CMS Preparations for Early LHC Physics

Joint Theory-CMS Seminar
May 31, 2007

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LHC is built to discover new physics

Long list of possible scenarios

Higgs

SUSY

Extra Dimensions, $Z'$

Substructure, contact interactions

Something “as yet unthought of”

First, have to get the detector running and make the measurements that form the foundation on which we can look for new physics
Looking for something new

Finding a signal for new physics means understanding all the SM backgrounds

As an example...

Single Top

- Long list of backgrounds
- Each background is made up of many pieces as well
- CMS has to start back at the beginning
Looking for something new

- $W^+W^-$
- $W^+$
- $W$
- $WZ$
- $Z$
- $b$-tag
- $e$
- $\mu$
- $\gamma$
- jets
- $\tau$
- MET
- $TT$
- single top
Since we don’t know when/where new physics might appear, CMS needs to be ready as early as possible

- Have to calibrate and align the detector
- At the same time, commission trigger and DAQ

General strategy:
- Prepare as much as possible beforehand, using cosmic rays, test beam, etc.
- “Rediscover the Standard Model”
- Use the clear, well-known signals of SM to commission the detector
CMS Detector

- Pixel Tracker
- Superconducting solenoid
- Hadronic calorimeter
- EM calorimeter
- 20m
- "detectors"
Data Samples

Ignore the exact date of the LHC turn-on or the speed of the luminosity ramp-up

Today consider four data samples

1. Early data running: $< 10 \text{ pb}^{-1}$
   - Initial luminosity starting $\sim L=10^{28}$
   - Detector alignment, calibration from cosmics, sources, MC

2. $10 \text{ pb}^{-1}$

3. $100 \text{ pb}^{-1}$
   - First data-driven alignment, calibration being applied

4. $1 \text{ fb}^{-1}$ ($\sim 6$ months running at $L=10^{32}$)

For each data sample:
- What Standard Model physics can we measure?
- How can we use the data to improve detector performance?
Approximate event rates for different samples
(making a few reasonable assumptions about efficiency)

<table>
<thead>
<tr>
<th>Channel</th>
<th>10 pb⁻¹</th>
<th>100 pb⁻¹</th>
<th>1 fb⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>W→μν</td>
<td>10⁵</td>
<td>10⁶</td>
<td>10⁷</td>
</tr>
<tr>
<td>Z→μμ</td>
<td>10⁴</td>
<td>10⁵</td>
<td>10⁶</td>
</tr>
<tr>
<td>tt→μνX</td>
<td>10²</td>
<td>10³</td>
<td>10⁴</td>
</tr>
</tbody>
</table>

Comparable statistics to Tevatron after 100 pb⁻¹
The Minus-end Muon Systems in SX5 being commissioned using cosmics
Early Physics with Tracker

One of the earliest results to come from CMS could involve simple distributions of tracks

Transverse-Momentum Distributions of Charged Particles Produced in \( \bar{p}p \) Interactions at \( \sqrt{s} = 630 \) and 1800 GeV

Measurements of inclusive transverse-momentum spectra for charged particles produced in proton-antiproton collisions at \( \sqrt{s} \) of 630 and 1800 GeV are presented and compared with data taken at lower energies.

Charged particle multiplicity in pp collisions at \( \sqrt{s} = 14 \) TeV

We report on a measurement of the mean charged particle multiplicity in minimum bias events, produced in the central region \( |\eta| < 1 \), at the LHC in pp collisions with \( \sqrt{s} = 14 \) TeV, and recorded in the CMS experiment at CERN. The events have been selected by a minimum bias trigger, the charged tracks reconstructed in the silicon tracker and in the muon chambers. The track density is compared to the results of Monte Carlo programs and it is observed that all models fail dramatically to describe the data.

- A. De Roeck
Physics with Early Data

Early data is good for both physics and for starting data-driven detector calibrations

- Min bias measurements to understand tune underlying event

- Improve alignment with high $P_T$ tracks

- Refine calorimeter calibrations
  - Zero-bias triggers used to measure noise
  - Isolated tracks compared to test beam data for HCAL
  - $\pi^0, \eta \rightarrow \gamma \gamma$ for in situ ECAL calibration
Huge jet cross-section, many orders above Tevatron

Another early CMS paper?

