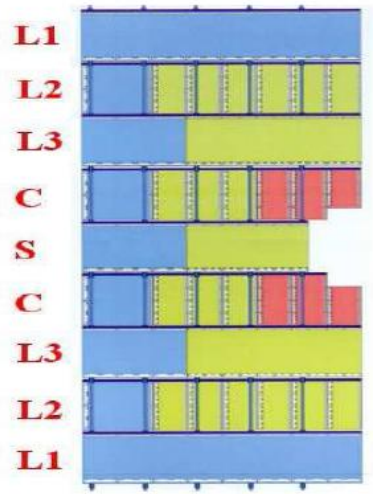
- A **muon trigger system** (MTR) selects muons based on their transverse momentum to reject background from π and K decays.



The muon trigger system

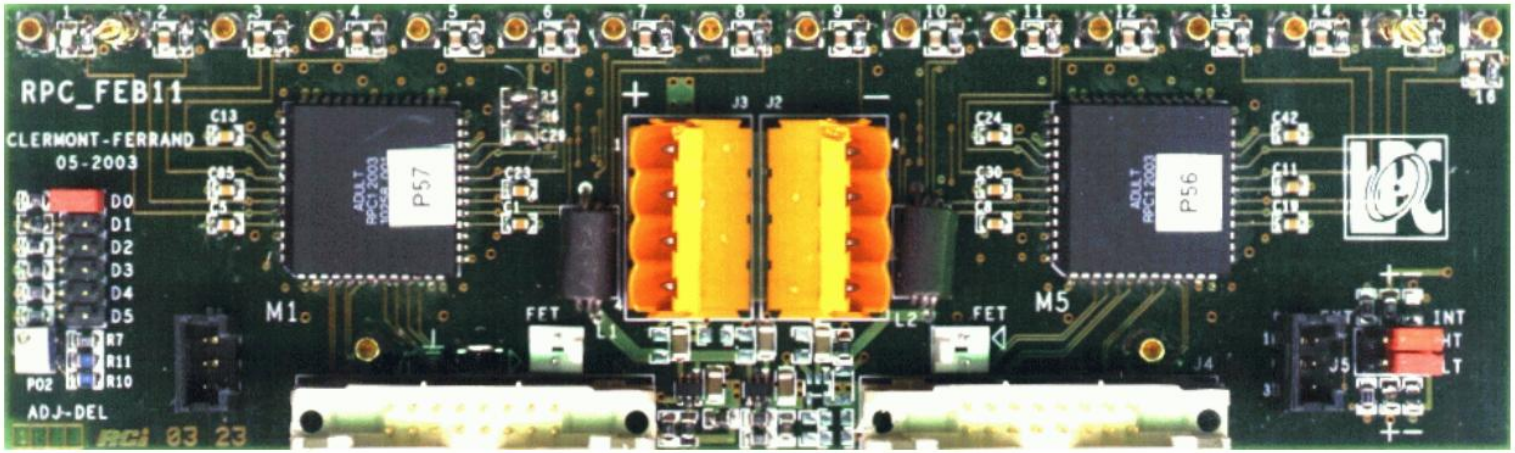
- 72 single-gap low-resistivity bakelite RPCs arranged in 4 planes.
- Read out by means of $\sim$ 21000 copper strips of different widths: 1, 2 and 4 cm.
- RPC working conditions in LHC–Run1 and LHC–Run2:





Resolution:	few mm, few ns
Electrodes material:	bakelite ($\rho \sim 10^9$ Ω·cm)
Working mode:	maxi-avalanche
Gas mixture:	89.7% $C_2H_2F_4$ – 10% C_4H_{10} – 0.3% SF_6
Relative humidity:	37%
Working point:	$10.1 \div 10.4$ kV

Present front-end electronics



Since the beginning of LHC operations, MTR has been equipped with **ADULT** (**A DUaL T**hreshold) front-end electronics:

- no amplification of the signal, only discrimination;
- symmetric threshold set at 7 mV (for most of the data taking);
- possibility to work in avalanche and streamer mode with the same FEE;
- in these conditions the average charge per hit is $\gtrsim 100$ pC (see Gabriele's presentation of Monday).

Rate limitations and upgrade of the muon trigger

- Safe operation limits in the present conditions (from R&D):

Max counting rate	Cumulative charge[1]
50 hits/s/cm^2	50 mC/cm^2

- Values foreseen for LHC–Run3 (from 2020 onwards) in Pb–Pb collision at an interaction rate of 50 kHz (times a safety factor of 2):

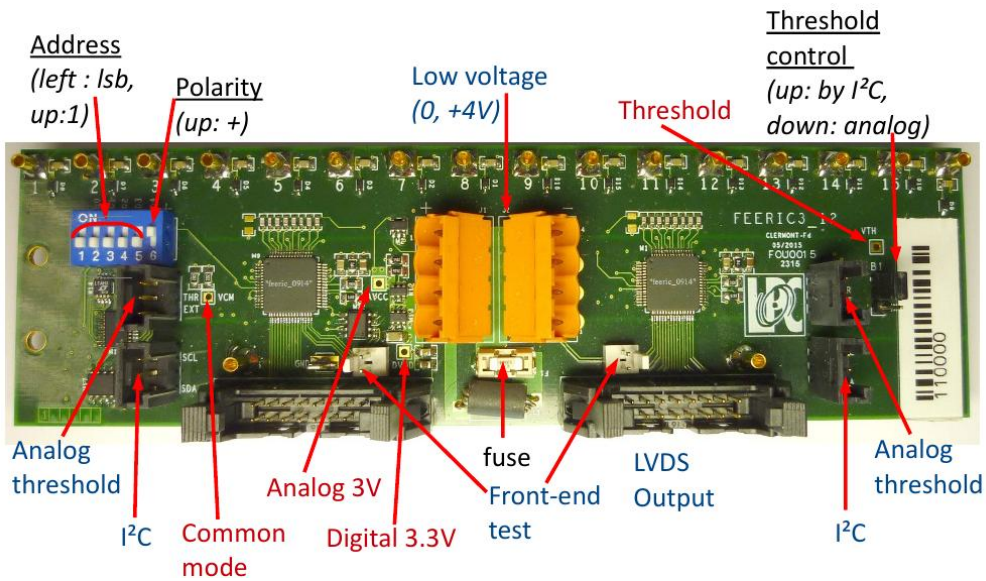
Mean counting rate	Max counting rate	Cumulative charge
75 hits/s/cm^2	125 hits/s/cm^2	100 mC/cm^2

- To guarantee safe operation in the new scenario, the charge per hit must be reduced. Target reduction is a factor $3 \div 5$.
- Possible solution: operate the RPC in avalanche mode lowering the gain $\Rightarrow$ FEE with amplification.
- An upgrade of the read-out system is also foreseen in order to deal with the increased event rate (not discussed here).

