Physics and Grid Computing
@
Large Hadron Collider

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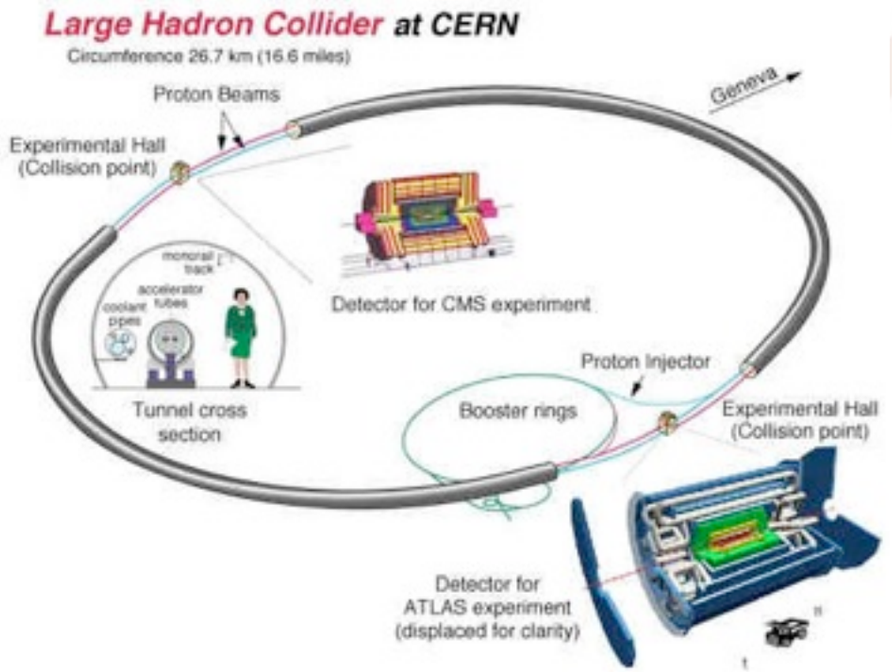
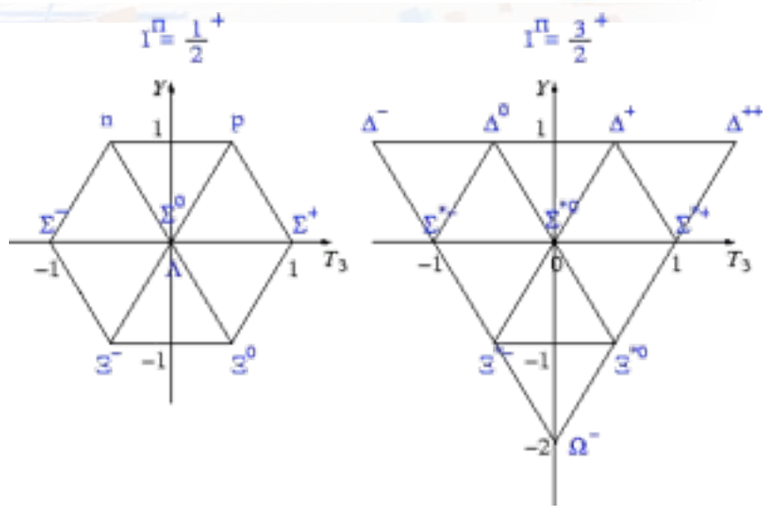
The Large Hadron Collider (LHC)

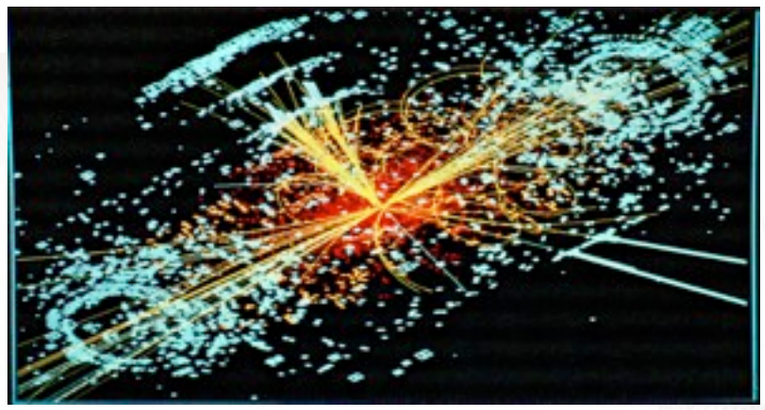
Large : It is a 17 mile tunnel built 100 meters underground, equipped with superconducting magnets that are kept at temperature colder than the outer space

