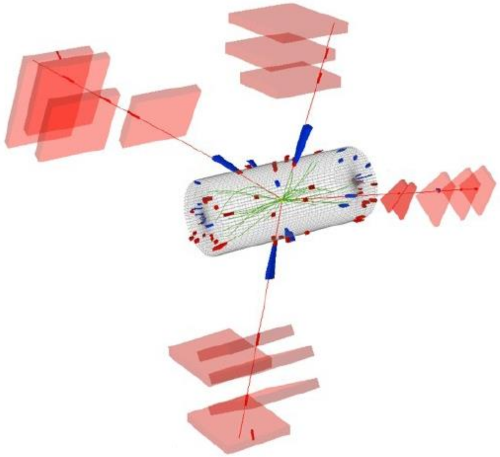
Muon detection and identification challenges:
Possible technology evolution over the next two decades



Marcello Abbrescia

with the contribution from:

R. Cardarelli, P. Iengo, O. Kortner, M. Titov, S. Vlachos

First Annual FCC Meeting

Introduction: goals for this talk

➢Understand the guidelines for the design of the muon system for FCC-hh

i.e. would we be able to design a muon system for FCC-hh now?

Many questions:

➢Can a single detector technology be used:

✓for tracking and triggering

✓for all muon subsystems (barrel/endcap/very-forward)

(this is NOT the current choice)

➢Is a single technology the correct choice in any case?

➢Is(are) this technology(ies) available now?

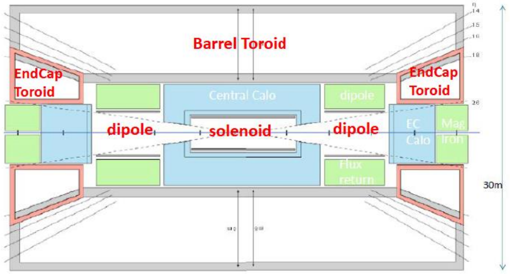
or

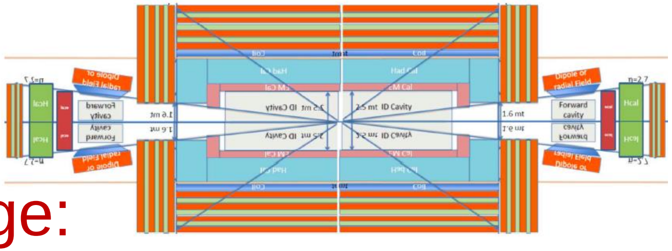
➢Which is the path for the optimizion of the present technologies or the development of new ones?

Muon systems detectors at FCC-hh

Let us consider the “worst” conditions foreseen at the moment:

✓L= 2.5 ÷(5) x 10^{35} $cm^{-2}s^{-1}$
✓Bunch Crossing = 25 ns, or 5 ns
✓Pile Up 900@25 ns, 180@5 ns BC separation
✓20 ab^{-1} integrated luminosity

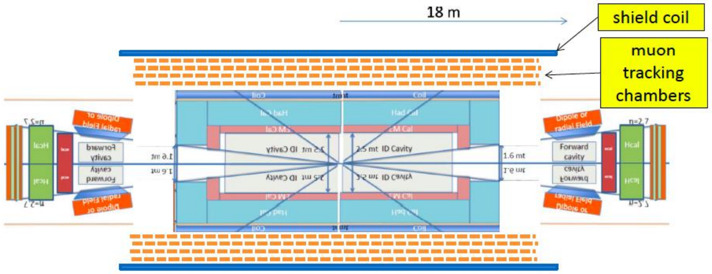




Muon systems for FCC-hh will be very large:

Considering a large solenoid (similar order of magnitudes in other cases as well)

✓o(10000) m^2 in the barrel
✓~ 3000 m^2 in the endcap
✓~ 300 m^2 in the very forward



➢Given the requirement on the area, almost unthinkable to use technologies different from gaseous detectors.

Muon systems detectors at FCC-hh

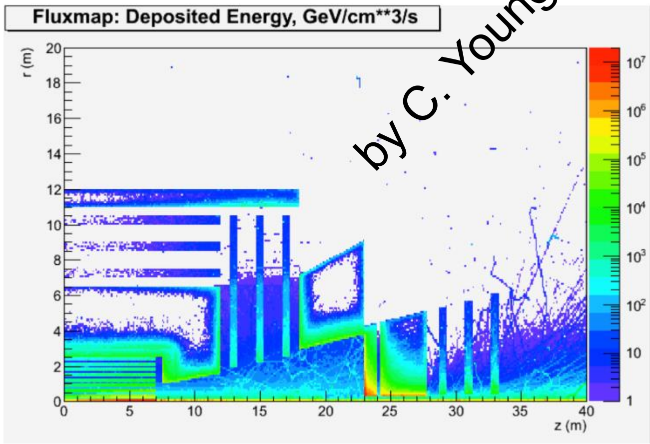
Have to provide Bunch Crossing identification

✓time resolution ≤ 1 ns for 5 ns BC

✓time resolution ≤ 7 ns for 25 ns BC

✓o(100) ps could be desirable for specific applications:

- ➢Time structure of the event, Pile Up mitigation, Muon tagging
- ➢Generally difficult to achieve, requires a strong physics case



Have to operate in high background

(very large uncertainties depending on shielding, actual structure,ect)

✓o(few kHz/cm^2) in the barrel

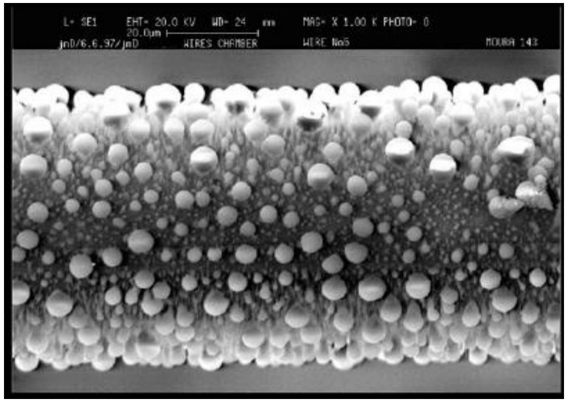
✓o(10-50 kHz/cm^2) in the endcap

✓Even more o(100 kHz/cm^2) in the forward regions,

by C. Young

	Barrel Shielded	Barrel Unshielded	Endcap
Dose (Gy/year)	50	500	
Fluence (KHz/cm^2)	5	250	

Muon systems detectors at FCC-hh



Have to operate for ≈ 20 years

✓Aging issues to be carefully considerated

✓Detector will be exposed to a radiation level about 10 times higher than HL-LHC@same presudorapidity (2x higher cross section, 4x higher peak luminosity)

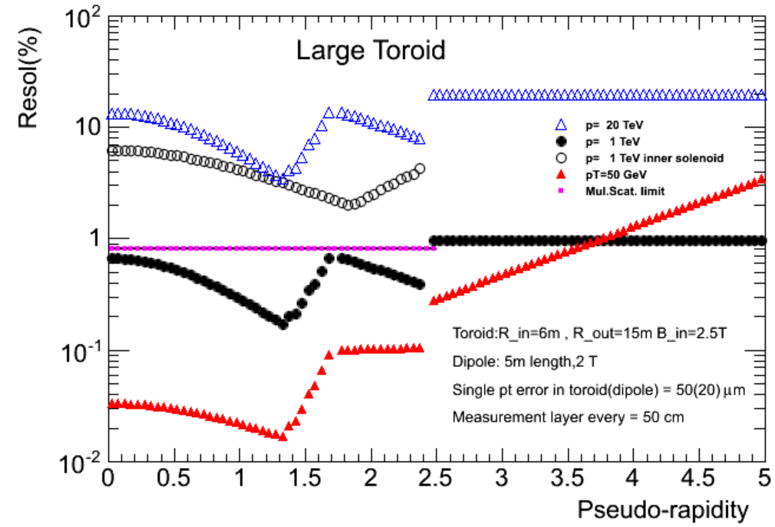
- ➢10-25 C/cm for wire chambers
- ➢3 C/cm^2 for RPC

✓None of the present detectors have been tested up to those values

Have to provide tracking capabilities(?)

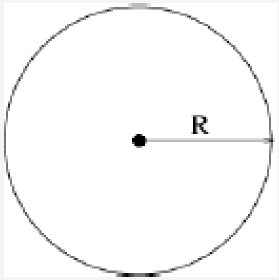
…in certain positions/scenarions,
or this will be provided by the inner tracker?

