Projections on new, exotic scenarios

from ATLAS and CMS experiments

Leonardo Benucci on behalf of CMS experiment

Antwerp University, Belgium
What does Exotica mean

Both ATLAS and CMS have groups ("Exotica") responsible for searches of new physics (mostly non-SUSY)....

New Gauge Bosons?

Split SUSY?

ZZ/WW resonances?

Technicolor?

Extra Dimensions?

Black Holes???

Little Higgs?

Hidden Valleys?

Leonardo Benucci, "Projections on new, exotic scenarios", Blois 2010, 15-20th July 2010
What does Exotica mean

t...that can present many different signatures:

- high jet multiplicity
- very large MET
- high energy di-jet
- new lepton+jet or lepton+MET resonant states
- high energy di-lepton (or multilepton)
- significant energy deposit during non-collision time

Leonardo Benucci, “Projections on new, exotic scenarios”, Blois 2010, 15-20th July 2010

Perspectives for Exotica signal

LHC delivered luminosity has exceeded 0.2 pb⁻¹

→ we are on the way to approach current exclusion limits for some analyses in exotica sectors

CMS:
- many analyses at 10 TeV have been rescaled at 7 TeV
- results on di-jet mass and di-jet ratio with real data will be presented at ICHEP
- many other analyses aiming to look at real data and/or 7 TeV in the making

ATLAS:
- published many Exotica analyses at 14 TeV, some at 10 TeV
- recently published MC-based results at 7 TeV: W'/Z'. Will be presented at ICHEP

Leonardo Benucci, “Projections on new, exotic scenarios”, Blois 2010, 15-20th July 2010
ATLAS sensitivity prospects to $W'$ and $Z'$ in the decay channels $W' \rightarrow \ell \nu$ and $Z' \rightarrow \ell^+ \ell^-$ at $\sqrt{s} = 7$ TeV

The ATLAS collaboration

Abstract

The ATLAS sensitivities to a high-mass dilepton resonance, and to a lepton-neutrino resonance, are evaluated using full detector simulation. These evaluations use, as benchmarks, models in which new heavy gauge bosons (denoted as $W'$ and $Z'$) have the same couplings as their SM counterparts: SSM, Z. Phys. C45 (1989) 109

→ look for high-mass dilepton or lepton-neutrino resonances

**Tevatron limits**


- electron selection based on size of calorimeter cells, containment, association with an Inner Detector track, shower shape cuts and quality of the track
- muons selection using good matching between Muon Spectrometer and Inner Detector
- lepton for $Z'(W')$ with $p_T > 20(50)$ GeV, $|\eta| < 2.5$, $\Sigma_{\Delta R < 0.3} p_T^{\text{tracks}} / p_T^{\text{lepton}} < 0.05$

Syst. effects (after 10 pb$^{-1}$):
- luminosity uncertainty (10%)
- electron id. efficiency: affecting 14%(11%) in the $Z'(W')$ case
- $\mu$ id. efficiency: affecting 21%(15%) in the $Z'(W')$ case
ATLAS study at 7 TeV (PHYS-COM-2010-381):
A total integrated luminosity of 50 pb-1 is enough to extend the \( W' \) exclusion to 1.5 TeV
100 pb-1 would be enough to extend the \( Z' \) exclusion to 1.3 TeV
CMS projections @ 7 TeV

Centre-of-mass energy:
7 TeV

Integrated luminosities:
between 1 pb$^{-1}$ and 100 pb$^{-1}$

Some examples of the expected reach of CMS are shown

The prospects are preliminary, and based on existing studies at higher energies

CMS Note 2010/008

The results given here should be considered as a rough indication of the new physics reach of CMS at 7 TeV, pending more detailed studies
From 10 TeV to 7 TeV

Several studies have been made at 10 TeV by CMS Collaboration

CMS PAS EXO-09-012, CMS PAS EXO-09-004, CMS PAS EXO-09-009, CMS PAS EXO-09-013, CMS PAS EXO-09-004, CMS PAS EXO-09-010, CMS PAS EXO-09-001...

To obtain results at 7 TeV, extrapolations from existing studies at 10/14 TeV have been performed:

- applying simple scaling of cross sections for signal and backgrounds
- considering the same relative effect from systematics

No attempts of analysis re-optimization at 7 TeV have been made
The “rescaling” has been performed using the parton luminosity ratios for $q\bar{q}$ and $gg$ interactions, for the LHC operating at 7 TeV and 10 TeV, as a function of the invariant mass of the produced final state.


