ILD muon system

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On behalf of the ILD collaboration

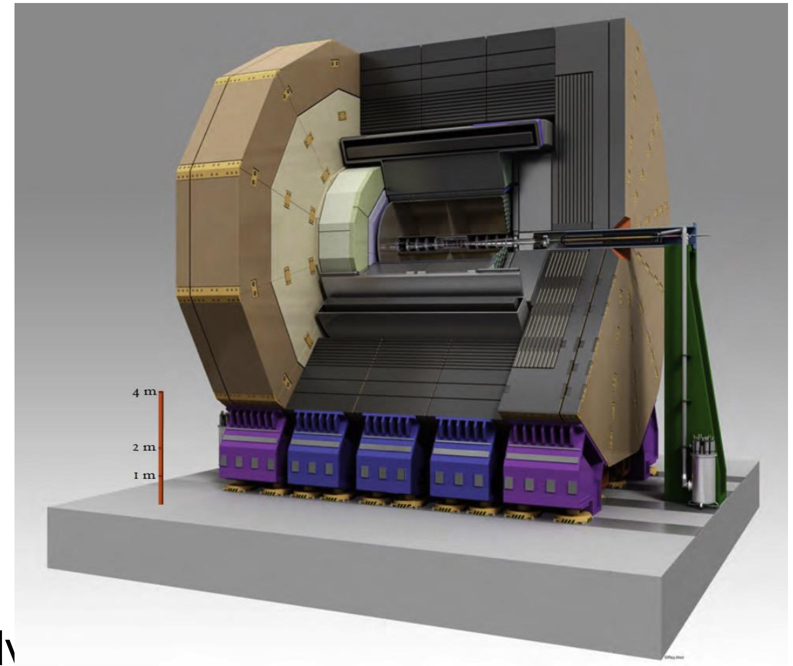
Disclaimer:

In this presentation I report a study that was performed a few years ago on the role of muon system in ILD concept. The work was led by V. Saveliev (National Research Nuclear University, Russia). All the merit is his and that of the colleagues who contributed to.

I dd my grain of salt by mentioning the work we did within ILD to develop RPC and MRPC that can be excellent candidates, but not the only ones, to equip the muon system

Muon system in ILD

It was conceived to fulfil a few goals



- Identification of muons/punch-crossing hadrons

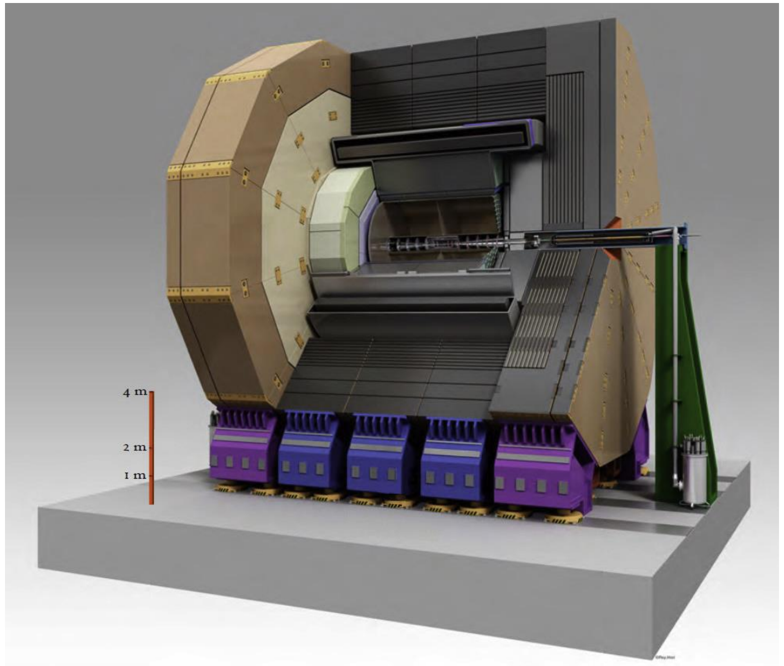
- Tracking for PFA. The momentum precision is provided by inner tracker (VTX, Si, TPC)

- Tail catcher for HCAL: showers that are not fully contained (6 λ_I) could be better reconstructed and their energy better estimated thanks to the information they leave in the muon system.

- Long Lived Particle. Muon system could contribute to their discovery/study

- Trigger: This function was absent in the ILD@ILC but for FCCee it needs to be considered

Muon system in ILD



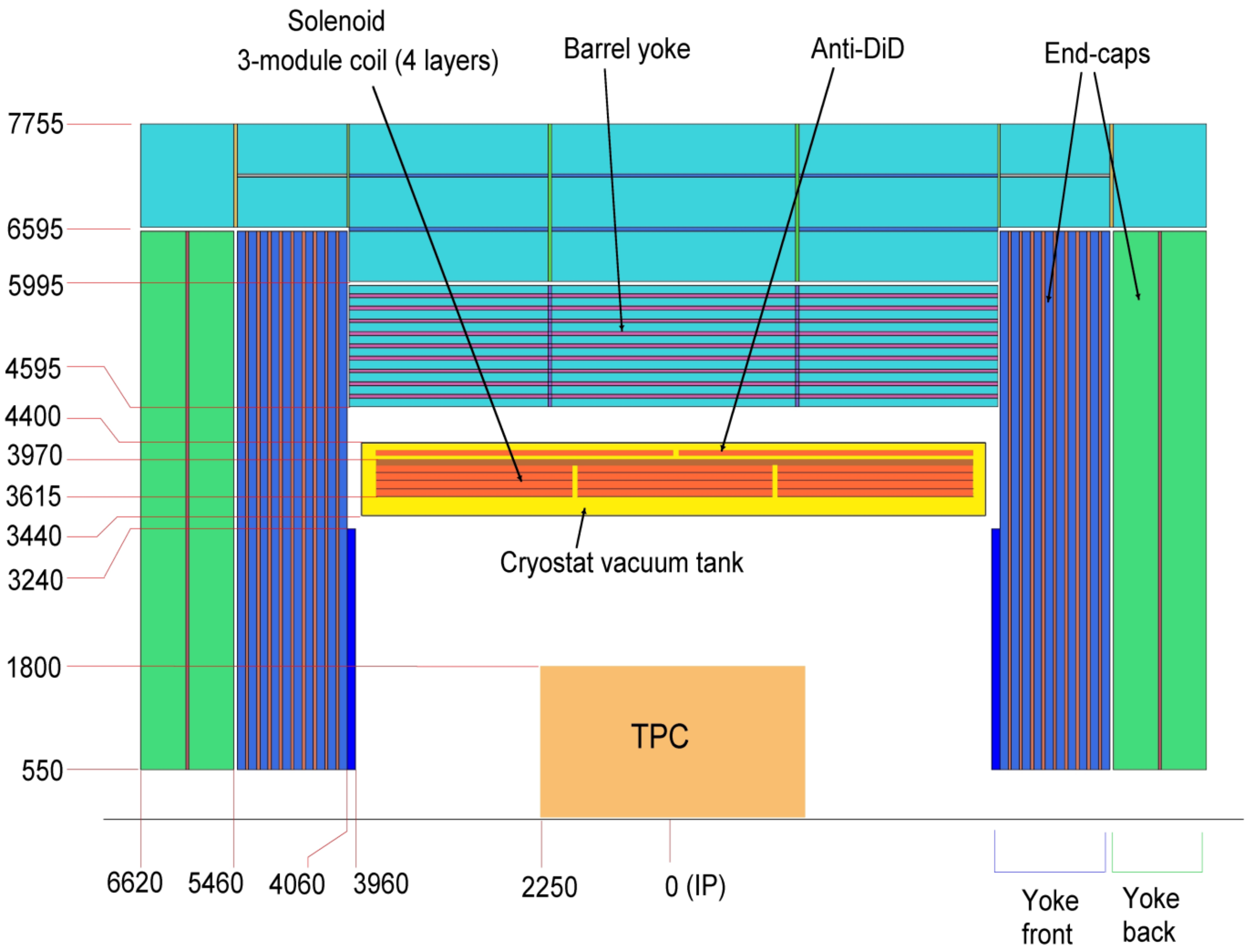
Several questions were on the table for the muon detectors

