Rate capability and gamma rejection studies of thin-gap RPC detectors with thin phenolic glass electrodes

***16th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD23)** - Siena (Italy), 25-29 September 2023*

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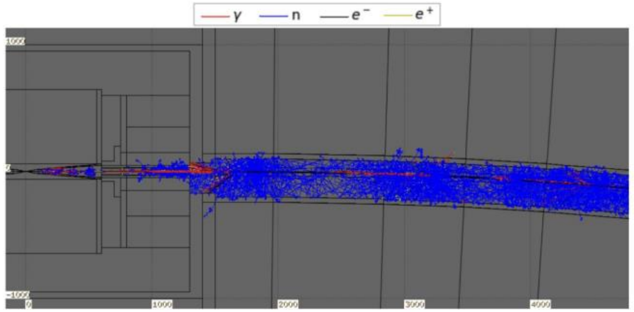
Muon detectors for future muon collider

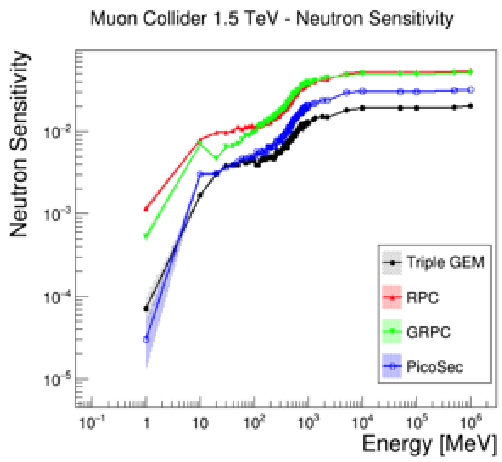
- Huge number of particles, mainly from muon decays
- Detector R&Ds ongoing for muon system
  - Current glass-RPCs are limited in rate capability and space resolution
  - Current MPGD limited in time resolution
  - R&D goal: develop a detector able to reach good performance on all the three items

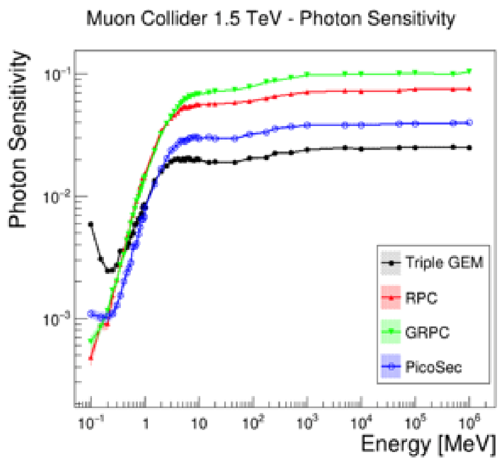


Considered detector technologies:
Double-gap Glass RPC
Double-gap HPL RPC
Triple-GEM
Picosec

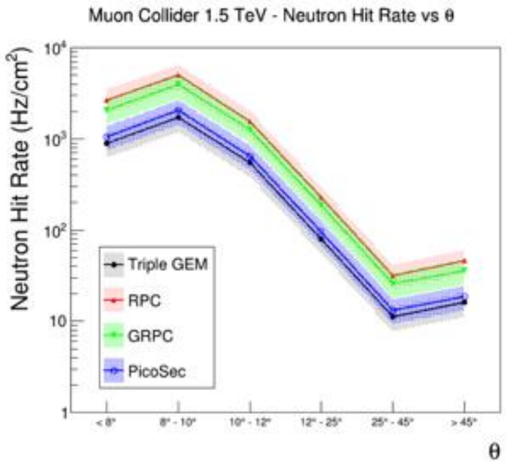
Geant4.10.06 simulation to study the response of the detectors to BIB @ 1.5 TeV

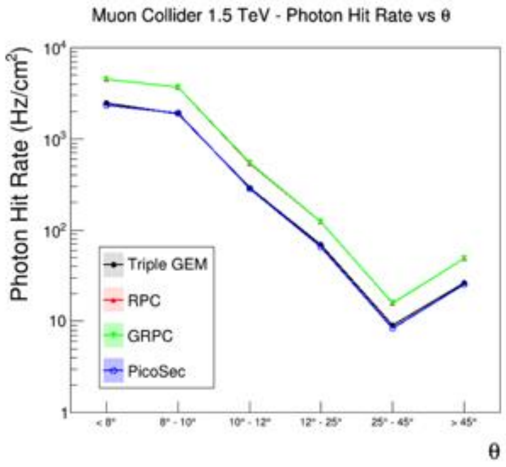
Sensitivity to neutrons and photons





Expected hit rate from neutrons and photons





arXiv:2203.07224v1 [physics.ins-det] 14 Mar 2022

Improve the performance

The RPC detector can cover a wide spectrum of applications, adapting to experimental needs by varying the design parameters. Generally, single gap detectors are used in large muon detection systems with the main purpose of providing the trigger signal and tagging the BC associated with the triggered event.

Constraints in upgrading experiments: limited time for R&D and ageing studies, comply with existing infrastructure, high probability of success in the short term

Electrode material unchanged, thicknesses within production limits, possible to gain mainly from the development of a new FE electronics (Rate capability -> 10kHz/cm^2, time resolution 350 ps)

Long-term R&D allows you to change any parameter: material, thicknesses, electronics, geometry, gas!
Different parallel projects**: thin gap – thin electrode**, Resistive Cylindrical Chamber (RCC), GaAs RPC, **new materials.**

In these tests a feasibility study was carried out certifying the performance of thin single gap RPC with thin phenolic glass electrodes

Spatial resolution:

- **Reduce the avalanche discharge dimensions**
- Reduce the strip pitch
- Improve the FE electronics sensitivity

Time resolution

- **Reduce the primary ionization jitter**
- **Improve the signal slew-rate**

Rate Capability

- Reduce the electrode resistivity
- **Reduce the electrode thickness**
- **Reduce the charge per count**

- **Spatial resolution: 130 um (G Aielli et al 2014 JINST 9 C09030, link)**
- **Time resolution: 350 ps with 1 mm gas-gap (A. Rocchi and S. Simsek, RPC conference 2023, link1 link2**
- **Rate capability: 10 kHz/cm^2 RPC ATLAS BIS (S. Simsek, RPC conference 2023, link)**

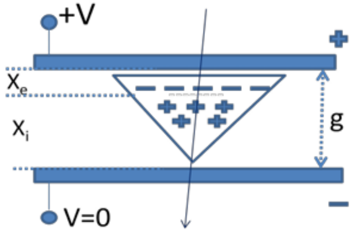
Thin gap – thin electrode – bi-gap

Gap configuration

Mono-gap

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

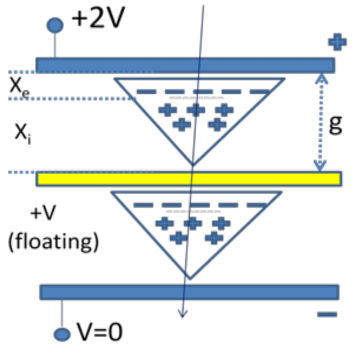
+ 2D tracking, construction
- time resolution limited by the gap thickness broad charge distribution



Serial 2-gap

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

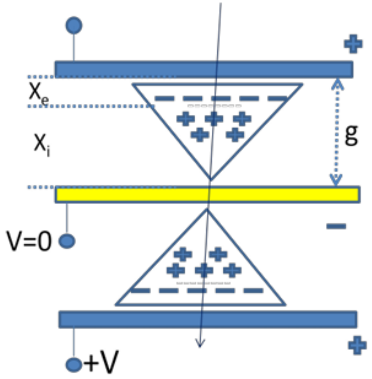
+ 2D tracking; time resolution improves as n-gap, narrower charge distribution
- Construction; works fine with high radiation, power supply



