The discovery of the Higgs boson and its properties

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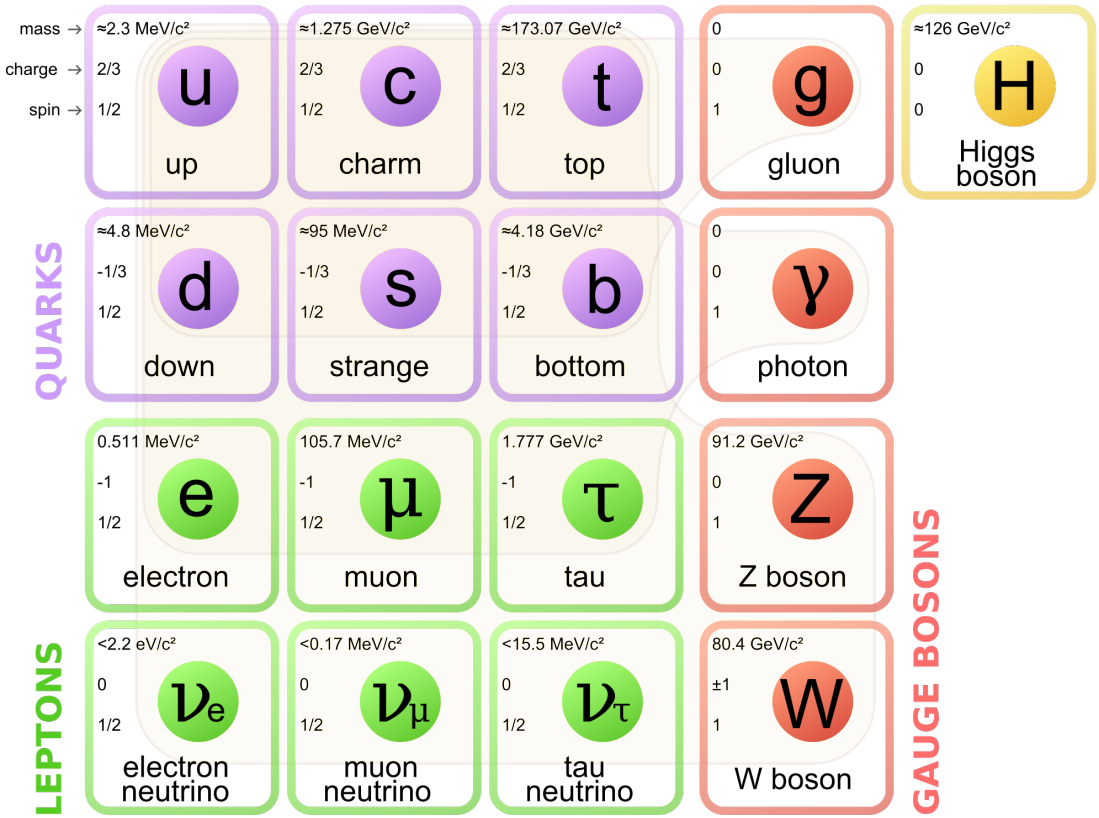
Outline

- Standard Model and the Higgs boson
- Large Hadron Collider (LHC) and ATLAS
- Z boson resonance
- Discovery of the Higgs boson

