

# ILD muon system

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On behalf of the ILD collaboration

## **Disclaimer:**

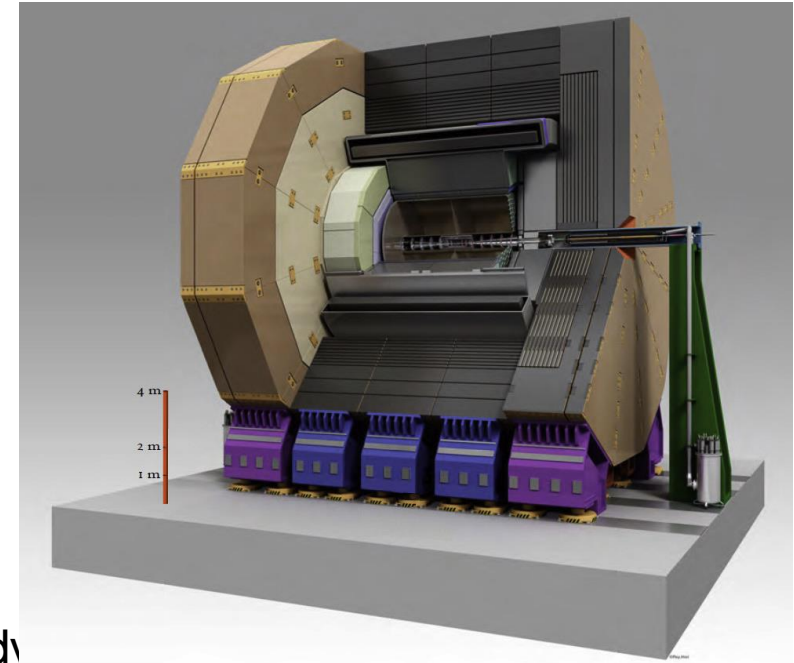
In this presentation I report a study that was performed a few years ago on the role of muon system in ILD concept. The work was led by V. Saveliev (National Research Nuclear University, Russia). All the merit is his and that of the colleagues who contributed to.

I did 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 ( $6 \lambda_1$ ) 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



