New GAMBIT fits of the MSSM electroweakino sector

Anders Kvellestad, University of Oslo
On behalf of the GAMBIT Collaboration

SUSY 2024 — Madrid, June 11, 2024

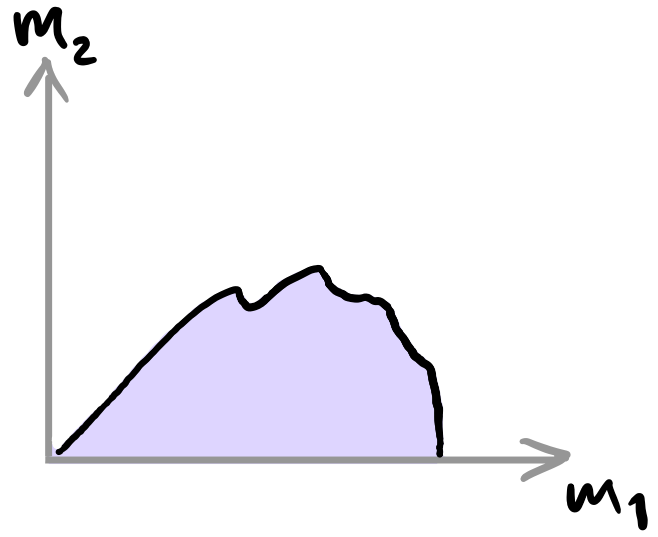
UNIVERSITETET
I OSLO

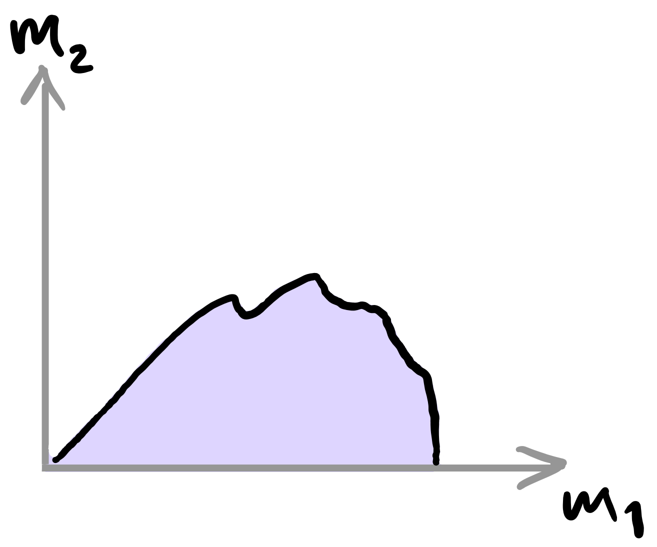
As a community we can **learn far more physics** from an experimental result that is **reinterpretable** compared to one that is not.

What we have learned at time of publication

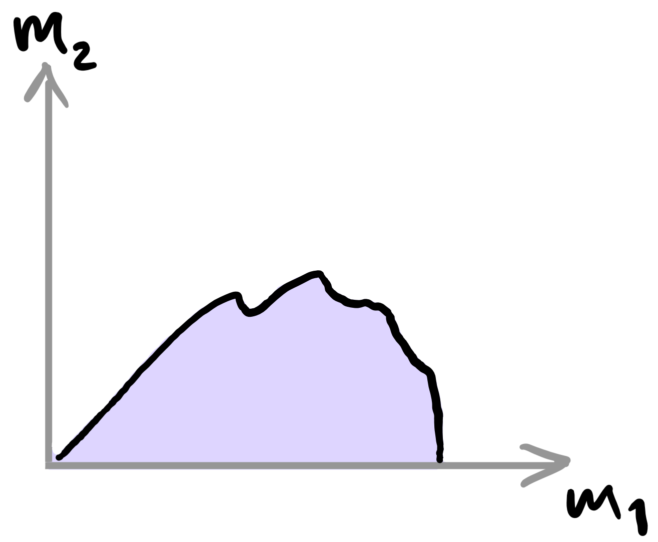
What we have learned long after publication

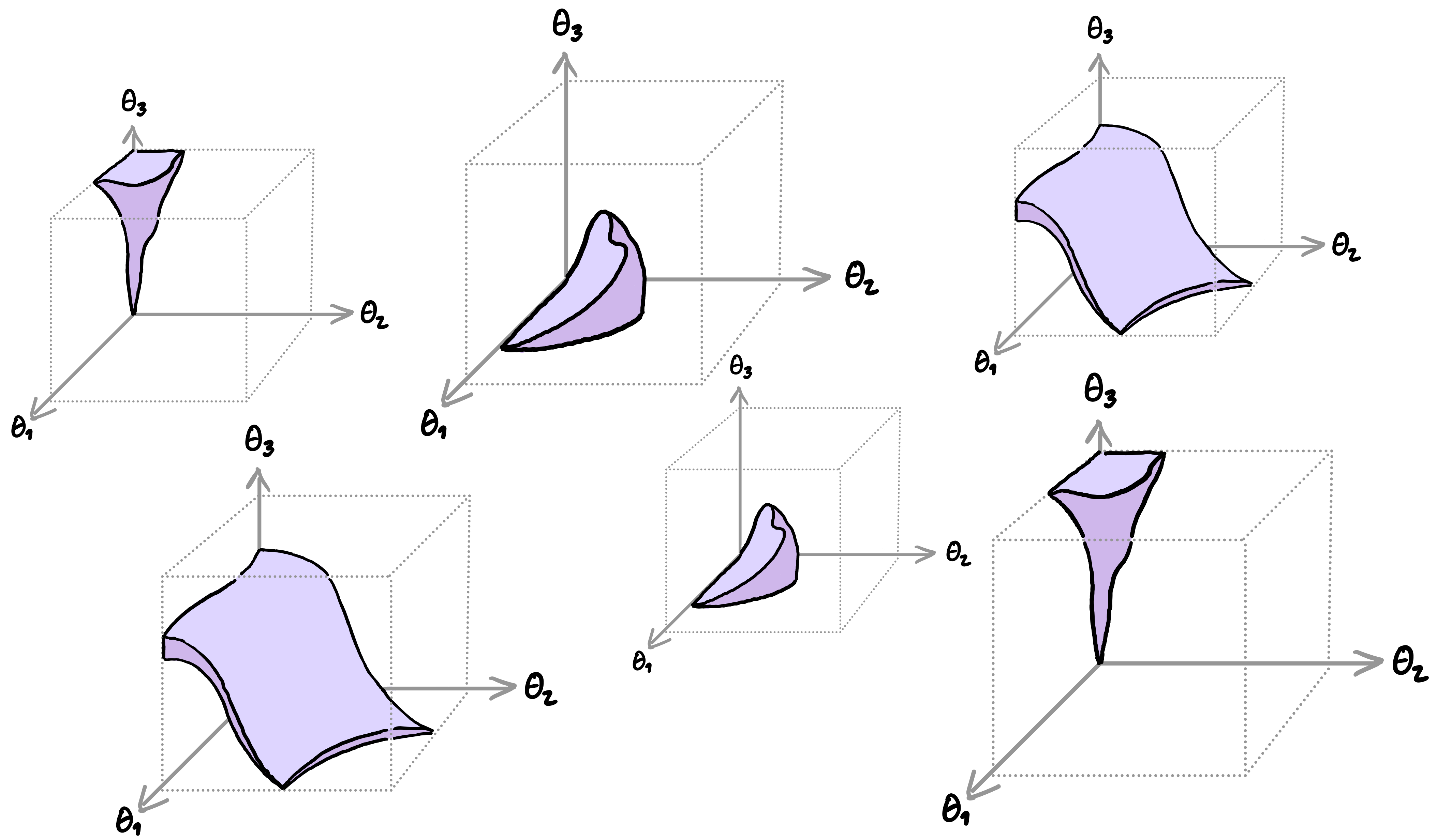
Impossible to reinterpret





Possible to reinterpret





Understanding the full implications of [experimental] searches requires the interpretation of the experimental results in the context of many more theoretical models than are currently explored at the time of publication.

HEP Software Foundation [arxiv:1712.06982]

See also:

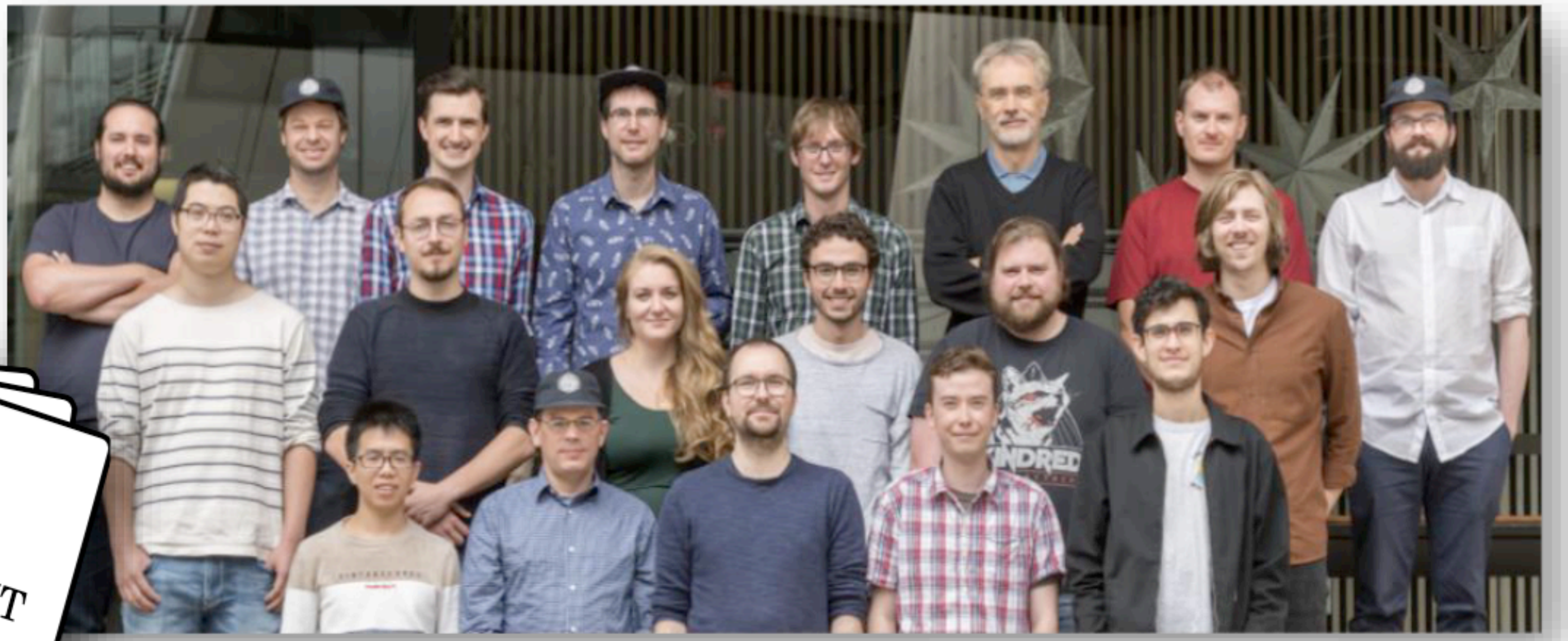
- *Publishing statistical models: Getting the most out of particle physics experiments* **[arxiv:2109.04981]**
- *Reinterpretation of LHC Results for New Physics: Status and Recommendations after Run 2* **[arxiv:2003.07868]**
- *Simple and statistically sound strategies for analysing physical theories* **[arxiv:2012.09874]**

A **huge thank you** to everyone who works hard to produce some cutflow, a SimpleAnalysis code snippet, an efficiency map, a JSON likelihood file, …

GAMBIT: The Global And Modular BSM Inference Tool

gambit.hepforge.org   github.com/GambitBSM   EPJC 77 (2017) 784   arXiv:1705.07908

- Extensive model database, beyond SUSY
- Fast definition of new datasets, theories
- Extensive observable/data libraries
- Plug&play scanning/physics/likelihood packages
- Various statistical options (frequentist /Bayesian)
- Fast LHC likelihood calculator
- Massively parallel
- Fully open-source

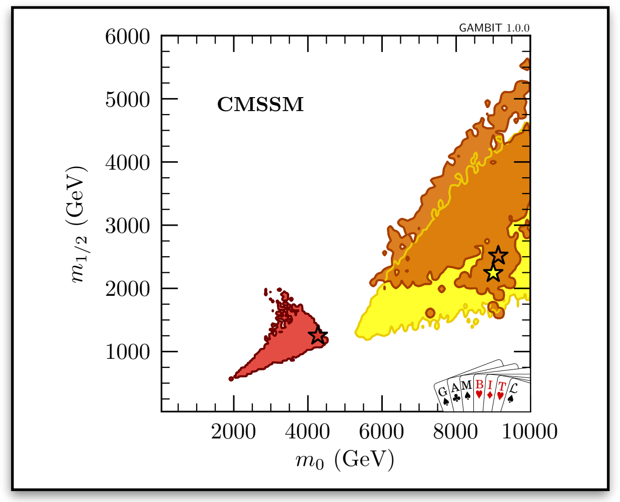


Members of: ATLAS, Belle-II, CLiC, CMS, CTA, Fermi-LAT, DARWIN, IceCube, LHCb, SHiP, XENON

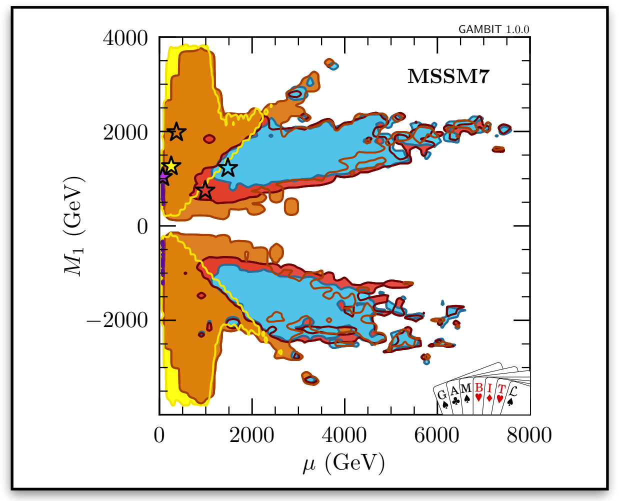
Authors of: BubbleProfiler, Capt'n General, Contur, DarkAges, DarkSUSY, DDCalc, DirectDM, Diver, EasyScanHEP, ExoCLASS, FlexibleSUSY, gamLike, GM2Calc, HEPLike, IsaTools, MARTY, nuLike, PhaseTracer, PolyChord, Rivet, SOFTSUSY, SuperIso, SUSY-AI, xsec, Vevacious, WIMPSim

Recent collaborators: V Ananyev, P Athron, N Avis-Kozar, C Balázs, A Beniwal, S Bloor, LL Braseth, T Bringmann, A Buckley, J Butterworth, J-E Camargo-Molina, C Chang, M Chrzaszcz, J Conrad, J Cornell, M Danninger, J Edsjö, T Emken, A Fowlie, T Gonzalo, W Handley, J Harz, S Hoof, F Kahlhoefer, A Kvellestad, M Lecroq, P Jackson, D Jacob, C Lin, FN Mahmoudi, G Martinez, H Pacey, MT Prim, T Procter, F Rajec, A Raklev, JJ Renk, R Ruiz, A Scaffidi, P Scott, N Serra, P Stöcker, W. Su, J Van den Abeele, A Vincent, C Weniger, A Woodcock, M White, Y Zhang ++

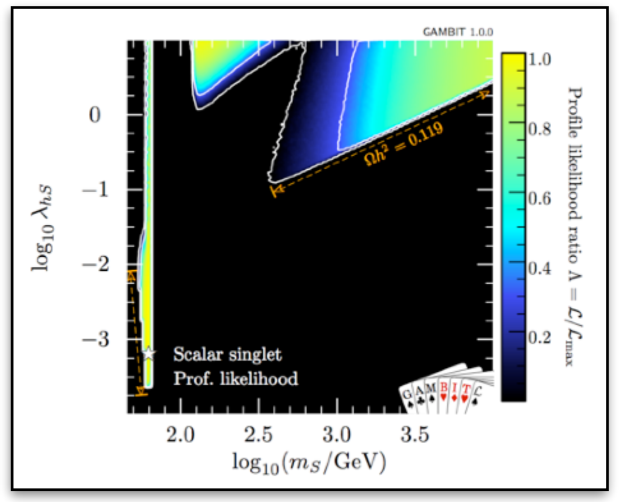
80+ participants in many experiments and numerous major theory codes



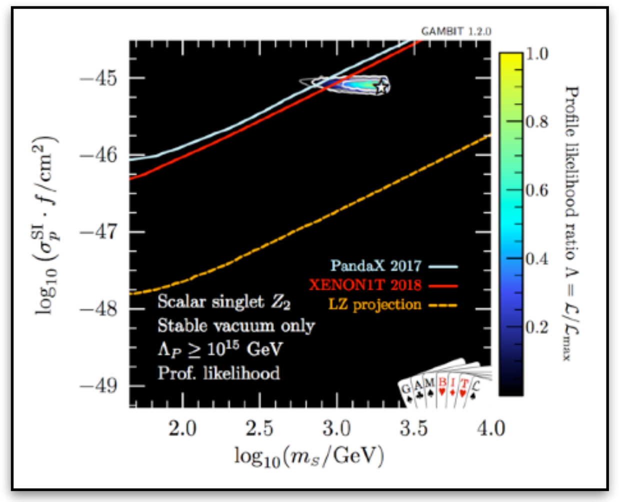
GUT-scale SUSY: 1705.07935



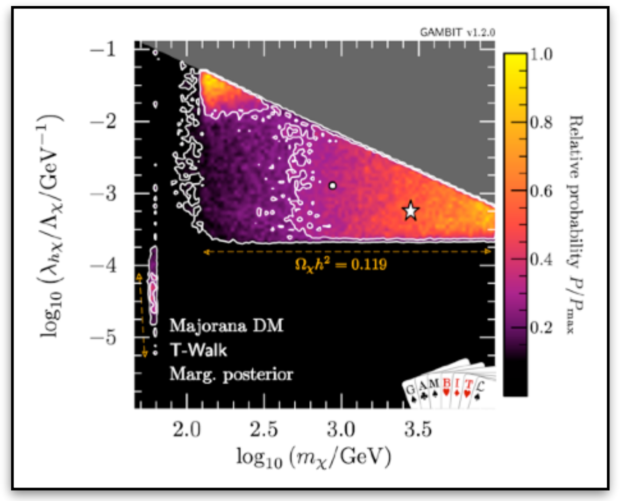
MSSM7: 1705.07917



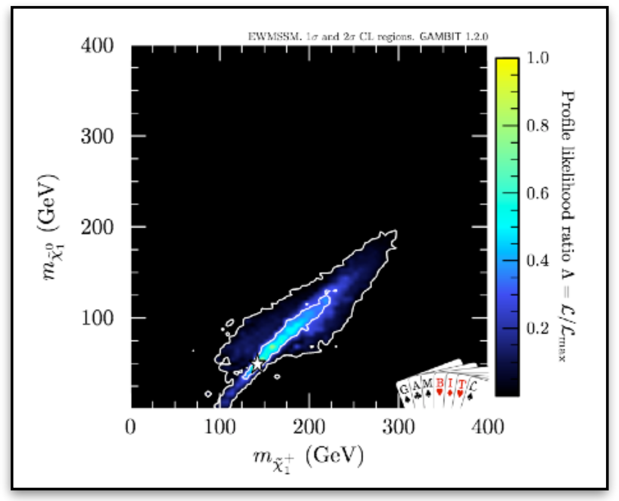
Scalar Higgs portal DM: 1705.07931



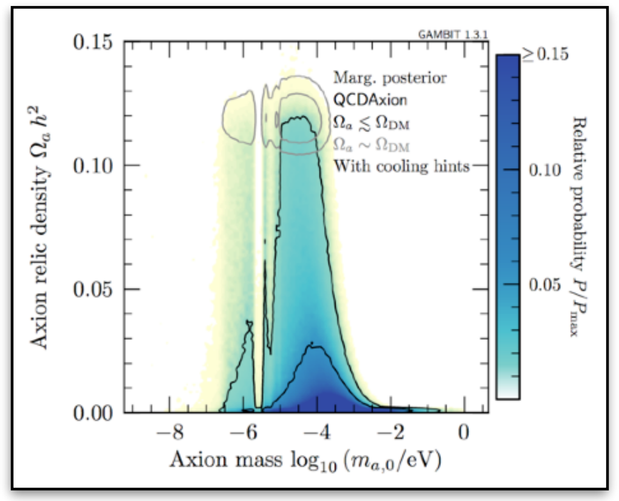
Scalar Higgs portal DM w/ vac. stability: 1806.11281



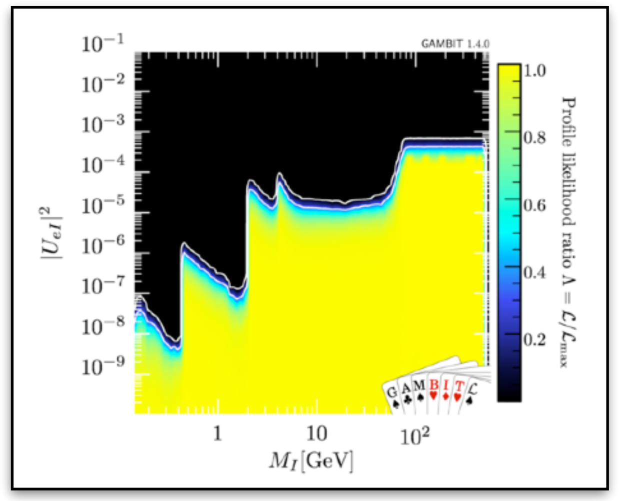
Vector and fermion Higgs portal DM: 1808.10465



