Collider Scene Investigation

CSI: Jets + MET
THE SECOND SEASON

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Goal with CMS
Why Jets+MET?
$\sigma_{BSM} \sim 50$ pb
Tasks at a Glance
Sign-up!!!

Physics with Jets+MET Topology

January 14, 2009
The CMS SUSY and EXOTICA groups have a set of vigorous programs to discover new particle(s). The LPC Jets+MET topology group will help such CMS programs in the following final states:

- $E_T^{\text{miss}} + \text{Jets}$
- $E_T^{\text{miss}} + \text{Jets} + \tau's$
- $E_T^{\text{miss}} + \text{Jets} + b's$ (e.g., $h \rightarrow bb$)
- $E_T^{\text{miss}} + \text{Jets} + t's$ (e.g., gluino $\rightarrow t\bar{t} + \text{neutralino}$)

As a group, we will actively involved in various common tasks such as $\tau$ ID, $b$ tagging, and missing $E_T$ clean-up/calculation/correction in the CMS SUSY and EXOTICA groups to maximize the success of the CMS new particle hunting in the initial conditions up to 1 fb$^{-1}$ for now. This obviously also leads us to make strong connections with Dijet topology group and $\tau/b$ object groups. ...
Start with “Running” Couplings

e.g., QCD

\[ \alpha_s(Q^2) = \frac{12\pi}{(11n_{\text{color}} - 2n_{\text{flavor}}) \log(Q^2/\Lambda^2)} \]

\[ n_f = 6 \text{ (quark flavors); } n_c = 3 \text{ (colors)} \]

The Nobel Prize in Physics 2004

David J. Gross
Kavli Institute for Theoretical Physics
University of California, Santa Barbara, USA

H. David Politzer
California Institute of Technology (Caltech), Pasadena, USA

Frank Wilczek
Massachusetts Institute of Technology (MIT), Cambridge, USA

Introduction to High Energy Physics by D. H. Perkins

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A Hint of Beyond-SM at Tera-scale

$M_{\text{SUSY}} \sim 500-3000 \text{ GeV/c}^2$
and two (and only two)
Higgs doublets

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Why Jets+MET at the LHC?

Example: SUSY with R-parity Conservation

- $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$, or $\tilde{q}\tilde{q}$ production will be dominant, followed by their decays (e.g., $\tilde{q} \rightarrow q\tilde{\chi}_2^0$). → Jets
- R-parity conservation
  - Stable lightest supersymmetric particle (LSP)
  - If LSP is the lightest neutralino ($\tilde{\chi}_1^0$),
    - it will escape the detector → MET ($E_T$)
    - $\tilde{\chi}_1^0 = $ Cold Dark Matter candidate → Cosmology
  - Thus, the evidence of SUSY-like new physics will appear in the Jets+MET final states.

Cosmology + LHC

= [Exciting Motivation] + [Right Place & Timing]

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CBS comedy “Big Bang Theory” (Season 2 Episode 5, Oct 20, 2008)
\[ \tilde{\chi}_2^0 \rightarrow \tau^+ \tau^- \rightarrow \tau^+ \tau^- \tilde{\chi}_1^0 \]

hep-ph/0603128

\[ \tilde{\chi}_2^0 \rightarrow h \tilde{\chi}_1^0 \rightarrow b\bar{b} \tilde{\chi}_1^0 \]

hep-ph/0808.1372

\[ \tilde{g} \rightarrow t\bar{t} \tilde{\chi}_2^0 \rightarrow (jjb)(jjb)(ll\tilde{\chi}_1^0) \]

T. Kamon, Talk at "The LHC and Dark Matter"
Univ. of Michigan, Jan. 7, 2009

\[ M(\tau\tau) [\text{GeV}] \]

\[ M(bb) [\text{GeV}] \]

\[ M(jjb) [\text{GeV}] \]

\[ m_0 (\text{GeV}) \]

\[ m_{1/2} (\text{GeV}) \]

O. Buchmuller, CMS Physics Days, July 23, 2008

**Discovery curve obtained from simple signal and background XS-scaling**
A SUSY Excess – Not Discovery

[Stage 1] Is this a real excess? We need to understand MET.
   → Detector Performance Group or DPG (especially, HCAL)
   → Physics Object Group or POG (especially, jets, MET, tau, b)
   → Physics Analysis Group or PAG (especially, SUSY and EXOTICA)

[Stage 2] What kind of excess? We need to identify e, μ, τ, b, t.
   → POG
   → PAG (especially, Kinematical reconstructions)
“Supersymmetrists, Beware!” (J. Ellis, SUSY07)

Experimental Observation of Events with Large Missing Transverse Energy Accompanied By a Jet or Photon(s) in ppbar Collisions at /s = 540 GeV

Abstract

We report the observation of five events in which a missing transverse energy larger than 40 GeV is associated with a narrow hadronic jet and of two similar events with a neutral electromagnetic cluster (either one or more closely spaced photons). We cannot find an explanation for such events in terms of backgrounds or within the expectations of the Standard Model.

