Recent Results on Searches Beyond the Standard Model From the LHC

PING TAN - University of Iowa

on behalf of
ATLAS/CMS Collaborations

**SUSY + Exotica**

: expanded into 6 plenary talks + ~25 parallel talks in the recent LHCP conference

Sorry if your favorite subject is missed here. **Focus on latest new results with full 2012 data!**
∗ Last July’s discovery completes the SM.
∗ Properties of the new boson is very much SM Higgs-like: more in Jaco Konigsberg’s talk, “LHC Higgs”
∗ A triumph of the SM.

4-D space-time
∗ SU(3)_c×SU(2)_L×U(1)_Y
∗ EWSB: Higgs mechanism
∗ 3 generations of quarks/leptons

✦ Most compelling experimental evidence for Beyond-the-SM physics:
   SM only accounts for ~4% of Universe
✦ Many extensions of SM: SUSY, Extra-dimensions, fourth-generation, lepto-quarks, black-holes, hidden-valley, ...
✦ Many predicted experimental signature have been extensively searched for at LHC

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**SM - “the Giant’s Shoulder”**

- Extensive SM program to provide solid ground: details in Joao Guimaraes da Costa’s talk, “SM at LHC”.
- Theoretical input is vital.

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**2012 CMS data:**
- ~ 25 fb⁻¹
- ~ 100M $W(\mu\nu)$
- ~ 6M $Z(\mu\mu)$
- ~ 100K $tt\bar{t}$ (mu+jets)

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**Proton - (anti)proton cross sections**

- 8 TeV
- ~ 10,000,000,000
- ~ 10,000
- ~ 1 (new physics?)
Narrow Dilepton Resonances

- Well motivated in theory; $Z^\prime_{\text{SSM}}$, superstring inspired-$Z^\prime_\psi$ (E(6) model), RS-Graviton
- **Demonstrated discovery potential**: $J/\psi$, $\Upsilon$, $Z$
- Utilize best strength of the detectors.

$m_{ee}=1776$ GeV

CMS-PAS-EXO-12-061

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No sign of any “excess”, either.

Good cross check against each other (very critical in presence of a signal)

ATLAS-CONF-2013-037
Bayesian approach.

CMS: set limit on a ratio, $\sigma \times BF(Z')/\sigma \times BF(Z)$; ATLAS: set limit on $\sigma \times BF(Z')$

Take home upper-limits (depending on models):
- e.g. $Z'_{SSM} < 2.86$ TeV(@95% C.L.), ATLAS
- $< 2.96$ TeV(@95% C.L.), CMS

More model-specific interpretation: Randall-Sundrum graviton, (e.g. ATLAS-CONF-2013-037)
Top Quark

- Well studied since its discovery in 1995 by Tevatron experiments.
- Large Yukawa couplings, mass, lifetime, ...
  → Unique opportunity to couple to new physics: top partners, $W'(tb)$, ttbar resonances
  → enriched in 3rd-generation SUSY searches
- Reconstructed ttbar invariant mass in $e+4jets + MET$

resolved: W-b well separated

0 lepton: + 6 jets, “all hadronic”
1 lepton: + 4 jets+MET
2 lepton: + 2 (b)-jets+MET
Tops could be heavily boosted at LHC: top-color $Z'$ decays, Kaluza-Klein gluon excitations, Utilize jet substructure to tag “top”-jet

- ATLAS, (ATLAS-CONF-12-065)
  Plehn, Spannowsky, Takeuchi, arxiv: 111.5034
- CMS,
“top” jet reconstruction (“top” tagger) can enhance kinematic reach

Validate in leptons+jets sample,

>~2 TeV $Z'\to tt\bar{t}$: significantly gain from boosted tops
Combined with “resolved” (or “threshold”) distributions to improve sensitivities.

“Resolved” (or “threshold”) ttbar: top daughters are well-separated/no “top” jet reconstruction involved.
No “excess” has been observed. Model-dependent limits are set.

