Searches for other non-SUSY new phenomena at the LHC

Enrique Kajomovitz, Duke University
on behalf of
ATLAS and CMS
“Exotics”

Many extensions of to the SM have been proposed over the years. Models are usually motivated to solve one of the “big” questions

- Use models as guidance where to look
- Signature Driven → Try to cover all possible signatures
- Interpret results using benchmark models

- 1-jet + MET
- jets + MET
- 1 lepton + MET
- Same-sign dilepton
- Diphoton Resonance
- Diphoton + $P_{T}^{miss}$
- Multileptons
- Lepton-jet resonance
- Gamma-jet resonance
- Diboson resonance
- Z+MET
- W/Z+gamma resonance
- Top-antitop preduction
- Lepton-Jets
- Microscopic blackholes
- Dijet Resonance

Supersymmetry
Extra-Dimensionns
Technicolor
Little Higgs
GUT
Hidden Valley
Leptoquarks
Composittess
4th generation (t’, b’)
LRSM, heavy neutrino
DM

...
Search for Resonances and Quantum Black Holes with Dijets

- New resonance interacting with q/g
- A quantum black hole decaying to jj

- Narrow dijet resonances
- Narrow bb resonances
- Wide resonances
- Quantum black holes

Use “wide jets” to reduce sensitivity to gluon radiation
- Seed formation from the two leading jets in the event
- Add jets within $\Delta R < 1.0$

Signal Regions according to b-tag multiplicity
- Tagging efficiency strongly depends on the target resonance mass

Background is estimated with by fitting observed spectrum with empirical model
Search with Dilepton Mass Spectra

- Probe resonances and broad deviations from the SM background
  - \( \mu \mu \) and ee final states
  - Limits presented in very generic form; easy to reinterpret

**Resonance search:** unbinned ML fit

**Non resonant analysis:** count above certain \( m \) and compare with expectation

In resonance search use only shape to be less sensitive to absolute background level

Limits in terms of \( R_\sigma \)
- ratio of \( \text{NP}(\sigma \times \text{BR}) / \text{Z}(\sigma \times \text{BR}) \)

Main background is \( Z/\gamma \)
- Generate shape at NLO
- Absolute normalization from CR

Similar search in ATLAS: arxiv1405.4123 excludes SSM \( Z' \) with \( m < 2.9 \) TeV
Search for high mass resonances decaying to $\tau\tau$

Models with a non-lepton-universal $Z'$
- High mass of the top quark

SSM $Z'$ benchmark
- $Z'$ couples the same as SM $Z$

Use both $\tau_{lep}$ and $\tau_{had}$
- Analyze results separately per $\tau\tau$ cat.
- Combine results

Counting experiment:
$$\sqrt{m_T^2(\tau_1, \tau_2) + m_T^2(\tau_1, E_{miss}^T) + m_T^2(\tau_2, E_{miss}^T)}$$

Threshold for cut is optimized per signal

**had-had**
Main background is $Z/\gamma$ est. from MC
Multijet using fake factor method

**lep-had**
Main background is $W+J$

---


Enrique Kajomovitz, Duke
Search for W/Z+H resonances

Motivation: Compositeness, GUT
Benchmarks: HVT, MWTC

Signature:
- Leptonic decay for the vector boson (Z\(\to\)vv/ll, W\(\to\)lv)
- H\(\to\)bb

Examine the VH mass and look for a localized excess
- Categorize events according to the number of charged leptons
- Further subdivision according to number of b-tagged jets (1 to 2 btaggs)

Background estimation:
- Dominant background is W/Z+j; simulation with data-based corrections
- Multi-jet background; data driven
- tt/single top; normalized using control region fit

for Z(vv)H(bb) \[ m_{VH}^T = \sqrt{(E_T^b + E_T^{miss})^2 - (p_T^b + E_T^{miss})^2} \]
Search for $W/Z+H$ resonances

Motivation: Compositeness, GUT
Benchmarks: HVT, MWTC

Signature:
- Leptonic decay for the vector boson ($Z \rightarrow \nu\nu/\ell\ell$, $W \rightarrow \ell\nu$)
- $H \rightarrow b\bar{b}$

Examine the VH mass and look for a localized excess
- Categorize events according to the number of charged leptons
- Further subdivision according to number of b-tagged jets (1 to 2 btaggs)

