15th Topical Seminar on Innovative Particle and Radiation Detectors

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Università di Roma Tor Vergata

Istituto Nazionale di Fisica Nucleare

Upgrade of the Resistive Plate Chamber detector for the high-background environments

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Outline

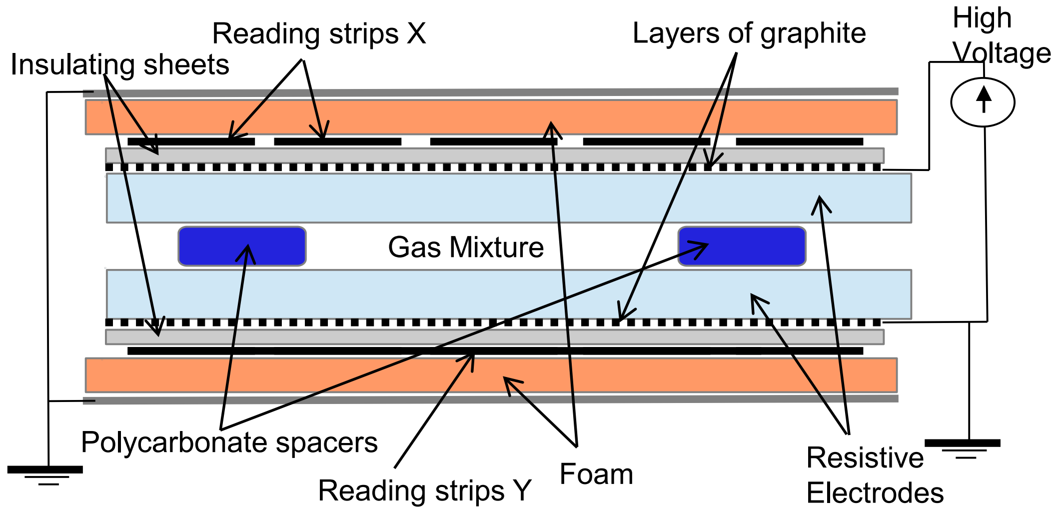
- ***RPC detector and its rate capability***
- ***The new Front End Electronics***
  a) *Silicon BJT preamplifier*
  b) *Full-custom Silicon-Germanium HJT Discriminator*
- ***RPC performance***
  - *Efficiency curve*
  - *Cluster Size*
  - *Output signal width distribution*
  - *Time Resolution*
  - *Rate capability*
- ***Conclusion & Next to come***

RPC rate capability and improvements for high rate experiments

The **RPC rate capability** is mainly limited by the current that can be driven by the high resistivity electrodes.

$$V_{gas} = V_a - R \cdot I$$

$$V_{gas} = V_a - \rho \cdot \frac{d}{S} \cdot \langle Q \rangle \cdot S \cdot \Phi_{particles} = V_a - \rho \cdot d \cdot \langle Q \rangle \cdot \Phi_{particles}$$



1. Decrease the electrode resistivity; large technological effort with the risk of increasing its operating current, causing a possible ageing problems due to the more current driven.

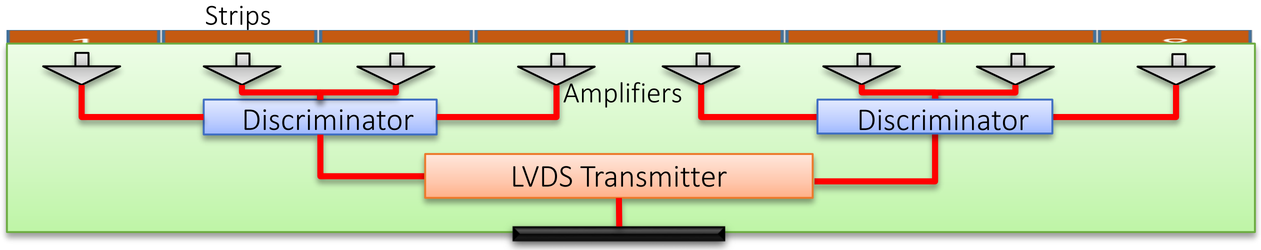
1. Electrode thickness reduction; similar effect obtained with the reduction of the resistivity.

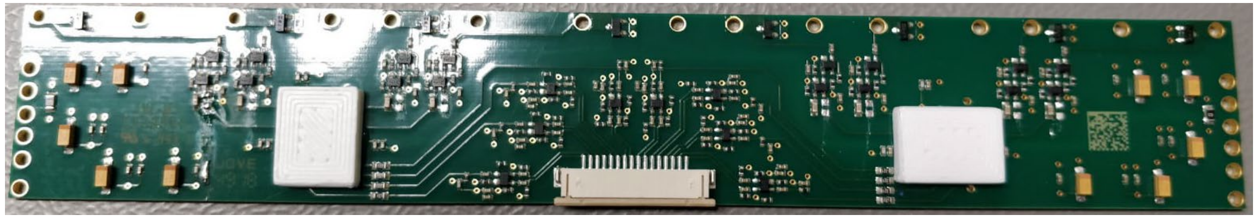
1. **Reduce the average charge per count Q; This method is the only one that permits to increase the rate capability while operating the detector at fixed current. No further ageing test required**

$\langle Q \rangle$ reduction requirements:

- Very sensitive FE electronics with an excellent signal to noise ratio
- High suppression of the noise induced inside the detector by the electronics and by external sources
- Very careful optimization of the chamber structure as a Faraday cage.

The new generation of RPC detectors





Amplifier parameters

- Silicon standard components
- Gain: 0.2-0.4 mV/fC
- Power consumption: 3-5 V   1–2 mA
- Band-width: 100 MHz

Discriminator parameters

- SiGe full custom
- Power consumption: 2-3 V   4-5 mA
- Threshold: 0.5 mV
- Band-width: 100 MHz

	New generation RPC
Detector	Mono gas gap
Gas Gap width	1 mm
Electrode Thickness	1.2 mm
Gas Mixture	95% TFE, 4.7% i-C4H10, 0.3% SF6
Time Resolution	0.4 ns
Space Resolution	1 mm

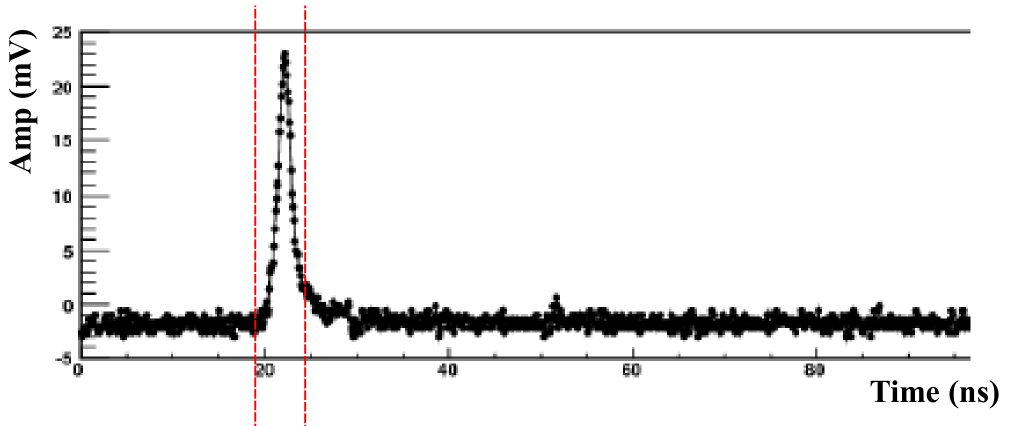
1. Minimum Threshold of 0.3 mV
2. Detectable signal of *1-2 fC*

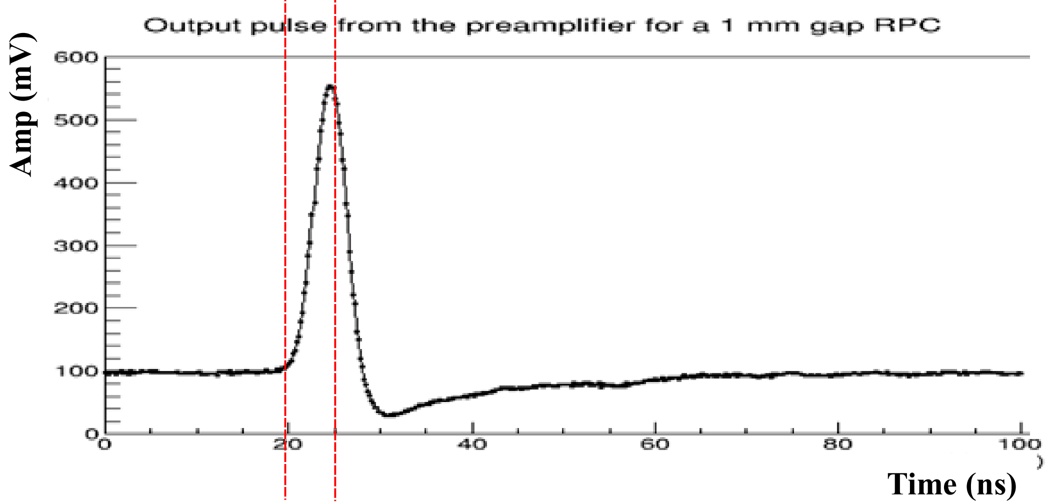
} Reduction of factor 5-10 in the charge produced inside the gas gap → **Rate capability up to some kHz/cm^2**

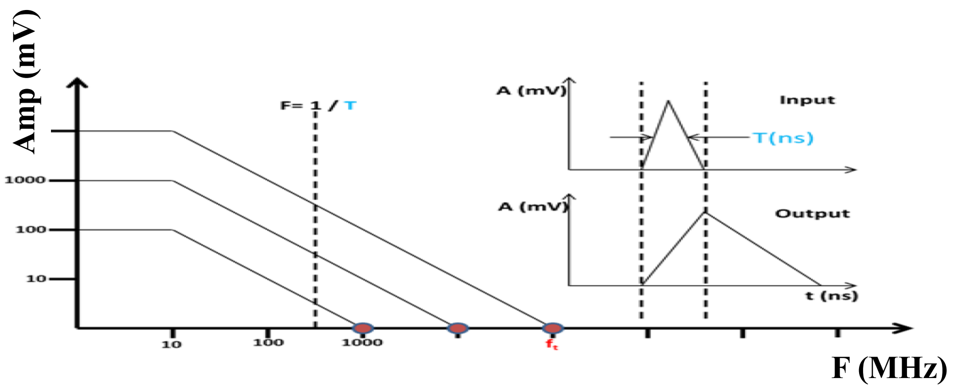
1. Time-over-threshold measurement achievable directly within the Front-End

Silicon BJT preamplifier

The preamplifier developed in Rome Tor Vergata for the RPCs is made in **Silicon Bipolar Junction Transistor** technology. The main feature of this new kind of amplifier is a fast charge integration with the possibility to match the input impedance to a transmission line.



