Observation of a Higgs-like Boson at the Large Hadron Collider

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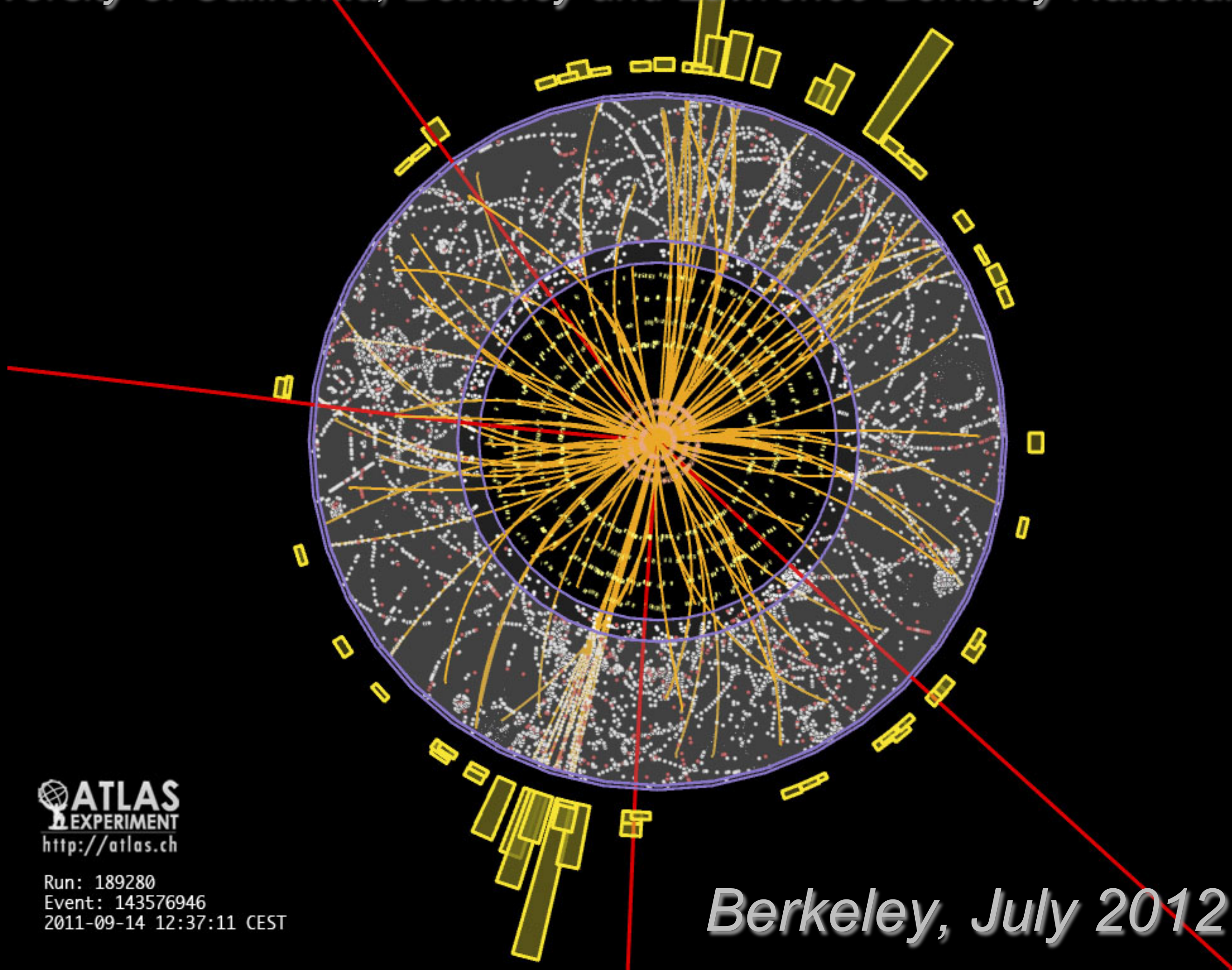
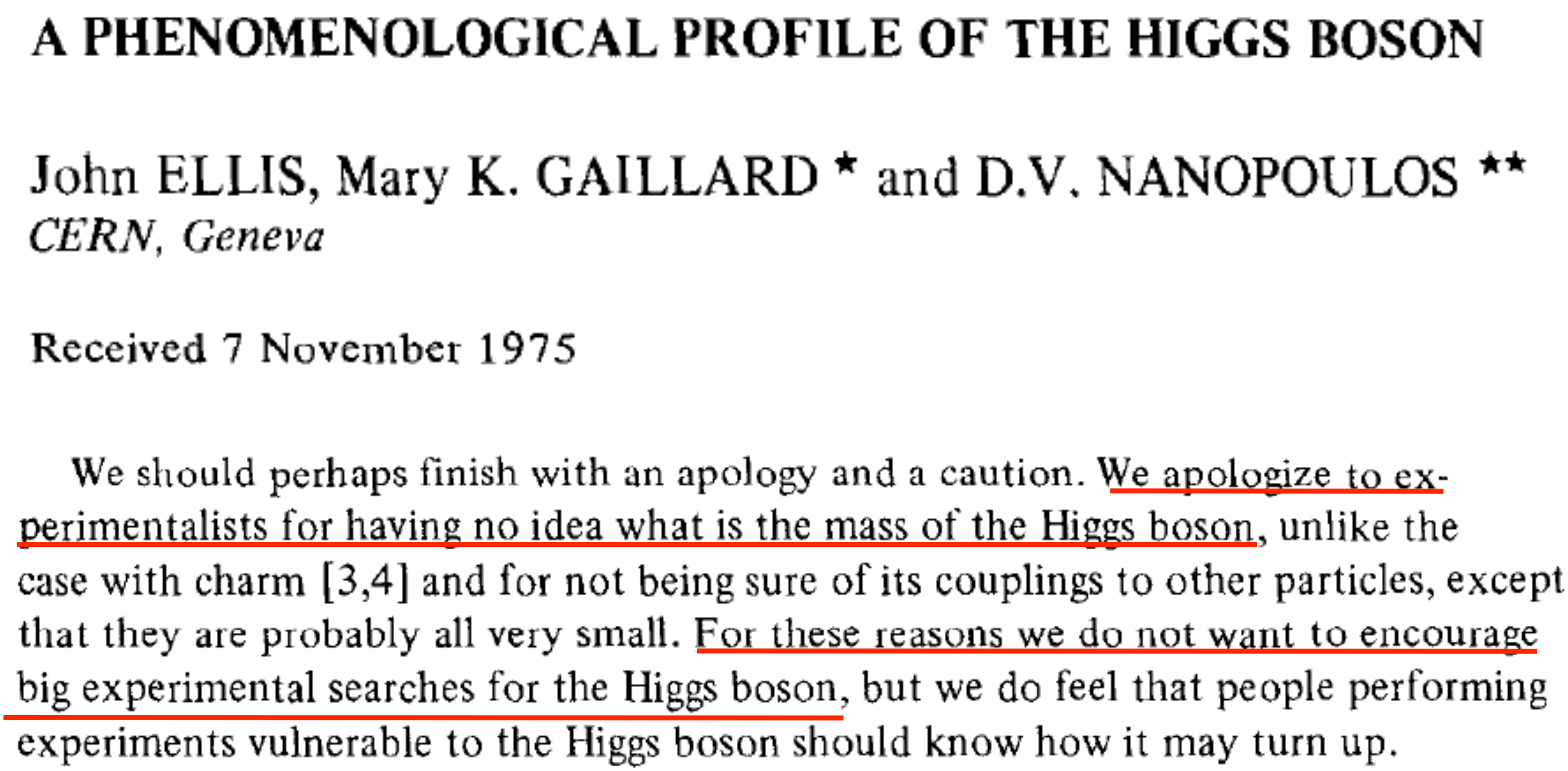


Berkeley, July 2012



A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

John ELLIS, Mary K. GAILLARD * and D.V. NANOPOULOS **
CERN, Geneva

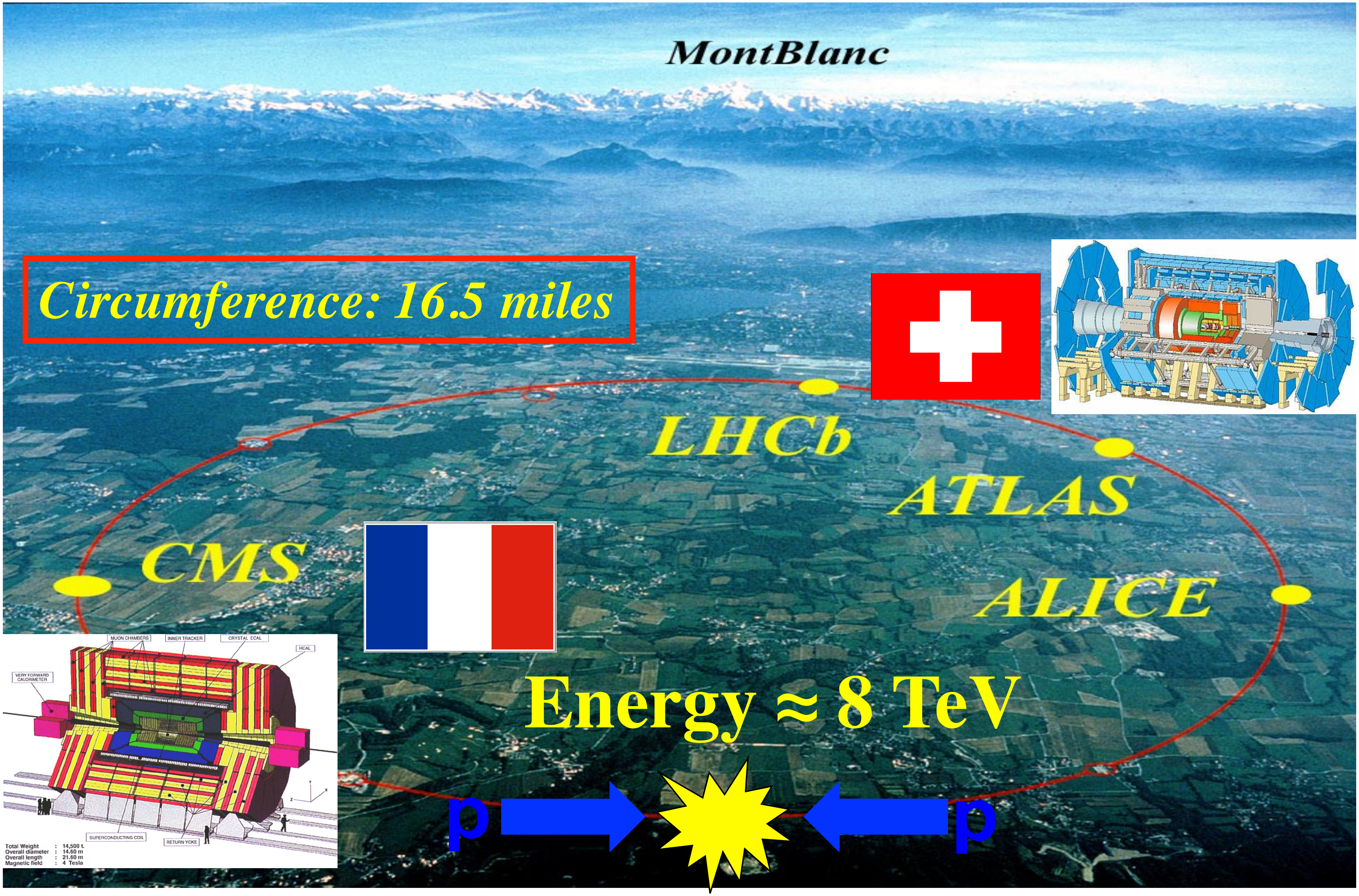
Received 7 November 1975

We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3,4] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

