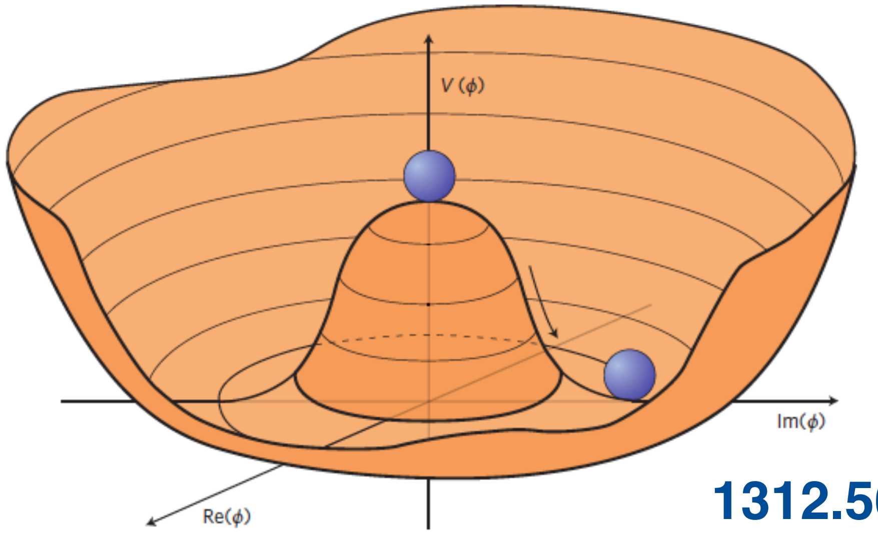
Fermilab

CMS in 10 minutes

Christian Herwig (FNAL)
New Perspectives
June 21, 2022

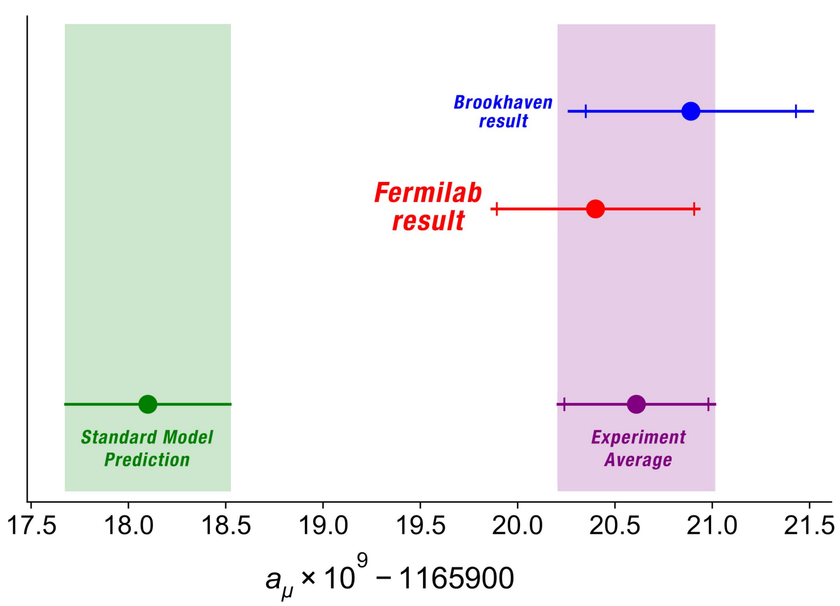
Physics questions

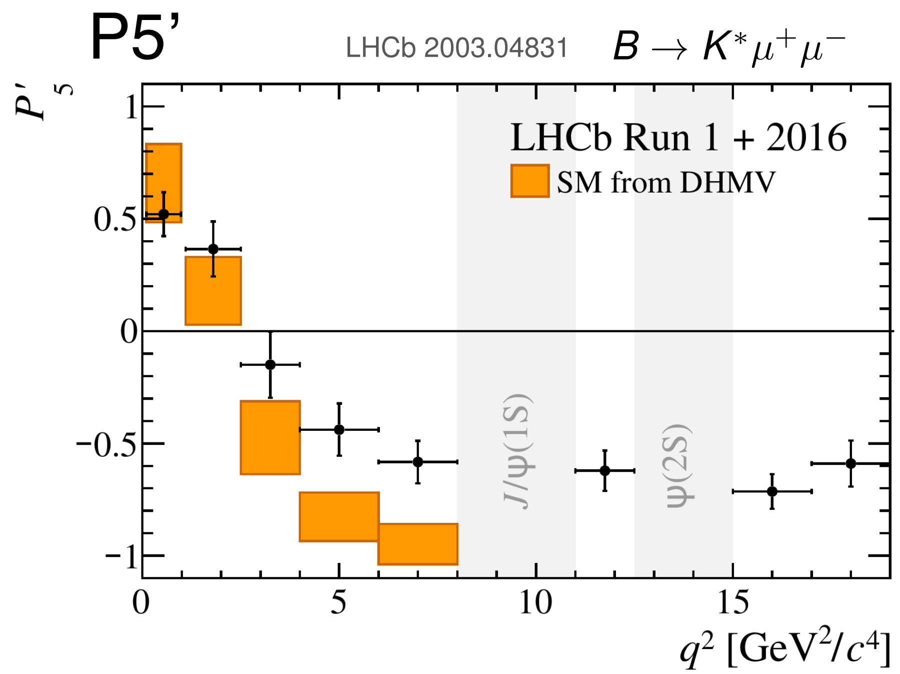
Is there more to electroweak symmetry breaking than a single, light Higgs?



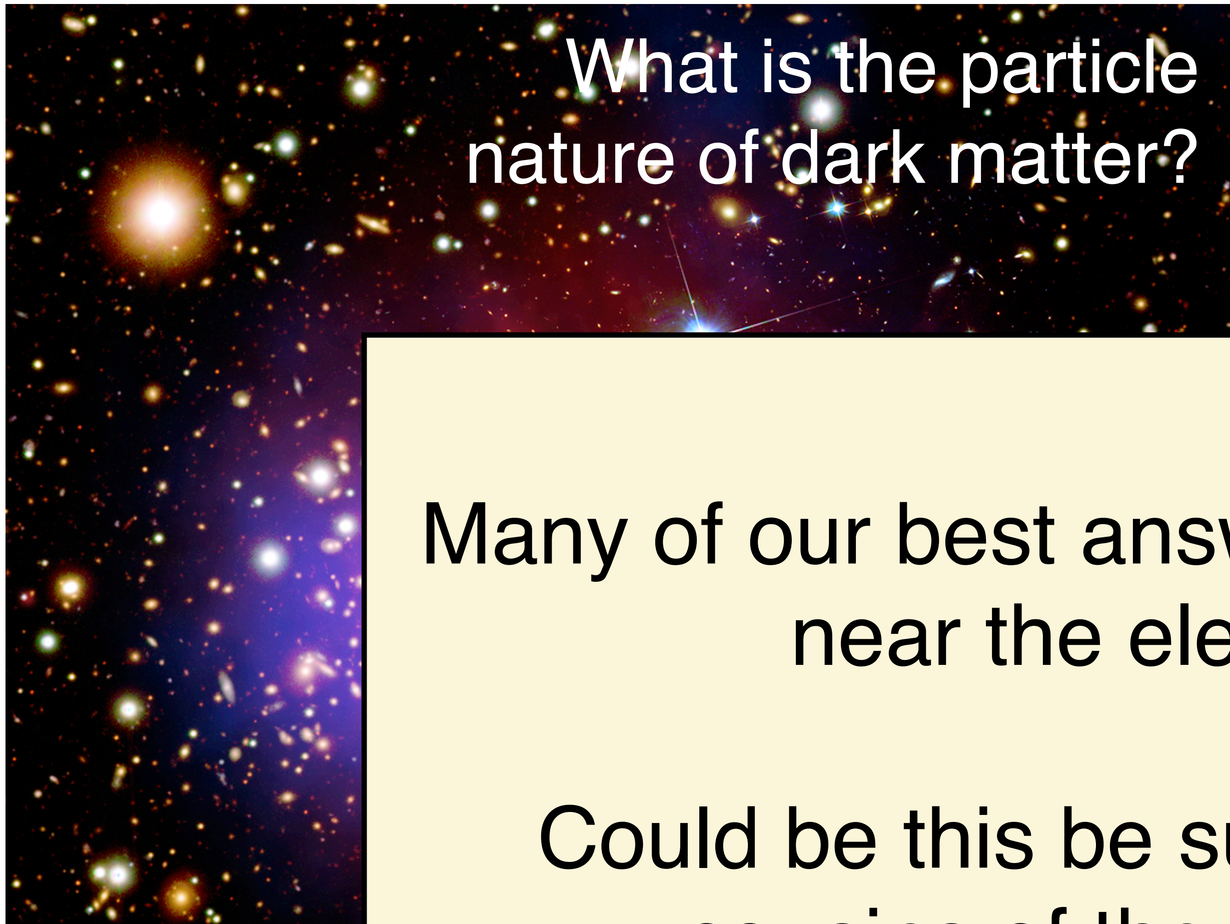
1312.5672

Do new, heavy particles explain the low-energy anomalies?

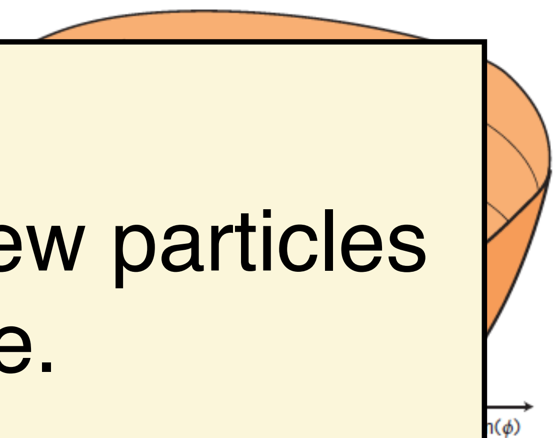




Physics questions



Is there more to electroweak symmetry breaking than a single, light Higgs?

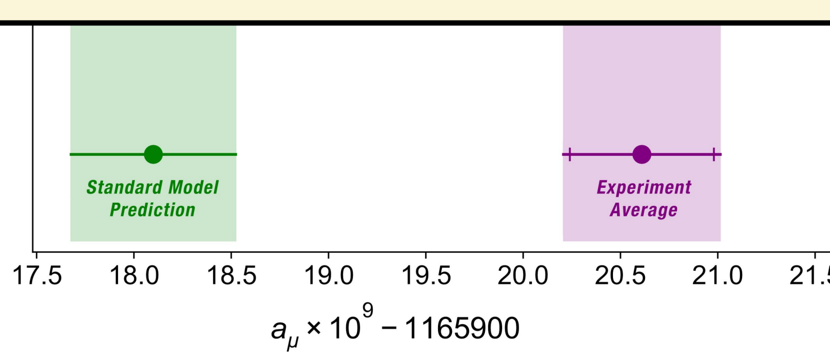


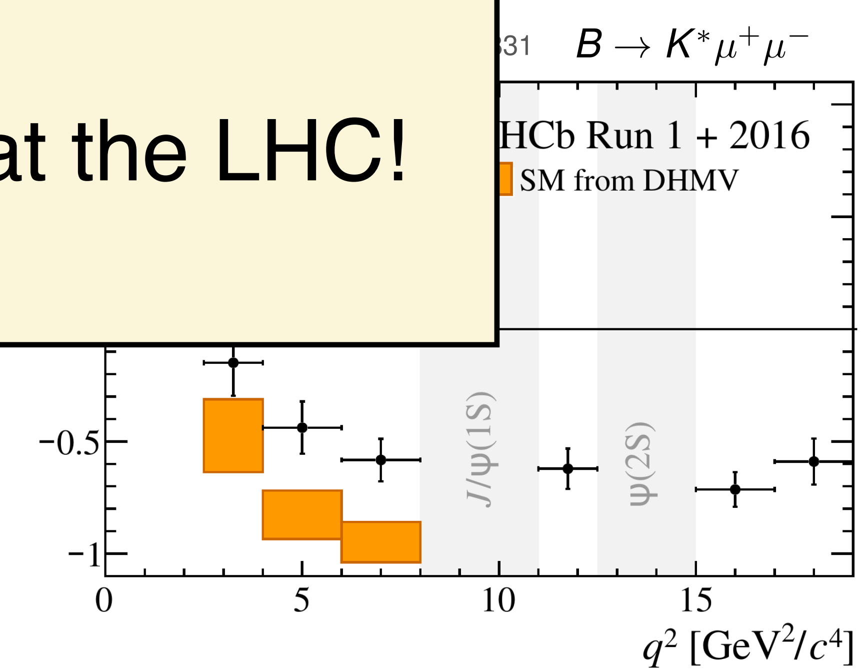
Many of our best answers predict new particles near the electroweak scale.