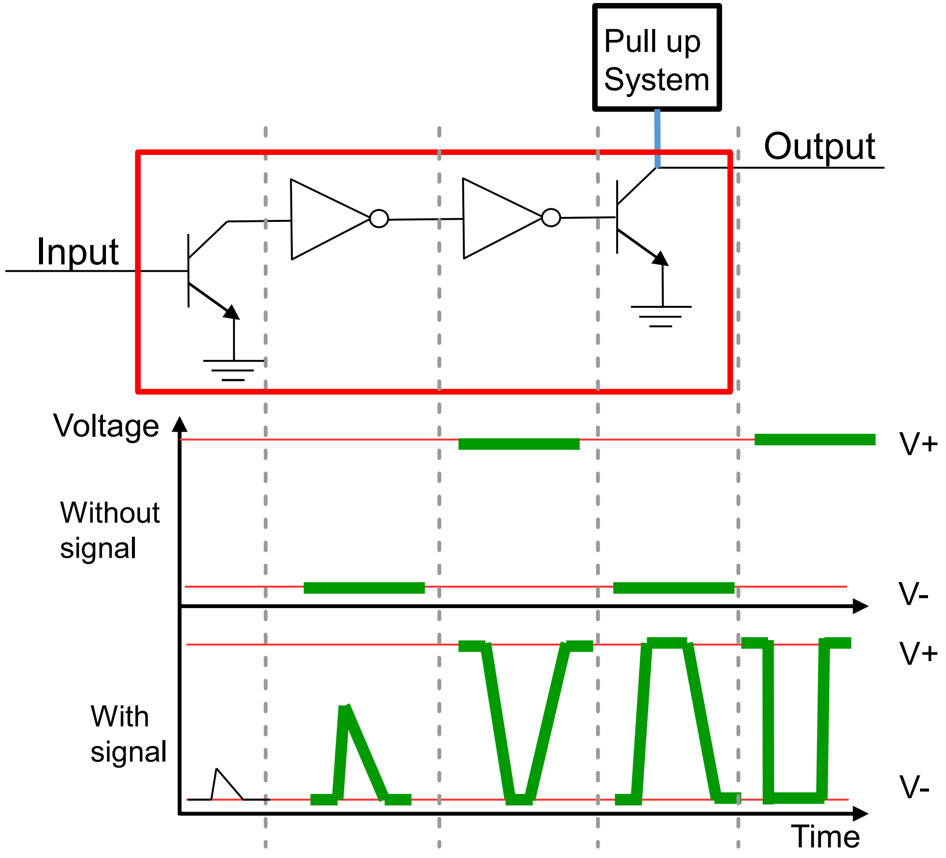




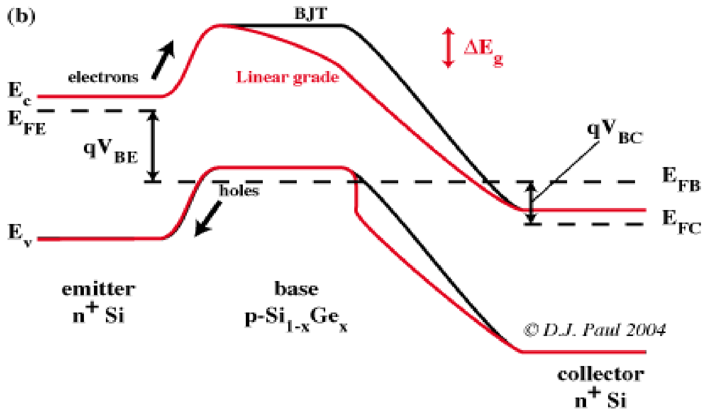
Voltage supply	3–5 Volt
Sensitivity	2–4 mV/fC
Noise (independent from detector)	4000 e^- RMS
Input impedance	100–50 Ohm
B.W.	10–100 MHz
Power consumption	10 mW/ch
Rise time $\delta(t)$ input	300–600 ps
Radiation hardness	1 Mrad, 10^{13} n cm^{-2}

With this kind of preamplifier it is possible to reduce $\langle Q \rangle$ of up to a factor 10 with respect to ATLAS RPCs performance

Full-Custom Silicon-Germanium HJT Discriminator



The new full-custom Discriminator circuit dedicated to the RPCs for high rate environment is developed by using **the Silicon-Germanium HJT technology.**
The main idea behind this new discriminator is the limit amplifier. If the signal surpasses the threshold, it will be amplified until saturation giving as output a square wave.

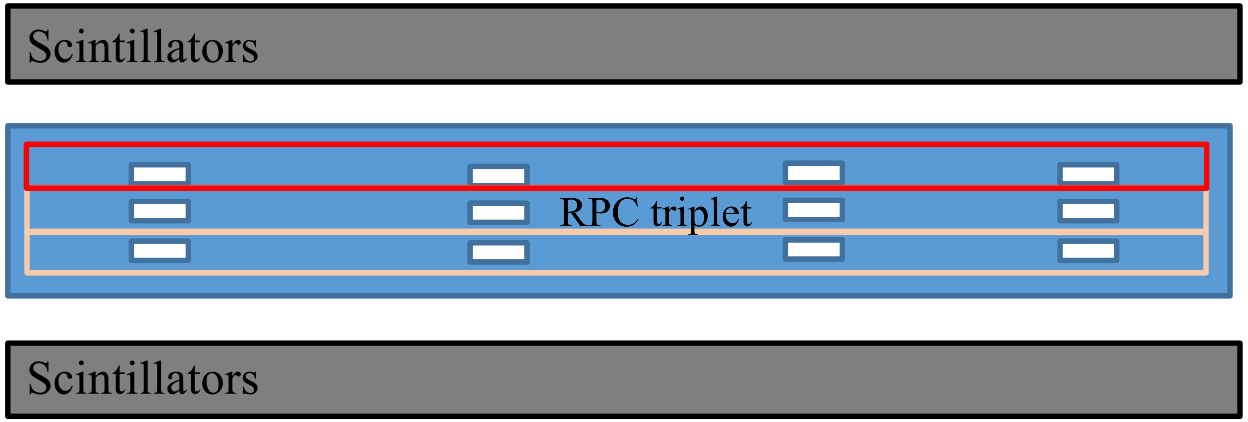


Improvement in the transition frequency and a much higher charge amplification

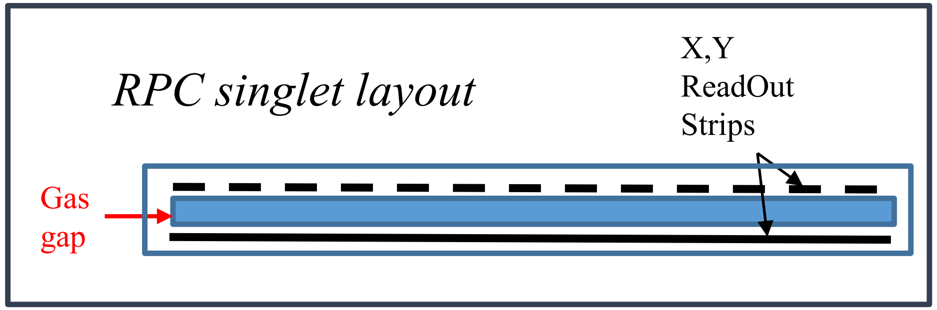
- **Minimum threshold achievable 0.3-0.5 mV**
- **Time-over-threshold measurement directly with the discriminator**
- **Threshold linearity up to a minimum pulse width of 3 ns**

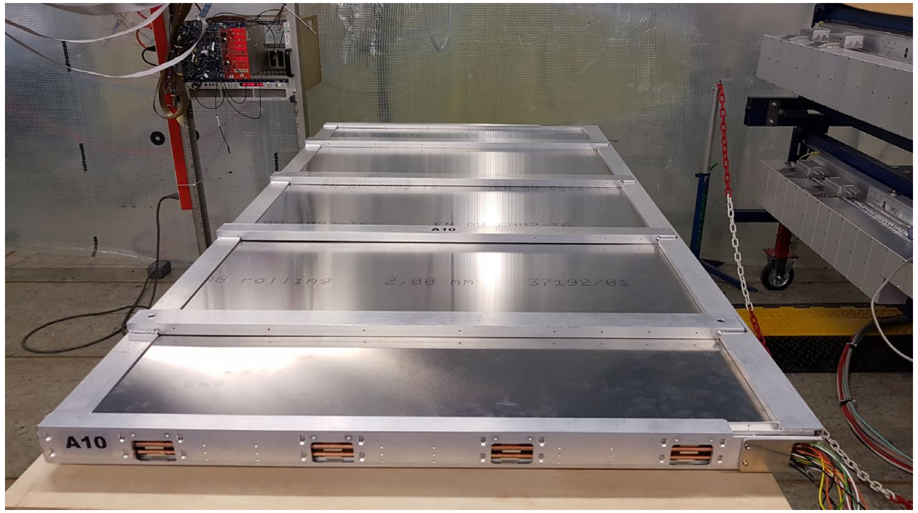
The principle of SiGe heterojunction bipolar transistor (HJT) is to introduce a Silicon-Germanium impurity in the base of the transistor. The advantage of this device is that the band structure introduces a drift field for electrons into the base of the transistor, thus producing a ballistic effect that reduces the base transit time of the carriers injected in the collector

RPC performance – Cosmic ray test



- 2 layers of scintillators (20 cm x 60 cm) as trigger coincidence + 1 chamber at fixed HV
- 100 ns coincidence window
- 15 Hz trigger rate
- 3 singlets 200 cm x 110 cm



