Sabine Kraml, LPSC Grenoble, CNRS - IN2P3

New developments in SModelS

for the SModelS collaboration: M. Altakach, SK, A. Lessa, S. Narasimha, T. Pascal, H. Reyes Gonzalez, W. Waltenberger

essentially SModelS v2.3, presented in arXiv:2306.17676

Reinterpretation: methods and tools

Review in Section III of 2003.07868

This Talk

Reproduce
experimental analysis
in a Monte Carlo simulation

"recasting"

Reuse
simplified model results
(σ_{95}, signal A×ε)

Assumes that A×ε doesn't change too much w.r.t. original model

CHECKMATE

MADAnalysis 5

RIVET
Contur

ADL

ColliderBit

(+ATLAS SimpleAnalysis)

Test of
BSM hypothesis

SModelS

See also talk by T. Pascal this morning

SModelS working principle

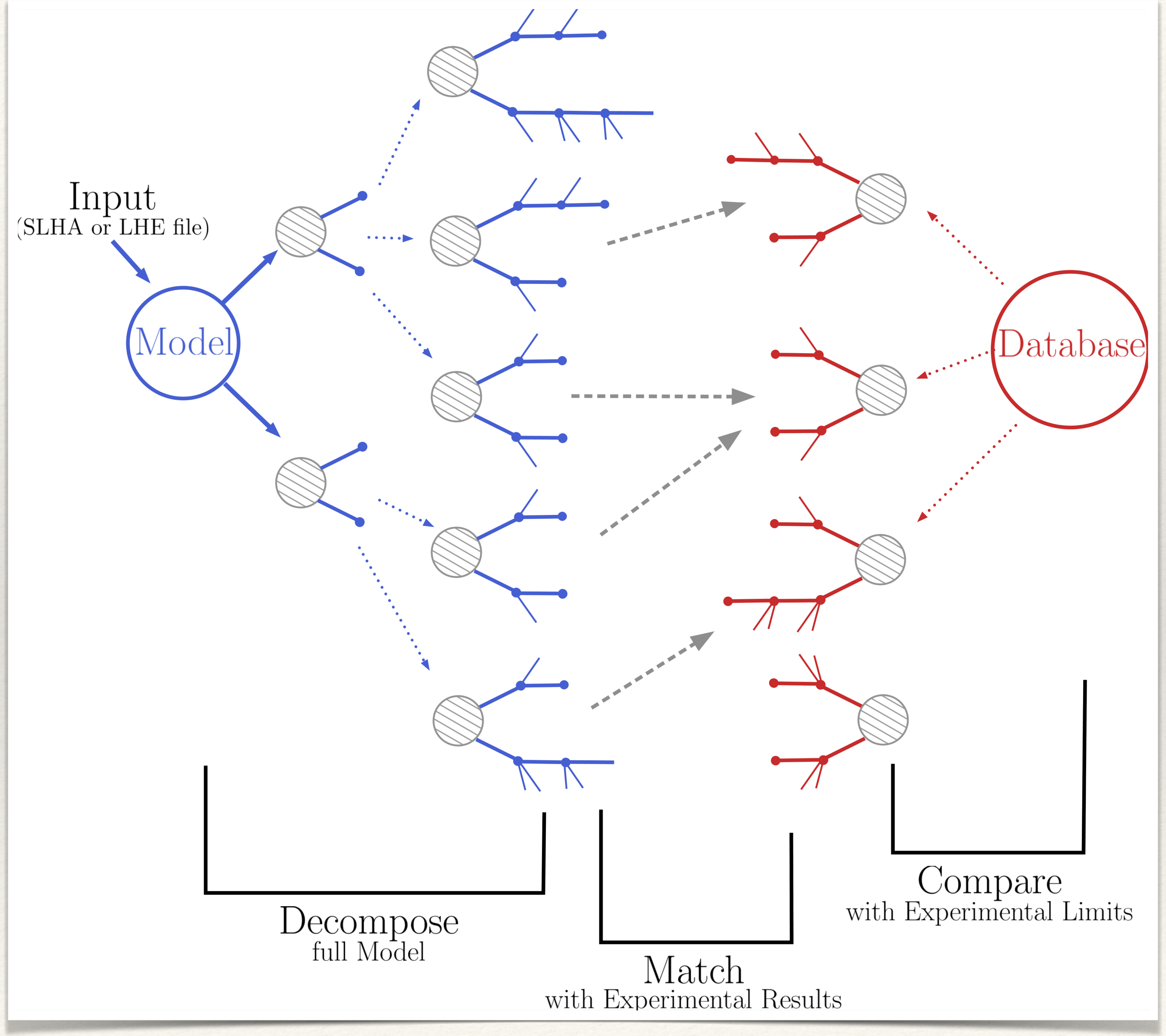
https://smodels.github.io

- **Decompose** the signatures of **full BSM scenarios into simplified model components**, which are then confronted against the experimental constraints from a **large database of results**.

- Input: SLHA files with mass spectrum, decay tables and cross sections; *alternative: parton-level events (LHE).*

- Options set in `parameters.ini` file; or can use SModelS as python library

- Any BSM model with a Z_2-like symmetry!



Pros and cons

- Assumes that **signal acceptances** are to good approximation **the same** as in original experimental result.

  Valid for **simple rescaling** of production and decay rates (σ×BR); other cases need to be **verified**, e.g. spin or production mode dependence.

- Applicable also for ML-based analyses
  (difficult to impossible to recast)

- Advantages are simplicity and **speed!**
  → **very fast** b/c no MC simulation needed
  → well suited for large scans and model surveys

- **Large database** of experimental results

- ATLAS and CMS, Run1 and Run2, **prompt and long-lived results** all **treated simultaneously**

- Easy **classification of** unconstrained cross section, **missing topologies**

- **Often conservative:** coverage depends on variety of available simplified-model results

simplified model approach (SModelS)

Create **SLHA file**
with mass spectrum and decay tables
⬇
add **production cross sections**
(SModelS xseccomputer or micrOMEGAs)
⬇
compute all **signal weights** :
σ×BR×BR…
⬇
sum **matching elements**
⬇
find and apply A×ε (or σ_{95}) values
from **experimental results**
⬇
statistical evaluation‡
(background numbers usually from exp. pub.)

automated

‡ in case exp. result is σ_{95}: only allowed/excluded

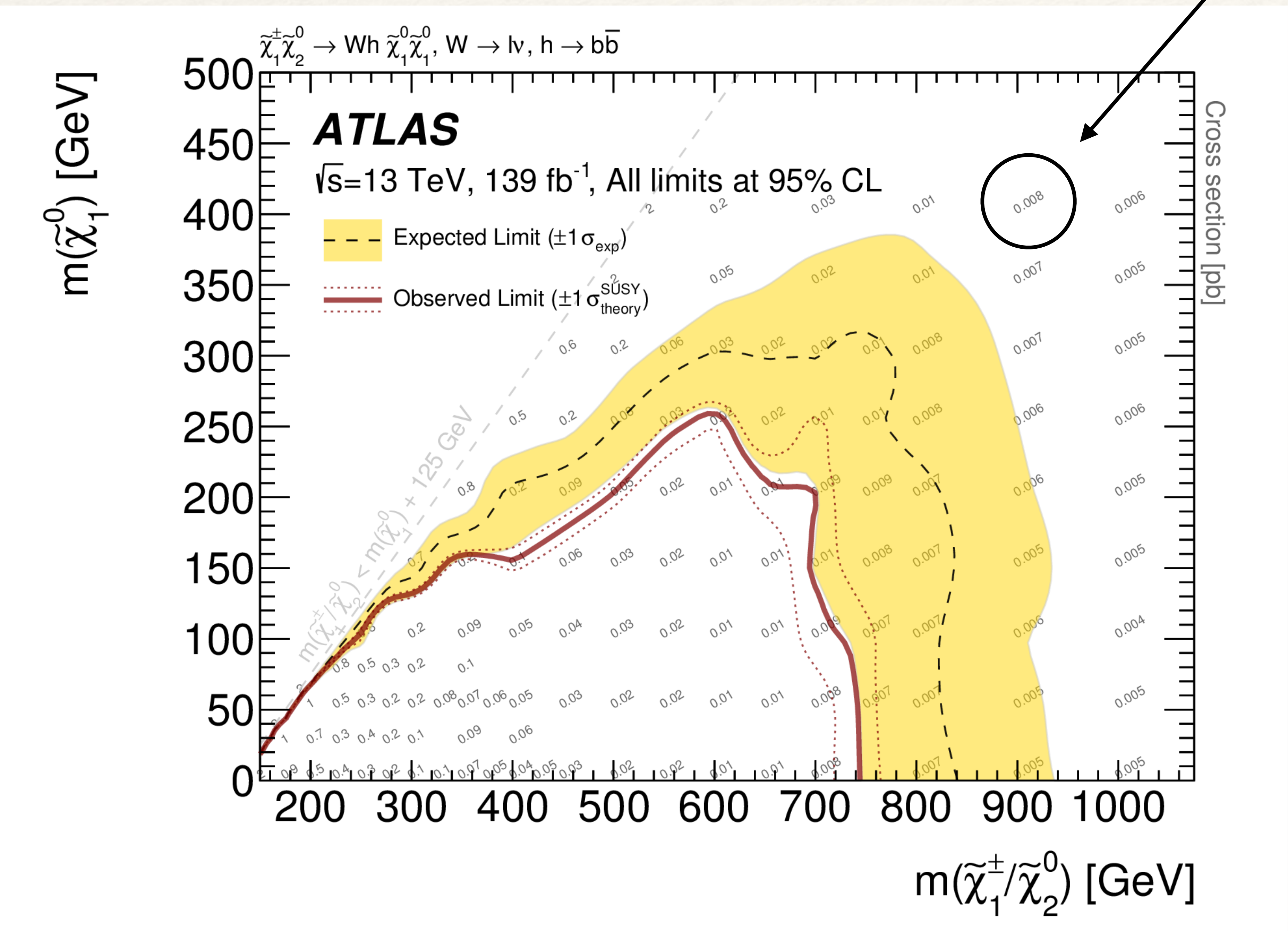
SModelS v2.3

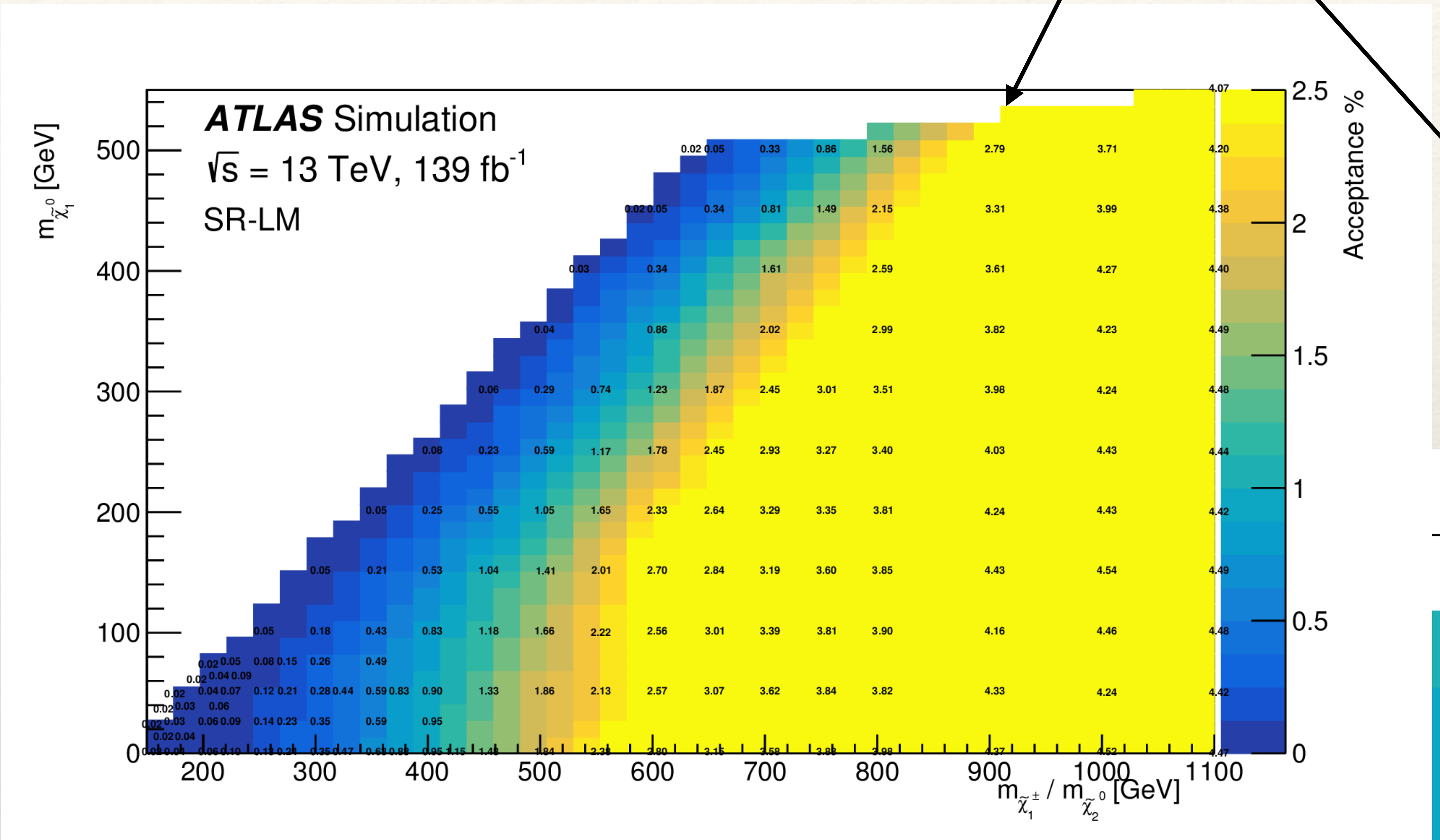
arXiv:2306.17676

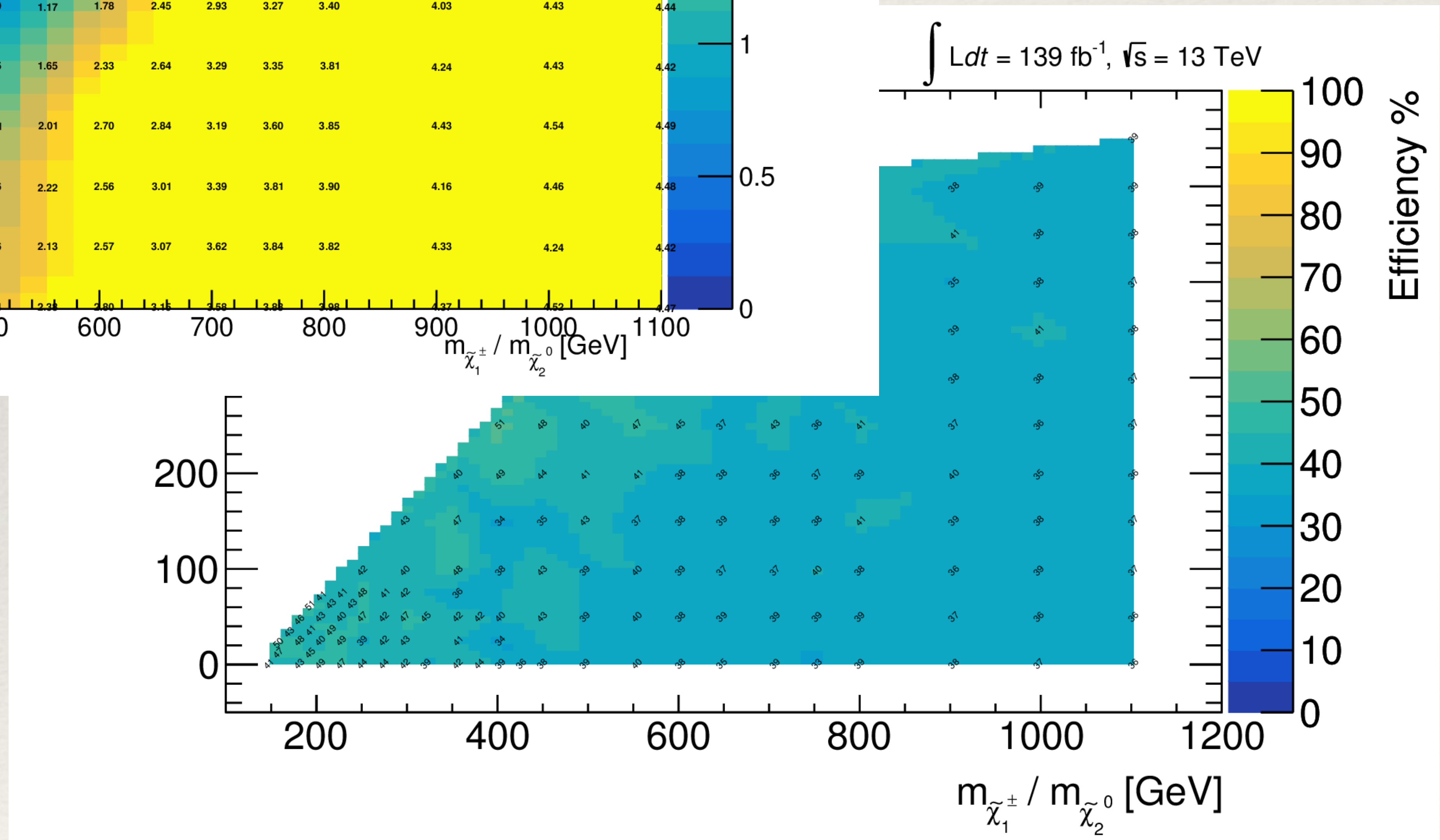
- Refactored statistics modules — "SPEY ready"
  - SR combination with simplified likelihood (SL) and HistFactory models (pyhf)
  - added support for SLv2: Gaussian with a skew, arXiv:1809.05548
- User-defined **combination of analyses**
  - `combineAnas = [list of analyses]` option in parameters.ini file
  - combinations matrix: can define & track inter-analyses combinability at the level of whole analyses as well as individual signal regions (→ `isCombinableWith` method)
- **Database extension**: added 9 ATLAS + 12 CMS analyses
  - total of 111 analyses, 17 ATLAS and 13 CMS for full Run 2 luminosity
  - database "add-ons": non-aggregated SRs, full_llhds, …
- Physics show-case: impact for EW-ino sector of the MSSM