[1] Maximum charge reached in aging tests.

New front-end electronics: specifications

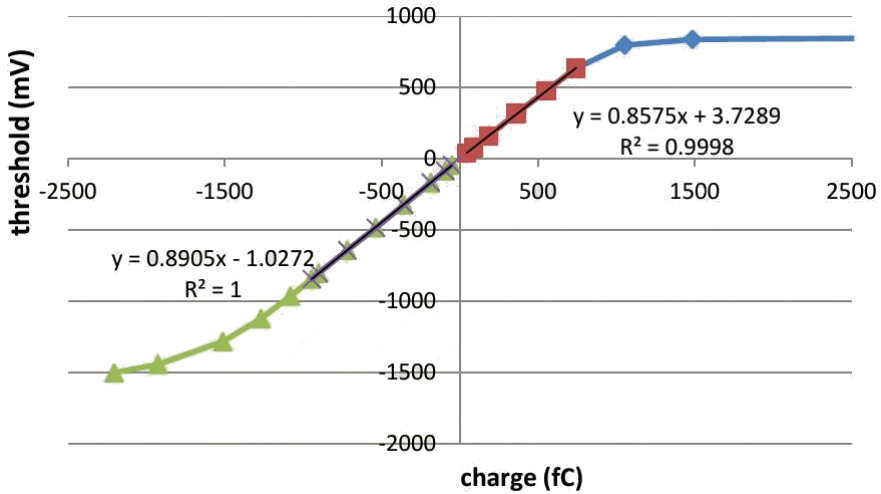
- **FEERIC** (**F**ront-**E**nd **E**lectronics **R**apid **I**ntegrated **C**ircuit).
- R&D started in 2012: 3 different versions developed at LPC of Clermont-Ferrand (France).
- Main functions: amplification, discrimination, LVDS output.
- Possibility to set thresholds remotely.



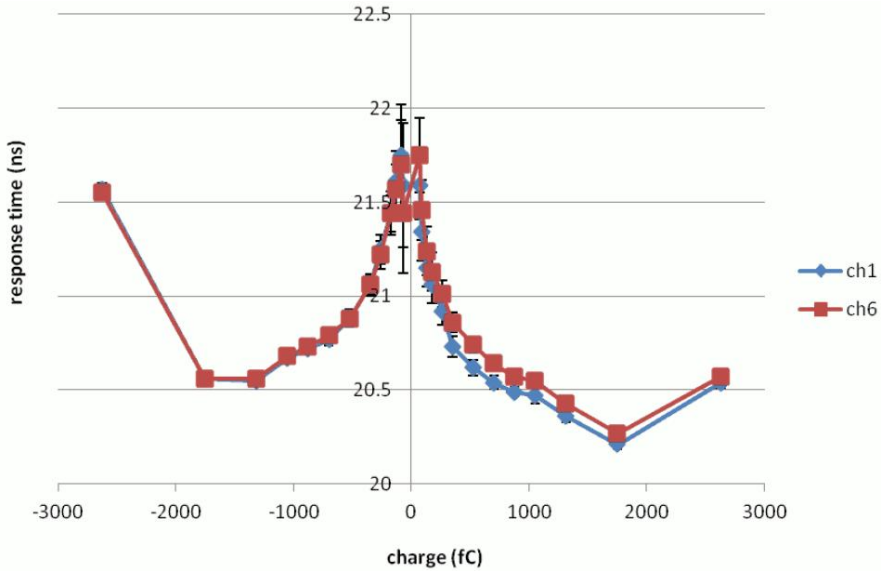
ASIC technology	0.35 µm CMOS
Number of ch.	8
Input polarity	±
Dynamic range (linear gain)	q < 1 pC
Input noise (rms)	< 2 fC
Power cons.	< 100 mW/ch
Power supply	3 V
One-shot	100 ns
Time jitter (rms)	< 1 ns for q > 100 fC
Time walk	< 2 ns for q > 100 fC
Output format	LVDS, 23±2 ns
Gain	1 mV/fC

New front-end electronics: performance

- Direct gain of ~ 0.86 mV/fC in the range ± 1 fC.

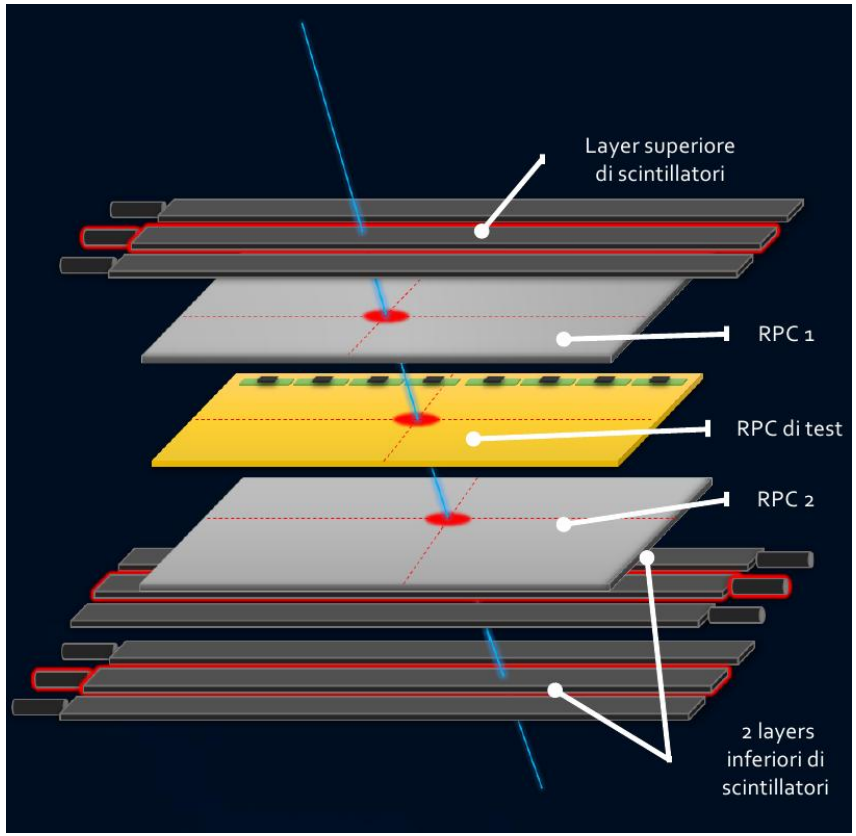


- Response time $20 \div 22$ ns, with a jitter of < 200 ps for $q = 200$ fC.
- Cross-talk $< 2\%$.

