Constraints on New Physics from ATLAS, CMS and LHCb

Marie-Hélène Genest
The LHC and the detectors
The LHC and the detectors
ATLAS: General purpose
large and light

38 countries, 174 institutions, 3000 scientists, 1000 students

7000 tons
The LHC and the detectors
CMS: General purpose small and heavy

39 countries, 169 institutes, 3170 members including 800 students

Total Weight : 14,500 t.  
Overall diameter: 14.60 m  
Overall length : 21.60 m  
Magnetic field : 4 Tesla
The LHC and the detectors
LHCb: one arm forward spectrometer

15 countries, 55 institutes, 804 members
The LHC in 2011

<table>
<thead>
<tr>
<th>2011/ Design</th>
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<tbody>
<tr>
<td>Colliding bunches</td>
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<tr>
<td>Energy/beam</td>
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<td>Bunch spacing</td>
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<td>Luminosity</td>
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Searches for new physics... are too many to review all in this talk!

To give you an idea, here are some ATLAS-only summary plots of BSM searches, with selected results from SUSY (left) and non-SUSY (right) models...
Searches for new physics

• I will thus focus mainly on what I am most familiar with, that is some SUSY searches

• Here are the links for more results from ATLAS, CMS and LHCb:
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults
  http://lhcb.web.cern.ch/lhcb/Physics-Results/LHCb2012_Winter_Results.html

• There are also many clickable links throughout the talk, to get more information on the searches presented
Inclusive SUSY searches
Is BSM physics around the corner?

multi-Jets + n leptons + $E_T^{\text{miss}}$

Standard Model backgrounds: tt, W+jets, Z+jets, QCD jets, dibosons...
Other signal/BG discrimination variables

- Azimuthal angle ($\Delta \phi$) between jets and $E_T^{\text{miss}}$
- Scalar $p_T$ sum of objects: $H_T = \sum_i p_T^{\text{jet},i} + \sum_i p_T^{\text{lepton},i} + \sum_i p_T^{\text{photon},i}$
- Effective mass: $m_{\text{eff}} = H_T + E_T^{\text{miss}}$

There are also more complex event variables offering discrimination, for example the razor variable:

Searches for the pair production of two heavy particles, each decaying to an unseen LSP plus jets, using the idea of event hemispheres. All the reconstructed objects in each hemisphere are combined into a single "mega-jet" ($\rightarrow$ dijet topology). Introduce a frame $R$, which is the longitudinally boosted frame that equalizes the magnitude of the two mega-jets 3-momenta and construct the observables:

$$M_R = \sqrt{(|\vec{p}_{j1}| + |\vec{p}_{j2}|)^2 - (p_{z1}^2 + p_{z2}^2)}$$

$$M_T^R = \sqrt{E_T^{\text{miss}}(p_T^{j1} + p_T^{j2}) - E_T^{\text{miss}} \cdot (p_T^{j1} + p_T^{j2})^2}$$

$$R = \frac{M_T^R}{M_R}$$

**Peaks at** $M_\Delta = \frac{M_S^2 - M_{\text{LSP}}^2}{M_S}$

**Edge at** $M_\Delta$

**Ratio of two estimators of SUSY scale** – describes transverse shape of event
Razor analysis

Various signal regions defined in the $M_R$ vs $R$ plane, with or without leptons.

Exclude up to 1.35 TeV squarks and gluinos for $m_{\text{gluino}} \sim m_{\text{squark}}$
# Jets + missing ET

No discrepancy with respect to SM predictions

Degenerated 1\textsuperscript{st} & 2\textsuperscript{nd} generation squarks, LSP mass set to 0 (results hold up to \(~\sim\)200 GeV).
Probing GMSB

- In GMSB models, the LSP is the gravitino, the next-to-lightest SUSY particle (NLSP) determines phenomenology

- Neutralino or slepton NLSP: 2-lepton + jets + MET
  - ATLAS-CONF-2011-156
- Stau NLSP: tau(s) + jets + $E_T^{miss}$
  - 1204.3852
  - 1203.6580
Probing GMSB

wino / higgsino NLSP:

\[ Z + \text{jets} + E_T^{\text{miss}} \]

Bino NLSP:

\[ 2 \text{ photons} + \text{jet} + E_T^{\text{miss}} \]

In this case as well, the limits on the gluino mass are rather stringent...
3rd generation

Can be lighter than the other two, naturalness points to a light third generation

Gluino-mediated searches

Lepton + b-jets + $E_T^{\text{miss}}$ final state

PAS-SUS-11-028
3rd generation

Direct searches

2 b-jets + MET + MCT*

* cotransverse mass of the bjet system

GMSB model

Z -> ee, $\mu\mu$ + jets (1b) + MET

PRL 108 (2012) 181802

$\tilde{b}_1 \rightarrow b \tilde{\chi}_1^0$, $\tilde{t}_1 \rightarrow b \tilde{\chi}_1^+$

