WG3: more ideas and discussion

Workshop on the physics of HL-LHC, and perspectives at HE-LHC
CERN - 30 October 2017

Speakers
H. Baer, R. Ruiz, M.A. Sanchis-Lozano, A. Iyer, S. Chekanov, D. Barducci, S. Westhoff, S. Amoroso

Additional material is available on the Indico page of this session
Radiative natural SUSY at HL- and HE-LHC
Howard Baer, University of Oklahoma

- In light of recent LHC bounds (m(glno)>2 TeV, m(t1)>1 TeV) and m(h) requiring TeV-scale highly mixed top squarks, concern has arisen about an emerging Little Hierarchy problem characterized by m(weak)~100 GeV << m(SUSY)~multi-TeV rendering perhaps SUSY as "unnatural"
- We propose an improved naturalness measure based upon scalar potential minimization condition

\[ m_Z^2/2 = \frac{m_{H_u}^2 + \sum_{d} (m_{H_d}^2 + \sum_{u} \tan^2 \beta - 1)}{\tan^2 \beta - 1} - \mu^2 \sim -m_{H_u}^2 - \sum_{u} \tilde{t}_{1,2}^2 - \mu^2 \]

This leads to upper bounds from naturalness:
- m(higgsinos)~100-300 GeV (the lighter the better)
- m(t1)<~3 TeV
- m(glno)<~6 TeV

<table>
<thead>
<tr>
<th>process</th>
<th>current</th>
<th>HL-LHC</th>
<th>HE-LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>glno-glno</td>
<td>m(glno)&gt;2 TeV</td>
<td>~2.8 TeV</td>
<td>5.5 TeV</td>
</tr>
<tr>
<td>t1-t1</td>
<td>m(t1)&gt;1 TeV</td>
<td>1.3 TeV</td>
<td>3.5 TeV</td>
</tr>
<tr>
<td>SSdB (winos)</td>
<td>x</td>
<td>m(W2)~1 TeV</td>
<td>?</td>
</tr>
<tr>
<td>z1 z2j-&gt;l+lb+j+MET</td>
<td>barely</td>
<td>mu~250 GeV</td>
<td>?</td>
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</tbody>
</table>

Conclusions:
1. SUSY still natural;
2. hunt for nSUSY has only begun;
3. HL-LHC handle most SUSY with ino-mass unification;
4. other (e.g. mirage) may require HE-LHC to complete search

arXiv:1604.07438
1612.00795
1702.06588
1708.09054
1710.09103

HB, Barger,Gainer, Huang,Tata, Savoy, Mustafayev, Sengupta, Serce
Low-Scale Type I Seesaws:
(Pseudo-Dirac $N + $ sizable mixing)

- $gg \rightarrow N\nu_\ell$ dominant channel for $\sqrt{s} \gtrsim 20 - 25$ TeV [1706.02298]
- FeynRules file [1602.06957]

New SeeSaws@Colliders review by Y. Cai, T. Li, T. Han, RR (this week!)

Left-Right Symmetric Models:
($W_R^\pm, Z_R, H^{\pm \pm},$ Majorana $N$)

- High-mass $W_R$ decays to light $N$
  $\implies$ $N$ decays are collimated
  $\implies$ neutrino jets! [1607.03504]
- Sensitivity to $M_{W_R} \lesssim 20$ (35) with 100 (2500) fb$^{-1}$ at 100 TeV
Searching for new physics in multiparticle production @ HL-LHC

M.A. Sanchis-Lozano, IFIC - University of Valencia


Particle correlations and multiplicity moments
(similar to searches for QGP)

$H_q$ normalized cumulants (oscillations seen at lower energies)

**pp 14 TeV**

- **Green**: expected from extrapolation & QCD
- **Red**: new physics, e.g. hidden valley sectors

New physics yields wider oscillations!

**pp 27 TeV**

- **Green**: expected from extrapolation & QCD
- **Red**: new physics, e.g. hidden valley sectors

New physics yields even wider oscillations!
Dissecting `multi' photon resonances at the LHC

Possible `di'-'photon final states

Heavy Resonance. What is its spin?

Give up isolation and switch to photon jets!

Strategy!!

