Linearity and rate capability measurements of RPC with semi-insulating crystalline electrodes operating in avalanche mode

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XV WORKSHOP ON RESISTIVE PLATE CHAMBERS AND RELATED DETECTORS RPC2020
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Perspectives

❑ High Rate

- The transition from the streamer to the avalanche regime paves the way to collider experiment applications (ALICE, CMS, ATLAS), moving the intrinsic rate capability up to ~1 kHz/cm². The HPL electrodes guarantee stable operation up to a total integrated charge of 0.3 C/cm² .

  -> Effective rate capability significantly limited by the experiment lifetime and luminosity

- The improvements on the FE electronics and detector design shift the intrinsic rate capability up to ~7 kHz/cm².
- A lower charge threshold would further improve the intrinsic rate capability, allowing the use of RPC detectors in very high radiation background environments
- **A new material immune to the ageing effect should improve the effective rate capability of a factor ten, just with $10^{10}\ \Omega cm$ resistivity**

❑ Calorimetry

- So far, the intrinsic linearity limit of the RPCs for multiple synchronous particles was measured only in the streamer operating mode.
- The use of RPCs in calorimetry was proposed for collider experiments and was just exploited for cosmic ray experiments ->Large Area (~5000 m²), low cost, thin active medium (≤ 2 mm), long lifetime, operate in high magnetic fields…

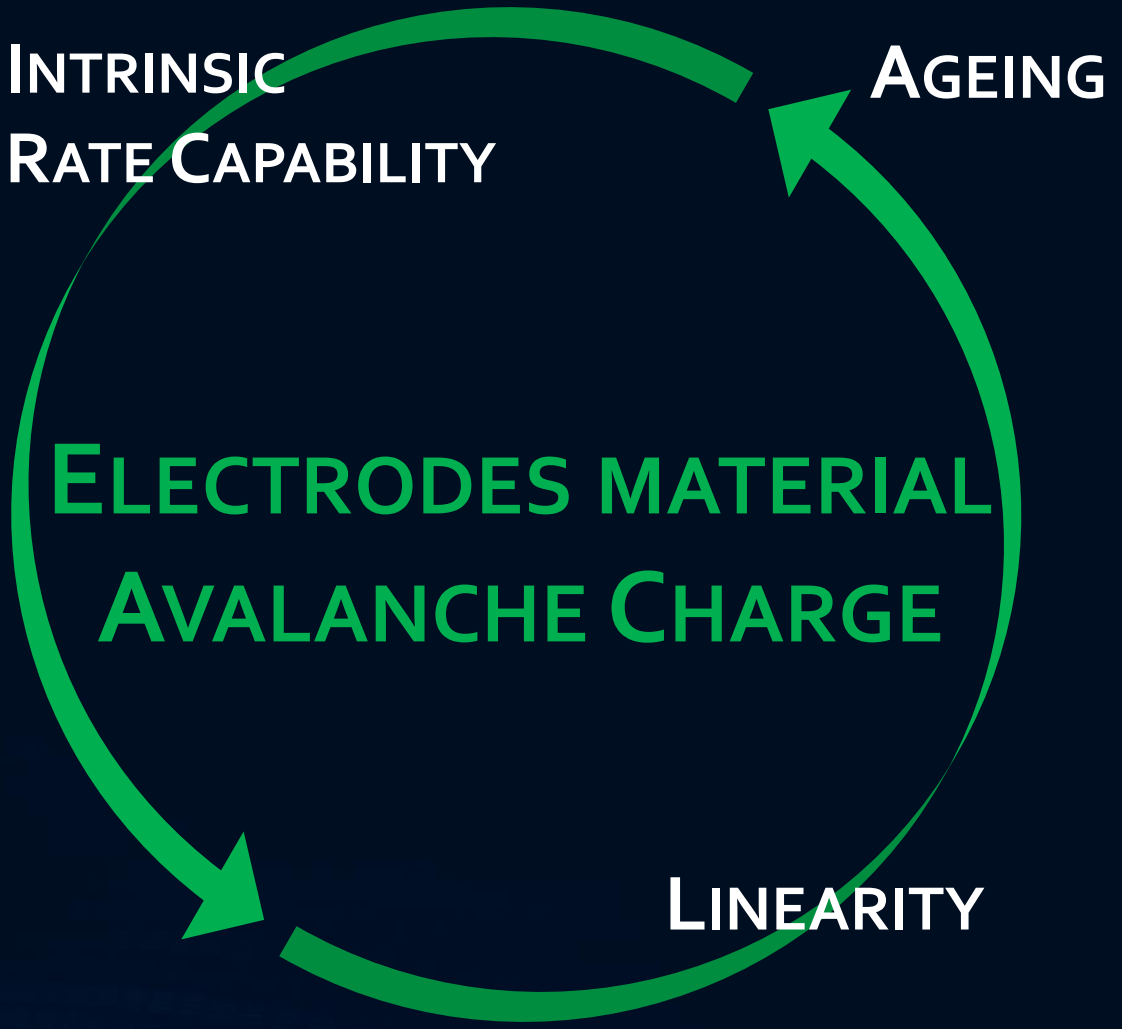
Limiting Factors and proposal

Different electrode material
(Semi Insulating Gallium Arsenide Wafers):
[T. Franke et al. Potential of RPCs for tracking, NIM Section A, Volume 508]

- Thickness 0.6 mm
- Resistivity 1.4×10^8 Ωcm

New FE electronics:
[R.Cardarelli et al, Performance of RPCs and diamond detectors using a new very fast low noise preamplifier, JINST 8 P01003]

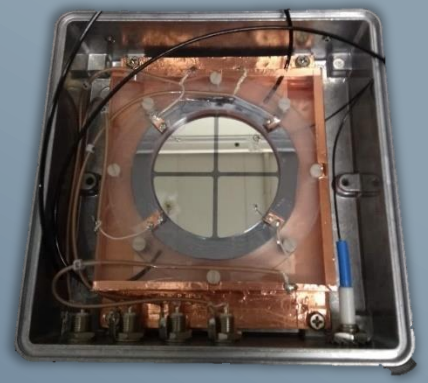
- Charge amplifier (2-4 mV/fC Sensitivity)
- Risetime 0.3 ns
- Input impedance 100 Ω
- Bandwidth 10-100 MHz



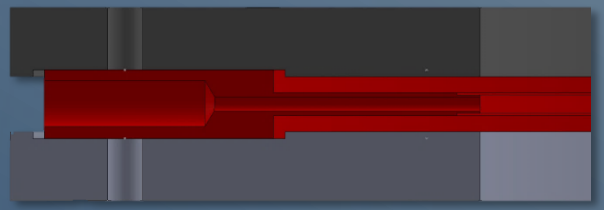
Thanks to Prof. M. Lucci for the GaAs metallization

Prototype design

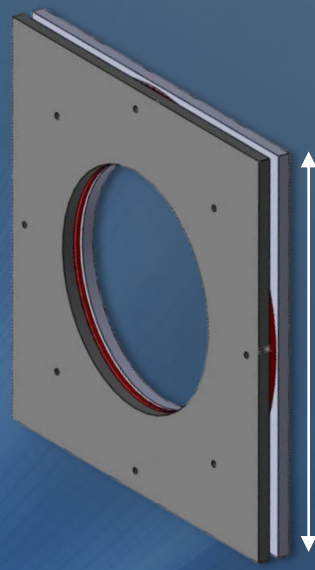
- Gas gap thickness 1 mm
- Active area 6.25 cm²
- Four readout pads

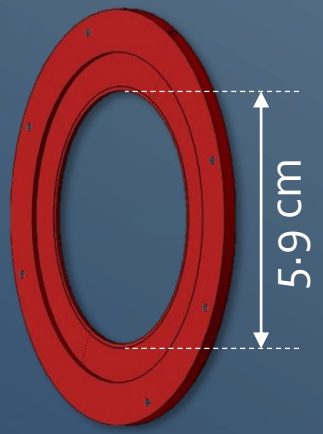


Gas inlet ø 2 mm -> ø 0.6 mm



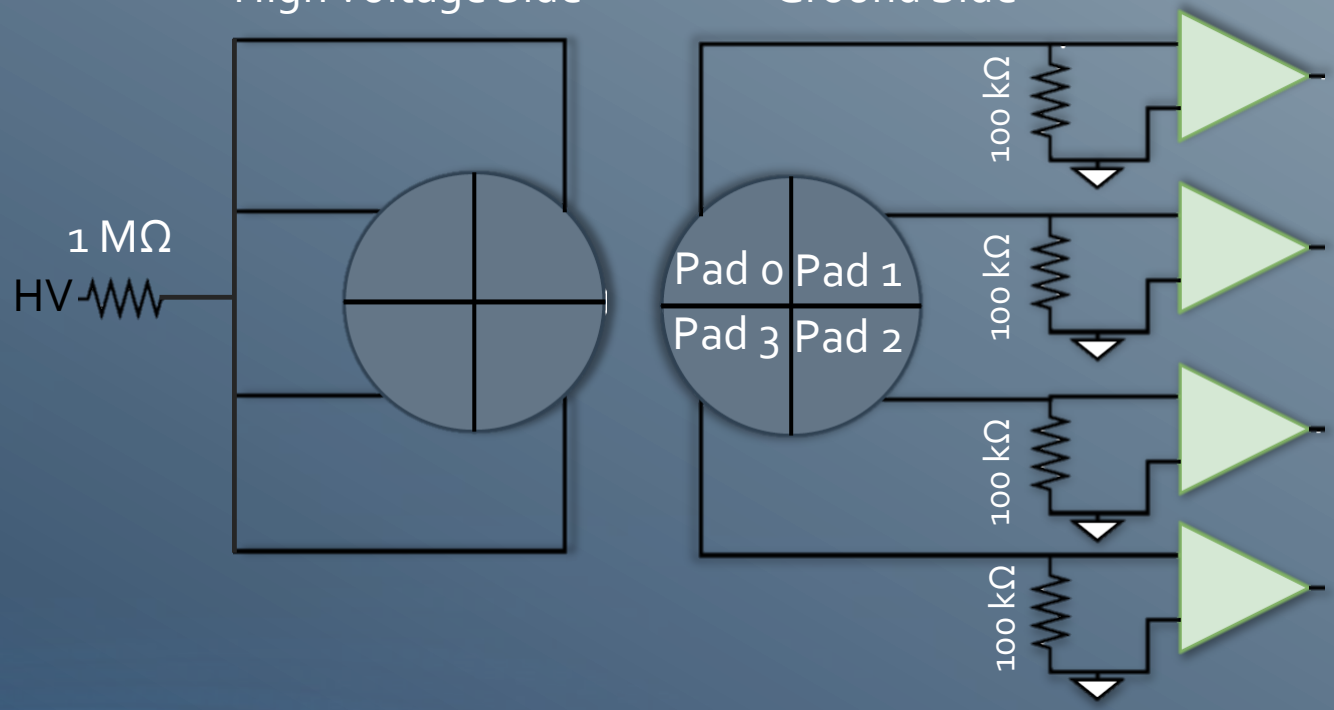
Wafers holder | Wafers spacer 1 mm





High Voltage Side

Ground Side



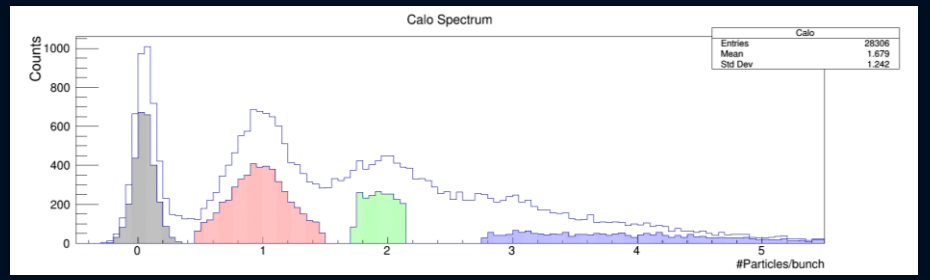
Linearity response

(Experimental setup at BTF LNF)

