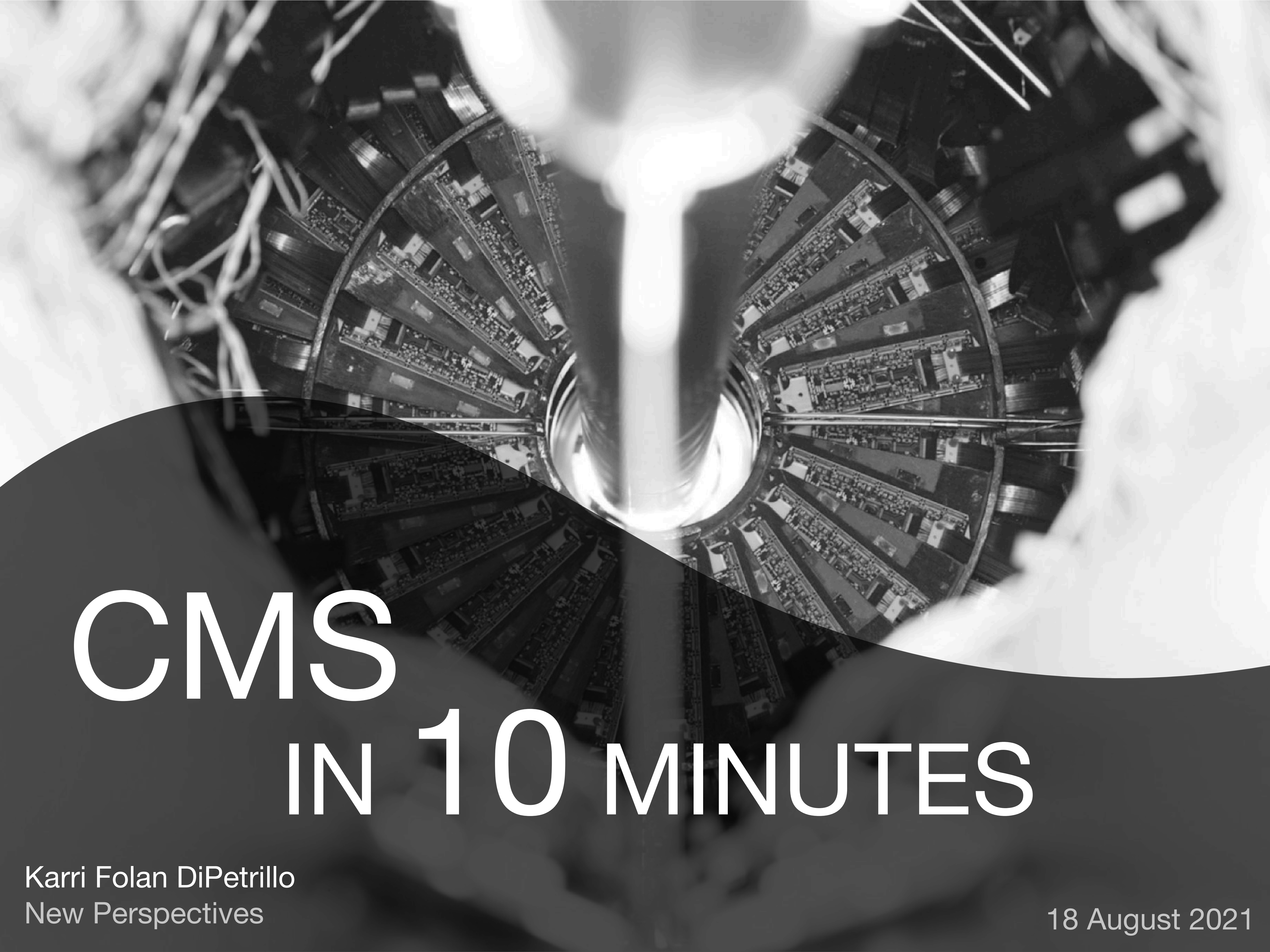


CMS IN 10 MINUTES

Karri Folan DiPetrillo
New Perspectives

18 August 2021

Why high energy physics?

Goal: discover evidence of physics
beyond the Standard Model

Working on CMS is an *effective* and *exciting* way
to search for new particles at the TeV scale

Dark matter

Extra Dimensions

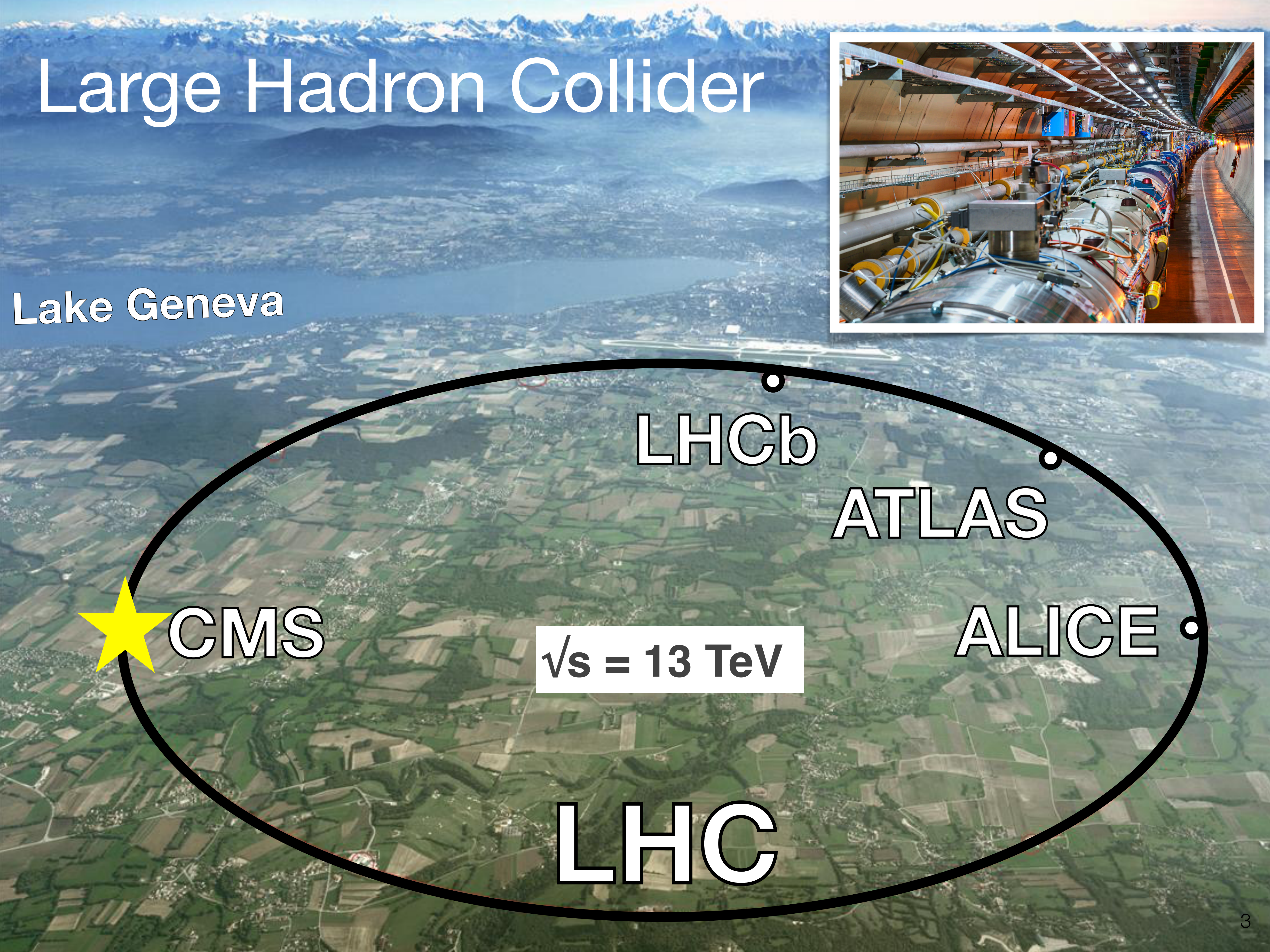
Supersymmetry

Neutral Naturalness

Micro Black Holes

High energy colliders have a long history of success,
including the discovery of the Higgs Boson

Large Hadron Collider



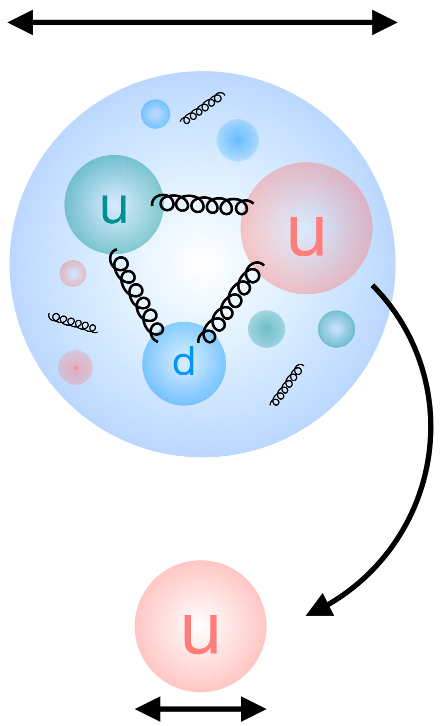
Colliding quarks and gluons

Quantum mechanics tells high energies ↔ small distances

LHC 13 TeV energy probes distance scales of ~10^{-19} m

Protons

10^{-15} m



Partons

quarks, gluons

≤10^{-18} m

LHC is actually colliding quarks/gluons, which carry a fraction of the proton's momentum

