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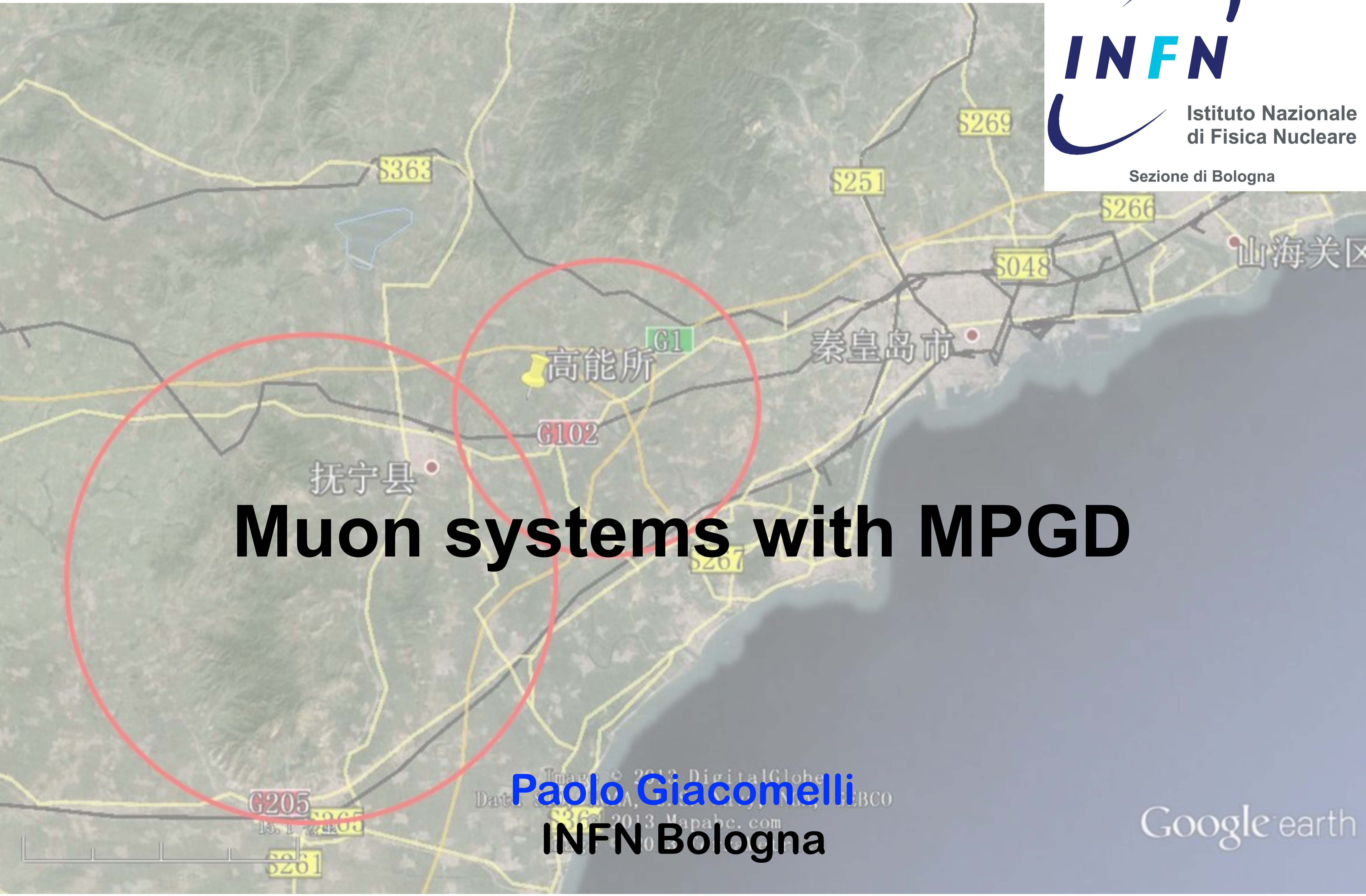


Muon systems with MPGD

Paolo Giacomelli
INFN Bologna

Outline

- Brief overview of future collider detectors
- Muon systems with MPGD
- A few practical examples
- INFN involvement
- Conclusions

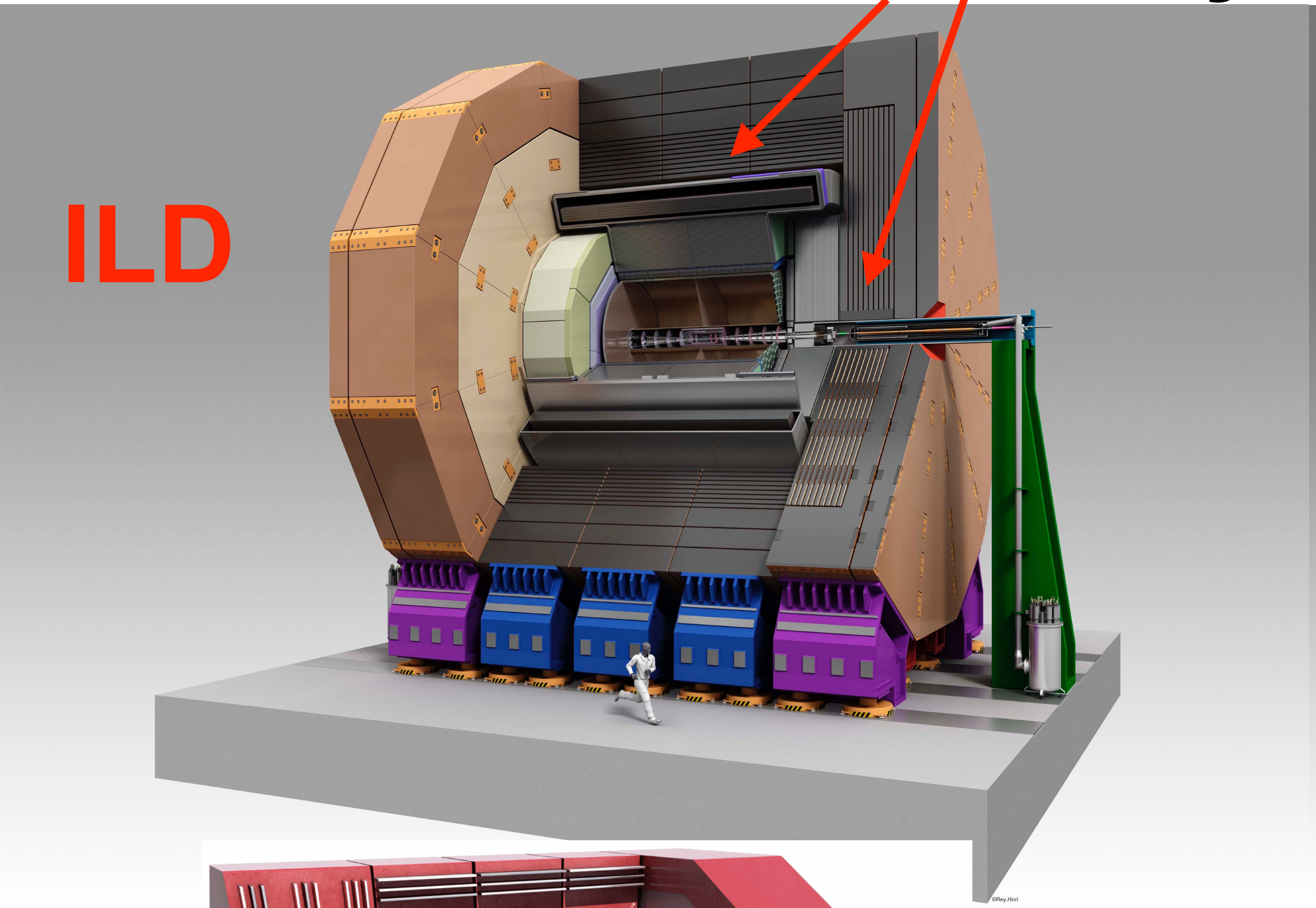
Detectors for CEPC and SppC

- Detectors for CEPC could be built right now. They can be thought as developments of the LEP detectors, like the ILD and SID detectors for ILC
- Detectors for SppC are much more challenging and will require extensive R&D before being realised.
  - R&D for HL-LHC is a good starting point, but technologies will have to be pushed even further for SppC (and FCC-hh)
- In both cases muon detectors will be extremely large and will cover ~10000 m^2 in the barrel and 3-5000 m^2 in the forward region
- Micro Pattern Gas Detectors (MPGD) could be used now to build a muon system for CEPC, and, with a significant R&D, should be able to cope with the harsher conditions of SppC.

