CMS Collisions Exposed

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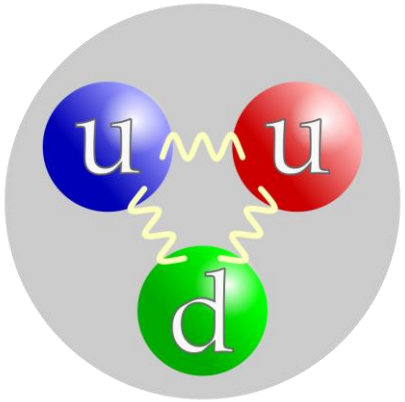
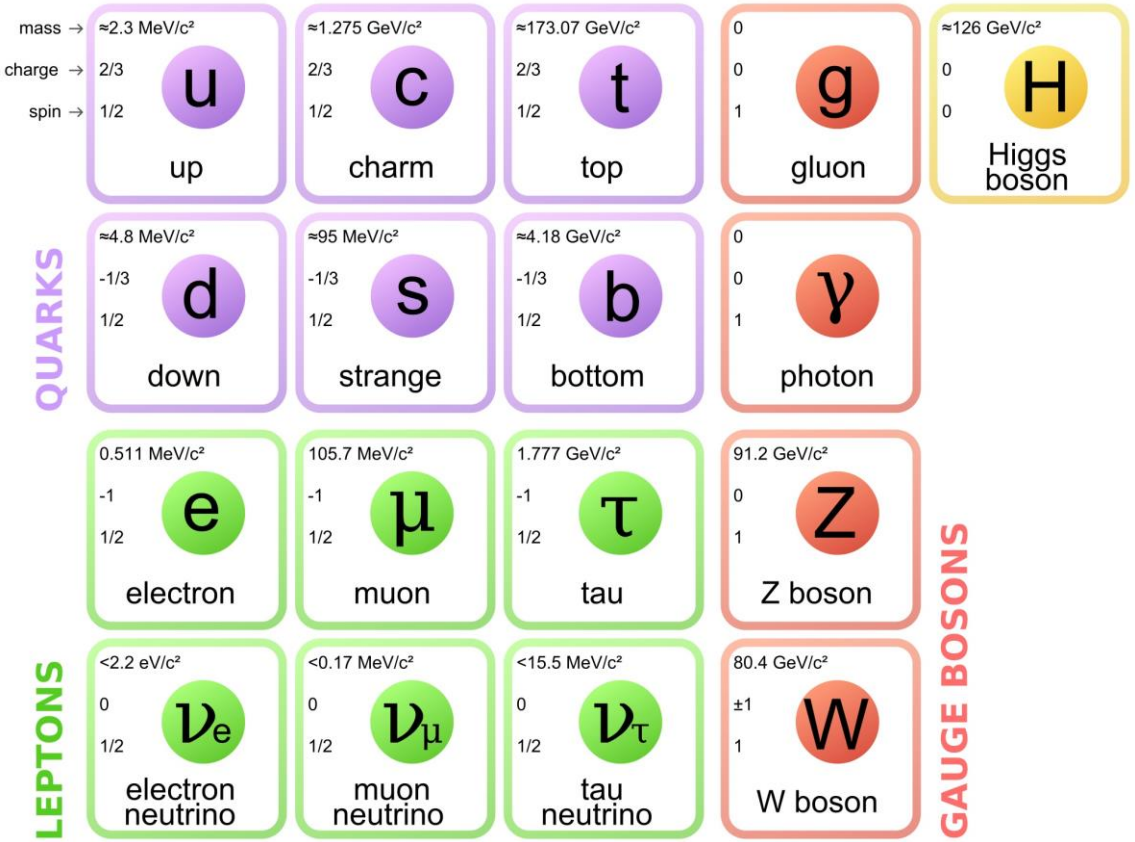
The Standard Model (SM)

- SM can explain three types of interaction (EM, Strong and Weak)
- For each type of interaction there is a mediator (gauge bosons)
- Quarks interact via EM, strong and weak interaction.
- Leptons interact only via EM and weak interaction
- Generations of Quarks and leptons according to masses

Quarks form bound state called hadrons



Proton



Beyond Standard Model (BSM)

Standard model is unable to explain a bunch of phenomenon'

- **Graviton** - Gravitational force or its mediator **"graviton"** is not included in standard model
- **Dark Matter** - SM cannot explain the observations of dark matter from astronomical data
- **Neutrino oscillations** - SM predicts neutrinos to be massless. But **"neutrino oscillations"** predicts they have some finite mass.

