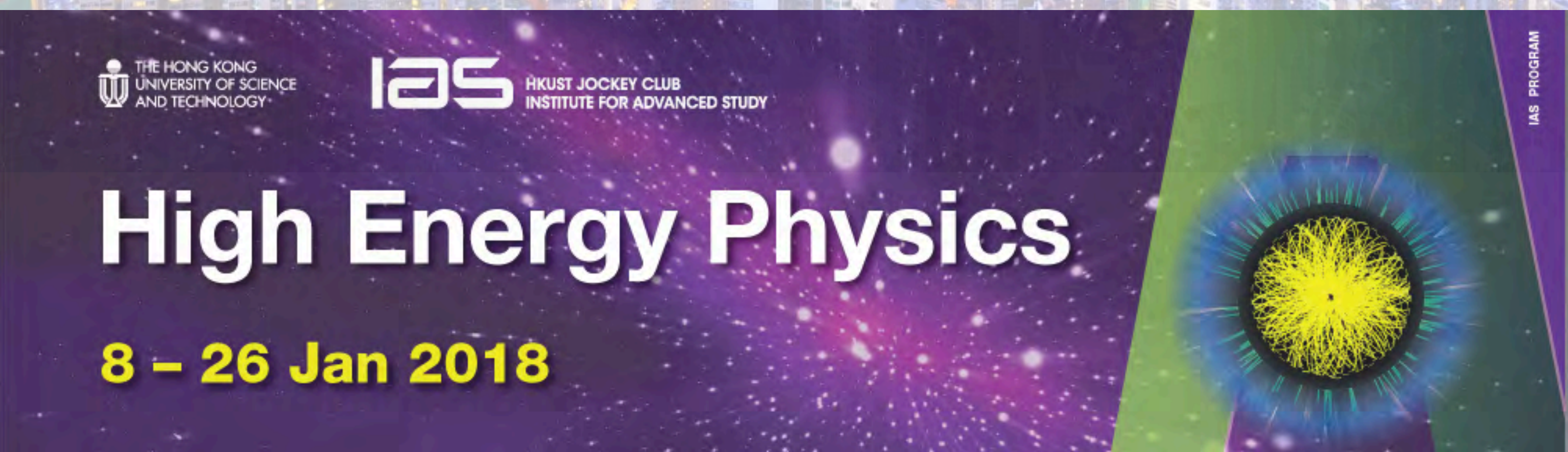
IAS 2018 conference
HKUST, Hong Kong

Istituto Nazionale di Fisica Nucleare

Muon detectors and MPGDs

P. Giacomelli
INFN Bologna



Overview

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- **An example of a new MPGD: the μRWell and its application for future muon systems**
- **Conclusions**

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For evident reasons of price, gas detectors are the obvious choice for equipping these extremely large surfaces.

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- Muon detectors in large HEP experiments are used to measure the muon momentum with a pretty good resolution and to provide a standalone muon trigger and the BX identification (at least in hadron colliders). This translates into a required time resolution of a few ns.

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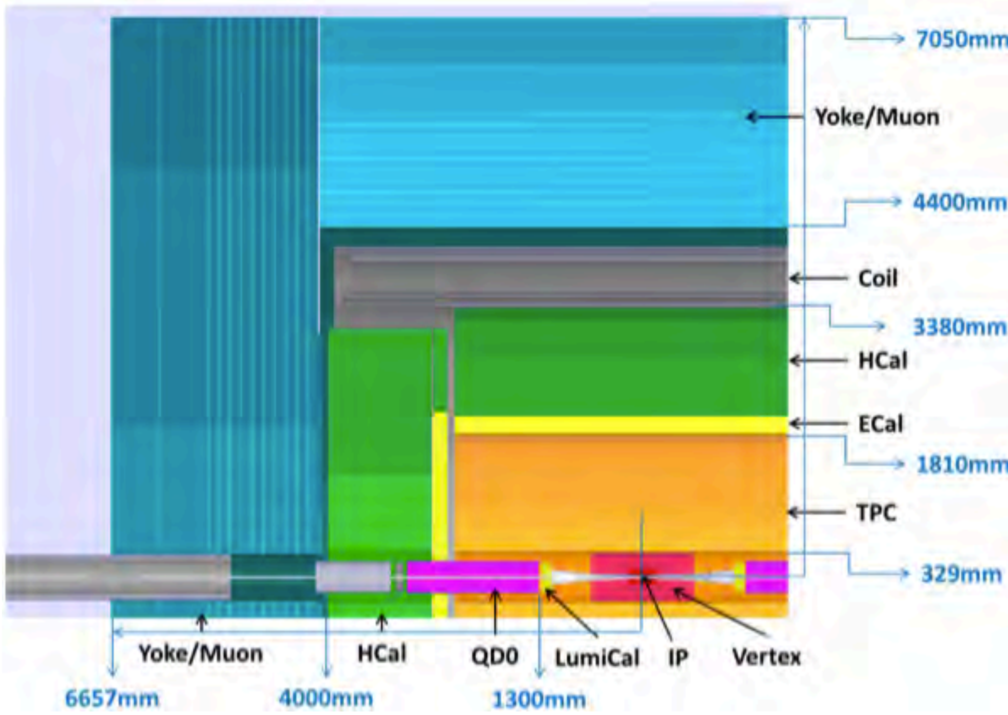
In the baseline option, inspired from ILD, the muon detection system is composed of two layers of RPC stations.

An upgrade of the muon detector by using MPGDs could provide a much finer space resolution with a similar time resolution at a relatively modest increase in price.

The fine space resolution of the detectors could allow to obtain a standalone muon momentum measurement and to trace back the muon stabs to the tracker tracks.



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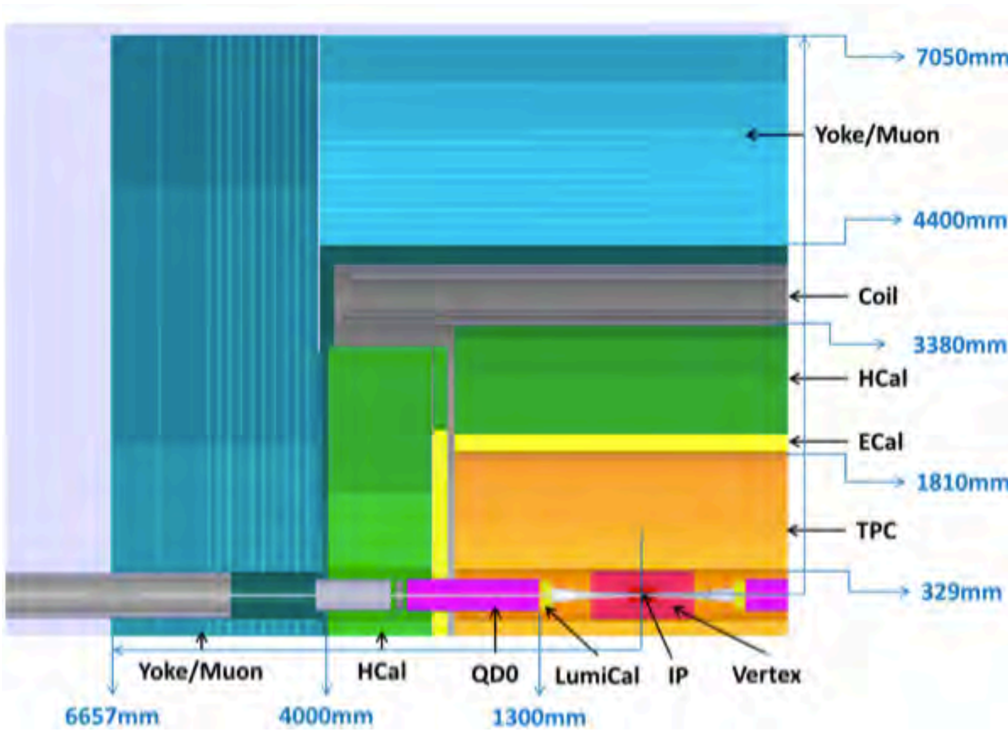
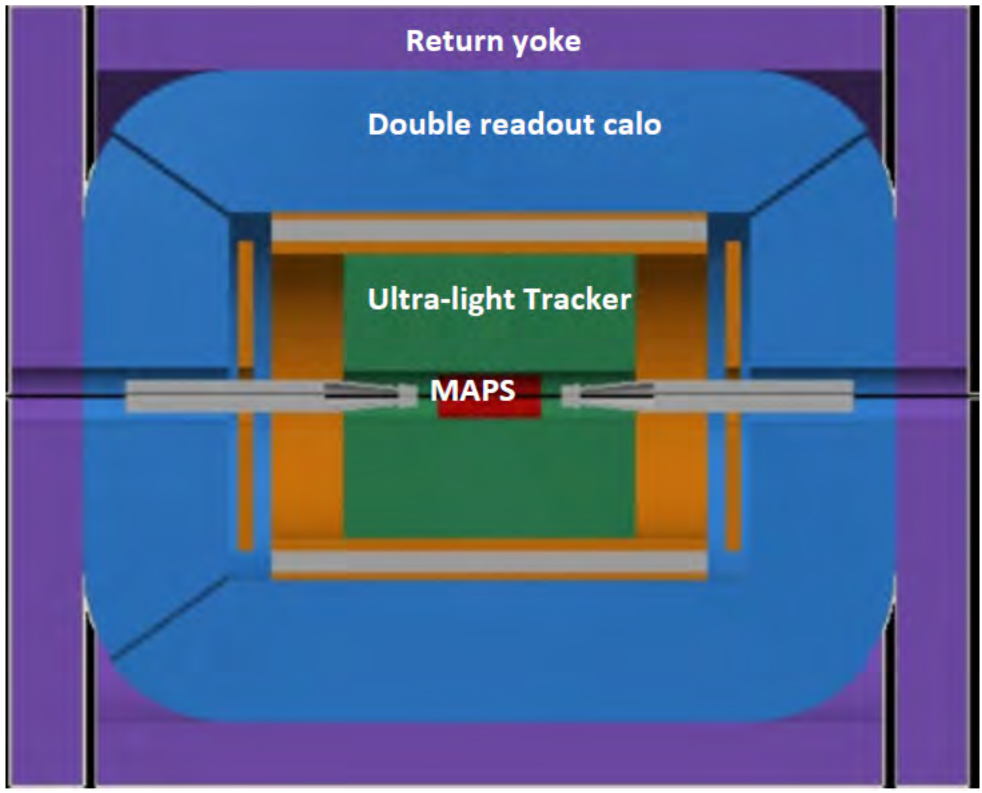
In the IDEA detector concept, a muon detection system, made of three MPGD stations interleaved in the iron return yoke, is already foreseen.





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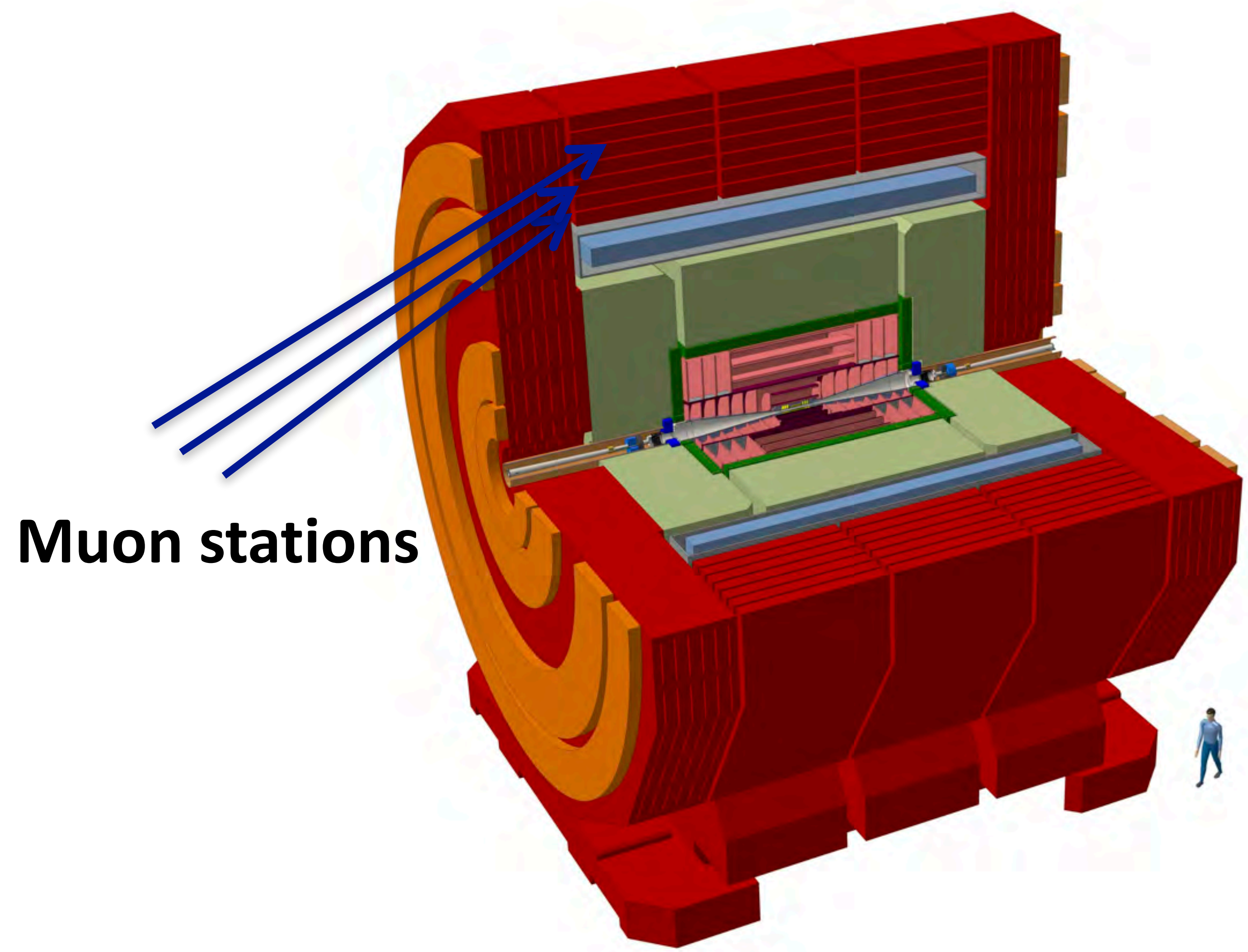

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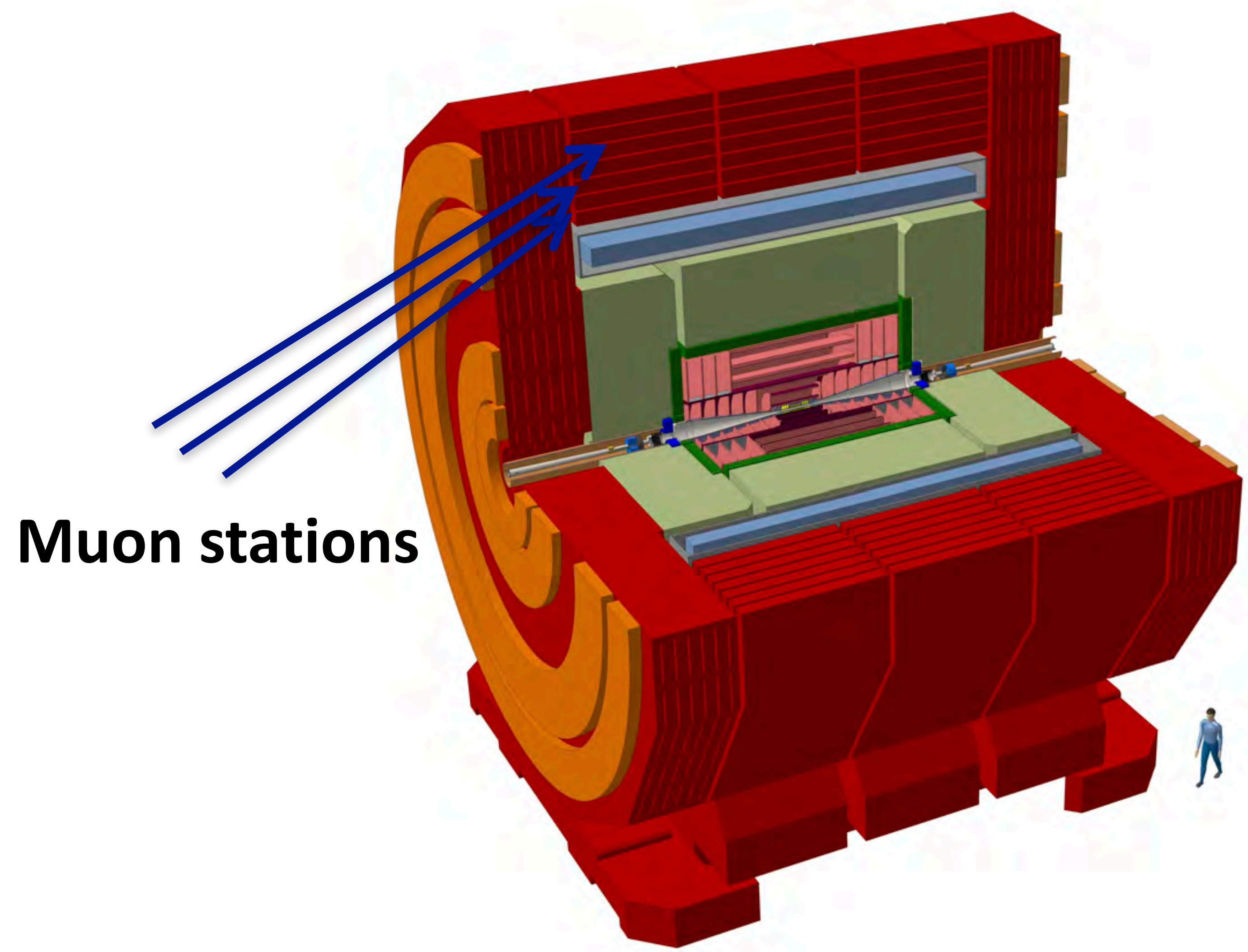

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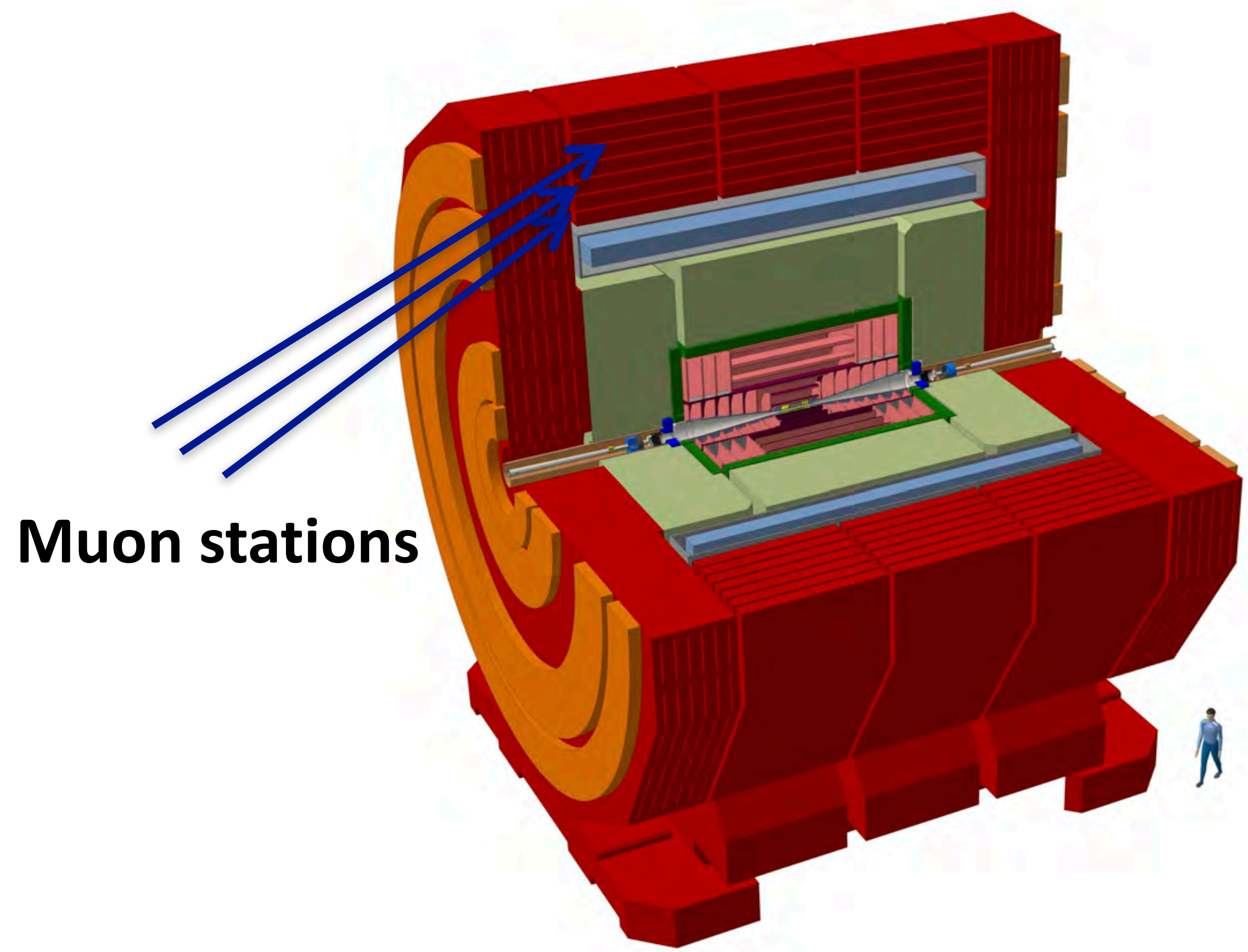

There is also the IDEA concept, discussed in the previous slide.

Muon detector for SppC or FCC-hh

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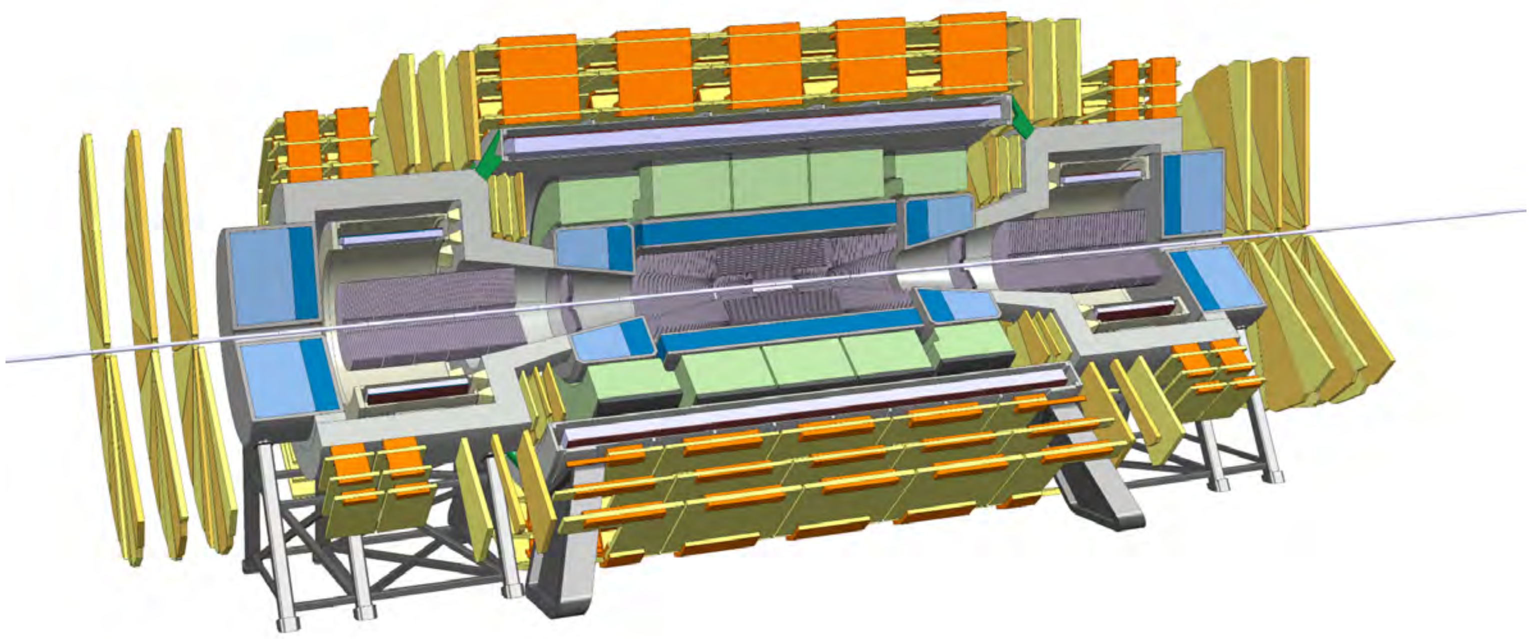
FCC-hh detector



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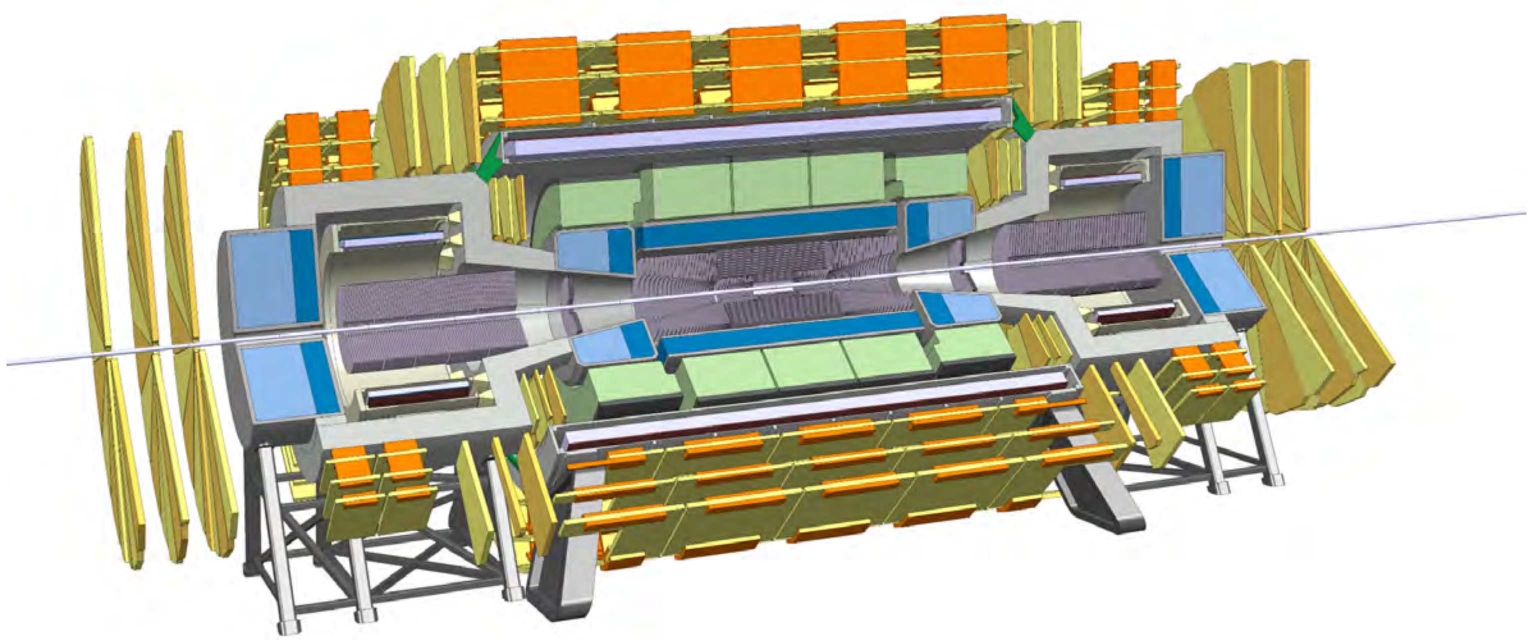

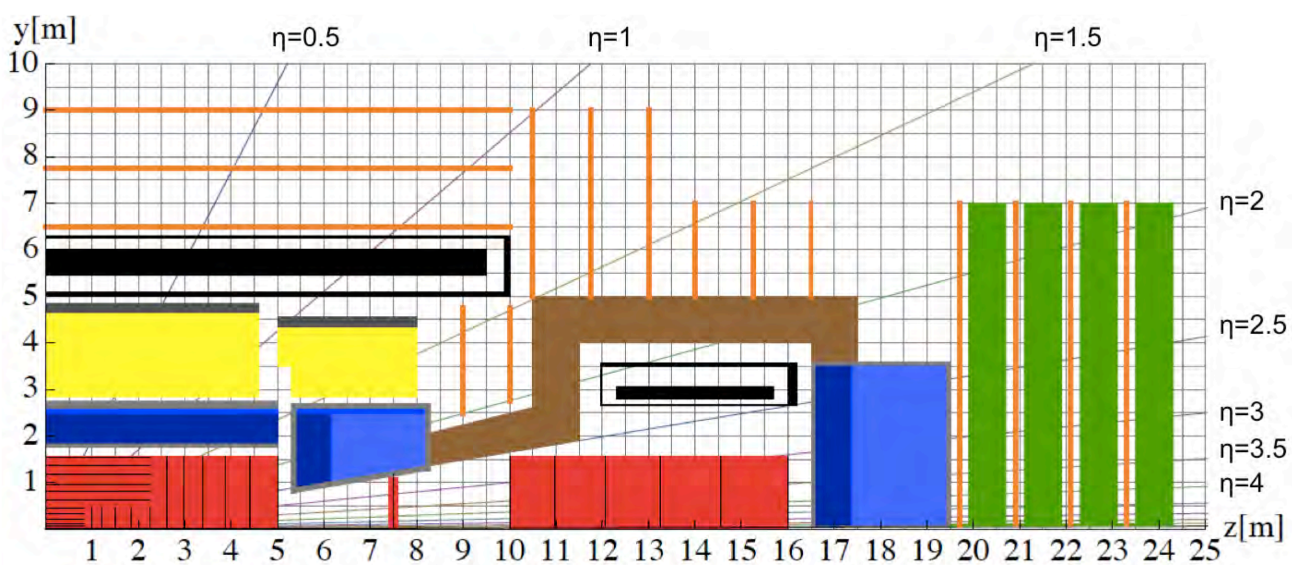

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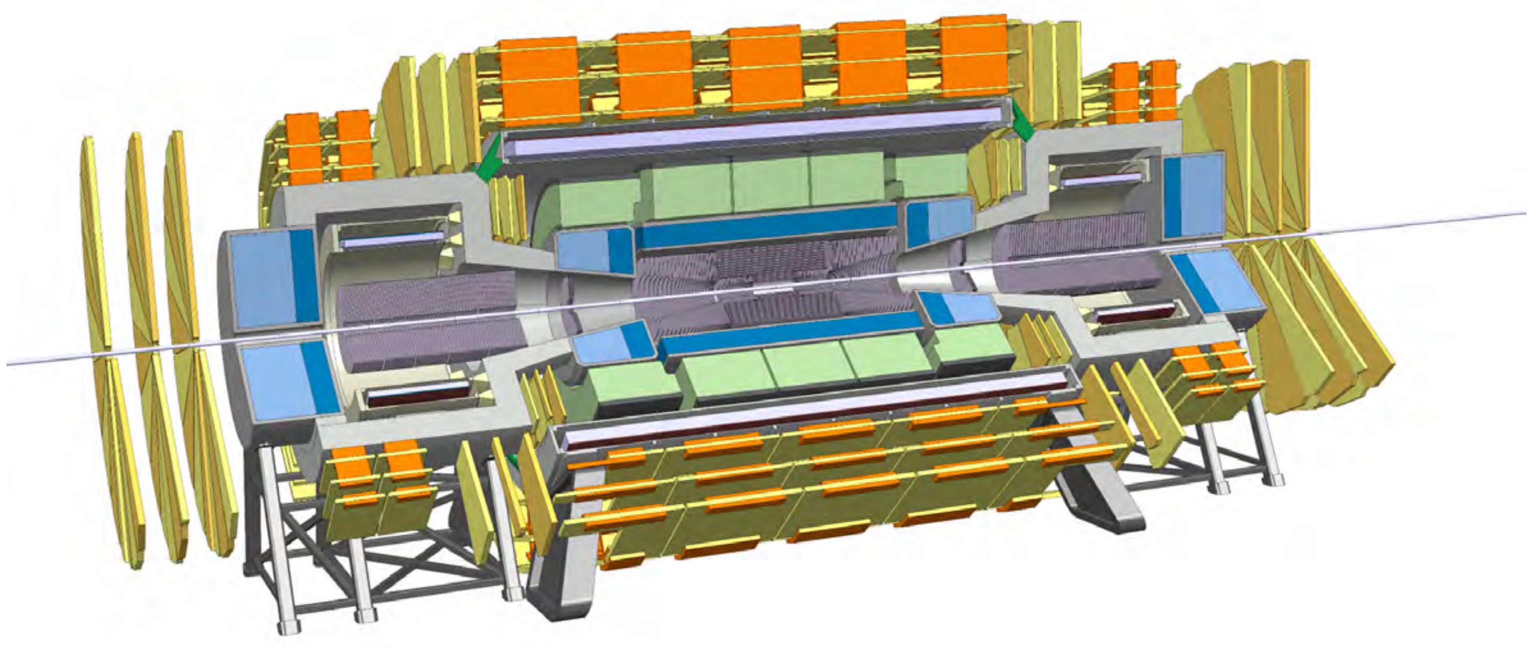

