BSM at the LHC

- 250-300 analyses SUSY+exotica, CMS+ATLAS, 7+8TeV during run I

- no significant deviation from the Standard Model, but incredibly extensive and valuable information to constrain the Beyond the Standard Model panorama

- Large amount of results brings new challenges in understanding consequences for beyond the Standard Model physics
BSM at the LHC

- A **wide variety of searches**, in principle covering most of the bases

- Results have been presented in terms of **specific models** and of **simplified models** (more on it later)

- Experimental collaborations are **limited** by computational **resources** and **manpower** for constraining all the BSM models out there

- → **need for reinterpretation** ("recasting") of experimental results outside ATLAS and CMS collaborations
Certain questions force theorists to extrapolate ("recast") experimental results into new territory

- powerful very general statements are contained in ATLAS/CMS results but not immediately available (e.g. what’s the limit on particle “X” irrespective of its decay modes?)

- are there “holes” in these searches which have been left out?

- what is the relative performance of two different searches in excluding a specific model?

  (often surprises are found)
Simplified models 101

- **Simplified models** for LHC searches are the equivalent of S,T,U,V... parameters for EW precision data
  - simple models involving only few particles with simple decay modes
  - Idea: break up a full model in terms of simplified models. Full event yield of a model in a search → sum of yields of simplified models = sum of \( N_{\text{ev}} = L \times \sigma \times \text{BR's} \times \varepsilon \).
  - \( \sigma \) and BR's: fast to compute
  - \( \varepsilon \): time consuming and needed as function of particle masses → Compute once & reuse for many different models.
  - Very powerful method if enough simplified models are available
  - Too few simplified models presented by the experimental collaborations (resources limitations) → theorists step in to fill in the gaps → recasting!
Recasting experimental analyses 101

Take search X setting limits for model A

Write code to mock up search X
(not enough info → introduce approximations)

Generate events for model A,
use them with mocked-up
analysis, compare results with
published experimental results

Use mocked-up analysis
with model B

Extract approximate limits of
search X for model B

Extrapolation!!

Validation (most time consuming part)

Repeat for many many analyses…
The bottomline:

Recasting experimental analyses has been proven successful by 100+ papers...

... but the question about extrapolations is always lurking. (Few examples of too naive extrapolations)
In principio…

• Until few years ago:
  • **PGS4/Delphes** for fast detector simulation, but needed to be tuned to ATLAS/CMS
  • Each “practitioner” had her/his **own implementation**+validation of **analyses** in some form
  • **Rivet**: database of unfolded SM measurements for MonteCarlo tuning
  • **Recast** proposal: protocol to submit BSM event files to experiments for investigation during their spare time

Recasting accessible only to few “practitioners”
...today

Generate & process MC events → CheckMATE, Atom, Drees et al. 1312.2591, I.W.Kim, M.P., K.Sakurai, A.Weiler, to be released soon → MadAnalysis, ... Conte et al, 1206.1599, 1405.3982, 1407.3278

Use simplified models and spectrum and BR’s information from SLHA file → Fastlim, SmodelS, ... M.P., K.Sakurai, A.Weiler, L.Zeune, 1402.0492, Kraml et al. 1412.1745, 1312.4175

+ Recast soon as web interface to (some of) these tools
...today: prompt vs. non-prompt

- Both recasting and usage simplified models increasingly straightforward for prompt searches
- Significantly less developed for non-prompt searches
- No available tools, everyone write her/his own code
- In some cases event generation requires hacking (dark showers, hadronization, …)
...today: prompt vs. non-prompt

- **Simplified model results**, when available, are present only for **few points in parameter space** (1D results as function of lifetime) → recasting needed!

- **Less amount of information available** for validation of non-prompt analyses (extrapolations??)

- Nevertheless, a few **recasting works** are out there (see e.g. talks of Cui and Tweedie)
Simplified models are useful to quickly “recast” results in more complete models.

