Istituto Nazionale di Fisica Nucleare

Workshop on the circular e^+e^- collider
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e^+e^- Muon detectors overview

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INFN Bologna

Overview

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- **Requirements of Muon detectors**

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- **Micro Pattern Gas Detectors (MPGD)**
- **Conclusions**

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D. Denisov, ILC Snowmass Workshop 2005

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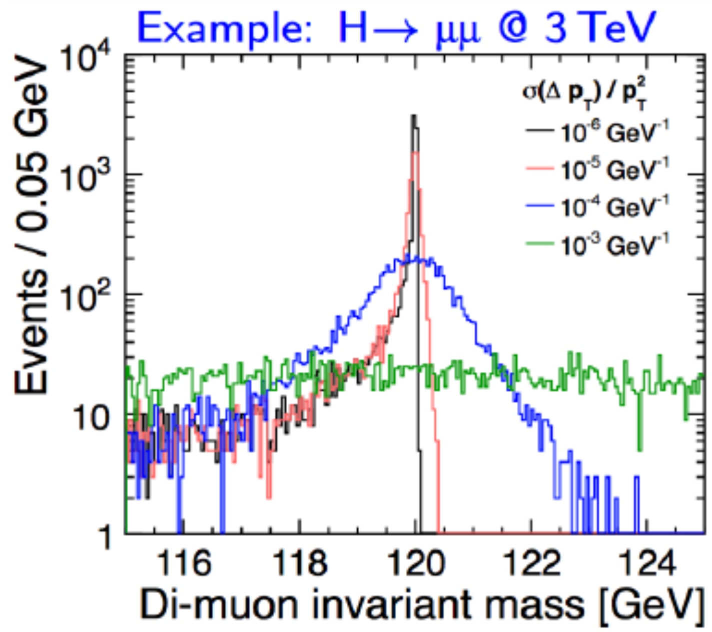
- Mass producible by <u>industry</u>

Muon detectors requirements

CLIC Detector requirements from physics

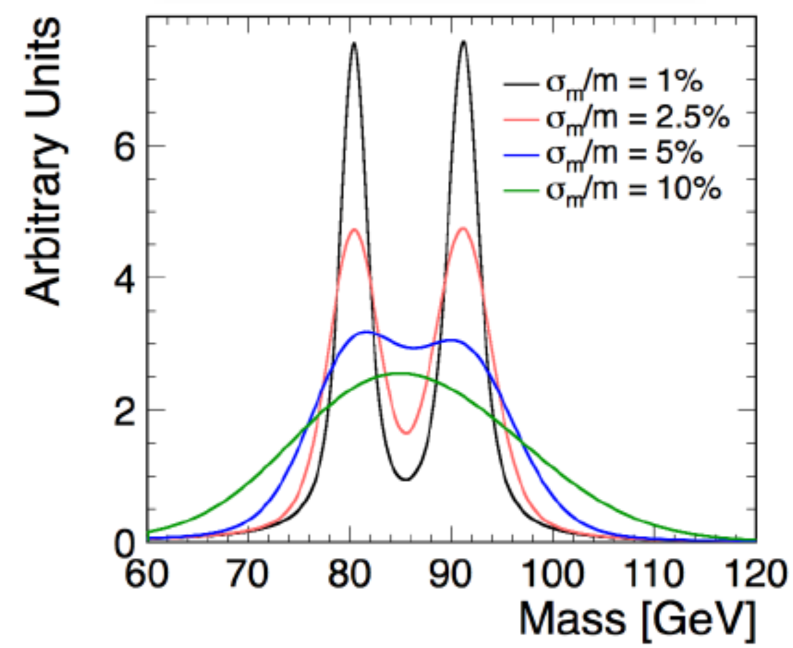
- momentum resolution
  - Higgs recoil mass, Higgs coupling to muons, BSM (smuon and neutralino masses)
  - for high p_T tracks

$$\sigma_{p_T}/p_T^2 \simeq 2\times10^{-5} GeV^{-1}$$



- 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)

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

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Muon detectors for CepC

Muon detector characteristics

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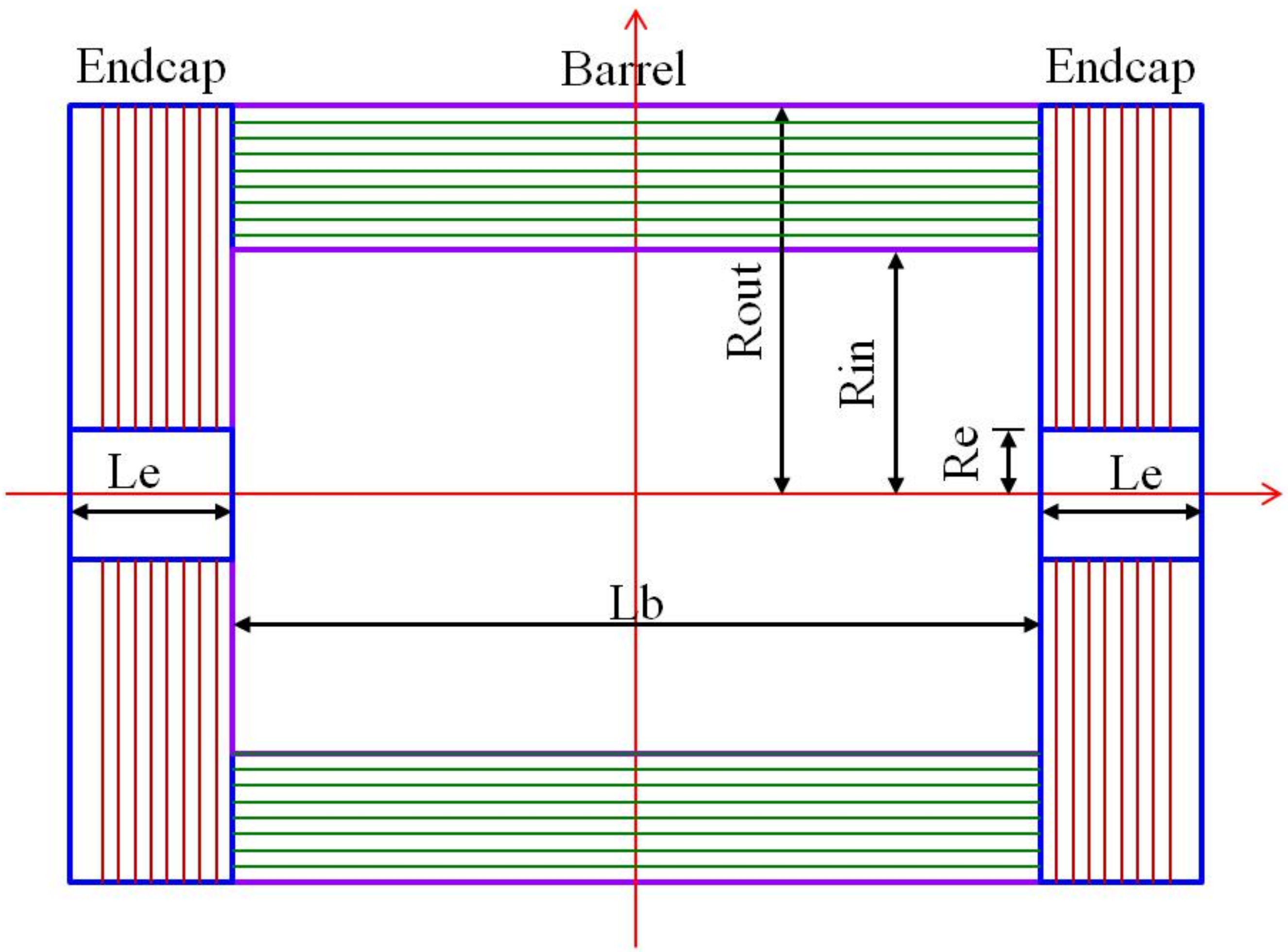

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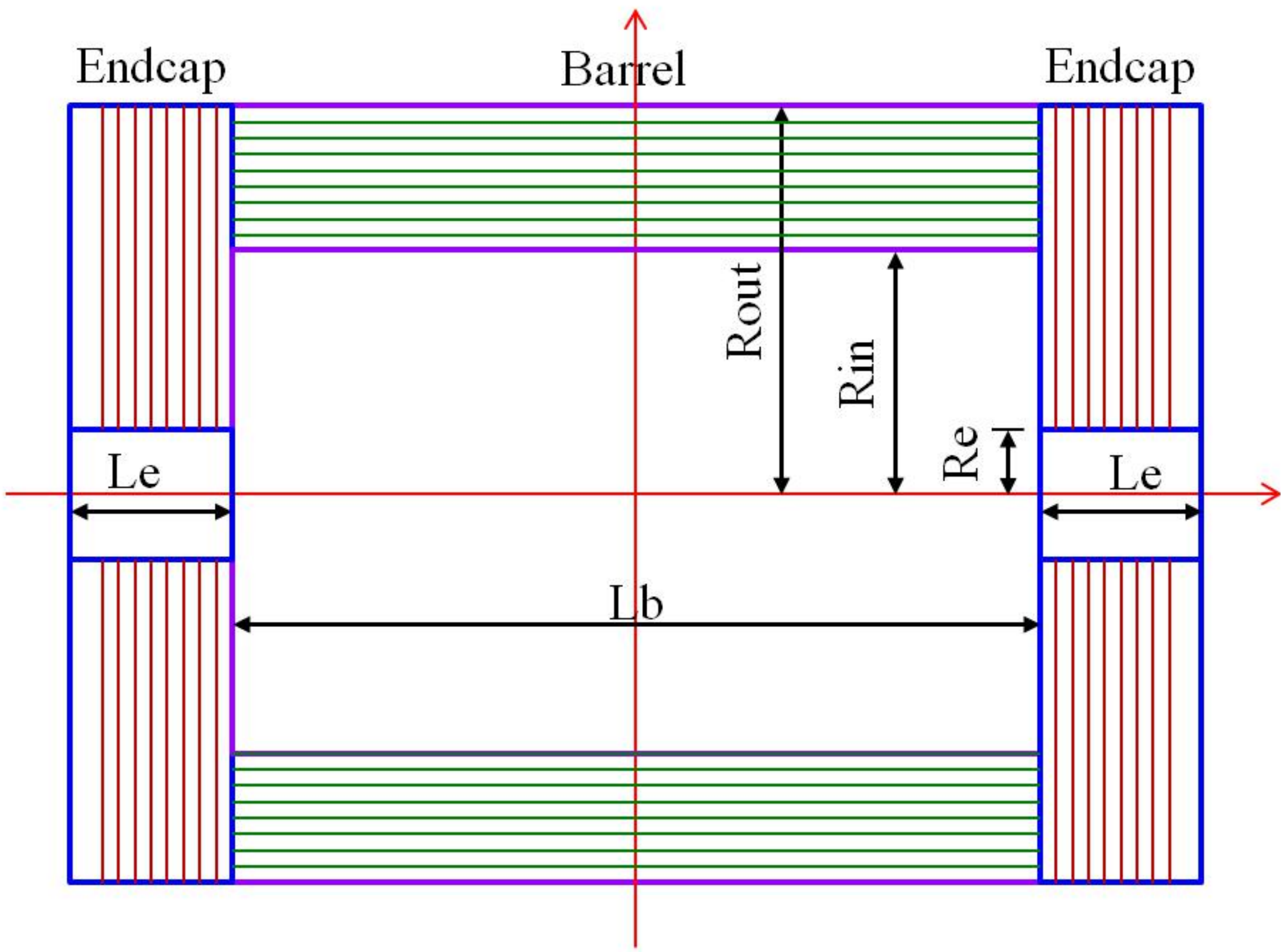

Table 7.1: The baseline design parameters of the CEPC muon system

Parameter	Possible range	Baseline
Lb/2 [m]	3.6 – 5.6	4.0
Rin [m]	3.5 – 5.0	4.4
Rout [m]	5.5 – 7.2	7.0
Le [m]	2.0 – 3.0	2.6
Re [m]	0.6 – 1.0	0.8
Segmentation	8/10/12	12
Number of layers	6 – 10	8
Total thickness of iron	6 – 10λ ($\lambda = 16.77$ cm)	8λ (136 cm) (8/8/12/12/16/16/20/20/24) cm
Solid angle coverage	$(0.94 - 0.98) \times 4\pi$	0.98
Position resolution [cm]	$\sigma_{r\phi}$: 1.5 – 2.5	2
	σ_z : 1 – 2	1.5
Detection efficiency ($E_\mu > 5$ GeV)	92% – 99%	95%
Fake($\pi \to \mu$)@30GeV	0.5% – 3%	$< 1\%$
Rate capability [Hz/cm^2]	50 – 100	~60
Technology	RPC	RPC (super module, 1 layer readout, 2 layers of RPC)
	μRWell	
Total area [m^2]	Barrel	~4450
	Endcap	~4150
	Total	~8660

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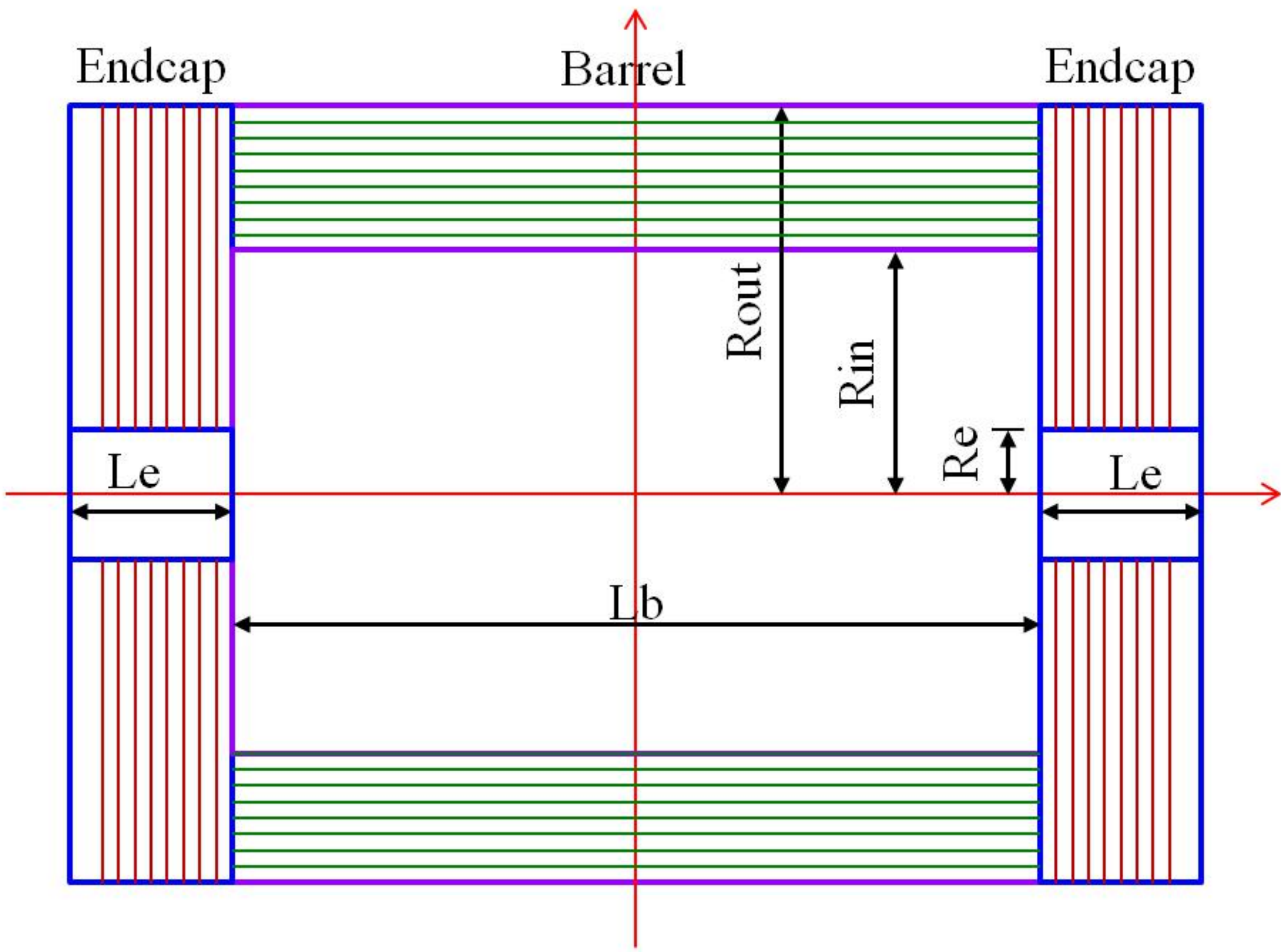

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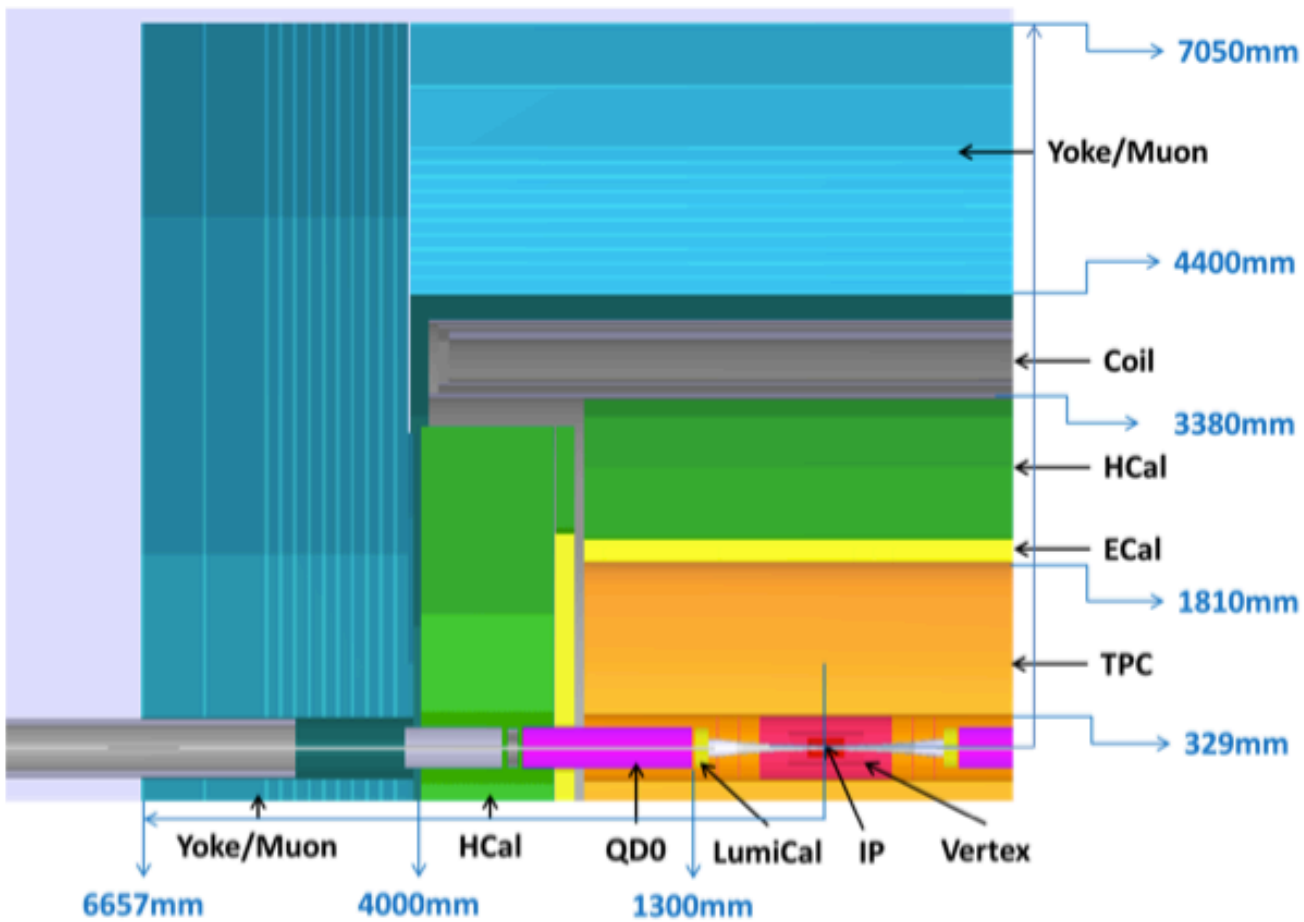
Detection efficiency ($E_\mu > 5$ GeV)	92% – 99%	95%
Fake($\pi \to \mu$)@30GeV	0.5% – 3%	$< 1\%$
Rate capability [Hz/cm^2]	50 – 100	~60
Technology	RPC	RPC (super module, 1 layer readout, 2 layers of RPC)
	μRWell	
Total area [m^2]	Barrel	~4450
	Endcap	~4150
	Total	~8660

Muon detectors for CepC

Muon detectors for CepC



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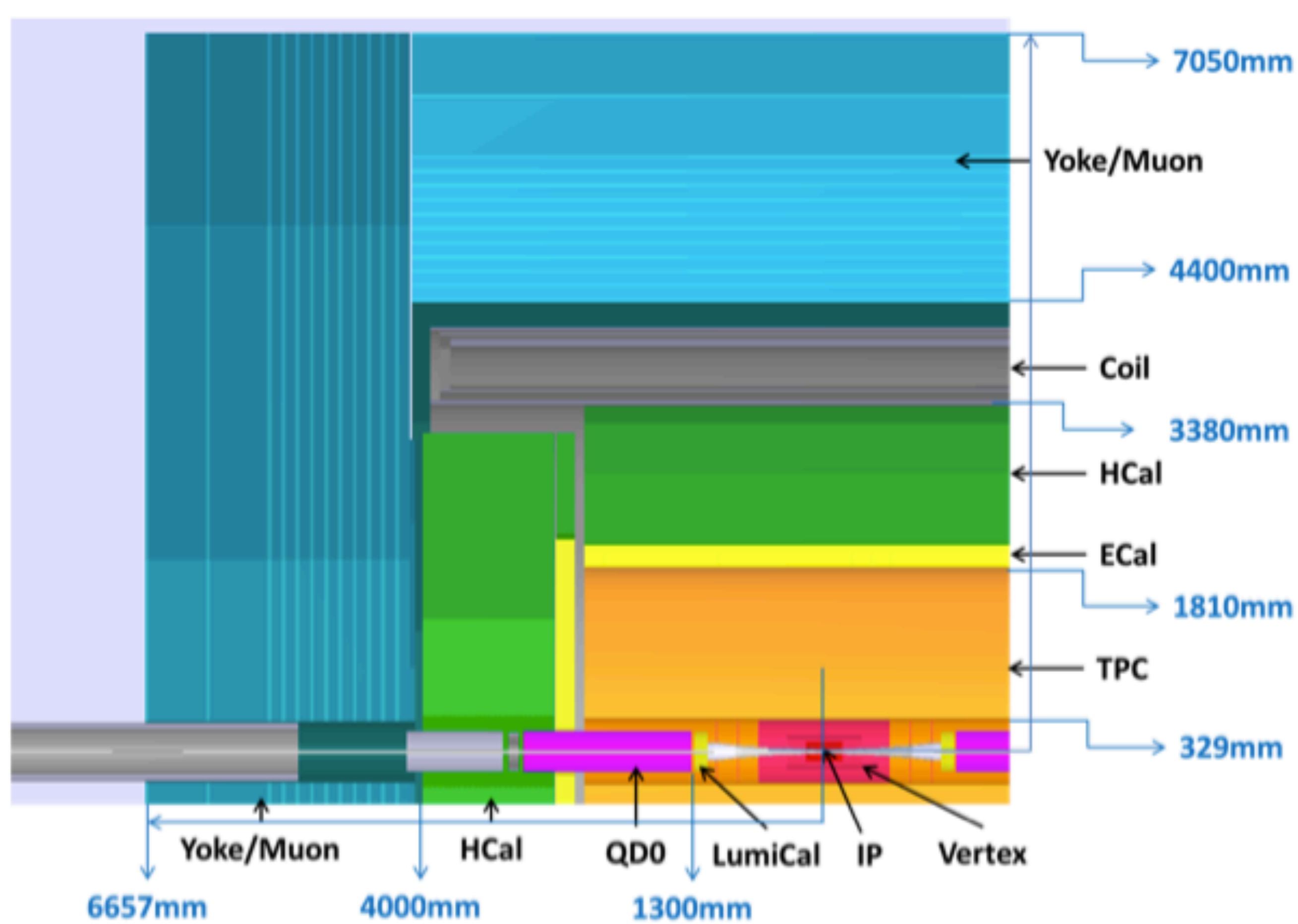