✓20-50 μm or better spatial resolution to provide 10% p_T resolution at a few TeV

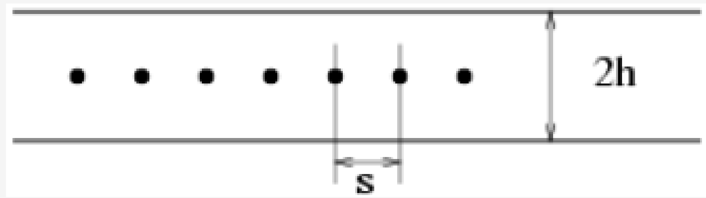


Gaseous detectors technologies@LHC

Geiger- Müller (1908), 1928
Drift Tube (1968)

1) 

G. Charpak, 1968
Multi Wire Proportional Chamber

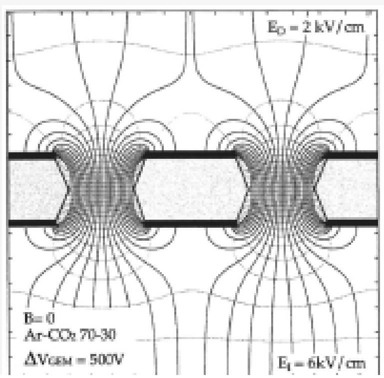
2) 

R. Santonico, 1980
Resistive Plate Chamber

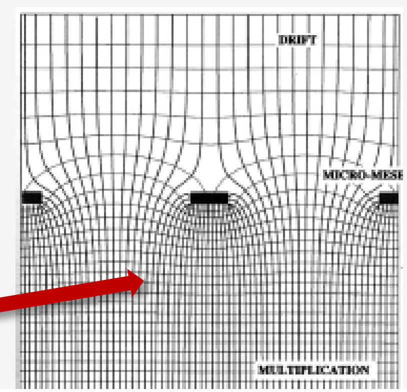
3) 

… will at HL-LHC be joined by:

F. Sauli (1997)
Gas Electron Multiplier

4) 

I. Giomataris et al. (1996)
Micro-mesh gaseous chamber (Micromegas)

5) 

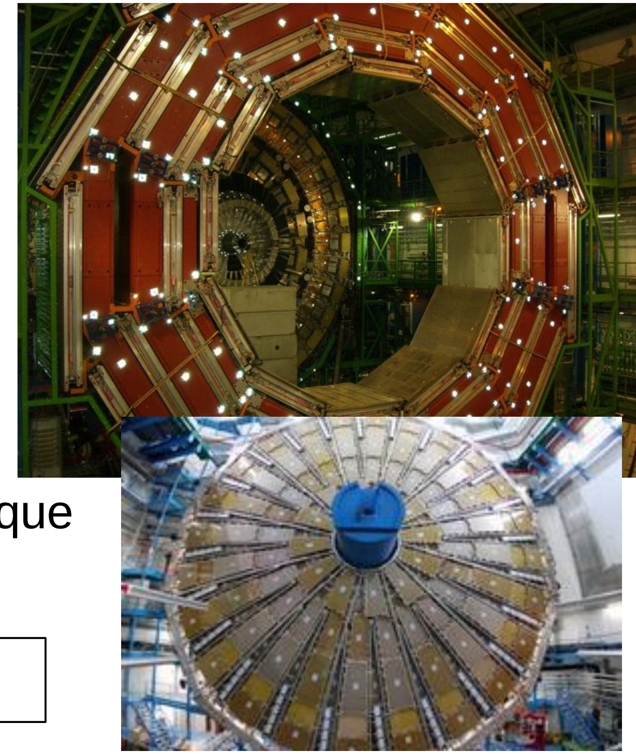
… Which will be the first examples of Micro Pattern Gas Detectors used to cover large surfaces: o(100m^2)

Resistive Plate Chambers

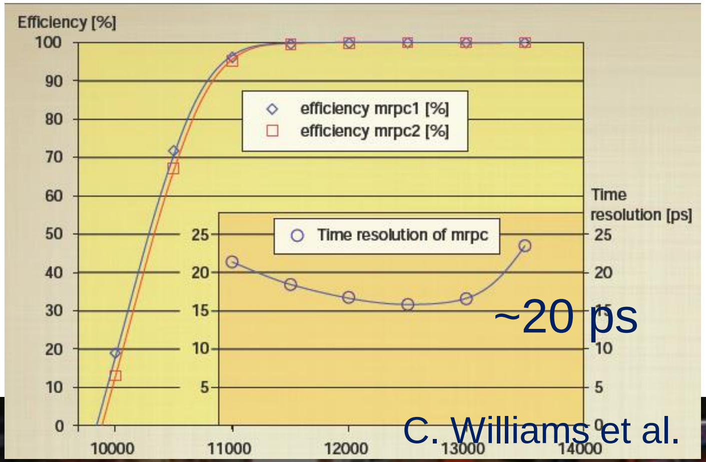
- ➢Used in all major experiments @LHC
  - ✓A lot of running experience accumulated
- ➢Adapt to cover large surfaces
- ➢Simple, robust, easy to use

They are unique in the world of gaseous detectors in the sense that their whole volume is active for avalache multiplication

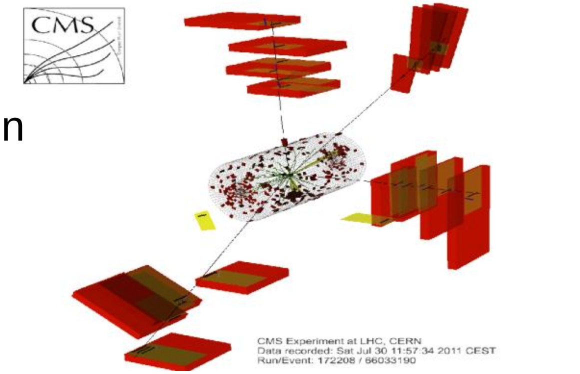
Parallel plate detectors seem –at the moment- the unique technology able to provide a ≈ 1 ns time resolution



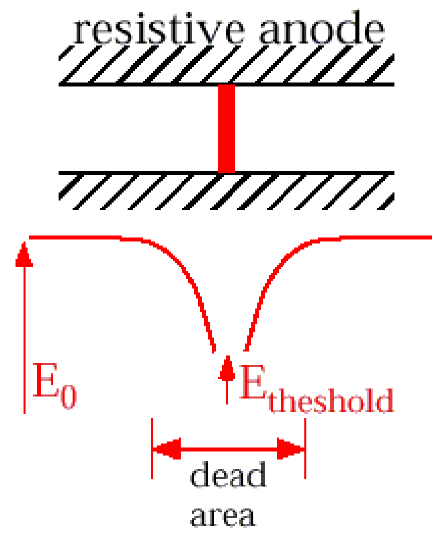
Difficult to imagine a Muon System without them



- ➢In the mulitigap configuration even < 50 ps time resolution reacheable
- ✓Maximum time resolution ever!



RPC: performance increase



- Being resistive devices (by definition) they are intrinsically characterized by a time constant: τ ~ρε
- Rate capability has been their historical "limit"
  - originally used for cosmics rays experiments

- The issue is to improve rate capability

✓ from o(100 Hz/cm^2) → LHC "now"
(R&D performed at mid 90s)
- to o(1 kHz/cm^2) →HL-LHC
- to o(10 kHz/cm^2) → FCC-hh