The Standard Model and the Higgs boson



The Large Hadron Collider (LHC) and ATLAS

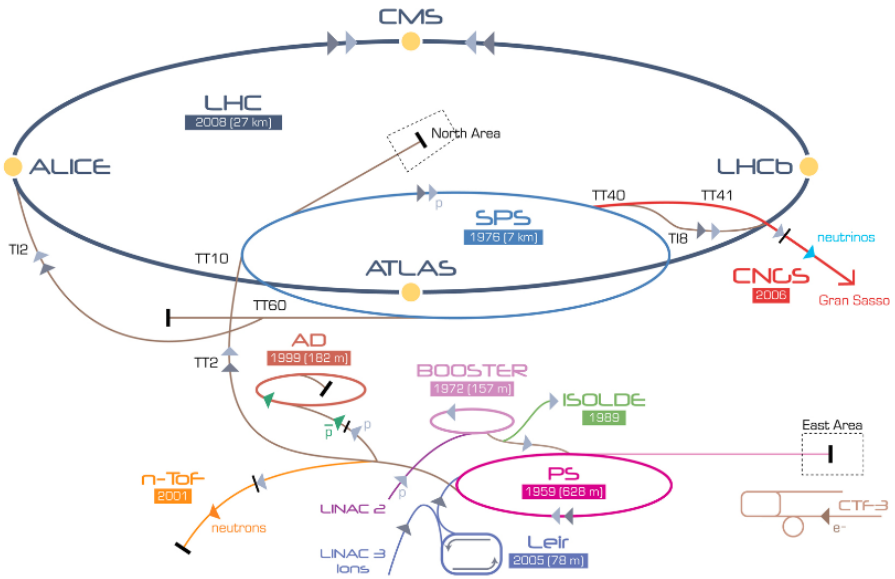


Figure : A schematic of particle accelerators feeding into each other and the four experiment around LHC.

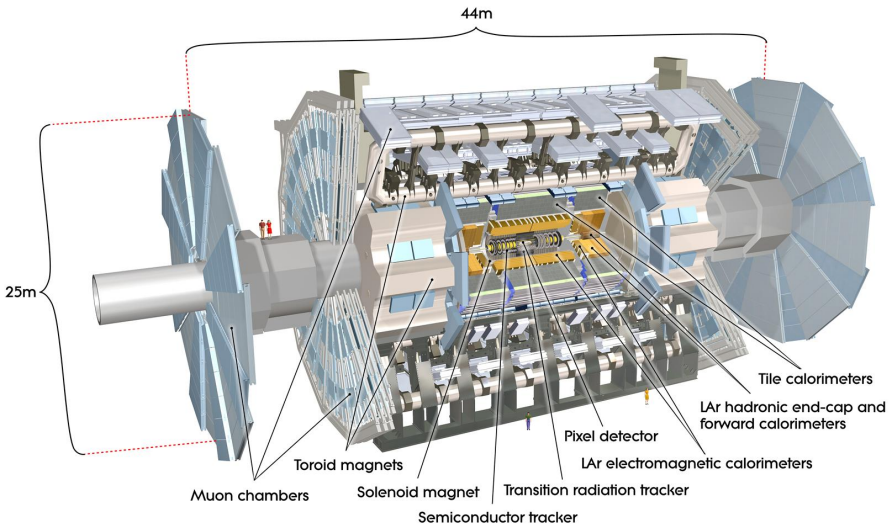
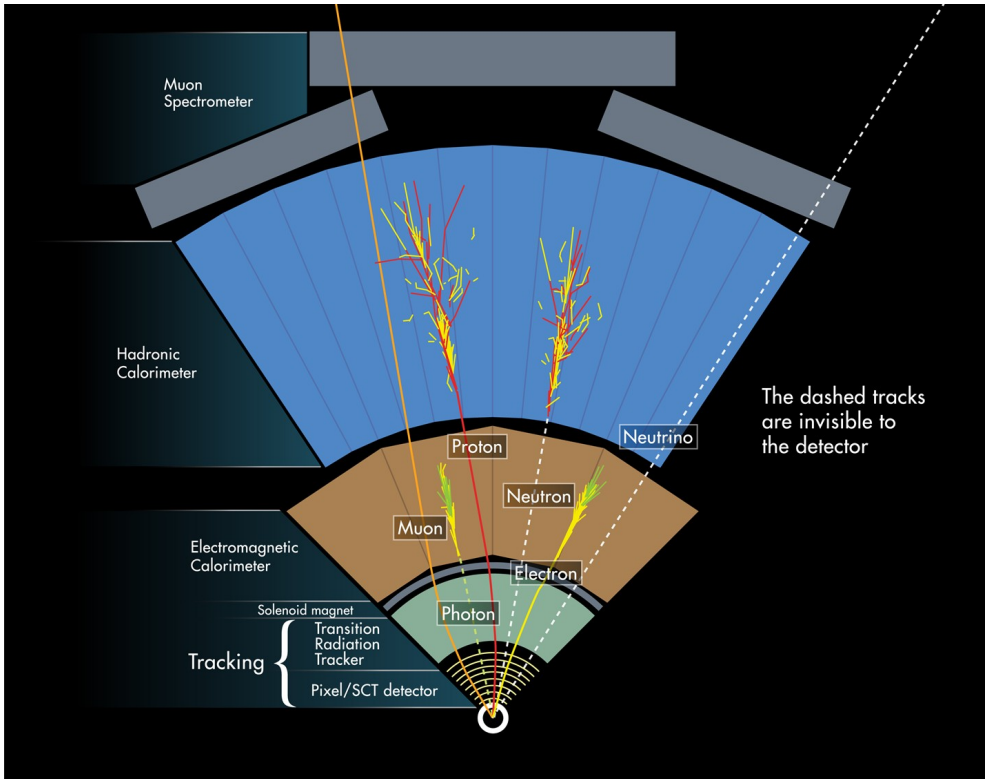