1- Where to place it

2-Which granularity

3-Which technologies

Muon system @ ILD



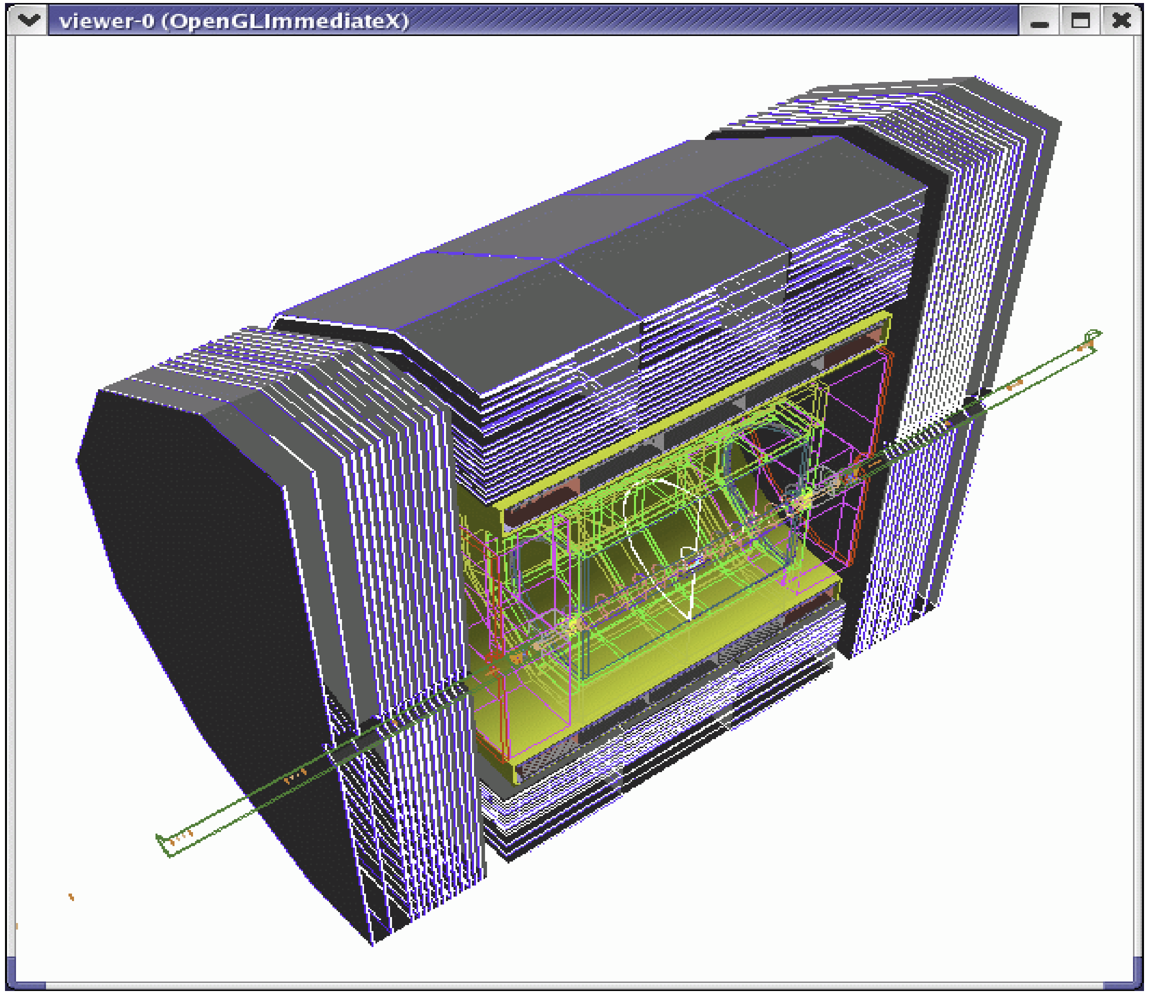
Yoke:
- Barrel: 10x100 +3x560 mm
- EndCup: 10x100 +2x560 mm

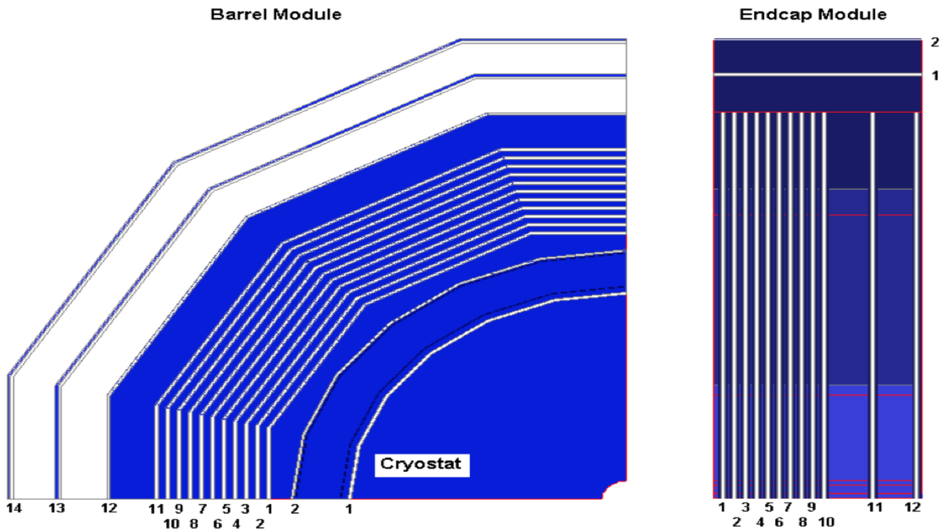
Cryostat:
- Cylinder with 40 mm thick inner wall
  and 30 mm thick outer wall
- 750 mm distance between walls

- **Coil:**
- 3x1650à mm + 2x1200 mm

Muon Detector System:
- Double Sensitive Layers in the Yoke Gaps

Muon system @ ILD



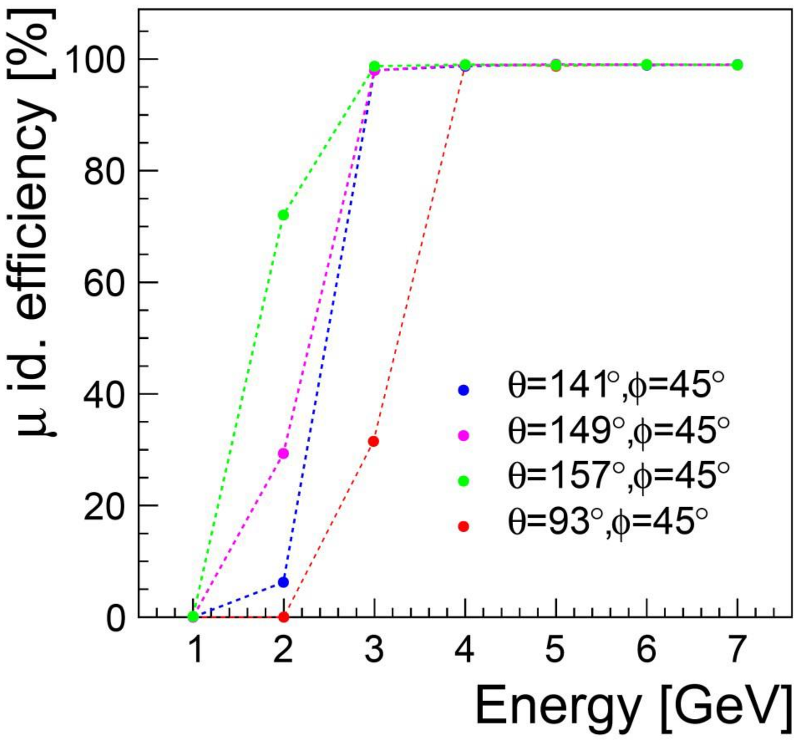


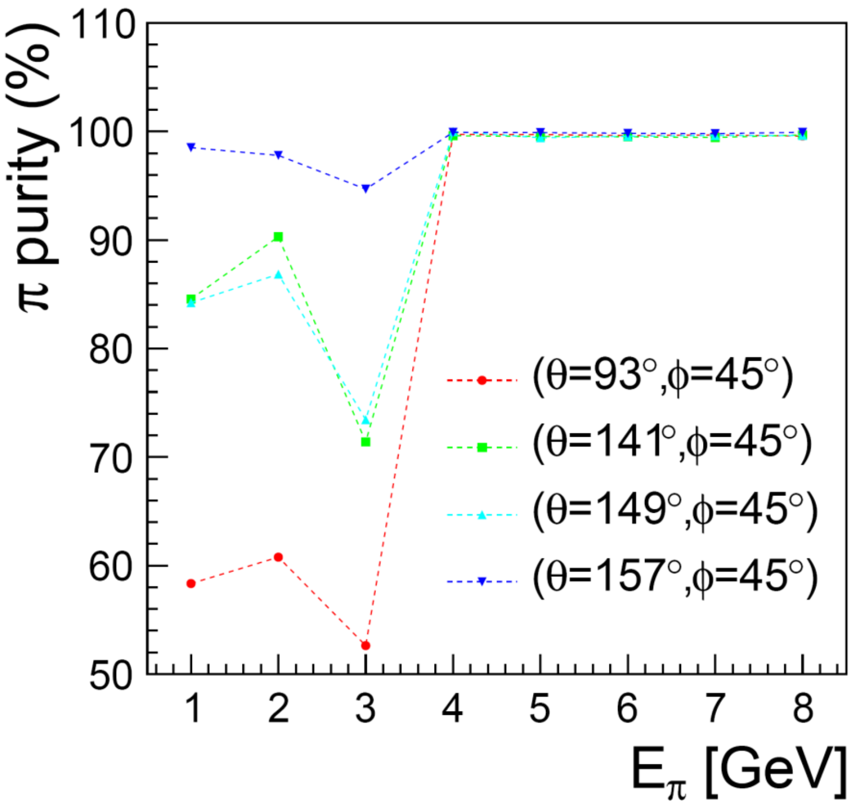
- 14 (12) active layer for the barrel (endcap) region, interleaved with iron slabs of return yoke.
- scintillator strips read out by SiPM through WLS or RPC (X&Y)