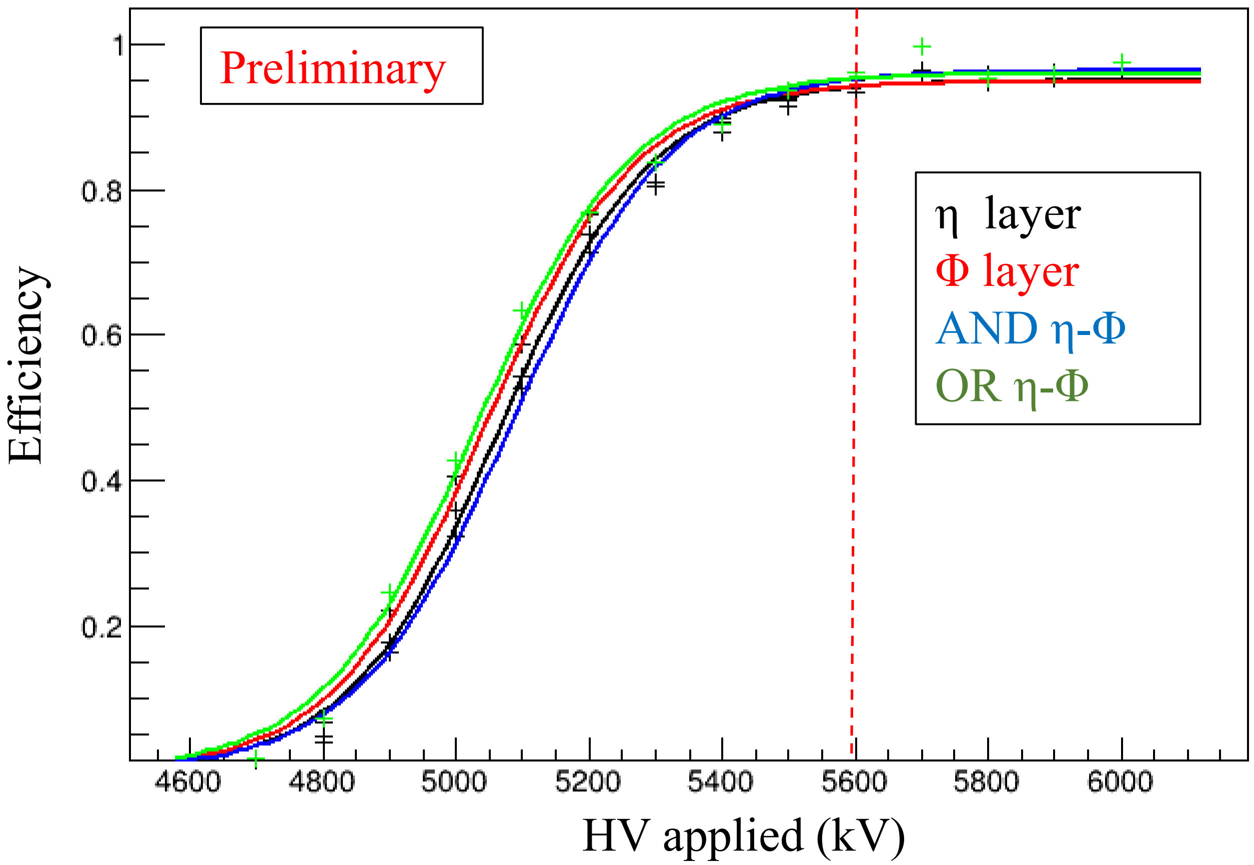


Performance tests:

- Efficiency curve
- Cluster size
- Output Width distribution
- Time Resolution

RPC performance – Efficiency curve

Efficiency curve averaged all over the singlet surface

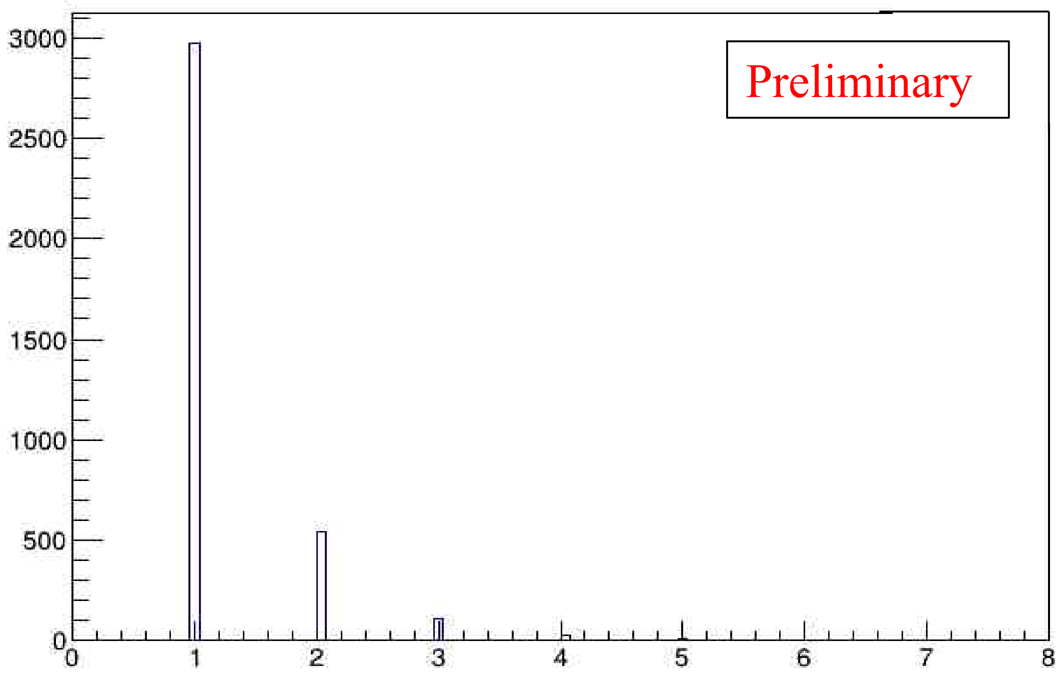


- Between 95%-96% of efficiency at 5,6kV
- The Front-End electronics threshold is set to the middle of its dynamic range for both readout layers

Efficiency curve shows the expected behaviour with the desired efficiency level

RPC performance – Cluster size

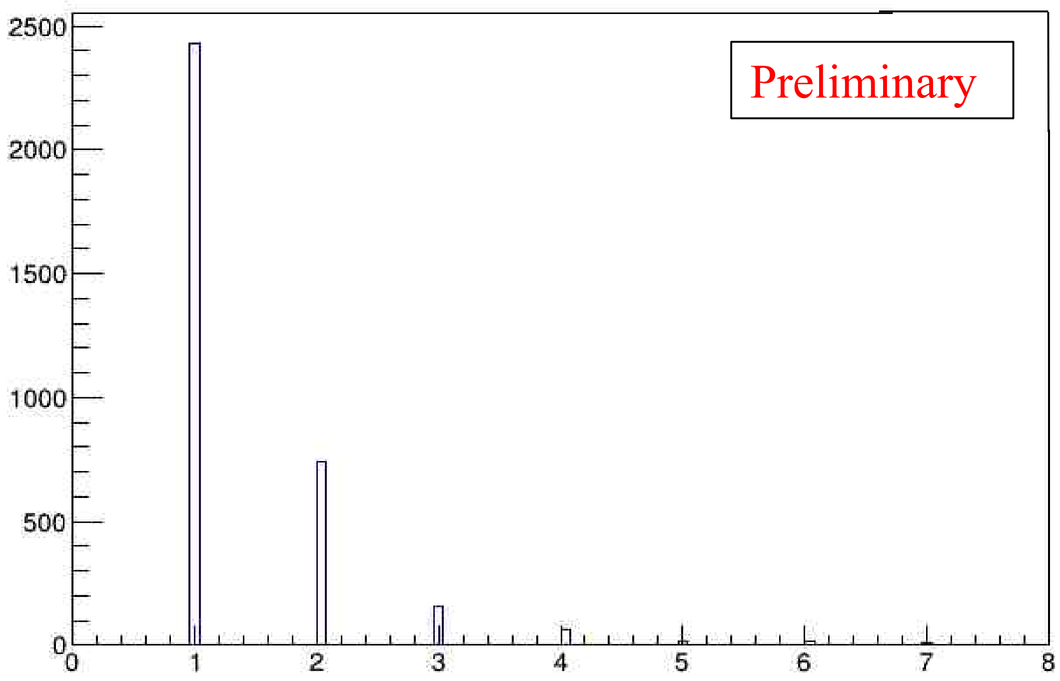
Cluster Size of η layer Averaged all over the surface



