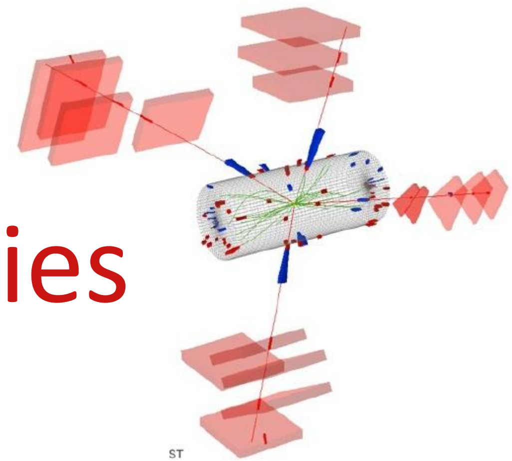
Muon systems@FCC-hh: Limits of present technologies

(i.e. playing the devil's advocate)



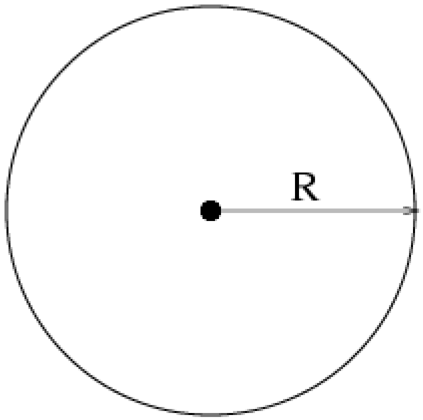
M. Abbrescia

FCC-hh mini-Workshop on Detector Technologies

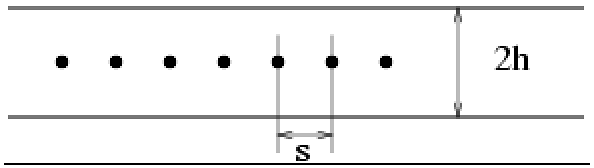
Gaseous detector geometries

These 3 basic gas detector geometries are widely used at the LHC:

Geiger- Müller (1908)
Drift Tube (1968)



G. Charpak, 1968
Multi Wire Proportional Chamber



R. Santonico, 1980
Resistive Plate Chamber

They are well known devices for many years …
… but several aspects have improved dramatically since their invention, and are still improving:

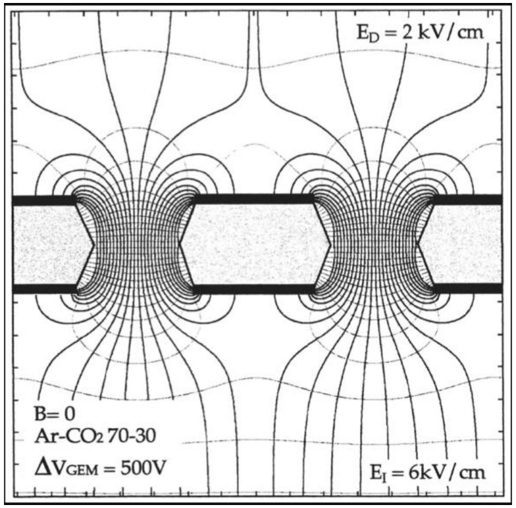
1. Readout electronics (integration, radiation resistance)
2. Understanding and optimization of detector physics effects
3. Improvement in ageing characteristics due to special gases and materials
4. Geometry and detector characteristics

Their performance during Run 1 has been excellent

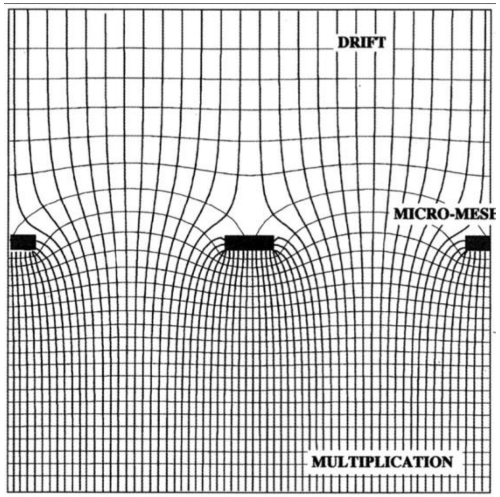
“Near” future

Ever before High-Luminosity LHC (construction has already started!) the previous technologies will be joined in by:

F. Sauli (1997)
Gas Electron Multiplier



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



… Which will be the first examples of Micro Pattern Gas Detectors used to cover large surfaces: o(100m^2)
- Used for high space resolution tracking/triggering in high rate environments (CMS/ATLAS endcaps, ALICE TPC)

