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Performance studies of thin-gap RPC detectors with thin phenolic glass electrodes

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RPC DESIGN AND APPLICATIONS

RPCs cover wide applications range, changing design to fulfill different experimental needs:

- single gap bakelites RPCs for large muon detection and triggering systems;
- Multigap glass RPCs for timing;
- Single gap glass RPCs for calorimetry
- ...

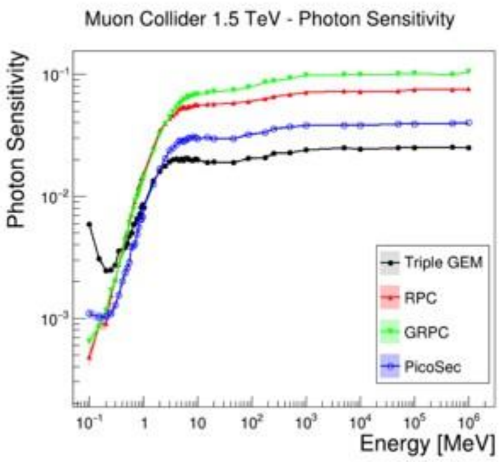
In view of new experiments and applications, numerous R&D are underway, and several technologies are being compared:

Multigap vs Single Gap --- Glass vs Bakelite vs new materials --- MPGD vs RPC vs MRPC --- gaseous vs solid state detectors

Common goal is the same: sub-ns time resolution, micrometric spatial resolution, high-rate capability and radiation hardness

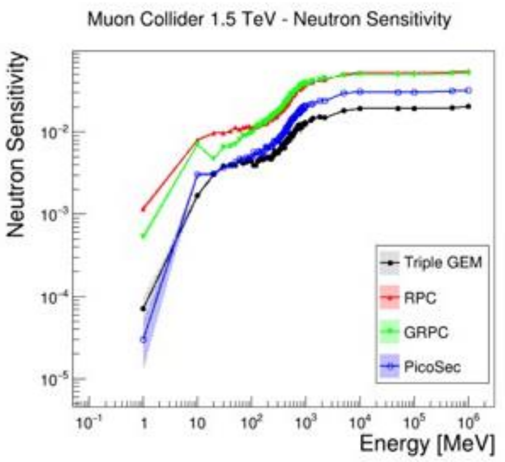
… but … COST EFFECTIVE!

IN THIS RACE THE RISK IS TO REMAIN CLOSED IN CATEGORIES, LOOKING AT EACH OF THEM IN AS THE LATEST STATE-OF-THE-ART APPLICATION



SOME TECHNOLOGIES RISK BEING LABELED WITHOUT CONSIDERING THEY CAN BE EXPRESSED IN THE MOST VARIED FORMS!

arXiv:2203.07224v1 [physics.ins-det]



GOOD RECIPES FOR RPCs R&D

- Difficulty: easy - impossible
- Preparation: 1 ys – 20 ys
- Quantity: 1 ch - 1Mchs / 10 cm^2 - 10 km^2
- Cheap - expensive

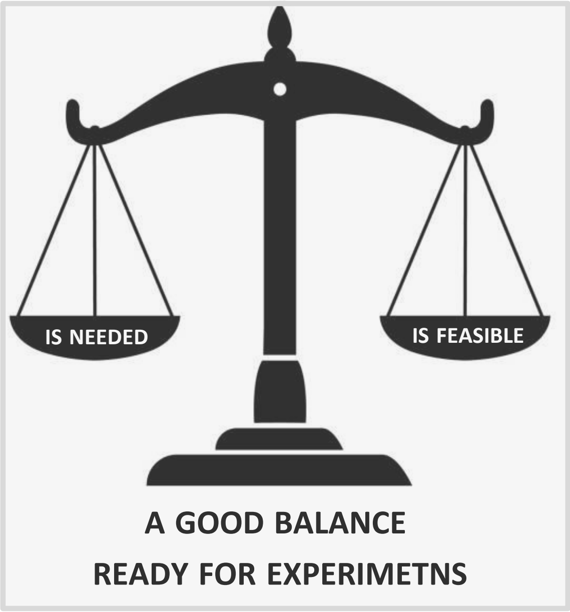
INGREDIENTS

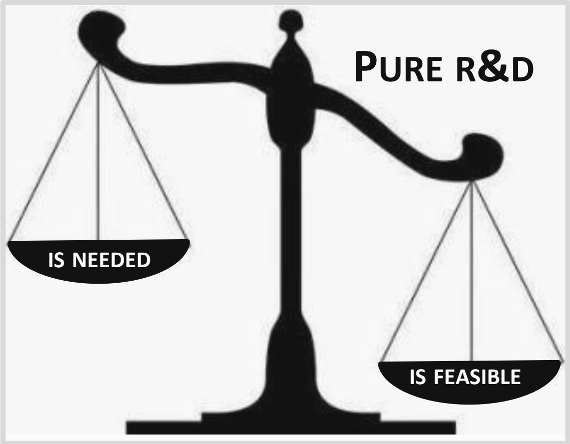
- **MATERIALS:** SEMICONDUCTORS (GaAs, DOPED GLASS), PHENOLIC GLASS, GLASS, BAKELITE
- **ELECTRODE CONFIGURATIONS:** THIN ELECTRODE, THICK ELECTRODE
- **GAP:** THIN GAP, LARGE GAP, MULTI GAP (SERIAL/PARALLEL)
- **GAS:** AVALNCHE REGIME, STREAMER REGIME – ECO FRIENDLY/DOESN'T MATTER
- **PICK-UP CONFIGURATION:** PADS, STRIPS (SINGLE SIDE READ-OUT/FRONT-BACK READ-OUT), AC DECOUPLED/DIRECT
- **GEOMETRY:** PLANAR, CYLINDRICAL….?

EACH OF THESE POINTS HAS WEAKNESSES AND STRENGTHS

- **FE-ELECTRONICS:** THE MORE SENSITIVE, THE BETTER

We can combine all the elements with limitless imagination!





Or, with a fuzzy or precise idea of the application, choosing the ingredients to achieve a specific purpose, applying a conservative approach even if not with the best achievable performance.

A RECIPE FOR A SIMPLE R&D

CHECK THE MAXIMUM PERFORMANCE ACHIEVABLE WITH A SIMPLE AND CONSERVATIVE CONFIGURATION, TUNING THE CONSTRUCTION PARAMETERS (THIN GAP – THIN ELECTRODES – DOUBLE GAP):

Mono gap

$$Q_{prompt} \sim Q_{tot} \frac{X_e}{g};$$

+ 2D tracking; construction
- Time resolution limited by gap thickness; broad charge distribution

Parallel 2-gap

$$Q_{prompt} \sim 2 \cdot \bar{Q}_{tot} \frac{X_e}{g};$$

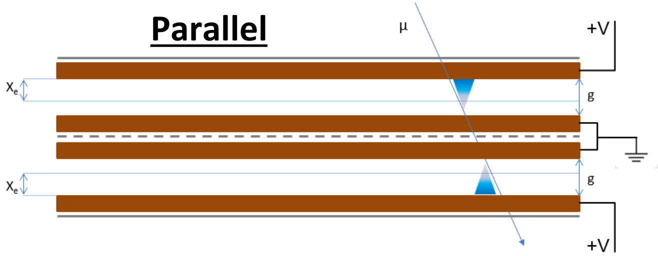
+narrow charge distribution; doubled collected charge, construction, time resolution power supply
- 1D tracking, limited to 2 gaps