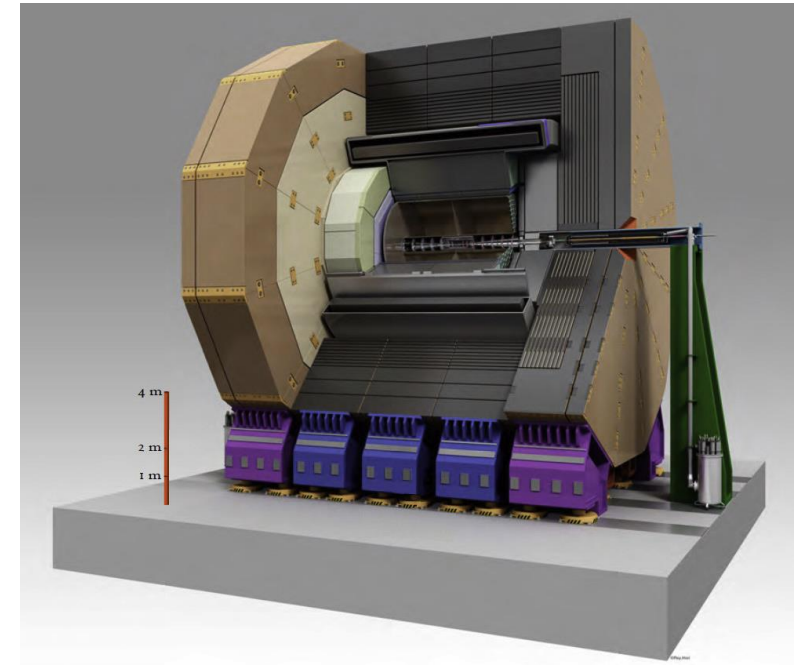
# Muon system in ILD

Several questions were on the table for the muon detectors

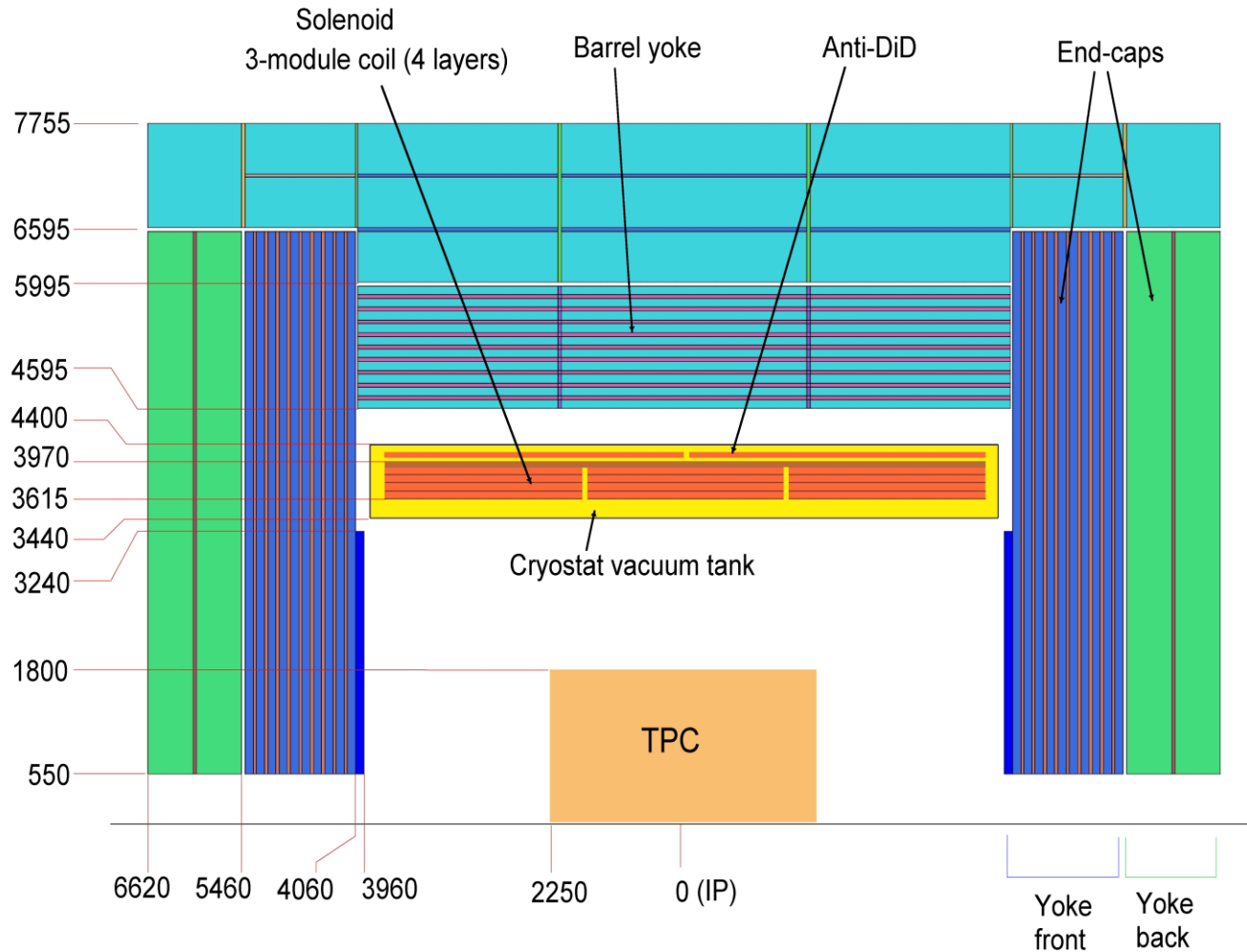
1- Where to place it

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

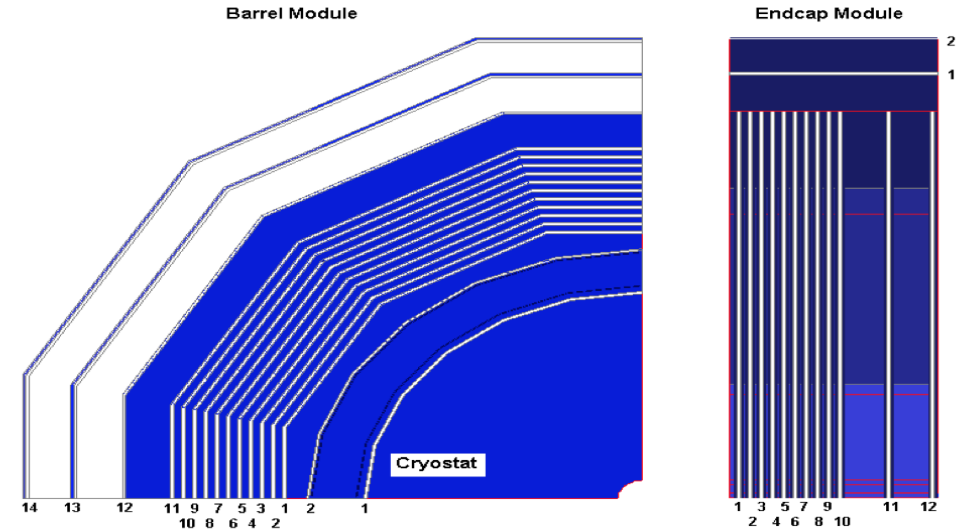
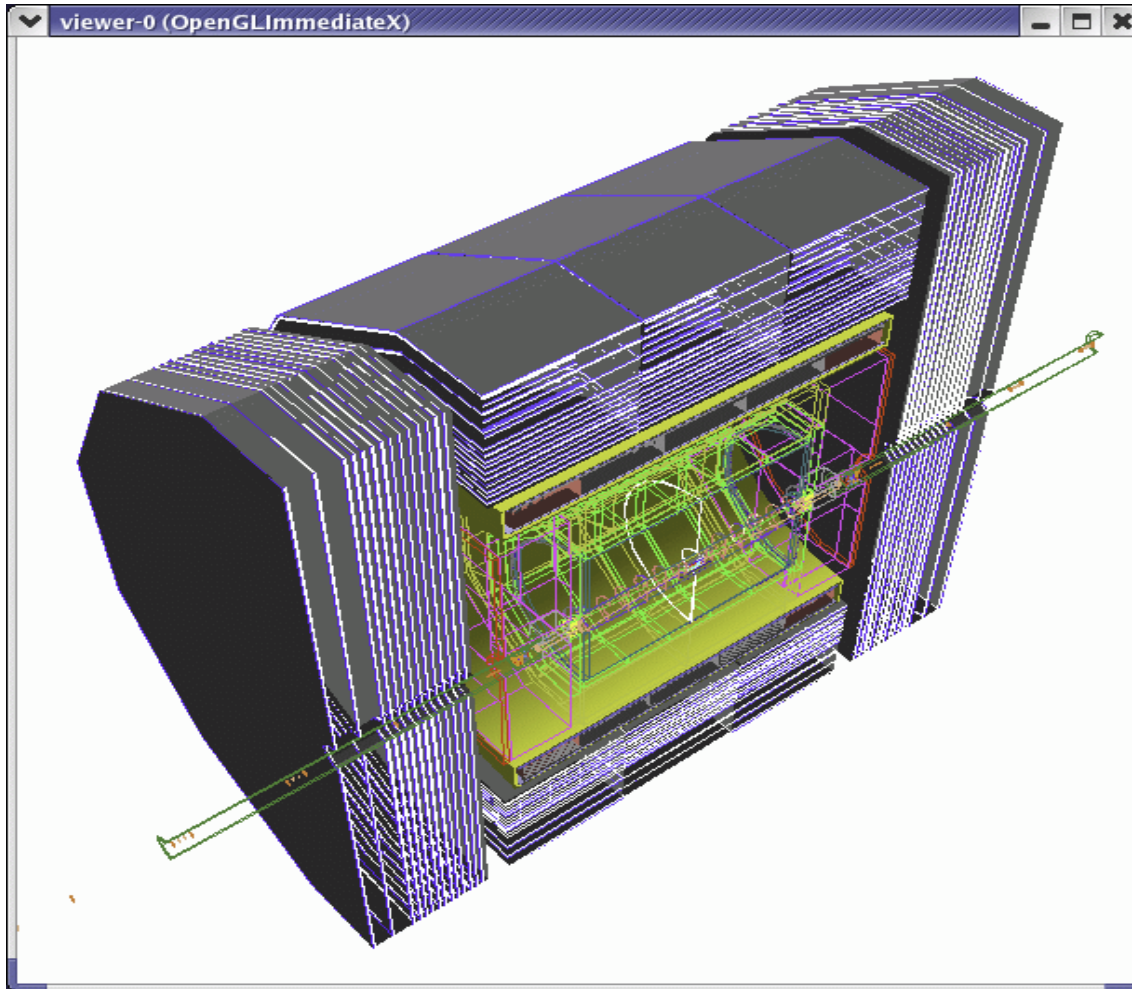
## Coil:

- 3x1650 mm + 2x1200 mm

## Muon Detector System:

- Double Sensitive Layers in the Yoke Gaps

# Muon system @ ILD

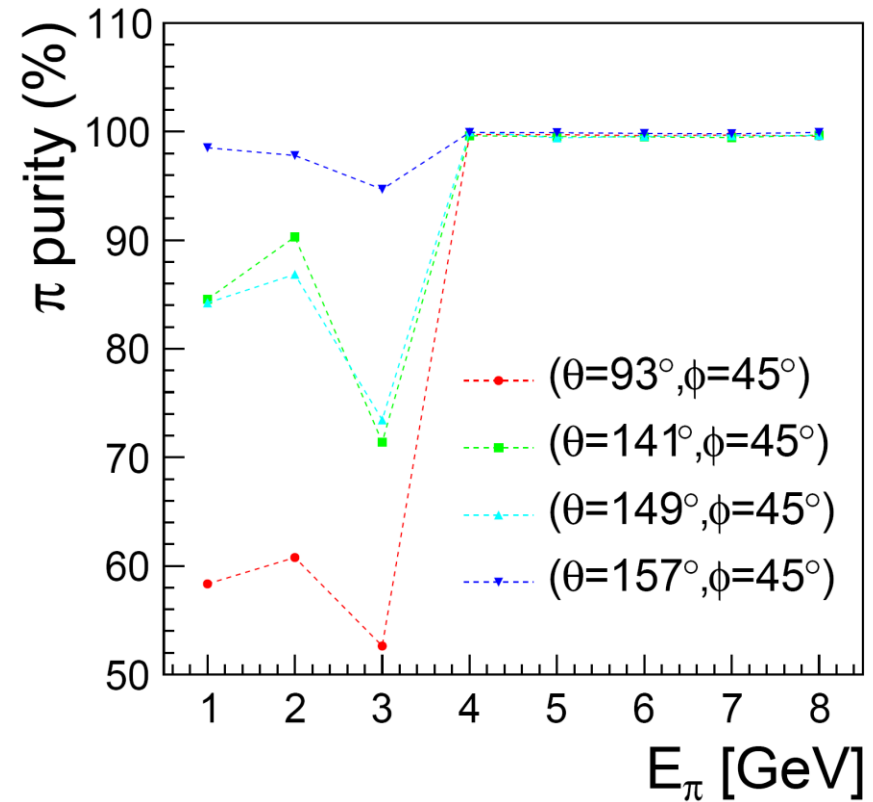
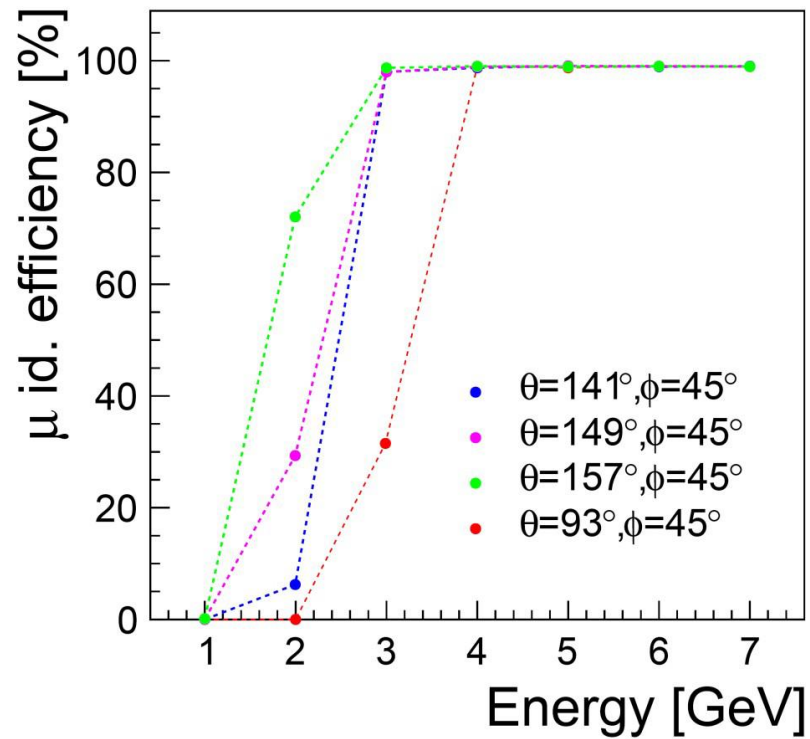


- ❖ 14 (12) active layer for the barrel (endcap ) region, interleaved with iron slabs of return yoke.
- ❖ scintillator strips read out by SiPM through WLS or RPC (X&Y)

