Early Discovery Channels in CMS

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on behalf of the Compact Muon Solenoid (CMS) collaboration

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“Early discovery channels”

- Based on recent LHC schedules, we can hope for about 100 \( pb^{-1} \) of 10 TeV collisions in 2009
- Full re-analysis at 10 TeV is under study, but most production cross-sections will be reduced by about a factor of 2, depending on mass
- In this talk: 14 TeV analyses reoptimized for 100 \( pb^{-1} \)
  - new results, post-Physics TDR
  - roughly what we may see this year

Outline of this talk

1. CMS detector
2. Standard Model: rediscovery, service measurements, and new modes
3. Brief note on SUSY
4. Di-object signature searches: \( e^+ e^- \), \( \mu^+ \mu^- \), jet-jet, jet-\( \not{E}_T \), . . .
5. Heavy, long-lived particles and other models
Nearly $4\pi$ general-purpose detector
- All-silicon tracker
- Solenoidal magnetic field
- Highly-redundant muon tracking system (44 muon layers in barrel)
Rediscovering the Standard Model

- Signals and backgrounds at $10 \text{ pb}^{-1}$

  $e^\pm \nu$ or $e^+ e^-$

  $W^\pm$

  missing transverse energy

  $\mu^\pm \nu$ or $\mu^+ \mu^-$

  transverse mass

- $Z^0$

  $e^+ e^-$ mass

  $\mu^+ \mu^-$ mass

- Top quarks observable with $10–100 \text{ pb}^{-1}$ (see Oliver’s talk)
Using the SM for future discoveries

- Determine electron and muon efficiencies by tagging one leg of a $Z \rightarrow \ell\ell$, probing the other (right)

- $W^\pm$ charge asymmetry (below)

\[
A(\eta) = \frac{(d\sigma/d\eta)(W^+) - (d\sigma/d\eta)(W^-)}{(d\sigma/d\eta)(W^+) + (d\sigma/d\eta)(W^-)}
\]

- probes $u/d$ PDFs for other analyses
- depends only on detector issues that are currently being studied with real data in cosmic ray asymmetry
Discoveries in the Standard Model

- $Zb\bar{b}$ and di-bosons (re-discovery):
  - background for Higgs searches  
    $$H \rightarrow ZZ \rightarrow 4\mu, \text{SUSY } H \rightarrow 2\tau(\mu)$$

- Higgs boson? Even a heavy Higgs?
  - $H \rightarrow ZZ$ sensitivity starts at 3 fb$^{-1}$  
    (for 95% C.L. in $200 < M_H < 400$ GeV)
  - $H \rightarrow WW$ has $\sim 10$ signal, $\sim 10$ background events at 100 pb$^{-1}$  
    with a boosted decision tree analysis
  - comparable to Tevatron’s reach
SUSY at 100 pb$^{-1}$ (briefly)

- From the Physics TDR (which focuses on 1 fb$^{-1}$ and above)
- See Oliver and Anwar’s talks for more details on SUSY modes
Di-object signature searches

- Look for a (high) mass peak or enhancement in inclusive $X$-$Y$ pairs, where $X$ and $Y$ are reconstructed “physics objects” like $e^{\pm}$, jet, $\not{E}_T$

- Between a specific-model hunt and completely generic search
  - physics motivation is strong but loosely-specified:
    - **di-muon**: electroweak couples to leptons, easiest to identify
    - **di-electron**: electroweak couples to leptons, high-resolution calorimetry at high energy
    - **di-jets**: new physics may be strongly interacting, high statistics
    - **jet-$\not{E}_T$**: dark matter shows up as missing energy
    - **$t\bar{t}$**: new physics will likely be coupled to the third generation *(demands new techniques because $W$ and $b$ jets overlap in boosted tops)*
    - **di-tau**: new physics will likely be coupled to the third generation
    - **$\gamma\gamma$**: easy way to identify spin-2 parent
  - small set of simply defined channels (good for low statistics)

- Also help to commission the reconstruction of physics objects for more sophisticated analyses
Di-electrons/muons: $Z'$, RS-1 $G^*$

$Z'_\psi \rightarrow e^+ e^-$

$Z'_\psi \rightarrow \mu^+ \mu^-$

- Easiest-to-identify signature of new self-adjoint bosons (and therefore a very early analysis)