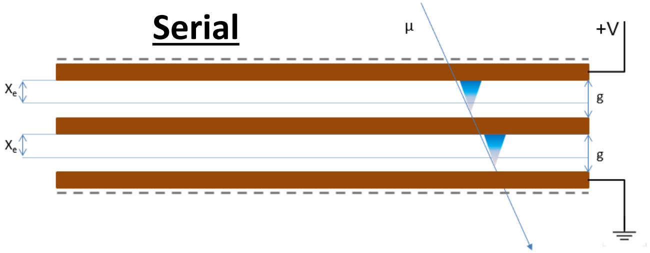
Serial 2-gap

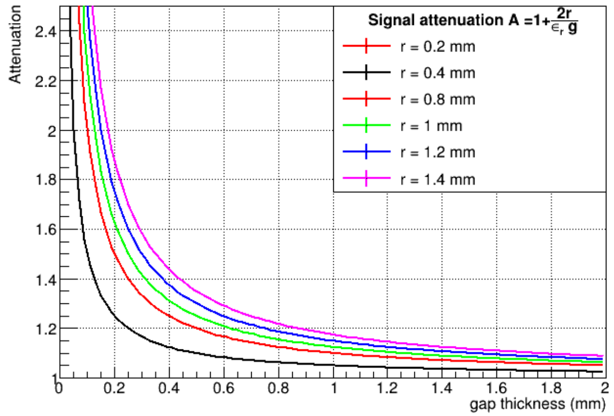
$$Q_{prompt} \sim \bar{Q}_{tot} \frac{X_e}{g};$$

+ 2D tracking; time resolution improve as n-gaps, narrow charge distribution
- Construction; power supply; HV balancing; Eco-Gas,

- Reduce the gap thickness down to the detection limit
- Reduce the electrode thickness to keep the attenuation below 2
- Parallel 2-gap configuration, best for low gain operation
- Read-out with the best FE-electronics







r is the electrode thickness,
g is the gas gap thickness

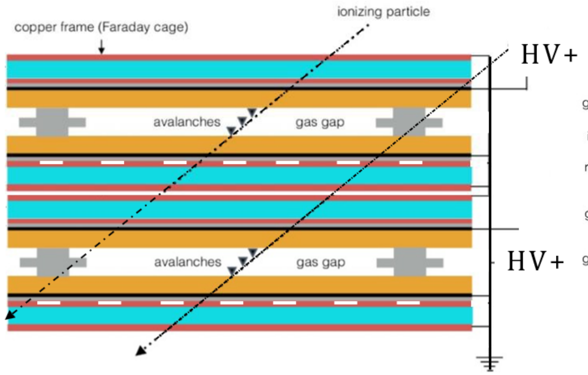
DETECTOR DESIGN

Single-gap RPCs are typically made with glass or Bakelite electrodes. For electrode thicknesses below 0.8 mm the material must be replaced by woven glass phenolic laminate, due to its excellent mechanical properties (available in sheets down to 250 µm). Two configurations were studied: **parallel gas-gap** with shared readout, **two independent single gap.**

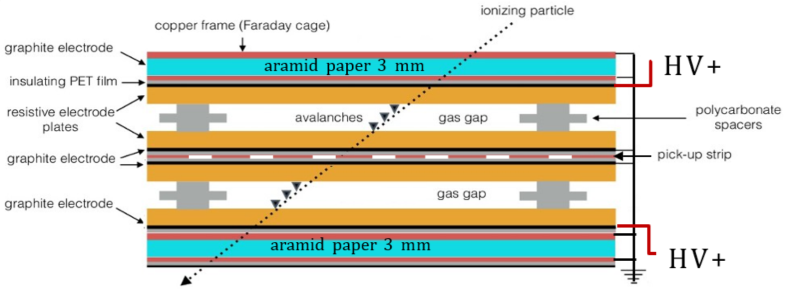
Detector features

- Gap configurations: 2 parallel/single gap
- Electrode thickness: 0.4 mm
- Gas-gap thickness: 0.2 mm
- Active surface: 8 cm x 30 cm
- Spacer lattice: 3 cm x 3.5 cm
- Electrode material: phenolic glass

Efficiency-spatial resolution- time resolution



Efficiency – rate capability



Phenolic glass properties:

- Electrical Resistivity, Average value: 4.60×10^{12} Ω cm
- Dielectric Constant, Average value: 5.10
- Dielectric Breakdown, Average value: 30000 V

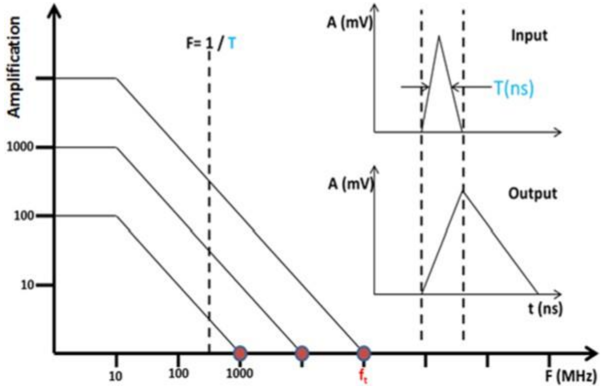
Read-out pick-up:

- 8 mm wide, 10 mm pitch
- 3 mm aramid paper plates
- 8 channels Charge sensitive FE-E

2013 JINST 8 P01003

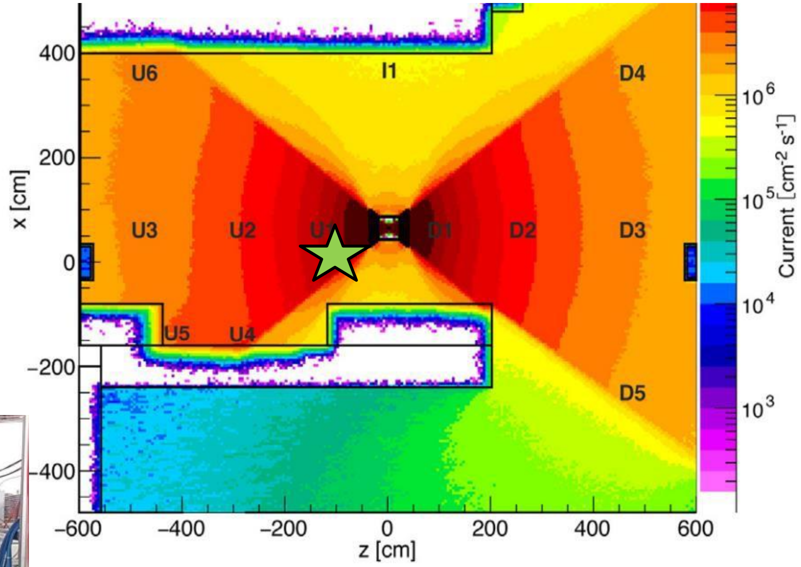
Voltage supply	3–5 Volt
Sensitivity	2–4 mV/fC
Noise (independent from detector)	4000 e⁻ RMS
Input impedance	100–50 Ohm
B.W.	10–100 MHz
Power consumption	10 mW/ch

Front end electronics



GIF++ AND H8 SET-UPs

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



Gif++ environment

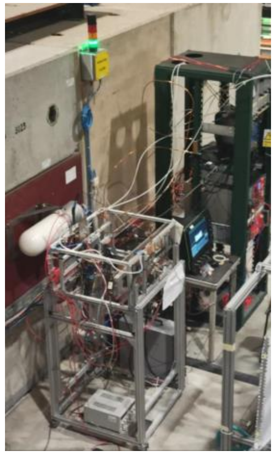
- 14.9 TBq ^{137}Cs source (662 keV photons 33% - 54%) with constant photon current in the xy plane for 662 keV photons
- 180 GeV/c muons beam

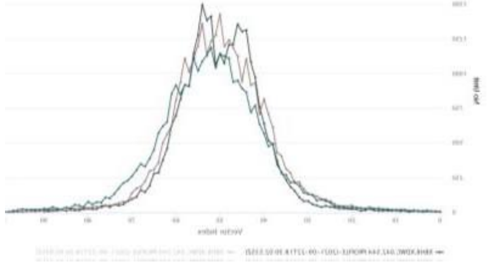
Setup was placed in the upstream region U1 where the maximum photon current is 4.3×10^7 photons/(cm^2 s).
The nominal RPC photon efficiency is order of ~10^{-3} so the maximum expected photons counting rate is order 40 kHz/cm^2.