The simulation was made with Scint of 3 cm width

## Muon system impact

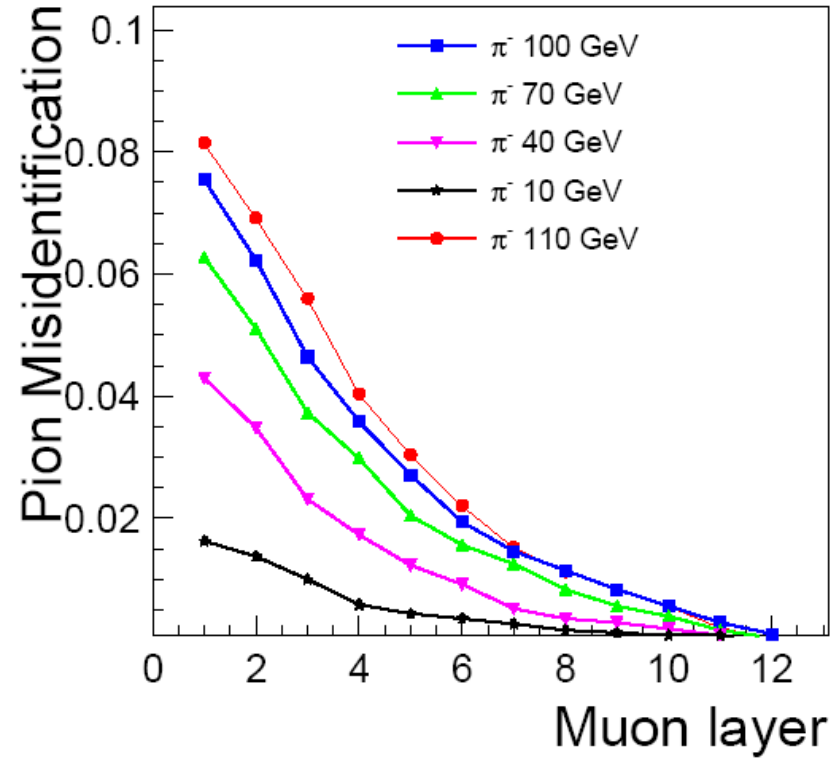
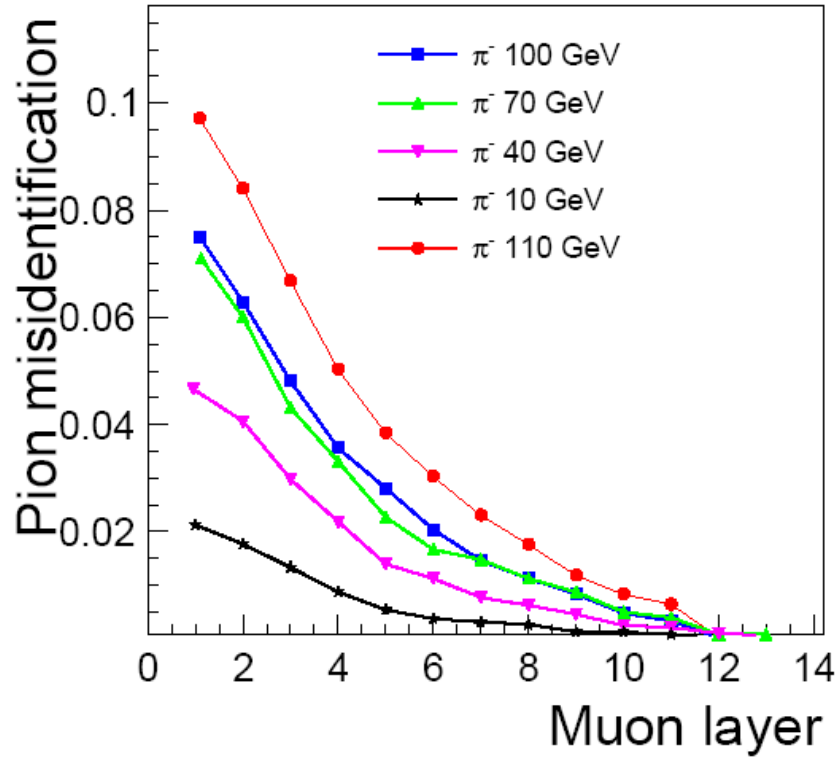
Excellent pion/muon separation at energies  $> 4$  GeV



- ❖ Effect of the coil material for soft muons: the  $\mu$ -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

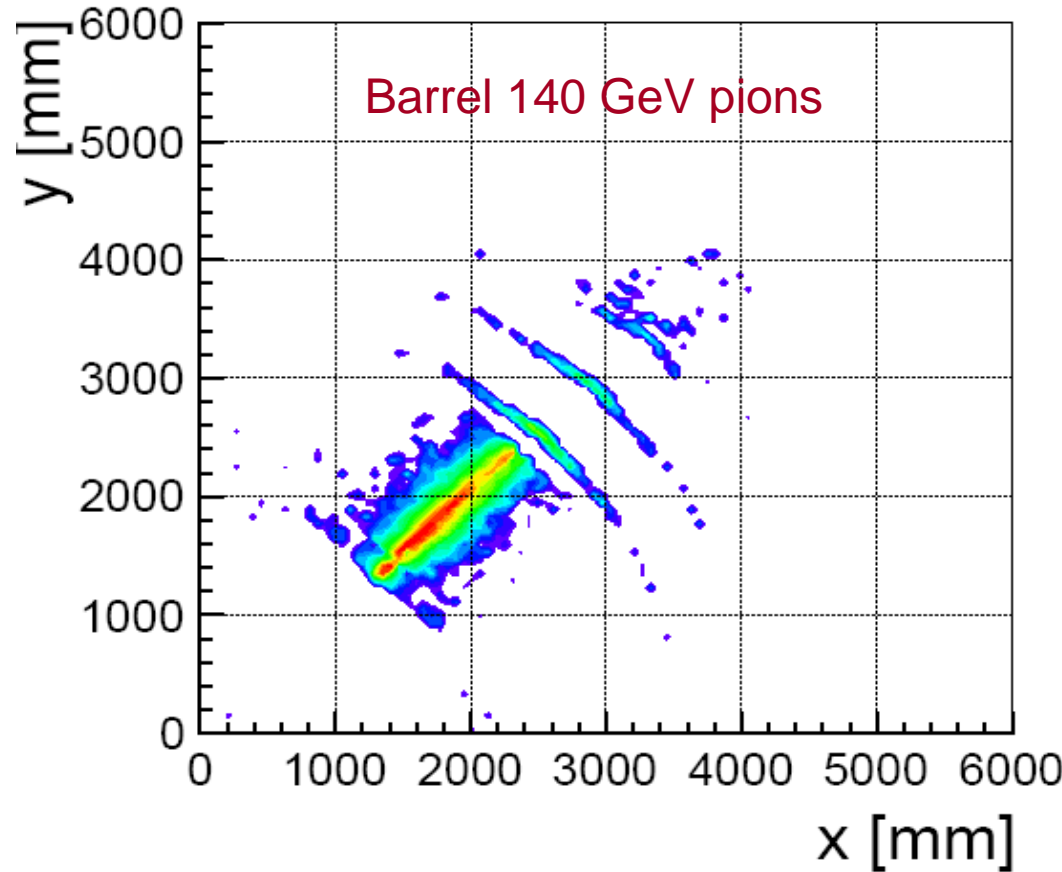
The pion misidentification as a function of the number of instrumented layers



