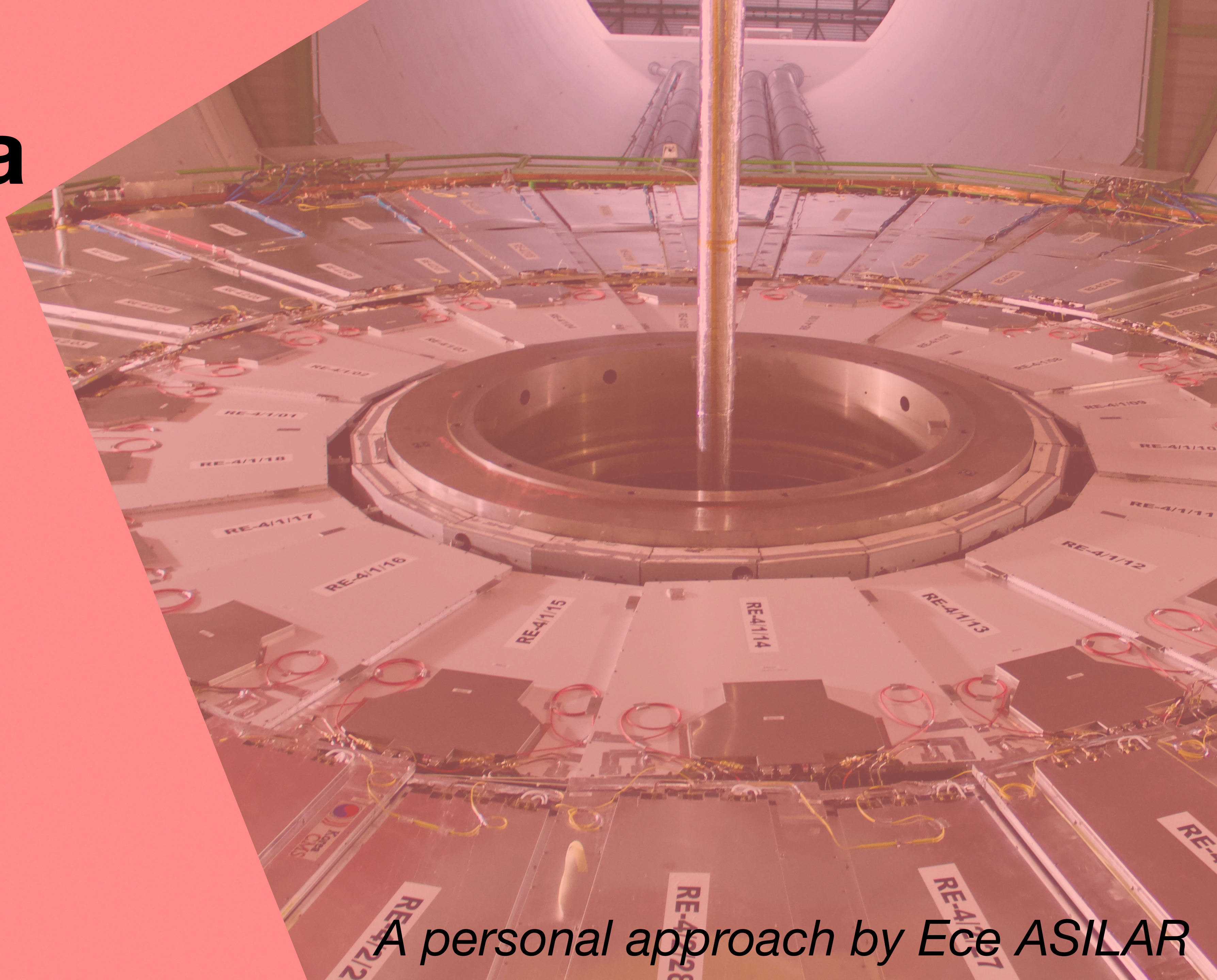


All you need to know for

Becoming a detector physicist

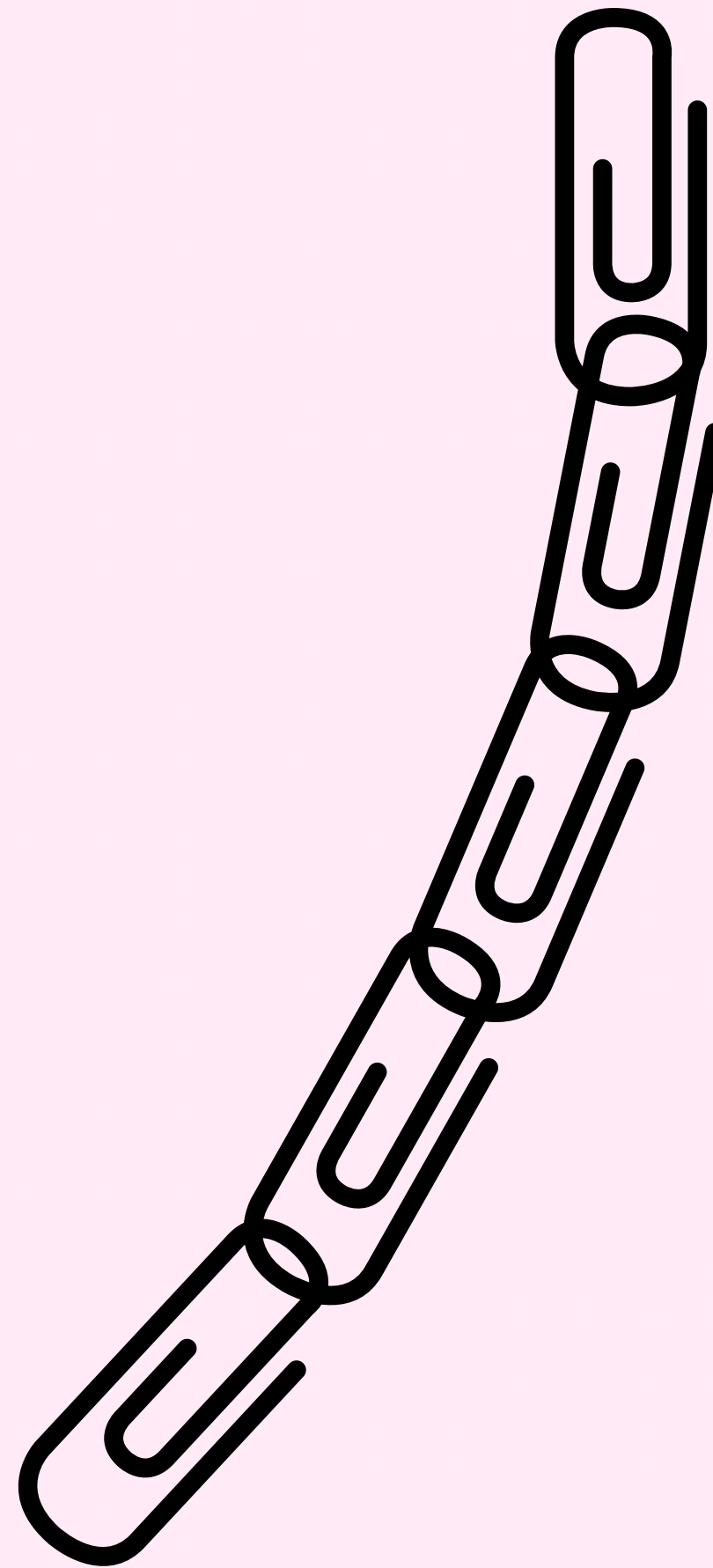
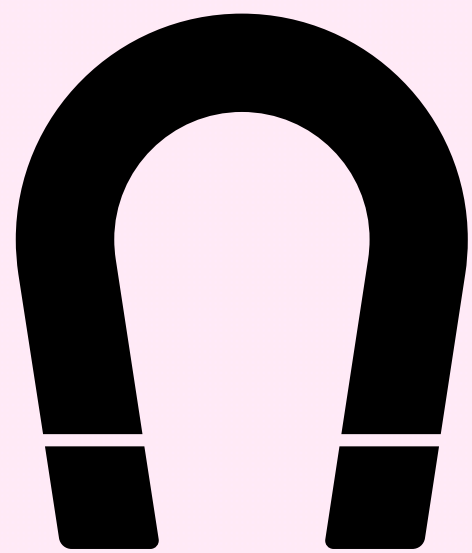


18/08/2026

A personal approach by Ece ASILAR

THE BIG IDEA

What is really a detector ?



Chain paper clips together
Hold it near a "strong"
magnet — it bends.

Congratulations !!!
you've built a magnetic-
field detector.

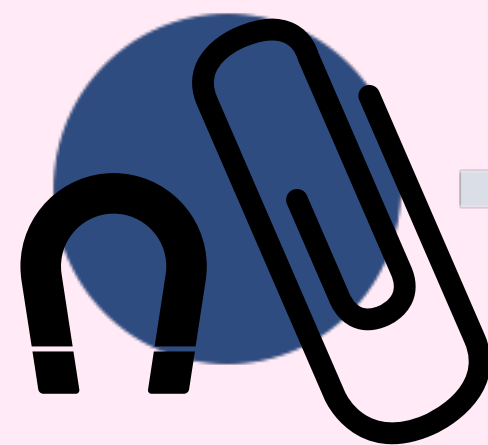
It has no readout, no trigger, no
electronics — but it satisfies the core
idea: something whose measurable
state changes in response to what you
want to learn about.

THE BIG IDEA

From Paper Clip to Precision Instrument

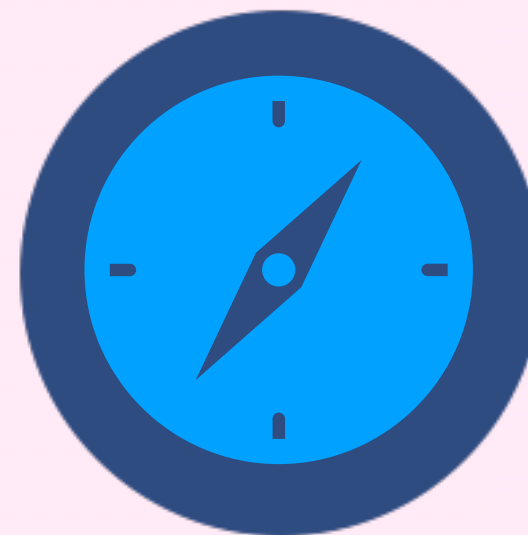
The paper clip works because the field is strong and close by. Most of what we want to learn about the universe is not so easy to reach
— rare particles, faint signals, tiny effects hidden under enormous backgrounds.

As the physics gets more hidden, the “paper clip” has to grow: more sensitive sensors, faster electronics, split-second decisions, layers of calibration.



Paper clip

one bend, one hand



Compass / simple sensor

one measurement, calibrated



Multi-million-channel detector

thousands of people, decades

THE BIG IDEA

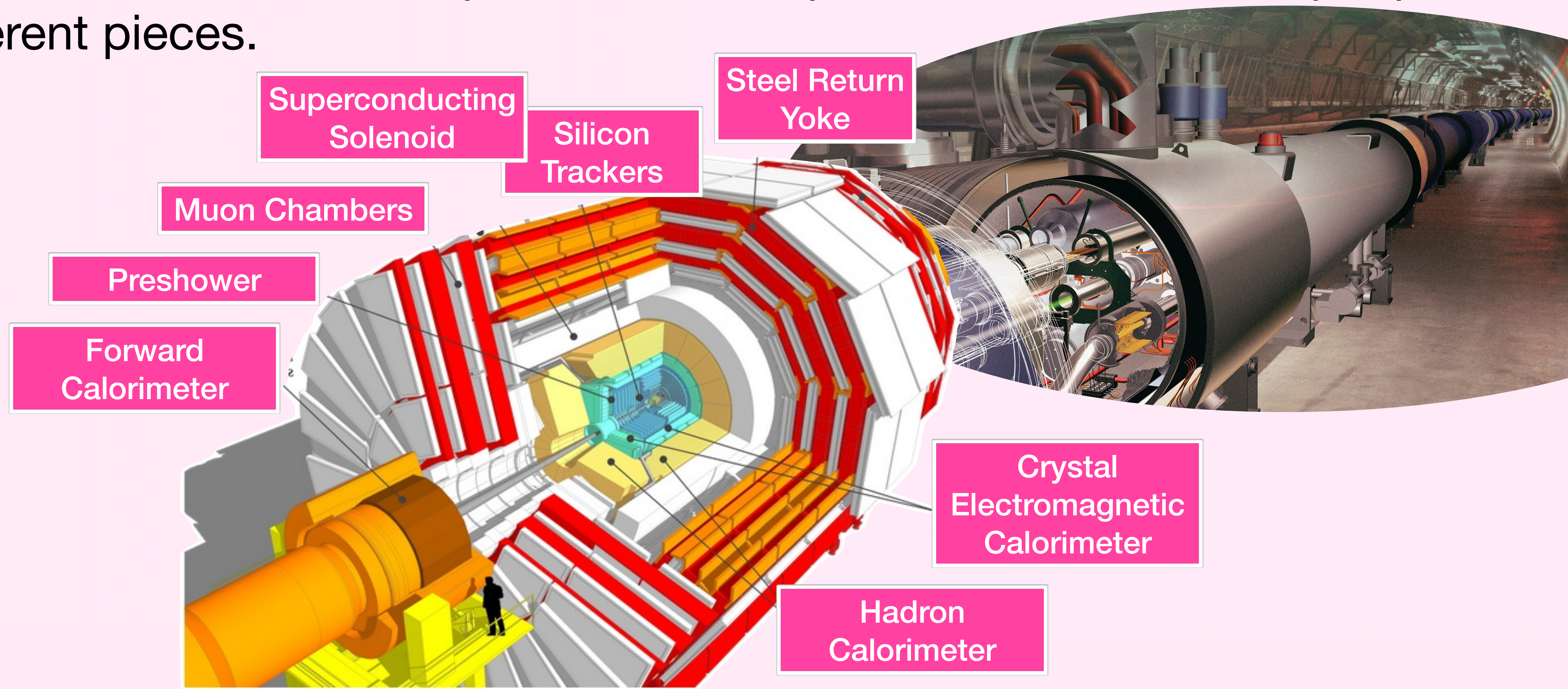
Too Complex for One Person Alone

Past a certain point, no one person can design, build, and run the whole thing. So the problem is broken into pieces — like a puzzle — and different people own different pieces.

