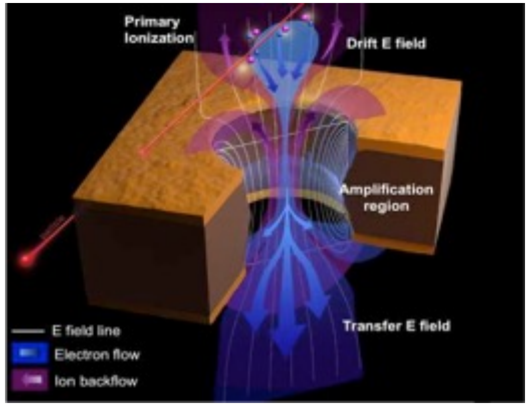
Tracking DRD – MPGD (Micro-Pattern Gaseous Detectors)

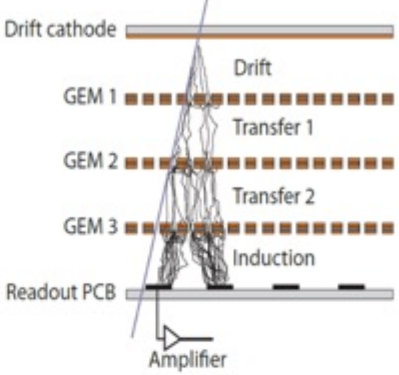
Fabien Jeanneau

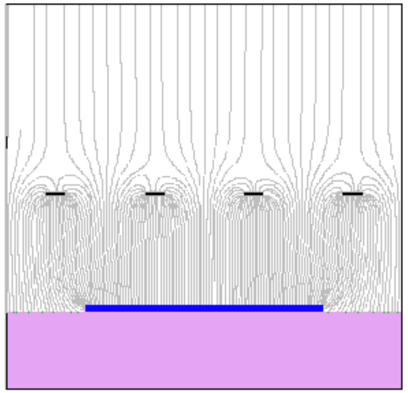
4th FCC/DRD France Workshop, Strasbourg (22-24 Nov. 2023)

MPGD since 1996

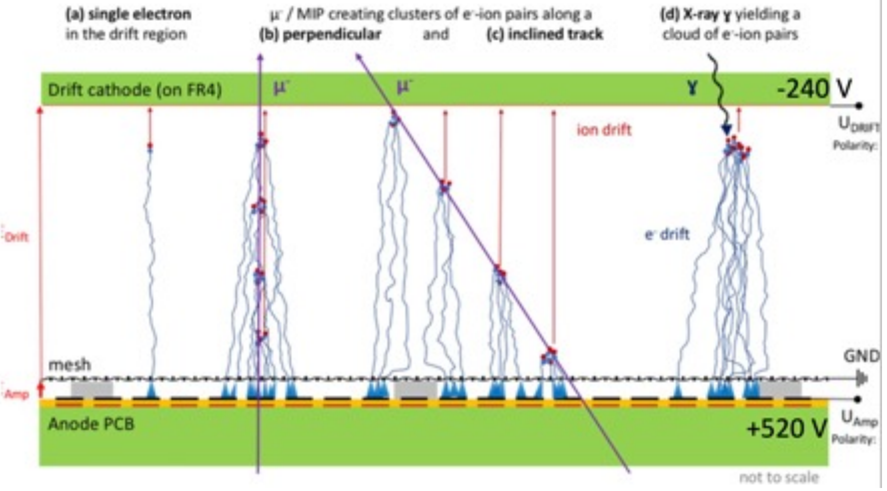


GEM
(F. Sauli, 1997)





Micromegas
(I. Giomataris, 1996)



Features:

- High gain (**10^4 to 10^6**)
- Position resolution ~ **100 µm**
- Time resolution < **10 ns**
- Large area, low mass, low cost
- High rate capability (**~1MHz/cm²**) :
  - Uniform electric field and fast ion collection
- Excellent radiation hardness and aging
- Materials and manufacturing processes coming from PCB industry
- Versatile architecture and possible technological hybridation
- Very dynamic field of research, lots of applications

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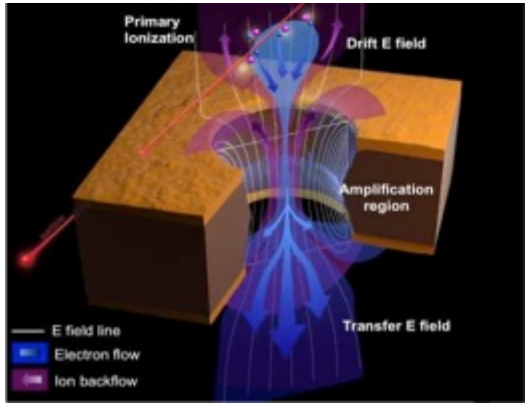

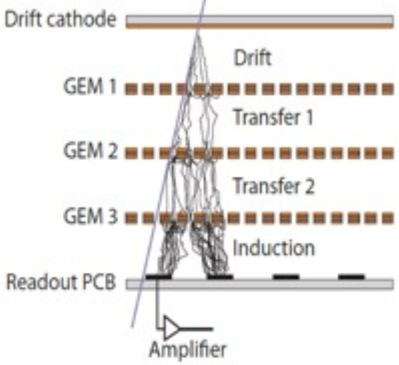

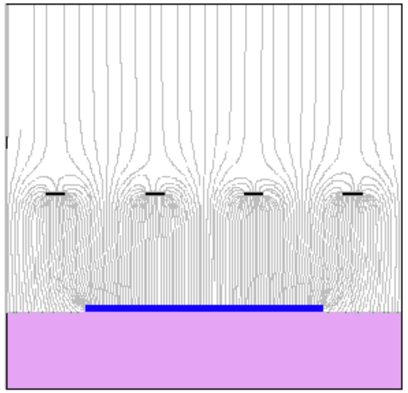

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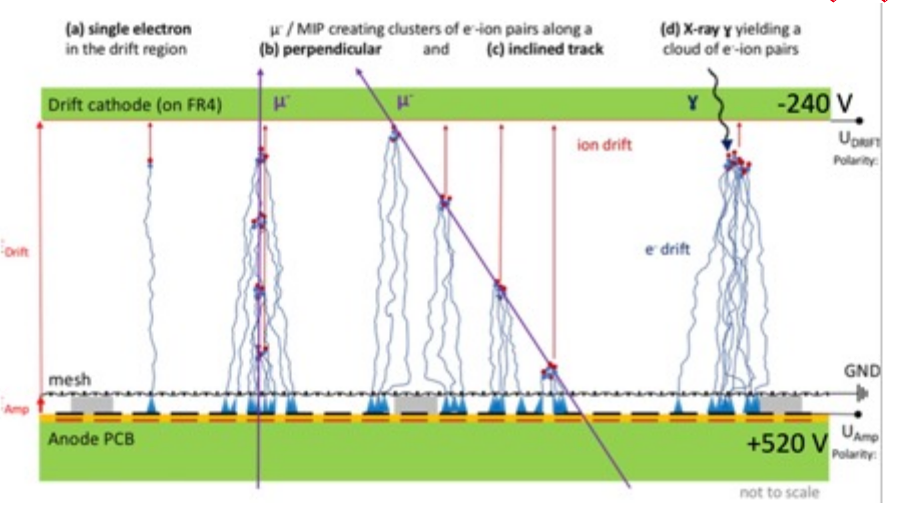

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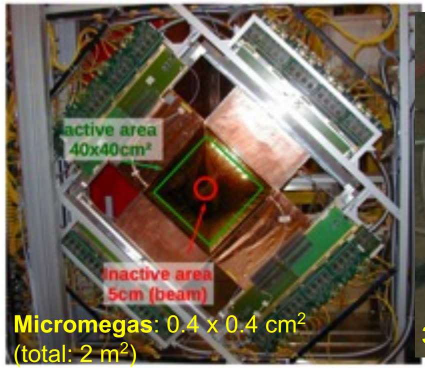
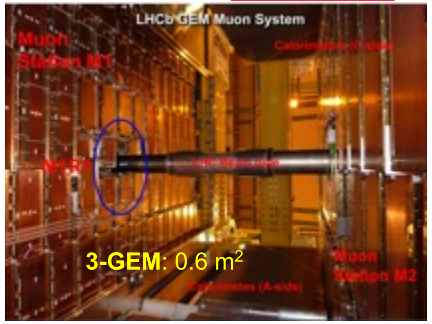
COMPASS



Max.rate: Up to 100 kHz/cm²
Spatial res.: ~70-100µm(strip), ~120µm (pixel)
Time res.: ~ 8 ns

LHCb



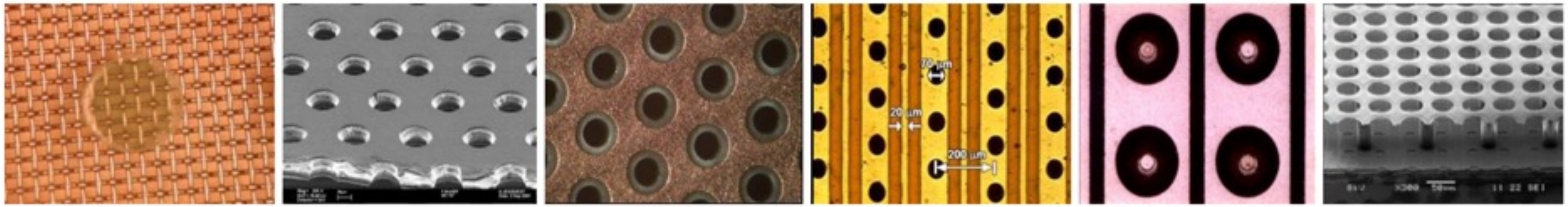
Max.rate:500 kHz/cm²
Spatial res.: ~ cm
Time res.: ~ 3 ns

TOTEM

Max.rate:20 kHz/cm²
Spatial res.: ~120µm
Time res.: ~ 12 ns

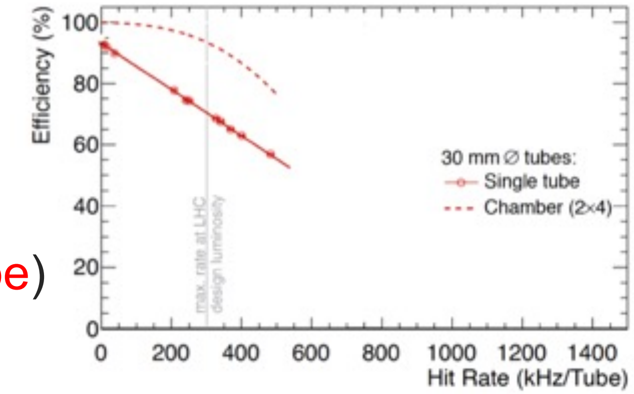
RD51 since 2009

- RD51 have been created in 2009 in order to foster and mutualize the R&D effort on MPGD
- Proposal in 2008: « The proposed R&D collaboration, RD51, aims at facilitating the development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for applications in basic and applied research. »



