Laboratorio computazionale di particelle e astroparticelle

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1 Cross sections and decay rates

1.1. Calculate the total widths of the Z and W bosons and the t quark and compare with the PDG

1.2. Calculate the total width of a Higgs boson of 200 GeV mass, and compare with results by the LHC Higgs Working Group.

1.3. Calculate the width of the muon. Note that you need to choose a MG model where the muon has a mass (`sm-full`).

1.4. $t\bar{t}$ production at hadron collider come from both $q\bar{q}$ annihilation and gg fusion.

(a) Find the LO cross sections for $t\bar{t}$ production at Tevatron ($p\bar{p}$ collider with $\sqrt{S} = 2$ TeV) and LHC ($\sqrt{S} = 13$ TeV). Which initial parton contributions are dominating in the two cases?

(b) Perform a scan varying the top mass m_t and compute the cross section at the LHC for values of m_t between 170 and 180 GeV.

(c) Re-perform the scan but with the decayed process

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generate p p > t t~, t > w+ b, t~ > w- b~
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and compare with the previous point.

1.5. One of the discovery channels for the Higgs boson has been di-photon. Compute the signal production cross section for $gg \to h \to \gamma\gamma$ using the `heft` model. Compute the cross section for the background $pp \to \gamma\gamma$, with a cut $p_T(\gamma) > 20$ GeV, and compare. What is the signal/background (S/B) ratio? Then modify the cuts in order to define a window around the Higgs mass with ± 10 GeV, ± 5 GeV and ± 1 GeV.

1.6. Consider the process $e^+e^- \to W^+W^-$ and compute the cross section for centre-of-mass eneriges between 200 GeV and 1 TeV. Show that, if diagrams with the three gauge-boson vertices (γW^+W^- and ZW^+W^-) are discarded, the cross section grows with energy, while this is not the case if all diagrams are kept. Compare with Fig. 5.1 of 1302.3415.
(For a lepton collider, use `lpp1/2=0` in the `run_card`).

2 Events

2.1. Consider $pp \to Z$ production: verify that the rapidity of the Z boson is bounded in the region $|y(Z)| < \frac{1}{2}\log\frac{S}{m_Z^2}$ (look at what happens changing S or m_Z).

2.2. Plot the energy spectrum of the electron in the muon decay (exercise 1.3).

2.3. Plot the invariant-mass spectrum for exercise 1.5, for signal and background.

2.4. Consider $e^+e^- \to t\bar{t}g$. Show that, for decreasing values of m_t, the gluon is predominantly produced close to the top/anti-top direction (plot the $\Delta R(t, g)$ distribution).

3 Parton shower

3.1. Consider $pp \to e^+e^-$ production. Plot the transverse momentum of the pair $p_T(e^+e^-)$, and the distance between the electrons, $\Delta R(e^+, e^-)$. How do these observables look at parton level (without shower) and after shower? Explain.

3.2. Consider $pp \to e^+e^-$ production, including up to one extra jet. Generate a merged sample and compare the $p_T(e^+e^-)$ distribution, as well as the transverse momentum distribution of the hardest (j_1) and second-hardest jet (j_2).