CEPC calorimetry workshop
IHEP, Beijing

Muon detectors and MPGDs

P. Giacomelli
INFN Bologna

Overview

Overview

- **Muon detectors at existing large HEP experiments**

Overview

- **Muon detectors at existing large HEP experiments**
- **Muon detectors for future accelerators (ILC, CepC, SppC, FCC-ee, FCC-hh, CLIC)**

Overview

- **Muon detectors at existing large HEP experiments**
- **Muon detectors for future accelerators (ILC, CepC, SppC, FCC-ee, FCC-hh, CLIC)**
- **Micro Pattern Gas Detectors (MPGD)**

Overview

- **Muon detectors at existing large HEP experiments**
- **Muon detectors for future accelerators (ILC, CepC, SppC, FCC-ee, FCC-hh, CLIC)**
- **Micro Pattern Gas Detectors (MPGD)**
- **An example of a new MPGD: the μRWell and its application for future muon systems**

Overview

- **Muon detectors at existing large HEP experiments**
- **Muon detectors for future accelerators (ILC, CepC, SppC, FCC-ee, FCC-hh, CLIC)**
- **Micro Pattern Gas Detectors (MPGD)**
- **An example of a new MPGD: the μRWell and its application for future muon systems**
- **Conclusions**

Muon detectors in large HEP experiments

Muon detectors in large HEP experiments

Most current large detector experiments have a cylindrical structure closed at the two ends by 2 endcaps.

Muon detectors in large HEP experiments

Most current large detector experiments have a cylindrical structure closed at the two ends by 2 endcaps.

Detectors for future accelerators (ILC, CepC, SppC, FCC-ee, FCC-hh, CLIC) adopt a similar design.

Muon detectors in large HEP experiments

Most current large detector experiments have a cylindrical structure closed at the two ends by 2 endcaps.

Detectors for future accelerators (ILC, CepC, SppC, FCC-ee, FCC-hh, CLIC) adopt a similar design.

All these detectors have a length exceeding 20m and a radius of at least 7-8m.

Muon detectors in large HEP experiments

Most current large detector experiments have a cylindrical structure closed at the two ends by 2 endcaps.

Detectors for future accelerators (ILC, CepC, SppC, FCC-ee, FCC-hh, CLIC) adopt a similar design.

All these detectors have a length exceeding 20m and a radius of at least 7-8m.

Muon detection systems need to identify muons and measure their momentum with accurate precision. In hadronic collisions they also have to provide a standalone muon trigger and BX identification.

Muon detectors in large HEP experiments

Most current large detector experiments have a cylindrical structure closed at the two ends by 2 endcaps.

Detectors for future accelerators (ILC, CepC, SppC, FCC-ee, FCC-hh, CLIC) adopt a similar design.

All these detectors have a length exceeding 20m and a radius of at least 7-8m.

Muon detection systems need to identify muons and measure their momentum with accurate precision. In hadronic collisions they also have to provide a standalone muon trigger and BX identification.

Muon systems are typically composed of several stations (ranging from 2 to 7) of detectors interleaved in the iron yoke (or in air) at several meters from the IP.

Muon detectors in large HEP experiments

Most current large detector experiments have a cylindrical structure closed at the two ends by 2 endcaps.

Detectors for future accelerators (ILC, CepC, SppC, FCC-ee, FCC-hh, CLIC) adopt a similar design.

All these detectors have a length exceeding 20m and a radius of at least 7-8m.

Muon detection systems need to identify muons and measure their momentum with accurate precision. In hadronic collisions they also have to provide a standalone muon trigger and BX identification.

Muon systems are typically composed of several stations (ranging from 2 to 7) of detectors interleaved in the iron yoke (or in air) at several meters from the IP.

The barrel part of a muon detection system has dimensions of a few thousands of m^2, while the endcaps are typically about half of this size.

Muon detectors in large HEP experiments

Most current large detector experiments have a cylindrical structure closed at the two ends by 2 endcaps.

Detectors for future accelerators (ILC, CepC, SppC, FCC-ee, FCC-hh, CLIC) adopt a similar design.

All these detectors have a length exceeding 20m and a radius of at least 7-8m.

Muon detection systems need to identify muons and measure their momentum with accurate precision. In hadronic collisions they also have to provide a standalone muon trigger and BX identification.

Muon systems are typically composed of several stations (ranging from 2 to 7) of detectors interleaved in the iron yoke (or in air) at several meters from the IP.

The barrel part of a muon detection system has dimensions of a few thousands of m^2, while the endcaps are typically about half of this size.

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

Muon detectors in large HEP experiments

Muon detectors in large HEP experiments

Gas detectors used for muon detection systems can be separated into three main groups:

Muon detectors in large HEP experiments

Gas detectors used for muon detection systems can be separated into three main groups:

- Wire detectors (DTs, CSCs, MDT, etc.)

Muon detectors in large HEP experiments

Gas detectors used for muon detection systems can be separated into three main groups:

- Wire detectors (DTs, CSCs, MDT, etc.)
  - Relatively simple construction, good space and time resolution

Muon detectors in large HEP experiments

Gas detectors used for muon detection systems can be separated into three main groups:

- Wire detectors (DTs, CSCs, MDT, etc.)
    - Relatively simple construction, good space and time resolution
- RPCs

Muon detectors in large HEP experiments

Gas detectors used for muon detection systems can be separated into three main groups:

- Wire detectors (DTs, CSCs, MDT, etc.)
  - Relatively simple construction, good space and time resolution
- RPCs
  - Simple and cheap construction, very good time resolution, poor space resolution

Muon detectors in large HEP experiments

Gas detectors used for muon detection systems can be separated into three main groups:

- Wire detectors (DTs, CSCs, MDT, etc.)
  - Relatively simple construction, good space and time resolution
- RPCs
  - Simple and cheap construction, very good time resolution, poor space resolution
- Micro Pattern Gas Detectors (GEM, MicroMegas, μRWell, etc.)

Muon detectors in large HEP experiments

Gas detectors used for muon detection systems can be separated into three main groups:

- Wire detectors (DTs, CSCs, MDT, etc.)
  - Relatively simple construction, good space and time resolution
- RPCs
  - Simple and cheap construction, very good time resolution, poor space resolution
- Micro Pattern Gas Detectors (GEM, MicroMegas, μRWell, etc.)
  - Newer technology, provides both good space and time resolution. Uses PCB methods and can be mass produced by industry.

Muon detectors in large HEP experiments

Gas detectors used for muon detection systems can be separated into three main groups:

- Wire detectors (DTs, CSCs, MDT, etc.)
  - Relatively simple construction, good space and time resolution
- RPCs
  - Simple and cheap construction, very good time resolution, poor space resolution
- Micro Pattern Gas Detectors (GEM, MicroMegas, μRWell, etc.)
  - Newer technology, provides both good space and time resolution. Uses PCB methods and can be mass produced by industry.

- 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.

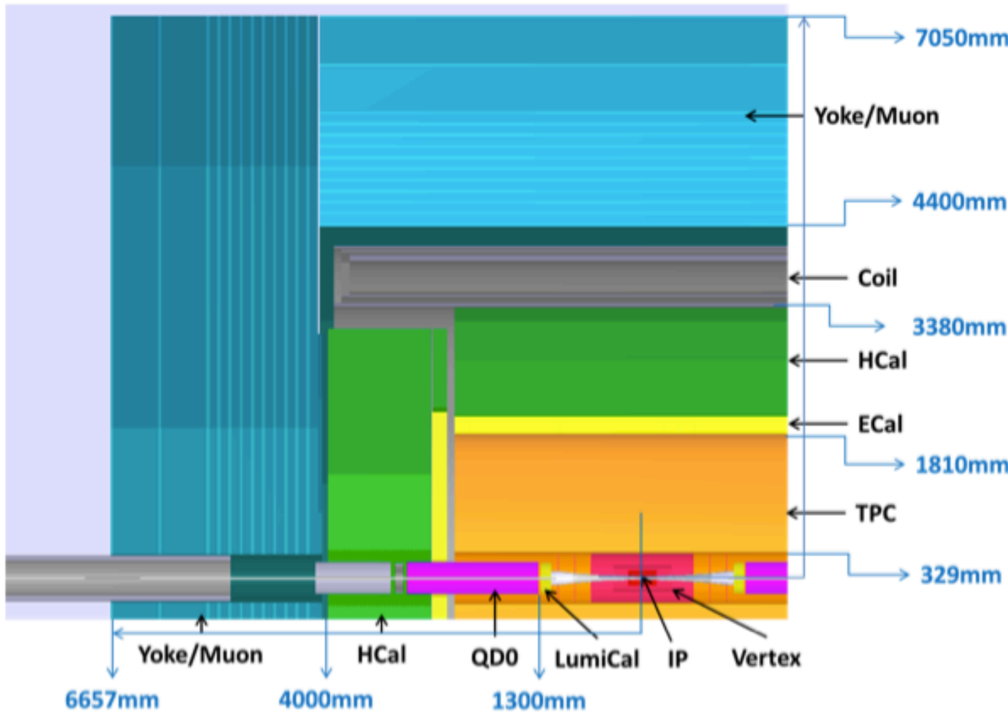
Muon detectors for CepC

Muon detectors for CepC

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.



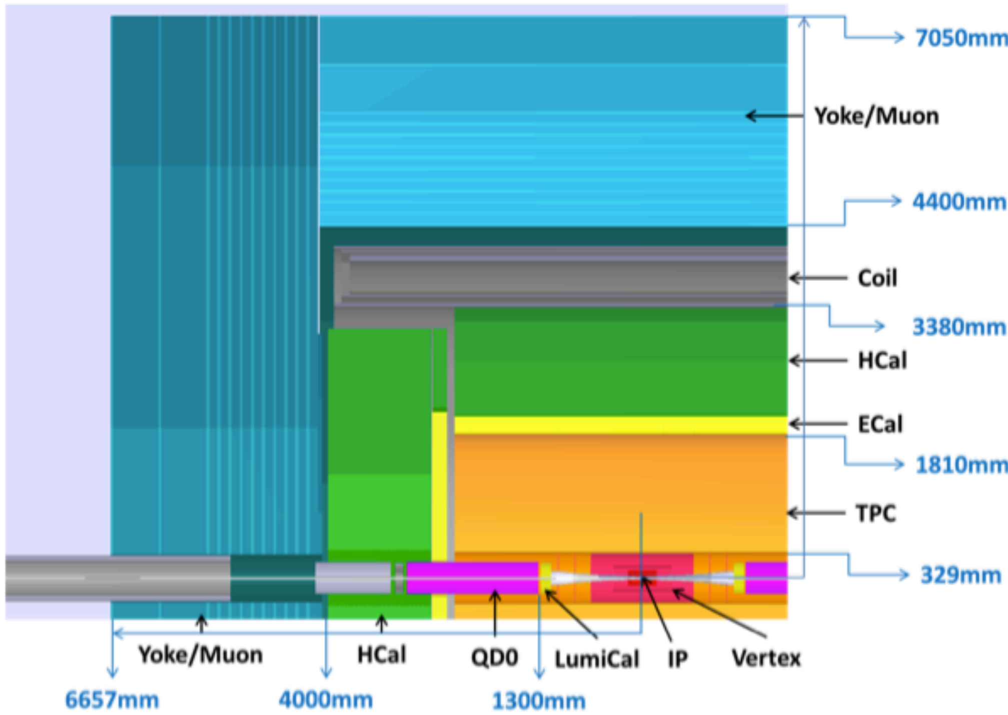
Muon detectors for CepC

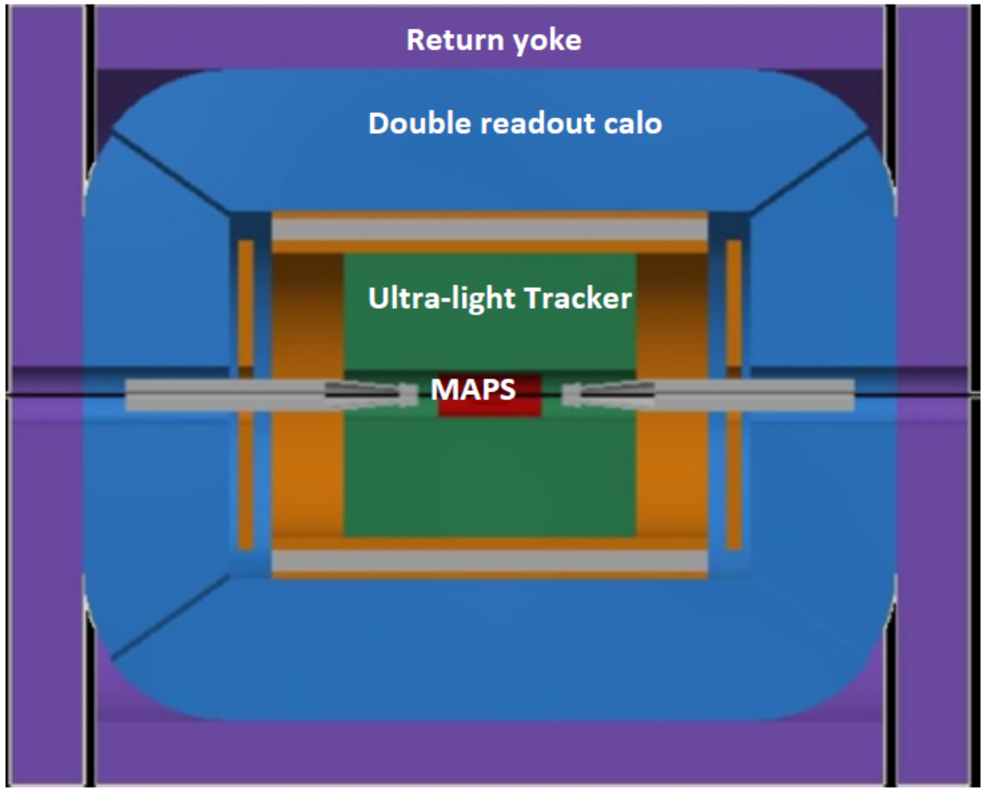
In the baseline option, inspired from ILD, the muon detection system is composed of two layers of RPC stations.

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.

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





Muon detectors for FCC-ee

Muon detectors for FCC-ee

There are two detector concepts for FCC-ee: a CLIC-inspired detector and IDEA.

Muon detectors for FCC-ee

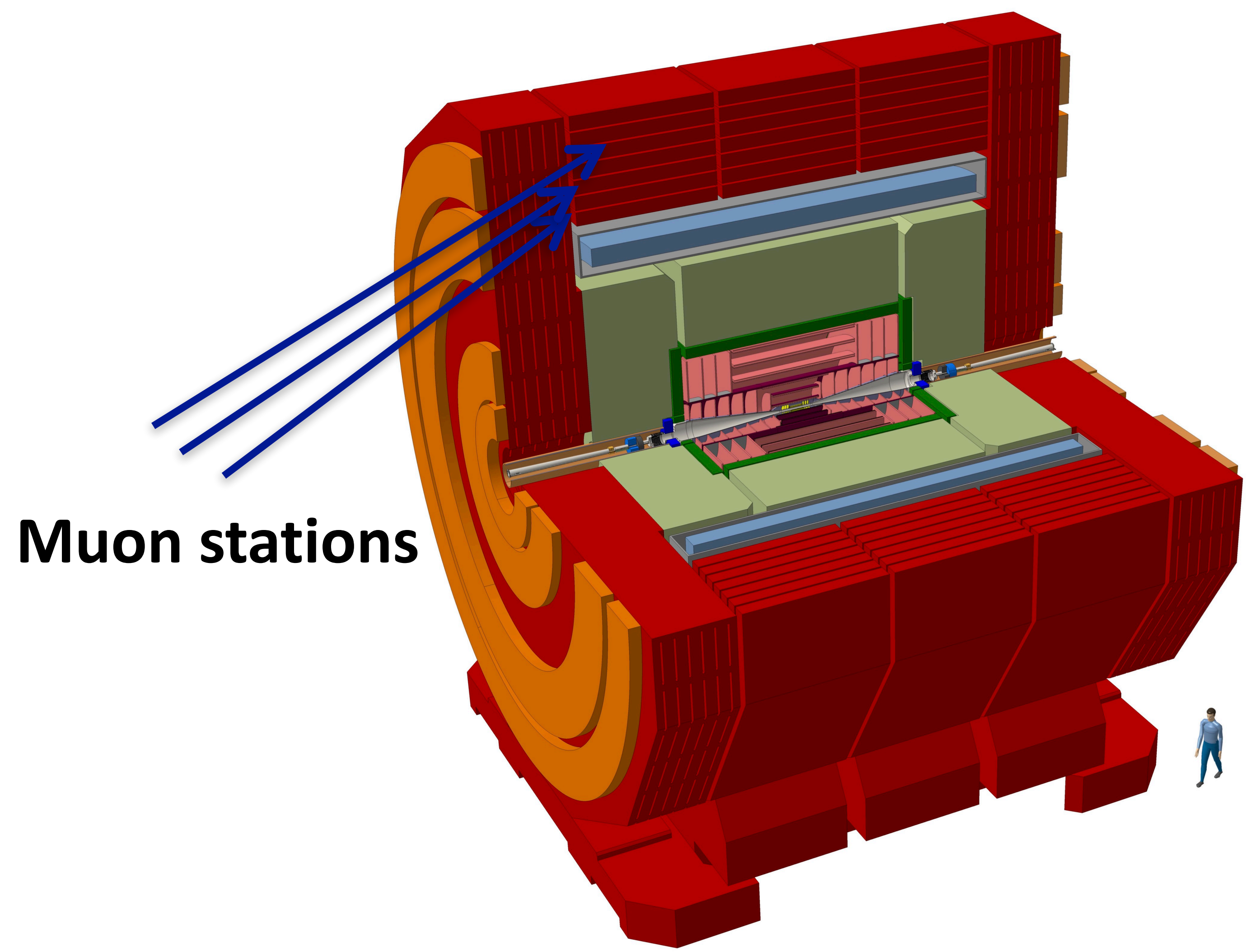
There are two detector concepts for FCC-ee: a CLIC-inspired detector and IDEA.

In the CLIC-inspired detector the muon system is made of 7 muon stations interleaved in the iron return yoke, and every muon station is made of RPCs.

Muon detectors for FCC-ee

There are two detector concepts for FCC-ee: a CLIC-inspired detector and IDEA.

In the CLIC-inspired detector the muon system is made of 7 muon stations interleaved in the iron return yoke, and every muon station is made of RPCs.

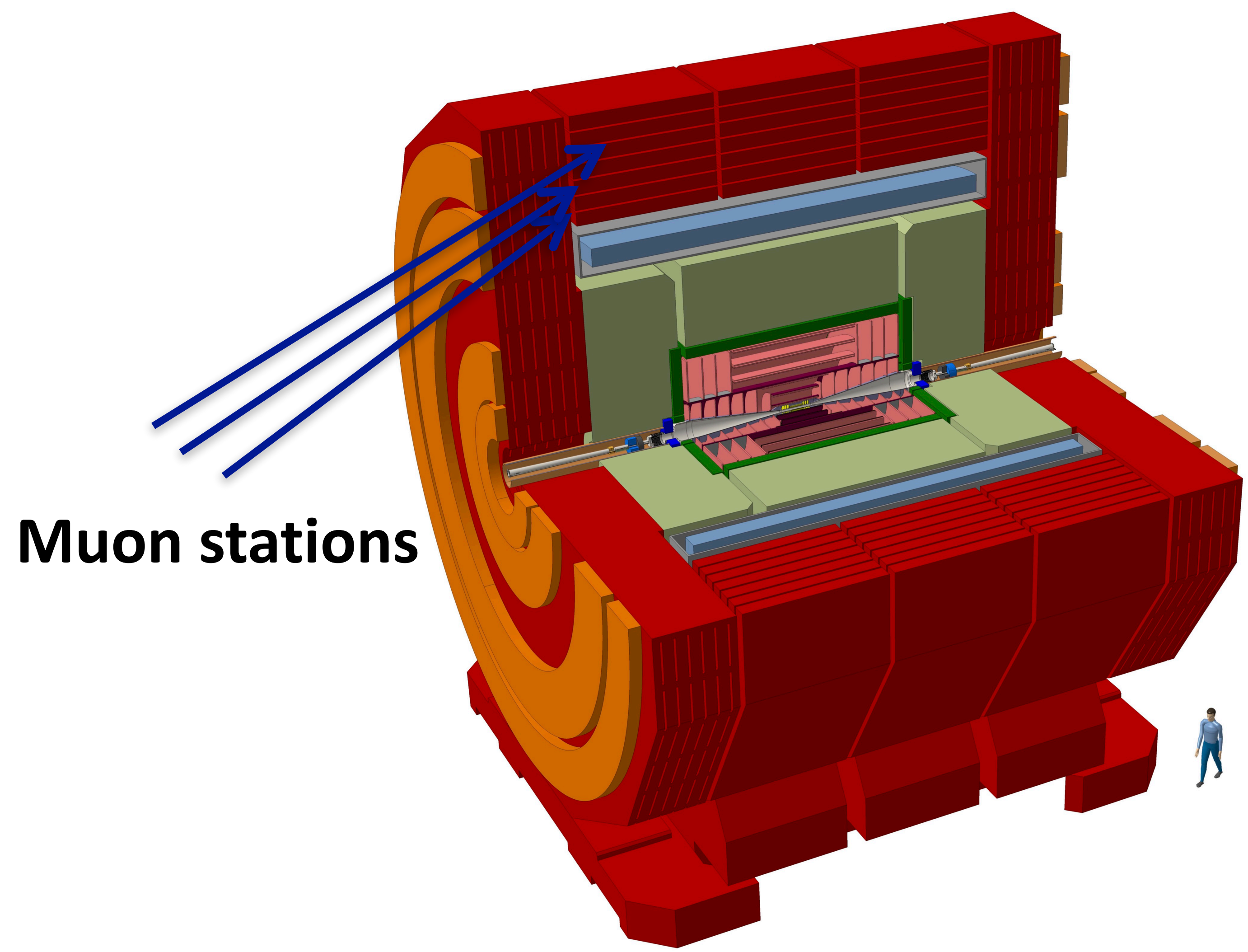


Muon detectors for FCC-ee

There are two detector concepts for FCC-ee: a CLIC-inspired detector and IDEA.

In the CLIC-inspired detector the muon system is made of 7 muon stations interleaved in the iron return yoke, and every muon station is made of RPCs.

Also this muon detector could be improved by adopting finer space resolution MPGDs.

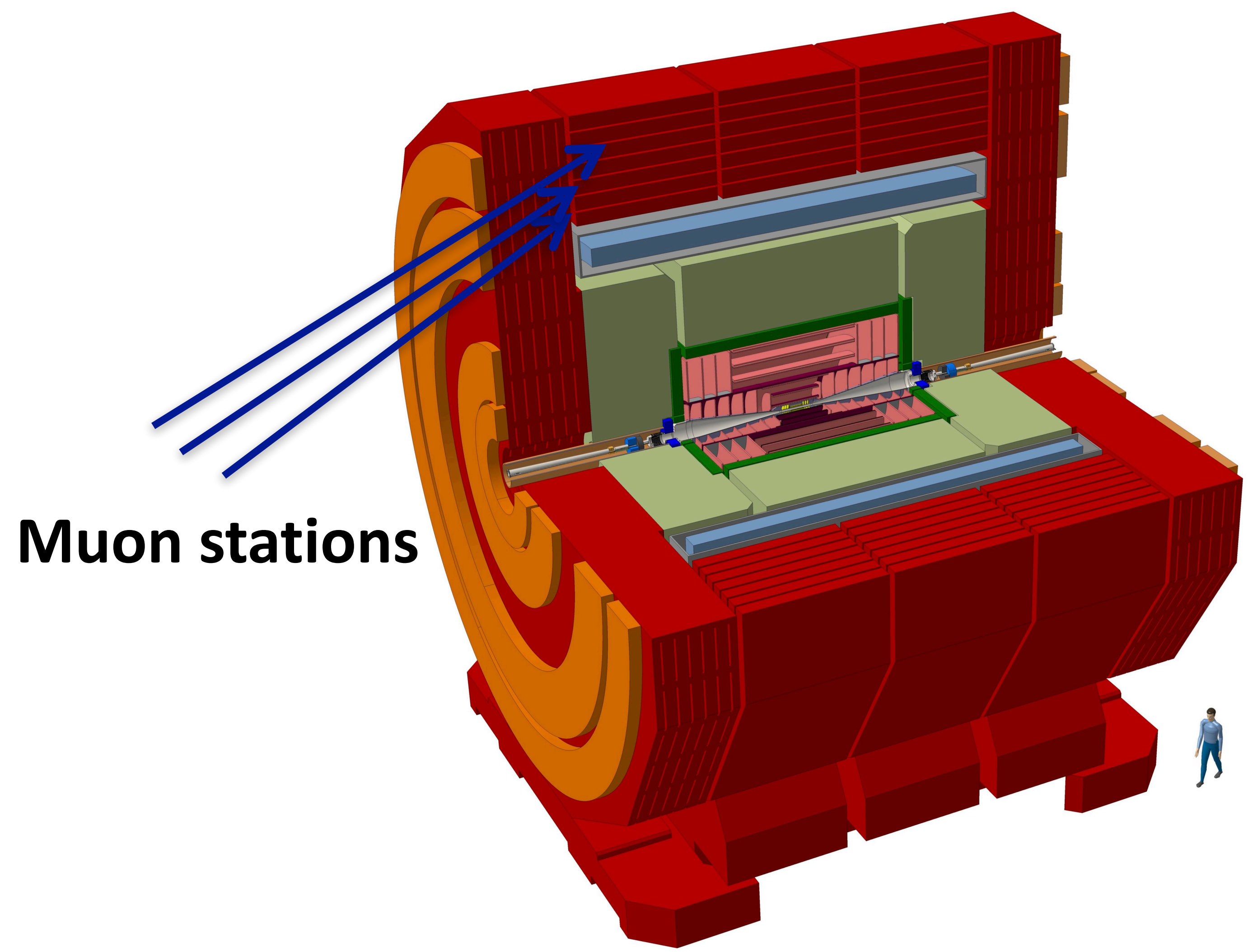


Muon detectors for FCC-ee

There are two detector concepts for FCC-ee: a CLIC-inspired detector and IDEA.

In the CLIC-inspired detector the muon system is made of 7 muon stations interleaved in the iron return yoke, and every muon station is made of RPCs.

Also this muon detector could be improved by adopting finer space resolution MPGDs.



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

Principle of operation of MPGDs

Principle of operation of MPGDs

Improve gas detectors

Principle of operation of MPGDs

Improve gas detectors

Slow ion motion
Limited multi-track separation

→

Reduce multiplication region size
Faster ion evacuation
Higher spatial resolution

S. Franchino, 2016

Principle of operation of MPGDs

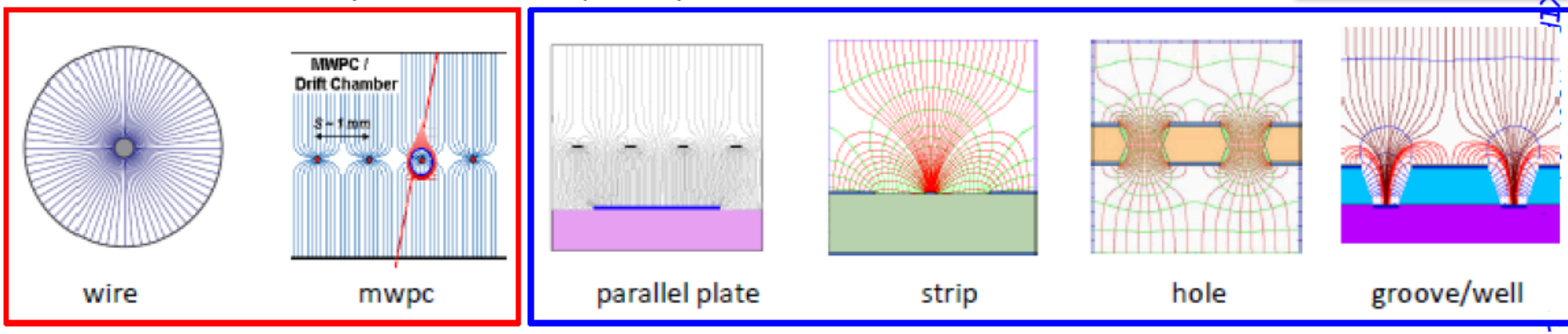
Improve gas detectors

Slow ion motion
Limited multi-track separation

Reduce multiplication region size
Faster ion evacuation
Higher spatial resolution

S. Franchino, 2016

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



Principle of operation of MPGDs

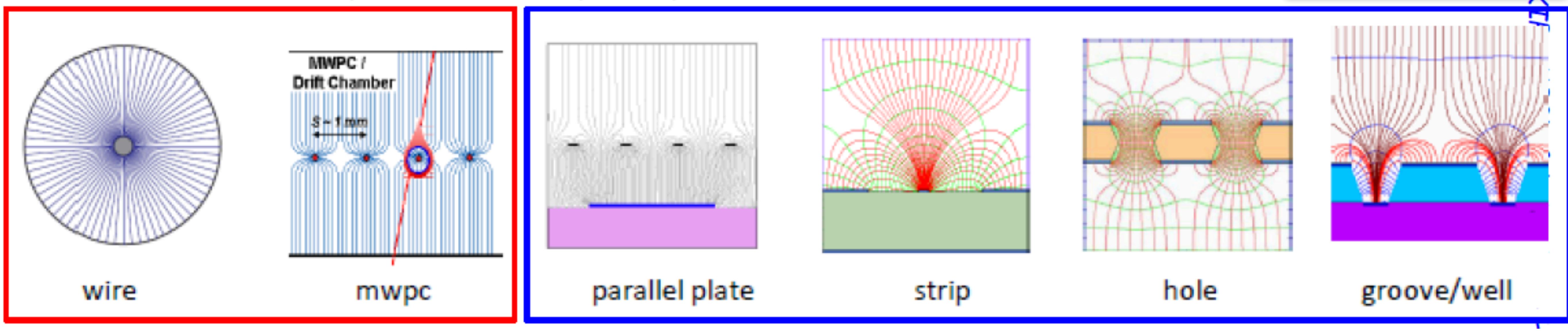
<u>Improve gas detectors</u>

Slow ion motion
Limited multi-track separation

Reduce multiplication region size
Faster ion evacuation
Higher spatial resolution

S. Franchino, 2016

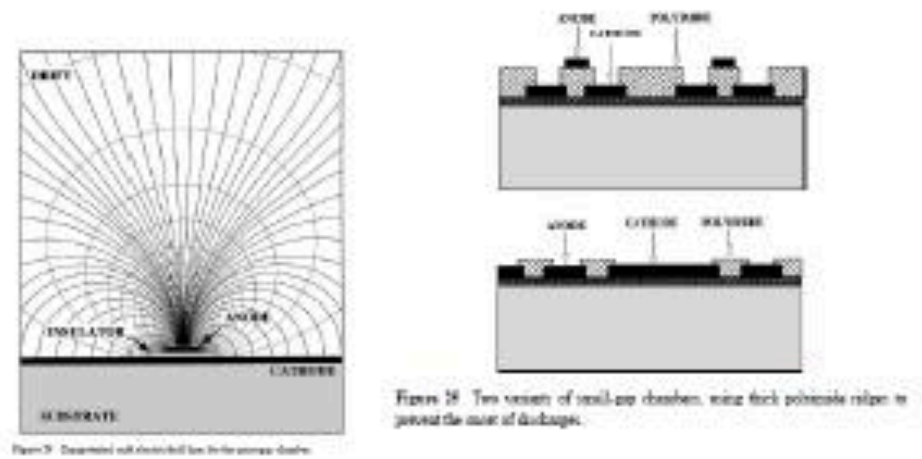
First MPGD: Micro Strip Gas Chamber (MSGC) OED, 1988



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

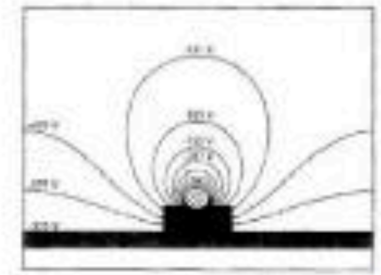
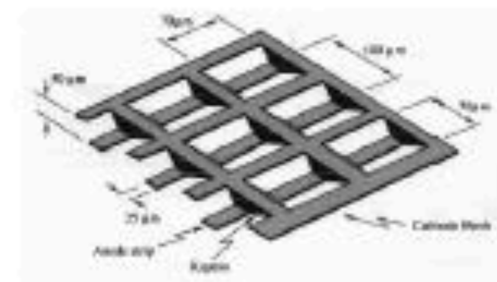


Figure 2.27 Scheme of a MGWC with equipotential and field lines. The circle filled with lines is the section of an anode wire [CHRISTOPHEL1997]

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

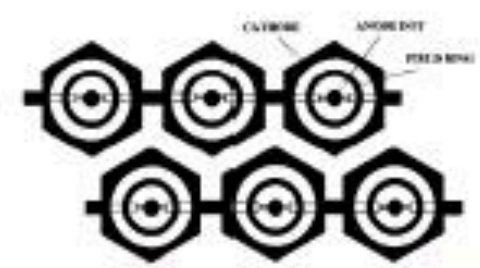
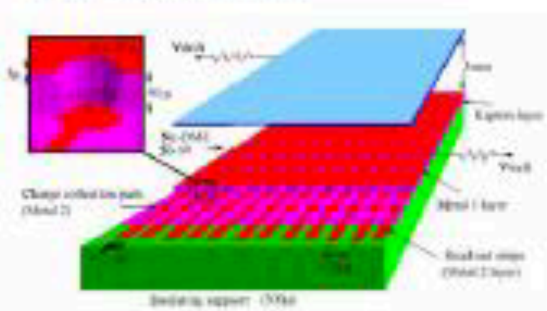


Figure 26 Schematics of the microdot chamber. A pattern of metallic anode dots surrounded by field and cathode electrodes is implemented on an insulating substrate, using microelectronics technology. Anodes are interconnected for readout.