Figure : A schematic of the ATLAS detector showing how the sub-detectors are arranged around the point of collision.

Particle signatures at ATLAS



The Z boson resonance ($Z \longrightarrow e^- e^+$)

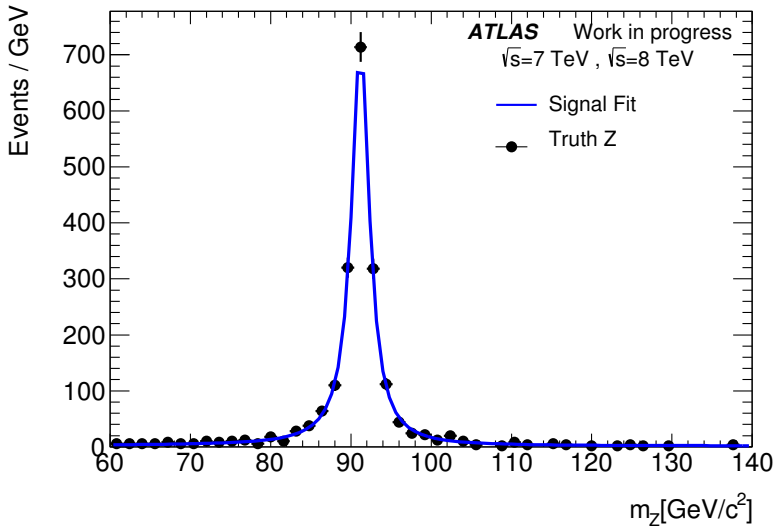


Figure : The m_Z^{truth} spectrum of the Z boson fitted with a Breit-Wigner curve. The center of the resonance corresponds to $m_0 = m_Z^{truth} = 91.20 \pm 0.05$ GeV$/c^2$ and $\Gamma_Z^{truth} = 2.70 \pm 0.09$ GeV$/c^2$ as it is expected from the PDG table.

Breit-Wigner distribution function

$$f(m; m_0, \Gamma, N) = \frac{N}{(m^2 - m_0^2)^2 + m_0^2\Gamma^2}, \tag{1}$$

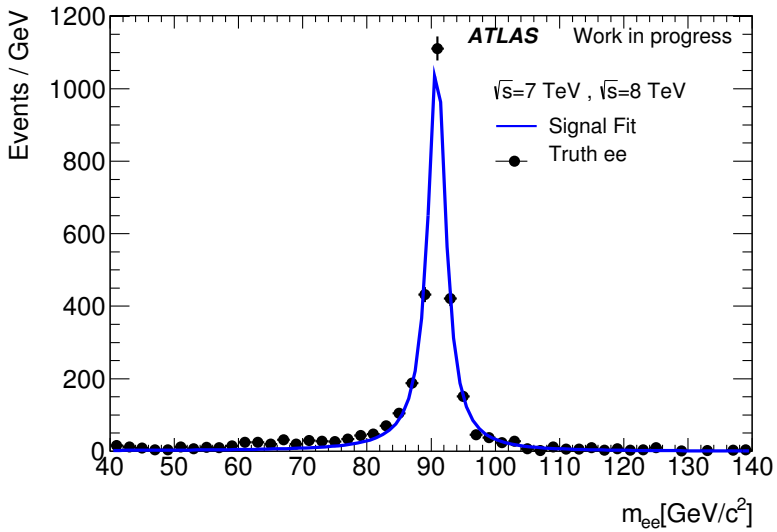


Figure : The m_{ee}^{truth} spectrum of the Z boson plotted from the truth data, $m_{ee}^{truth} = 90.89 \pm 0.05$ GeV$/c^2$ and $\Gamma_{ee}^{truth} = 3.36 \pm 0.09$ GeV$/c^2$