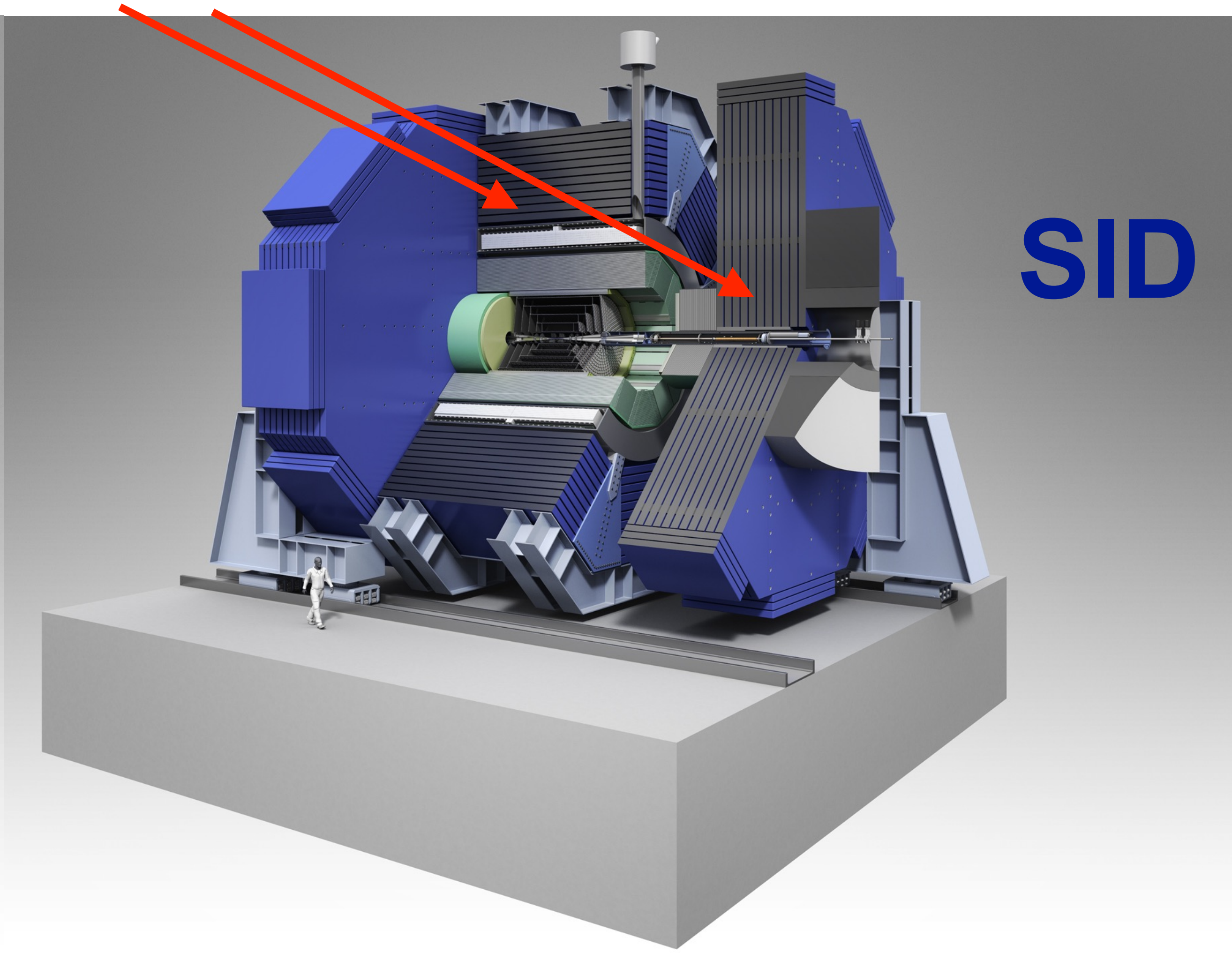
ILC and CLIC detectors

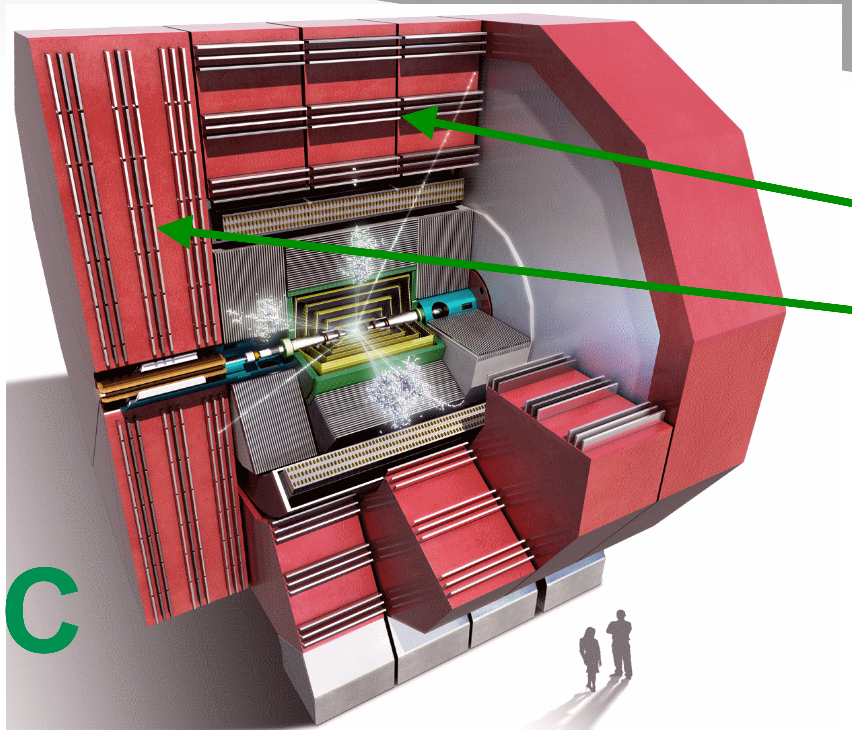
Muon system

ILD



SID





Muon system

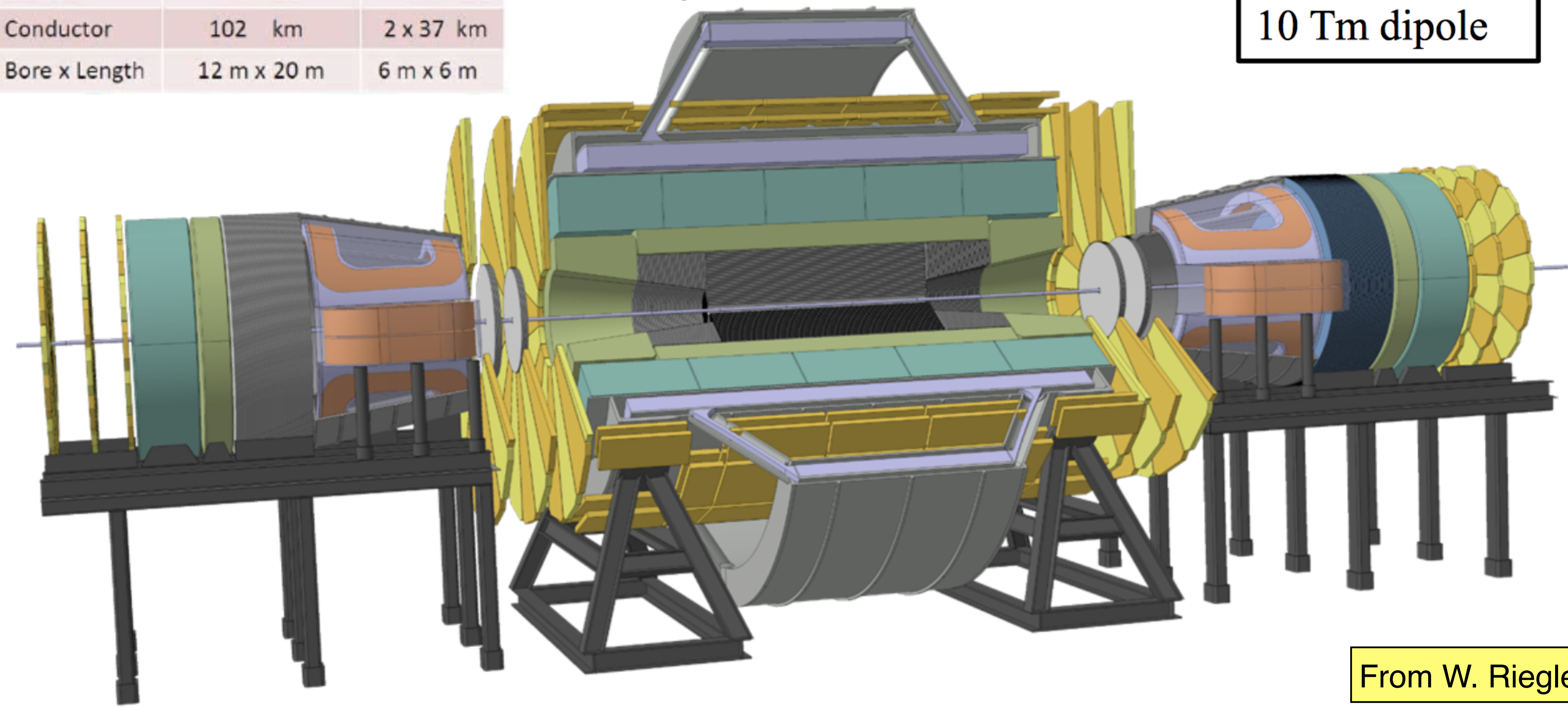
CLIC

Baseline FCC-hh detector

	Twin Solenoid	Dipole
Stored energy	53 GJ	2 x 1.5 GJ
Total mass	6 kt	0.5 kt
Peak field	6.5 T	6.0 T
Current	80 kA	20 kA
Conductor	102 km	2 x 37 km
Bore x Length	12 m x 20 m	6 m x 6 m

King Size Detector!
Diameter 27m
Length 60m

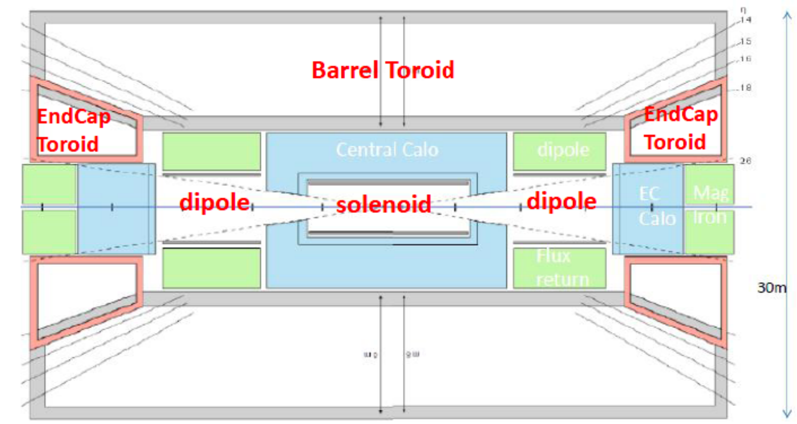
Twin solenoid
6 Tesla
12m bore
10 Tm dipole



From W. Riegler

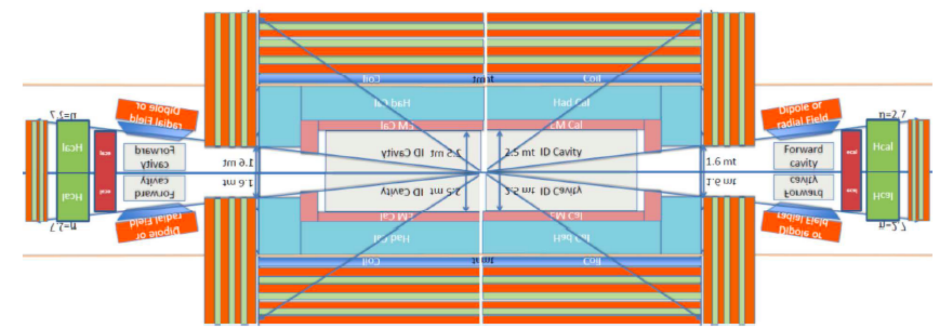
But magnet system would cost close to 0.7 BCHF!! Reasonable?

Muon systems with MPGD



Let us consider the "worst" SppC or FCC-hh conditions foreseen at the moment:

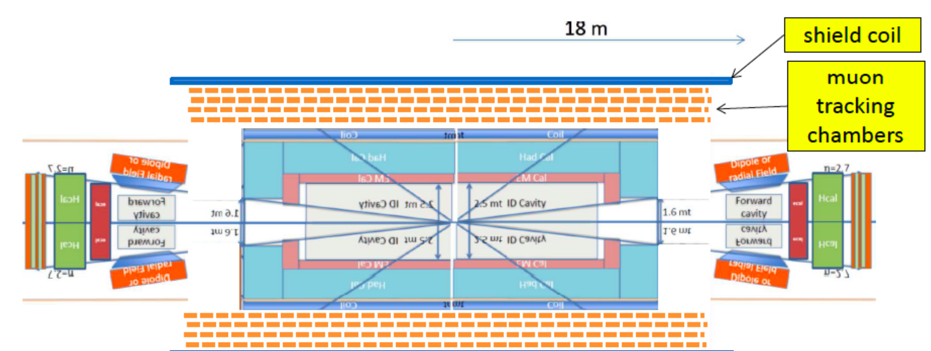
- ✓ L= 2.5 ÷(5) x 10^{35} $cm^{-2}s^{-1}$
- ✓ Bunch Crossing = 25 ns, or 5 ns
- ✓ Pile Up 900@25 ns, 180@5 ns BX separation
- ✓ 20 ab^{-1} integrated luminosity



Muon systems for CEPC-SppC will be very large:

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

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



➢ Given the requirement on the surface, almost unthinkable to use technologies different from gas detectors.

From M. Abbrescia

Muon systems with MPGD

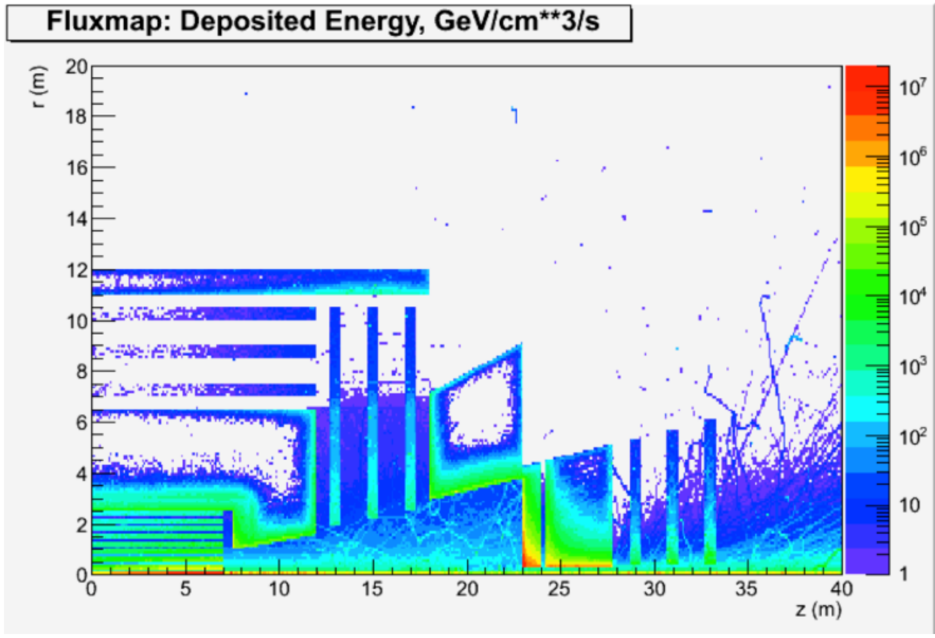
Have to provide Bunch Crossing identification

- ✓ time resolution ≤ 1 ns for 5 ns BC
- ✓ time resolution ≤ 7 ns for 25 ns BC
- ✓ o(100) ps could be desirable for specific applications:
  - ➢ Time structure of the event, Pile Up mitigation, Muon tagging
  - ➢ Generally difficult to achieve, requires a strong physics case

Have to operate in high background

(very large uncertainties depending on shielding, actual structure,etc.)