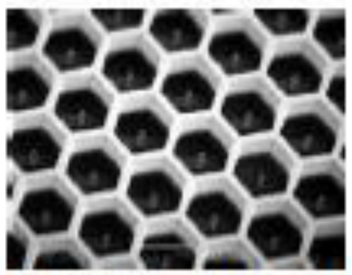
Biagi SF, Jones TJ. Nucl. Instrum. Methods A361:72 (1995)

MicroWELL



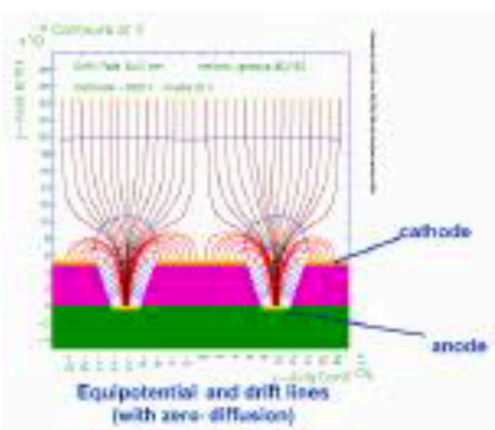
R. Bellazziniet al Nucl. Instr. and Meth. A423(1999)125

MicroPin



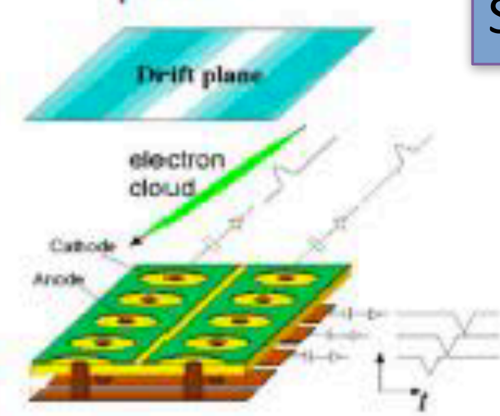
P. Rehak et al., IEEE Nucl. Sci. Symposium seattle 1999

MicroGroove



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

μPIC



Ochi et al NIMA471(2001)264

S. Franchino, 2016

3rd July 2014 DT Training Seminar 15

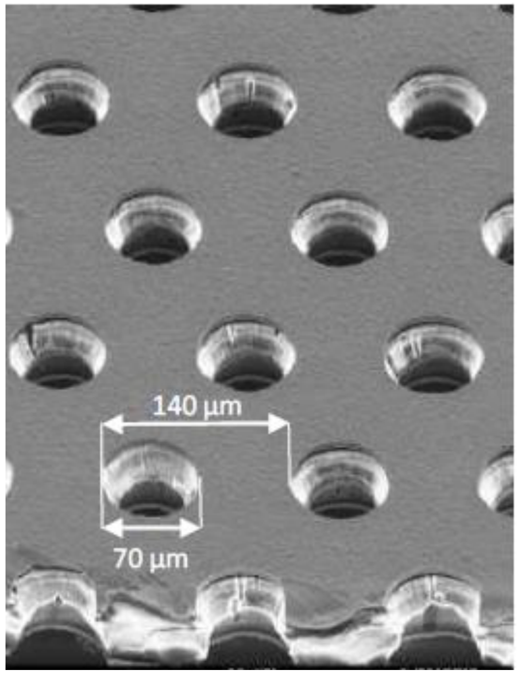
More recent MPGDs

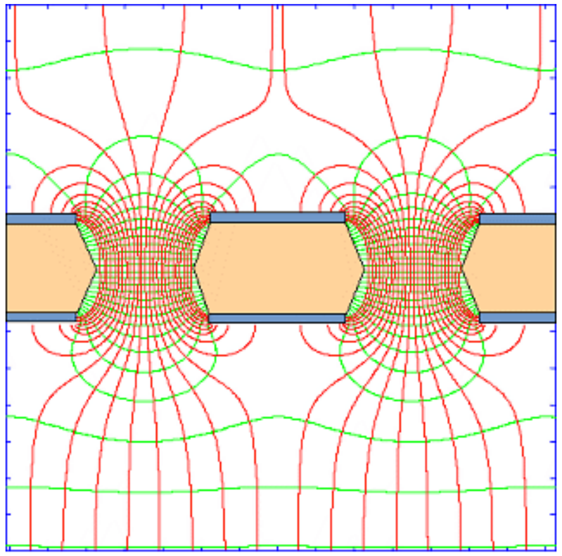
S. Franchino, 2016

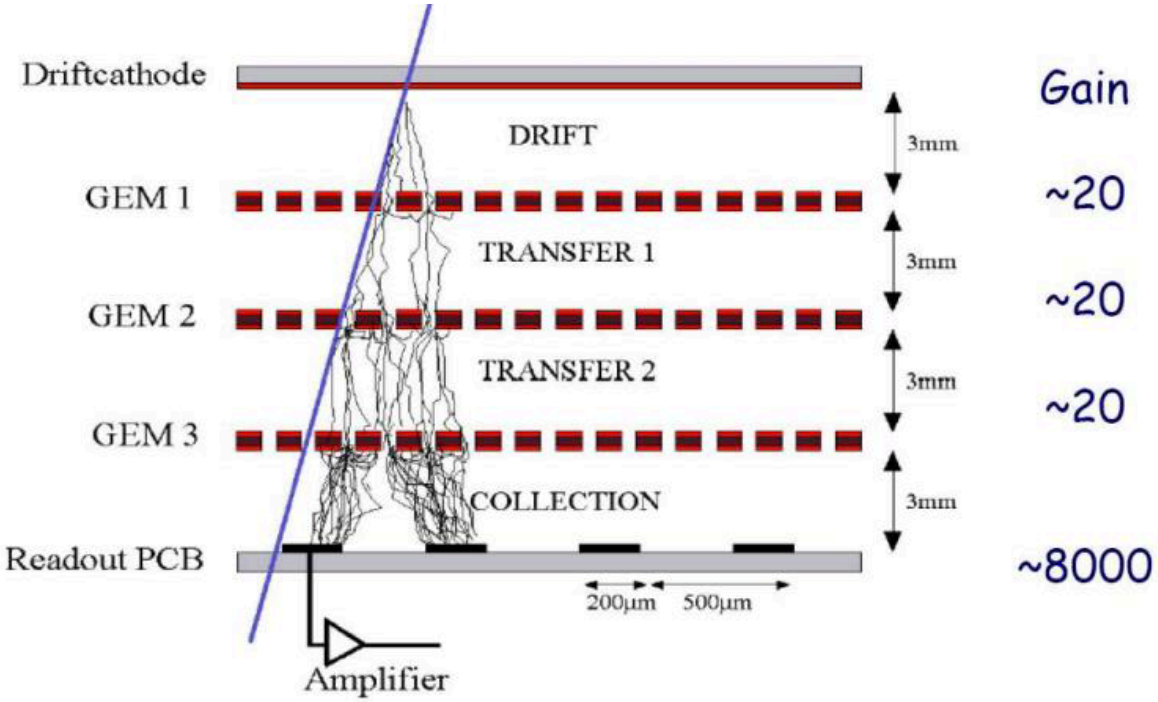
More recent MPGDs

F. Sauli, NIM. A386(1997)531

GEM (std, Thick, glass, …)





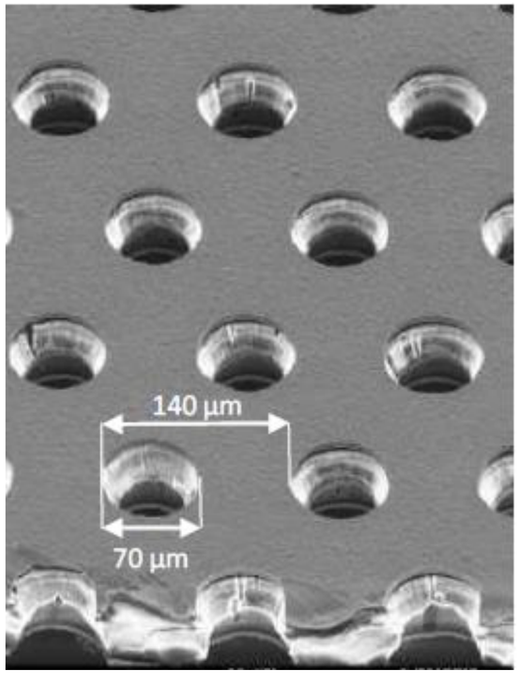


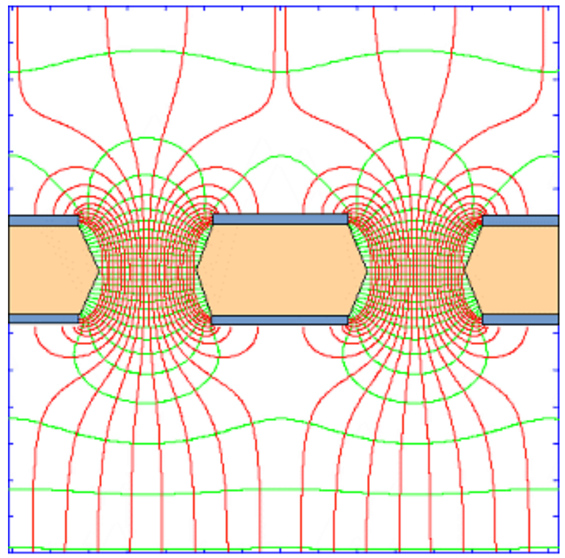
S. Franchino, 2016

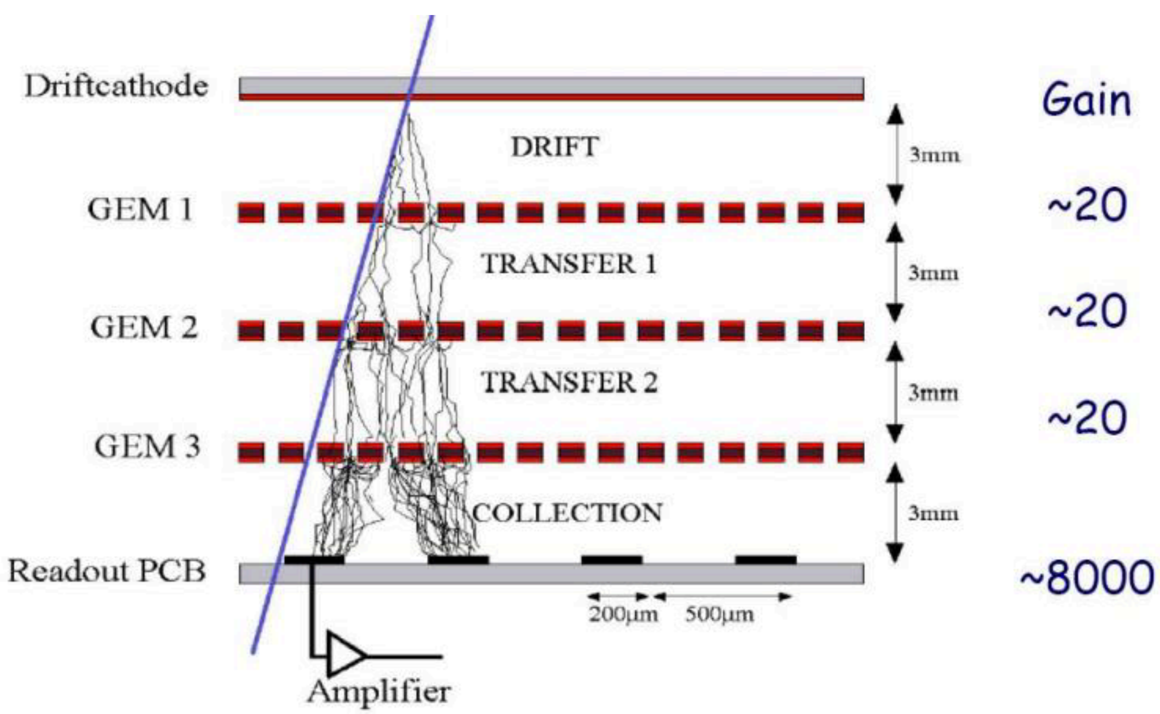
More recent MPGDs

F. Sauli, NIM. A386(1997)531

GEM (std, Thick, glass, …)

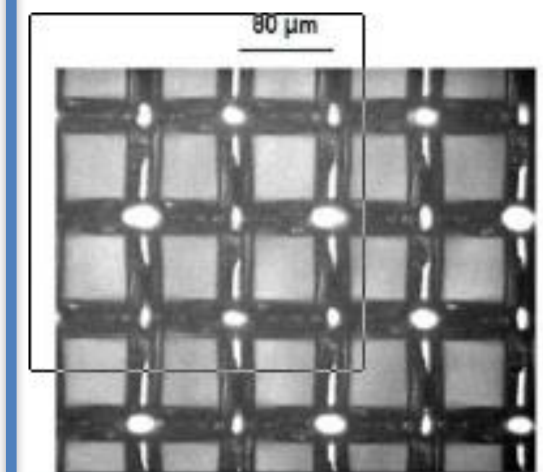


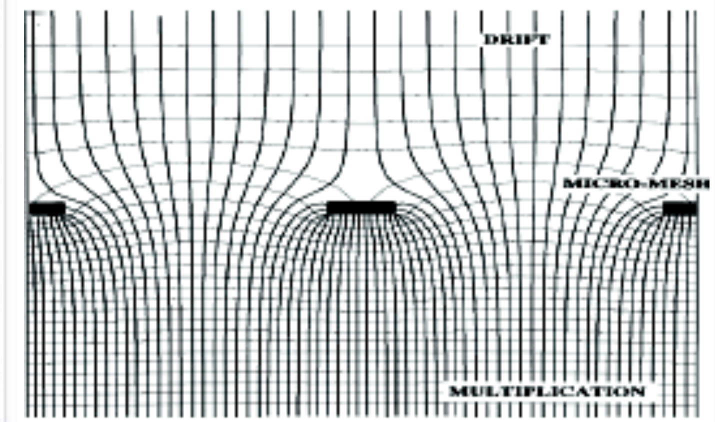


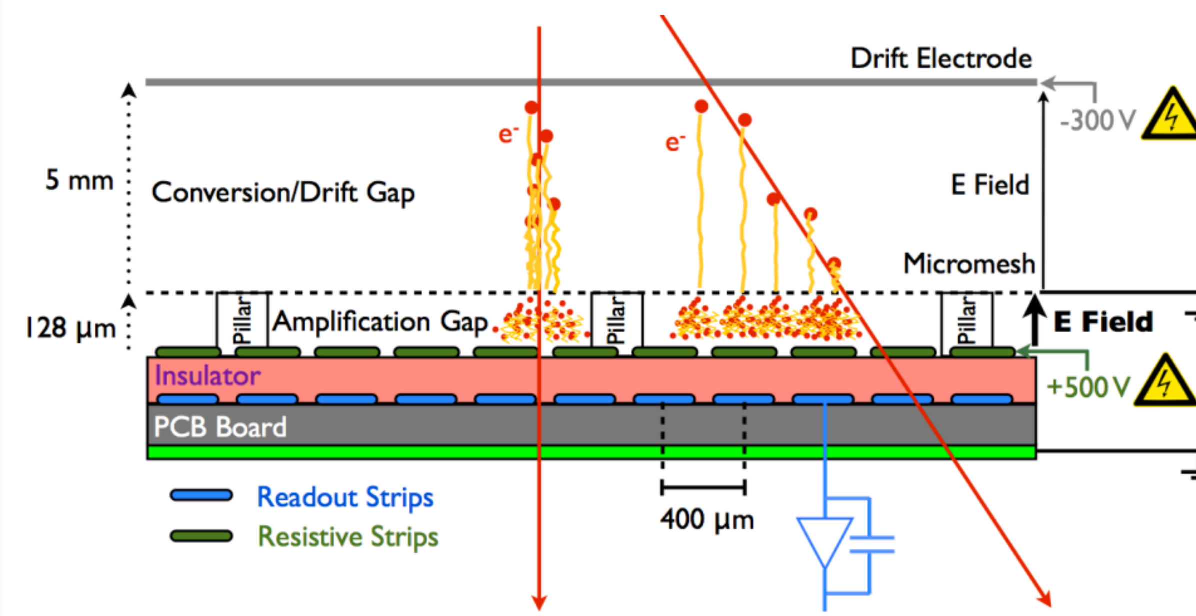


I. Giomataris et al., NIM A 376 (1996)

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





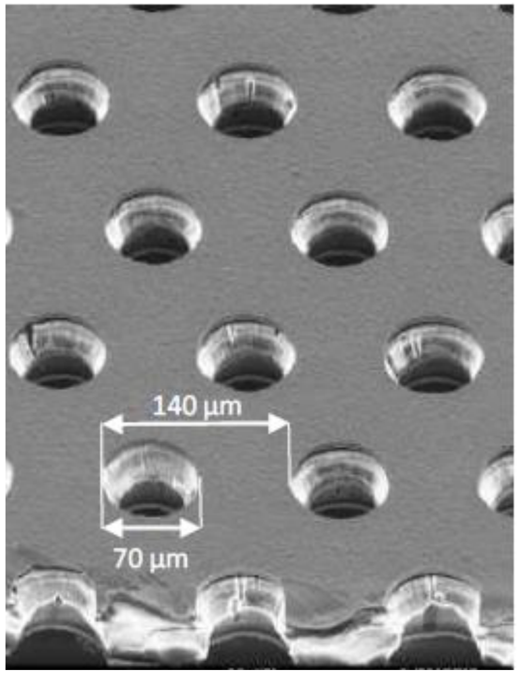


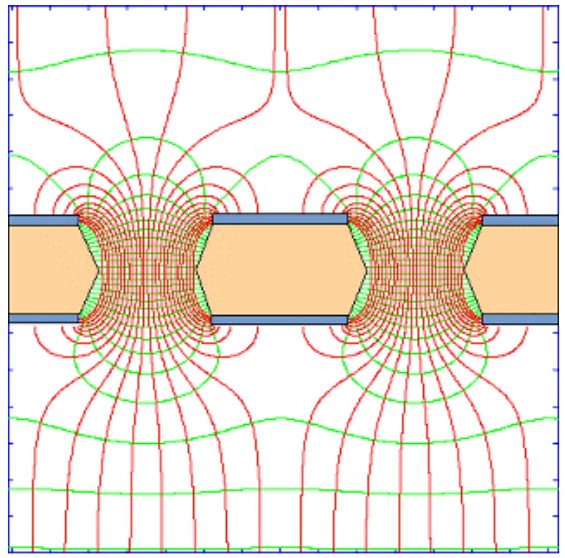
S. Franchino, 2016

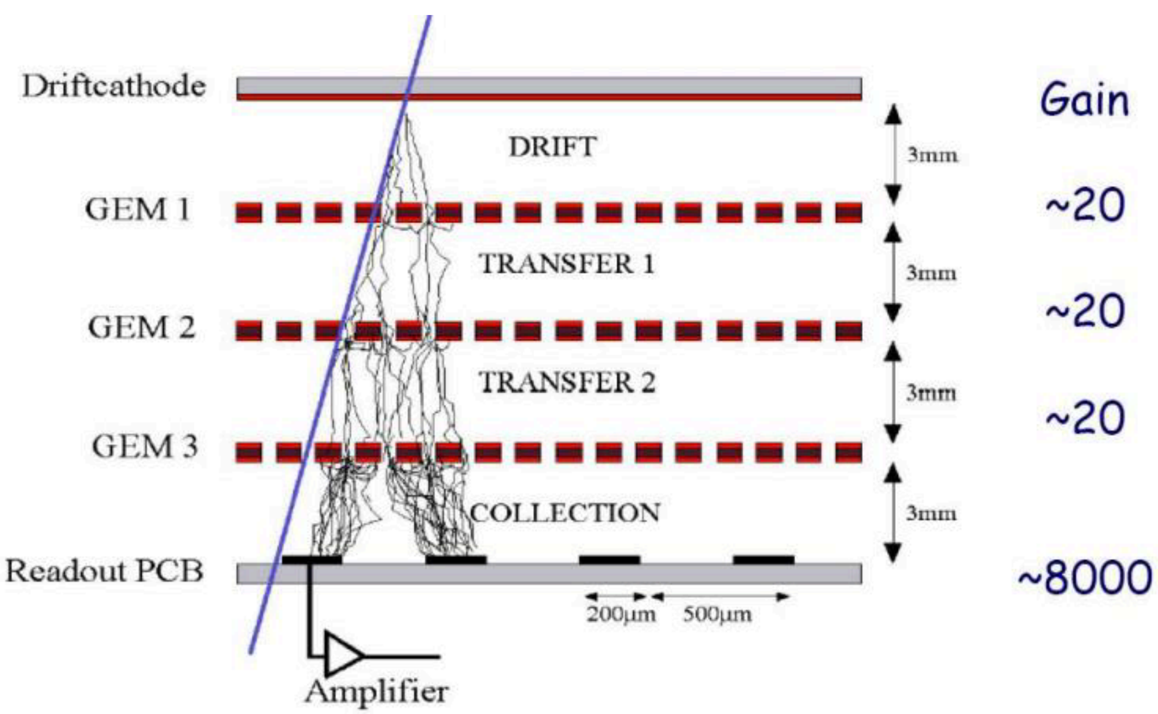
More recent MPGDs

F. Sauli, NIM. A386(1997)531

GEM (std, Thick, glass, …)

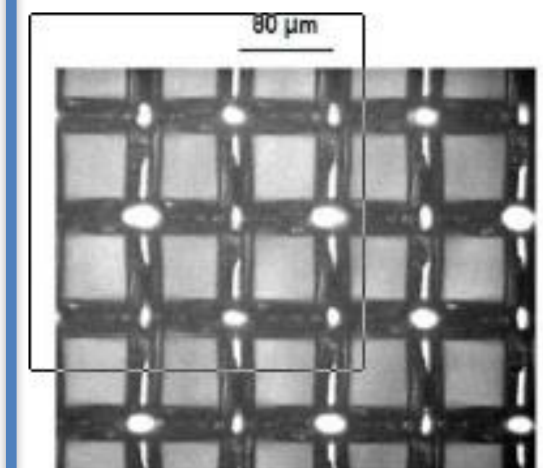


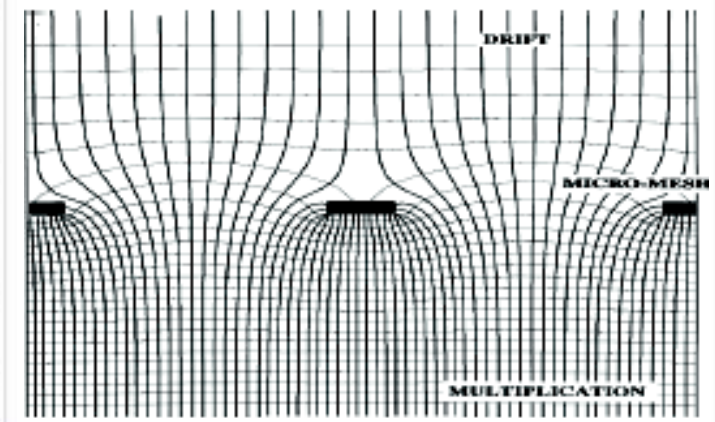


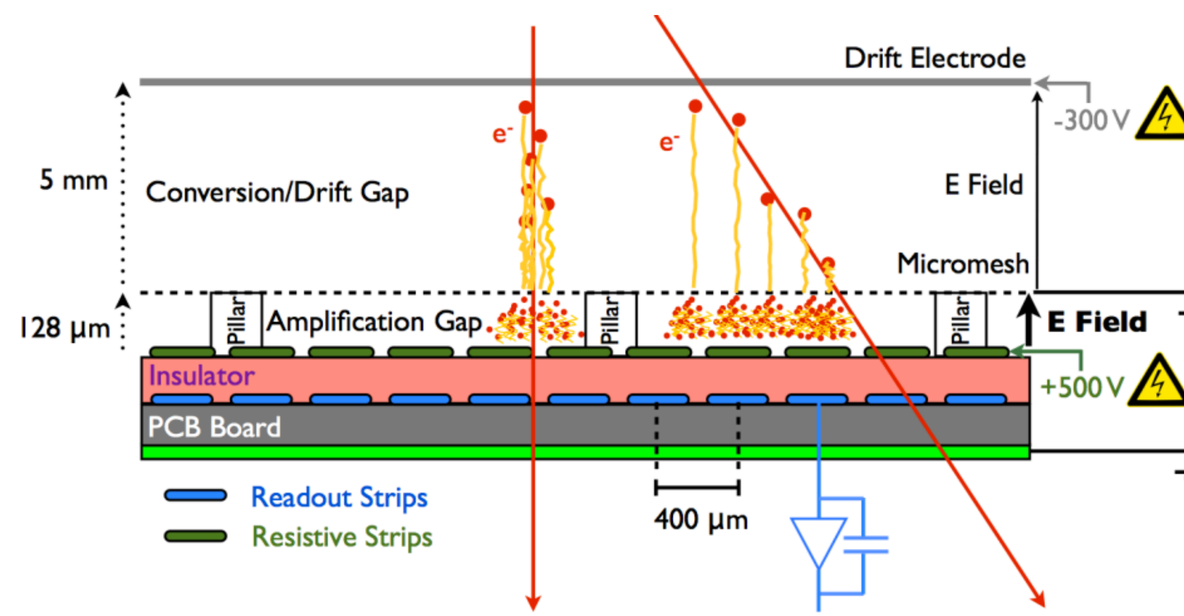


I. Giomataris et al., NIM A 376 (1996)

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







Ageing: OK (no thin wires)

Spark protection: multiple amplification stages, resistive electrodes

S. Franchino, 2016

Properties of MPGDs

Properties of MPGDs

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

Properties of MPGDs

- Gas multiplication and/or readout are performed by “micro patterns” instead of conventional wire chambers
- Fine patterning realized with PCB photolithography techniques

Properties of MPGDs

- Gas multiplication and/or readout are performed by “micro patterns” instead of conventional wire chambers
- Fine patterning realized with PCB photolithography techniques
  - Fine position resolution (< 100 microns)

Properties of MPGDs

- Gas multiplication and/or readout are performed by “micro patterns” instead of conventional wire chambers
- Fine patterning realized with PCB photolithography techniques
  - Fine position resolution (< 100 microns)
  - Good timing resolution (< 10 nsec)

Properties of MPGDs

- Gas multiplication and/or readout are performed by “micro patterns” instead of conventional wire chambers
- Fine patterning realized with PCB photolithography techniques
  - Fine position resolution (< 100 microns)
  - Good timing resolution (< 10 nsec)
  - High rate capability (> 10^7 counts/mm)

Properties of MPGDs

- Gas multiplication and/or readout are performed by "micro patterns" instead of conventional wire chambers
- Fine patterning realized with PCB photolithography techniques
  - Fine position resolution (< 100 microns)
  - Good timing resolution (< 10 nsec)
  - High rate capability (> 10^7 counts/mm)
  - Excellent radiation hardness

Properties of MPGDs

- Gas multiplication and/or readout are performed by “micro patterns” instead of conventional wire chambers
- Fine patterning realized with PCB photolithography techniques
  - Fine position resolution (< 100 microns)
  - Good timing resolution (< 10 nsec)
  - 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

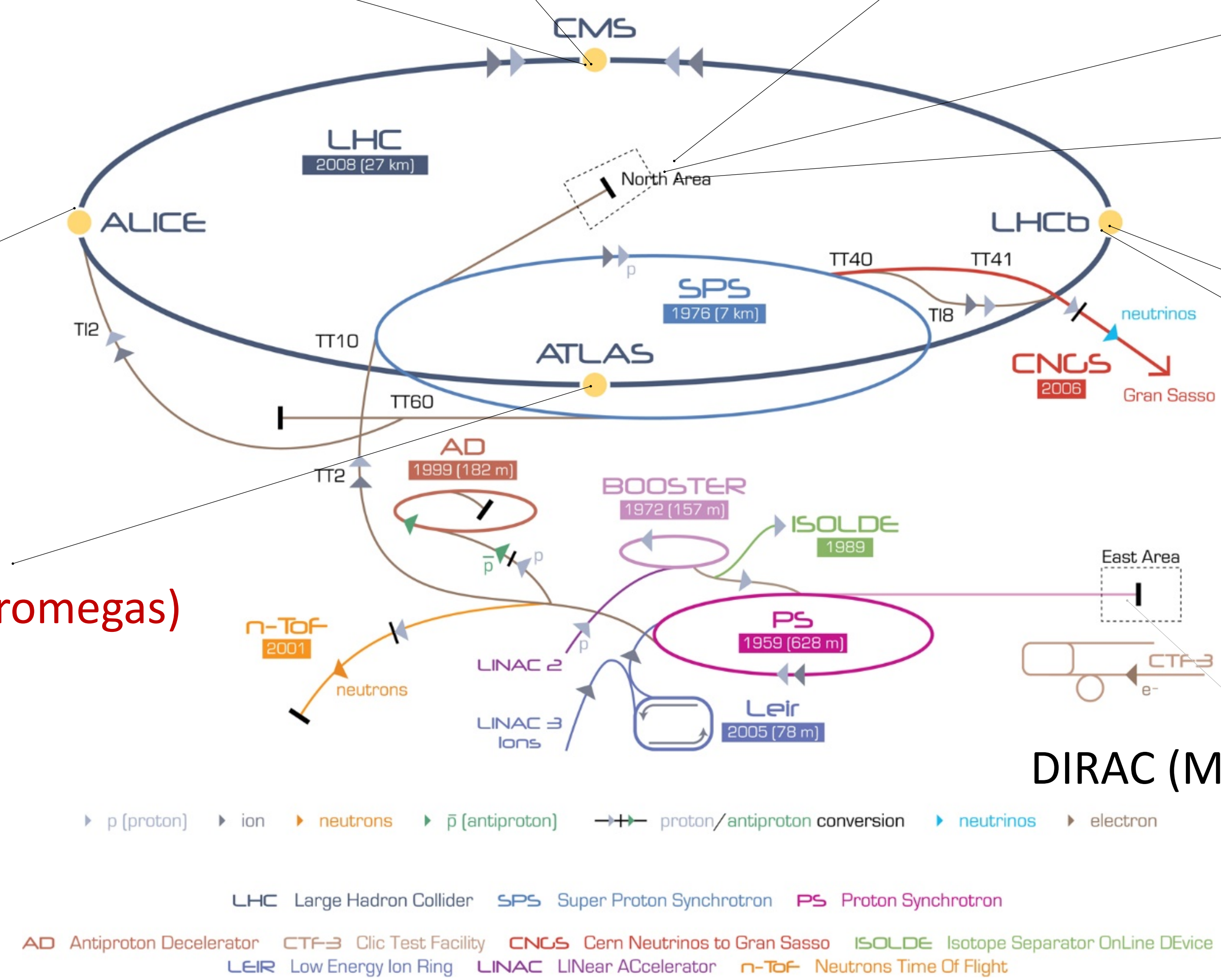
TOTEM (GEM)

