Exercises for Tutorial 5

Gavin Salam, Edinburgh Jet Lectures
Tutors: Enrico Bothmann, Leonardo Vernazza

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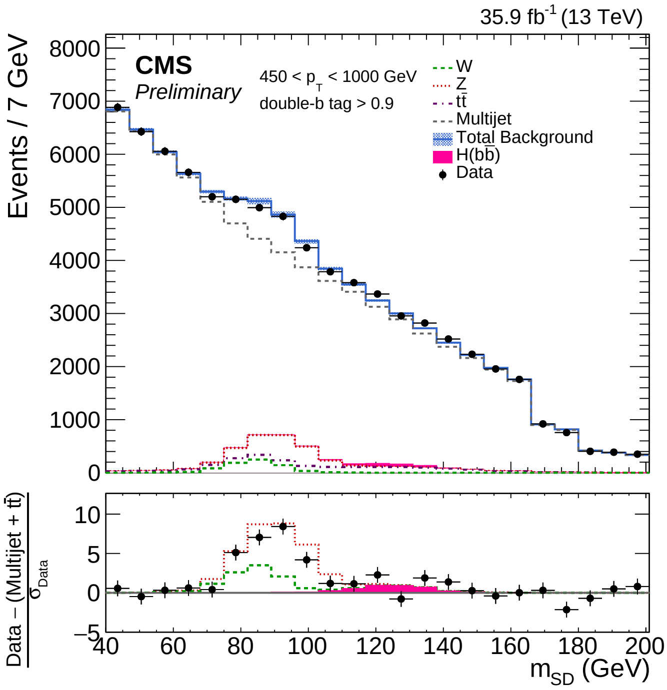

Figure 1: Fig. 4b from CMS-HIG-17-010-PAS

Figure 1 shows the a result from CMS that came out at the beginning of the week: it's the result of a high-p_T analysis, using jet substructure techniques (including mMDT/SD) to identify hadronic resonances, together with double b-tagging to specifically pull out $b\bar{b}$ decays. The $Z \to b\bar{b}$ peak is visible with $> 5\sigma$ and is the first observation of clear hadronic $Z \to b\bar{b}$ decay at the LHC. It's important because it validates the technique to help look for $H \to b\bar{b}$, which has never been seen and is the dominant decay of the Higgs. The small $H \to b\bar{b}$ bump is hardly visible in data ($\sim 1.5\sigma$), but will improve as more events are collected. This also offers the best chance to see Higgs production at high p_T, a powerful probe of the top-loop in gluon fusion ($gg \to Hg$).

The tutorial walks you through some of the features of boosted W/Z/H identification, again with Pythia to generate the event samples.

1 Mass of a boosted resonance

Consider a highly boosted hadronically-decaying resonance such as a Z, W or Higgs boson, with mass m and transverse momentum $p_t \gg m$.

- If jet that contains the boosted resonance and an additional massless particle with transverse momentum Λ at a distance r from the resonance, what is the squared jet mass? Work in the approximation that $r \ll 1$.
- Now assume a constant density ρ per unit rapidity and azimuth of soft radiation from pileup and underlying event. For a jet of radius R (doing the calculation for $R \ll 1$), what is the total contribution to the squared jet mass?
- If the jet radius is fixed, how will the jet mass be affected as p_t grows large?
- Similarly, what will happen if the jet radius is chosen dynamically to just contain the resonance decay products (recall the formula for their angular separation from the lecture).

2 Reconstructing boosted W's

If you cloned the tutorials previously, now do

```
git stash
git pull
```

and then go to the directory `tutorial-4/code`. Otherwise download a fresh zip file, unpack it and edit the `Makefile` in the above directory so that the path to Pythia points to where you built it previously.

The code generates high-p_T $pp \to WW$ events and then examines the two hardest jets, each of which should contain a W and plots the mass of each jet. Look at the code to see how it works (for now ignoring the commented part about mMDT–SoftDrop) and then build it with "`make`".

- Run

  ```
  ./main01 -MPI off -ptmin 500 -R 1.0
  gnuplot all-plots.gp
  ```

  Note the options to control the minimum jet p_T and whether MPI is generated. Look at the plot that is produced (`all-plots.pdf`) and see the mass peak for the W.

- Reduce the R value. At what point does the W mass peak disappear? Does this coincide with your expectations?

- Return to using $R = 1$. Turn on MPI (`-MPI on`) and see what happens to the mass peak. Then increase the p_T to 2000 GeV and see how the W-mass peak further changes.

- Now uncomment the commented piece of code, which implements the a simplified version of the "modified mass-drop tagger" (mMDT, $\mu = 0$), which is also known as SoftDrop (SD, $\beta = 0$). (The code is arguable simpler than the name!).

  Recompile and run the code and examine the new plots: p. 2 of the plot file shows the mass of the mMDT/SD jets. How does this compare to the mass of the plain jets?