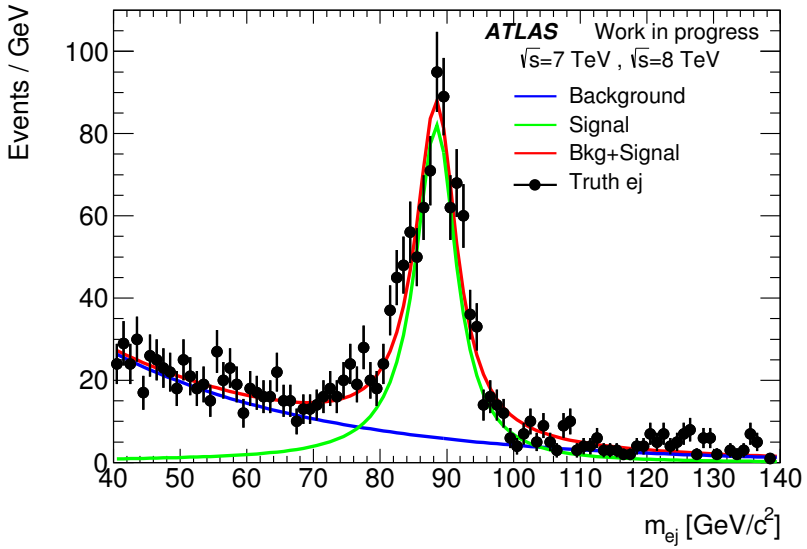


Figure : A Breit-Wingner curve and exponential function fitted to the m_{ej}^{truth} spectrum of the Z boson reconstructed from the MC data, where e denotes an electron and j is either an electron or a jet. The peak of the Breit-Wigner function is found to be at $m_{ej}^{truth} = 88.41 \pm 0.21$ GeV$/c^2$ and the width of $\Gamma_{ej}^{truth} = 7.43 \pm 0.51$ GeV$/c^2$ which corresponds to m_{ej}^{truth}

Exponential function

$$g(m; A, \zeta) = Ae^{-\zeta m} \tag{2}$$

This function is used to model combinatorial background

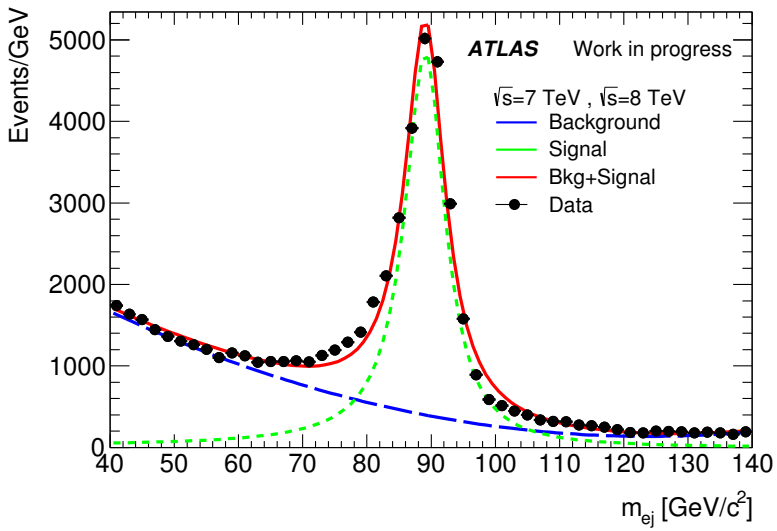


Figure : The $m_{ej}^{recon.}$ spectrum of the Z boson constructed from the data and fitted with a Breit-Wigner curve. The fitted values are found to be $m_0 = m_{ej}^{recon.} = 89.05 \pm 0.04$ GeV$/c^2$ and the width is $\Gamma_{ej}^{recon.} = 7.63 \pm 0.09$ GeV$/c^2$.

