# Performance and Accomplishments of CMS and Totem in 2016

*Zeynep Demiragli* *
*on behalf of the CMS Collaboration*

** Massachusetts Institute of Technology*

# CMS Collaboration and It's Goals

The **CMS experiment** is an international **scientific collaboration**, involving about **3500 scientists, engineers, and students** from **199 institutes in 46 countries**.

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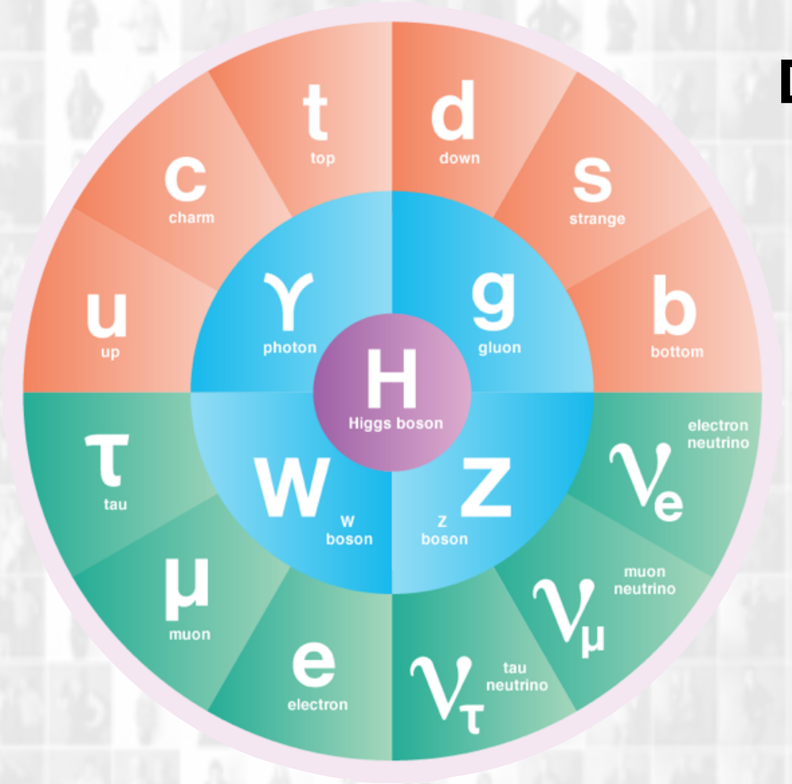


**Standard Model**

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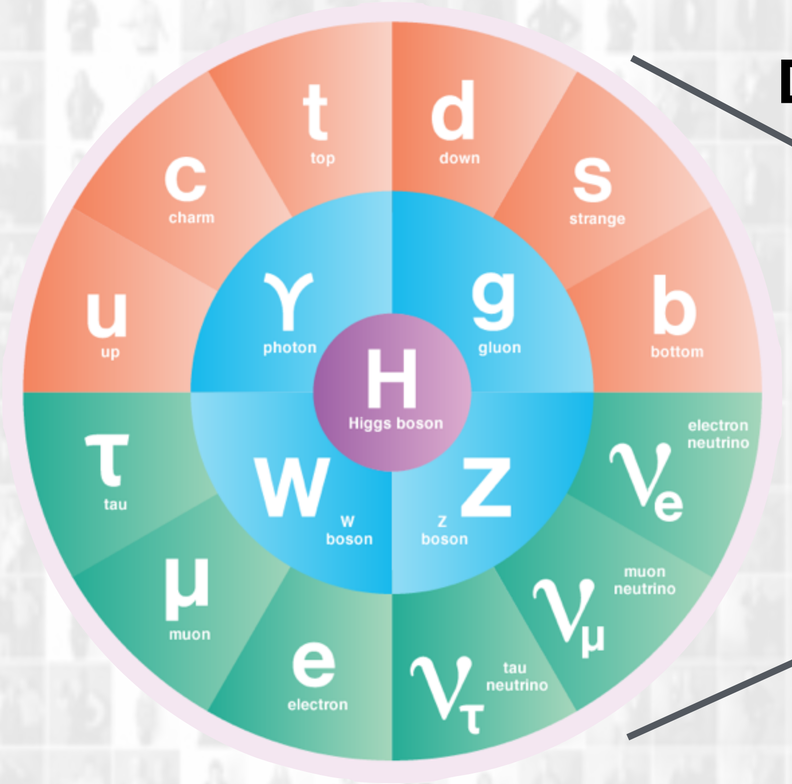


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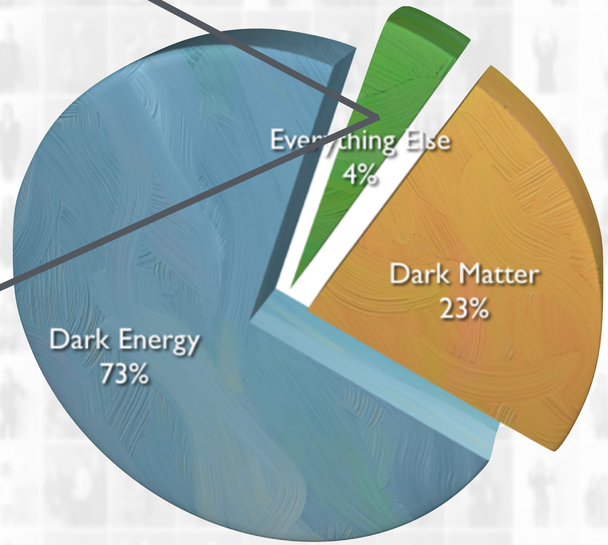
but… there is **more than "just" the Higgs**



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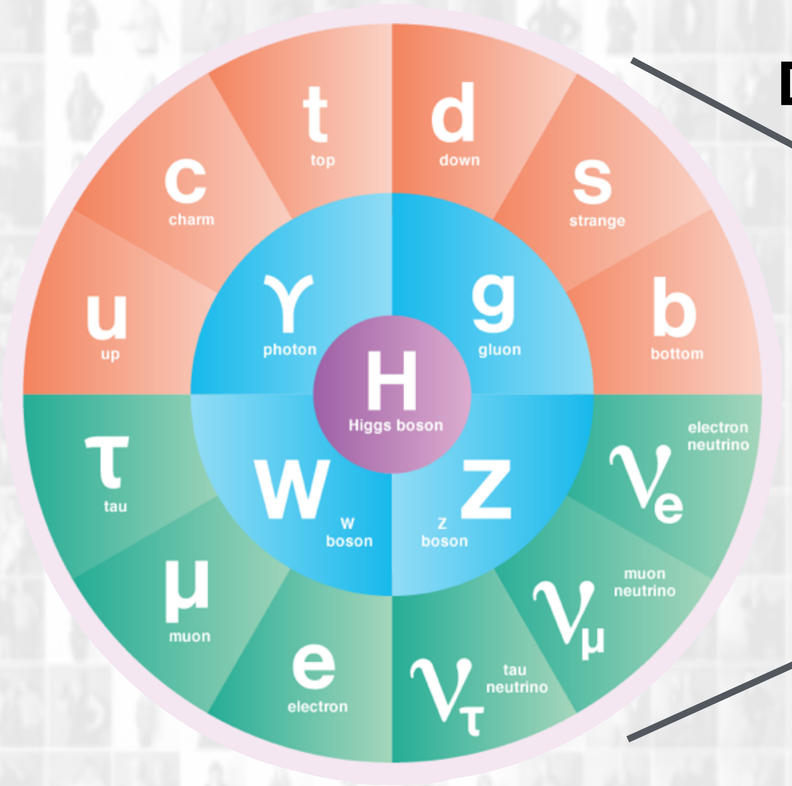


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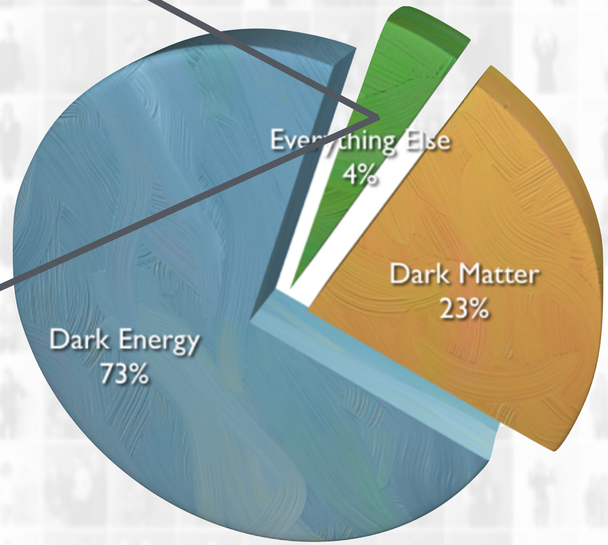
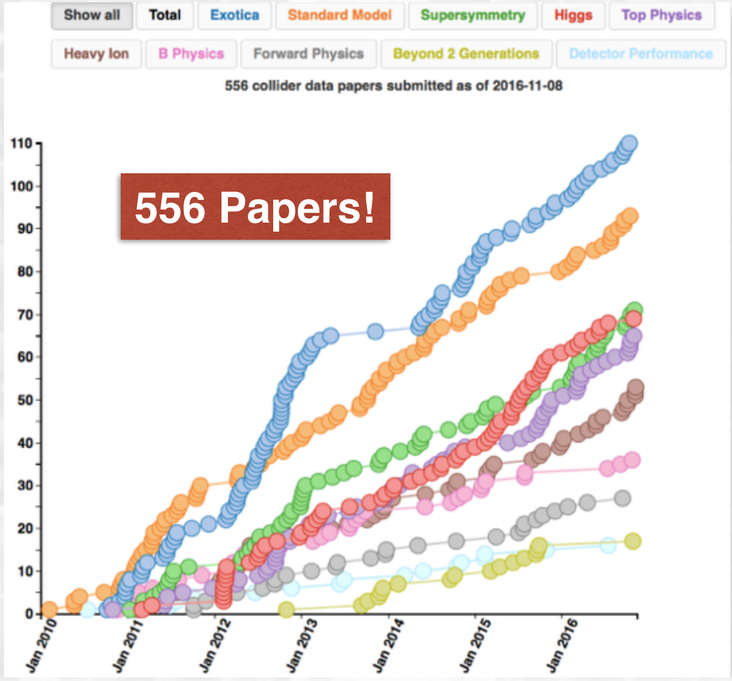
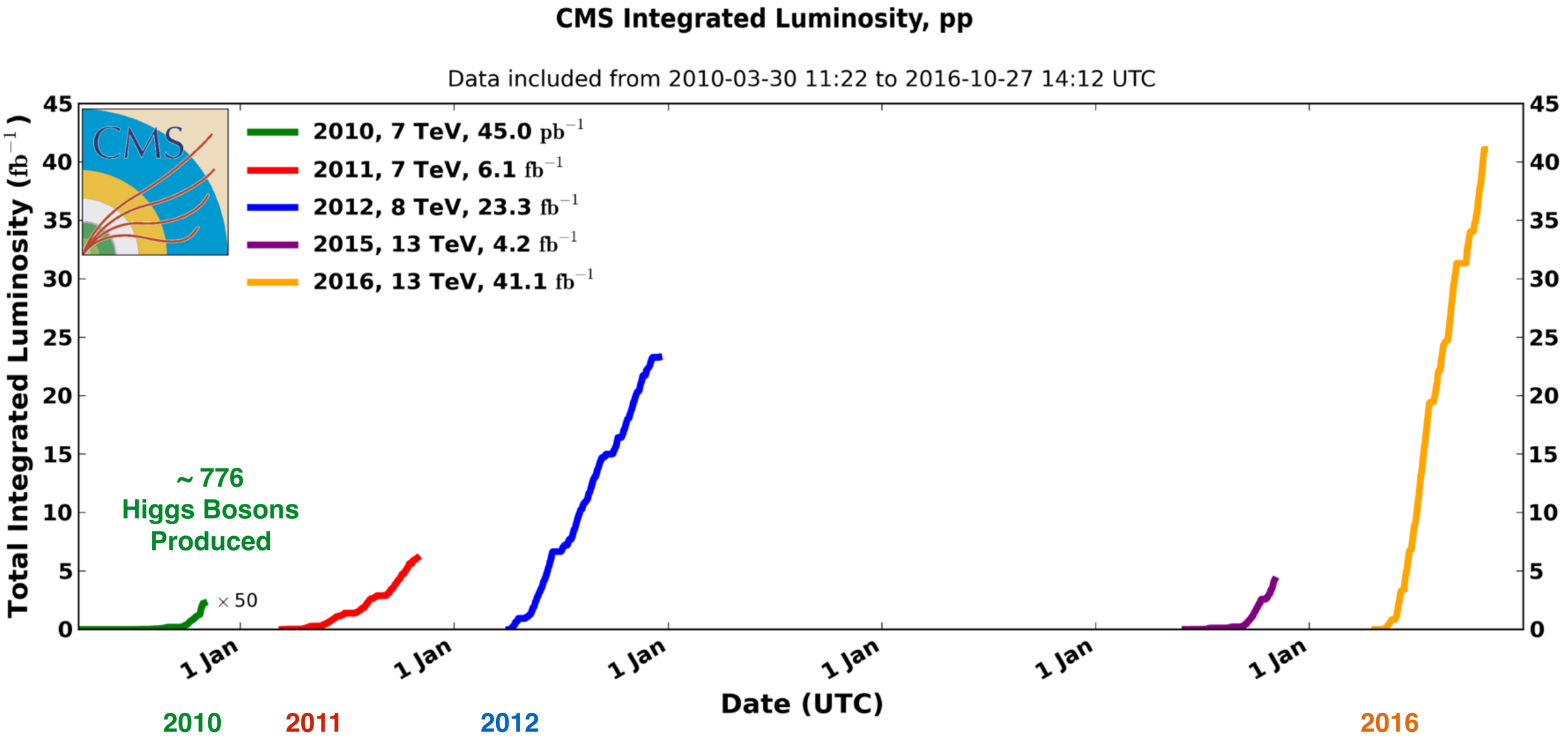


# CMS Data Taking History



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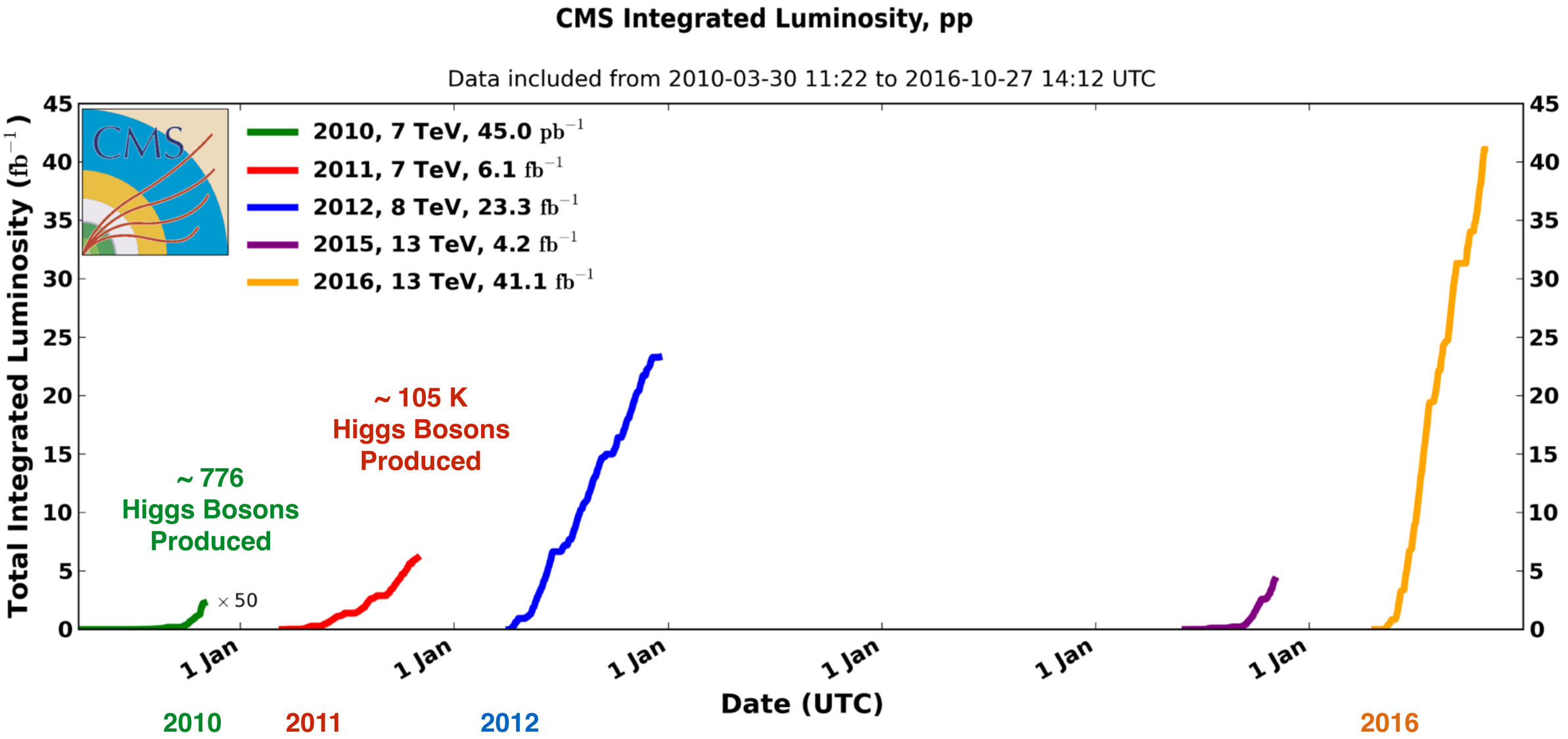

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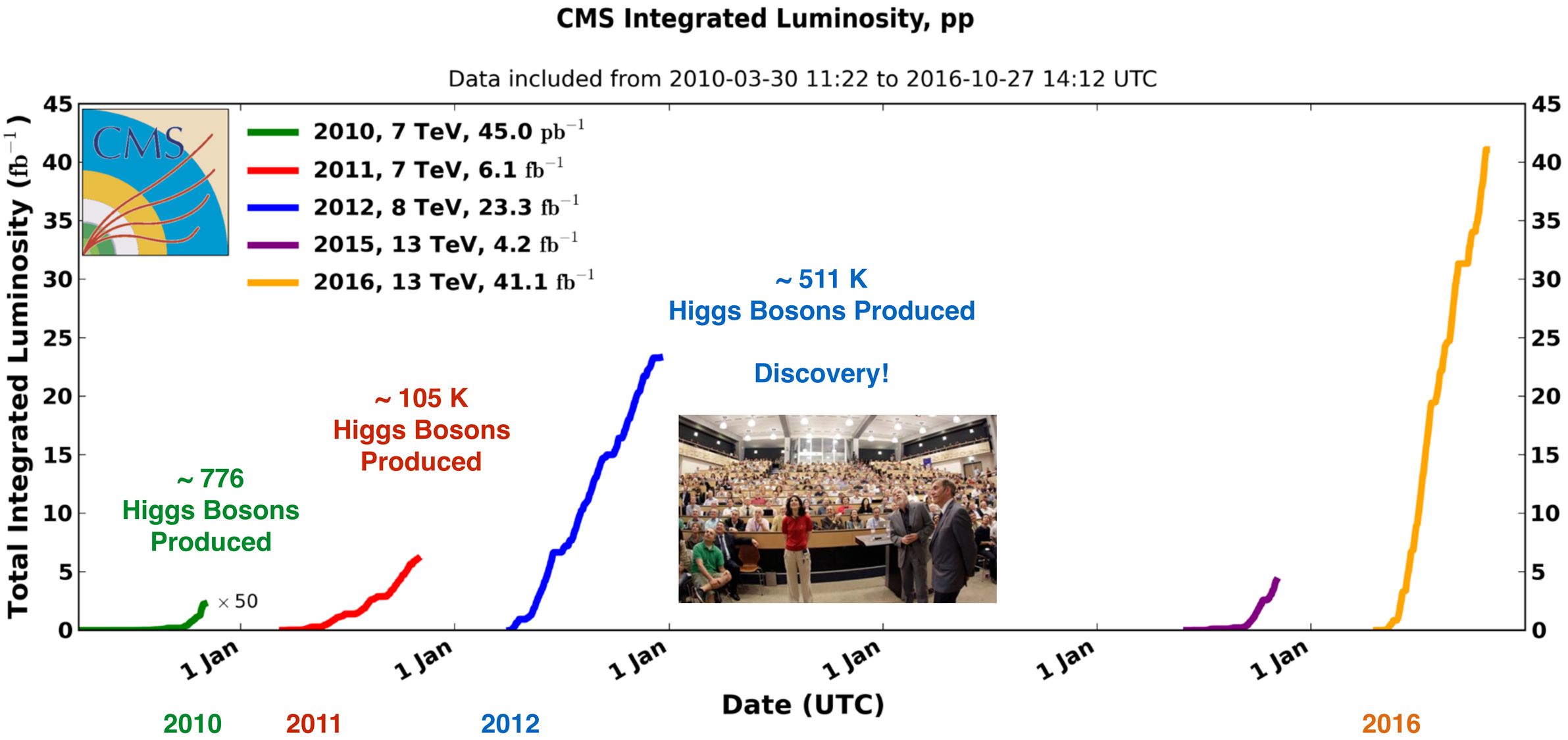

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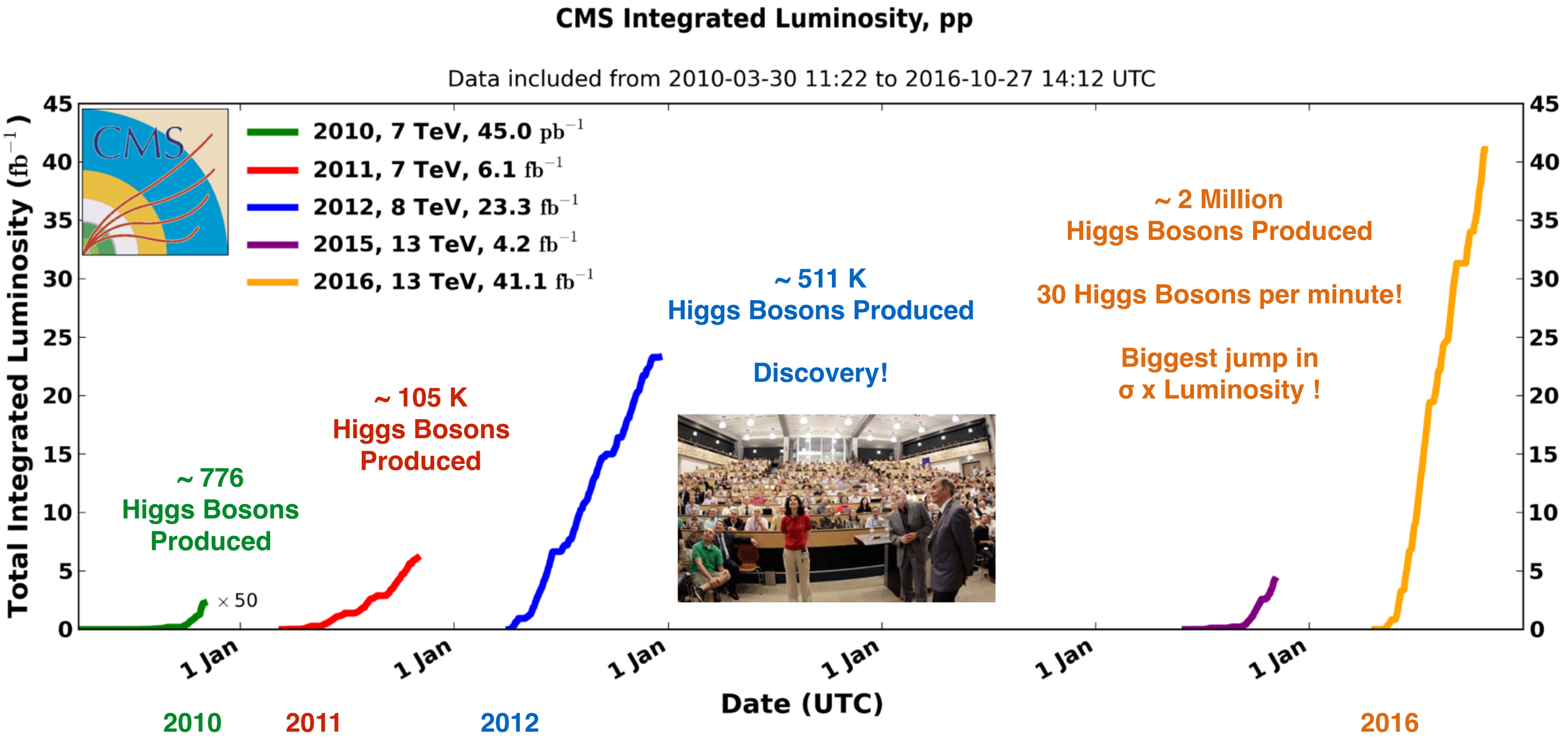
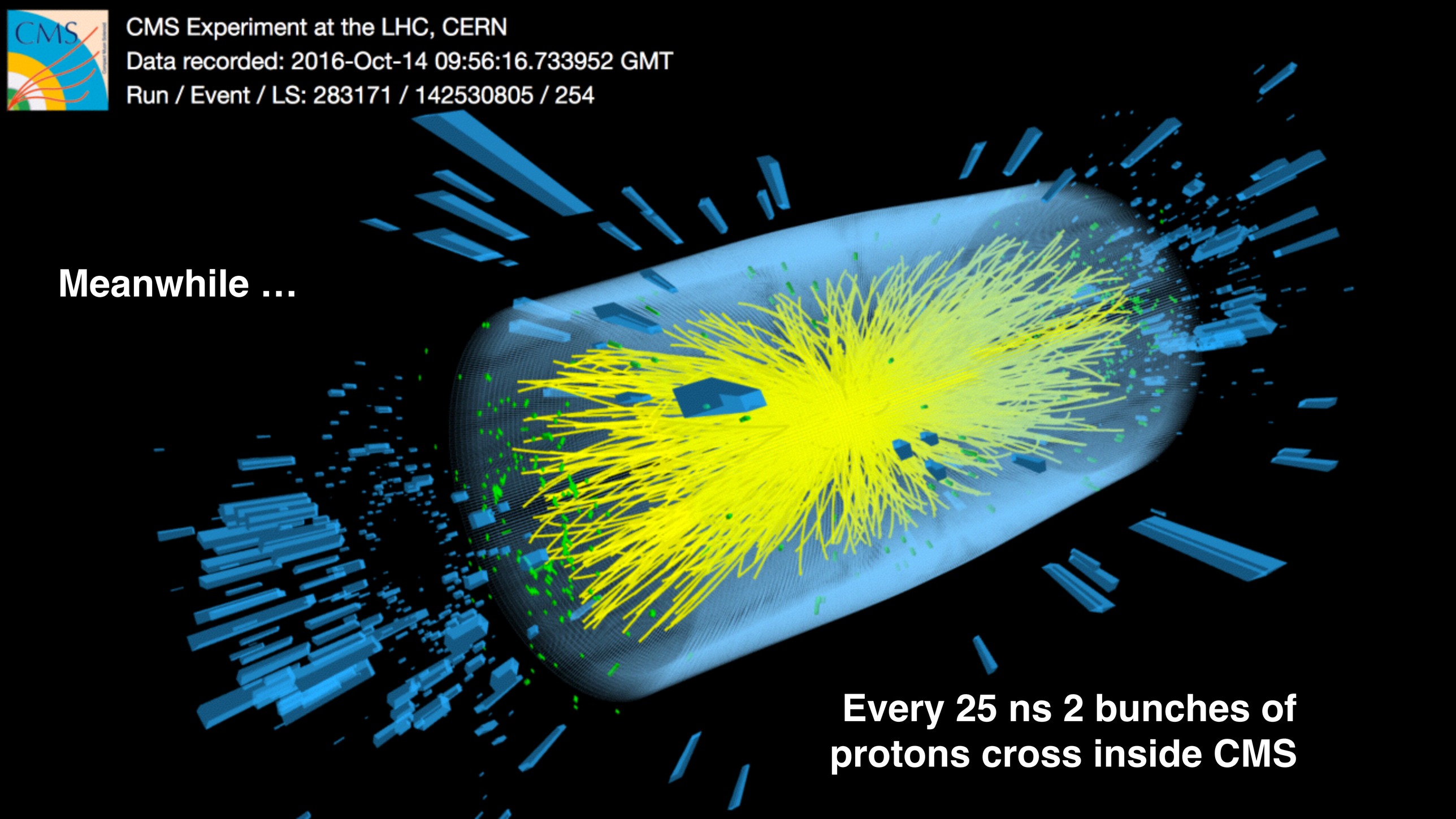
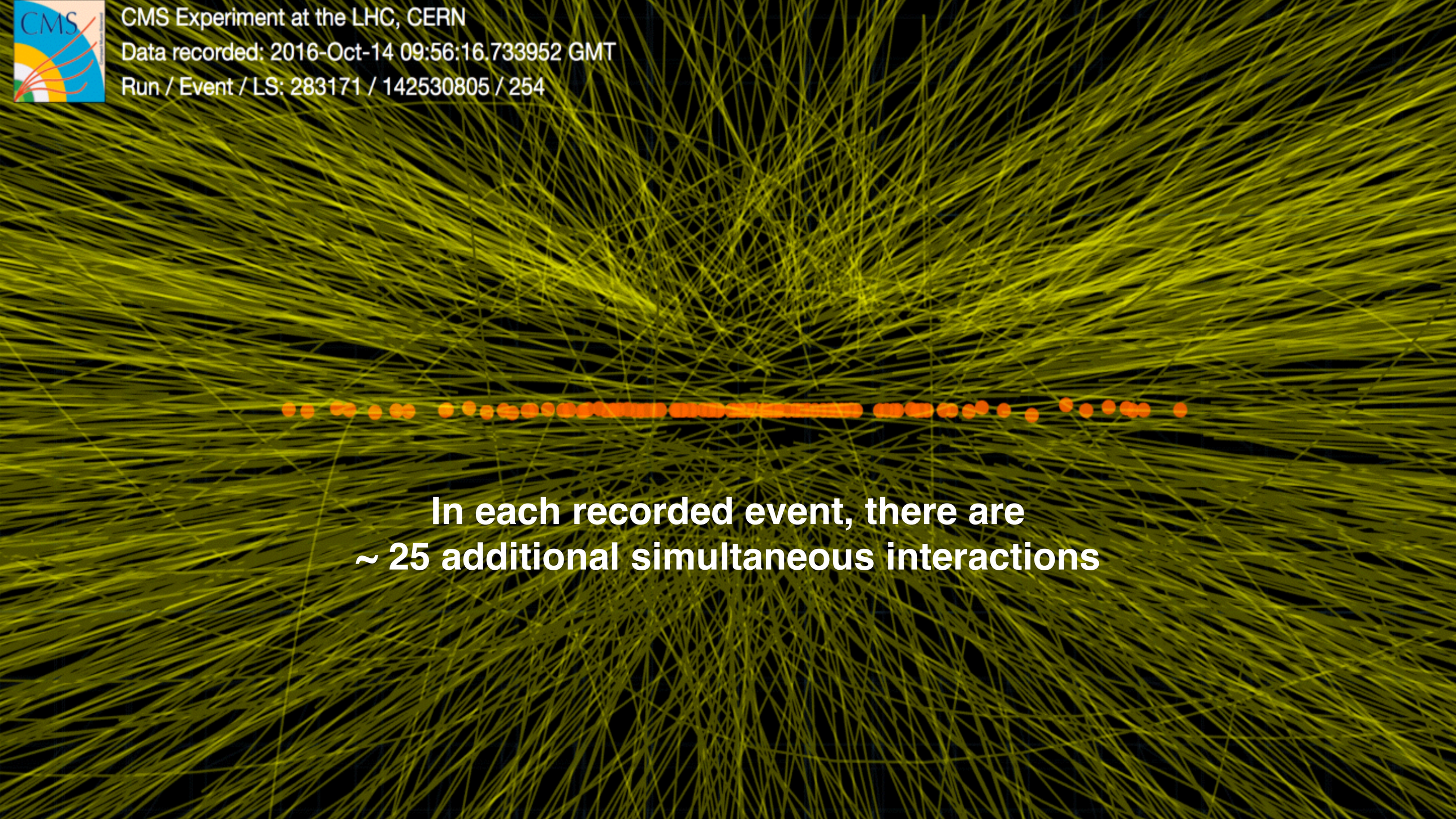