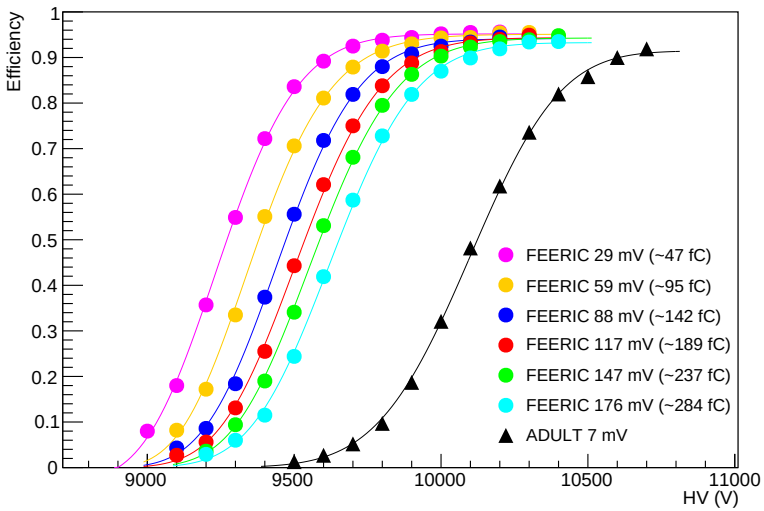


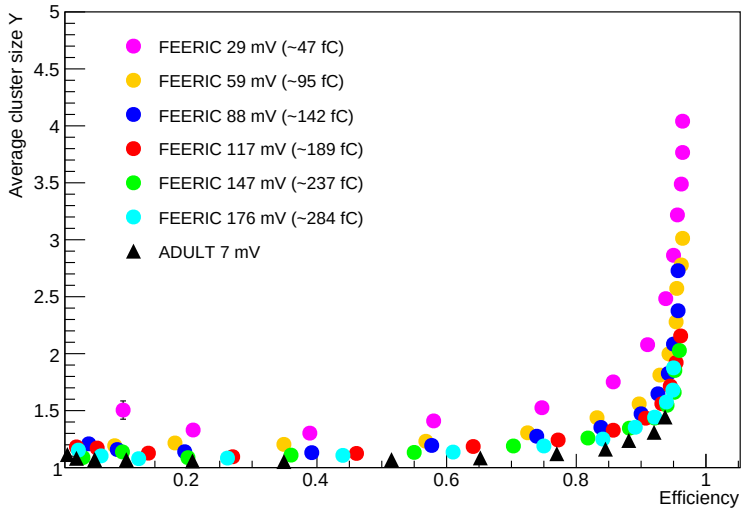
Turin test bench

- One RPC equipped with FEERIC has been tested with cosmic rays.
- Experimental setup in Turin (Italy)
  - three arrays of scintillators as cosmic-ray trigger;
  - two RPCs for tracking.
- RPC equipped with strips of 2 cm.
- Same gas mixture employed in ALICE.
- Study of efficiency and cluster size vs HV for different thresholds.



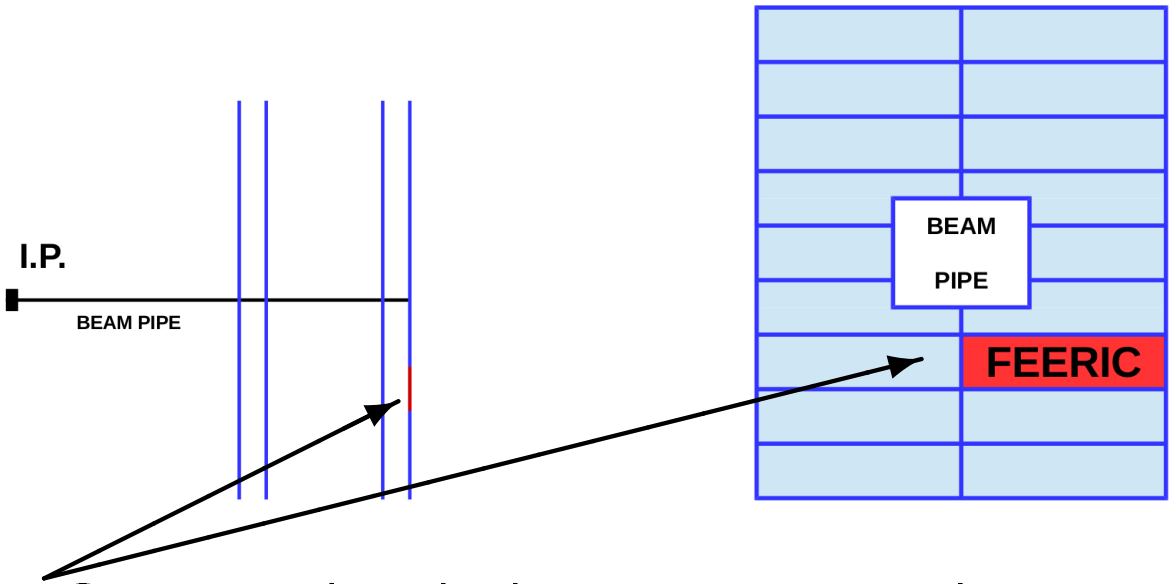
First results with cosmic rays





- Comparison of the two electronics: ADULT FEE and FEERIC.
- The gain in HV with the new FEE with respect to ADULT is around $700 \div 800$ V (depending on the threshold).
- The cluster size increases with decreasing thresholds and is slightly higher than one measured with a non-amplified FEE ($\Rightarrow$ different signal distribution).
- Caveat: working point in Turin (~ 10700 V) is different than the working point at CERN due to different pressure.