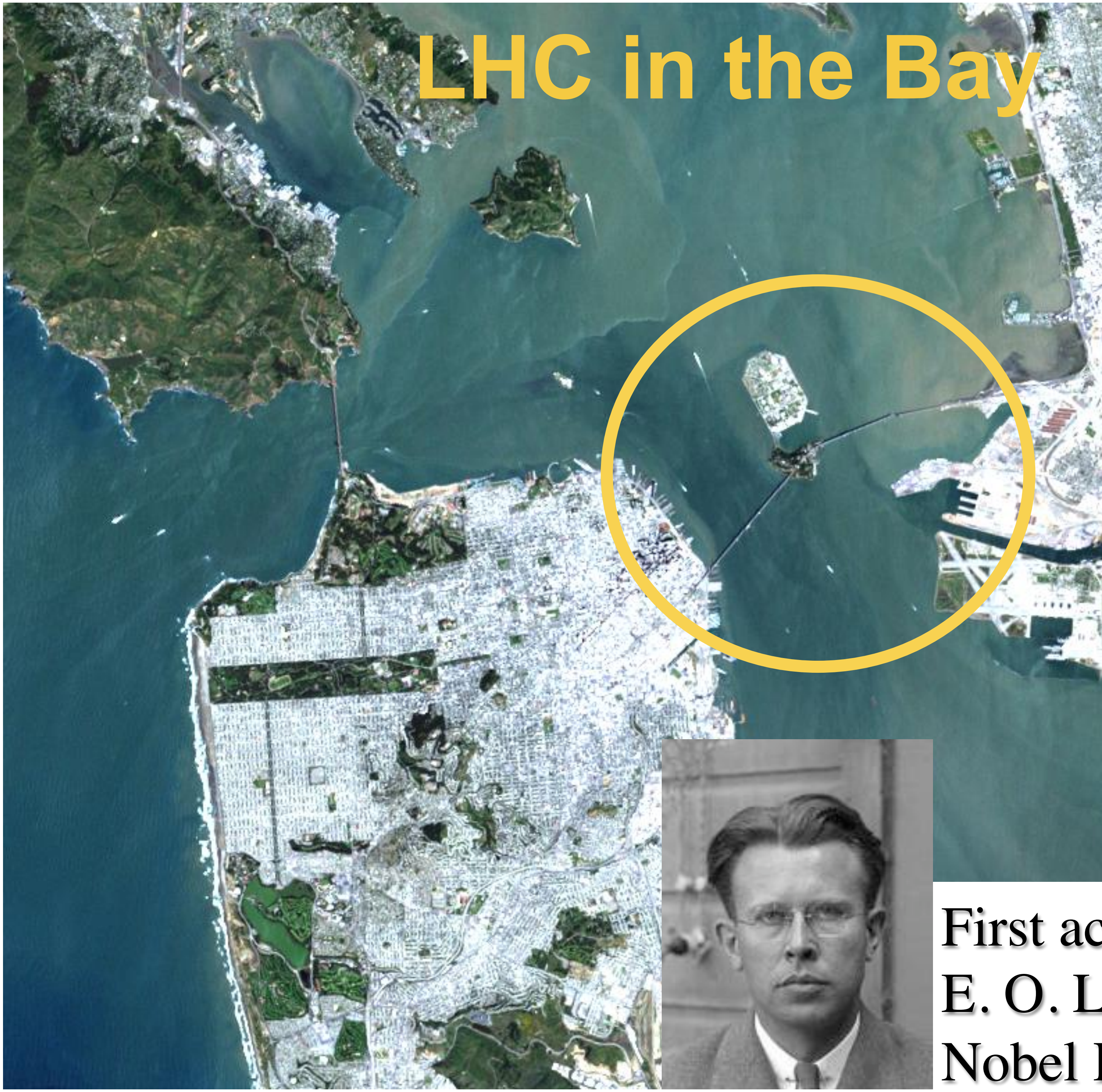
… a lot happened …

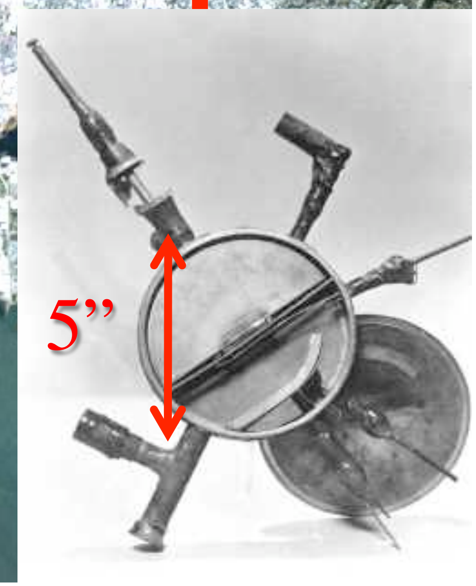
by the mid 90's the Higgs boson was considered the most critical particle to be found experimentally

The Large Hadron Collider (LHC)