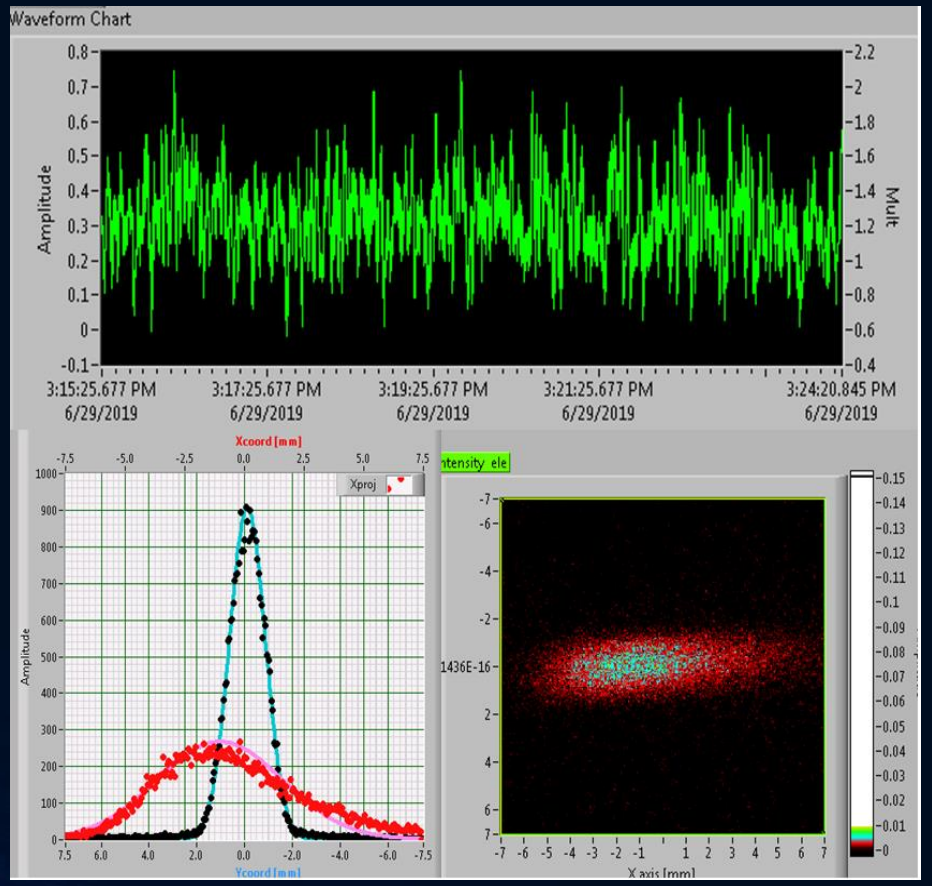
Beam energy	250 MeV
Bunch lenght	10 ns (microbunched 0,35 ns)
LINAC repetition rate	40 Hz
Beam spot size	σ_x~2 mm; σ_y~1 mm
Beam particles	e^-

DAQ LeCroy 7300A: 3GHz; 10GS/s

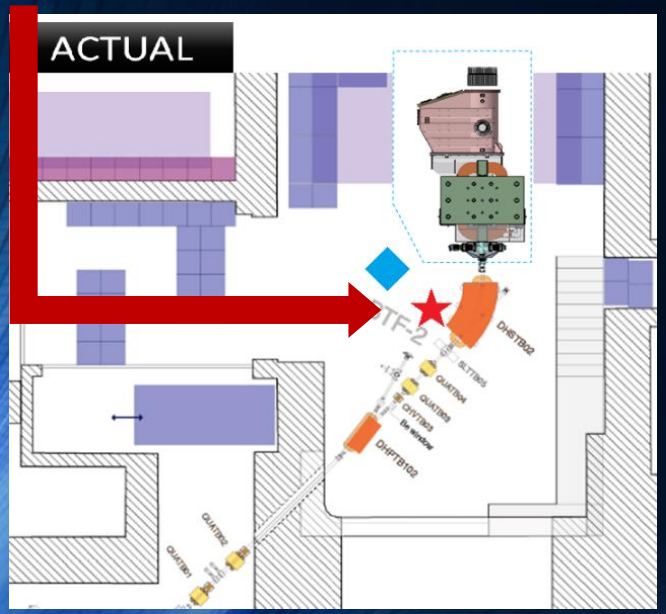
Offline multiplicity on CALO BTF



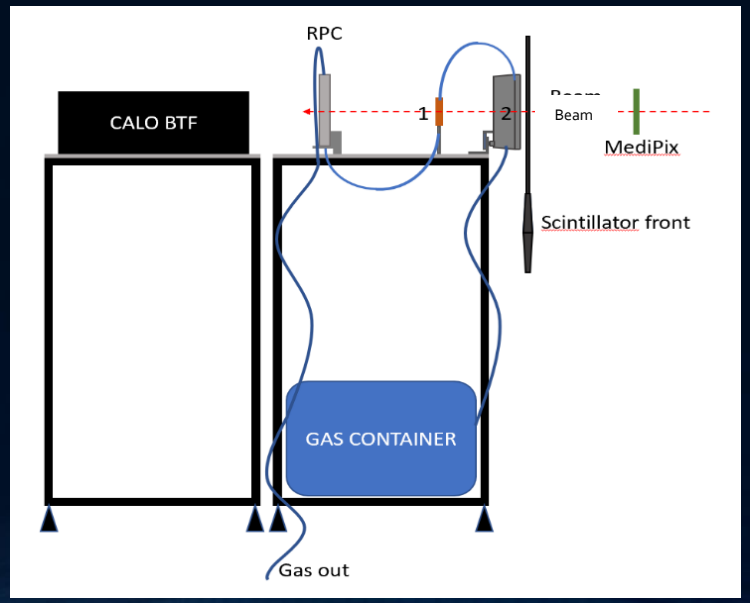
Online beam monitoring on MediPix



We were here !



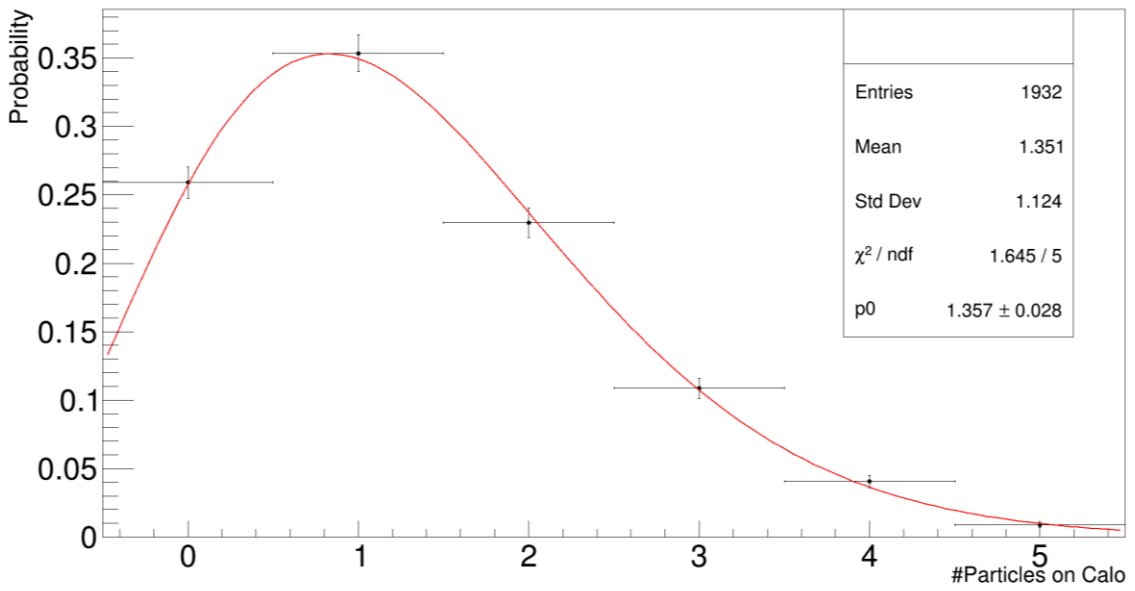
$95\%C_2H_2F_4+4.5\%iC_4H_{10}+0.5\%SF_6$

