LHC Prospects for QCD, Electroweak and Top

101st LHCC Interaction
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The Road Ahead

Begin by understanding the basic objects: leptons, photons, jets, missing ET…

Continue by combining them to form complex final states like top.

Often these have similar signatures as searches.

New Physics!

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The Road Ahead

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Continue by combining them to form complex final states like top.

Often these have similar signatures as searches.

If you’re going to spend significant time on this road, wouldn’t you like to look at the scenery?

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Outline

• I will discuss some of the interesting attractions on this road, concentrating on milestones of 100-200 pb\(^{-1}\) and 1 fb\(^{-1}\).
  – Hard QCD
  – W’s, Z’s
  – Top

• This talk is intended to be mostly illustrative and qualitative.
  – By it’s nature, it will be somewhat episodic
  – There will be a lot of scaling and extrapolations
  – I am afraid I will omit far more than I can include
Both experiments see jets, and are busy producing a jet energy scale for the summer conferences.
Jets: After The First Inverse Nanobarn

- We expect to reach jets with $E_T$’s of around 1.4 TeV after the first 100 pb$^{-1}$
- Also, jets with $E_T$’s of around 1.7 TeV after the first fb$^{-1}$
- Reminder: as a rule of thumb, the sensitivity to a contact interaction $\Lambda$ is roughly 4x the $E_T$ of the most energetic jet.
  - We expect to have world-class limits very soon.

NLO QCD jet spectrum – no detector effects included

Thanks to Steve Ellis for making this
  - Aside: shows the value in having a strong theory group (including visitors) nearby.
W’s and Z’s

The LHC is producing W’s and the experiments are reconstructing them.

Kevin showed this event this morning, but I am showing it again because I like it.

- Each experiment expects ~25,000 Z’s and ~250,000 W’s (for each flavor) every 100 pb$^{-1}$.
  - In the past, we have discussed the utility of these events for calibration, etc.
  - I’d like to highlight a few physics measurements possible – beyond the obvious cross-sections and $p_T$ spectra.
“W Asymmetry”

- At the Tevatron, there is an $\eta$-dependence to the W lepton spectrum
  - Due to two factors:
    - The quark PDFs
    - The W decay distribution (known)
  - Because it’s proton-antiproton, this is an odd function of $\eta$.

- At the LHC, the same thing happens.
  - It depends more on sea quark PDFs (no valence antiquarks)
  - Because it’s proton-proton, this is an even function of $\eta$.
  (“Asymmetry” is not the best word, but the terminology stuck.)

At 7 TeV, we get the same W yield at ~150 pb$^{-1}$. However, the asymmetry is expected to be larger at lower energy.
W Mass

- **A very challenging measurement**
  - Limited by systematic uncertainties

- Today’s measurement with the most events is D0’s, based on 500K W’s.
  - Each experiment will collect a comparable amount of data after ~200 pb$^{-1}$
  - A large data set is a necessary, but not sufficient condition to do this measurement.

- Historically, systematic uncertainties track statistical uncertainties
  - More events let you better understand and control these systematics, in particular the lepton energy scale.

- While not a fast measurement, it is an important measurement
  - One important difference at 7 TeV vs. 14 TeV: the QCD corrections are smaller
In the 2010-11 Run, the LHC will substantially increase the kinematic range available for study.

In particular, W production allows probing low x, high $Q^2$ quarks and antiquarks.

The 7 TeV data “fills the gap” between the Tevatron and a 14 TeV LHC.

From CTEQ: these are the inputs to CTEQ5
Top Quark “Rediscovery” – Dileptons

- Signature is 2 leptons, 2 jets + missing $E_T$.

- With $\sim 10$ pb$^{-1}$, we expect a convincing signal
  - Each experiment will have $\sim 30$ events with an expected background of 5 or 6.

- Even with 5 pb$^{-1}$, many will find the signal plausible:
  - Each experiment will have $\sim 15$ events over a background of around 3.

- At 1 pb$^{-1}$, interesting event displays will start to appear at conferences
  - “Here’s an event with many features one would expect from top pair production.”

### Expected 10 pb$^{-1}$ sensitivity (per experiment)

<table>
<thead>
<tr>
<th>Channel</th>
<th>N(Signal)</th>
<th>N(background)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e - \mu$</td>
<td>14</td>
<td>2.5</td>
</tr>
<tr>
<td>$e - e$</td>
<td>4.3</td>
<td>1.1</td>
</tr>
<tr>
<td>$\mu - \mu$</td>
<td>6.6</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>25</strong></td>
<td><strong>5.5</strong></td>
</tr>
</tbody>
</table>

ATL-PHYS-PUB-2009-086 + scaling to 10 pb$^{-1}$ @ 7 TeV.

