BSM theory perspectives for Run 3 and beyond

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June 5th 2024
Topics in BSM

- BSM is in part “opinion based”, in part “evidence based”

- Driven by the shortcomings of the SM that we deem as important and timely to work on

- We are sure of nothing, but we try to imagine everything about how things could be and make sense of it.

- Lots of “ideas” build on past experience:
  - in the 60s & 70s: “Gauge symmetry worked for QED let us do it for the other forces”
  - today: “The Higgs boson might be a composite like the pion, that is the lightest of the mesons” or “Symmetry protects the masses of fermions, let us do the same for Higgs boson(s)” or “There are flavors of fermions, let us do the same for Higgs boson(s)”
Well recognized topics (including at this conference)

• “Straight Face” Supersymmetry
• EFT for decoupled New Physics
• BSM in Higgs (single couplings, self-coupling)
• New Vector-Like Fermions, Vector Resonances, Scalars
• Used to be “off the beaten path”:
  • Dark Sectors (with and without resonances)
  • (Very) Light Particles (may overlap with Dark sector)
  • Long Lived Particles

See Andrea Thamm, Dipan Sengupta earlier in this conference
Outline

• Run3 and HL-LHC highlights and strategic goals:
  • Precision era in SM measurements and BSM (look under every rock, even those you are “sure” they will bring no results)
  • Re-interpretation and re-use of results (SModelS, CheckMATE, Contour, …)
  • Impact on indirect limits for Future Colliders (rate $\sim M_{NP}^{-4}$)
  • High-$p_T$ precision era
LHC has excluded light new physics, period.
LHC has excluded light new physics, period.

**ATLAS SUSY Searches** - 95% CL Lower Limits

**August 2023**

<table>
<thead>
<tr>
<th>Model</th>
<th>Signature</th>
<th>[GeV (fb^{-1})]</th>
<th>Mass limit</th>
<th>Reference</th>
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<tbody>
<tr>
<td>q, g → qg*</td>
<td>0 + 1 jets</td>
<td>140</td>
<td>≥ 0.23-1.35</td>
<td>[1908.08215]</td>
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<td>g → gg*</td>
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<td>c + 2 jets</td>
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*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.*

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**ATLAS Preliminary**

\[ \sqrt{s} = 13 \text{ TeV} \]
LHC has excluded light new physics, period.

**ATLAS** Preliminary

$\sqrt{s} = 13$ TeV, 136 - 140 fb$^{-1}$

$pp \rightarrow \tilde{\chi}^{0\pm}_2, \tilde{\chi}^{0\pm}_2, \tilde{\chi}^{0\pm}_1, \tilde{\chi}^{0\pm}_1, \tilde{\chi}^{0\pm}_1, \tilde{\chi}^{0\pm}_1$ (Higgsino)

All limits at 95% CL

- Observed limits
- Expected limits

$3\ell + \text{Soft } 2\ell$, arXiv:2106.01676, 1911.12606, $m(\tilde{\chi}^{0}_2) = m(\tilde{\chi}^{0}_1) + 2\Delta m(\tilde{\chi}^{\pm}_1, \tilde{\chi}^{0}_1)$

Disappearing track, arXiv:2201.02472, $m(\tilde{\chi}^{0}_2) = m(\tilde{\chi}^{0}_1)$

LEP2 $\tilde{\chi}^{\pm}_1$ excluded

Theoretical prediction for pure Higgsino

Has it?

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Measurements of $W^+W^-$ production in decay topologies inspired by searches for electroweak supersymmetry

ATLAS Collaboration

CERN, 1211 Geneva 23, Switzerland

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Abstract This paper presents a measurement of fiducial and differential cross-sections for $W^+W^-$ production in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS experiment at the Large Hadron Collider using a dataset corresponding to an integrated luminosity of 139 fb$^{-1}$. Events with exactly one electron, one muon and no hadronic jets are studied. The fiducial region in which the measurements are performed is inspired by searches for the electroweak production of supersymmetric charginos decaying to two-lepton final states. The selected events have moderate values of missing transverse momentum and the ‘transverse mass’ variable $m_T$, which is widely used in searches for supersymmetry at the LHC. The ranges of these variables are chosen so that the acceptance is enhanced for direct $W^+W^-$ production and suppressed for production via top quarks, which is treated as a background. The fiducial cross-section and particle-level differential cross-sections for six variables are measured and compared with two theoretical SM predictions from perturbative QCD calculations.

| $|\Delta\phi_{ll}|$ | ATLAS (13 TeV, 139 fb) | Sherpa 2.2.2, l=1.0$^*$ | Sherpa 2.2.2, l=1.2$^*$ | Sherpa 2.2.2, l=1.5$^*$ |
|------------------|------------------------|--------------------------|--------------------------|--------------------------|
| 0                | 0.10 ± 0.12 (stat.)    | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      |
| 0.5              | 0.10 ± 0.12 (stat.)    | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      |
| 1.0              | 0.10 ± 0.12 (stat.)    | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      |
| 1.5              | 0.10 ± 0.12 (stat.)    | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      |
| 2.0              | 0.10 ± 0.12 (stat.)    | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      |
| 2.5              | 0.10 ± 0.12 (stat.)    | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      |
| 3.0              | 0.10 ± 0.12 (stat.)    | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      | 0.09 ± 0.13 (stat.)      |
Measurements of $W^+ W^-$ production in decay topologies inspired by searches for electroweak supersymmetry

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Abstract

This paper presents a measurement of fiducial and differential cross-sections for $W^+ W^-$ production in proton-proton collisions at $\sqrt{s} = 13$ TeV using the ATLAS experiment at the Large Hadron Collider, corresponding to an integrated luminosity of 139 fb$^{-1}$. Events with exactly one electron, one muon and no hadronic jets are studied. The fiducial region in which the measurements are performed is inspired by searches for the electroweak production of supersymmetric charginos or neutralinos. This analysis complements measurements at the LHC. The ATLAS experiment \cite{ATLAS} has previously measured and compared with two theoretical SM predictions $\text{WW}^{\pm}$ production in topologies as associated with the decay of SUSY particles decaying into final states with two leptons and jets. This analysis includes additional constraints on BSM models.