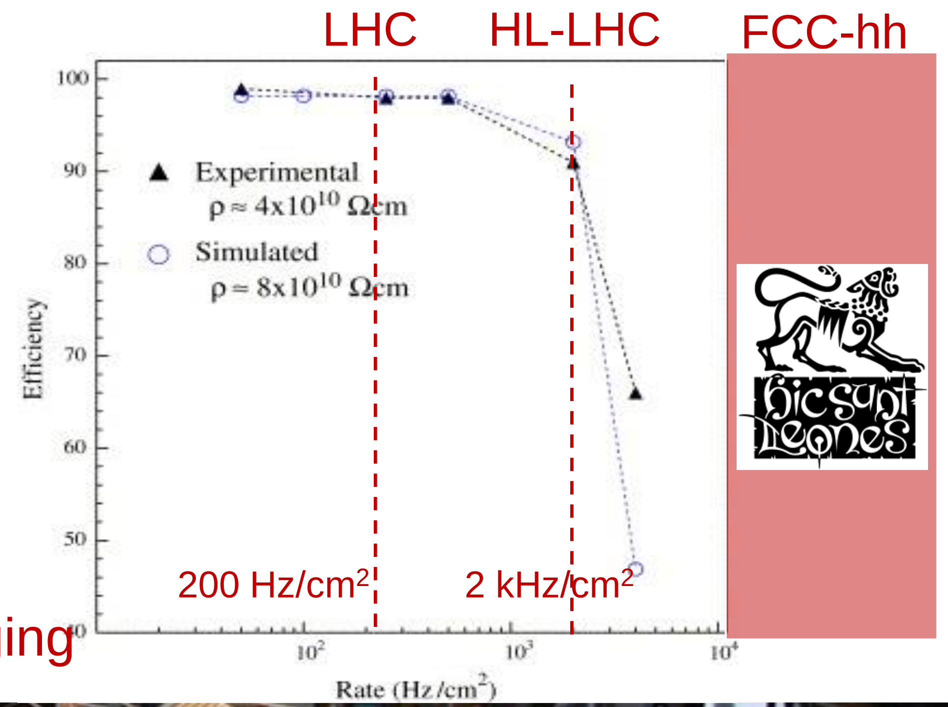
Many possible solutions under study

✓Still waiting for the final "blessing" from the experiments

✓Extensive tests at GIF++ planned for 2015-16

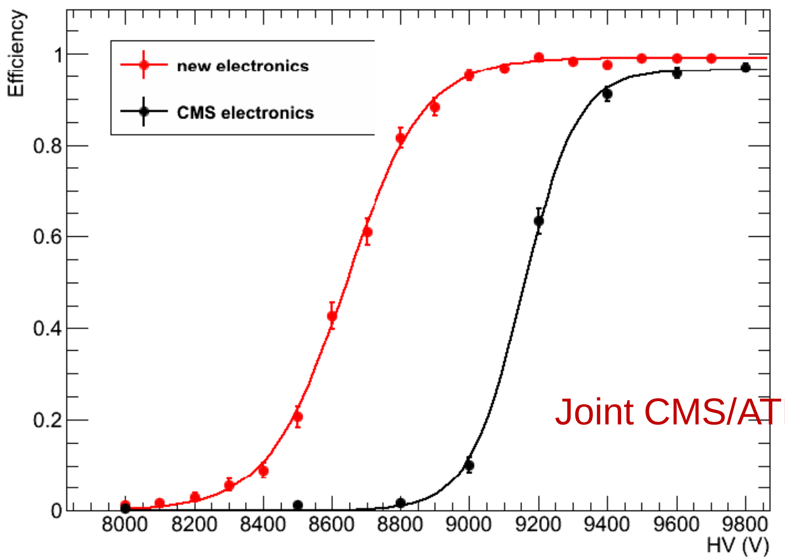
Not difficult to reach it istantaneously

- But to keep it for 20 years without aging



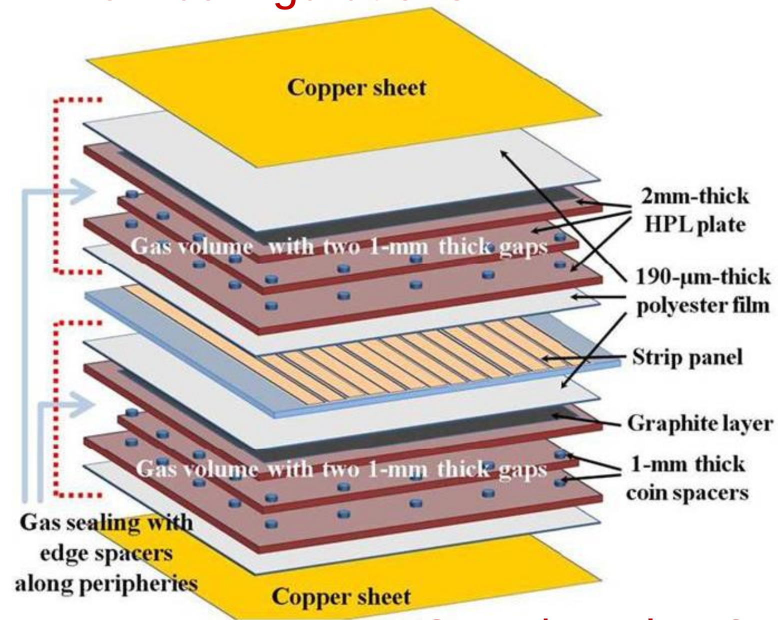
RPC: Possible solutions

New electronics



Joint CMS/ATLAS R&D

New configurations



S. Park et al., KODEL

- ➢Transfer part of the needed amplification from gas to front-end electronics

…like it was done in 1990s

- ➢Use more gaps
- ➢Smaller gap/electrode thickness

to optimize the induced signal/charge ratio

- ➢Use other materials: glass, lower resistivity bakelite

Very nice overview talk by R. Santonico during last ECFA HL-LHC workshop

Are these solutions adapt also for FCC-hh?

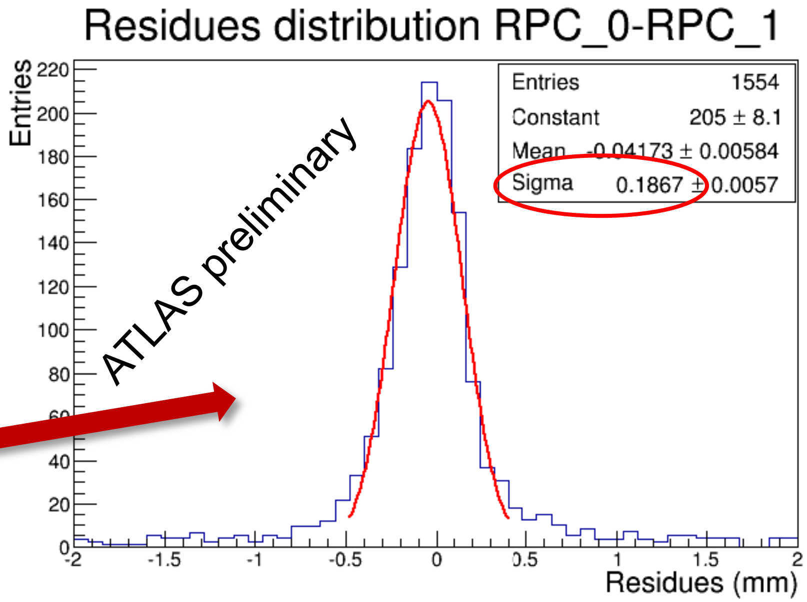
RPC: Interesting features

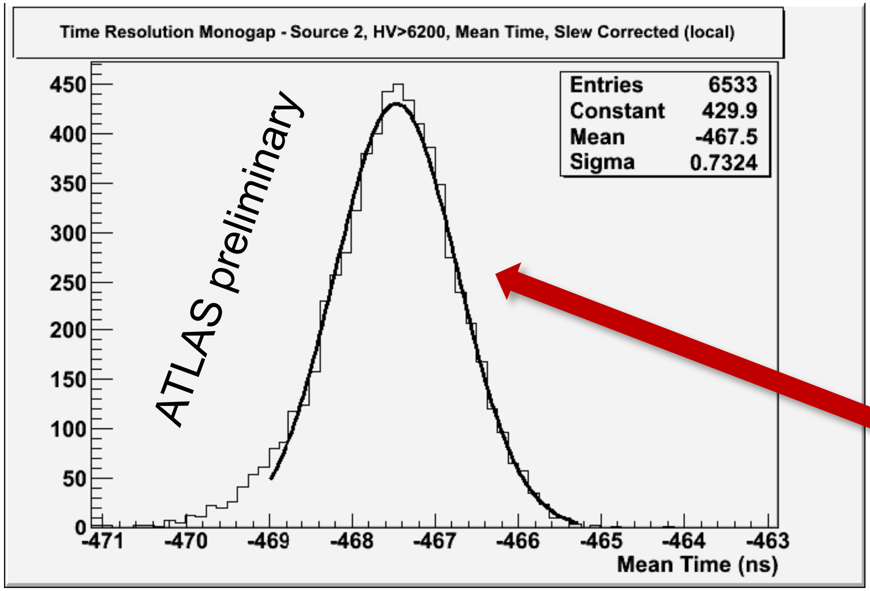
Avalanche dimensions similar in many gaseous detectors

✓This suggests that high space resolution can be also reached in RPC, with appropriate strip pitch and electronics

