Spey: smooth inference for reinterpretation studies

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Based on arXiv: 2307.06996 [hep-ph]

8th workshop on (Re)interpretation of the LHC results for new physics

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Durham University

Durham University

Science & Technology Facilities Council

MCnet

IP3

Sales pitch of the talk

What are we overcoming here?

- Not enough information to construct a reliable likelihood
- How can we improve the accuracy of the simplified likelihoods?
- Full likelihoods can become computationally intensive; can we simplify them without sacrifice? (Spoiler alert: ML!)
- There are many different software to test hypotheses; how can we combine them?

Outline

- Introduction
- (Better) simplified likelihoods
- Including existing packages
- Combining likelihoods
- Conclusion

Introduction

Statistical Models

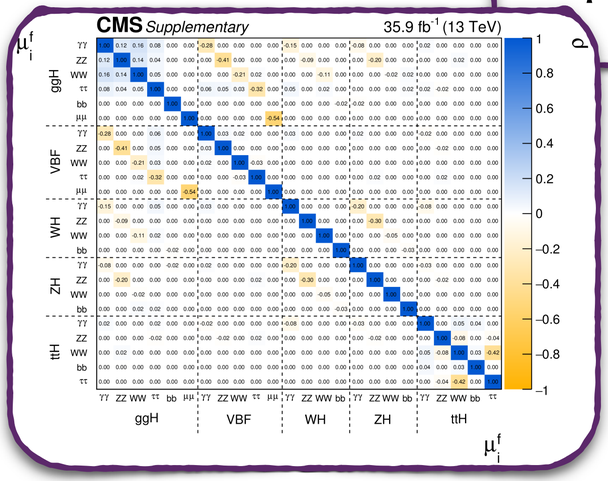
Why important?

ATLAS SUSY and Exotics workshop
S. Kraml '20

- The mathematical description of the analysis is provided within its statistical model.
- A likelihood enables the standard statistical approaches to extract information.
- *i.e.* how reasonably aligned the theoretical predictions with the experimental observations?

Les Houches Recommendations (EPJC '12)