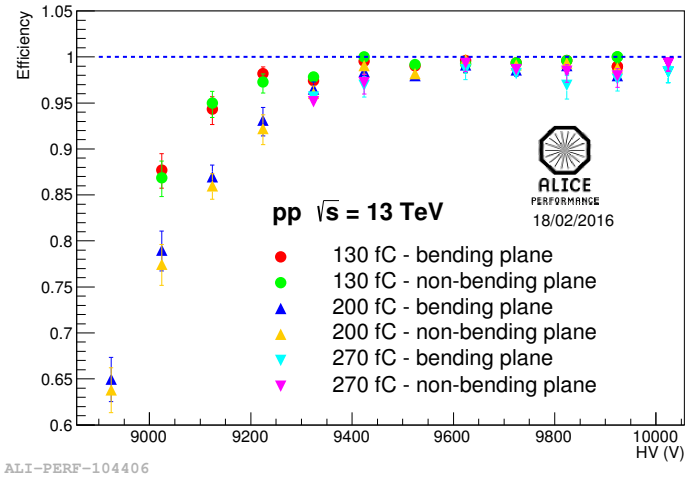
FEERIC in ALICE

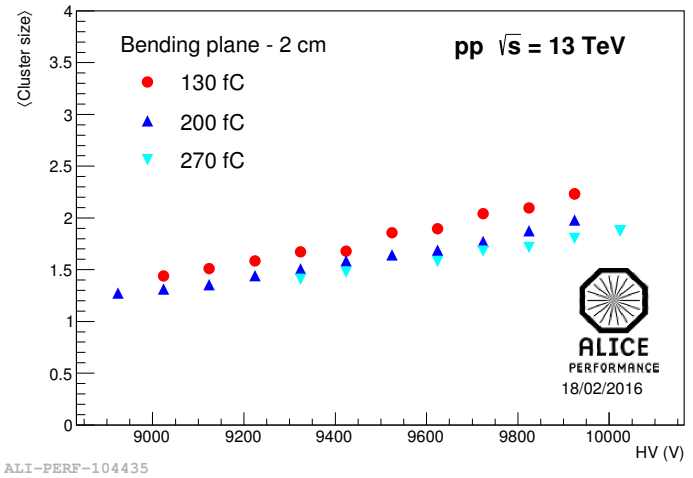


- One RPC equipped with the new FEE in February 2015 (4^{th} plane).
- Strips of 2 and 4 cm (horizontal and vertical).
- Same gas mixture and humidity as other RPC.
- Data collected throughout 2015:
  - pp collisions at $\sqrt{s} = 13$ TeV ($\mathcal{L}_{max} = 5 \cdot 10^{30}$ Hz/cm^2);
  - pp collisions at $\sqrt{s} = 5$ TeV ($\mathcal{L}_{max} = 2 \cdot 10^{30}$ Hz/cm^2);
  - Pb–Pb collisions at $\sqrt{s_{NN}} = 5$ TeV ($\mathcal{L}_{max} = 10^{27}$ Hz/cm^2).

Choice of the working point

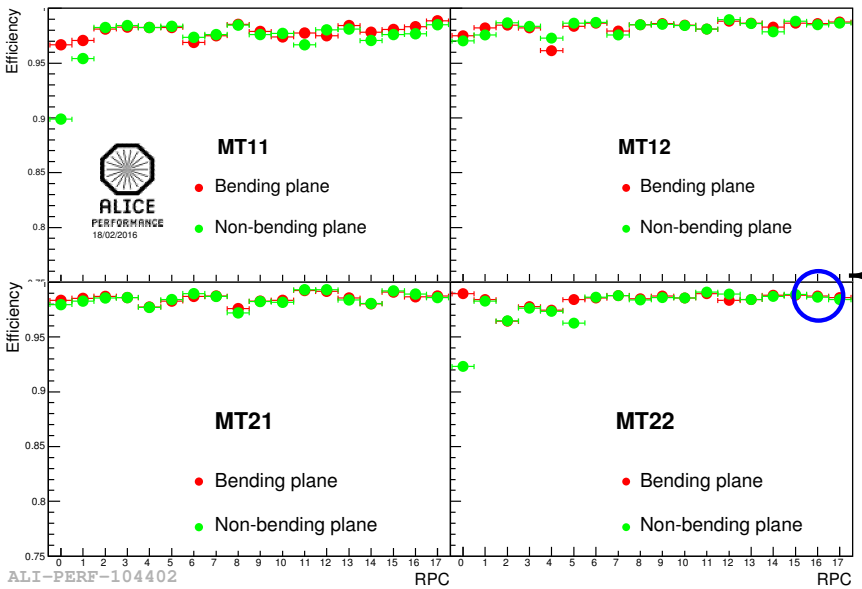
- HV and threshold scan with early pp collisions.

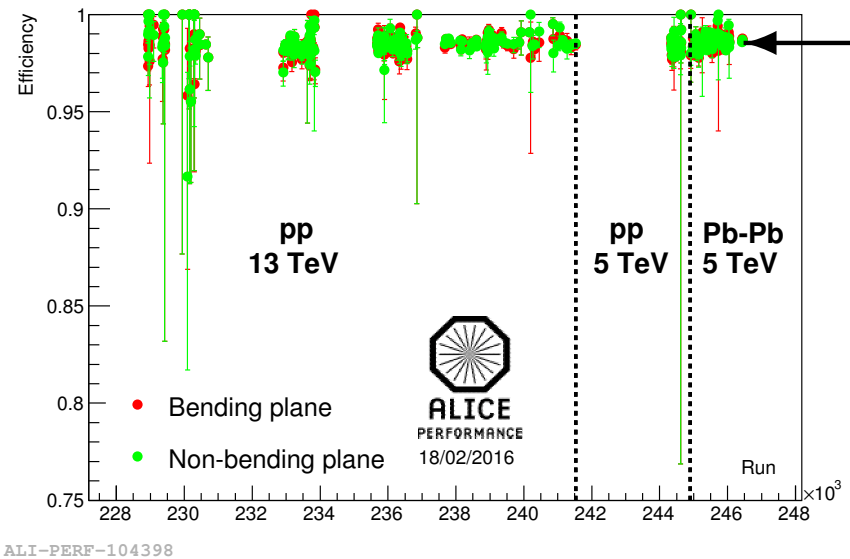




- Full efficiency reached by all thresholds and both polarities.
- Cluster size slightly larger than the one measured with ADULT at higher HV (~ 1.6 vs ~ 1.4).
- Working point at 9375 V and 130 fC (-750 V w.r.t. ADULT).
- No noise observed for threshold > 60 fC for both polarities.
- Results are in full agreement with measurements made with cosmic rays in Turin.

