LHC Detectors

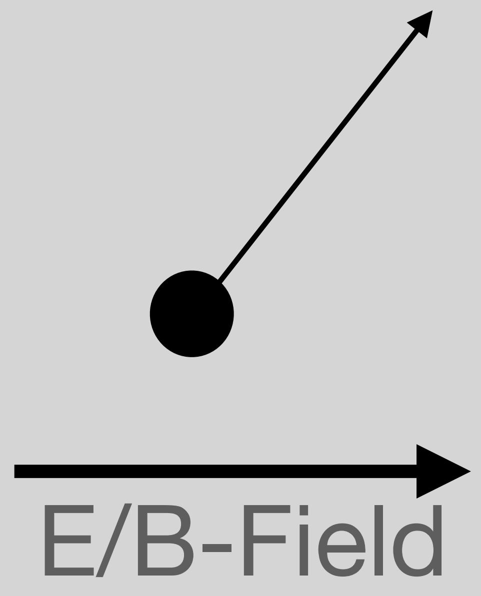
CSU-NUPAX/CERN IRES Program

Johan S Bonilla
Feb 22nd and 24th, 2022

See Particle Data Group at LBNL

What is a Particle?

Classical



Quantum Mechanics

$$\psi_n(x) = \sqrt{\frac{1}{2^n\, n!}} \cdot \left(\frac{m\omega}{\pi\hbar}\right)^{1/4} \cdot e^{-\frac{m\omega x^2}{2\hbar}} \cdot H_n\left(\sqrt{\frac{m\omega}{\hbar}}x\right),$$

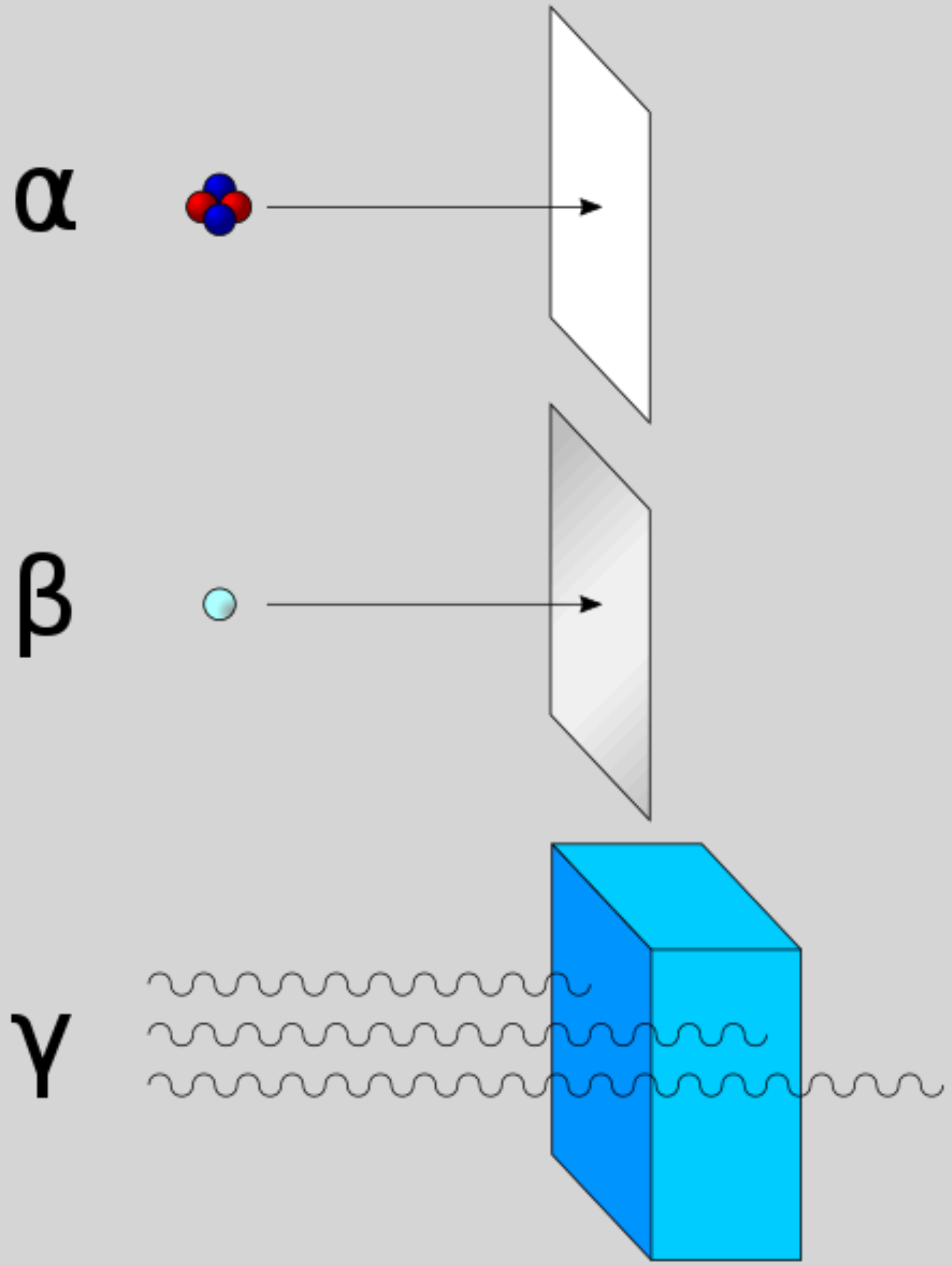
Does NOT play nice
with special relativity

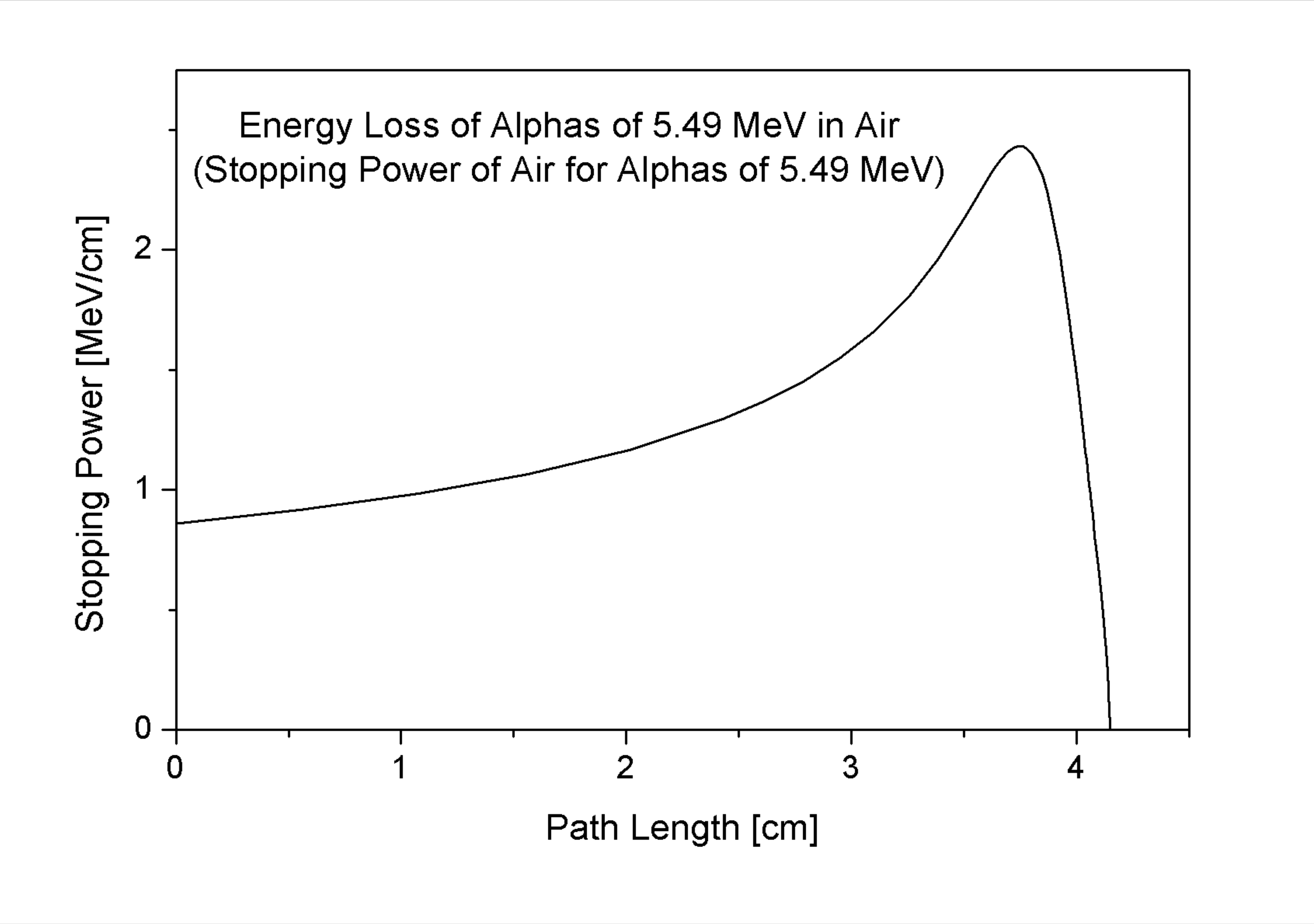
Quantum Field Theory

$$\hat{\phi}(\mathbf{x},t) = \int \frac{d^3p}{(2\pi)^3}\frac{1}{\sqrt{2\omega_{\mathbf{p}}}}\left(\hat{a}_{\mathbf{p}}e^{-i\omega_{\mathbf{p}}t+i\mathbf{p}\cdot\mathbf{x}} + \hat{a}^{\dagger}_{\mathbf{p}}e^{i\omega_{\mathbf{p}}t-i\mathbf{p}\cdot\mathbf{x}}\right).$$

$$\mathcal{L} = \frac{1}{2}(\partial_\mu\phi)(\partial^\mu\phi) - \frac{1}{2}m^2\phi^2 - \frac{\lambda}{4!}\phi^4,$$

Rutherford+Villard (1899)





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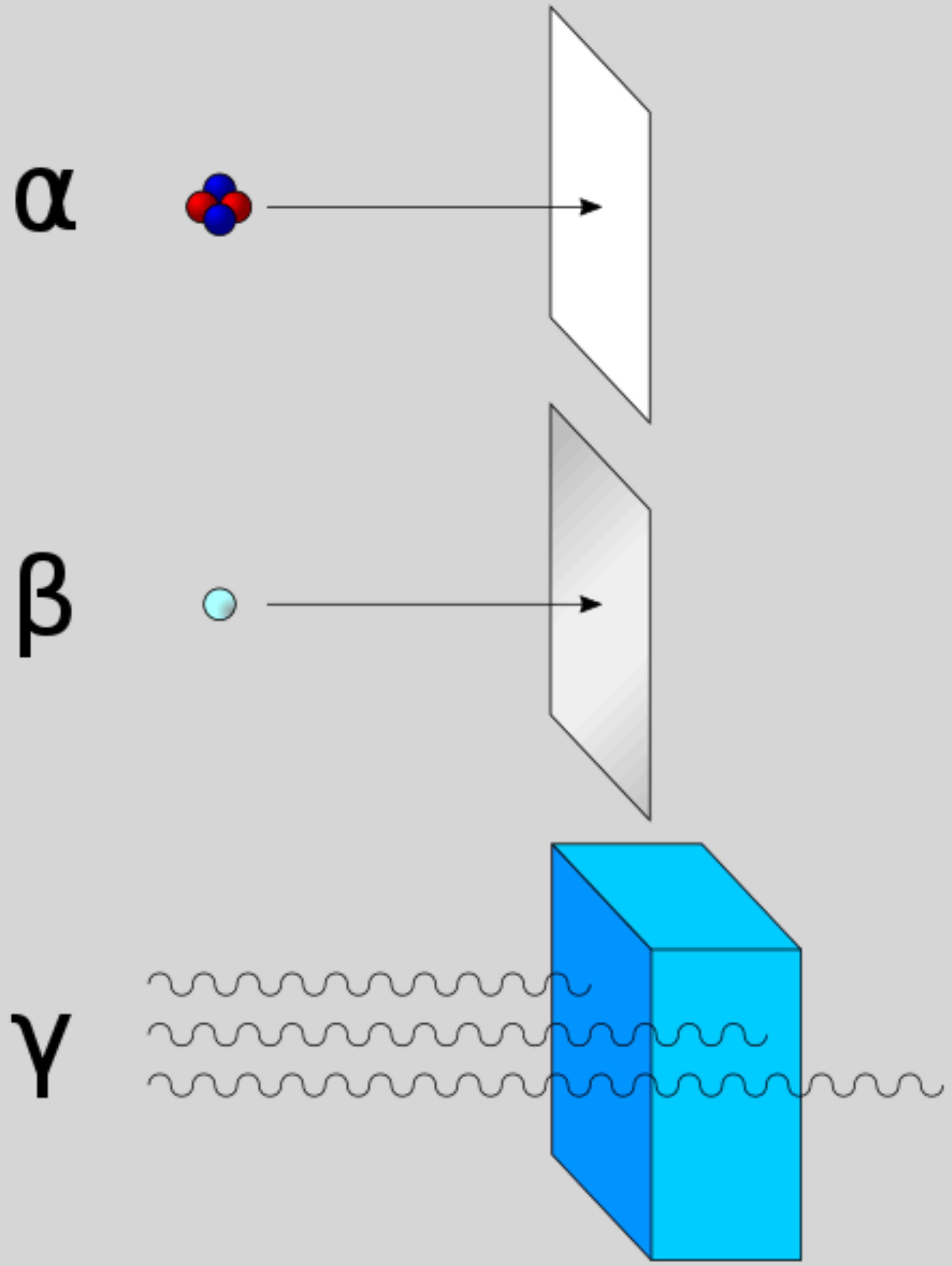
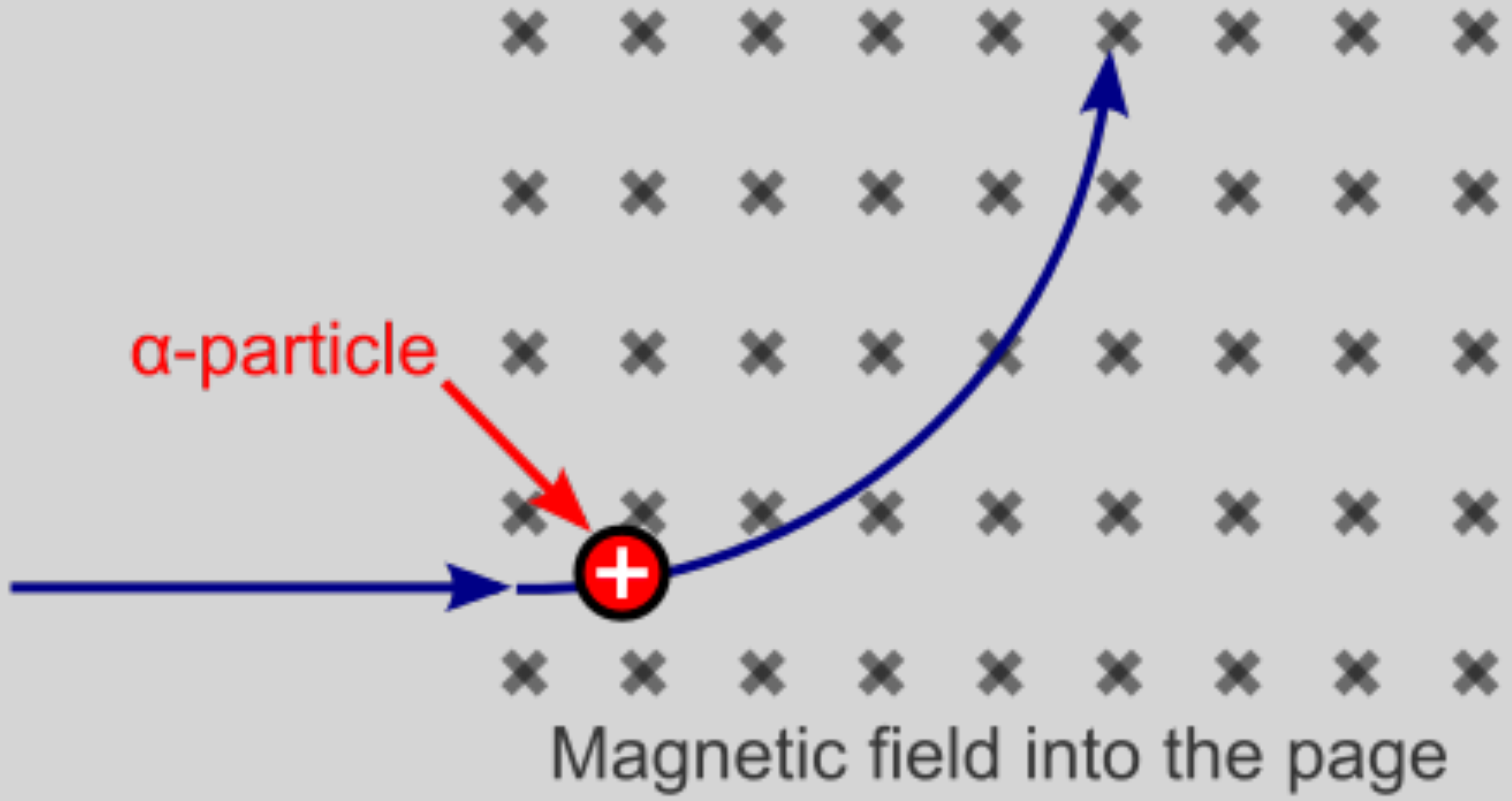
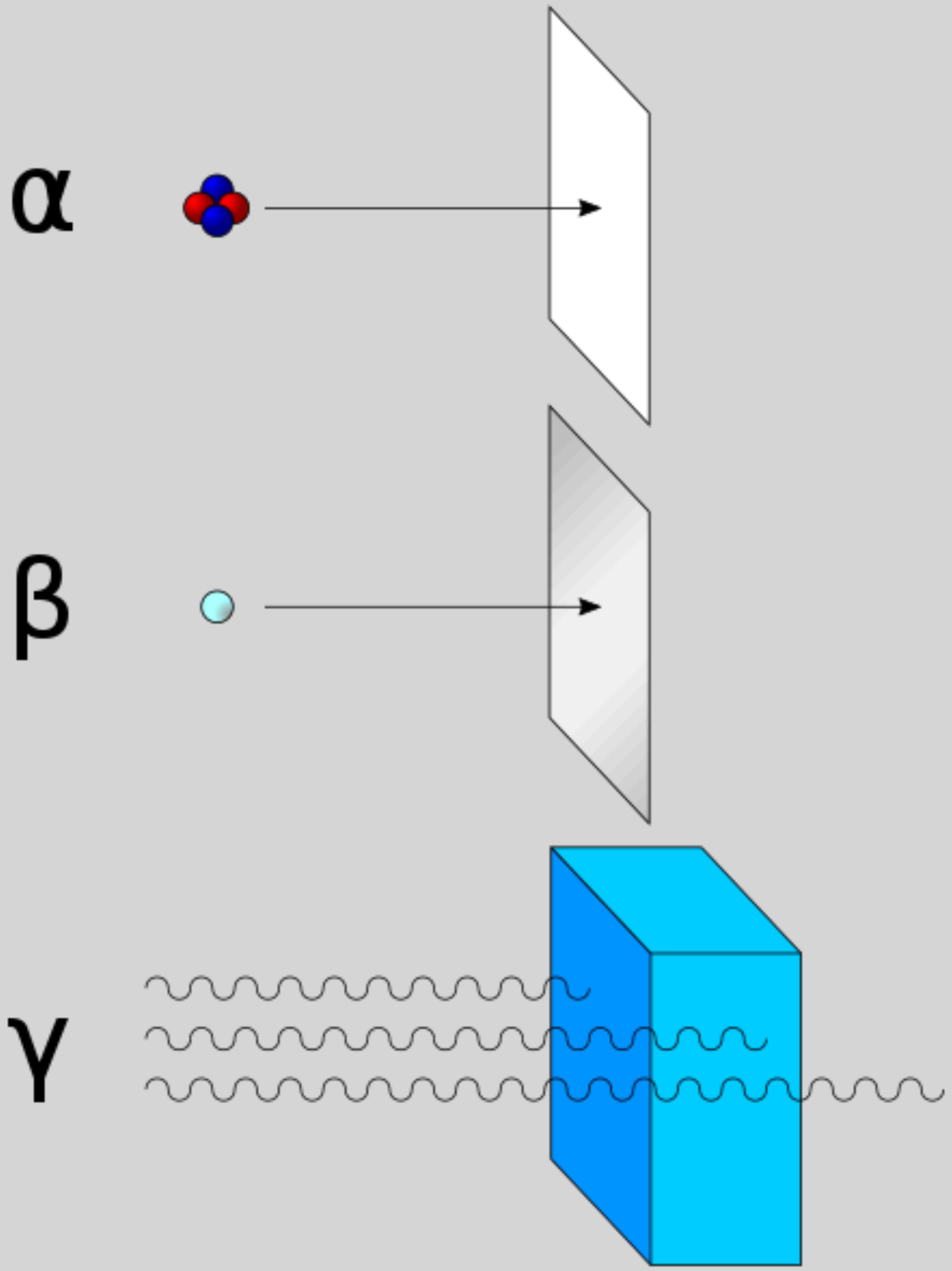




What Kinds of Particles Are There?



= ?

= ?

= ?

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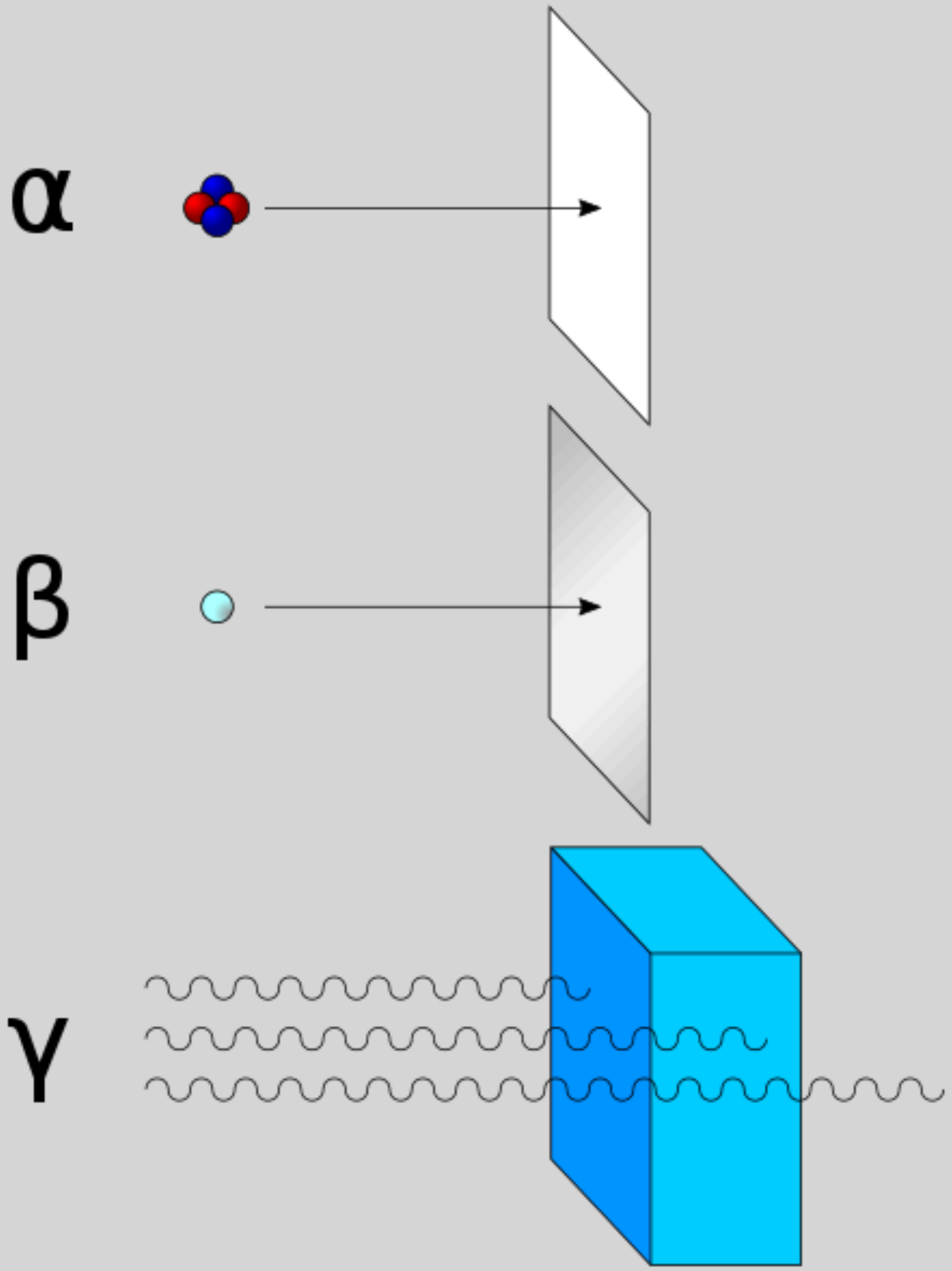

= ? = meson/hadron

= ?

= ?