Simplified likelihoods from CMS



CMS-NOTE-2017-001

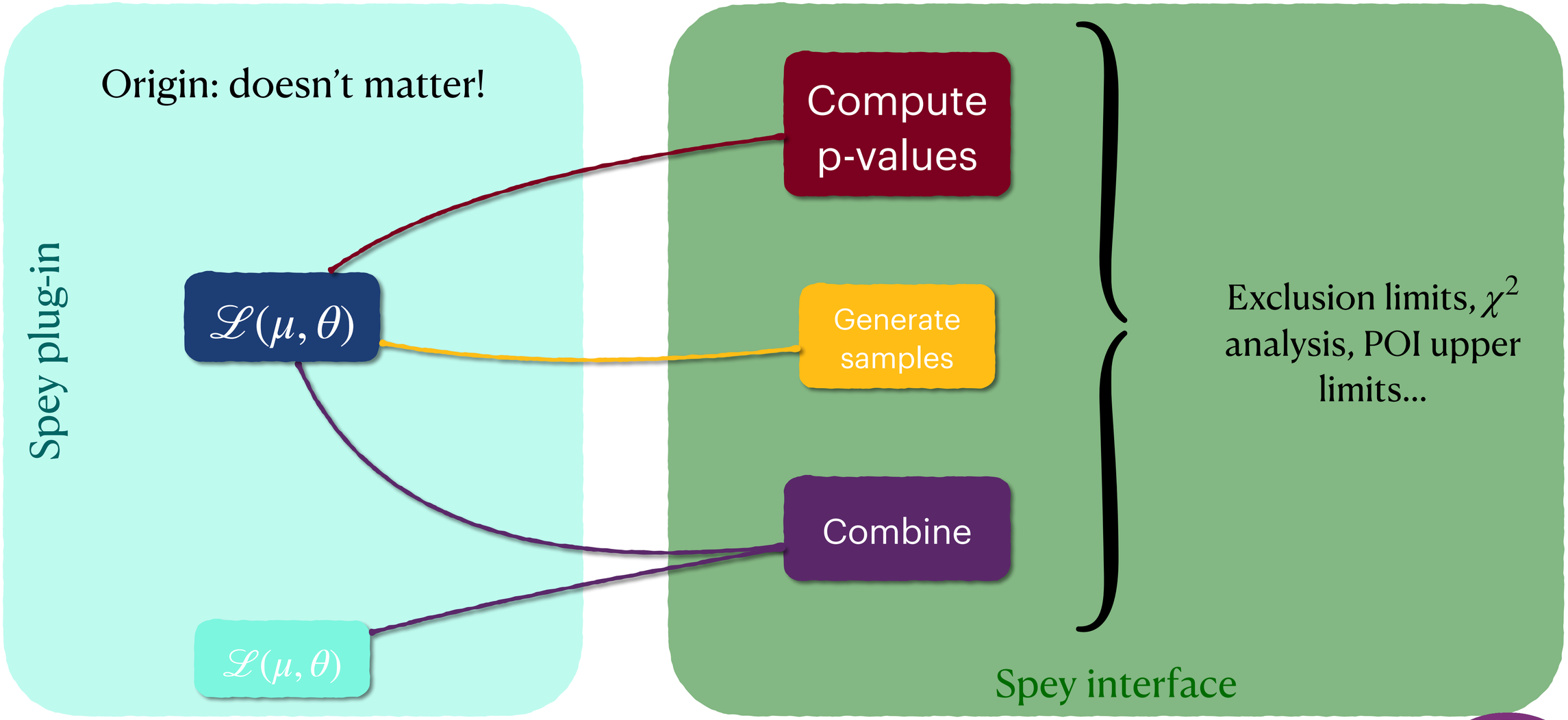
Full likelihoods from ATLAS

pyhf
∂ifferentiable
ℒikelihoods

ATL-PHYS-PUB-2019-029

Spey demystified

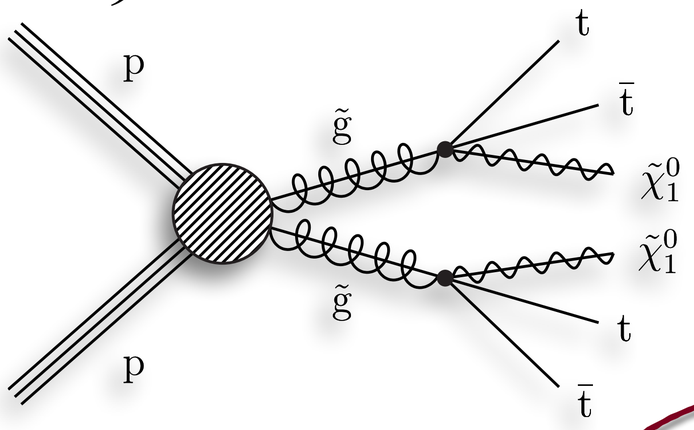
```
$ pip install spey
```



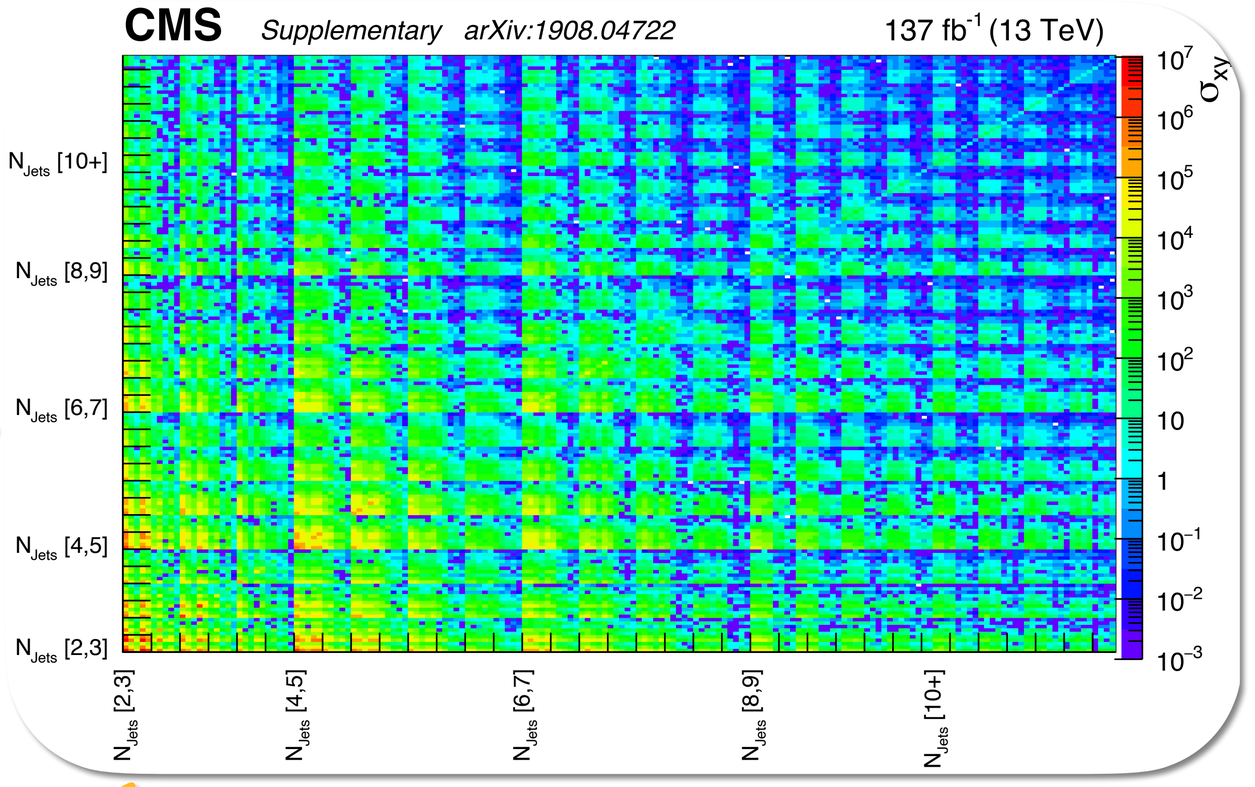
(Better) Simplified Likelihoods

Simplified likelihoods

CMS-SUS-19-006



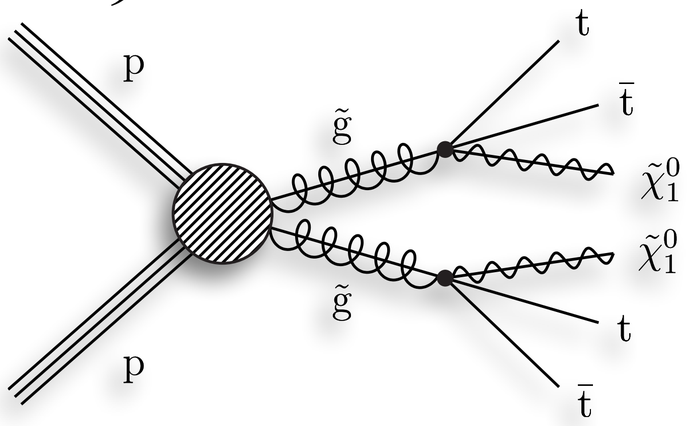
$$\mathscr{L}(\mu,\theta) = \left[\prod_{i\in\text{bins}} \text{Poiss}\left(n^i \,|\, \mu n_s^i + n_b^i + \theta^i \sigma_b^i\right)\right] \cdot \mathcal{N}\left(\theta \,|\, 0,\rho\right)$$



186 signal regions!