Efficiency stability

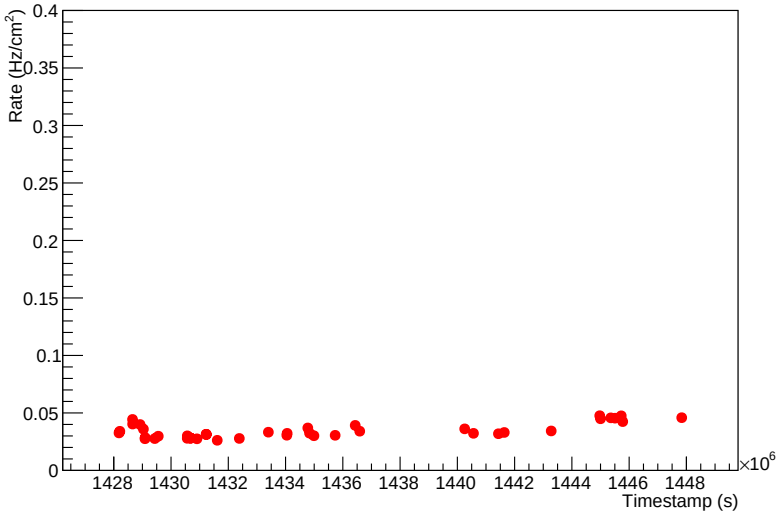




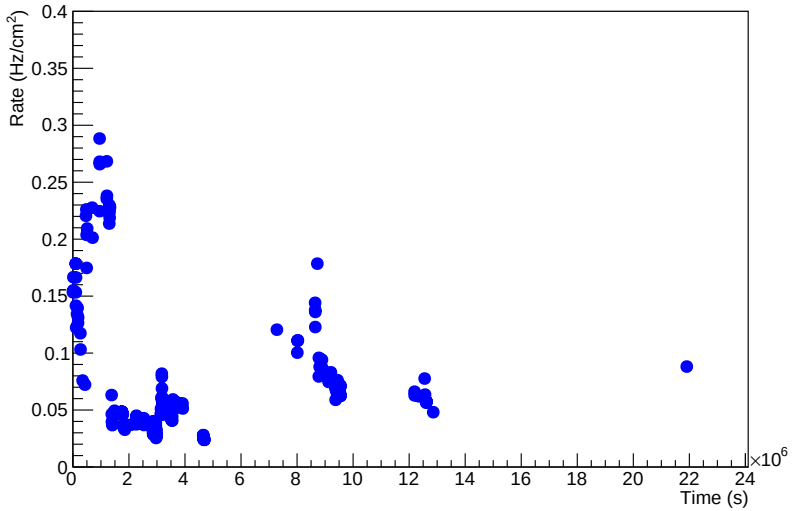
- The efficiency of the RPC equipped with FEERIC is very similar to those of other RPC (or slightly better).
- A good stability of the same RPC is observed throughout the data taking period for both planes.

Dark rate

Average (2015)



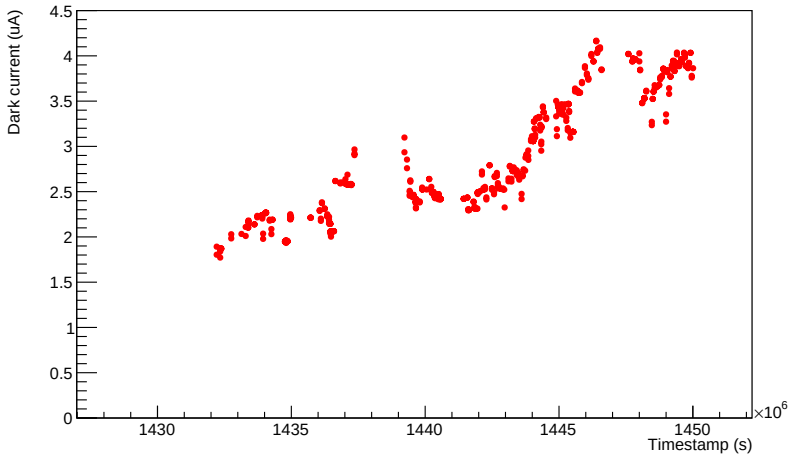
RPC with FEERIC (2015)



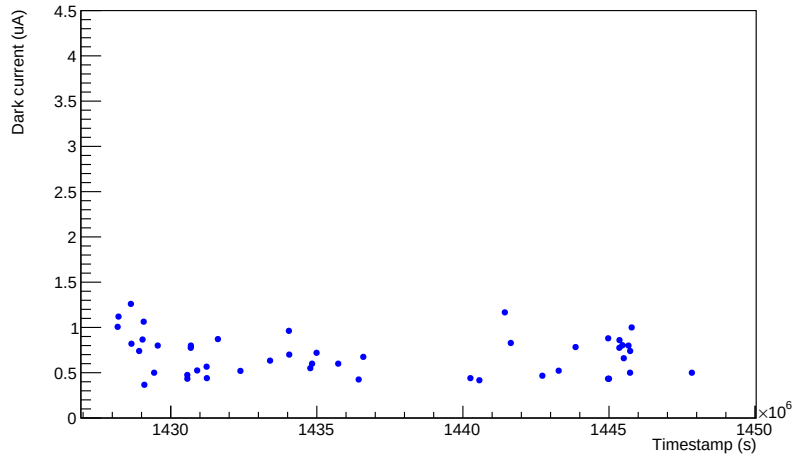
- Cosmic data used for evaluating the noise of the RPC.
- The dark rate measured with FEERIC is higher than the average (around 0.03 Hz/cm^2, see Gabriele's talk of Monday), but typically below 0.1 Hz/cm^2.
- The bump at the beginning of the measurement is in coincidence with the HV–threshold scan.