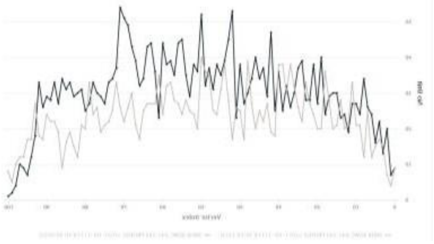
H8 line:

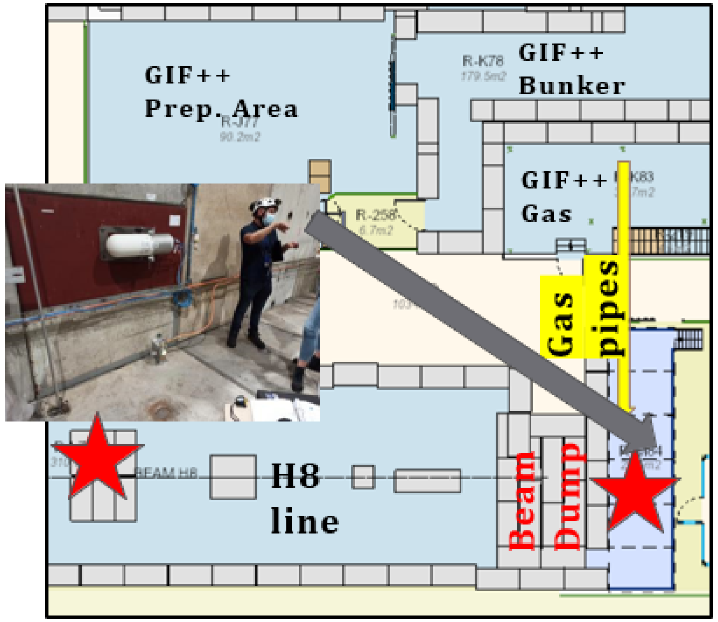
180 GeV/c muons beam;
The test was carried out in two positions:
Platform PPE168, behind the beam dump platform.
Two beam configurations:

- Primary muon beam (23 mm x 23 mm RMS),
- Dumped pions beam (spread).