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

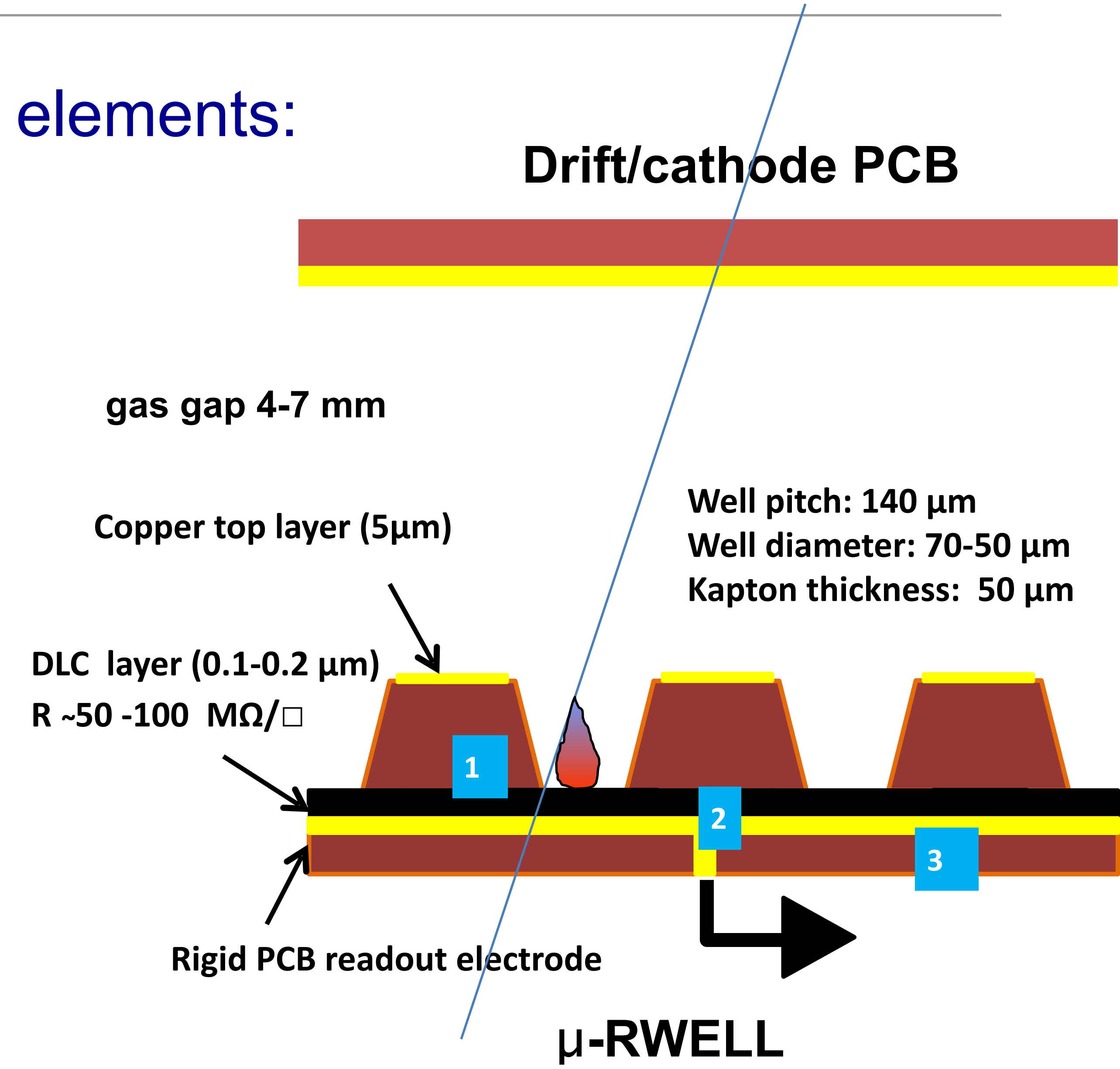
The μRWell technology

The μRWell technology

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

The μRWell technology

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

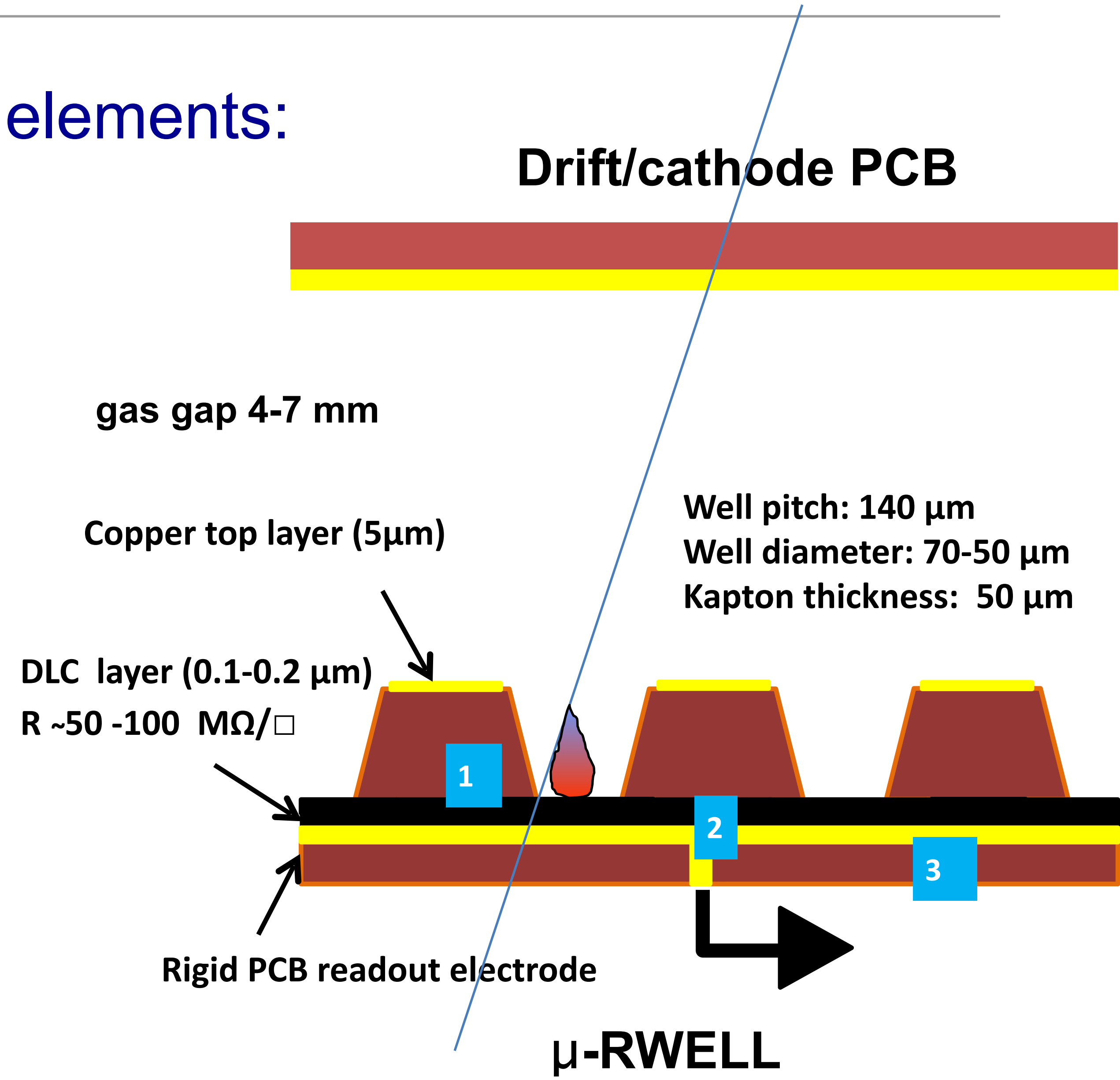


G. Bencivenni et al., 2015_JINST_10_P02008

The μRWell technology

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

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



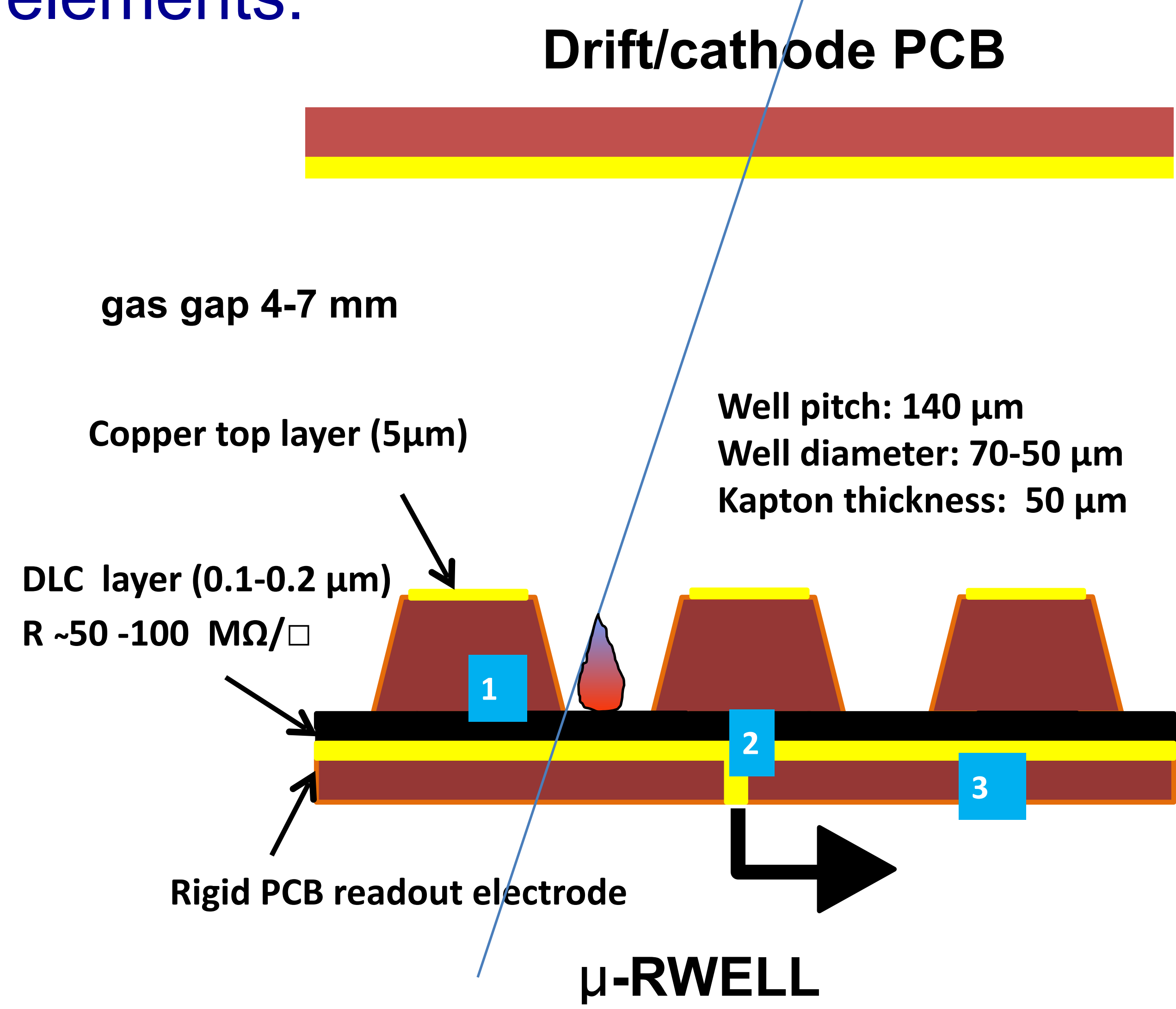
G. Bencivenni et al., 2015_JINST_10_P02008

The μRWell technology

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

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

1. a "**suitable WELL patterned kapton foil** as "amplification stage"



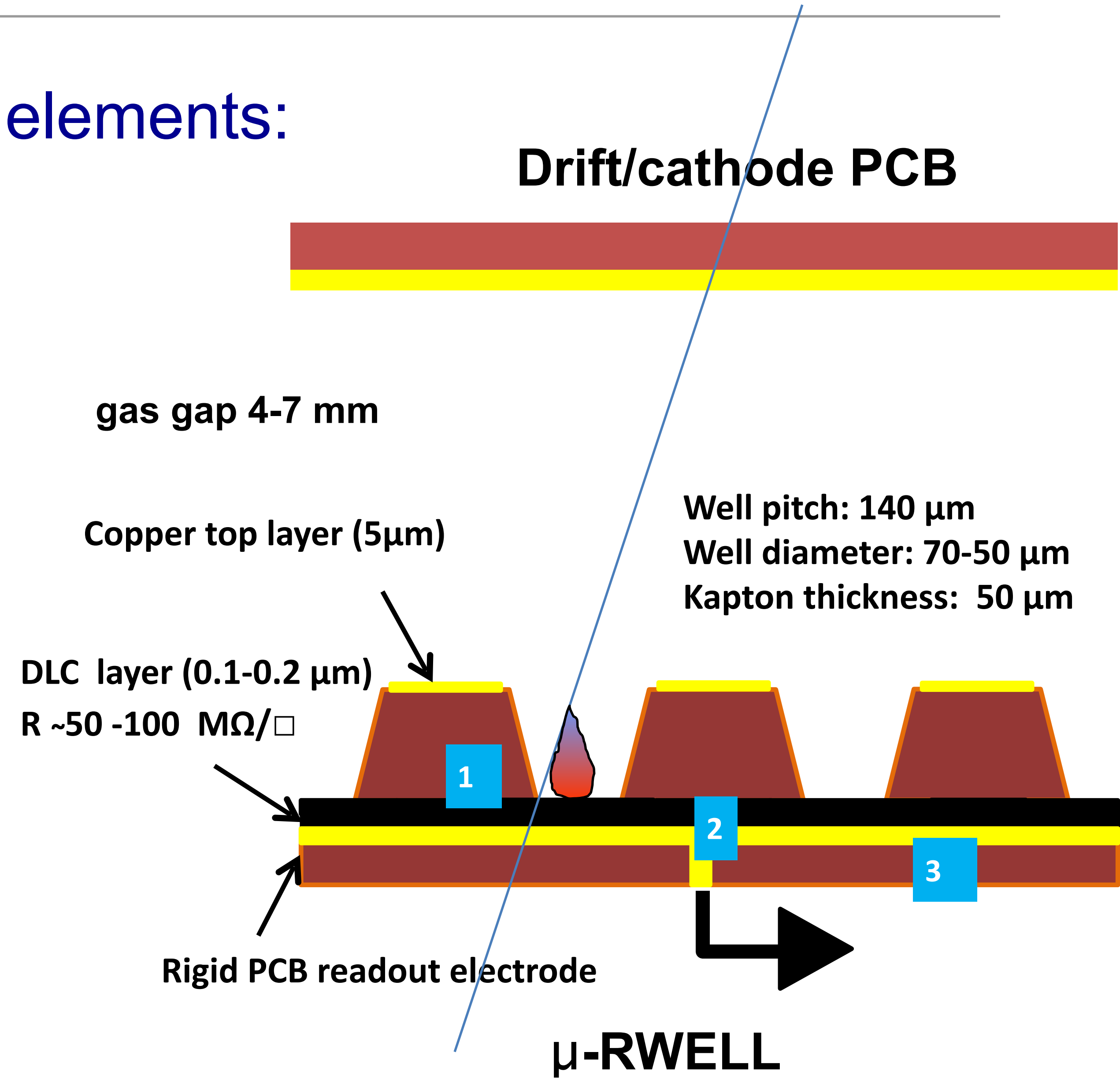
G. Bencivenni et al., 2015_JINST_10_P02008

The μRWell technology

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

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

1. a "**suitable WELL patterned kapton foil** as "amplification stage"
2. a **"resistive stage"** for the discharge suppression & current evacuation



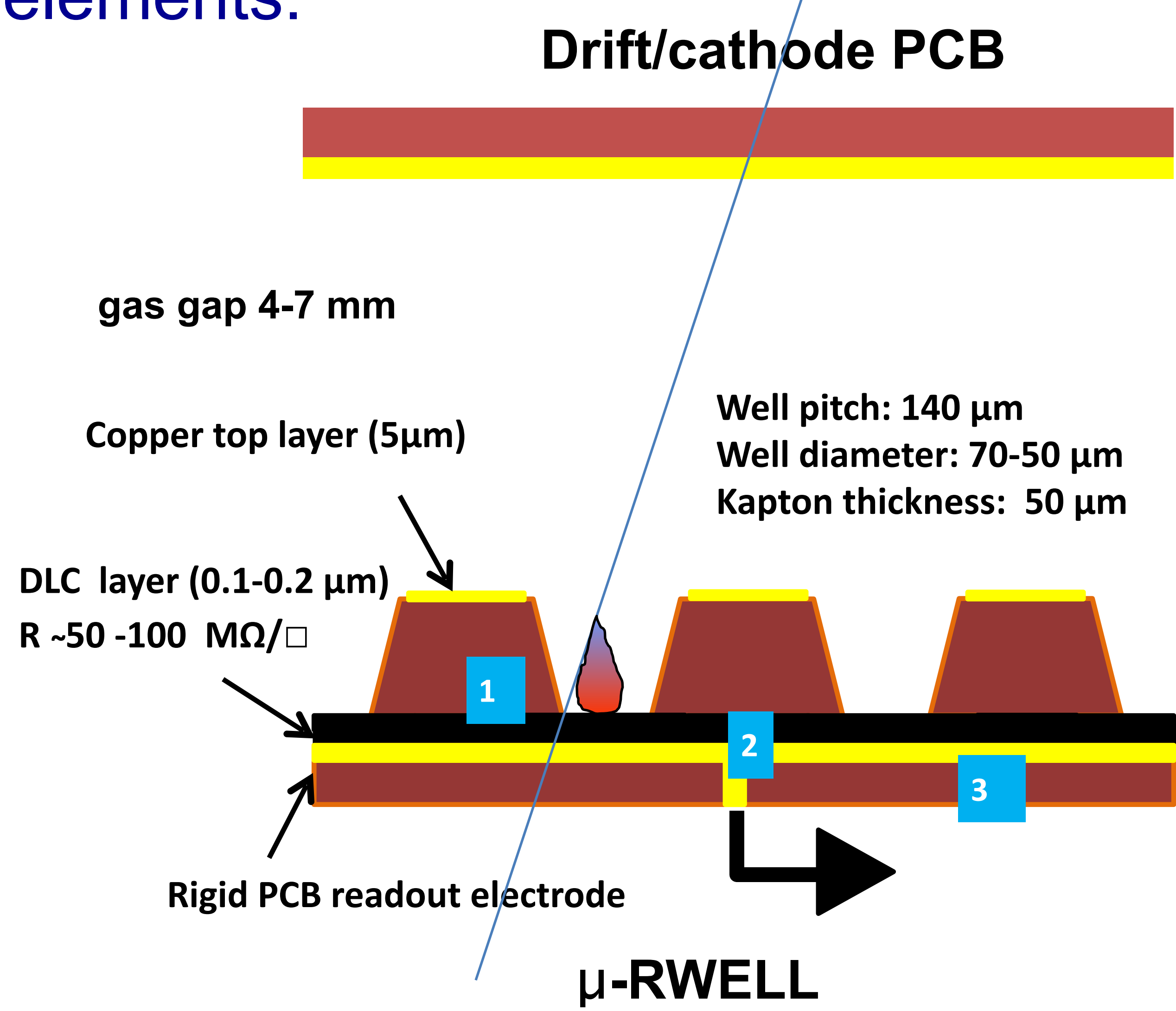
G. Bencivenni et al., 2015_JINST_10_P02008

The μRWell technology

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

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

1. a “**suitable WELL patterned kapton foil** as “amplification stage”
2. a **“resistive stage”** for the discharge suppression & current evacuation
   i. “Low particle rate” (LR) ~ 100 kHz/cm^2**:** single resistive layer → surface resistivity ~100 MΩ/□ (CMS-phase2 upgrade - SHIP)



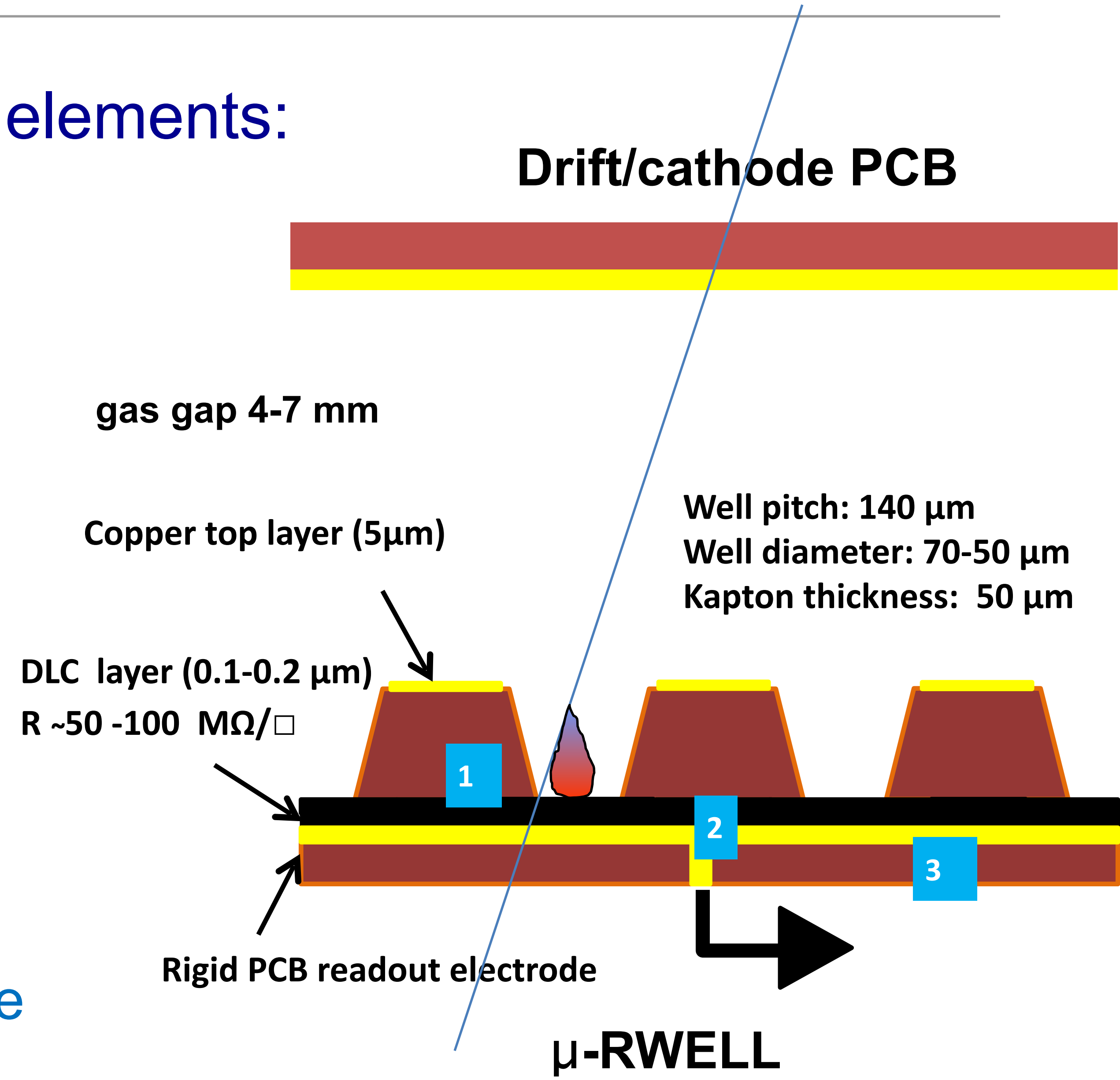
G. Bencivenni et al., 2015_JINST_10_P02008

The μRWell technology

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

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

1. a "**suitable WELL patterned kapton foil** as "amplification stage"
2. a **"resistive stage"** for the discharge suppression & current evacuation
   - **i. "Low particle rate" (LR)** ~ 100 kHz/cm²**:** single resistive layer → surface resistivity ~100 MΩ/☐ (CMS-phase2 upgrade - SHIP)
   - **ii. "High particle rate" (HR)** > 1 MHz/cm²: more sophisticated resistive scheme must be implemented (MPDG_NEXT- LNF & LHCb-muon upgrade)



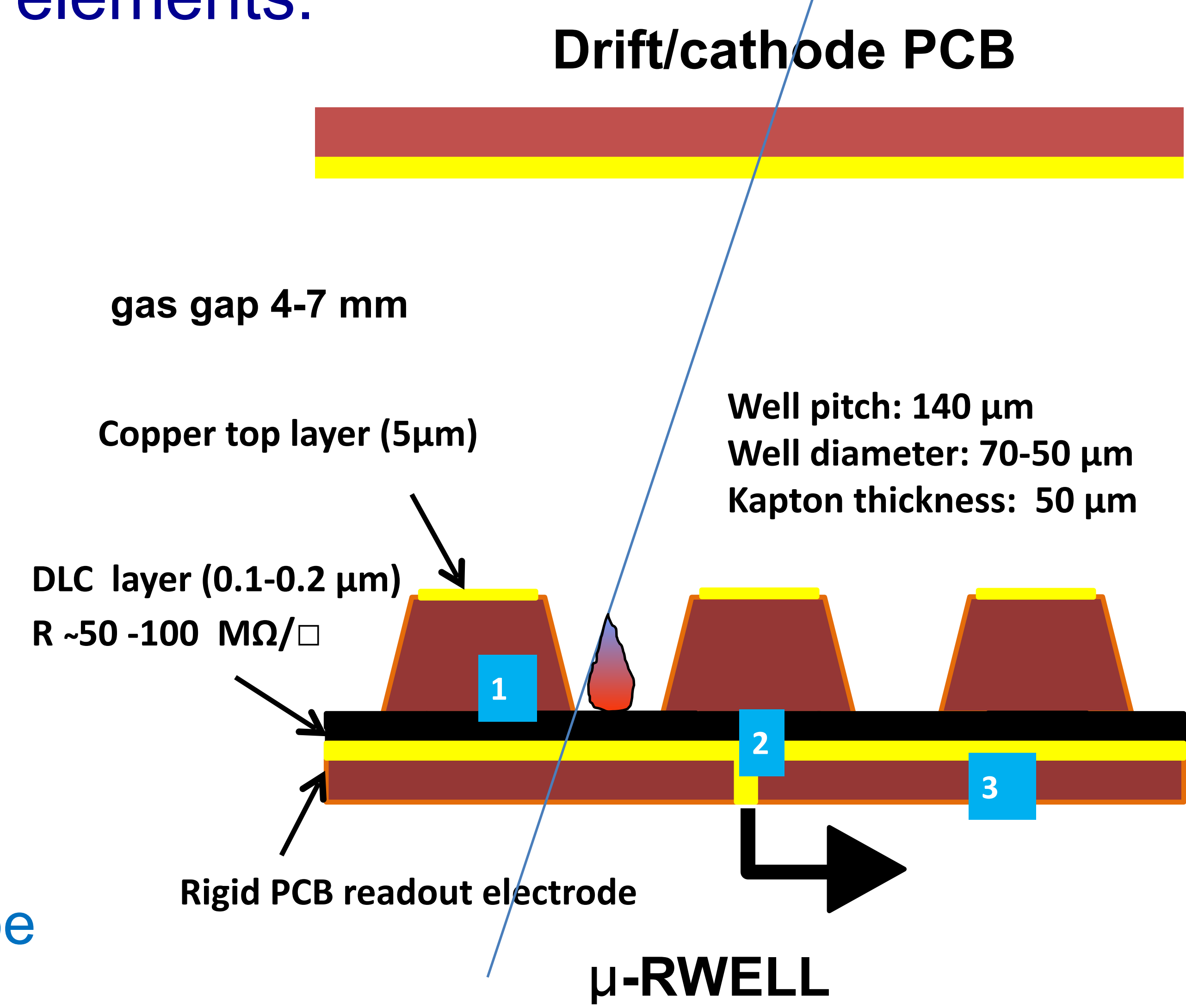
G. Bencivenni et al., 2015_JINST_10_P02008

The μRWell technology

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

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

1. a “**suitable WELL patterned kapton foil** as “amplification stage”
2. a **“resistive stage”** for the discharge suppression & current evacuation
   - **i. “Low particle rate” (LR)** ~ 100 kHz/cm²**:** single resistive layer → surface resistivity ~100 MΩ/☐ (CMS-phase2 upgrade - SHIP)
   - **ii. “High particle rate” (HR)** > 1 MHz/cm²: more sophisticated resistive scheme must be implemented (MPDG_NEXT- LNF & LHCb-muon upgrade)
3. a **standard readout PCB**



