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Higgs Physics for Teachers Academy

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OUTLINE

- What is the Higgs particle?
- Discovery of the Higgs
- What do we know about the Higgs?
- Higgs Physics

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WHAT IS THE HIGGS PARTICLE?

- The Higgs particle was predicted in order to unify the electromagnetic and weak interactions:
- The electromagnetic force is carried by the photon, which is massless
- The weak interaction is carried by two massive particles: the charged W and the neutral Z, which have substantial mass (this makes the weak interaction weaker than the electromagnetic interaction with the same coupling)

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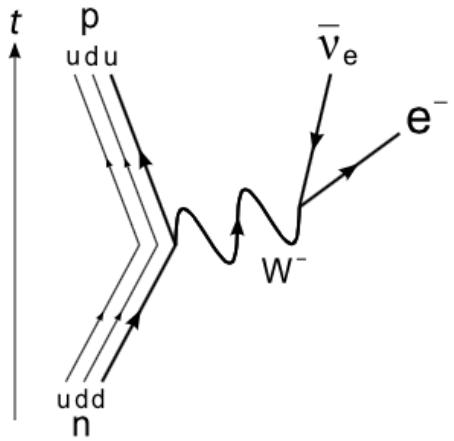
WHAT IS THE HIGGS PARTICLE?

- Typical weak interaction: nuclear beta decay

$$n \rightarrow p + e^- + \bar{\nu}_e.$$

- This can be pictured as



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WHAT IS THE HIGGS PARTICLE?

- The mass of the Z is 91.2 GeV/c^2

(the mass of a proton is about 1 GeV/c^2)

- The mass of the W is 80.4 GeV/c^2

- In order to have these particles together with the photon in a valid theory we need the Higgs mechanism, which introduces the Higgs particle.

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WHAT IS THE HIGGS PARTICLE?

- Electroweak Symmetry Breaking:

  The electromagnetic and weak interactions can be unified into a single interaction – the electroweak interaction – if the gauge particles that carry these forces are massless. The photon, which carries the electromagnetic force, is massless, but the particles that carry the weak force have substantial mass, explaining why the weak force is weaker than the electromagnetic force. This unification can still work if a new scalar boson, the Higgs boson, is introduced, allowing the particles that carry the weak force to be massive.

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WHAT IS THE HIGGS PARTICLE?

- The Higgs particle is a quantized manifestation of a field (the Higgs field) that generates mass through its interaction with other particles
- This mechanism was proposed by Brout, Englert, and Higgs.

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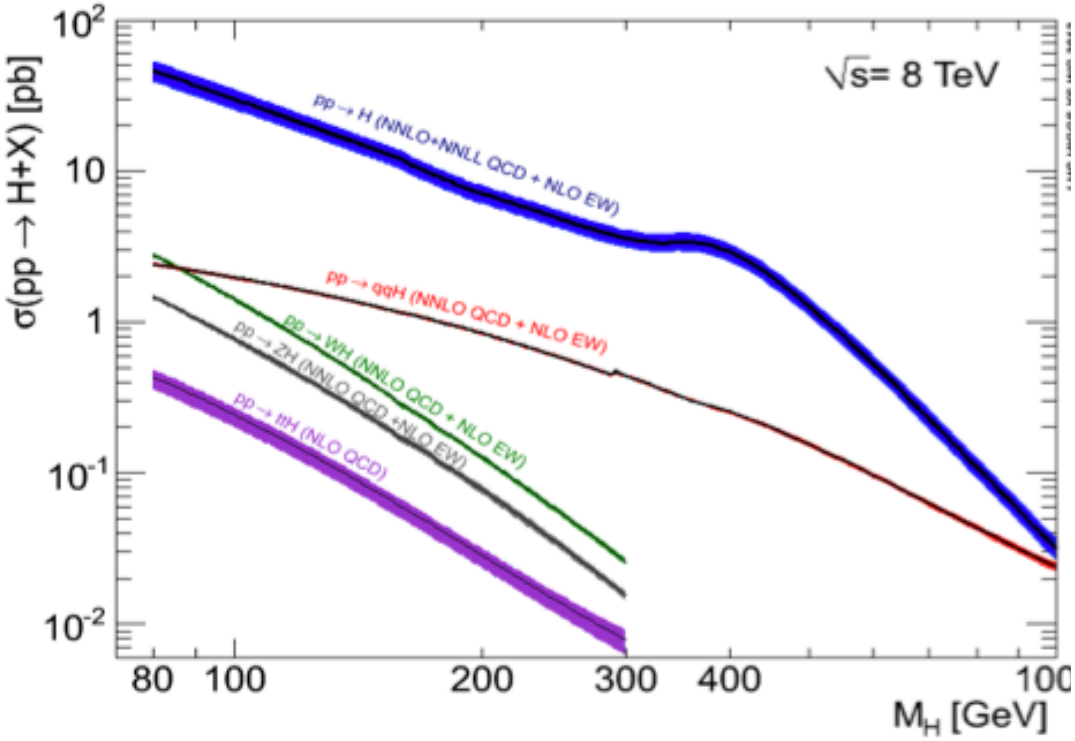
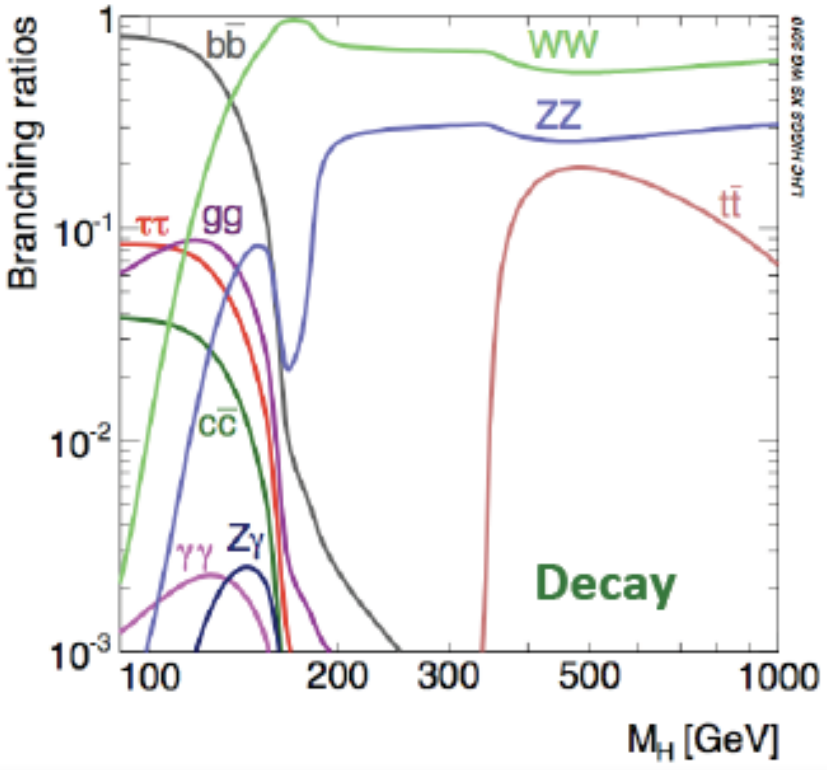
DISCOVERY OF THE HIGGS