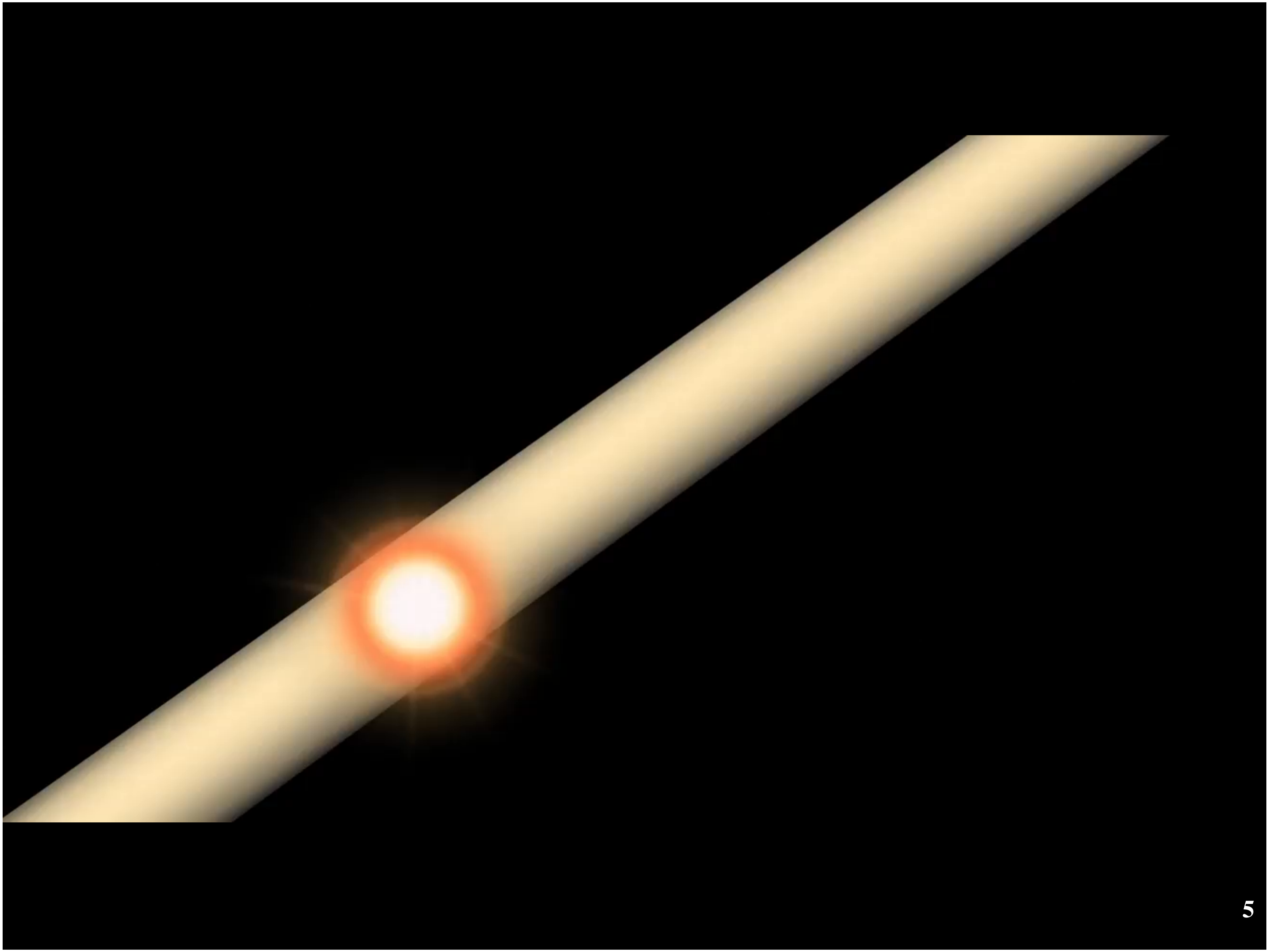


LHC in the Bay

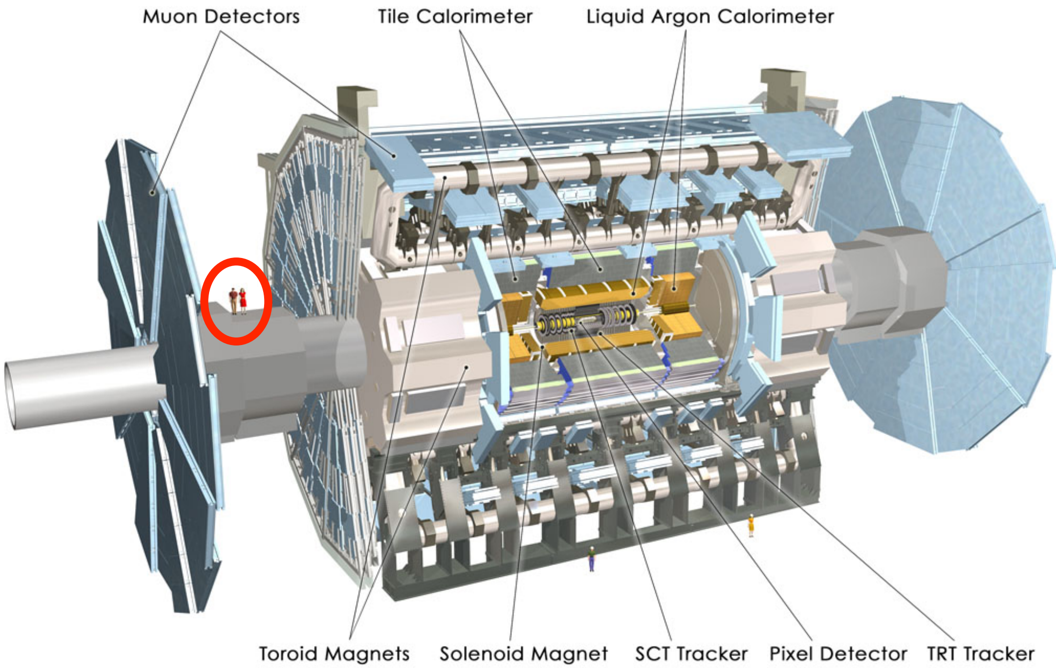


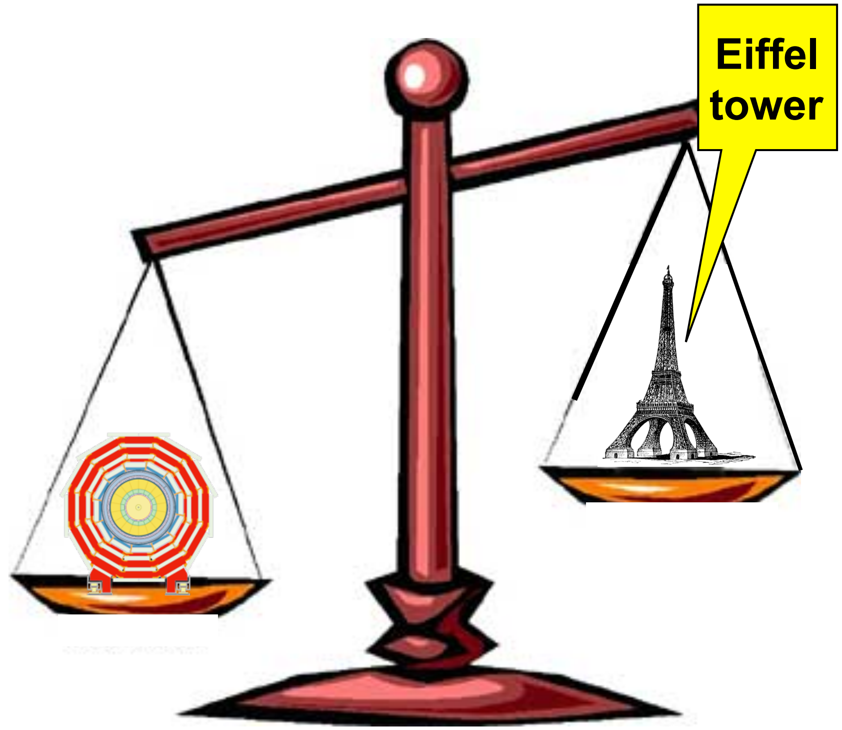


First accelerator ever:
E. O. Lawrence
Nobel Prize 1939



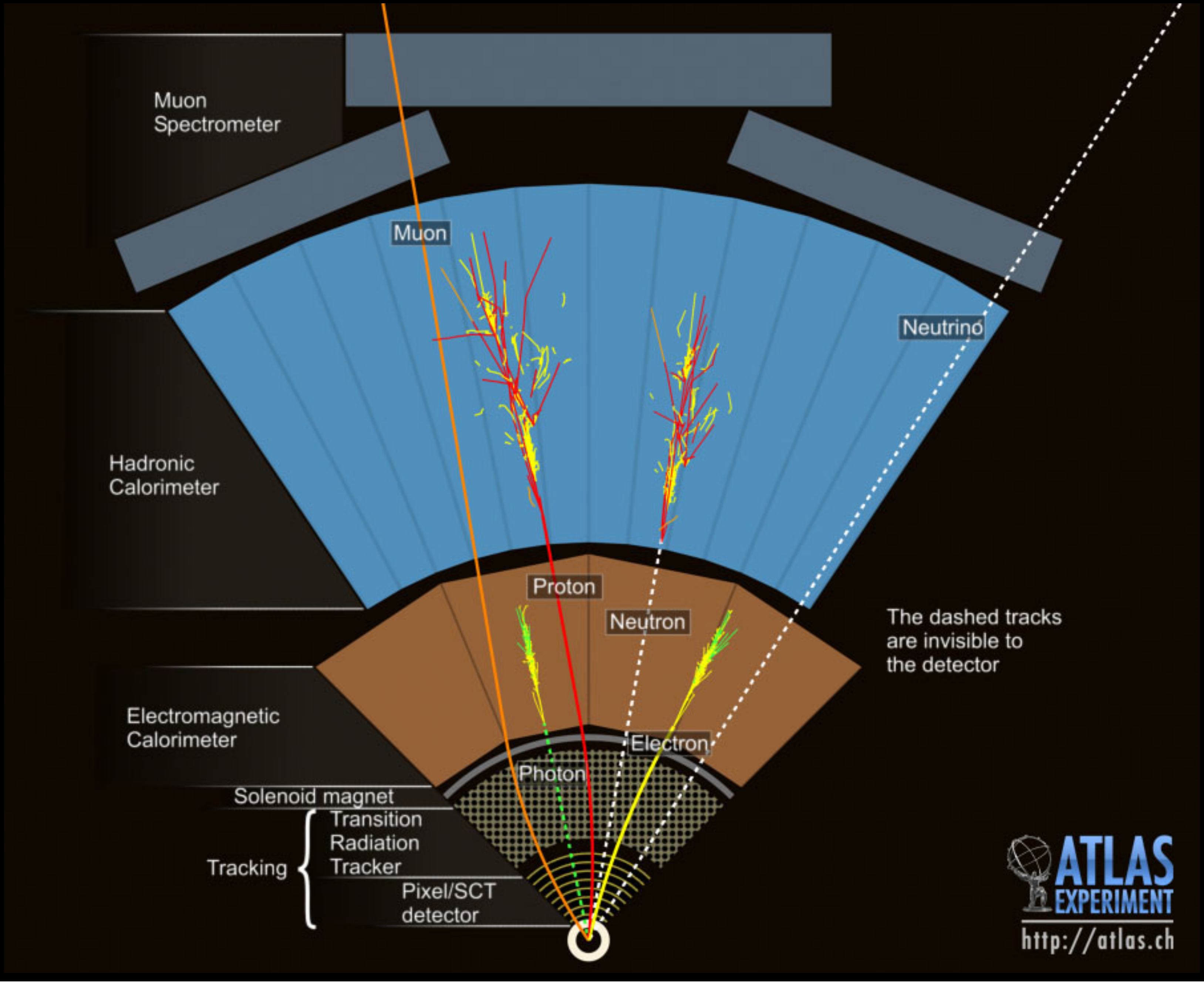
ATLAS and CMS Detectors



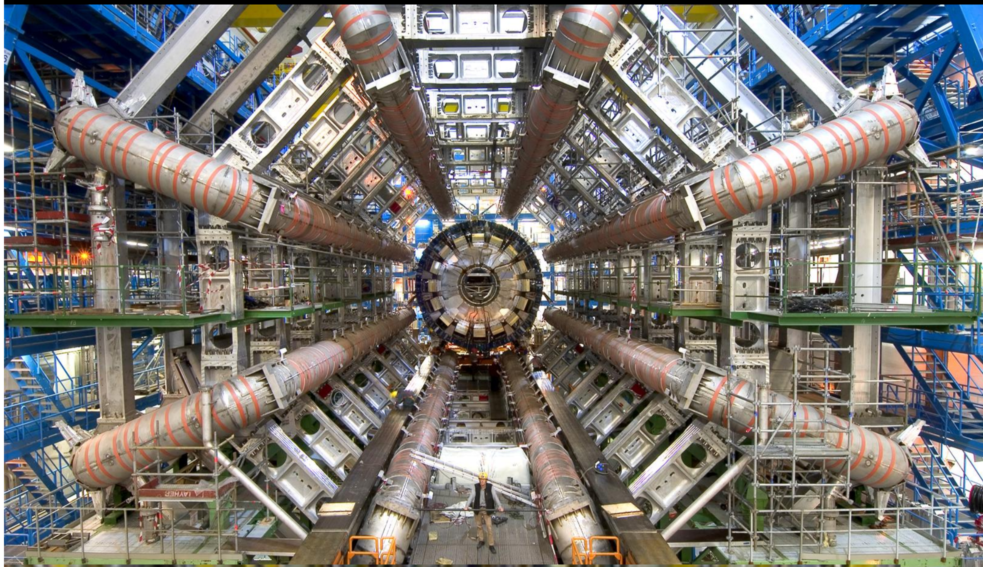


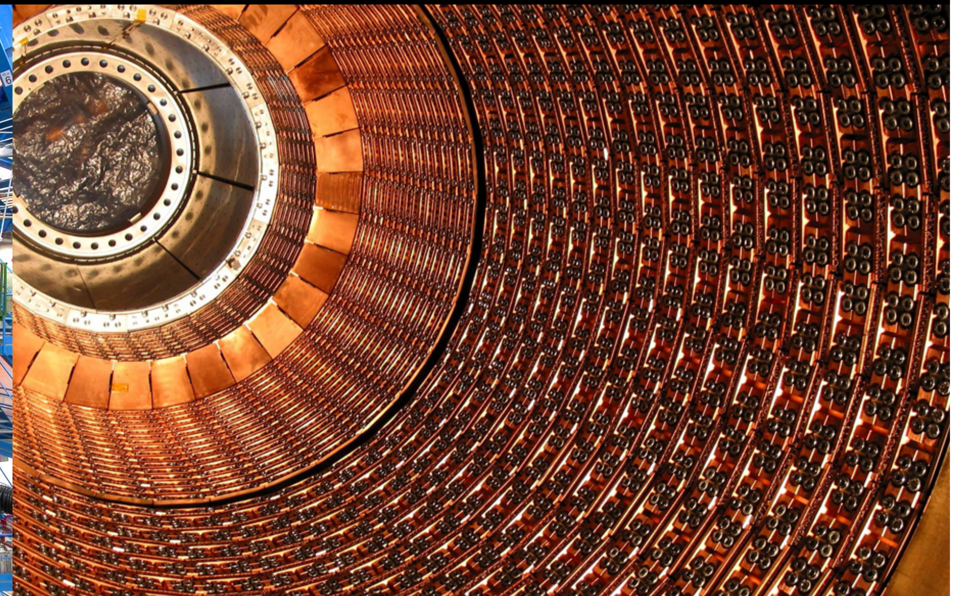
	Weight (tons)	Length (m)	Height (m)
ATLAS	7,000	42	22
CMS	12,500	21	15

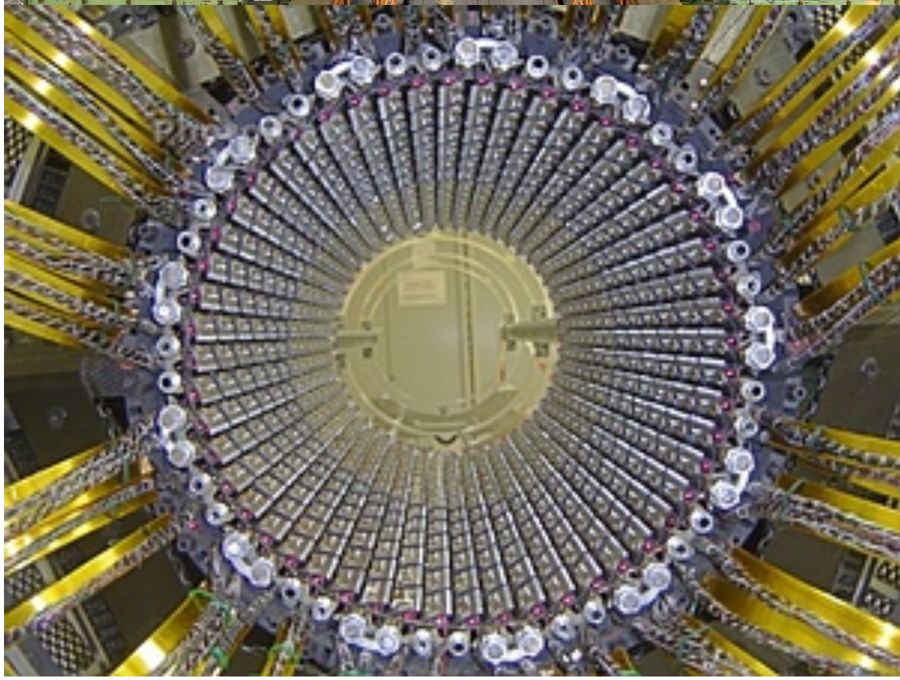
How the Detectors work



How the Detectors look

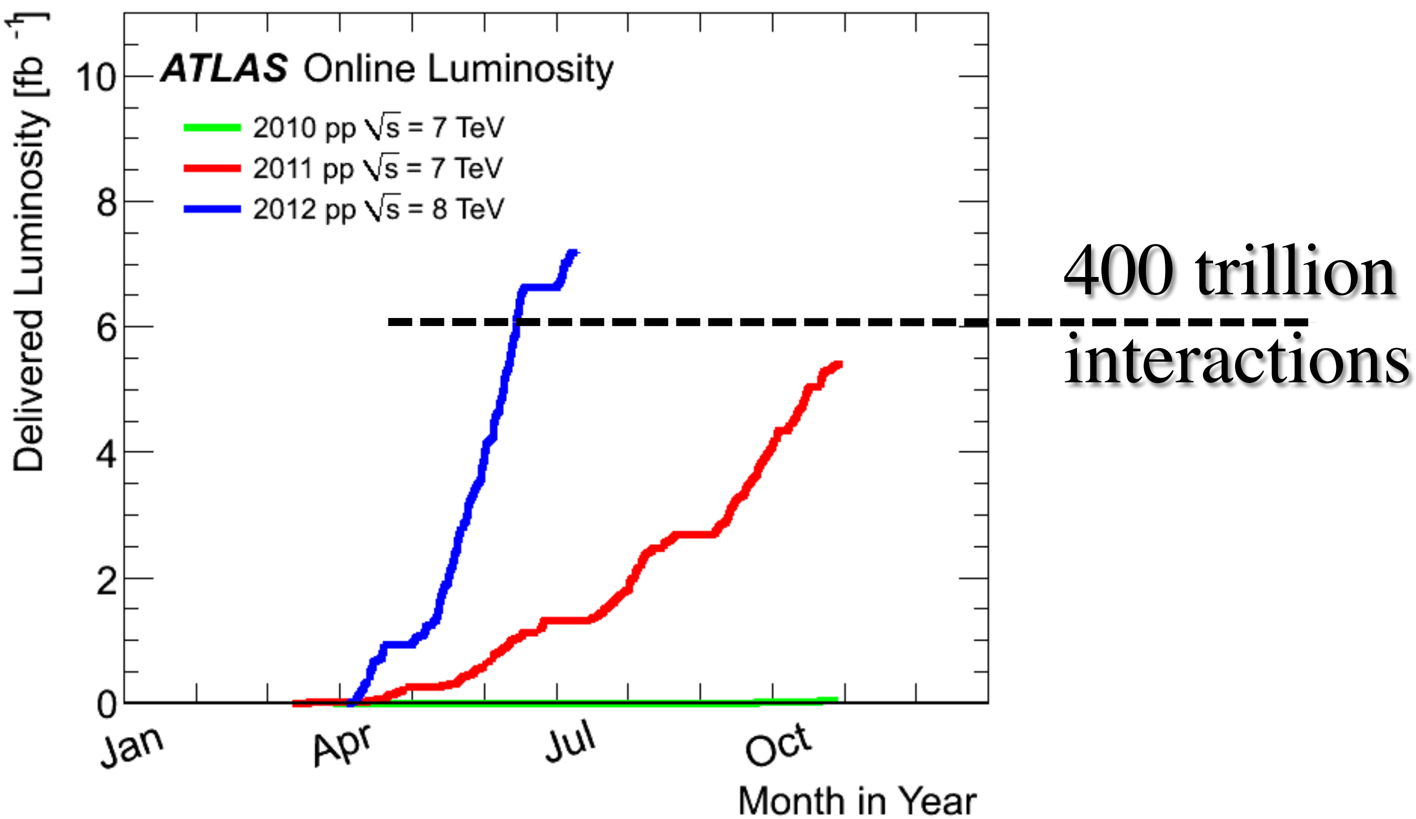






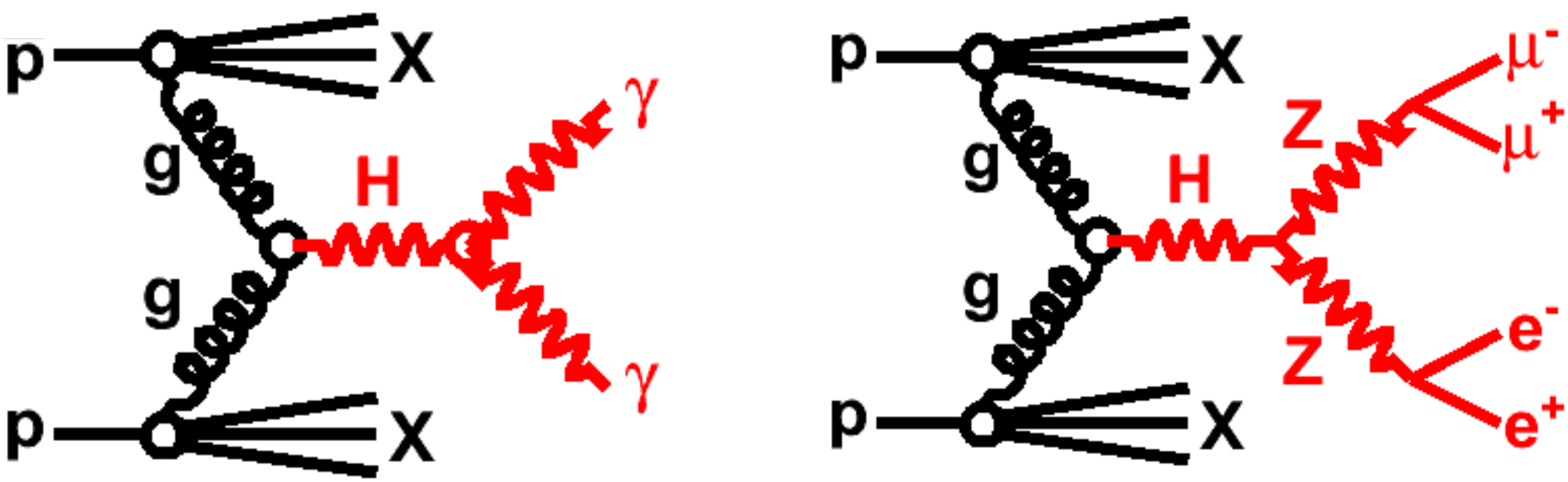
Berkeley's pixel crew 2007

LHC Data Taking: 2010-2012



- **24/7 operation typically from March – October each year**
- **800 trillion proton-proton interaction have taken place in LHC so far (2011 + 2012)**
  - **0.5 billion interactions per second**
  - **about 200 of them are expected to be observable Higgs events**