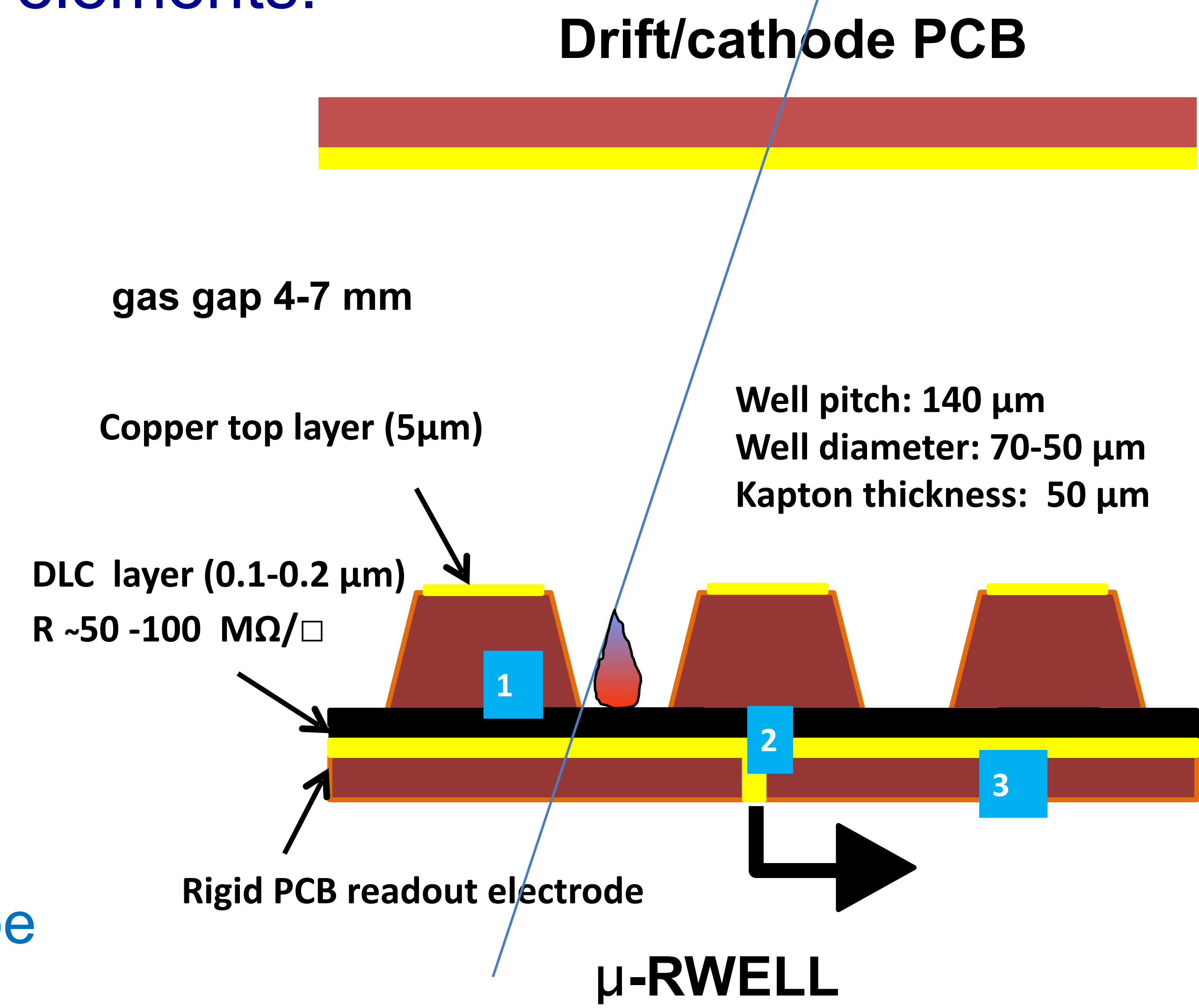
G. Bencivenni et al., 2015_JINST_10_P02008

The µRWell technology

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

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

1. a "**suitable WELL patterned kapton foil** as "amplification stage"
2. a **"resistive stage"** for the discharge suppression & current evacuation
   i. **"Low particle rate" (LR)** ~ 100 kHz/cm²**:** single resistive layer → surface resistivity ~100 MΩ/☐ (CMS-phase2 upgrade - SHIP)
   ii. **"High particle rate" (HR)** > 1 MHz/cm²: more sophisticated resistive scheme must be implemented (MPDG_NEXT- LNF & LHCb-muon upgrade)
3. a **standard readout PCB**



G. Bencivenni et al., 2015_JINST_10_P02008

Collaboration of INFN, CERN, Eltos

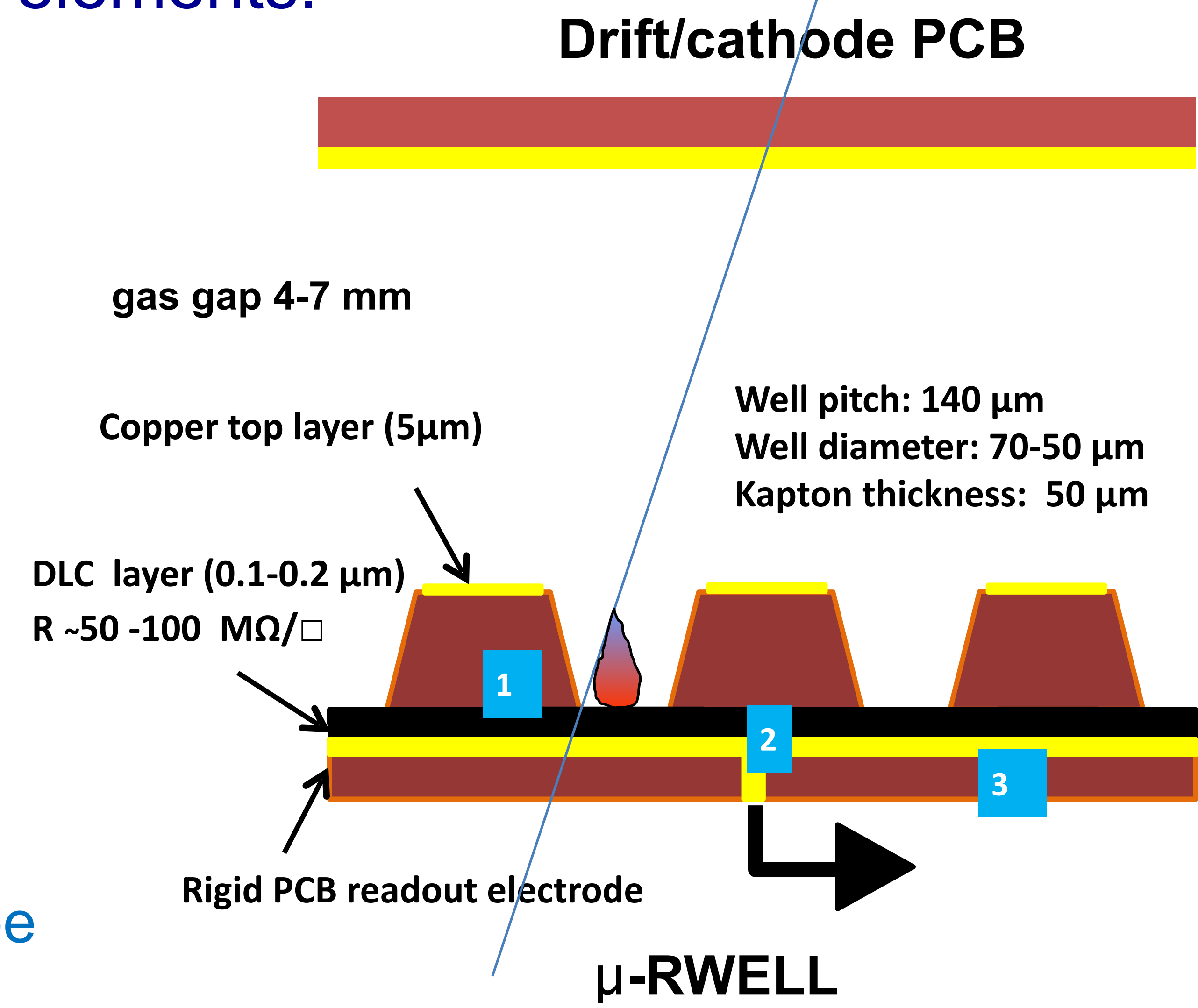
The μRWell technology

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

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

1. a "**suitable WELL patterned kapton foil** as "amplification stage"
2. a **"resistive stage"** for the discharge suppression & current evacuation
   - **i. "Low particle rate" (LR)** ~ 100 kHz/cm^2**:** single resistive layer → surface resistivity ~100 MΩ/□ (CMS-phase2 upgrade - SHIP)
   - **ii. "High particle rate" (HR)** > 1 MHz/cm^2: more sophisticated resistive scheme must be implemented (MPDG_NEXT- LNF & LHCb-muon upgrade)
3. a **standard readout PCB**

Collaboration of INFN, CERN, Eltos



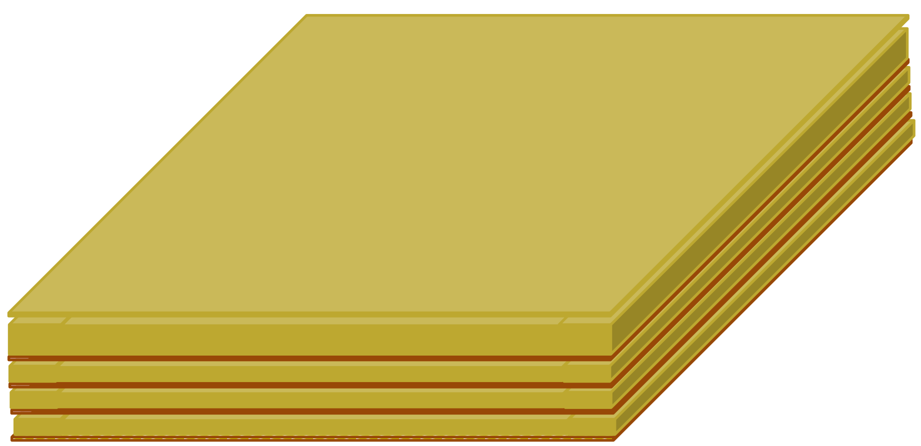
G. Bencivenni et al., 2015_JINST_10_P02008

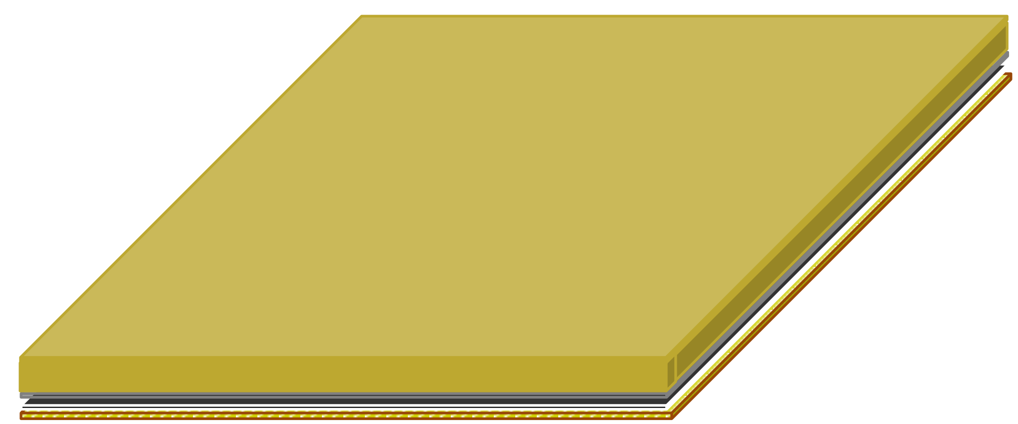
Major **advantages** wrt. GEM

- 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

μ-RWELL features

μ-RWELL features

- μ-RWELL guiding principles
  - Retain the same excellent performances of GEM and MicroMegas
  - Improve the resistance to sparks
  - Simplify the components construction and final assembly

μ-RWELL features

- μ-RWELL guiding principles
  - Retain the same excellent performances of GEM and MicroMegas
  - Improve the resistance to sparks
  - Simplify the components construction and final assembly
- Simpler construction
  - Only 1 kapton foil instead of 3 (GEM)
  - Single amplification layer
  - Simpler etching of the kapton foil

μ-RWELL features

- μ-RWELL guiding principles
  - Retain the same excellent performances of GEM and MicroMegas
  - Improve the resistance to sparks
  - Simplify the components construction and final assembly
- Simpler construction
  - Only 1 kapton foil instead of 3 (GEM)
  - Single amplification layer
  - Simpler etching of the kapton foil
- More robust
  - Resistive DLC layer makes the detector very spark safe

μ-RWELL features

- μ-RWELL guiding principles
  - Retain the same excellent performances of GEM and MicroMegas
  - Improve the resistance to sparks
  - Simplify the components construction and final assembly
- Simpler construction
  - Only 1 kapton foil instead of 3 (GEM)
  - Single amplification layer
  - Simpler etching of the kapton foil
- More robust
  - Resistive DLC layer makes the detector very spark safe
- Simpler final assembly
  - Kapton foil glued to PCB: no stretching needed

μ-RWELL features

- μ-RWELL guiding principles
  - Retain the same excellent performances of GEM and MicroMegas
  - Improve the resistance to sparks
  - Simplify the components construction and final assembly
- Simpler construction
  - Only 1 kapton foil instead of 3 (GEM)
  - Single amplification layer
  - Simpler etching of the kapton foil
- More robust
  - Resistive DLC layer makes the detector very spark safe
- Simpler final assembly
  - Kapton foil glued to PCB: no stretching needed

- Less components, simpler construction → **significant cost reduction**

μ-RWELL features

- μ-RWELL guiding principles
  - Retain the same excellent performances of GEM and MicroMegas
  - Improve the resistance to sparks
  - Simplify the components construction and final assembly
- Simpler construction
  - Only 1 kapton foil instead of 3 (GEM)
  - Single amplification layer
  - Simpler etching of the kapton foil
- More robust
  - Resistive DLC layer makes the detector very spark safe
- Simpler final assembly
  - Kapton foil glued to PCB: no stretching needed

- Less components, simpler construction → **significant cost reduction**

- Technology transfer to industry (Eltos, Techtra) started 2 years ago

CMS GE1/1 μ-RWELL prototype at H8 test beam

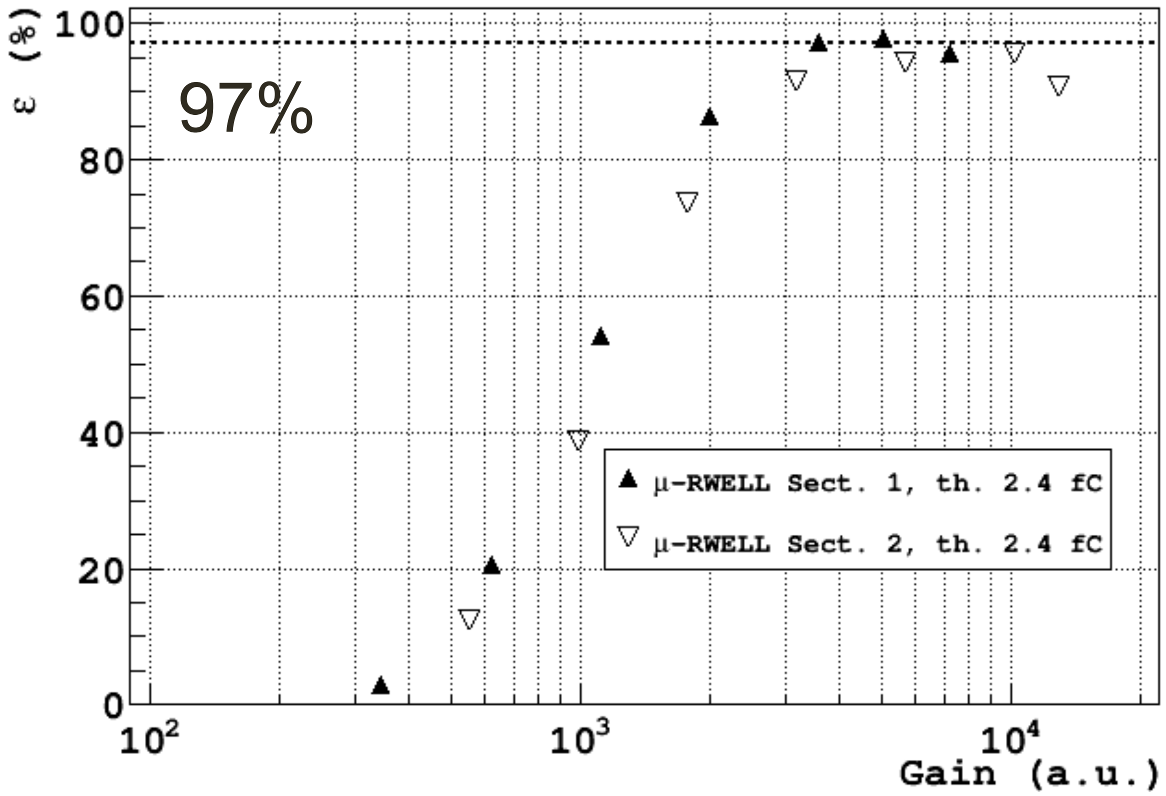
CMS GE1/1 μ-RWELL prototype at H8 test beam

$Ar/CO_2/CF_4$ 45/15/40

VFAT FEE

CMS GE1/1 μ-RWELL prototype at H8 test beam

Efficiency

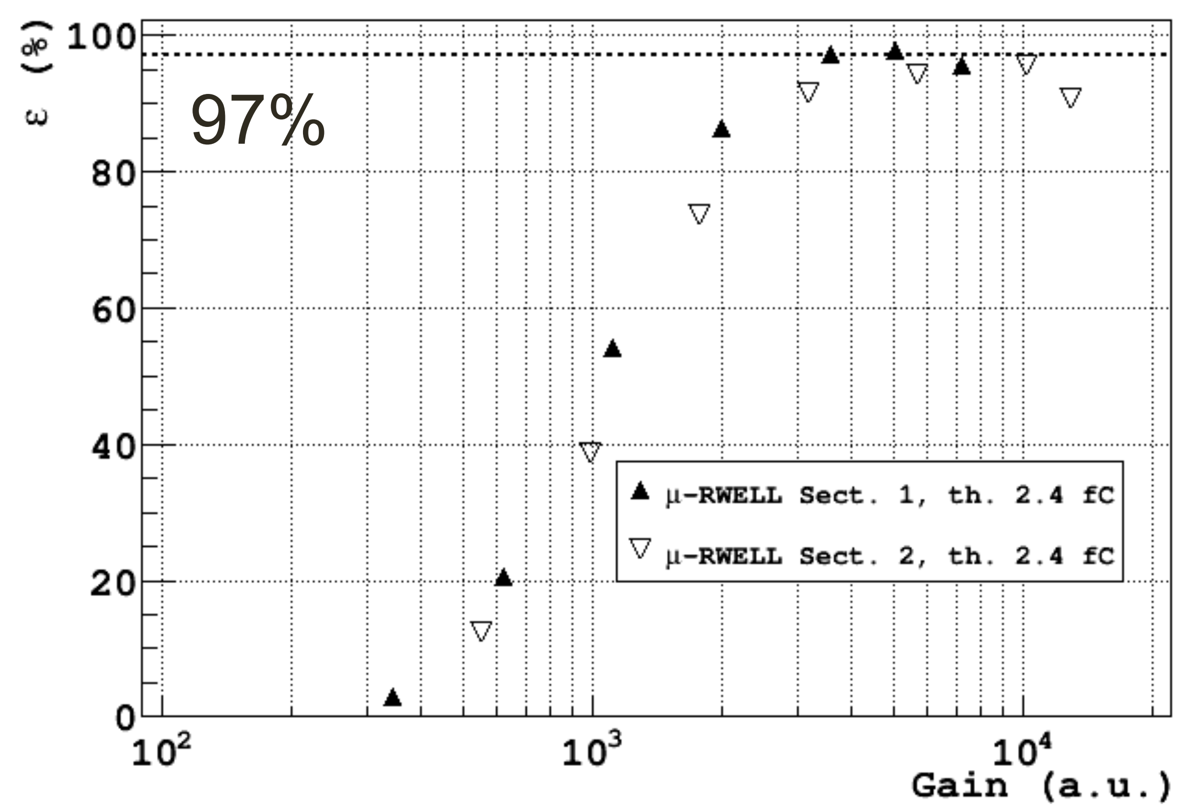


$Ar/CO_2/CF_4$ 45/15/40

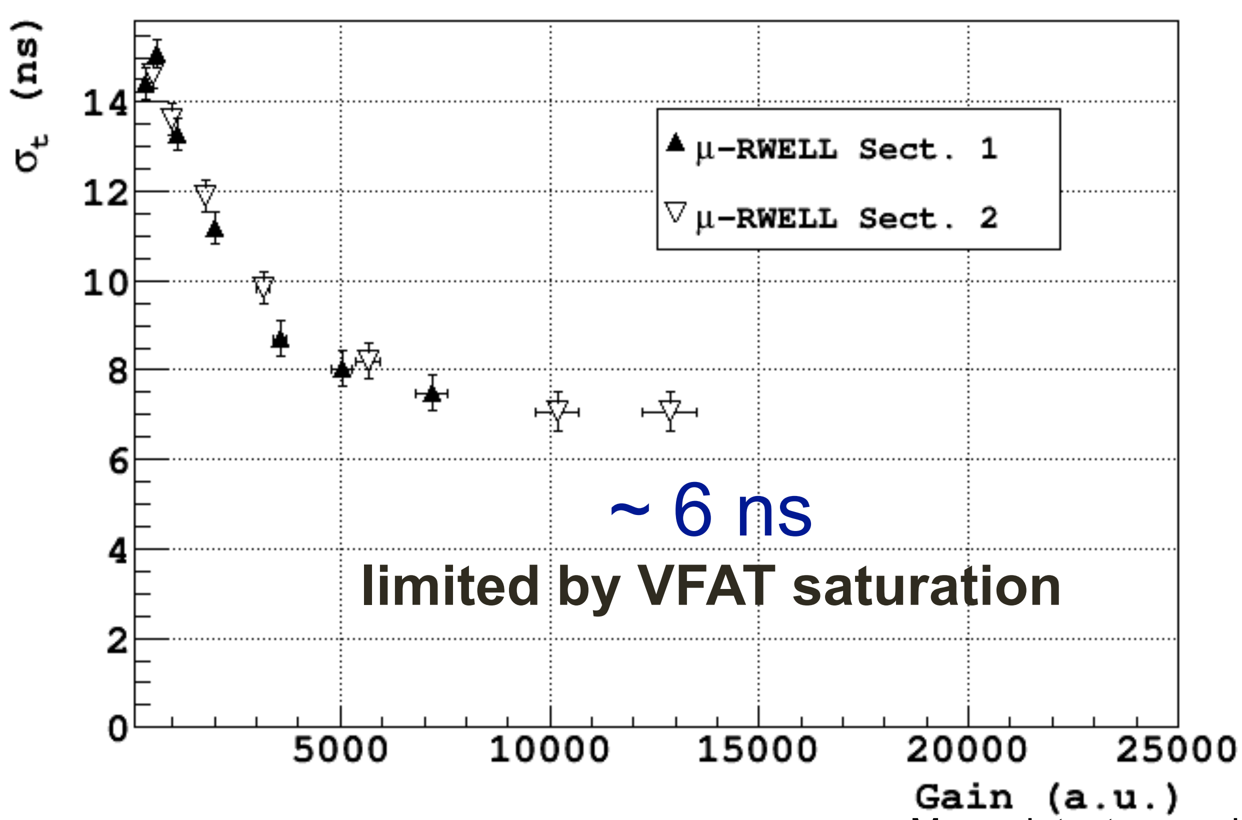
VFAT FEE

CMS GE1/1 μ-RWELL prototype at H8 test beam

Efficiency



Time resolution



$Ar/CO_2/CF_4$ 45/15/40

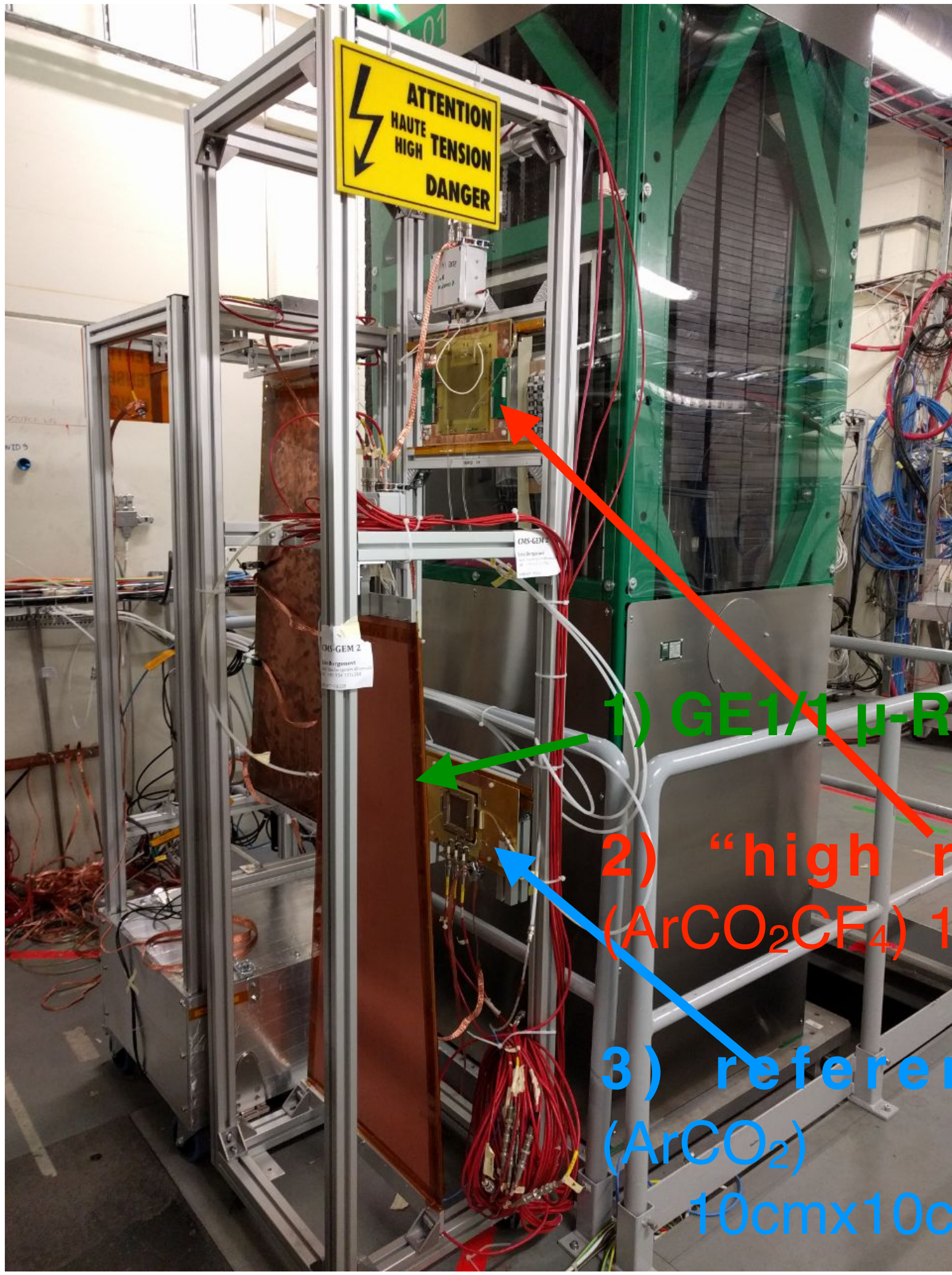
VFAT FEE

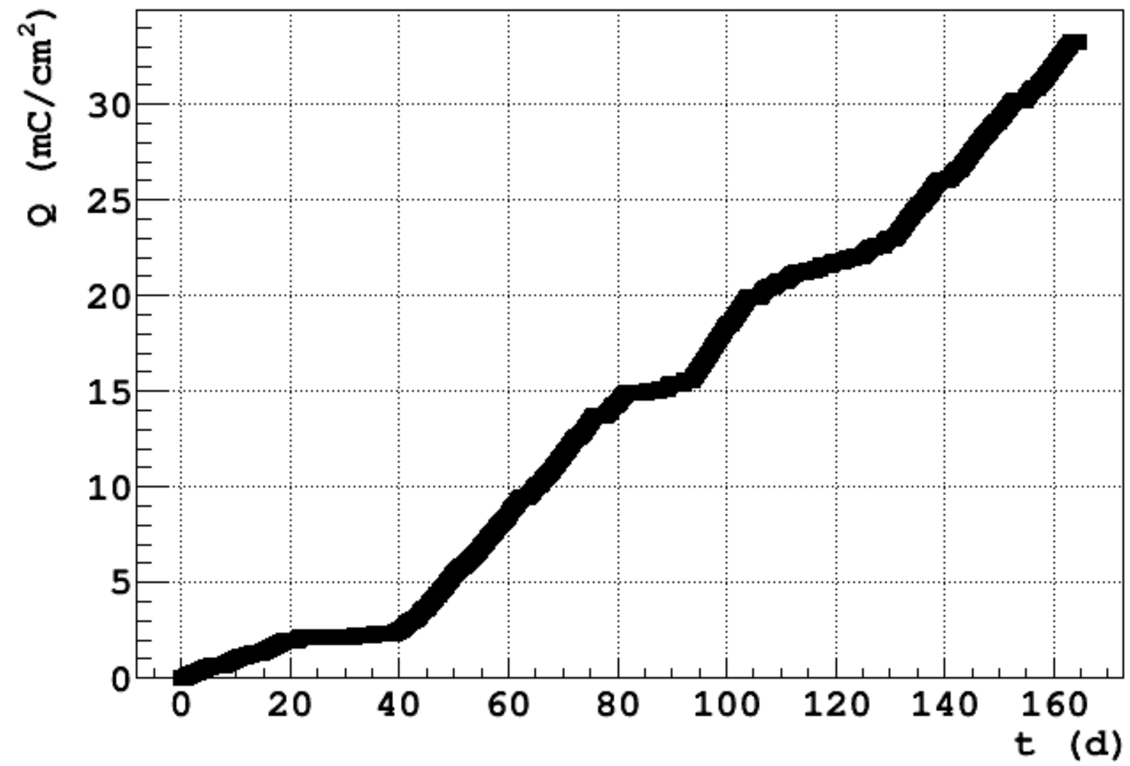
CMS GE1/1 μRWell: GIF++ ageing test

CMS GE1/1 μRWell: GIF++ ageing test

μRWell prototypes exposed inside the GIF++

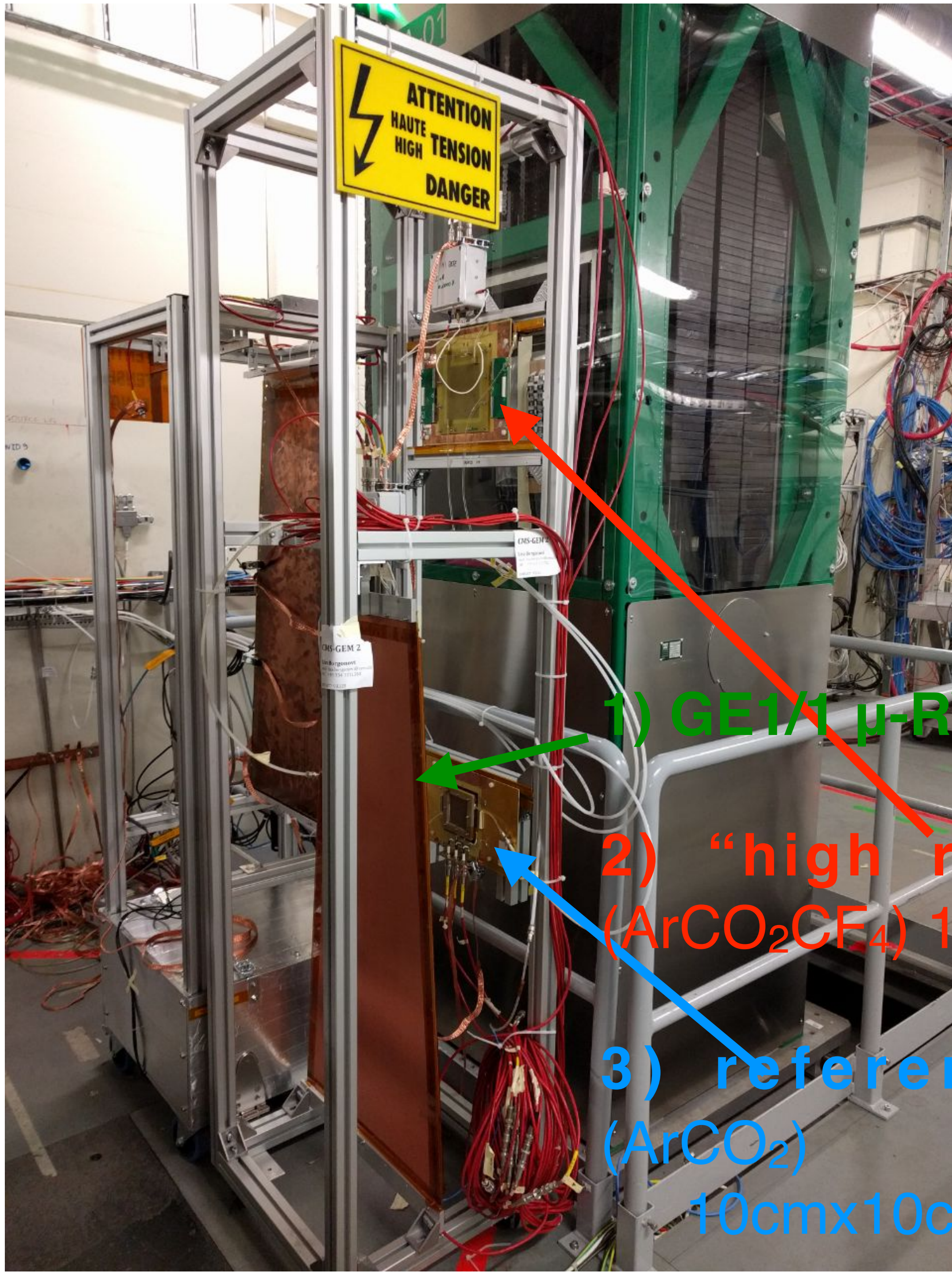
CMS GE1/1 μRWell: GIF++ ageing test





μRWell prototypes exposed inside the GIF++

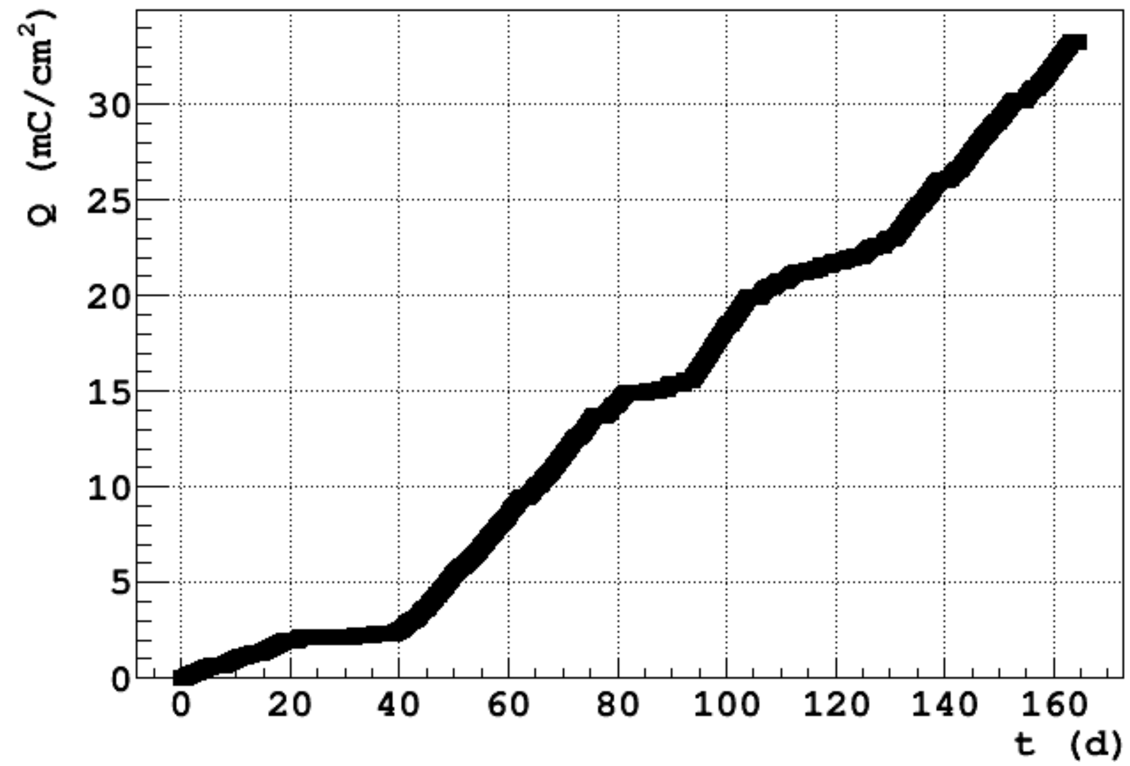
CMS GE1/1 μRWell: GIF++ ageing test



1) GE1/1 μ-RWell ($ArCO_2$)