Simplified likelihoods

CMS-SUS-19-006



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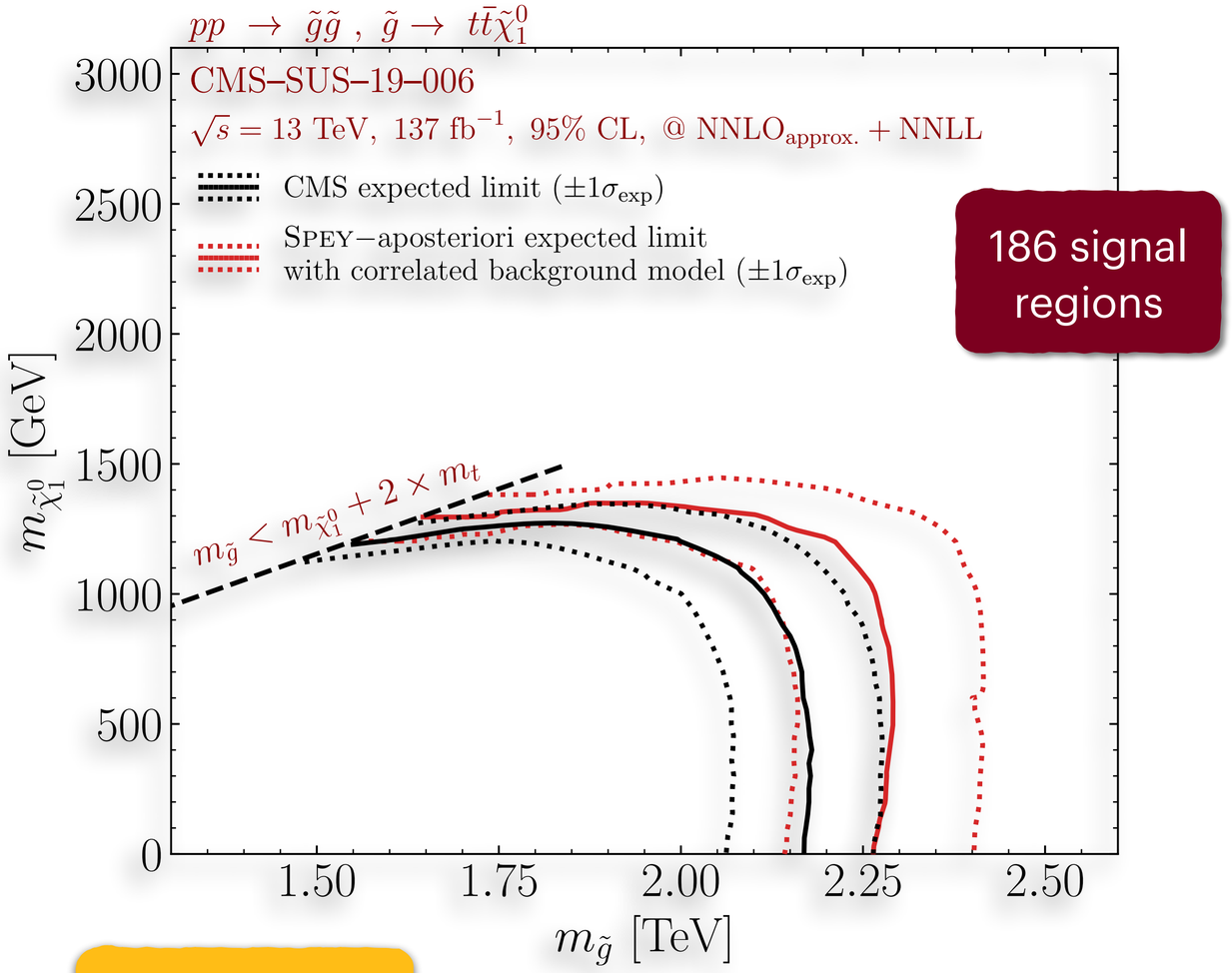