This is one example of reaching the finest control and the highest scrutiny for a measurement of SM final states (in observables that useful for BSM searches)
STANDARD & MODEL
SEARCH & MEASURE
The diagram illustrates the hierarchy of scales in the Standard Model Effective Field Theory (SMEFT) compared to the electroweak scale. The vertical axis represents $\log N$, while the horizontal axis represents $p_T^\ell$. The regions are labeled as follows:

- **sub-electroweak**
- **circa-electroweak**
- **supra-electroweak**

The scale of the SM is denoted as $m_{SM}$, and the electroweak scale is indicated as $\sim m_{SM}$. The upper limit on the energy scale is denoted as $\leq \text{TeV}$. The figures $2310.13687, 2404.17574$ Agashe, Airen, RF, Kim, Kotwal, Ricci, Sathyan and $2301.04407, 2312.09794$ Bagnaschi, Corcella, RF, Sengupta are cited for further reading.
Well Calibrated Data

\[ \log N \sim \frac{1}{m_{SM}} \]
\[ \sim m_{SM} \]
\[ \lesssim \text{TeV} \]
\[ \gg m_{SM} \]

sub – electroweak

circa – electroweak

SMEFT

supra – electroweak

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Well Calibrated Data

SM Measurements

\( \sim \log N \)

\( \lesssim m_{\text{SM}} \)

\( \gtrsim \text{TeV} \)

\( p_T^e \)

SMEFT

sub – electroweak

circa – electroweak

supra – electroweak

\( \gg m_{\text{SM}} \)
\[ m_{\text{SMEFT}} \gg m_{\text{SM}} \]

\[ m_{\text{SMEFT}} \sim m_{\text{SM}} \approx \log N \lesssim \text{TeV} \]

Well Calibrated Data

"hard" new physics where everyone is looking

SM Measurements

sub – electroweak

circa – electroweak

supra – electroweak

\[ p_T^\ell \]

\[ \gg m_{\text{SM}} \]

\[ \text{ circa } \]

\[ \text{ TeV } \]
Well Calibrated Data

SM Measurements

"hard" new physics where everyone is looking

\[
\begin{align*}
S & \geq m_{SM} \\
M & \sim \log N \lesssim \text{TeV} \\
E & \gg m_{SM}
\end{align*}
\]

sub – electroweak
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supra – electroweak

Well Calibrated Data

SM Measurements

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\[
\begin{align*}
S & \geq m_{SM} \\
M & \sim \log N \lesssim \text{TeV} \\
E & \gg m_{SM}
\end{align*}
\]
SMEFT $\gg m_{SM}$

$\sim m_{SM}$

$\sim$ TeV

"hard" new physics where everyone is looking

Well Calibrated Data

SM Measurements

$\sim \log N$

sub – electroweak
circa – electroweak

supra – electroweak

$\gg m_{SM}$

$P_T^\ell$

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The post-fit ratio of data to MC, while the lighter points indicate the ratio before the fit. The hatched band represents the post-fit ratio of data to MC, while the lighter points indicate the ratio before the fit.

The ATLAS $\ell^+\ell^-$ channel, post-fit, is shown in the figure. The Jacobian peak, there is opportunity for BSM searches where the optimal S/B ratio is reached.

The supra-electroweak region contains the high-$p_T$ tails of different models that we consider. Systematic uncertainties can be handled with data and MC for (a) $E_\mathrm{T}$, (b) $W$-channel, (c) the Jacobian peak, where the optimal S/B ratio is reached.

The ten nuisance parameters inducing the largest shifts on the fitted value of $m_W$ are ranked according to the shift induced on its post-fit value using the (a) data and MC, (b) pre-fit impact on distributions and the CT18 PDF set. For a given NP hypothesis, the shifts are shown in the combined PLH fits, and the shifts in $m_W$ can be seen in the figure. The shifts for the various NP hypotheses are shown in the figure, and the shifts in $m_W$ can be seen in the figure.

See Yongbin Feng, Giuseppe Bozzi earlier in this conference.
$S \& M$ 

$E \& A$ 

$R \& C$ 

$H \& A$ 

$S \& M \& E \& A \& R \& C \& H \& A$ 

$\lesssim m_W \approx m_W$ 

$\gtrsim m_W$ 

$\gtrsim m_W$ 

$\sim \log N$ 

$\lesssim \frac{1}{2} m_W$ 

$\sim m_W$ 

$\lesssim \text{TeV}$ 

$\lesssim m_W$ 

$\gtrsim m_W$ 

SMEFT 

$P_T \ell$ 

sub - electroweak 

circa - electroweak 

$\lesssim m_W$ 

$\gtrsim m_W$ 

$\gtrsim m_W$ 

$\gtrsim m_W$ 

$m_W$ analysis
"light" new physics where everyone is "measuring" the SM
"light" new physics in between tail-searches and measurements

- Hadrophilic $Z'$
- MSSM $\tilde{\ell} \tilde{\nu}$

$S \approx m_W$

$\sim m_W$

$\gtrsim m_W$

$\ll m_W$

$\gg m_W$

$\sim \log N$

$\lesssim m_W$

$\gtrsim m_W$

$\lesssim \text{TeV}$

$\gtrsim \text{TeV}$

$\lesssim m_W$

$m_W$ analysis

SMEFT

$p_T^\ell$

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ties, aimed at measuring that reached percent and even sub-percent accurately the main target for the experimental collaborations lies on the various sources of uncertainties, which is expected.

As shown in Fig. 3, for $0$, $g$, $\phi$, $\nu_3$ (Fig. 1 left), modifying the kinematic constraints in principle shift the measurement of new physics comes from regions of the kinematic distributions in which the SM processes are floated. The key observation is that NP produces kinematic distributions, and is therefore used to measure $\mu$ and $\tau$ productions in the MSSM. RHIC ($\sigma$)

The strategy is in addition to neutrinoless double beta decay, which is heavily used for detector calibration [1, 6] and may affect the calibration of the MCs, "calibrating away" signs which are used to compute the experimental value is extracted from the systematic uncertainties are usually present.

The distributions and is often used for heavy BSM physics searches, like the $W$-boson mass measurement: (a) Hadrophilic $Z'$, (b) Leptophilic $Z_{\tau\mu}$, (c) Neutrinophilic scalar, (d) Heavy neutrino.

\[ \sum_{i=1}^{N} S_i \times \mu_i \]

The sample might affect the distributions and is often used for heavy BSM physics searches, like the $W$-boson mass measurement: (a) Hadrophilic $Z'$, (b) Leptophilic $Z_{\tau\mu}$, (c) Neutrinophilic scalar, (d) Heavy neutrino.
The majority of the sensitivity to new physics parameter space is (T, \mu_B^2), unless otherwise specified. For the CDF projections, we construct \mu_1, \mu_2, \mu_3, \mu_4.