- The choice of the $M_X$ working point has been driven by hard scale, invariant mass or lower energy cut for the different analyses.
- Parton luminosities has been computed from PYTHIA.
- Cross-sections for background @ 7 TeV approximately known already.

**Disclaimer:**

*for CMS, only the 10 TeV analyses that underwent this procedure are reported here*
Fourth generation

- Pair of heavy bottom-like 4th generation quark may be produced in pp collision
  \[ M(b') > M(t) + M(W) \]
- \( b'^-b' \rightarrow t^-tW^+W^- \) followed by 2 or 3 W and t → W leptonic decays

- \( M(b') > 485 \text{ (405) GeV} \) after 200(60) pb\(^{-1}\) (95% C.L.

- Approximately 3.5 times more integrated luminosity is required for a 7 TeV LHC run to match the reach at 10 TeV
- With ~100 pb\(^{-1}\) of 7 TeV data, sensitivity is expected to surpass the current Tevatron lower b' mass limit

Tevatron limits (arXiv:0912.1057):
\[ M(b') > 325 \text{ GeV (95% C.L.)} \]

CMS study at 10 TeV (PAS-EXO-09-012):
\[ M(b') > 485 \text{ (405) GeV after 200(60) pb}\(-1\) (95% C.L.)

Leonardo Benucci, “Projections on new, exotic scenarios”, Blois 2010, 15-20th July 2010
Extra dimension: di-photon

- there's a number $\delta$ of extradimensions, compactified over a torus with radius $R$.
- SM is confined in the torus surface, gravity can propagate in the bulk.
- there's a $M_D$ scale related to Planck mass: $M_{Pl}^2 \sim M_D^{\delta+2} R^\delta$.
- among possible signatures:
  - di-photons from Graviton mediation
  - missing energy from production of a real Graviton (see next slides)

- 5th dim is compactified on a circle projected into a segment.
- the 4-dimensional metric depends on the extra-dimensional coordinate $y$:
  $$ds^2 = \exp (-2k|y|) \eta_{\mu\nu} dx^\mu dx^\nu - dy^2$$
- scale of the IR brane is "red-shifted" wrt UV brane:
  $$m_{IR} \sim m_{EW}, \ m_{UV}, \ M_{Pl} \rightarrow R \sim 12k^{-1}$$
- among possible signatures:
  - di-photons (but also di-leptons) from Graviton mediation
Di-photon from RS

- photons with $p_T > 100$ GeV, $|\eta|<1.5$
- look at the invariant mass $M(\gamma\gamma)>700$ GeV and search for resonance
- (only samples at $c=k/M_{\gamma\gamma}=0.01$ have been produced)

**Tevatron limits**
$M_\gamma>300$ (900) GeV for $c=0.01$ (0.1)

**CMS study at 10 TeV**
(PAS-EXO-09-009):
$M_\gamma>1.35$ TeV for $c=0.1$ after 100 pb$^{-1}$

- The equivalent luminosity for a 7 TeV run is ~4 times higher than that at 10 TeV
- With 50 pb$^{-1}$ of 7 TeV data the sensitivity of the search surpasses that at the Tevatron

Leonardo Benucci, “Projections on new, exotic scenarios”, Blois 2010, 15-20th July 2010
Significantly higher (a factor of ~8) luminosity is required in a 7 TeV run compared to that at 10 TeV

even with 50 pb\(^{-1}\) of 7 TeV data, the sensitivity of the search already surpasses the current Tevatron limits.

**Table: 95% C.L. Lower Limits on M\(_S\)**

<table>
<thead>
<tr>
<th>(n_{ED})</th>
<th>50 pb(^{-1})</th>
<th>100 pb(^{-1})</th>
<th>200 pb(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.0 TeV</td>
<td>2.2 TeV</td>
<td>2.4 TeV</td>
</tr>
<tr>
<td>3</td>
<td>2.5 TeV</td>
<td>2.7 TeV</td>
<td>2.9 TeV</td>
</tr>
<tr>
<td>4</td>
<td>2.1 TeV</td>
<td>2.2 TeV</td>
<td>2.4 TeV</td>
</tr>
<tr>
<td>5</td>
<td>1.9 TeV</td>
<td>2.0 TeV</td>
<td>2.2 TeV</td>
</tr>
<tr>
<td>6</td>
<td>1.7 TeV</td>
<td>1.9 TeV</td>
<td>2.0 TeV</td>
</tr>
<tr>
<td>7</td>
<td>1.6 TeV</td>
<td>1.8 TeV</td>
<td>1.9 TeV</td>
</tr>
</tbody>
</table>
MET or MHT (> 200-250 GeV)
jet quality cuts (0.1<EMF<0.9, veto for isolated tracks, pointing etc.), $p_T$ cuts (150-200 GeV), multi-jet veto
cuts on $\Delta \Phi$(MHT/MET- 1$^{st}$/2$^{nd}$ jets)
look for excess in MHT or MET