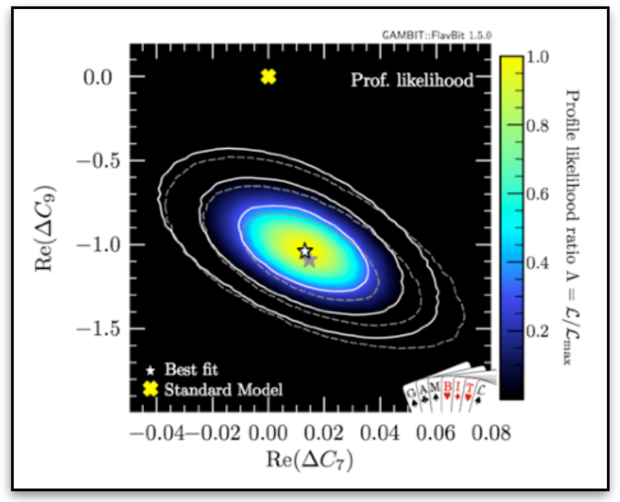
EW-MSSM: 1809.02097



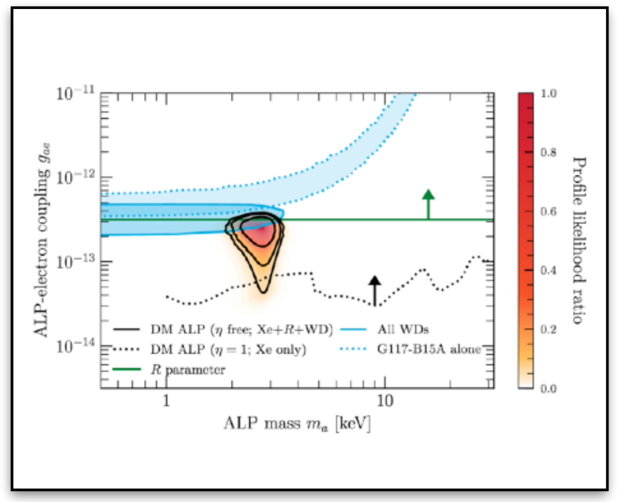
Axion-like particles: 1810.07192



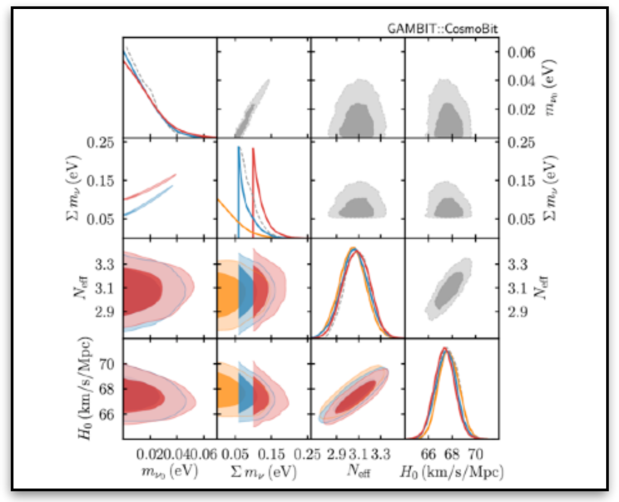
Right-handed neutrinos: 1908.02302



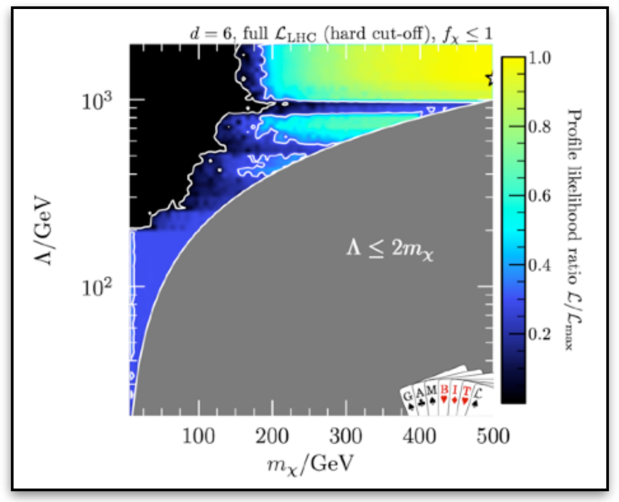
Flavour EFT: 2006.03489



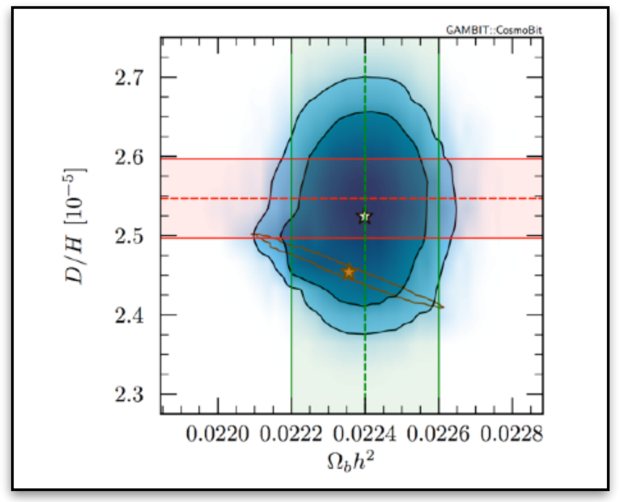
More axion-like particles: 2007.05517



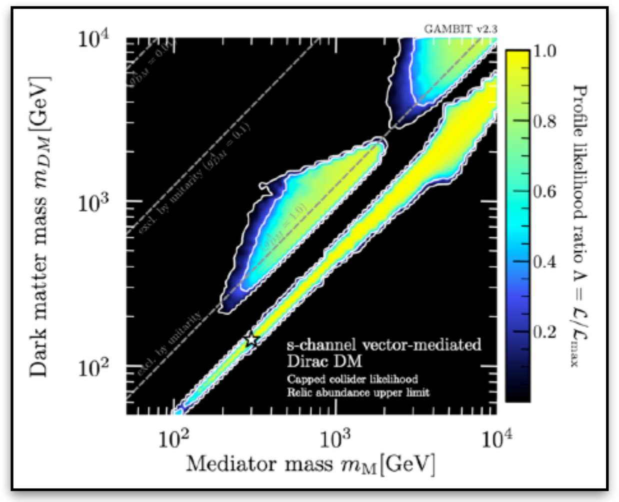
Neutrinos and cosmo: 2009.03287



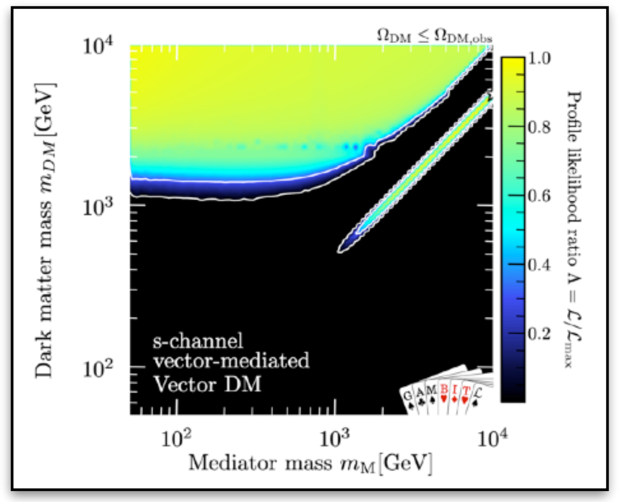
Dark matter EFTs: 2106.02056



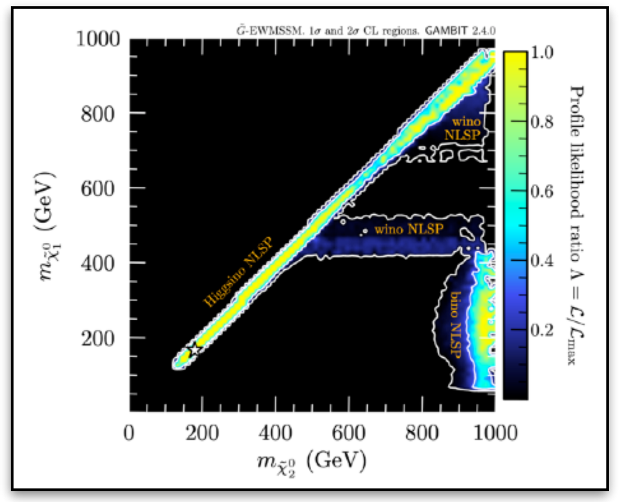
Cosmo ALPs: 2205.13549



Simplified DM, scalar/fermion: 2209.13266



Simplified DM, vector: 2303.08351



EW-MSSM w/ light gravitino: 2303.09082

Plus new results on sub-GeV DM! See slides from Tomas Gonzalo's talk

Simulation-based EWino fits with GAMBIT

Question:

What are the 13 TeV collider constraints on the chargino/neutralino sector of the MSSM?
(MSSM ≠ simplified model)

Method:

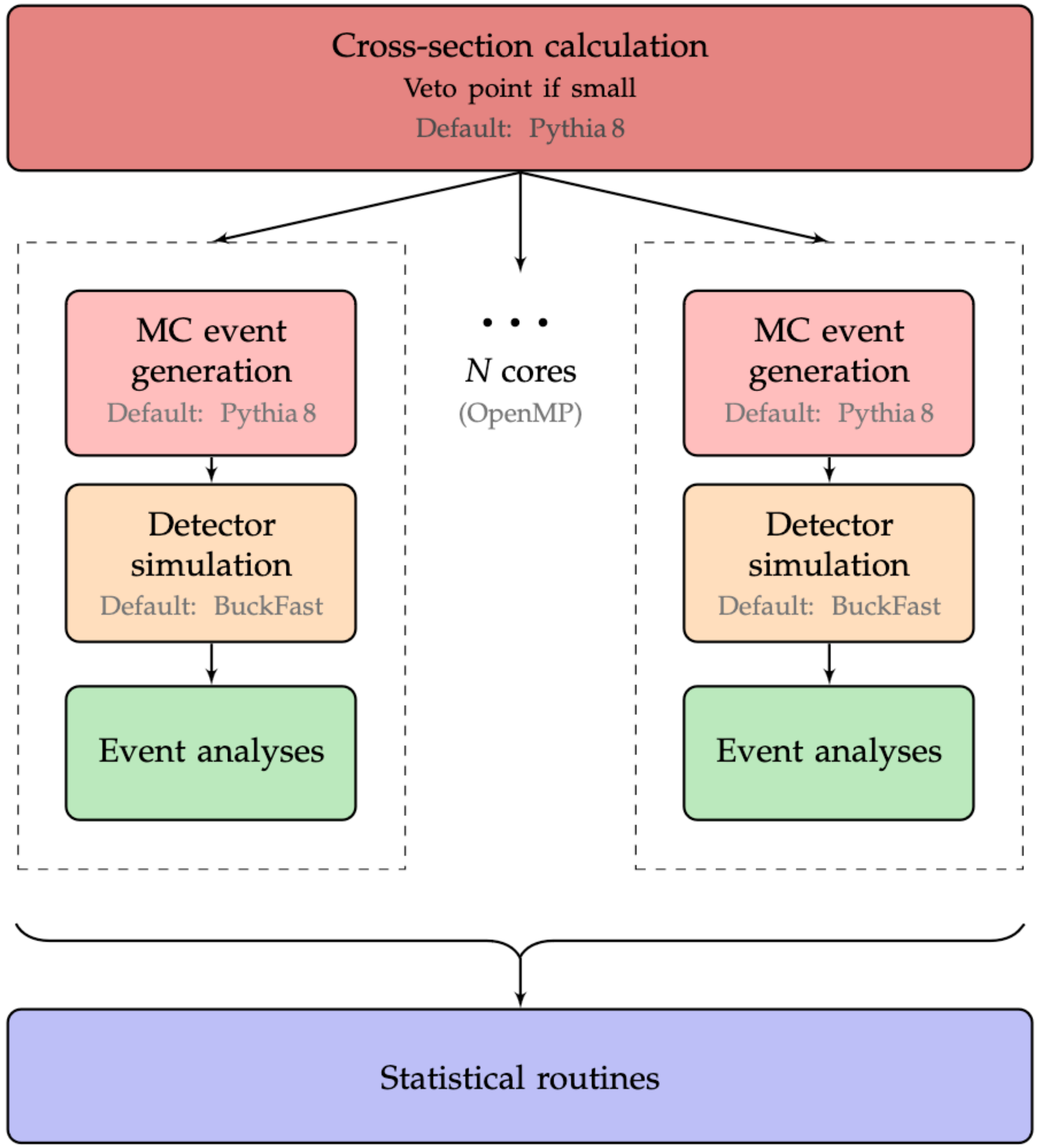
— Scan 4D EWino parameter space w/ adaptive sampler
— *At every point:* Run MC simulations of 13 TeV searches
— Calculate joint likelihood function for all searches
— Produce profile likelihood plots

Main challenges:

— Computational cost
— Reproduce ATLAS/CMS searches w/ sufficient accuracy

ColliderBit

- For **each parameter point** in a scan:
  - Run **Pythia simulations** of all relevant SUSY processes
  - Pass events through **fast detector simulation** (four-vector smearing + efficiencies)
  - Pass events through **our implementations of ATLAS and CMS searches**
    - → signal predictions for all SRs
  - Compute **a combined likelihood** for the parameter point
    - We combine as many analyses and SRs as we reasonably can, given available info
  - Plus an analogous pipeline for measurements, using Rivet + Contur



Two models: EWMSSM and G-EWMSSM

EWMSSM

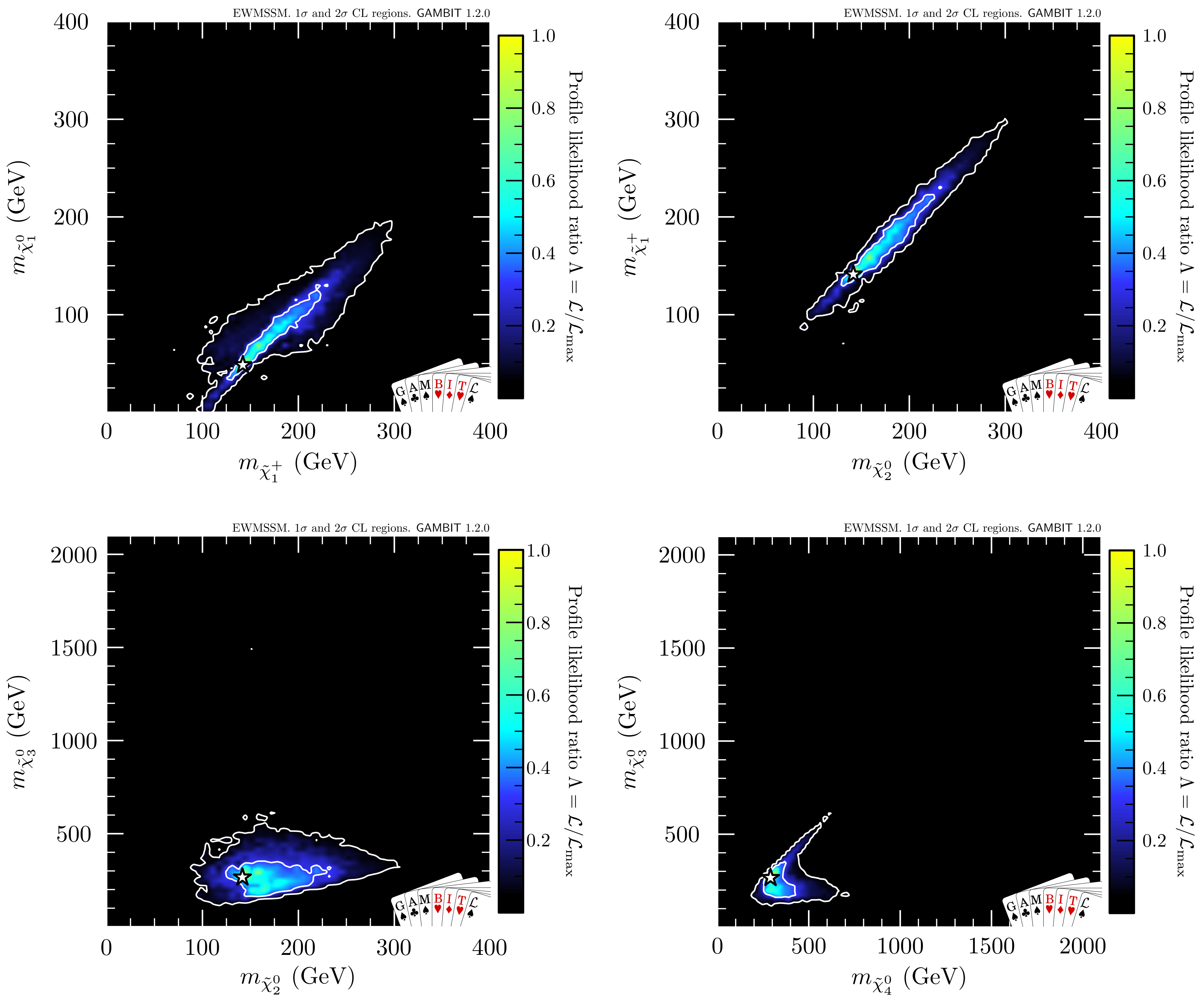
- **MSSM** w/ neutralinos and charginos within LHC reach
- **6 SUSY particles below 1.5 TeV**: 4 neutralinos, 2 charginos
- **4D theory parameter space**: M1, M2, mu, tan beta

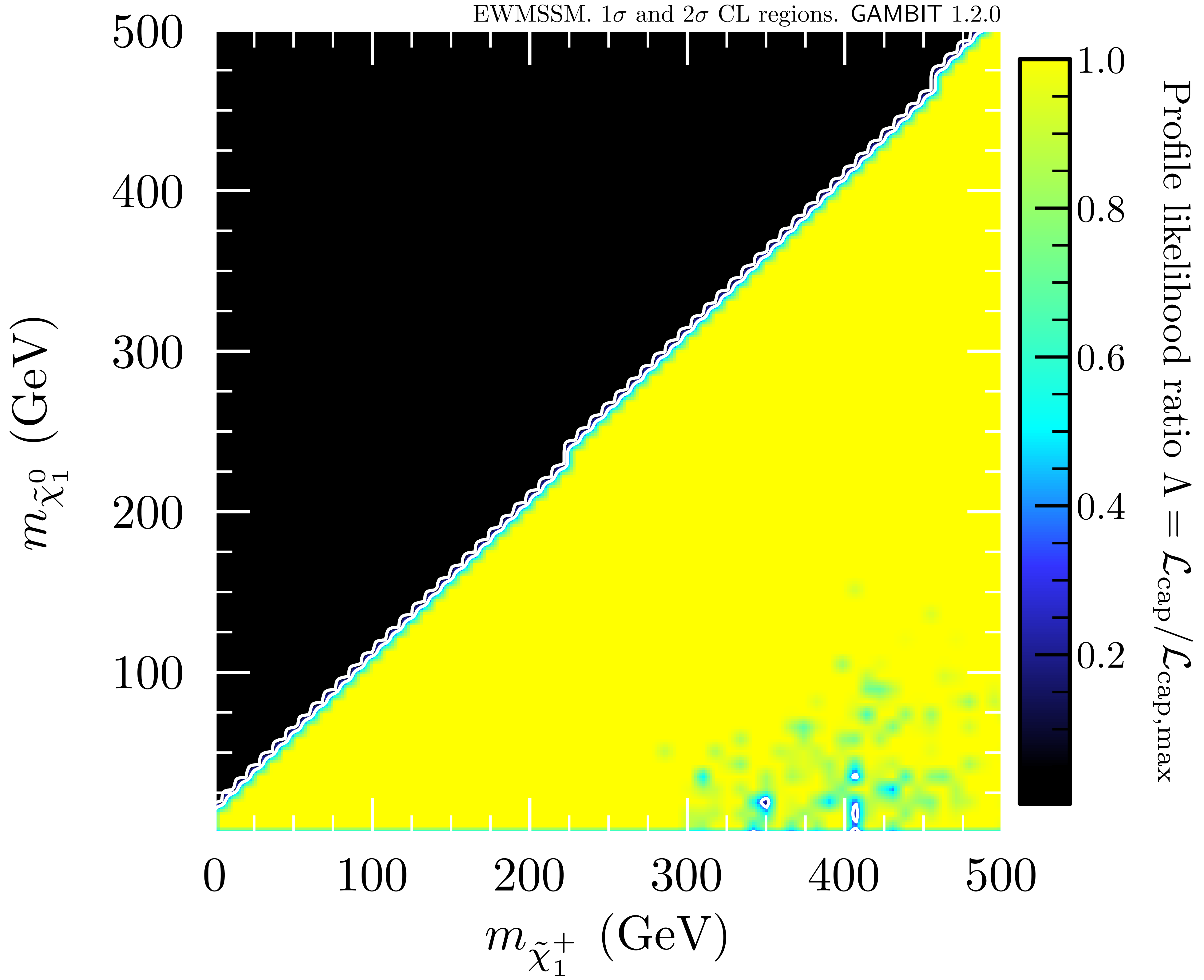
G-EWMSSM

- **EWMSSM + near-massless gravitino** (1eV gravitino, for prompt decays)
- **7 SUSY particles below 1.5 TeV**: 4 neutralinos, 2 charginos, 1 gravitino
- Same 4D parameter space, quite different collider pheno

Back in 2019: EWMSSM

[1809.02097]
- 12 ATLAS/CMS searches
- LEP cross-section limits



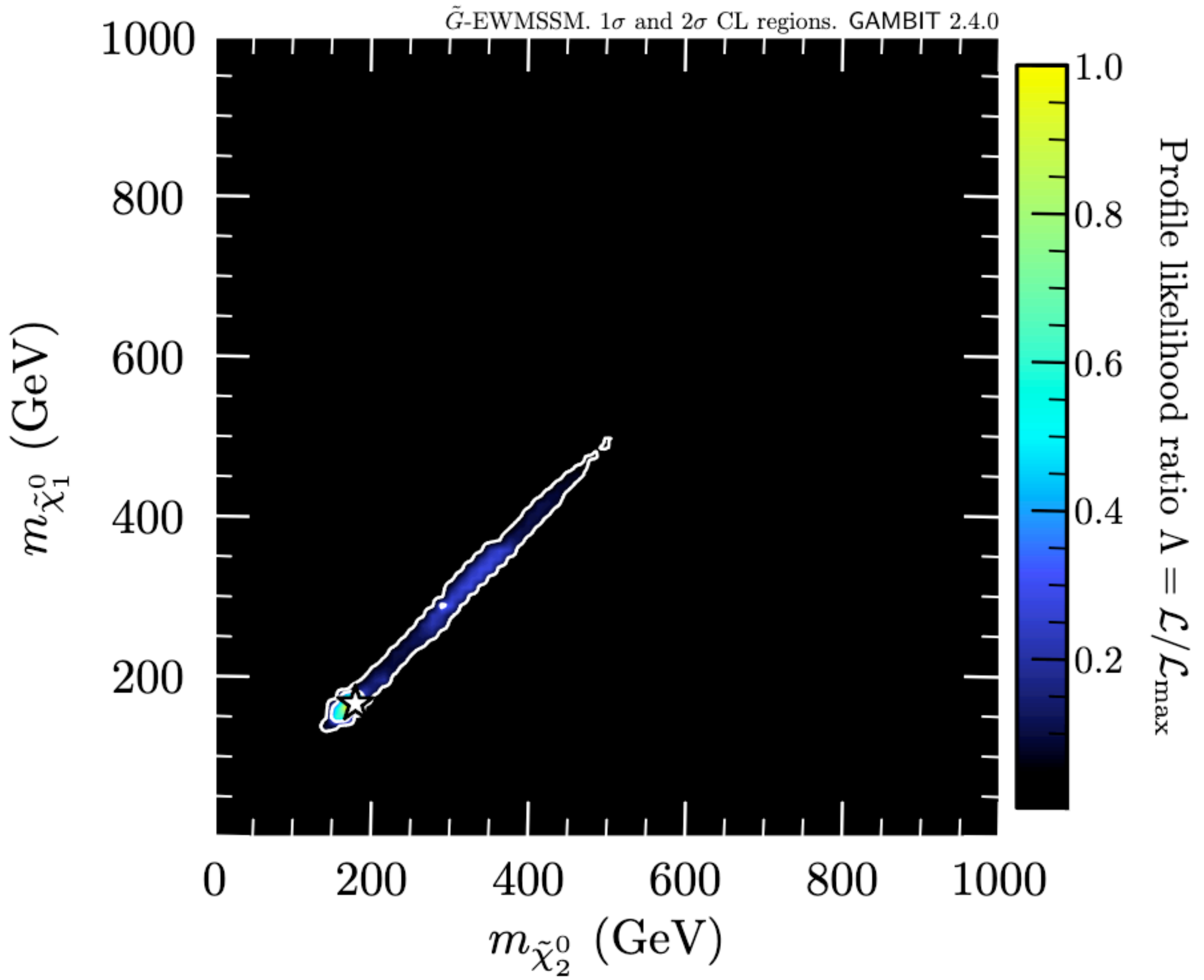


Identified a possible explanation for a pattern of (at the time interesting) excesses across multiple ATLAS searches

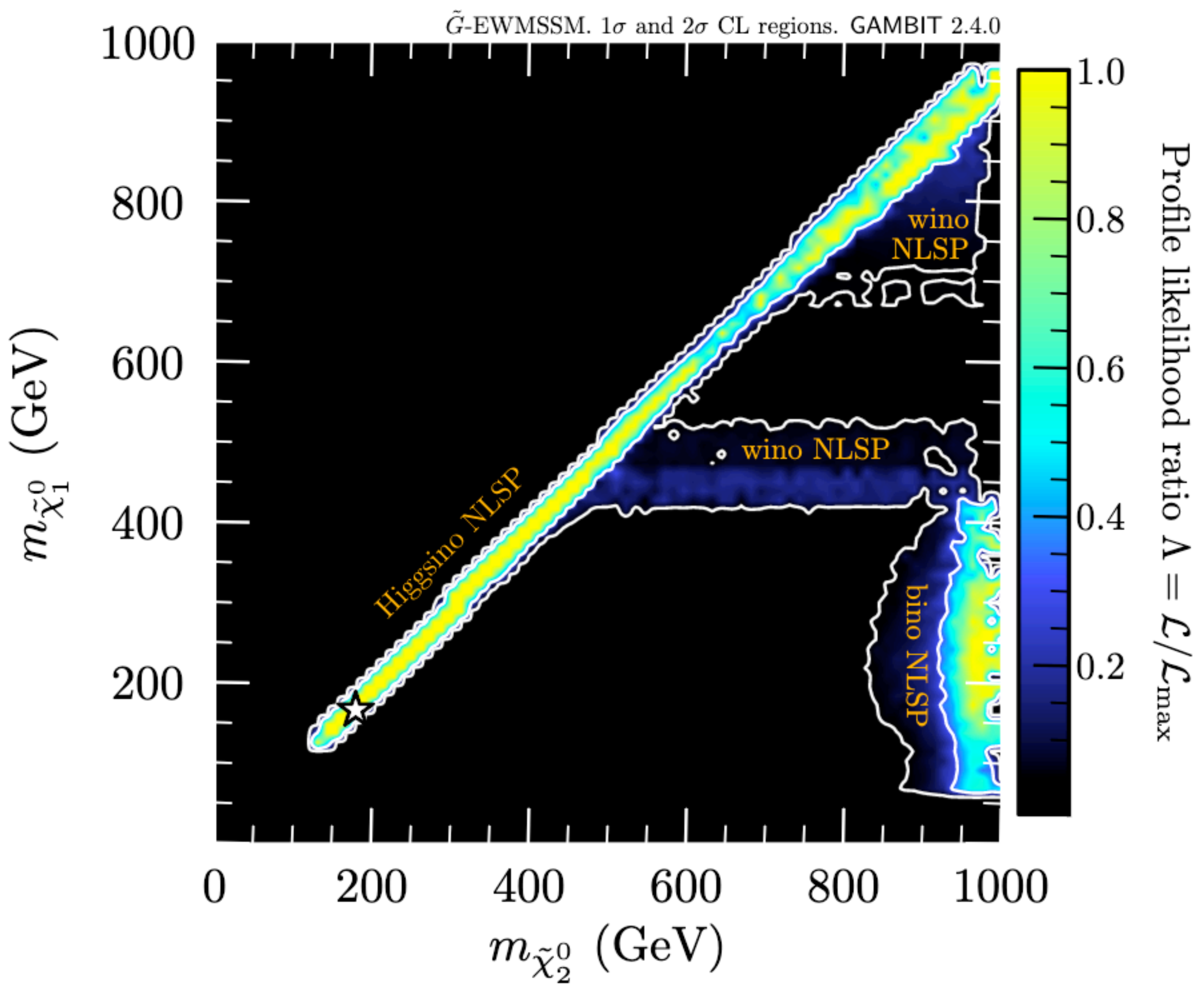
Comparing to SM rather than to the best-fit point: Found that no point in the chargino-neutralino mass plane was conclusively ruled out at that time

