Status and perspectives of the «Standard RPCs»

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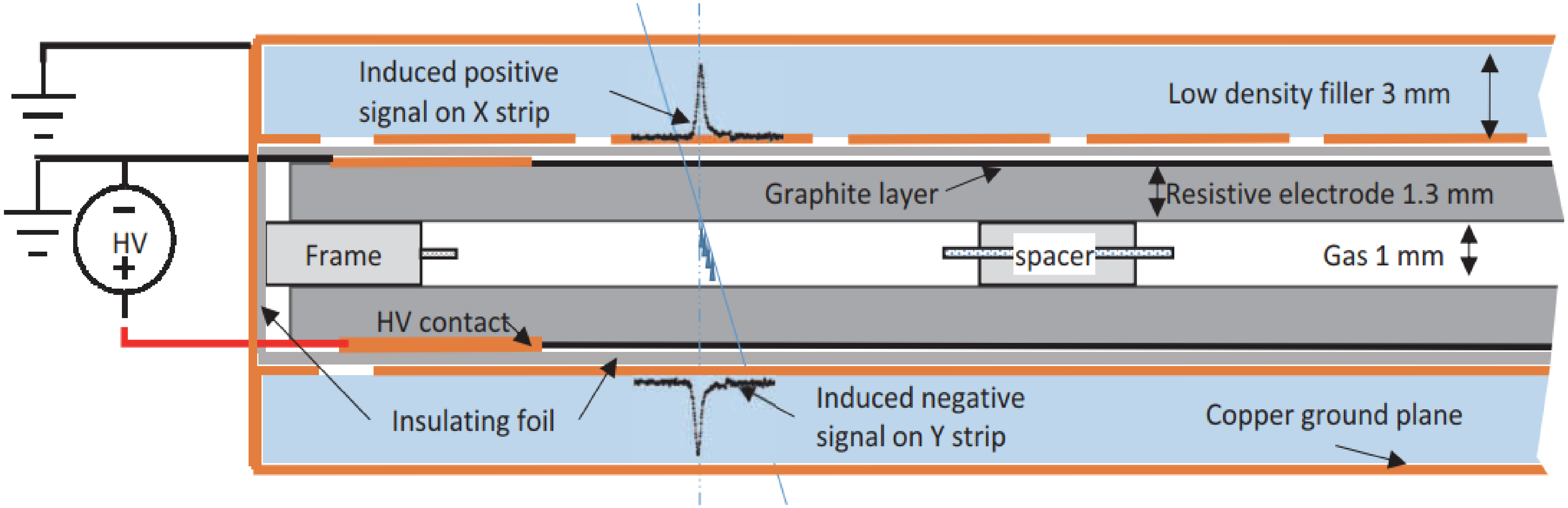
What does it mean «standard»

- In this presentation «standard RPC» is defined as a device consisting of a gas gap sandwiched between two resistive plates connected to a voltage generator, as it was conceived a long time ago
- This definition excludes for example multiple gap RPCs where the multiple gaps are created by introducing ***floating*** electrodes which, due to the working mechanism, automatically assume the correct intermediate potential between the two external electrodes that are connected to the voltage generator.
- This mechanism, according to tests carried out, requires a minimum working rate, and therefore a minimum working current, to insure that the electric field is the same in all gaps. These multiple gap RPCs can achieve extremely good time resolution and proven to be a very suitable device for ToF measurements
- This talk is concentrated on standard RPCs leaving the task to describe other kind of RPC to the corresponding experts

RPC gas gap sanwiched between the two read out strip panels



Gas gap components

a. High Pressure Laminates electrode plates
b. Graphite electrodes
c. Insulating PET foil   d) spacers

Standard gap free parameters

A wide range of parameters can be chosen to optimize a standard gap for specific purposes

- Gas gap size. The gap size regulates the signal duration (and therefore the charge) which is approximately proportional to it. Taking as reference the 2 mm gap widely used so far (total delivered charge some 20 pC and time resolution about 1 ns, mainly depending on the amplitude correction accuracy) substantially narrower gap sizes show a proportionally smaller signal charge and lower time fluctuations. This means an increased rate capability and timing accuracy. This improved performance requires however, to be preserved, a front end electronics with a lower charge threshold.

- Electrode resistivity and thickness. The electrode resistivity regulates, for a given working current, the voltage applied to the electrodes and therefore subtracted to the gas. A decrease of resistivity increases the rate capability. It is to be stressed however that a high rate capability obtained mainly via a very low resistivity would generate potential aging problems. It is therefore saver to increase the rate capability by lowering the charge-threshold of the front end electronics. The electrode thickness affects the total electrode resistance (thinner electrodes → lower resistance) and the electrode capacitance. Thinner electrodes increase the fraction of charge induced on the read out pads

A deeper insight to the importance of the electrode thickness

- As already said, thinner electrodes reduce the distance between the avalanche growing in the gas and the read-out pads. This increases the induced charge [ref] thus improving the rate capability

- This effect can be numerically expressed by the ratio electrode-thickness/gas-gap-size=t/gε
- The most important consequence is that the reduced charge induction due to the electrode thickness can be relatively modest for t/gε<<1 but extremely relevant for t/gε >=1
- Thin gap RPCs cannot be made with thick electrodes otherwise the charge induced on the read out pads, compared with that delivered in the gas, becomes very small