Parallel 2-gap

$$Q_{prompt} \sim 2 < Q_{tot} > \frac{X_e}{g};$$

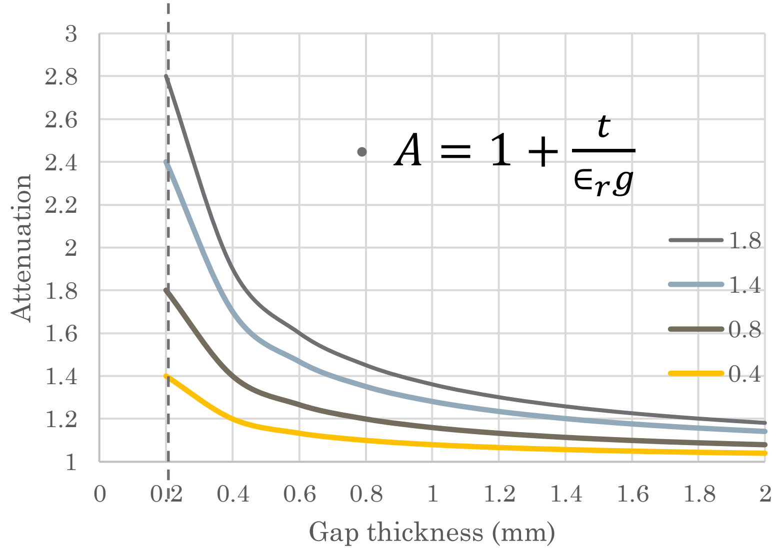
+narrower charge distribution, doubled collected charge, construction, better time resolution with respect to mono-gap, power supply
-1D tracking, limited to 2 gaps



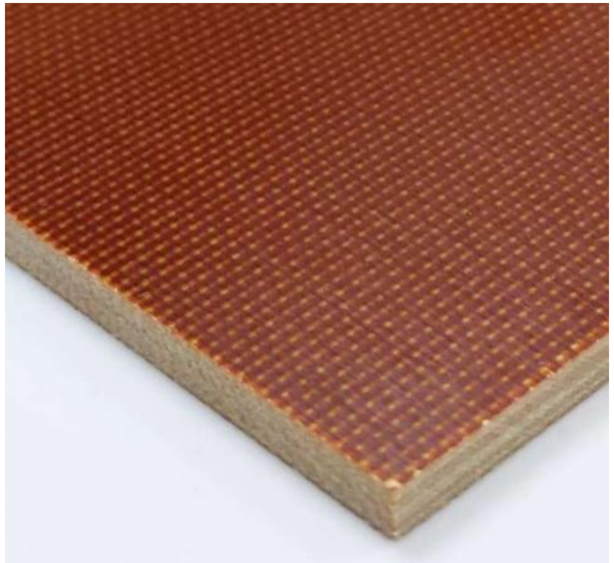
Strategy:

- 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

Induced signal attenuation



Detector design (components)



Single-gap RPCs are typically made with glass or Bakelite electrodes. For electrode thicknesses below 0.8 mm the material has been replaced by woven glass phenolic laminate, due to its excellent mechanical properties (available in sheets up to 250 um)

<u>Phenolic glass properties:</u>

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

<u>Detector features</u>

- Gap configurations: 2 parallel gap / 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

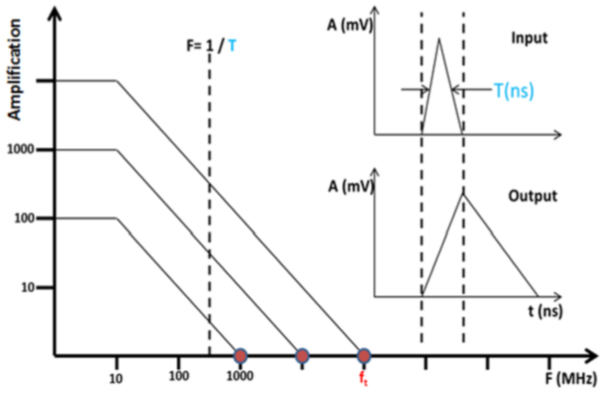
Read-out strip:

- 8 mm wide, 10 mm pitch
- 3 mm aramidic paper plates
- 8 channels

<u>Front end electronics</u>

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

2013 JINST 8 P01003



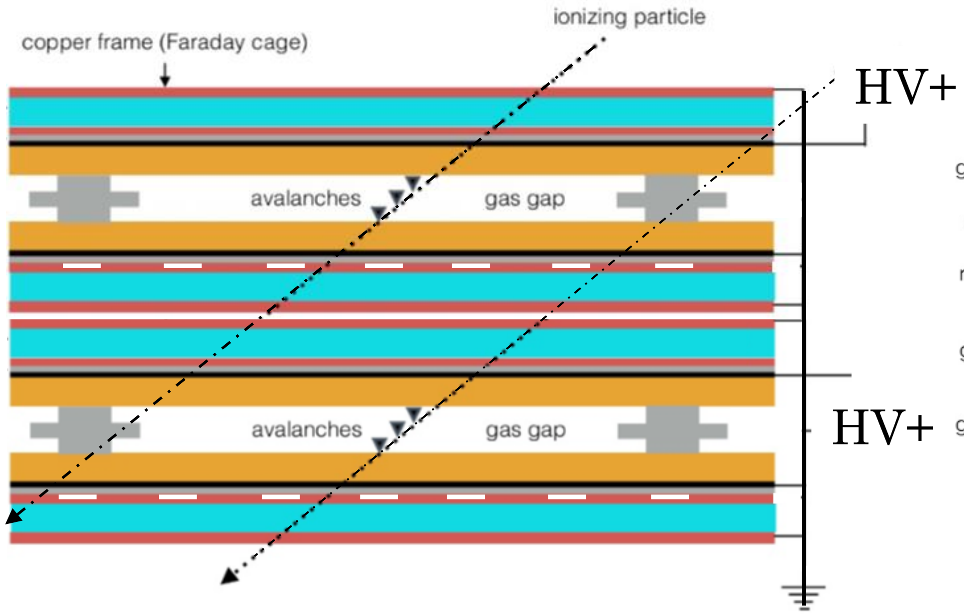
Detector design (layout)

Two configurations were studied:

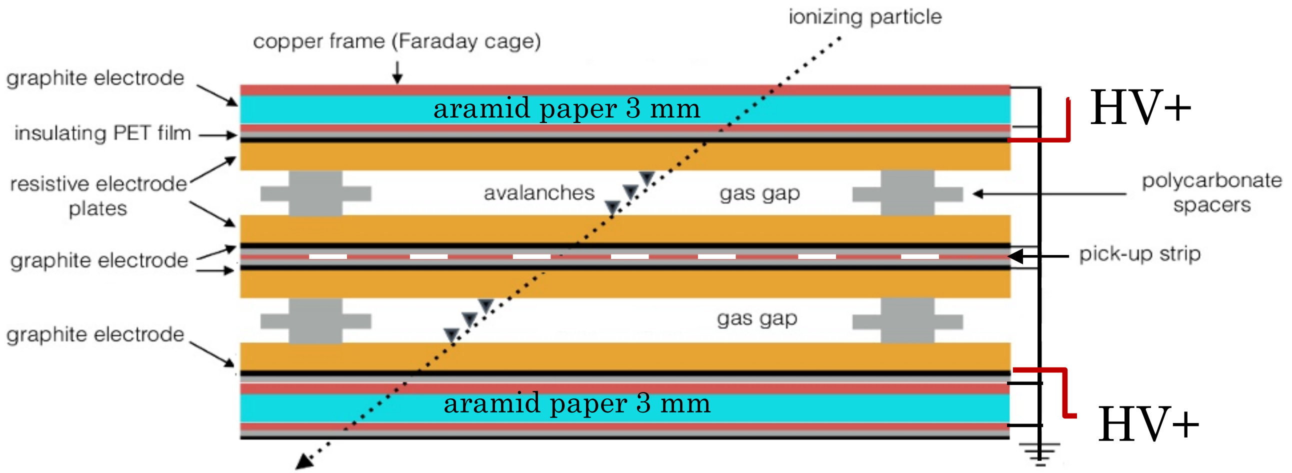
- **parallel gas-gap** with shared readout, to achieve the best performance in terms of **rate capability**;
- **Two independent single gap**, to carry out a comparative measurement of efficiency and measure the **temporal and spatial resolution**