Muon systems detectors at FCC-hh

For the “typical” (worst?) conditions: $L=10^{35}\ cm^{-2}s^{-1}$ Bunch Crossing = 5 ns:

Muon systems detectors for FCC-hh will:

-Be very large o(10000m^2) barrel, ≈ 3000m^2)endcap + very forward region

-Have to provide Bunch Crossing identification (baseline scenario)

- time resolution ≤ 1 ns

-Have to provide tracking capabilities

- spatial resolution ≤ 100 μm

-Operate in high background

-o(10 kHz/cm^2 in the barrel), o(100kHz/cm^2) in the endcap

-Even more in the very forward regions

- Have to operate for ≈ 20 years, integrating 10 HL-LHC

-Aging issue to be carefully considerated

✓Given the requirement on the area, almost unthinkable to use technologies differen from gaseous detectors.

✓Overall, requirements (almost) an order of magnitude better than HL-LHC

✓Most likely not all these characteristics can be achieved with a single device

Trends: performance increase

Resistive Plate Chambers:

Parallele plate detectors seem –at the moment- the unique technology capable of providing a time resolution < 1 ns

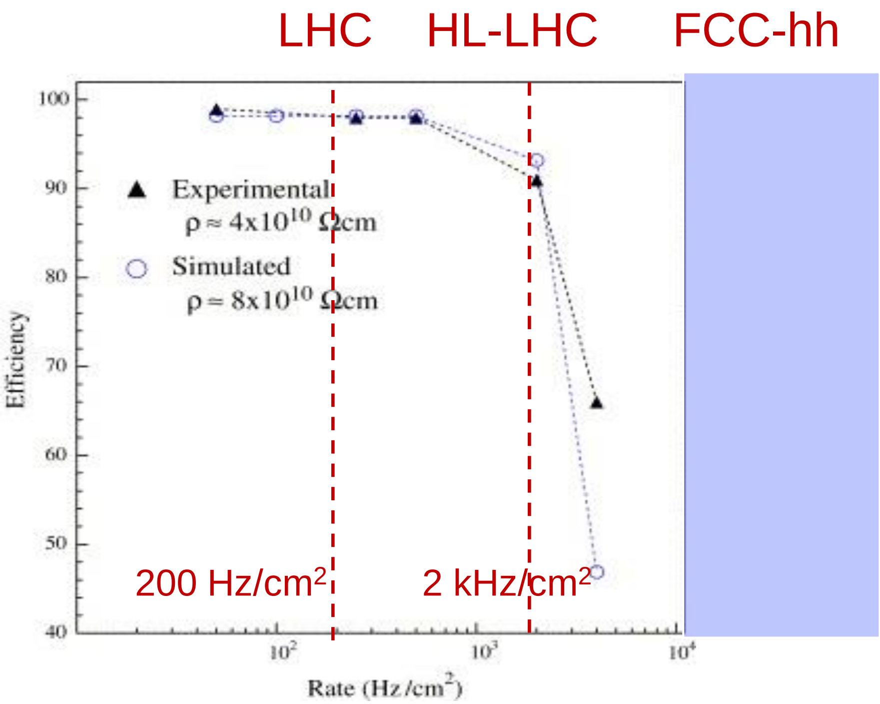
Difficult to imagine a Muon System without them

- Improve the rate capability
- ✓ from o(100 Hz/cm²) --- LHC "now"
  - → o(1 kHz/cm²) --- HL-LHC
  - → o(10 kHz/cm²) --- FCC-hh

Many possible solutions under study

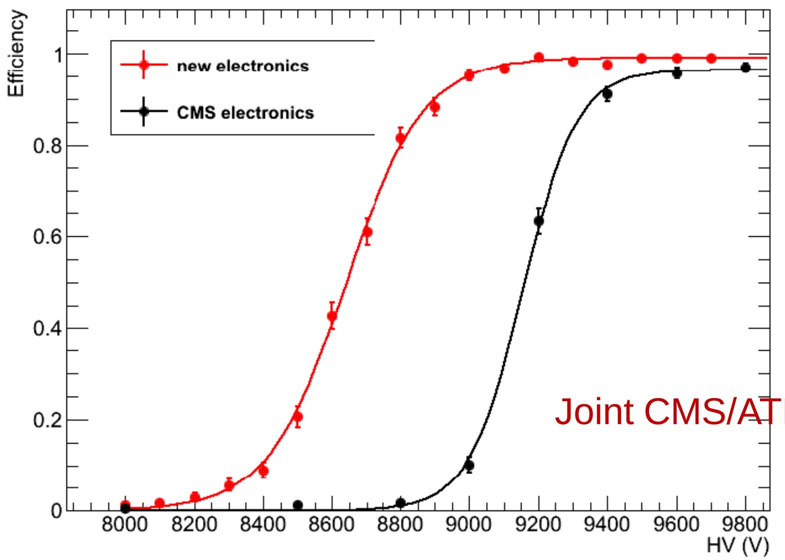
-Still waiting for the final "blessing" from the experiments

