SUSY Global Fits With CEPC Using GAMBIT

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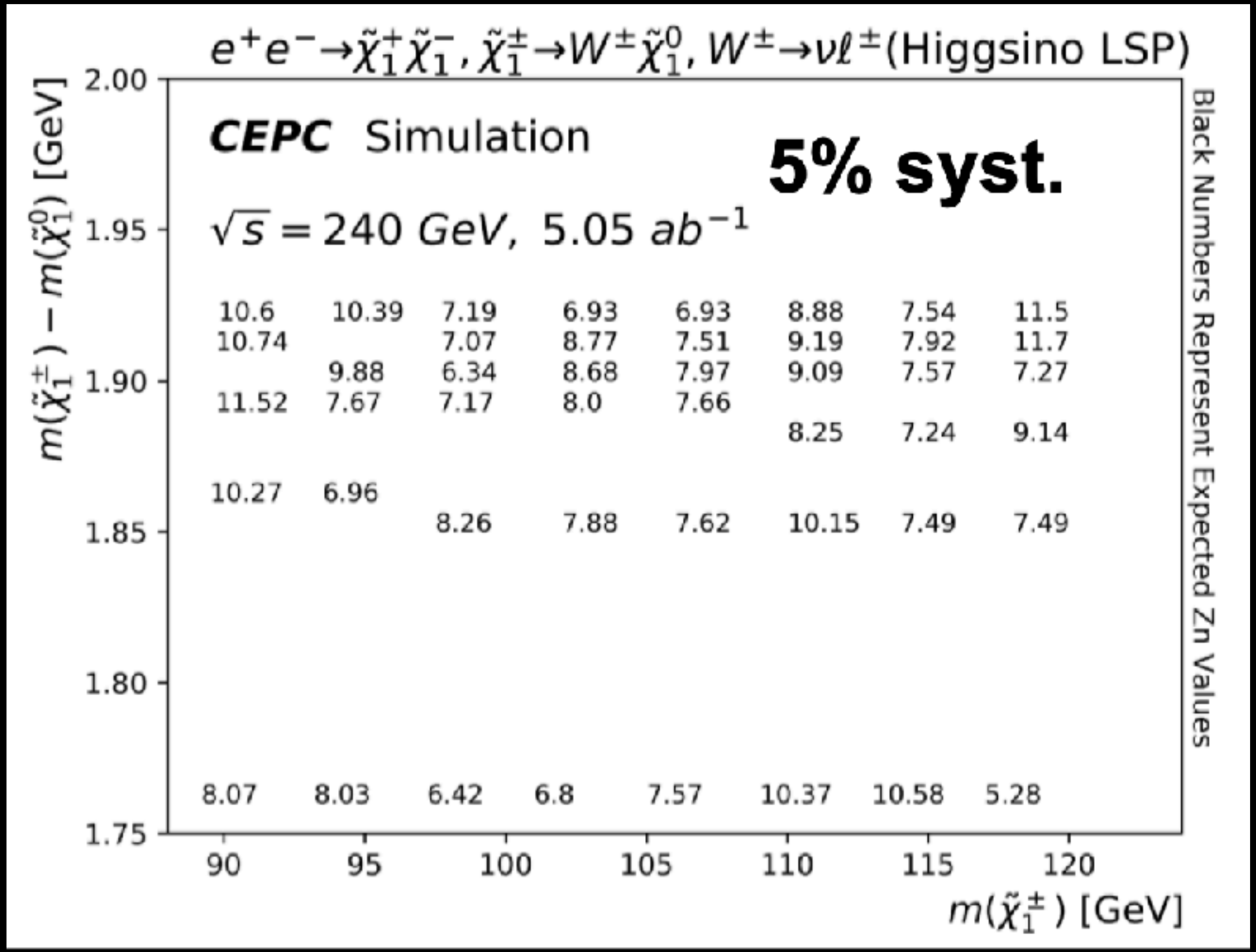
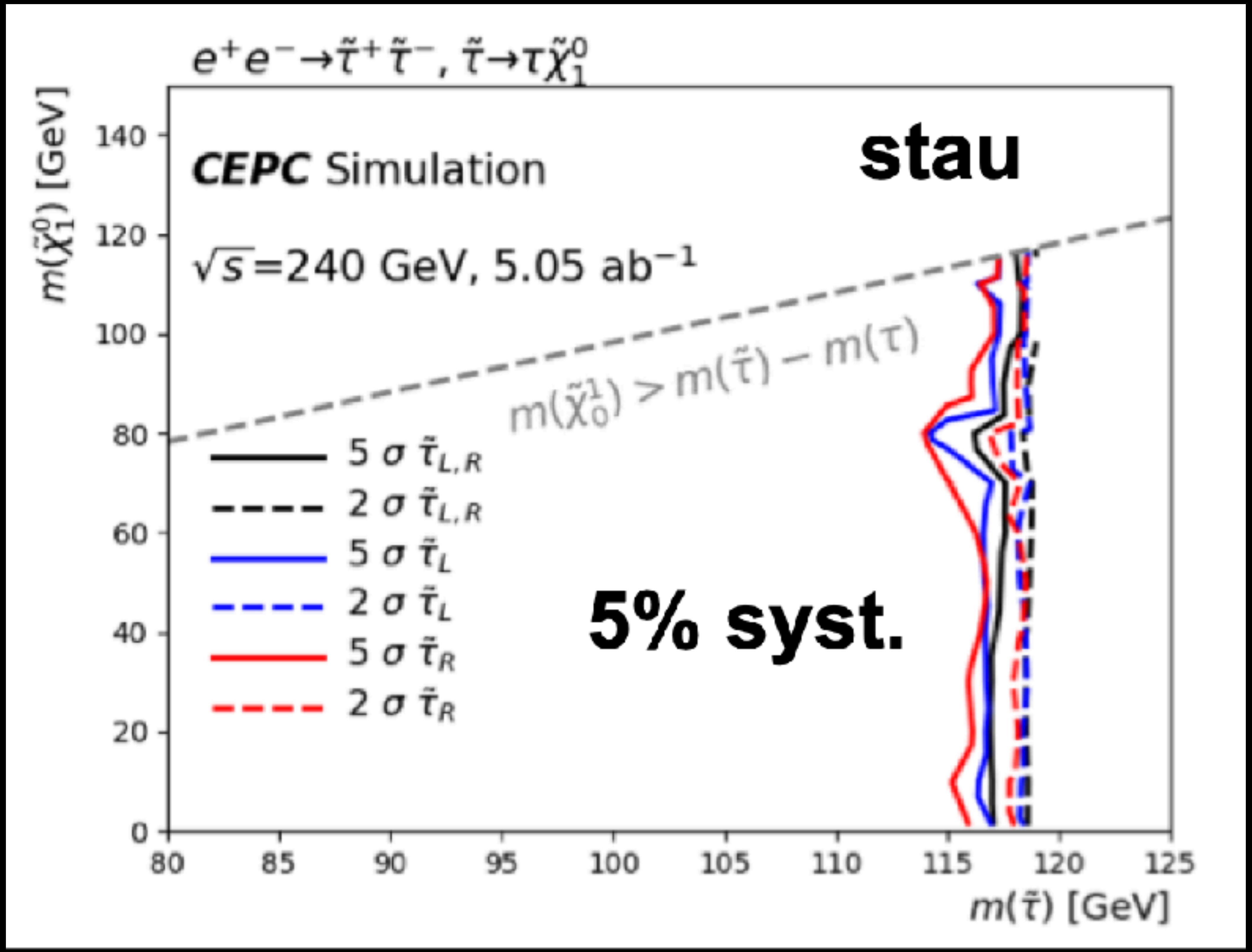
The 2021 international workshop on the high energy Circular Electron-Positron Collider