Pion misidentification

# Muon system impact

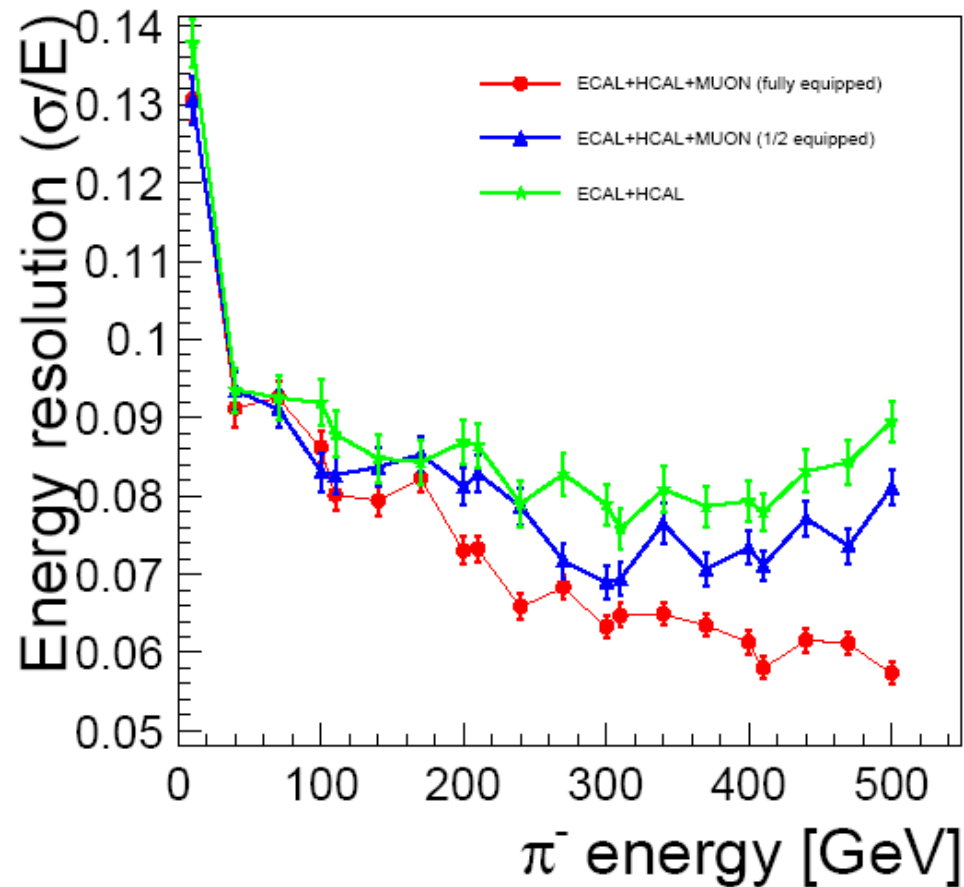
Tail catcher role



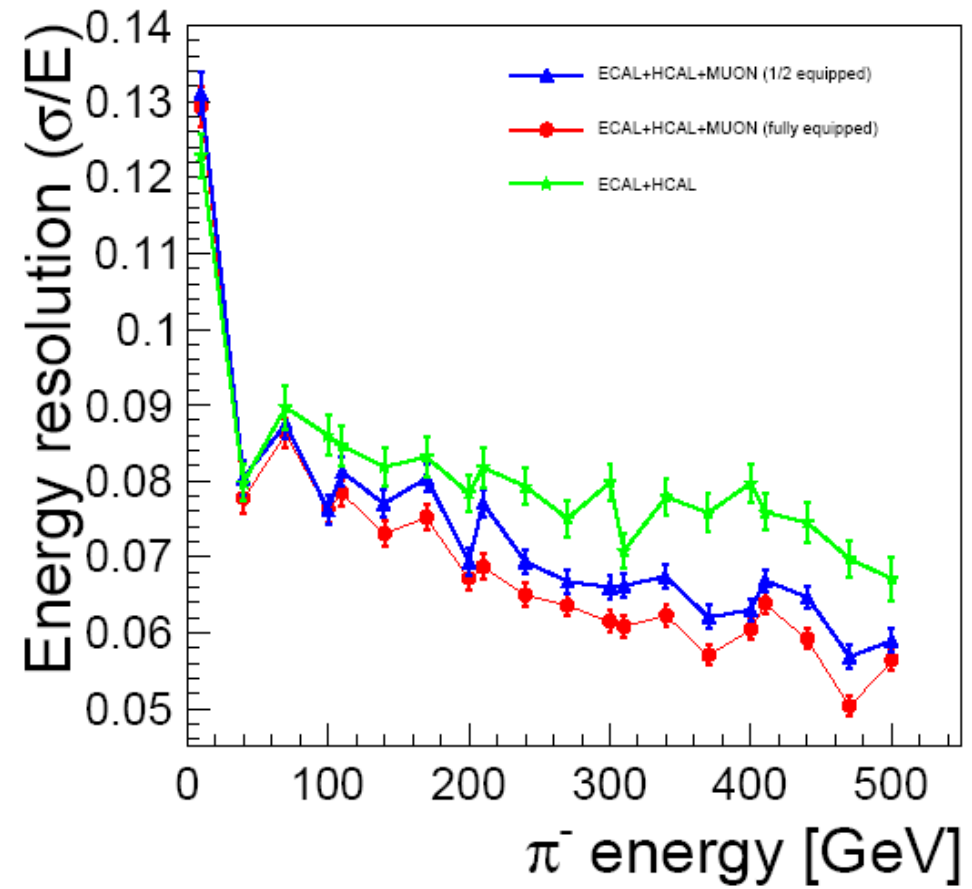
Having good granularity of the muon system could help to reconstruct the tail shape and then improve on energy reconstruction using MVT

# Muon system impact

Tail catcher role



Barrel

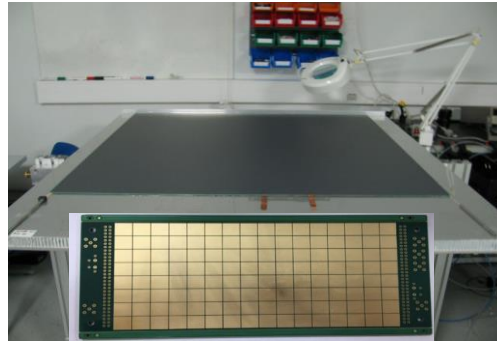
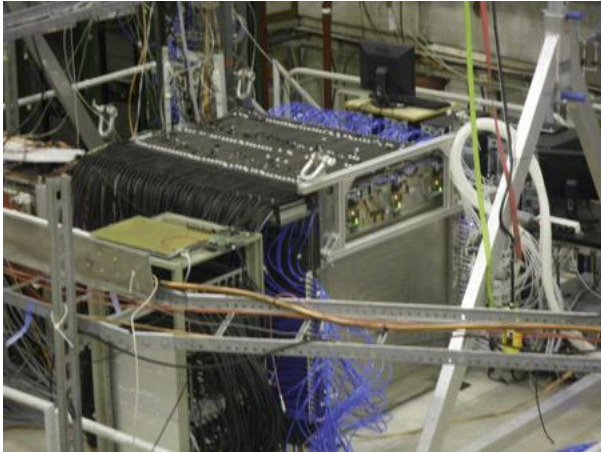


EndCup

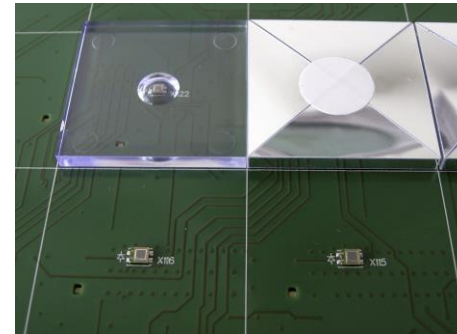
## Which technology?

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

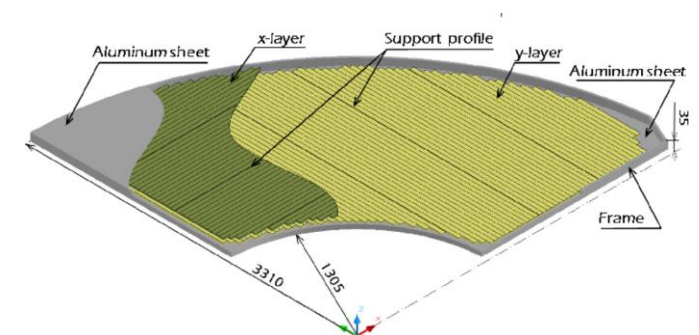
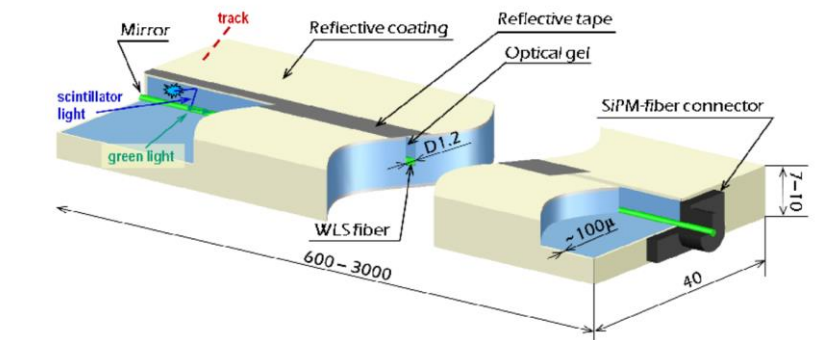
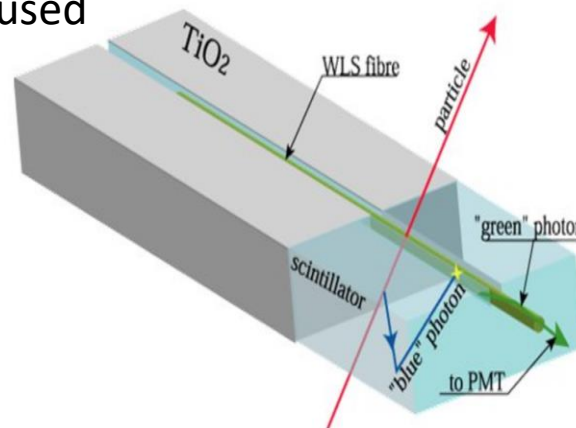
Robustness, efficiency, high rate capability

## 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

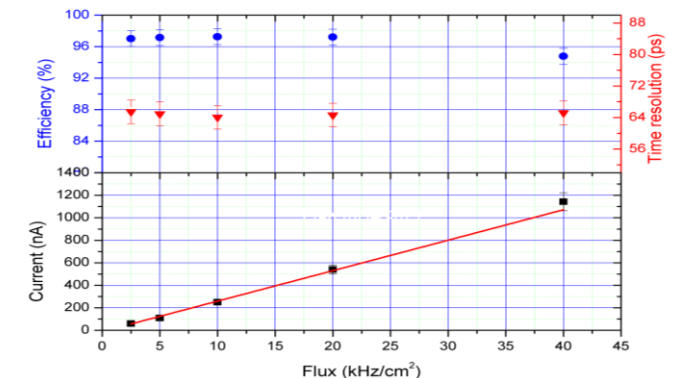
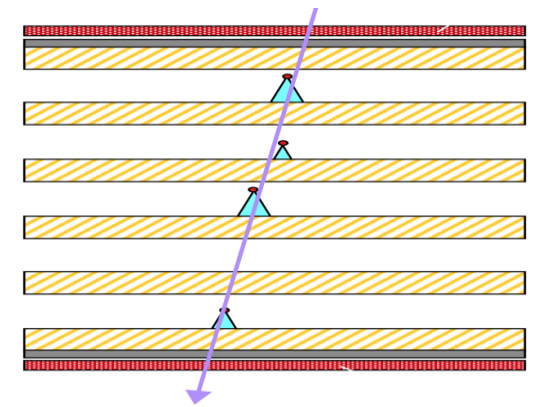
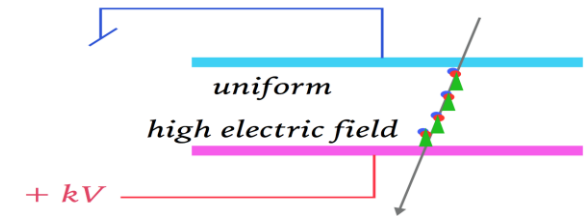
Two kinds of electrodes have been used up to now