Cluster Size

Average cluster size η = 1.3 - 1.5

Cluster Size of Φ Averaged all over the surface

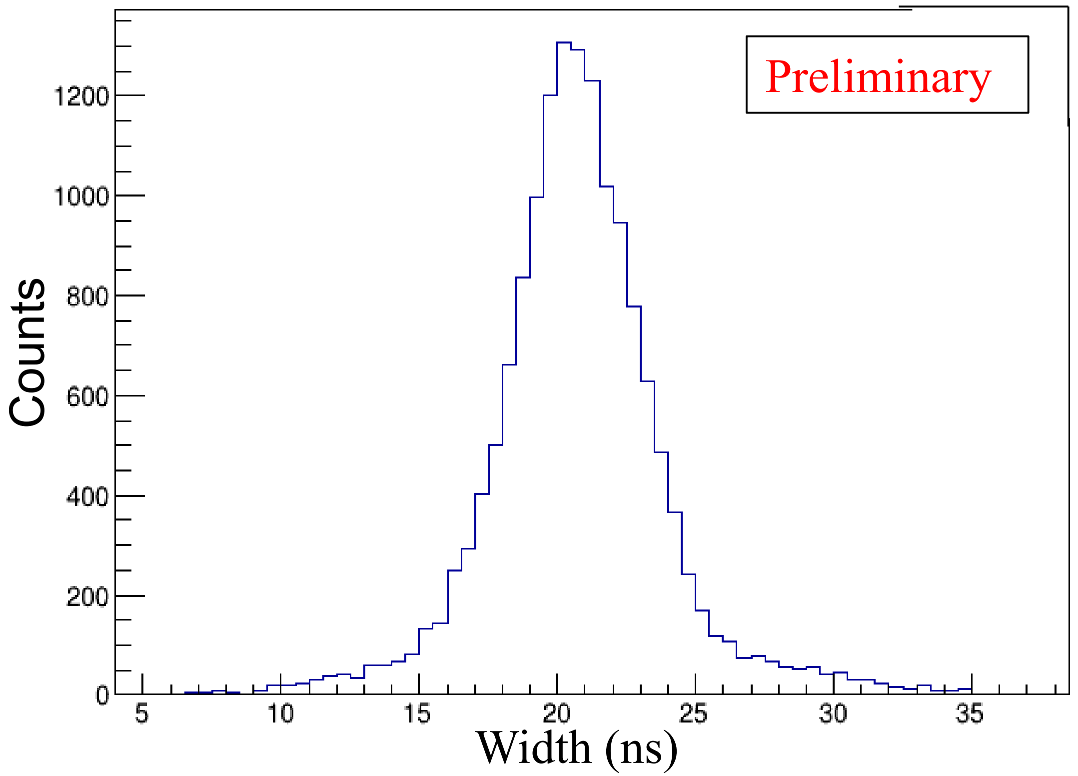


Cluster Size

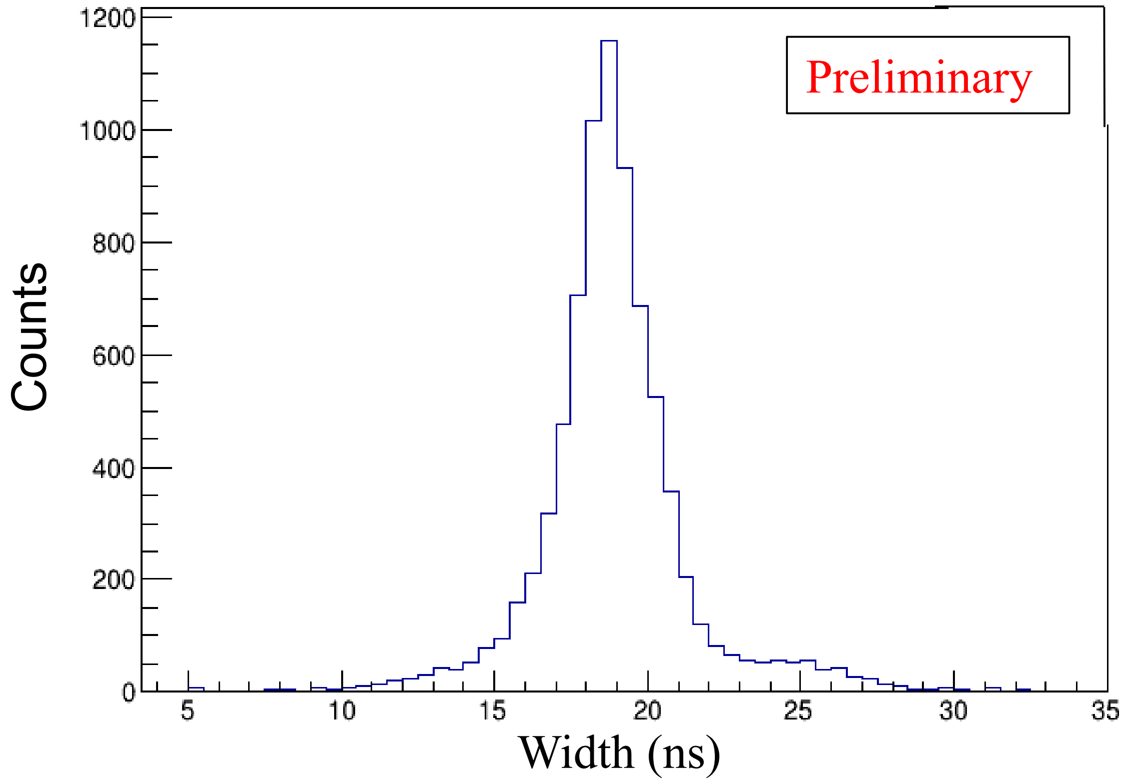
Average cluster size Φ = 1.4 - 1.8

RPC performance – Output signal width distribution

η Output Signal Width distribution



Φ Output Signal Width distribution

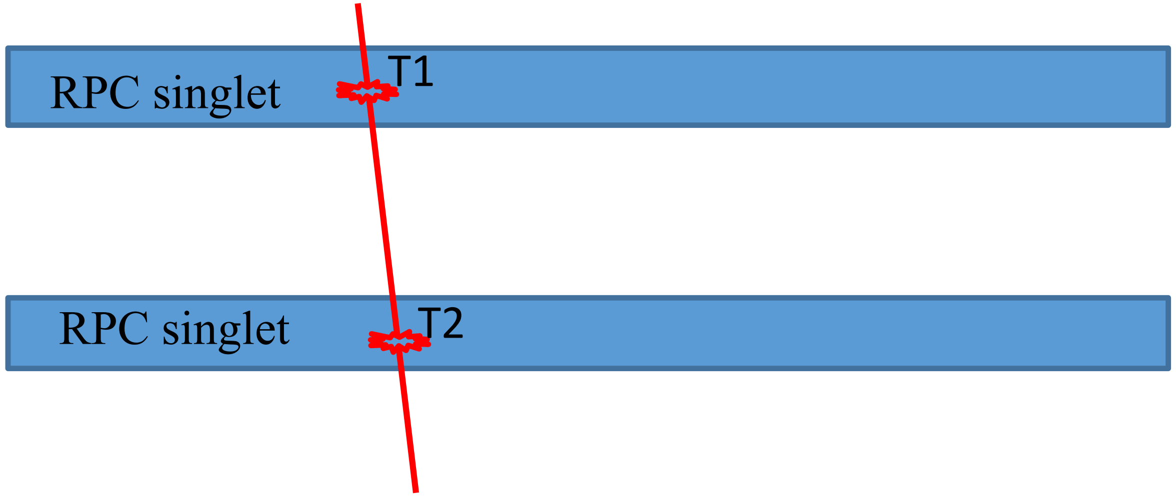


Obtained by taking the width of the first signal of each cluster at HV=5.6 kV

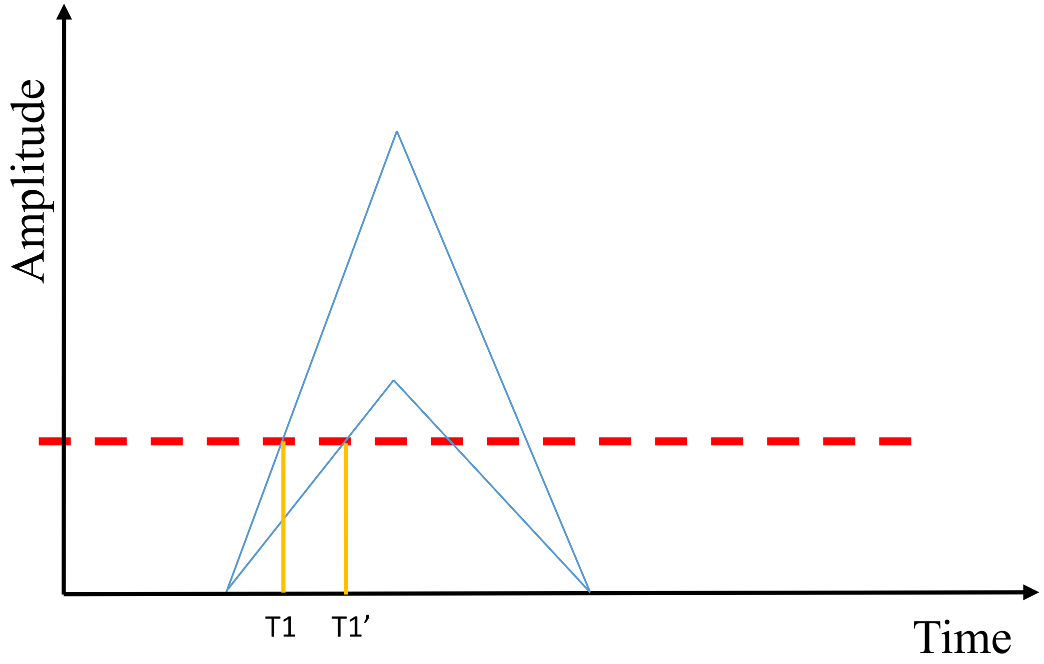
- Time over Threshold measurement
- Time walk correction for the time resolution

RPC performance – Time resolution

Time of Flight method for Time resolution calculation



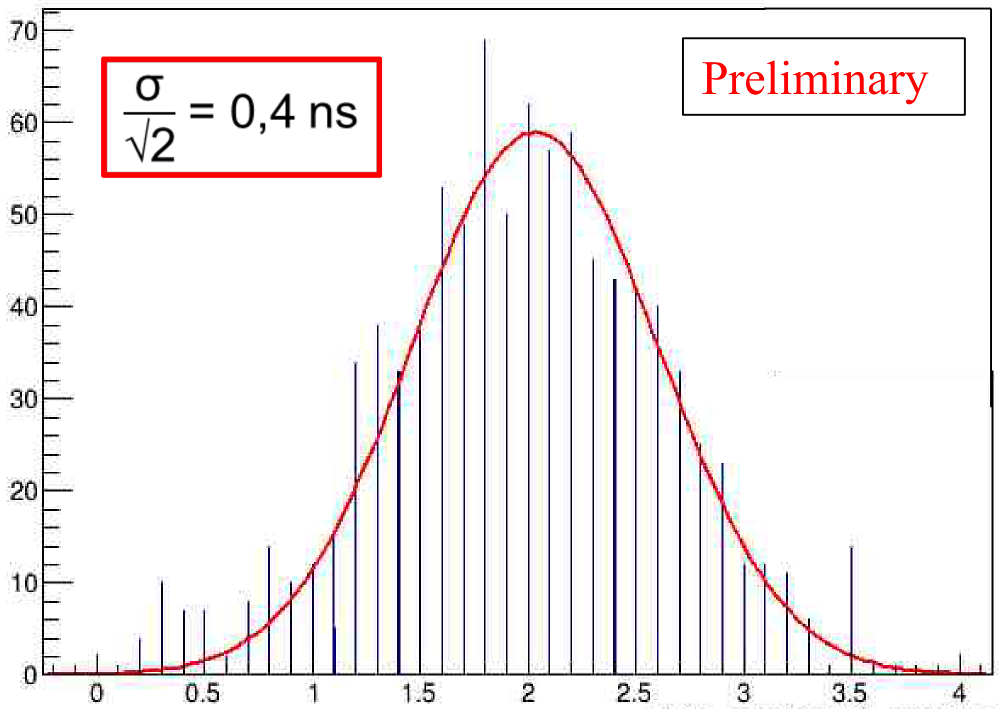
Time resolution calculated as the sigma of the gaussian fit over the distribution of the difference between the arrival time of the signals of the 2 singlets (ΔT)



Time walk effect can be corrected by using the function F(Amplitude), which correlate the time when the signal passes the threshold and its amplitude

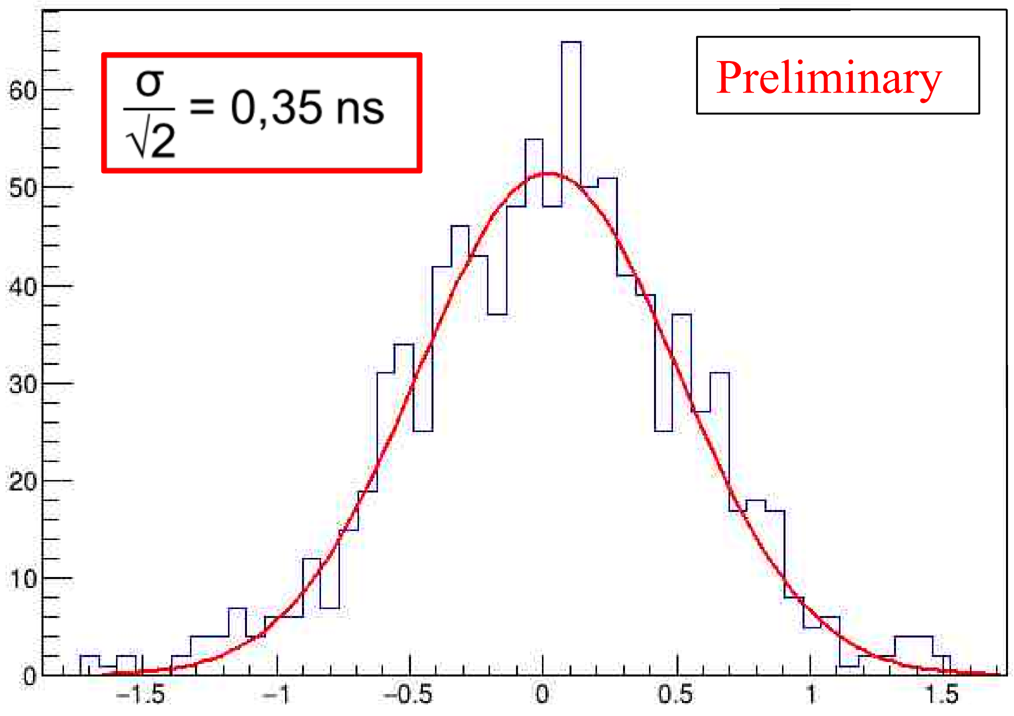
RPC performance – Time resolution

Time resolution without correction



ΔT (ns)

