Gaseous Calorimeters

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Gaseous detectors for High Granularity Calorimeters

The Task Force 1 is devoted to gaseous detectors
The TF1 symposia took place on 29th April: https://indico.cern.ch/event/999799/
Today, only things directly linked to gaseous calorimeters will be presented

Resistive Plate Chambers (RPC) and Micro Pattern Gas Detectors (MPGD) are good candidates as active medium of high granularity sampling calorimeters

In general* they
- are robust and less expensive than others (as solid state detectors)
- can cover large areas
- can be segmented in different size pads, being capable achieve 50-100 microns space resolution
- are radiation hardness
- stand for high rates
- have good time resolution (5-10 ns, that in some cases can/could decreased to the ps level)

(* the specific characteristics depends on each detector type)

Some response uniformity challenges

When covering large areas the uniformity of the response could be a challenge, and it is more important when using the detector as calorimeter

For tracking/muons ➔ signal should be high enough to produce a signal over a threshold everywhere with high efficiency, once passing this threshold differences on the total collected charge are not very important to insure uniformity.

For calorimeters ➔ differences on the response could impact on the total charge collected affecting the energy resolution

Limits on sizes:

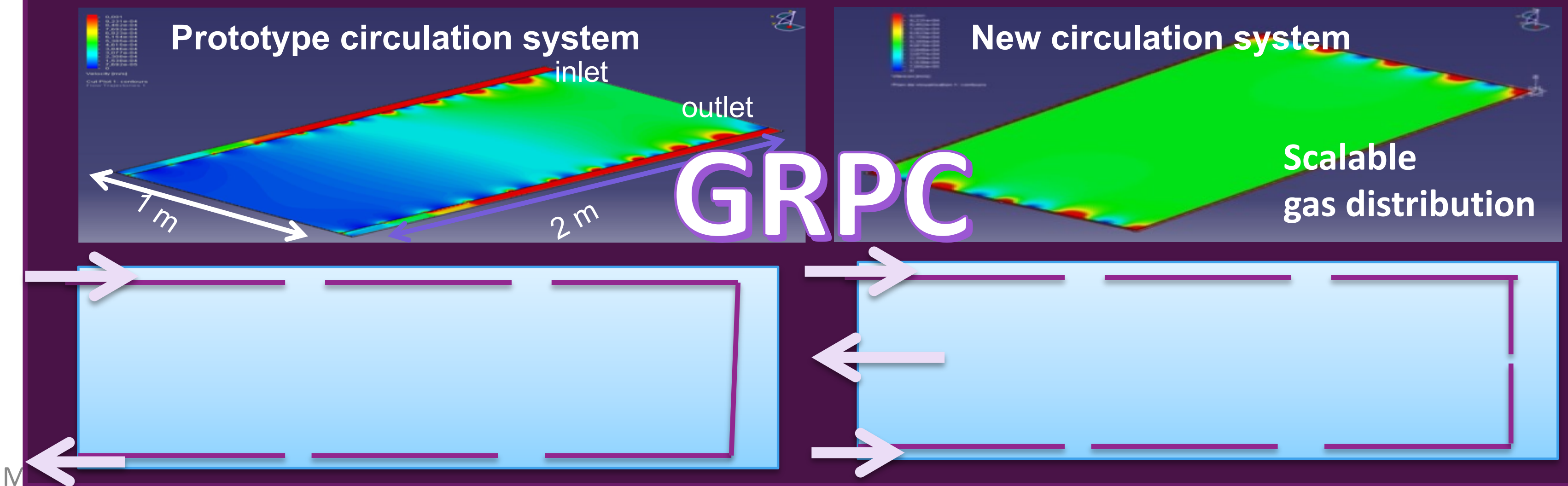
Even if all these detectors can easily cover larger areas, in most cases they must be done using smaller modules

➔ This can create **dead zones/inhomogeneities degrading the performance**

Gas homogeneity & time stability: Gas mixture & environmental conditions can lead to **changes in the gain**

➔ External gas systems, gas distribution inside the chambers and appropriate fast monitoring are part of the game

Gas distribution design inside the chamber needs to be scalable for larger modules.



EXAMPLE: GAS DISTRIBUTION

Simulation of gas distribution used for a 1x1 m2 RPC extrapolated to a 1x2 m2 RPC shows is not appropriate.

New distribution shows a homogeneous distribution of the gas in the full volume

Some response uniformity challenges: PCB & Chamber sizes

PCB: The industrial manufacturing of **PCB boards is limited to 60 cm wide**

Putting smaller units together

a) Can increase the dead space or induce more inhomogeneities
b) Needs extra connectors between boards towards the external readout/DAQ, making the detector electronics less robust

The small sizes also Impose a **limit on the module size of some detectors as MICROMEGAS** (MM), built with the "bulk MM" method in which the mesh is embedded into the readout PCB structure

Very good planarity of PCB, where the readout pads are located, is required

(to insure good contact for readout or proper amplification) and this must be also combined with thinner material

➔ Not easy to produce large PCB boards with high planarity

Chamber: **Chamber sizes can be limited by other reasons beyond the PCB limitations.**

GEM foils are limited to ~61 cm wide due to machine (previous method 10x10, and 30x30 after 2012).

This new method is expensive and the price increase with the size

Due to this limit, CMS phase-2 GEM 2/1 chambers, will be made or 4 modules, and the gap between 2 adjacent modules is 3.55 cm wide. A super-chamber is made of 2 chambers and they overlap, (not applied on calorimeter)

Timing in gaseous detectors

Gaseous detectors can provide easily time resolutions between ~3-10 ns (depending on the type of the detector)
Resolutions of hundreds or even tens of picoseconds could be also achievable for some of them.

