RPC detectors for Mathusla

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By R. Santonico

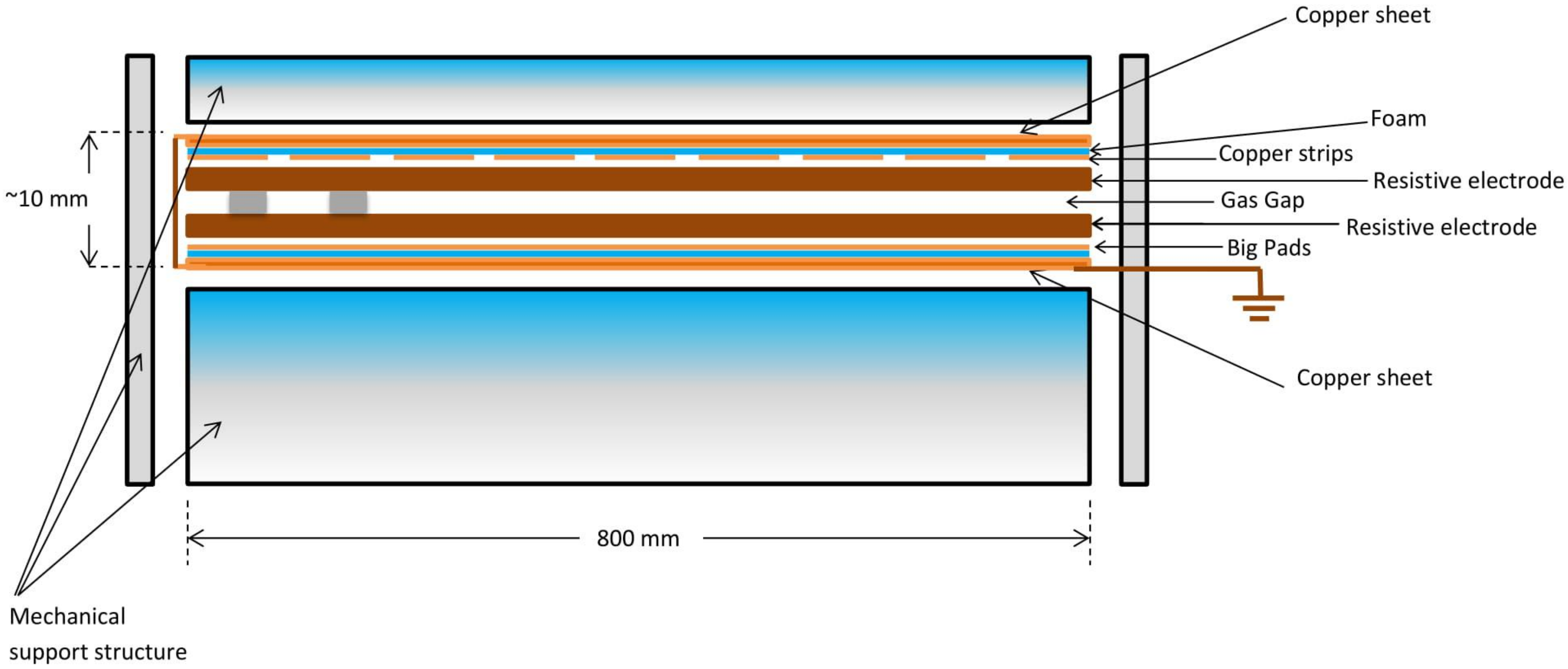
The purpose of this talk

- An RPC detector for Mathusla is one of the options under consideration. Other options are under study and will be presented
- Even in the RPC hypothesis, several configurations are possible
- This talk presents an idea of how an RPC tracker can be optimized for Mathusla taking into account the fundamental requirements of the experiment
  - Excellent tracking capability with very high discrimination power between down-going and up-going particles → space and time resolutions about $1\ cm\ x\ 1\ ns$
  - Multipurpose approach: *search for LL particles* and *cosmic ray physics* with the same detector → measure single hits and hit densities exceeding $10^4\ m^{-2}$ in the core of a very high energy shower
  - Unprecedented sensitive area: $50{,}000\ m^2$ for Mathusla 100
  - → quality-to-cost ratio optimization
- The detector proposed here intends to fulfill all the above requirements. Other solutions may be proposed fulfilling the same requirements

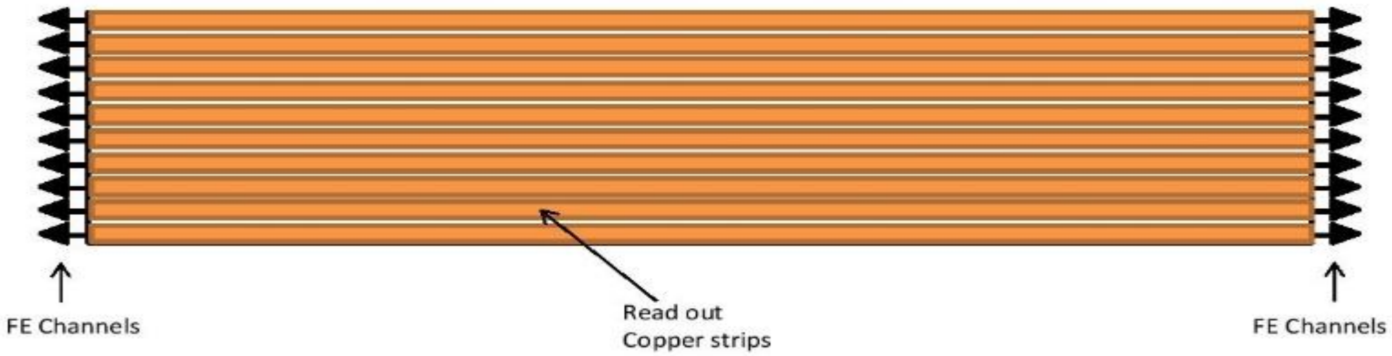
Detector layout

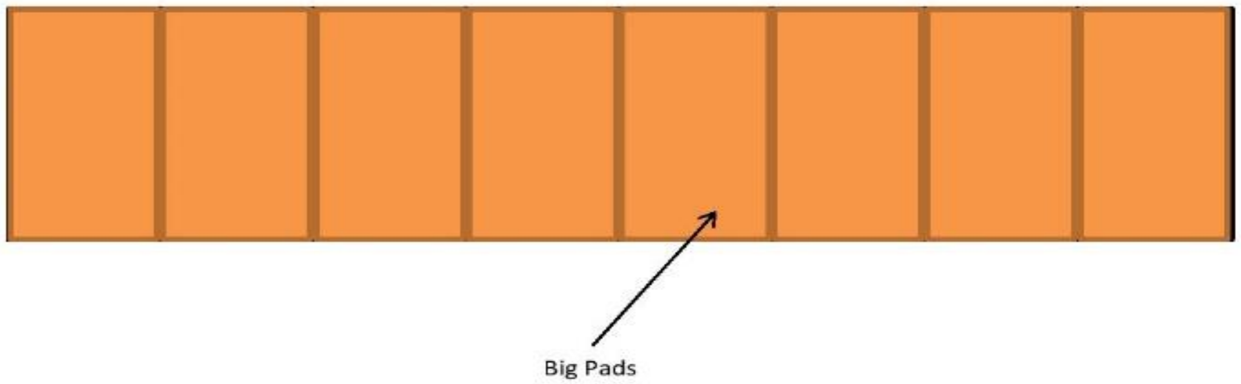
- Gas volumes
  - Resistive electrodes of phenolic High Pressure Laminates (bakelite), 1.2 mm thick
  - Gas gap $1\ mm$; wider gaps up to $2\ mm$ can be considered
  - size: about $3.20\ x\ 0.8\ m^2$
- Read out
  - by strips about $25\ mm$ wide and $3.20\ m$, equipped with front end electronic circuits at both ends, in order to reconstruct the longitudinal coordinate through the signal arrival times at the two ends of the strip
  - expected resolution: $\sim 1.5\ cm$ in the longitudinal direction (with $100\ ps$ TDC resolution) and $\sim 0.5\ cm$ in the transversal direction by means of the charge centroid of contiguous strips
  - In order to make the space resolution symmetrical, different detector layers have strips oriented alternatively in the x and y direction
  - different from Atlas read out, which has strips oriented in both directions
  - Advantages: i) a reduction of the read out channels with a relevant simplification of the detector complexity; ii) an unambiguous association of the x and y coordinates, in the case of several simultaneous particles crossing the same chamber. This eliminates the ghost-hit problem
- Analog read out
  - by means of "big pads" of size 80x80 cm2, working as large capacitances integrating the charge of all hits falling on them
  - Allows to measure very high hits densities at the core of a very high energy shower

