Recasting LLP searches with GAMBIT

Anders Kvellestad, University of Oslo

on behalf of the GAMBIT Collaboration

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I. Introduction:
GAMBIT & ColliderBit
GAMBIT: The Global And Modular BSM Inference Tool

- Fast definition of new datasets and theoretical models
- Plug and play scanning, physics and likelihood packages
- Extensive model database – not just SUSY
- Extensive observable/data libraries

ATLAS
F. Bernlochner, A. Buckley, P. Jackson, M. White

LHCb
M. Chrząszcz, N. Serra

Belle-II
F. Bernlochner, P. Jackson

Fermi-LAT
J. Conrad, J. Edsjö, G. Martinez, P. Scott

CTA
C. Balázs, T. Bringmann, M. White

CMS
C. Rogan

IceCube
J. Edsjö, P. Scott

XENON/DARWIN
B. Farmer, R. Trotta

Theory
P. Athron, C. Balázs, S. Bloor, T. Bringmann,
J. Cornell, J. Edsjö, B. Farmer, A. Fowlie, T. Gonzalo,
J. Harz, S. Hoof, F. Kahlhoefer, S. Krishnamurthy,
A. Kvellestad, F.N. Mahmoudi, J. McKay, A. Raklev,
R. Ruiz, P. Scott, R. Trotta, A. Vincent, C. Weniger,
M. White, S. Wild

31 Members in 9 Experiments, 12 major theory codes, 11 countries
GAMBIT
What’s in the box?

Core
• Models

Physics modules
• ColliderBit: fast LHC sim, Higgs searches, LEP SUSY limits
• DarkBit: relic density, gamma ray signal yields, ID/DD likelihoods
• FlavBit: wide range of flavour observables & likelihoods
• SpecBit: spectrum objects, RGE running
• DecayBit: decay widths
• PrecisionBit: precision BSM tests

Statistics and sampling
• ScannerBit: stats & sampling (Diver, MultiNest, T-Walk, ++)

Backends (external tools)

EPJC, arXiv:1705.07908
EPJC, arXiv:1705.07919
EPJC, arXiv:1705.07920
EPJC, arXiv:1705.07933
EPJC, arXiv:1705.07936
EPJC, arXiv:1705.07959
ColliderBit

- **Higgs**: Connect HiggsBounds and HiggsSignals as backends (more to come)

- **LEP limits (SUSY)**: Calculate $\sigma \times BR$ and check against published limits

- **LHC particle searches**: Full Poisson likelihood from fast MC simulation of LHC searches
  - Parallellized MC event generation and analysis loop inside ColliderBit
  - Event generation with Pythia 8
  - Fast detector simulator: BuckFast (4-vector smearing)

- **Focus on speed**, as required for use in global fits

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**Table 1:**

<table>
<thead>
<tr>
<th>Num. cores</th>
<th>Time (sec)</th>
<th>Speedup</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>81</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>48</td>
<td>3.2</td>
</tr>
<tr>
<td>4</td>
<td>79</td>
<td>6.1</td>
</tr>
<tr>
<td>8</td>
<td>79</td>
<td>6.1</td>
</tr>
<tr>
<td>14</td>
<td>79</td>
<td>6.1</td>
</tr>
<tr>
<td>20</td>
<td>81</td>
<td>5.9</td>
</tr>
</tbody>
</table>

**Fig. 1:**

Schematic diagram of the processing chain for LHC likelihoods.

**Fig. 2:** Within.

**Fig. 3:** [arXiv:1705.07919]
**ColliderBit**

- **Higgs**: ColliderBit currently supports the HiggsBounds and HiggsSignals packages.
- **LEP limits**: LEP limits (SUSY) and Higgs searches are included.
- **LHC particle searches**: LHC particle searches include LEP limits (SUSY) and Higgs searches.
- **Parallelisation**: The event analysis is parallelised using OpenMP.
- **Event analyses**: Event analyses include Fast detector simulation with BuckFast and Event analyses.
- **Focus on speed**: Focus on speed, as required for use in global fits.

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### Cross-section calculation

- **MC event generation**: Default: Pythia 8
- **Detector simulation**: Default: BuckFast
- **Event analyses**

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### Table: Time taken for the cross-section calculation

<table>
<thead>
<tr>
<th>Num. cores</th>
<th>Time taken</th>
<th>Speedup</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 s</td>
<td>1×</td>
</tr>
<tr>
<td>2</td>
<td>2 s</td>
<td>1×</td>
</tr>
<tr>
<td>4</td>
<td>4s</td>
<td>1×</td>
</tr>
<tr>
<td>8</td>
<td>8 s</td>
<td>1×</td>
</tr>
<tr>
<td>16</td>
<td>16 s</td>
<td>1×</td>
</tr>
<tr>
<td>32</td>
<td>32 s</td>
<td>1×</td>
</tr>
<tr>
<td>64</td>
<td>64 s</td>
<td>1×</td>
</tr>
<tr>
<td>128</td>
<td>128 s</td>
<td>1×</td>
</tr>
<tr>
<td>256</td>
<td>256 s</td>
<td>1×</td>
</tr>
<tr>
<td>512</td>
<td>512 s</td>
<td>1×</td>
</tr>
<tr>
<td>1024</td>
<td>1024 s</td>
<td>1×</td>
</tr>
</tbody>
</table>

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### Statistical routines

- **Default**: BuckFast
- **Pythia 8**: For an earlier similar approach, see Ref. [38]
- **GAMBIT**: A single evaluation of just the statistical routine with added NLL corrections exists in GAMBIT.