Cross section tables

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Efficiency tables

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<td>50</td>
<td>0.09</td>
</tr>
<tr>
<td>...</td>
<td></td>
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</tbody>
</table>

Topologies

\[
\sum_i (\sigma \cdot BR)_i \times \epsilon_i^{(a)} \times L_{\text{int}} = N_{\text{SUSY}}^{(a)}
\]

Information on SRs:

\[
N_{UL}^{(a)}, N_{SM}^{(a)}, N_{obs}^{(a)}
\]

Output:

\[
N_{\text{SUSY}}^{(a)}/N_{UL}^{(a)}, CL_s^{(a)}
\]

No MC sim. required

Fastlim

http://fastlim.web.cern.ch/fastlim/

Papucci, KS, Weiler, Zeune 1402.0492

K. Sakurai, MC4BSM talk
Using simplified models

- SUSY Les Houches input file (SLHA) restricts usage to SUSY models (for the moment, due to lack of a standard for x-section info, workarounds for non-SUSY models in the pipeline)

- Limits on single point in model parameter space can be evaluated in $\mathcal{O}(1 \text{ sec}) \rightarrow$ amenable for large scans

- $\sigma$ and $\varepsilon$ tables are pre-computed

- Can use $\varepsilon$ from:
  - Published experimental results on simplified models
  - Recasting using CheckMATE, Atom, …

- $\sigma > 0, \varepsilon \geq 0$: missing search/topology reduces event yield $\rightarrow$ bounds always conservative!!
Using simplified models

- Shortcomings:
  - neglected:
    - interference, finite widths: negligible in weakly coupled models
    - production mechanism variations, chirality and spin correl’: $O(20\%)$ in most of the cases
  - complexity for generating $\varepsilon$ tables:
    - limit topologies to 2-3 steps cascades

For other cases, other tools need to be used…
Simplified models for long-lived particles

• Naively same paradigm can be utilized for long-lived searches:

\[
\epsilon(m_1, m_2, \ldots) \rightarrow \epsilon(m_1, m_2, \ldots, c\tau)
\]

• OK for events with few “well-isolated” long-lived particles (SUSY RPV, “sparse” lepton jets, …)

• introducing lifetime may reduce maximum depth of cascade (complexity)
Simplified models for long-lived particles

• Various simplified topologies already considered by experiments:

• Results as function of $c\tau$ for few mass points

• No full efficiencies for any topologies $\rightarrow$ need to recast almost everything
Simplified models for long-lived particles

- For hidden valleys with dark forces producing higher multiplicities / FSR radiation / showers parameters easily proliferate

\[ \epsilon(m_1, m_2, \ldots) \rightarrow \epsilon(m_1, m_2, \ldots, c\tau, \alpha_D, \Lambda_D, \ldots) \]

- large dimensionality: unless degeneracies of parameters and/or efficiencies factorize, production of efficiency maps for simplified topologies becomes quickly intractable

- Recasting only option in these cases? (less accessible to broader audience: exactly the cases where at the moment more tool hacking is required : ( )}
Recasting & detectors

• Recasting long-lived searches requires new “object” definitions

• In current recasting tools object are defined via combination of:
  
  • event-dependent information (e.g. isolation)

  • event-independent truth-vs-detector corrections (e.g. tagging efficiencies, smearing, …) to bring results within $O(10-20\%)$ for signal events
Recasting & detectors

- E.g., hadronic taus recipe:
  - take jet
  - look at event decay history to see if any parent of particle in jet was a $\tau$
  - count charged particles inside a smaller cone in the jet to define 1-, (2-), 3-prong
  - apply efficiency/rejection for specific prong-ness as function of $p_T$, $\eta$ of jet
    (adapted from $\tau$ commissioning paper, validated against few searches/SM measurements)
  - implicit assumption: efficiency is uncorrelated among taus in same event
    (reasonable bc if too close they would likely be merged in same jet both in simulation and real-life)

Event dependent, truth-level info

Event independent info
Recasting for long-lived particles

• Similar procedure could be applied to new “objects” in long-lived searches

  • detector geometry (regions of ID, ECAL, HCAL, muon) easily taken into account

  • easy to take into account properties used in selection, such as impact parameters, kinematic properties and multiplicities of decay products, EM vs. hadronic energy depositions (roughly), …

• then in principle correct for the discrepancies between truth- and detector-level…
Many open questions, hard to extrapolate from currently available public info:

- How “isolated” these objects have to be for this procedure to work?