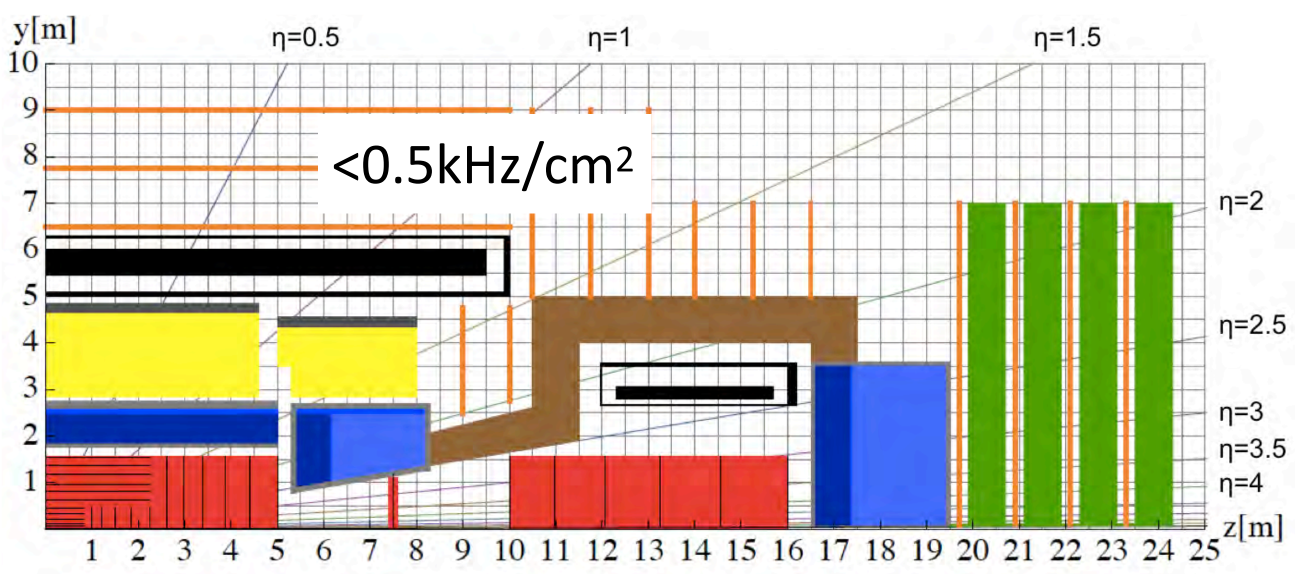

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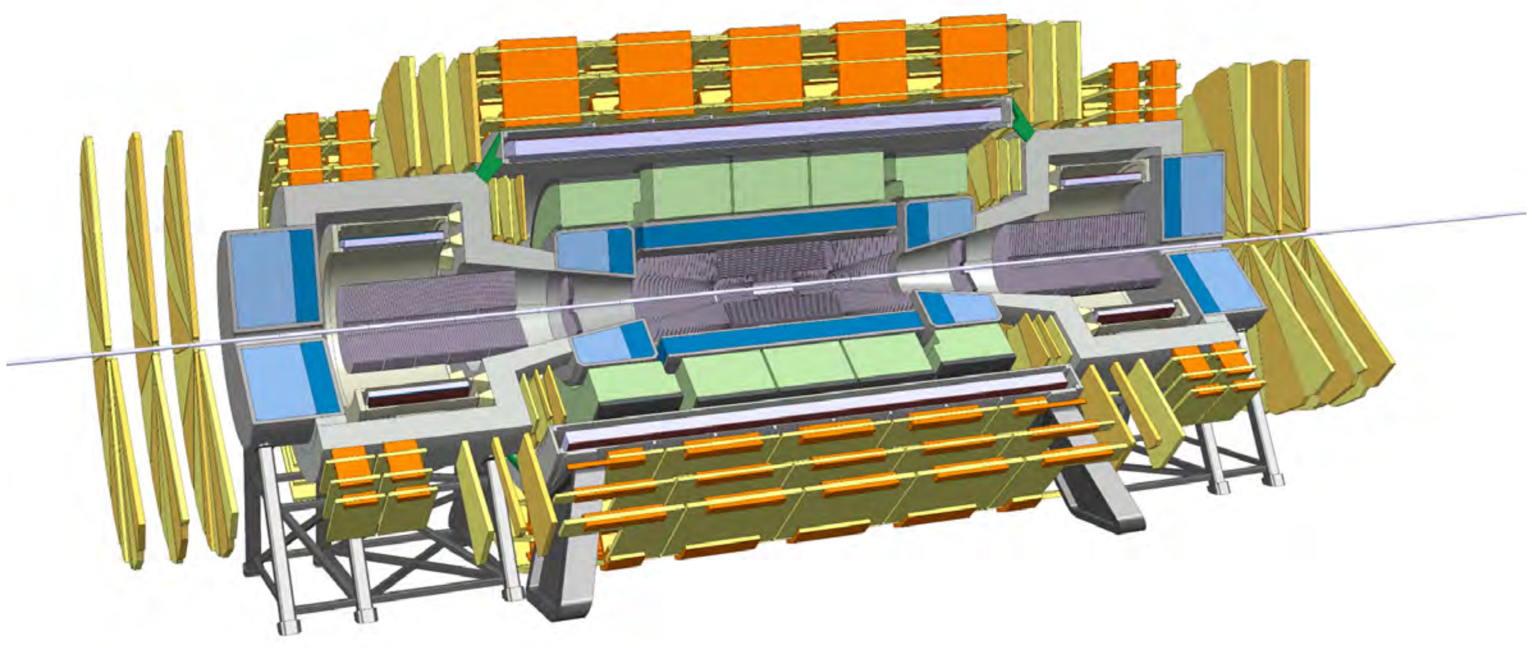

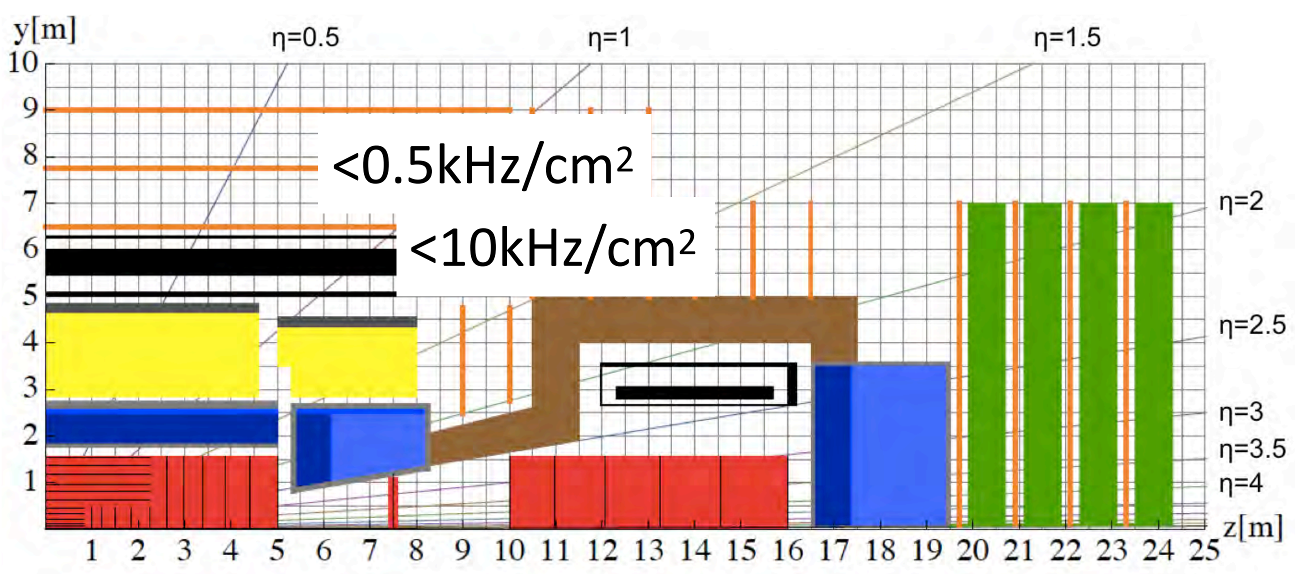

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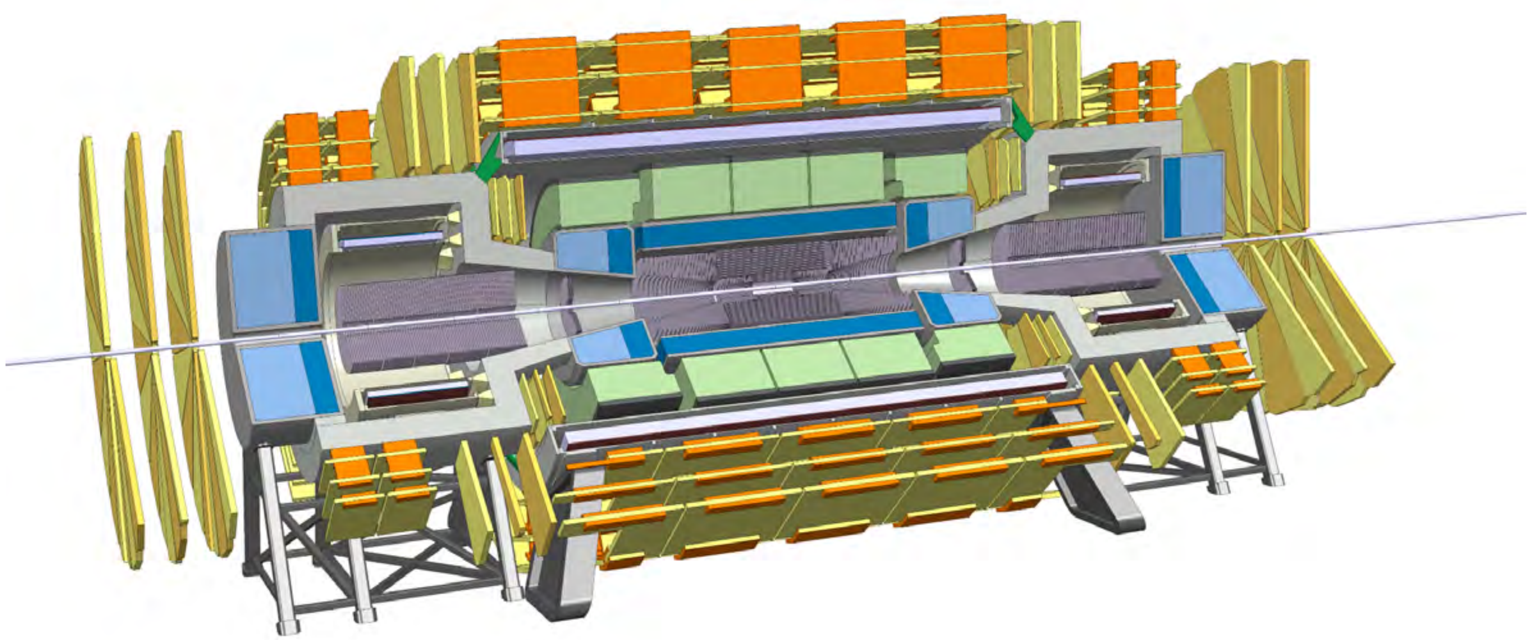

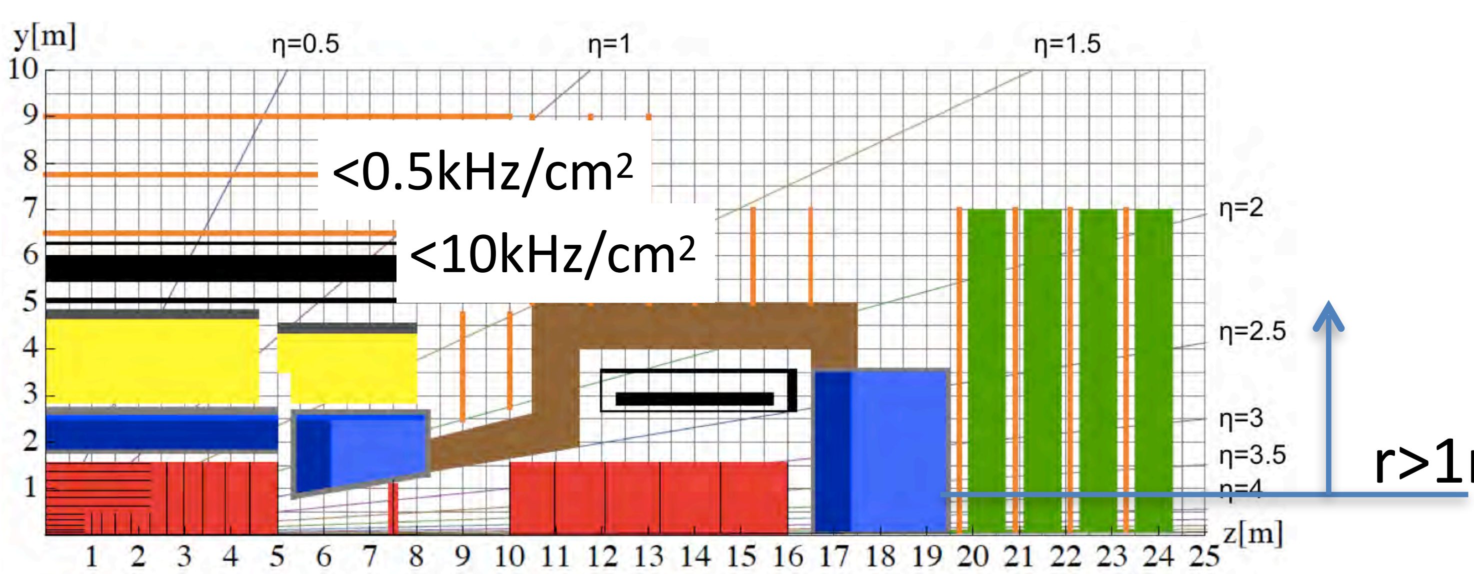

r>1m rate<500kHz/cm2

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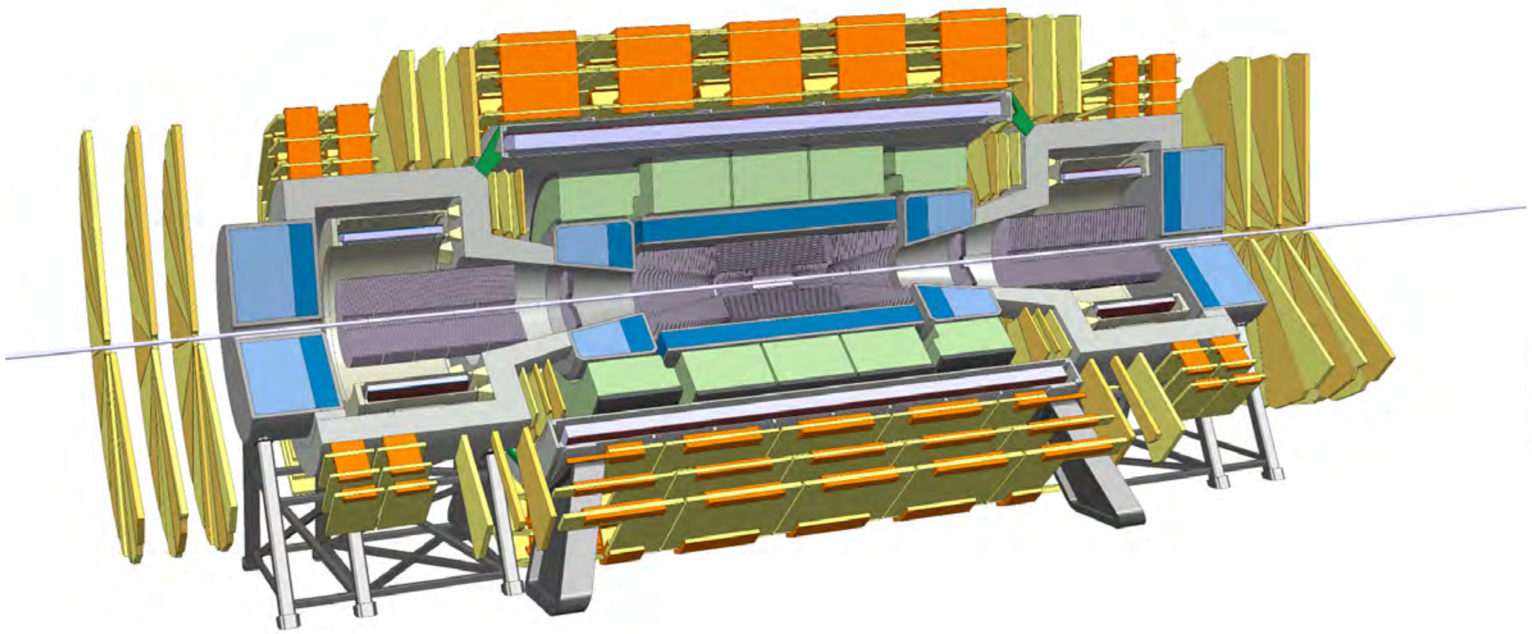

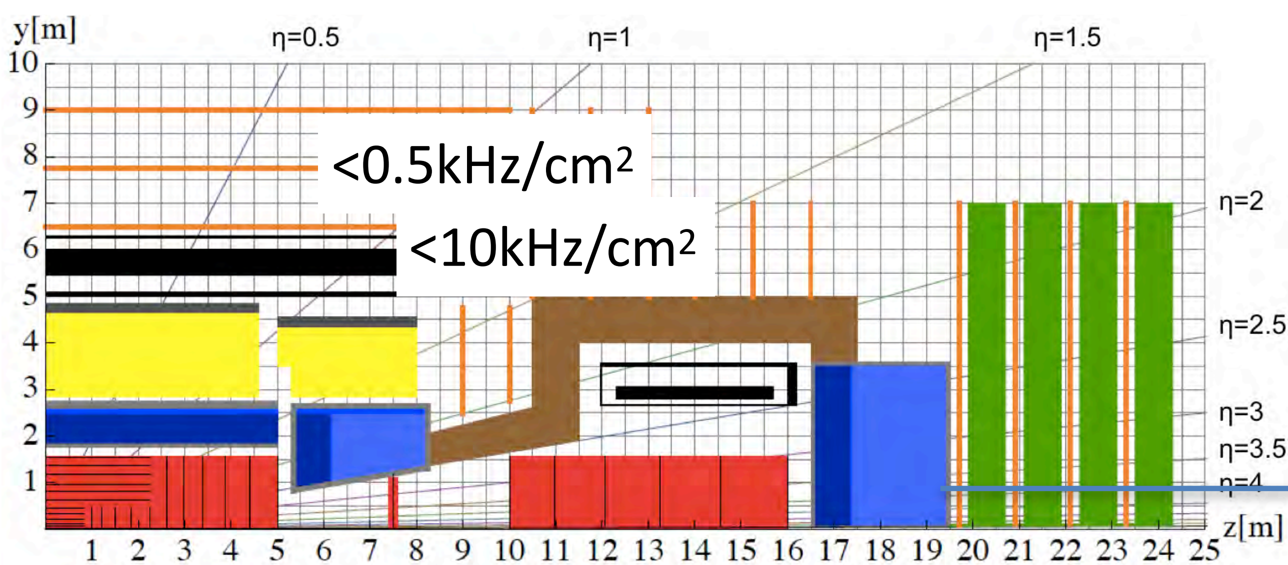

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ATLAS muon system HL-LHC rates (kHz/cm²):
- MDTs barrel: 0.28
- MDTs endcap: 0.42
- RPCs: 0.35
- TGCs: 2
- Micromegas and sTGCs: 9-10

Table 4.5: Expected rates on the muon detector when operating at an instantaneous luminosity of 2×10^{33} cm^{-2}s^{-1} at a collision energy of 14 TeV. The values are averages, in kHz/cm^2, over the chamber with the minimum illumination, the whole region and the chamber with maximum illumination. The values are extrapolated from measured rates at 8 TeV.

LHCb

Region	Minimum	Average	Maximum
M2R1	162 ± 28	327 ± 60	590 ± 110
M2R2	15.0 ± 2.6	52 ± 8	97 ± 15
M2R3	0.90 ± 0.17	5.4 ± 0.9	13.4 ± 2.0
M2R4	0.12 ± 0.02	0.63 ± 0.10	2.6 ± 0.4
M3R1	39 ± 6	123 ± 18	216 ± 32
M3R2	3.3 ± 0.5	11.9 ± 1.7	29 ± 4
M3R3	0.17 ± 0.02	1.12 ± 0.16	2.9 ± 0.4
M3R4	0.017 ± 0.002	0.12 ± 0.02	0.63 ± 0.09
M4R1	17.5 ± 2.5	52 ± 8	86 ± 13
M4R2	1.58 ± 0.23	5.5 ± 0.8	12.6 ± 1.8
M4R3	0.096 ± 0.014	0.54 ± 0.08	1.37 ± 0.20
M4R4	0.007 ± 0.001	0.056 ± 0.008	0.31 ± 0.04
M5R1	19.7 ± 2.9	54 ± 8	91 ± 13
M5R2	1.58 ± 0.23	4.8 ± 0.7	10.8 ± 1.6
M5R3	0.29 ± 0.04	0.79 ± 0.11	1.69 ± 0.25
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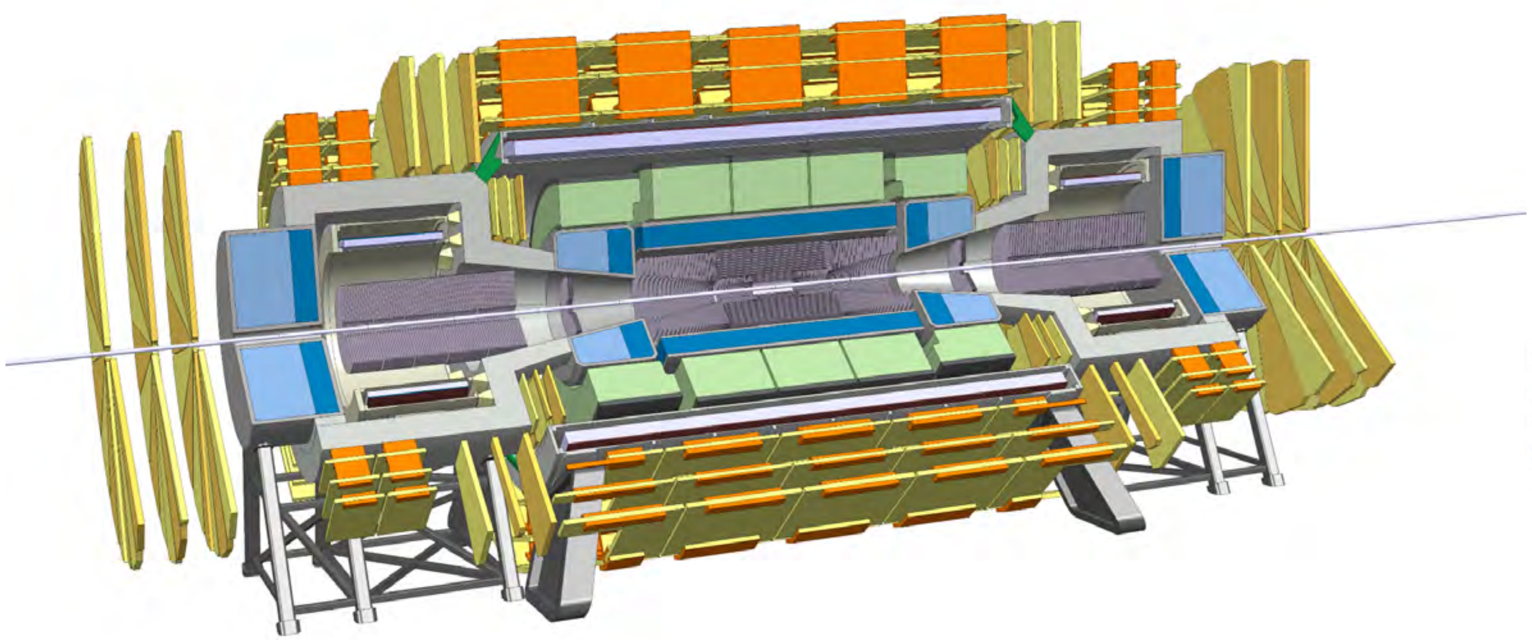

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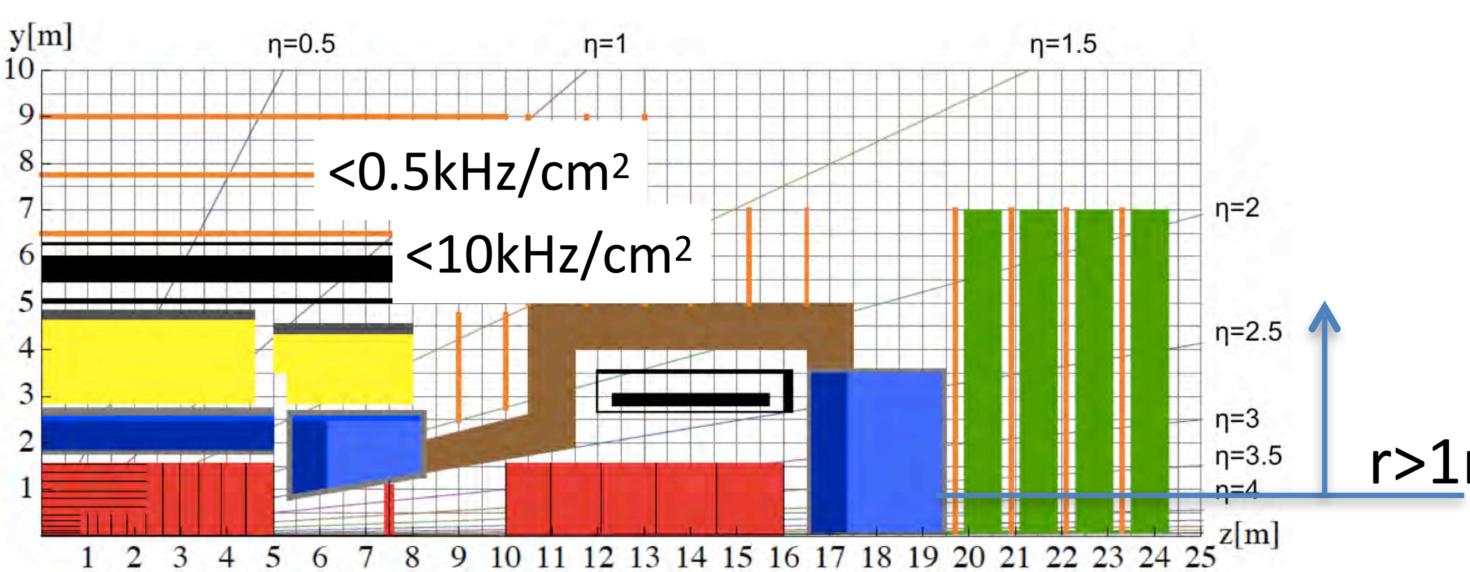

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HL-LHC muon system gas detector technologies, and especially MPGDs, would work for most of the SppC or FCC-hh detector area

Principle of operation of MPGDs

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Improve gas detectors

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Limited multi-track separation

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- Higher spatial resolution

S. Franchino, 2016

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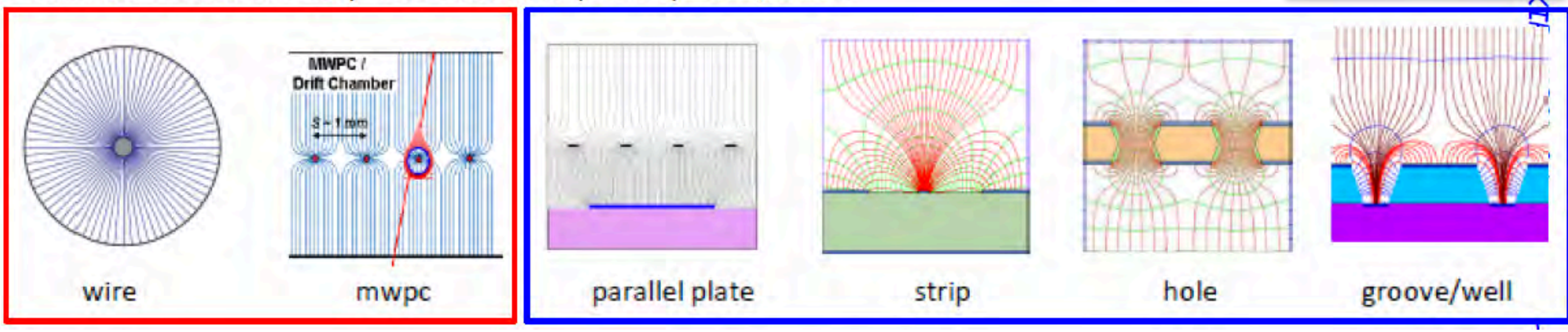
S. Franchino, 2016

First MPGD: Micro Strip Gas Chamber (MSGC) OED, 1988



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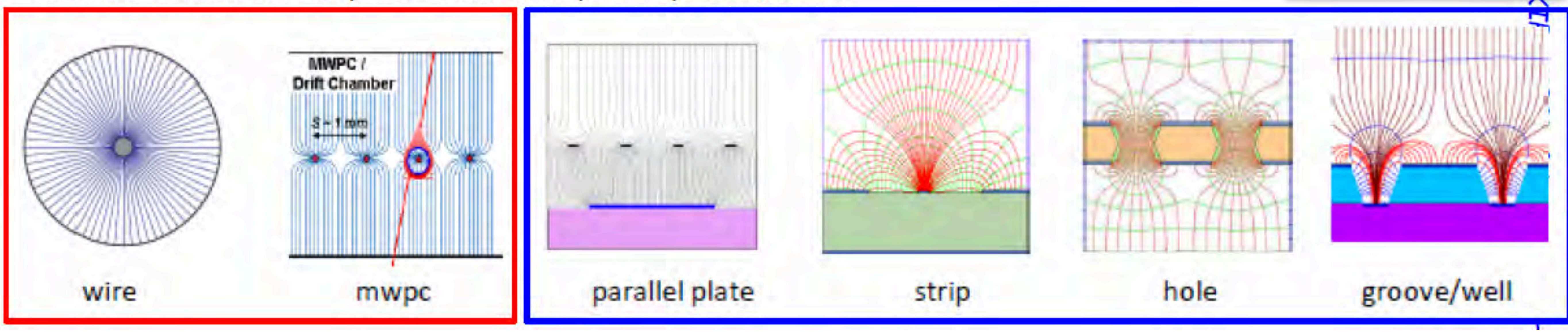
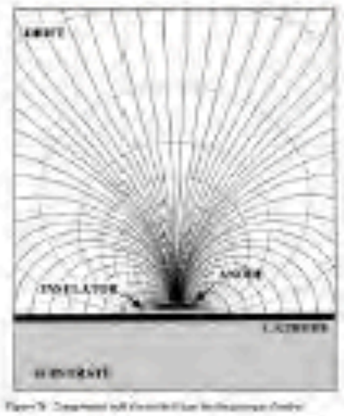


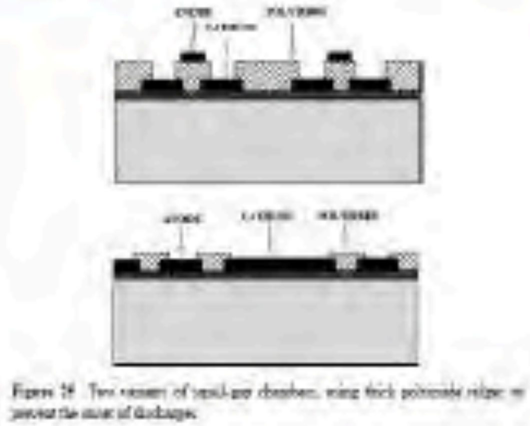
Reduce the size of the detecting cell (~100 μm) using chemical etching techniques
Use PCB technology to obtain very fine electrodes O(10 μm)
Same working principle as proportional wire chambers