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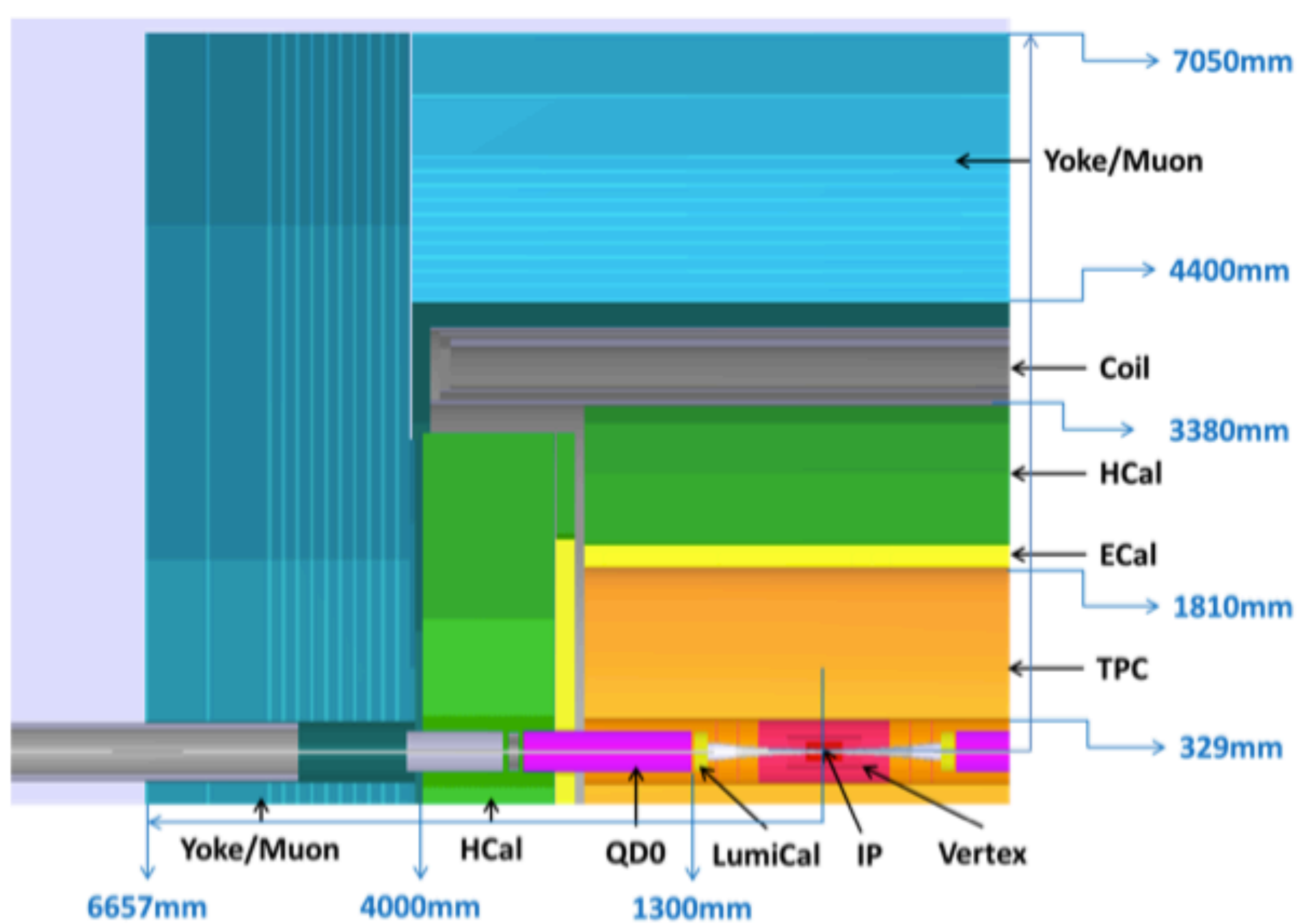

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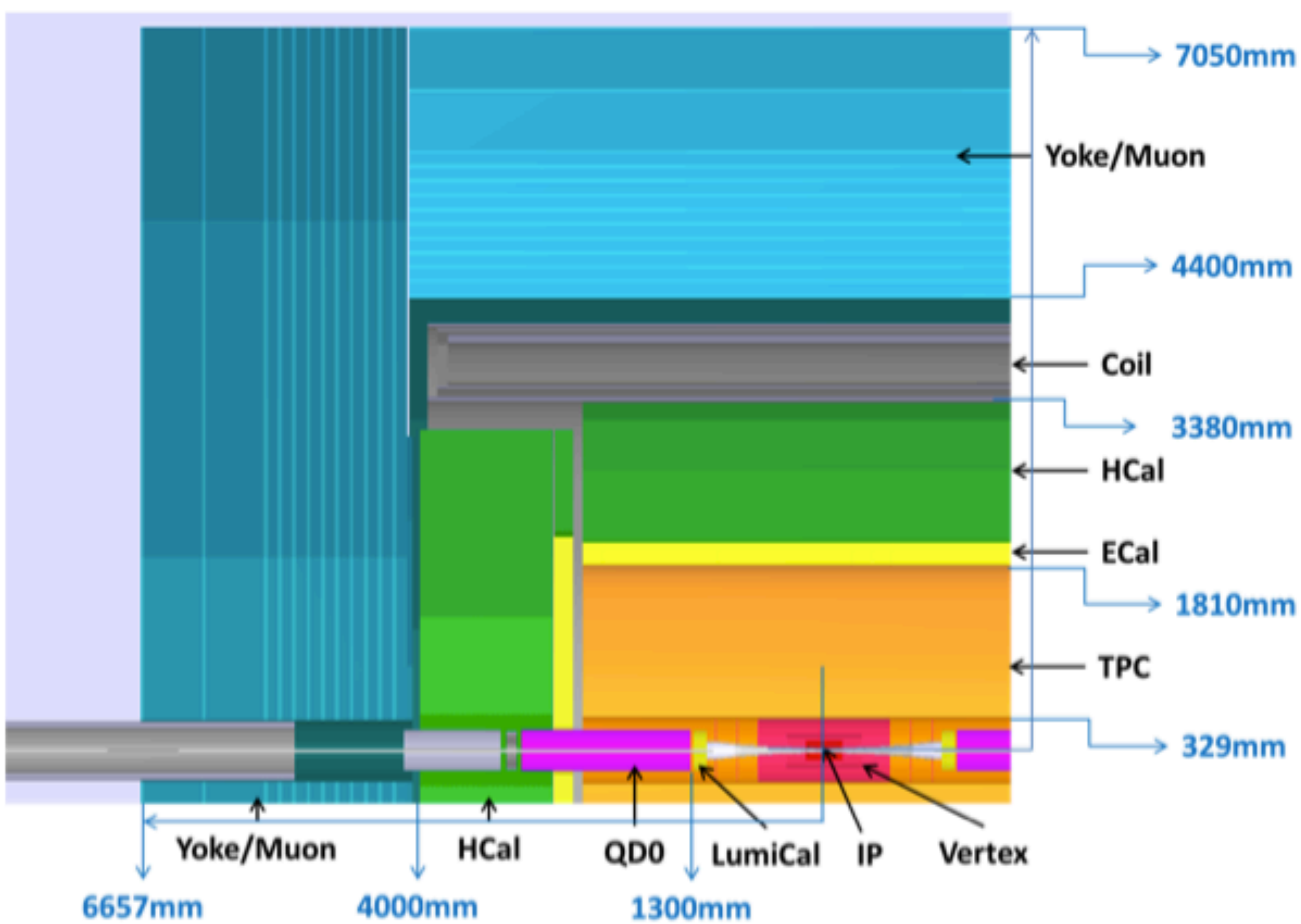
MPGDs could provide a finer space resolution (~ 200 μm) with a similar time resolution at a relatively modest increase in price.



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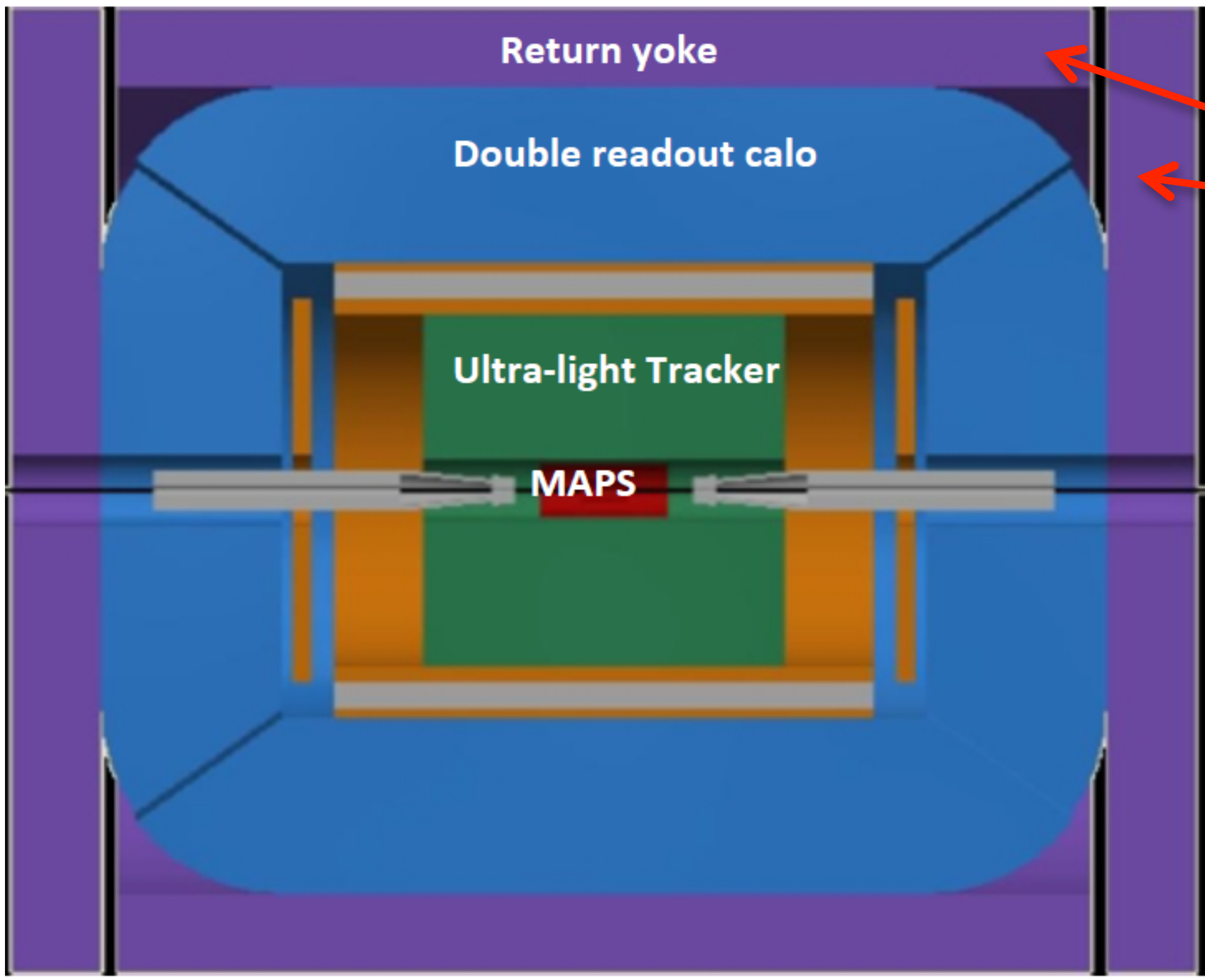

IDEA

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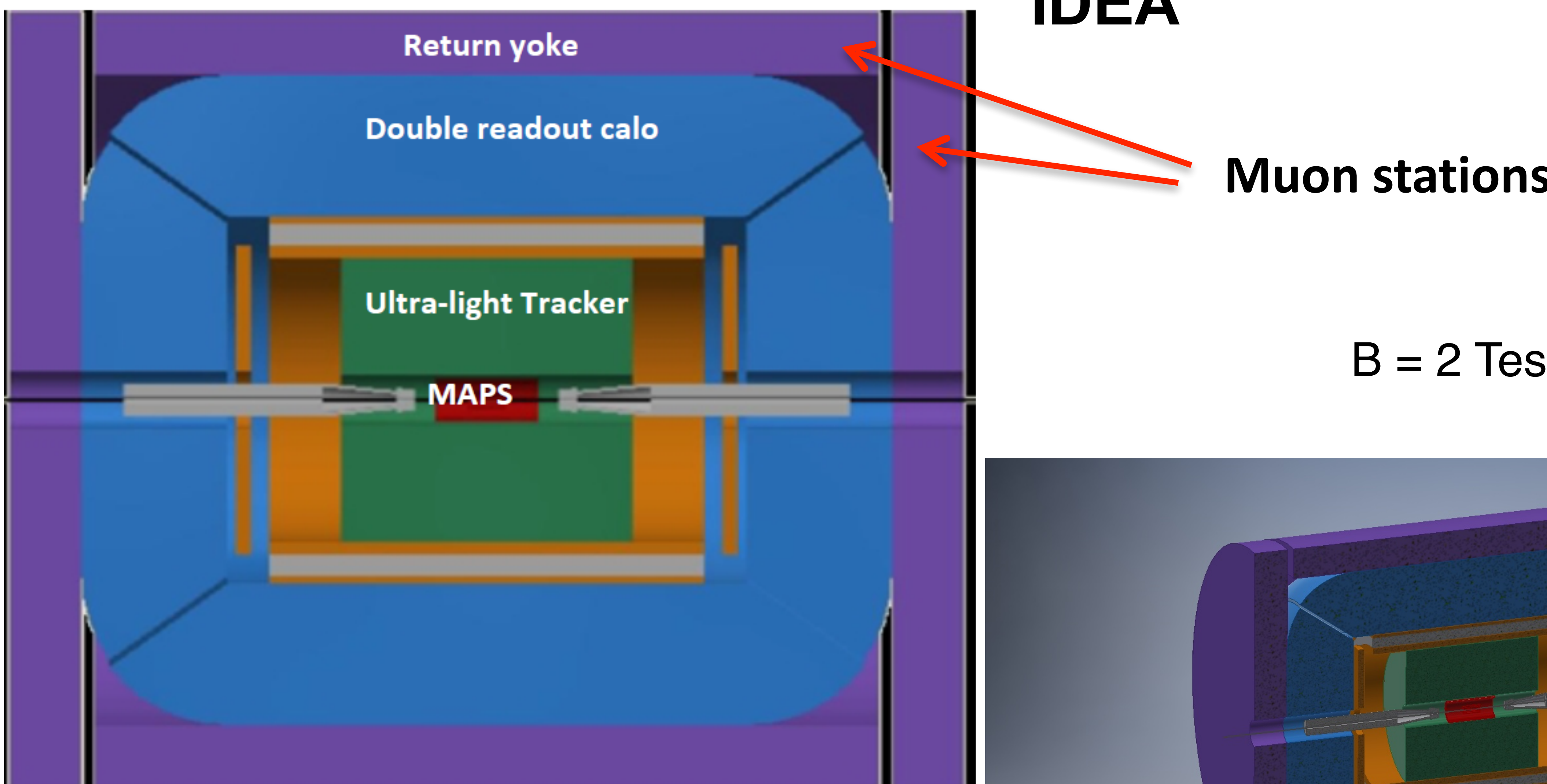

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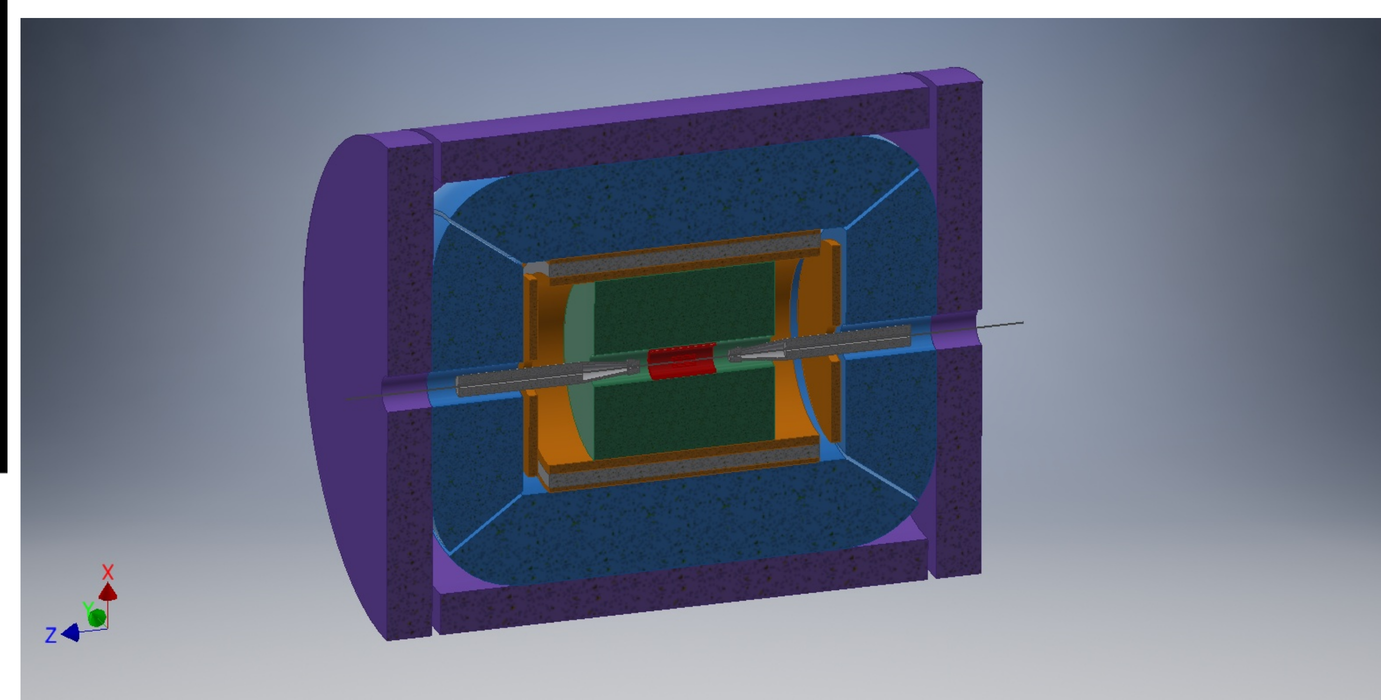

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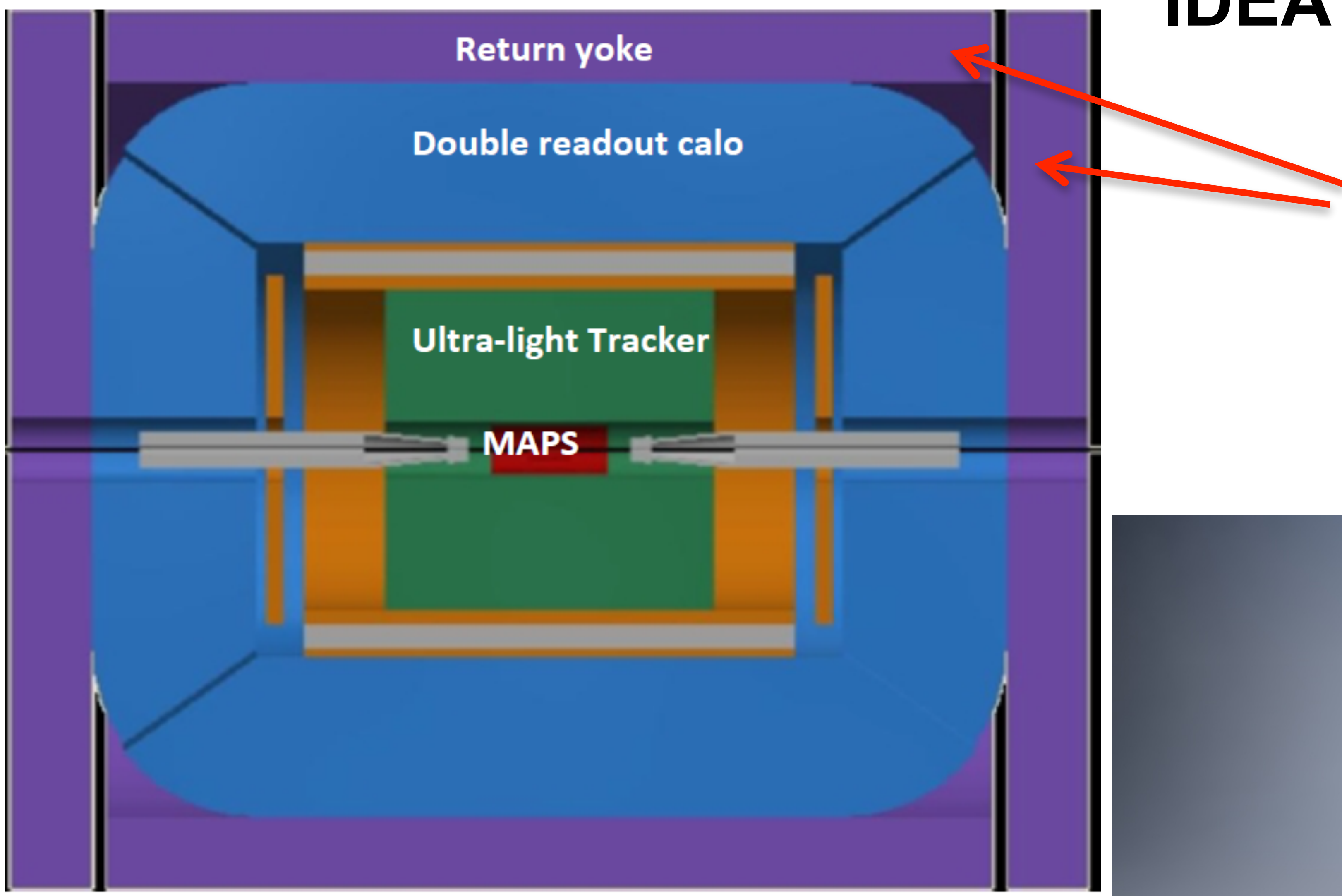

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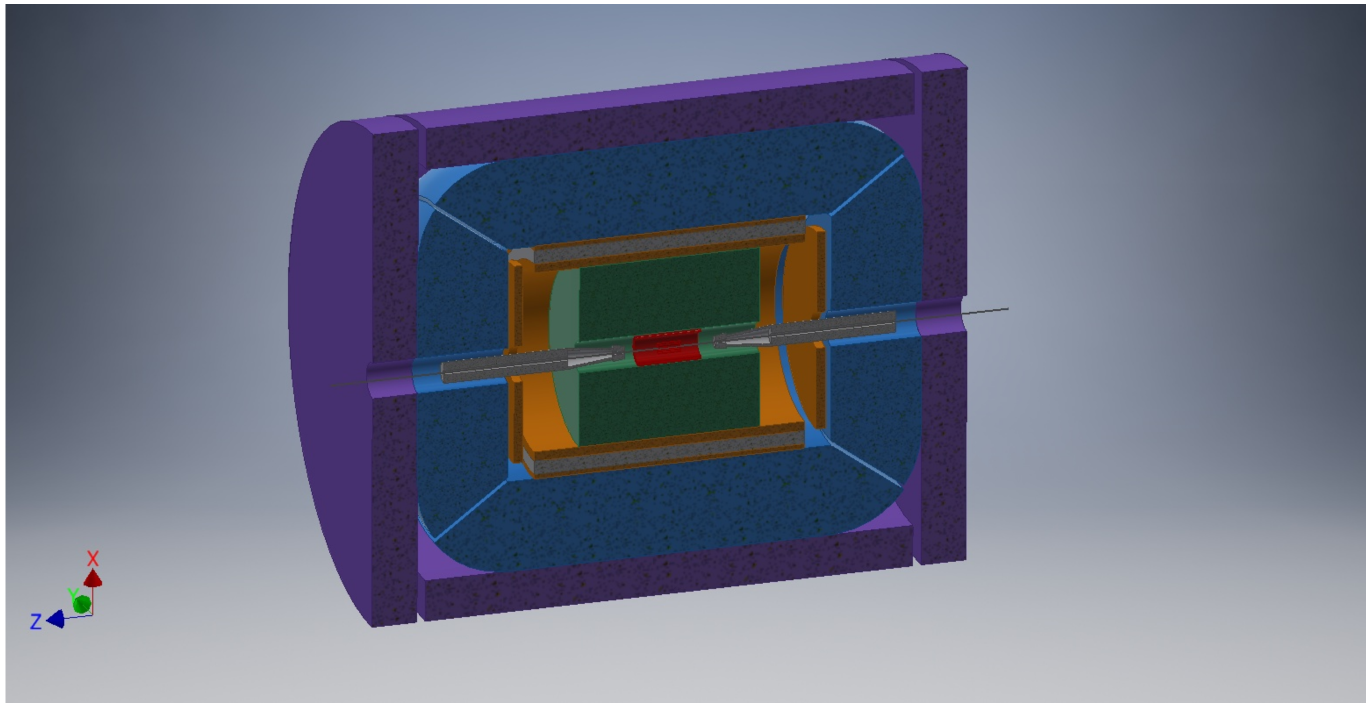

μ-RWELL have demonstrated very high detection efficiency and therefore no need to have more than 4 layers.