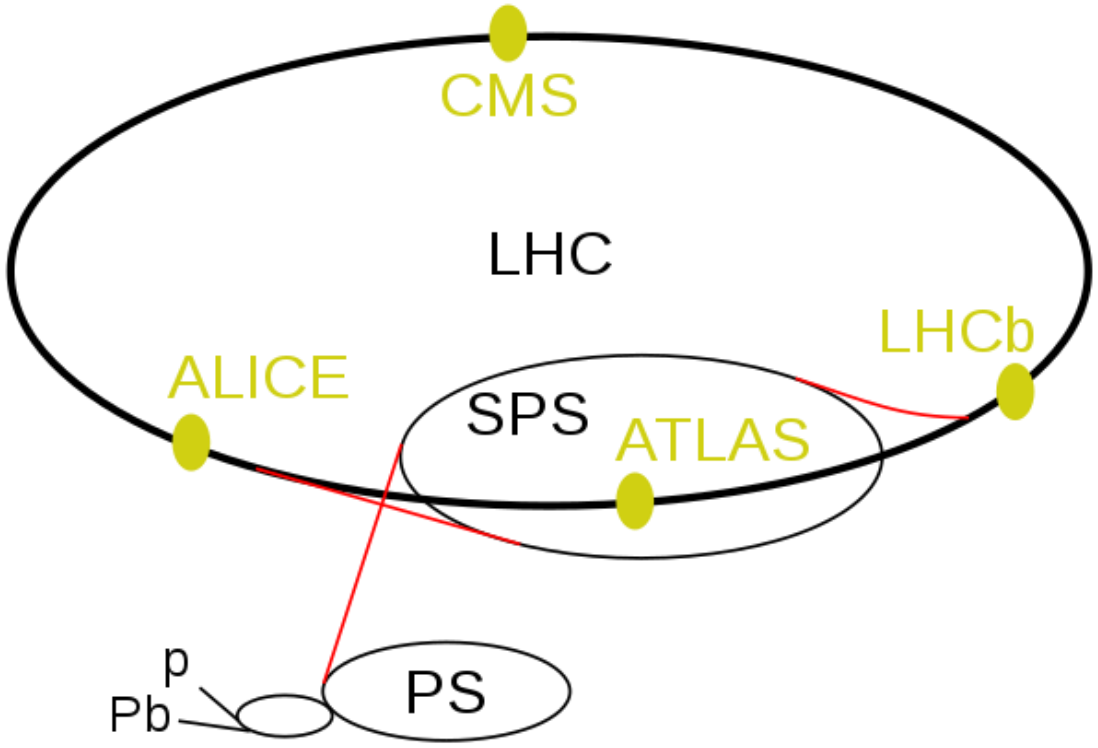
So we need something beyond the SM theory to explain for these phenomenon!!!

Need some experiment to validate the theory

The LHC

The LHC (Large Hadron Collider)

- 27 km Ring
- Pressure – 10^(-9) Pa
- Temperature – 1.9 K
- Collides proton bunches and Pb at the end of a run
- Current COM energy = 13.6 TeV (Run3)
- Earlier Run 1 = 7 and 8 TeV
- Run 2 = 13 TeV
- Bunch spacing – 25 ns
- Collision Rate – 40MHz
- 10^(11) protons in 1 bunch
- 4 – detectors(ATLAS, CMS, ALICE and LHCb)