- Long lever arm in muon tracking system helps to resolve straight tracks and high redundancy helps to distinguish delta rays from TeV muon showering
Measuring cross-section relative to $Z^0$ reduces systematic uncertainties:

- integrated luminosity will only be known to 10–20% in early data
- PDF uncertainties from $q\bar{q}$ initial states are reduced in the ratio

95% C.L. upper limit on an unobserved $Z_{\psi}$ cross-section

$$\approx \left(10–30 \times 10^{-6}\right) \times Z^0 \text{ cross-section}$$
Di-jets: contact interactions, $q^*$, SUSY

- Enhanced production at high mass (for central $|\eta|$: contact interactions
- Resonance peaks: excited quarks ($q^*$), new bosons $Z'$, RS-1 $G^*$
- Angular correlation: direct-decay SUSY e.g. $\tilde{q}\tilde{q} \rightarrow q\chi^0_1 q\chi^0_1$

\[ \alpha_T = \frac{E_T(jet\ 2)}{M_{\text{transverse} \ inv}(jets\ 1&2)} \]

(L. Randall and D. Tucker-Smith arXiv:0806.1049)
$E_T + 1$ or more jets: ADD gravitons

- Simple signature: $E_T + 1$ jet is the missing energy analogue of a di-object search
- Application: if extra dimensions lower the Plank mass to the TeV scale, real gravitons would be emitted in quark/gluon collisions (ADD model and variations)
- Optimistic case in 100 pb$^{-1}$ pictured below: number of dimensions $\delta = 2$ compactification scale $M_D = 2$ TeV

Significance in 100 pb$^{-1}$

3 is 99.6% C.L.
5 is a 5$\sigma$ discovery
Missing energy is a physics object commissioned in simple signatures, to be used later in dark matter searches

Decomposition of $\not{E}_T$ resolution (top plot)

$$\sigma(\not{E}_T) = A \oplus B \sqrt{\sum \not{E}_T - D} \oplus C (\sum \not{E}_T - D)$$

A. electronic noise, pile-up, underlying event
B. statistical sampling in calorimeter towers
C. non-linearities, cracks, dead material
D. effect of noise, etc. on $\sum \not{E}_T$

where $\not{E}_T = |\text{vector missing momentum}|$
and $\sum \not{E}_T = \text{the scalar sum}$

Snapshot from real data: response of calorimeter towers to muons, a $\not{E}_T$ correction, as seen in cosmic rays (bottom plot)

See James Lamb and Paolo Rumerio’s talks for more
Heavy, long-lived charged particles

- New particles might be charged and live long enough to be detected (split SUSY, part of WIMP sector...)

- Unusual detector signature: would look like a muon with the wrong timing in the CMS drift tubes (top figure) and low-velocity $dE/dx$ in silicon tracker

- Requiring a correlation yields low backgrounds at high mass: 500 GeV stop from split SUSY with 100 pb$^{-1}$ shown at bottom-right
Other new results

- $W' \rightarrow e\nu$ (plot at right)
  - enlarged gauge groups usually predict a new $W'$ as well as $Z'$
  - can also be thought of as an $e + \slashed{E}_T$ di-object search

- $b'b' \rightarrow WWWW bb$
  - 1–4 leptons + 2 $b$-jets
  - 100 pb$^{-1}$ 95% exclusion at the few-pb level up to $M_{b'} = 480$ GeV (well below predicted cross-section for these masses)

- Heavy Majorana neutrino $\rightarrow \ell W_R$ with $W_R \rightarrow$ jet jet
  - signature 1: dijet mass peak + 2 leptons (produced through $W_R$)
  - signature 2: dijet mass peak + 1 lepton (produced through $Z_R$)

- Model Unspecific Search in CMS (MUSiC)
  - 300–400 combinations of $e$, $\mu$, $\gamma$, jet, $\slashed{E}_T$
Conclusions

- With 100 pb$^{-1}$, we can do more than “rediscover the Standard Model”

- Di-object searches are a simple way to address broad classes of new physics with small statistics, and at the same time improve our understanding of the detector response

- Understanding the detector with real data will be key to all analyses, early and long-term

- Trigger and pattern recognition are also being made sensitive to unusual detector signatures like long-lived charged particles, $R$-hadrons that stop in the calorimeter or cavern, etc.

- Not everything was included in this talk, I hoped to highlight those analyses which can be performed with low statistics
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See https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults for more