In the first configuration the total thickness of the detector is only 8.2 mm, 7 mm for each detector in the second.

Efficiency-spatial resolution- time resolution



Efficiency – rate capability



Gif ++ Set-Up

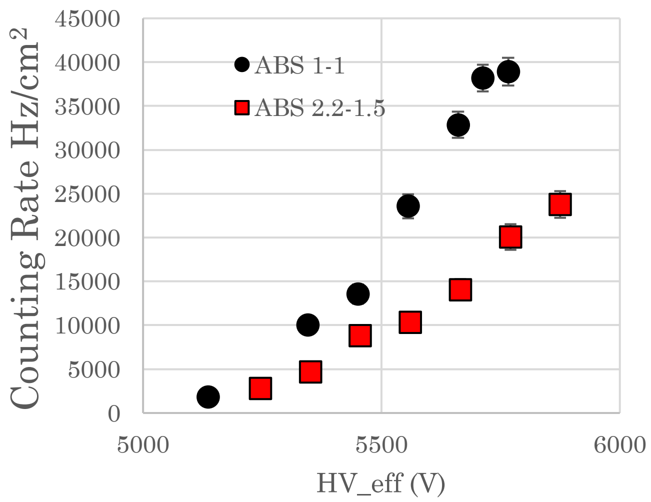
D. Pfeiffer et al, The radiation field in the Gamma Irradiation Facility GIF++ at CERN.

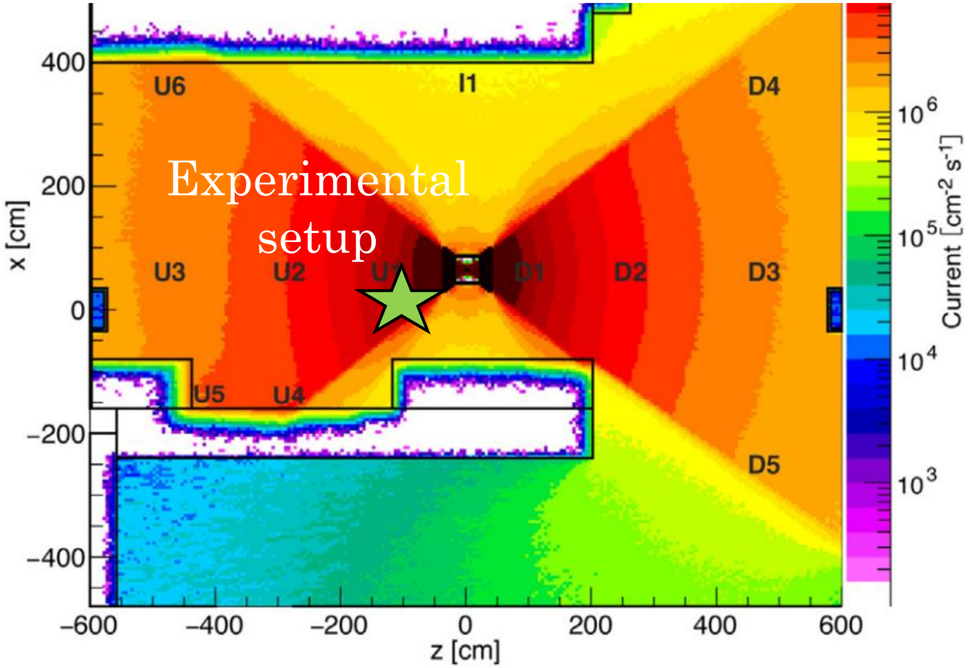
Nominal Attenuation	Filter Combination	Measured data: Dose Rate [mGy/h]	Measured data: Dose Attenuation
1	A1 B1 C1	470.00	–
1.5	A1 B2 C1	400.00	1.2
2.2	A1 B1 C2	211.00	2.2
4.6	A1 B1 C3	105.00	4.5
10	A2 B1 C1	55.00	8.8

The setup was placed in the upstream **region U1 where the maximum photon current is $4.3 \times 10^7 \frac{photons}{cm^2 s}$**.
The nominal RPC photon efficiency is order of $\sim 10^{-3}$ so the maximum expected photons counting rate is $\sim$40 kHz/cm^2