$\tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$

$\tilde{c} \rightarrow c \tilde{\chi}_1^0$

ATLAS

$\int L dt = 2.05$ fb$^{-1}$, $\sqrt{s} = 7$ TeV

stop pair in GMSB Natural model

$\tilde{b}_1 \rightarrow b \tilde{\chi}_1^0$ forbidden

$\tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$

$\tilde{c} \rightarrow c \tilde{\chi}_1^0$

Reference point

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Direct gaugino

What about the electroweak sector?

\[ \text{3-lepton } + E_T^{\text{miss}} + Z\text{-veto} + b\text{-jet veto} \]
Probing 'invisible' production

Two search channels:
Jet + $E_T^{\text{miss}}$
$\gamma + E_T^{\text{miss}}$

Assumptions:
- Dirac particles
- heavy particle mediating interactions with dark sector can be integrated out

arXiv:1204.0821
EXO-11059-Winter2012
Long-lived particles

- If the mass gap between NLSP and LSP is very small, metastable NLSP can be produced
- Search for high-\(p_T\) tracks that stop in outer TRT in jets+MET events

\[ \text{ATLAS-CONF-2012-034} \]

Exclude AMSB models with \(m(\chi_1^+) < 90 \ (118)\ \text{GeV}\) and \(0.2 \ (1) < \tau < 90 \ (2)\ \text{ns}\)
Precision measurements: $B \rightarrow \mu \mu$

SM prediction:
\[ SM \, B(B_s \rightarrow \mu \mu) = (3.2 \pm 0.2) \times 10^{-9} \]
\[ SM \, B(B \rightarrow \mu \mu) = (0.1 \pm 0.01) \times 10^{-9} \]

Branching ratio very sensitive to new physics

CDF has an excess (10 fb$^{-1}$):
\[ B(B_s \rightarrow \mu \mu) = (1.3^{+0.9}_{-0.7}) \times 10^{-8} \]

CMS limit at 95% CL (5 fb$^{-1}$):
\[ B(B_s \rightarrow \mu \mu) < 7.7 \times 10^{-9} \]
\[ B(B \rightarrow \mu \mu) < 1.8 \times 10^{-9} \]
Precision measurements: $B \to \mu\mu$

Set the most stringent upper limits to date at 95% CL:

- $B(B_s \to \mu\mu) < 4.5 \times 10^{-9}$
- $B(B \to \mu\mu) < 1.03 \times 10^{-9}$

With the 2012 data, expect a $3\sigma$ evidence if $BR(B_s \to \mu\mu)$ is SM

[X. Vidal, Pheno12]
And the search continues...

• The searches are now becoming very diversified, the accumulation of statistics allow new channels to open up
• But so far, in the new physics searches, it's been limits, limits, limits
• 2012:
  • 4 TeV / beam
  • already more than 2 fb\(^{-1}\)
  • luminosity at 6.0 \(\times 10^{33}\) cm\(^2\) s\(^{-1}\)
  • 15 fb\(^{-1}\) by the end of the year
BACKUP slides...
Object identification

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Object</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>j</td>
<td>Jet</td>
<td>Cluster in EM and hadronic calorimeters (and inner tracker)</td>
</tr>
<tr>
<td>γ</td>
<td>Photon</td>
<td>EM cluster without matching track</td>
</tr>
<tr>
<td>e</td>
<td>Electron</td>
<td>EM cluster with matching track</td>
</tr>
<tr>
<td>μ</td>
<td>Muon</td>
<td>Matching tracks in inner and muon trackers</td>
</tr>
<tr>
<td>τ</td>
<td>Tau lepton</td>
<td>Narrow jet with matching track(s)</td>
</tr>
<tr>
<td>MET</td>
<td>Missing $E_T$</td>
<td>$p_T$ required to balance all of the above (and more)</td>
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</tbody>
</table>
Inclusive searches are already producing stringent limits on gluinos and the first two generations of squarks... If it exists, where could SUSY be hiding?
Contransverse Mass

\[ m_{\text{CT}}^2 = [E_T(b_1) + E_T(b_2)]^2 - [p_T(b_1) - p_T(b_2)] \]

- \( \tilde{b}_1 \tilde{b}_1 \) events: Endpoint at \( \frac{m(\tilde{b}_1)^2 - m(\tilde{\chi}_1^0)^2}{m(\tilde{b}_1)} \)
- \( t\bar{t} \) events: Endpoint at \( \approx 135 \text{ GeV} \)