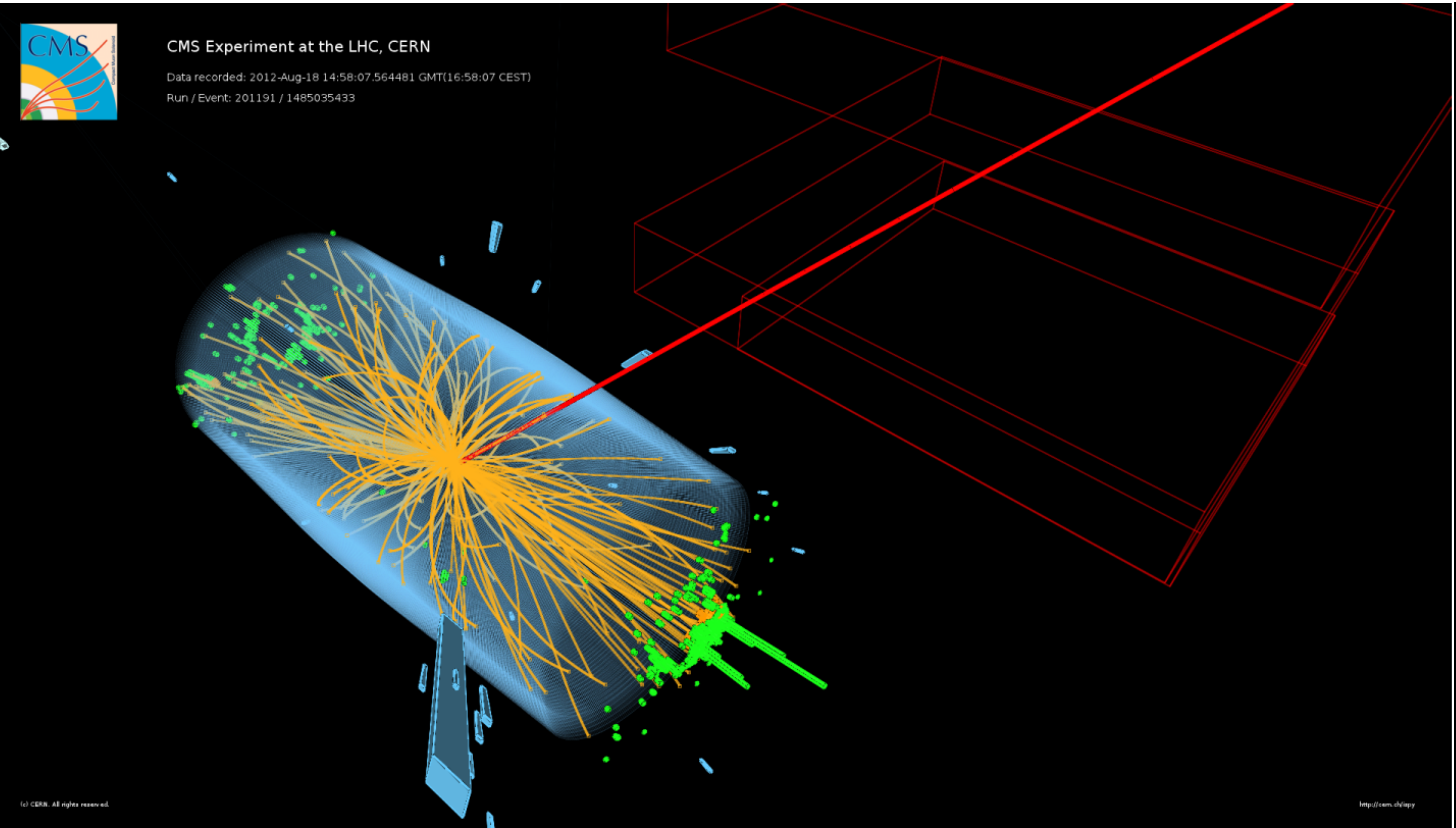
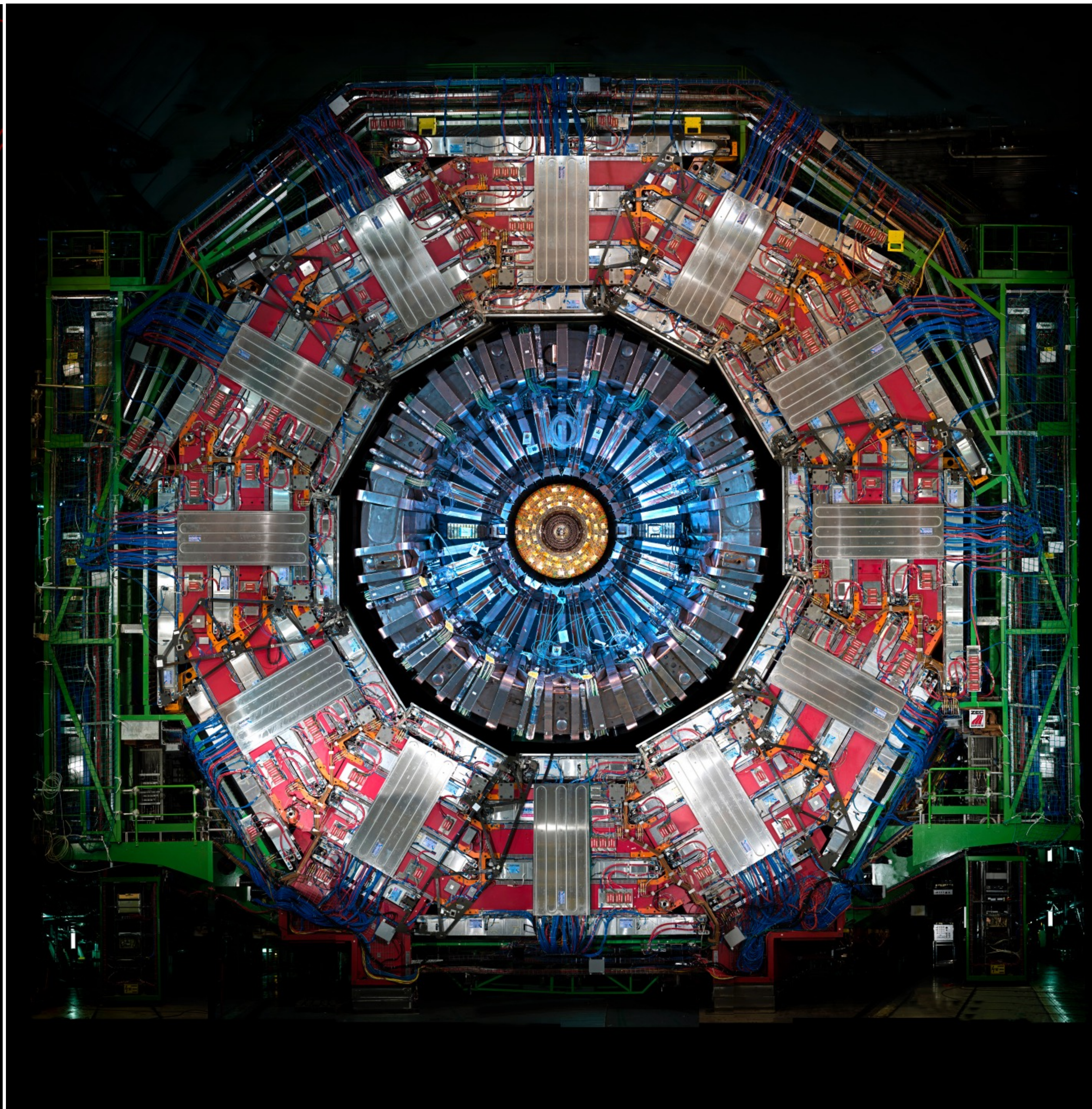
Getting to know the Higgs boson.

Valeria Botta (DESY)

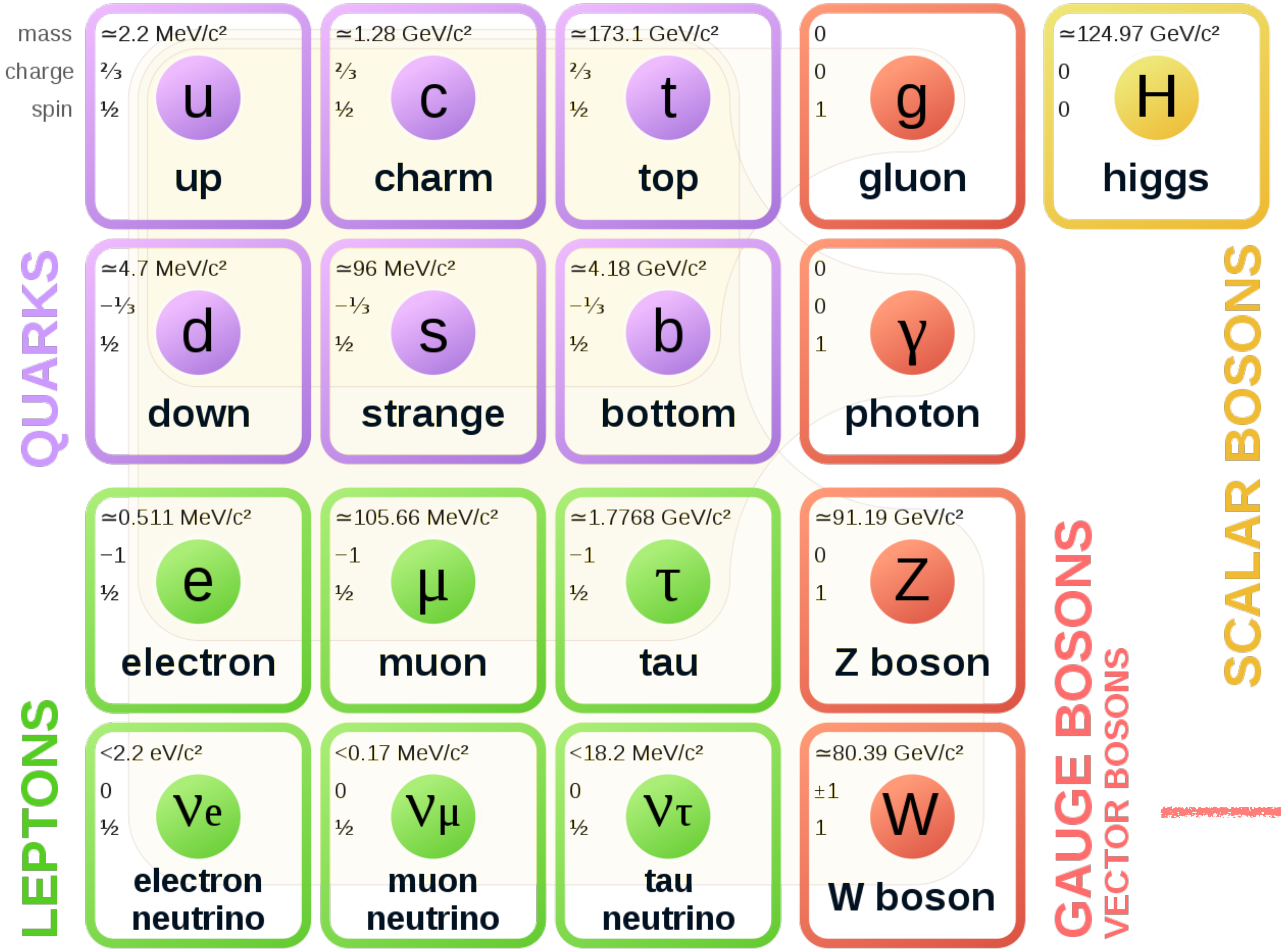
DESY Science Day 2020





The elementary particles

Matter constituents



The Higgs boson

subject of my PhD (and current) work

Force mediators

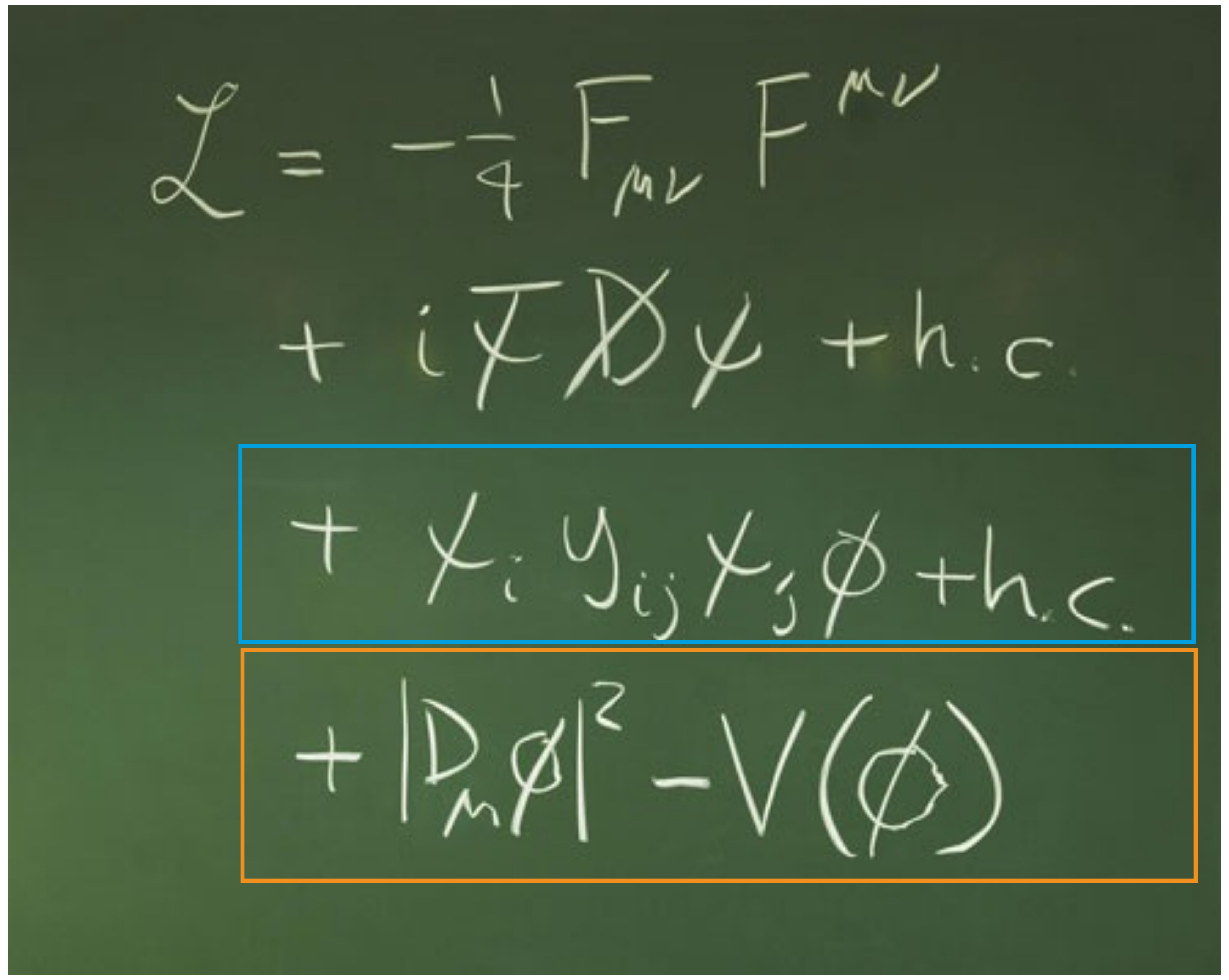
- The way how these particles *interact* is described by the ***Standard Model***