- ✓ o(few kHz/cm^2) in the barrel
- ✓ o(10-50 kHz/cm^2) in the endcap
- ✓ Even more, o(100 kHz/cm^2) in the forward regions

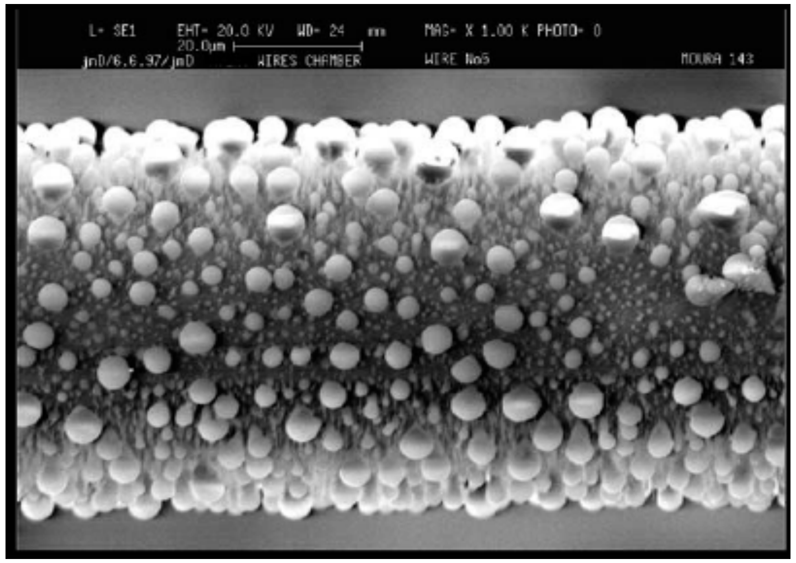


by C. Young

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

From M. Abbrescia

Muon systems with MPGD



Have to operate for ≈ 20 years

✓ Ageing issues to be carefully considered

✓ Detector will be exposed to a radiation level about

10 times higher than HL-LHC@same pseudorapidity (SppC)

(2x higher cross section, 4x higher peak luminosity)

➢ 10-25 C/cm for wire chambers

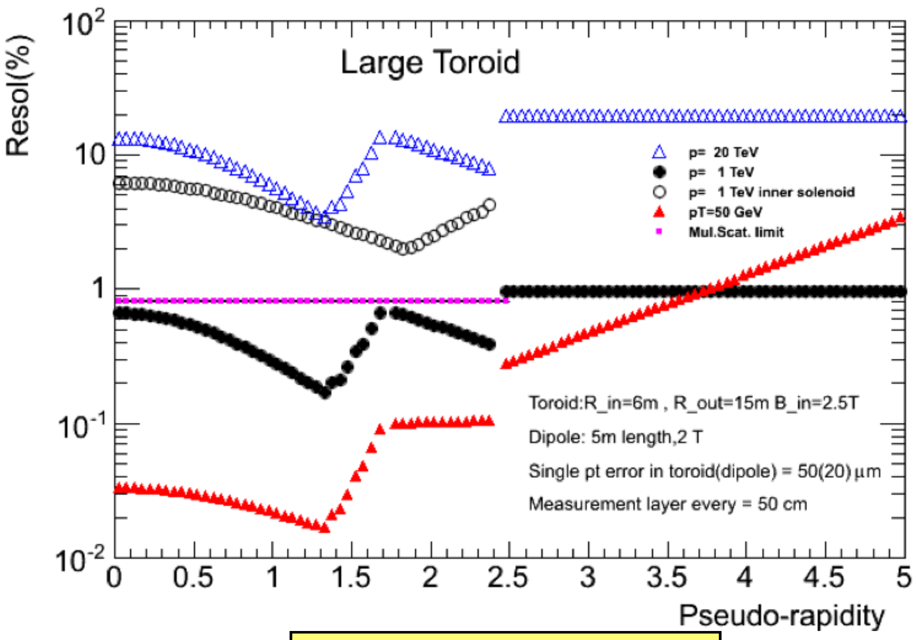
✓ None of the present detectors have been tested up to those values

Have to provide tracking (?)

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

✓ 20-50 μm or better spatial resolution

to provide 10% p_T resolution at a few TeV

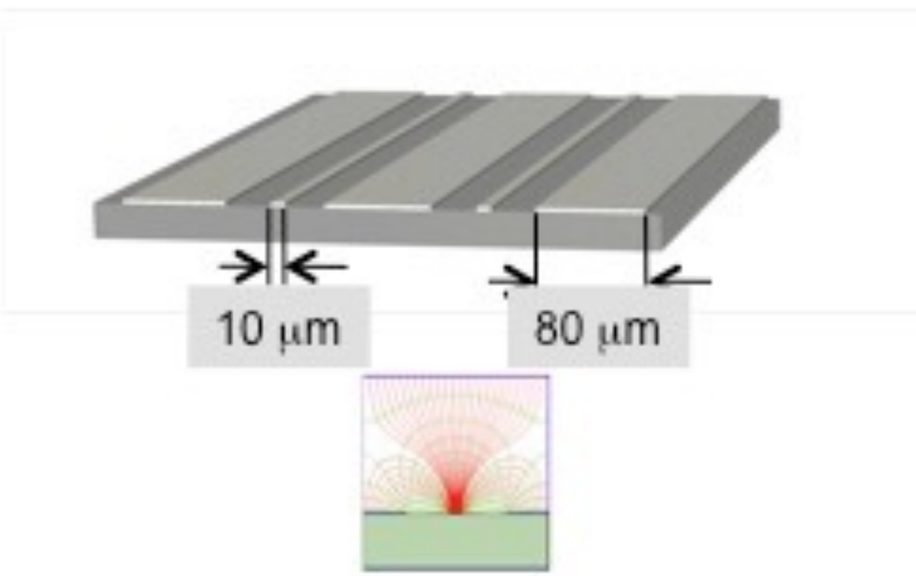


From M. Abbrescia

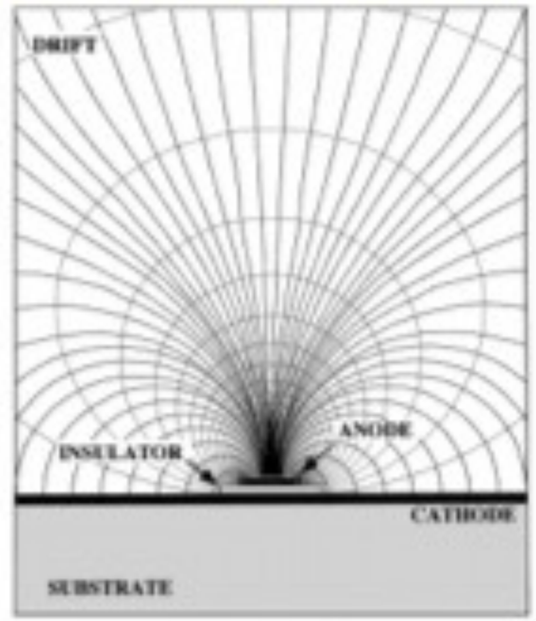
Have to provide trigger

The MPGD zoo of the 90s

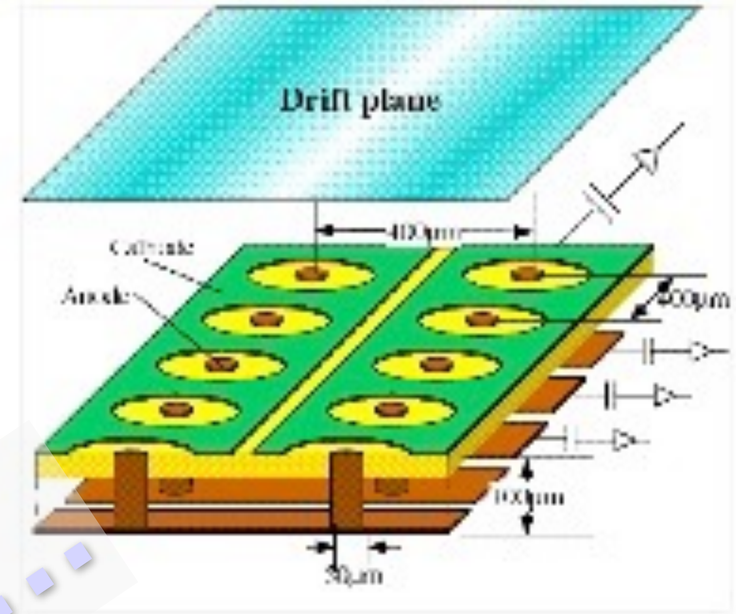
Microstrip Gas Chamber
[A. Oed, NIM A263, 351 (1988)]



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

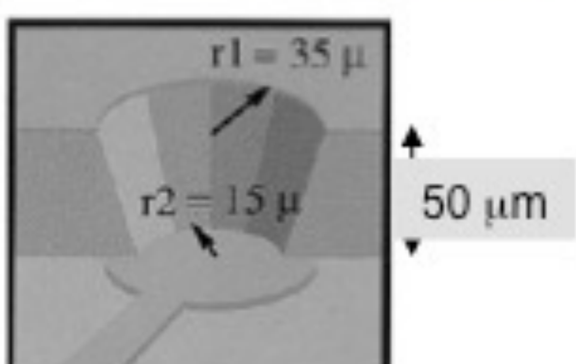


Microdot Chamber
[S.F. Biagi et al., NIM A361, 72 (1995)]

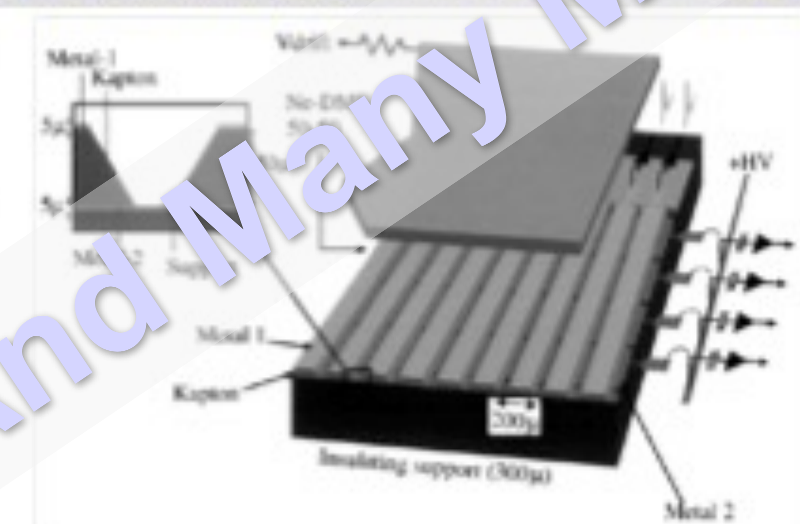


Compteur à Trous (CAT)
[F. Bartol et al., J. Phys. III 6, 337 (1996)]

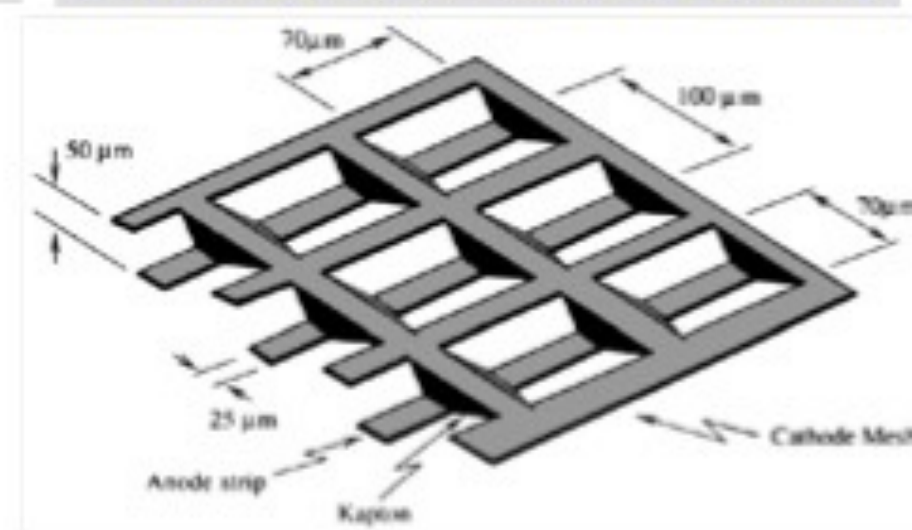
WELL Detector (µCAT)
[R. Bellazzini et al., NIM A423, 125 (1999)]



Micro Groove Counter
[Bellazzini et al., NIM A424, 444 (1999)]



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

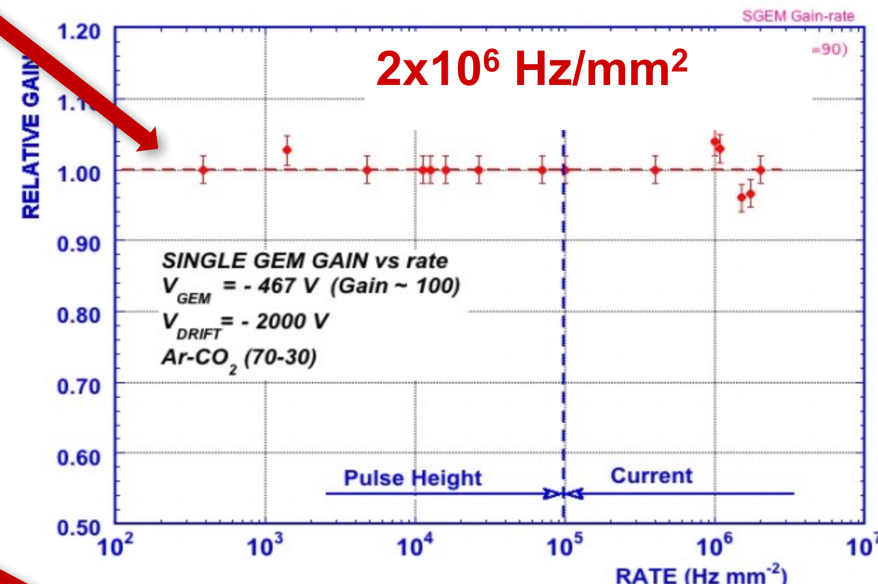


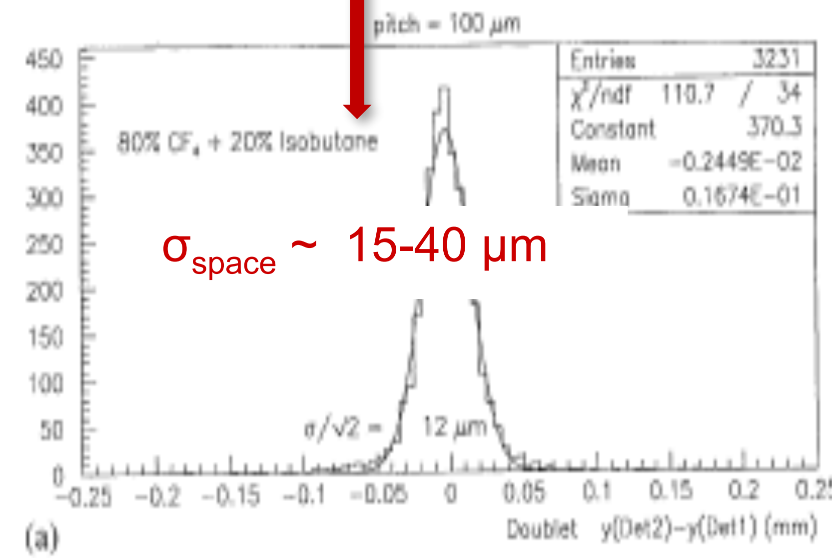
And Many More ....