CMS Experiment at the LHC, CERN
Data recorded: 2016-Oct-14 09:56:16.733952 GMT
Run / Event / LS: 283171 / 142530805 / 254
Meanwhile …
Every 25 ns 2 bunches of
protons cross inside CMS


CMS Experiment at the LHC, CERN
Data recorded: 2016-Oct-14 09:56:16.733952 GMT
Run / Event / LS: 283171 / 142530805 / 254
In each recorded event, there are
~ 25 additional simultaneous interactions

# CMS Operations in Run 2

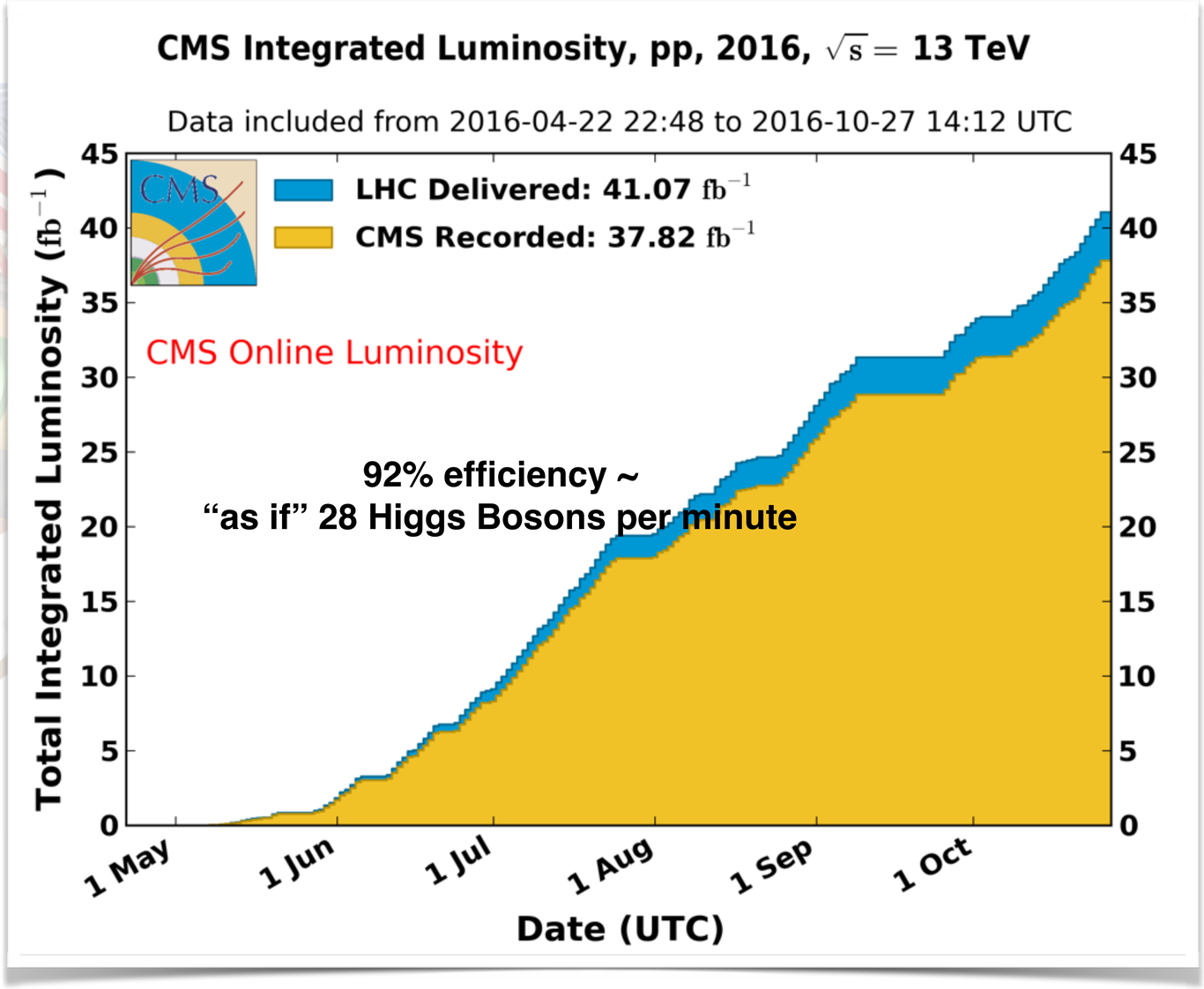
**CMS in 2016 operated with high efficiency**

- more than **96%** detector active
- **92%** data taking efficiency

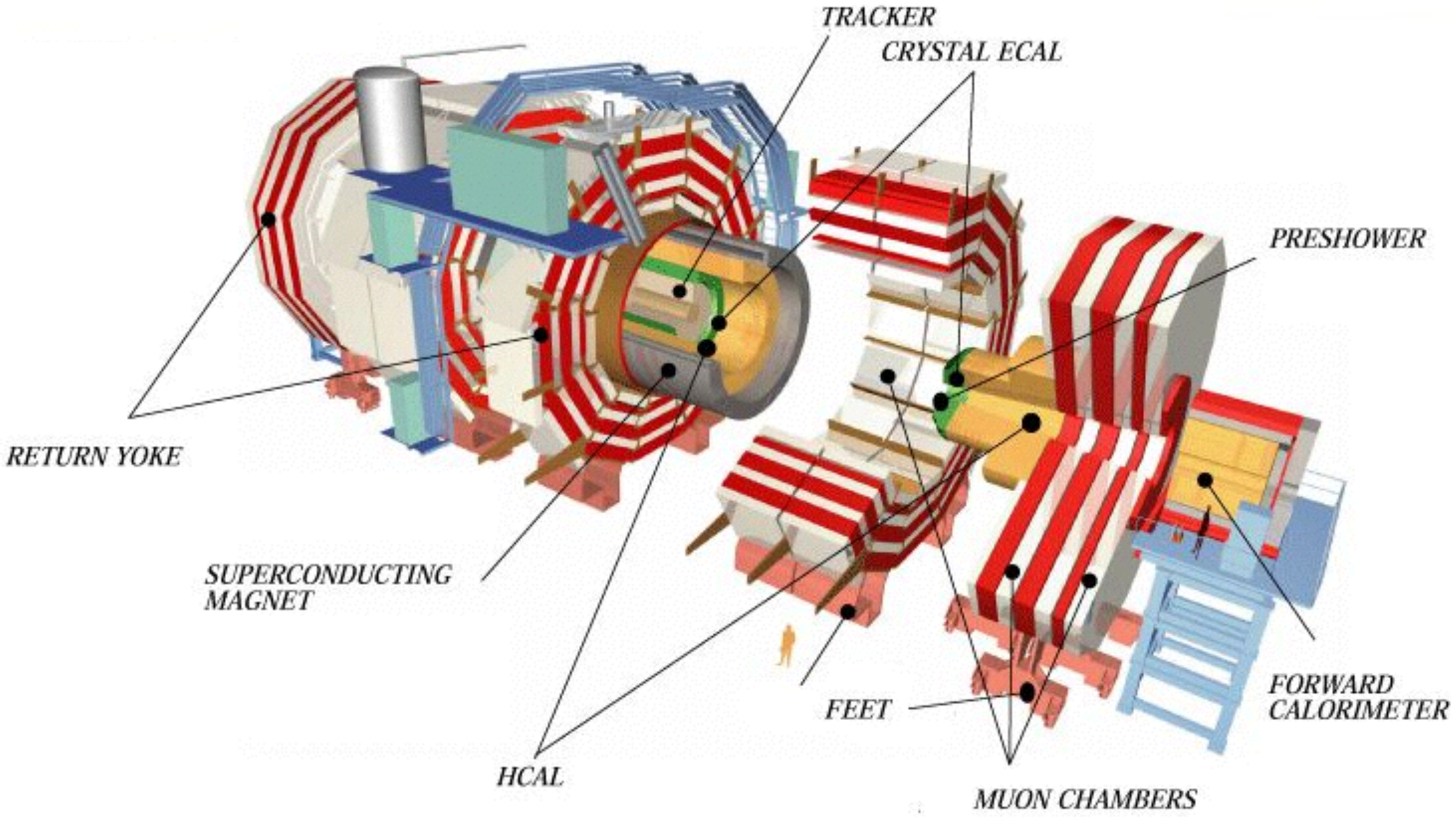
**SUPERCONDUCTING MAGNET**

**Cryo system repaired and cleaned.**

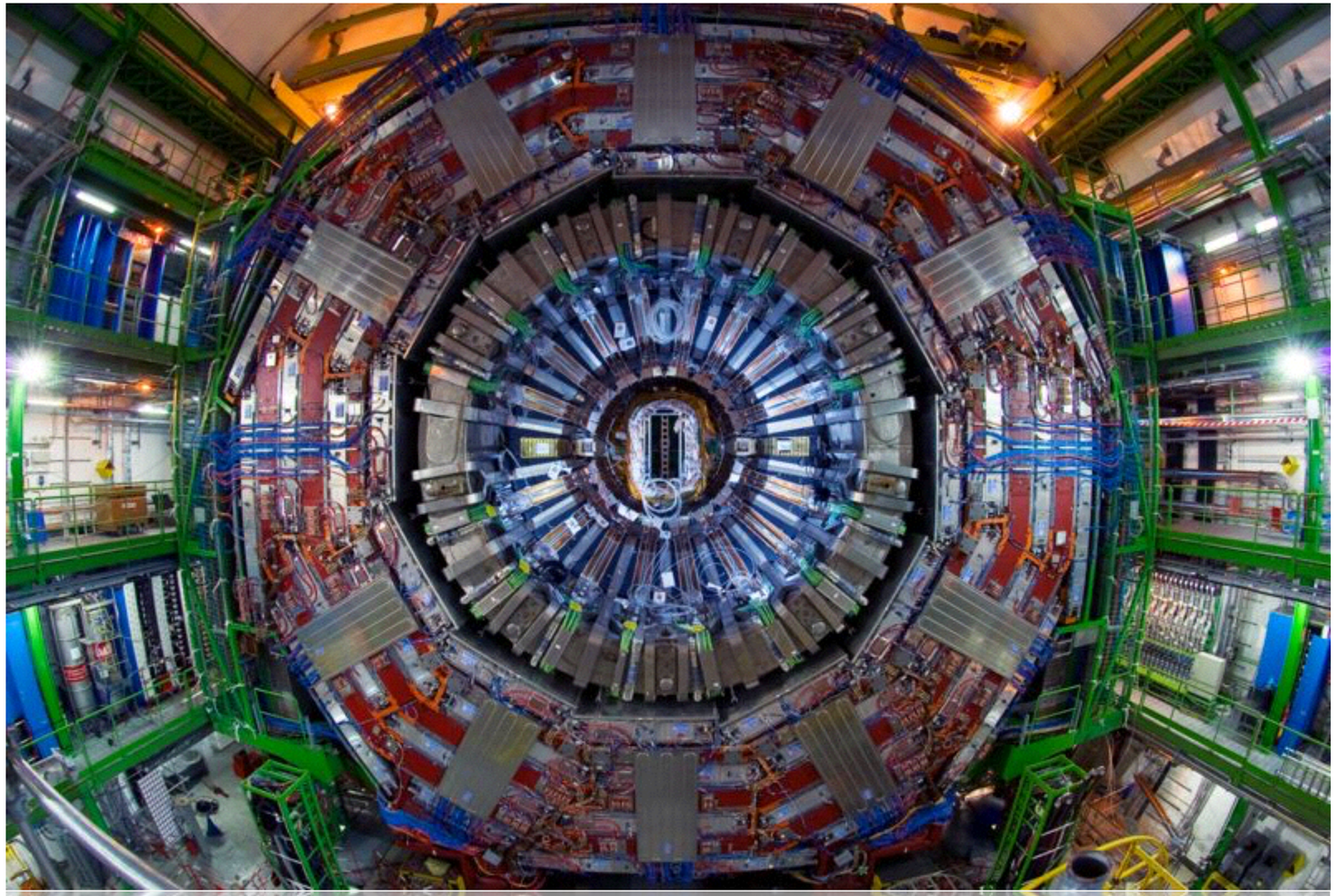
**100% Uptime during 2016!**



# CMS Detector



# What CMS "Really" is…



a 3D digital camera with
**~100 Million pixels**

.. and can take up to
**40 million pictures per second!**

We can **record** only **~ 1000 events/s**

Interesting collisions are very rare
(some < 1 per 10 billion!)

**We must pick the good ones and decide fast!**

**Keep? Throw away?**

# CMS Trigger System in Run2

*CMS has a 2 tier triggering system to make this decision*

**40M events / s**

## Level-1 System

*Fast readout of the detector*
***Limited granularity***

*Hardware based: FPGA-based*
*~4 μs to take a decision*

# CMS Trigger System in Run2

*CMS has a 2 tier triggering system to make this decision*

**40M events / s**

Increased granularity + new chip architecture is fully commissioned

**Leve**

*Fast readout of the detector*

***Limited granularity***

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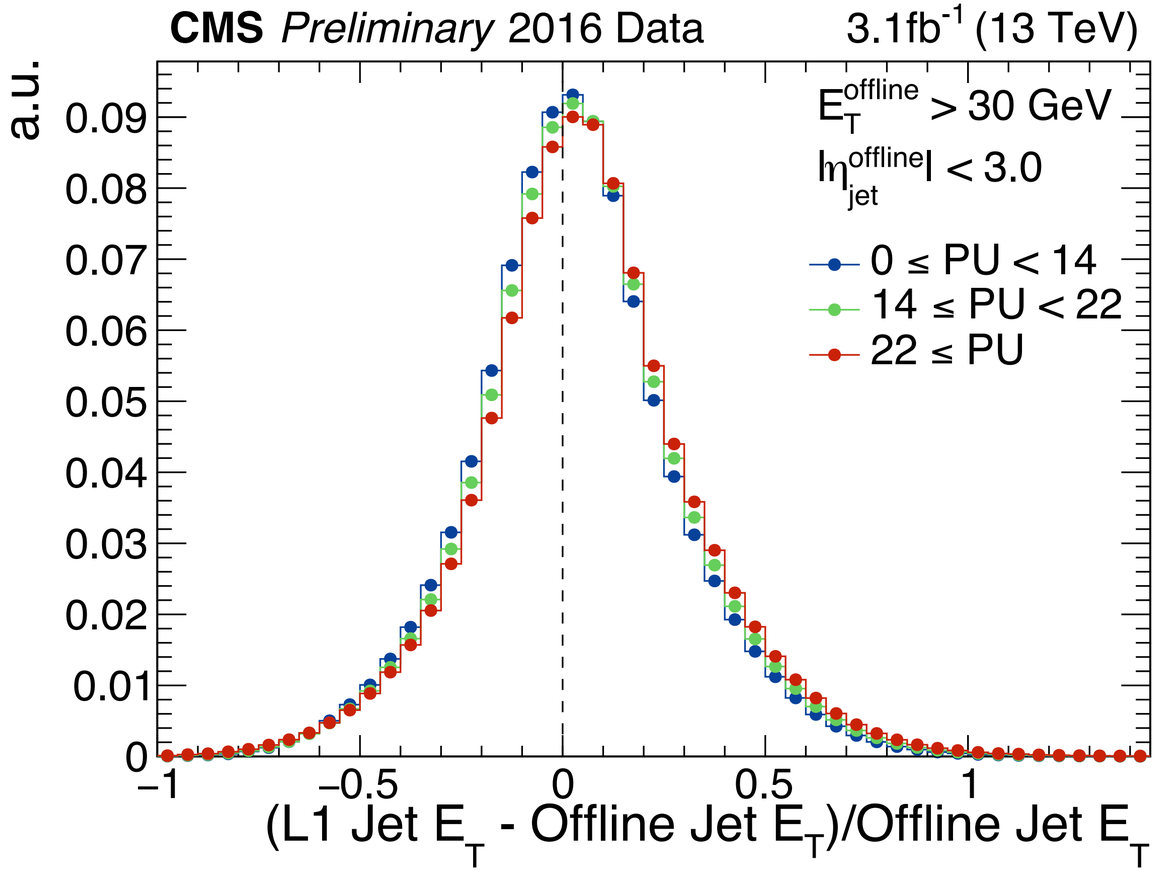
***Advanced pile up subtraction techniques***



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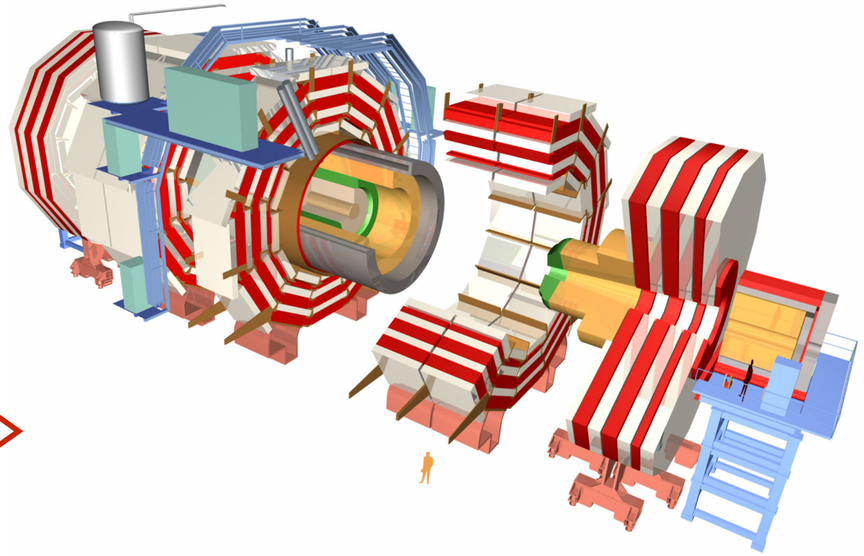
Increased granularity + new chip architecture is fully commissioned

**100K events / s**



**Level-1 Trigger**

*Fast readout of the detector*

***Limited granularity***

*Hardware based: FPGA-based*

*~4 μs to take a decision*

**High Level Triggering**

*Full readout of the detector*

***Higher granularity***

*Software based: runs on commercial PCs*

*~200 ms to take a decision*

# CMS Trigger System in Run2

*CMS has a 2 tier triggering system to make this decision*

**40M events / s**

**Leve**

Increased granularity + new chip architecture is fully commissioned

*Fast readout of the detector*

***Limited granularity***

Extended the HLT Farm capacity by 40%

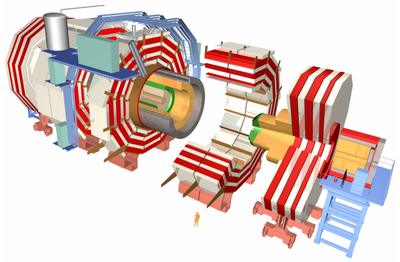
*Hardware based: FPGA-based*

*~4 μs to take a decision*

*Software based: runs on commercial PCs*

*~200 ms to take a decision*

# LHC / CMS Computing: Tier System



~100 TB / day

## Tier-0:

- Promptly reconstructs data

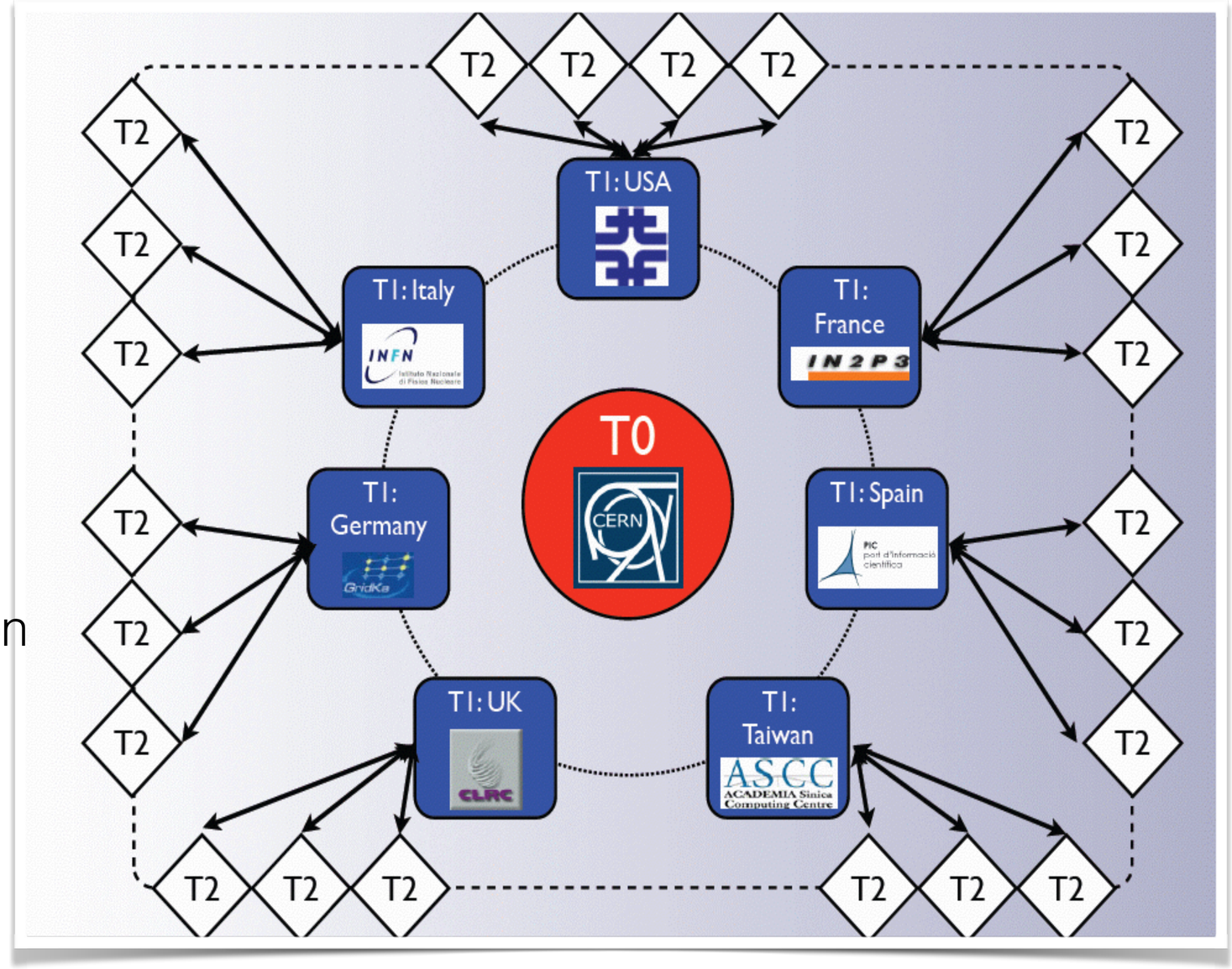
~300 TB / day

## 7 Tier-1s:

- Responsible for simulation production

## ~50 Tier-2s

- Allows for distributed data analysis



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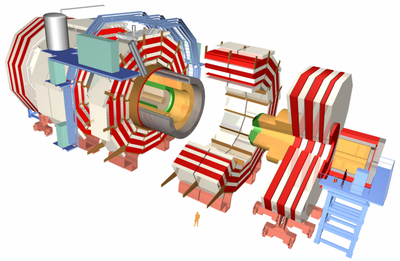