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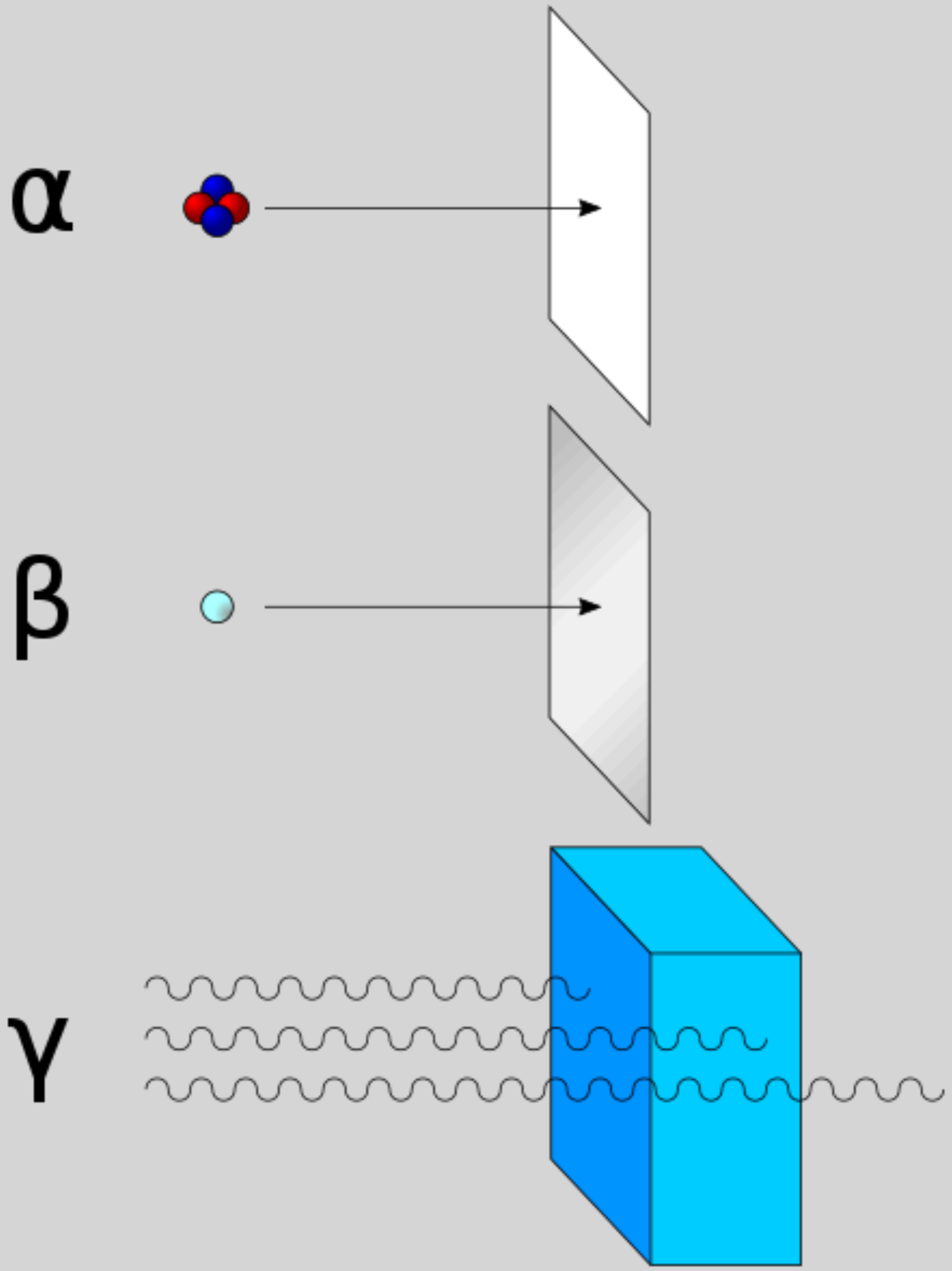

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= ? = electron/positron

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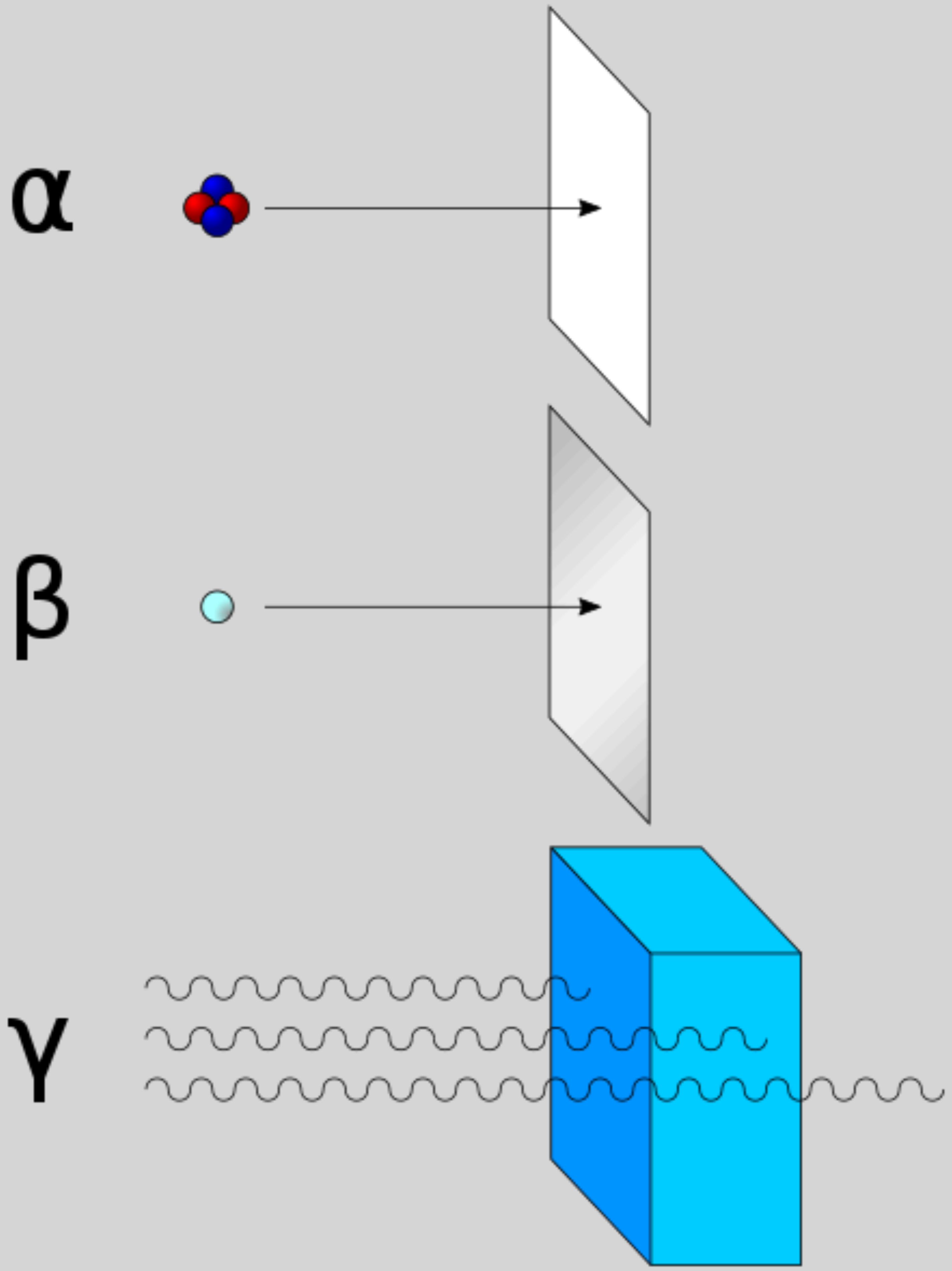

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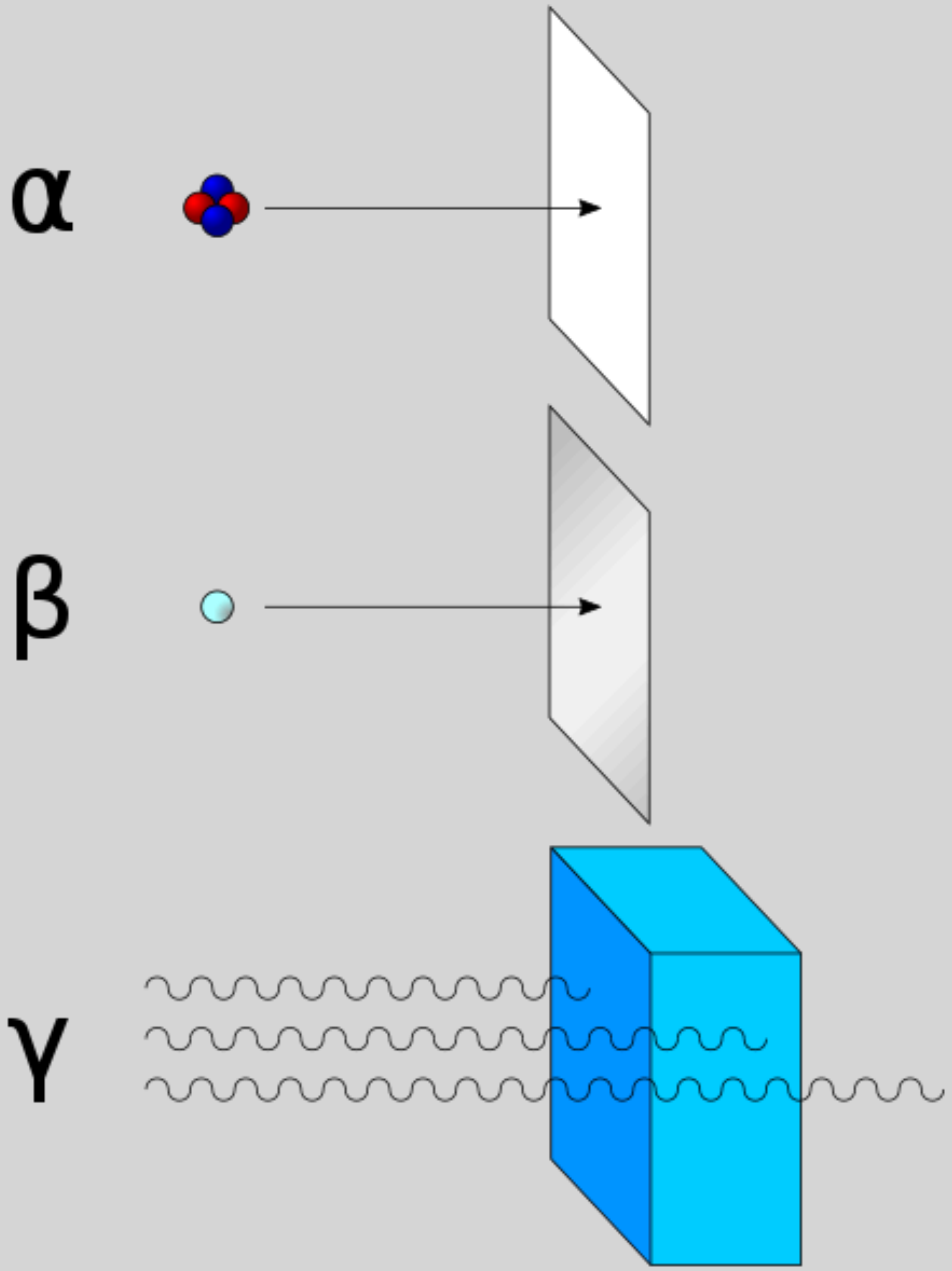

= ? = meson/hadron => heavy, electric+color charge

= ? = electron/positron

= ? = photon

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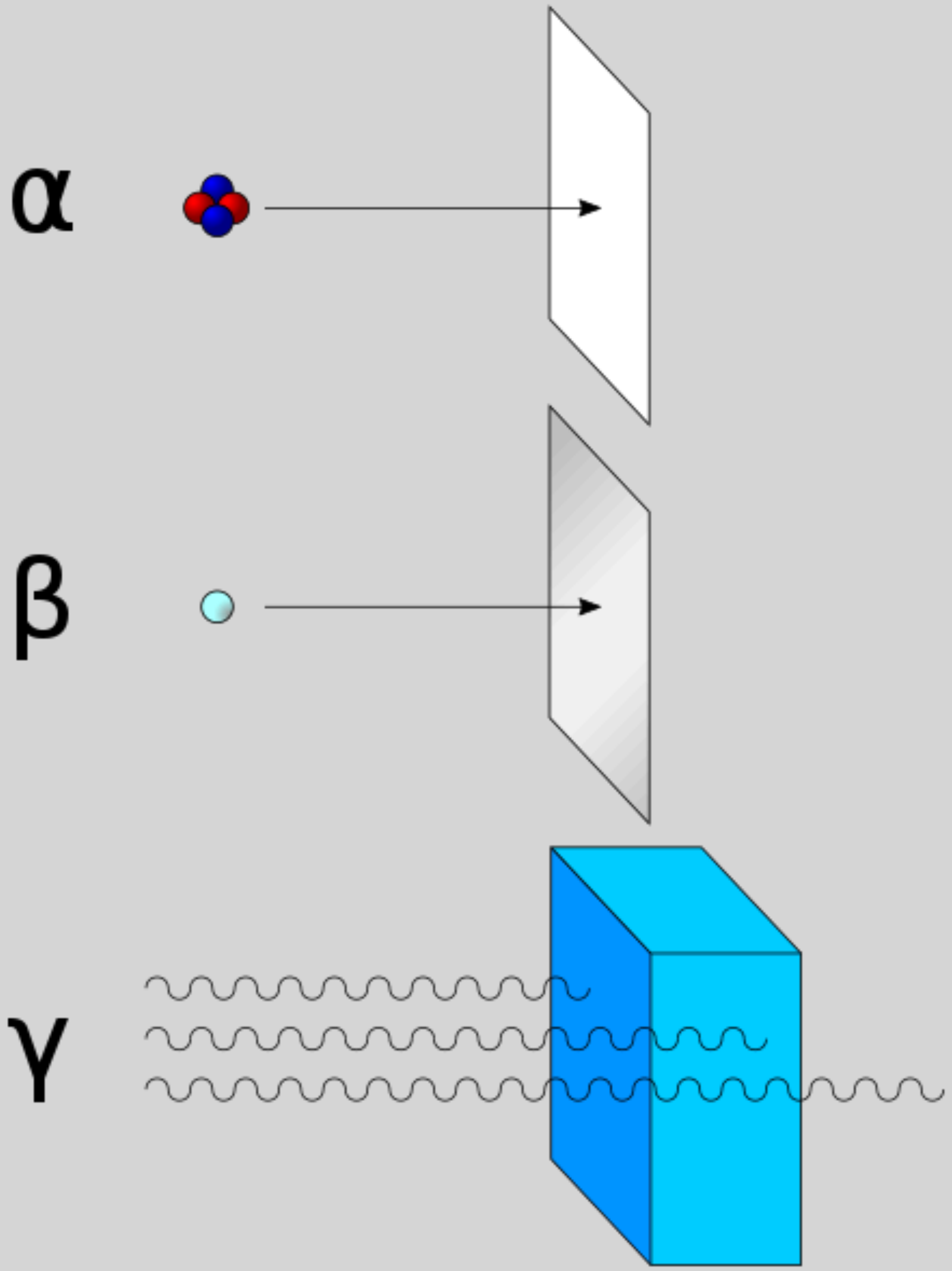

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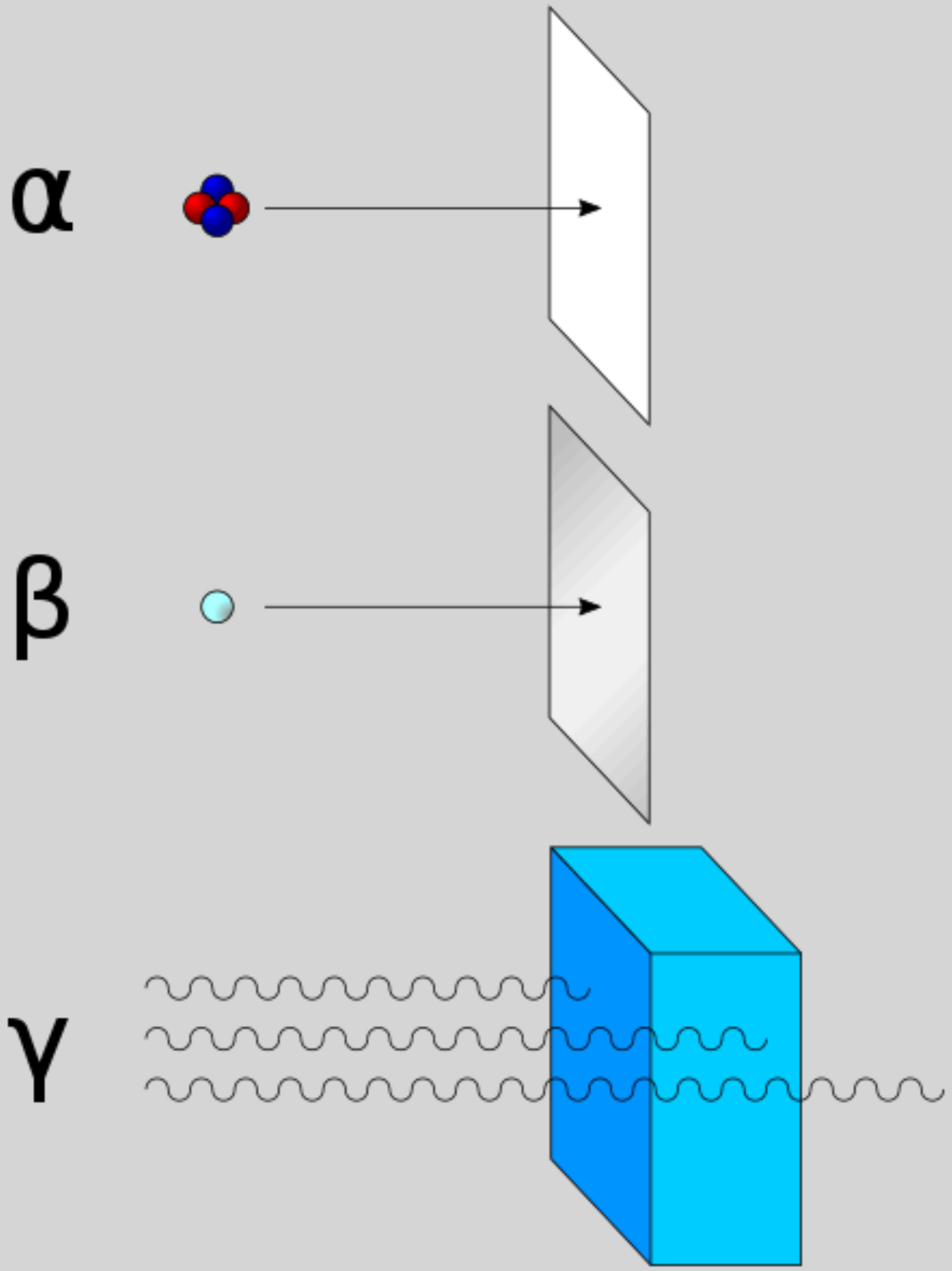

= ? = meson/hadron => heavy,
electric+color charge

= ? = electron/positron => light,
electric charge

= ? = photon => massless,
carries energy+momentum
interacts electromagnetically

What Other Kinds of Particles Are There?

MANY meson/hadron

Charged Leptons:
electron, muon, tau

Vector Bosons: W/Z

Scalar Boson: H

What Other Kinds of Particles Are There?

MANY meson/hadron

electric+color charge
Which are long lived?

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electric charge
only electron stable
How far can muons travel?

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W +/-1 electrica charge,
Z and Higgs neutral
How do we ‘see’ these?

Don’t Forget Neutrinos!

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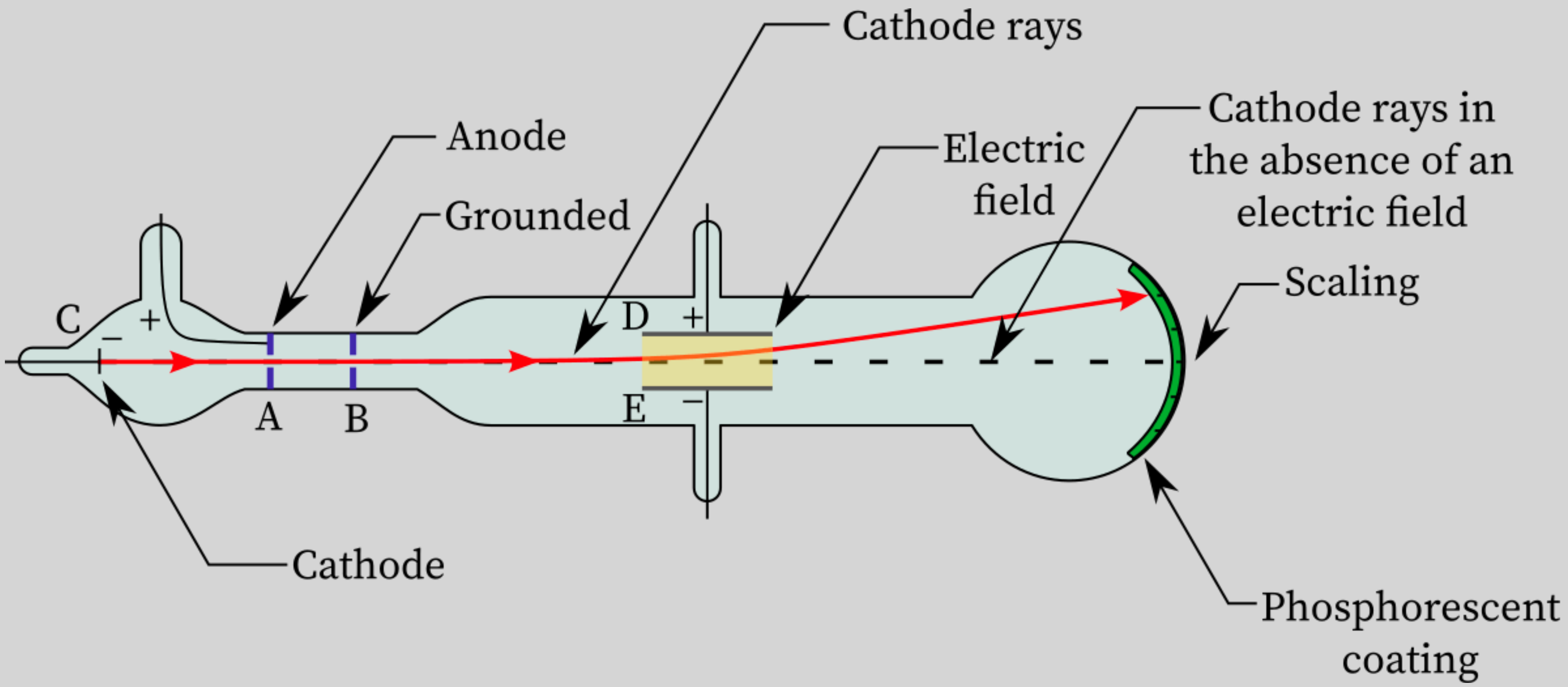
Previous->Future Experiments

Cathode Ray => Electrons



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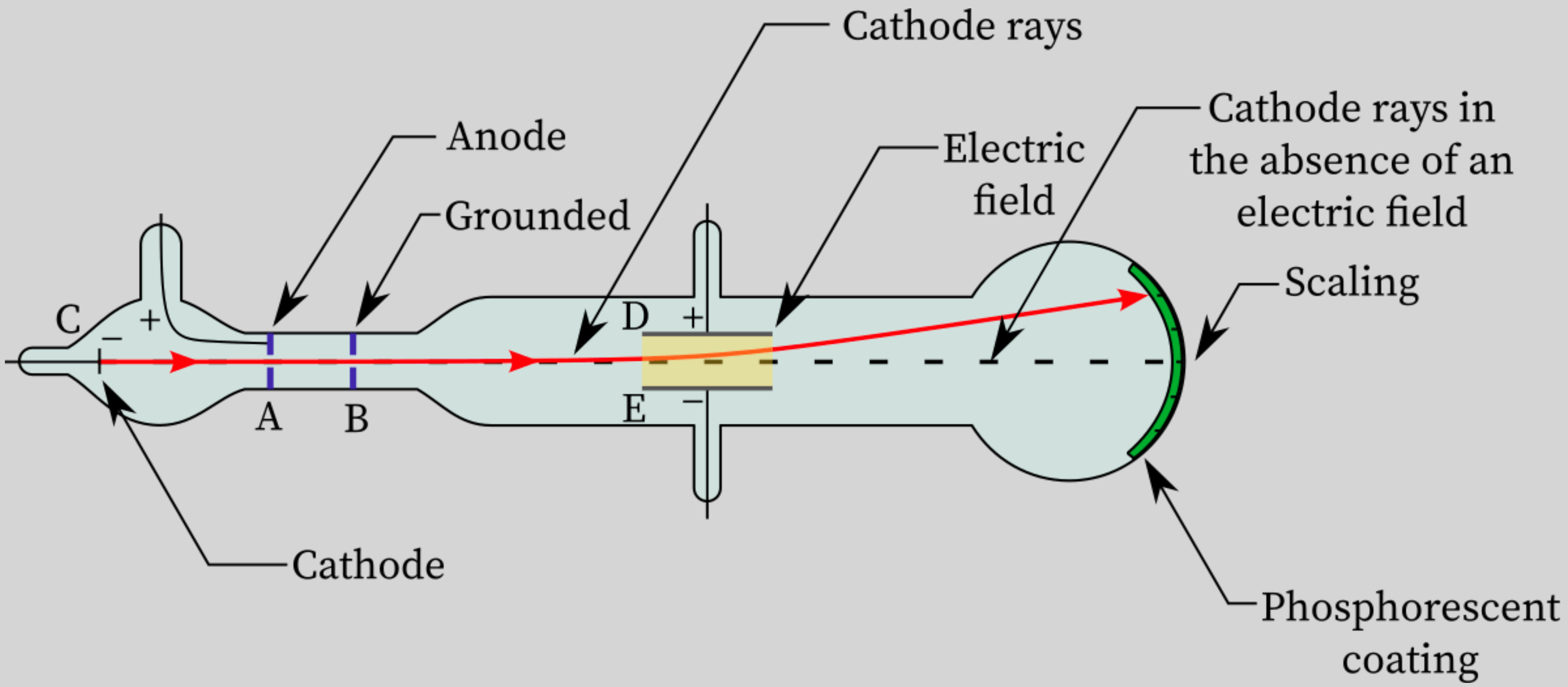
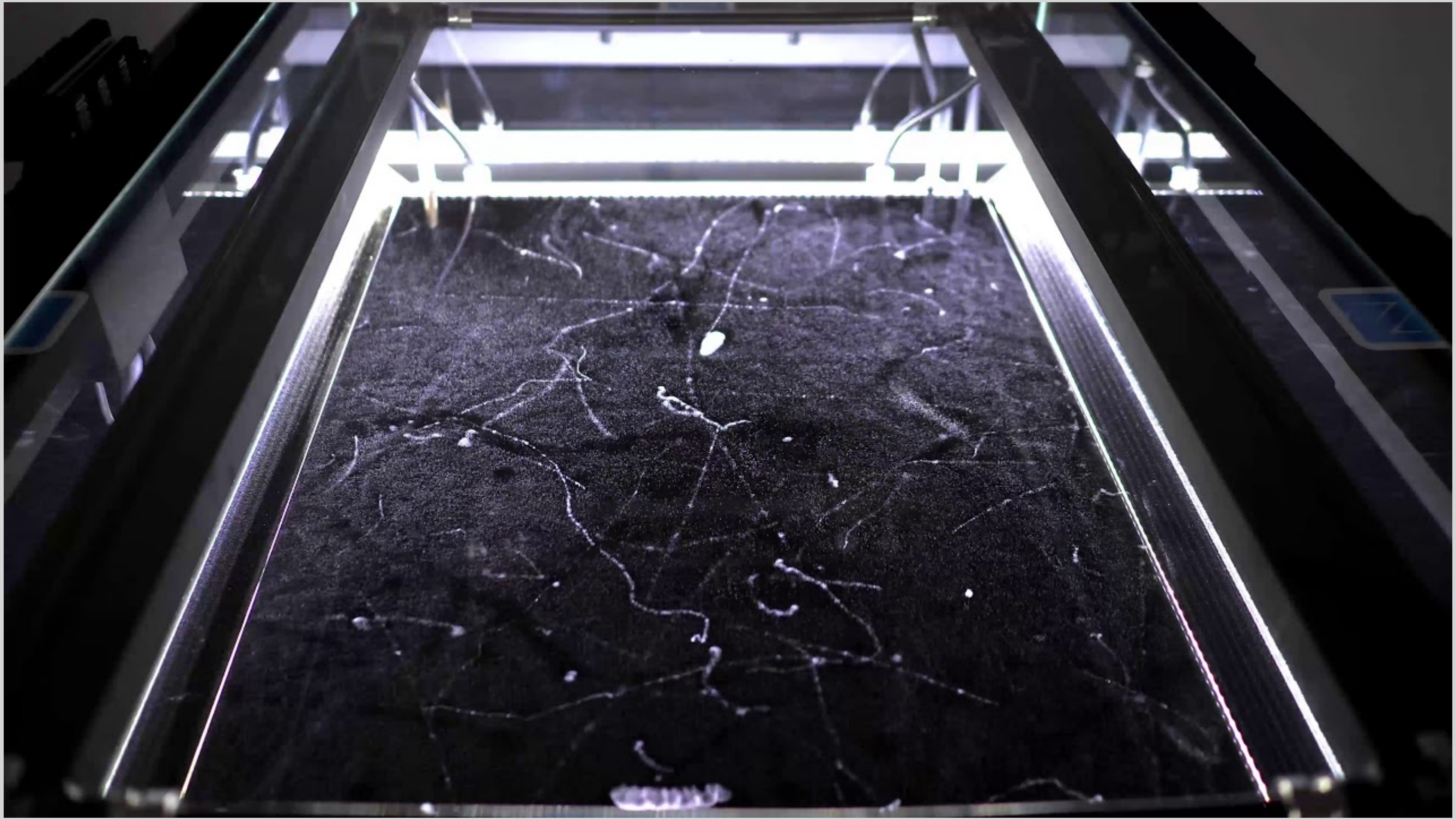
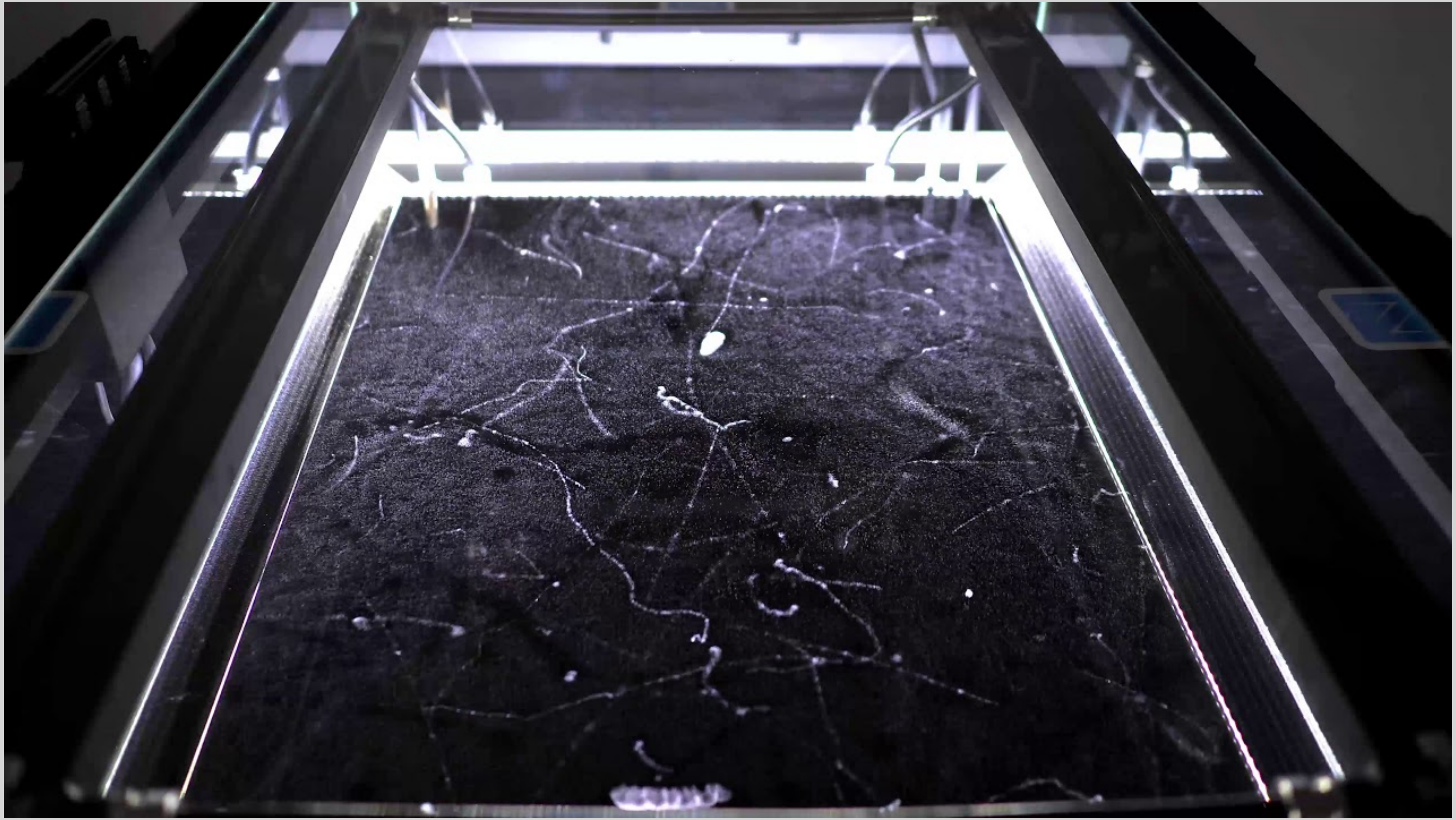