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



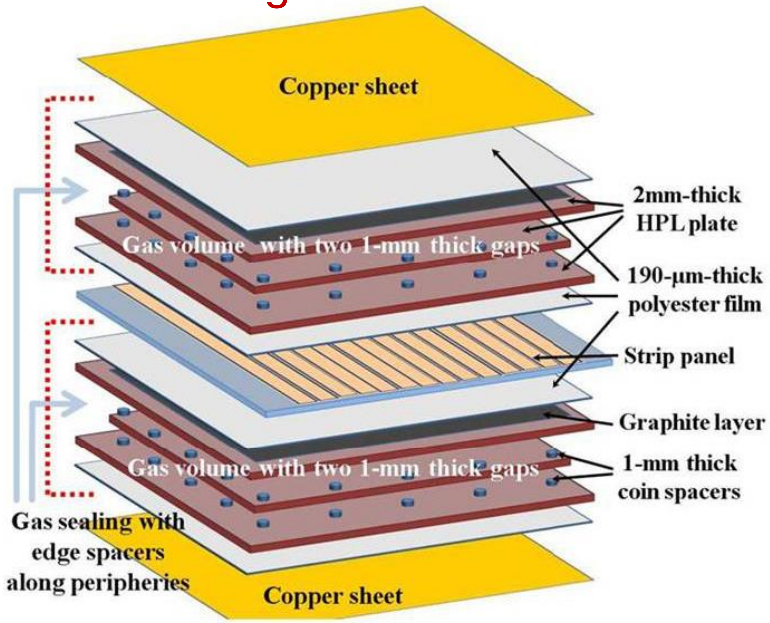
Possible solutions

New electronics



Joint CMS/ATLAS R&D

New configurations



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? In particular for what concerns the aging effects