~100 TB / day

**Tier-0:**

- Promptly reconstructs d

~300 TB / da

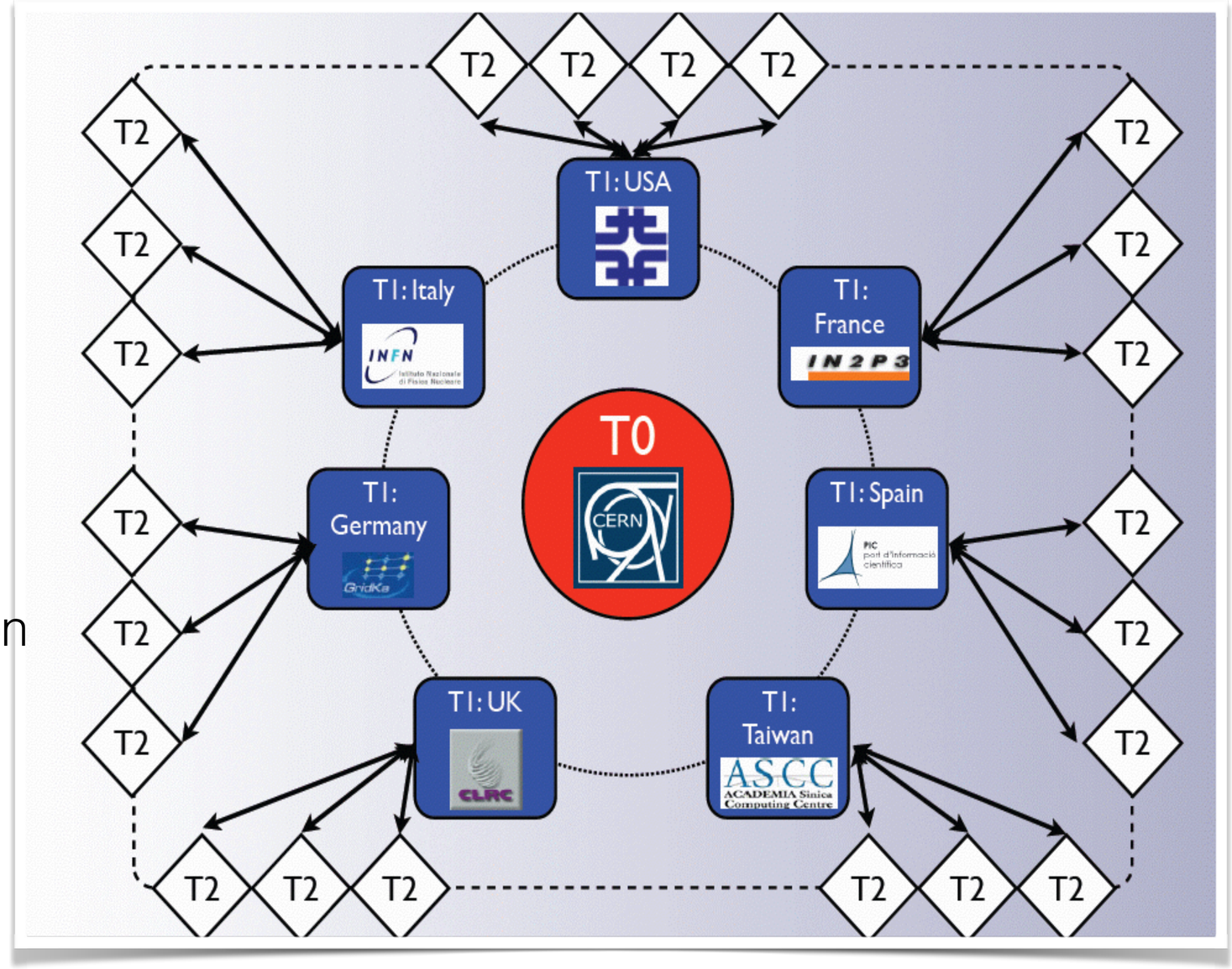
**1s:**

- for simulation production

Resources are heavily used!
100% of the CPUs are occupied

**~50 Tier-2s**

- Allows for distributed data analysis

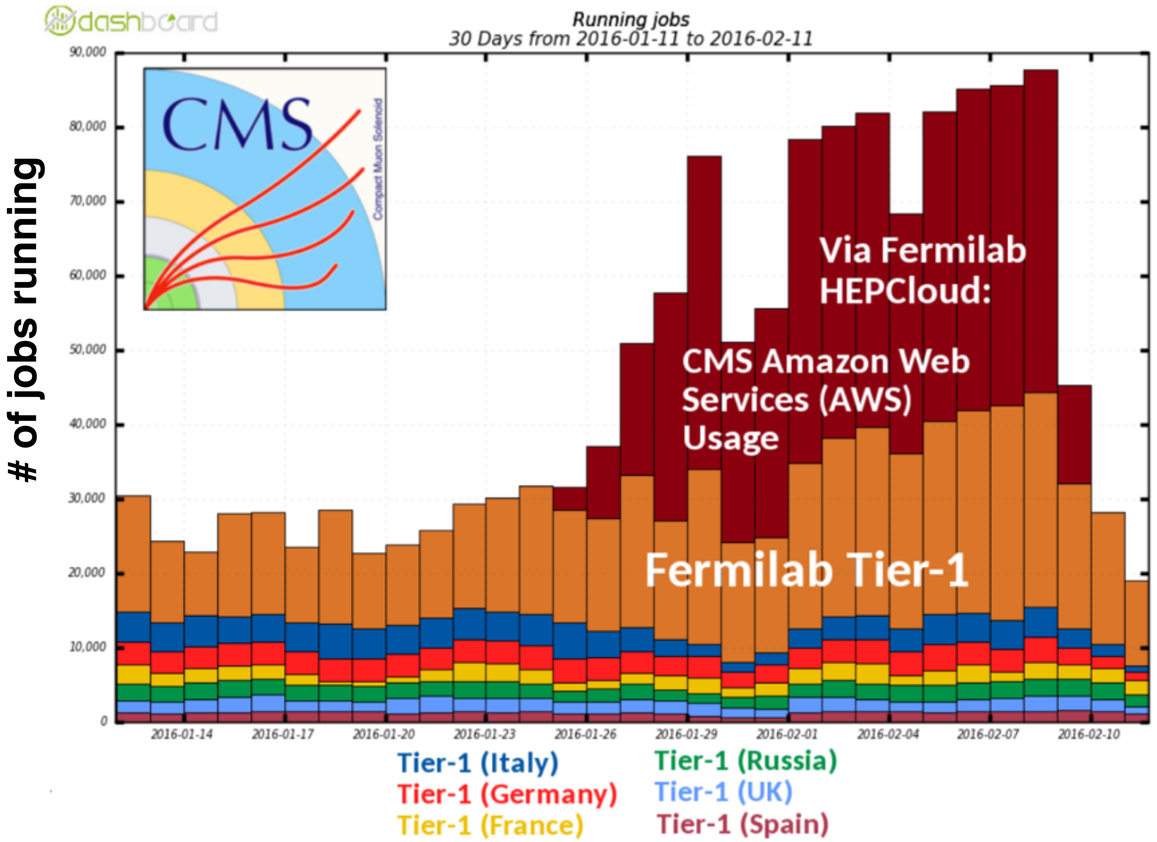


# CMS Computing: Cloud

**Challenge**: How can we have additional CPUs?

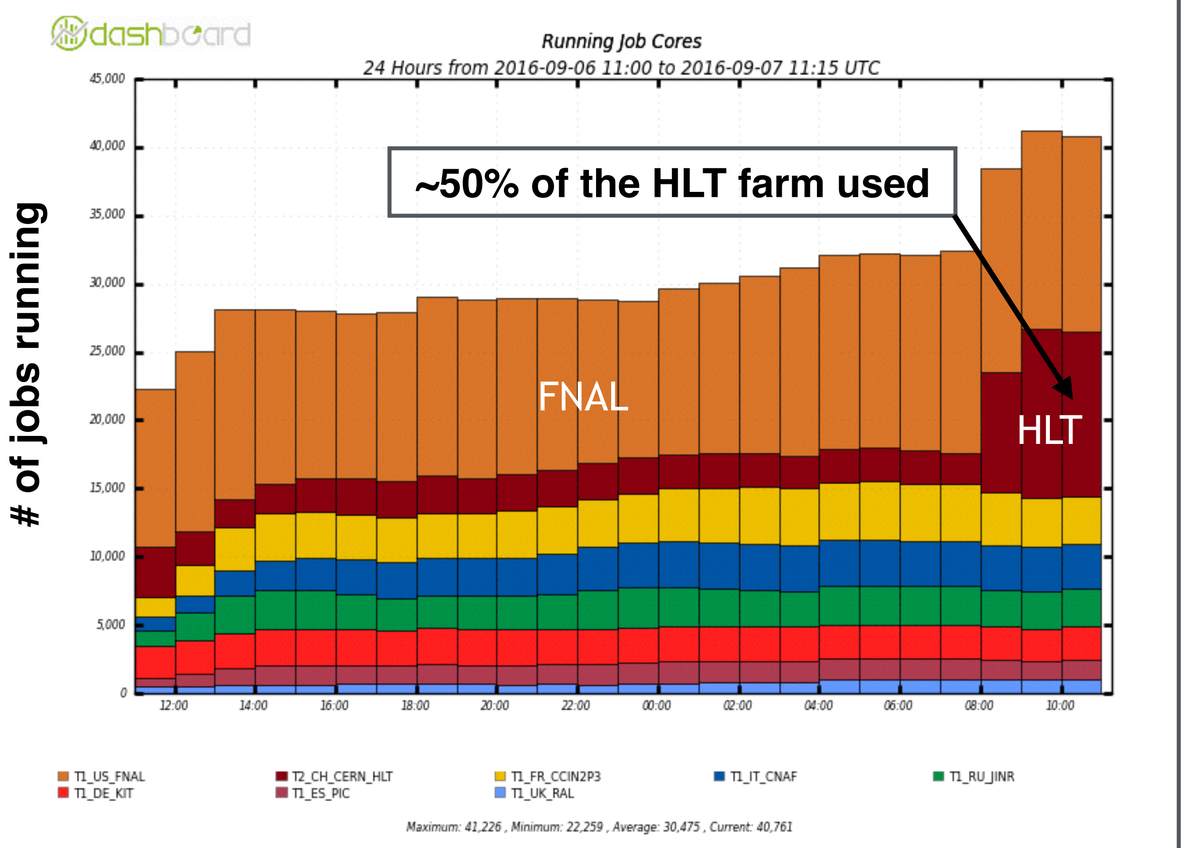
amazon

Use of amazon web servers



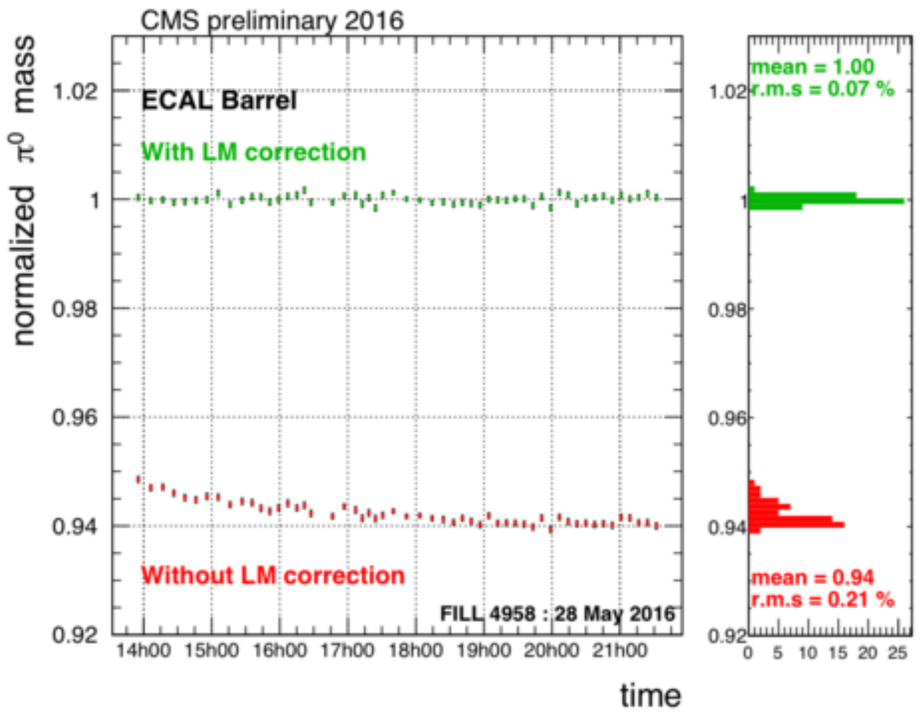

## Online HLT Farm

Use of the farm when it is idle

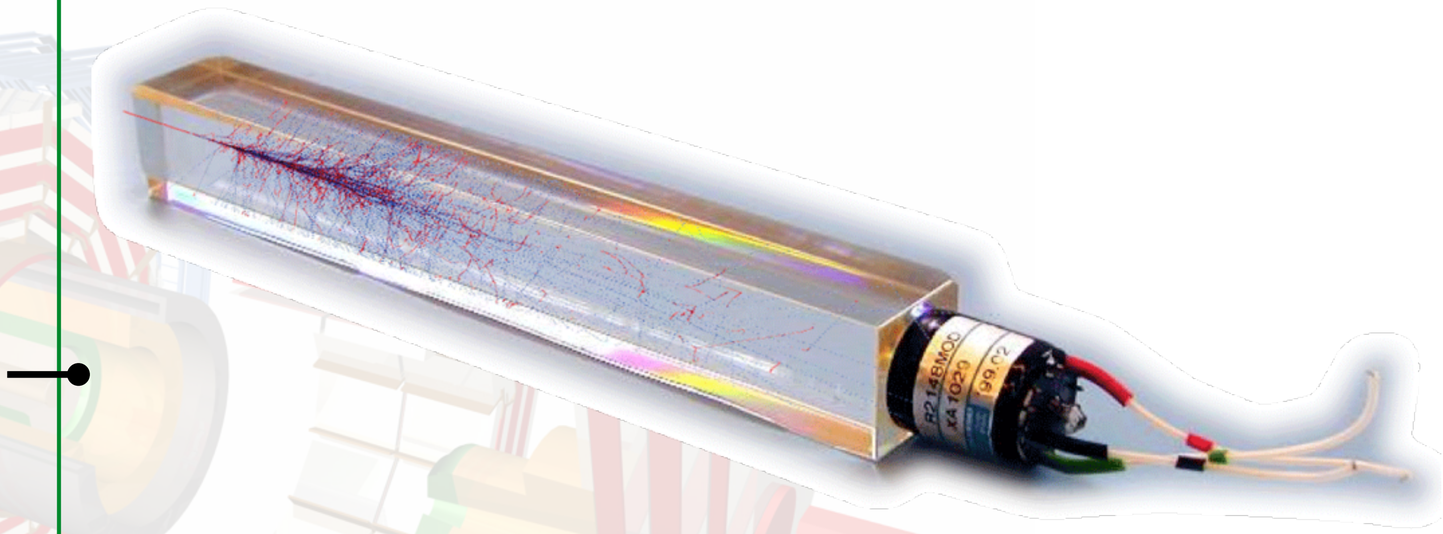


# CMS Calibrations in Run 2

## Electromagnetic Calorimeter:
Firmware and software updates




**ECAL calibration uses a laser to monitor and correct for transparency loss**

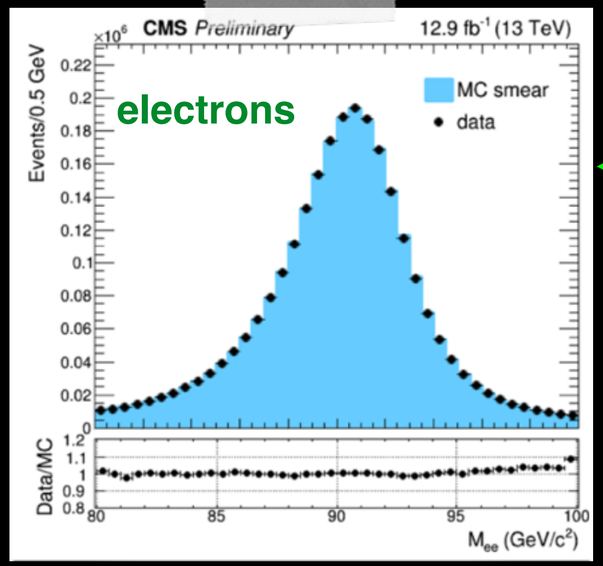


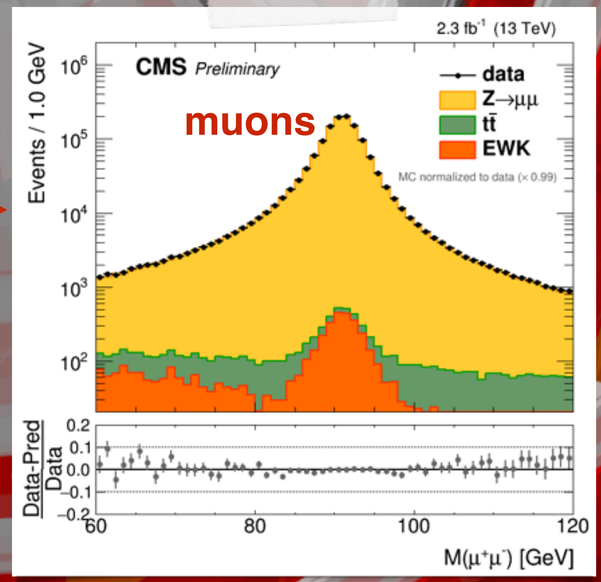
ECAL is made out of **transparent crystals.**

These crystals get “**cloudy**” when **radiated.**

This **biases** the **energy measurement**

CMS Experiment at the LHC, CERN
Data recorded: 2016-Jul-08 23:47:39.259242 GMT
Run / Event / LS: 276525 / 2665335317 / 1561



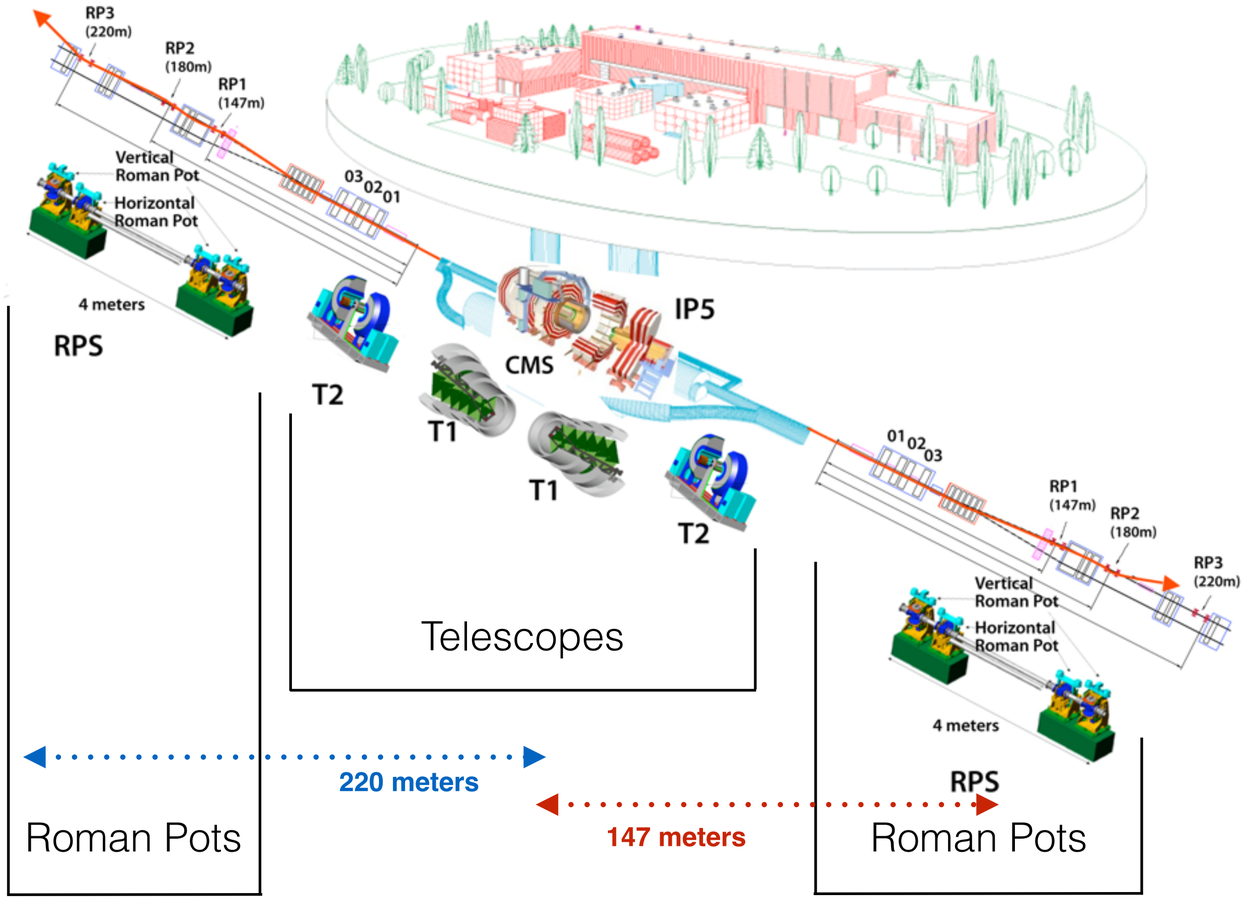




**Extremely well calibrated detector.**

**Excellent agreement in simulation and data.**

# TOTEM Experiment

The TOTEM experiment involves about 100 scientists from 16 institutes in 8 countries.



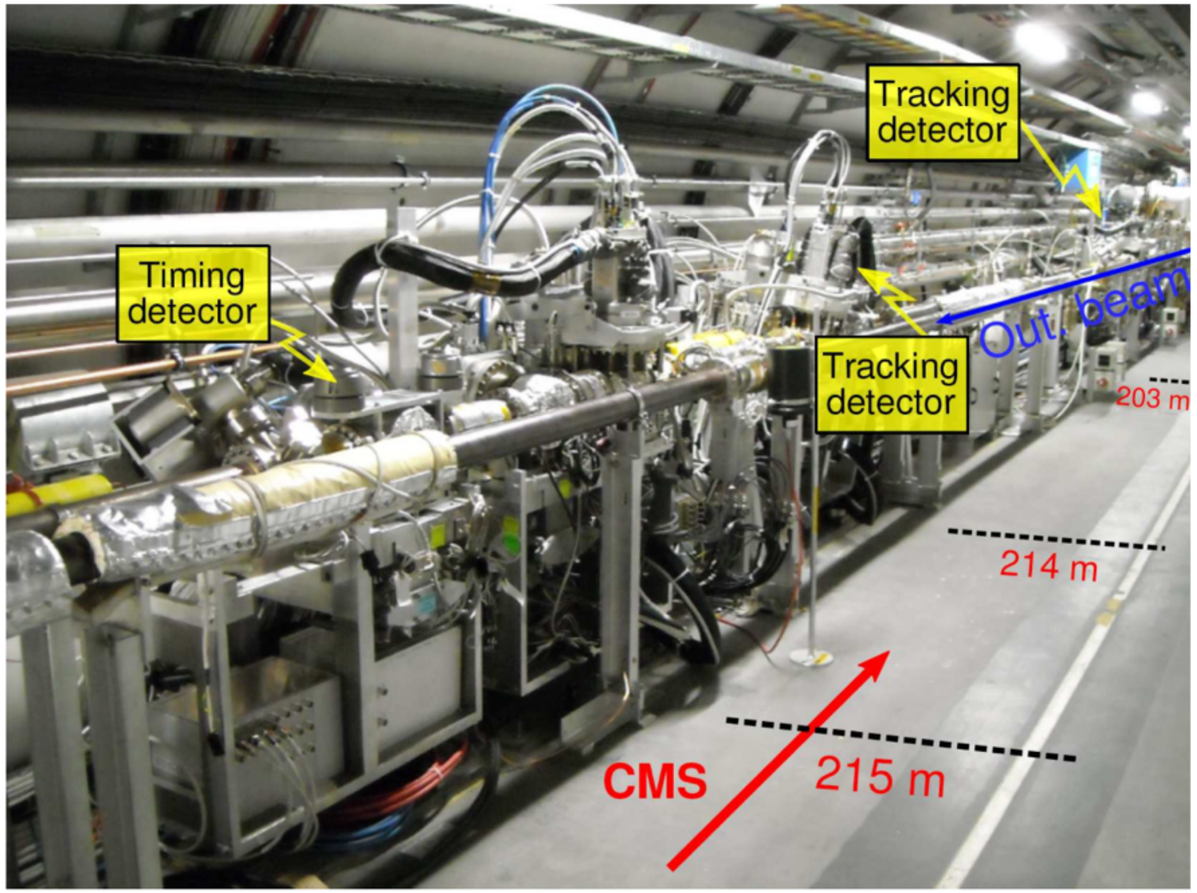

**TOTEM experiment** is designed to take **precise measurements** of protons as they emerge from collisions **at small angles.**

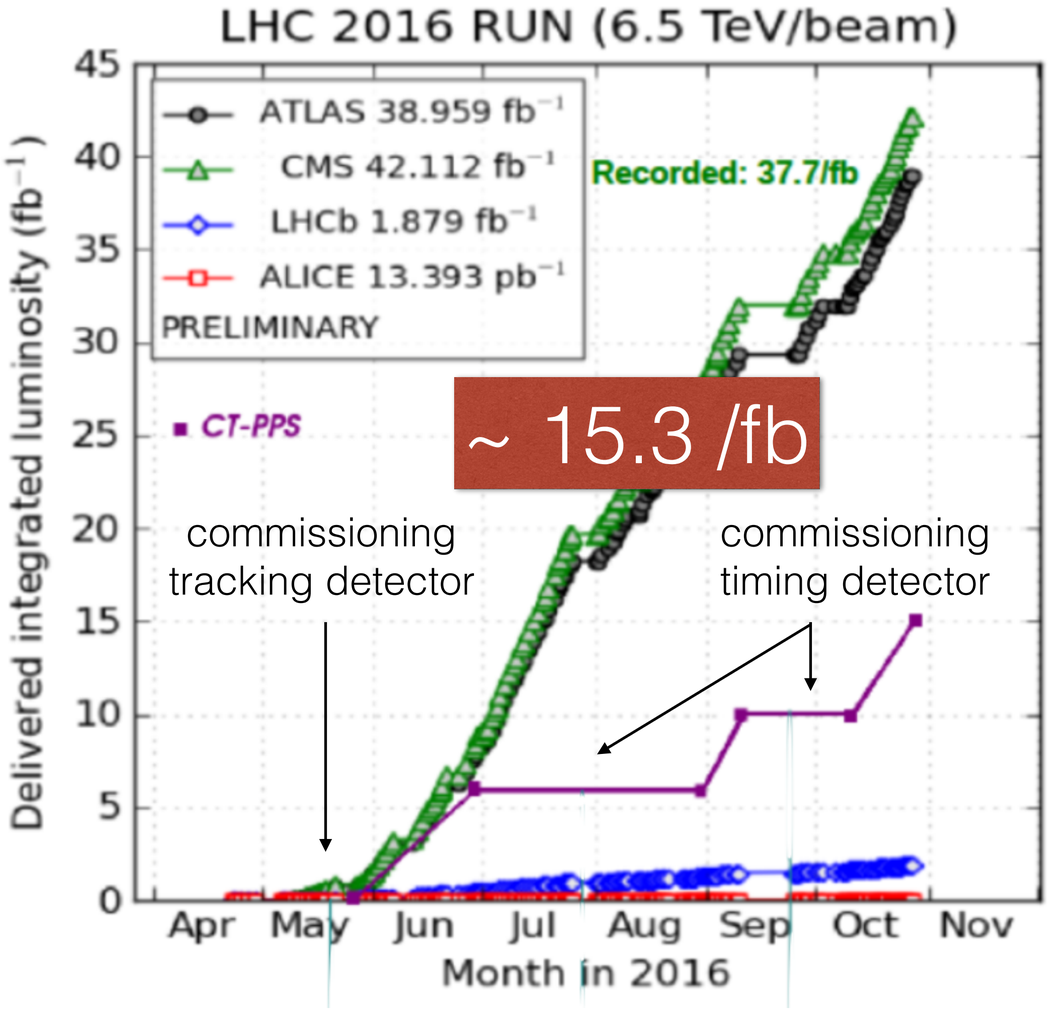
This region is known as the '**forward**' direction and is **inaccessible by other LHC experiments**.