Hot Stuff => Negatively-Charged Particles (Electrons)

Cloud Chamber



Cloud Chamber



Accidental Discovery of the Muon

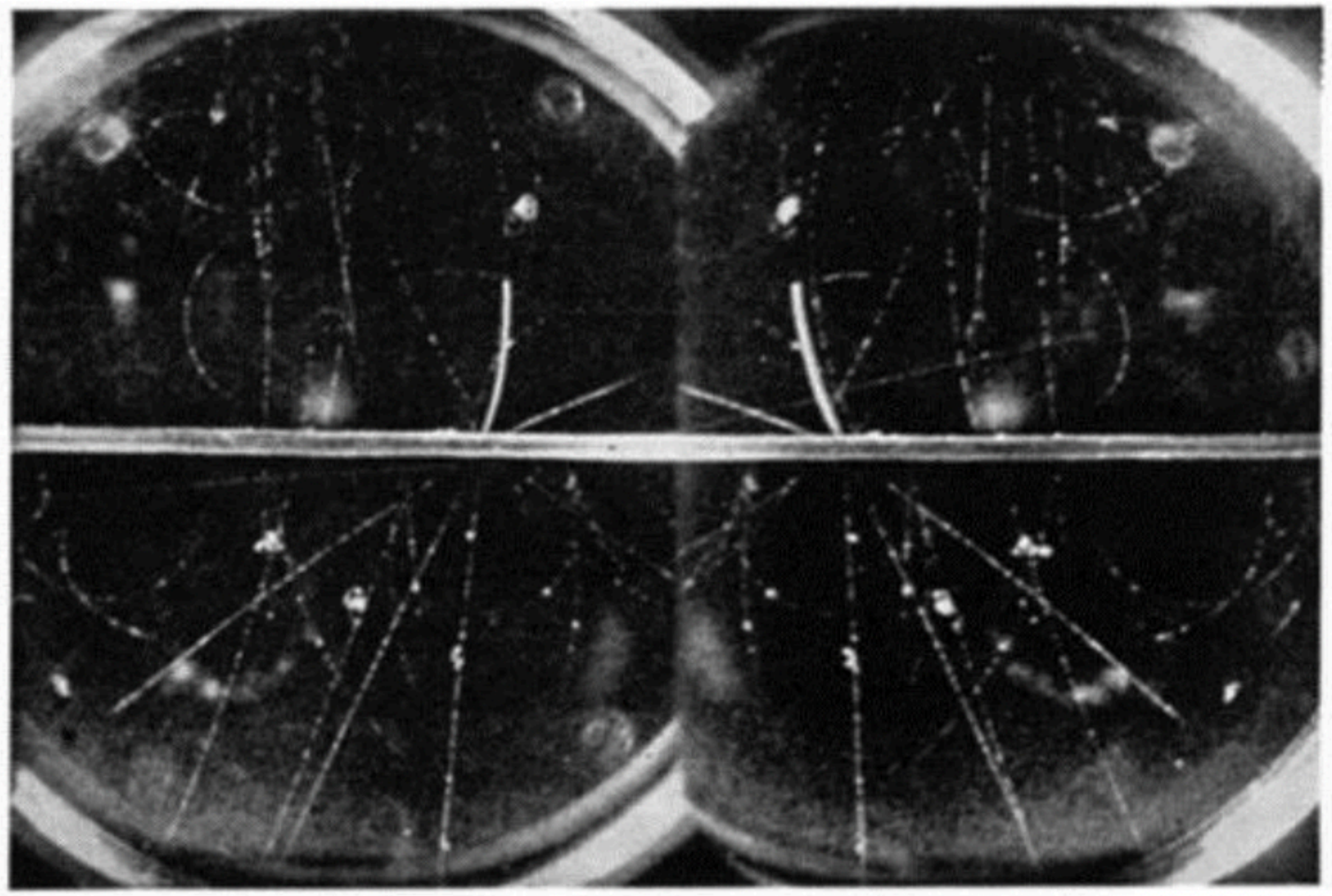


FIG. 12. Pike's Peak, 7900 gauss. A disintegration produced by a nonionizing ray occurs at a point in the 0.35 cm lead plate, from which six particles are ejected. One of the particles (strongly ionizing) ejected nearly vertically upward has the range of a 1.5 MEV proton. Its energy (given by its range) corresponds to an $H\rho = 1.7 \times 10^5$, or a radius of 20 cm, which is three times the observed value. If the observed curvature were produced entirely by magnetic deflection it would be necessary to conclude that this track represents a massive particle with an e/m much greater than that of a proton or any other known nucleus. As there are no experimental data available on the multiple

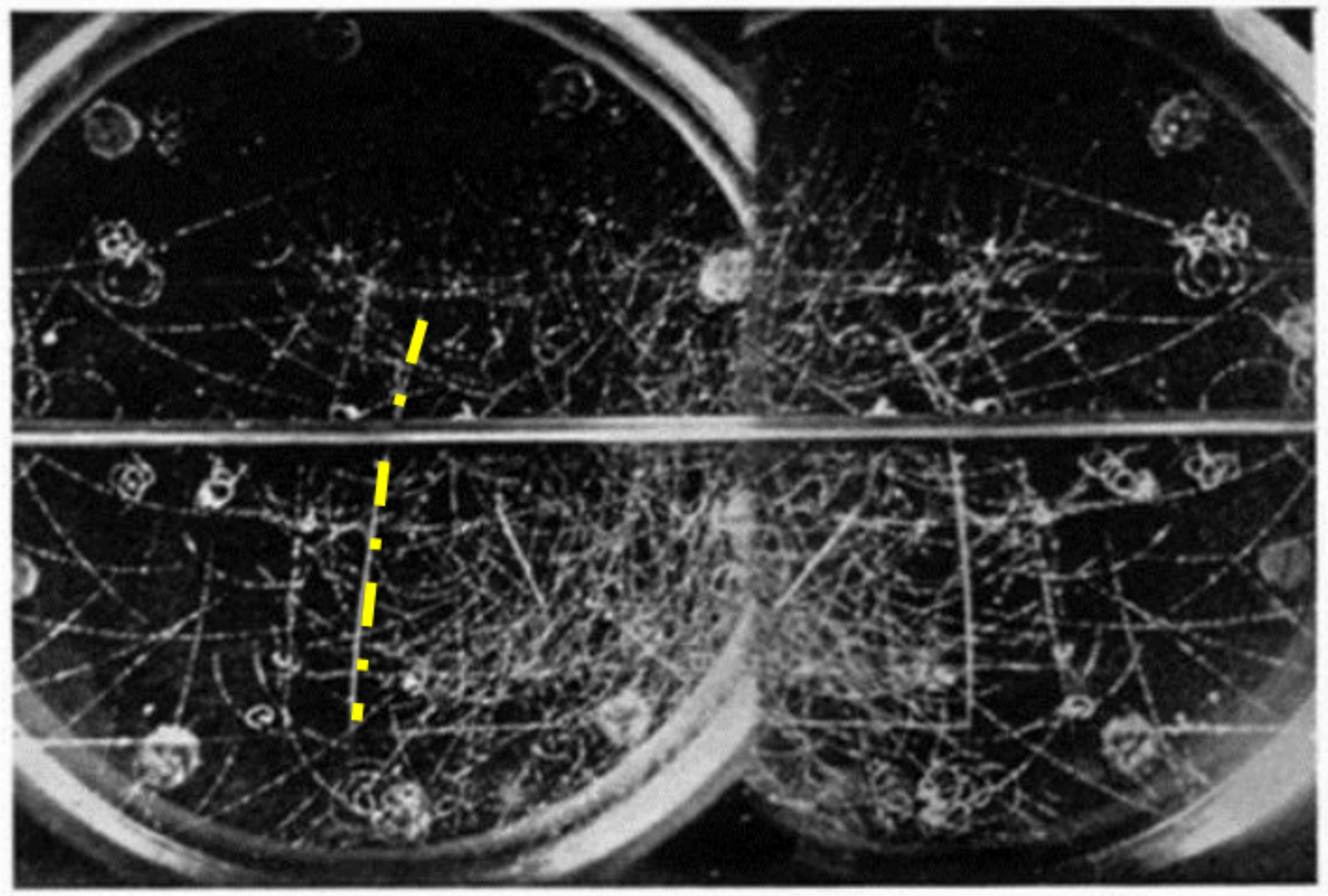


FIG. 13. Pasadena, 4500 gauss. A complex electron shower not clearly defined in direction, and three heavy particles with specific ionizations definitely greater than that of electrons. The sign of charge of two of these heavy particles represented by short tracks cannot be determined, but the assumption that they represent protons is consistent with the information supplied by the photograph. The third heavy track appears above the 0.35 cm lead plate where it has a specific ionization not noticeably different from that of an electron. It penetrates the lead plate and appears in the lower half of the chamber as a nearly vertical track near the middle. Below the plate it shows a greater ionization than an electron, and is deviated in the magnetic field to indicate a positively charged particle. Its $H\rho$ is apparently at most 1.4×10^5 gauss cm, which corresponds to a proton energy of 1 MEV and a range of only 2 cm in the chamber, whereas the observed range is greater than 5 cm. A difficulty of the same nature was discussed in the description of the previous photograph.

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Neutrino Beams

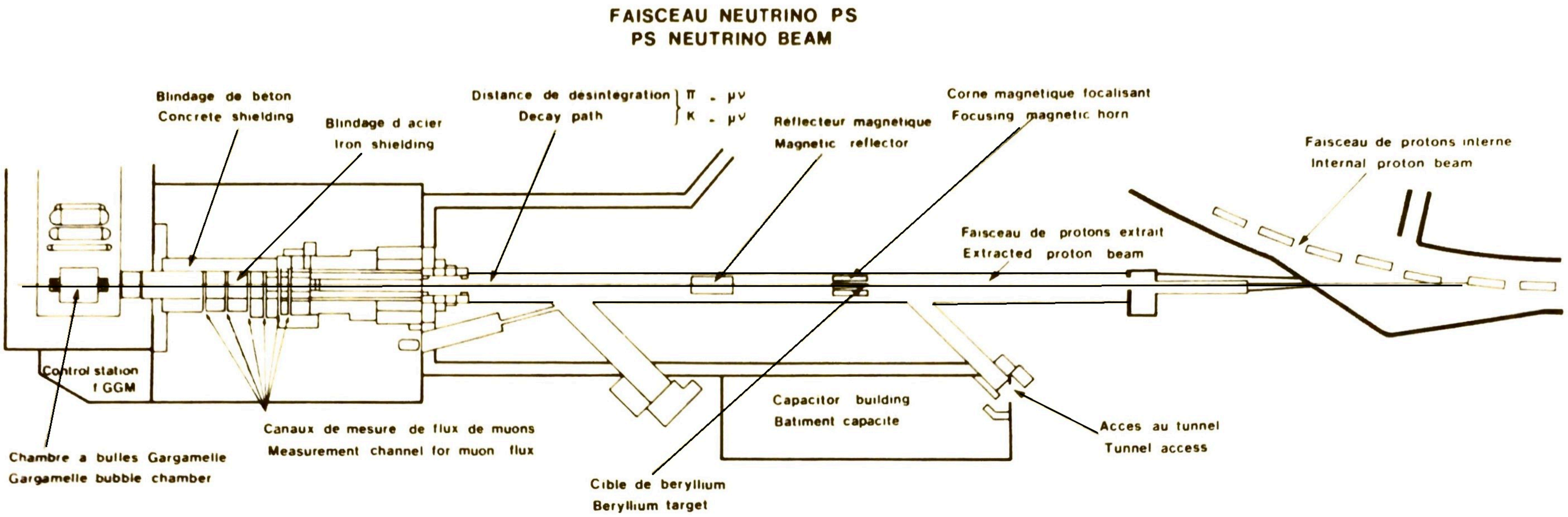
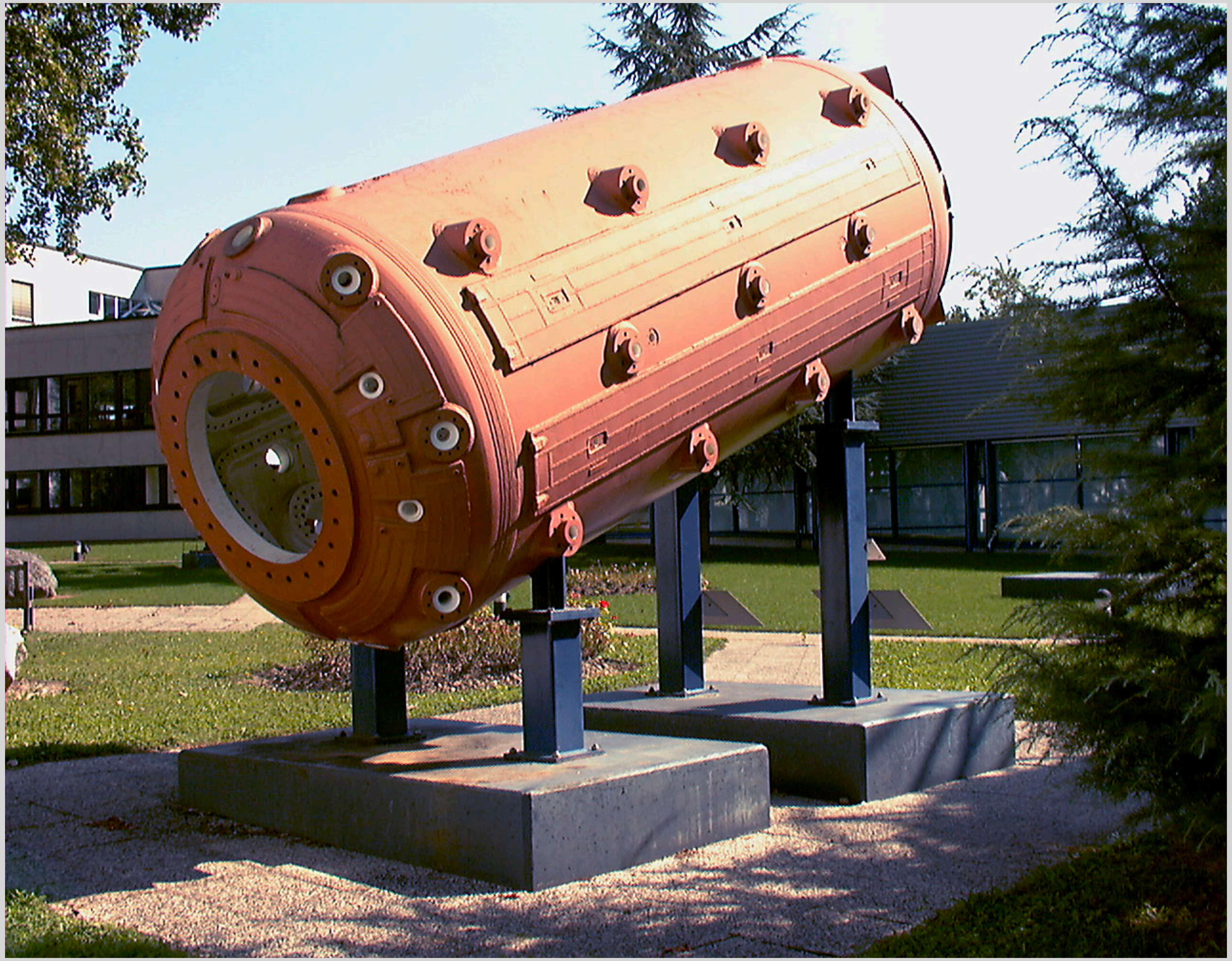
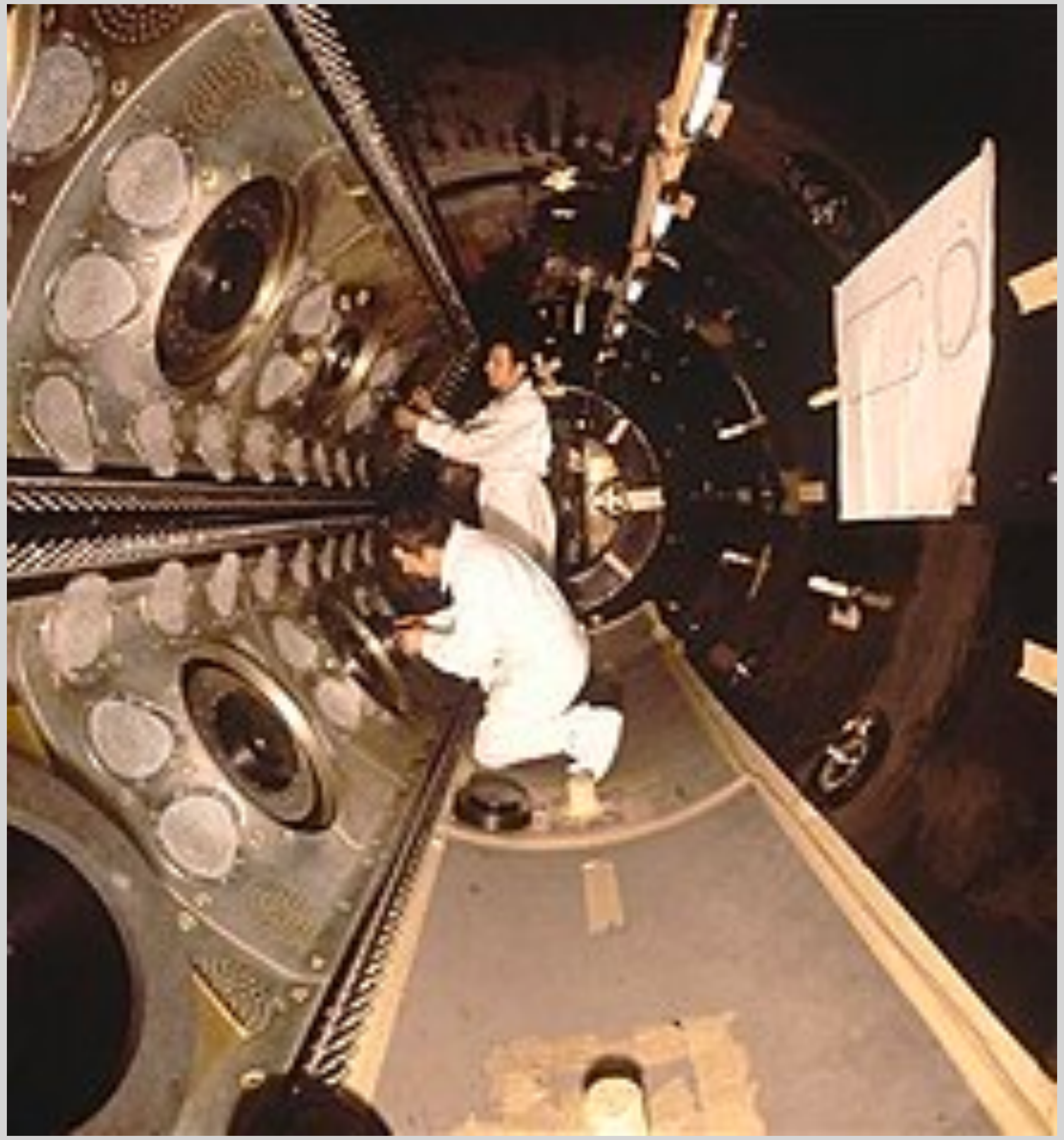


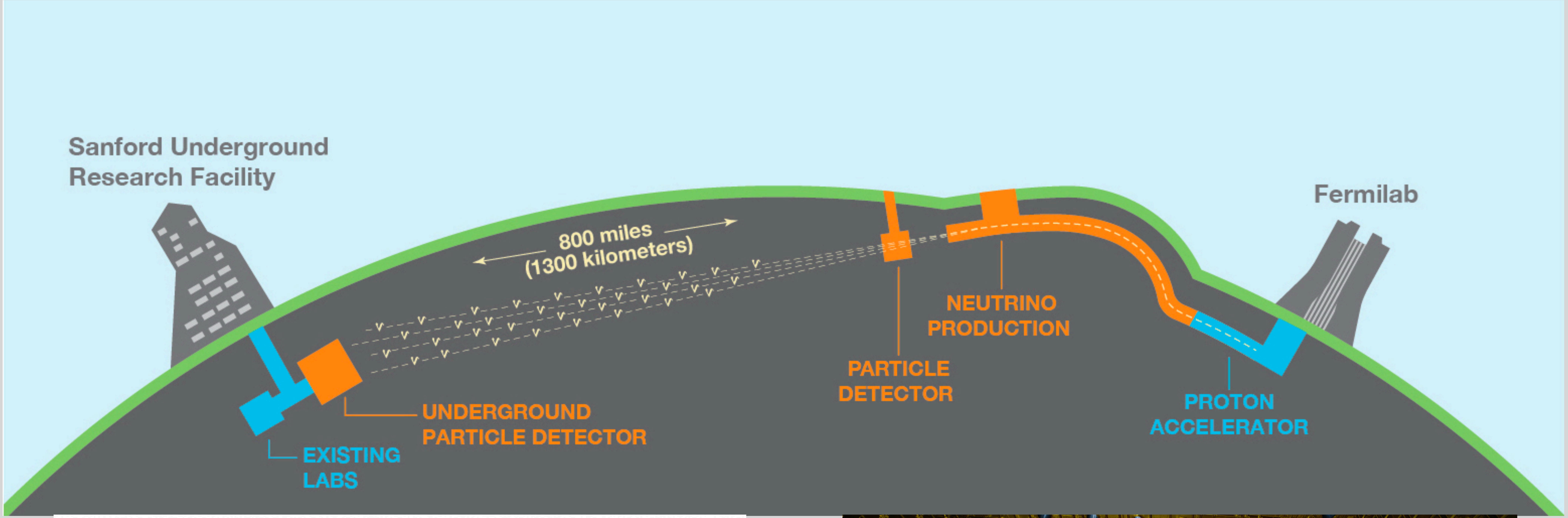
Fig. 1-2. The CERN neutrino beam lay-out.