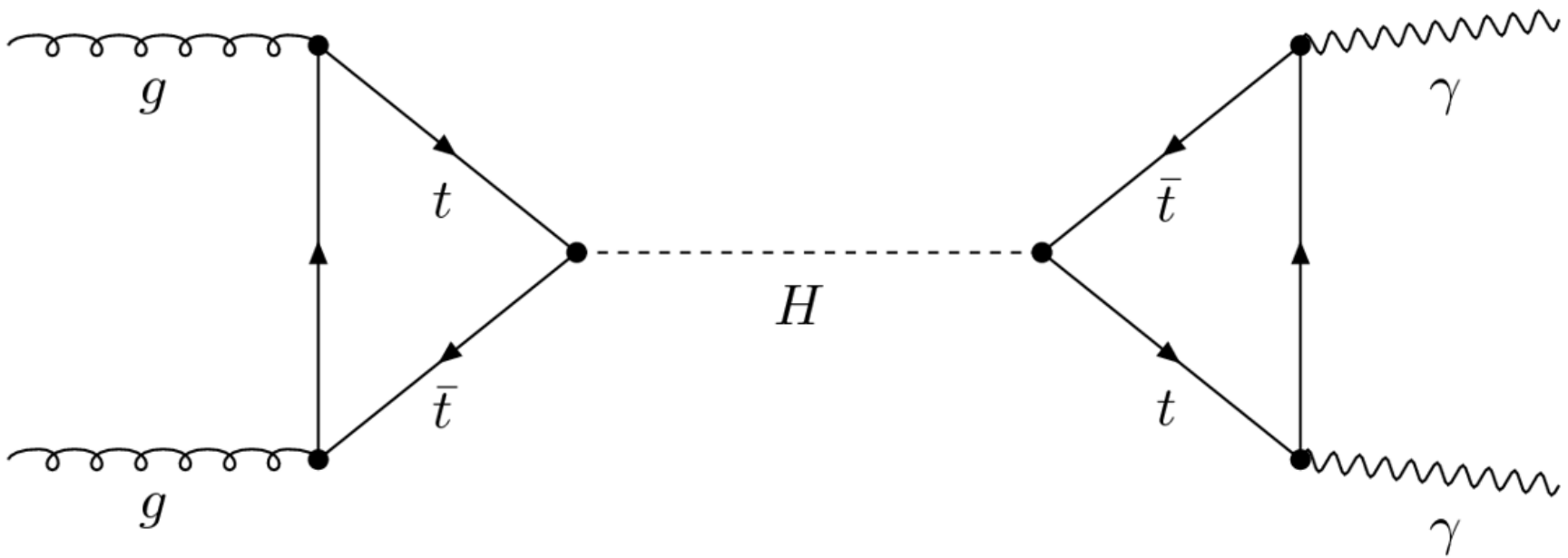


Located at CERN, Geneva

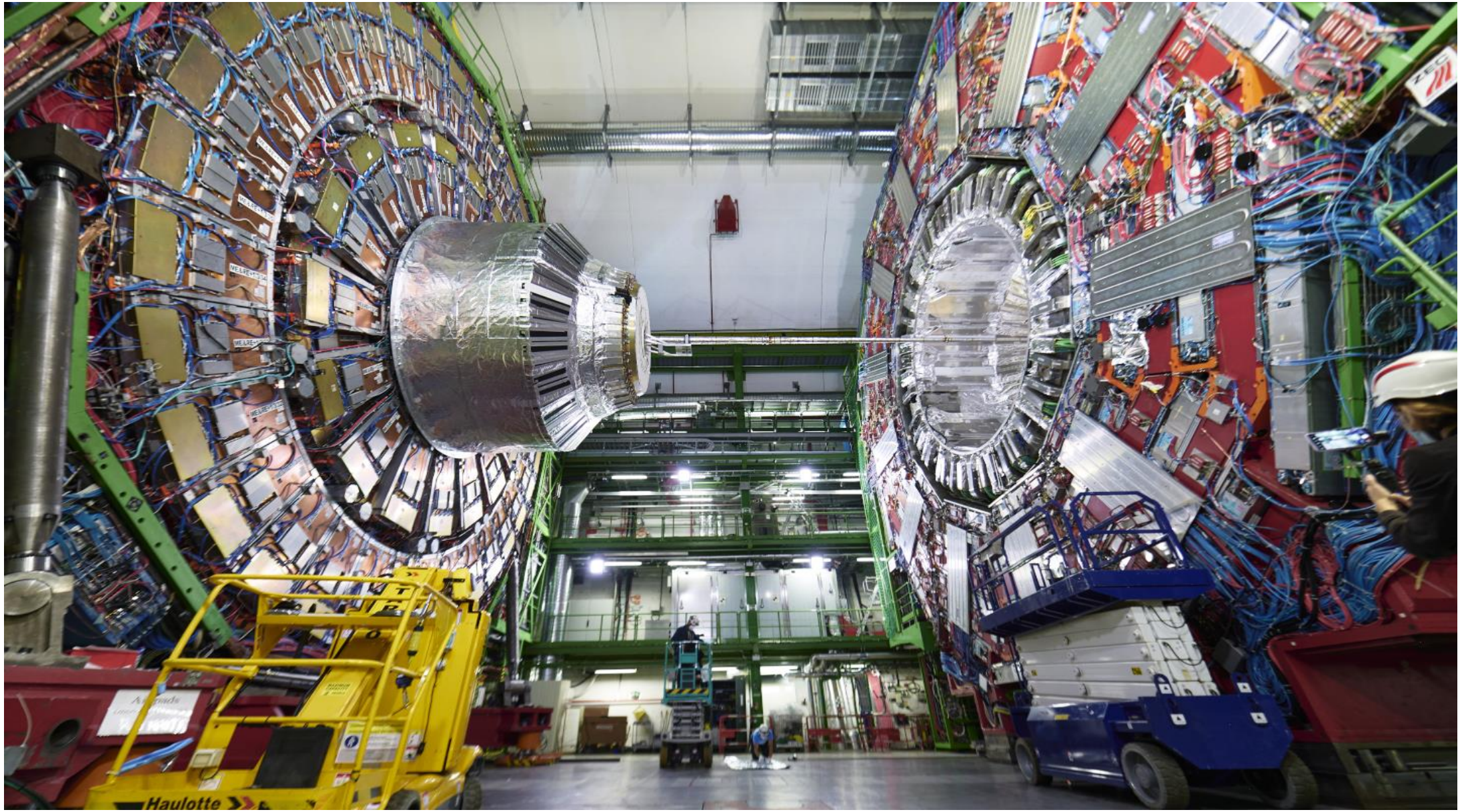
We here at IISER Pune are a part of CMS experiment