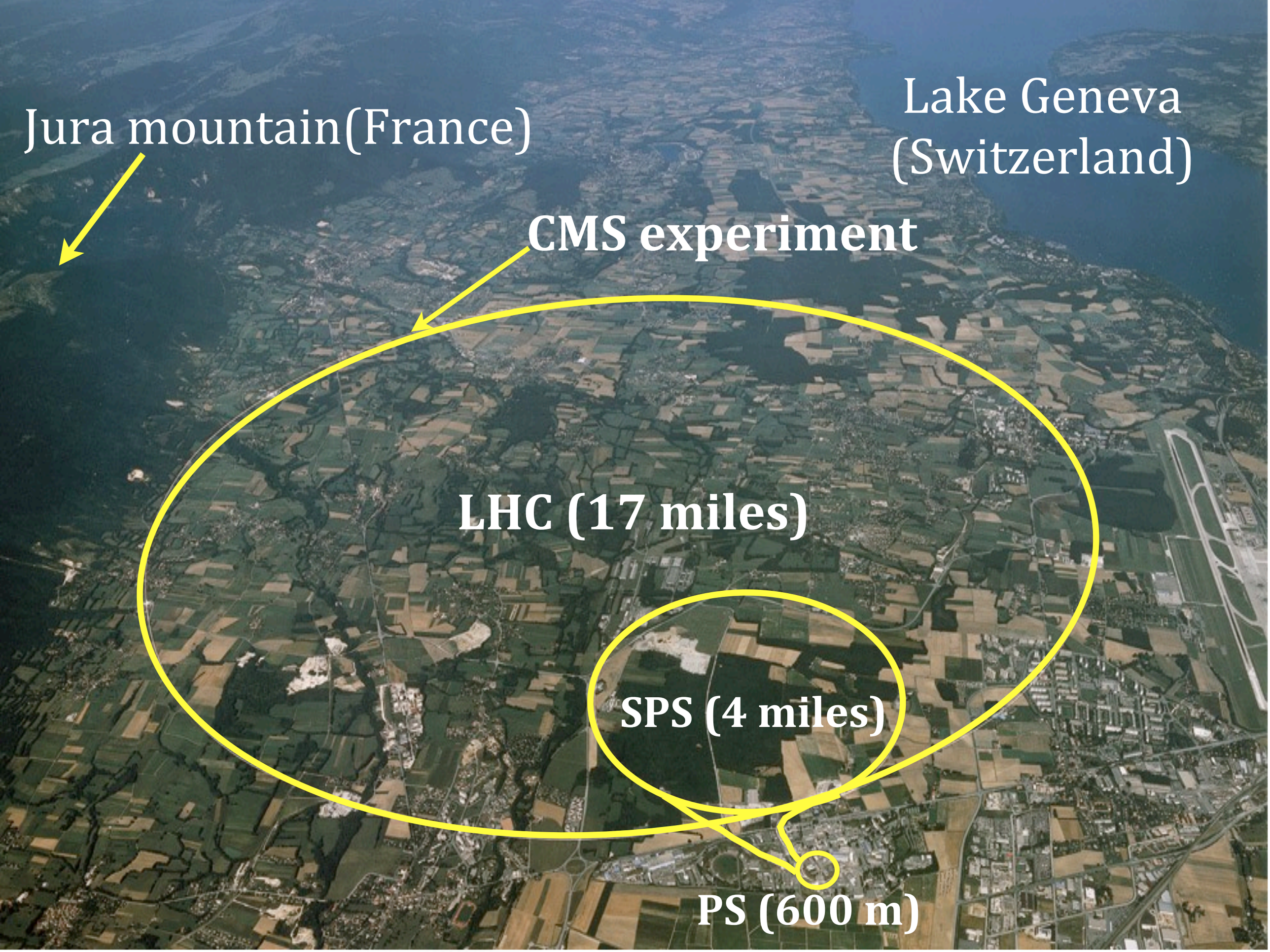


Hadron : Category of particles (e.g. proton, neutron)



Collider : It collides protons after accelerating them close (99.9991%) to the speed of light




Jura mountain(France)
Lake Geneva
(Switzerland)
CMS experiment
LHC (17 miles)
SPS (4 miles)
PS (600 m)

Some More Facts

LHC proton-proton collision

Each Proton has energy 7 Trillion Electron Volts (TeV)

14 TeV is the total collision energy

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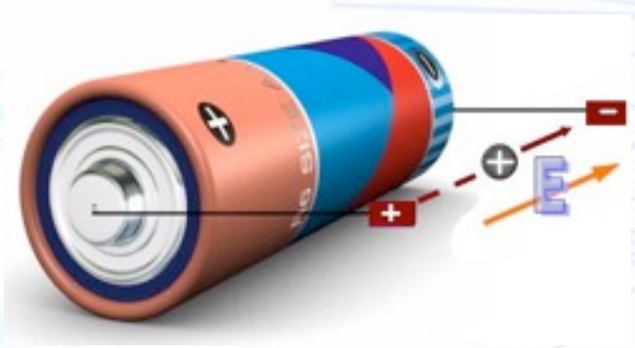

Consider a common 1.5 V battery
Energy it provides to each electron 1.5 eV
($1.5 \times 1.6 \times 10^{-19}$ Joules)

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Consider a common 1.5 V battery
Energy it provides to each electron 1.5 eV
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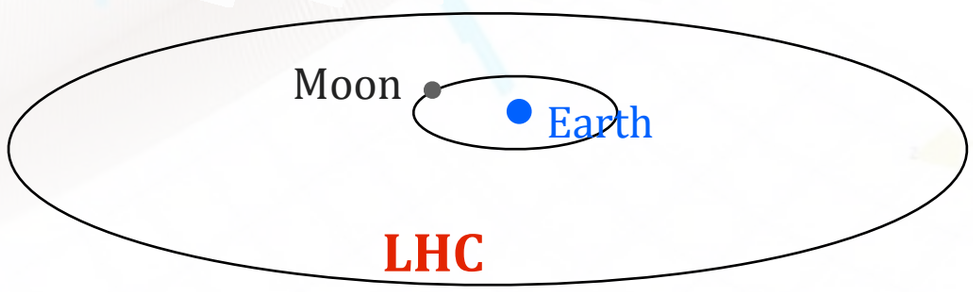
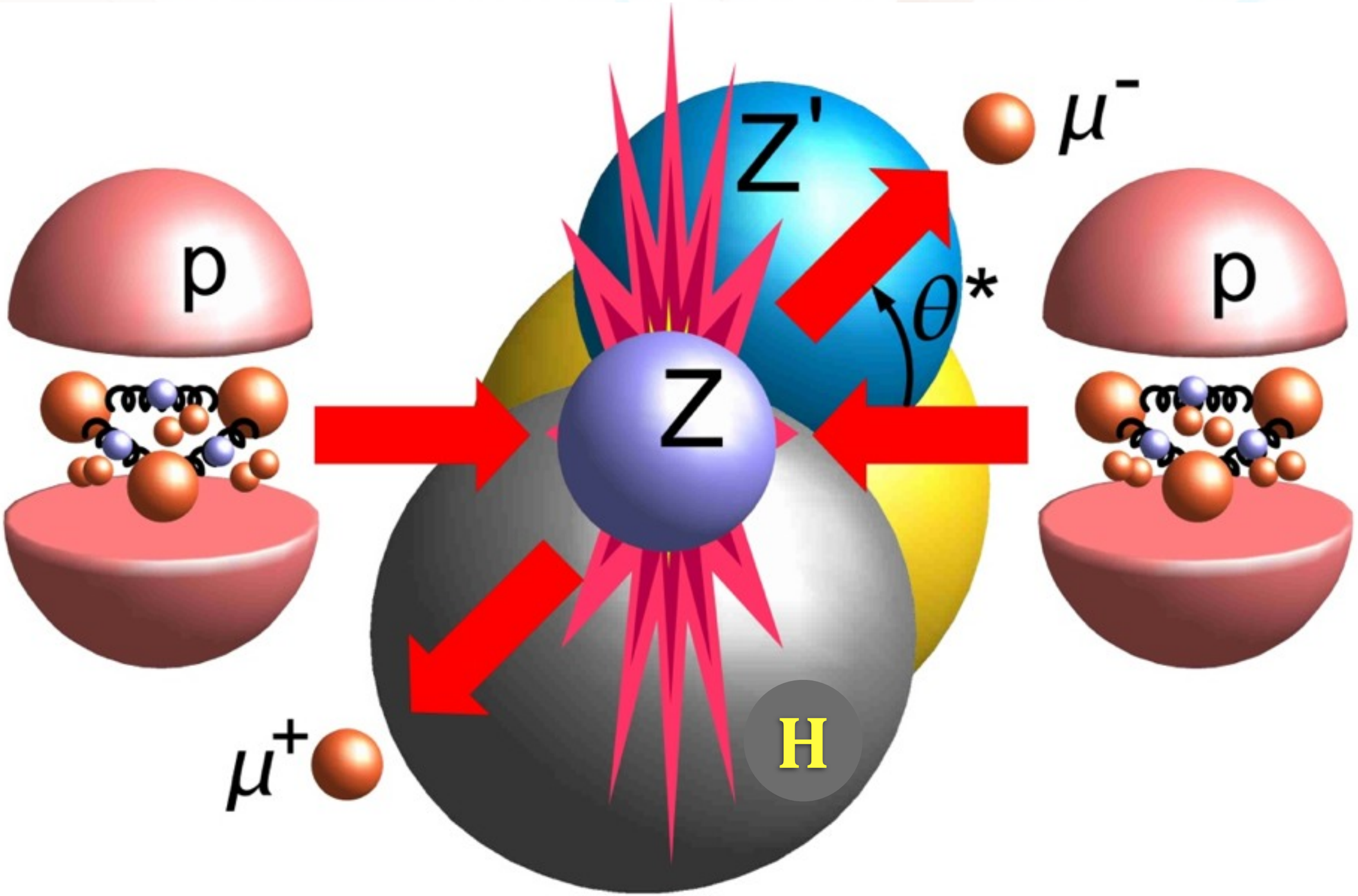
So, for a proton of 7 TeV one would need
~5 trillion batteries