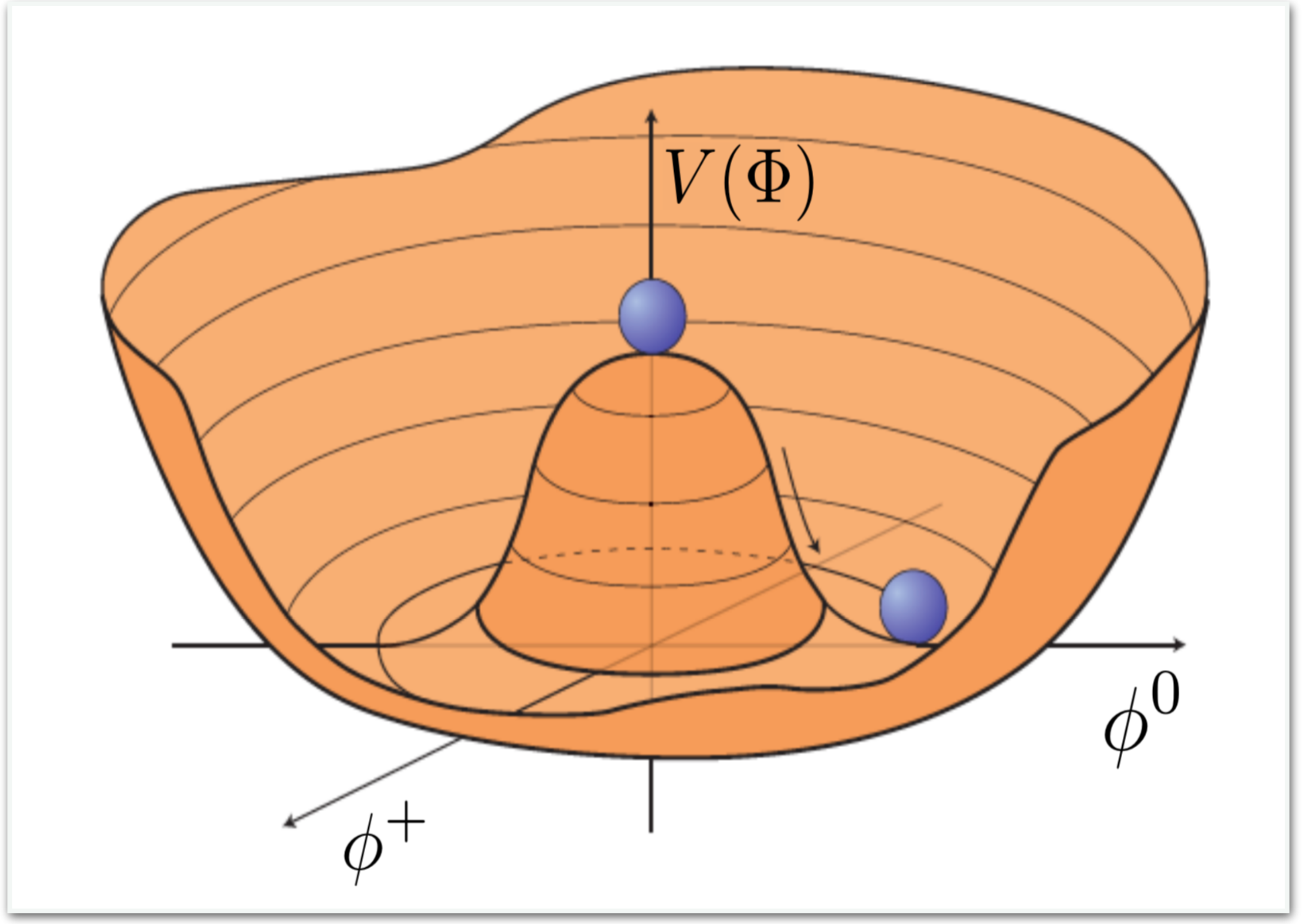
The Higgs boson

- The Standard Model is built on gauge invariance principle
  - Does not allow massive gauge bosons → **W and Z masses?**

- **Solution** proposed by Peter Higgs & others (1964)
  - Add one scalar field to the theory, with a particular shape of the potential
  - The electroweak gauge symmetry is spontaneously broken
    - Mass terms for the W and Z bosons
    - Fermion masses from *ad-hoc* **Yukawa** terms

- Implication: there must be a **new particle, the Higgs boson**, with unknown mass!
- The search for it lasted *almost 50 years*