2023: G-EWMSSM

[2303.09082]
- 27 ATLAS/CMS searches
- Many «SM measurements»
- LEP cross-section limits



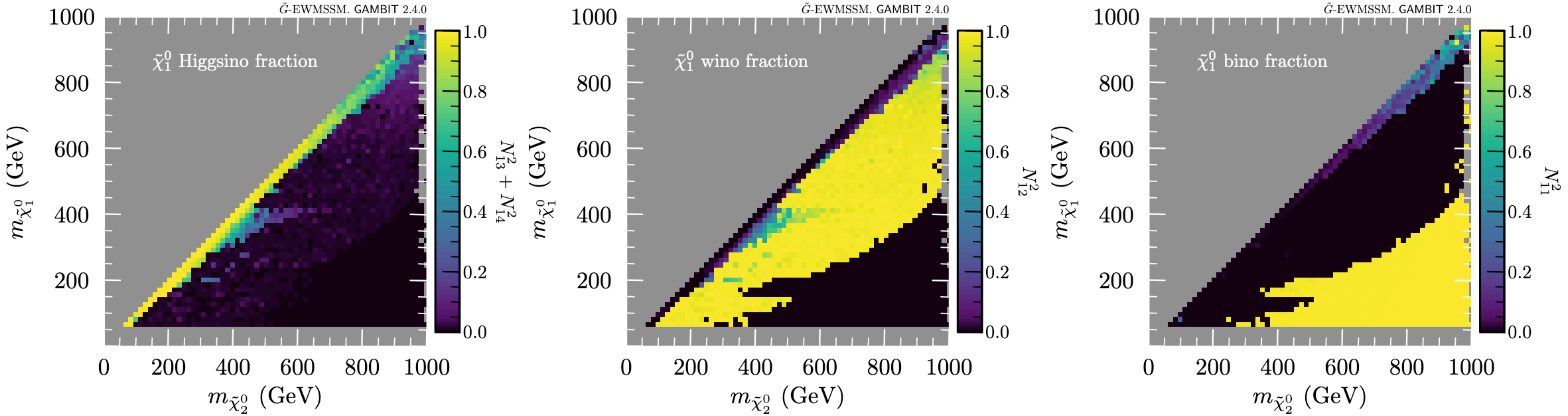
Scenario with light higgsinos → Z/H + gravitino could partly fit small excesses in searches for leptons + MET and b-jets + MET



Comparing to SM rather than to the best-fit point: Strong constraints, but several scenarios survive

2023: G-EWMSSM

[2303.09082]
- 27 ATLAS/CMS searches
- Many «SM measurements»
- LEP cross-section limits

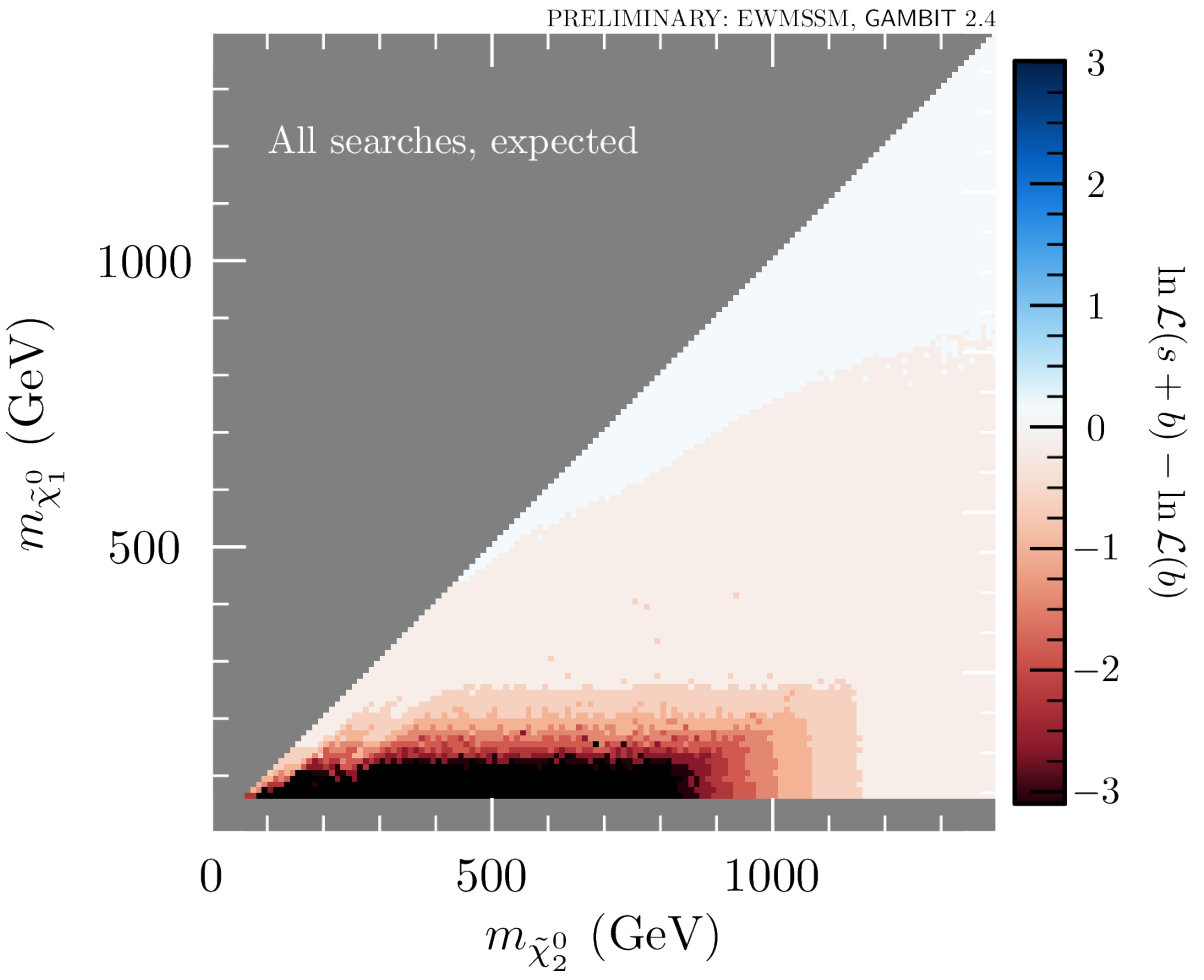


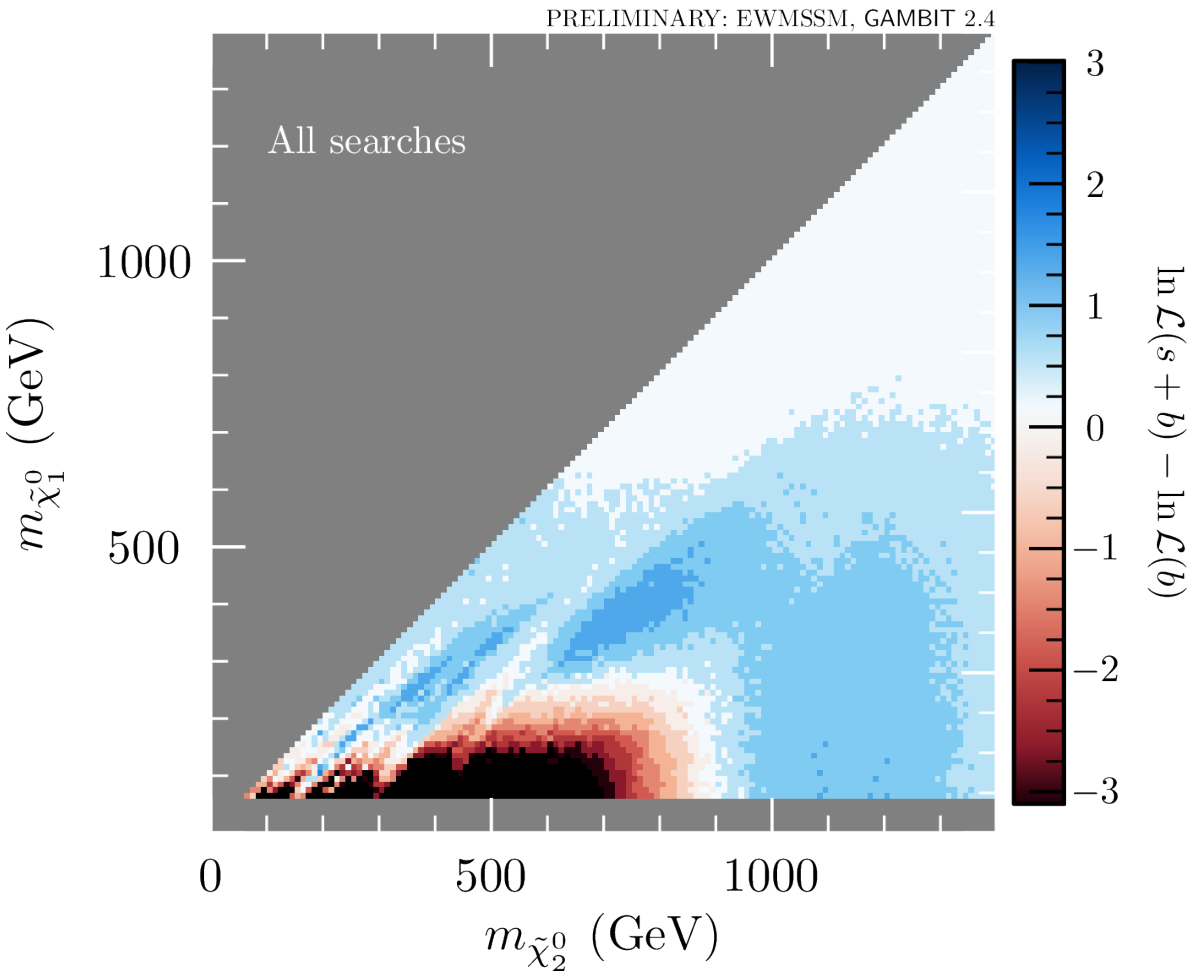
Profile likelihoods can be complicated: Neighbouring points in e.g. a mass plane can belong to very different theoretical scenarios

Ongoing work: **EWMSSM and G-EWMSSM after Run 2**

EWMSSM: Preliminary

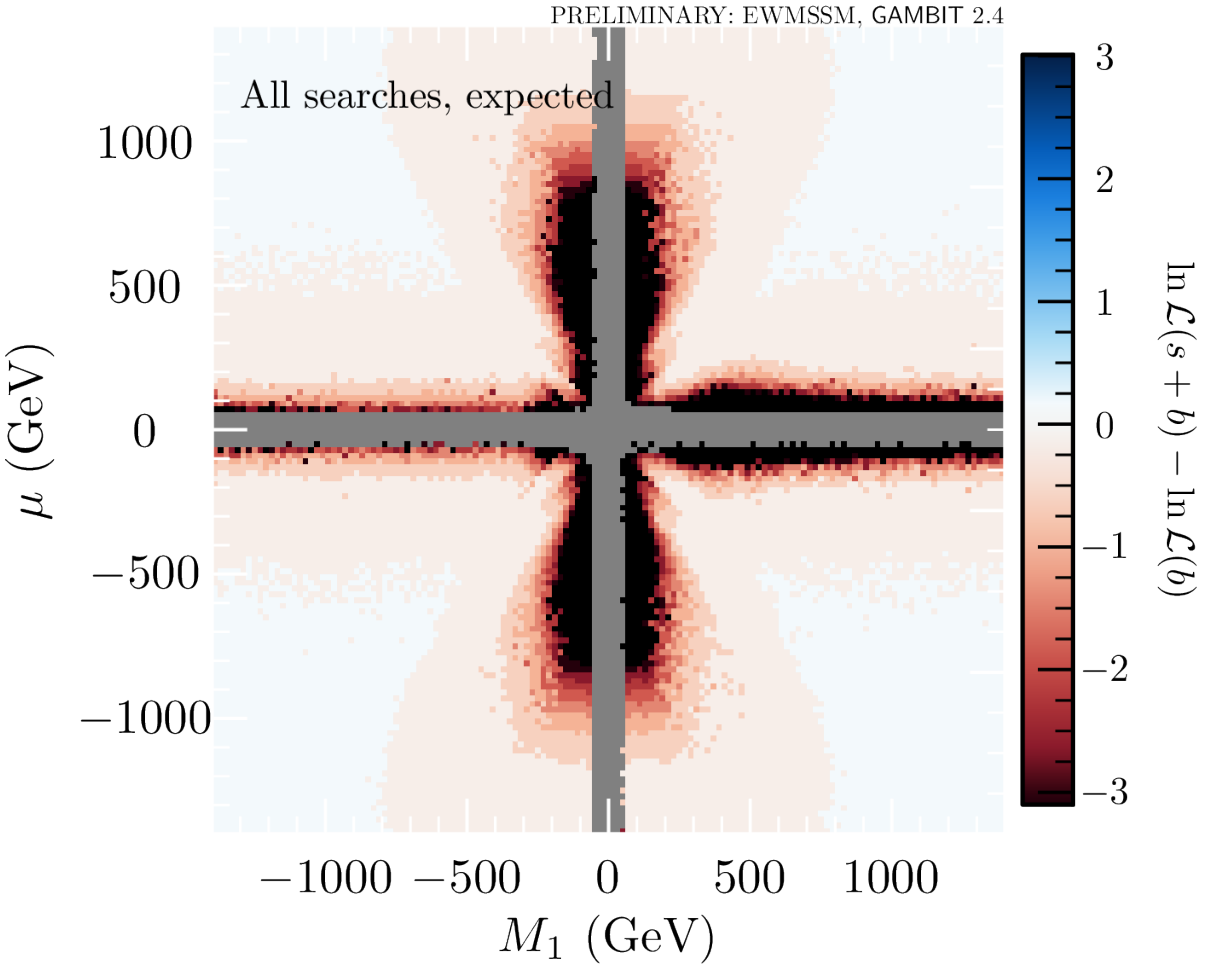
- 34 ATLAS/CMS searches
- LEP cross-section limits
- TODO: SM measurements

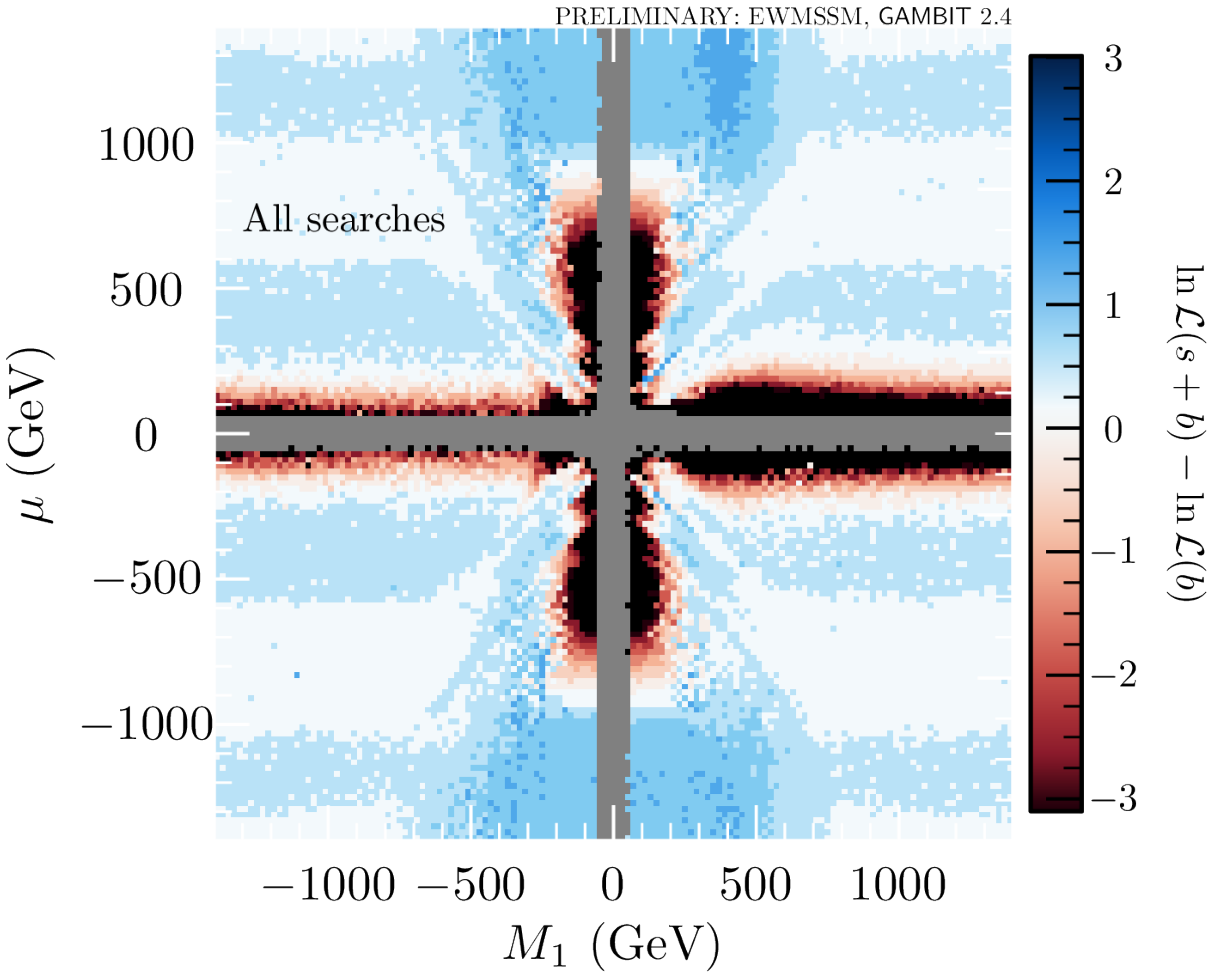




EWMSSM: Preliminary

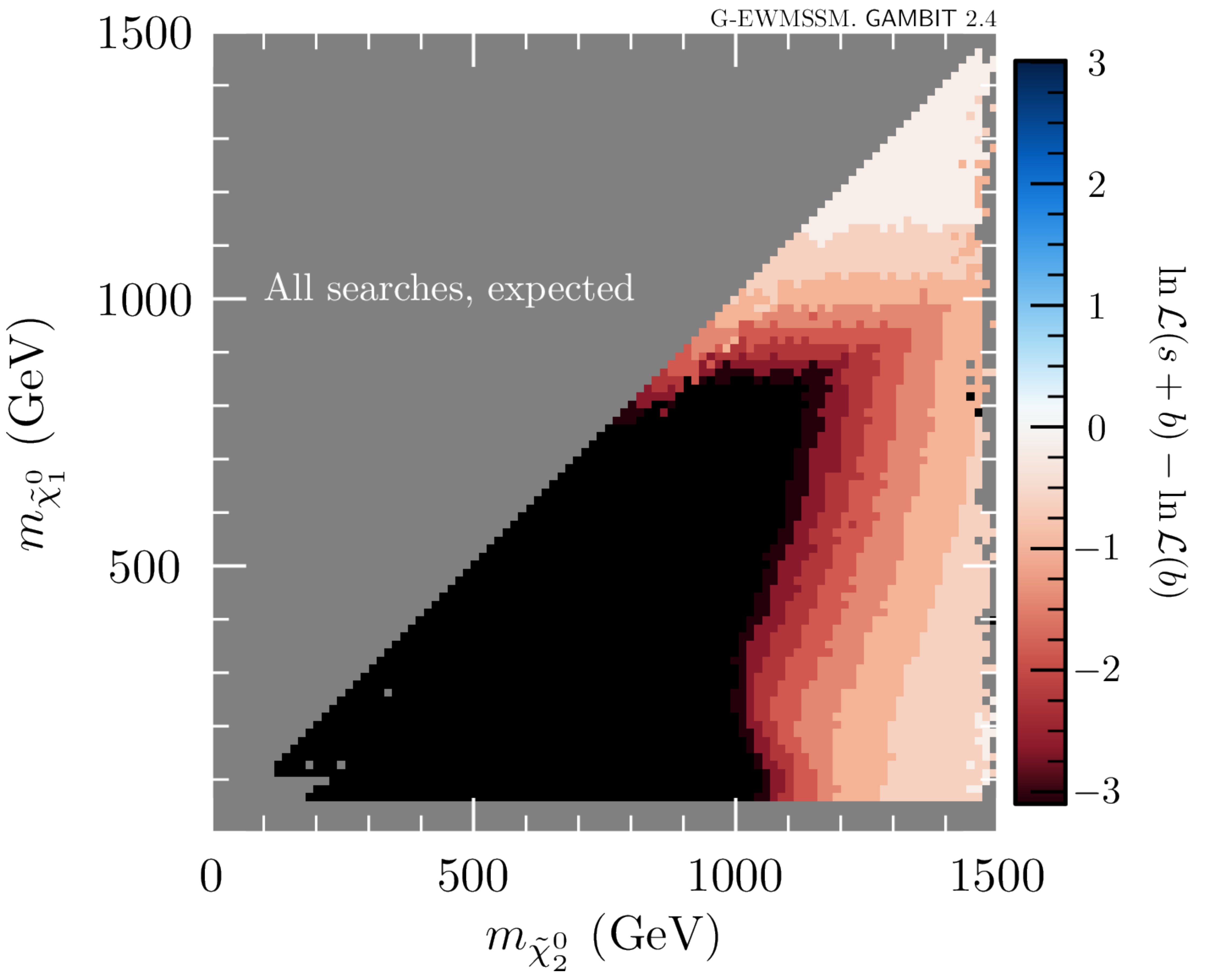
- 34 ATLAS/CMS searches
- LEP cross-section limits
- TODO: SM measurements