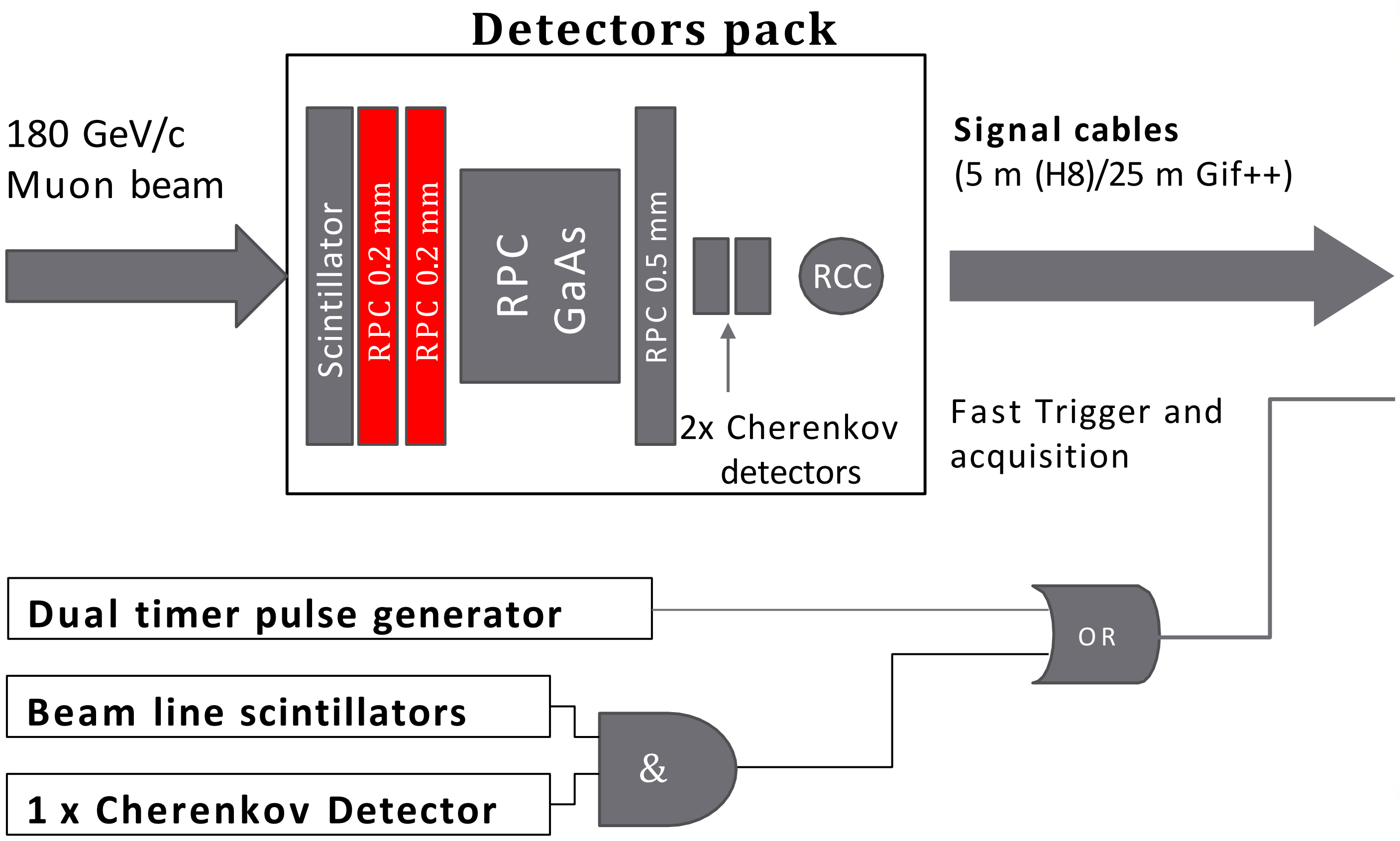






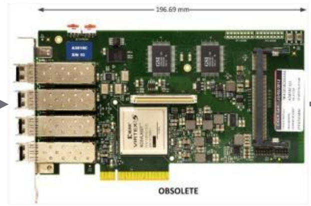
SET-UP DESCRIPTION

Gas Mixture: 94.7% TFE + 5% iC4H10 + 0.3% SF6
Line 1 -> Wet
Line 2 -> Dry



Caen 1742 32ch digitizer 12 bit, 5 GS/s, set to 200 ns Time window

USB link

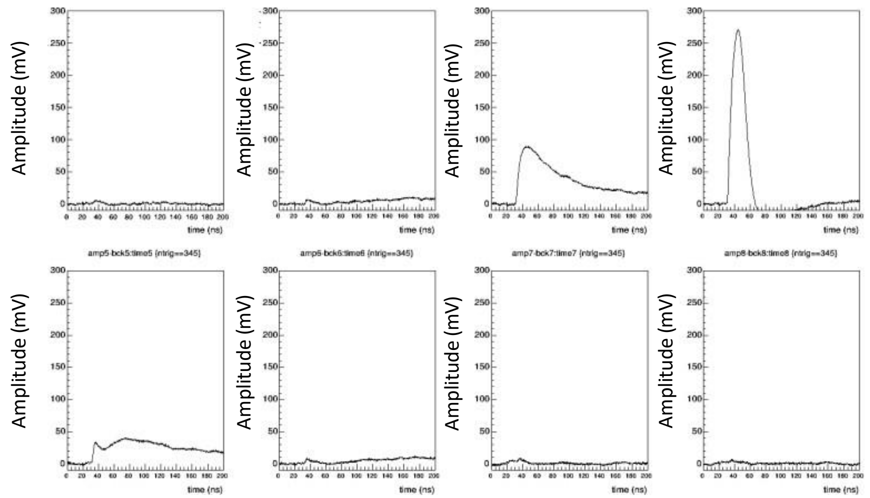


Optical Link

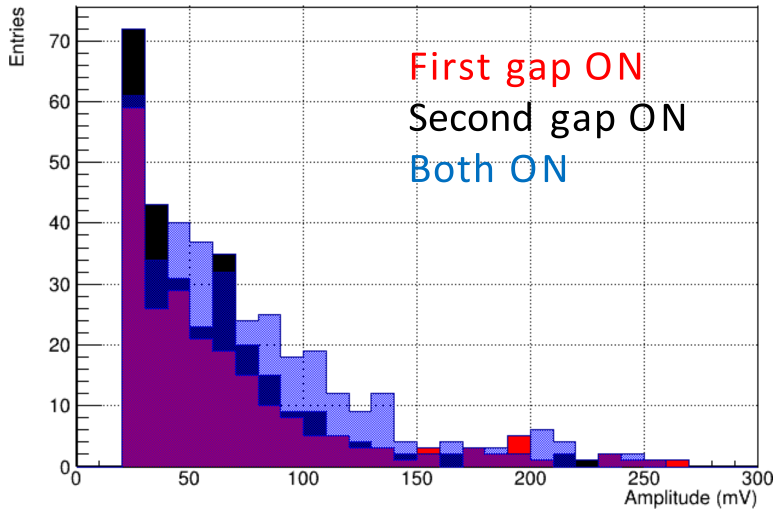
For the Gif++ test a Dual timer has been used to acquire out of spill events in way to measure the photons counting rates

SIGNAL SHAPE (PARALLEL BI-GAP CONFIG)

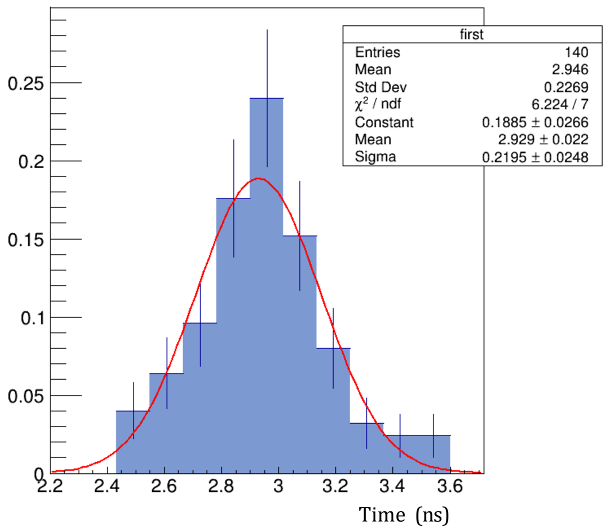
- Signals shape was studied @50% of efficiency by comparing the t w o configurations: one gap ON vs Two gaps ON;
- Signal shape depends on the distance between the hit position and the read-out channel (direct induction + ch-cross talk)
- Amplitude distributions show a clear increase of the pulses charge in two gas-gap ON case.
- Amplified signals rise time (10%-90%) distribution picks at 3 ns



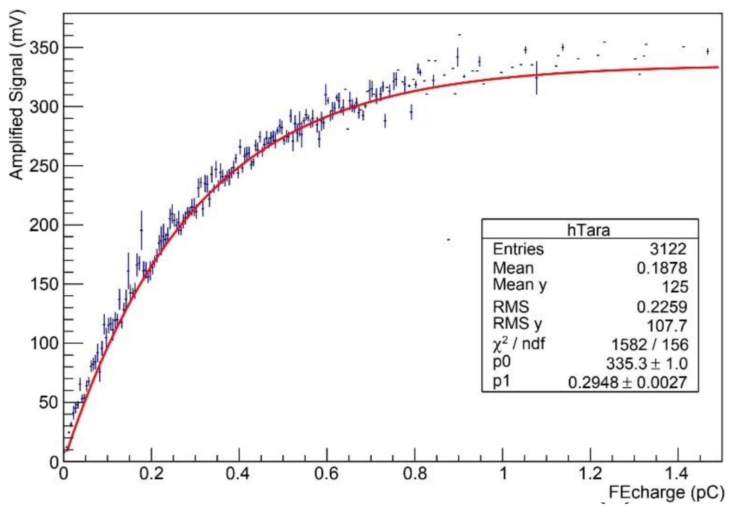
Amplitude distributions



Rise time



Amplitude vs FEcharge @Vee=3.5V



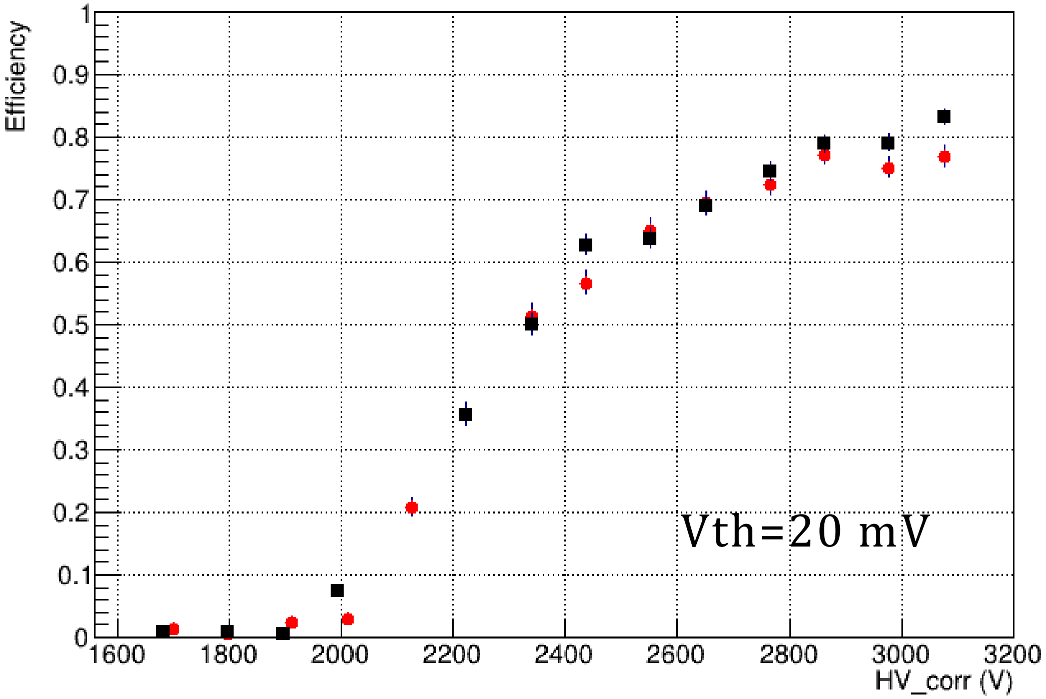
EFFICIENCY SINGLE GAP VS PARALLEL BI-GAP

A data rejection was carried out by discarding all cases in which a random pulse entered the pedestal window.