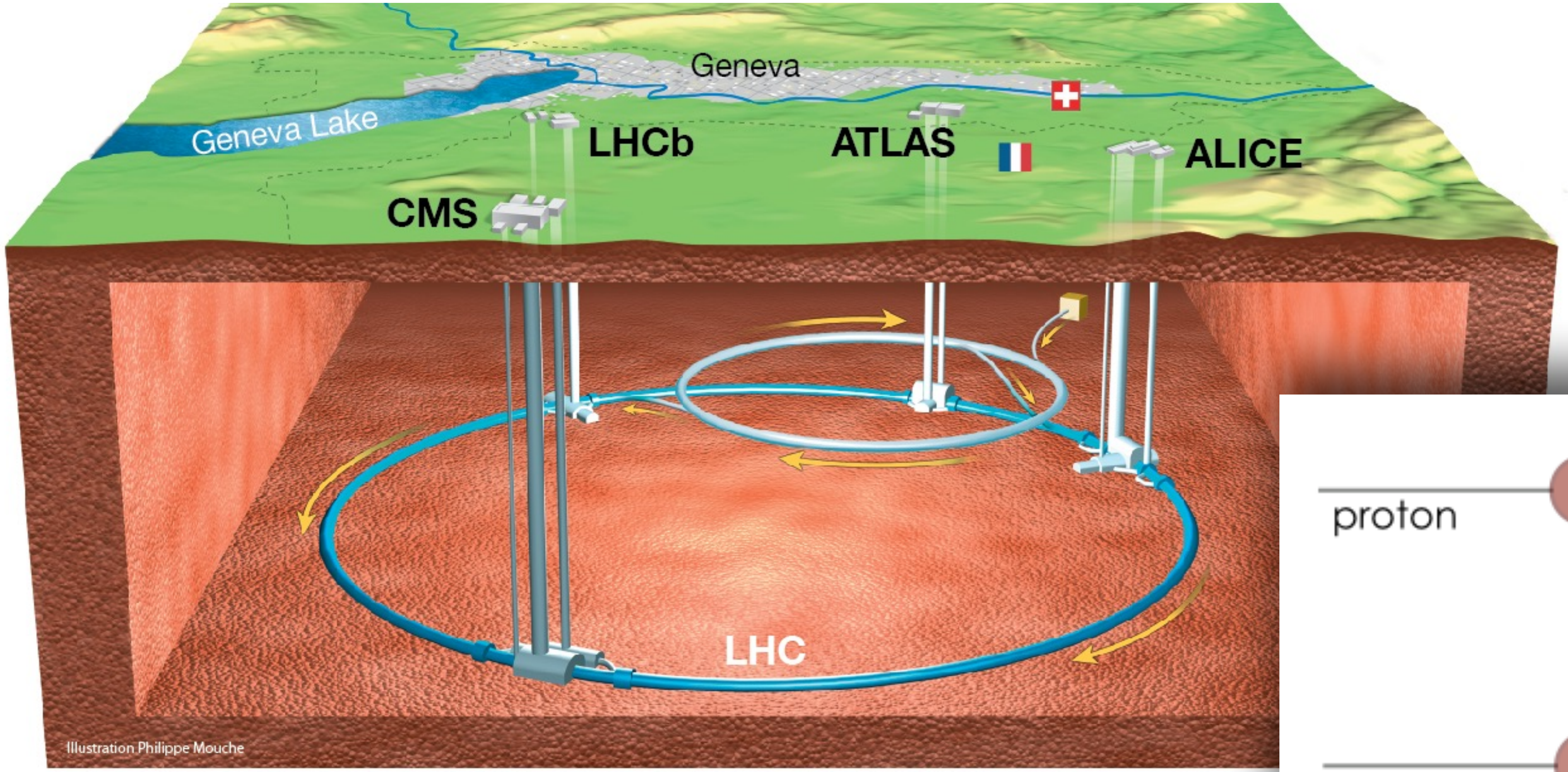


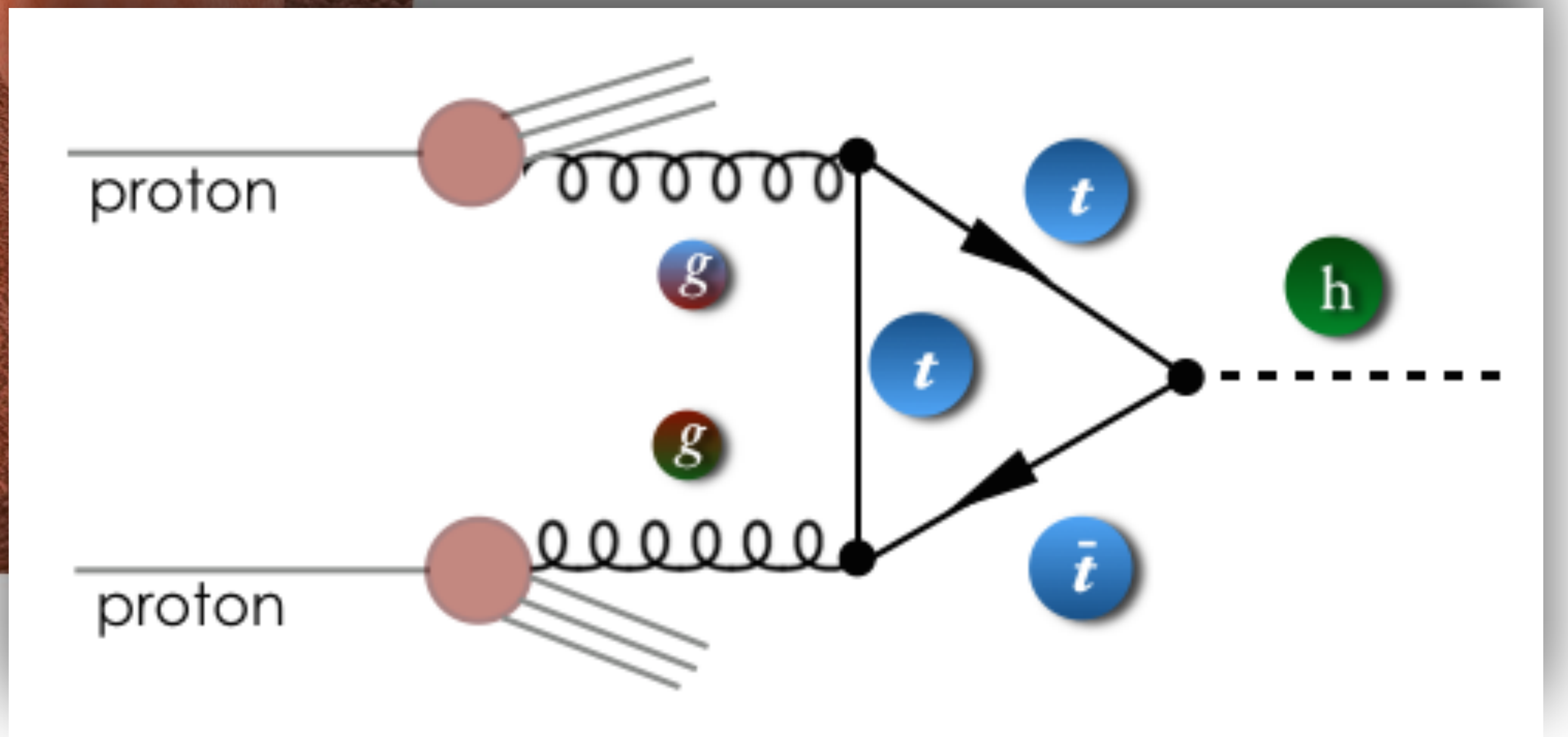
A Higgs-boson *factory*

How can we "see" it? First, we try to produce it

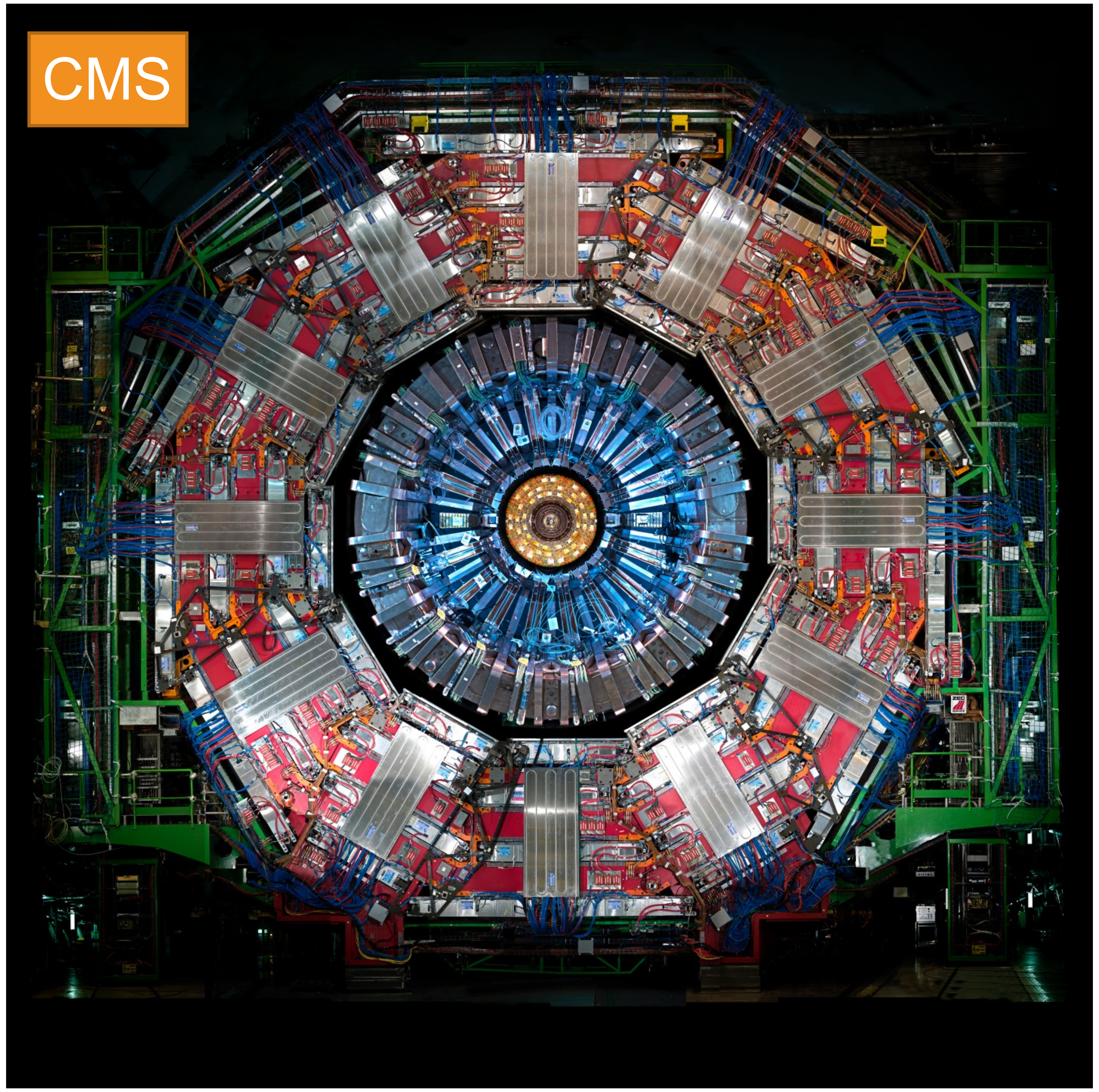
The Large Hadron Collider @ CERN

- Proton-proton collisions up to 13 TeV

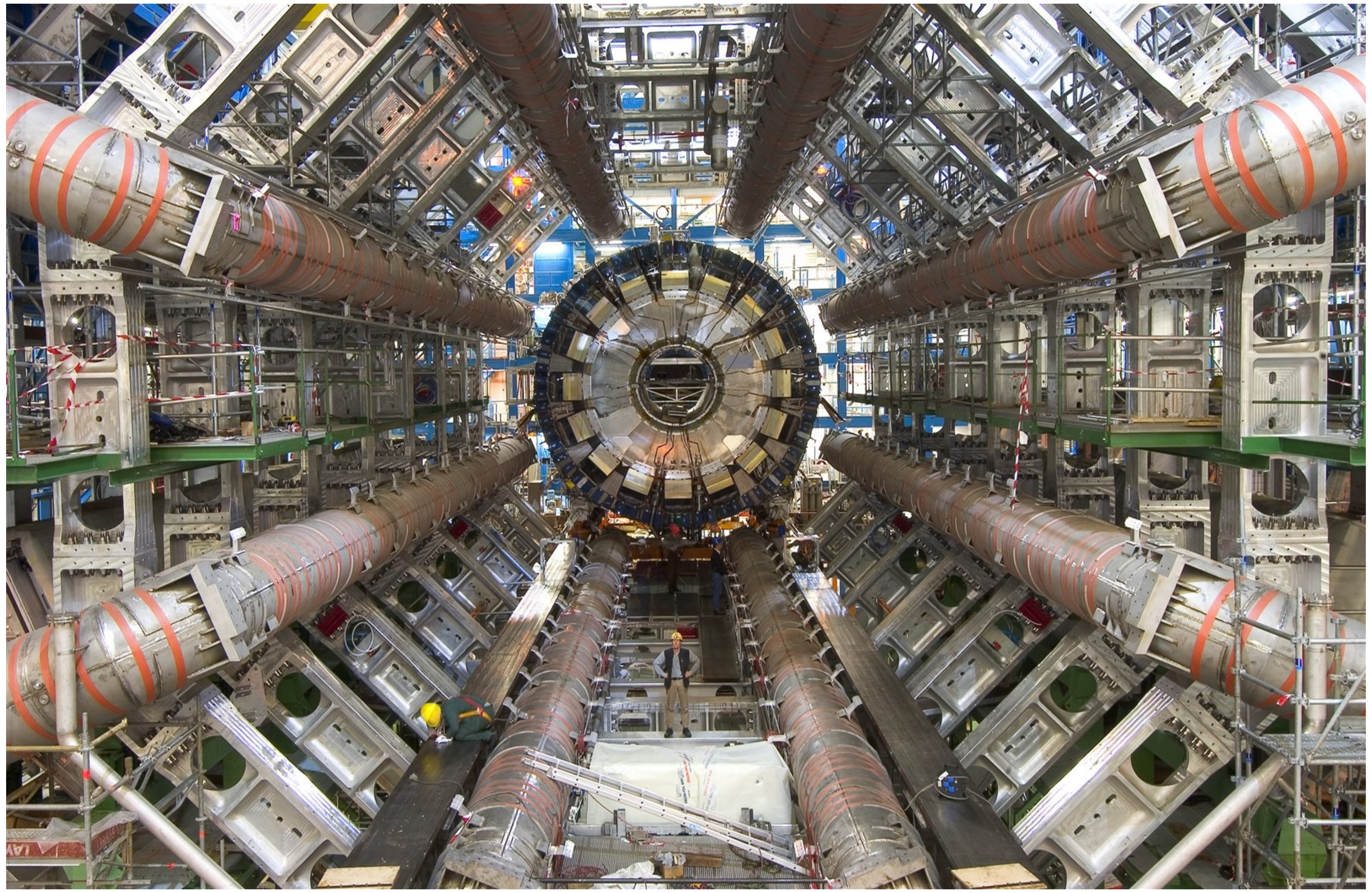




Our *eyes* to see the Higgs

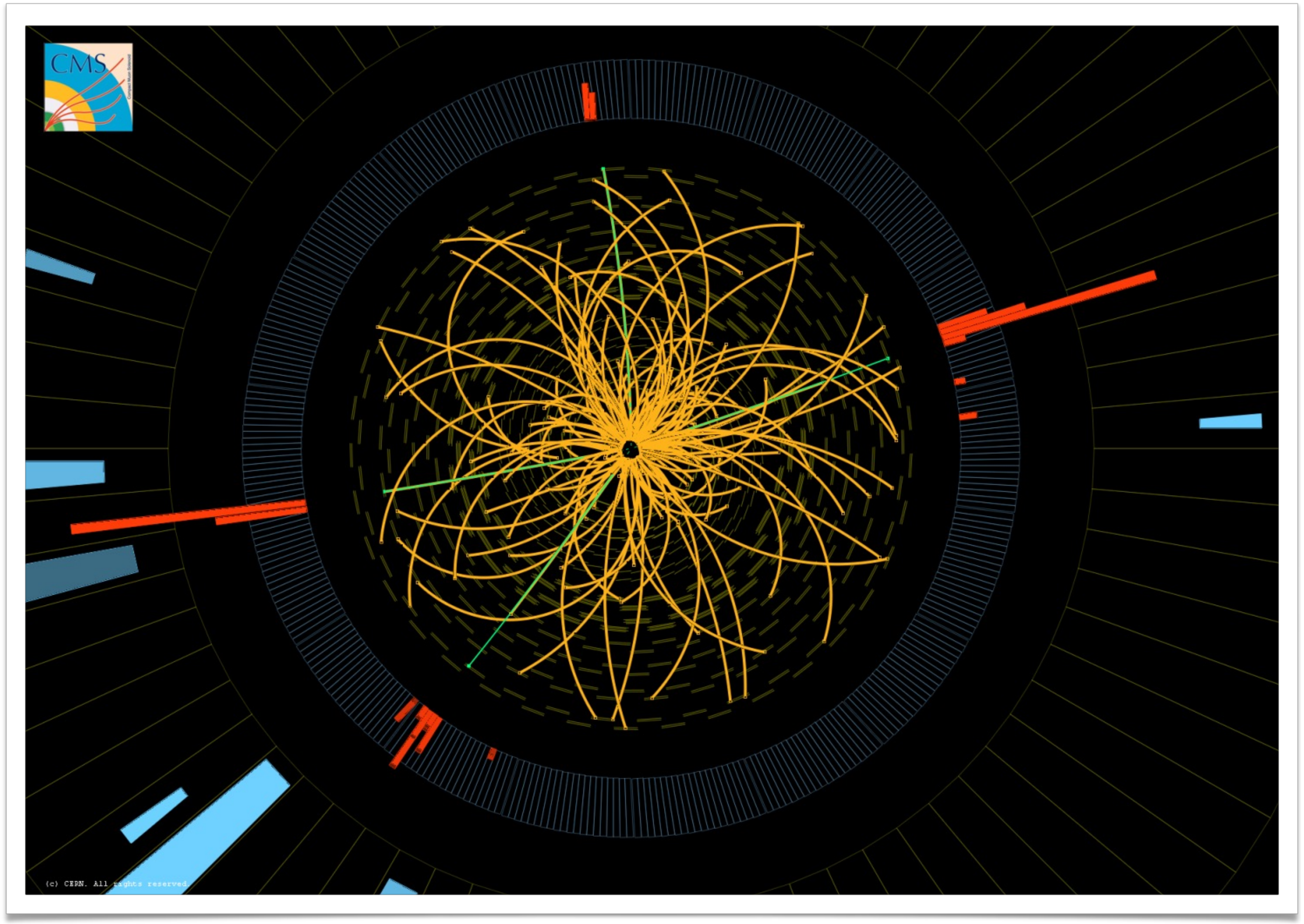


ATLAS



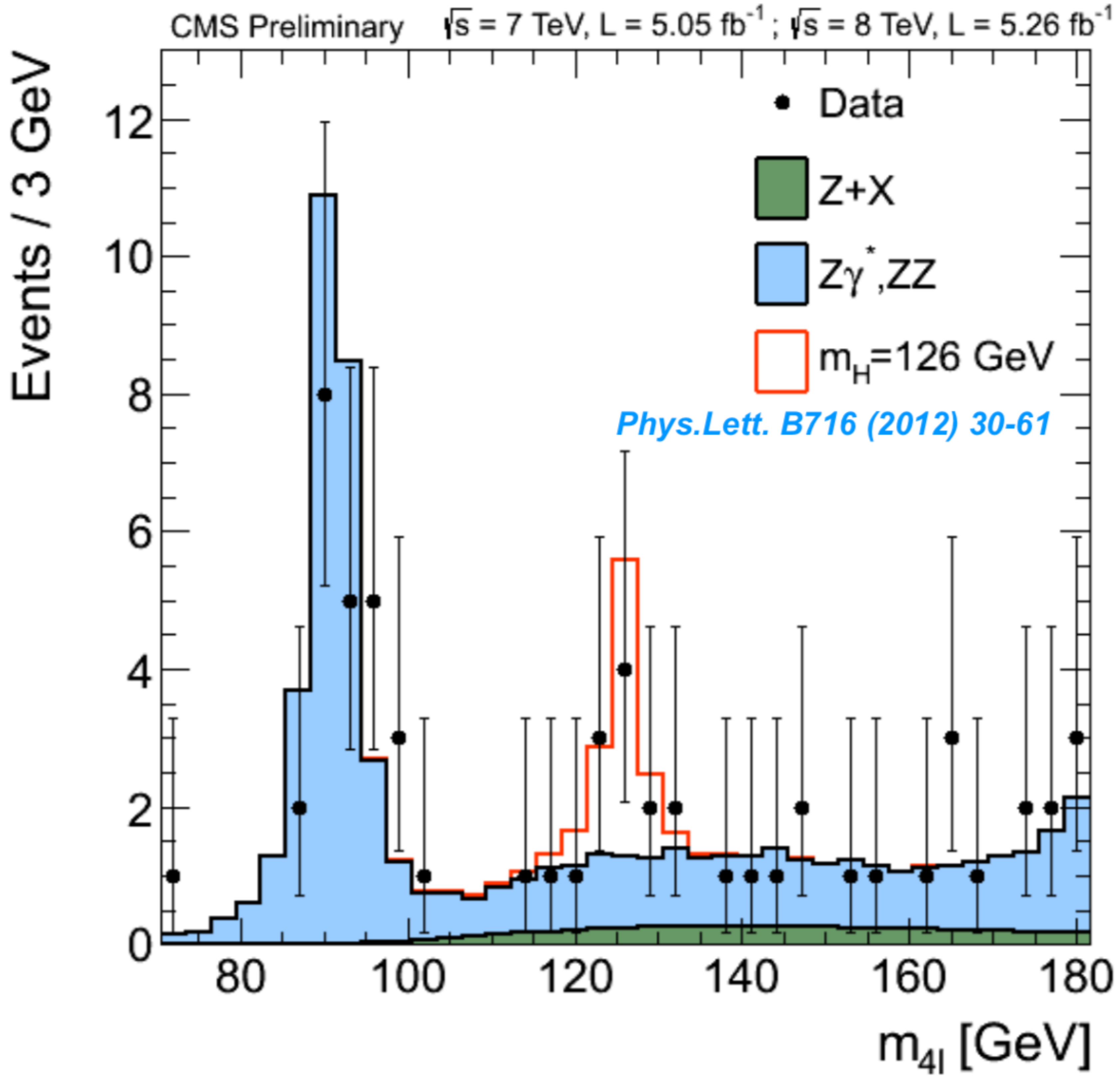
- The lifetime of the Higgs boson is extremely short: detect and measure the **decay products**
- **Largest and most complex detectors ever built**

A *picture* of the Higgs boson



After many of such pictures

A peak in the invariant mass distribution



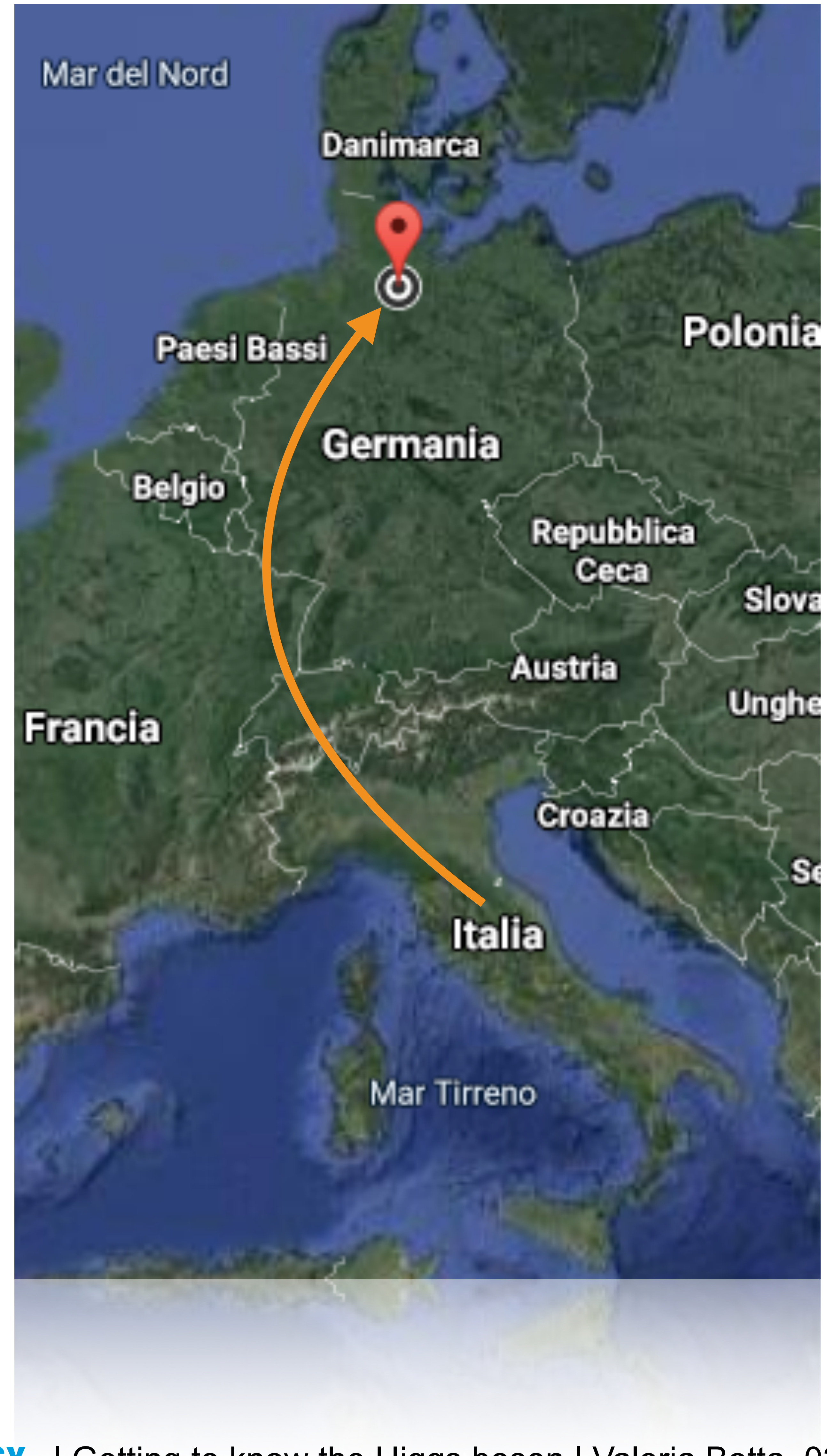
- It it repeats many times, can't just be by chance
  - The 5 sigma criterion