Experimental results used in SModelS

upper limit (UL) maps and **A×ε ‘efficiency’ maps (EM)**



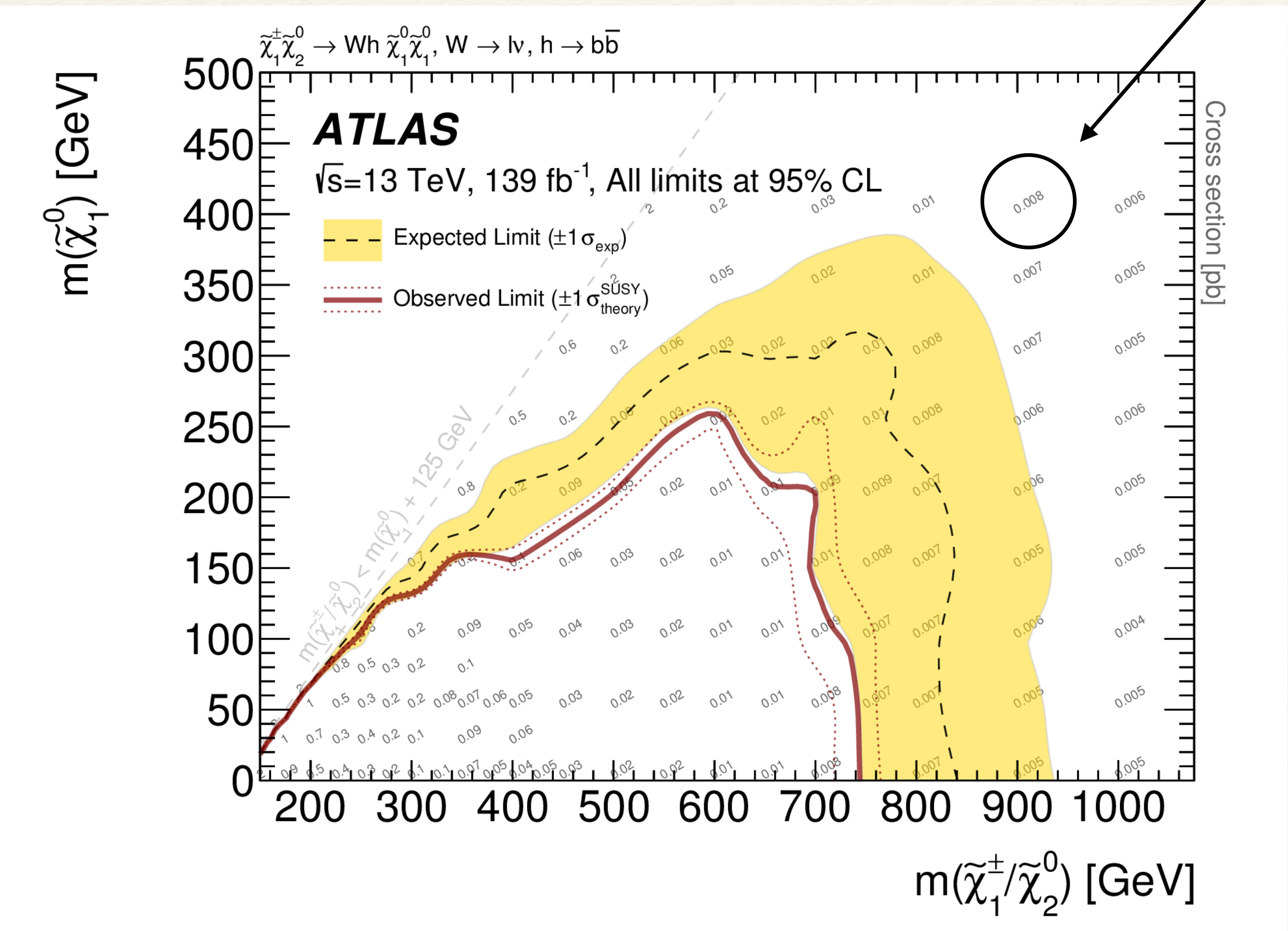




EMs can conveniently be extracted from pyhf patchsets !

Experimental results used in SModelS

upper limit (UL) maps



- Maps of 95% CL **upper limits on the signal cross section** (σ_{95}) as function of the simplified model parameters

$$r = \frac{[\sigma \times \mathrm{BR} \times \mathrm{BR}]}{\sigma_{95}}$$

← theory prediction for the signal

- Excluded if $r \geq 1$
- Binary decision: excluded or not

Experimental results used in SModelS

Maps of Aε as function of the simplified model parameters *for each SR*; allow us

- to **sum different contributions** to the same signal region

$$n_{\rm sig} = \sum A\epsilon \left[\sigma \times {\rm BR} \times {\rm BR}\right] \times \mathcal{L}$$

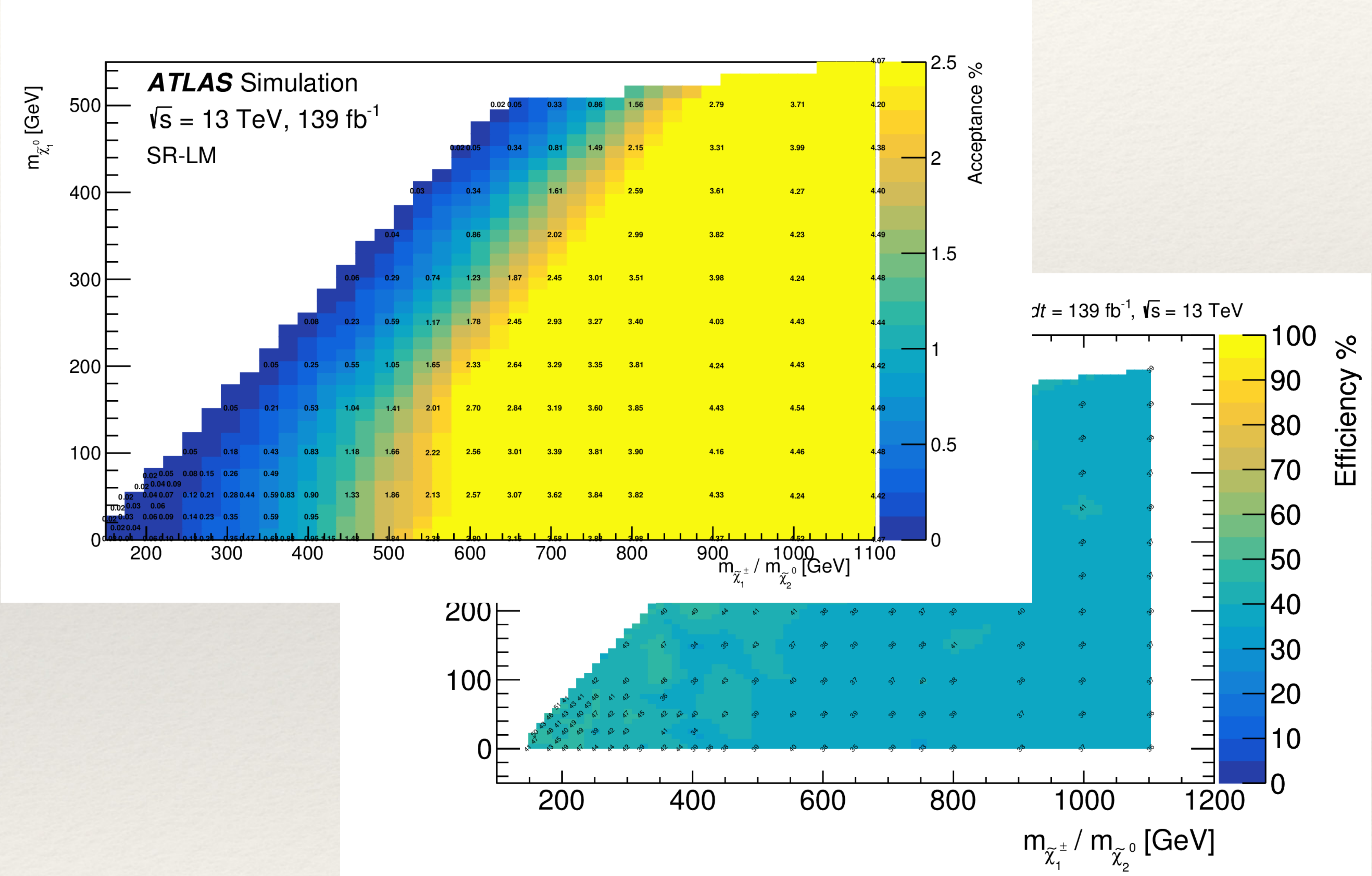
- given expected and observed numbers of events, **compute a likelihood** for the hypothesised signal *)

$$\mathcal{L}(\mu, \theta | D) = P(D|\mu s + b + \theta)\, p(\theta)$$

- do sophisticated statistical evaluations (likelihood ratio tests, confidence levels, p-values, etc.)

A×ε 'efficiency' maps (EM)

Can conveniently be extracted from pyhf patchsets !



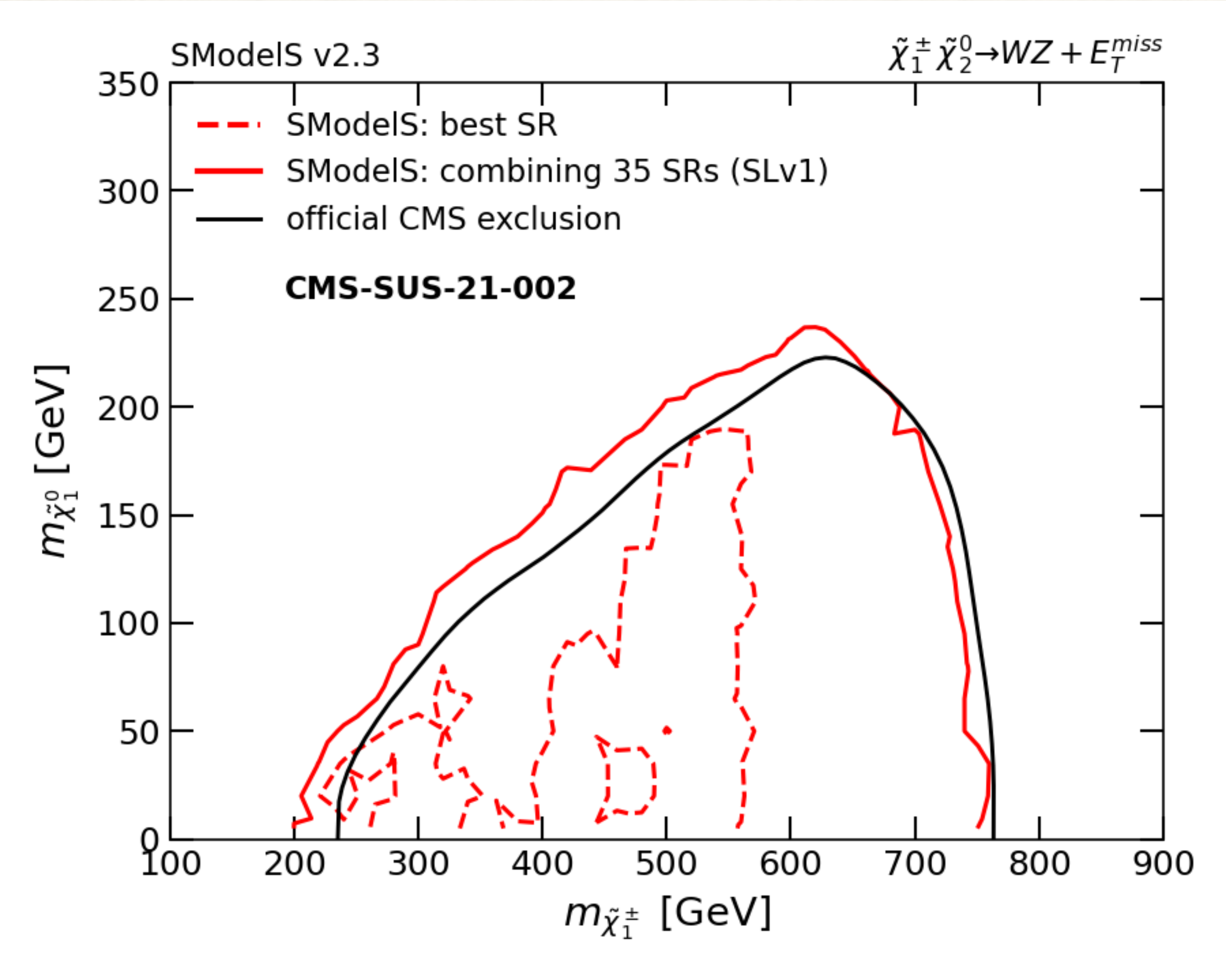
*) if information on correlations is available, SRs can be combined

Combination of signal regions

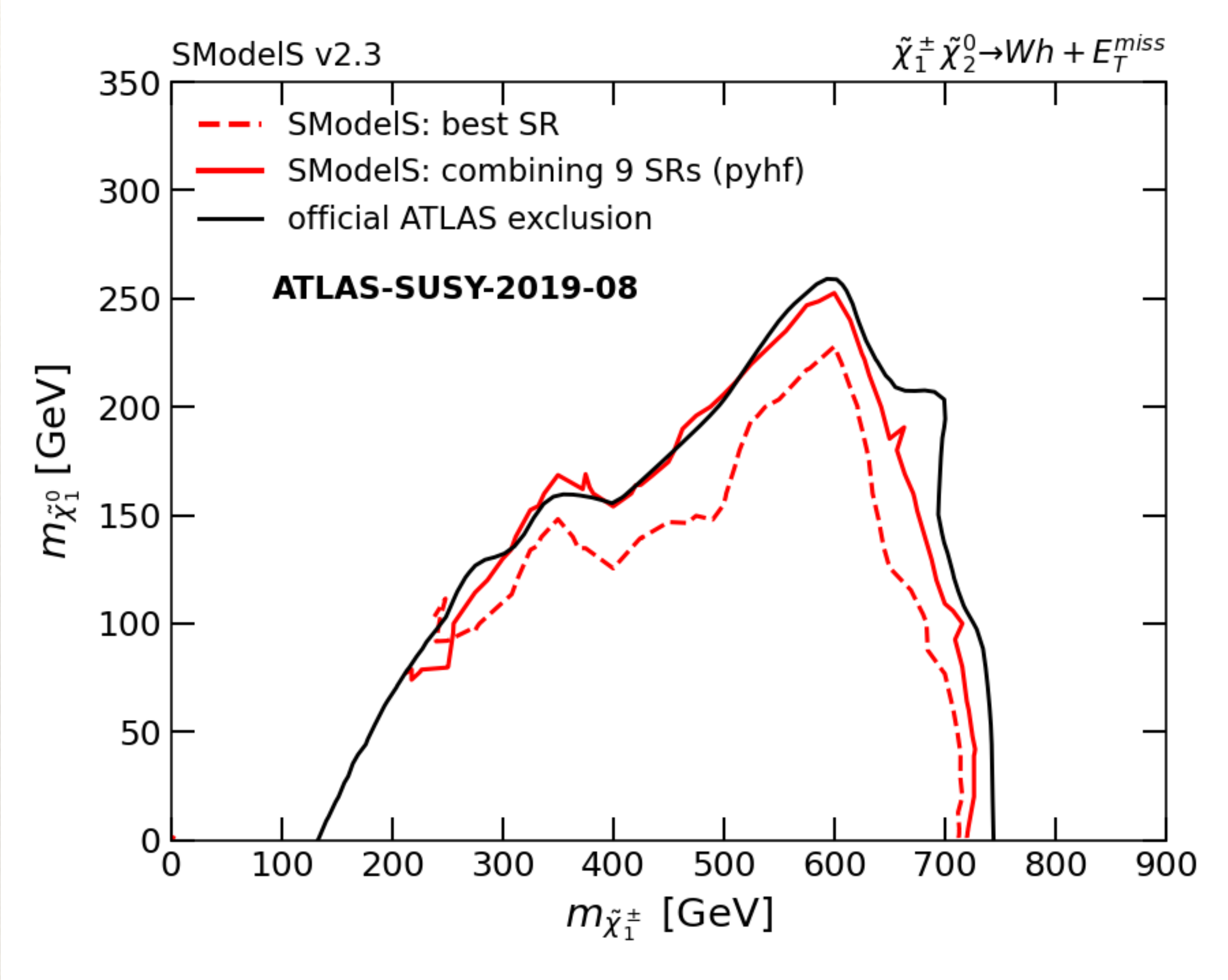
`combineSRs = True/False`

- Combination of SRs uses more of the data of an analysis; more reliable constraints
- Statistical modelling: covariance matrix (CMS) or HistFactory model (ATLAS)

simplified likelihood, SL



full likelihood, pyhf



As of v2.3, SModelS also makes use of the "SLv2" (Gaussian approx. with a skew)

For HistFactory models, we can now also include control regions!