Spatial resolution with the centroid method

$\sigma_{s,\ intrinsic} \sim 100\ \mu m$





Time resolution depens heaviliy on the gap thickness

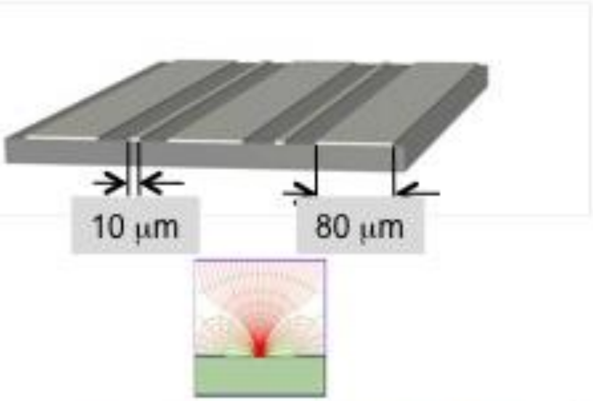
✓Performance increase can be obtained with slight modifications to the present design

Time resolution with 1 mm single gap RPC

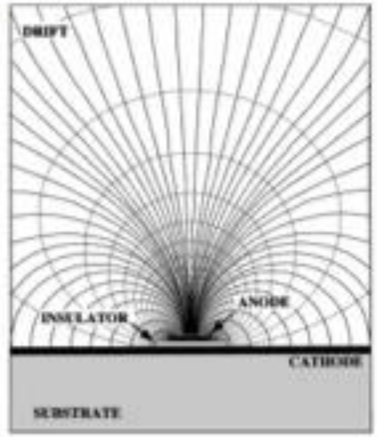
$\sigma_t \sim 0.5$ ns

The MPGD zoo of the 90s

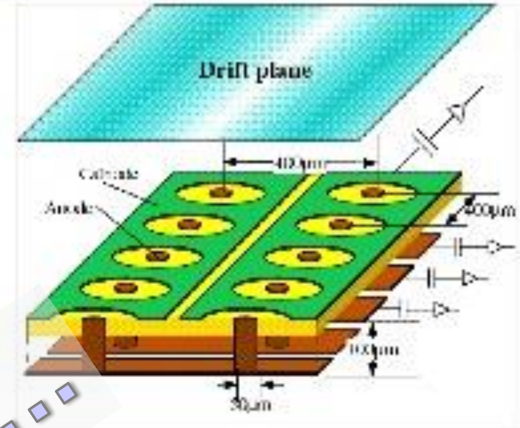
Microstrip Gas Chamber
[A. Oed, NIM A263, 351 (1988)]



Microgap Chamber (MGC)
[F. Angelini et al., NIM A335, 69 (1993)]



Microdot Chamber
[S.F. Biagi et al., NIM A361, 72 (1995)]

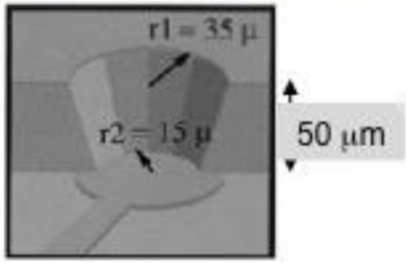


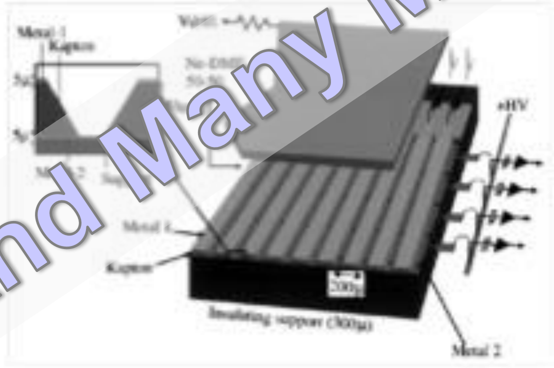
Compteur à Trous (CAT)
[F. Bartol et al., J. Phys. III 6, 337 (1996)]

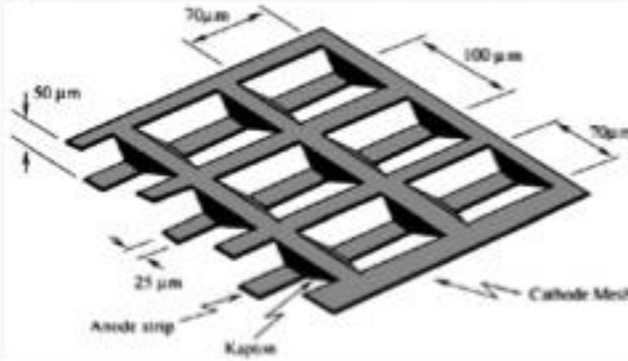
Micro Groove Counter [illegible]
[Bellazzini et al., NIM A42[illegible] (1999)]

Micro Wire Detector
[B. Adeva et al., NIM A435, 402 (1999)]

WELL Detector (µCAT)
[R. Bellazzini et al., NIM A423, 125 (1999)]



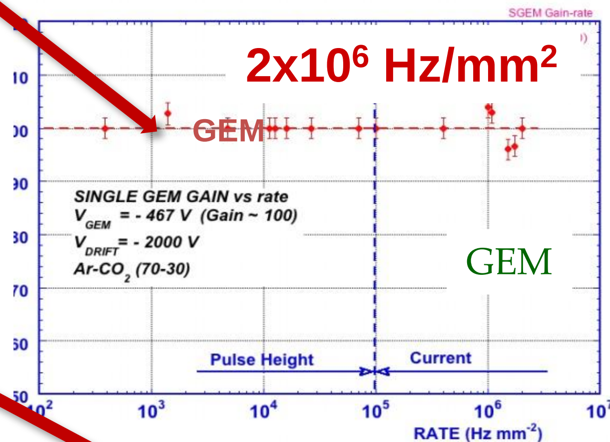


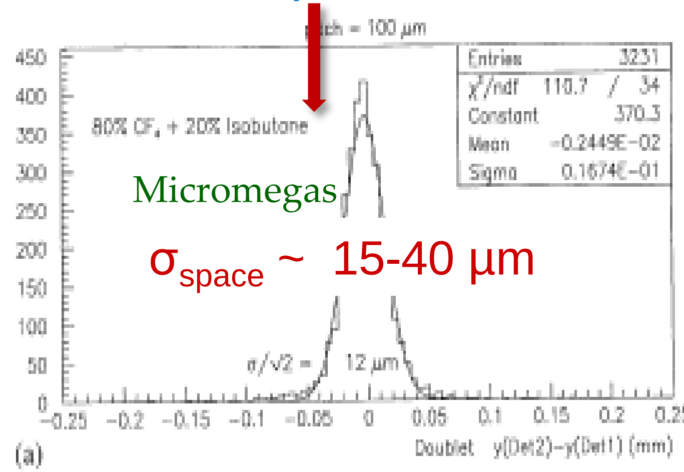


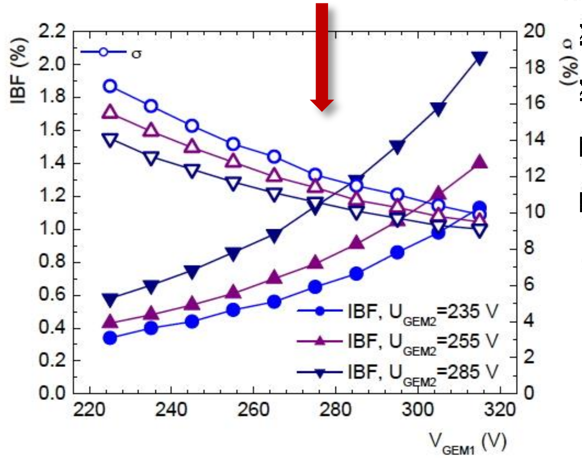
And Many More ….