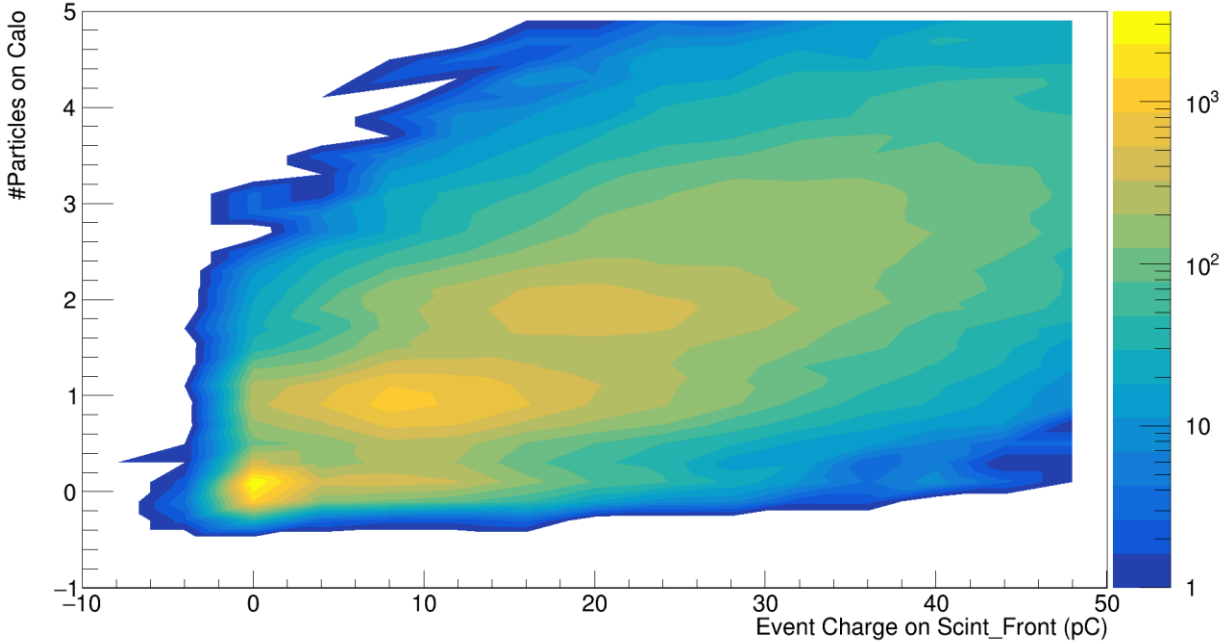


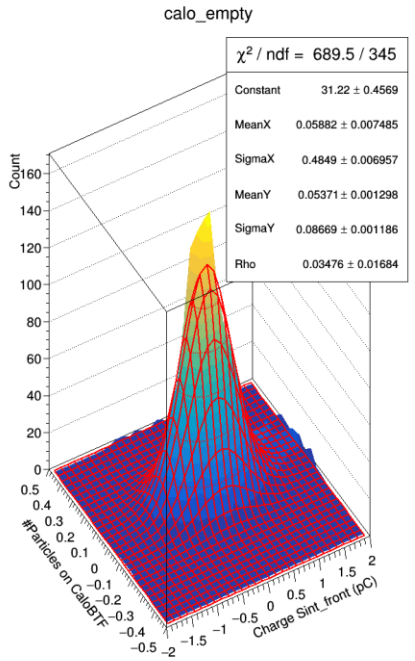
Linearity response

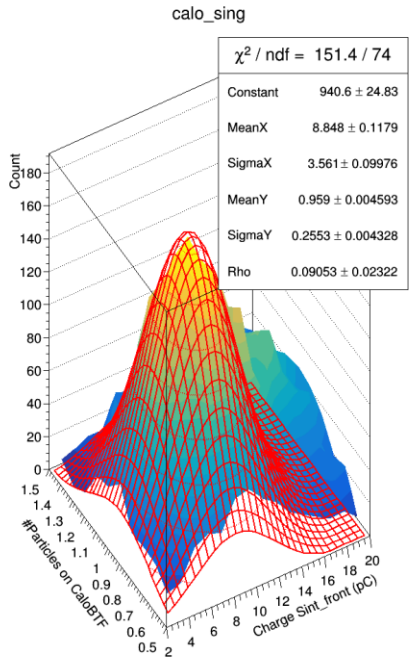
(Multiplicity reconstruction)

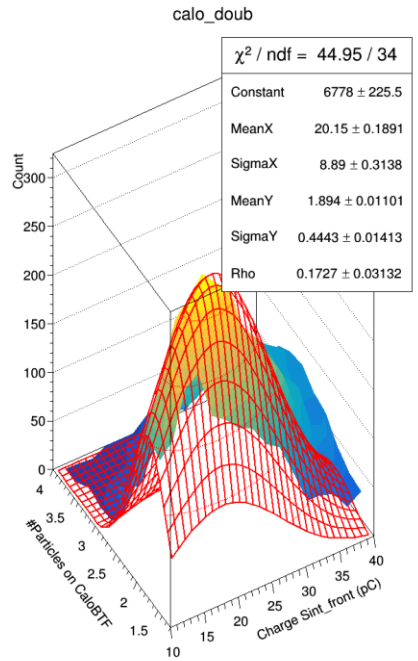
- The particles multiplicity in the bunch follows a Poisson statistics
- The BTF calorimeter multiplicity spectrum was related to the front scintillator charge to better reconstruct the bunch multiplicity. The peaks of the experimental distribution were fitted with a bivariate Gaussian distribution and the events on the distribution tails were removed from the sample space











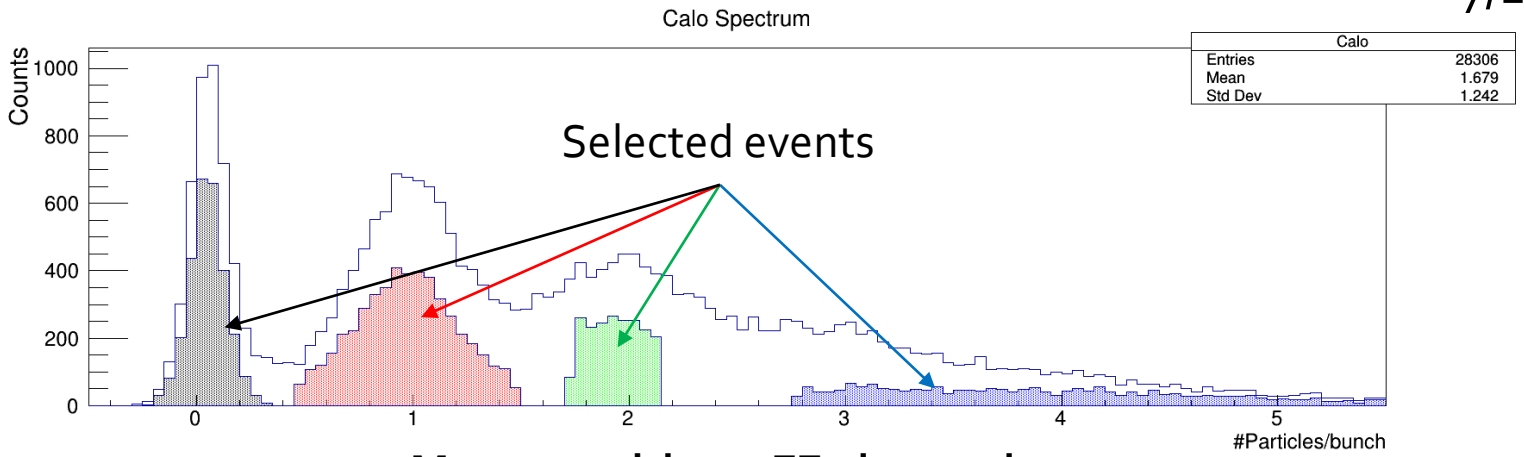
Linearity response
(Detector characterization)

The efficiency has been measured for different multiplicity selections as a function of the high voltage.

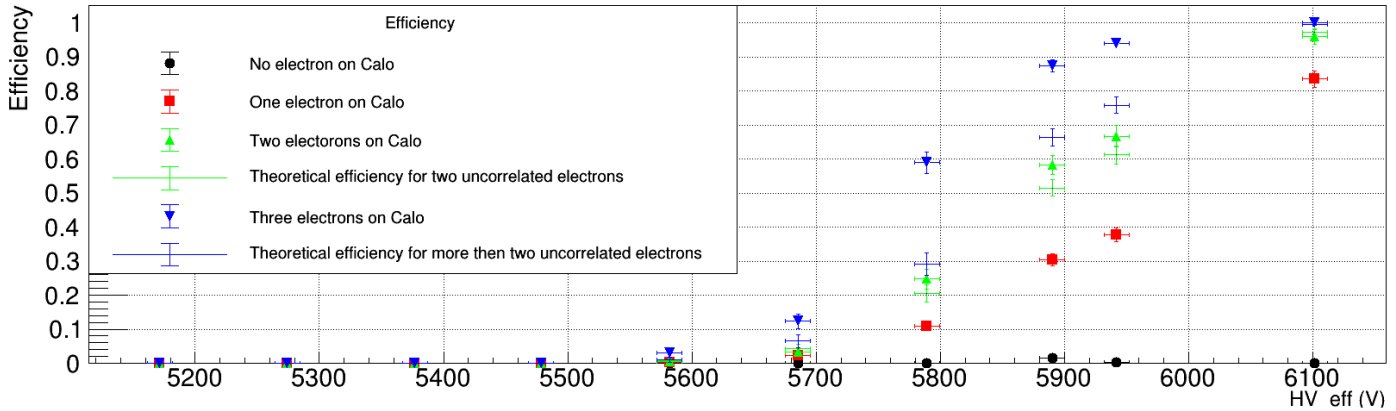
A signal has been considered efficient if the peak amplitude exceed 5 × $\sigma_{background}$

$\sigma_{background}$ is the standard deviation of the analogic signal baseline (~35 mV for this measurement)

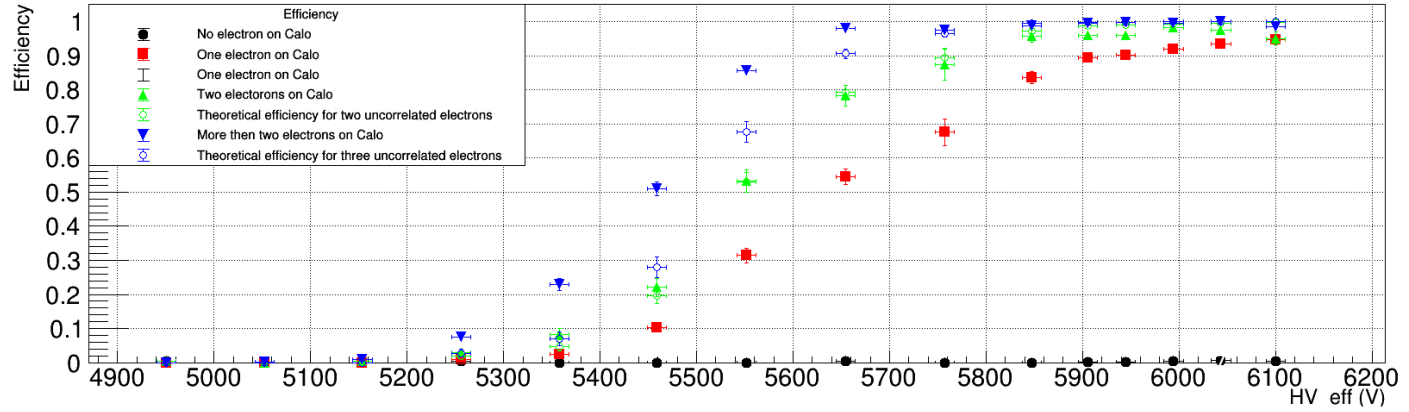
The experimental efficiencies are compared with the theoretical expected values (calculated supposing independent synchronous events)