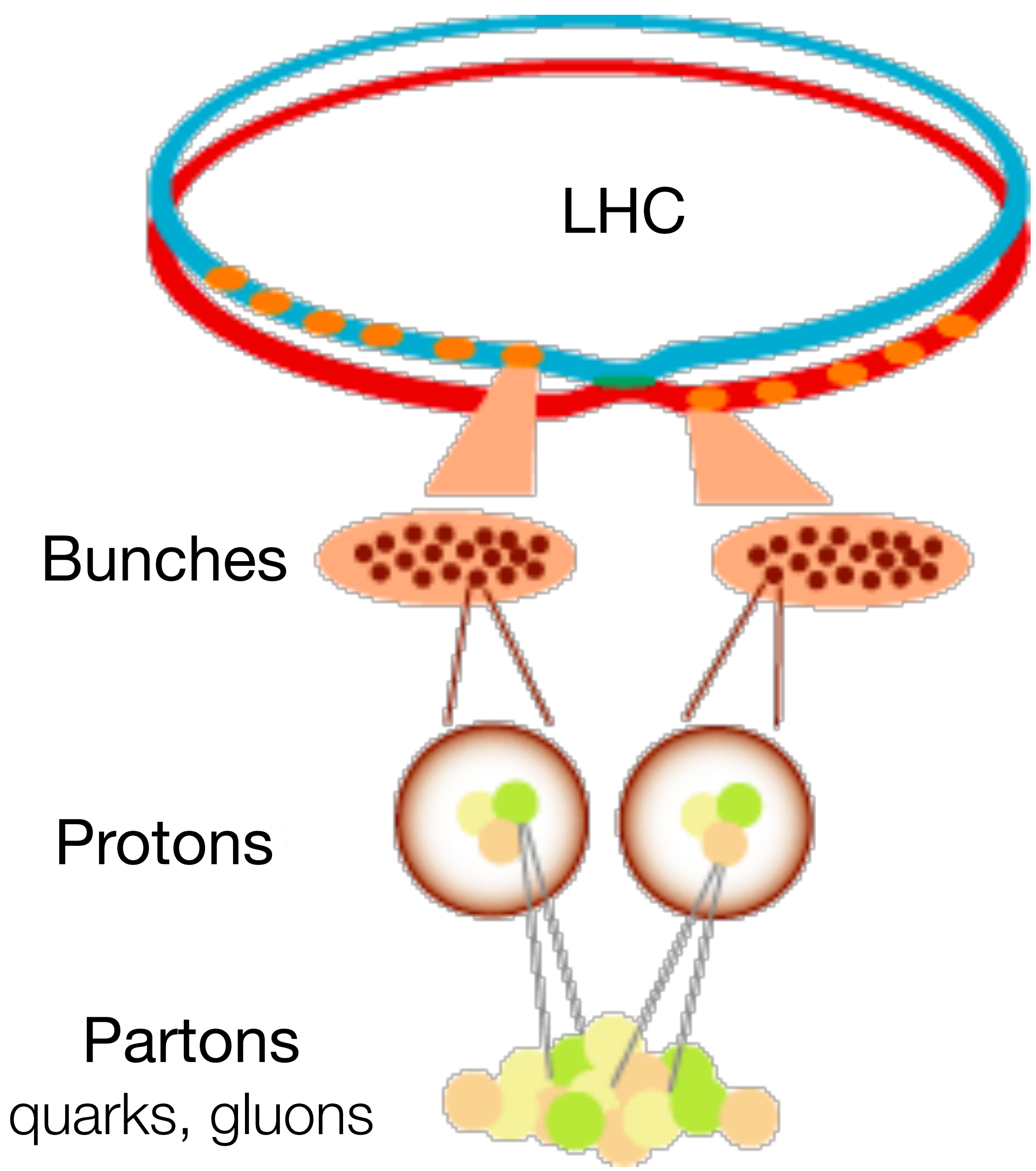
Most collisions are low momentum and not so interesting

Every so often we get a "hard" collision and produce heavy particles ($E=mc^2$)

Top pair: ~1 out of 75,000,000
Higgs boson: ~1 out of 1,200,000,000
3.5 TeV Z prime: ~1 out of 120,000,000,000,000

High rate of collisions

We need a very high rate of collisions to produce enough Higgs and tops to study



~3200 bunches of protons in each LHC ring

~110 billion protons per bunch

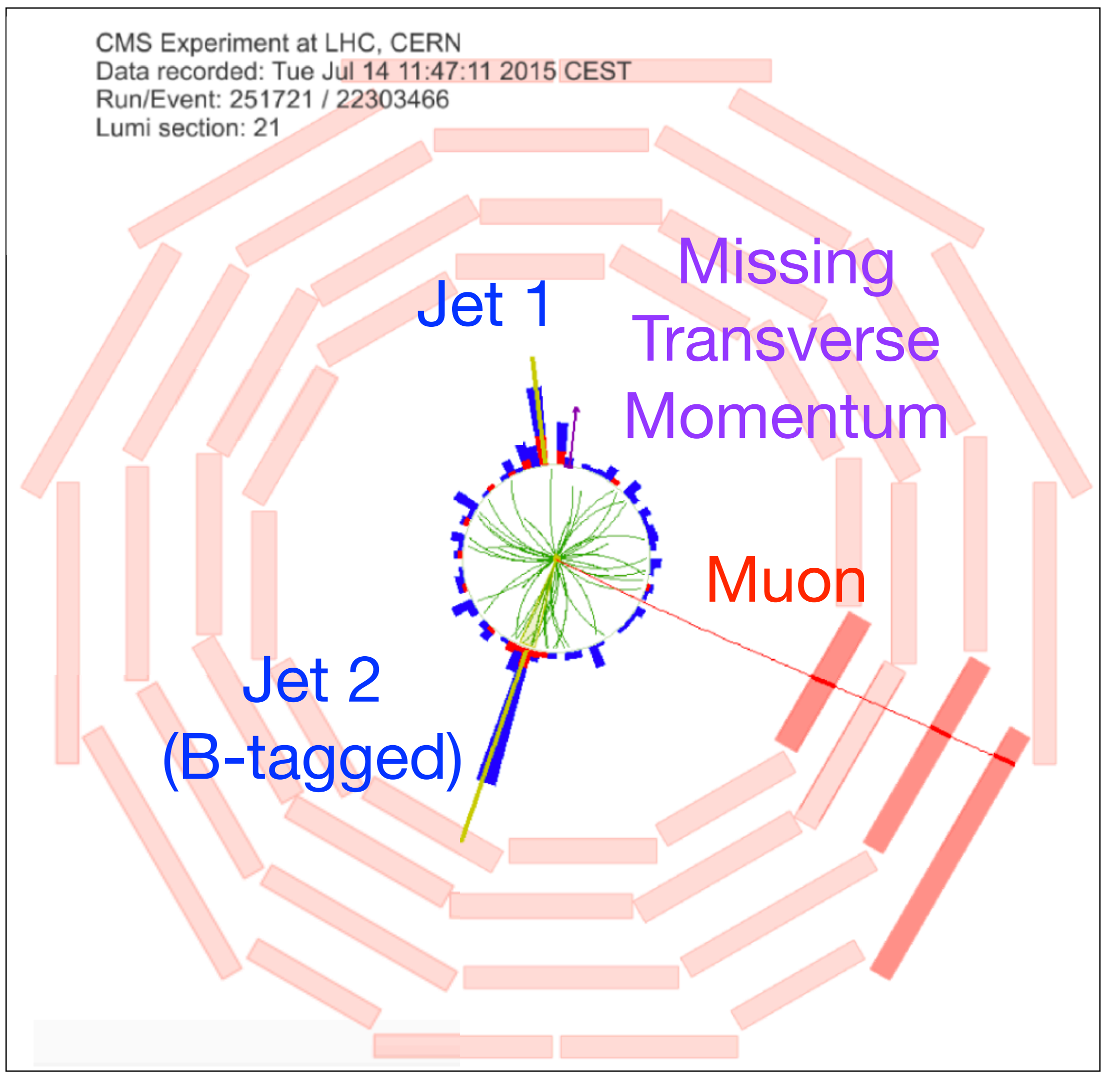
Bunches cross every 25 nanoseconds

~50 collisions per bunch crossing

2 billion collisions/second

Heavy particles decay

We never see the Higgs or the top quark, just their decay products
Vast majority of new particles expected to decay at interaction point



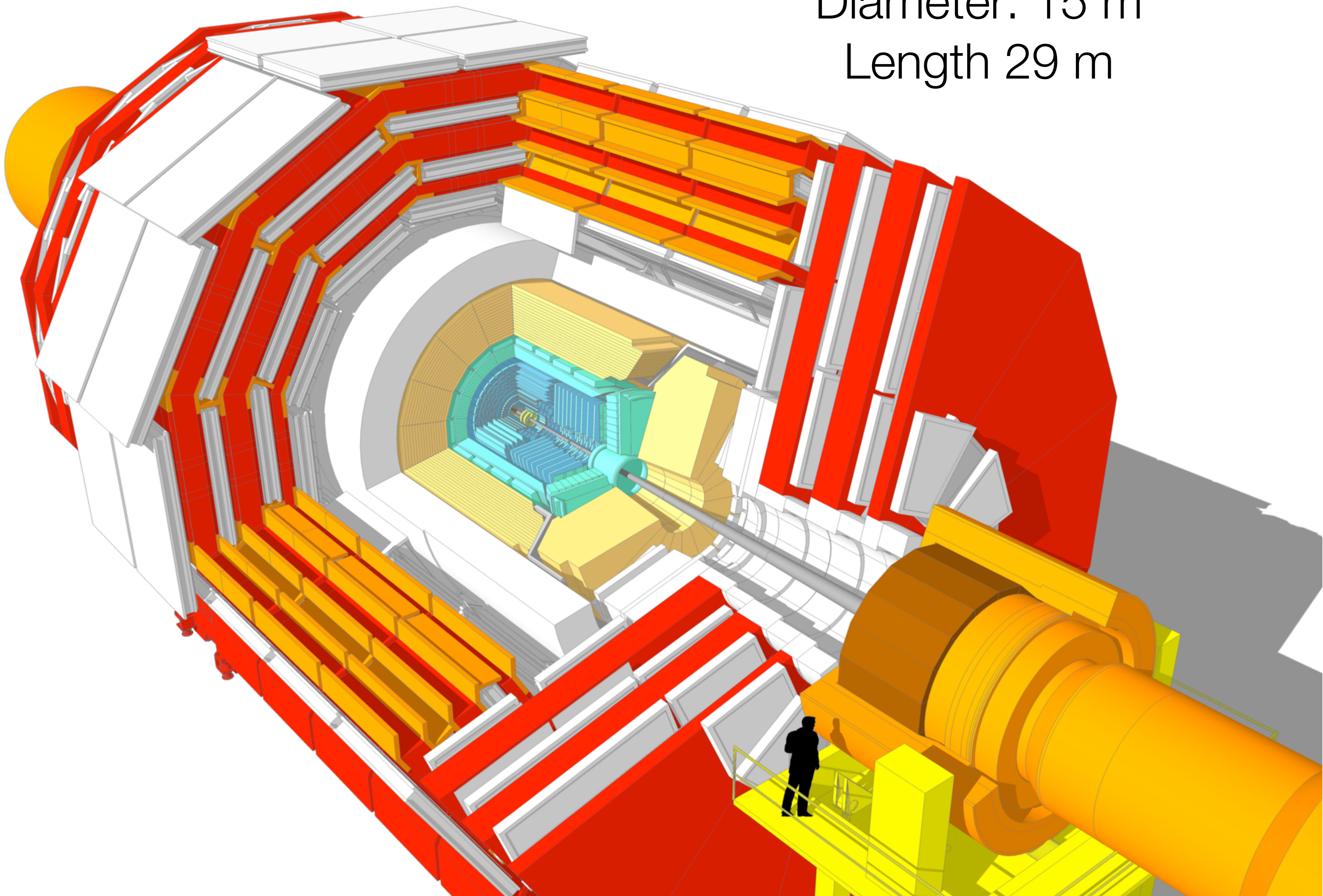
Single top event candidate

CMS goal: identify & measure all detector stable particles

Photons, γ
Electrons, e
Muons, μ
Charged hadrons, π, p
Neutral hadrons, n
Neutrinos, ν