Analysis quantified by solving

\[ R = \frac{1}{p(H_S|N \text{ events from } H_T)} \]

\[ = \frac{p(H_T|N \text{ events from } H_T)}{p(H_S|H_T|N \text{ events from } H_T)} \]

\[ \lambda = \left( -\frac{P_L}{P_J} \right) \]

B. Allanach, D. Bhatia, A. Iyer '17

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<thead>
<tr>
<th>Model</th>
<th>Process</th>
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<tbody>
<tr>
<td>S2</td>
<td>$pp \rightarrow S \rightarrow \gamma\gamma$</td>
<td>$pp \rightarrow S \rightarrow nn \rightarrow \gamma\gamma + \gamma\gamma$</td>
</tr>
<tr>
<td>S4</td>
<td>$pp \rightarrow S \rightarrow nn \rightarrow \gamma\gamma + \gamma\gamma$</td>
<td>$pp \rightarrow Z' \rightarrow n\gamma \rightarrow \gamma + \gamma\gamma$</td>
</tr>
<tr>
<td>V3</td>
<td>$pp \rightarrow Z' \rightarrow n\gamma \rightarrow \gamma + \gamma\gamma$</td>
<td>$q\bar{q} \rightarrow G \rightarrow \gamma\gamma$</td>
</tr>
<tr>
<td>$G2_{ff}$</td>
<td>$q\bar{q} \rightarrow G \rightarrow \gamma\gamma$</td>
<td>$gg \rightarrow G \rightarrow \gamma\gamma$</td>
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<td>$\bar{q}q \rightarrow G \rightarrow nn \rightarrow \gamma\gamma + \gamma\gamma$</td>
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Generic framework for identifying collimated states

Chakraborty, Iyer, Roy
arXiv:1707.07084
Precision searches in dijets at the HL-LHC and HE-LHC

S. Chekanov, T. Childers, D. Frizzell, J. Proudfoot, R. Wang
(ANL, USA)

Answered questions:

- How will searches in dijet masses evolve for the HL-LHC and HE-LHC?
- What are the model independent mass reach for 14 TeV and 27 TeV + lumi dependence?
- What are 95% C.L. upper limits for generic signals and \( Z' \rightarrow 2 \) jets?
- What are the exclusion limits for di b-jets and jets+leptons
  - EWK region < 1 TeV (not limited by jet trigger), sensitivity to V-bosons and top
- How to extract signals in dijets spanning 14 orders of magnitude in rate?
- Used simulations: Pythia8 multijets, W/Z/H and top. 100 B events
  - 10 M CPU*h on supercomputers at NERSC
- VLQs are predicted by many NP scenarios and under great experimental investigation
- Their couplings to SM quarks and bosons have a dominant chiral structure: Left or Right

Q: Could the HL/HE-LHC discriminate against the two hypotheses if a signal were observed?

$T, X_{\frac{5}{3}}, Z, W^+$

- **Longitudinal:** no information on the vertex structure
- **Polarised:** Harder objects for a right-handed coupling
Kinematic distributions can be used as discriminators

### HL-LHC

- 5σ VLQ discovery
- Current 95% CL exclusion

### HE-LHC

- 95% CL discrimination

**Discrimination possible in all the discovery range of the HL/HE-LHC**
Fermion Dark Matter at the future LHC
Ayres Freitas - Alexander Voigt - Susanne Westhoff - Jure Zupan

Can we test the Higgs portal \( \frac{y^2}{m} (H^\dagger H)(\chi \chi) \) at the LHC? - Not easy.

Virtual: Higgs couplings

Resonant: like SUSY

thermal WIMPs

\( \Delta m_{\chi} \)

HL/HE-LHC is sensitive to dark fermions up to the TeV scale.

Sphalerons and Instantons at Colliders

- The Standard Model has a non trivial vacuum structures with an infinite number of ground states differing by topological charges

  - These solutions cannot be described in ordinary perturbation theory

  ![Diagram](image)

  - In the EWK sector transitions between different vacua “Sphalerons” violate Baryon and Lepton number (B+L)

    \[ q_1 + q_2 \rightarrow 7\bar{q} + 3\bar{l} + n_B W(Z) + n_H H \]

  - SU(3) Instantons violate chirality

    \[ g + g \rightarrow V + (2n_f - 1)\bar{q}_R + n_f q_R + n_g g \]

- While no reliable estimate of their cross-sections exists sphalerons might be accessible at future high energy colliders and in some optimistic models even at 14 TeV

  - Due to the large number of gauge bosons produced one can define an effective search strategy looking at large lepton multiplicities

  ![Diagram](image)

- Small size Instantons have been searched for in DIS at HERA, with limits reaching the predicted range of cross-sections

  - Their cross-section is expected to be large at the LHC, where however no search has been performed so far

Simone Amoroso (CERN)