Detector proposed lay out



Pick up strips and “big pads”

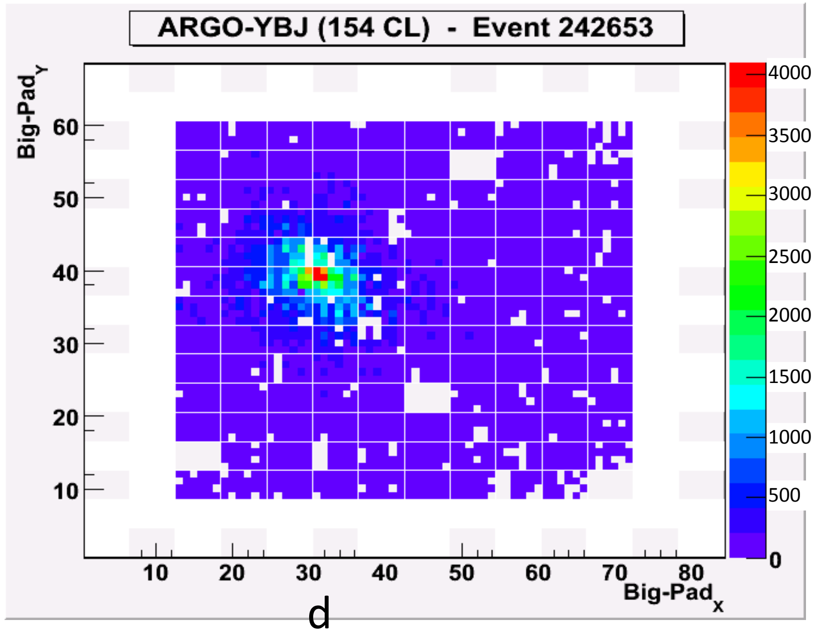




The RPC analog readout

Extending the dynamical range up to PeV

- 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



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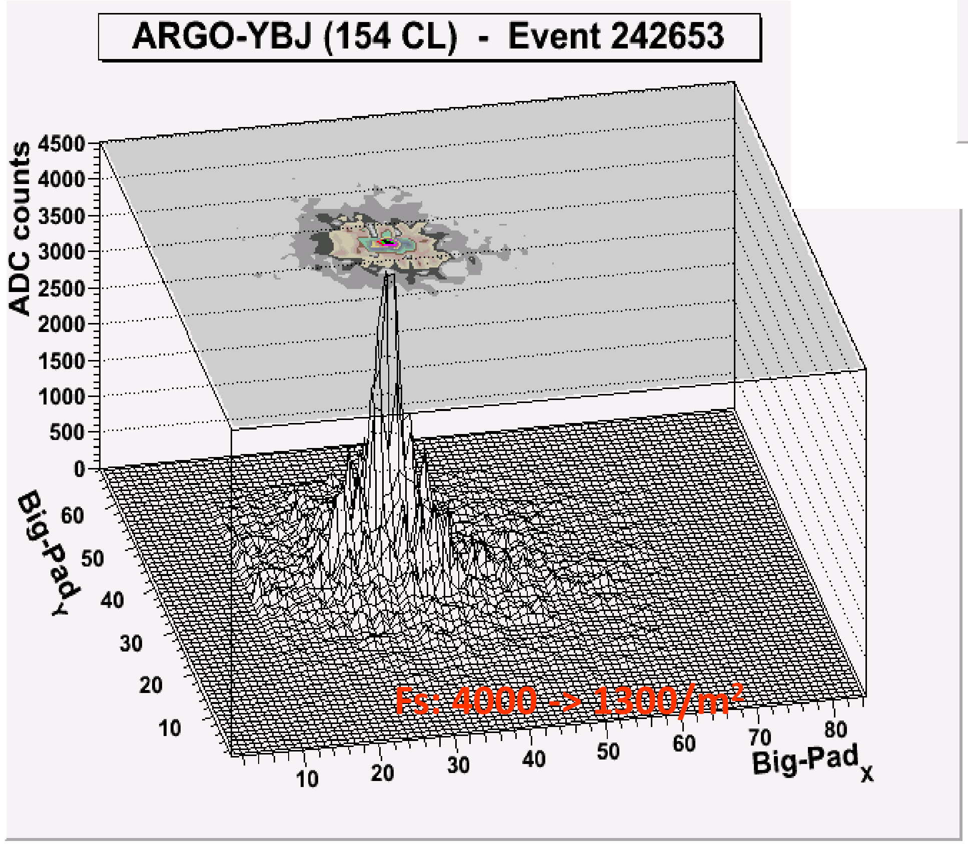
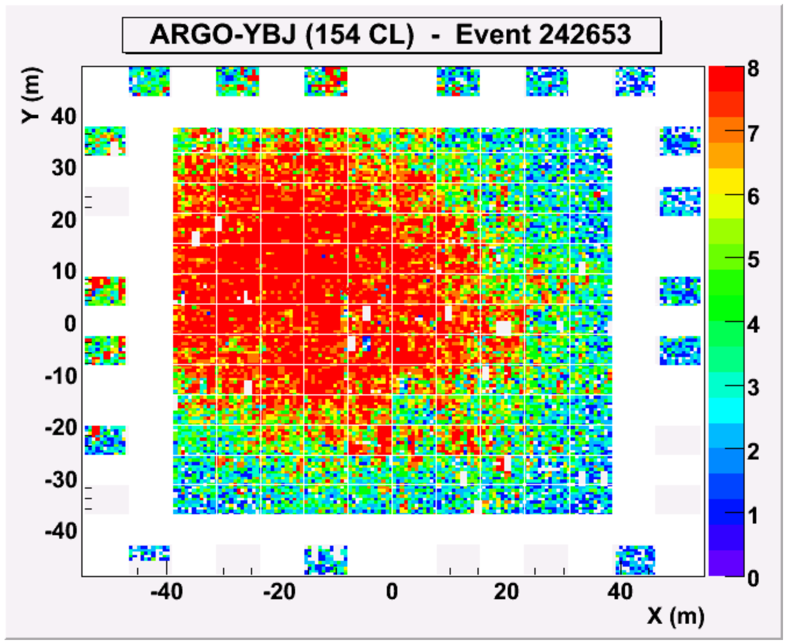
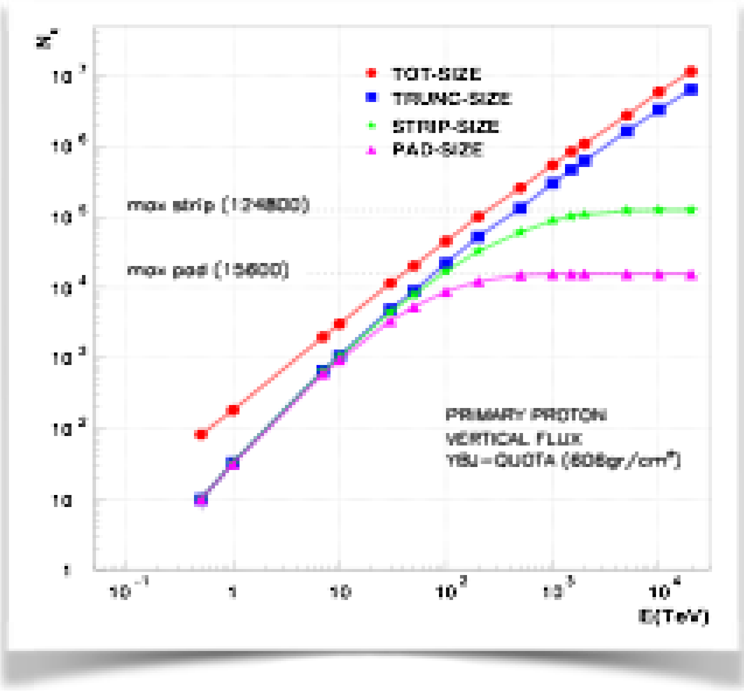
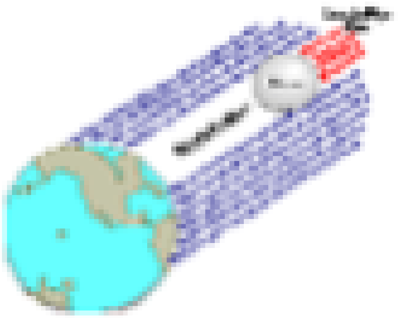
ARGO event