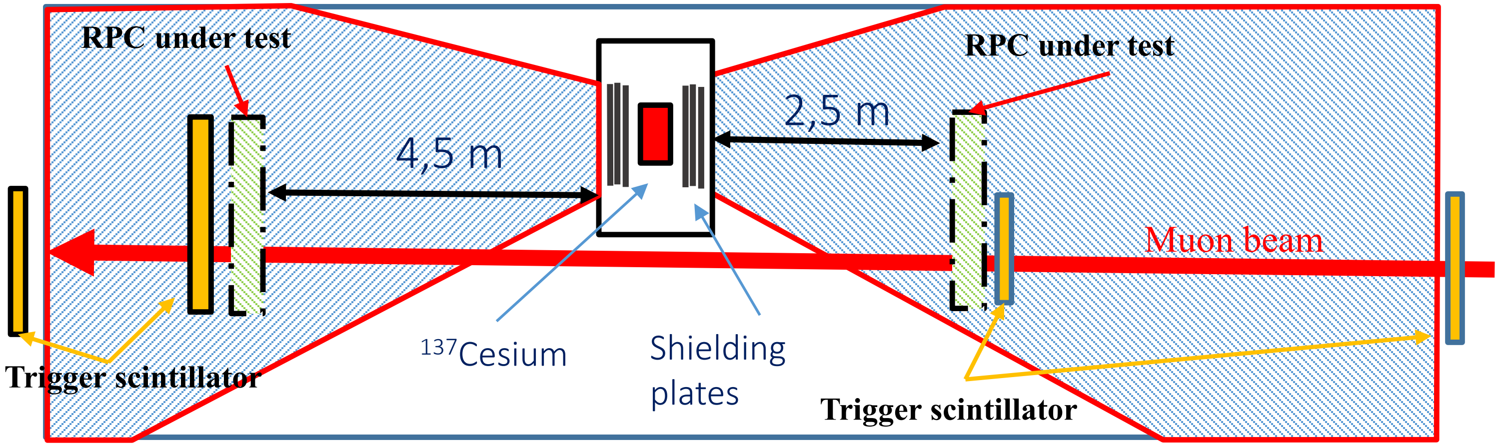
Time resolution with time walk correction

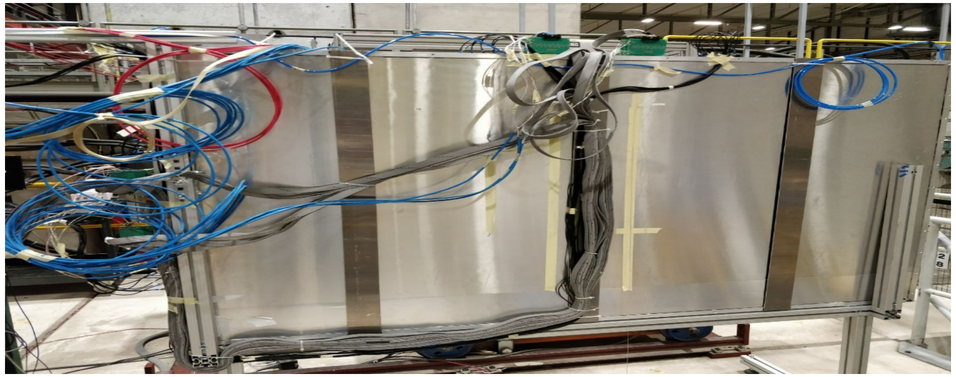


ΔT-F(A1)-F(A2) (ns)

RPC performance - Testbeam inside the CERN North Area

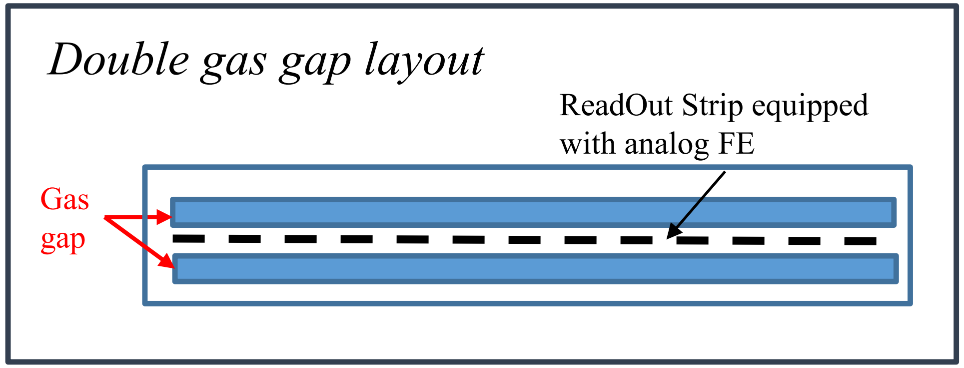
- 14 TBq ^{137}Cs source with the energy of the photons of around Eγ = 662 keV
- Movable shielding plates to regulate the intensity of the source.
- Muon beam composed by muons with a momentum up to 100 GeV/c, with a beam spot of around 10 cm^2

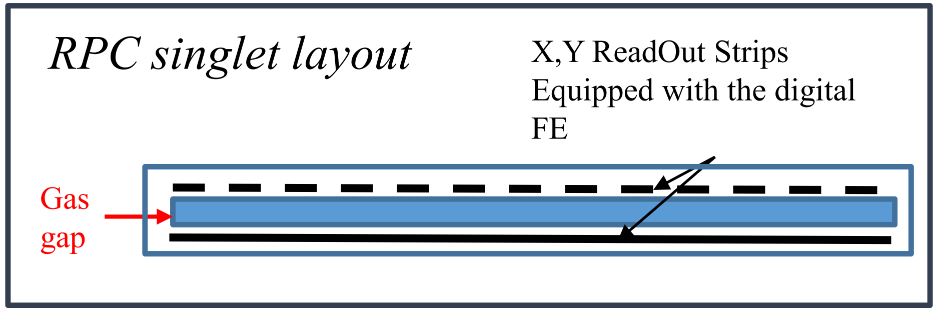




Measurement realized:

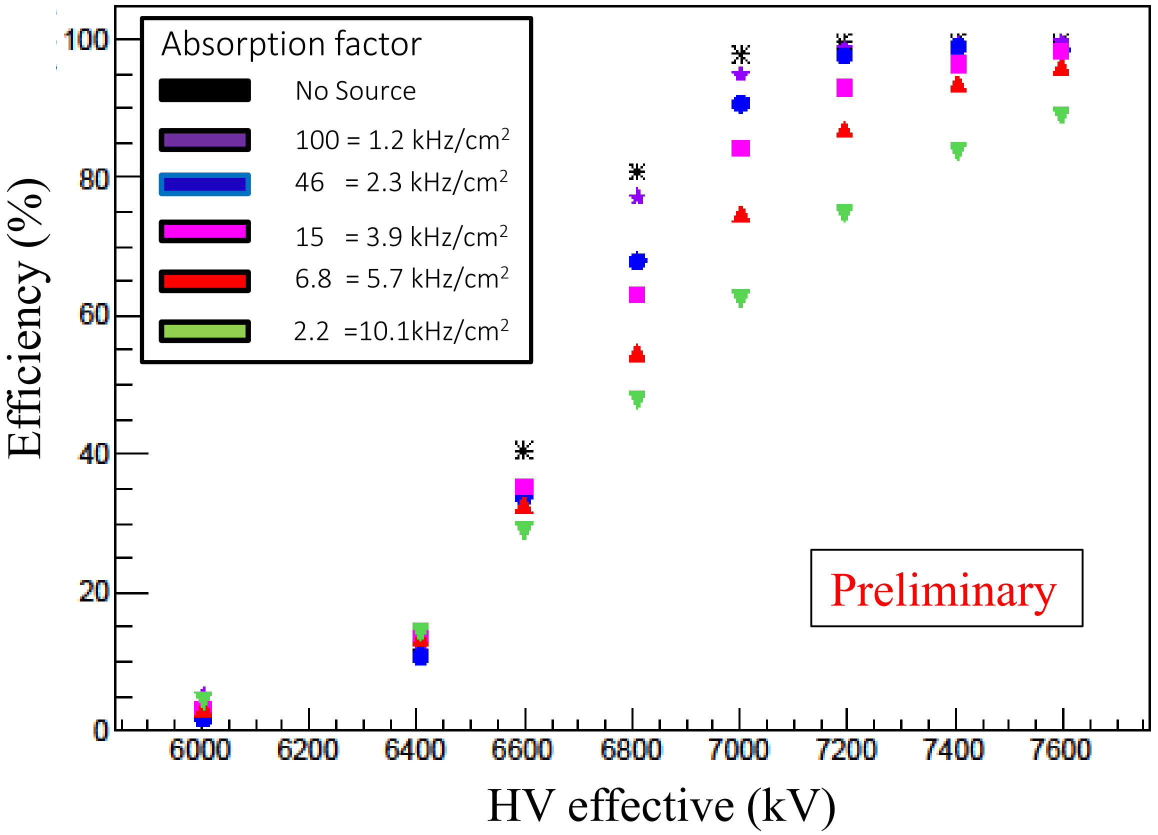
a) RPC overall test
b) LV Parameters “phase space” scans
   - Pull Up & Discriminator → System stability
   - Threshold & Amplifier → Effective threshold
c) Rate capability test

