ISP220 Final Exam Project Instructions
20 points

BPS1415

Thursday, May 4, 2017, 07:45-09:45

- STAPLE the sheets when you're done using the stapler at the front of the room.

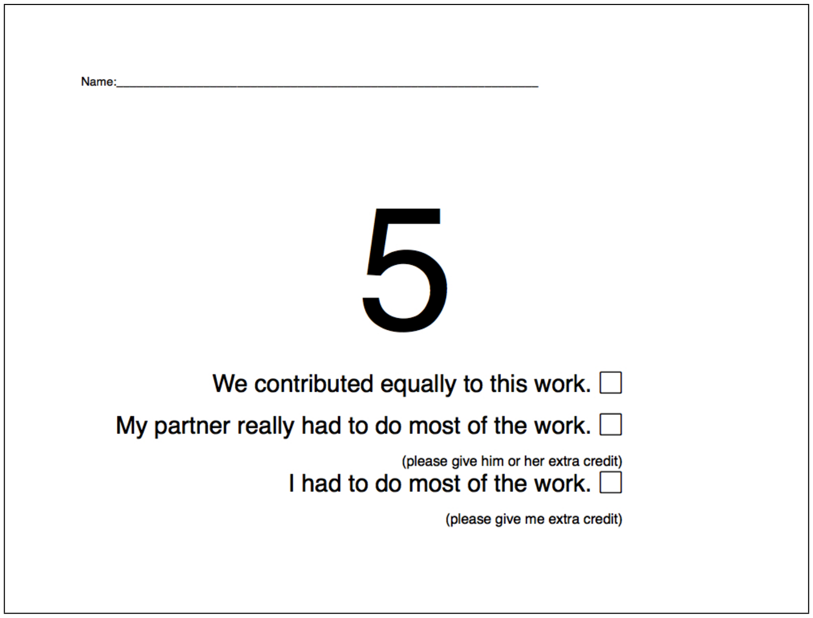
1 General Instructions

There is a coversheet, 2 worksheets, and 2 data sheets that you'll retrieve from the front of the room. They include:

- Two worksheets correspond to either the Fermilab Tevatron or the CERN LHC.
- There are two data sheets, one with Feynman Diagrams for the production of top quark pairs or Higgs Bosons at both the Fermilab and LHC accelerators. There's another data sheet for the decays of top quarks, Higgs Bosons, and Messenger Particles along with their Branching Ratios.
- The coversheet is the same as the "Code Sheet," described next:

Here is the order of events on Finals Day:

1. You will be given a Code Sheet with a single number on it, 1-8. An example is shown in Fig. 1. Notice that the Code Sheet also has items that need to be filled in. Do that privately when you hand it in at the end.
2. When we start the exercise, hold up your Code Sheet and find a partner with the same number as you. **Work only in pairs.**
3. Then the two of you are free to go anywhere in the BPS building to work on your two reactions. Be back by 09:45AM. (Um...on Thursday.) *Do not be late*, as I'll leave by 09:50AM since the room is busy during this week.
4. When you are done you'll staple together your Code Sheet (now acting as a cover sheet), and 2 worksheets. Then you'll fill out the front of the Code Sheet in the lecture hall, privately. **Not before.**



Name:____

5

We contributed equally to this work. ☐

My partner really had to do most of the work. ☐

(please give him or her extra credit)

I had to do most of the work. ☐

(please give me extra credit)

Figure 1: Someone's code sheet.