SLv2: Gaussian with a skew

arXiv:1809.05548

SLv1: Gaussian uncertainties

covariance matrix

#signal #bkg nuisances

$$\mathcal{L}(\mu,\theta|D) \propto \prod_{i=1}^{N} \mathrm{Pois}\left(n^i_{\mathrm{obs}}|\mu s_i + b_i + \theta_i\right)\ \exp\left(-\frac{1}{2}\vec{\theta}^T V^{-1}\vec{\theta}\right)$$

SLv2: small non-Gaussianities

correlation matrix

$$\mathcal{L}(\mu,\theta|D) \propto \prod_{i=1}^{N} \mathrm{Pois}\left(n^i_{\mathrm{obs}}|\mu s_i + \alpha_i + \beta_i\theta_i + \gamma_i\theta_i^2\right)\ \exp\left(-\frac{1}{2}\vec{\theta}^T \rho^{-1}\vec{\theta}\right)$$

first three statistical moments

$$V_{ij} = \beta_i\beta_j\rho_{ij} + 2\gamma_i\gamma_j\rho_{ij}^2$$

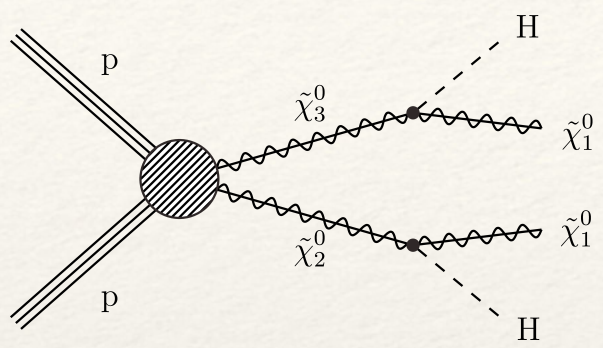
$$m_{3,i} = 6\beta_i^2\gamma_i + 8\gamma_i^3$$

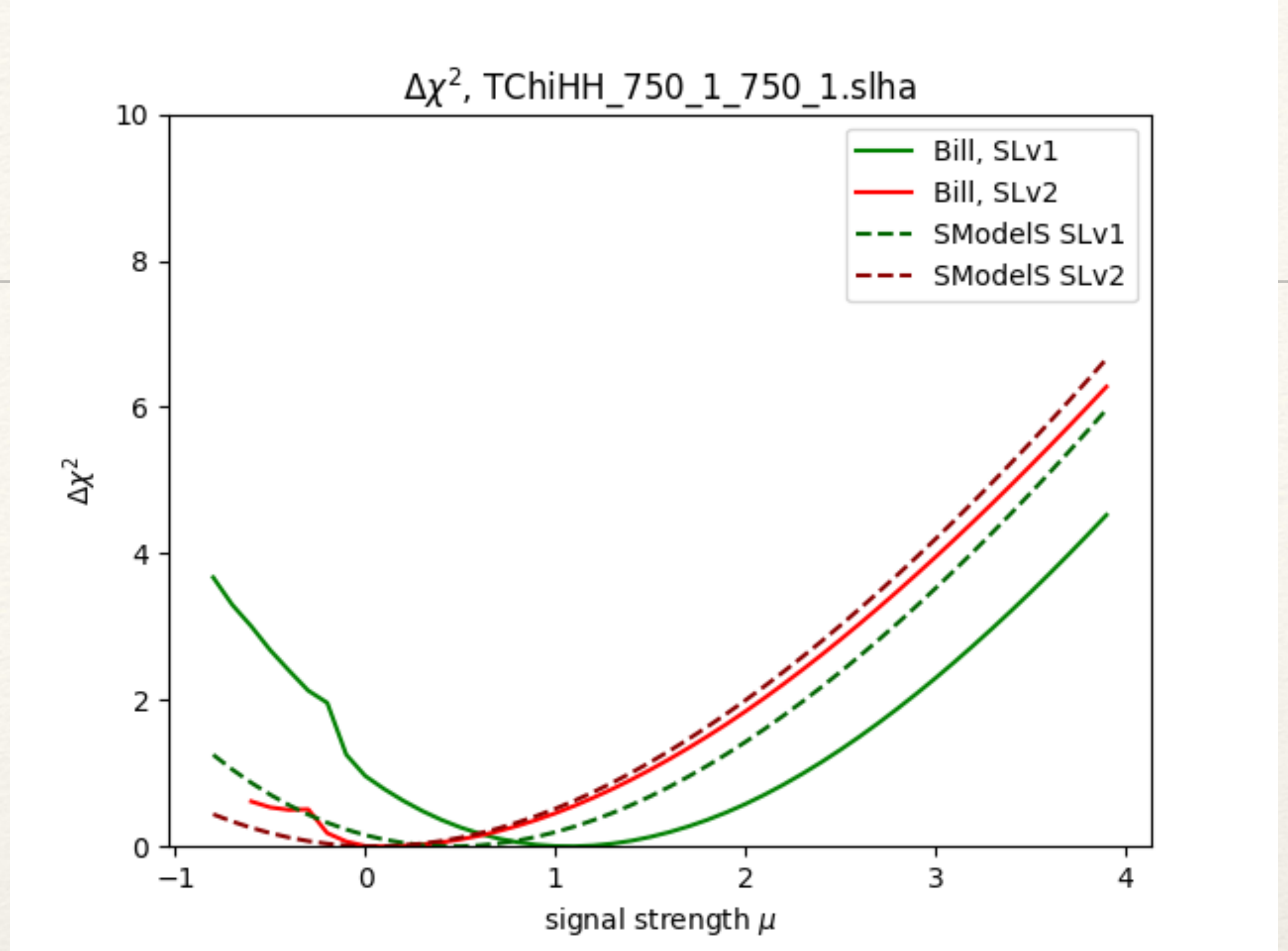
$$m_3 = \frac{2}{\delta_- + \delta_+}\left[\delta_- \int_{-\infty}^{0} x^3\,\mathrm{No}\left(x;0,\delta_-^2\right)dx + \delta_+ \int_{0}^{\infty} x^3\,\mathrm{No}\left(x;0,\delta_+^2\right)dx\right]$$

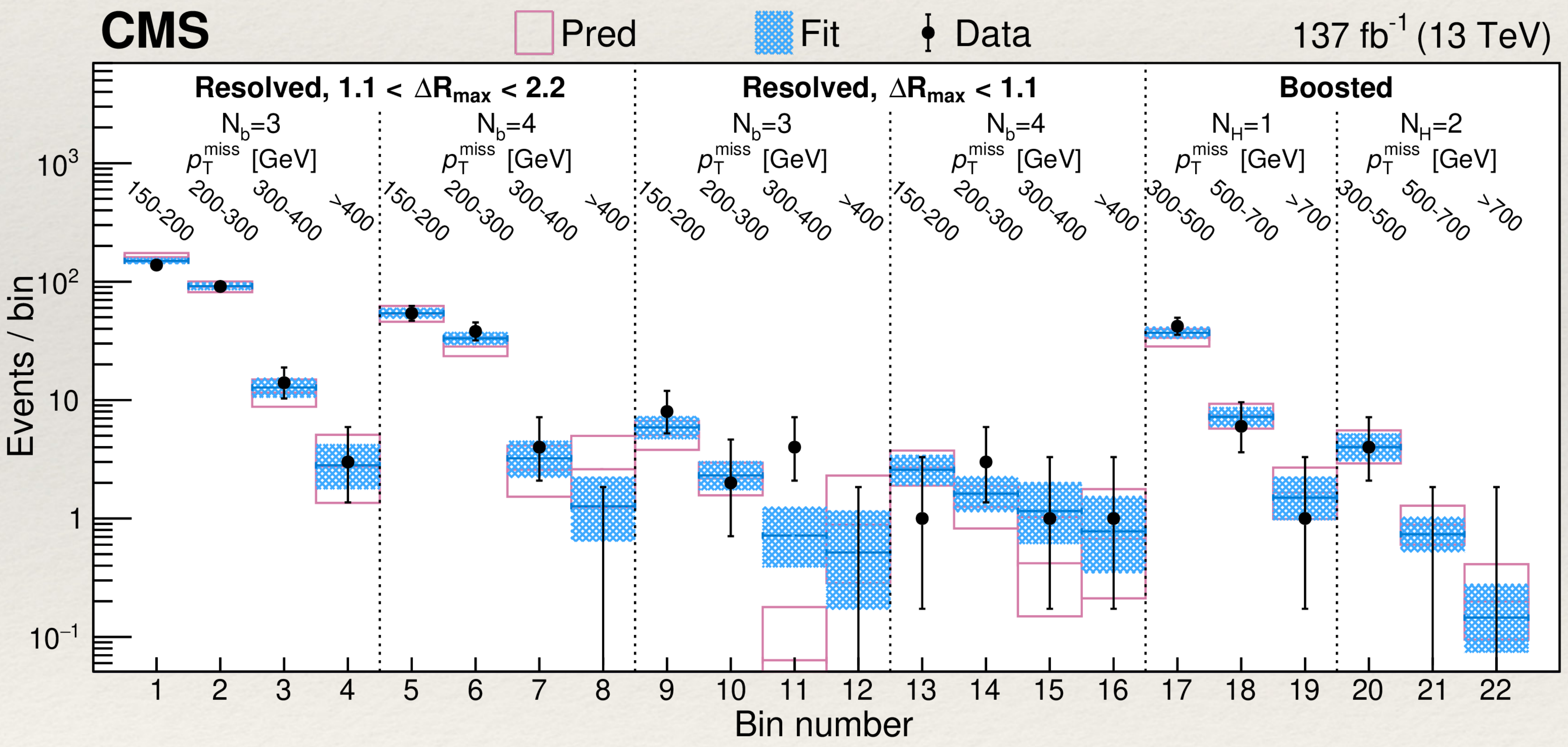
cf. talk by Bill Ford @ Dec 2022 workshop

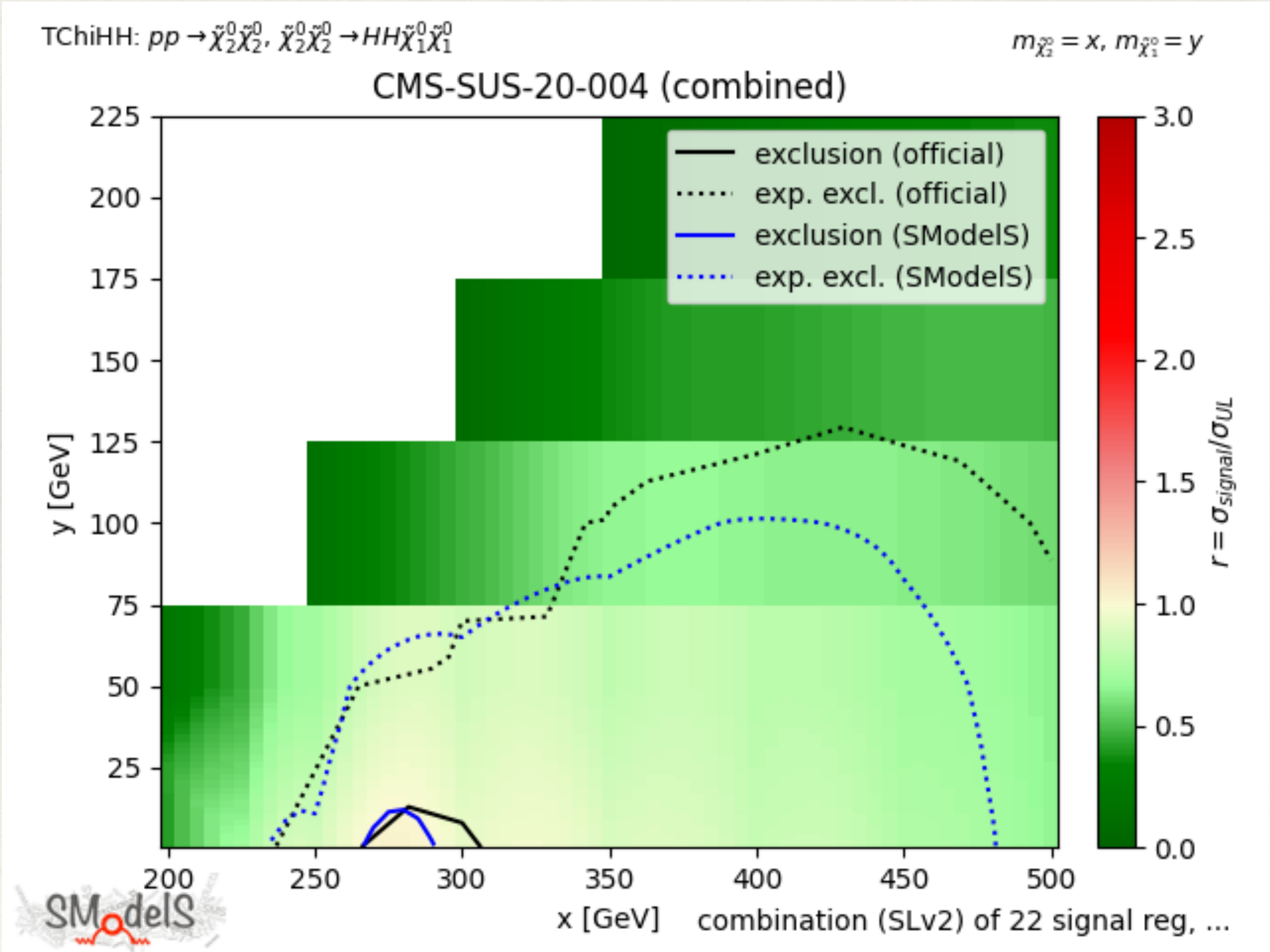
SLv2: Gaussian with a skew

- Currently used for 1 analysis: CMS-SUS-20-004
  [2 Higgs(→bb) + MET]









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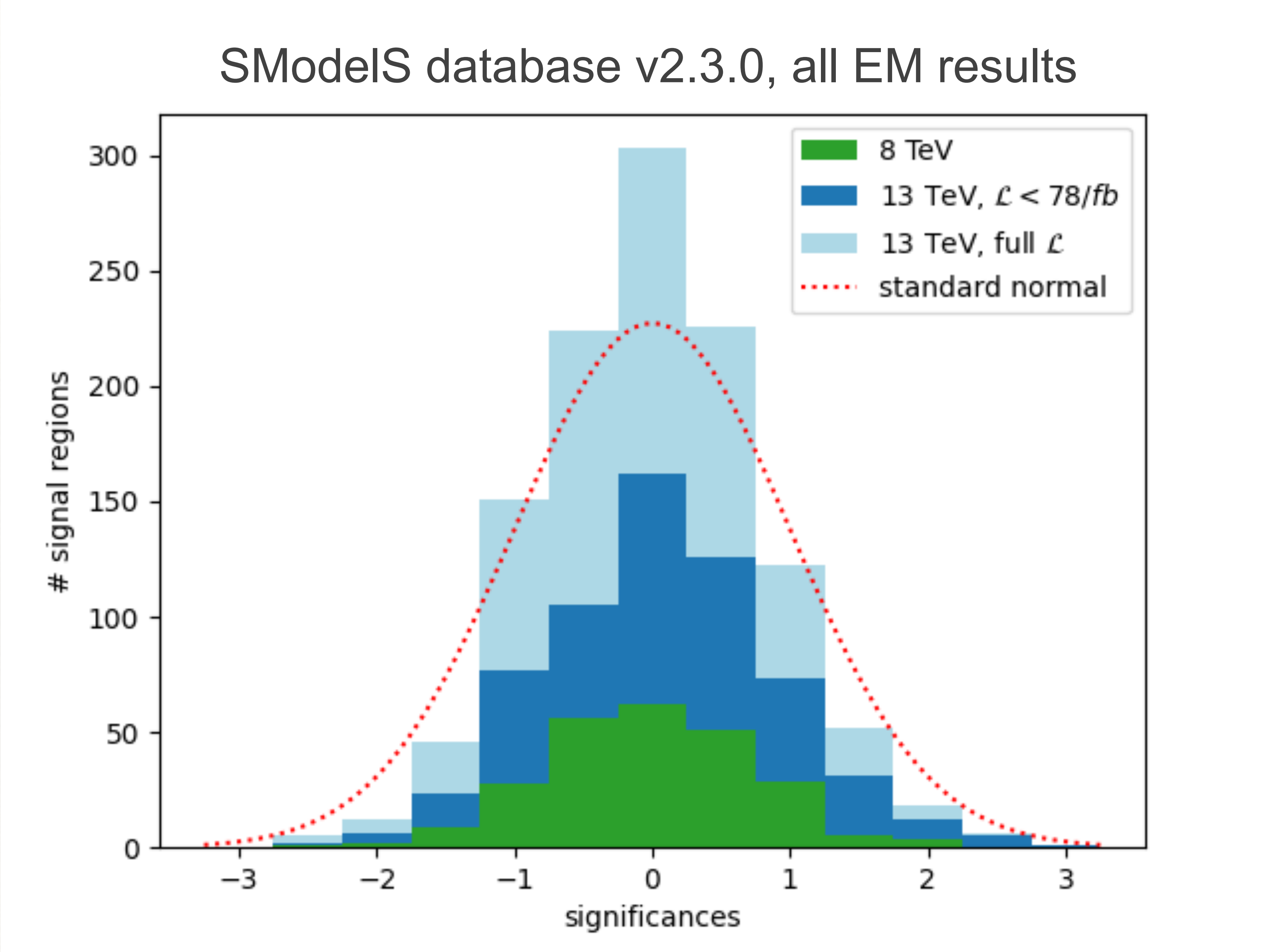
The Database

- In total exp. results from **111 ATLAS and CMS publications**
- Run 1: 15 ATLAS + 18 CMS analyses
- **Run 2: 38 ATLAS + 40 CMS** analyses
  (17 ATLAS+13 CMS for full luminosity)
- **10 LLP** searches: HSCP, disappearing tracks, displaced vertices
- New in v2.3.0: 9 ATLAS + 12 CMS;
  full set of available+useable EW-ino results



Significances with respect to the SM hypothesis, for all SRs (EM results) in the database. A standard normal distribution is expected if no new physics is in the data. New physics would manifest itself as an overabundance of large significances.