Exploring SUSY at CEPC

- Direct searches



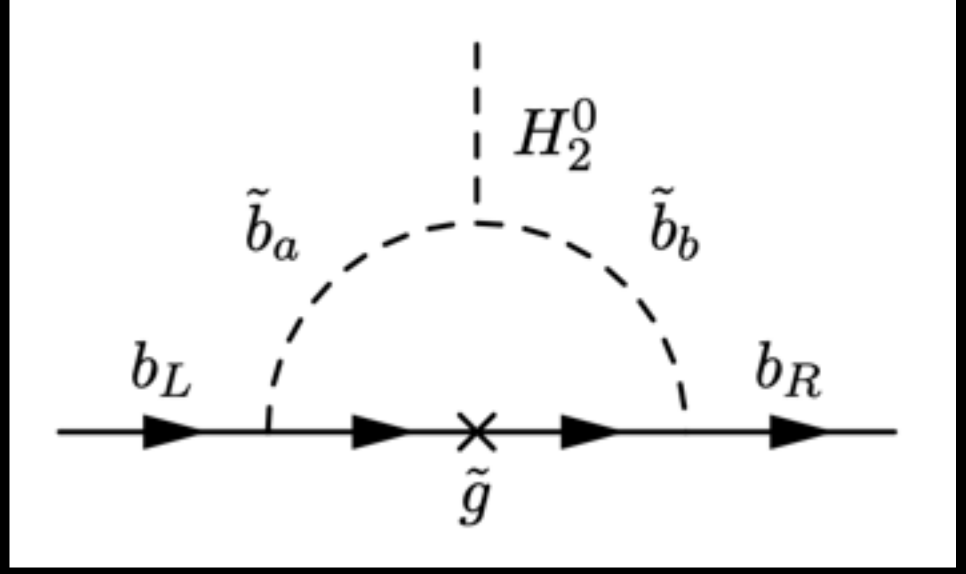
arXiv:2105.0613, J.R. Yuan, H.J. Cheng and X. Zhuang