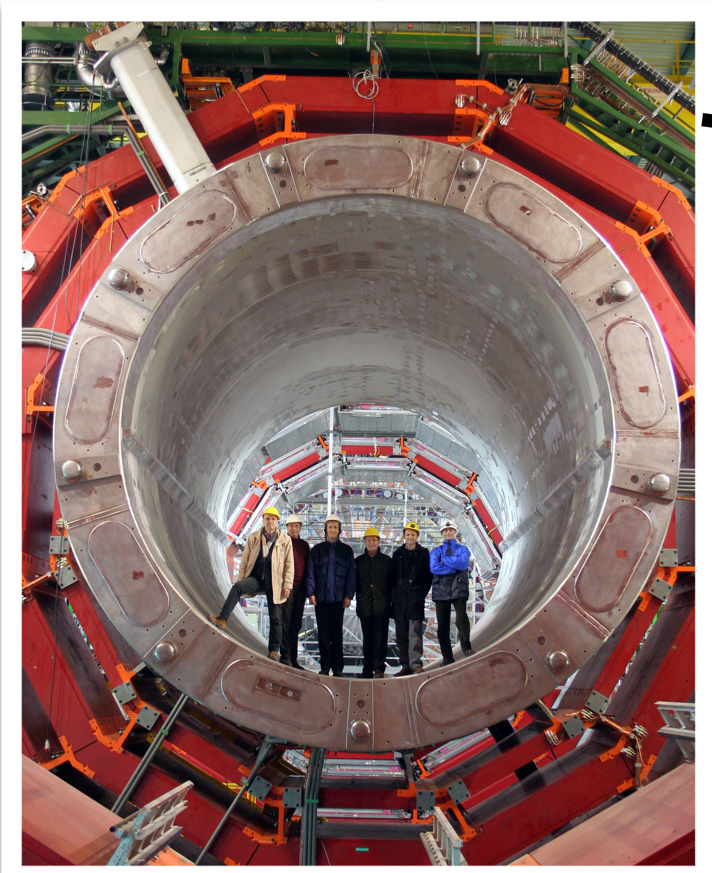
Compact Muon Solenoid (CMS)

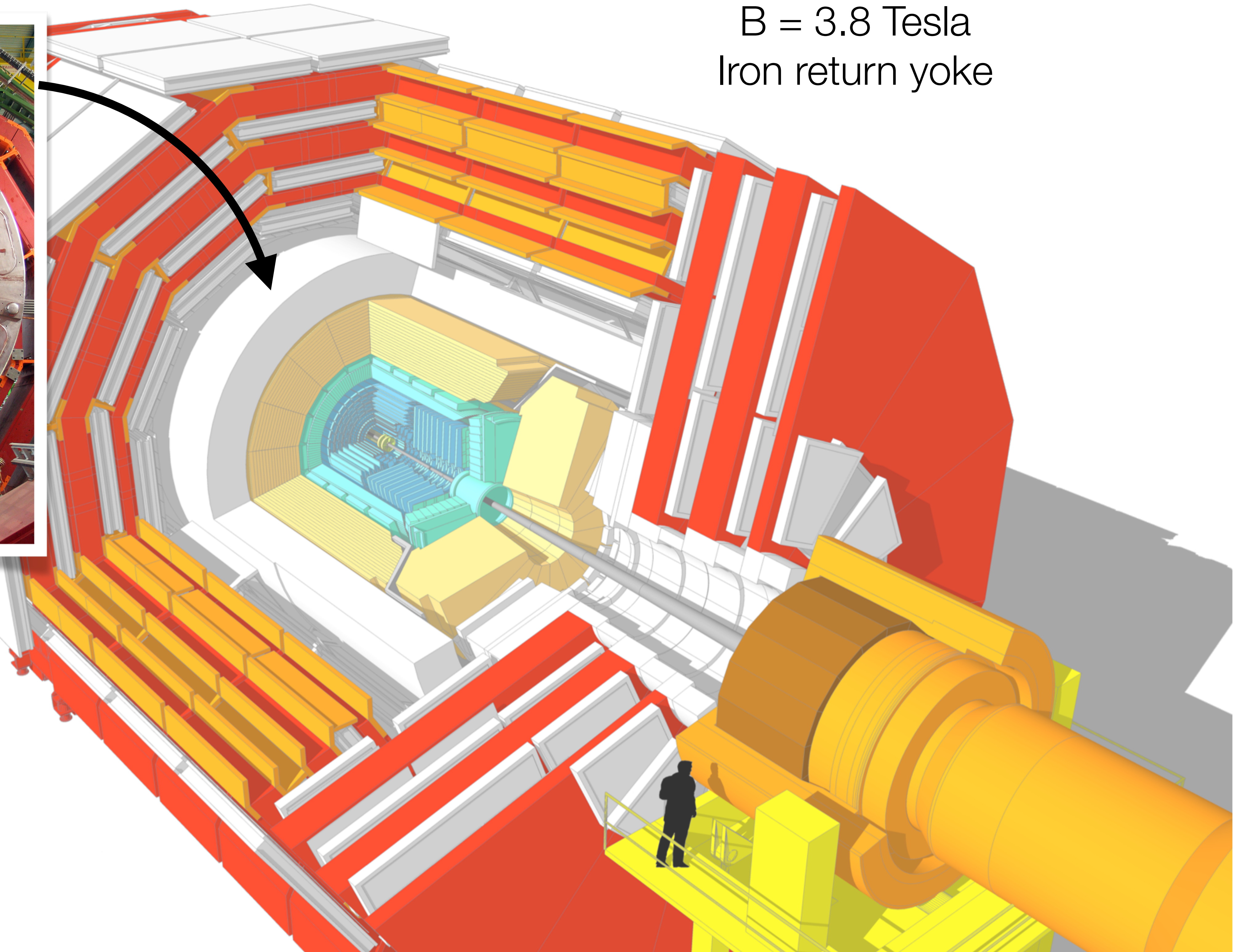
Cylindrical Geometry
Diameter: 15 m
Length 29 m



Compact Muon Solenoid (CMS)