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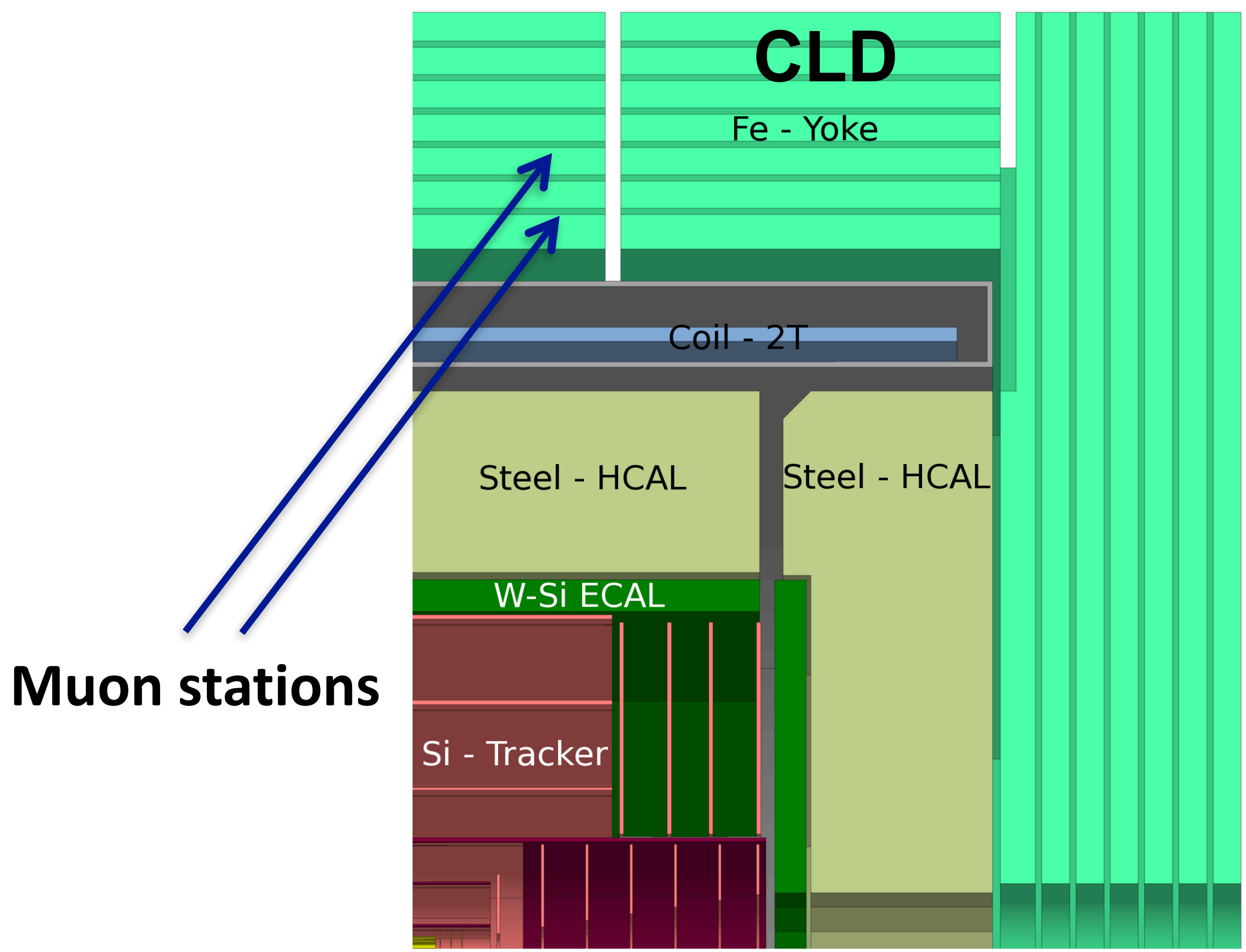

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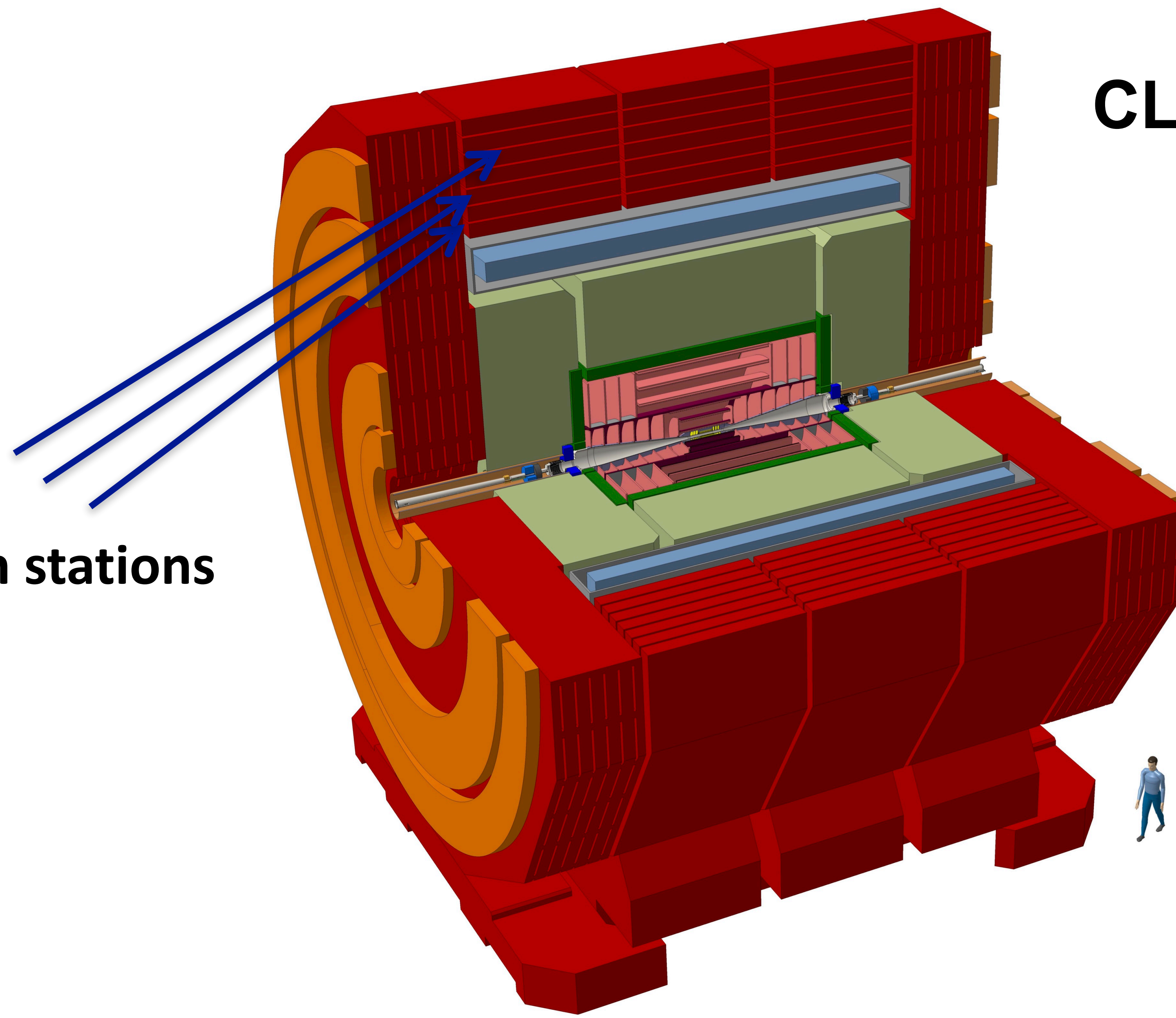
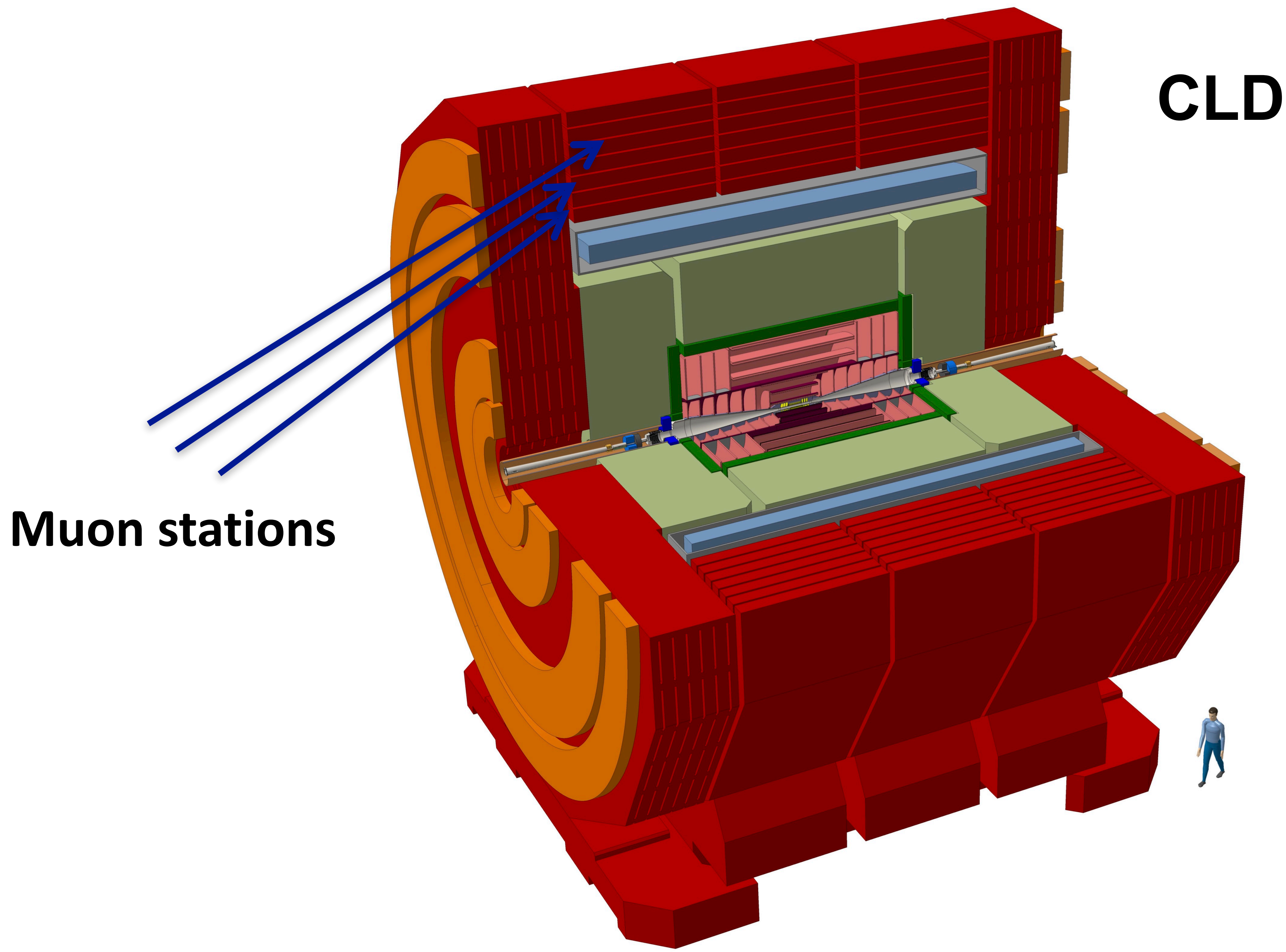


CLD

Muon stations

Muon detectors for FCC-ee

Also this muon detector could be improved by adopting finer space resolution MPGDs. Four stations would be sufficient.



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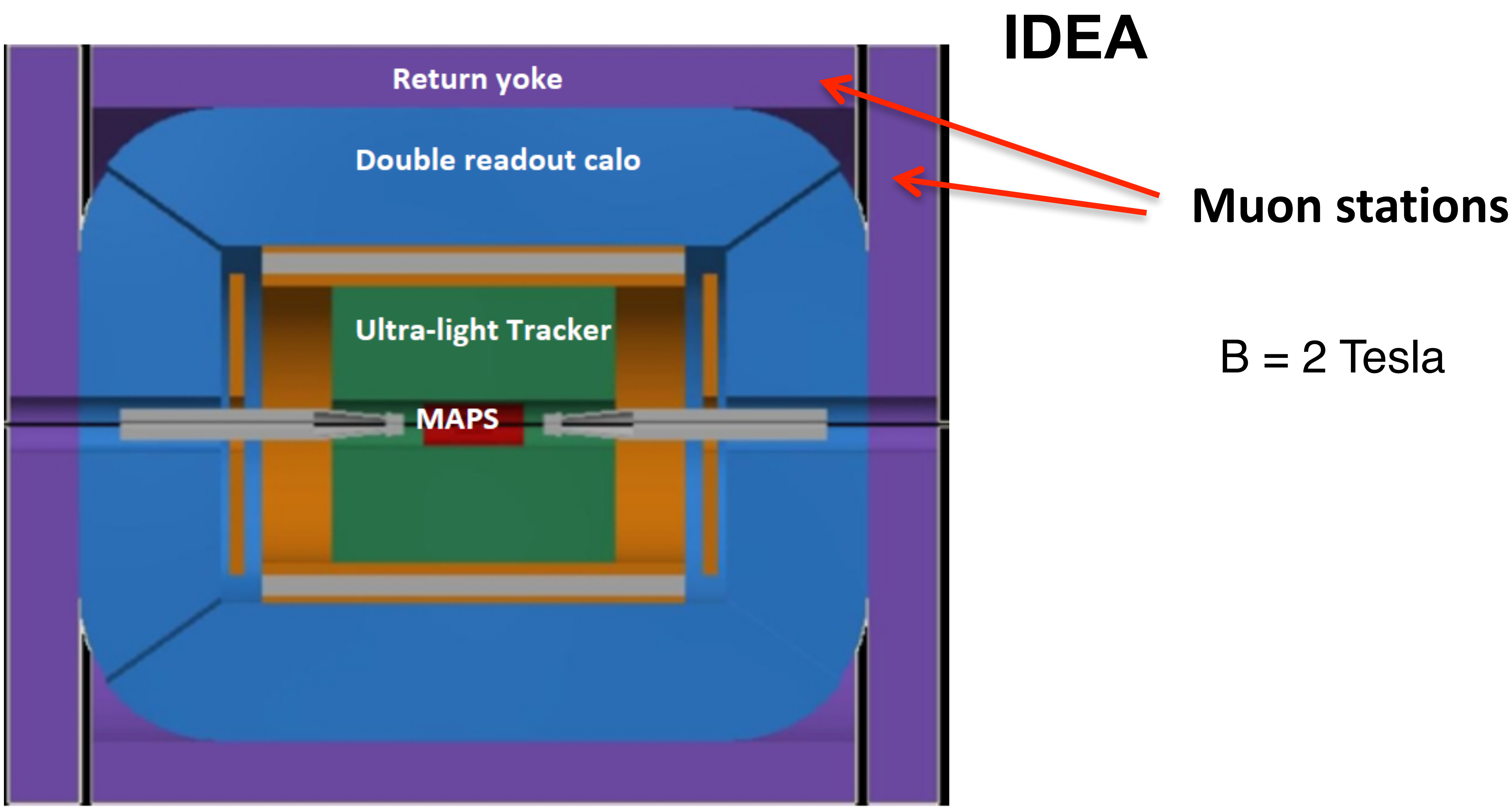

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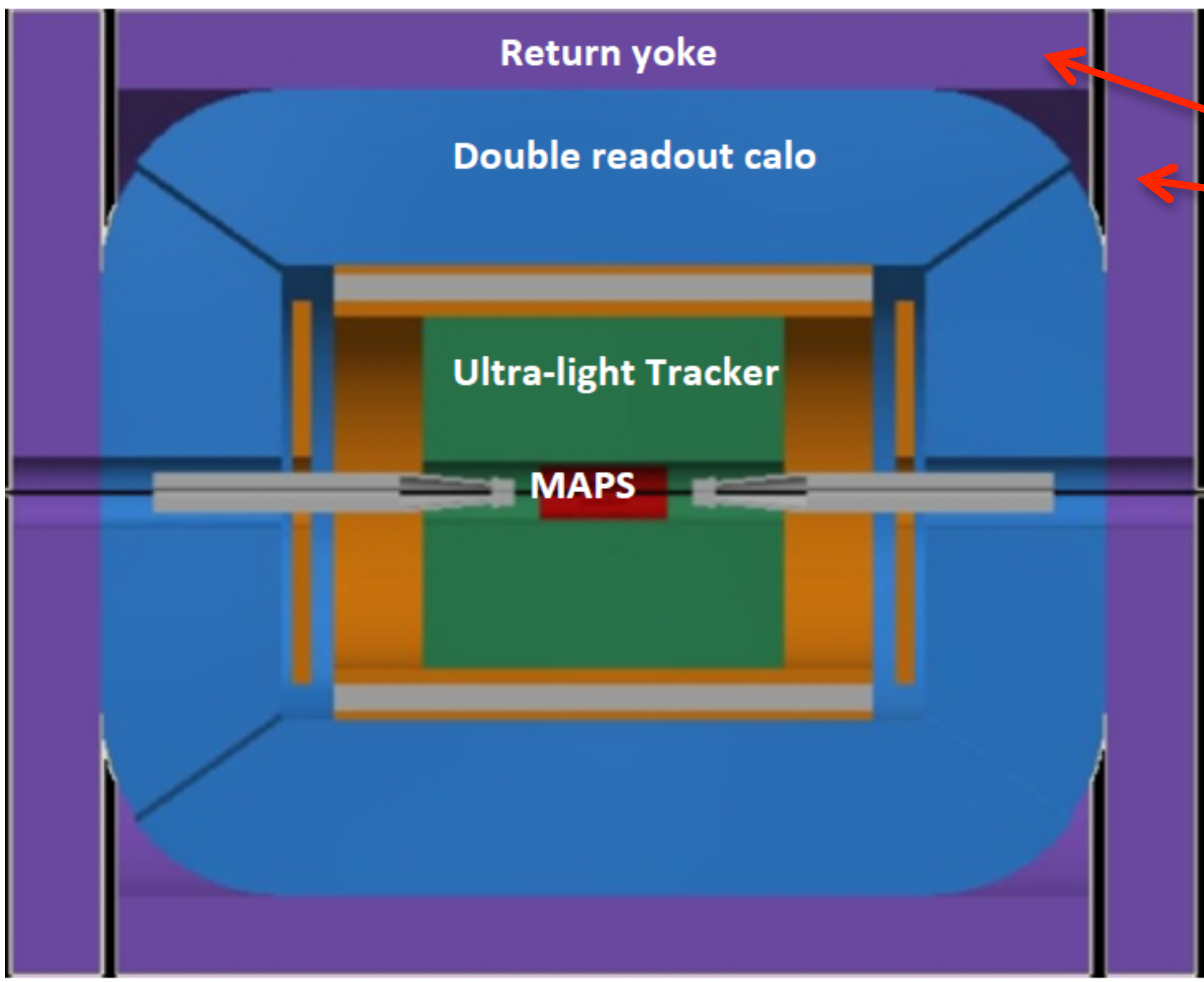

Muon stations

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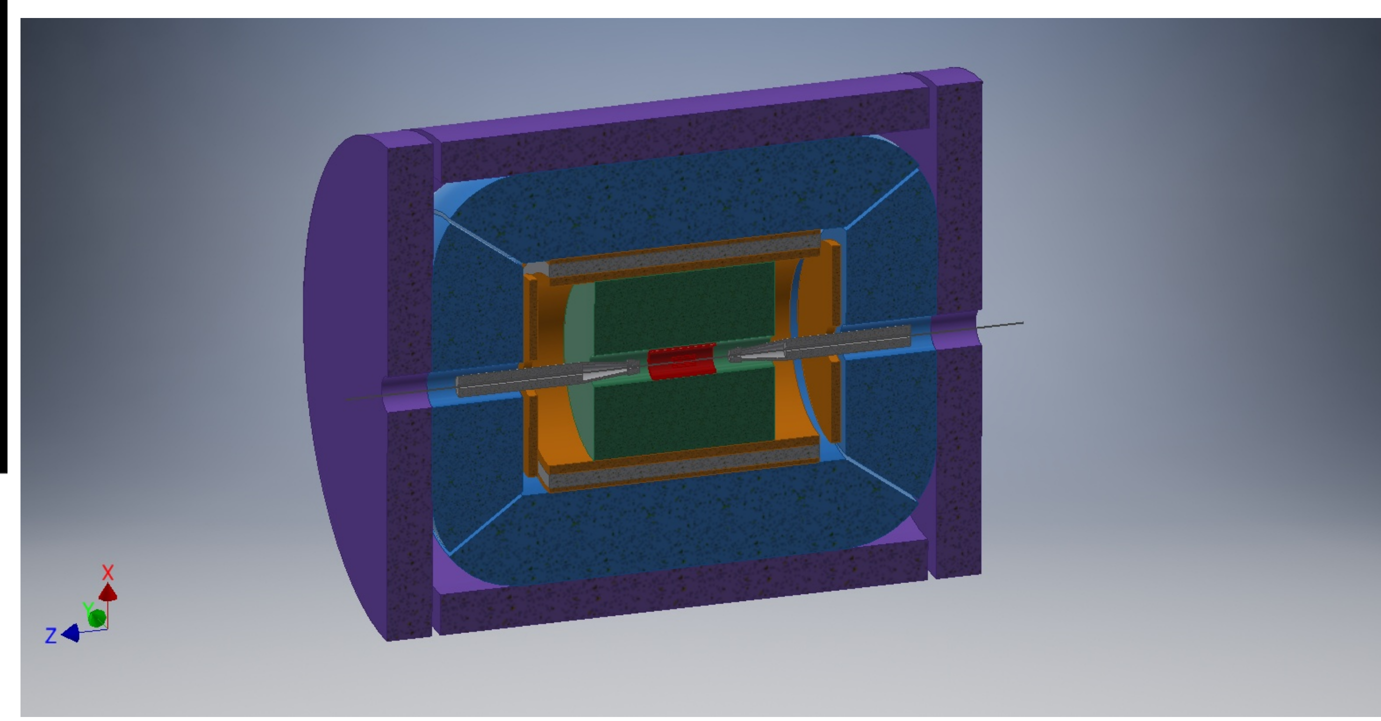

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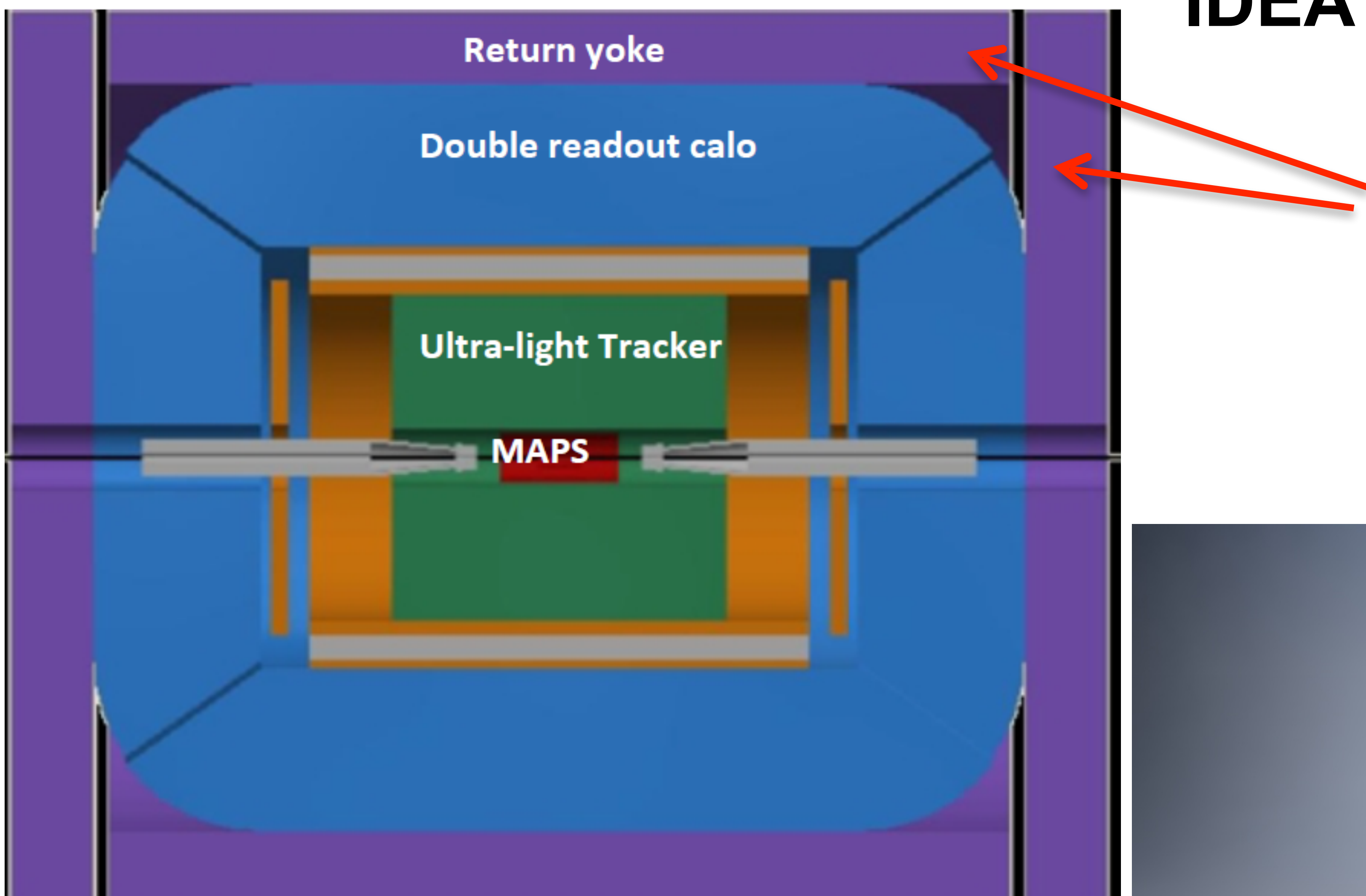

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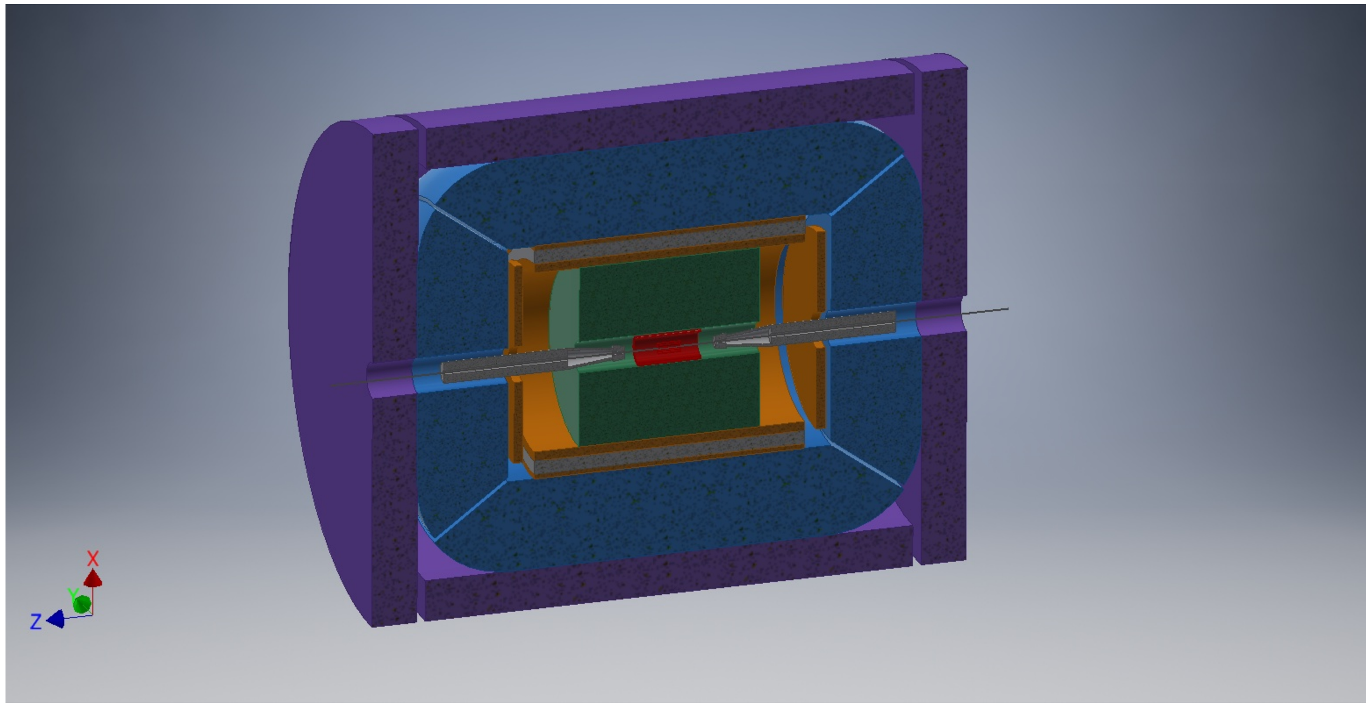

Single layer μ-RWELL efficiencies of >95% have been obtained and therefore no need for many layers.