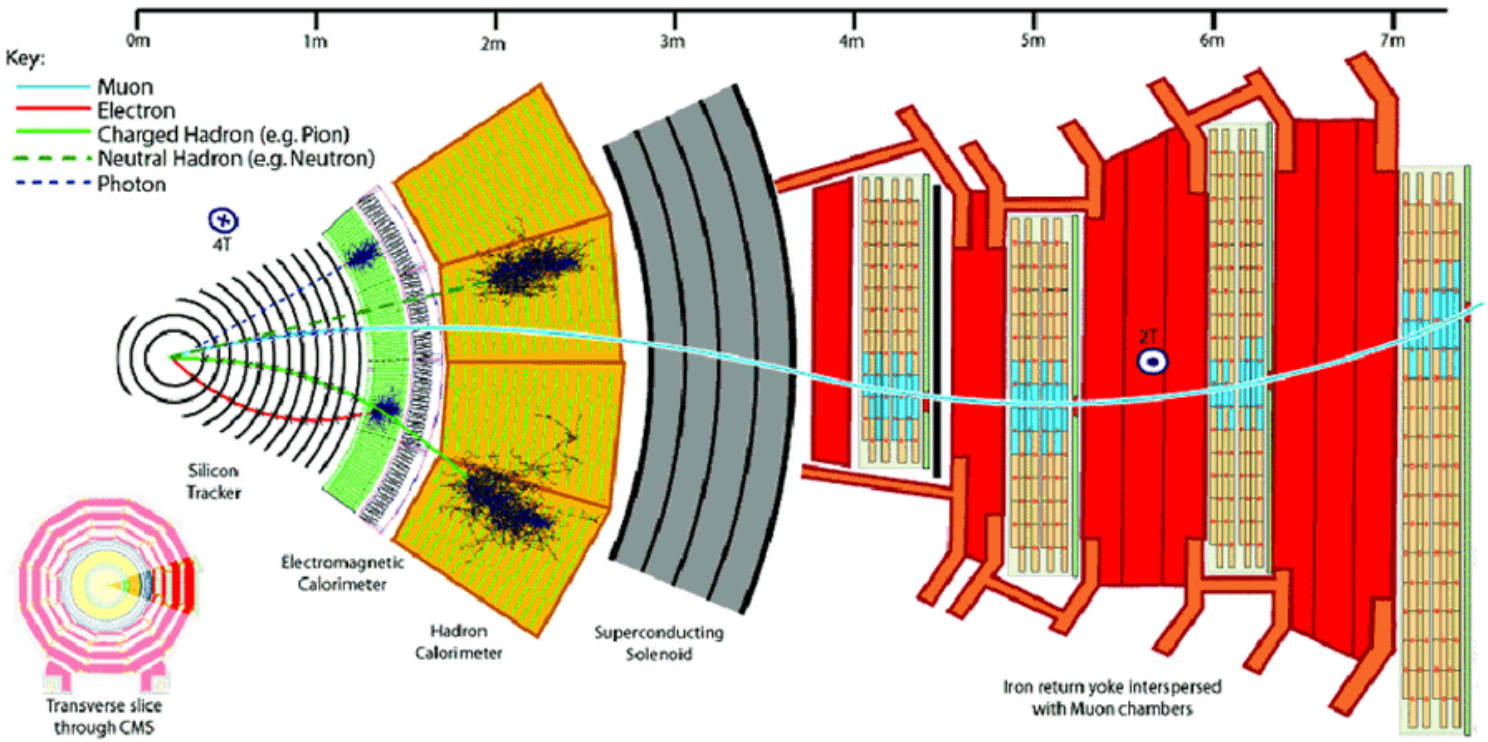
Every collision of protons is an **“event”**
At CMS every 25ns an **“event”** occurs.