Background estimation:
- Dominant background is $W/Z+j$; simulation with data-based corrections
- Multi-jet background; data driven
- $t\bar{t}$/single top; normalized using control region fit

$$m_{VH}^T = \sqrt{(E_{T}^{b\bar{b}} + E_{T}^{miss})^2 - (p_{T}^{b\bar{b}} + E_{T}^{miss})^2}$$
Searching for ZH resonances

Motivation: Compositeness, GUT
Benchmarks: HVT, Z'

Signature: $Z \rightarrow qq$ and $H \rightarrow \tau \tau$
Using all 6 $\tau \tau$ decay modes

Reconstruct $Z \rightarrow qq$:
- Fat-jet: Include all decay products
- Groom: Discard pileup, underlying event
- Tag: mass, n-subjettiness

Reconstruct $H \rightarrow \tau_h \tau_h$: ($\varepsilon = 92\%$)
- Narrow jets $\rightarrow$ Fat-jet
  - Split Fat-jet until large mass drop
  - Seed $\tau_h$ finding

Background estimation:
- Data control regions with transfer factors from simulation
- Simulation with SF (data/sim)
- ABCD

Searching for a WH resonance

**Signature:** $H \rightarrow bb + W \rightarrow l\nu$

**Reconstruct $H \rightarrow bb$:**
- Pruned jet
- Split pruned jet:
  - if the subjets’ $\Delta R > 0.3$ require two loose b-tags
  - if the subjets’ $\Delta R < 0.3$ require single loose b-tags

Special topological requirements to avoid possible instrumental backgrounds
Limits to HVT from VH resonances

Simplified phenomenological model: New Heavy vector $V^{+/0}$ couples to Higgs and gauge bosons via a combination of parameters $g_v c_H$, and to the fermions via $(g^2/g_v)c_F$.

$g_v$ is the strength of the new vector interaction $c_H/F$ are the couplings to the Higgs and Fermions respectively.
Motivation: New interactions, quark compositeness

At LHC dijet production is dominated by t-channel gluon exchange
QCD predicts:
- steeply falling $m_{jj}$
- angular distributions peaked at $|\cos \theta^*| = 1$ ($\theta^*$ is the polar scattering angle in the two parton COM frame)

Analyze:
$X = e^{|y_1-y_2|}$ in bins of $m_{jj}$
For jets with:
$|y_1-y_2| < 1.7$
$\frac{1}{2}(y_1+y_2) < 1.1$
$m_{jj} > 600$ GeV

QCD prediction estimated at LO
- reweighted to NLO
- corrected to take into account EW processes
Angular Analysis results

![Graph showing observed and expected lower limits for contact interactions](image)

- **Upper limit [TeV]**
  - 6
  - 8
  - 10
  - 12
  - 14
  - 16
  - 18

- **Observed**
- **Expected**
- **Expected ± 1σ**

**Contact interaction**

**ADD**
- $\Lambda_T$ (GRW)
- $M_S$ (HLZ) $n_{ED} = 2$
- $M_S$ (HLZ) $n_{ED} = 3$
- $M_S$ (HLZ) $n_{ED} = 4$
- $M_S$ (HLZ) $n_{ED} = 5$
- $M_S$ (HLZ) $n_{ED} = 6$

**CMS**

**Contact interaction**

- $\Lambda^+_{LL/RR}$
- $\Lambda^+_{VV}$
- $\Lambda^+_A$
- $\Lambda^+_{(V-A)}$

**Figure 3:** Observed (solid lines) and expected (dashed lines) 95% CL lower limits for the CI scales $L$ for different compositeness models (NLO), for the ADD model scale with GRW parameterization $T$ and for the ADD model scale with HLZ parameterization $S$. The gray bands indicate the corresponding uncertainties in the expected exclusion limits.
Search for Neutral Color-Octet Weak-triplet Scalars

- Sector breaking an extended gauge symmetry associated with a $G'$
- Fermion-anti fermion bound states
- Elementary particle from a non minimal GUT

Benchmark Model: $G'$, $\Theta$, $\phi$
- $m(G') = 2.3 \ m(\Theta^0) - \sigma: 125 - 2.2 \times 10^{-2} \ pb$
- $m(G') = 5 \ m(\Theta^0) - \sigma: 63.3 - 2.6 \times 10^{-3} \ pb$