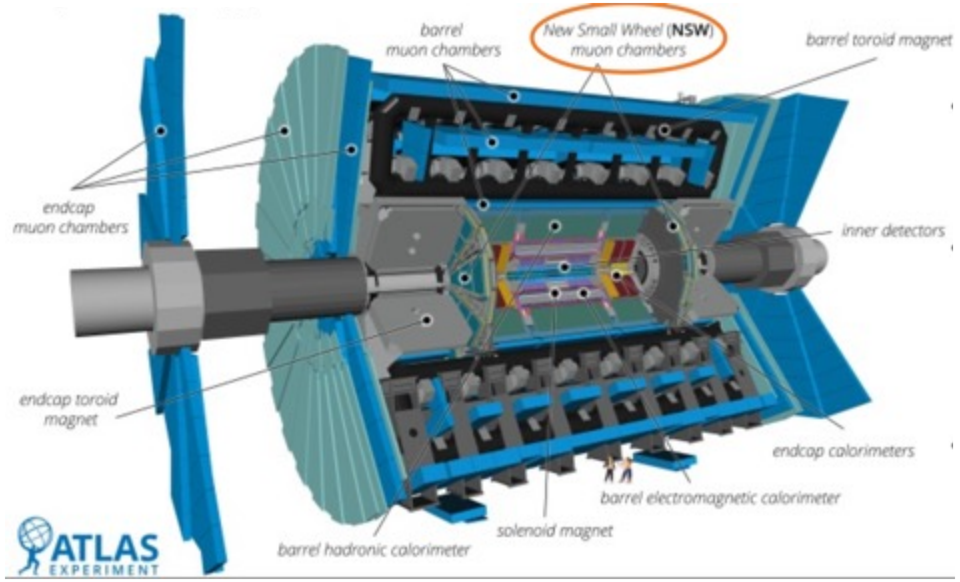
MicroMegas GEM THGEM MHSP microPIC Ingrid

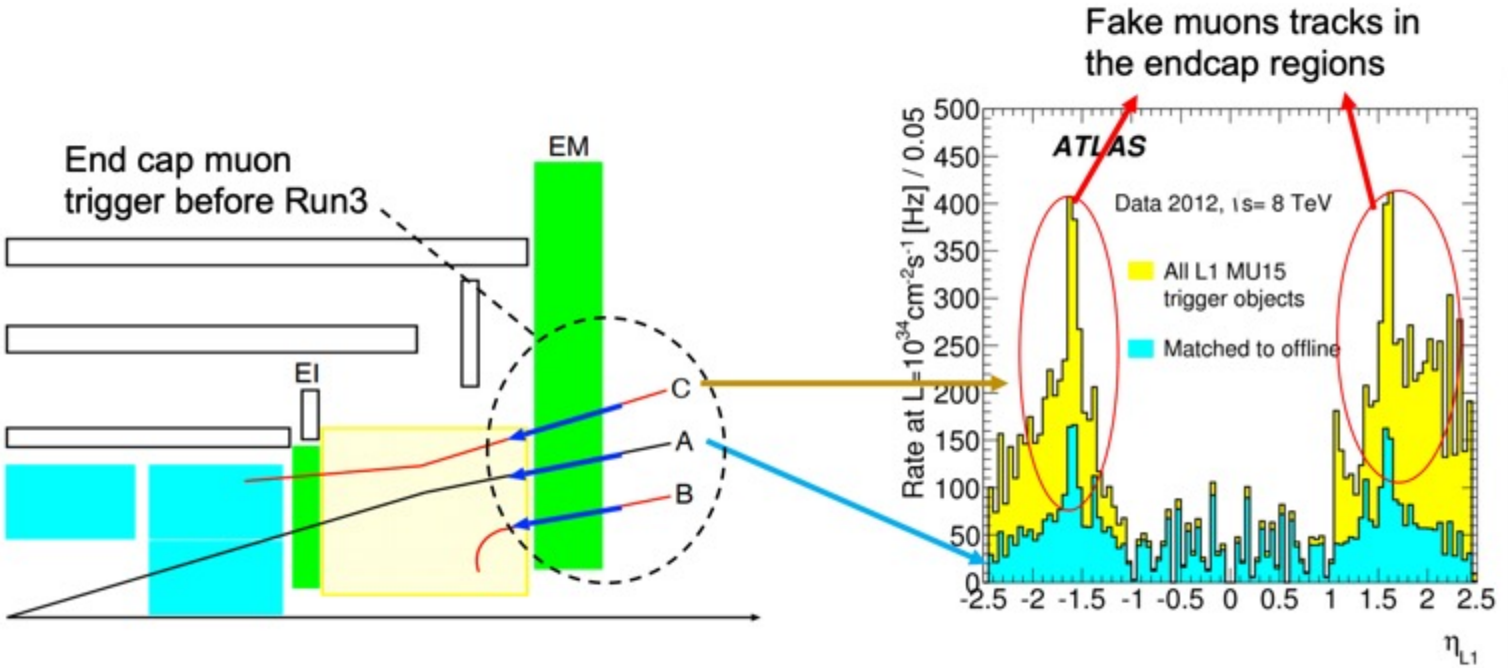
Micromegas: Atlas NSW



New Small Wheels (NSW) motivations, installed in 2021:

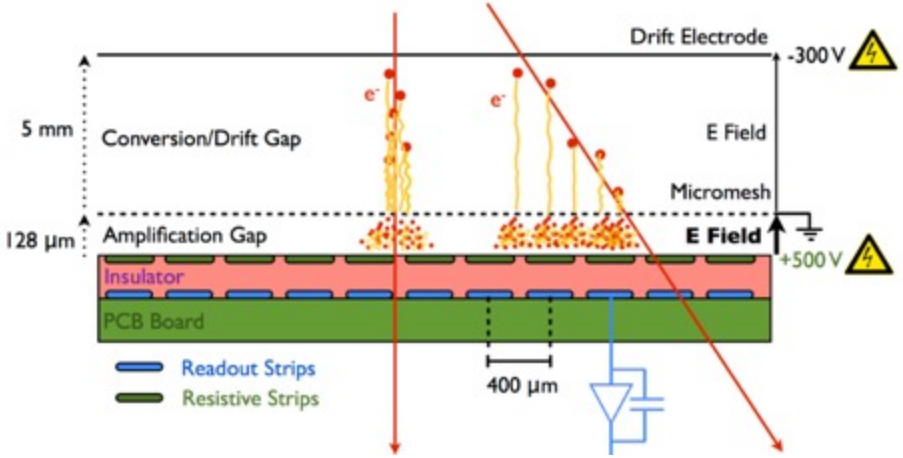
- **Tracking**: With an expected luminosity of 7.5×10^{34} cm^{-2} s^{-1}, rate in NSW will be up to 15 kHz/cm² (>1.5 MHz / MDT_tube)
- **Trigger**: reduction of the trigger rate and of the fake-track reconstruction in the $1.3 < \eta < 2.7$ region of ATLAS



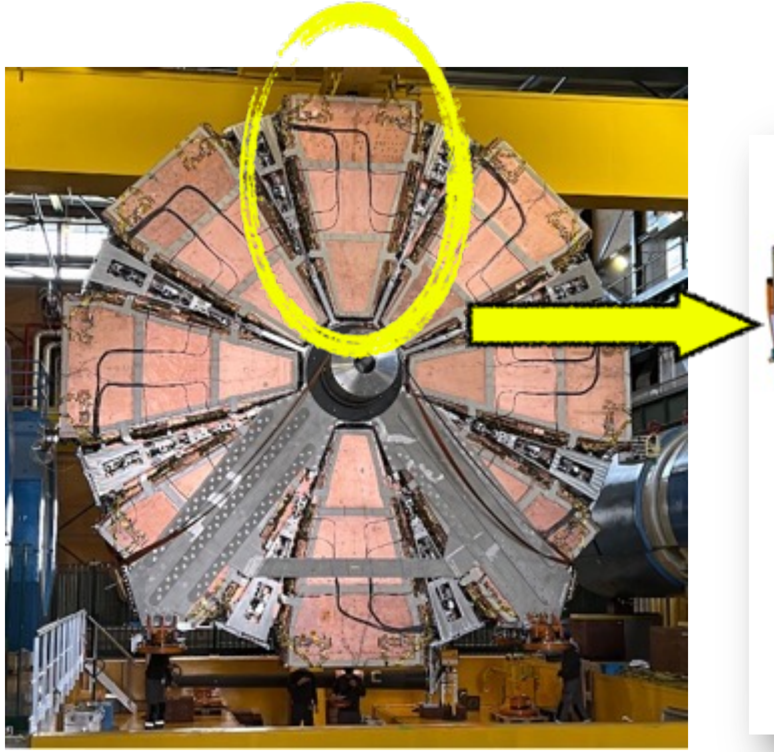


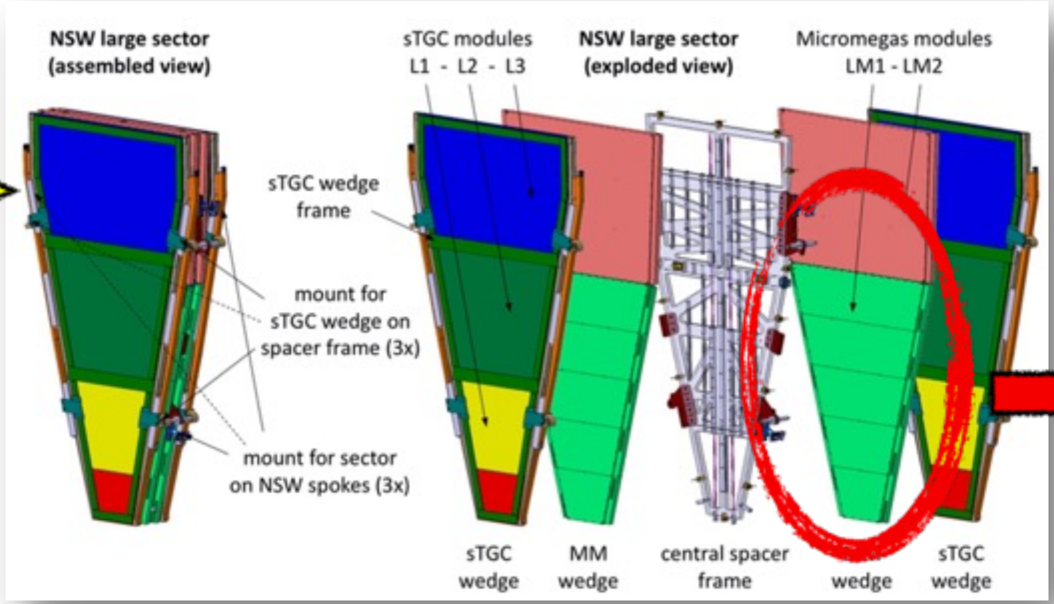
NSW-MM: project in brief

- 4 years of production (2017-2021)
- Large area to cover (1200 m^2)
- Each wheel contains 16 sectors (8 small and 8 large)
- Each sector is made up of 16 layers of detection (8 MM + 8 sTGC):
  - sTGC primarily for trigger purpose
  - MM primarily for tracking purpose

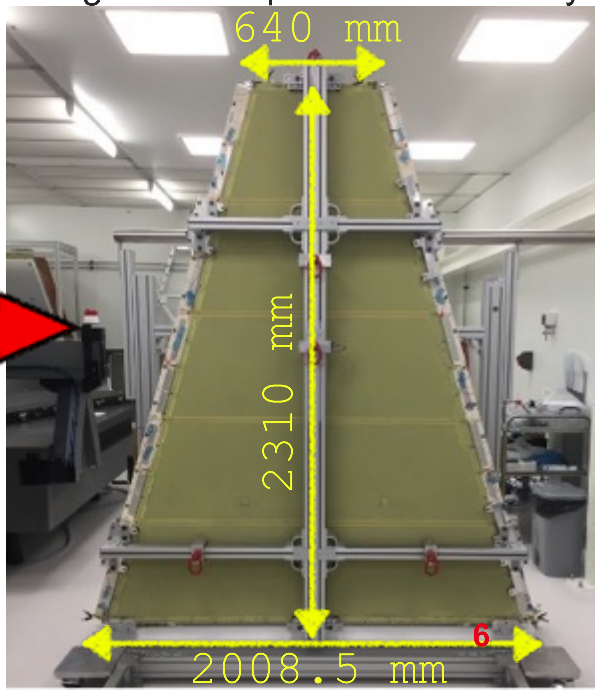


Construction sites (128 modules in total):
- SM1 → Italy/INFN
- SM2 → Germany
- LM1 → France/Saclay
- LM2 → Russia/Dubna – Greece/Thessaloniki (+ Cern)