July 4th, 2012 @ CERN

- **Discovery of the Higgs particle** announced on July 4th 2012 by ATLAS & CMS
  - **Nobel prize** 2013 to Higgs and Englert

Denis Balibouse, Pool/AP

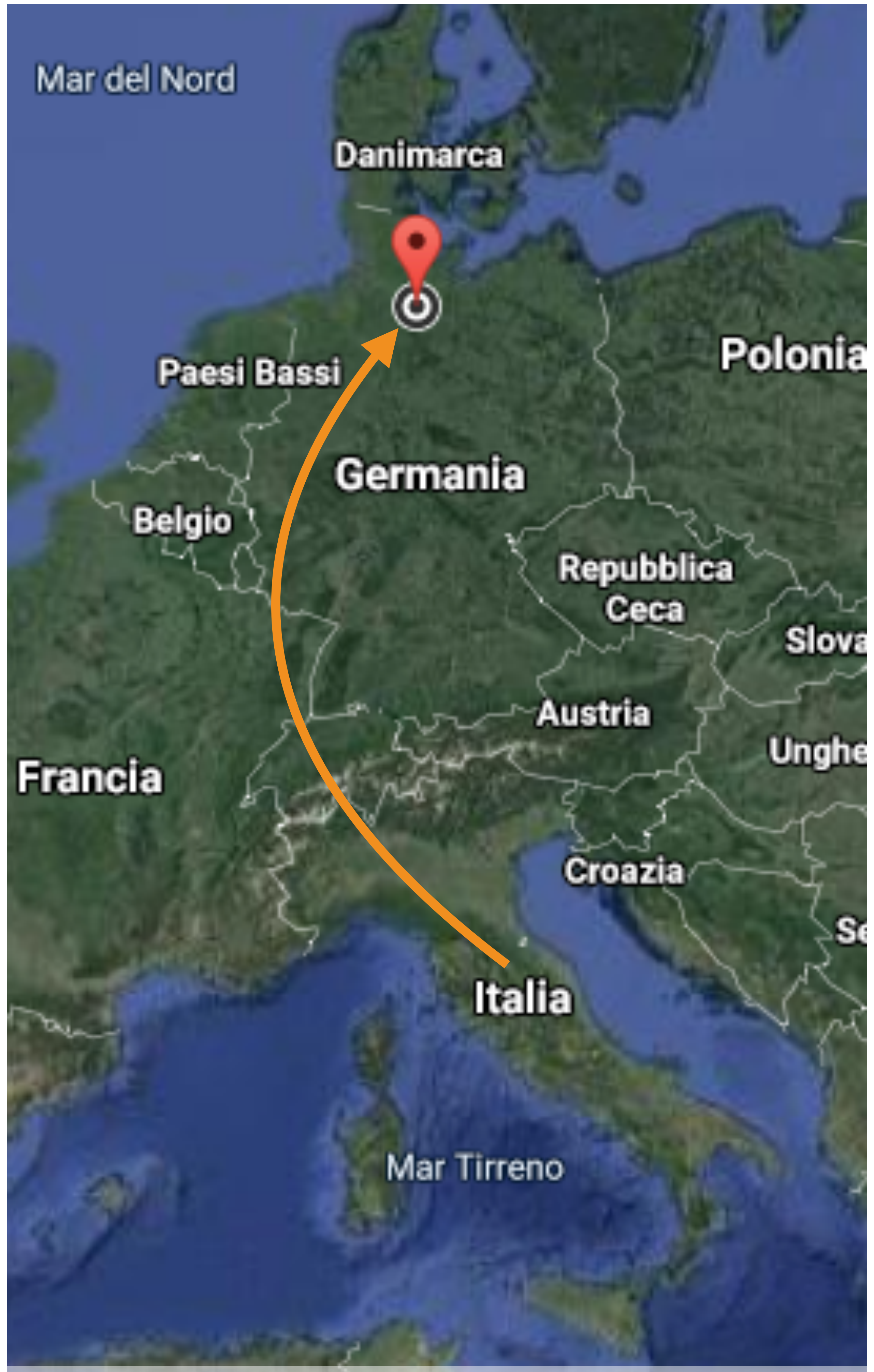
July 16th, 2012 @ DESY



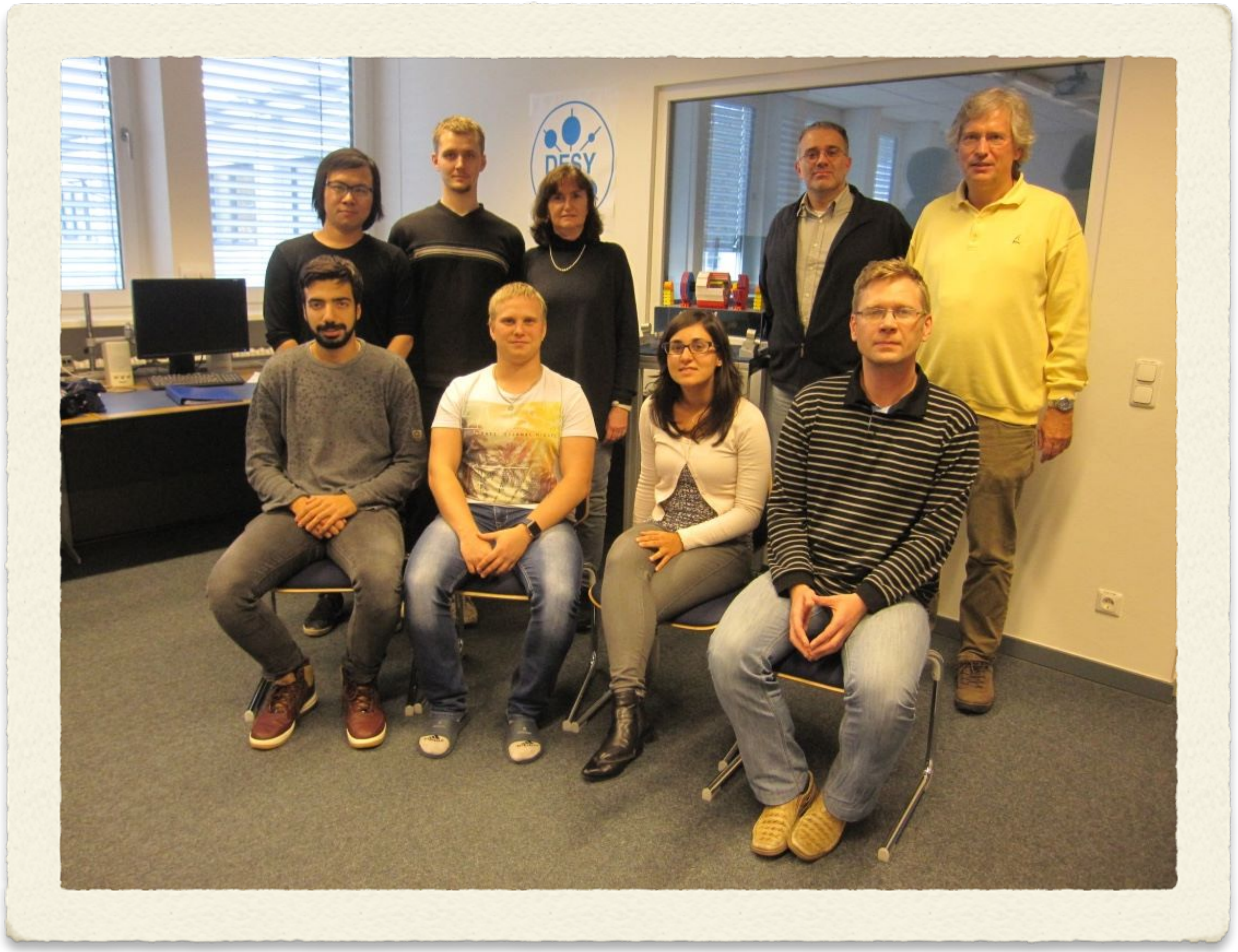
- I arrived as a **summer student**
  - Got a project on the **CMS** experiment (!)
  - First contact with real research

Group picture, Hamburg summer students 2012

A few years later…

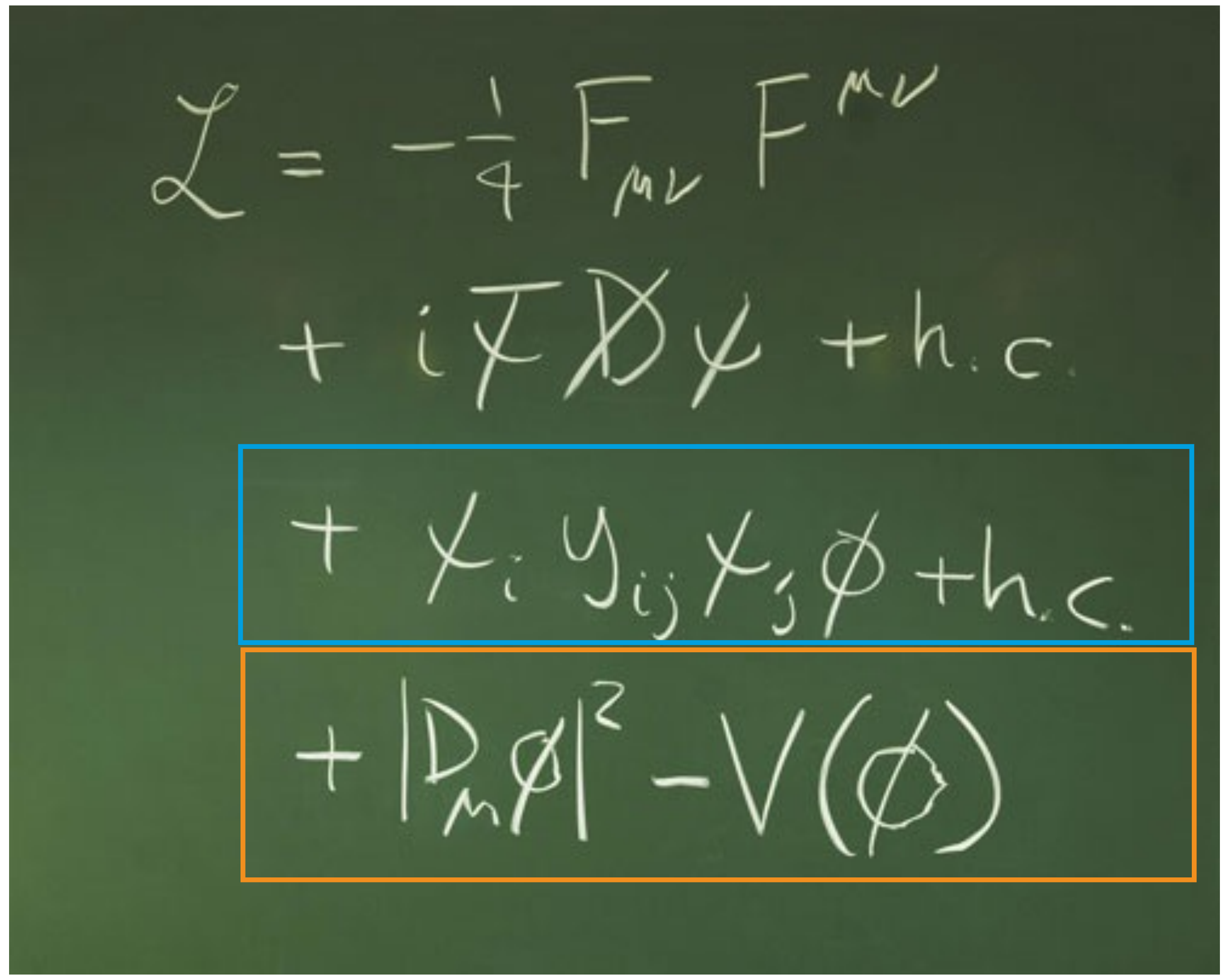


- Back to DESY for my PhD in 2015
- **Higgs boson measurement in the decay to tau leptons (CMS)**
  - Supervision of Prof. Elisabetta Gallo and Dr. Alexei Raspereza

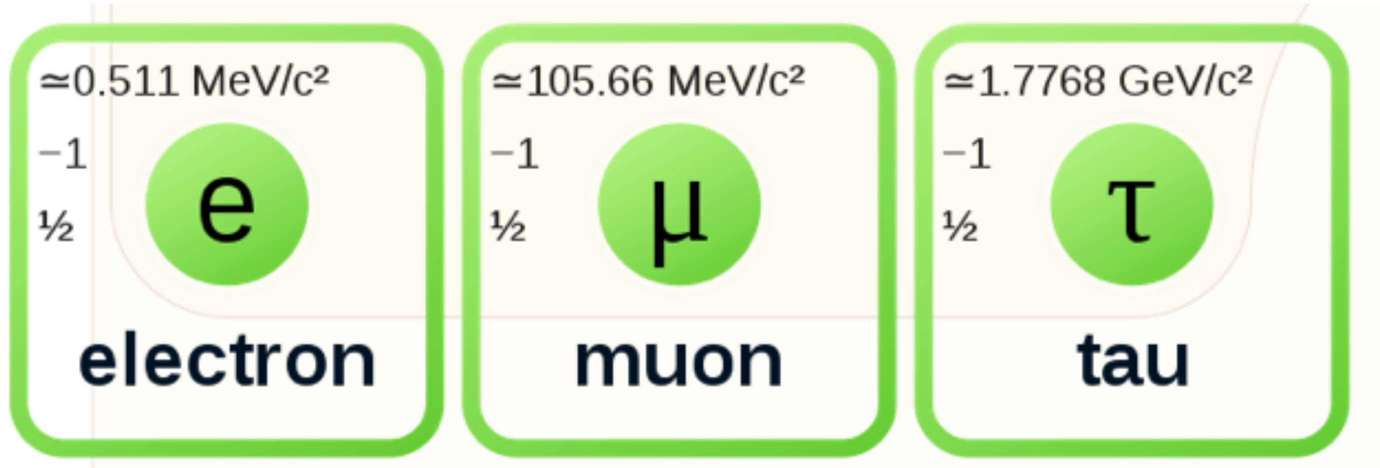


Why tau leptons?