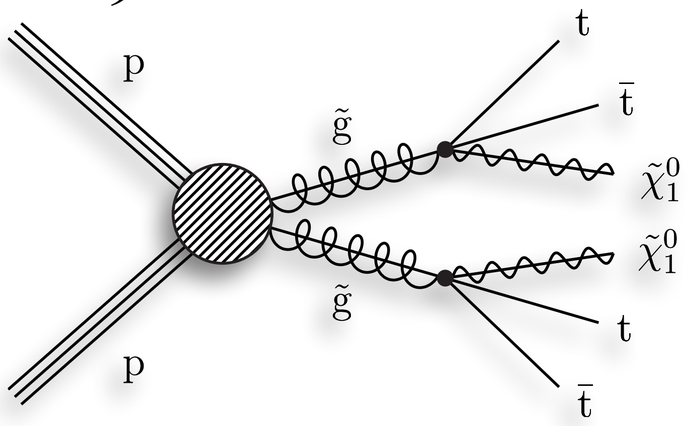
186 signal regions

Recast by MadAnalysis 5

CMS-NOTE-2017-001

Simplified likelihoods: third moment expansion

CMS-SUS-19-006

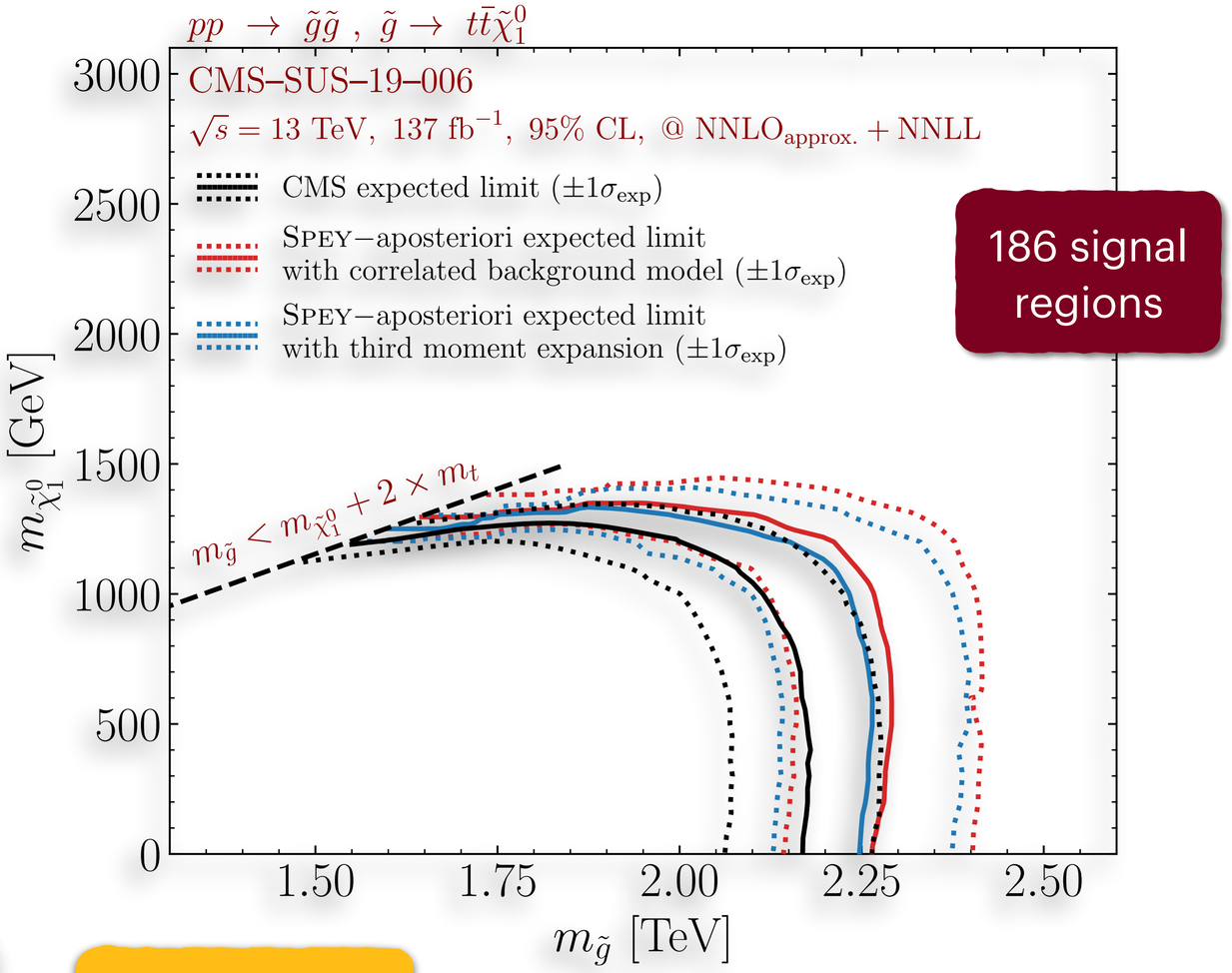


$$\mathscr{L}(\mu,\theta) = \left[\prod_{i\in\text{bins}} \text{Poiss}\left(n^i \,|\, \mu n_s^i + \bar{n}_b^i + A_i\theta_i + C_i\theta_i^2\right)\right] \cdot \mathcal{N}\left(\theta\,|\,0,\bar{\rho}\right)$$

$\bar{n}_b^i$:= the central value of the background

A_i := the effective sigma of the background uncertainty

C_i := asymmetry of the background uncertainty



186 signal regions

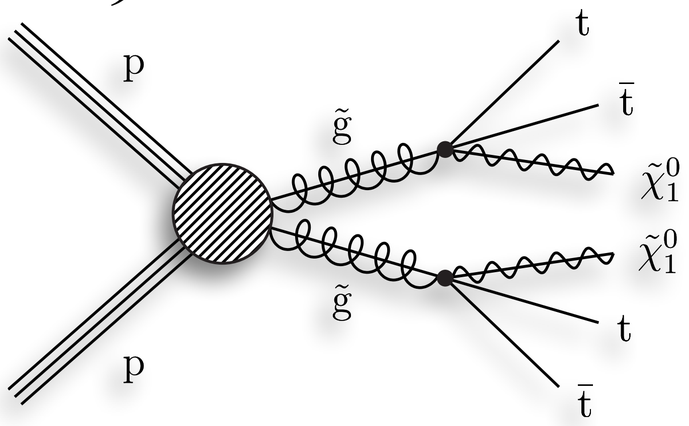
Recast by MadAnalysis 5

Buckley, Citron, Fichet, Kraml, Waltenberger, Wardle; JHEP '18

See Sabine's talk from yesterday!