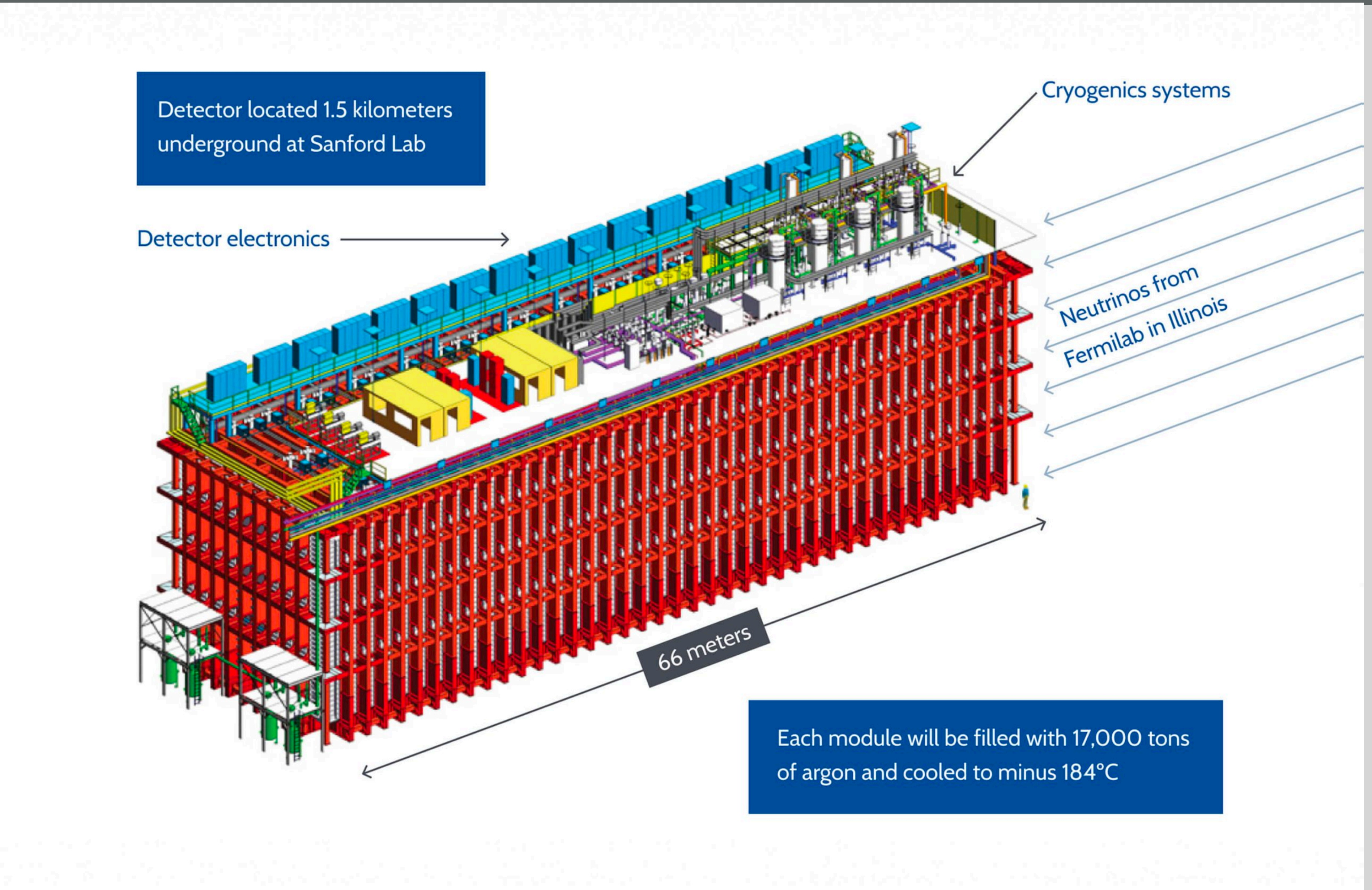
Gargamelle

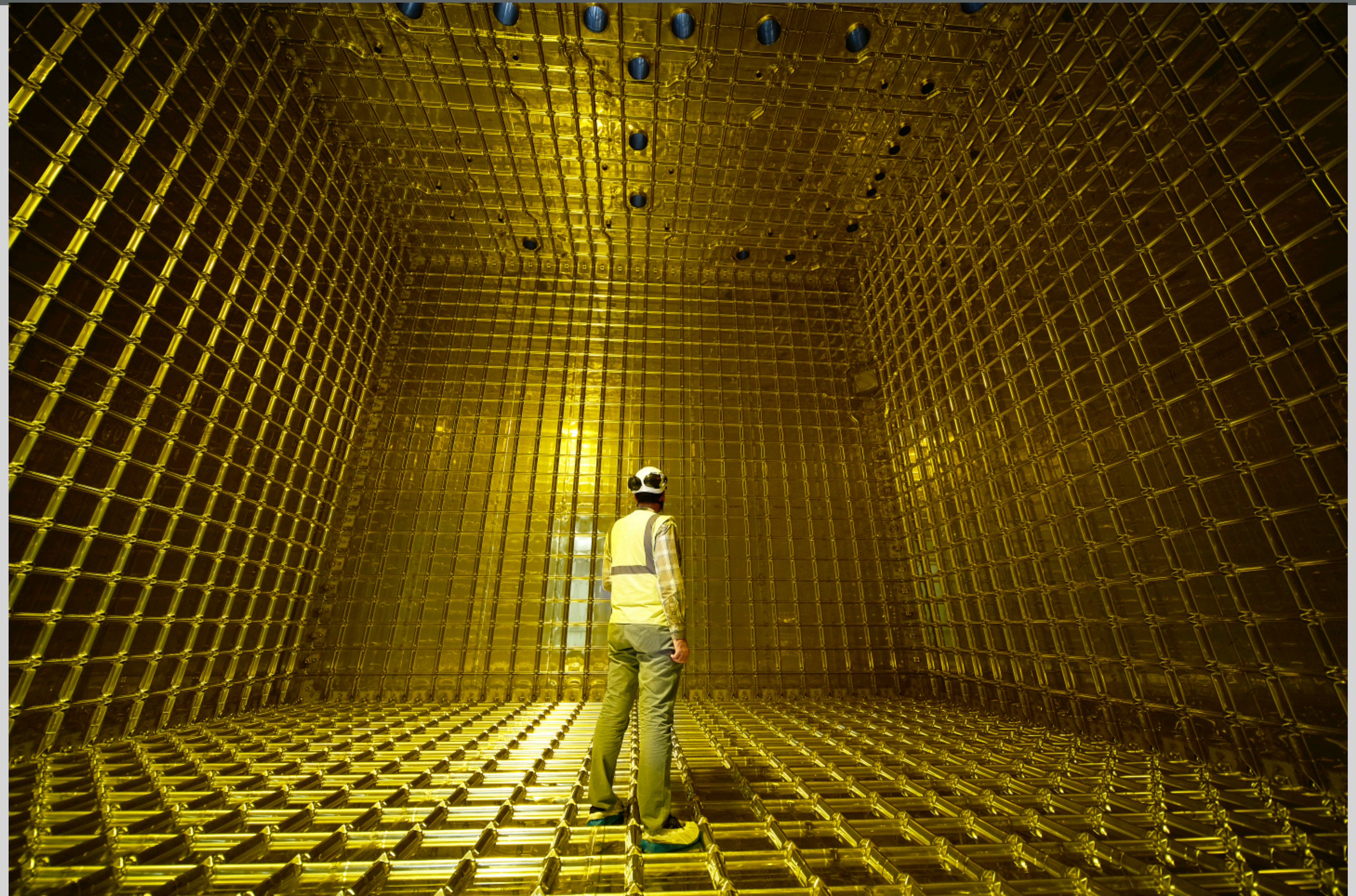




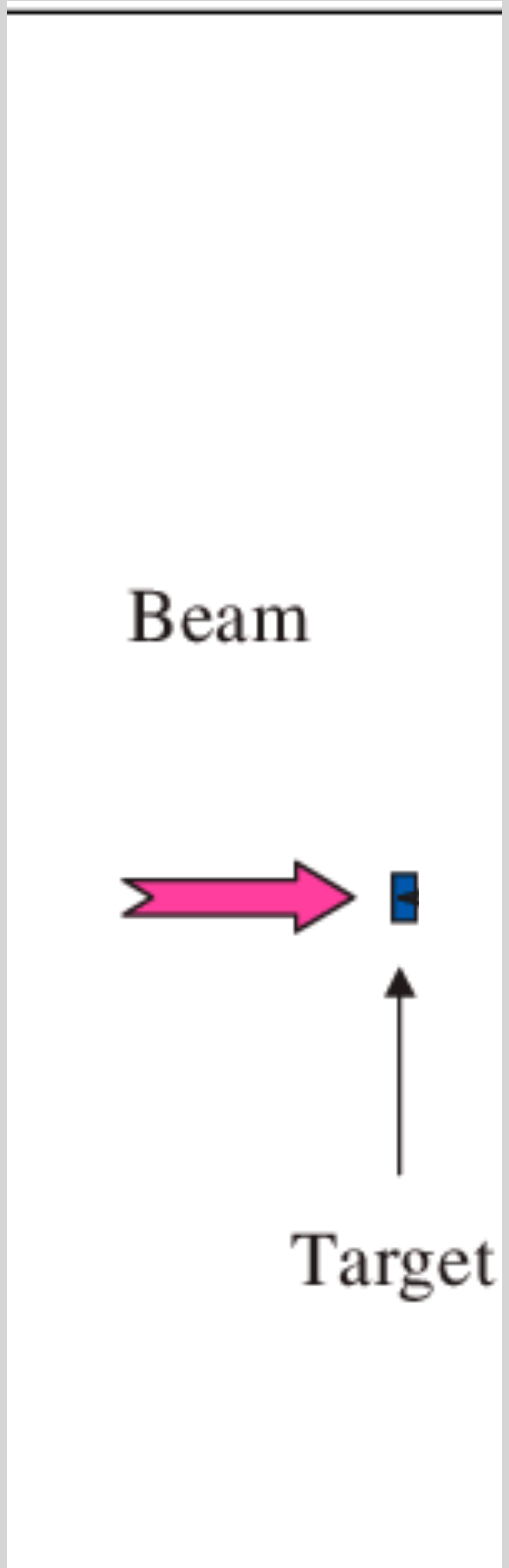
DUNE Experiment







General Collider Detector



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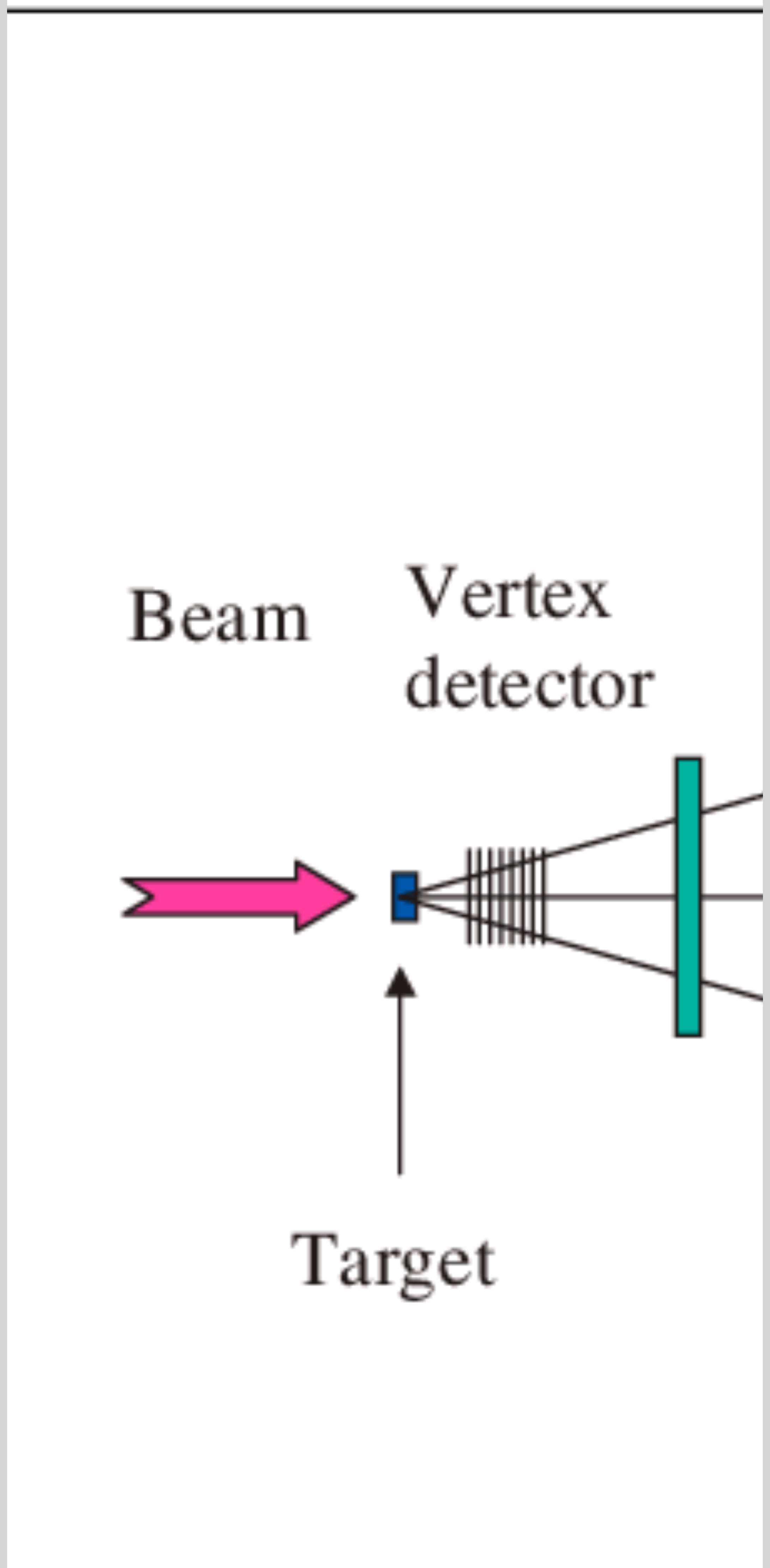

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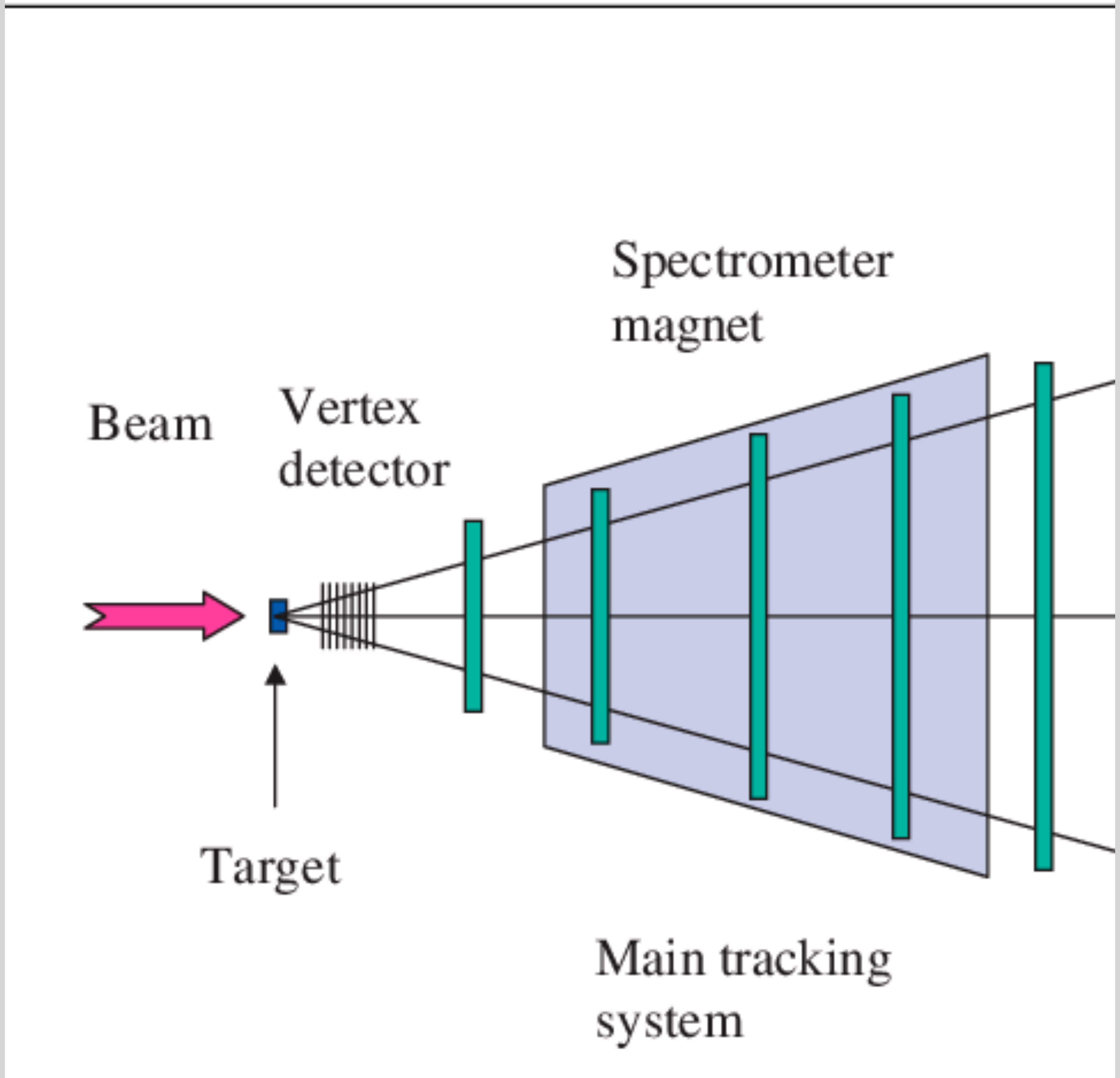

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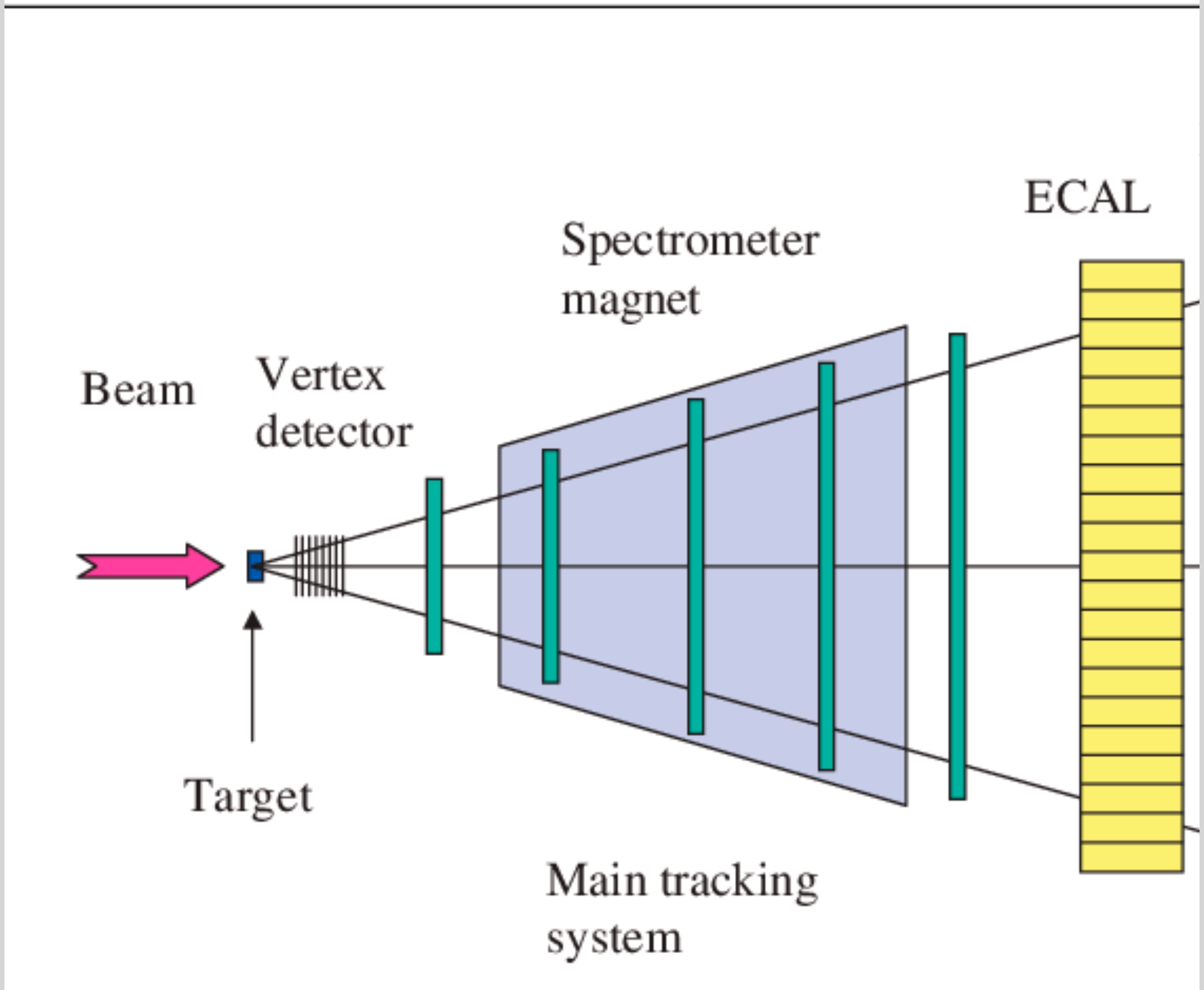

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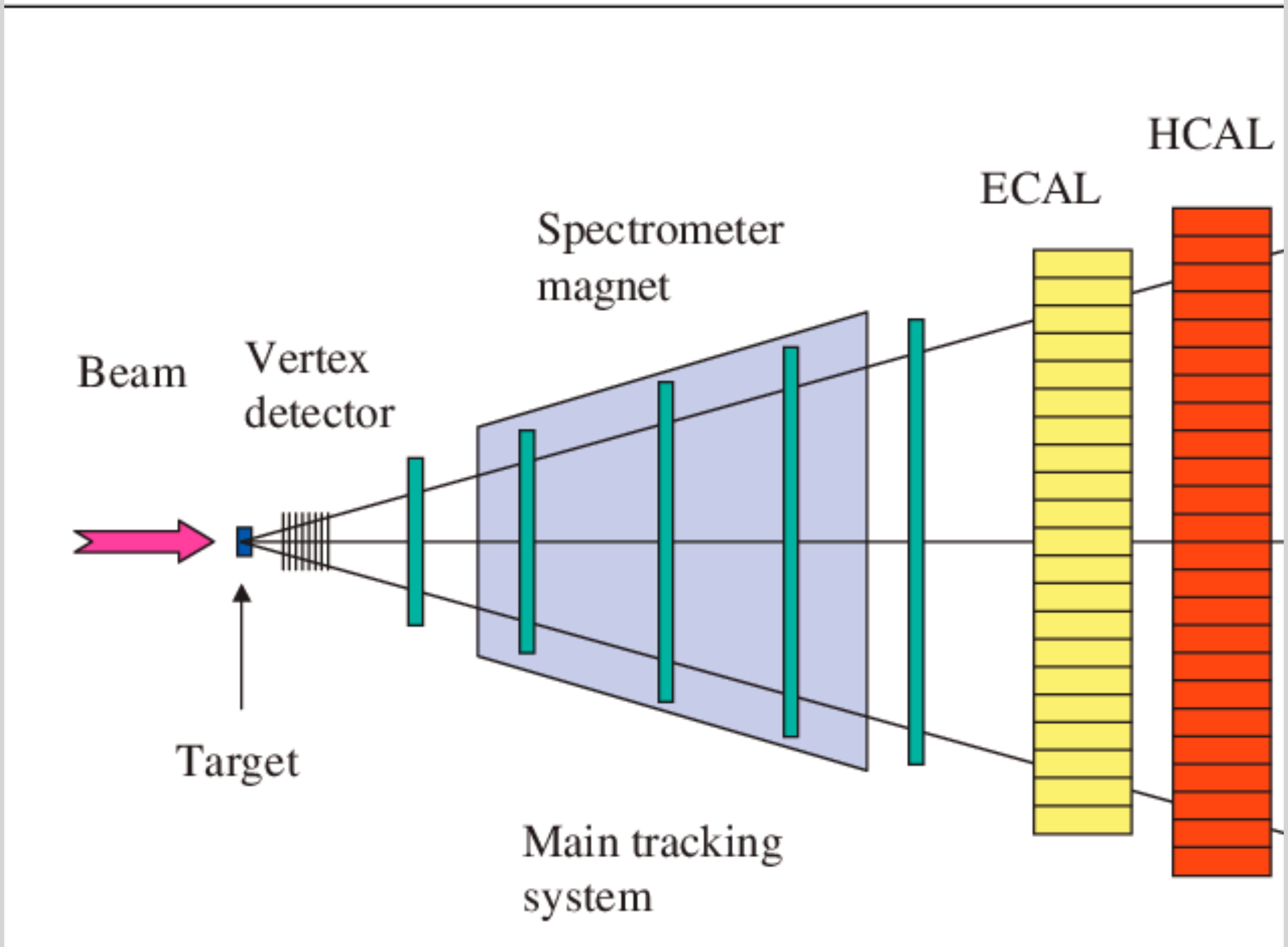