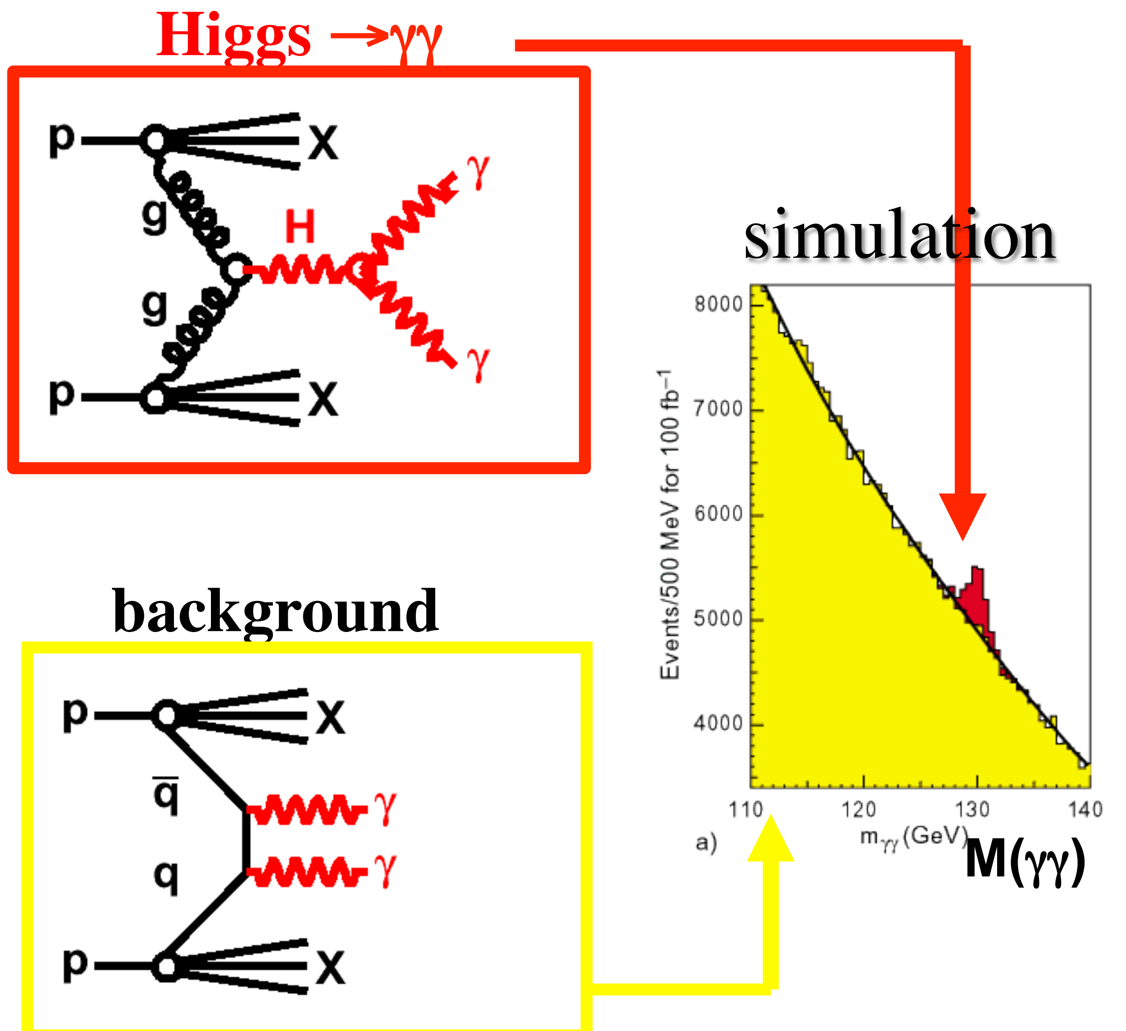
Production and Decay of a 126 GeV Higgs Boson



- Higgs boson is unstable and decays very quickly
  - 0.2% decay into **two photons**
  - 0.014% decay to **4 electrons or muons**
  - 99.8% of decays are harder to observe
    - also analyzed and important but will not explain here

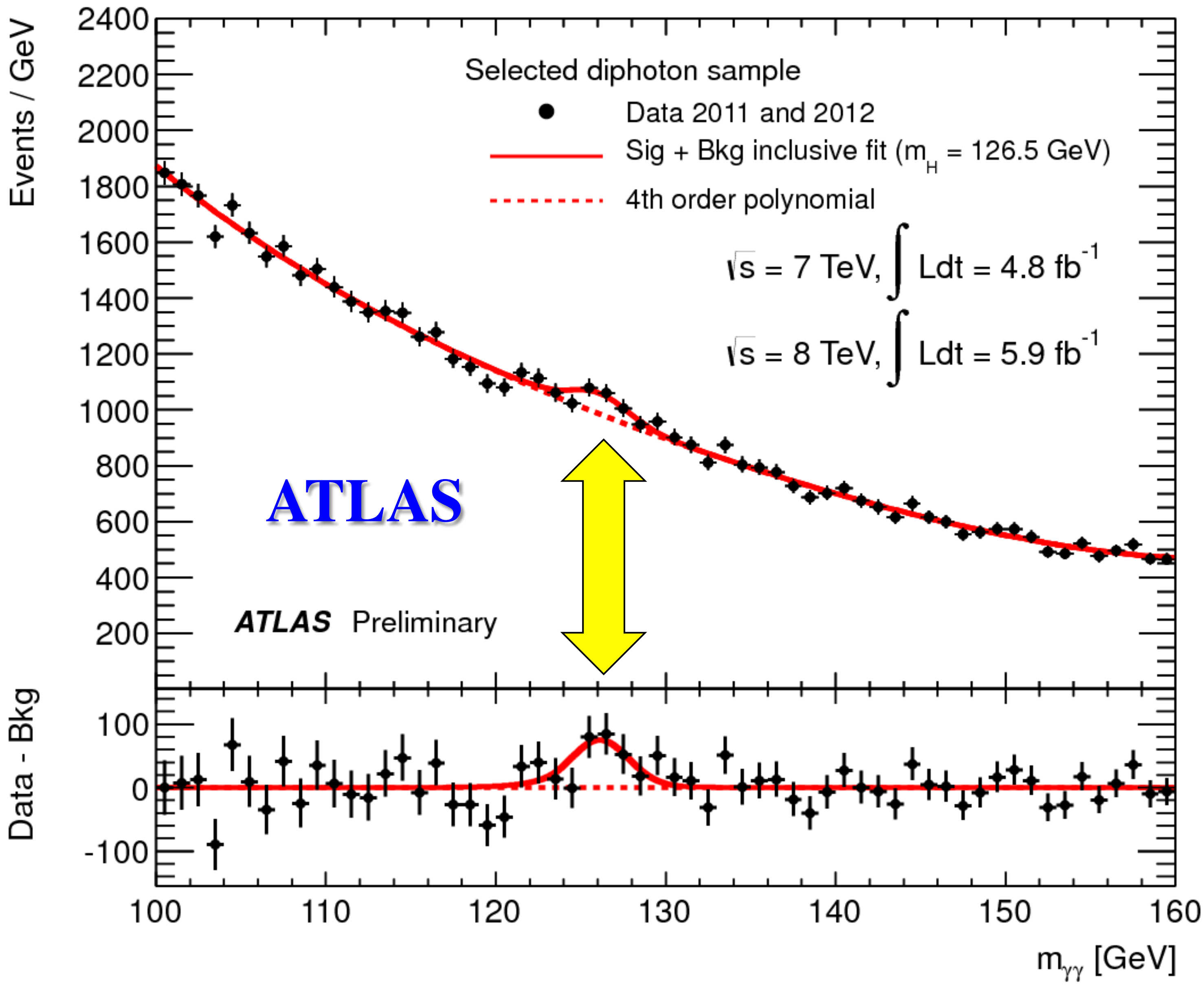
Finding the Higgs Boson (with photons)

- Higgs boson decays to two high energy photons
  - Higgs mass determined from energies and angles of photons
- Background process looks identical
  - 50 times larger rate