Measure without FE electronics

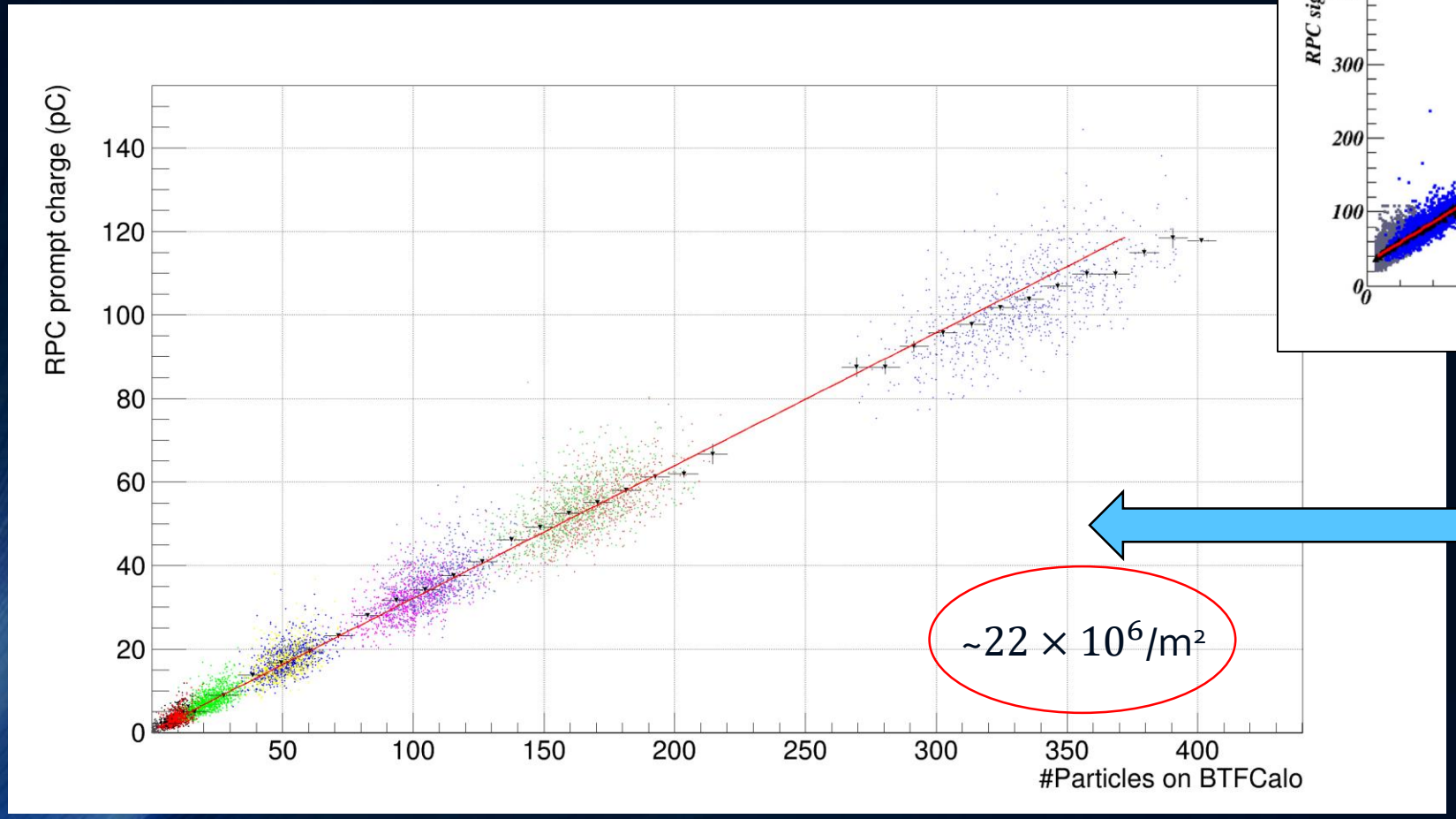


Measure with FE electronics

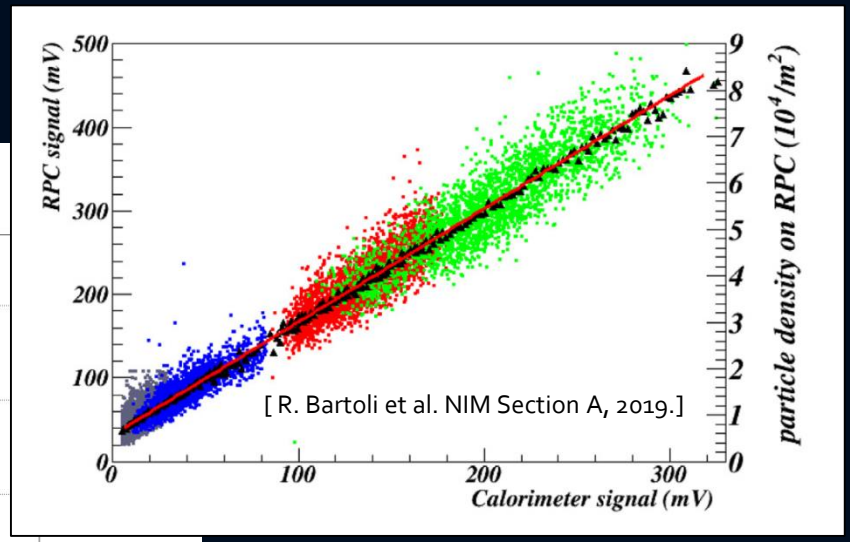


Linearity response
(Charge vs bunch multiplicity)

Linearity response in avalanche mode (1 mm gas gap thickness)



Linearity response in Streamer mode
(2 mm gas gap thickness) [1]
Gas mixture: 75% $C_2H_2F_4$ +15% Ar+10% iC_4H_{10}



47% of the particles in the bunch within 1σ beam spot (~ 6.28 mm²)

Readout pad size 6.25 cm²

Induced Prompt charge per count
$\bar{Q}_{prompt} = 0.45\ pC$

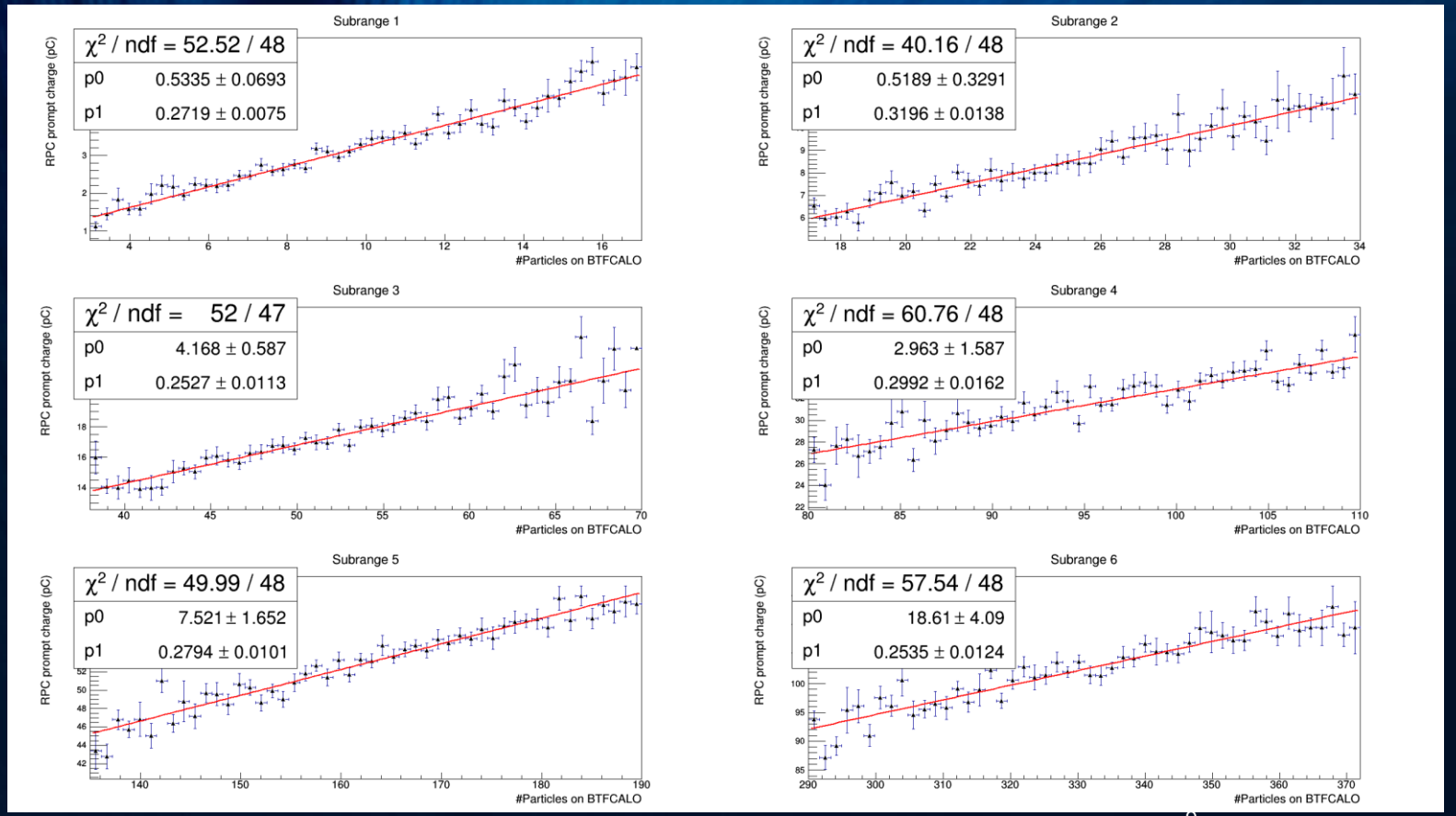
Subrange Linearity response (Charge vs bunch multiplicity)

SYSTEMATIC UNCERTAINTY

(Wide multiplicity range - long time measurement)

- Reference calorimeter high voltage changes during the measurement
- Beam position fluctuates due to multiple beam restart (DAϕNE cycles)
- Variations in the environmental conditions (air conditioning system down)

LINEARITY RESPONSE FOR EACH MULTYPLICITY SUBRANGE (CONFIDENCE LEVEL > 95%, FIT RESIDUALS HAVE GAUSSIAN SHAPE)