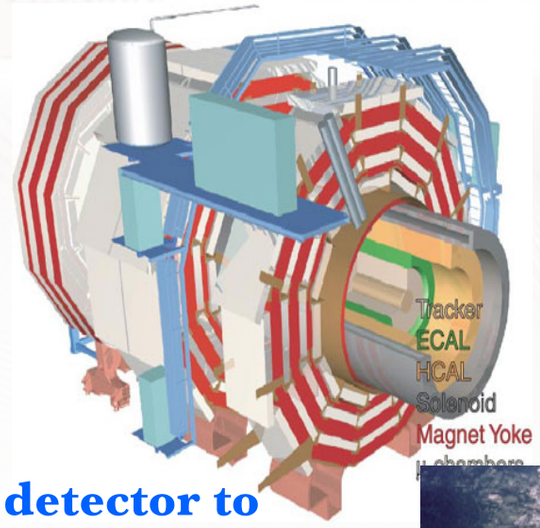
Covers a distance that has a radius
100 times the orbital radius of the Moon





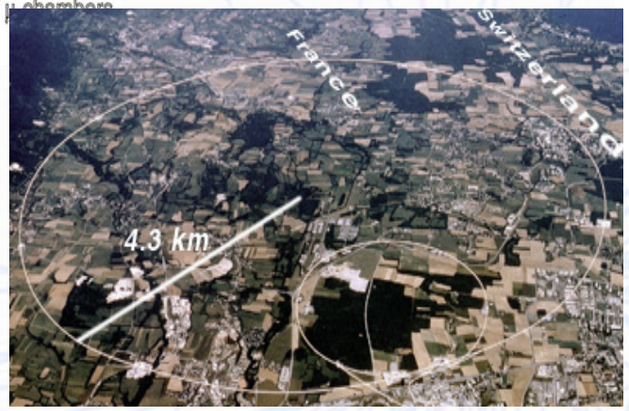
Collision of two protons may produce known and unknown particles

Particle Detectors at the LHC



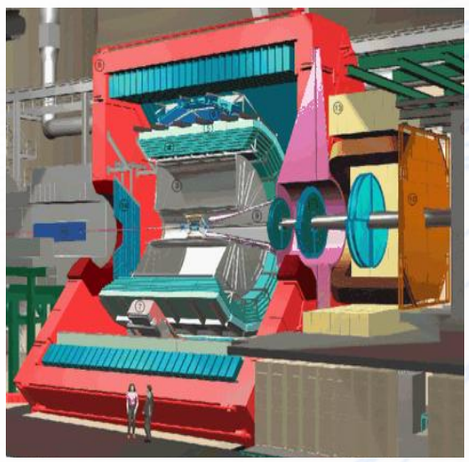
CMS

A general purpose detector to look for a variety of new physics



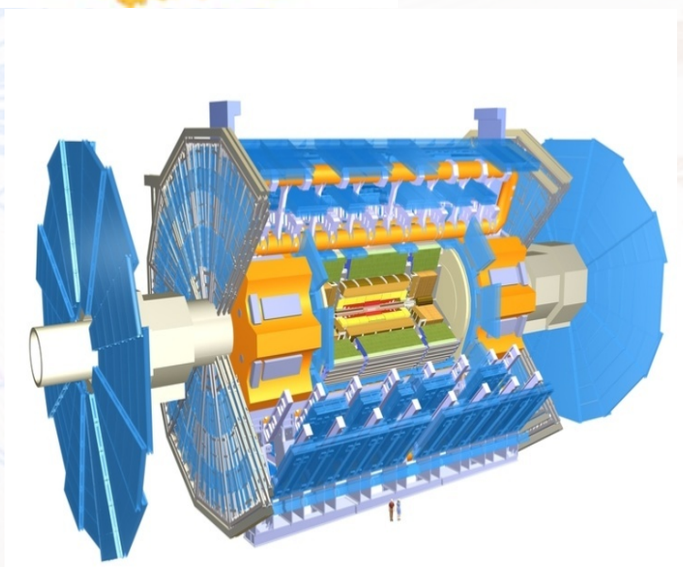
LHCb

Dedicated for studies focusing on the matter anti-matter asymmetry in the universe