2 The worksheet boogie

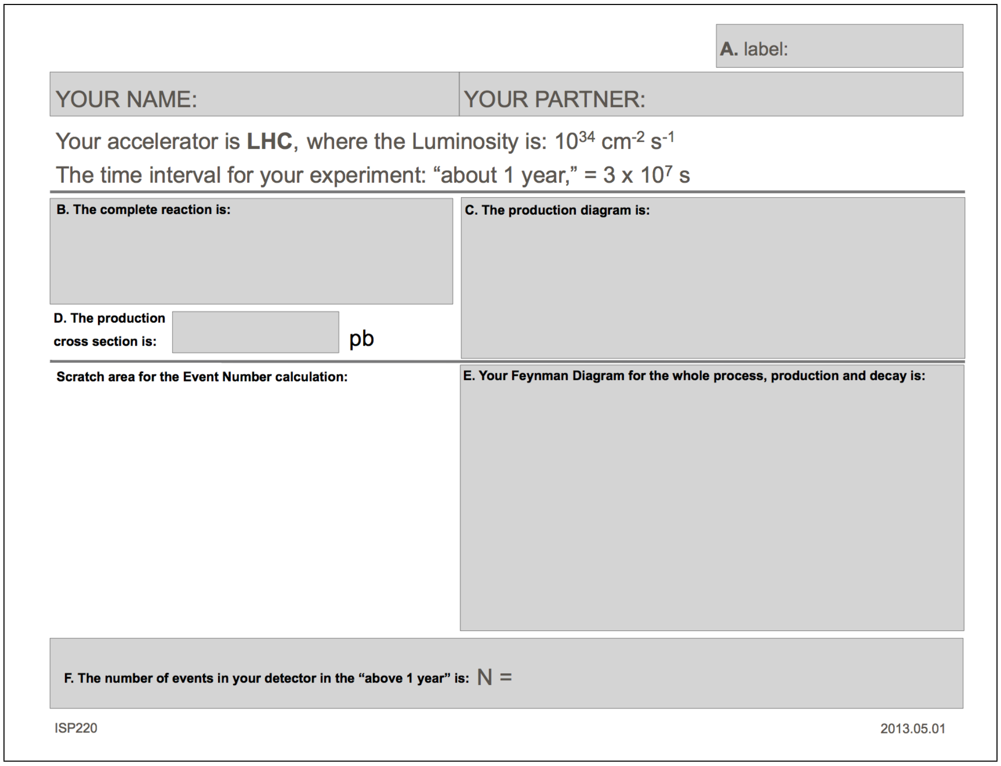
Your Code Sheet tells you what reactions and what accelerator you'll be working within. The Codes and corresponding reactions are at the end of this document.

You and your partner will each work on two worksheets. Figure 2 shows one of them. They will each tell you your accelerator, its luminosity, and the time frame over which you'll calculate the number of events. You draw or write in the gray regions.

On each worksheet you'll draw in the production diagram that corresponds to your reaction, the complete diagram from production through the decay corresponding to your reaction, and to calculate the number of events. You'll also draw in how that final state will appear in one of your detector sheets. You'll do this twice, once for a top quark reaction and once for a Higgs Boson reaction.

2.1 Example Worksheet, Workflow

1. The first thing you need to do is add your name and your partner's name on each worksheet.
2. Next you need to put the code in Box A in the upper right-hand corner of each



A. label:

YOUR NAME: YOUR PARTNER:

Your accelerator is **LHC**, where the Luminosity is: 10^{34} cm^{-2} s^{-1}

The time interval for your experiment: “about 1 year,” = 3 x 10^7 s

B. The complete reaction is:

C. The production diagram is:

D. The production cross section is: pb

Scratch area for the Event Number calculation:

E. Your Feynman Diagram for the whole process, production and decay is:

F. The number of events in your detector in the “above 1 year” is: N =

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Figure 2: A picture of one of the worksheets.

worksheet.

3. Let’s suppose that your reaction is listed as:

$$pp \to C + D \to wx + yz$$

which we’ll take to mean that particles C and D are each unstable (they could be Higgs Bosons or Top Quarks in our work) and that they decay like: $C \to wx$ and $D \to yz$, respectively. Rewrite the formula for the whole reaction just like the above in Box B. Here, A and B will either be pp or $p\bar{p}$. Write the production reaction just like that.

4. You’d look on the chart of production diagrams and find the right one and draw it into Box C. For this example, it would look like Fig. 3. But, you must draw it with the right *elementary* particles that actually collide. If the accelerator is the LHC, then A and B in your diagram would be $g + g$ as the colliding particles. If the accelerator is Fermilab, then the diagram would be $q + \bar{q}$ are the colliding particles.

5. Fill in the production cross section in Box D from the data sheet.
6. Next you would find the decays that are relevant for your process and draw a complete Feynman Diagram all the way to the end products which would be q, b, or leptons. This you would enter in Box E and it would look like Fig. 4. Again, draw the diagram for elementary particles in the initial state, not for protons or antiprotons.
7. Next you would calculate the number of events you would see in the detector corresponding to a year at the accelerator which is assigned to you. The luminosity is on each worksheet. You can enter your result as "events/y" in Box F.