Could be this be supersymmetry, heavier cousins of the Z, lepto-quarks…?

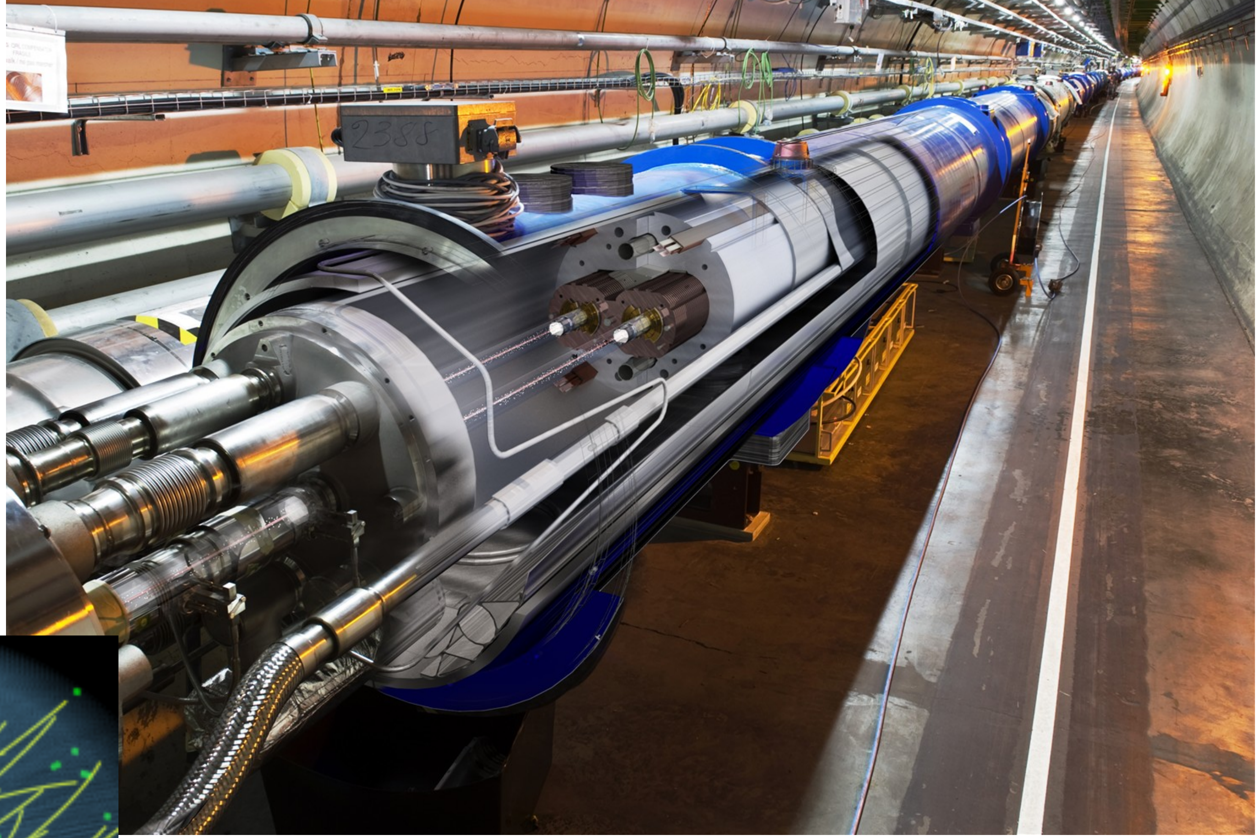
All of this and more may show up at the LHC!

Do new, hea
explain the
anomalies?