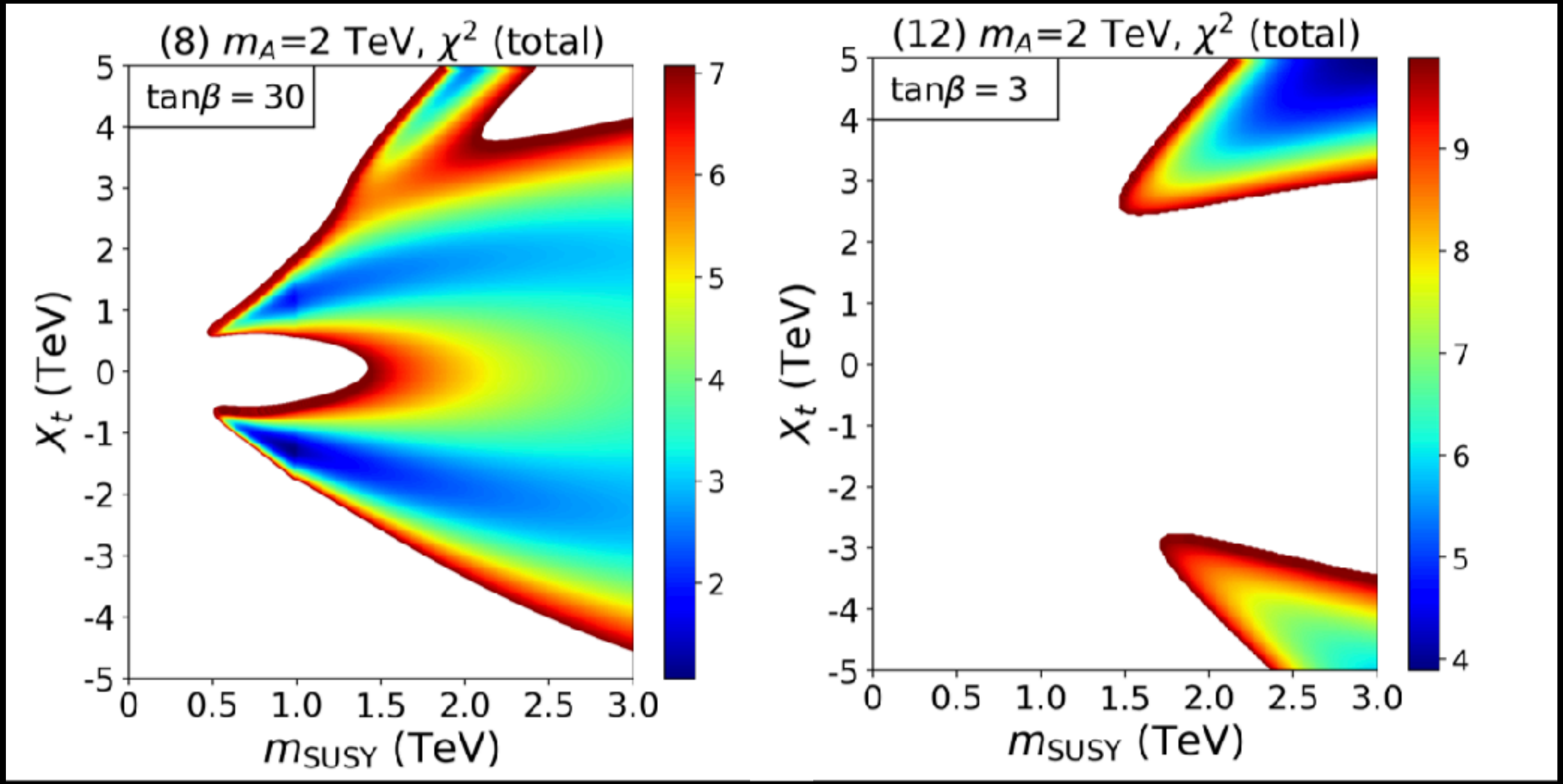
From Xuai Zhuang's slides at CEPC workshop

Exploring SUSY at CEPC

- Indirect searches



CEPC Higgs fit only



arXiv:2010.09782, H. Li, H. Song, S. Su, W. Su, J. M. Yang

- MSSM contribution to κ_b, the Higgs coupling normalized to the SM value, is

$$\kappa_b = -\frac{\sin\alpha_{eff}}{\cos\beta}\tilde{\kappa}_h^b,$$

$$\tilde{\kappa}_h^b = \frac{1}{1+\Delta m_b}\left(1 - \Delta m_b \frac{1}{\tan\alpha_{eff}\tan\beta}\right)$$