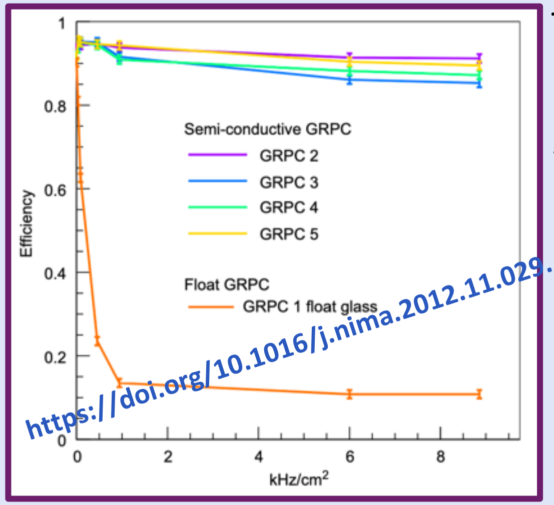
Not yet clear which is the precision required (some simulations must be done, but this is a effort independent of the technology)

This have to be accompanied by ASICs with fast preamplifier, precise discriminator and excellent TDC

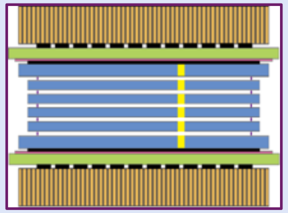
One example is the PETIROC ASIC developed for CMS muon upgrade RPCs. **jitter < 20 ps rms @ Q>0.3 pC**

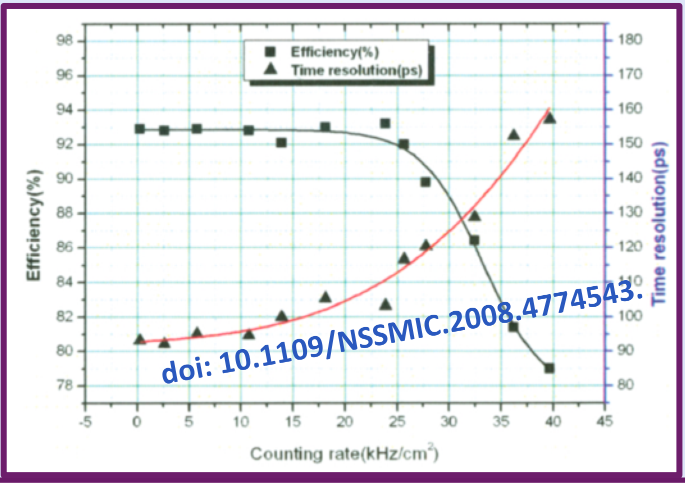
Some examples of sub-ns time resolution

A good candidate is the *Multi-gap RPC (MRPC)*

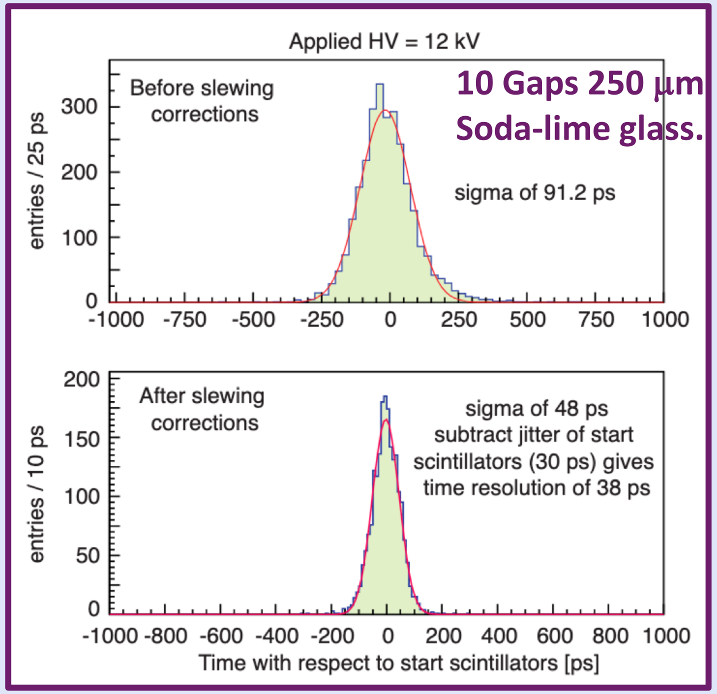


The main limitations is the high rate capability, due to the thin float glass resistivity, but, there are new materials with $\rho \sim 10^{9-10}\ \Omega/cm^2$ as some Semi conductor low resistivity glass.