- The Higgs boson was discovered in decays to bosons (ɣ, Z)
- Direct measurement of coupling to fermions fundamental to probe its nature

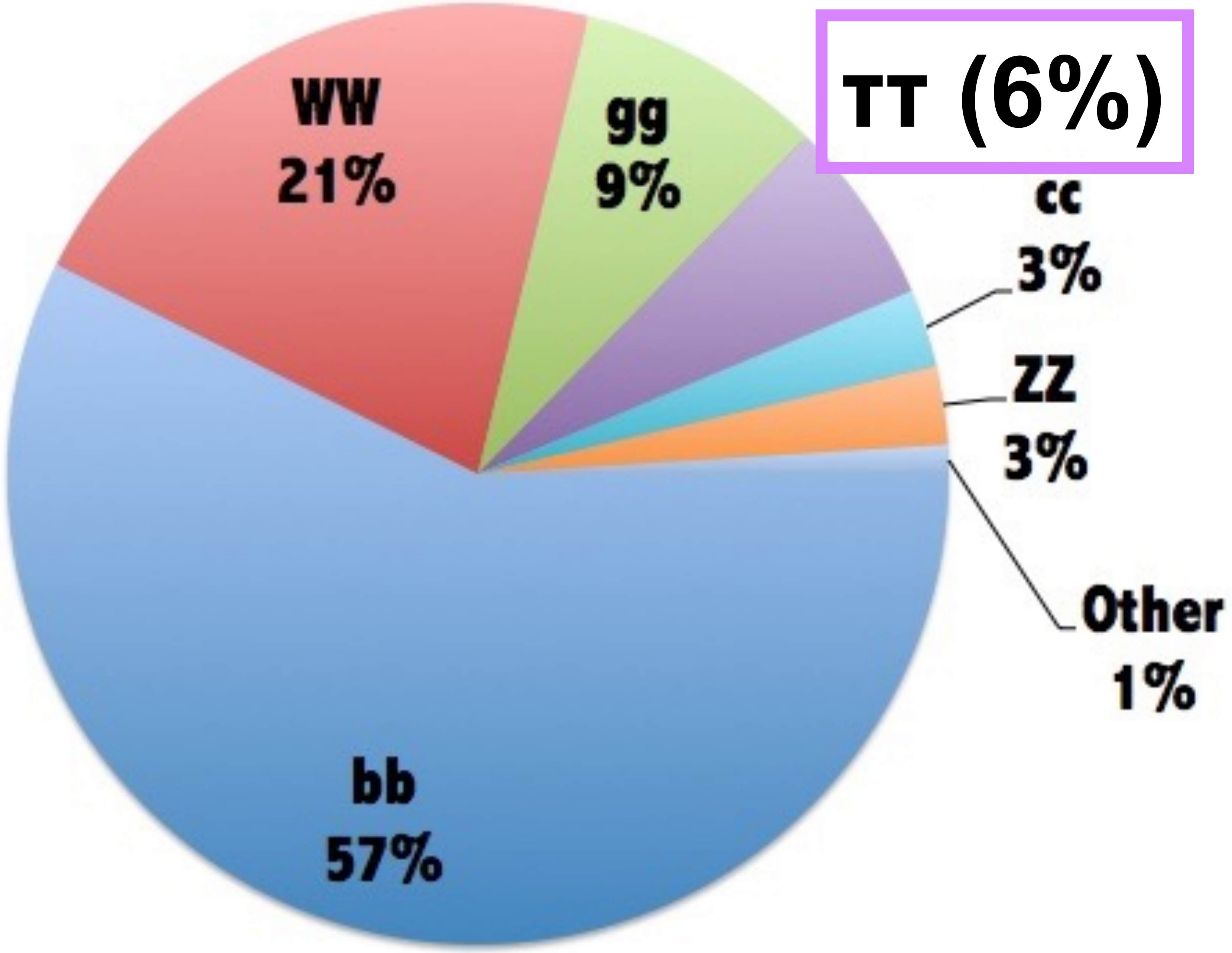


- Higgs coupling proportional to mass

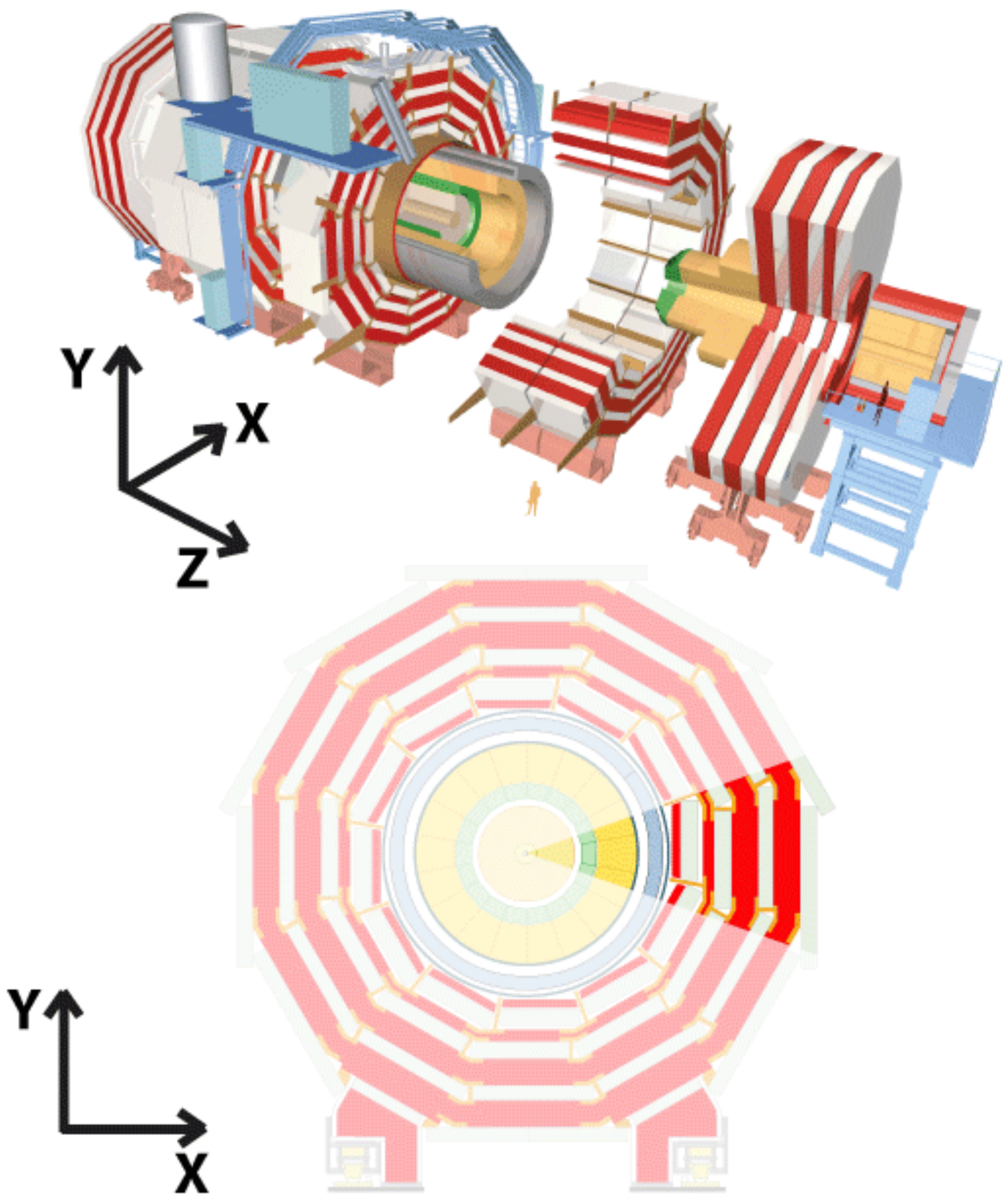


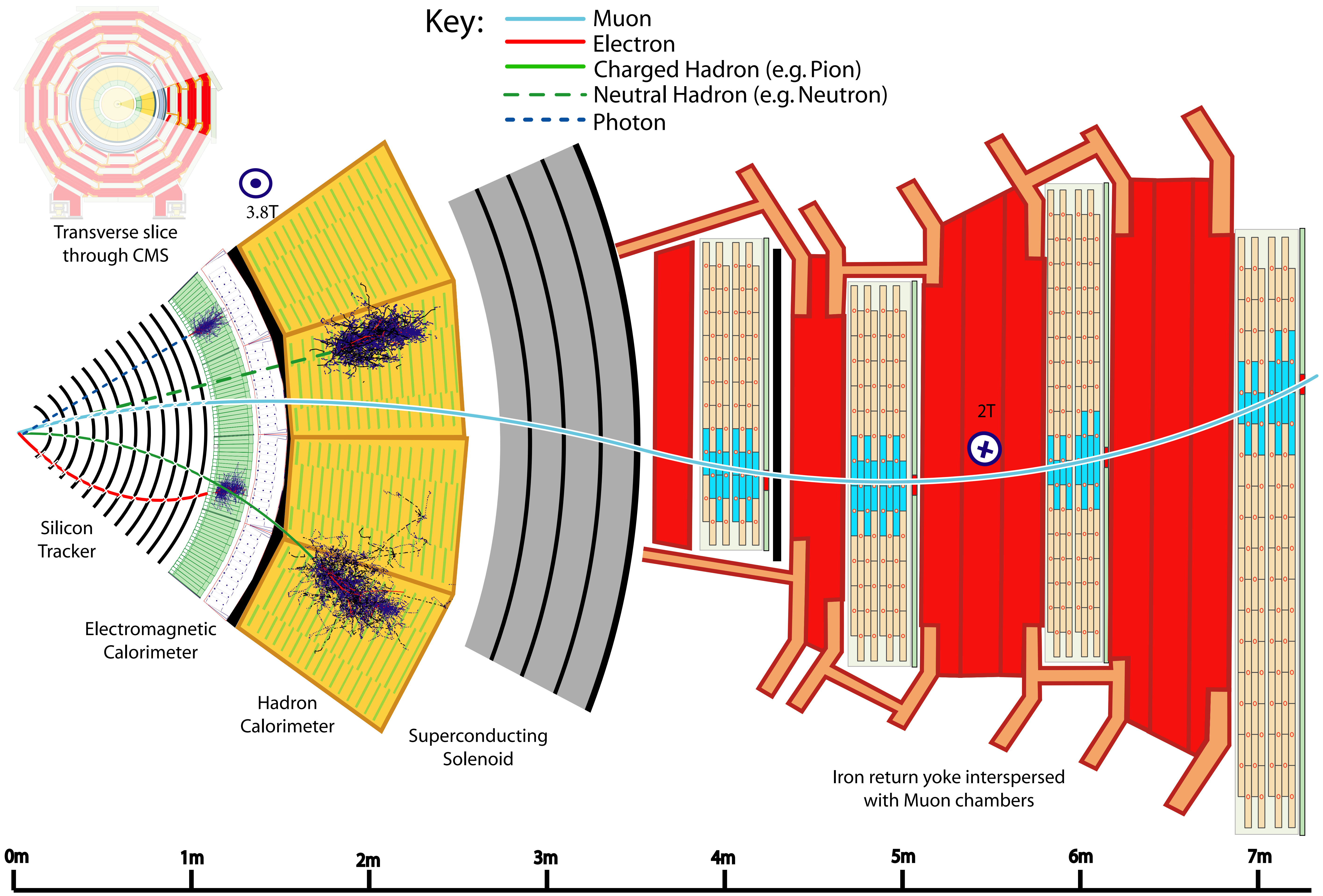
light → heavy

- Decay to tau tau is the **most important channel** despite its low branching fraction
  - Measurement of decays to bb suffers from large backgrounds



Detecting and measuring particles

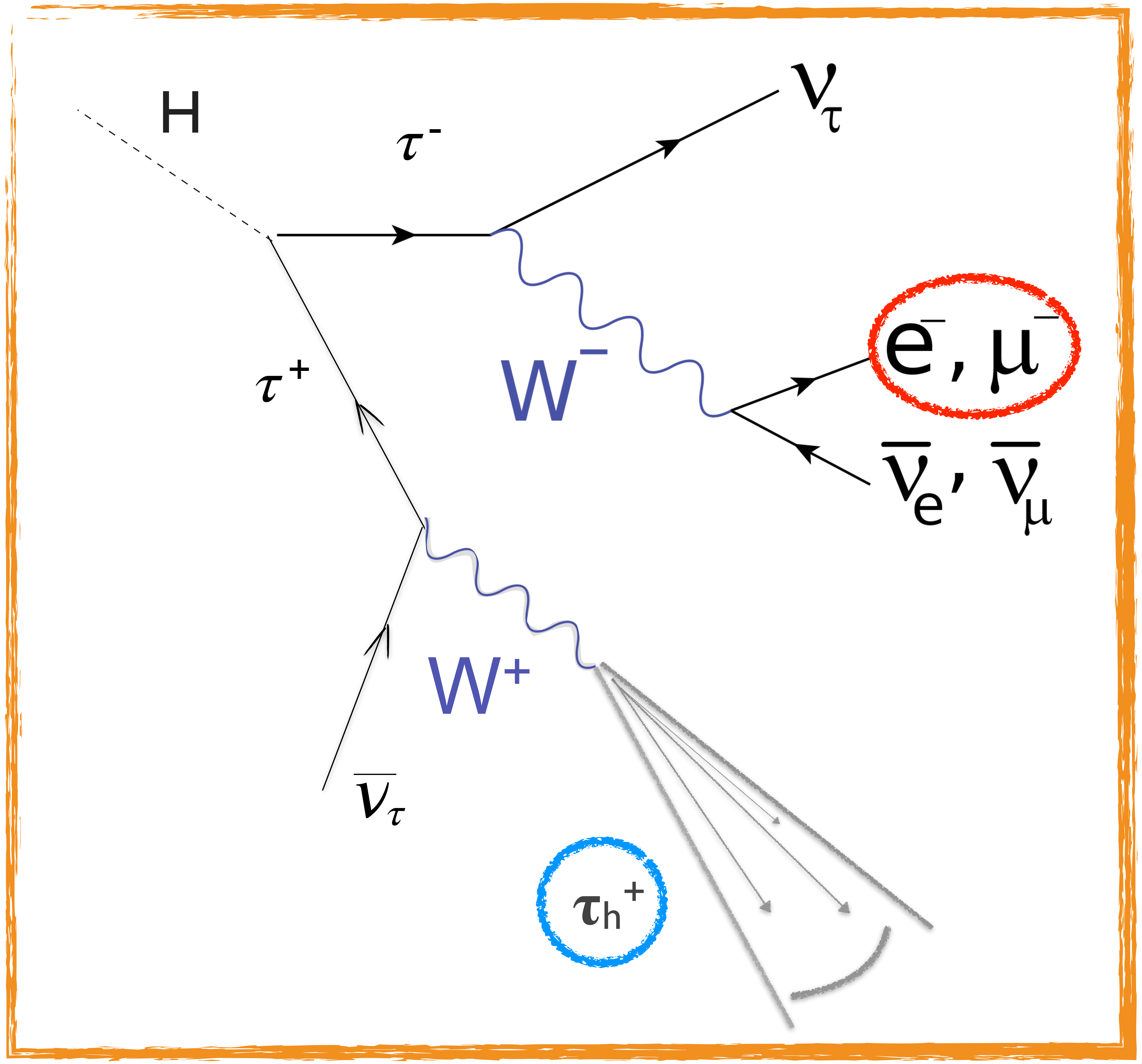




- Information from different subsystems exploited to identify and optimally reconstruct particles