Remember about the Branching Ratios: they are probabilities. Each of your scenarios has two or three decaying particles so you will form the product of the Branching Ratios for each. So for example, suppose the reaction was $A + B \to C + D$ in which C and D both separately decay as $C \to wx$ and $D \to yz$ with Branching Ratios BR_C and BR_D, respectively. Then the number of events of $A + B \to C + D \to wx + yz$ would require multiplying the number of all events of $A + B \to C + D$ times the quantity $BR_C \times BR_D$. Notice that w, x, y, or z could also decay further.

The number of events for this example would then be

$$N = \sigma \times \text{Luminosity} \times \Delta t \times BR_C \times BR_D$$

remembering the units.

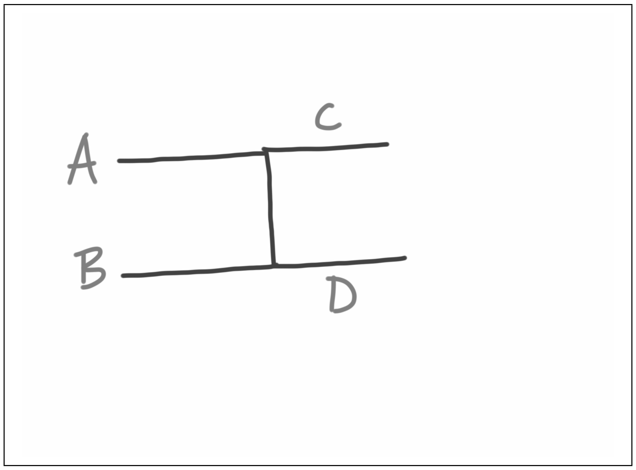

Figure 3: A fake production Feynman Diagram, which you'd draw into the upper dark box.

A few things to note:

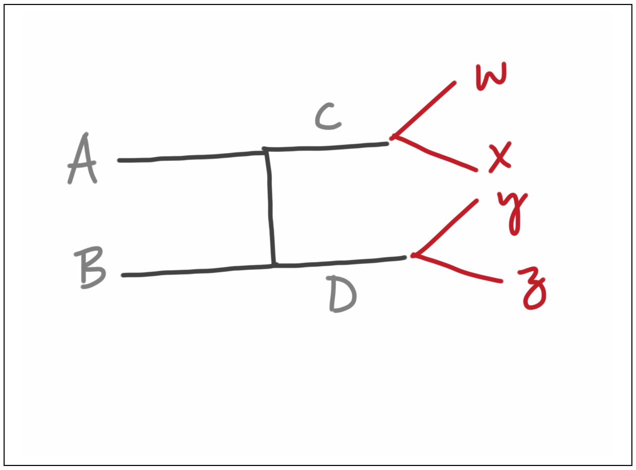

Figure 4: The complete diagram that you'd draw for $pp \to C + D \to wx + yz$.

- What I'll grade on your worksheet is what's filled in within the gray shaded regions.
- We are not going to be concerned about electric charges or particle-antiparticle designation. This is to simplify your drawing (and my grading!). So while you might have a reaction that is really $pp \to t\bar{t}$ followed by a particular decay for each of the top quarks...we'll ignore their charges, which is a particle, and which is an antiparticle. We'll write instead $pp \to tt$ and ignore the charge of W bosons and whether a lepton is e or $\bar{e}$ and so on.
- A notational alert: in the example, suppose that w subsequently decayed into $i + j$ and that y decayed into $m + n$, that is: $w \to i + j$ and $y \to m + n$, then I would write for the whole reaction

$$AB \to CD \to wx + yz \to ijx + mnz.$$

- Remember: if the accelerator is the LHC, then $g + g$ would be the colliding particles. If the accelerator is Fermilab, then $q + \bar{q}$ are the colliding particles. So if your coded reaction is pp or $p\bar{p}$ then you'll know what to write in Box C.
- If you have b quarks in your final state, treat them like any other quark.