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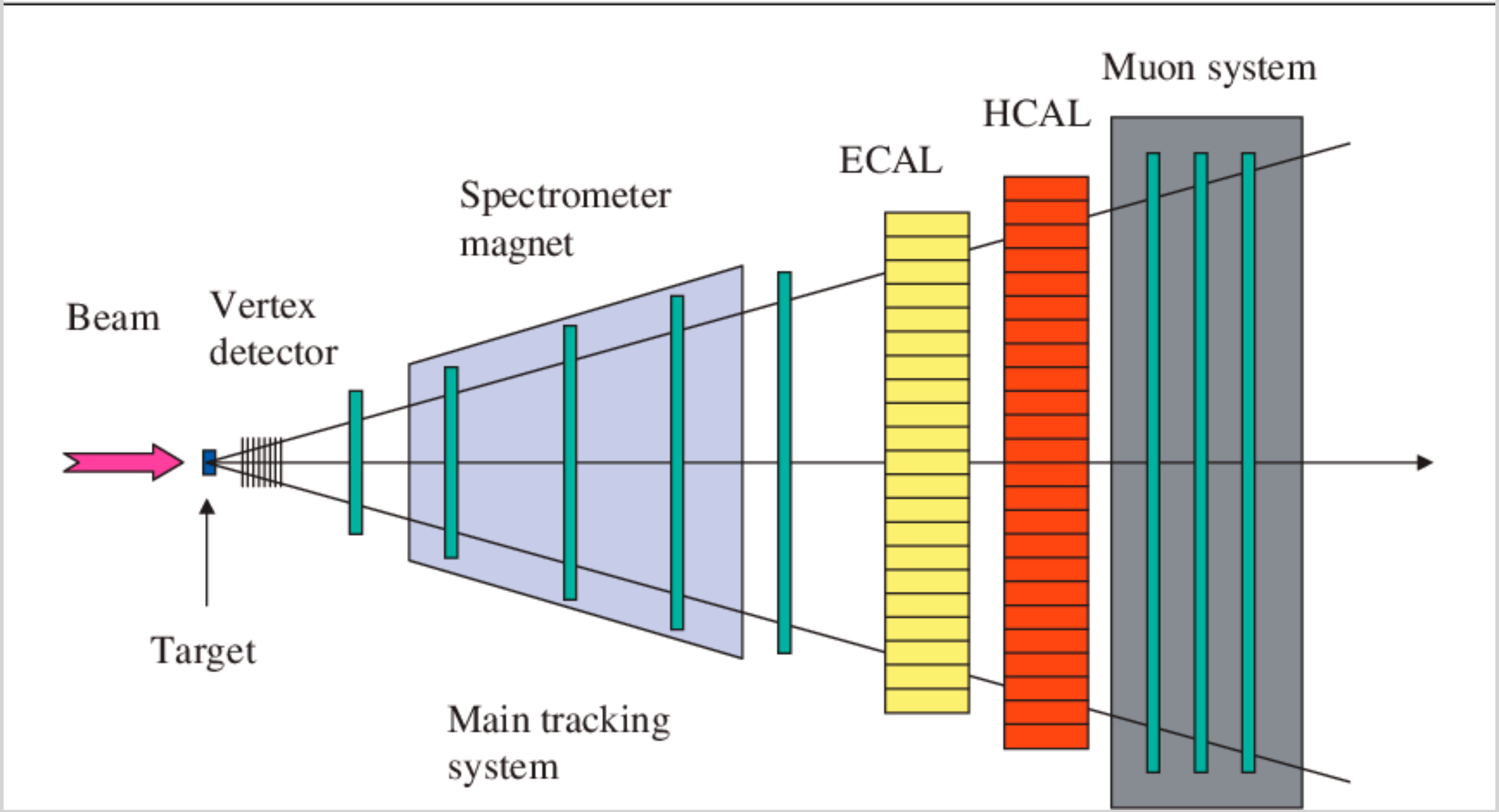
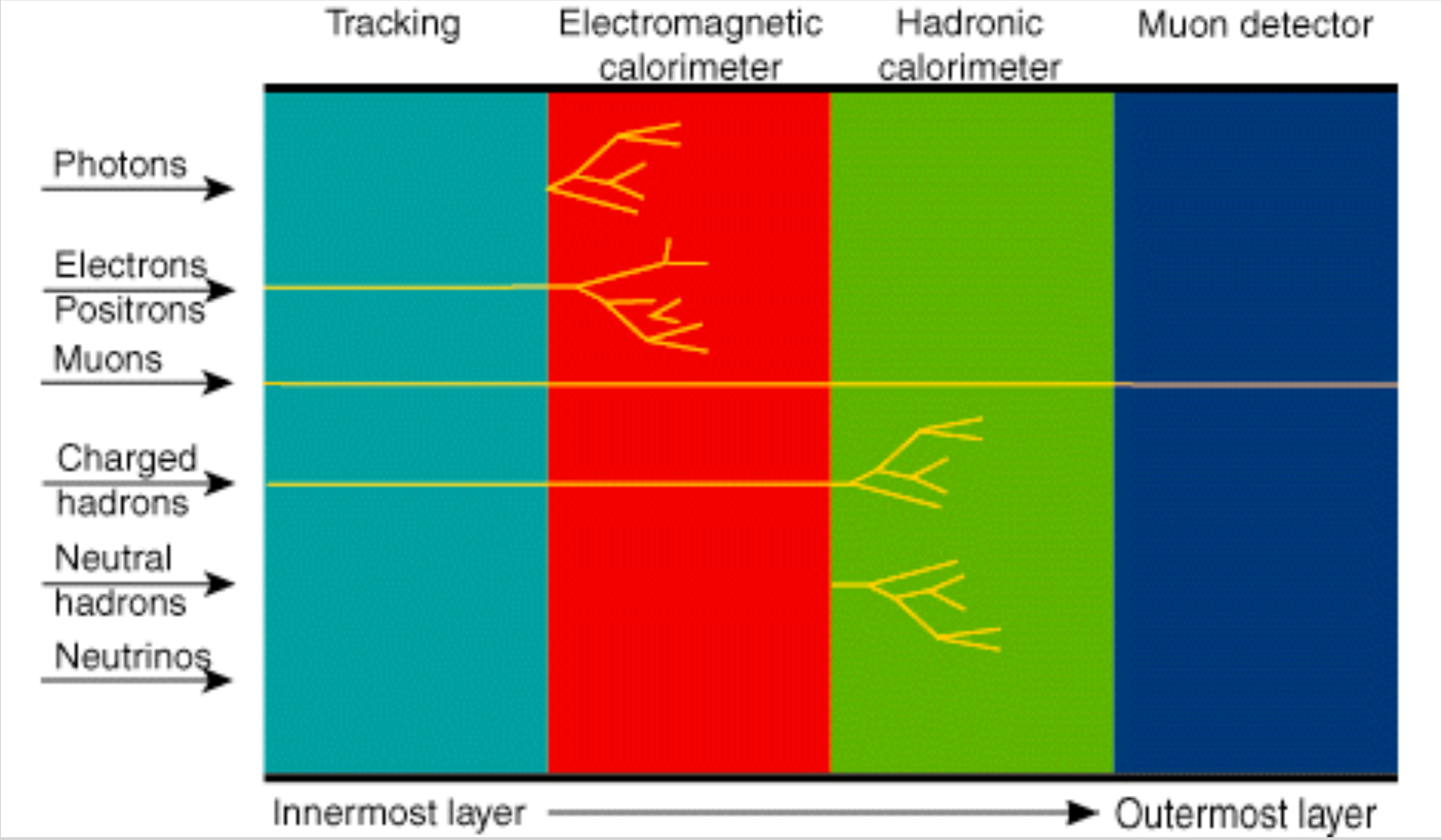
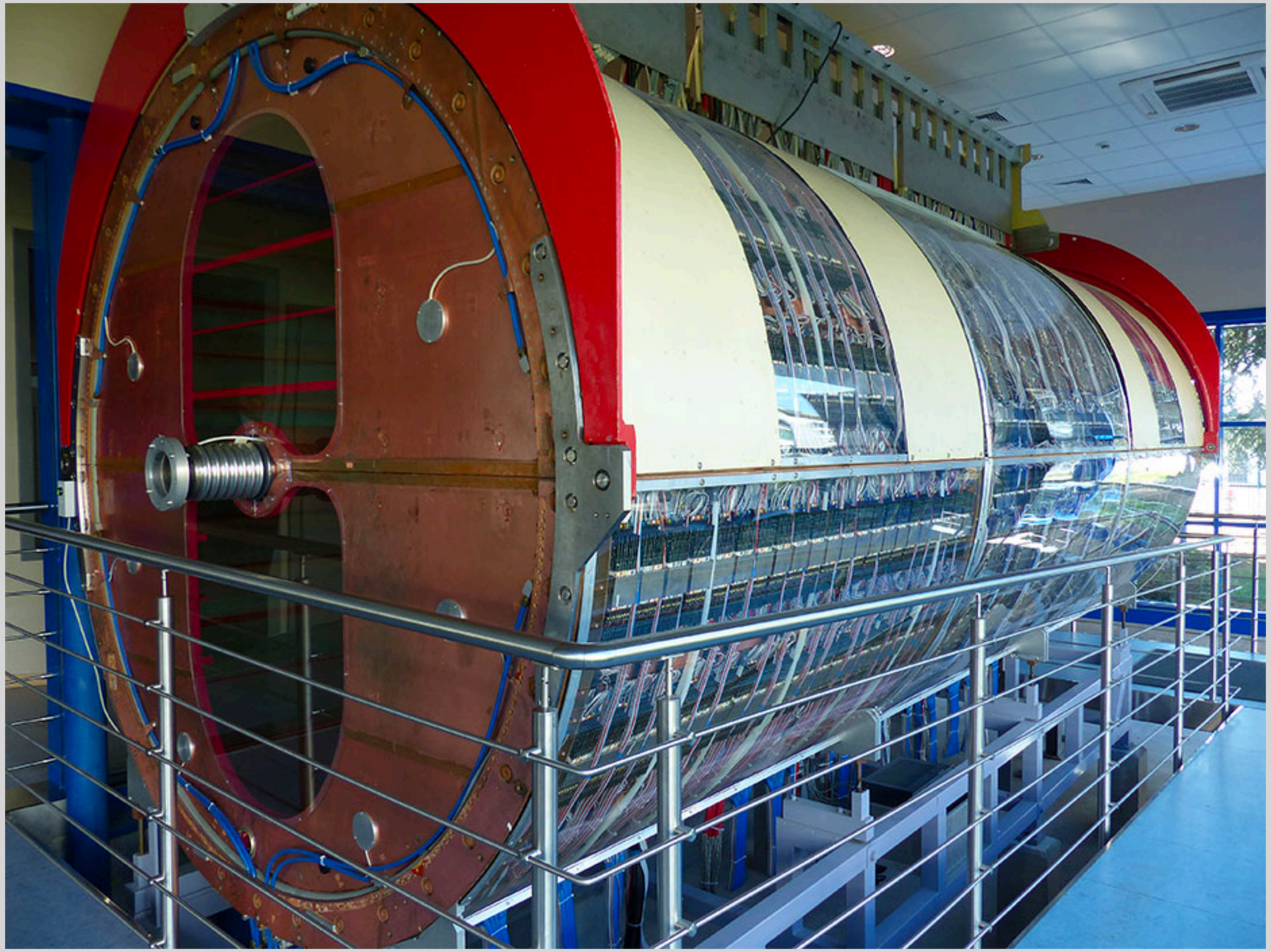
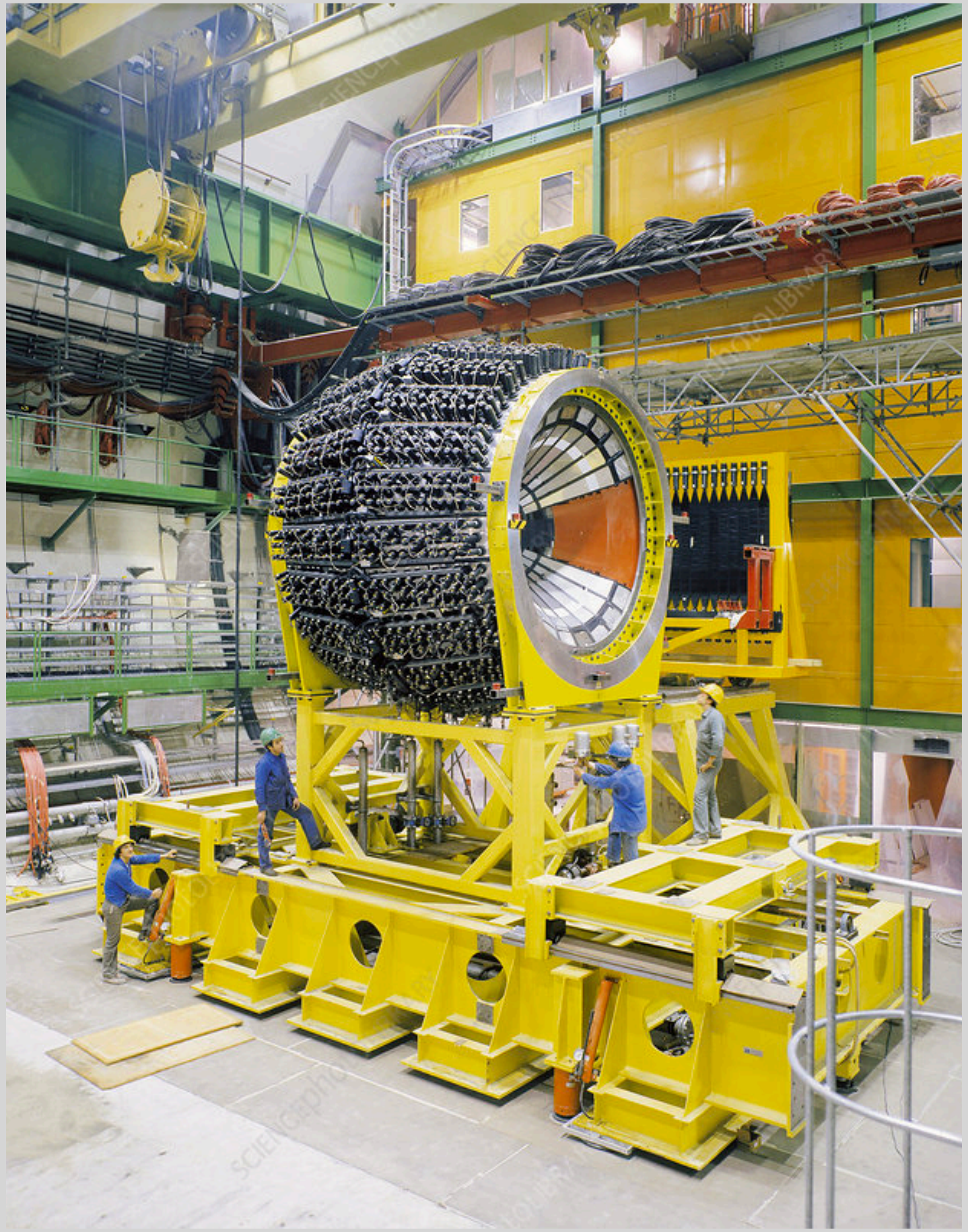


Particle Detection

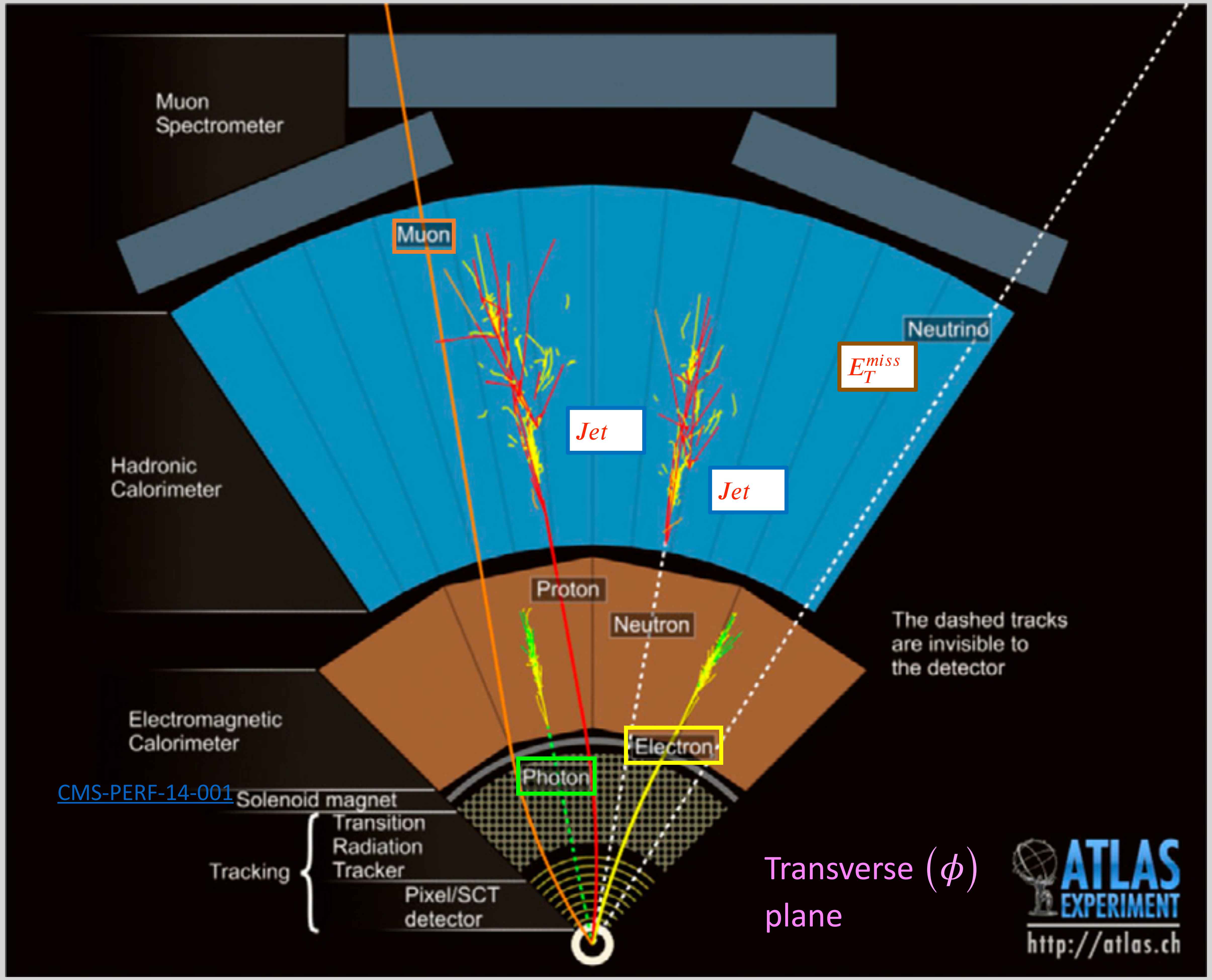


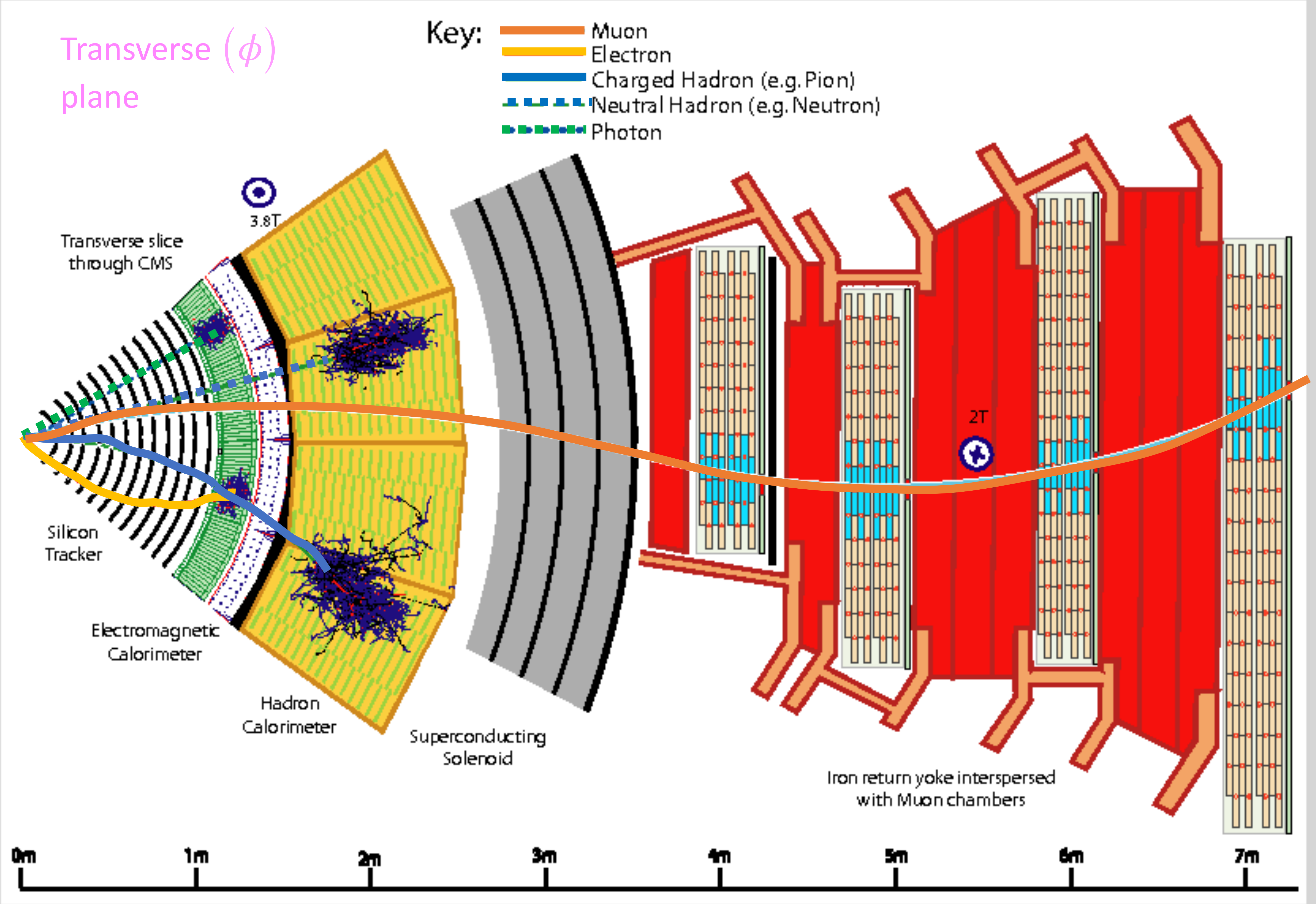
UA1 and UA2





Detecting Particles with ATLAS/CMS





Electron: Charged, EM

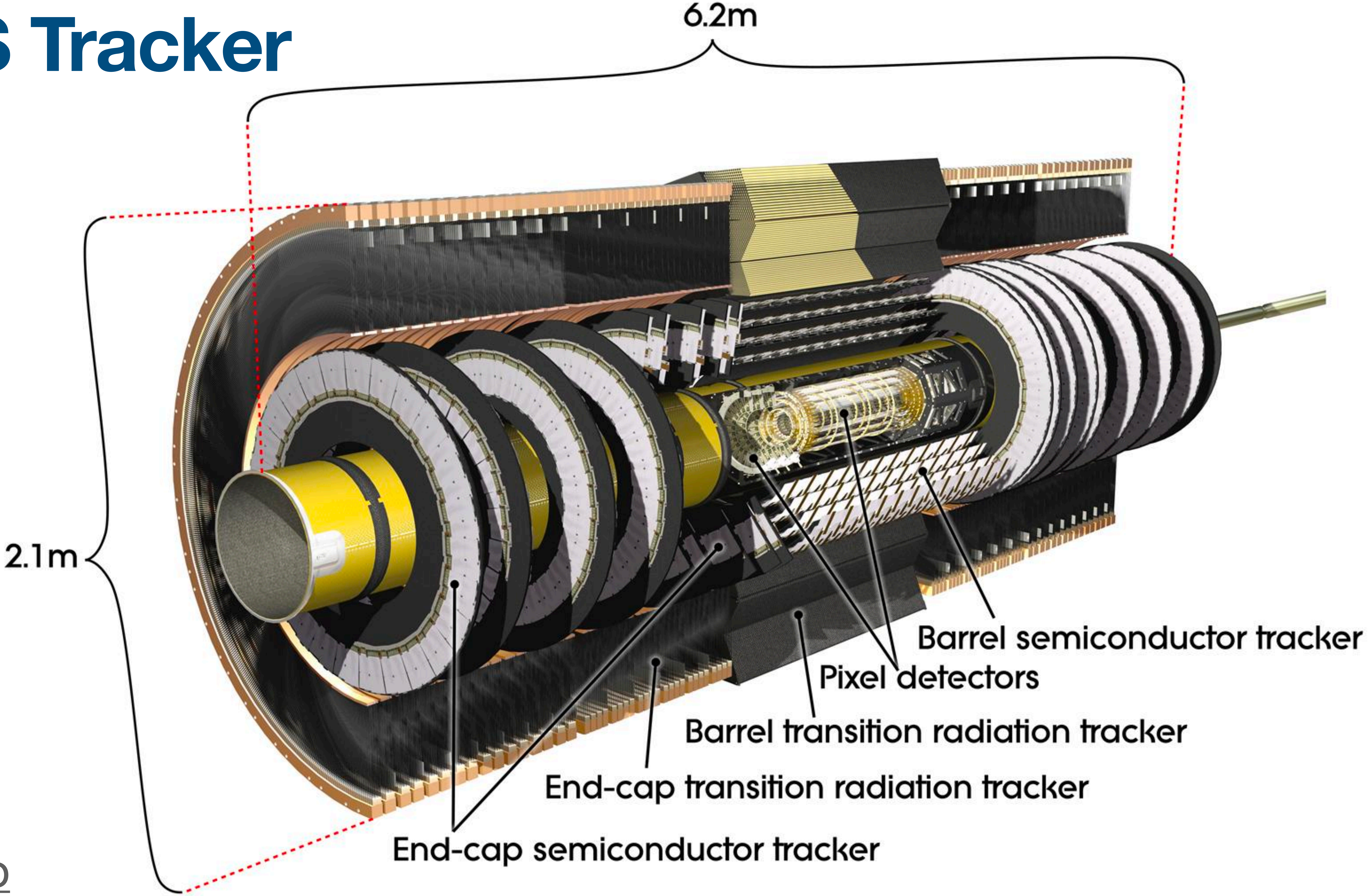
Photon: Neutral, EM

Muon: Charged, MIP

Jet: Calorimeter Object

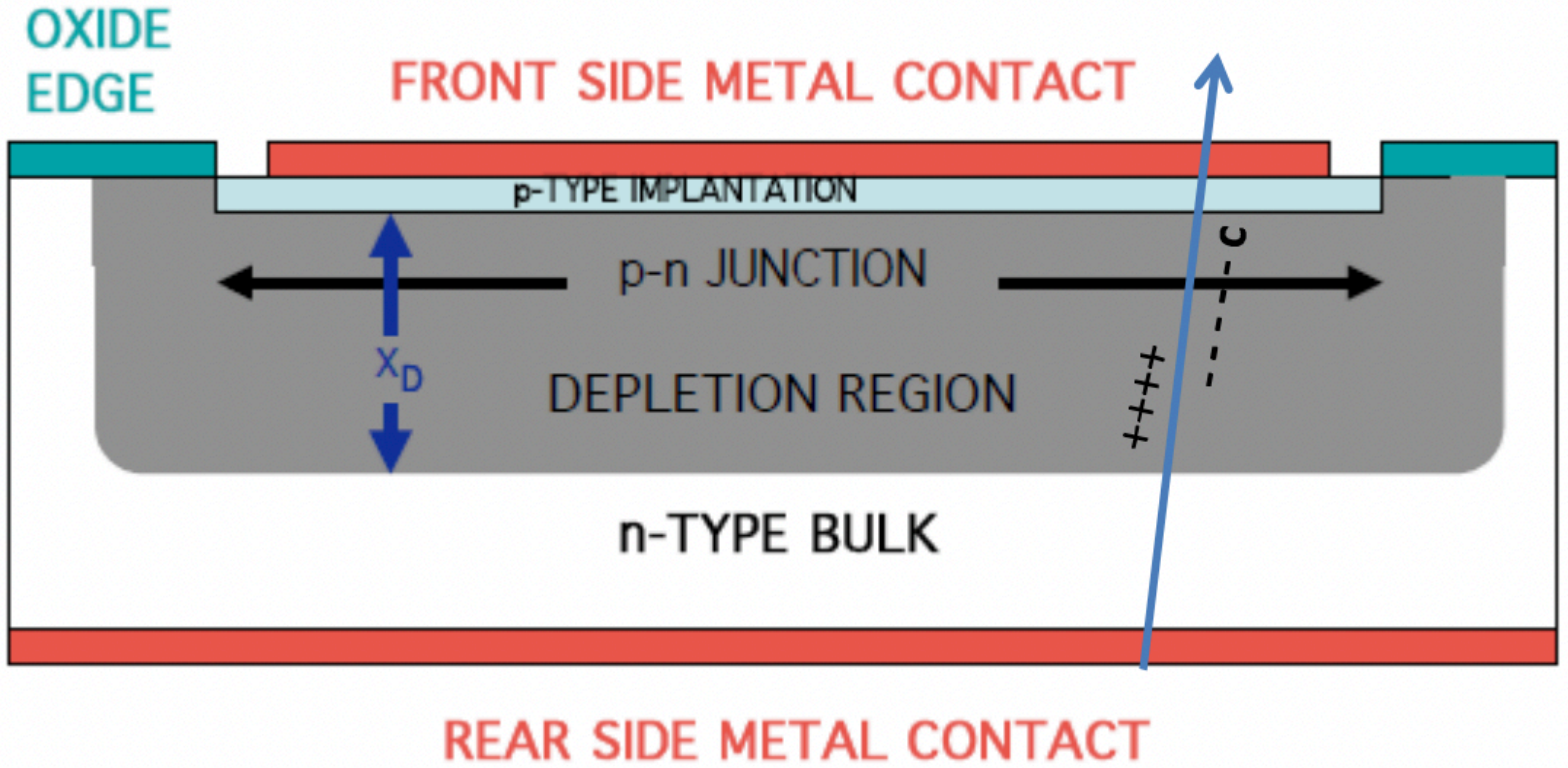
E_T^{miss}: Missing Energy (Transverse)