- Conversion region (low E field)
- High E field in well localised regions where multiplication happens

Evolution of MPGDs

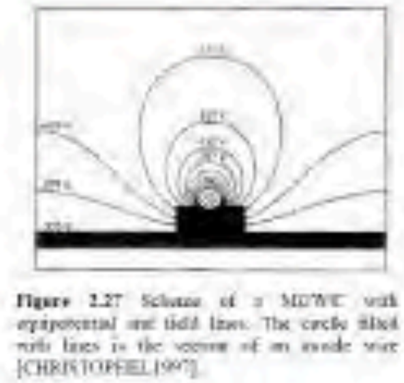
Micro Gap Chambers





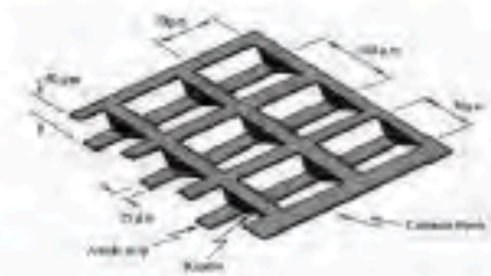
Angelini F, et al. Nucl. Instrum. Methods A335:69 (1993)

Micro Gap Wire Chamber



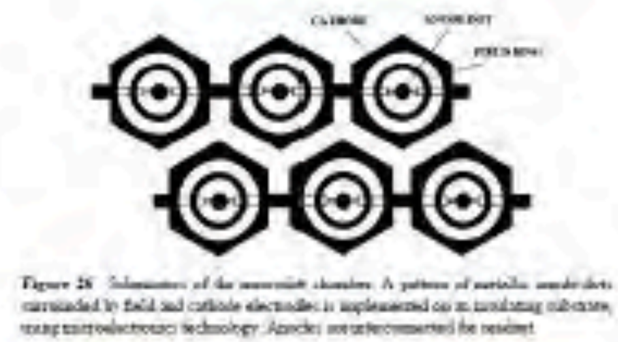
E. Christophel et al, Nucl. Instr. and Meth, vol 398 (1997) 195

Micro Wire Chamber



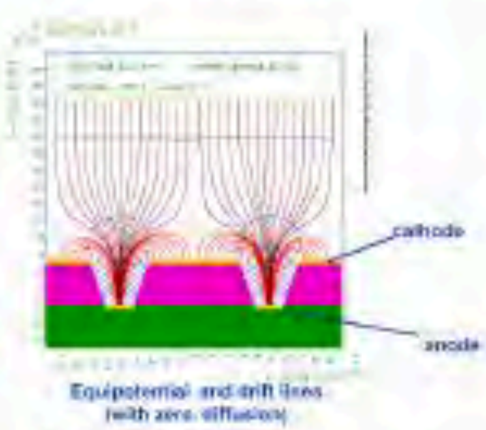
B. Adeva et al., Nucl. Instr. And Meth. A435 (1999) 402

MicroDot



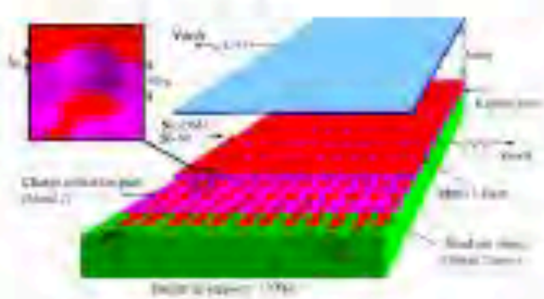
Biagi SF, Jones TJ. Nucl. Instrum. Methods A361:72 (1995)

MicroGroove



R. Bellazzini et al
Nucl. Instr. and Meth. A424(1999)444

MicroWELL

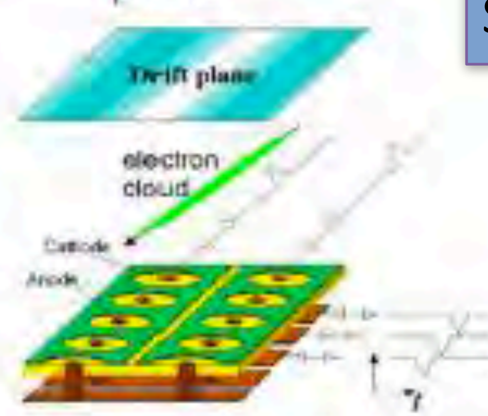


R. Bellazziniet al
Nucl. Instr. and Meth. A423(1999)125

MicroPin

P. Rehak et al., IEEE Nucl. Sci. Symposium seattle 1999

μPIC



Ochi et al NIMA471(2001)264

3rd July 2014 DT Training Seminar 15

S. Franchino, 2016

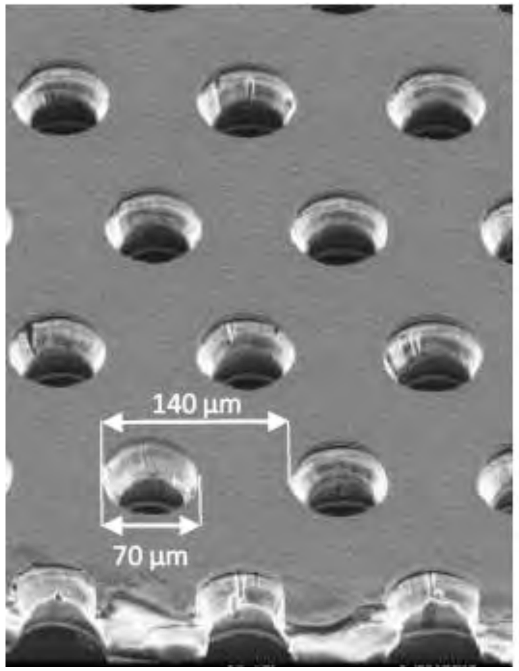
More recent MPGDs

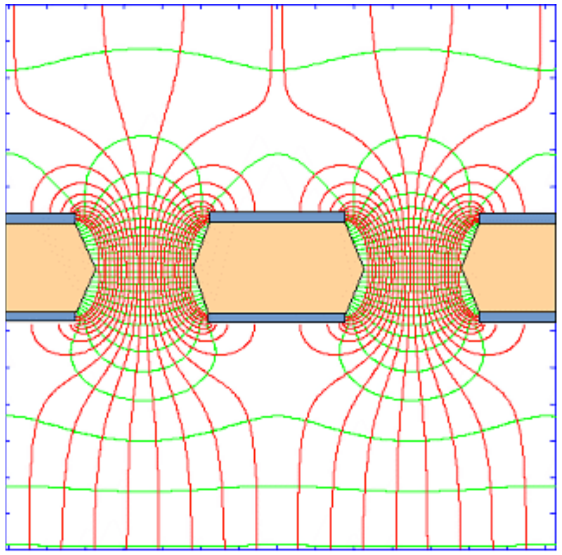
S. Franchino, 2016

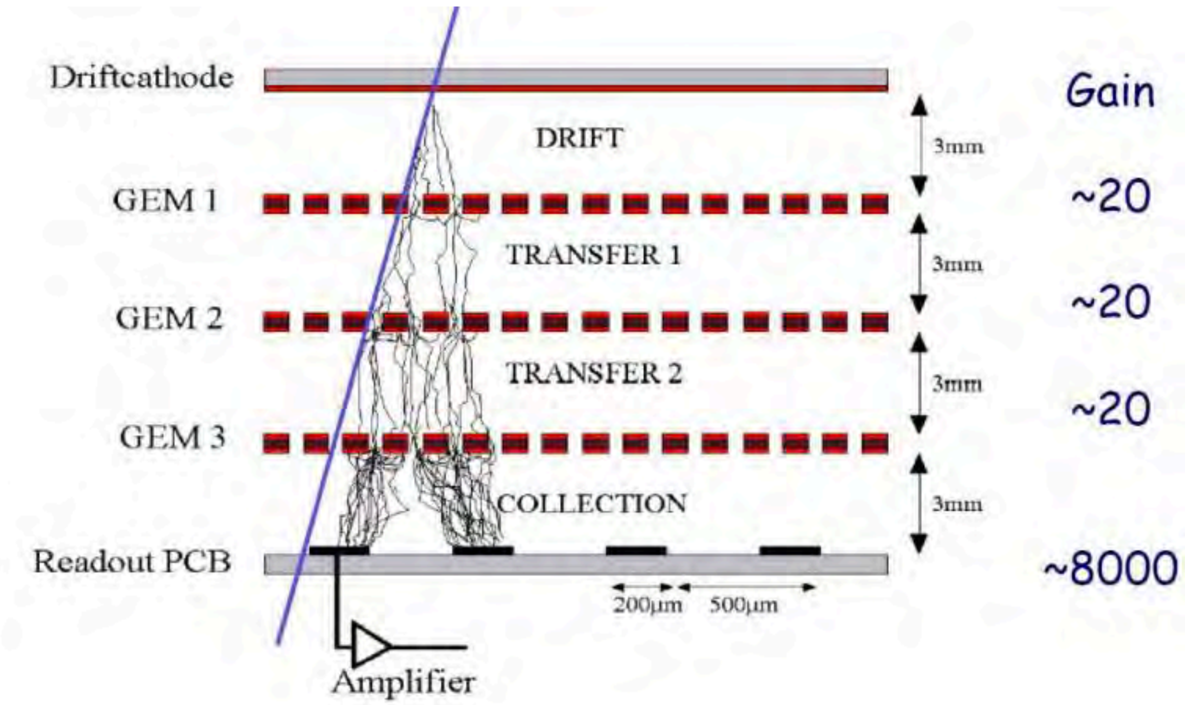
More recent MPGDs

F. Sauli, NIM. A386(1997)531

GEM (std, Thick, glass, …)







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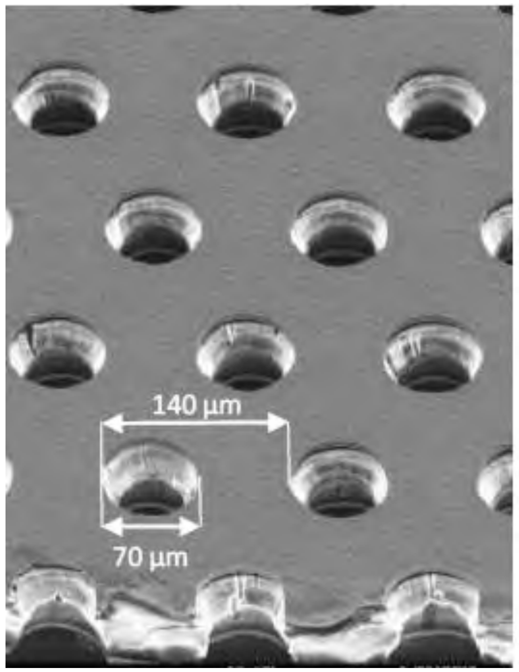
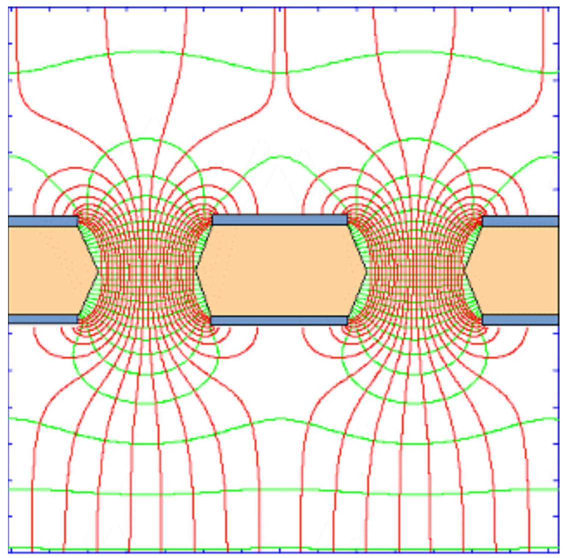
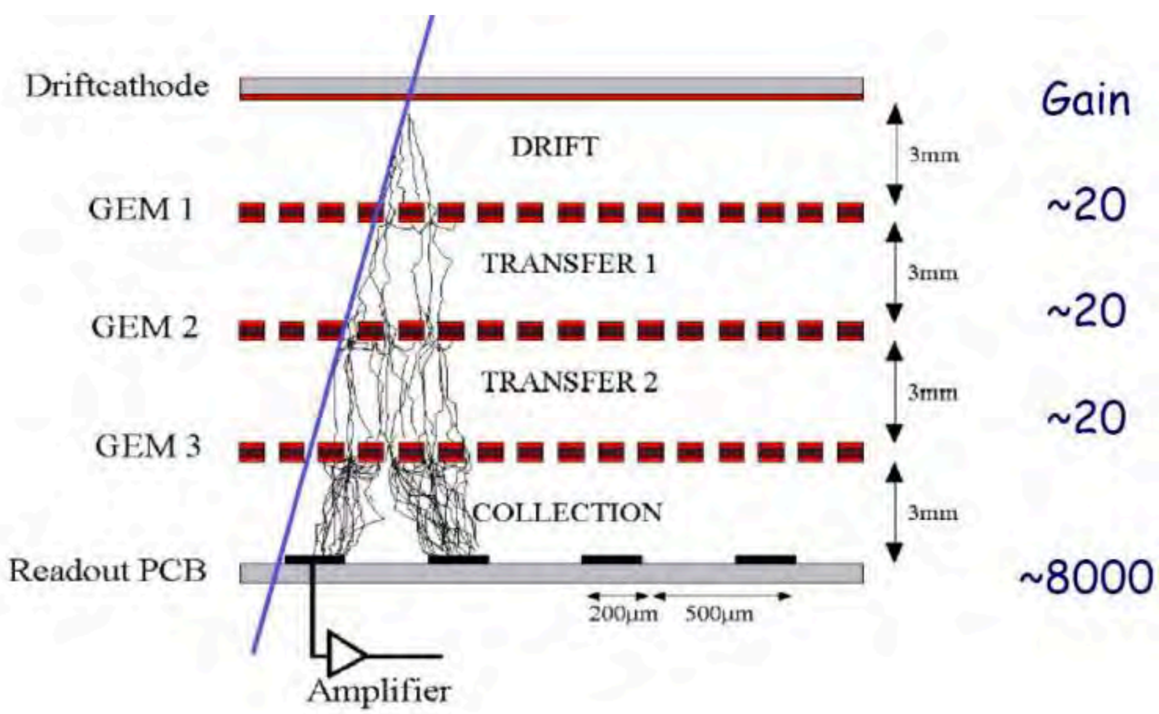
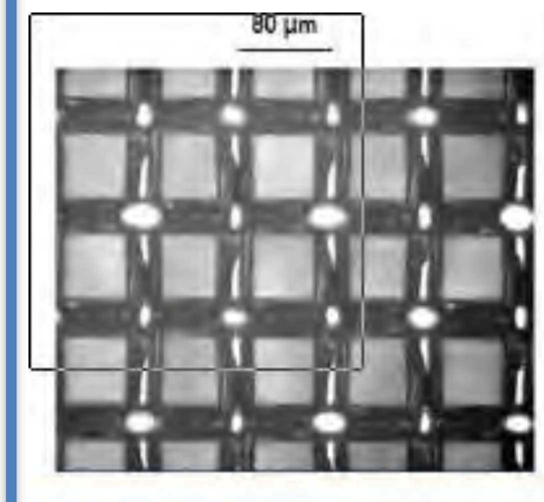


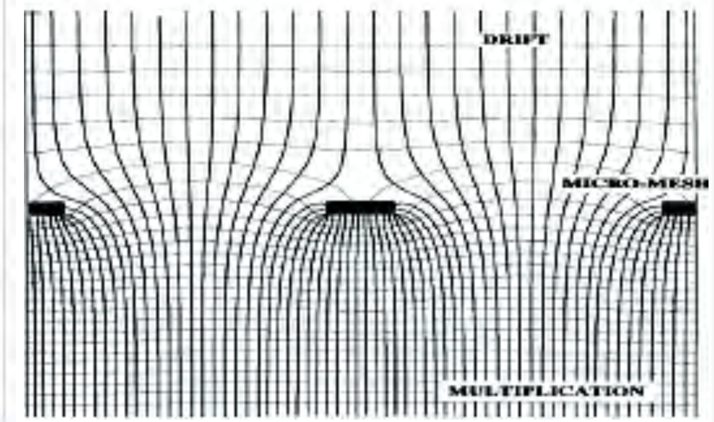


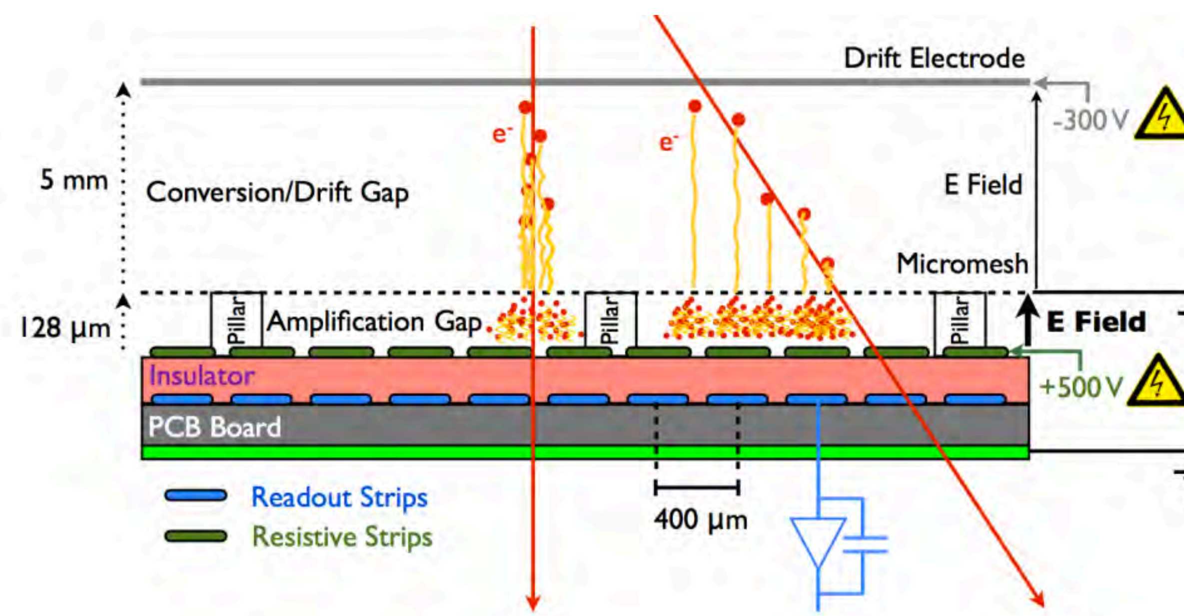


I. Giomataris et al., NIM A 376 (1996)

Micromegas
(bulk, micro bulk, resistive, ..)





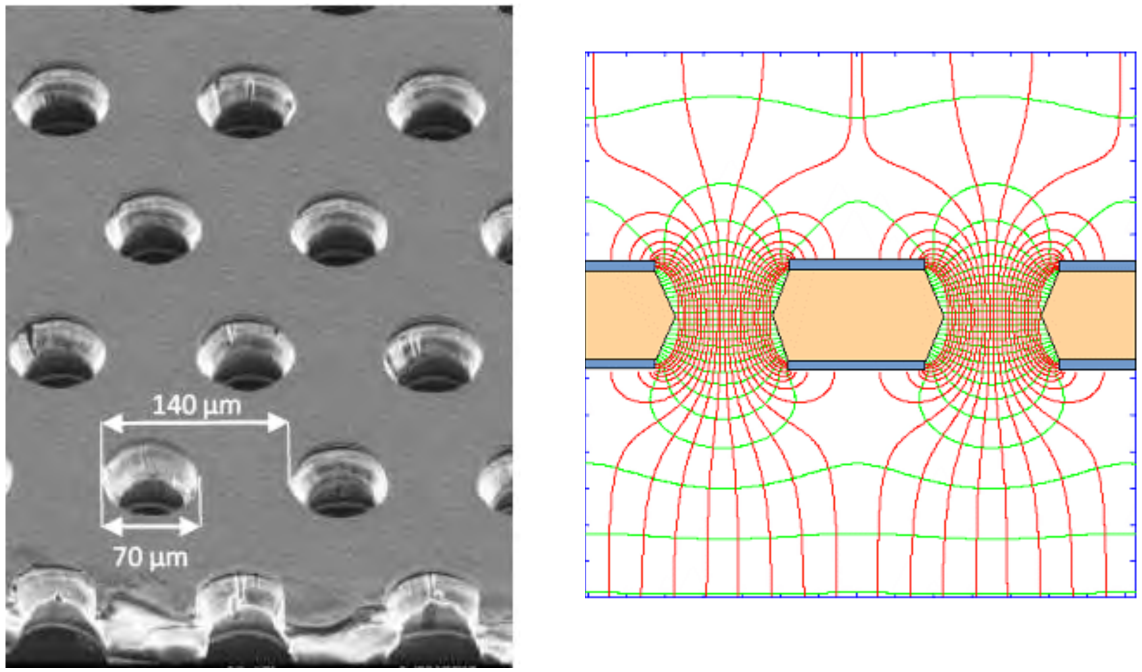


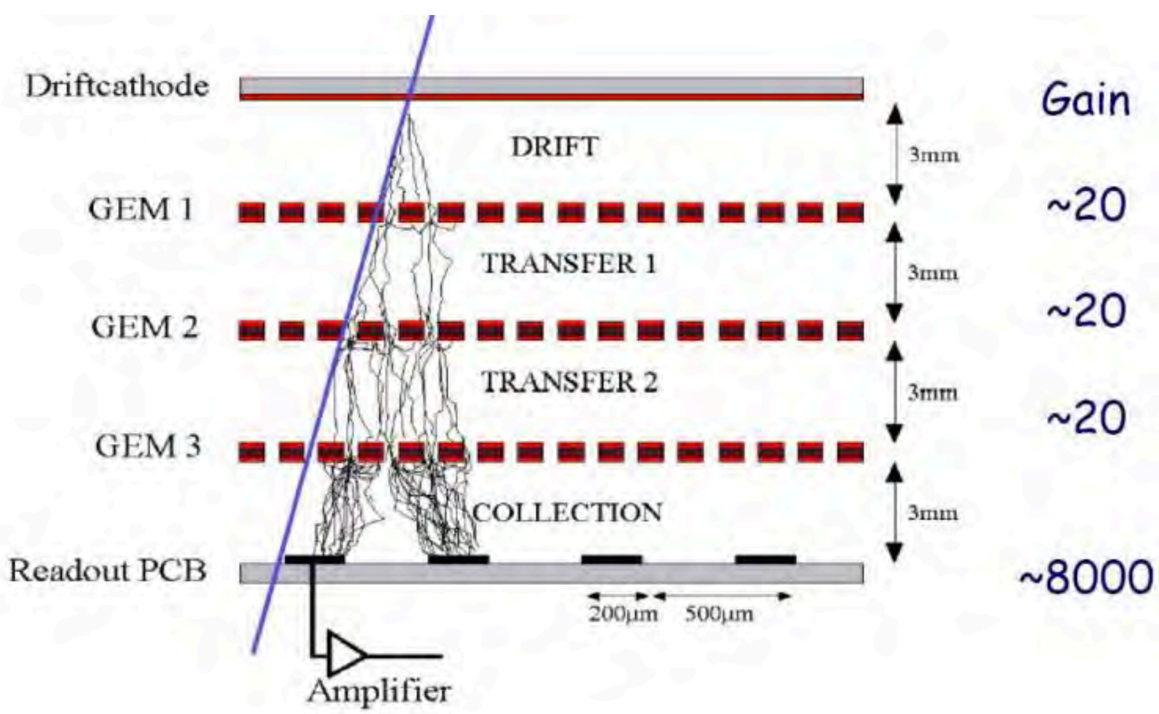
S. Franchino, 2016

More recent MPGDs

F. Sauli, NIM. A386(1997)531

GEM (std, Thick, glass, …)





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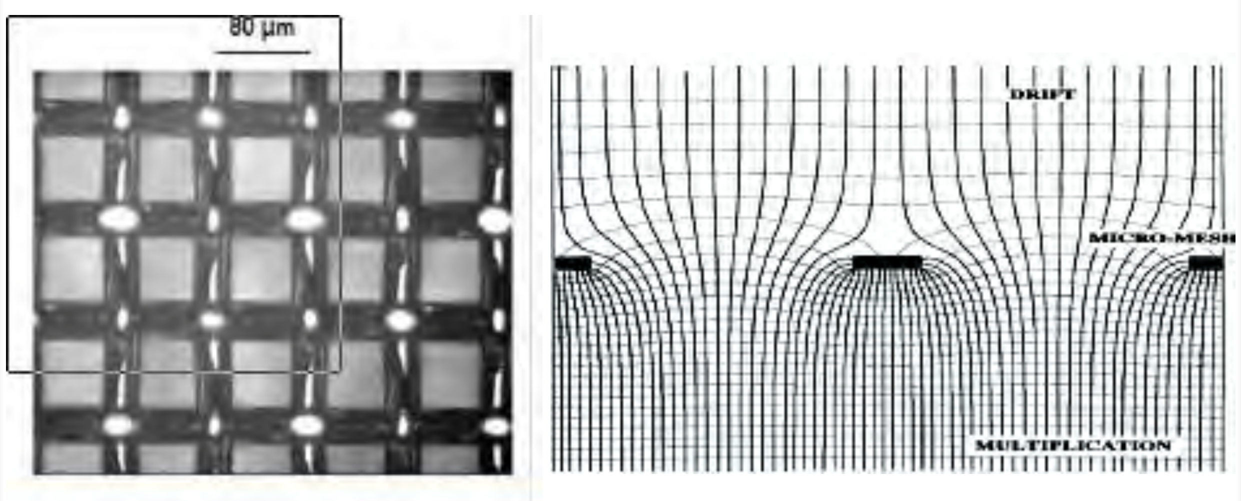

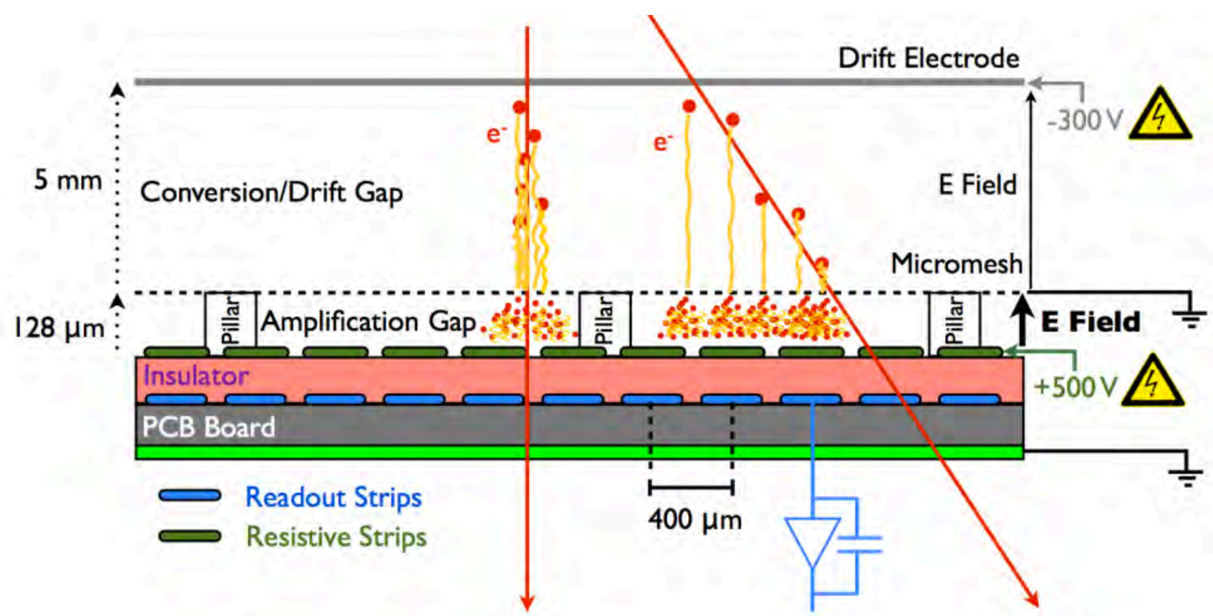

S. Franchino, 2016

Ageing: OK (no thin wires)

Spark protection: multiple amplification stages, resistive electrodes

Properties of MPGDs

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- Gas multiplication and/or readout are performed by "micro patterns" instead of conventional wire chambers

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  - High rate capability (> 10^7 counts/mm)
  - Excellent radiation hardness
  - Use components that can be mass produced by industry

MPGDs at CERN

Some of them running,
Some of them approved for upgrades
Some of them under evaluation

E. Oliveri, MPGD2017

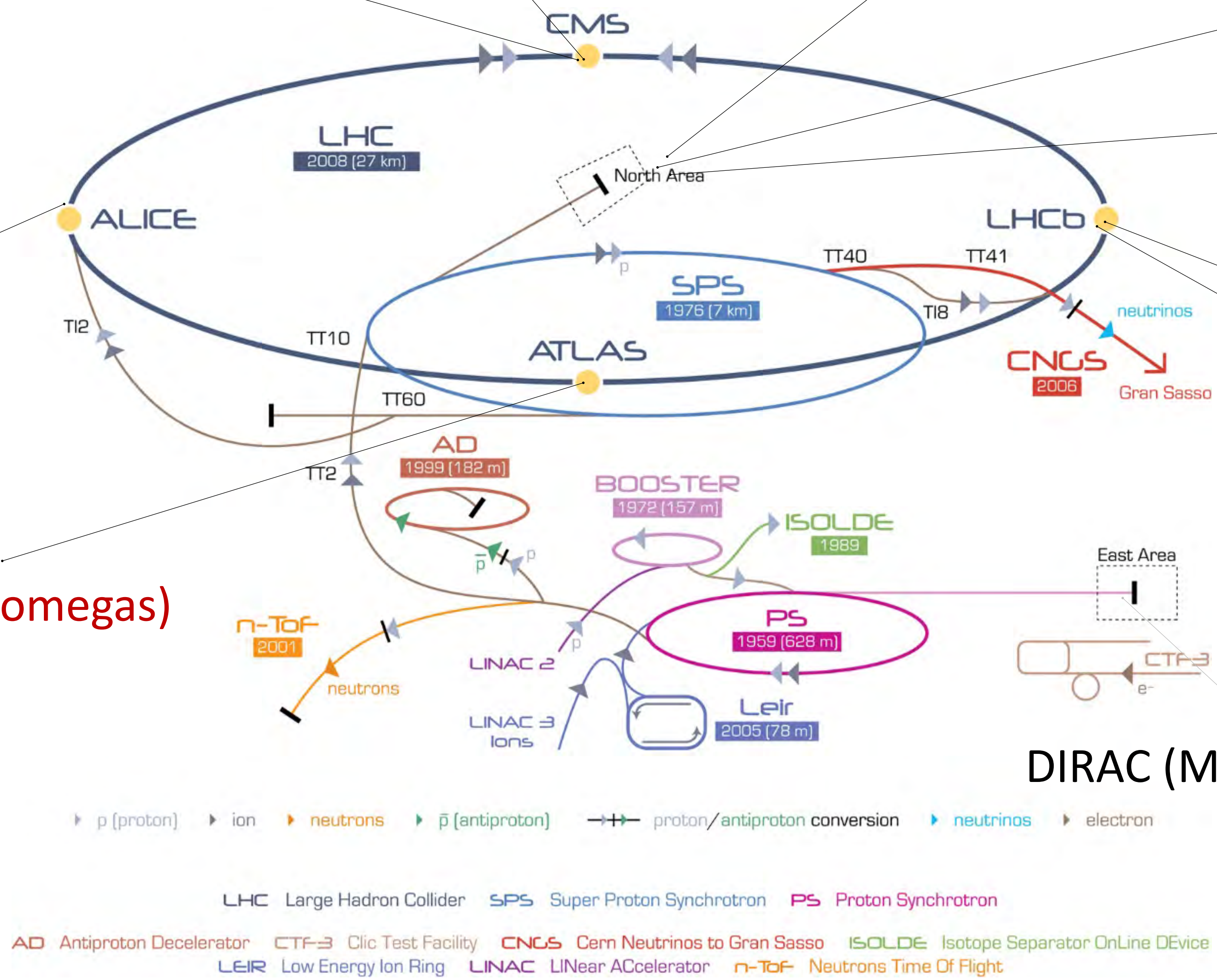
TOTEM (GEM)

