New Physics at the (HL)LHC and LHeC

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For the LHeC Study Group
BSM group (coordinators: G. Azuelos, E. Perez)

Supersymmetry

Extra Dimension and RS resonances

New gauge bosons (W’, Z’) and more

LHeC MiniWorkshop, LPCC-CERN
April 18th 2013
Searching for new physics

Standard Model: remarkably successful description of known phenomena, but requires new physics at the (multi)TeV scale.

Extra Dimensions
- Large, warped, or universal extra dimensions
- Might provide:
  - Dark Matter candidate
  - Solution to Hierarchy problem
  - Unification of forces
- Searches for new heavy particles, black holes..

Strong EW symmetry breaking
- Modern variants of Technicolor
- Might provide:
  - Dark Matter
  - Hierarchy problem
- Possibly search for composite Higgs, new heavy vector bosons (Z’, W’...), 4th generation of quarks

Supersymmetry
- Introduce heavy superpartners, scalar particles, light neutral Higgs
- More than 100 parameters even in MSSM

Composite (SUSY) theories
  - Composite Higgs and top
“The LHC is the primary machine to search for physics beyond the SM at the TeV scale. The role of the LHeC is to complement and possibly resolve the observation of new phenomena...”

LHeC CDR

- Overview of the New Physics program @ LHeC
  - Contact interactions, excited leptons, Extra Dimension
  - Leptoquarks
  - R-parity violation SUSY and other uncharted scenarios

Emphasis on complementarities with (High Lumi) LHC:
  - Implication of LHC findings for LHeC reach
  - How LHeC can complement and resolve observation of new phenomena at the LHC
  - Implication of LHeC PDF constraints for the LHC

Based on LHeC CDR studies (100 fb-1 @ $10^{33}$ instead of current $10^{34}$ expected) and High Luminosity LHC studies made for ATLAS European Strategy document
NP in inclusive DIS at high $Q^2$

- At these small scales new phenomena not directly detectable may become observable as deviations from the Standard Model predictions.
- A convenient tool: effective four-fermion contact interaction

Observed as modification of the $Q^2$ dependence $\Rightarrow$ all information in $d\sigma/dQ^2$
Also parametrized as form factors

$$4\text{-fermion interaction} \Rightarrow M_{eq\rightarrow eq} \sim \Lambda^{-2}$$

$\Lambda$: Compositeness scale

$\Rightarrow$ LQ mass ($\gg \sqrt{s}$) or Modified Planck Scale in ED models

$$\mathcal{L} = \frac{4\pi \varepsilon}{\Lambda^2} j_{\mu}^{(e)} j^{\mu(q)}; \quad q = u, d; \quad \varepsilon = \pm 1$$

$$j_{\mu}^{(f=e,q)} = \eta_L \bar{f}_L \gamma_\mu f_L + \eta_R \bar{f}_R \gamma_\mu f_R + h.c.$$
If contact terms originate from a model where fermions are composite, scale proportional to composite object radius

\[ f(Q^2) = 1 - \frac{1}{6} \langle r^2 \rangle Q^2, \]

\[ \frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} f_e^2(Q^2) f_q^2(Q^2) \]

Radius (\( \rightarrow \) distribution of EWK charge within q) reach below 10^{-19} cm

ATLAS and CMS constraints on 4-quarks CI (expected @ few 10's TeV for 14 TeV LHC - not directly related to EWK R)
Contact interactions (eeqq)

- New currents or heavy bosons may produce indirect effect via new particle exchange interfering with $\gamma/Z$ fields.
- Reach for $\Lambda$ (CI eeqq): 25-45 TeV with 10 fb-1 of data depending on the model.

Similar to LHC

ATLAS and CMS constraints on eeqq CI (expected up to 30-40 TeV at c.o.m. 14 TeV LHC)
CI at LHC and LHeC

- LHC: Variation of DY cross section for CI model
  - Cannot determine simultaneously $\Lambda$ and sign of interference of the new amplitudes wrt SM ($\varepsilon$)

LHeC: sign $\varepsilon$ from asymmetry of $\sigma/\sigma_{sm}$ in e+p and e-p data

Ex: negative interference too small to be disentangled
High mass Drell-Yan

Both CMS and ATLAS searching for deviations in $m(ll)$ tails

- Non resonant searches for ED (interference) sensitive to tails of DY distributions thus to PDF
  - For HL-LHC need to study in context with experimental uncertainties (calibrations)
HL-LHC: Dilepton Resonances