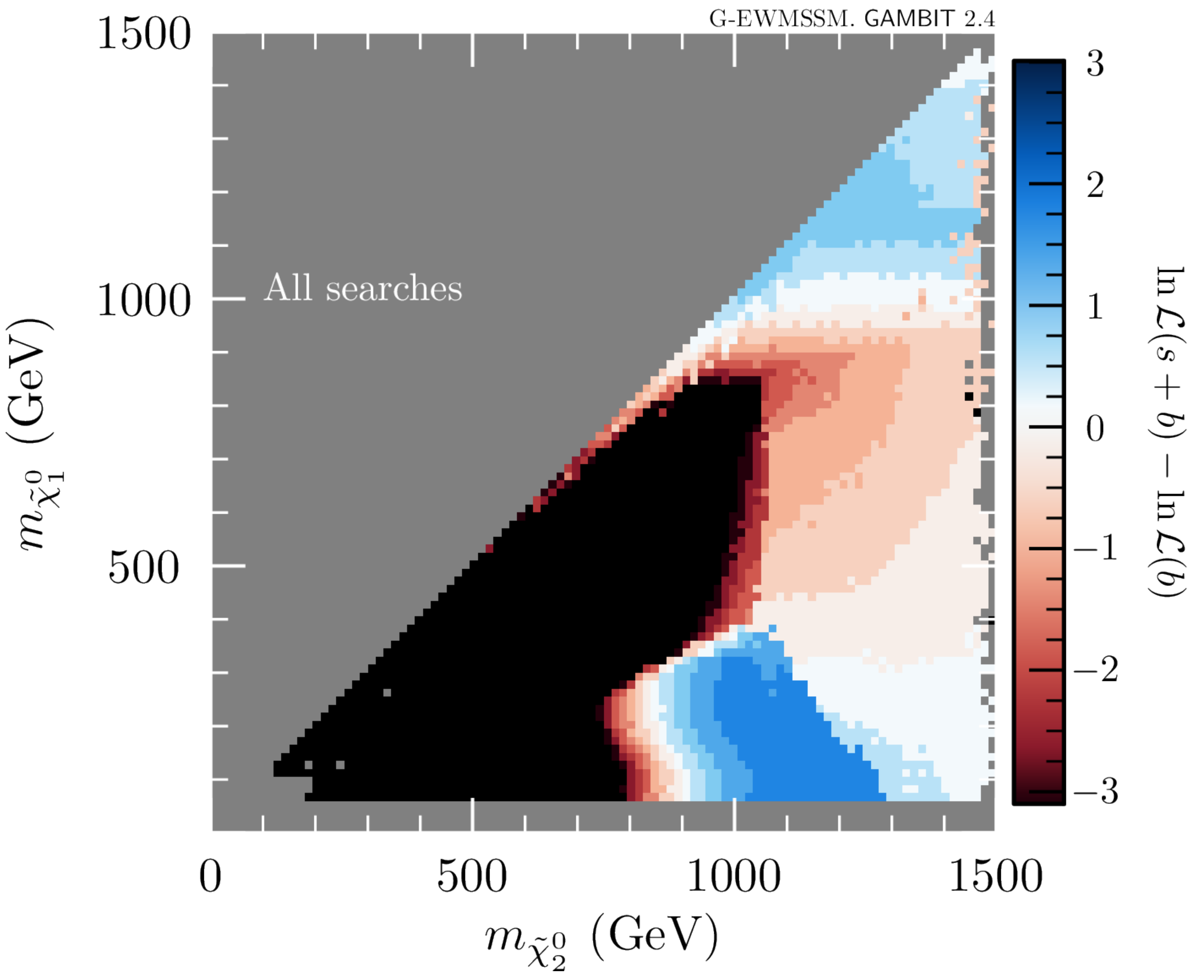




G-EWMSSM: Preliminary

- 34 ATLAS/CMS searches
- LEP cross-section limits
- TODO: SM measurements

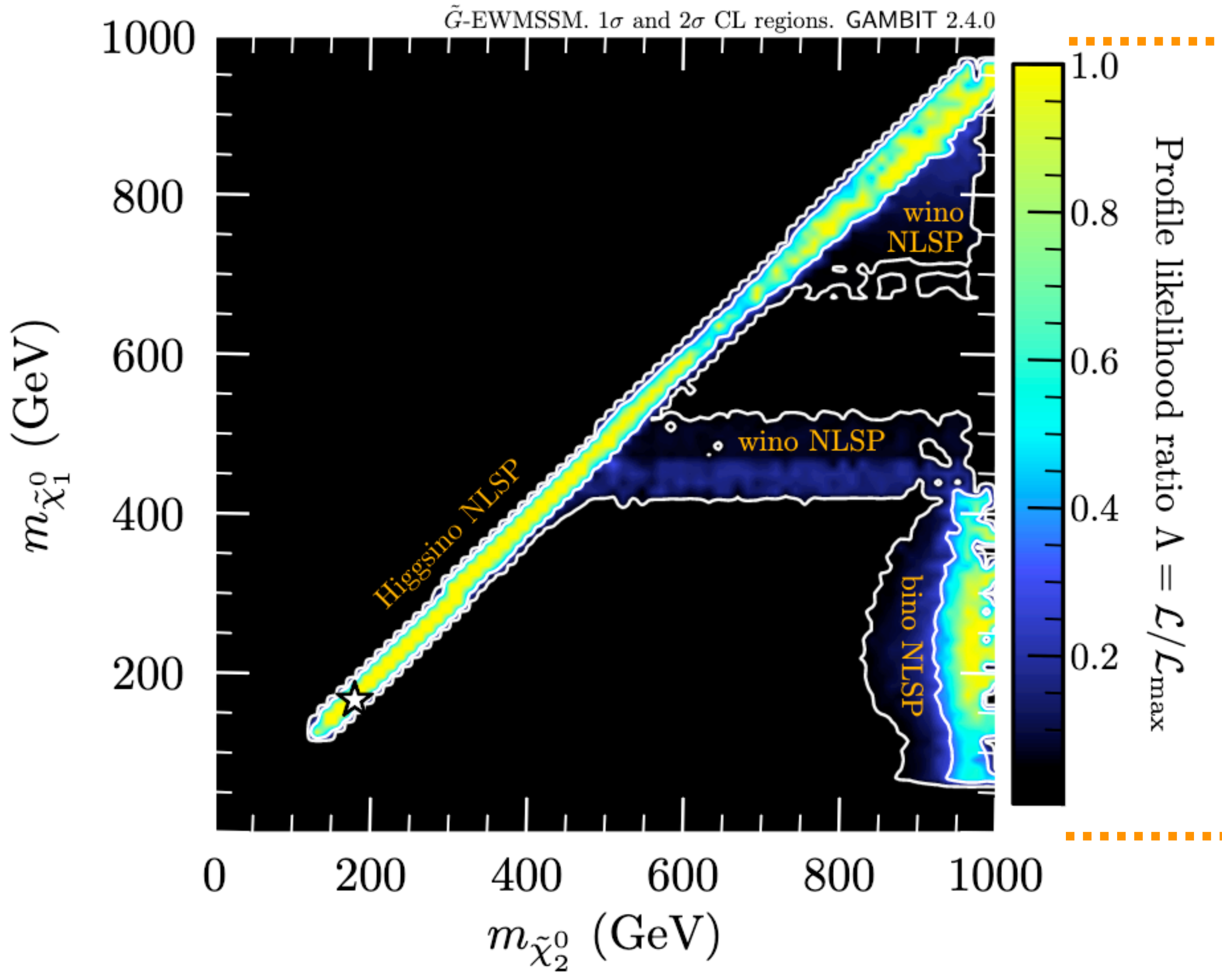


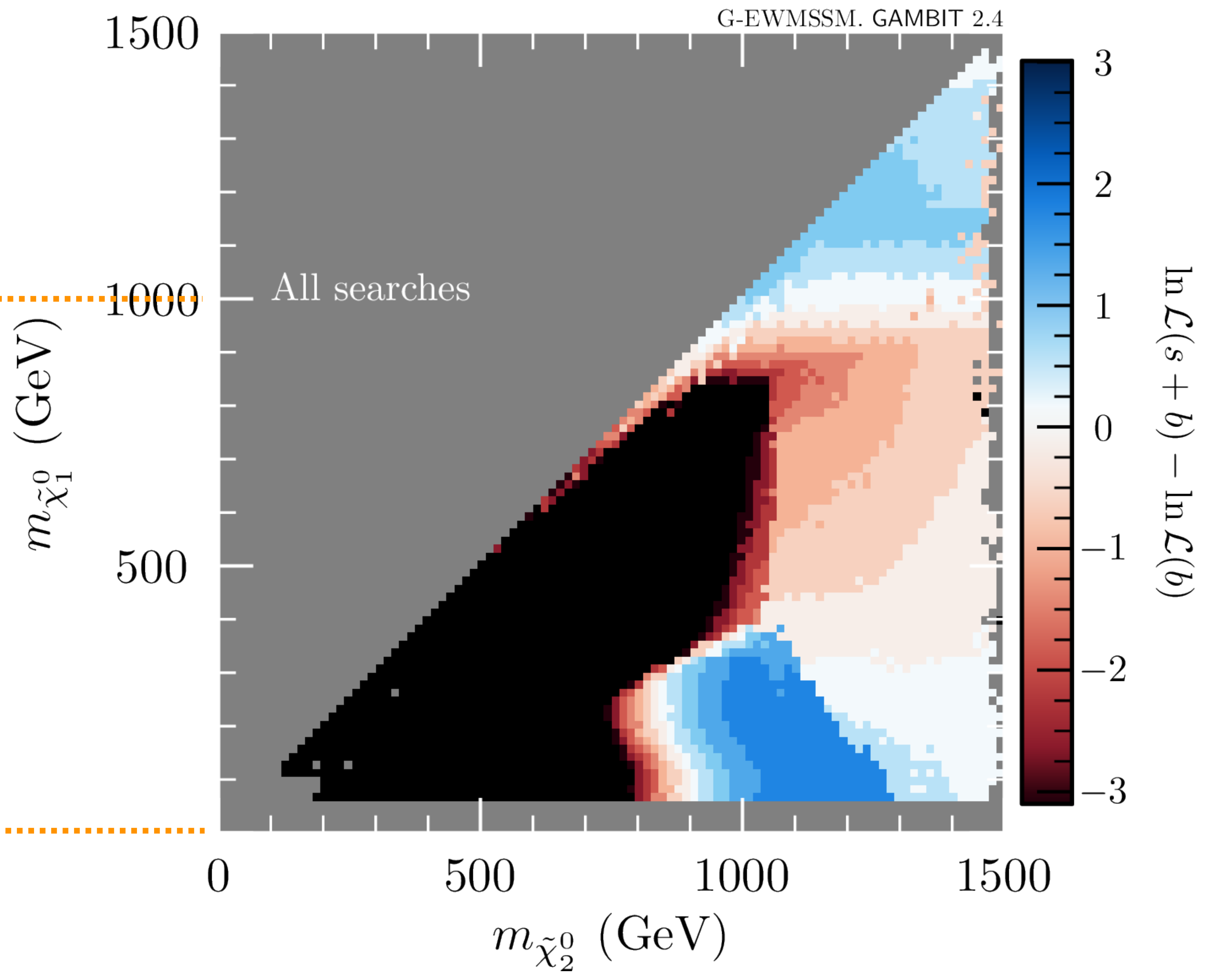


G-EWMSSM: Preliminary

- 34 ATLAS/CMS searches
- LEP cross-section limits
- TODO: SM measurements

Compared to 2023 G-EWMSSM study:

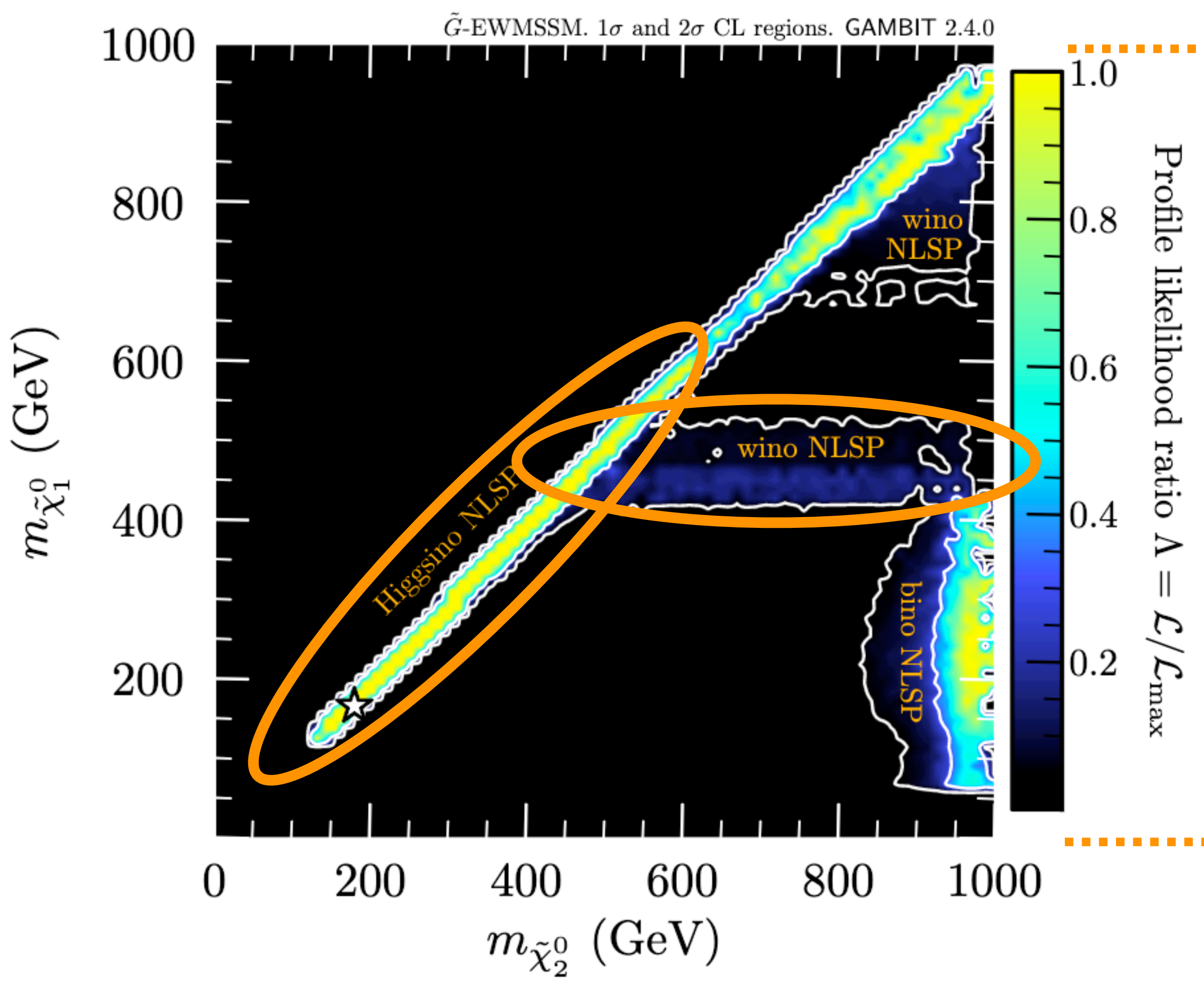


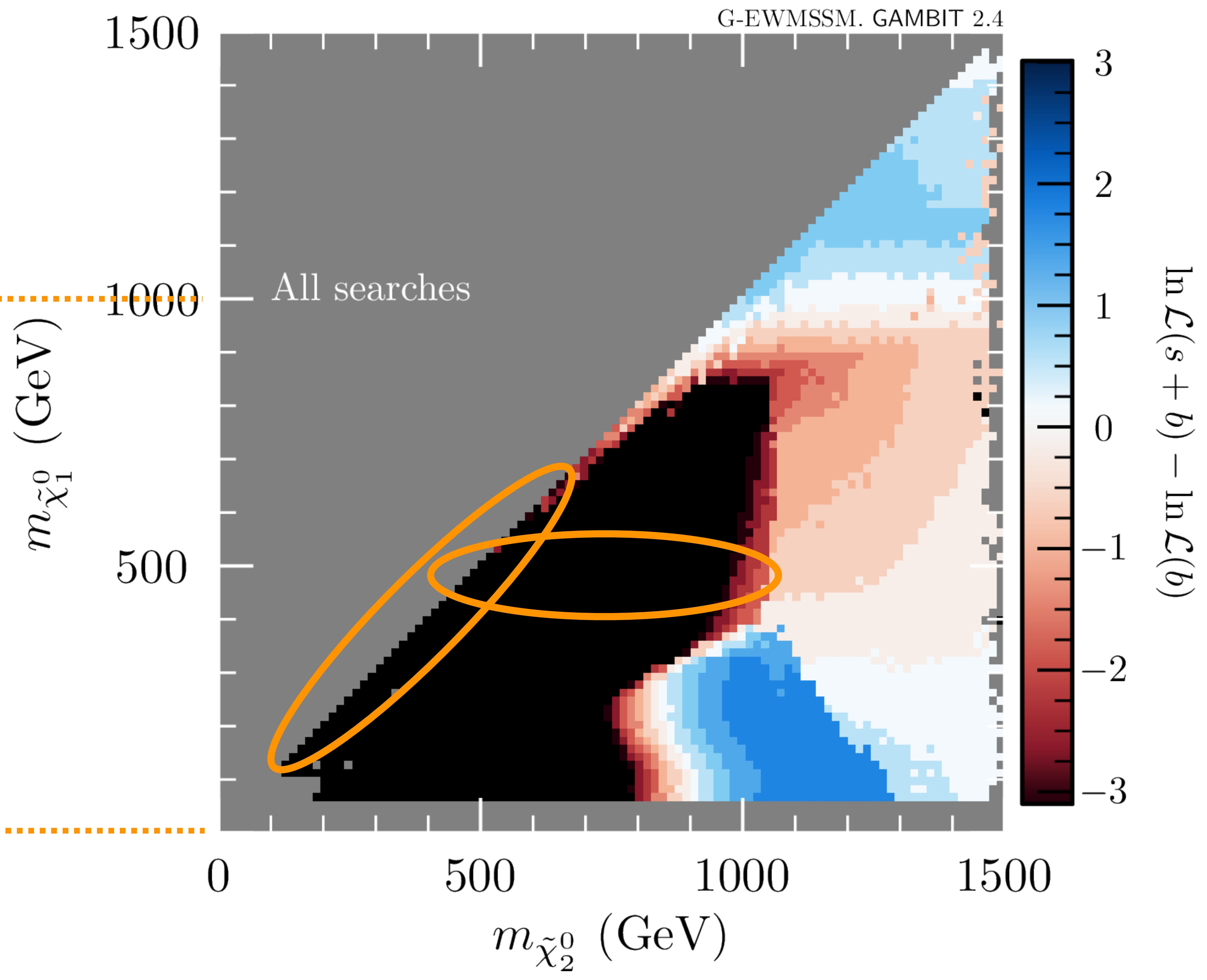


G-EWMSSM: Preliminary

- 34 ATLAS/CMS searches
- LEP cross-section limits
- TODO: SM measurements

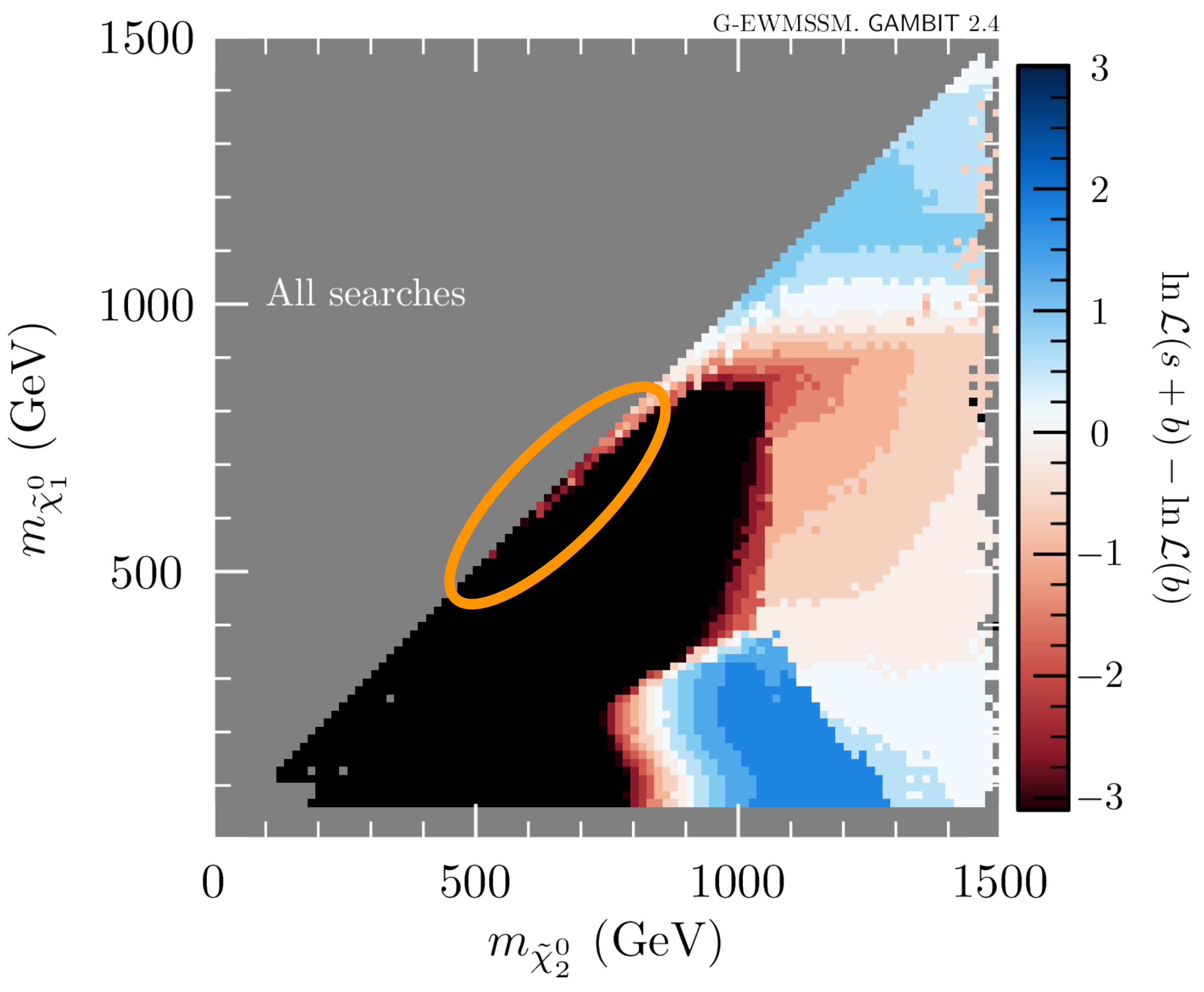
Compared to 2023 G-EWMSSM study:
Stronger constraints on higgsino and wino NLSP scenarios