- The theory predicts the cross sections and branching ratios, but not the mass





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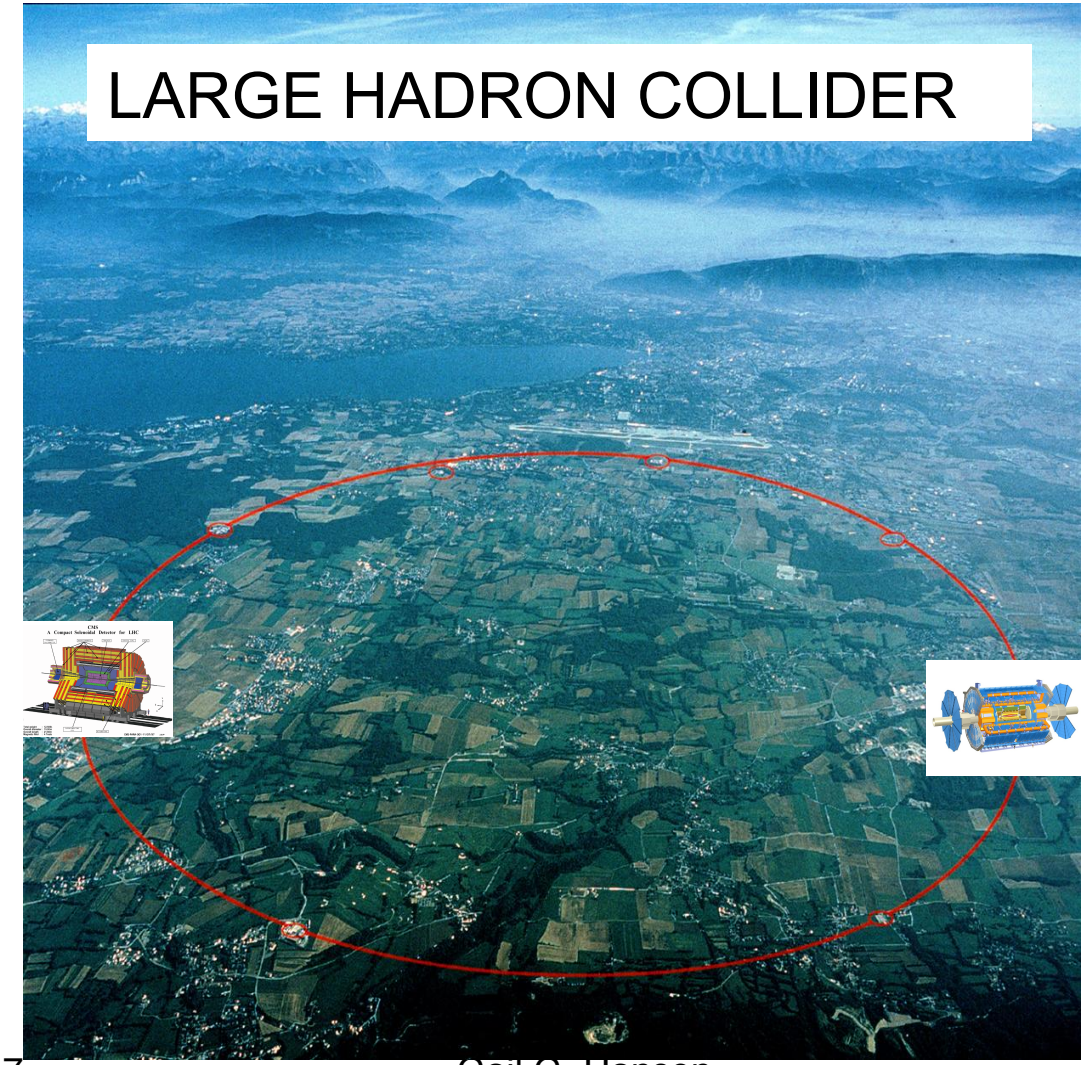
DISCOVERY OF THE HIGGS