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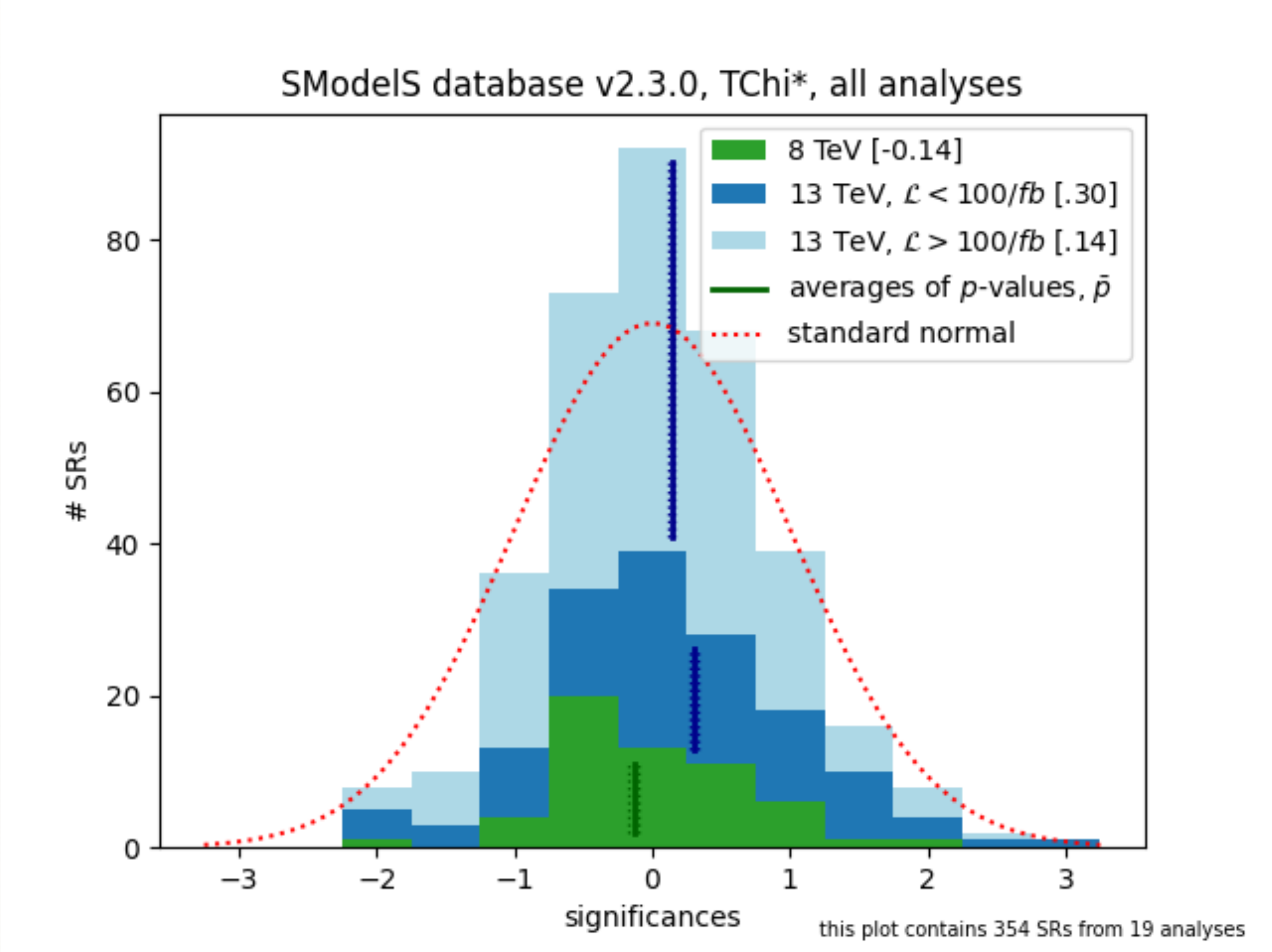

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Run 2 analyses in the v2.3.0 database

(ID in bold: new in v2.3.0)

ID	Short Description	$\mathcal{L}$ [fb^{-1}]	UL_{obs}	UL_{exp}	EM	comb.
ATLAS-SUSY-2015-01	2 b-jets	3.2	✓			
ATLAS-SUSY-2015-02	1ℓ stop	3.2	✓		✓	
ATLAS-SUSY-2015-06	0ℓ + 2–6 jets	3.2			✓	
ATLAS-SUSY-2015-09	jets + 2 SS or $\geq 3\ell$	3.2	✓			
ATLAS-SUSY-2016-06	disappearing tracks	36.1			✓	
ATLAS-SUSY-2016-07	0ℓ + jets	36.1	✓		✓	
ATLAS-SUSY-2016-08	displaced vertices	32.8	✓			
ATLAS-SUSY-2016-14	2 SS or 3 ℓ's + jets	36.1	✓			
ATLAS-SUSY-2016-15	0ℓ stop	36.1	✓			
ATLAS-SUSY-2016-16	1ℓ stop	36.1	✓		✓	
ATLAS-SUSY-2016-17	2 OS ℓ	36.1	✓			
ATLAS-SUSY-2016-19	2 b-jets + τ's	36.1	✓			
ATLAS-SUSY-2016-24	2–3 ℓ's, EWK	36.1	✓		✓	
ATLAS-SUSY-2016-26	$\geq 2\,c$-jets	36.1	✓			
ATLAS-SUSY-2016-27	jets + γ	36.1	✓		✓	
ATLAS-SUSY-2016-28	2 b-jets	36.1	✓			
ATLAS-SUSY-2016-32	HSCP	31.6	✓	✓	✓	
ATLAS-SUSY-2016-33	2 SFOS ℓ's	36.1	✓			
ATLAS-SUSY-2017-01	$Wh(bb)$, EWK	36.1	✓			
ATLAS-SUSY-2017-02	0ℓ + jets	36.1	✓	✓		
ATLAS-SUSY-2017-03	multi-ℓ EWK	36.1	✓		✓	
ATLAS-SUSY-2018-04	2 hadronic taus	139.0	✓		✓	PYHF
ATLAS-SUSY-2018-05	2ℓ + jets, EWK	139.0	✓		✓	PYHF
ATLAS-SUSY-2018-05	2ℓ + jets, strong	139.0			✓	
ATLAS-SUSY-2018-06	3ℓ, EWK	139.0	✓	✓	✓	
ATLAS-SUSY-2018-08	2 OS ℓ	139.0	✓		✓	
ATLAS-SUSY-2018-10	1ℓ + jets	139.0	✓		✓	
ATLAS-SUSY-2018-12	0ℓ + jets	139.0	✓	✓	✓	
ATLAS-SUSY-2018-14	displaced vertices	139.0			✓	PYHF
ATLAS-SUSY-2018-22	multi-jets	139.0	✓		✓	
ATLAS-SUSY-2018-23	$Wh(\gamma\gamma)$, EWK	139.0	✓	✓		
ATLAS-SUSY-2018-31	$2b + 2h(bb)$	139.0	✓		✓	PYHF
ATLAS-SUSY-2018-32	2 OS ℓ	139.0	✓		✓	PYHF
ATLAS-SUSY-2018-40	$2b + 2h(\tau\tau)$	139.0	✓	✓	✓	
ATLAS-SUSY-2018-41	hadr. EWK search	139.0	✓	✓	✓	SLv1
ATLAS-SUSY-2018-42	charged LLPs, dE/dx	139.0	✓	✓	✓	
ATLAS-SUSY-2019-02	2 soft ℓ's, EWK	139.0	✓		✓	SLv1
ATLAS-SUSY-2019-08	$1\ell + h(bb)$, EWK	139.0	✓		✓	PYHF
ATLAS-SUSY-2019-09	3ℓ, EWK	139.0	✓	✓	✓	PYHF

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CMS-PAS-EXO-16-036	HSCP	12.9	✓			
CMS-PAS-SUS-16-052	ISR jet + soft ℓ	35.9	✓		✓	SLv1
CMS-SUS-16-009	0ℓ + jets, top tag	2.3	✓	✓		
CMS-SUS-16-032	2 b- or 2 c-jets	35.9	✓			
CMS-SUS-16-033	0ℓ + jets	35.9	✓	✓	✓	
CMS-SUS-16-034	2 SFOS ℓ	35.9	✓			
CMS-SUS-16-035	2 SS ℓ	35.9	✓			
CMS-SUS-16-036	0ℓ + jets	35.9	✓	✓		
CMS-SUS-16-037	1ℓ + jets with MJ	35.9	✓			
CMS-SUS-16-039	multi-ℓ, EWK	35.9	✓		✓	SLv1
CMS-SUS-16-041	multi-ℓ + jets	35.9	✓			
CMS-SUS-16-042	1ℓ + jets	35.9	✓			
CMS-SUS-16-043	$Wh(bb)$, EWK	35.9	✓			
CMS-SUS-16-045	$2\,b + 2\,h(\gamma\gamma)$	35.9	✓			
CMS-SUS-16-046	high-p_T γ	35.9	✓			
CMS-SUS-16-047	γ + jets, high H_T	35.9	✓			
CMS-SUS-16-048	2 OS ℓ, soft	35.9			✓	SLv1
CMS-SUS-16-050	0ℓ + top tag	35.9	✓	✓	✓	SLv1
CMS-SUS-16-051	1ℓ stop	35.9	✓	✓		
CMS-SUS-17-003	2 taus	35.9	✓			
CMS-SUS-17-004	EWK combination	35.9	✓			
CMS-SUS-17-005	1ℓ + jets, top tag	35.9	✓	✓		
CMS-SUS-17-006	jets + boosted $h(bb)$	35.9	✓	✓		
CMS-SUS-17-009	SFOS ℓ	35.9	✓	✓		
CMS-SUS-17-010	2ℓ stop	35.9	✓	✓		
CMS-SUS-18-002	γ + (b-)jets, top tag	35.9	✓	✓		
CMS-SUS-18-004	2–3 soft ℓ's	137.0	✓	✓		
CMS-SUS-18-007	$2h(\gamma\gamma)$, EWK	77.5	✓	✓		
CMS-EXO-19-001	non-prompt jets	137.0			✓	
CMS-EXO-19-010	disappearing tracks	101.0			✓	
CMS-SUS-19-006	0ℓ + jets, MHT	137.0	✓	✓	✓	SLv1
CMS-SUS-19-008	2–3ℓ + jets	137.0	✓	✓		
CMS-SUS-19-009	1ℓ + jets, MHT	137.0	✓	✓		
CMS-SUS-19-010	jets + top and W-tag	137.0	✓	✓		
CMS-SUS-19-011	2ℓ stop	137.0	✓	✓		
CMS-SUS-19-013	jets + boosted Z's	137.0	✓	✓		
CMS-SUS-20-001	SFOS ℓ	137.0	✓	✓		
CMS-SUS-20-002	stop combination	137.0	✓	✓		
CMS-SUS-20-004	$2\,h(bb)$, EWK	137.0	✓	✓	✓	SLv2
CMS-SUS-21-002	hadr. EWK search	137.0	✓	✓	✓	SLv1

LLP

full Run-2 luminosity: 17 ATLAS, 13 CMS

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CMS-EXO-19-010	disappearing tracks	101.0			✓	
CMS-SUS-19-006	0ℓ + jets, MHT	137.0	✓	✓	✓	SLv1
CMS-SUS-19-008	2–3ℓ + jets	137.0	✓	✓		
CMS-SUS-19-009	1ℓ + jets, MHT	137.0	✓	✓		
CMS-SUS-19-010	jets + top and W-tag	137.0	✓	✓		
CMS-SUS-19-011	2ℓ stop	137.0	✓	✓		
CMS-SUS-19-013	jets + boosted Z's	137.0	✓	✓		
CMS-SUS-20-001	SFOS ℓ	137.0	✓	✓		
CMS-SUS-20-002	stop combination	137.0	✓	✓		
CMS-SUS-20-004	2 $h(bb)$, EWK	137.0	✓	✓	✓	SLv2
CMS-SUS-21-002	hadr. EWK search	137.0	✓	✓	✓	SLv1

LLP

EW-ino

full Run-2 luminosity: 17 ATLAS, 13 CMS

(note 16/17 of ATLAS but only 5/13 of CMS analyses provide EMs)

Case study for EW-inos (MSSM)

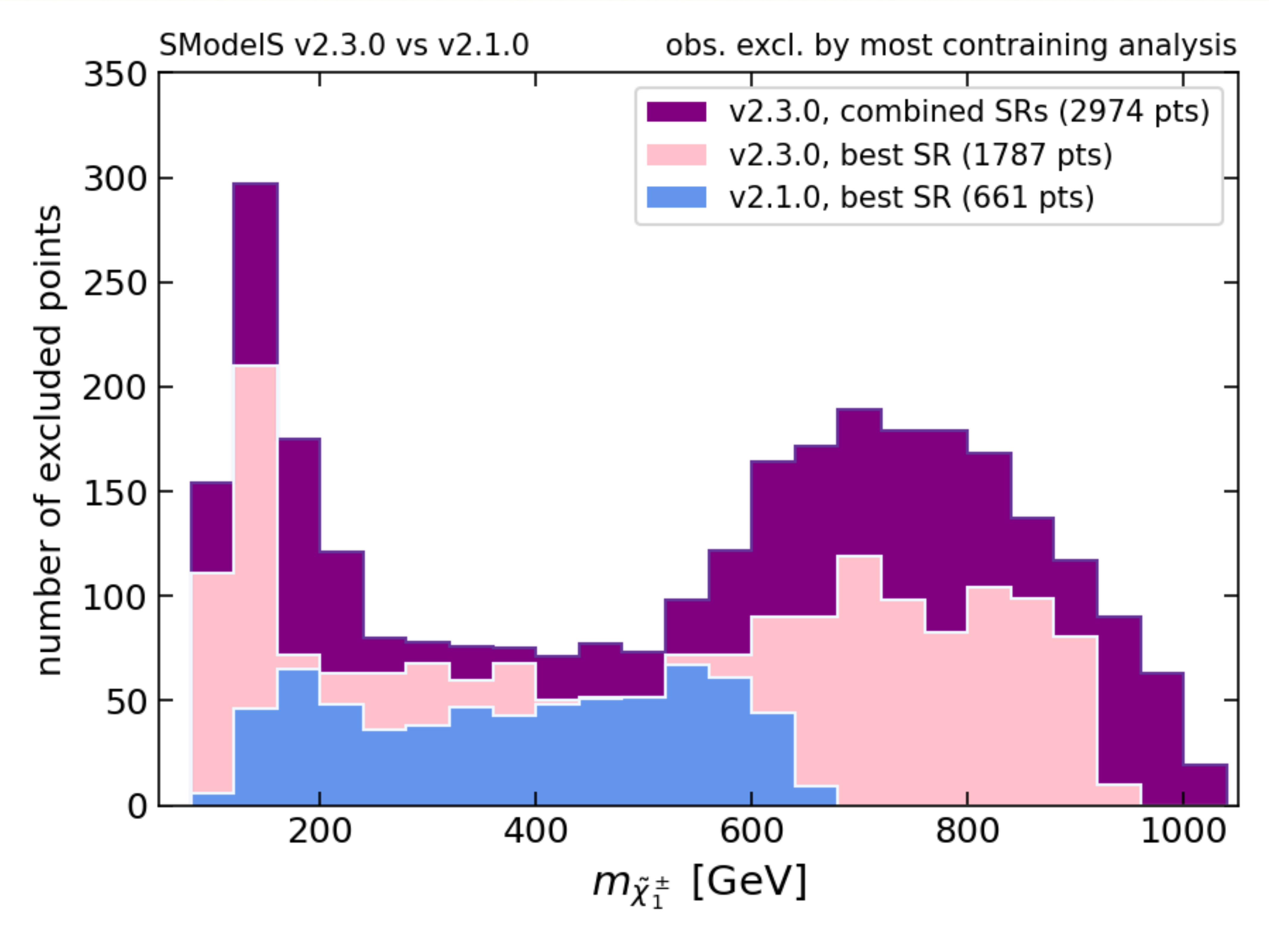
arXiv:2306.17676

- Random scan over EW-ino parameters from arXiv:2112.00769

$$\begin{aligned} 10\ \text{GeV} < & \quad M_1 \quad < 3\ \text{TeV}, \\ 100\ \text{GeV} < & \quad M_2 \quad < 3\ \text{TeV}, \\ 100\ \text{GeV} < & \quad \mu \quad < 3\ \text{TeV}, \\ 5 < & \quad \tan\beta \quad < 50 \end{aligned}$$

All other soft masses set to 10 TeV.

- Total ~100K points → select subset with $m_{\tilde{\chi}_1^0} < 500\ \text{GeV},\ m_{\tilde{\chi}_1^\pm} < 1200\ \text{GeV},$ and only prompt decays (no wino-LSP) : 18.5K points for evaluation with v2.3



Combination of analyses

`combineAnas = [user-defined list]`

- SModelS now also provides the possibility to combine likelihoods from different analyses, under the assumption that they are approximately uncorrelated.
- Combined likelihood is computed as $\mathcal{L}_C(\mu) = \prod_{i=1} \mathcal{L}_i(\mu\, s^i)\,.$
- Interesting for two reasons:
  - The signal of a particular BSM scenario may be manifest in different final states, which are constrained by different analyses → want to know the combined effect
  - Experimental analyses are statistical in nature, so always subject to over- or under-fluctuations (observed limits being weaker or stronger than expected ones).

    → again want to know the combined effect

parameters.ini

```
[options]
checkInput = True ;Set True to check the input file for possible errors

doInvisible = True ;Set True if invisible compression should be performed, False
elsewise

doCompress = True ;Set True if mass compression should be performed, False elsewise

computeStatistics = True ;Set True to compute the likelihoods L_BSM, L_SM and L_max
for EM-type results.

testCoverage = True ;Set True if topologies not covered by experiments (missing
topologies) should be identified, False otherwise

combineSRs = True ;Set True to combine signal regions when covariance matrix or pyhf
JSON likelihood is available. Caution, increases runtime! False uses only best SR
(faster).

combineAnas = ATLAS-SUSY-2018-41,CMS-SUS-2021-002 ; list of statistically independent
analyses to combine. Works for EM-type results only. Use with care! (Also, for the
time being, it is advisable to use only if combineSRs=False)

reportAllSRs = False ;Set True to report all signal regions, instead of best signal
region only.

[…]
```

arXiv:2306.17676

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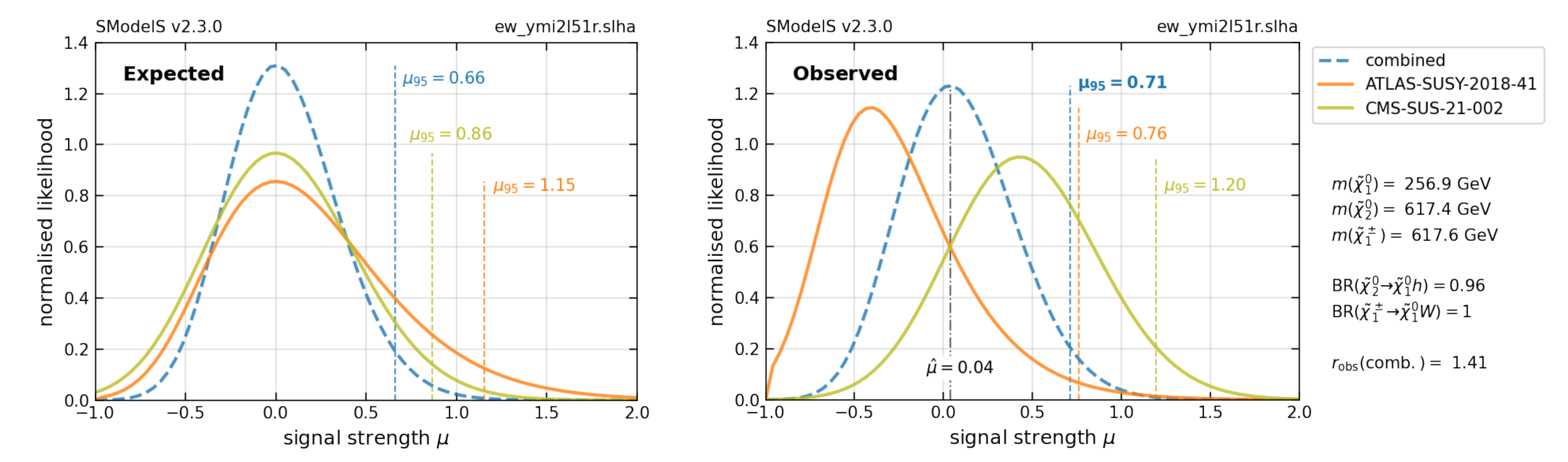