ALICE

The Heavy-Ion program to study the quark-gluon plasma



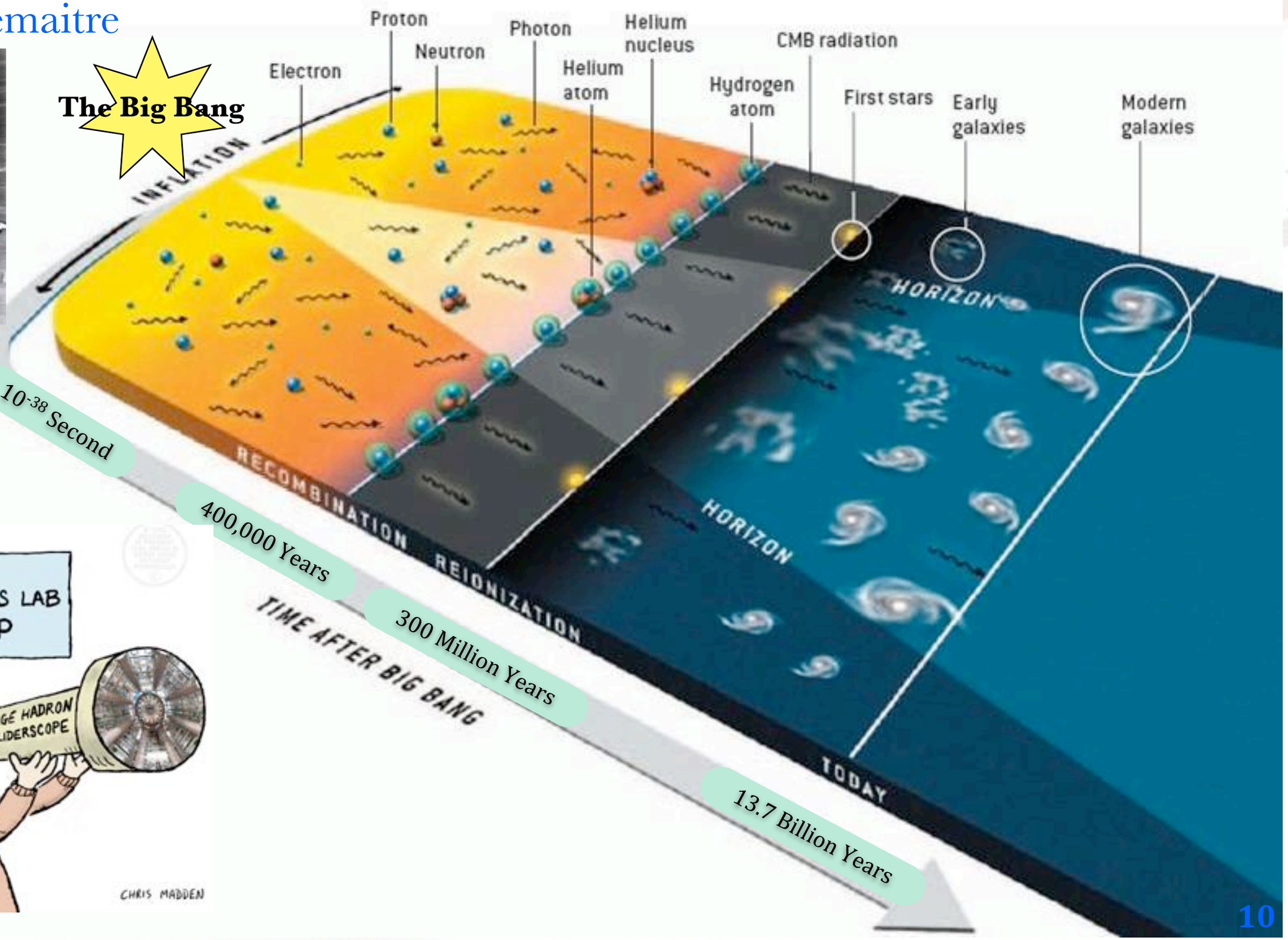
ATLAS

(Same purpose as CMS)

Particle Physics

Connecting the very big to the very small

Georges Lemaitre



Some Unanswered Questions

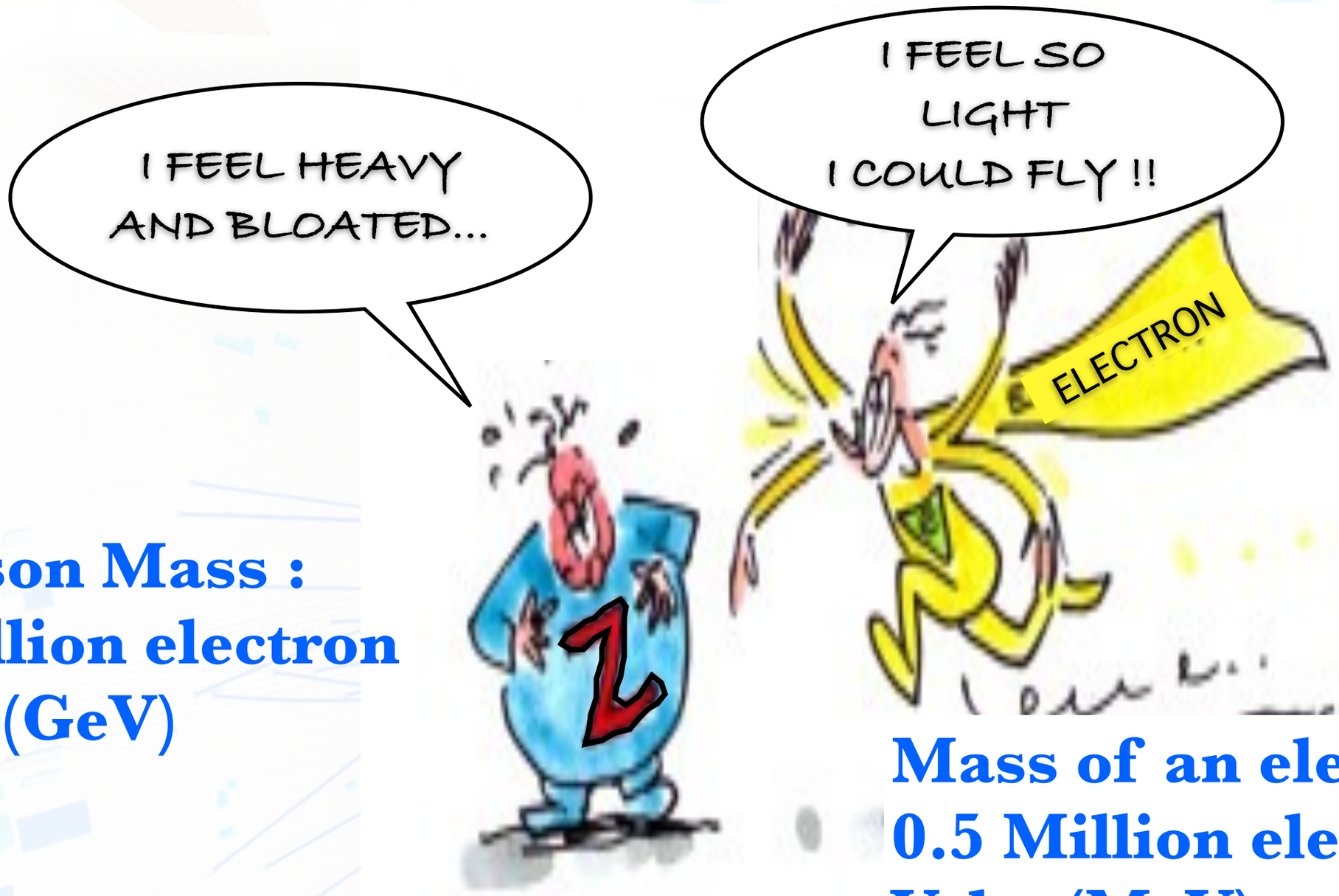
- Are current theories explains the dynamics of all the particles and forces well enough to describe the universe ?

- What is the origin of mass ?

- Is there a single force at high energy ?

- Why matter content of the universe is only ~5% ? What is dark matter and dark energy ?

Origin of Mass



Z-boson Mass :
91 Billion electron Volts (GeV)

Mass of an electron :
0.5 Million electron Volts (MeV)

Particles have very different masses, why ?