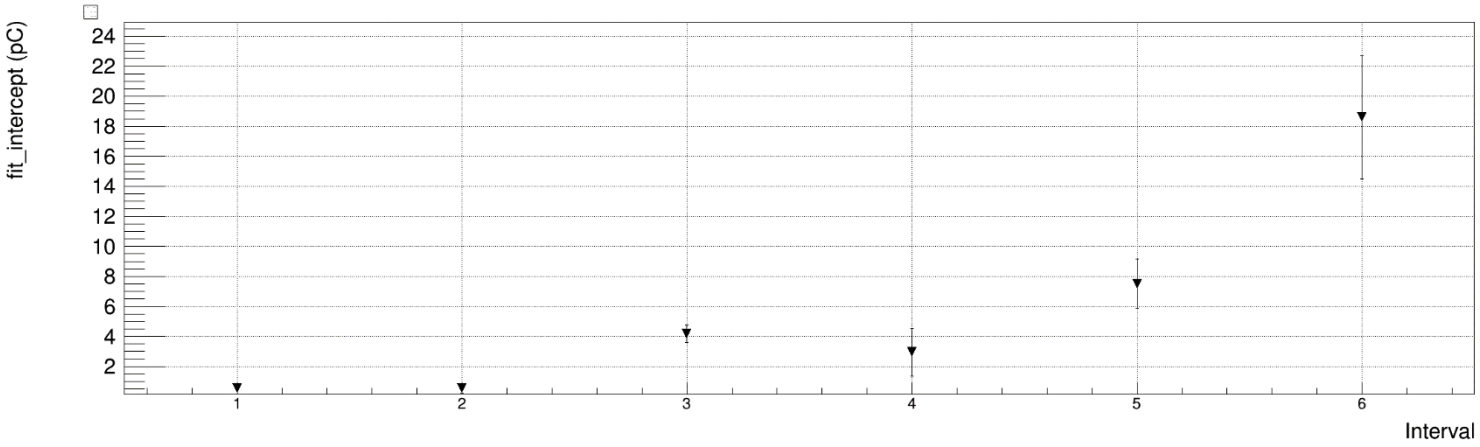


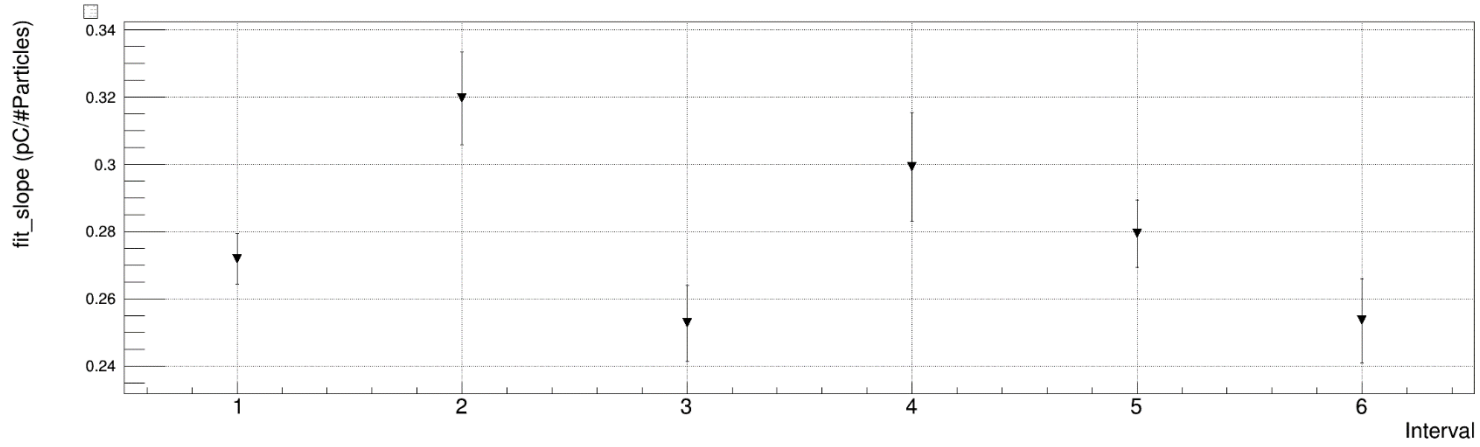
Linearity response results (Fit parameters)

The increase of the fits intercepts suggests the presence of relevant systematic uncertainties

The fits slopes don't show a correlation with the subranges

Fit Intercepts and slopes for different subranges





Linearity response results

The Resistive Plate Chamber Detector with GaAs electrodes, operated in avalanche mode, shows a linear response in each subrange with respect to the bunch multiplicity up to

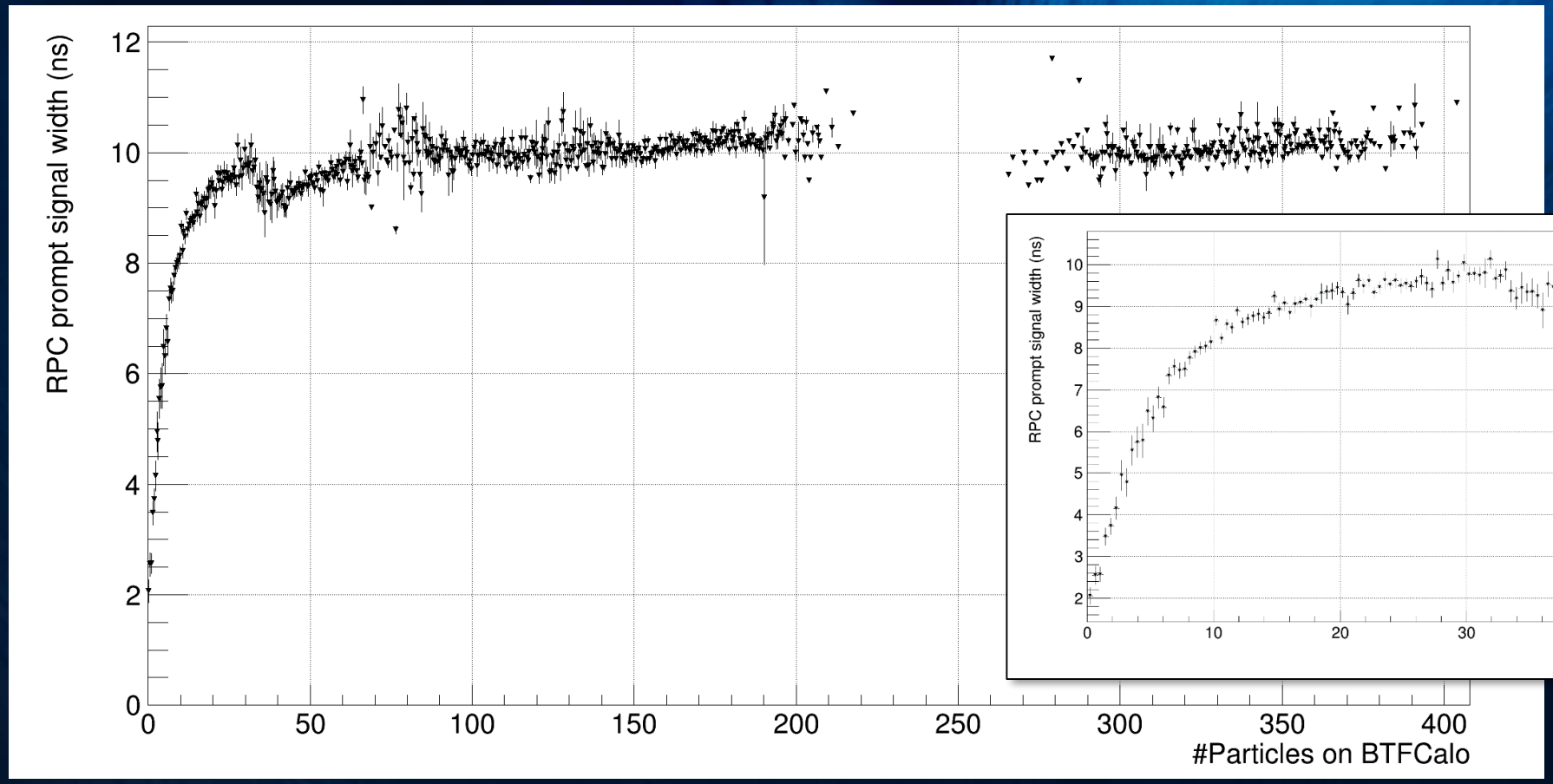
$$\sim 22 \times 10^6 \text{ Particles/m}^2$$

To be compared to the streamer mode linear response

$$\sim 8 \times 10^4 \text{ Particles/m}^2$$

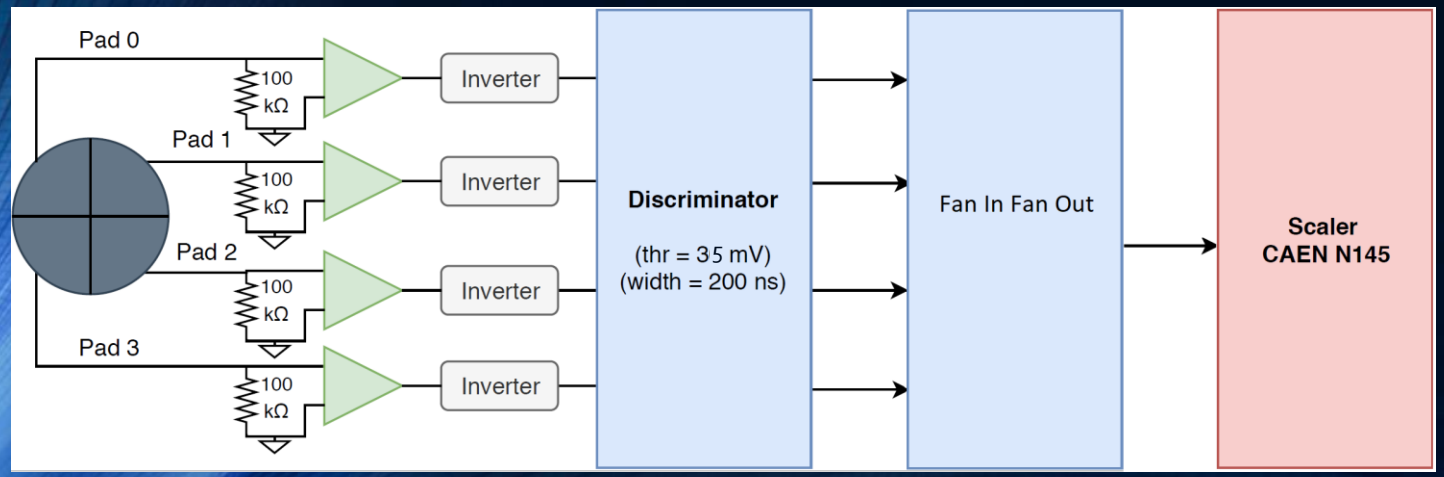
Time response (Time width vs bunch multiplicity)

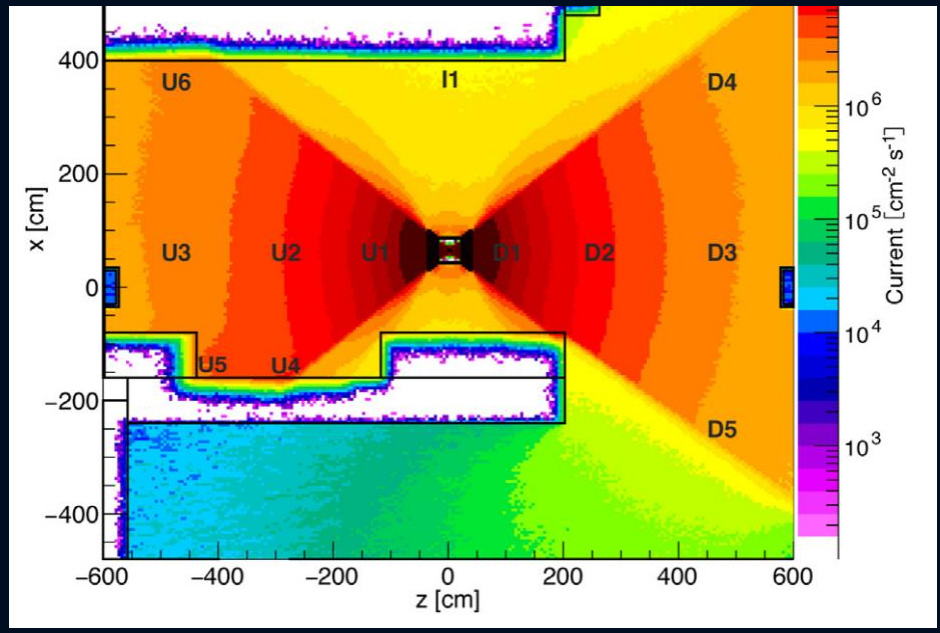
NUMBER OF PARTICLES APPROACHES THE NUMBER OF MICROBUNCHES (~28) → PROMPT SIGNAL WIDTH SATURATES TO BUNCH DURATION