**TOTEM and CMS collaborations** have coordinated the use of their detectors to **perform combined measurements** that will lead to results of unprecedented accuracy!

# CMS Totem Precision Proton Spectrometer (CT-PPS)

CT-PPS is a magnetic spectrometer that uses the LHC magnets and detector stations, to bend protons to measure their trajectories. **It is fully integrated into CMS DAQ + Reconstruction Software**

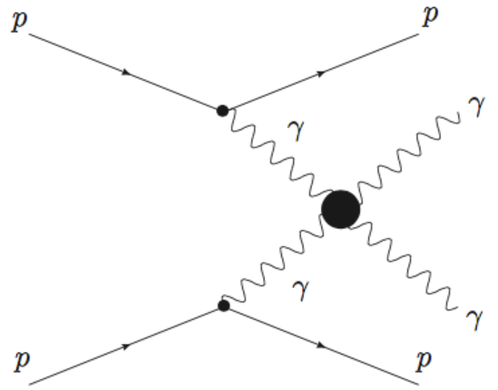


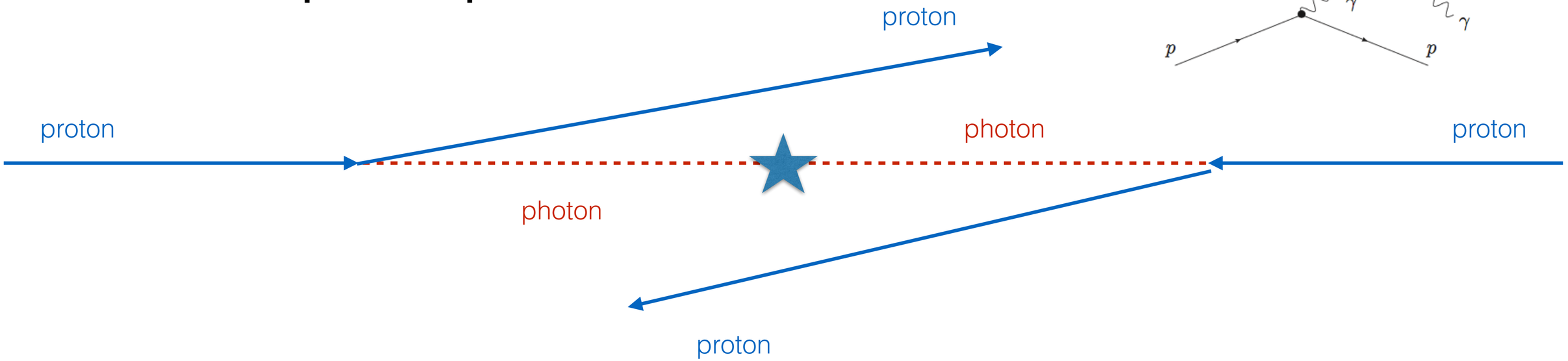



# CMS Totem Precision Proton Spectrometer (CT-PPS)

**You can do very unique physics:**

For example: photon-photon Fusion, where LHC “becomes” a **photon & photon collider**!



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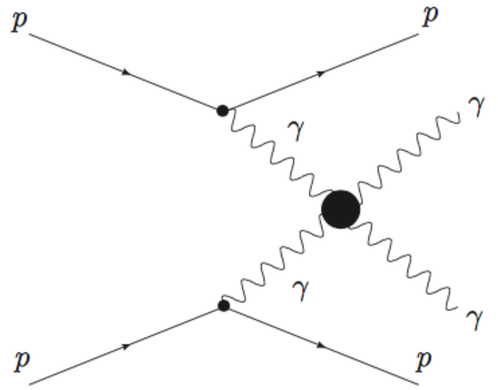
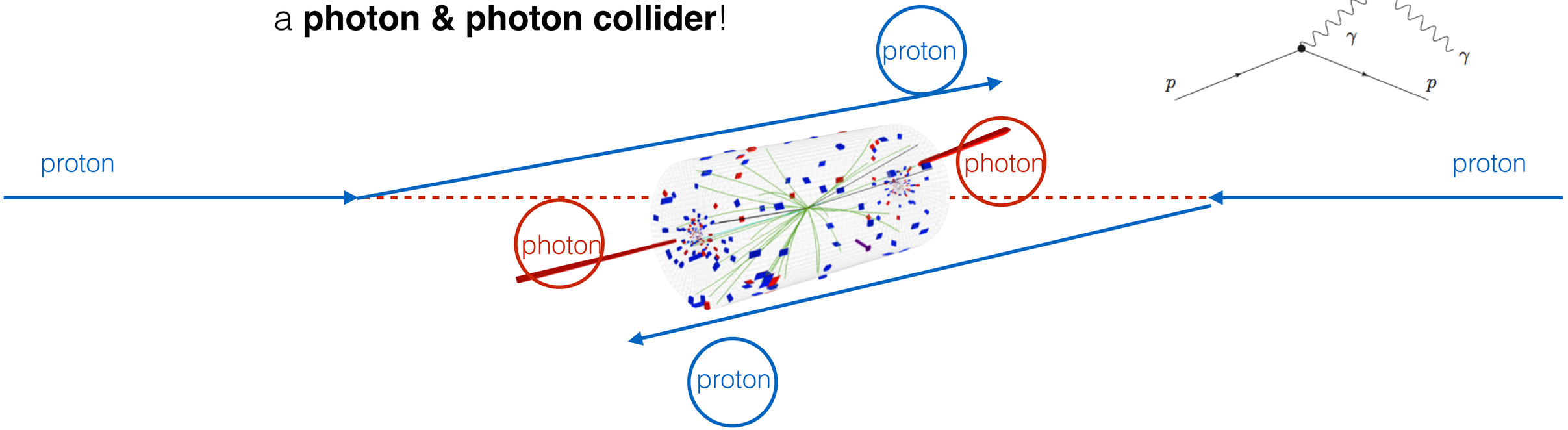
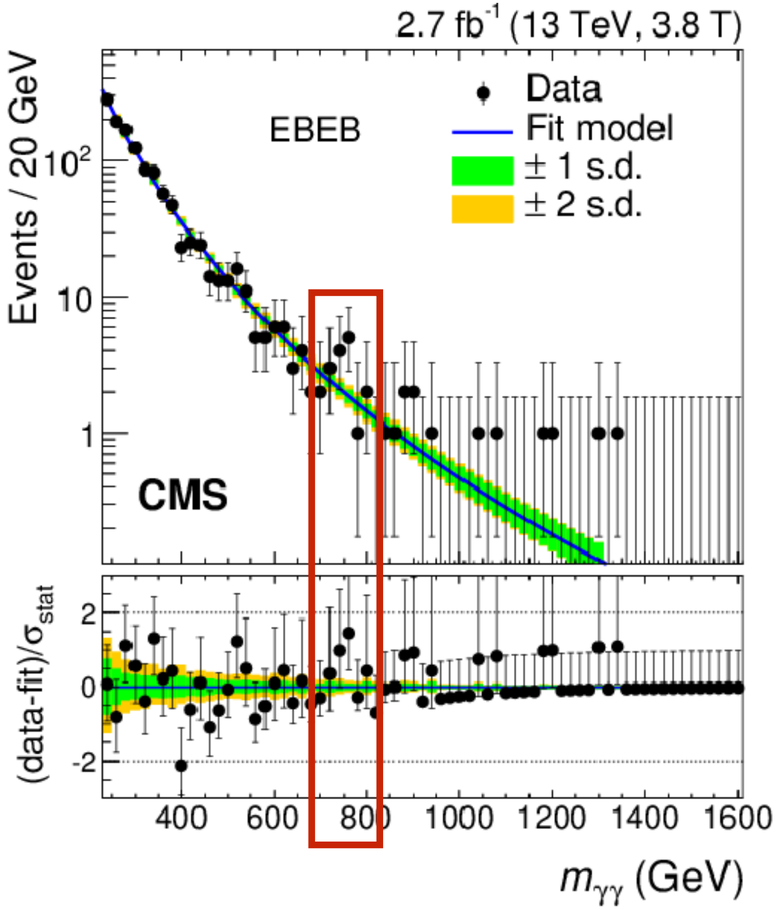



**General Strategy:**

Require correlation between observables reconstructed with the **CMS** central detector and those from the protons reconstructed in the **Totem** detectors

# 750 GeV Di-Photon Bump (Almost a New Particle)




Late 2015

We were excited about the possibility of a NEW particle at 750 GeV!

**"Birth"** of 750 GeV bump

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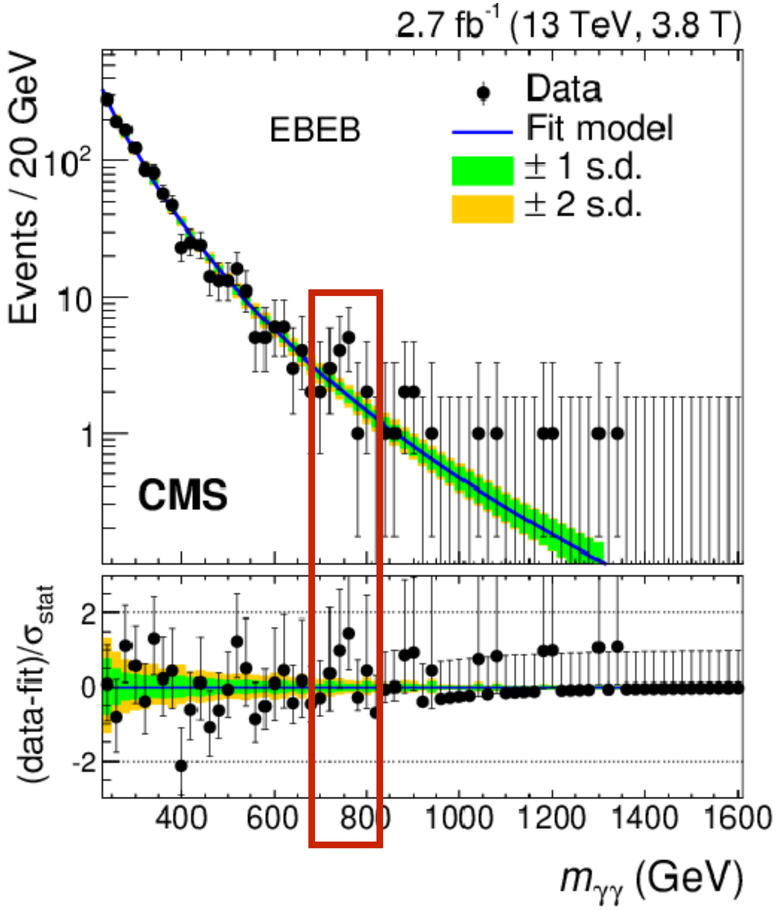


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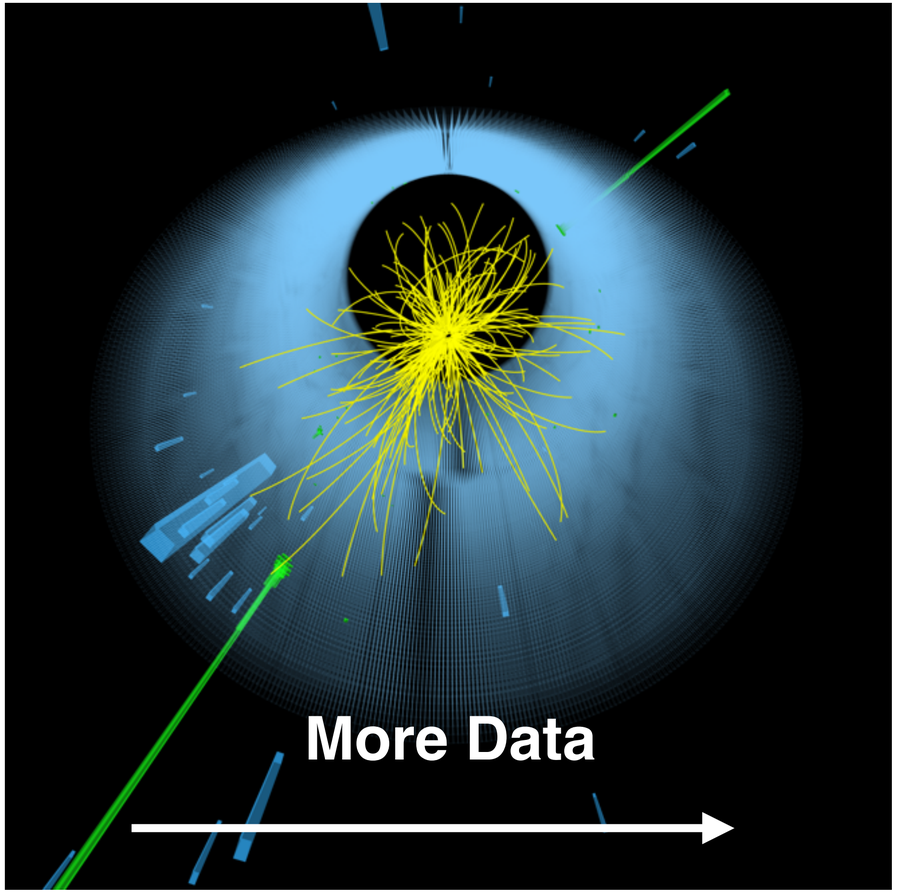

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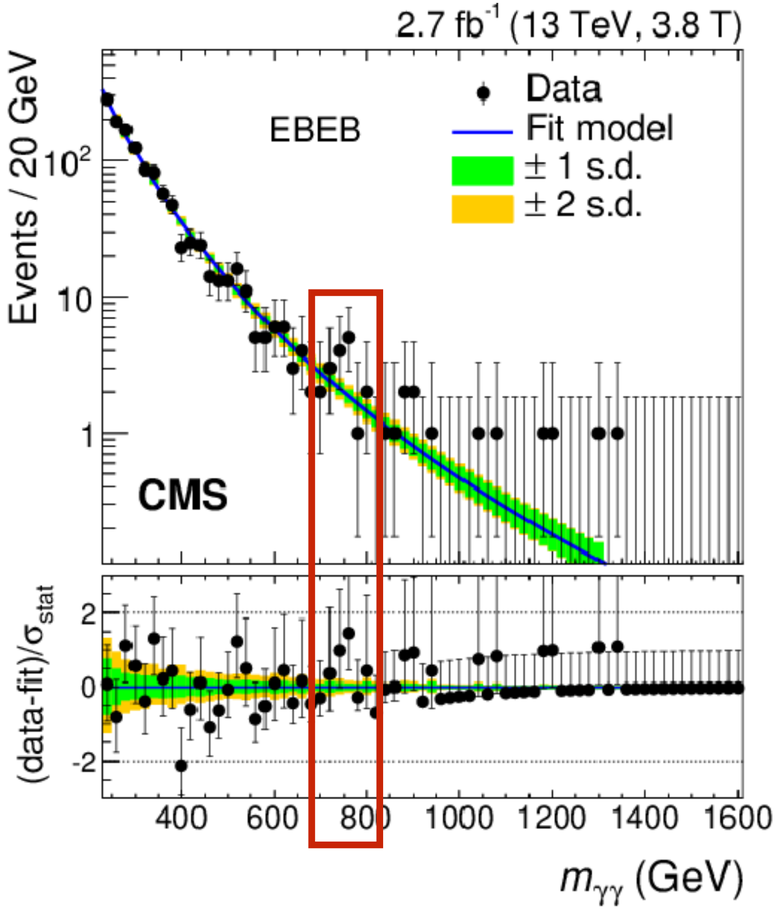


Late 2015

**"Birth"** of 750 GeV bump

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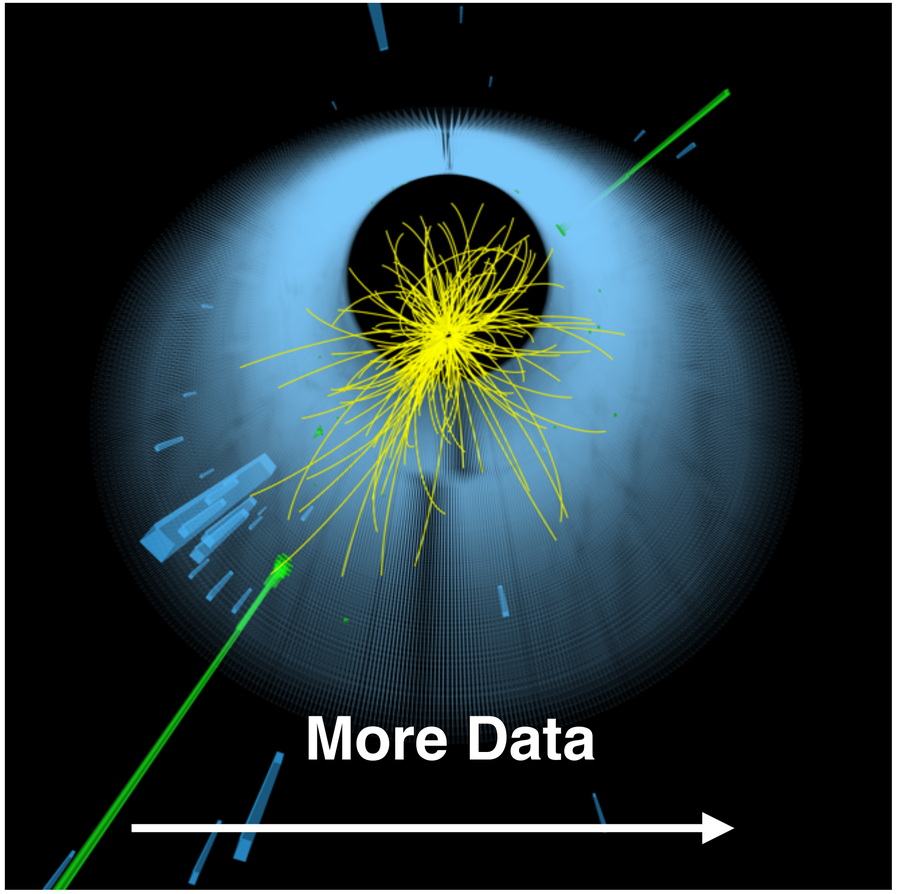
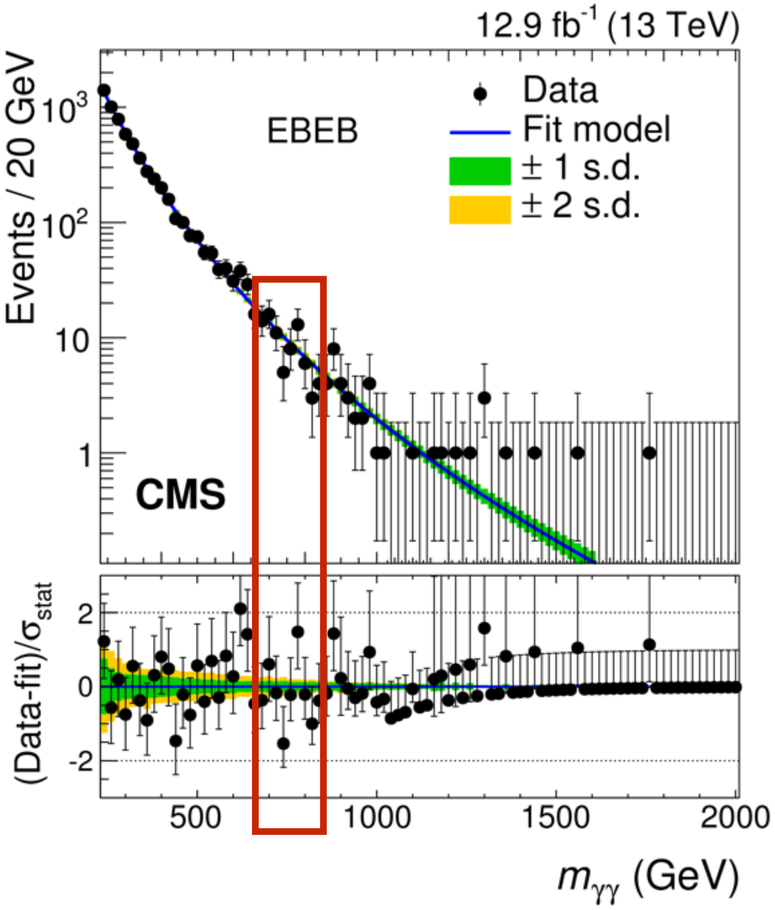
Nature wasn't that kind …



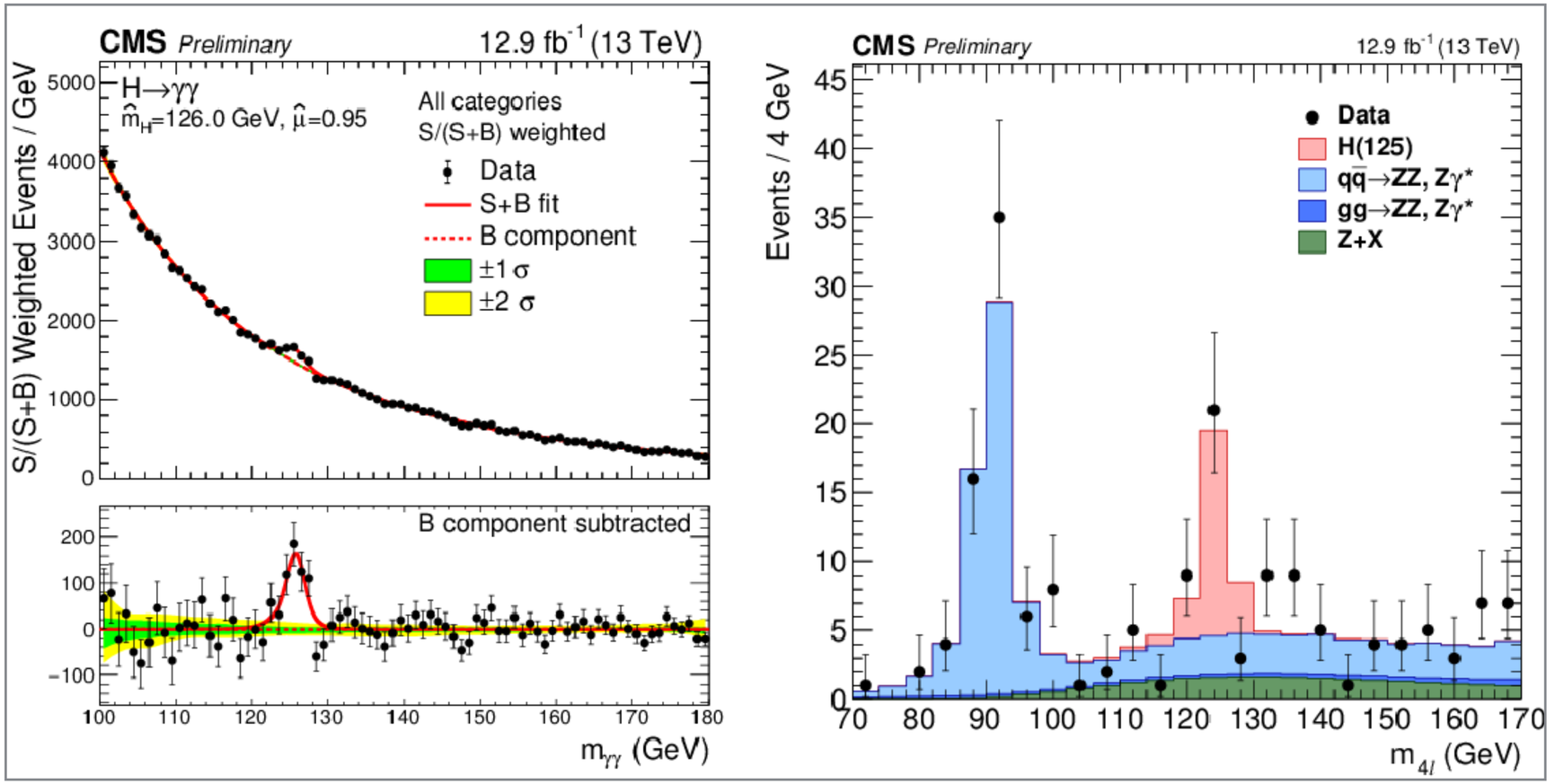




Mid 2016

**"Death"** of 750 GeV bump

# Higgs Re-Discovery

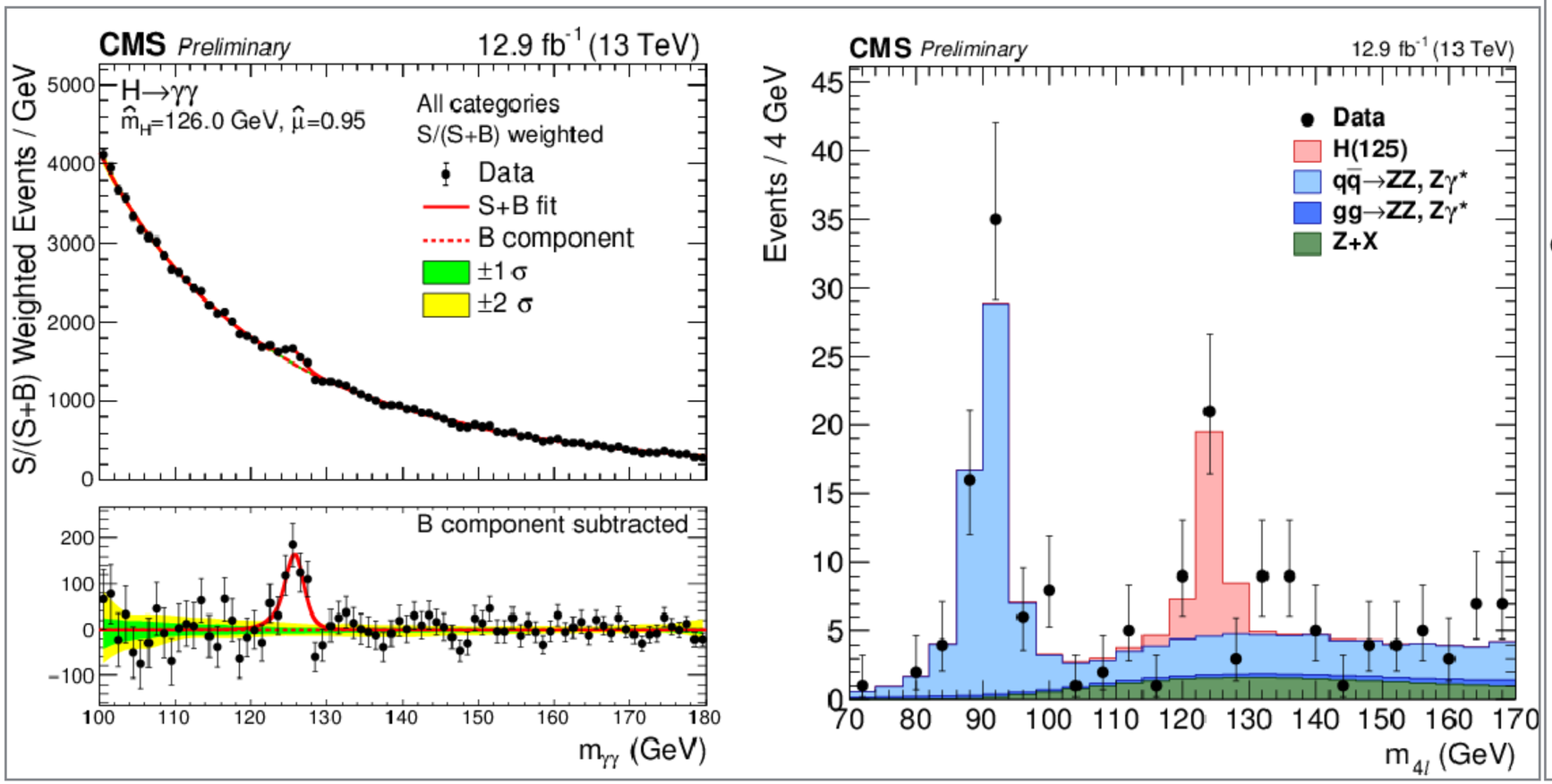
We did succeed in the **(re)discovery** of the Higgs boson!