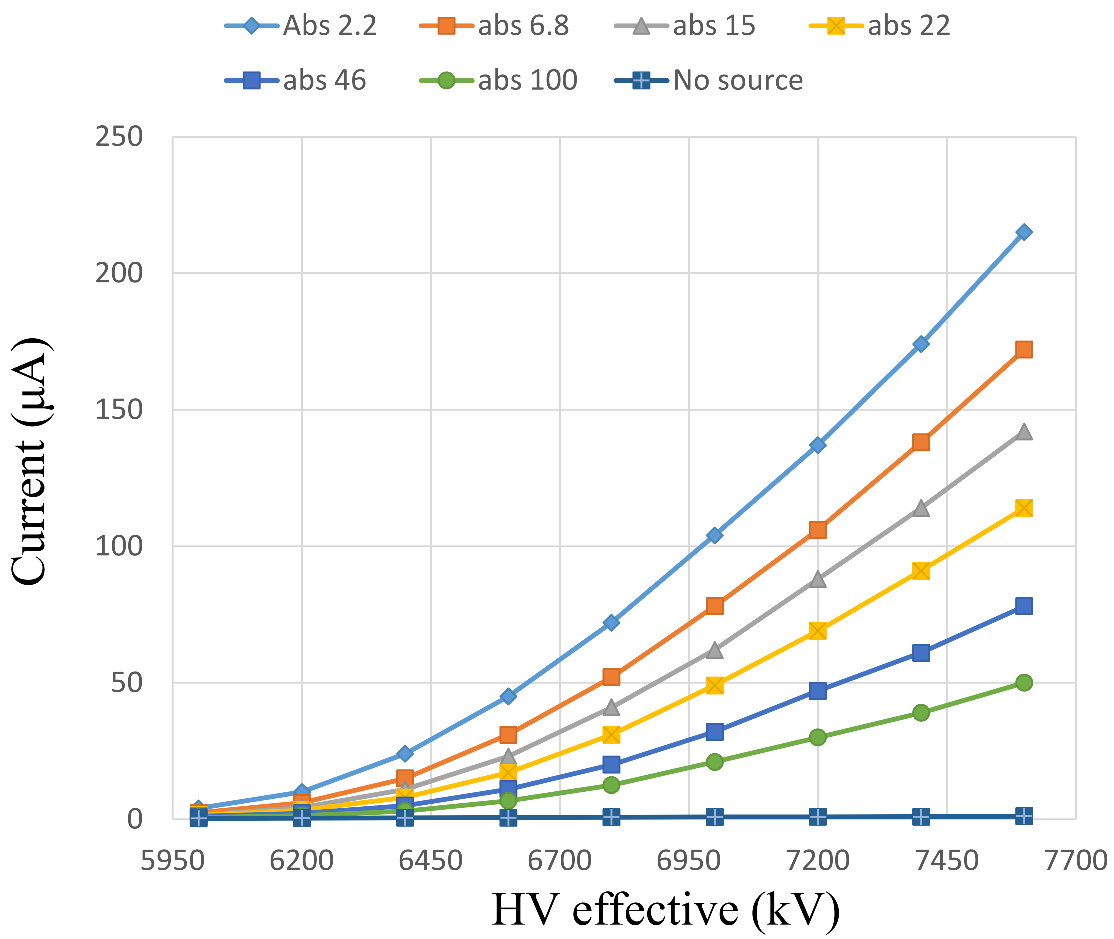




RPC performance – Rate capability

Efficiency curve for different absorption factor





Conclusions

The new generation of RPC detector equipped with the newly developed Front-End electronics achieved the following:

1. **Overall desired performance**

2. **Time Resolution of 350 ps**

3. ***Rate capability up to 10* kHz/cm^2**

Thank you

Back up

Full-Custom Amplifier

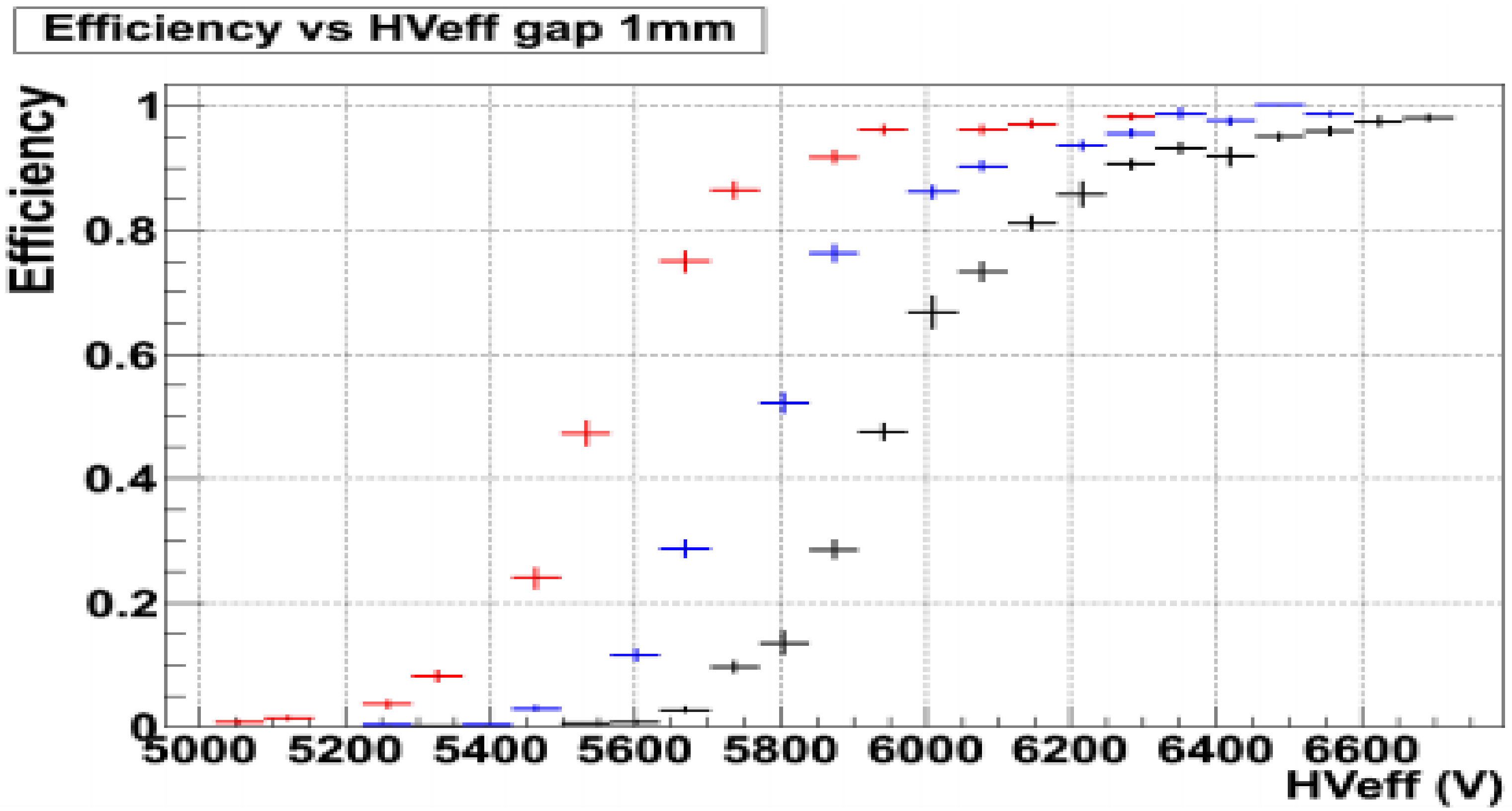
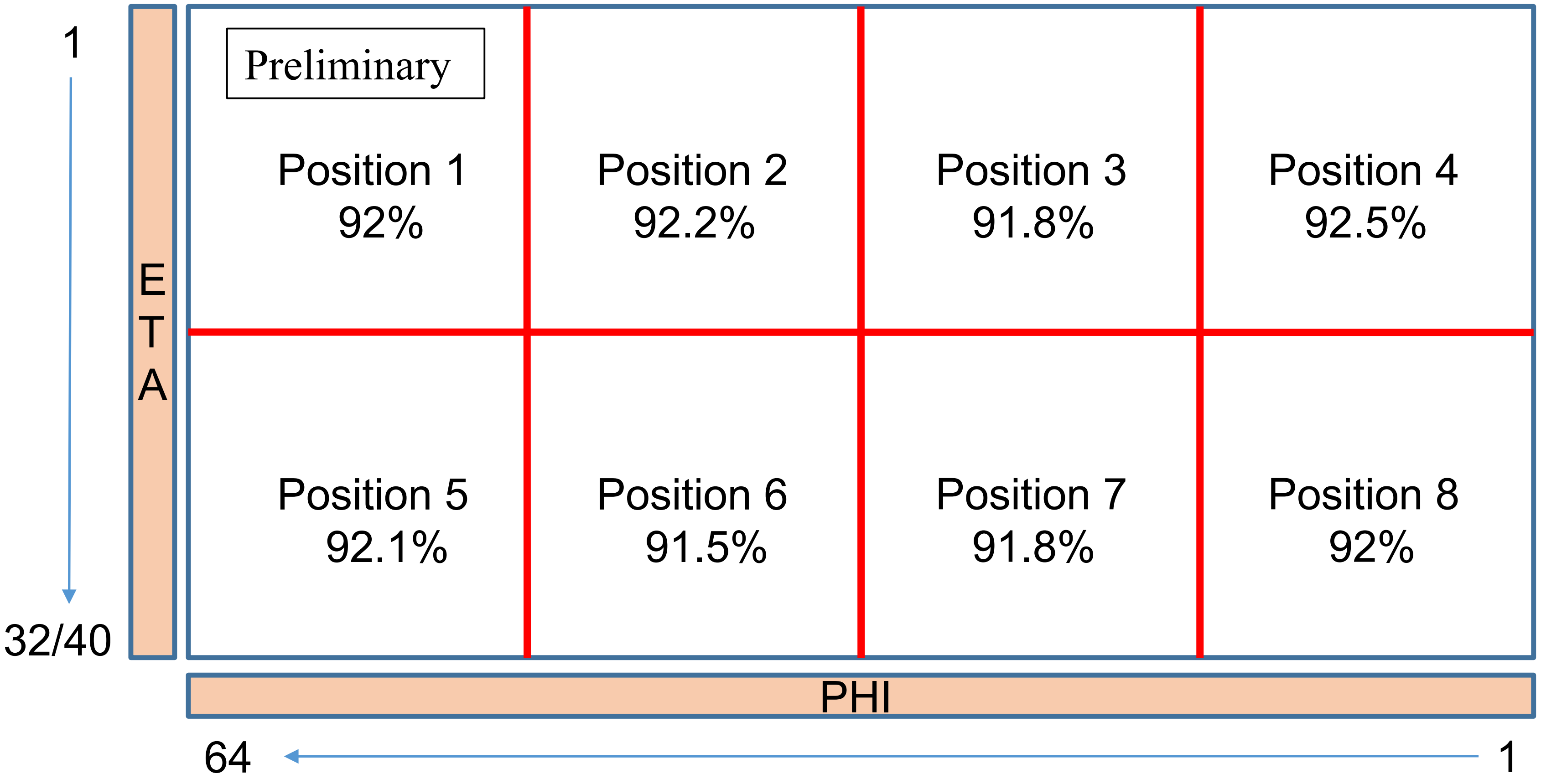


Figure 3. Efficiency curves RPC 1mm gap. In red SiGe FE; in blue Si FE; in black oscilloscope analysis with 1.5mV threshold.