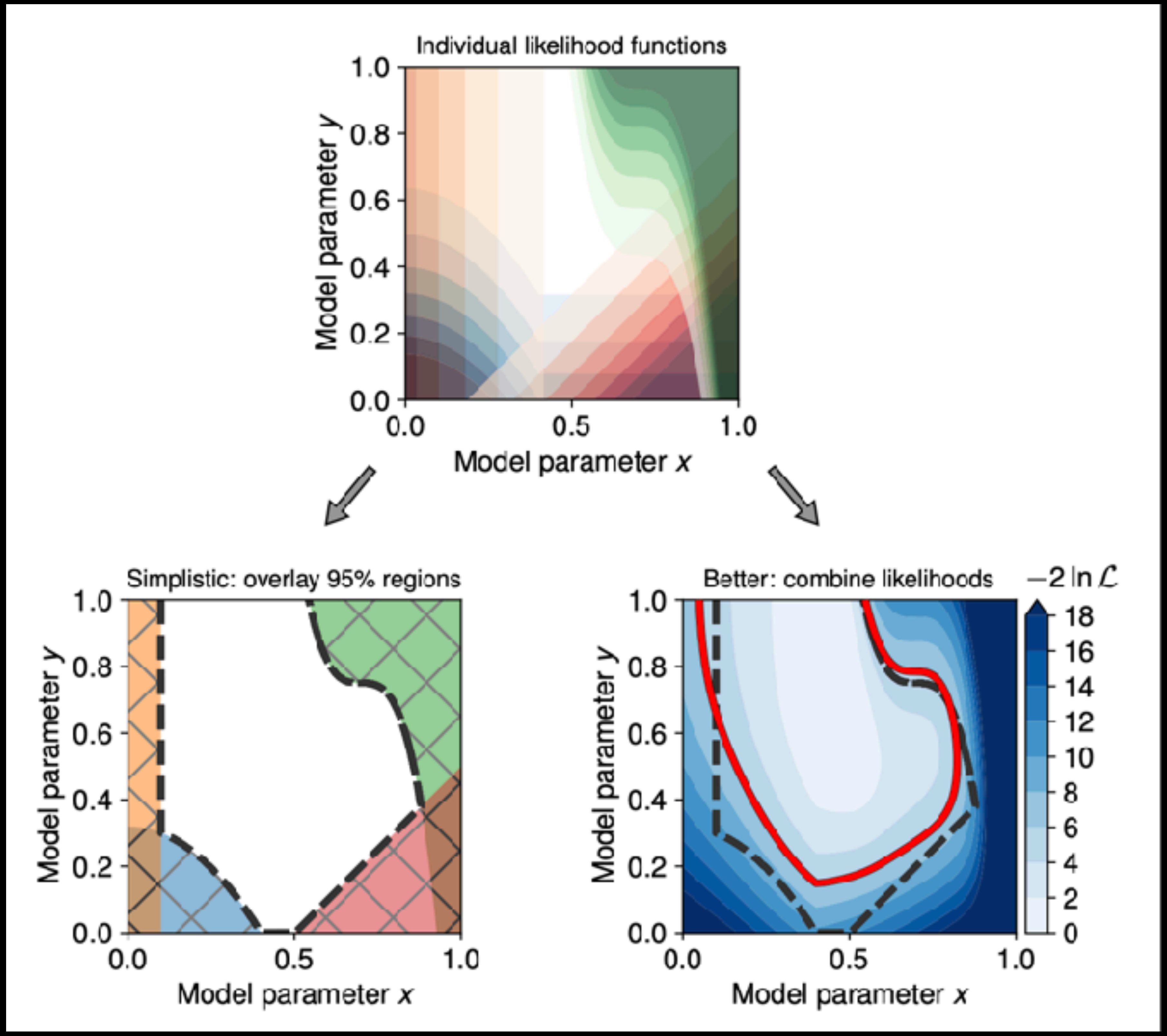
- The loop contribution of the stop sector is