Large Module produced in Saclay



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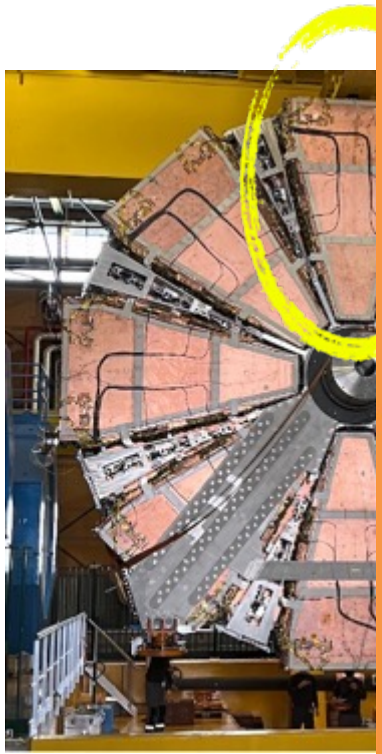

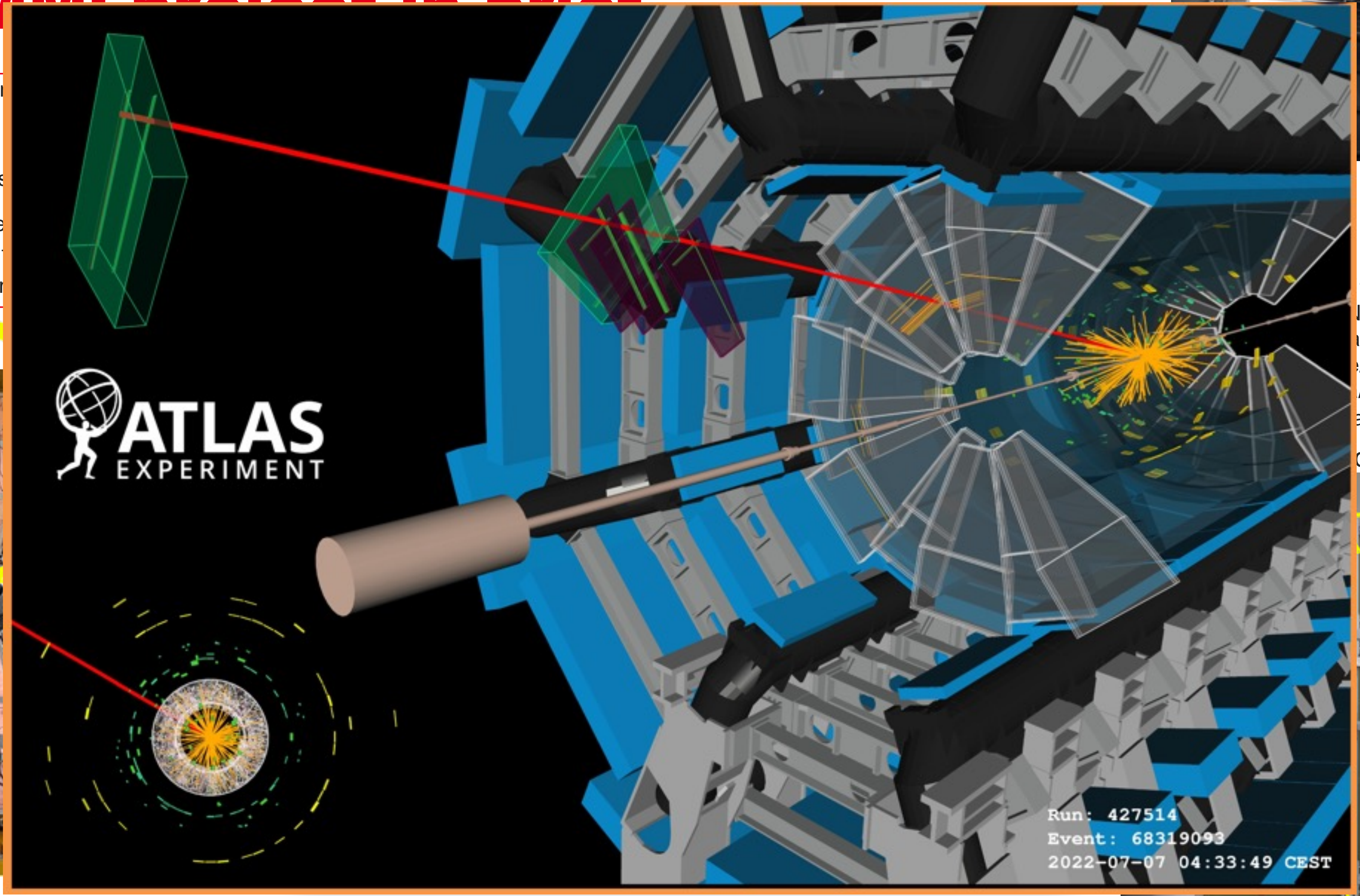

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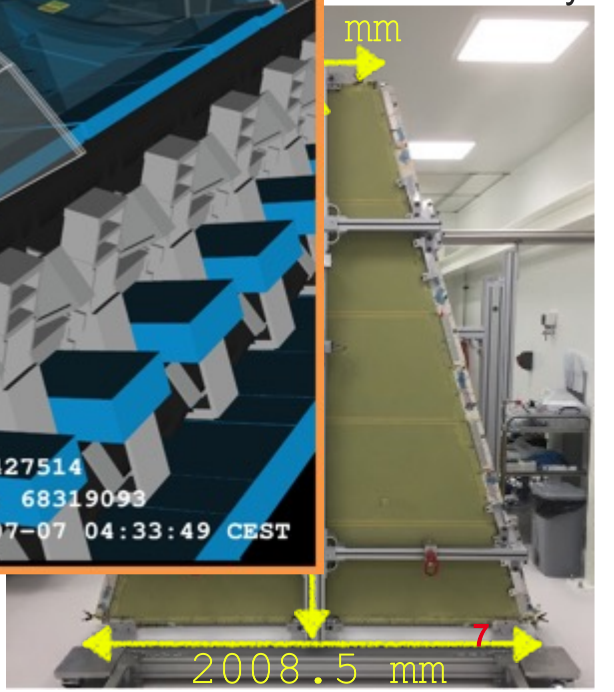
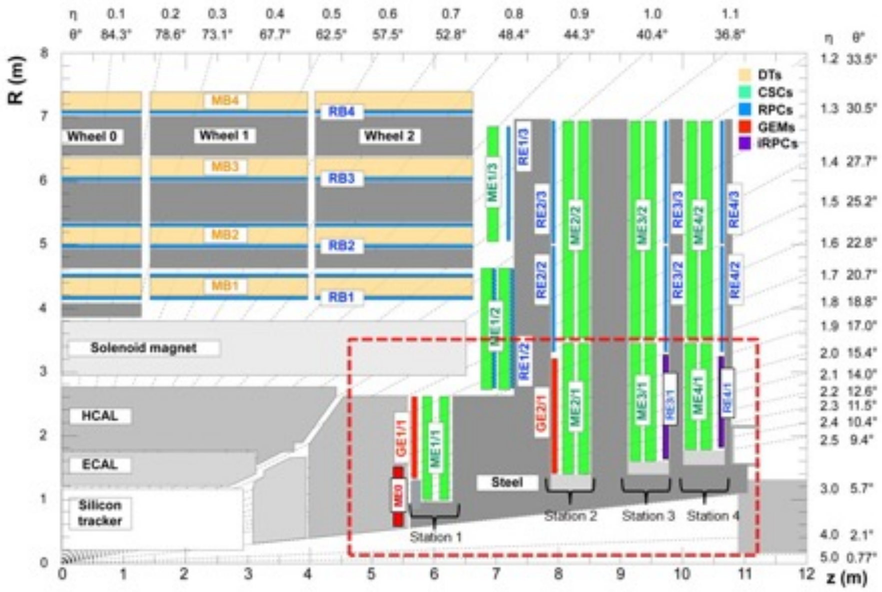
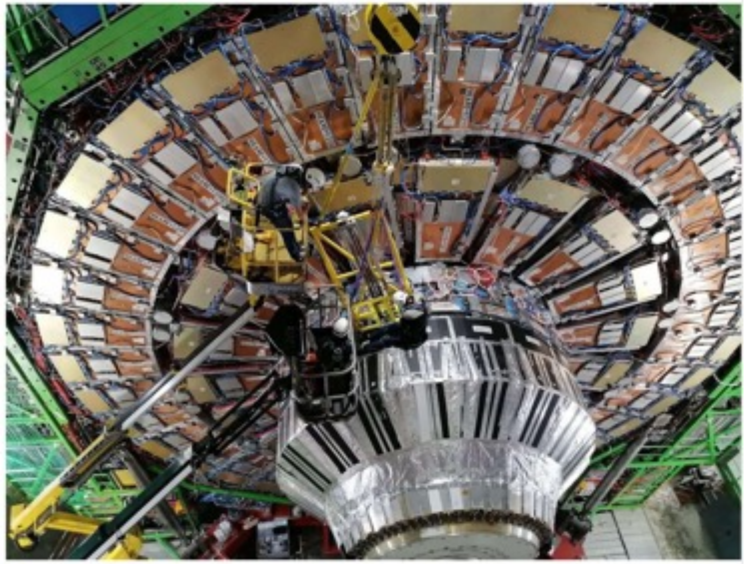
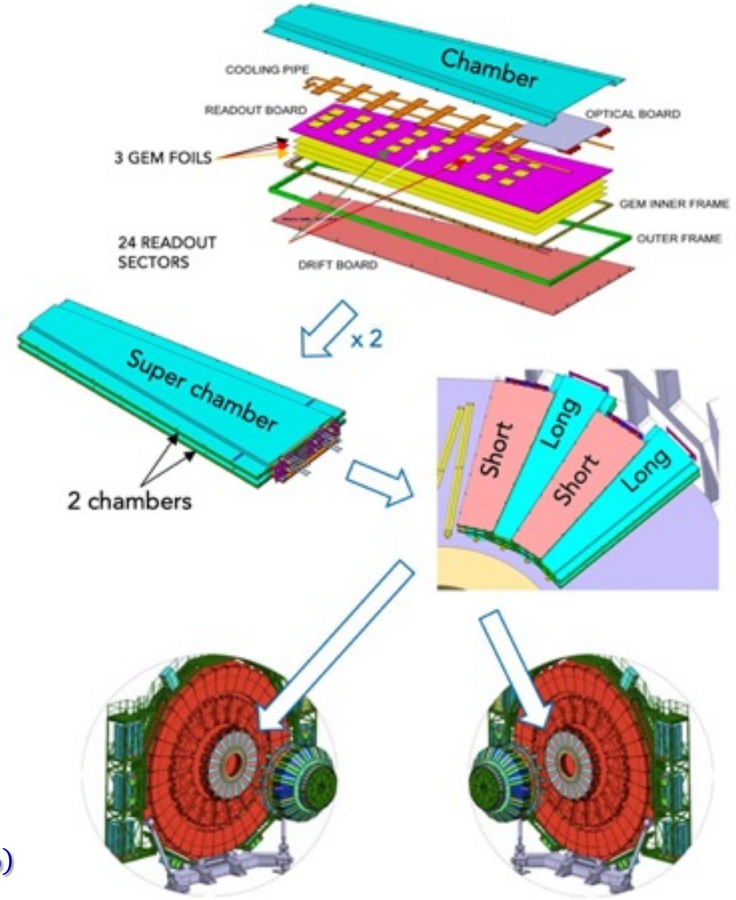


GEM for CMS



September 2020: 144 GEM GE1/1 chambers installed





Additional station GE2/1 and ME0

→ **same technical solution successfully adopted for the GE1/1**

GE21 Detector System

- 72 chambers arranged in 2 layers installed
- On-chamber and off-chamber
  - 4 triple GEM modules per chamber
- 20^0 Chambers, layout similar to GE1/1, but covering much larger surface. (1.62<h<2.43)
- hit rate < 2 kHz/cm^2 (GE1/1 was up to 5 kHz/cm^2)