ATLAS Tracker

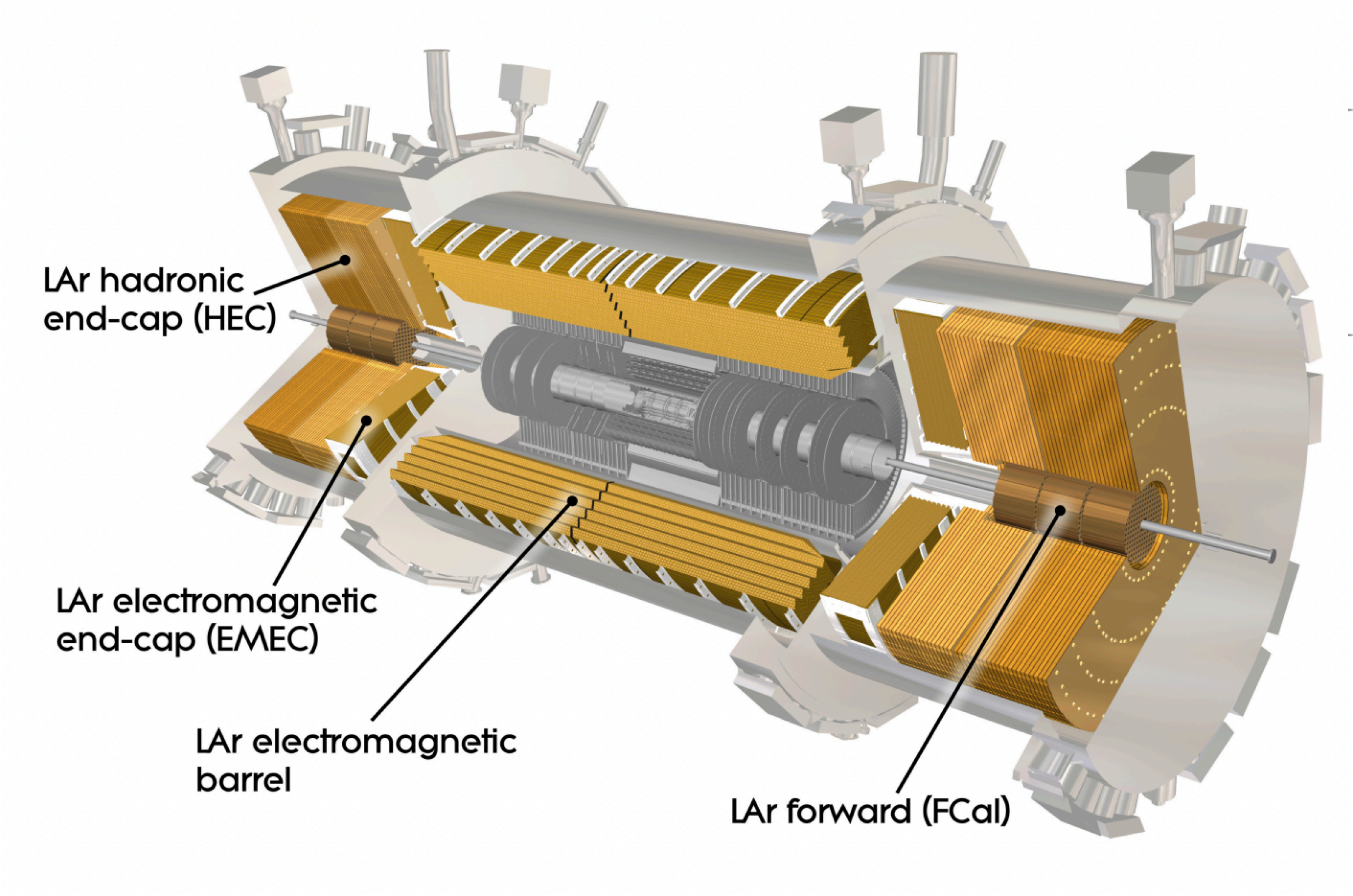


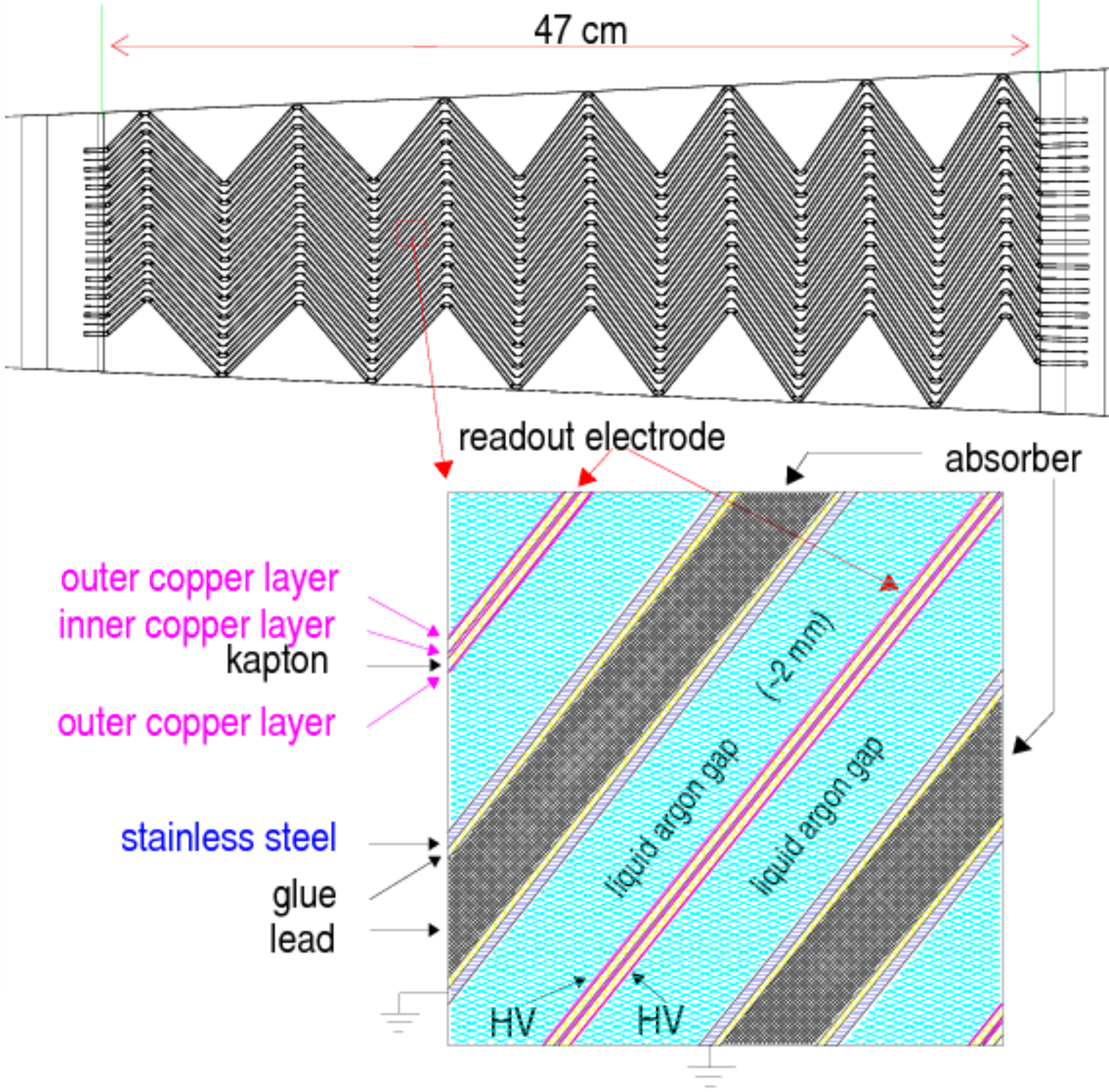
See Video

Silicon (Semiconductor) Strip Detectors

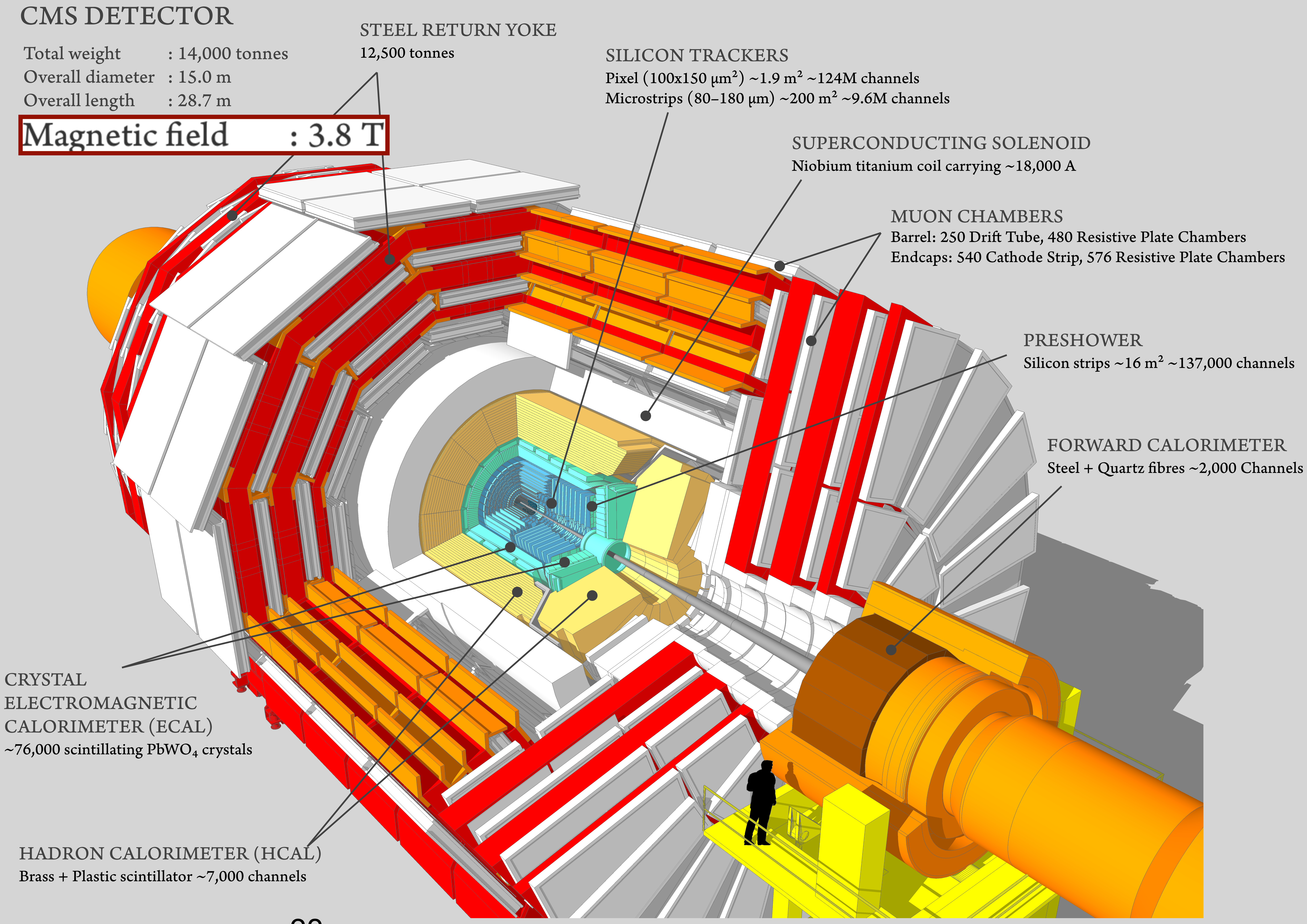


Liquid Argon Calorimeter





The Compact Muon Solenoid



J. Phys.: Conf. Ser. 513 022032

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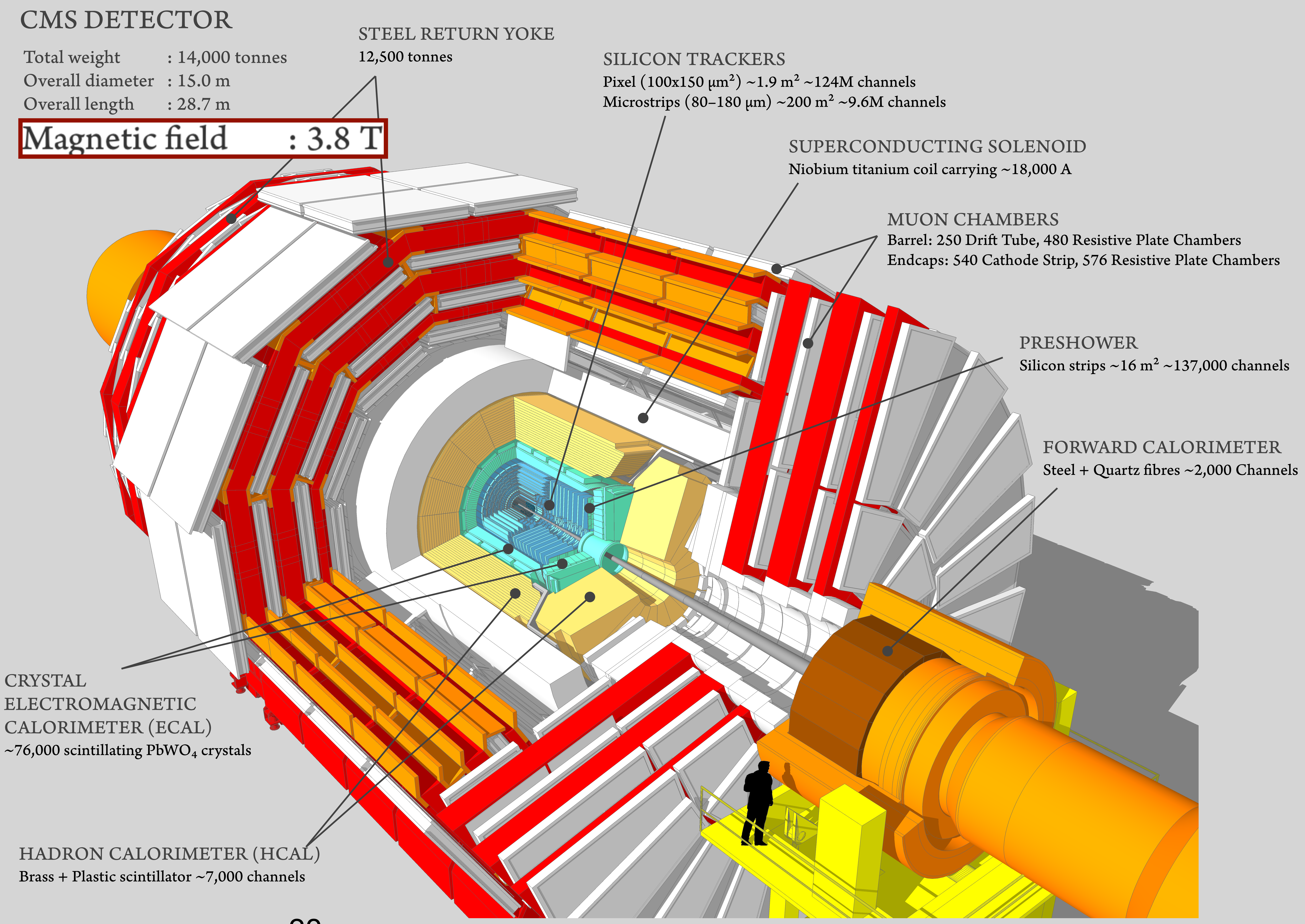

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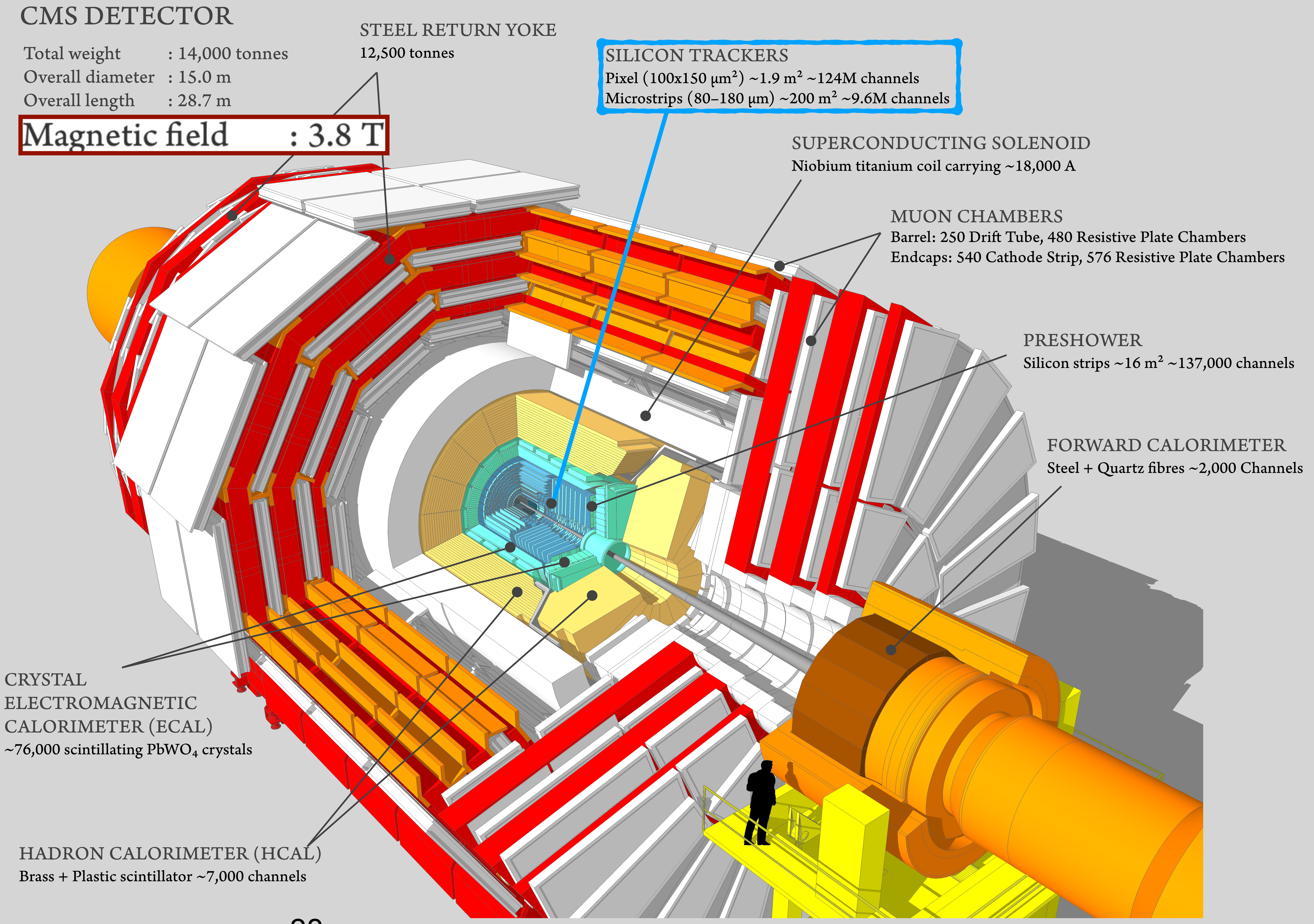
The Compact Muon Solenoid

- High resolution silicon tracking in $|\eta| < 2.4$



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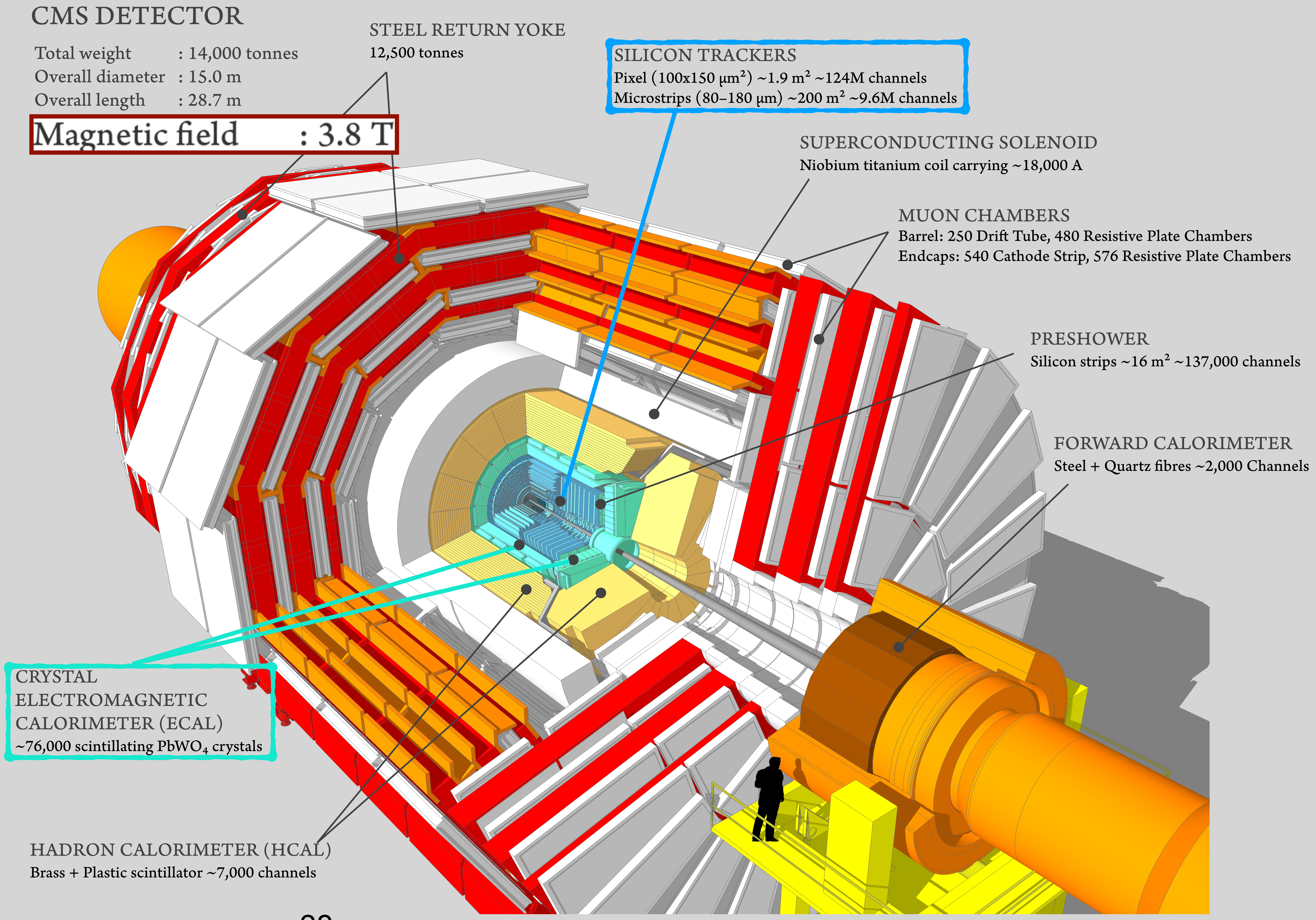

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- Brass Hadron Calorimeter
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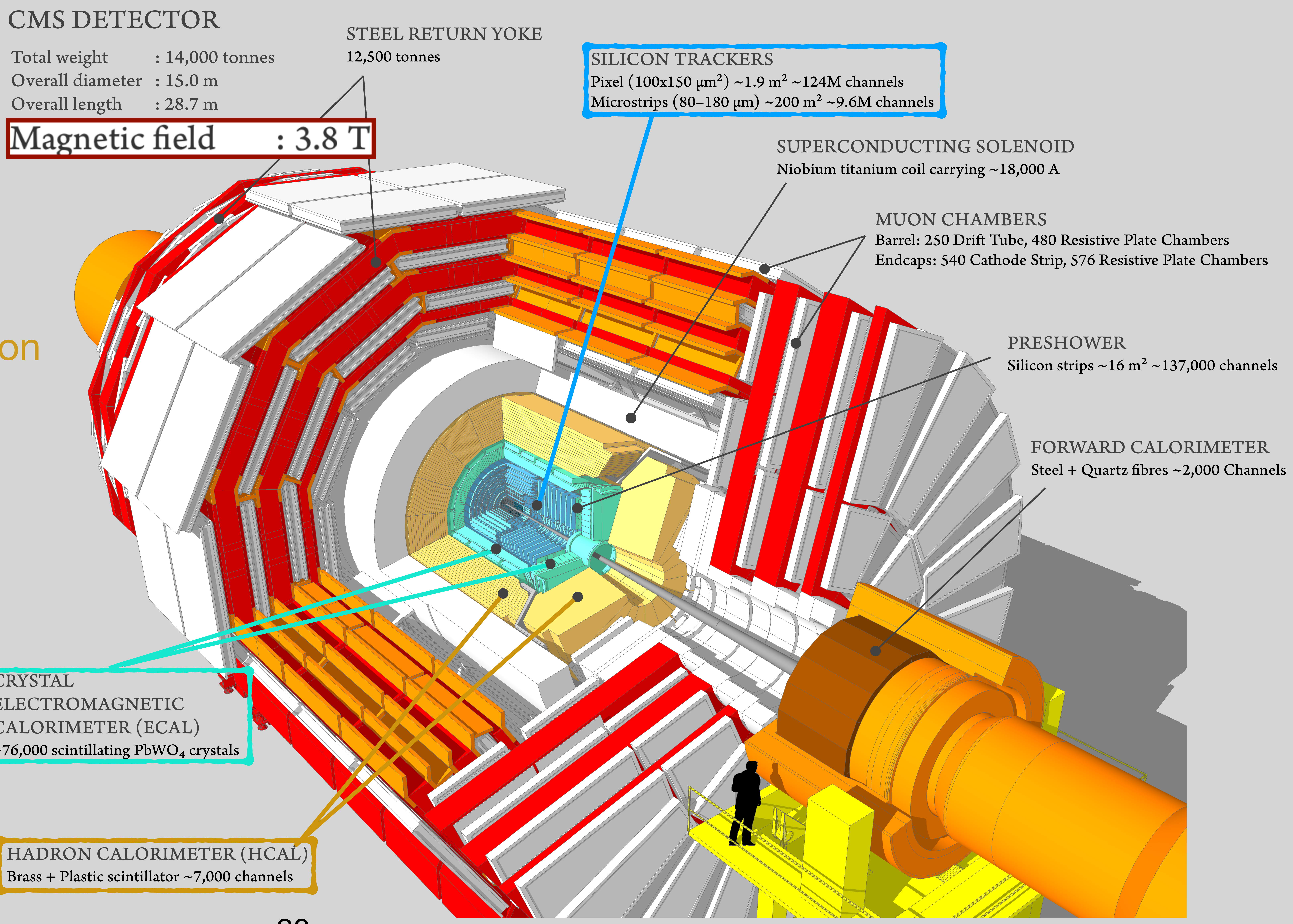

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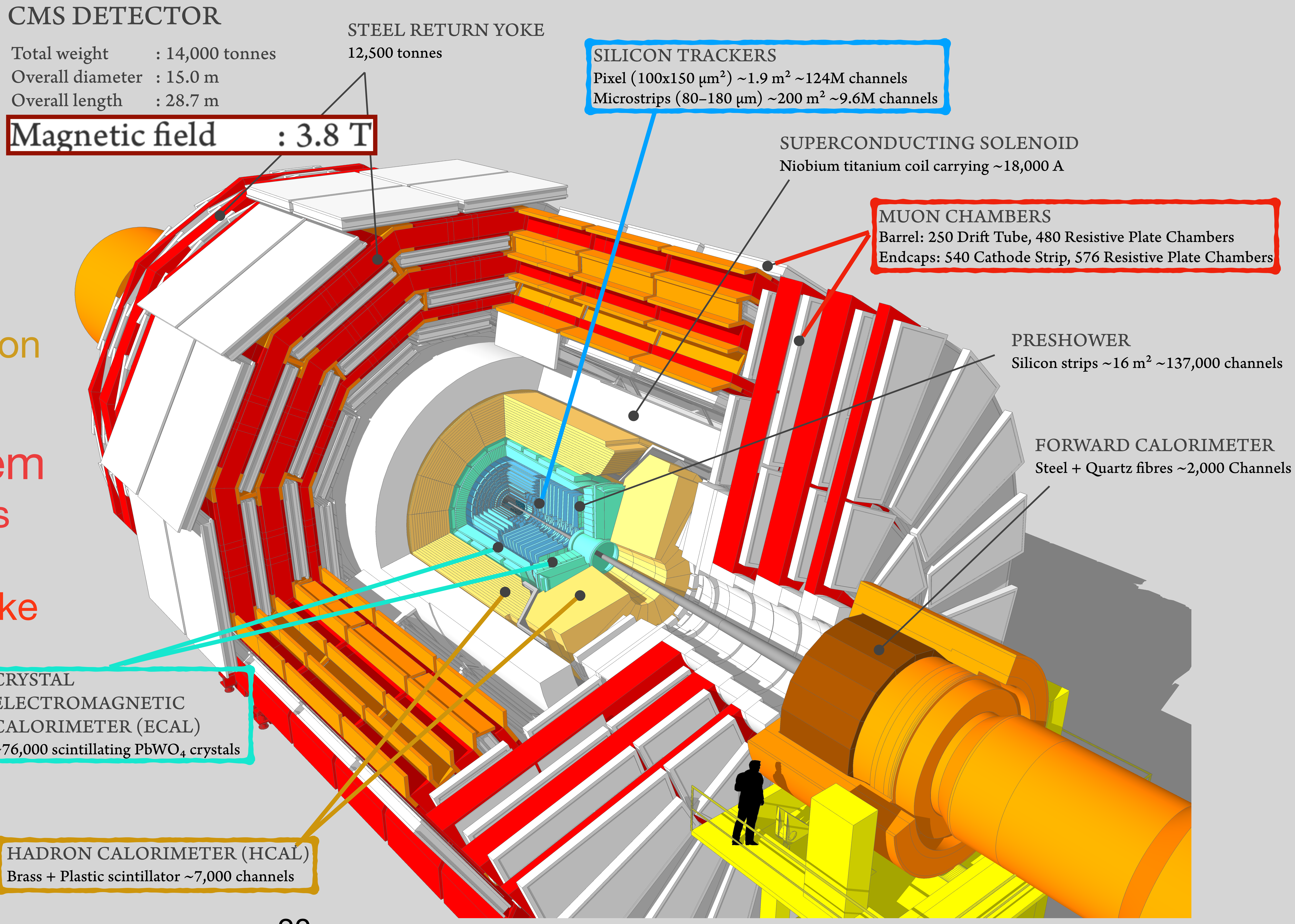
  — Provides excellent energy resolution for strongly-coupled parton showers
- Excellent, Robust Muon System
  — Superconducting solenoid creates 3.8T magnetic field in tracker and calorimeters, 2T is steel return yoke



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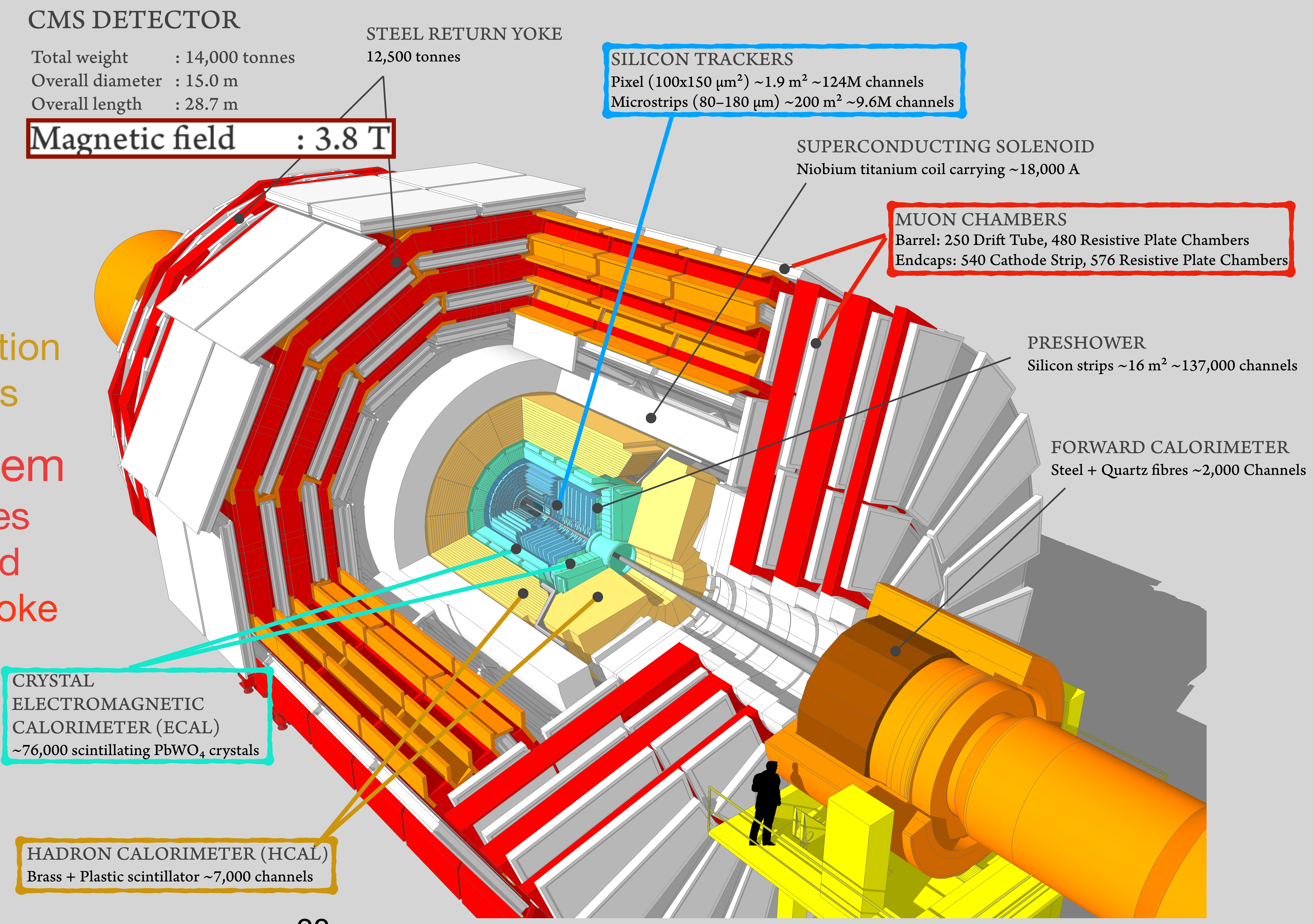
  — Provides excellent energy resolution for strongly-coupled parton showers
- Excellent, Robust Muon System
  — Superconducting solenoid creates 3.8*T* magnetic field in tracker and calorimeters, 2*T* is steel return yoke
- **Cost: ~500 MCHF**
  + ~200 MCHF (Upgrades)



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What Are Cathode Strip Chambers (CSCs)?

