CMS Compact Muon Solenoid

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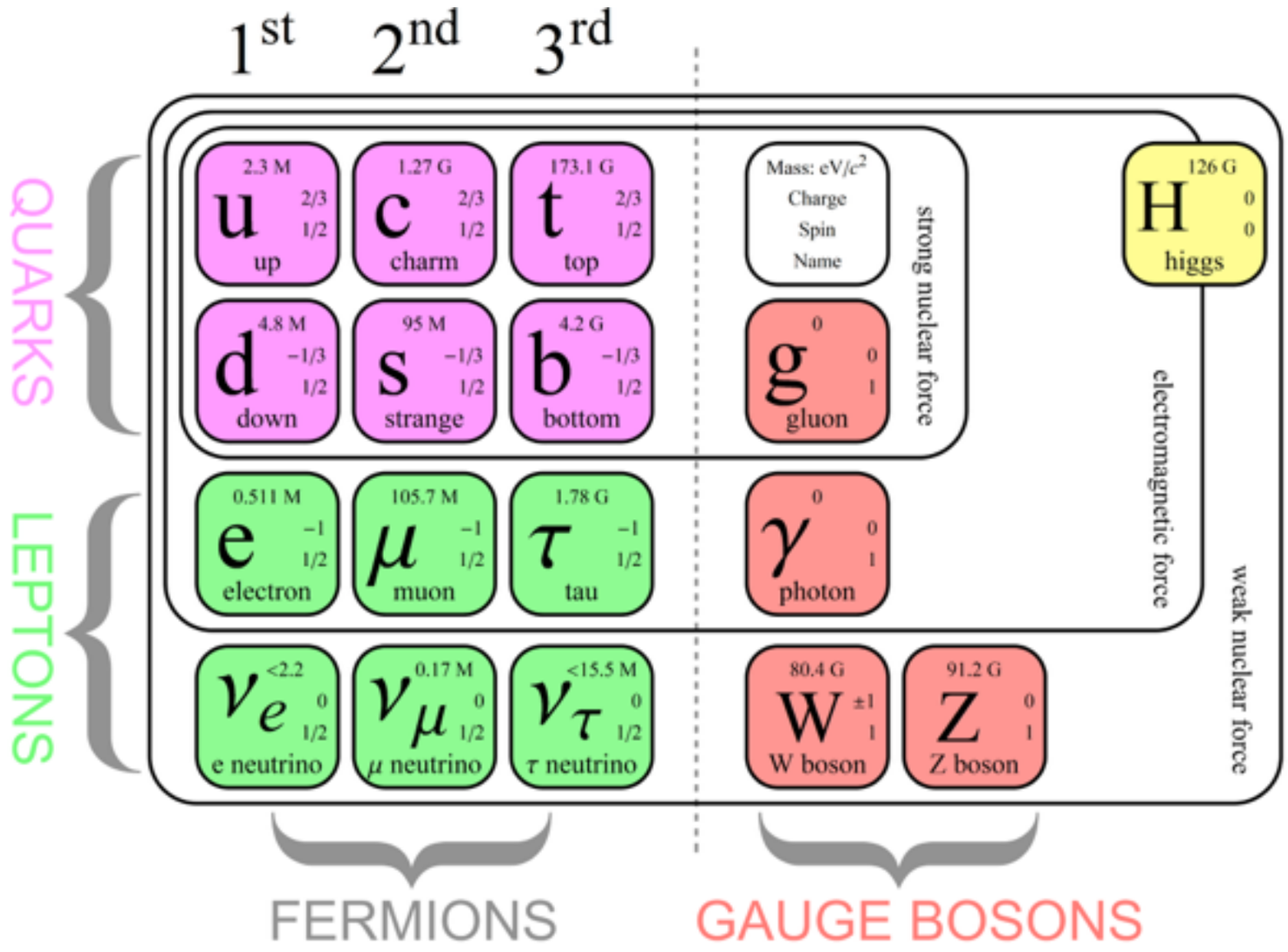
Standard Model and Open Questions

After the **Higgs Boson** discovery, the Standard Model is a complete model:

- Particles
- Forces
- Higgs
- …



BUT

…still many questions remain unanswered:

- Hierarchy problem
- Dark Matter & Dark Energy
- CP violation
- Matter-Antimatter asymmetry
- Neutrino masses

High Energy Physics

A possible answer may come from the study of
High Energy Physics

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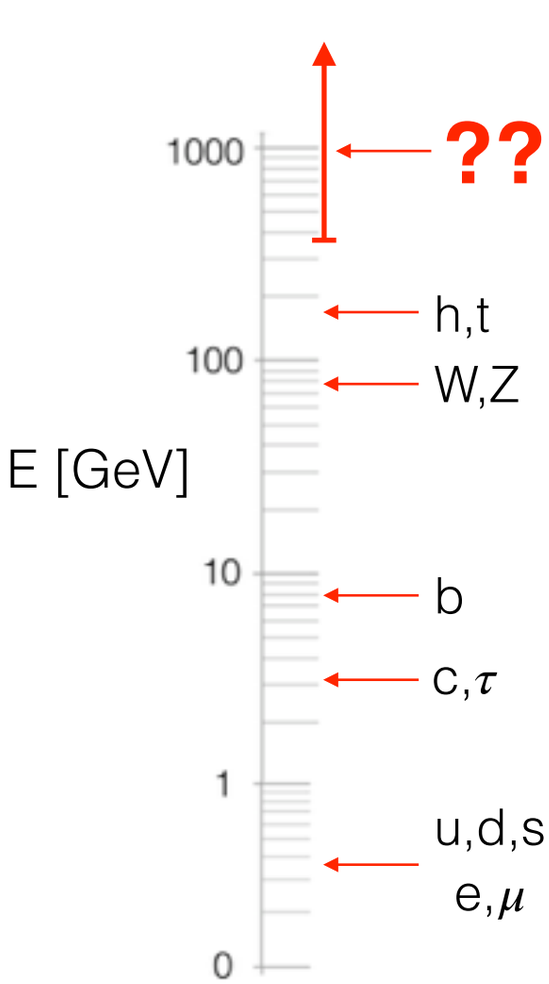
Why HEP?