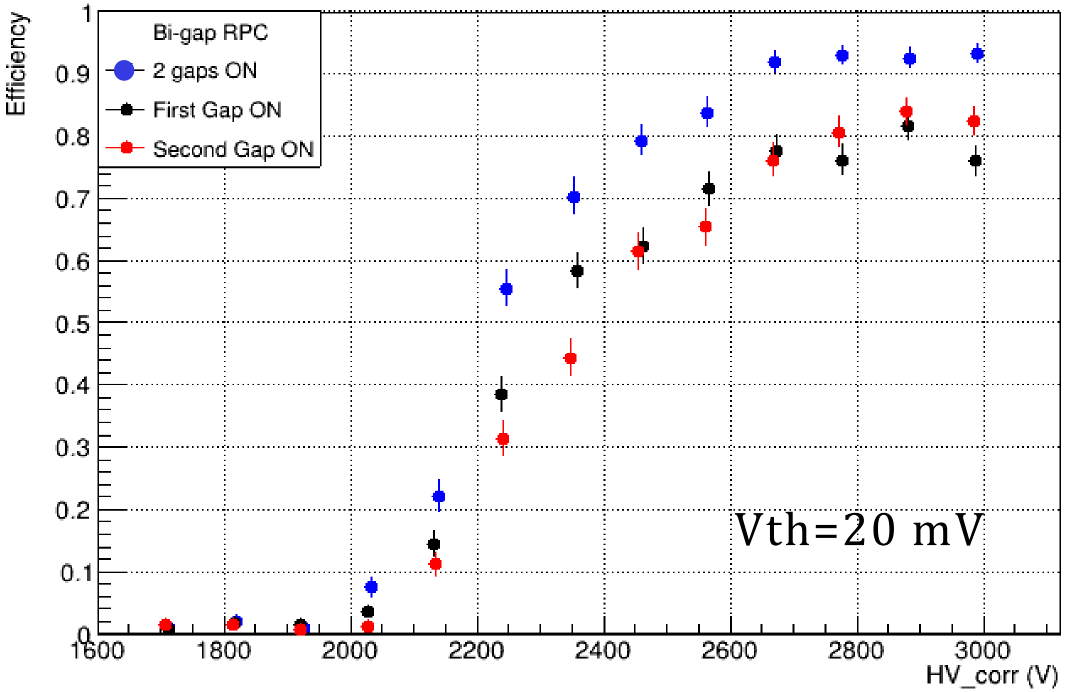
Both configurations, working with a single gas gap, show a plateau efficiency of approximately 80% due to the 0.2 mm gap thickness.

By operating both gas gaps in parallel, an increase in efficiency of approximately 10% is observed, as well as a faster rise due to the narrower charge distribution.

Independent detectors configuration

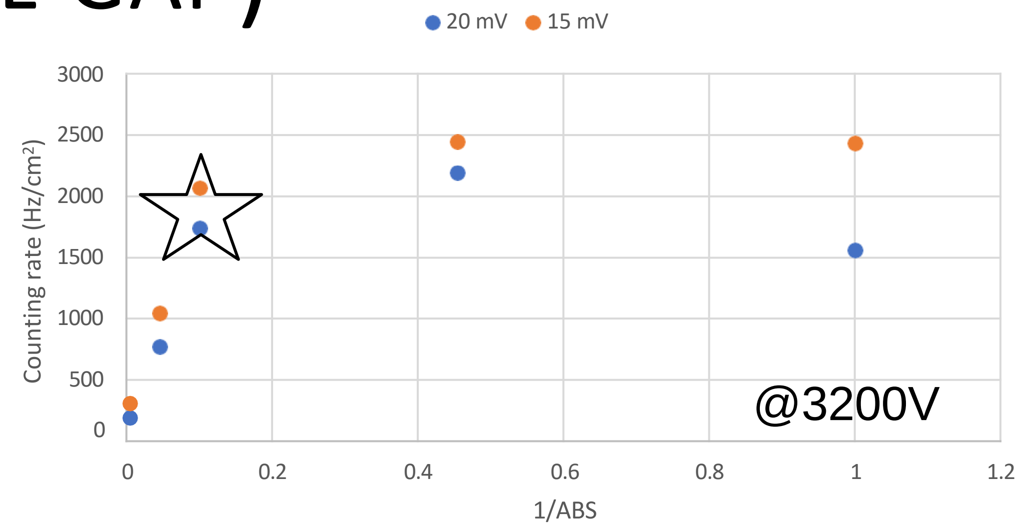


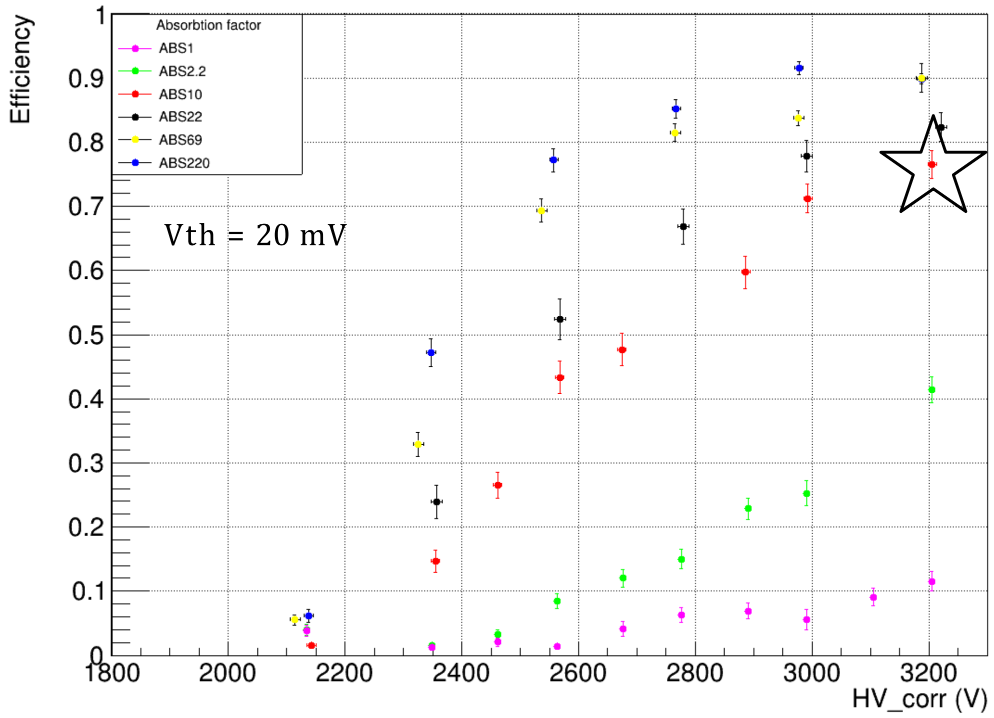
Parallel gas gap configuration



RATE CAPABILITY (PARALLEL GAP)

- The Rate capability measurement was carried out in the configuration with **two parallel gaps with both gaps ON**, **measuring the efficiency to 180 GeV/c muons and the counting rate outside the spill**.
- Comparing the measured counting rate, at maximum efficiency, with the expected photon flux in position U1 @ ABS 22 (2.8 10^6 photons/cm^2 s^{-1}), **a raw estimation of the photon sensitivity is 3÷5 x 10^{-4}.**
- The average electrode **resistivity** value estimated from the efficiency curves shift is within the range **2 ÷ 4 x 10^{12} Ωcm.**
- Although the supply of phenolic glass did not allow the resistivity of the material to be calibrated, a rate capability of approximately **2 kHz/cm^2 at 75% efficiency is observed.**