- ATLAS: KK gluon <2.0 TeV (@ 95% C.L.)
- CMS: <2.5 TeV (@ 95% C.L.)
  (difference largely due to different dataset)
- More model-specific limits in public analysis summary (or conference note)
- Beautiful idea, strong implication, a zoo of new “SUSY” particles, ...
- A whole set of striking experimental signatures
- Theoretical input is very critical:
- Large phase space has been explored at 7 TeV LHC run, e.g. CMSSM

**SUSY**

**SUPERSYMMETRY**

- m$_0$: scalar particle mass at GUT scale
- m$_{1/2}$: gauginos mass at GUT scale

Similar constraints by ATLAS
Signature-based → Model-specific searches:

focus on R-parity violating SUSYs, (low MET region)  
[SM particle: R=1; SUSY particles: R=-1]

“Natural” SUSY with relatively light gluinos/3rd-generation squarks, (confront to discovery of the Higgs boson)

...
Searches for Direct Stop Pair Production

✦ Similar final state as ttbar production.
✦ Latest result in “lepton + 4 jets + MET” final state

CMS-SUS-13-011

✦ Differ from ttbar: larger transverse mass
✦ Additional sensitivity by combining other kinematic variables, into Boosted Decision Tree output.
✦ Cut & count on BDT output

\[
m_T > 120 \text{ GeV} \quad m_T = \sqrt{2 \, p_T(l) \, p_T(\nu) \, (1 - \cos(\phi(l) - \phi(\nu)))}
\]
✧ BDTs are optimized to different regions of parameter space

✧ Polarization of tops can result in small variations of limits.

CMS-SUS-13-011

✧ Simplified Model Spectra: assume a single production and one decay channel with 100% BF

stop: ~ 625 GeV
neutralino: ~ 225 GeV,
Different specific decay modes are explored to cover the whole phase space (each assumed 100% BF)

More results are to come during summer (stay tuned)

CMS-SUS-13-011: 1 lepton + jets + MET
4 tops in the final state, very rich final state

- Explored 7-10 jets + MET
- 19 signal regions: jet multiplicity + flavor content/composite jet mass

**Signal Region**

$H_T$: scalar sum of jets $p_T > 40 \text{ GeV}$, $|\eta| < 2.8$

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**Gluino-mediated Stop Production - All Hadronic Final State**

- ATLAS Preliminary
- $\tilde{t}\tilde{b}$ production
- $\tilde{g}\tilde{t}$ production
- $\tilde{g}\tilde{g}$ production

- Signal region:
  - Jet multiplicity + flavor content/composite jet mass
  - $H_T$ requirement
  - $p_T > 40 \text{ GeV}$
  - $|\eta| < 2.8$

- Background prediction vs. data comparison

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**ATLAS**

- $L dt = 20.3 \text{ fb}^{-1}$
- Multi-jet + $t\bar{t}$
- Single top
- Sherpa $t\bar{t} \rightarrow q\bar{t}$
- MadGraph $t\bar{t}$
- Sherpa $W + b$
- Sherpa $W \rightarrow (e,\mu,\tau)v$
- Sherpa $Z$
- $m(\tilde{g}) > m(\tilde{t})$

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**ATLAS-CONF-2013-054**
Combined mass reach:

- **Gluino**: up to ~1.2-1.3 TeV
- **Neutralino**: up to ~500-600 GeV

\[ \tilde{g} \tilde{g} \text{ production, } \tilde{g} \rightarrow t\tilde{\chi}_1^0, \sqrt{s} = 8 \text{ TeV} \]
LHC experiments have been actively exploring the TeV scale in all different perspectives. excellent detector performance/high quality LHC data, novel experimental techniques, creative theoretical inputs, ...

No BSM physics has been observed.

Nature could come up with surprise in current 7+8 TeV data
Look forward to the coming LHC Run 2 at 13(or 14) TeV
“Once in lifetime” opportunity to harvest the LHC data!
Global electro-weak fit to check consistence of the SM,
$s = 8$ TeV

$G^* \rightarrow \pi$
Dijet Resonances

- ATLAS di-jet searches used up to 13 fb$^{-1}$
- Interesting extension of CMS dijet searches: tagging b-jets with $p_T$ up to 0.8 TeV
- A whole literature of multi-jet resonance searches.