The Higgs Mechanism

Interaction (couplings) with the **Higgs field** generate masses

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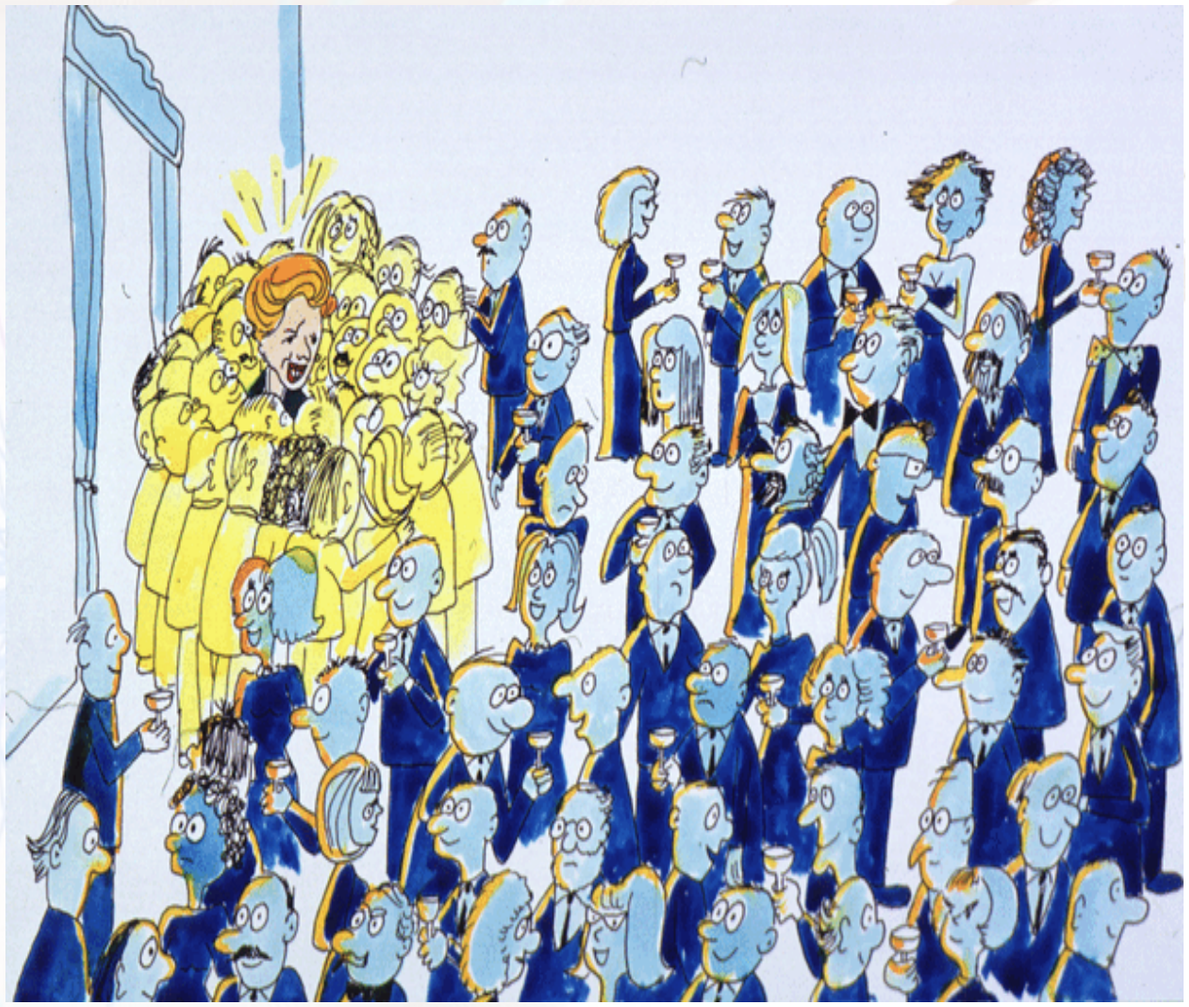
Interaction (couplings) with the **Higgs field** generate masses

- Imagine a room full of journalists (they are the Higgs field)

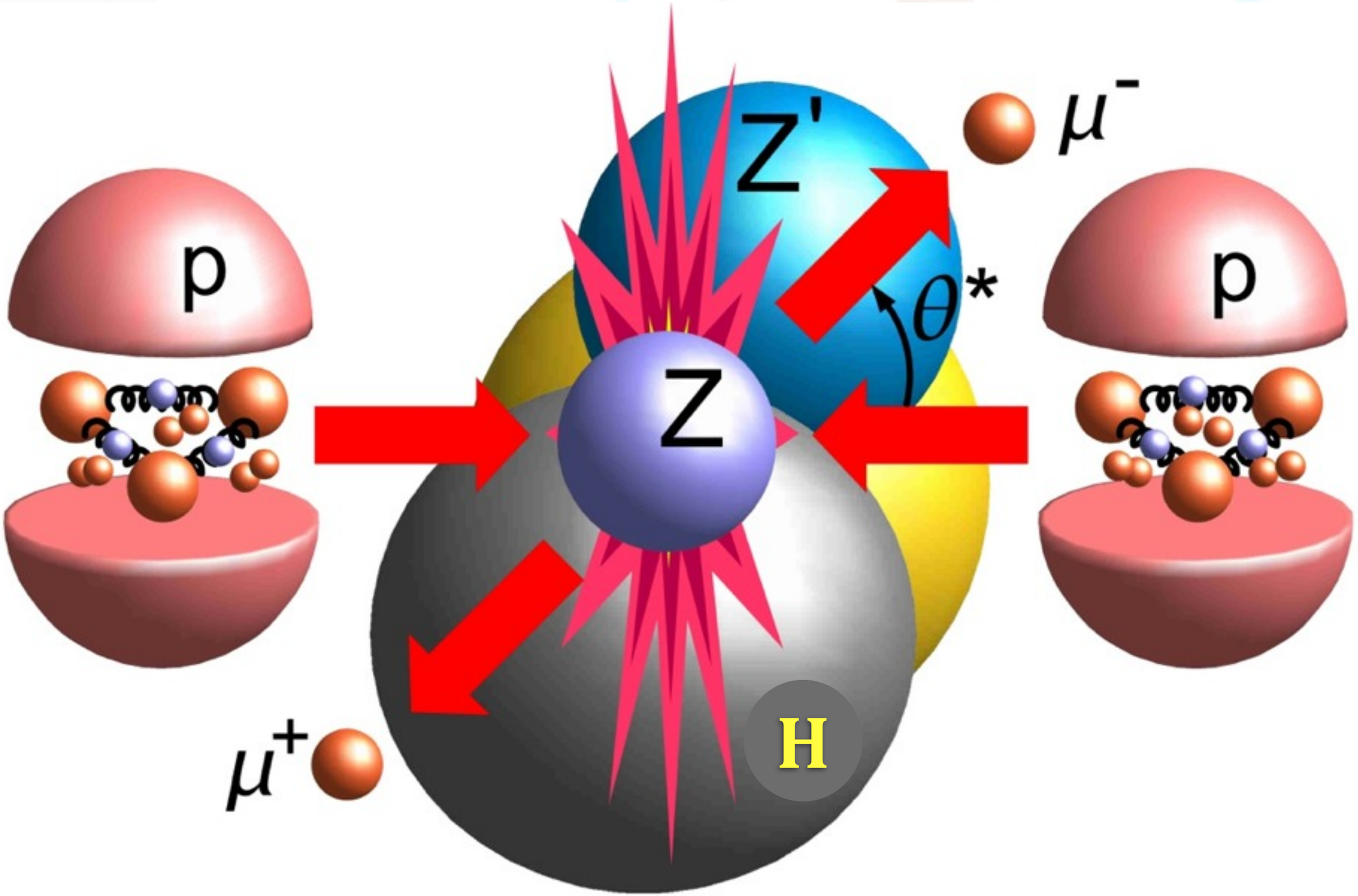
- A famous politician (particle) walks into the room, everyone gather around and this impedes the motion of the politician (giving mass to the particle)

- The stronger the interaction the particle becomes massive



The Higgs Mechanism

- How the Higgs gives mass to itself ? (via self-interaction)
- Now imagine a rumor got away in the room
- The Higgs field clumps together, providing mass to itself and creating a Higgs boson



Collision of two protons may produce known and unknown particles

proton-proton collision events

- LHC has a event rate of about 1 Giga-Hz (10^9 Hz)
- A Higgs Boson is expected at a rate of at least 10^{-2} Hz

- Keeping all the collision events that LHC produces is close to impossible
- Special hardware level algorithms (Triggers) are designed to keep "interesting" event and discard everything else
- CMS experiment keeps event at a rate of 10^5 Hz in order to get analyzed further and discard later if needed