High Mass



E ~ 1/t

Higher energy means
"*going back in time*"

↓

possibility to explore
the universe
conditions just after
the Big Bang

p ~ 1/λ

Higher energy means
higher spatial resolution

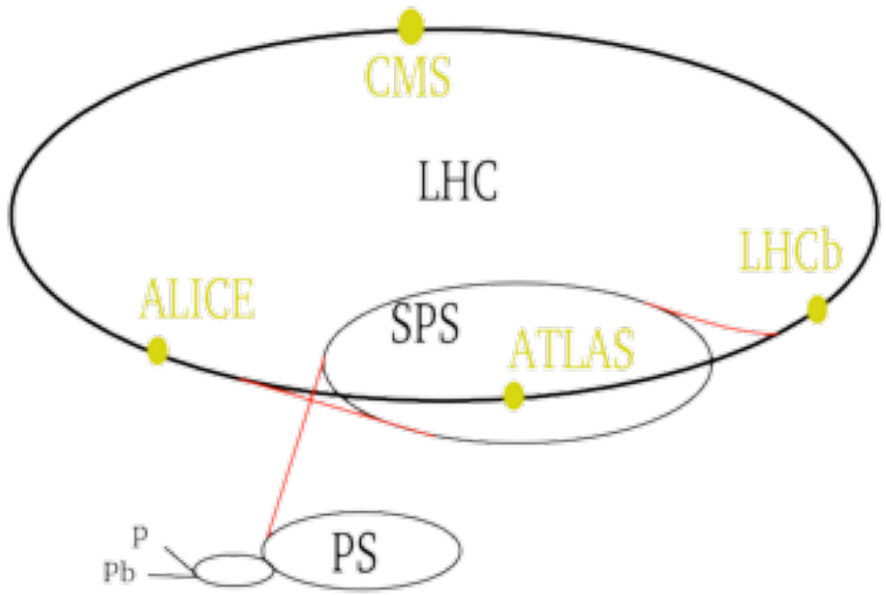
↓

possibility to explore
the substructure
of particles
and
their interactions

LHC & CMS Experiment

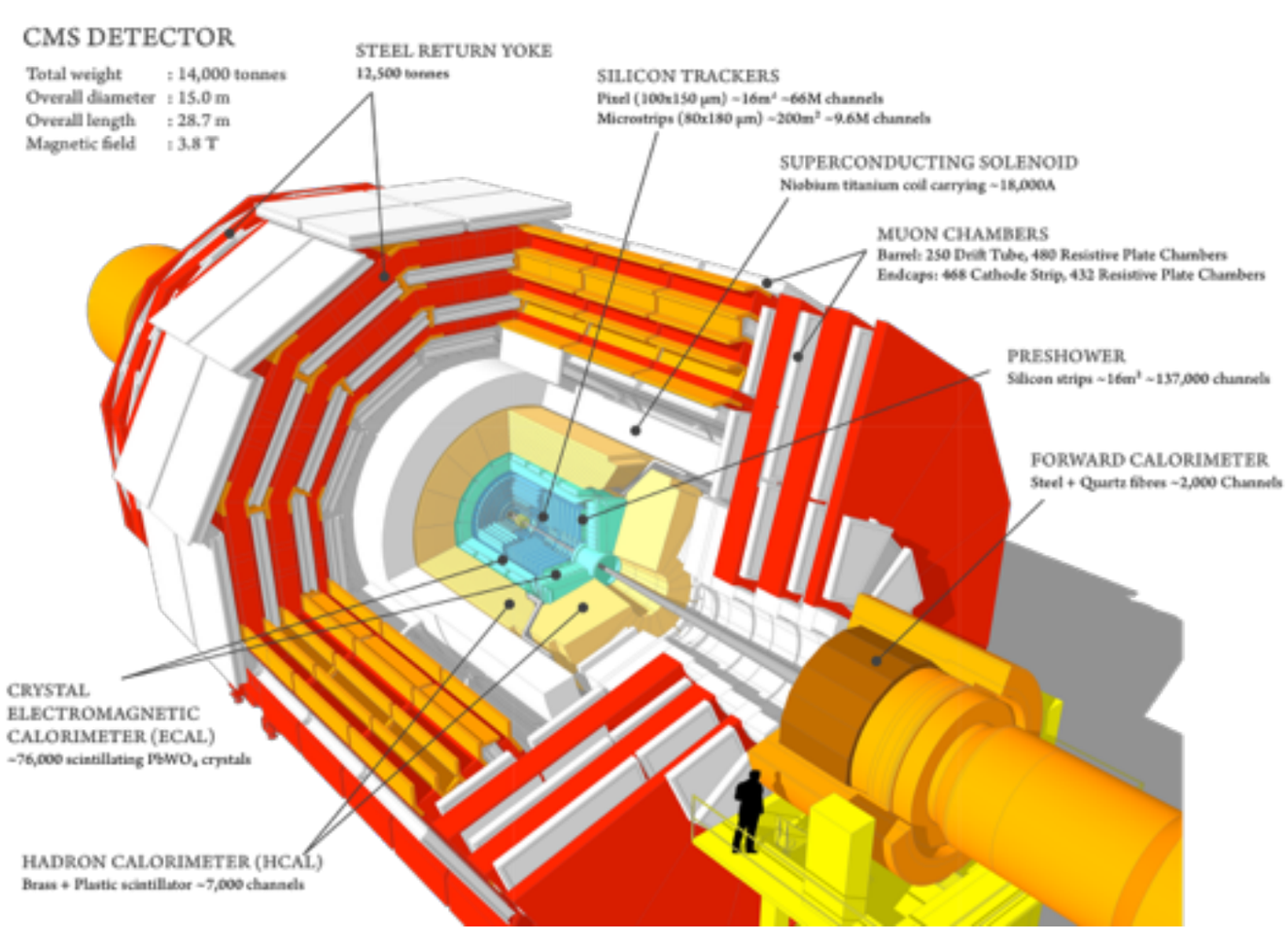
LHC is a proton accelerator:

- Collisions at $\sqrt{s}$ = 13 TeV
- Protons in bunches containing 10^{11} particles, colliding every 25 ns (40 million times a second!!)
- About 40 proton-proton collisions for every bunch crossing

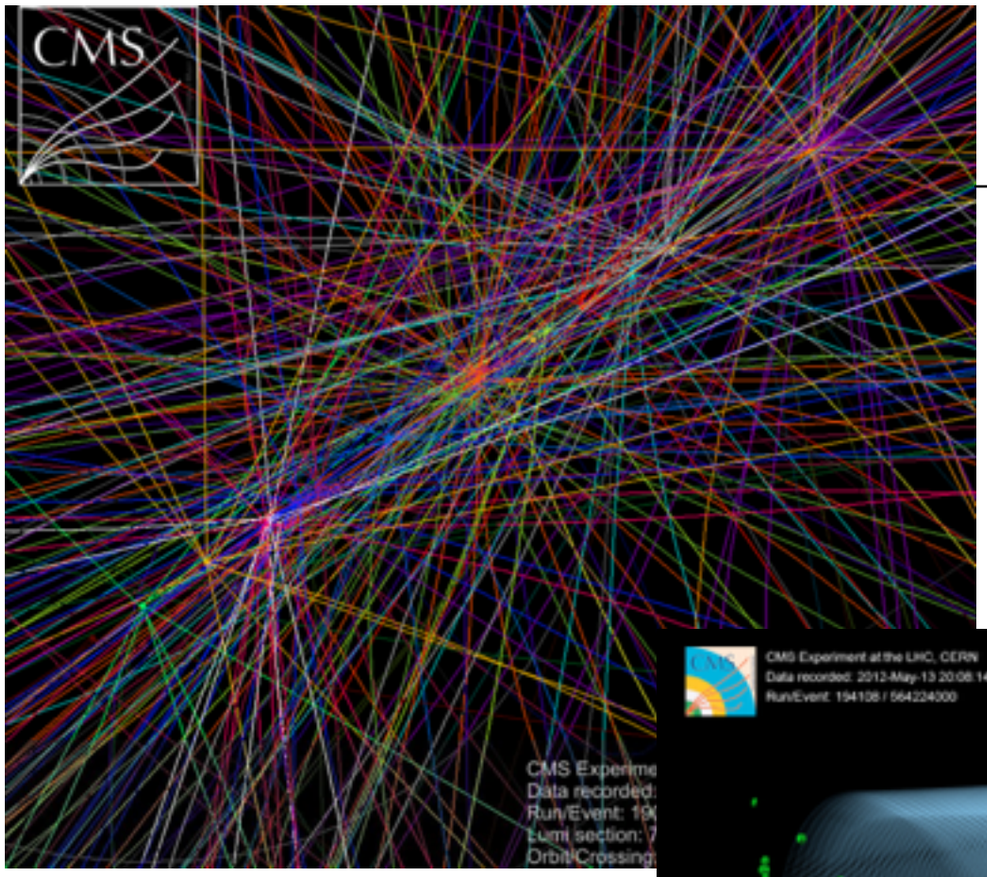


CMS is a general purpose experiment, made up of many *sub-detectors*:

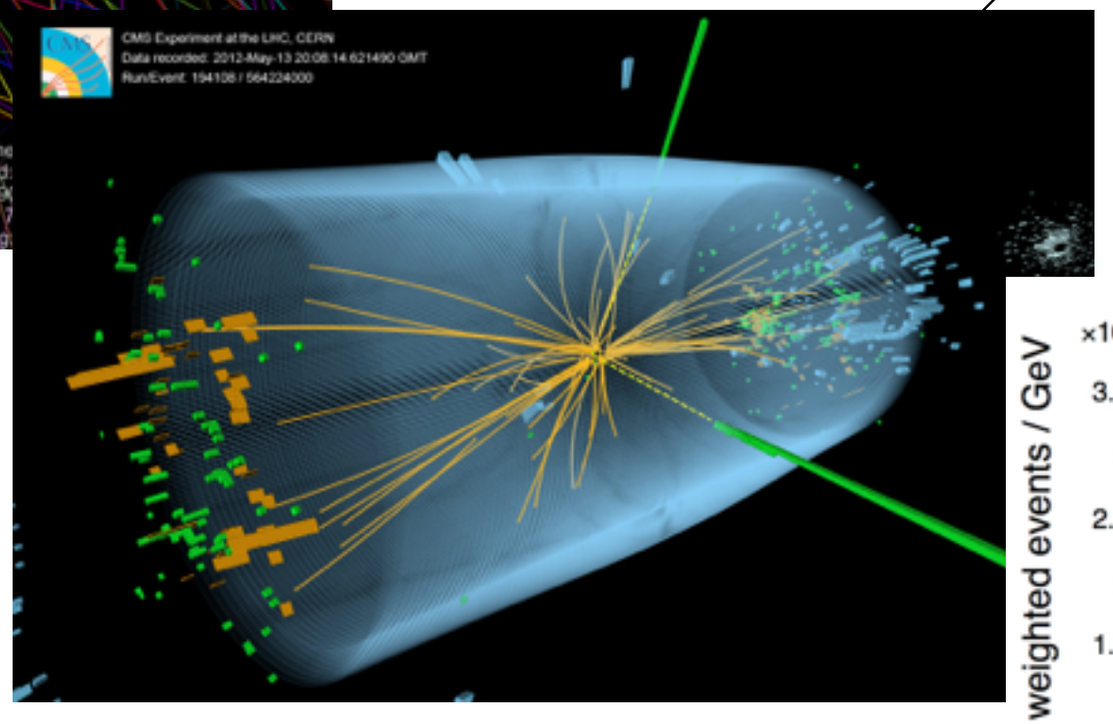
- Pixel+Strips: to reconstruct tracks from charged particles
- Superconductive Solenoid: to bend particle tracks and measure their momentum
- ECAL+HCAL: calorimeters to reconstruct the energy of charged and neutral particles
- Muon Chambers: to detect muons
- Trigger: to reduce event rate from 10^9 to 10^2 Hz and still keep all the physics interesting events