LHC@13TeV

- SM(\mu_\nu_\mu)
- \mu_\nu_4

Normalized kinematic distributions for the models presented in Sec. 3.2.

Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>m_{\nu_4}</td>
<td>10 GeV</td>
</tr>
</tbody>
</table>

Figure 5

The impact of this model on the determination of MET and the transverse momentum of the lepton from the SM decay of the W-boson mass is not a crucial input. This is because the majority of the sensitivity to new physics parameter space is (T, \mu_B^2), unless otherwise specified. For the CDF projections, we construct \mu_1, \mu_2, \mu_3, \mu_4.

In Fig. 5, we present our results for this scenario. We focus on the (m_T, E_T) plane for different detector e.

In principle, the electron final state can be equally sensitive, but we do not pursue it as it involves different detector e.

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Systematic uncertainties are usually applied also to the transverse momentum of the lepton from the SM decay of the W-boson mass.

68% CL, m_{\nu_4} = 10 GeV

- LHC: sys=0.5%, \rho_T
- LHC: sys=0.5%, m_T
- LHC: sys=0.1%, \rho_T
- LHC: sys=0.1%, m_T
- CDF: sys=1%, \rho_T
- CDF: sys=1%, m_T

CDF: sys=1%

CDF: sys=1%, m_T

CDF: sys=1%, \rho_T

CDF: sys=1%

CDF: sys=1%, m_T

CDF: sys=1%, \rho_T

CDF: sys=1%

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CDF: sys=1%
S\textbf{EARCH} & M\textbf{EASURE}

in $\ell + m_{\text{ET}}$

**NEW PHYSICS SOFTENS THE SPECTRUM**

(d) Heavy neutrino

---

**NEW PHYSICS AS WELL AS MW**

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LHC@13TeV

- SM($\mu\nu_\mu$)
- $\mu\nu_4$

---

**FLOAT NEW PHYSICS AS WELL AS MW**

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Measurements are relatively rare, thus a moderately S/B is typical for this search strategy. Thus, after W(10 GeV) for the "neutrinophilic scalar" (blue lines), (T
Sec.
Sec.
CDF

LHC@13TeV

\[ m_{\nu_4} = 10 \text{ GeV} \]

<table>
<thead>
<tr>
<th>LHC: syst=0.5%, ( \rho_T )</th>
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<td>68% CL, ( m_{\nu_4} = 10 \text{ GeV} )</td>
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\[ \Delta m_{\nu_4}(\text{GeV}) \]

\[ |U_{4\mu}|^2 \]

\[ |U_{4\mu}|^2 \]

\[ \Delta m_{\nu_4}(\text{GeV}) \]

\[ |U_{4\mu}|^2 \]

The sub-electroweak region contains the Jacobian peak (at \( \nu_4 \)). The analysis ranges of \( E_T \) are 70–140 GeV for different models that we consider.

The overall e-constraint in this scenario is quite mild, considering the values of \( \rho \) and \( \rho_T \).

Our constraints are expected to be roughly the same for electrons (\( \mu/\nu_4 \)).

The reference points in the new physics parameter space are (\( \mu \), \( \nu_4 \)). For our LHC projections, we construct 2 GeV bins for 25 GeV bins for 0.5 GeV, allowing us to reach the per-mill level lines show roughly where the distribution would change with the inclusion of various BSM constraints are extracted from the (\( W, W^* \)) plane.

The circa-electroweak region.

The new physics mixing parameter. Our assessment of the optimal range for this search needs to be determined by the experimental overall uncertainty on the (\( \nu_4 \), \( m_{\nu_4} \)) plane is presented in the left panel of Fig. 3.

The Jacobian peak (at \( \nu_4 \)).

The analysis ranges of \( E_T \) are 70–140 GeV for different detector e.

The overall e-constraint in this scenario is quite mild, considering the values of \( \rho \) and \( \rho_T \).

Our constraints are expected to be roughly the same for electrons (\( \mu/\nu_4 \)).
Measurements of the "heavy neutrino" (green lines), and

---

In Figure 3, we assume careful testing of this step, we assume bins for $m_W$ is not a crucial input. This is because the majority of the sensitivity to $m_W$ comes from high-intensity meson decay studies. We do not show this in this scenario. We focus on the $(\mu, \nu_\mu)$ plane is presented in the left panel of Figure 3. For heavier $m_W$, this gives conservative bounds on this new physics mixing parameter. Our constraints are expected to be roughly the same for electrons ($e$) and muons ($\mu$), with different models that we consider.

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NEW PHYSICS SOFTENS THE SPECTRUM

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Figure 3

**NEW PHYSICS SOFTENS THE SPECTRUM**

- LHC@13TeV
  - SM(μ νμ)
  - μ ν4

**SEARCH & MEASURE**

in ℓ + mET

**FLOAT NEW PHYSICS AS WELL AS M_W**

**SHIFT IN M_W**

- ATLAS δm_W

**COUPLINGS AROUND GWPF BOUNDS**

https://indico.cern.ch/event/1253590/ - June 5th 2024 - Roberto Franceschini - LHCP 2024 Boston - Northeastern University
- Sensitivity from $\ell + \text{mET}$ beyond present bounds
- Possible shift on $m_W$ needs further scrutiny
- Key importance of the level of systematic uncertainty
Search & Measure in $\ell + m_{\text{MET}}$

\[ \begin{align*}
q & \rightarrow W^* l \\
\bar{q} & \rightarrow \bar{W} \bar{l} \\
W^* & \rightarrow l Z \\
Z & \rightarrow \mu^+ \mu^- \\
\end{align*} \]

Additional signal events come from...

We obtain the kinematic distributions through...

The first model that we consider is the...

The semi-invisible final state of leptonic...

Metabolism

The re-

in the the bin

In this model

We estimate the sensitivity and the impact of our NP

The dashed lines in the lower panel are obtained

Figure 1

The masses

Unless indicated otherwise. In the SUSY projections, we include the no pileup (...

The semi-invisible final state of leptonic...