- These events pass through 3 levels of algorithms before being pushed into cpu and storage clusters around the world (**LHC Computing Grid**)
- Collision events are accumulated over time and analyzed in order to discover new phenomenon

LHC Grid Computing

10^9 events per second

Experiment

~PBytes/sec

Online System

~200-1500 MBytes/sec

CERN/Outside Resource Ratio ~1:2
Tier0/(Σ Tier1)/(Σ Tier2) ~1:1:1

Tier 0 +1

CERN Center
PBs of Disk;
Tape Robot

Tier 1

10 - 40 Gbps

IN2P3 Center

RAL Center

INFN Center

FNAL Center

Tier 2

~10 Gbps

Tier2 Center

Tier 3

1-10 Gbps

Institute

Physics data cache

1 to 10 Gbps

Workstations

Tier 4

15 Petabytes per year

Physicist sitting at uw-Madison

UW-Madison Tier-2 center

- UW-Madison is one of the seven Tier-2 data centers in the USA
- It provides 4K CPU cores and about 3 Petabytes of storage space
- Users around the world process data using UW Tier-2 everyday (24/7 and through out the year)
- Grid computing infrastructure at UW-Madison is a vital part of the OSG and LHC

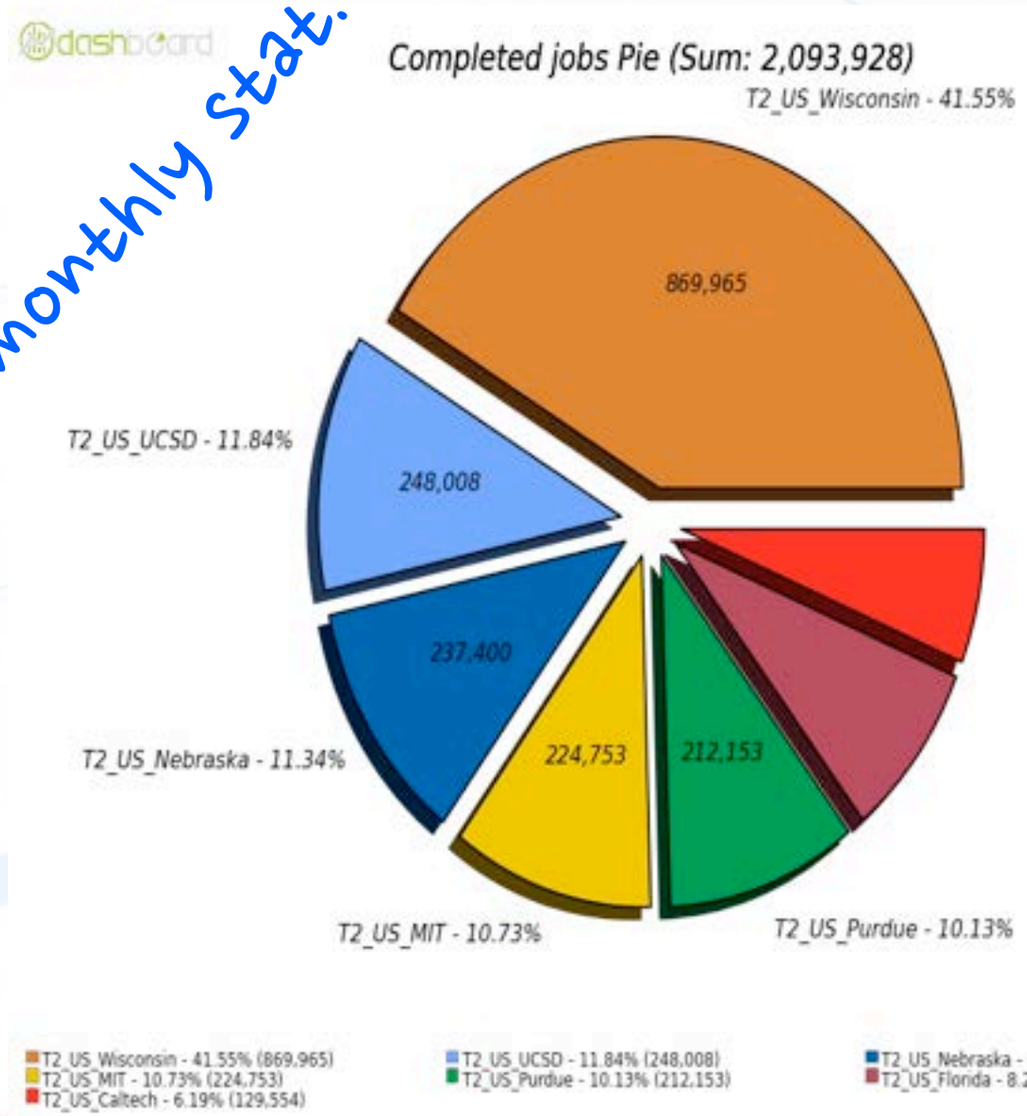
Example of Workflow at UW