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

Rate GaAs-RPC same position

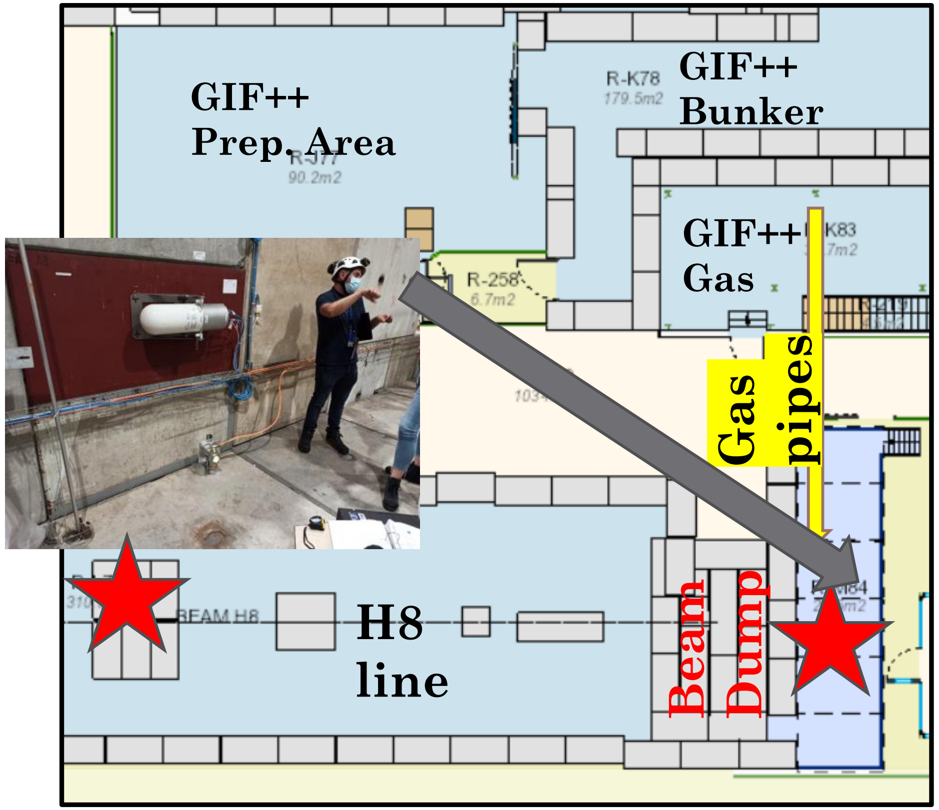


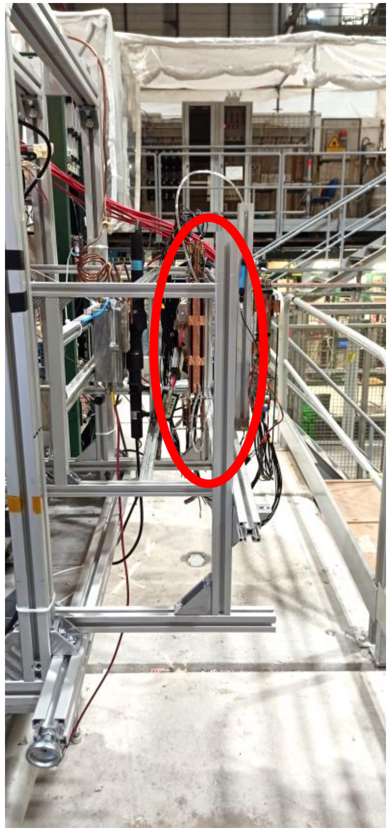


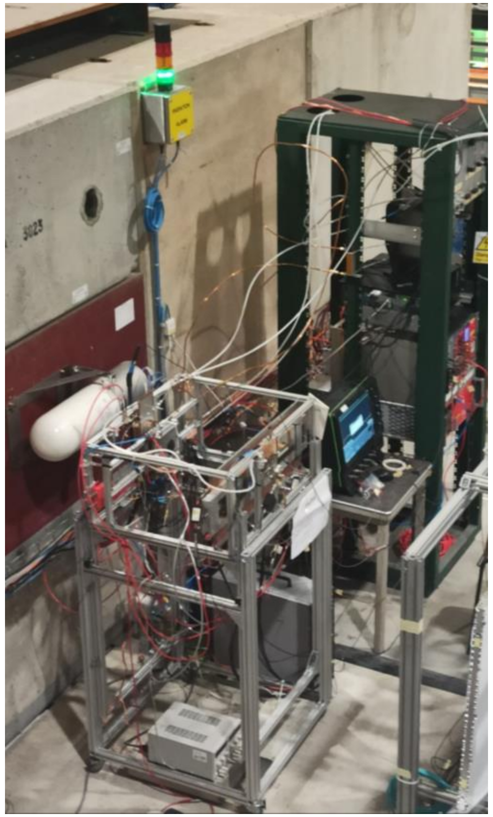
H8 Set-Up

The test was carried out in two phases, respectively for the parallel gap and single independent gap configuration:

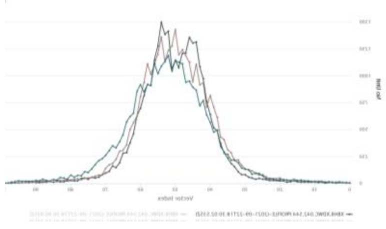
- both cases the set-up was placed behind the beam dump.
- Two beam configurations: Primary muon beam (23 mm x 23 mm RMS), Dumped Pions beam (spread)
- Tests performed in PPE168 with better beam configuration are still under analysis



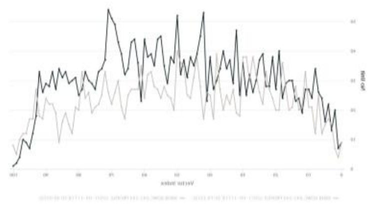




Primary muon beam



Pions dumped in front of detector



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

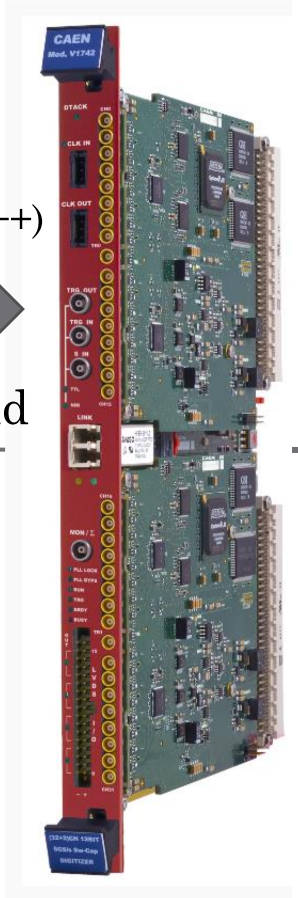
Detectors pack

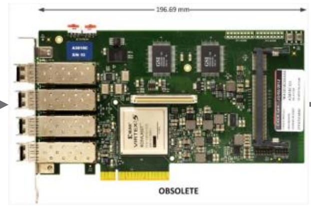
180 GeV/c
Muon beam

Scintillator
RPC 0.2 mm
RPC GaAs
RPC 0.5 mm
RCC
2x Cherenkov detectors

Signal cables
(5 m (H8)/25 m Gif++)

Fast Trigger and acquisition





Optical Link
Caen 3818

Wdt 60 ns

Dual timer pulse generator
Beam line scintillators
1 x Cherenkov Detector

OR
&

Wdt 20 ns

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

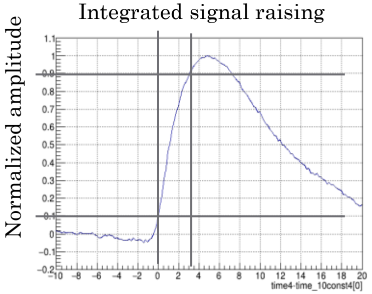
Signal shape (bi-gap config)

- The shape of the signals was studied @50% of efficiency by comparing the configurations in which only one gas-gap is ON with the case of two gaps ON.

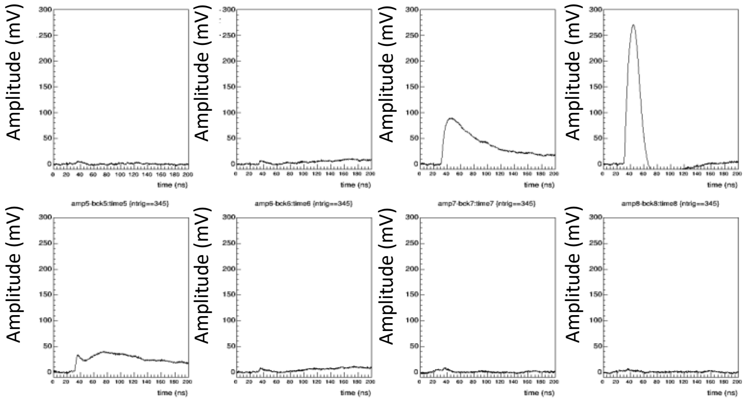
- The amplitude distributions show a clear increase of the pulses charge in the case with both gas-gap ON

- The rise time, calculated as the difference between the times measured at 90% and 10% of the maximum, has an average value of 3 ns