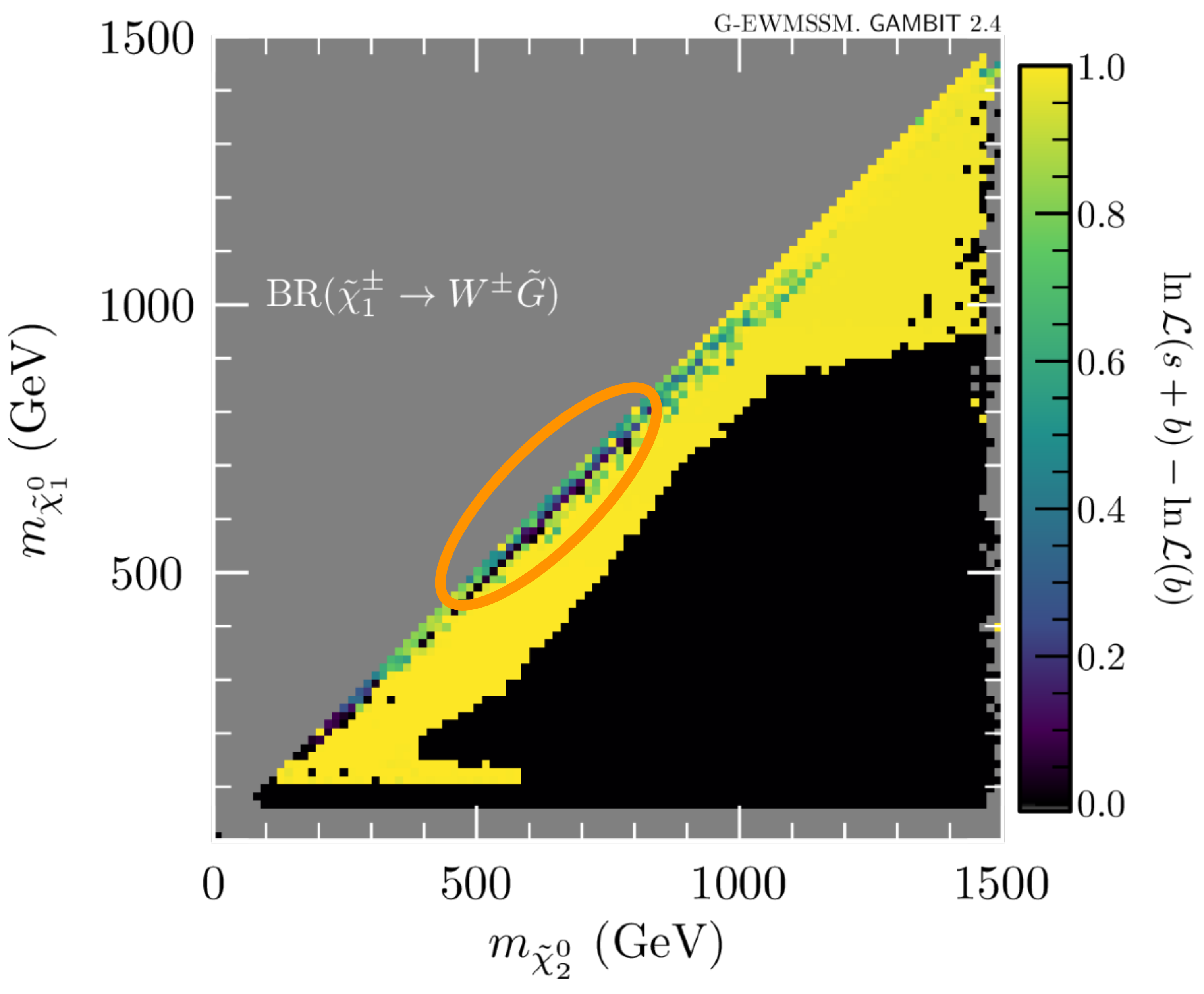


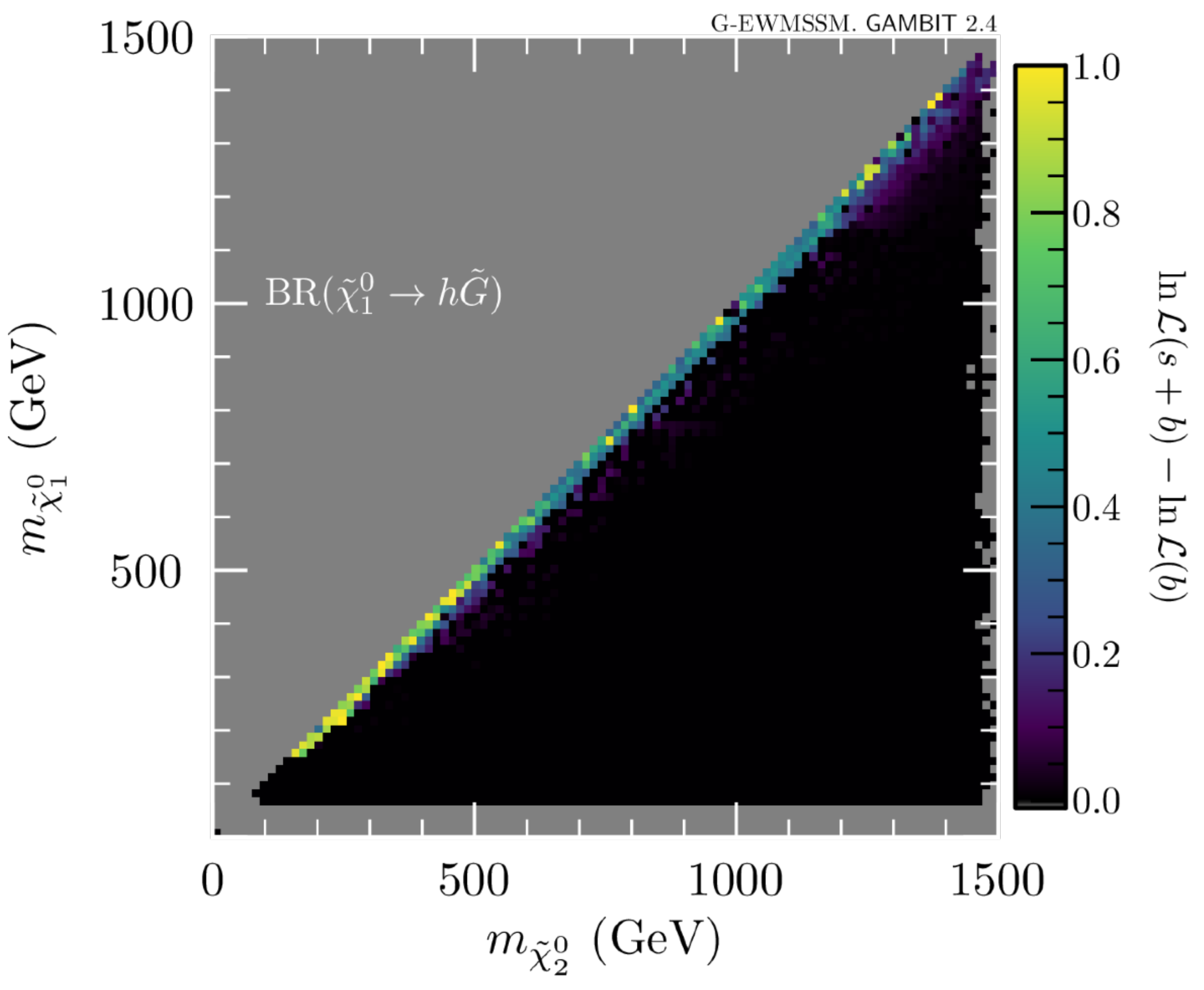


G-EWMSSM: Preliminary

- 34 ATLAS/CMS searches
- LEP cross-section limits
- TODO: SM measurements



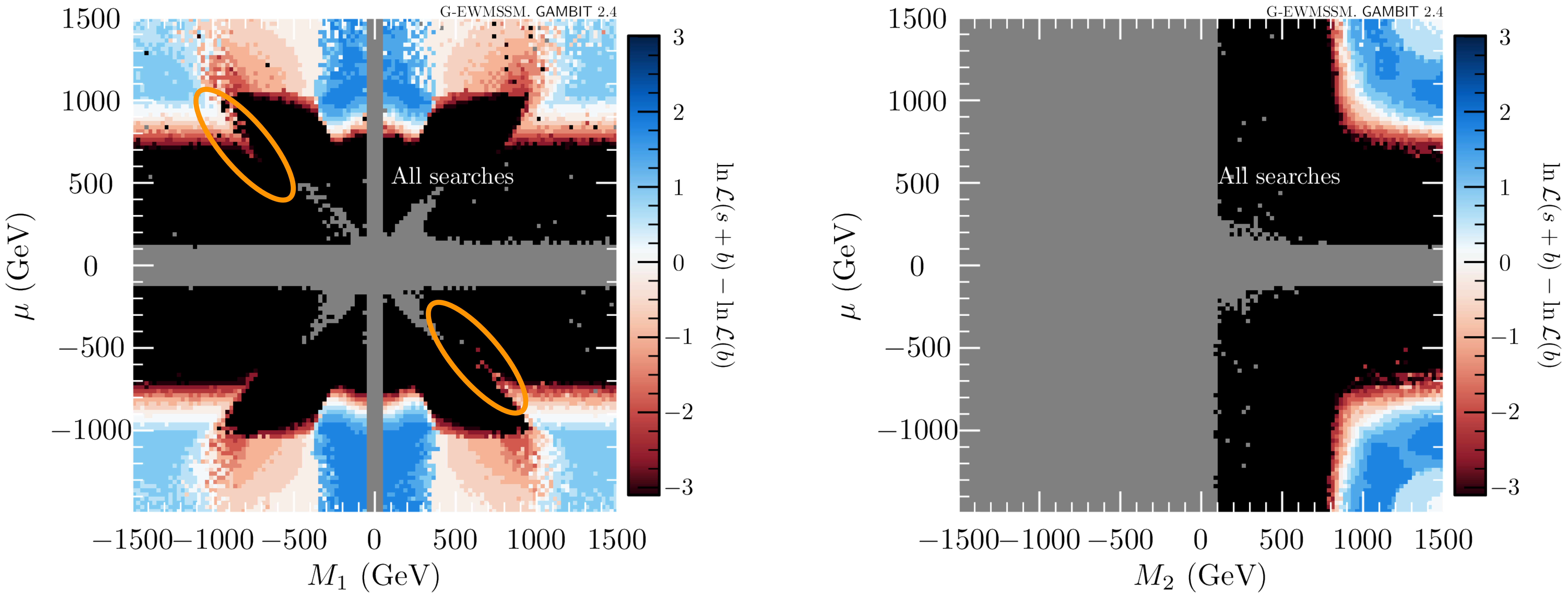




Lowest-mass non-excluded higgsino scenarios violate the common simplified model assumption that N2/C1 always decay to N1 + soft stuff

G-EWMSSM: Preliminary

- 34 ATLAS/CMS searches
- LEP cross-section limits
- TODO: SM measurements



…and these scenarions are higgino-bino mixture scenarios (M1 ~ mu)

Summary

- *To what extent is [your favourite model] constrained by the LHC? Can [your favourite model] really explain some pattern of excesses?*
- We need **high-detail reinterpretation studies**, based on **combined likelihoods** for all relevant searches/measurements
- Reinterpretation is how we **maximise the scientific impact of experimental results**
- With **GAMBIT** we are currently performing large, simulation-based global fits of the EWino sector
- New results (and associated code release) coming soon

Bonus tracks

Included searches

Report	Luminosity (inv fb)	Final state
CMS-SUS-20-003	137	1 lep + b-pair + Etmiss
CMS-SUS-20-004	137	4b + Etmiss
CMS-SUS-18-004	137	2/3 soft lep + Etmiss
CMS-SUS-19-010	137	0 lep + multi-jet + Etmiss
CMS-SUS-21-002	137	0 lep + large radius jets
CMS-SUS-21-009	137	photon + jets + Etmiss
CMS-SUS-20-001	137	2 OC SF lep + Etmiss
CMS-SUS-17-010	36	2 OC lep + Etmiss
CMS-SUS-19-006	137	0 lep + jets + Etmiss
CMS-SUS-16-051	36	1 lep. + jets + Etmiss
CMS-SUS-17-012	36	1 photon, 1 lep. + Etmiss
CMS-SUS-17-001	36	2 lep. + jets + Etmiss
CMS-SUS-17-011	36	2 Photons + Etmiss
CMS-SUS-19-008	137	2/3 SS lep + jets + Etmiss
CMS-SUS-19-012	137	3 lep + ETmis

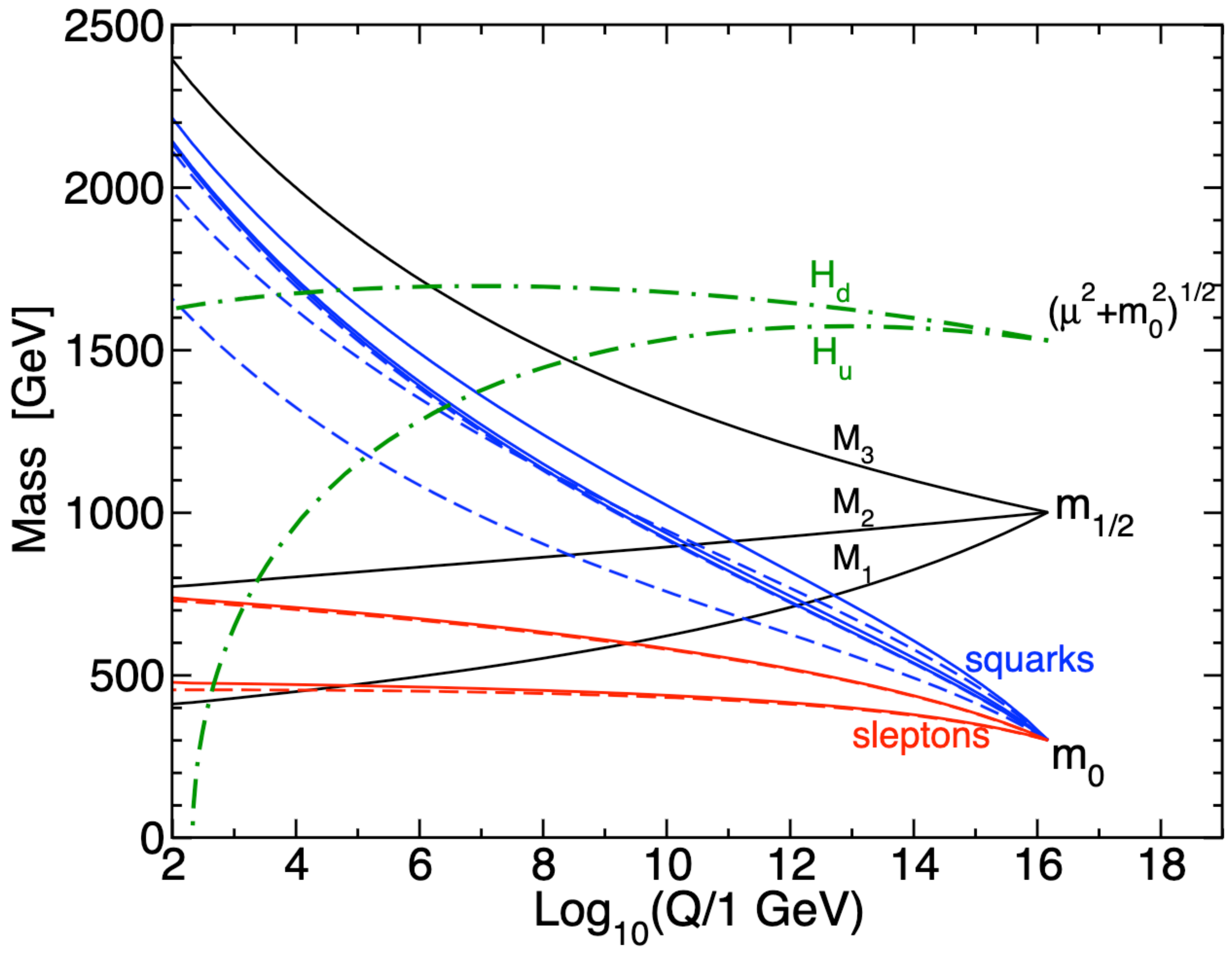
Report	Luminosity (inv fb)	Final state
ATLAS-SUSY-2019-08	139	1 lep + bb + ETmiss
ATLAS-SUSY-2019-02	139	2 lep + ETmiss
ATLAS-SUSY-2018-05	139	2 lep + jets + ETmiss
ATLAS-SUSY-2018-06	139	3 lep + jets + ETmiss
ATLAS-SUSY-2019-22	139	2/3 lep + ETmiss
ATLAS-SUSY-2019-18	139	taus + bjets + ETmiss
ATLAS-SUSY-2018-21	139	bjets/2 OC SF lep + ETmiss
ATLAS-SUSY-2020-16	139	4b + ETmiss
ATLAS-SUSY-2018-22	139	0 lep + jets + ETmiss
ATLAS-SUSY-2018-41	139	large radius jets + ETmiss
ATLAS-SUSY-2018-08	139	2 OC lep + jets + ETmiss
ATLAS-SUSY-2018-32	139	2 lep + ETmiss
ATLAS-SUSY-2019-09	139	3 lep + ETmiss
CERN-EP-2021-021	139	4 lep + ETmiss
ATLAS-SUSY-2016-28	36	bjets + ETmiss
ATLAS-SUSY-2018-09	139	2/3 lep + jets + ETmiss
ATLAS-SUSY-2016-27	36	2 photon + ETmiss
ATLAS-SUSY-2018-11	139	1 photon + ETmiss
ATLAS-CONF-2018-019	80	photon + ETmiss

Reminder:
Theory space is a strange, implausible place

- «Everyone» would assign **negligible prior belief** to **almost all points** in the **low-scale MSSM parameter space**
- MSSM expresses our ignorance of SUSY breaking
- Any «elegant»/«economic»/«reasonable» high-scale model maps to some tiny subspace of the low-scale MSSM
- And any simplified model plane maps to some strange hypersurface through low-scale MSSM

- A «large» exclusion in simplified model space:
  - **Maybe large**, **maybe small** impact on MSSM

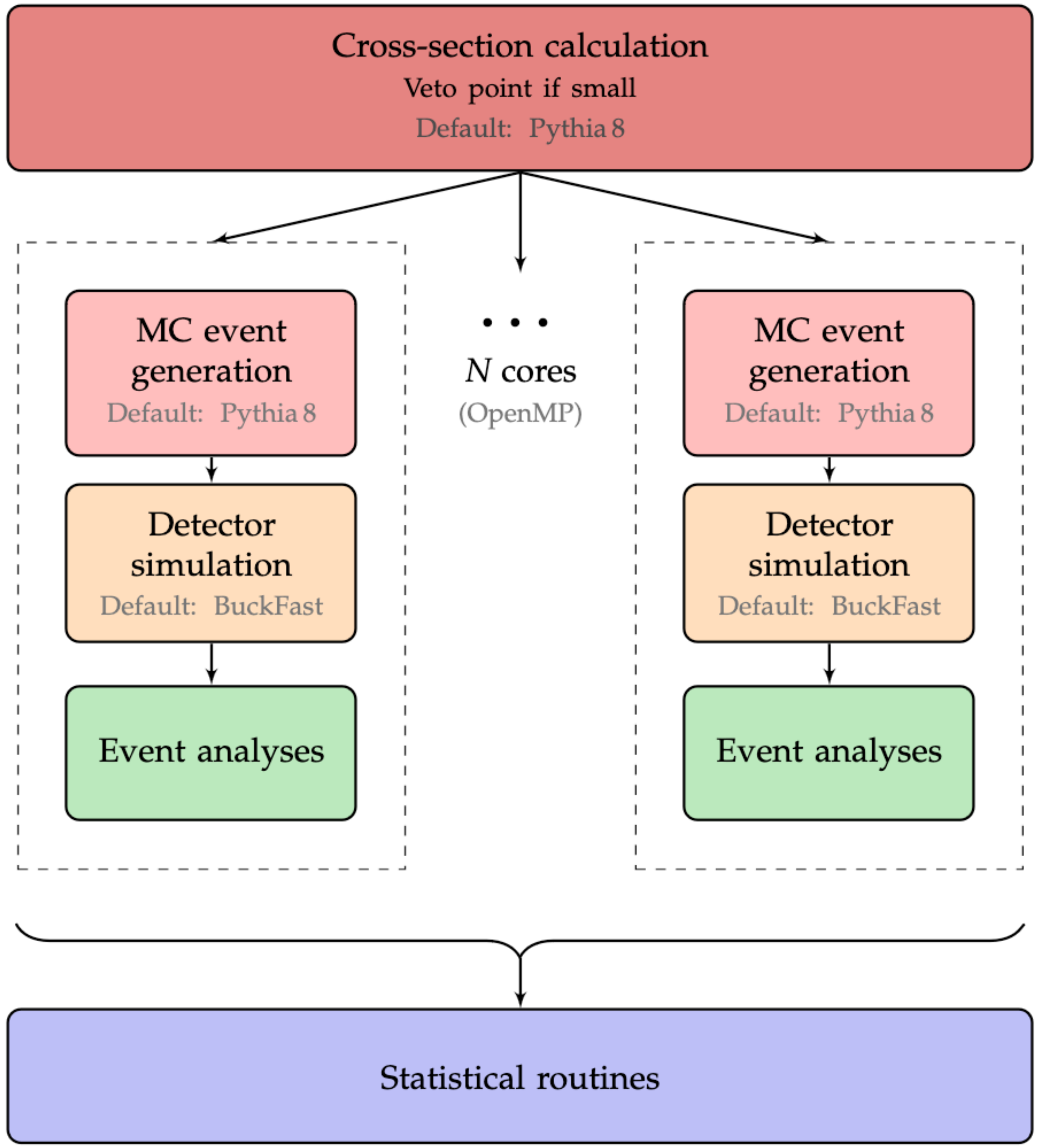
- A «large» exclusion in low-scale MSSM
  - **Maybe decisive**, **maybe negligible** impact on the space of plausible high-scale models



[hep-ph/9709356]

What we do in ColliderBit

- For **each parameter point** in a scan:
  - Run **Pythia simulations** of all relevant SUSY processes
  - Pass events through **fast detector simulation** (four-vector smearing + efficiencies)
  - Pass events through **our implementations of ATLAS and CMS searches**
    - → signal predictions for all SRs
  - Compute **a combined likelihood** for the parameter point
    - We combine as many analyses and SRs as we reasonably can, given available info
  - Plus an analogous pipeline for measurements, using Rivet + Contur

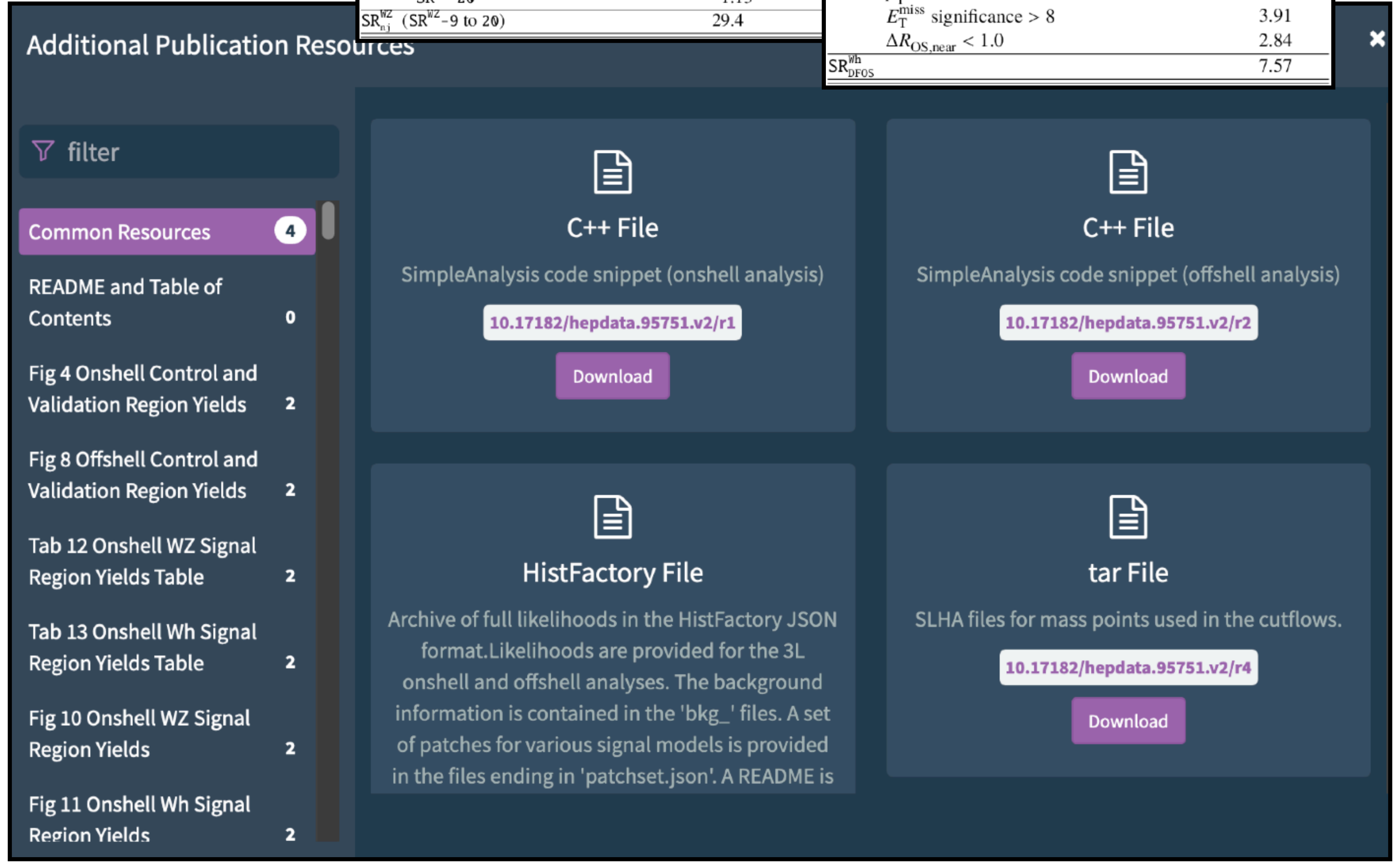


The information we need

- **Implementing the analysis:**
  - Clear analysis description in the paper
  - SimpleAnalysis code snippets
  - Reusable NNs?
- **Validating our implementation:**
  - Cutflows for benchmark points
    - Clear definition of signal model (SLHA file)
    - Any preselections not mentioned in cutflow?
    - How many MC events generated?
- **Fully utilising the data (and improving stability):**
  - Full likelihoods, JSON (ATLAS)
  - Correlation matrices for simplified likelihoods (CMS)

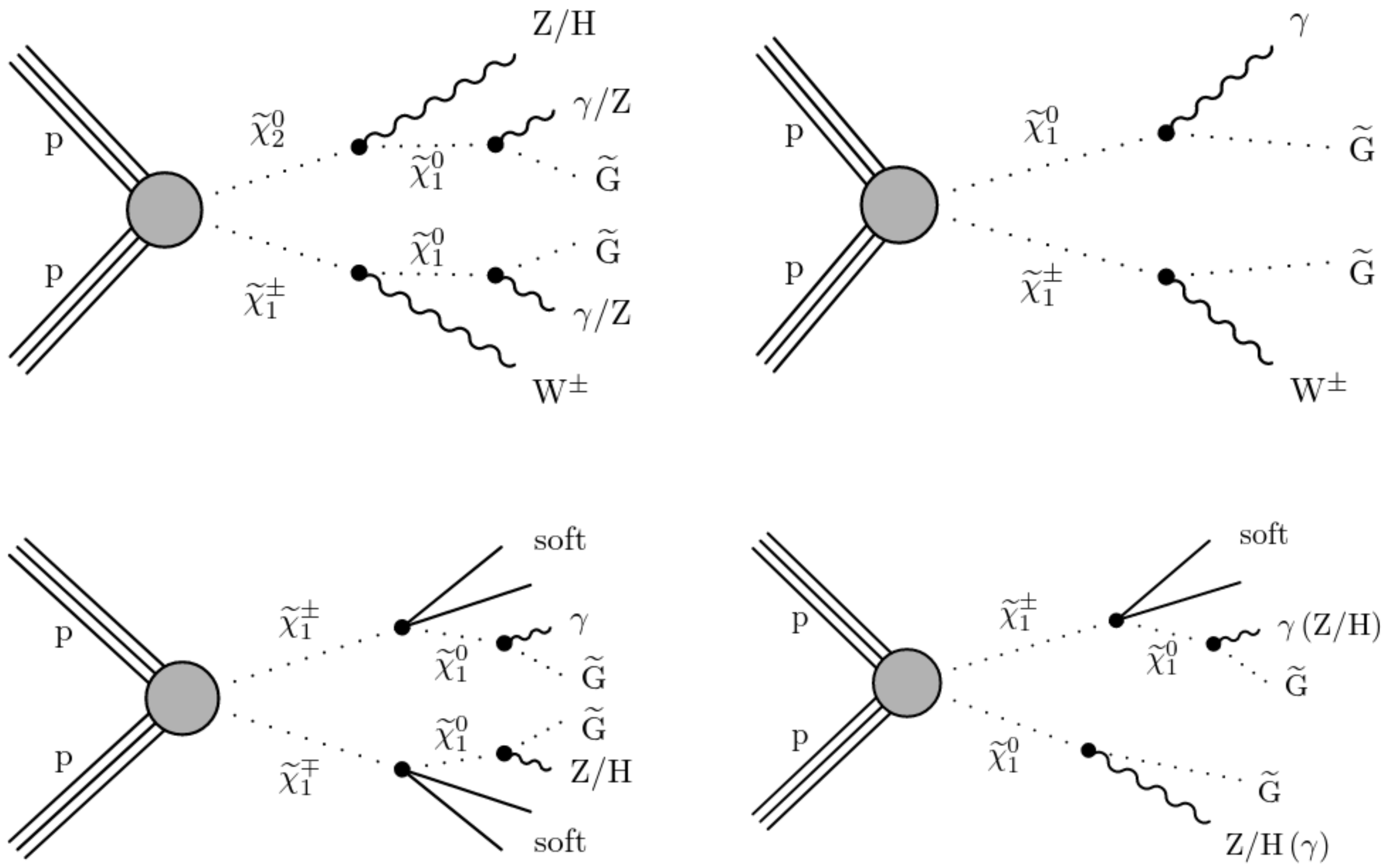
	$m(\tilde{\chi}^0_2, \tilde{\chi}^0_1)$ [GeV]	
Selection	(300, 200)	(600, 100)
$\mathcal{L} \times \sigma$	53784	2799
$\mathcal{L} \times \sigma \times$ BF	1760	
$\mathcal{L} \times \sigma \times$ BF $\times$ filt. eff.	1322	
3 isolated lepton selection, lepton $p_T^{1,2,3} > 25, 20, 10$ GeV, $E_T^{miss} > 50$ GeV	227	
$n_{SFOS} \geq 1$	226	
Trigger selection	222	
$n_{b-jets} = 0$	209	
Resonance veto $m_{\ell\ell} > 12$ GeV	209	
$\lvert m_{3\ell} - m_Z \rvert > 15$ GeV	203	
$m_{\ell\ell} \in [75, 105]$ GeV	196	
with MC to data weight	186	
$n_{jets} = 0$	76.4	
with MC to data weight	73.3	
$m_T \in [100, 160]$ GeV	26.7	
SR^{WZ}-1	20.9	
SR^{WZ}-2	4.86	
SR^{WZ}-3	0.78	
SR^{WZ}-4	0.14	
$m_T > 160$ GeV	5.80	
SR^{WZ}-5	4.64	
SR^{WZ}-6	0.16	
SR^{WZ}-7	0	
SR^{WZ}-8	0	
SR^{WZ}_{0j} (SR^{WZ}-1 to 8)	31.4	
$n_{jets} > 0$, $H_T < 200$ GeV	97.5	
with MC to data weight	91.8	
$m_T \in [100, 160]$ GeV	29.6	
SR^{WZ}-9	8.75	
SR^{WZ}-10	3.46	
SR^{WZ}-11	0.54	
SR^{WZ}-12	0	
$m_T > 160$ GeV	9.50	
SR^{WZ}-13	7.19	
SR^{WZ}-14	1.53	
SR^{WZ}-15	0.09	
SR^{WZ}-16	0	
$n_{jets} > 0$, $H_T > 200$ GeV	22.2	
$H_T^{lep} < 350$ GeV	20.9	
with MC to data weight	19.3	
$m_T > 100$ GeV	10.8	
SR^{WZ}-17	2.53	
SR^{WZ}-18	3.12	
SR^{WZ}-19	1.09	
SR^{WZ}-20	1.13	
SR^{WZ}_{nj} (SR^{WZ}-9 to 20)	29.4	