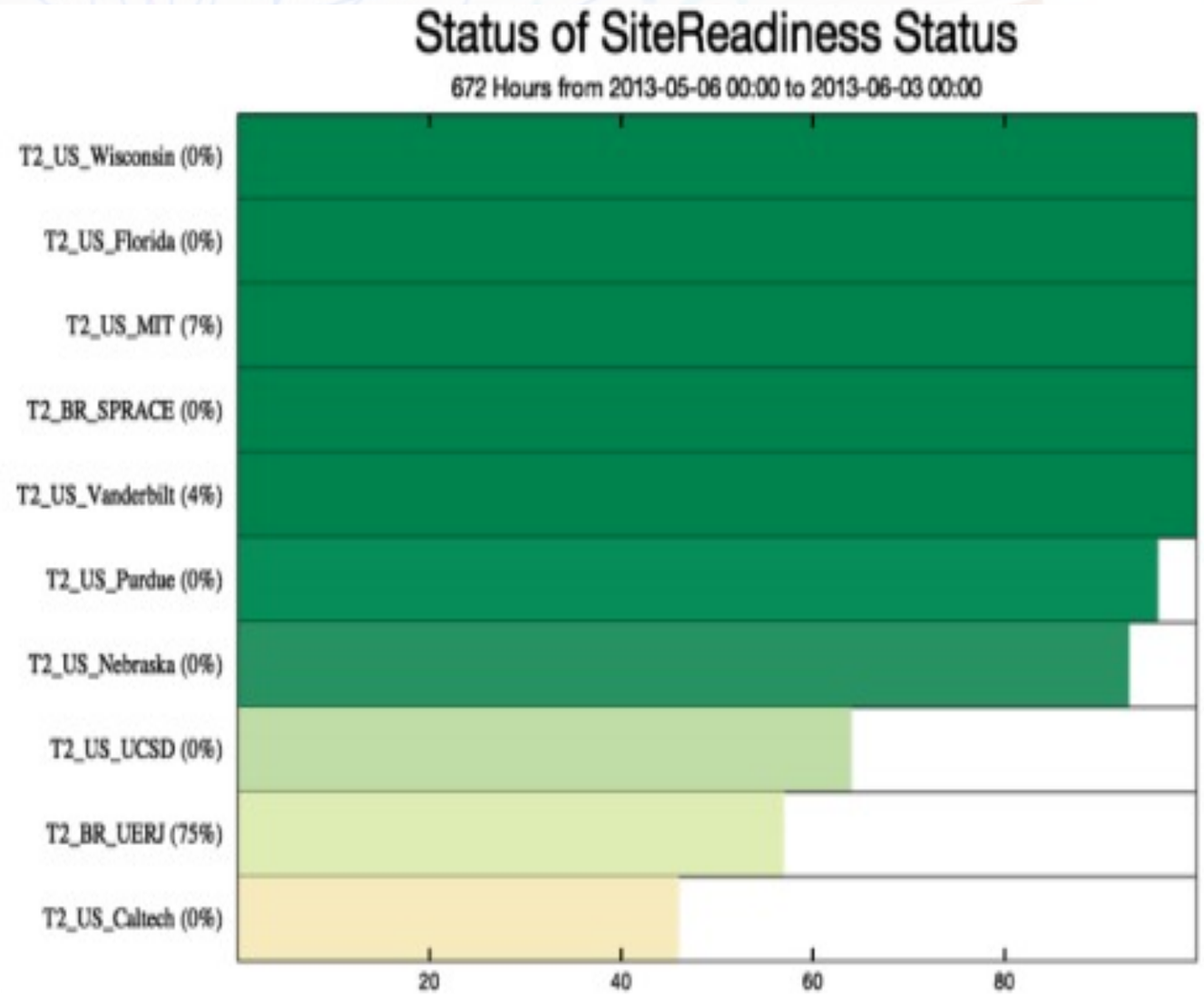
- LHC data stored in the Tier-2 centers are C++ objects (mostly)
- A student (user) writes C++ algorithms to decode data and analyze them
- User sends her algorithms (also known as **jobs**) to machines at Tier-2
- It loops over the data using 4K available CPUs and store their output in the available 3 Petabytes of storage
- It uses the High-Throughput-Computing, **CONDOR** that provides the infrastructure to analyze huge amount of data fast and efficiently
- The jobs use storage data access infrastructures; **XROOTD, HADOOP, HDFS** to access data from the computing cluster
- User's job output can be stored either at the UW-Tier-2 or any other Tiers around the world

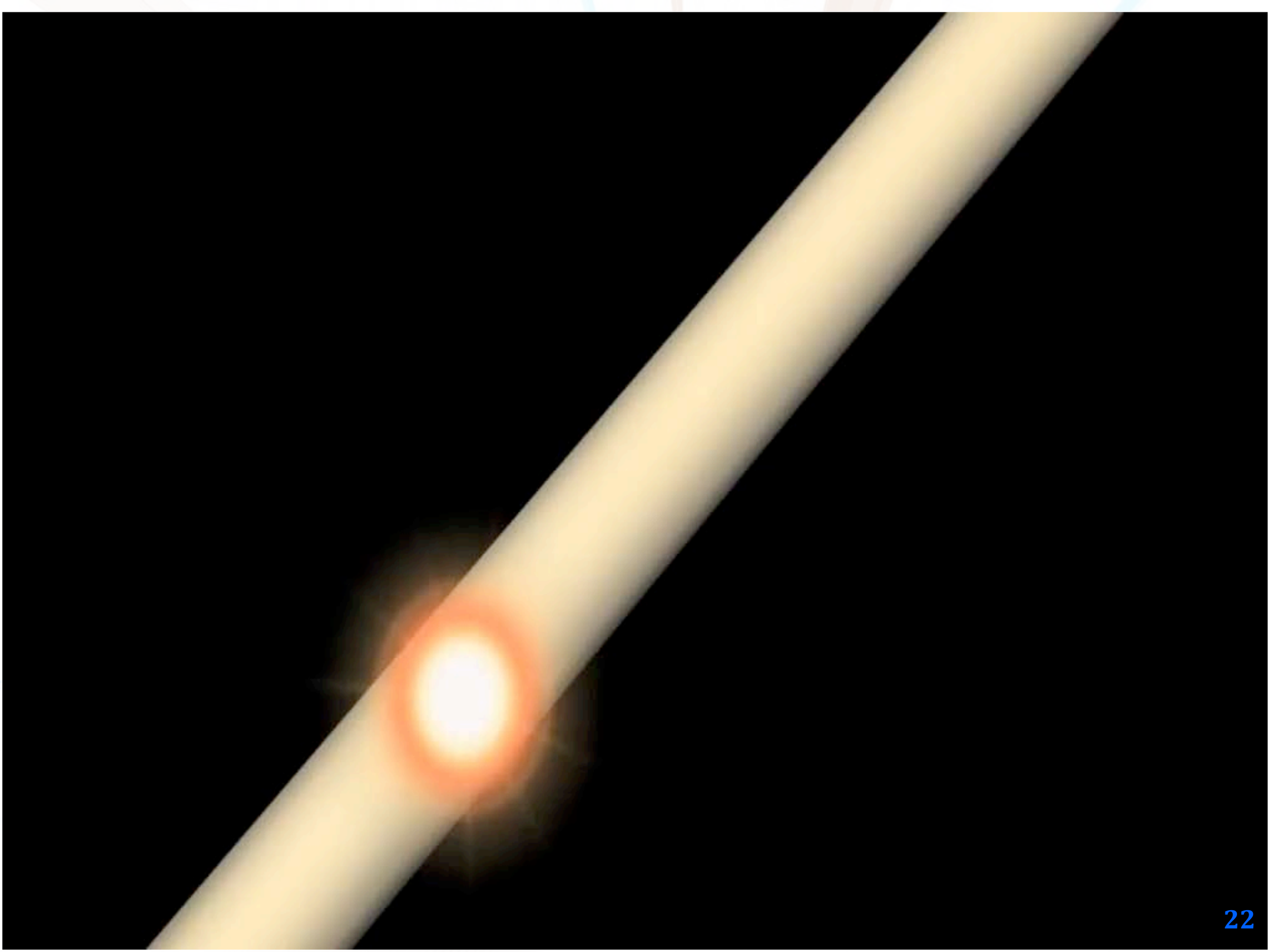
Tier-2 performance

- Every single activity is closely monitored by automated configurations
- Monitoring is one of the important aspects of a data center to solve problems and enhance performance
- UW-Tier-2 has site-admins (physicists and software engineers) who do these tasks, so that users have one less thing to worry about