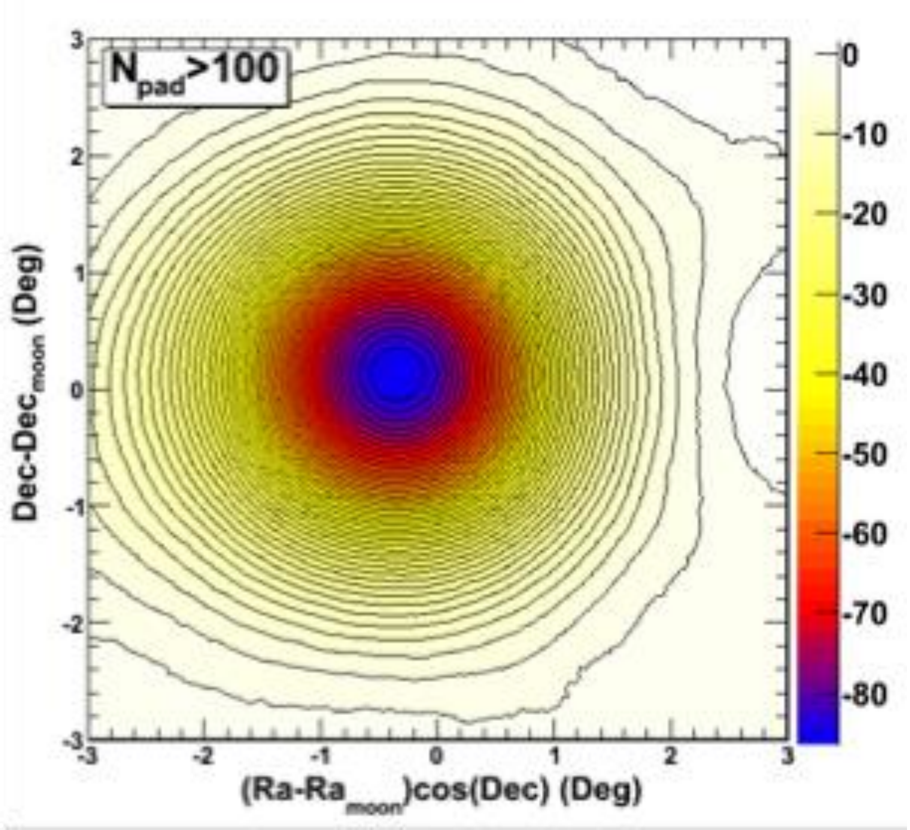


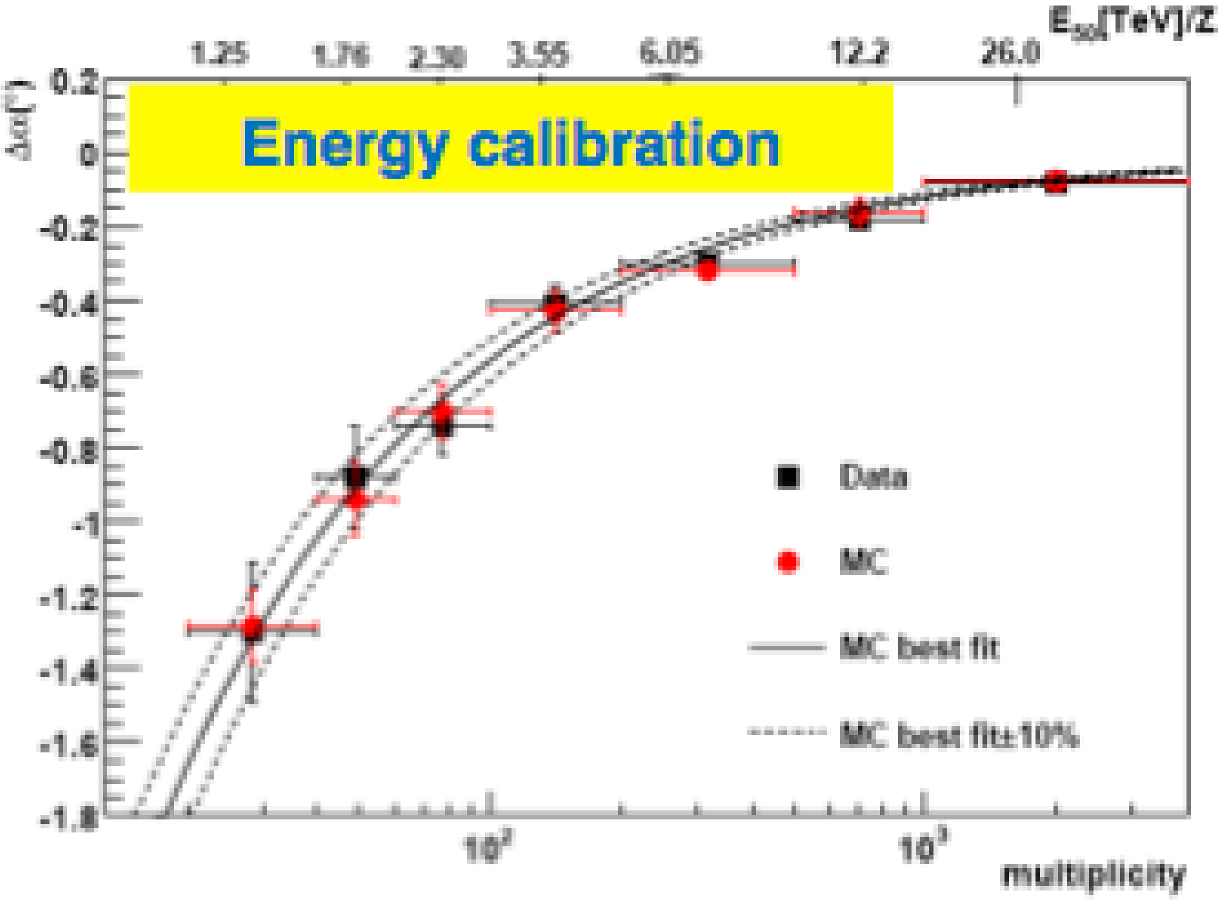




Energy scale calibration







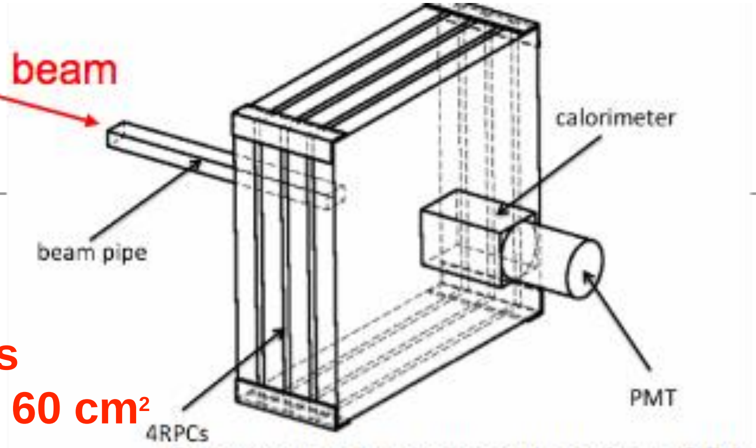
$N \approx 21 \cdot (E_{TeV}/Z)^{1.5}$

10% uncertainty estimated in the energy range 1 – 30 (TeV/Z).

Intrinsic linearity: test at the BTF facility

Linearity of the RPC @ BTF in INFN Frascati Lab:

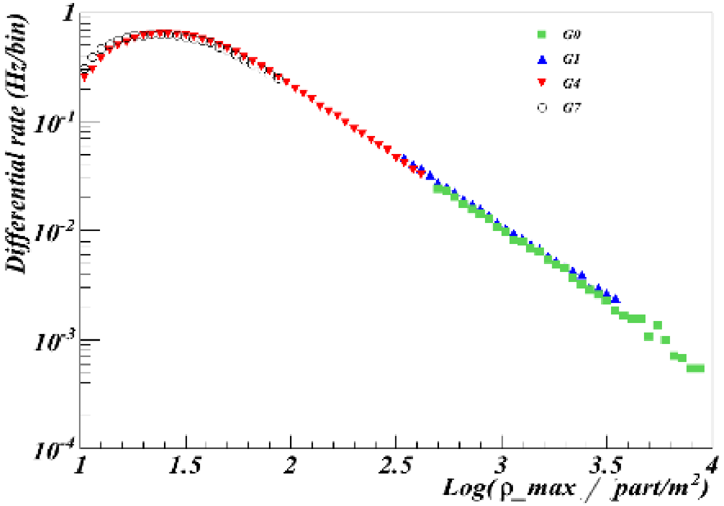
- *electrons (or positrons)*
- *E = 25-750 MeV (0.5% resolution)*