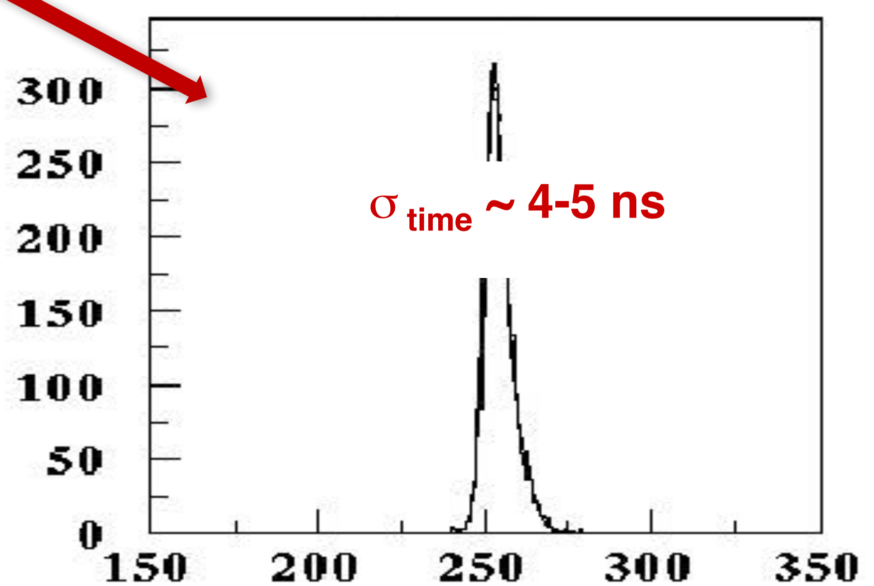
Muon systems with MPGD

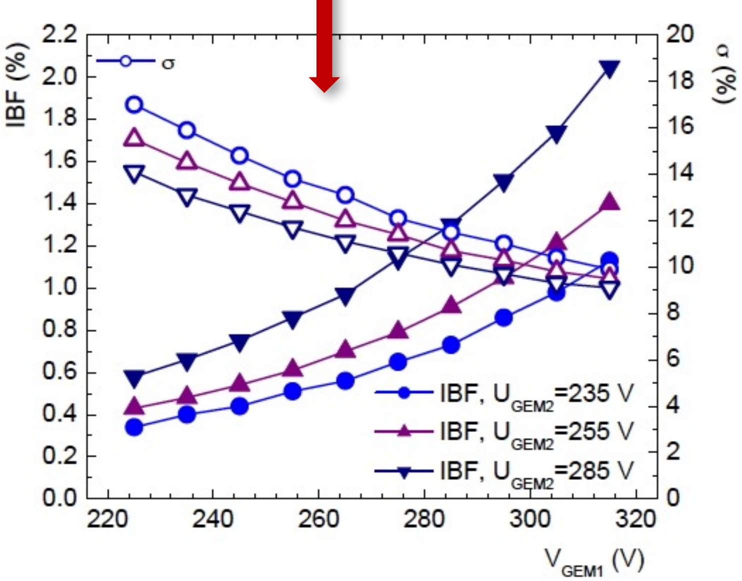
MPGD

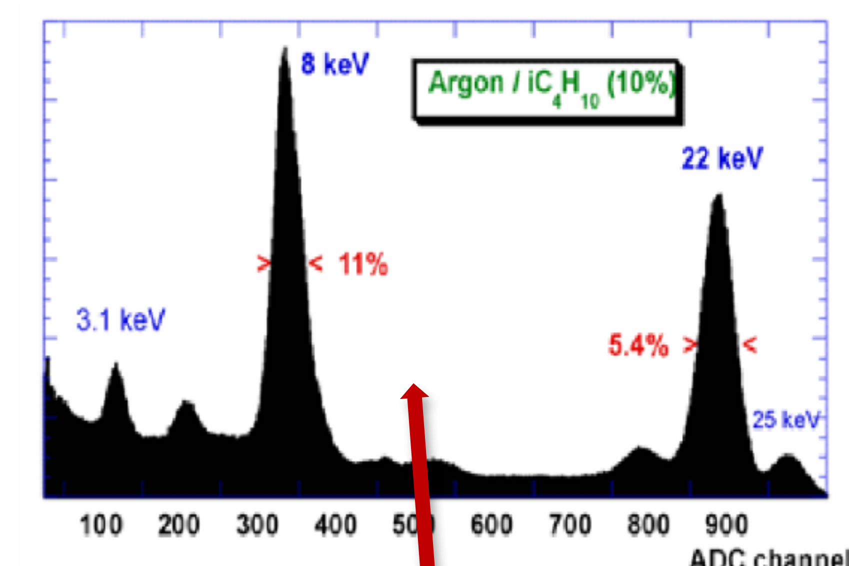
- ✓ High rate capability
- ✓ Excellent radiation hardness
- ✓ Large active areas / industrial production
- ✓ Good timing resolution
- ✓ Ion backflow/photon feedback reduction
- ✓ Excellent spatial resolution











- ✓ Good Energy Resolution

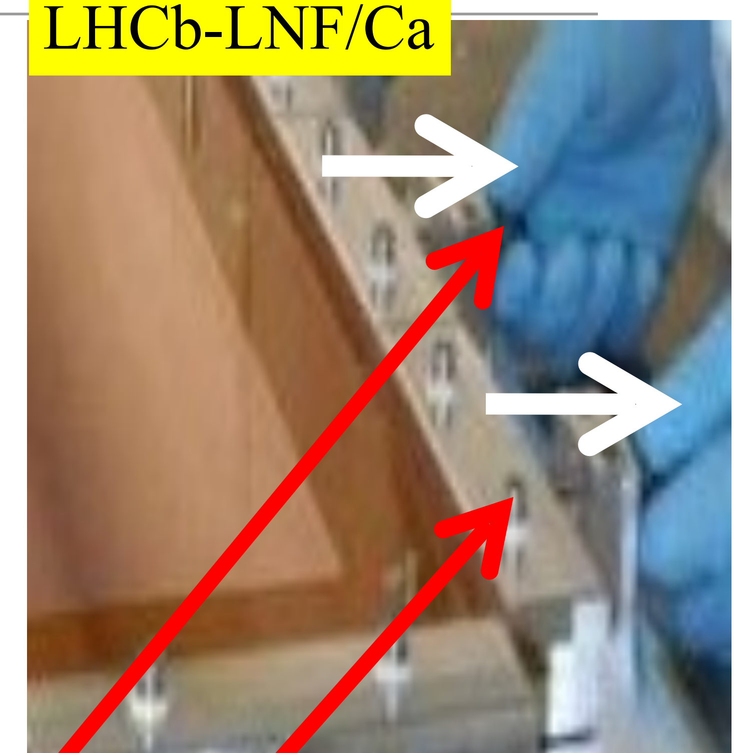
From M. Abbrescia

Muon systems with MPGD

- MPGDs suitable for a CEPC muon system
- Use of the current detector technologies at SppC implies an important R&D to overcome some of the present limits
- This R&D has already started for HL-LHC, but will need to be pushed further (at least quantitatively) for SppC:
- Micro Pattern Gas Detectors
  - ✓ Large scale production: will o(several 1000 m^2) production and operation (electronics, stability, …) of MPGDs be feasible?
- All detectors:
  - ✓ Ageing issues must be carefully studied and taken care of!
  - ✓ Gas issues have to be taken care of: gas is the “core” of a gas detector. Study eco-friendly (low global warming power) gas mixtures

From M. Abbrescia

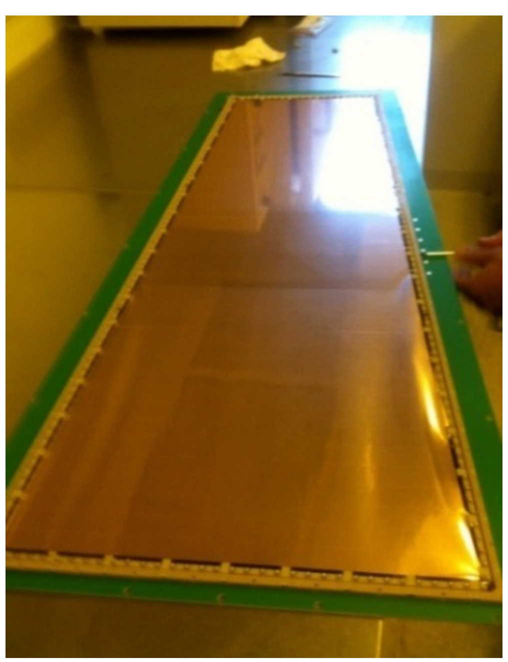
GEMs: the construction challenge



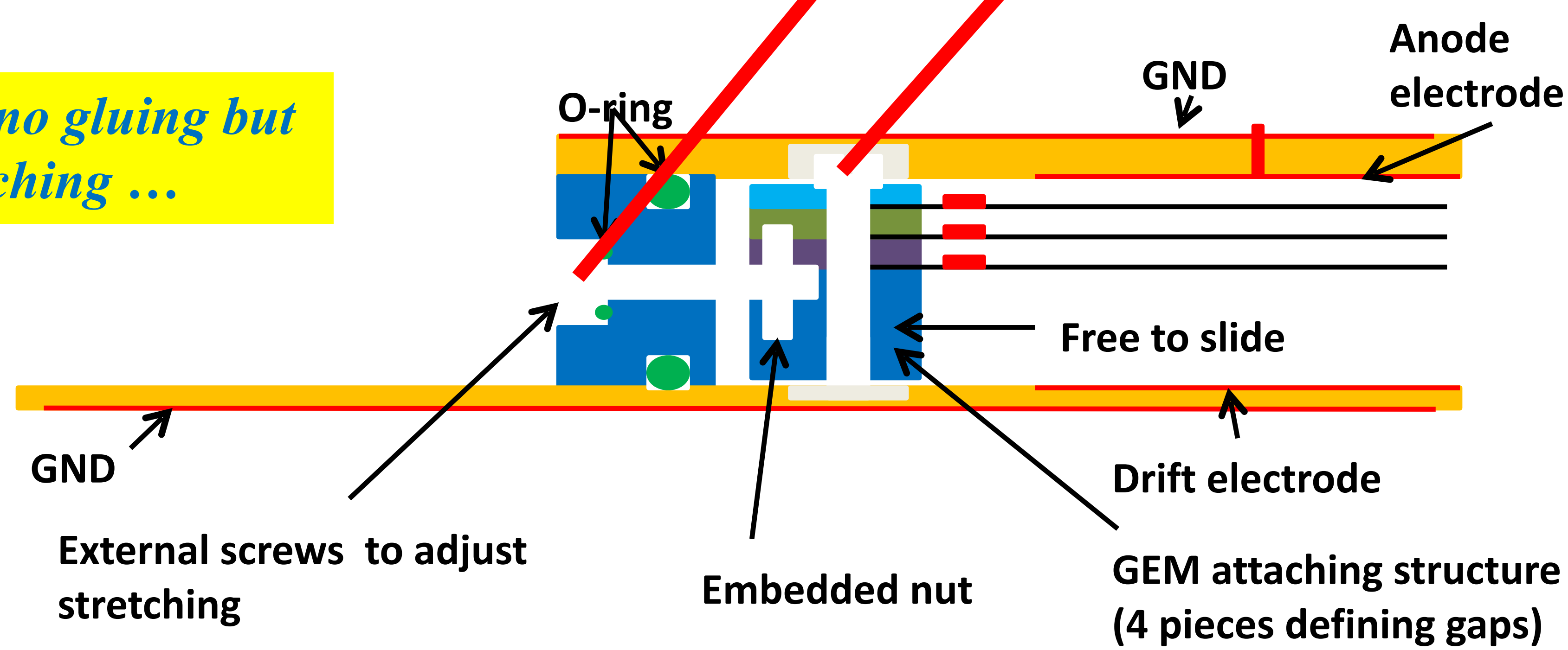
The construction of the GEM requires some assembly steps such as **the stretching of the 3 GEM foils,** with a quite **large mechanical tension** to cope with **➔ ~1 kg/cm**.