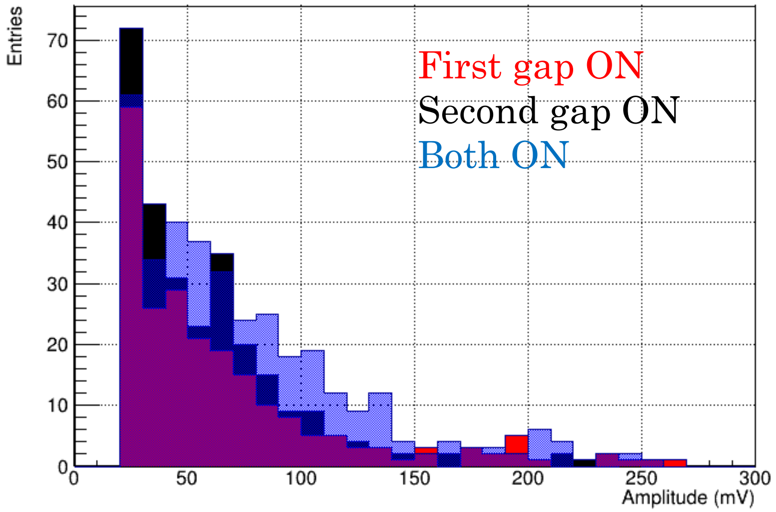
Integrated signal raising



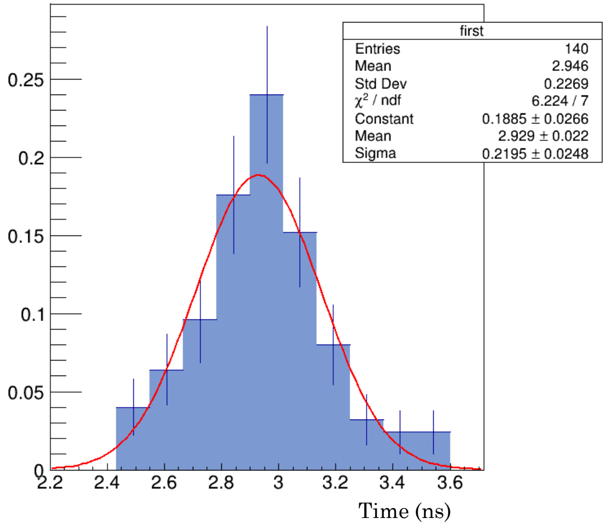
Channel cross talk



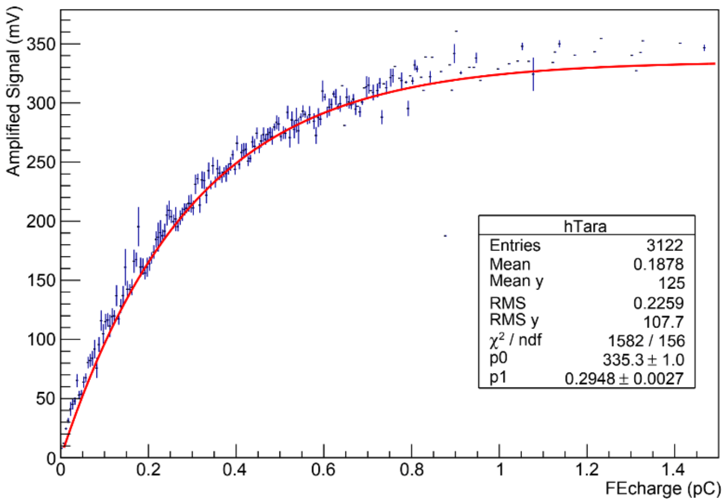
Amplitude distributions



Rise time



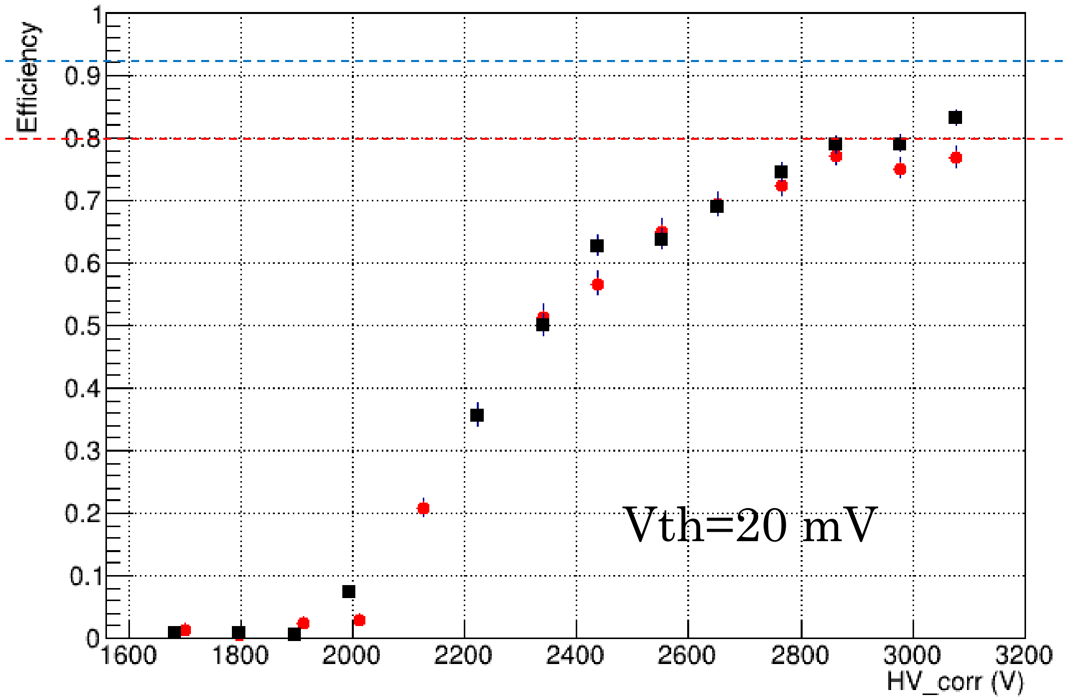
Amplitude vs FEcharge @Vee=3.5V



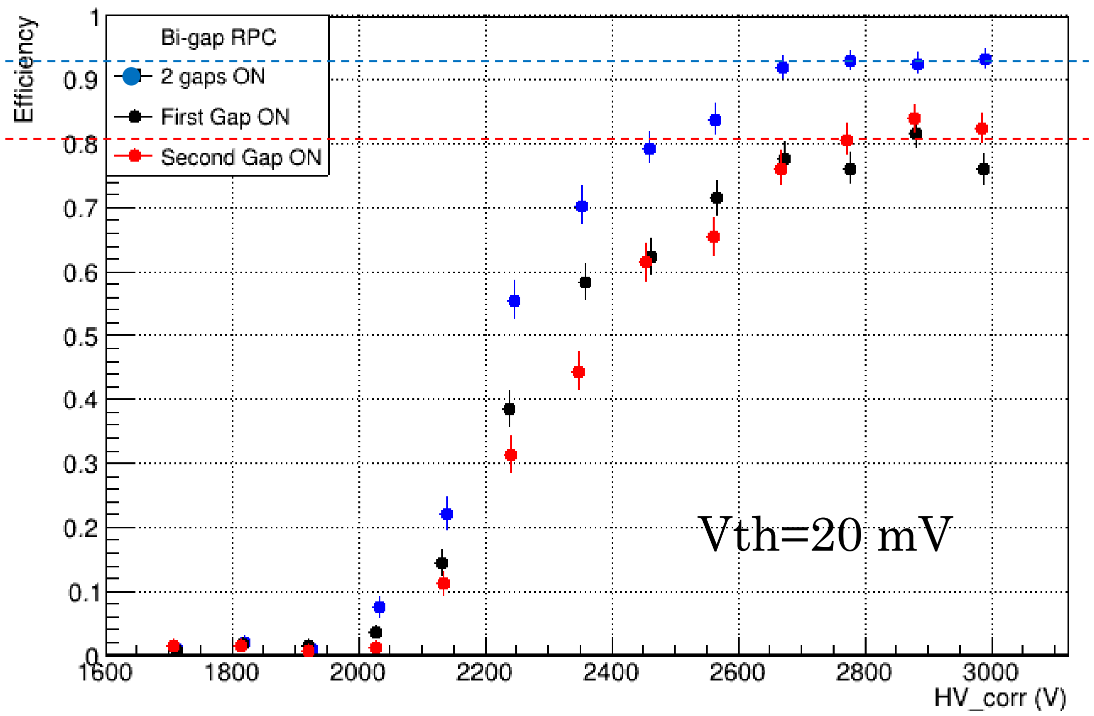
Efficiency single gap vs bi-gap

Both configurations, working with a single gas gap, show a plateau efficiency of approximately 80% due to the 0.2 mm gap thickness. In the double gap configuration, the efficiency curve rises slightly faster, due to a better pickup configuration.
By operating with 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