Tevatron limits (arXiv:0807.3132):
$M_D > 1.40$ (1.04) TeV for $\delta = 2(4)$

CMS study at 10 TeV
(PAS-EXO-09-013):
$M_D > 3.8$ (3.2) TeV for $\delta = 2(4)$ after 200 pb$^{-1}$

~3 x int. lumi. of 10 TeV run is required to reach similar sensitivity at 7 TeV
Even with ~10 pb$^{-1}$ of int. lumin. the sensitivity is expected to surpass that at the Tevatron
High energy di-leptons

Resonant structure in di-e/μ invariant mass predicted by several models

- RS models (spin 2)
- SSM (spin 1), arXiv:hep-ph/9504216

**di-electron:**

Tevatron limits


M(Z’) > 700-1000 GeV depending on the model

M_s > 900 (700) GeV for c=0.1 (0.05)

CMS study at 10 TeV

(PAS-EXO-09-006):

M(Z’) > 1.26-1.59 TeV depending on the model

M_s > 1.49(1.21) TeV for c=0.1 (0.05)

after 100 pb^{-1}

**di-muons:**

Tevatron limits


M(Z’) > 982 GeV

M_s > 921 GeV for c=0.1

CMS study at 14 TeV

(PAS-SBM-07-002), 5σ discovery:

M(Z’) > 1.15-1.60 TeV depending on the model

M_s > 1.25/1.15/0.5 TeV for c=0.1/0.05/0.01

after 100 pb^{-1}
High energy di-leptons

- dedicated high energy electron selection (calorimeter+tracker isolation, shower shape, calo containment etc.)
- look at $M(ee)$ with $E_T(e)>50$ GeV
- isolated, opposite charge muons
- look at $M(\mu\mu)$ with $p_T(\mu)>20$ GeV
- now a dedicated high-$\mu$ selection is in place

$\sim 3(10) \times \text{int. lumi. of 10(14) TeV run is required to reach similar sensitivity at 7 TeV}$

The sensitivity of the Tevatron searches will be superseded with approximately 100 pb$^{-1}$ of 7 TeV data

Leonardo Benucci, “Projections on new, exotic scenarios”, Blois 2010, 15-20th July 2010
Lepto-quark searches

Leptoquarks (LQ) are new exotic particles conjectured to have both B and L number. Predicted by GUT, Technicolor, composite models (Ann. Rev. Nucl. Part. Sci. 49 (1999) 389-434)

- carry color charge and fractional charge
- scalar or vector
- decay primarily into leptons and quarks:
  \[ \text{LQ} \rightarrow e^+ u/d \text{ (1st generation), LQ} \rightarrow \mu^+ c/s \text{ (2nd generation)} \]

Experimental study:
- pair production with the same generation
- resonant final state \( ee(\mu\mu)jj \)

**First generation:**
  - \( M_{LQ} > 156 \text{ GeV for } \beta = 1 \)
  - CMS study at 10 TeV
  - (PAS-EXO-08-010):
    - \( M_{LQ} > 570/445/350 \text{ GeV for } \beta = 1/0.5/0.3 \) after 100 pb\(^{-1}\)

**Second generation:**
  - \( M_{LQ} > 316 \text{ GeV for } \beta = 1 \)
  - CMS study at 10 TeV
  - (PAS-EXO-09-010):
    - \( M_{LQ} > 250 - 500 \text{ GeV for } \beta = 0.2 - 0.7 \) after 100 pb\(^{-1}\)

Leonardo Benucci, "Projections on new, exotic scenarios", Blois 2010, 15-20th July 2010
Lepto-quark searches

- $1^{\text{st}}$ generation
  - isolated $e$, $p_T(e)>30$ GeV, $p_T(jet)>50$ GeV, $|\eta(jet)|<3$, $M(ee)>100$ GeV
  - optimized cut on scalar sum of jet+$e$ $p_T$
  - look at invariant mass $M(ej)$