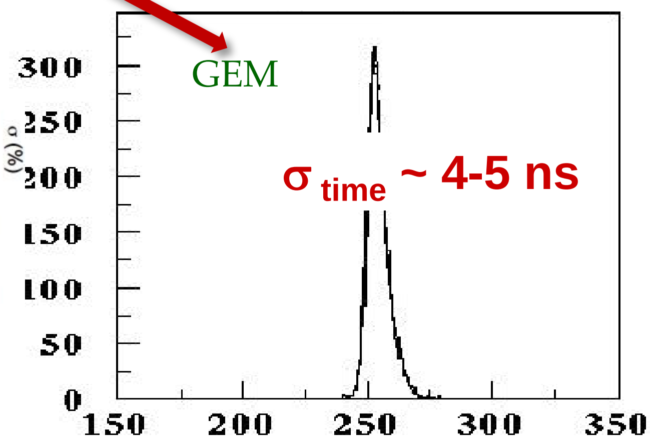
Why Micro-Pattern Gaseous Detectors are attractive for FCC-hh

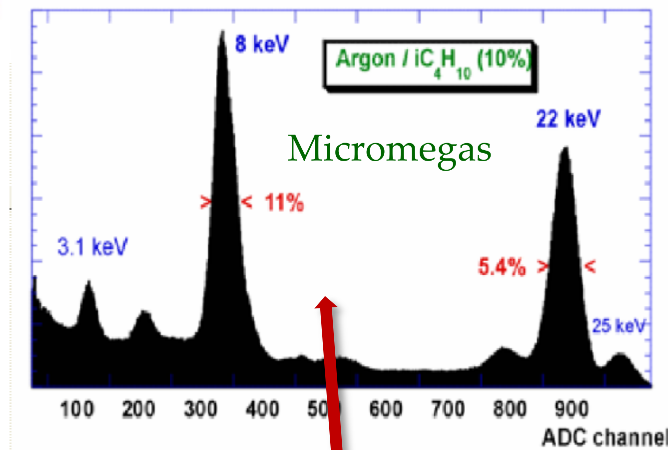
- ✓ High rate capability
- ✓ Excellent radiation hardness
- ✓ Large active areas / industrial production
- ✓ Good timing resolution
- ✓ Ion backflow/photon feedback reduction
- ✓ Excellent spatial resolution
- ✓ Good Energy Resolution







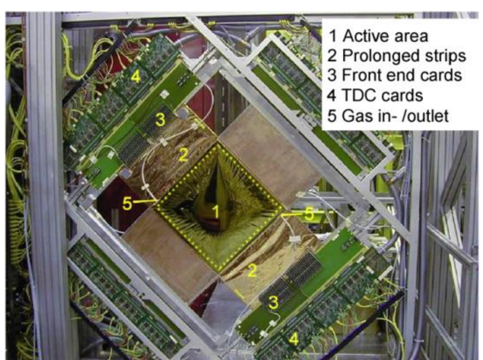


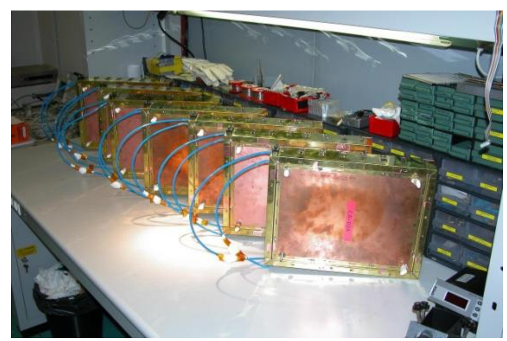


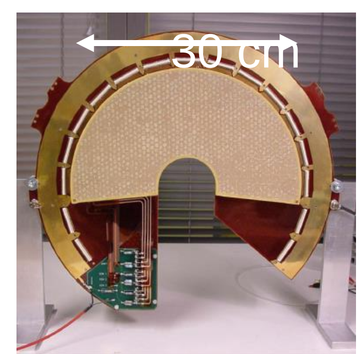
MPGDs in running experiments

Exp.	#	Type	Readout	# of ch.	Size (cm^2)	Gas	σ_{space} (μm)	σ_{time} (ns)	ε (%)
COMPASS	22	GEM	2-D strips	1536	31×31	Ar/CO_2 (70/30)	70	12	>97
	12	MM	1-D strips	1024	40×40	$Ne/C_2H_6/CF_4$ (80/10/10)	90	9	>97
LHCb	24	GEM	pads	192	10×24	$Ar/CO_2/CF_4$ (45/15/40)		4.5	>97
TOTEM	40	GEM	pads + strips	1536 + 256	30 × 20	Ar/CO_2 (70/30)	~70 (θ)		>92

MPGDs have accumulated a lot of running experience with excellent results… but







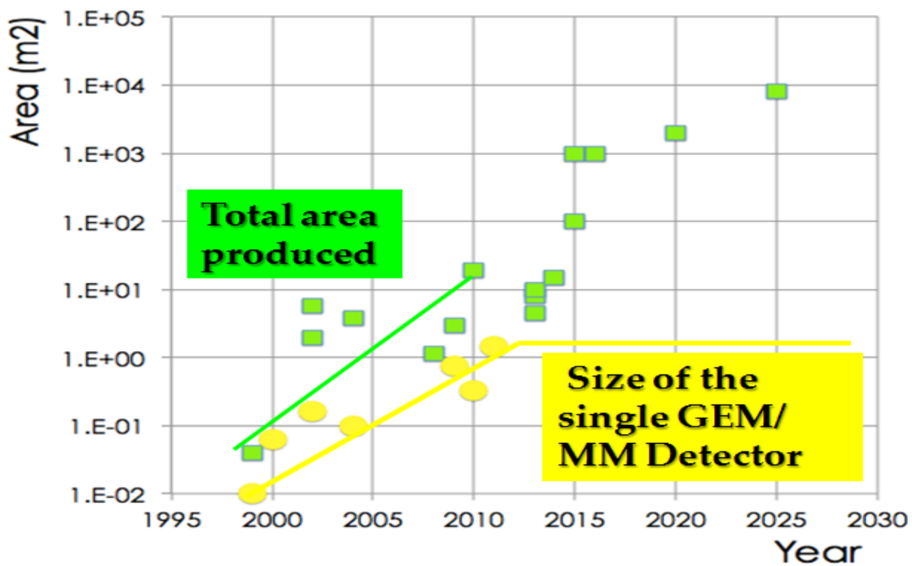
Trends: Micro Pattern Gas Detectors

Increase covered surface!

MPGDs are now a mature technology

- ✓Thanks also to synergic efforts like RD51
- ✓They exist in different form
- ✓Important technological breaktthrougs

Advances in photolithography → Large Area MPGDs (~ m^2 unit size)



	Detector surface	Foil Area
LHCb Muon system (now)	0.6 m^2	4 m^2
ALICE TPC	45 m^2	180 m^2
CMS Muon system	335 m^2	1100 m^2
ATLAS (MMs)	140 m^2	560 m^2

GEMs

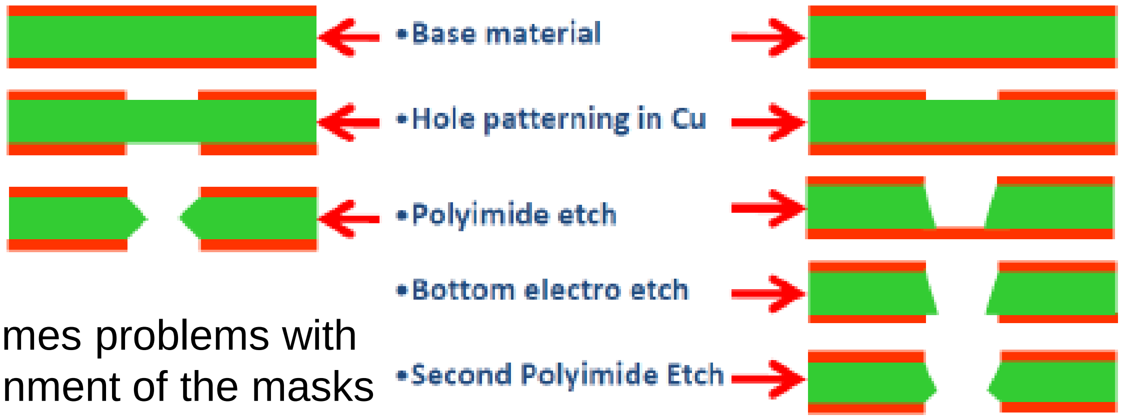
Use of MPGDs in ATLAS, CMS, ALICE is a huge step forward

In FCC-h MPGDs could be quite useful in regions where rate is too high for RPCs and tracking is needed