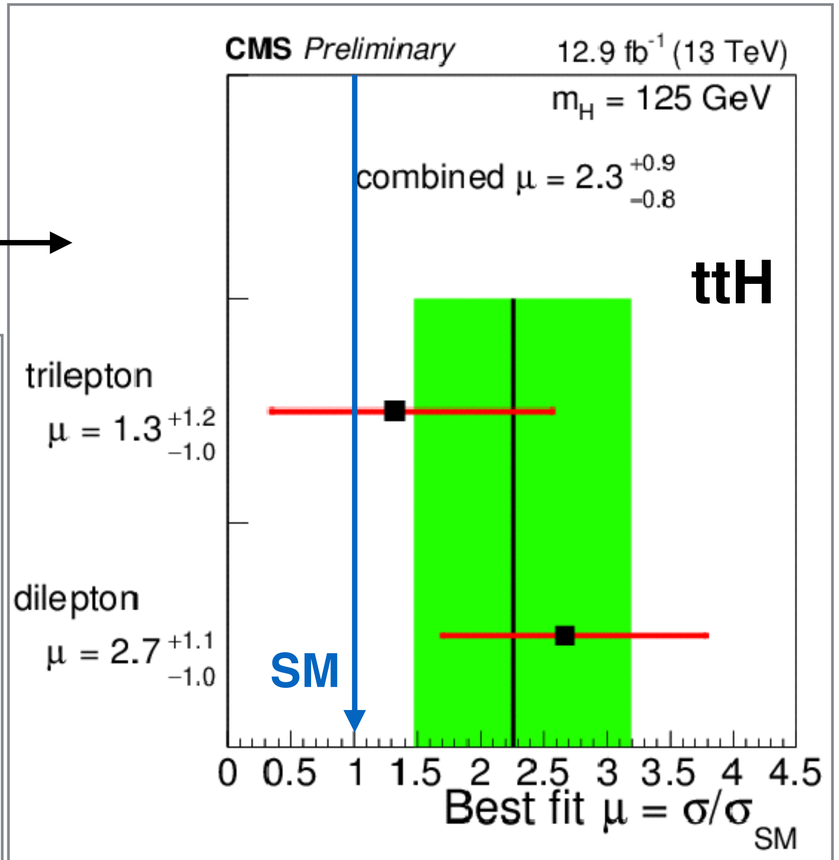


# Higgs Re-Discovery and More

We did succeed in the **(re)discovery** of the Higgs boson!

We are closing in on its **rare** production modes

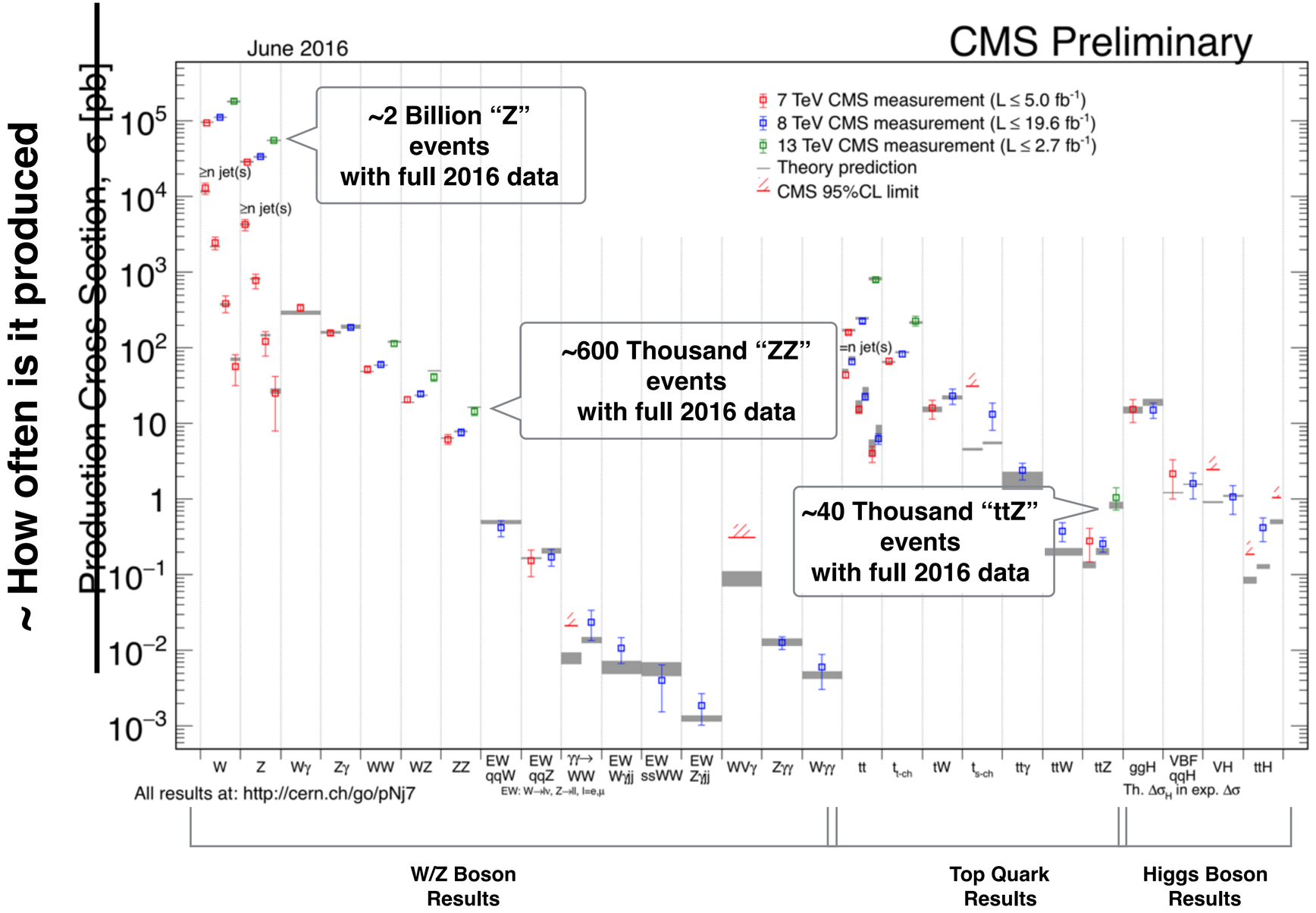



And the new data hints at something "**more***" than Standard Model ?

* Measurement is currently compatible with SM within the uncertainty of the measurement

# Everything Standard Model: Stairway to Heaven



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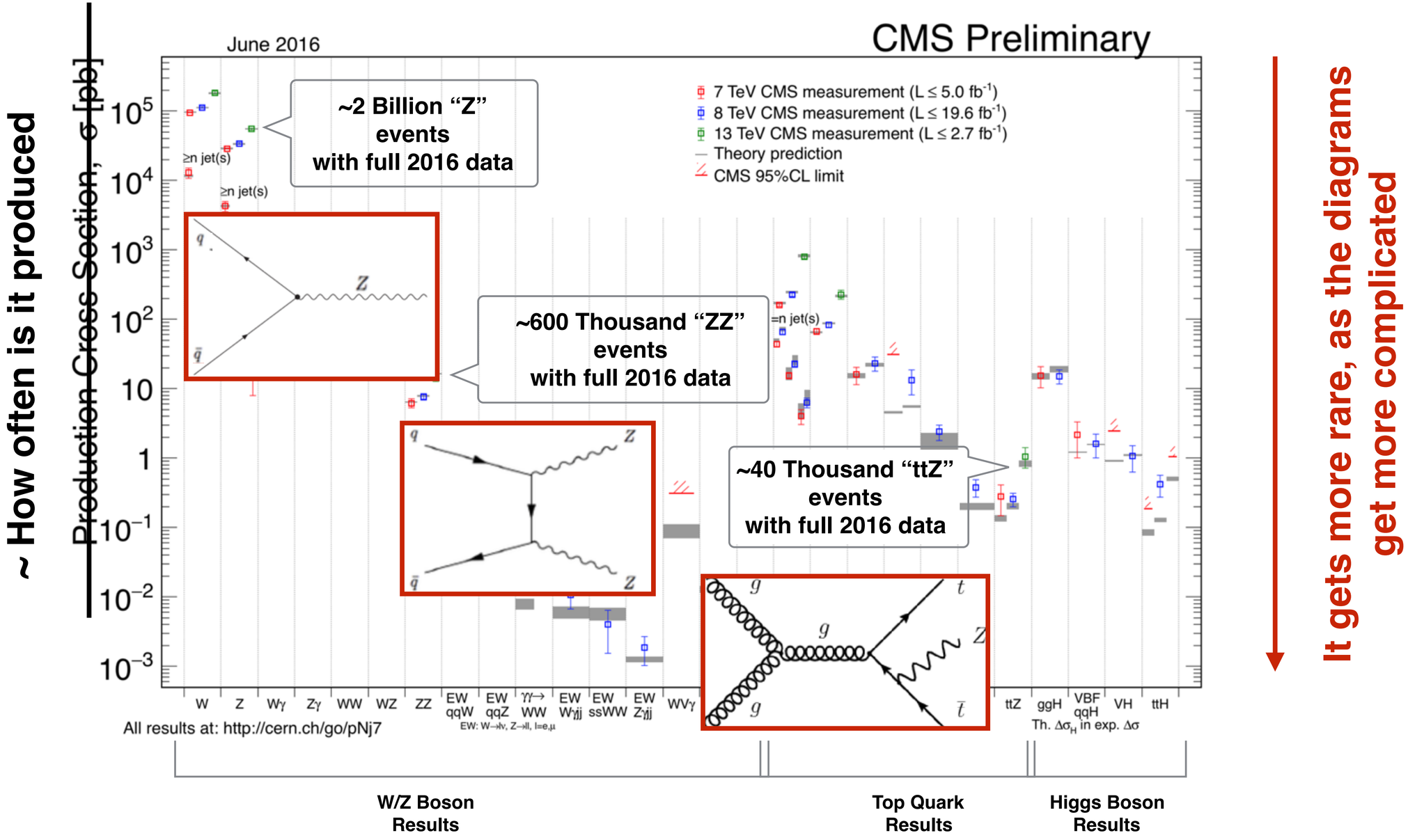

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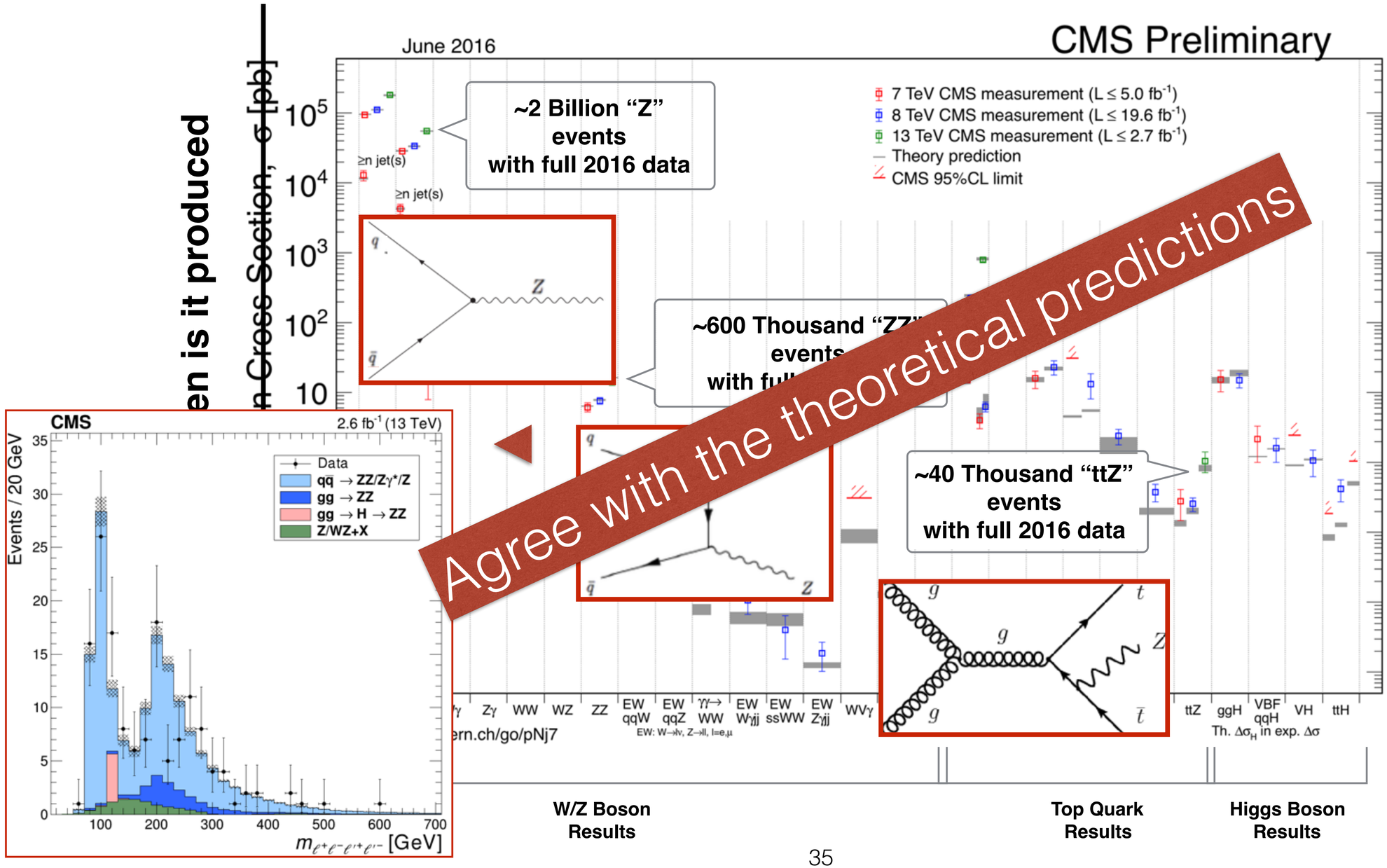

# Everything Beyond Standard Model

and if you thought Standard Model processes were rare …

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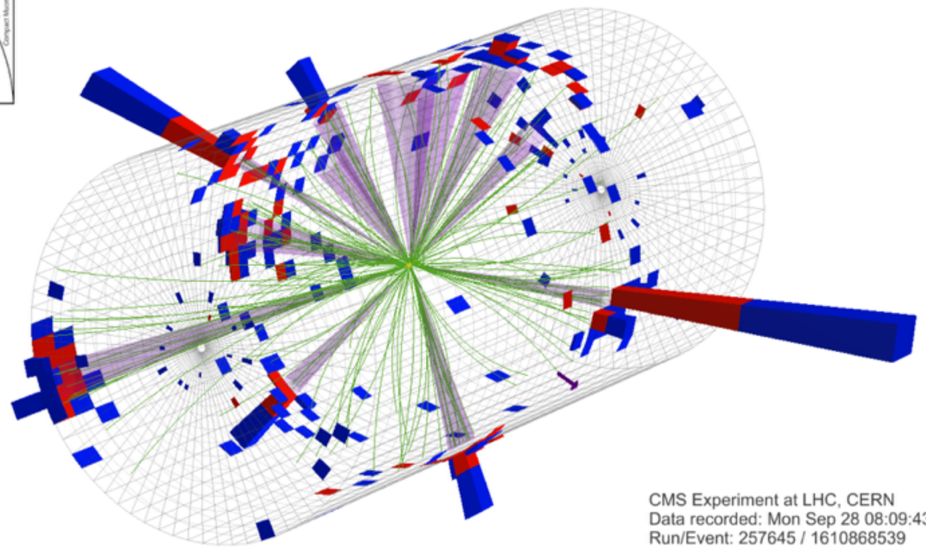


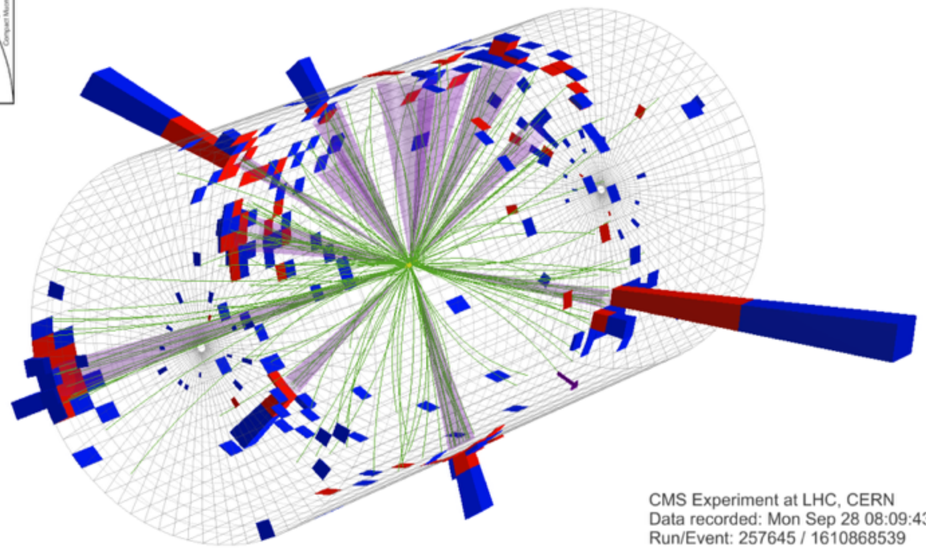

Producing **Black Holes**:

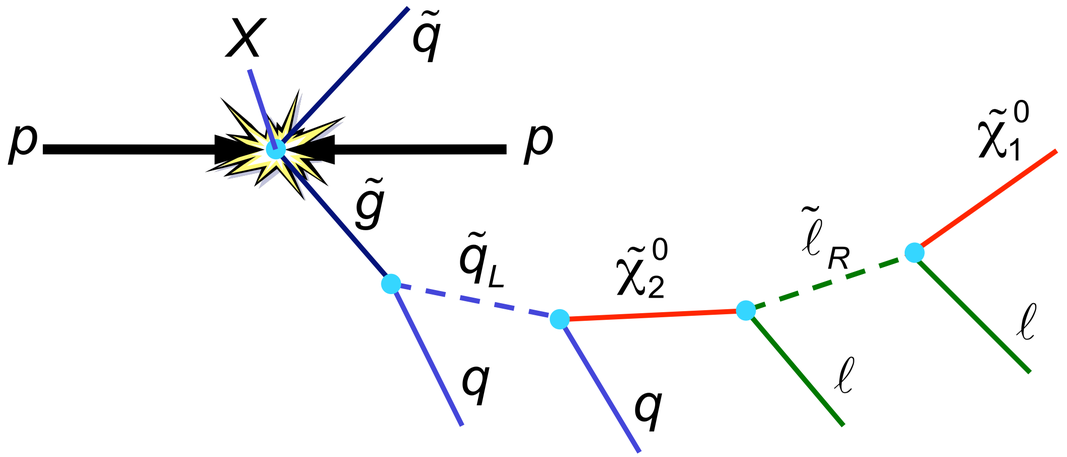
(one of the) expected final state is with

**12 Jets!**

# Everything Beyond Standard Model

and if you thought Standard Model processes were rare …




Producing **Black Holes**:

(one of the) expected final state is with

**12 Jets!**

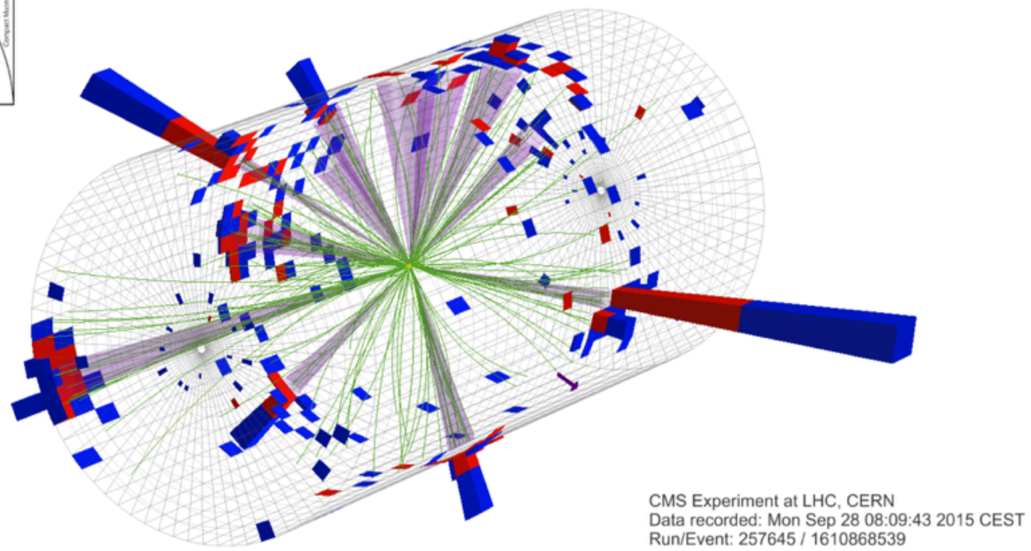
Producing **Super Symmetric particles**:

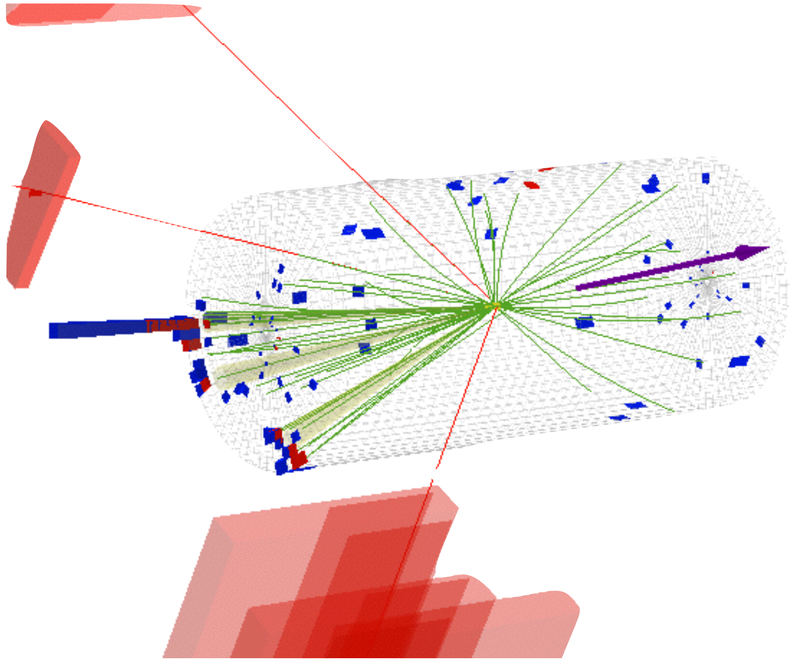
(one of the) expected final state is with

**2 Jets + 2 Leptons + Missing Energy!**

# Everything Beyond Standard Model

and if you thought Standard Model processes were rare …



Producing **Black Holes**:

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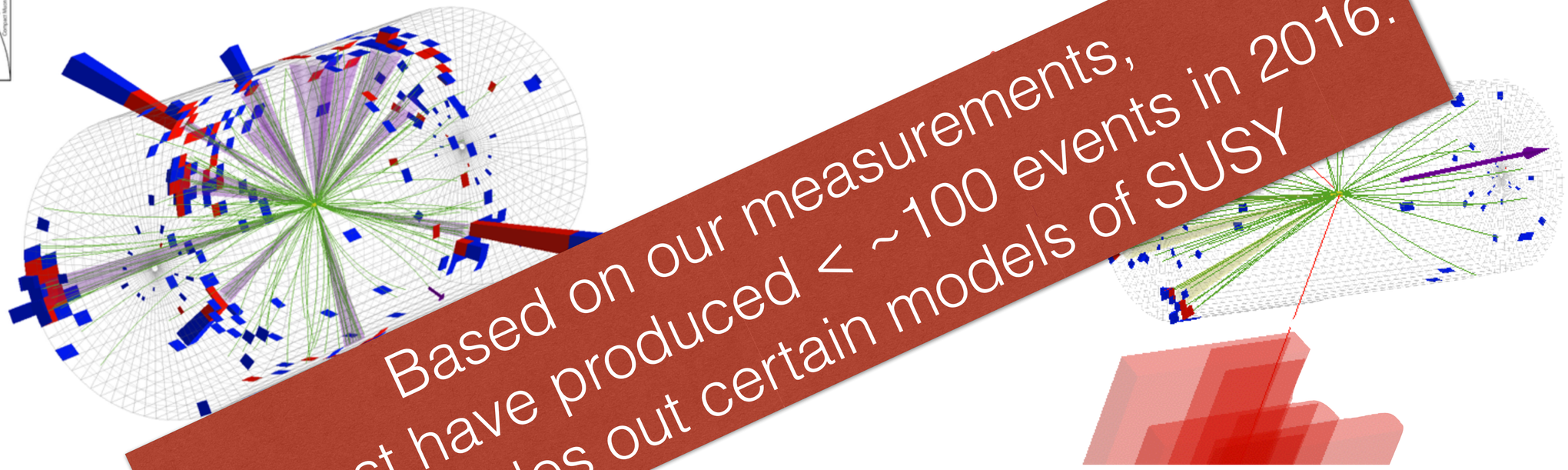
# Everything Beyond Standard Model

and if you thought Standard Model processes were rare …



Based on our measurements,
we must have produced < ~100 events in 2016.
This rules out certain models of SUSY