Muon detectors for ILC

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SID Muon detector

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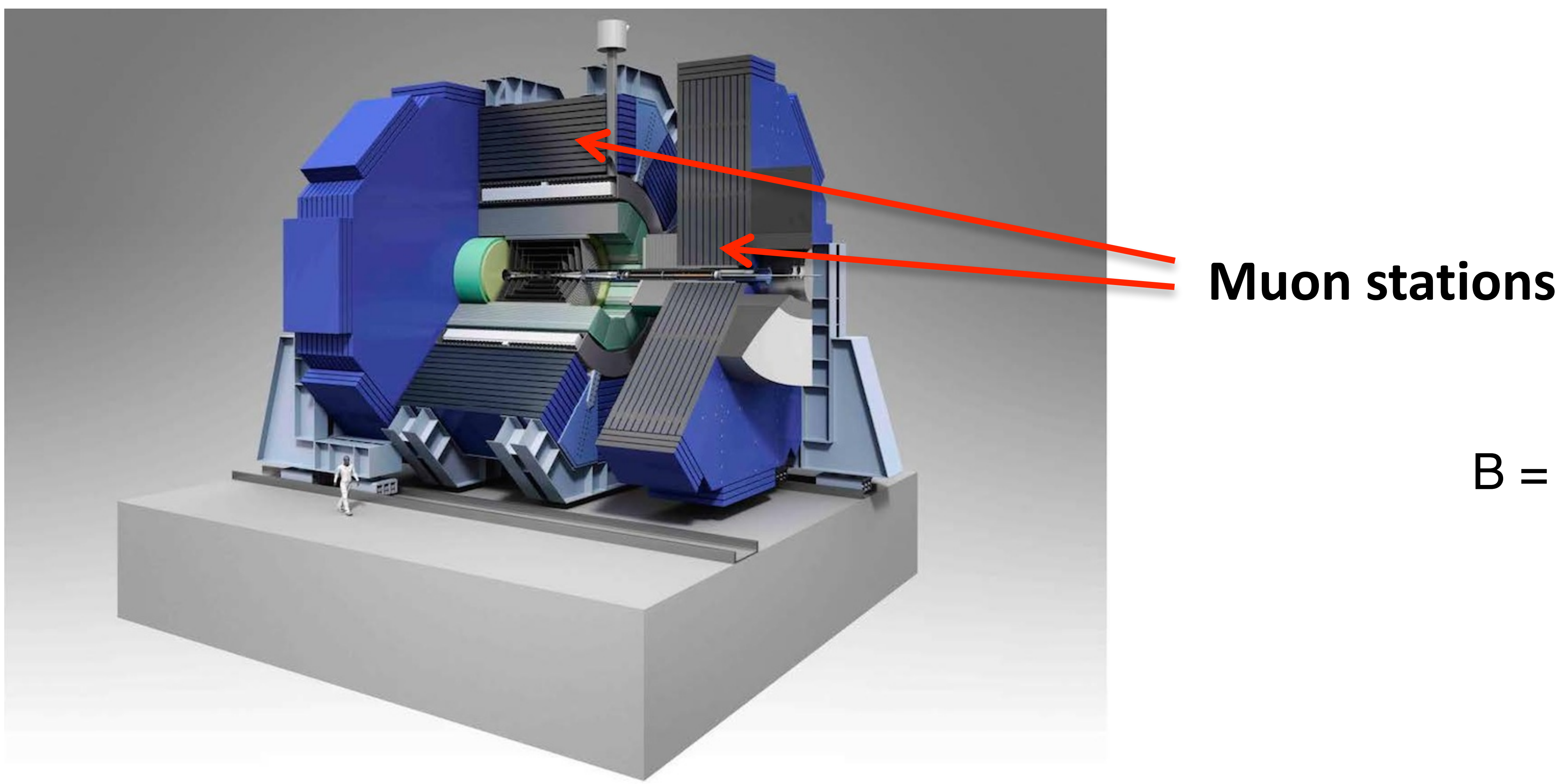
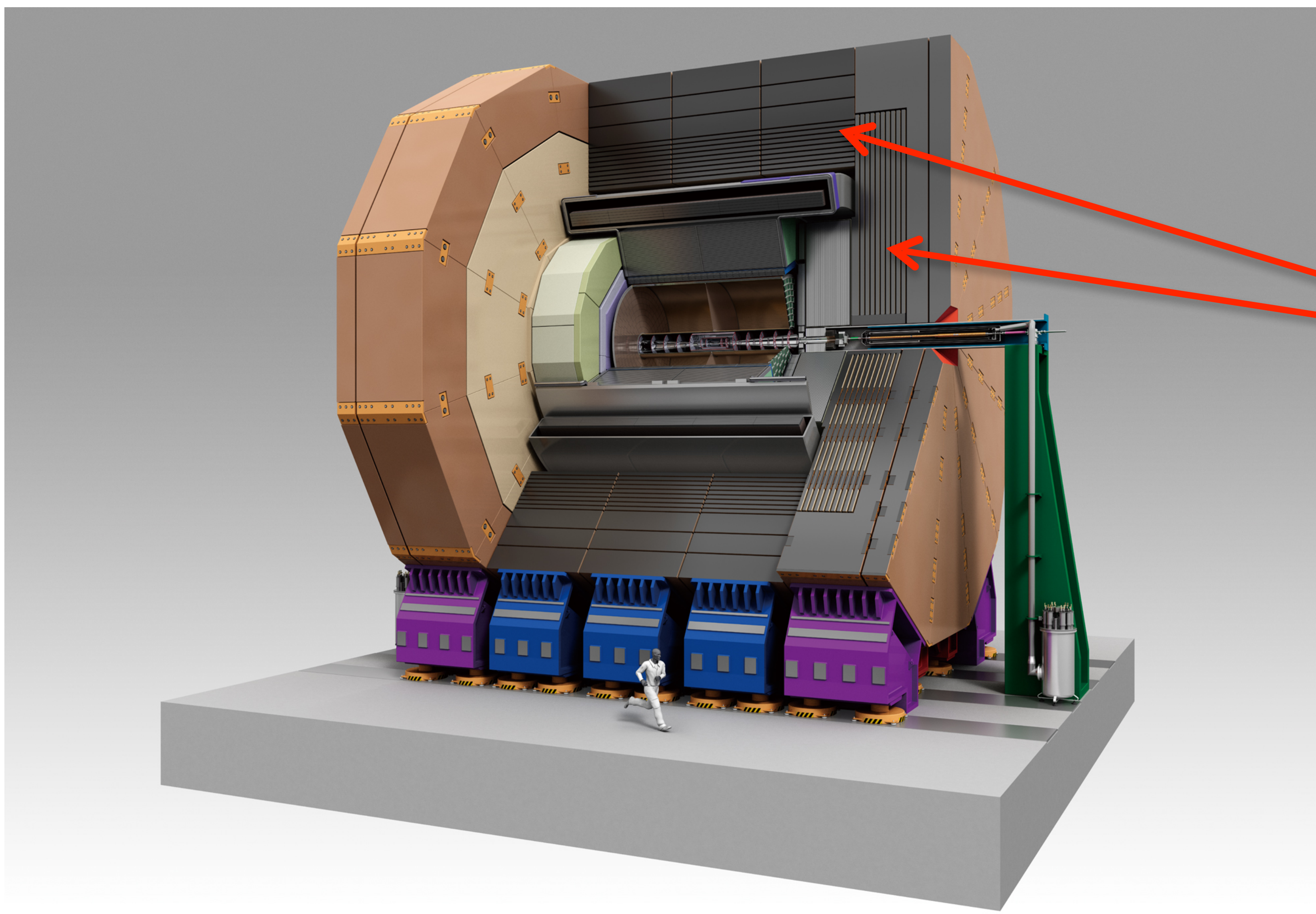


B = 5 Tesla

Muon detectors for ILC



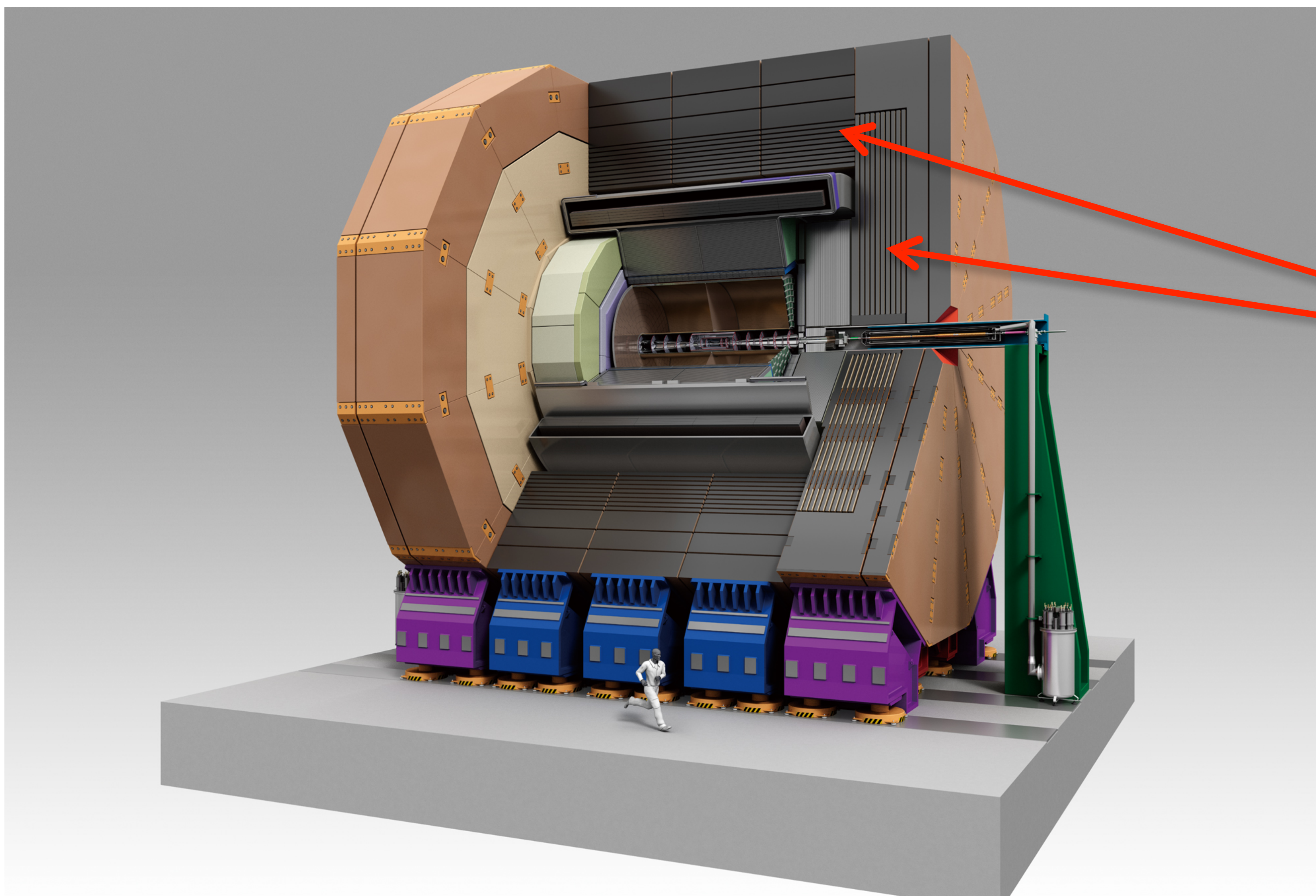
Muon stations

B = 3.5 Tesla

Muon detectors for ILC

ILD Muon detector

14 layers in the barrel and 12 in the endcaps interleaved in the iron return yoke. The technology adopted is scintillator bars (2.5-3 cm wide, 7-10 mm thick) with wavelength shifting fibres and SiPM. Space resolution O(1 cm). RPCs (1x1 cm^2 pads) are considered as a possible option.



Muon stations

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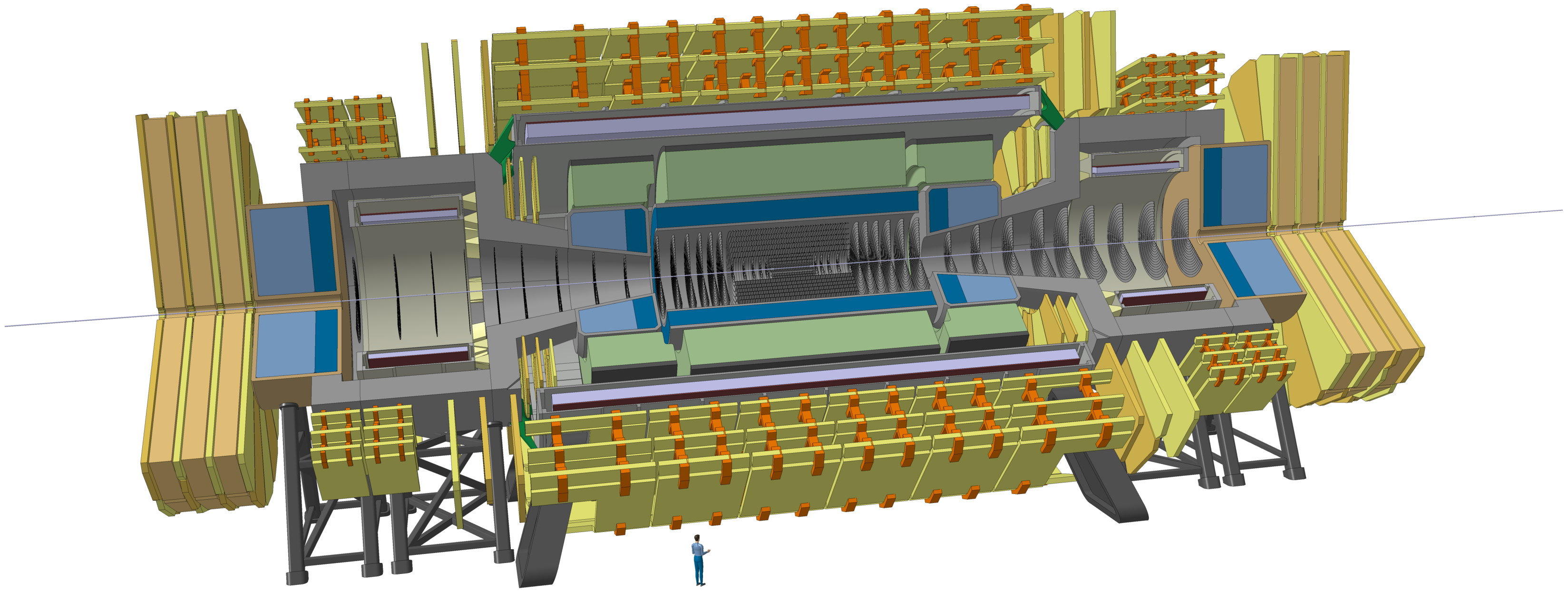
Muon detector for FCC-hh

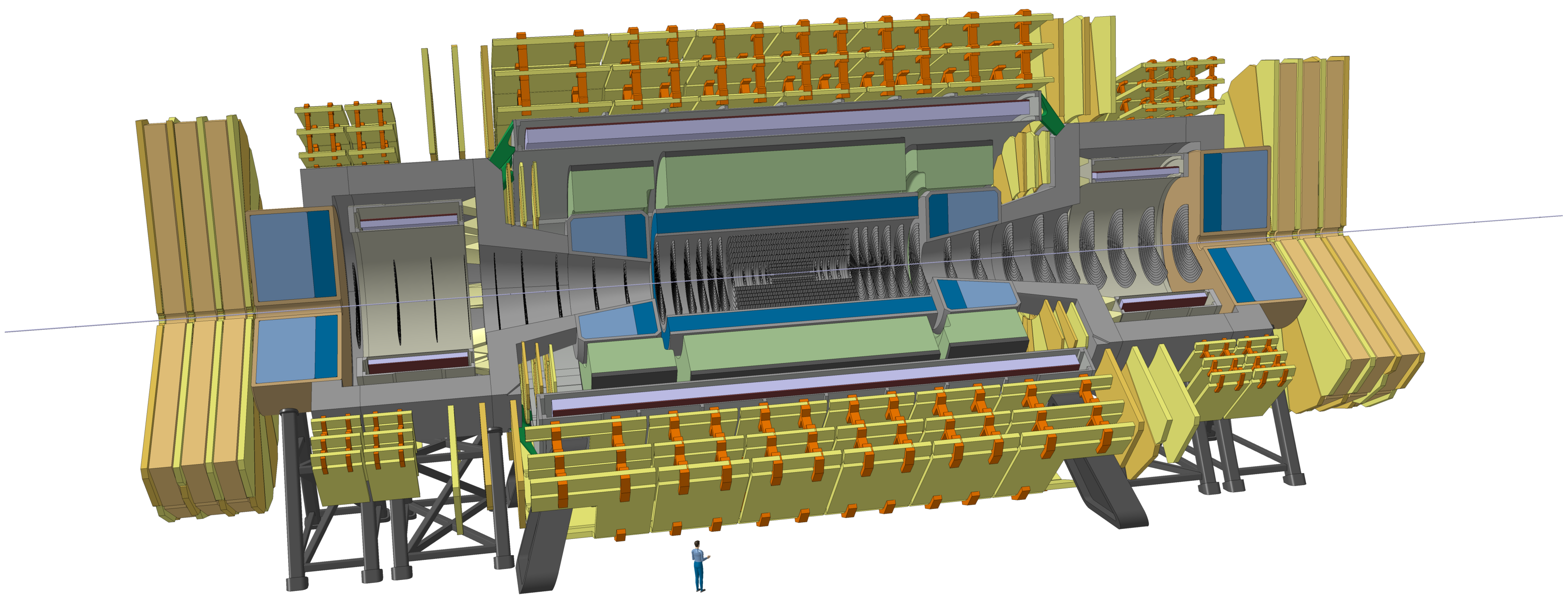
Muon detector for FCC-hh

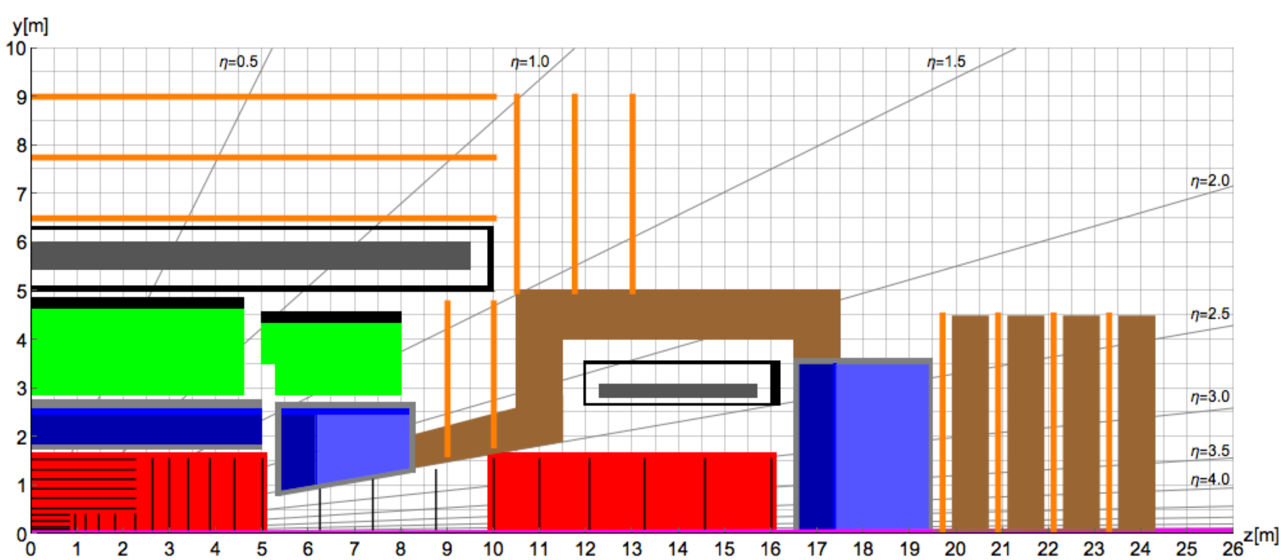
FCC-hh detector



Muon detector for FCC-hh

FCC-hh detector





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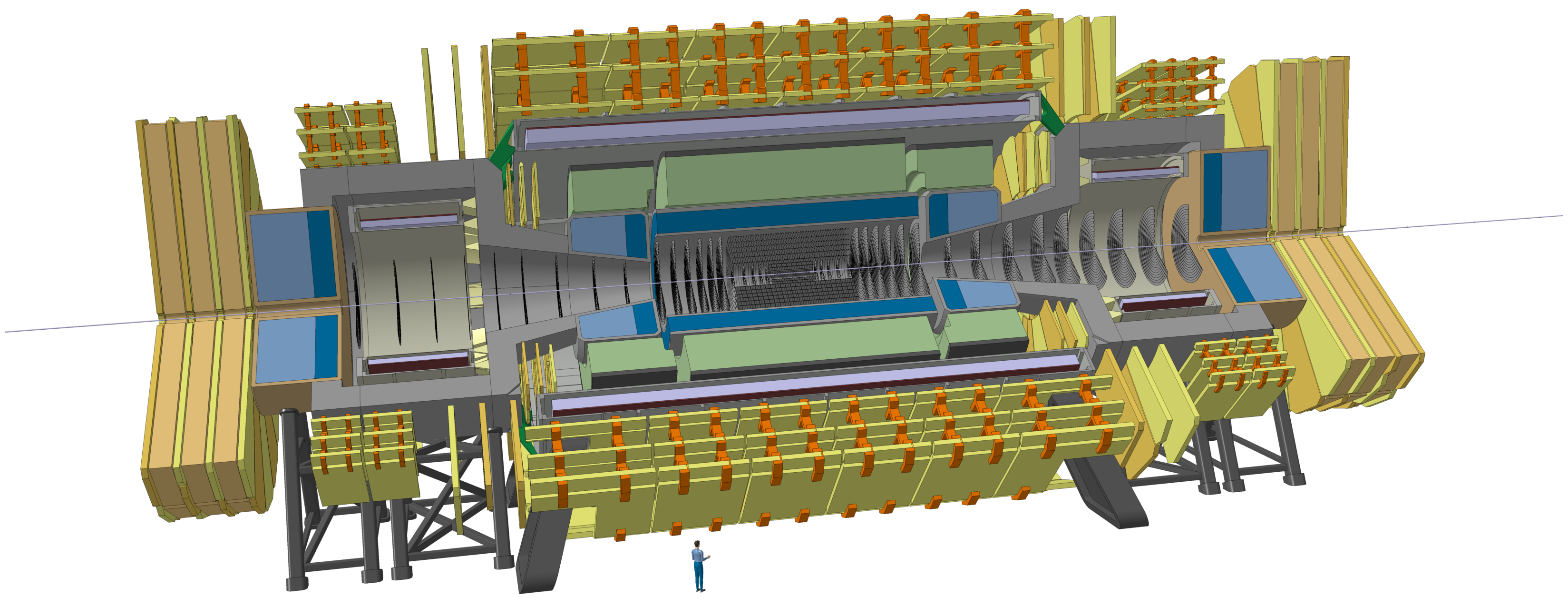