In between these regions, just above

LHC@13 TeV

2404.17574

LHC@13 TeV

2404.17574

2404.13687 - Agashe, Airen, Franceschini, Kim, Kotwal, Ricci, Satghyan

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trino beam-dump experiments [26, 35].

decay (versus 2-body) softens the contributions, as seen in Fig. 3 for a benchmark value of (Fig. 1 left), modifying the kinematic distributions, can affect of the width on the ratio is

We obtain the kinematic distributions through analysis. Ref. [33] studied a specific example of category (B) only. Moreover, in the following, we use a Monte Carlo (MC) simulation via

ties [5, 6], aimed at measuring that reached percent [1] and even sub-percent uncertainties are usually systematically. We denote this the circa-electroweak region.

Figure 2 contains the Jacobian peak (at [1]), the expected effect of our NP hypothesis on the sample of (3)

The sub-electroweak region contains the Jacobian peak (at [1]), systematic uncertainties can

The term belongs to category (A), the

eV

Figure 2

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In the context of the LHAPDF, 2-dimensional parameter spaces are used for a variety of searches, from K-/B-factories, distributions of contains states such as slepton searches. The main target for the experimental collaborations lies on the various sources of uncertainties, which is expected to be mainly due to the production of jet-flavored leptons. The first model that we consider is the one that we test the New Physics hypothesis with no constraints from the SM. We denote this the supra-electroweak region. The highest sensitivity to these effects is achieved when looking at the production of a 3-body decay of the Z-boson, namely \( \mu \nu \), within the SM. The sensitivity and impact of our NP hypothesis on the measurement of the Z-boson mass is within the per-cent level systematics. We denote this the circa-electroweak region. The effects of the width on the measurement of the Z-boson mass are also modified by NP. The effect of our NP hypothesis on the sample of events with appropriate kinematic cuts, such as those imposed in the ATLAS card, is included. Additional constraints arise when considering the production mechanism of the Z-boson gauging baryon number (see [32] and references therein). Overall, our two papers thus represent an unexplored parameter space of slepton searches.

Figures 1 and 3: Normalized transverse mass distributions for \( \ell + \text{mET} \) and \( \ell \ell \) events. The dashed gray lines indicate systematics.
SEARCH & MEASURE in $\ell + m_{\text{MET}}$

- **Search & Measure**
- **in $\ell + m_{\text{MET}}$**

Diagram:

- $W^* \rightarrow l \tilde{\chi}_0^0$
- $\mu$ and $\tilde{\chi}_0^0$
- $q, \bar{q}$
- MET

Plots:

- Normal distribution vs. $m_T$ [GeV]
- $m_{\tilde{\chi}_0^0}$ vs. $m_{\tilde{\chi}_1^0}$

---

**Possible Bounds from Precision $\ell + m_{\text{MET}}$**

**Present Bound** $\ell$

**Present Bound** $\ell\ell$

[Image of plots and diagrams]

---

[Link to event details]

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The test of the interaction in Eq. (showing the parameter space for also report the main constraints from other searches. In particular, masses below described in Sec. Figure 4, we report 9 di \[ m = 0. \] See main text for details. In the right panel of Fig. 34, we give the sensitivity projections on the \( (M, \Delta m_{\nu}) \) plane, for a fixed value \( m_{\nu} = 10 \) GeV. Right panel: 95% CL reach on the \( (E^{\text{miss}}_{\text{T}}, M_{\nu}) \) plane. Current constraints from invisible Higgs decays are taken from \[ \text{Fig. 1}, \text{systematic uncertainties are usually } \] \( \text{no loop} \). We omit this bound by only \( \text{implementing the analysis for this model.} \) Unlike in the previous models, the emission of \( B \) bosons decays to invisible gets an unphysical divergence for low masses \( m_{\nu} < 2.2 \). Additional constraints on the region of interest are expected from DUNE and by a direct decay to invisible gets an unphysical divergence for low masses \( m_{\nu} < 2.2 \).
proposed analysis for variations of systematics, statistical treatment, and assumed lumi-
the line of \[ and this strengthens the corresponding bound. Thus, we obtain the band in Fig.
decay to invisible gets an unphysical divergence for low masses

corrections to
of clarity of the figure. Regarding the bound from

(c) Neutrinoophilic scalar

(a) Hadrophiilic $Z'$

(b) MSSM slepton-sneutrino

(c) Neutrinophilic scalar

POSSIBLE BOUNDS FROM PRECISION $\ell + \text{MET}$

PRESENT BOUNDS FROM $h, Z \to \text{inv}$

https://indico.cern.ch/event/1253590/ - June 5th 2024 - Roberto Franceschini - LHCP 2024 Boston - Northeastern University
(c) Neutrinoophilic scalar

(a) Hadrophilic $Z'$

Possible bounds from precision $\ell + \text{mET}$

Present bounds from $h, Z \to \text{inv}$

Possible bounds from mono-$X$
• Every SM measurement is a new physics search.

• Every BSM search is a SM measurement (of some quantity)

This is a widely applicable lesson
Run3 and HL-LHC the ideal time to apply it!
Every SM measurement is a new physics search.

Every BSM search is a SM measurement (of some quantity)

This is a widely applicable lesson. Run3 and HL-LHC the ideal time to apply it!
Every SM measurement is a new physics search.

Every BSM search is a SM measurement.
"hard" new physics where everyone is looking
Targeted new physics scenario

\[ t \rightarrow bW \rightarrow b\ell\nu \]

\[ \tilde{t} \rightarrow b\chi^+ \rightarrow b\ell\nu\chi^0 \]

Due to small mass differences between the NP states each energy release gives “soft” leptons and/or (b-)jets.

New physics that gives only “soft” leptons and (b-)jets is not the target of “Search for …”
Targeted new physics scenario

$t \rightarrow bW \rightarrow b\ell\nu$

Due to small mass differences between the NP states each energy release gives "soft" leptons and/or (b-)jets.

Ideally one would have to devise a search analysis that can deal with O(10) GeV $p_T$ leptons and (bottom) jets.

All the accurate work on these leptons and jets is already in place for the measurements of top quark properties!
Is this New Physics scenario excluded?

It is objectively difficult, if not impossible, to cover all the possible scenario that new physics can populate.

Especially hard with a bunch of 2D plots …

FROM THE CAPTION: The production cross-section is for pure Wino $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$. 