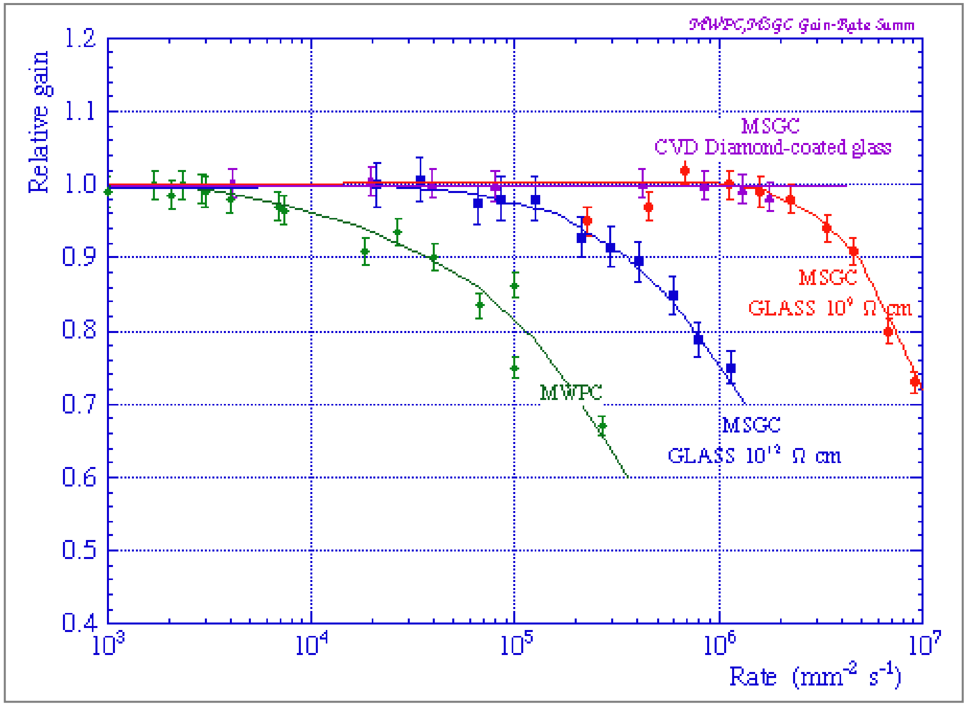
Trends: performance increase

Micro Pattern Gas Detectors: Increase covered surface

They exist in (many) different forms

MPGDs are now a mature technology

✓Thanks also to synergic effort like RD51



	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

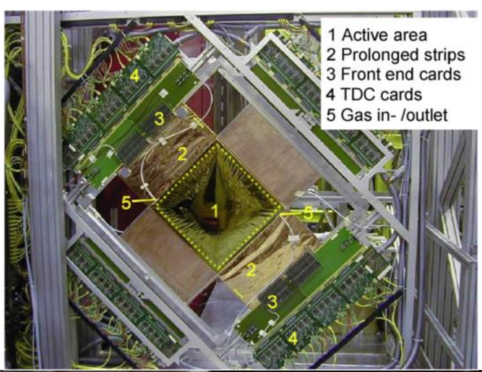
They can provide excellent spatial resolution o(100μm) and “NO” rate limitations

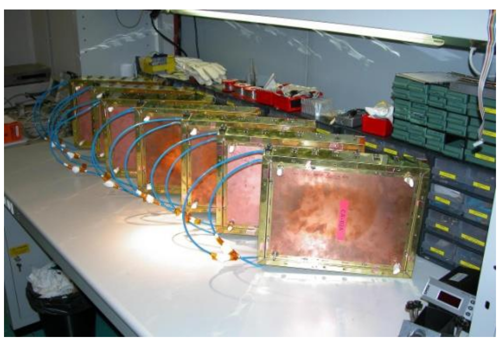
If FCC-hh Muon Systems have to provide some kind of tracking, difficult to imagine them without MPGDs

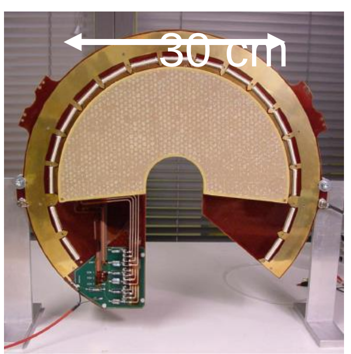
MPGDs in running experiments

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

Use of MPGDs in ATLAS, CMS, ALICE is a huge step forward → important technological breakthroughs!