THE BIG IDEA

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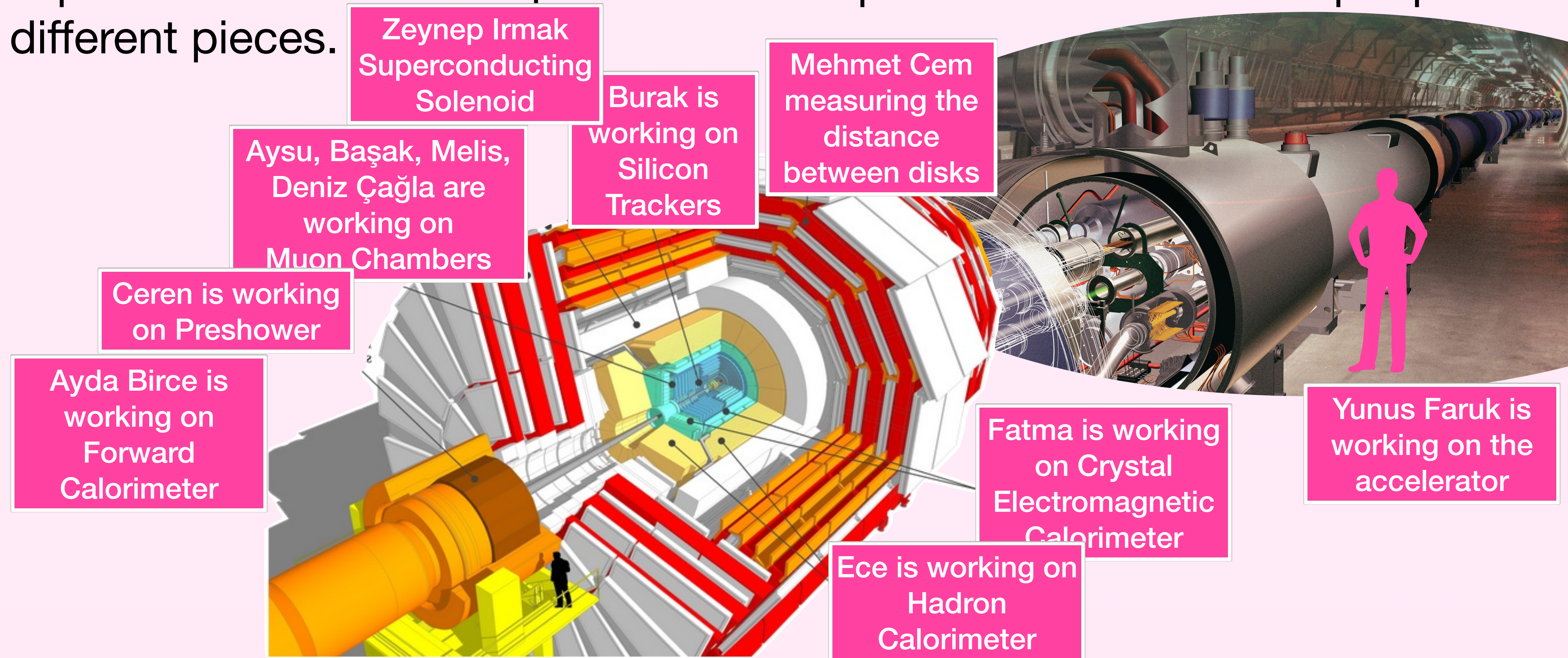
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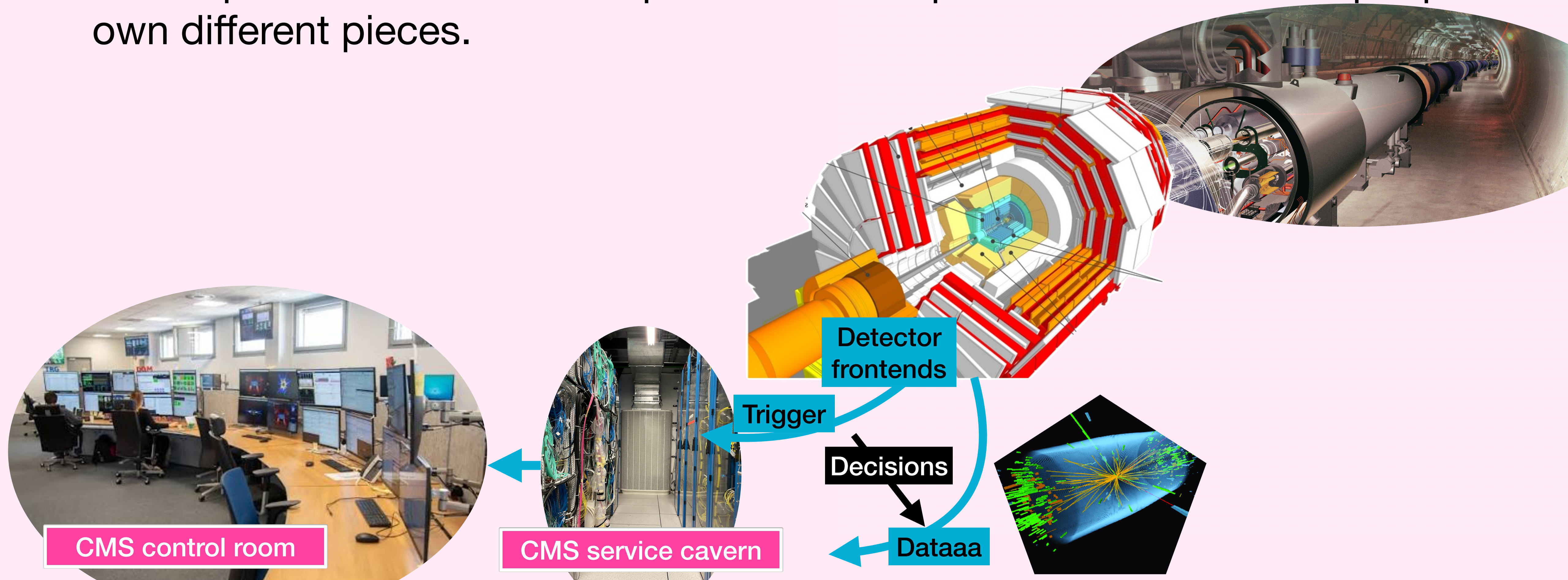
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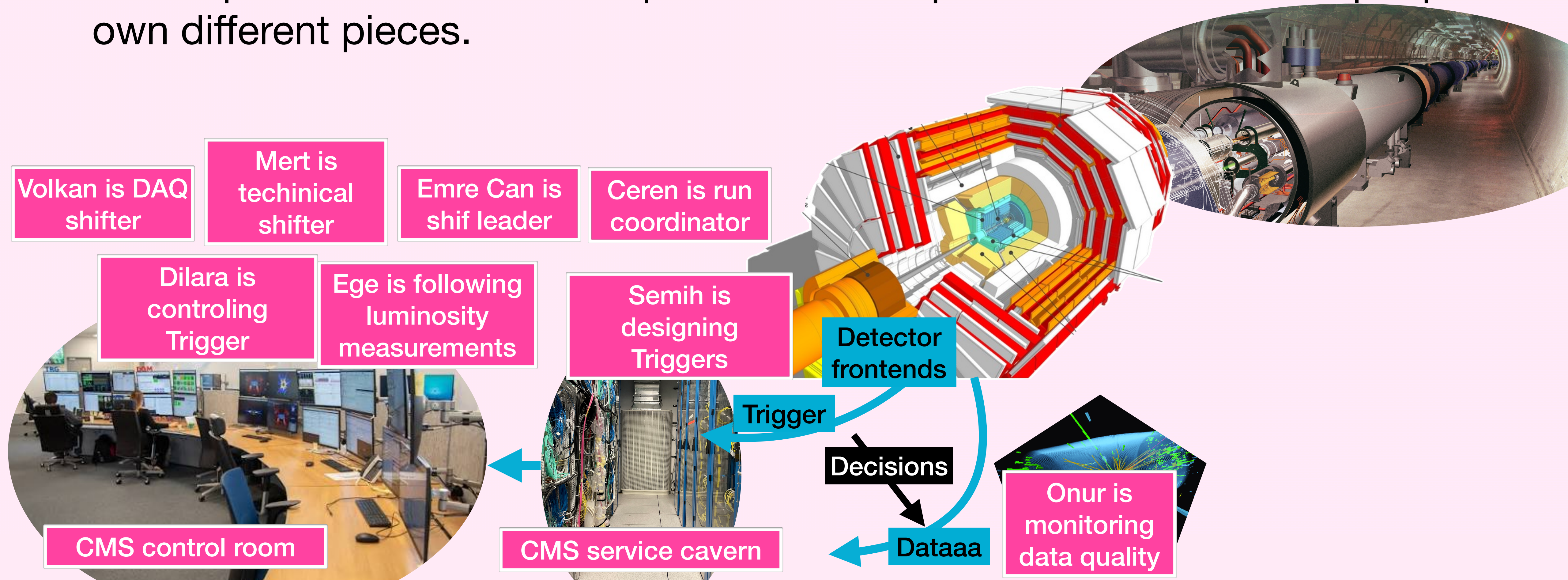
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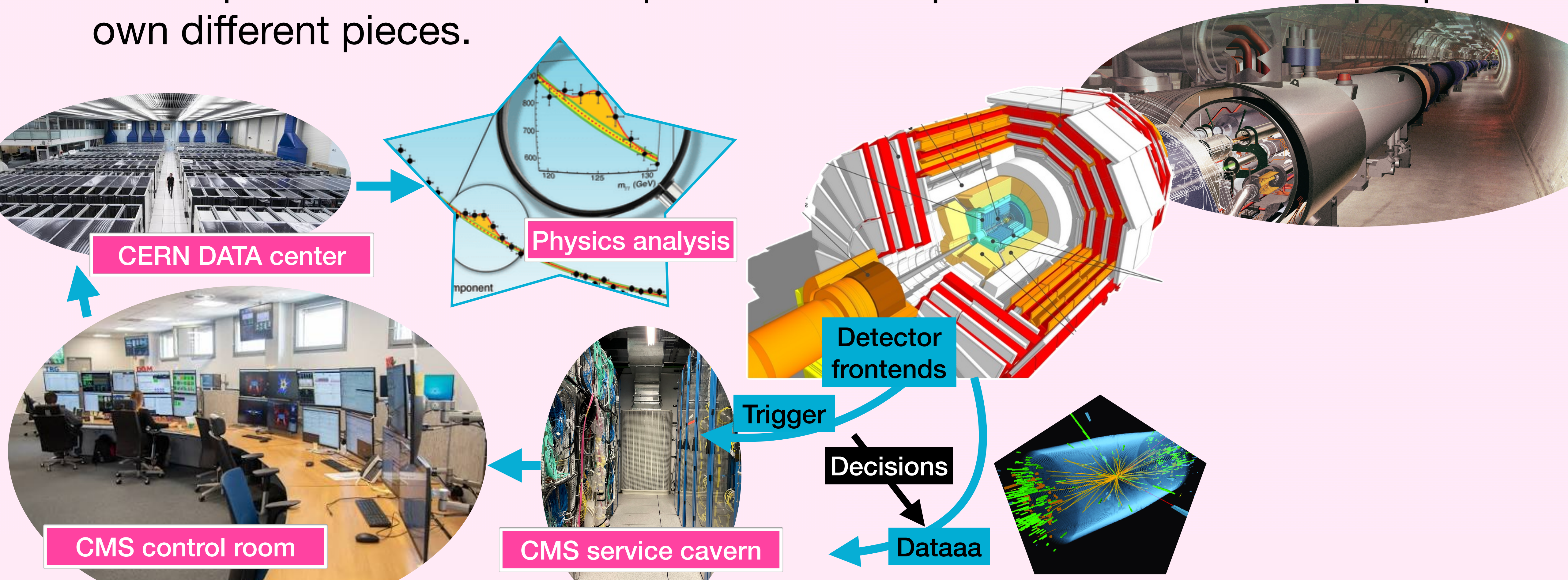
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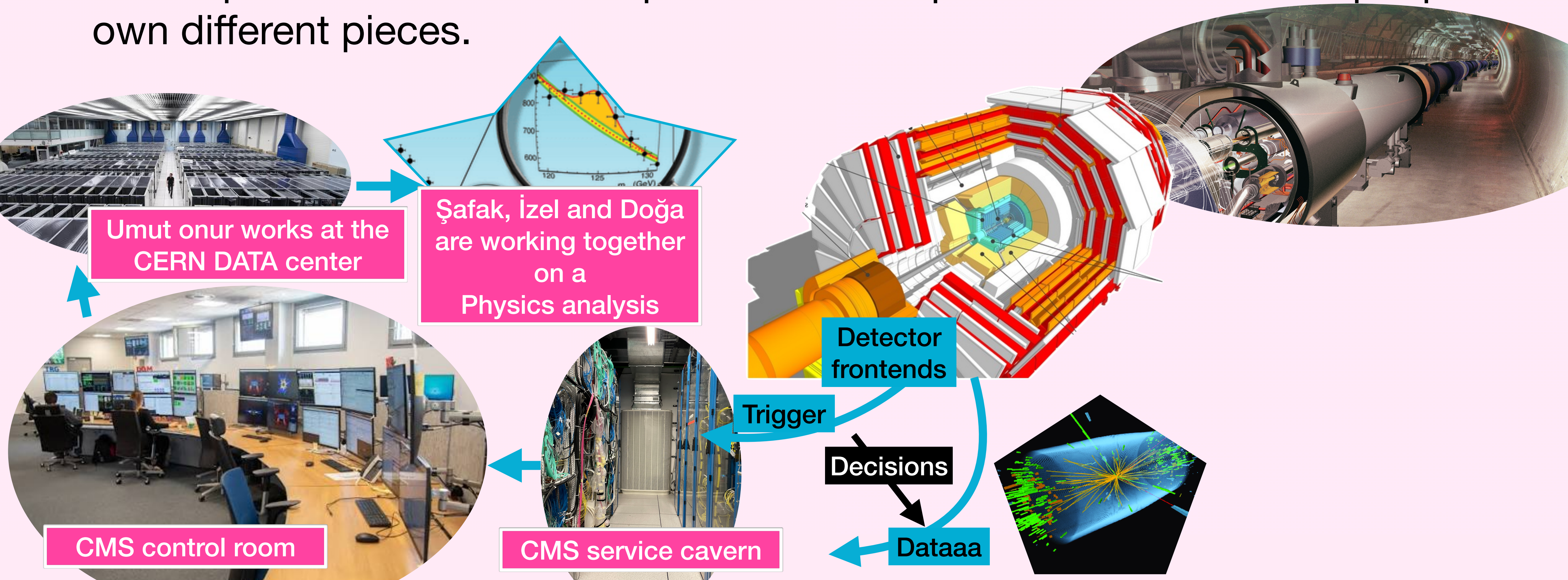
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THE BIG IDEA