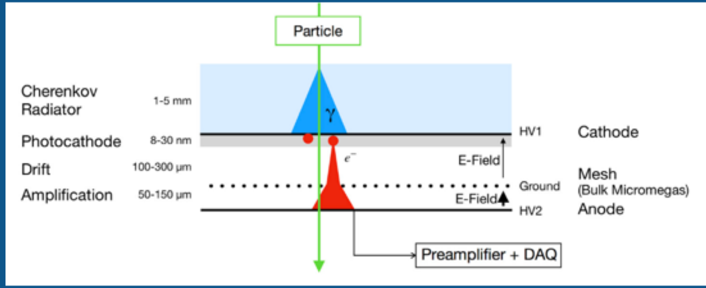




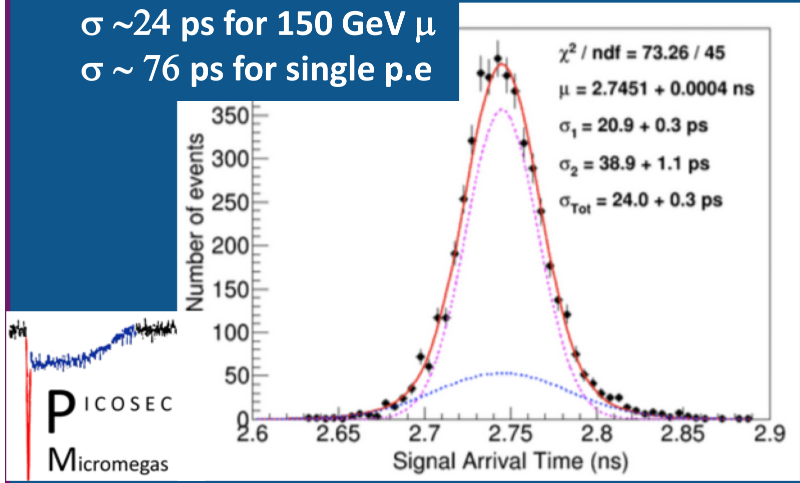
ALICE TOF **MRPC Time distributions**



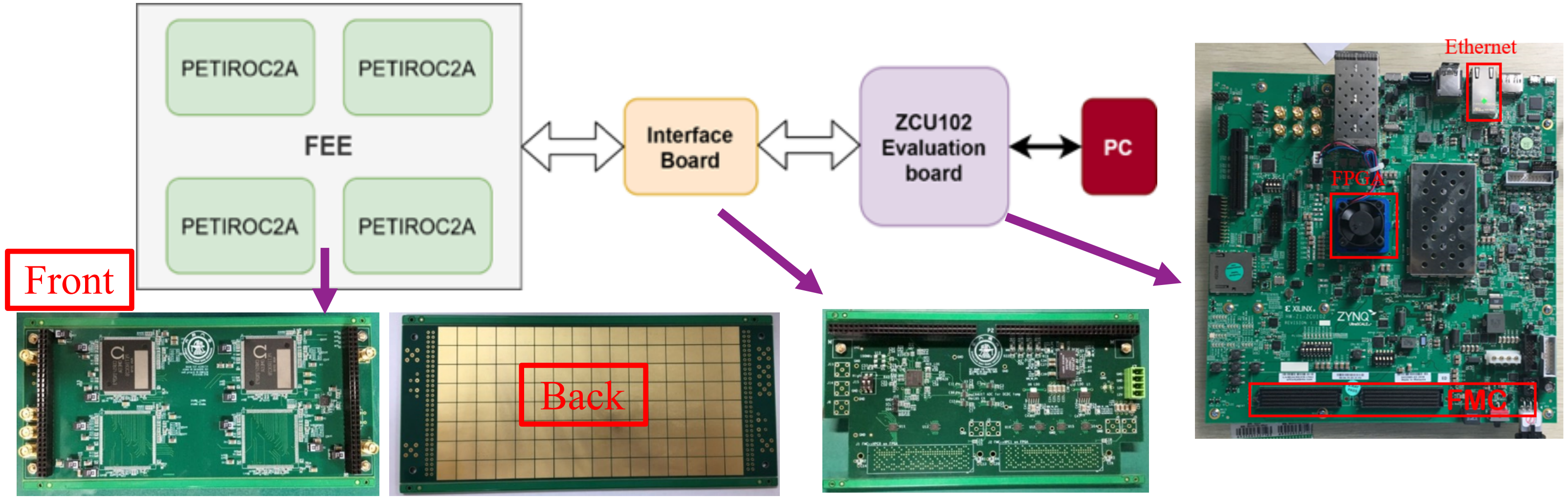
The **PICOSEC Micromegas detector** combines a Cherenkov radiator, a photocathode and a Micromegas-based amplification stage into a high-precision timing detector



σ ~24 ps for 150 GeV µ
σ ~ 76 ps for single p.e

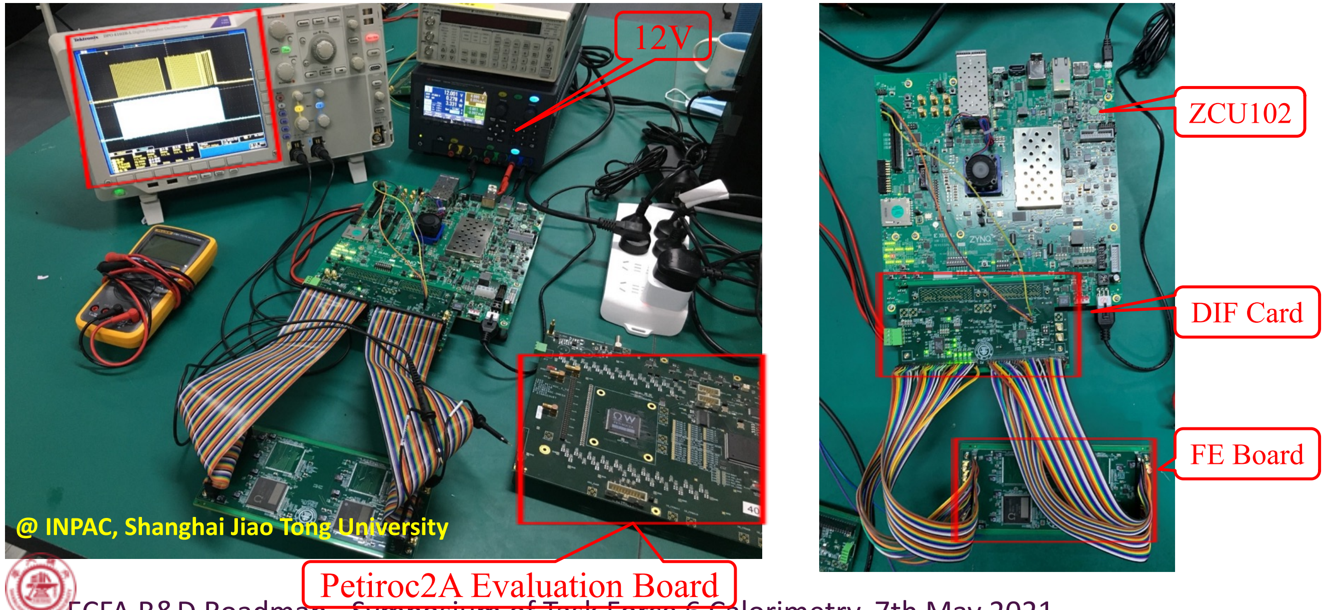


Prototype of MPRC Timing Electronics. Ongoing R&D



- Front-End Electronics for MRPC readout with high timing resolution
- The system includes a front-end board (FEB), a detector interface card (DIF) and a data acquisition system(DAQ) based on ZCU102.
- It uses PETIROC ASICs

Test System and Setup



SOME R&D RELATED TO GASEOUS DETECTORS FOR CALORIMETERS

Prototypes with gaseous detectors – SDHCAL with RPC

Detector: **GRPC (Glass Resistive Plate Chambers)** operating in **avalanche mode**

1x1 cm^2 pads. Semi-Digital Readout, 2bits - **3 thresholds**

➔ It counts **how many** and **which pads** have a **signal larger than one of the 3 thresholds**

Embedded electronics:

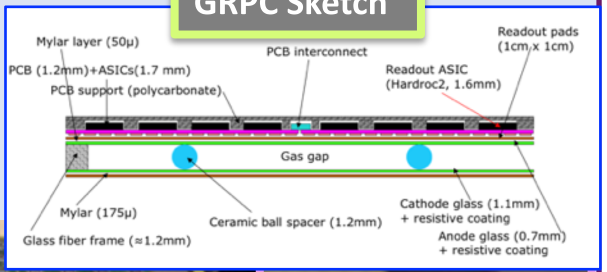
PCB separated from the GRPC by a mylar layer (50μm).