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

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

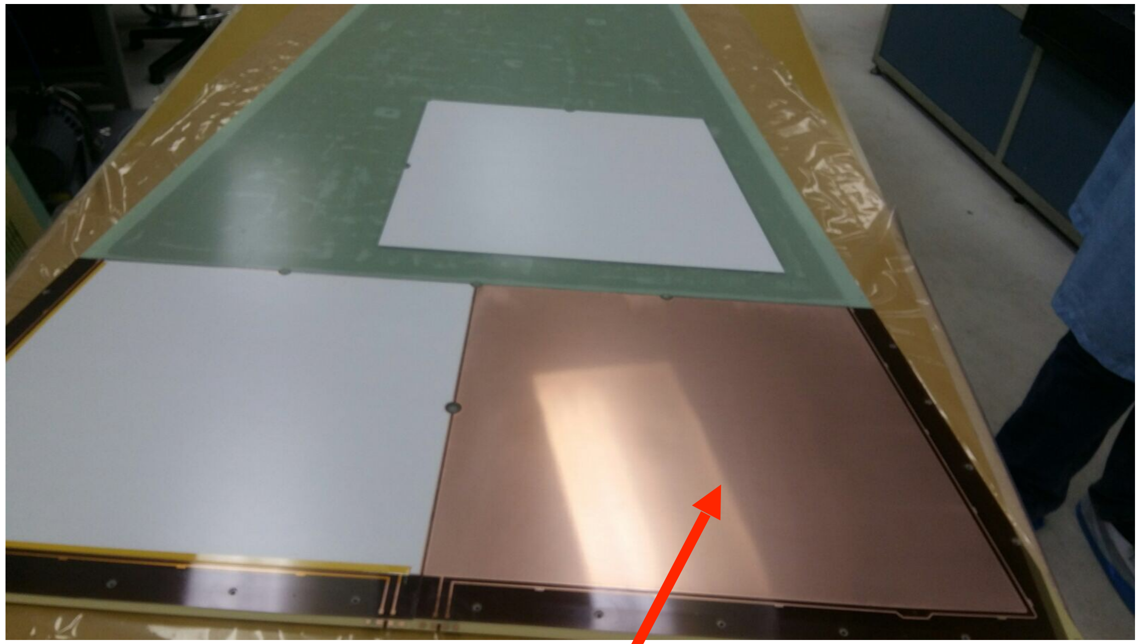


GE1/1 has accumulated a dose of ~32 mC/cm^2 (more than 10 times the dose after 10 years of HL-LHC)

μRWell prototypes exposed inside the GIF++

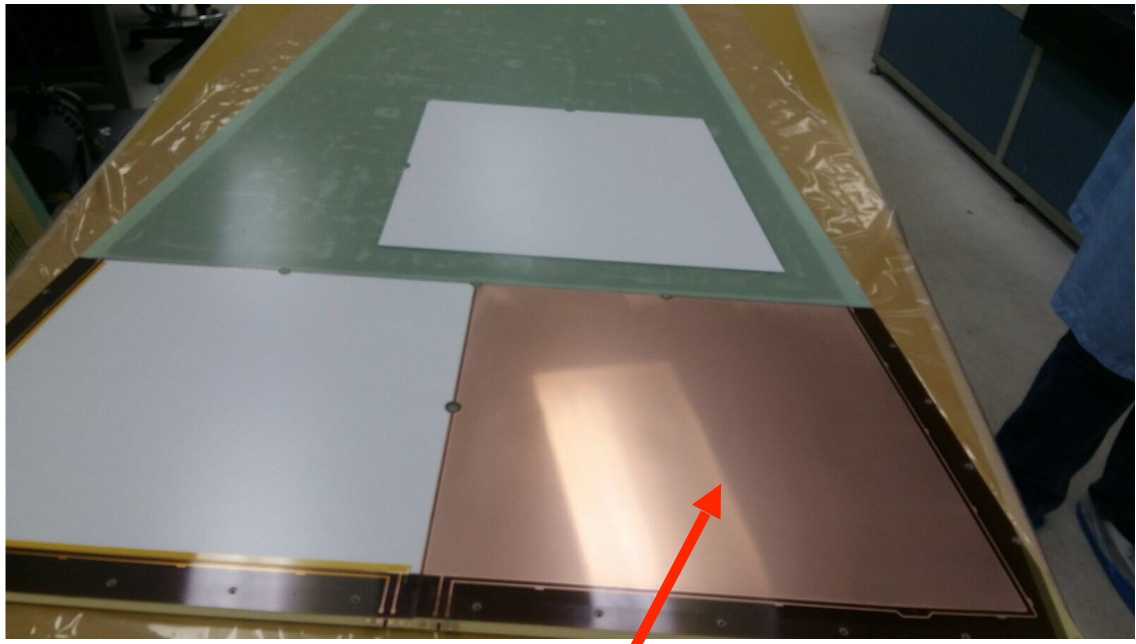
CMS GE2/1 sector μ-RWELL prototype

CMS GE2/1 sector μ-RWELL prototype



M4 μ-RWELL

CMS GE2/1 sector μ-RWELL prototype



M4 μ-RWELL

M4 μ-RWELL prototype is a trapezoid of ~55-60x50 cm^2

Largest μ-RWELL ever built and operated!

CMS GE2/1 sector μ-RWELL prototype

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

M4 μ-RWELL

M4 μ-RWELL prototype is a trapezoid of ~55-60x50 cm^2

Largest μ-RWELL ever built and operated!

CMS GE2/1 sector μ-RWELL prototype

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)

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

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

M4 μ-RWELL

M4 μ-RWELL prototype is a trapezoid of ~55-60x50 cm^2

Largest μ-RWELL ever built and operated!

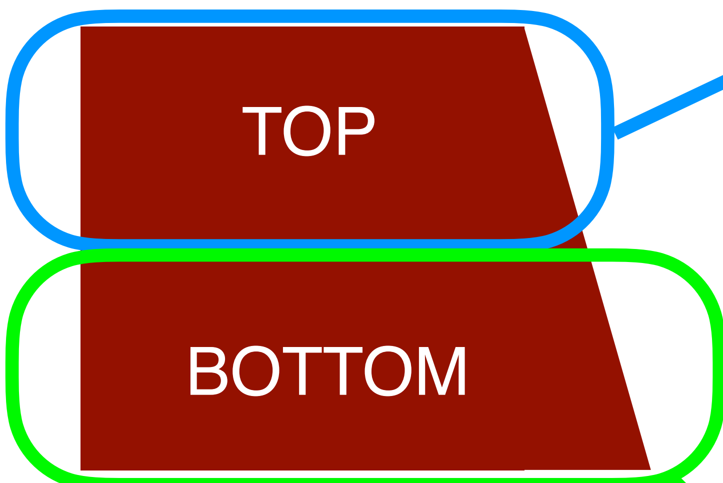
CMS M4 μ-RWELL: homogeneity

Efficiency = # hits (Tracker 1 & Tracker 2 & M4 right) / # hits (Tracker 1 & Tracker 2)

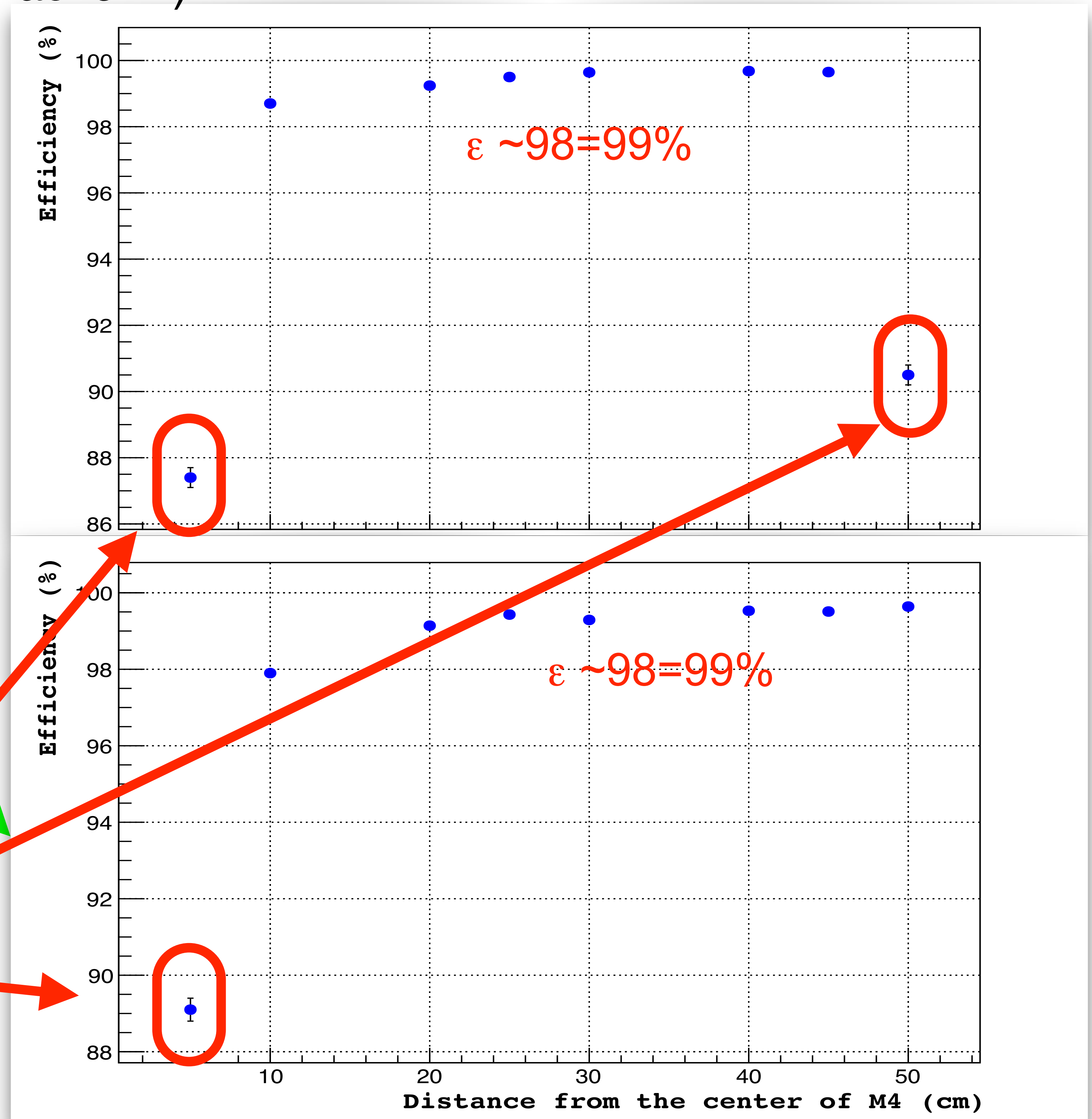
Muon beam

M4 right side:

- Drift Field = 3.0 kV/cm
- $V_{\mu\text{-RWELL}}$ = 530 V



M4 right scheme



Beam on the edge of the detector

NOT inefficiency!!

Summary of results with μ-RWELLs

Summary of results with μ-RWELLs

- CMS GE1/1 prototype at H8 test beam in 2016
  - Very good time resolution, σ_t <6 ns (about 4.5 ns obtained)
  - Fully efficient for a gain of >3000
  - Tested with a rate up to ~35 kHz/cm^2 (only limited by beam rate)

Summary of results with μ-RWELLs

- CMS GE1/1 prototype at H8 test beam in 2016
  - Very good time resolution, σ_t <6 ns (about 4.5 ns obtained)
  - Fully efficient for a gain of >3000
  - Tested with a rate up to ~35 kHz/cm^2 (only limited by beam rate)
- Position resolution
  - μ-RWELL prototypes have obtained position resolution of ~60 μm

Summary of results with μ-RWELLs

- CMS GE1/1 prototype at H8 test beam in 2016
  - Very good time resolution, σ_t <6 ns (about 4.5 ns obtained)
  - Fully efficient for a gain of >3000
  - Tested with a rate up to ~35 kHz/cm^2 (only limited by beam rate)
- Position resolution
  - μ-RWELL prototypes have obtained position resolution of ~60 μm
- GIF++ ageing (radiation tolerance) test
  - Tested with global irradiation up to 100 kHz/cm^2 for CMS prototype
  - Gain stability up to 20000
  - No dark current, no discharges
  - Q_{int} > Q_{int} ~ 32 mC/cm^2

Summary of results with μ-RWELLs

- CMS GE1/1 prototype at H8 test beam in 2016
  - Very good time resolution, σ_t <6 ns (about 4.5 ns obtained)
  - Fully efficient for a gain of >3000
  - Tested with a rate up to ~35 kHz/cm^2 (only limited by beam rate)
- Position resolution
  - μ-RWELL prototypes have obtained position resolution of ~60 μm
- GIF++ ageing (radiation tolerance) test
  - Tested with global irradiation up to 100 kHz/cm^2 for CMS prototype
  - Gain stability up to 20000
  - No dark current, no discharges
  - Q_{int} > Q_{int} ~ 32 mC/cm^2

Summary of results with μ-RWELLs

- CMS GE1/1 prototype at H8 test beam in 2016
  - Very good time resolution, σ_t <6 ns (about 4.5 ns obtained)
  - Fully efficient for a gain of >3000
  - Tested with a rate up to ~35 kHz/cm^2 (only limited by beam rate)
- Position resolution
  - μ-RWELL prototypes have obtained position resolution of ~60 μm
- GIF++ ageing (radiation tolerance) test
  - Tested with global irradiation up to 100 kHz/cm^2 for CMS prototype
  - Gain stability up to 20000
  - No dark current, no discharges
  - Q_{int} > Q_{int} ~ 32 mC/cm^2
- Technology Transfer with the Eltos and Techtra companies

Summary of results with μ-RWELLs

- CMS GE1/1 prototype at H8 test beam in 2016
  - Very good time resolution, σ_t <6 ns (about 4.5 ns obtained)
  - Fully efficient for a gain of >3000
  - Tested with a rate up to ~35 kHz/cm^2 (only limited by beam rate)
- Position resolution
  - μ-RWELL prototypes have obtained position resolution of ~60 μm
- GIF++ ageing (radiation tolerance) test
  - Tested with global irradiation up to 100 kHz/cm^2 for CMS prototype
  - Gain stability up to 20000
  - No dark current, no discharges
  - Q_{int} > Q_{int} ~ 32 mC/cm^2

- Technology Transfer with the Eltos and Techtra companies
- Large 50-60x50 cm^2 μ-RWELL modules built
  - Exposed at the CERN H4 test beam in July 2017
  - Excellent uniformity! Efficiency between 98-99% over the whole surface.

Summary of results with μ-RWELLs

- CMS GE1/1 prototype at H8 test beam in 2016
  - Very good time resolution, σ_t <6 ns (about 4.5 ns obtained)
  - Fully efficient for a gain of >3000
  - Tested with a rate up to ~35 kHz/cm^2 (only limited by beam rate)
- Position resolution
  - μ-RWELL prototypes have obtained position resolution of ~60 μm
- GIF++ ageing (radiation tolerance) test
  - Tested with global irradiation up to 100 kHz/cm^2 for CMS prototype
  - Gain stability up to 20000
  - No dark current, no discharges
  - Q_{int} > Q_{int} ~ 32 mC/cm^2

- Technology Transfer with the Eltos and Techtra companies
- Large 50-60x50 cm^2 μ-RWELL modules built
  - Exposed at the CERN H4 test beam in July 2017
  - Excellent uniformity! Efficiency between 98-99% over the whole surface.

μRWELL-based muon detector for CepC

B = 2 Tesla

Baseline

μRWELL-based muon detector for CepC

In the IDEA detector, the muon detection system is made of 3 μRWELL-based stations interleaved in the iron return yoke.

Typical geometry with a central barrel hermetically closed by 2 endcaps.

B = 2 Tesla

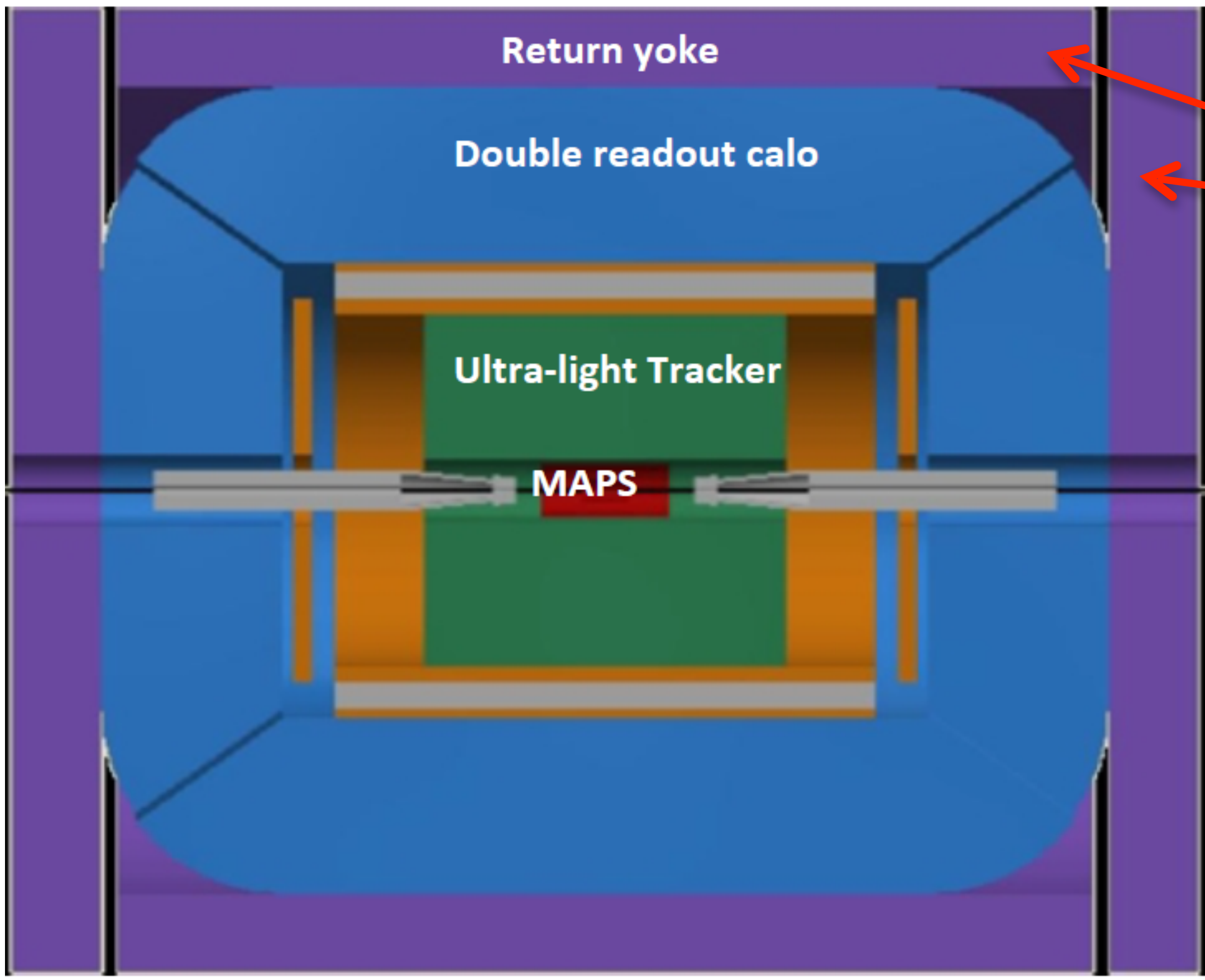
Baseline

μRWELL-based muon detector for CepC

In the IDEA detector, the muon detection system is made of 3 μRWELL-based stations interleaved in the iron return yoke.

Typical geometry with a central barrel hermetically closed by 2 endcaps.

IDEA



Muon stations

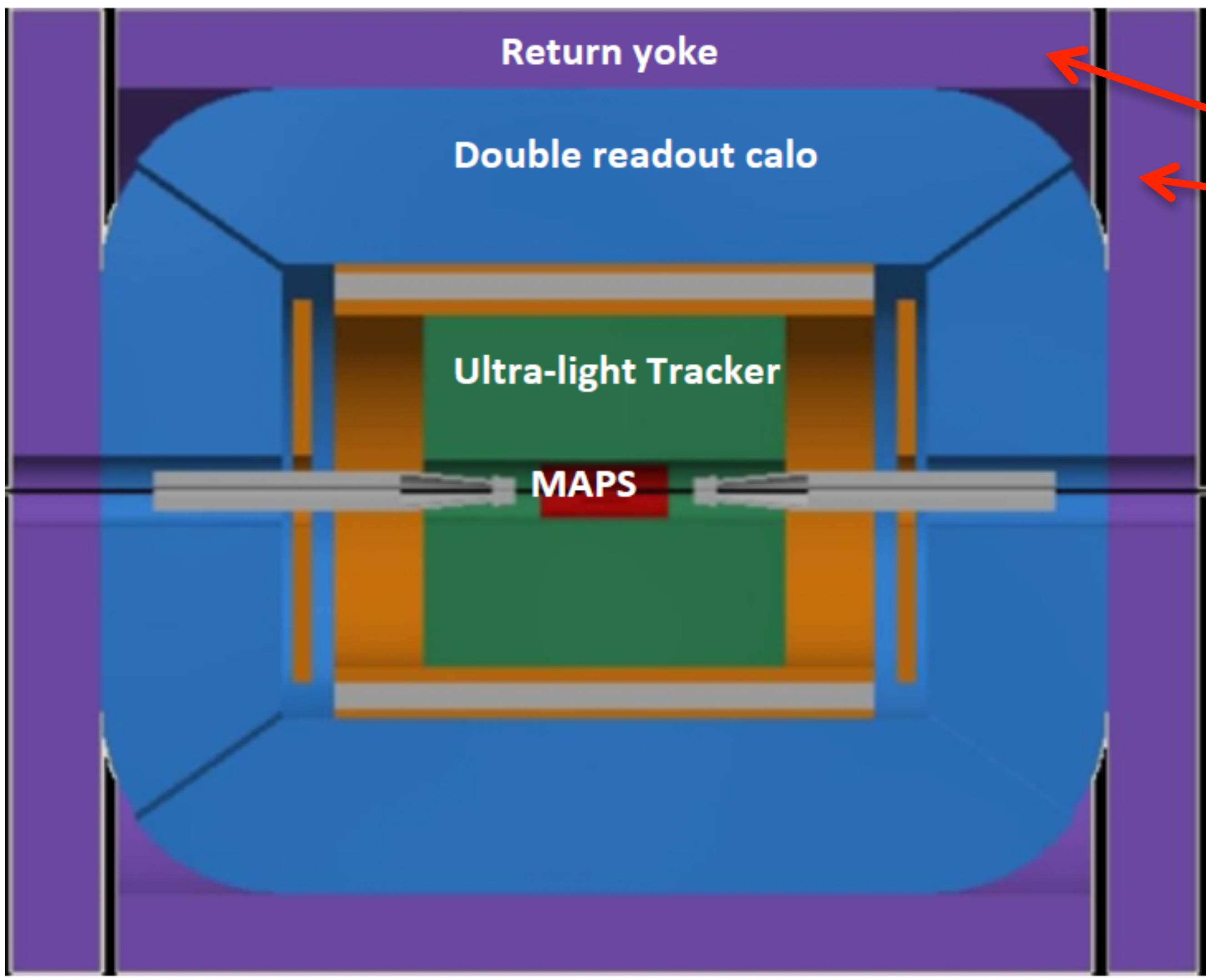
B = 2 Tesla

Baseline

μRWELL-based muon detector for CepC

In the IDEA detector, the muon detection system is made of 3 μRWELL-based stations interleaved in the iron return yoke.

Typical geometry with a central barrel hermetically closed by 2 endcaps.



IDEA

Muon stations

B = 2 Tesla

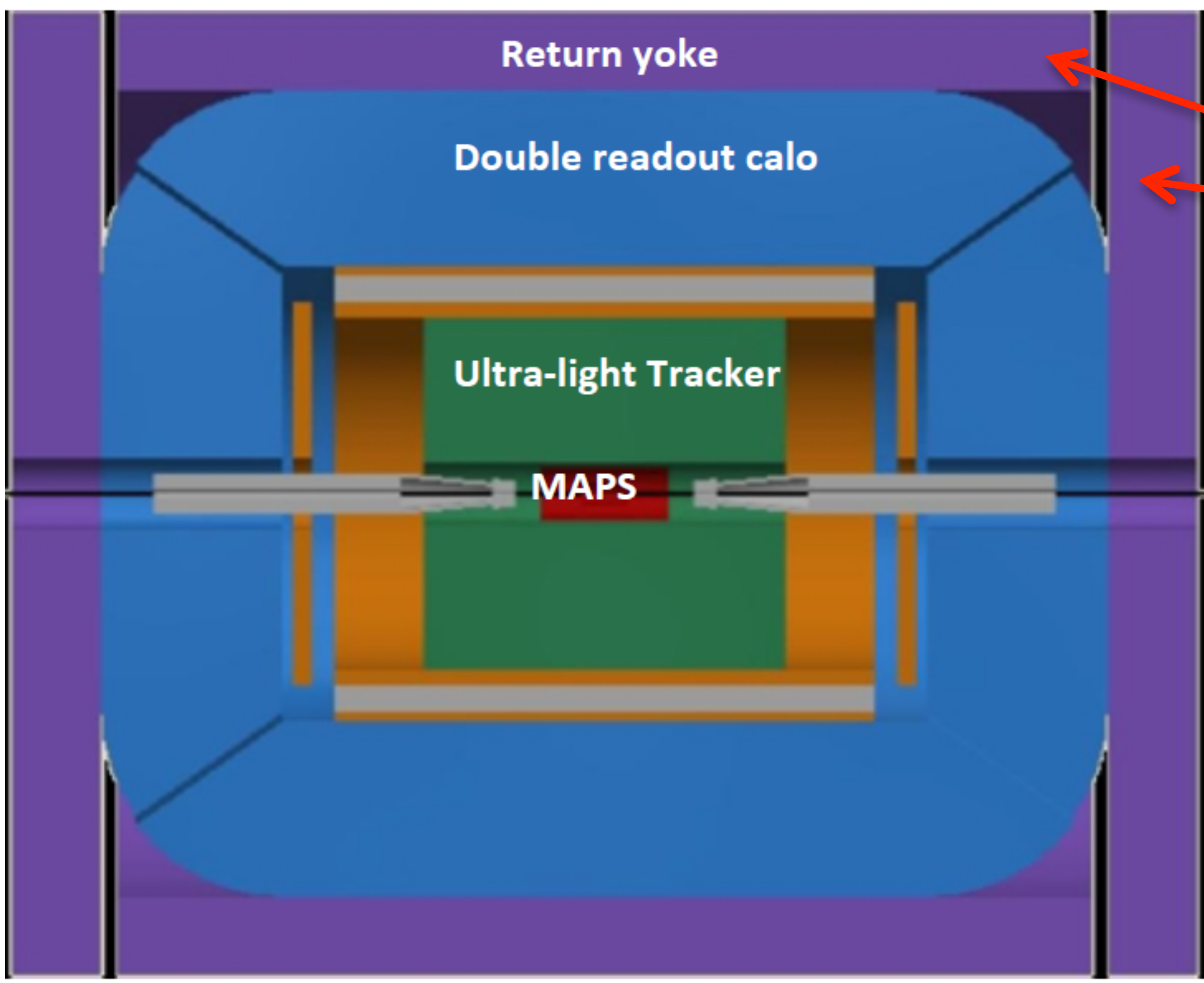
Baseline

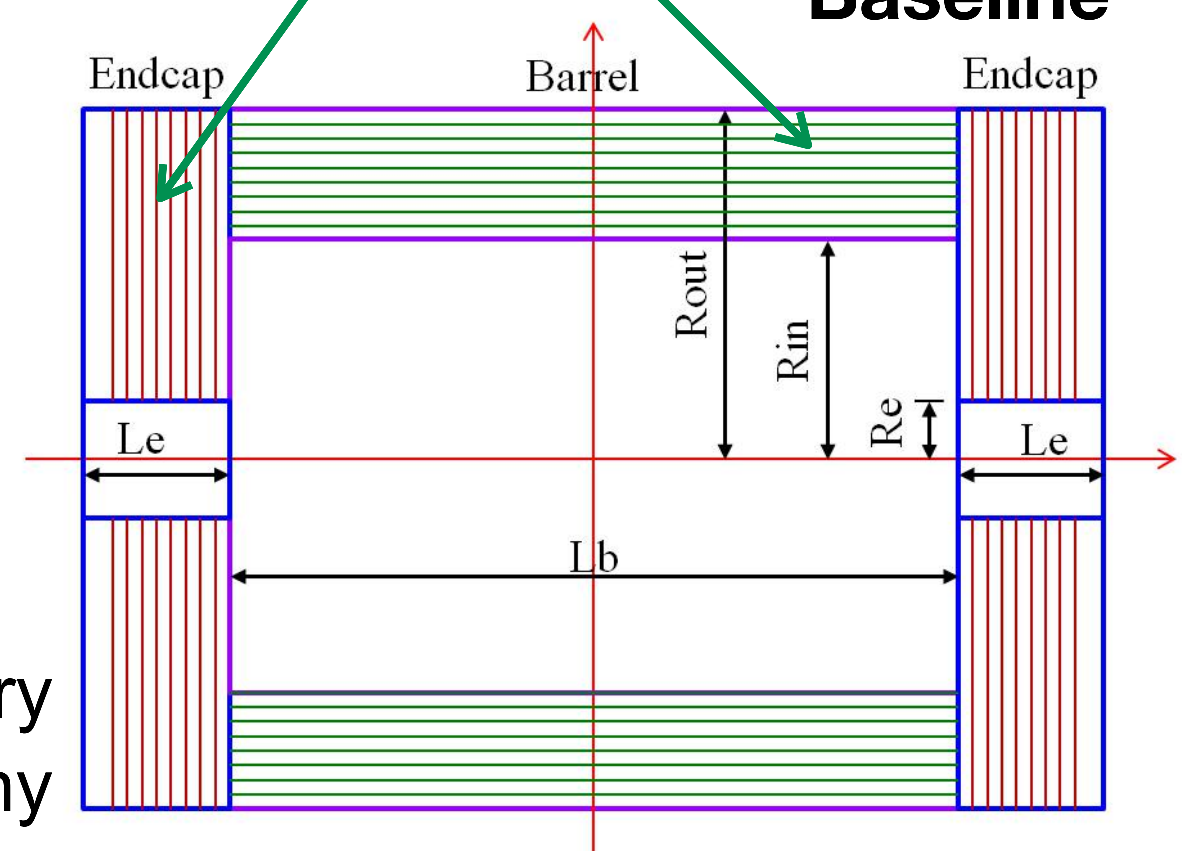
μRWELL detectors have demonstrated very high detection efficiency → no need of many layers. Baseline could also use this technology.