ME0 Detector System

- 36 Stacks 6 layers each
- 20^0 Stacks, Module Size comparable with GE1/1 chamber but covering high eta region (2<h<2.8)
- Background ~ 10^2 higher that GE2/1, very demanding from performance point of view

GE1/1 chamber

- **Triple-GEM chambers**
- **Gas mixture Ar/CO_2 (70/30%)**
- **Large area $O(m^2)$**
- **Covering $1.5 < |\eta| < 2.2$**

- **144 trapezoidal Long and Short chambers**
- **24 readout sectors per chamber**
- **128 radial strips for each sector**
- **Digital readout**

- **72 Super Chambers (2 coupled chambers)**
- **Each Super Chamber covers $10.15°$ (overlap)**

GEM fo

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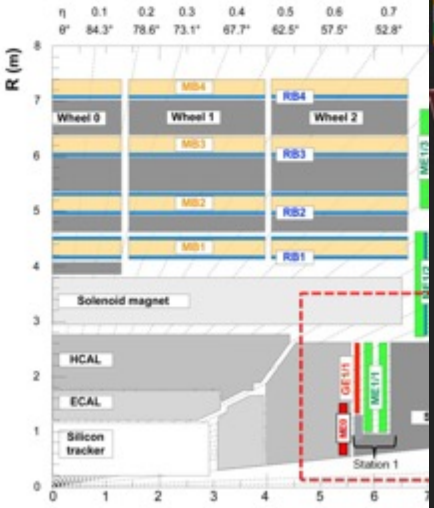

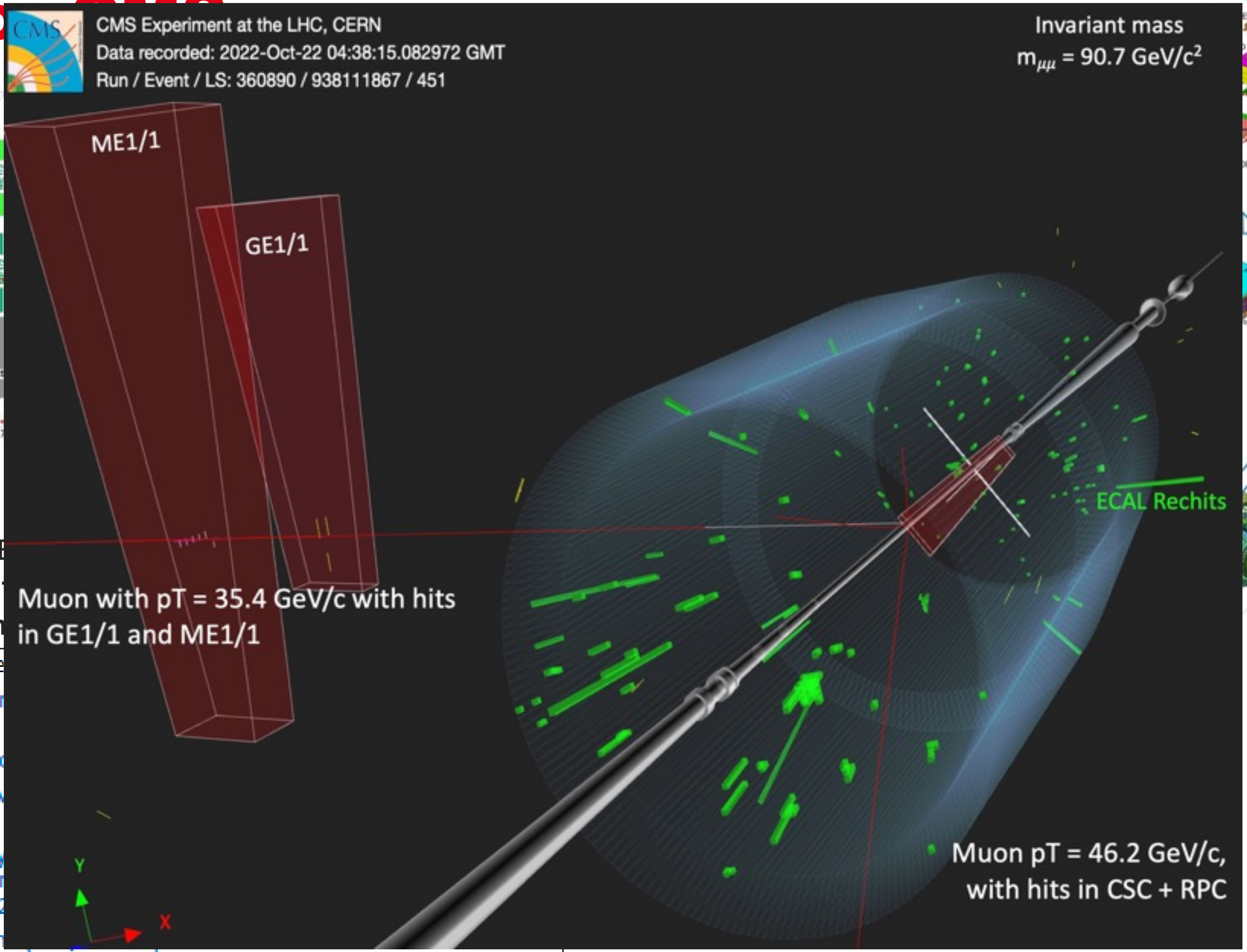

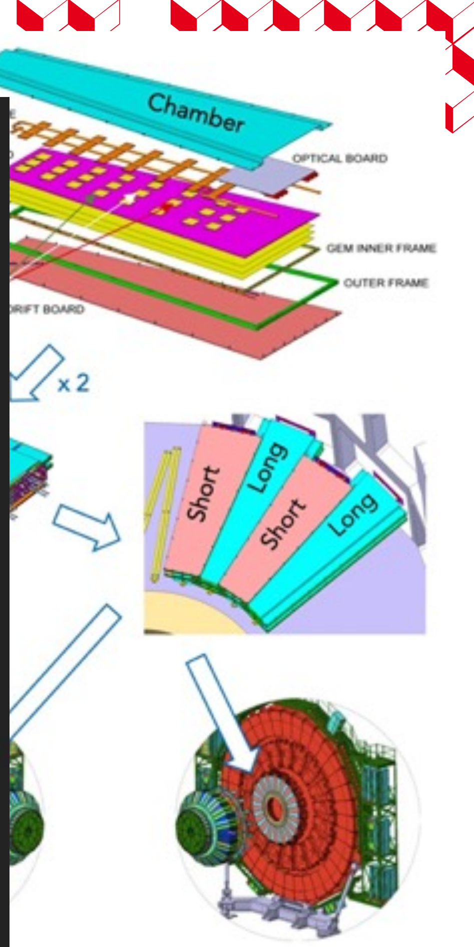

Additional station GE

→ **same technical solu**

adopted for th

GE21 Detector Syste

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- On-chamber and
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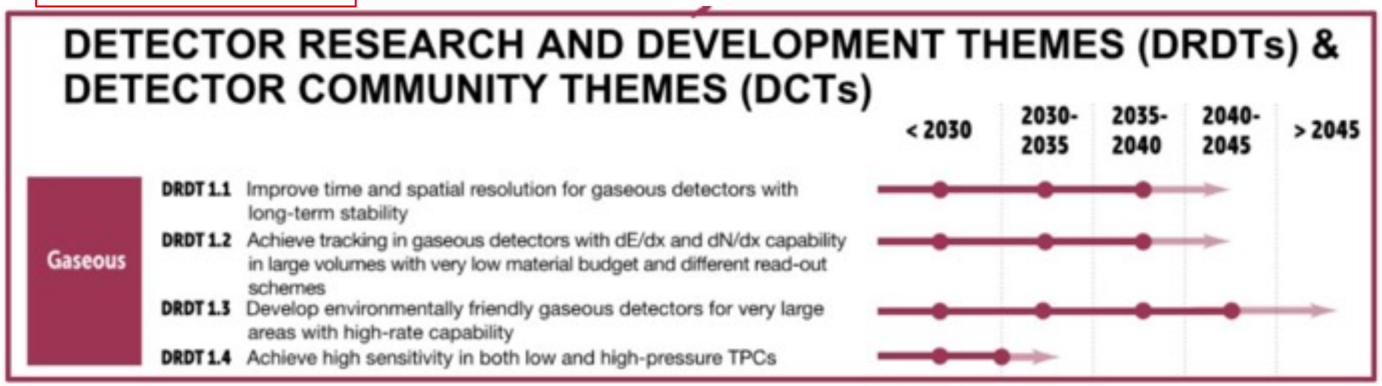
- 20^0 Chambers, lay GE1/1, but coverin surface. (1.62<h<2
- hit rate < 2 kHz/cm 5 kHz/cm²)

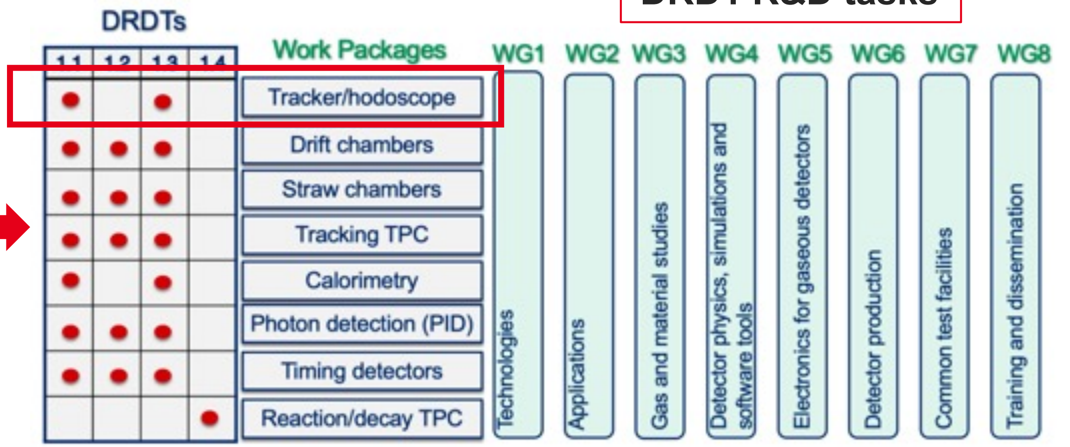
RD51 to DRD1 (MPGD to Gaseous Detectors)

- DRD1 for MPGD is in the continuity of the existing RD51 with the same kind of organisation
- Inclusion of other technologies (Wire chambers, RPCs, …) → larger community
- 7 french labs interested: Irfu, Ganil, IJCLab, Polytechnique, Grenoble, LSSB, Lyon
- Scientific organization in **Working Groups**: knowledge, expertise sharing
- R&D projects:
  - **Common projects** → short-term blue-sky R&D (Collaboration Common Funds)
  - **Work Packages** → long-term projets following strategic ECFA R&D Detector Roadmap (dedicated fundings)

ECFA Roadmap



DRD1 R&D tasks



RD51 ... ors)