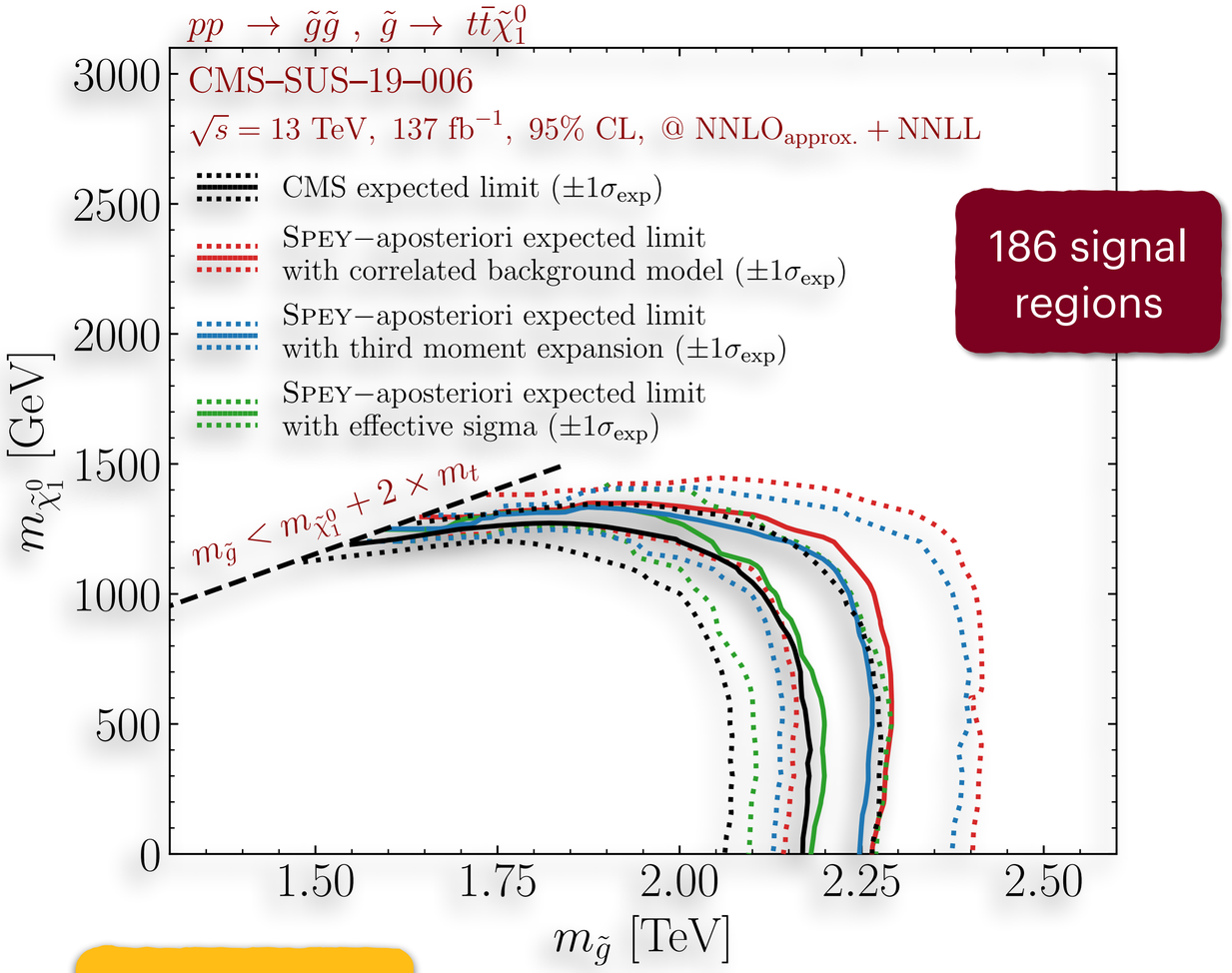
Simplified likelihoods: effective sigma

CMS-SUS-19-006



$$\mathscr{L}(\mu,\theta) = \left[\prod_{i\in\text{bins}} \text{Poiss}\left(n^i \,|\, \mu n_s^i + n_b^i + \theta^i \sigma_{\text{eff}}^i(\theta^i)\right)\right] \cdot \mathcal{N}\left(\theta \,|\, 0,\rho\right)$$

$$\sigma_{\text{eff}}^i(\theta^i) = \sqrt{\sigma_i^+\sigma_i^- + (\sigma_i^+ - \sigma_i^-)(\theta^i - n_b^i)}$$



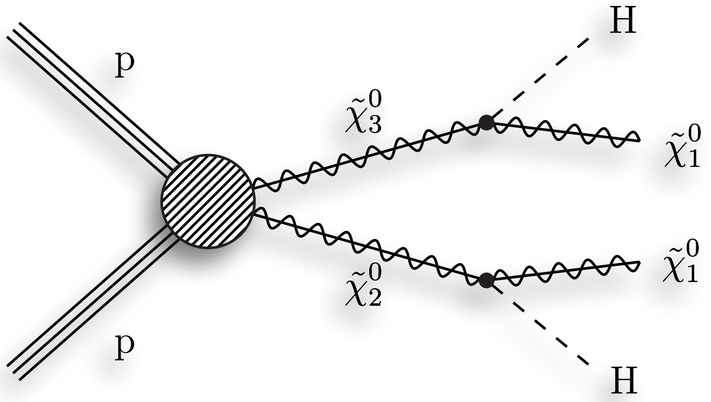
186 signal regions

Recast by MadAnalysis 5

Barlow, '04

Simplified likelihoods: effective sigma

CMS-SUS-20-004



$$\mathscr{L}(\mu,\theta) = \left[\prod_{i\in\text{bins}} \text{Poiss}\left(n^i \,|\, \mu n_s^i + n_b^i + \theta^i \sigma_{\text{eff}}^i(\theta^i)\right)\right] \cdot \mathcal{N}\left(\theta \,|\, 0,\rho\right)$$

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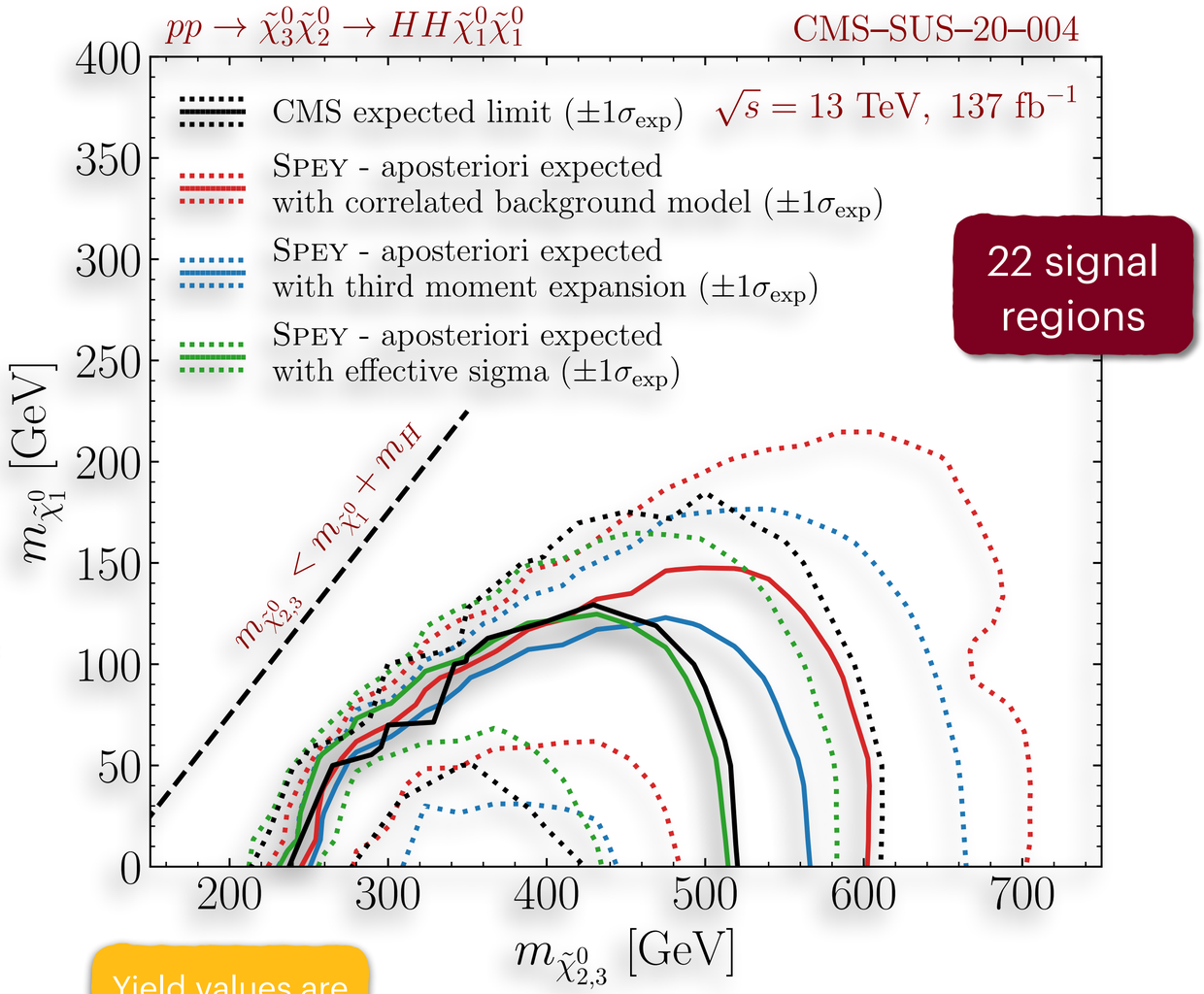