The simulation was made with Scint of 3 cm width

Muon system impact

Excellent pion/muon separation at energies > 4 GeV

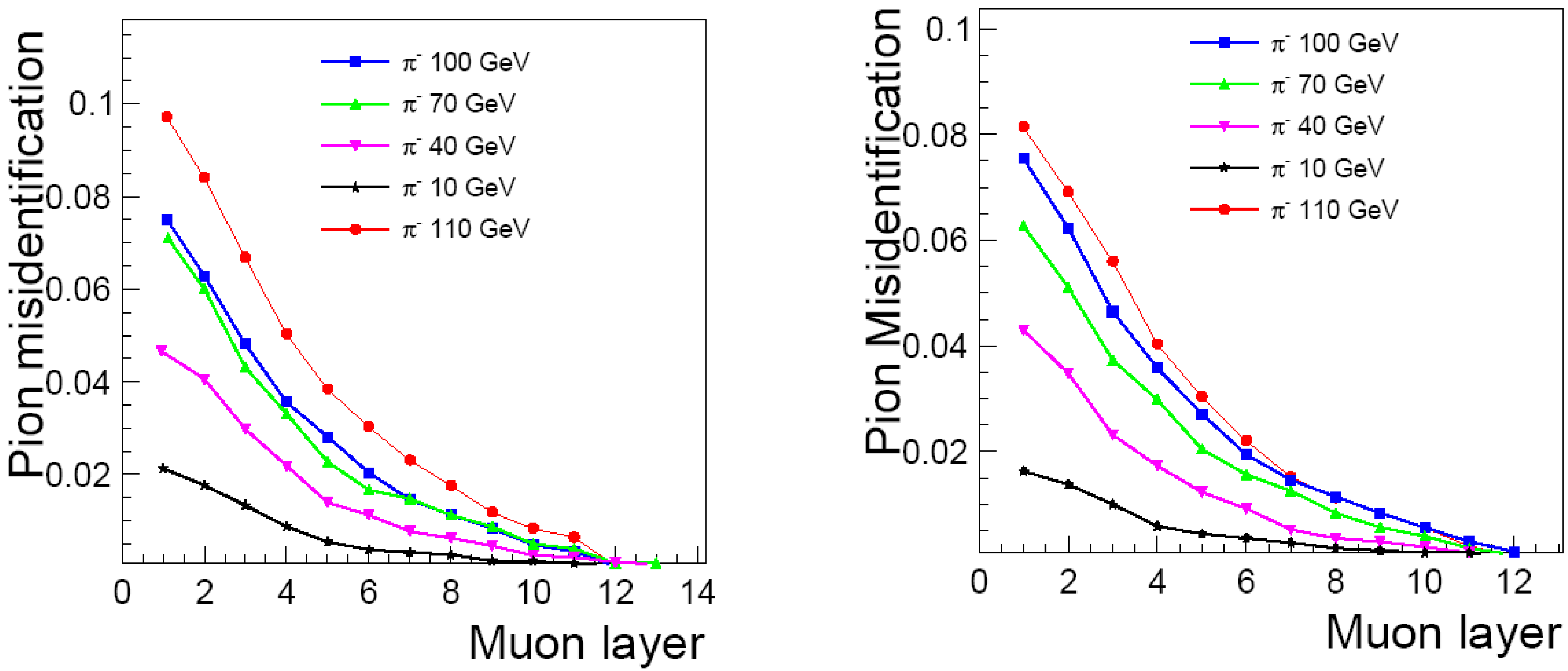




- Effect of the coil material for soft muons: the μ-id based only on the muon system is weak for energy lower than 4 GeV.
- $\pi \rightarrow \mu + \nu$ can be misidentified as muon. Granularity could be helpful

Muon system impact

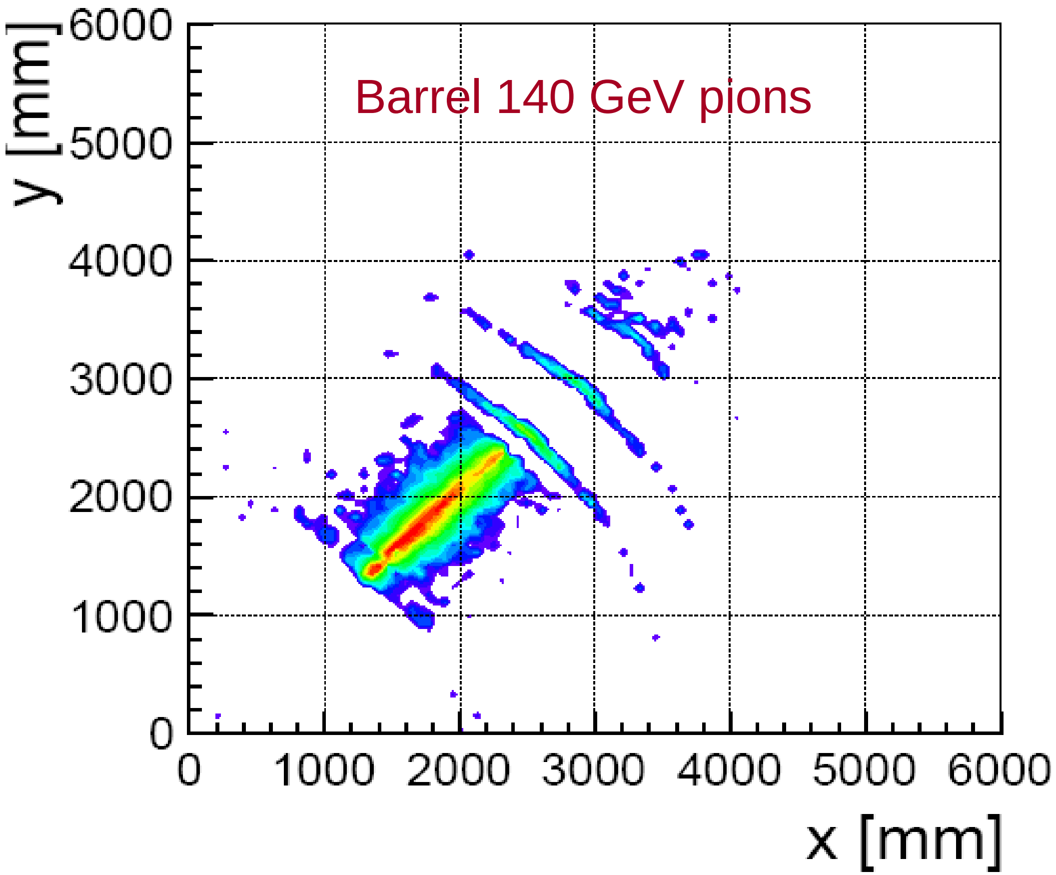
The pion misidentification as a function of the number of instrumented layers



Pion misidentification

Muon system impact

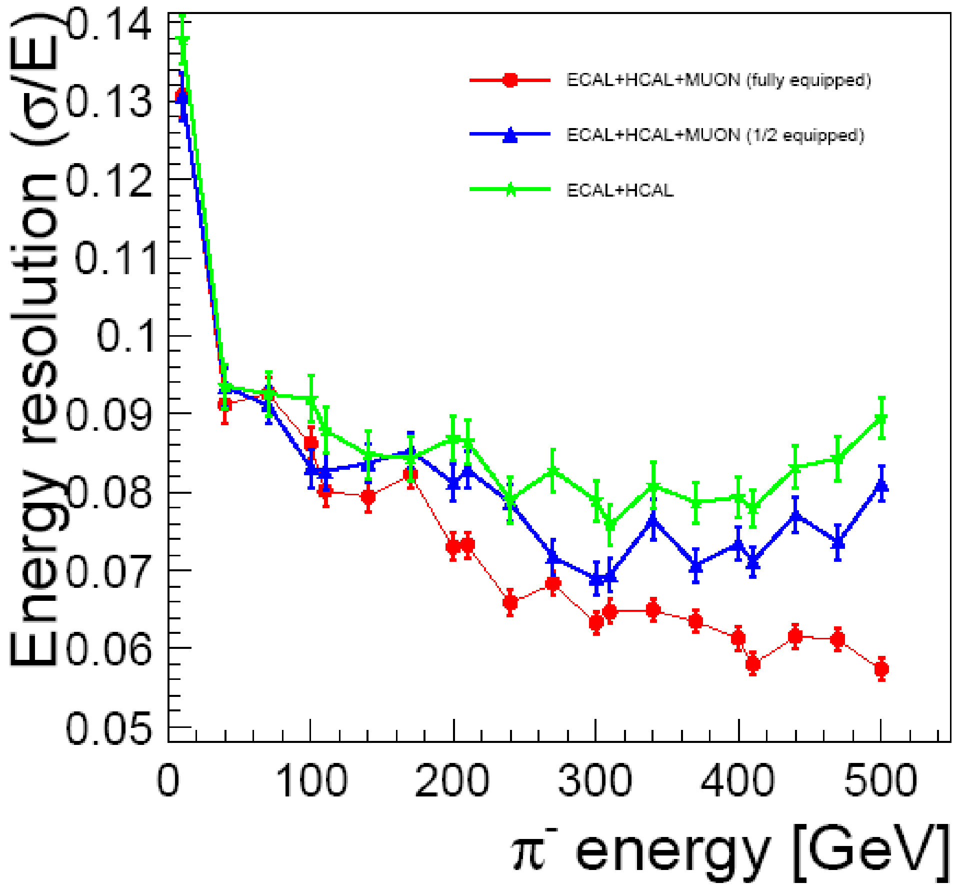
Tail catcher role



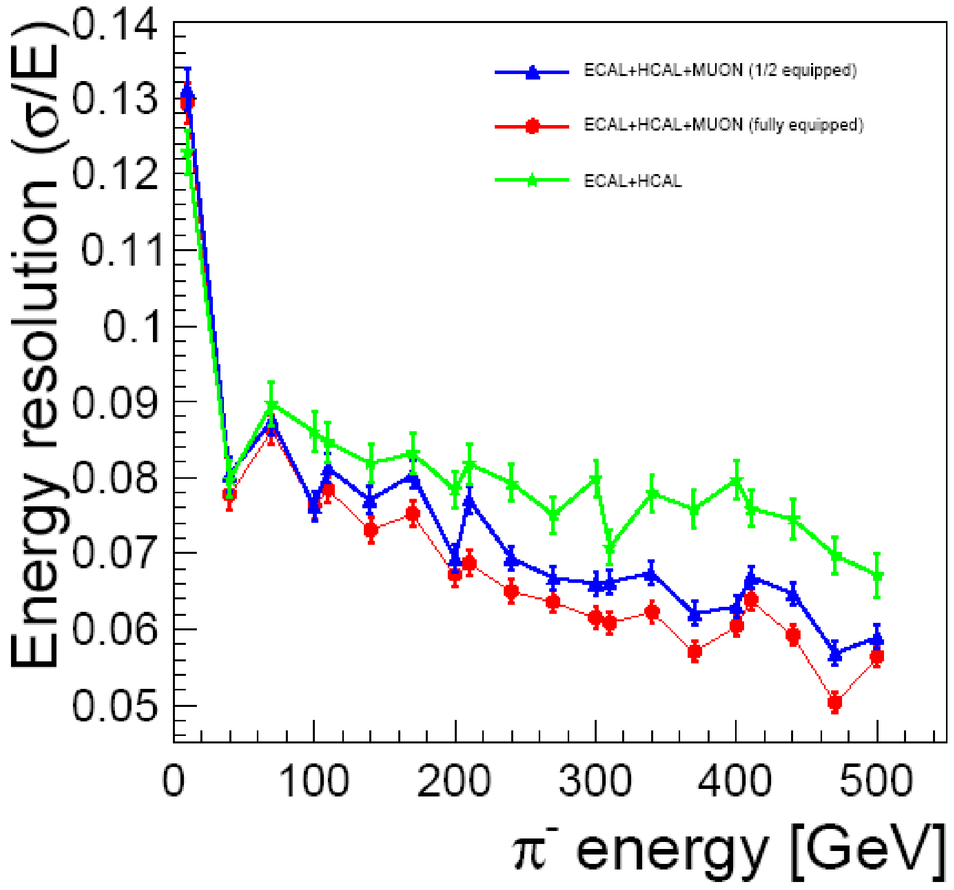
Having good granularity of the muon system could help to reconstruct the tail shape and then improve on energy reconstruction using MVT