μRWELL-based muon detector for CepC

In the IDEA detector, the muon detection system is made of 3 μRWELL-based stations interleaved in the iron return yoke.

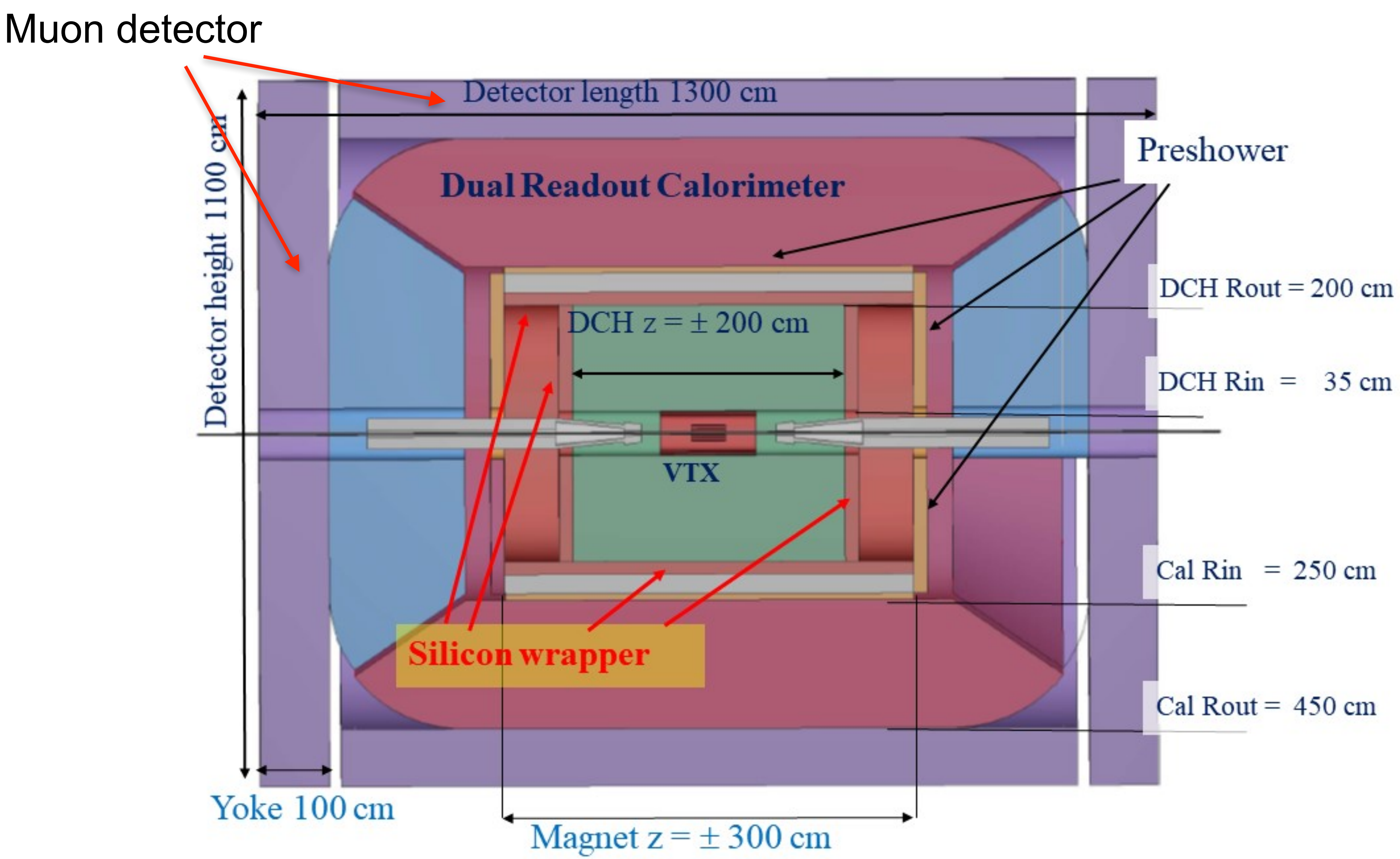
Typical geometry with a central barrel hermetically closed by 2 endcaps.





μRWELL detectors have demonstrated very high detection efficiency → no need of many layers. Baseline could also use this technology.

The IDEA detector



In the IDEA concept, μRWell detectors are foreseen for the preshower and the muon detector.

Similar in size, 50x50 cm^2, but with different strip pitch, 400 μm in the preshower and 1500 μm in the muon detector.

IDEA Muon detector characteristics

IDEA Muon detector characteristics

- Muon detector with 3 stations in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
  - Total muon detector surface 2800 m^2

IDEA Muon detector characteristics

- Muon detector with 3 stations in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
  - Total muon detector surface 2800 m^2
- μRWELL detector dimensions 50 x 50 cm^2

IDEA Muon detector characteristics

- Muon detector with 3 stations in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
  - Total muon detector surface 2800 m^2
- μRWELL detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)

IDEA Muon detector characteristics

- Muon detector with 3 stations in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
  - Total muon detector surface 2800 m^2
- μRWELL detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)
- Total number of channels ~4 million

IDEA Muon detector characteristics

- Muon detector with 3 stations in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
  - Total muon detector surface 2800 m^2
- μRWELL detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)
- Total number of channels ~4 million
- Position resolution ~270-300 μm per layer in both spatial directions

IDEA Muon detector characteristics

- Muon detector with 3 stations in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
  - Total muon detector surface 2800 m^2
- μRWELL detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)
- Total number of channels ~4 million
- Position resolution ~270-300 μm per layer in both spatial directions
- Provides standalone muon momentum measurement

IDEA Muon detector characteristics

- Muon detector with 3 stations in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
  - Total muon detector surface 2800 m^2
- μRWELL detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)
- Total number of channels ~4 million
- Position resolution ~270-300 μm per layer in both spatial directions
- Provides standalone muon momentum measurement
- Time resolution ~ 5-6 ns

IDEA Muon detector characteristics

- Muon detector with 3 stations in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
  - Total muon detector surface 2800 m^2
- μRWELL detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)
- Total number of channels ~4 million
- Position resolution ~270-300 μm per layer in both spatial directions
- Provides standalone muon momentum measurement
- Time resolution ~ 5-6 ns

IDEA Muon detector characteristics

- Muon detector with 3 stations in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
  - Total muon detector surface 2800 m^2
- μRWELL detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)
- Total number of channels ~4 million
- Position resolution ~270-300 μm per layer in both spatial directions
- Provides standalone muon momentum measurement
- Time resolution ~ 5-6 ns
- Detectors mass producible by industry

IDEA Muon detector characteristics

- Muon detector with 3 stations in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
  - Total muon detector surface 2800 m^2
- μRWELL detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)
- Total number of channels ~4 million
- Position resolution ~270-300 μm per layer in both spatial directions
- Provides standalone muon momentum measurement
- Time resolution ~ 5-6 ns

- Detectors mass producible by industry
- Quality control can be performed by collaborating institutes

Muon detector dimensions, channels, cost

Muon detector dimensions, channels, cost

- Muon detector with 3 layers in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2

Muon detector dimensions, channels, cost

- Muon detector with 3 layers in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
- μRWELL Detector dimensions 50 x 50 cm^2

Muon detector dimensions, channels, cost

- Muon detector with 3 layers in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
- μRWELL Detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)

Muon detector dimensions, channels, cost

- Muon detector with 3 layers in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
- μRWELL Detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)
- Total number of channels ~4 million

Muon detector dimensions, channels, cost

- Muon detector with 3 layers in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
- μRWELL Detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)
- Total number of channels ~4 million
- Position resolution ~300 μm per layer in both spatial directions

Muon detector dimensions, channels, cost

- Muon detector with 3 layers in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
- μRWELL Detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)
- Total number of channels ~4 million
- Position resolution ~300 μm per layer in both spatial directions
- Time resolution ~ 5-6 ns

Muon detector dimensions, channels, cost

- Muon detector with 3 layers in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
- μRWELL Detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)
- Total number of channels ~4 million
- Position resolution ~300 μm per layer in both spatial directions
- Time resolution ~ 5-6 ns

Muon detector dimensions, channels, cost

- Muon detector with 3 layers in both barrel and endcaps
  - Barrel surface ~900 x 2 (layers) = 1800 m^2
  - Endcap surface ~500 x 2 (layers) = 1000 m^2
- μRWELL Detector dimensions 50 x 50 cm^2
- Strip pitch ~ 1500 μm (1.5 mm)
- Total number of channels ~4 million
- Position resolution ~300 μm per layer in both spatial directions
- Time resolution ~ 5-6 ns

- Today's μRWELL cost ~5 keuro/m^2
  - Mass production by industry should decrease this cost by at least a factor of 2 → 2.5 keuro/m^2
  - Cost of the whole muon detector ~7 Meuro
  - Cost of electronics and services ~12-14 Meuro
  - Total cost ~20 Meuro

Preshower dimensions, channels, cost

Preshower dimensions, channels, cost

- Preshower detector with 1 layers in both barrel and endcaps
  - Barrel surface ~77 x 2 (layers) = 160 m^2
  - Endcap surface ~37 x 2 (layers) = 75 m^2

Preshower dimensions, channels, cost

- Preshower detector with 1 layers in both barrel and endcaps
  - Barrel surface ~77 x 2 (layers) = 160 m^2
  - Endcap surface ~37 x 2 (layers) = 75 m^2
- μRWELL Detector dimensions 50 x 50 cm^2

Preshower dimensions, channels, cost

- Preshower detector with 1 layers in both barrel and endcaps
  - Barrel surface ~77 x 2 (layers) = 160 m^2
  - Endcap surface ~37 x 2 (layers) = 75 m^2
- μRWELL Detector dimensions 50 x 50 cm^2
- Strip pitch ~ 400 μm

Preshower dimensions, channels, cost

- Preshower detector with 1 layers in both barrel and endcaps
  - Barrel surface ~77 x 2 (layers) = 160 m^2
  - Endcap surface ~37 x 2 (layers) = 75 m^2
- μRWELL Detector dimensions 50 x 50 cm^2
- Strip pitch ~ 400 μm
- Total number of channels ~550 thousand

Preshower dimensions, channels, cost

- Preshower detector with 1 layers in both barrel and endcaps
  - Barrel surface ~77 x 2 (layers) = 160 m^2
  - Endcap surface ~37 x 2 (layers) = 75 m^2
- μRWELL Detector dimensions 50 x 50 cm^2
- Strip pitch ~ 400 μm
- Total number of channels ~550 thousand
- Position resolution ~60-70 μm per layer in both spatial directions

Preshower dimensions, channels, cost

- Preshower detector with 1 layers in both barrel and endcaps
  - Barrel surface ~77 x 2 (layers) = 160 m^2
  - Endcap surface ~37 x 2 (layers) = 75 m^2
- μRWELL Detector dimensions 50 x 50 cm^2
- Strip pitch ~ 400 μm
- Total number of channels ~550 thousand
- Position resolution ~60-70 μm per layer in both spatial directions
- Time resolution ~ 5-6 ns

Preshower dimensions, channels, cost

- Preshower detector with 1 layers in both barrel and endcaps
  - Barrel surface ~77 x 2 (layers) = 160 m^2
  - Endcap surface ~37 x 2 (layers) = 75 m^2
- μRWELL Detector dimensions 50 x 50 cm^2
- Strip pitch ~ 400 μm
- Total number of channels ~550 thousand
- Position resolution ~60-70 μm per layer in both spatial directions
- Time resolution ~ 5-6 ns

Preshower dimensions, channels, cost

- Preshower detector with 1 layers in both barrel and endcaps
  - Barrel surface ~77 x 2 (layers) = 160 m^2
  - Endcap surface ~37 x 2 (layers) = 75 m^2
- μRWELL Detector dimensions 50 x 50 cm^2
- Strip pitch ~ 400 μm
- Total number of channels ~550 thousand
- Position resolution ~60-70 μm per layer in both spatial directions
- Time resolution ~ 5-6 ns

- Today's μRWELL cost ~5 keuro/m^2
  - Mass production by industry should decrease this cost by at least a factor of 2 $\rightarrow$ 2.5 keuro/m^2
  - Cost of the whole muon detector ~0.6 Meuro
  - Cost of electronics and services ~1.5 Meuro
  - Total cost ~2 Meuro

Conclusions

Conclusions

- The IDEA Muon detector based on a 3 station configuration in both barrel and endcap regions

Conclusions

- The IDEA Muon detector based on a 3 station configuration in both barrel and endcap regions
- Each station made of two layers of μRWELL detectors (could use one layer of detectors with bidimensional readout)

Conclusions

- The IDEA Muon detector based on a 3 station configuration in both barrel and endcap regions
- Each station made of two layers of μRWELL detectors (could use one layer of detectors with bidimensional readout)
- Total surface: ~1800 m^2 (barrel) and ~1000 m^2 endcaps
  - ~2800 m^2 of monodimensional μRWELL detectors
  - ~1400 m^2 of bidimensional μRWELL detectors

Conclusions

- The IDEA Muon detector based on a 3 station configuration in both barrel and endcap regions
- Each station made of two layers of μRWELL detectors (could use one layer of detectors with bidimensional readout)
- Total surface: ~1800 m^2 (barrel) and ~1000 m^2 endcaps
  - ~2800 m^2 of monodimensional μRWELL detectors
  - ~1400 m^2 of bidimensional μRWELL detectors
- Dimensions of single μRWELL detectors 50x50 cm^2
  - 333 channels per detector (monodimensional)

Conclusions

- The IDEA Muon detector based on a 3 station configuration in both barrel and endcap regions
- Each station made of two layers of μRWELL detectors (could use one layer of detectors with bidimensional readout)
- Total surface: ~1800 m^2 (barrel) and ~1000 m^2 endcaps
  - ~2800 m^2 of monodimensional μRWELL detectors
  - ~1400 m^2 of bidimensional μRWELL detectors
- Dimensions of single μRWELL detectors 50x50 cm^2
  - 333 channels per detector (monodimensional)
- Position resolution ~270-300 μm

Conclusions

- The IDEA Muon detector based on a 3 station configuration in both barrel and endcap regions
- Each station made of two layers of μRWELL detectors (could use one layer of detectors with bidimensional readout)
- Total surface: ~1800 m^2 (barrel) and ~1000 m^2 endcaps
  - ~2800 m^2 of monodimensional μRWELL detectors
  - ~1400 m^2 of bidimensional μRWELL detectors
- Dimensions of single μRWELL detectors 50x50 cm^2
  - 333 channels per detector (monodimensional)
- Position resolution ~270-300 μm
- Time resolution ~5-7 ns

Conclusions

- The IDEA Muon detector based on a 3 station configuration in both barrel and endcap regions
- Each station made of two layers of μRWELL detectors (could use one layer of detectors with bidimensional readout)
- Total surface: ~1800 m^2 (barrel) and ~1000 m^2 endcaps
  - ~2800 m^2 of monodimensional μRWELL detectors
  - ~1400 m^2 of bidimensional μRWELL detectors
- Dimensions of single μRWELL detectors 50x50 cm^2
  - 333 channels per detector (monodimensional)
- Position resolution ~270-300 μm
- Time resolution ~5-7 ns
- Efficiency >97% per station

Conclusions

- The IDEA Muon detector based on a 3 station configuration in both barrel and endcap regions
- Each station made of two layers of μRWELL detectors (could use one layer of detectors with bidimensional readout)
- Total surface: ~1800 m^2 (barrel) and ~1000 m^2 endcaps
  - ~2800 m^2 of monodimensional μRWELL detectors
  - ~1400 m^2 of bidimensional μRWELL detectors
- Dimensions of single μRWELL detectors 50x50 cm^2
  - 333 channels per detector (monodimensional)
- Position resolution ~270-300 μm
- Time resolution ~5-7 ns
- Efficiency >97% per station
- Muon detector provides a standalone muon momentum measurement

Conclusions

- The IDEA Muon detector based on a 3 station configuration in both barrel and endcap regions
- Each station made of two layers of μRWELL detectors (could use one layer of detectors with bidimensional readout)
- Total surface: ~1800 m^2 (barrel) and ~1000 m^2 endcaps
  - ~2800 m^2 of monodimensional μRWELL detectors
  - ~1400 m^2 of bidimensional μRWELL detectors
- Dimensions of single μRWELL detectors 50x50 cm^2
  - 333 channels per detector (monodimensional)
- Position resolution ~270-300 μm
- Time resolution ~5-7 ns
- Efficiency >97% per station
- Muon detector provides a standalone muon momentum measurement
- Mass production of detectors by industry

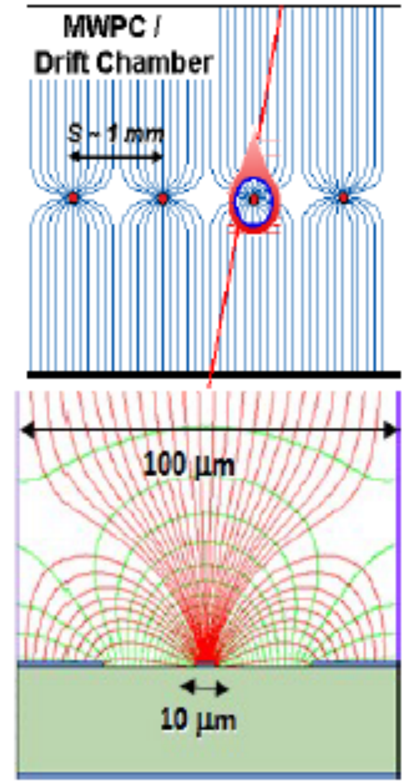
Conclusions

- The IDEA Muon detector based on a 3 station configuration in both barrel and endcap regions
- Each station made of two layers of μRWELL detectors (could use one layer of detectors with bidimensional readout)
- Total surface: ~1800 m^2 (barrel) and ~1000 m^2 endcaps
  - ~2800 m^2 of monodimensional μRWELL detectors
  - ~1400 m^2 of bidimensional μRWELL detectors
- Dimensions of single μRWELL detectors 50x50 cm^2
  - 333 channels per detector (monodimensional)
- Position resolution ~270-300 μm
- Time resolution ~5-7 ns
- Efficiency >97% per station
- Muon detector provides a standalone muon momentum measurement
- Mass production of detectors by industry
- μRWELL technology suitable also for baseline solution

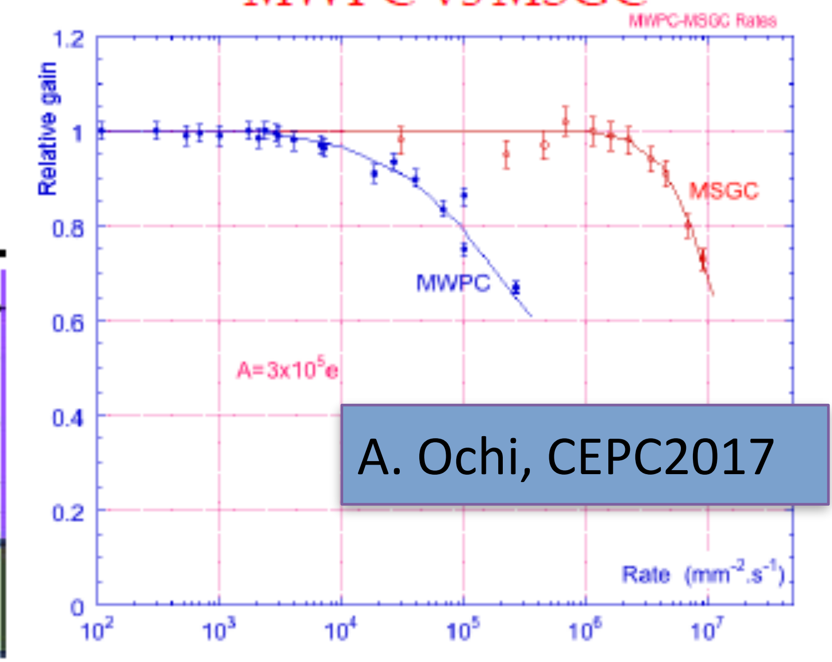
Backup

Micro Pattern Gaseous Detector Technologies

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

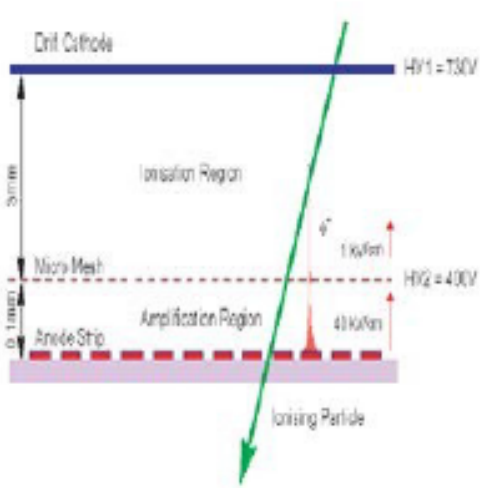


Rate Capability:
MWPC vs MSGC

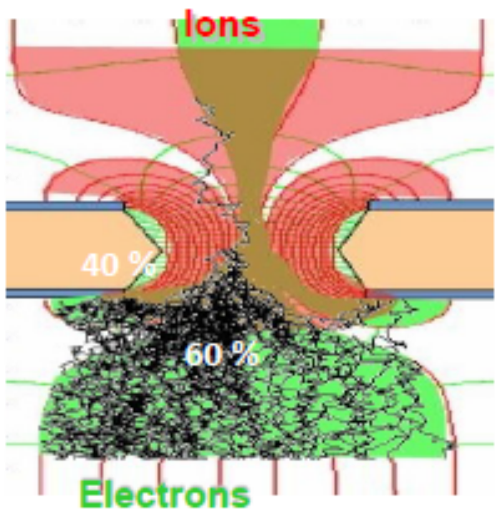


A. Ochi, CEPC2017

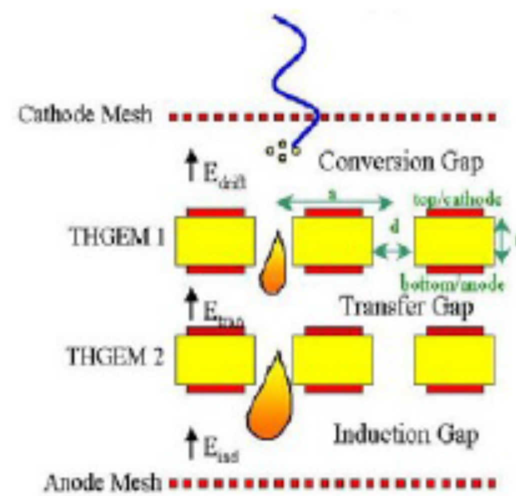
Micromegas



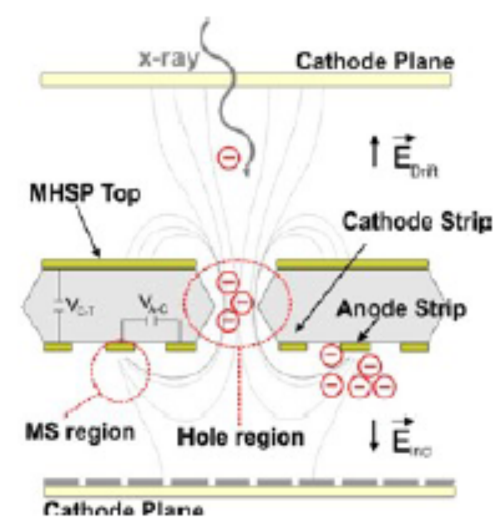
GEM



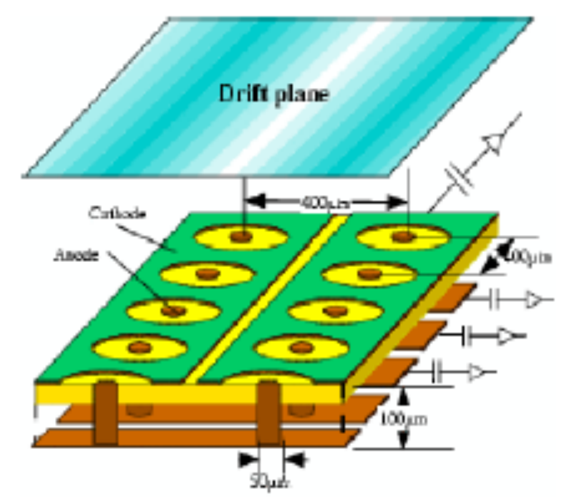
THGEM

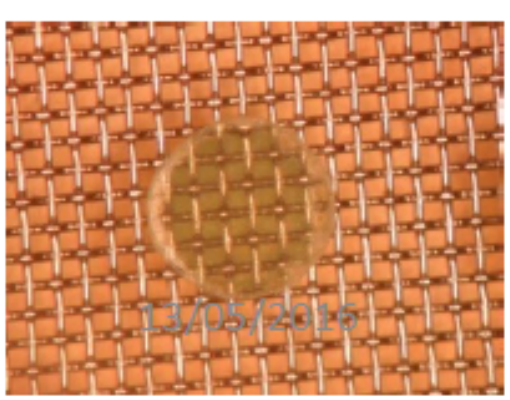
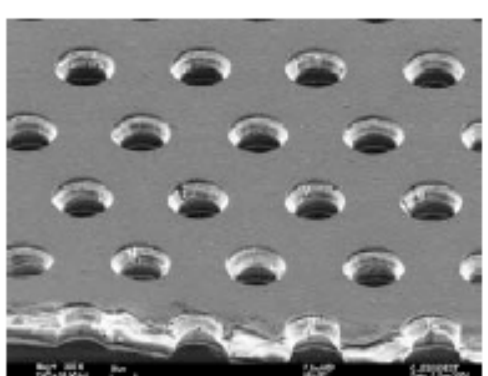
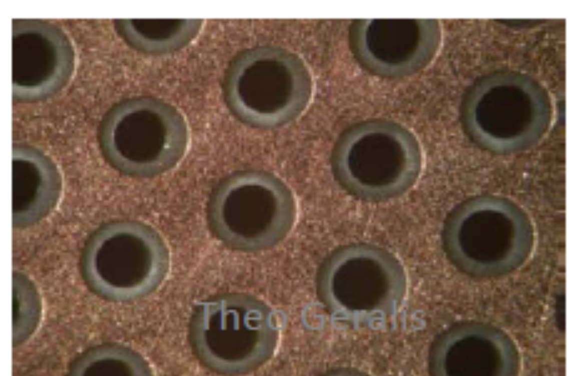
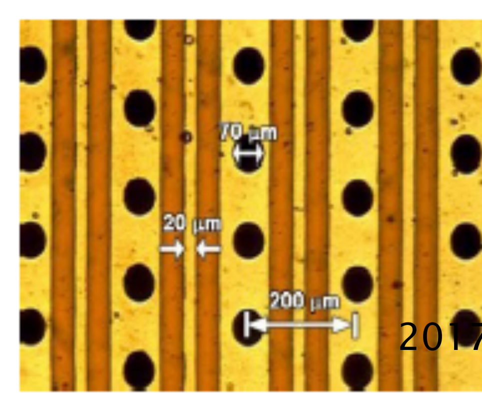