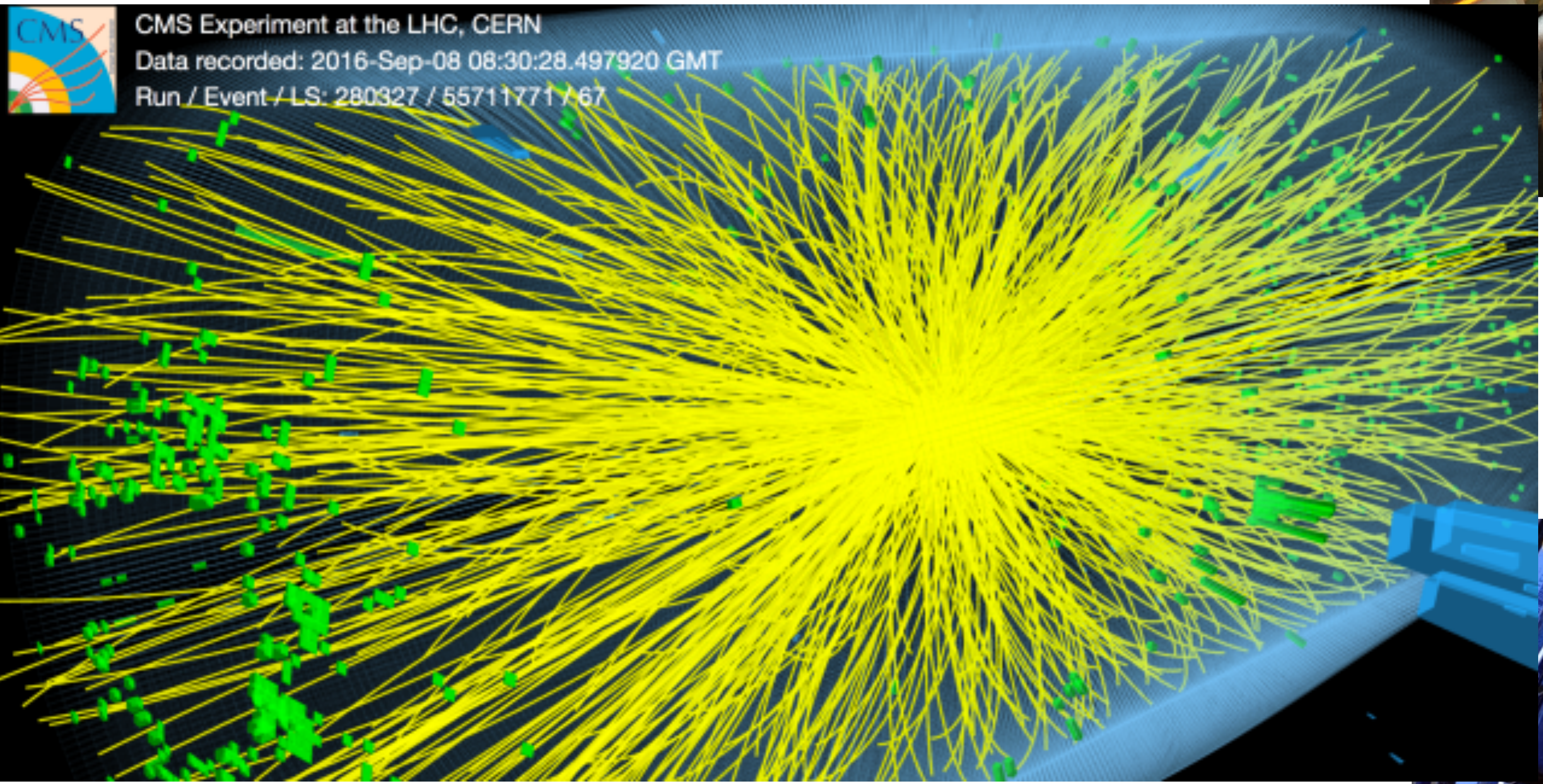




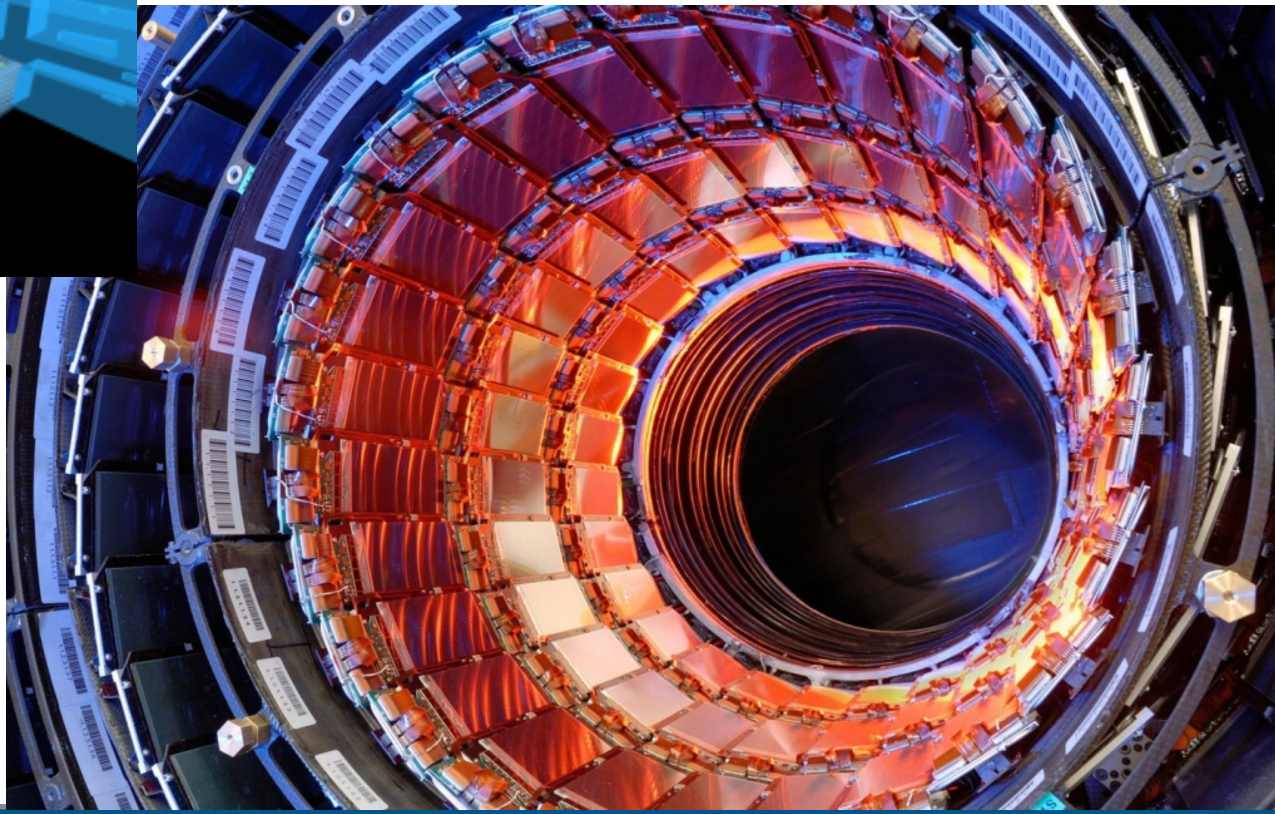
Keys for Physics @ CMS



High collision energies



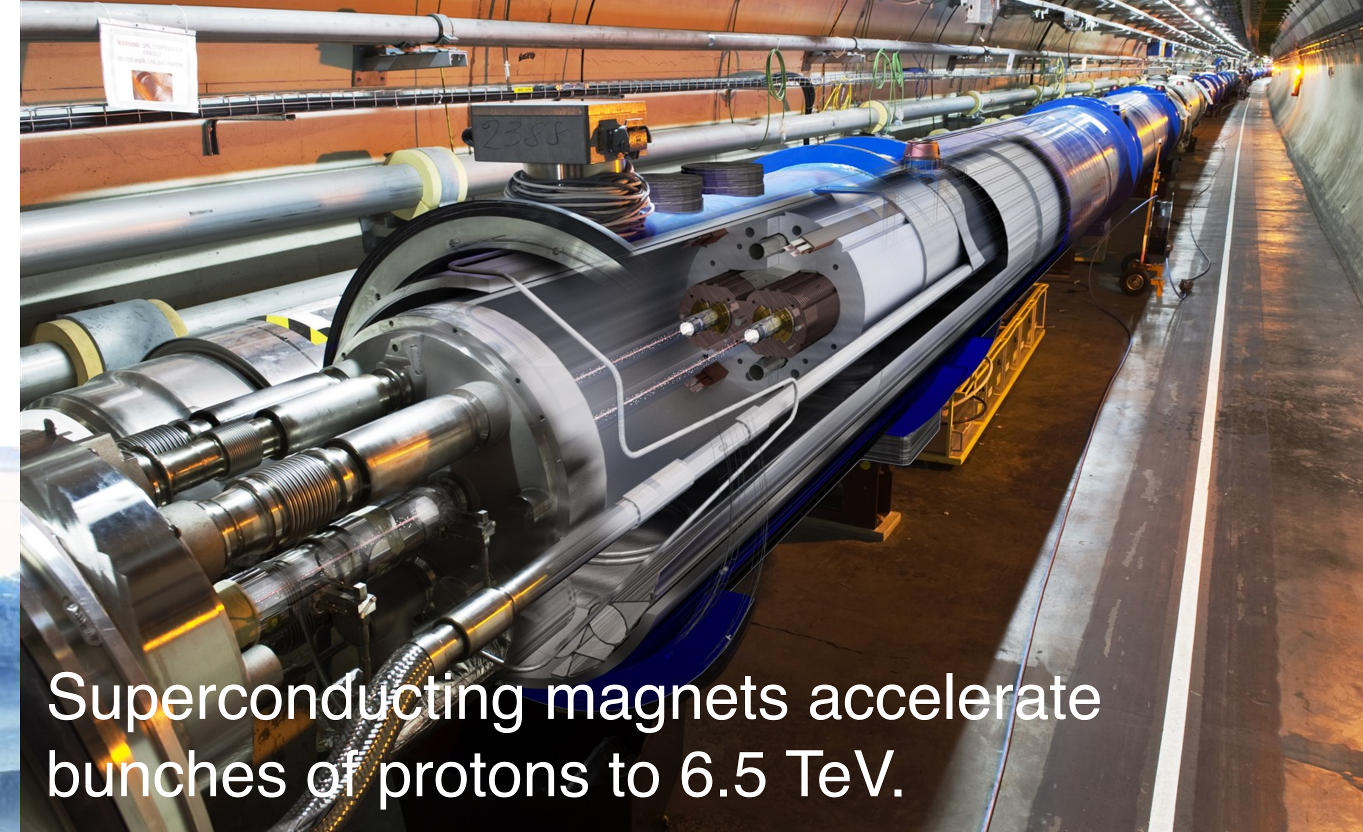
Huge data volumes

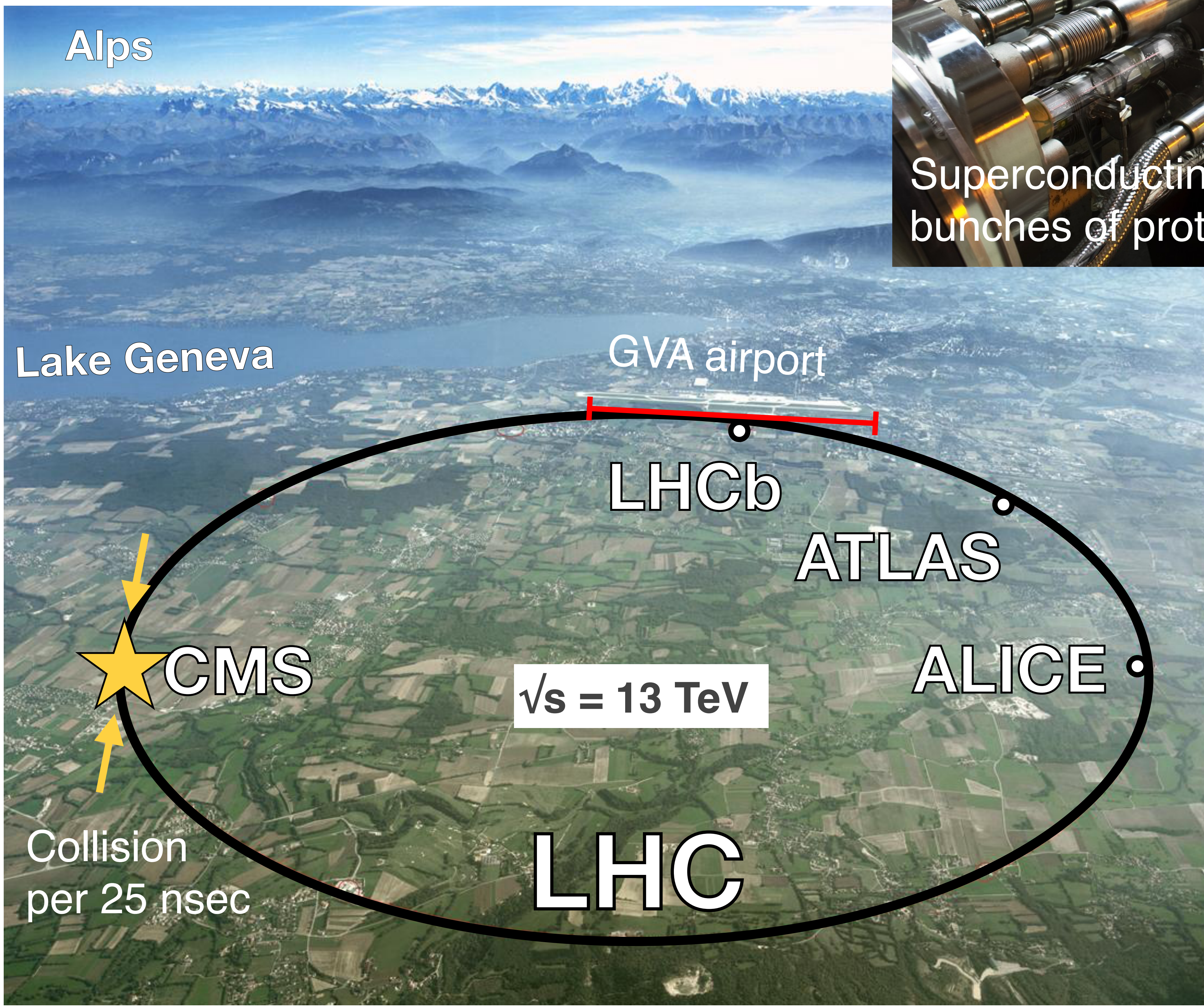


State-of-the-art detectors

The high-energy frontier

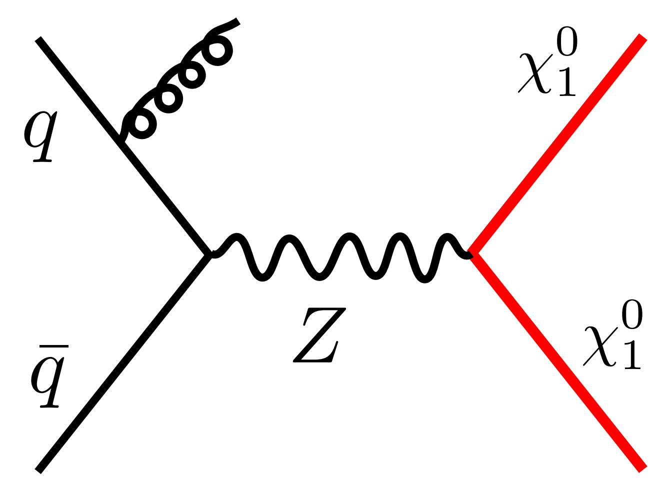
CERN's accelerator complex delivers high-energy proton collisions to CMS at the LHC.



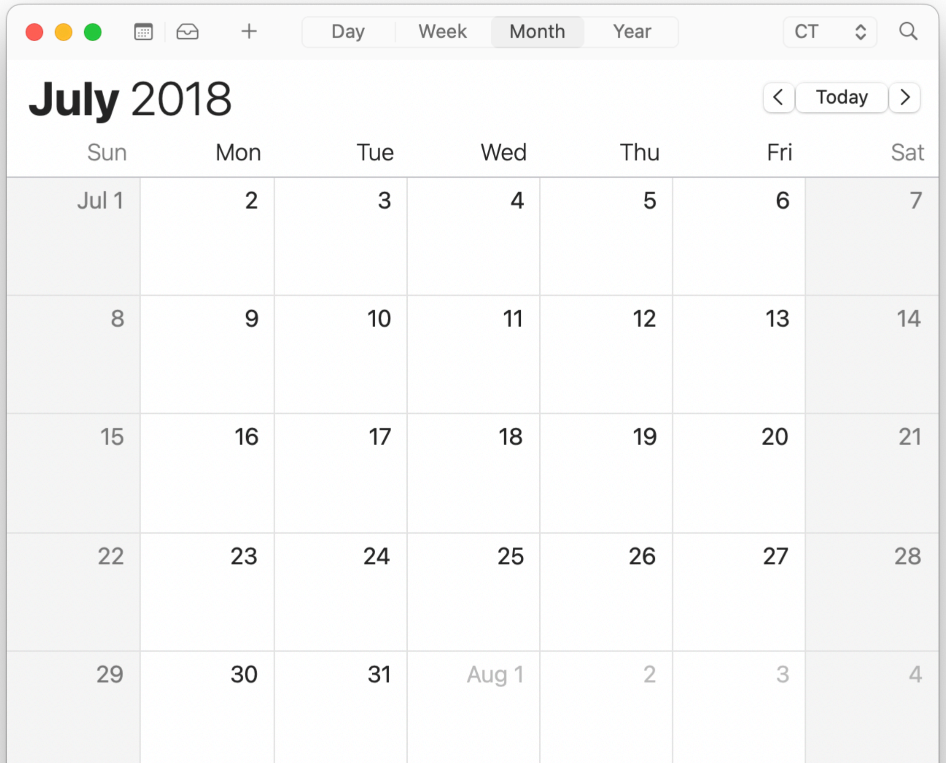


Energy to directly produce the heaviest particles from colliding quarks and gluons.