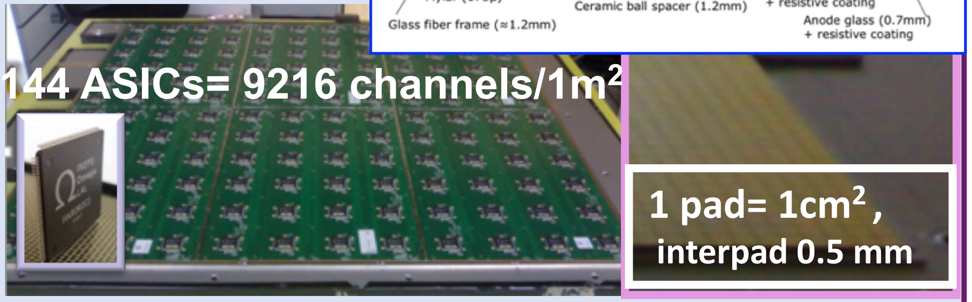
➔ Bottom: **1x1cm2 pads**

➔ Top: **HARDROC** (**HA**dronic **R**pc **R**ead**O**ut **C**hip) & related connections

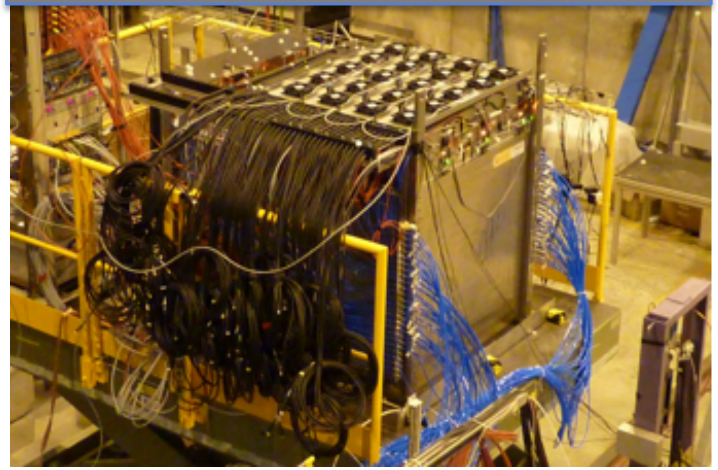
Power-pulsed electronics: In **stand-by during dead time** in between ILC Collisions or spills in beam tests

GRPC Sketch



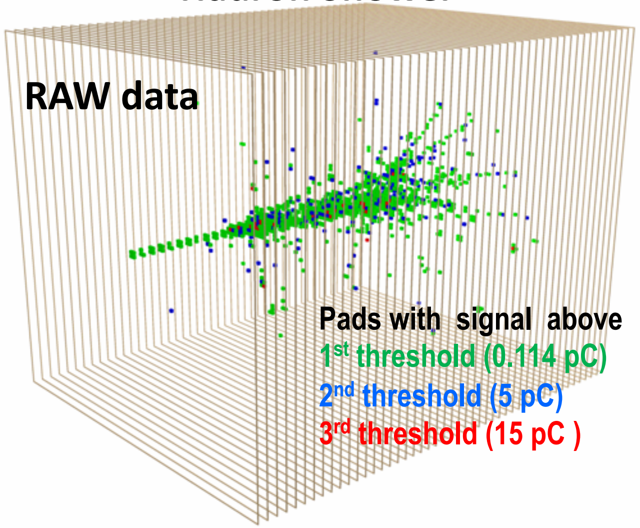


~1.3m^3 prototype at CERN Test Beam



~ half million channels!!

Hadron Shower



Excellent detailed view of shower development

SDHCAL RPC – 1m3 prototype selected results

Energy Reconstruction – SemiDigital Readout

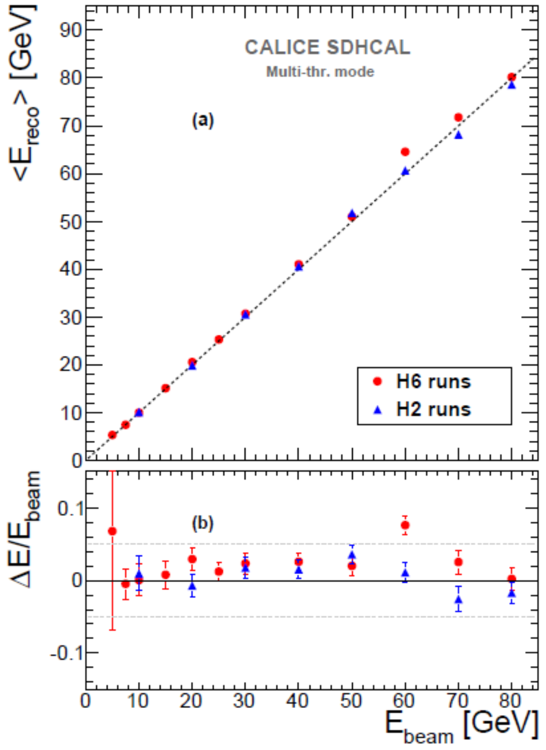
$E_{rec} = \alpha(N_{tot})\,N_1 + \beta(N_{tot})\,N_2 + \gamma(N_{tot})\,N_3$

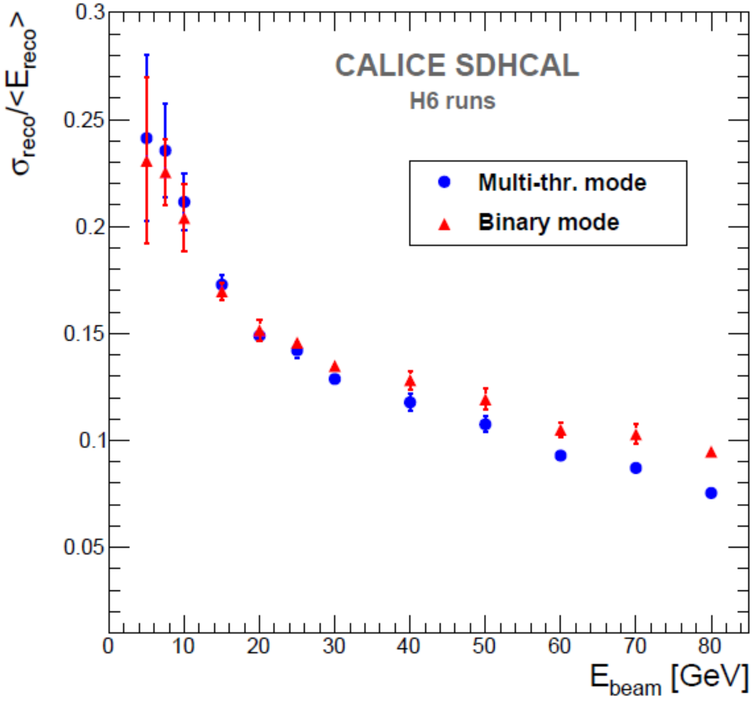
$N_{tot} = N_1 + N_2 + N_3$

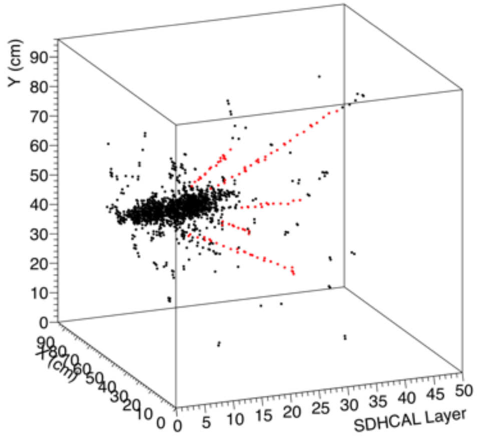
N_1 = Nb. of pads with **first threshold <signal < second threshold**
N_2 = Nb. of pads with **second threshold <signal < third threshold**
N_3 = Nb. of pads with **signal> third threshold**