Dominant background is $Z+j$ (50%+)
- SF (data/MC) in CR, NLO weighting
- Uncertainty from difference in data-pred in sidebands
- $t\bar{t}$, $tW$, $tt$:
  - MC with Data / MC correction from e/m final states
- Diboson from MC

Mixing through Vector like quark: Assume BR = 0.5

One-loop diagram: BR set by mass of $\Theta$

CMS PAS EXO-12-007

Enrique Kajomovitz, Duke
Search for heavy neutrinos with leptons and jets

Neutrinos oscillations $\rightarrow$ neutrino mass
Seesaw mechanism: Heavy $N$

Produce $N$ through s-channel

CMS - Clean final state:
- Two same sign muons: small backgrounds
- Increase statistics using $W \rightarrow qq$

ATLAS –
Include

CMS: arXiv: 1501.05566  ATLAS to be published
Limits on $N$ and $|V_{\ell N}|^2$
Vector Like Quarks

- LHC accessible top partners appear in many “natural” extensions to the SM because the new particle plays an important role in regulating the higgs mass.

**Pair production:** strong production driven by the mass of the new particles.

**Single production:** Particles are too heavy to be produced in pairs, cross section driven by couplings.

Decay can involve tops, bottoms, higgs, W, Z.
Search using b-jet, two same sign leptons or three leptons

- Vector like quarks, chiral b', 4-top production (sgluon splitting), BSM flavor changing higgs coupling

-Clean signature, few SM processes have these final states:
- SM dibosons, tri-bosons, tt+W/Z/H, tt+WW, H+W/Z, tWZ, tH (from simulation)
- Instrumental backgrounds using matrix method

- $n_{\text{jets}}>1$ and $n_{b\text{-jets}}>0$
- two same sign leptons or three leptons
- Z veto for same sign electrons
- missing $E_T>40$ GeV and $H_T>400$ GeV
- Further optimization of SR depending on benchmark model

<table>
<thead>
<tr>
<th>Definition</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+e^- + e^+\mu^- + \mu^+\mu^- + eee + e\mu + \mu\mu + N_j \geq 2$</td>
<td>$\sigma \times BR(\text{fit})\ [\text{pb}]$</td>
</tr>
<tr>
<td>$400 &lt; H_T &lt; 700$ GeV</td>
<td></td>
</tr>
<tr>
<td>$N_b = 1$</td>
<td>$E_T^{\text{miss}} &gt; 40$ GeV</td>
</tr>
<tr>
<td>$N_b = 2$</td>
<td>$E_T^{\text{miss}} &gt; 40$ GeV</td>
</tr>
<tr>
<td>$N_b \geq 3$</td>
<td>$E_T^{\text{miss}} &gt; 40$ GeV</td>
</tr>
<tr>
<td>$H_T \geq 700$ GeV</td>
<td></td>
</tr>
<tr>
<td>$N_b = 1$</td>
<td>$40 &lt; E_T^{\text{miss}} &lt; 100$ GeV</td>
</tr>
<tr>
<td>$40 &lt; E_T^{\text{miss}} &lt; 100$ GeV</td>
<td>SRVLQ4</td>
</tr>
<tr>
<td>$N_b = 2$</td>
<td>$E_T^{\text{miss}} &gt; 100$ GeV</td>
</tr>
<tr>
<td>$N_b \geq 3$</td>
<td>$E_T^{\text{miss}} &gt; 100$ GeV</td>
</tr>
<tr>
<td>$E_T^{\text{miss}} &gt; 40$ GeV</td>
<td>SRVLQ7</td>
</tr>
<tr>
<td>$H_T &gt; 450$ GeV</td>
<td></td>
</tr>
<tr>
<td>$N_b \geq 1$</td>
<td>$E_T^{\text{miss}} &gt; 40$ GeV</td>
</tr>
</tbody>
</table>
CMS: Search for b’ with multileptons

b’ VL partner to b-quark
Consider decays:
- b’ → tW
- b’ → bZ
- b’ → bH
After top decays 6 possible final states
bbWWW, bbZZ, bbWWZ, bbHH, bbW, bbH

Select events with at least 3-leptons
Consider τ decays too
Classify according to n-lepton, lepton flavor and charge, jet-flavor, and kinematic quantities

CMS: B2G-13-003
Search for a VLQ B with lepton, missing $E_T$ and jets

1 isolated lepton, missing $E_T$, jets (at least 1 b-jet)