Muon system impact

Tail catcher role



Barrel

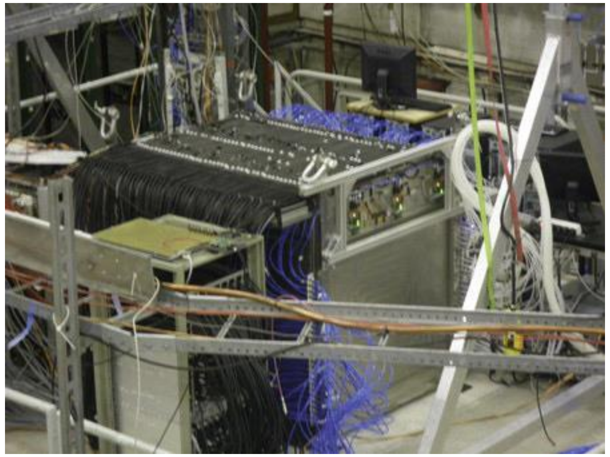


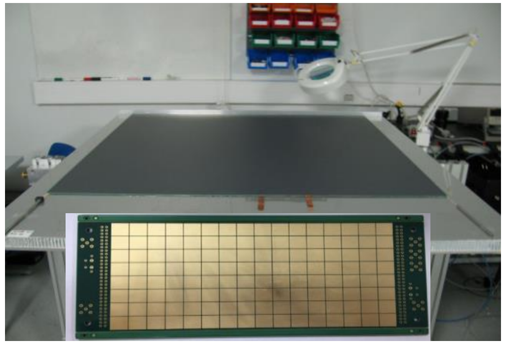
EndCup

Which technology?

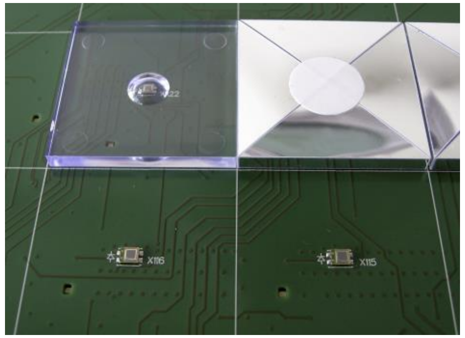
Two HCAL technologies are proposed for ILD

(T)-SDHCAL based on (M)RPC of 1 cm x 1cm





AHCAL based on scintillating tiles of 3 cm x 3 cm



The active medium of each can be used as a muon detector

The readout needs not to be as granular as the HCAL for the muon system

Nevertheless all other technologies could be proposed for ILD muon system

Scintillators

Advantages

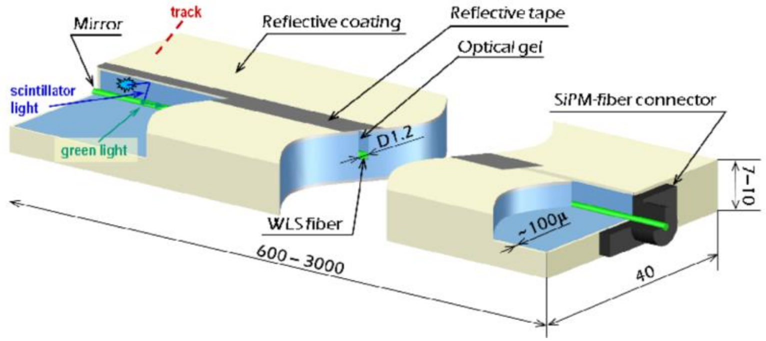
Robustness, efficiency, high rate capability

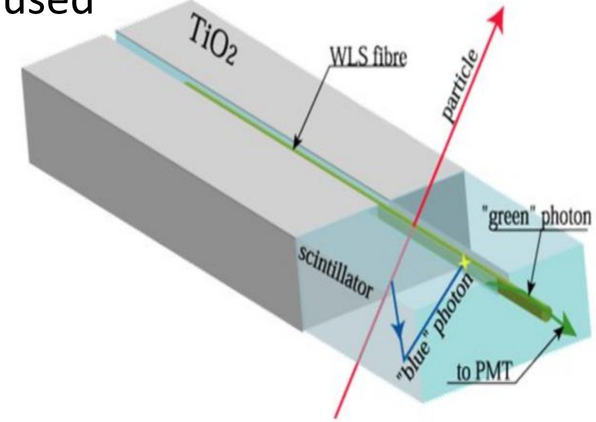
Limitations

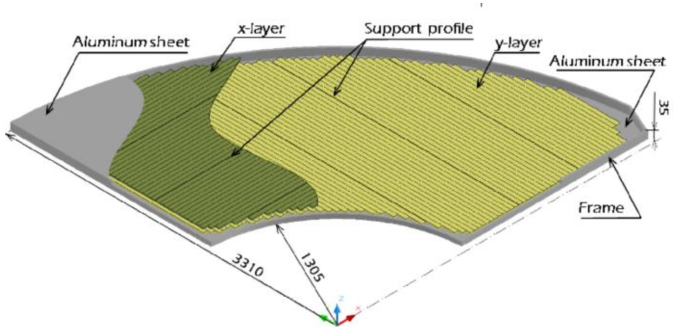
→segmentation, cost, SiPM rather noisy

Scintillators are not very often used as a muon detector in big experiments
They are used essentially as Bars equipped
with WLS and read out by photo-detectors :
MaPMT as in OPERA or SiPM as
intended in Belle2 and SiD.

Tiles proposed for AHCAL could be also used







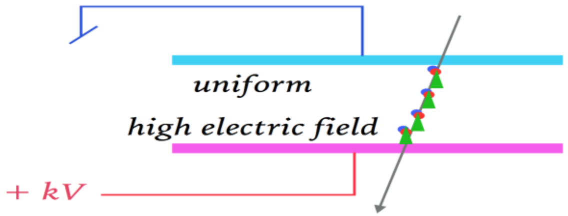
Resistive Plate Chamber

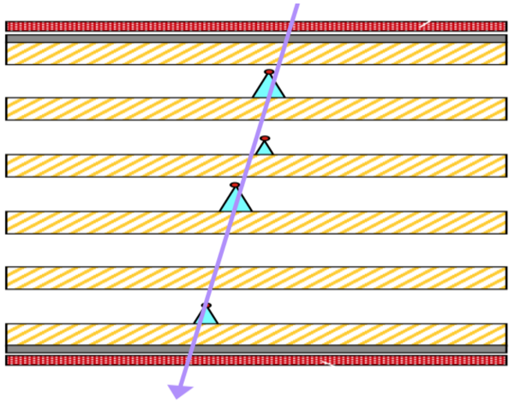
Advantages

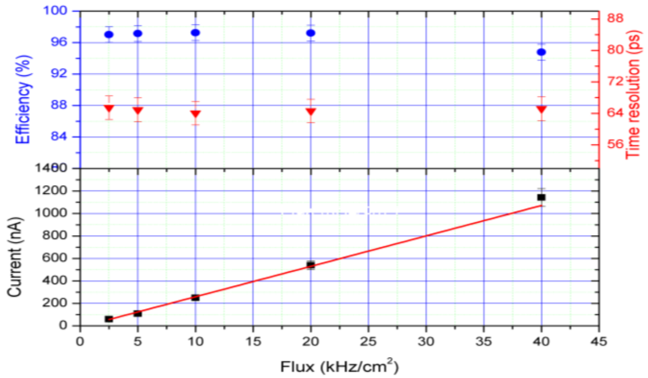
Simplicity, robustness, efficiency, sparks free, fast timing (in particular in MRPC) and cost effectiveness

Limitations

→ Rate detection capability , gas mixtures currently used are not eco-friendly







Two kinds of electrodes have been used up to now

HPL (Bakelite) : L3, BaBar, OPERA, CMS, ATLAS, ALICE, DAYABAY
needs "good" linseed oil treatment and humidity
Glass : Belle, ALICE, STAR

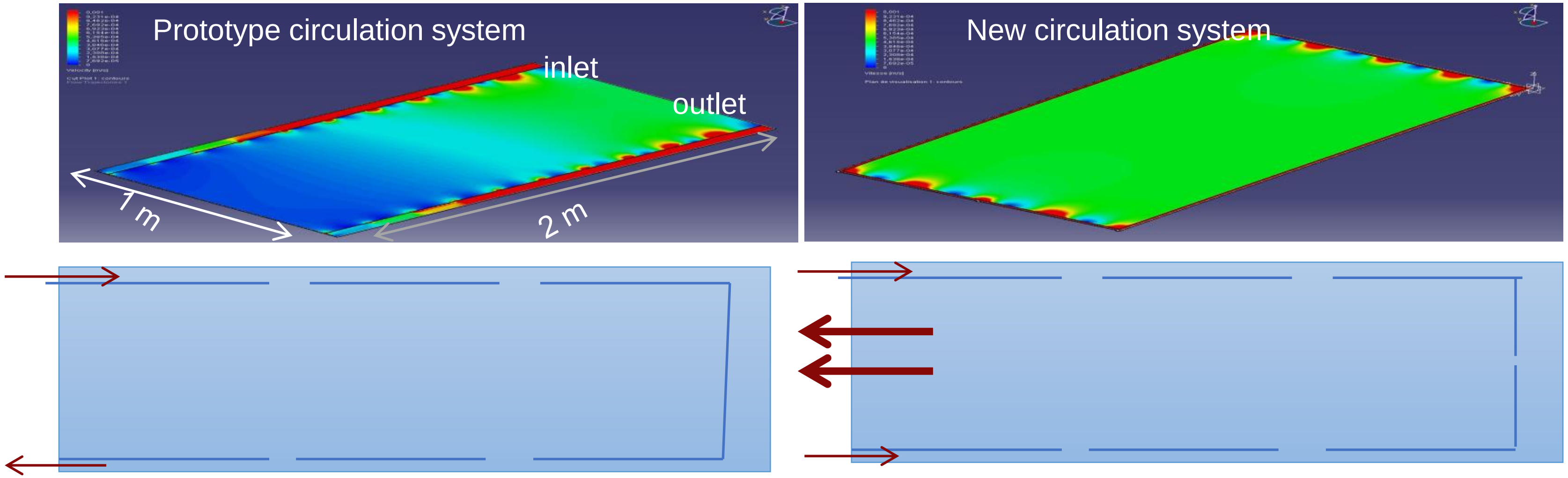
Limited rate capability (unless moderate resistivity electrodes are used or MRPC)