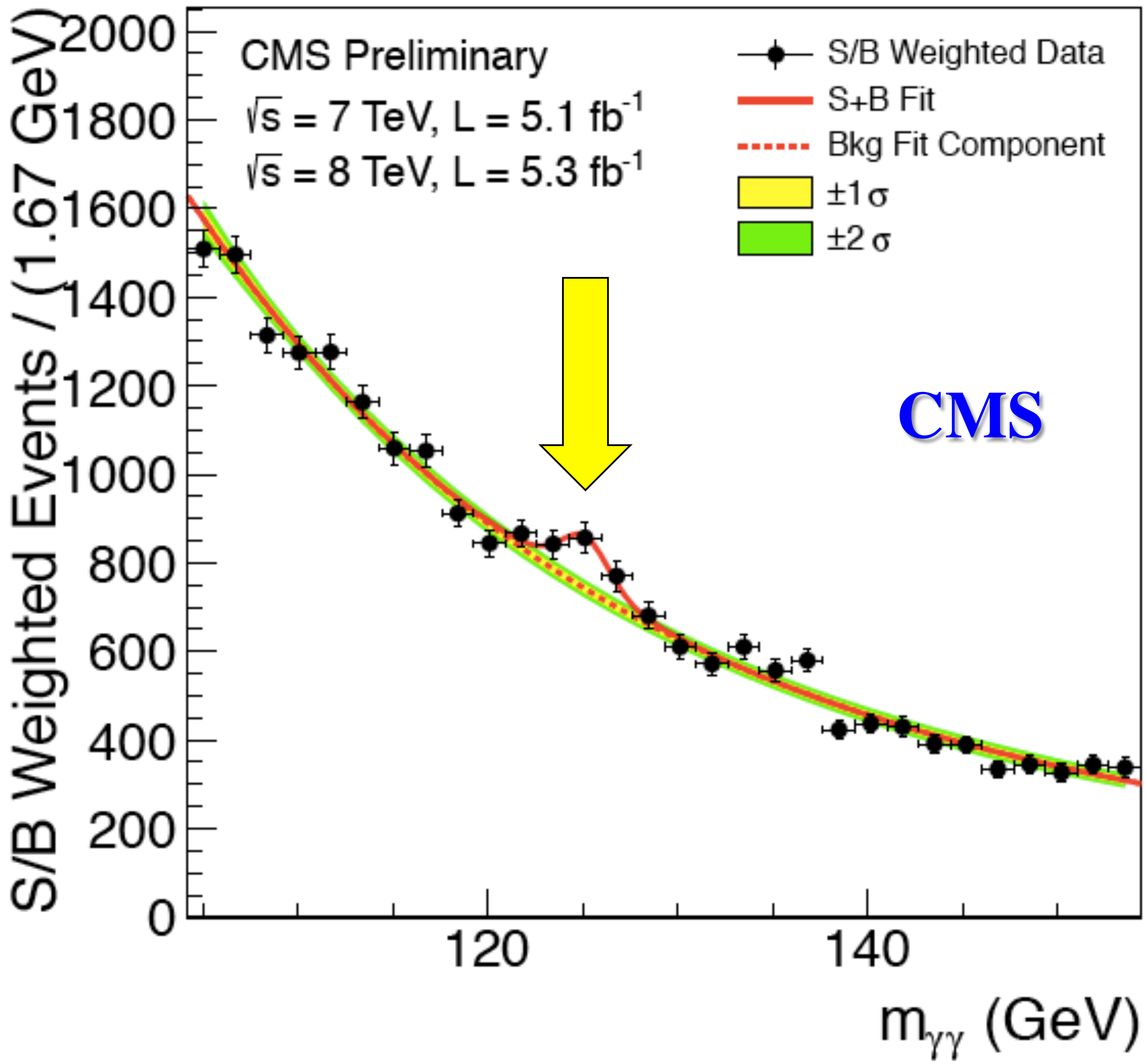


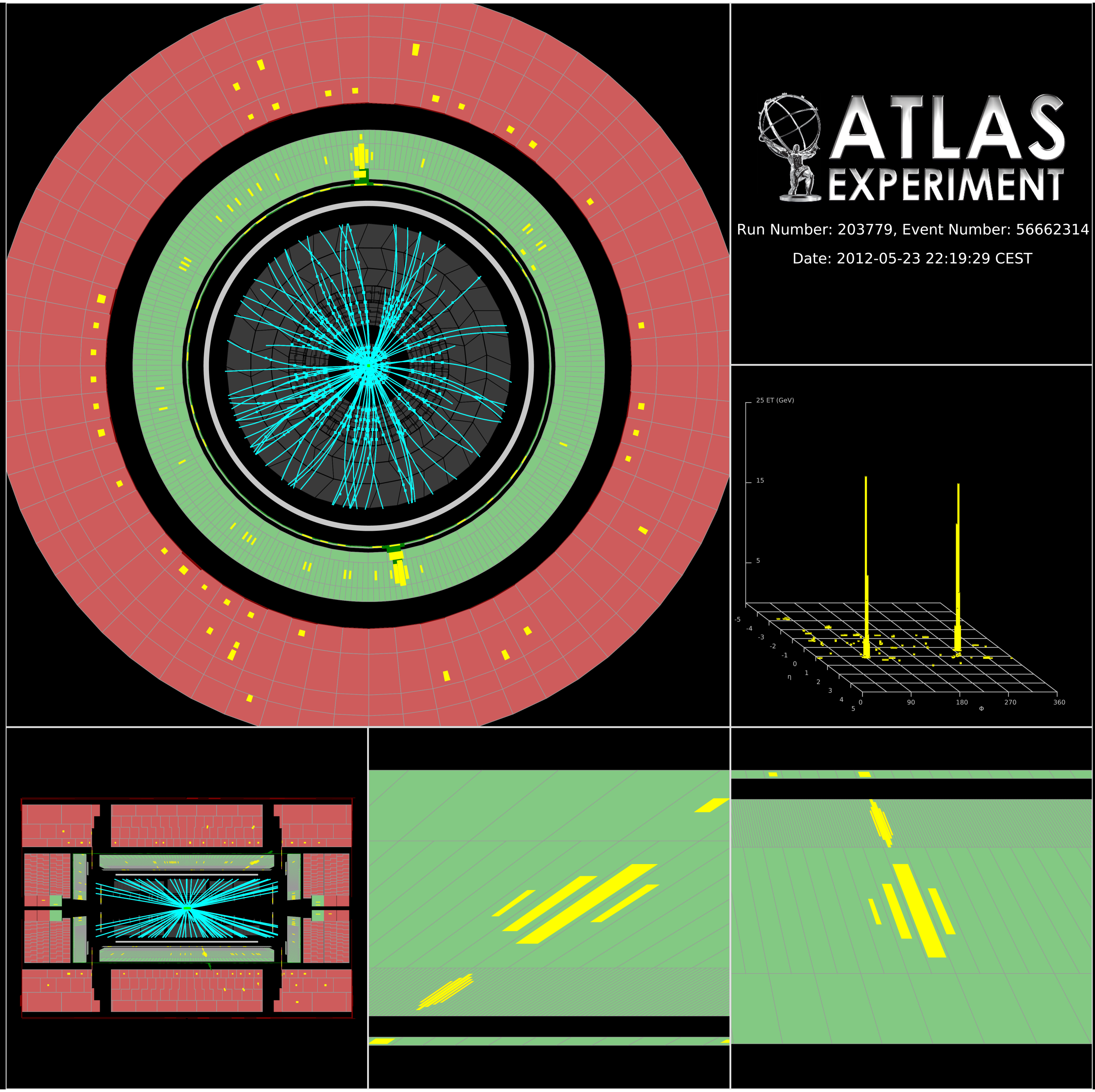
$$M_{Higgs} \approx M(\gamma\gamma) = 2\, E_1\, E_2\, (1-\cos\alpha)$$

ATLAS Diphoton Mass Distribution

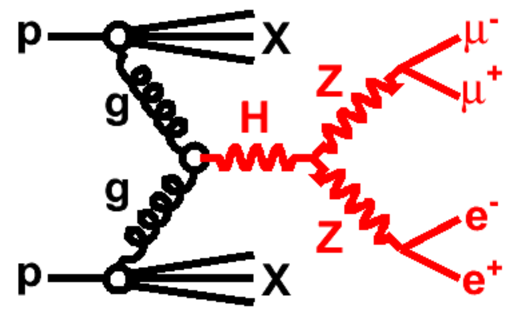


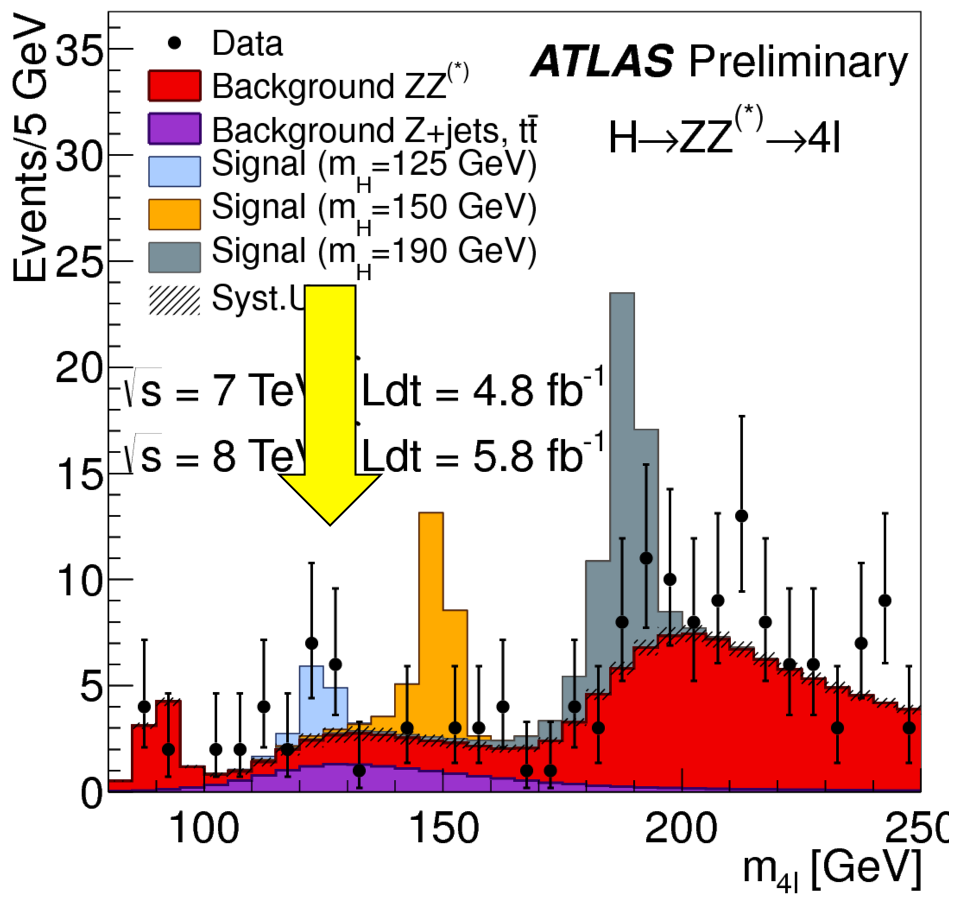
CMS Diphoton Mass Distribution

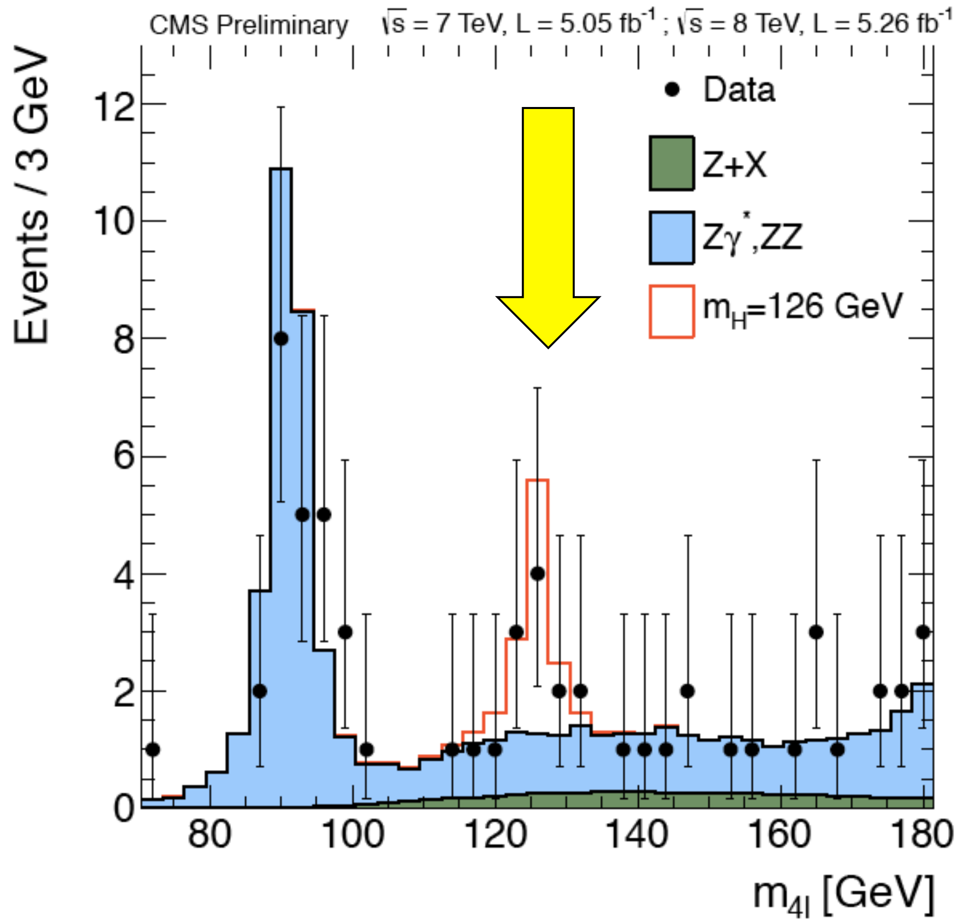


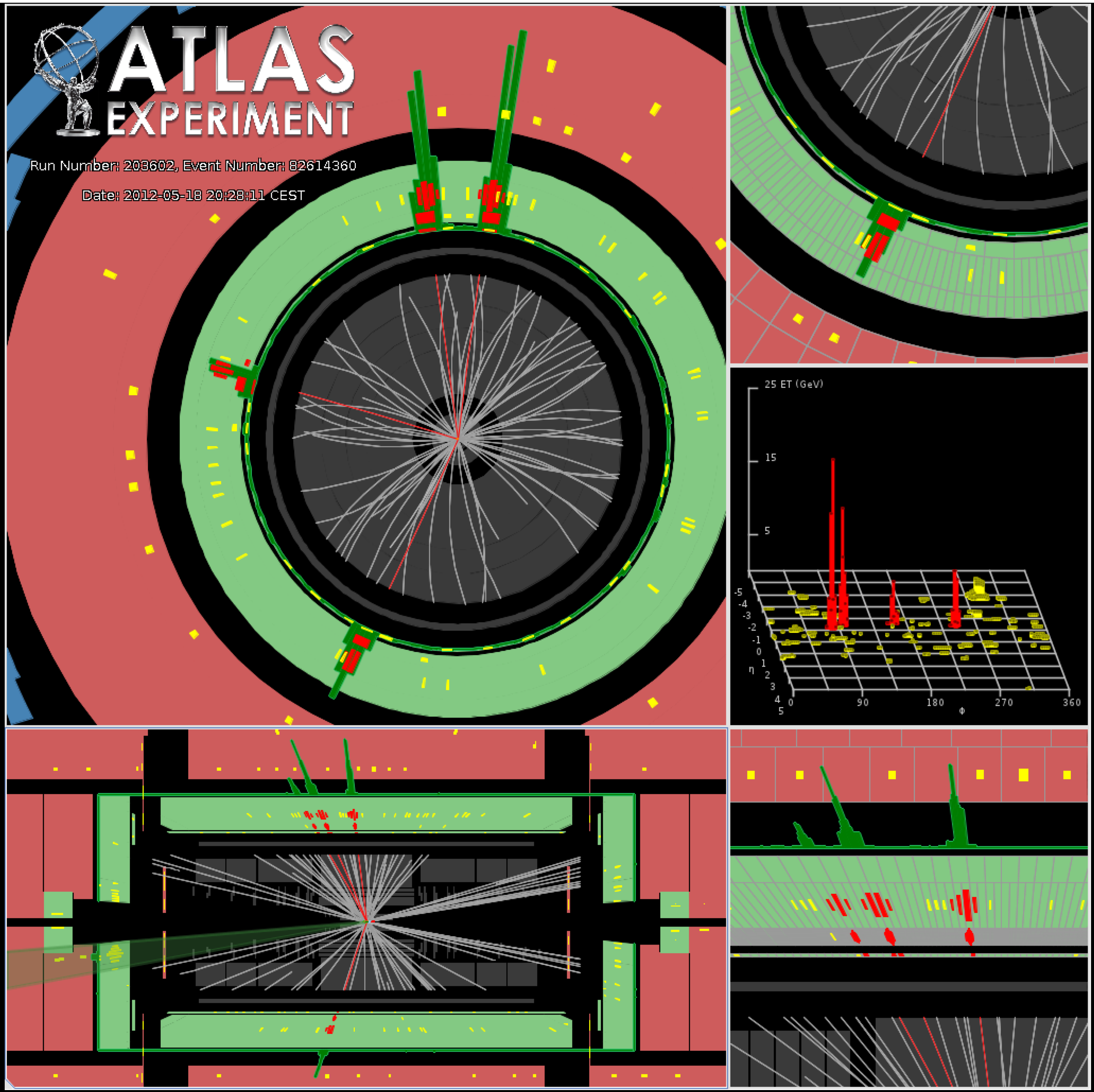

ATLAS EXPERIMENT
Run Number: 203779, Event Number: 56662314
Date: 2012-05-23 22:19:29 CEST
25 ET (GeV)
15
5
-5
-4
-3
-2
-1
0
1
2
3
4
5
η
0
90
180
270
360
Φ