$\tilde{t}$ singlet
Bino - Higgsino
Higgsino-like

$\chi_0 \sim m(\tilde{\chi}_0) = m(Z) + m(h)$

\[ m_{\tilde{t}} \approx 200 \text{ GeV} \]
\[ m_{\chi^\pm} \approx 170 \text{ GeV} \]
\[ m_{\chi^0} \approx 130 \text{ GeV} \]
Recast bounds on the NP scenario

\[
\begin{align*}
&\tilde{t}_\pm \\
&\chi^0 \\
&\chi_0
\end{align*}
\]

A point that made the development of this idea in practice very difficult for years is the objective difficulty to test if a new physics scenario is excluded by present searches that were not tailored for that scenario.
There are scenarios in the MSSM that cannot be excluded by the searches presently included in SModelS (they even give the right Higgs boson mass at 1-loop, and the correct Higgs boson couplings, but never mind, just a lucky strike)
There are scenarios in the MSSM that cannot be excluded by the searches presently included in SModelS (they even give the right Higgs boson mass at 1-loop, and the correct Higgs boson couplings, but never mind, just a lucky strike)
Recast bounds on the NP scenario

using all analyses included in SModelS

comprising 5744 individual maps from 1152 distinct signal regions, 100 different SMS topologies, from a total of 111 analyses

There are scenarios in the MSSM that cannot be excluded by the searches presently included in SModelS (they even give the right Higgs boson mass at 1-loop, and the correct Higgs boson couplings, but never mind, just a lucky strike)

$r < 1$

$m_{\tilde{t}} \sim 200 \text{ GeV}$

$m_{\chi^\pm} \sim 170 \text{ GeV}$

$m_{\chi^0} \sim 130 \text{ GeV}$

$r \approx 1$

$m_{\tilde{t}} = 200 \text{ GeV}$

$m_{\tilde{\chi}^0} \approx 130 \text{ GeV}$

$m_{\tilde{\tau}} \approx 200 \text{ GeV}$

$m_{\tilde{\chi}^\pm} \approx 170 \text{ GeV}$

$m_{\chi^0}$

neutralino mass

$r < 1$

$r \sim 1$

chargino mass
Top precision measurements in “search mode”

\[ t \rightarrow bW \rightarrow b\ell v \]
\[ \tilde{t} \rightarrow b\chi^+ \rightarrow b\ell\chi^0 \]

The rise \((m_{b\ell} > 0)\)

Other observables can be used as well \((p_{T,\ell}, m_{T2}, E_b, \ldots)\), a full likelihood study in principle
Sensitivity to the NP scenario

$S\&Mea$ in $t\bar{t}$

template $\chi^2$ analysis using published uncertainties

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Sensitivity to the NP scenario

Event counts as a function of $m_{b_l}^\text{min}$ for the CMS experiment.

Template $\chi^2$ analysis using published uncertainties.

Significance ATLAS-CONF-2019-038-PreFit

$\Delta \approx \Delta$

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Sensitivity to the NP scenario

- Sensitivity from $m_{b\ell\ell}$ beyond present bounds
- Possible shift on $m_t$ needs further scrutiny
- Key importance of the level of systematic uncertainty

https://indico.cern.ch/event/1253590/ - June 5th 2024 - Roberto Franceschini - LHCP 2024 Boston - Northeastern University
High mass frontier: *Every GeV counts*

As the integrated luminosity grows we can see more and more of the **high-x tails of the parton distribution functions** that result in high-mass or high-$p_T$ events.

This progress may seem obvious, and sometimes is dismissed as “incremental”.

On the contrary, in Run3 and HL-LHC we will explore truly new territory at the high-mass frontier with significant impact on the status of BSM.

2 TeV $\rightarrow$ 3 TeV

https://indico.cern.ch/event/1253590/ - June 5th 2024 - Roberto Franceschini - LHCP 2024 Boston - Northeastern University
Every GeV counts

Full Run2 analyses reach (and sometimes exceed) 3 TeV

Run3 and HL-LHC will determine indirect reach of future $e^+e^-$

(e.g. $e^+e^- \to tc$ and $BR(t \to Zc)$ above observable level at future Higgs and top factory)

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Every GeV counts

Full Run2 analyses reach (and sometimes exceed) 3 TeV

- Future $e^+e^-$ factories expected to probe new physics indirectly
- Indirect effects are highly sensitive to the mass scale of new physics (e.g. non-interfering new physics/EFT

$\text{Run3 and HL-LHC will determine indirect reach of future } e^+e^-$

(e.g. $e^+e^- \rightarrow tc$ and $BR(t \rightarrow Zc)$ above observable level at future Higgs and top factory)

https://indico.cern.ch/event/1253590/ - June 5th 2024 - Roberto Franceschini - LHCP 2024 Boston - Northeastern University
Electroweak just starts to be interesting

Full Run2 analyses finally comparable to LEP probes of Higgs compositeness and universal NP

$$O_{\varphi q}^{1(ij)} = (\varphi \bar{q} \gamma^\mu q_j), \quad O_{\varphi q}^{3(ij)} = (\varphi \bar{q} \gamma_\mu \gamma_5 q_j), \quad C_{\varphi q}^{-} = C_{\varphi q}^{1(33)} - C_{\varphi q}^{3(33)}$$

$$-\frac{W}{4m_W^2} \left( D_\rho W_{\mu\nu}^a \right)^2 - \frac{Y}{4m_W^2} \left( \partial_\rho B_{\mu\nu} \right)^2$$

LHC measures the size of the Higgs boson

https://indico.cern.ch/event/1253590/ - June 5th 2024 - Roberto Franceschini - LHCP 2024 Boston - Northeastern University
Electroweak just starts to be interesting
Full Run2 analyses finally comparable to LEP probes of Higgs compositeness and universal NP

- Run3 and HL-LHC will take the size of the Higgs boson
- Probes of new electroweak matter, including (fractions of) Dark Matter enabled by Run3 and HL-LHC

\[ \frac{W}{4m_W^2} (D_\rho W^a_{\mu\nu})^2 \]
\[ - \frac{\mathcal{Y}}{4m_W^2} (\partial_\rho B_{\mu\nu})^2 \]
Conclusions: Plenty of opportunities on all the spectrum

$sub$-electroweak and $circa$-electroweak

“Every SM measurement is a new physics search. Every BSM search is a SM measurement”

Clearly a Run3 and HL-LHC “specialty” because needs high-precision and time is needed to bring systematics and theory under control. Top quark and electroweak physics are ideal terrain, but this is a general strategy.
Conclusions: Plenty of opportunities on all the spectrum

*sub*-electroweak and *circa*-electroweak

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Conclusions: Plenty of opportunities on all the spectrum

*supra*-electroweak

Clearly a Run3 and HL-LHC “specialty” because needs *large-*x in the parton distribution functions. Impact on the “TeV” scale, that might become $O(10)$ TeV by the end of HL-LHC. Can alter the landscape for future colliders!