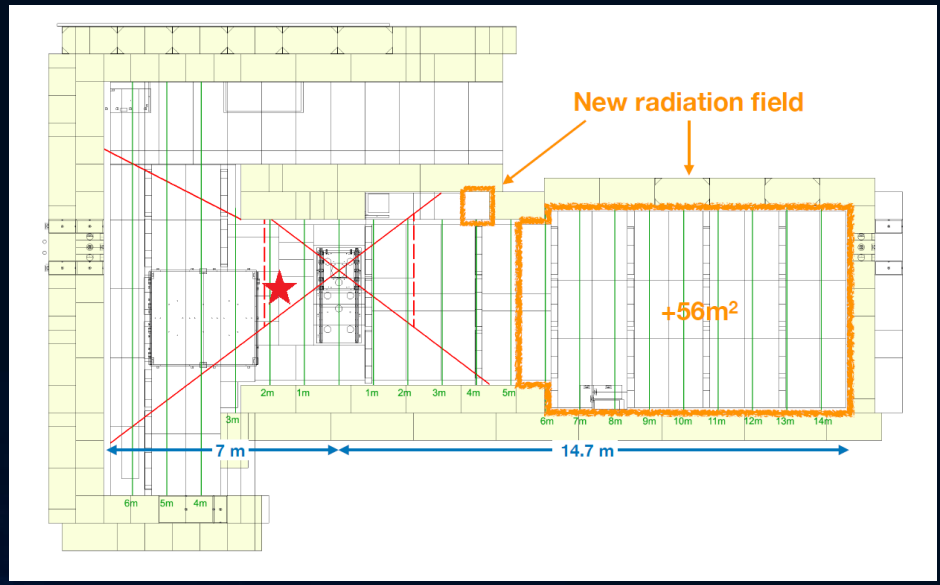
Rate Capability (experimental setup)

- Rate capability measured counting the signals (discriminated with 30 mV threshold on 50 Ω) in 100 s time interval
- 14.9 TBq ^{137}Cs source (662 keV photons 33% - 54%)
- Measurement repeated for different high voltage working points and different source absorbers (ABS1=no absorber, maximum flux ~10^7 Hz/cm²)
- No photon converter on the electrode surface ->RPC photon efficiency ~ 5×10^{-3} (to be measured for GaAs RPC) -> maximum photons counting rate ~50 kHz/cm²





D. Pfeiffer et al, The radiation field in the Gamma Irradiation Facility GIF++ at CERN



Rate Capability (Counting rate)

Counting rates for different filter absorption factors

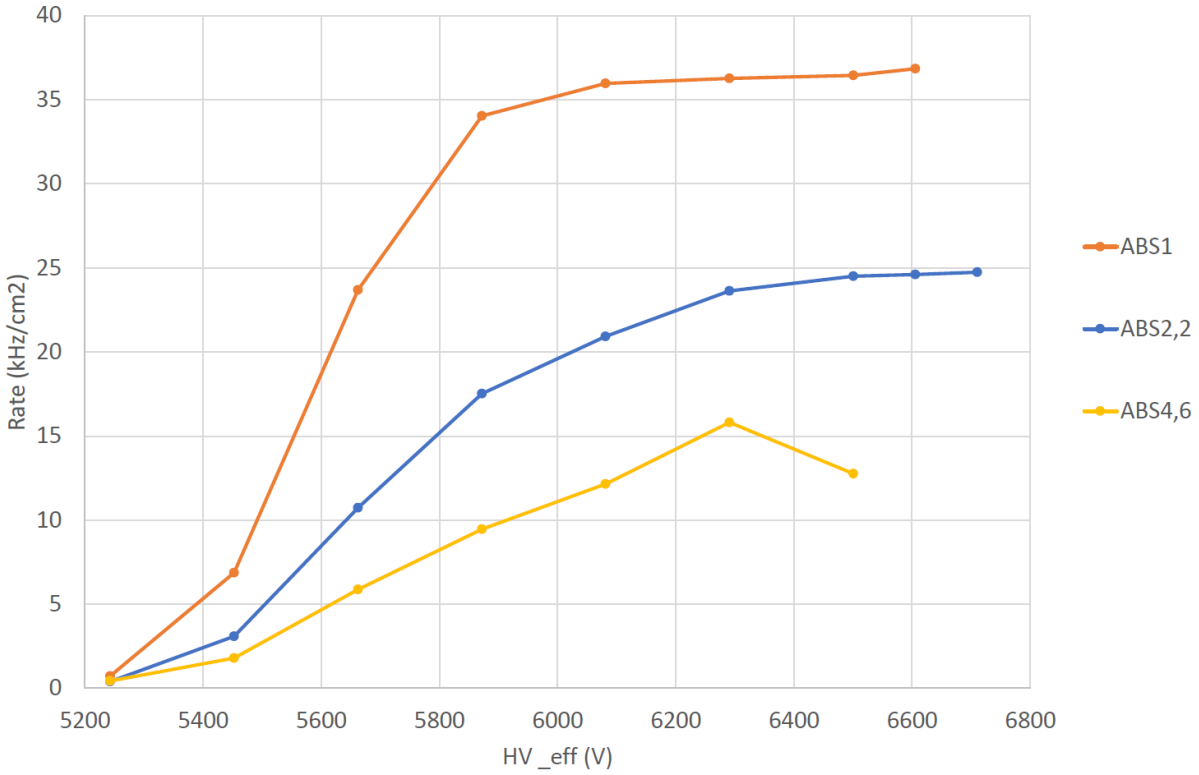
- photon flux decreases as the ABS increases
- efficiency knee point previously measured at 5850V with threshold set to 35 mV on 50 Ω.

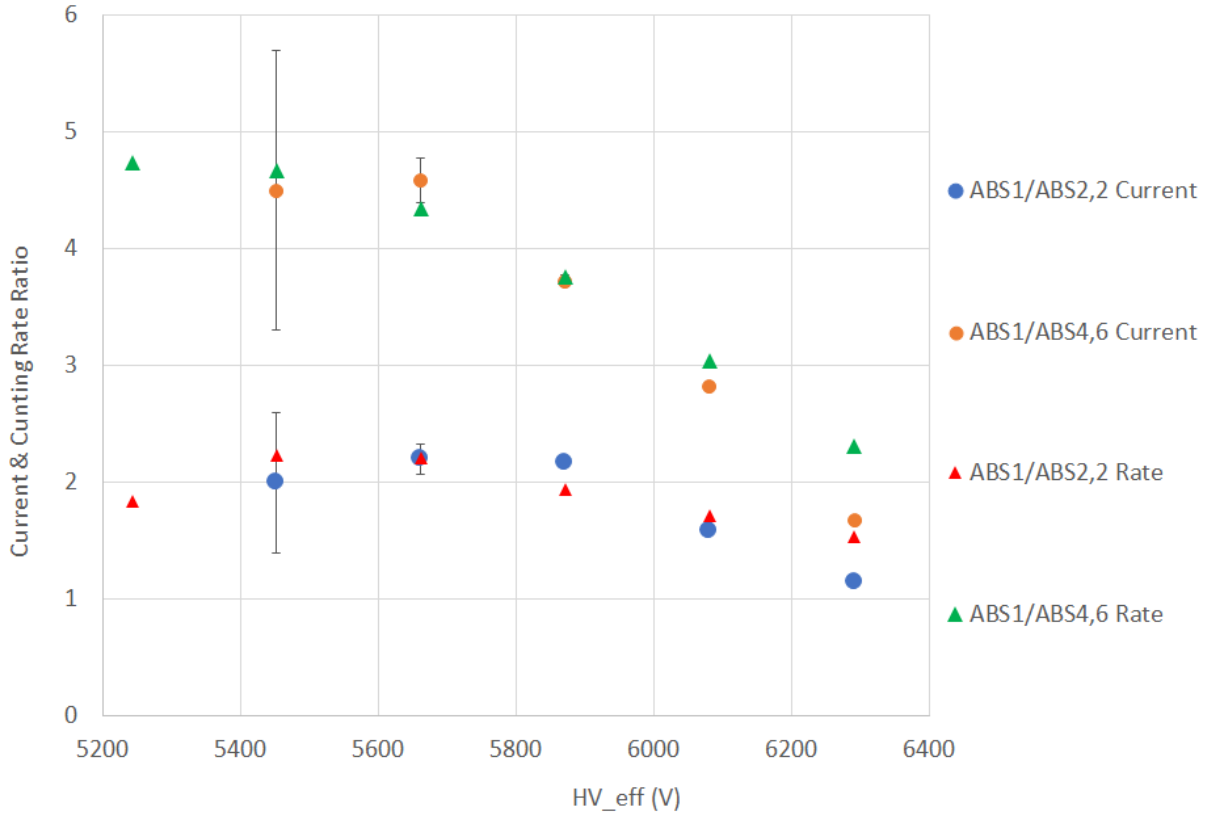
Expected ratios (without saturation)

$$\frac{I_1}{I_{2.2}} = \frac{\Phi_1 * \bar{Q}}{\Phi_{2.2} * \bar{Q}} = \frac{\Phi_1}{\Phi_{2.2}} = \frac{2.2 * \Phi_{2.2}}{\Phi_{2.2}} = 2.2$$

$$\frac{I_1}{I_{4.6}} = \frac{\Phi_1 * \bar{Q}}{\Phi_{4.6} * \bar{Q}} = \frac{\Phi_1}{\Phi_{4.6}} = \frac{4.6 * \Phi_{4.6}}{\Phi_{4.6}} = 4.6$$

Counting rate and current ratios are consistent with the ABS ratios up to ~5800 V





Rate capability results

The measurement shows that this GaAs-RPC prototype can count up to

$\sim 36 \times 10^3$ Hz/cm²
in uniform high energy photons field

The measured rate at 5870 V (efficiency knee point) is :

$\sim 34 \times 10^3$ Hz/cm² without absorber

$\sim 17.5 \times 10^3$ Hz/cm² without ABS=2.2
$\sim 9.5 \times 10^3$ Hz/cm² without ABS=4.6

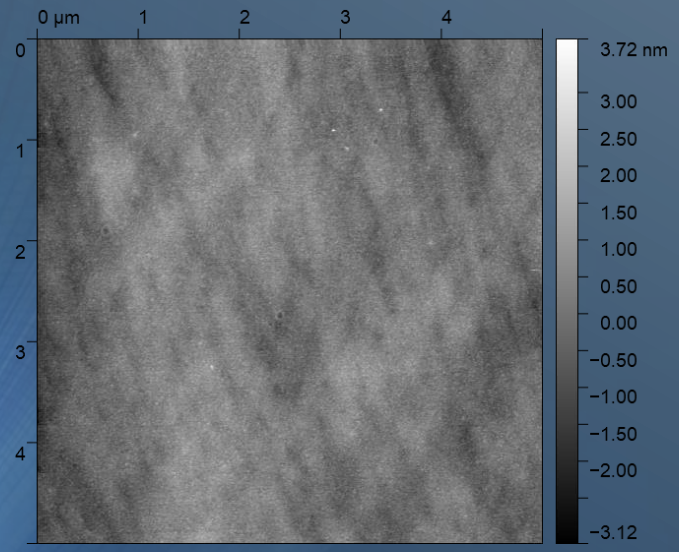
These values are significantly limited by the high threshold value set to 35 mV due to the improvable shieldings and ground connections