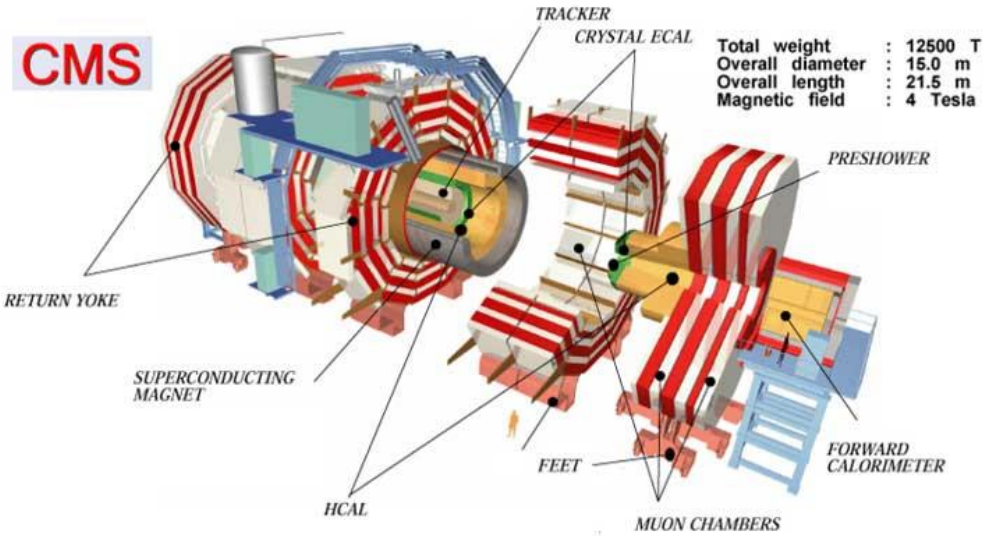
A **“process”** is a particular Feynman Diagram that occurred during the event.



THE CMS (Compact Muon Solenoid)