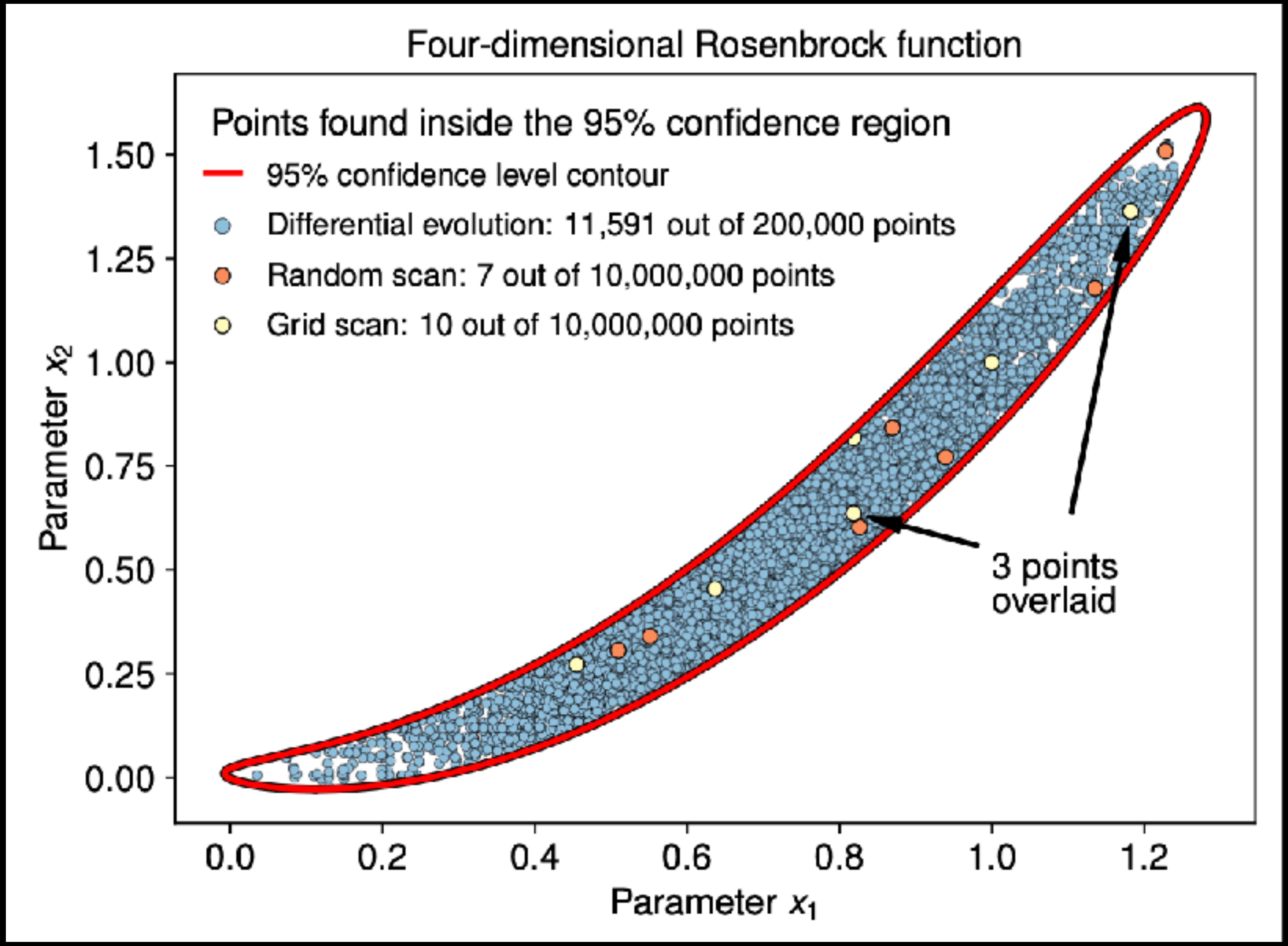
$$\Delta m_b^{stop} = \frac{h_t^2}{16\pi^2}\mu A_t \tan\beta I(m_{\tilde{t}_1}, m_{\tilde{t}_2}, \mu)$$

Exploring SUSY at CEPC

- Global fit

arXiv:2012.09874





Exploring SUSY at CEPC

- Global fit including present likelihood:

$$\mathscr{L}_{\text{Present+CEPC}} = \mathscr{L}_{\text{CEPC}}\mathscr{L}_{\text{Present}}$$

$$= \mathscr{L}_{\text{CEPC}}\mathscr{L}_{\text{collider}}\mathscr{L}_{\text{DM}}\mathscr{L}_{\text{flavor}}\mathscr{L}_{\text{EWPO}}\cdots$$

- This is extremely time consuming.
- A short cut is to utilise data sampled using $\mathscr{L}_{\text{Present}}$.

Likelihood term
LHC sparticle searches
LHC Higgs
LEP Higgs
ALEPH selectron
ALEPH smuon
ALEPH stau
L3 selectron
L3 smuon
L3 stau
L3 neutralino leptonic
L3 chargino leptonic
OPAL chargino hadronic
OPAL chargino semi-leptonic
OPAL chargino leptonic
OPAL neutralino hadronic
$B_{(s)} \to \mu^+\mu^-$
Tree-level B and D decays
$B^0 \to K^{*0}\mu^+\mu^-$
$B \to X_s\gamma$
a_μ
W mass
Relic density
PICO-2L
PICO-60 F
SIMPLE 2014
LUX 2015
LUX 2016
PandaX 2016
SuperCDMS 2014
XENON100 2012
IceCube 79-string
γ rays (Fermi-LAT dwarfs)
ρ_0
σ_s and σ_l
$\alpha_s(m_Z)(\overline{MS})$
Top quark mass