Improvements in the GEM construction process has been recently introduced by R. de Oliveira (NS2 detector assembly scheme): **no gluing, no soldering, no spacer in the active area ➔ re-opening of the detector if repairs needed became possible.**

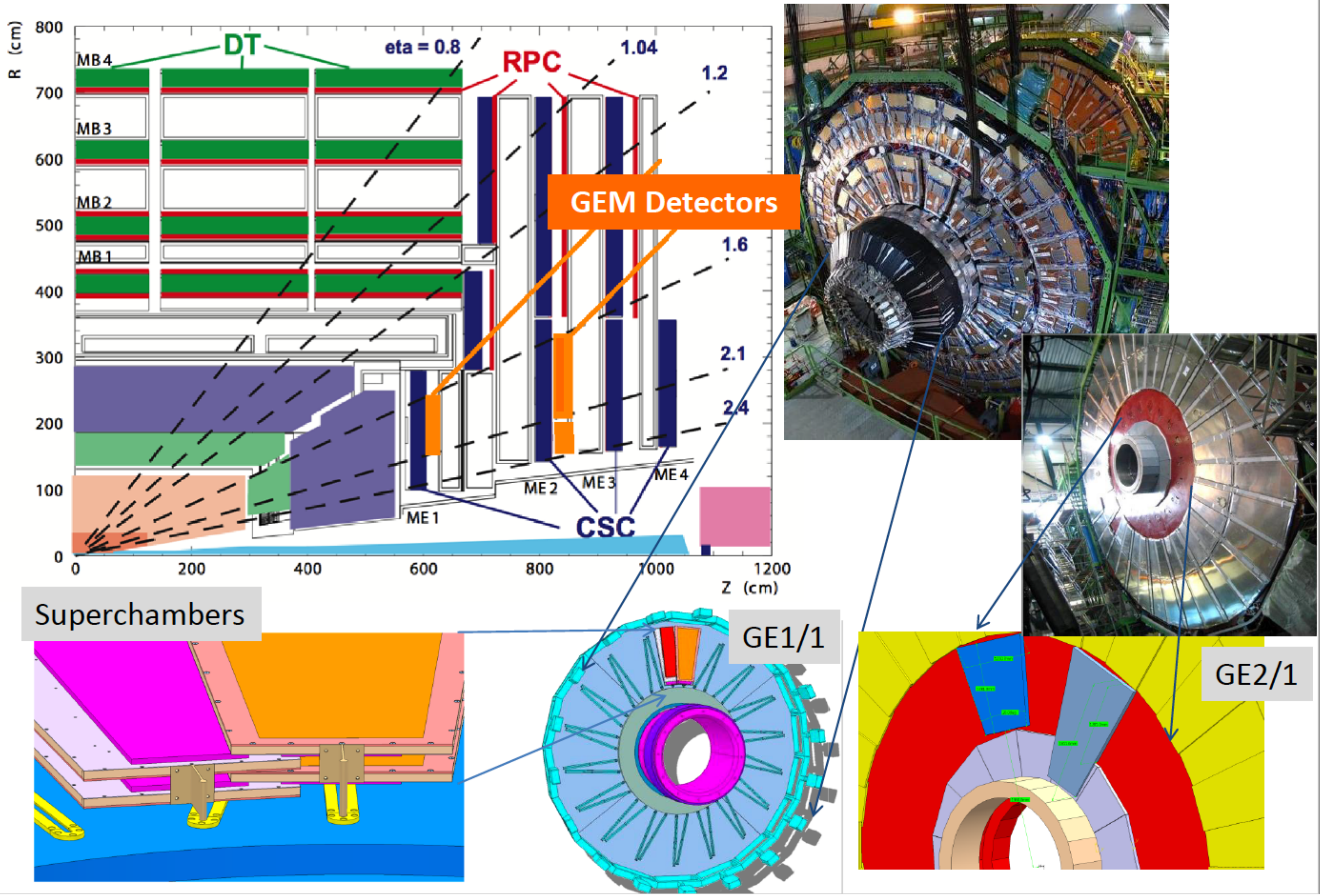
But the GEM construction still remains a demanding & complex operation ➔ requiring delicate stretching with specialized man-power.



NS2(CERN): no gluing but still stretching …



CSC GEM upgrade

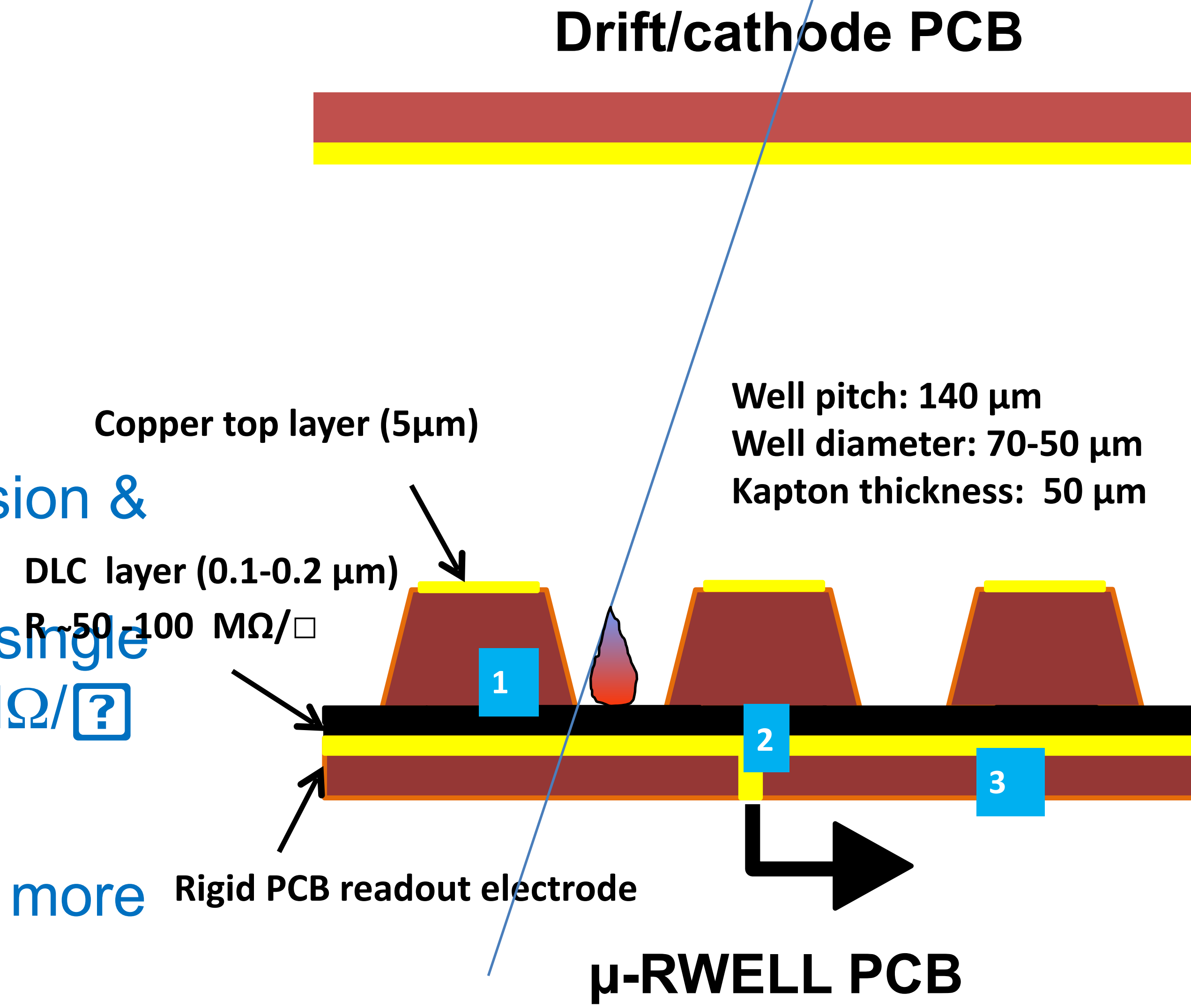


The μ-RWELL architecture

The μ-RWELL detector is composed by 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)** >> 100 kHz/cm^2: 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

From G. Bencivenni

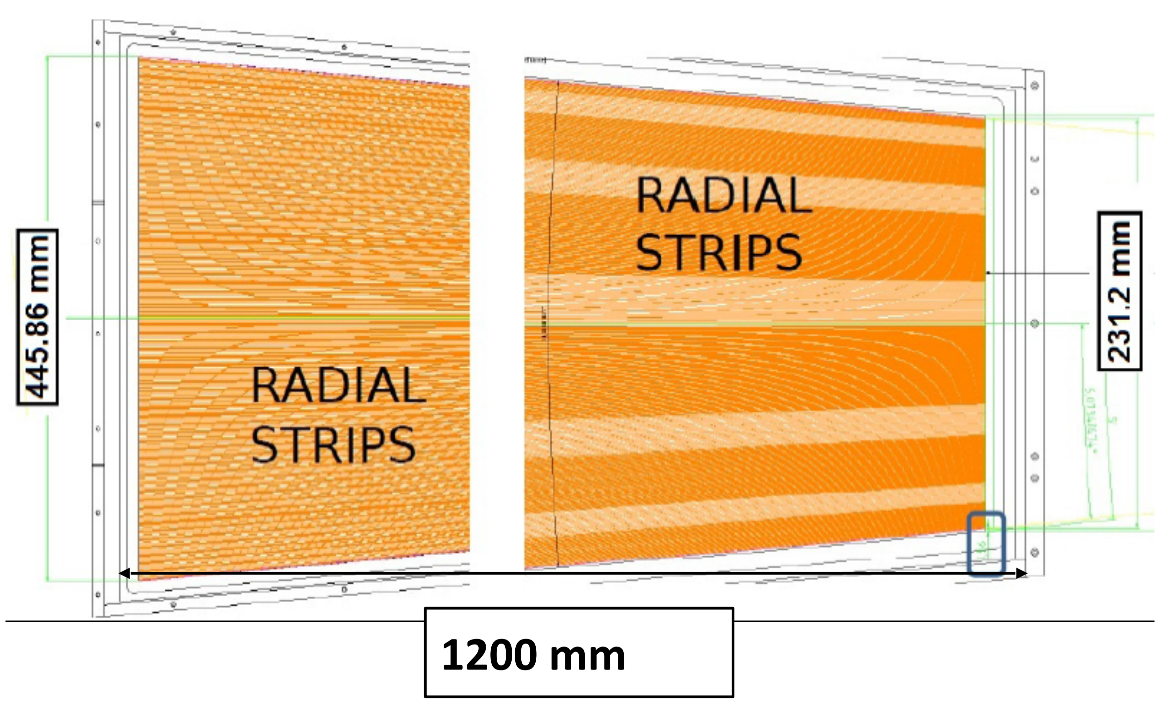
Towards large area & detector engineering

In the framework of the **CMS-phase2 muon upgrade** we are developing **large size μ-RWELL**. The **R&D** is performed in strict collaboration with Italian industrial partners (**ELTOS SpA & MDT**). The work will be performed in **two years** with following schedule:

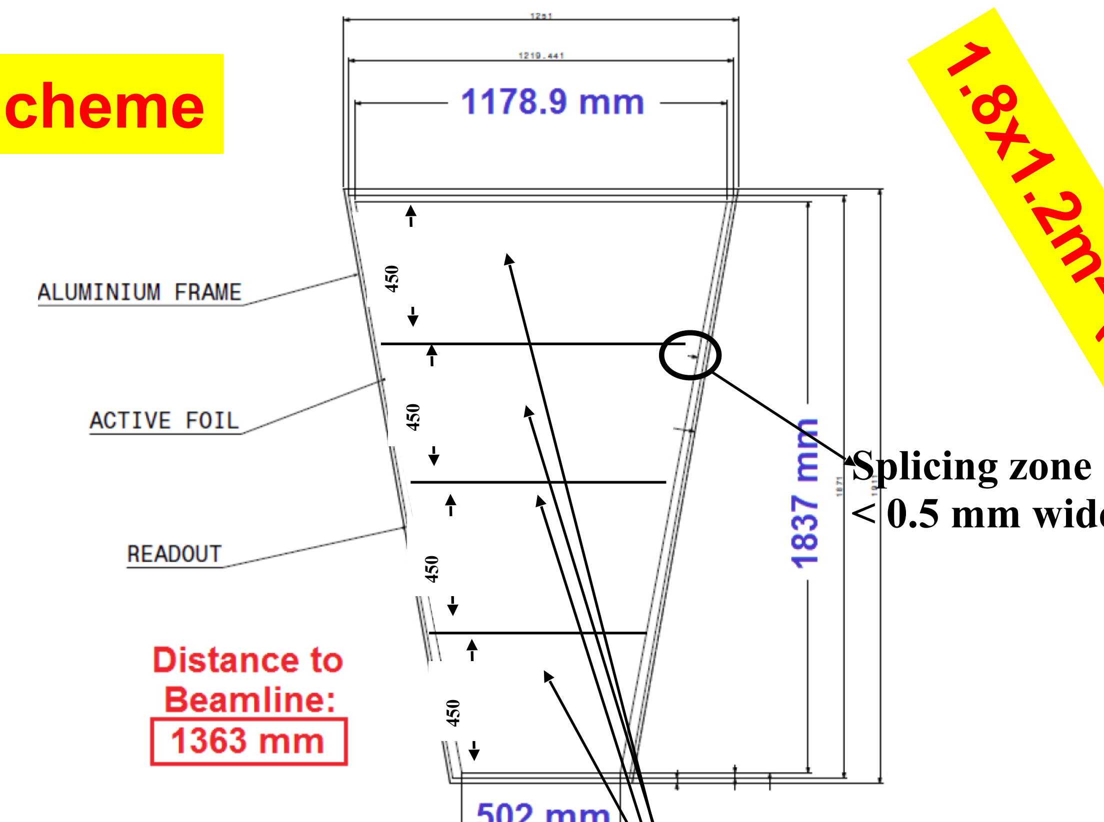
1. Construction & test of the first **$1.2 \times 0.5 m^2$ (GE1/1) μ-RWELL** **2016**
2. Mechanical study and mock-up of $1.8 \times 1.2\ m^2$ (GE2/1) μ-RWELL **12/2016**
3. Construction & test of the first **$1.8 \times 1.2 m^2$ (GE2/1) μ-RWELL** **12/2017- 6/2018**