α , β , γ are **quadratic functions** of N_{tot}
They are computing by minimizing

$\chi^2 = (E_{beam} - E_{rec})^2 / E_{beam}$

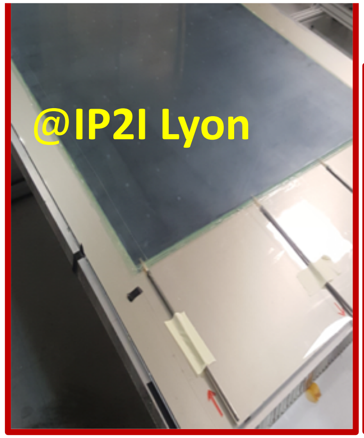


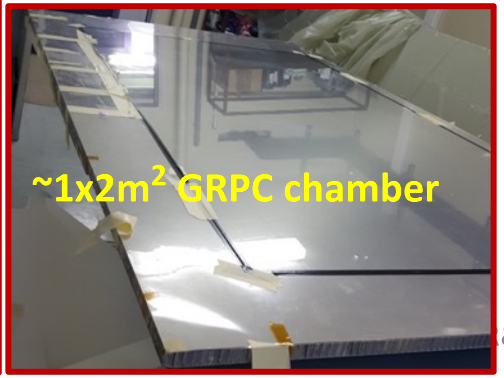




Shower track reconstruction
Using the Hough Transform

SDHCAL RPC – Towards larger prototypes





Absorber plates planarity after roller leveling

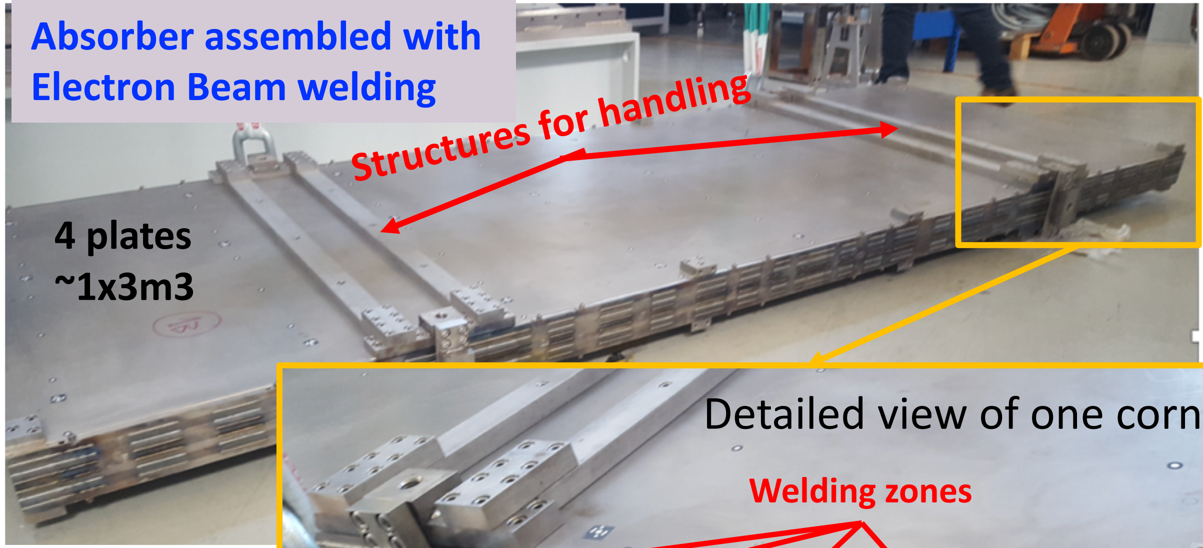
Roller Leveling

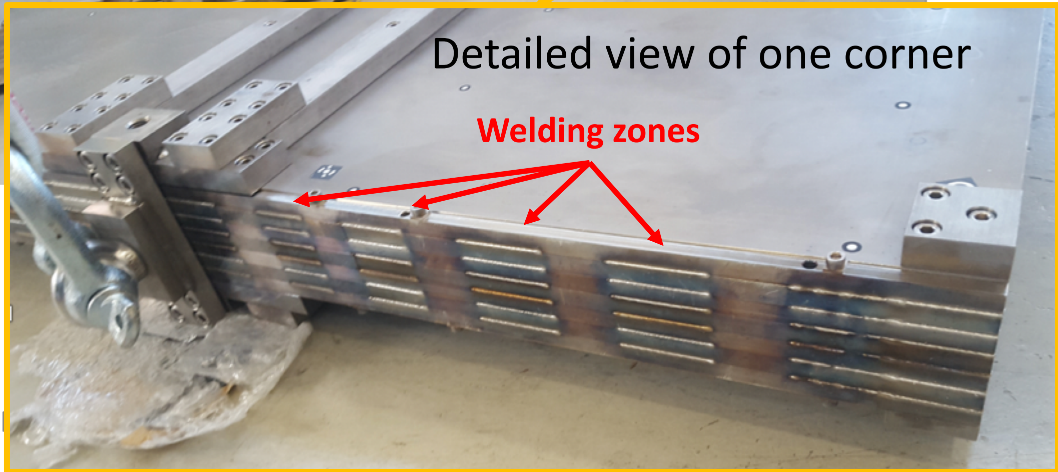
Planarity

Planarity (µm)	Plate A		Plate B		Plate C	
	Side 1 up	Side 2 up	Side 1 up	Side 2 up	Side 1 up	Side 2 up
Average	469,3	852,6	511,6	596,3	983,4	1038,0

Plate D		Plate E	
Side 1 up	Side 2 up	Side 1 up	Side 2 up
458,7	546,1	610,2	521,9