	$m(\tilde{\chi}^0_2, \tilde{\chi}^0_1)$ [GeV]
Selection	(190, 60)
$\mathcal{L} \times \sigma$	303527
$\mathcal{L} \times \sigma \times$ BF	10927
$\mathcal{L} \times \sigma \times$ BF $\times$ filt. eff.	1174
3 isolated lepton selection, lepton $p_T^{1,2,3} > 25, 20, 10$ GeV, $E_T^{miss} > 50$ GeV	192
Trigger selection	186
$n_{b-jets} = 0$	171
$n_{SFOS} \geq 1$	137
Resonance veto $m_{\ell\ell} > 12$ GeV	133
$\lvert m_{3\ell} - m_Z \rvert > 15$ GeV	110
with MC to data weight	104
$m_{\ell\ell} < 75$ GeV	56.2
$n_{jets} = 0$ ($SR^{Wh}_{low-m_{\ell\ell}-0j}$)	22.3
SR^{Wh}_{SFOS}-1	8.26
SR^{Wh}_{SFOS}-2	1.57
SR^{Wh}_{SFOS}-3	0.50
SR^{Wh}_{SFOS}-4	5.97
SR^{Wh}_{SFOS}-5	0.64
SR^{Wh}_{SFOS}-6	2.67
SR^{Wh}_{SFOS}-7	2.75
$n_{jets} > 0$, $H_T < 200$ GeV ($SR^{Wh}_{low-m_{\ell\ell}-nj}$)	26.5
SR^{Wh}_{SFOS}-8	2.95
SR^{Wh}_{SFOS}-9	5.28
SR^{Wh}_{SFOS}-10	1.59
SR^{Wh}_{SFOS}-11	0.63
SR^{Wh}_{SFOS}-12	5.55
SR^{Wh}_{SFOS}-13	2.91
SR^{Wh}_{SFOS}-14	0.68
SR^{Wh}_{SFOS}-15	5.48
SR^{Wh}_{SFOS}-16	1.39
$n_{SFOS} = 0$	34
with MC to data weight	33.5
$n_{jets} = 0$	14.8
$p_T^{\ell_3} > 15$ GeV	12.2
E_T^{miss} significance > 8	5.36
$\Delta R_{OS,near} < 1.2$	4.73
$n_{jets} \in [1, 2]$	15.6
$p_T^{\ell_3} > 20$ GeV	9.4
E_T^{miss} significance > 8	3.91
$\Delta R_{OS,near} < 1.0$	2.84
SR^{Wh}_{DFOS}	7.57



[SUSY-2019-09]

EW SUSY w/ light gravitino at the LHC



Usual ATLAS/CMS simplified model:

- Production of lightest neutralinos/charginos
- 1-2 fixed branching ratios
- Near massless gravitino as LSP

Parameter space

M_1 M_2 μ $\tan\beta$

Neutralinos

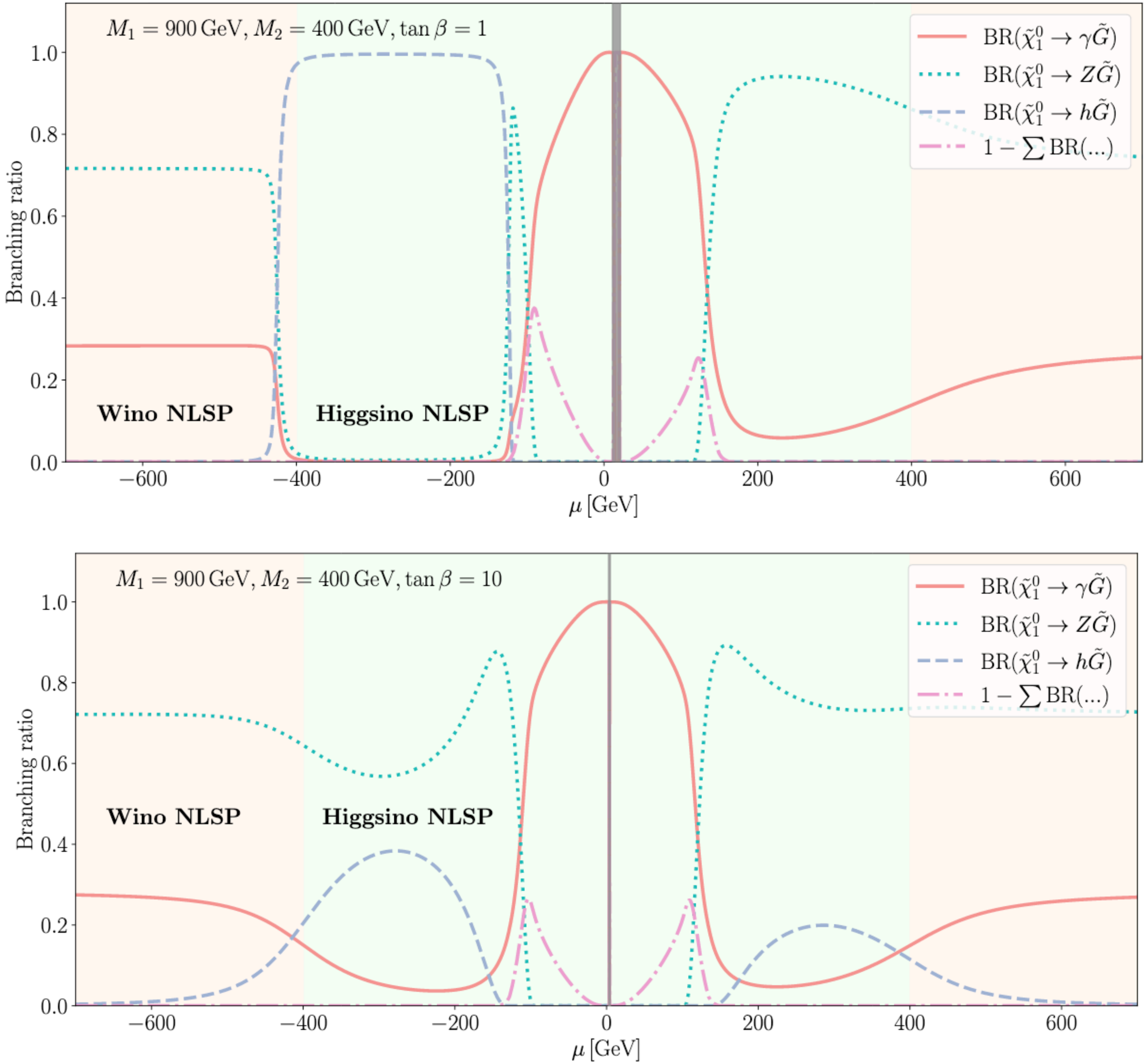
$$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$$

$$M_N = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g'vc_\beta & \frac{1}{2}g'vs_\beta \\ 0 & M_2 & \frac{1}{2}gvc_\beta & -\frac{1}{2}gvs_\beta \\ -\frac{1}{2}g'vc_\beta & \frac{1}{2}gvc_\beta & 0 & -\mu \\ \frac{1}{2}g'vs_\beta & -\frac{1}{2}gvs_\beta & -\mu & 0 \end{pmatrix}$$

Charginos

$$\psi^\pm = (\tilde{W}^+, \tilde{H}_u^+, \tilde{W}^-, \tilde{H}_d^-)$$

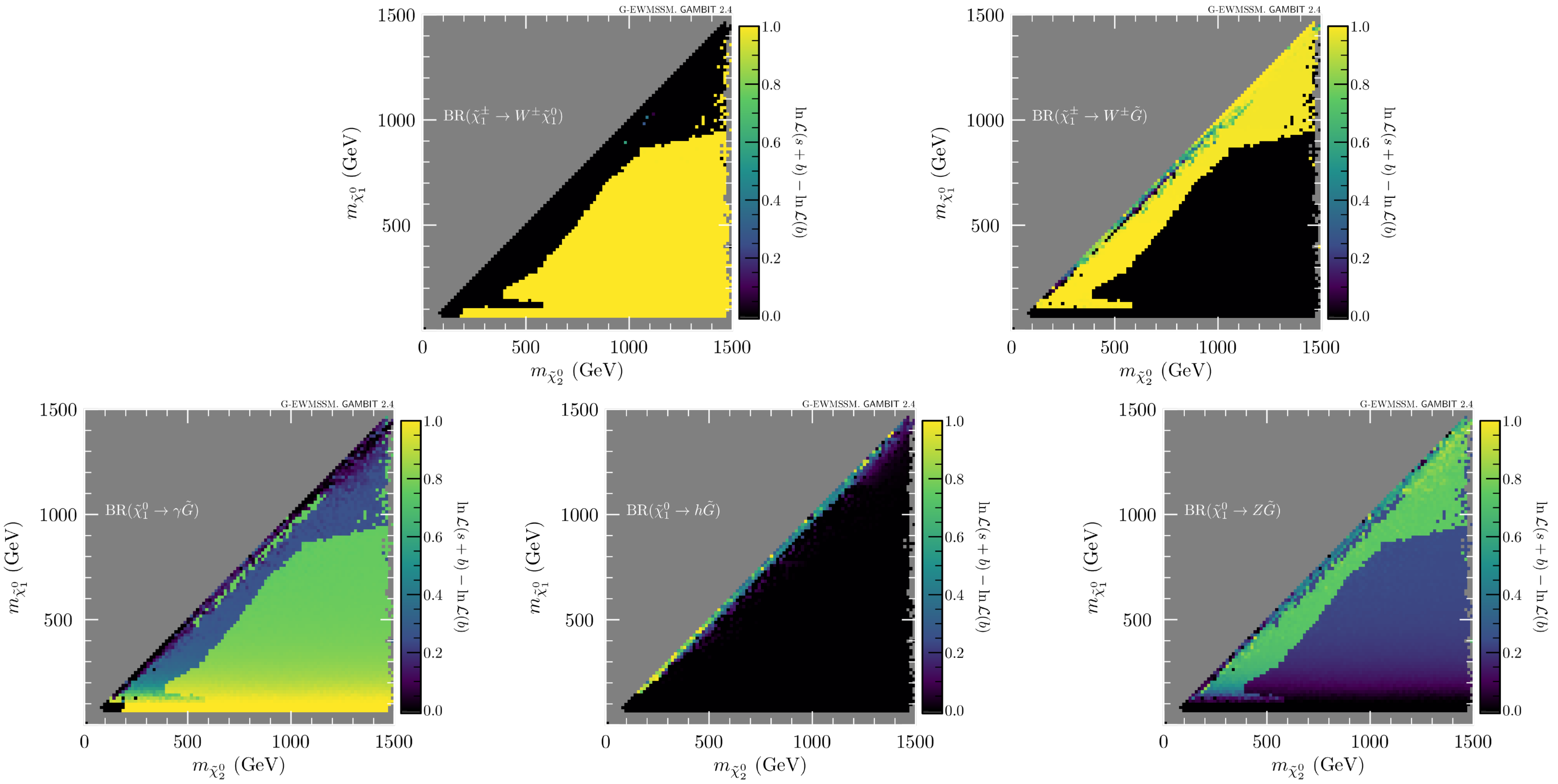
$$M_C = \begin{pmatrix} 0 & X^T \\ X & 0 \end{pmatrix}, \quad \text{where} \quad X = \begin{pmatrix} M_2 & \frac{gvs_\beta}{\sqrt{2}} \\ \frac{gvc_\beta}{\sqrt{2}} & \mu \end{pmatrix}.$$



$M_1 = 900\,\text{GeV}, M_2 = 400\,\text{GeV}, \tan\beta = 1$
$\text{BR}(\tilde{\chi}_1^0 \to \gamma\tilde{G})$
$\text{BR}(\tilde{\chi}_1^0 \to Z\tilde{G})$
$\text{BR}(\tilde{\chi}_1^0 \to h\tilde{G})$
$1 - \sum \text{BR}(...)$
Wino NLSP
Higgsino NLSP
Branching ratio
μ [GeV]
$M_1 = 900\,\text{GeV}, M_2 = 400\,\text{GeV}, \tan\beta = 10$
$\text{BR}(\tilde{\chi}_1^0 \to \gamma\tilde{G})$
$\text{BR}(\tilde{\chi}_1^0 \to Z\tilde{G})$
$\text{BR}(\tilde{\chi}_1^0 \to h\tilde{G})$
$1 - \sum \text{BR}(...)$
Wino NLSP
Higgsino NLSP
Branching ratio
μ [GeV]

G-EWMSSM: Preliminary

- 34 ATLAS/CMS searches
- LEP cross-section limits
- TODO: SM measurements



[2303.09082]

2023: G-EWMSSM

Search label	Luminosity	Source
ATLAS_2BoostedBosons	$139\,\text{fb}^{-1}$	ATLAS hadronic chargino/neutralino search [100]
ATLAS_0lep	$139\,\text{fb}^{-1}$	ATLAS 0-lepton search [101]
ATLAS_0lep_stop	$36\,\text{fb}^{-1}$	ATLAS 0-lepton stop search [102]
ATLAS_1lep_stop	$36\,\text{fb}^{-1}$	ATLAS 1-lepton stop search [103]
ATLAS_2lep_stop	$139\,\text{fb}^{-1}$	ATLAS 2-lepton stop search [104]
ATLAS_2OSlep_Z	$139\,\text{fb}^{-1}$	ATLAS stop search with Z/H final states [105]
ATLAS_2OSlep_chargino	$139\,\text{fb}^{-1}$	ATLAS 2-lepton chargino search [106]
ATLAS_2b	$36\,\text{fb}^{-1}$	ATLAS 2-b-jet stop/sbottom search [107]
ATLAS_3b	$24\,\text{fb}^{-1}$	ATLAS 3-b-jet Higgsino search [108]
ATLAS_3lep	$139\,\text{fb}^{-1}$	ATLAS 3-lepton chargino/neutralino search [109]
ATLAS_4lep	$139\,\text{fb}^{-1}$	ATLAS 4-lepton search [110]
ATLAS_MultiLep_strong	$139\,\text{fb}^{-1}$	ATLAS leptons + jets search [111]
ATLAS_PhotonGGM_1photon	$139\,\text{fb}^{-1}$	ATLAS 1-photon GGM search [112]
ATLAS_PhotonGGM_2photon	$36\,\text{fb}^{-1}$	ATLAS 2-photon GGM search [113]
ATLAS_Z_photon	$80\,\text{fb}^{-1}$	ATLAS Z + photon search [114]
CMS_0lep	$137\,\text{fb}^{-1}$	CMS 0-lepton search [115]
CMS_1lep_bb	$36\,\text{fb}^{-1}$	CMS 1-lepton + b-jets chargino/neutralino search [116]
CMS_1lep_stop	$36\,\text{fb}^{-1}$	CMS 1-lepton stop search [117]
CMS_2lep_stop	$36\,\text{fb}^{-1}$	CMS 2-lepton stop search [118]
CMS_2lep_soft	$36\,\text{fb}^{-1}$	CMS 2 soft lepton search [119]
CMS_2OSlep	$137\,\text{fb}^{-1}$	CMS 2-lepton search [120]
CMS_2OSlep_chargino_stop	$36\,\text{fb}^{-1}$	CMS 2-lepton chargino/stop search [121]
CMS_2SSlep_stop	$137\,\text{fb}^{-1}$	CMS 2 same-sign lepton stop search [122]
CMS_MultiLep	$137\,\text{fb}^{-1}$	CMS multilepton chargino/neutralino search [123]
CMS_photon	$36\,\text{fb}^{-1}$	CMS 1-photon GMSB search [124]
CMS_2photon	$36\,\text{fb}^{-1}$	CMS 2-photon GMSB search [125]
CMS_1photon_1lepton	$36\,\text{fb}^{-1}$	CMS 1-photon + 1-lepton GMSB search [126]

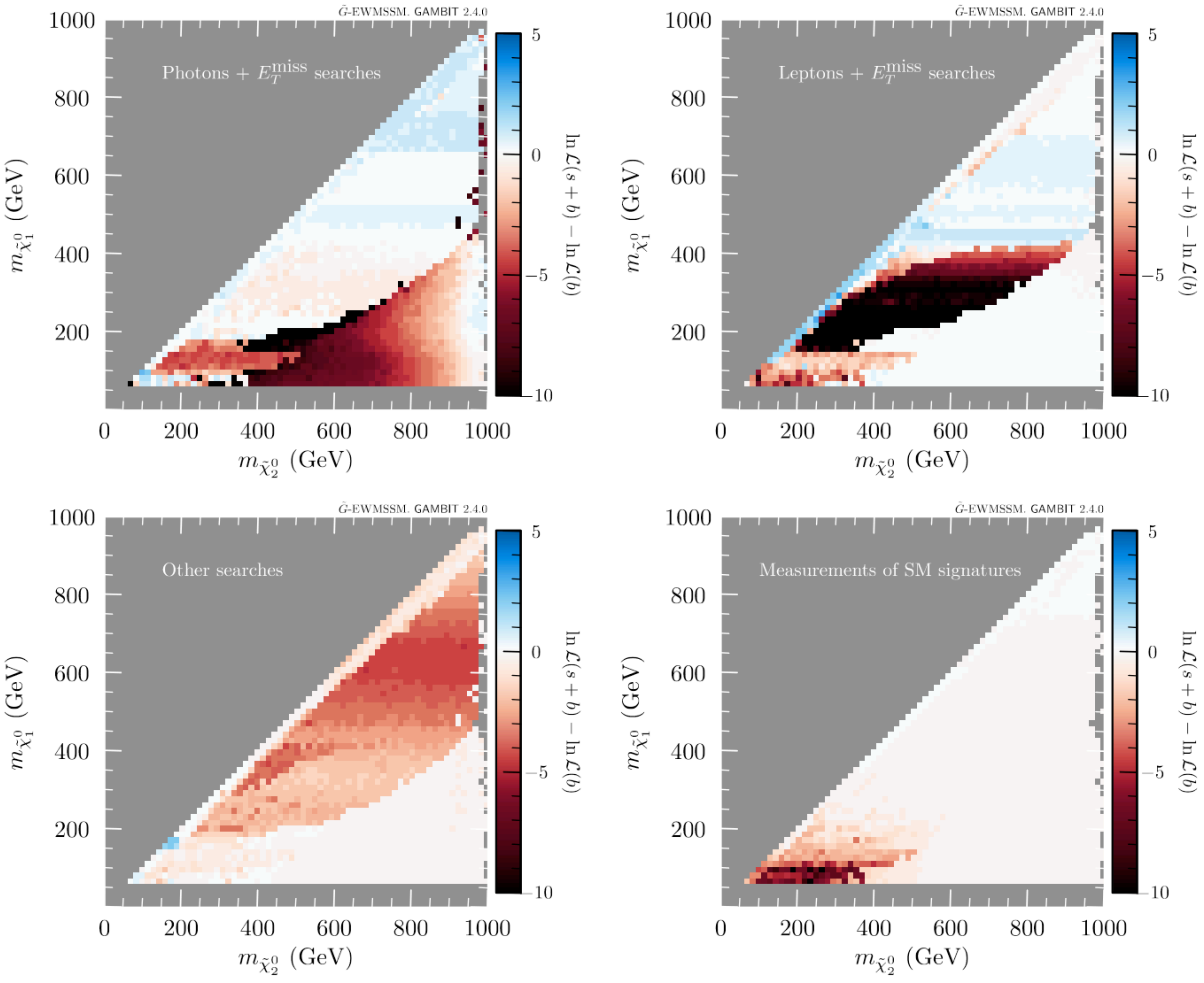
[2303.09082]

2023: G-EWMSSM

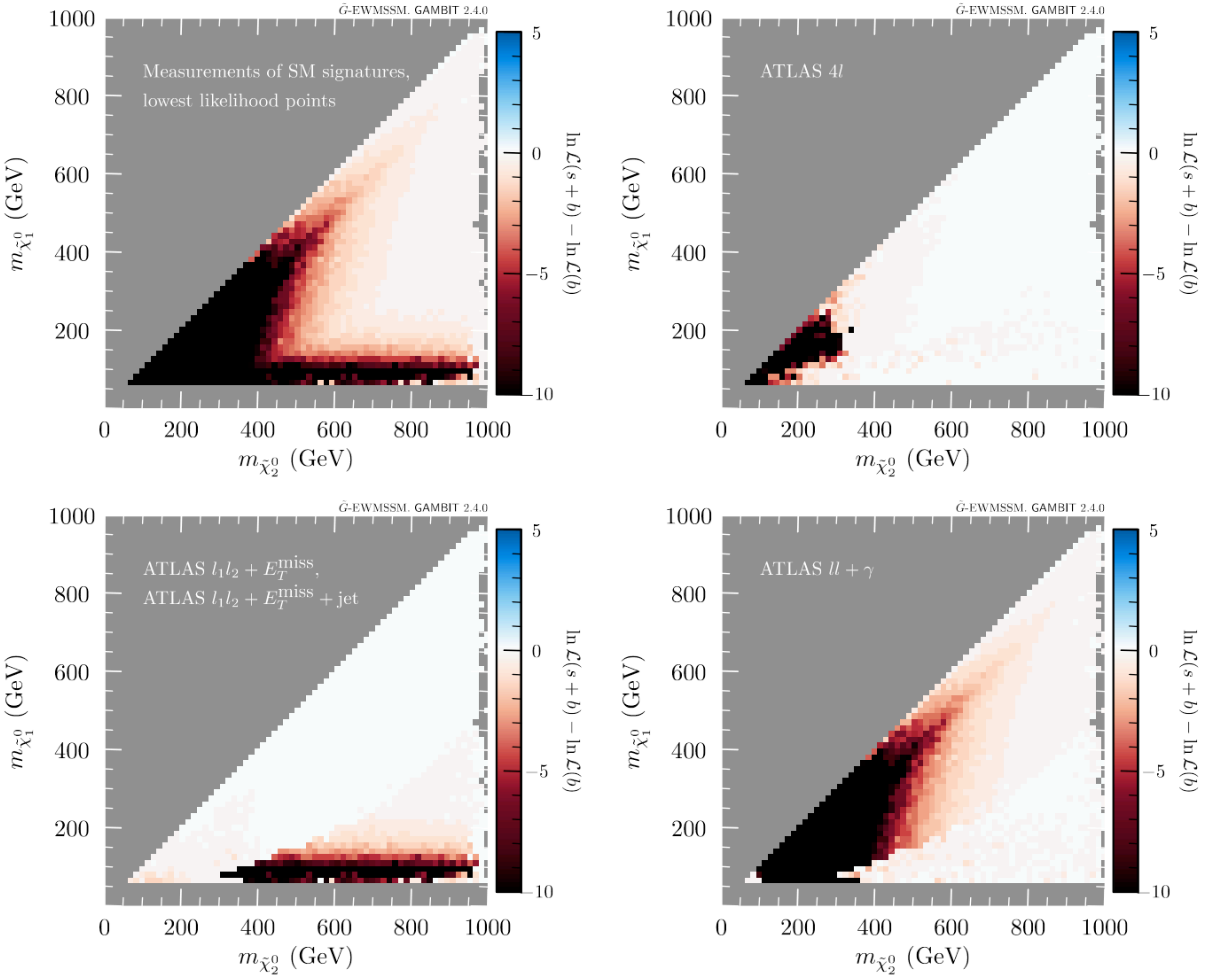
- Series of parameter scans w/ GAMBIT
- Scanner: **Diver** (differential evolution)
- Per point: **simulate 16M SUSY events** (Pythia, via ColliderBit)
- CPU cost: tens of millions of CPU hours…
- **Likelihoods**:
  - **15 ATLAS + 12 CMS searches** (in ColliderBit)
  - **22 «pools» of 45 ATLAS, CMS and LHCB measurements** (Contur+Rivet, via ColliderBit)
  - apply relevant LEP cross-section limits (in ColliderBit)