$1.2 \times 0.5 m^2$ (GE1/1) μ-RWELL

LR scheme



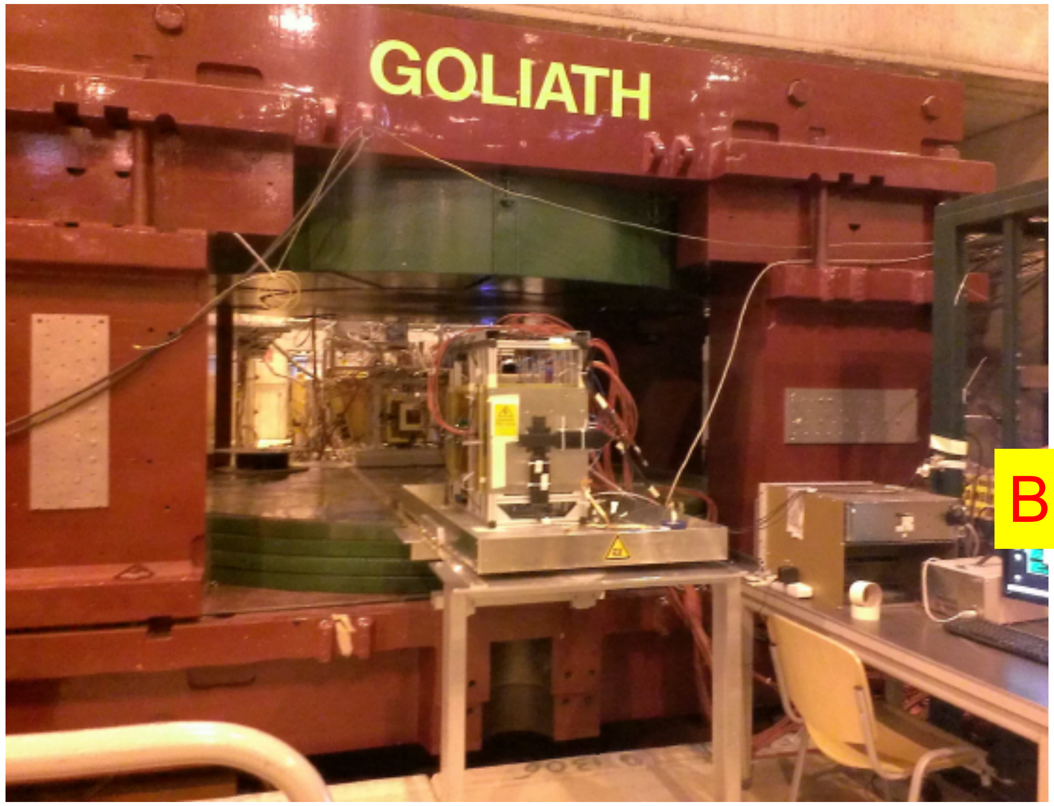
From G. Bencivenni



$1.8 \times 1.2 m^2$ (GE2/1) μ-RWELL

Four PCB μ-RWELL spliced with the same technique used for large ATLAS MM + only one cathode closing the detector

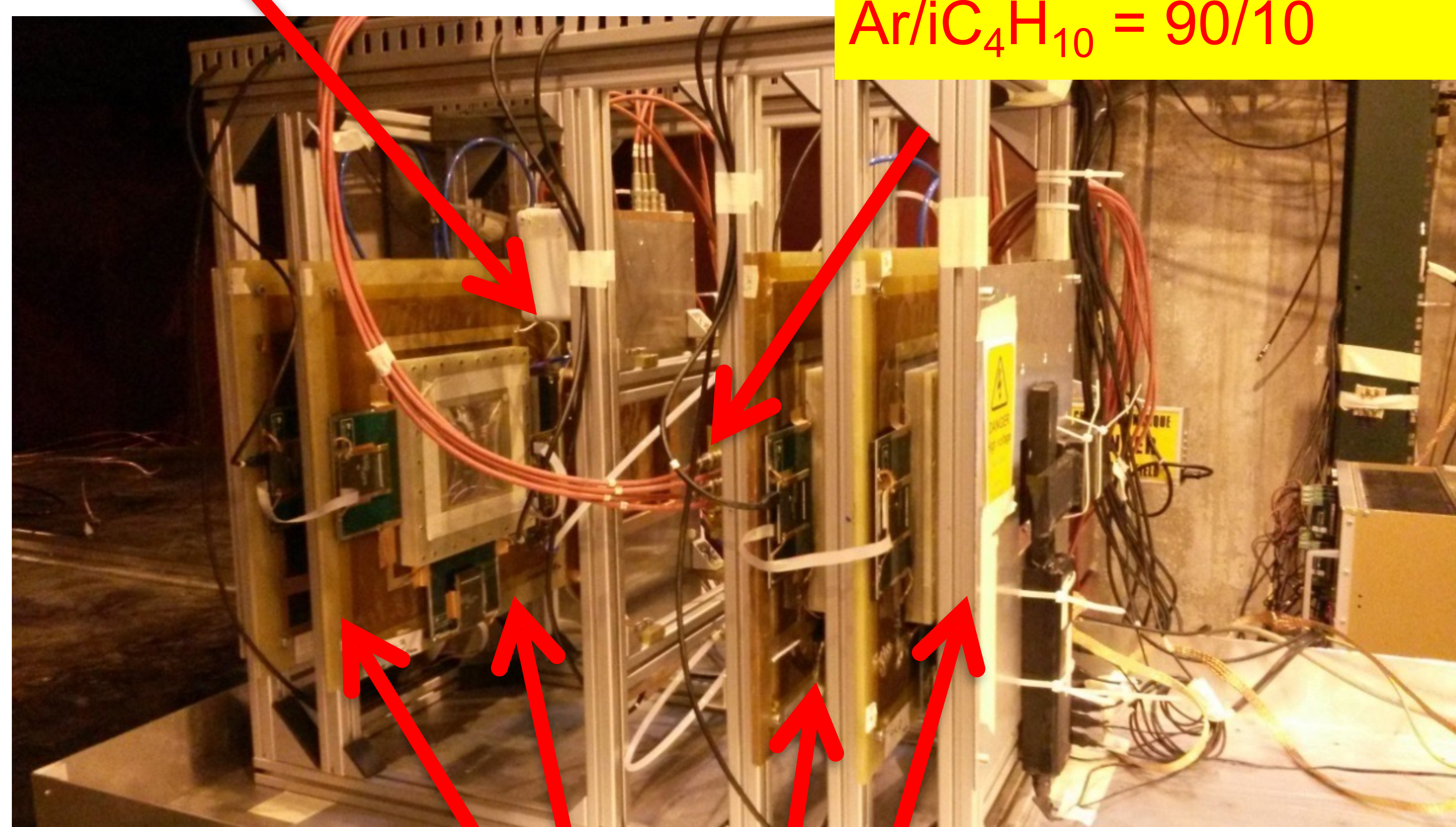
The μ-RWELL performance: Beam Tests



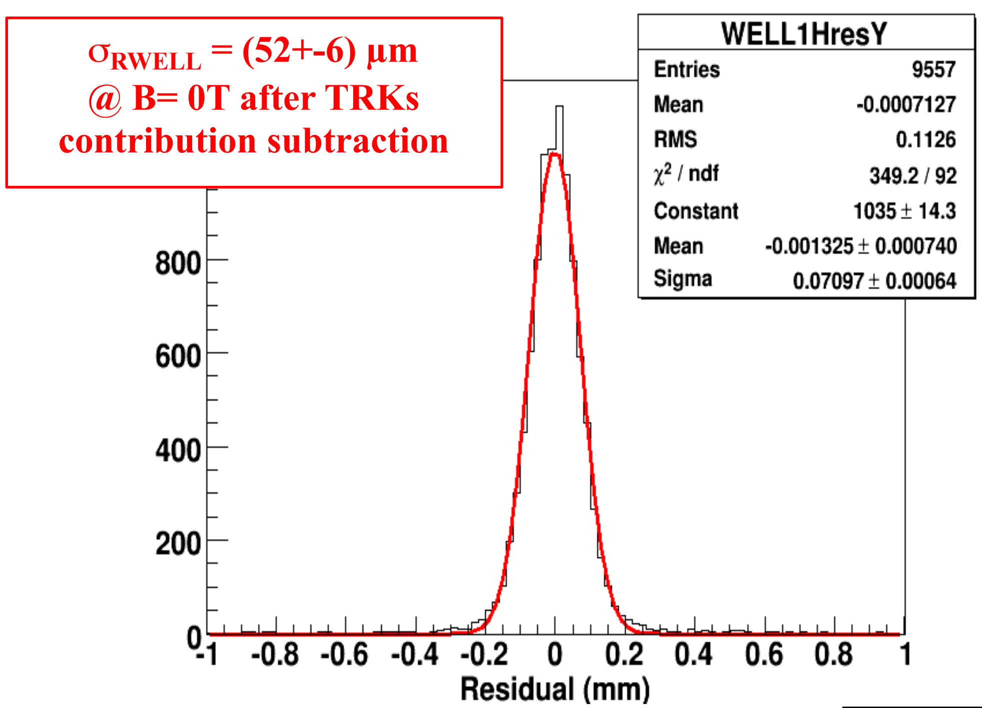
H4 Beam Area (RD51)
Muon beam momentum: 150 GeV/c
Goliath: B up to 1.4 T

μ-RWELL prototype
12-80-880 MΩ /□
400 μm pitch strips
APV25 (**CC analysis**)
Ar/iC_4H_{10} = 90/10

BES III-GEM chambers



GEMs Trackers



From G. Bencivenni

INFN
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Sezione di Bologna

INFN and MPGD detectors

- INFN groups have a very good experience on MPGD detectors. They have been active in this domain for several years.
- Many technologies have been developed and tested
  - GEMs
  - THGEMs
  - MicroMegas
  - μRwell
- Need to transfer these technologies to industry. Work started in conjunction with a few european and asian industries.
- R&D pursued in several contexts: RD51, HL-LHC Phase 2 upgrades, AIDA-2020
- R&D also started on eco-friendly gas mixtures