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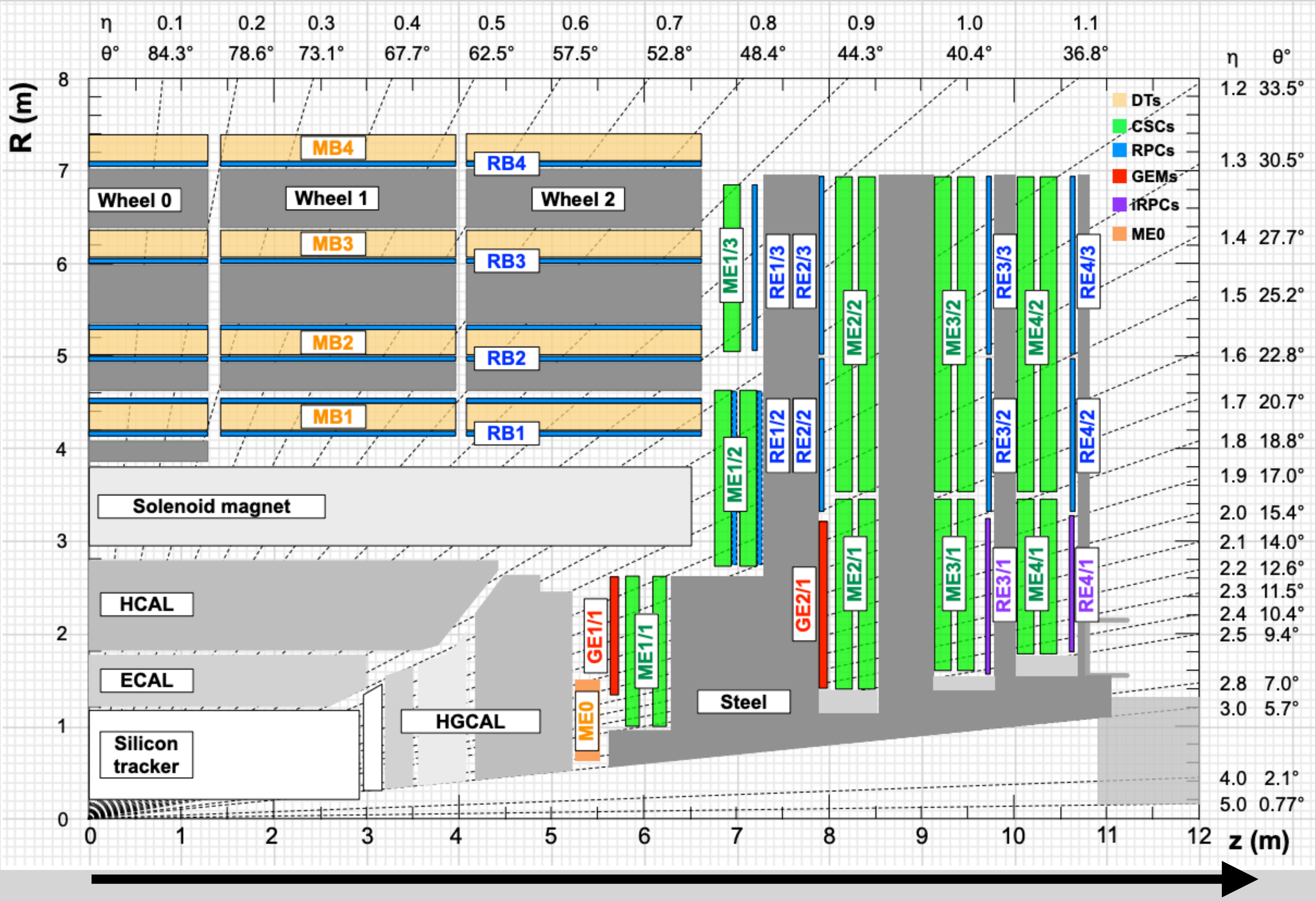
- Muon system employs different technologies
  - Barrel: Drift Tube + Resistive Plate Chamber (RPC)
  - End-Caps: CSC + RPC + Gas Electron Multipliers (GEM)



CMS-TDR-016

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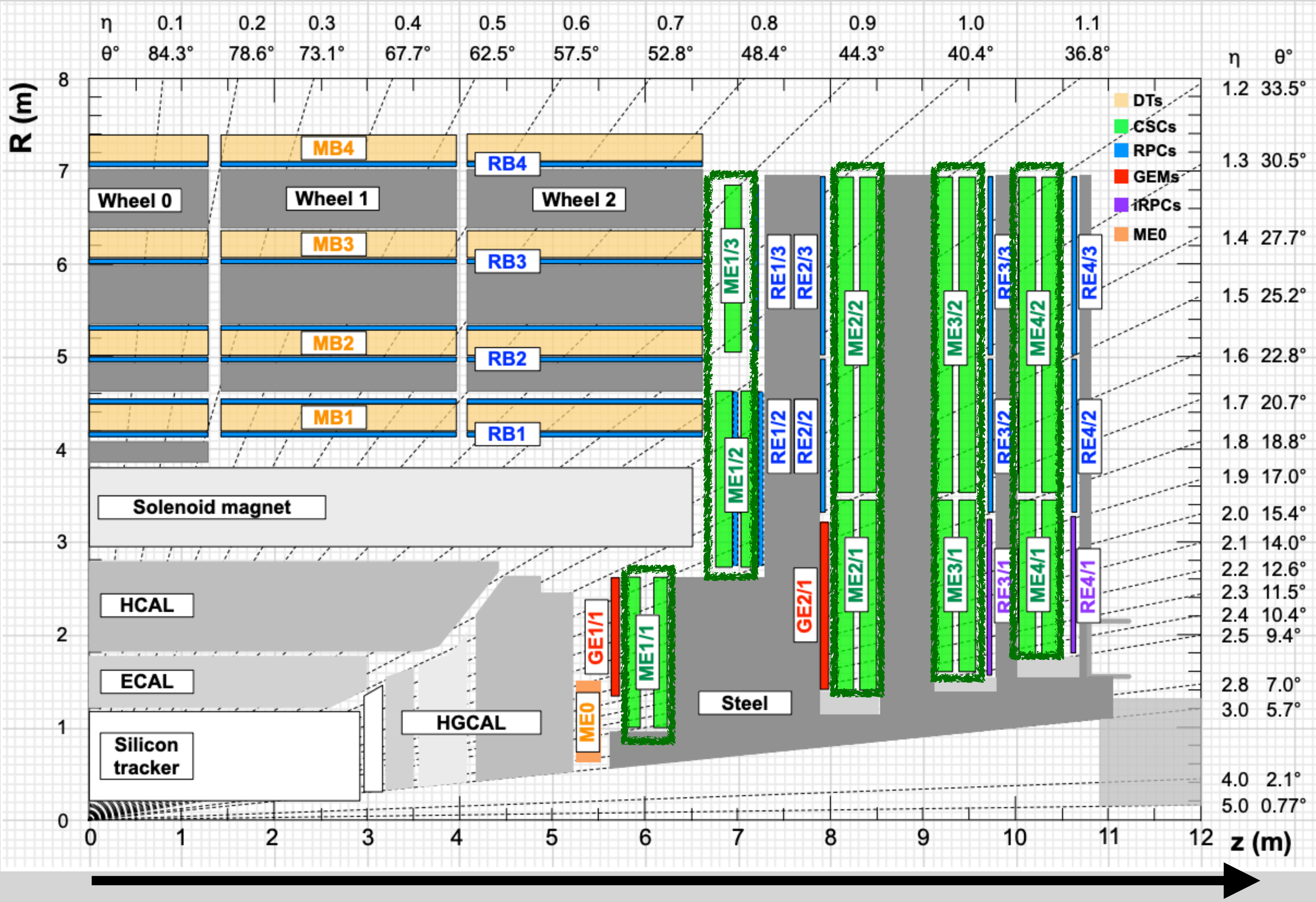

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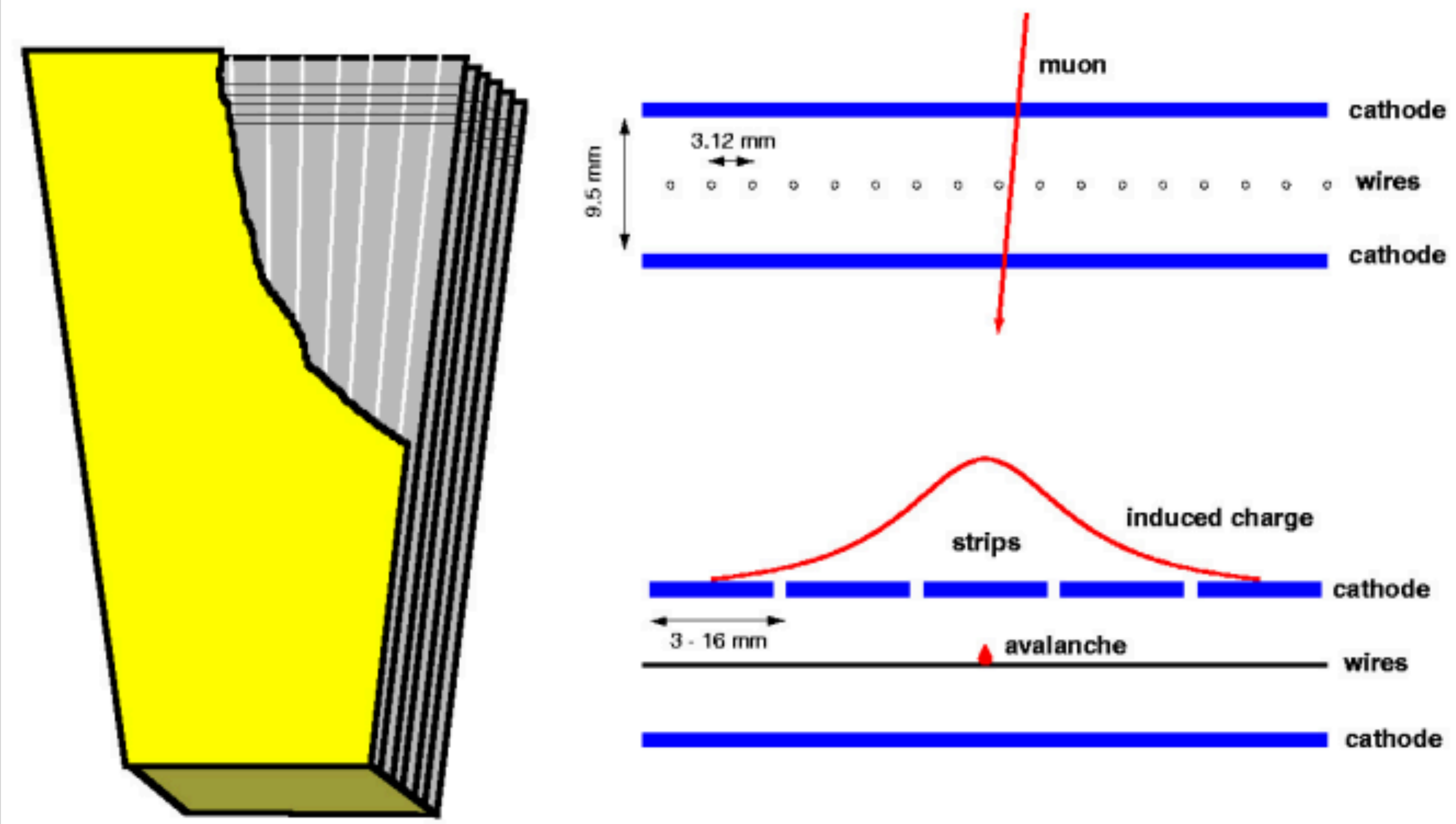
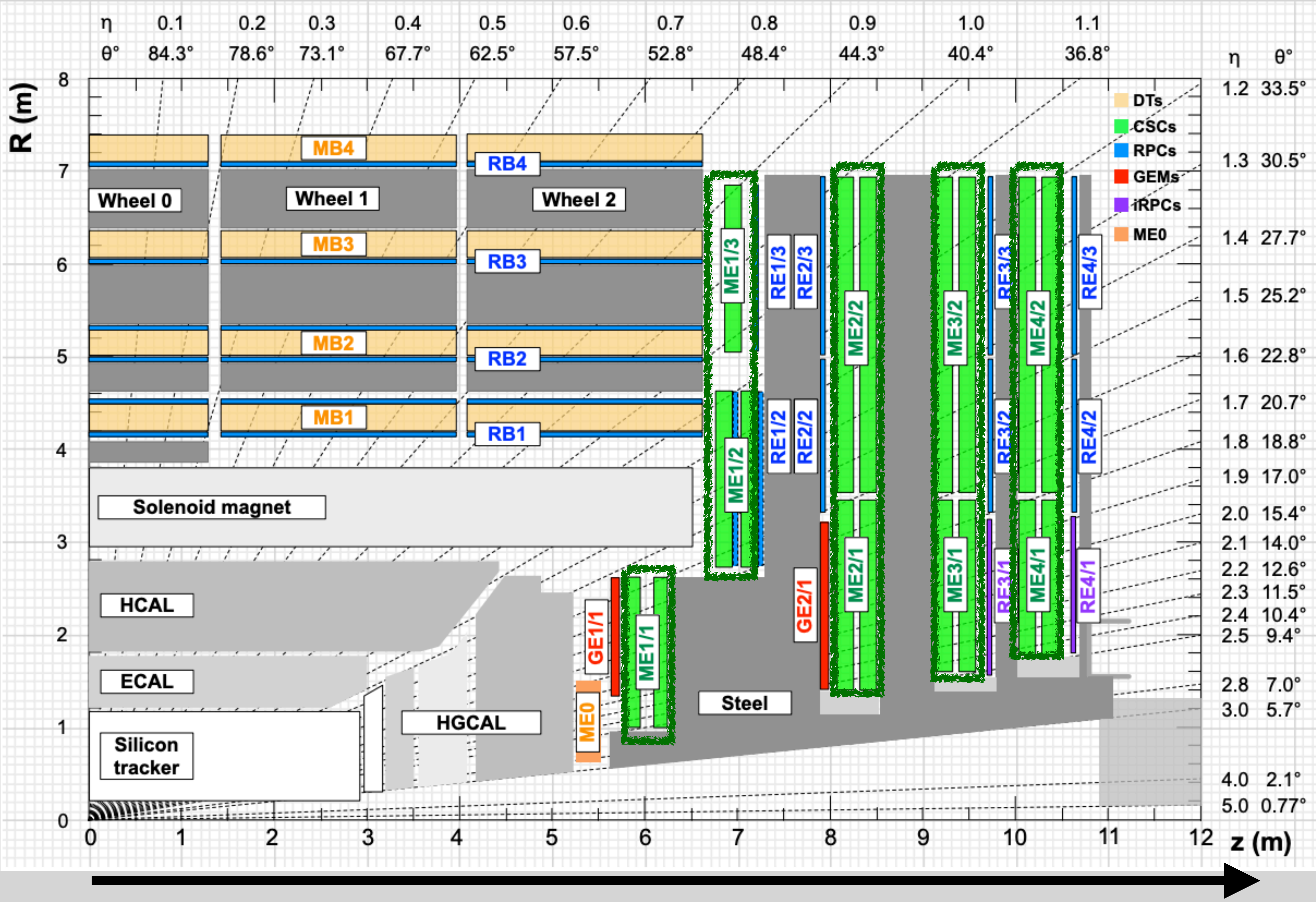
- CSCs are 6-layers of wires (anodes) and strips (cathodes) in $Ar/CO_2/CF_4$ gas mixture
  - Traversing muons ionize gas at HV
  - Avalanche signal read by anode and cathode electronics





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  - Traversing muons ionize gas at HV
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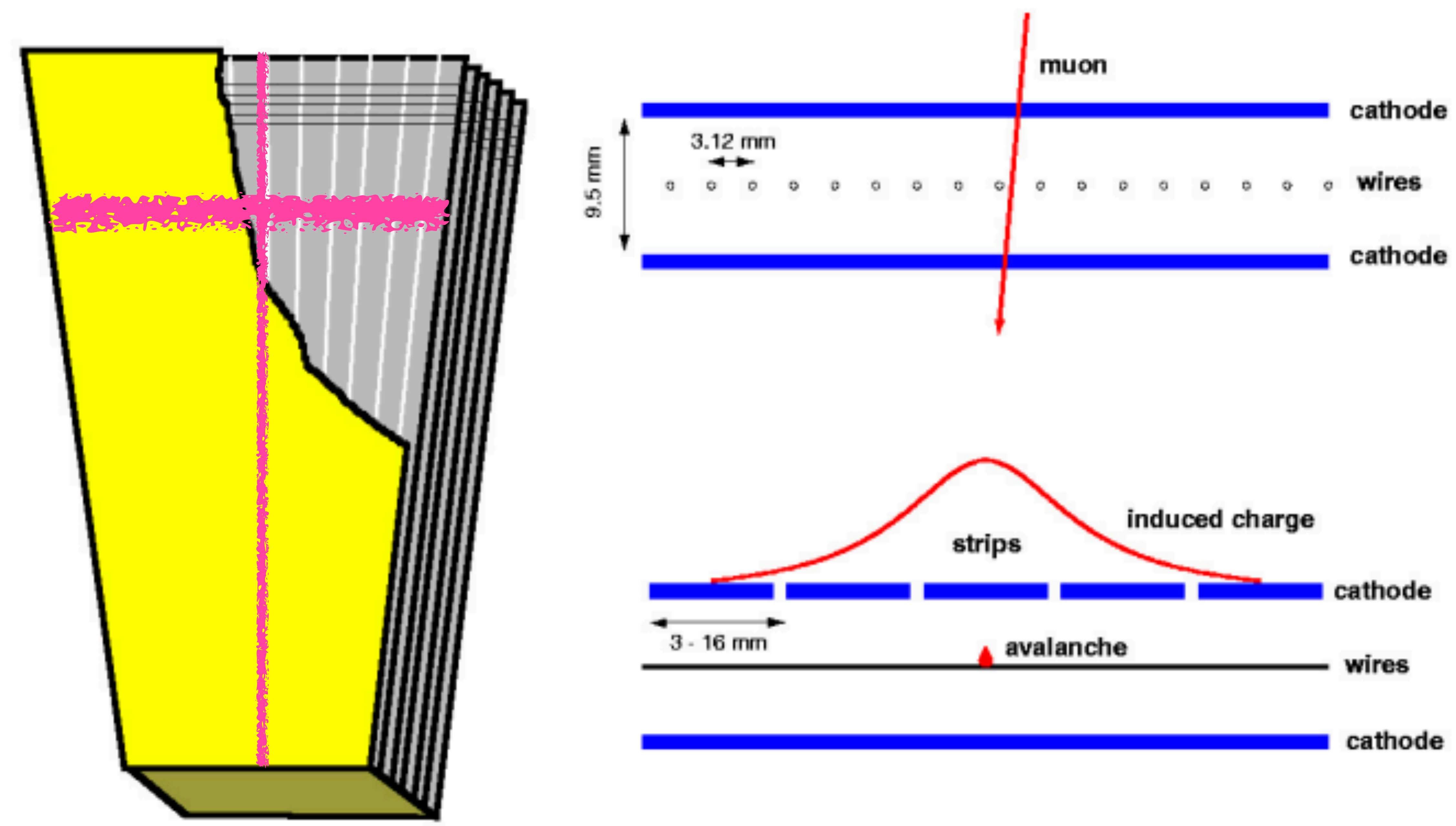
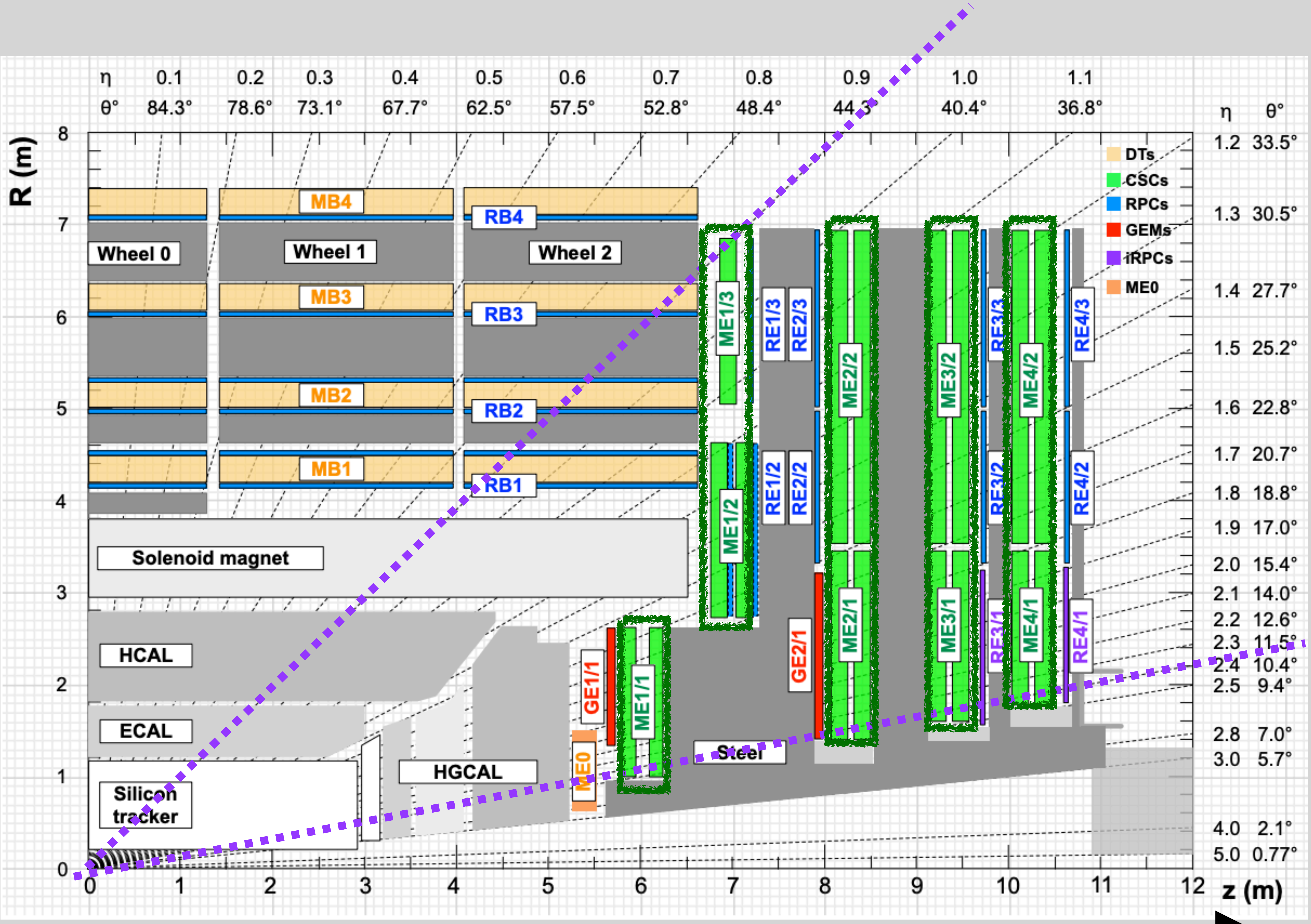
- CSCs measure <u>4D</u> position, $|\eta| \in [0.9, 2.4]$
  - Work great in intense, non-uniform magnetic fields





[CMS-TDR-016](CMS-TDR-016)