- *<N>=1÷10^8particles/pulse*
- *10 ns pulses, 1-49 Hz*
- *beam spot uniform on 3×5 cm*



4 RPCs
60 x 60 cm^2

Calorimeter: lead glass block from OPAL, PMT a Hamamatsu R2238.

Good overlap between 4 scales with the maximum density of the showers spanning over three decades



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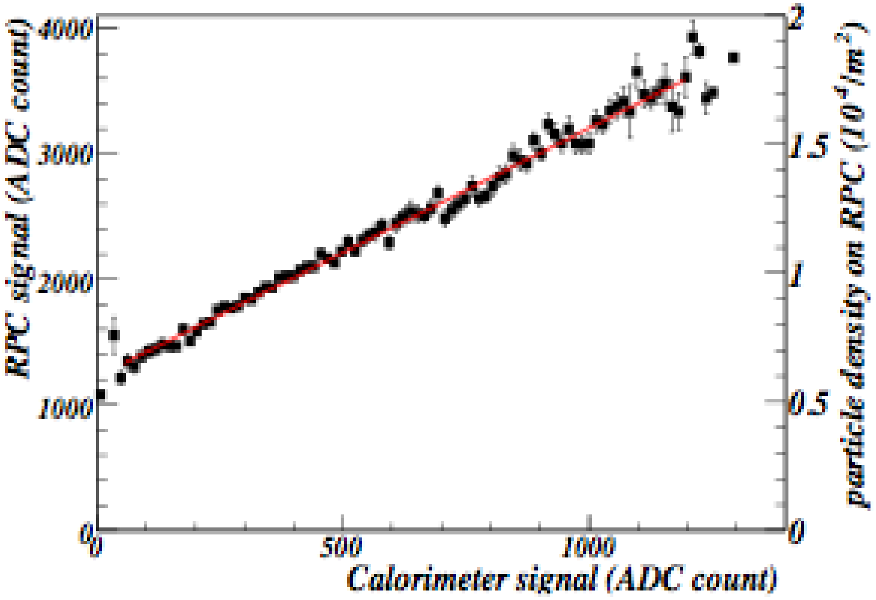
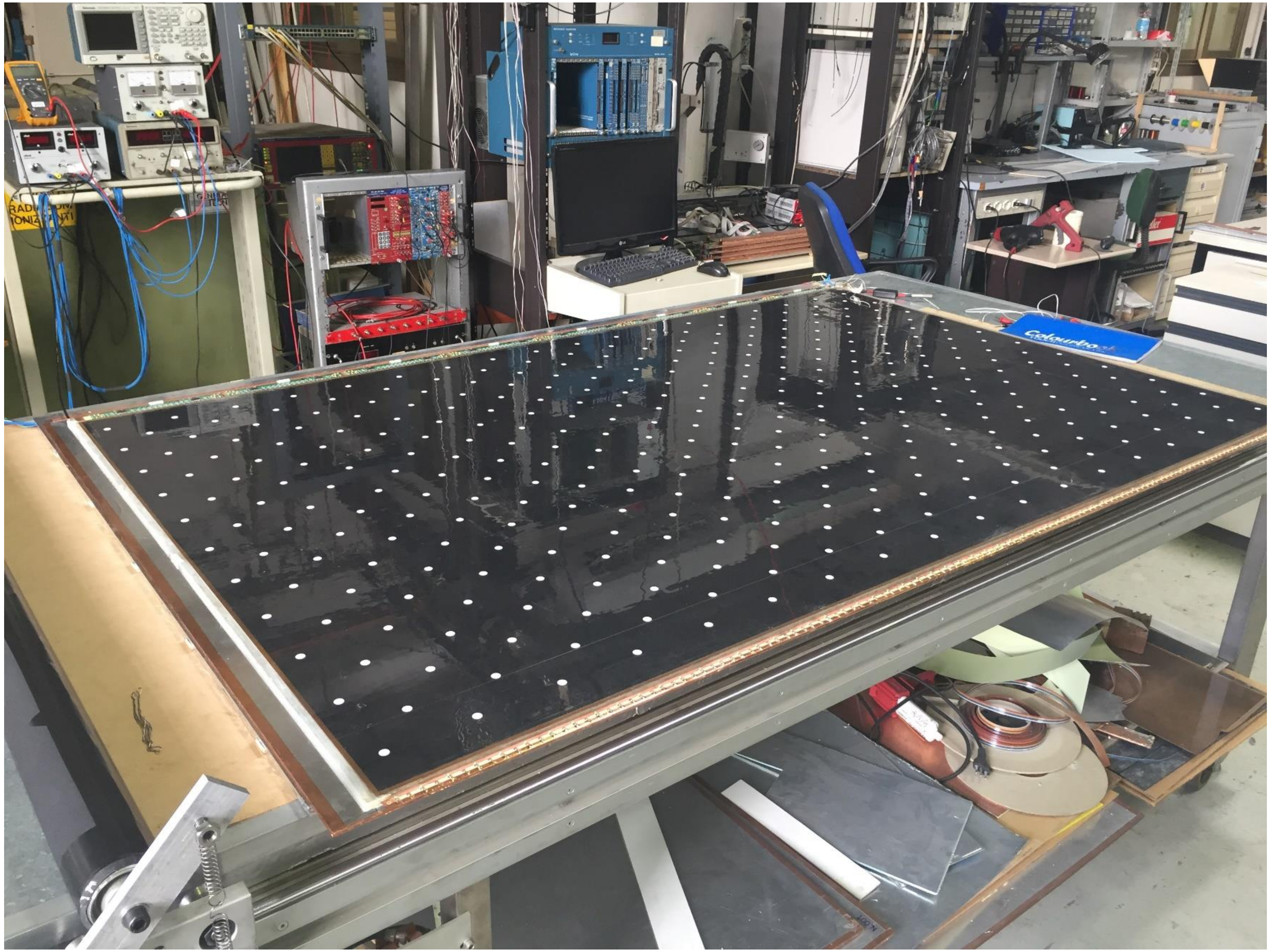
The RPC signal vs the calorimeter signal