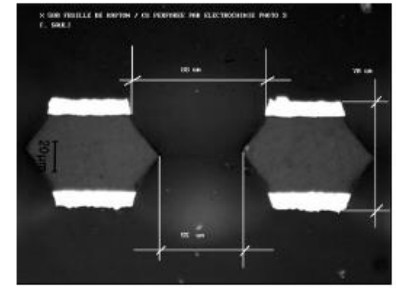
Achieved 40x40cm^2

GEMs: Technological breakthroughs

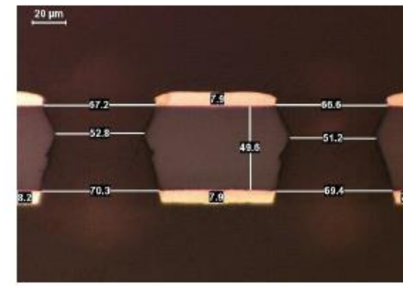
Single side etching technique



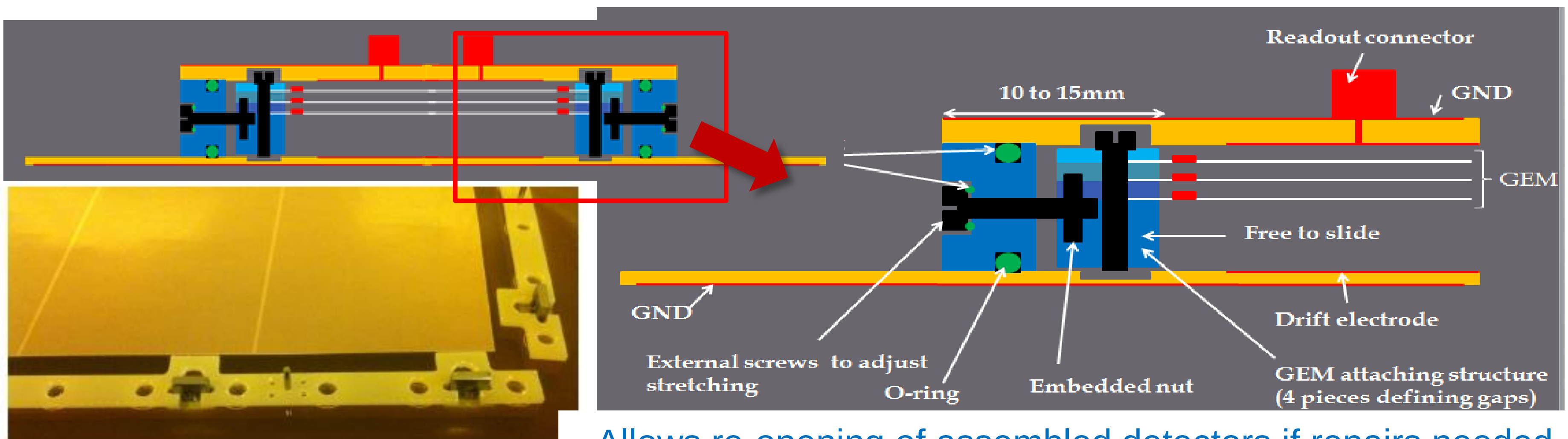
Overcomes problems with the alignment of the masks



Achieved 200x60cm^2



Stretching assembly technique without glue without spacers (CERN)



Allows re-opening of assembled detectors if repairs needed

MMs: technological breakthroughs

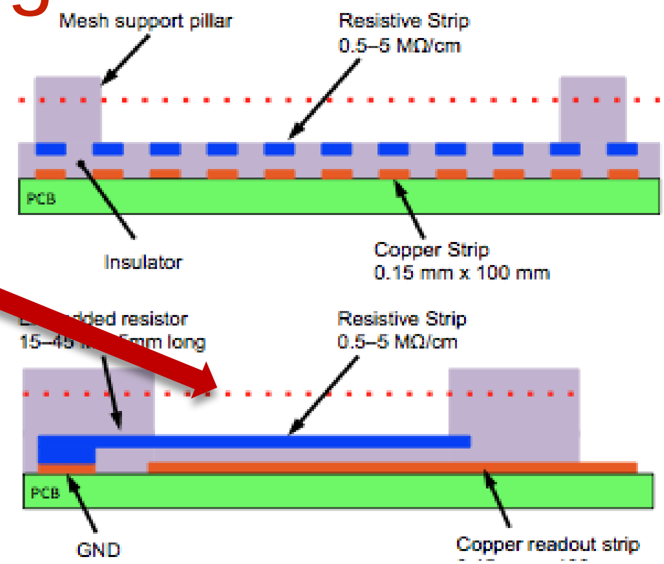
Resistive strips for spark immunity

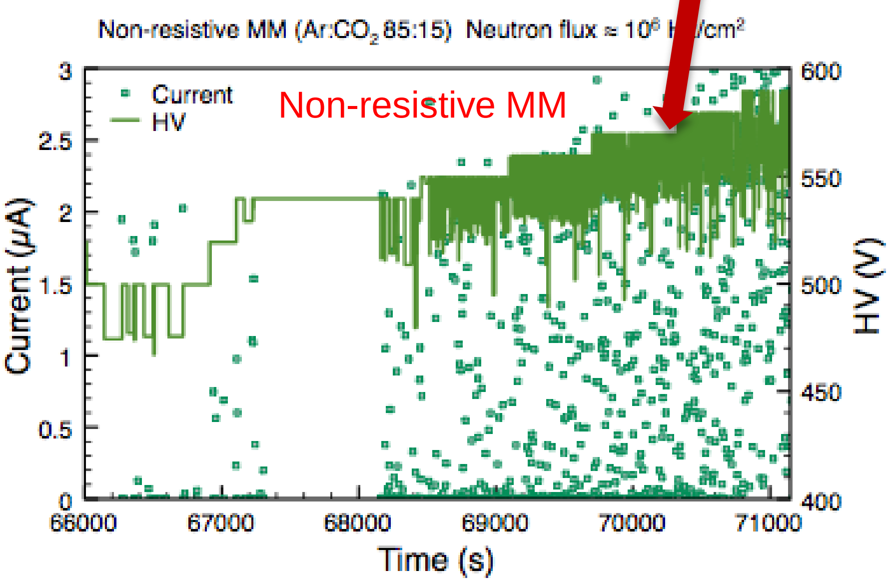
➢ Same principle as resistive plates devices:

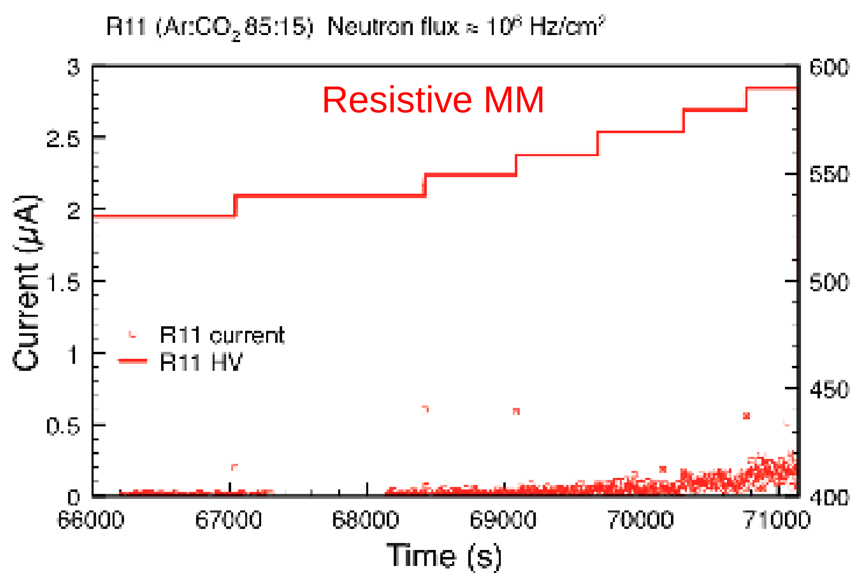
✓ Put resistive strips on top of the readout (conductive) strip

✓ electric field is locally dumped in case of large discharges

Voltage drops due to small discharges drastically reduced







Wire chambers for FCC-hh

They are widely used in the LHC experiments to provide muon tracking

➢Will this be required @ FCC-hh?