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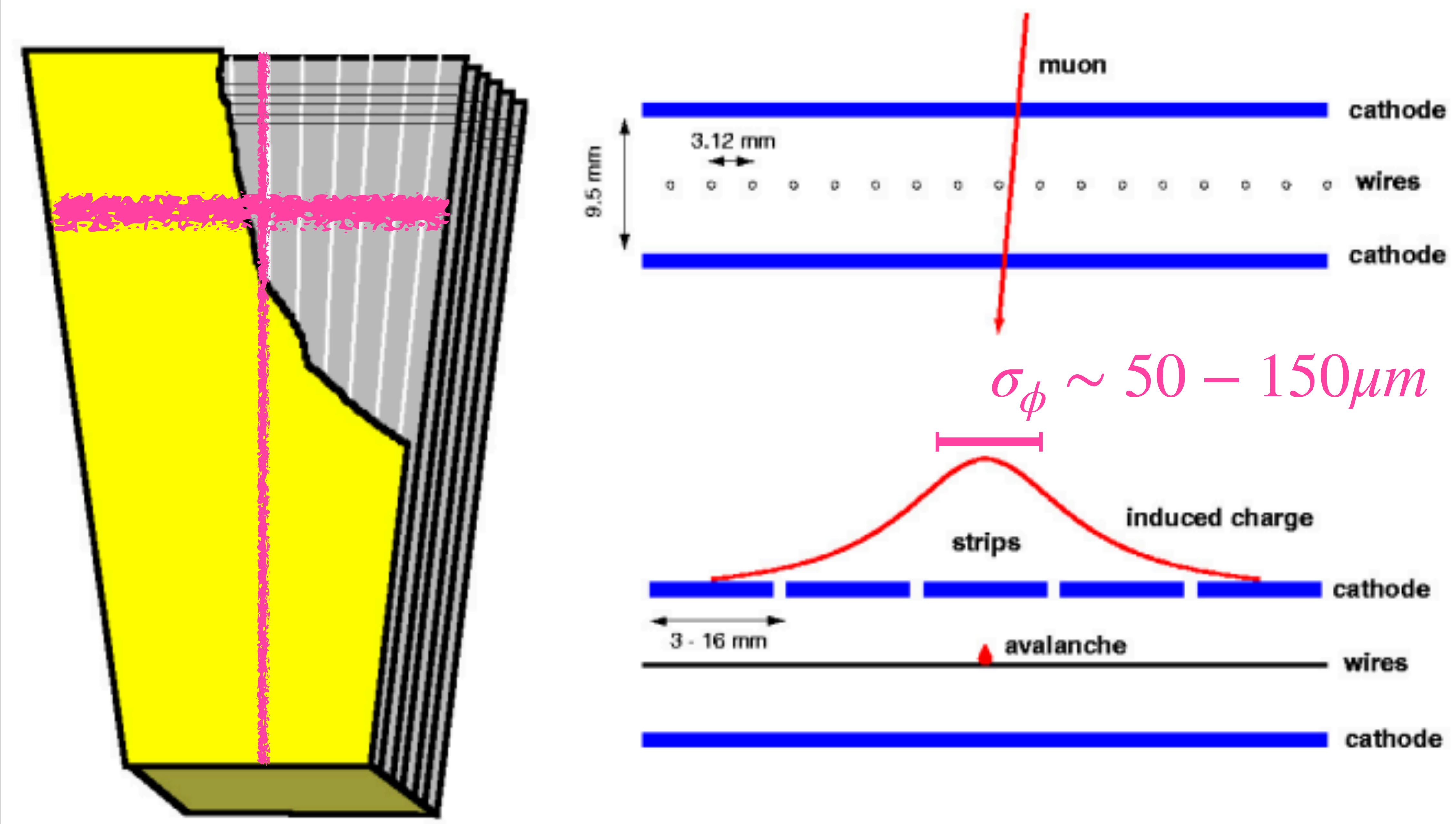
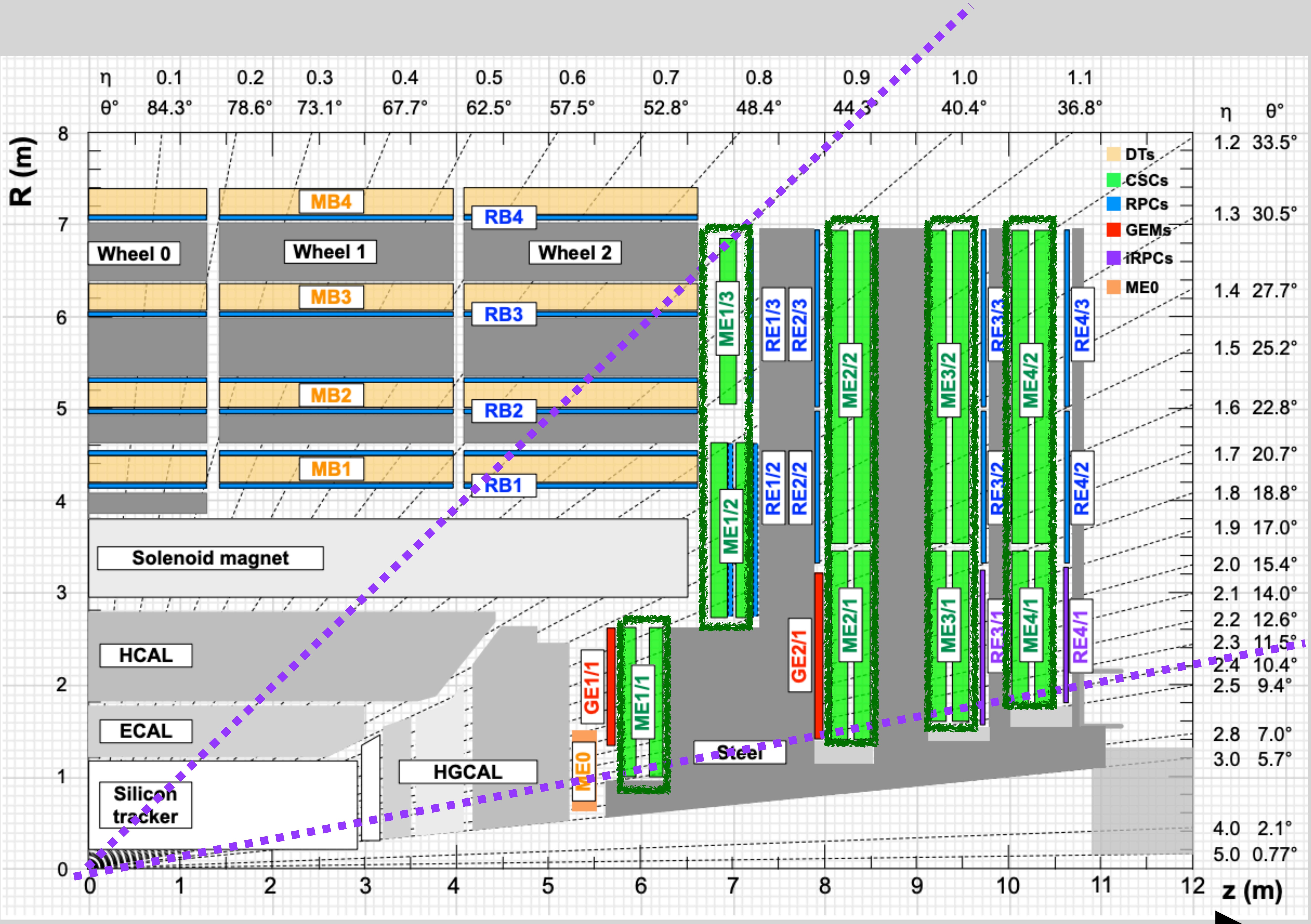
  - Traversing muons ionize gas at HV
  - Avalanche signal read by anode and cathode electronics
- CSCs measure <u>4D</u> position, $|\eta| \in [0.9, 2.4]$
  - Work great in intense, non-uniform magnetic fields





CMS-TDR-016

What Are Cathode Strip Chambers (CSCs)?

- Muon system employs different technologies
  - — Barrel: Drift Tube + Resistive Plate Chamber (RPC)
  - — End-Caps: CSC + RPC + Gas Electron Multipliers (GEM)
- CSCs are 6-layers of wires (anodes) and strips (cathodes) in $Ar/CO_2/CF_4$ gas mixture
  - — Traversing muons ionize gas at HV
  - — Avalanche signal read by anode and cathode electronics
- CSCs measure 4D position, $|\eta| \in [0.9, 2.4]$
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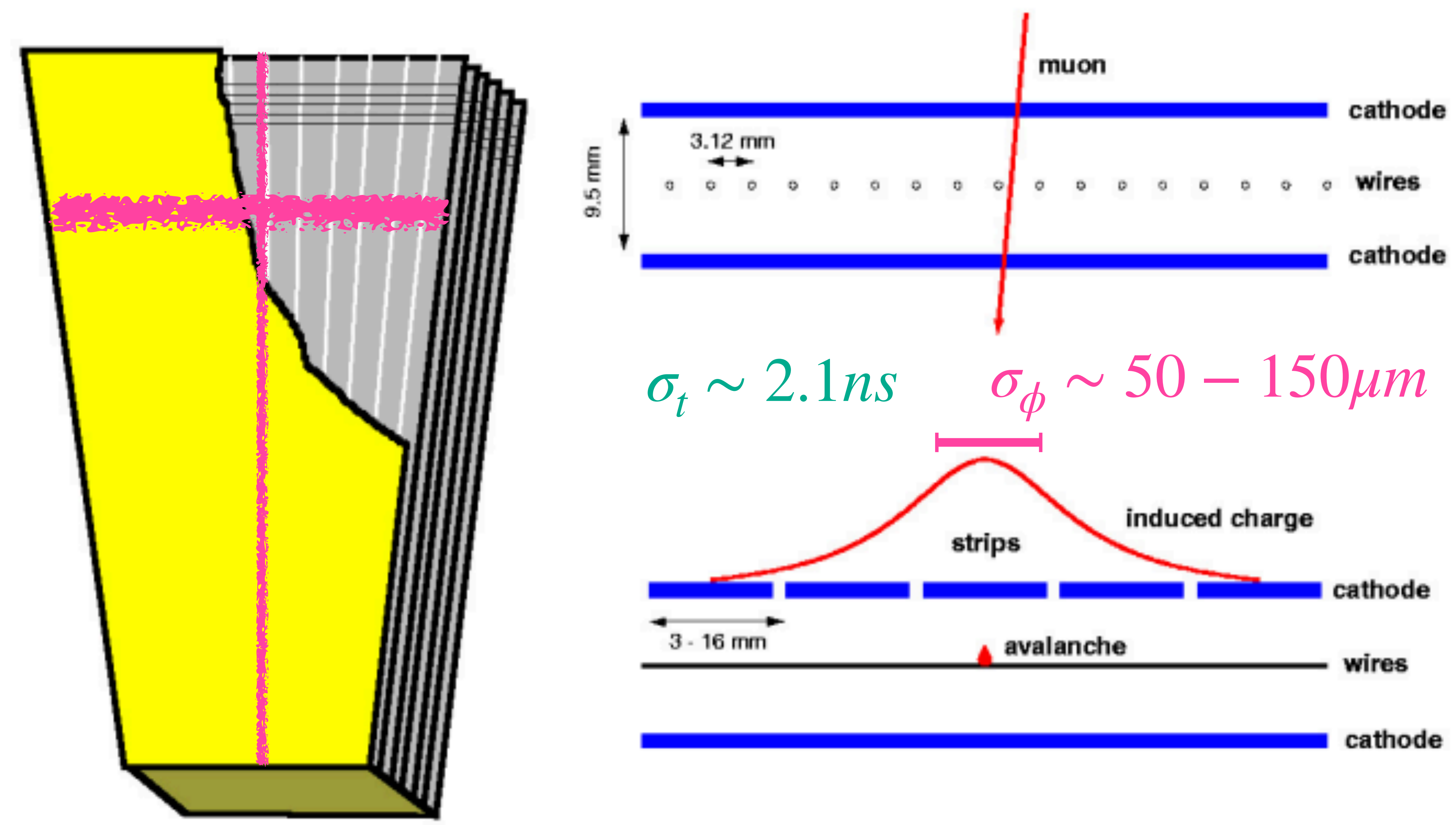
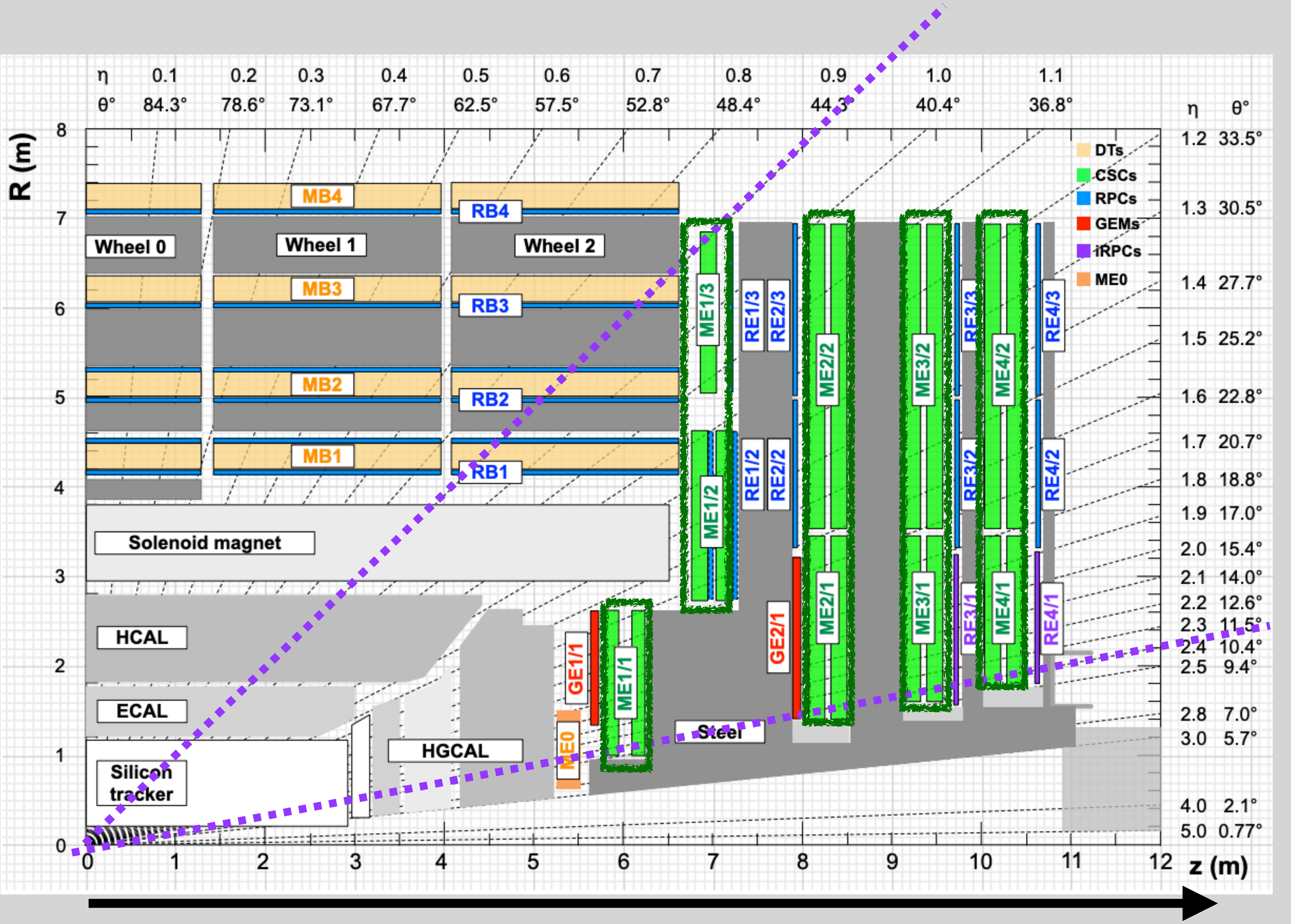
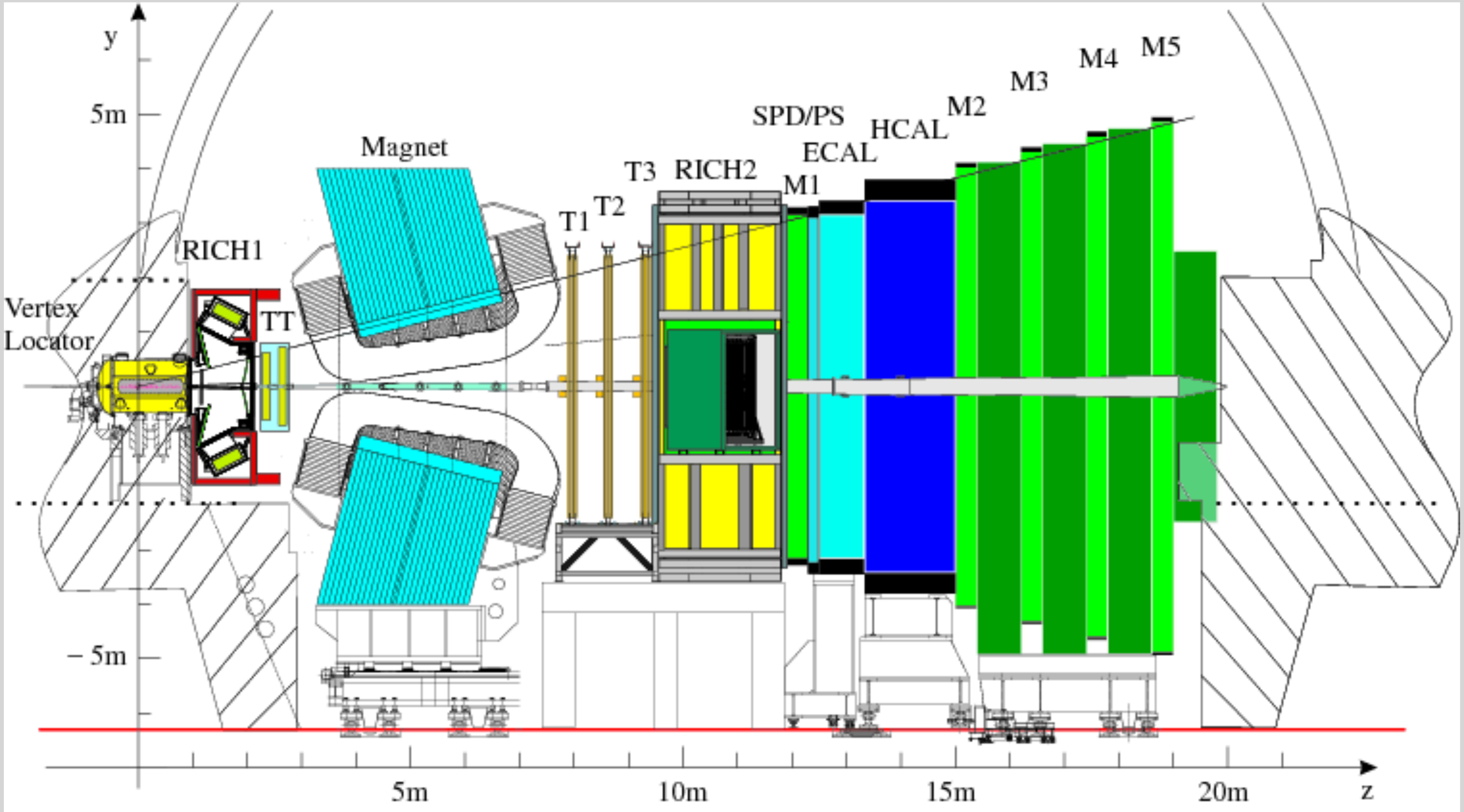
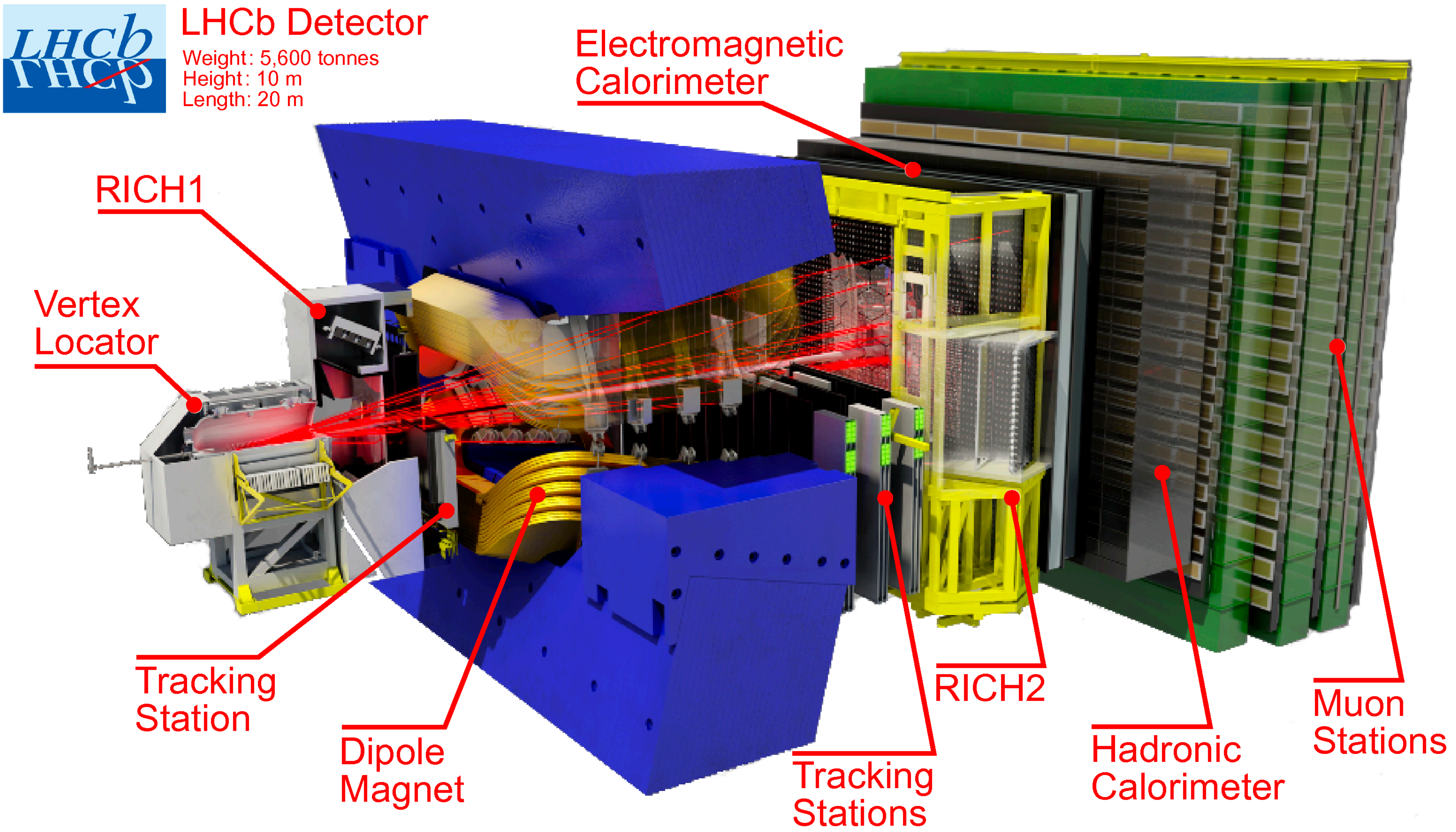




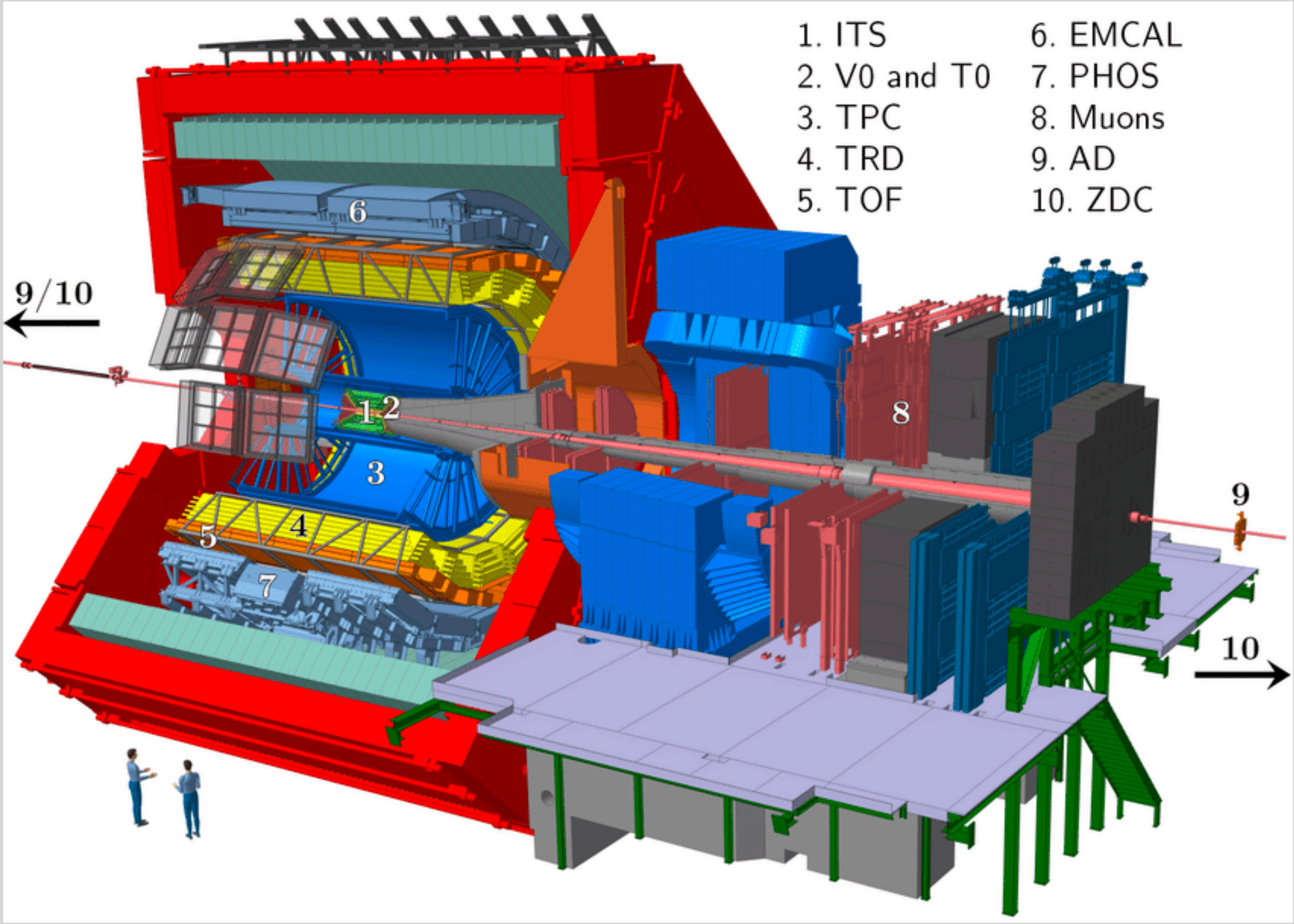
[CMS-TDR-016]



y
5m
−5m
Magnet
T1
T2
T3
RICH2
SPD/PS
ECAL
HCAL
M1
M2
M3
M4
M5
RICH1
TT
Vertex
Locator
5m
10m
15m
20m
z


LHCb
LHCb Detector
Weight: 5,600 tonnes
Height: 10 m
Length: 20 m
Electromagnetic Calorimeter
RICH1
Vertex Locator
Tracking Station
Dipole Magnet
Tracking Stations
RICH2
Hadronic Calorimeter
Muon Stations

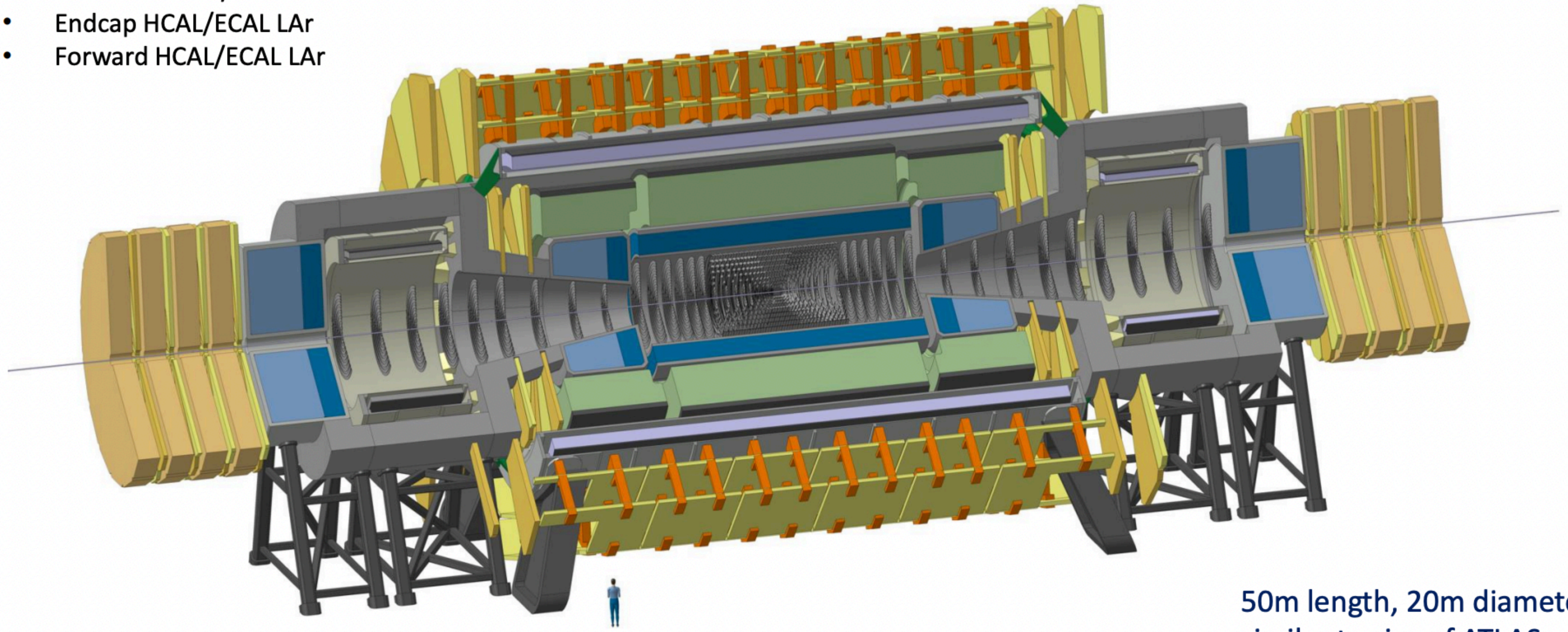
ALICE


1. ITS
2. V0 and T0
3. TPC
4. TRD
5. TOF
6. EMCAL
7. PHOS
8. Muons
9. AD
10. ZDC
9/10
1
2
3
4
5
6
7
8
9
10

FCC-hh Reference Detector

W. Riegler

- 4T, 10m solenoid, unshielded
- Forward solenoids, unshielded
- Silicon tracker
- Barrel ECAL LAr
- Barrel HCAL Fe/Sci
- Endcap HCAL/ECAL LAr
- Forward HCAL/ECAL LAr



50m length, 20m diameter
similar to size of ATLAS

Comparison to ATLAS & CMS

W. Riegler