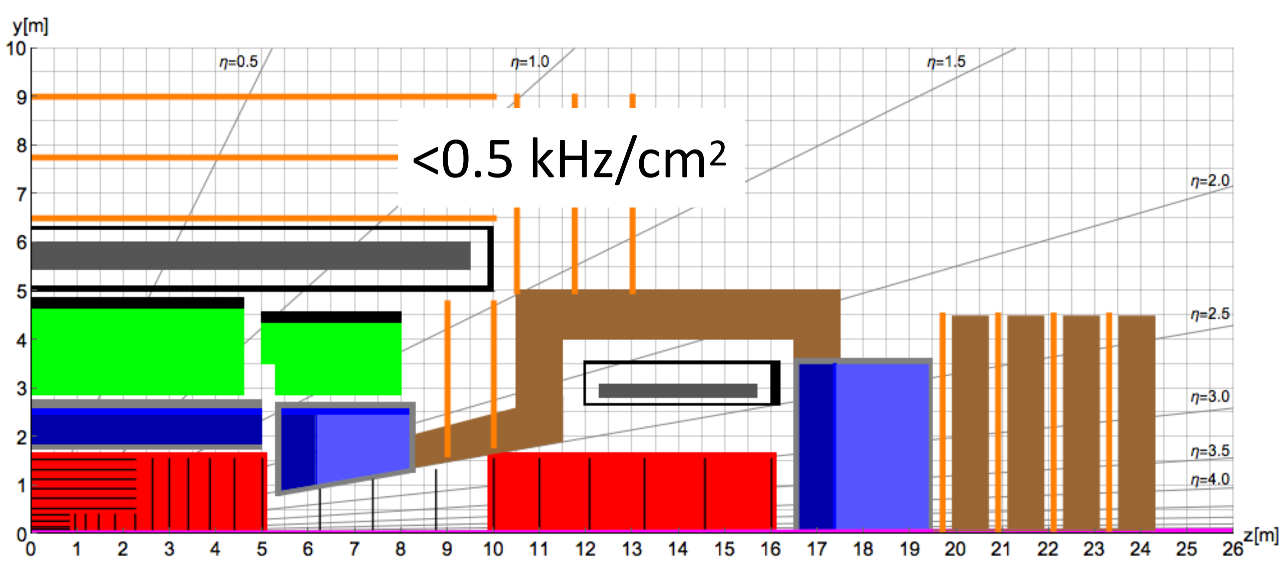

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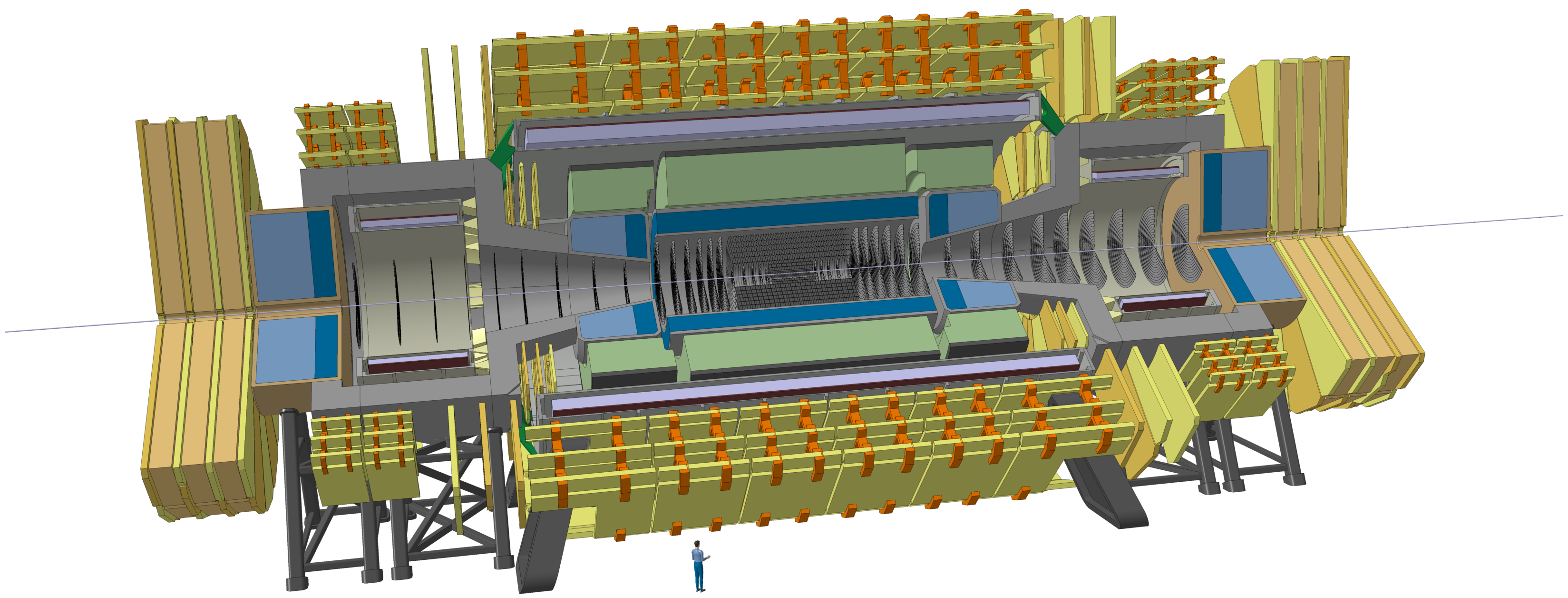

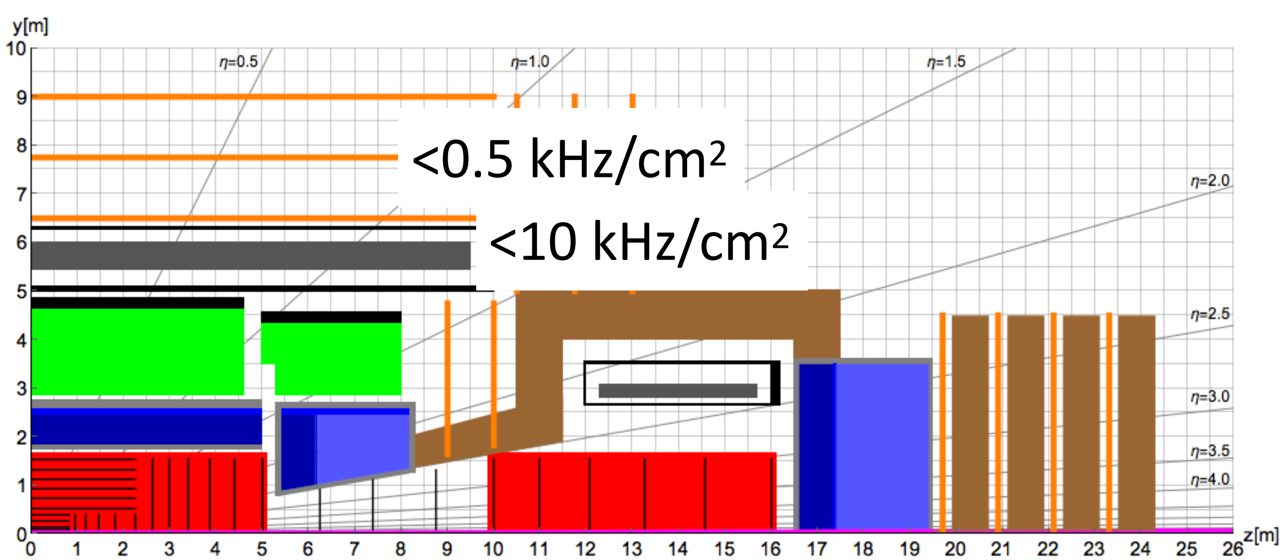

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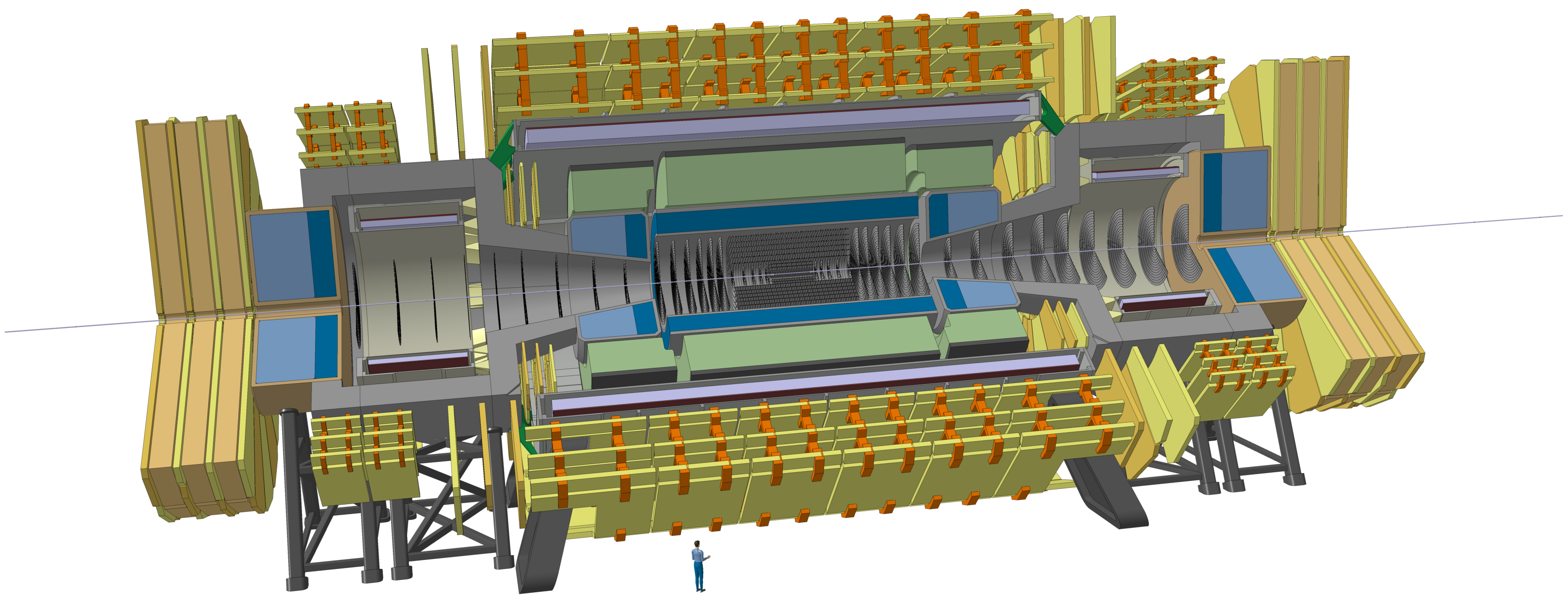

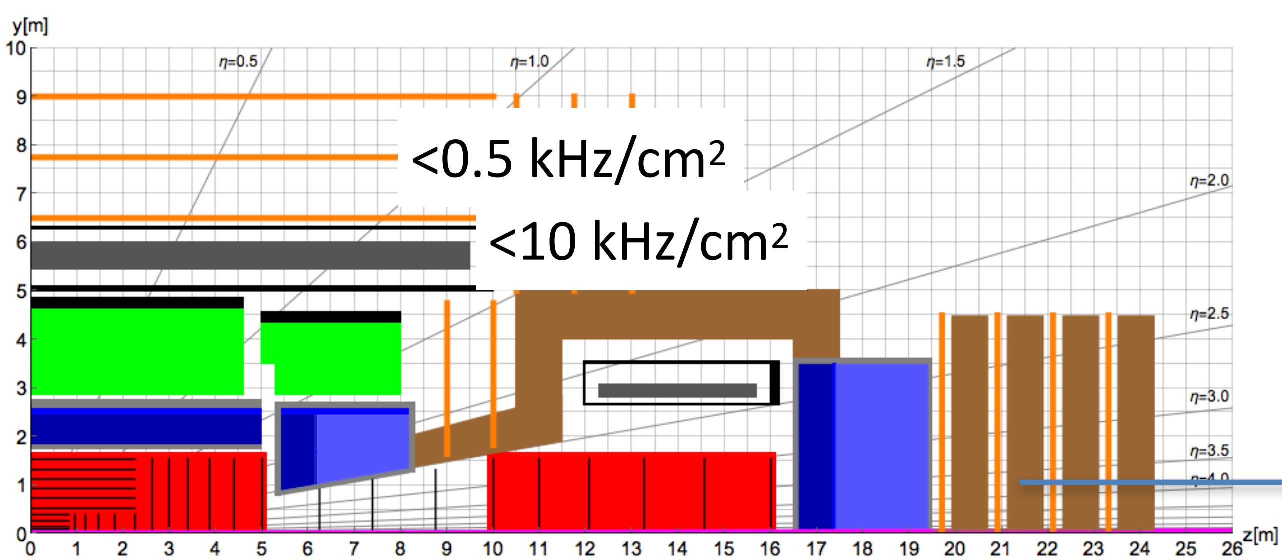

r>1m rate<500 kHz/cm^2

Muon detector for FCC-hh

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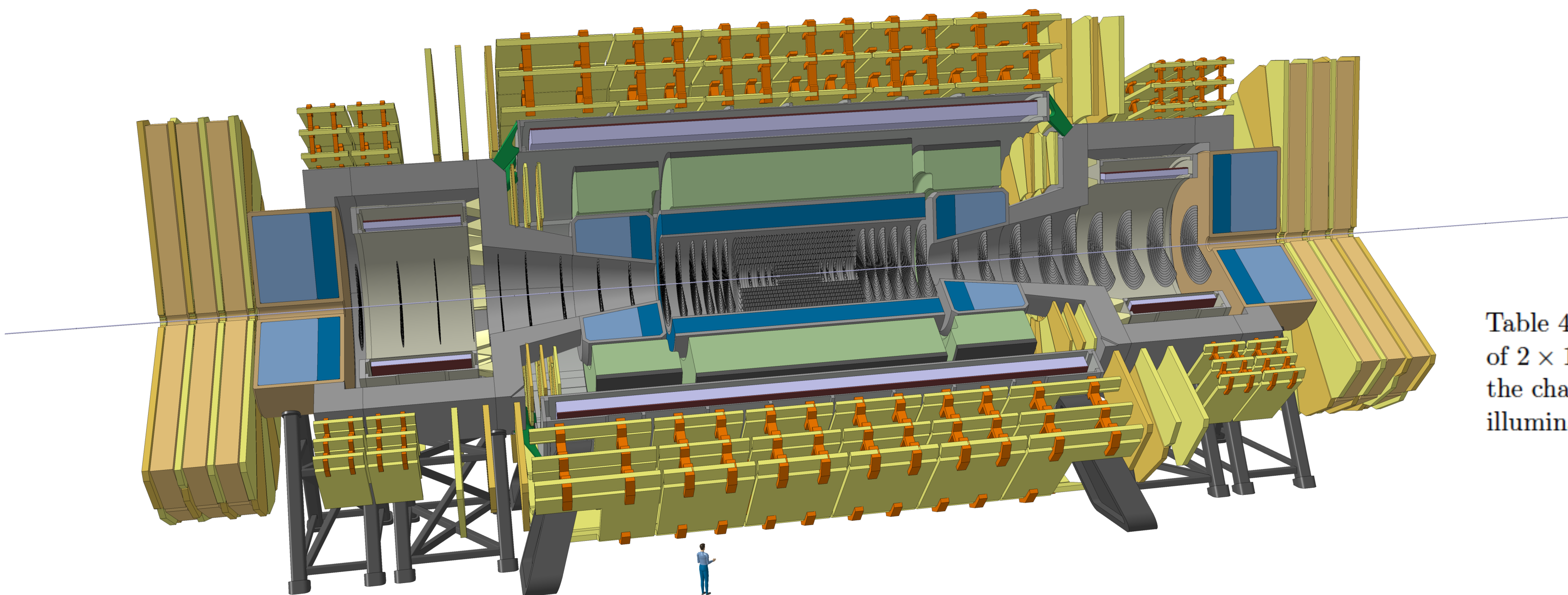

ATLAS muon system HL-LHC rates (kHz/cm2):

MDTs barrel:	0.28
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RPCs:	0.35
TGCs:	2
Micromegas and sTGCs:	9-10

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

LHCb

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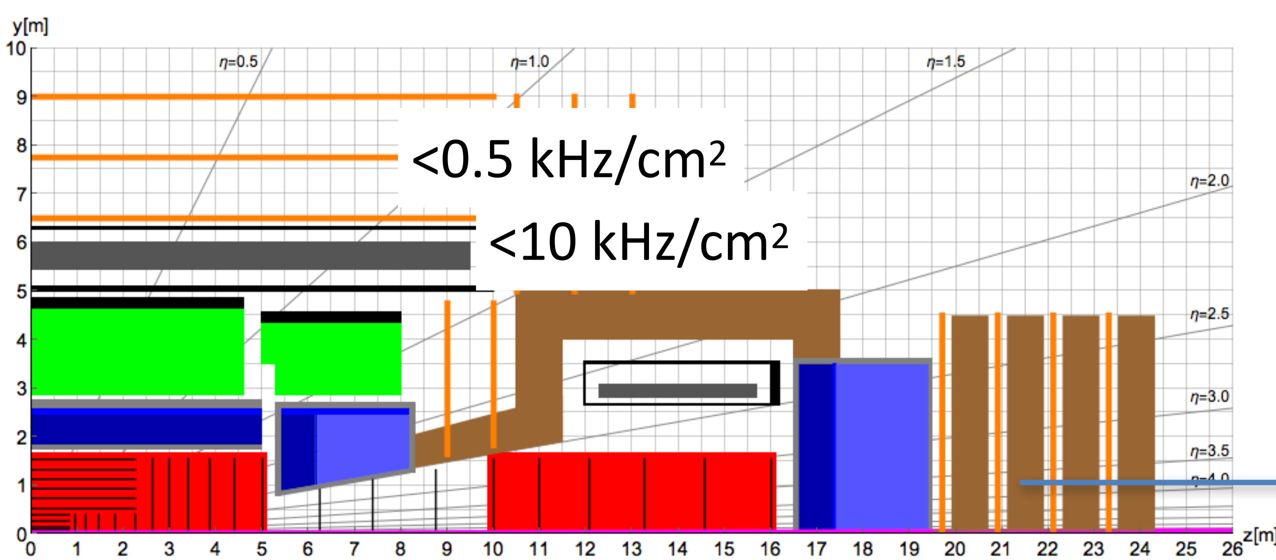

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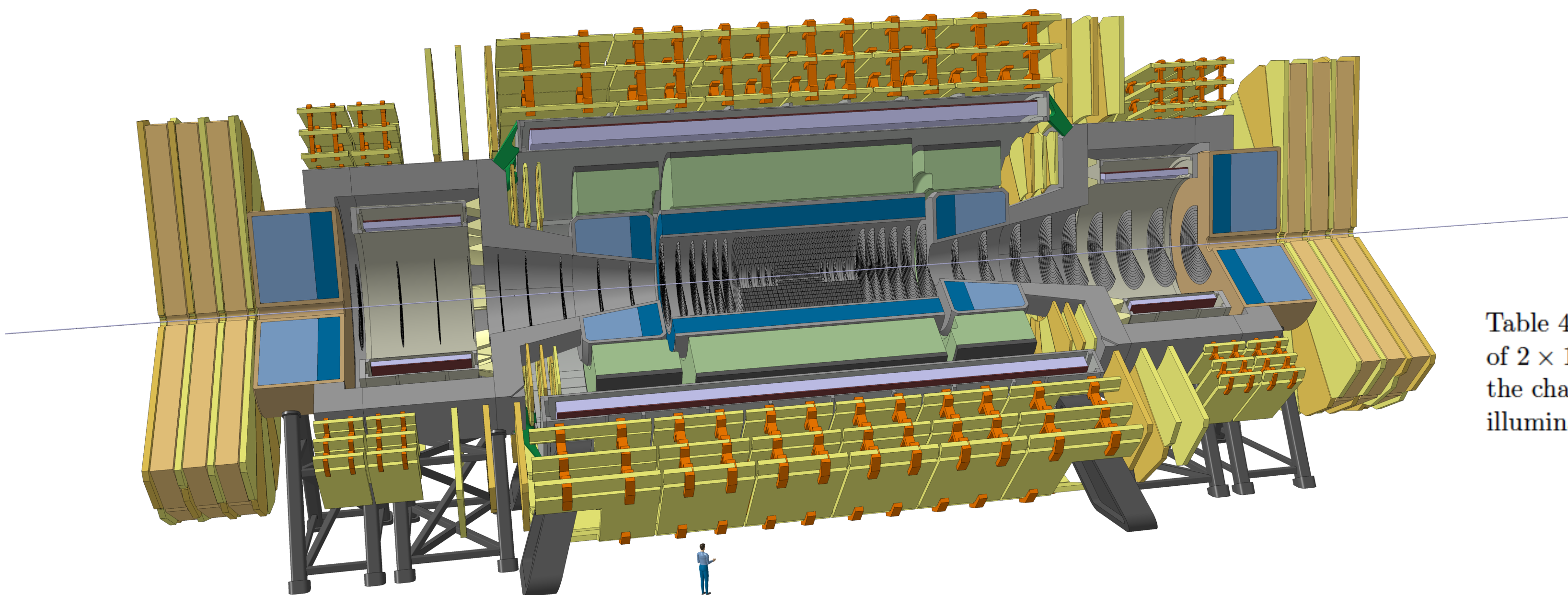

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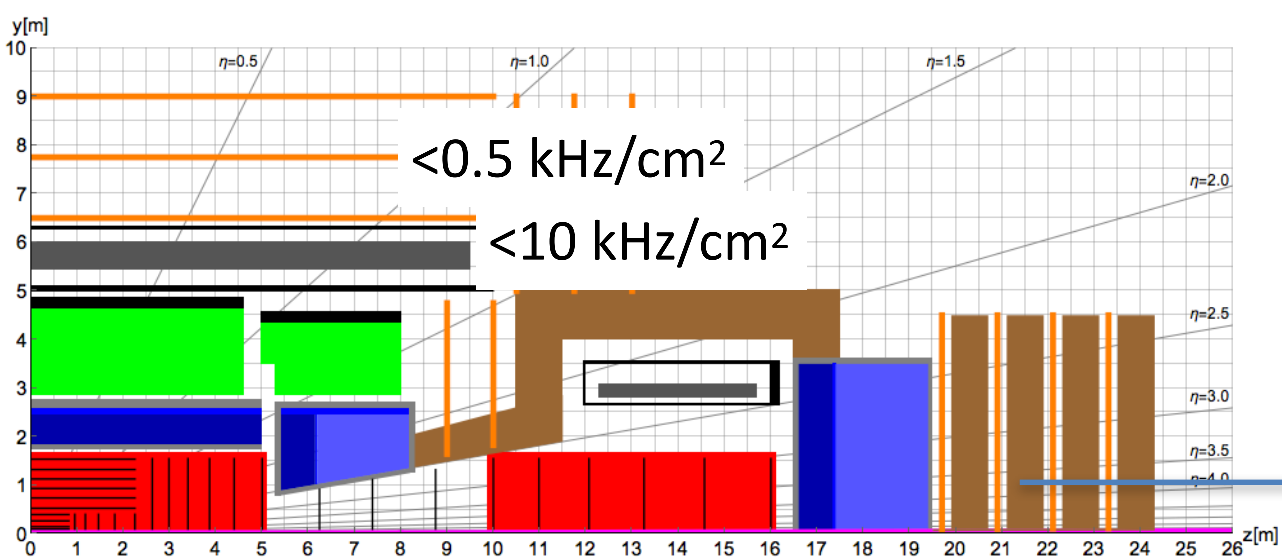

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HL-LHC muon system gas detector technologies, and especially MPGDs, would work for most of the FCC-hh detector area.