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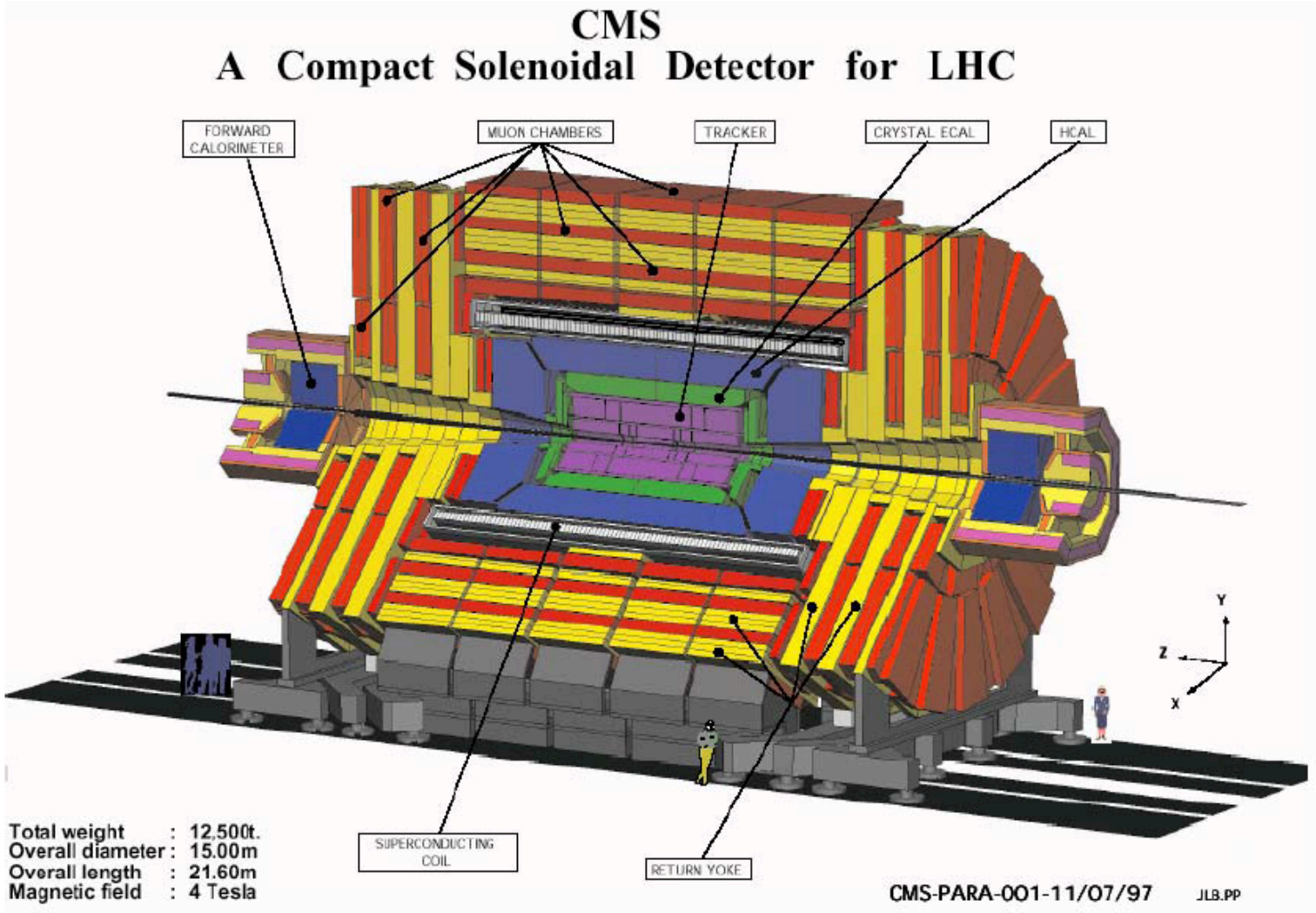
COMPACT MUON SOLENOID



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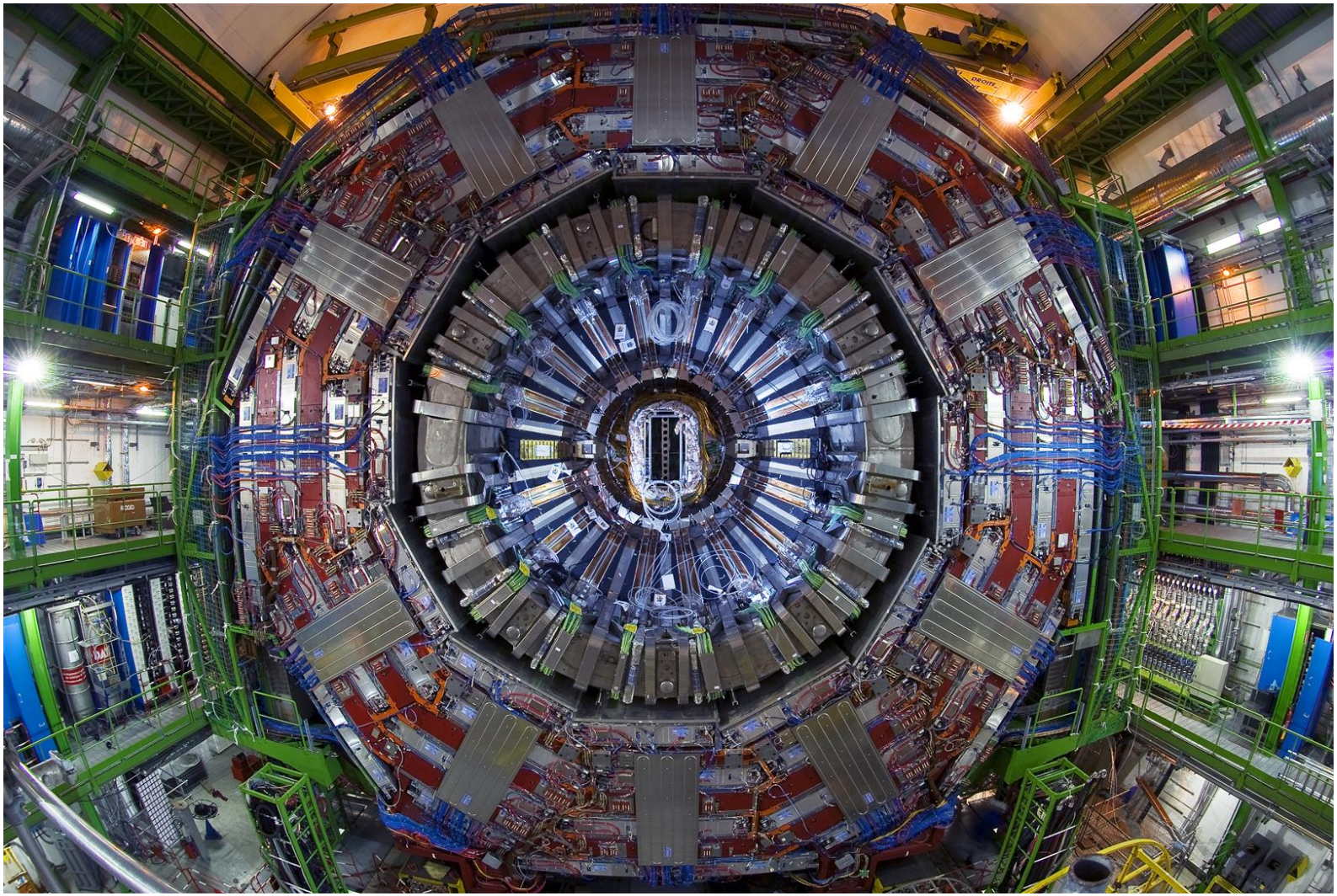
THE CMS DETECTOR