Including new states (Z' or dark matter?) or the rare SM (W, Z, H, top quark)



Large sample of events (I)



→**200k Higgs**

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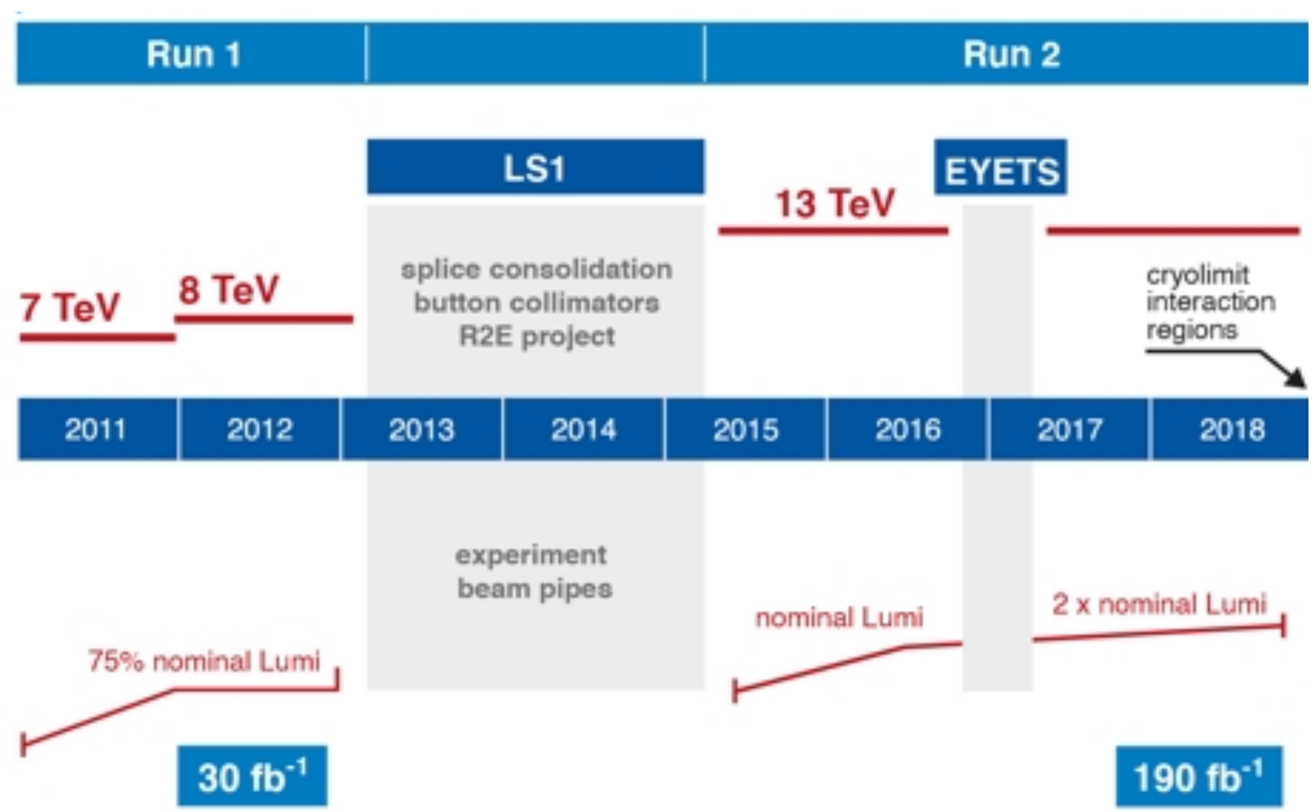
→**…**

At peak running, the LHC provided CMS

~200k Higgs bosons every week!

(and 8 million Z bosons, 80 million Ws!)



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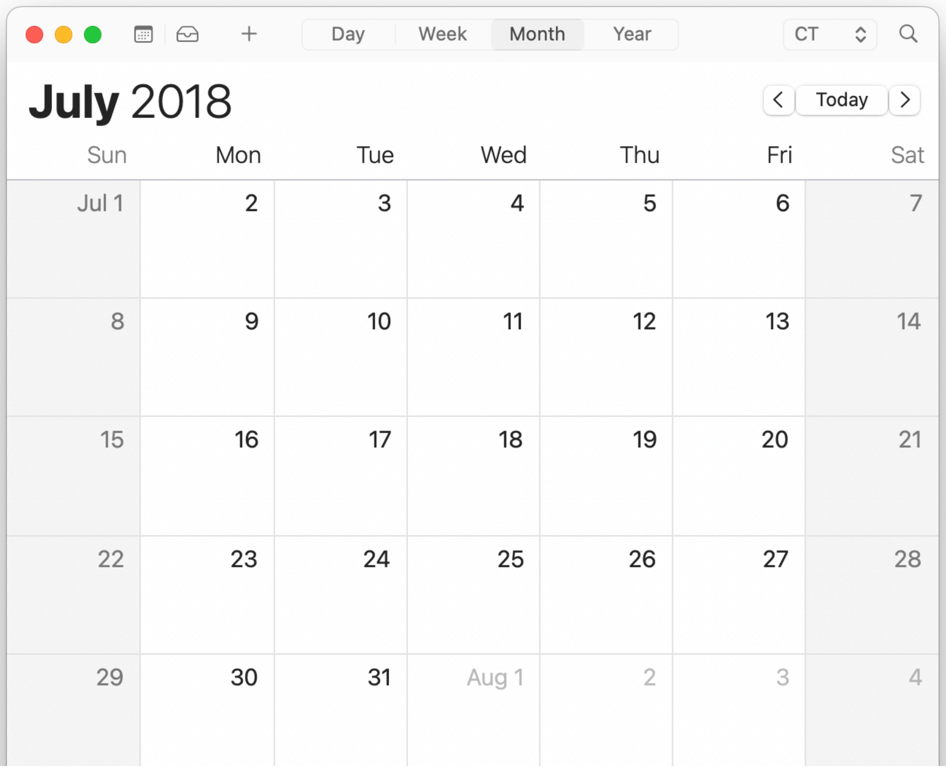

→**200k Higgs**

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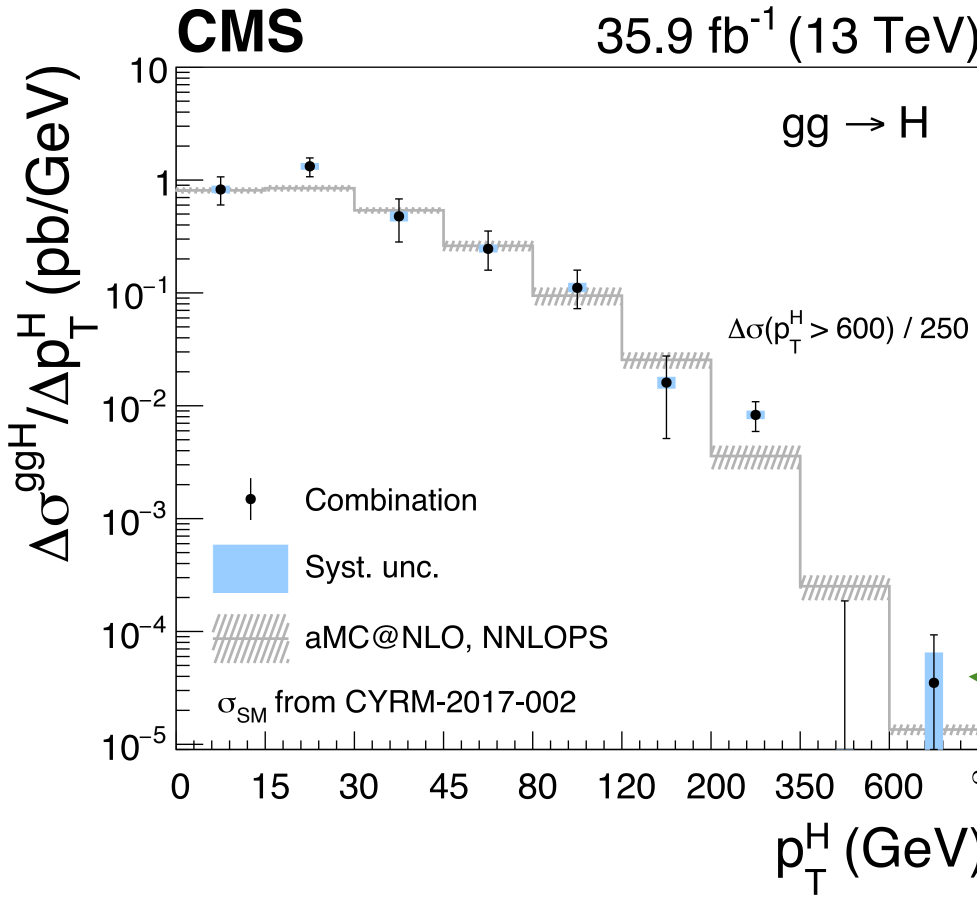
→**…**



Enables high-precision study of the Higgs!

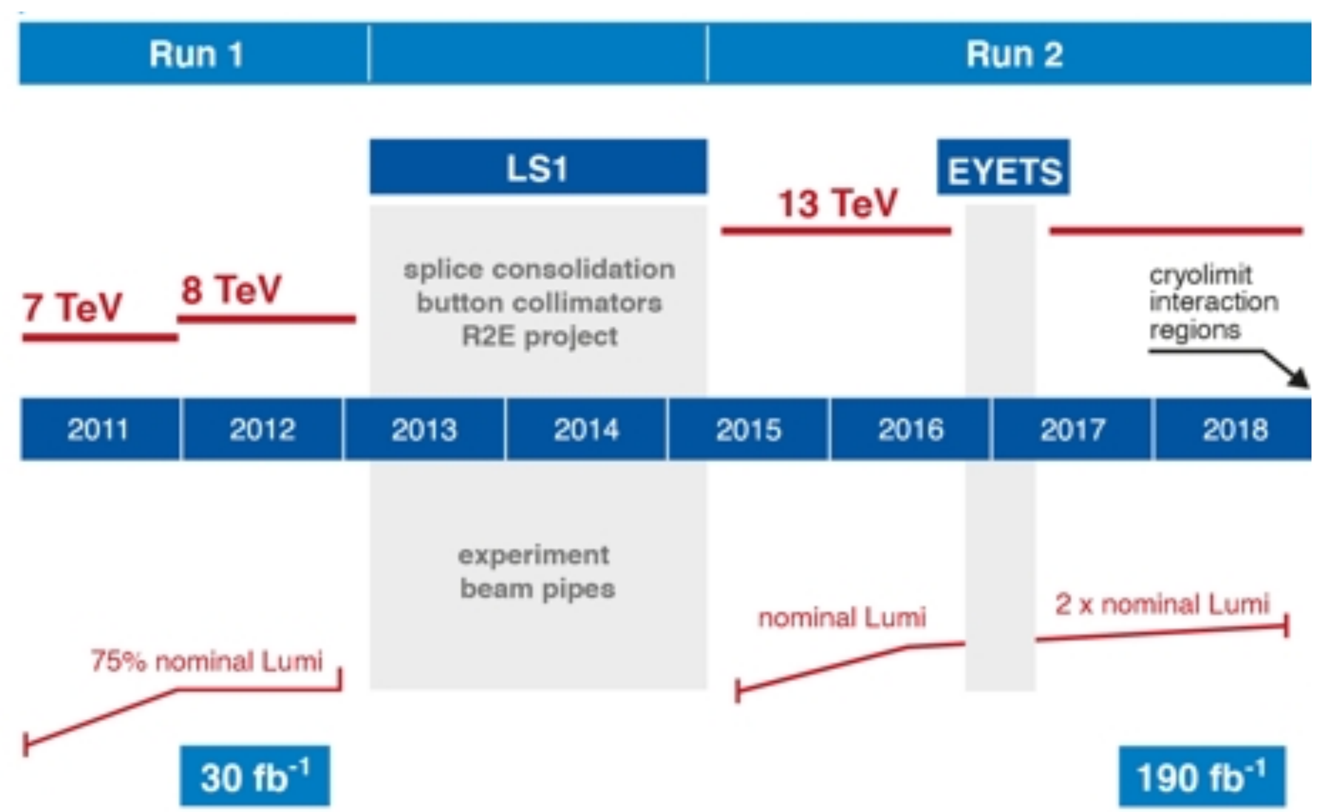
At peak running, the LHC provided CMS

~200k Higgs bosons every week!