MRPC provides excellent timing and higher rate capabilities (low charge)
High rate capabilities could be obtained using low resistive electrode materials (Tsinghua glass, dopped PEEK, etc)

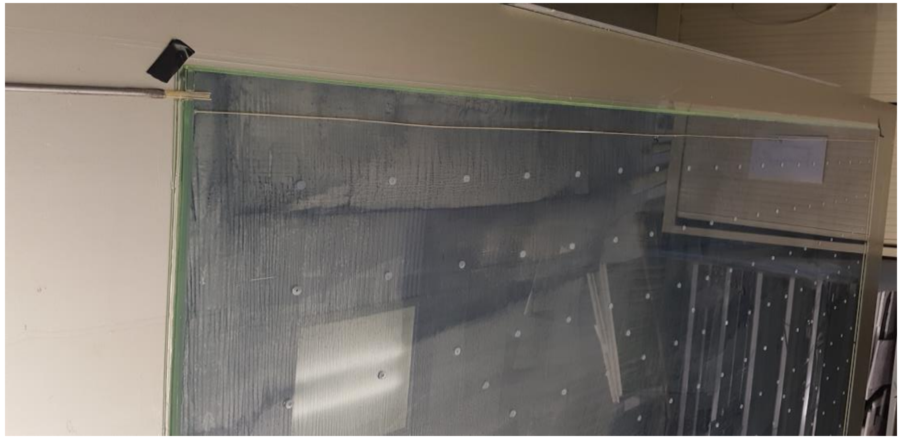
(M)RPC

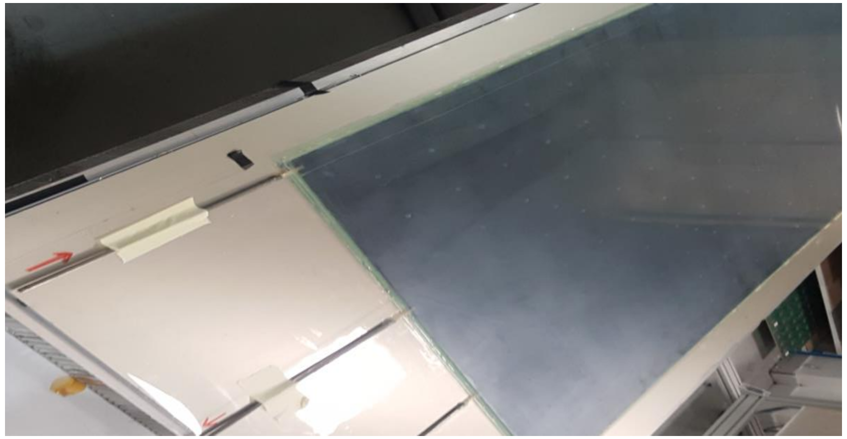
RPC

Construction and operation of efficient and precise large single GRPC is now well known



Cassette conception to ensure good contact between the detector and electronics is still to be improved

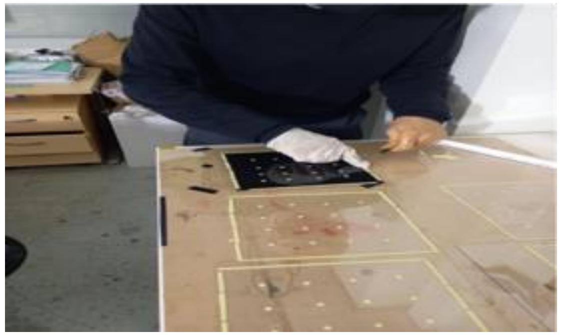


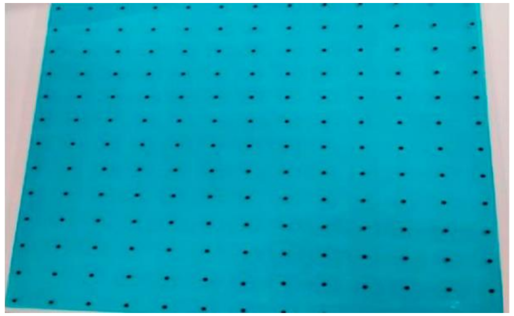


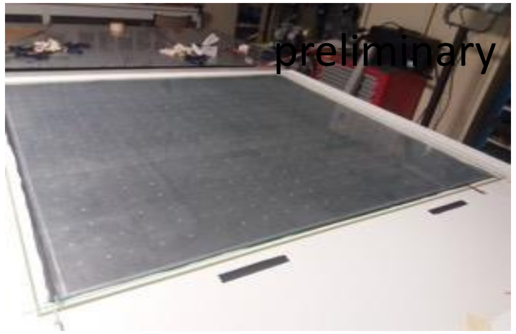
RPC→ MRPC

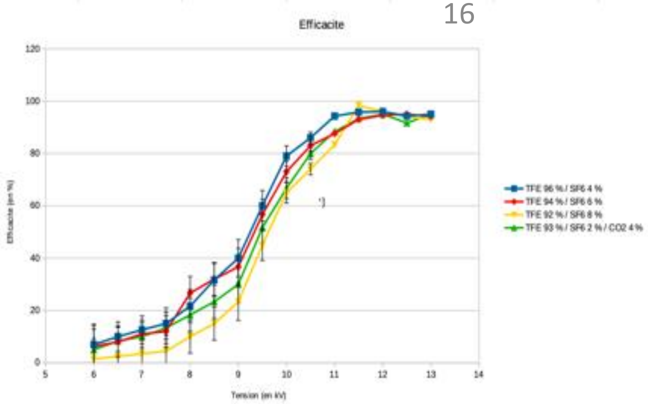
- MRPC provides excellent time resolution (down to 50-70 ps with 2x4 gpas)→ ToF, LLP,….
- MRPC has higher detection rate

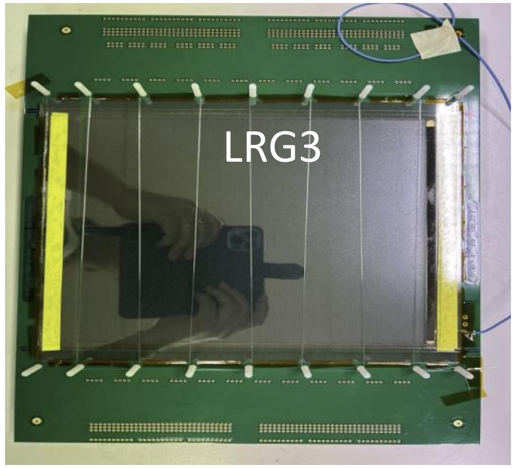
New way of producing MRPC was developed in Lyon→ easy production, cheap detector