CMS(GEM, μRWELL)

COMPASS(2TGEM+mm, micromegas, GEM)

GLACIER(LEM)

NA48 (micromegas)



ALICE(GEM)

LHCb (GEM, μRWELL)

ATLAS(micromegas)

CAST(micromegas,InGrid)

DIRAC (MSGC-GEM)

RED = LHC

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements / Remarks
ATLAS Muon System Upgrade: Start: 2019 (for 15 y.)	High Energy Physics (Tracking/Triggering)	Micromegas	Total area: 1200 m^2 Single unit detect: (2.2x1.4m^2) ~ 2-3 m^2	**Max. rate**:15 kHz/cm^2 **Spatial res.:** <100μm **Time res.:** ~ 10 ns **Rad. Hard.:** ~ 0.5C/cm^2	- Redundant tracking and triggering; Challenging constr. in mechanical precision:
ATLAS Muon Tagger Upgrade: Start: > 2023	High Energy Physics (Tracking/triggering)	μ-PIC	Total area: ~ 2m^2	**Max.rate**:100kHz/cm^2 **Spatial res.:** < 100μm	
CMS Muon System Upgrade: Start: > 2020	High Energy Physics (Tracking/Triggering)	GEM, μRWell	Total area: ~ 143 m^2 Single unit detect: 0.3-0.4m^2	**Max. rate**:10 kHz/cm^2 **Spatial res.:** ~100μm **Time res.:** ~ 5-7 ns **Rad. Hard.:** ~ 0.5 C/cm^2	- Redundant tracking and triggering
CMS Calorimetry (BE) Upgrade Start > 2023	High energy Physics (Calorimetry)	Micromegas, GEM	Total area: ~ 100 m^2 Single unit detect: 0.5m^2	**Max. rate**: 100 MHz/cm^2 **Spatial res.:** ~ mm	Not main option; could be used with HGCAL (BE part)
ALICE Time Projection Chamber: Start: > 2020	Heavy-Ion Physics (Tracking + dE/dx)	GEM w/ TPC	Total area: ~ 32 m^2 Single unit detect: up to 0.3m^2	**Max.rate**:100 kHz/cm^2 **Spatial res.:** ~300μm **Time res.:** ~ 100 ns **dE/dx:** 12 % (Fe55) **Rad. Hard.:** 50 mC/cm^2	- 50 kHz Pb-Pb rate; - Continues TPC readout - Low IBF and good energy resolution
TOTEM: Run: 2009-now	High Energy/ Forward Physics (5.3≤|eta| ≤ 6.5)	GEM (semicircular shape)	Total area: ~ 4 m^2 Single unit detect: up to 0.03m^2	**Max.rate**:20 kHz/cm^2 **Spatial res.:** ~120μm **Time res.:** ~ 12 ns **Rad. Hard.:** ~ mC/cm^2	Operation in pp, pA and AA collisions.
LHCb Muon System Run: 2010 - now	High Energy / B-flavor physics (muon triggering)	GEM	Total area: ~ 0.6 m^2 Single unit detect: 20-24 cm^2	**Max.rate**:500 kHz/cm^2 **Spatial res.:** ~ cm **Time res.:** ~ 3 ns **Rad. Hard.:** ~ C/cm^2	- Redundant triggering
FCC Collider Start: > 2035	High Energy Physics (Tracking/Triggering/ Calorimetry/Muon)	GEM,THGEM Micromegas, μ-PIC, InGrid	Total area: 10.000 m^2 (for MPGDs around 1.000 m^2)	**Max.rate**:100 kHz/cm^2 **Spatial res.:** <100μm **Time res.:** ~ 1 ns	Maintenance free for decades

M. Titov, MPGD2017

GEM / Micromegas : ATLAS and CMS upgrades

Development and optimization of large-area MPGDs for tracking and triggering

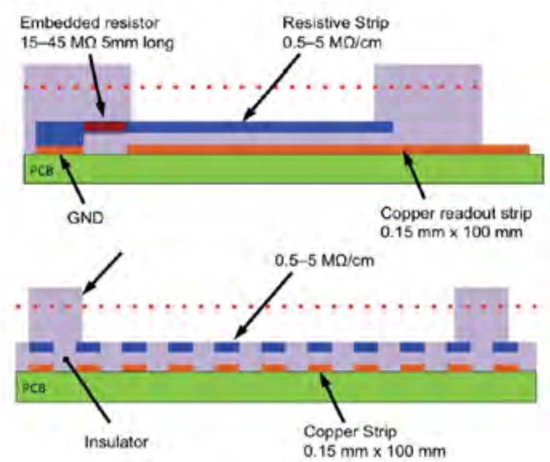
MM for the ATLAS Muon System Upgrade:

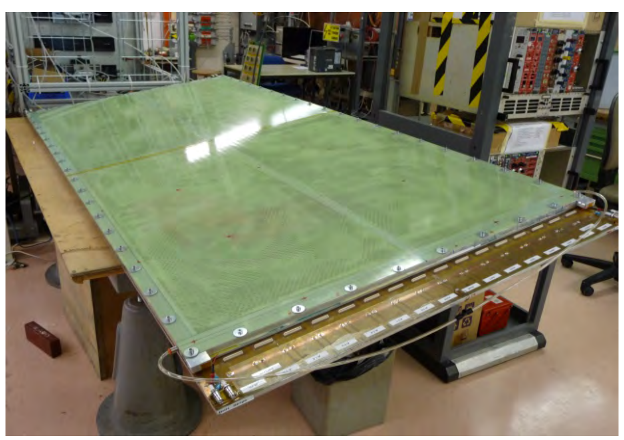
Standard Bulk MM suffers from limited efficiency at high rates due to discharges induced dead time

Solution: Resistive Micromegas tecgnology:

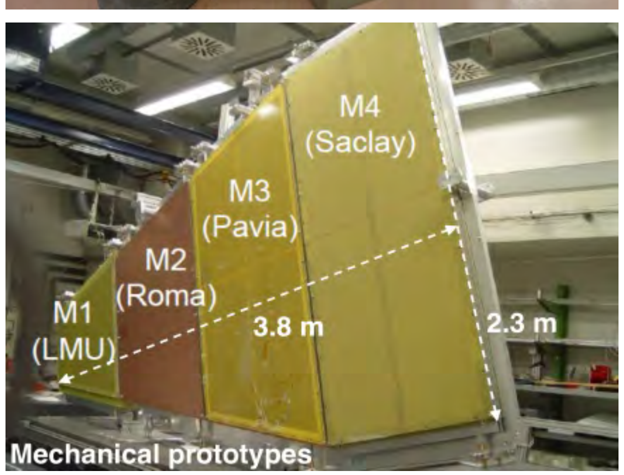
→ Add a layer of resistive strips above the readout strips

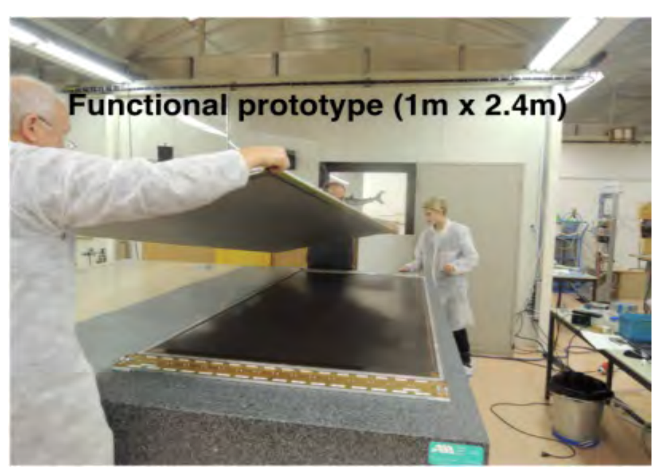
❖ Spark neutralization/ suppression (sparks still occur, but become inoffensive)





2.4 x 1m² MM resistive chamber constructed and characterized at CERN RD51 lab





GEMs for the CMS Muon System Upgrade:

Single-mask GEM technology (instead of double-mask)

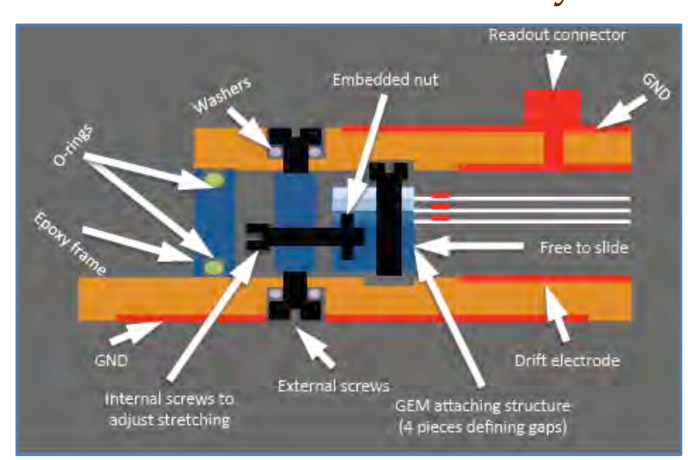
→ Reduces cost /allows production of large-area GEM

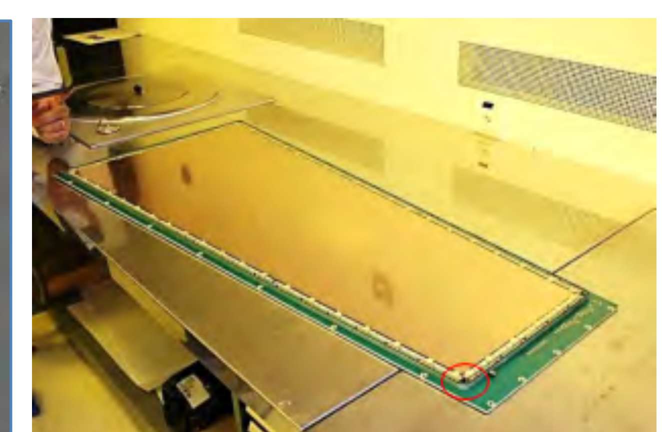
→ R&D: 6 generations of triple-GEM detectors

Generation I	Generation II	Generation III	Generation IV	Generation V	Generation VI
The first 1m-class detector ever built but still with spacer ribs and only 8 sectors total. **Ref.: 2010 IEEE (also RD51-Note-2010-005)**	First large detector with 24 readout sectors (3x8) and 3/1/2/1 gaps but still with spacers and all glued. **Ref.: 2011 IEEE. Also RD51-Note-2011-013.**	The first sans-spacer detector, but with the outer frame still glued to the drift. **Ref.: 2012 IEEE N14-137.**	First detector with complete mechanical assembly; no more gluing parts together! **MPGD 2013; and IEEE2013.**	Nearly final CMS design: stretching apparatus that is now totally inside gas volume. **Ongoing test beam campaign for final performance measurements.**	Latest detector design; **to be installed in CMS.** Optimized final dimensions for max. acceptance and final eta segmentation. **Ongoing test beam campaign for DAQ**

M. Titov, MPGD2017

Assembly optimization: self-stretching technique: assembly time reduction from 3 days → 2 hours

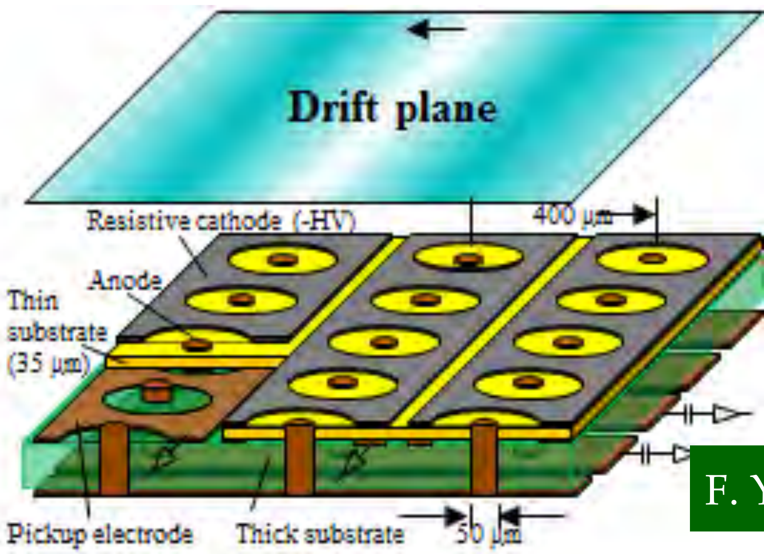


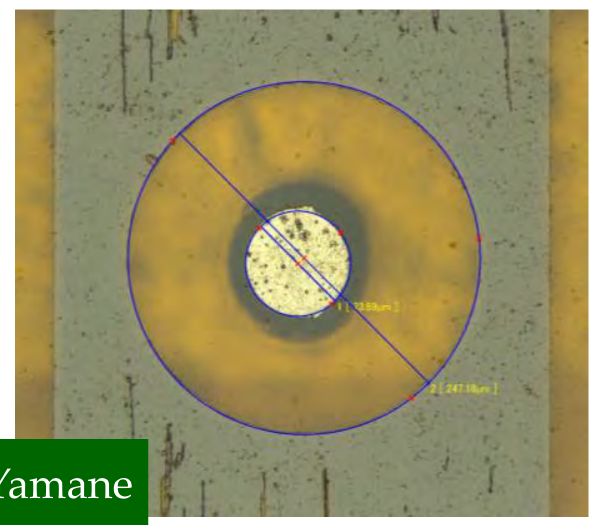


μPIC / μRWELL for ATLAS Large-η Tagger Phase II Upgrade

- Proposed for Phase II upgrade (~2023)
- Need high granularity ~ 0.1mm
- BG rate > 100kHz/cm² (HIP, gamma)
- Rate tolerant, Pixel type detector needed

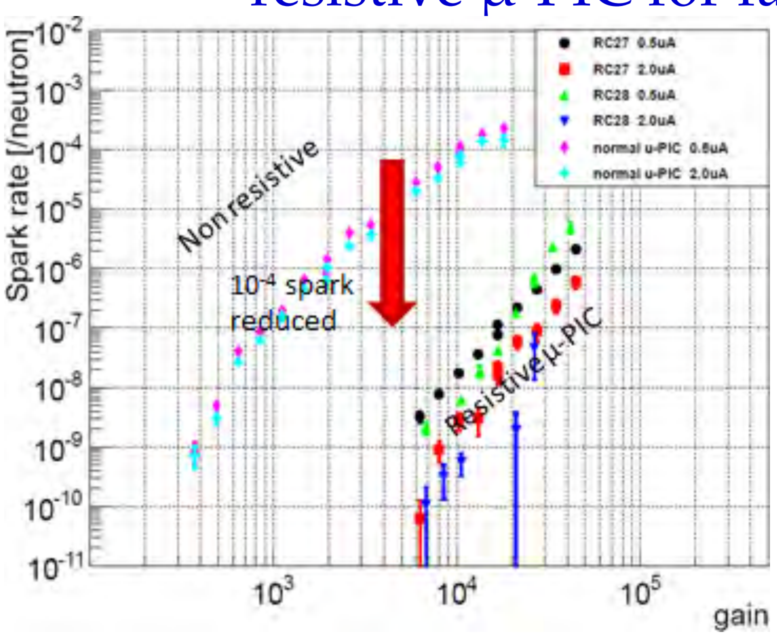
μ-PIC with resistive Diamond-LC electrodes:





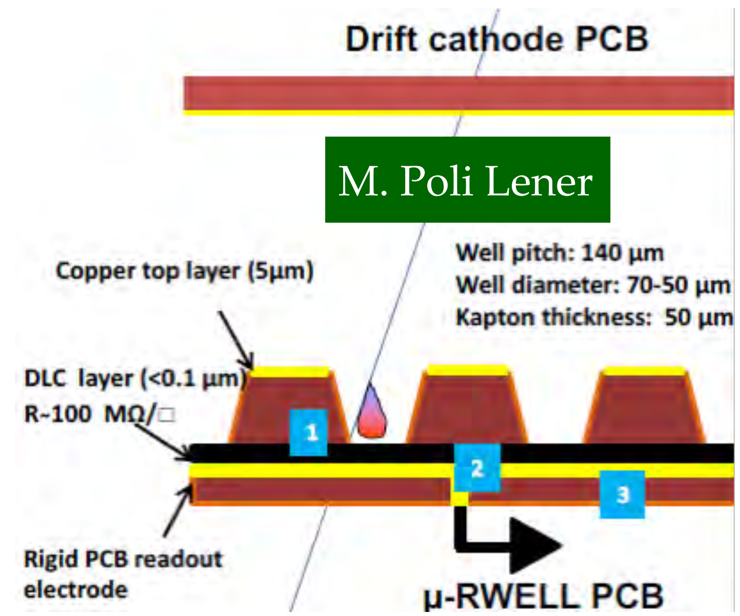
F. Yamane

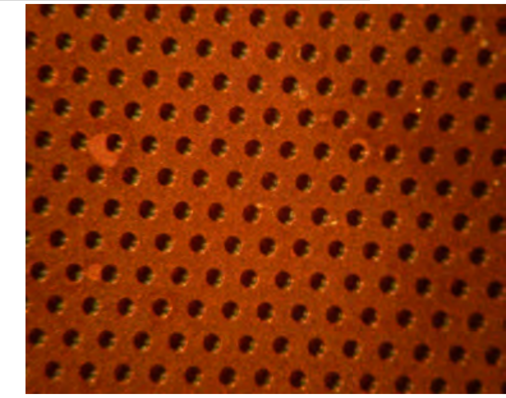
Spark rate reduction using resistive μ-PIC for fast neutron

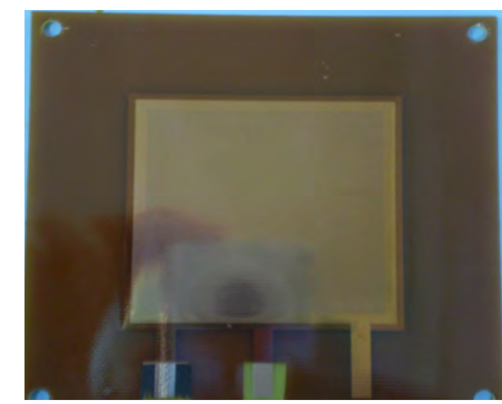


Resistive μ-PIC using sputtered C:

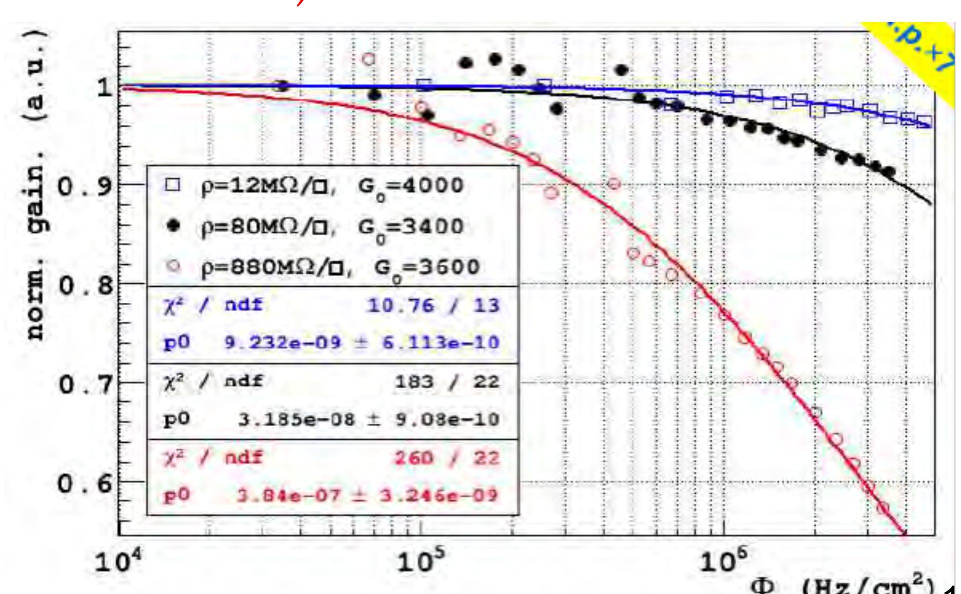
μ-RWELL Detector:





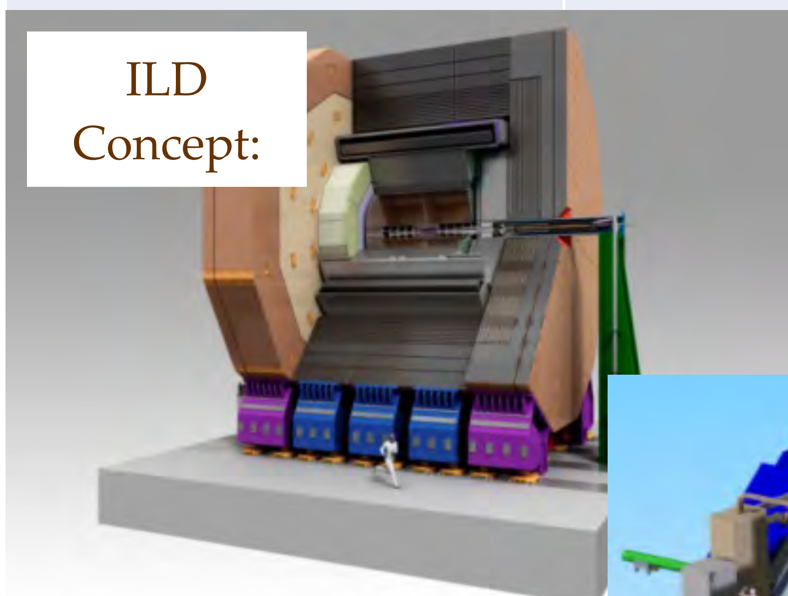


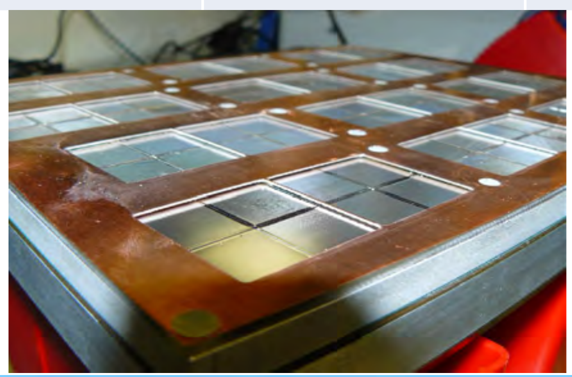
- Very reliable
- Almost completely *discharge-free*
- adequate for high particle rates O(1MHz/cm²) thanks to the *segmented-resistive-layer*
- suitable for large area applications (1.8 x 1.2 m² proto was tested in 2017)

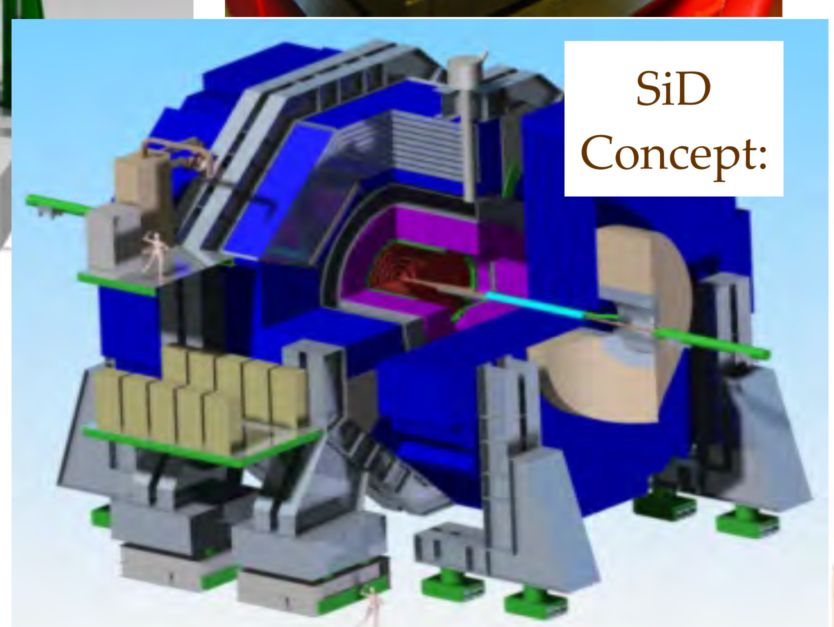


MPGD Technologies for the ILC

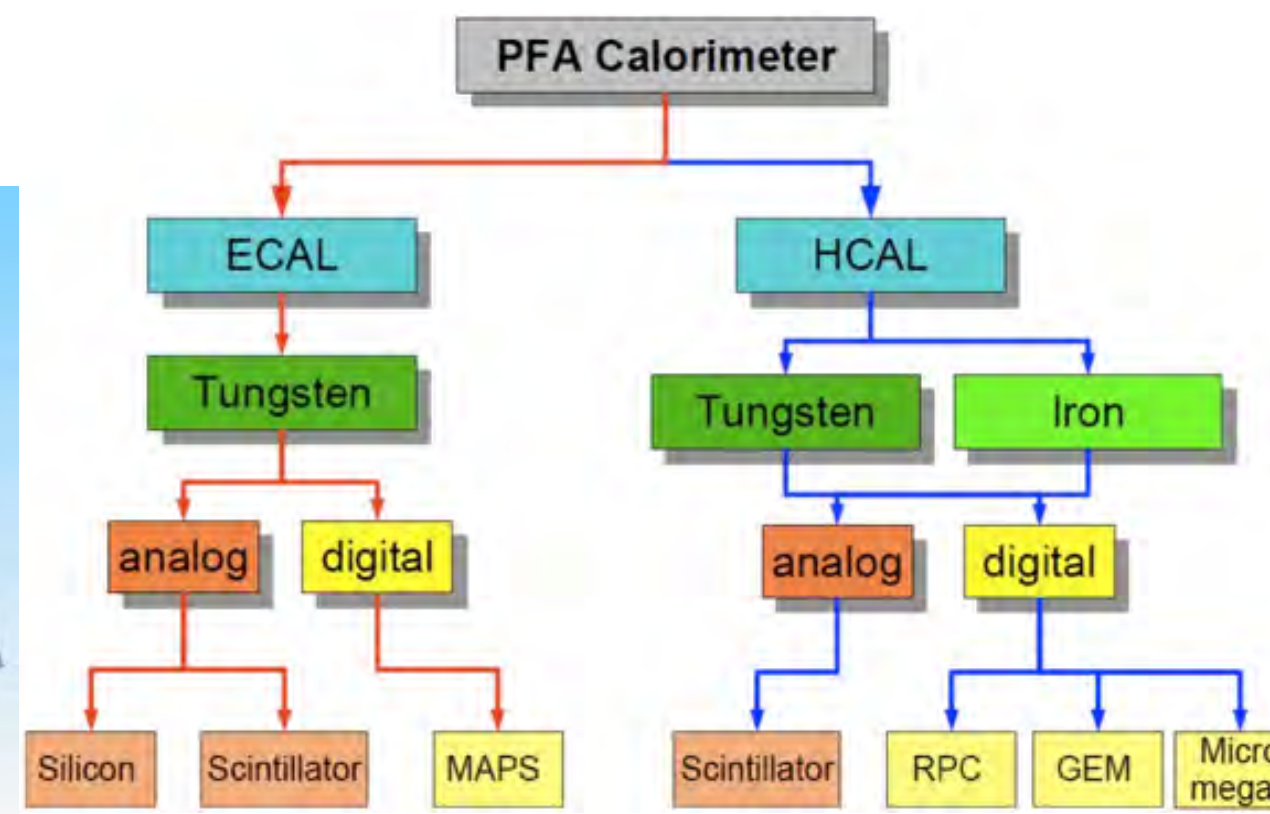
Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements/ Remarks
ILC Time Projection Chamber for ILD: Start: > 2030	High Energy Physics (tracking)	Micromegas GEM (pads) InGrid (pixels)	Total area: ~ 20 m^2 Single unit detect: ~ 400 cm^2 (pads) ~ 130 cm^2 (pixels)	**Max. rate:** < 1 kHz **Spatial res.:** <150μm **Time res.:** ~ 15 ns **dE/dx:** 5 % (Fe55) **Rad. Hard.:** no	Si + TPC Momentum resolution : $dp/p < 9*10^{-5}$ 1/GeV Power-pulsing
ILC Hadronic (DHCAL) Calorimetry for ILD/SiD Start > 2030	High Energy Physics (calorimetry)	GEM, THGEM RPWELL, Micromegas	Total area: ~ 4000 m^2 Single unit detect: 0.5 - 1 m^2	**Max.rate:**1 kHz/cm^2 **Spatial res.:** ~ 1cm **Time res.:** ~ 300 ns **Rad. Hard.:** no	Jet Energy resolution: 3-4 % Power-pulsing, self-triggering readout







Particle Flow Calorimetry (ILD/SiD):



The μRWell technology

The μRWell technology

The μ-RWELL detector is composed of two elements:
the **cathode** and the μ**-RWELL_PCB .**

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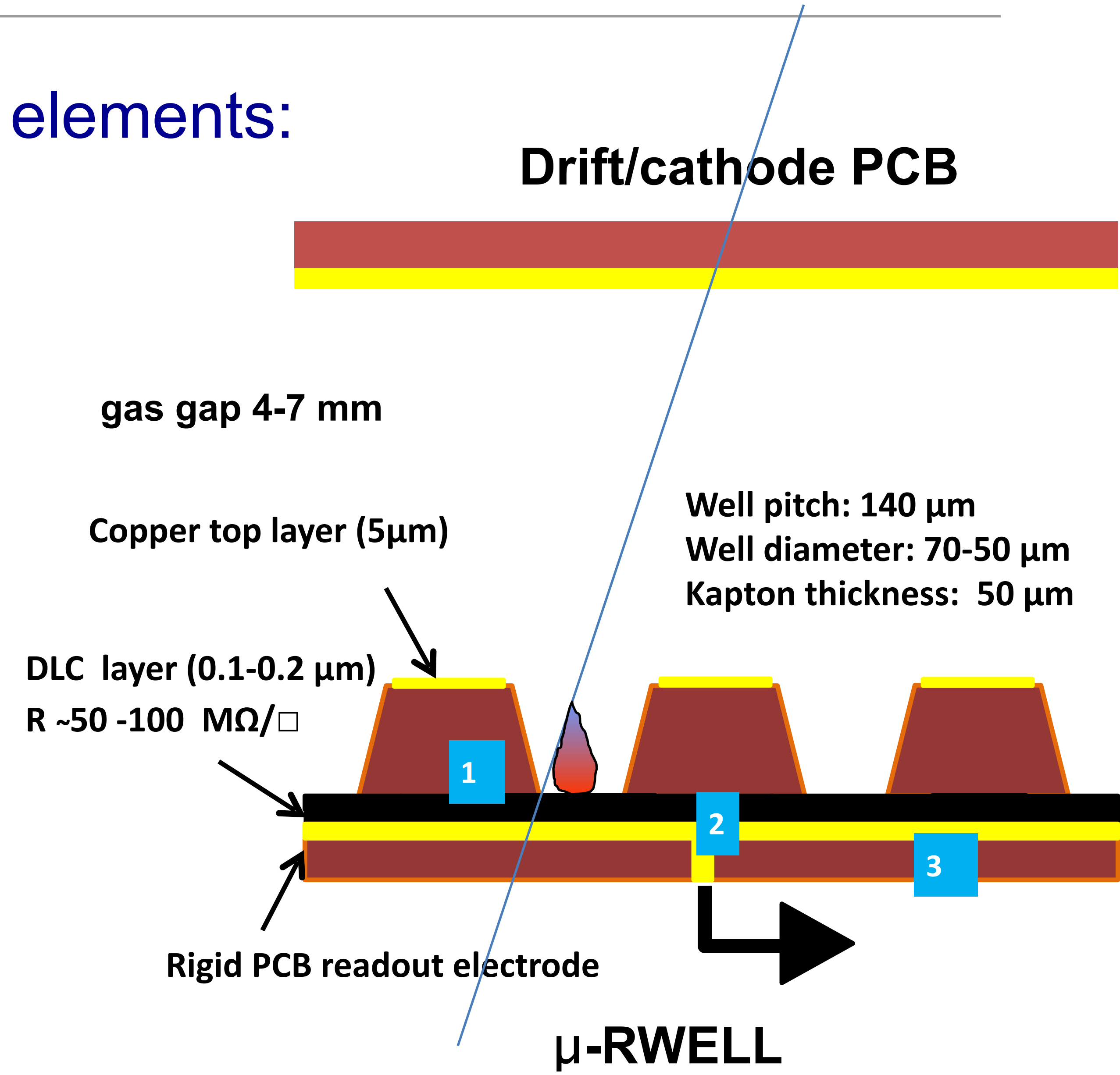