Higgs boson decaying to two Z bosons

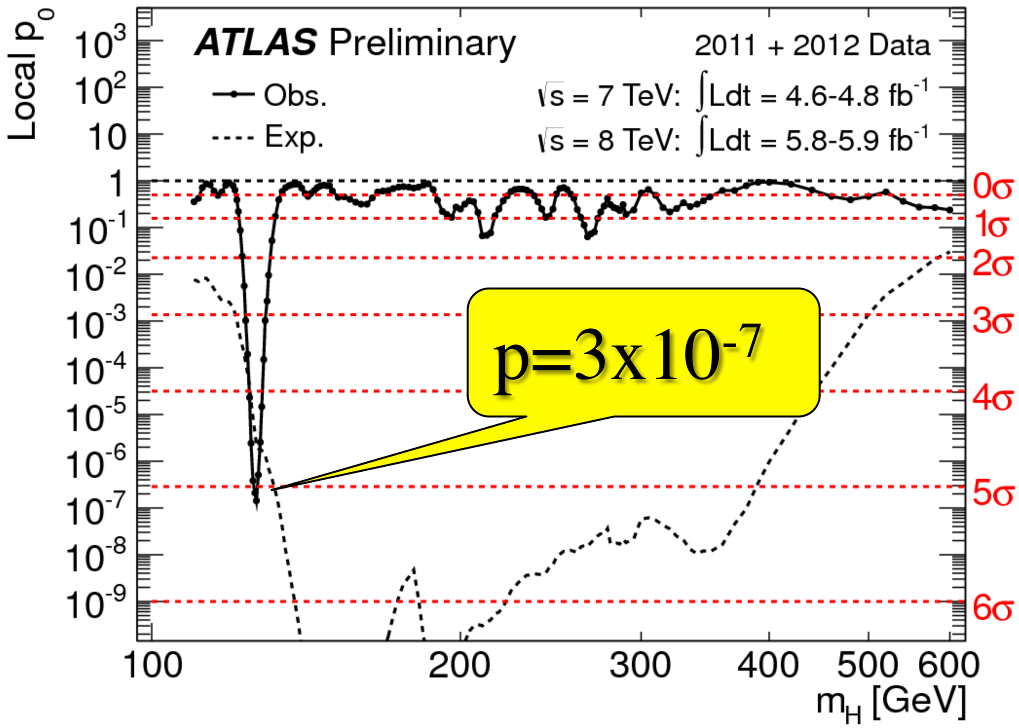







ATLAS
EXPERIMENT
Run Number: 203602, Event Number: 82614360
Date: 2012-05-18 20:28:11 CEST
25 ET (GeV)
15
5
η
φ
0
90
180
270
360

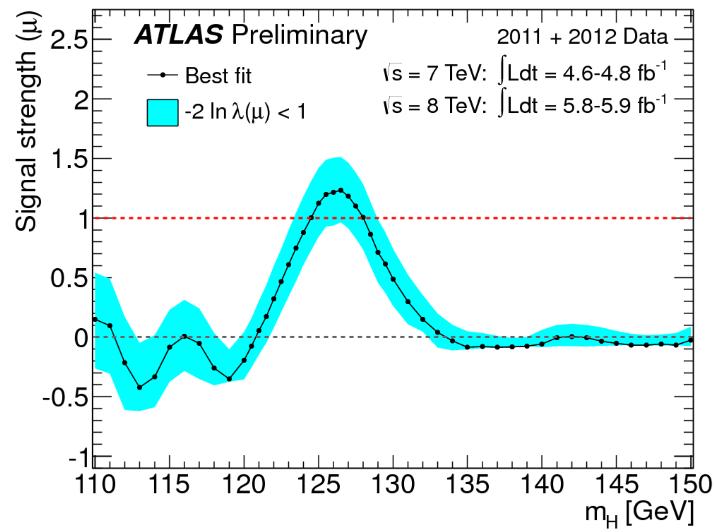
Probability of statistical fluctuation



- Only 1 in 3.5 million experiments would see this "by chance" without new particle being there
  - less than throwing 8 dice and getting 8 sixes

Discovery of a New Particle!

- Properties similar to those of Higgs boson
  - It is definitely a boson with an even spin (0, 2, …)
  - Signal strength consistent with expectation



  - An era of measurements now starts that will show
    - if this particle is a Higgs boson
    - If its properties agree with simplest model as proposed in 1964

Conclusions

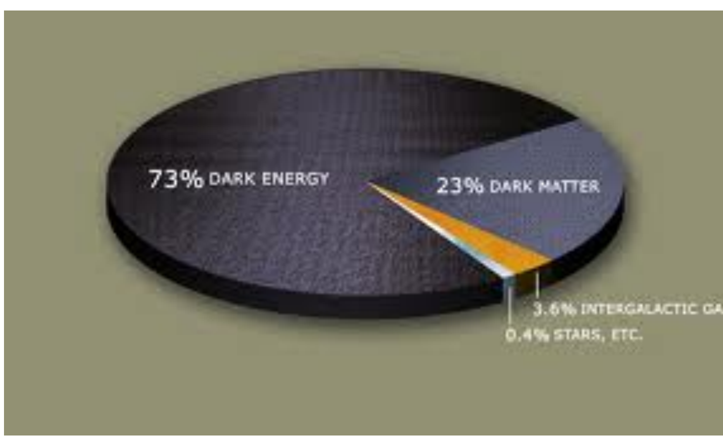
Fabiola Gianotti, ATLAS spokesperson

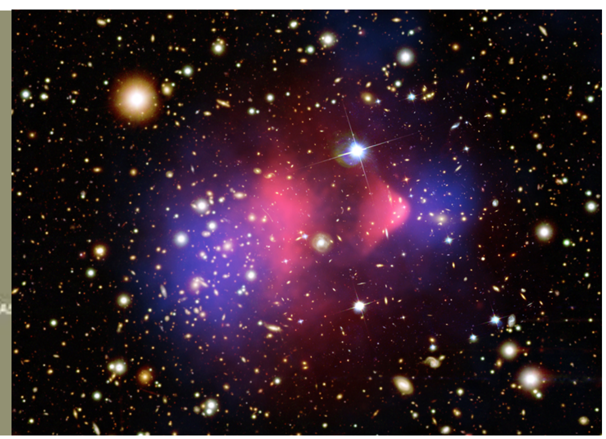
Peter Higgs

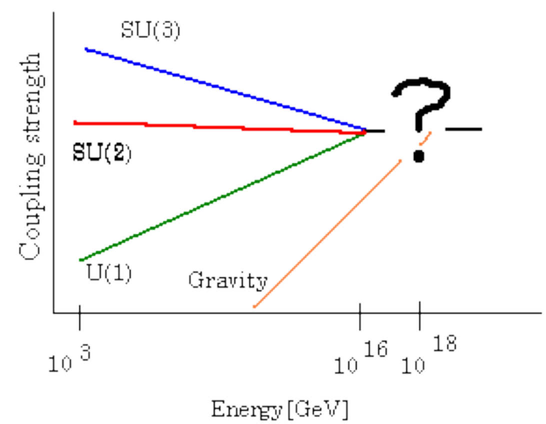
- **New particle observed consistent with Higgs boson**
  - Mass is about 126 x proton mass
  - Observed independently in two experiments
  - significance of observation is 1 / 3.5 million

Outlook

- **It may or may not be the Higgs boson**
  - Several theories suggest that it may deviate in detail from the most simple version proposed in 1964
    - E.g. in some theories there are 5 Higgs bosons
  - Measurement in near future will tell us
- **Many puzzles remain in Standard Model**
  - Many other analyses ongoing in parallel at LHC
    - More than 300 LHC papers in 2.5 years
  - Maybe this is the first of many discoveries!!







More Information

- Information, explanations, movies, images …
  - http://public.web.cern.ch
  - http://atlas.ch
  - http://cmsinfo.cern.ch/outreach

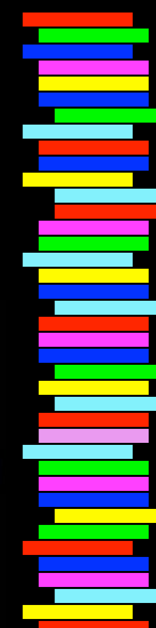
Backup Slides

LHC milestones

- March 2007: last dipole magnet installed
- September 2008: first beam but major accident prevents LHC startup in 2008
- Nov. 2009: first collisions at injection energy (900 GeV)
- March 2010: first collisions at 7 TeV
  - 3.5 time higher energy than Tevatron
- End of 2010: L=40 pb^{-1} of data recorded
  - Sufficient to make many tests of Standard Model and to test supersymmetry beyond Tevatron
  - Not enough to test the Higgs
- End of 2011: L=5 fb^{-1} of data recorded
  - nearly 100 times more than 2010
  - Sufficient to probe Higgs boson over much of the mass range

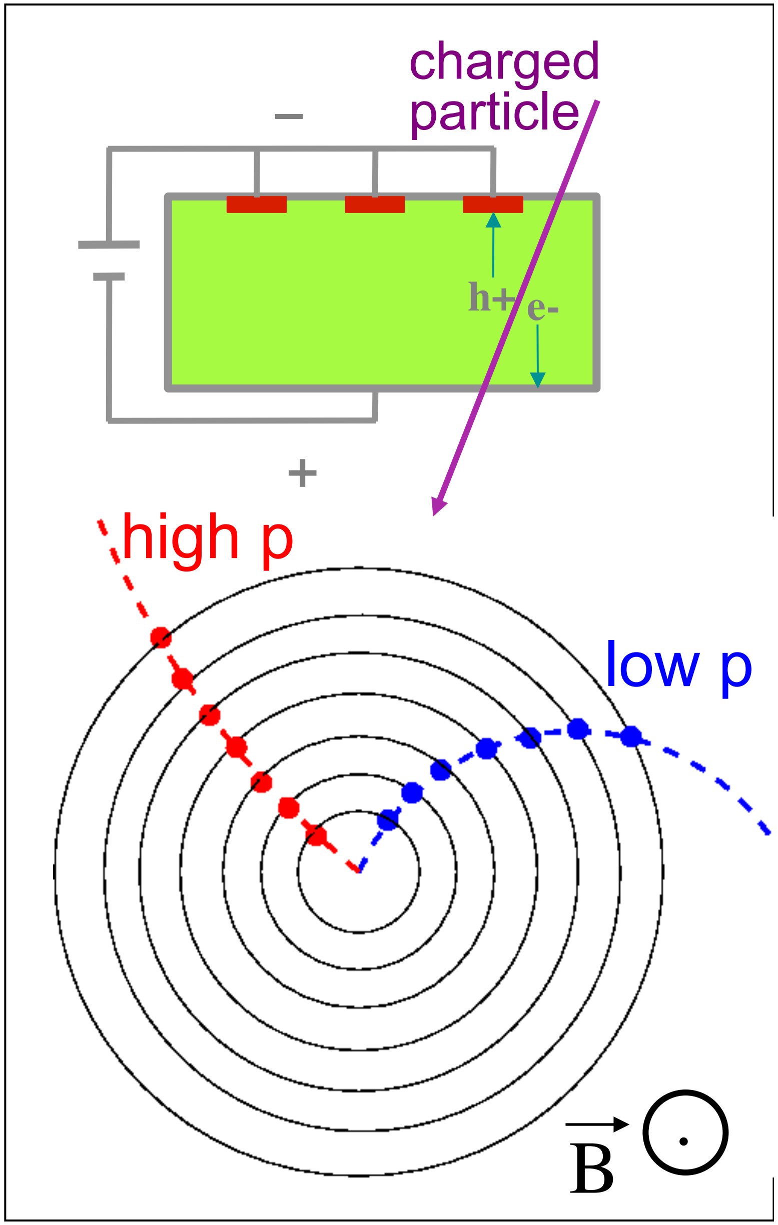
Enormous Data Volumes

- **Pushing the computing limits!**
  - 1 second of LHC data: 1000 GigaBytes
    - **10,000 sets of the Encyclopedia Britannica**
  - 1 year of of LHC data: 10,000,000 GB
    - **25 km tower of CD's (~2 x earth diameter)**
  - 10 years of LHC data:
    - **All the words spoken by humankind since its appearance on earth**
- **Solution: the "Grid"**
  - Global distribution of CPU power
    - More than 100 CPU farms worldwide share computing power
    - Arranged in clouds