Ageing
(Preliminary)

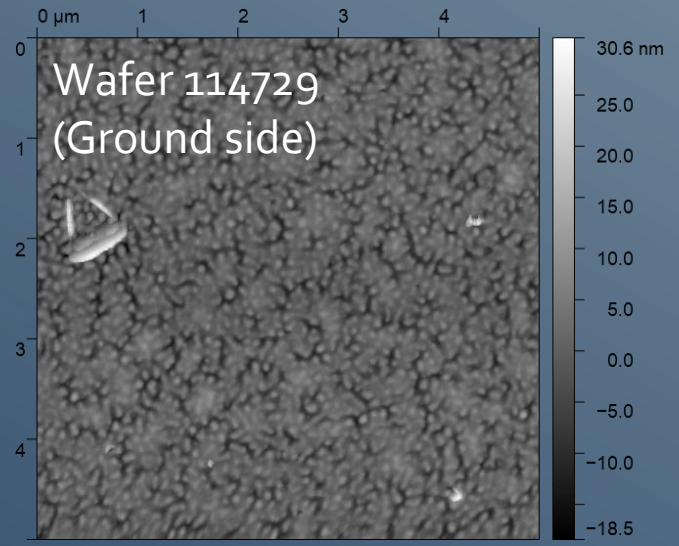
The surfaces of two used wafers have been analyzed with the Atomic Force Microscopy

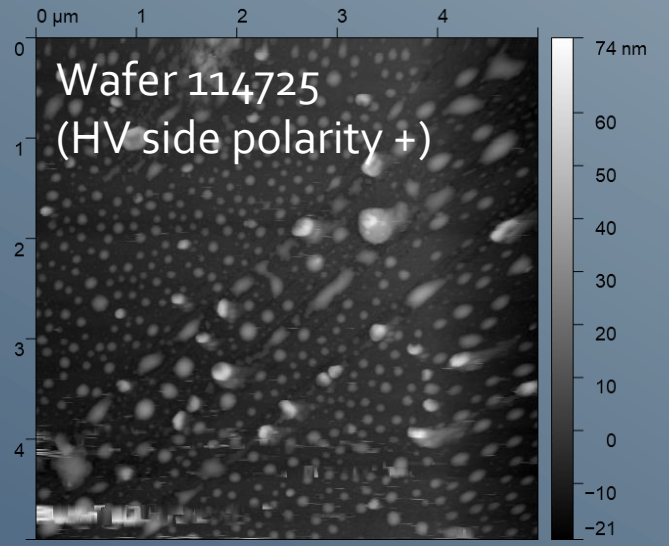
- Microstructures 58-96 n m tall with different shapes were found at the center of the wafer
- The edge of the wafer (out of the detector active region) shows a uniform flat surface