Dielectron and dimuon channels explored for 14 TeV and Phase I (II) luminosity:
- Example from dielectron selection:

Sensitivity up to about 8 TeV

<table>
<thead>
<tr>
<th>model</th>
<th>300 fb⁻¹</th>
<th>1000 fb⁻¹</th>
<th>3000 fb⁻¹</th>
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<tr>
<td>$Z_{SSM}' \to ee$</td>
<td>6.5</td>
<td>7.2</td>
<td>7.8</td>
</tr>
<tr>
<td>$Z_{SSM}' \to \mu\mu$</td>
<td>6.4</td>
<td>7.1</td>
<td>7.6</td>
</tr>
</tbody>
</table>
Excited fermions

- Can be produced directly if their mass is below the compositeness scale

- gauge interaction Lagrangian

\[ \mathcal{L} = \frac{1}{2\Lambda} \overline{f}_R^* \sigma_{\mu\nu} \left[ gf \frac{\tau^a}{2} W^a_{\mu\nu} + g' f' B_{\mu\nu} + g_s f_s \frac{\lambda^a}{2} G^a_{\mu\nu} \right] f_L \Rightarrow \sigma \sim \frac{|f|^2}{\Lambda^2} \]

similar Lagrangian for 4th family lepton: replace couplings by anomalous couplings

- contact interaction Lagrangian

\[ \mathcal{L} = \frac{4\pi}{2\Lambda^2} \bar{j}_\mu j^\mu; \quad j_\mu = \eta_L \bar{f}_L \gamma_\mu f_L + \eta'_L \bar{f}'_L \gamma_\mu f'_L + \eta''_L \bar{f}''_L \gamma_\mu f''_L + h.c. + (L \leftrightarrow R) \Rightarrow \sigma \sim \frac{3 |\eta|^2}{\Lambda^4} \]

At the LHC:
Stringent limits, which only apply to the contact interaction case

<table>
<thead>
<tr>
<th>$\Lambda$ (TeV)</th>
<th>$e^*$ (TeV)</th>
<th>$\mu^*$ (TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>expected limit (TeV)</td>
<td>2.28</td>
<td>2.13</td>
</tr>
<tr>
<td>observed limit (TeV)</td>
<td>2.17</td>
<td>2.13</td>
</tr>
</tbody>
</table>
Excited fermions

- For gauge interaction, LHeC cross section much higher
- Very good sensitivity

Upper limit @ 95% CL (area above curves excluded)

Exclusion $f/\Lambda = 1/M^* \rightarrow 1.2 \,(1.5) \text{ TeV for } \sqrt{s} \, 1.4(1.9) \text{ TeV}
Leptoquarks (LQ)

- By providing both $B$ and $L$ in the initial state, the LHeC is ideal to study the properties of new bosons with couplings to an $e$-$q$ pair

- **Leptoquarks**
  - Color-triplet bosons, couple to leptons and baryons of same generation
  - Can be scalar or vector
  - Masses at GUT scale, in various GUT theories as E6, some extended TC models also predict LQ at TeV-scale
  - Also $\rightarrow$ squarks in RPV SUSY (see later)

In narrow-width approx, production cross section $\sim \lambda^2 q(x)$
At LHC, mostly pair production (from gg or qq)
- if $\lambda$ not too strong (0.3 or lower), cross section independent on $\lambda$
- Exclude up to 900 GeV for 1° generation
- Expect to exclude up to 1.2 (1.5) TeV at 14 TeV 300 fb$^{-1}$ for scalar (vector)-LQ
LQ production at LHC and LHeC

- At LHeC, single particle production
  - Probe LQ up to TeV scale

Scalar LQ, $\lambda = 0.1$, single production

- LHeC, $e^+ d$ ($E_e = 70$ GeV)
- LHeC, $e^- \bar{d}$ ($E_e = 70$ GeV)
- LHeC, $e^+ d$ ($E_e = 140$ GeV)
- LHeC, $e^- \bar{d}$ ($E_e = 140$ GeV)

$t$-channel exchange in $e^+e^-$ production

Pair production

Contact term for high mass LQ

$\Rightarrow$ distortion of NC cross section
LQ properties

- If LQ observed at LHC → At LHeC can measure fermion number, flavor structure, chiral structure (from polarization of beam)
- Ex.: Fermion number:
  - Parton density $u,d >> ubar,dbar → \sigma(F=0)$ larger in $e+p$, $\sigma(F=2)$ larger in $e-p$

\[
A = \frac{\sigma_{e^+} - \sigma_{e^-}}{\sigma_{e^+} + \sigma_{e^-}} \begin{cases} < 0 \text{ for } F=2 \\ > 0 \text{ for } F=0 \end{cases}
\]
R-parity violating SUSY