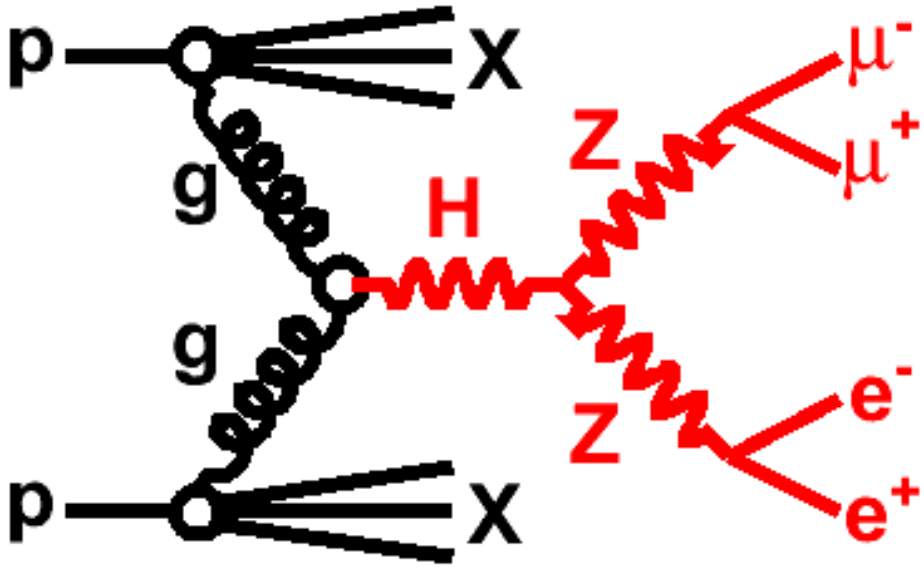


Silicon Tracking Detectors

- Charged particle traverses gas or silicon
  - Sets free electrons
    - Measured charge gets collected at electrodes
  - Thus we find out position of particle
    - Resolution typically 15 μm
- Detector placed inside magnetic field:
  - Lorentz force: $\mathbf{F}_L \sim q\,\mathbf{v} \times \mathbf{B}$
- Hits along trajectory are fit to form a track
  - deviation from straight line proportional to momentum (**p~v**)
  - Direction of curvature tells us the electric charge



Higgs decaying to two Z bosons



Proceedings of LHC Workshop (Aachen, 1990): H→ 4l signals m_H=130, 150, 170 GeV
$\sqrt{s}$ = 16 TeV, 100 fb^{-1}

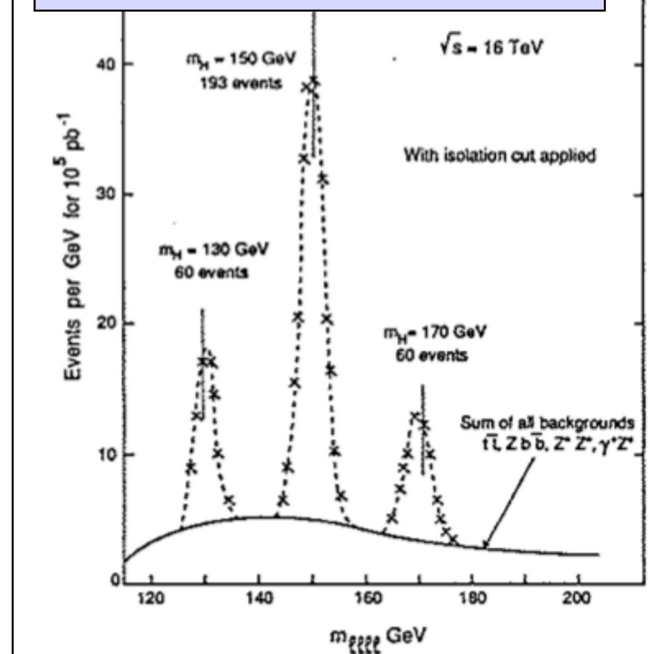
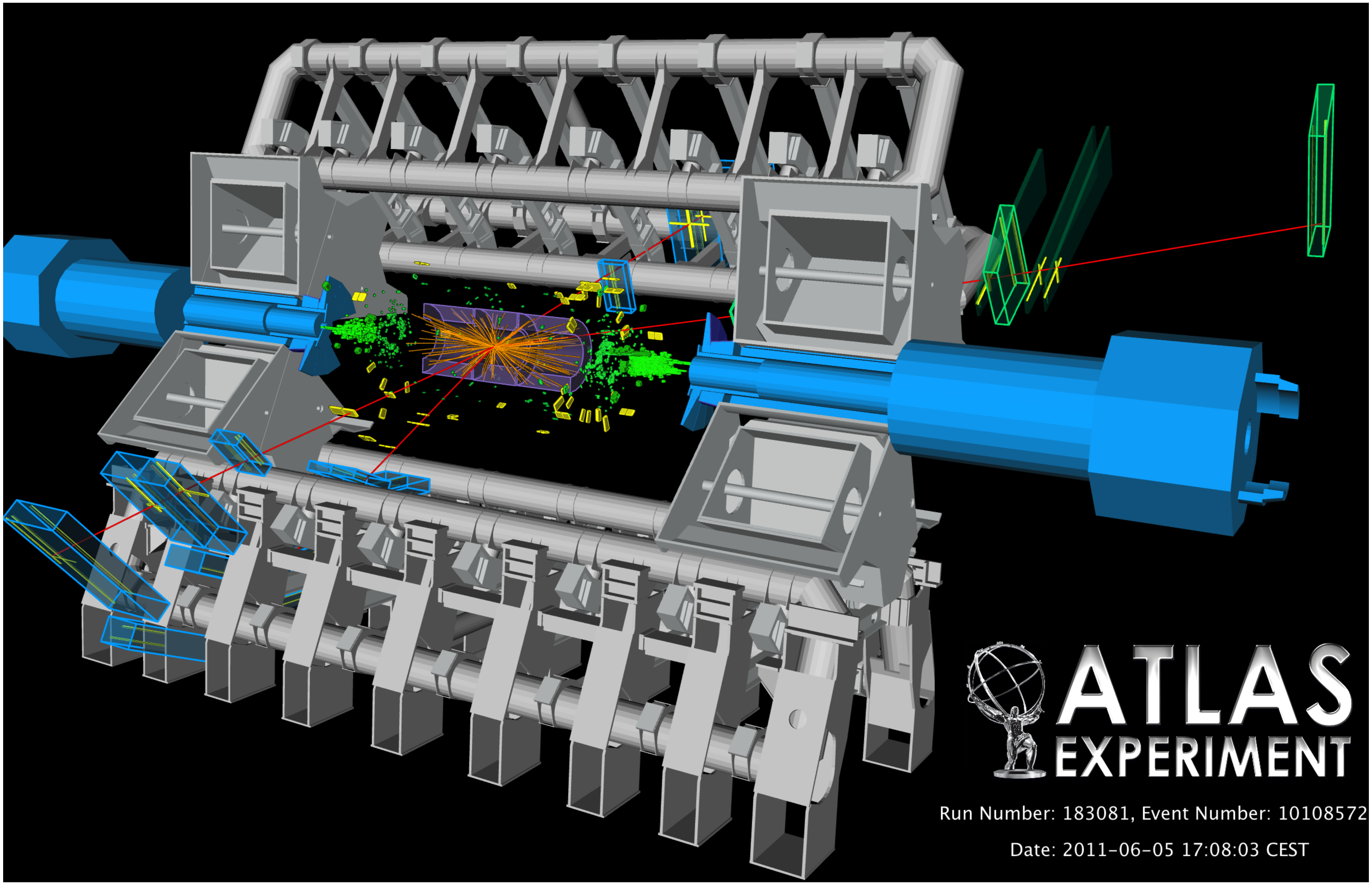


Fig. 10

- Expect about 5 events in current dataset
- Number of background events about 5

Another Higgs Boson Candidate Event



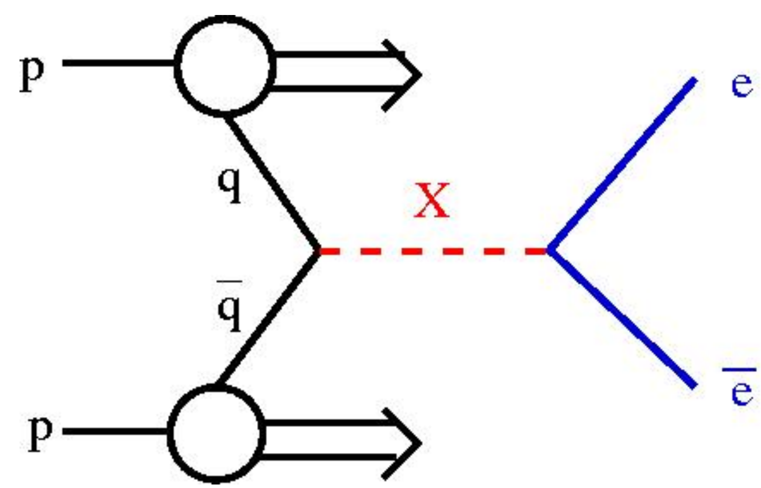
Units and Numbers

- Mass is measured in electronVolt/c^2 where c = speed of light
  - $1\ eV/c^2 = 1.8 \times 10^{-36}\ kg$
  - $m_{proton} = 1\ GeV/c^2 = 2 \times 10^{-27}\ kg$

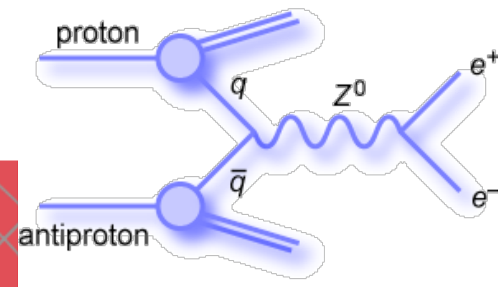
We will mostly use the unit "GeV"= Gigaelectronvolt = proton mass

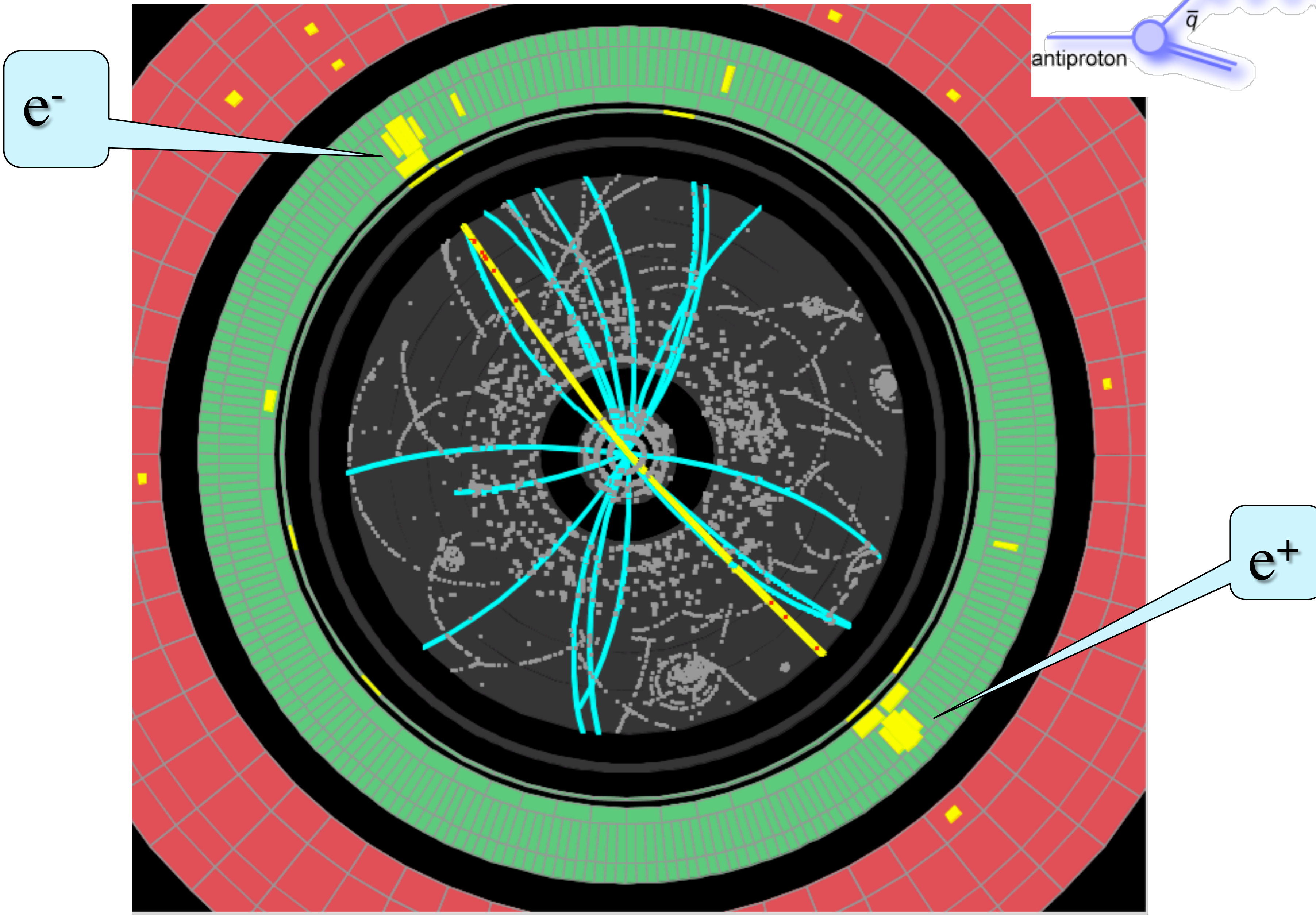
Energy and mass are equivalent: $E=mc^2$