Dark current

Average (2015)

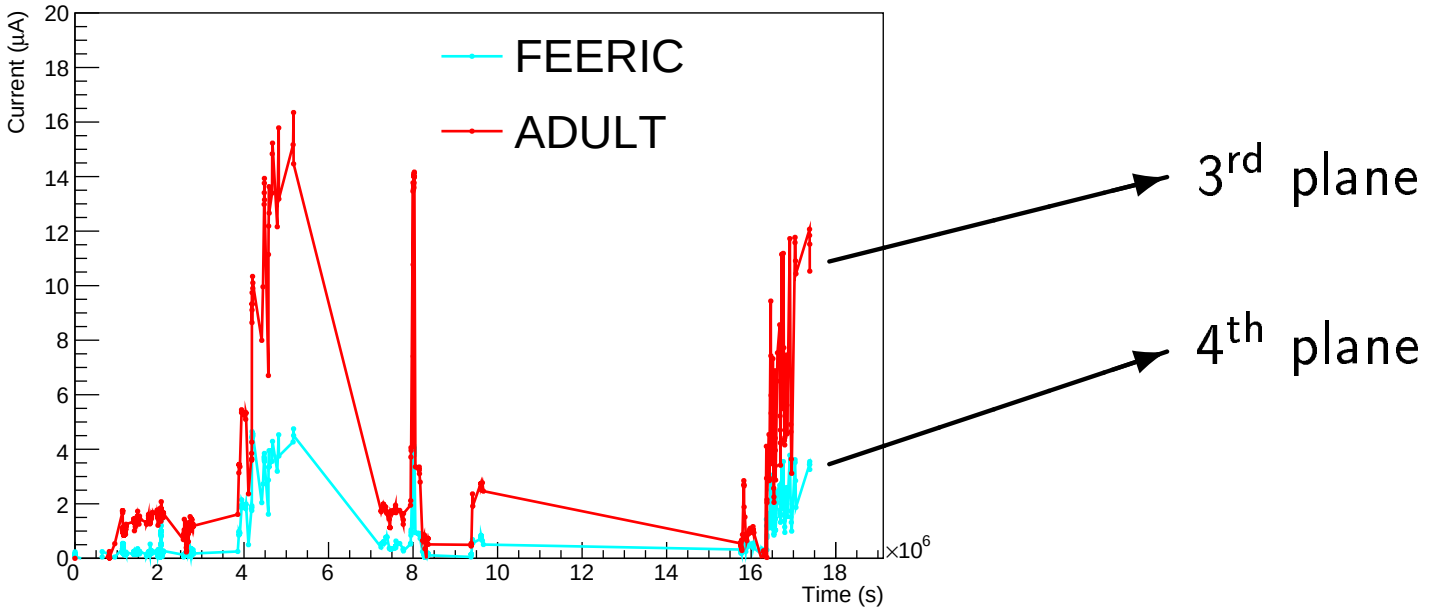


RPC with FEERIC (2015)



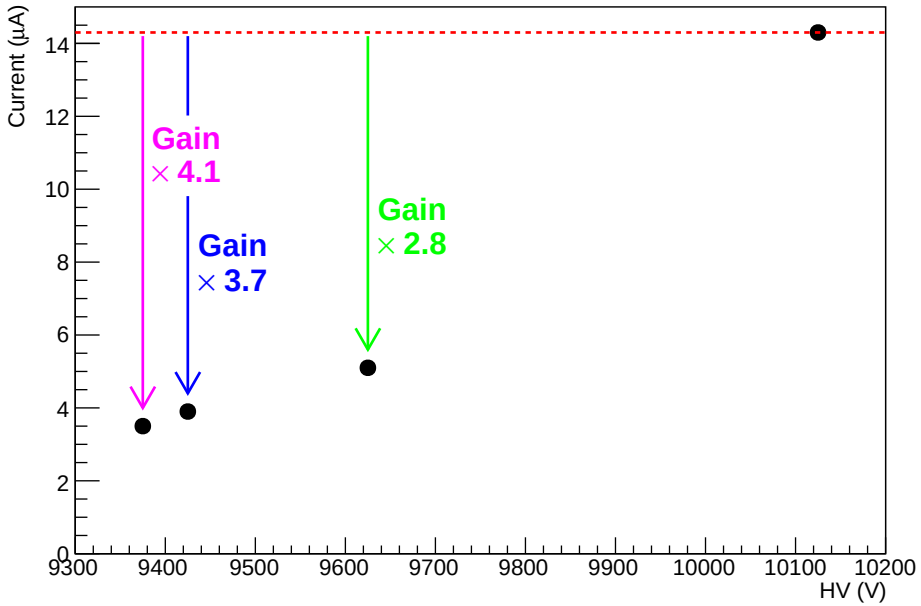
- Dark current is measured without beam (calibration runs or cosmic data taking).
- The value averaged over the RPC with old FEE increases slightly in time in correspondence with high intensity pp runs and Pb-Pb collisions (see Gabriele's talk of Monday).
- The dark current with FEERIC (right) is constant and well below the average (left).

Current in pp and Pb–Pb collisions



- Dark current component subtracted.
- Clear dependence on the beam conditions: peaks in correspondence with high intensity pp runs and Pb–Pb collisions.
- Two RPCs in the same position but different planes: with FEERIC the current induced by particles is reduced by a factor $4 \div 5$.

Gain in charge



- HV scan of the current measured by the RPC equipped with FEERIC at a constant interaction rate.
- Dark current subtracted.
- Gain of a factor 4 when moving from the ADULT HV to the FEERIC HV.

Conclusions

With the new FEERIC front-end electronics prepared in view of the MTR upgrade the following results have been achieved:

- with a FEERIC threshold of 130 fC, the working point can be lowered by 750 V maintaining an efficiency larger than 95%;
- the possibility to apply a lower HV prevented the increase of the dark current visible in most of the other RPCs;
- the cluster size and the dark rate are above the average values, but still well within specifications in these conditions;
- the charge is reduced by a factor ~ 4 at the new working point;
- the FEERIC noise measurements show that there may be room for lowering the threshold with further gain in HV and charge.