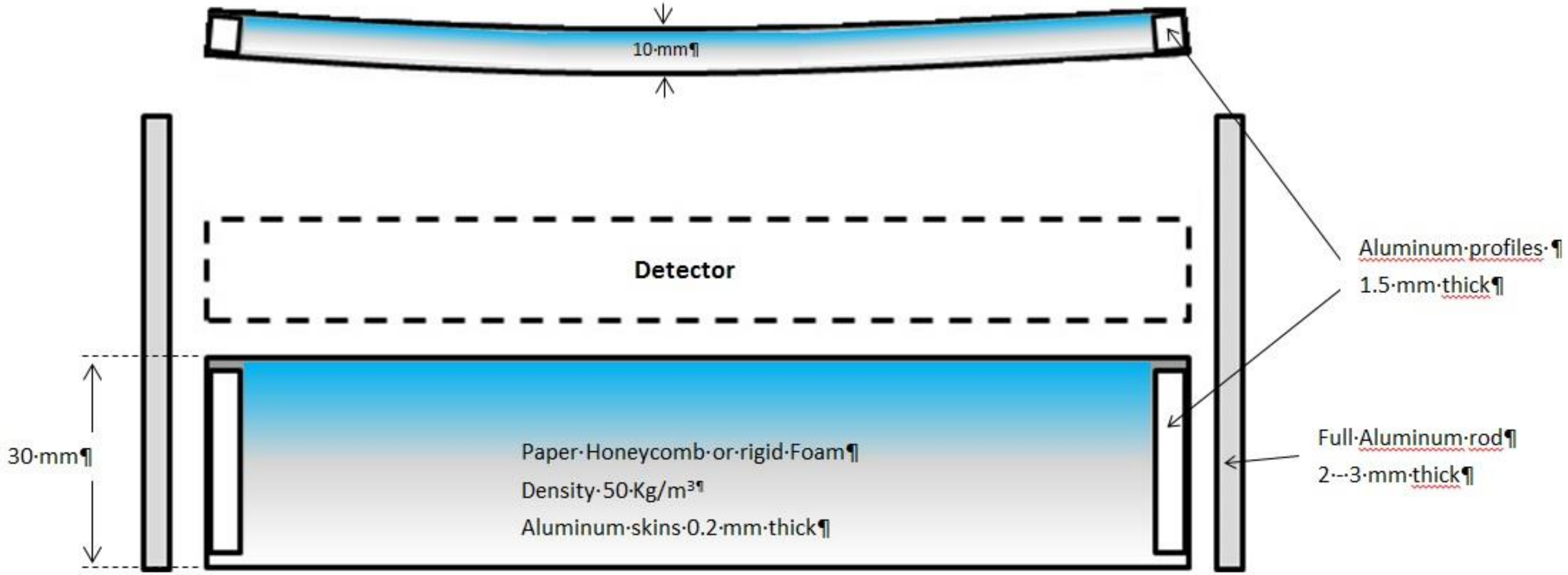


➔ Linearity up to ≈ 2 · 10^4 particle/m^2

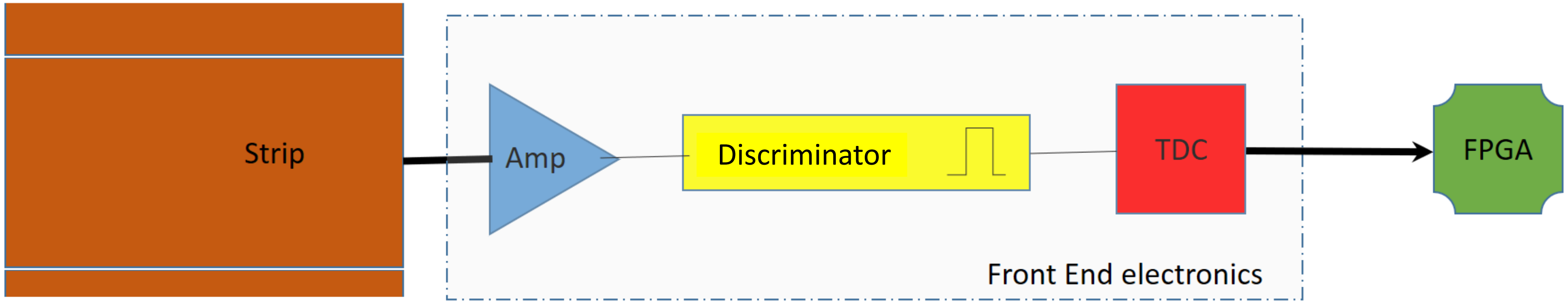
A BIS 7 gas volume (almost) final prototype



The mechanical support



Front-End electronics (in development)



The fist two stages, amplifier and discriminator, have been already developed as the front end electronics of the Atlas BIS 7/8 chambers, to be installed during the next long shut down. The third stage TDC is still under development and will be integrated in the front end electronics in the next future