Designed to target: $\text{BB} \rightarrow \text{ttWW} \rightarrow \text{bbWWWWW}$
But has sensitivity to other T and B signatures

Main background is SM $\text{tt}$, and $\text{W}+$jets events

Large jet multiplicity is expected $\rightarrow$ combinatorial background is large
Use $H_T$ (scalar sum of $p_T$ + missing $E_T$) as a measure of the mass scale

Use multivariate Boosted Decision Tree analysis as main analysis tool, and cut-base analysis as cross check

$H_T$, $\Delta R(\text{lep}, b1)$, $\min(\Delta R(\text{lep}, W_{\text{had}}) E(b1))$, $N_{\text{jet}}$, $<\Delta R(j_i, j_m)$, $N_b$, $pT(\text{lep})$, $N_V$
T quarks decaying to top+Higgs in the fully hadronic channel

Search for pair production of T→tH
T→tH→(bjj)(bb)

Apply top tagging and Higgs tagging:
- t: Sub-structure; subjet b-tag; mass
- H: Filtered large-R jet; 2-subjet b-taggs mass requirements
Categorize events based on Higgs tag multiplicity

Two discriminating variables are combined into a likelihood ratio after event selection
-m_{bb}: Higgs candidate
-H_T: Characterize large hadronic activity

*similar in ATLAS-CONF-2015-012
Limits on VLQ CMS

CMS Searches for New Physics Beyond Two Generations (B2G)
95% CL Exclusions (TeV)

- Vector-like Q'
- Vector-like T'
- Vector-like B'
- Dark matter

Excluded Mass (TeV)

0 0.2 0.4 0.6 0.8 1 1.2 1.4

Excluded Mass (TeV)

0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

- $q_{uu}^{(combined)}$
- $Z(1.2\%)^{(combined)}$
- $g_{q_{u}}^{(dilep)}$
- $Z(1.2\%)^{(dilep)}$
- $g_{q_{u}}^{(semilep)}$
- $Z(1.2\%)^{(semilep)}$
- $g_{q_{u}}^{(all-had)}$
- $Z(1.2\%)^{(all-had)}$
- $W^{(lep)}$
- $W^{(had)}$
- $t^{(dilep)}$
- $t^{(semilep)}$
- $ct(\phi=2 cm(e^{+}\mu)}$

- $tt$ Resonances
- $tb$ Resonances
- Excited tops
- Displaced tops

Enrique Kajomovitz, Duke
Limits on VLQ ATLAS

\[ \text{Expected 95\% CL mass limit [GeV]} \]

\[ \text{Observed 95\% CL mass limit [GeV]} \]

\[ \text{Summary results: Same-Sign ll, } Zb/t + X, Wt + X, Hb + X \]

\[ \text{ATLAS-CONF-2015-012} \]

\[ \text{Status: March 2015} \]

\[ \text{\( \sqrt{s} = 8 \text{ TeV}, 20.3 \text{ fb}^{-1} \)} \]
### Run-1 summary: ATLAS