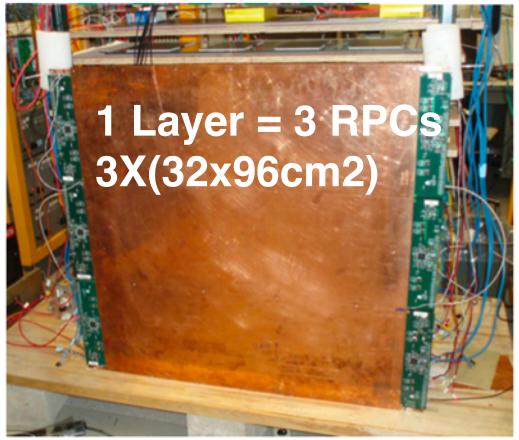
Absorber assembled with Electron Beam welding



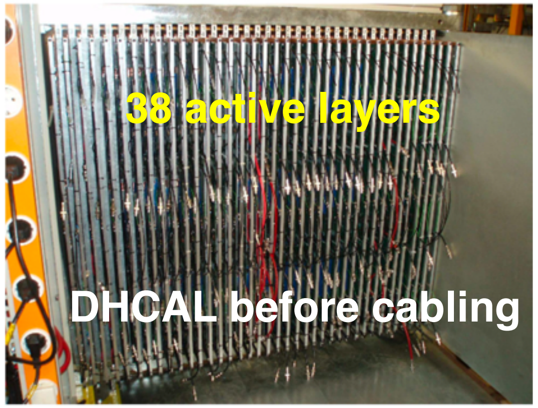


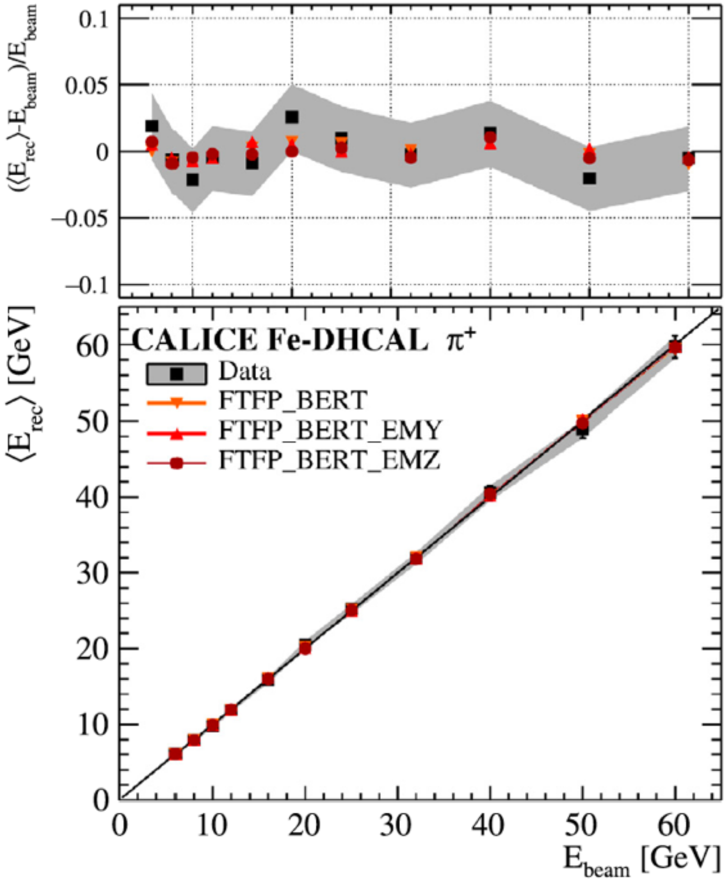
DHCAL – RPC

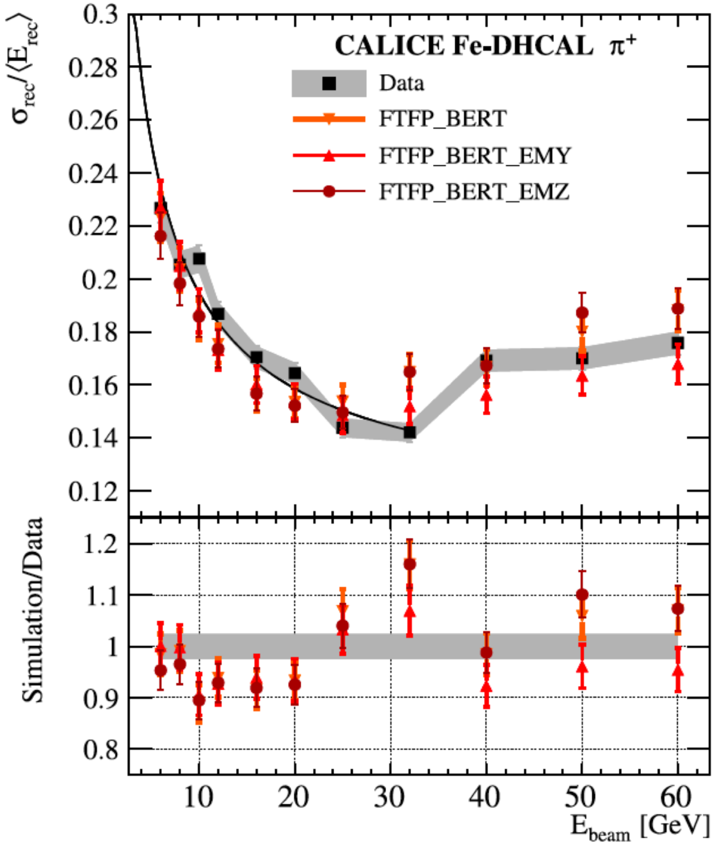
C. Adams *et al* 2016 *JINST* **11** P07007