**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)

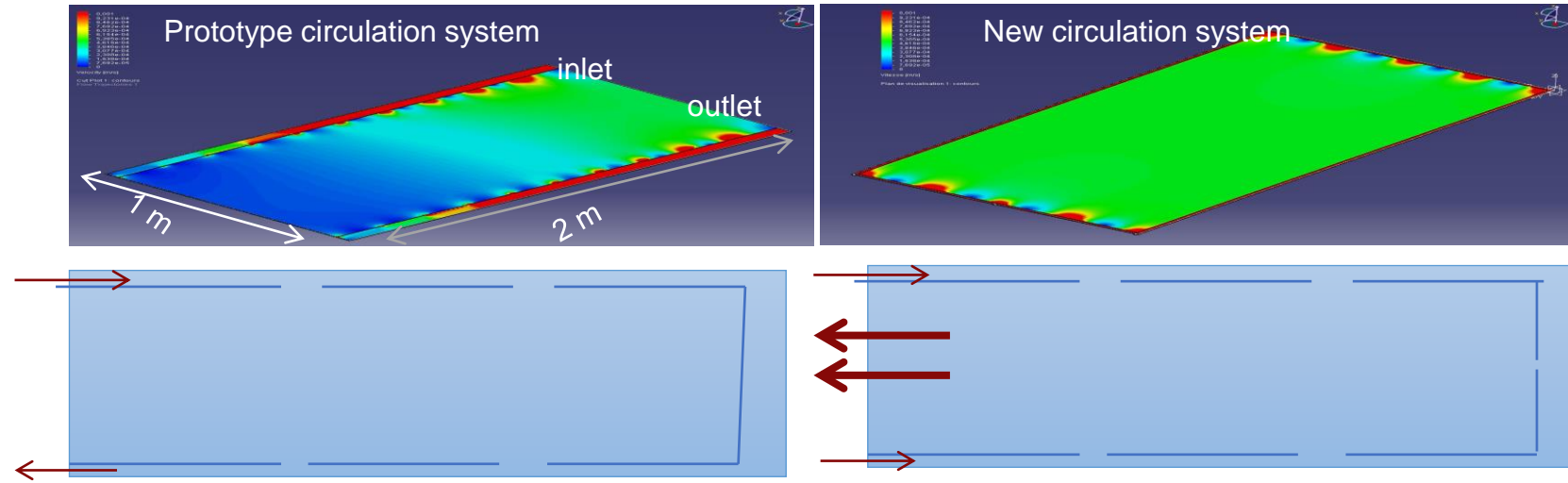
MRPC provides excellent timing and higher rate capabilities ( low charge)  
High rate capabilities could be obtained using low resistive electrode materials  
(Tsinghua glass, dopped PEEK, etc)



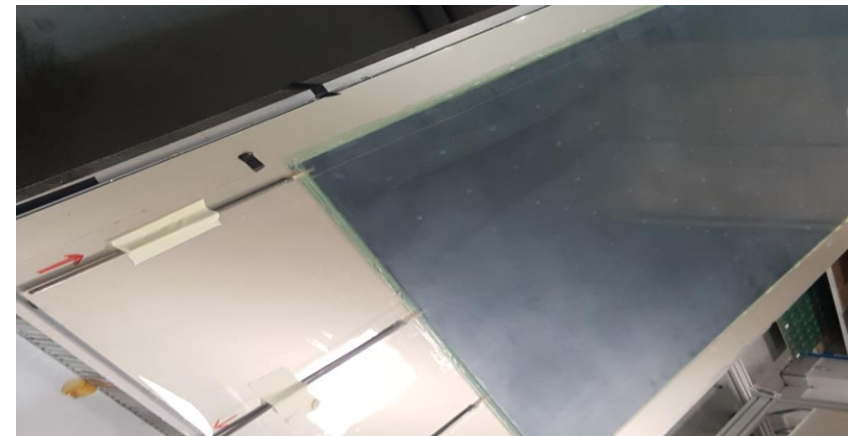
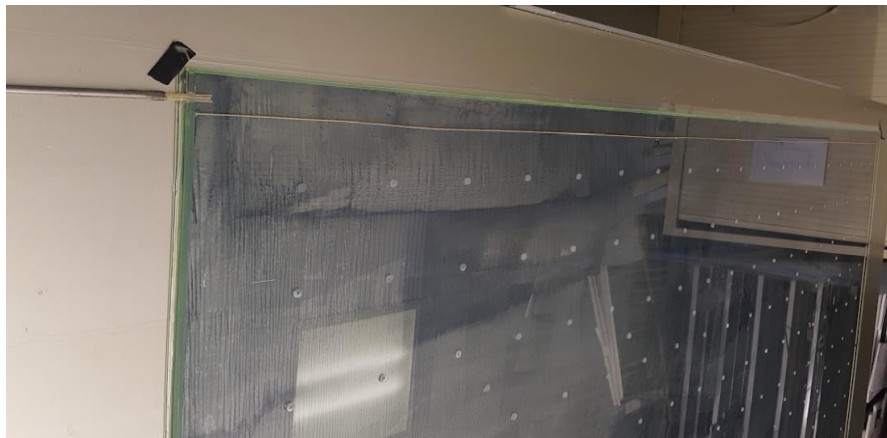
**(M)RPC**

# RPC

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

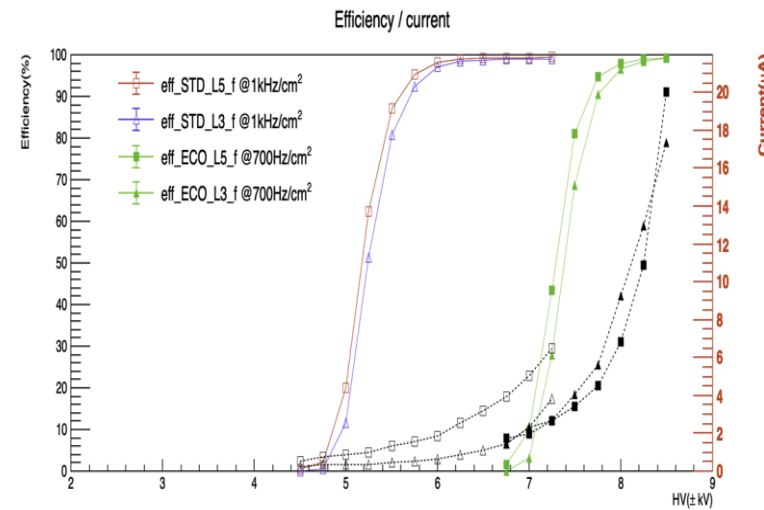
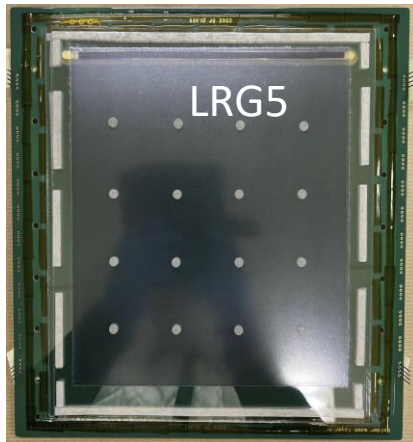
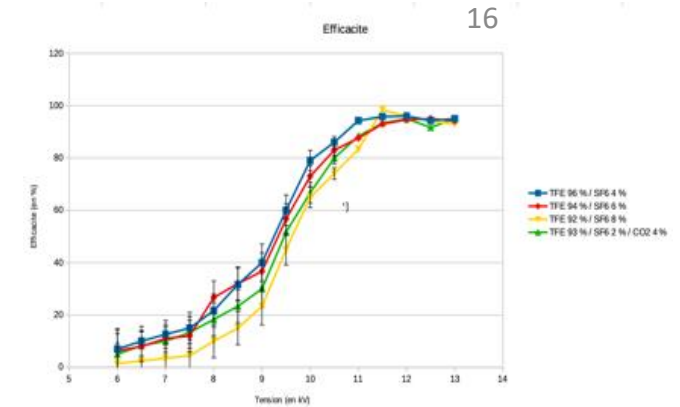
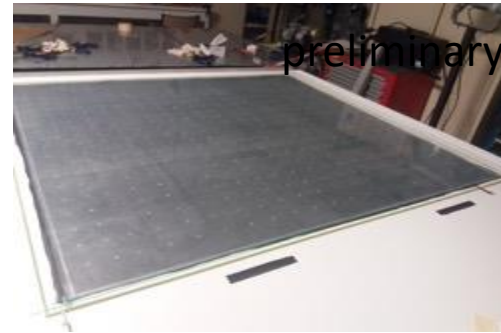