BIS78 RPCs performance – Modules homogeneity



Efficiency at 5.6 kV
For each position tested

The efficiency shows an homogeneous behaviour all over the singlet surface within the statistical fluctuation

Full-Custom ASIC Discriminator

- Optimal characteristic function with the possibility of an easy regulation of the threshold from a minimum value of few mV (see Fig. 4)
- Very small transition region of around 300 µV, practically negligible when the discriminator is used within the RPC (see Fig 4).
- Time-over-threshold measurement directly with the discriminator (see Fig 5).
- Minimum pulse width of 3 ns ; for shorter signal the discriminator goes into a charge regime with a threshold in charge (see Fig 6).

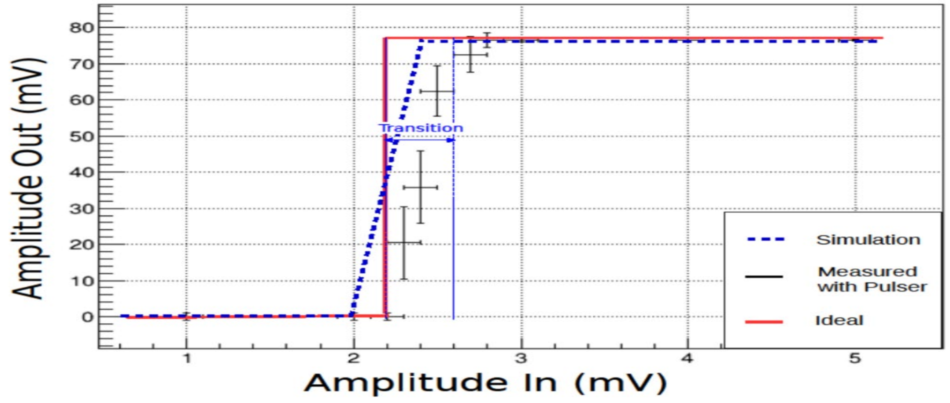


Figure 4: Characteristic function of the discriminator in Si-Ge HJT technology

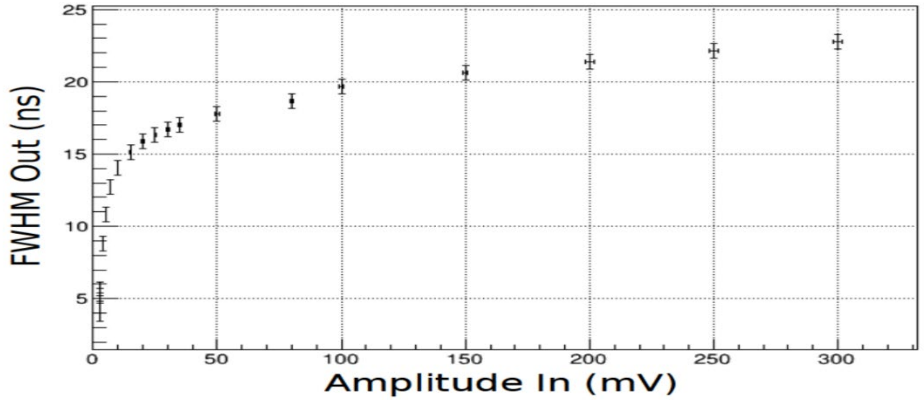


Figure 5: Dynamic of the time-over-threshold of the discriminator prototype in SiGe HJT technology.

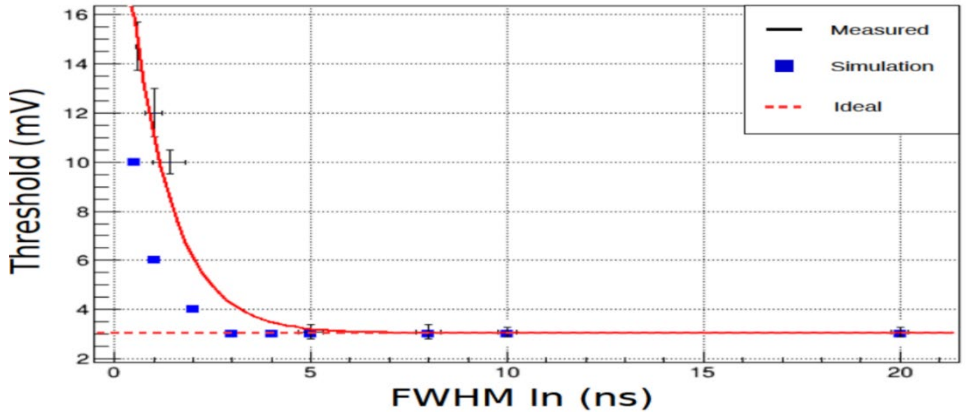
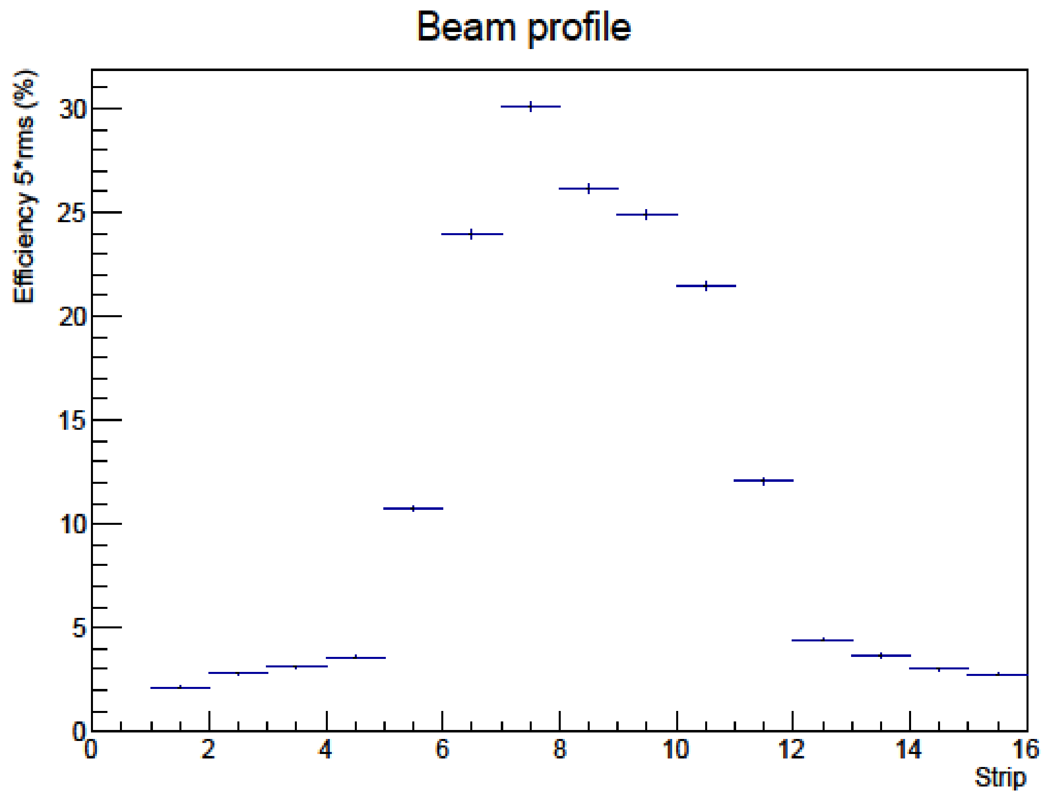


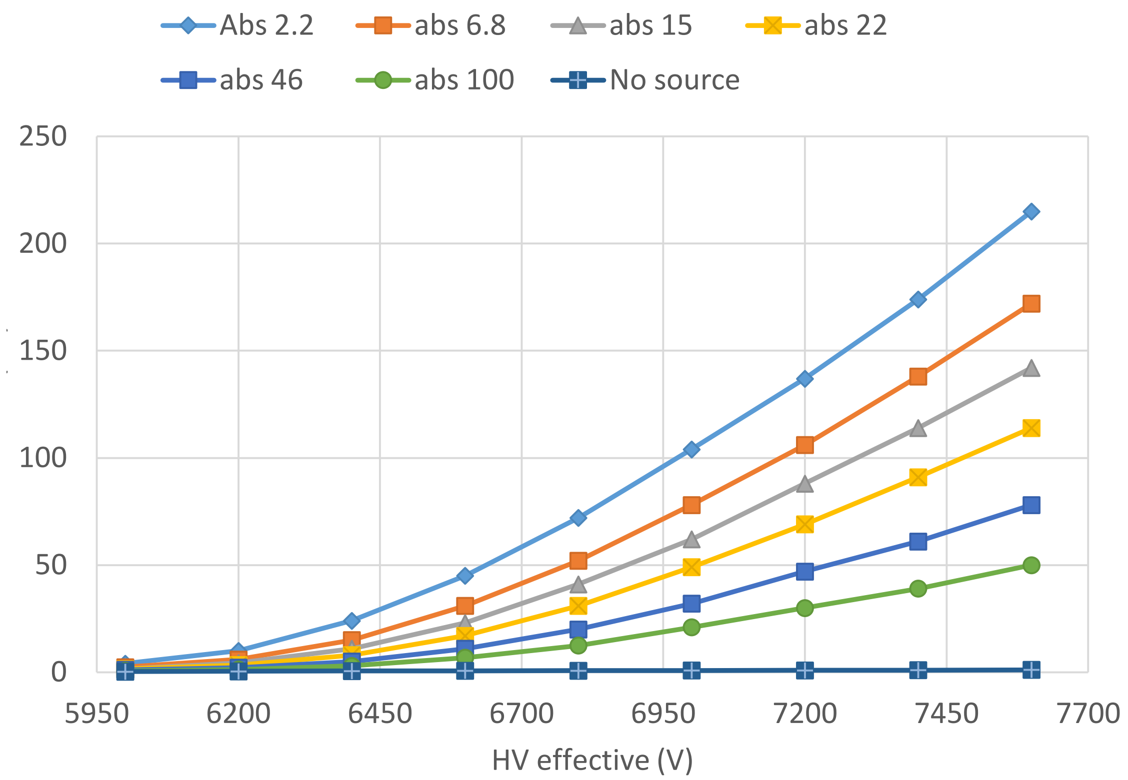
Figure 6: Minimum pulse width of the new Si-Ge prototype with the simulated and the ideal behavior of a discriminator compared