- Anyway the behaviour of thin gap-thin electrodes must be better investigated (see the A. Rocchi talk) at the GIF- cern and BTF at the Frascati-lab or simply with cosmic rays tests

The new Atlas-BI (Inner Barrel) RPC system as an evolution of "Standard RPC"

The Atlas BI muon trigger, in comparison with the existing BML-BOL system, will operate at a substantially higher rate both for increased LHC luminosity and decreased distance from the interaction region [ref]

The required increase of rate capability was obtained trying to keep at the minimum the operating current increase to avoid ageing effects. The main effort was addressed to minimize the delivered charge per count

- Keep the electrode resistivity around 5 10^10 Ohm cm
- Reduce the gas gap size from 2 mm (BML-BOL legacy RPC) to 1 mm
- Lower the front end electronics threshold to few fC. This increased FE sensitivity overcompensates the lower signal charge due to the narrower gap, thus further increasing the rate capability

Another relevant parameter change concerned the resistive electrode thickness
Thinner electrodes reduce the distance between the avalanche growing in the gas and the read-out pads. This increases the induced charge thus improving the rate capability.

- Electrode thickness reduced from 1.8 mm to 1.4 mm.
- The lower mechanical rigidity due to he thinner electrodes is compensated by reducing spacer distance from 100 mm to 70 mm

The front end electronics

- A *wise* general concept about the FE electronics is that it must be adapted to the corresponding RPC application: not too modest - not too high
- The main RPC problem, concerning high counting rate applications like collider physics, is the limited current that can flow across the resistive electrodes, taking also into account ageing effects

- Therefore the traditional leading idea for the RPC front-end electronics is to *tranfer from the gas to the front-end electronics a relevant part of the charge amplification* needed to make the signal visible

- A very low threshold minimizes the required charge per count and therefore the working current. However this requires to shield the detector against external noise at a level adequate to the chosen loe threshold, the physical limit being the intrinsic thermal noise of the FE circuit

Atlas BI front end electronics

The new Atlas FE electronics points to two main challenges

A very low discrimination threshold, 2-3 fC

Integrate the TDC circuit inside the fron end board
Achieving this goal is a crucial improvement for large for large systems to eliminate complex cabling

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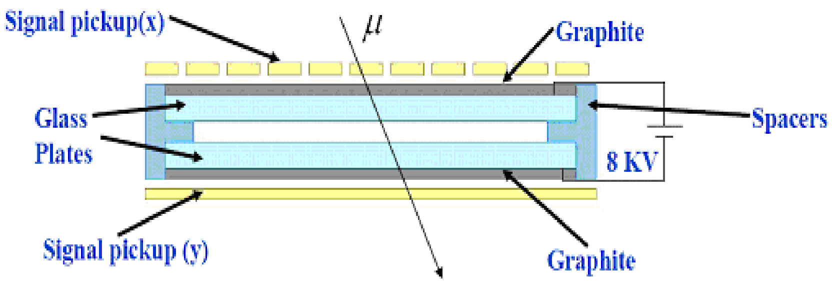
The twin gap design

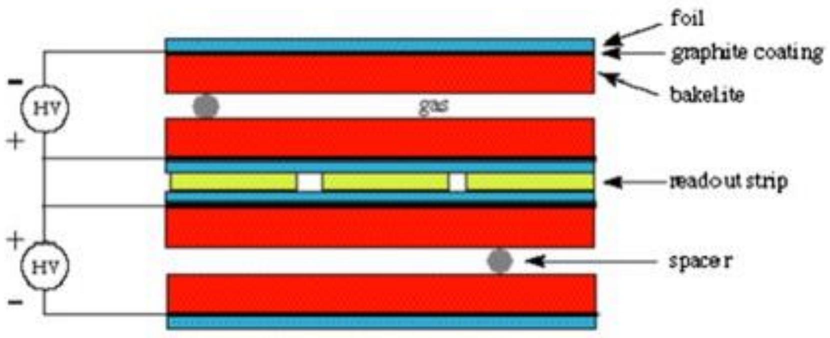
- Two standard gaps can be assembled together with a single readout strip plane sandwiched between them
- Both avalanches growing in the two gaps induce charge on the same strip thus doubling the signal
- This solution was adopted by CMS for the first generation chambers and is followed also in the new project
- In general this RPC design is the optimal one whenever, for improving rate capability and timing performance, a thin gap, 0.5 mm or less, is chosen. The twin gap design improves the detection efficiency if needed.