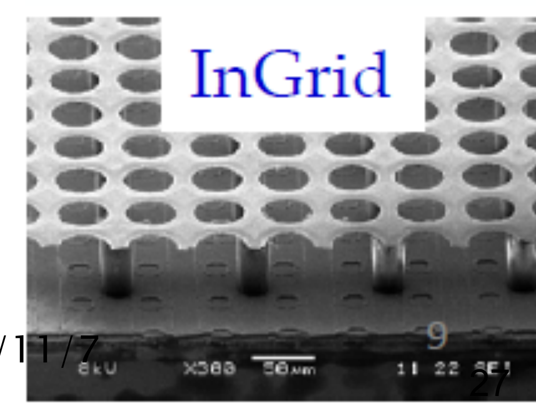
MHSP



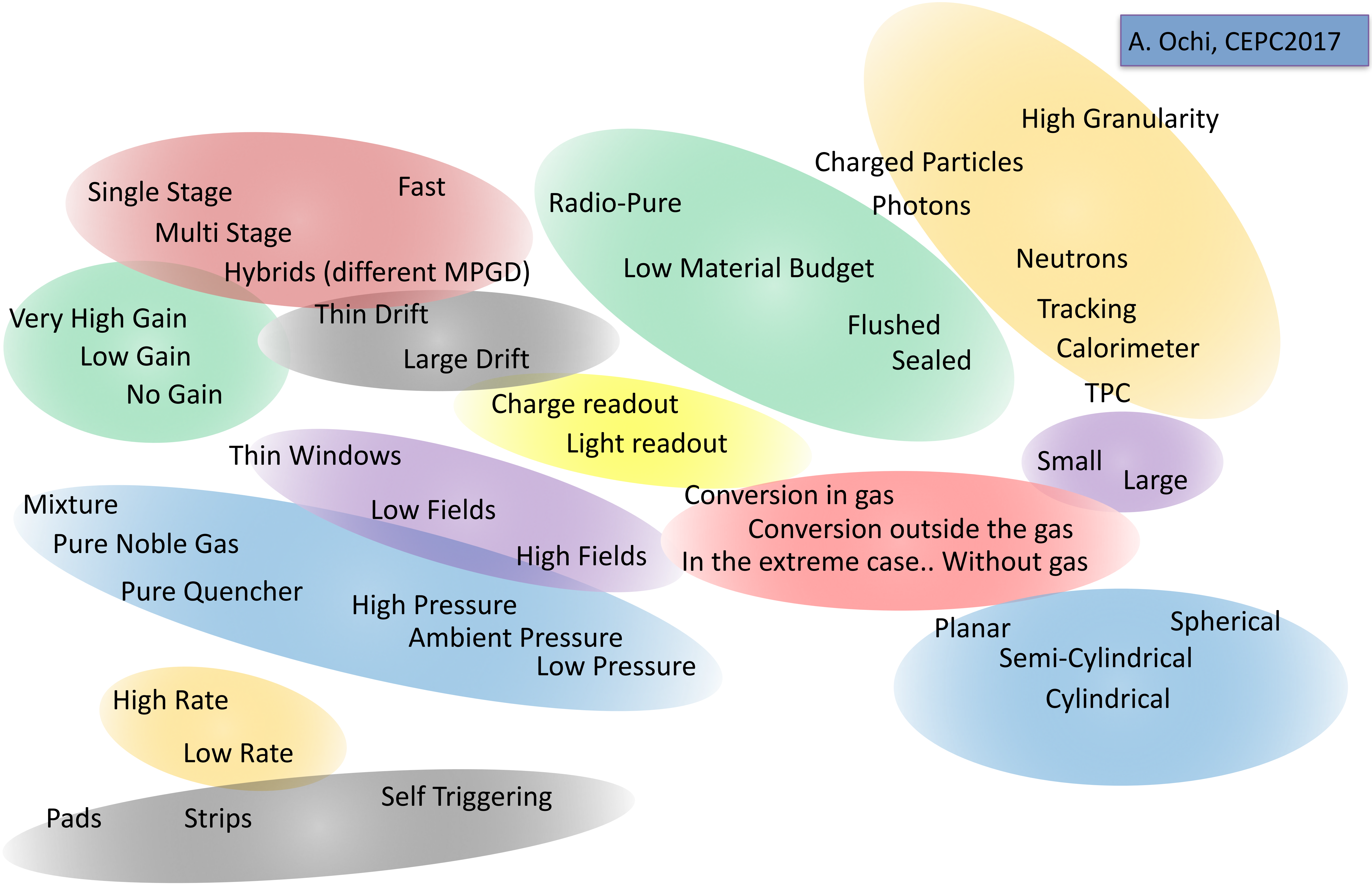
μPIC





MPGDs: one of the most versatile technologies



GEM / Micromegas : ATLAS and CMS upgrades

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

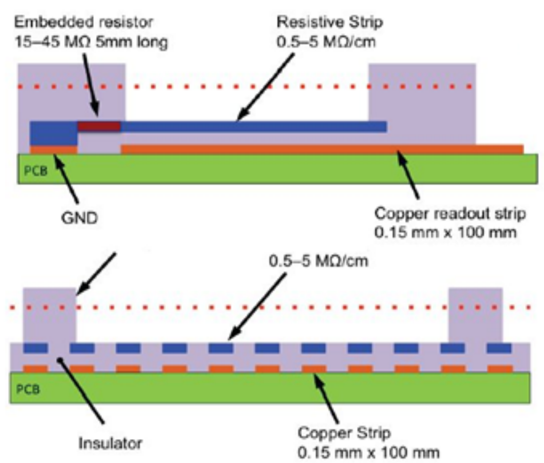
MM for the ATLAS Muon System Upgrade:

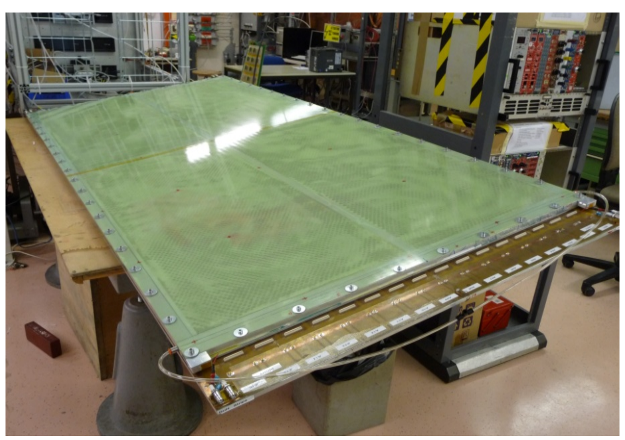
Standard Bulk MM suffers from limited efficiency at high rates due to discharges induced dead time

Solution: Resistive Micromegas tecgnology:

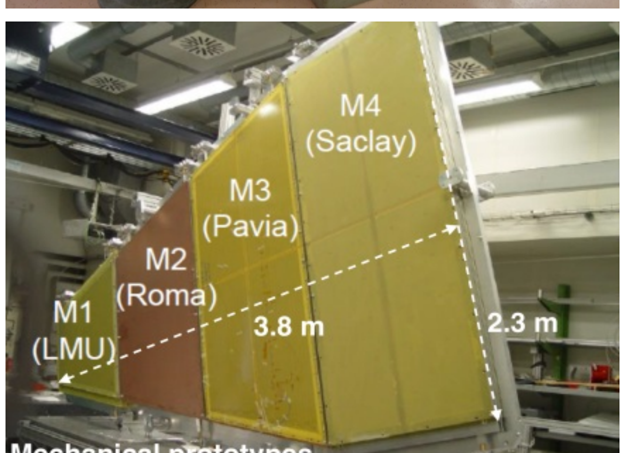
→ Add a layer of resistive strips above the readout strips

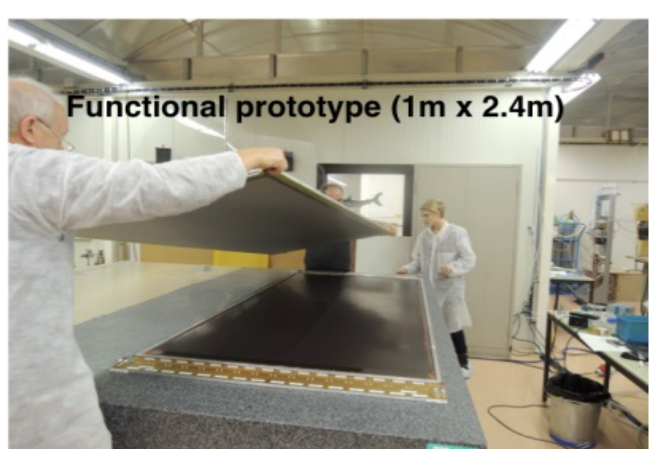
❖ Spark neutralization/ suppression (sparks still occur, but become inoffensive)





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



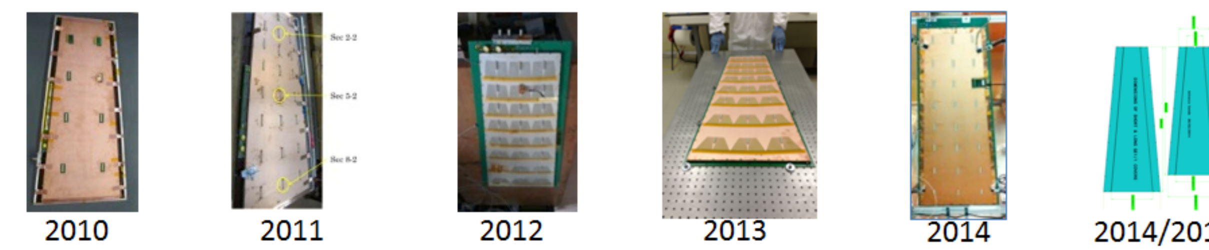


GEMs for the CMS Muon System Upgrade:

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

→ Reduces cost /allows production of large-area GEM

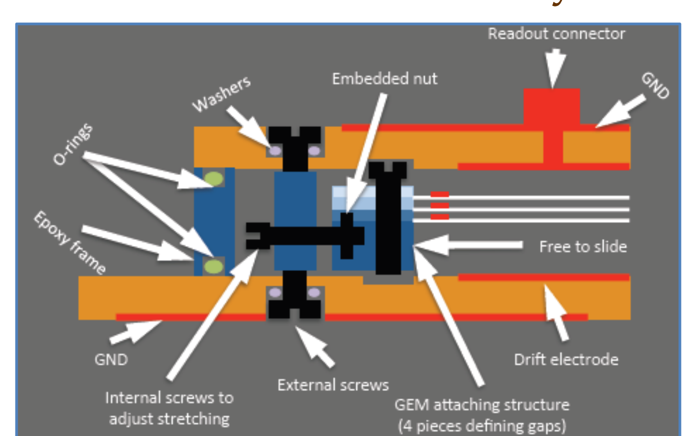
→ R&D: 6 generations of triple-GEM detectors

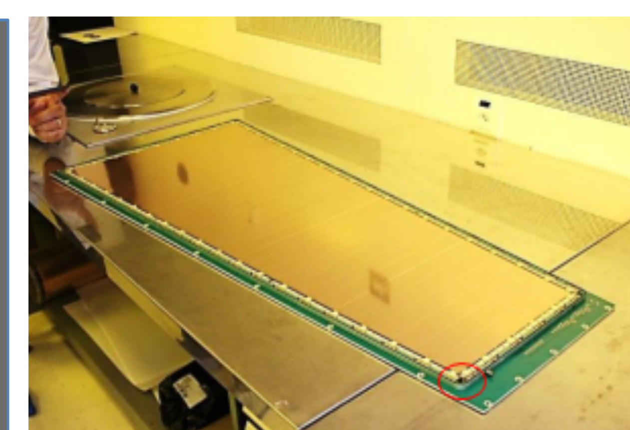


Generation I	Generation II	Generation III	Generation IV	Generation V	Generation VI
The first 1m-class detector ever built but still with spacer ribs and only 8 sectors total. **Ref.: 2010 IEEE (also RD51-Note-2010-005)**	First large detector with 24 readout sectors (3x8) and 3/1/2/1 gaps but still with 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

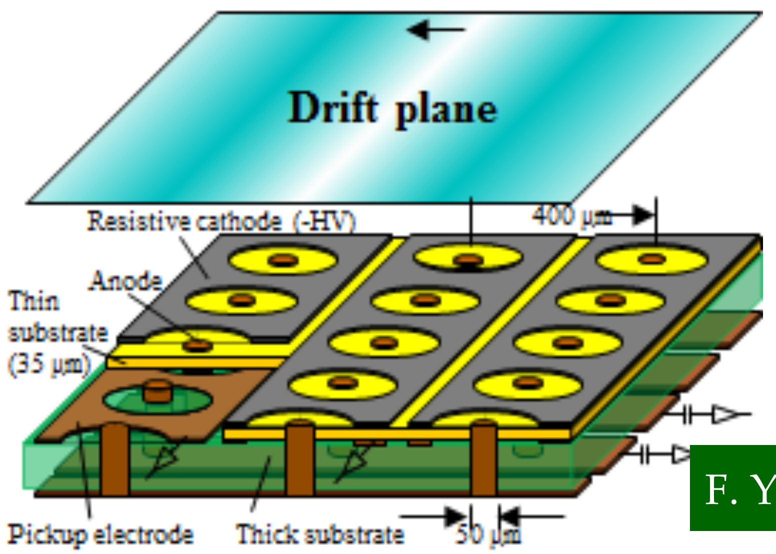


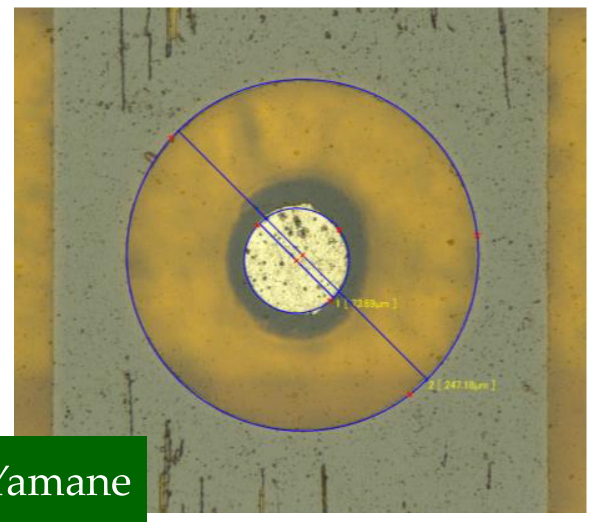


μPIC / μRWELL for ATLAS Large-η Tagger Phase II Upgrade

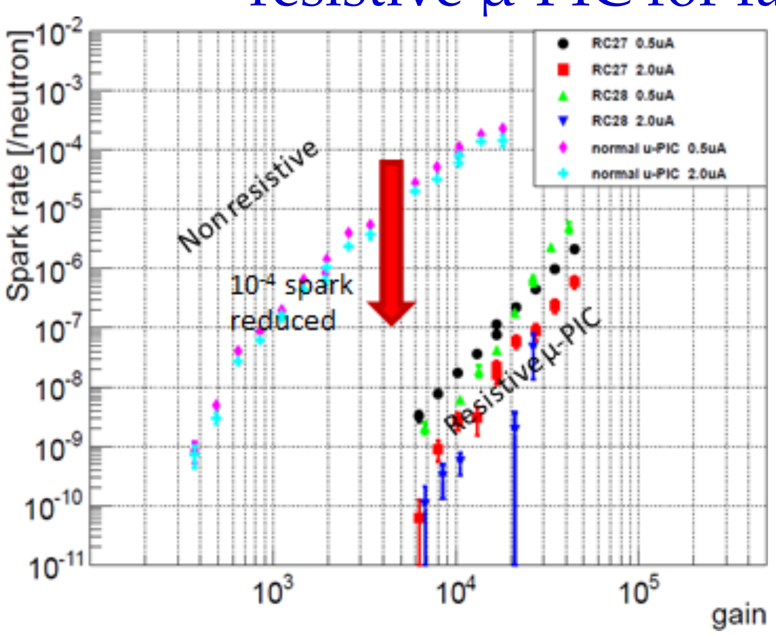
- Proposed for Phase II upgrade (~2023)
- Need high granularity ~ 0.1mm
- BG rate > 100kHz/cm^2 (HIP, gamma)
- Rate tolerant, Pixel type detector needed

μ-PIC with resistive Diamond-LC electrodes:

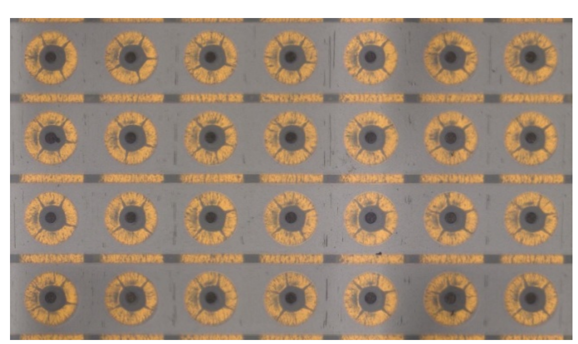




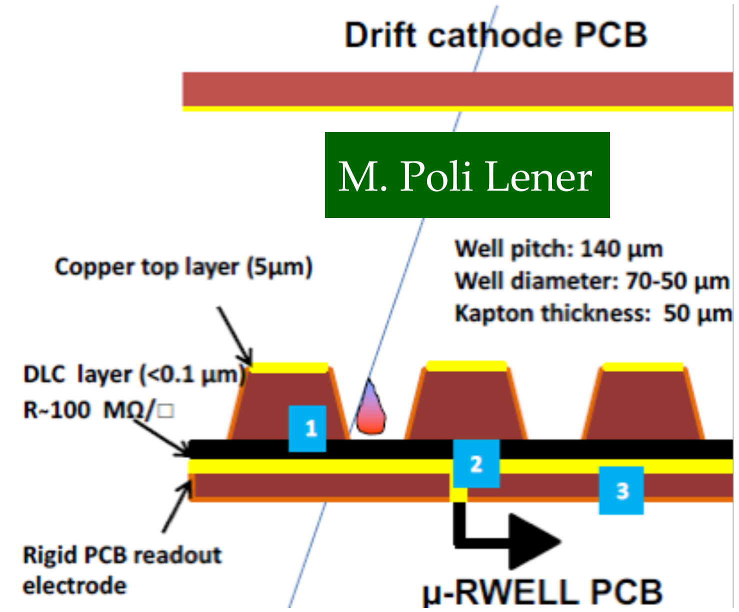
Spark rate reduction using resistive μ-PIC for fast neutron

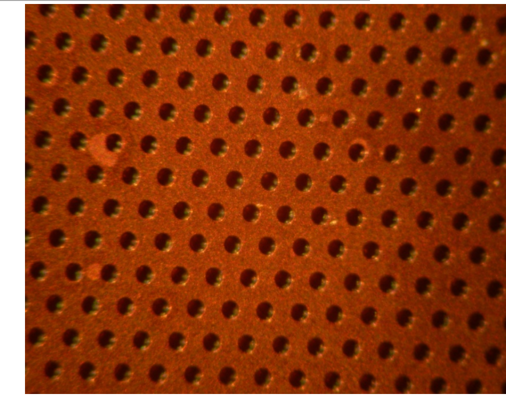


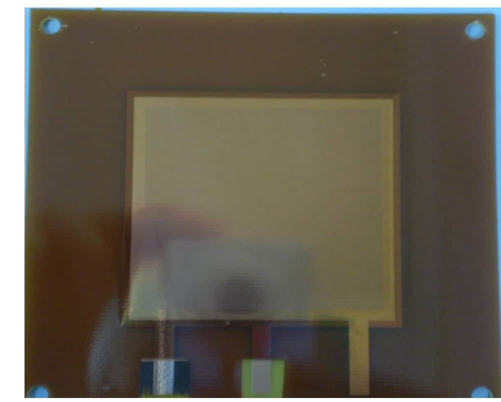
Resistive μ-PIC using sputtered C:



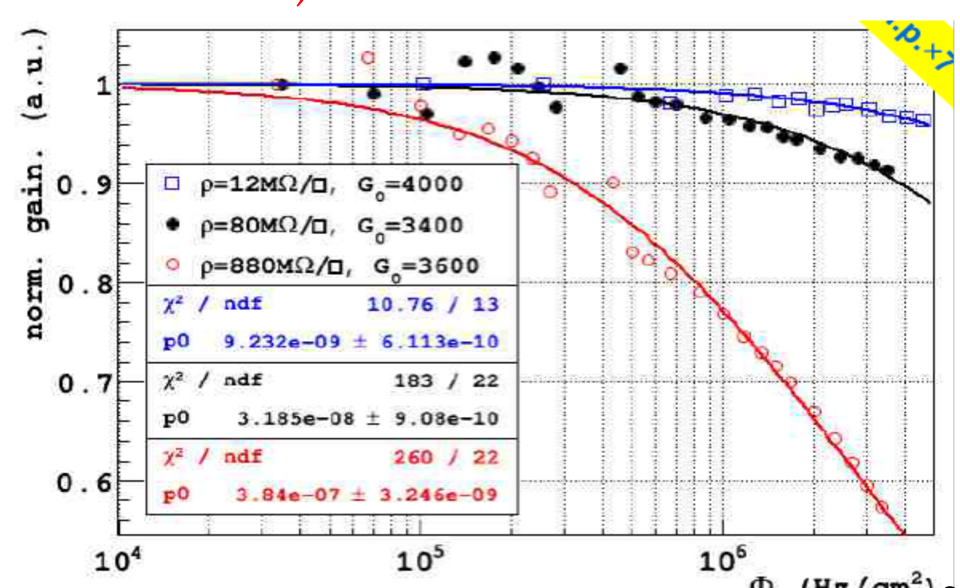
μ-RWELL Detector:





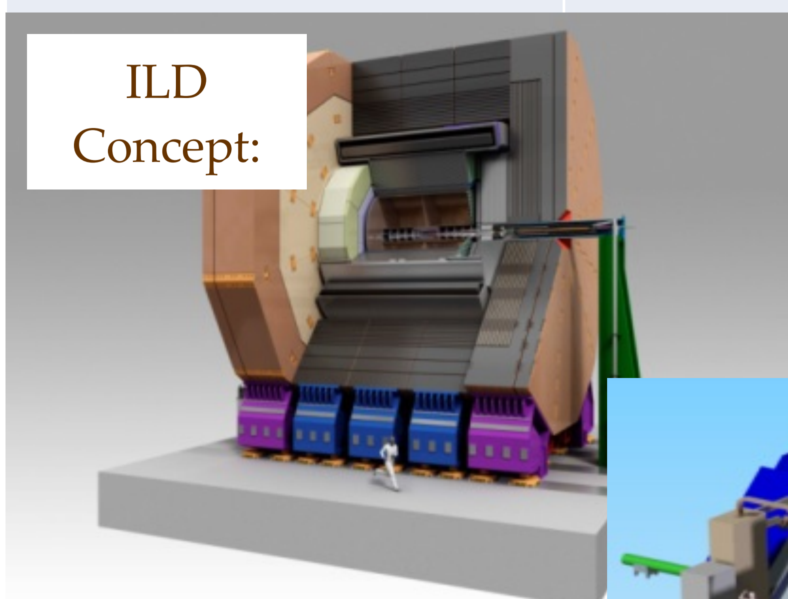


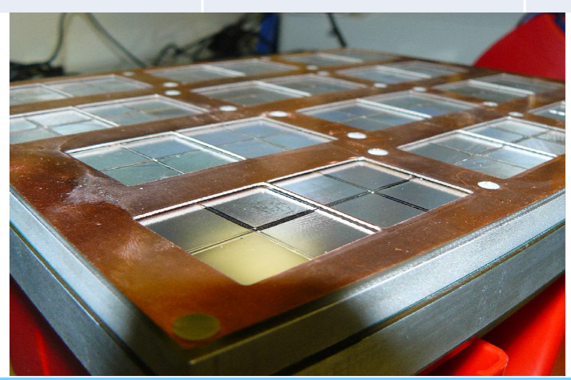
- Very reliable
- Almost completely *discharge-free*
- adequate for high particle rates O(1MHz/cm^2) thanks to the *segmented-resistive-layer*
- suitable for large area applications (1.8 x 1.2 m^2 proto was tested in 2017)

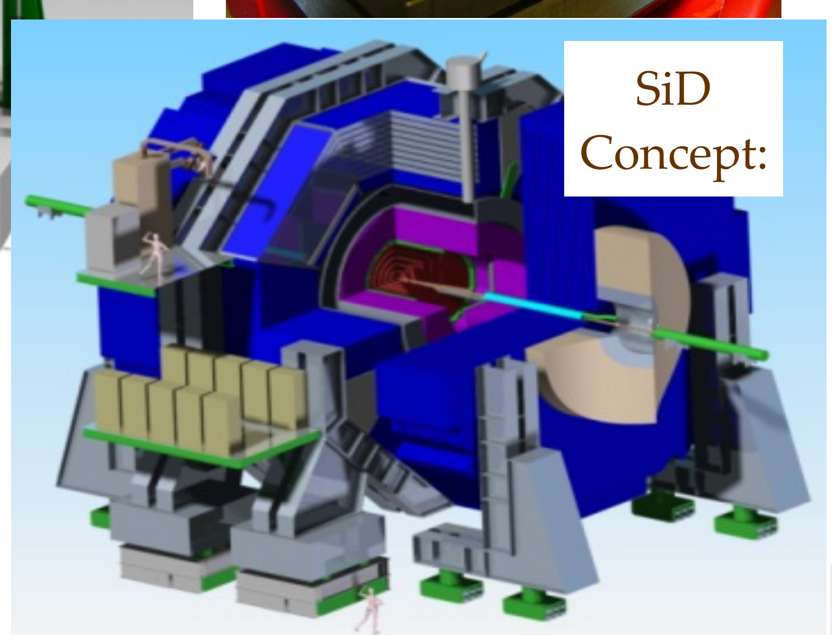


MPGD Technologies for the ILC

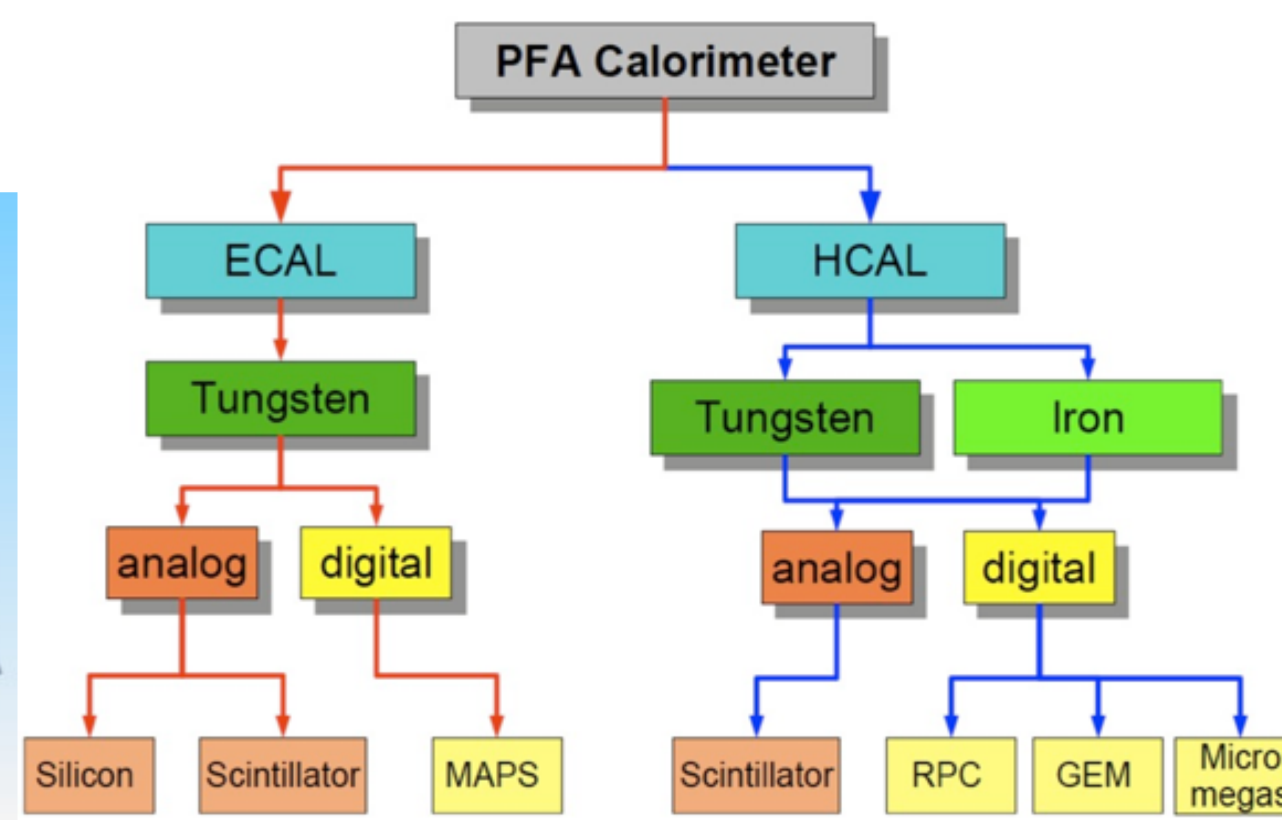
Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements/ Remarks
ILC Time Projection Chamber for ILD: Start: > 2030	High Energy Physics (tracking)	Micromegas GEM (pads) InGrid (pixels)	Total area: ~ 20 m² Single unit detect: ~ 400 cm² (pads) ~ 130 cm² (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 m² Single unit detect: 0.5 - 1 m²	**Max.rate:**1 kHz/cm² **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):



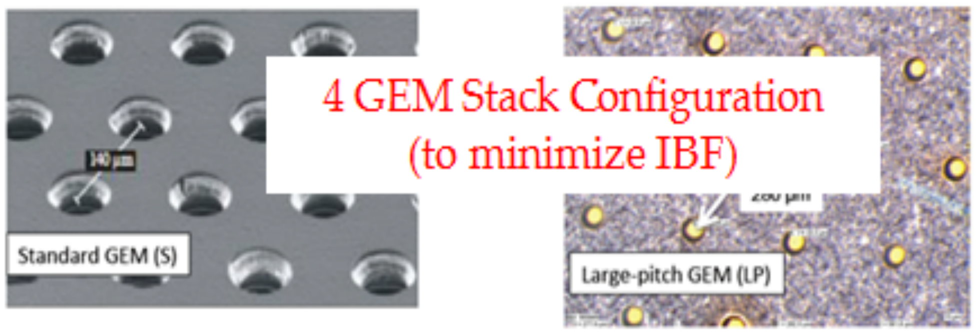
Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements / Remarks
ATLAS Muon System Upgrade: Start: 2019 (for 15 y.)	High Energy Physics (Tracking/Triggering)	Micromegas	Total area: 1200 m^2 Single 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

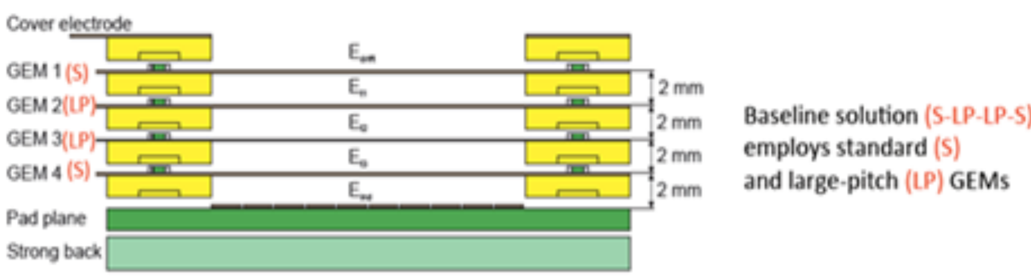
ALICE TPC Endplate upgrade with GEMs

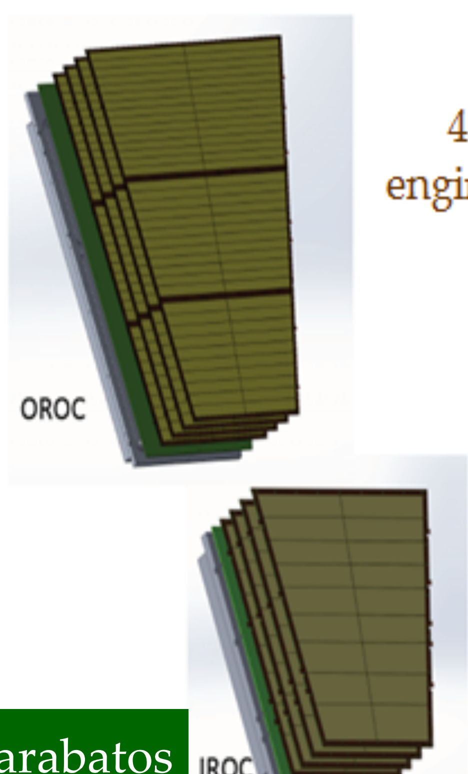
ALICE TPC Upgrade → replace MWPC with 4-GEM (to limit space charge effects)

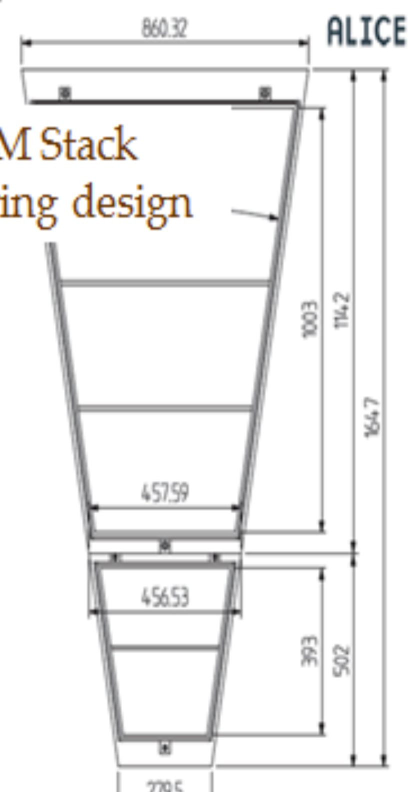
- ➢ Continuous TPC readout for 50 kHz Pb-Pb readout
- ➢ Maintain physics requirements: IBF < 1%, energy; σ(E)E < 12% achieved