Chamber type	Rate Capability	Spatial resolution
Thin gap chambers	500 Hz /cm^2	2 mm
Cathode strip chambers	few kHz/cm^2	40 µm
CMS drift-tube chambers	≈500 Hz/cm^2	70 µm
ATLAS MDT chambers	≈500 Hz/cm^2	35 µm

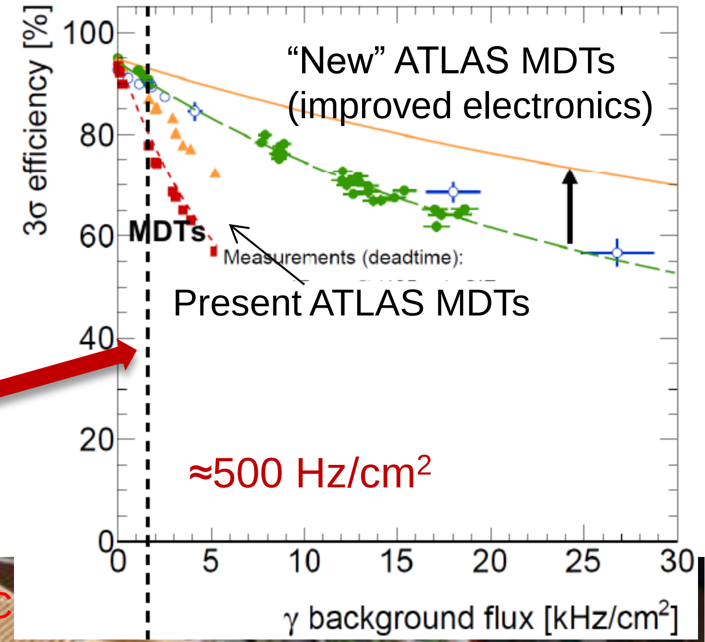
✓They can provide good space resolution

Over large surfaces at reasonable cost

✓Good understanding of the aging processes

Aging is not the limiting factor

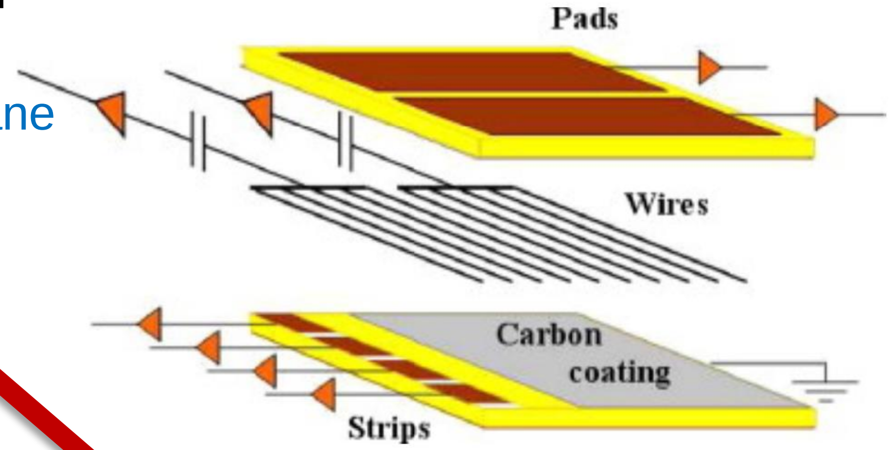
However they are approaching their limits in the present design in terms of rate capability



Small strips thin gap chambers (sTGC)

sTGCs are an evolution of the existing TGC optimized for

- ➢High rate capability up to 20 kHz/cm^2
- ➢High spatial resolution ~100 µm per wire plane

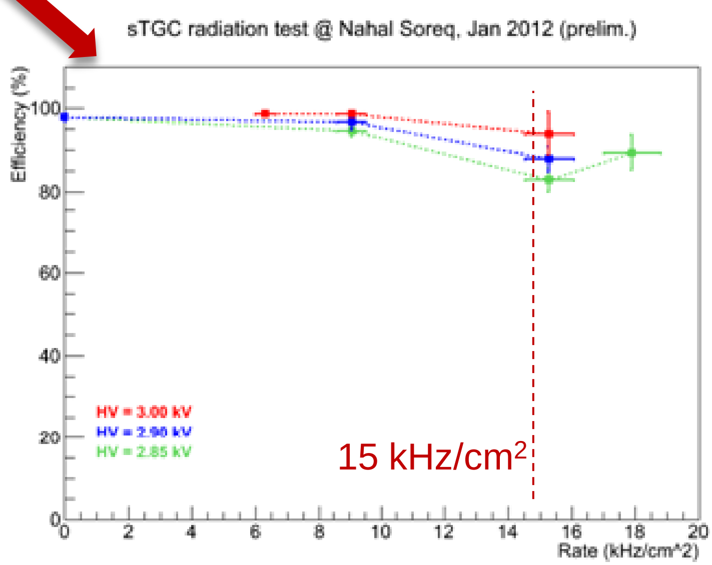


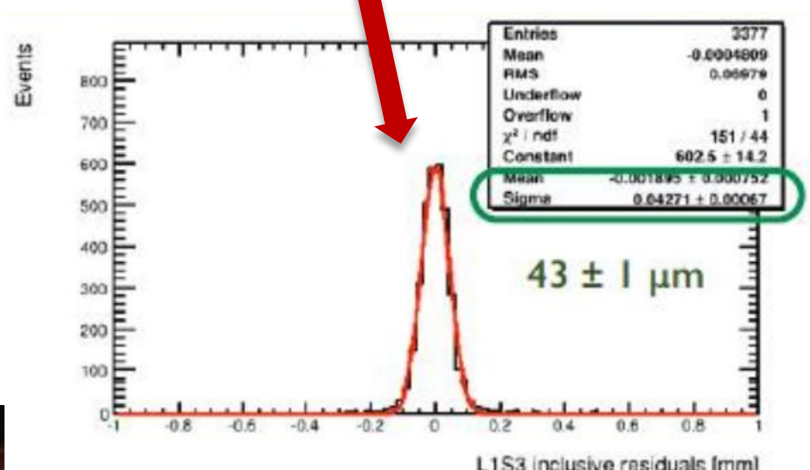
High rate capability is achieved by:

- ✓Low surface resistivity coating
- ✓Increased capacitance between strips and cathod (same transparency)

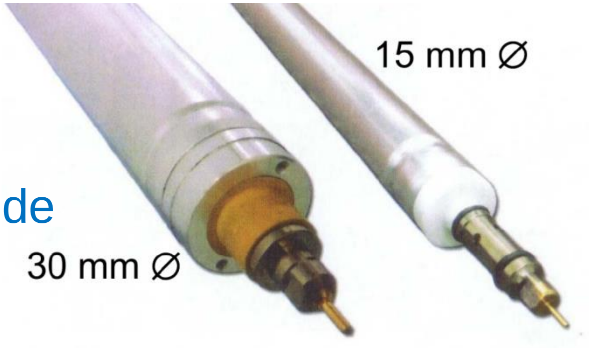
High spatial resolution achieved by:

- ✓Small strip pitch (3.2 mm)
- ✓Use of the charge centroid method
- ✓Better alligment of the strips of the layers



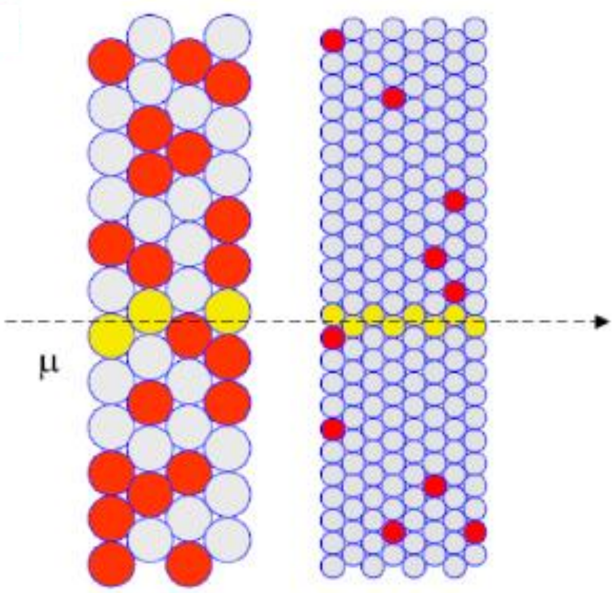


ATLAS sMDT



Change tube parameters + improve electronics

- ➢ Drift tube diameter reduced by a factor 2: MDT → sMDT
  - ✓Increase rate capability by almost an order of magnitude
  - ✓Chamber thickness reduced by a factor 2
  - ✓Occupancy reduced by a factor 8
  - ✓Improved signal/background ratio

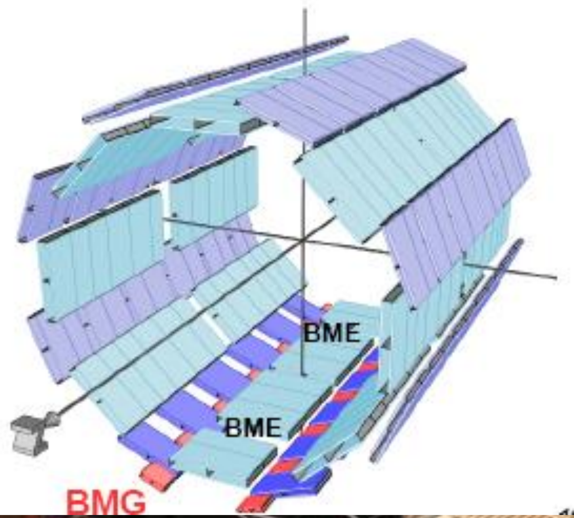


Advantages:

✓Reuse and optmize of the present proven technology (no aging up to 6 C/cm)