Muon detectors in large HEP experiments

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  - time resolution, σ_t, of 5-10 ns
- MPGDs could replace wire detectors, scintillator slabs and RPCs at a comparable price if they are mass produced by Industry

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Improve gas detectors

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Limited multi-track separation

Reduce multiplication region size
Faster ion evacuation
Higher spatial resolution

S. Franchino, 2016

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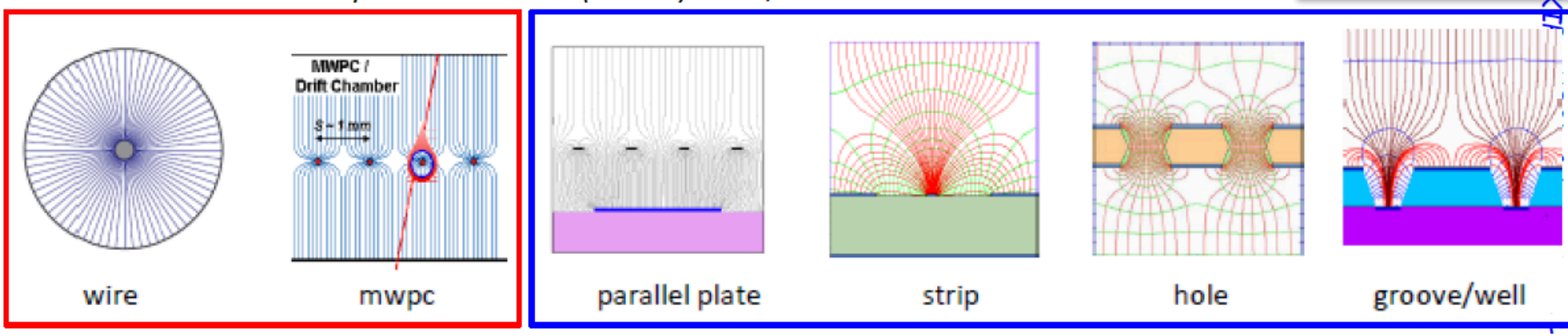
First MPGD: Micro Strip Gas Chamber (MSGC) OED, 1988



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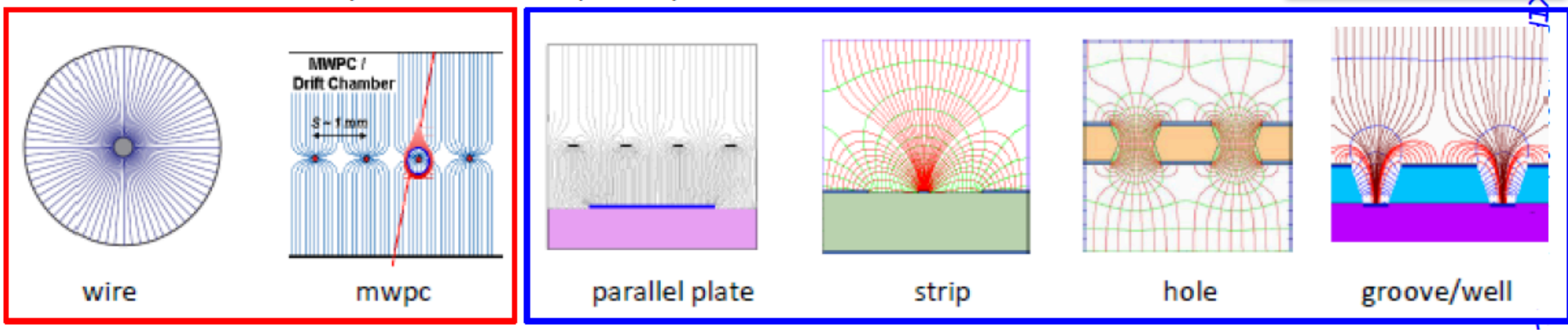
Faster ion evacuation
Higher spatial resolution

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

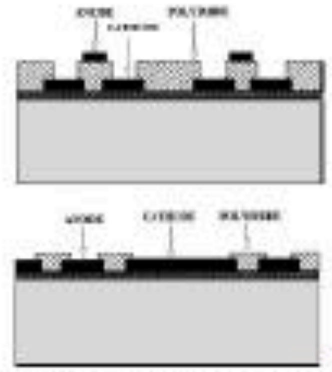
S. Franchino, 2016



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

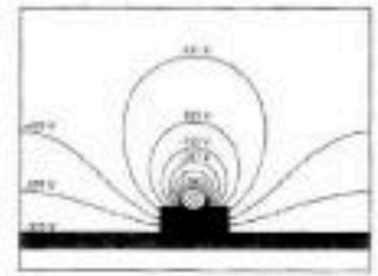
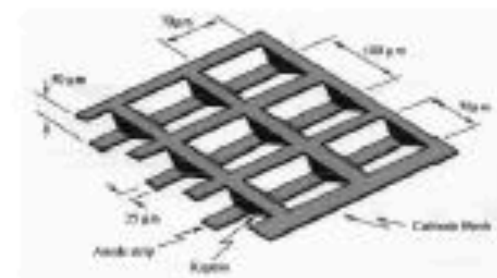


Figure 2.27 Scheme of a MGWC with equipotential and field lines. The circle filled with lines is the section of an anode wire [CHRISTOPHEL1997]

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

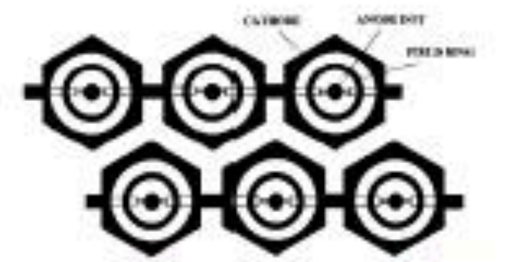
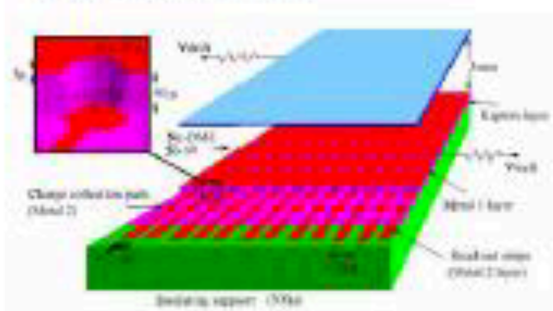


Figure 26 Schematics of the microdot chamber. A pattern of metallic anode dots surrounded by field and cathode electrodes is implemented on an insulating substrate, using microelectronic technology. Anodes are interconnected for readout.

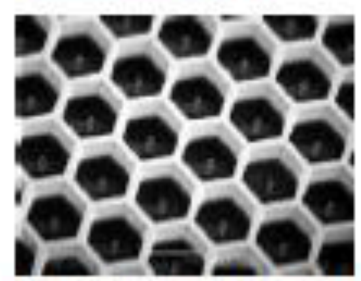
Biagi SF, Jones TJ. Nucl. Instrum. Methods A361:72 (1995)

MicroWELL



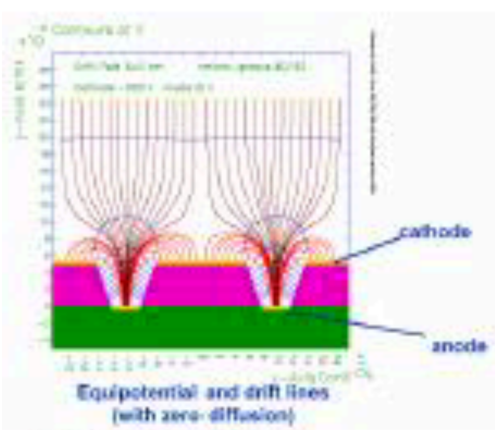
R. Bellazziniet al
Nucl. Instr. and Meth. A423(1999)125

MicroPin



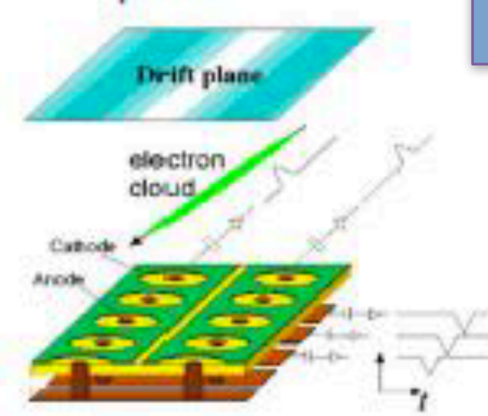
P. Rehak et al., IEEE Nucl. Sci. Symposium seattle 1999

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

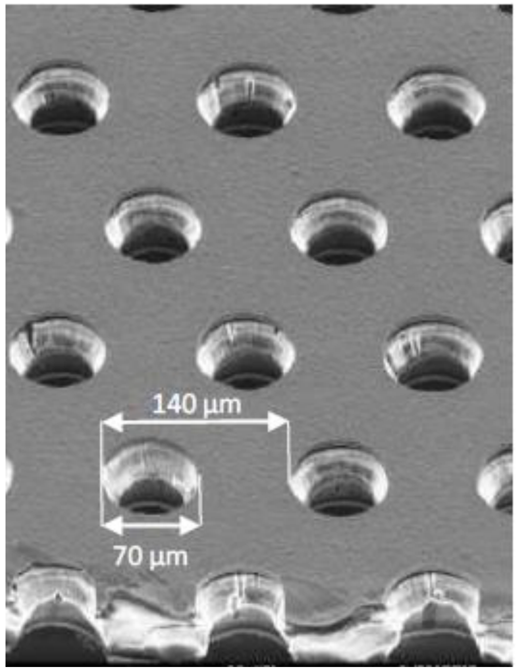
More recent MPGDs

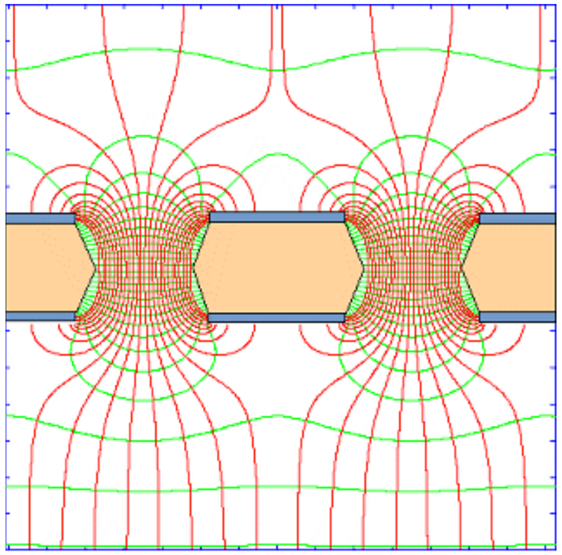
S. Franchino, 2016

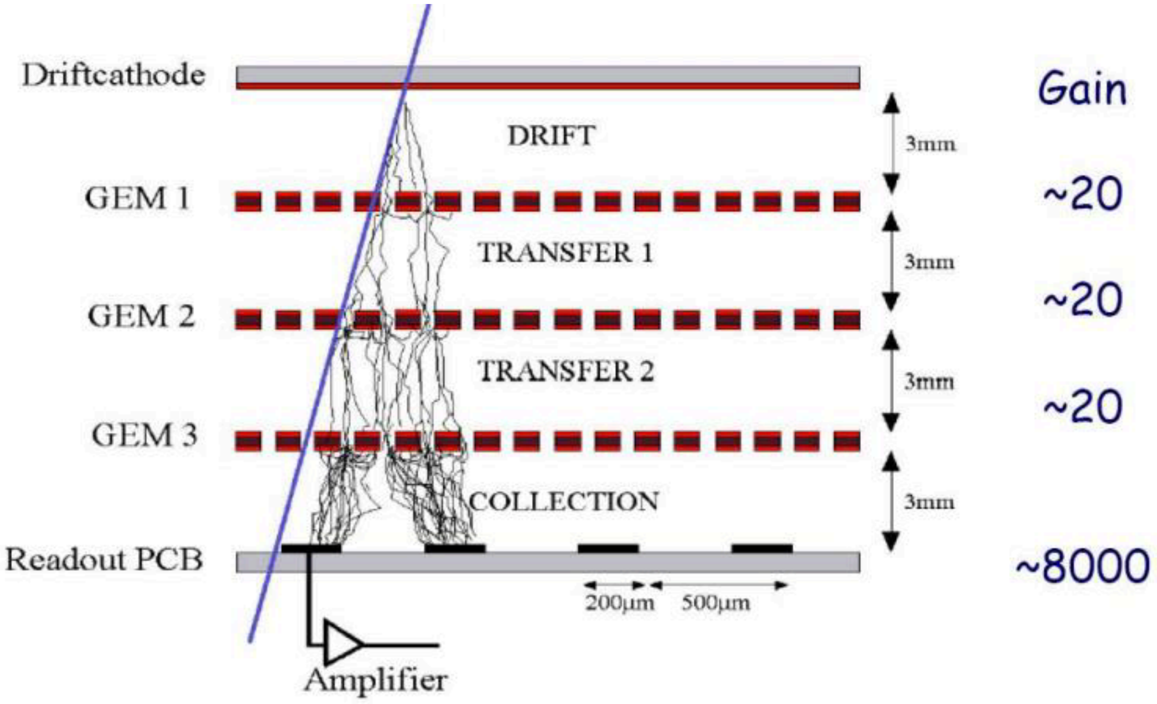
More recent MPGDs

F. Sauli, NIM. A386(1997)531

GEM (std, Thick, glass, …)







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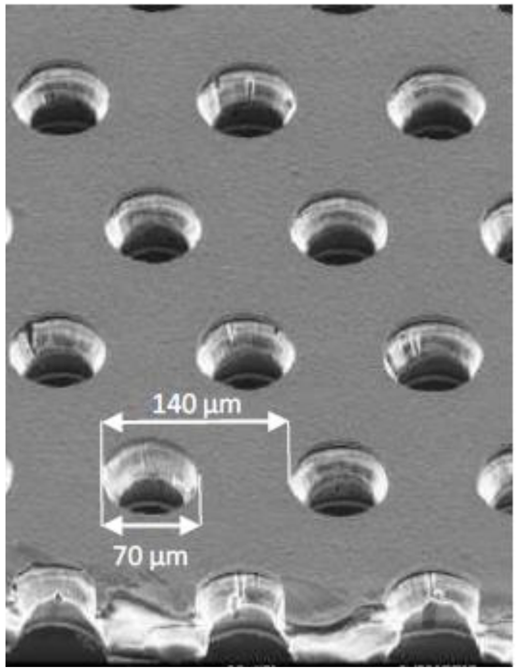
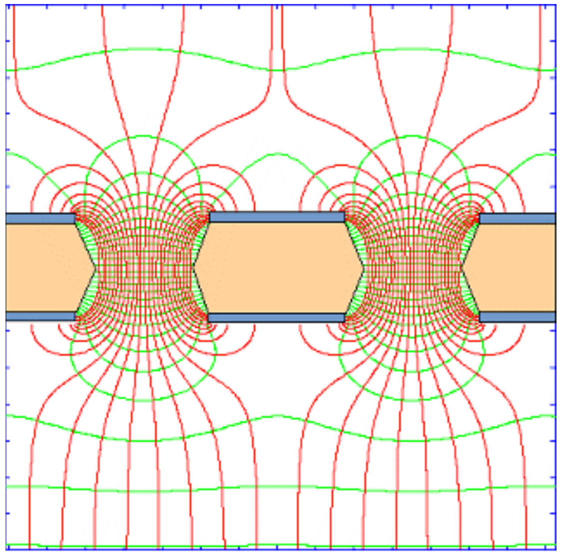
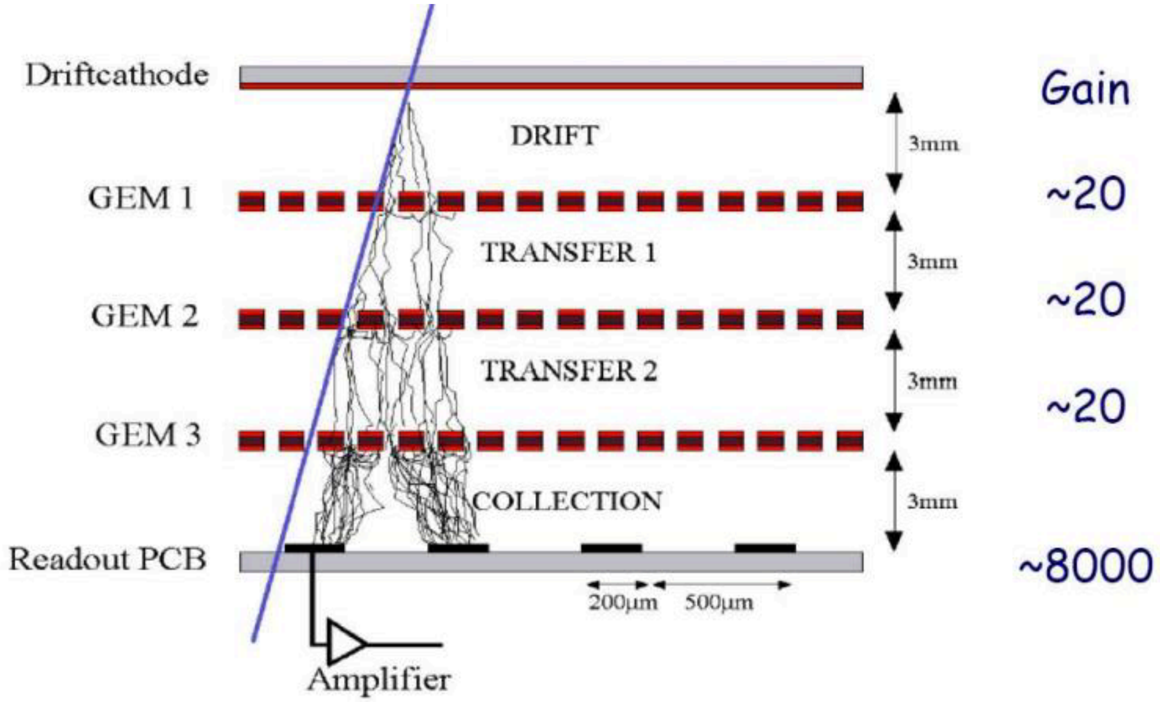
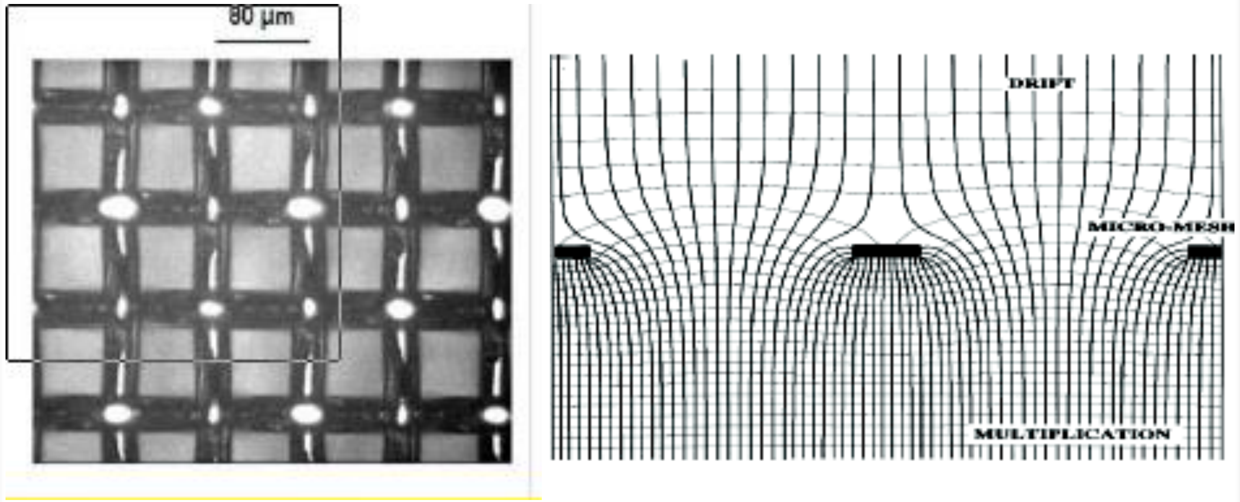


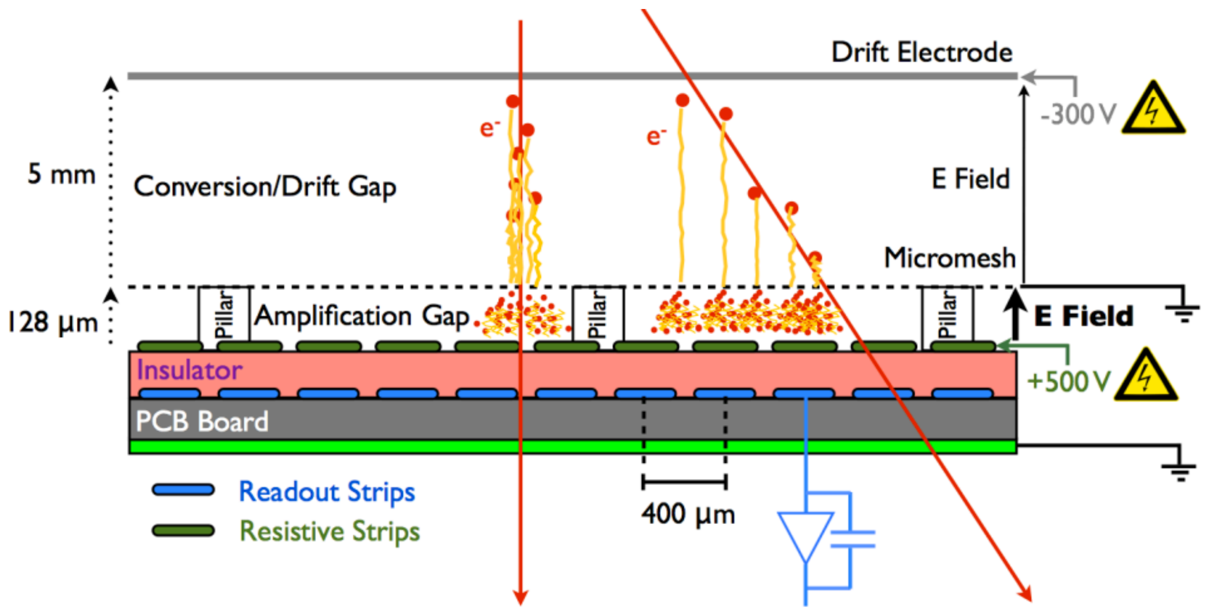




I. Giomataris et al., NIM A 376 (1996)

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





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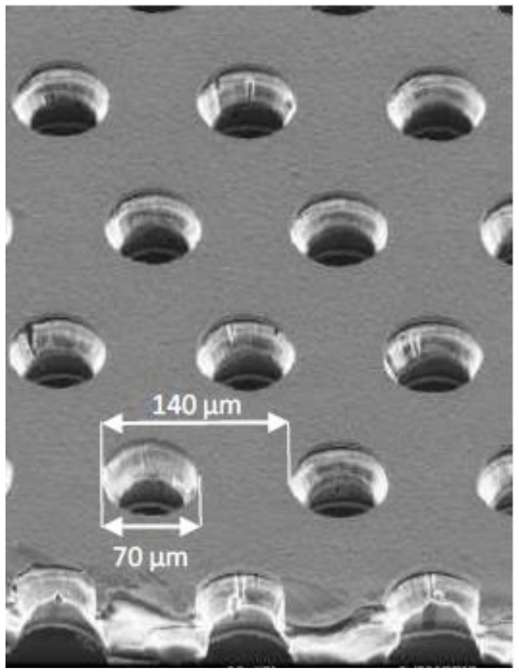

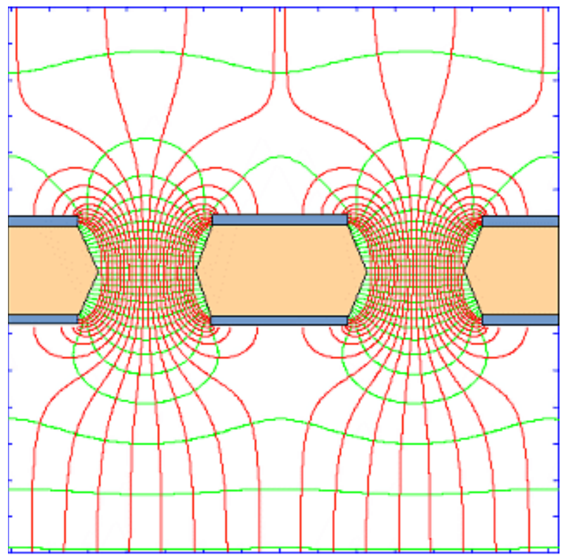

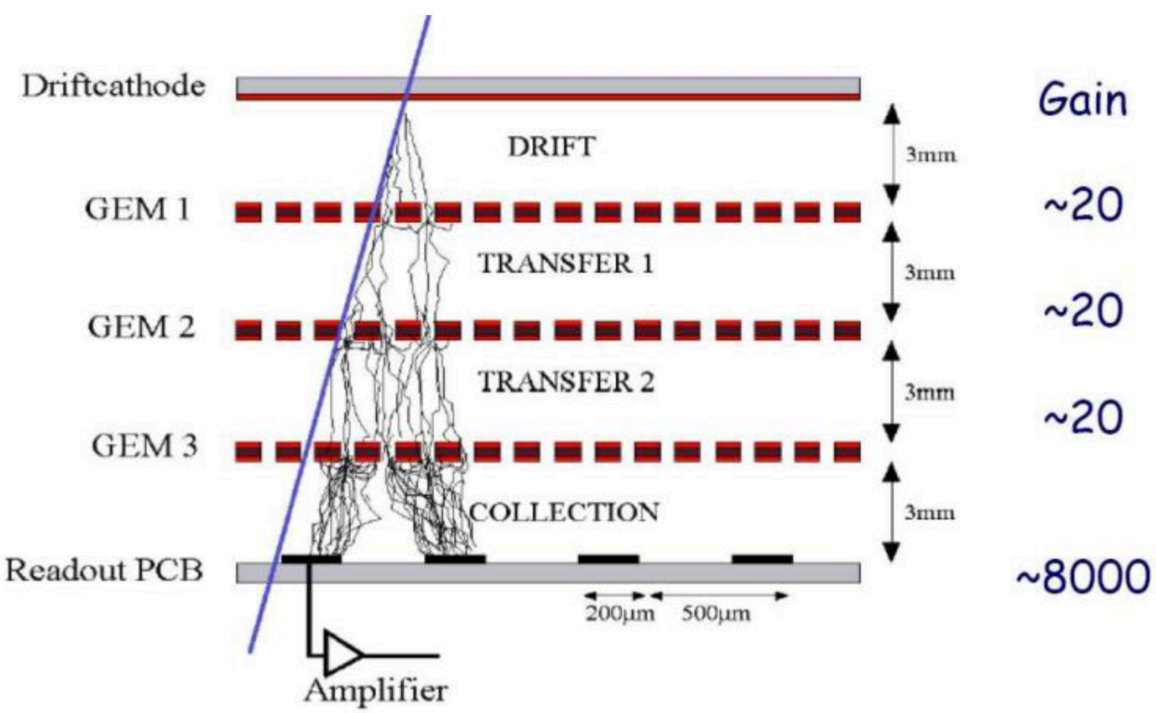

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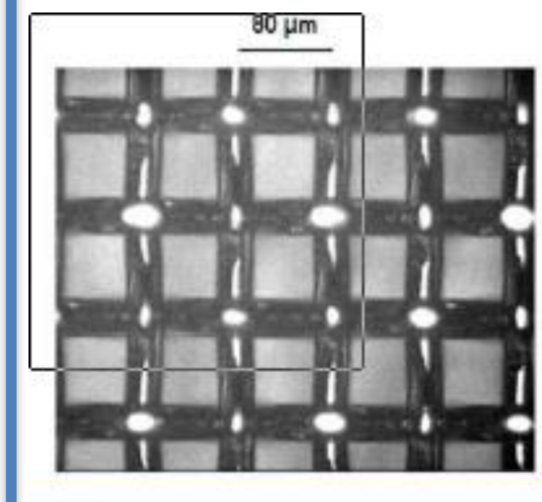
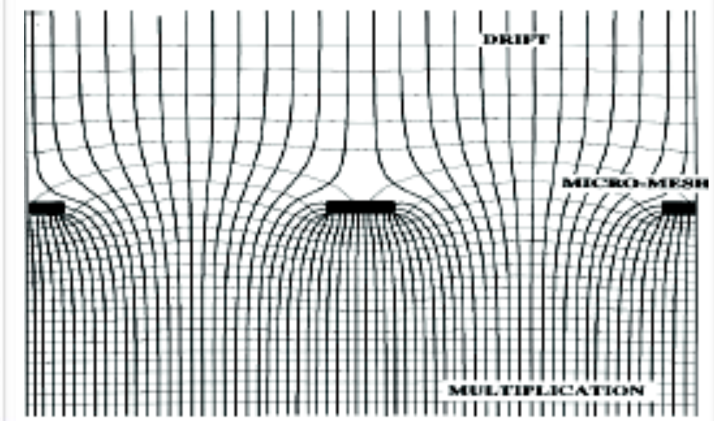
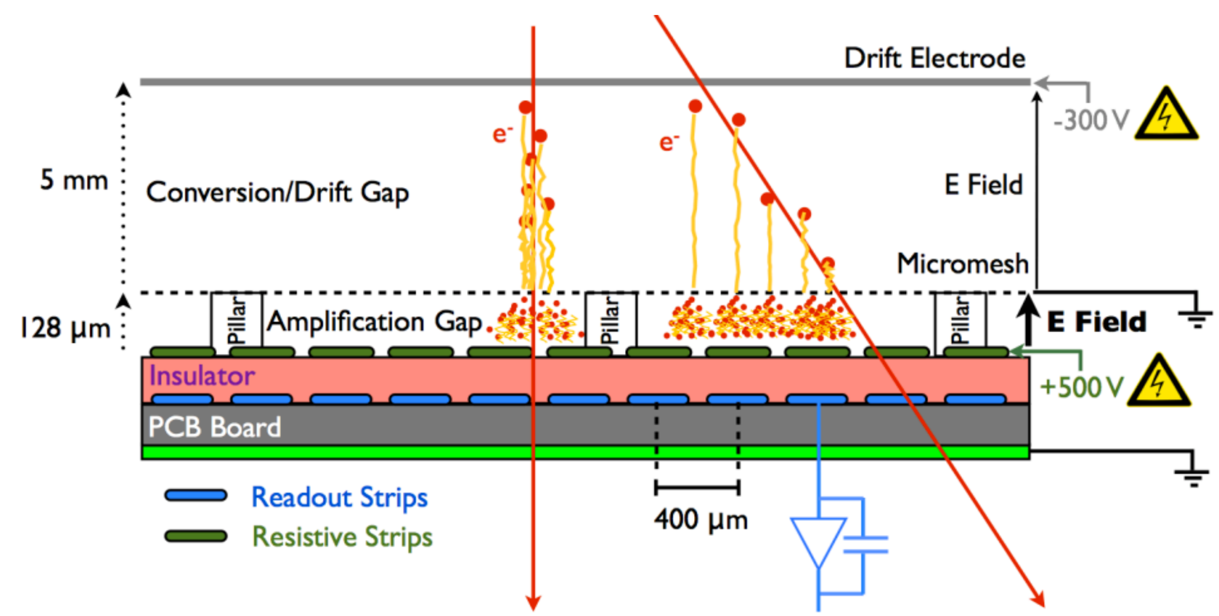