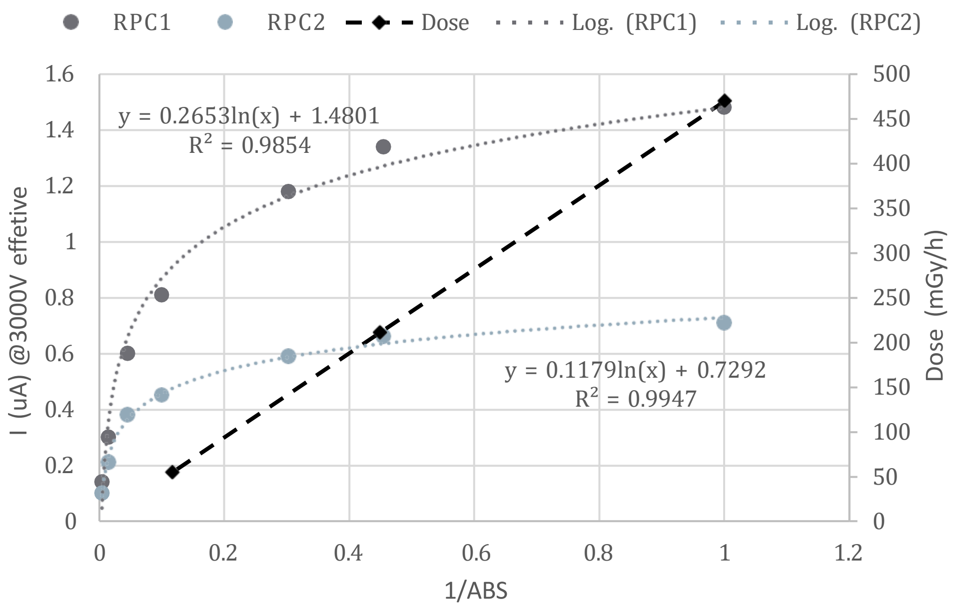


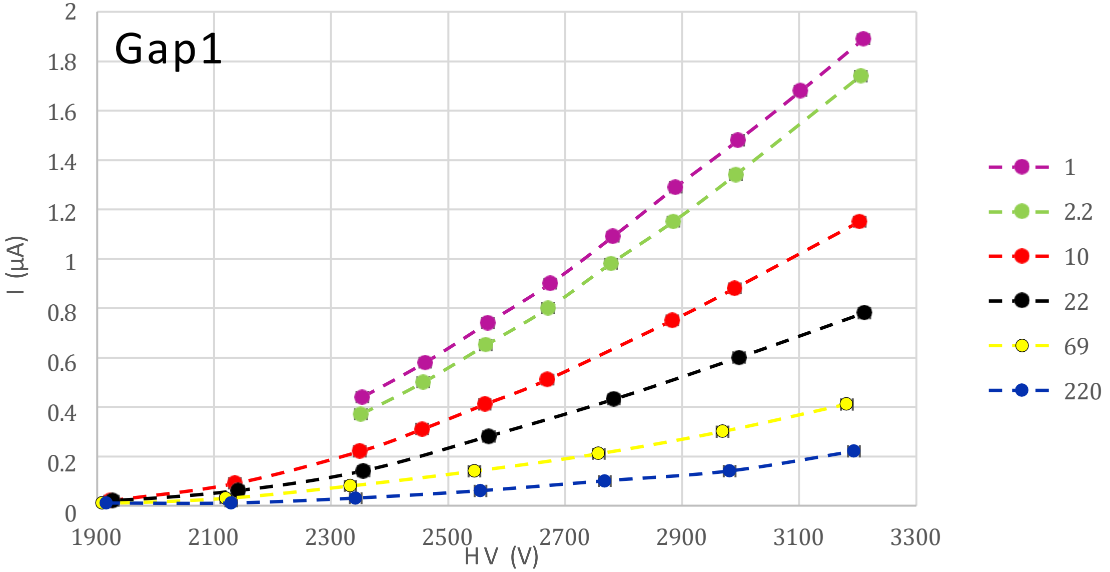
Current

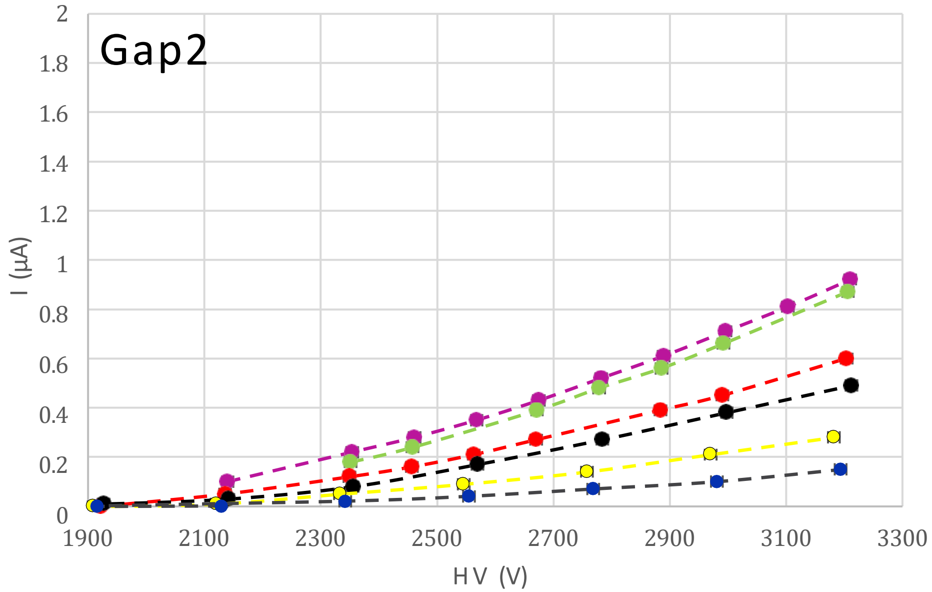
- The current measured under irradiation shows a **clear saturation at ABS2.2 (4.8 MHz of photon flux)**, in agreement with the rate and efficiency measurements.

- The two gas-gaps surprisingly show different current absorption. The same behavior was observed without irradiation.

- Currents of the two gas gaps became uniform with a post-test conditioning.

