Combining Orthogonal LHC New Physics Searches

Presentation by Jamie Yellen
This work forms part of the TACO project
(Testing Analyses’ COrelations)

“Strength in numbers: optimal and scalable combination of LHC new-physics searches”

https://arxiv.org/abs/2209.00025

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Sample of 18 CMS and ATLAS Analyses

ATLAS-SUSY-2013-02  ATLAS-SUSY-2019-08
ATLAS-SUSY-2013-21  CMS-SUS-13-012
ATLAS-SUSY-2015-06  CMS-SUS-19-006
ATLAS-SUSY-2016-07  CMS-SUS-16-033
ATLAS-SUSY-2018-04  CMS-SUS-16-039
ATLAS-SUSY-2018-06  CMS-SUS-16-048
The Overlap Matrix
$\sqrt{s} = 8$ TeV

$\sqrt{s} = 13$ TeV
Exclusivity Matrix

Boolean “mask” of overlap matrix where true is defined as having an overlap below threshold T.
Full Set of paths starting from SR₀
(SRₙ = N)

\[ \{\{0\}, \{0, 1\}, \{0, 2\}, \{0, 5\}, \{0, 3\}, \{0, 6\}, \{0, 7\}, \{0, 8\}, \{0, 1, 2\}, \{0, 1, 5\}, \{0, 1, 6\}, \{0, 1, 7\}, \{0, 1, 8\}, \{0, 2, 3\}, \{0, 3, 5\}, \{0, 3, 6\}, \{0, 3, 7\}, \{0, 3, 8\}\]
71 allowed combinations 
(SRN = N)
\[[0, 1, 2], [0, 1, 5], [0, 1, 6], [0, 1, 7], [0, 1, 8], [0, 2, 3], [0, 3, 5], [0, 3, 6], [0, 3, 7], [0, 3, 8], [0, 1], [0, 2], [0, 5], [0, 3], [0, 6], [0, 7], [0, 8], [0], [1, 2], [1, 5], [1, 6], [1, 7], [1, 8], [1], [2, 3, 4, 9], [2, 3, 4], [2, 3, 9], [2, 4, 9], [2, 3], [2, 4], [2, 9], [2], [3, 4, 5, 9], [3, 4, 6, 9], [3, 4, 7, 9], [3, 4, 8, 9], [3, 4, 5], [3, 5, 9], [3, 4, 6], [3, 4, 7], [3, 4, 8], [3, 4, 9], [3, 6, 9], [3, 7, 9], [3, 8, 9], [3, 5], [3, 4], [3, 6], [3, 7], [3, 8], [3, 9], [3], [4, 5, 9], [4, 6, 9], [4, 7, 9], [4, 8, 9], [4, 5], [4, 6], [4, 7], [4, 8], [4, 9], [4], [5, 9], [5], [6, 9], [6], [7, 9], [7], [8, 9], [8]]

71 allowed combinations
(SRN = N)
Directed Acyclic Graph
Node -> Signal Region
Hereditary Depth First Search
Hereditary Depth First Search

When building a set of signal regions, any additional signal region must have minimum overlap with all previous signal regions in the set.
\[ \emptyset \cap \emptyset \cap \emptyset = \emptyset \]
Hereditary Depth First Search

Algorithm available in the paper and on the TACO GitLab
Weighted Edge:

\[ \omega_i = -2 \ln \left( \frac{L_{i+1}}{L_{i+1,\text{max}}} \right) \]
Weighted Edge:

Best Path = \( \max \left\{ \left\{ \sum_{i \in p_{j}} \omega_i \right\}_{j} \right\} \)
Weighted Hereditary Depth First Search
Results:

Simplified models
pMSSM-19 Reinterpretation: Bino
pMSSM-19: Bino

Expected

Observed
pMSSM-19: Bino

\[
P(\text{combined} | \text{single})
\]

\[
P(\text{single} | \text{combined})
\]

Expected pMSSM-19: Bino

SModelS
pMSSM-19: Bino

\[ P(\text{combined} \mid \text{single}) \]

\[ P(\text{single} \mid \text{combined}) \]

Observed pMSSM-19: Bino
The Combinations can be viewed as a directed acyclic graph, on which a weighted hereditary longest-path computation can be used to identify the best-expected SR combination for limit-setting on any given BSM model.
Thank You

Any Questions?
Weighted Hereditary Depth First Search

When building a set of signal regions, an upper limit on the available weight can be evaluated by calculating the LLR sum of the remaining signal regions with minimum overlap with the current set.
**Note:**
Line colours are used solely to distinguish between different paths.
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Rank matrix in order of preference for each model point i.e. upper limit or r-value