G. Bencivenni et al., 2015_JINST_10_P02008

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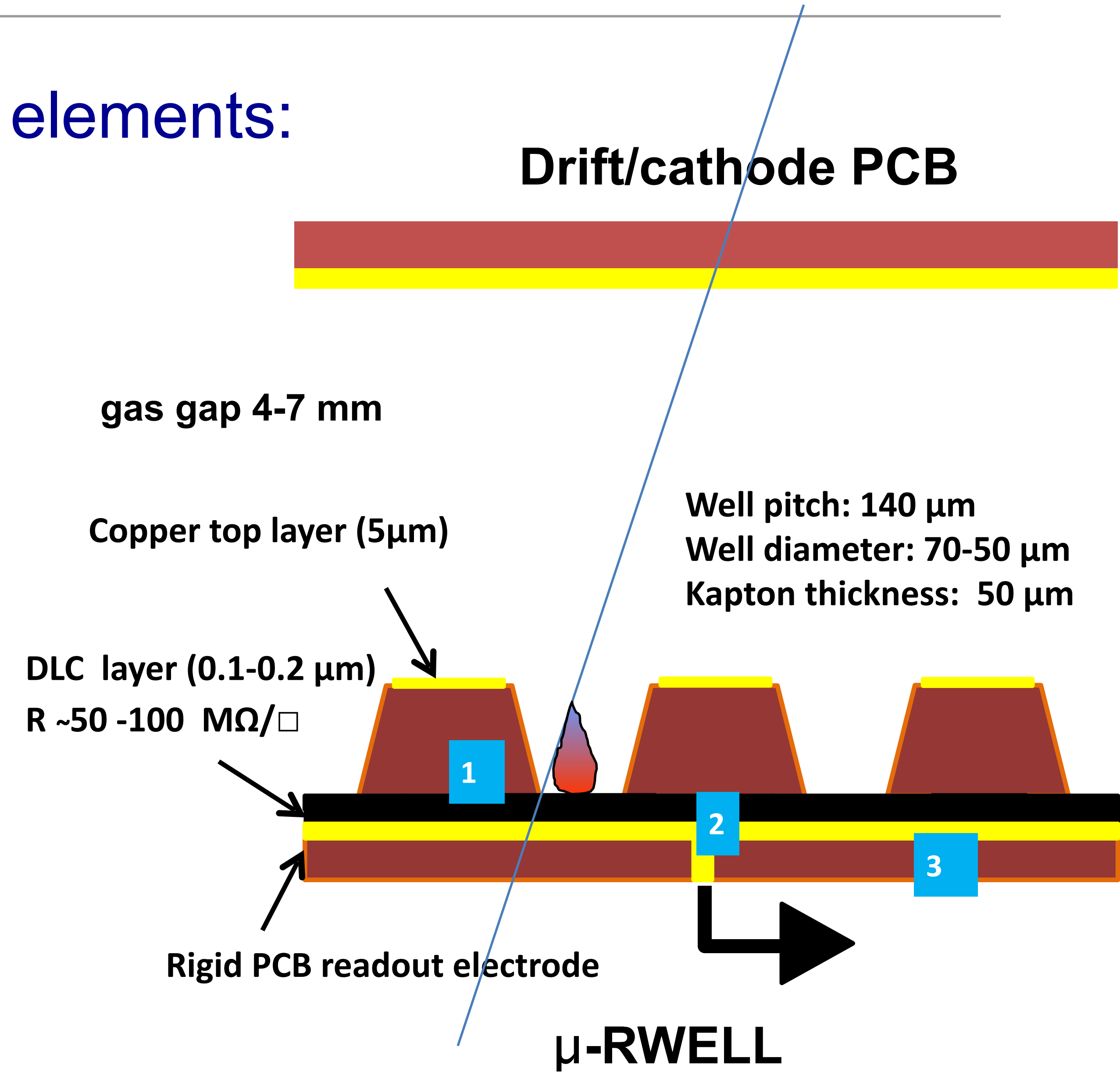
The **μ-RWELL_PCB** is realized by **coupling:**



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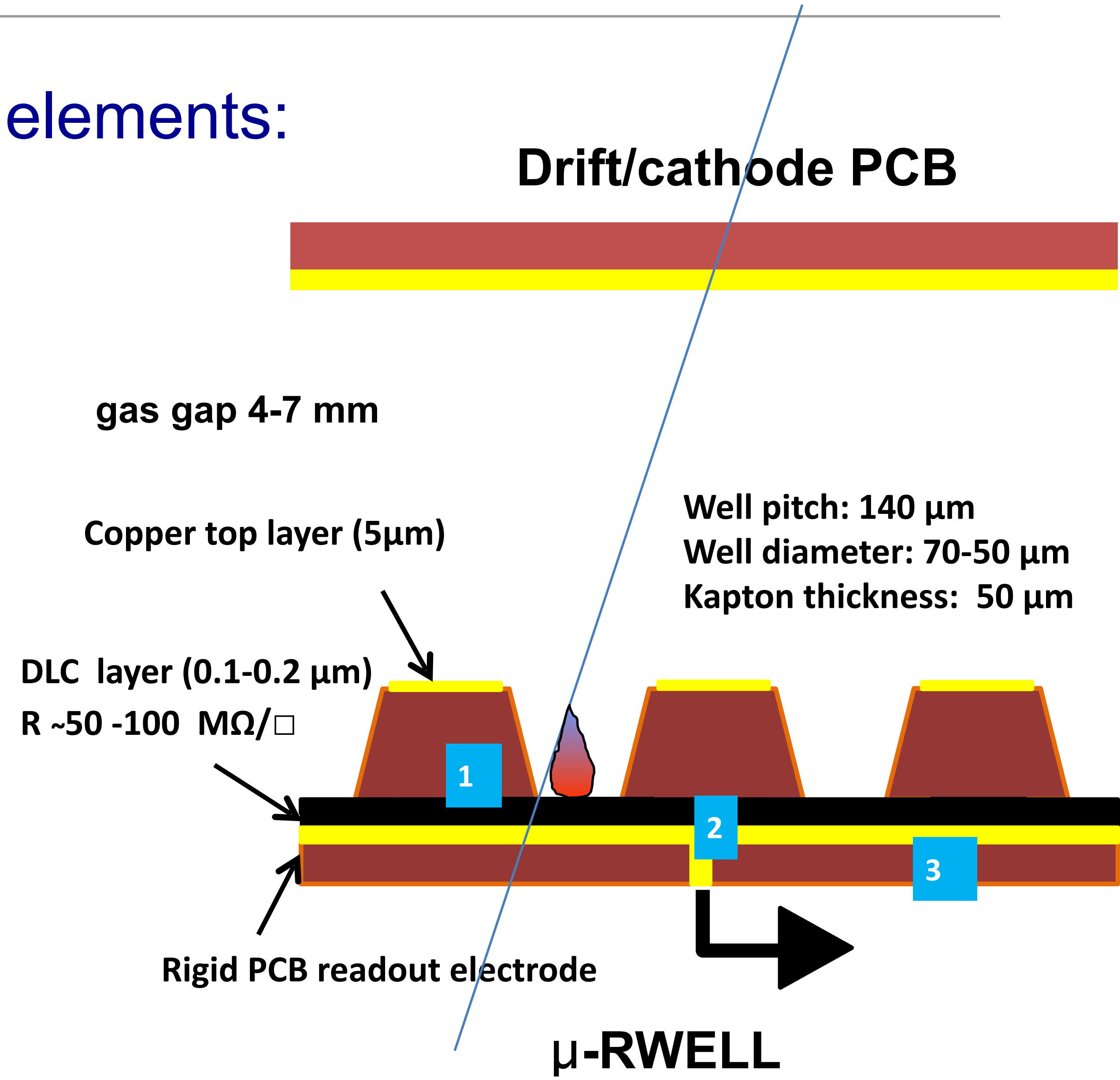

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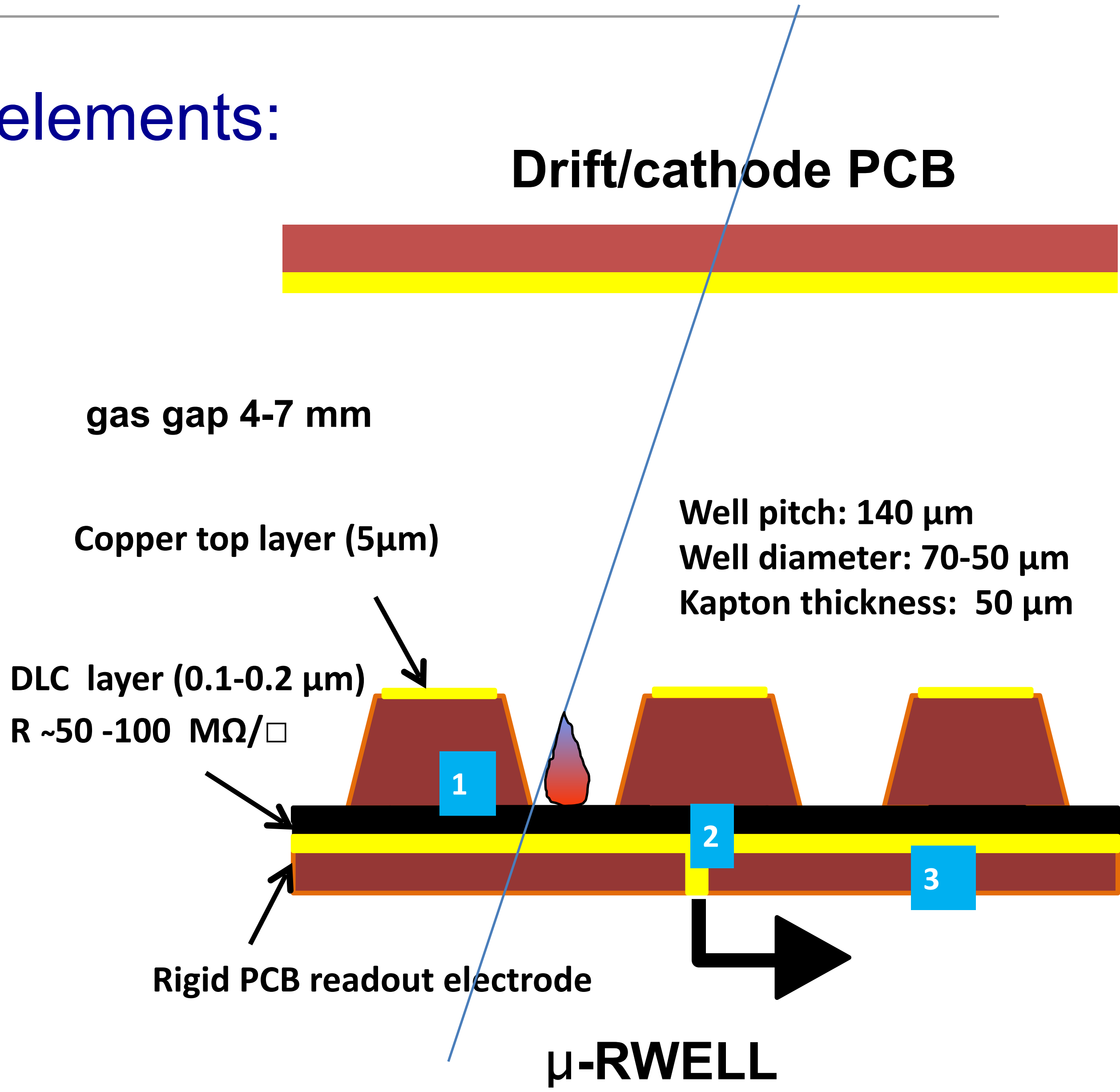

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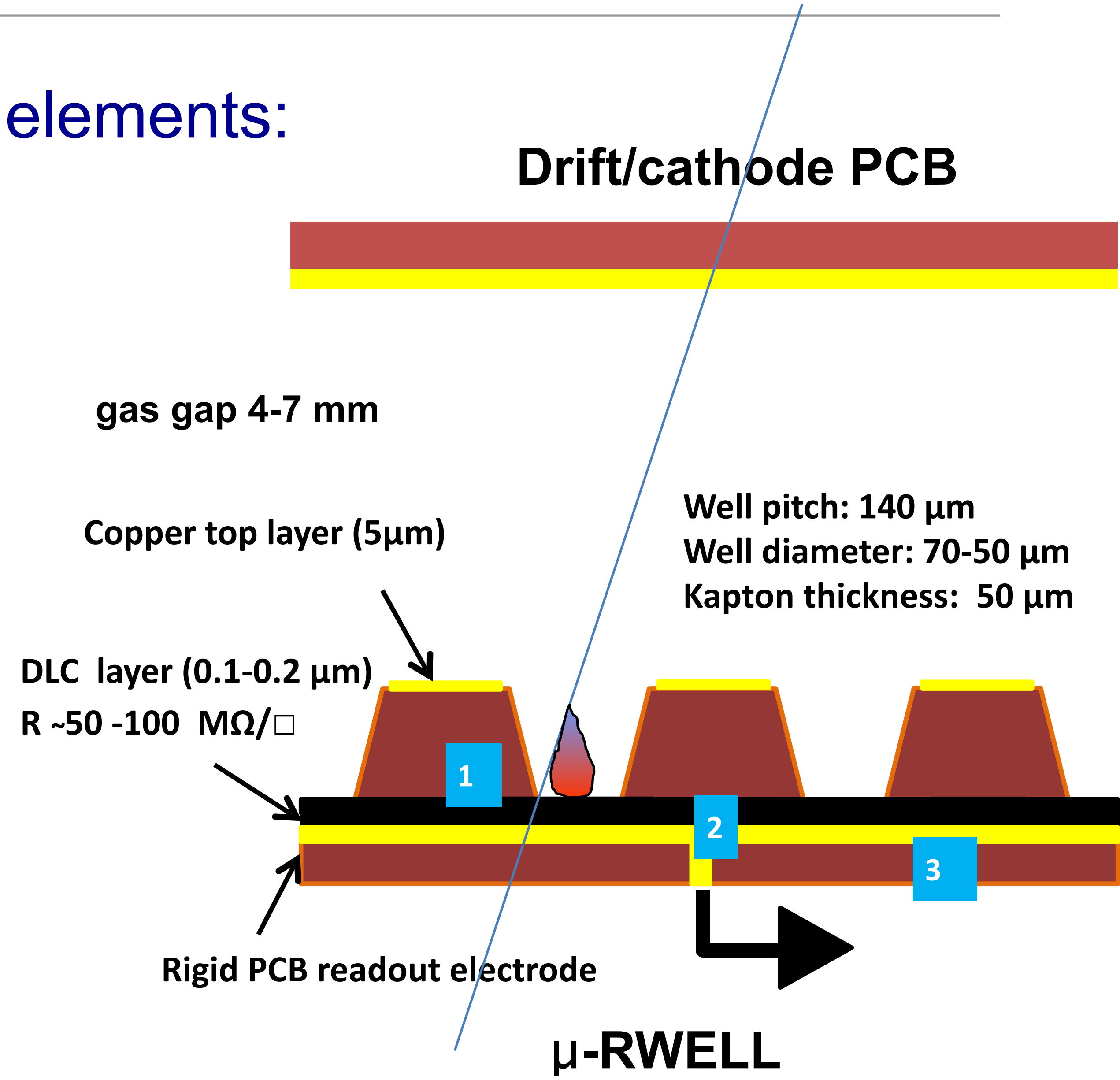

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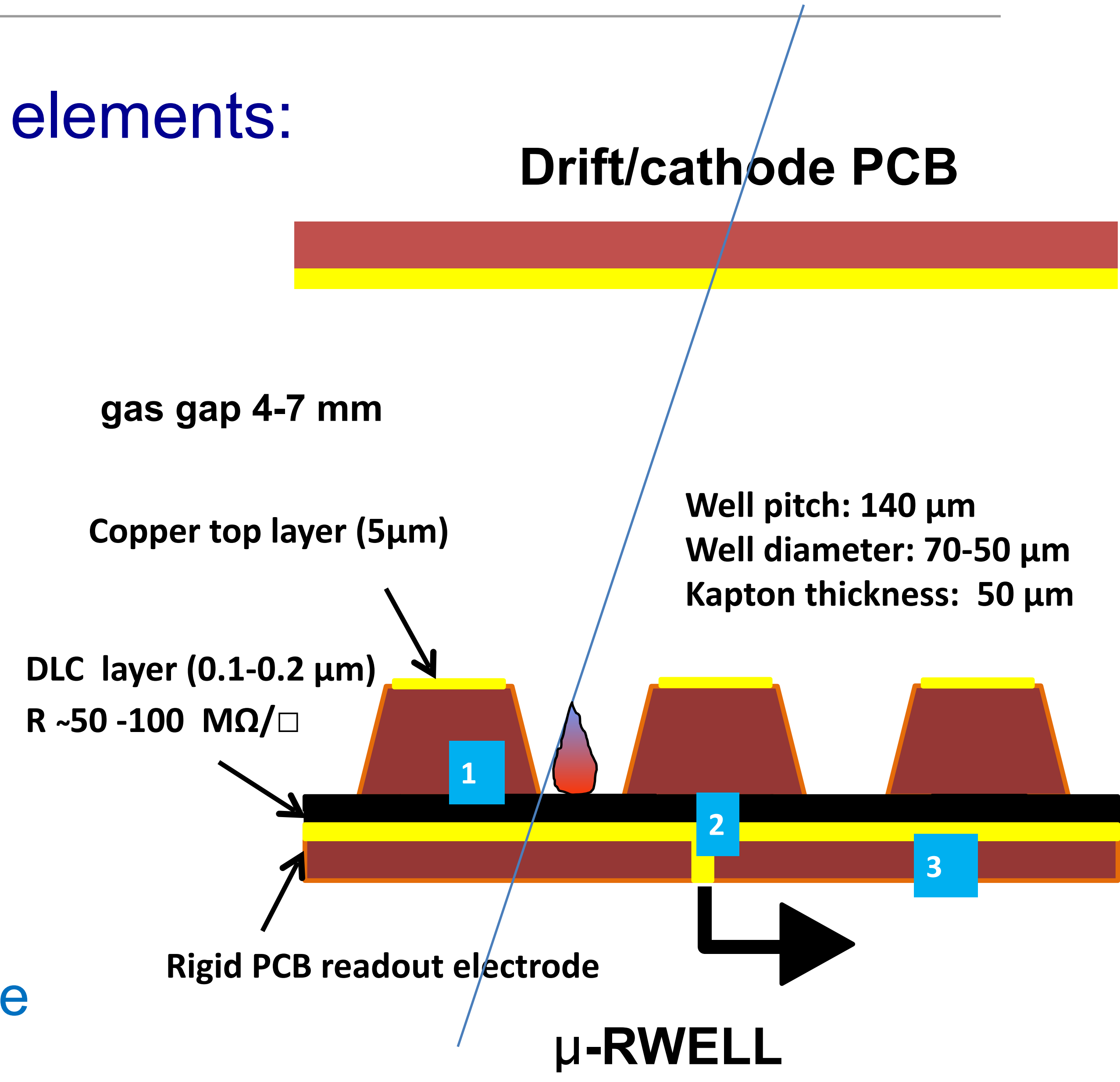

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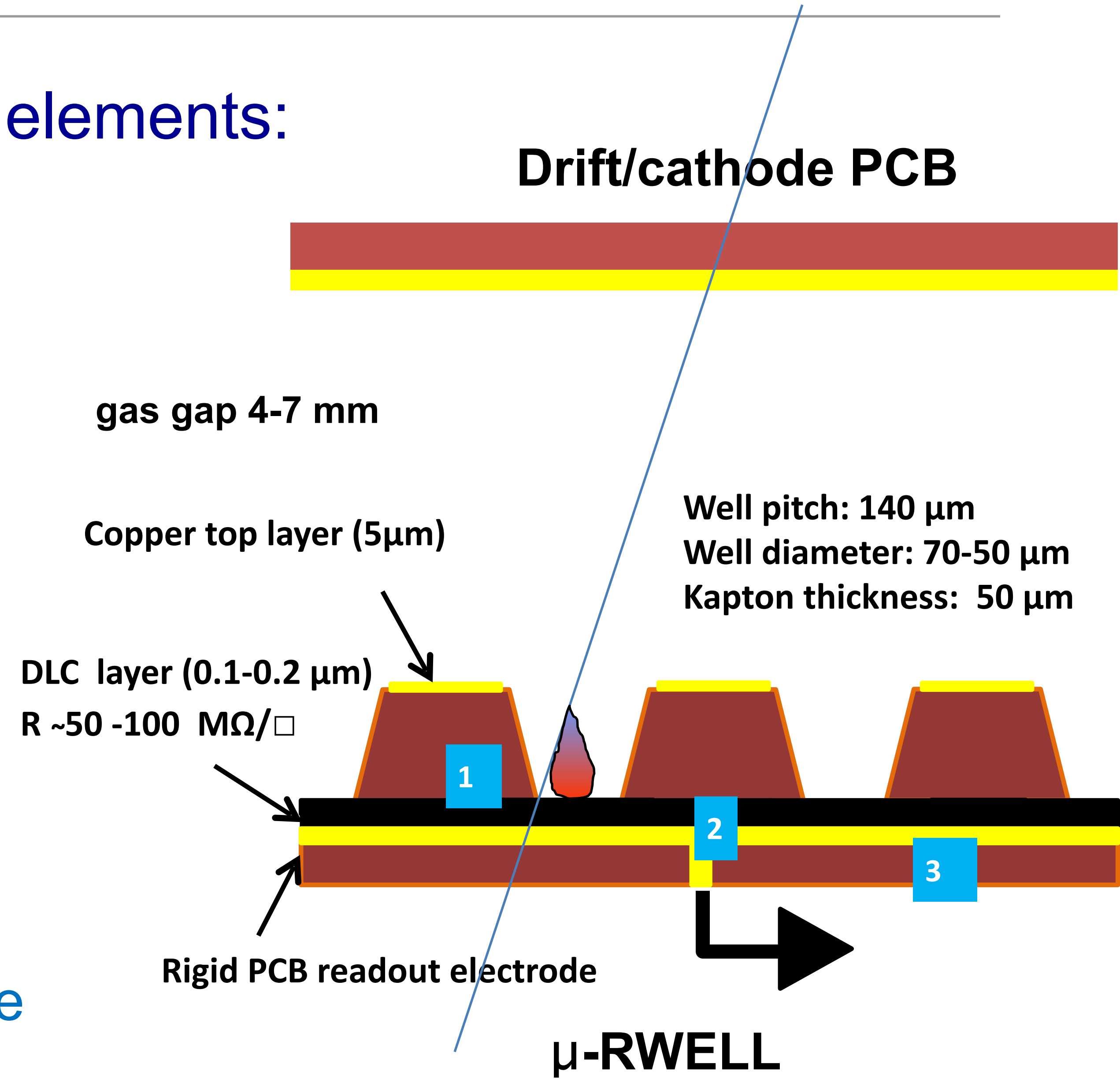
3. a **standard readout PCB**



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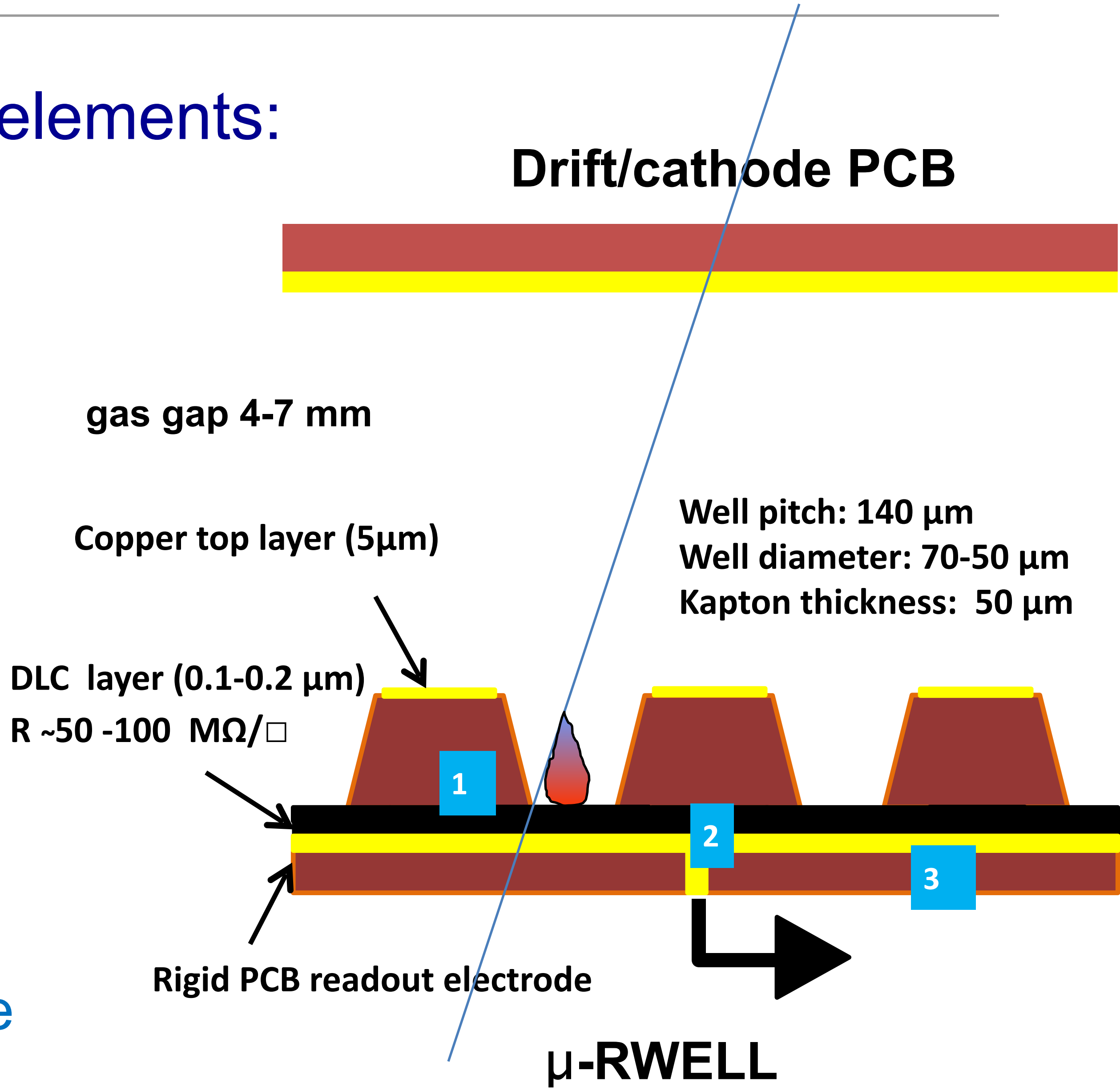

G. Bencivenni et al., 2015_JINST_10_P02008

Collaboration of INFN, CERN, Eltos

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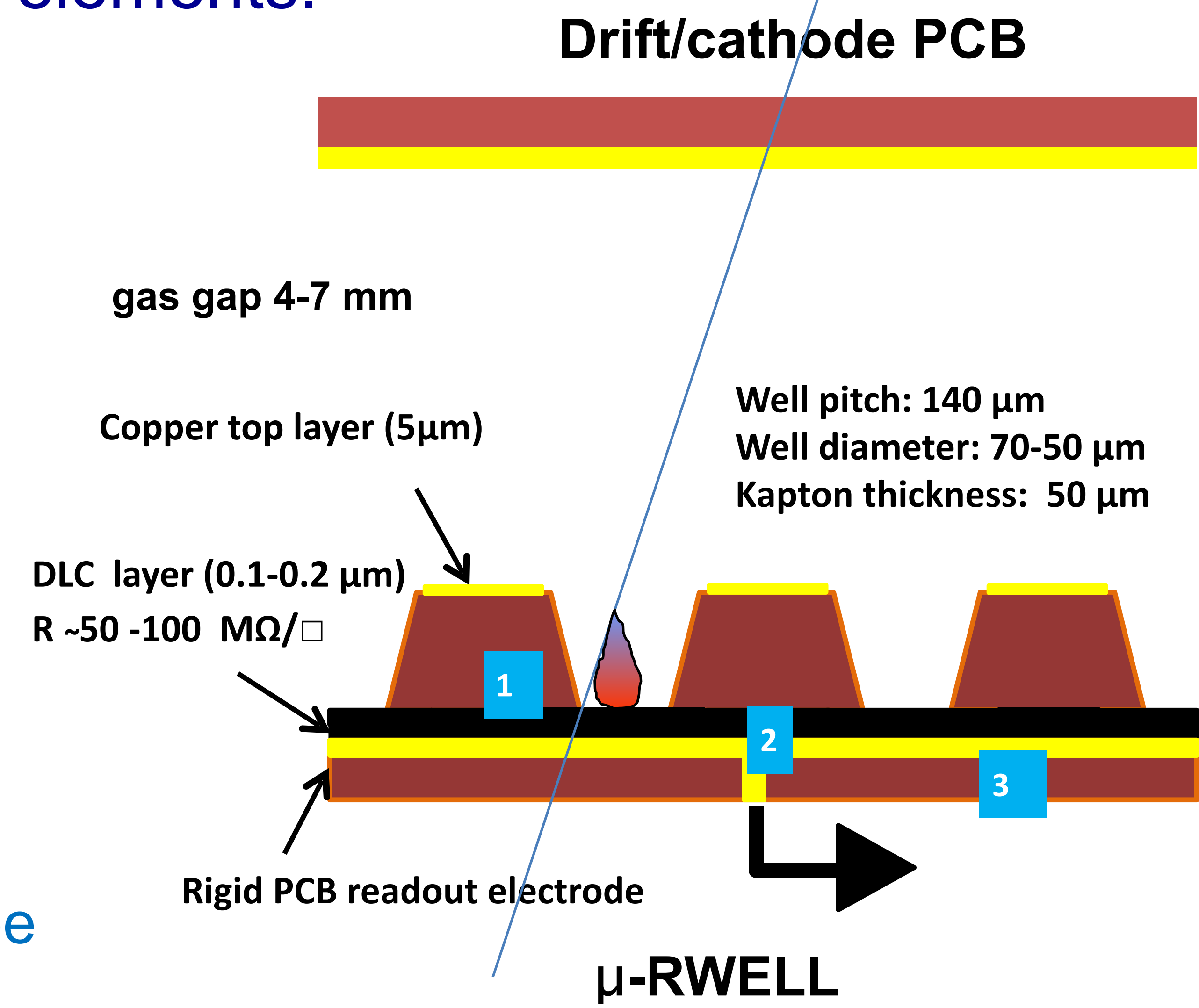