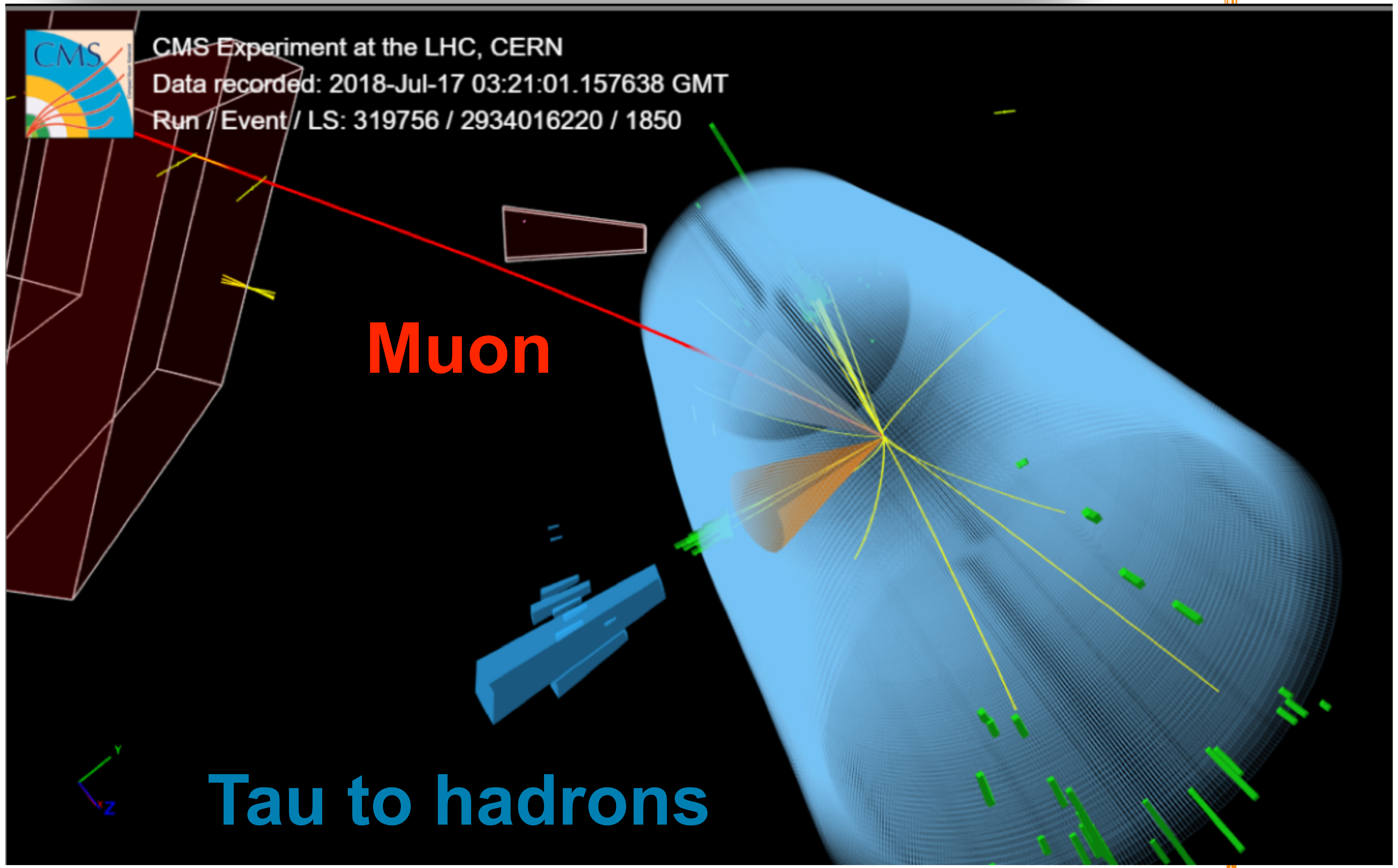
How does a H(ττ) event look like?

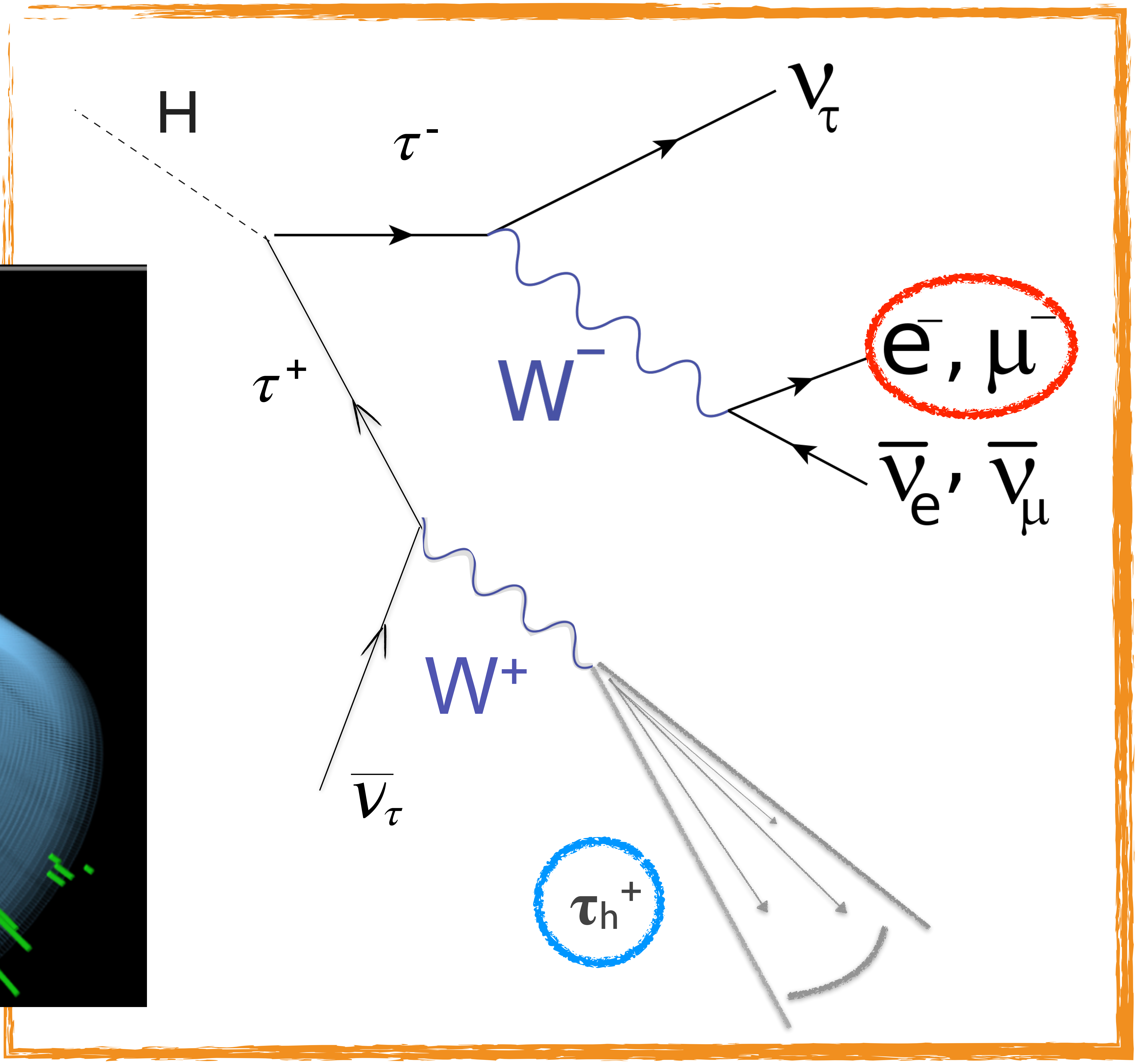
- It depends on how the tau lepton decays
  - Charged hadrons (τ_{had}) + a neutrino
  - Muon or electron + neutrinos



How does a H(ττ) event look like?

- It depends on how the tau lepton decays
  - Charged hadrons (τ_{had}) + a neutrino
  - Muon or electron + neutrinos



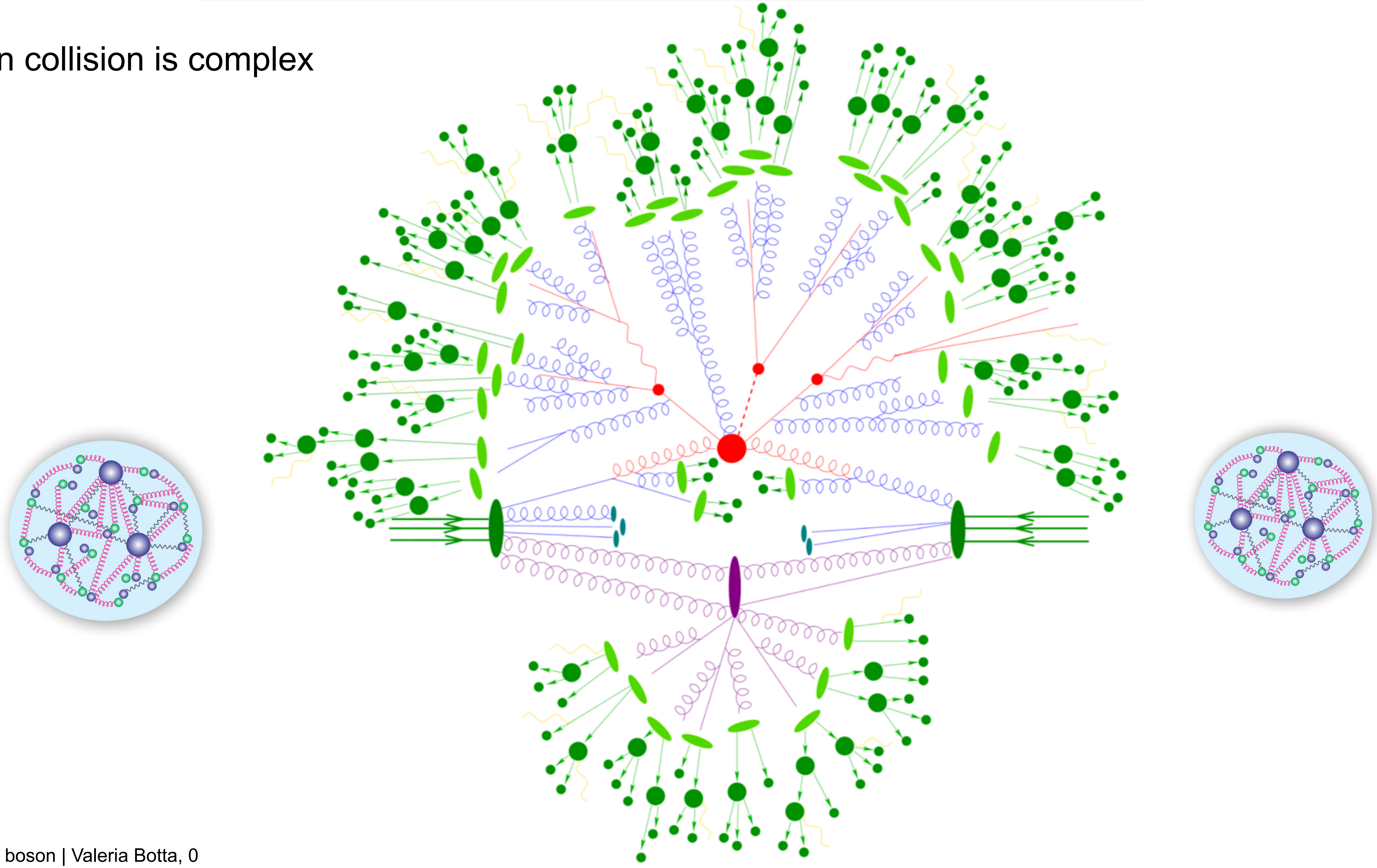


What are the challenges?

1. Many collisions happen at the same time @ the LHC

What are the challenges?

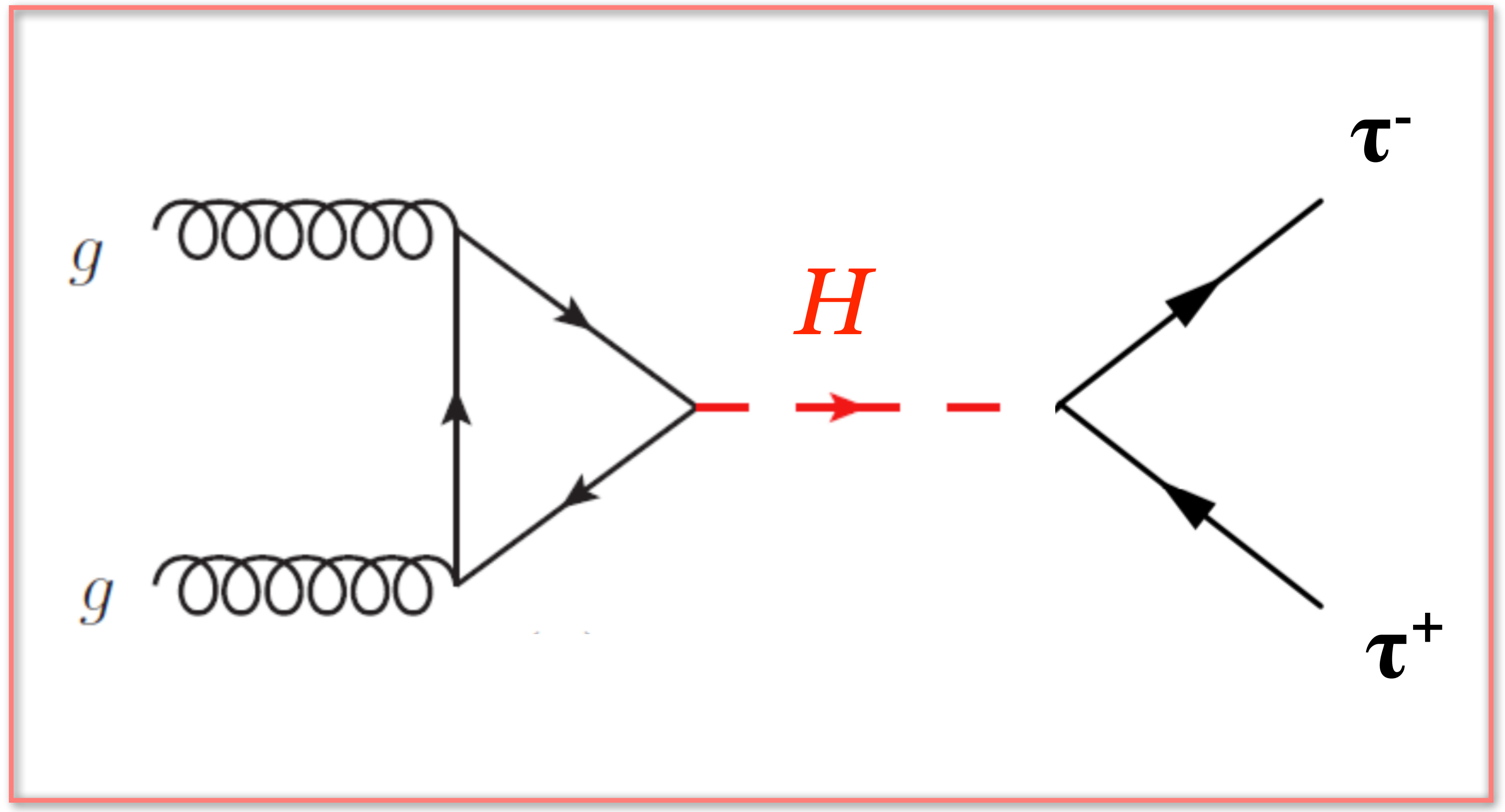
2. A proton-proton collision is complex



What are the challenges?