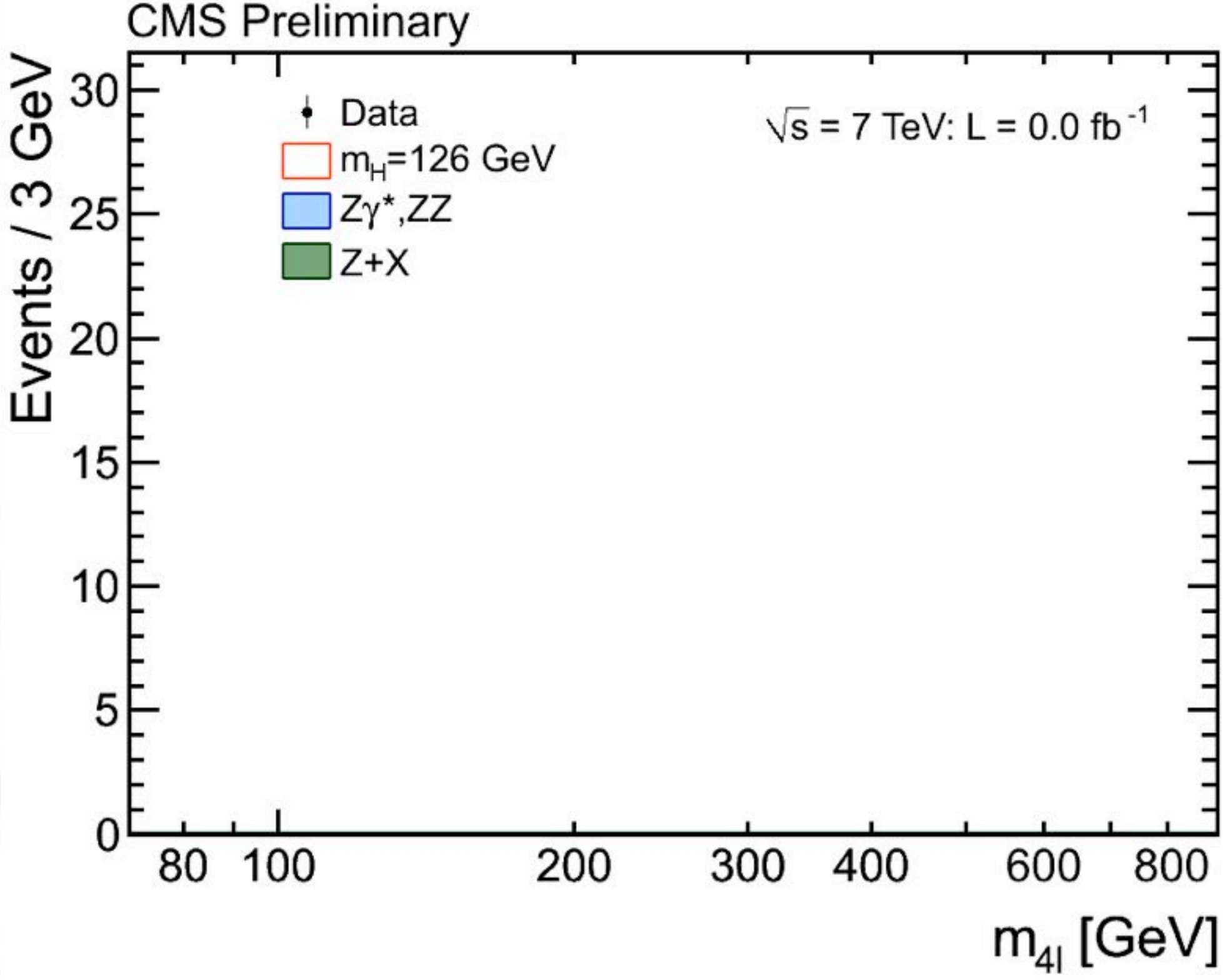
monthly stat.



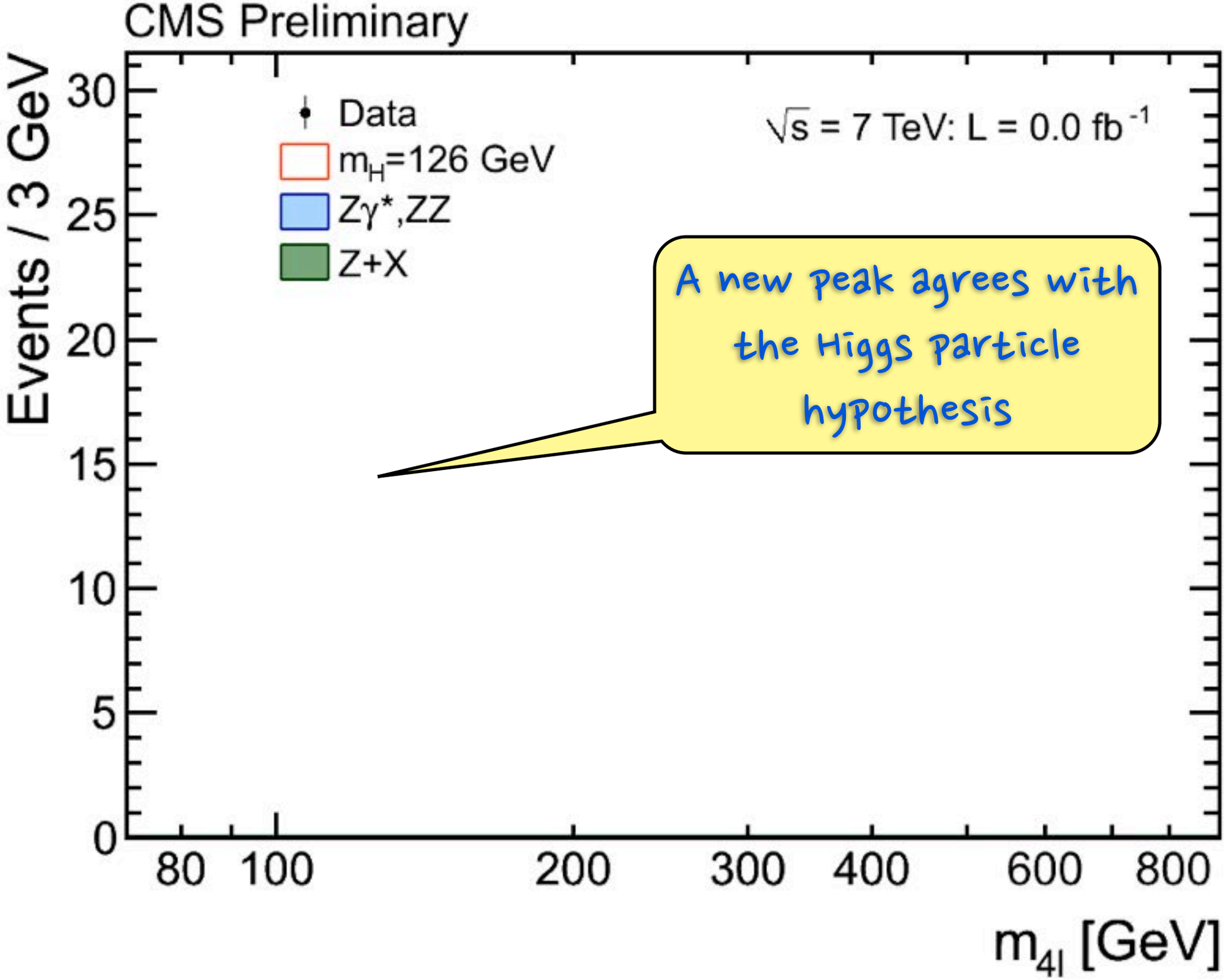




Accumulation of Events



Discovery of Higgs-like particle



SUM IT UP

Grid computing is a inseparable part of the Large Hadron Collider

The Higgs boson discovery at the LHC wouldn't have been possible without the Grid Computing effort

Hopefully many more discoveries when LHC resumes in 2015....