- Which parameters are the efficiencies function of? Do they factorize in indep. functions with less arguments? (not feasible to use efficiencies depending on more than 3(-4) correlated parameters…)

- Can pile-up effects be mostly lumped into these efficiency/smearing functions as in the case of prompt objects?

- …
Conclusions

• Recasting analyses can provide feedback to the experimental program by extracting more model-independent results, highlighting “holes” in searches, evaluating the relative strengths of different searches

• For prompt searches:
  
  • Mature tools for recasting searches for prompt objects using conventional reconstructed objects (leptons, jets, photons, Missing ET, …)
  
  • Simplified model approach useful for large parameter scans

  • Agreement to release sufficient information to allow recasting helps with analyses’ validation
Conclusions

• For long lived searches this program is less mature:
  • No tools for recasting searches -> new code needs to be written and limit efforts to the realm of few practitioners
  • Unclear how further one can push the simplified topologies approach
  • Further work needed to understand how to incorporate detector effects in current tools
  • Further work needed to understand which kind of information is necessary from experiment to allow recasting (implementation and validation)
Backup
CheckMATE in a nutshell…

**Input**
- event files (.hep or .hepmc)
- cross sections and total sys. errors

**Experimental Publications**

**Output**
- For all signal regions...
  - theoretical signal / experimental upper limit, CI(s)(signal, background, observed).
  - State if input model is excluded or allowed.

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**CheckMATE**

**Delphes**
- Simulate track reconstruction.
- Determine energy deposits of all particles.
- Apply identification efficiencies for photons and leptons.
- Cluster jets.
- Perform energy/momentum smearings on reconstructed objects.
- Evaluate total missing energy.
- Check isolation conditions for photons and leptons.
- Apply b- and tau-tags on jets.

**Analyses**
- Perform overlap removals, trigger efficiencies, kinematical cuts,…
- Follow experimental analyses as closely as possible.
- Count how many events fall into various signal regions.

**Evaluation**
- Find signal region with largest expected exclusion potential
- Compare expected signal to experimental observation

**Processed ROOT files**

J.S.Kim, talk at MC4BSM 2015
**Atom** *(Automatic Test of Models) in a nutshell…*

- Events
- Applying search strategies
- Database of analyses
- Plots
- Efficiencies
- Warnings
- Statistics
- “Theorist-level” Limits
- Further processing in Mathematica

*(fork of) Rivet*
# Atom vs CheckMATE

<table>
<thead>
<tr>
<th>Atom</th>
<th>CheckMATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Built around Delphes</td>
<td>• Fork of Rivet (~backward compatible for analyses)</td>
</tr>
<tr>
<td>• Uses re-tuned Delphes for reco</td>
<td>• Uses truth + eff + smear for reco (via simple param cards)</td>
</tr>
<tr>
<td>• O(30) analyses</td>
<td>• 100+ analyses</td>
</tr>
<tr>
<td>• Tools for helping implementing new analyses</td>
<td>• Tools for helping implementing new analyses</td>
</tr>
<tr>
<td></td>
<td>• Tool for automatic validation</td>
</tr>
<tr>
<td></td>
<td>• Warnings of potential extrapolation problems</td>
</tr>
<tr>
<td>• Output: limits + ROOT file from Delphes</td>
<td>• Output: limits, distribution plots, warnings</td>
</tr>
</tbody>
</table>