The RPC CMS project

Experiment		Subsystem	Resistive Plates	Mode	Gaps
ALICE	Avalanche	μ Spectrometer	Bakelite	Avalanche	1
ATLAS		μ Spectrometer	Bakelite	Avalanche	1
CMS		μ Spectrometer	Bakelite	Avalanche	2



Single gap



CMS double gap

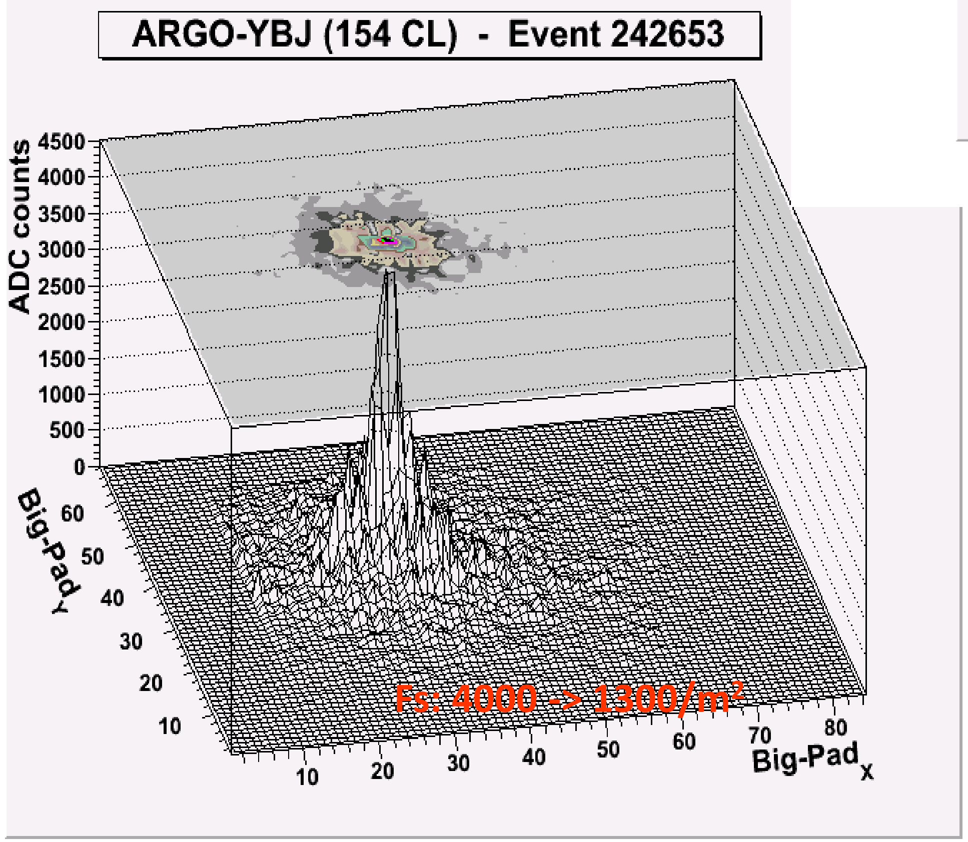
RPCs as ground based detectors of Extensive Air Showers (EAS)

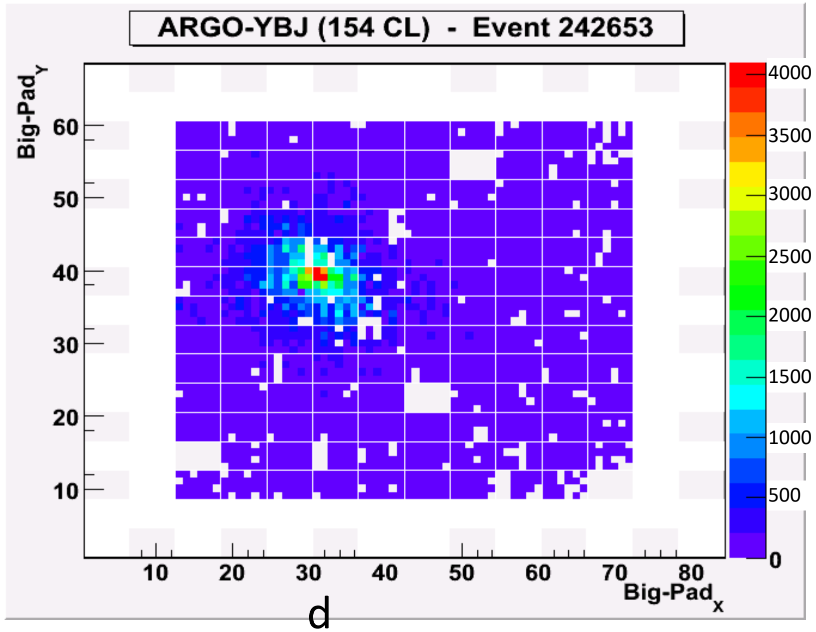
- Argo (Tibet 4300 m asl) is the first cosmic ray detector making exclusive use of RPC
- The primary cosmic ray direction, in ground based detectors, is obtained by imaging the atmospheric shower with simultaneous position-time measurements of the particles produced in the atmosphere
- The required accuracy is defined by the shower front thickness, about 1 m, which limits the space x time required accuracy to few tens of centimeters x 1-2 ns
- The required rate capability, the CR rate at about 5000 m asl, is very modest
- These requirements look much more modest than the corresponding ones in collider physics
- Indeed the strong requirements of the CR physics are elsewhere