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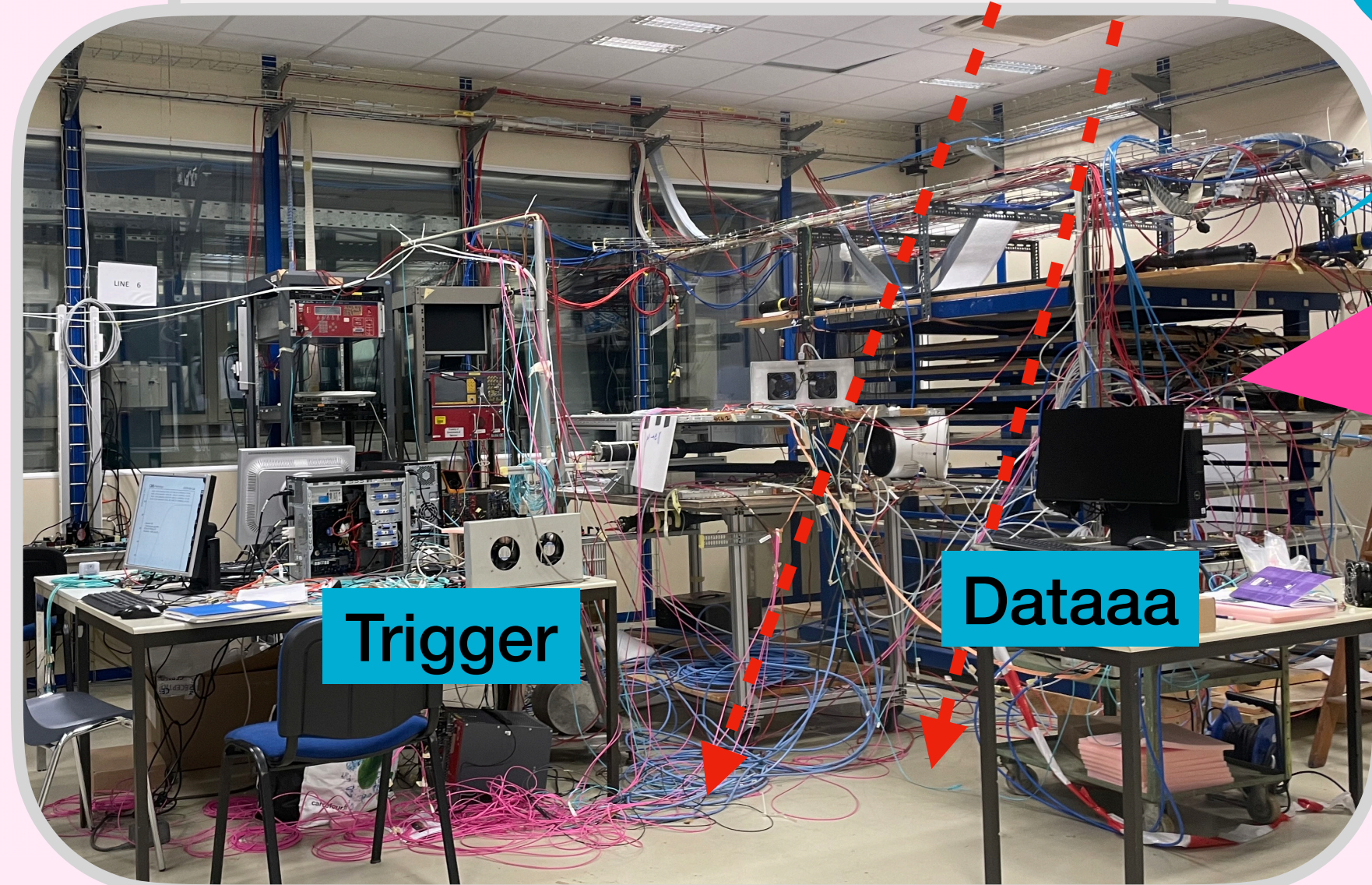
PREVIEW

Three occasions but one idea

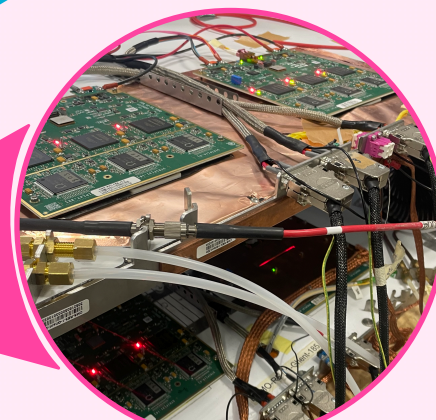
Watch how the same chain — detector, readout, trigger — takes shape differently in each of these settings.

Cosmic Tests

Quality control of chambers with cosmic muons — before installing them on CMS



Scintillating detectors for muon triggering



Detector frontends

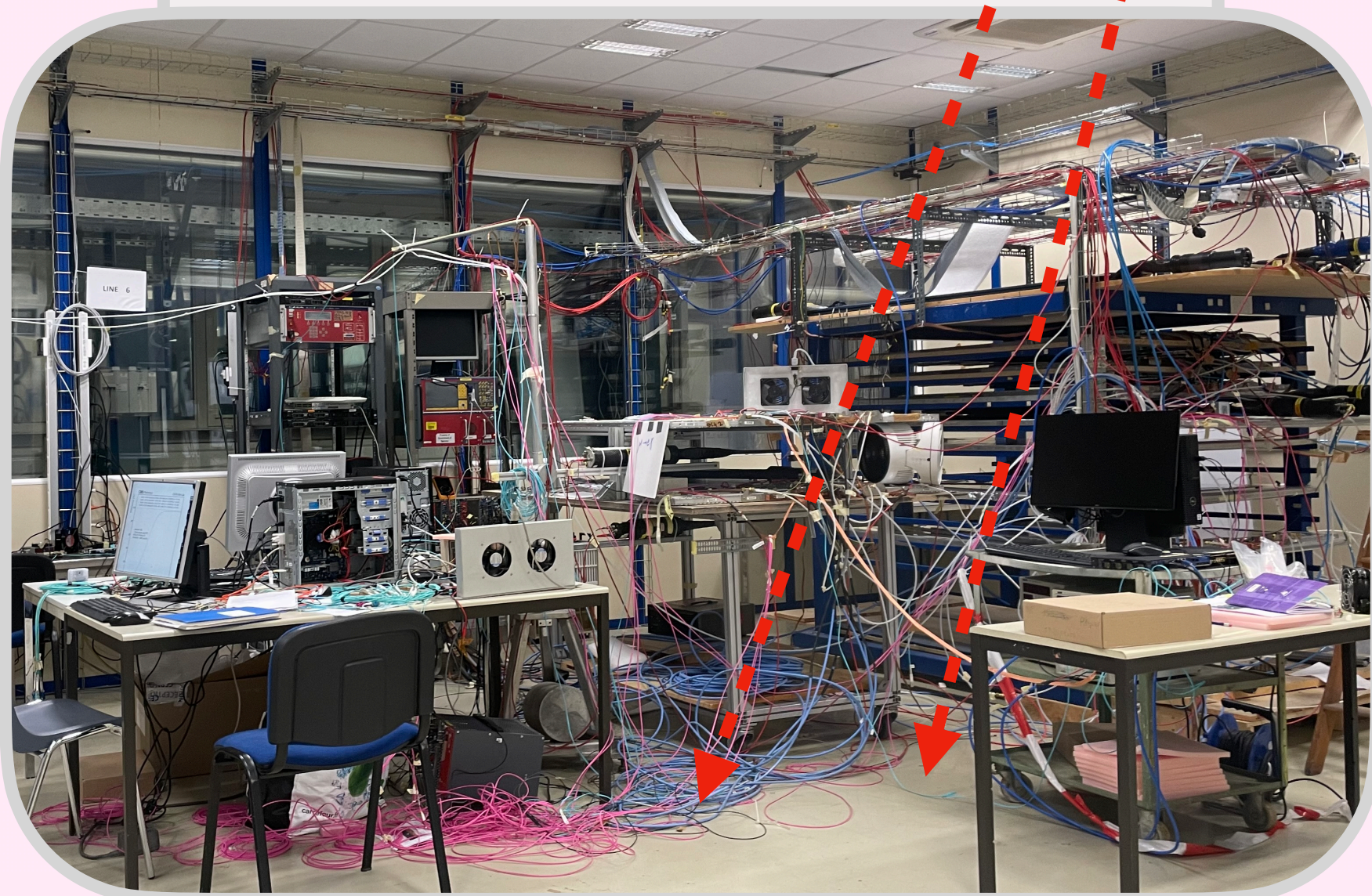
PREVIEW

Three places but one idea

Watch how the same chain — detector, readout, trigger — takes shape differently in each of these settings.

Cosmic Tests

Quality control of chambers with cosmic muons — before installing them on CMS



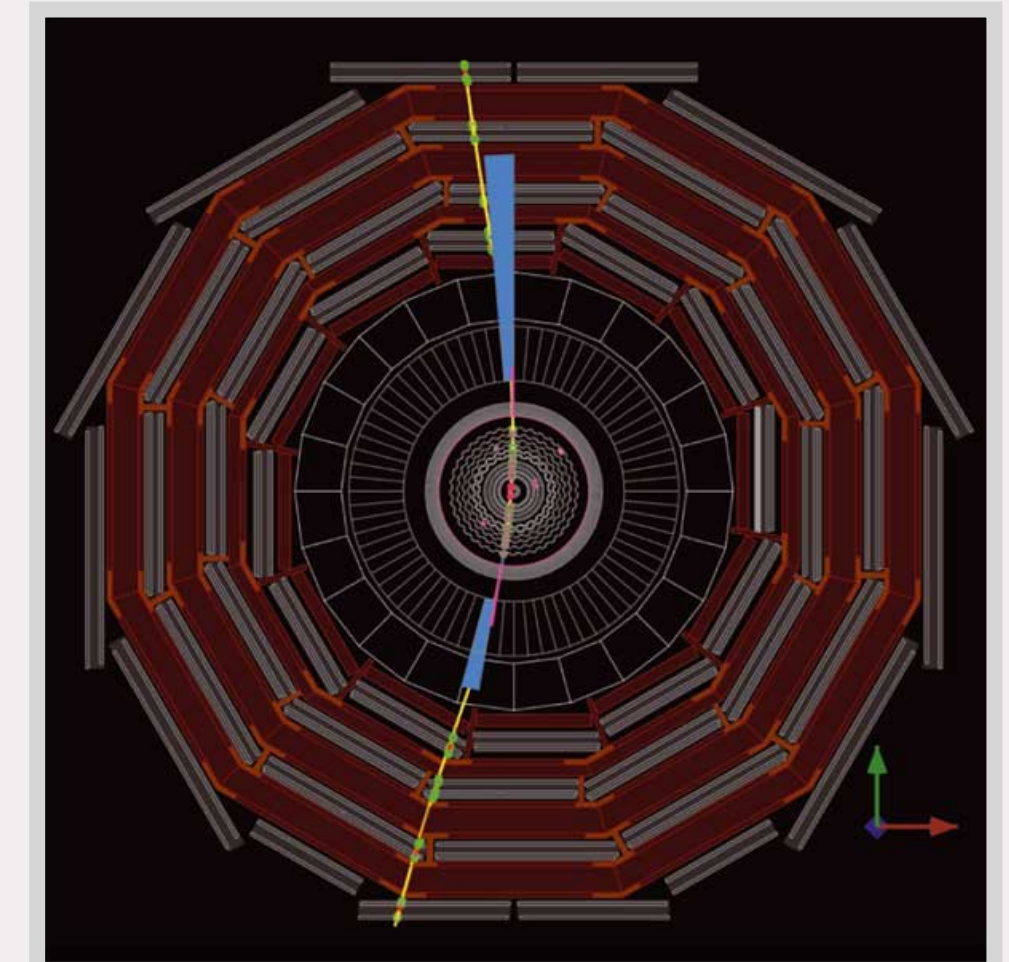
Test beam

Commissioning of chambers with muon beam and a background — before installing them on CMS

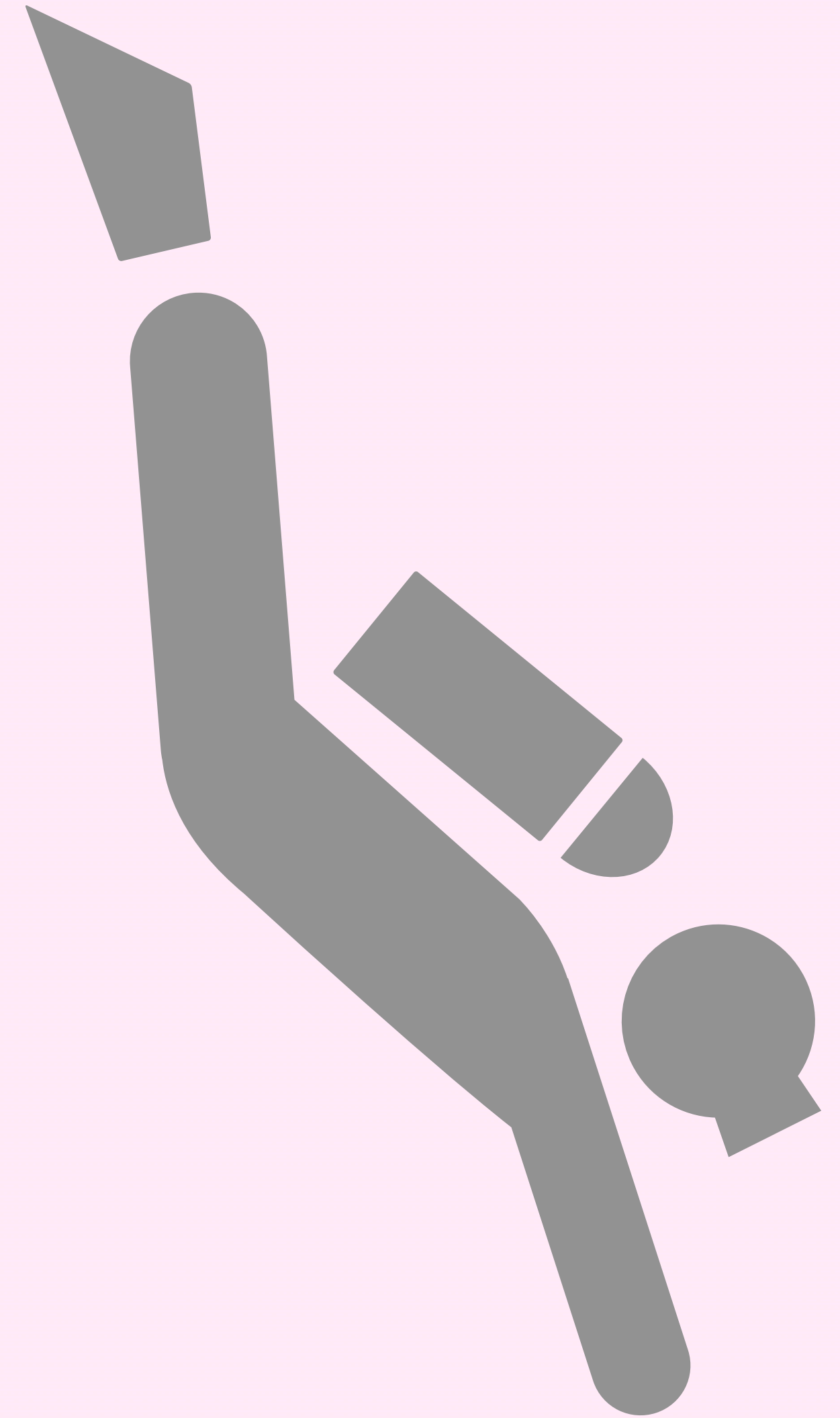


CMS

Commissioning chambers with cosmic muons — before real LHC beam ever arrives.