Squarks in RPV models could be an example of ‘Leptoquarks’

- **R-parity** = \((-1)^{3(B-L)+2s}\) (R = 1 for SM particles, -1 for MSSM partners)

If not conserved (RPV) \(\rightarrow\) different terms, couplings constraint by proton decay

\[
W_{RP} = \lambda_{ijk} \hat{L}_i \hat{L}_j \hat{E}^C_k + \lambda'_{ijk} \hat{L}_i \hat{Q}_j \hat{D}^C_k + \epsilon_i \hat{L}_i \hat{H}_u + \chi''_{ijk} \hat{U}^C_i \hat{D}^C_j \hat{D}^C_k
\]

\(\Delta L = 1, 9\) \(\lambda\) couplings, 27 \(\lambda'\) couplings
Plethora of new couplings, only partially constraints (m/100 GeV)

<table>
<thead>
<tr>
<th></th>
<th>(\lambda_{ijk} L_i L_j \bar{E}^C_k)</th>
<th>(\lambda'_{1jk} L_1 Q_j \bar{D}^C_k)</th>
<th>(\lambda'_{2jk} L_2 Q_j \bar{D}^C_k)</th>
<th>(\lambda'_{3jk} L_3 Q_j \bar{D}^C_k)</th>
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</thead>
<tbody>
<tr>
<td>weakest</td>
<td>0.07</td>
<td>0.28</td>
<td>0.56</td>
<td>0.52</td>
</tr>
<tr>
<td>strongest</td>
<td>0.05</td>
<td>(5 \cdot 10^{-4})</td>
<td>0.06</td>
<td>0.11</td>
</tr>
</tbody>
</table>
Various constraints on RPV scenarios

**ATLAS SUSY Searches** - 95% CL Lower Limits (Status: March 26, 2013)

- **MSUGRA/CMSSM:** 0 lep + $j_S + E_T^{miss}$
- **MSUGRA/CMSSM:** 1 lep + $j_S + E_T^{miss}$
- **Pheno model:** 0 lep + $j_S + E_T^{miss}$
- **Gluino med. $\tilde{g}$ ($\tilde{q} = \tilde{u}$):** 1 lep + $j_S + E_T^{miss}$
- **GMSB (N LSP):** 2 lep (OS) + $j_S + E_T$
- **GMSB (t LSP):** 1 lep + $j_S + E_T$
- **GGM (bino LSP):** $\gamma + E_T$
- **GOM (wino LSP):** $\gamma + E_T$
- **GGM (higgsino-bino LSP):** $\gamma + E_T$

**8 TeV, all 2012 data**
- **8 TeV, partial 2012 data**
- **7 TeV, all 2011 data**

**Evil direct**

- $\chi^0$ pair prod. (AAMS): long-lived $\chi$
- Stable $\tilde{G}$, R-hadrons: low $\tilde{b}$, $\tilde{t}$
- GMSB, stable $\tilde{r}$, low $\tilde{b}$

**Low-energy particles**

- $\chi^0$ non-pointing photons
- $\chi^0$ heavy displaced vortex (LV): $p + \chi^0, \chi^0 + \nu
- Linear RPV CMSSM: 1 lep + $j_S + E_T^{miss}$
- $\chi^0$ resonance pair
- Scalar gluon 2-jet resonance pair 3
- WIMP interaction (DS, Dirac $\chi^0$): “monojet”+$E_T^{miss}$

**10$^-1$**

**10**

**4/18/2013**

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SUSY and RPV scenarios

Still, several final states to explore:
- LSP no longer stable
- Can be something like
- > 700 possibilities + bilinear couplings!

Result:
- RPV SUSY under-constrained although several searches in progress
- limits depend on couplings assumptions
For squark production:
- $\lambda'$ couplings relevant in $e^{-}p$ production
- Decays: direct or via cascade

![Diagram showing squark production and decays](image)

Current limits up to HERA mass-bound
- Strong lepto-quark constraints from LHC to be taken into account if RPV~100%
- Cascade decays (via RPC vertex) lead to more complex and under-constrained signatures

Reach up to 1 TeV with LHeC
- Feasibility of these searches will depend on LHC findings (useful in case of evidence 😊)

For couplings of em. strength ($\lambda_{1j1}^{I}, \lambda_{11k}^{I} \approx 0.3$)
- $M_{\tilde{u}, \tilde{c}, \tilde{t}} \geq 275$ GeV at 95% CL.
- $M_{\tilde{d}, \tilde{s}, \tilde{b}} \geq 290$ GeV at 95% CL.