Edge



Center



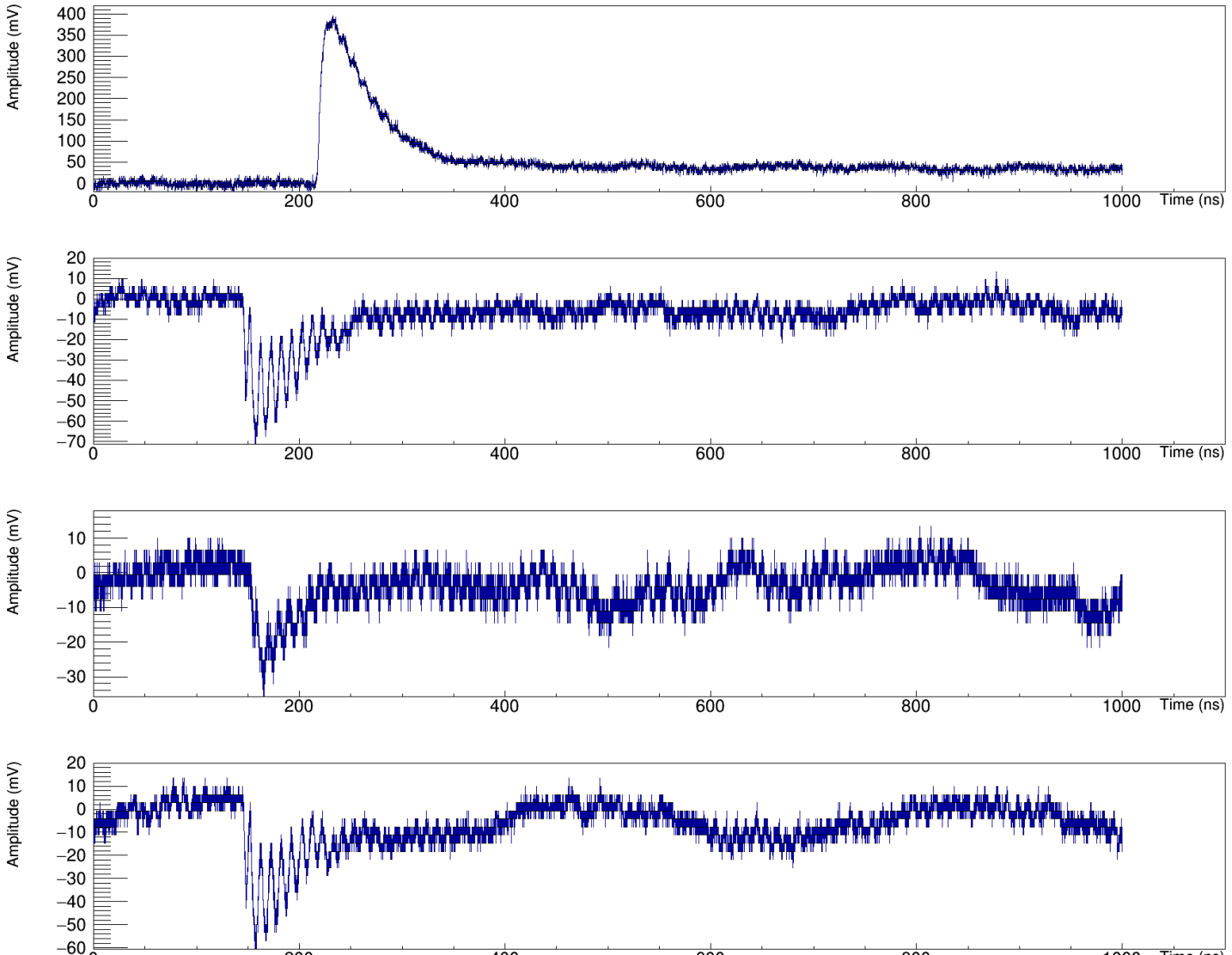


Thanks to Prof. Ernesto Placidi

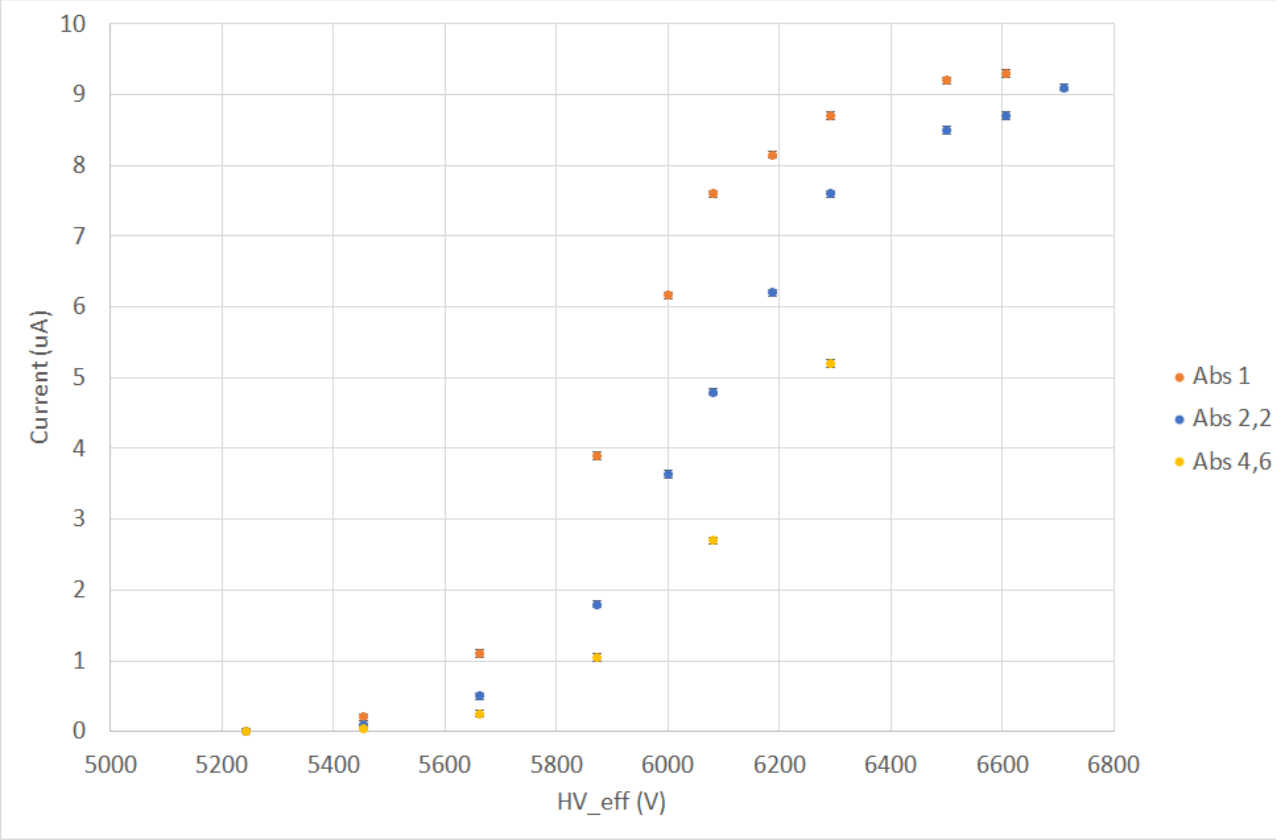
Conclusions

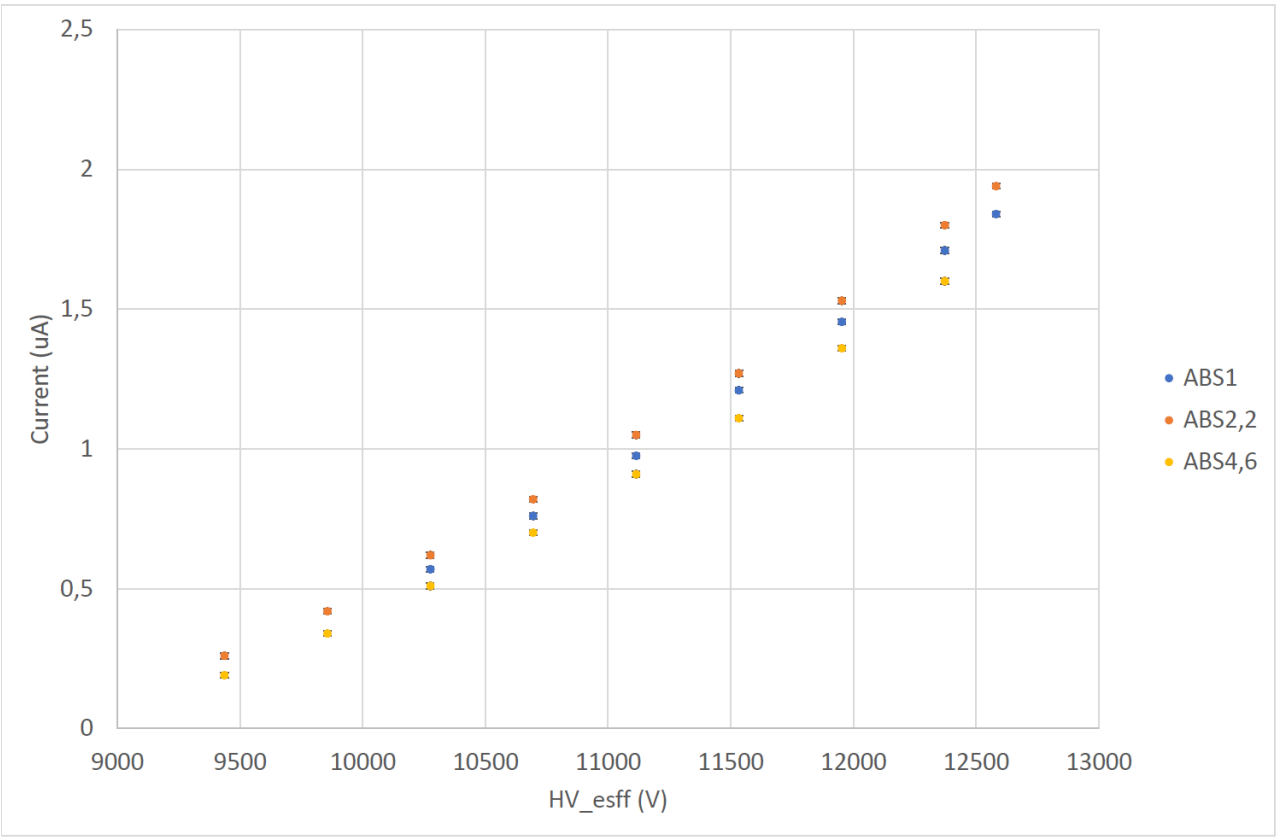
- RPCs with Semi-Insulating electrodes have been found simple to buil. The excellent wafer surface uniformity allows using this material without linseed oil coating.
- The maximum measured counting rate is $\sim 36 \times 10^3$ Hz/cm² in a uniform high energy photons flux $\sim 10^7$ Hz/cm². Counting rate ratios and currents ratios agree with the expected values for high voltages lower than 5700 V. A small counting rate saturation has shown at 5870 V (discrimination threshold=35 mV) .
- We can claim, with more than 95% confidence level, that the RPC response is linear in each multiplicity range up to $\sim 22 \times 10^6$ particles/cm² .
- The ageing problem should be further investigated changing the gas humidification and components

Waveforms with FE

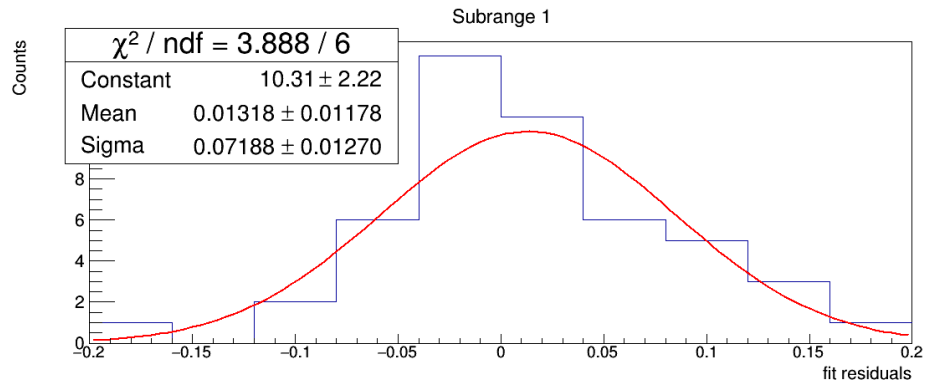


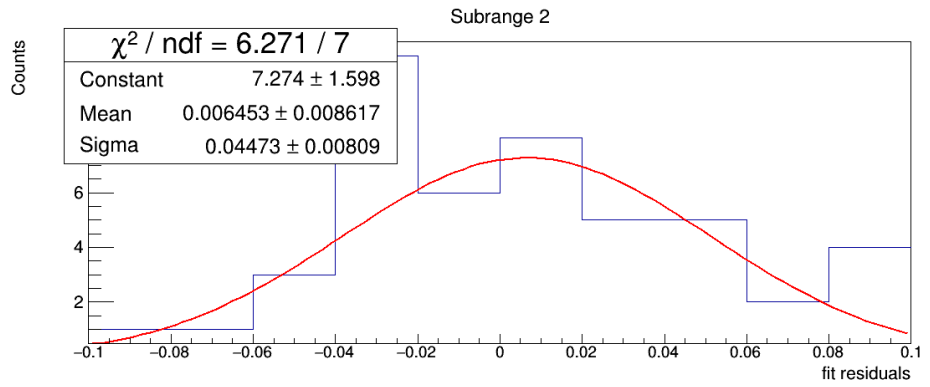
Bakelite vs GaAs currents

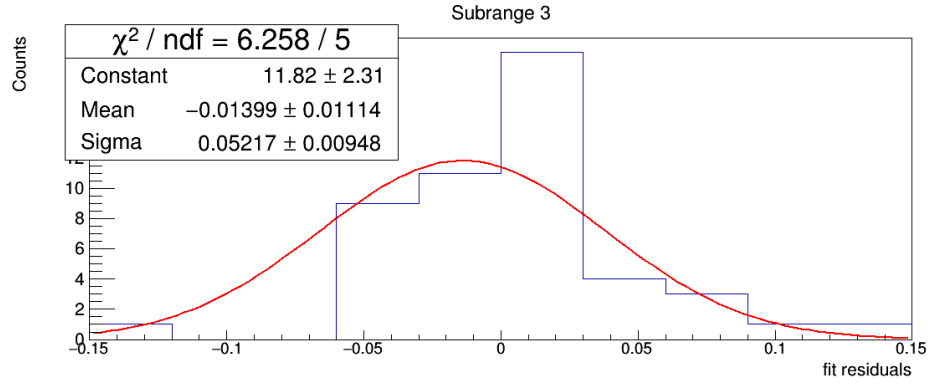


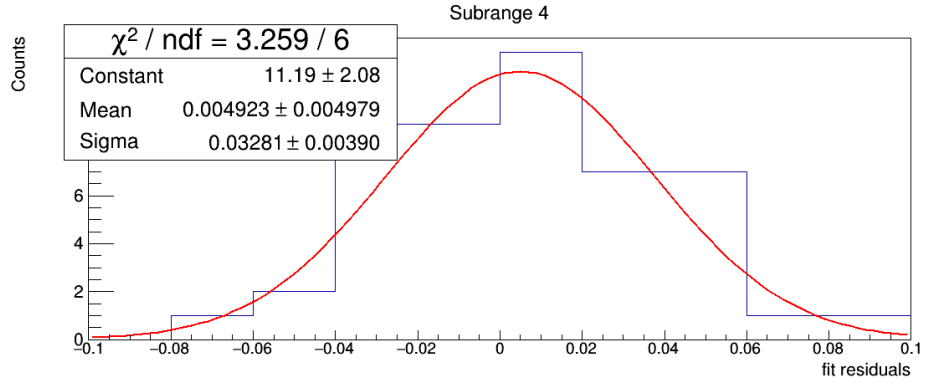


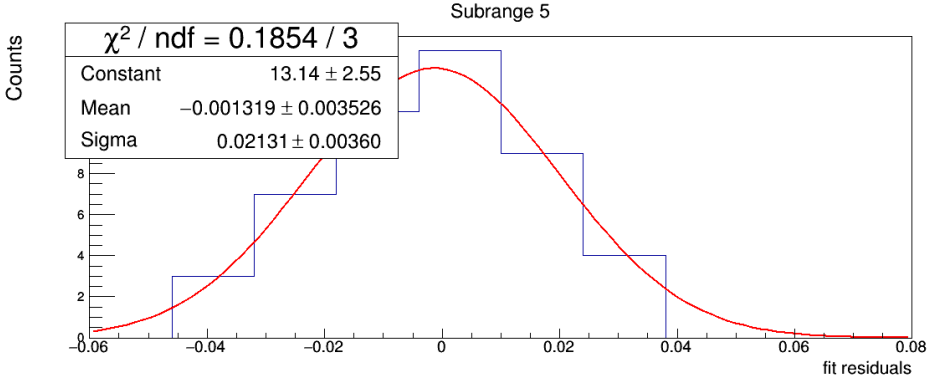
Fit Residuals

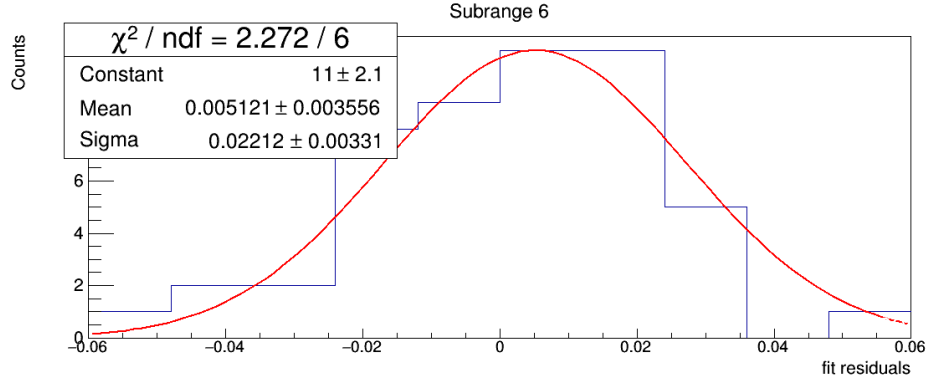












Outline

- RPC detector perspectives
- RPC detector limiting factors: linearity, rate capability, ageing
- New electrodes material and FE electronics
- Prototype design
- Linearity Response
- Rate Capability
- Ageing (preliminary)
- Conclusions