Readout = 1 bit (digital

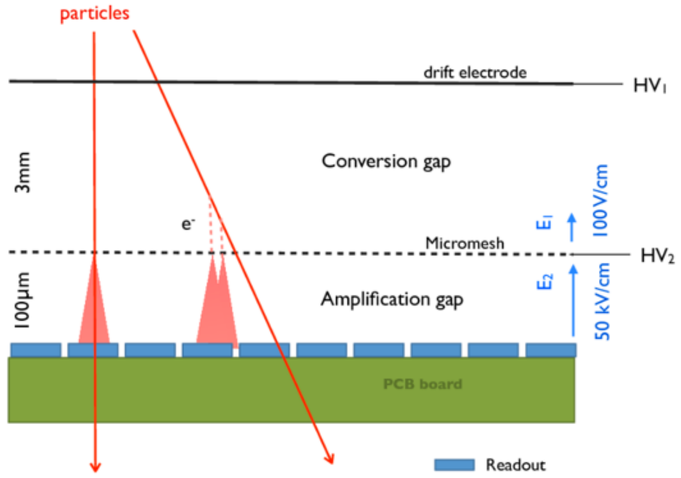






https://doi.org/10.1016/j.nima.2019.05.013

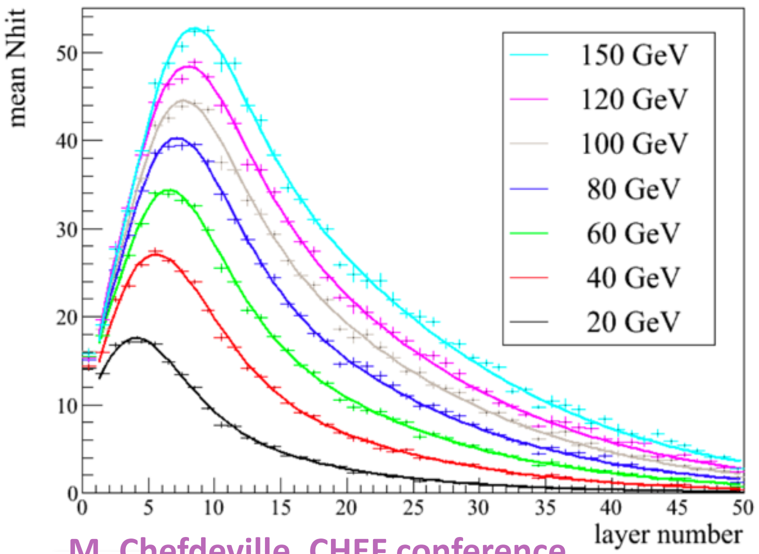
SDHCAL - Micromegas



Micromegas prototype of 1x1m2 consisting of six independent Micromegas boards

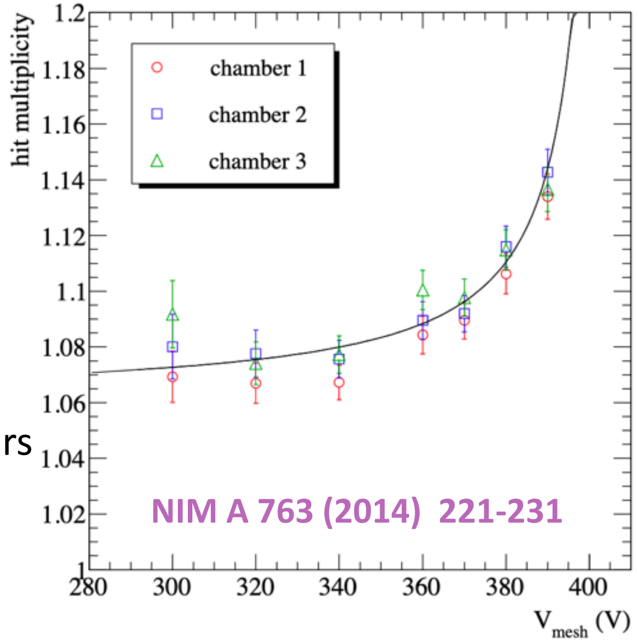
Tested together with the RCP at the SDHCAL 1m3 prototype at CERN/SPS
By substituting RPC layers 10, 20, 35 and 50 by Micromegas

Longitudinal profile of pions showers (low thr.)



M. Chefdeville, CHEF conference, Paris, 22nd-25th of April 2013

Profile was computed despite of having only 4 chambers available, thanks to the fluctuations on the shower starting layer



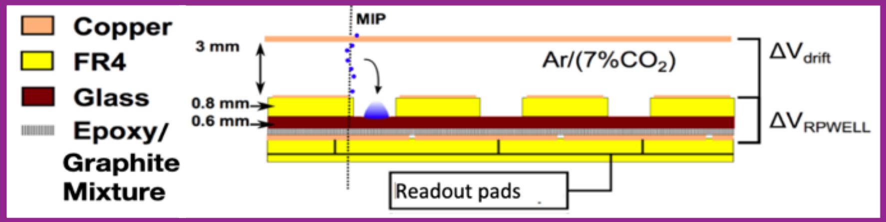
Similar performance for all chambers
Hit multiplicity ~1.1

The SCREAM project
Sampling Calorimeter with Resistive Anode MPGD

Goal: construct the first MPGD-based sampling calorimeter combining **two technologies**:

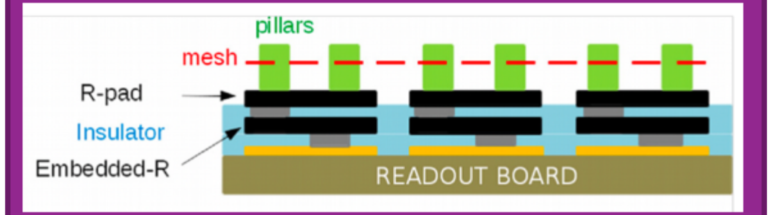
NIM A 824 (2016) 510

RPWELL



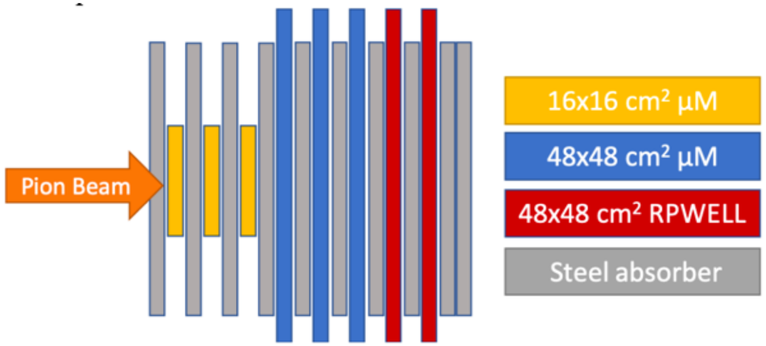
Gas mixture:
Ar:CO_2 93:7

Resistive MICROMEGAS



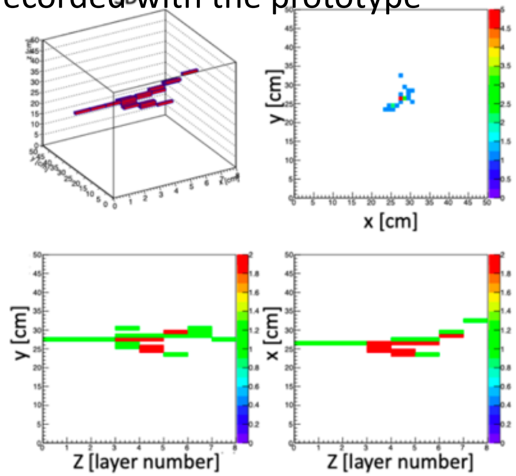
Test beam setup at CERN/PS in Aug 2018

J. Phys.: Conf. Ser.1498 012040

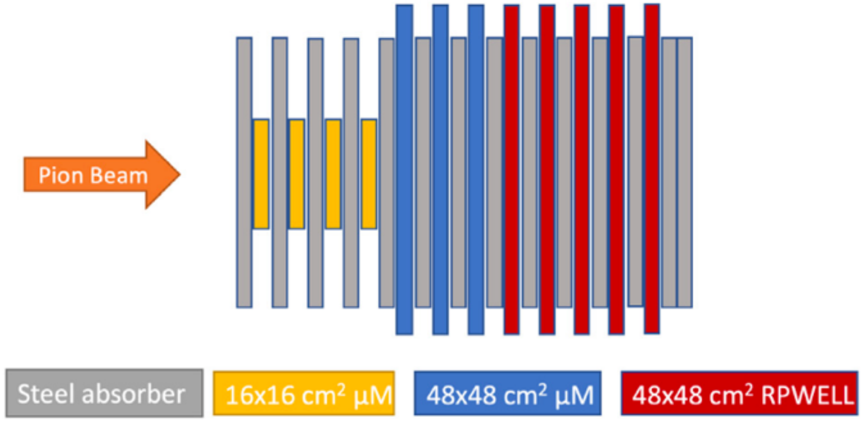


semi-digital readout electronics based on the MICROROC chip

4 GeV pion shower recorded with the prototype

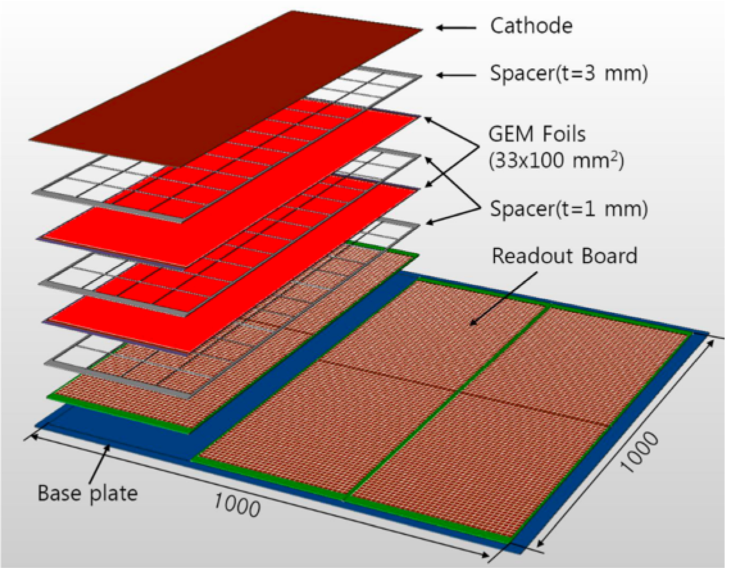


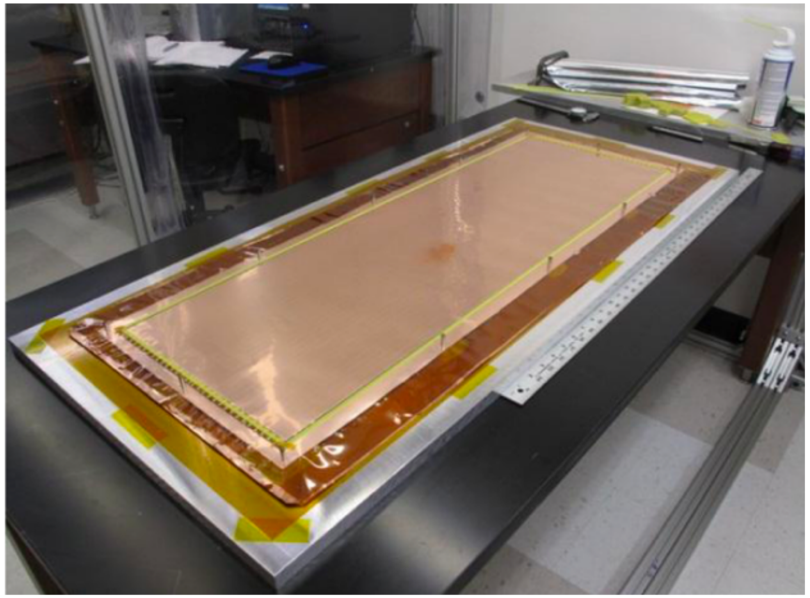
Test beam setup at CERN/PS in Nov 2018



NIMA 958 (2020), 162861

Production of GEM for DHCAL





Design for a 1m x 1 m GEM DHCAL plane, using 100x33 cm2 foils

100x33 cm2 chamber under assembly

Other things to be taken into account

- The gas mixture is an important part of the detectors.

  Some of them use greenhouse gases for improving the performance, for aging protection…

  ➔ Is important the actual R&D ongoing at CERN for decreasing the emissions and moreover for using alternative eco gases mixtures.

  In other cases mixtures as Ar/CO2 works well and are indeed being used in the detectors showed in this presentation

- The recent R&D has been done for the hadronic calorimeters, but the gaseous detectors could also be appropriate for the electromagnetic ones. Indeed, the possibility of having high lateral segmentation with a relative low cost from the point of view of the detector itself

- The R&D has been mainly oriented to e+e- colliders, but the application to hadron colliders, as the FCC-hh, experiments can be feasible, anyway extra and specific R&D is mandatory. Some gaseous detectors will operate at the very demanding conditions of the HL-LHC in the endcap high eta region (as GEM) for muon detectors but they have not yet been too much study for calorimeter putposes.

- As for any other type of calorimeter, the high precision mechanics is important, mainly for high granularity calorimeters for which we aim to achieve a demanding performance. In general is **not easy to find companies to collaborate** with for prototyping and R&D (**not all the needed machines are available at the lab workshops**, **mainly for the heavy and big pieces of what we call "small" prototypes)**


THANK YOU
FOR YOUR
ATTENTION