Physics @ CMS

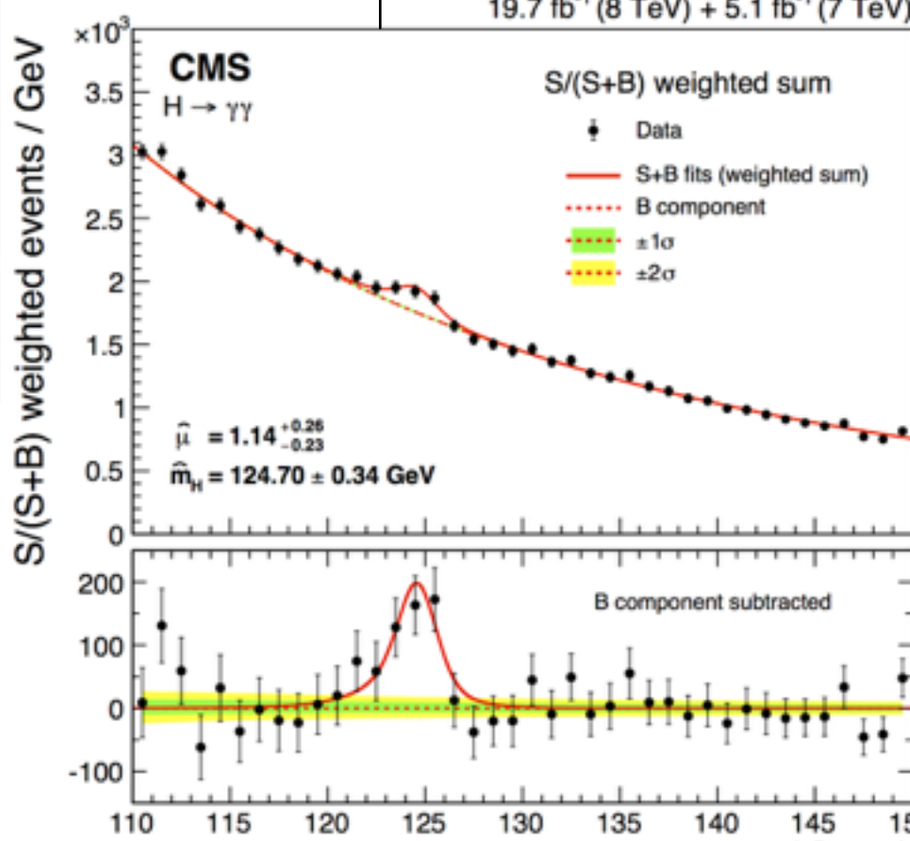


Record the particles with CMS sub-detectors



Analyse data to extract information

Obtain Physics results



Hardware

Software

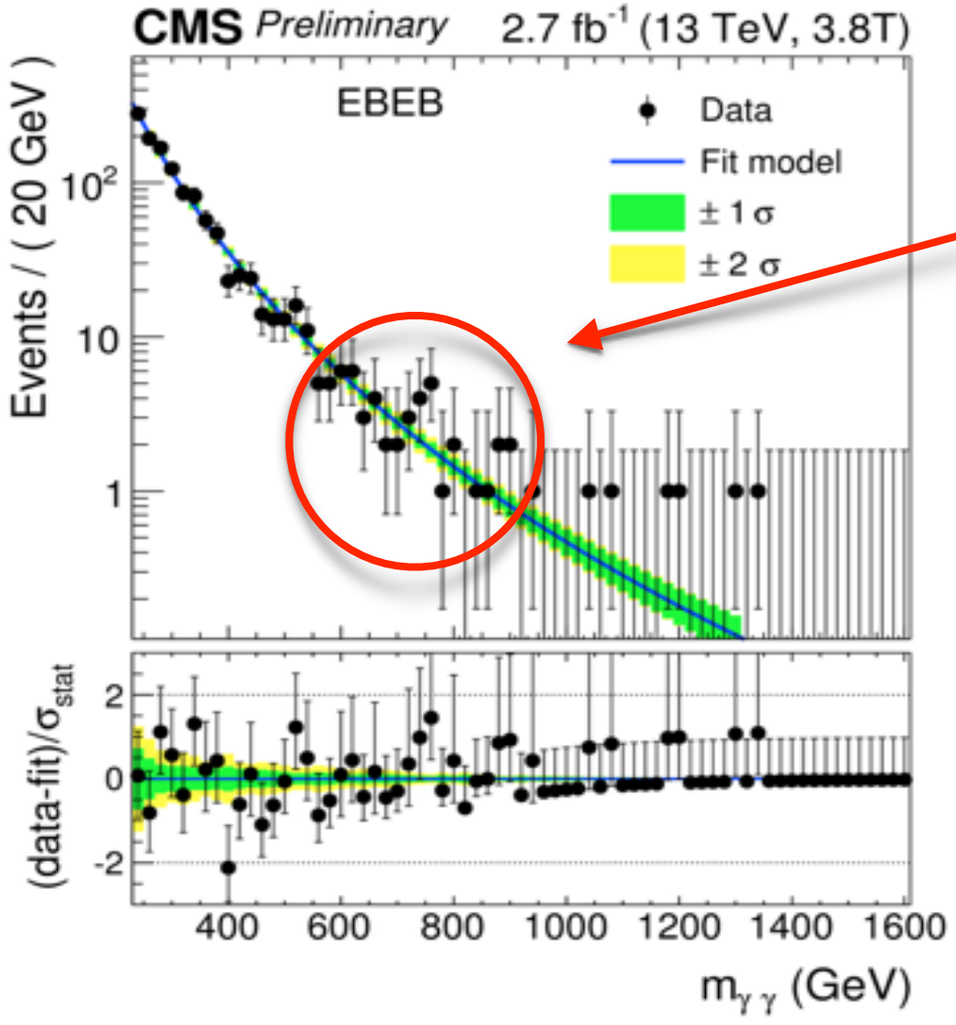
Brain

How an analysis works: $X \to \gamma\gamma$

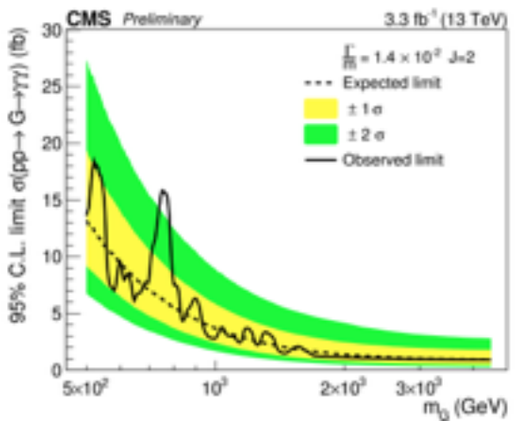
- The goal is to search **new particles** decaying in two photons
- Select **2 energetic photons**:
  - from which Primary Vertex?
  - are these real photons? (or just background?)

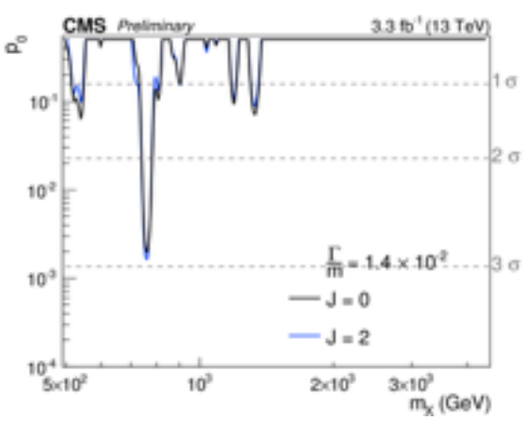
Machine Learning Techniques

- Create the $\gamma\gamma$ **invariant mass spectrum**…



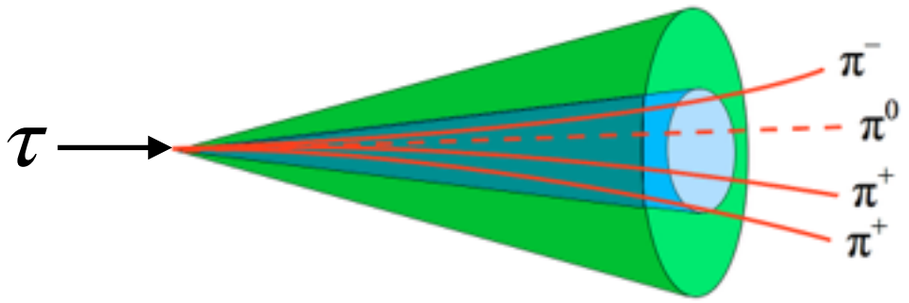
…and look for bumps with adequate statistical techniques!