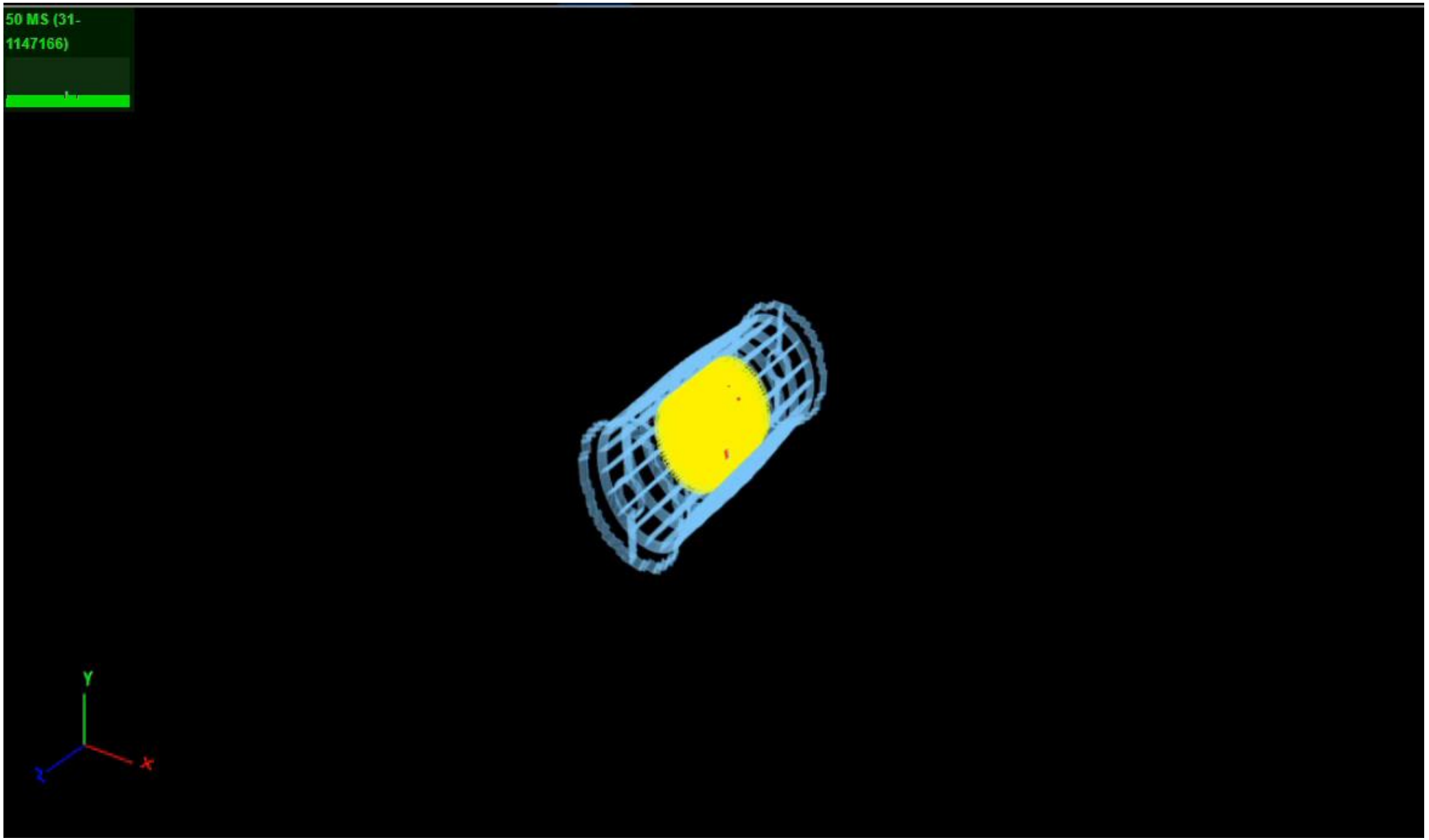




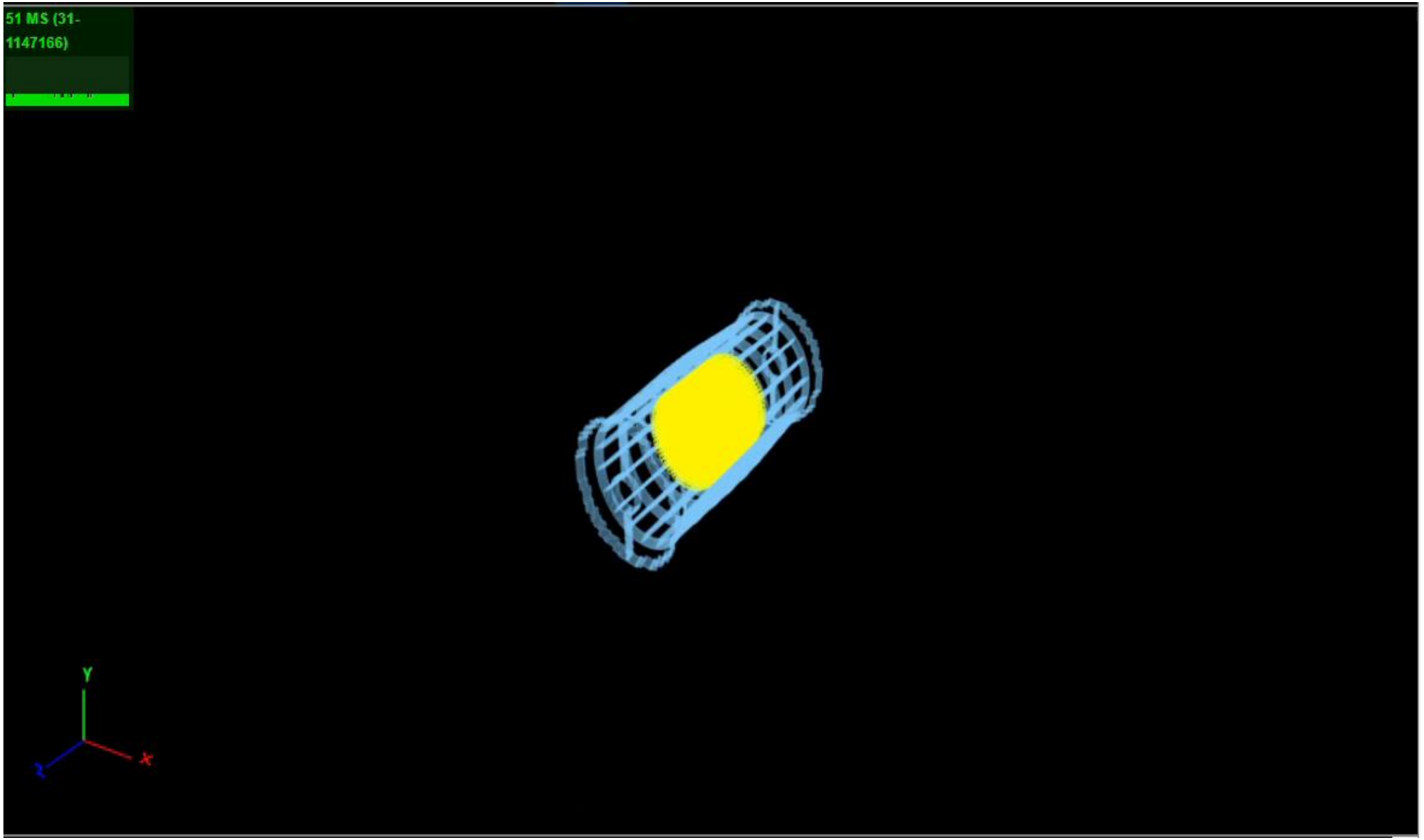
Magnetic Field of 3.8 T at the centre of the detector
Diameter - 15m
Length – 21.5m
Total Weight – 12,500 Tonnes

L1 - **Silicon Tracker** (Charged particles leaves tracks in the tracker)
L2 - **ECAL** or Electromagnetic Calorimeter (Electrons and photons deposits almost all of their energy in ECAL)
L3 - **HCAL** or Hadron Calorimeter (Hadrons deposits almost all their energy in HCAL)
L4 - **Muon Chambers** (Where Muon hits are recorded)

Higgs to diphoton process ($H \rightarrow \gamma\gamma$)



Higgs to 4 muons process ($H \rightarrow \mu\mu\mu\mu$)



Challenges to be addressed

1. We are not colliding single protons but bunches (10^{11}) of protons.

Q. Which collisions to consider??
Answer: We are interested in only the most energetic collision or collision with highest momentum transfer (highest q^2)

Q. What happens to other "soft" collisions (low-energy collisions)?
Answer: They appear as **"pile-ups"** in the collisions or simply noise

There are pileup mitigation algorithms in place at CMS reduce these effects of pileups.

2. When these collisions takes place its just too much amount of data and we at present don't have the hardware capability to store all the information stored in a collision event.

We apply triggers during data taking which are like filters and saves the event only if it passes certain conditions.
We collide protons at a rate of 40MHz but after applying all the triggers it reduces to 1.5 khz.