ATLAS-CONF-12-148

CMS-PAS-EXO-12-023

$q^*: <3.84$ TeV (95% C.L.)

e.g., $b^*: \notin [1.34, 1.54]$ TeV (95% C.L.)

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The plots display the observed and expected 95% CL upper limits on the cross section times acceptances for different masses. The limits vary with the mass and different values of $\frac{\sigma_G}{m_G}$, where $\sigma_G$ is the cross section and $m_G$ is the mass. The CMS logo and the ATLAS-CONF-2012-148 identifier are also present.
ATLAS-CONF-2012-065

- ATLAS has extensively studied and optimized the HEPTopTagger
  - Plehn, Spannowsky, Takeuchi, arXiv:1111.5034

- HEPTopTagger reclusters the large-R jet using a smaller distance parameter
  - Removes soft, wide-angle radiation

- Left with 3 decay products of top quark reconstructed as subjets

$$R_{\text{filt}} = \min[0.3, \frac{\Delta R_{j_1j_2}}{2}, \frac{\Delta R_{j_1j_3}}{2}, \frac{\Delta R_{j_2j_3}}{2}]$$

$$m_{ab} = M_W (1 \pm 0.15) \quad (a, b = j_1, j_2, j_3)$$
Different specific decay modes are explored to cover the whole phase space (each assumed 100% BF)

More results are to come during summer (stay tuned)

- CMS-SUS-13-011: 1 lepton + jets + MET

- ATLAS: (0-2) leptons + jets + MET

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**ATLAS-CONF-2013-054**

**Ping Tan, University of Iowa**

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**ATLAS**

\[ L dt = 20.3 \text{ fb}^{-1} \]

Preliminary Multijet Combined

- **Expected limit** (±1 \( \sigma_{\text{exp}} \))
- **Observed limit** (±1 \( \sigma_{\text{SUSY theory}} \))

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**mSUGRA/CMSSM**:

- \( \tan(\beta) = 30 \)
- \( A_0 = -2m_0 \)
- \( \mu > 0 \)

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**m_{\tilde{g}} (GeV)**

- \( m_{\tilde{g}} = m(t) + m(\tilde{t}) \)

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**m_{\tilde{t}_1} (GeV)**

- \( \tilde{g}(1400 \text{ GeV}) \)
- \( \tilde{g}(1000 \text{ GeV}) \)
- \( \tilde{g}(900 \text{ GeV}) \)

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**m_0 (GeV)**

- \( m_0 (1000 \text{ GeV}) \)
- \( m_0 (2000 \text{ GeV}) \)
- \( m_0 (3000 \text{ GeV}) \)

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\( m_{\tilde{g}} \rightarrow t \tilde{t}^0_1 \) (On-shell)
There are many ongoing analyses with the 8 TeV (and even in 7 TeV) LHC data:
e.g., “parked” CMS data is largely un-explored
The newly discovered Higgs boson opens a completely new door for BSM physics.

LHC Run 2

ratios of parton luminosities
at 7 TeV LHC and 14 TeV LHC

J. Stirling et. al, PDF4LHC
Summary of Gluino-mediated Stop Production

Combined mass reach:

✦ Gluino: up to ~1.2-1.3 TeV
✦ Neutralino: up to ~500-600 GeV
✦ Different analyses/datasets; exclusion are similar
A whole set of exotic experimental signatures:
Heavy stable charged particle (HSCP)/Stable massive particles (SMP),
Displayed fermions/jets/vertices/,
non-pointing photons,
lepton-jets, ...

Theoretical motivations: R-parity conserved SUSY, extra-dimension with KK-parity.
Charged heavy particle with $\beta < 1$; special care in reconstruction

- $\beta$ reconstruction
dE/dx (silicon tracker), Time-of-Flight with muon system

CMS PAS-EXO-12-026

$\sqrt{s} = 7$ TeV, $L = 5.0$ fb$^{-1}$, $\sqrt{s} = 8$ TeV, $L = 18.8$ fb$^{-1}$

- stop: $\sim 0.8$-0.9 GeV
- gluino: $\sim 1.2$-$1.3$ TeV, depending on models

arxiv: hep-ex/1305.0491 (submitted to JHEP)