(submitted to Phys. Lett. B)
Typical Statistics at 10 TeV / $\mathcal{L} = 10$ pb$^{-1}$

(*) Assume $\mathcal{L} = 10$ pb$^{-1}$, include acceptance, initial reconstruction and ID efficiency

<table>
<thead>
<tr>
<th>Event Channel</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum bias</td>
<td>$10^{12}$</td>
</tr>
<tr>
<td>Jet, $E_T &gt; 25$ GeV</td>
<td>$3 \times 10^{10}$</td>
</tr>
<tr>
<td>Jet, $E_T &gt; 140$ GeV</td>
<td>$3 \times 10^{6}$</td>
</tr>
<tr>
<td>$\gamma$ + Jet, $E_T &gt; 20$ GeV</td>
<td>$3 \times 10^{6}$</td>
</tr>
<tr>
<td>$W \rightarrow \ell\nu$</td>
<td>30,000</td>
</tr>
<tr>
<td>$Z \rightarrow \ell\ell$</td>
<td>3,000</td>
</tr>
<tr>
<td>$t\bar{t} \rightarrow \ell\nu 4q$</td>
<td>100</td>
</tr>
</tbody>
</table>
### Nailing Down $\sigma_{BSM} = 50 \text{ pb in } 1 \sim 1000 \text{ pb}^{-1}$

<table>
<thead>
<tr>
<th>( \mathcal{L} )</th>
<th>( N_{\text{prod}} ) (events)</th>
<th>( A_{\text{total}} \sim 10% )</th>
<th>… Many people are working on Major Effort &amp; Papers</th>
<th>Detectors &amp; Physics Objects.</th>
<th>Trigger/DPG/POG/Topology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 pb(^{-1} )</td>
<td>50</td>
<td>5</td>
<td>Commissioning $\alpha_T$, MET, and $M_{\text{eff}}$ using QCD events</td>
<td>HCAL operation Trigger menu</td>
<td></td>
</tr>
<tr>
<td>10 pb(^{-1} )</td>
<td>500</td>
<td>50</td>
<td>Understanding $\alpha_T$, MET, and $M_{\text{eff}}$ using $Z(\rightarrow ll)+\text{jets}$, $W(\rightarrow l\nu)+\text{jets}$, $\gamma+\text{jet} &amp; tt$</td>
<td>High-quality jet objects High-quality e/( \mu ) rejection High-quality $\tau$ ID High-quality b tagging High-quality $\gamma$ ID High-quality MET/Cleanup Basic selection cuts &amp; SUSY-PAT</td>
<td></td>
</tr>
<tr>
<td>100 pb(^{-1} )</td>
<td>5,000</td>
<td>500</td>
<td>Retuning $\alpha_T$, MET, and $M_{\text{eff}}$ using $Z+\text{jets}$, $W+\text{jets}$, $\gamma+\text{jet} &amp; tt+\text{jets}$</td>
<td>(<em>) $\alpha_T$ in QCD events (</em>) $W+\text{jets}$, $Z+\text{jets}$, $tt+\text{jets}$ (*) Search for SUSY …</td>
<td></td>
</tr>
<tr>
<td>1 fb(^{-1} )</td>
<td>50,000</td>
<td>5,000</td>
<td>(*) Observation of SUSY …</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( \alpha_{T} \sim 250 \text{ pb for } tt \rightarrow bW, bW \rightarrow b\nu, b\bar{\nu} \) \( \text{Note: } \alpha_T(\text{LHC})/\alpha_T(\text{Tevatron}) \approx 100 \)

**Evidence for SUSY**

**Observation of SUSY**
Tasks at a Glance

(1) QCD & EWK – dominant backgrounds for new physics
   ✓ QCD smearing function (Elif, Taylan, …)
   ✓ $\alpha_T$ for QCD rejection (Mehmet, Taylan, …)
   ✓ MET using $W/Z/\gamma+jets$ (Sue Ann, …)
   ✓ MET using $Z(\rightarrow \nu\nu)+jets$ (Jim, …)
   ✓ MET using $tt+jets$ (Duong, …)
   ✓ Tau ID using $Z\rightarrow \tau\tau$ (Alfredo, …)

(2) Detector commissioning effort from SUSY view point
   ✓ MET DQM (Ken, …)
   ✓ MET cleanup (Alfredo, Ming, Michael, … by HCAL ROC team)
   ✓ MET monitoring trigger for HPD noise study (Alfredo at HCAL-DPG)
   ✓ MET Triggers (Jim, …)
   ✓ MET in CRAFT (Mehmet, …)

(3) Preparing analysis tool for all-hadronic final states
   ✓ SUSY $b's$ (Harold, …), $\tau's$ (Jonathan, …), $W's$ (…)
   ✓ Black Hole High multiplicity high-$E_T$ jets (Romulus, …)

(4) Early SUSY-related paper(s) using $\alpha_T$ in $n$-jet final states

(5) More …
Effort = Manpower × Challenge × Creativity

$\sqrt{s} = 10$ TeV & $\mathcal{L} = 50$ pb$^{-1}$
– still powerful for BSM searches –

** Discovery curve obtained from simple signal and background XS scaling