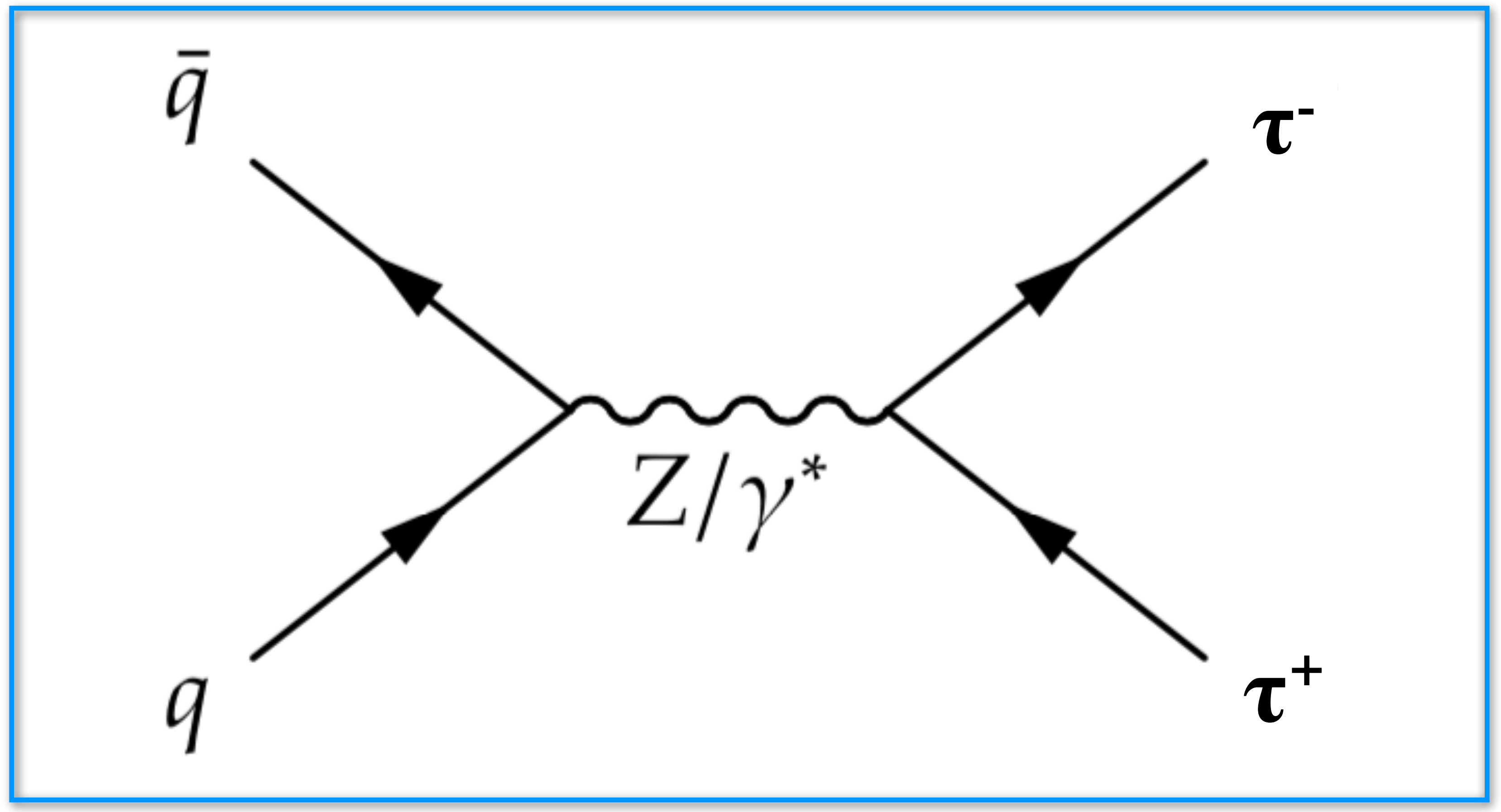
3. The production of a Higgs boson is rare. The same particle content can be produced by other processes

Signal



1 event

Irreducible background



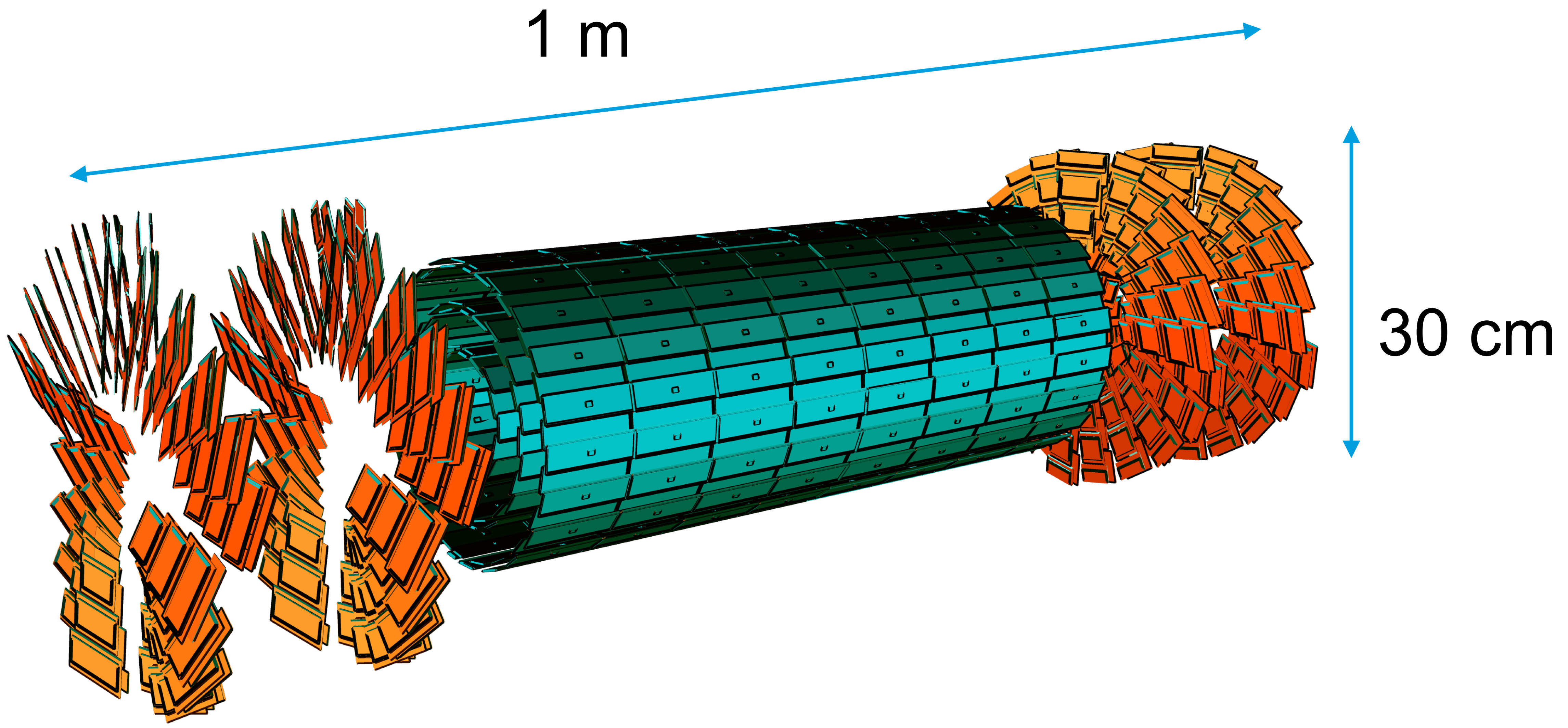
700 events

- Z and H bosons have different masses —> precise measurement of the particle momentum is crucial

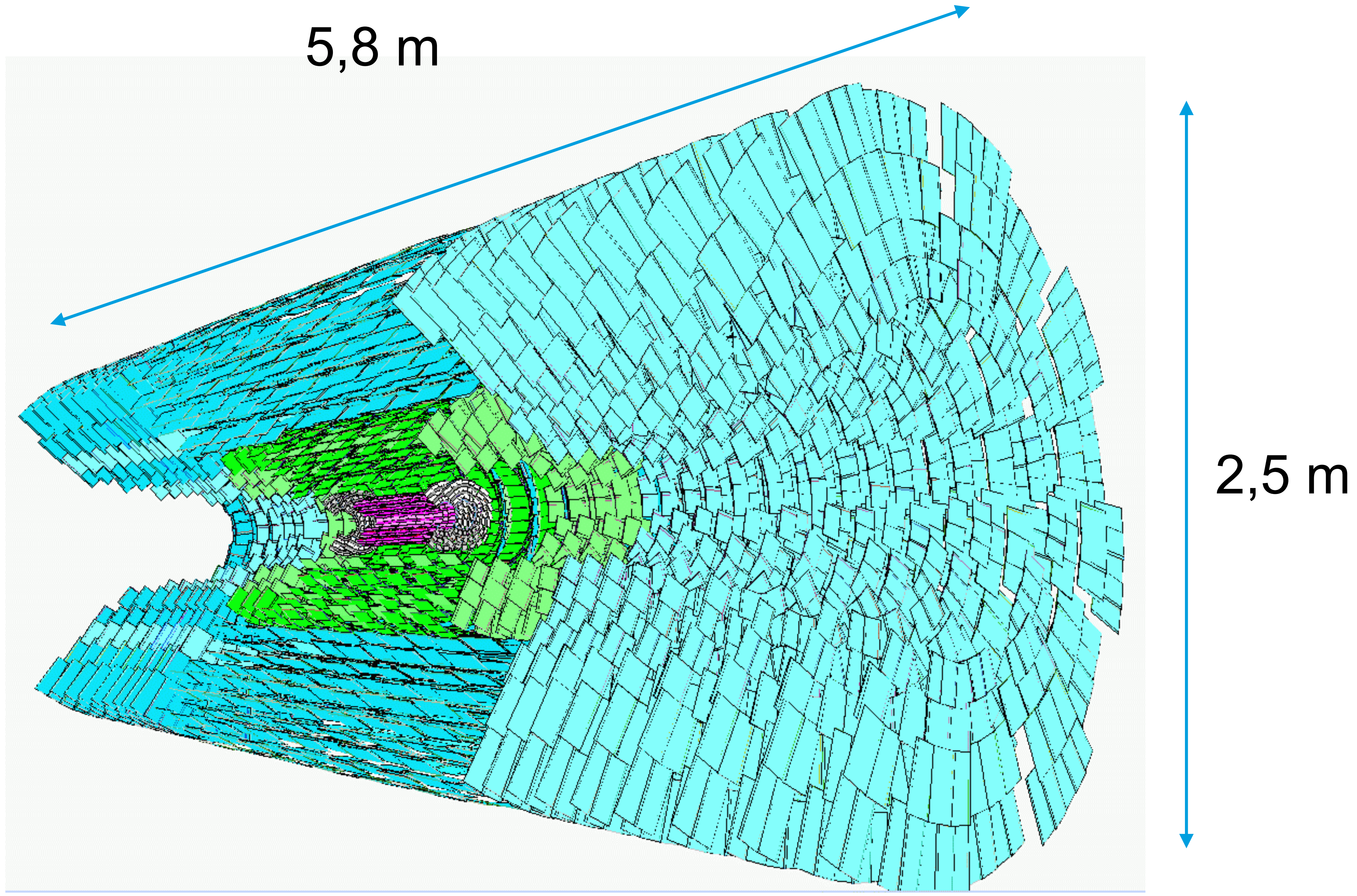
The CMS inner tracker

- The largest silicon tracker
- A very large magnetic field (3.8 T)
- Complemented by the muon spectrometer (increase leverage arm)