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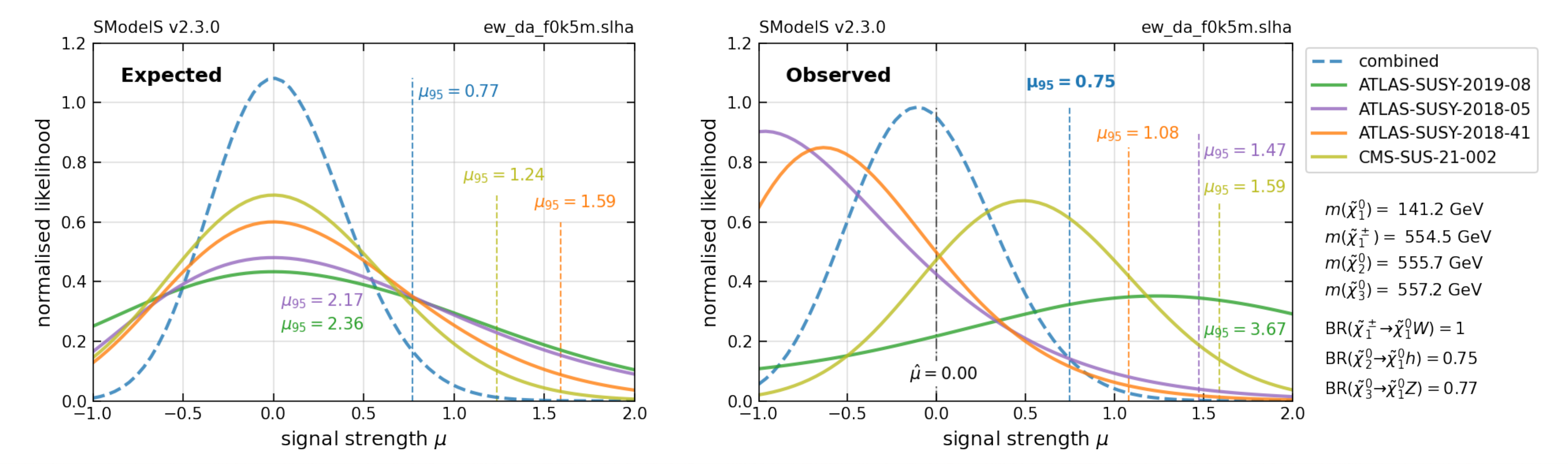
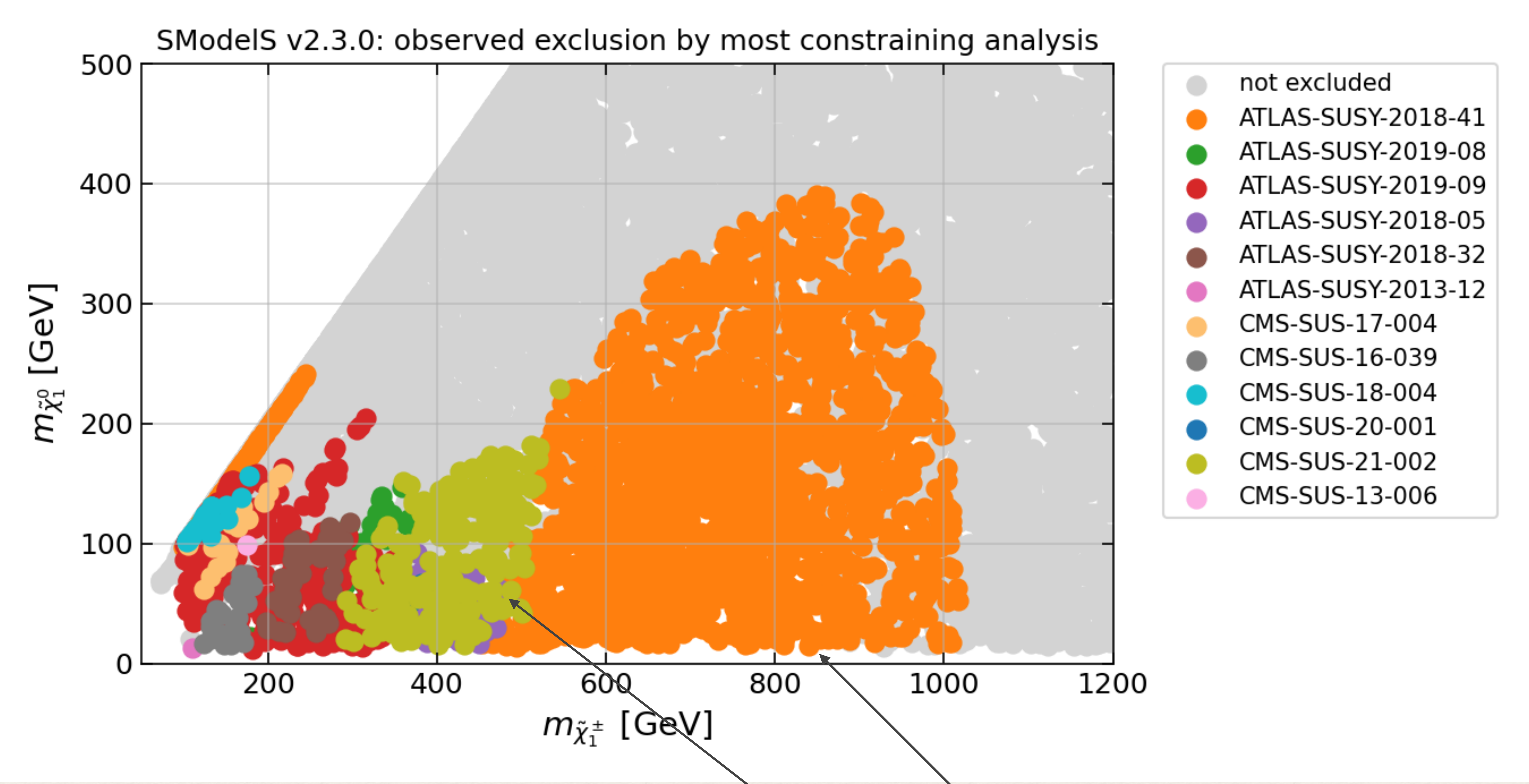


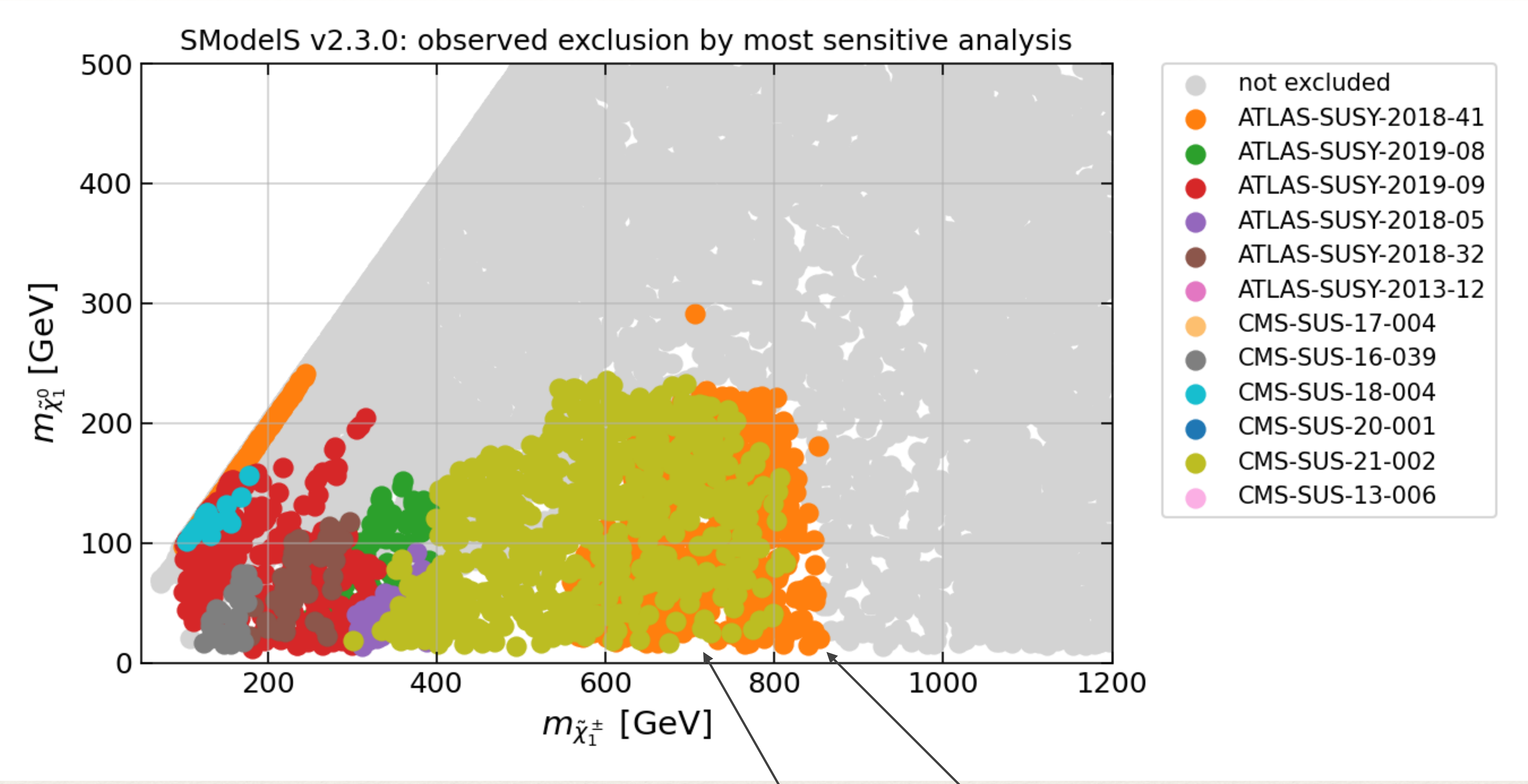
EW-ino case study: exclusion by most constraining analysis …



hadr.
Wh
WZ
WZ
WW
Wh, WZ
Wh, WZ
WZ
WZoff
WZ,ZZ
hadr.

CMS and ATLAS hadronic
EW-ino searches (boosted bosons)

… versus exclusion by most *sensitive* analysis



hadr.
Wh
WZ
WZ
WW
Wh, WZ
Wh, WZ
WZ
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WZ,ZZ
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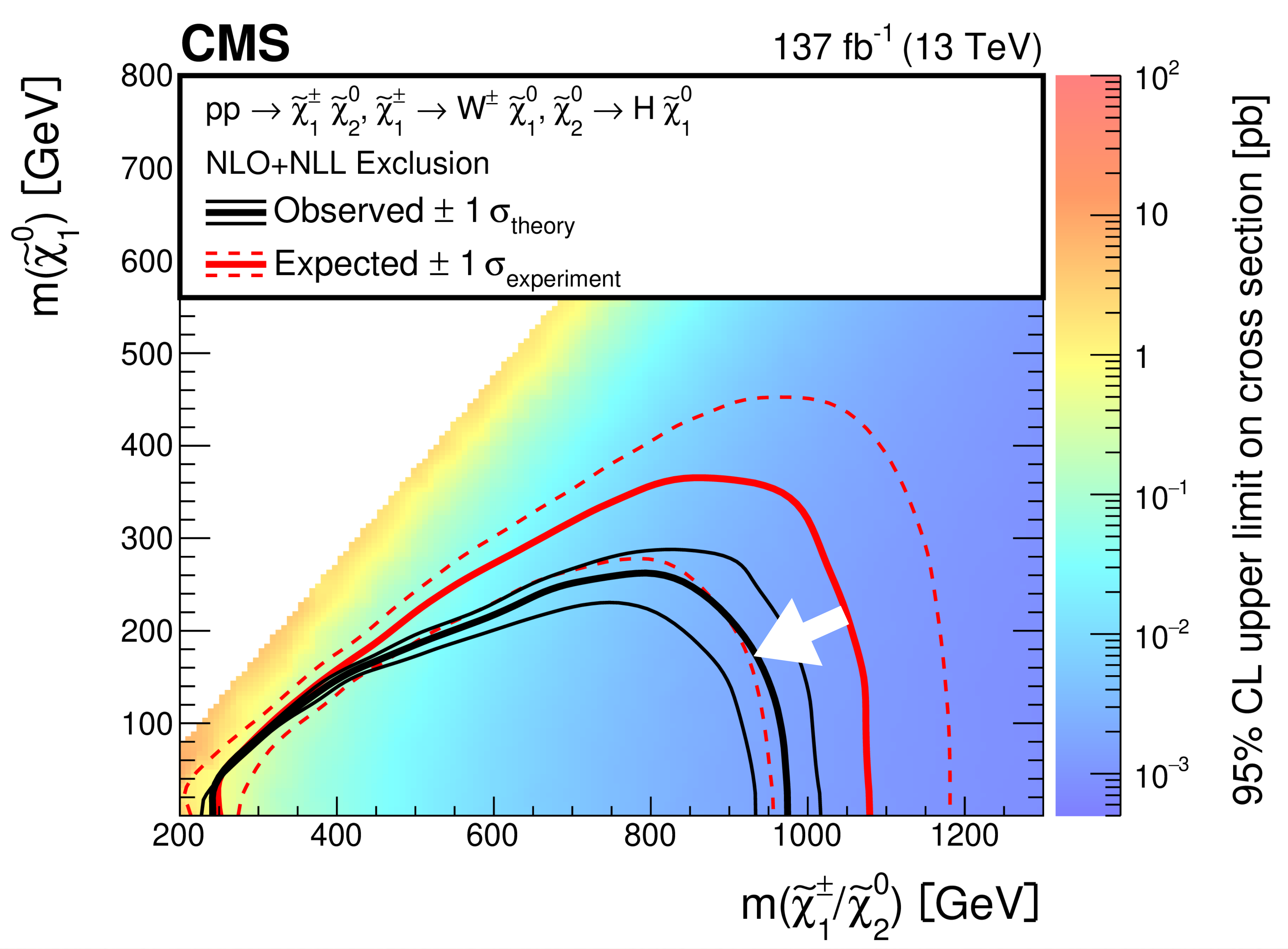
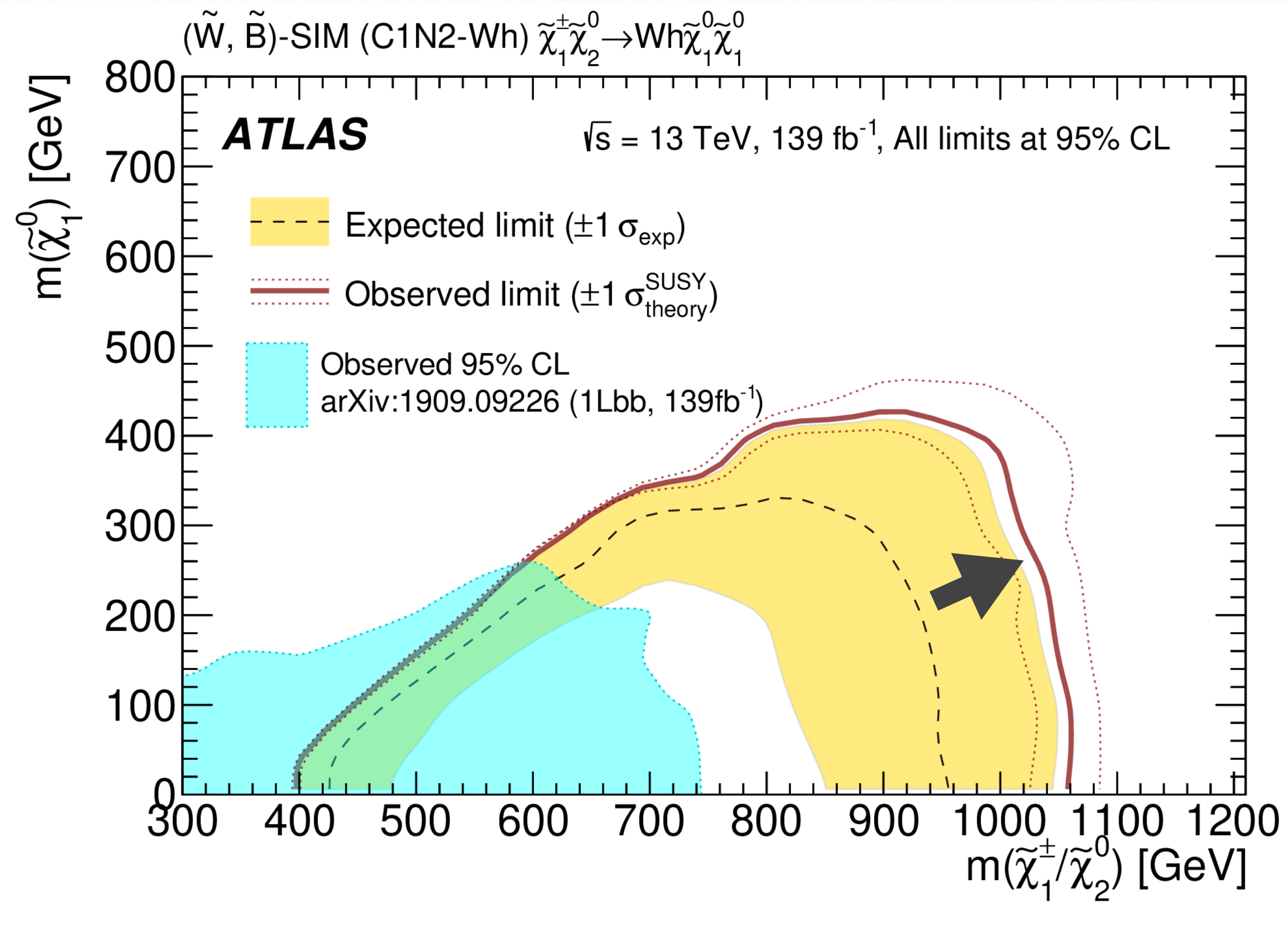
CMS and ATLAS hadronic
EW-ino searches (boosted bosons)

- Reason: CMS and ATLAS hadronic EW-ino searches have similar sensitivity, but while CMS has a small excess, the ATLAS analysis observes a deficit of events and thus sets a stronger individual limit
- Strong motivation for combining ….