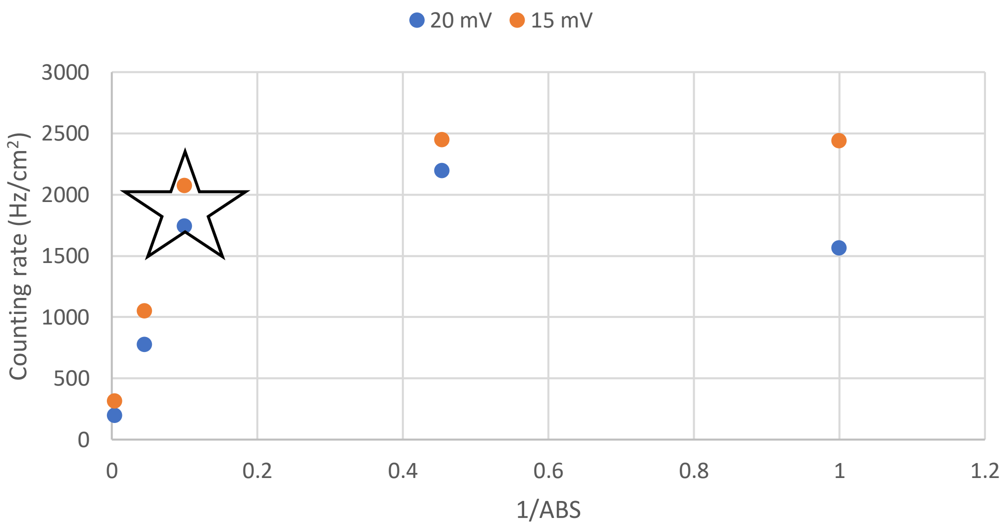


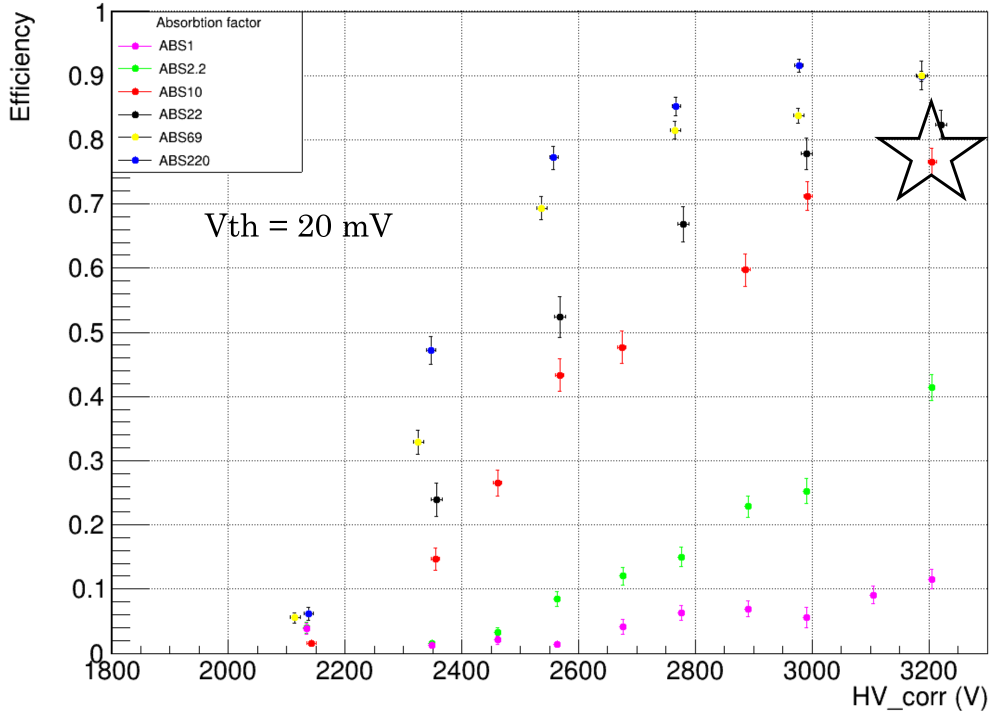
Parallel gas gap configuration



Rate capability

- The Rate capability measurement was carried out in the **configuration with two parallel gaps**, measuring the efficiency to 180 GeV/c muons and the counting rate outside the spill.
- The average electrode resistivity value measured from the shift of the efficiency curves is within the range **2.2 – 2.7 x 10^{12} ohm-cm**
- 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, excellent for resistivity of the order of 10^{12} ohm-cm.
- The counting rate with absorption factor 10 must be compared with the expected photon flux in position U1, equal to **4.8 MHz/cm^2**. The efficiency to photons emitted by ^{137}Cs is **4 x 10^{-4}**
- The photon sensitivity is a factor of two lower when compared to what was measured for an RPC detector with GaAs electrodes with a thickness of 0.65 mm