Superconducting Solenoid
Largest in the world
B = 3.8 Tesla
Iron return yoke



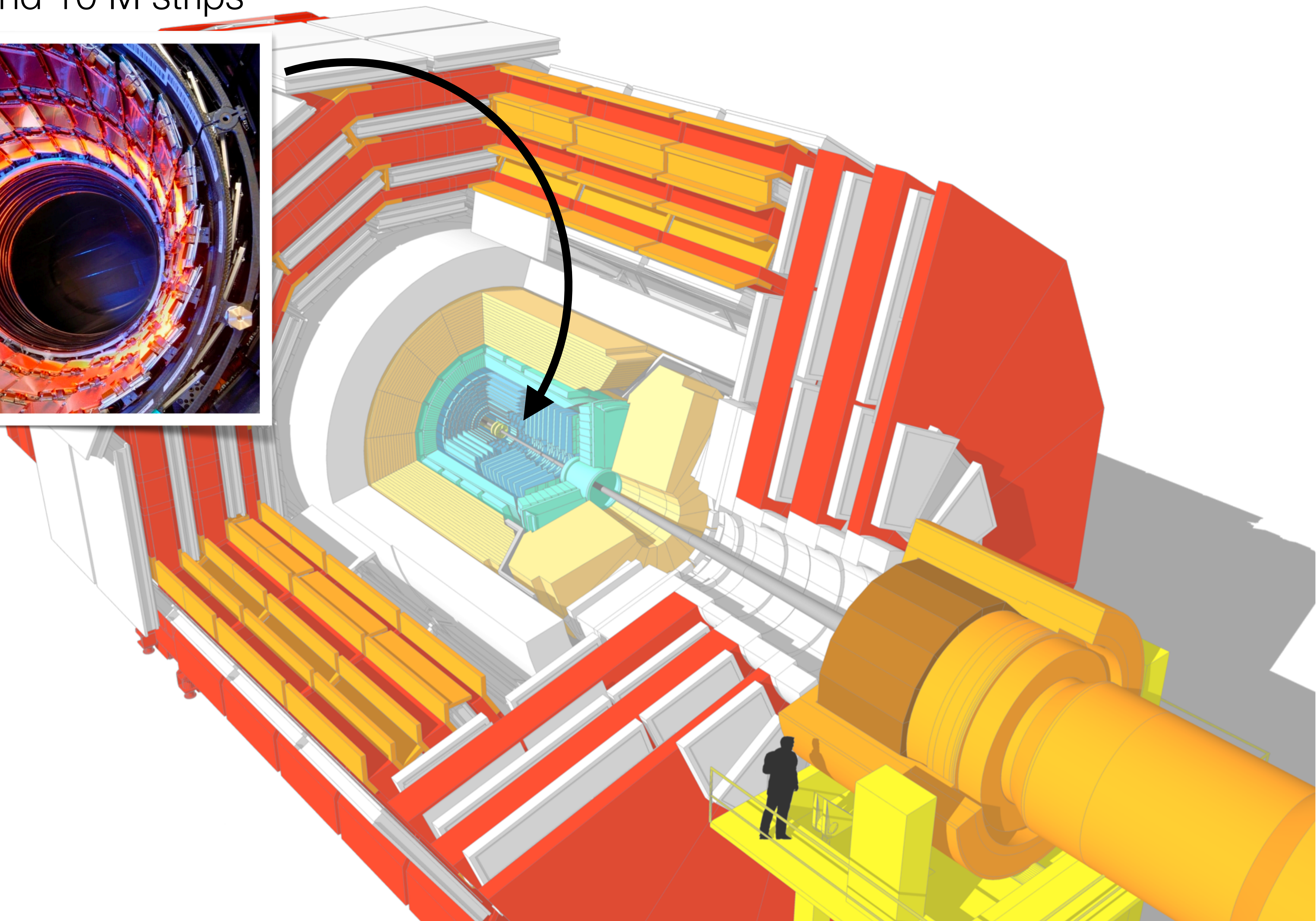


Bends charged particles

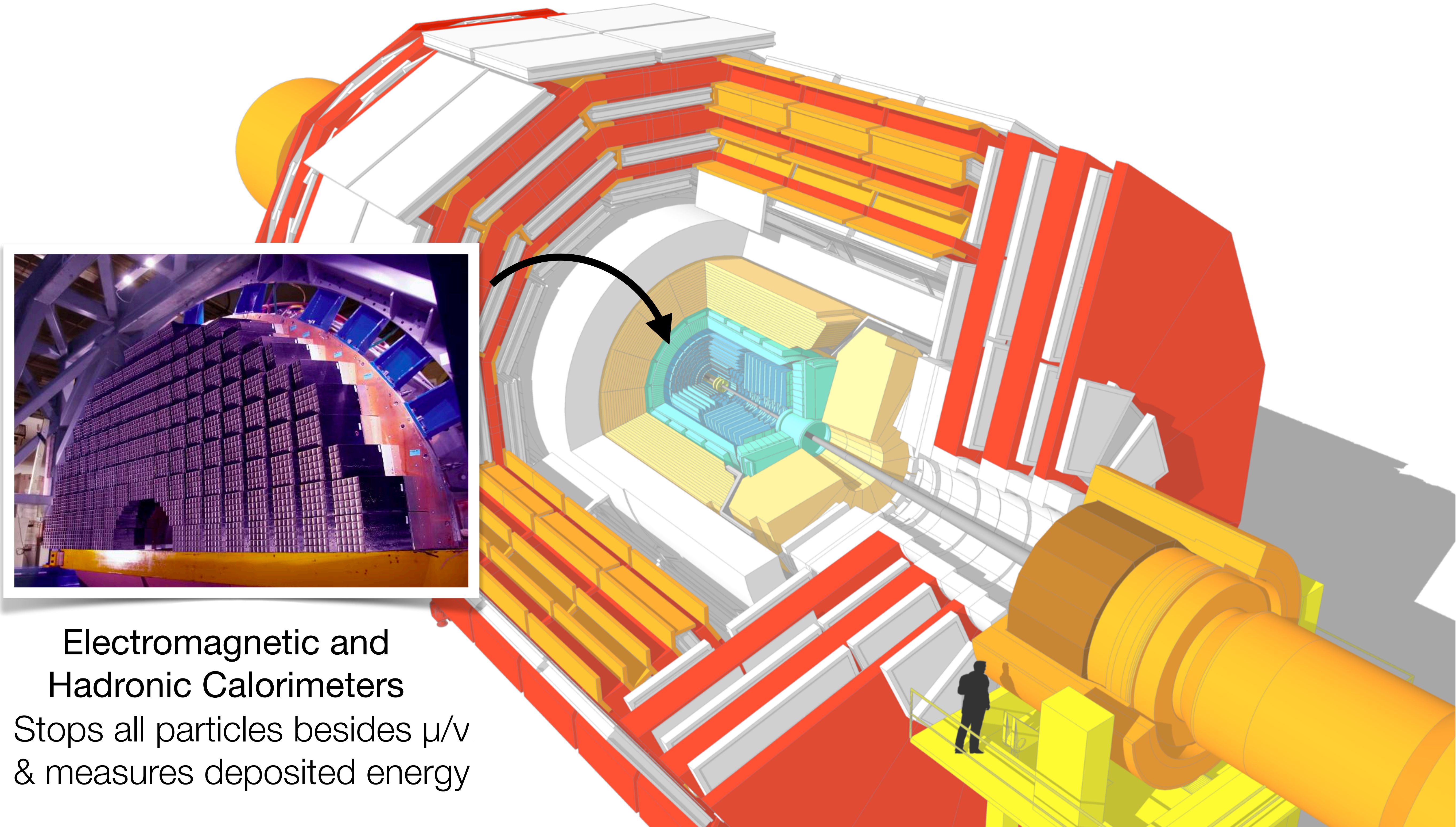
$$R = \frac{p}{q \cdot B}$$

Compact Muon Solenoid (CMS)

Silicon Tracker
Trajectories of charged particles
124 M pixels and 10 M strips



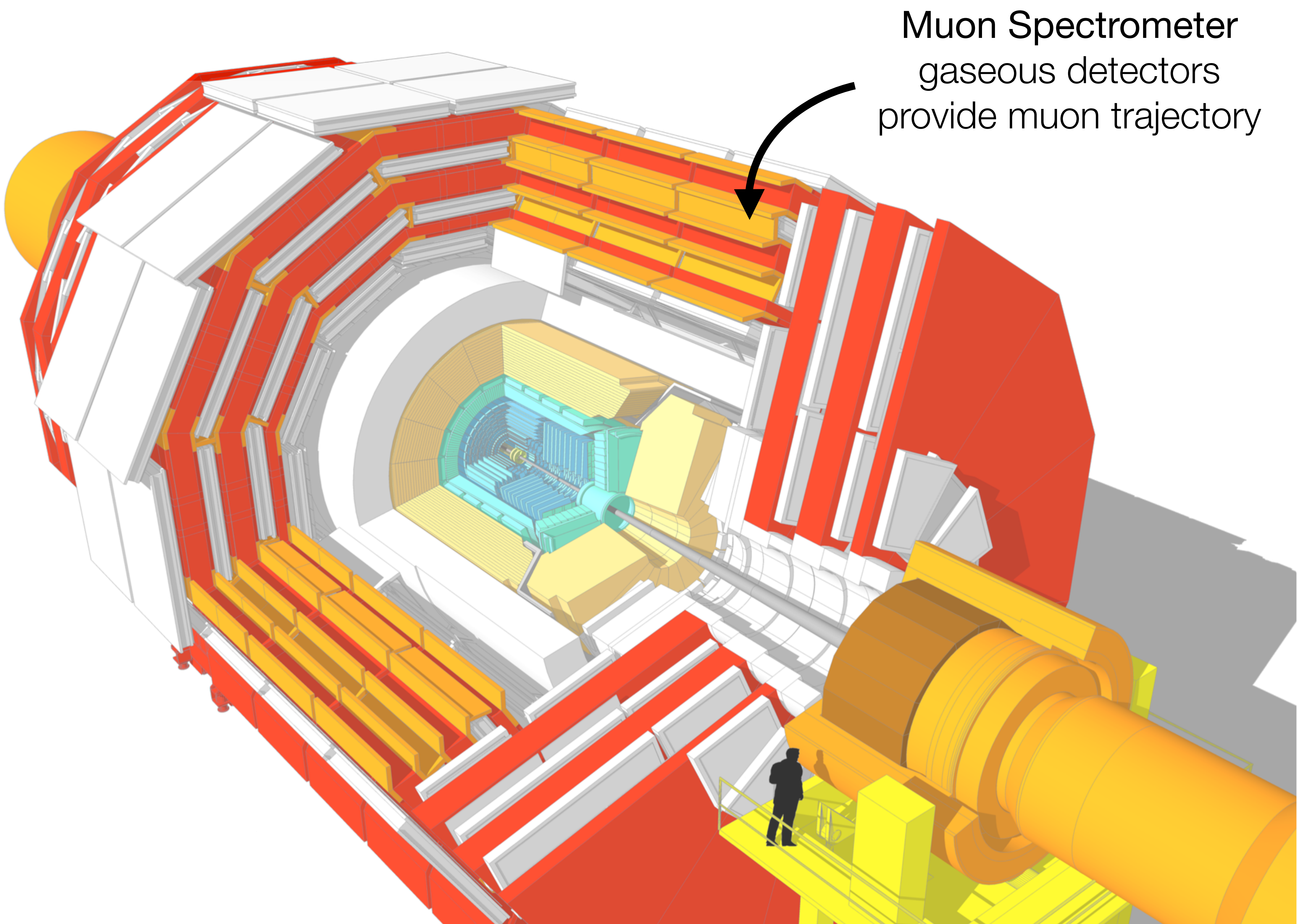
Compact Muon Solenoid (CMS)