![Graph showing excluded parameter space](image)
Lot of efforts on RPC scenarios

Strong constraints on first (and second) generation squarks and other scenarios
RPC scenarios: strong production

- Strong constraints on gluino (1.4 TeV) and squark masses (up to 1.6 TeV) under certain assumptions
  - 1\textsuperscript{st} and 2\textsuperscript{nd} generation squarks degenerate
  - Compressed scenarios difficult
Selectron-squark pair production

From last workshop:

- Could extend a bit over the LHC slepton sensitivity
- Possible information on couplings by playing with $e^+ / e^- / L / R$

Cross-section sizeable when $\Sigma M < 1$ TeV i.e. if squarks are “light”, could observe selectrons up to $\sim 500$ GeV.

Are the current constraints really strong enough?
Non-degenerate 1\textsuperscript{st} and 2\textsuperscript{nd} generation squarks

- Review of current constraints on usual assumption on mass degenerate of 1\textsuperscript{st} and 2\textsuperscript{nd} generation squarks:

\begin{align*}
&\text{Fully degenerate} \\
&\text{Vertical splitting, still MFV & no problem!}
\end{align*}

Will depend on LHC boundaries on these scenarios → might be hard considering the increasing trigger thresholds in MET and jet pT

LHC - LHeC interplay for SUSY

- If no evidence for RPC SUSY is found in Run II, sparticles might become out of reach for LHeC
- Still, interplay in terms of PDF quite relevant
- Based on results shown for ES document and ATLAS PhaseII LoI

Strategy:
- Consider three benchmark kind of processes: squark-gluino, stop, chargino/neutralino production

- If No deviations from the SM observed in 300/fb
  - Extension of sensitivity (mass & cross section reach) with 3000/fb
- Deviations from the SM observed in 300/fb
  - Signal characterization with 3000/fb
Search for squark/gluinos

- Select events with high pT jets, high MET and HT
  - Sensitivity expressed as 95% CL exclusion limit and 5σ discovery
  - An increase of integrated luminosity from 300 fb⁻¹ to 3000 fb⁻¹ improves the sensitivity to sq/gl by approximately 400-500 GeV
  - Decay chain might be complex, including Z or Higgs → exploit m(bb)

Higgs boson in complex SUSY decay chain can be identified
Strong production

- \( \text{xsection} \approx 2.5 \text{ pb} \) for \( m = 1000 \text{ GeV} \), \( \approx 0.01 \text{ pb} \) for \( m(\text{squark, gluino}) = 2 \text{ TeV} \) \( \rightarrow \) clearly, high stats samples are needed.

\[ \sigma (pp \rightarrow \tilde{g}\tilde{g}/\tilde{q}\tilde{q}/\tilde{q}\tilde{g} + X) [\text{pb}] \]
\[ \sqrt{s} = 14 \text{ TeV}; \quad m_{\tilde{g}} = m_{\tilde{q}} \]
NLO+NLL

**mSUGRA reference point:**
\( m_0=650, m_{1/2}=975, \text{xs} 1.1E-05 \text{ nb} \)

Decay chain might be complex, including Z or Higgs
Gluon distributions

High x: $x_g$ and valence quarks: resolving new high mass states!

Figure 4.17: Relative uncertainty of the gluon distribution at $Q^2 = 1.9 \, \text{GeV}^2$, as resulting from an NLO QCD fit to HERA [1] alone (green, outer), HERA and BCDMS (crossed), HERA and LHC (light blue, crossed) and the LHeC added (blue, dark). Left: logarithmic $x$, right: linear $x$. 
If we see deviations from SM, will be important to characterize the physics underneath. First studies on the case of strong production (M. Kramer 2011)

- driven by gluon pdf at large \( x \)
- sizeable uncertainty \( \approx \pm 25\% \) for \( m \approx 1 \) TeV

- driven by valence quark pdfs at large \( x \)
- small uncertainty \( \approx \pm 5\% \) for \( m \approx 1 \) TeV
Impact of improved PDF fits on theoretical predictions for SUSY process:

Example: gl-gl production (assuming m_{gl} = m_{sq})