S. Franchino, 2016

Ageing: OK (no thin wires)

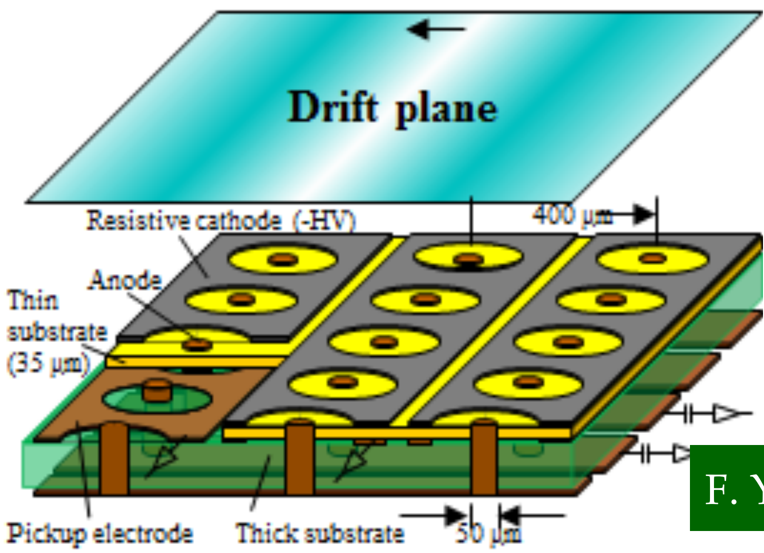
Spark protection: multiple amplification stages, resistive electrodes

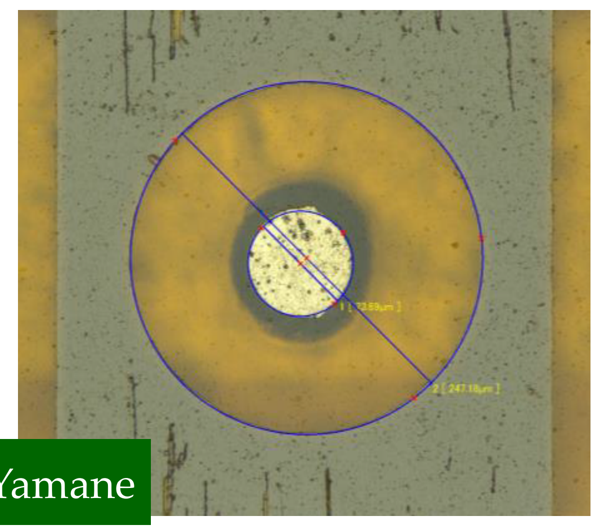
μPIC / μ-RWELL for ATLAS Large-η Tagger Phase II Upgrade

µPIC / µ-RWELL for ATLAS Large-η Tagger Phase II Upgrade

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

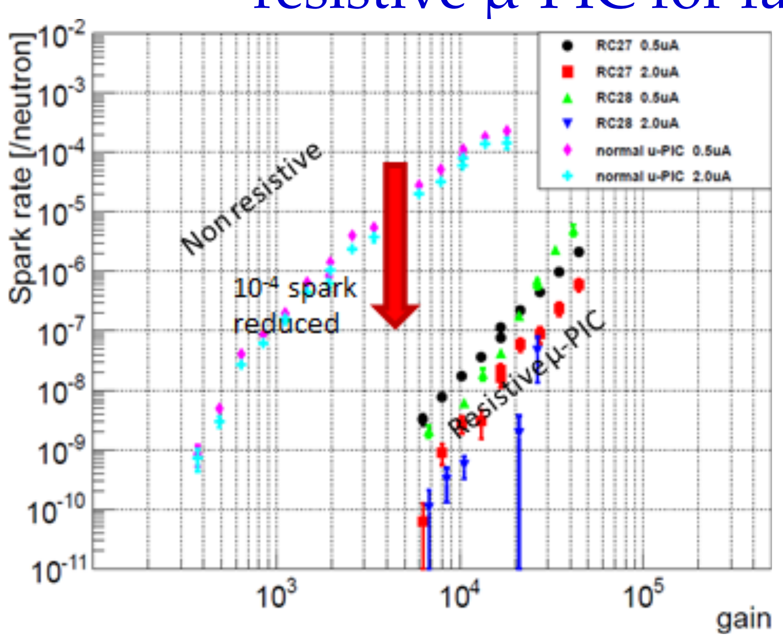
µ-PIC with resistive Diamond-LC electrodes:



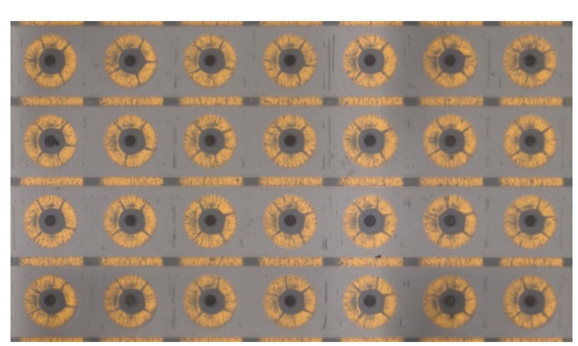


F. Yamane

Spark rate reduction using resistive µ-PIC for fast neutron



Resistive µ-PIC using sputtered C:



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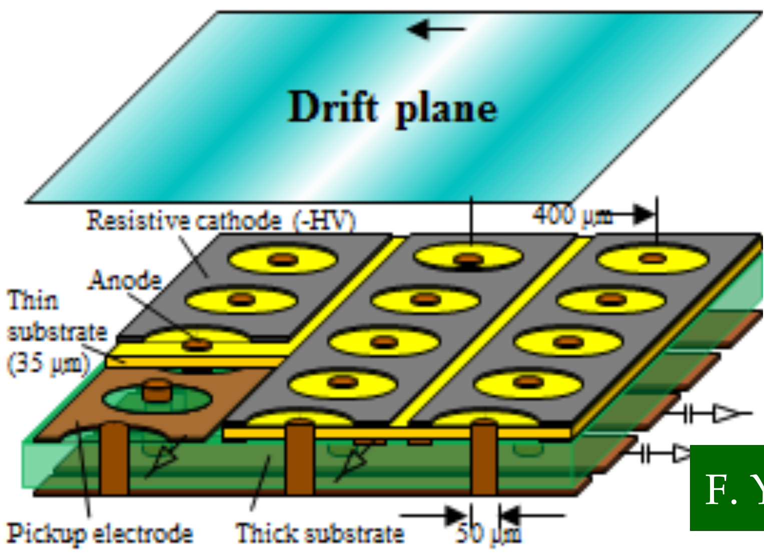
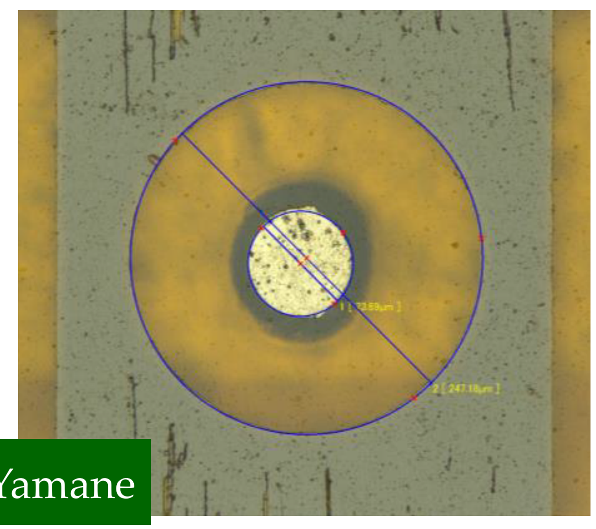
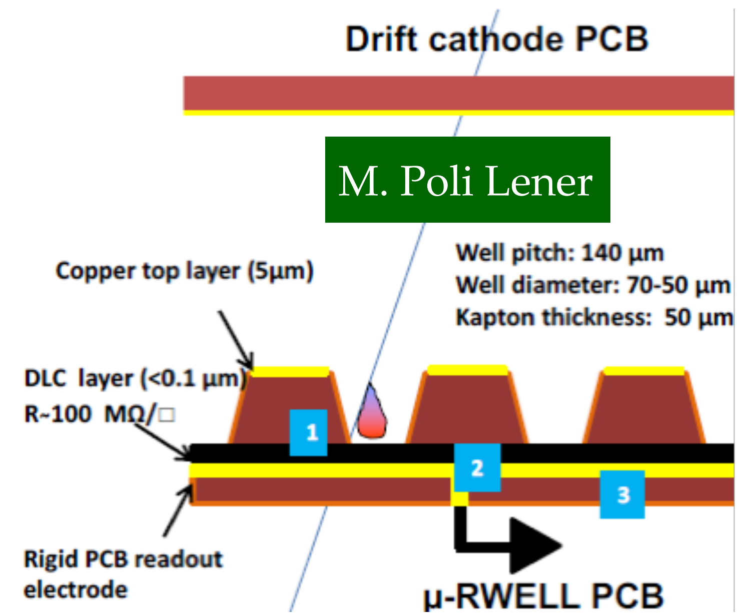
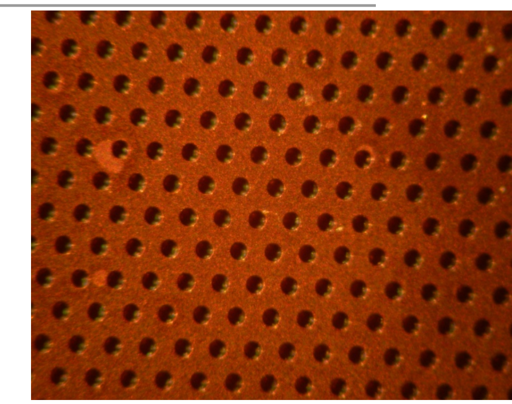
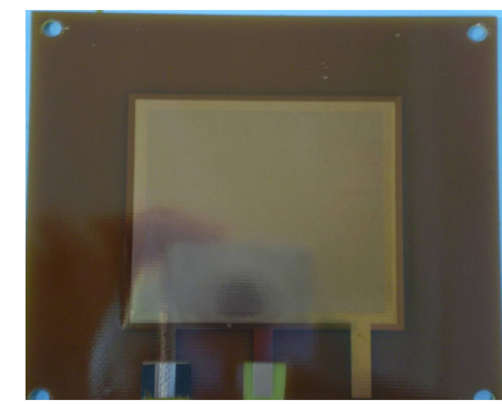




μ-RWELL Detector:

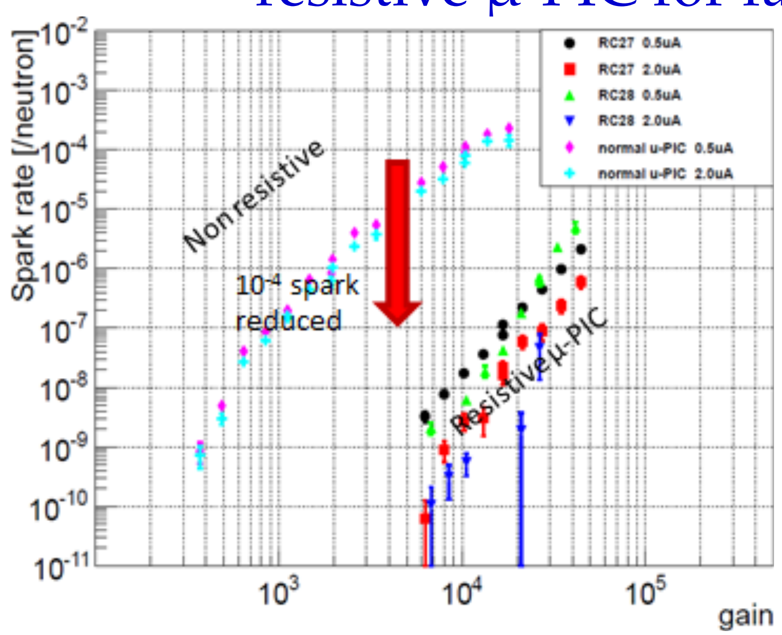






- Very reliable
- Almost completely *discharge-free*
- adequate for high particle rates O(1MHz/cm²) thanks to the *segmented-resistive-layer*
- suitable for large area applications (1.8 x 1.2 m² proto was tested in 2017)

Spark rate reduction using resistive μ-PIC for fast neutron



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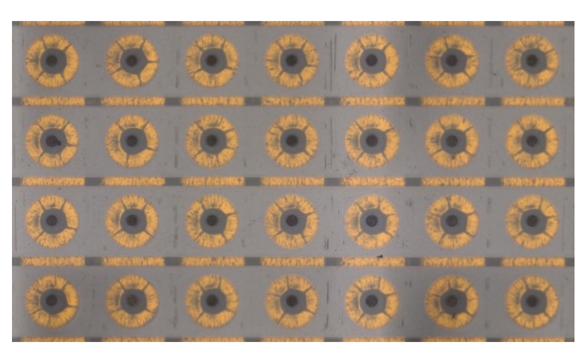

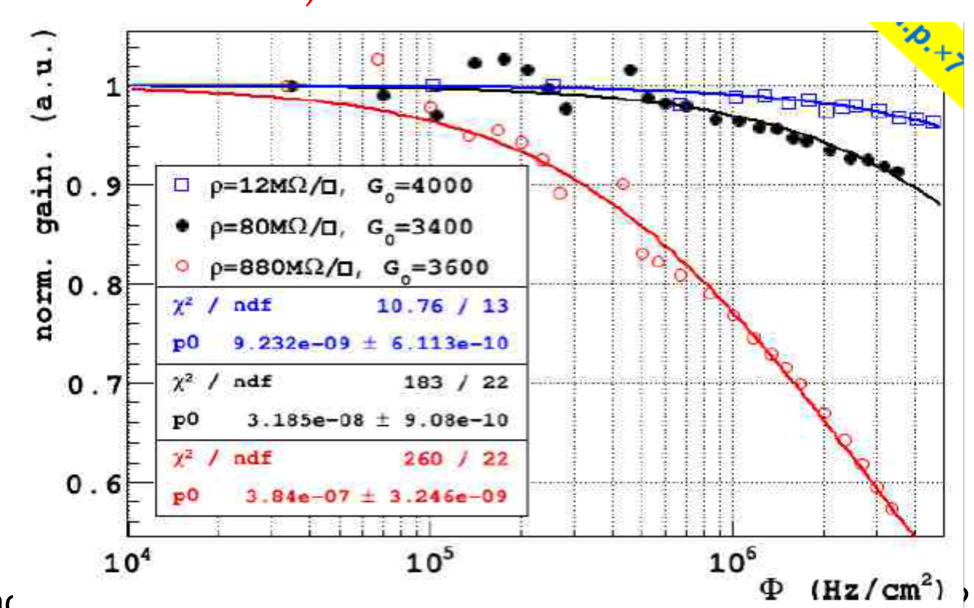

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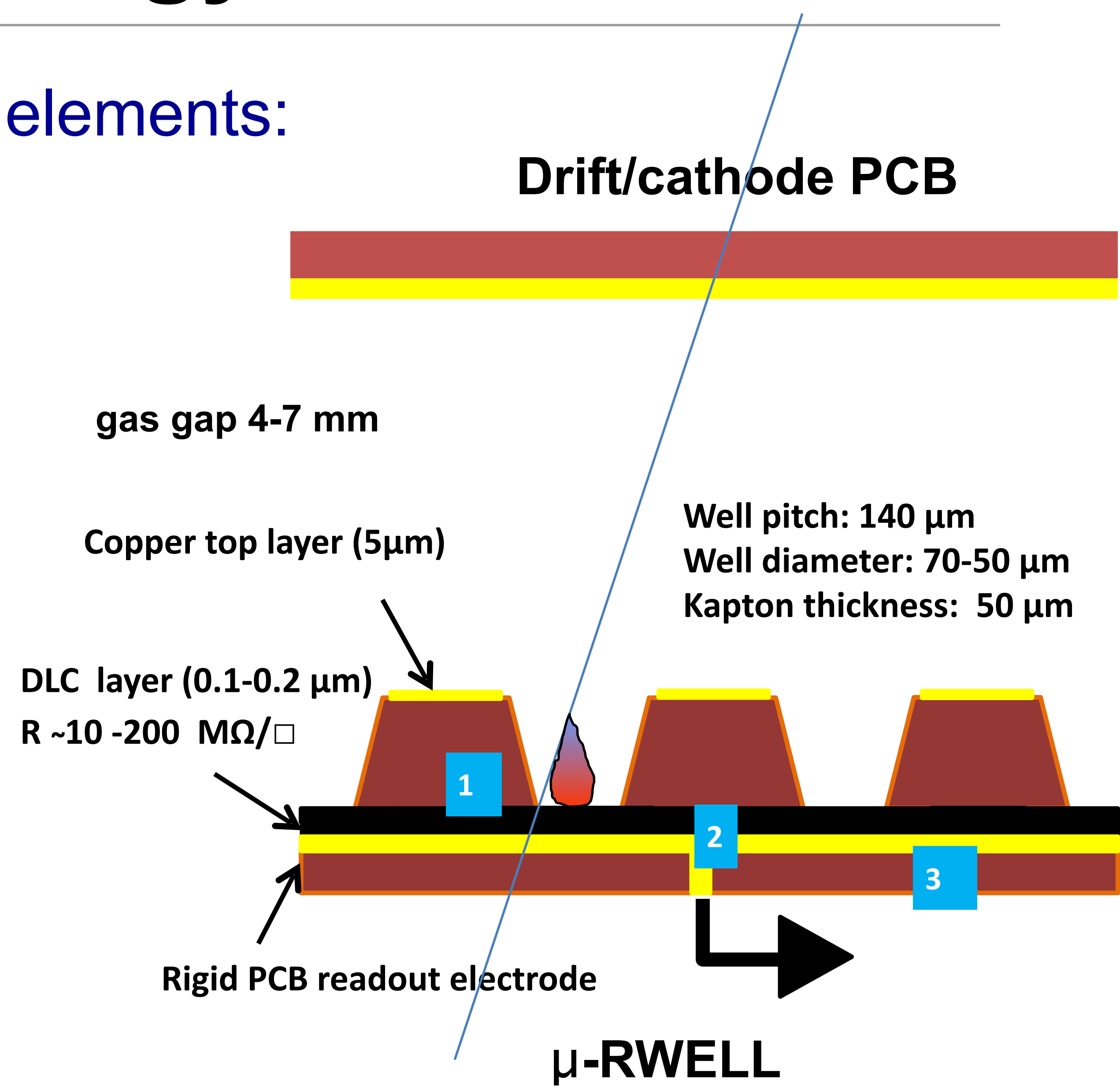

G. Bencivenni et al., 2015_JINST_10_P02008

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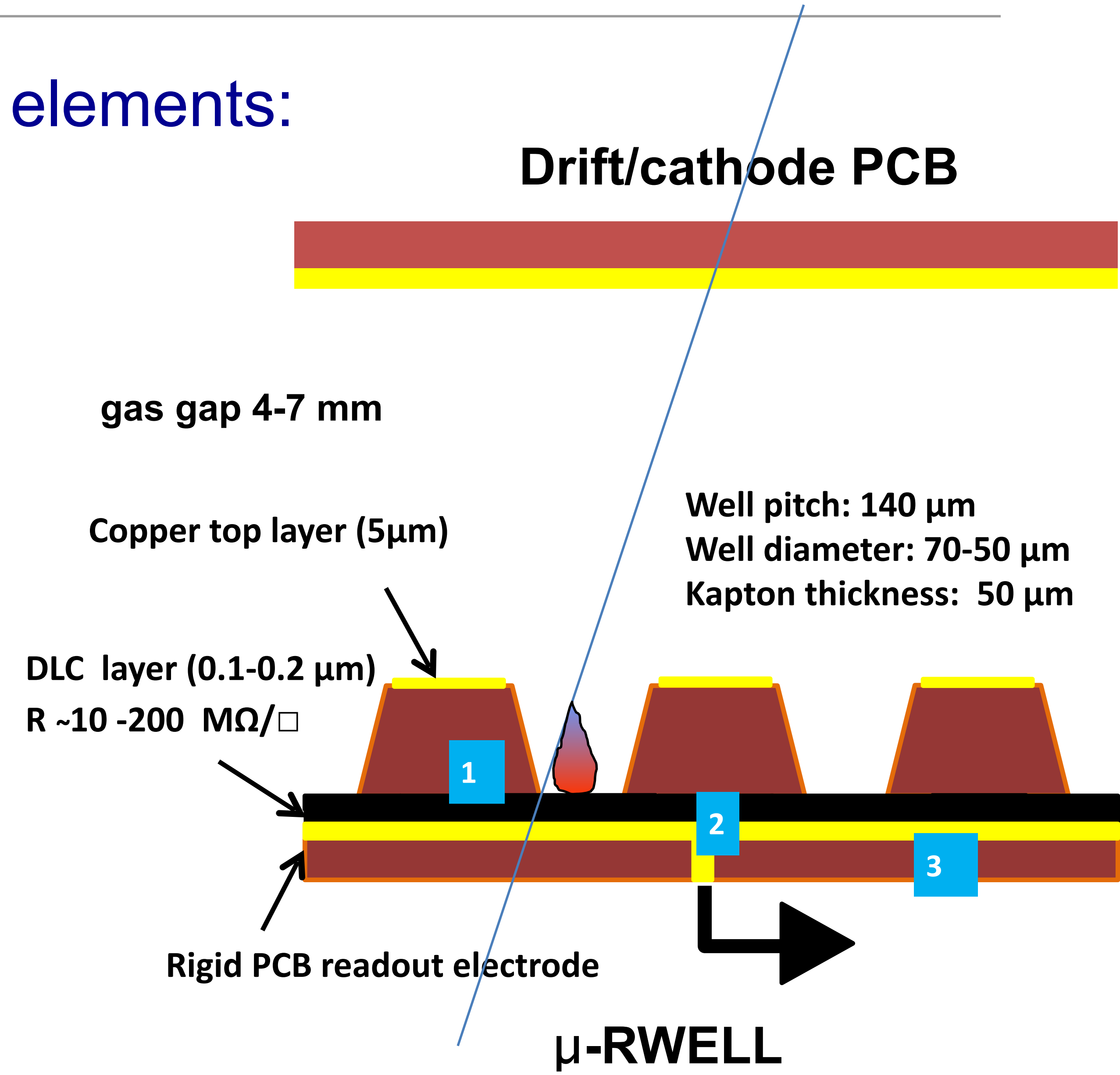