2023: G-EWMSSM

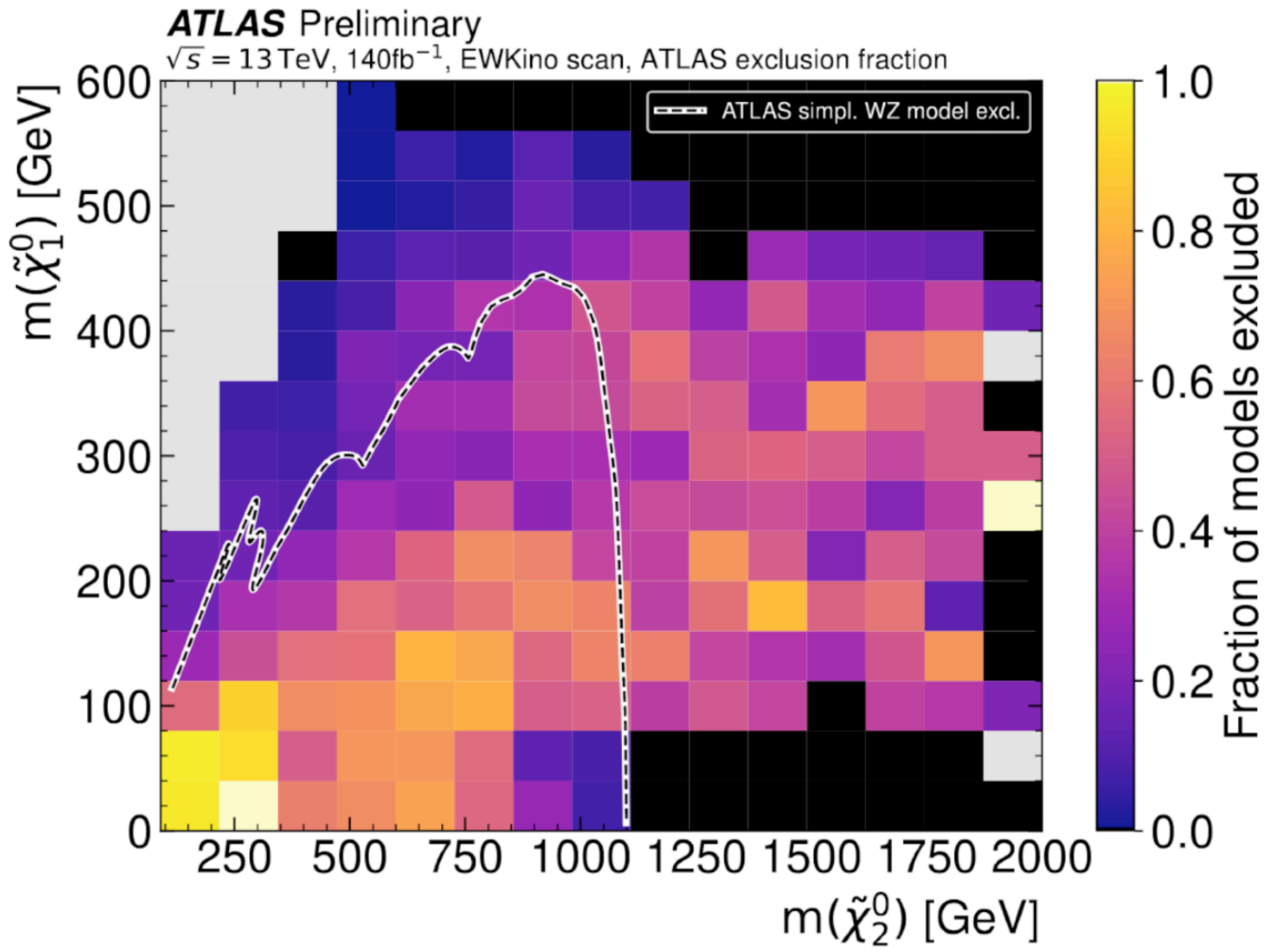
[2303.09082]



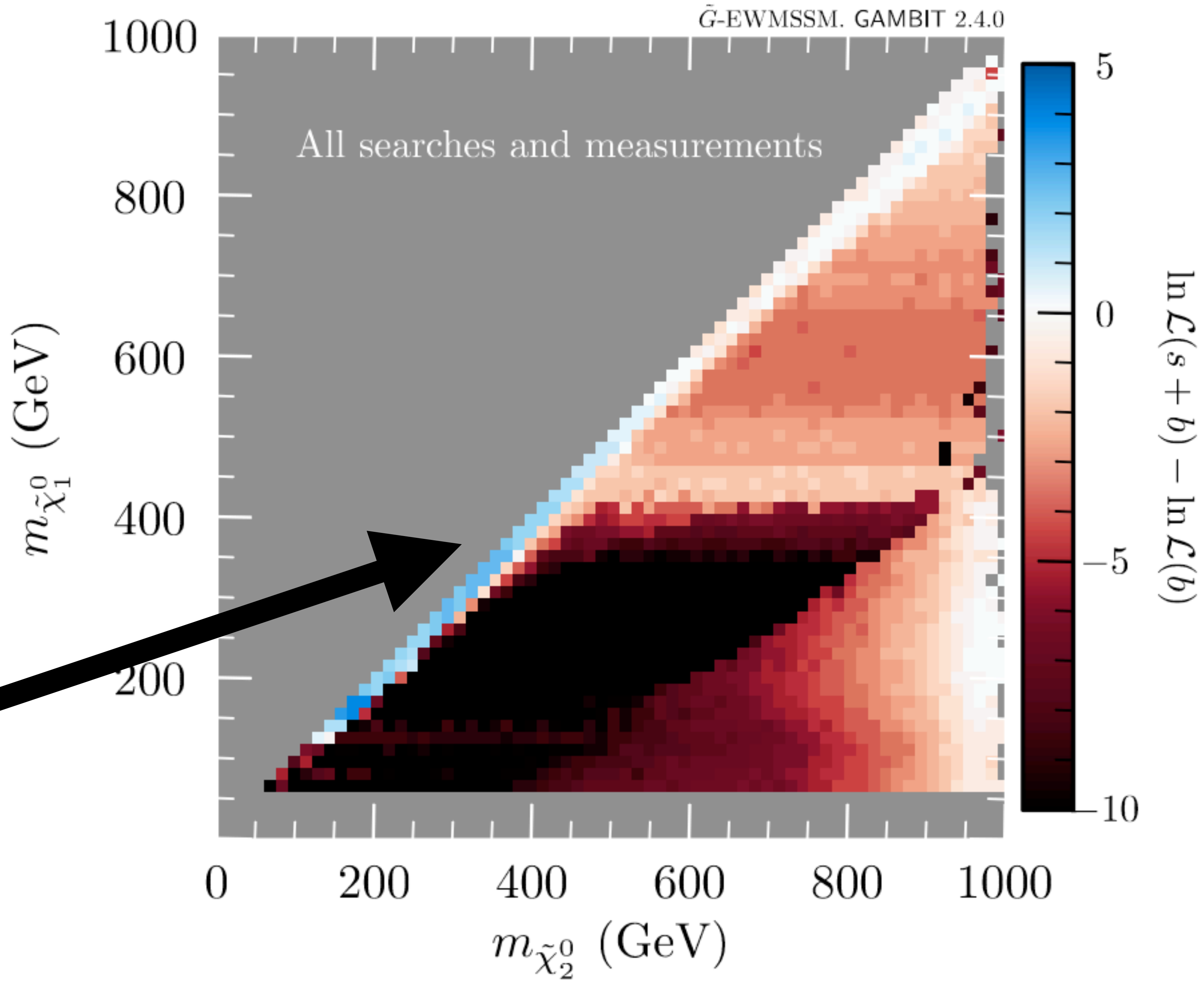
2023: G-EWMSSM



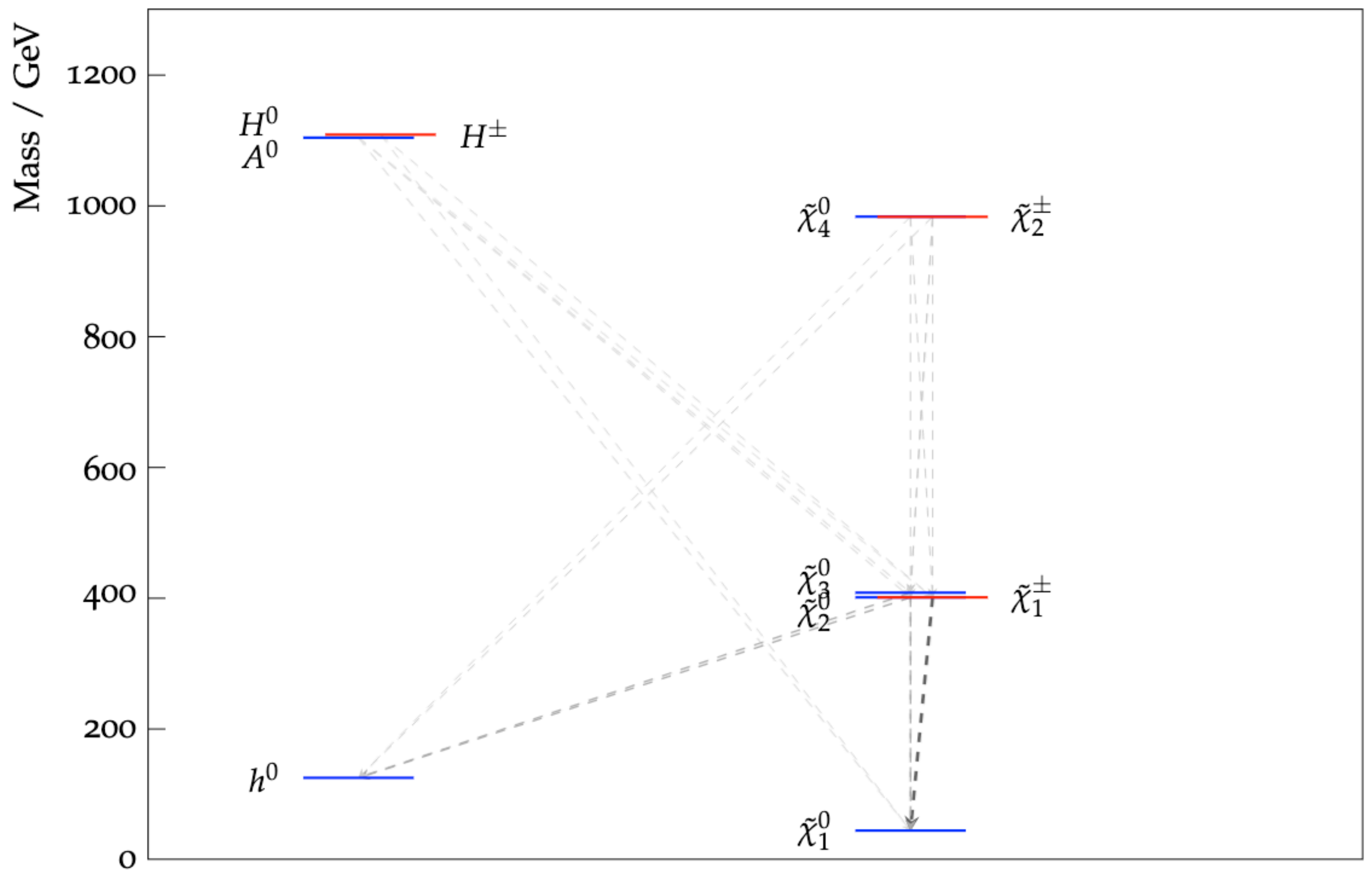
[2303.09082]

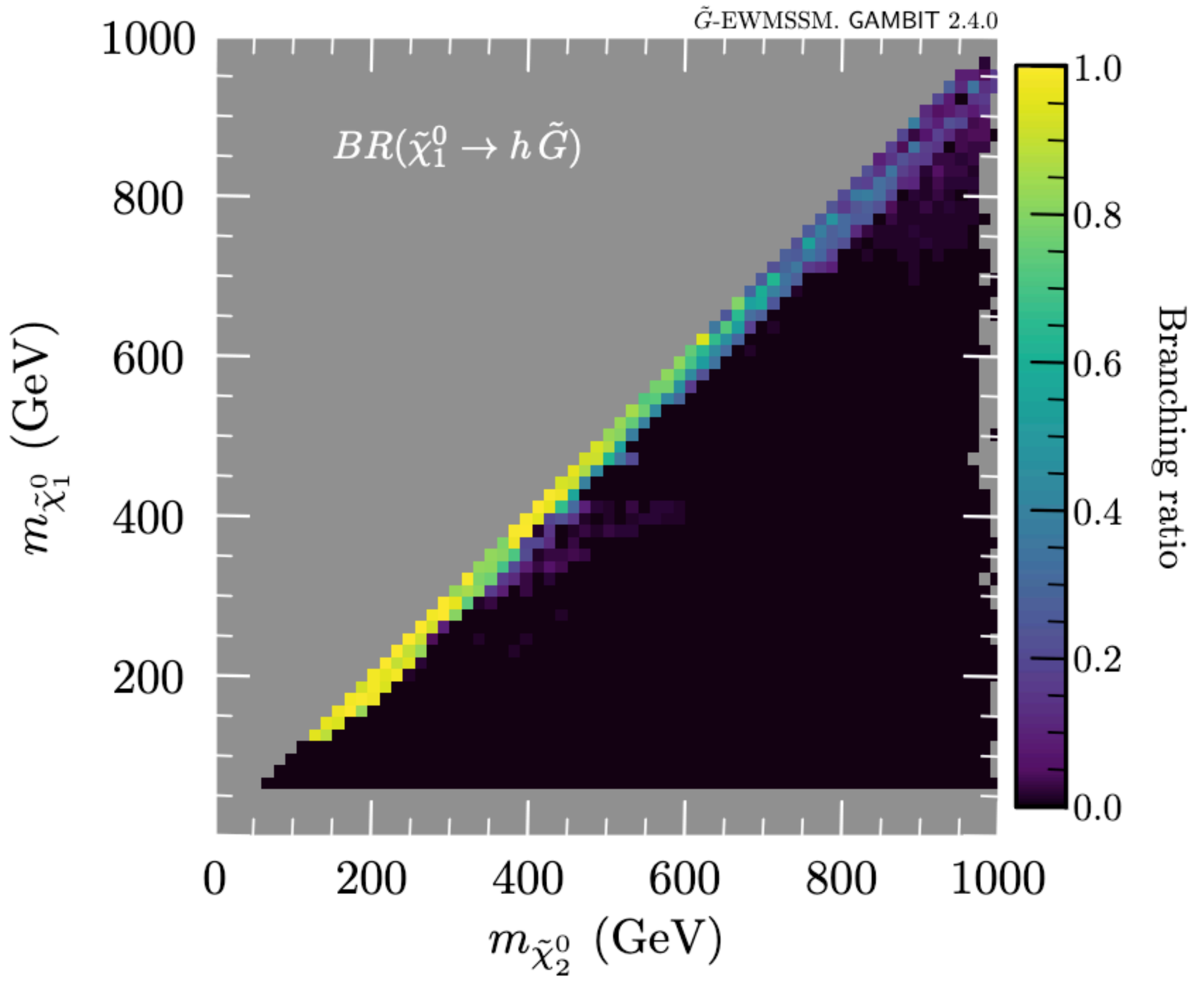


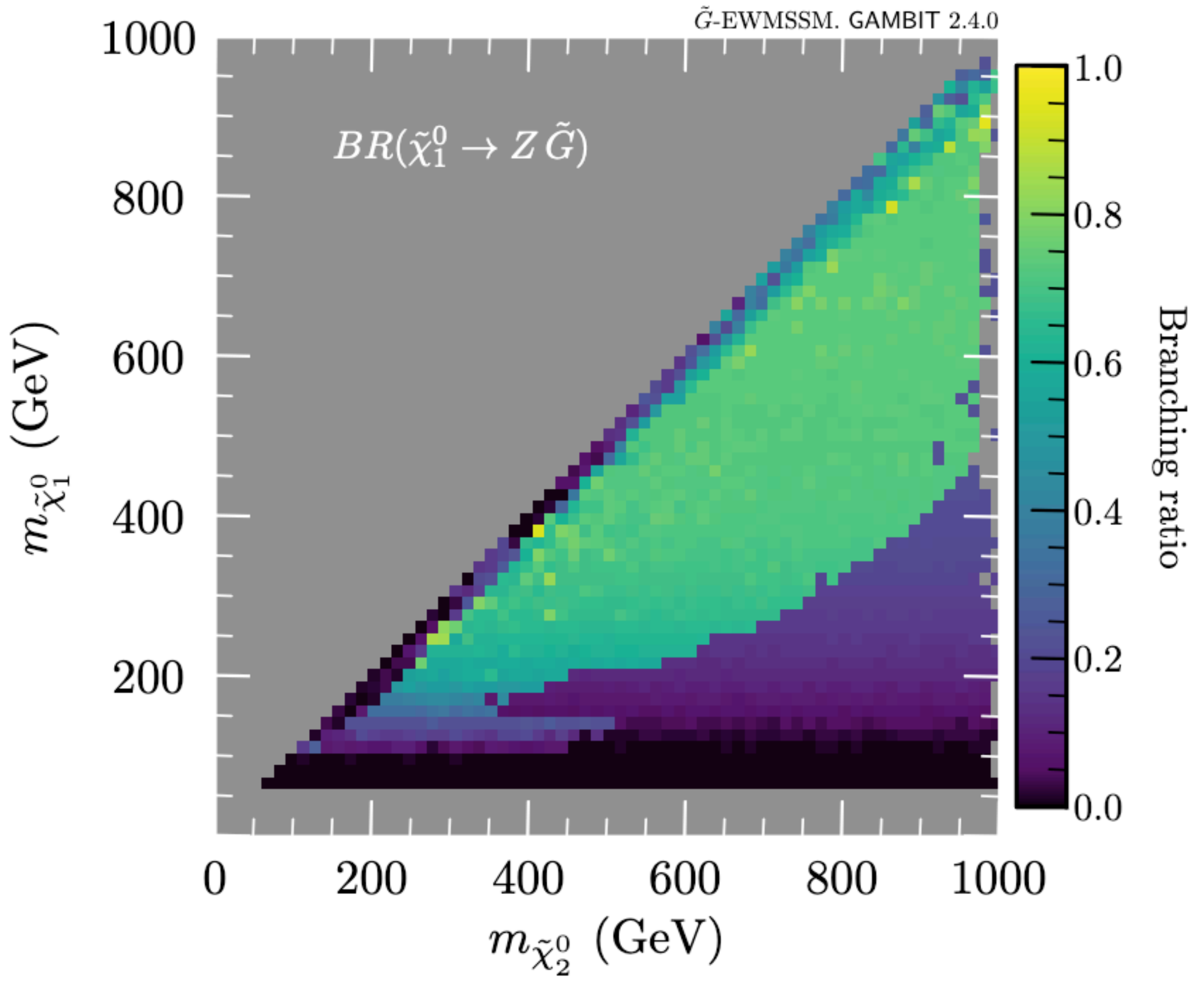
[ATLAS-CONF-2023-055]



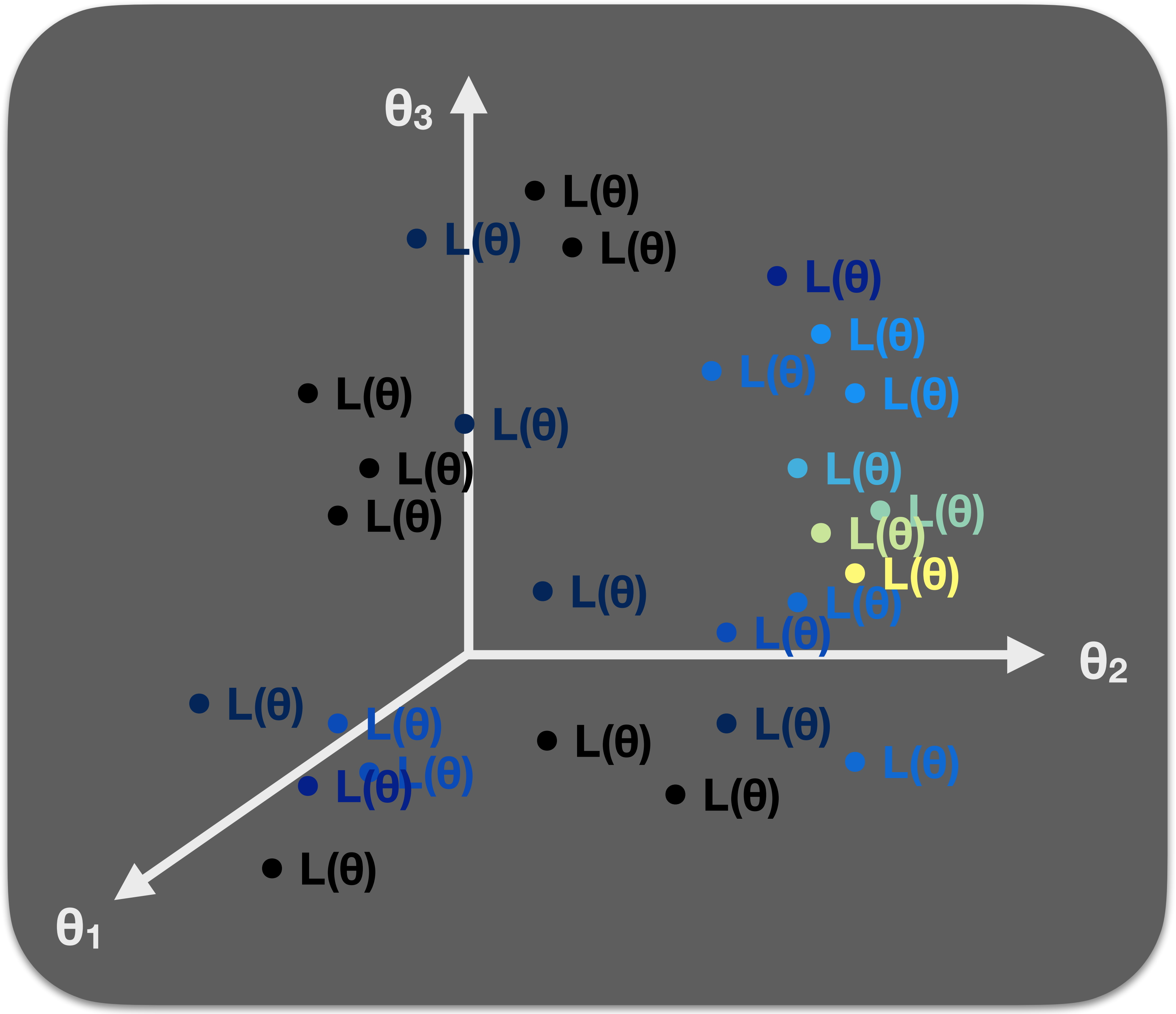
Quite similar scenarios







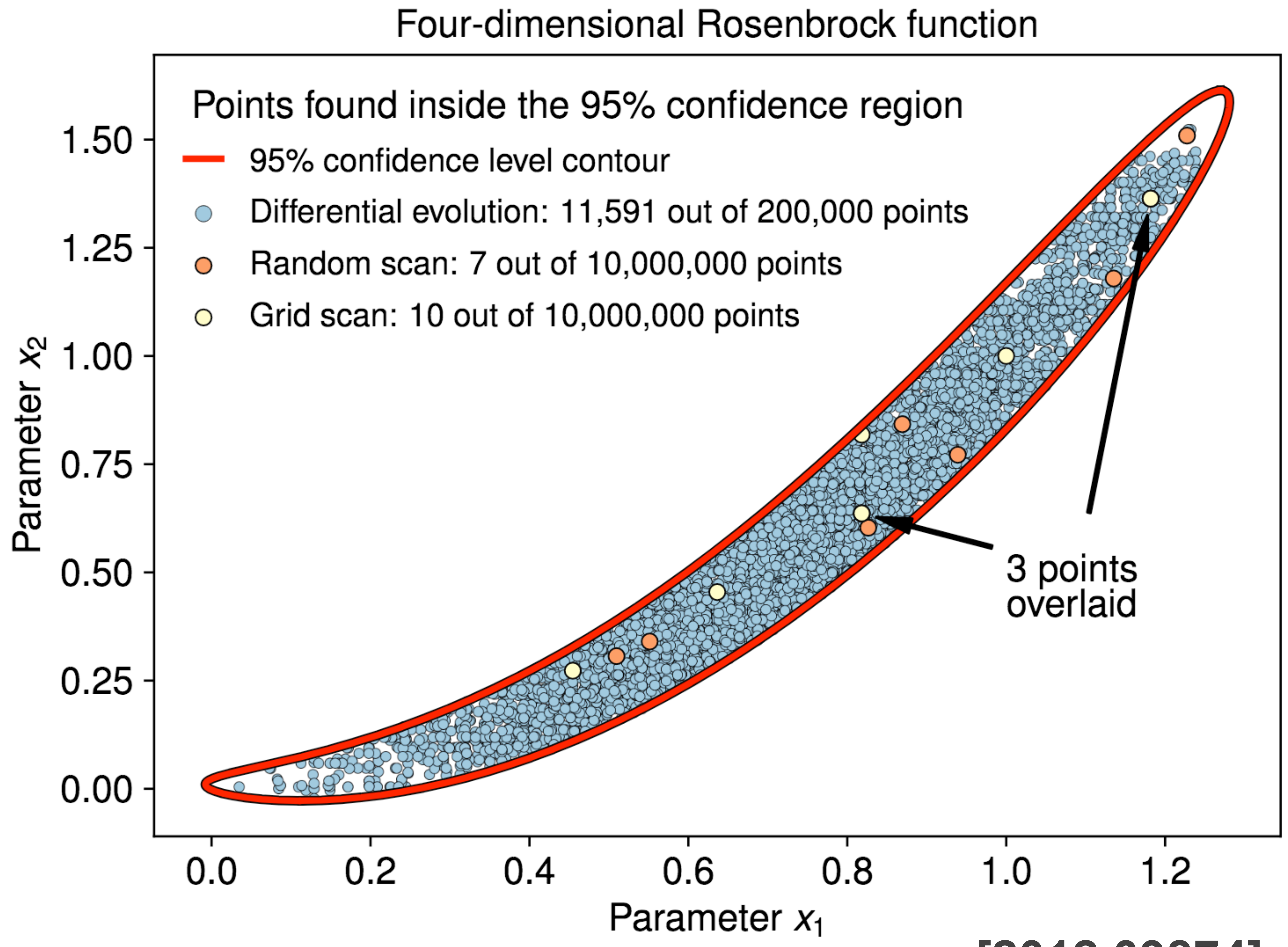
- **Explore the model parameter space** (θ_1, θ_2, θ_3, …)
- At every point θ: **compute all predictions(θ) → evaluate likelihood L(θ)**



- Region of highest L(θ) or lnL(θ): **model's best simultaneous fit to all data**
(but not necessarily a *good* fit, or the most probable θ…)

Why the need for speed?