- resonant new physics captured by high lumi
- *supra*-electroweak
  - $\gg m_W$
- *circa*-electroweak
  - $\lesssim m_W$
- *sub-*electroweak
  - $\lesssim m_W$

Plenty of opportunities on all the spectrum
Conclusions: Plenty of opportunities on all the spectrum

$supra$-electroweak

Clearly a Run3 and HL-LHC “specialty” because benefits of large-$\chi$ and some precision, thus time and work is needed to bring systematics and theory under control. $Higgs$ and $top$ compositeness, $electroweak$ matter probed to unprecedented levels.

non-resonant new physics "amplified" by high energy

sufficiently large-$x$ $Higgs$ $g g s to peak electroweak$

Conclusions:
Plenty of opportunities on all the spectrum

https://indico.cern.ch/event/1253590/ - June 5th 2024 - Roberto Franceschini - LHCP 2024 Boston - Northeastern University
Conclusions

• Plenty of opportunities on all the spectrum
  • Luminosity of order of fractions of ab$^{-1}$ from Run3 and HL-LHC enable unprecedented sensitivity to key aspects of SM and BSM physics
  • New physics searches intertwined with measurement of SM quantities in the “sub-electroweak” and “circa-electroweak” phase-space
  • High-mass “supra-electroweak” regime will cover new ground in Higgs boson and top quark compositeness, probes of electroweak matter, flavor and electroweak symmetry dynamics ⇒ important and broad impact on the experimental program and future colliders
Thank you
SEARCH & MEASURE
in $\ell + \text{mET}$

The discrepancy between the SM prediction (see for instance [3, 4]) and our understanding of nature. The reach for the better control of the hadronic activity at CDF which is largely insensitive to pileup, hence we use it for each $m_{W'}$.
Search & Measure

in $\ell + m_{\text{MET}}$

Possible bounds from precision $\ell + m_{\text{MET}}$

Present bounds from Tritdent

The sensitivity to NP also modifies the determination within the SM. Hence, the same analysis can be used for tuning the boson production model on data [15]. Thus probing NP giving any on-shell $W$-boson mass sample might affect our considered models. Moreover, in the following, we don't include them in our analysis.

Figure 4: 68% CL projected sensitivity to $m_{W}$.

This paradigm is general, having already been at least shown in three possibilities:

- (A) the “scalar portal” [45] fall in category (A). For the neutrinophilic “neutrinophilic scalar” of [44] or the “Dirac neutrino singlet” – or right-handed slepton – are heavy, thus having negligible cross-sections.
- (B) the Z-mediator of [52], which is the LSP, has a mass below the reach for the LHC (ATLAS) [47–51]. Sleptons heavier than the LEP bound have negligible cross-sections.
- (C) the NP also modifies the EW fit [2] in order to shift the value to the recent and most precise measurement by CDF [1].

When the lightest neutralino $\tilde{\chi}_{1}^{0}$ is the LSP, $\tilde{\chi}_{1}^{0}$ is called a singlet – or right-handed slepton. There are the couplings of $\tilde{\chi}_{1}^{0}$ to $\tilde{\chi}_{1}^{0}$, $\mu$-portal, and $\nu$-portal. The dynamical model (MSSM) [46], which only belongs to category (B), has the added value to be independent of any on-shell $W$-boson mass sample.
The sensitivity to the NP hypothesis. Assuming that the NP can be classified, we expect the sensitivity projection. Prior knowledge is very important for the determination of the region of interest. In this scenario, both the sneutrino and neutralino are considered as mass eigenstates.

The systematics on the kinematic distributions shown in Ref. [33] are below 0.5%. Therefore, we also consider per-bin systematics. Interestingly, less constrained models such as those with some invisible, unspecified dark-sector states. The qualitatively new aspect of this measurement is the extraordinary precision of the LHC measurements and of the corresponding theory SM predictions. This precision might even imply a preference towards positive values.

The average number of pileup events per bunch crossing is 50. For this analysis, positively and negatively charged leptons are considered. The sensitivity to these events is limited by the background and the detector resolution.

We now turn to the test of the NP hypothesis. Assuming that the NP can be classified, we expect the sensitivity projection. Prior knowledge is very important for the determination of the region of interest. In this scenario, both the sneutrino and neutralino are considered as mass eigenstates.

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SEARCH & MEASURE
in ℓ + mET

New Physics softens the spectrum

Possible bounds from precision ℓ + mET

Present bounds from Trident

The term \( m_\ell \) describes the interaction of the \( \ell \) with the mediators, which can be either \( \mu \) or \( \tau \). The squared mass difference \( \Delta m_\ell^2 \) is related to the mass of the mediator, and it can be measured through the decay \( \ell \rightarrow \mu \nu \nu' \) or \( \ell \rightarrow \tau \nu \nu' \). The mixing angle \( \theta_{\ell\nu} \) is another important parameter that affects the decay rates of the lepton, and it can be constrained through the measurement of the branching ratios.

The lepton mass is a fundamental parameter in the SM, and any deviation from its measured value could indicate the presence of new physics. The measurement of the muon mass, for example, is performed through the decay \( \mu \rightarrow e \nu \nu' \) and \( \mu \rightarrow 3\nu \nu \). The precision of these measurements is crucial for testing the SM and searching for NP.

In the context of the LHC, the search for NP is often performed through the analysis of rare processes, such as the production of tetraquarks or the decay of gauge bosons. These processes can provide signatures that are specific to NP, and they can be used to set bounds on the parameters of the NP models. The search for NP at the LHC is an ongoing and active area of research, with many new results being presented at conferences such as this.