This, however, is not the whole story: these aren’t just jets – they are $b$-jets. The above table does not make use of this - additional confirmation can be obtained via flavour tagging.

Cross-section scaling used:

$$\sigma (tt)_{7} \approx 40\% \sigma (tt)_{10}$$

$$\sigma (W + \text{jets})_{7} \approx 45\% \sigma (W + \text{jets})_{10}$$
Flavour Tagging Today

- Both experiments are studying flavour tagging with the data in hand.
  - Many tagged jets have been found, sometimes correlated with nearby leptons or second tags in the event

- The emphasis is on “early taggers”
  - Not necessarily the ultimate performance, but can be understood quickly.
Top Quark “Rediscovery” – Lepton+Jets

- Here too, a few pb\(^{-1}\) gets us to an interesting region
  
  - This N\(_{\text{jets}}\) plot is for 20 pb\(^{-1}\) at 10 TeV; so it looks similar to what we would expect for ~50 pb\(^{-1}\) at 7 TeV.
  
  - At 7 TeV and 10 pb\(^{-1}\), we expect ~60 top events per lepton flavour per experiment over a background of ~40 in the 4 jet, 5 jet and 6+ jet bins.

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Again, this is done without flavour tagging, which can be used to confirm the top content of the W+multijet sample.

Cross-section scaling used:

\[
\sigma (t\bar{t})_{10} \approx 40\% \quad \sigma (t\bar{t})_{10}
\]

\[
\sigma (W + \text{jets})_{7} \approx 45\% \quad \sigma (W + \text{jets})_{10}
\]

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The Next Few Hundred pb$^{-1}$

- Each experiment expects top yields of
  - Dilepton: $\sim$400 per 100 pb$^{-1}$
  - Lepton ($e$ & $\mu$) + Jets: $\sim$1400 per 100 pb$^{-1}$ (with large variations depending on selection requirements)

- By the end of 2010, the LHC will have samples comparable to the Tevatron’s.

- By the end of 2011, the top samples will be substantially larger

- The physics program with a few hundred pb$^{-1}$ will look very familiar
  - Top cross-section (at a new energy)
  - Top mass (at the end of the year you will see averages over 4 experiments, not 2)
  - Single Top
  - Rare decays
Top Production with More Data

Top pair production in the lepton+jets mode with \(\sim500\ \text{pb}^{-1}\) at 7 TeV. This analysis has an \(m(jj) = m(W)\) requirement.

The background has a large component from misassignment: b-tagging will help.

- Single top production is quite challenging
  - The top pair background is enormous
  - The uncertainty on the backgrounds is larger than the expected signal: makes a pure counting experiment impossible

\[ \sim1\ \text{fb}^{-1} \text{ at 7 TeV} \]
Rare Top Decays (I)

- The limits on the FCNC decays $t \rightarrow qZ$ and $t \rightarrow q\gamma$ are driven by the top quark pair yield: more tops implies a better limit.

- The measurement of $BF(t \rightarrow Wb)/B(t \rightarrow Wq) (=R)$ is driven by the knowledge of the $b$-tagging efficiency.
  - CMS has developed a technique to do this in a data-driven manner:
    - Start with top dilepton ($e-\mu$) events
      - The purest sample we have
      - We would like to know $R$, $\varepsilon_b$ and the non-top contamination in the sample
    - Measure the number of events with 0, 1 and 2 tags.
      - The ratios $N_2/N_1$ and $N_1/N_0$ depend differently on $R$ and $\varepsilon_b$ (i.e. not only on their product)
    - Correct for misassignment
      - I won’t describe the two techniques here.
Rare Top Decays (II)

- With 250 pb\(^{-1}\) of 10 TeV data, CMS expects a ±9% measurement of \(R\).
  - This is the present PDG uncertainty
  - The systematic uncertainties are uncorrelated between this measurement and the Tevatron’s.
- This corresponds to ~600 pb\(^{-1}\) of 7 TeV data: mid-2011 in the present schedule
- The volume of the LHC top dataset allows us to do measurements in different ways than the Tevatron:
  - For example, restricting ourselves to the cleanest \(e-\mu\) channel.
- This makes combination easier, but more importantly, adds robustness
  - Independent systematic uncertainties
Summary

• The LHC is not *about to start* an interesting physics program

• The LHC is *in the midst* of an interesting physics program!
  – Involving 900 GeV, 2.36 TeV and 7 TeV data

• This program will
  – Permit measurements in new regions:
    • The new region in the x-\(Q^2\) plane – including TeV-scale jets
    • The new region of top physics opened up by having many thousands of events
  – Provide many thesis opportunities for our graduate students
  – Will build the foundation for our searches for new physics – *see Oliver’s talk (next).*