- Inverse of the detector respond

$$\begin{aligned} \alpha &= m_{ej}^{truth} - m_{Z}^{truth} \\ &= -2.48 \pm 0.16 \text{ GeV/c}^2, \end{aligned} \tag{3}$$

$$\begin{aligned} m_Z &= m_{ej}^{recon.} - \alpha \\ &= 91.53 \pm 0.12 \text{ GeV/c}^2. \end{aligned} \tag{4}$$

The discovery of the Higgs boson ($H \longrightarrow \gamma\gamma$)

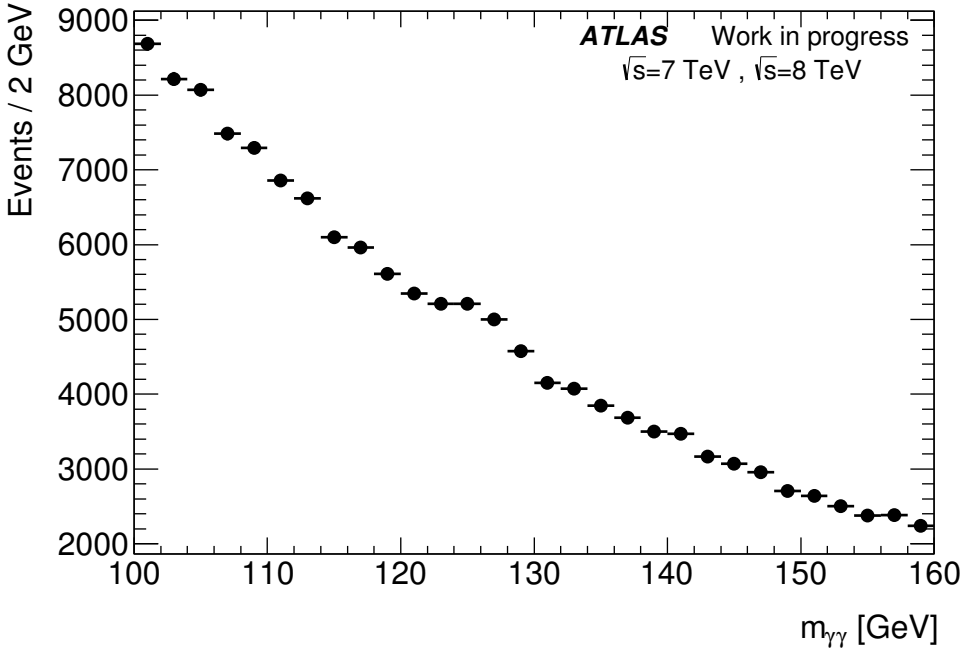


Figure : The diphoton invariant mass $m_{\gamma\gamma}$ spectrum, showing all the events passing the diphoton event selection. This data was collected from the ATLAS experiment.

Hypothesised functions

1)

$$g(m; A, \zeta) = Ae^{-\zeta m} \tag{5}$$

2)

$$h(m; m_0, \Gamma, N, A, \zeta) = f(m; m_0, \Gamma, N) + g(m; A, \zeta) \tag{6}$$