G. Bencivenni et al., 2015_JINST_10_P02008

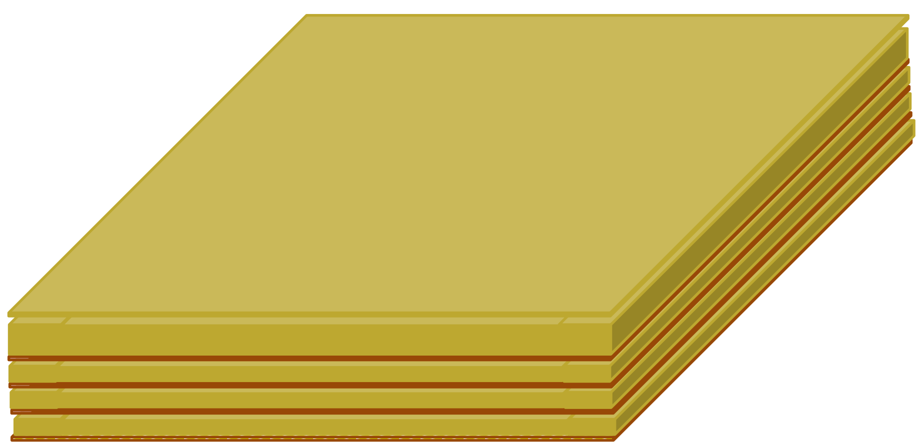
Collaboration of INFN, CERN, Eltos

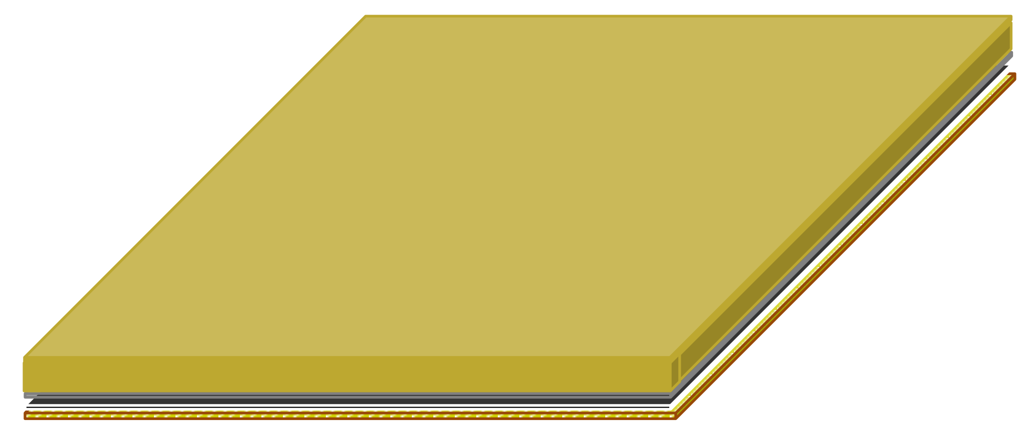
Major **advantages** wrt. GEM

- 1 kapton foil instead of 3
- No stretching
- Spark safe

The μRWell: a GEM-MM mixed solution

A natural evolution of the GEM technology





G. Bencivenni - RD51 Mini-week - 2016

GEM detector sketch

MM detector sketch

The μRWell: a GEM-MM mixed solution

A natural evolution of the GEM technology

μRWell

G. Bencivenni - RD51 Mini-week - 2016

μRWell-GEM evolution

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  - Retain the same excellent performances of GEM
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- Less components, simpler construction → significant cost reduction

CMS GE1/1 μRWell prototype at H8 test beam

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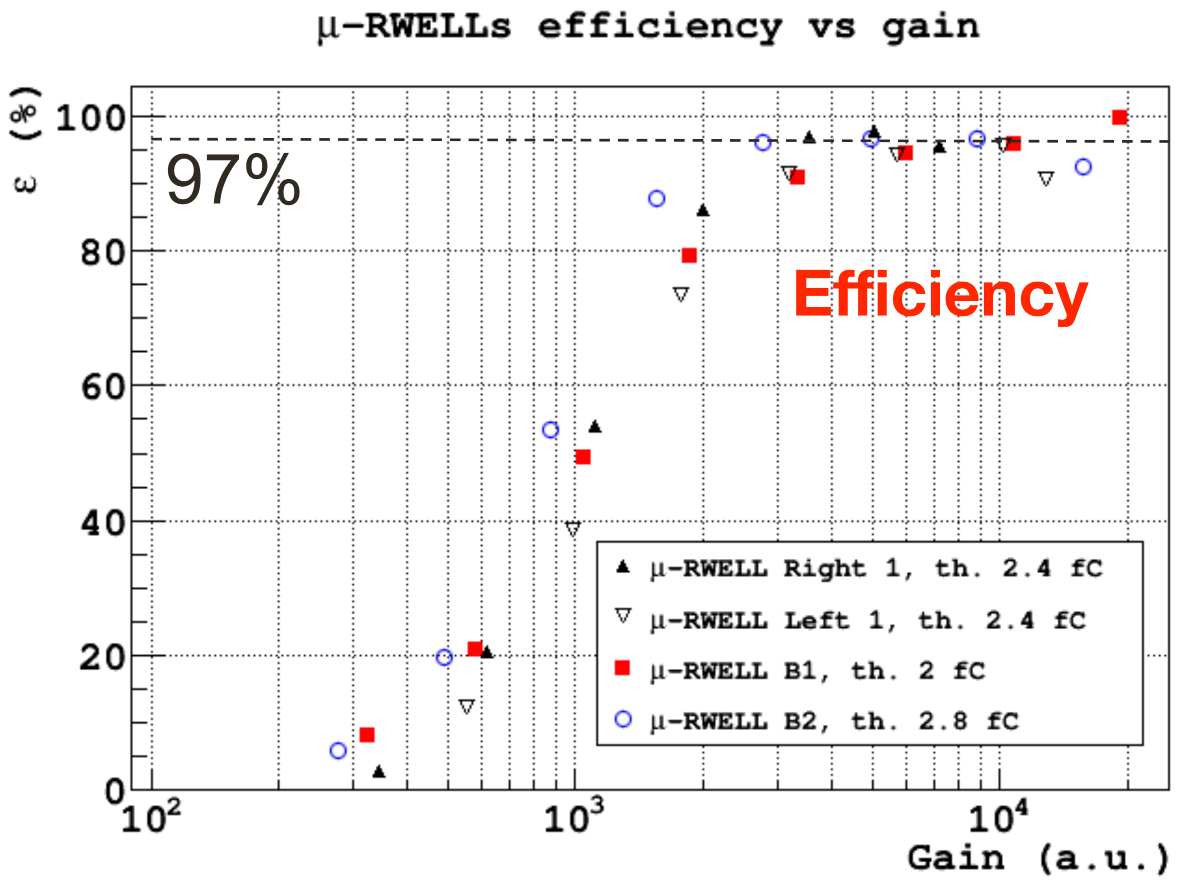

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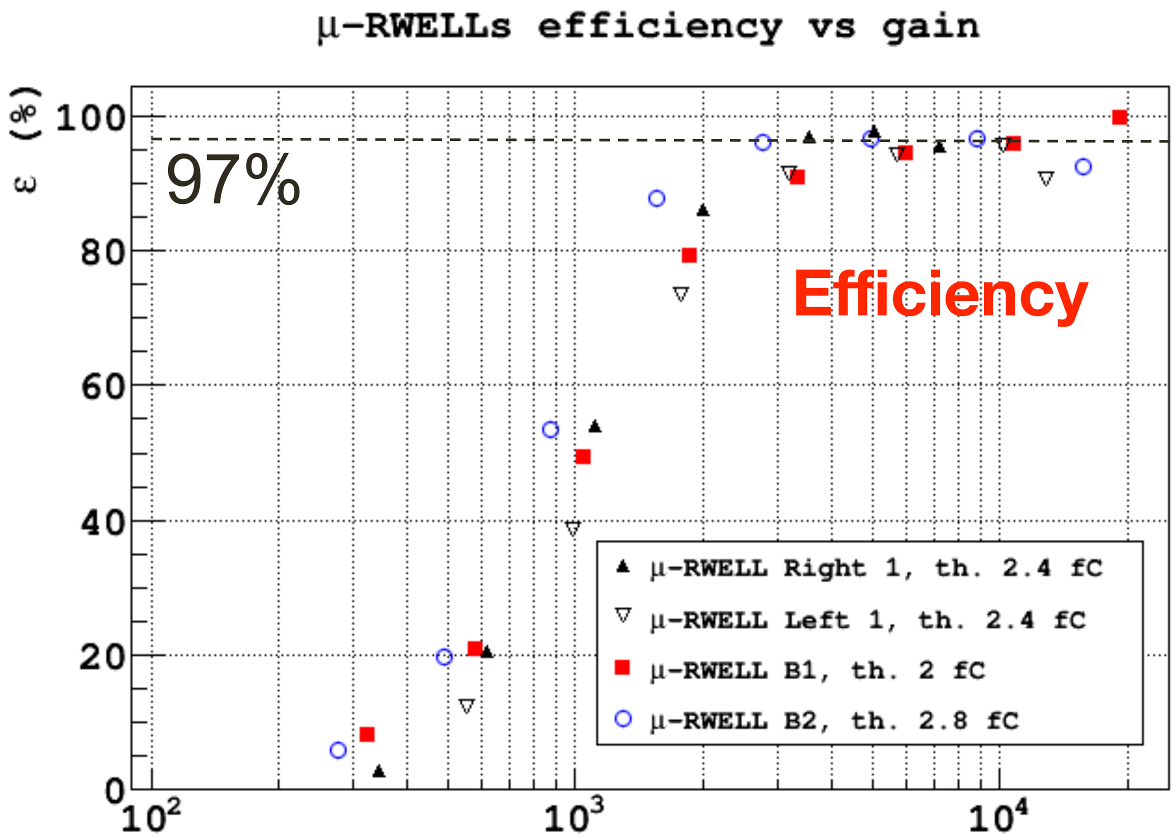

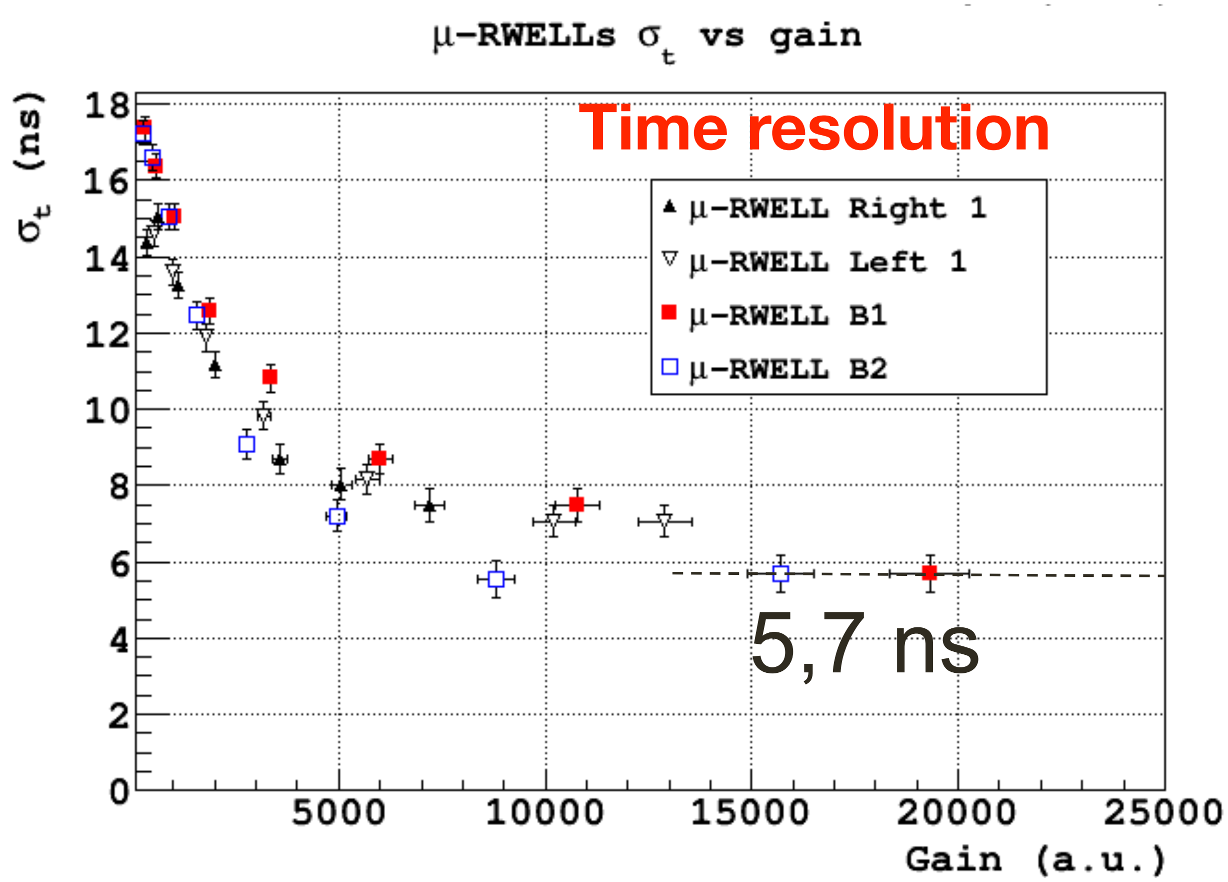

CMS GE1/1 μRWell: GIF++ ageing test

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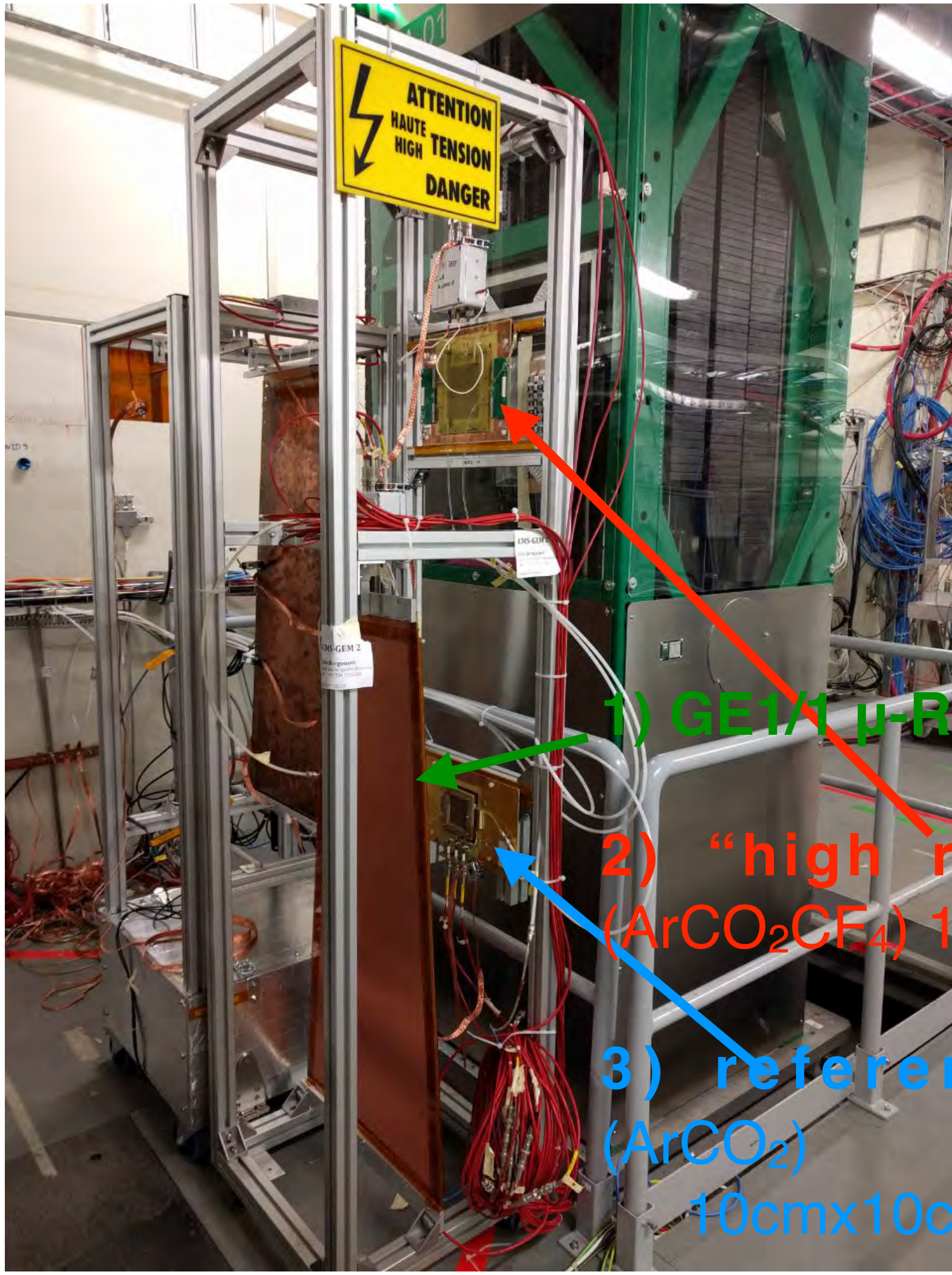

1) **GE1/1 μ-RWell** ($ArCO_2$)

2) **"high rate" μ-RWell** ($ArCO_2CF_4$) 10cmx10cm

3) **reference μ-RWell** ($ArCO_2$) 10cmx10cm

μRWell prototypes exposed inside the GIF++

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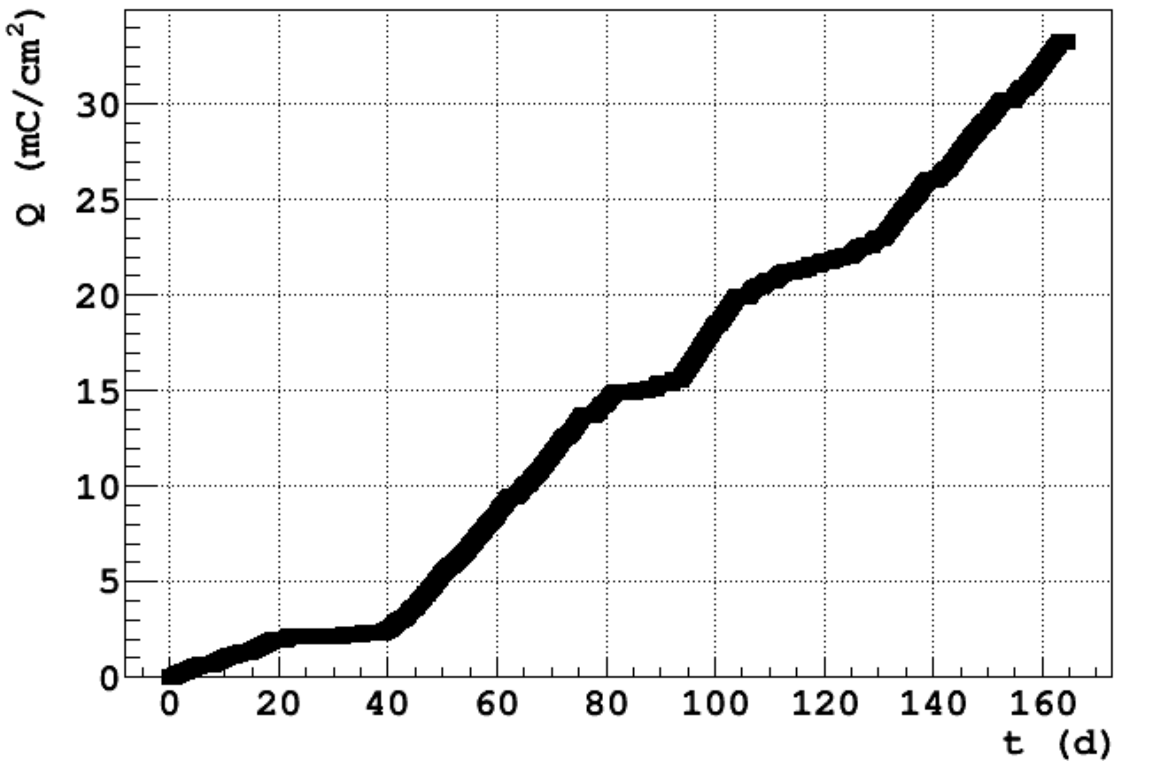

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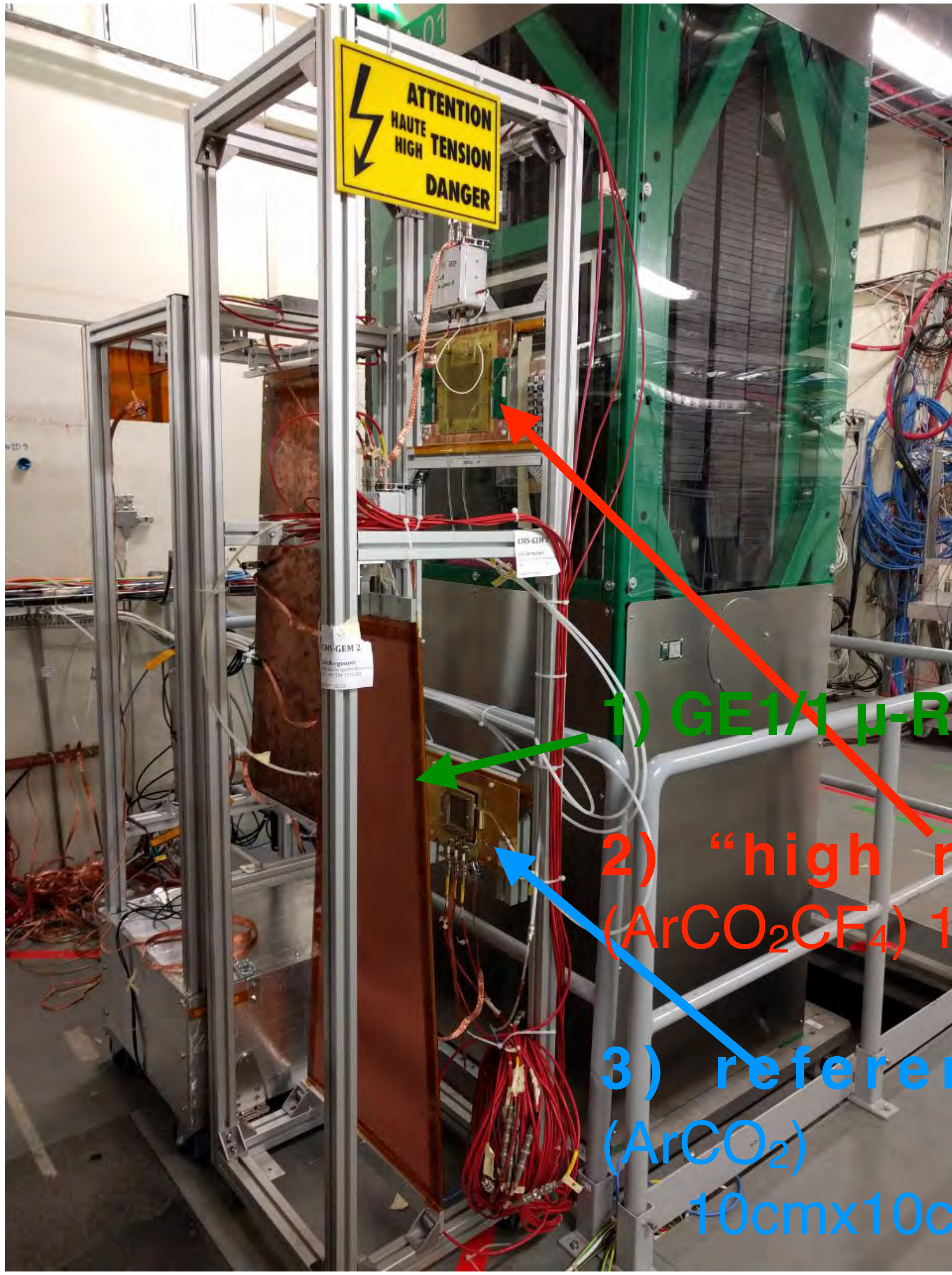

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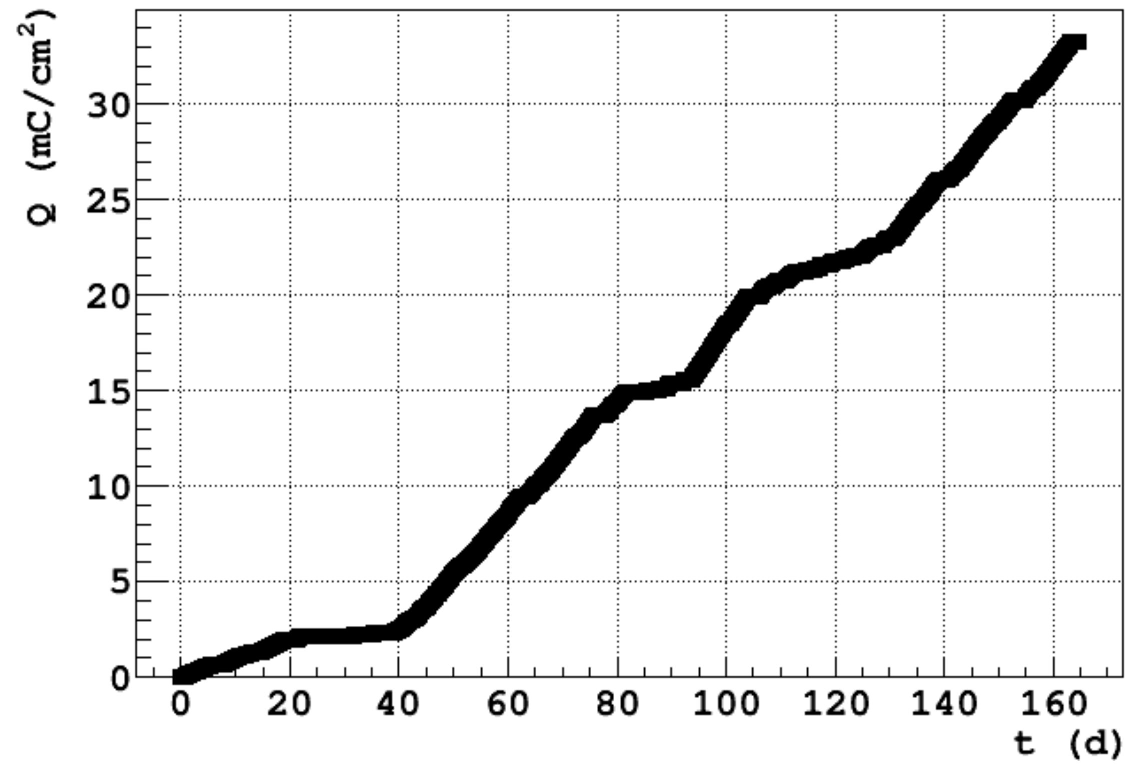

GE1/1 has accumulated a dose of ~32 mC/cm² (more than 10 times the dose after 10 years of HL-LHC)

μRWell prototypes exposed inside the GIF++

CMS GE2/1 sector μRWell prototype

CMS GE2/1 sector μRWell prototype

GE2/1 20^0 sector with M4 μRWells
(2 m height, 1.2 m base)

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M4 μRWell

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H4 test beam with 150 GeV muons:

- Voltage scan (amplification scan)
- Uniformity scan across the surface of the detector at 530 V (~12000 gain, still to be conditioned)
- Small high rate prototype reached a gain of $\sim 10^5$ and a rate of ~ 700 khz/cm^2

The excellent results obtained demonstrate the great collaboration between INFN-Eltos and Rui de Oliveira's lab

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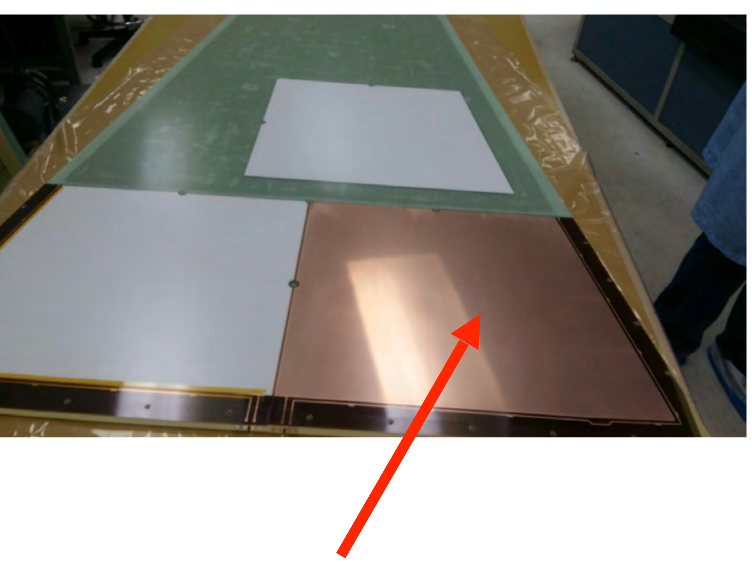

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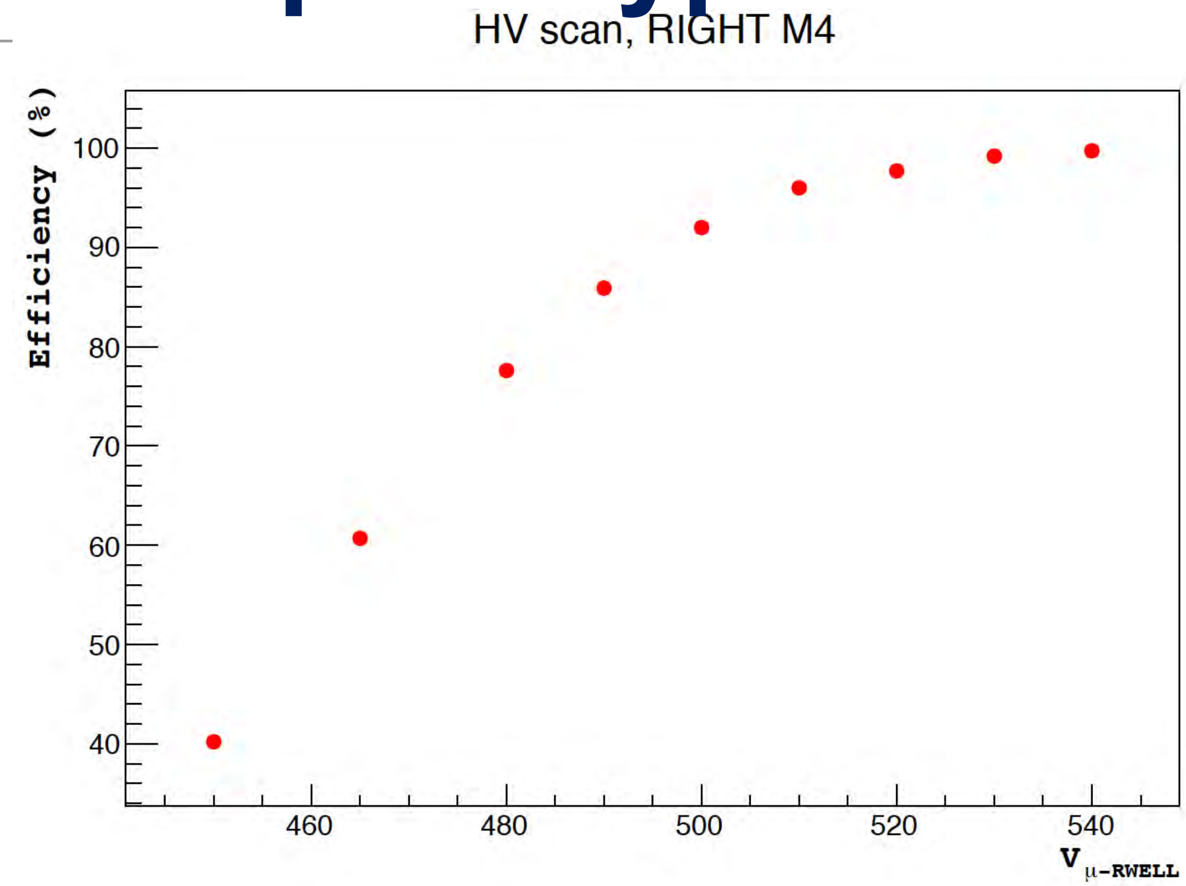

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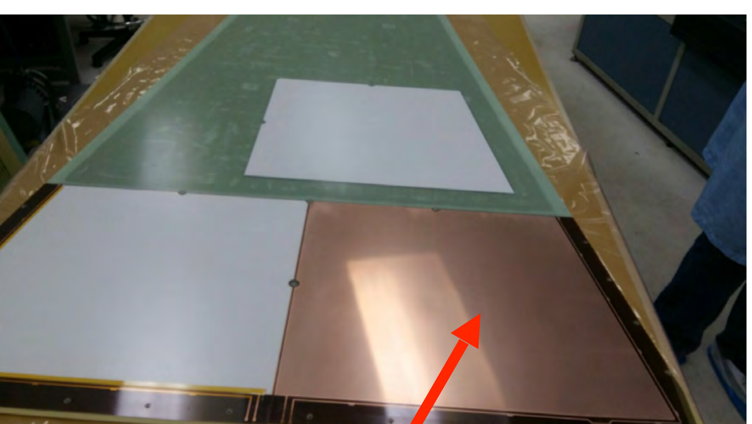