**ATLAS Exotics Searches** - 95% CL Exclusion

*Status: March 2015*

<table>
<thead>
<tr>
<th>Model</th>
<th>$\ell, \gamma$</th>
<th>Jets</th>
<th>$E_{\text{miss}}$</th>
<th>$\int L , dt$ [fb$^{-1}$]</th>
<th>Mass limit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADD Gox + $g/\gamma$</td>
<td></td>
<td></td>
<td></td>
<td>20.3</td>
<td>2.8 TeV</td>
<td></td>
</tr>
<tr>
<td>ADD non-resonant $t\bar{t}$</td>
<td>$2\ell, \mu$</td>
<td>$\geq 1j$</td>
<td>Yes</td>
<td>20.3</td>
<td>2.8 TeV</td>
<td></td>
</tr>
<tr>
<td>ADD QBH $\to t\gamma$</td>
<td>$1\ell, 1j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>5.8 TeV</td>
<td></td>
</tr>
<tr>
<td>ADD QBH</td>
<td>$2\ell$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>5.8 TeV</td>
<td></td>
</tr>
<tr>
<td>ADD QBH high $N_{\text{no}}$</td>
<td>$2\ell, \mu$ (SS)</td>
<td></td>
<td></td>
<td>20.3</td>
<td>5.8 TeV</td>
<td></td>
</tr>
<tr>
<td>ADD BH high $\Sigma_{\text{ST}}$</td>
<td>$\geq 1\ell, \mu \geq 2j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>5.8 TeV</td>
<td></td>
</tr>
<tr>
<td>ADD BH high multijet</td>
<td>$\geq 2j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>5.8 TeV</td>
<td></td>
</tr>
<tr>
<td>RS $G_{\text{QH}}/G_{\text{H}}$</td>
<td>$2\ell, j, \mu$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>2.68 TeV</td>
<td></td>
</tr>
<tr>
<td>RS $G_{\text{QH}}/G_{\ell}$</td>
<td>$2\ell, j, \mu$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>2.68 TeV</td>
<td></td>
</tr>
<tr>
<td>Bulk RS $G_{\text{QH}} \to ZZ$</td>
<td>$2\ell, 2j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.2 GeV</td>
<td></td>
</tr>
<tr>
<td>Bulk RS $G_{\text{QH}} \to WW$</td>
<td>$2\ell, 2j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.2 GeV</td>
<td></td>
</tr>
<tr>
<td>Bulk RS $G_{\text{QH}} \to H H \to bb bb$</td>
<td>$1\ell, 2j$, $\geq 1b, \ell b\gamma$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>960 GeV</td>
<td></td>
</tr>
<tr>
<td>Bulk RS $G_{\text{QH}} \to $$^{(1)}$</td>
<td>$2\ell, \mu$ (SS)</td>
<td></td>
<td></td>
<td>20.3</td>
<td>960 GeV</td>
<td></td>
</tr>
</tbody>
</table>

### ATLAS Preliminary

\[ \int L \, dt = (1.0 - 20.3) \, \text{fb}^{-1} \]

\[ \sqrt{s} = 7, 8 \, \text{TeV} \]

### Gauge bosons

<table>
<thead>
<tr>
<th>Model</th>
<th>$\ell, j$</th>
<th>Jets</th>
<th>$E_{\text{miss}}$</th>
<th>$\int L , dt$ [fb$^{-1}$]</th>
<th>Mass limit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSM $Z \to \ell \ell$</td>
<td>$2\ell, \gamma$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>2.8 TeV</td>
<td></td>
</tr>
<tr>
<td>SSM $Z \to t\bar{t}$</td>
<td>$2\ell, t$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>2.8 TeV</td>
<td></td>
</tr>
<tr>
<td>EGM $W \to \ell\ell\ell$</td>
<td>$3\ell, \gamma$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>2.8 TeV</td>
<td></td>
</tr>
<tr>
<td>EGM $W \to q\ell\ell$</td>
<td>$2\ell, 2j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.52 TeV</td>
<td></td>
</tr>
<tr>
<td>HVT $W \to \ell\ell\ell$</td>
<td>$1\ell, 2b$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.47 TeV</td>
<td></td>
</tr>
<tr>
<td>LRSM $W_{\ell\ell}$</td>
<td>$2\ell, 2b$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.82 TeV</td>
<td></td>
</tr>
<tr>
<td>LRSM $W_{\ell\ell}$</td>
<td>$0\ell, 1b, \ell, j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.76 TeV</td>
<td></td>
</tr>
</tbody>
</table>

### DM

<table>
<thead>
<tr>
<th>Model</th>
<th>$\ell, j$</th>
<th>Jets</th>
<th>$E_{\text{miss}}$</th>
<th>$\int L , dt$ [fb$^{-1}$]</th>
<th>Mass limit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFT D5 operator (Dirac)</td>
<td>$0\ell, j, 1j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>875 GeV</td>
<td>1.9 TeV</td>
</tr>
<tr>
<td>EFT D9 operator (Dirac)</td>
<td>$0\ell, j, 1j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>875 GeV</td>
<td>1.9 TeV</td>
</tr>
</tbody>
</table>

### LO

<table>
<thead>
<tr>
<th>Model</th>
<th>$\ell, j$</th>
<th>Jets</th>
<th>$E_{\text{miss}}$</th>
<th>$\int L , dt$ [fb$^{-1}$]</th>
<th>Mass limit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scalar LO $1^1$st gen</td>
<td>$2\ell, j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Scalar LO $2^2$nd gen</td>
<td>$2\ell, j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Scalar LO $3^3$rd gen</td>
<td>$2\ell, j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>VLD $T^T \to W^+ \ell^\pm, W^\pm X^\mp$</td>
<td>$2\ell, 2j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>VLD $T^T \to Z^\pm, X^\mp$</td>
<td>$2\ell, 2j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>VLD $B^B \to Z^\pm, X^\mp$</td>
<td>$2\ell, 2j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>VLD $B^B \to W^\pm, X^\mp$</td>
<td>$2\ell, 2j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