Proc **…holes**:

(one of the) e…cted final state is with

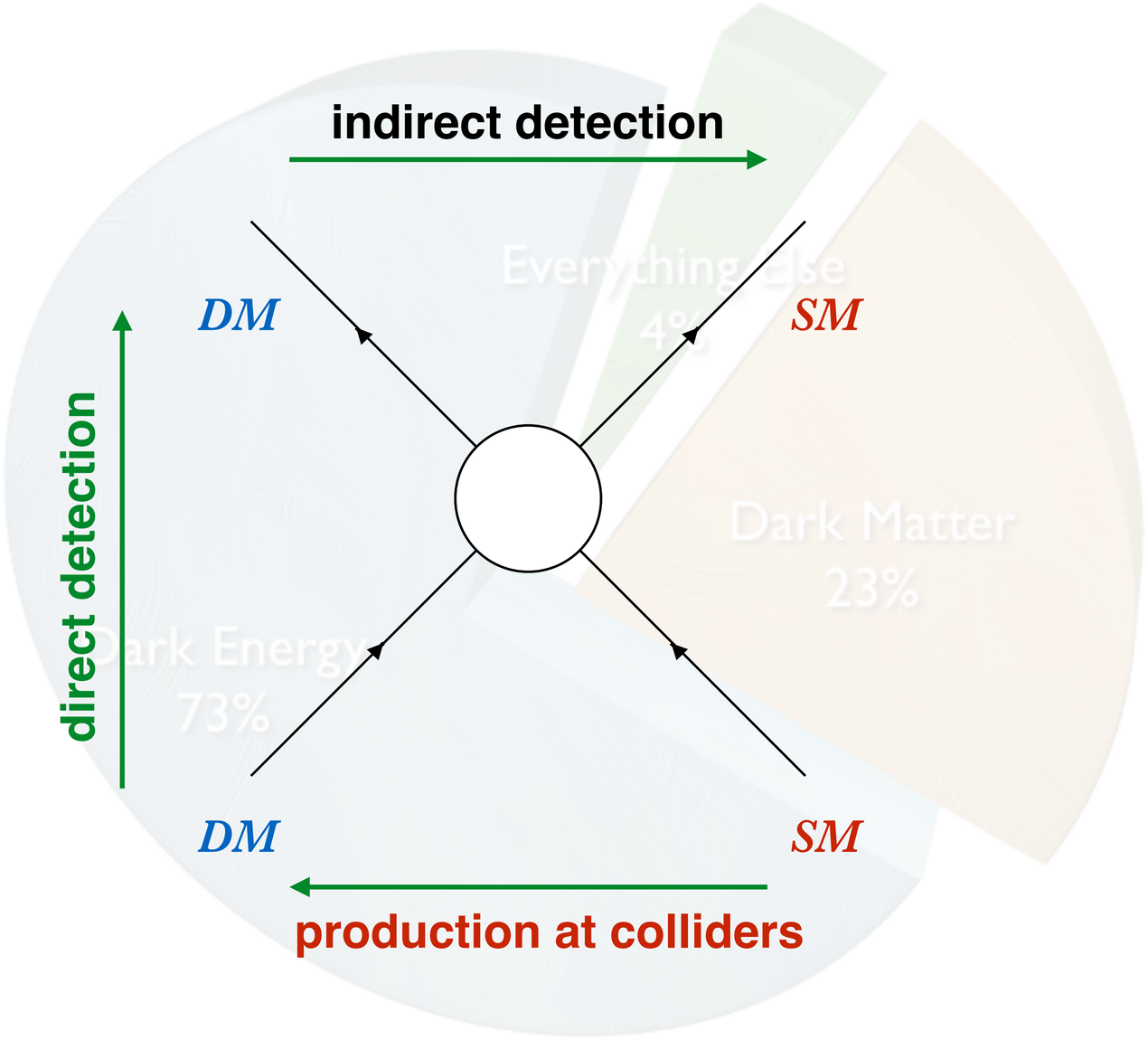
**12 Jets!**

Producing **Super Symmetric particles**:

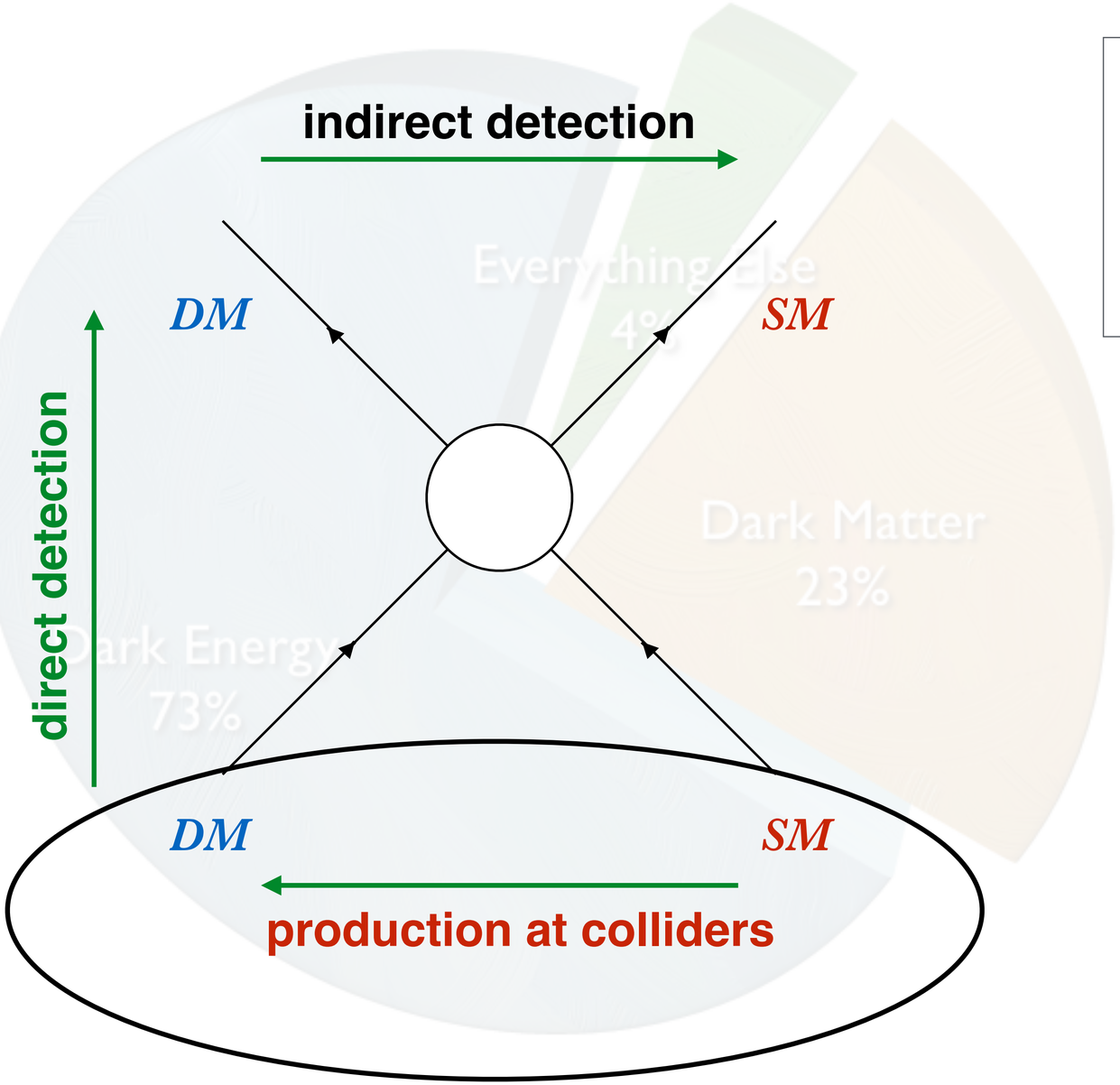
(one of the) expected final state is with

**2 Jets + 2 Leptons + Missing Energy!**

# Everything Beyond: Dark Matter

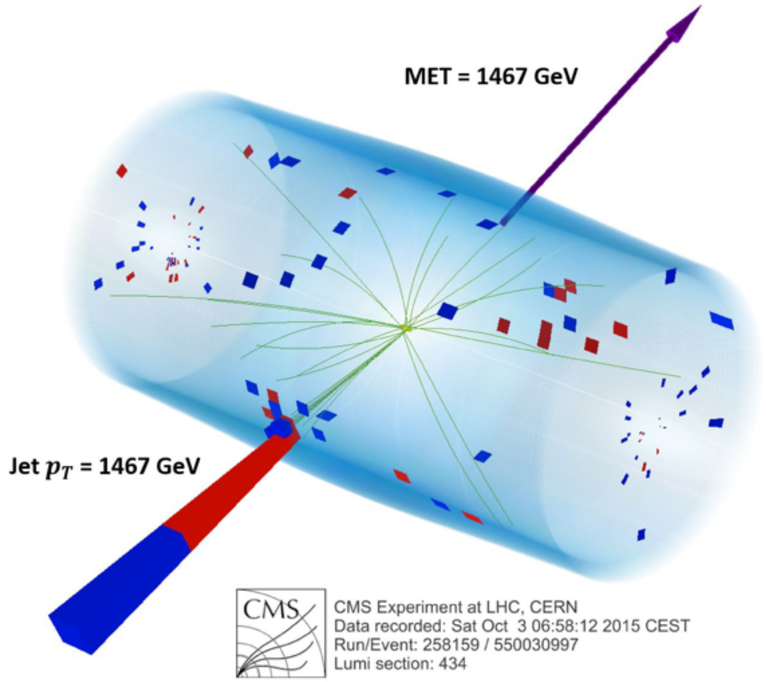


# Everything Beyond: Dark Matter

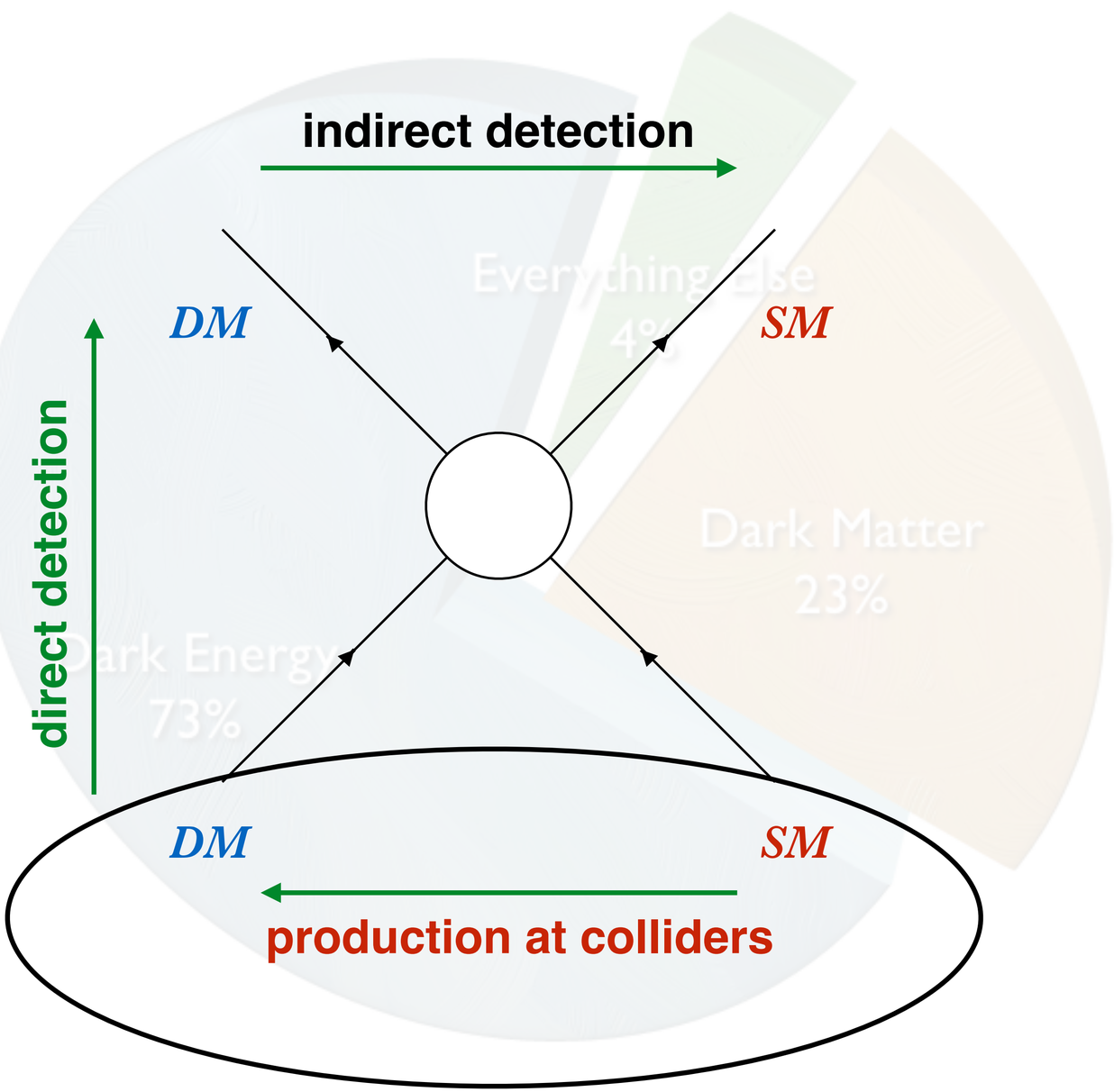


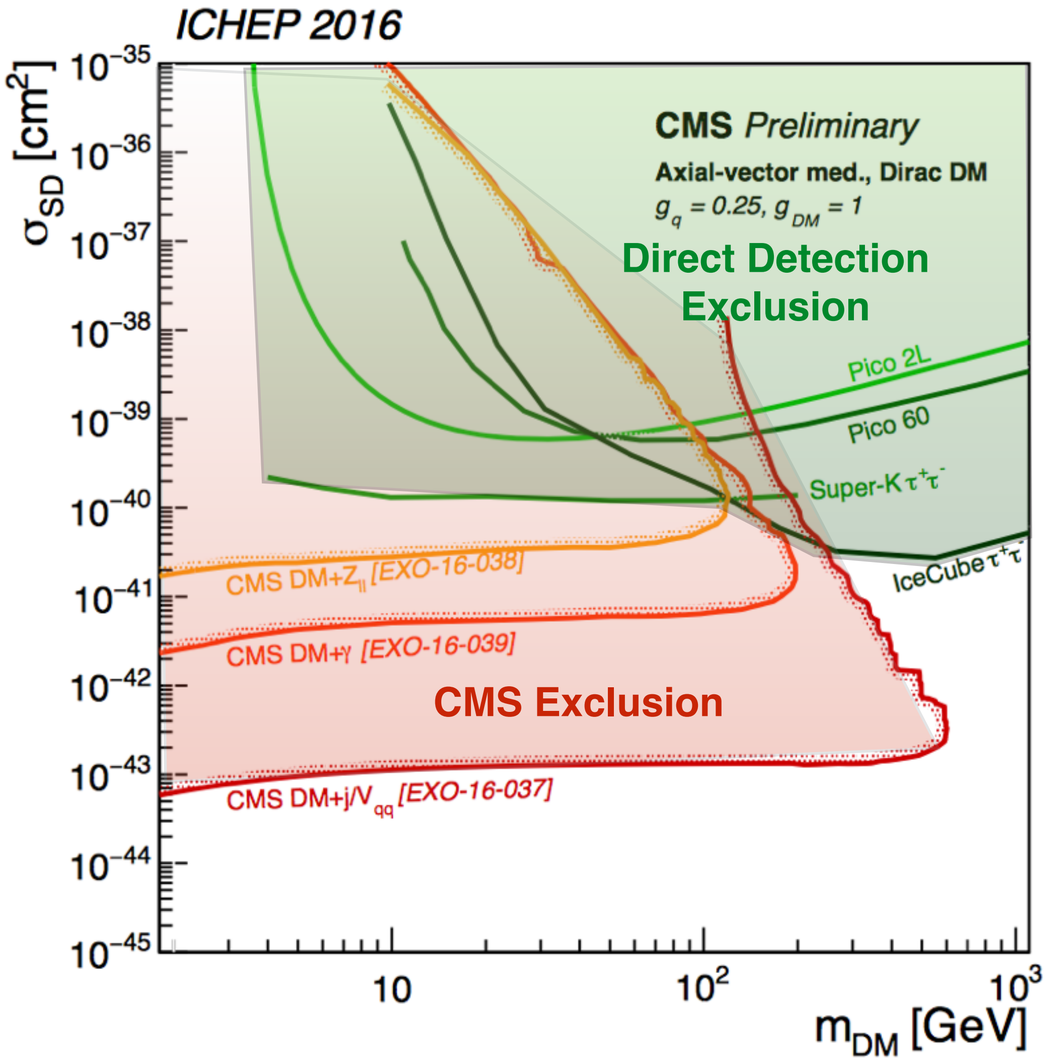

Dark Matter is **weakly interacting (WIMP)**, and it will leave **no signature in the CMS detector**

The existence of **missing energy** in the event could mean => **Dark Matter**



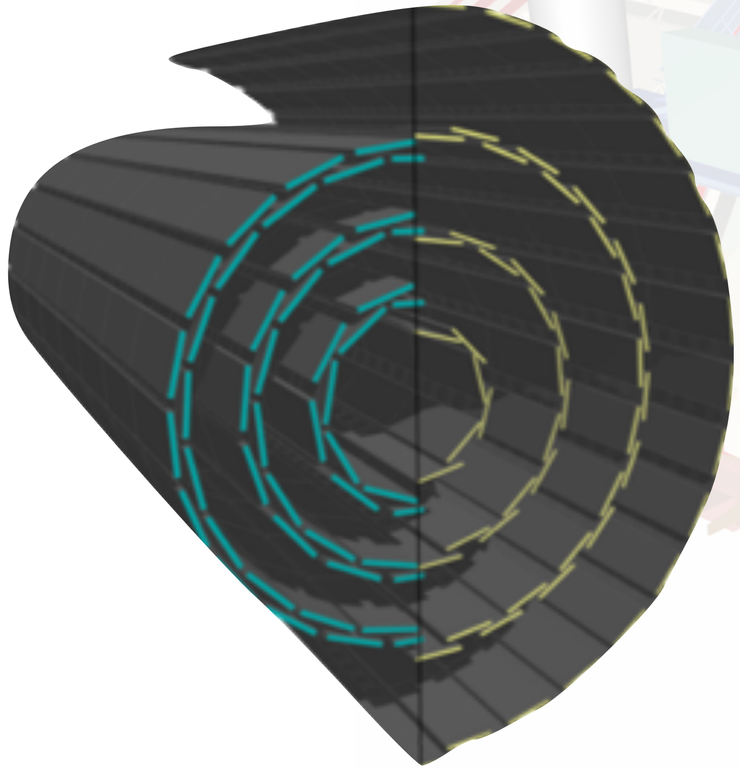
# Everything Beyond: Dark Matter



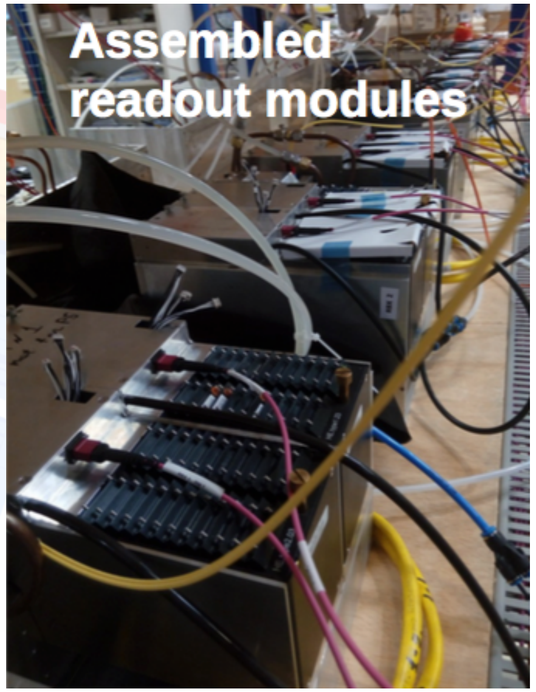

LHC has complementary sensitivity to other dark matter searches!

# In the Mean time..
# Working Towards the Next Generation of the Detector



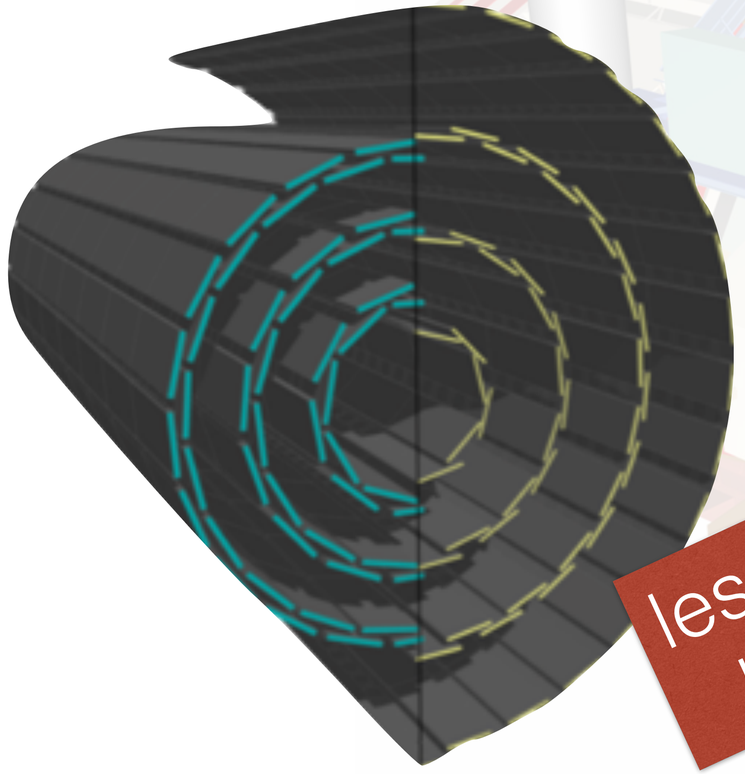
HCAL endcap:
- New photodetectors
- Faster and more radiation hard electronics

HCAL Forward:
- Updating front-end electronics to suppress anomalous noise




Additional Layer in Pixels
- Offline software is being developed
- Integration in progress

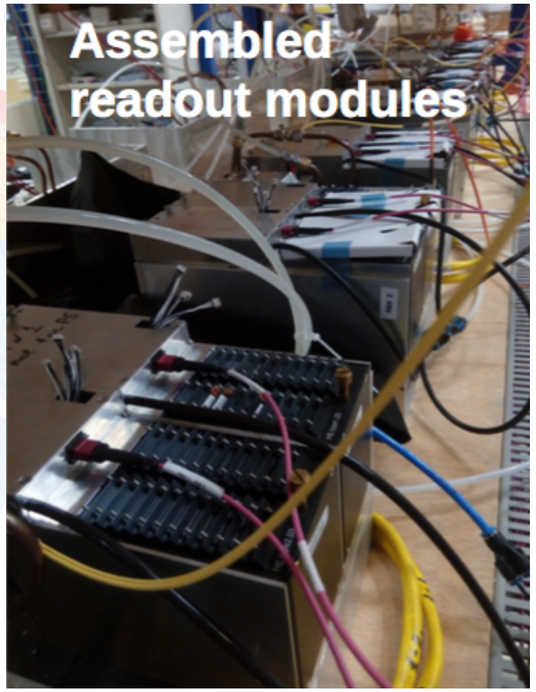
# In the Mean time..
# Working Towards the Next Generation of the Detector



HCAL endcap:
- New photodetectors
- Faster ar more radiation hard electronics

less background + more signal
higher chance of discovery!

-orward:
g front-end electronics
suppress anomalous noise




Additional Layer in Pixels
- Offline software is being developed
- Integration in progress

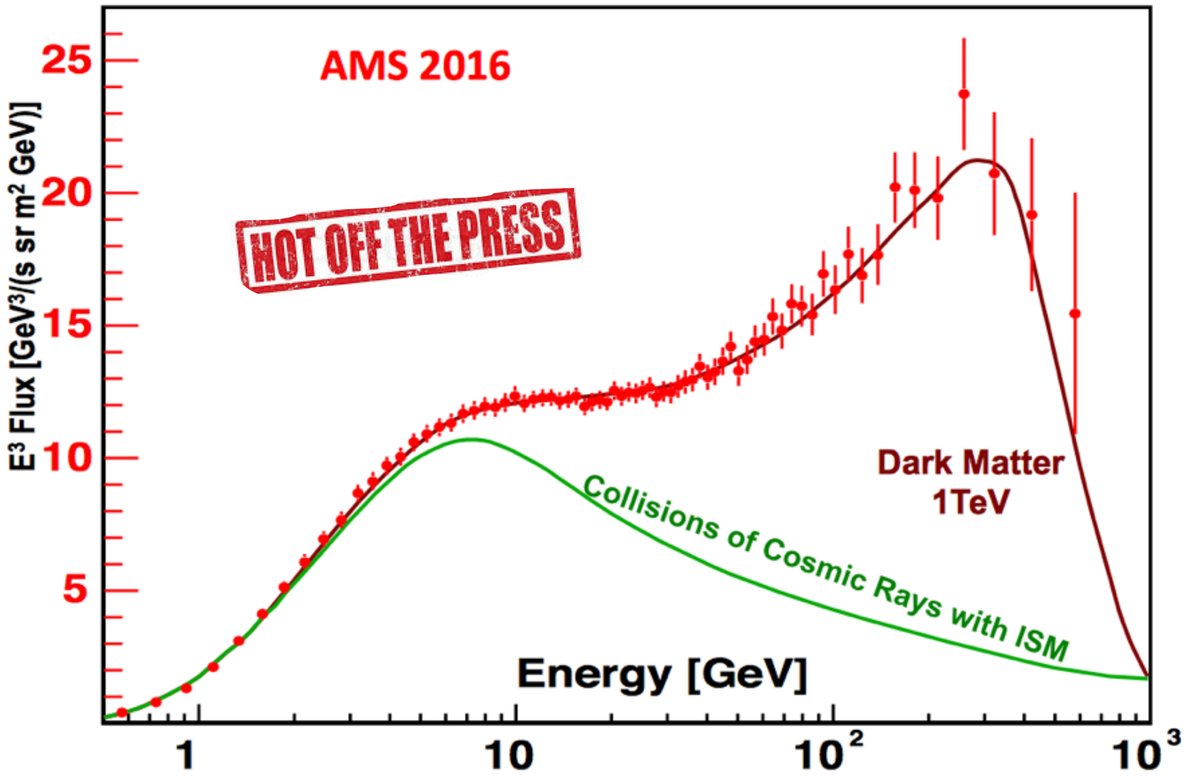
But … all this is only the beginning of a long journey …
CMS is excited to keep analyzing the full 2016 data and is looking forward to collecting more collisions!
We are grateful for the support from the collaborating nations and funding agencies!