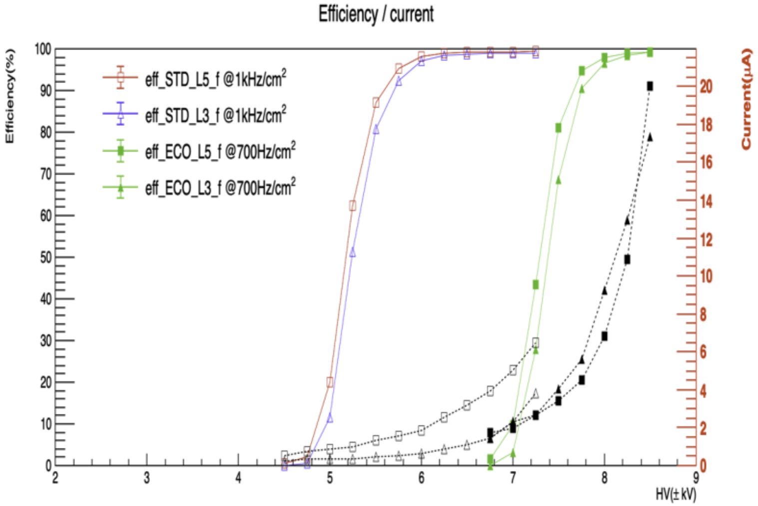










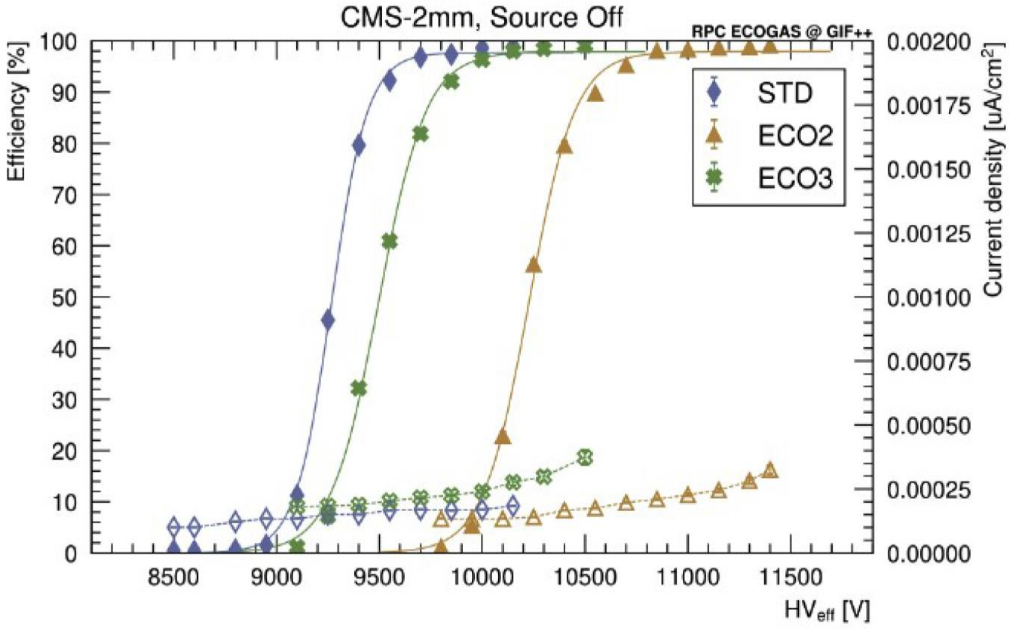


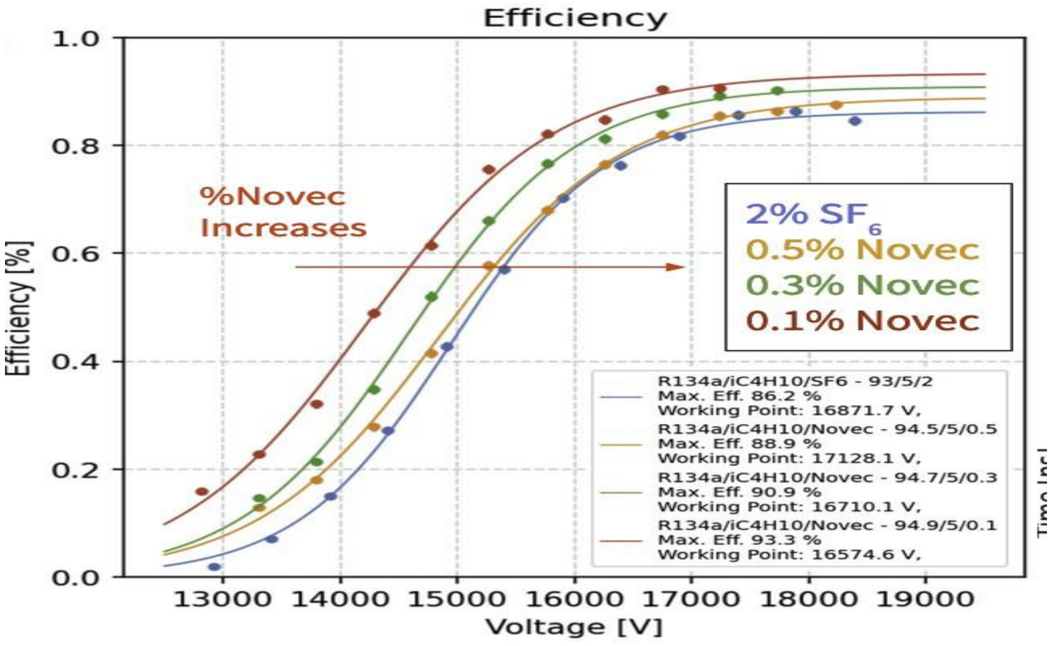
Credit:
Yw. Baek
Js. Kim

Eco-friendly gas mixtures

Mixture	$C_2H_2F_4$ [%]	HFO [%]	CO_2 [%]	iC_4H_{10} [%]	SF_6 [%]	tCO_2e
STD	95.2	0	0	4.5	0.3	3384
ECO3	0	25	69	5	1	762
ECO2	0	35	60	4	1	763

M. Verzeroli

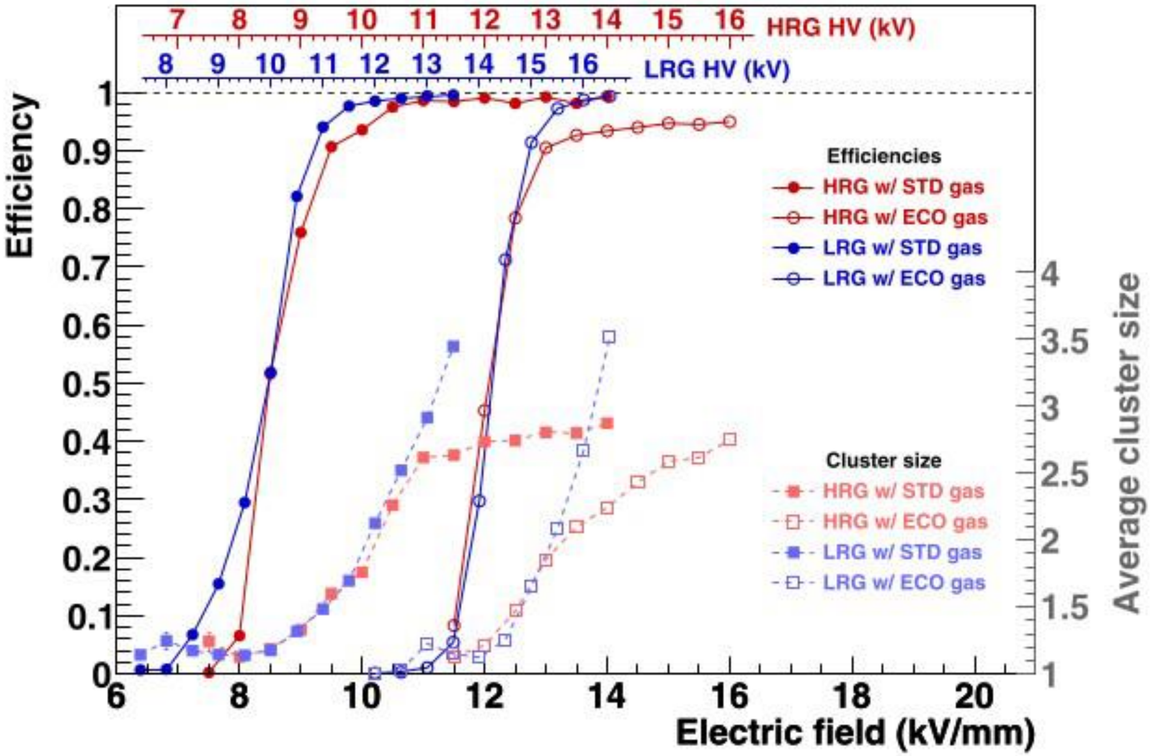




HFO+NOVEC+CO2 to be tested in near future

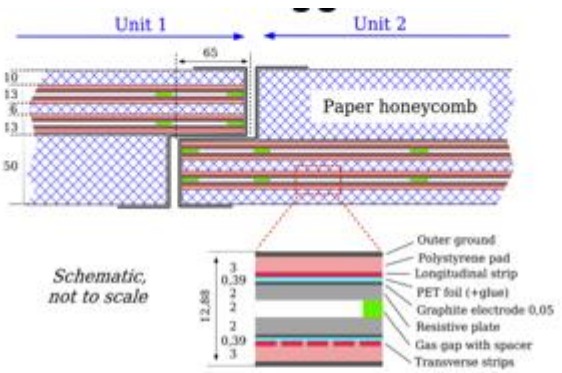
Eco-friendly gas mixtures

MRPC with pure HFO: Nuclear Inst. and Methods in Physics Research, A 1061 (2024) 169104



(M)RPC Readout

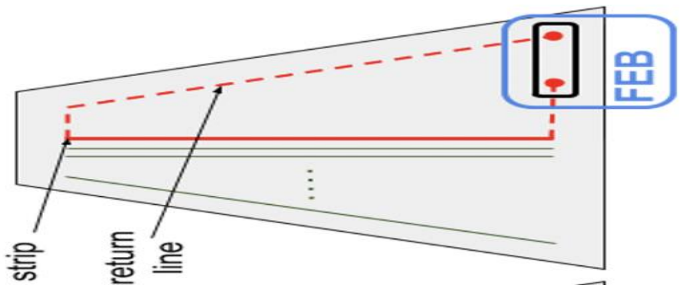
Readout of RPC



There are several ways to read out RPC:

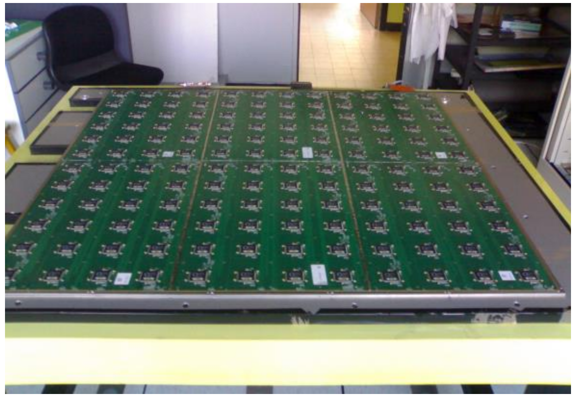
- Using **one-end readout pick-up strips** (either one direction on the anode side as for c CMS RPC or two directions: one on the anode and one on the cathode as for ATLAS)

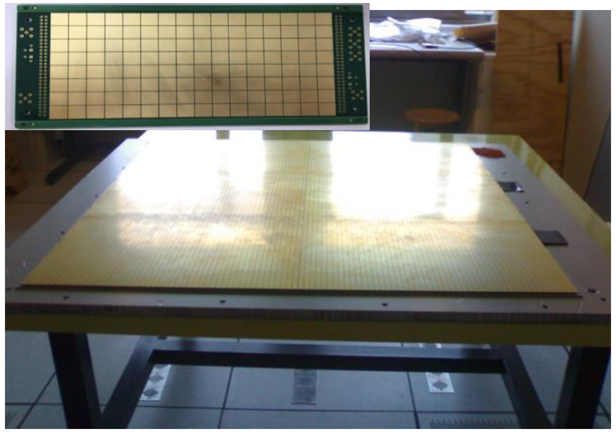
- **two-end readout** using **excellent time measurement** as the one proposed for **CMS iRPC** upgrade project



σ_x :0.4 cm
σ_y : 1.6 cm

- Using **pick-up PADs** as for SDHCAL (CALICE)