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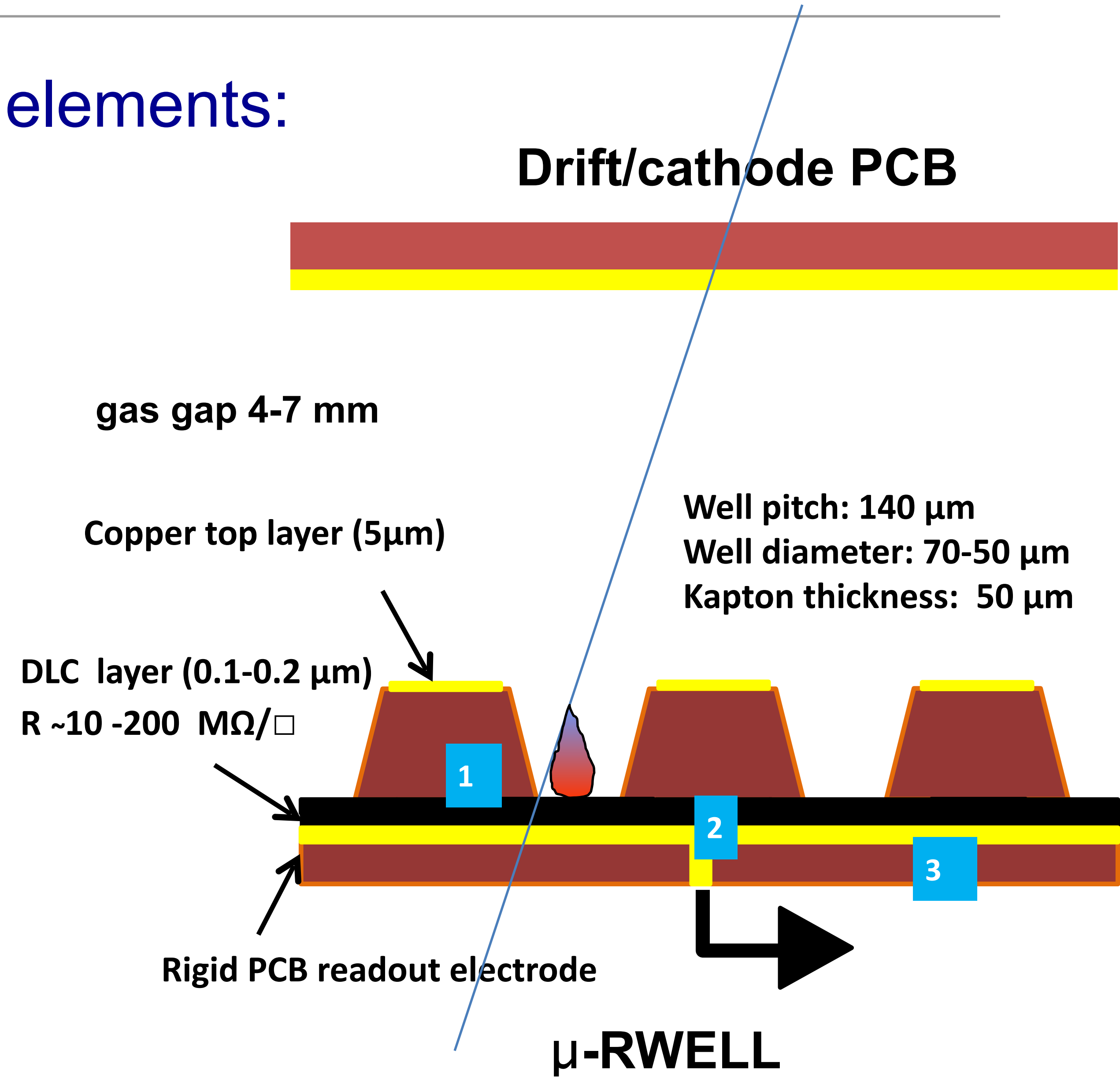

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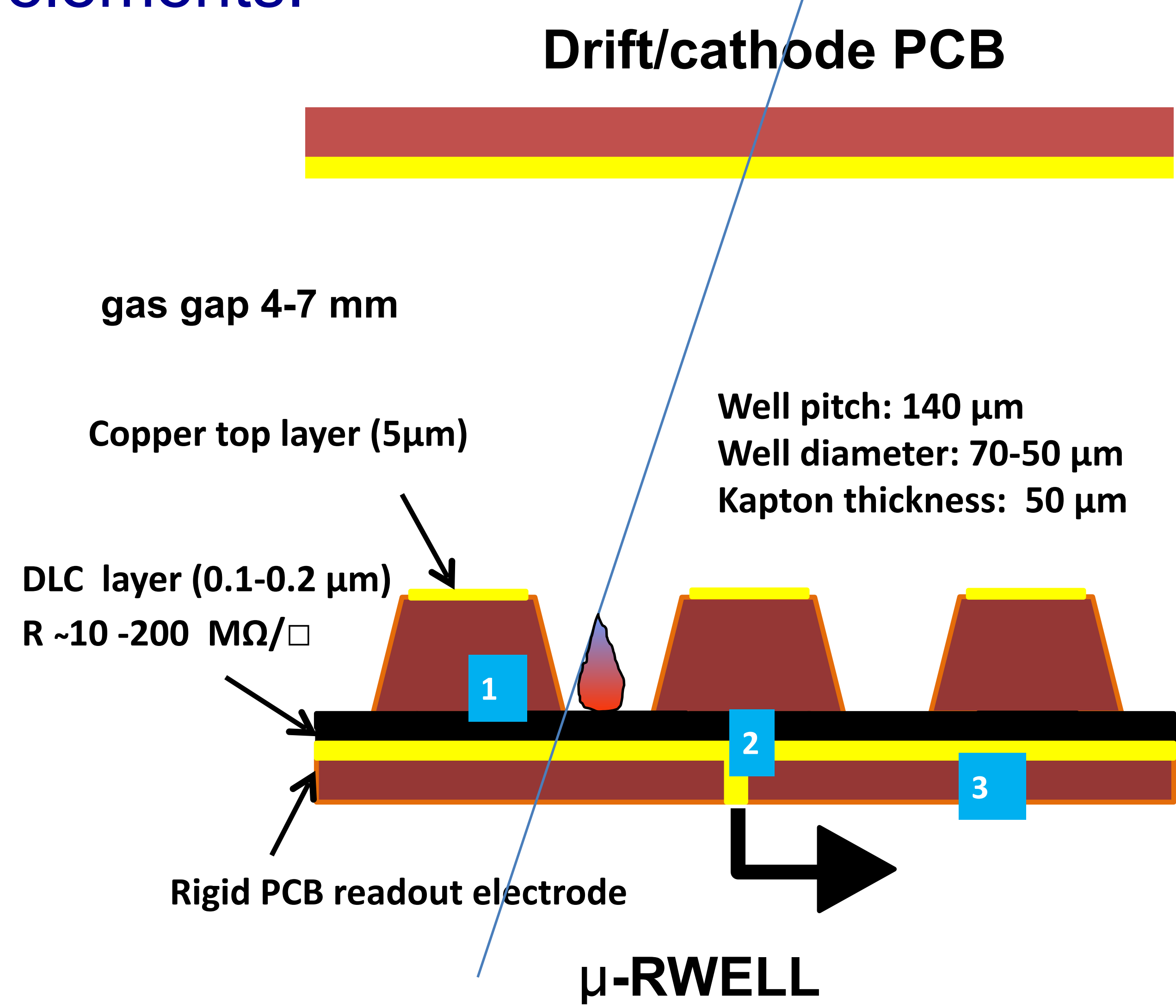

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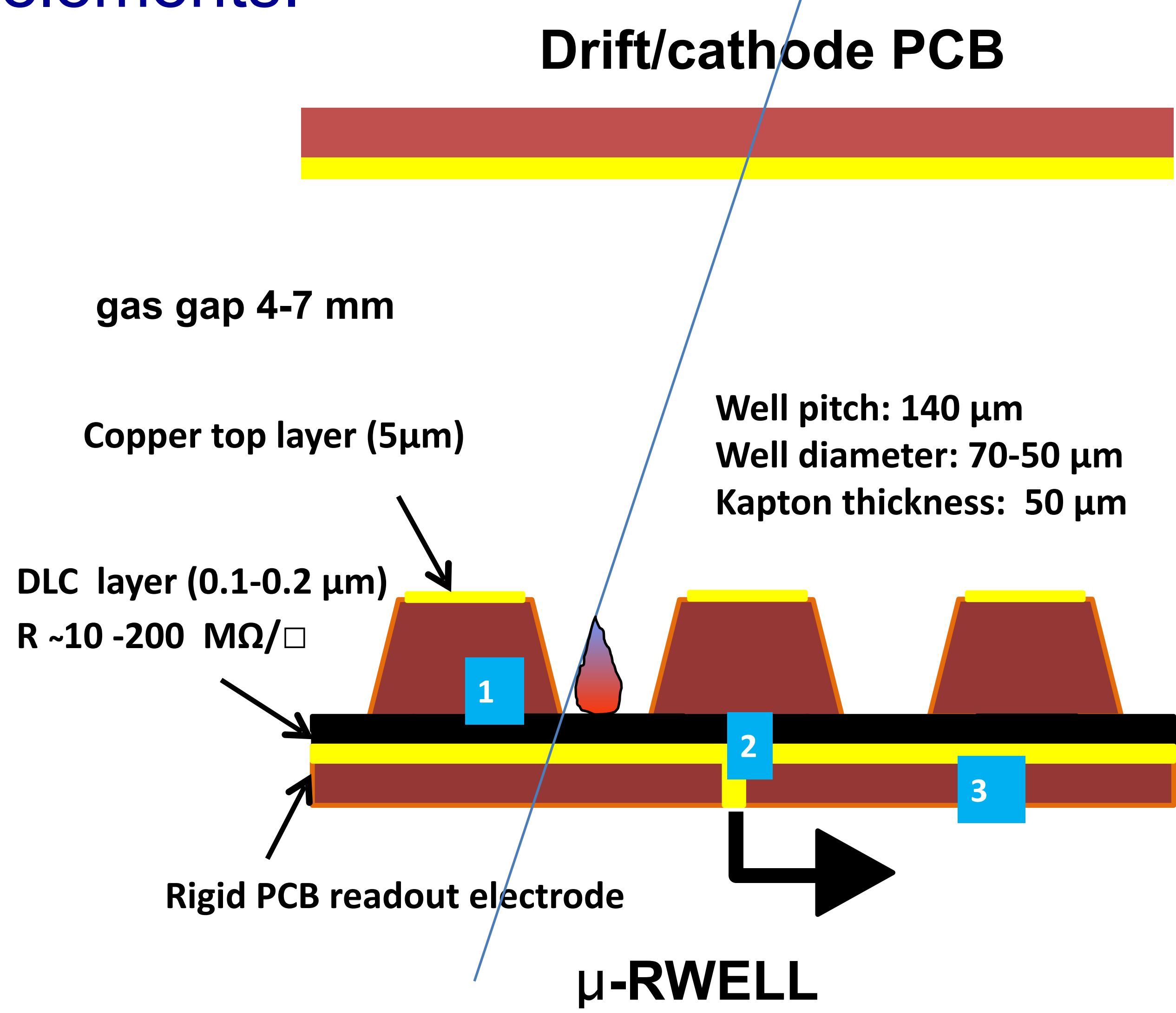

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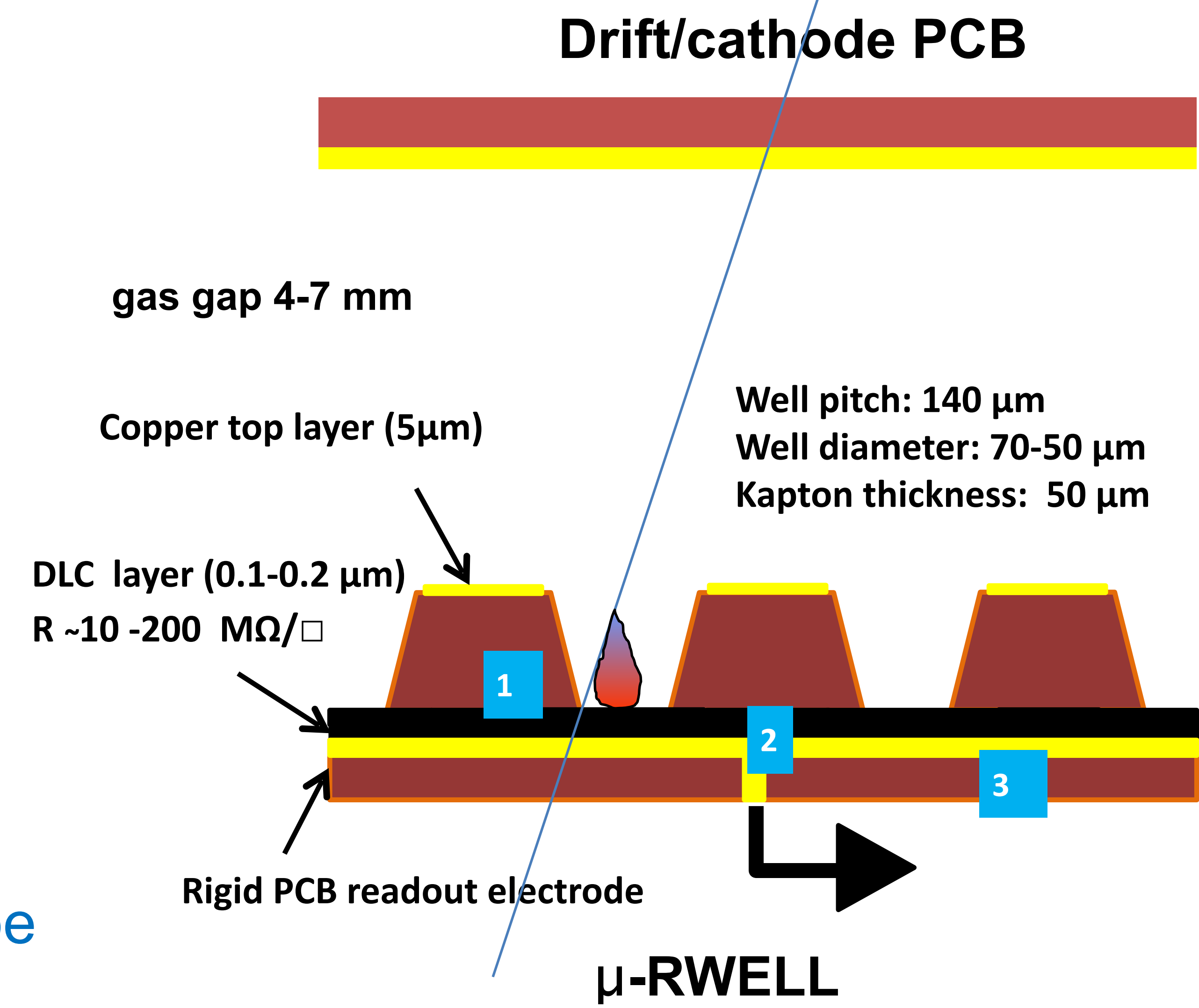

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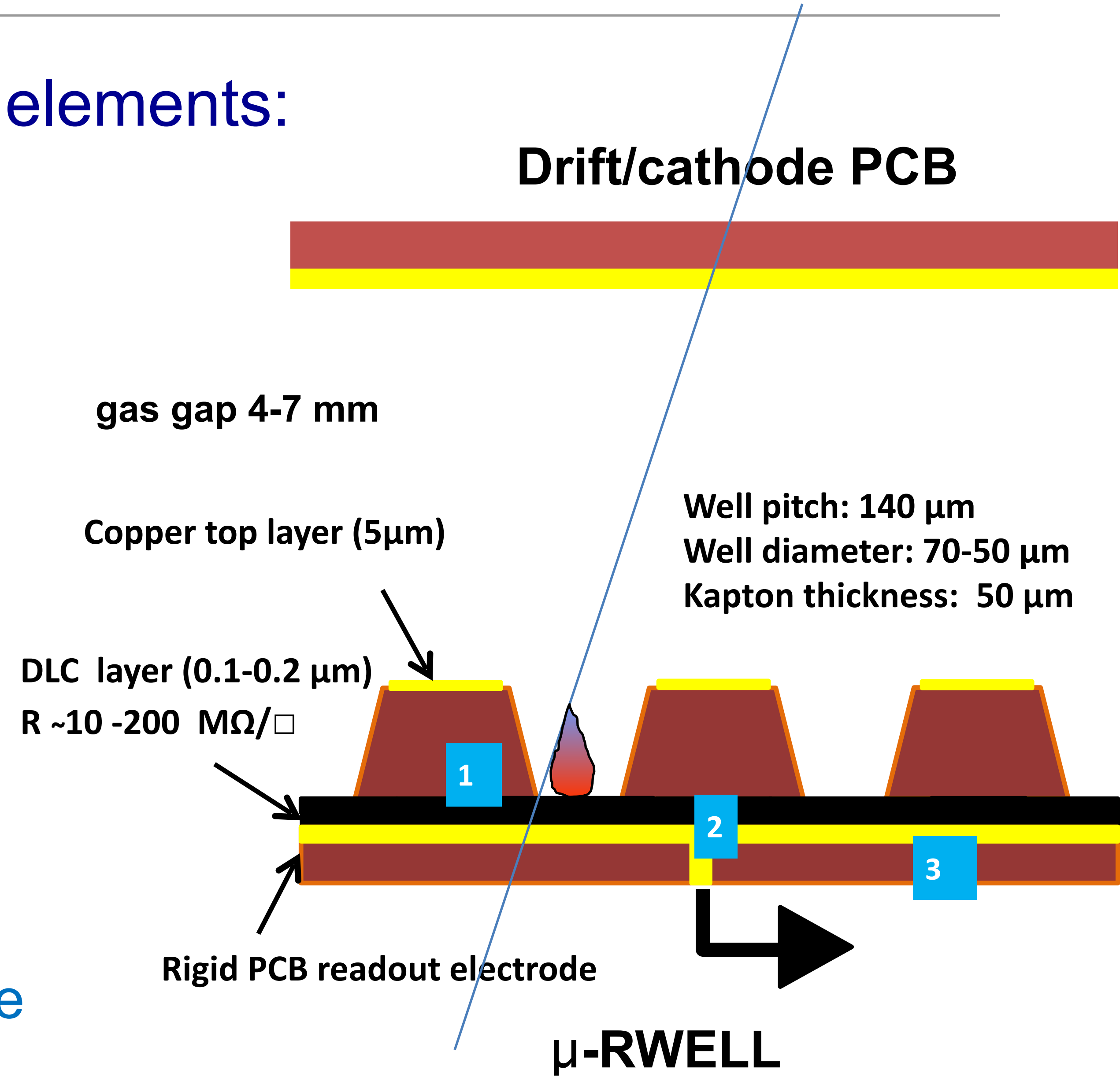

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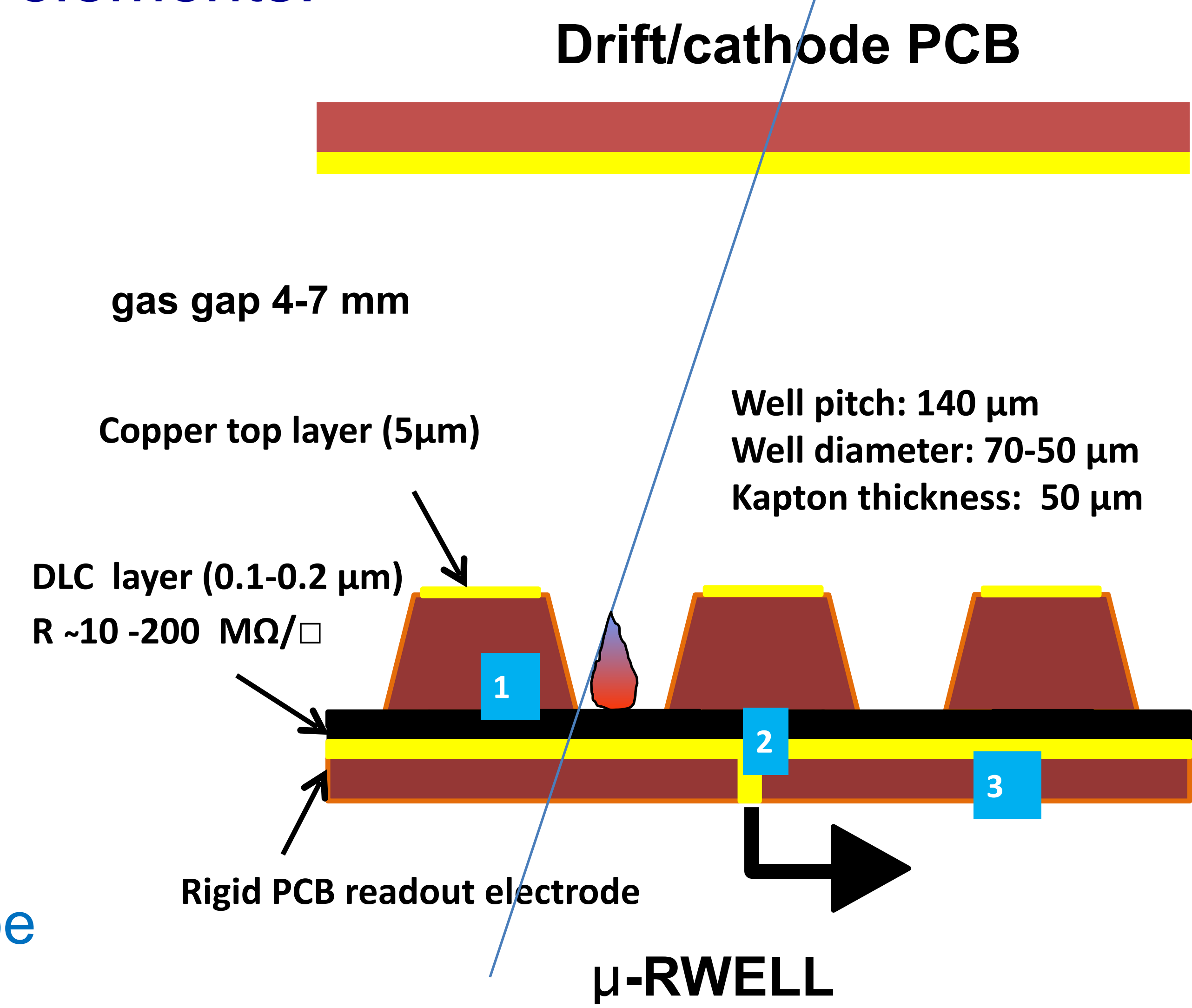

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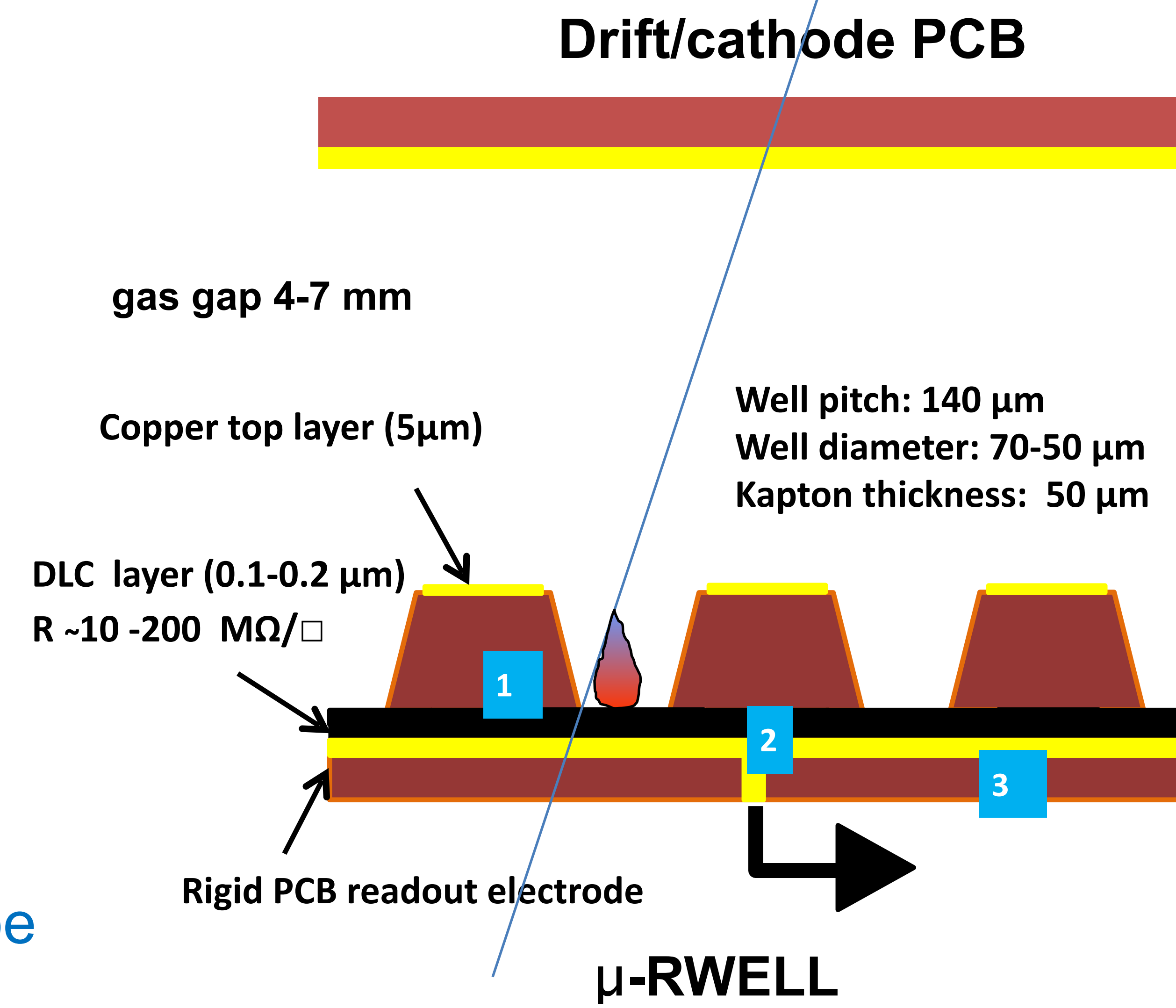

G. Bencivenni et al., 2015_JINST_10_P02008

Major advantages wrt. GEM

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

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  - Use components that can be mass produced by industry

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- The IDEA detector concept for CepC (and FCC-ee) implements μ-RWELL

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Backup