Figure 5: Calculation of gluino pair production in NLO SUSY-QCD using Prospino [16] and assuming squark mass degeneracy and equality of squark and gluino masses for illustration. The error bands are around central values (solid lines) and correspond to the uncertainty quotations of the various PDF groups. The red band of uncertainty for the LHeC corresponds to the statistical and systematic errors including their correlations as treated in the NLO QCD fit described in the CDR.
Impact on discovery/exclusion reach

- PDF uncertainties impact discovery / exclusion reach:
  - Total yields
  - Shape variations on discriminating quantities (in progress)

Caution: very very preliminary, mostly as illustration (UL for $gl$-$gl$ courtesy of G.Redlinger)

Impact on discovery/exclusion contours under various PDF hypothesis in progress

$LHC \at 14\ TeV \ 3 \ ab^{-1}, M(squark) > 4 \ TeV$

Note: impact of PDF uncertainties on SM background also not negligible
However $\rightarrow$ mitigated by usage of Control Regions and semi data-driven estimate
Summary and outlook

- LHeC provides complementarities to the LHC SUSY search program in the twenties
  - Ideal to search and study properties of new bosons with couplings to electron-quark
  - Direct searches for CI, excited fermions, leptoquark, RPV SUSY, RPC SUSY in specific scenarios such as compressed, non-degeneracy for squarks
  - Interplay with HL-LHC to constraints on PDF crucial for model testing in case of observed deviations → an independent precision measurement of PDFs will be important for an efficient use of the high luminosity for setting reliable high mass limits
Back-up
PDF for LHC

- Use precision Drell-Yan (W,Z) data to constraint PDFs

Very high precision required for any constraint on PDFs

Towards high mass the PDF uncertainties rise, strongly towards the edge ($V_S \times \rightarrow 1$...
Other properties of LQs

- Spin:
  - LHC: LQ-LQ leads to angular distributions depending on g-LQ-LQ coupling
  - LHeC: \( \cos \theta^* \) distribution of LQ decay is sensitive to spin

\[
\text{scalar: flat } d\sigma/dy \\
\text{vector: } d\sigma/dy \sim (1 - y)^2 \quad \left[ y = \frac{1}{2}(1 + \cos \theta^*) \right] \\
\text{NC: } \sim y^2
\]

- BR to neutrinos (good S/B for \( \nu \)-q)
- Coupling measurement, once spin and charge is determined

\[
\sigma_{\text{prod}} \sim (2J + 1) \lambda^2
\]
LQ isospin family

Classification used here (BRW framework)

<table>
<thead>
<tr>
<th>$F = 2$</th>
<th>Prod./Decay</th>
<th>$\beta_e$</th>
<th>$F = 0$</th>
<th>Prod./Decay</th>
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<td></td>
<td>Scalar Leptoquarks</td>
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<tr>
<td>$1/3S_0$</td>
<td>$e_L^{-}u_L \rightarrow e^{-}u$</td>
<td>$1/2$</td>
<td>$5/3S_{1/2}$</td>
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<td>$e_R^{-}\bar{u}_R \rightarrow e^{-}\bar{u}$</td>
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<tr>
<td>$4/3\tilde{S}_0$</td>
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<td>$4/3S_1$</td>
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<td>$1/3S_1$</td>
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<td>1/2</td>
<td></td>
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</tr>
</tbody>
</table>

Table 5.1: Leptoquark isospin families in the Buchmüller-Rückl-Wyler model. For each leptoquark, the superscript corresponds to its electric charge, while the subscript denotes its weak isospin. $\beta_e$ denotes the branching ratio of the LQ into $e + q$. 

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Squark mass splitting

- Large splitting is possible \((A. \text{Weiler})\)

\[
(\delta_{ij}^q)_{MM} = \frac{1}{\tilde{m}_q^2} \sum_\alpha (K_M^q)_{i\alpha} (K_M^q)_{j\alpha}^* \Delta \tilde{m}_{q\alpha}^2
\]

Seiberg & Nir

mixing / misalignment between
SM Yukawas and squark mass matrices

If by symmetry: \(K_{ij} \sim \text{diagonal} \Rightarrow O(1) \text{ mass splitting allowed!} \)

Gedalia et. al

Example:
- \(m_{\text{gluino}} = 1.3 \text{ TeV}\)
- \(m_{Q1} = 550 \text{ GeV}\)
- \(m_{Q2} = 950 \text{ GeV}\)