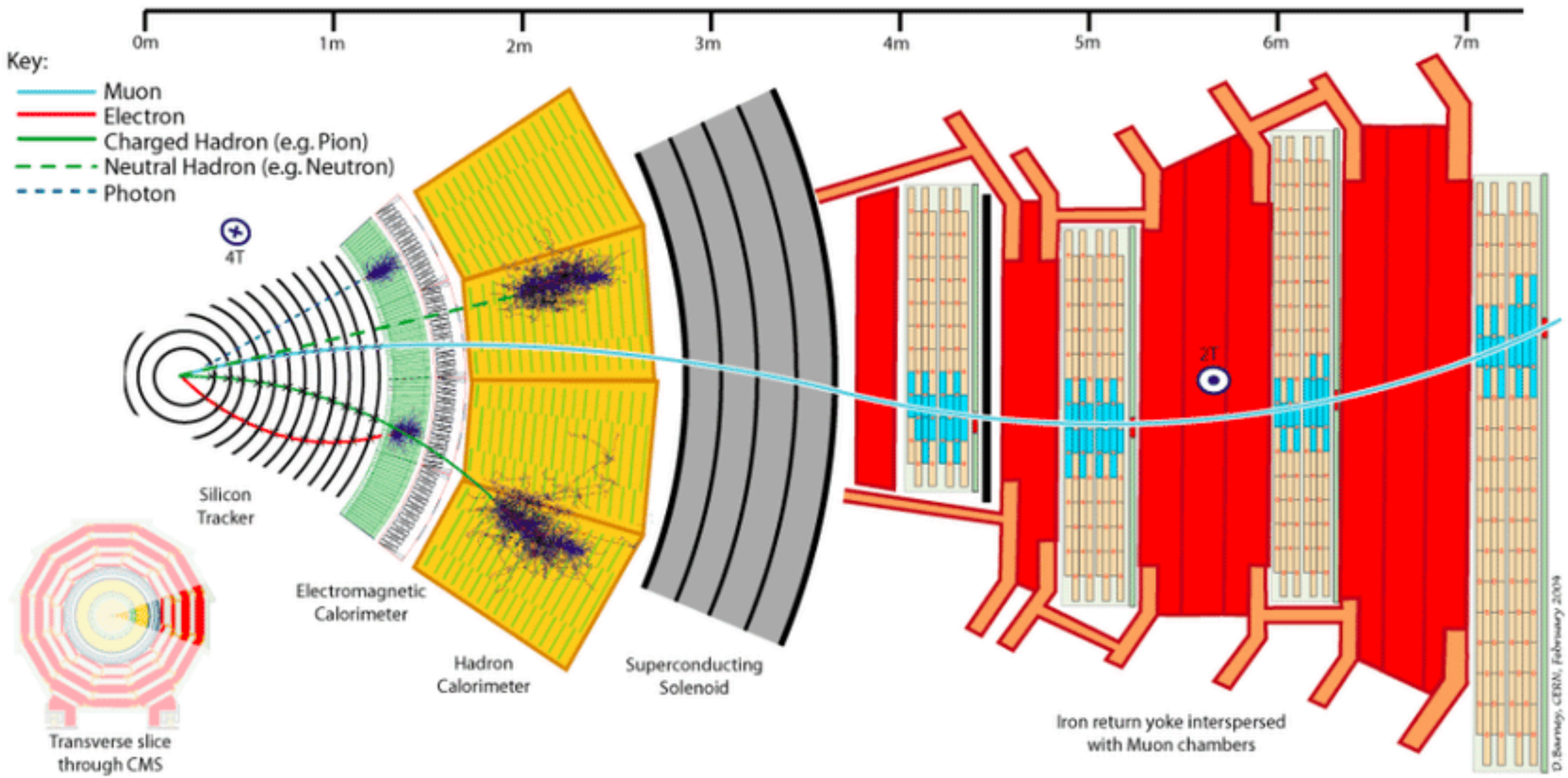
Electromagnetic and
Hadronic Calorimeters

Stops all particles besides μ/ν
& measures deposited energy

Compact Muon Solenoid (CMS)



Particle Identification



indirectly infer the presence of non-interacting particles (neutrinos/dark matter) as missing transverse momentum, p_T^{miss}

One last challenge

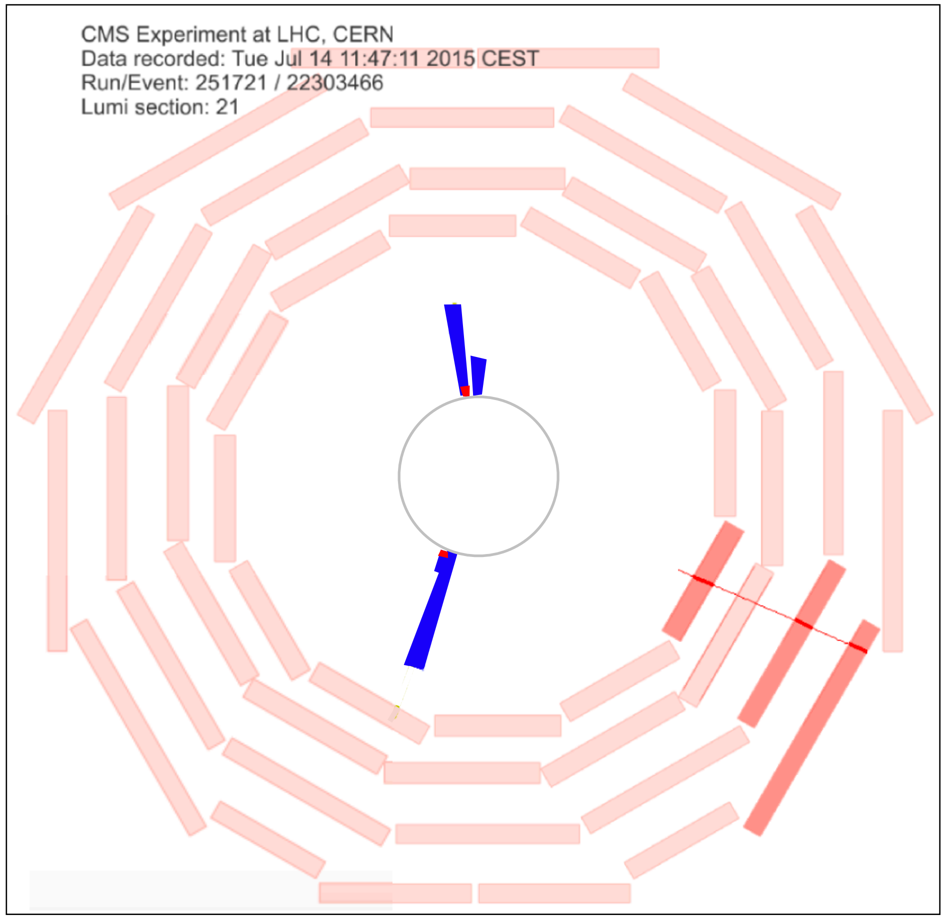
We can only save 0.004% of LHC events

The trigger decides in real-time which events to keep

Step 1

hardware-based : coarse muon and calorimeter information

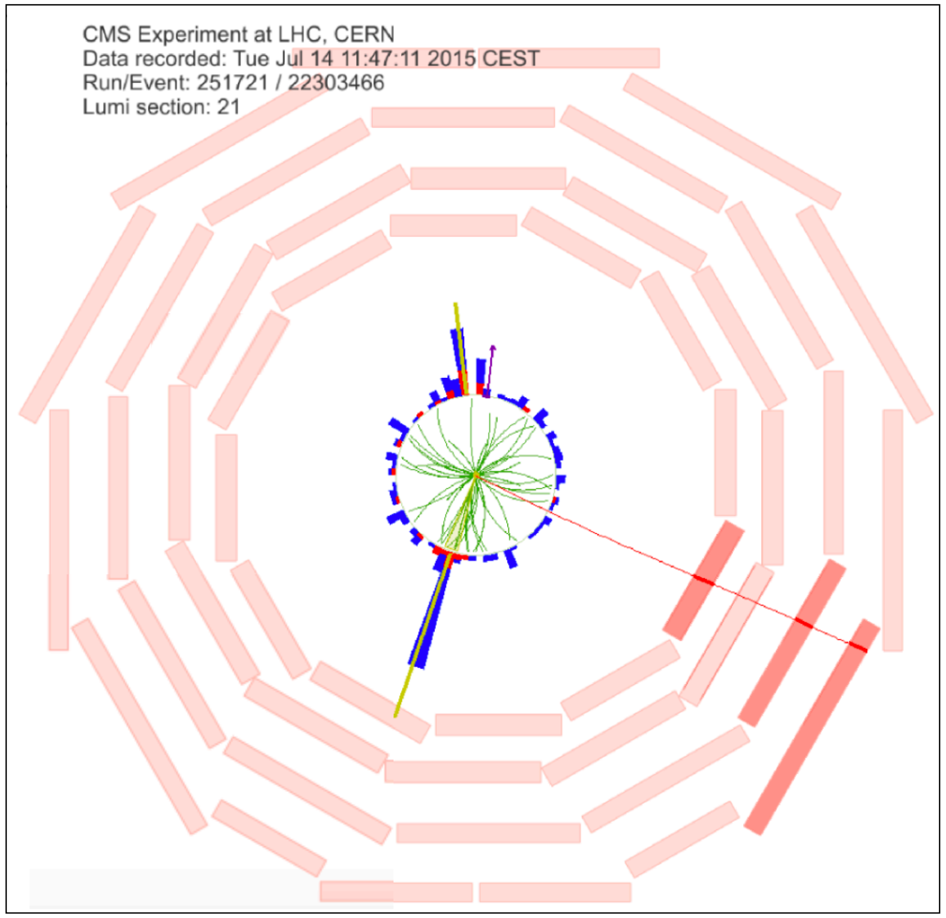
No tracking information!



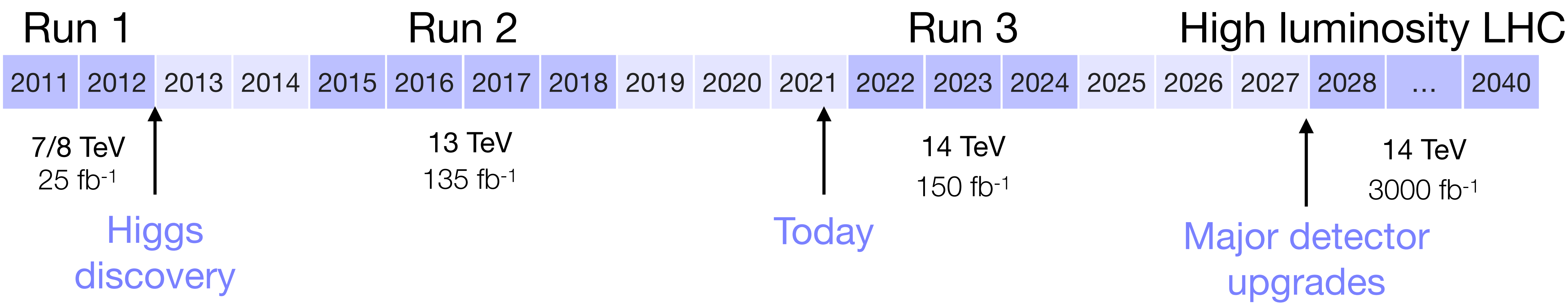
Step 2

software-based: nearly full detector information in region of interest

Fast/limited reconstruction!



The road to discovery



Looking forward

We've only collected 5% of full LHC dataset!