- DRD1 ... tion
- Scienti
- R&D pr
  - **Com**
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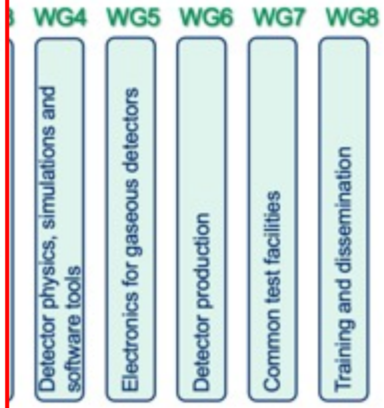
#	Task	Performance Goal	DRD1 WGs	ECFA DRDT	Comments	Deliv. next 3y	Interested Institutes
T1	Increase photocathode efficiency and develop robust photoconverters	Improve: - Longevity - QE - Extend to the visible range - Rad-hardness up to 10^{11} n_{eq}/cm^2	WG3 (3.1C), WG6, WG7 (7.1-4)	1.1	- Study hydrogenated nanodiamonds - Study diamond-like carbon (DLC)	- Demonstrate the performance of nanodiamond-powder photocathodes in terms of their chemical reactivity and ageing - Provide a detailed characterization of QE of new photocathode materials, e.g. DLC	INFN-TS, CERN, HIP, IRFU/CEA, NISER Bhubaneswar, U Coimbra, LMU, U Aveiro, RBI, Wigner, BNL
T2	IBF suppression, discharge protection	- IBF reduction down to 10^{-4} and below - Stable, high gain operation up to 10^5-10^6 - Operation in magnetic field	WG1, WG4, WG7 (7.1,5)	1.2	- Multi-MICROMEGAS detectors - Zero IBF detectors - New structures (Cobra, M-THGEM,) and coating materials (Mo) - Grids: bi-polar grids, gating GEM	- Demonstrate a small-area new structure or stack of structures providing stable operation at high gains and low IBF performance	USTC, RIKEN, INFN-TS, INFN-PD, INFN-PV, TUM, WIS, U Bonn, HIP, IRFU/CEA, NISER Bhubaneswar, CERN, MSU, SBU, JLab, U Coimbra, IPPLM, U Aveiro, RBI, BNL
T3	Gas studies	- Develop eco-friendly gas radiators and, in particular, explore alternatives to CF_4	WG1, WG3 (3.2A), WG4, WG7 (7.2,4)	1.1, 1.3	- Identification of eco-friendly gas mixtures free from greenhouse gases - Alternatives to CF_4 for optical readout		CERN, NISER Bhubaneswar, HUJI, GSSI, INFN-PD, INFN-TS, AGH-Krakow, IPPLM, USC/IGFAE, U Aveiro
T4	FEE	- Stability at high input capacitance - Low noise - Large dynamic range	WG5	1.2		- Present an ASIC concept/prototype	IFUSP, NISER Bhubaneswar, INFN-PD, INFN-TS, AGH-Krakow, IPPLM, U Manchester, MSU, SBU, JLab, DIPC
T5	Enhance mechanics	- High-pressure operation - Improve gas tightness	WG6	1.3			NISER Bhubaneswar, HUJI, GSSI, USC/IGFAE, CERN, MSU, JLab, DIPC, IPPLM, RBI
T6	Precision measurements	- Time resolution $\leq$ 100 ps - Spatial resolution $\leq$ 1 mm	WG7.2		- MPGD: PICOSEC		CERN, IPPLM, BNL

ECFA Roadmap

R&D tasks



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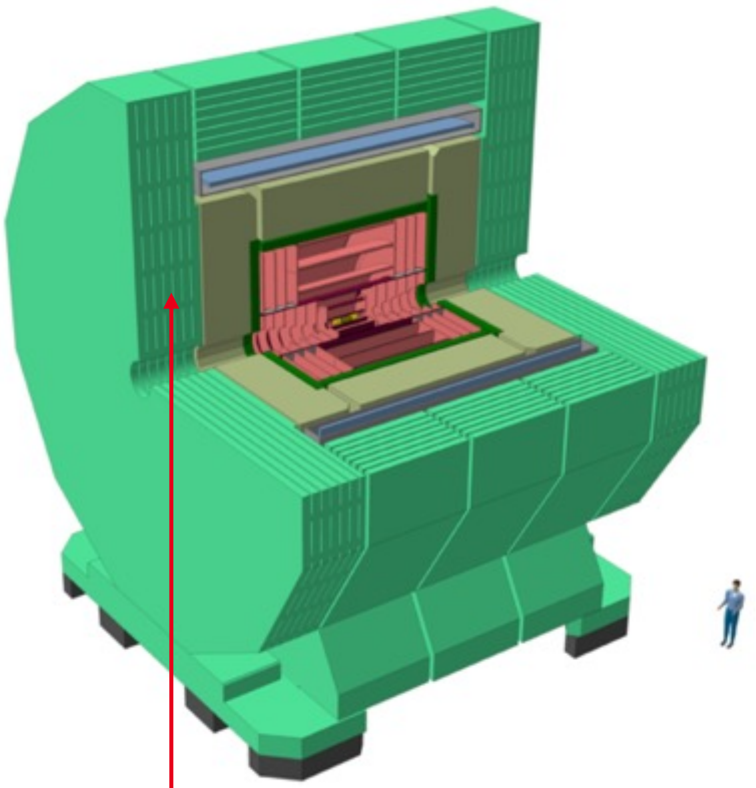
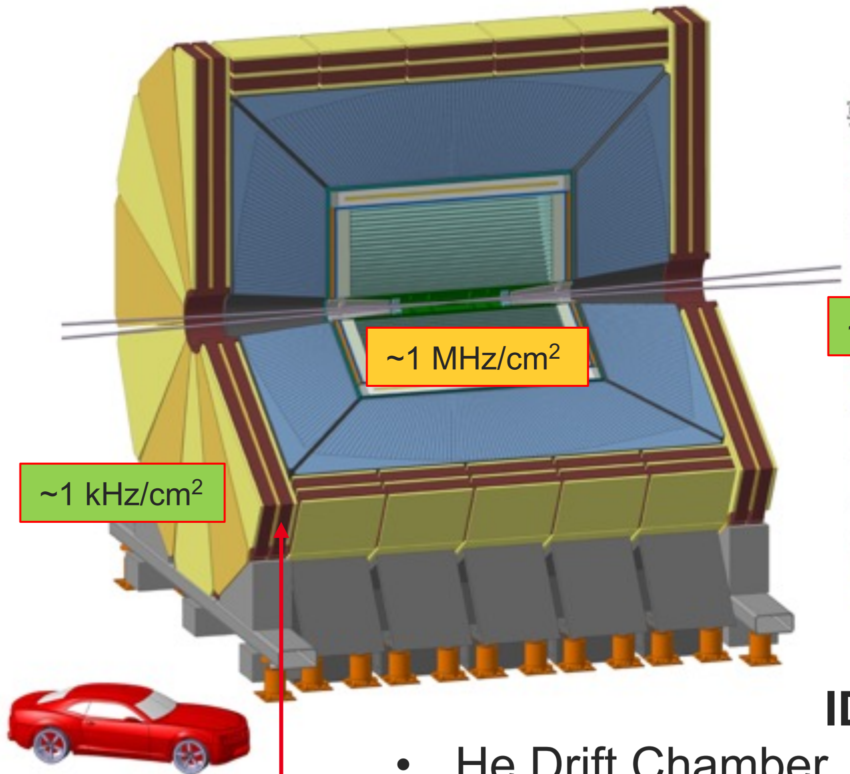
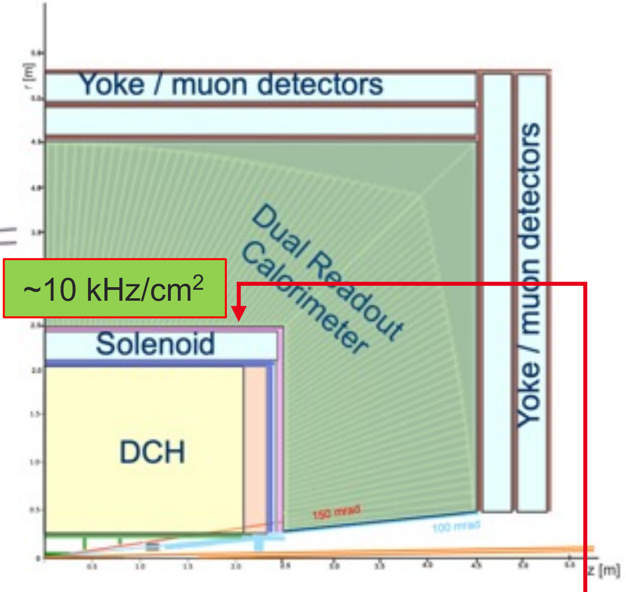
Possible use of MPGDs in future detectors at FCC-ee







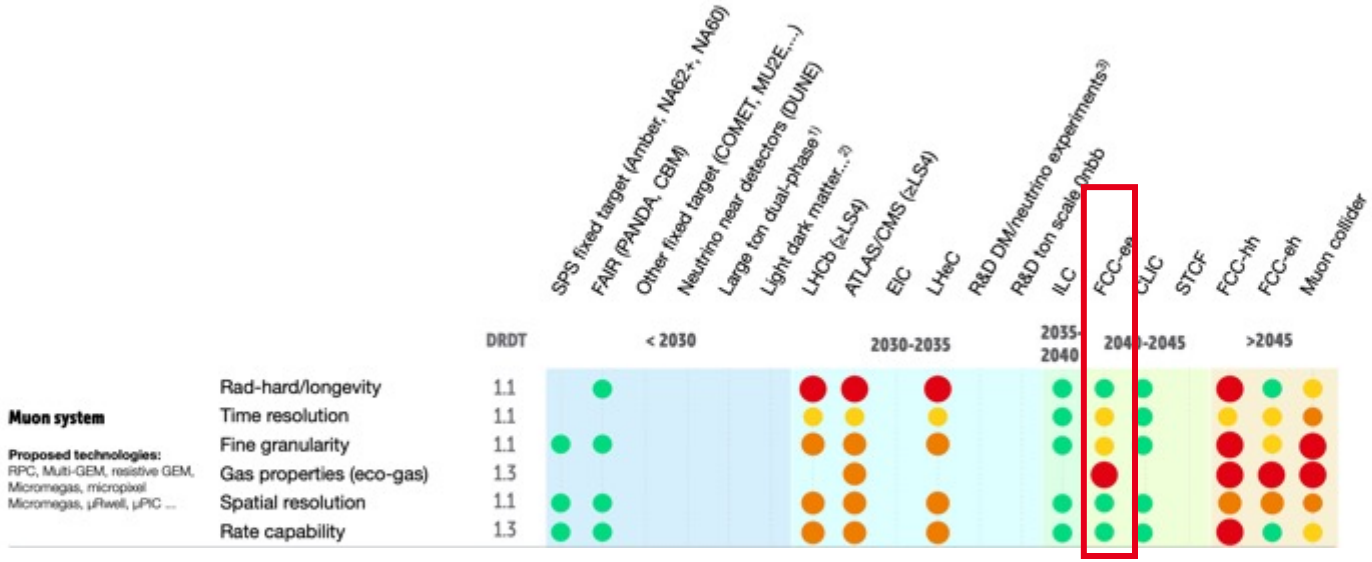
CLD

- Full silicon tracker
- High granularity calorimeter
- Solenoid outside calorimeter
- 2T field
- Muon stations: 6 layers RPC

IDEA

- He Drift Chamber
- Dual readout calorimeter
- Solenoid inside calorimeter
- 2T field
- Muon stations: 3 layers MPGD (μ-RWELL)
- Preshower detector (MPGD)

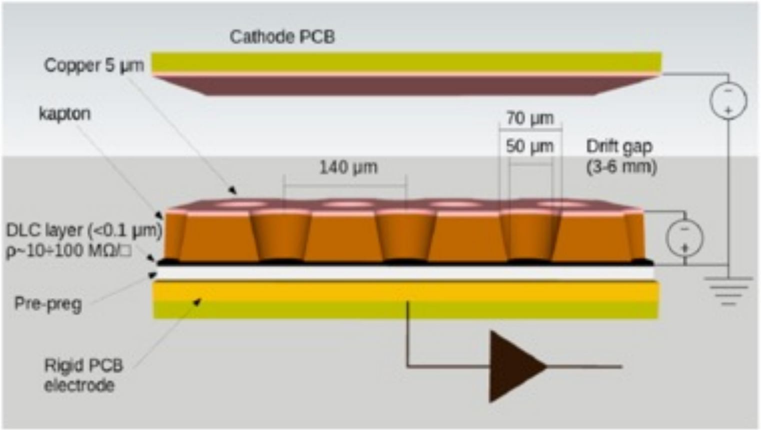
MPGD for muon systems: example of µ-RWELL