The figure shows the current status of the search for NP at the LHC, with blue and red bands indicating the excluded regions for different NP models. The green band represents the current bound on the muon mass, and the yellow band represents the possible bounds from precision studies. The left panel shows the mass difference \( \Delta m_\ell^2 \) as a function of the production mass \( m_\ell \), with the blue band indicating the current bound from the LHC, and the red band indicating the possible bounds from precision studies. The right panel shows the distribution of the missing transverse momentum \( m_T \) as a function of the mediator mass \( m_\ell \), with the green band indicating the current bound from the LHC, and the blue band indicating the possible bounds from precision studies.

The figure also highlights the importance of precision measurements in setting bounds on NP, and the role of the LHC in providing a competitive environment for ongoing searches for NP.
Recast analysis

Table 8: Summary of the preselection criteria applied in the SRs of the off-shell WZ selection. In rows where only one value is given it applies to all regions. ‘-’ indicates no requirement is applied for a given variable/region.

<table>
<thead>
<tr>
<th>Variable</th>
<th>SR_{SR_{h}} ( + ) dijet</th>
<th>SR_{SR_{h}} ( - ) dijet</th>
<th>SR_{SR_{WQ}} ( + ) dijet</th>
<th>SR_{SR_{WQ}} ( - ) dijet</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_{lep} ) ( \neq 1 )</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>( m_{T}^{lep} ) [GeV]</td>
<td>( &gt; 1 )</td>
<td>( \geq 1 )</td>
<td>( \geq 1 )</td>
<td>( \geq 1 )</td>
</tr>
<tr>
<td>( E_{T}^{miss} ) [GeV]</td>
<td>( &gt; 50 )</td>
<td>( &gt; 50 )</td>
<td>( &gt; 200 )</td>
<td>( &gt; 200 )</td>
</tr>
<tr>
<td>( E_{T}^{miss} ) significance</td>
<td>( &gt; 1.5 )</td>
<td>( &gt; 3.0 )</td>
<td>( &gt; 3.0 )</td>
<td>( &gt; 3.0 )</td>
</tr>
<tr>
<td>( E_{T}^{miss} ) [GeV]</td>
<td>( &gt; 10 )</td>
<td>( &gt; 4.5(3.0) ) for ((\mu))</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>min ( \Delta R_{lep} )</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
</tbody>
</table>

Table 2: Summary of the preselection criteria applied in the SRs of the on-shell WZ and \( Wb \) selections. In rows where only one value is given it applies to all regions. ‘-’ indicates no requirement is applied for a given variable/region.

<table>
<thead>
<tr>
<th>Variable</th>
<th>SR_{SR_{h}}</th>
<th>SR_{SR_{h}}</th>
<th>SR_{SR_{WQ}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_{lep} ) ( \neq 1 )</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>( m_{T}^{lep} ) [GeV]</td>
<td>( &gt; 12 )</td>
<td>( &gt; 12 )</td>
<td>(-)</td>
</tr>
<tr>
<td>( E_{T}^{miss} ) [GeV]</td>
<td>( &gt; 50 )</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>( m_{lep} ) [GeV]</td>
<td>( \geq 1 )</td>
<td>( \geq 1 )</td>
<td>( \geq 0 )</td>
</tr>
<tr>
<td>( m_{T}^{lep} ) [GeV]</td>
<td>( \in [75, 105] )</td>
<td>( \notin [75, 105] )</td>
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<td>( &gt; 15 )</td>
<td>( \geq 15 )</td>
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</table>

dedicated analyses for compressed scenarios are included in the recast

https://indico.cern.ch/event/1253590/ - June 5th 2024 - Roberto Franceschini - LHCP 2024 Boston - Northeastern University
In this talk I will elaborate on this theme and provide directions on how to use the measurements of $m_{bl}$ to test new physics scenarios.

The message can be spread to other observables: 1D distributions of $p_T, \ell, m_{T2}, E_b, \ldots$; 2D distributions as well; a full likelihood study in principle.
Targeted new physics scenario

t→ bW → bℓν

Due to small mass differences between the NP states each energy release gives “soft” leptons and/or (b-)jets.

New physics that gives only “soft” leptons and (b-)jets is not the target of “Search for …”
Targeted new physics scenario

\[ t \rightarrow bW \rightarrow b\ell\nu \]

\[ \tilde{t} \rightarrow b\chi^+ \rightarrow b\ell\nu\chi^0 \]

Due to small mass differences between the NP states each energy release gives "soft" leptons and/or (b-)jets.

Ideally one would have to devise a search analysis that can deal with O(10) GeV \( p_T \) leptons and (bottom) jets.

All the accurate work on these leptons and jets is already in place for the measurements of top quark properties!
Recast bounds on the NP scenario
at several stop quark mass values

neutralino mass

\[ m_{\tilde{t}} \simeq 180 \text{ GeV} \]

\[ m_{\tilde{t}} \simeq 200 \text{ GeV} \]

\[ m_{\tilde{t}} \simeq 220 \text{ GeV} \]
Recast bounds on the NP scenario
at several stop quark mass values

\[ m_\tilde{t} \simeq 180 \text{ GeV} \]

\[ m_\tilde{t} \simeq 200 \text{ GeV} \]

\[ m_\tilde{t} \simeq 220 \text{ GeV} \]

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Workflow

Easily reproducible with well known codes.

SLHA-based → can be injected in Pythia in your experiment software framework(!)

- Generate MSSM model in SPheno 4.0.1 → SLHA file
- Elaborate the SLHA file with SModelS 2.3.3 (using SR combination)
- Find $r < 1$ or $r > 1$ (soon available on Zenodo for those who want to inject signals in their top quark property measurements)
- Run Pythia 8.3 to generate SM $t\bar{t}$ “background” and $pp \rightarrow \tilde{t}\tilde{t}$ signal events (relies on Pythia SLHA interface) → compute any distribution after selection cuts
- For simplicity we compute the correctly paired $m_{b\ell}$, which is different from CMS and ATLAS choices (interesting question to find out what is the best pairing strategy)
Significance estimator

\[ m_{\tilde{t}} \approx 200 \text{ GeV} \]

\[ z = \sqrt{\sum_i \left( \frac{S_i}{\delta B_i} \right)^2} \]

**Significance ATLAS-CONF-2019-038-PreFit**

\[ m_{\tilde{t}} = 200 \text{ GeV} \]

**Significance ATLAS-CONF-2019-038-PostFit**

\[ m_{\tilde{t}} = 200 \text{ GeV} \]

**CMS pre-fit**

**ATLAS pre-fit**

**ATLAS post-fit**

---

https://indico.cern.ch/event/1253590/ - June 5th 2024 - Roberto Franceschini - LHCP 2024 Boston - Northeastern University
Significance estimator

\[ z = \sqrt{\sum_i \left( \frac{S_i}{\delta B_i} \right)^2} \]

\[ m_{\tilde{t}} \approx 200 \text{ GeV} \]

**ATLAS pre-fit**

**CMS pre-fit**

**ATLAS post-fit**

---

**TABLE I. Chargino and neutralino masses, input parameters**

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<tr>
<th>Parameter</th>
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<th>M3</th>
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**References**: [31, 36]
**Significance estimator**

\[ m_\tilde{t} \approx 200 \text{ GeV} \]

\[
z = \sqrt{\sum_i \left( \frac{S_i}{\delta B_i} \right)^2},
\]

Injecting MSSM signals in the \( m_{bl\ell} \) analyses we expect to obtain *new bounds on new physics*.