Measurement of inclusive jet cross section in pp collisions at 14 TeV

We present results from the measurement of the inclusive jet cross section for jet transverse energies from 100 to 1500 GeV in the pseudorapidity range $0.1 < |\eta| < 1.4$. The results are based on 18 $pb^{-1}$ of data collected by the CMS Collaboration at the Large Hadron Collider at CERN. The data are consistent with previously published results. The data are also consistent with QCD predictions given the flexibility allowed from current knowledge of the proton parton distributions.

- K. Lassila-Perini
Physics with $\sim 10$ pb$^{-1}$

- Expected numbers of events:
  
  $70k \ W \to l\nu , \ 10k \ Z \to l^+l^-$
  
  $50$ dilepton $ttbar, \ \sim 350$ lepton+jets $ttbar$

- Measure $W$ and $Z$ production cross-section
  
  Understand efficiency (esp. isolation) from data
  
  Understand bkgd from data

- Observe top pair production
  
  First complex event topology to be reconstructed
  
  Probably requires $20-30$ pb$^{-1}$
Observation of top at 14 TeV

Simple reconstruction without b-tagging

- Use semi-leptonic top events with exactly 4 jets
- Select 3 highest $\Sigma P_T$ jets
- Two jets with highest $\Sigma P_T$ are $W$
- Background from $W+4$ jets

Details in ATLAS note atl-phys-pub-2005-024
Jet Calibrations from Data

Initial calibrations from sources, test beam, and MC

- Can be refined with very early data
- To go further, use dijet and photon-jet balancing

MC corrections flatten response vs. eta

10^5 events per point
Missing $E_T$

Two parts to Missing $E_T$:

Understanding high MET tails
Resolution on real MET

Cleaning up tails:
- Some clean up without beam from calibrations, etc.
- Use data to understand beam backgrounds
- Tools taken from Tevatron, but need study at LHC

Measure MET Resolution
- Effect of pile-up?
- Improvement w/jet corrections

~$0.97 \times \sqrt{\Sigma E_T}$

Run II
V. Shary
CALOR04
Evolution of the Trigger

At turn-on Level 1 trigger will be wide open

- Low Sum $E_T$ in calorimeter or any muon

$L=10^{28-29}$ start adding simple triggers

- Calorimeter - low $E_T$ electron (5 GeV) or jet (10 GeV)
- Low $P_T$ muon (3 GeV)
- Use High Level Trigger to control rate to tape

Two parallel strategies as luminosity, trigger rates rise:

- Keep lower thresholds on some triggers by adding conditions
  - Isolation, Had/EM for electrons
  - Isolation, extra quality cuts on muon
- Raise thresholds on unrestricted triggers
  - No added conditions on these triggers
Physics with $\sim 100$ pb$^{-1}$

- Expected numbers of events:
  
  $1M \ W \rightarrow l\nu$ , $100k \ Z \rightarrow l^+l^-$
  
  $400$ dilepton $ttbar$, $2500$ lepton+jets $ttbar$
  
  $1000$ Jets $P_T>1$ TeV

- Dijet masses up to $\sim 5$ TeV
- First $W$ and $Z$ with taus
- First real top measurements
  - Measure top cross-section
  - Measure top mass
  - Use top sample to verify JES, b-tagging efficiency
Dijet Analysis with 100 pb$^{-1}$

- Trigger strategy carefully defined to match thresholds, prescales to avoid gaps in sensitivity
- Lowest threshold triggers to match with Tevatron
- Use data-driven jet corrections

Statistical precision < 3% for dijet masses < ~1.5TeV
Top cross-section with $\sim 100 \text{ pb}^{-1}$

Same reconstruction as before in lepton+jets events

- Invariant mass of 3 highest $\Sigma P_T$ jets
- No b-tags or kinematic fit

Good statistical precision, but systematics (especially on mass) may still be large

Sample should be large enough, with good purity, that the b-tagging efficiency or jet energy scale can be cross-checked in the data
Tracker Alignment with Data

Most important issue in getting optimal performance from the tracker will be alignment

- Efficiency expected to be high
  - mostly unaffected by misalignment
- Early alignment from survey, cosmic rays, beam gas
- Need high $P_T$ muons from $W$ and $Z$ to improve alignment,
  - $\sim 100k \ Z \rightarrow \mu \mu$ in $100 \ pb^{-1}$
Effect of Tracker Alignment