22 signal regions

Yield values are provided by CMS

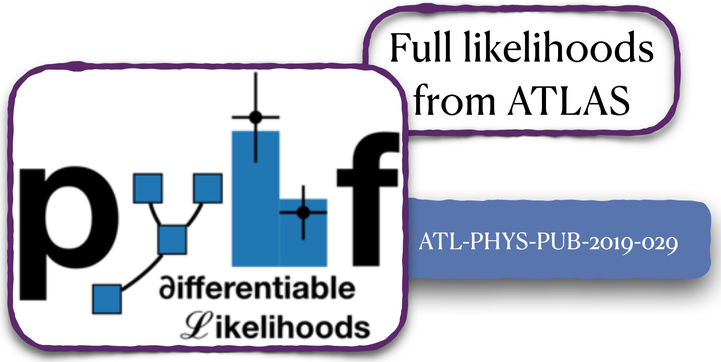
Barlow, '04

Including existing packages

Full likelihoods

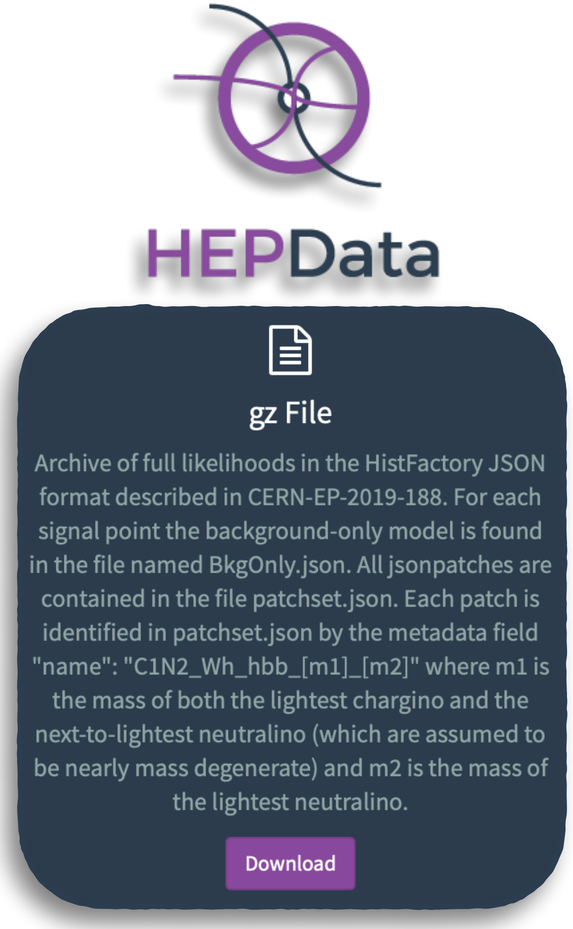
No need to reinvent the wheel!

See Krzysztof & Sabine's talk from yesterday!



- ATLAS shares HistFactory-like JSON files to form full profile likelihoods.
- Each file includes detailed information on backgrounds and corresponding nuisance parameters.

```
$ pip install spey-pyhf
```