Unlike standard searches that suffer from the softness of the leptons and jets, this analysis leverages the softness of \( \ell \) and jets.
Significance estimator

\[ z = \sqrt{\sum_i \left( \frac{S_i}{\delta B_i} \right)^2} \]

the presence of the BSM signal is in general limited to low \( m_{b\ell} \), because of the massive invisible \( \chi^0 \) (or other invisible state) mass

the analysis is not sensitive to the transition from on-shell to off-shell \( W \)

\( m_{\tilde{t}} \approx 200 \text{ GeV} \)

TABLE I. Chargino and neutralino masses, input parameters

<table>
<thead>
<tr>
<th>BM</th>
<th>( m_{\tilde{t}} )</th>
<th>( m_{\chi^0} )</th>
<th>( m_{\chi^+} )</th>
<th>( m_{\chi^0} )</th>
<th>( \Delta m_{\chi^0} )</th>
<th>( \Delta m_{\chi^+} )</th>
<th>( \Delta m_{\chi^0} )</th>
<th>( \Delta m_{\chi^+} )</th>
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<td>4.2,22.5 2.4,13.7 2.4,13.7</td>
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<td>7.2,36.3 3.6,18.2 3.6,18.2</td>
<td>1.9,3.7 1.1,2.1 1.1,2.1</td>
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<td>1.9,3.7 1.1,2.1 1.1,2.1</td>
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<td>2.2,4.5 1.1,2.1 1.1,2.1</td>
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</tbody>
</table>
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the presence of the BSM signal is in general limited to low \( m_{b\ell} \), because of the massive invisible \( \chi^0 \) (or other invisible state) and fall (end-point) \( \sim 2 \).

the analysis is not sensitive to the transition from on-shell to off-shell \( W \).
Conclusion and outlook

The (HL)LHC will give us more and more data.
If we want to exploit them at best we need to

- make the result available in a most reusable way
  - Recast Exercises are very useful!
- start leveraging the strategies not pursued much so far
  - measure SM in places we had not traditionally done it
  - search BSM where is not usually sought for

- $m_{bl}$ is a clear example where a Search&Measure approach works that brings new BSM models under the scope, plus it strengthens the “precision” of the SM measurement carried out with the same data
- more precision observables can be used
Thank you
Active self-treatment of a facial wound with a biologically active plant by a male Sumatran orangutan

Isabelle B. Laumer, Arif Rahman, Tri Rahmaet, Uli Azhari, Hermansyah, Sri Suci Utami Atmoko & Caroline Schueller

Abstract

Although self-medication in non-human animals is often difficult to document systematically due to the difficulty of predicting its occurrence, there is widespread evidence of such behaviors as whole leaf swallowing, bitter pith chewing, and fur rubbing in African great apes, orangutans, white handed gibbons, and several other species of monkeys in Africa, Central and South America and Madagascar. To the best of our knowledge, there is only one report of active wound treatment in non-human animals, namely in chimpanzees. We observed a male Sumatran orangutan (*Pongo abelii*) who sustained a facial wound. Three days after the injury he selectively ripped off leaves of a liana with the common name Akar Kuning (*Fibraurea tinctoria*), chewed on them, and then repeatedly applied the resulting juice onto the facial wound. As a last step, he fully covered the wound with the chewed leaves.

Found in tropical forests of Southeast Asia, this related liana species are known for their analgesic, antipyretic, and diuretic effects and are used in traditional medicine to treat various diseases, such as dysentery, diabetes, and malaria. Previous analyses of plant chemical compounds show the presence of furanoditerpenoids and protoberberine alkaloids,
Next we simulate the contribution to $m_{b\ell}$ for each parameter space point using Pythia 8.3 [42] in the region of phase space identified by the following selection:

$$p_T(\ell) \geq 25 \text{ GeV}, \quad |\eta(\ell)| < 2.5,$$
$$p_T(j) \geq 25 \text{ GeV}, \quad |\eta(j)| < 2.5,$$  \hspace{1cm} (1)

for jets made with anti-kT [43] algorithm with $R = 0.4$ and separations between jets and leptons $\Delta R(\ell, j) > 0.2$, $\Delta R(j, j) > 0.4$ and $\Delta R(\ell, \ell) > 0.1$. This is a selection closely following that of the experimental collaborations, e.g. [16, 18, 36], except for minor differences in the selection for $\ell = e$ and $\ell = \mu$ that we do not pursue. We have considered variations of the cuts and found

$$z = \sqrt{\sum_i \left( \frac{S_i}{\delta B_i} \right)^2},$$

for jets made with anti-kT [43] algorithm with $R = 0.4$ and separations between jets and leptons $\Delta R(\ell, j) > 0.2$, $\Delta R(j, j) > 0.4$ and $\Delta R(\ell, \ell) > 0.1$. This is a selection closely following that of the experimental collaborations, e.g. [16, 18, 36], except for minor differences in the selection for $\ell = e$ and $\ell = \mu$ that we do not pursue. We have considered variations of the cuts and found

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<th>$A_t$</th>
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TABLE I. Chargino and neutralino masses, input parameters $\mu$, $M_1$ and $A_t$, all given in GeV for few benchmarks (BM). Resulting value of $r$ computed from SModelS 2.2.1 and the range of the significance eq. (2) expected from the $m_{b\ell}$ spectrum analysis using ATLAS [16] or CMS [31] measurements. The low (high) end the significance range corresponds to uncertainties on the $m_{b\ell}$ spectrum before (after) a fit using SM predictions for the known backgrounds.