Outlook

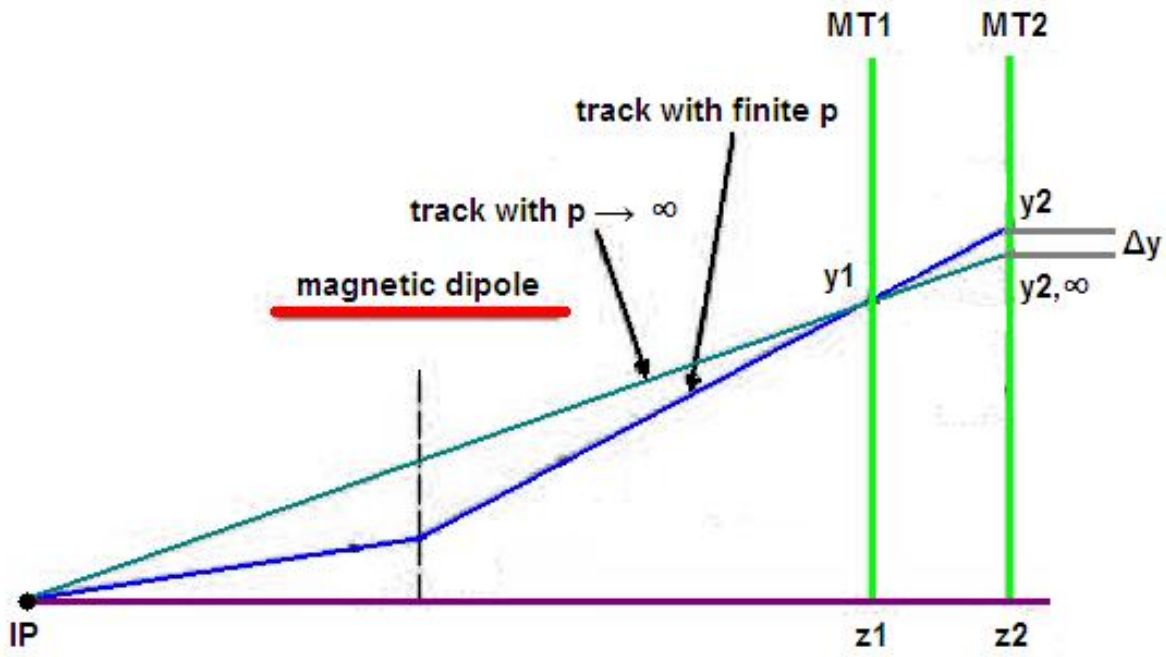
Those are the milestones of the project:

- 2014 Q1 – 2015 Q3:
  front-end card design, prototype and pre-serie (✓)
- 2015 Q4 – 2017 Q4:
  front-end card production (ongoing)
- 2018 Q3 – 2019 Q3:
  installation and commissioning

The next Production Readiness Review will take place in April.