3 Data you'll need

- The conversion from picobarns to cm^2 is:

$$1\text{pb} = 10^{-36}\text{cm}^2$$

- The Branching Ratios for W Boson decays are (notice that we'll not consider τ leptons, so this doesn't add to 100%):

$$\begin{aligned} BR(W \rightarrow e + \nu_e) &= 0.1 \text{ (which is 10\%)} \\ BR(W \rightarrow \mu + \nu_\mu) &= 0.1 \text{ (which is 10\%)} \\ BR(W \rightarrow q + q') &= 0.7 \text{ (which is 70\%)} \end{aligned}$$

- I didn't emphasize this in class, but the Z^0 Boson decays into lepton-antilepton and quark-antiquark pairs. It's neutral, so the decay products are of opposite charges. In order to preserve Lepton Numbers and Baryon Numbers, the decay products are always a fermion and its corresponding antifermion.
- The Branching Ratios for Z Boson decays that you'll need are:

$$\begin{aligned} BR(Z^0 \rightarrow e + e) &= 0.04 \text{ (which is 4\%)} \\ BR(Z^0 \rightarrow \mu + \mu) &= 0.04 \text{ (which is 4\%)} \\ BR(Z^0 \rightarrow q + q) &= 0.7 \text{ (which is 70\%)} \end{aligned}$$

- The Higgs Boson decays into everything that's less than half of its mass. We're presuming a low-mass Higgs Boson here (unlike the Honors Project which assumed a high mass Higgs Boson) and so the Branching Ratios that you'll need are:

$$\begin{aligned} BR(H^0 \rightarrow bb) &= 0.6 \text{ (which is 60\%)} \\ BR(H^0 \rightarrow Z^0 Z^0) &= 0.03 \text{ (which is 3\%)} \end{aligned}$$

- The Fermilab Luminosity is $10^{32}\text{cm}^{-2}\text{s}^{-1}$ and the LHC Luminosity is $10^{34}\text{cm}^{-2}\text{s}^{-1}$.
- We'll calculate for an approximate year: $\Delta t = 3 \times 10^7$ seconds.
- The number of events is: $N = \sigma(\text{production}) \times \text{Luminosity} \times \Delta t \times BR\text{s}$. Watch out for the units.
- Here are the reactions that go with the codes, 1-8:

Fermilab: Top quark pair and Higgs Boson production.

1 $p\bar{p} \rightarrow tt \rightarrow Wb + Wb \rightarrow e\nu_e b + qq'b$

$p\bar{p} \rightarrow W \rightarrow W + H^0 \rightarrow \mu\nu_\mu + bb$

2 $p\bar{p} \rightarrow tt \rightarrow Wb + Wb \rightarrow \mu\nu_\mu b + qq'b$

$p\bar{p} \rightarrow W \rightarrow W + H^0 \rightarrow e\nu_e + bb$

3 $p\bar{p} \rightarrow tt \rightarrow Wb + Wb \rightarrow e\nu_e b + \mu\nu_\mu b$

$p\bar{p} \rightarrow W \rightarrow W + H^0 \rightarrow qq' + bb$

4 $p\bar{p} \rightarrow tt \rightarrow Wb + Wb \rightarrow \mu\nu_\mu b + \mu\nu_\mu b$

$p\bar{p} \rightarrow W \rightarrow W + H^0 \rightarrow qq' + bb$

LHC: Top quark pair and Higgs Boson production.

5 $pp \rightarrow tt \rightarrow Wb + Wb \rightarrow e\nu_e b + qq'b$

$pp \rightarrow H^0 \rightarrow Z^0 + Z^0 \rightarrow \mu\mu + \mu\mu$

6 $pp \rightarrow tt \rightarrow Wb + Wb \rightarrow \mu\nu_\mu b + qq'b$

$pp \rightarrow H^0 \rightarrow Z^0 + Z^0 \rightarrow ee + ee$

7 $pp \rightarrow tt \rightarrow Wb + Wb \rightarrow qq'b + qq'b$

$pp \rightarrow H^0 \rightarrow Z^0 + Z^0 \rightarrow ee + \mu\mu$

8 $pp \rightarrow tt \rightarrow Wb + Wb \rightarrow \mu\nu_\mu b + e\nu_e b$

$pp \rightarrow H^0 \rightarrow Z^0 + Z^0 \rightarrow qq + qq$