LHC sparticle searches →

ATLAS_13TeV_MultiLEP_strong_139invfb
ATLAS_13TeV_RJ3L_lowmass_36invfb
ATLAS_13TeV_RJ3L_2Lep2Jets_36invfb
ATLAS_13TeV_RJ3L_3Lep_36invfb
ATLAS_13TeV_2OSLEP_chargino_80invfb
ATLAS_13TeV_2OSLEP_chargino_binned_80invfb
ATLAS_13TeV_2OSLEP_chargino_inclusive_80invfb
ATLAS_13TeV_2OSLEP_chargino_139invfb
ATLAS_13TeV_2OSLEP_chargino_inclusive_139invfb
ATLAS_13TeV_2OSLEP_chargino_binned_139invfb
ATLAS_13TeV_2OSLEP_Z_139invfb
ATLAS_13TeV_2LEPsoft_139invfb
ATLAS_13TeV_4LEP_36invf
ATLAS_13TeV_4LEP_139invf
ATLAS_13TeV_1Lep2b_139invfb
ATLAS_13TeV_2b2H_sbottom_139invfb
ATLAS_13TeV_2b2W_stop_139invfb
ATLAS_13TeV_2bMET_36invfb
ATLAS_13TeV_3b_24invfb
ATLAS_13TeV_3b_discoverySR_24invfb
ATLAS_13TeV_3b_36invfb
ATLAS_13TeV_3b_discoverySR_36invfb
ATLAS_13TeV_HtoPhotons_139invfb
ATLAS_13TeV_PhotonGGM_36invfb
ATLAS_13TeV_ZGammaGrav_CONFNOTE_80invfb
ATLAS_13TeV_MONOJET_36invfb

Exploring SUSY at CEPC

- Indirect searches

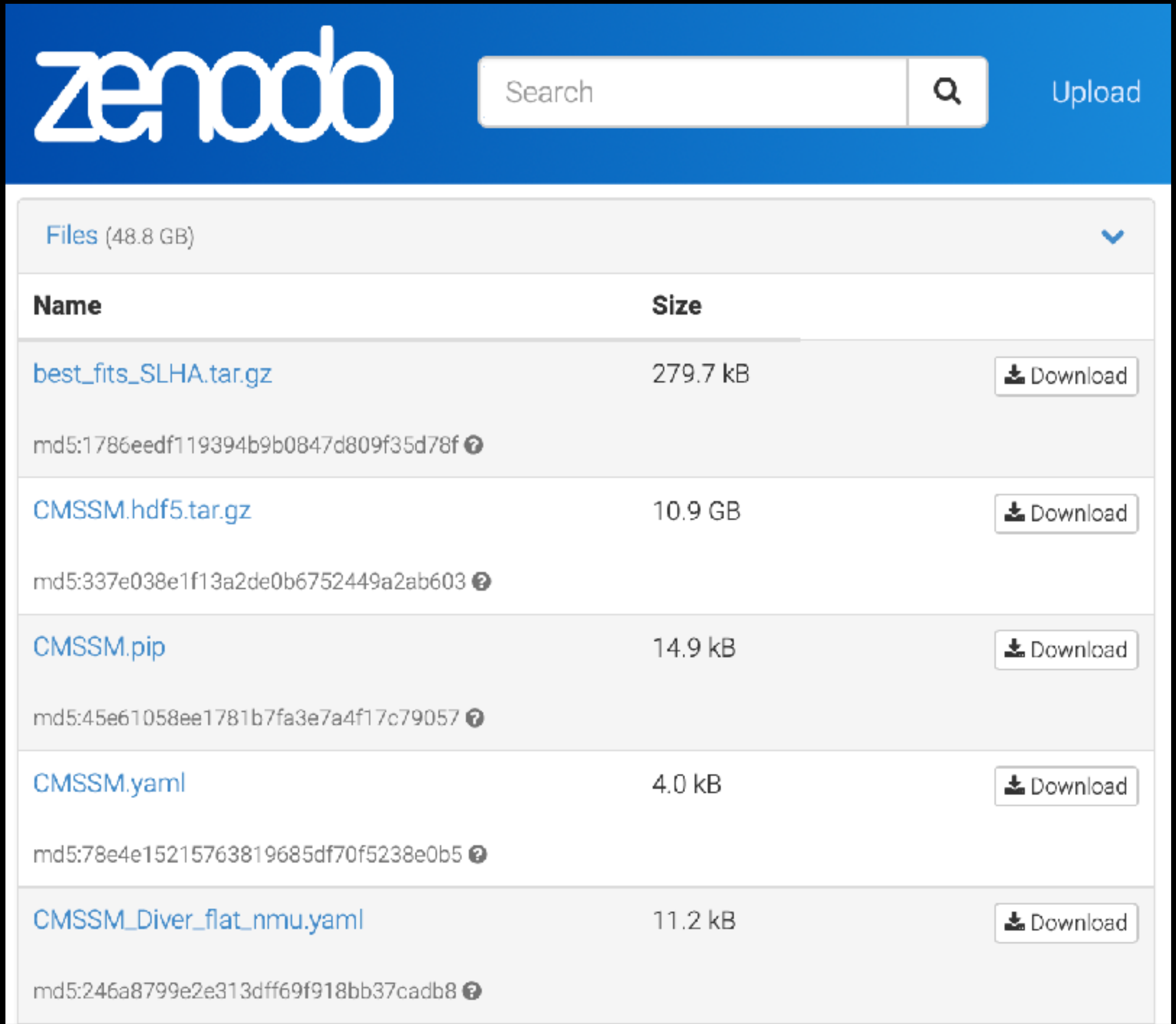
- Global fits with present likelihood:

$$\mathscr{L}_{\text{Present+CEPC}} = \mathscr{L}_{\text{CEPC}}\mathscr{L}_{\text{Present}}$$

$$= \mathscr{L}_{\text{CEPC}}\mathscr{L}_{\text{collider}}\mathscr{L}_{\text{DM}}\mathscr{L}_{\text{flavor}}\mathscr{L}_{\text{EWPO}}\cdots$$

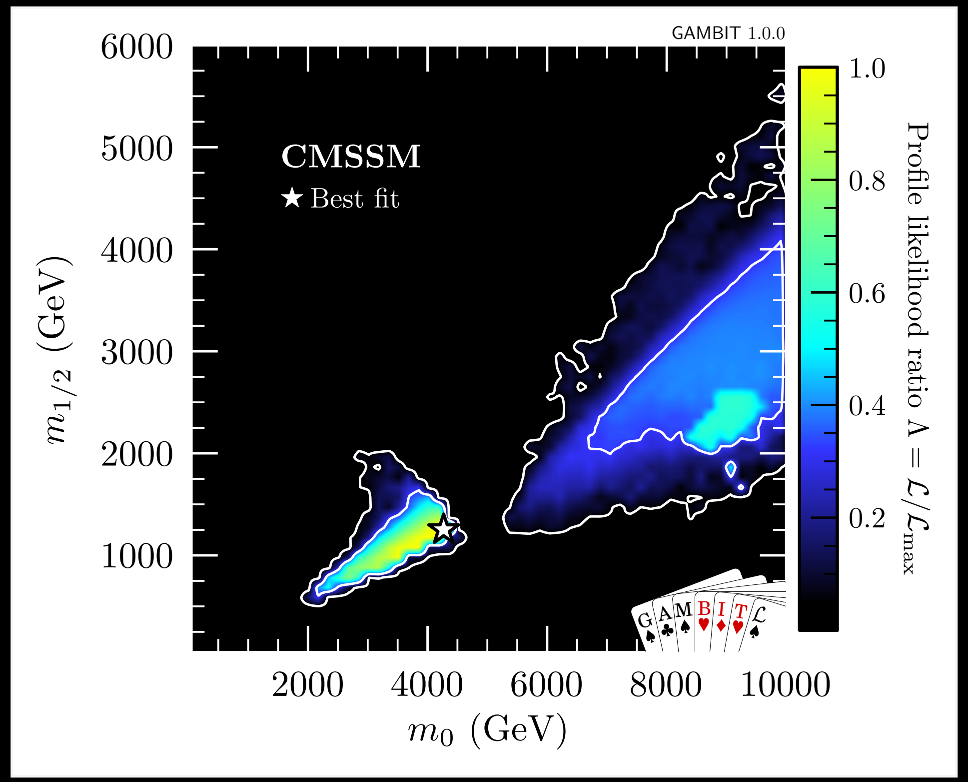
- This is extremely time consuming.

- A short cut is to utilise data sampled using $\mathscr{L}_{\text{Present}}$.