**Let's
dive into
details !**



PART 1 - BASIC PRINCIPLES

What we want to know of a particle?

- ❑ **The type**
- ❑ **Charge**
- ❑ **Momentum**
- ❑ **Energy**
- ❑ **Time**

PART 1 - BASIC PRINCIPLES

Turning an Interaction Into a Signal

Electromagnetic interactions

1. Excitation/Ionisation (of the atoms of the traversed material)
2. Bremsstrahlung
3. Emission of Cherenkov light
4. Emission of Transition Radiation
5. Photoelectric effects, Compton scattering, pair production

Weak Interactions

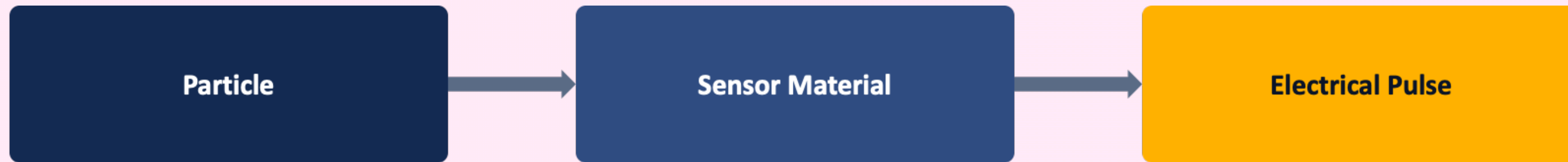
1. Weak decays of unstable particles produced inside or near the detector.
2. Beta decay ($n \rightarrow p + e^- + \bar{\nu}_e$, or nuclear beta decay more generally) — not something you see in a collider detector per se

Strong interactions

1. Hadronic (nuclear) interactions — a hadron (pion, proton, neutron...) colliding inelastically with a nucleus in the absorber material, producing a cascade of secondary hadrons.
2. Elastic / quasi-elastic nuclear scattering — a hadron scattering off a nucleus without necessarily breaking it apart

PART 1 - BASIC PRINCIPLES

Particle to Signal



PART 2 - FOCUSED

How do we observe the characteristics of a particle at the CMS Experiment ?

In CMS,
identifying these five properties for each particle comes from combining information across the detector's concentric layers

— CMS calls this approach "Particle Flow":

for every particle, tracks and energy clusters from the tracker, ECAL, HCAL, and muon system are matched together to produce a single consistent identification and four-momentum.

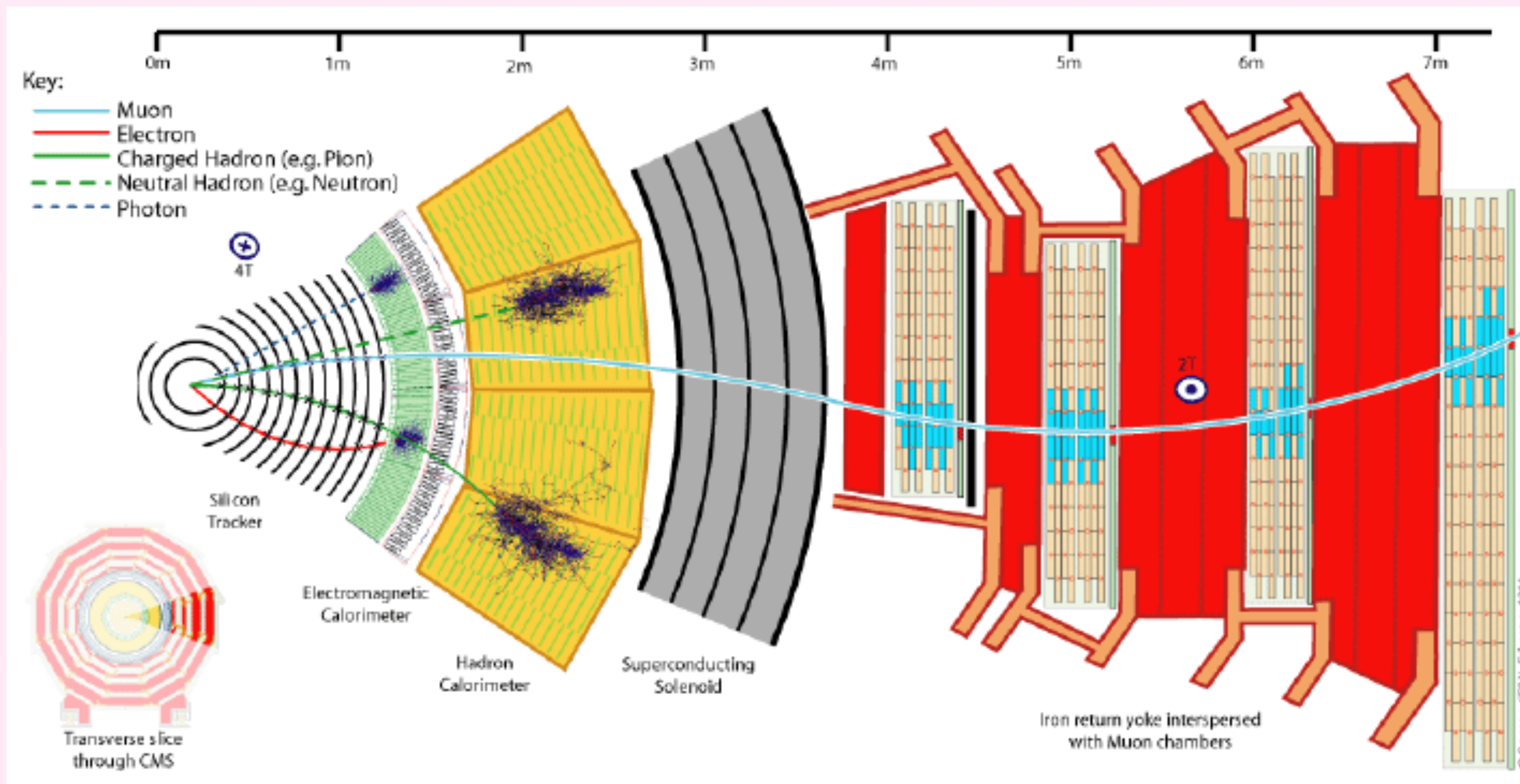
PART 2 - FOCUSED

TYPE

No single subdetector determines this alone; it's the combination of signatures that does:

- Photon: an energy deposit in the ECAL with no matching track in the tracker (neutral, leaves no track).
- Electron: a tracker track that matches an ECAL energy cluster ($E/p \approx 1$).
- Charged hadron (pion, kaon, proton): a tracker track plus an energy deposit in the HCAL (often some in the ECAL too).
- Neutral hadron (neutron, etc.): an energy deposit in the HCAL with no matching track.
- Muon: the most distinctive signature — a track that starts in the tracker and survives all the way through the ECAL, the HCAL, the superconducting magnet, and the iron return yoke, depositing only minimum-ionizing (MIP-like) energy along the way, then leaves another track in the outermost muon chambers (Drift Tubes, CSC, RPC). This "punch-through" pattern essentially identifies a muon on its own.
- Neutrino: never seen directly. Since the initial transverse momentum in a pp collision is ~ 0 , any imbalance in the summed transverse momentum of all visible particles (missing transverse energy, MET) signals the presence of one or more neutrinos.
- Tau lepton: not reconstructed directly, but inferred from its decay products — typically a narrow "tau-jet" (1 or 3 charged hadrons plus neutral pions), or, for leptonic decays, an electron/muon plus missing energy.

PART 2 - FOCUSED



PART 2 - FOCUSED

CHARGE

Read from the direction the track curves inside the 3.8 T superconducting solenoid field (Lorentz force, $F = qv \times B$): positive and negative charges bend in opposite directions. Neutral particles leave no curving track at all.

MOMENTUM

Computed from that same track's radius of curvature: $p_T [\text{GeV}] \approx 0.3 \times B[\text{T}] \times R[\text{m}]$. Higher-momentum particles produce straighter (larger-radius) tracks; measuring this precisely depends on the excellent spatial hit resolution of the pixel and silicon-strip tracker layers. For neutral, massless particles like photons, momentum instead comes directly from the calorimeter energy measurement ($E = p$).