CMS-SUS-21-002

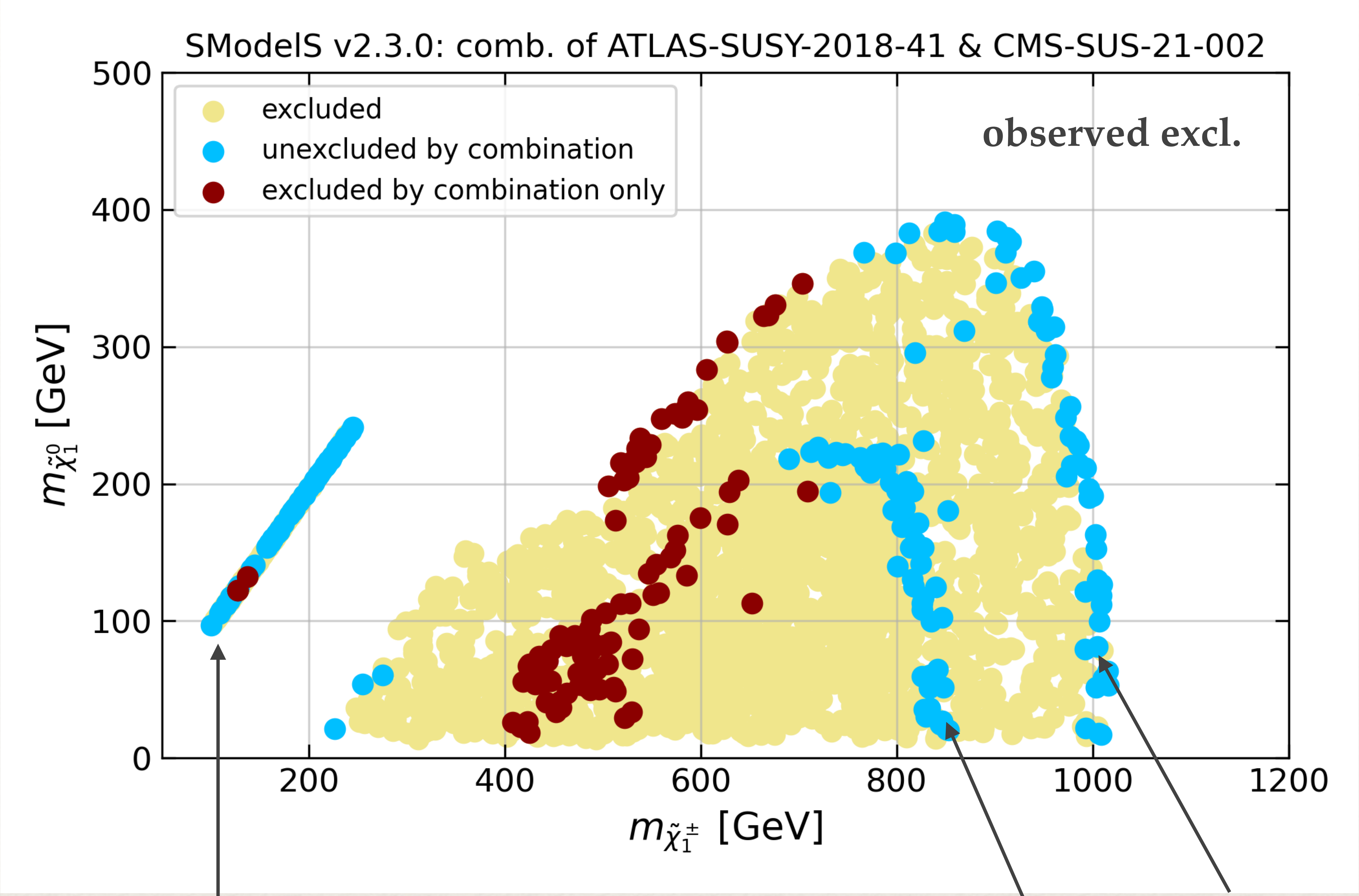


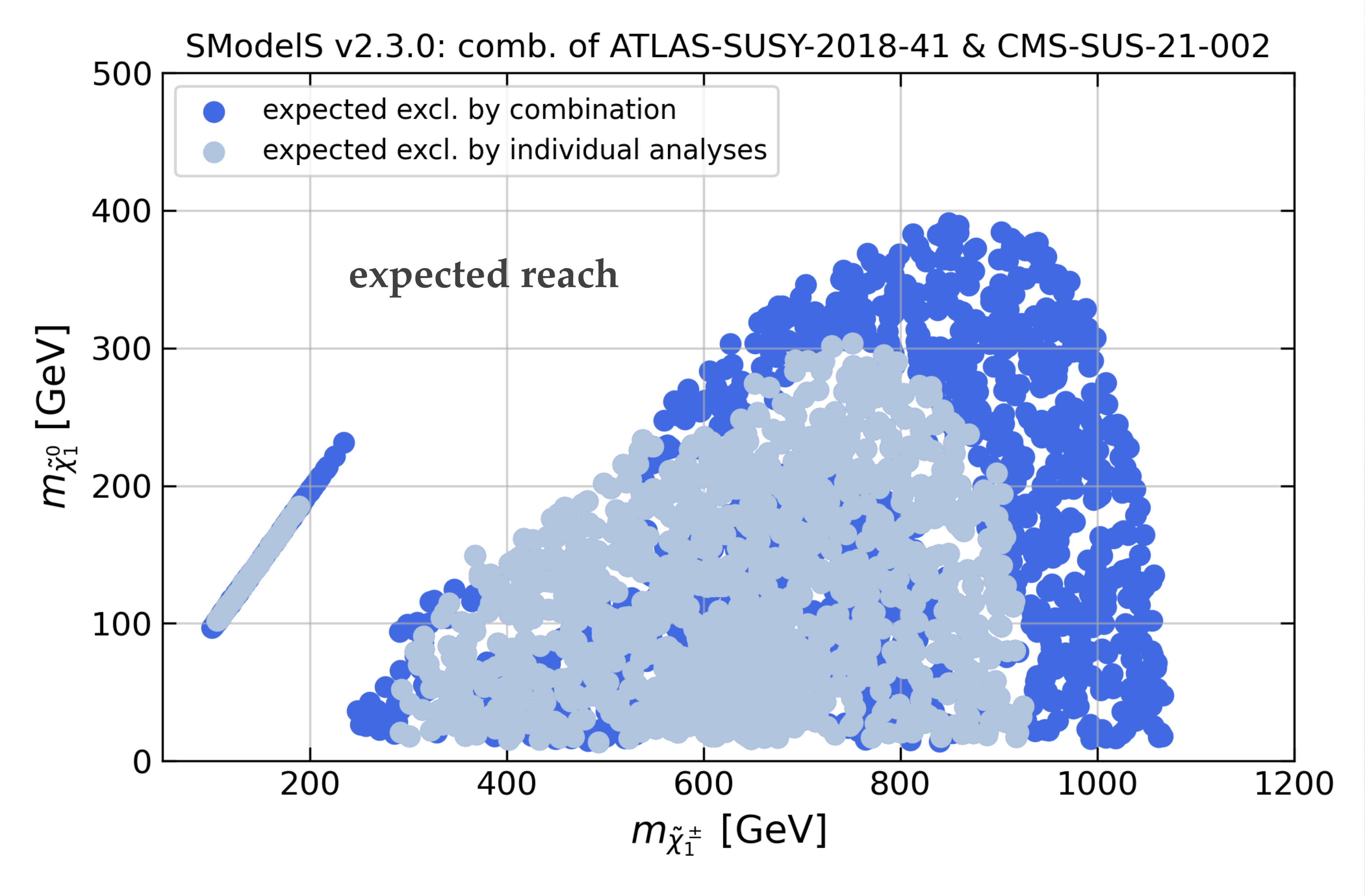
ATLAS-SUSY-2018-41



Combining ATLAS and CMS hadronic EW-ino searches

combineAnas = [ATLAS-SUSY-2018-41,CMS-SUS-21-002]





Higgsino LSP scenarios

Higgsino-bino scenarios

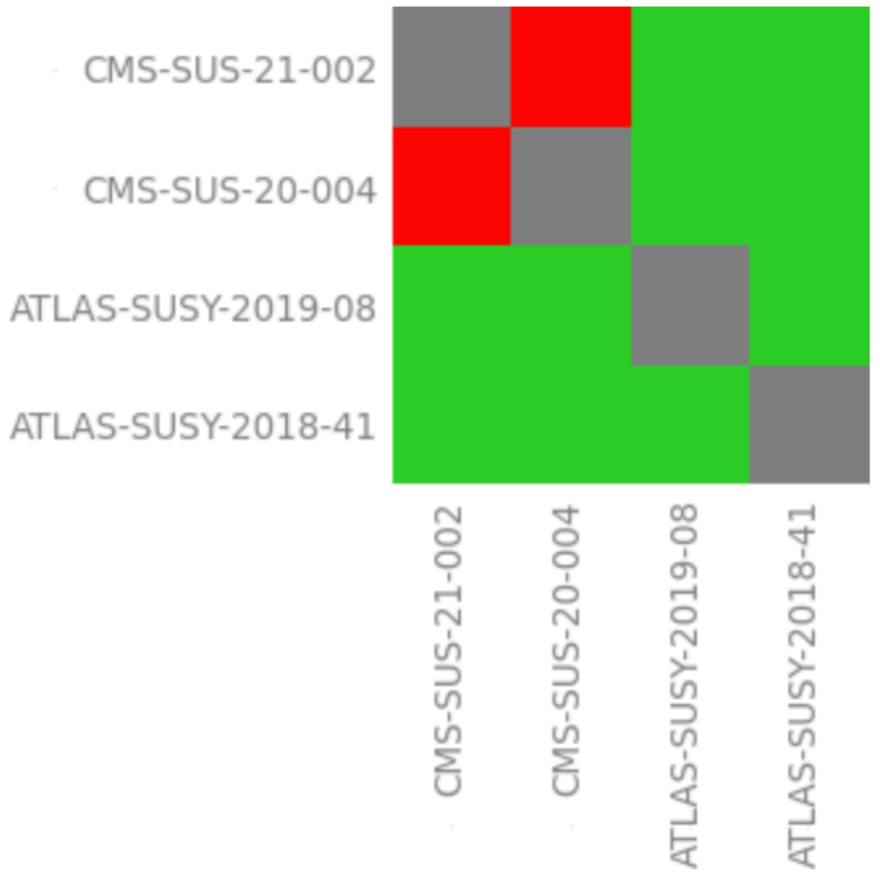
Wino-bino scenarios

See talk by Timothée Pascal for dynamic, optimised combination of all orthogonal EW-ino results

How To: Use a combinations matrix to keep track of combinabilities

```
In [3]:
# a combinations matrix is just a dictionary with combinable analyses as both keys and values.
# we assume symmetricity! (if A is combinable with B, then B is combinable with A)
# Also, CMS results are automatically assumed to be combinable with ATLAS results,
# and 8 TeV with 13 TeV results.
combinationsmatrix = { "ATLAS-SUSY-2018-41": [ "ATLAS-SUSY-2019-08"]}
# also define a list of analyses we are interested in
analyses = [ "CMS-SUS-21-002", "ATLAS-SUSY-2018-41", "ATLAS-SUSY-2019-08", "CMS-SUS-20-004"]
```

here is a visualisation of the combinations matrix for the analyses under consideration:




```
In [4]:
## Load the official database:
db = Database("official", combinationsmatrix=combinationsmatrix)
results = db.getExpResults(analysisIDs=analyses, dataTypes = [ "efficiencyMap"])
print ( f"we have selected {len(results)} analyses" )

we have selected 4 analyses
```

```
In [8]:
# get the predictions
predictions = list ( theoryPredictionsFor(results, toplist, combinedResults=True ) )
```

```
In [9]:
# let's have a quick look at the predictions, and the (expected) r-values
[ (x.dataset.globalInfo.id, "r_exp=", round(x.getRValue(expected=True),3)) for x in predictions ]

Out[9]: [('ATLAS-SUSY-2018-41', 'r_exp=', 0.869),
 ('ATLAS-SUSY-2019-08', 'r_exp=', 0.961),
 ('CMS-SUS-21-002', 'r_exp=', 1.158)]
```

```
In [10]:
for i,pr1 in enumerate(predictions[:-1]):
    id1 = pr1.dataset.globalInfo.id
    for pr2 in predictions[i+1:]:
        id2 = pr2.dataset.globalInfo.id
        combinable = pr1.dataset.isCombinableWith(pr2.dataset)
        print ( f"can I combine {id1} with {id2}? {'yes' if combinable else 'no'}" )

can I combine ATLAS-SUSY-2018-41 with ATLAS-SUSY-2019-08? yes
can I combine ATLAS-SUSY-2018-41 with CMS-SUS-21-002? yes
can I combine ATLAS-SUSY-2019-08 with CMS-SUS-21-002? yes
```

combine!

```
In [11]:
# given [10] from above, we are allowed to combine the three analyses listed below
analyses = [ "CMS-SUS-21-002", "ATLAS-SUSY-2018-41", "ATLAS-SUSY-2019-08"]
combiner = TheoryPredictionsCombiner.selectResultsFrom ( predictions, analyses )
```

```
In [12]:
# the combined expected r value must be above the individual expected r-values
round(combiner.getRValue(expected=True),3)

Out[12]: 1.674
```

https://smodels.readthedocs.io/en/latest/combinationsmatrix.html

Conclusions

- SModelS is an easy-to-use **public tool for the fast reinterpretation** of LHC searches on the basis of simplified-model results. Available from GitHub and PyPI.
- **Large database** covering a total of 111 ATLAS and CMS publications
  - Run 2: 38 ATLAS + 40 CMS analyses (17 ATLAS+13 CMS for full luminosity).
  - Coverage mostly limited by variety and kind of simplified-model EMs available
- Simultaneous treatment of **prompt and long-lived** signatures.
- v2.3 comes with the ability to **combine likelihoods from different analyses**:
  - statistically more rigorous constraints,
  - opens the way for DIY global LHC likelihood analyses.

✓ All results from arXiv:2306.17676 are available on Zenodo.

Conclusions

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Thanks to all ATLAS and CMS analysis teams who take care that their results are reusable !!

backup

Case study for EW-inos (MSSM)

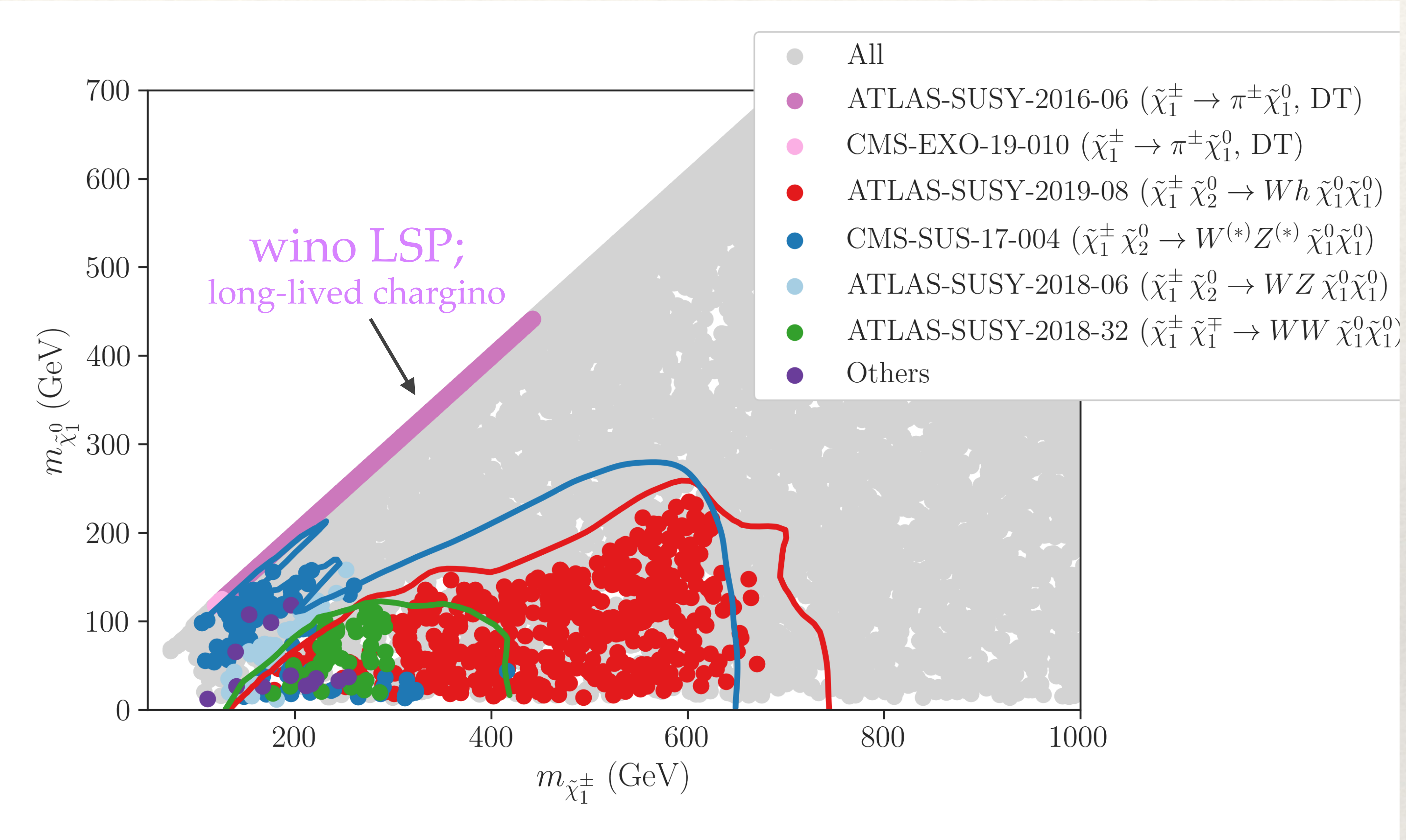
- Random scan over EW-ino parameters from arXiv:2112.00769

$$
\begin{aligned}
10\ \text{GeV} < &\quad M_1 \quad < 3\ \text{TeV},\\
100\ \text{GeV} < &\quad M_2 \quad < 3\ \text{TeV},\\
100\ \text{GeV} < &\quad \mu \quad < 3\ \text{TeV},\\
5 < &\quad \tan\beta \quad < 50
\end{aligned}
$$

All other soft masses set to 10 TeV.