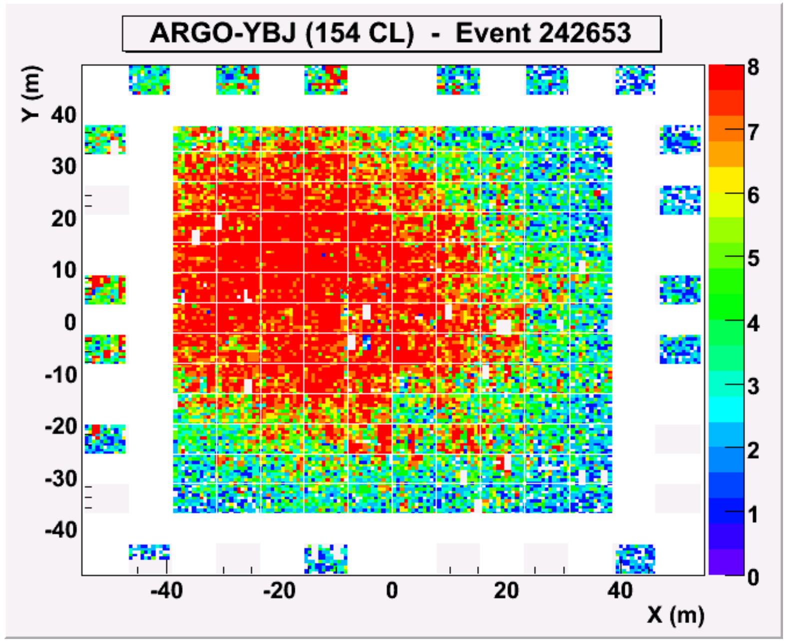
The RPC analog readout

Extending the dynamical range up to PeV

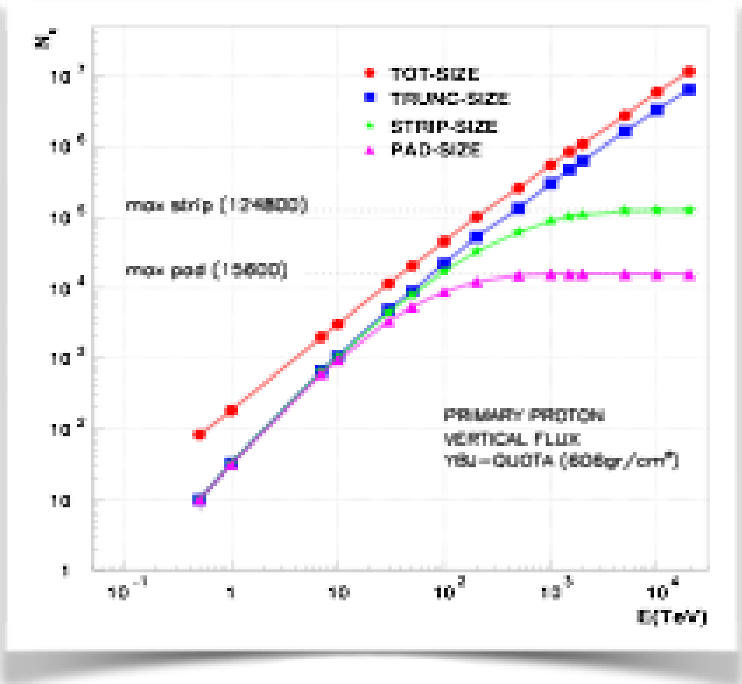
ARGO event







- Is crucial to extend the covered energy range above 100 TeV, where the strip read-out saturates
- Max digital density ~20/m^2
  Max analog dens ~10^4/m^2
- Access the LDF in the shower core
- Sensitivity to primary mass
- Info/checks on Hadronic Interactions



Strong detector requirements of the CR physics

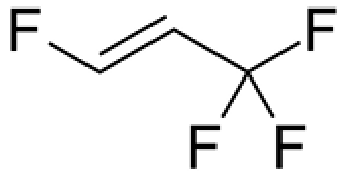
- Large or very large detection area depending on the primary energy range
- Working reliability in hostile environment and low maintenance needs
- Good capability to measure high hit density in the shower core that can exceed 10^5 m^-2
- –> CR physics requires a very different kind of RPC than the collider physics
- .

RPC optimized for ground based EAS detection

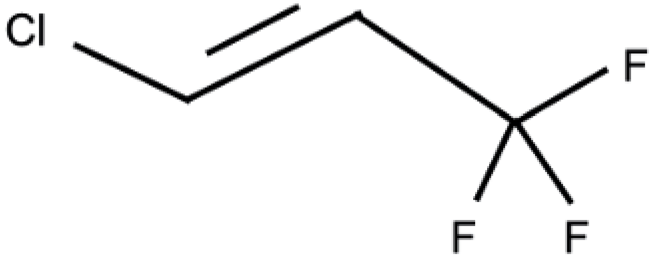
- This optimization requires a strong simplification of detector structure concerning
  - Gap construction
  - Mechanical support
  - Read out
- The optimization of the read out pads is the most challenging item because the classical strip-readout is not adequate in this case,
  - Squared pads pads of 40-50 cm side would be perfect for timing purposes and would drastically reduce the required pad number
  - BUT…would the large pad capacitance spoil the signal amplitude and the timing performance?
  - This problem is under study but preliminary results are encouraging

Search for new ecofrienly RPC gases

- This is a non easy problem for the RPC community
- «Standard mixture» mainly composed of complex/heavy gaseous components as good UV photons absorbers.
- CO_2 too simple molecule → modest UV absorber →less effective streamer suppression
- Two new molecules tested:

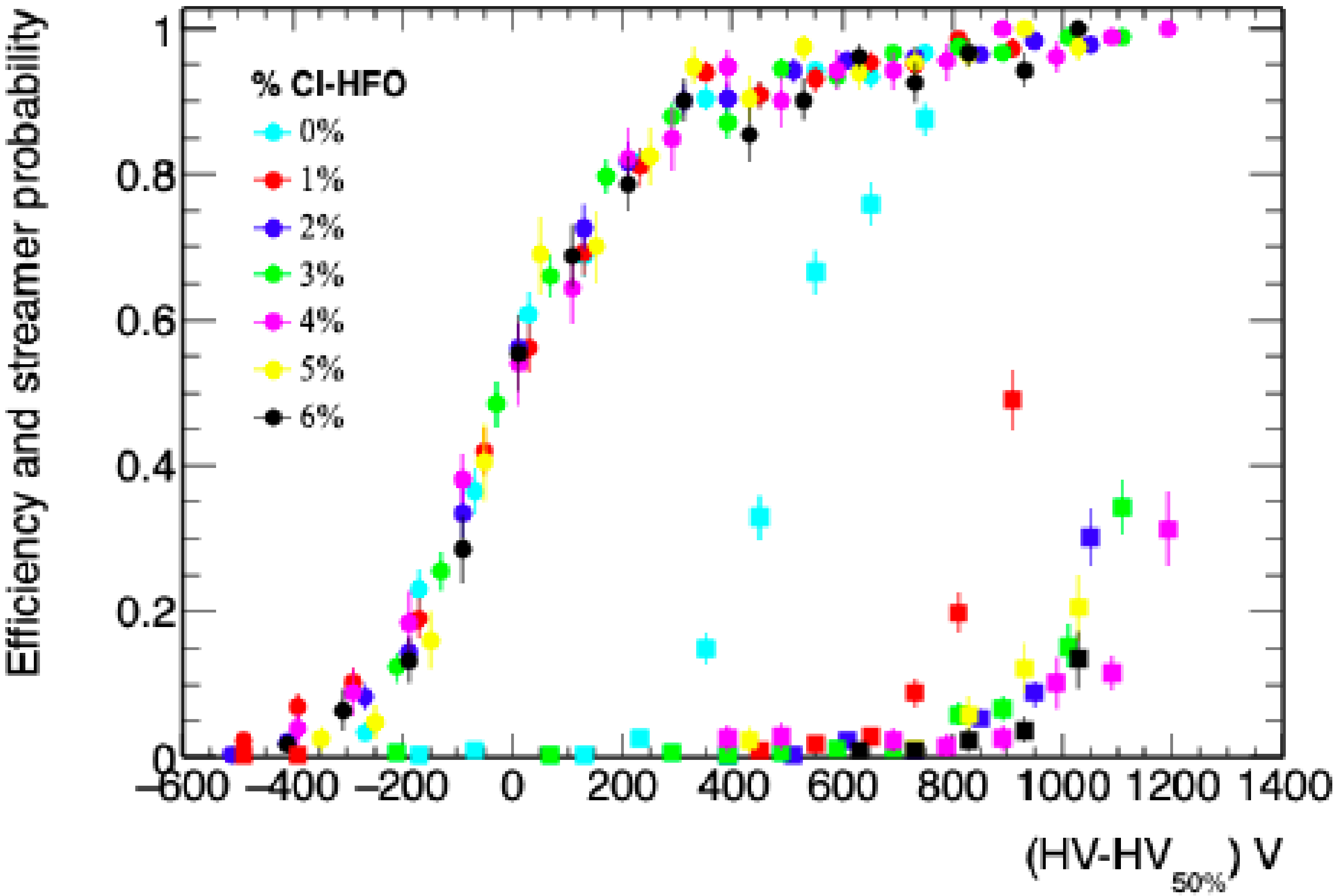


Tetra-fluoro-propene replacing tetra fluoro ethane

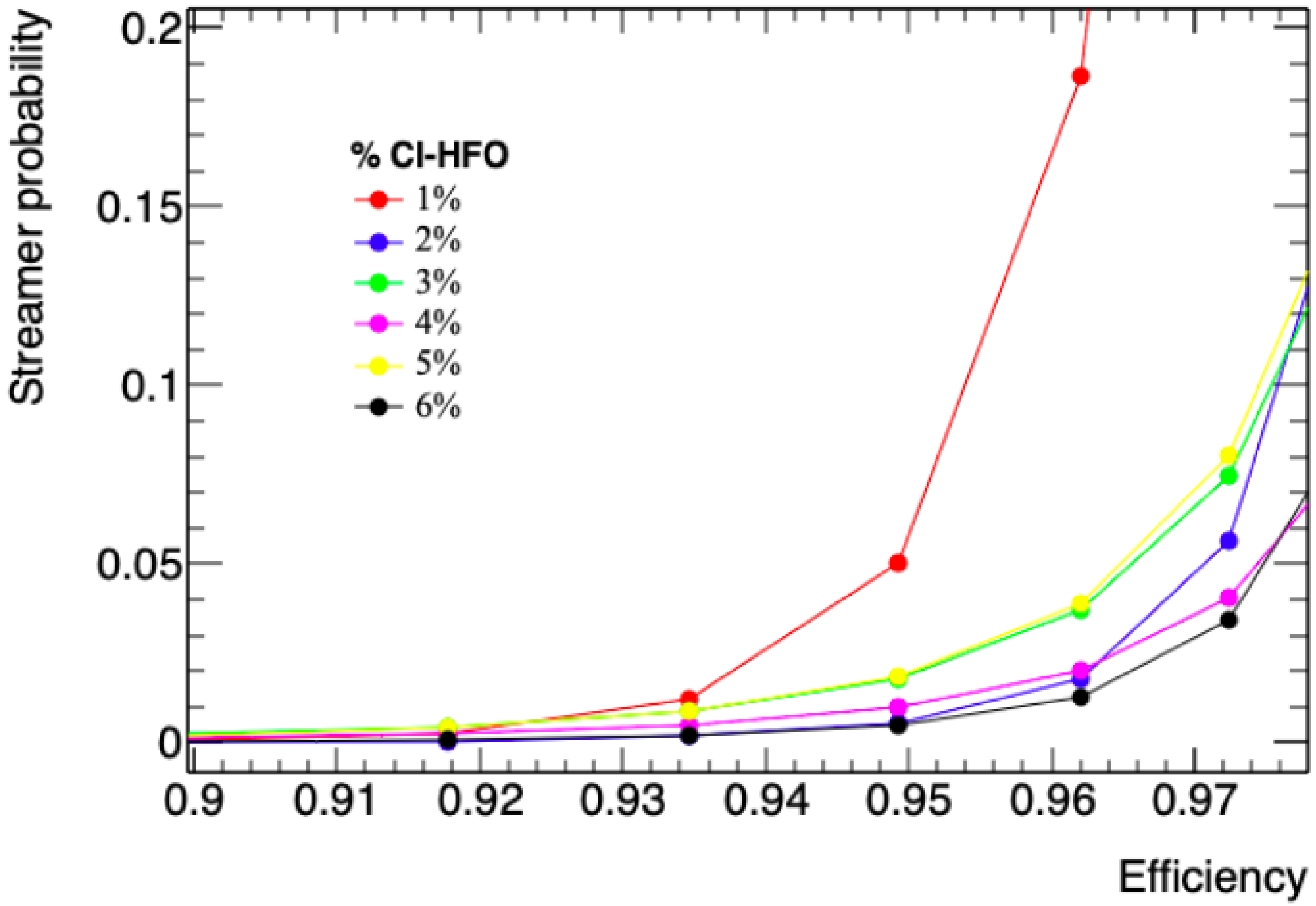


Cl-Three-fluoro-propene replacing SF6