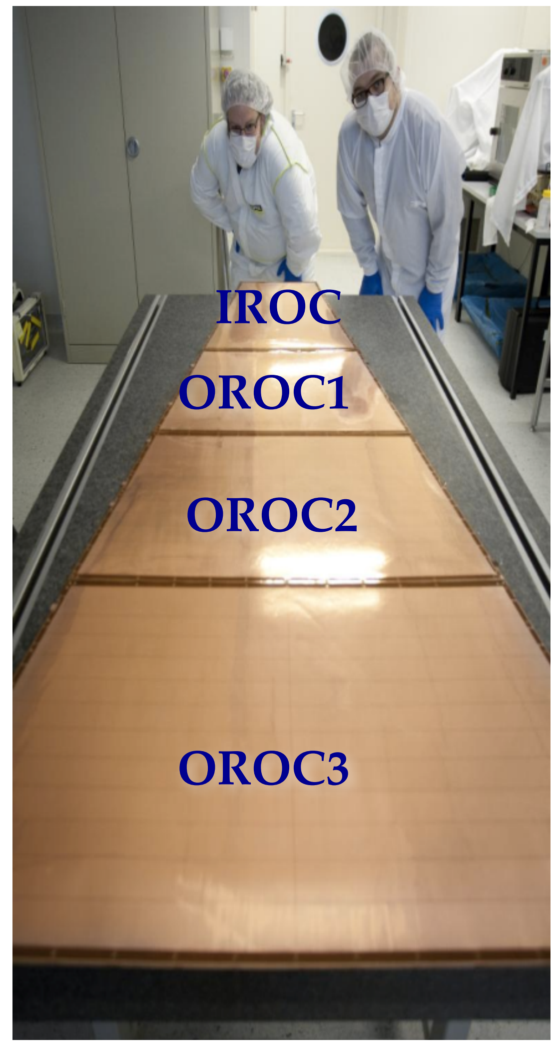
4 GEM Stack Configuration (to minimize IBF)





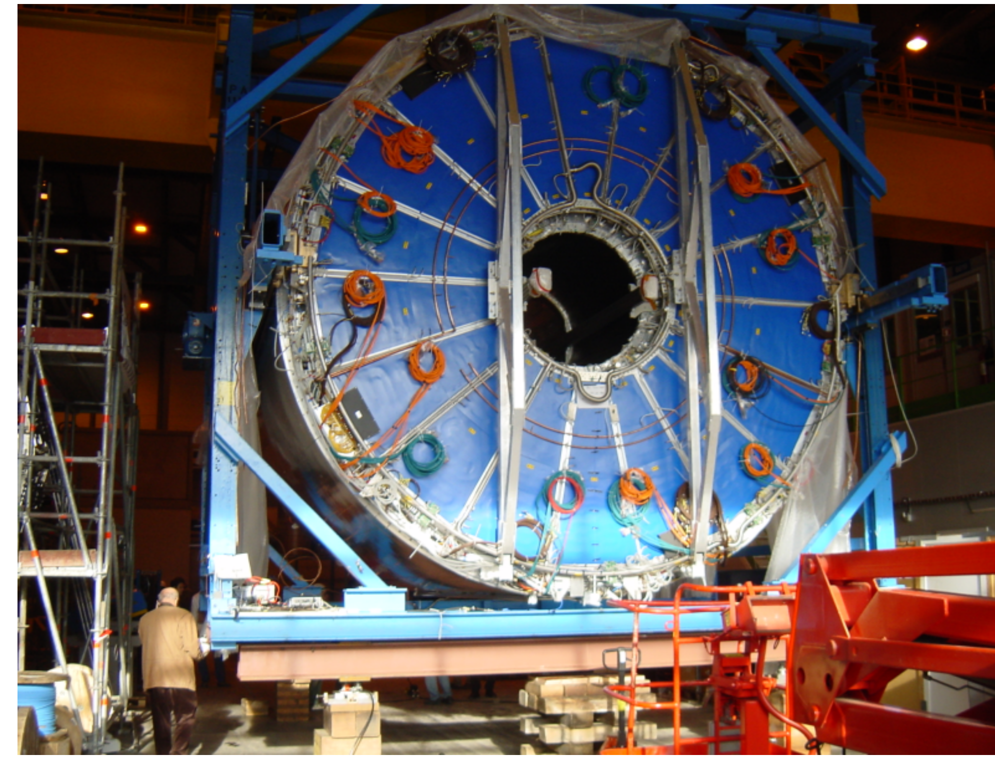


4 GEM Stack engineering design



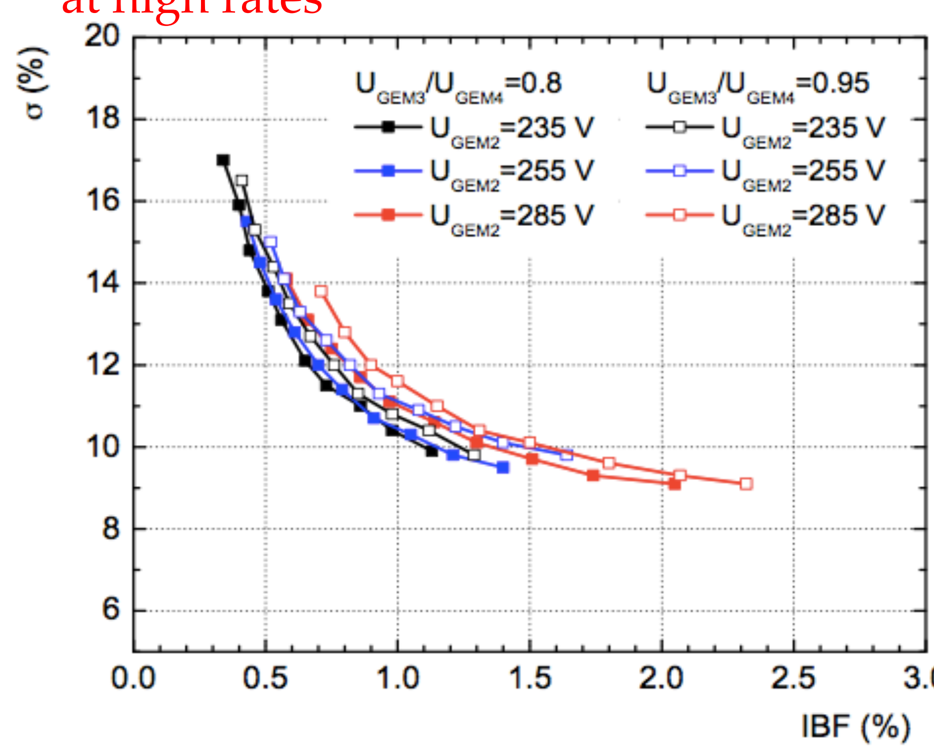
Preproduction:

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



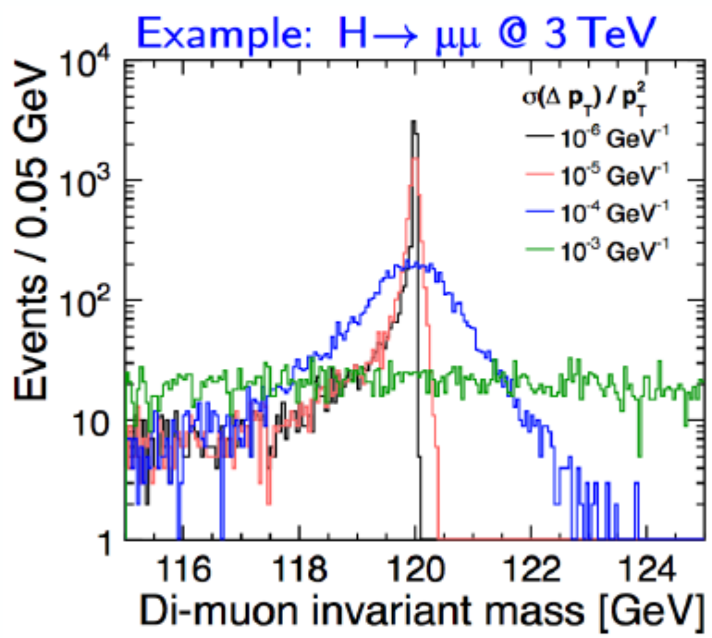
C. Garabatos

Muon detector for FCC-ee

CLIC Detector requirements from physics

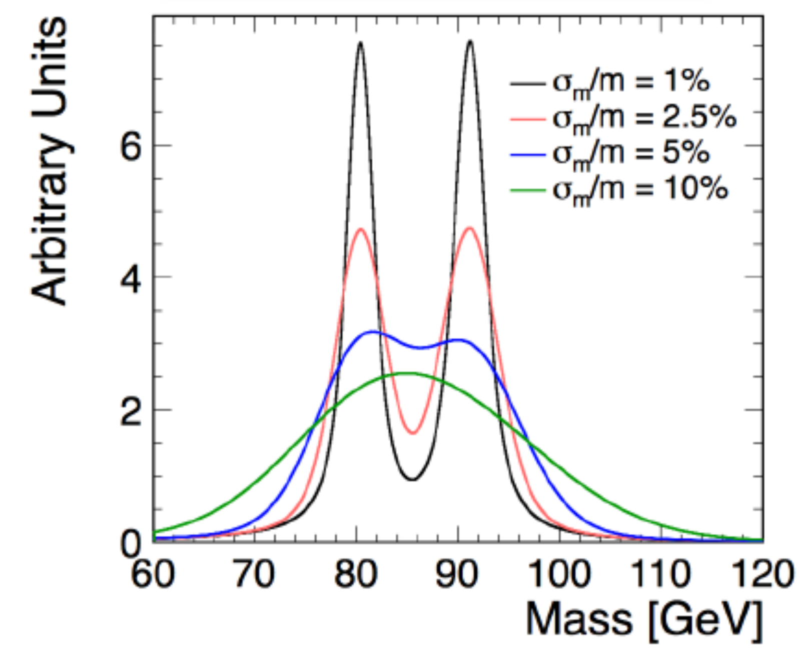
- momentum resolution
  - Higgs recoil mass, Higgs coupling to muons, BSM (smuon and neutralino masses)
  - for high p_T tracks

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



- 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

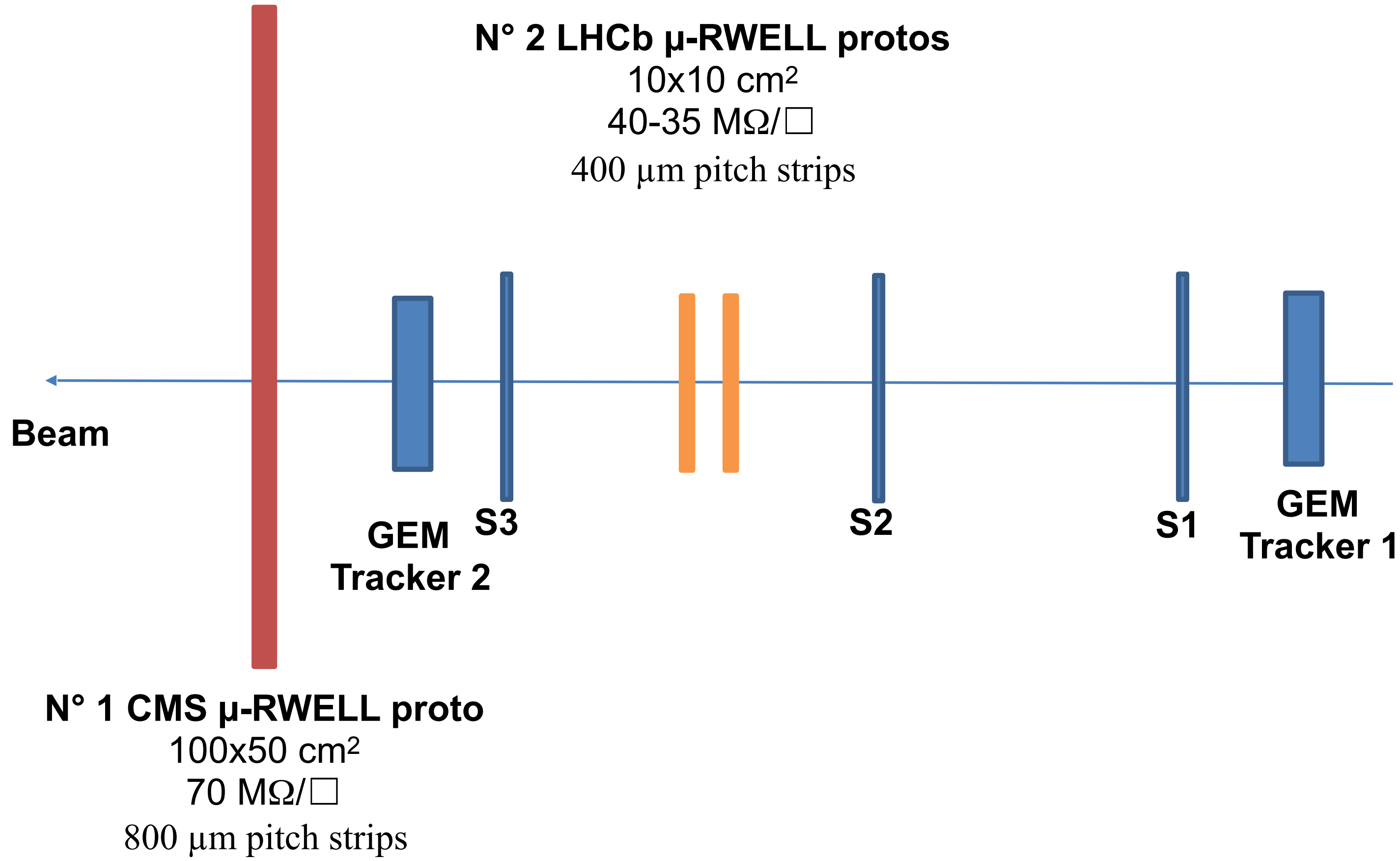
- forward coverage
  - electron and photon tagging (e.g. dark matter studies)

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: GIF++ ageing test

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

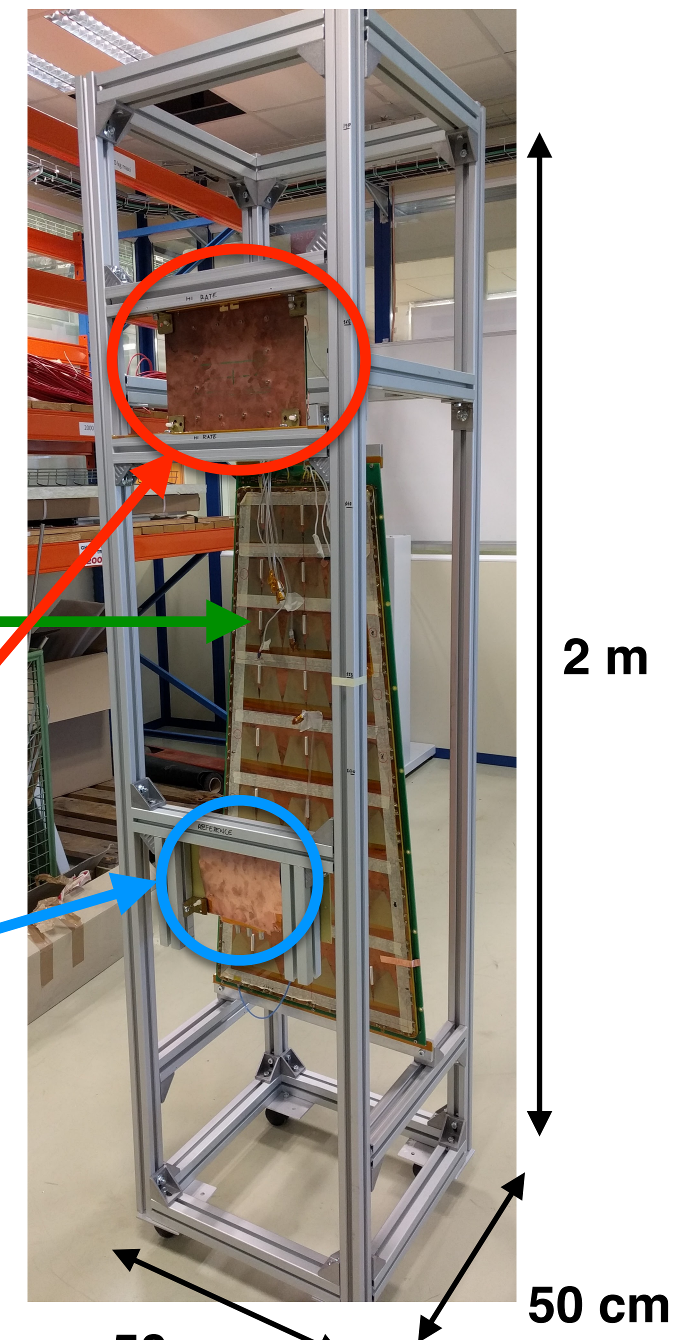
Motivations:
Need to qualify the behaviour and performance of μ-RWell detectors in a harsh radiation environment.

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

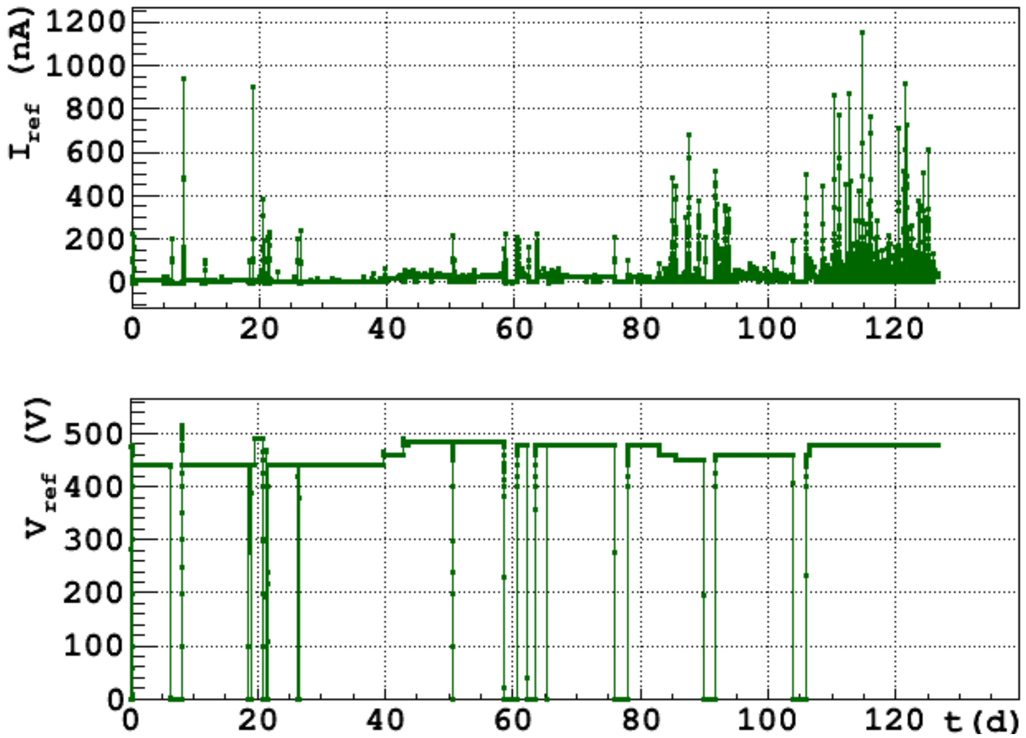
1) GE1/1 μ-RWell ($ArCO_2$)

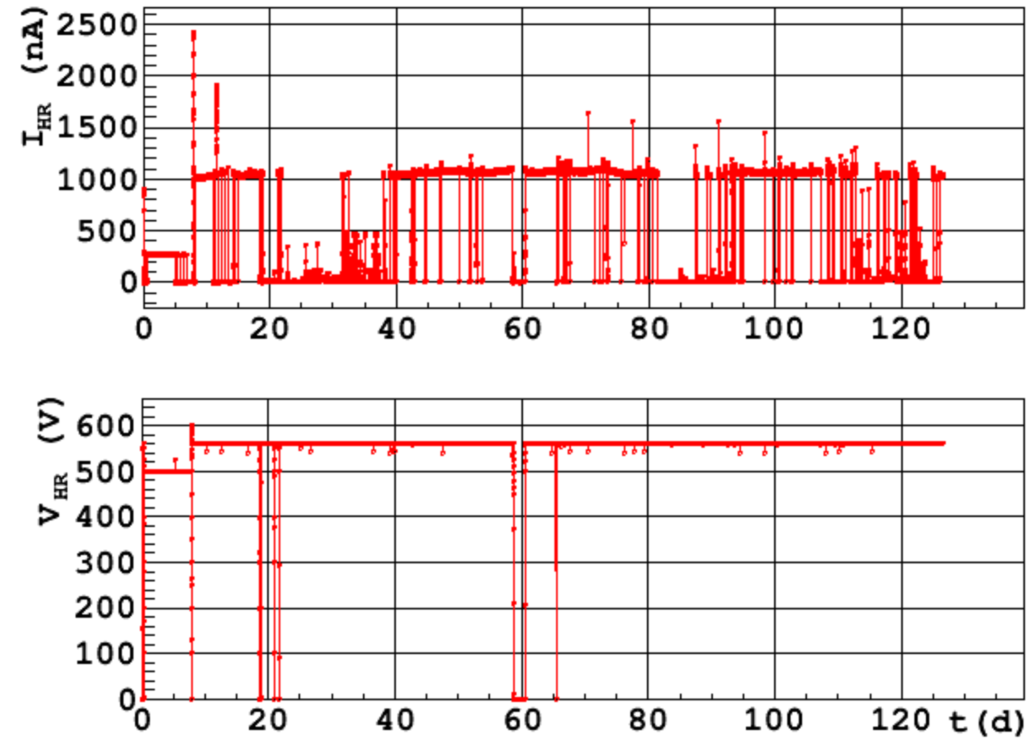
2) "high rate" μ-RWell ($ArCO_2CF_4$)
10cmx10cm

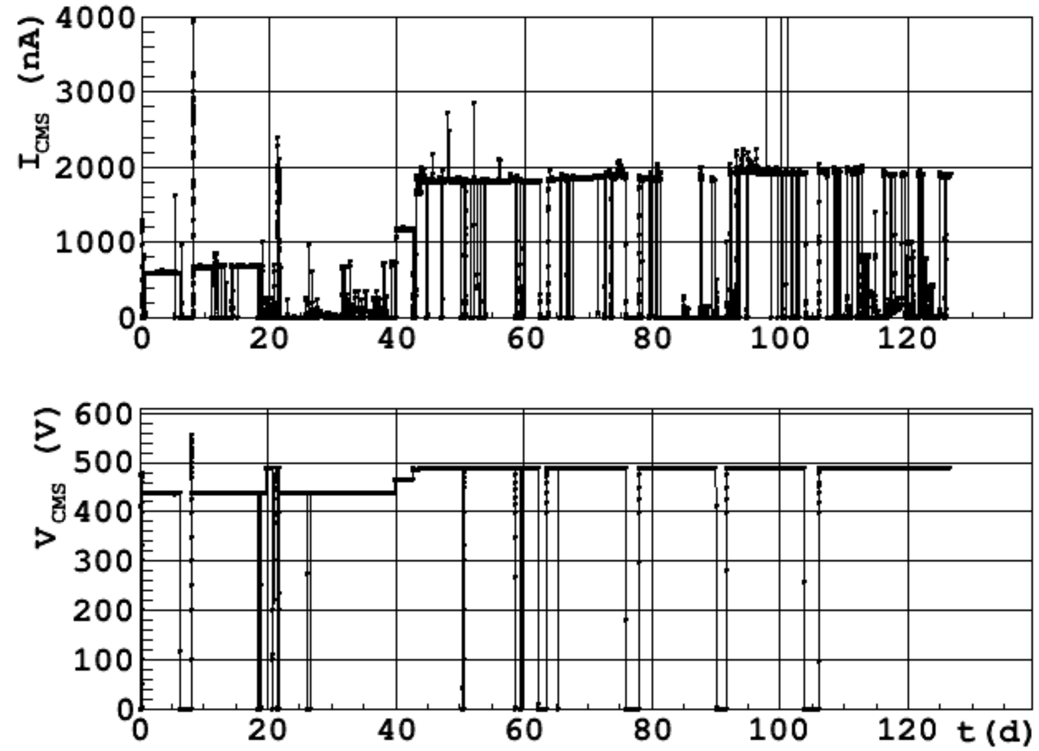
3) reference μ-RWell ($ArCO_2$)
5cmx5cm



GE2/1 μRWell: GIF++ ageing test





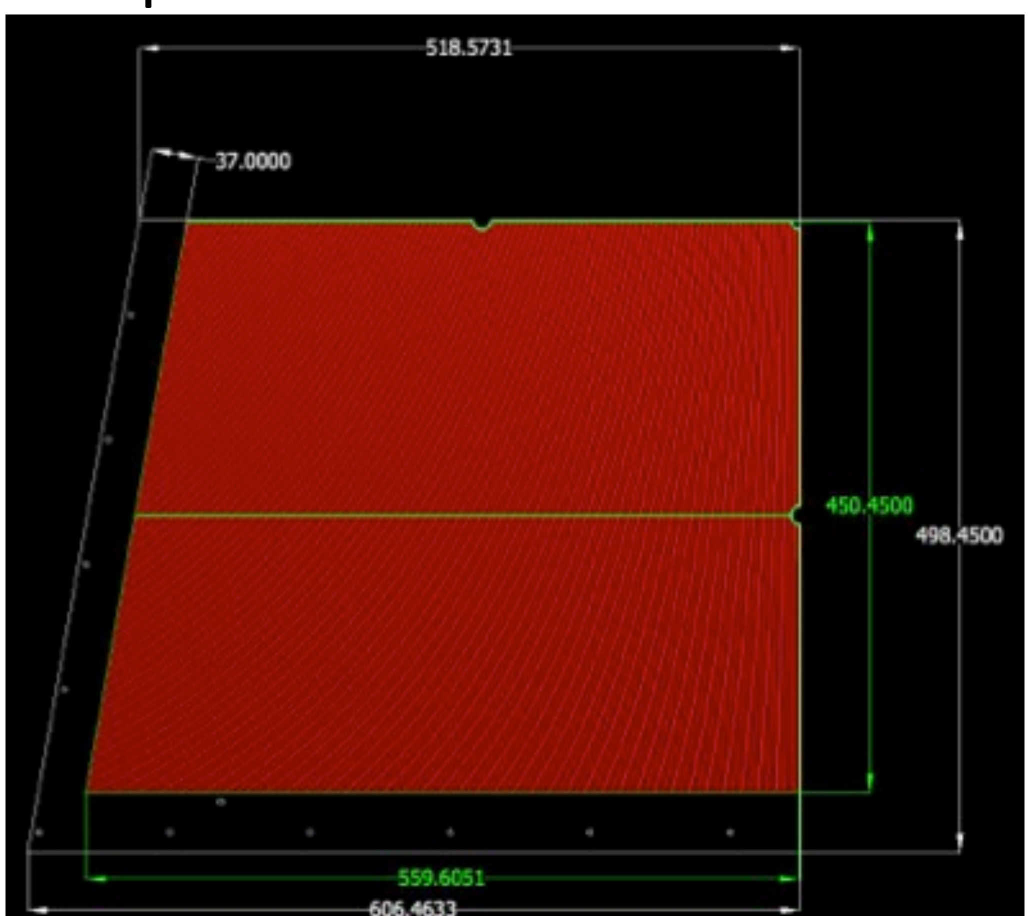


Highest spikes are of the order of 1-2 μA. This further demonstrates the intrinsic robustness of μRWell.

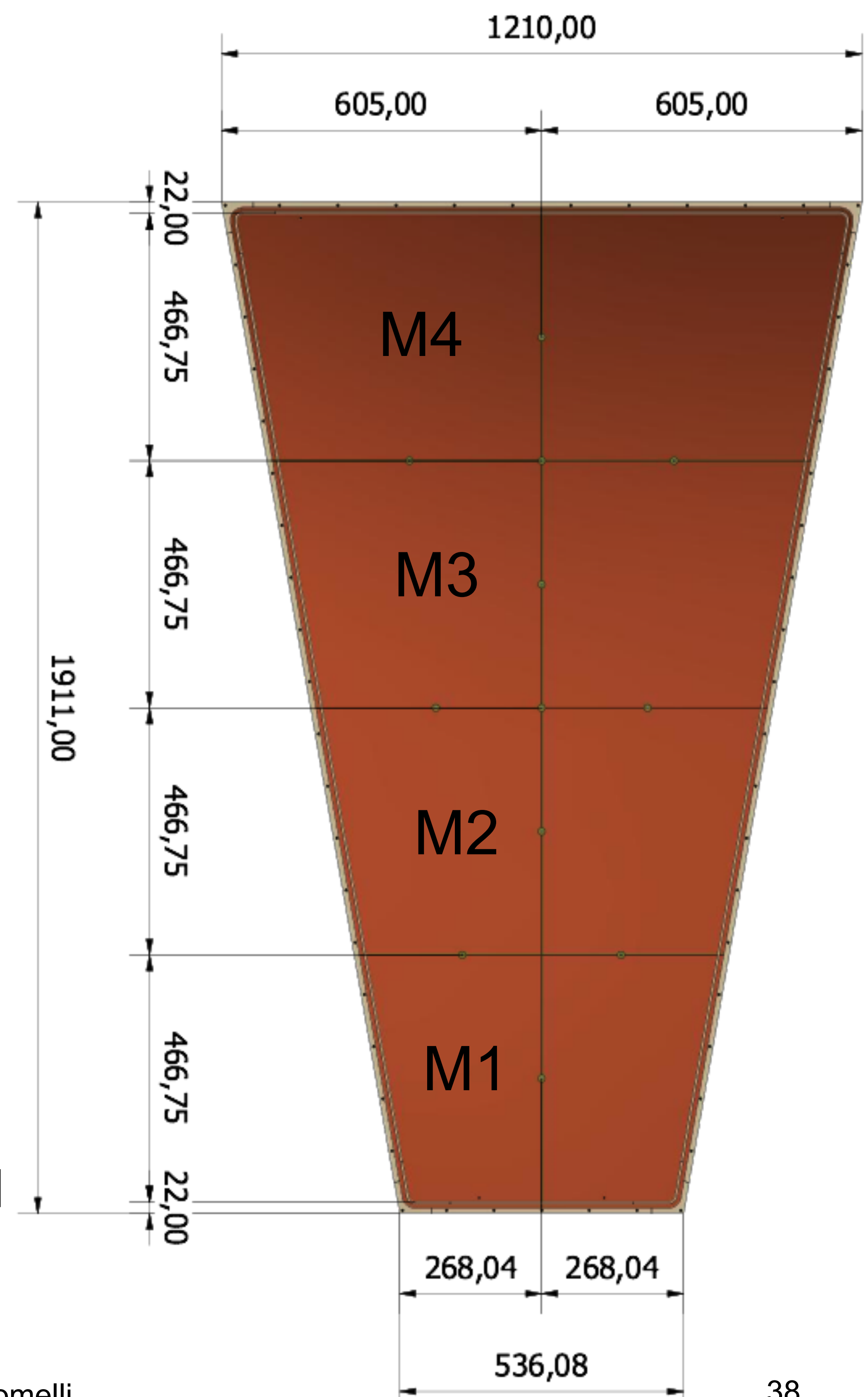
GE2/1 alternative option: μRWell

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