### Heavy quarks

<table>
<thead>
<tr>
<th>Model</th>
<th>$\ell, j$</th>
<th>Jets</th>
<th>$E_{\text{miss}}$</th>
<th>$\int L , dt$ [fb$^{-1}$]</th>
<th>Mass limit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exicted quark $q \to \gamma\ell$</td>
<td>$1\ell, 1j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.5 TeV</td>
<td></td>
</tr>
<tr>
<td>Exicted quark $q \to \gamma\ell$</td>
<td>$2\ell, 2j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.5 TeV</td>
<td></td>
</tr>
<tr>
<td>Exicted quark $b \to \gamma\ell$</td>
<td>$2\ell, 2j, 1b, 1j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.5 TeV</td>
<td></td>
</tr>
<tr>
<td>Exicted lepton $\tau \to \ell\gamma$</td>
<td>$2\ell, 1j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.5 TeV</td>
<td></td>
</tr>
<tr>
<td>Exicted lepton $\nu \to \ell\gamma$</td>
<td>$3\ell, 1j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.5 TeV</td>
<td></td>
</tr>
</tbody>
</table>

### Excited fermions

<table>
<thead>
<tr>
<th>Model</th>
<th>$\ell, j$</th>
<th>Jets</th>
<th>$E_{\text{miss}}$</th>
<th>$\int L , dt$ [fb$^{-1}$]</th>
<th>Mass limit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSTC $\gamma \to W^\pm$</td>
<td>$1\ell, j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.5 TeV</td>
<td></td>
</tr>
<tr>
<td>LSTC Majorana $\nu$</td>
<td>$2\ell, 2j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.5 TeV</td>
<td></td>
</tr>
<tr>
<td>Higgs triplet $h^{(1)}$</td>
<td>$2\ell, 1j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.5 TeV</td>
<td></td>
</tr>
<tr>
<td>Higgs triplet $h^{(2)}$</td>
<td>$3\ell, j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.5 TeV</td>
<td></td>
</tr>
<tr>
<td>Monopole (non-res prod)</td>
<td>$1\ell, 1j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.5 TeV</td>
<td></td>
</tr>
<tr>
<td>Multi-charged particles</td>
<td>$1\ell, j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.5 TeV</td>
<td></td>
</tr>
<tr>
<td>Magnetic monopoles</td>
<td>$1\ell, j$</td>
<td></td>
<td></td>
<td>20.3</td>
<td>1.5 TeV</td>
<td></td>
</tr>
</tbody>
</table>

### Other

\[ \sqrt{s} = 7 \, \text{TeV} \]

\[ \sqrt{s} = 8 \, \text{TeV} \]

### Mass scale [TeV]

<table>
<thead>
<tr>
<th>Mass limit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0 TeV</td>
<td>1502.01518</td>
</tr>
<tr>
<td>9.0 TeV</td>
<td>1407.2940</td>
</tr>
<tr>
<td>8.0 TeV</td>
<td>1311.2006</td>
</tr>
<tr>
<td>7.0 TeV</td>
<td>1407.1376</td>
</tr>
<tr>
<td>6.0 TeV</td>
<td>1308.4075</td>
</tr>
<tr>
<td>5.0 TeV</td>
<td>1405.4254</td>
</tr>
<tr>
<td>4.0 TeV</td>
<td>1405.4123</td>
</tr>
<tr>
<td>3.0 TeV</td>
<td>1409.6190</td>
</tr>
<tr>
<td>2.0 TeV</td>
<td>1503.9467</td>
</tr>
</tbody>
</table>

*Only a selection of the available mass limits on new states or phenomena is shown.*
Enrique Kajomovitz, Duke
Conclusion

• In Run-1 we have searched for new physics in a wide variety of signatures

• Unfortunately, it seems that no New Physics is reachable with $20\text{fb}^{-1}$ at 8 TeV
  – Very stringent limits on New Physics... for some models we were sensitive up to few TeV!

• Run-2 is coming soon
  – Many searches will surpass the Run-1 sensitivities even with very small datasets ($1\text{fb}^{-1}$) stay tuned!