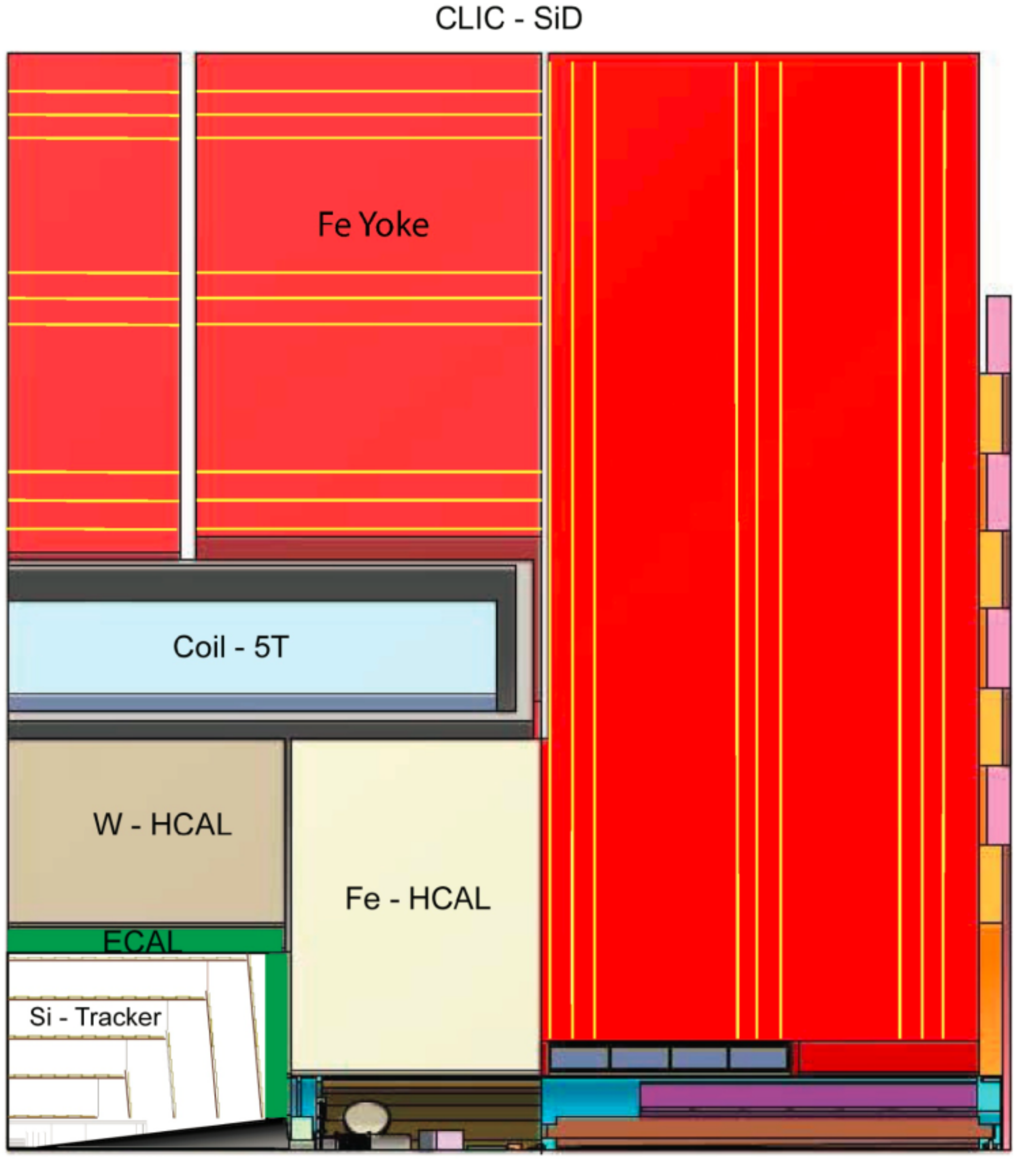
Summary

- MPGDs offer a very attractive solution for future muon systems at CEPC, SppC and FCC
- MPGDs fulfil these requirements:
  - Precise spatial resolution o(50 μm)
  - Good timing resolution o(1 ns). Specialised MPGDs (FTM) could reach o(100 ps)
  - High rate capability (still to be improved for the very forward region at SppC)
  - Modular
  - Cost effective
- R&D started for developing large area detectors suitable for mass production
- A few companies are collaborating already, will look for more industrial partners
- INFN has started a work package dedicated to the study of MPGDs for building muon systems for future experiments

Backup slides

Design of FCC-ee Detectors

Adapted from ILC/CLIC detector: Experience with LEP detectors and ~20 years R&D for LC



Some physics differences

-- Lower maximum energy 400GeV vs. >1000 GeV

➔ Momentum & energy resolution requirements

-- Higher statistics – need matching systematics

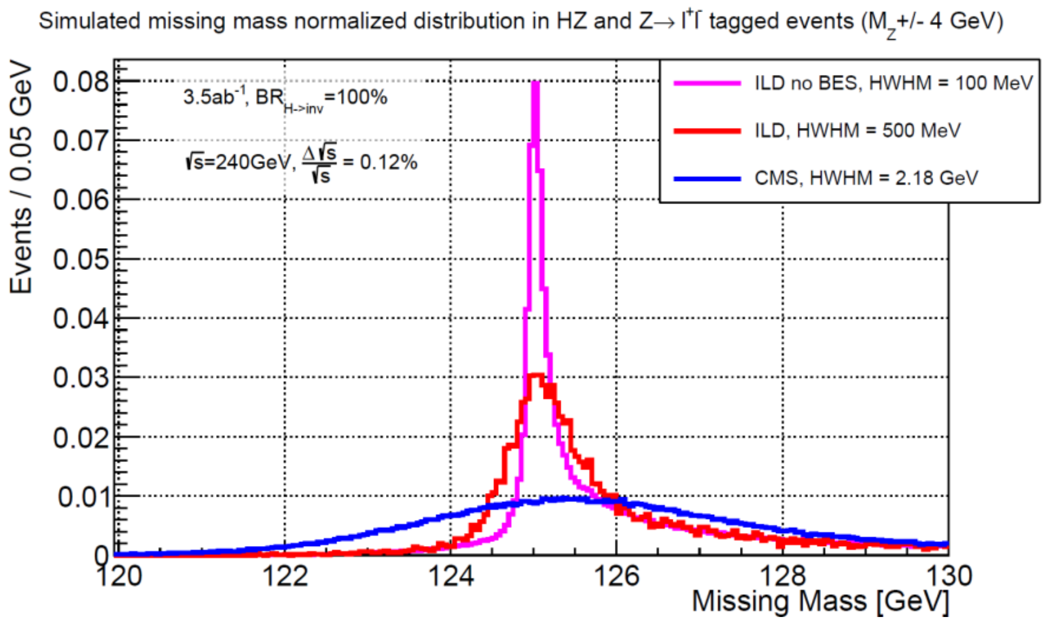
Some technical differences

-- High physics rate: 100 kHz Zs, must keep all.

-- No bunching → cooling issues

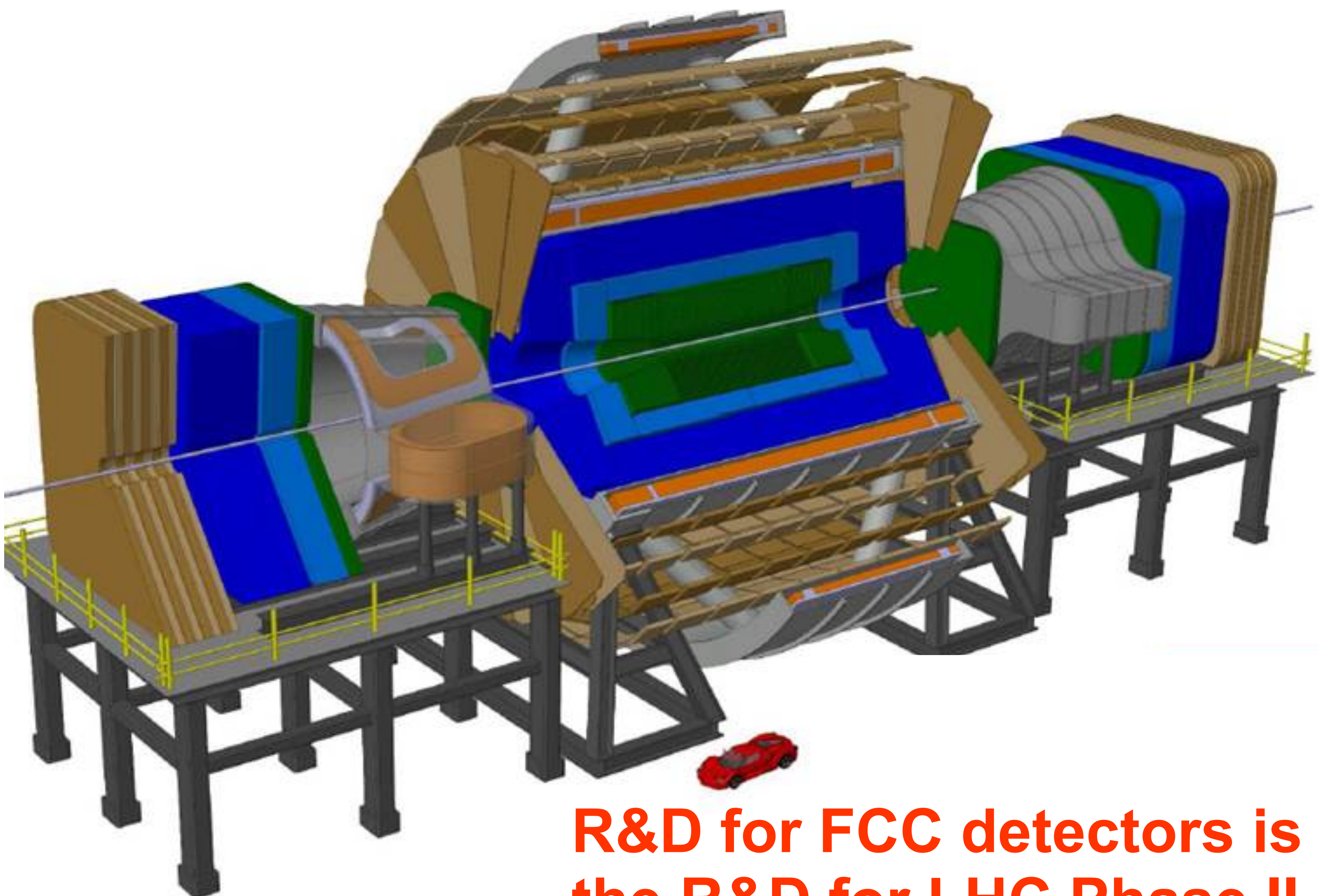
-- better definition of beam energy and lower beam induced backgrounds

Example:
Improved Higgs missing mass due to lower σ_{Ecm} @ FCC-ee ➔



Detector Concepts for 100 TeV pp

A B=6 T, R=6 m solenoid with shielding coil and 2 dipoles has been engineered in detail.
Different alternative magnet systems are also being explored.

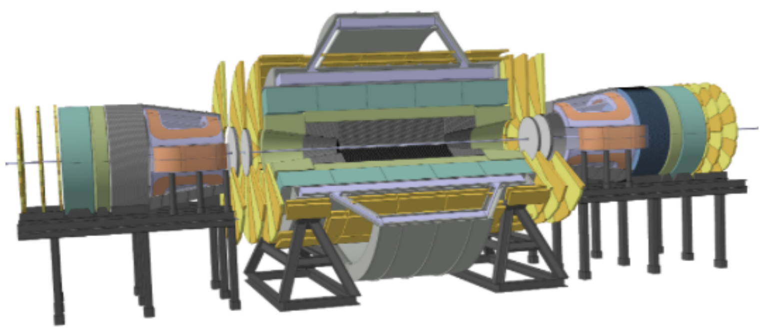


Some design challenges:

- **large η acceptance**
- **radiation levels of >50 x LHC Phase II**
- **pileup of ~1000**

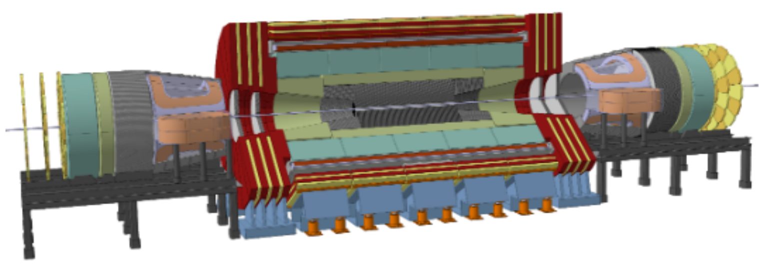
R&D for FCC detectors is a natural continuation of the R&D for LHC Phase II upgrade

Other ideas for a FCC-hh detector

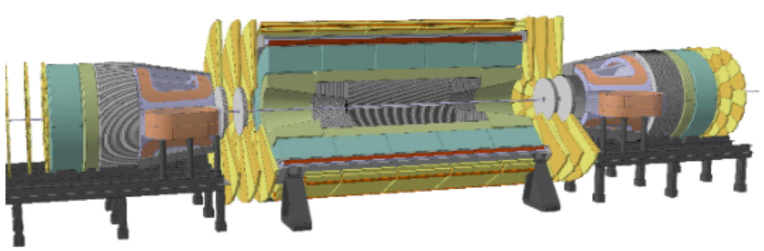


Twin solenoid with dipoles (min. shaft diameter 27.5m)

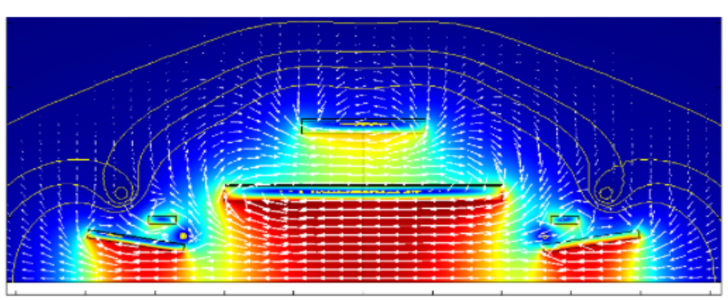
Cheaper/simpler systems?
Reduce dimensions/field of magnet system?