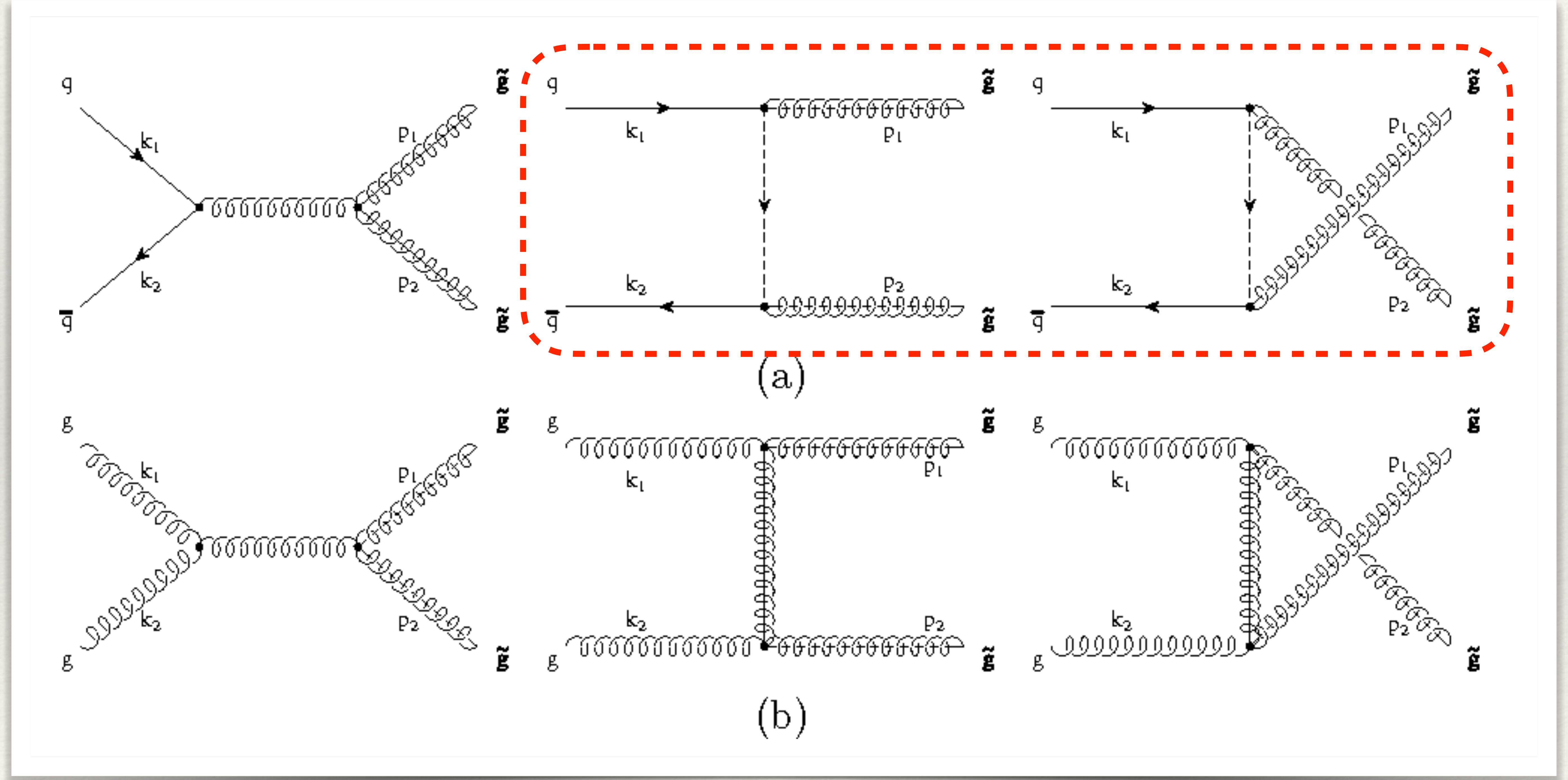
- Mass spectrum and decays computed with Softsusy 4.1.11, Xsections at LO with Pythia8.
  (+NLO with Prospino2 for pts with $r > 0.7$)

SModelS v2.1



Signal acceptances to good approximation the same ?

- SModelS ignores details of the production modes (*s*- or *t*-channel, intermediate states, …)
- Example: experimental results for gluinos usually assume decoupled squarks and vice-versa



Feynman diagrams for gluino pair production: (a) quark-antiquark initial states, (b) gluon-gluon initial states.
Figure credit: Gehrmann, Maitre, Wyler, NPB 2004

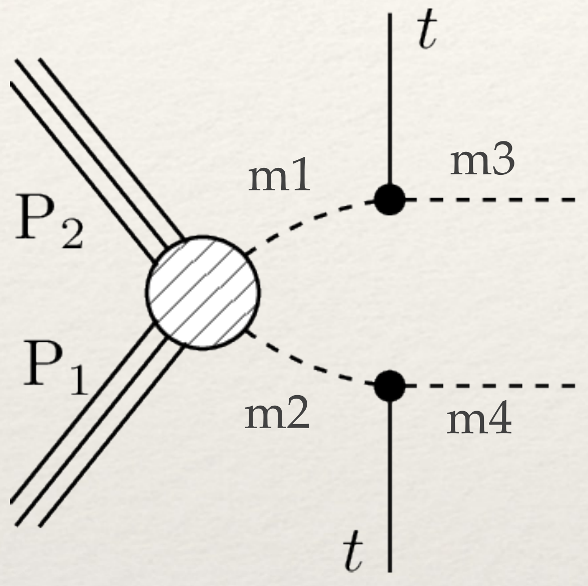
SModelS assumes that presence of squark contribution won't significantly change gluino kinematic distributions

→ signal acceptances and limits on cross sections remain valid

see arXiv:1312.4175

Signal acceptances to good approximation the same ?

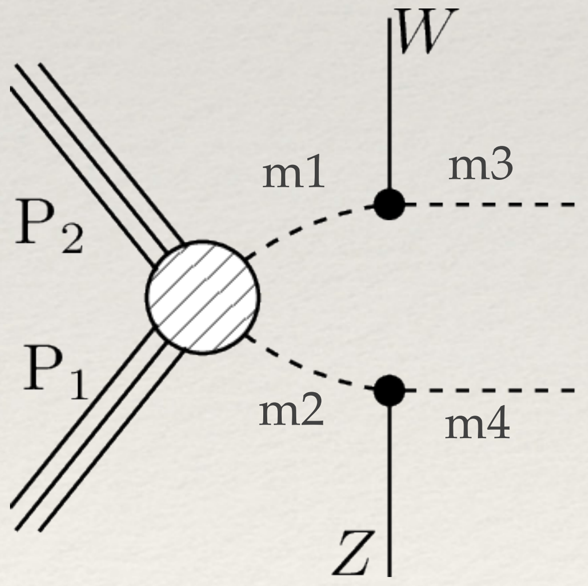
- For "prompt" signatures, SModelS ignores quantum numbers of BSM particles other than their masses



topology: [[[t]], [[t]]] … "T2tt"
masses: (m1,m3), (m2,m4)
final states: (MET, MET)

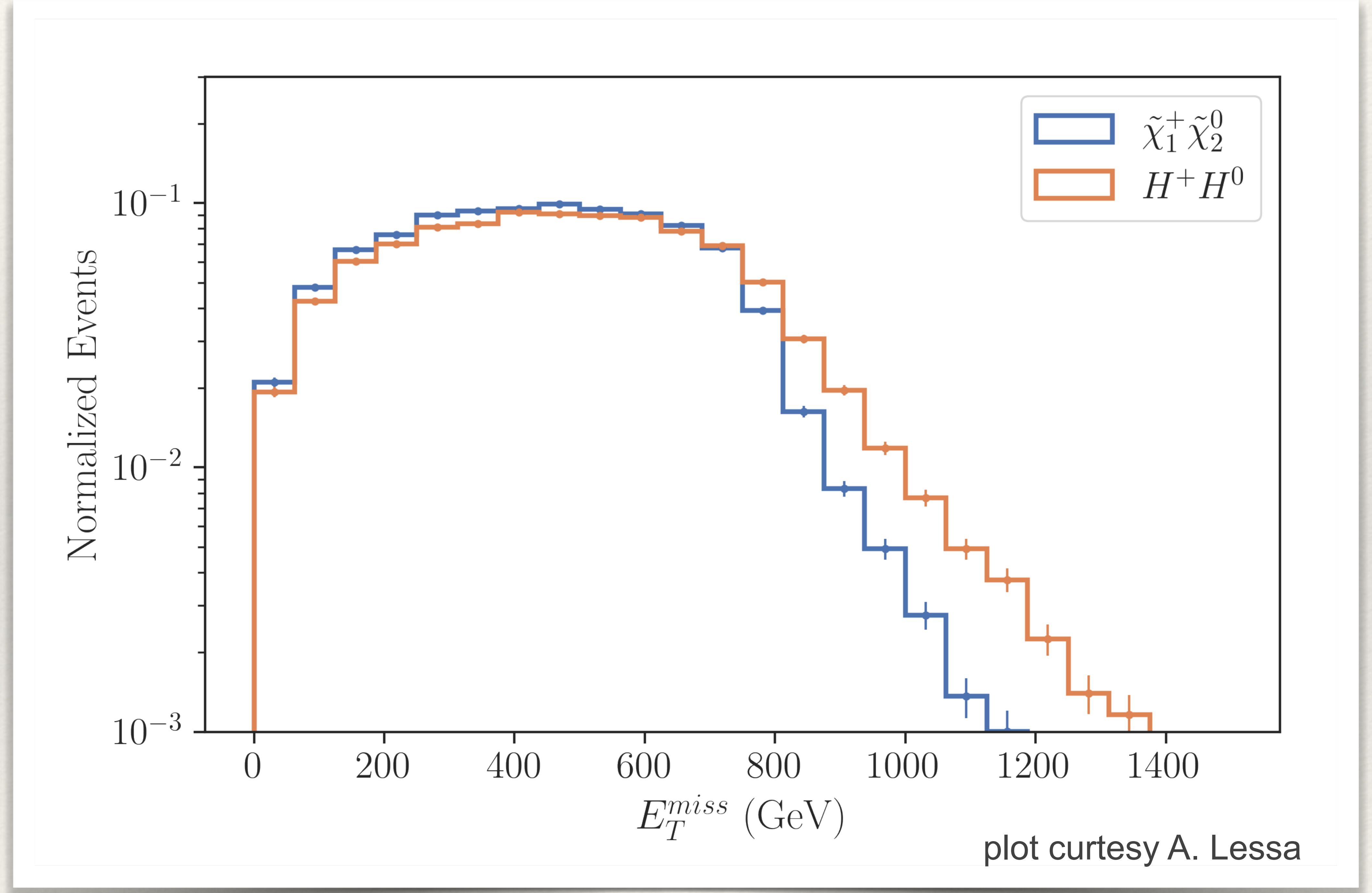
Typically stop → top +LSP, but same signature from fermonic top partner

validity studied in arXiv:1607.02050



topology: [[[W]], [[Z]]] … "TChiWZ"
masses: (m1,m3), (m2,m4)
final states: (MET, MET)

A priori chargino/neutralino, but also *H±H⁰* in inert doublet model



$pp \to \tilde\chi_1^\pm\tilde\chi_2^0 \to W^\pm Z\,\tilde\chi_1^0\tilde\chi_1^0$ versus $pp \to H^\pm H^0 \to W^\pm Z\,A^0 A^0$

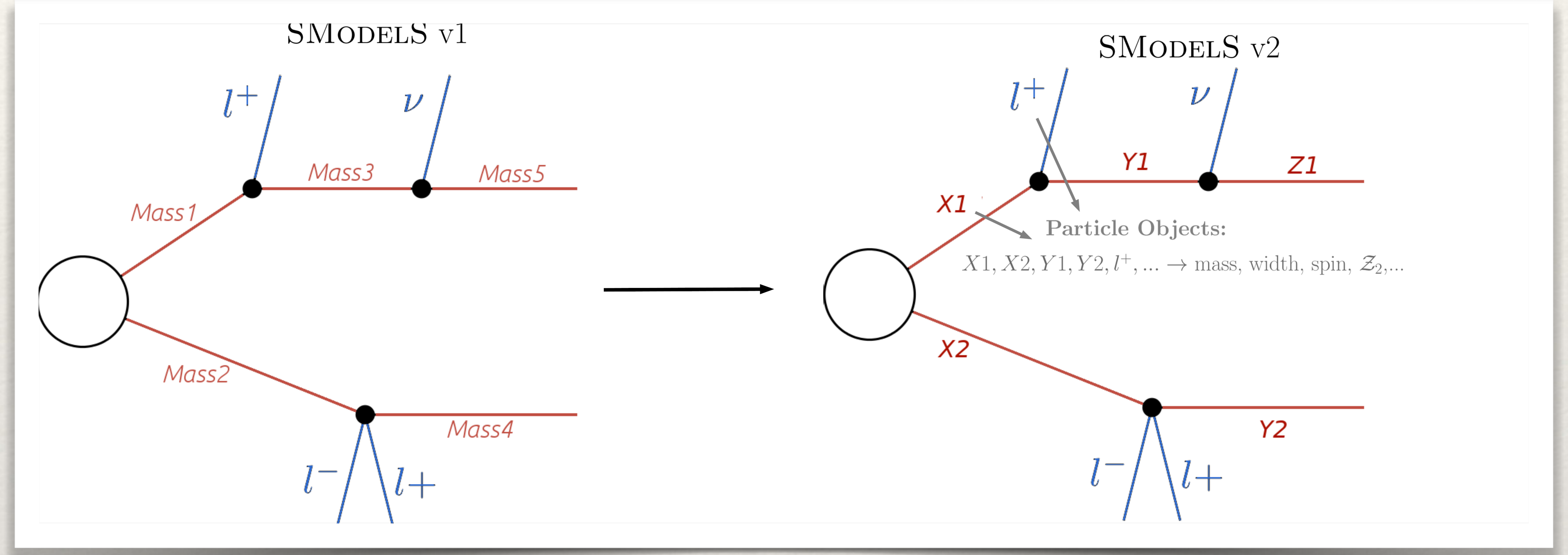
$m(\text{mothers}) = 800$ GeV, $m(\text{daughters}) = 100$ GeV

Extended topology description in v2 series

arXiv:2112.00769

- So far, the simplified model description involved only the structure of the topology (**number of vertices** in each branch, and number and type of **SM final states** in each vertex) and the **masses of the BSM particles**

- Now extended by **flexible number of attributes** for the BSM particles, such as **spin**, charge, **decay width**, etc.

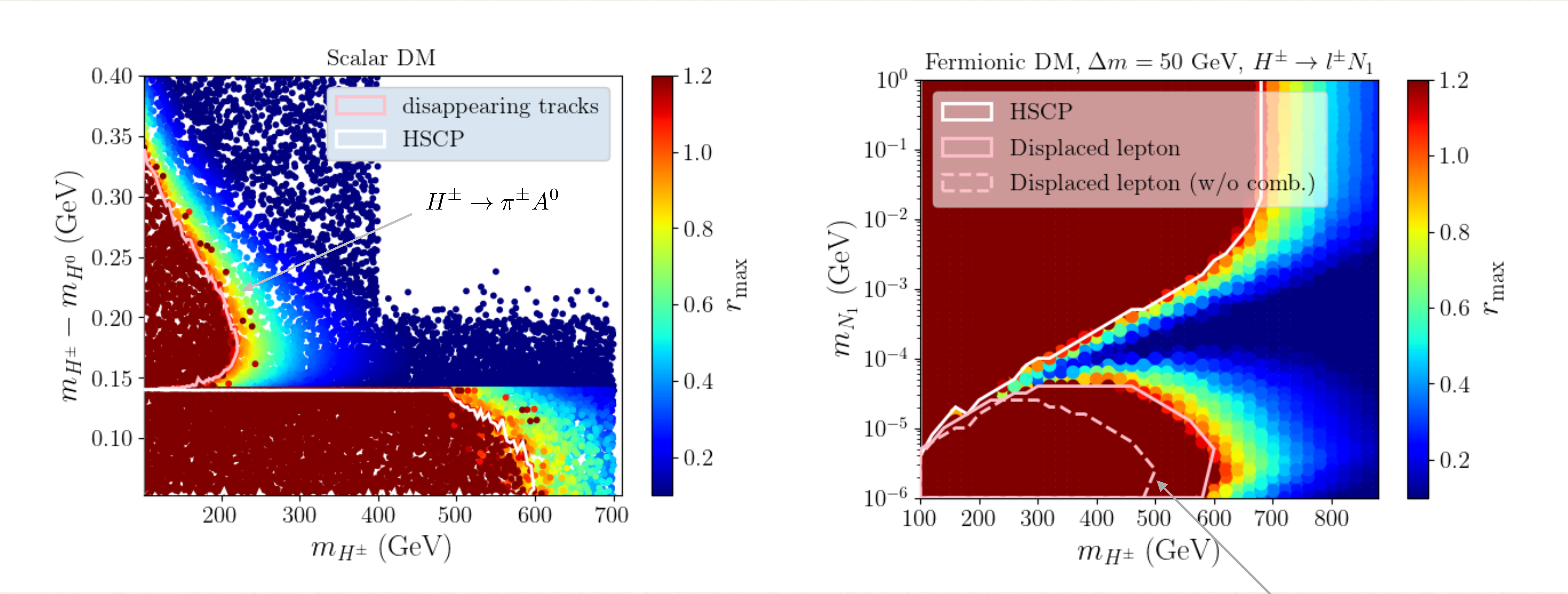


- Allows in particular for a better treatment of **long-lived particle (LLP) signatures**.
  - width-dependent results
  - spin often matters (e.g. disappearing tracks: trigger on ISR jet)

- heavy stable charged particles
- disappearing tracks
- displaced leptons
- displaced jets

LLP example: charged scalars in scotogenic model

- Supplements the SM by an additional SU(2) scalar doublet, Φ, (“inert doublet”) and three sterile neutrinos, N. The new fields are taken to be odd under a new Z_2-parity, while the SM fields are even.
- Lightest new state is stable and a dark matter (DM) candidate; can be neutral scalar or sterile neutrino (fermion).



$$r = \frac{\text{theory prediction}}{\text{experimental limit}}$$

Limit without signal region combination;
>100 GeV weaker

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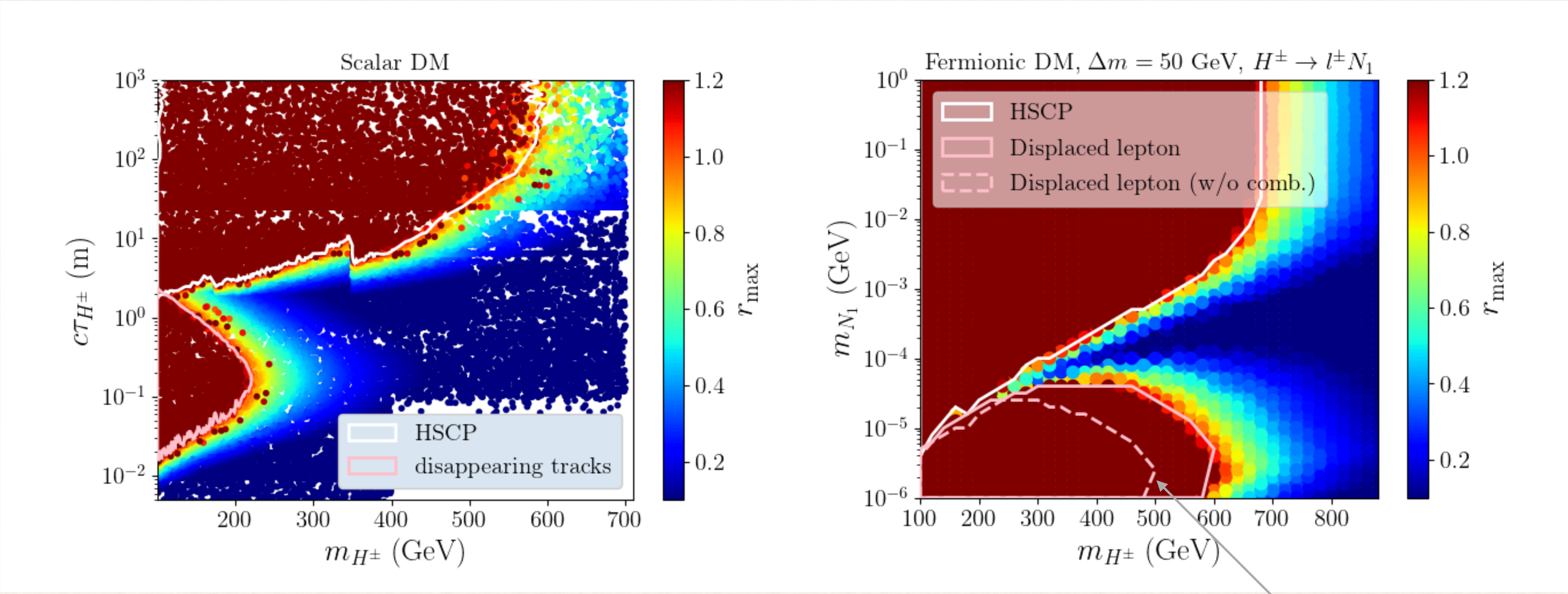