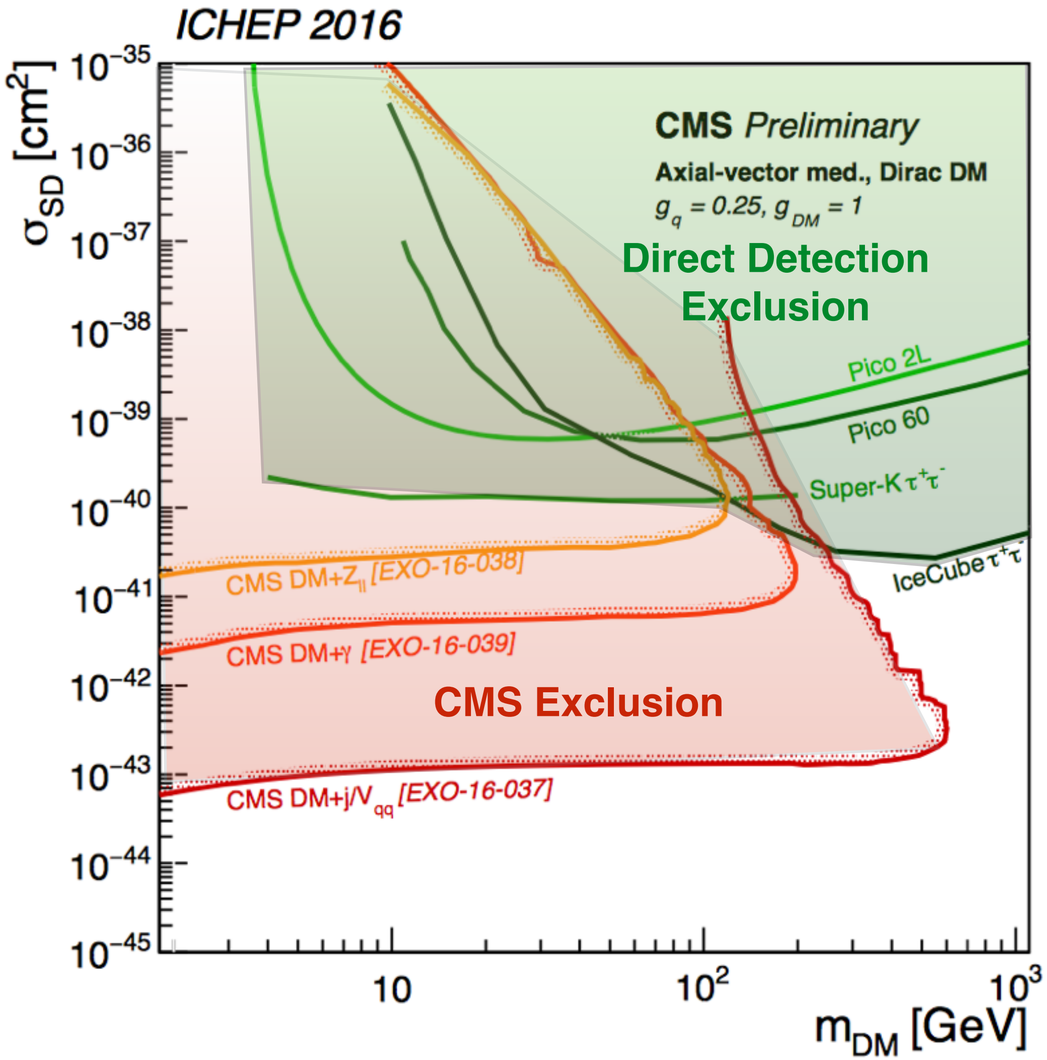
# Back Up

# Everything Beyond: Dark Matter

Latest AMS results were found to be compatible with a **1 TeV Dark Matter**

**CMS is on the verge of being sensitive to this dark matter mass.**




LHC has complimentary sensitivity to other dark matter searches!

# CMS Detector in Run 2

**CMS in 2016 operated with high efficiency**

- more than 96% detector active
- 92% data taking efficiency

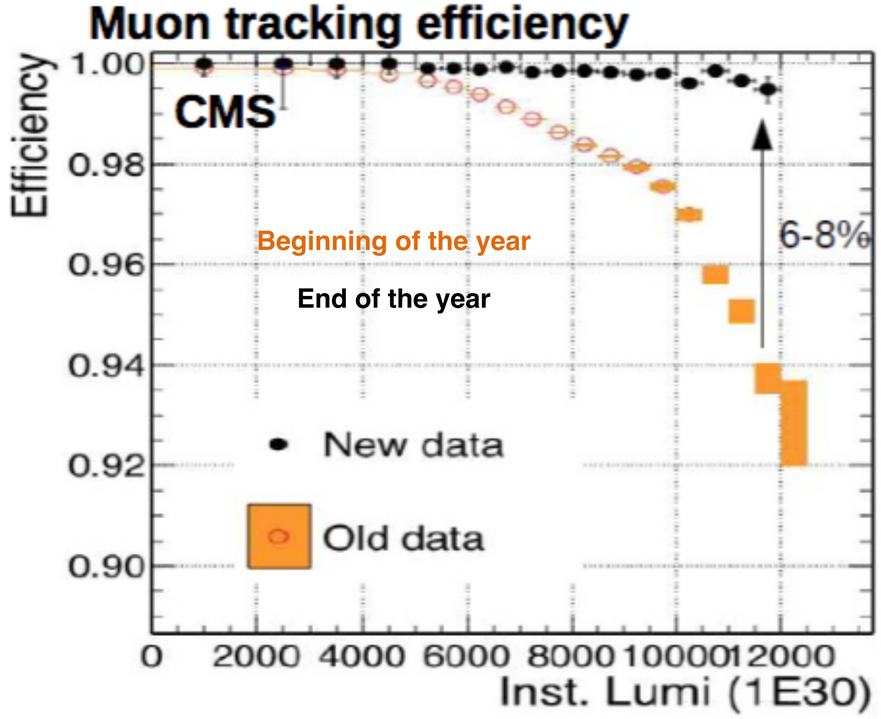
**SUPERCONDUCTING MAGNET**

Repaired and cleaned

100% Uptime during 2016!

## TRACKER

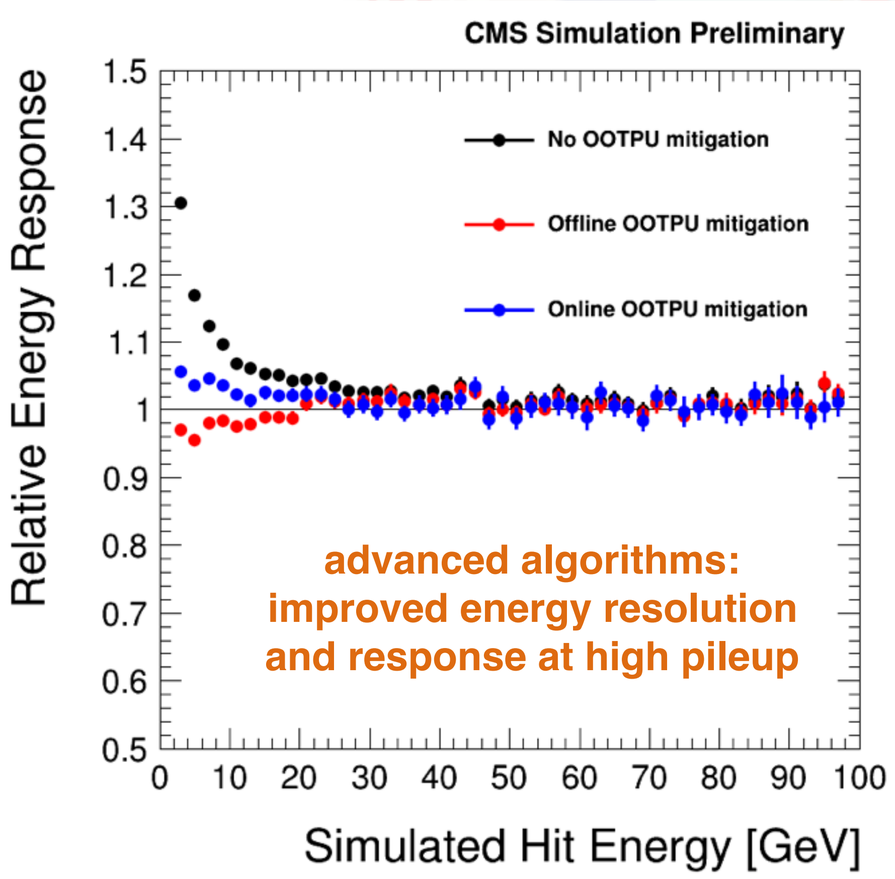
- New front-end electronics
- Fixed saturation effects in the pre-amplifier of the readout chip



# CMS Detector in Run 2

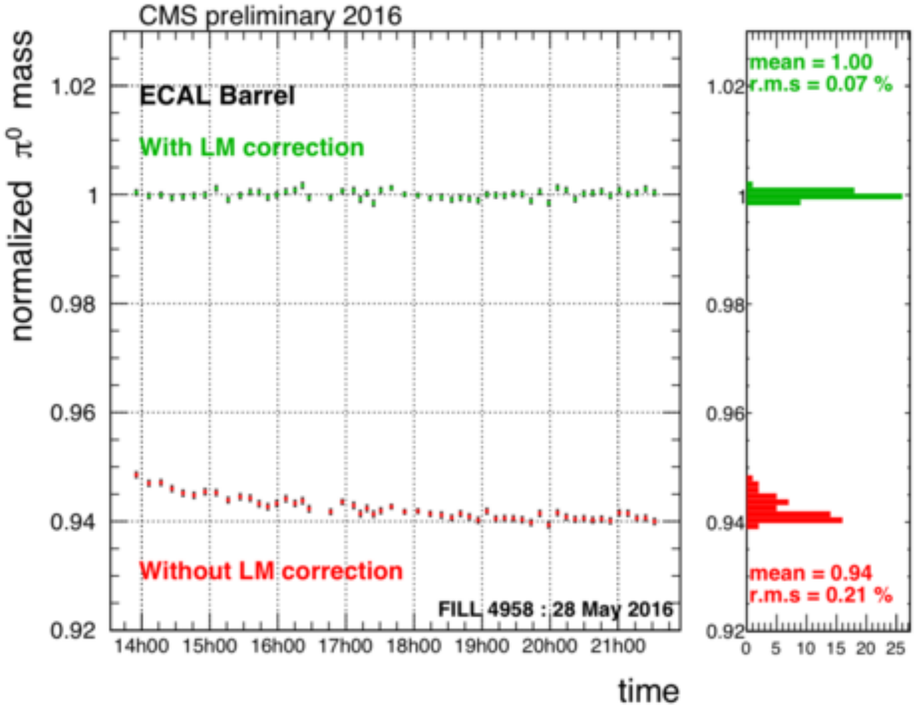
## HCAL

**New photodetectors**
**Faster and more robust electronics**



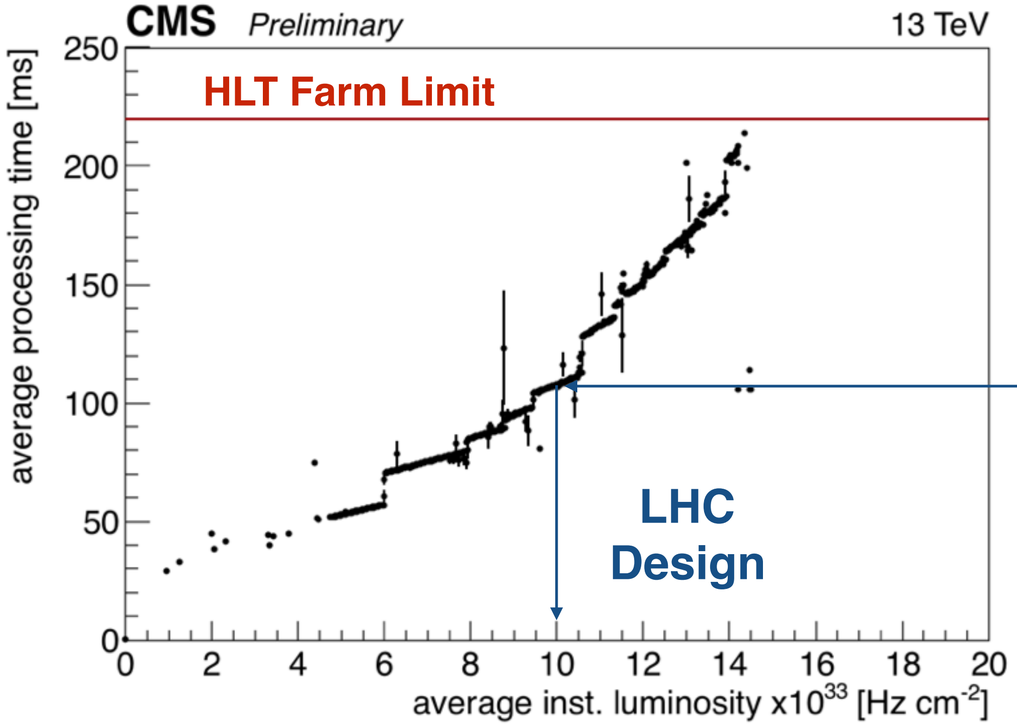

## ECAL

**Firmware and software updates**




**ECAL calibration uses a laser to monitor and correct for transparency loss**

# Data Acquisition Highlights for CMS in Run 2



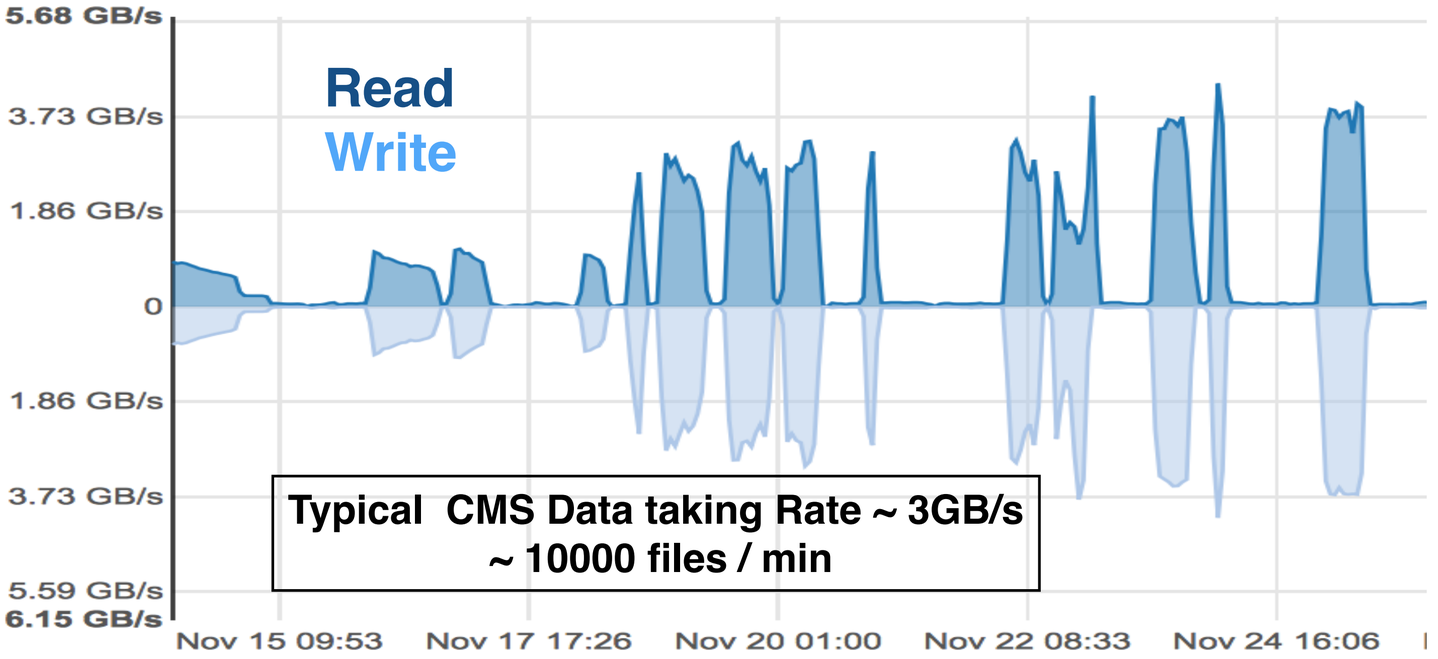

## High Level Trigger

- better matching with offline reconstruction
- **main goal:** keep pileup dependence under control

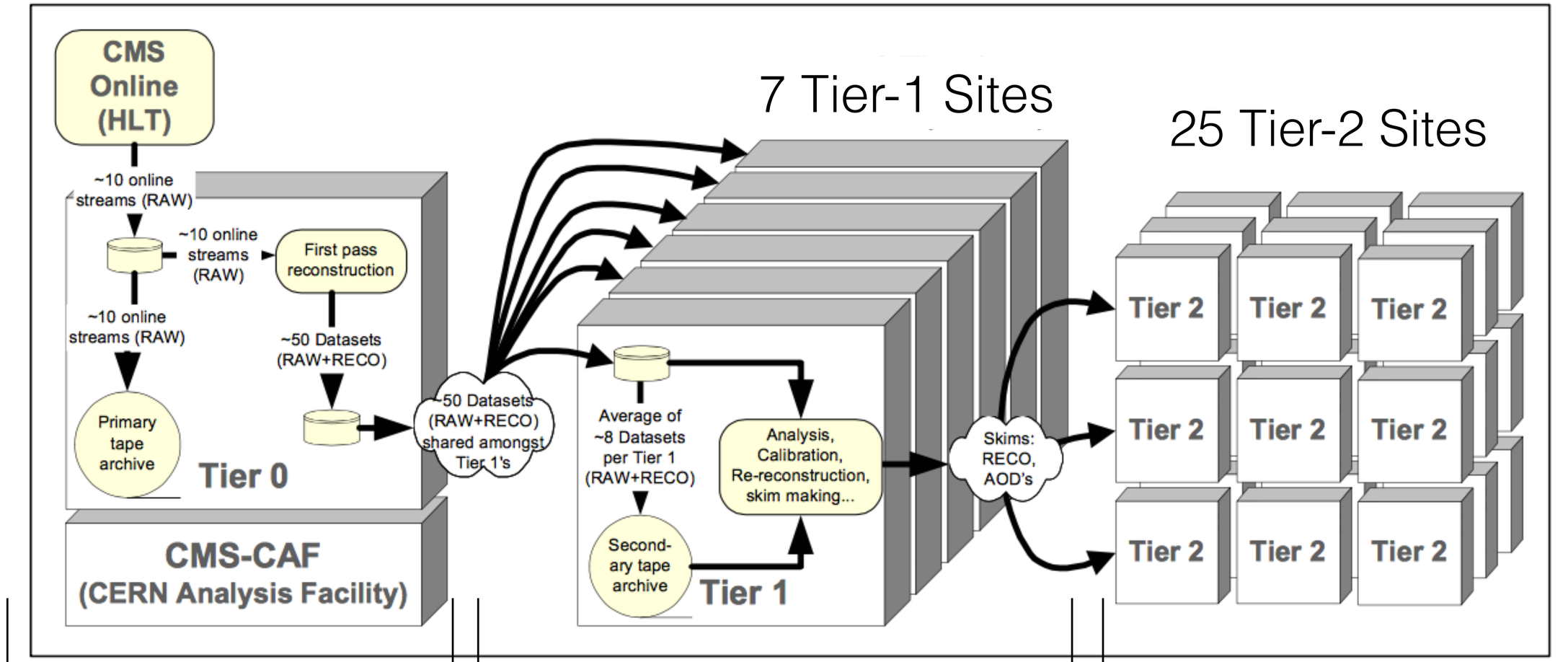
**HLT Farm able to cope with higher than design luminosity**

## Upgraded DAQ (file based system)

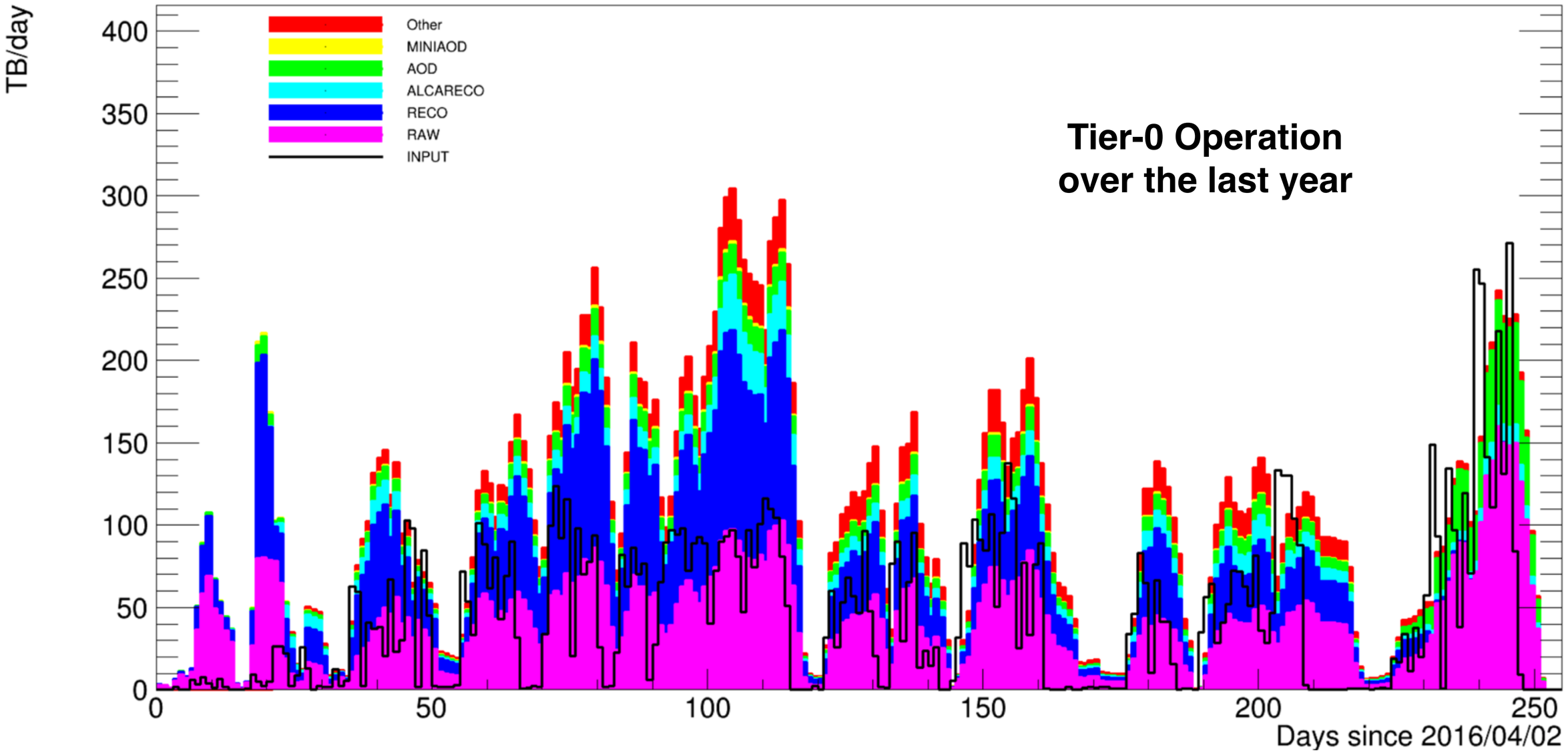
- Fully commissioned in 2015 but in 2016:
  - Doubled online file system capacity
  - x2 read & write performance



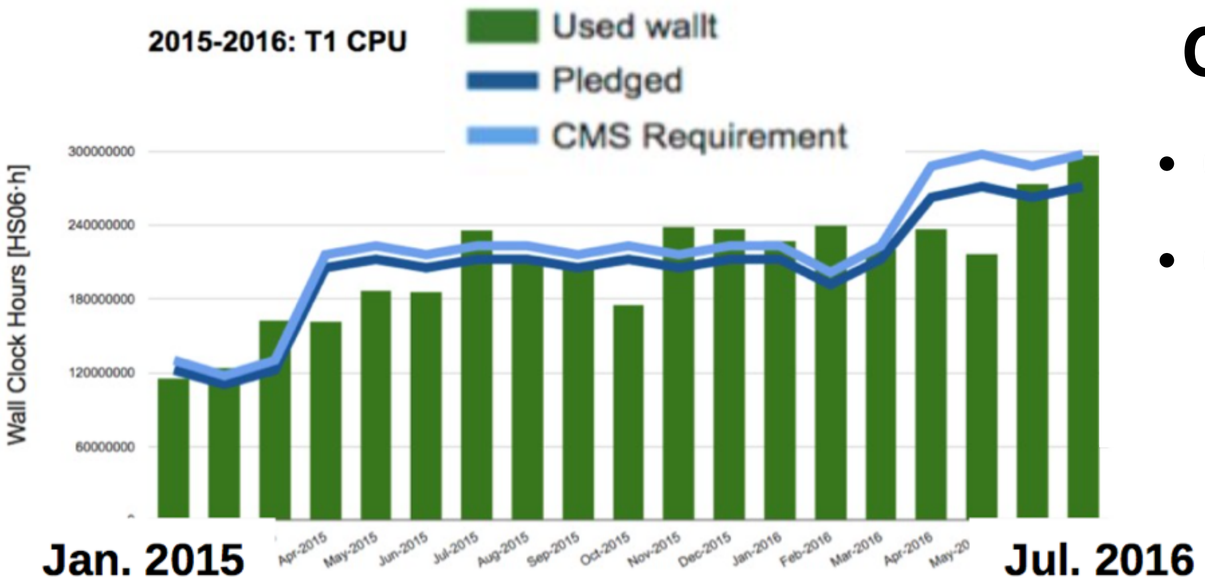
# CMS Computing: Tier System



# CMS Computing: Tier-0 Overview

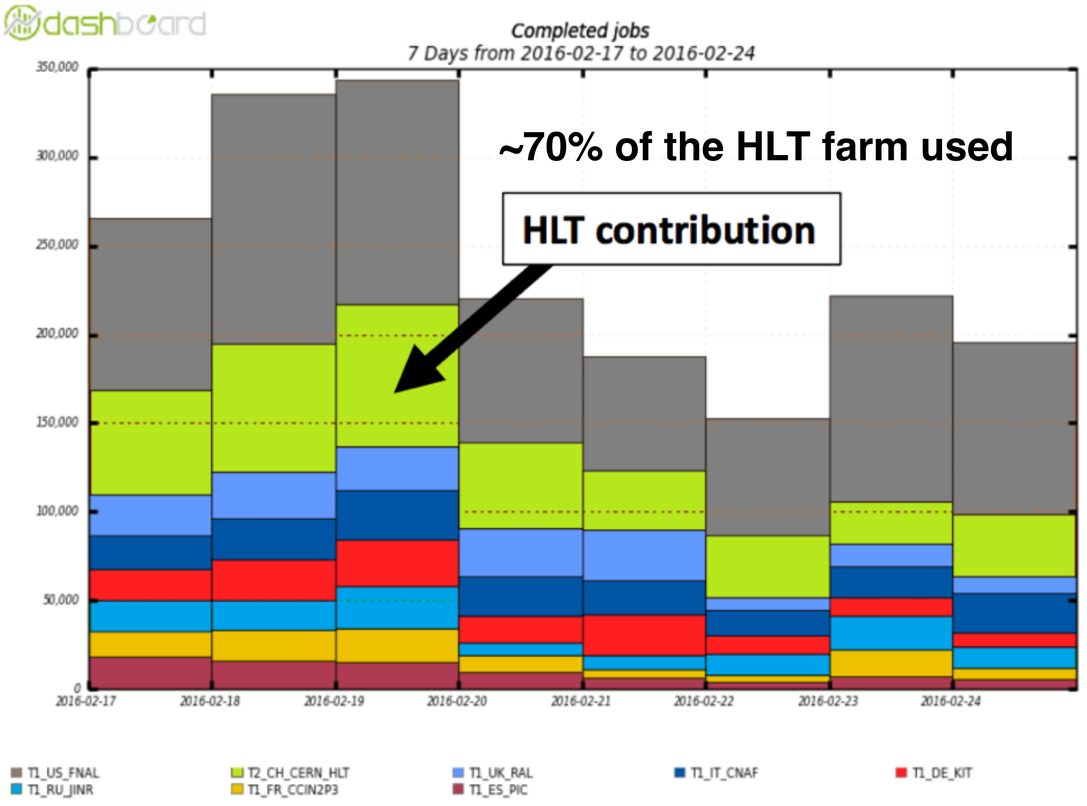


# CMS Computing: T1s and Cloud




## Computing resources are heavily used:

- CPU usage at T1 level : ~103% of the pledges
- CPU usage at T2 level : ~122% of the pledges