Efficiency and streamer probability vs % Cl-HFO

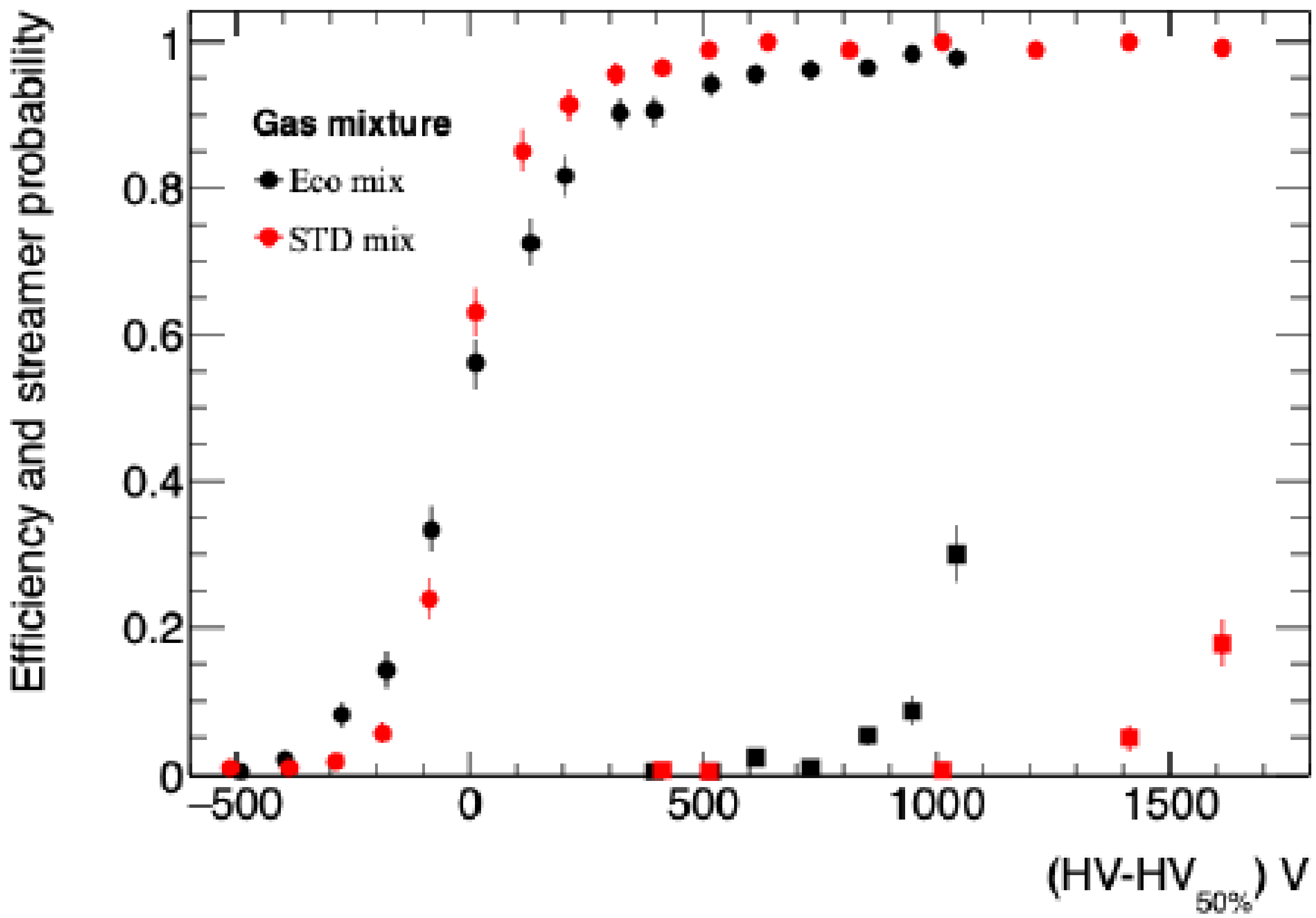


Streamer probability vs Efficiency

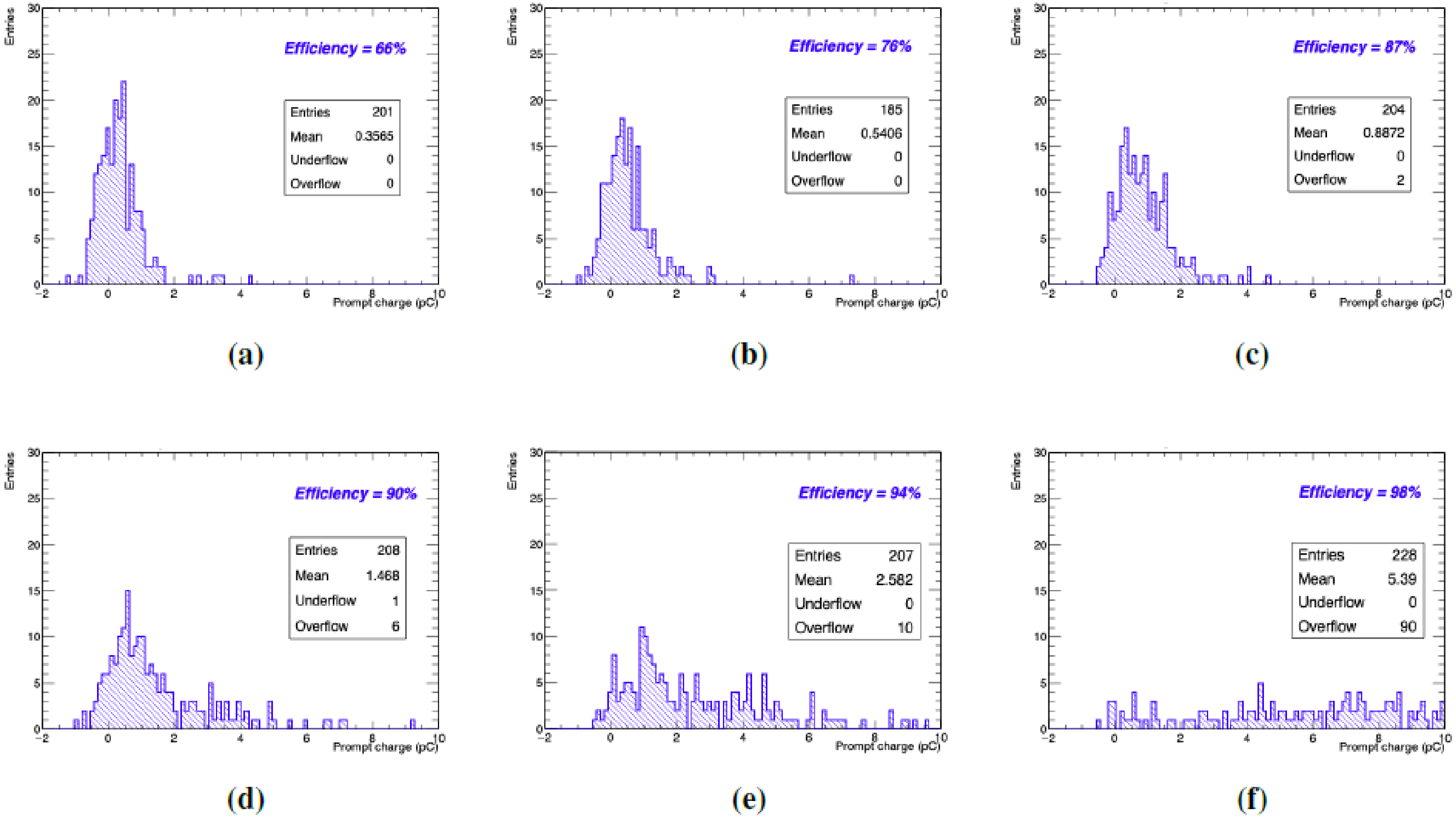


Comparison Eco-mixture with STD mixture

CO_2/F-HFO/i-C_4H_{10}/Cl-HFO=76/15/7/2



Total prompt charge distribution at different efficiencies for the ecogas mixture CO_2/F-HFO/i-C_4H_{10}/Cl-HFO =76/15/7/2