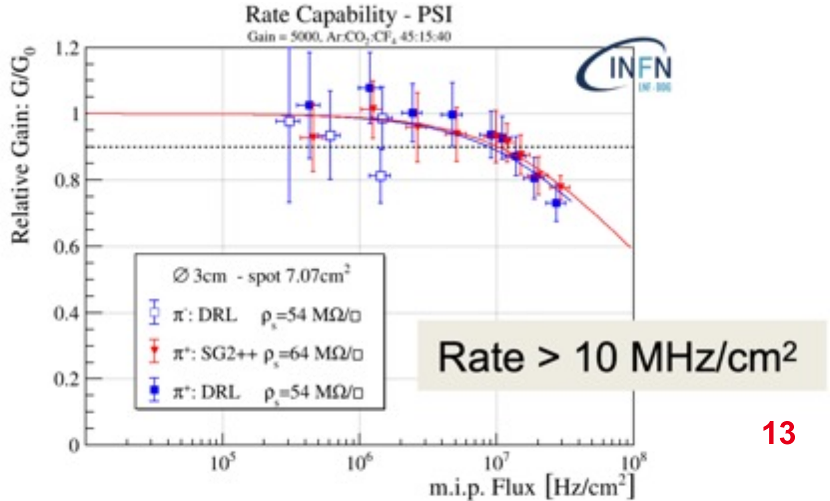


Requirements for future collider experiments :

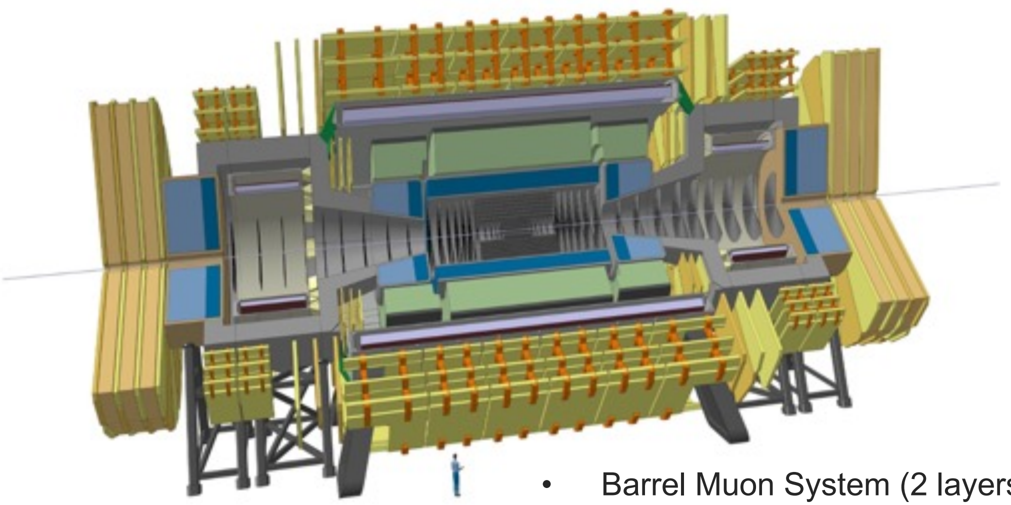
- Muon identification with highest efficiency (98%) and at least 3 points along a muon track
- Resolve bunch crossings → time resolution ~ 1 ns
- Fast Level-1 trigger response should be achievable
- Momentum resolution: $\sigma p_T/p_T^2$ ~ 1-2 x 10^{-5} GeV^{-1} (1 to 2% at 1 TeV)
  - Magnetic field of 2 to 4 Tesla → spatial resolution of a few hundred microns
- Production of detector parts in industry.
- Eco friendly gas mixtures

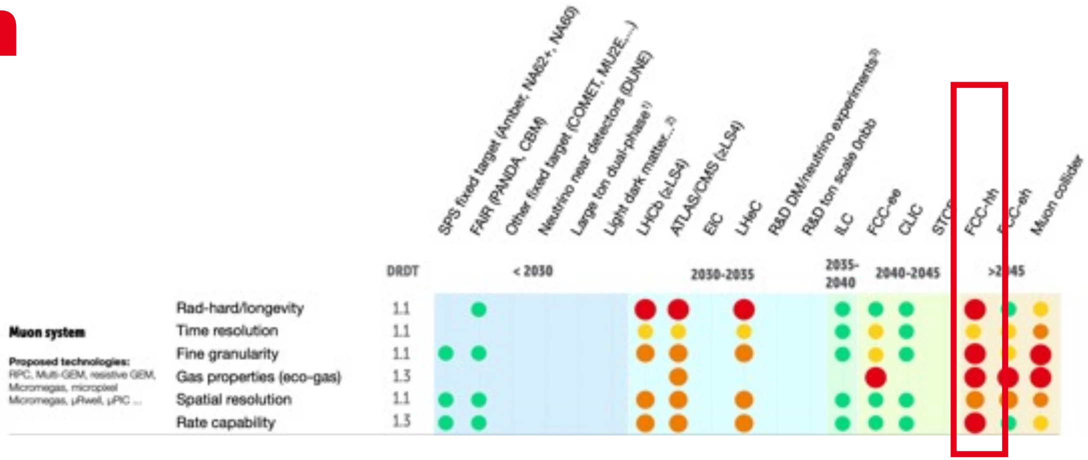
Example of the IDEA detector (>2030):
- 3 muons stations in the return yoke
- Total area → 3000 m^2 (225 m^2 for PS)
- Performance:
  - Max. rate → <1 kHz/cm^2 (10 kHz/cm^2 for PS)
  - Spatial res. → ~150 µm (60-80 µm for PS)
  - Time res. → 5-7 ns





Muon detectors for FCC-hh

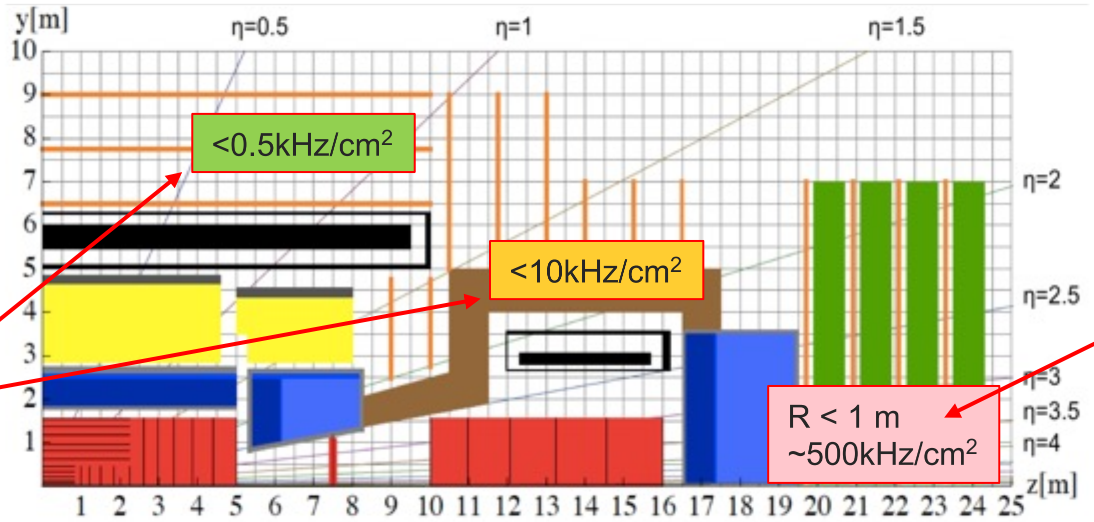




- Barrel Muon System (2 layers): 2000 m^2
- Endcap Muon System (2 layers): 500 m^2
- Forward Muon System (4 layers): 320 m^2

Current MPGD technologies used for the HL-LHC Muon System will be applicable for most of the FCC detector areas

Atlas Muon System @ HL-LHC (kHz/cm²)	
MDTs Barrel	0.28
MDTs Endcap	0.42
RPCs	0.35
TGCs	2
NSW (Micromegas + sTGCs)	Up to 25

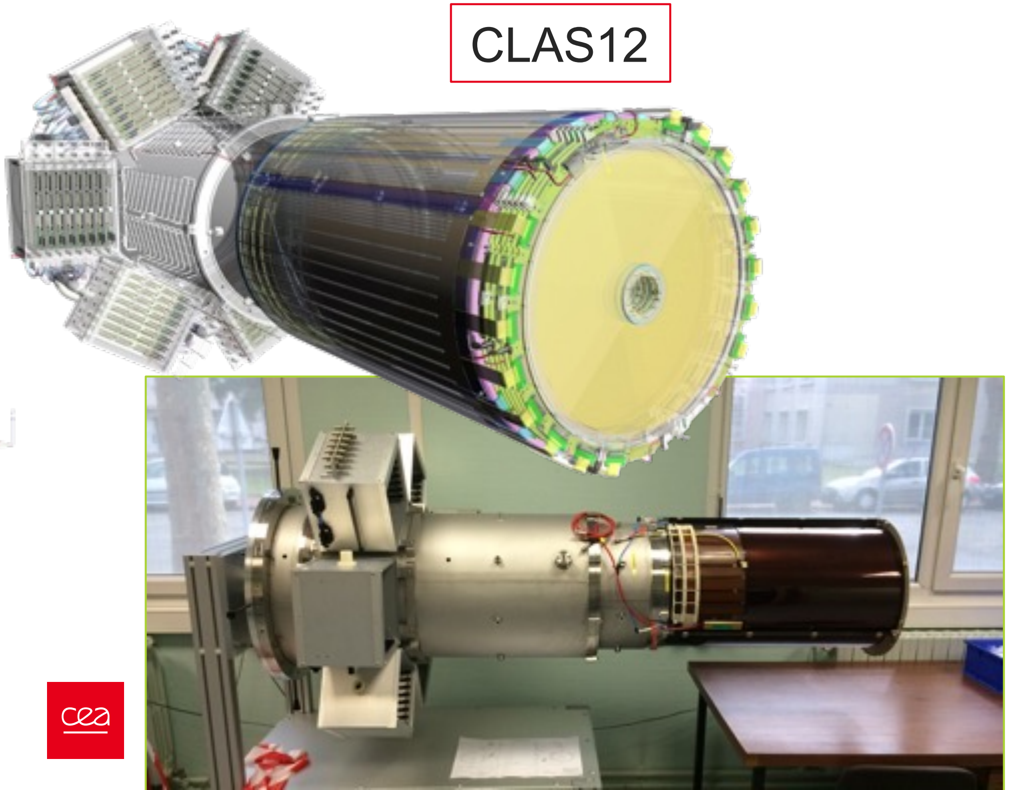


More R&D studies are needed for the very forward region:
- Radiation hardness
- Hydrocarbon-free gas mixtures

Trackers: examples

- 4 m² of Micromegas detectors (resistive, bulk)
- **Forward Detectors (Disks)**
  - High particle rate (30MHz) → ~30 kHz/cm^2
  - 0.7% X/X0
  - Spatial resolution better than 200 µm
  - Time resolution better than 20 ns
- **Cylindrical Barrel (Curved Tiles)**
  - High magnetic field (5T)
  - Less than 0.5% X/X0 per layer (6 layers, 10 cm)
  - Spatial resolution better than 200 µm
  - Time resolution ~20 ns