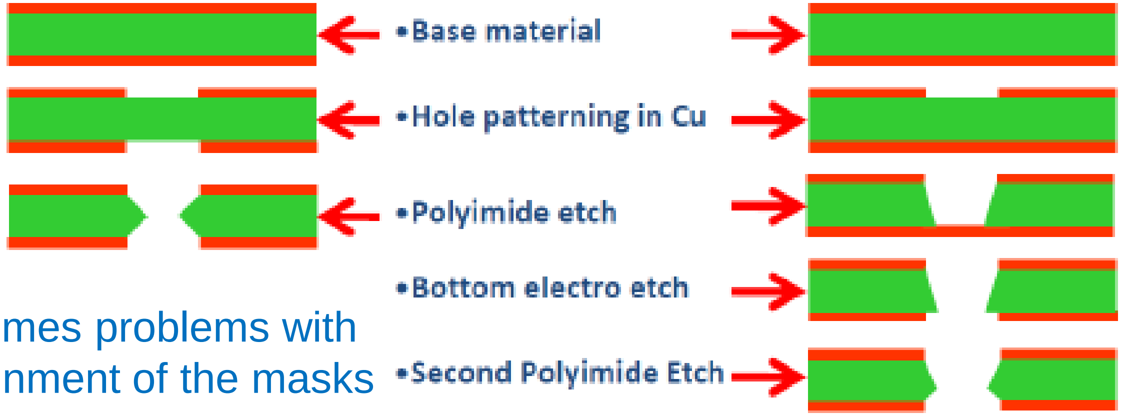






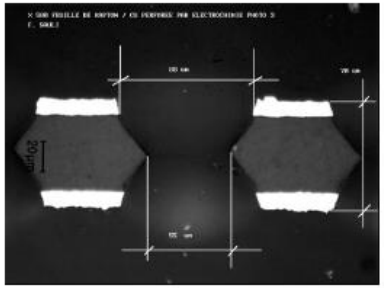
GEMs: Technological breakthroughs

Single side etching technique

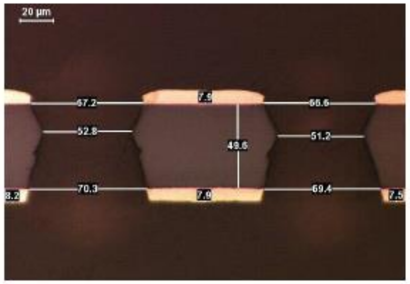


Overcomes problems with the alignment of the masks

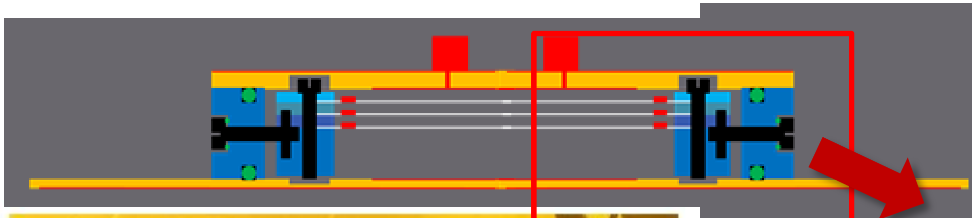
Achieved 40x40cm^2

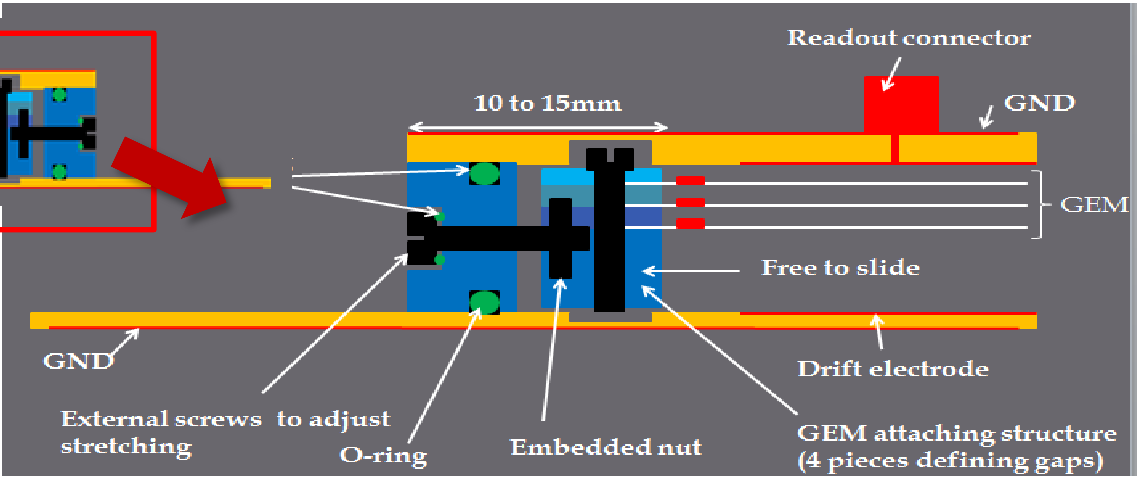


Achieved 200x60cm^2



Stretching assembly technique without spacers