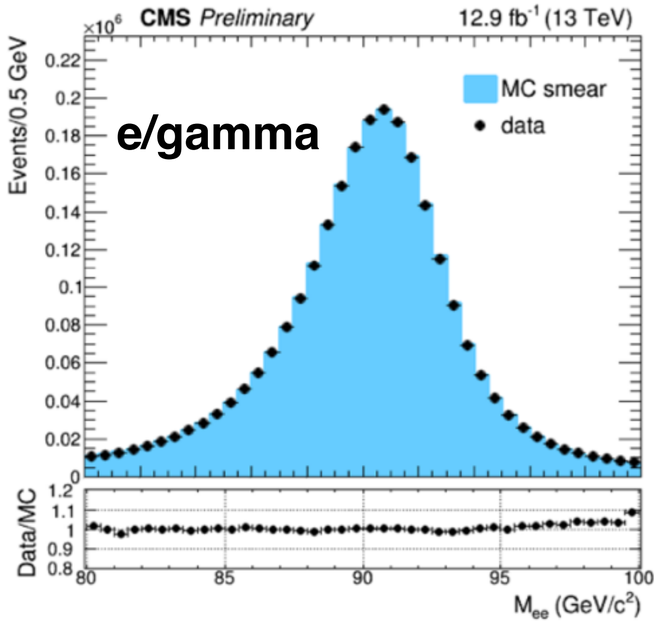


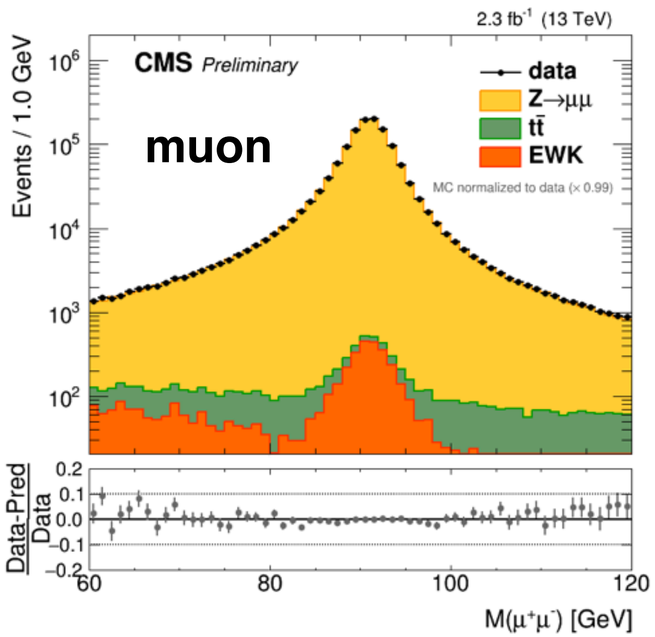

**Online HLT Farm** size is **equivalent to a T1,** and is idle when there is no data taking.

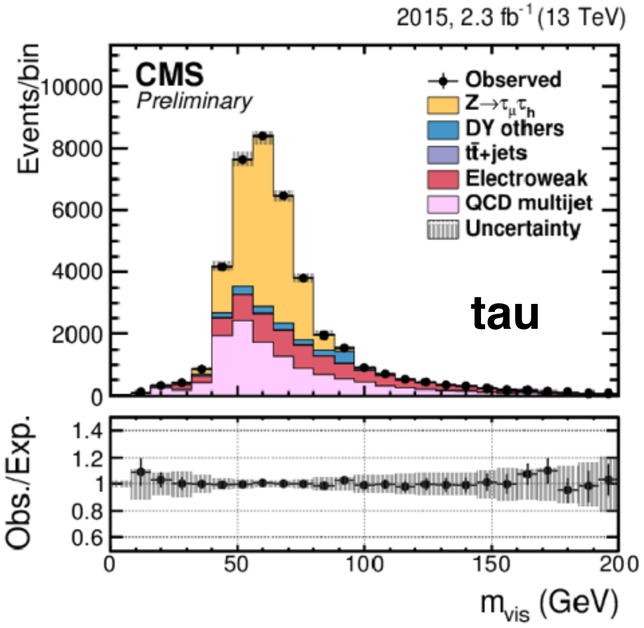
**Proposal**: Provide computing power from HLT Farm during inter-fills => **Cloud!**

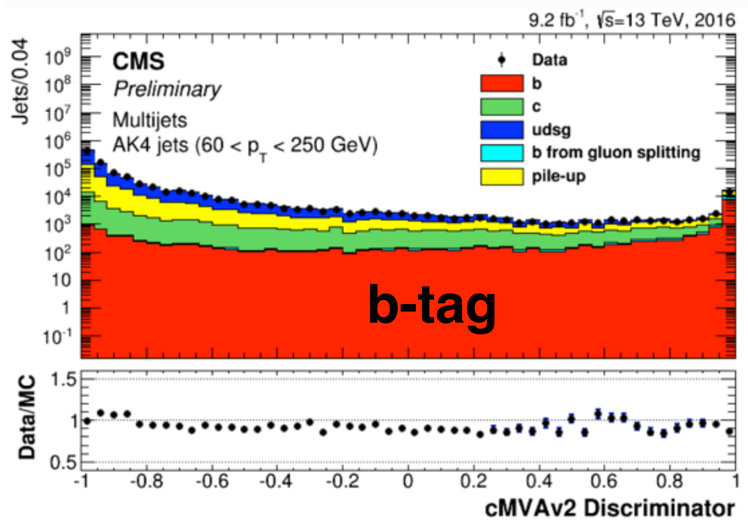
# Object Reconstruction and Identification

## Excellent Scale and Resolution of e/gamma, muon and tau objects



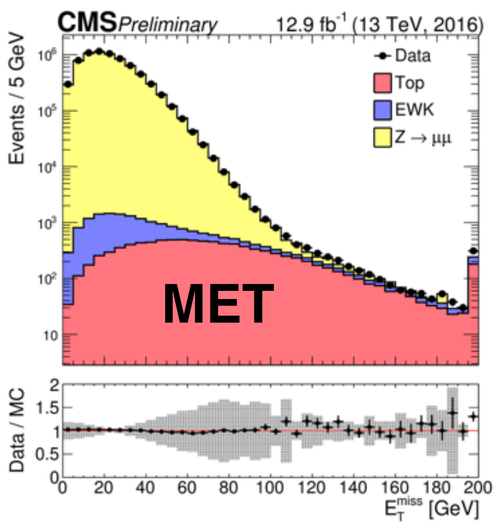



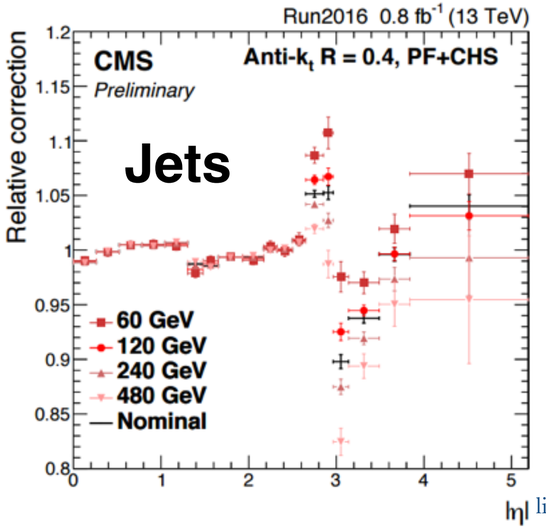



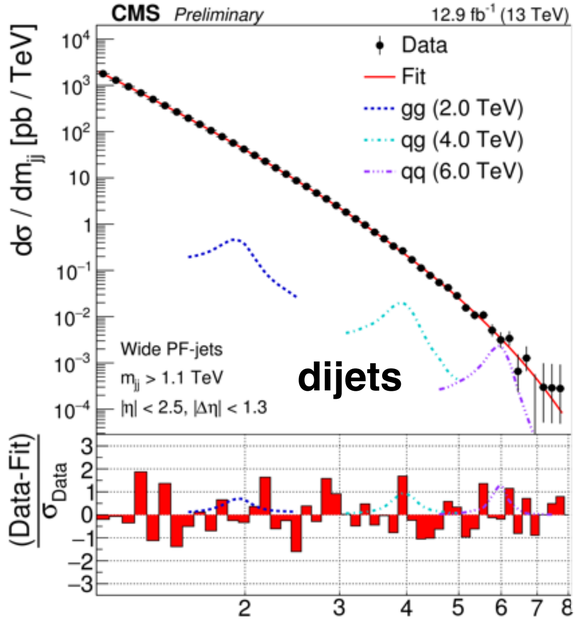

**Excellent modeling of b-tagging discriminators and MET**

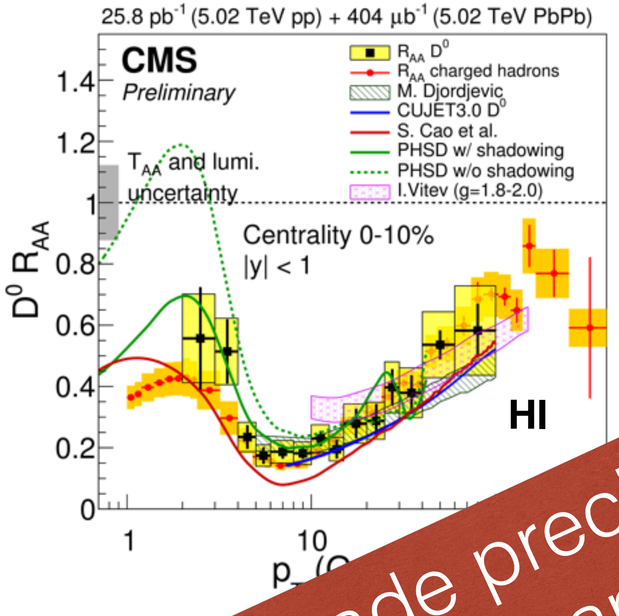
**Excellent scale for Jets**

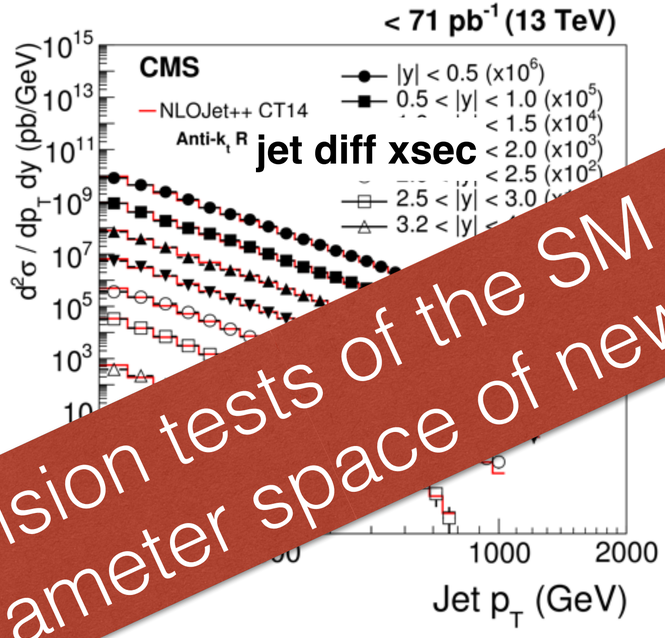


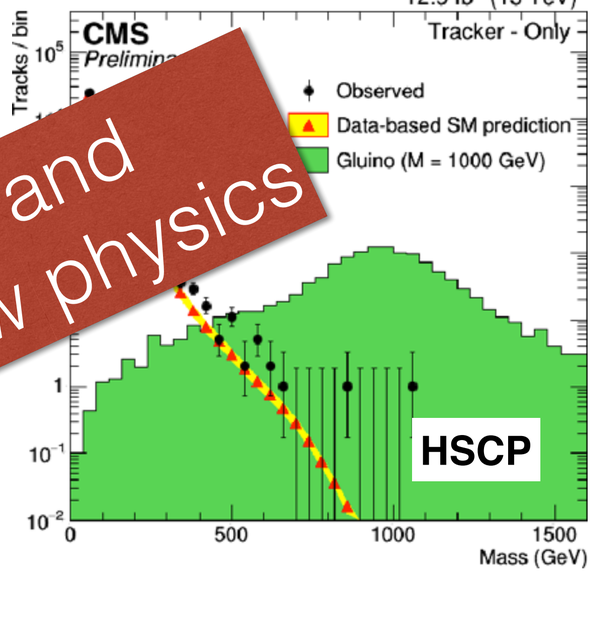



# (Subset of) Everything Else

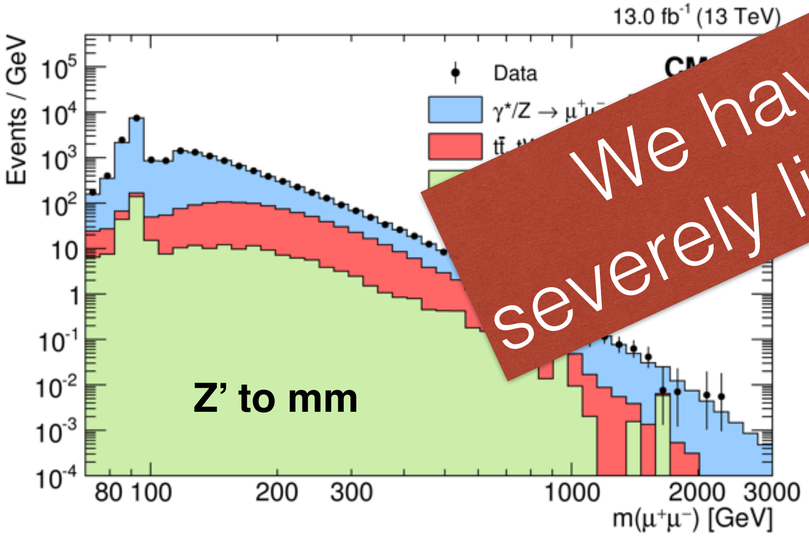


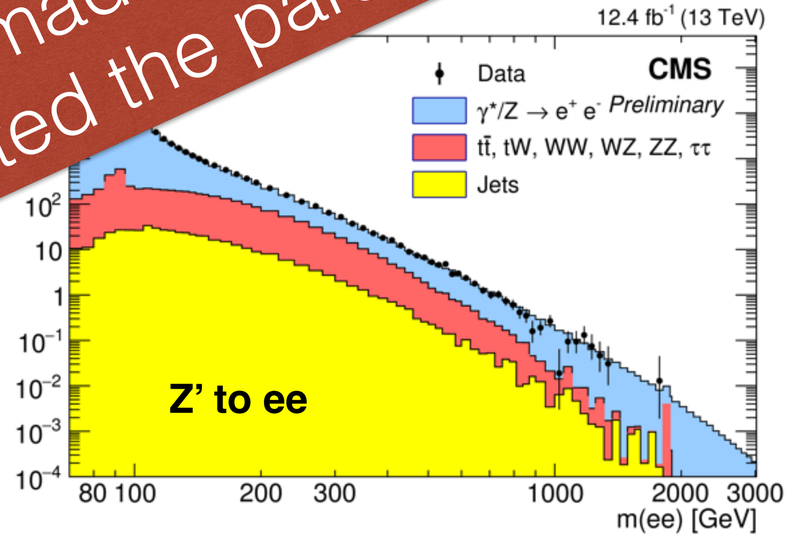



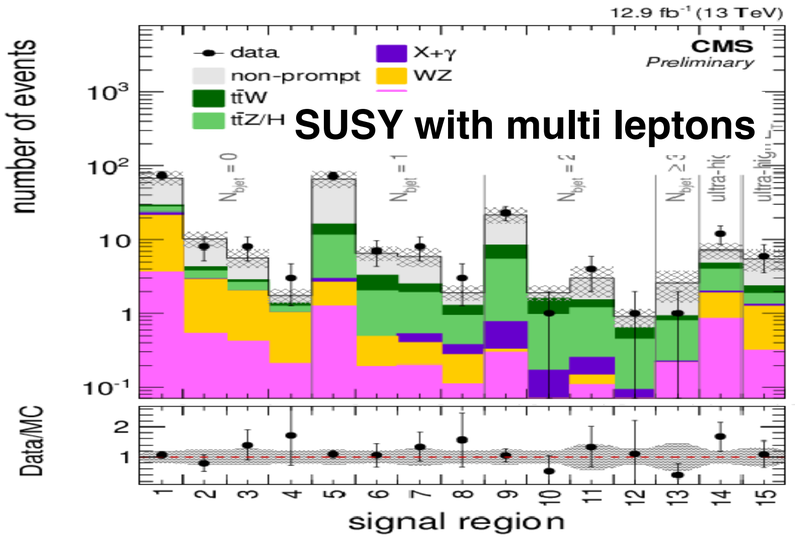




We have made precision tests of the SM and severely limited the parameter space of new physics



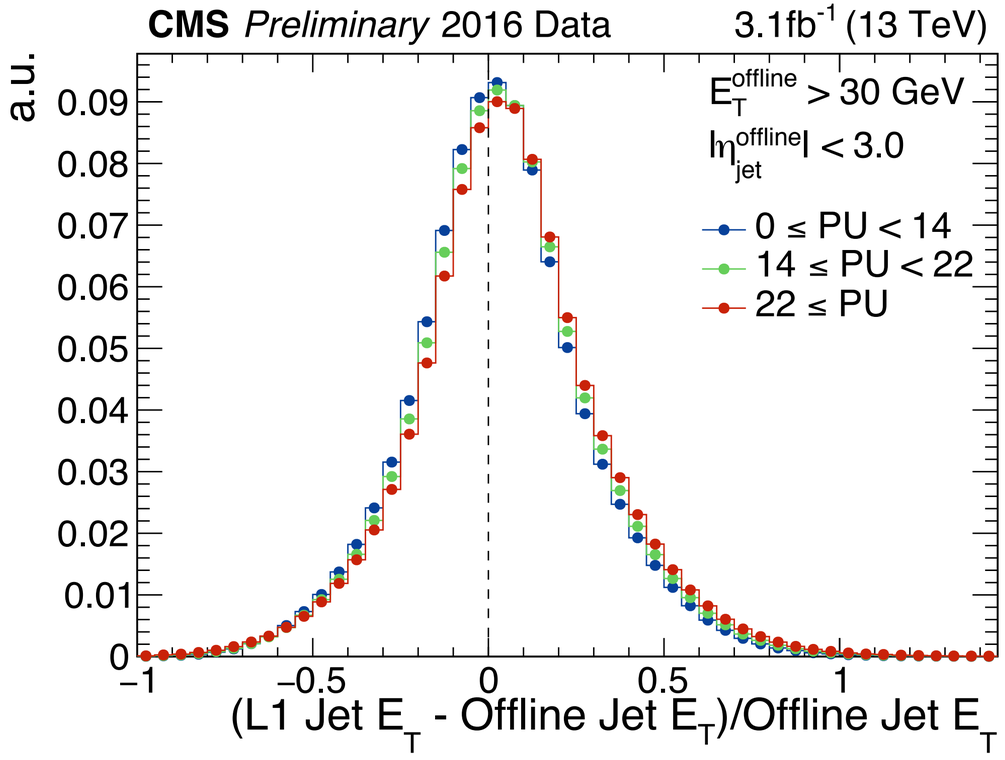



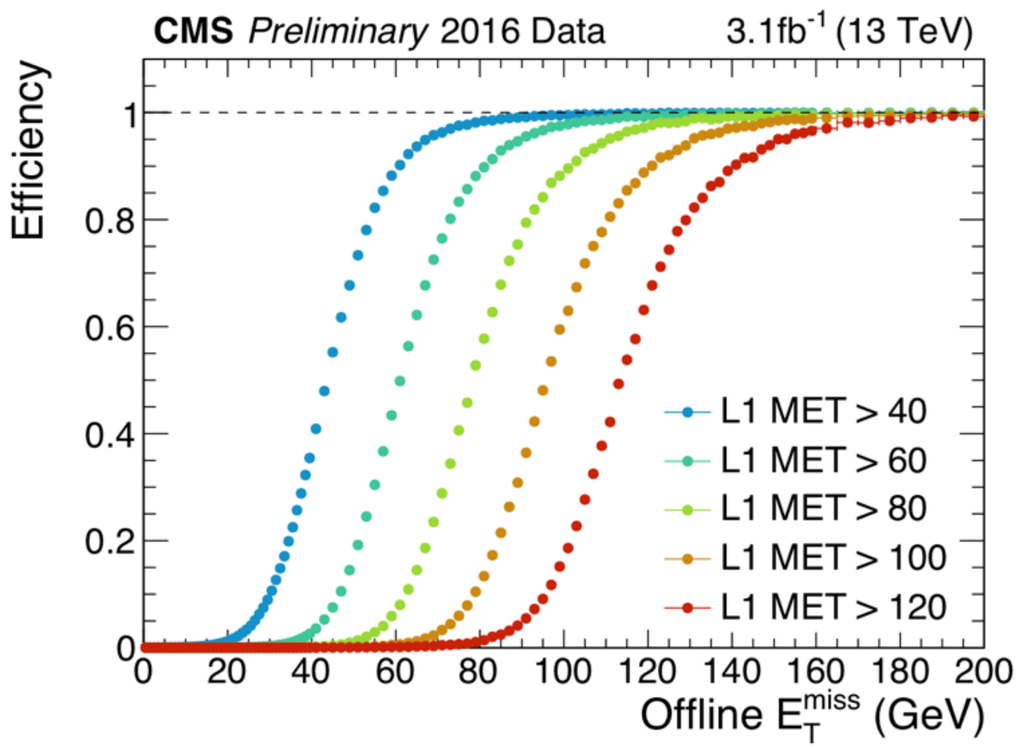
# Data Acquisition Highlights for CMS in Run 2

## L1 Upgrade: **Fully commissioned**

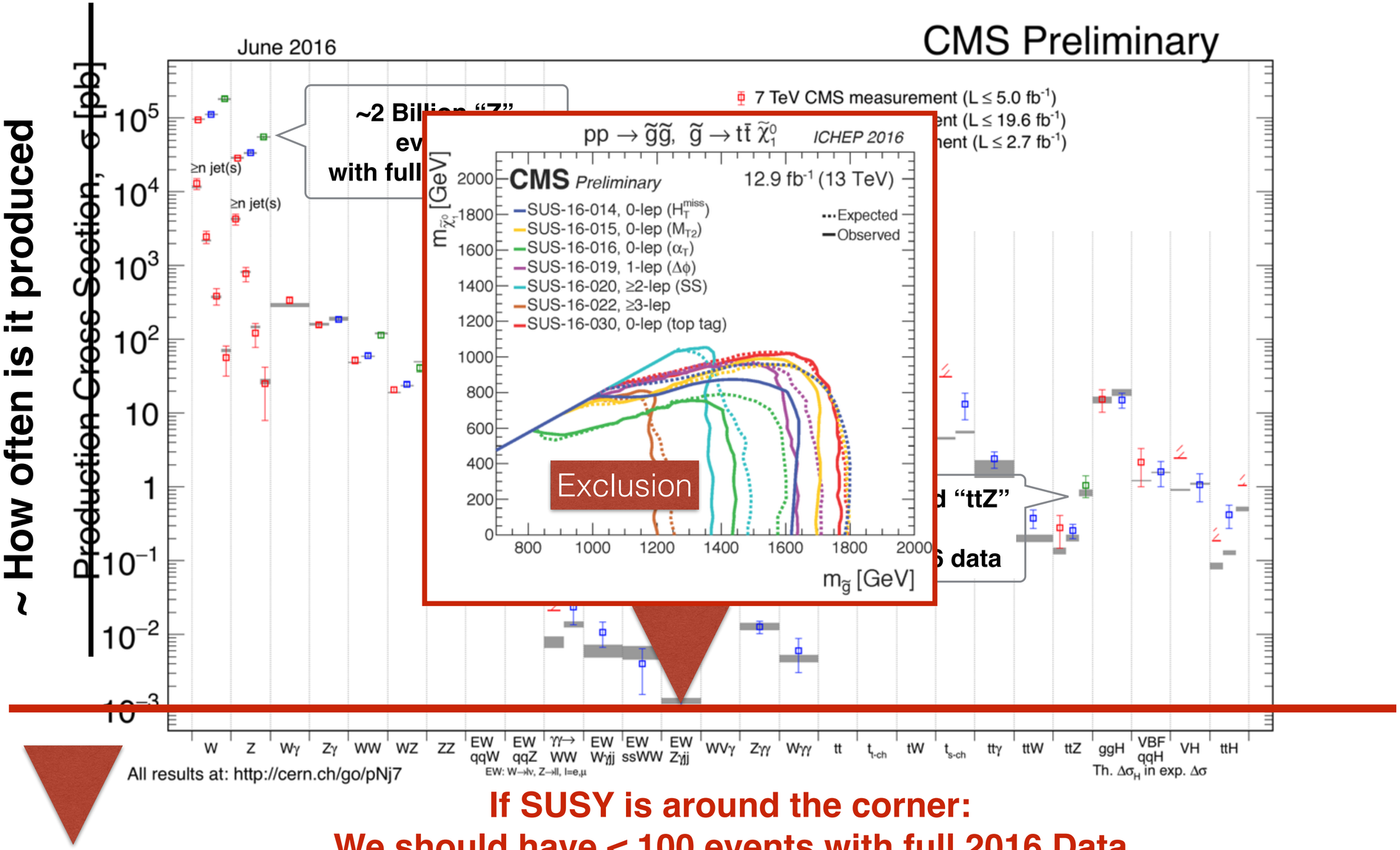
- Higher granularity and processing capabilities
- FPGA-based (Field Programmable Gate Array) architecture

**Stable data taking with high quality since May 2016 at higher luminosities**



# Everything Beyond: Super Symmetry




**If SUSY is around the corner:**
**We should have < 100 events with full 2016 Data**