- Einstein's famous formula: **$E=mc^2$**
  - c = speed of light, m = particle mass, E = particle energy
- Collide 2 protons with E=3,500 GeV
  - Total energy: E=7,000 GeV
  - Can create particle X with mass $m_X < 7{,}000\ GeV/c^2$
  - Most particles we create live only for a very short fraction of a second and then decay, e.g.X decays to electron and anti-electron



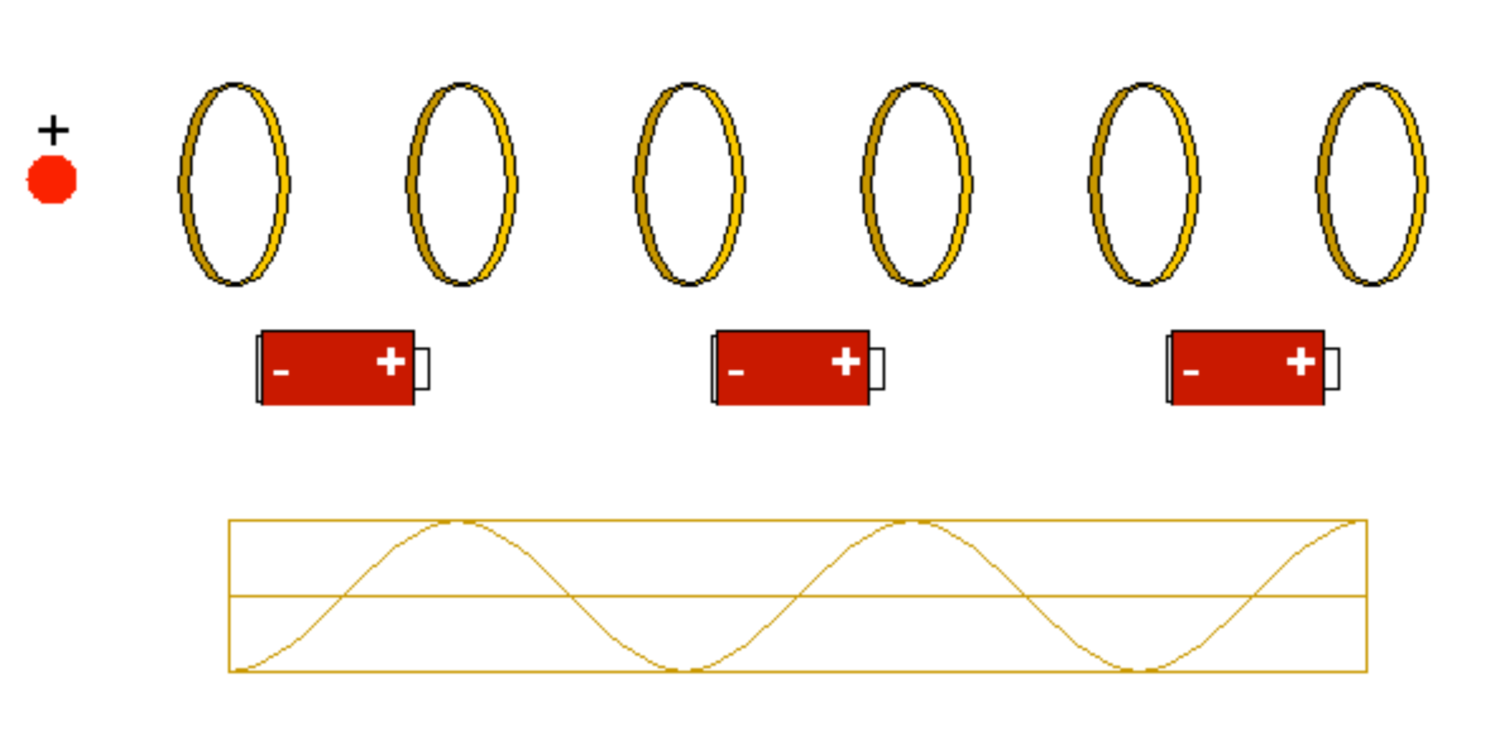
A real LHC Z boson Event





How particles get accelerated

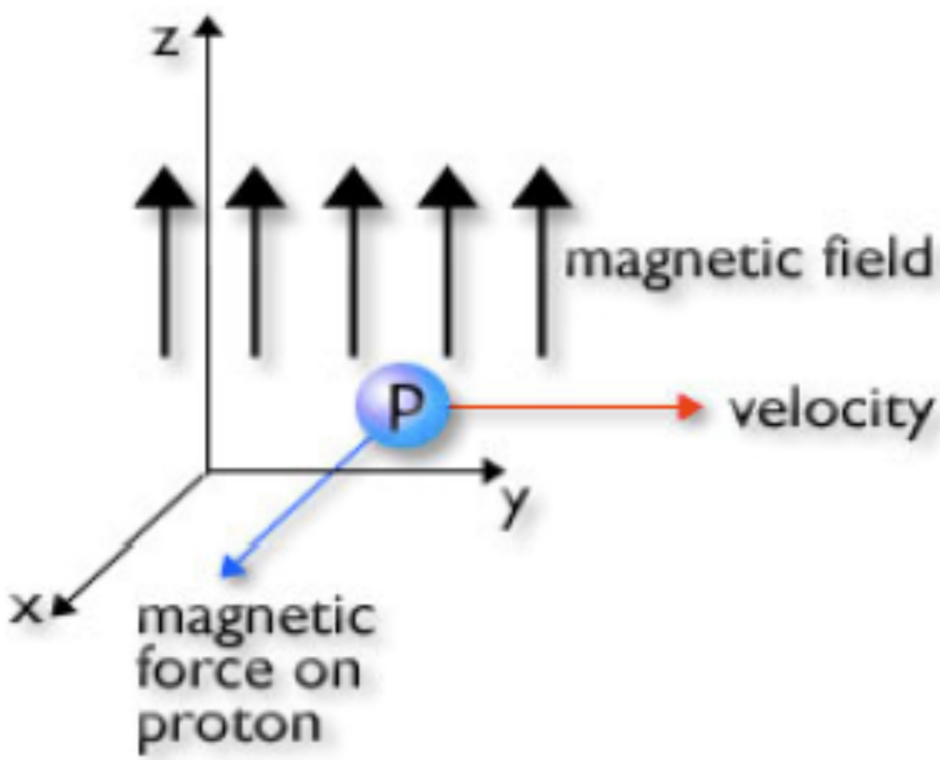
With F=qE (Maxwell) and F=ma (Newton)
Acceleration: **a = qE/m**

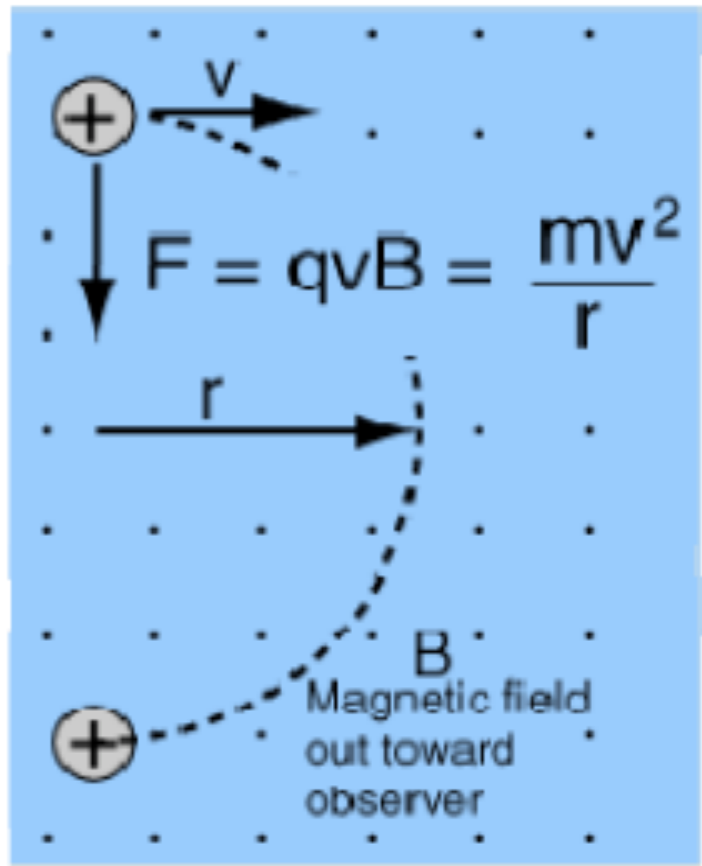


eV= "electron Volt" = energy of one electron after passing through field with voltage of 1V

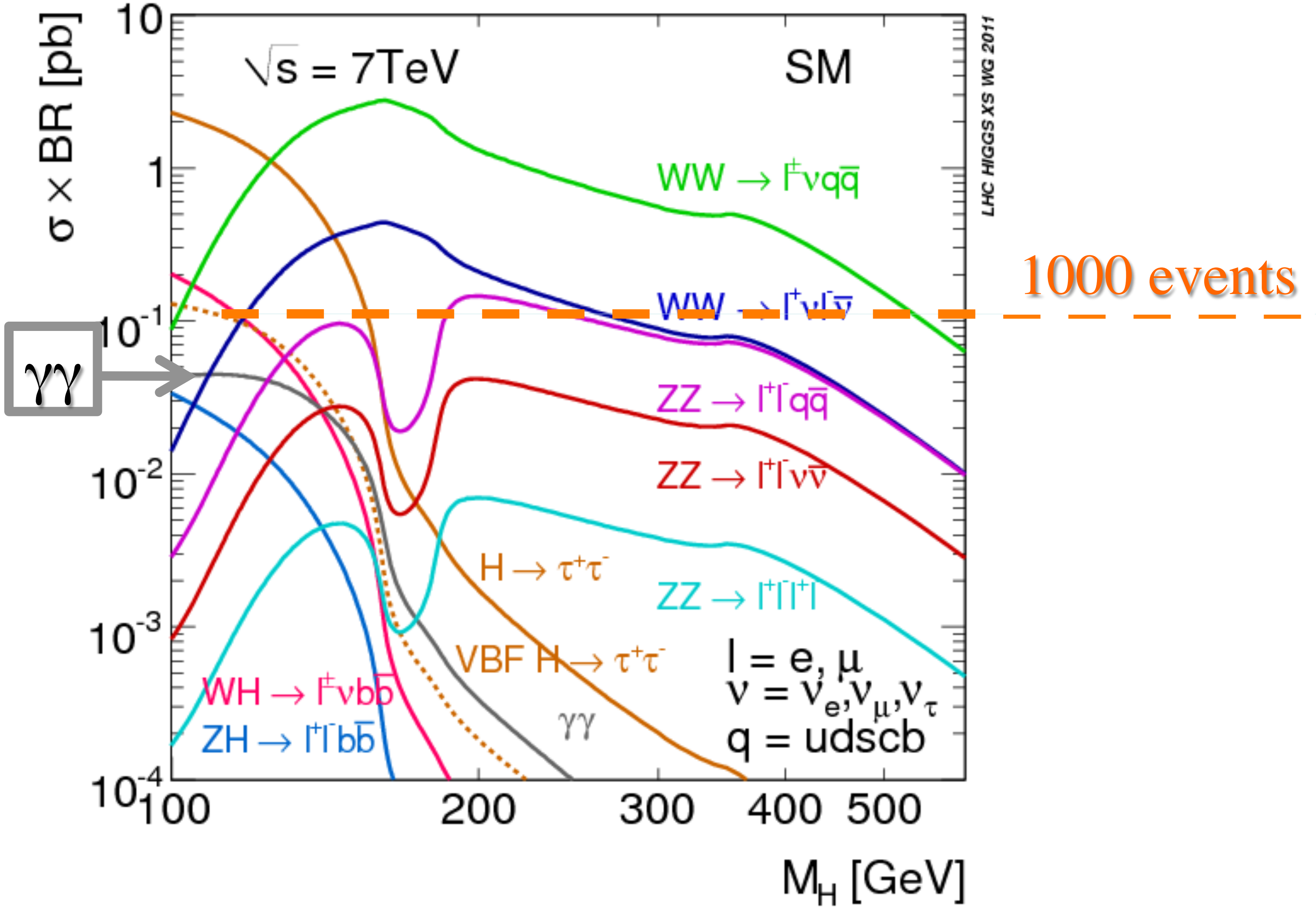
How particles get bent in circle

Magnets are used to steer the beam in circle using the Lorentz force ($F=qvB = mv^2/r$)





Rate of Events produced



LHC Accelerator

- Energy 80 million times larger than 5” cyclotron
- Cost = $10 billion
- US and Berkeley joined project in 1994