Short term: 0.1-1 fb\(^{-1}\)
Long term: > 1 fb\(^{-1}\)

Early misalignment affects momentum, mass resolution

Above 1 TeV, muon system becomes important
Physics with \( \sim 1 \text{ fb}^{-1} \)

- Expected numbers of events:
  
  \[
  10M \text{ } W \rightarrow l\nu \text{ , } 1M \text{ } Z \rightarrow l^+l^-
  \]
  
  2000 dilepton ttbar, 12000 lepton+jets ttbar
  
  10000 Jets \( P_T > 1 \text{ TeV} \)

- Extending dijet spectrum up to \( \sim 6 \text{ TeV} \)
- W+jets and Z+jets
- Dibosons
- First real top measurements
  
  - Observe single top, fully hadronic top decays
  
  - Use top sample to measure JES, b-tagging efficiency
Diboson Production with $\sim 1 \text{ fb}^{-1}$

- Look for $WZ \rightarrow 3$ leptons (e or $\mu$)
- Reject events with second Z candidate
- Reject events with jets above 25 GeV

### Expected Events in 1 fb$^{-1}$

<table>
<thead>
<tr>
<th>channel</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>WZ</td>
<td>96.8</td>
</tr>
<tr>
<td>ZZ</td>
<td>5.2</td>
</tr>
<tr>
<td>ttbar</td>
<td>2.8</td>
</tr>
<tr>
<td>$\mu\mu bb$</td>
<td>11.4</td>
</tr>
<tr>
<td>$ee bb$</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Trigger strategy extended to “Ultra” high threshold to avoid prescale on highest threshold trigger

Statistical precision < 3% for dijet masses < ~2.5TeV
Using top for Jet Energy Scale

- Start with lepton + 4 jets events with tight kinematic selection
- Require exactly two b-tagged jets
  - Remaining two jets should be from W
  - Correct combination found with efficiency \( \sim 80\% \)
- Further reduce background with cuts on \( P_T(W) \) and \( m_{\text{top}} \)
  - \( 1 \text{ fb}^{-1} \): \( \sim 700 \) signal events

To obtain JES, rescale all jets by \((1+\Delta C)\) to obtain new \( m(W) \) distribution

Get \( \Delta C \) from best fit to PDG \( m(W) \)

Similar procedure using \( m(W) \) and \( m(\text{top}) \) can be used for b-jets
Measure b-tag efficiency in data

Tight kinematic requirements to optimize efficiency for choosing correct jet pairing

Yields pure b-jet sample to measure tagging efficiency

(Important for any later $H \to bb$ search)
Activities at the LPC

Many experts resident at the LPC

- Simulation: Daniel Elvira, Harry Cheung
- Jets, Missing $E_T$: Rob Harris, Marek Zielinski
- Electrons, photons: Yuri Gershtein, Colin Jessop, Jeff Berryhill
- Muons: Eric James, Michael Schmitt
- Tracking: Kevin Burkett, Steve Wagner
- Trigger: Kaori Maeshima, Greg Landsberg
- Taus: Alexei Safonov
- b-tagging: Cecilia Gerber, Meena Narain
- Physics: Boaz Klima
- Offline Software: Liz Sexton-Kennedy

Plus many detector experts as well
Activities at the LPC

Physics activities still ramping up

Next Friday, Saturday: Mini-Workshop on Early CMS Physics

Friday:
- Discussion of CMS plans for physics
- Discussion of common areas of interest

Saturday:
- Tutorials to get people going with analysis

http://www.uscms.org/LPC/lpc_wkshp/early_physics_jun07.html
Conclusions (I)

- LHC offers the possibility of exciting discoveries
- Lots of work ahead to prepare, but we should be able to use clear SM signals in the commissioning
- Some milestones along the way
  - With 10 pb$^{-1}$
    - Measure W and Z cross-sections
    - Observe top production
  - With 100 pb$^{-1}$
    - Measure top production
- Measurements with 1 fb$^{-1}$ should go beyond the current Tevatron precision
Conclusions (II)

If we have done a good job, then with 1 fb\(^{-1}\) of data we might see something new

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