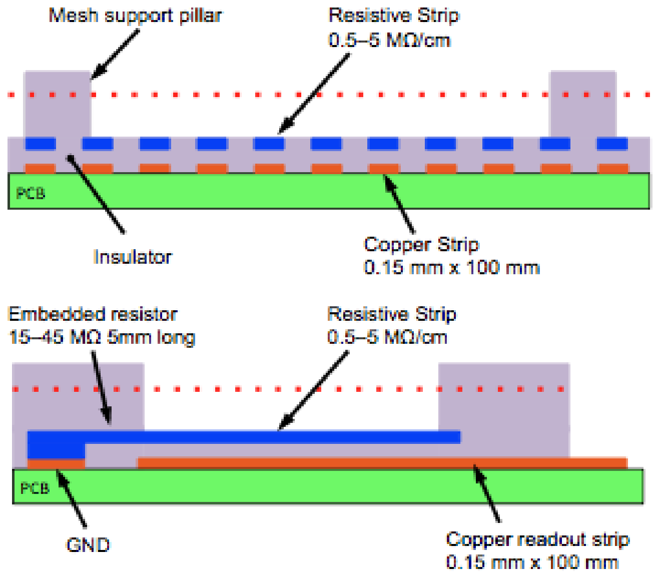




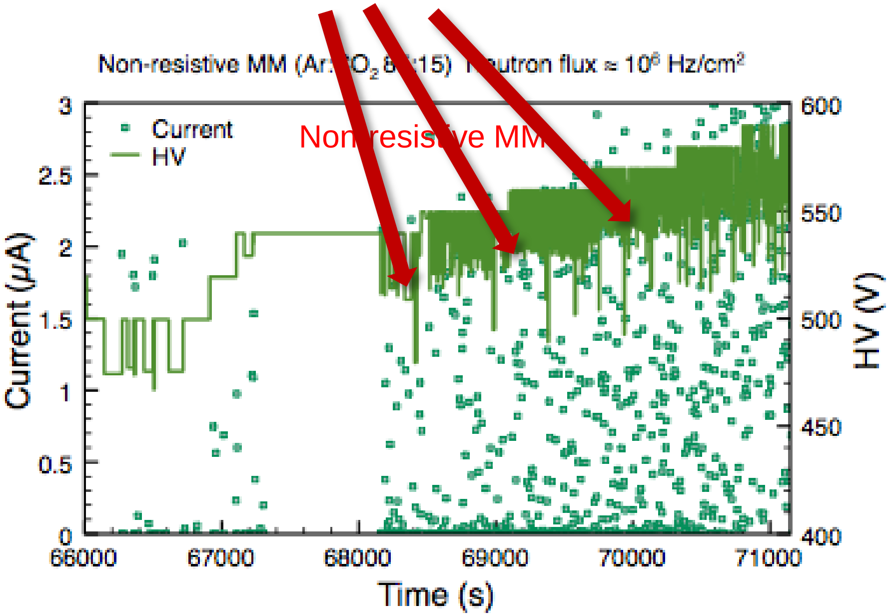
Allows re-opening of assembled detectors if repairs needed

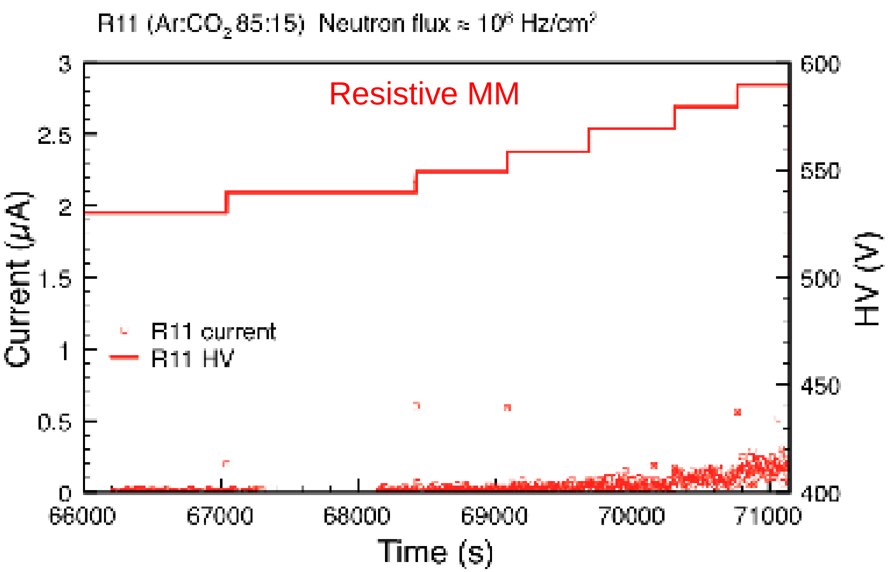
MMs: Resistive strips for spark immunity

Same principle as resistive plates devices:
✓electric field is locally dumped in case of large discharge by protecting the device with resistive strips on top of the readout (conductive) strips