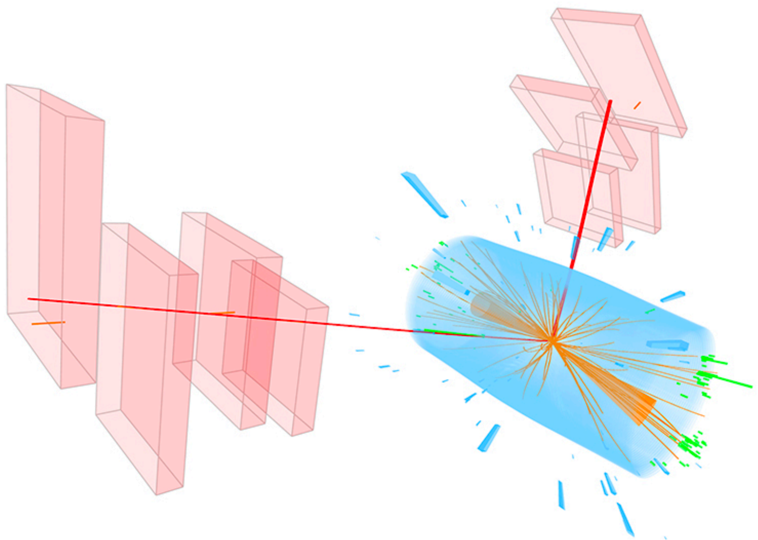
Upgrading CMS detector for the High luminosity LHC

New emphasis on rare and challenging processes to figure out where new physics could be hiding

What is rare or challenging?

Rare: low production rate

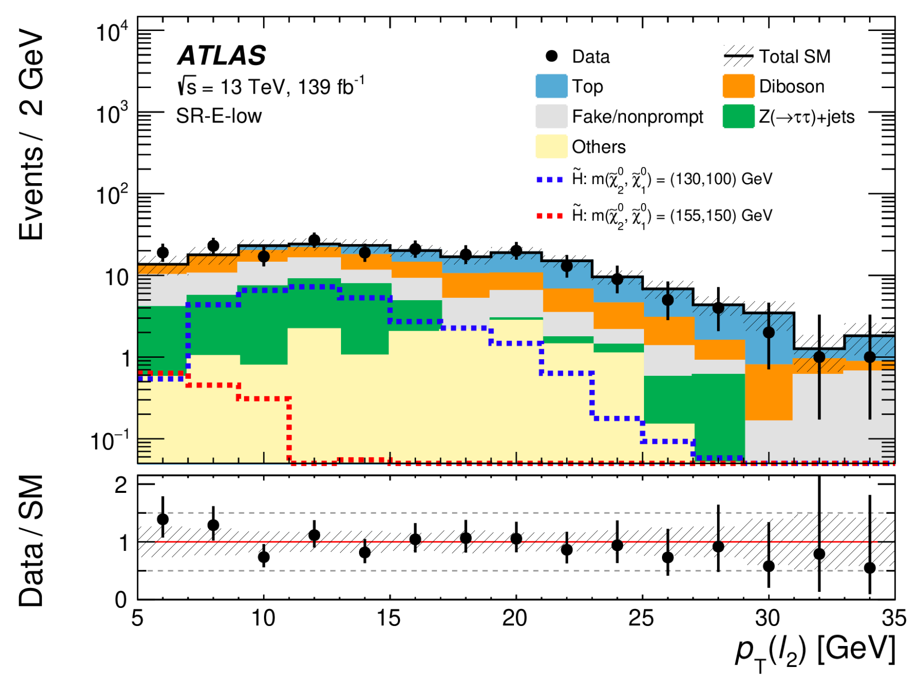
Higgs → μμ:
1/5000 decays



First evidence with
Run 2 data!

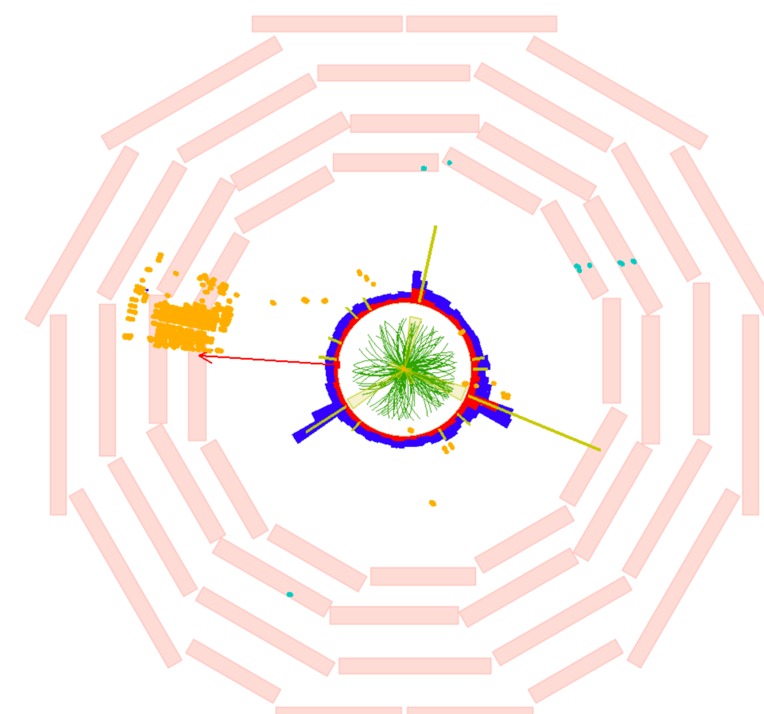
Soft: low momentum

Electroweak Supersymmetry



Run 2: first sensitivity to
Higgs-superpartners since LEP!

Quirky: unconventional
signatures



New triggers &
reconstruction methods for
long-lived particles in Run 3!

New capabilities

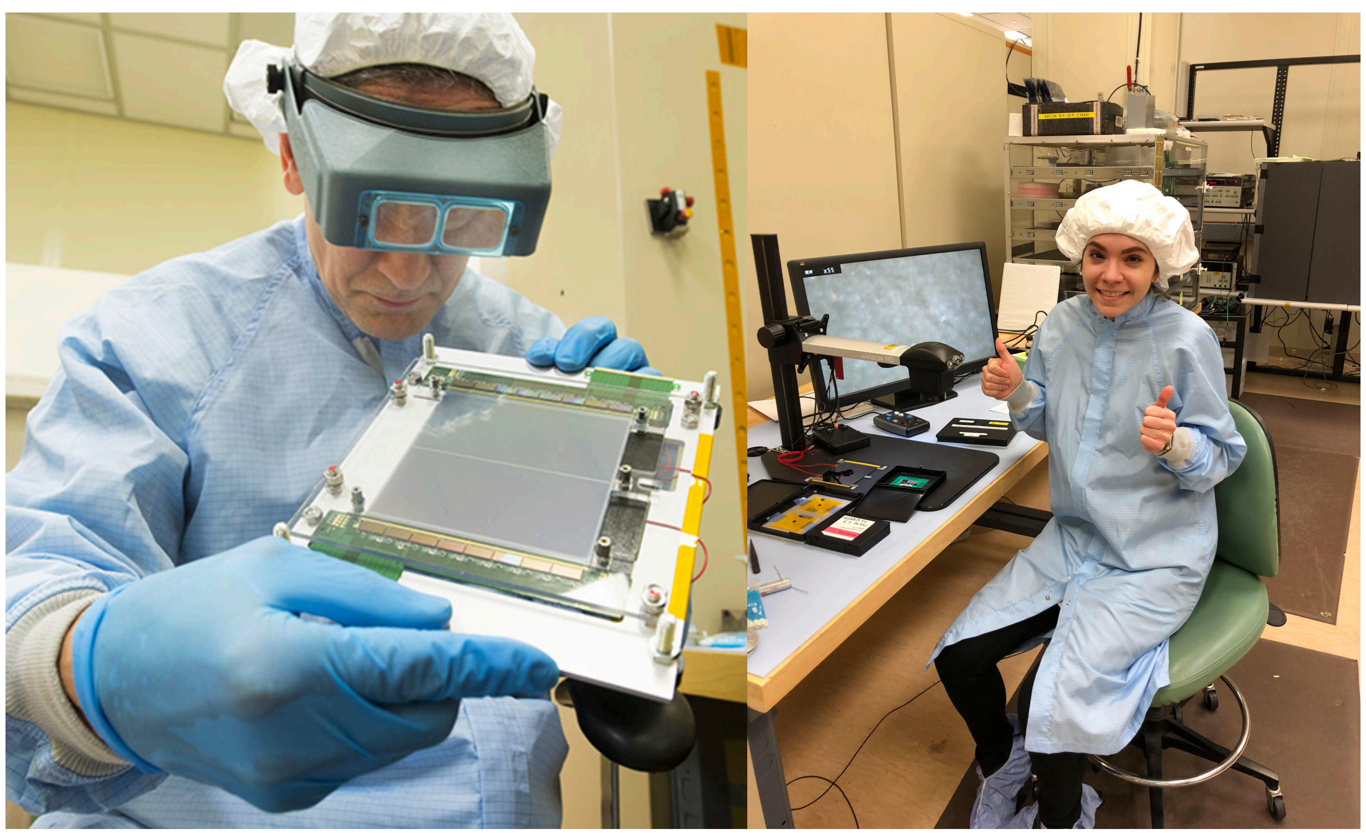
Upgrading CMS detector for the High luminosity LHC