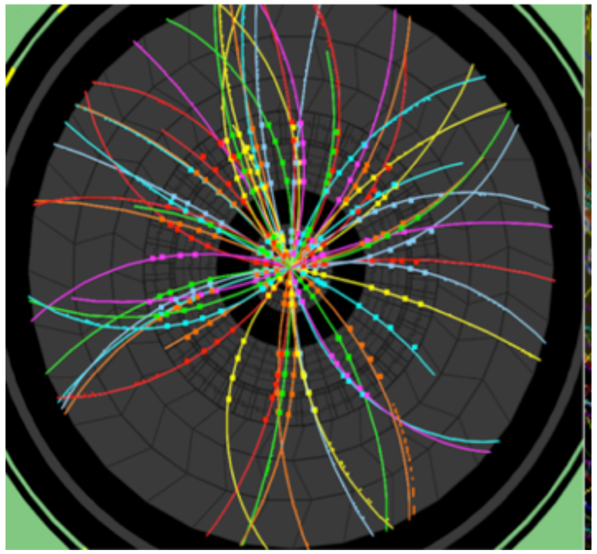
(and 8 million Z bosons, 80 million Ws!)

Over the course of 6 years of Run 1+2

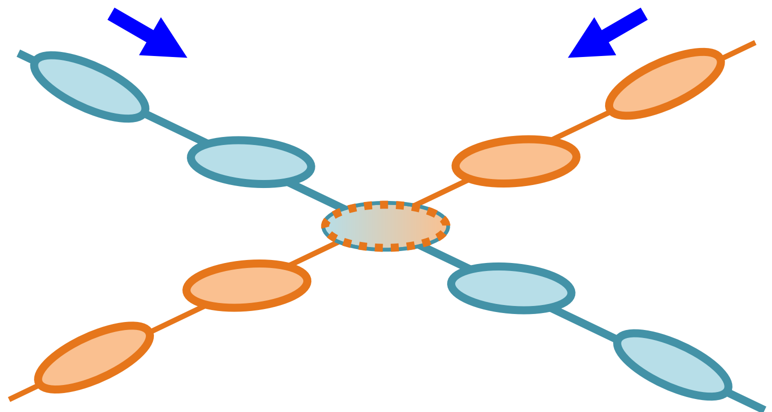
Total of **8 million Higgs** delivered!



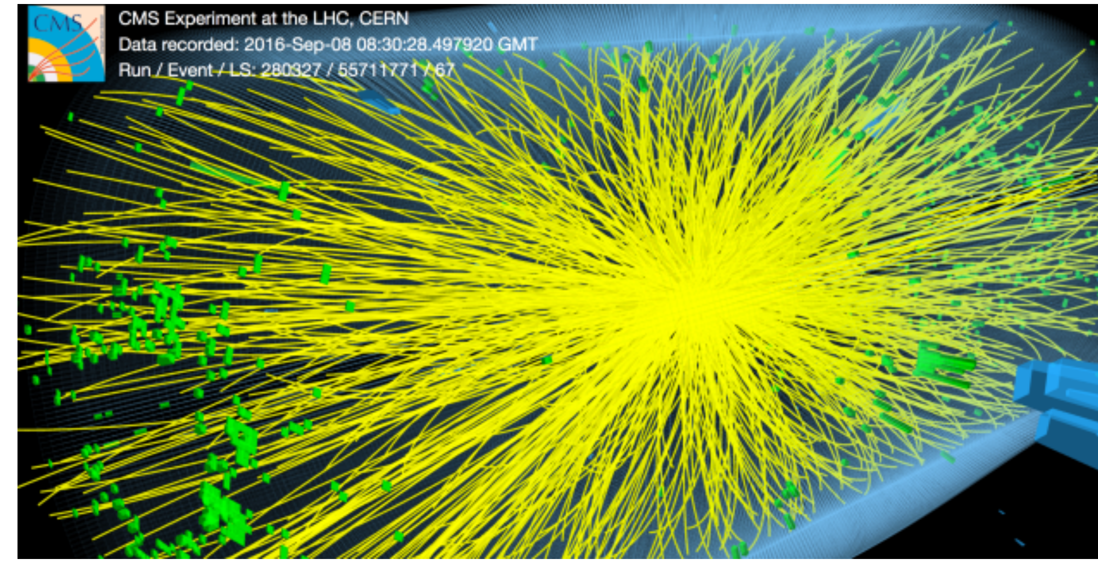
Large sample of events (II)



Early Run 1:
2 collisions / event



Denser proton bunches

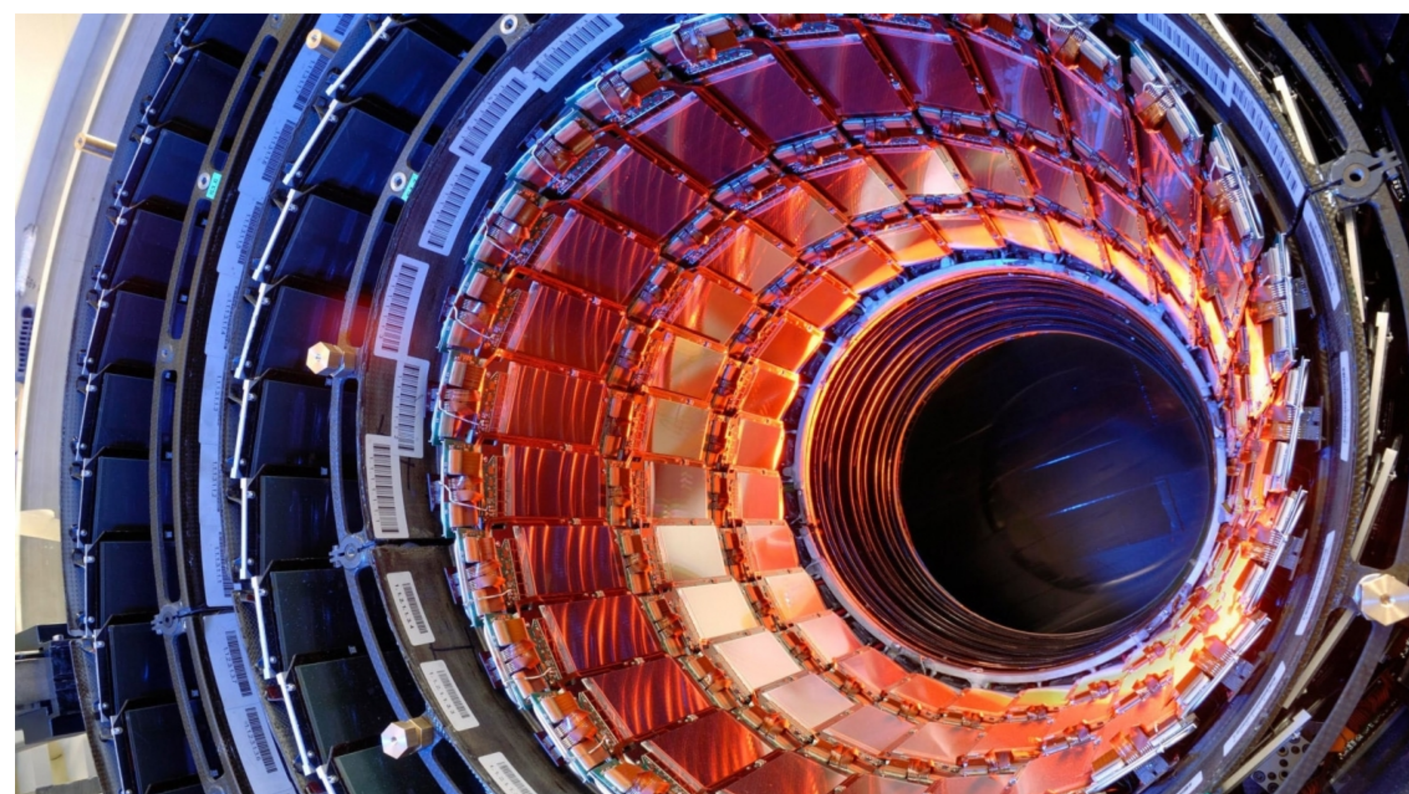


Run 2:
an 86 collision event!

Many proton collisions = many chances to produce Higgs, dark matter, …

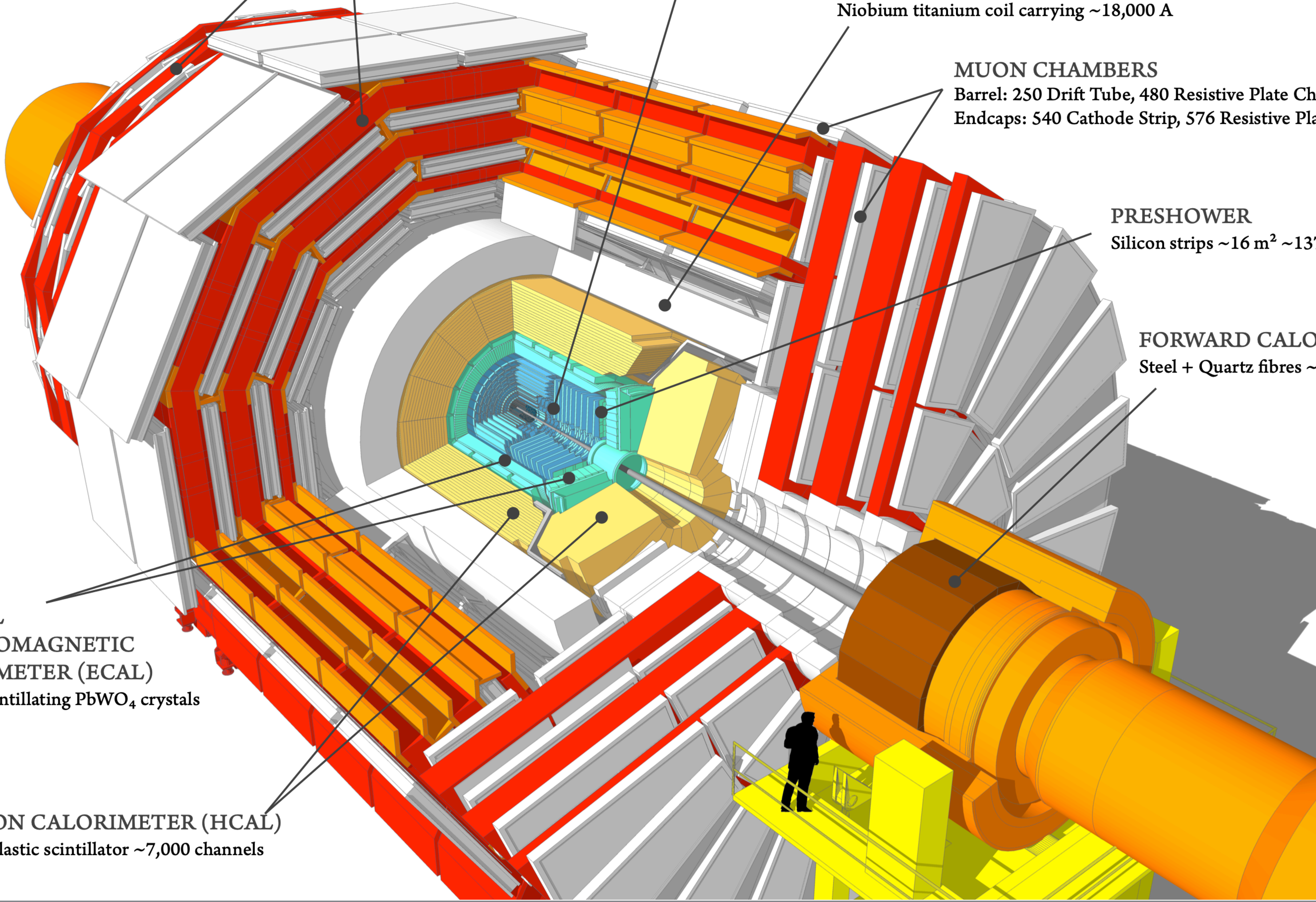
In practice, this leads to one "interesting" collision plus N-1 "pile-up".