CLAS12



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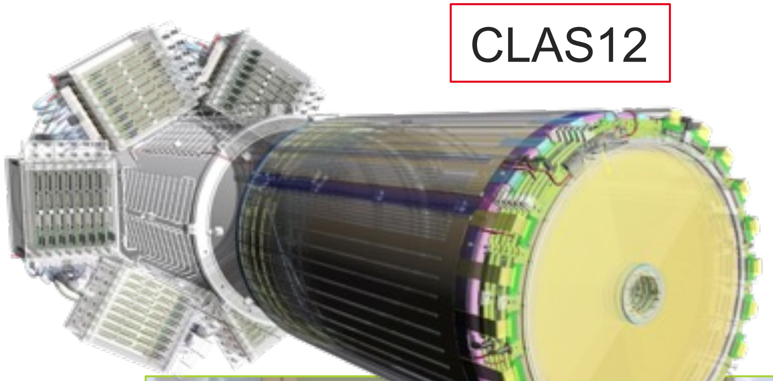
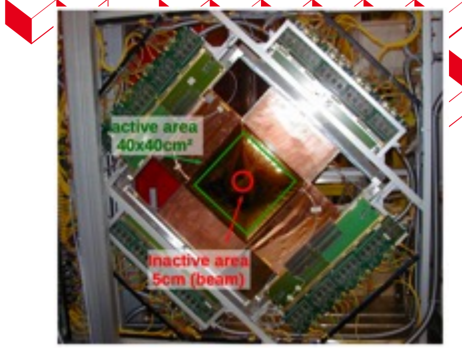
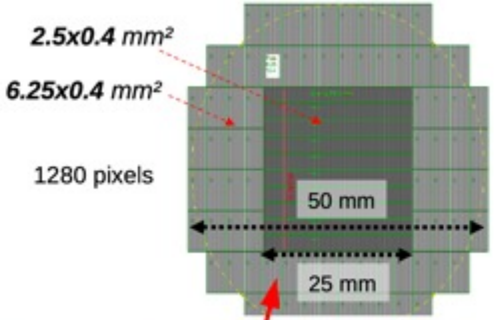
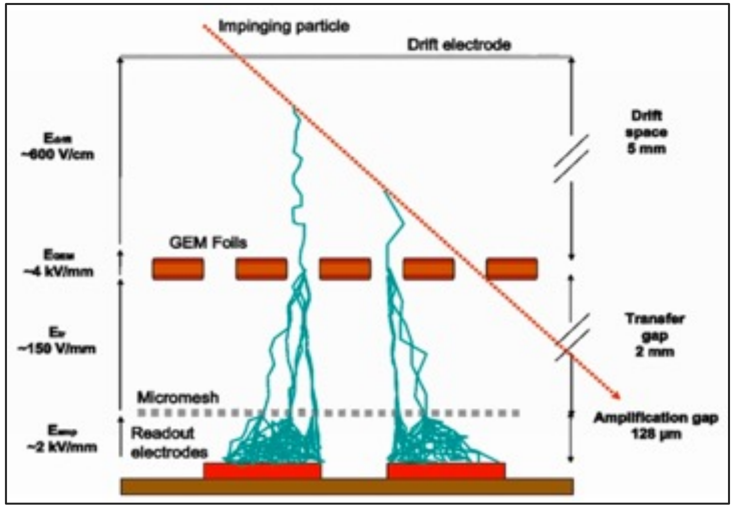


COMPASS

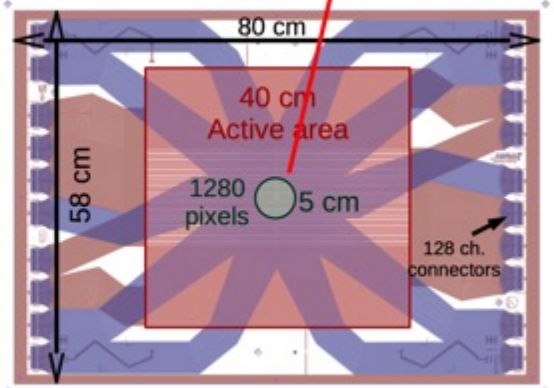
- **Too high flux for strips in center**
  - Expected particle flux > 10 MHz/cm^2
  - > 500 kHz/channel with strip read-out → would lead to 10% electronics inefficiency
- **Rectangular pixels + strips in periphery**
  - 400 µm pitch pixels, like strips → same spatial resolution
  - 1280 pixels + 1280 strips
  - 40x40 cm2 total active area
  - Material budget ~0.38% X0 per plane

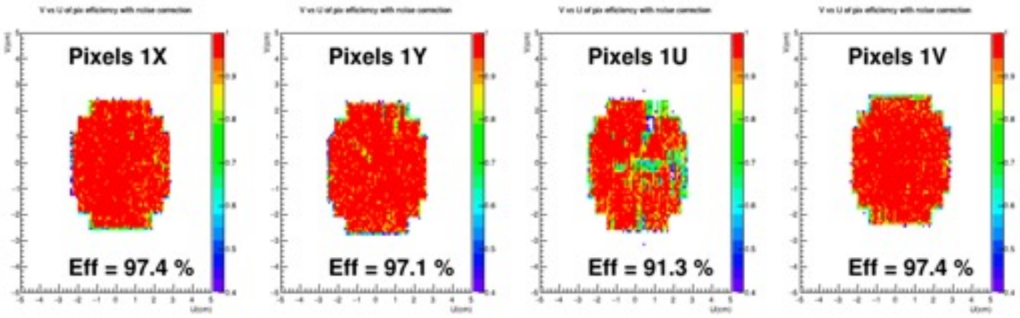






Hybrid structure: GEM + Micromegas





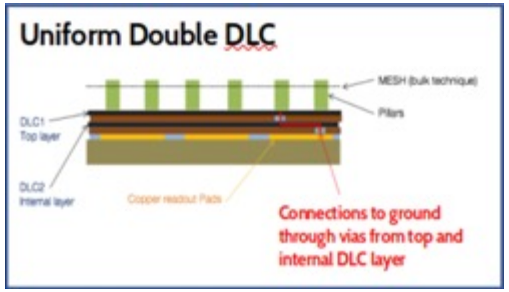
MPGD R&D axes

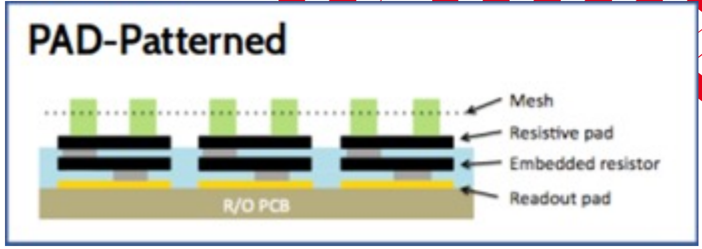
- Spatial resolution: typical 100 µm
  - Fine granularity → large elx channels
  - Charge spreading → resitivity vs rate
  - Capacitive sharing (2D readout)

- Limitations to time resolution: typical few ns
  - Gas mixture (greenhouse gases issue)
  - Field homogeneity (flat electro-formed meshes for MM vs woven meshes)

- Simplified architecture → single-stage design
  - Resistive anodes needed (trade-off with rate capability)
  - Less material budget
  - Advantage for assembly, mass production and cost (Mosaic)
  - Cylindrical shape

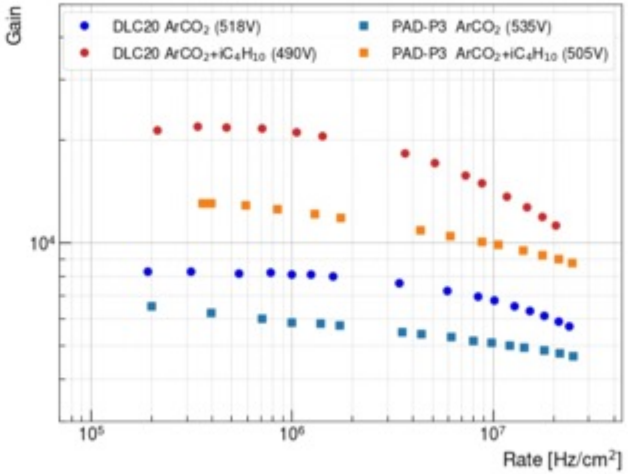
- Aging studies
  - Material aging (DLC)
  - Resistivity vs time and radiations

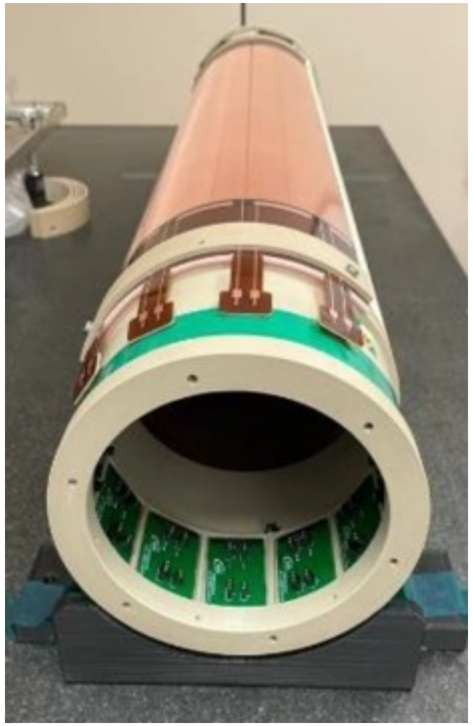


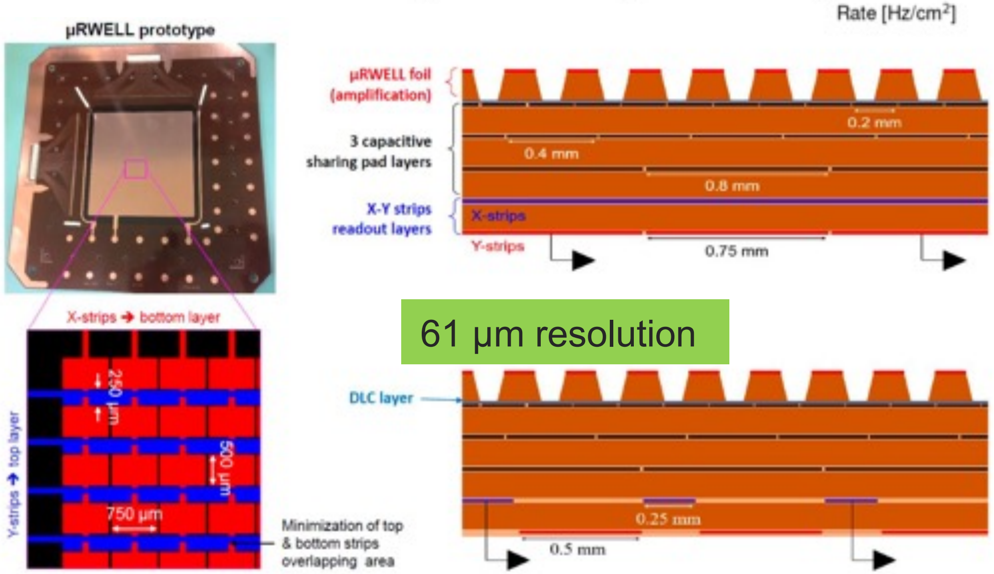


Resistive Pads MM
(for HL-LHC Forward Muon Tagger)
- Gain above 2.10^4
- Very high rate (>10MHz/cm^2)
- Stable conditions