- First, BSM parameter spaces are **high-dimensional**!
  - And theorists have limited CPU resources :)
- Second, in **global fits** we seek statistically rigorous conclusions about **regions of BSM parameter spaces**
  - Need properly **converged** explorations of the **likelihood function / posterior distribution**
  - Must use **adaptive sampling algorithms**, that focus on higher-likelihood regions
  - So the problem is **not trivially parallelisable** (we can't just sample first, simulate later)



[2012.09874]

Detailed model → many parameters → high-dimensional parameter space

High-dimensional spaces are exponentially tricky to explore…

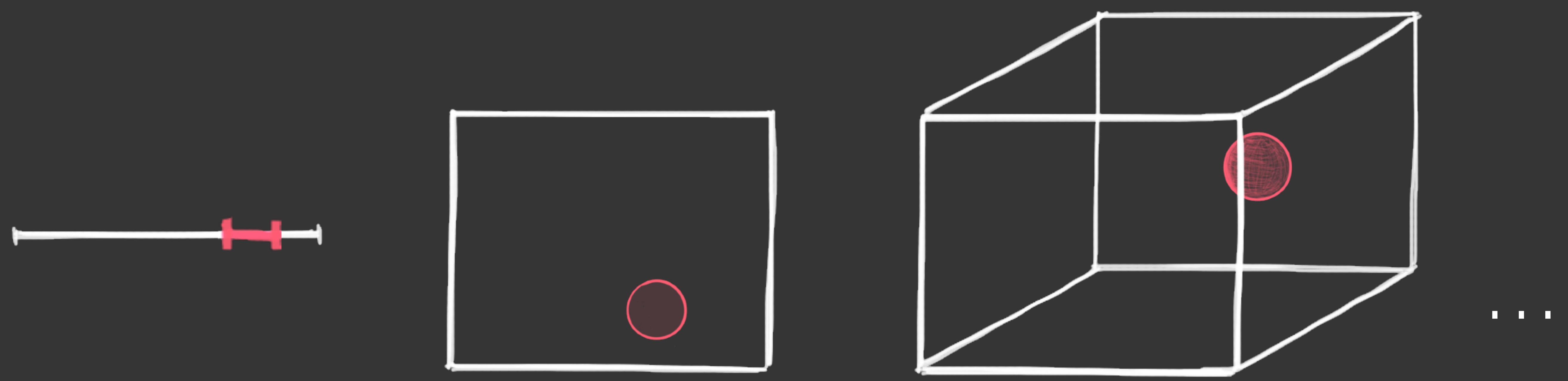
- For given sample density, the number of required samples increases exponentially
    - 0.01 resolution for a 1D unit interval: 100 points
    - 0.01 resolution for a 10D unit cube: $100^{10} = 10^{20}$ points
- The volume of any interesting region decreases exponentially fast with D
- A uniformly sampled point is «always» near at least *one* of the walls…
- …and it's also «always» the surface of a sphere with radius sqrt(D/3)
- Relative differences in distances between points vanish («loss of contrast»)

Detailed model → many parameters → high-dimensional parameter space

High-dime

- For give
  - 0.01 re
  - 0.01 re
- The volu
- A unifor
- …and it'

$$\lim_{D\to\infty} \frac{V_{\text{interesting}}}{V_{\text{total}}} = 0$$



- Relative differences in distances between points vanish («loss of contrast»)

Detailed model → many parameters → high-dimensional parameter space

High-dimensional spaces are exponentially tricky to explore…

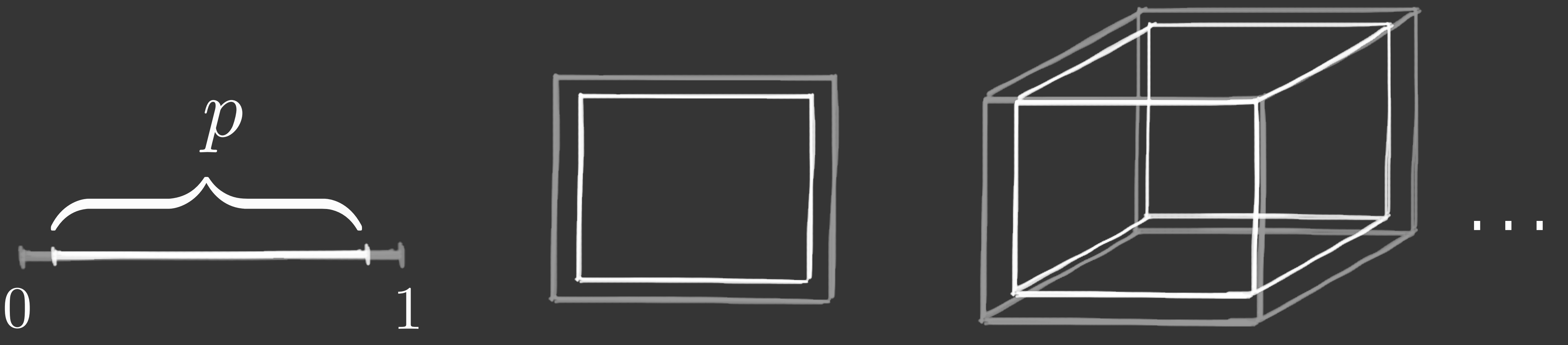
- For given sample density, the number of required samples increases exponentially
  - 0.01 resolution for a 1D unit interval: 100 points
  - 0.01 resolution for a 10D unit cube: $100^{10} = 10^{20}$ points
- The volume of any interesting region decreases exponentially fast with D
- A uniformly sampled point is «always» near at least *one* of the walls…
- …and it's also «always» the surface of a sphere with radius sqrt(D/3)
- Relative differences in distances between points vanish («loss of contrast»)

Detailed model → r

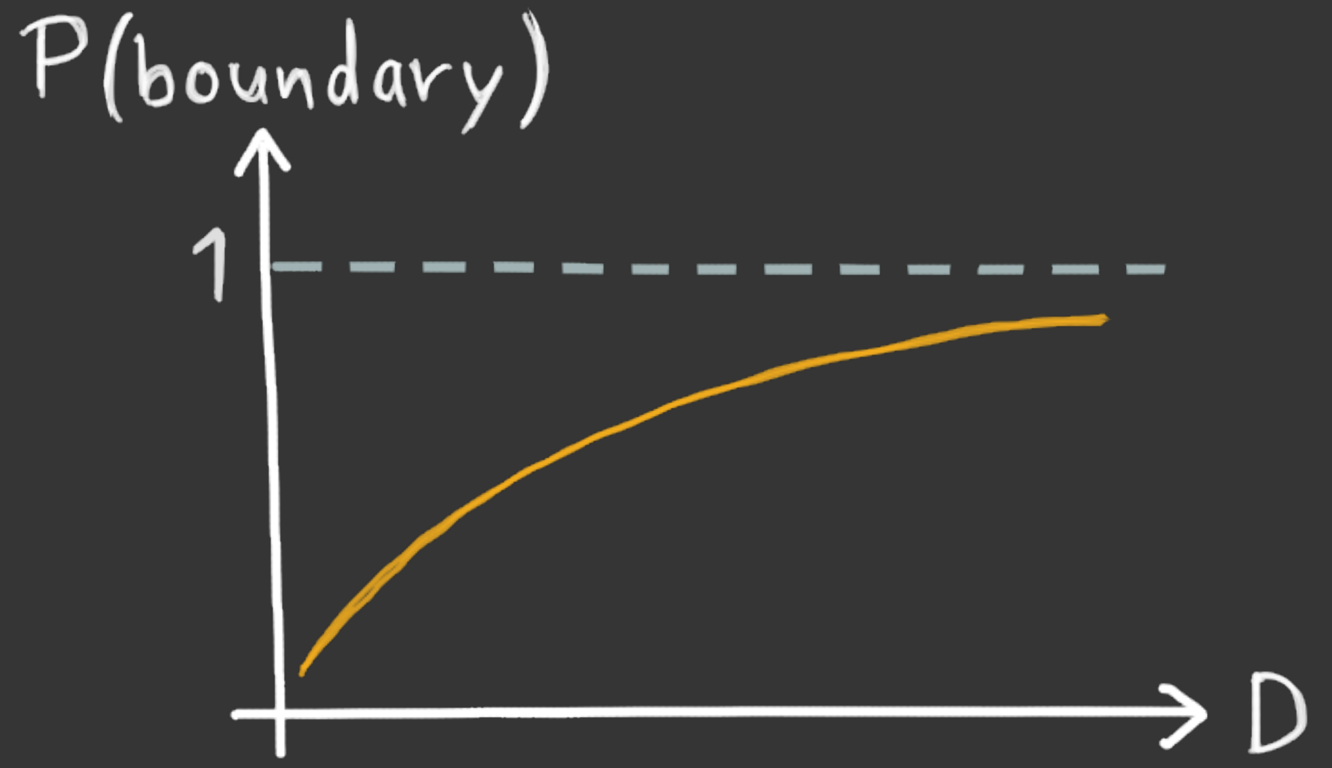
High-dimensional

- For given sample ... ly
  - 0.01 resolution fo
  - 0.01 resolution fo
- The volume of ar
- A uniformly samp
- …and it’s also «a
- Relative differenc

$$\vec{x} = (x_1, x_2, \ldots, x_D) \quad x_i \sim U(0,1)$$



$$P(\text{boundary}) = 1 - P(\text{not boundary}) = 1 - p^D$$



Detailed model → many parameters → high-dimensional parameter space

High-dimensional spaces are exponentially tricky to explore…

- For given sample density, the number of required samples increases exponentially
  - 0.01 resolution for a 1D unit interval: 100 points
  - 0.01 resolution for a 10D unit cube: $100^{10} = 10^{20}$ points
- The volume of any interesting region decreases exponentially fast with D
- A uniformly sampled point is «always» near at least *one* of the walls…
- …and it's also «always» the surface of a sphere with radius sqrt(D/3)
- Relative differences in distances between points vanish («loss of contrast»)

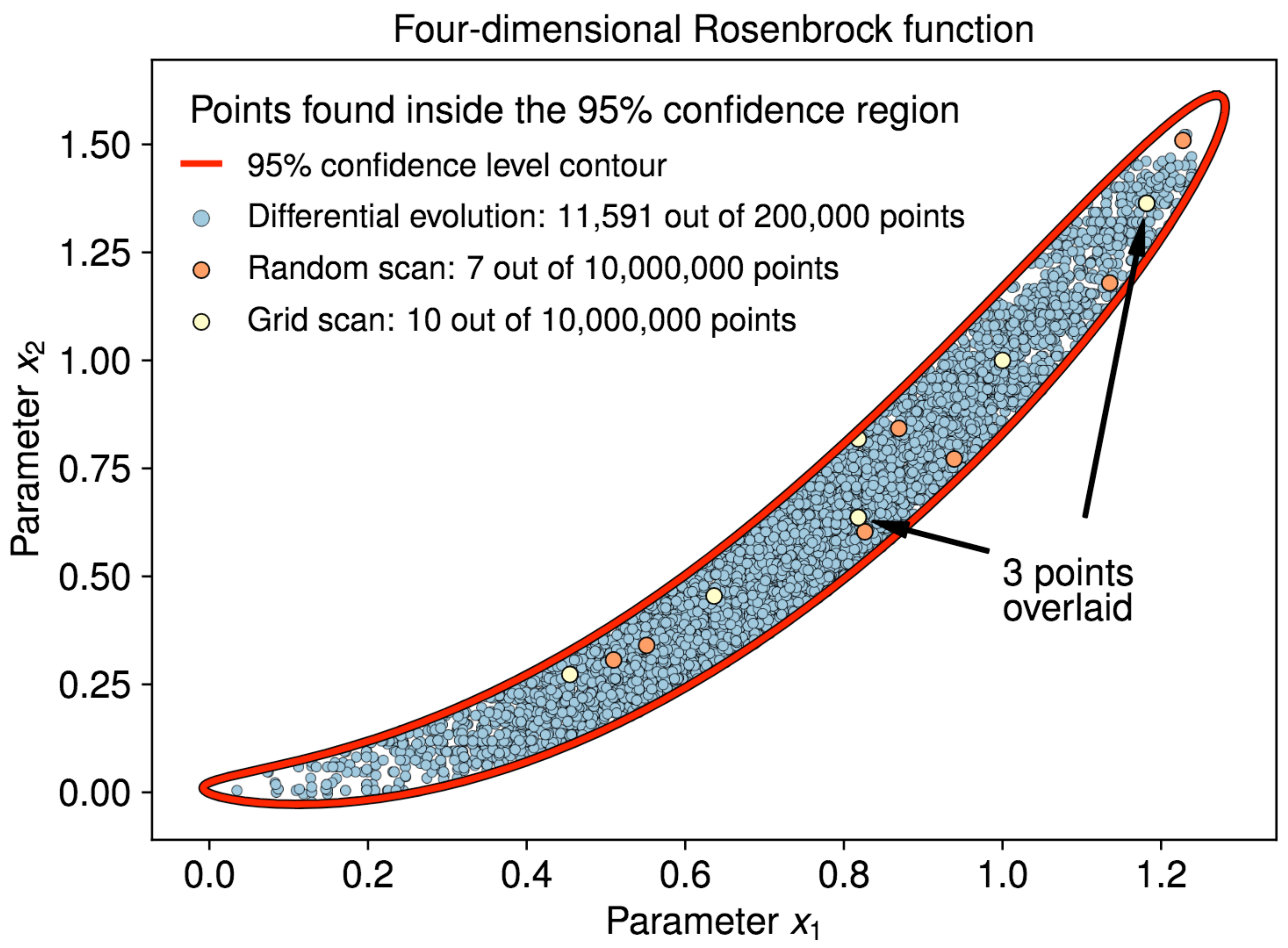
Consequence:
Detailed physics models → huge computational challenge

$$[\text{large number of observables}]$$
$$\times$$
$$[\text{long calculation time per observable per parameter point}]$$
$$\times$$
$$[\text{huge number of points required to explore parameter space}]$$
$$\approx$$
$$\infty$$

So we must:

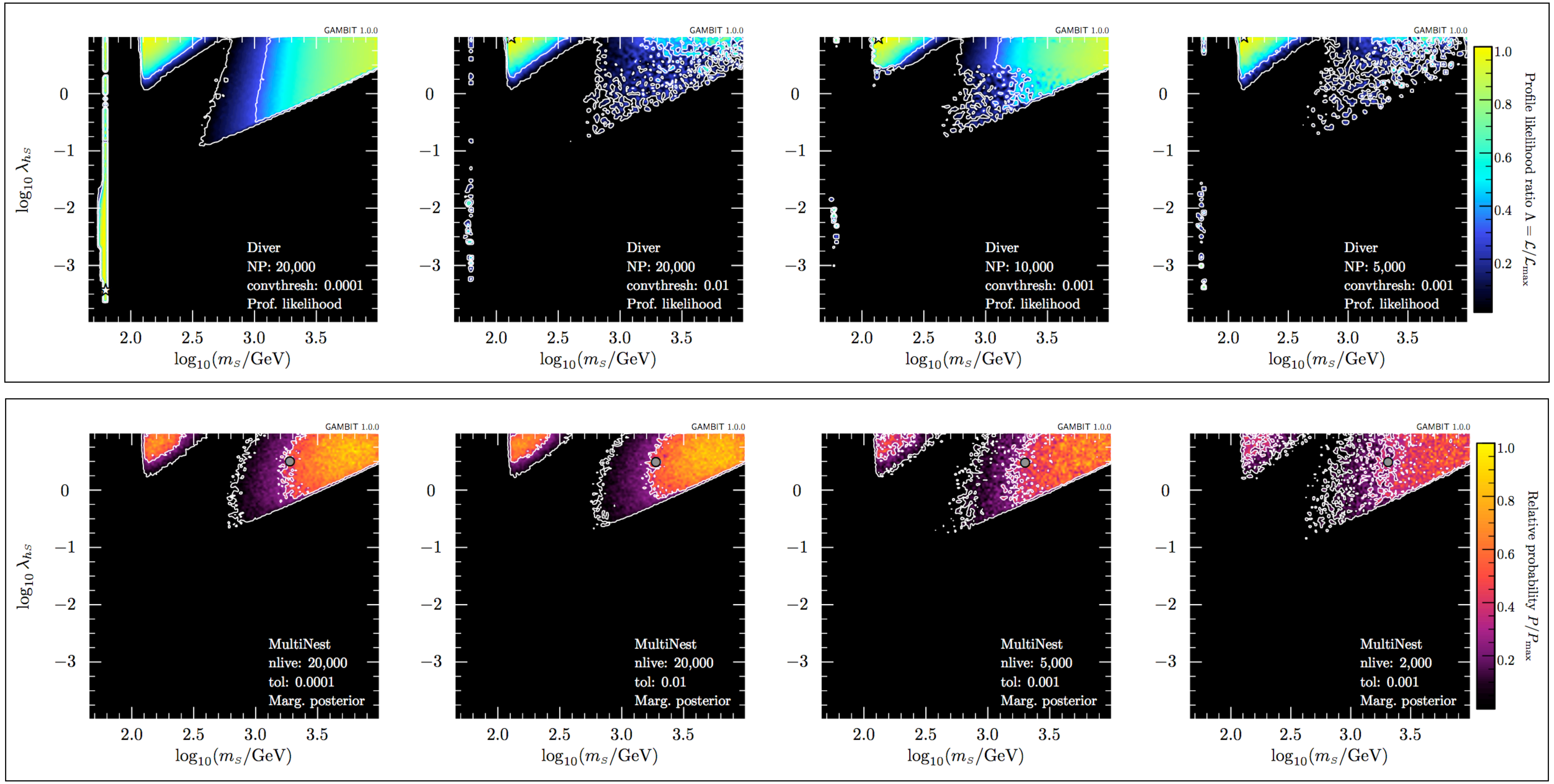
- speed up our physics computations where we can
- pick our parameter samples wisely
- maximise the usefulness of the CPU hours we spend

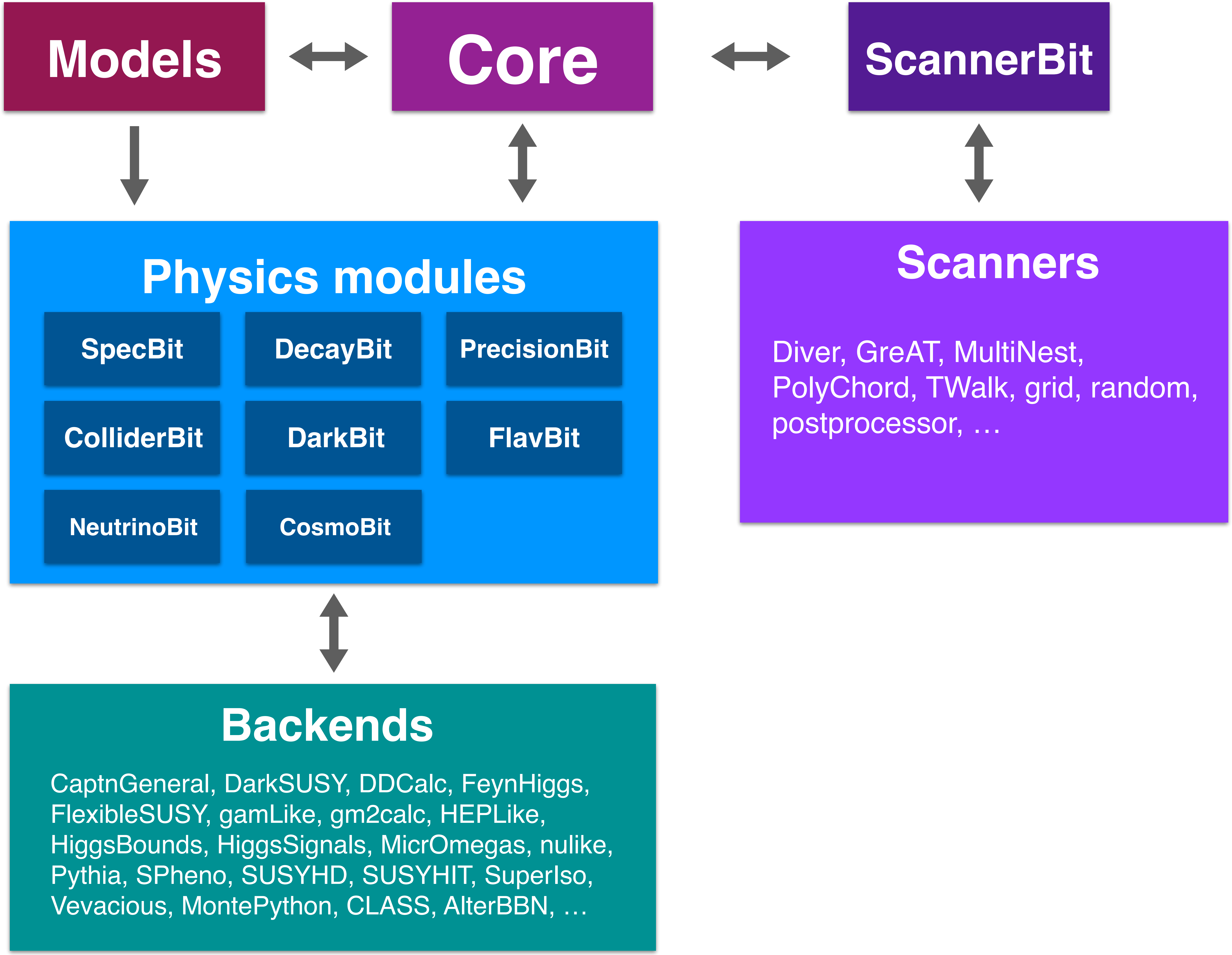
Parameter space exploration



[2012.09874]

Parameter space exploration




Models
Core
ScannerBit
Physics modules
SpecBit
DecayBit
PrecisionBit
ColliderBit
DarkBit
FlavBit
NeutrinoBit
CosmoBit
Scanners
Diver, GreAT, MultiNest, PolyChord, TWalk, grid, random, postprocessor, …
Backends
CaptnGeneral, DarkSUSY, DDCalc, FeynHiggs, FlexibleSUSY, gamLike, gm2calc, HEPLike, HiggsBounds, HiggsSignals, MicrOmegas, nulike, Pythia, SPheno, SUSYHD, SUSYHIT, SuperIso, Vevacious, MontePython, CLASS, AlterBBN, …

When optimising searches on simplified models, at what point do we start losing rather than gaining sensitivity to volumes of «similar» theory space?