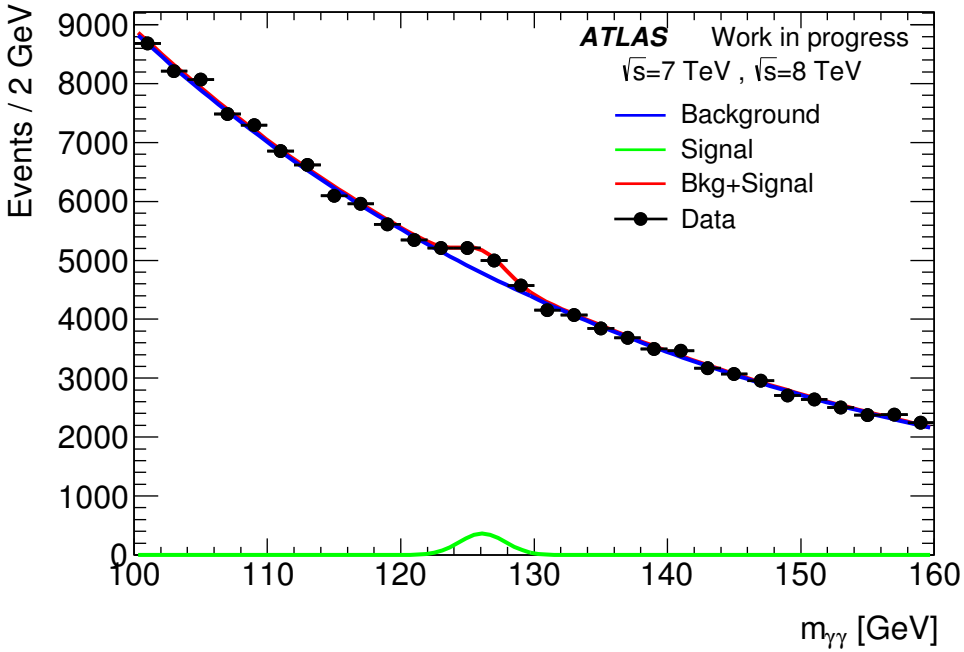


Figure : The spectrum of diphoton invariant mass $m_{\gamma\gamma}$ together with the signal models described above. The blue curve shows the background component fit. The signal fit is shown with the green curve. The red curve shows the sum of the signal plus background model when the mass of Higgs boson is fixed to 126 GeV.

- Test for the goodness of the fit
  - assume the null hypothesis ($g(m; A, \zeta)$) fits the data,
  - statistical analysis
    - chi-square test

$$\ln(\bar{y}) = \sum_j \frac{(y_j - f_j(s+b))^2}{f_j(s+b)} - \sum_j \frac{(y_j - f_j(b))^2}{f_j(b)} = \Delta\chi^2$$

    - calculations of the p-value using incomplete gamma function $p(s, \Delta\chi^2) = \int_{\Delta\chi^2}^{\infty} t^{s-1} e^{-t} dt$ given the null hypothesis
  - accepting or rejecting the null hypothesis based on the p-value.

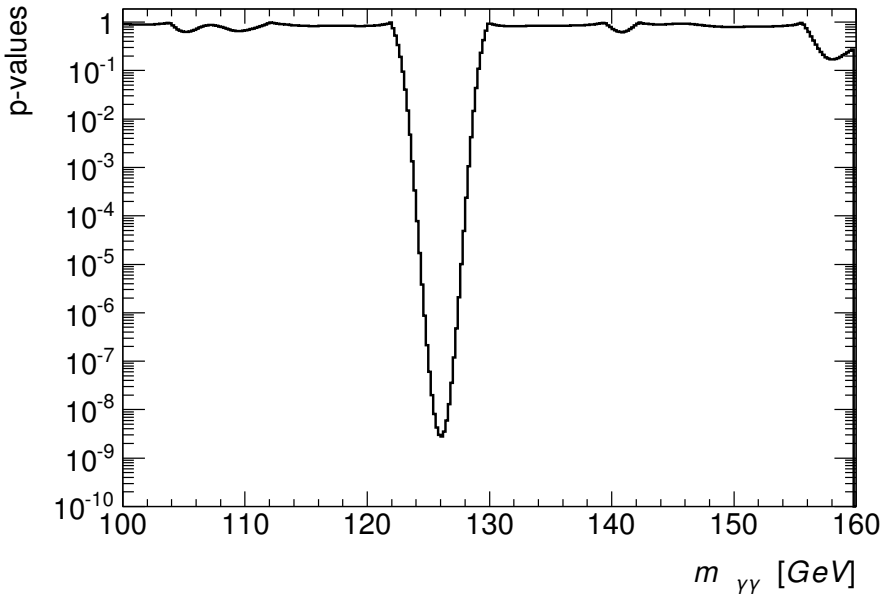


Figure : The observed behaviour of the test statistic p-value as a function of the test mass m_H in the low mass range. This shows the evidence of a particle at $m = 126$ GeV.

Thank you for listening