M. Iodice, MPGD 2022







https://doi.org/10.1016/j.nima.2022.167782

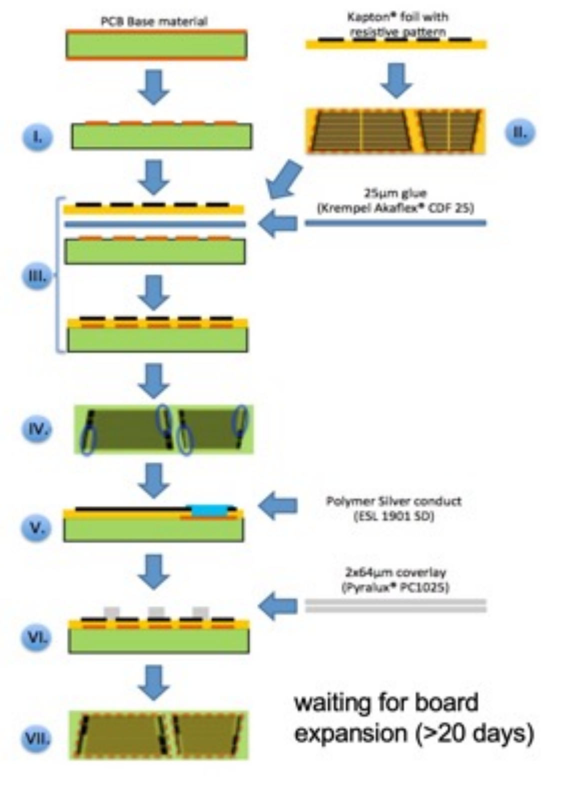
Cylindrical low-mass µRWELL (for Super Charm Tau Factory)

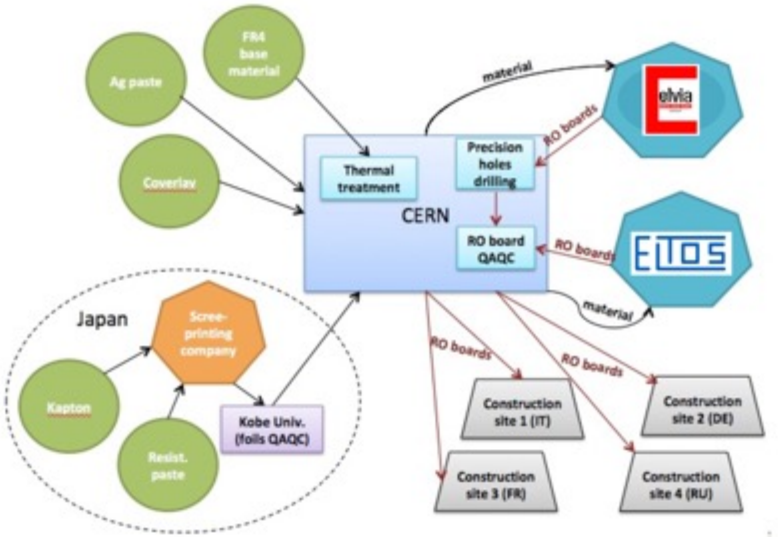
Industrialization: example of Atlas NSW

- Large area (~1000 m^2)
- Mass production: 2800 boards / 32 references
- Large element size: up to 45 x 220 cm^2
- PCB manufacturing technology
- Quality Control

Full production in industry
2 companies: ELVIA (FR), ELTOS (IT)

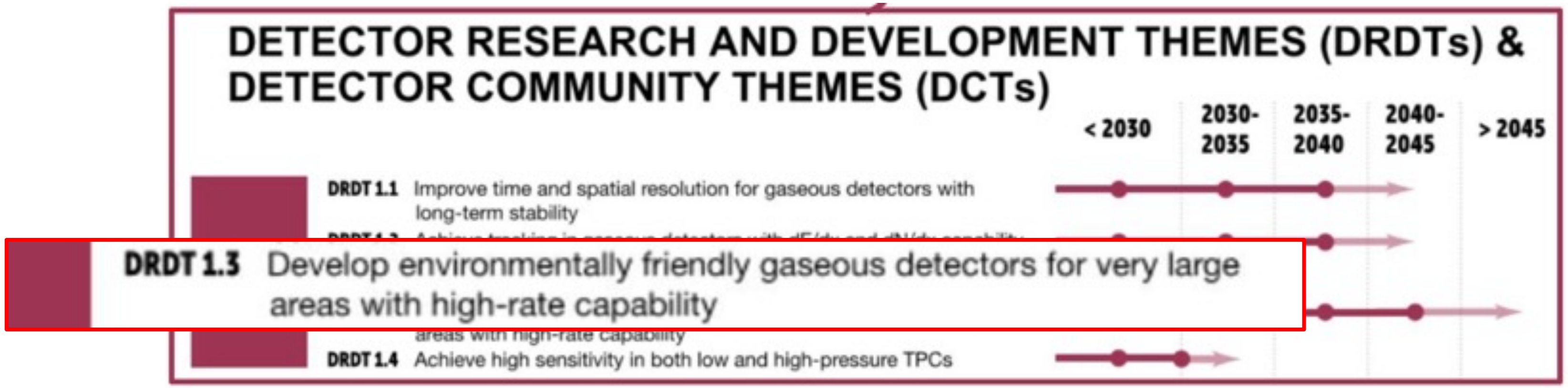
PCB manufacturing process
(R&D → industry)





See **P. Iengo** (https://indico.cern.ch/event/1219224/contributions/5130760/)

Eco-gases



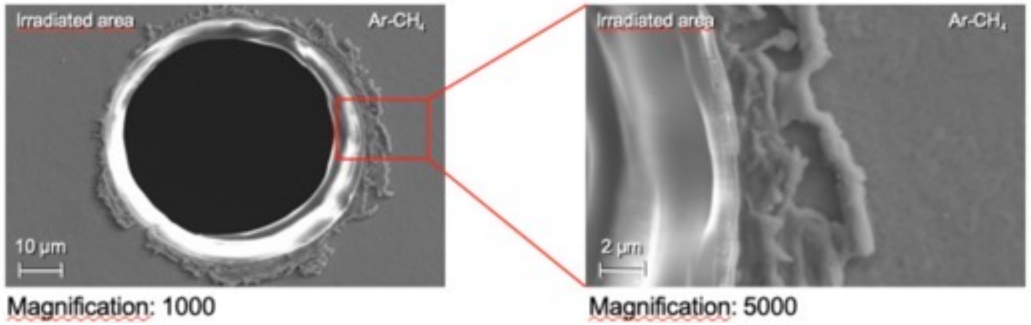
See talk by **B. Mandelli** in 3rd International Aging Conference 2023
https://indico.cern.ch/event/1237829/contributions/5637221/

- In the face of concerns about climate change, we need to find alternatives to greenhouse gases (CF_4, C_4F_{10}, SF_6, …) extensively used for time resolution, mitigation of aging phenomena, etc.
- Reduction of industrial production will make procurement difficult
- Aging and performance studies are fondamental → dedicated WG in DRD1
- R&D axes:
  - Recirculation
  - Recuperation
  - Alternative gas mixtures
  - Destruction

Aging effects

See talks by
F. Sauli, M. Titov and V. D'Amico in 3rd International Aging Conference 2023
https://indico.cern.ch/event/1237829/contributions/5637200/
https://indico.cern.ch/event/1237829/contributions/5637193/
https://indico.cern.ch/event/1237829/contributions/5609449/

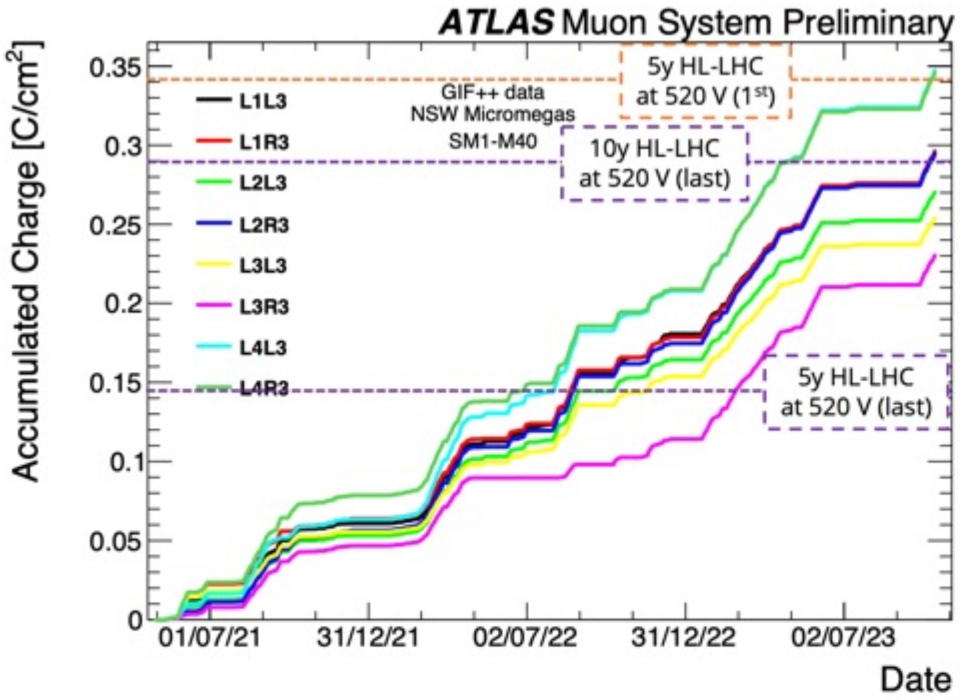
- Aging studies are needed on:
  - New components (frame, oring, insulators, …)
  - New architecture
  - Gas mixtures
- Different radiation types (X, n, gammas, …)
- Very difficult to extrapolate a necessarily short aging period compared to long-term experience near future accelerators.



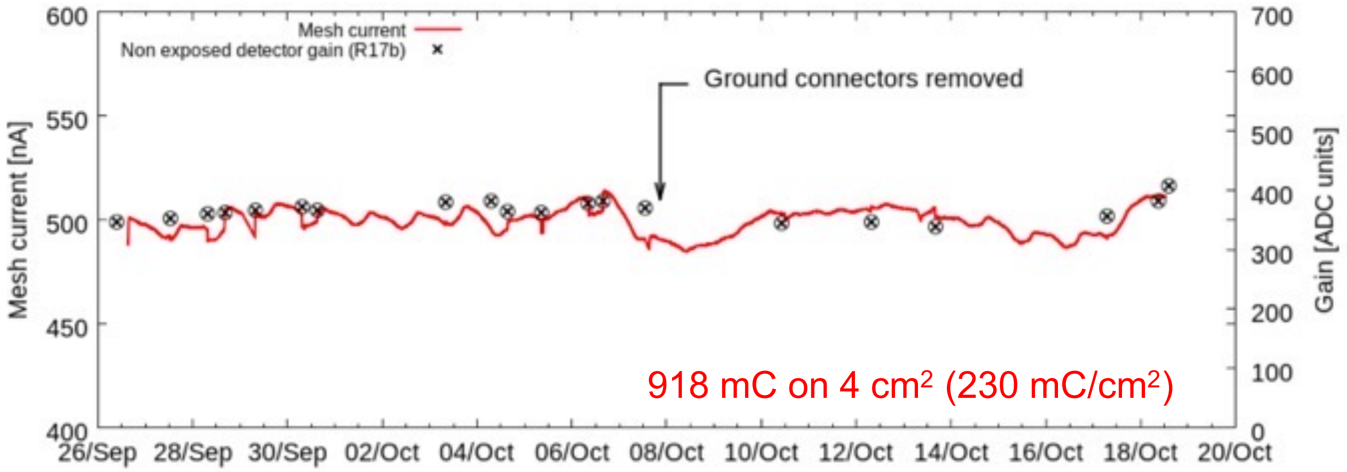
Hydrocarbon deposit on copper (Alice TPC)

Long term irradiation studies on MM (NSW) @ GIF++

^{137}Cs 662 keV Gammas ~11.6 TBq



Several years of HL-LHC equivalent have been accumulated so far, with no general decrease in performance observed



Conclusion

- MPGD technologies are suitable to the future FCC environment and are very good options for muon chambers and, possibly, next-generation trackers (or time detector around Drift Chamber or TPC).

- Very large unity modules, as in Atlas NSW, is not mandatory and a mosaic geometry is certainly a good option to study (wrt production, cost, maintenance, …)

- Aging studies are a first importance as well as problematics related to the greenhouse gas mixture

- Scaling from small prototypes to large areas need a strong development plan (prototype policy)

- A lot of proposals for µRWELL technology → very good results but newest MPGD technology (never installed in an experiment…)

Merci !