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SEARCH CHANNELS USED

- $H \rightarrow \gamma\gamma$

  Narrow peak on top of large irreducible background

  Depends on energy resolution of electromagnetic calorimeter; very small fraction of H's decay to γγ

- $H \rightarrow ZZ$

  Clean signal, small background, but only decays of Z's to ee or μμ are used

- $H \rightarrow WW$

  Cannot fully reconstruct the H since W decays to eν or μν are used and ν's are invisible

- $H \rightarrow \tau\tau$

  Similar problems to WW; τ's decay to eνν, for example

- $H \rightarrow b\bar{b}$

  Large background, which is reduced using associated production with a W or a Z

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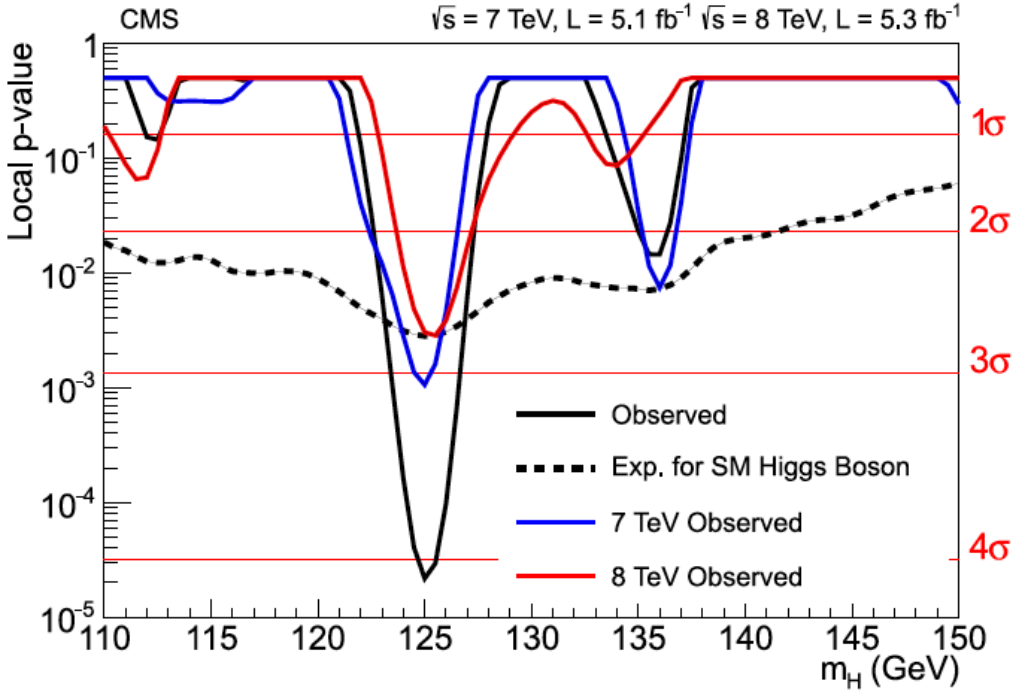
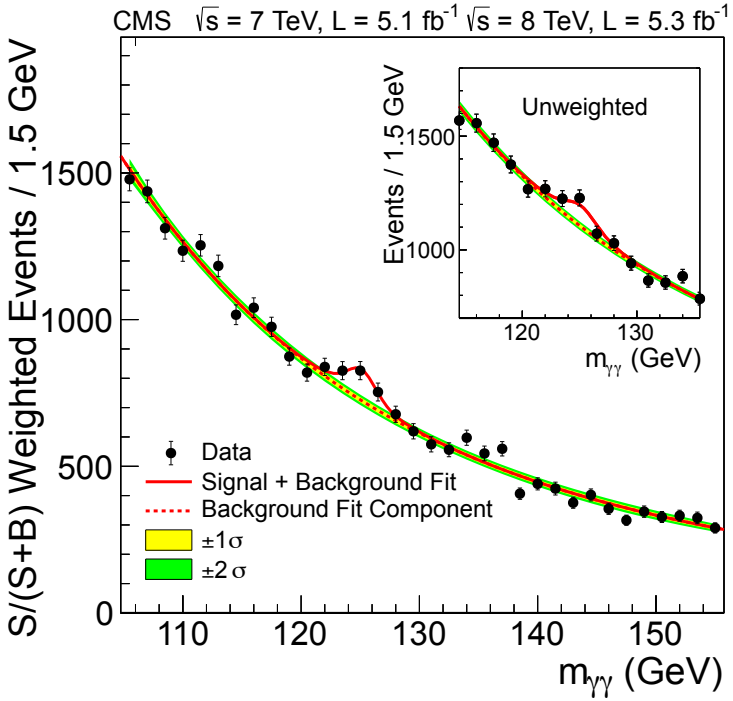
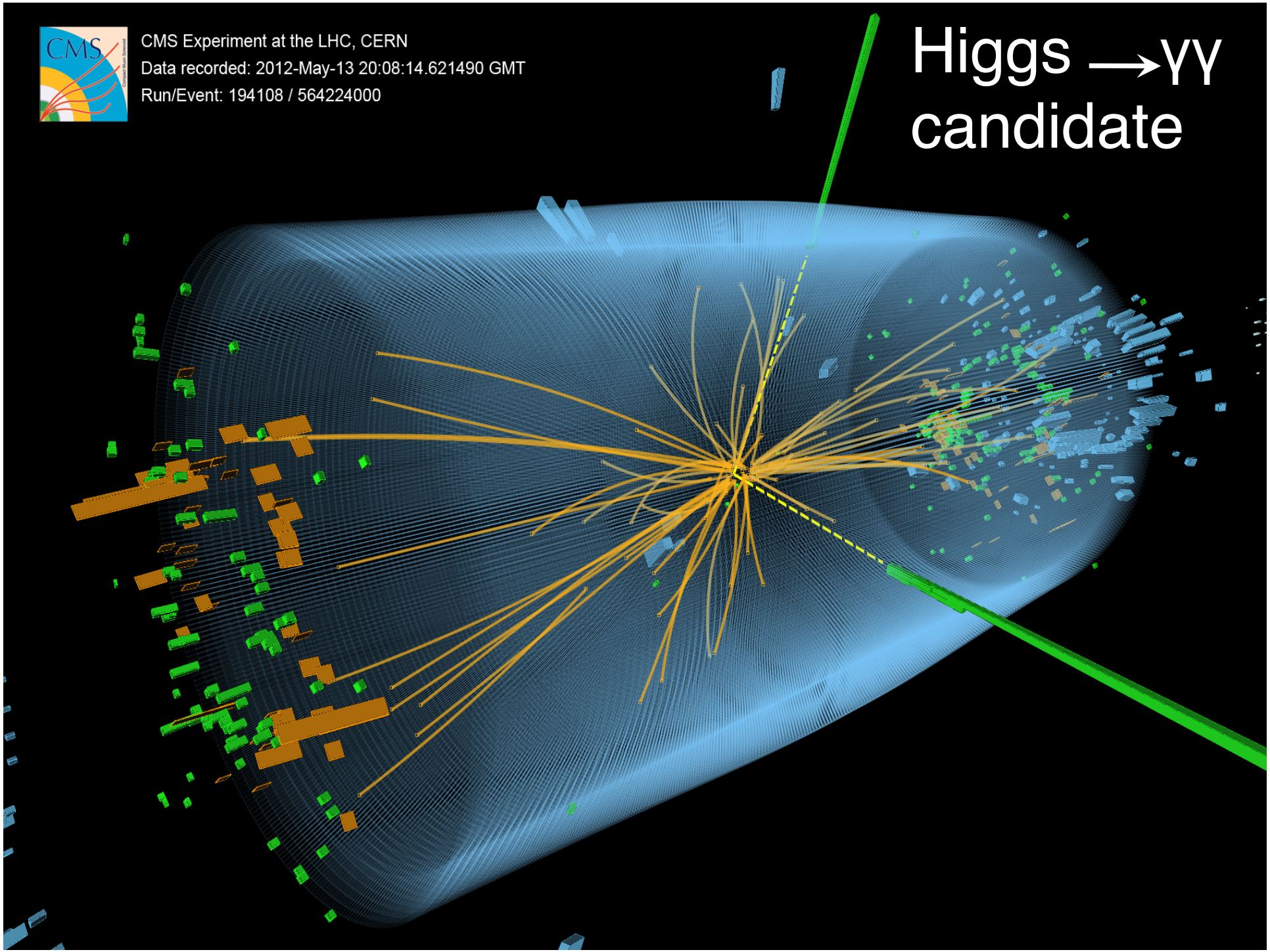
DISCOVERY OF THE HIGGS

$H \rightarrow \gamma\gamma$






CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
Higgs → γγ
candidate

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DISCOVERY OF THE HIGGS

$H \rightarrow ZZ$

- ZZ → 4e, 4μ, and 2e 2μ are analyzed separately
- The two "Z" invariant masses are required to be within 40–120 GeV and 12–120 GeV (m_Z = 91 GeV)
- Kinematic discriminator K_D used to reduce background