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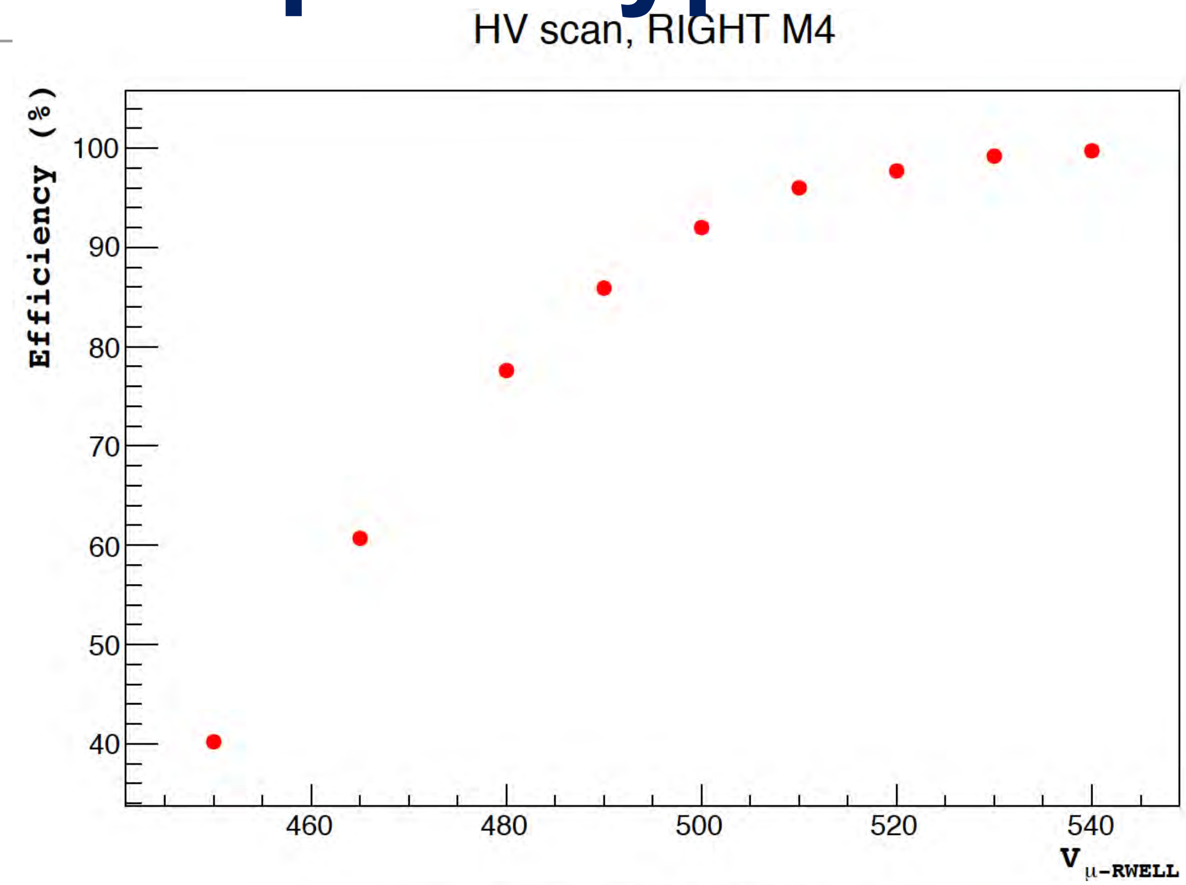

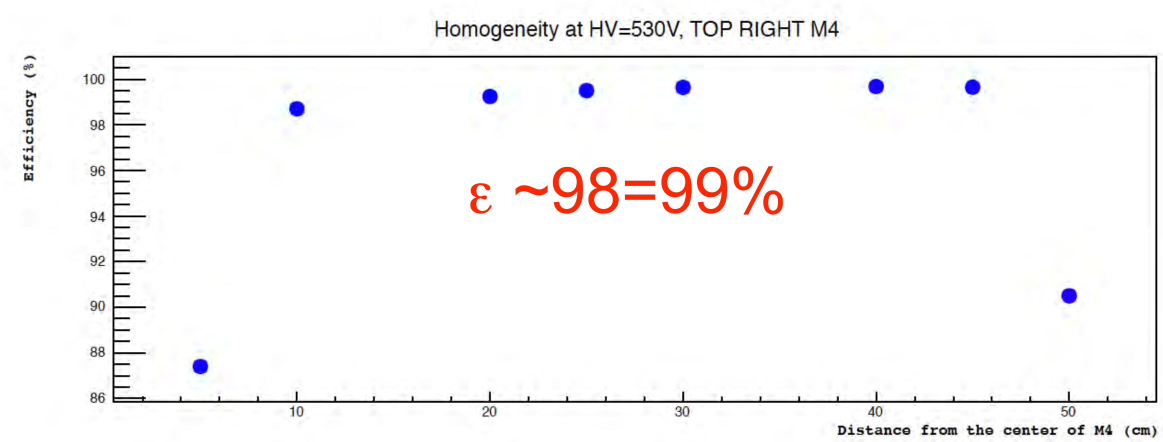

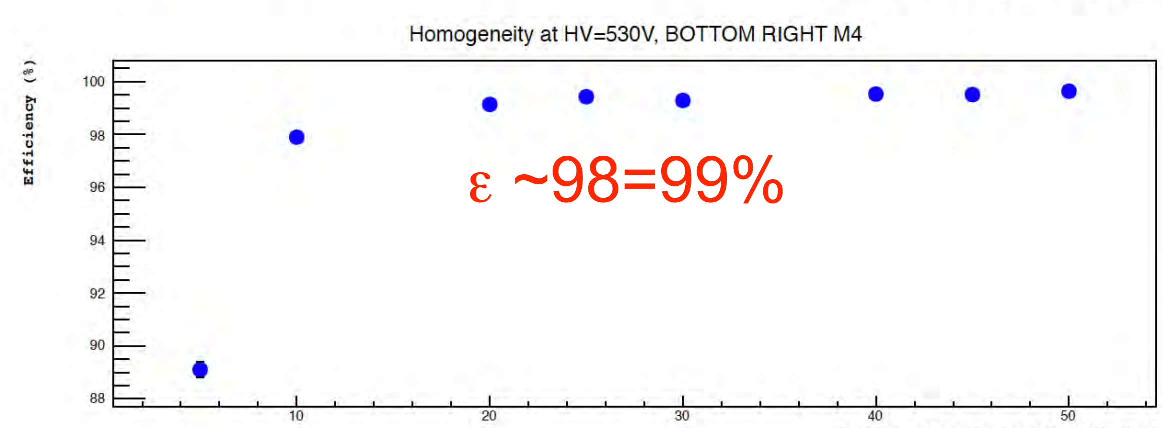

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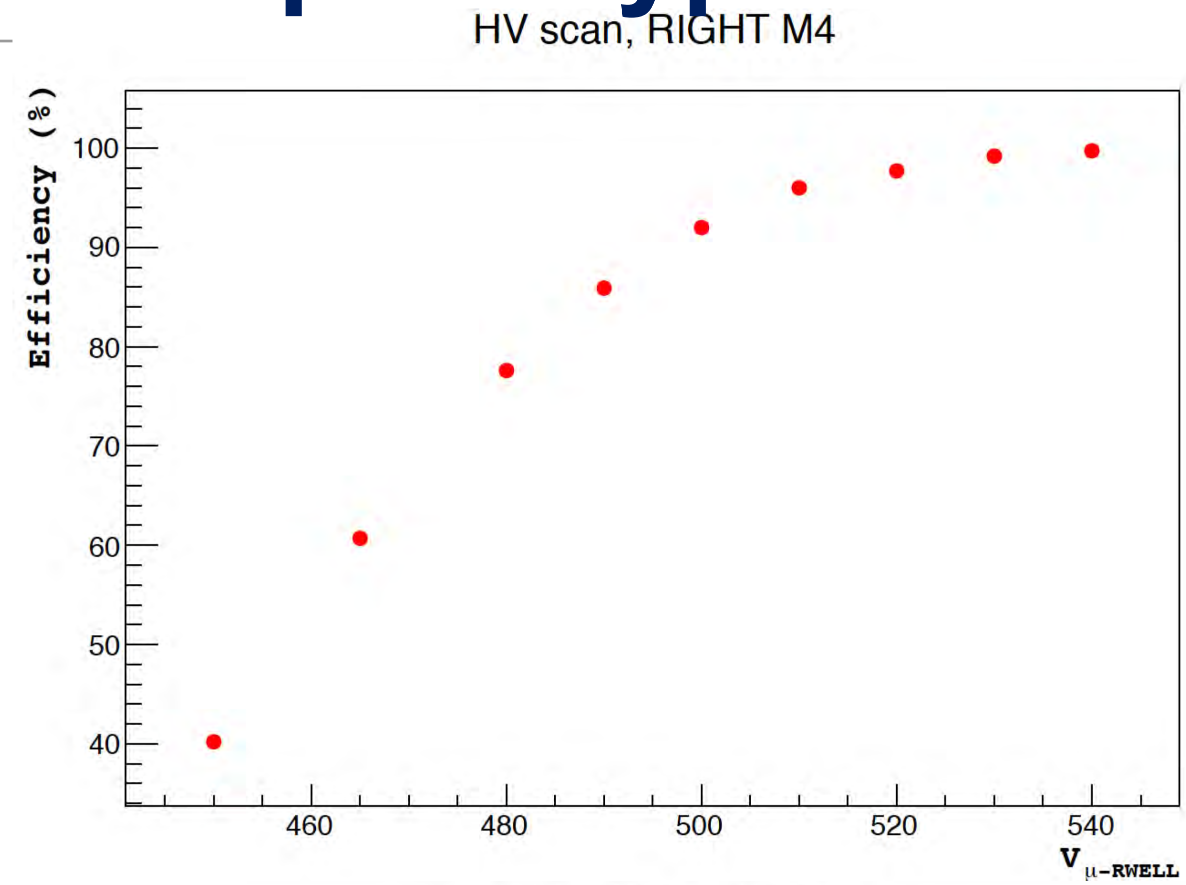

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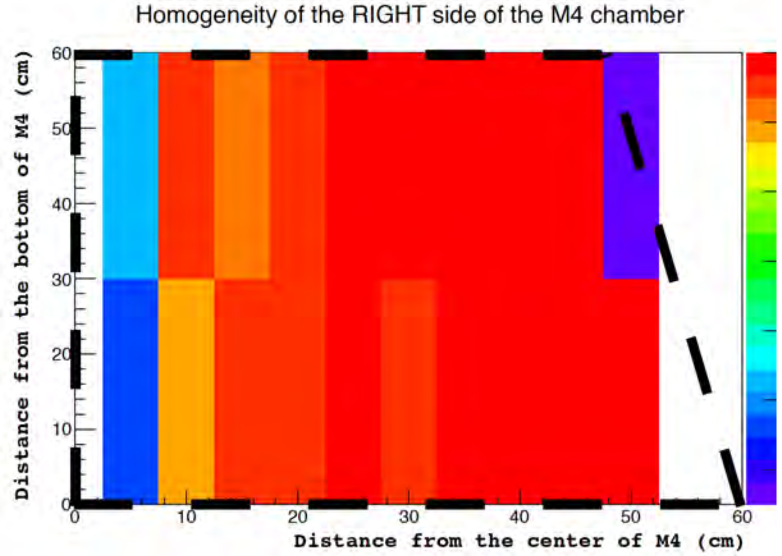

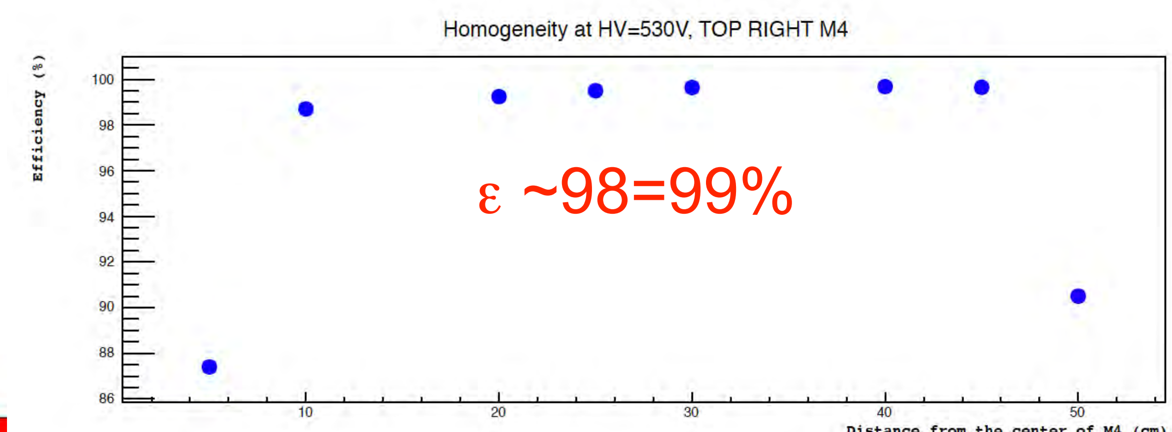

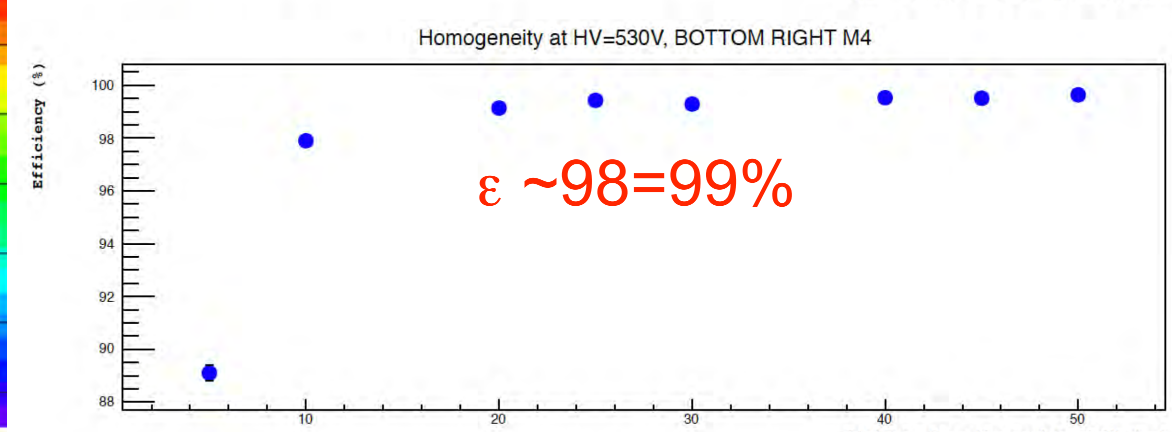

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- μRWell M4 modules built
  - Assembled in mockup
  - Exposed at the H4 test beam in July 2017
  - Excellent uniformity! Efficiency between 98-99% over the whole surface.

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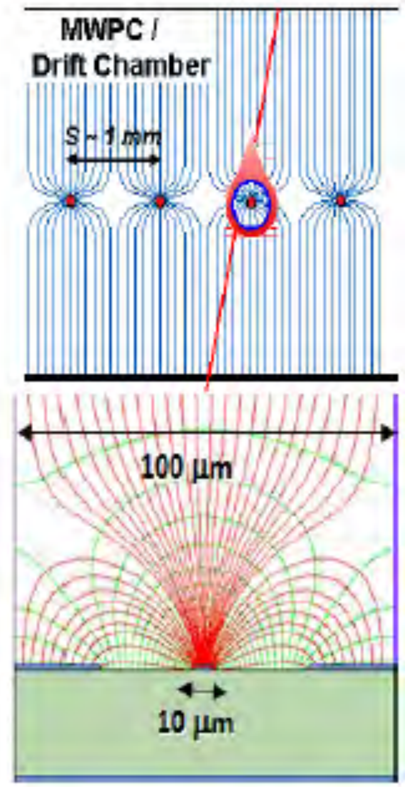
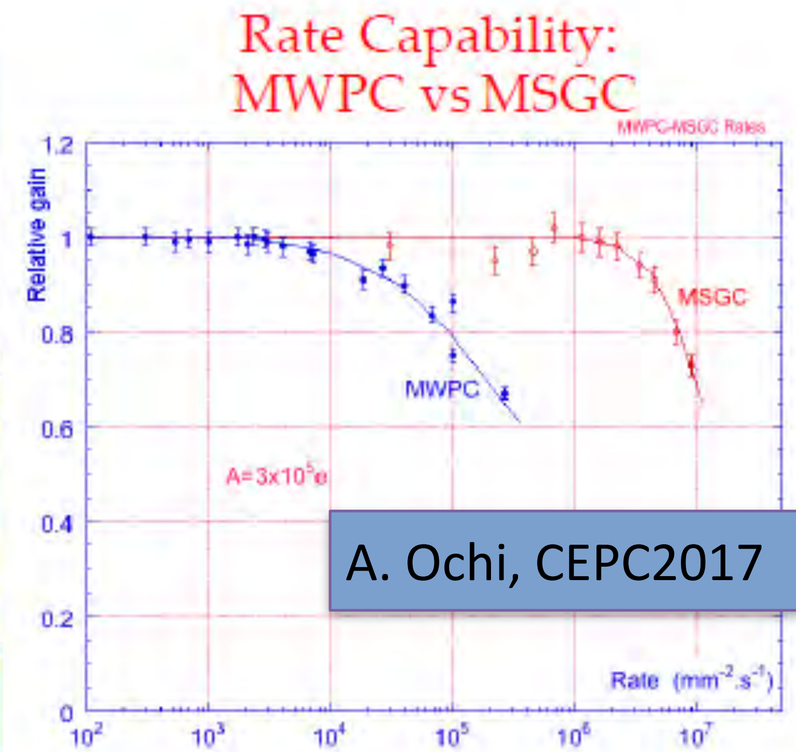
  - Provide excellent momentum resolution and a robust muon trigger
- MPGDs, and μRWell in particular, is also a suitable technology to realise the muon systems of large detectors at future hadron colliders (SppC, FCC-hh)

Backup

Micro Pattern Gaseous Detector Technologies

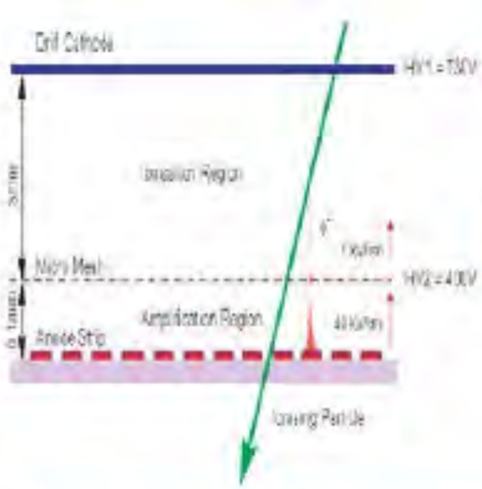
- Micromegas
- GEM
- Thick-GEM, Hole-Type and RETGEM
- MPDG with CMOS pixel ASICs ("InGrid")
- Micro-Pixel Chamber (μPIC)



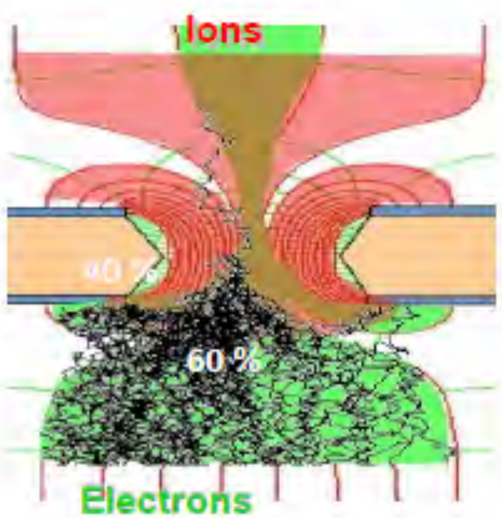


A. Ochi, CEPC2017

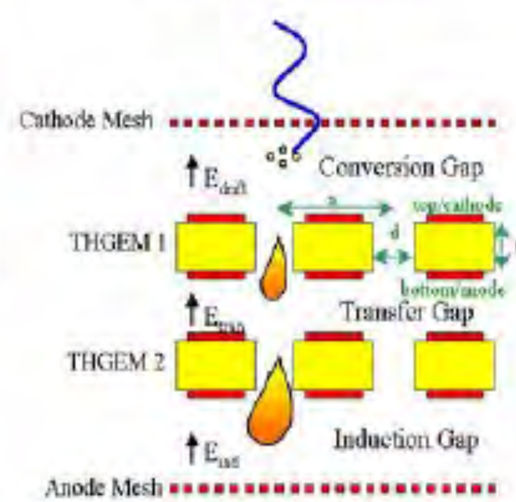
Micromegas



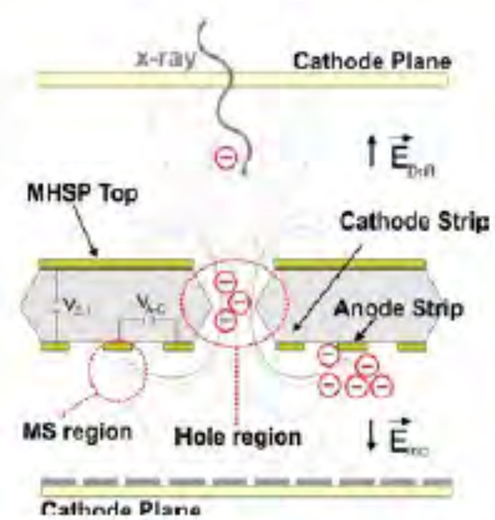
GEM



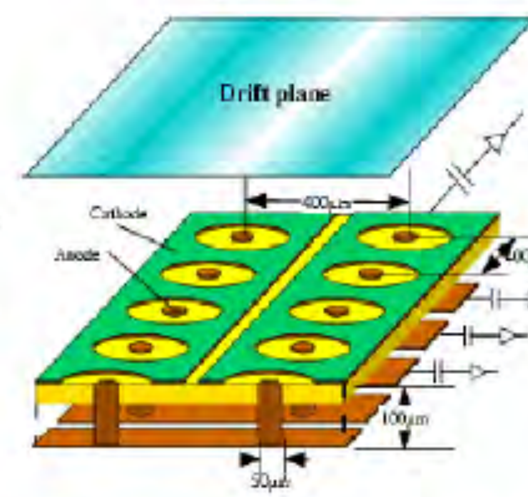
THGEM

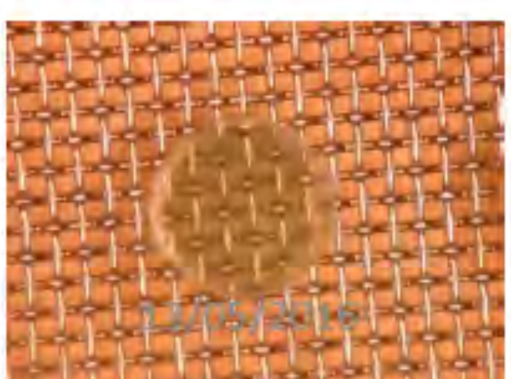


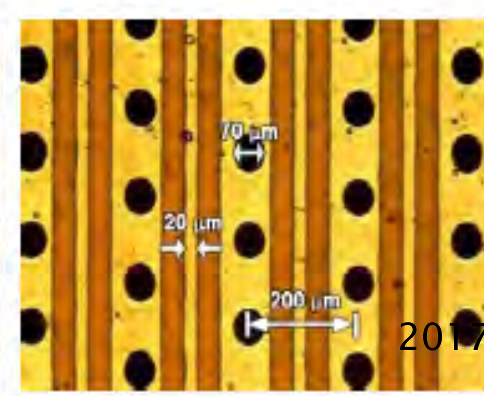
MHSP

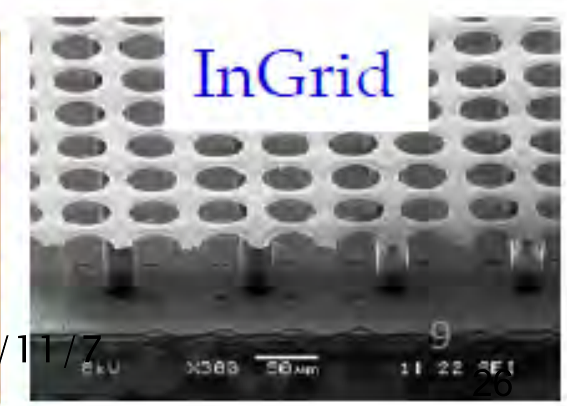


μPIC









MPGDs: one of the most **versatile** technologies

A. Ochi, CEPC2017

- Single Stage
- Multi Stage
- Fast
- Hybrids (different MPGD)

- Very High Gain
- Low Gain
- No Gain

- Thin Drift
- Large Drift

- Radio-Pure
- Low Material Budget
- Flushed
- Sealed

- High Granularity
- Charged Particles
- Photons
- Neutrons
- Tracking
- Calorimeter
- TPC

- Charge readout
- Light readout

- Small
- Large

- Thin Windows
- Low Fields
- High Fields

- Mixture
- Pure Noble Gas
- Pure Quencher
- High Pressure
- Ambient Pressure
- Low Pressure

- Conversion in gas
- Conversion outside the gas
- In the extreme case.. Without gas

- Planar
- Spherical
- Semi-Cylindrical
- Cylindrical

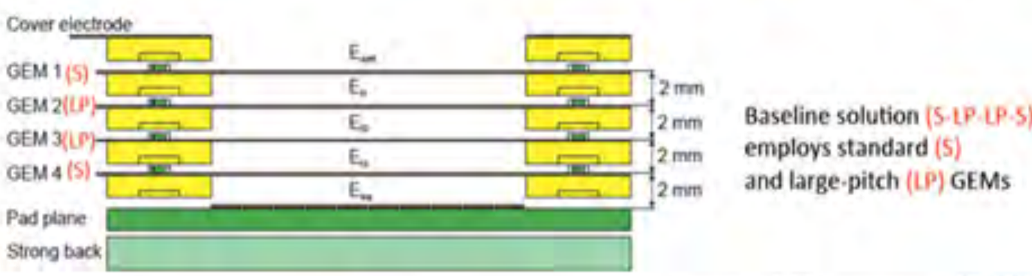
- High Rate
- Low Rate

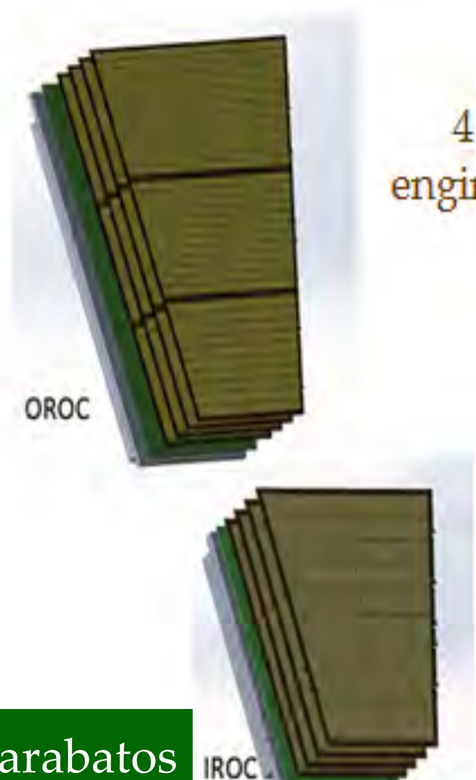
- Pads
- Strips
- Self Triggering

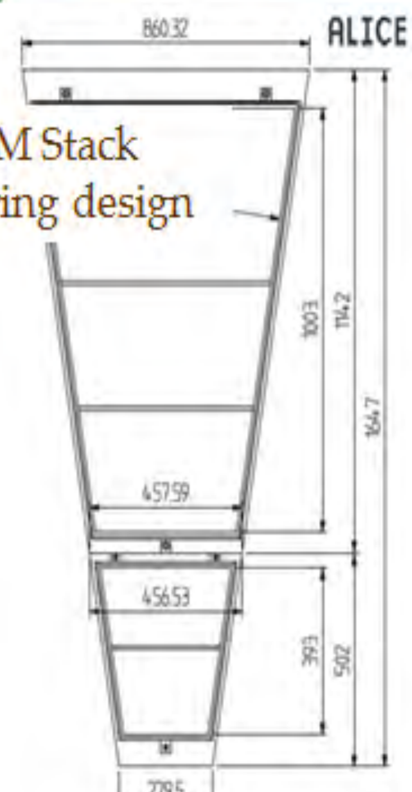
ALICE TPC Endplate upgrade with GEMs

ALICE TPC Upgrade → replace MWPC with 4-GEM (to limit space charge effects)

- ➢ Continuous TPC readout for 50 kHz Pb-Pb readout
- ➢ Maintain physics requirements:
  IBF < 1%, energy; σ(E)E < 12% achieved

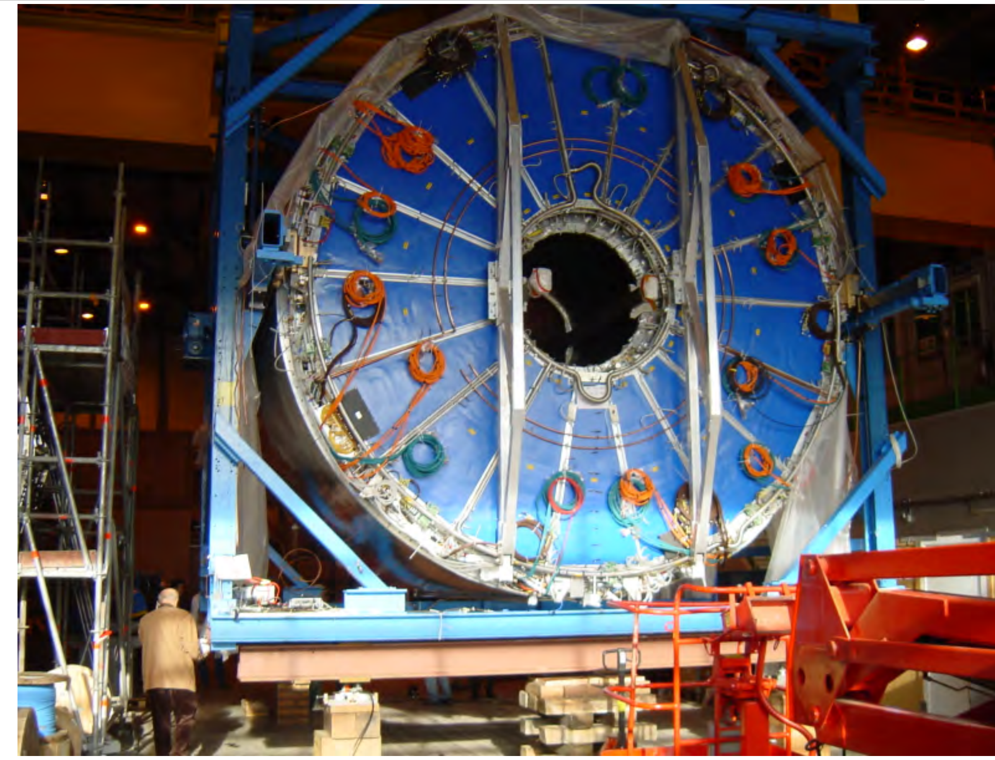




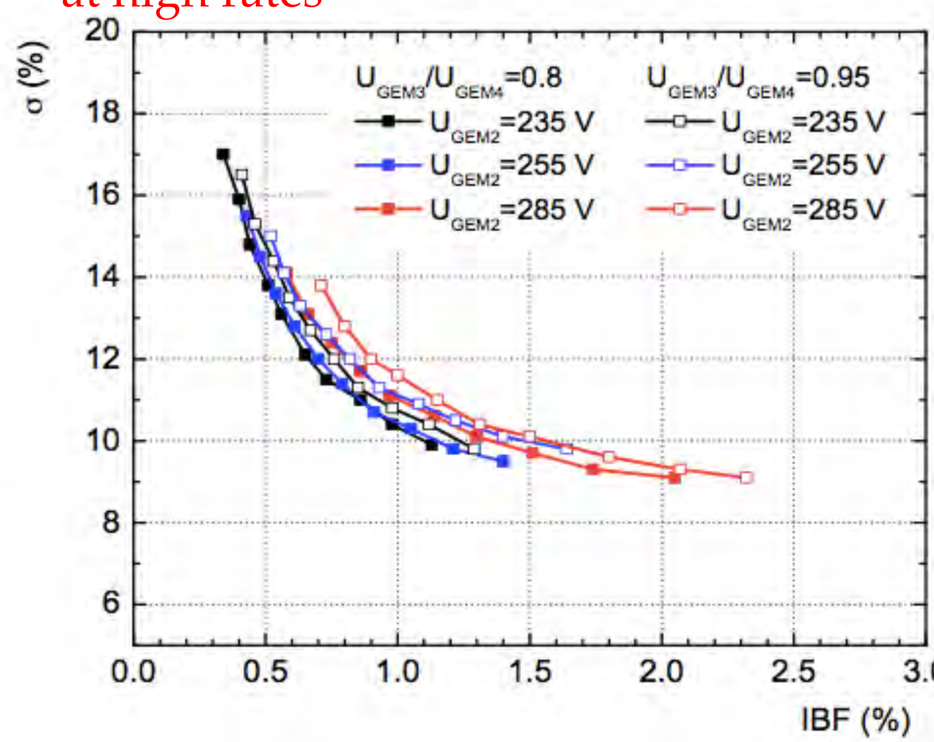


Preproduction:

Single-mask GEM allows for production of ~1 m foils



Ion Back Flow in a GEM system reduced from > 5 % (3 GEM) to < 1% (4 GEM)
→ discovered enhanced ion trapping at high rates



C. Garabatos

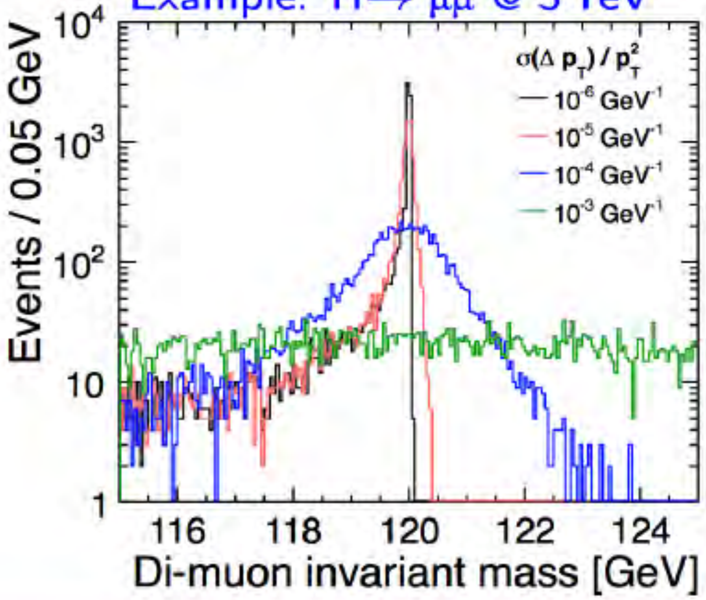
Muon detector for FCC-ee

CLIC Detector requirements from physics

- momentum resolution
  - Higgs recoil mass, Higgs coupling to muons, BSM (smuon and neutralino masses)
  - for high p_T tracks

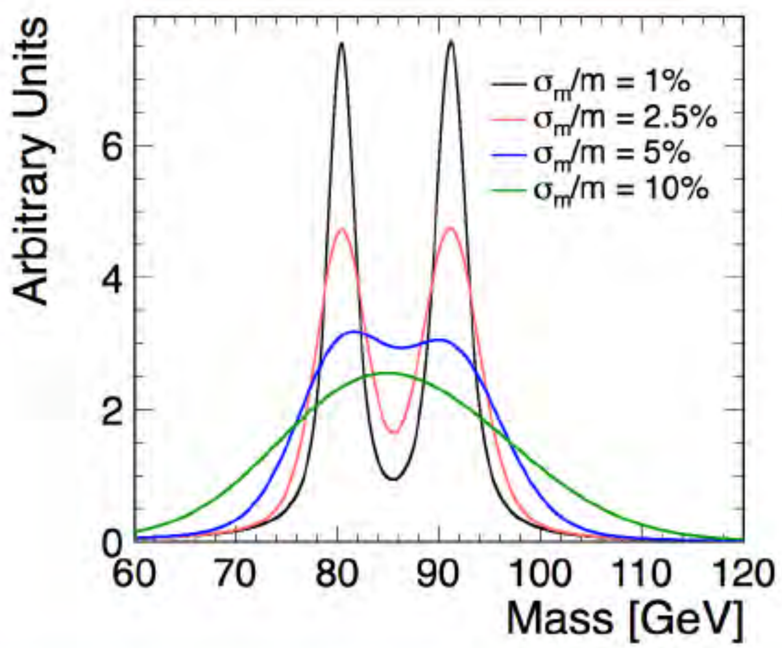
$$\sigma_{p_T}/p_T^2 \simeq 2 \times 10^{-5} GeV^{-1}$$

Example: H→ μμ @ 3 TeV



- jet energy resolution
  - W/Z di-jet mass separation
  - jet energy up to 1 TeV

$$\sigma_E/E \simeq 3.5\%$$



- impact parameter resolution
  - c/b tagging, Higgs BR

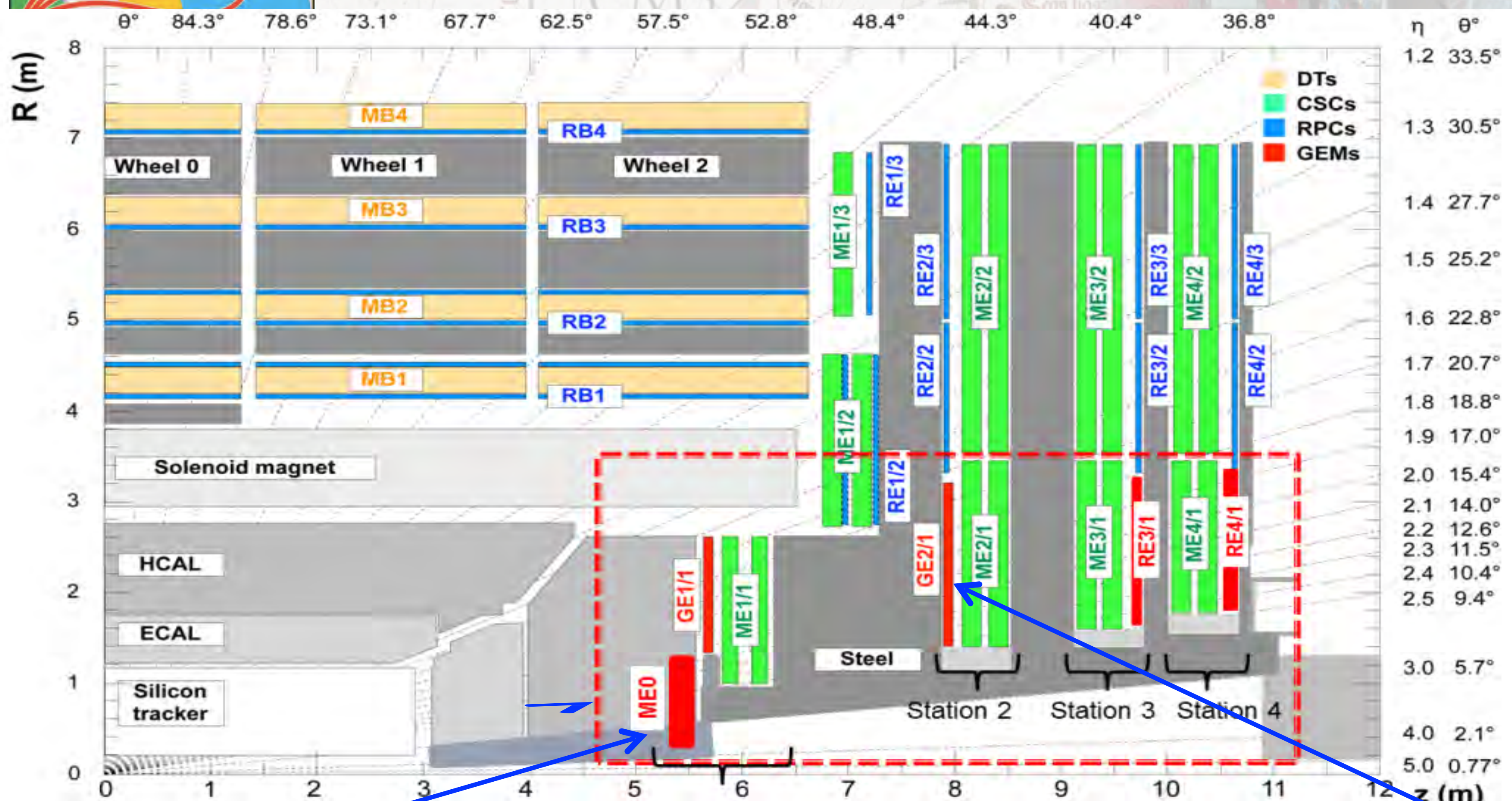
$$\sigma_{d_0}^2 = a^2 + \frac{b^2}{p^2 \sin^3\theta}$$

$$a \lesssim 5\mu m \quad b \lesssim 15\mu m GeV$$

- lepton ID efficiency > 95 %
  - over full energy range

- forward coverage
  - electron and photon tagging (e.g. dark matter studies)

GEM Phase 2 Forward muon system



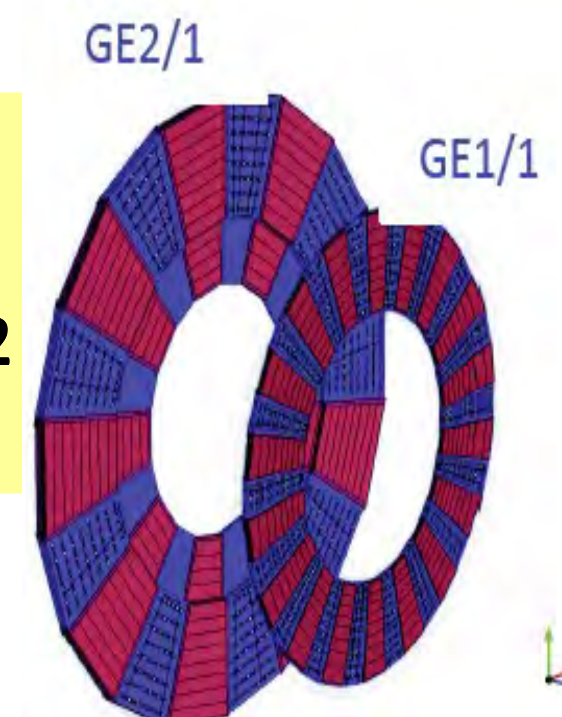
GE21 L1 trigger rate reduction, enhance via redundancy, reconstruction
ME0 detector extends coverage and performance of muon Id and trigger beyond η=2.4 up to η<2.8

ME0:

- **Muon tagger** at highest η (η <2.8)
- 36 20°super-module wedge each consists 6 layers of chambers.
- **Numb. of chambers: 216**
- **Installation: July 2024**

GE2/1:

- 1.6 < |η| < 2.4
- 36 20°super-chambers
- **Total number of chambers:72**
- **Installation: YETS 2022**



GEM Phase 2 : Trigger and reconstruction

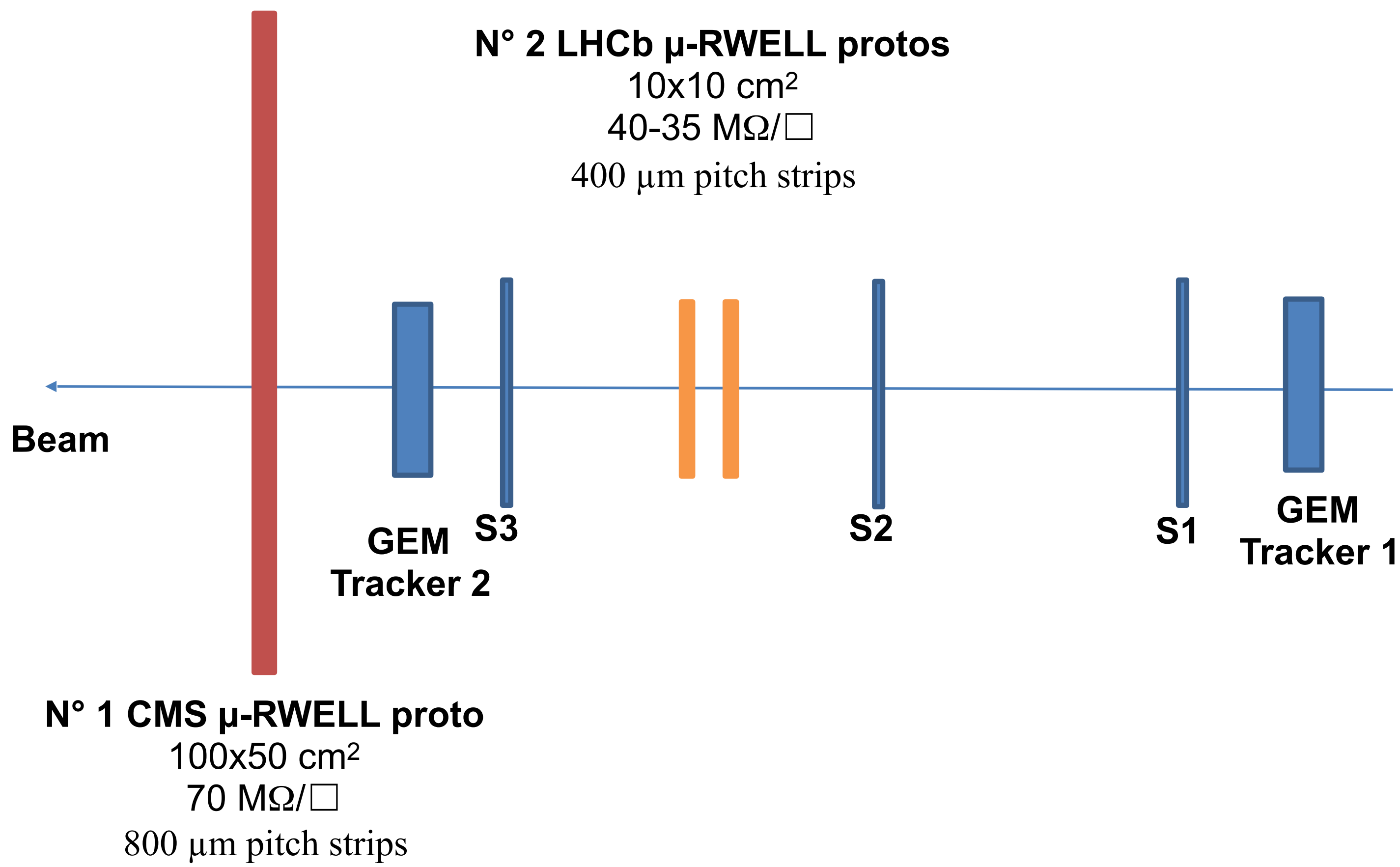
GE1/1 μRWell: test at H8 (nov. 2016)

1. Construction & test of the first **1.2x0.5m² (GE1/1) μ-RWELL** **2016**
2. Mechanical study and mock-up of 1.8x1.2 m² (GE2/1) μ-RWELL **2016-2017**
3. Construction of the first **1.8x1.2m² (GE2/1) μ-RWELL (only M4 active)** **01-09/2017**

GE1/1 μRWell prototype

H8 Beam Area (18th Oct. 9th Nov 2016)

Muon/Pion beam: 150 GeV/c



GE2/1 μRWell-GEM synergies

- Similar components (kapton foils, PCBs, etc.)
- Same gas mixture
- Same electronics
- Same cooling
- Same detector control system
- Same strips orientation and dimension
- Similar but simpler mechanical frames

↓

- Any improvement or cost reduction on kapton foils and PCBs will reflect directly also onto μRWell
- A GEM production site could easily and seamlessly transform into a μRWell assembly site
- The overall installation of GE2/1 would remain almost identical

GE2/1 μRWell: GIF++ ageing test

Context:
CMS Muon System, R&D Phase II Upgrade with MPGD: μ-RWell

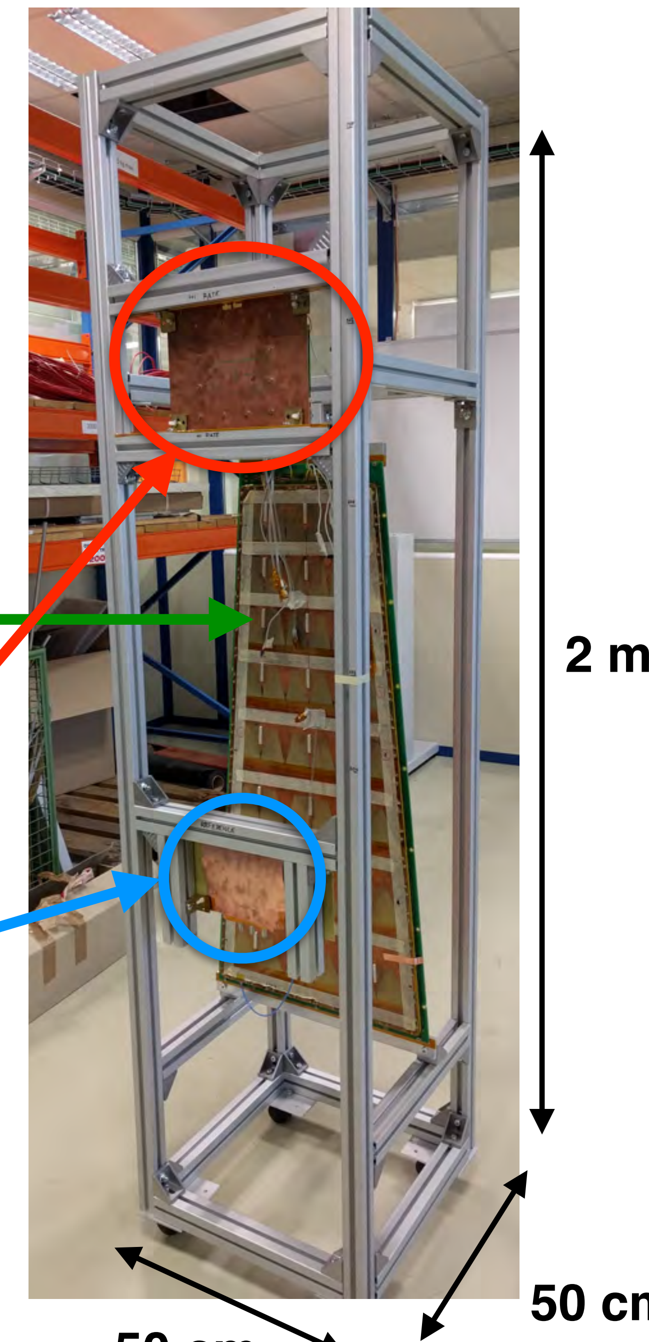
Motivations:
Need to qualify the behaviour and performance of μ-RWell detectors in a harsh radiation environment.

Duration of the test:
will stay at least 6 months. GE2/1 HL-LHC dose achievable in a short time (few weeks)

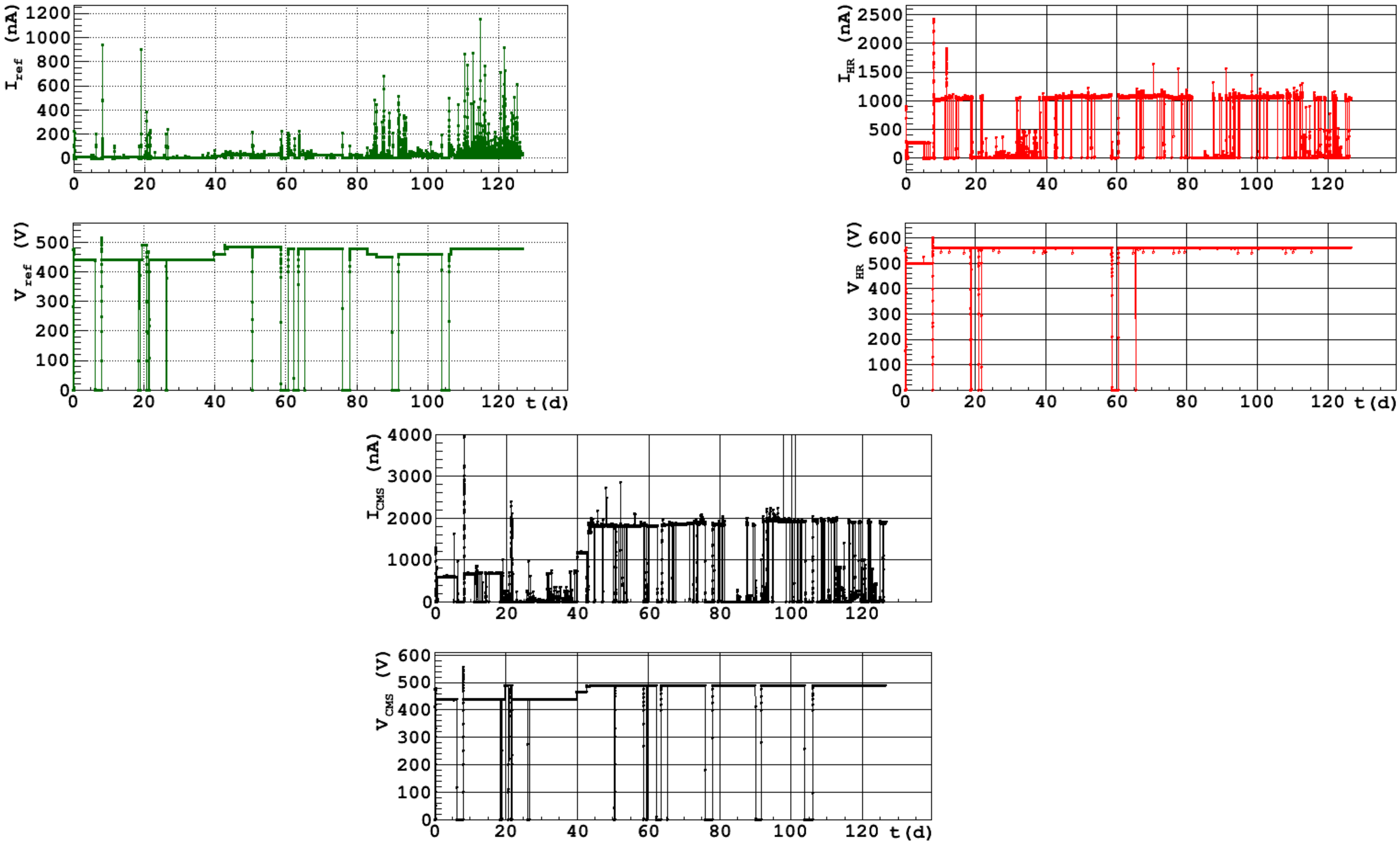
1) **GE1/1 μ-RWell** ($ArCO_2$)

2) **"high rate" μ-RWell** ($ArCO_2CF_4$)
10cmx10cm

3) **reference μ-RWell** ($ArCO_2$)
5cmx5cm



GE2/1 μRWell: GIF++ ageing test

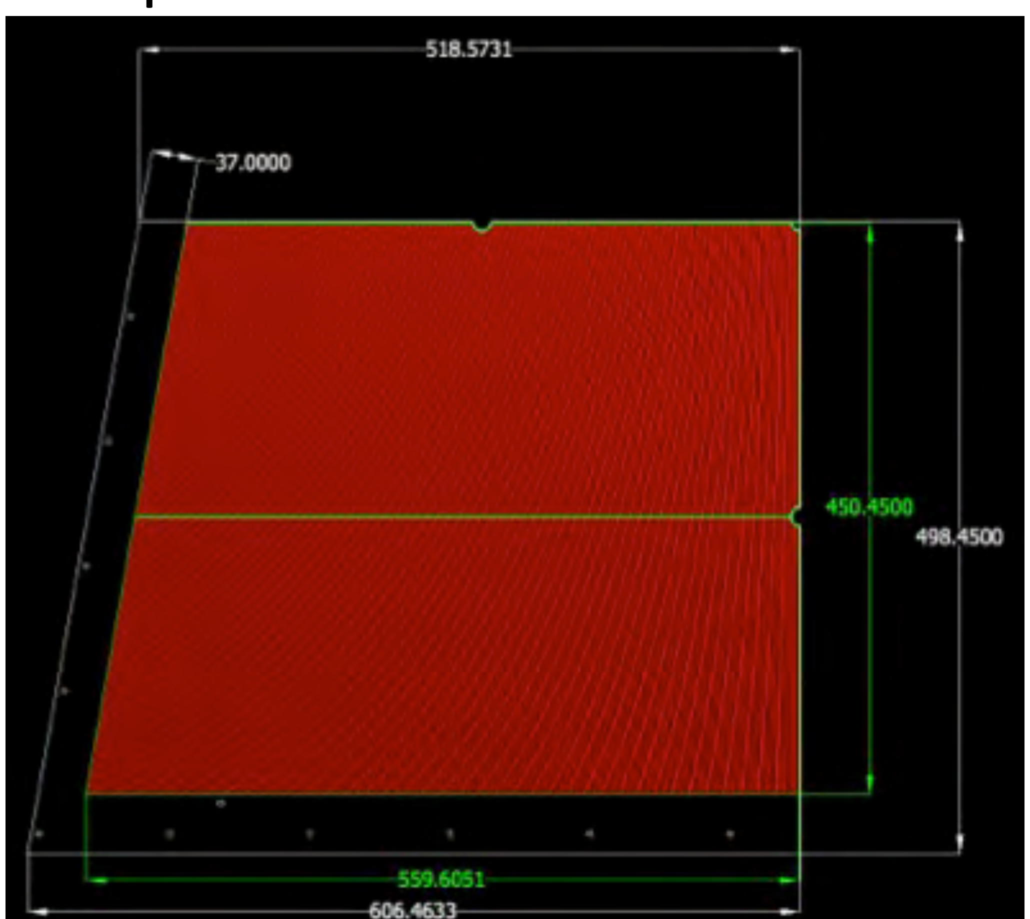


Highest spikes are of the order of 1-2 μA. This further demonstrates the intrinsic robustness of μRWell.

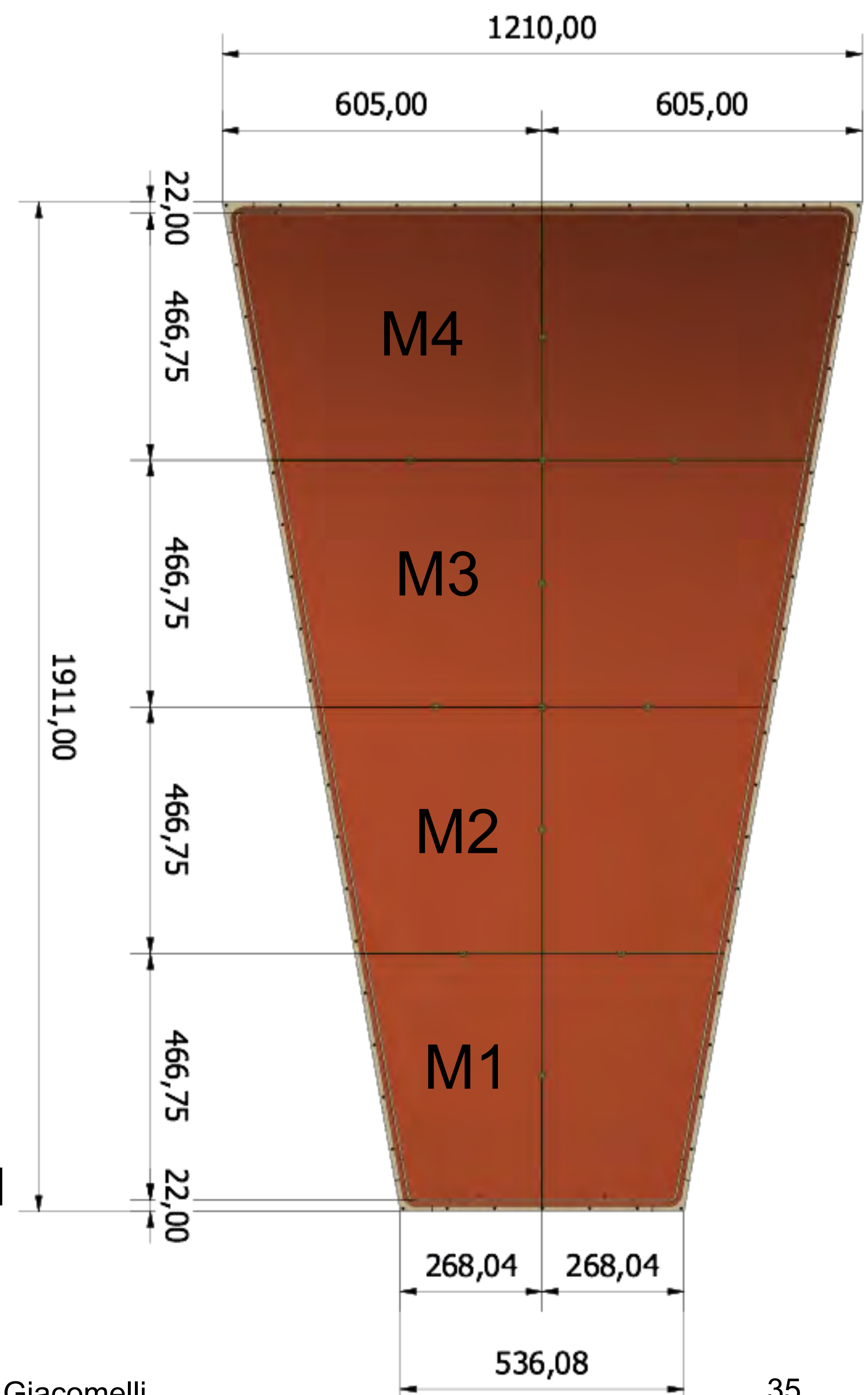
GE2/1 alternative option: μRWell

We have built a full scale GE2/1 sector with 2 M4 μ-RWELL operating detectors.

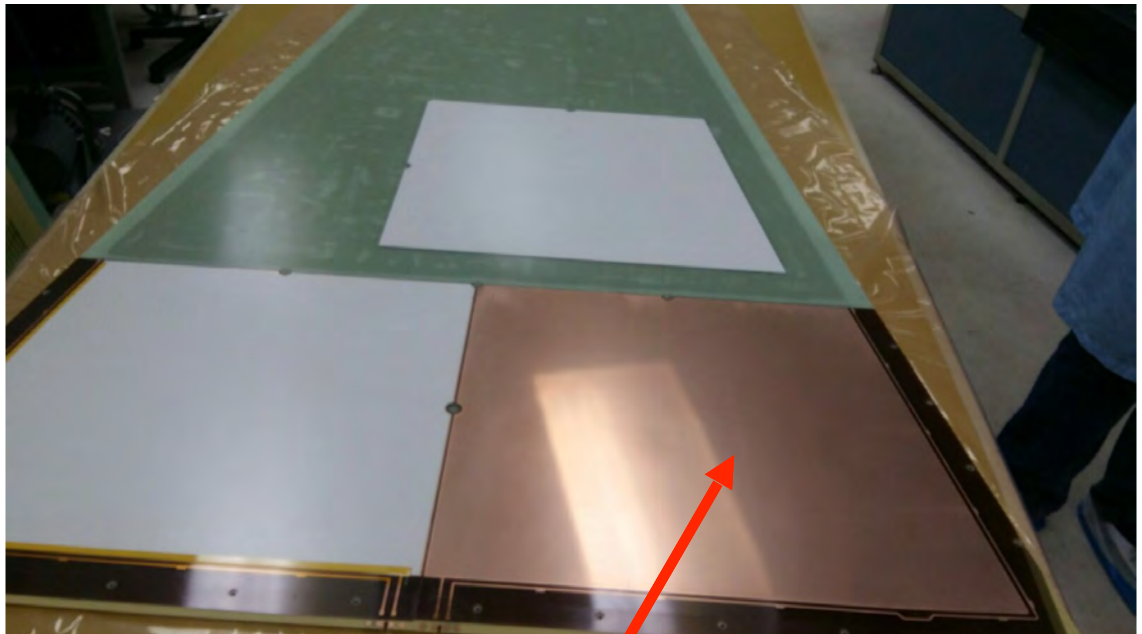
1) M4 left and right are mirrored.
2) Size: 606.5 x 498.5 x 1 mm
3) Strip layout inspired to the GE2/1 GEM option
4) Final drawing finished (Gatta-LNF)
5) DLCed foils ready (Ochi-Kobe)
6) Preliminary tests at ELTOS done
7) PCB production at Eltos done, then glueing with kapton foil



Modules fit within 74 mm splicing → dead space less than 0.01%



GE2/1 sector equipped with two active M4 μRWell



M4 μRWell

M4 μRWell detectors

Brought to H4 test beam on July 12th

Summary on μRWell

- μRWell is a natural evolution of the GEM technology, with the same performances but:
  - Simpler construction
  - Less components (1 stage of amplification only)
    - Typical gain 4000 (but has been shown to work up to >20000)
  - More robust
    - Spark safe, due to DLC layer
  - Simpler assembly
    - No stretching, kapton foil glued to PCB (in the future caption foil could be floating, making assembly even simpler…)

- CMS GE1/1 size μRWell prototype tested up to ~100 kHz/cm^2
- High rate μRWell prototypes exist for rates up 1 MHz/cm^2, tested at GIF up to 250 kHz/cm^2

- μRWell vs. GEM → significant cost reduction