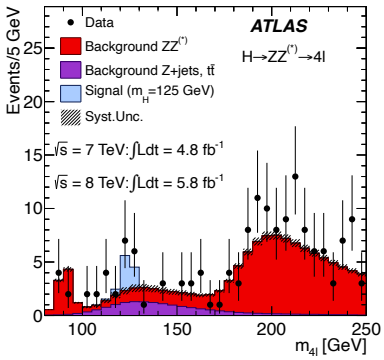
E Homework: Electroweak II (due Thu 8th May 5pm)

E.1 Electroweak dynamics

Sketch the cross-section $\sigma(e^-e^+ \to \text{hadrons})$ vs centre-of-mass energy $\sqrt{s}$ (figure 102), then draw the dominant tree-level Feynman diagram(s) for: (a) $\sqrt{s} < 40$ GeV, (b) $40 < \sqrt{s} < 80$ GeV, (c) $80 < \sqrt{s} < 100$ GeV, (d) $100 < \sqrt{s} < 160$ GeV, (e) $\sqrt{s} > 160$ GeV.

E.2 Higgs boson discovery

Consider the ATLAS discovery plot in the $h \to 4\ell$ channel to the right (same as figure 108a).



(a) Write down the 7 and 8 TeV cross-sections for $\sigma(pp \to h)$, Higgs h branching ratios $\mathscr{B}(h \to XX)$, and luminosities $\mathscr{L}$. For each of these four channels: $pp \to h \to 4\ell, \gamma\gamma, \ell\nu\ell\nu, \tau\tau$, draw the Feynman diagram and calculate the number of events $N = \sigma \times \mathscr{L} \times \mathscr{B}$. You may look up $\sigma, \mathscr{B}$ values in the PDG online or in figure 107b.

(b) Draw with Feynman diagrams for the red $ZZ^{(*)}$ backgrounds and discuss qualitatively what causes the peaks around $m_{4\ell} \approx 90$ GeV and $m_{4\ell} \approx 200$ GeV. Reading the data points $115 < m_{4\ell} < 130$ GeV, estimate the observed number of Higgs boson signal events and cross-section in femtobarns of $pp \to h$. Discuss experimental reasons why this estimate is lower than the theory prediction in (b).

E.3 Neutrino oscillations

Consider the neutrino oscillation length $L_{\text{osc}} = 4E/\Delta m^2_{ij}$ derived in the two-flavour model (§16.1). Restore the $\hbar c \simeq 197$ MeV fm units then calculate L_{osc} in kilometres for mass differences $\Delta m^2_{ij} = m^2_j - m^2_i = 1\,\text{eV}^2$, $1\,\text{meV}^2$ and $1\,\mu\text{eV}^2$. Look up the order-of-magnitude lengths for Earth's atmosphere and diameter, and Earth–Sun separation. Discuss the mass differences probed by atmospheric and solar neutrinos in relation to these distances.

E.4 Final presentation

Prepare a 10–15 minute talk with slides to present in finals week on a particle physics topic not covered in class. See the syllabus (§0.1) for e.g. topics, or discuss with the instructor.