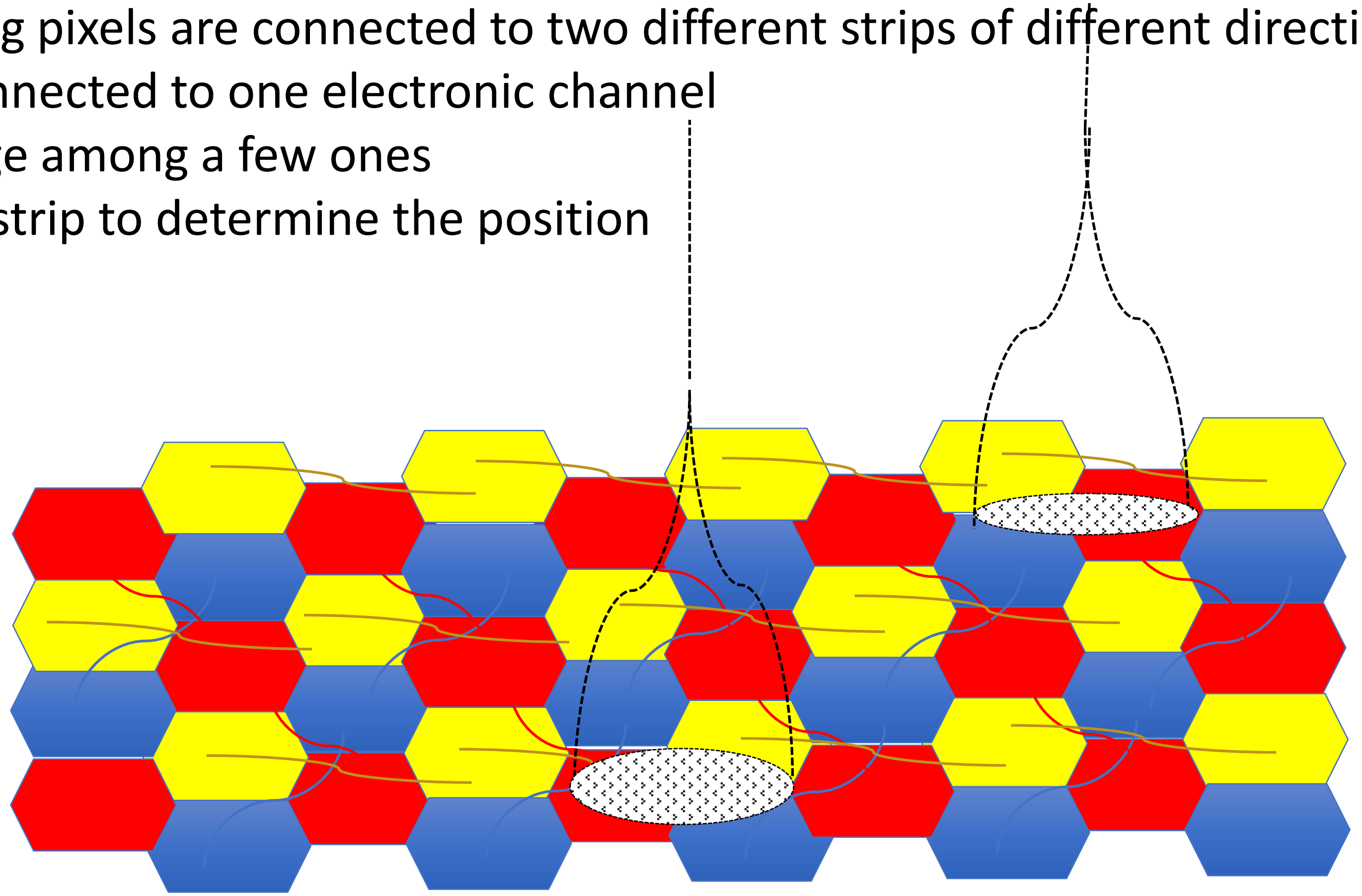




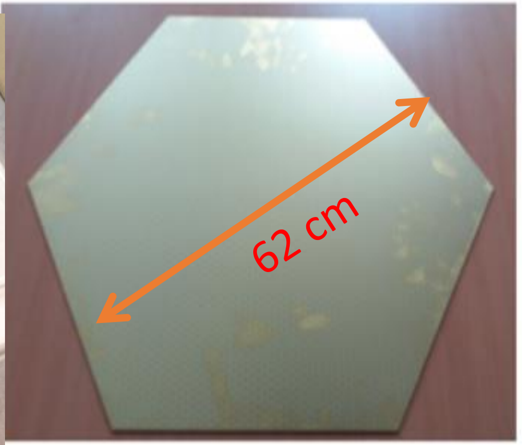
$\sigma_x = \sigma_y$ ~. 0.3 cm

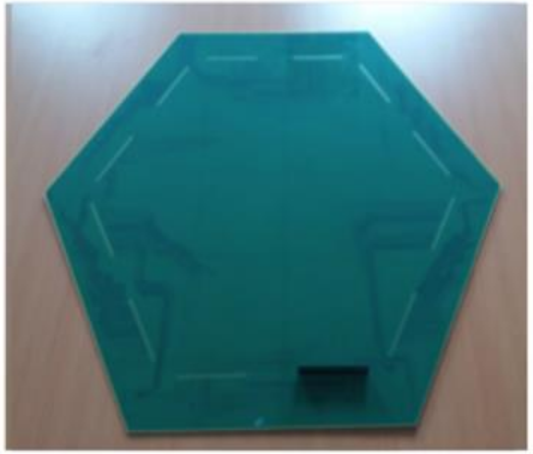
There is another solution

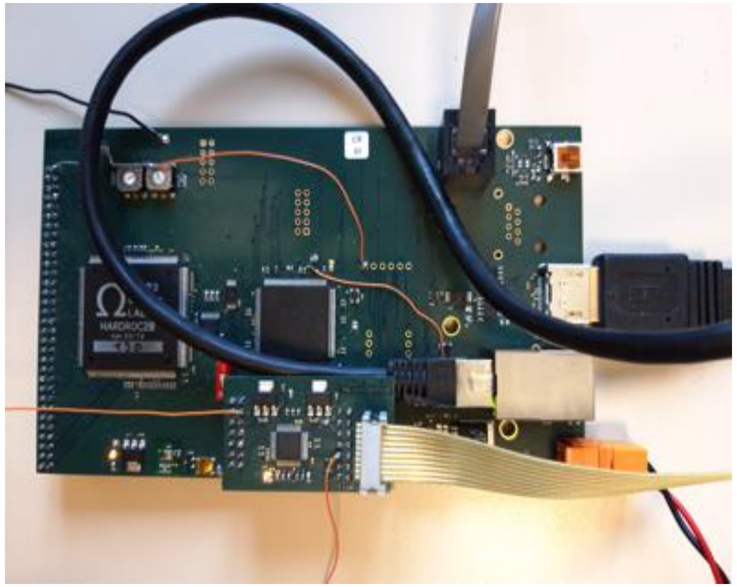
- Use pickup pads/pixels to have excellent granularity
- Connect the pads/pixels in a special way: **woven strips**
- Two neighboring pixels are connected to two different strips of different directions
- Each strip is connected to one electronic channel
- Share the charge among a few ones
- Cross the fired strip to determine the position



NXN → 3N : Reduction of electronic channels, power consumption and occupancy



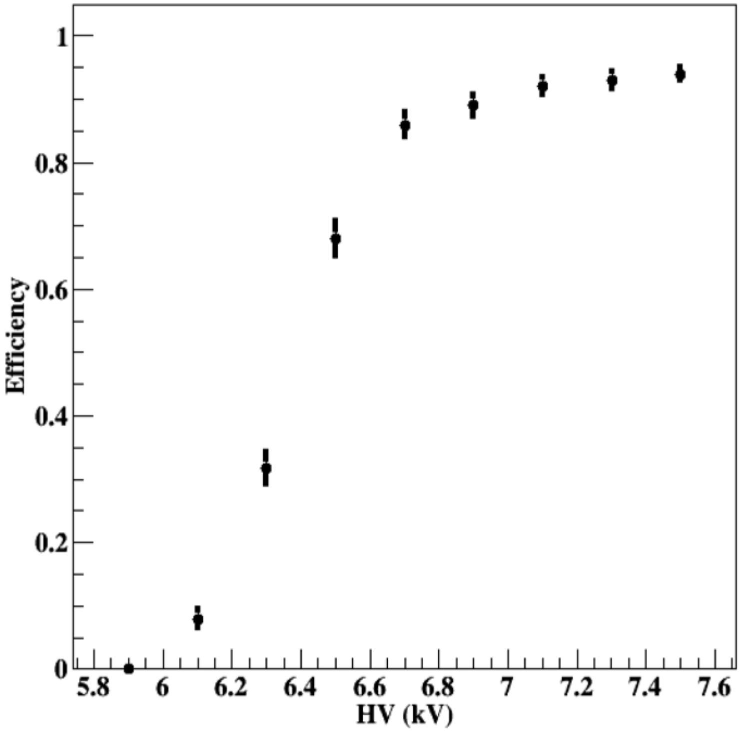




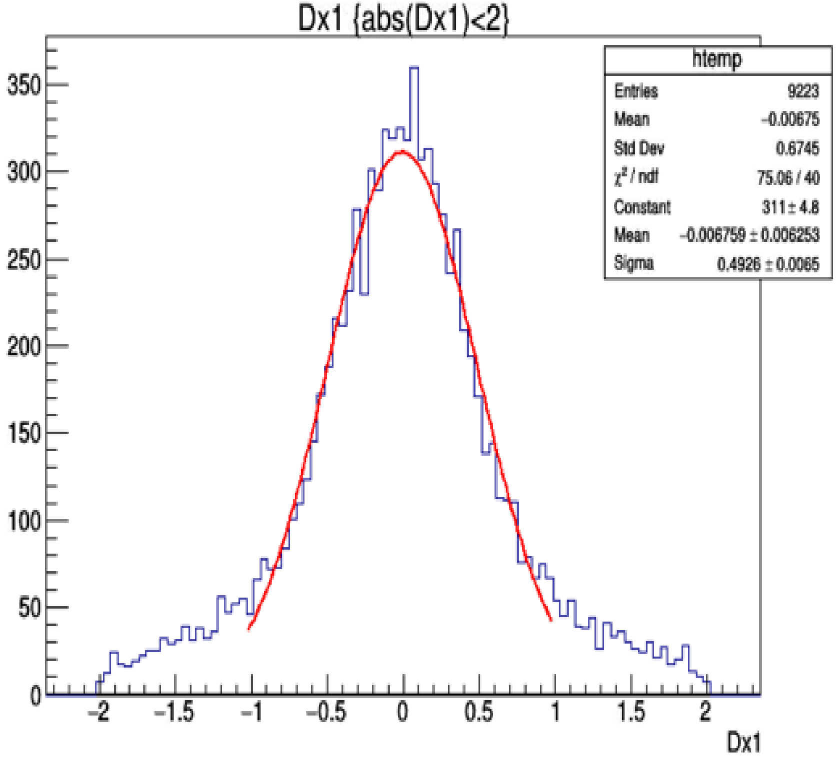
A board hosting

- One Hardroc ASIC
- One Microcontroller

To be plugged directly on the back of the PCB, on the edge to read out 64 woven strips.