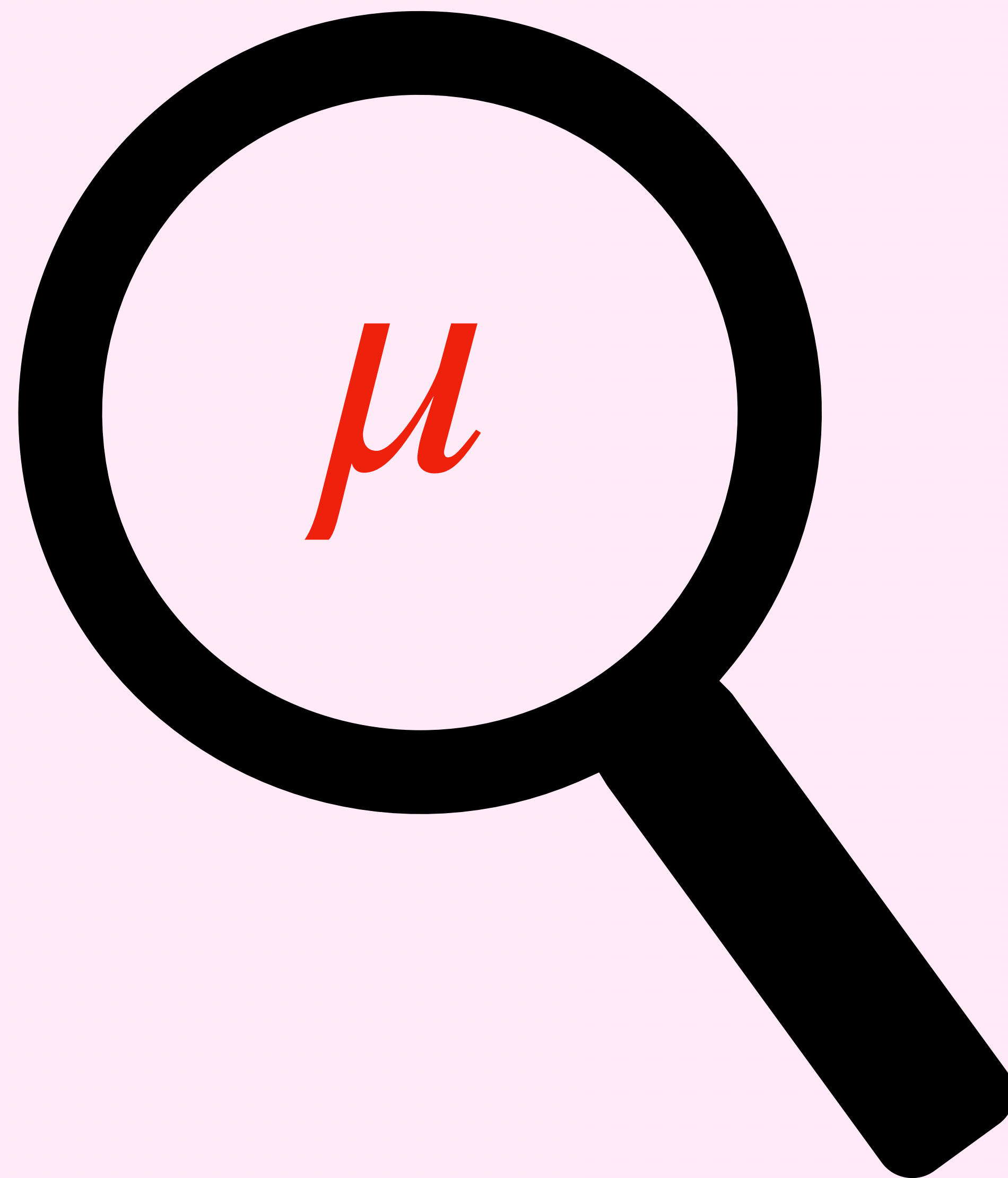
PART 2 - FOCUSED

ENERGY

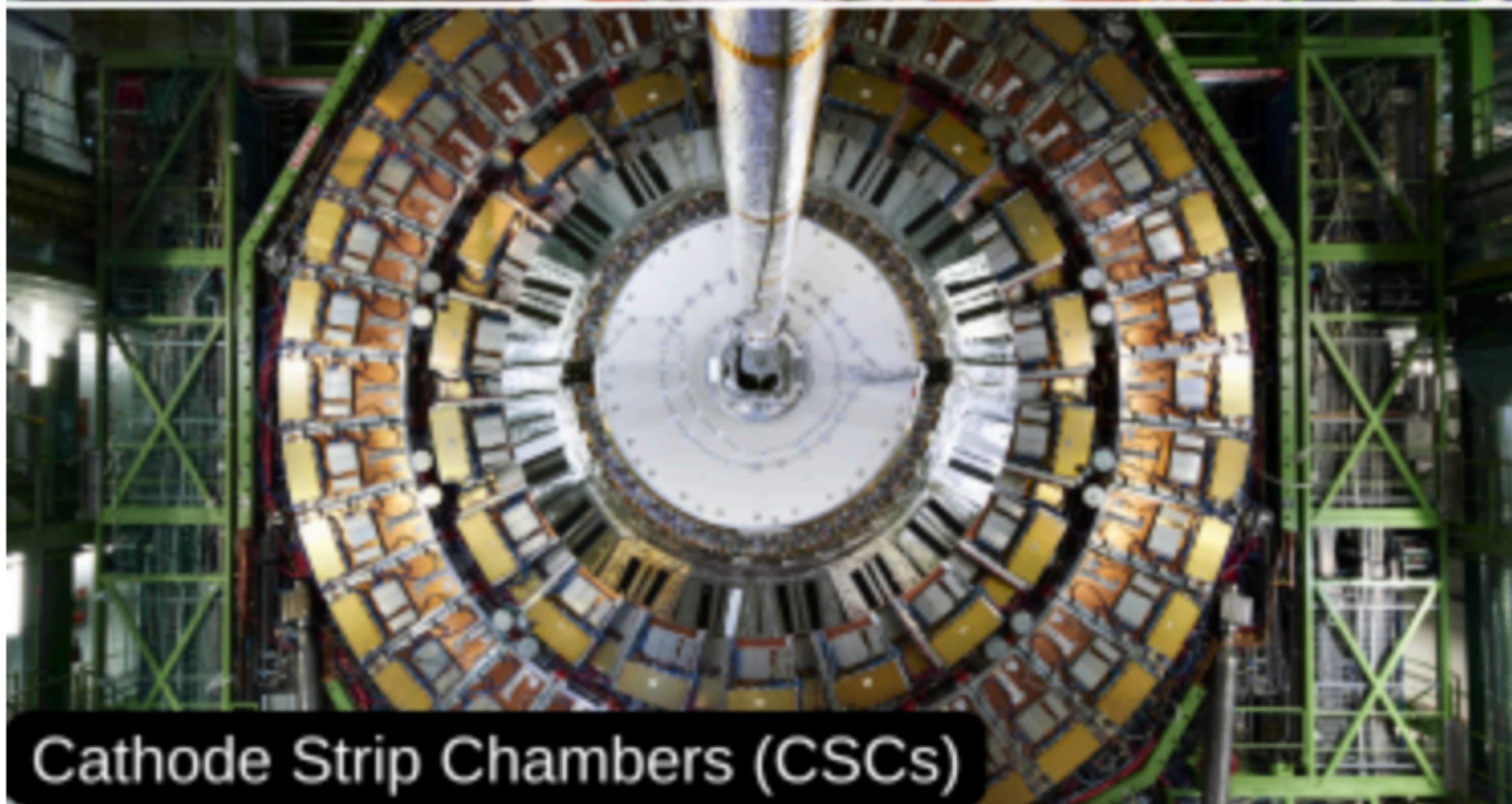
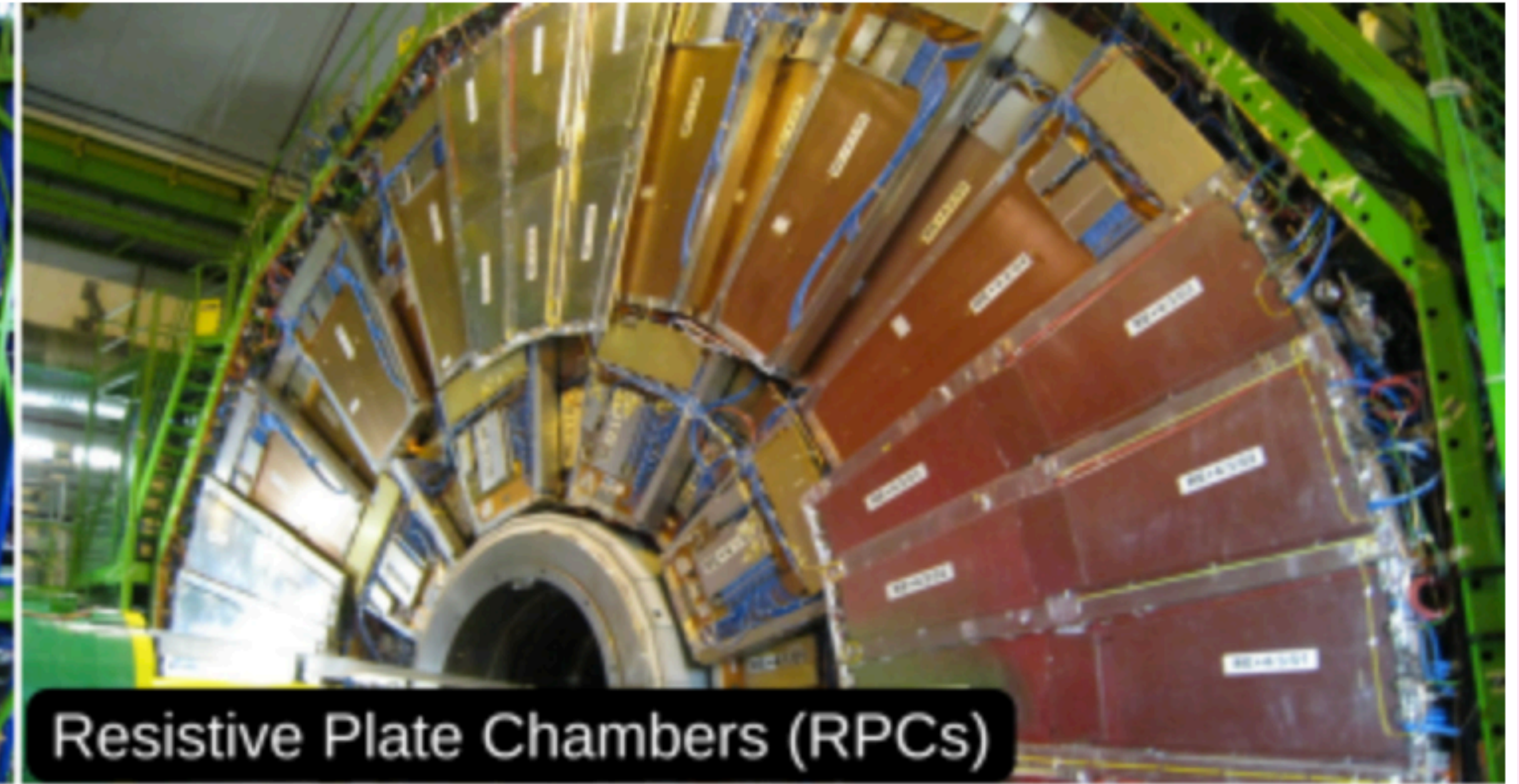
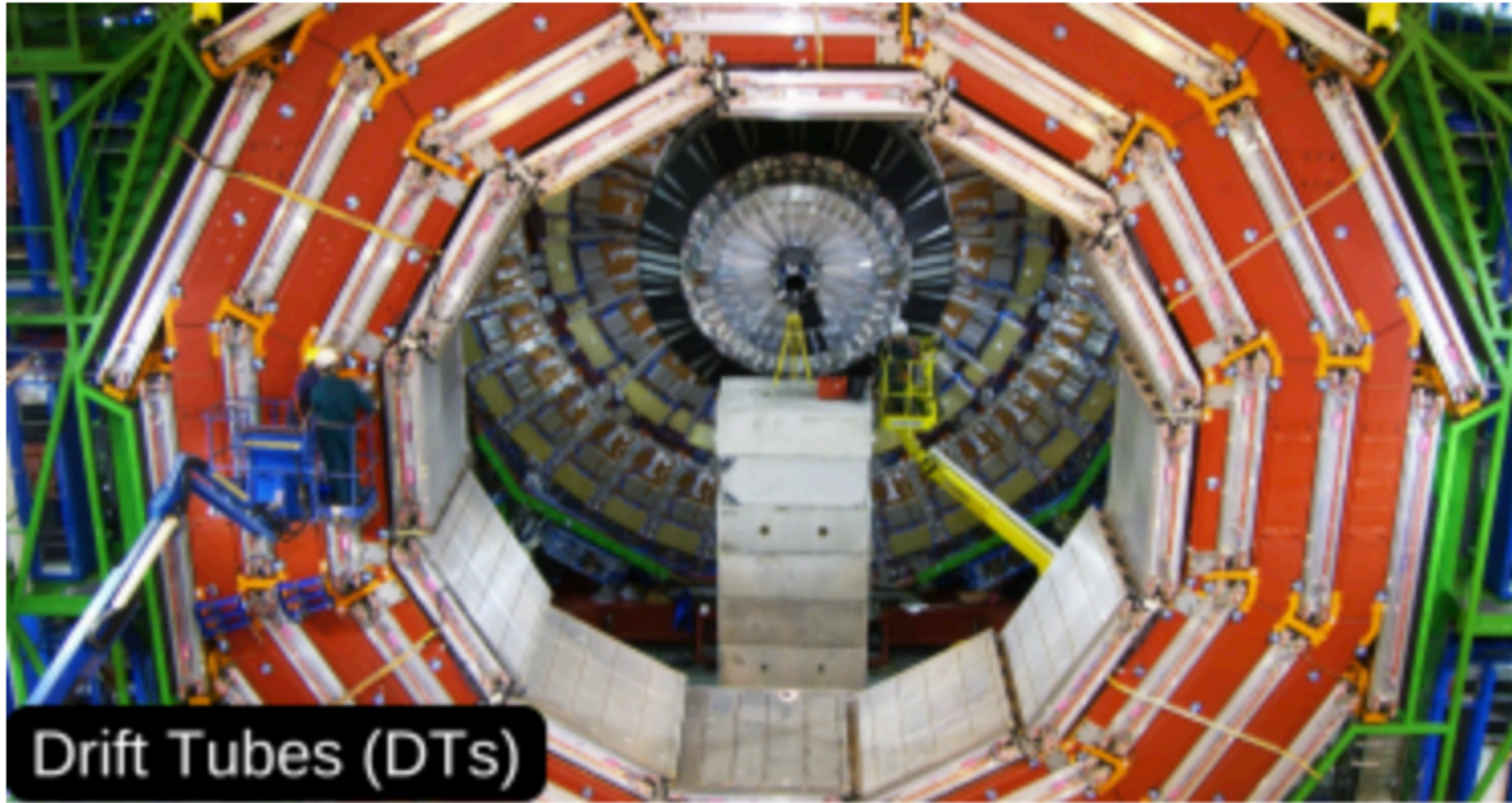
Electrons and photons deposit their energy as electromagnetic showers in the ECAL (lead tungstate, PbWO_4 , crystals), while hadrons deposit theirs as hadronic showers in the HCAL (a brass-and-scintillator sampling calorimeter) — in both cases the light output collected is proportional to the deposited energy. This doesn't work for muons, since they don't stop or shower in the calorimeters (they pass through as minimum-ionizing particles); instead, a muon's energy is derived from its momentum (measured in the tracker and muon system) combined with its known mass, via $E = \sqrt{(p^2c^2 + m^2c^4)}$.

TIME

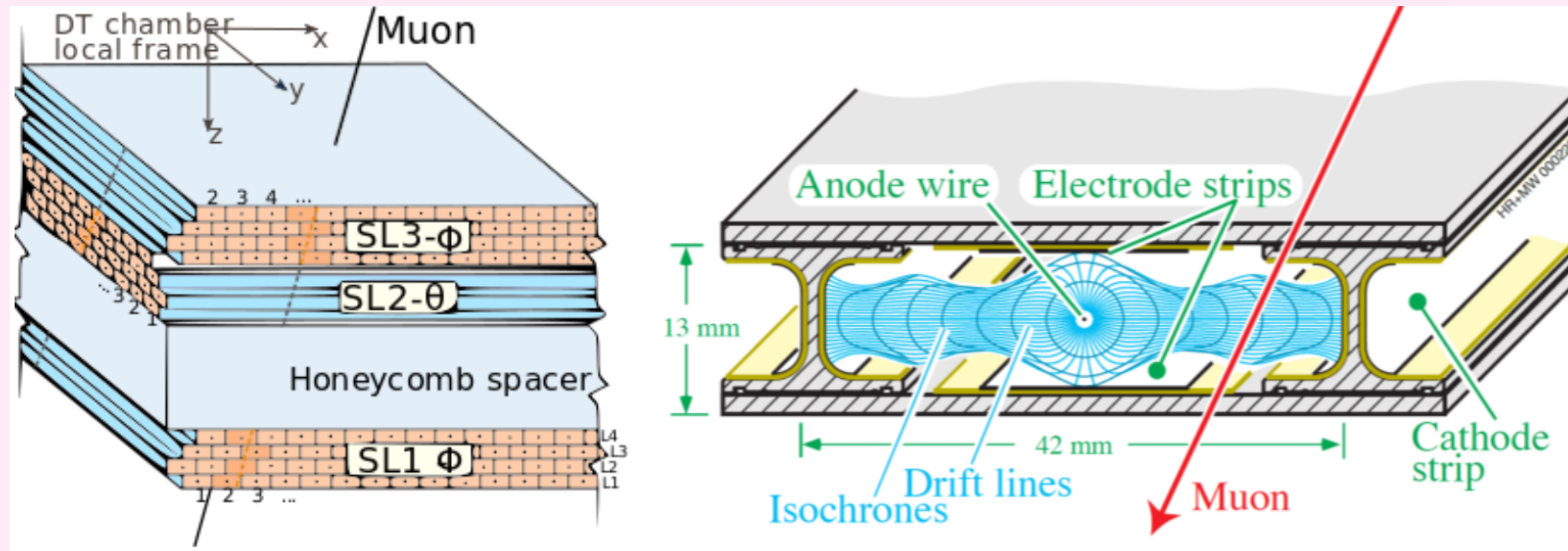
Traditionally, each subdetector's electronics record hit timing mainly to assign a signal to the correct bunch crossing (every 25 ns); the RPC muon chambers in particular are built for speed ($\sim 1\text{--}2$ ns resolution) and play a key role in the Level-1 trigger for this purpose. Beyond bunch identification, precision timing is now an emerging capability: as part of the High-Luminosity LHC upgrade, CMS is adding a dedicated MIP Timing Detector (MTD) that measures each charged track's time to $\sim 30\text{--}40$ ps resolution — enabling 4D reconstruction (3 spatial dimensions plus time) to separate overlapping collisions (pileup) within the same bunch crossing, and opening up particle identification via time-of-flight for lower-momentum particles.