Requires a detector, capable of precisely reconstructing many overlapping collisions!



CMS DETECTOR

Total weight	: 14,000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m
Magnetic field	: 3.8 T



CMS DETECTOR

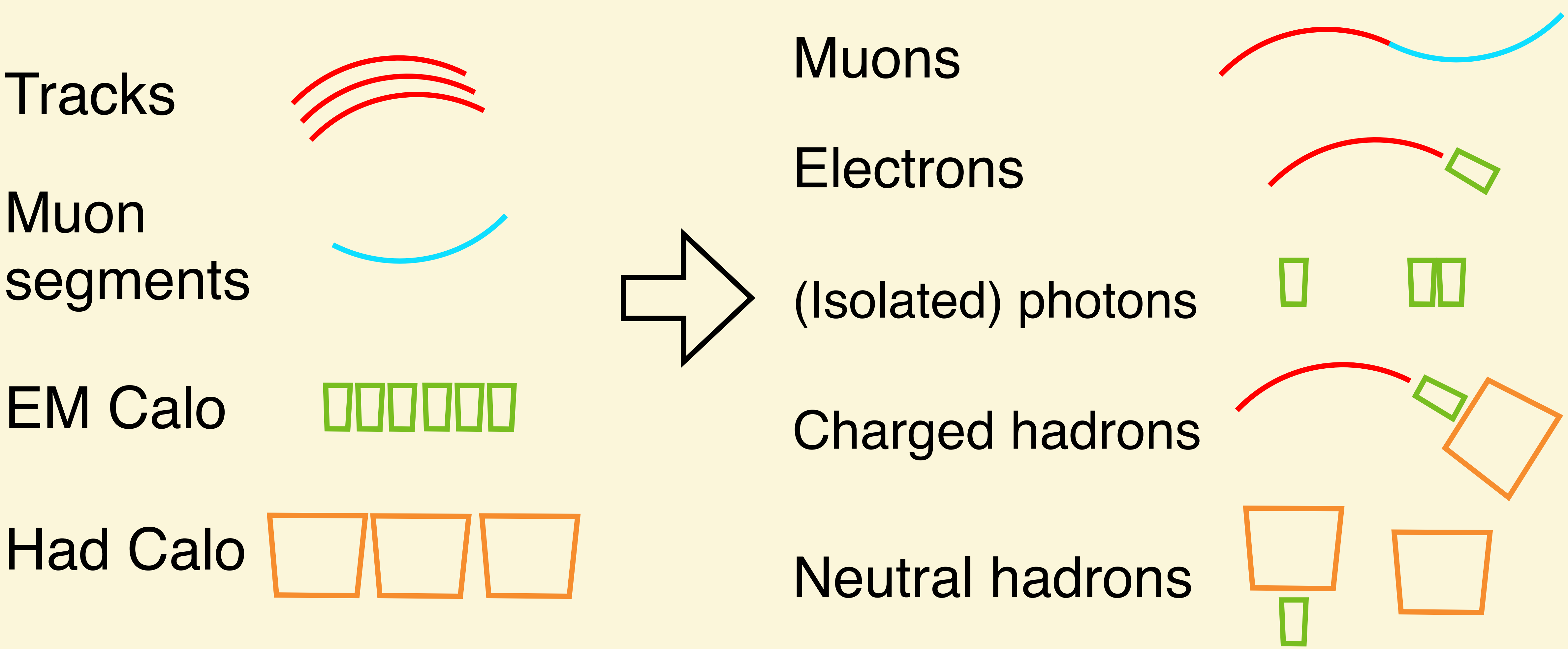
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel (100x150 μm²) ~1.9 m² ~124M channels
Microstrips (80–180 μm) ~200 m² ~9.6M channels

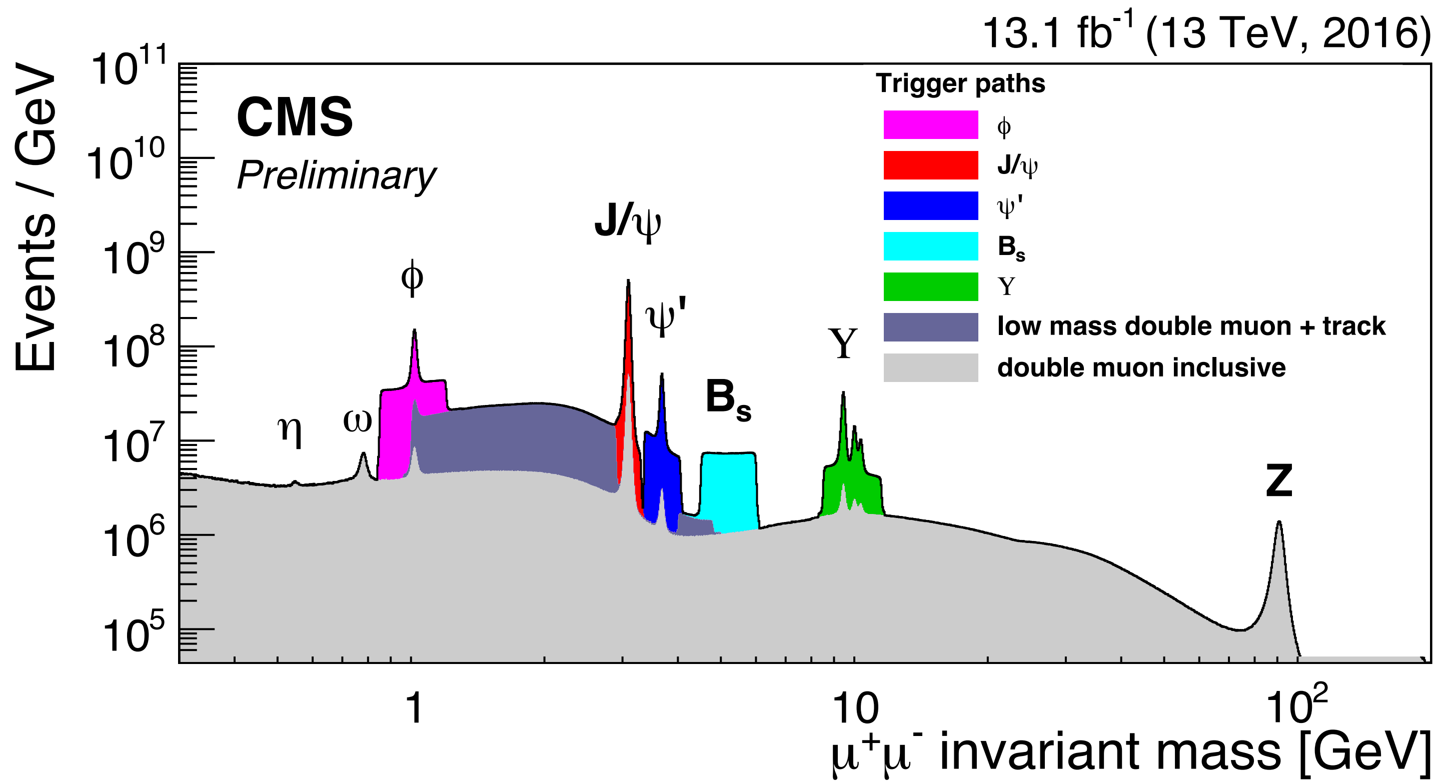
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000 A

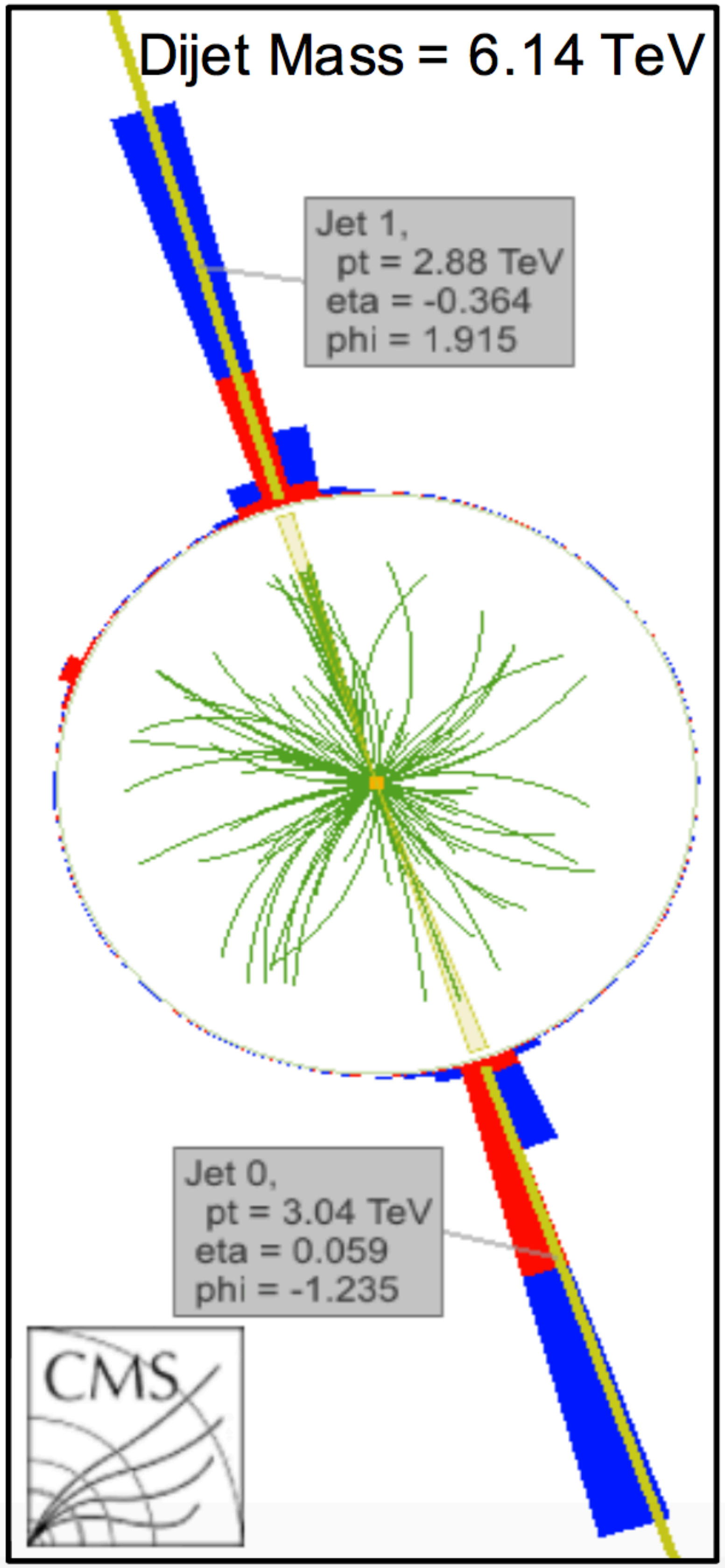
The **Particle Flow algorithm** combines information from across each sub-detector into a global event record.



HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

Sensitivity across orders of magnitude!





From **500 MeV di-muon resonances**…

…to **6 TeV di-jets**!

Putting it all together: a new physics search

A personal example: weakly-interacting dark matter

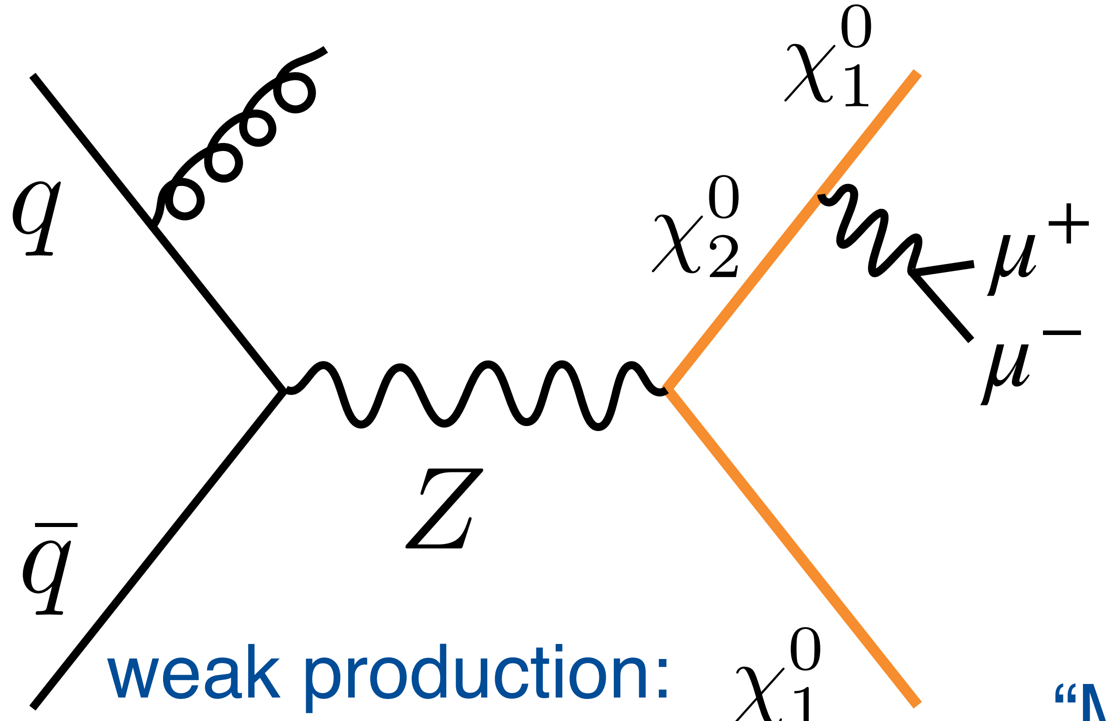
Weak interaction → may be produced at LHC

Interesting signatures beyond "missing momentum" for weak multiplets

Appears in both "minimal DM" models and UV-completions (e.g. SUSY)

Energetic jet from initial state radiation

Signature in the CMS detector:



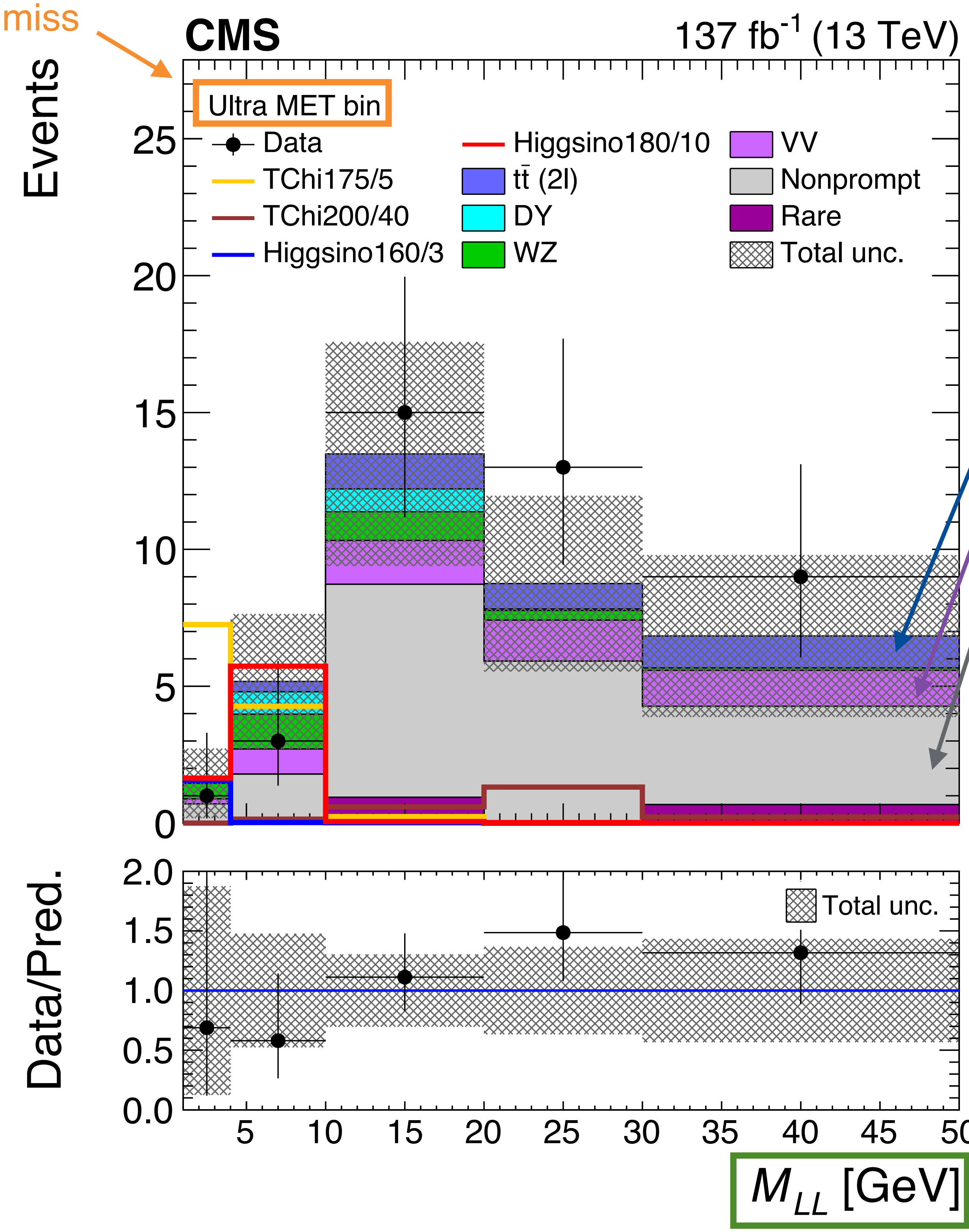
A pair of muons with ~GeV muon p_T

weak production: small σ(pp→χχ)

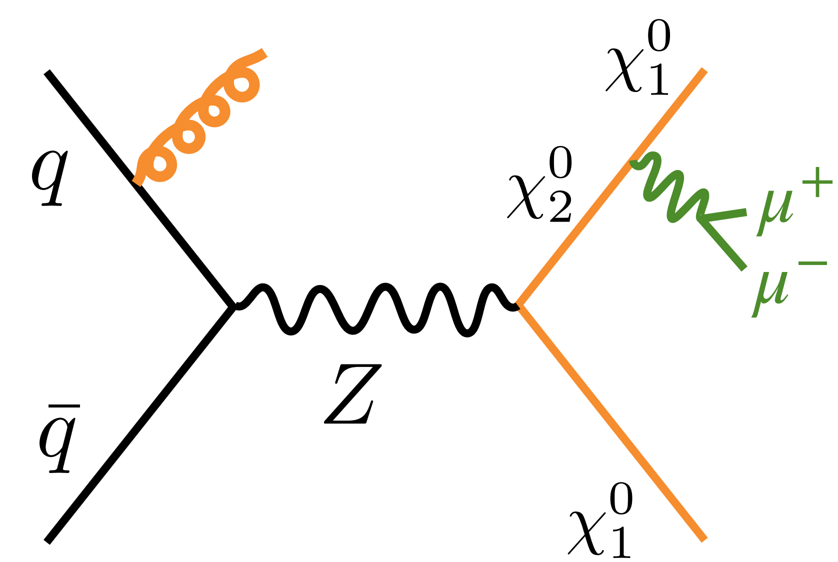
"Missing momentum"

Putting it all together: a new physics search

Selection:
Large $p_{T,miss}$



Stacked histograms:
Expected **backgrounds**



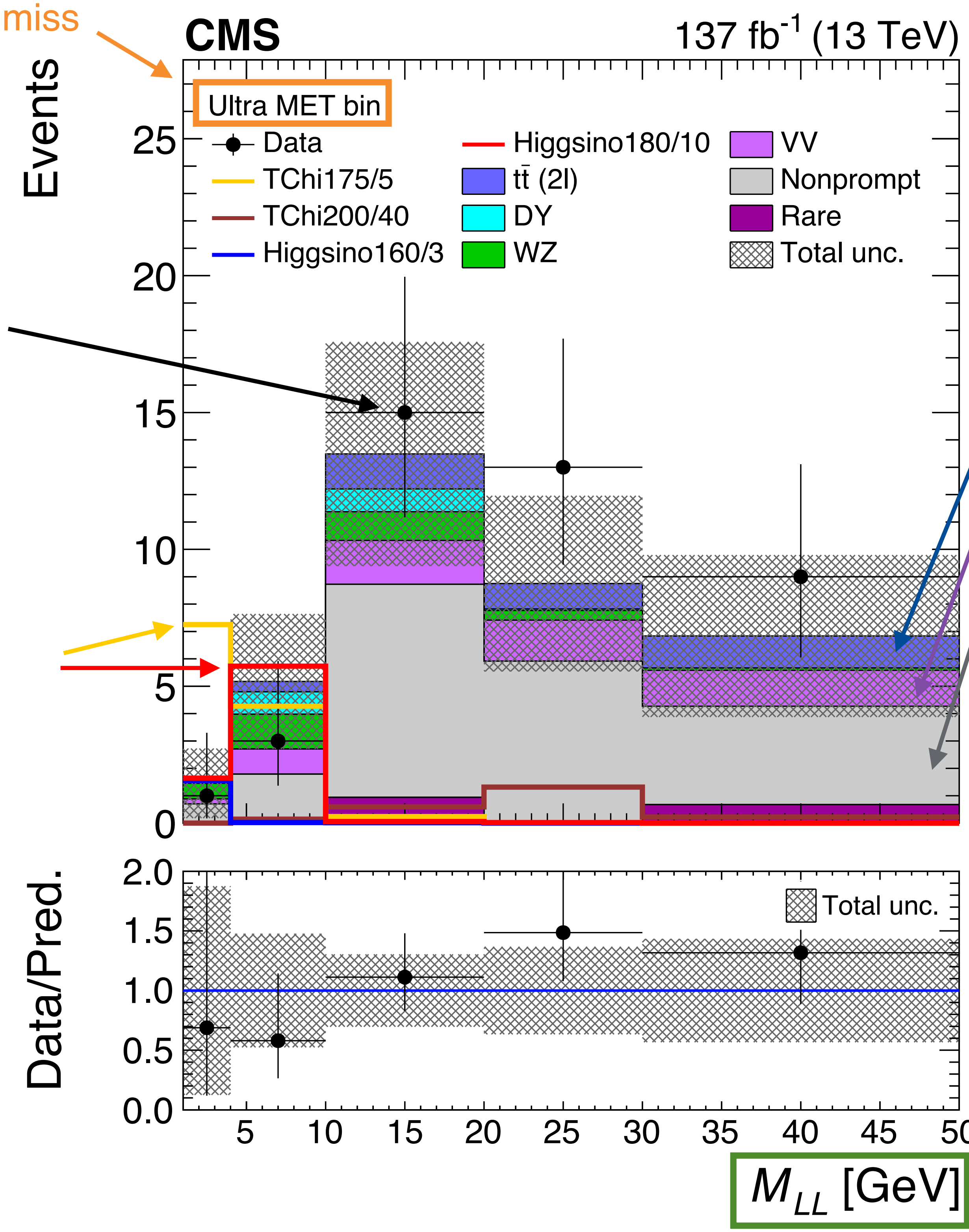
Bins: mass of the di-lepton system

Putting it all together: a new physics search

Selection:
Large $p_{T,miss}$

Black points:
number of events observed in **data**

Colored lines:
Predicted **signal** of dark matter (various models)