- right handed squarks split by arbitrary amount

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ESPP-Cracow meeting:

LHC after 4th JULY

LS1
INCREASE ENERGY TO 13-14 TeV

LS2
secure L ~ 10^{34} and reliability
Aiming at L ~ 2 \times 10^{34}
Start LIU

LS3 : HL-LHC
New IR
levelled L ~ 5 \times 10^{34}
Experiment upgrades

Figure 1: LHC baseline plan for the next ten years. In terms of energy of the collisions (upper line) and of luminosity (lower lines). The first long shutdown 2013-14 is to allow design parameters of beam energy and luminosity. The second one, 2018, is for secure luminosity and reliability as well as to upgrade the LHC Injectors.

LHC has still only delivered a small fraction of the effective parton-parton lumi \rightarrow discovery physics programme just getting started!

- Accelerator timescale driven by several aspects:
  - Radiation damage of LHC components
  - R&D and construction of LHC upgrades
  - Required schedule of detector upgrades
- Long Shutdown (LS) periods to install upgrades
- Possibility of an HE (High Energy) LHC still under discussion

LHC: The Roadmap to 2030
Searches for SuperSymmetry

- Very stringent constraints from LHC on strongly produced sparticles (1\textsuperscript{st}, 2\textsuperscript{nd} generation squarks, gluinos) $\rightarrow$ can be quite heavy (multi-TeV)
- Direct production of 3\textsuperscript{rd} generation squarks and weak gauginos is becoming accessible as the amount of integrated luminosity increases (low cross sections)

- If No deviations from the SM observed in 300/fb
  - Extension of sensitivity (mass & cross section reach) with 3000/fb

- Deviations from the SM observed in 300/fb
  - Signal characterization with 3000/fb
    - Determination of masses by measuring endpoints of visible mass distributions
    - Measurement of couplings and spin (via angular analysis)
Third generation

- If $sq/gl$ are not found $< 3$ TeV
  - Still the stop (and possibly sbottom) are among the most important SUSY particles to be found!
  - At $14$ TeV, stop cross section $\sim 10^{-20} \times xsect @ 7$ TeV

For $3000$ fb-1 of lumi $@$ $14$ TeV
- @ $600$ GeV: $720 \times 10^3$ events
- @ $1$ TeV: $24 \times 10^3$ events

- Analysis $< 1\%$ efficiency
- Acceptance depends on the decay mode

\[
\sigma^{NLO+NLL}_{pp \to \tilde{t}_1 \tilde{t}_1 + X} [pb]
\]

\[
\sqrt{S} = 14 \text{ TeV}
\]

\[
m_{\tilde{t}_1} [\text{GeV}]
\]

\[
100 \quad 200 \quad 300 \quad 400 \quad 500 \quad 600 \quad 700 \quad 800 \quad 900 \quad 1000
\]

<table>
<thead>
<tr>
<th>Mass</th>
<th>MSTW2008</th>
<th>CTE6.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 GeV</td>
<td>2.34 pb</td>
<td>2.19 pb</td>
</tr>
<tr>
<td>600 GeV</td>
<td>0.24 pb</td>
<td>0.23 pb</td>
</tr>
<tr>
<td>1 TeV</td>
<td>0.008 pb</td>
<td>0.008 pb</td>
</tr>
</tbody>
</table>

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Stop analyses

- For stop $\rightarrow t+\text{LSP}$: 1-lepton + MET + jets
- For stop $\rightarrow b+\text{chargino (C1 into W+N1)}$: 2-lepton (+MET,jets)
  - Discriminant: MET, MT2

An increase of integrated luminosity from 300 fb$^{-1}$ to 3000 fb$^{-1}$ improves the sensitivity to $sq/gl$ by approximately 200 GeV
- Can do more adding shape discriminants and / or boosted top reconstruction
Weak Production

- As for light stop, light gauginos well motivated by naturalness
- Rare process
  - @ 500 GeV chargino / neut 2 mass, expect $\sim 6 \times 10^4$ events for 3 ab$^{-1}$
- Direct access to weak gauginos
  - Mass hierarchy via kinematic edge studies (potential model dependent fit), couplings
- Search in the ‘classical’ three-lepton and ETmiss final state originating from the decay of $\chi^{1\pm}$ and $\chi^{20}$ as W+$\chi^{10}$ and Z+$\chi^{10}$ respectively
- arxiv.org/abs/1207.4846 by H. Baer addressed $\chi^{20} \rightarrow$ higgs+$\chi^{10}$

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