Voltage drops due to small discharges

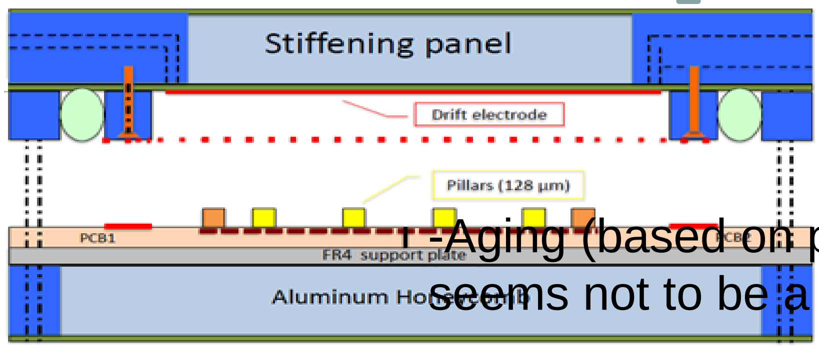


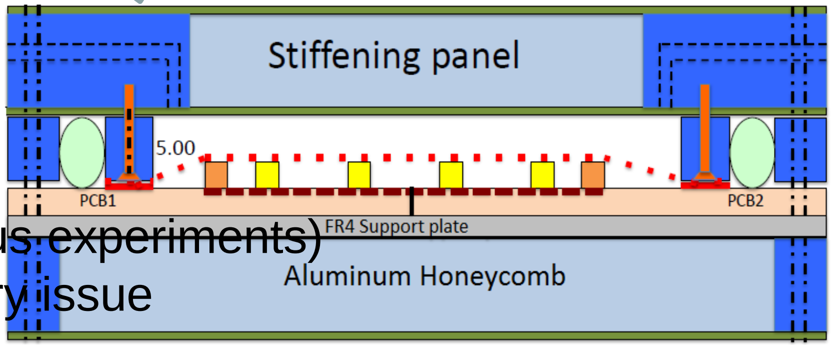


MMs: construction techniques

✓ Bulk technique replaced by ‘floating mesh’ configuration

Using also pillars to keep the mesh at a defined distance from the board, the mesh is integrated with the drift-electrode panel and placed on the pillars when the chamber is closed. This allows us to build very large chambers using standard printed-circuit boards





↑-Aging (based on previous experiments) seems not to be a primary issue

Open issues:

-Are the large scale production techniques suitable (also in terms of cost) for an increase in the areas covered up to several thousands of m^2 ?

-But also:

- Is that possible to improve time resolution? Could we be able to trigger in the highest rate regions with these devices?
- Aging will be an issue?

Wire chambers at FCC-hh

Limits expected: Rate Capability and Aging

Space charge effects

✓intrinsic limit for wire detectors, affects devices with large drift volumes,

✓notable case is ALICE TPC but still under control for most other wire detectors

Readout saturation (too high occupancy)

✓design limit

-segmentation, readout electronics

Aging

✓Current technologies validated for 10 years at LHC

✓Must face ~ one order of magnitude more integrated dose at HL-LHC

✓Even more at FCC-hh

Change of technology:

- ATLAS TRT

straw tubes ⇒ all-Si inner tracker

- ATLAS CSC/MDT ⇒ μMEGAs
- LHCb Outer Tracker

drift tubes ⇒ SciFi

Re-design with same detector technology:

can re-use services, software...

- ATLAS MDT ⇒ sMDT
- ATLAS TGC ⇒ sTGC
- Most detectors ⇒ new readout

ATLAS sMDTs

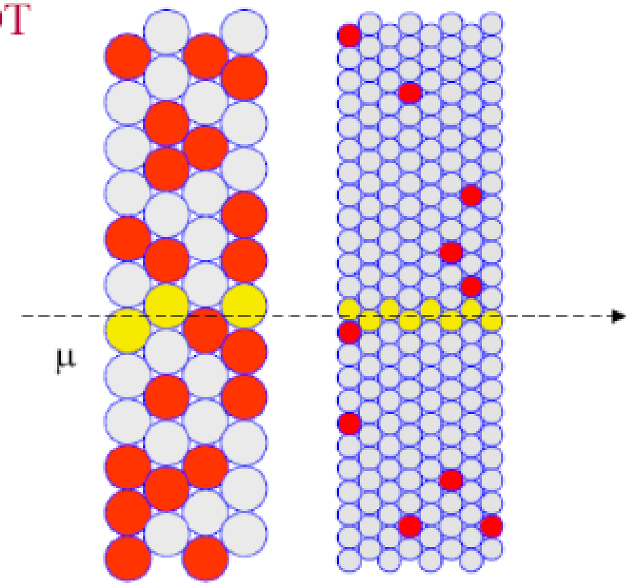
Drift tube diameter reduced by factor 2: MDT -> sMDT

- Increase rate capability by an order of magnitude, sufficient for max. rates at HL-LHC
- chamber thickness reduced by factor 2
- occupancy reduced by factor 8

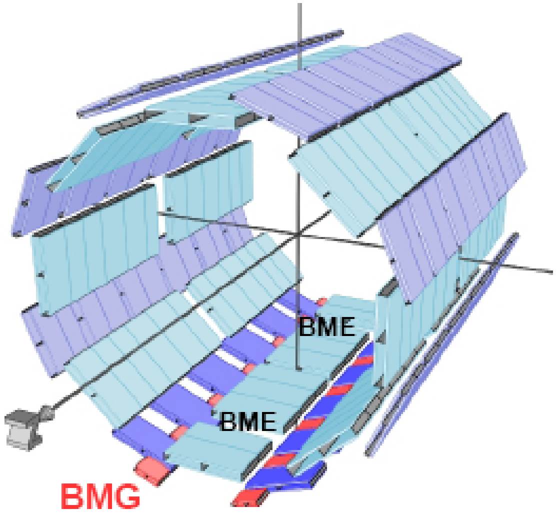
  ⇒ much improved signal/background

Advantages:

- Reuse and optimize existing proven technology (no aging up to 6 C/cm = 10x expected at HL-LHC)
- Full compatibility with existing services, reconstruction software and optical alignment system of ATLAS.