Front-End electronics - Amplifier

- A new Amplifier made in Silicon Bipolar Junction Transistor technology
- It is a fast charge integrator with the possibility to match the input impedance to a transmission line
- Performance table of the silicon BJT amplifier

Voltage supply	$3-5\ Volt$
Sensitivity	$2-4\ mV/fC$
Noise (detector independent)	$10^{3}\ e^{-}\ RMS$
Input impedance	$50-100\ Ohm$
Power consumption	$10\ mW/ch$
Radiation hardness	$1\ Mrad, 10^{13} n\ cm^{-2}$

The new Front-End electronics - Discriminator

- ➢ Full-custom Discriminator developed in Silicon-Germanium HJT technology
- ➢ Main features:

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

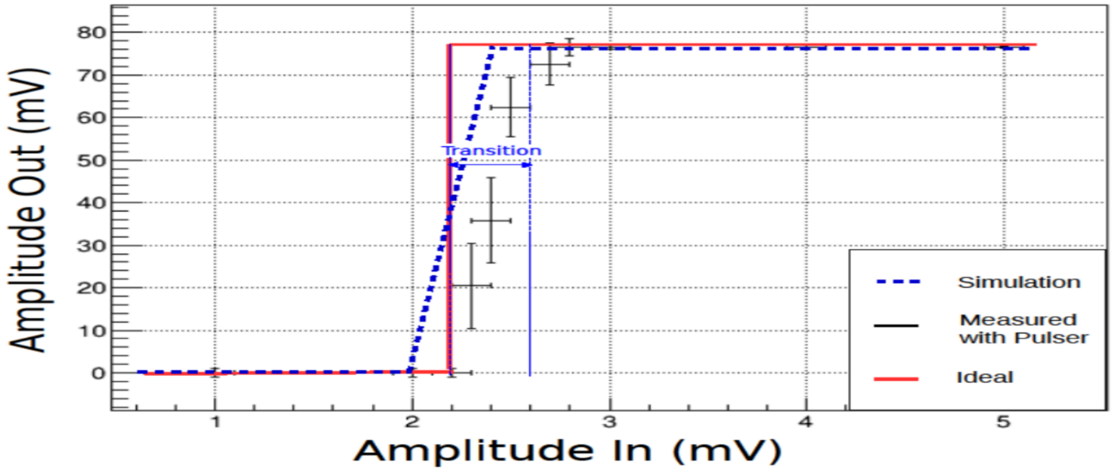


Figure 4: Characteristic function of the discriminator in Si-Ge HJT technology

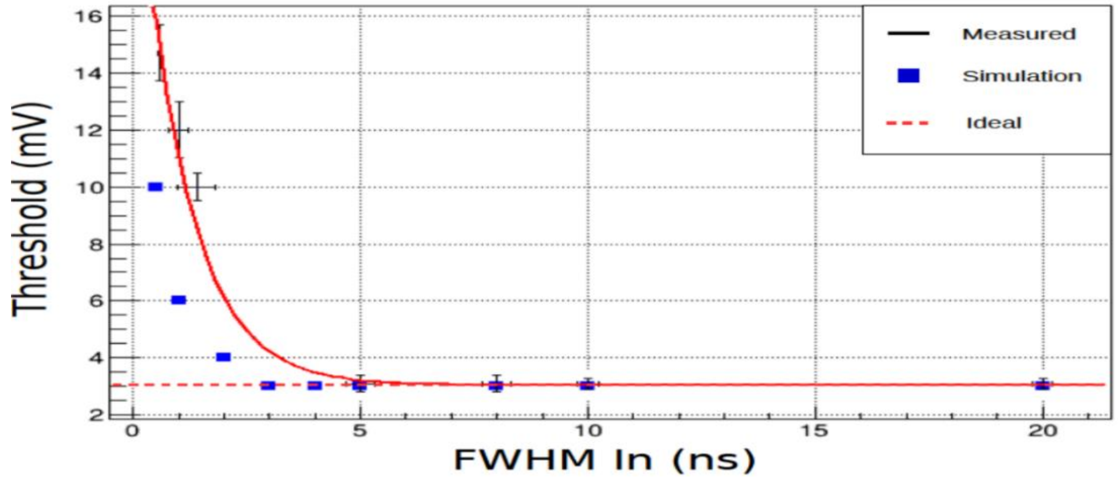


Figure 6: Minimum pulse width of the new Si-Ge prototype with the simulated and the ideal behavior of a discriminator compared

Front-End electronics - TDC

- It consists of four functional blocks: an internal oscillator (VCO), a counter, a memory and a serializer
- The TDC logic is designed to work both on the rising and falling edge of the event
- Expected time resolution 100 ps
- To be integrated in the front end circuit in the next future

Front end electronics – present situation

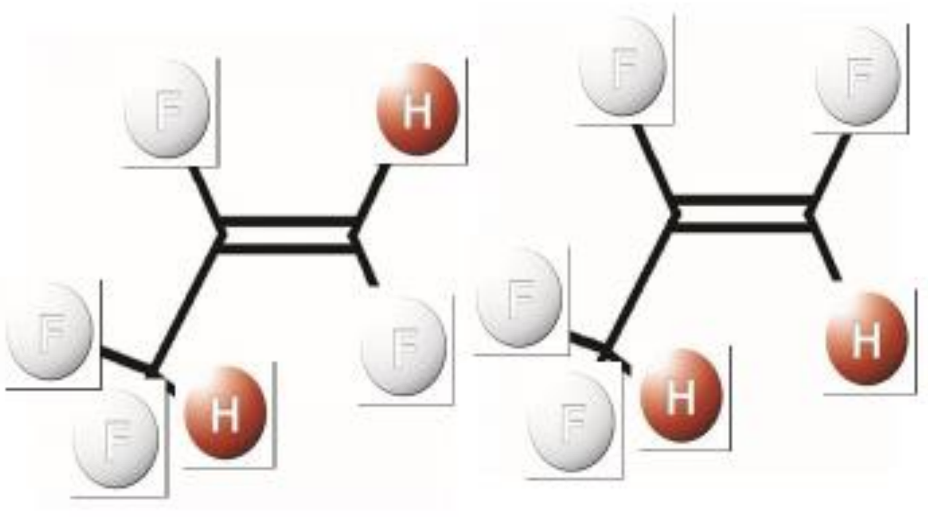
- The first two stages shown before, amplifier and discriminator, have been already integrated in the front end circuit that is going to be used in the Atlas BIS 7/8 chambers to be installed during the long shut down
- Full custom circuit produced by Europractice and delivered as a "non encapsulated" circuit. It has to be bonded on the printed circuit board by the industry responsible for the assembly of the front end boards
- Prototype 8-channel boards have been already produced for the Atlas BIS 7/8 project (see fig 2) and are presently under test
- The front end intrinsic time resolution $\sigma_{D,t} \approx 100\ ps$ → determines the a position accuracy $\sigma_y = v\frac{\sigma_{D,t}}{\sqrt{2}} \approx 14\ mm$ in the longitudinal direction, assuming $v \approx 0.2\ m/ns$