Time resolution comparison

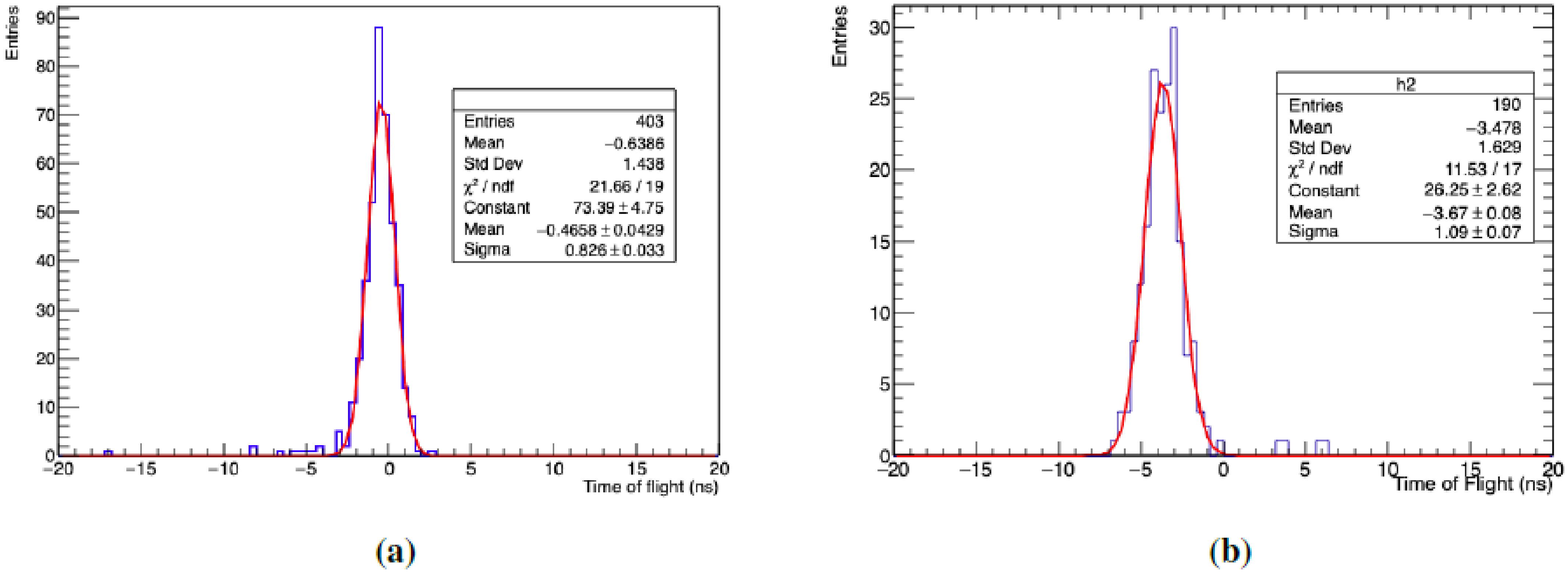


Figure 17. Time resolution for the (a) eco mixture (CO_2/F-HFO/i-C_4H_{10}/Cl-HFO=76/15/7/2) and the (b) standard mixture($C_2H_2F_4$/i-C_4H_{10}/SF_6=94.5/5/0.3).

A further remark about gas

- A relevant point not to be forgotten is the connection between the performance of the gas mixture and the performance of the front end electronics
- An increase of the FE sensitivity allows to reduce the operating voltage. If it is lowered below the streamer appearance point the corresponding gas becomes a good candidate for pure avalanche operation
- As an example the ecofriendly gas analyzed above allows to operate in streamerless mode BUT j ust at the limit. Lowering the voltage by some 400 V would give a very comfortable separation from the streamer point

- As mentioned before the present threshold of the Atlas BI FE electronics is about 3 fC
- A new amplifier in technology BCIMS SiGe developed by the University of Geneva might reduce the threshold to 0.5-0.3 fC.
- Lowering the operating voltage by 400 V would become achievable

Overview of future RPC perspectives

Further relevant RPC evolutions/applications are achievable in a relatively straight way at the level of large are chambers and complex systems

- Multigap-RPCs have still a relevant growth potential for large area ToF system with the goal of few picoseconds resolution
- Standard RPCs with twin gap configuration can track muons with stace x time resolution of 100 µm x 100 ps at the rate of 10^4/ cm2
- "Cylindrical RPCs" (see A. Rocchi talk) can operate at high pressure overcoming the 10 millibar limit of planar RPC. Particularly important for operating in free space (zero external pressure)
- Several practical applications are achievable. Muon tomography of very large objets is a very interesting one

Thank you

A very good RPC 2024