Four different technologies



Drift Tubes (DT)

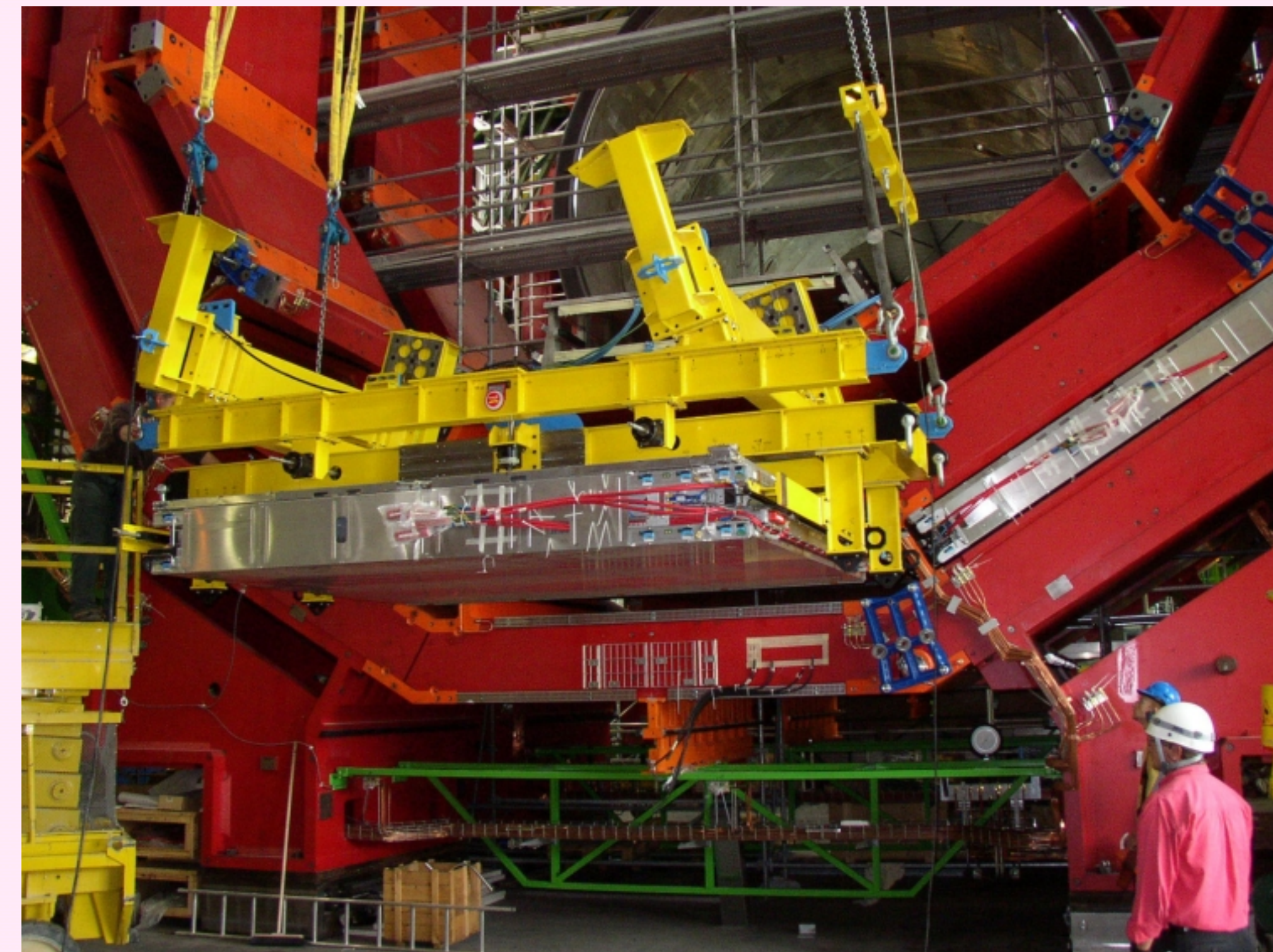


4cm-wide tube contains a stretched wire within a gas volume.

A muon or any charged particle passes through the volume, it knocks electrons off the atoms of the gas.

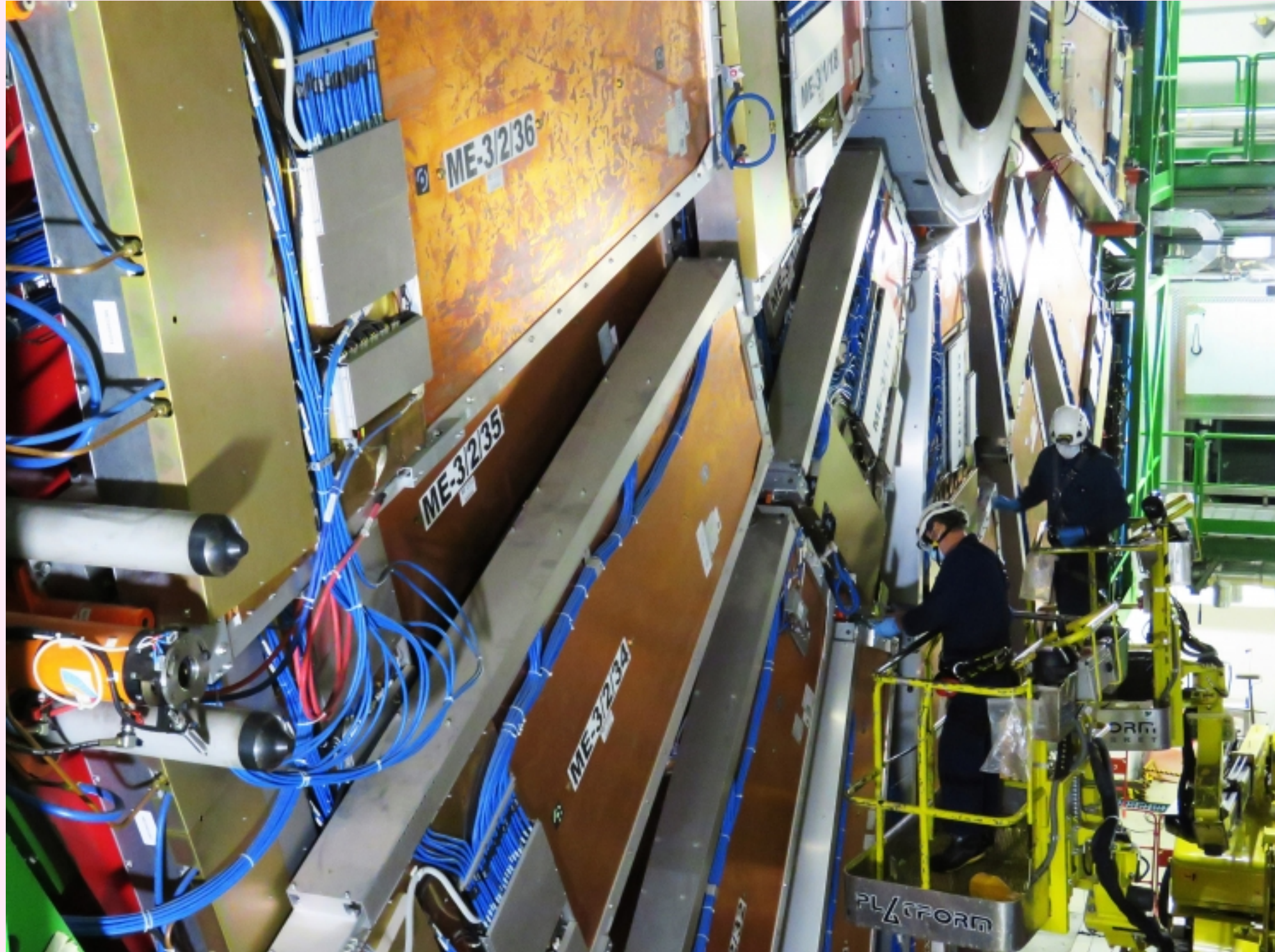
These electrons “drift” towards the anode following the electric field, ending up at the positively-charged wire where they are amplified and produce a measurable charge pulse.

Gas mixture – 85% Ar, 15% CO₂



By registering the time taken by the electrons to reach the wire, and since the drift velocity along the cell is a rather constant value, we can identify the exact crossing point of the muon along the cell. Each superlayer provides 4 points in 2D for the muons position.

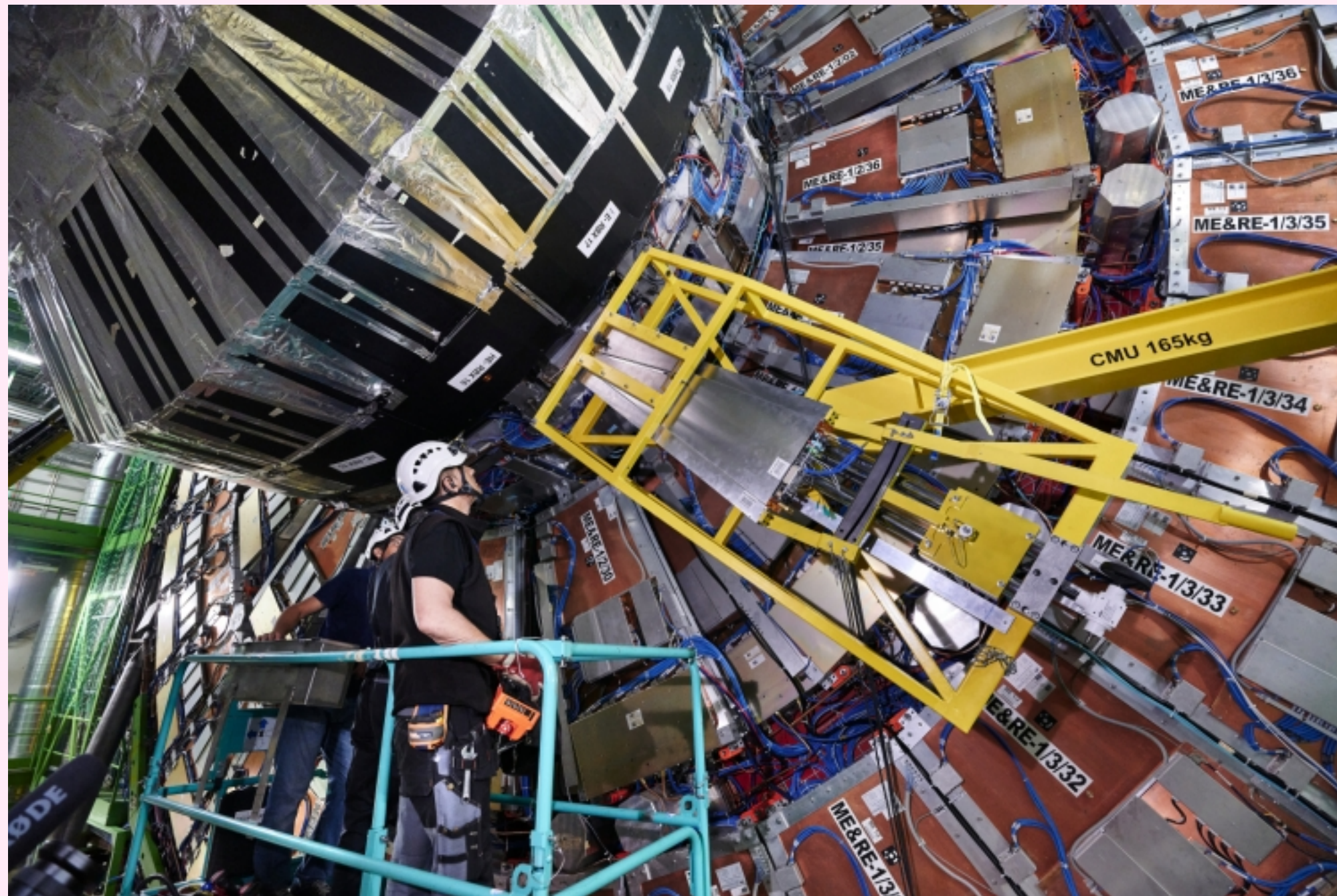
Cathode strip chambers (CSC)



Used in the endcap disks where the magnetic field is uneven and particle rates are higher than in the barrel. Consist of arrays of positively-charged anode wires crossed with negatively-charged copper cathode strips within a gas volume. When muons pass through, they knock electrons off the gas atoms, which flock to the anode wires creating an avalanche of electrons. Positive ions move away from the wire and towards the copper cathode, also inducing a charge pulse in the strips, at right angles to the wire direction.

Gas mixture – 50% CO₂ , 40% Ar, and 10% CF₄

GAS ELECTRON MULTIPLIER (GEM)



Gas electron multipliers (GEMs) are a new addition to the CMS muon system. They complement existing detectors in the forward regions close to the beampipe, where large radiation doses and high event rates will increase during Phase-2 of the LHC. The harsh environment imposes strict requirements on detector characteristics, requiring technologies with high rate capabilities—hence the choice of GEMs. In the endcaps, the GEM system will improve the measurement of the polar muon bending angle, allowing the trigger of the muon system to cope with the high rates. Additionally, GEMs will further extend the muon system coverage in the very forward regions.