Backup

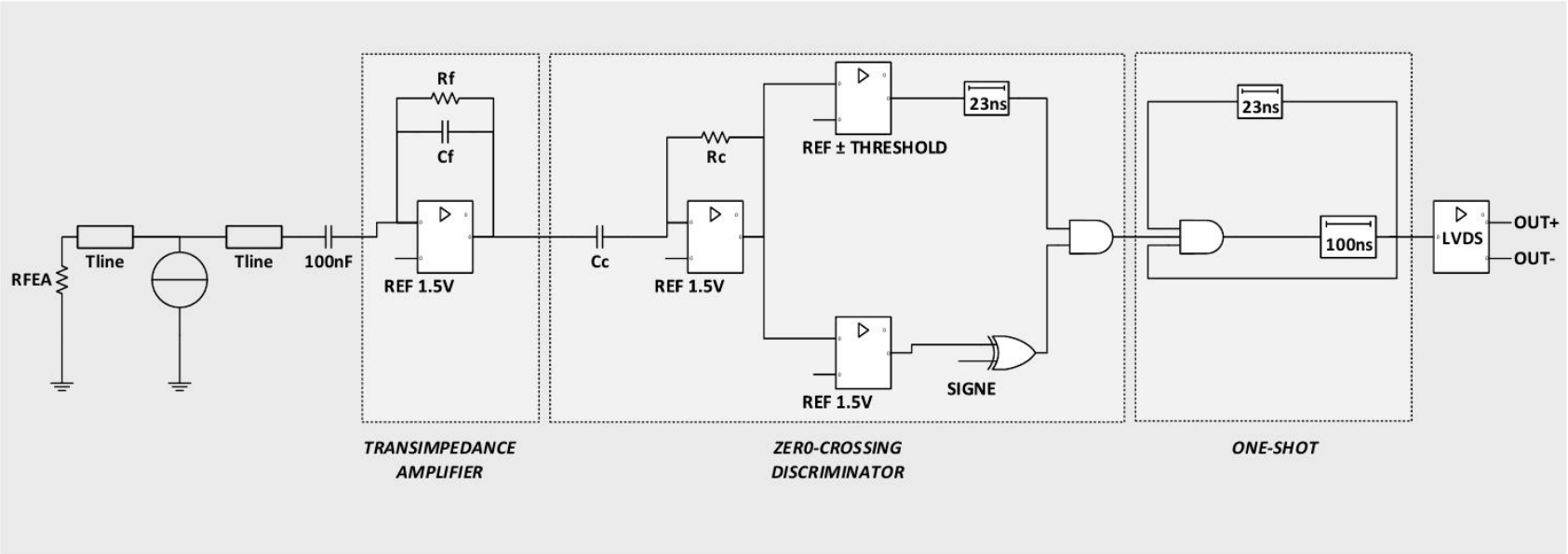
Trigger principle



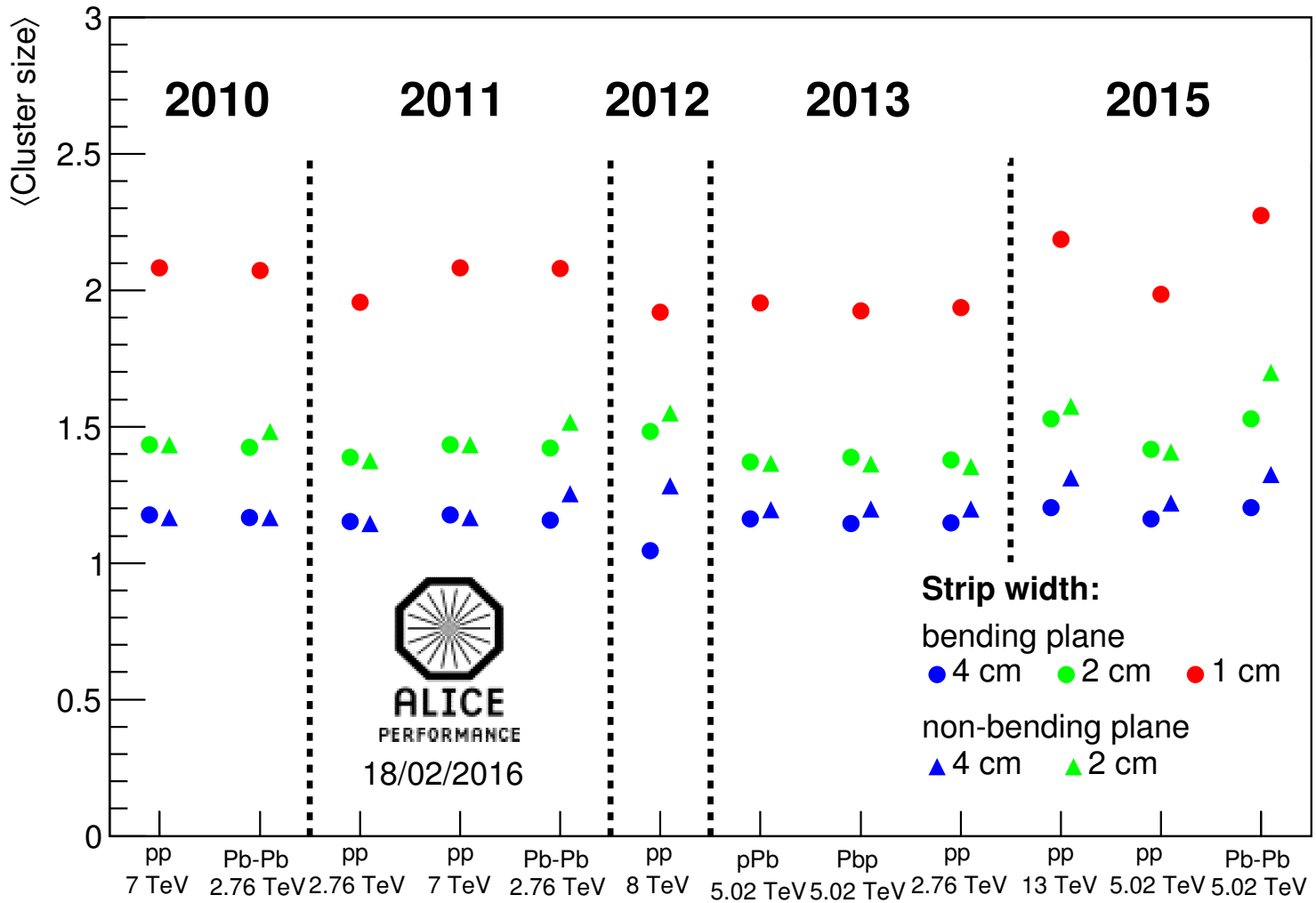
FEERIC specifications

	FEERIC ASIC	FEERIC board (with RPC strips)
ASIC technology	AMS CMOS 0,35 μm	=
Number of ch.	8	=
Polarity	$\pm$	=
Electronics noise (rms) Thresh. above noise	q $<$ 2 fC	= q $<$ 100 fC
Cross talk	$q_{thr}/q < 2$ % for q_{thr}=100 fC	=
Amplifier	trans-impedance	=
Discriminator	zero crossing	=
One-shot (monostable)	yes (100 ns)	=
Output format	LVDS 23 ns width	=
Gain in (linear) range	$\sim$1 mV/fC q $<$ 1 pC	$\geq$ 0.5 mV/fC =
Time jitter (rms)	$<$ 1 ns for 100 fC $<$ q $<$ 1 pC	=
Time walk	$<$ 1 ns for 100 fC $<$ q $<$ 1 pC	=
ch/ch max delay	$<$ 1 ns	=
ASIC/ASIC max delay	$<$ 2 ns	=
Power cons.	$<$ 100 mW/ch	=
Power supply	3 V	4 V

Architecture of FEERIC



Cluster size with ADULT



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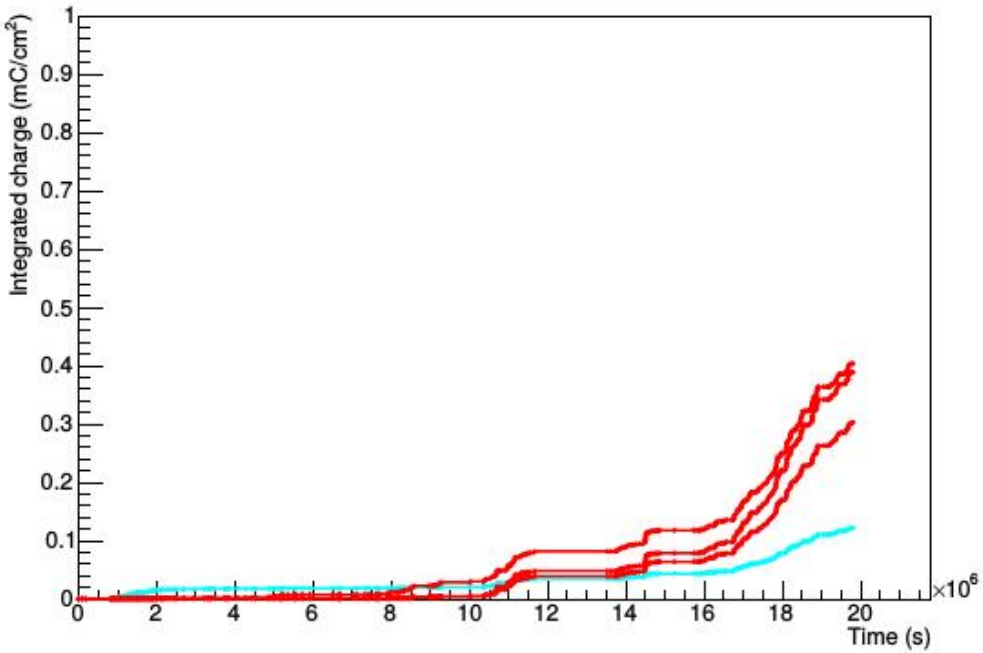
Integrated charge for FEERIC



- Comparison of the integrated charge for the four RPC in position inside_3 (3 equipped with ADULT, 1 with FEERIC).
- Final integrated charge well below 1 mC/cm^2.
- Significantly smaller integrated charge with FEERIC.