Cassette conception to ensure good contact between the detector and electronics is still to be improved



# 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

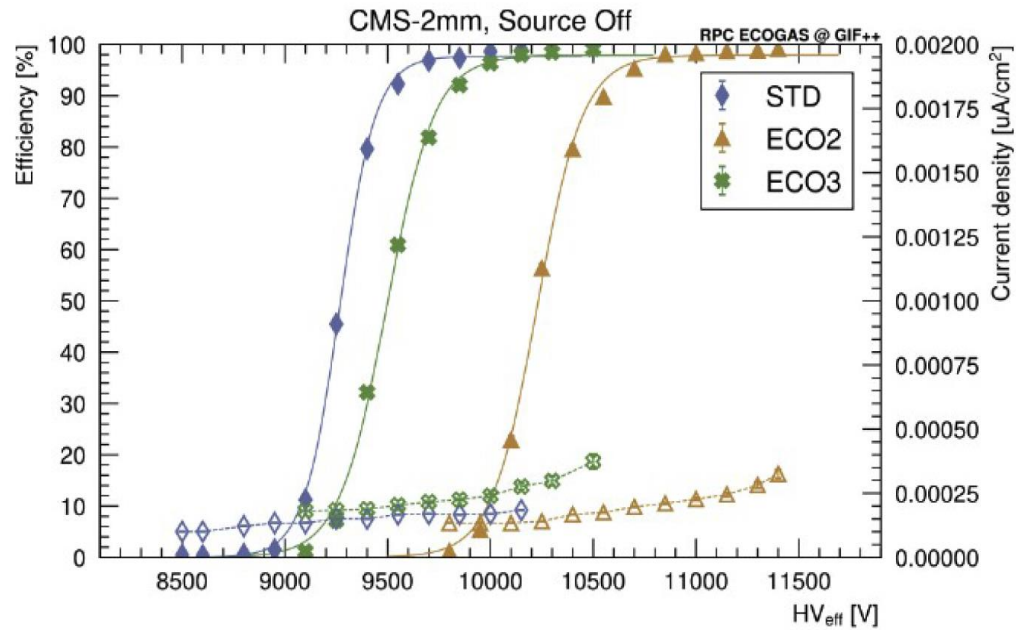


Credit:  
Yw. Baek  
Js. Kim

# Eco-friendly gas mixtures

Mixture	C <sub>2</sub> H <sub>2</sub> F <sub>4</sub> [%]	HFO [%]	CO <sub>2</sub> [%]	iC <sub>4</sub> H <sub>10</sub> [%]	SF <sub>6</sub> [%]	tCO <sub>2</sub> e
STD	95.2	0	0	4.5	0.3	3384
ECO3	0	25	69	5	1	762
ECO2	0	35	60	4	1	763

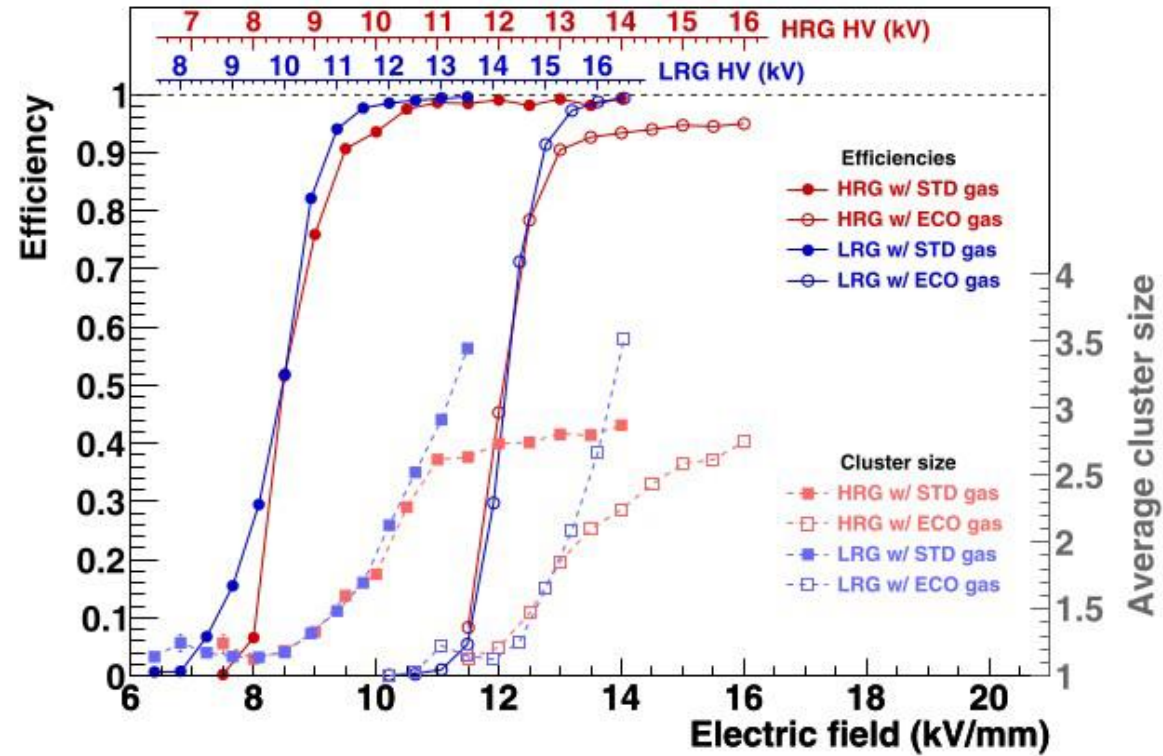
M. Verzeroli



HFO+NOVEC+CO<sub>2</sub> 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

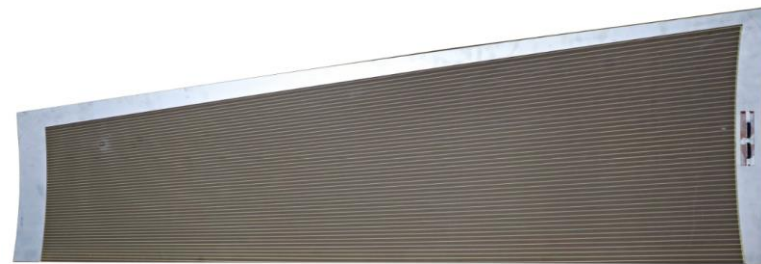
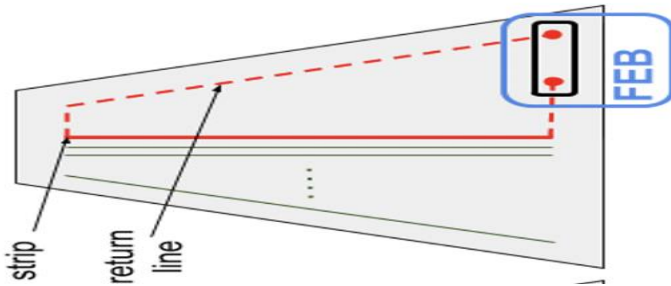
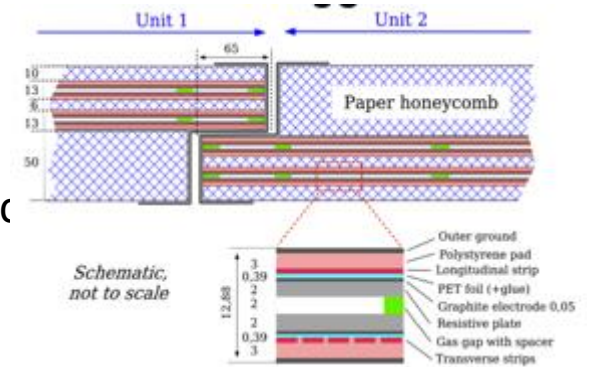


# **(M)RPC Readout**

# Readout of RPC

There are several ways to read out RPC:

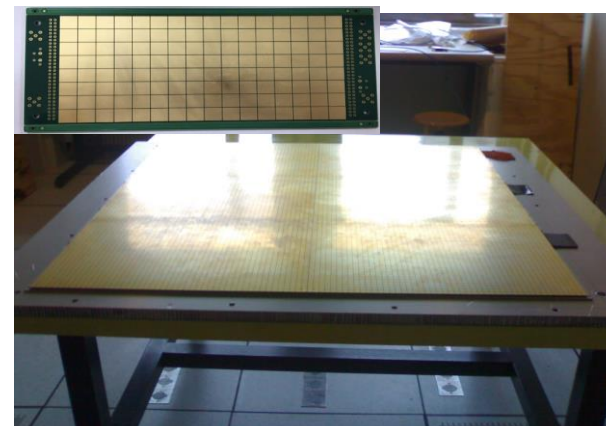
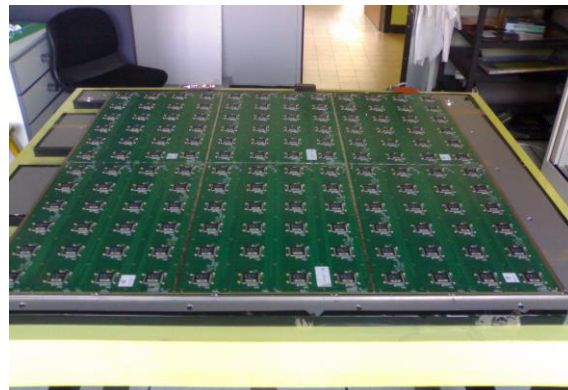
- ❖ Using **one-end readout pick-up strips** (either one direction on the anode side as for CMS RPC or two directions: one on the anode and one on the cathode as for ATLAS)
- ❖ **two-end readout** using **excellent time measurement** as the one proposed for **CMS iRPC** upgrade project



$$\sigma_x : 0.4 \text{ cm}$$

$$\sigma_y : 1.6 \text{ cm}$$

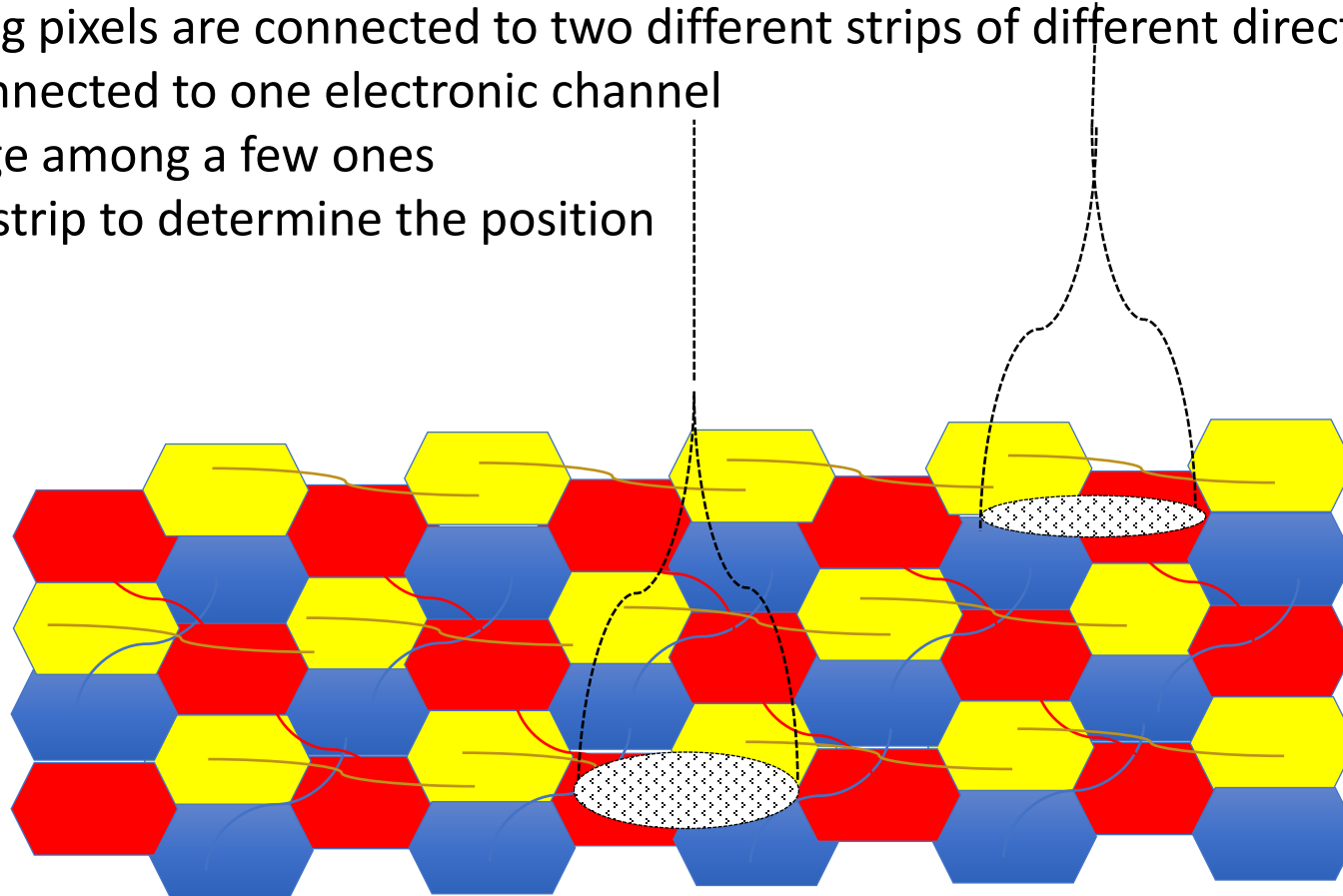
- ❖ Using **pick-up PADS** as for SDHCAL (CALICE)



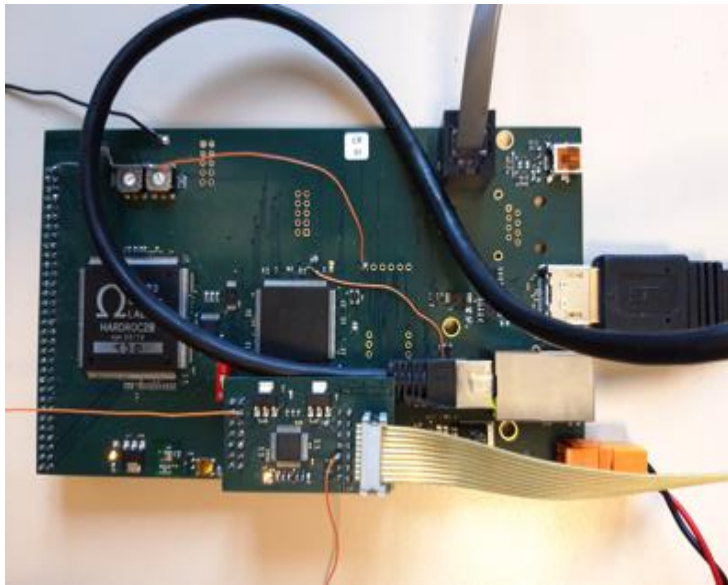
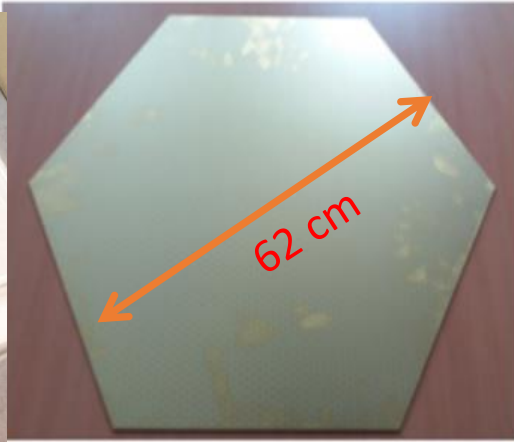
$$\sigma_x = \sigma_y \sim 0.3 \text{ cm}$$

## 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



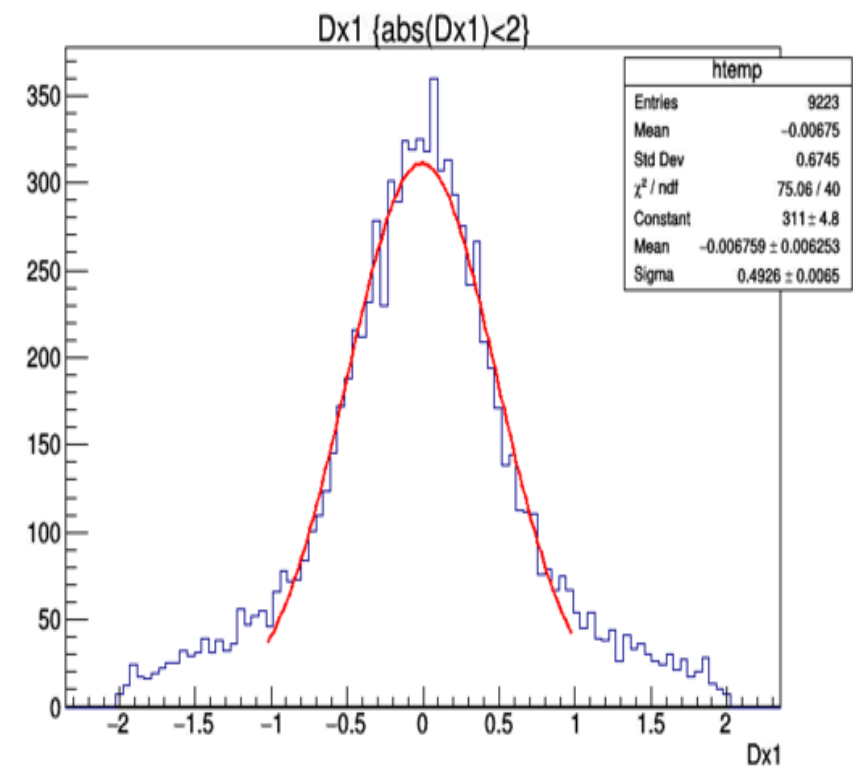
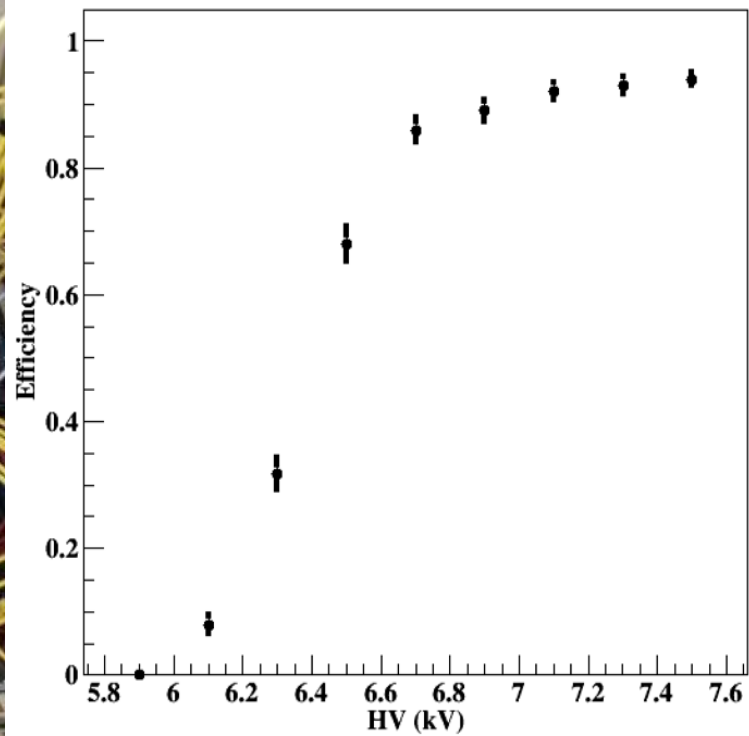
$N \times N \rightarrow 3N$  : Reduction of electronic channels, power consumption and occupancy