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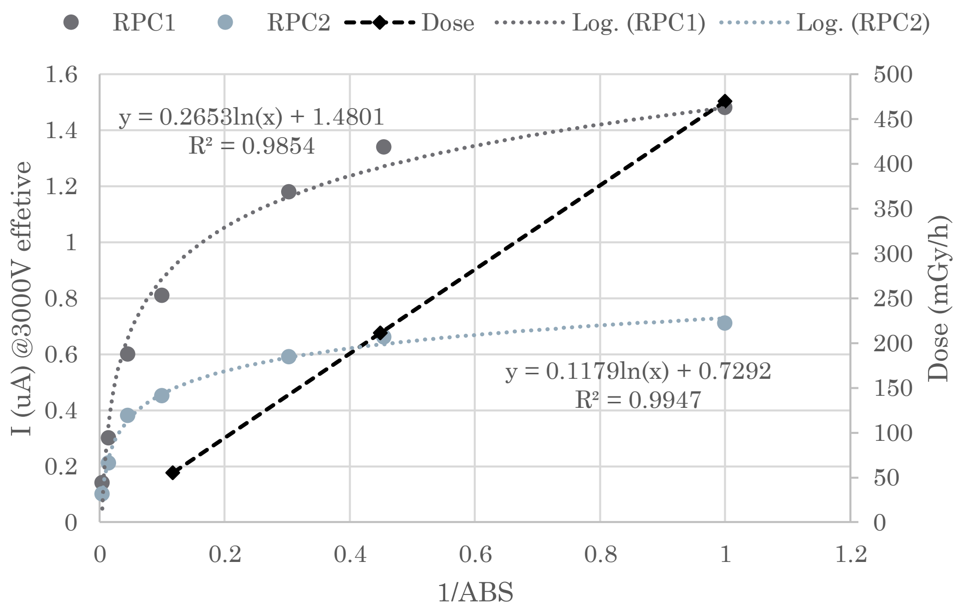
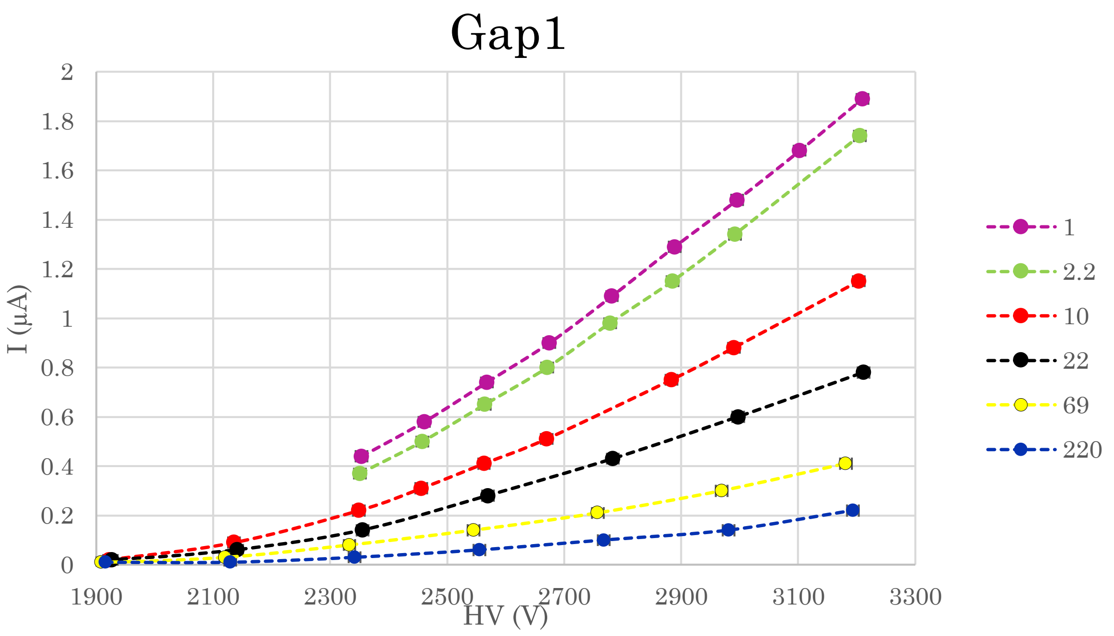
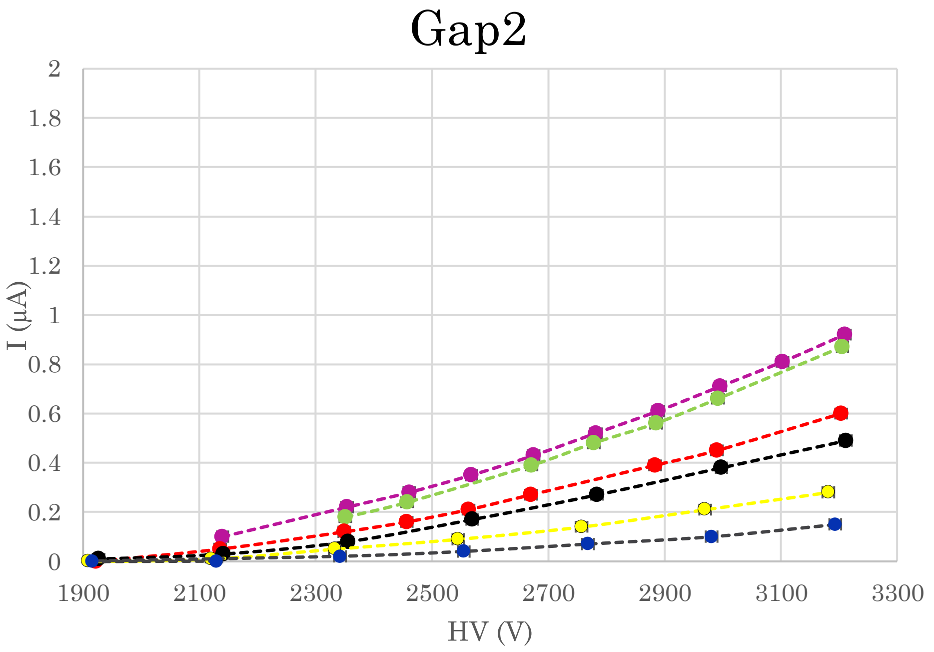
Current

- The current measured under irradiation shows a clear saturation above 4.8 MHz of photon flux, in agreement with the rate and efficiency measurements.
- The two gas-gaps show different current absorption, which cannot be justified by non-uniformity of construction. This could depend on a difference in terms of resistivity between the electrodes of the two gas volumes







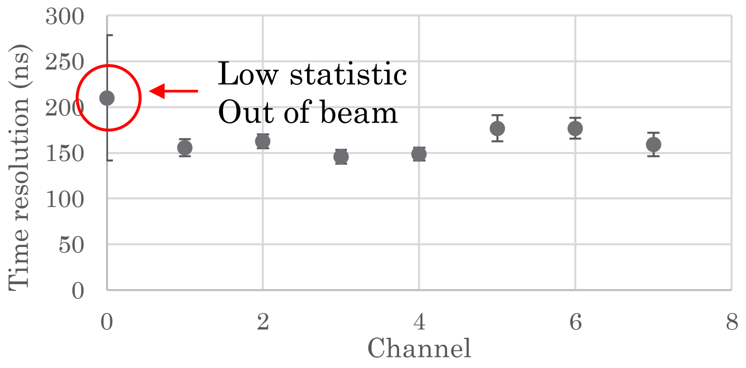
Time resolution

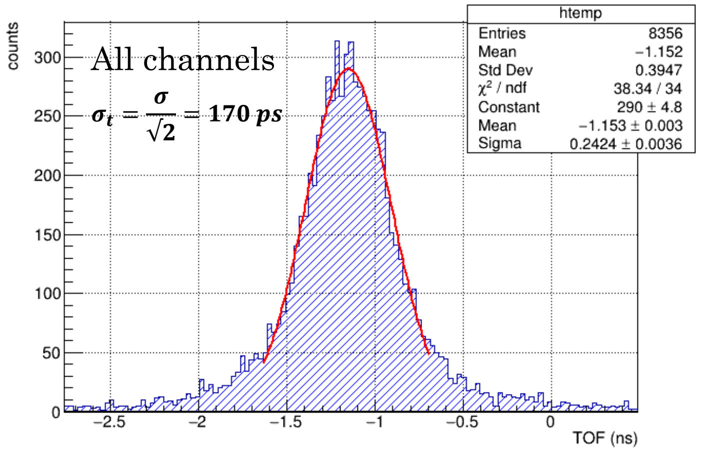
The intrinsic time resolution of an RPC detector scales almost linearly with the gas-gap thickness.
Below 200 ps is dominated by the contribution of the FE electronics noise and the read-out configuration.

The test was performed on the H8 beam dump platform, 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 due to saturation of the FE dynamic range.