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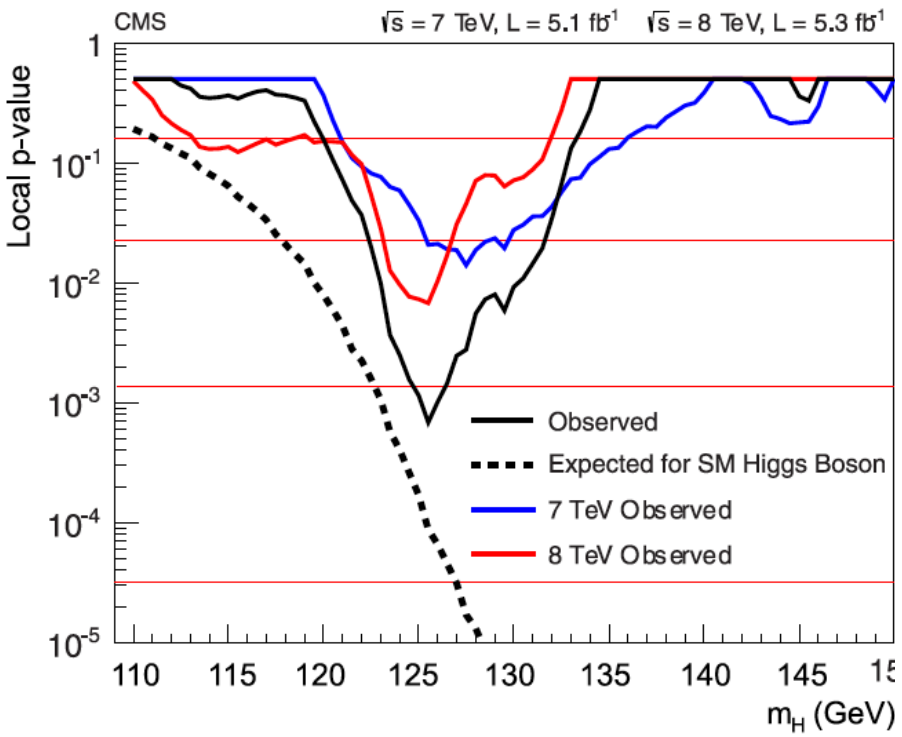
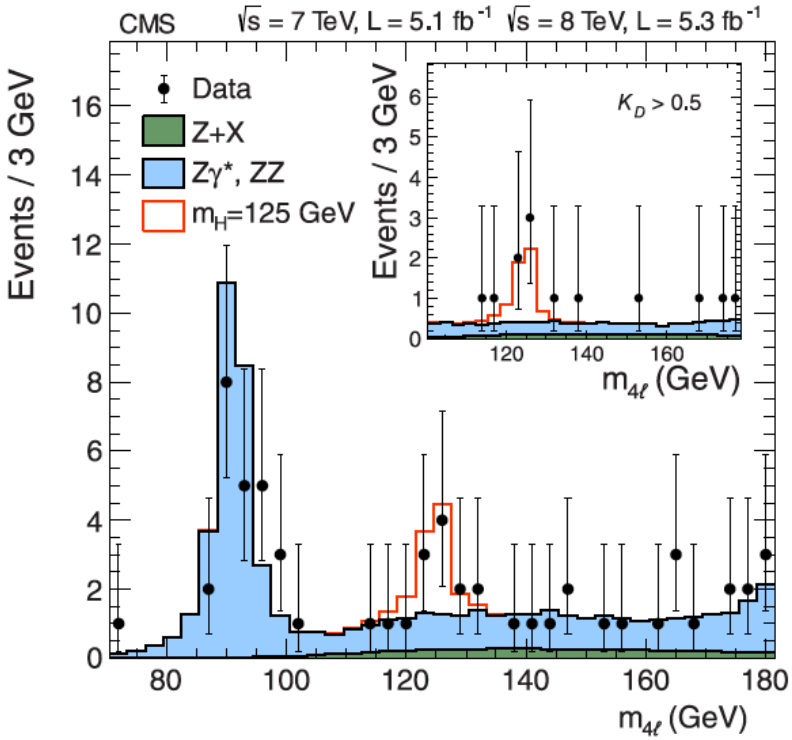
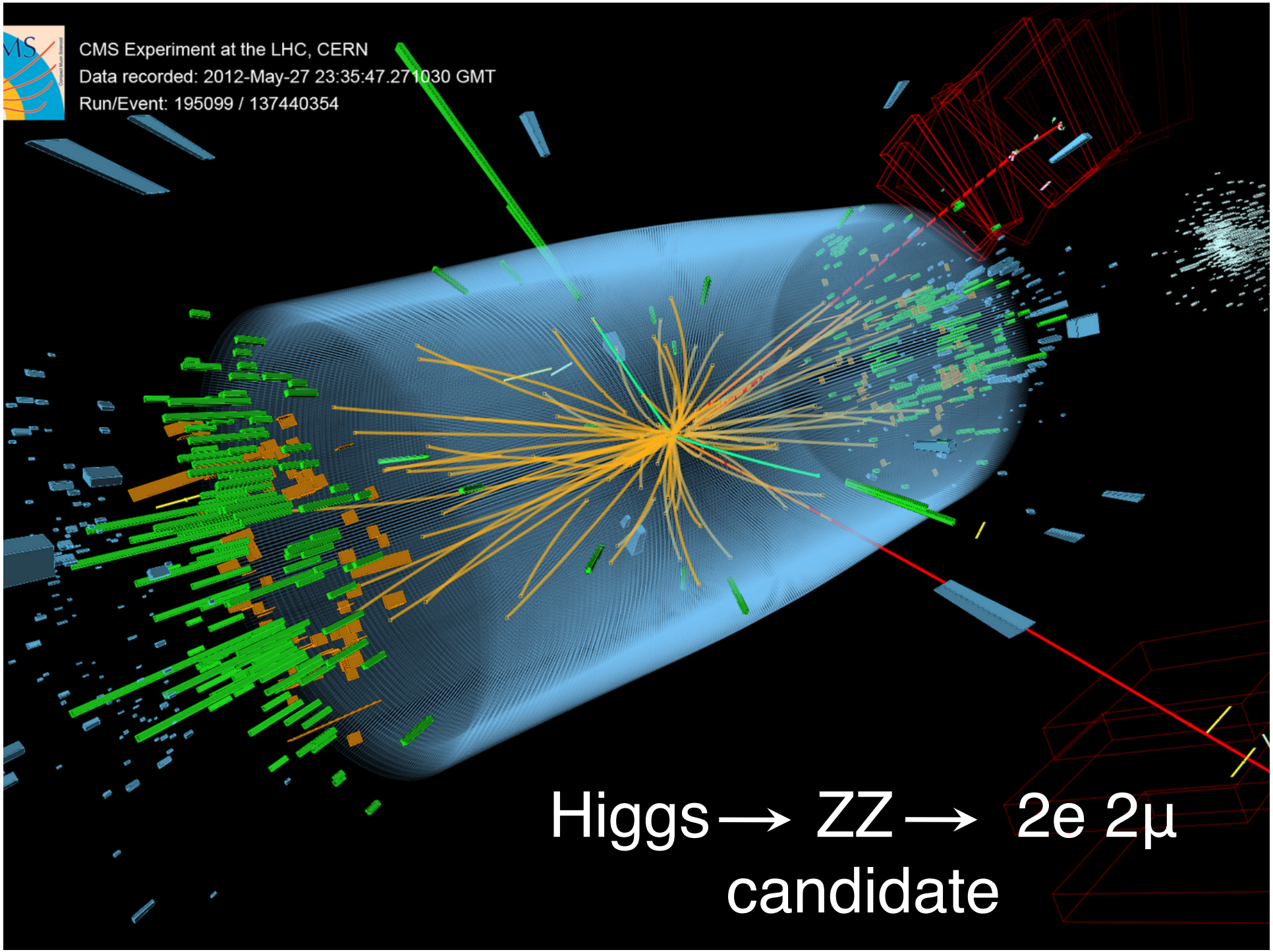
DISCOVERY OF THE HIGGS