PF (Particle Flow) Algorithm

Once a collision occurs we have the whole detector lit-up.
We have Tracker hits, Calorimeter deposits (ECAL and HCAL) and deposits from muon chambers.

But now what to do with all these information?

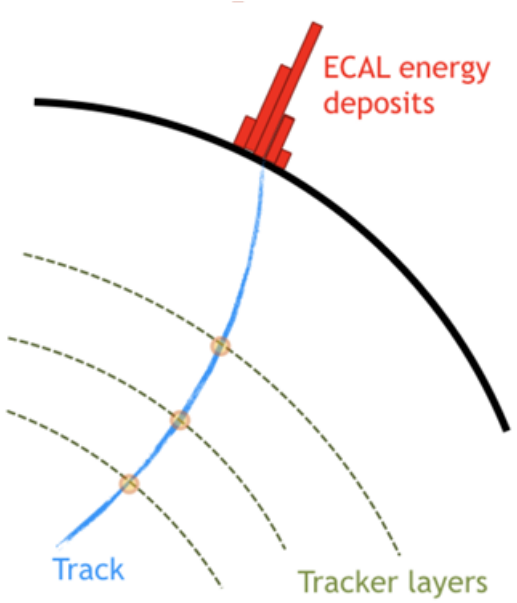
We run PF algorithm on all these info that we collected and its output can broadly be categorised into 5 categories:

- Electron
- Photon
- Muon
- Charged Hadron
- Neutral Hadron

How exactly PF does that?

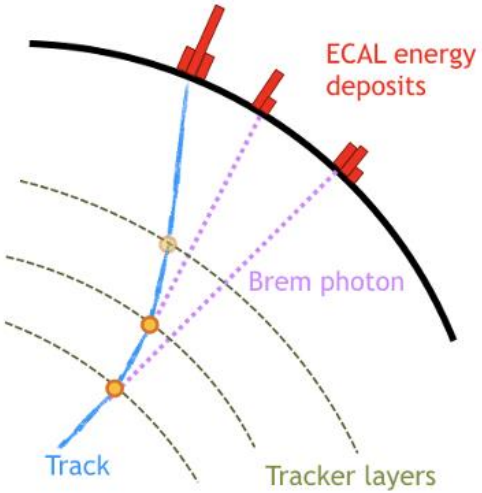
Its complicated!

But I will explain briefly how its done for electrons and photons.

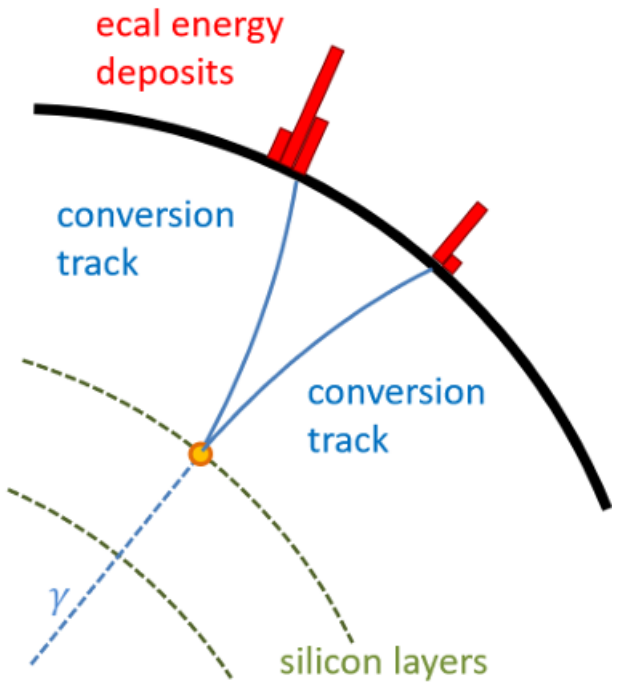


Track+ECAL deposit = electron

Not So Simple!!



Electron most of the time will do bremsstrahlung



Photons pair produce

Takeaway from this talk:

- This was a very basic intro to what is CMS.
- More focus on breadth than depth!
- CMS just has too many problems!
- What is the solution?
- Algorithms

Theory will take you only so far!