Need to cope with increased rate of collisions & radiation

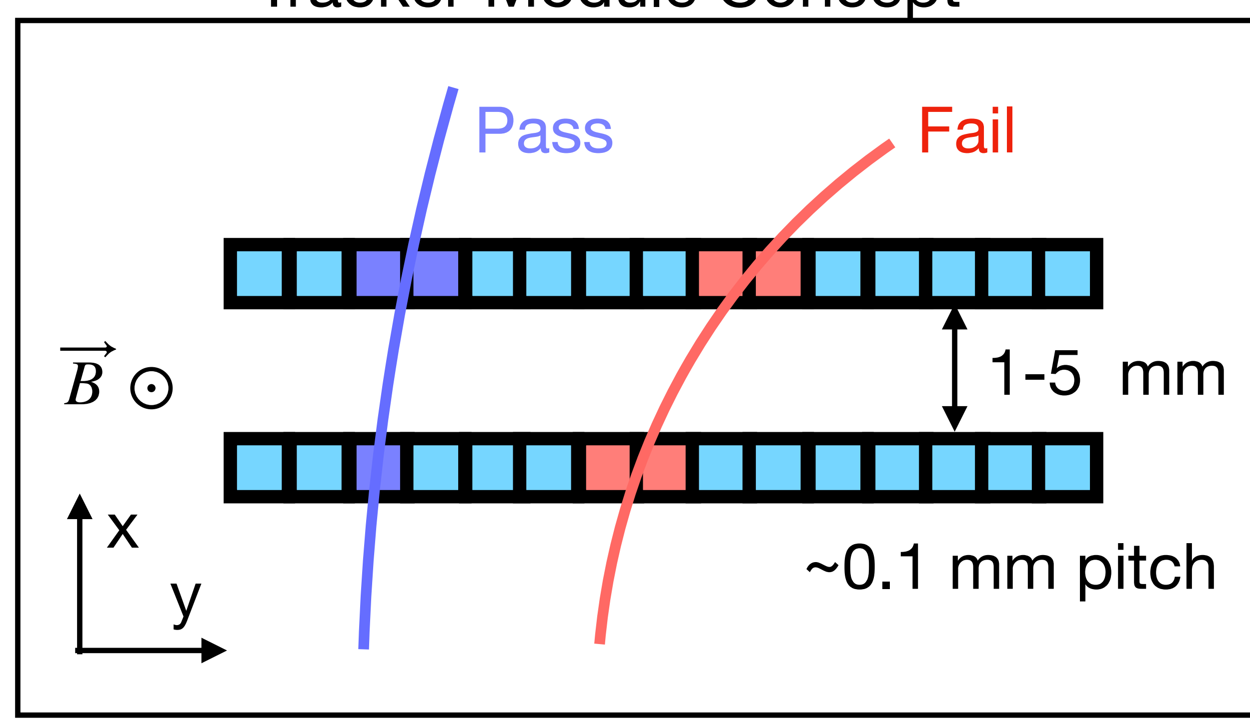
Example: Tracker Upgrade also opens up new physics potential!

1. Track reconstruction in 1st stage of the trigger
2. Outermost layer provides precise timestamp (50 ps)

Fermilab's Silicon Detector Facility



Tracker Module Concept



Summary

A taste of how the CMS experiment works
& exciting future prospects!

The CMS collaboration
2700 physicists
900 are students!

Fermilab's LHC Physics Center
350 users & 100 residents
from 50 universities

BACKUP

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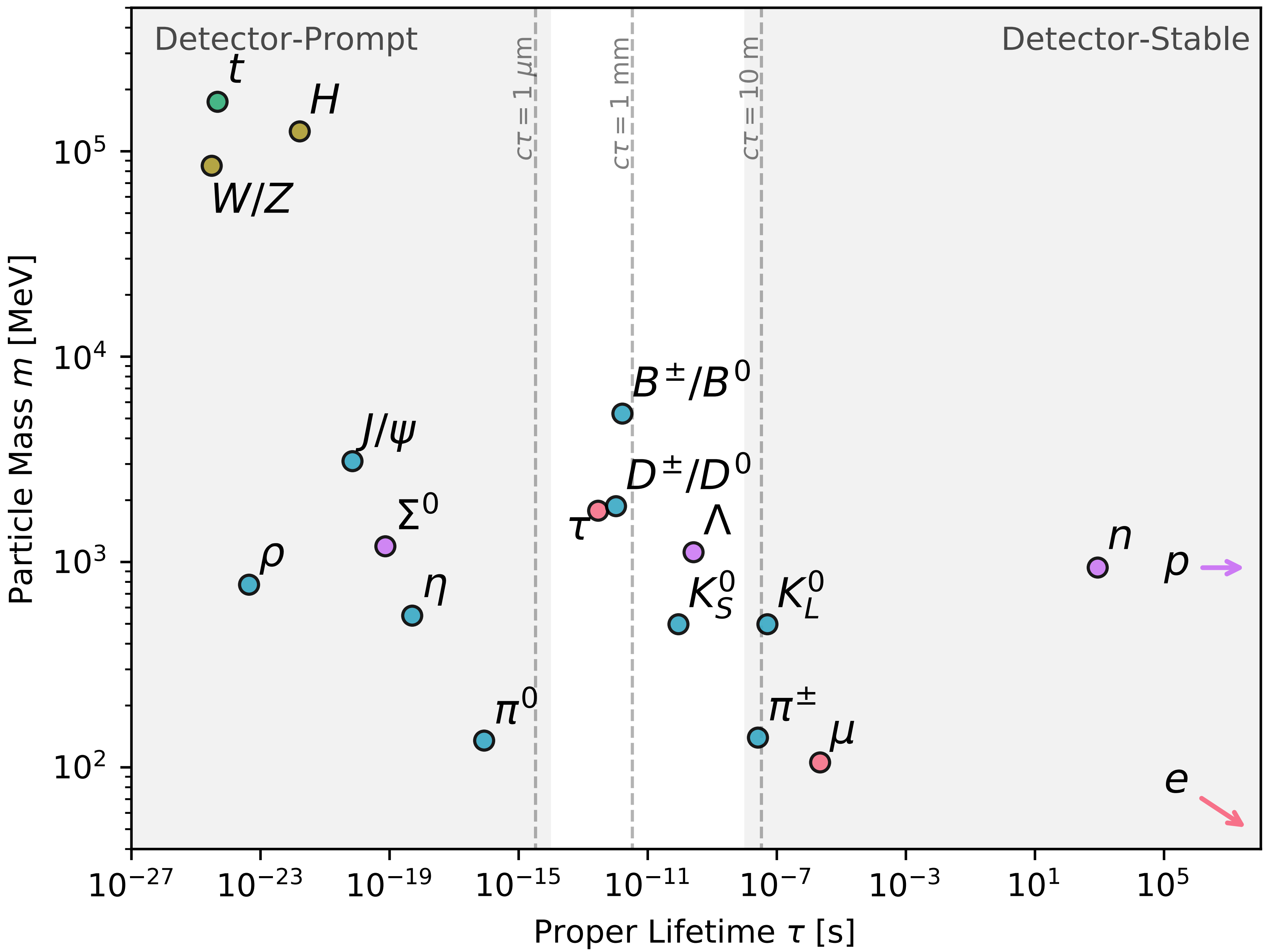
Particle lifetime



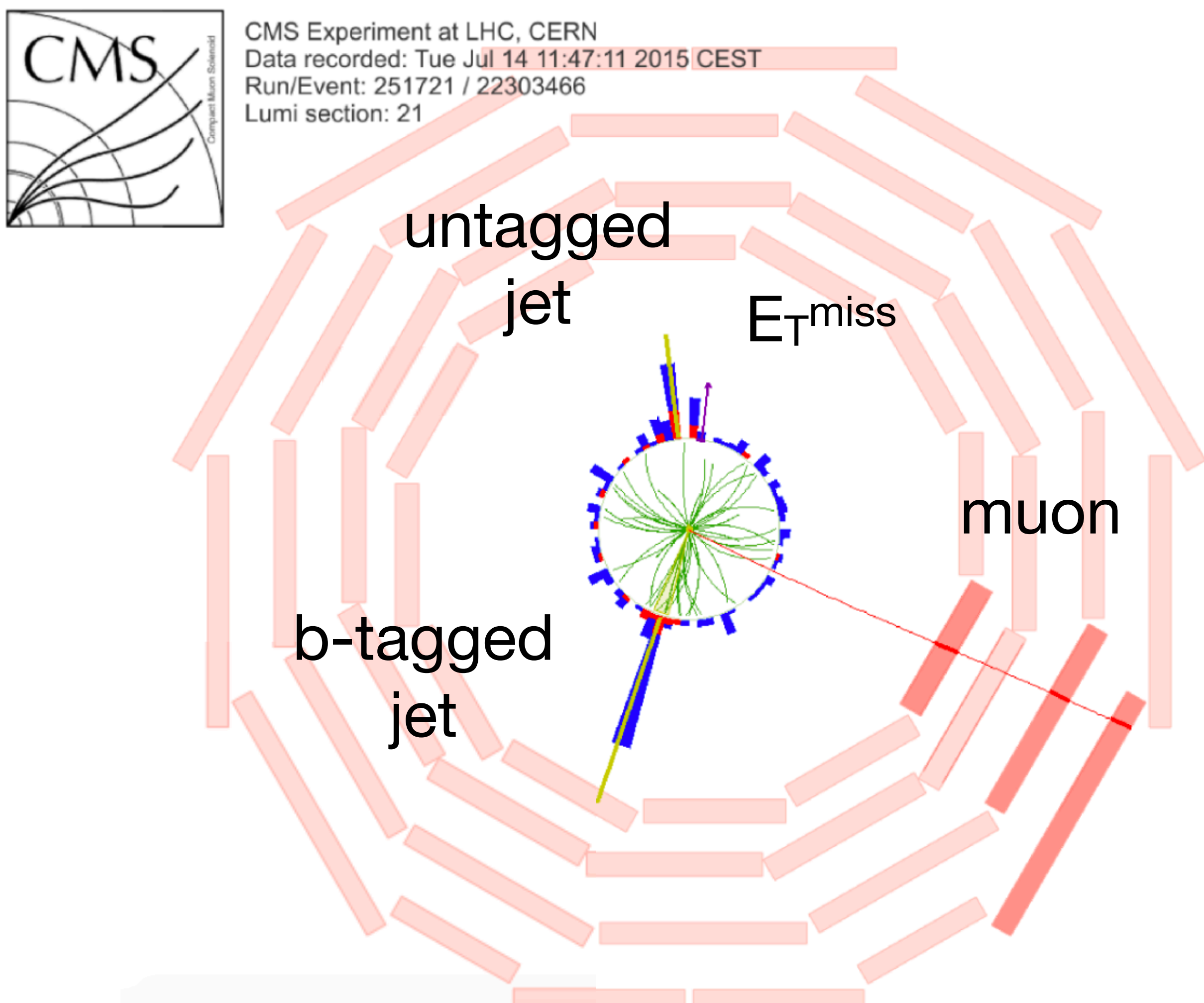
Data rates

Impossible to save all LHC events

If we saved everything, we'd accumulate as much data as as one year of Facebook uploads