✓Full compatibility with existing services, software and alignement system

Will be used to complement or replace MDT chambers where needed



Synergies: common issues

There are common issues that are naturally dealt with in a common approach

Example: the Quest for Eco-Gas

Due to the new regulations deriving from the Kyoto protocol the use of components of RPCs ($C_2H_2F_4$) and GEMs (CF_4) gas mixtures might be restricted

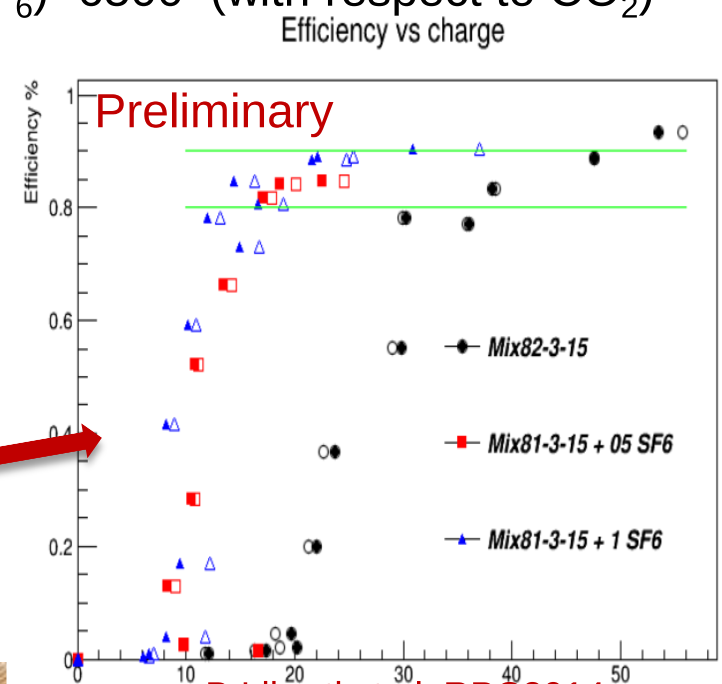
- Essentially due to their high (limit being <150) Global Warming Power:

$GWP(C_2H_2F_4) = 1430$ $GWP(CF_4)=6500$ $GWP(SF_6)=6500$ (with respect to CO_2)

A long R&D program is needed to analyze all the proposed gases and variants

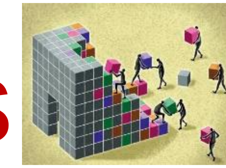
Test already started in various laboratories around the world (CERN, Frascati, Ghent, Rome, …) in a synergic way

One of the gas mixtures tested:
$Ar/C_4H_{10}/TP$ 83-3-15 with increasing % of SF_6



B.Liberti et al, RPC2014

Synergies: common test facilities

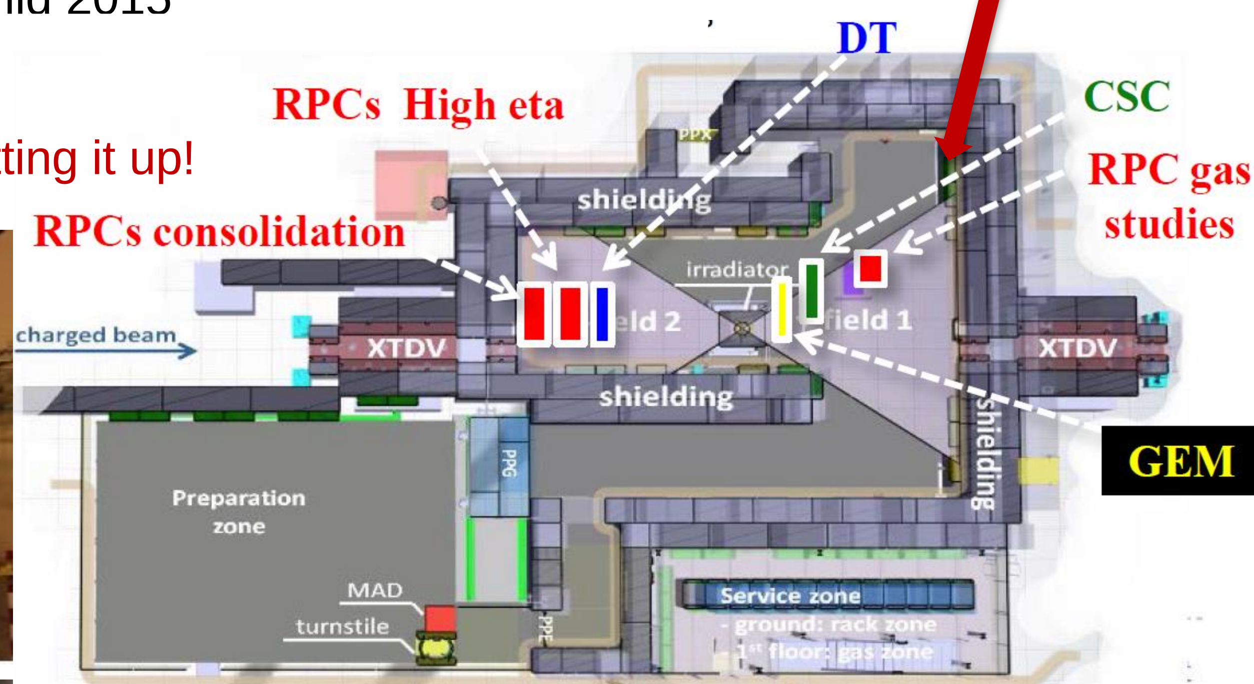


The set-up of a facility to test the new generation detectors in conditions as similar as possible to the ones foreseen in the future experiments s mandatory

- ➢ i.e. irradiation on the whole detector surface (to simulate photon and neutron background) provided by a 16.7 TBq ^{137}Cs source
- ➢ Detection performance on muons from the SPS beam
- ✓ Plan to be operational in mid 2015

The GIF++ as we want it

The GIF++ as it is now:
many thanks to the people setting it up!



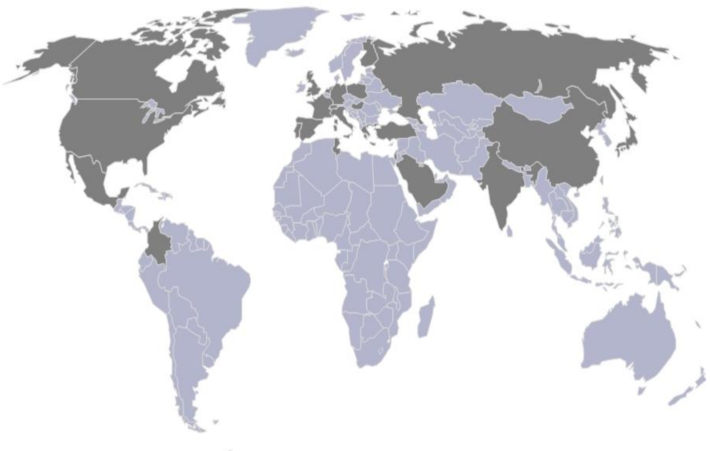
Synergies: sharing ideas

RD51 MPGD collaboration

✓Environment where groups performing R&D on various detectors meet
✓Where simulation people meet with experimentalists
http://rd51-public.web.cern.ch/rd51-public/Welcome.html

~500 Authors from
91 Institutes from 25 Countries

A fundamental boost is offered by RD51: from isolate MPGD developers to a world-wide net



The new born – still a proposal - RDxx for RPCs

✓RPCs exist in many flavours (trigger and timing RPCs, many materials)
✓Proposed to improve the communication already existing thanks to the bi-yearly RPC workshops

➢The ECFA Preparatory Groups
➢The FCC-hh Working Groups
Excellent environments to share ideas

Conclusions

➢Use of the current detector technologies at FCC-hh implies an important R&D to overcome some of the present limits

➢This R&D has already started for HL-LHC, but will need to be pushed further on (at least quantitevely) for FCC-hh:

➢Resistive Plate Chambers:

- ✓Rate capability: will 10 kHz/cm^2 for 20 years be reachable?

➢Micro Pattern Gas Detectors

- ✓Large scale production: will o(several 100 m^2) production and operation (electronics, stability, …) of MPGD be feasable?

➢Wire Chambers

- ✓Size reduction due to occupancy and rate issues has a limit for FCC-hh?

➢All detectors:

- ✓Aging issues must be carefully studied and taken care of!
- ✓Gas issues have to be taken care of: gas is the “core” of a gaseous detector

Hopefully the answer to most questions is: “YES”
… but we have to prove it!