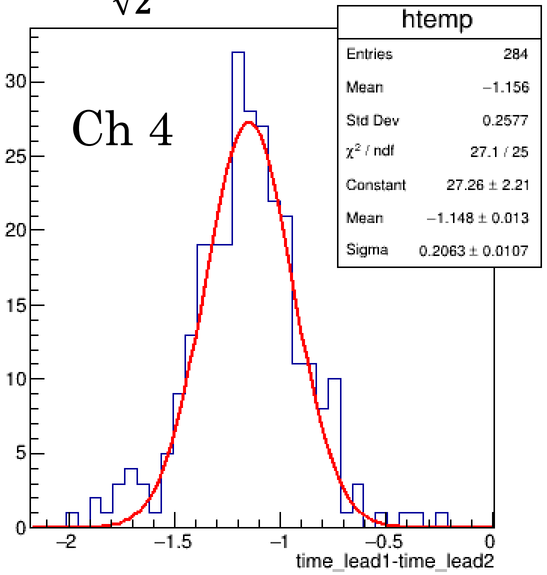
Methodology:

- measurement of the time when the signal rises above 10% of the maximum value (constant fraction)
- Compute the time difference between collinear readout ch, asking the channels to be the cluster leaders
- Gaussian fit performed to each time difference distribution
- Time resolution evaluated as sigma/sqrt(2)
- Preliminary results: time resolution of ~150 ps





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

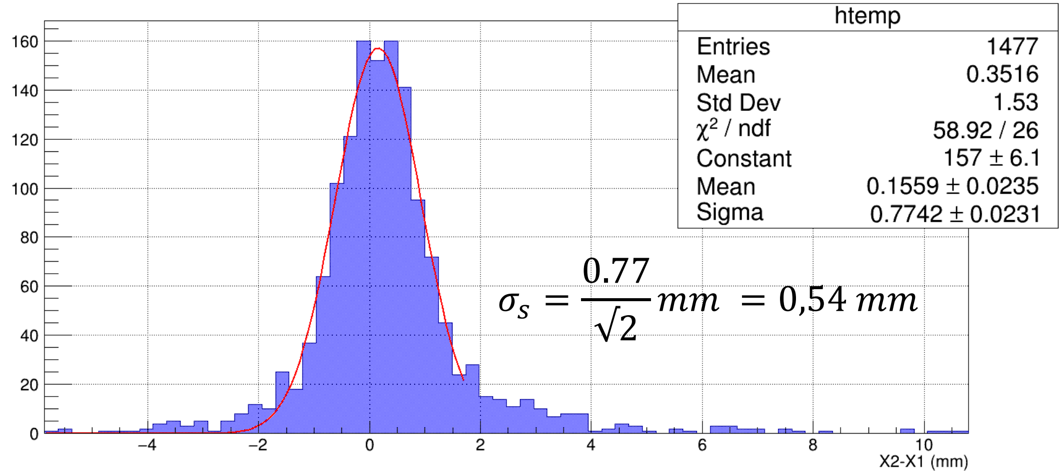


Spatial resolution

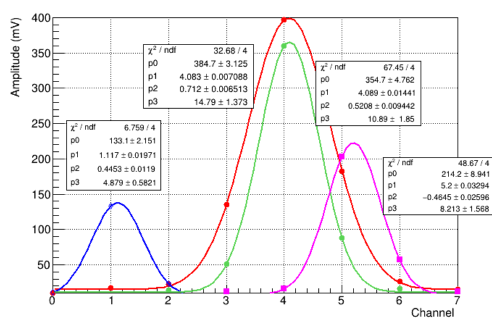
The charge centroid method exploits the diffusive effect of the electrode to reconstruct the position of the discharge center. It is effective for high cluster size. The cluster center has bean measured as the average of the Gaussian distribution calculated from the fit on the amplitude distribution of the peaks observed on the different channels.
The test was performed beyond the beam dump of the H8 beam line, with narrow muon beam (23 mm RMS).
Cluster size depends on many detector parameters:

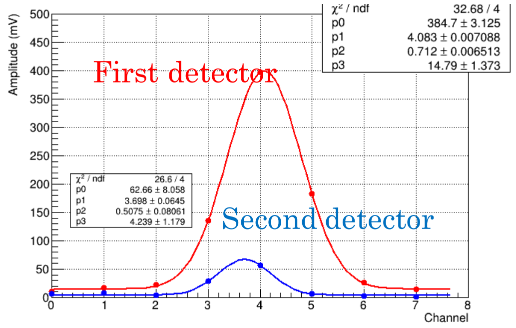
- Strip pitch (1 cm)
- Electrode (0.4 mm) and gap (0.2 mm) thickness
- Graphite layer resistivity (about 500 kΩ/□)
- FE electronics threshold (20 mV equivalent to 5 fC)

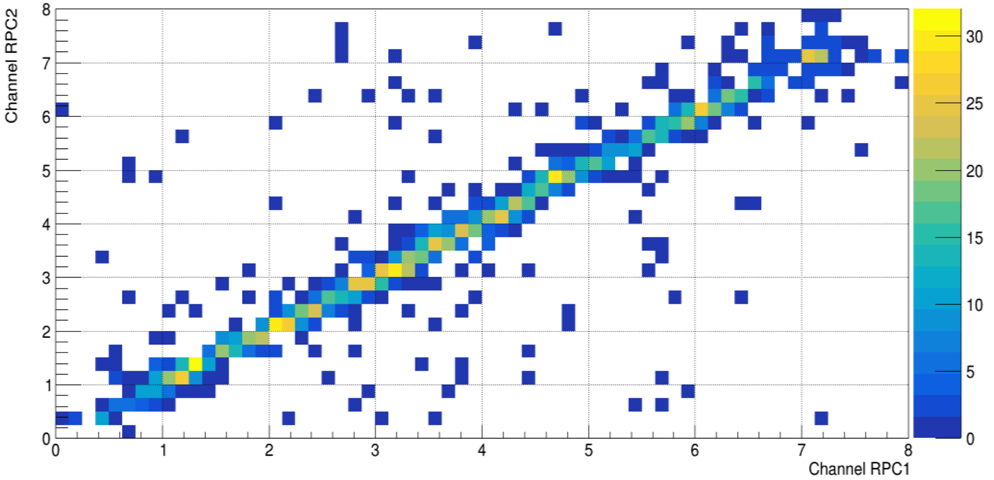
For a detector with a such thin gap and electrode it is essential to recalibrate the resistivity values of the graphite to cope with the reduction in the physical cluster size



$$\sigma_s = \frac{0.77}{\sqrt{2}} mm = 0{,}54\ mm$$







Perspective

The tests have shown how the thinning of the electrodes and gas gap lead to excellent results in terms of rate capability compared to expectations. The 0.4 mm phenolic glass electrode has sufficient rigidity to maintain adequate uniformity over a 0.2 mm gas gap.

To proceed with the next steps, it is necessary to set more selective aims and develop detectors optimized for a specific purpose:

Tracking – Timing – Rate capability:

- Reduce the graphite resistivity
- Reduce the strip pitch
- Reduce the phenolic glass resistivity by optimizing production processes and selection (RPCs with phenolic glass electrodes)

Triggering – Large surface – Low cluster size :

- Increase the graphite resistivity
- Increase the electrode rigidity

In any case it is necessary to:

- optimize the FE electronics for very narrow signals with rise-time of the order of 300 ps
- optimize the read-out panel coupling to improve the signal sensitivity

Conclusions

- Very compact and low material budget detectors ~ 8 - 7 mm total thickness depending on the configuration
- low power supply voltage needed (about 2700 V)
- With an RPCs with 0.4 mm phenolic glass electrodes, and 0.2 mm gas-gap we reached the following results
  - efficiency up to 95% with double parallel gap configuration
  - Time resolution of approximately 150 ps (with no corrections)
  - Position resolution with read-out strips with pitch of 1 cm of approximately 540 um (raw estimate, without precision mechanics and no external tracking system for the track impact position reconstruction)
- With parallel gap configuration, despite the high resistivity (~10^12 Ohm x cm)
  - Photon sensitivity of the order of 4 x 10^-4
  - Counting rate up to 2 kHz/cm^2 at 75% of efficiency (1kHz@80%)

In the near future, a test campaign is expected to study :

- aging of the phenolic glass electrode, selecting various types on the market.
- comparison of results between oiled and non-oiled electrodes,
- effect of gas humidity

Thank you for the attention