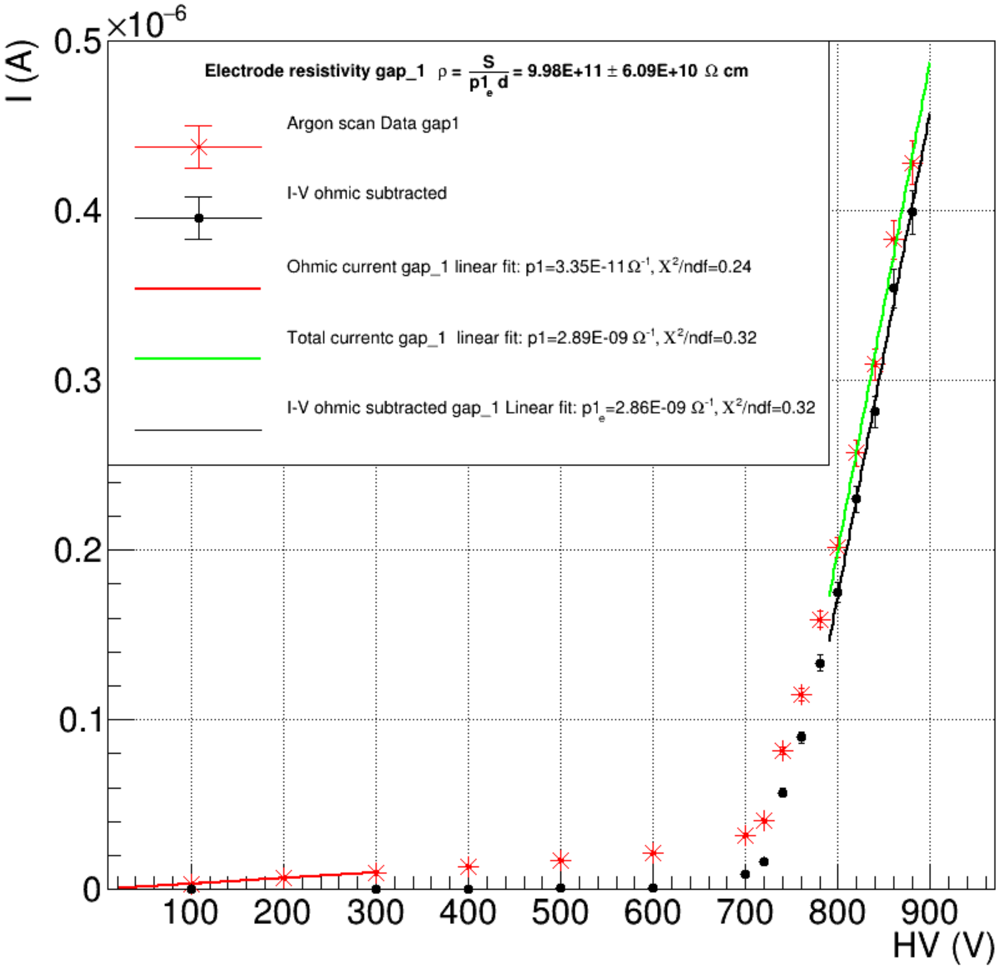


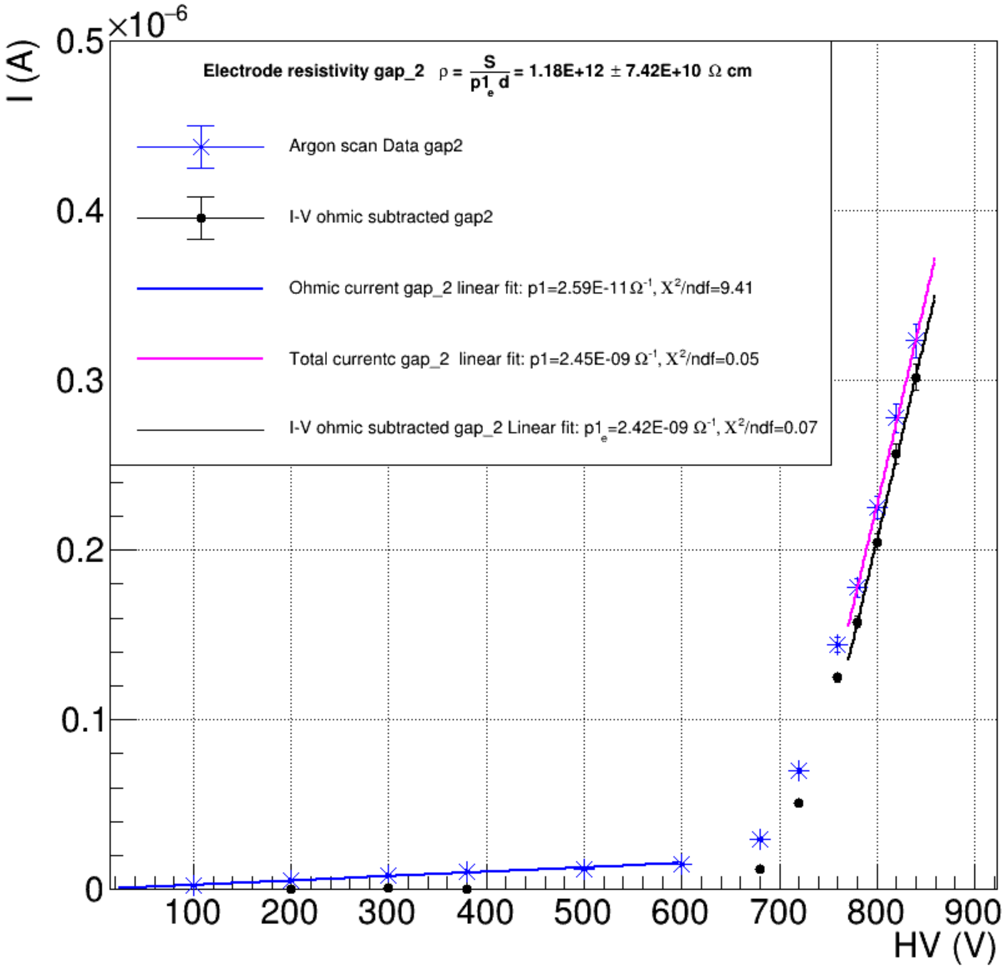




ARGON SCAN AND ELECTRODE RESISTIVITY

Gas gaps were flushed with pure Argon to measure electrodes resistivity thanks to a linear fit on the I-V data sets in the range after the gas ignition. In both cases Argon ignition occurs at 700 V.





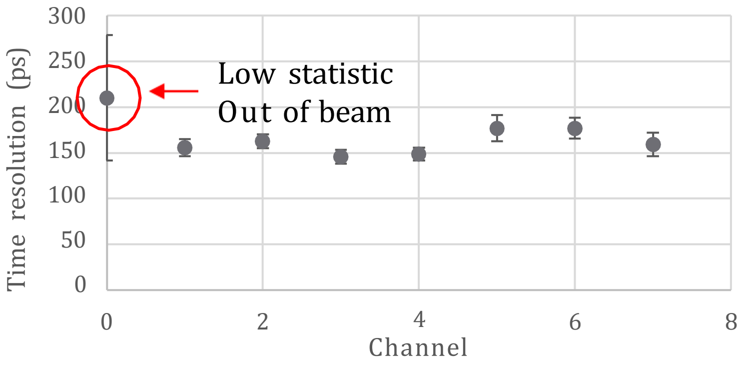
TIME RESOLUTION

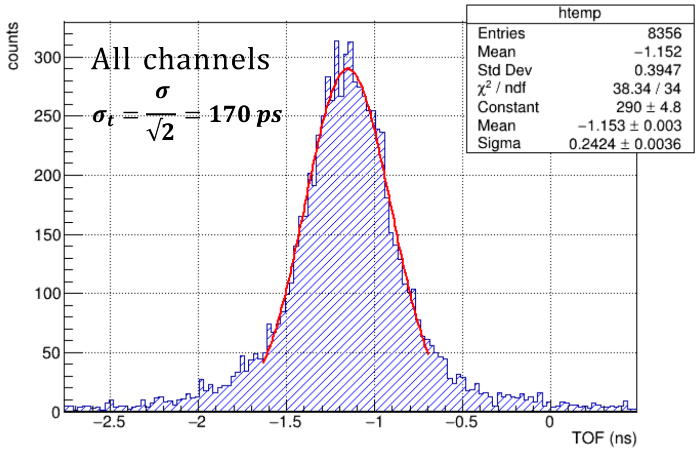
The intrinsic time resolution of an RPC detector scales almost linearly with the gas-gap thickness. Below 200 ps is dominated by the contribution of the FE electronics noise and the read-out configuration.

The test was performed on the H8 beam line, with narrow muon beam (23 mm RMS). We assume the two independent detectors have the same time resolution (same gap, same read-out system). No time walk correction applied.