We can only save ~1000 events per second
→ 30 petabytes per year

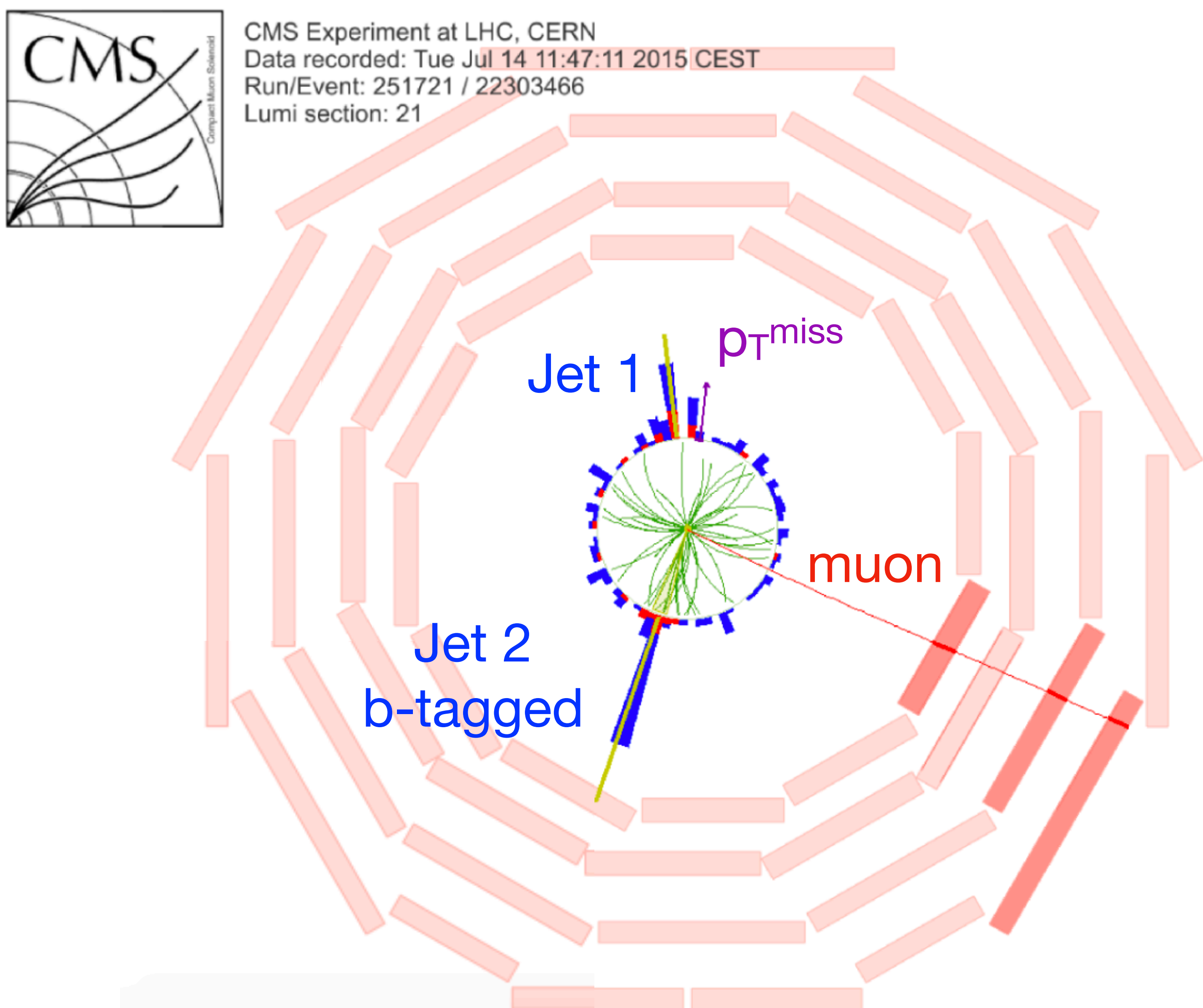
Must select ~1 in a million collisions
And we need to do it quickly!



1 RAW event = 1 MB
Reconstructed ~ 50 kB

Reconstruction

Single top candidate



From there, we can reconstruct more complicated objects, such as jets

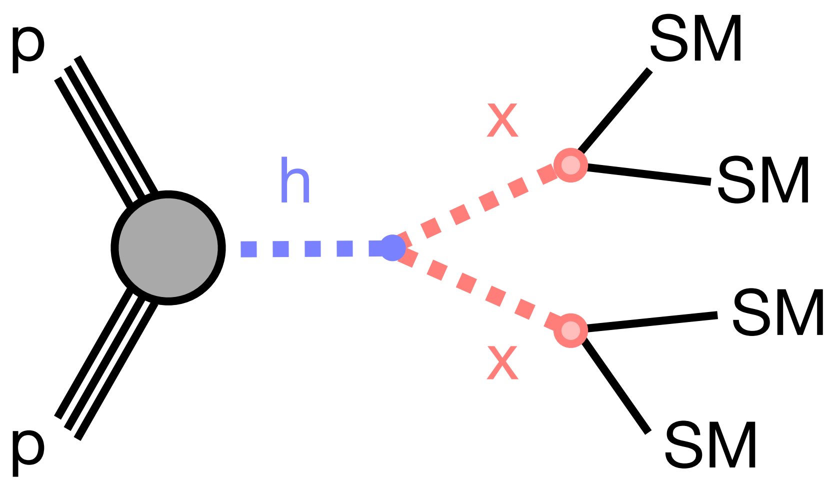
And indirectly infer the presence of neutrinos or dark matter as missing transverse momentum, p_T^{miss}

An example “rare process”

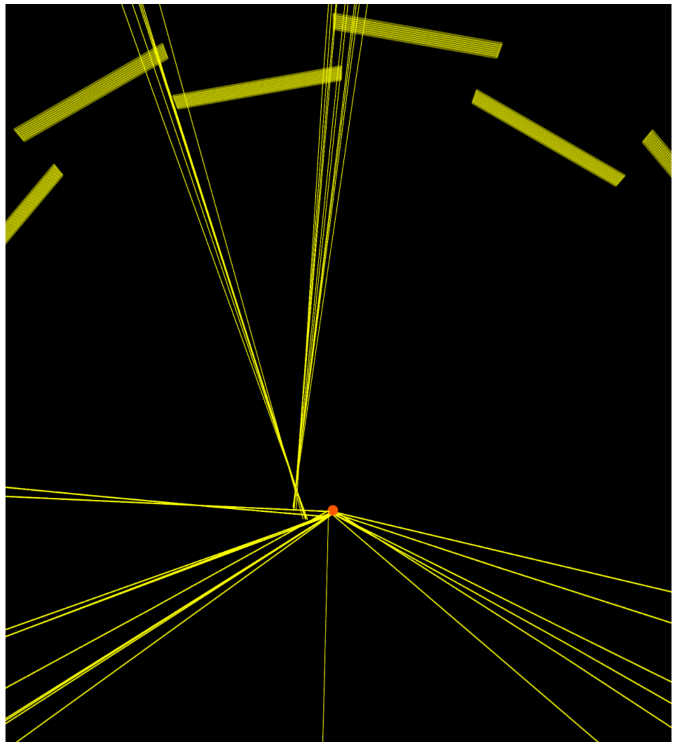
The Higgs boson could provide unique access to a hidden sector

results in “unconventional signatures” in the detector

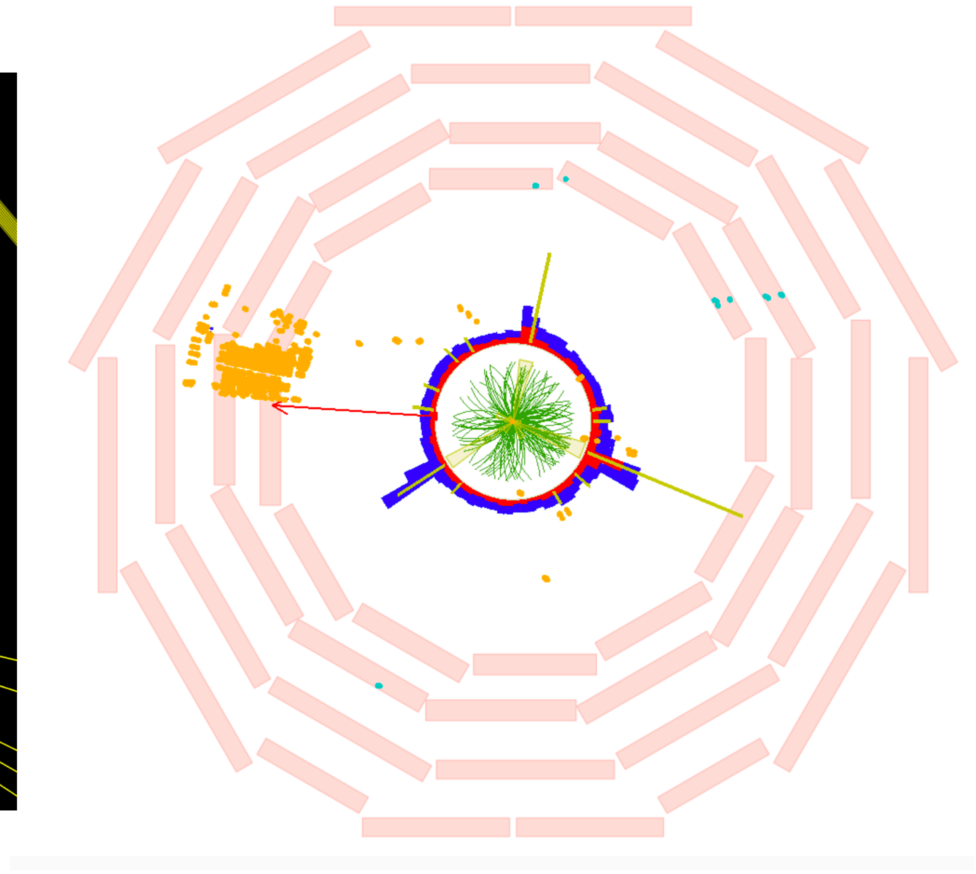
eg. Higgs decays
to two long-lived, x



displaced vertices



Muon System clusters



CMS wasn’t designed for these kind of signatures!

Run 2 analyses typically have low efficiency