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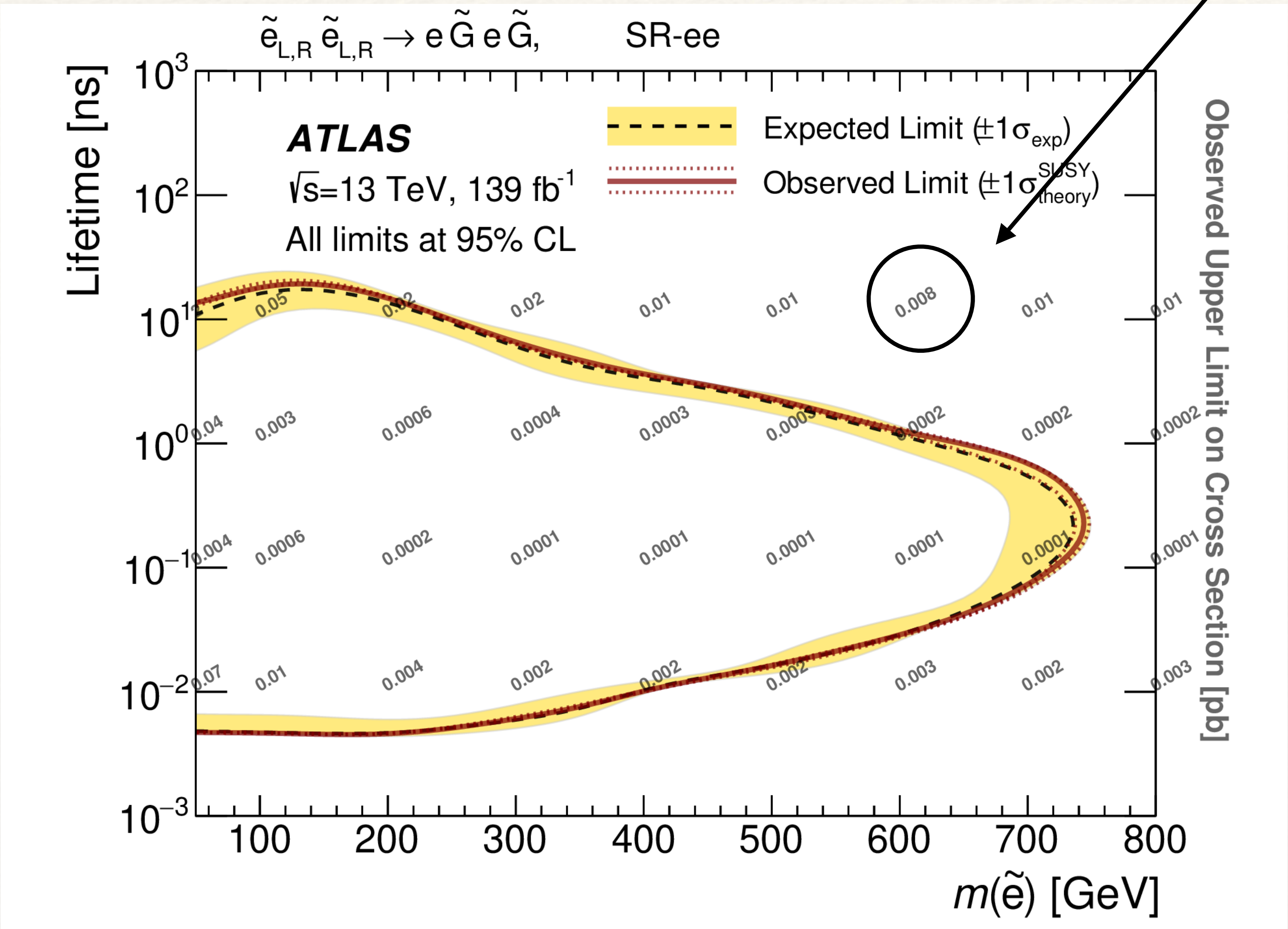
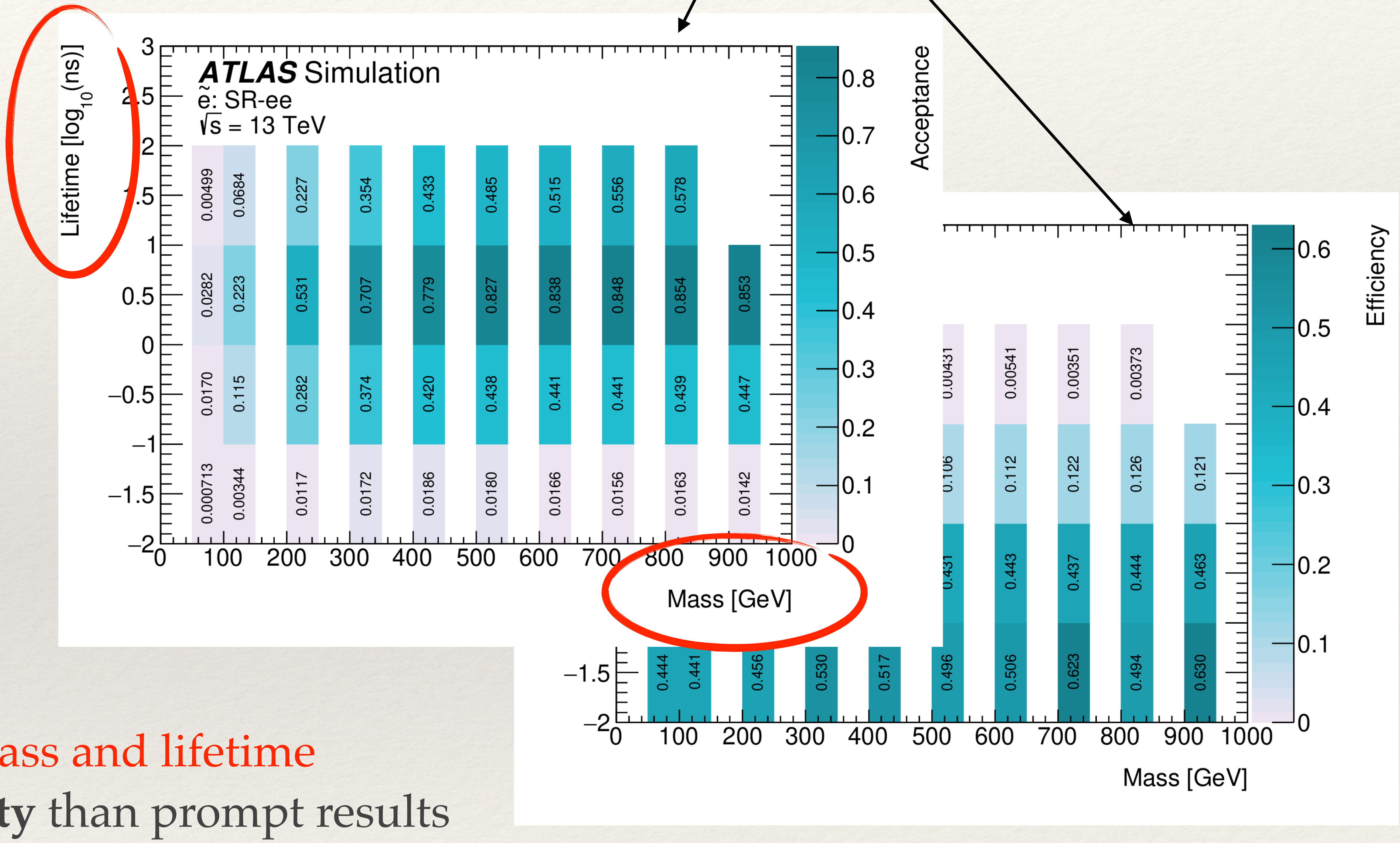
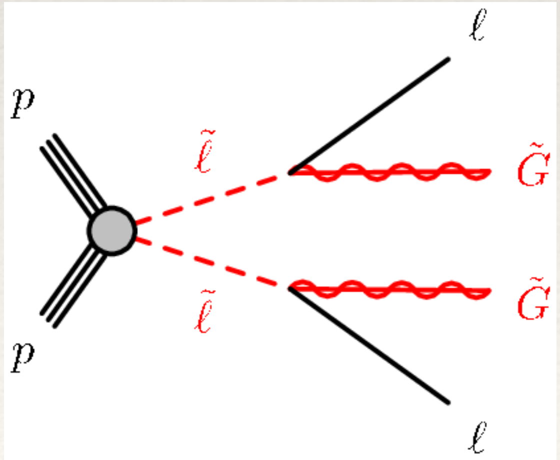
LLP results: maps in terms of mass and lifetime

upper limit (UL) maps and **A×ε 'efficiency' maps (EM)**







LLP results are 'maps' in terms of mass and lifetime
→ in principle **higher dimensionality** than prompt results

Spin dependence

- LLP decay length depends on the LLP boost and consequently on its spin
- Disappearing track analyses: pursued as searches for long-lived charginos
  - ATLAS-SUSY-2016-06, 36 / fb: we use efficiencies recasted by *Belyaev et al.* for both the fermion (chargino) and the scalar (charged Higgs) LLP cases. arXiv:2008.08581, Zenodo dataset
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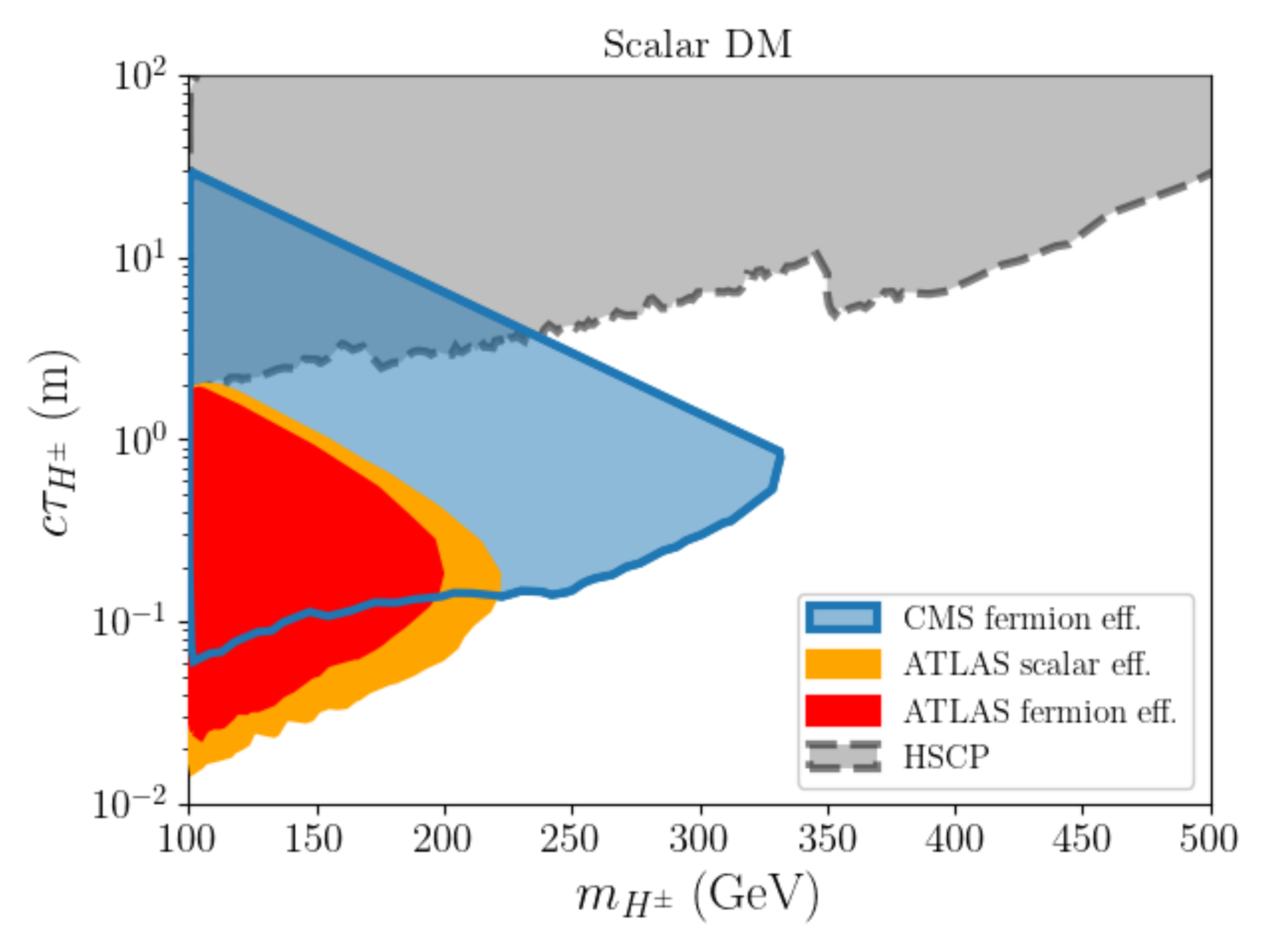
arXiv:2112.00769



Note: ATLAS-SUSY-2018-42, 139 / fb: official chargino results not reusable; not pure topologies but sum of 1 and 2 charged tracks (C1N2 and C1C1 prod.); recast in progress.

A. Lessa, talk at LLP workshop, June 2023

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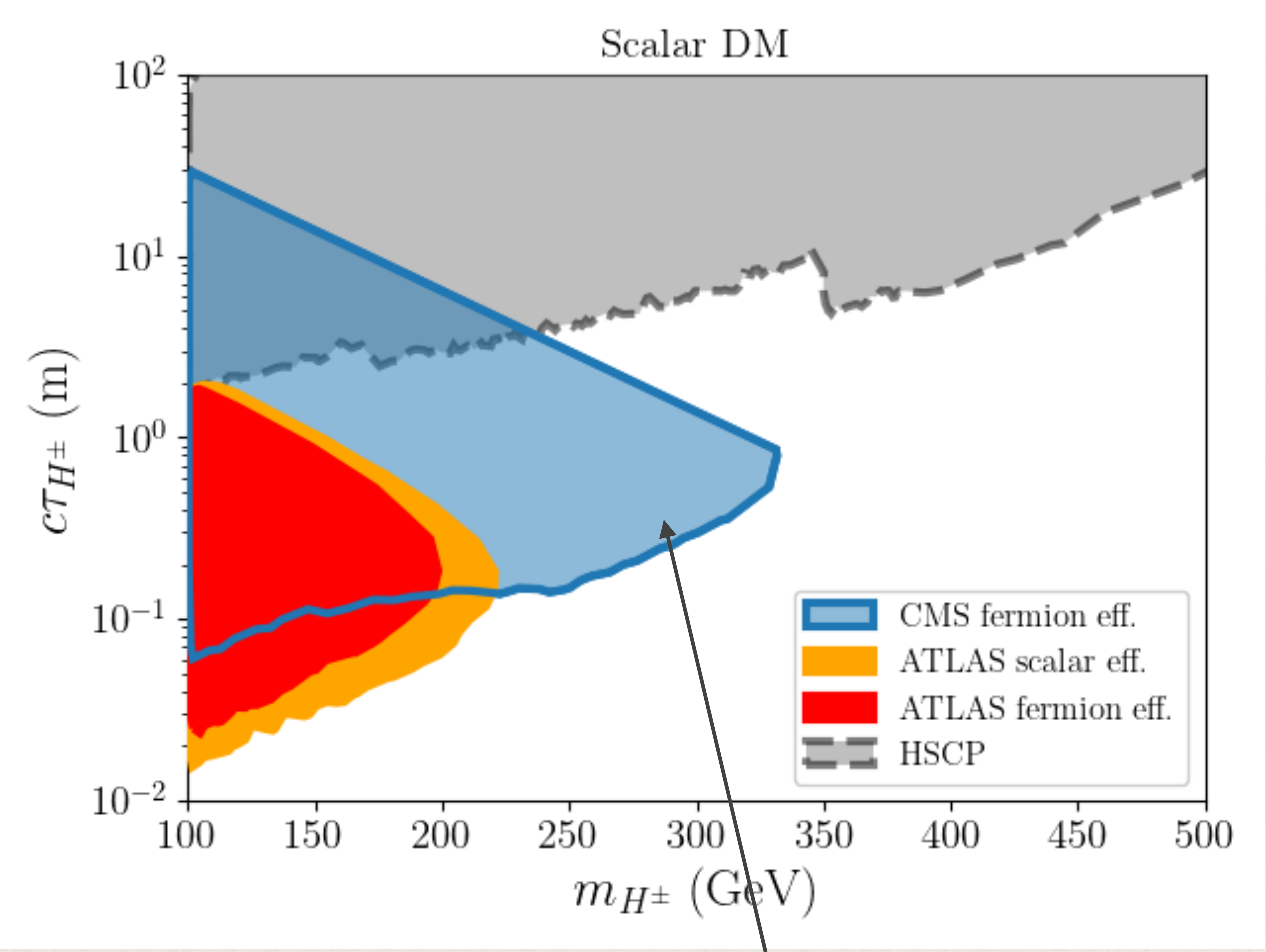

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Users who want to use the CMS result for scalar LLPs, have to "trick" SModelS into it; e.g. change qnumbers in model input, or download text database and change spin assignment for the CMS-EXO-19-010 maps.