Search of a new eco-friendly RPC gas for Mathusla

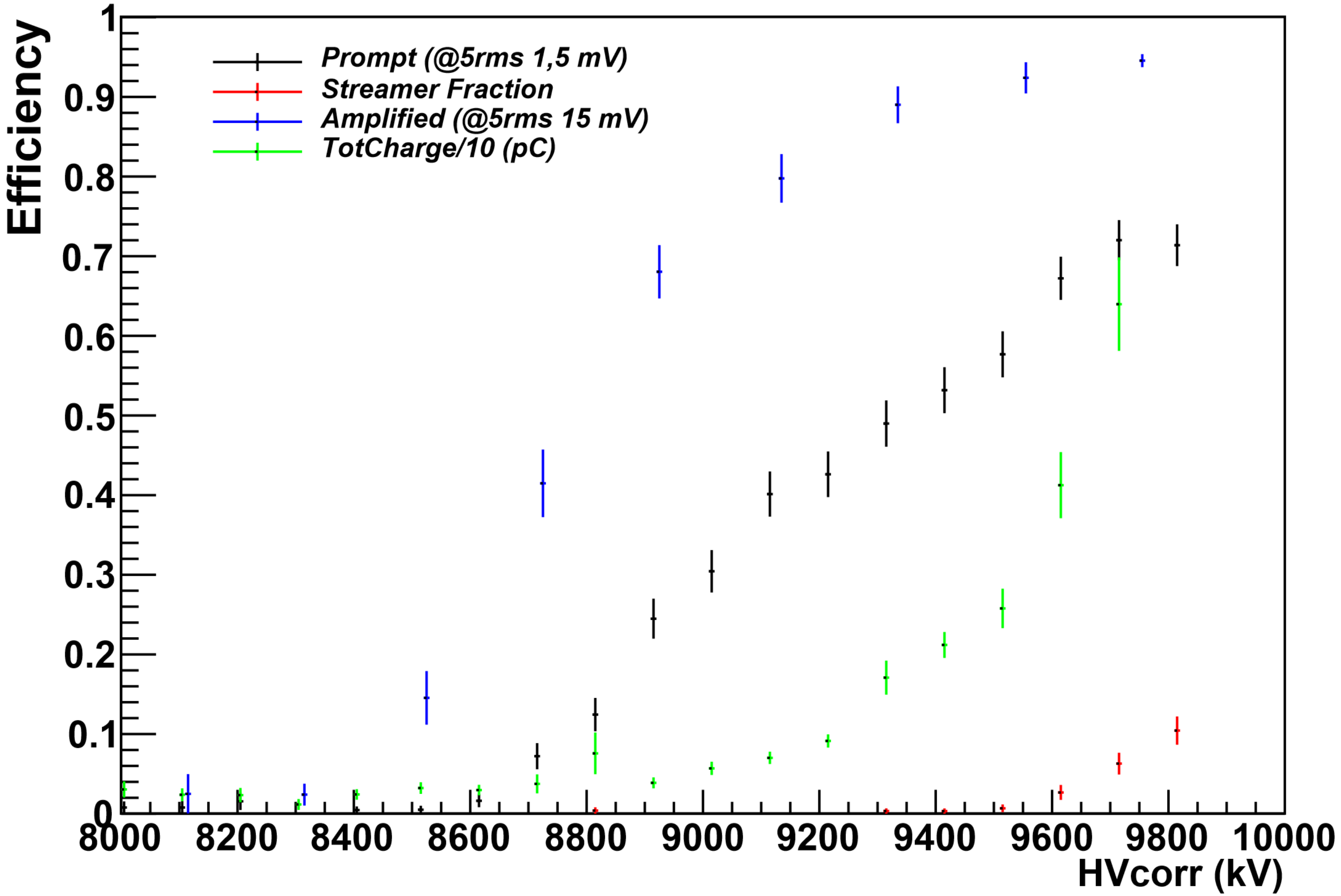
- Presently used gas mixtures are mainly based on the Tetra-Fluorine-Ethane, $C_2H_2F_4$ molecule, commercially known as Suva134a,
- The high Global Warming Power (GWP=1540) of this molecule demands for a new, RPC suitable, industrial gas
- A new gaseous component, the $C_3H_2F_4$ molecule (Tetra-Fluorine-Ethilene), with a GWP close to unity, is under study and relevant data are available
- The main problem of this gas, with for the chambers presently working in Atlas and CMS, is a substantial increase of the operating voltage. Mixtures with CO_2 have lower operating voltages but are not completely free from streamers at full efficiency
- For new chambers, with thinner gaps and the new front end electronics, the streamerless avalanche mode operation has been achieved at reasonable voltages with almost pure $C_3H_2F_4$