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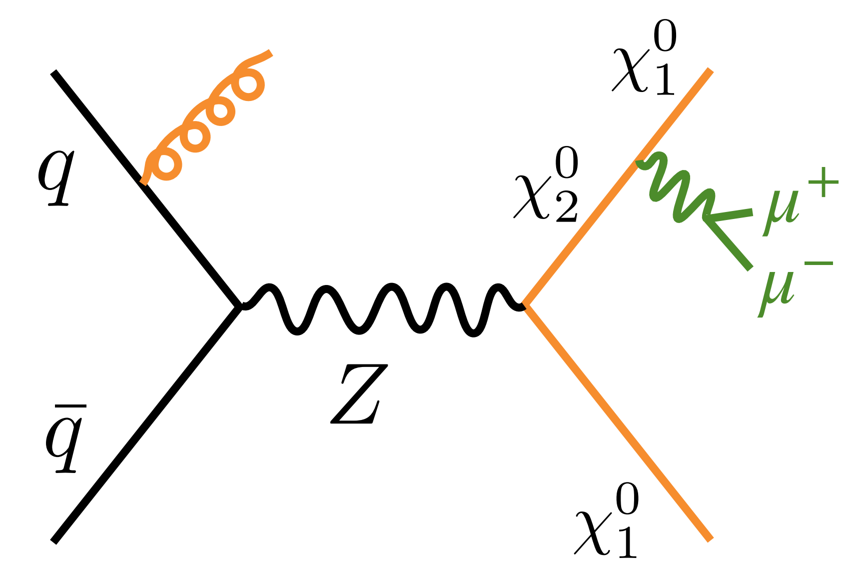

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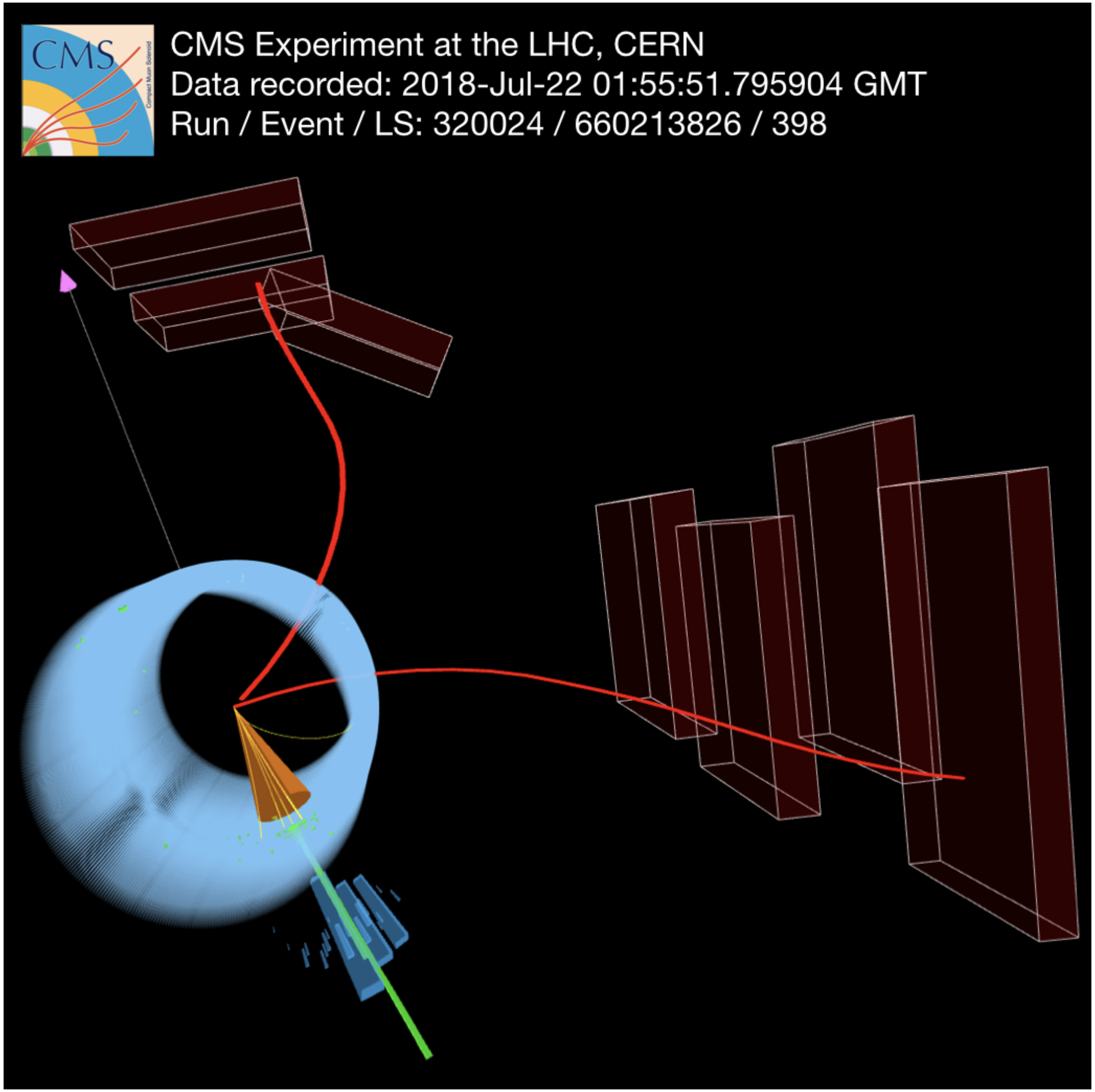


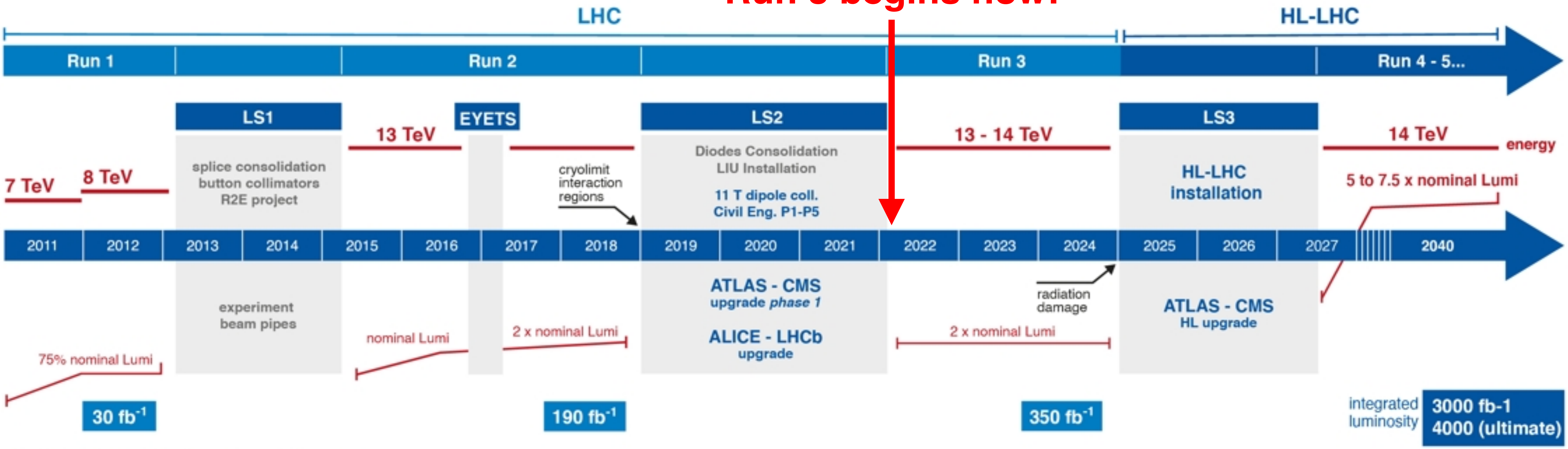
Observe a few signal-like events in data…

… but so far the total number is consistent with our backgrounds.

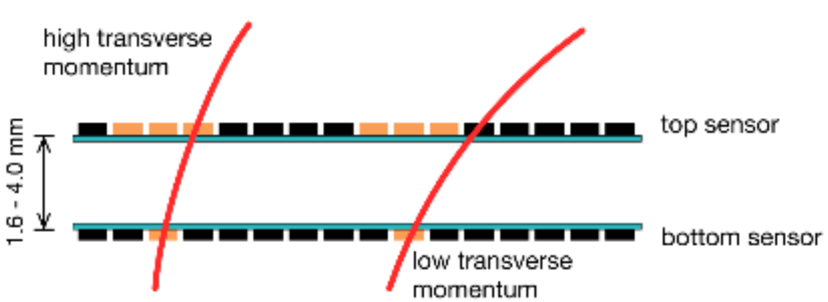
Looking ahead to the "high-luminosity LHC"

High-lumi LHC will provide an ultimate dataset **~20x larger than Run 2!**

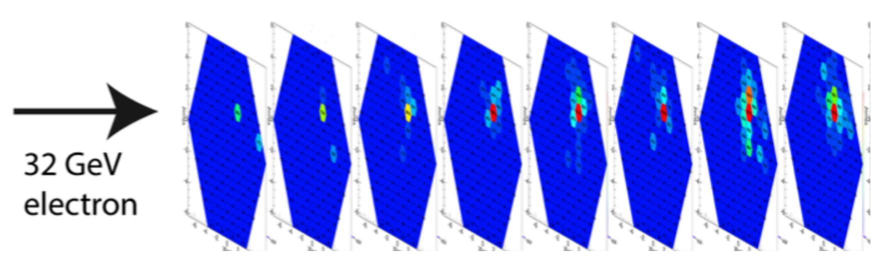
Run 3 begins now!



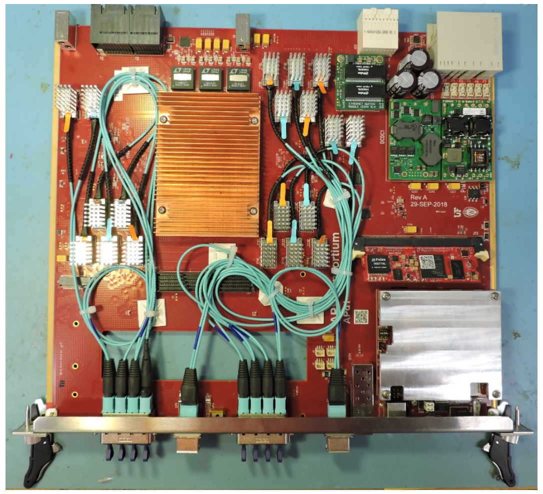
Adding a **new tracker**, **new high-granularity calorimeter**, **new trigger system** + more!



Trigger tracks



"5d" calorimeter images



New trigger hardware!