FOUR-LEPTON CHANNEL






CMS Experiment at the LHC, CERN
Data recorded: 2012-May-27 23:35:47.271030 GMT
Run/Event: 195099 / 137440354
Higgs → ZZ → 2e 2μ
candidate

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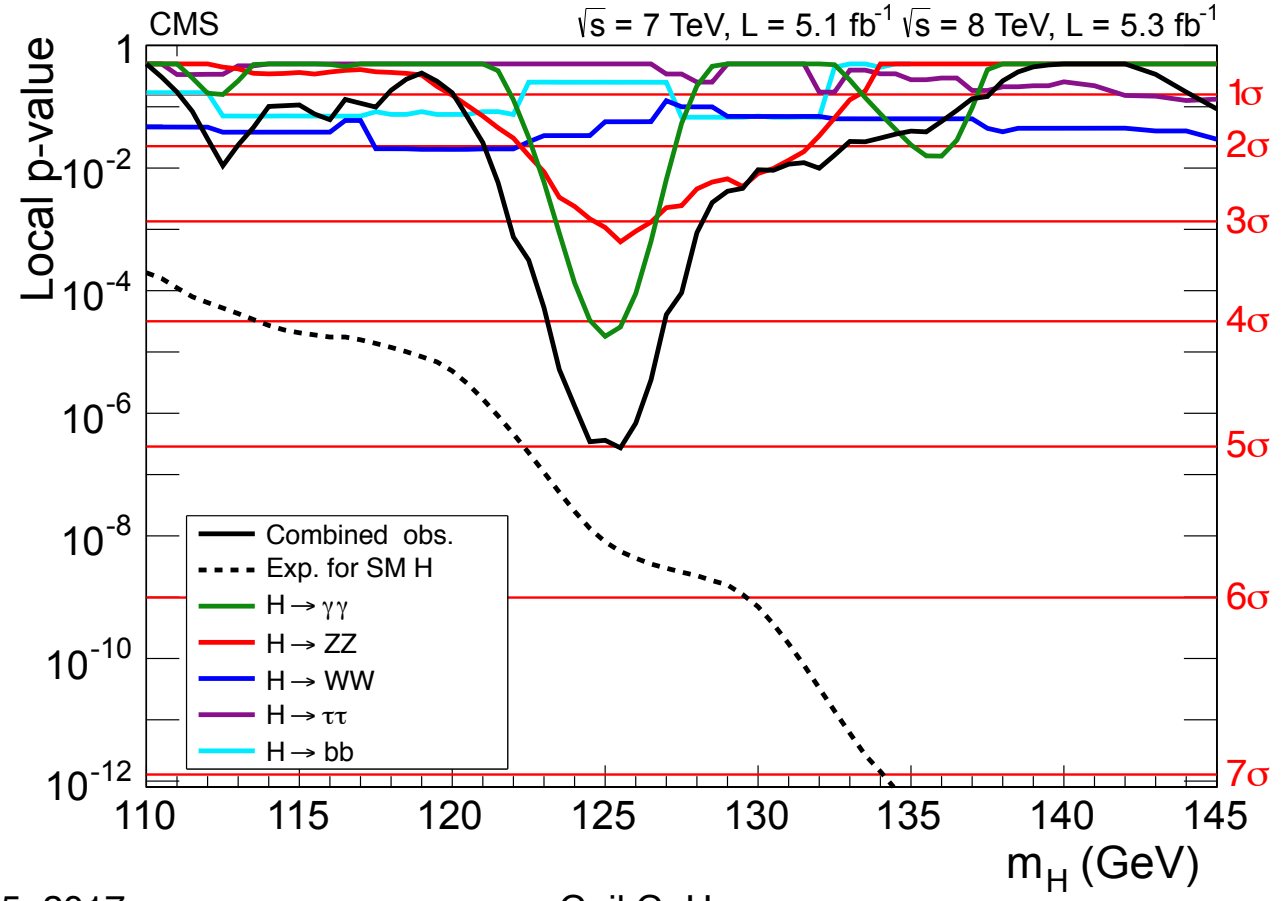
DISCOVERY OF THE HIGGS

PROBABILITY OF BACKGROUND-ONLY HYPOTHESIS



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DISCOVERY OF THE HIGGS

- An excess of events above the expected background, with a local significance of 5 σ, at a mass near 125 GeV
- The excess is most significant in the two decay modes with the best resolution, γγ and ZZ, and a fit to these signals gives a mass of

$$125.3 \pm 0.4 \text{ (stat.)} \pm 0.5 \text{ (syst.) GeV}$$

DISCOVERY BY ATLAS AND CMS ANNOUNCED JULY 4, 2012!