The RPC gas

The new molecule

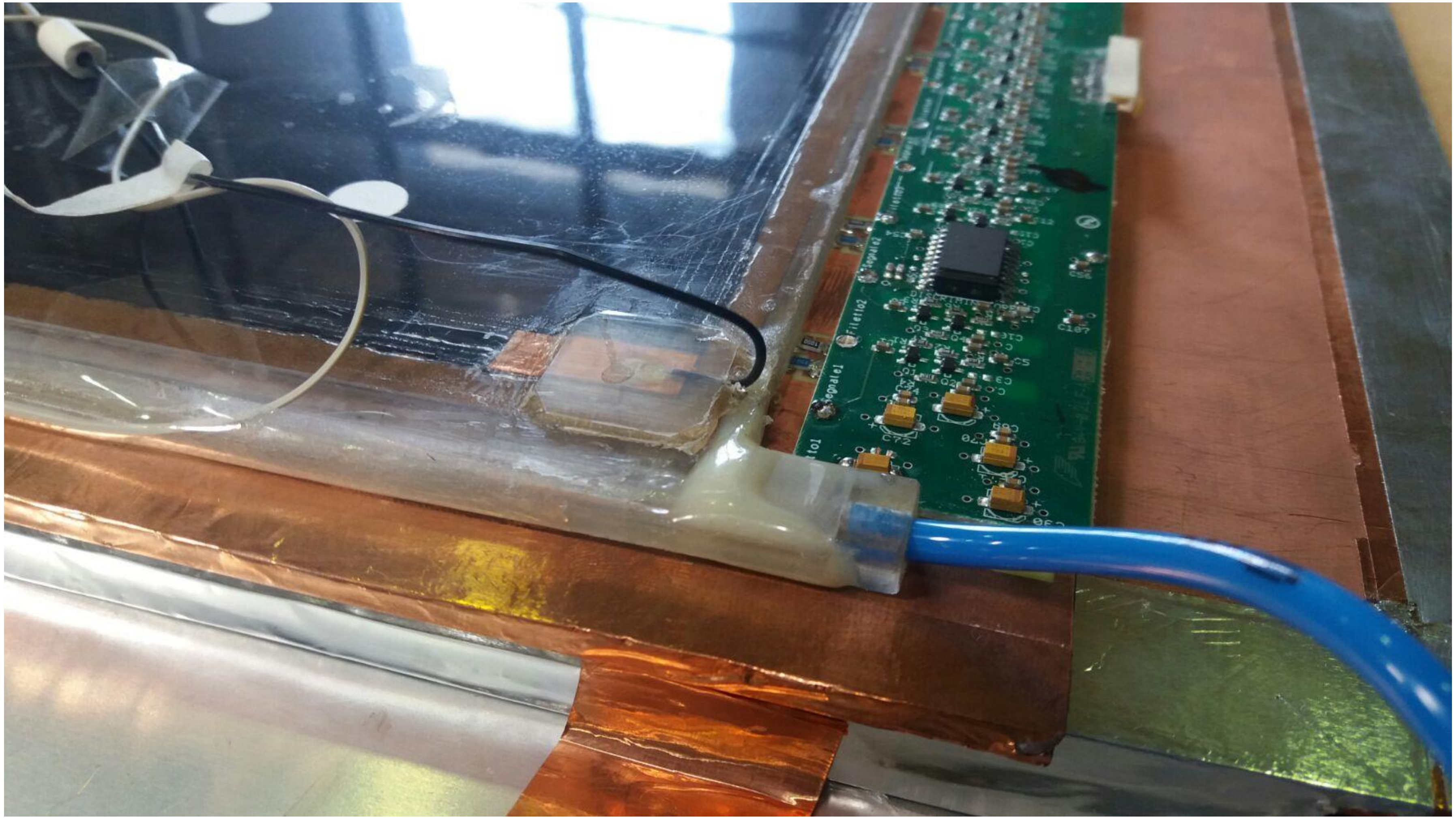


Performance of 1 mm gap with pure HFO

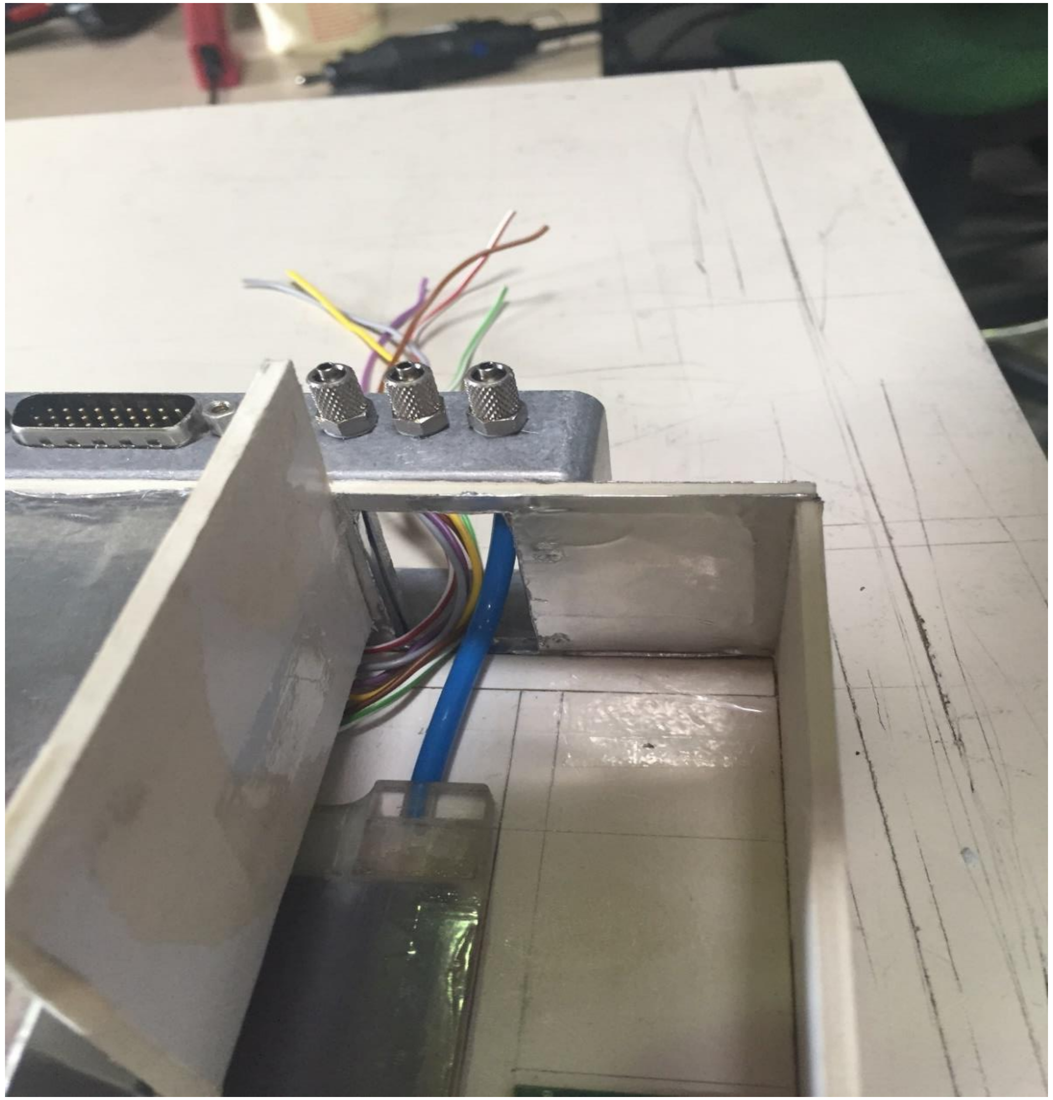


The gas pipe is inserted inside the gas gap

gas distribution channel visible in this BIS7 prototype (not needed in Mathusla)



Details of the gas connections



- The gas pipes, embodied in the cambers, are only a few centimeter long
- One end of each pipe is inserted in the gas gap
- The other end is connected to a professional, metallic gas connector
- This system is much more robust than the one of the existing Atlas RPCs

Cost evaluation…a difficult exercise

- gap material cost is **70 E/m2**

  This is a preliminary industrial quotation

- Gap construction including all materials (PET, spacers, graphite…) except the electrodes: 350 E /gap = **140 E/m2**

  Commercial offer

- Strip panels: **53 E/m2**

Commercial offer

- Mechanical support structure (in contact with the detector): needs to be evaluated on the basis of an engineering project

Front end electronics cost evaluation

- Strip size hypothesis (25 mm pitch, 3.2 m length) with FE at both ends of the → 25 FE channels/m^2 .
- Cost evaluation
  - Full custom production mask **200 kE**
  - Die production: 4 kE per wafer of 10 inch diam
  - Assuming 200 cm^2 useful area/wafer and 2 mm^2 per 8 channel chip → 80 000 channels/wafer → **0.05 E/ch**
  - DC test 0.5 E/die → **0.06 E/ch**
  - 8 channel printed board with all components and bonding **3.1 E/ch**

    recent offer for 2000 boards offer (could be substantially lower)
- Assuming **3.5 E/Ch** (rough evaluation) →

→ Front End electronics **88 E/m2**

Further costs

- This preliminary evaluation still do not include
  - Out of chamber electronics and DAQ
  - Power system
  - Gas system
  - Manpower to mount the front end boards on the strip panels
  - ….???
- A further relevant (in my opinion) cost is due to the overall mechanical structure needed to keep the detector suspended 20 m above the floor
- How much the detector weight impacts on the mechanical structure cost? Overall optimization needed

Industrial production strategies

- The RPCs can count now on several production sites in addition to the ones available in Europe: Korea (Kodel), China…→ a good condition for a large scale production
- The Mathusla 100 sensitive area is about twice the area of: Atlas+CMS+Argo+Opera all together → an ideal condition for innovative ideas and investments in new production facilities
- But…the multiplication of identical production facilities, one per production site, would be a waste of resources
- A good industrial approach is to have different production sites, each one specialized in a different item: strip panels, FE boards, gas gaps, mechanical supports… Each of these items will be shipped to CERN where the final assembly and test of the chambers will be performed

Conclusions

- The RPC detector is a very reliable choice for Mathusla
- A dedicated optimization of the detector is needed but there are good ideas on how to do that
- A challenging project for the RPC community !!!