BIS78 RPCs performance – Time resolution

➢ Beam profile for the analogic FE test

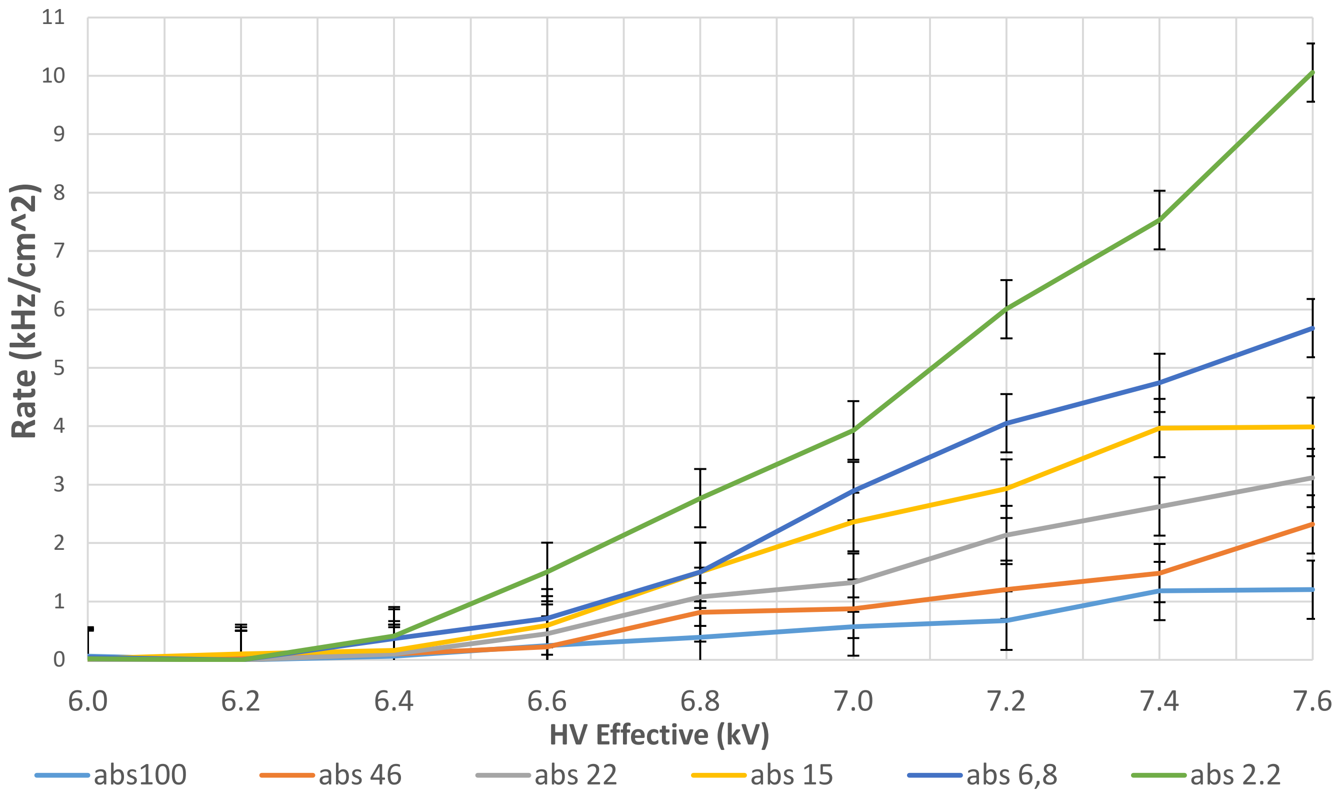


➢ I-V curves for different absorption factor



BIS78 RPCs performance – Time resolution

- Rate of converted photons for different absorption factor



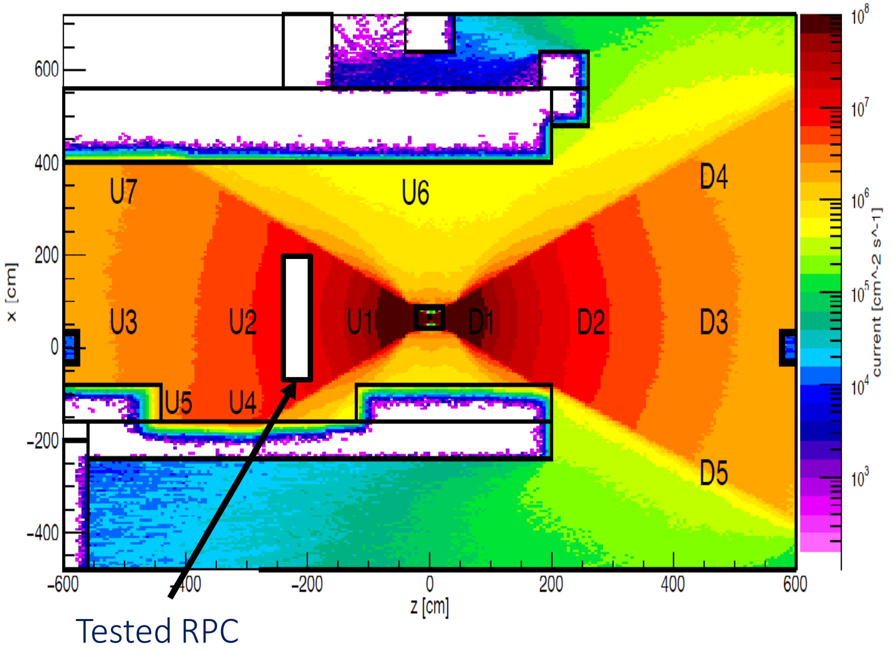
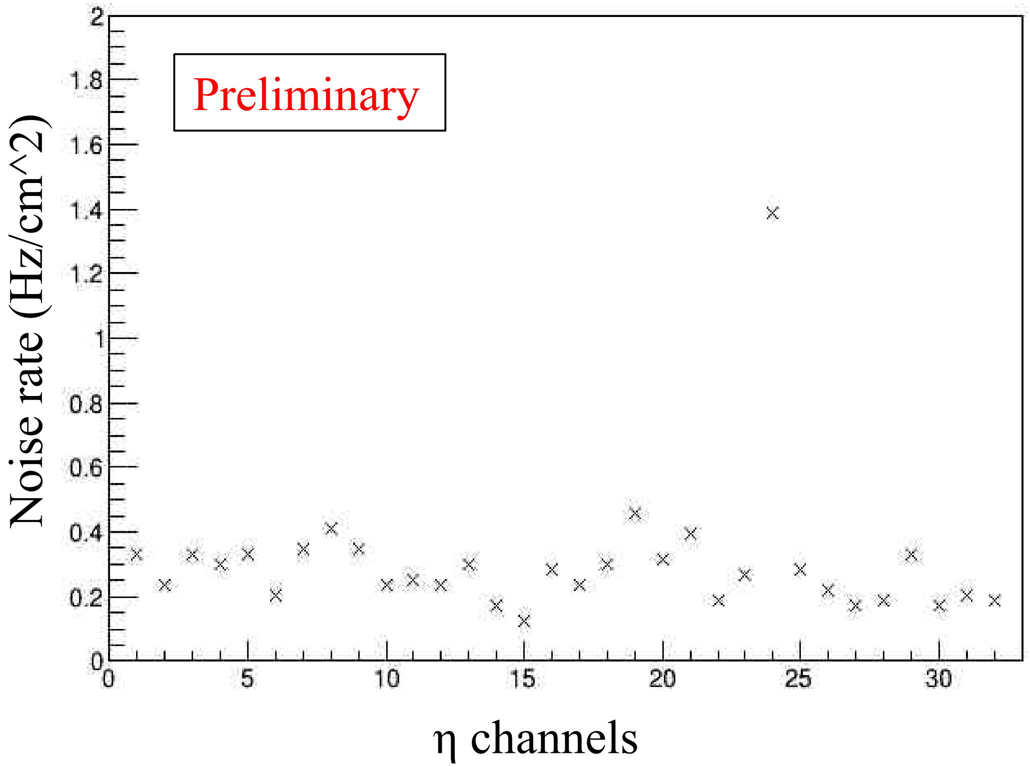


Figure 17. Total Current x: Downstream open, upstream open

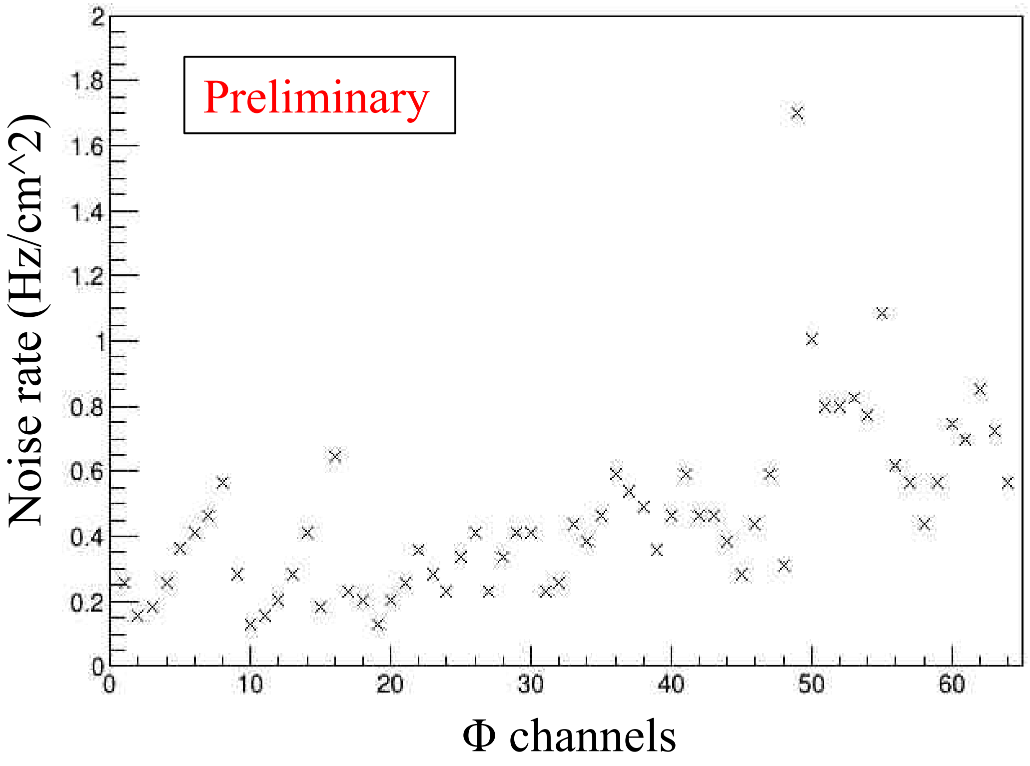
Simulation realized with Geant4 by the CERN experts

RPC performance – Noise rate map

Noise rate map of the η layer



Noise rate map of the Φ layer



Average channel noise of:

- η layer 0.2-0.3 Hz/cm^2
- Φ layer 0.4-0.6 Hz/cm^2