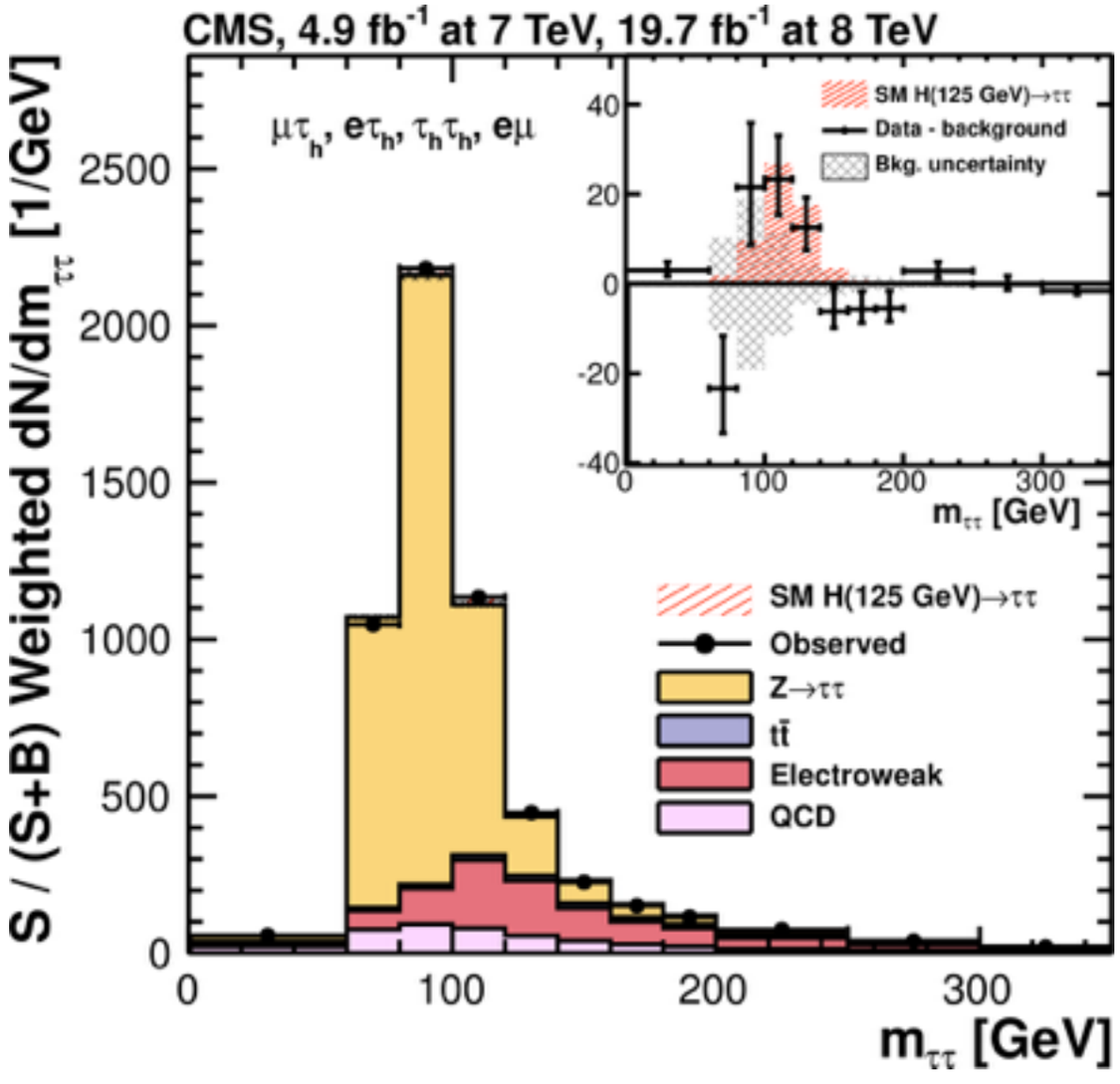


How an analysis works: H→ττ

- The goal is to reconstruct the **Higgs Boson** decaying in two *tau leptons*
- Reconstruction of ***tau* leptons**
  (τ leptons decay before reaching any sub-detector)



- Creation of **m($\tau\tau$) spectrum**



- Estimation of different **background** contributions:

  Z→$\tau\tau$, QCD, W-Jets …

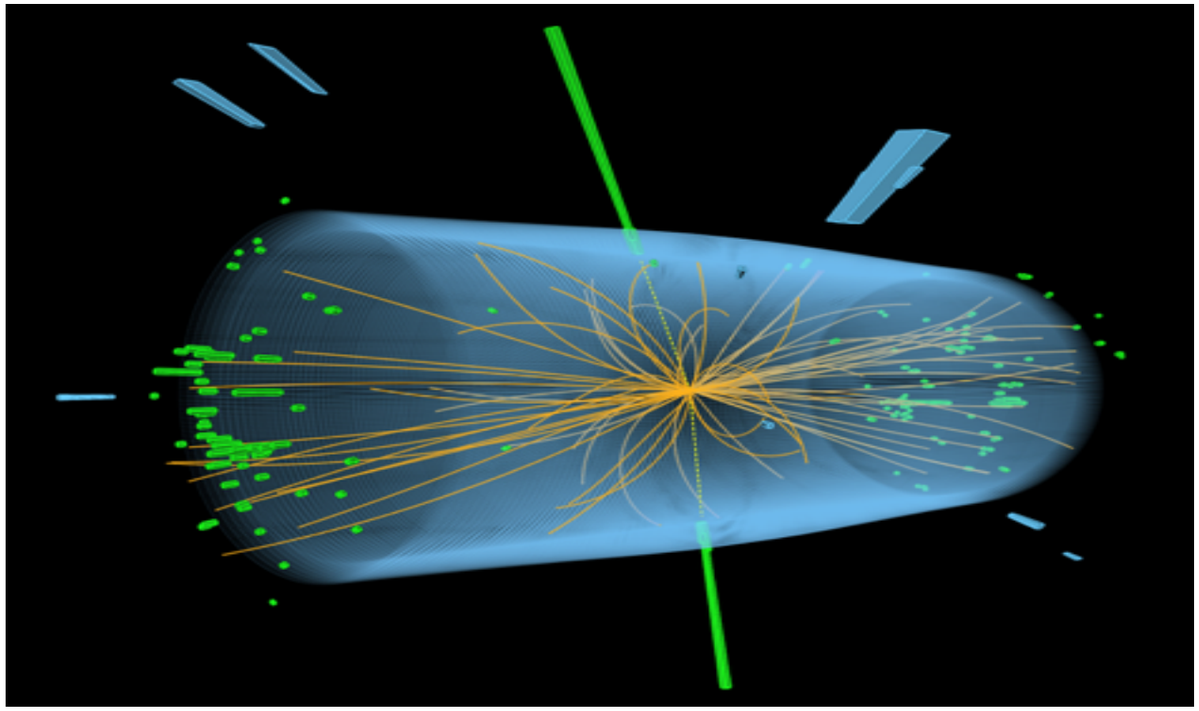
  ↓

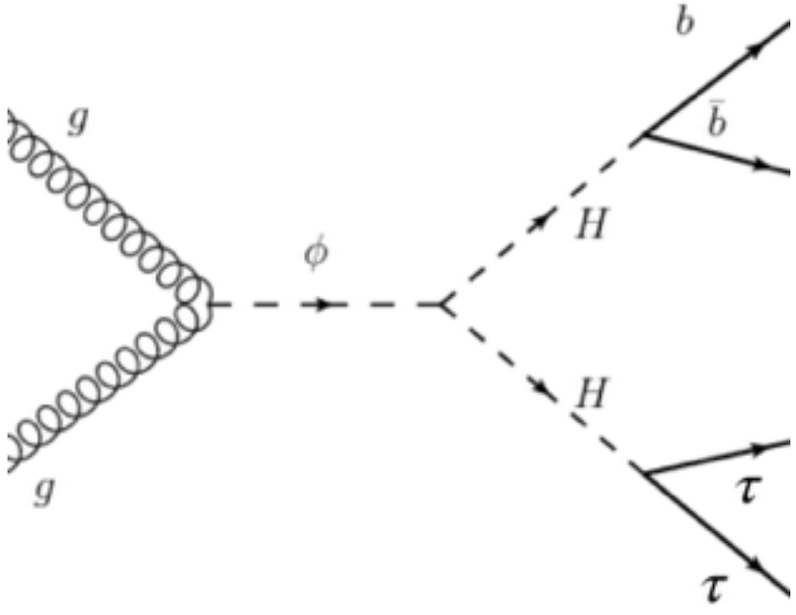
  …and search for excess of events

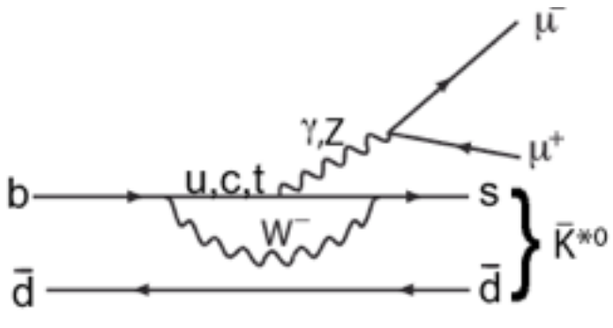
CMS & Milano-Bicocca: Analyses

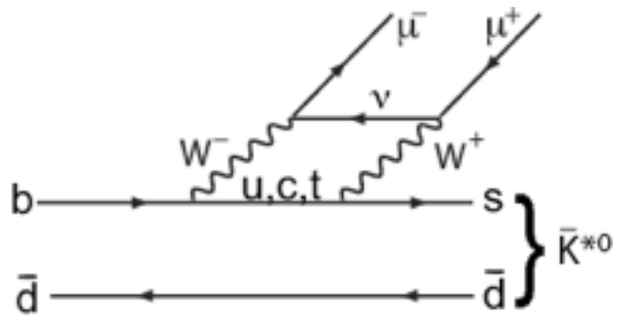
Standard Model analyses