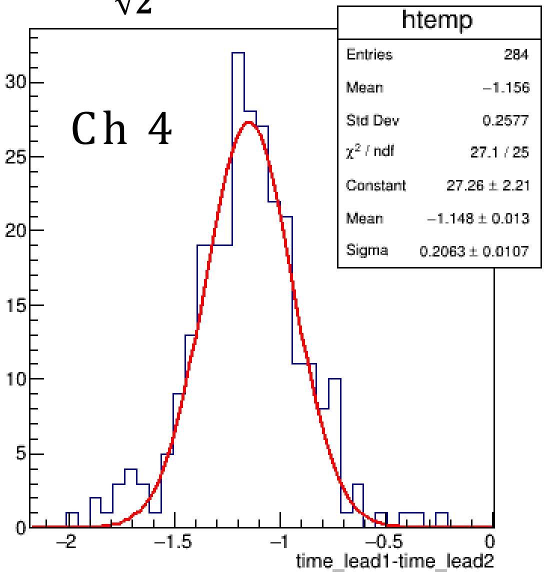
Method:

- measurement of the time when the signal rises above 10% of the maximum value of the leading channel in the cluster (constant fraction)
- Compute the time difference between the two gaps when the cluster leadings are collinear
- Gaussian fit performed to each channel time difference distribution
- Time resolution evaluated as $\sigma/\sqrt{2}$





$$\sigma_t = \frac{\sigma}{\sqrt{2}} = 145\ ps$$



SPATIAL RESOLUTION

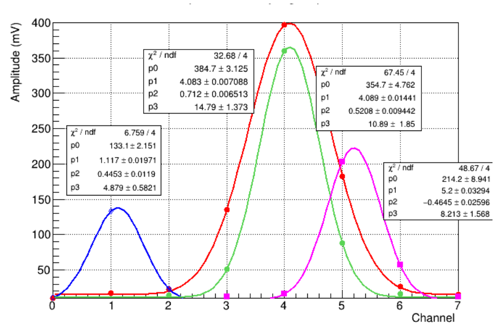
Charge centroid method exploits the diffusive effect of the electrode to reconstruct the position of the discharge center. It is effective for high cluster size. The cluster center has bean measured as the average of the Gaussian distribution fitted on the signal amplitudes of the different channels.

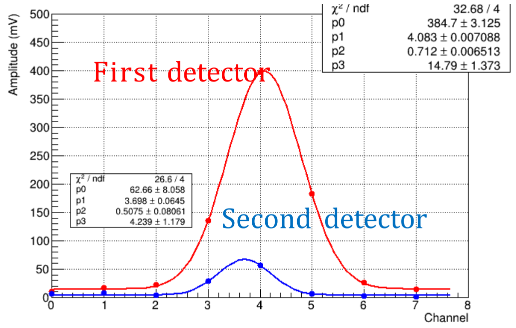
Since no reference detector was available, the spatial resolution was evaluated by comparing the positions measured by the two RPCs, assuming all tracks orthogonal to RPCs (this method depends on the beam shape and sets an upper limit) .

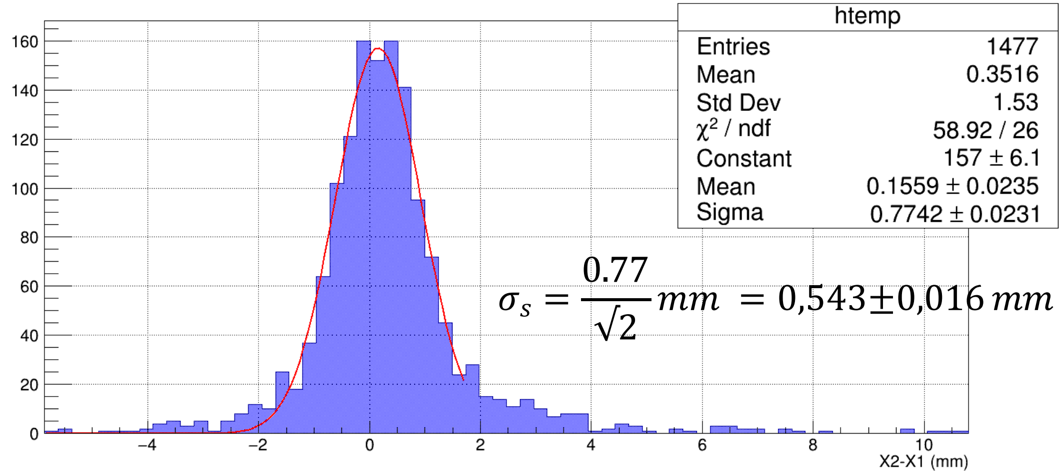
Cluster size depends on many detector parameters:

- Strip pitch (1 cm)
- Electrode (0.4 mm) and gap (0.2 mm) thickness
- Graphite layer resistivity (about 500 kΩ/□)
- FE electronics threshold (20 mV equivalent to 5 fC)

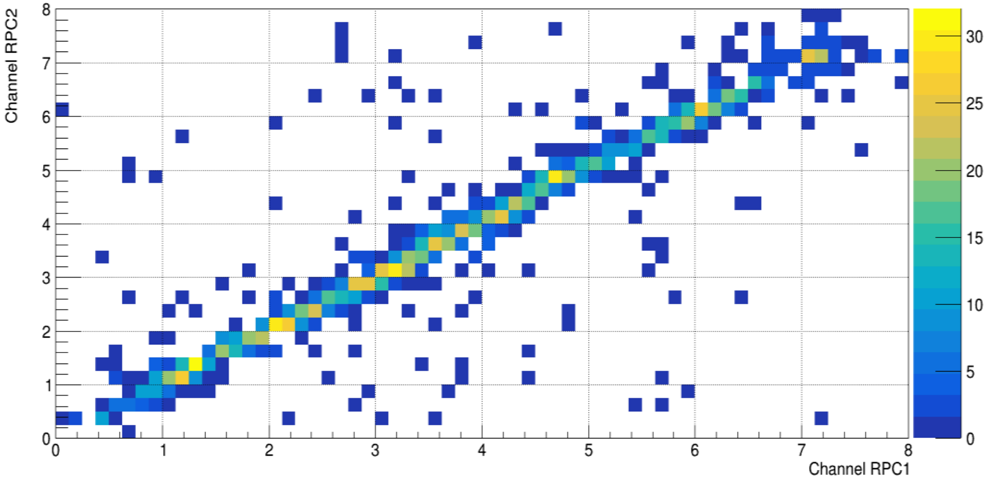
For a detector with a such thin gap and electrode it is essential to recalibrate graphite resistivity and strip pitch!







$$\sigma_s = \frac{0.77}{\sqrt{2}} mm = 0{,}543 \pm 0{,}016\, mm$$



CONCLUSIONS AND PERSPECTIVES

A Very thin and low material budget detector have been tested, showing good performance balance.

Cooperation of two parallel gaps increase efficiency up to 95% with time resolution less then 140 ps.

Irradiation tests show how thinning the electrodes and gas gap thickness leads to good results in terms of rate capability (**2 kHz/cm^2 at 75%**), despite the very high electrode resistivity **(>10^{12} Ωcm**).

Spatial resolution must be improved recalibrating graphite resistivity and readout pick-up.

Next steps depends on the application:
- **Tracking – Timing – high-rate capability**
- Reduce the graphite resistivity,
- reduce the strip pitch
- reduce the phenolic glass resistivity by optimizing production processes and selection.

Triggering – Large surface – Low cluster size :
- Increase the graphite resistivity
- Increase the electrode rigidity

For all the applications the FE electronics must be optimized for very narrow signals with rise-time order of 300 ps

Thank you for the attention

Conditioning