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### Event generation

- **Prospino 2.1** and **NLL-fast 2.1**: For a recent thorough exploration of the LO cross-section, sometimes by as much as a factor 2.1.4

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### Processors

- **Intel Core i5**: For a wide range of processors, this interpolation is limited to a single processor using Prospino 2.1 and NLL-fast 2.1.

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### Figures

- **Fig. 1**: With the improvement to NLO+NLL, the error from the full Poisson $\propto BR^6$ is clearly unusable in a scan where the set $\begin{bmatrix} A \\ B \\ C \end{bmatrix}$ and $\begin{bmatrix} D \\ E \end{bmatrix}$ increase with the sparticle masses because the PDFs are not exactly unity. Ties must be included in the total error budget. These factors in the MSSM up to a few $10^{-2}$ and $10^{-4}$.

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### Additional Notes

- **For many models, these are the state-of-the-art. For the LO cross-sections in BSM models are known to allow for a wide range of factorisation and renormalisation scales has been used. The factorisation and renormalisation scales has been used with the approximations used in the event and cross-section calculation as a function of the number of cores, for 100,000 SUSY events for the purposes of BSM searches and CMS analyses (see Section 2.1.7). In future releases we can anticipate that this choice, combined with the approximations used in the event and cross-section calculation as a function of the number of cores, for 100,000 SUSY events will reduce somewhat as PDF fits including higher-order corrections improve.

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### References

- **[arXiv:1705.07919]**
- **[arXiv:1705.07919]**
2. Current work: Simulation-less LLP recasting
Simulation-less recasts

- Get mass and lifetime predictions from SpecBit and DecayBit
- Production cross-section in ColliderBit
- Signal-specific maps of acceptance x efficiency from experimental analysis, in the plane of the LLP mass and lifetime

*A lot of very useful material provided on HepData*

- No event generation or detector simulation needed — perfect for large global fits
- Full Poisson likelihood, not only comparison to 95% CL limit
- First target: ATLAS disappearing track search for long-lived charginos (arXiv:1712.02118)
Mass and lifetime

- Masses from SpecBit (via FlexibleSUSY or SPheno)
- Lifetime from DecayBit calculations of decay widths at small mass splittings (not included in SDECAY)
- Chargino and stau decays implemented so far
  

- Future: Also connect SOFTSUSY-4 to SpecBit & DecayBit

\[ \tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 \pi^+ \pi^0 \pi^0 \]
\[ \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \pi^- \pi^0 \pi^0 \]
\[ \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \pi^- \pi^0 \pi^- \]
\[ \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \mu^- \nu \]
\[ \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 e^- \nu \]
\[ \tilde{\tau}_1^+ \rightarrow \tilde{\chi}_1^0 \tau^- \]
\[ \tilde{\tau}_1^+ \rightarrow \tilde{\chi}_1^0 \nu \]
\[ \tilde{\tau}_1^- \rightarrow \tilde{\chi}_1^0 \mu^+ \nu \]
\[ \tilde{\tau}_1^- \rightarrow \tilde{\chi}_1^0 e^+ \nu \]
Mass and lifetime

- **Todo**: Refine chargino lifetime with two-loop calculation of chargino—neutralino mass splitting (wino limit)

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Cross-sections and ColliderBit structure

- **Currently:**
  - Tree-level cross-sections from Pythia8

- **Ongoing work:**
  - Detach cross-section calculation from the parallelized event generation in ColliderBit
  - Allow cross-section input from backend
  - Fast evaluation of NLO SUSY cross-sections
  - Add simulation-less analyses as a new category of analyses in ColliderBit
3. Next step: Event-level LLP recasting
Next step: Event-level LLP recasting

- Use generator-level efficiency maps in decay radius and eta — code in place for doing this

- Slight tweaking of Pythia for decays at very small mass splittings

- Extend the ColliderBit analysis framework to include decay radius information
Conclusion and outlook

- Ongoing effort to implement LLP searches in ColliderBit

- Focus on speed — intended for use in large-scale global fits

- Starting with the simplest case: simulation-less recasting of SUSY LLP searches

- Some decay width calculations implemented, to be extended and refined

- Work ongoing on cross-section evaluations and extending the ColliderBit structure

- Next step: move on to event-level LLP recasting
Backup slides
Getting started with GAMBIT

Clone git repository from GitHub

• github.com/patscott/gambit_1.1

Download tarballs

• hepforge.org/downloads/gambit

Pre-compiled version with Docker

• docker run -it jmcornell/gambit

See quick start guide in arXiv:1705.07908
**GAMBIT**

First physics results

- **Scalar singlet dark matter**
  arXiv:1705.07931

- **GUT-scale MSSM**
  CMSSM, NUHM1, NUHM2
  arXiv:1705.07935

- **Weak-scale MSSM7**
  arXiv:1705.07917
All results publicly available

Results available on zenodo.cern.ch
- Parameter point samples (hdf5 files)
- GAMBIT input files for all scans
- Example plotting routines

Links at gambit.hepforge.org/pubs