- $2^{\text{nd}}$ generation
  - $p_T(\mu_1/\mu_2)>80/40$ GeV, $p_T(jet)>60$ GeV
  - $|\eta(\mu)|<2$, $|\eta(jet)|<3$
  - optimized cut on scalar sum of jet+$\mu$ $p_T$
  - look at invariant mass $M(\mu j)$

- $\sim 3 \times$ int. lumi. of 10 TeV run is required to reach similar sensitivity at 7 TeV
- Even with $\sim 10$ pb$^{-1}$ of int. lumin. the sensitivity is expected to surpass that at the Tevatron
Heavy Stable Charged Particles

- Many new physics scenarios predict the existence of new heavy quasi-stable charged particles

- split supersymmetry: large mass splitting between the new scalars and new fermions (JHEP 06 (2005) 073)
  - Gluinos can thus only decay through a highly virtual squark
  - hadronize into “R-hadrons” (charged or neutral)
  - charged, low-β R-hadrons, energy loss is sufficient to bring a significant fraction of the produced particles to rest inside the CMS detector volume
  - these “stopped” R-hadrons will decay seconds, day, or weeks later

- supersymmetry with R-parity (GMSB models, Phys. Rept. 322 (1999) 419)


- Universal Extra Dimensions model (Phys.Rev. D 64, 035002 (2001))
**Heavy Stable Charged Particles**

**Signature:**
These decays will be out-of-time with respect to LHC collisions and may well occur during beam gaps or interfill period.

- The identification of a HSCP relies on the fact that it can be slow ($v \ll c$) but with $p_T > 100$ GeV. It is then possible to measure the mass of a particle if both $\beta$ and the momentum are measured.

---

**Heavy Stable Charged Particle:**

- **Tevatron limits**
    - 0.31-0.04 pb for $60<\tau<300$ GeV
  - gluino search:
    - 171 $< M(\tilde{g}) < 206$ GeV
  - CMS study at 10 TeV
    - (PAS-EXO-08-003): sensitive to gluino masses above 1 TeV after 1 fb-1
    - stable $\sim \tau$ can be discovered with a few 100 pb-1

---

**Stopped Gluinos:**

- **Tevatron limits**
  - (Phys. Rev. Lett. 99 (2007) 131801): exclude a cross-section $\sim 1$ pb for stopped gluinos with $M(\tilde{g}) < 270$ GeV and lifetimes $30 \, \mu s < M(\tilde{g}) < 100$ h
  - CMS study at 10 TeV
    - (PAS-EXO-09-001): assuming an inst. lumi $\sim 10^{32}$ s$^{-1}$ cm$^{-2}$, lifetime larger than 1 week can be discovered in few days
Heavy Stable Charged Particles

95% C.L.:  
- based on a tracker-only selection  
- preselection based on $p_T$, $\beta$, numb. of hits
- int. lumi corresponding to 3 events (background negligible)

Discovery potential:
- combination of tracker and timing-info (from drift-tubes)

The reach beyond the Tevatron limits is achieved in the gluino and stop searches with just a few pb$^{-1}$ of 7 TeV data

~10 times more data are needed to reach the same sensitivity in a 7 TeV run as in 10 TeV

Leonardo Benucci, “Projections on new, exotic scenarios”, Blois 2010, 15-20th July 2010
Stopped Gluinos

- dedicated calorimeter jet trigger at times when there are no collisions
- as a consequence, the background does not depend on the machine energy and stays the same as in the 10 TeV analysis

the discovery beyond the Tevatron limits is possible with just ~2 weeks of data at high luminosity

but: at low luminosity one can’t even see an evidence for these particles, no matter how long the running period is

Leonardo Benucci, “Projections on new, exotic scenarios”, Blois 2010, 15-20th July 2010
Conclusions

- A very large sample of Exotica channels has been investigated by ATLAS and CMS experiments, at 14 and 10 TeV.

- Major improvements on current limits and potential for discovery have been clearly demonstrated.

- Both collaborations are working with the 7 TeV regime and commissioning with data.

- It is anticipated (CMS) that for most of the channels studied, running the machine at 7 TeV requires about $3(10)$ times more data to exceed current sensitivity compared to that in a 10 (14) TeV run.

- First results show that some current limits can be surpassed even before $1 \text{ pb}^{-1}$.

- Approaching to $\sim 100 \text{ pb}^{-1}$, most of current limits will be improved and possibility of discoveries will open up.
Conclusions

Standard Model
(Today)
Conclusions

Standard Model
(Today)

Standard Model + New Physics
(...few months from now)