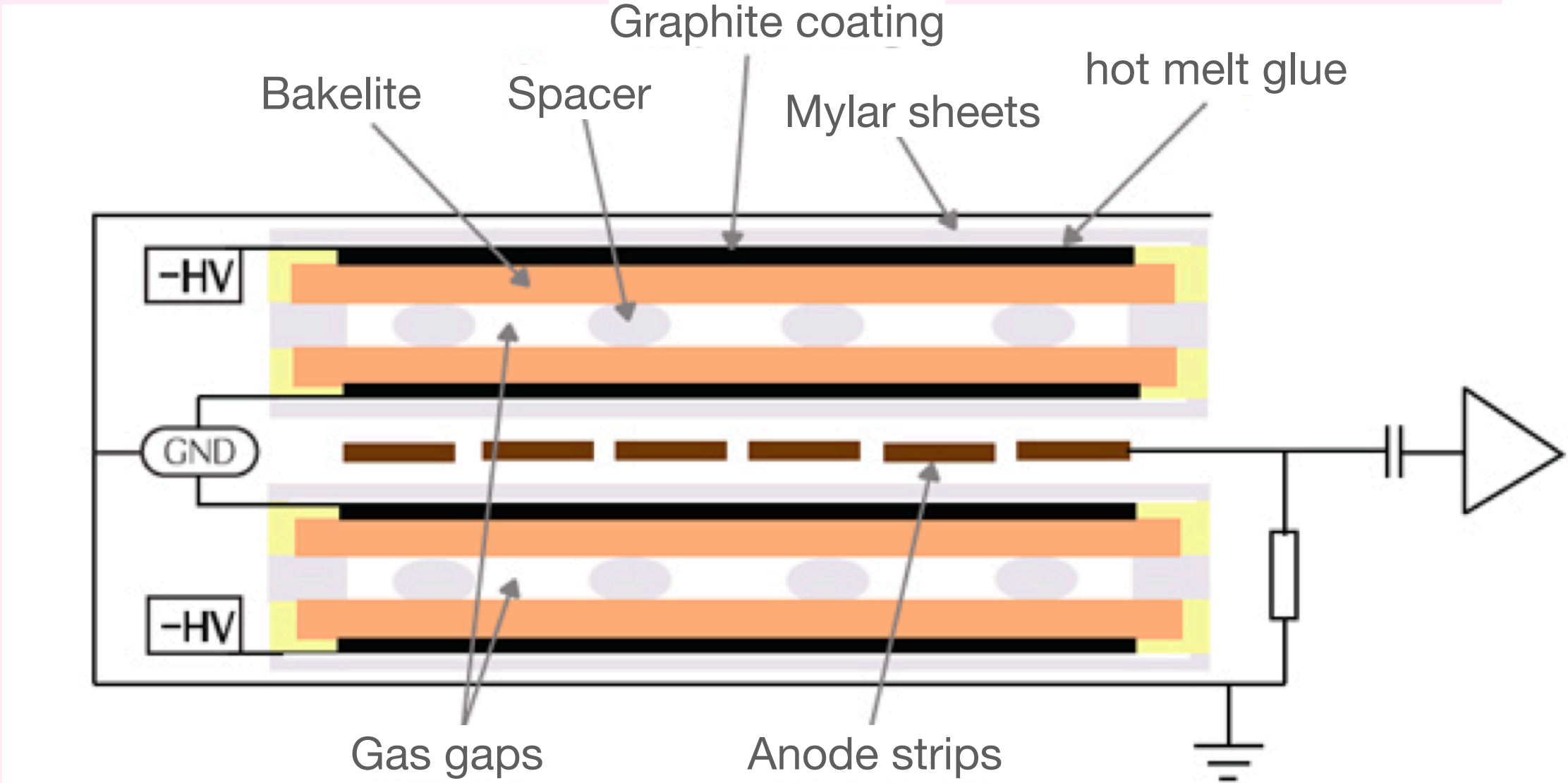
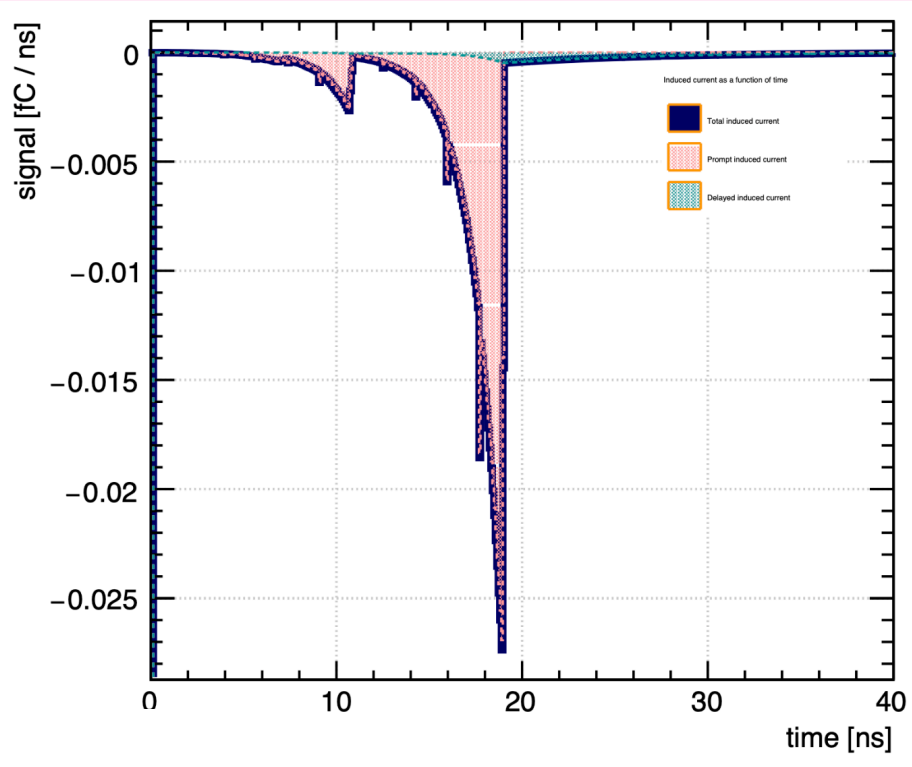
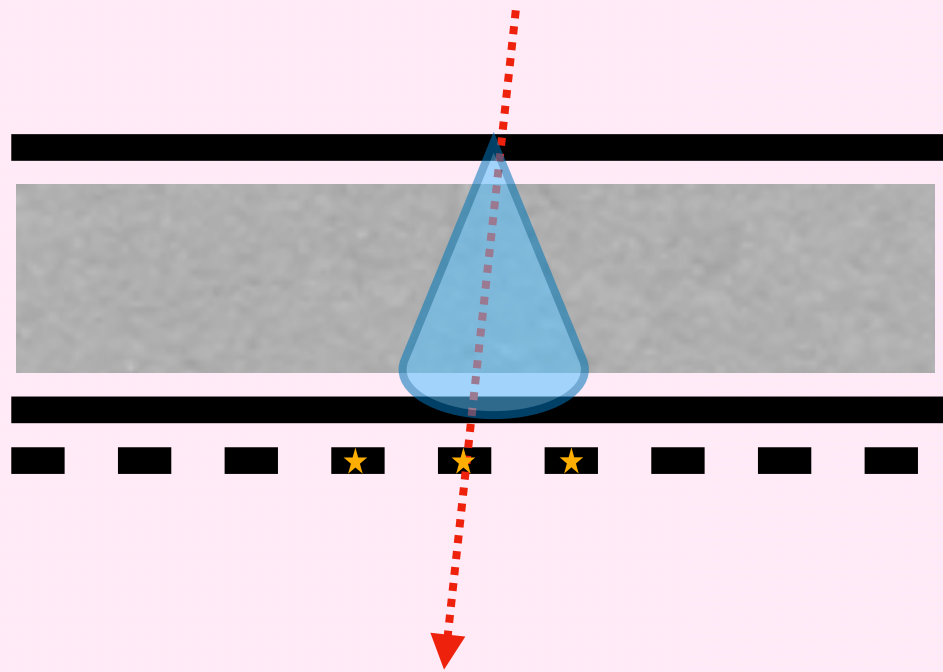
Like the other CMS muon subsystems, GEMs are gaseous detectors. Their key feature is the GEM foil, which consists of a 50 micrometer-thick insulating polymer (polyimide) surrounded on the top and bottom with copper conductors. Throughout the foil, microscopic holes are etched in a regular hexagonal pattern. The CMS GEM chambers consist of two PCBs, containing the gas volume, and a stack of three GEM foils in between. The chambers are filled with an Ar/CO₂ gas mixture, which is ionized by incident ionizing particles. A potential difference applied across the foils generates sharp electric fields in the holes. The electrons created during the ionisation process drift towards the foils and are multiplied in the holes. The resulting electron avalanche induces a readout signal on the finely spaced strips.

Gas mixture – 30% CO₂ , 70% Ar

Particle to Signal for an RPC



μ

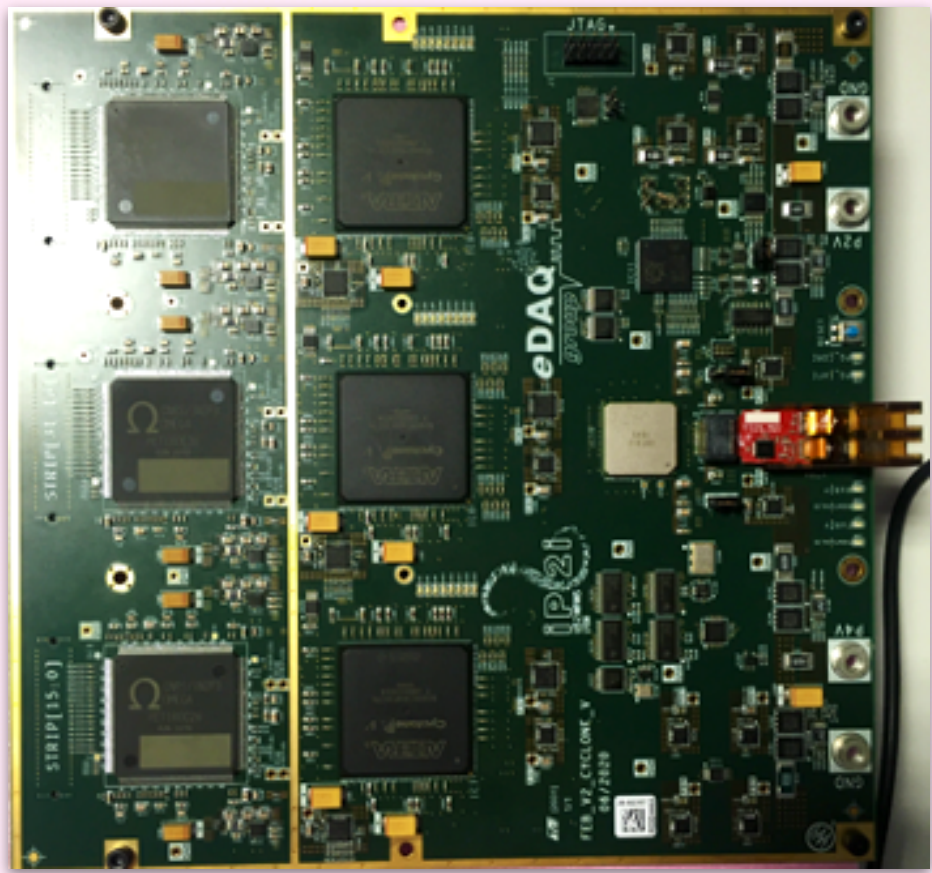


RESISTIVE PLATE CHAMBERS (RPC)

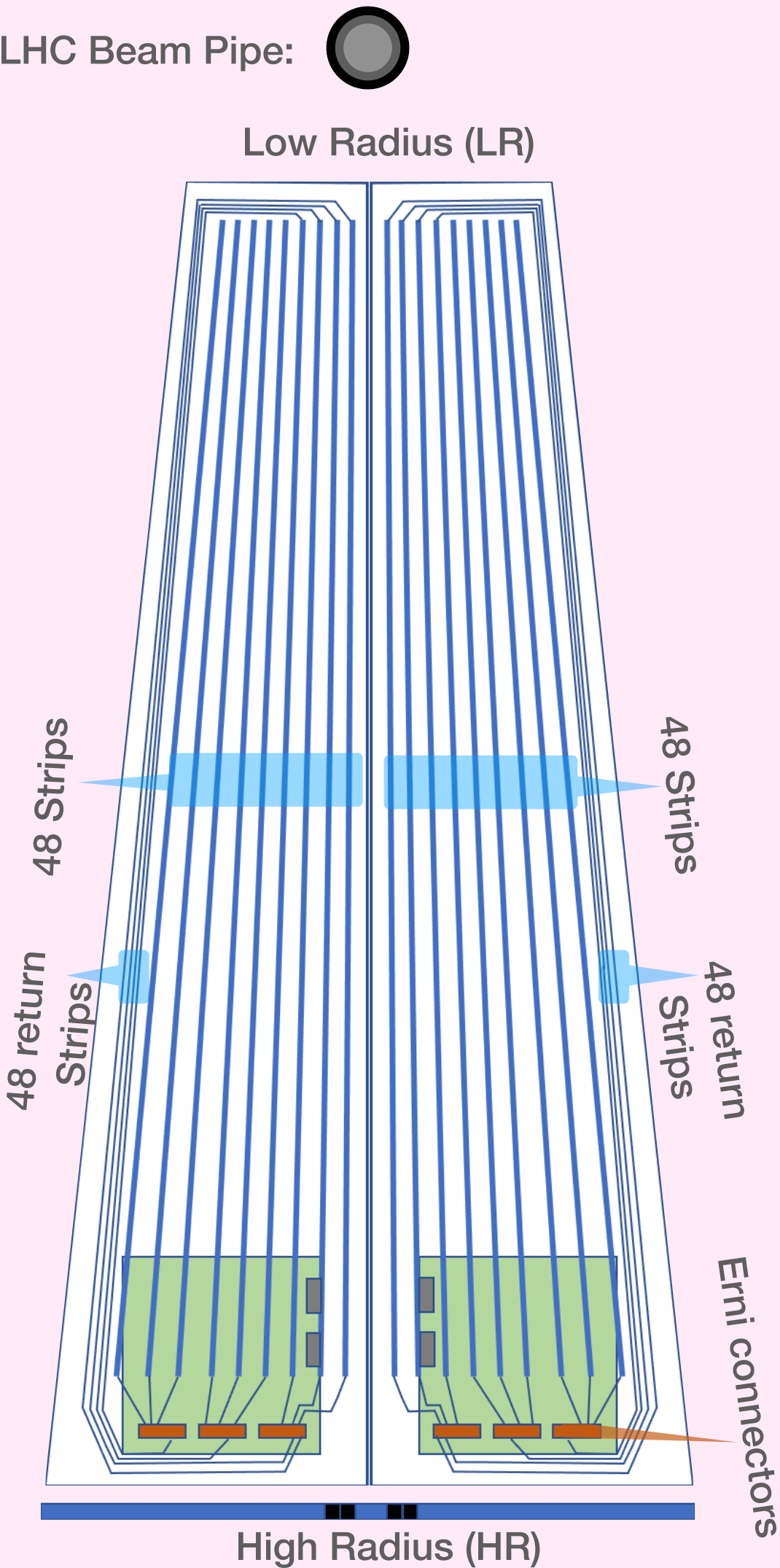
- Double-gap iRPC detectors
- Each gap made of two 1.4 mm low-resistivity (order of $10^{10} \Omega\text{cm}$)
- High Pressure Laminate electrodes Separated by a gas gap of the same thickness.