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DISCOVERY OF THE HIGGS

The Nobel Prize in Physics 2013

Photo: A. Mahmoud

François Englert

Prize share: 1/2

Photo: A. Mahmoud

Peter W. Higgs

Prize share: 1/2

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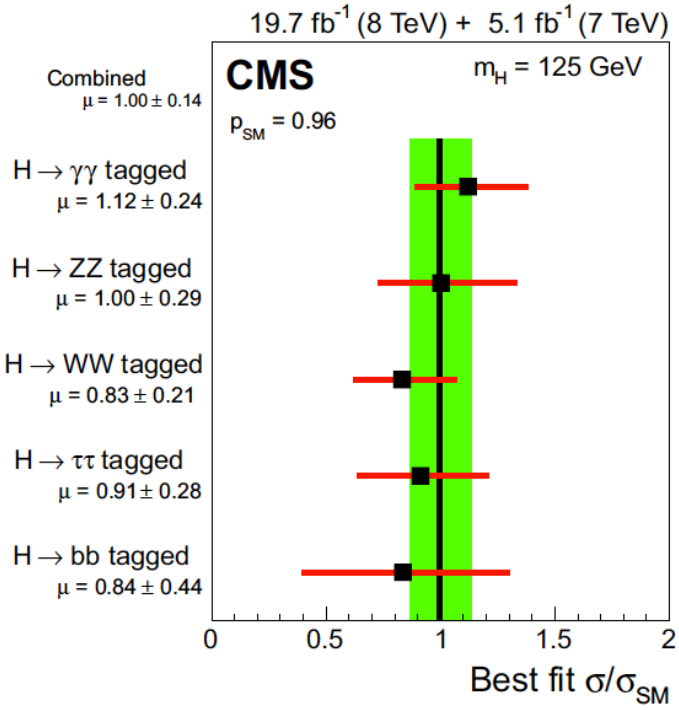
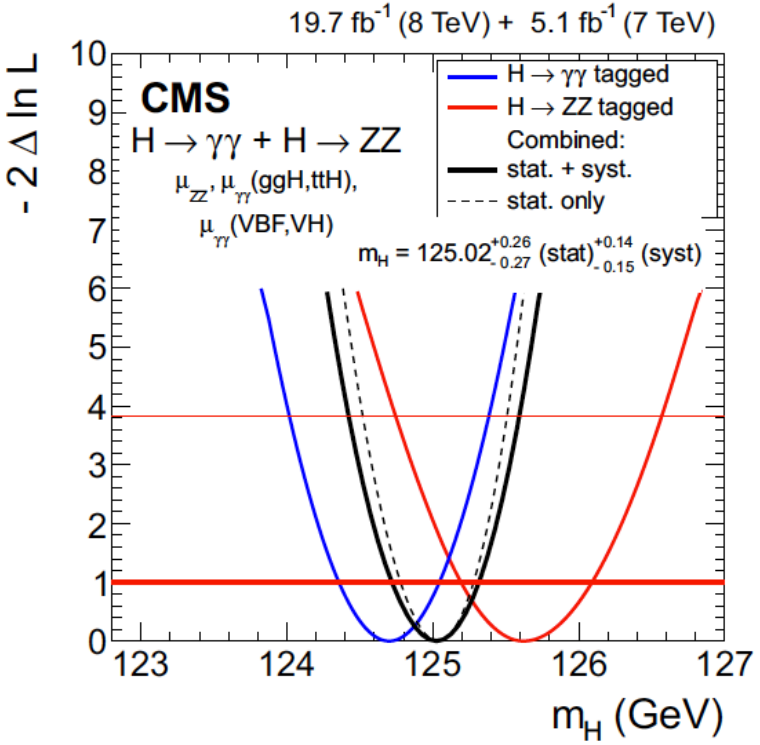
WHAT DO WE KNOW ABOUT THE HIGGS?

More data at 8 TeV until early 2013 – data sample approximately quadrupled

SIGNAL STRENGTH



HIGGS MASS



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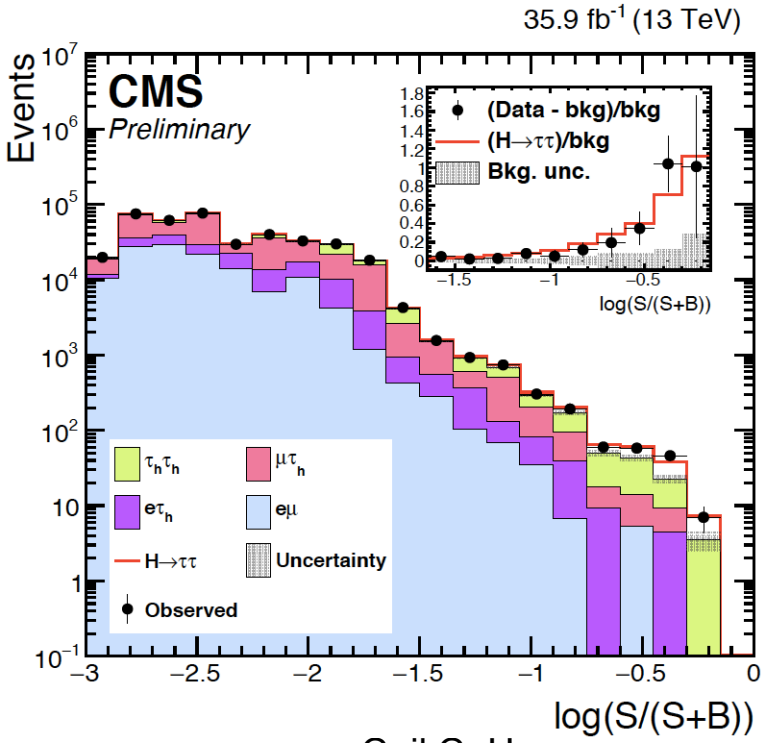
WHAT DO WE KNOW ABOUT THE HIGGS?

- Data taking at 13 TeV began in June 2015
- New results now coming out:



Observed (expected) significance 4.9σ (4.7σ) compared with 3.4σ (3.6σ) with Run 1 data

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FUTURE HIGGS PHYSICS

- Still looks like standard model
- More than one Higgs, for example as in supersymmetry?
- Higgs decays to Dark Matter?
- Two Higgs production