Momentum resolution for tracks with p_T O(10 GeV) at subpercent level



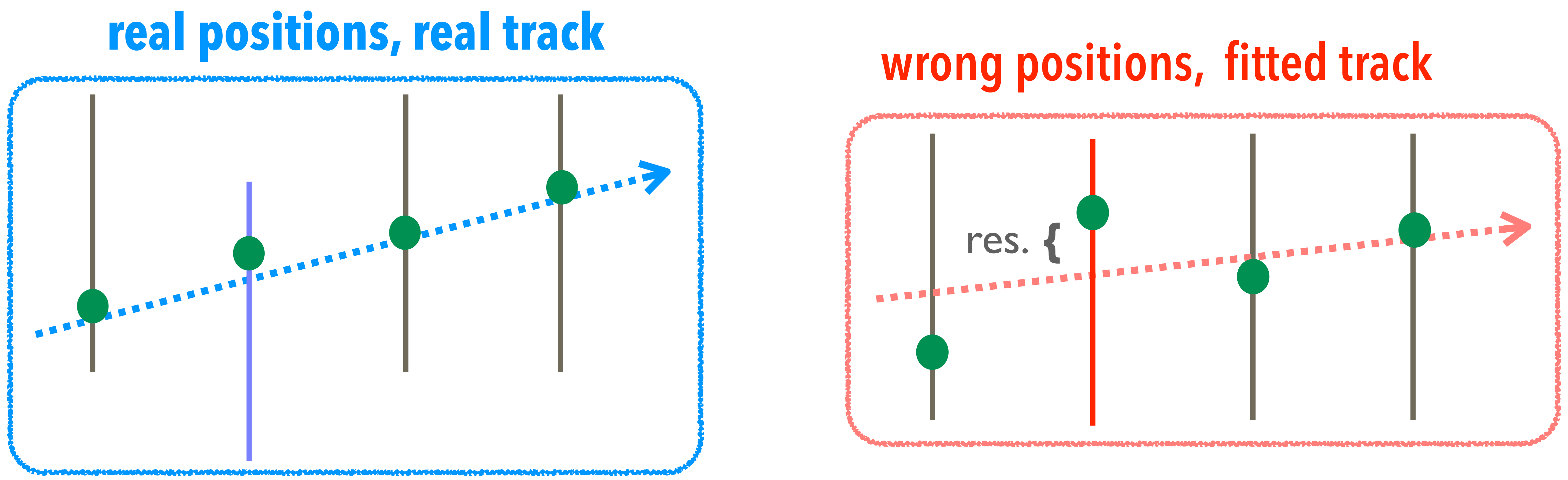
https://cds.cern.ch/record/1225466

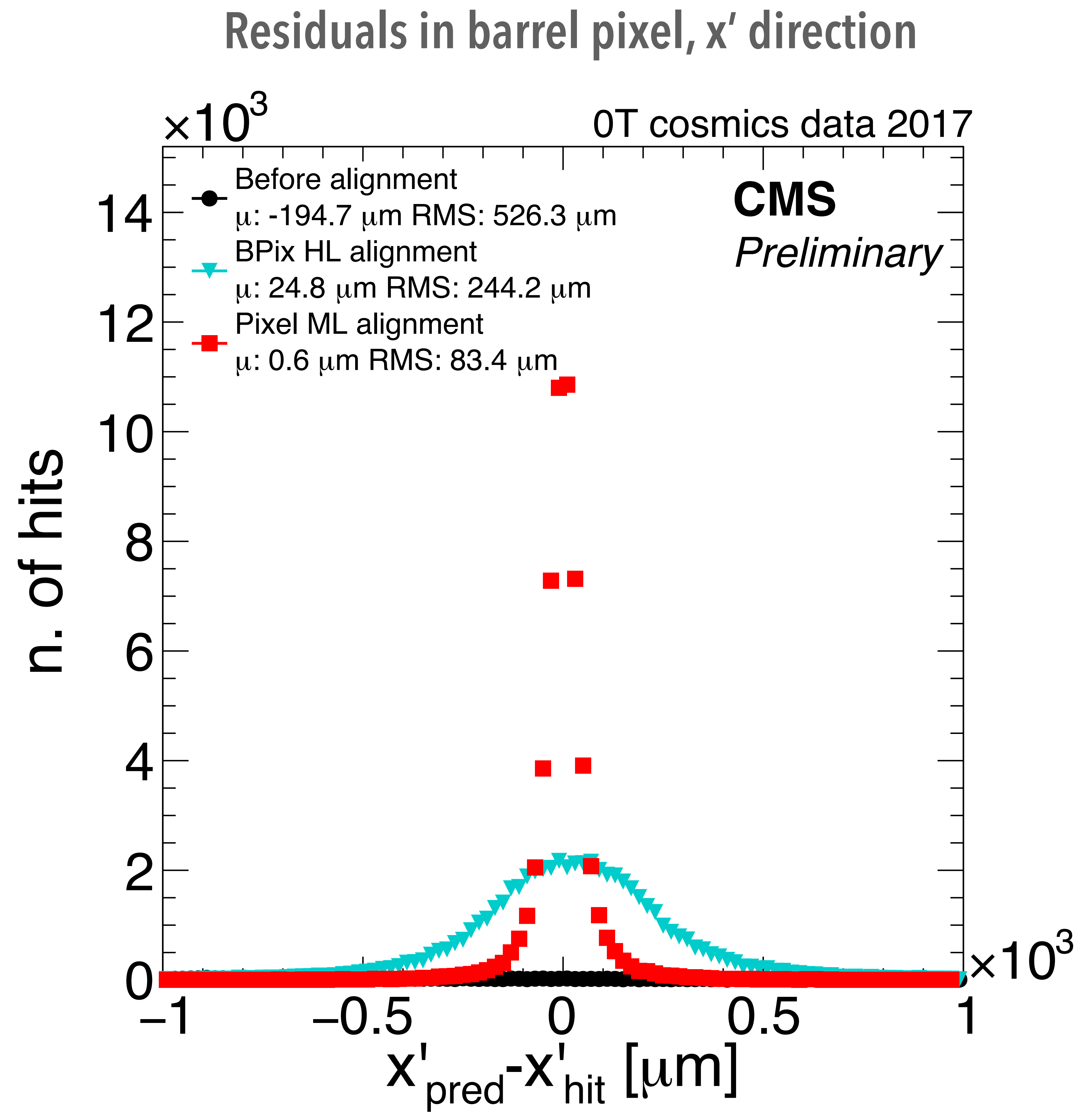


http://zitogiuseppe.com/cms/tracker2.gif

Calibration is essential: tracker alignment

- Tracks are reconstructed fitting a set of hits on the tracker modules.
- Assuming wrong modules positions leads to bias in the reconstructed track



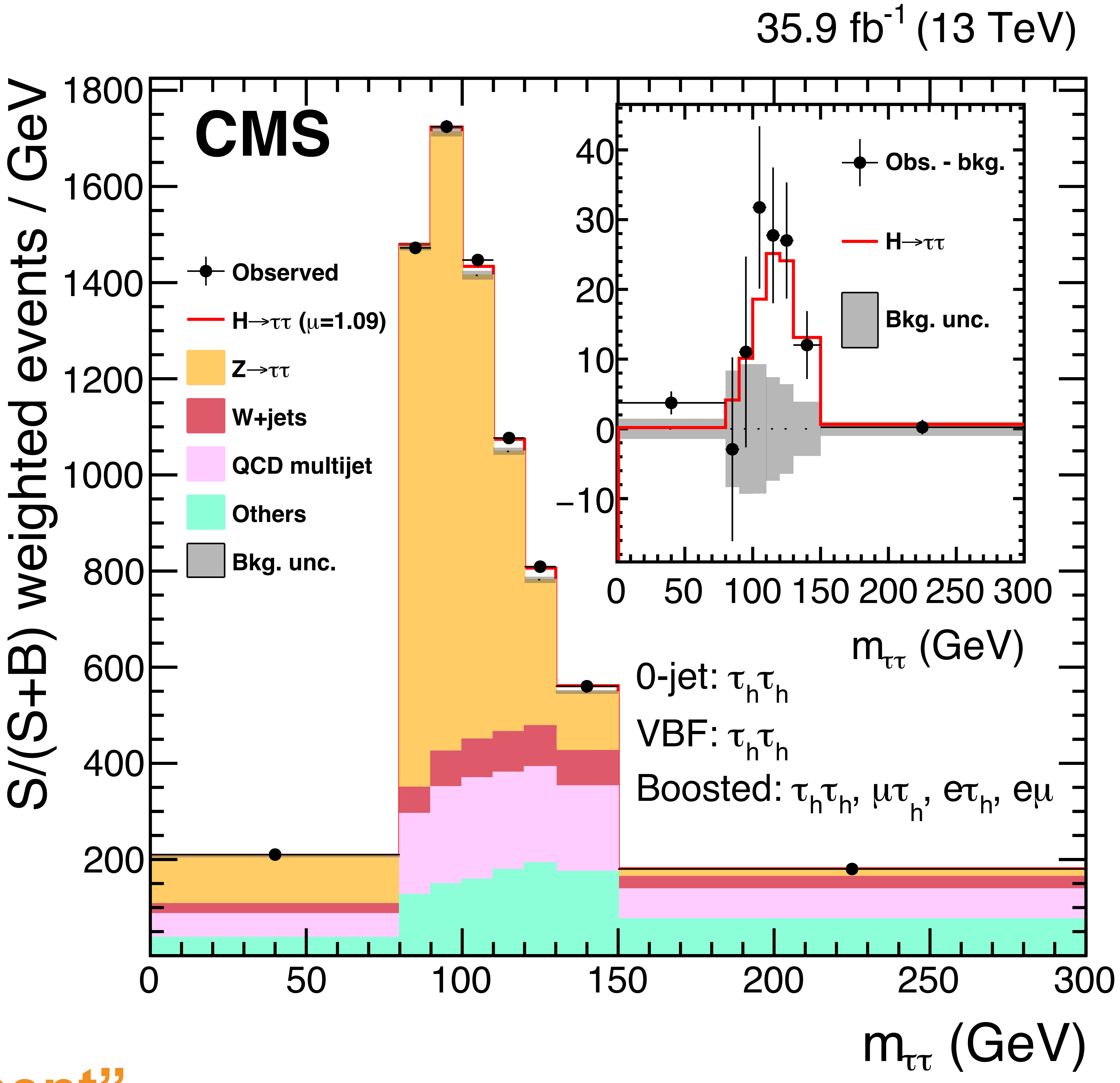


- Goal: measure position of single modules with a precision of a few micrometers

- My key contribution
  - **Study and execution of the first alignment of the new pixel detector (2017)**

The final results

- Despite a great detector and calibration, accurate data reconstruction, …
- Not possible to reject all backgrounds
  - Accurate simulation, corrections derived from data
- Excess of events as expected by a Higgs boson
  - Observed significance of 4.9 sigma
  - Cross section compatible with the expectation



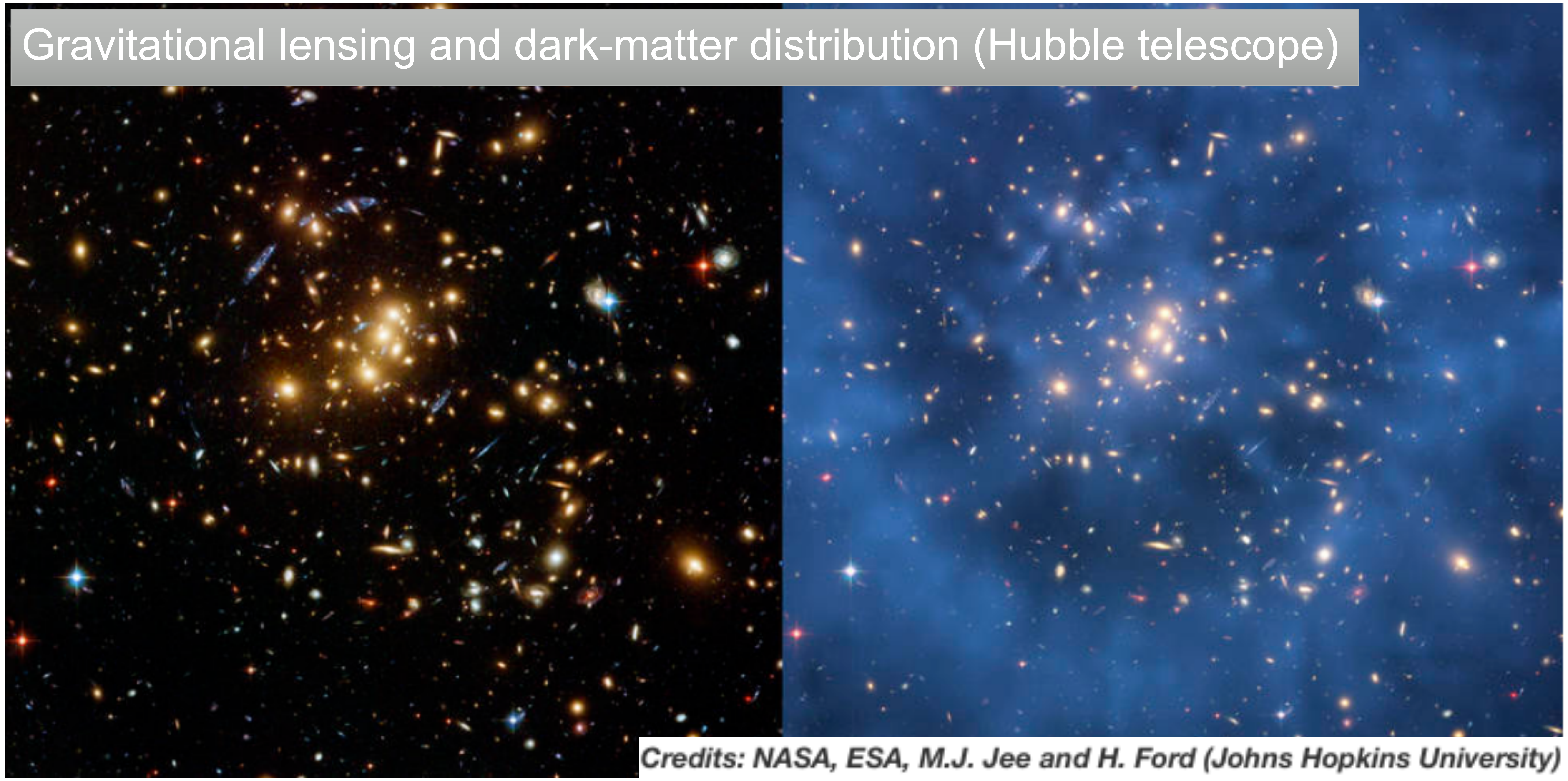
Combined with the 2012 result by CMS,

"First observation of H(ττ) decay by a single experiment"

Phys. Lett. B 779 (2018) 283

Standard Model

- Big open questions: dark matter, matter-antimatter asymmetry, ….



Actually, this is just the beginning

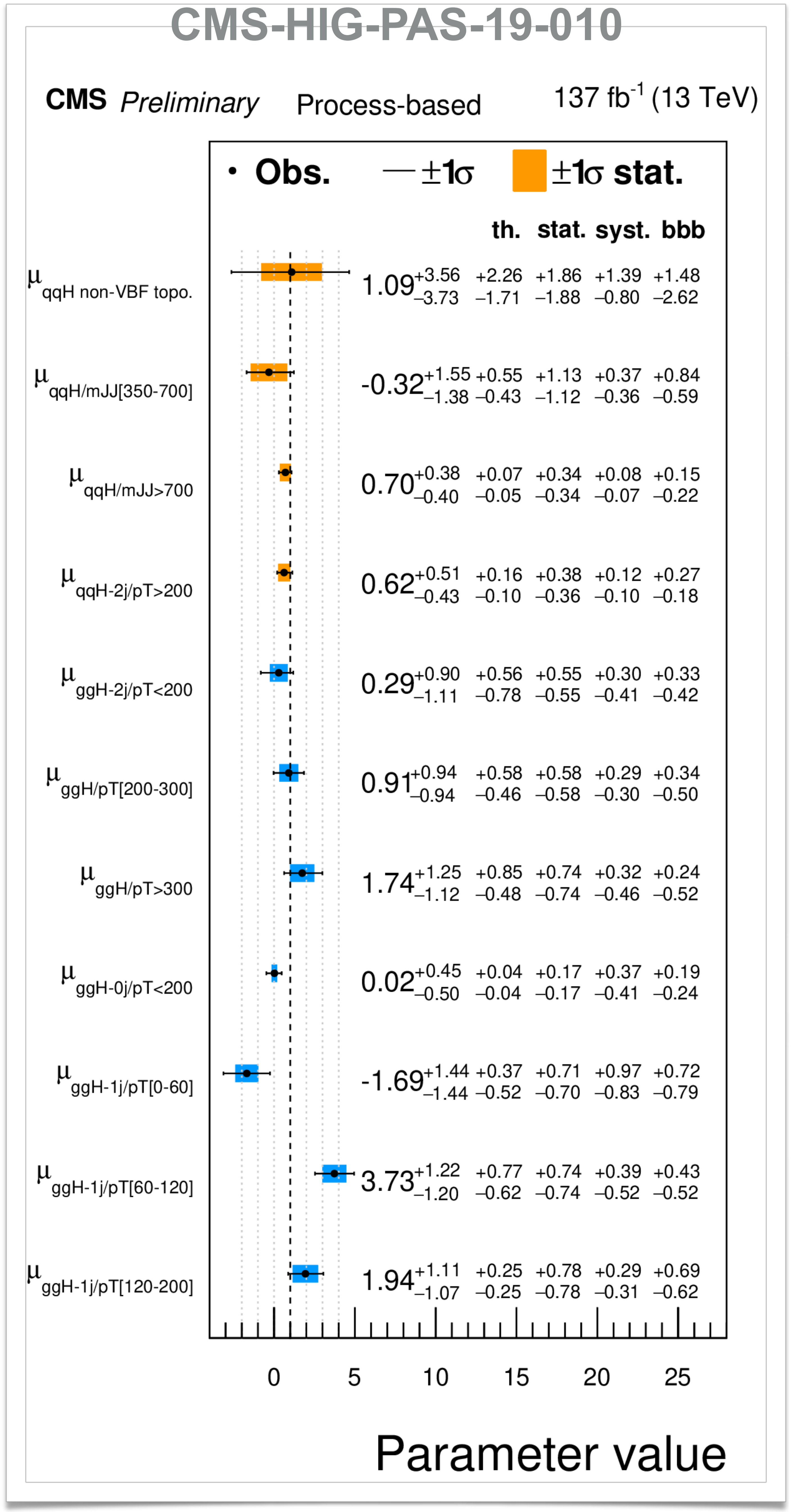
- Does the Higgs boson interact with ***unknown*** particles?
- Is there only ***one*** Higgs boson?
- Does the "Standard Model" Higgs boson behave as predicted?
  - More ***precise*** measurement, new effects can be small

Higgs physics is moving discovery to precision era

It's now that things start becoming interesting!

DESY is playing a key role in Higgs physics

- **Theory and both LHC experiments!**



Thank you for your attention.

Contact

Valeria Botta
DESY Hamburg

valeria.botta@desy.de