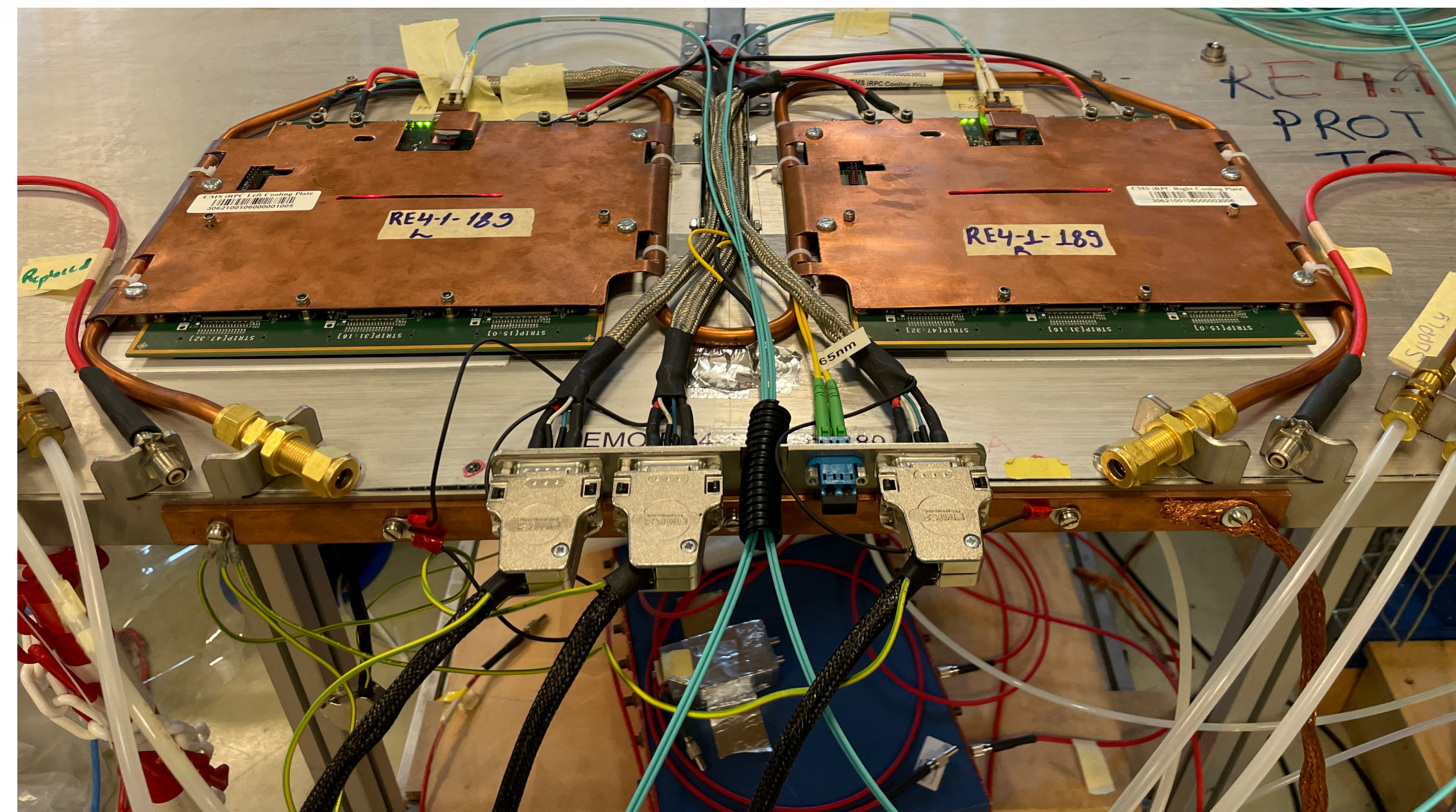
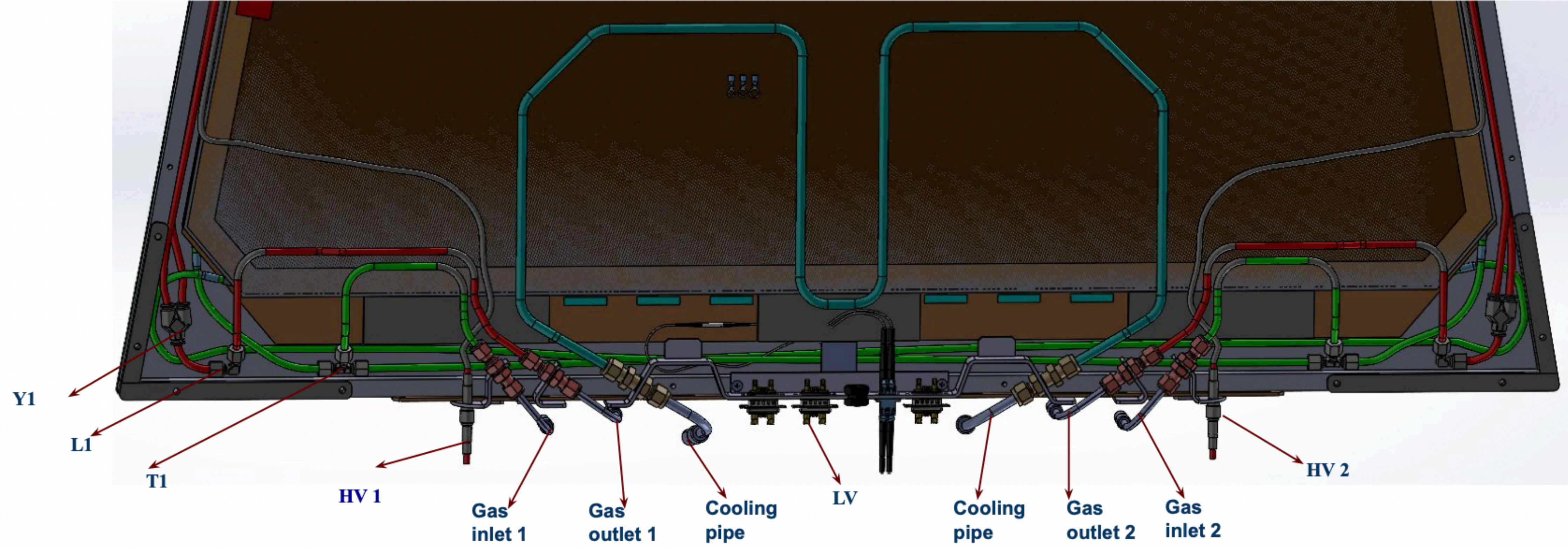
	iRPC	RPC
High Pressure Laminate thickness	1.4 mm	2 mm
Num. of Gas Gap	2	2
Gas Gap thickness	1.4 mm	2 mm
Resistivity (Ωcm)	$0.9 - 3 \times 10^{10}$	$1 - 6 \times 10^{10}$
Charge threshold	$< 50 \text{ fC}$	150 fC
space resolution (eta)	1.5 cm	20-28 cm
space resolution (phi) strip pitch driven	0.3-0.6 cm	0.8-1.9 cm
Intrinsic time resolution	0.5 ns	1.5 ns

- Two readout panels: made of a thin (0.6 mm) Printed Circuit Board (PCB)
- Each PCB has 48 strips and equipped with a FEB.
- To identify the position along the strip, the read out of the iRPC detectors is from both sides of a strip end, low radius (LR) and high radius (HR).



The LHC Beam Pipe:

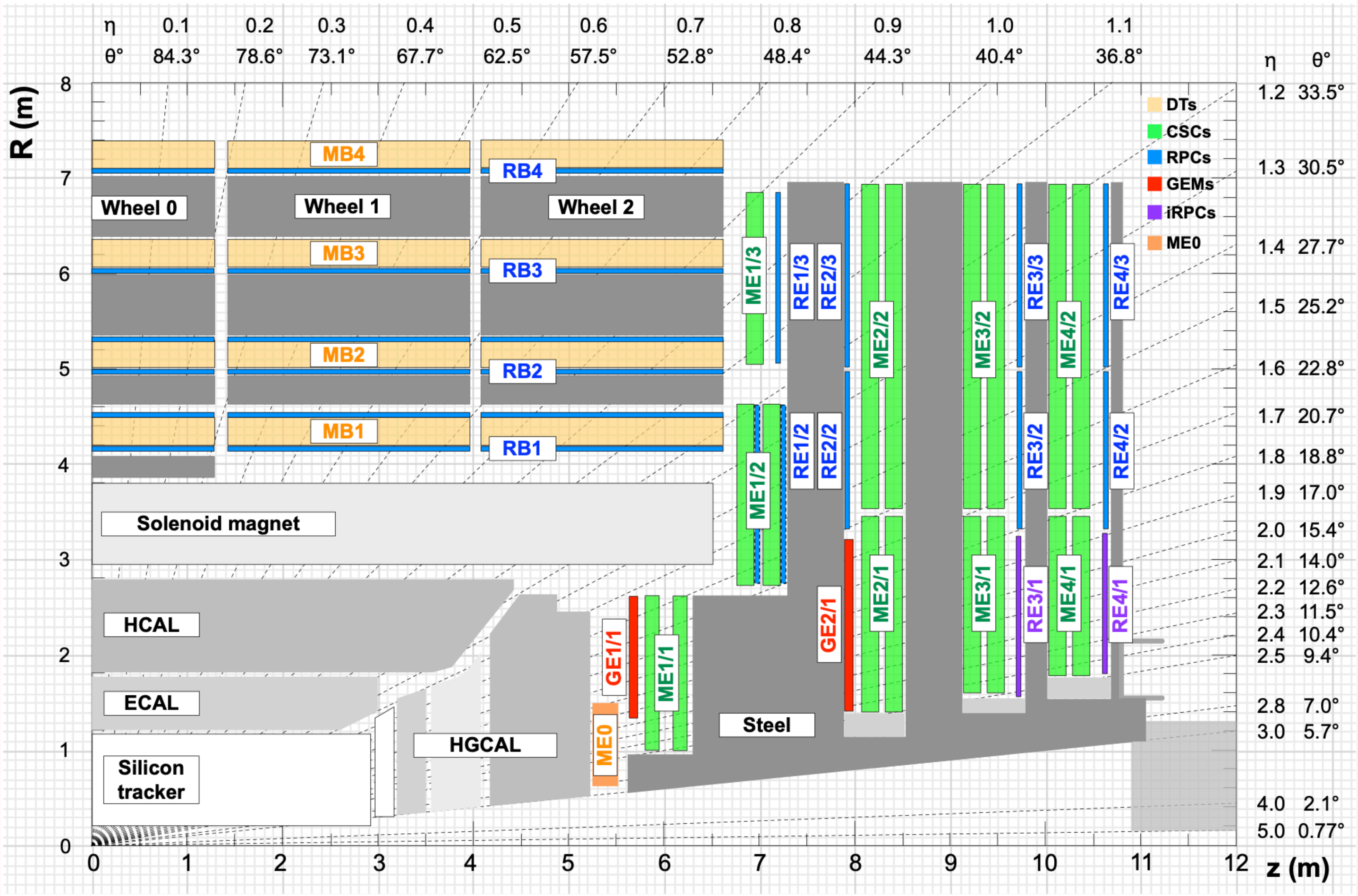




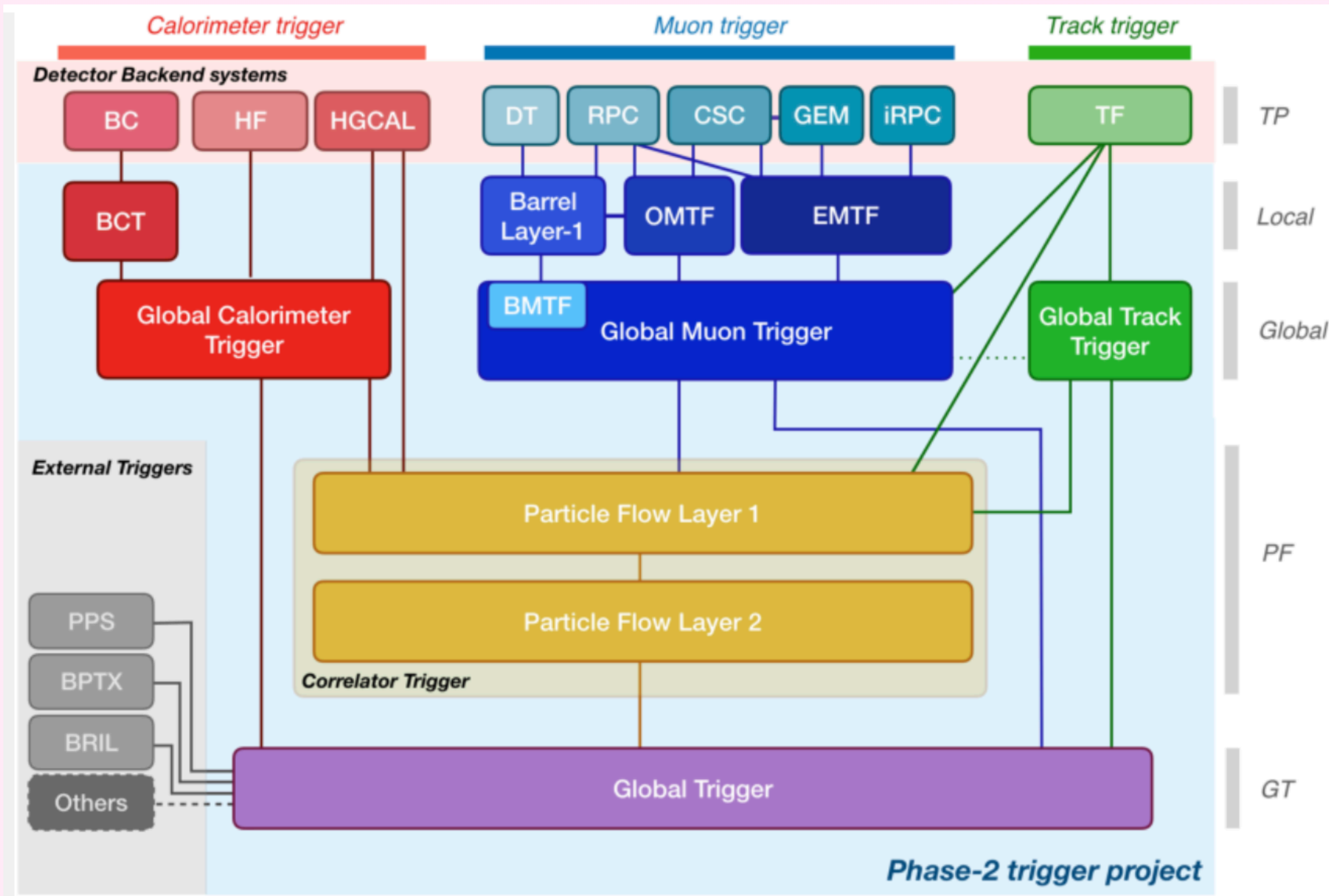
L'anneau blanc



CMS Slice



L1 Trigger



JOB Opportunities

TÜBİTAK 2232-A PROJECT

Research Positions Announcement

Project Name	Developing Trigger and Data Acquisition Systems for Long-Lived Particle Searches at High Luminosity LHC)
Project Coordinator	Dr. Ece Aşılar
Institution	İstinye Üniversitesi
Program	TÜBİTAK BİDEB 2232-A
Project Timeline	36 Months (February 2026 – February 2029)
Dead Line	01.09.2026

https://eceasilar.web.cern.ch/TechnicalPlots/Documents/2232-A_Ilan_English.docx.pdf

Saolun :)