A board hosting

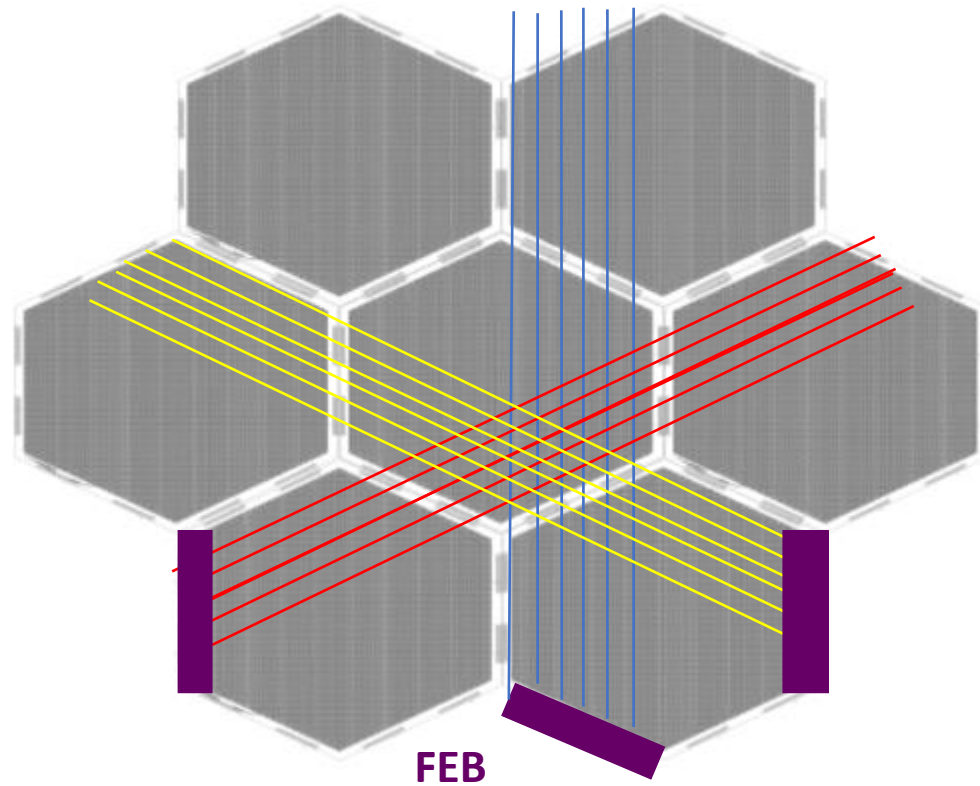
- One Hardroc ASIC
- One Microcontroller

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



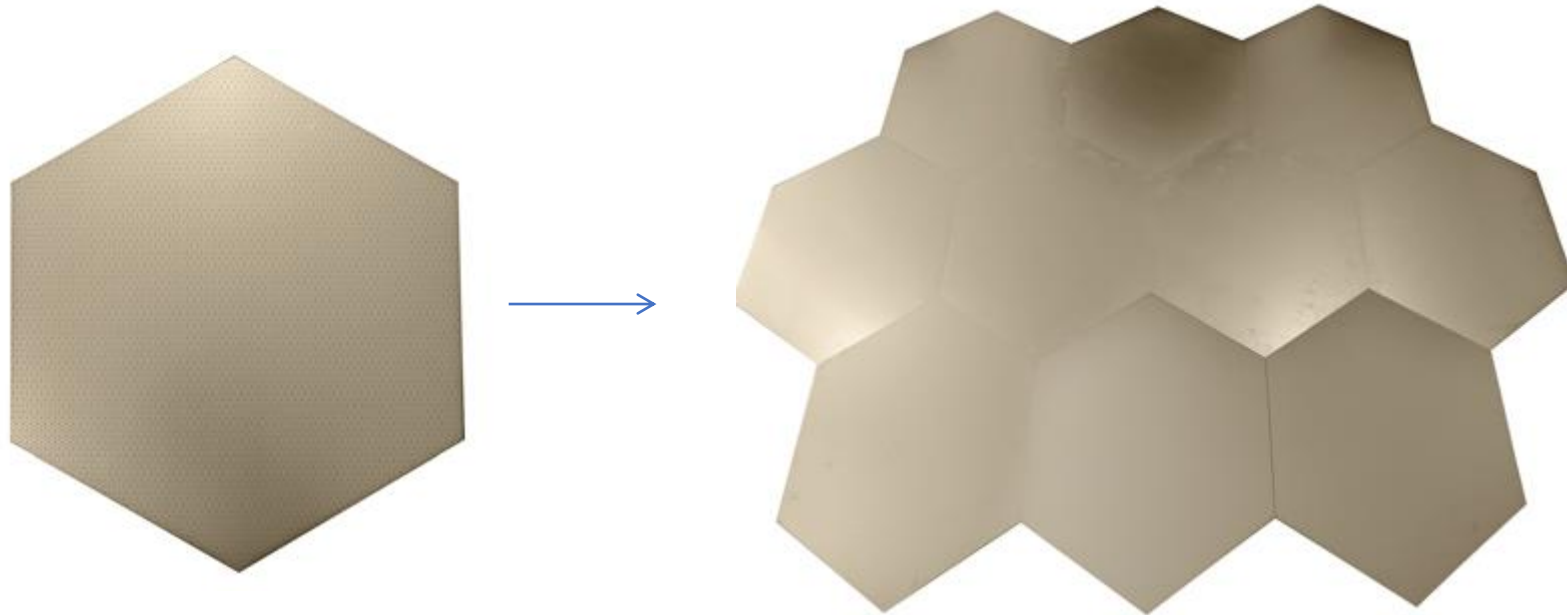
# Large surface detectors

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

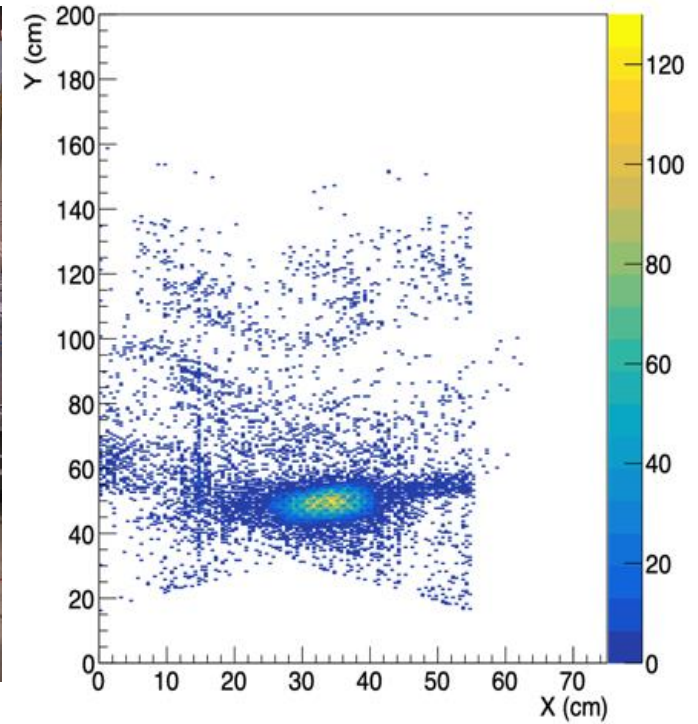


Large detection area can be instrumented by assembling easily many PCB.



## 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)