Search for the Higgs Boson and measurement of its properties:

- H → $\tau\tau$
- H → $\gamma\gamma$
- Vector Boson Fusion (VBF)





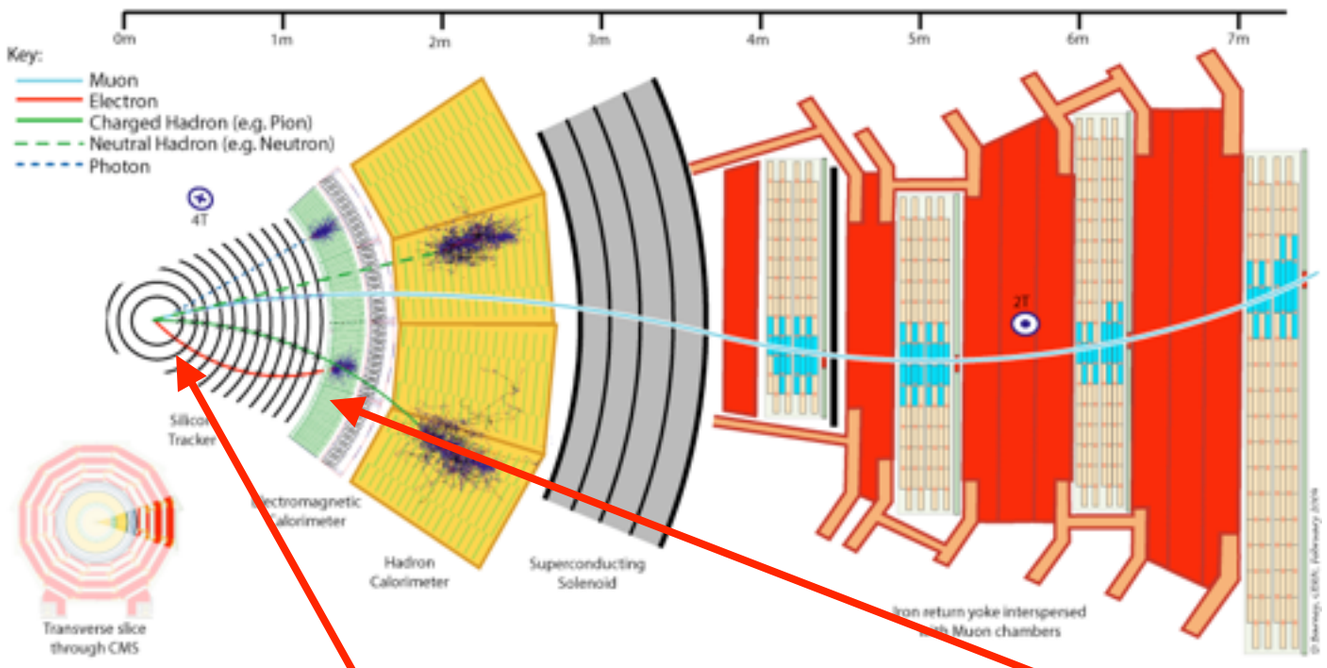




Beyond Standard Model analyses
Search for new particles (ϕ) indicating the presence of New Physics:

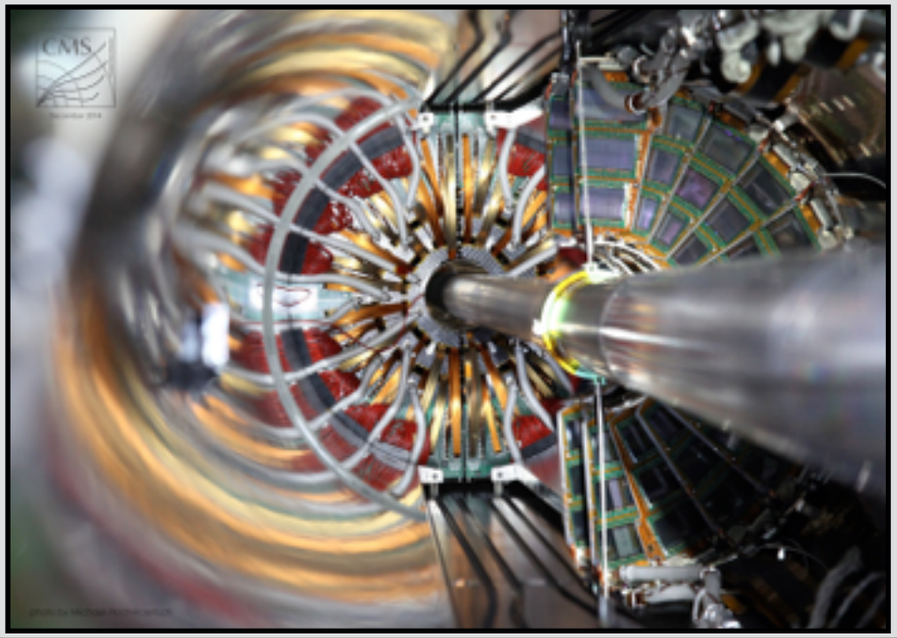
- ϕ → HH → bb$\tau\tau$
- ϕ → WW
- ϕ → $\gamma\gamma$
- b-physics (*e.g.* B_0 → $K^{0*}\mu\mu$)

CMS & Milano-Bicocca: Hardware



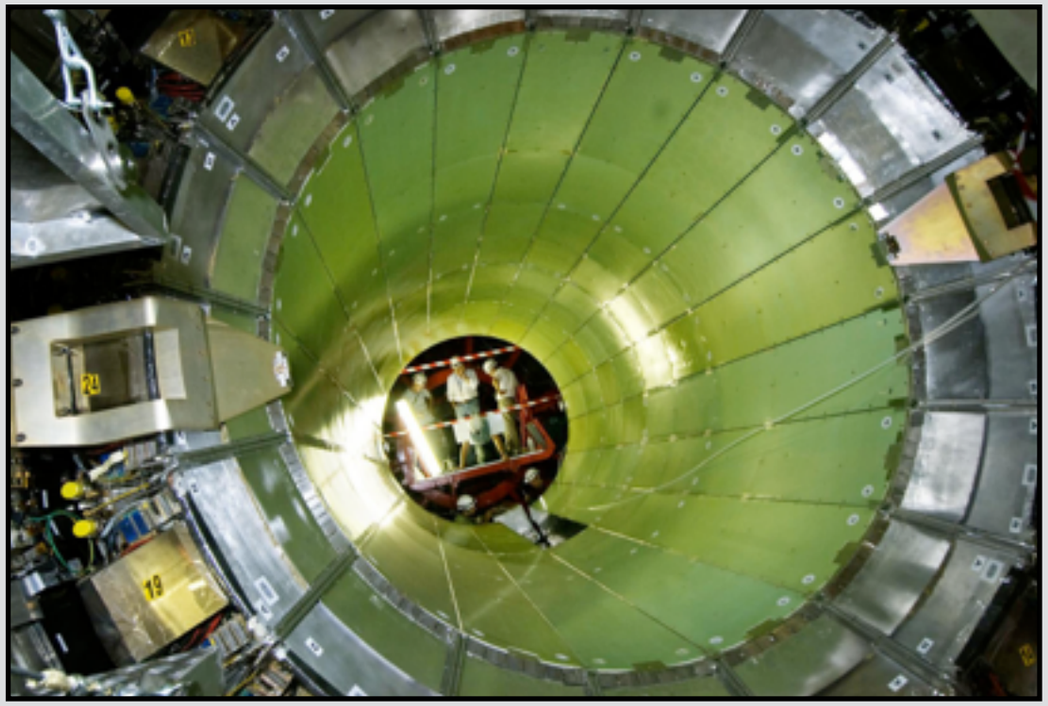
Pixel Tracker

- Study of track reconstruction
- Development of pixel detectors for CMS Upgrade



Electromagnetic Calorimeter

- ECAL calibration
- ECAL barrel upgrade
- Development of fast timing detector for CMS



Conclusions

CMS PhD students at Bicocca involved in several activities:

- **Data analysis**
- **Software & Hardware** development
- Collaboration with **international laboratories**:
    - CERN (Geneva)
    - Fermilab (Chicago)