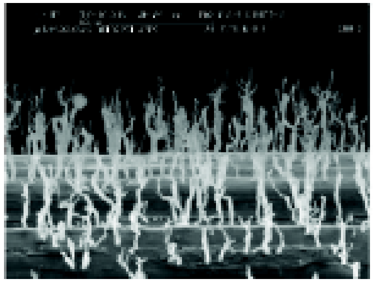
- Will be used to complement or replace MDT chambers where needed
  - 2 chambers already installed for Run2 in the "BME" region of Barrel Middle Layer where only 2 MDT stations (instead of 3) were available
    ⇒ improve $\sigma(p_\mu)$ by factor 2
  - 12 new Middle Layer chambers (BMG) for Phase 1
  - 32 chambers to replace Inner Layer MDTs in hottest regions for Phase 1
  - More need for sMDT in Phase 2 under study



From Paolo Iengo's talk last year:

Wire chambers: aging

- Aging of wire chambers is being studied since decades
- Main ageing effects:
  - Formation of 'whiskers' on the anode wires, mostly made of silicon compounds
  - Distortion of pulse height spectra, gain loss, noise rate etc



- Wire chambers for LHC have been designed and built according to general prescriptions to reduce aging effects:
  - No hydrocarbons in gas mixtures in drift chambers
  - No silicon material in the chambers and in the gas connections
  - Careful material selection (outgassing, radiation effects etc.)

No aging effect which can compromise the detector performance expected up to HL-LHC

- System longevity can be estimated according to R&D studies, early detector operations, extrapolation of working conditions; but (negative) surprises are always possible

Open issues:

-Aging at FCC-hh will still be under control?

- Will the solutions envisaged for HL-LHC (i.e. new readout, scaling in dimensions) suitable to overcome problems related to rate capability and occupancy at FCC-hh?

Synergies: common issues

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

Example: the Quest for Eco-Gas

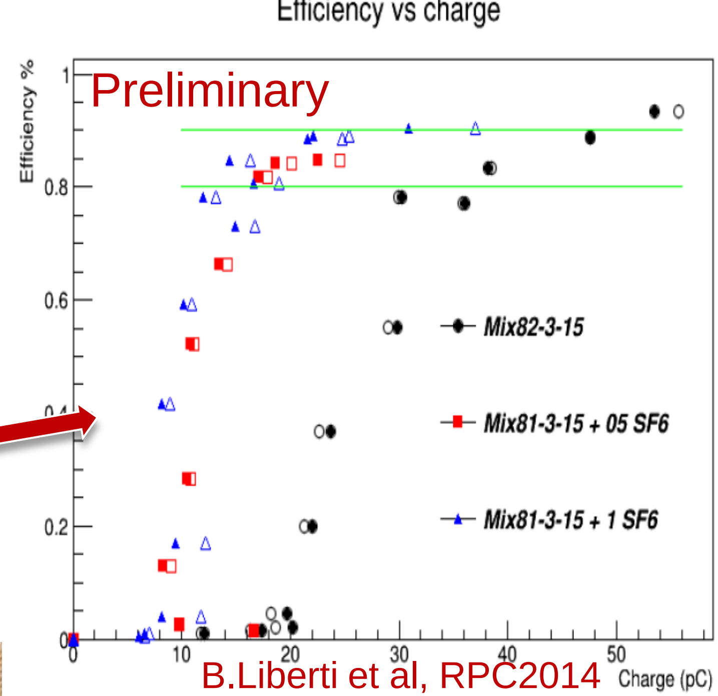
Due to the new regulations deriving from the Kyoto protocol the use of components of RPCs ($C_2H_2F_4$) and GEMs (CF_4) gas mixtures might be restricted

➢ 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

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 10-20 years be reachable?

➢Micro Pattern Gas Detectors
- ✓Large (large!) scale production: o(several 100 m^2) production and operation (electronics, stability, …) of MPGD will be feasable?

➢Wire Chambers
- ✓Size reduction due to occupancy and rate, and aging are an issue at 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!

Can the present technologies be used at FCC-hh?

Let us try to learn from the "experience" of HL-LHC.

The general strategy is:

-Keep the system performance stable despite a much harsher environment

This is done:

-Preserving the present detectors

-Which will be more than 10 years old when HL-LHC will start

-"Consolidation" activities

-Using new detectors

-Sometimes replacing the present detectors (i.e. ATLAS NSW)

-Sometimes putting new detectors in places still empty

- Already for HL-LHC we have to develop and build a new generation of gaseous detectors with performance an order of magnitude better than the present.
- **For FCC-hh we should do even more…**