Full likelihoods

```
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```
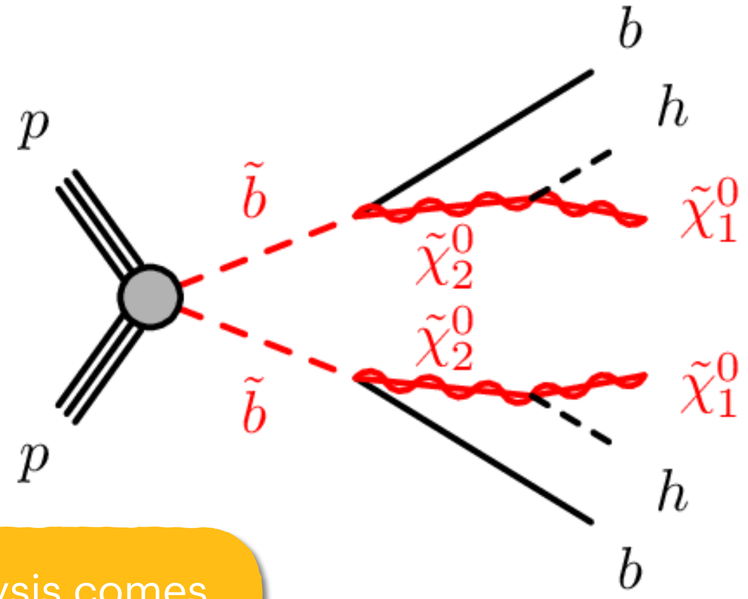
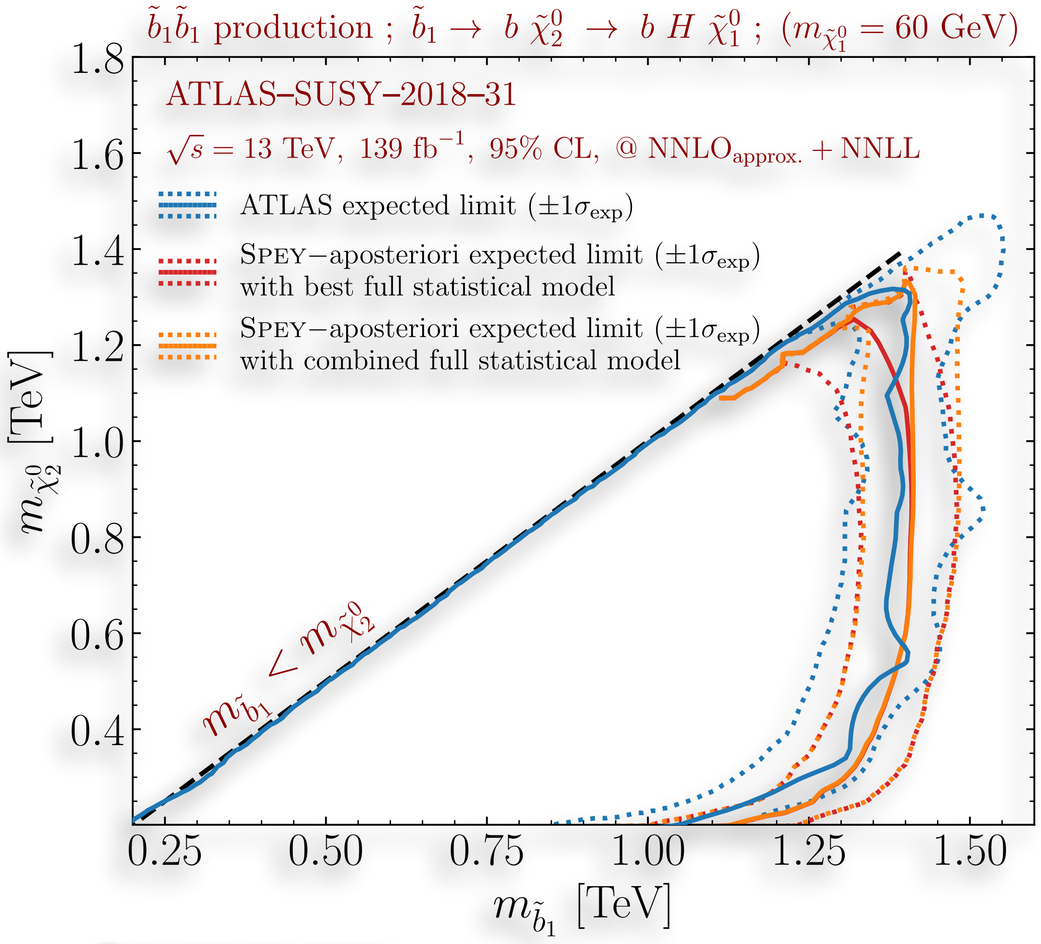



This analysis comes with three different super regions!

Full likelihoods include all the necessary information to mix and match nuisance parameters to combine them!



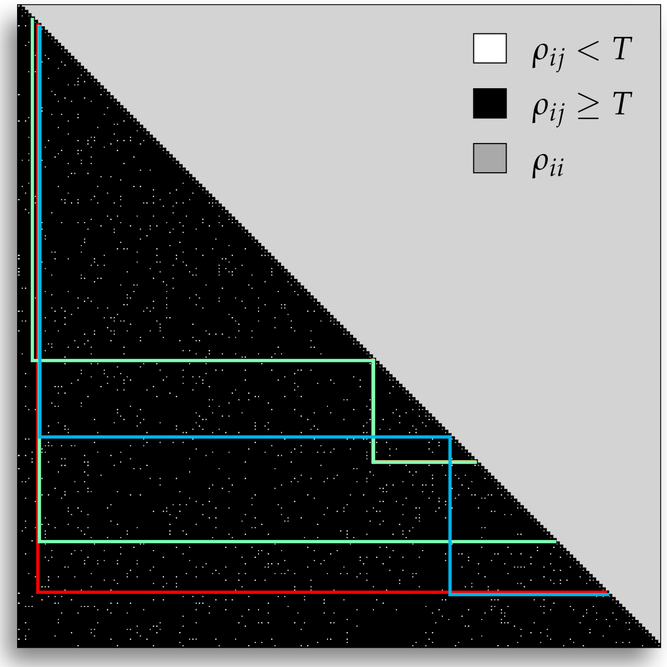
Recast by MadAnalysis 5

Combining likelihoods

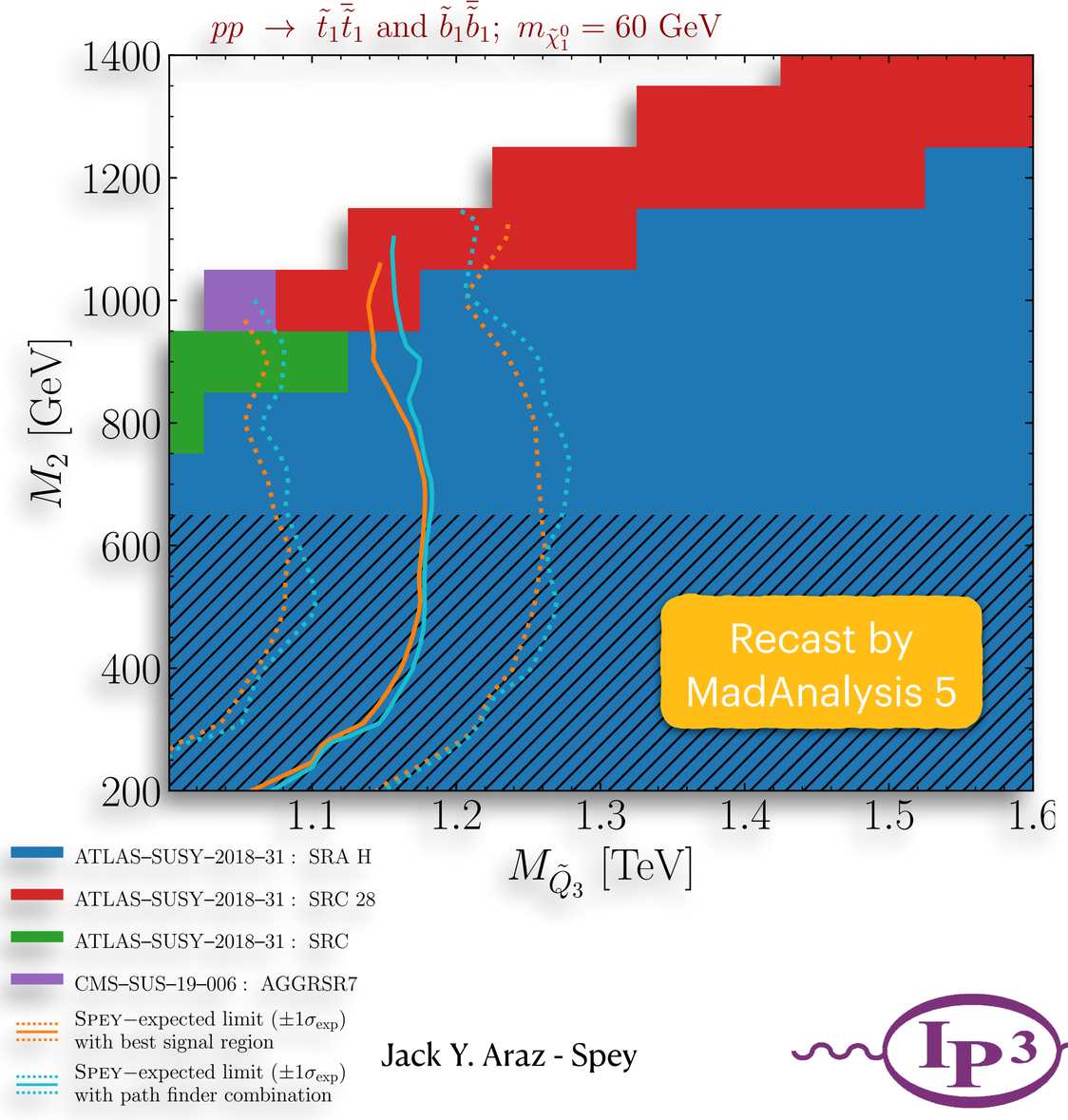
An MSSM example with TACO

$pp \to \tilde{b}_1\bar{\tilde{b}}_1$ and $\tilde{t}_1\bar{\tilde{t}}_1$

Combine non-overlapping regions to avoid correlations



JYA, Buckley, Fuks, Reyes, Waltenberger, Williamson, Yellen; SciPost '22



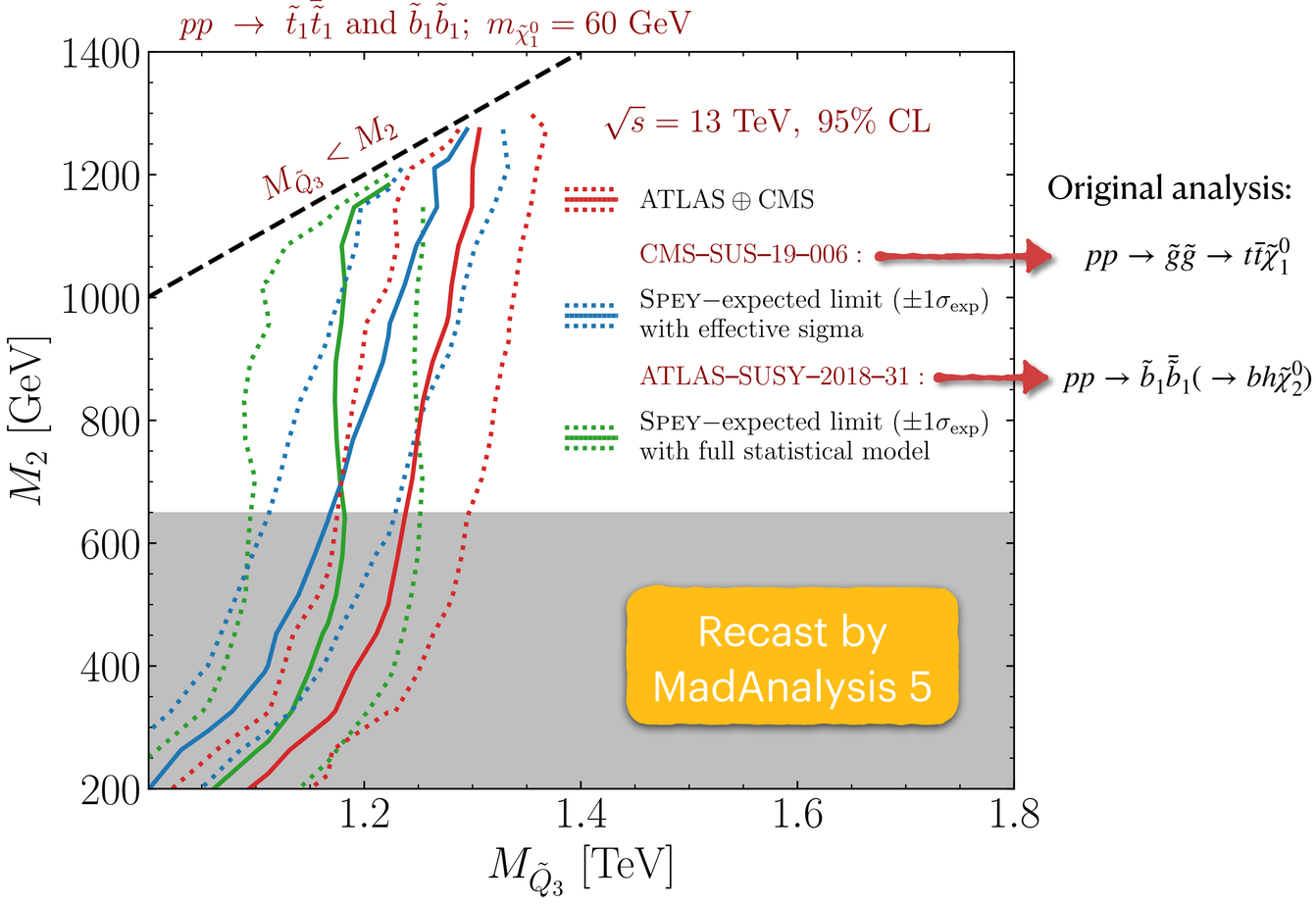
An MSSM example

$$\mathscr{L}' = \mathscr{L}_{\text{ATLAS}} \oplus \mathscr{L}_{\text{CMS}}$$

Full likelihood

Simplified likelihood with effective sigma model

A combination of analyses, rather than regions, contains much more information!



Original analysis:

CMS–SUS–19–006 : $pp \to \tilde{g}\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$

ATLAS–SUSY–2018–31 : $pp \to \tilde{b}_1\bar{\tilde{b}}_1(\to bh\tilde{\chi}_2^0)$

Assumes that likelihoods are not correlated

Conclusion

Conclusion

Spey online documentation

Spey arXiv:2307.06996

- Choosing the correct likelihood is as crucial as proper recast implementation!
- Spey acts as a hub for various likelihood implementations for hypothesis testing.
- The ability to study likelihoods in a backend-agnostic way opens up various possibilities, such as combinations.
- Spey offers an easily expandable plug-in system for future likelihood implementations.

Smarter simplified likelihood implementations

See Humberto's talk on Thursday!

Machine Learned likelihoods

See Nathan's talk after this!

Dedicated custom likelihoods for other experiments