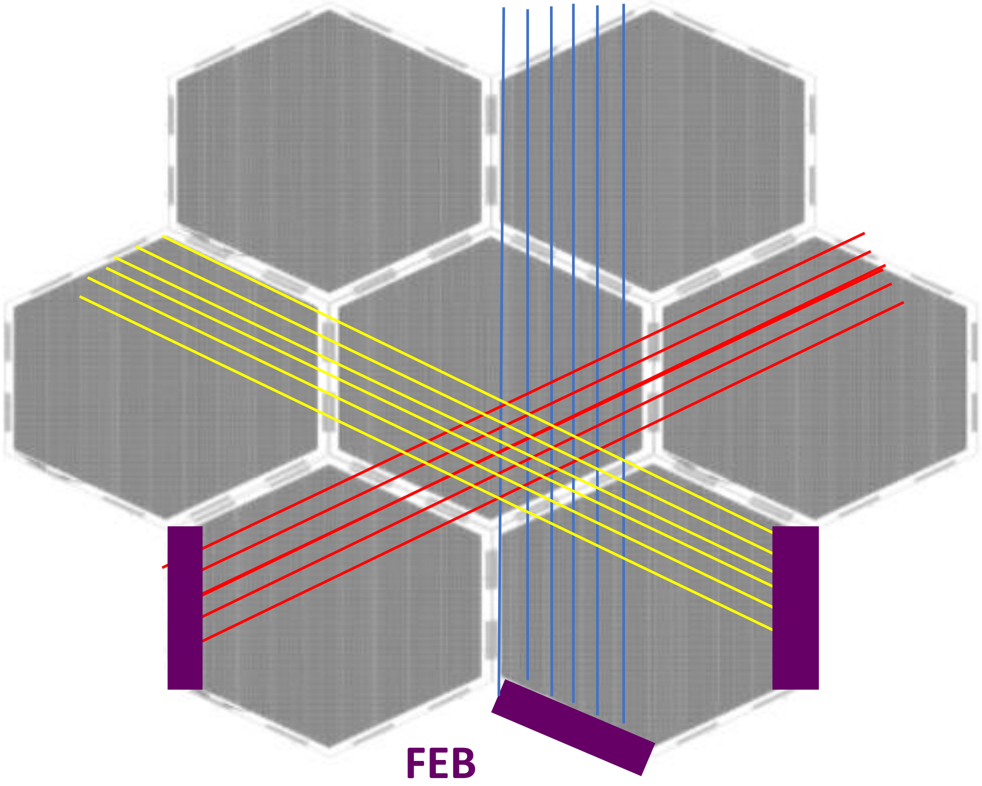
Efficiency
HV (kV)
0
0.2
0.4
0.6
0.8
1
5.8
6
6.2
6.4
6.6
6.8
7
7.2
7.4
7.6



Dx1 {abs(Dx1)<2}
htemp
Entries 9223
Mean -0.00675
Std Dev 0.6745
χ² / ndf 75.06 / 40
Constant 311 ± 4.8
Mean -0.006759 ± 0.006253
Sigma 0.4926 ± 0.0065
Dx1
0
50
100
150
200
250
300
350
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

Large surface detectors

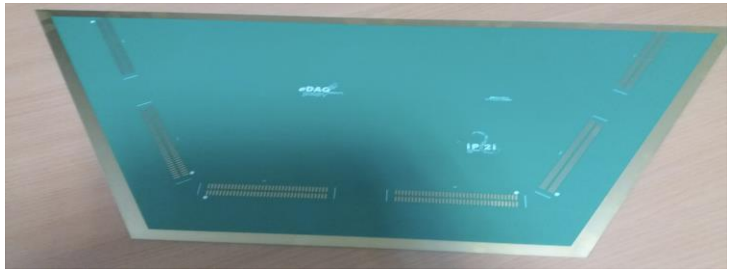
To instrument **(very) large gaseous detectors a** simple scheme is proposed:



"Well matched impedance will help to keep the signal in good shape for long distances"

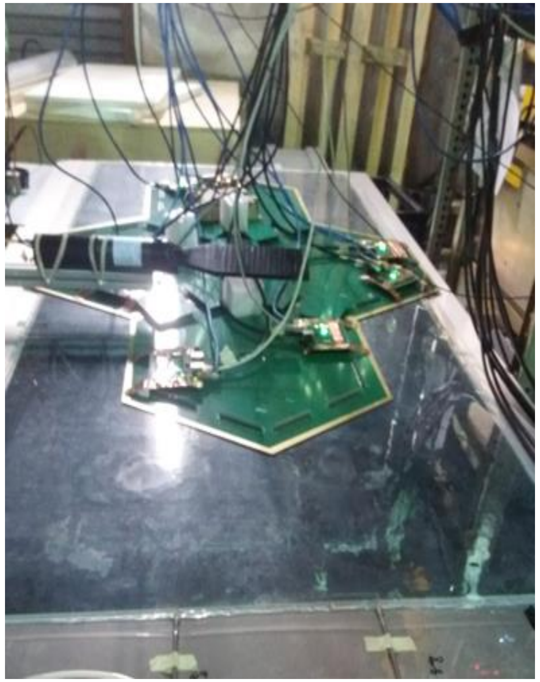
Large surface detectors

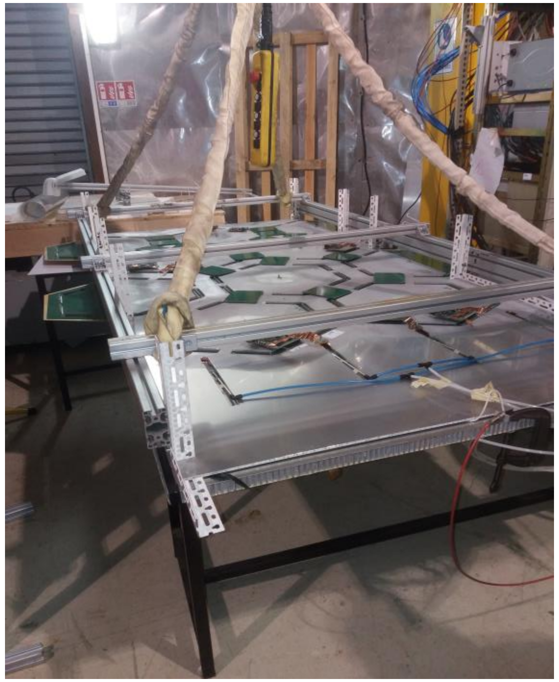
Large detection area can be instrumented by assembling easily many PCB.

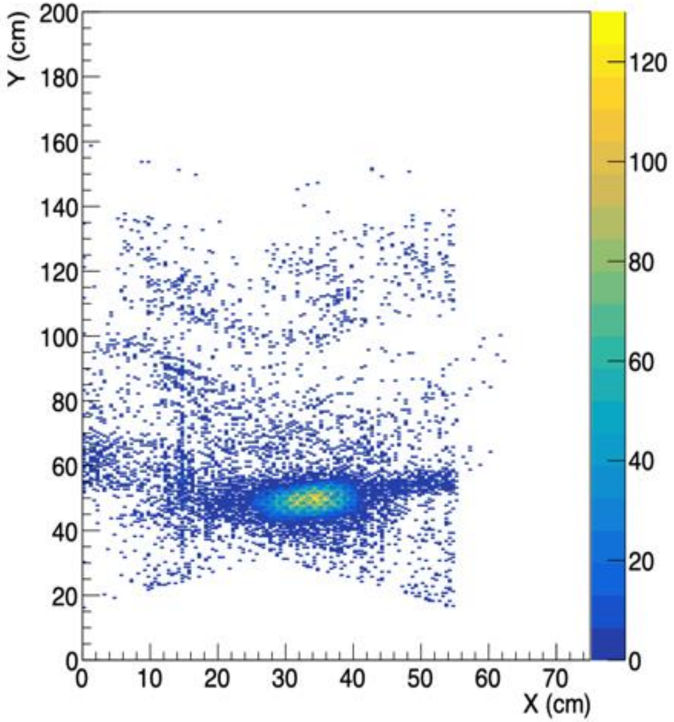


Large surface detectors

The new scheme is being tested on a large GRPC (2m x 1 m) with several PCBs
Reconstruction efficiency (1 direction efficiency is not included) is around 90%.







In addition the woven strips could be used to build a very large detector surrounding the whole experiment (ILD and the others) to look for LLP ($Z \rightarrow N \nu$). A work was already done with FCCee LLP group

Conclusions

Simulation work has been done a few years ago within the ILD framework to show the role of muon detectors

The segmentation (longitudinal and transversal) is not yet fixed

The technology options are still open even if those proposed for HCAL were studied

New generations of muon detectors could offer additional assets (timing, granularity at affordable cost..etc)