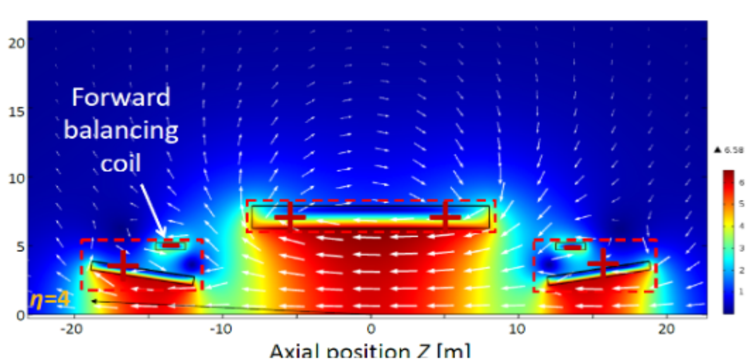
Partially shielded solenoid with dipoles



Unshielded solenoid with dipoles (min. shaft diameter 16.3m, if rotated under ground)



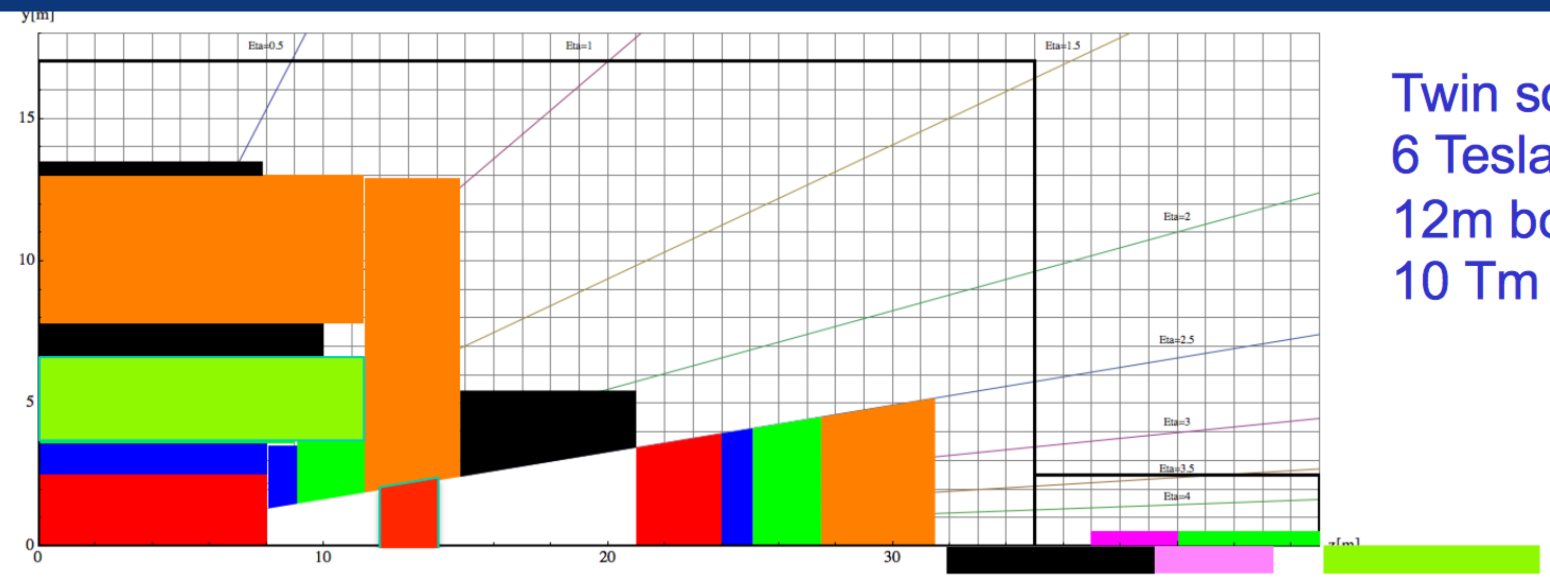
Twin solenoid with balanced conical solenoid



Unshielded solenoid with balanced conical solenoid

Herman Ten Kate, Matthias Mentink

Layout of a FCC-hh Detector



Twin solenoid
6 Tesla
12m bore
10 Tm dipole

Barrel:

Tracker available space:
R=2.1cm to R=2.5m, L=8m

EMCAL available space:
R=2.5m to R= 3.6m → dR= 1.1m

HCAL available space:
R= 3.6m to R=6.0m → dR=2.4m

Coil+Cryostat:
R= 6m to R= 7.825 → dR = 1.575m, L=10.1m

Muon available space:
R= 7.825m to R= 13m → dR = 5.175m
Revision of outer radius is ongoing.

Endcap:

EMCAL available space:
z=8m to z= 9.1m → dz= 1.1m

HCAL available space:
z= 9.1m to z=11.5m → dz=2.4m

Muon available space:
z= 11.5m to z= 14.8m → dz = 3.3m

Forward:

Dipole:
z= 14.8m to z= 21m → dz=6.2m

FTracker available space:
z=21m to R=24m, L=3m

FEMCAL available space:
Z=24m to z= 25.1m → dz= 1.1m

FHCAL available space:
z= 25.1m to z=27.5m → dz=2.4m

FMuon available space:
z= 27.5m to z=31.5m → dz=4m

Muon detector technologies

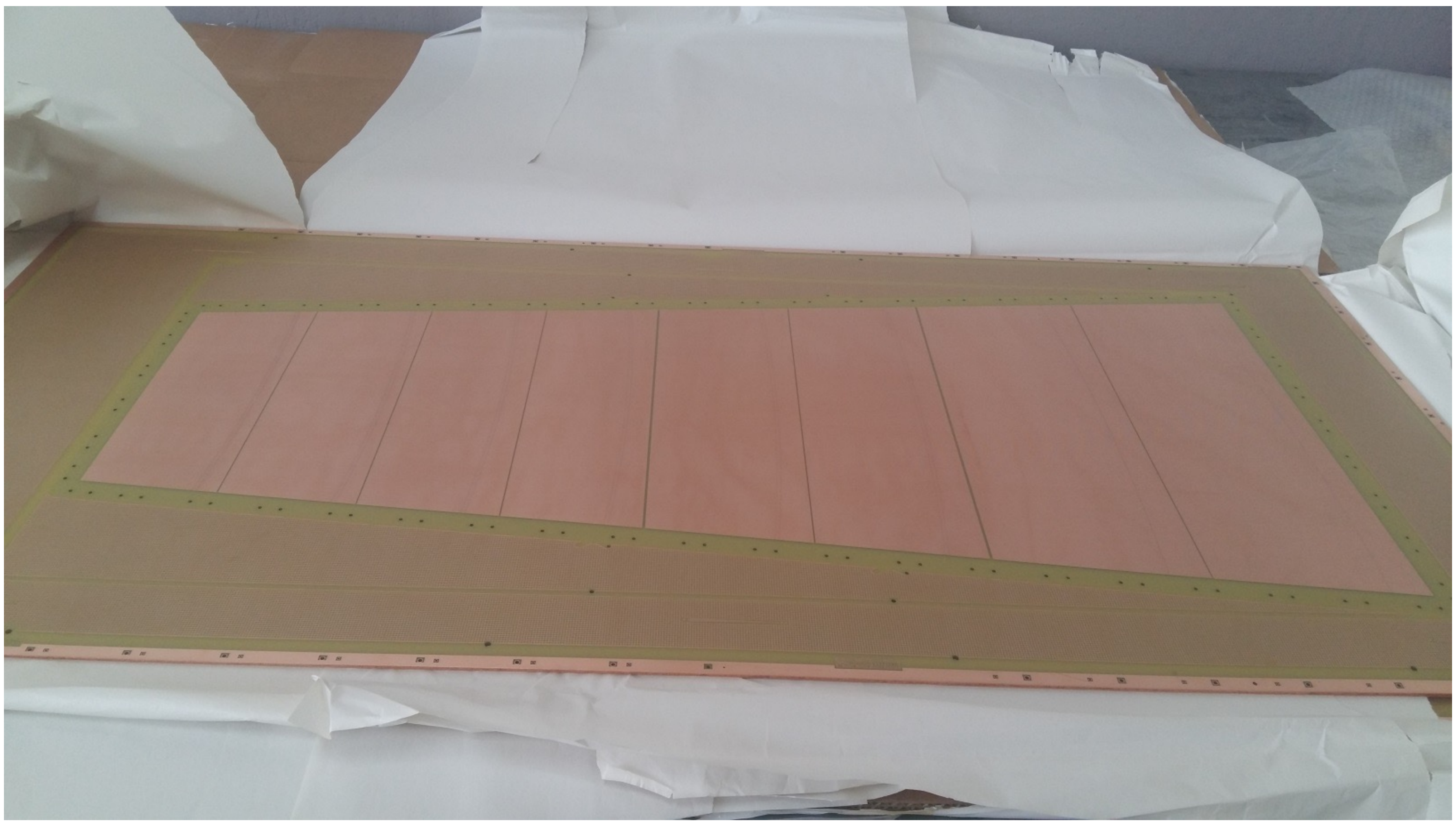
Muon Chamber Technology	Deployment	Comments
Drift Tubes with field shaper electrodes	Barrel Tracking & Triggering Cell resol'n ($r\phi$) < 250 μm	CMS
MDT (Monitored Drift Tubes) 3 cm dia.	Barrel Tracking Tube resol'n ($r\theta$) ~ 150 μm resolution	ATLAS
Small Diameter MDT 1.5 cm dia.	Tracking in some special regions of barrel	ATLAS
Cathode Strip Chambers (CSC)	Endcaps Tracking & CMS Triggering ATLAS: η strip pitch 5.5 mm, ϕ strip pitch 13 - 21 mm	CMS and ATLAS ($2<\|\eta\|<2.7$)
Micromegas	Endcaps Tracking & Triggering Readout pitch ~ 0.4 mm	ATLAS Phase I Upgrade New Small Wheel
Thin Gap Chambers (TGC)	Endcaps Triggering & Tracking 2nd coordinate	ATLAS 1st and 2nd stations Endcap
Small-strip Thin Gap Chambers (sTGC)	Endcaps Triggering & Tracking Fast enough for BC tagging 95% τ < 25 ns; 3 mm strip-pitch	ATLAS Phase I Upgrade New Small Wheel
Resistive Plate Chambers (RPC)	Barrel and Endcaps Triggering Fast τ ~ 3ns ATLAS: η strip pitch ~ 30 mm, ϕ strip pitch ~ 30 mm	ATLAS and CMS
Low Resistivity RPC	Higher rate capability 10^{10} Ωcm	R&D
Multi-gap Resistive Plate Chamber	Very fast τ ~ 50 ps	ALICE and R&D
GEMs (3 layer)	Endcaps Rate ~ 10^5Hz/cm^2 Fast τ ~ 4-5 ns	CMS Phase I Test & Phase II

From F. E. Taylor

Readout-PCB production @ ELTOS

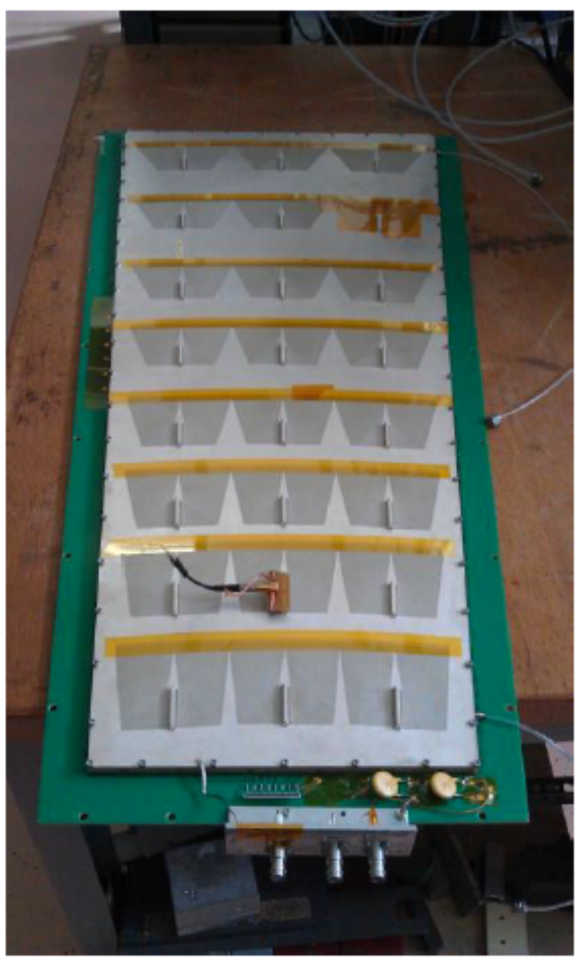
- ✓ **10 Feb:** ELTOS send formal offer for n.2 kit µ-RWELL (GE1/1 type)
- ✓ **25 Feb:** order for n.3 kit µ-RWELL completed

- ✓ **5 April:** PCB-readout (type GE1/1) completed at ELTOS



From G. Bencivenni

CSC GEM upgrade



NS2 Technique

- No spacers in active area
- Assembly time : 2 hours
- No gluing, no soldering
- Re-opening possible
- GEM exchange possible
- No stretch degradation with time
- Stretching more intense