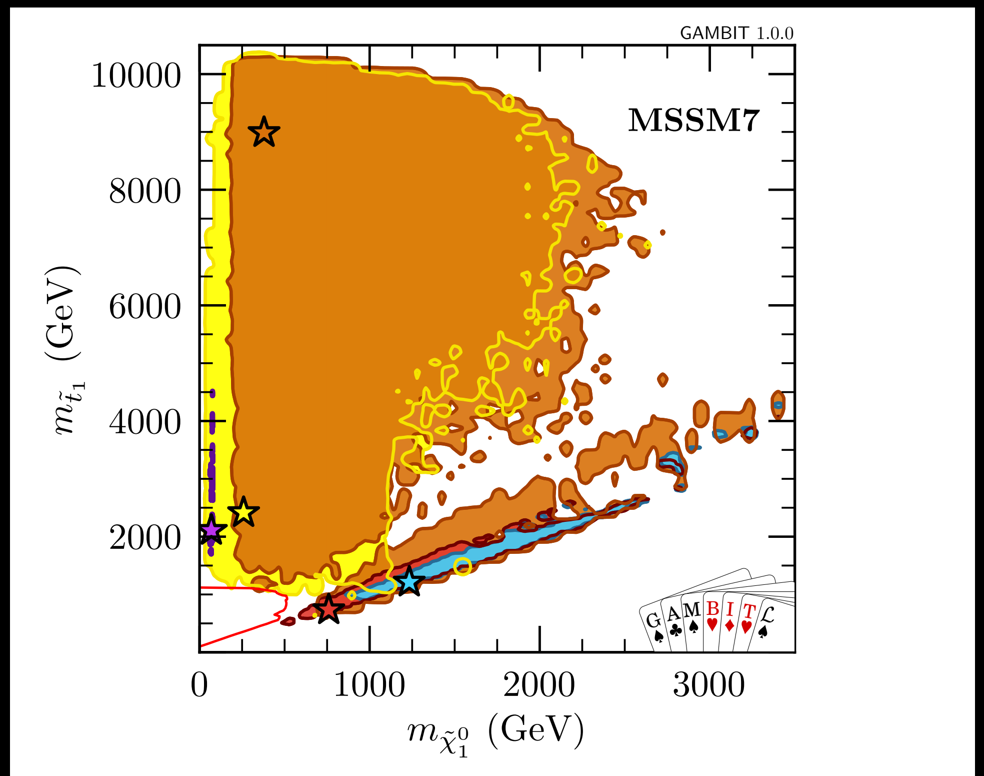


Name	Size	
best_fits_SLHA.tar.gz md5:1786eedf119394b9b0847d809f35d78f	279.7 kB	Download
CMSSM.hdf5.tar.gz md5:337e038e1f13a2de0b6752449a2ab603	10.9 GB	Download
CMSSM.pip md5:45e61058ee1781b7fa3e7a4f17c79057	14.9 kB	Download
CMSSM.yaml md5:78e4e15215763819685df70f5238e0b5	4.0 kB	Download
CMSSM_Diver_flat_nmu.yaml md5:246a8799e2e313dff69f918bb37cadb8	11.2 kB	Download

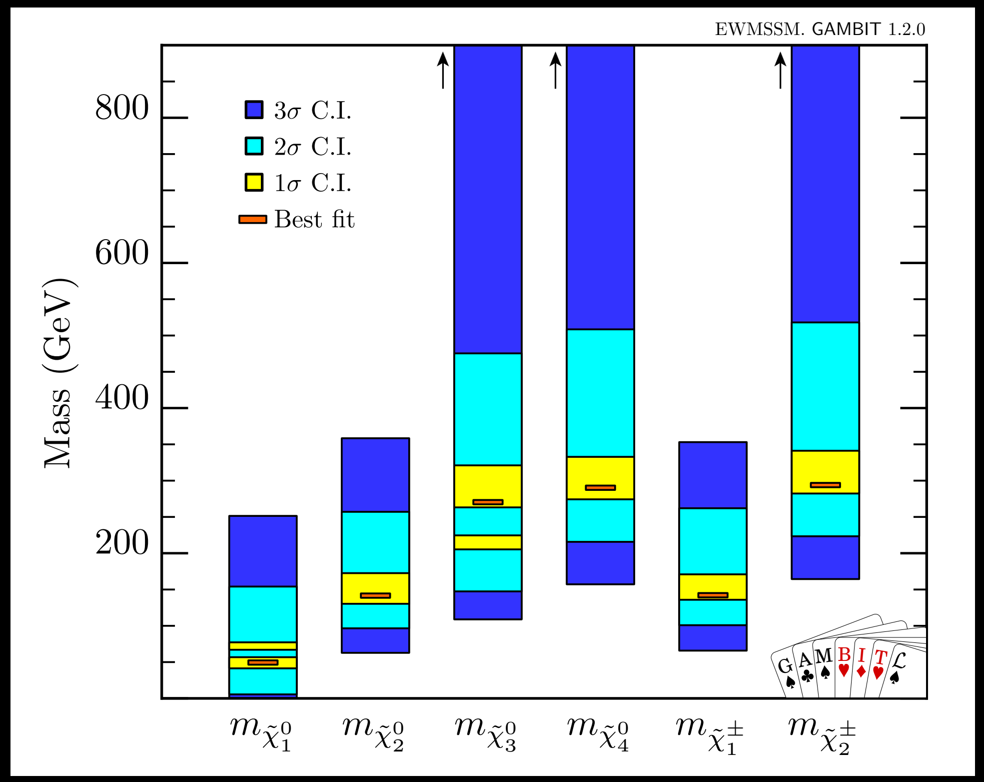
GAMBIT physics publications



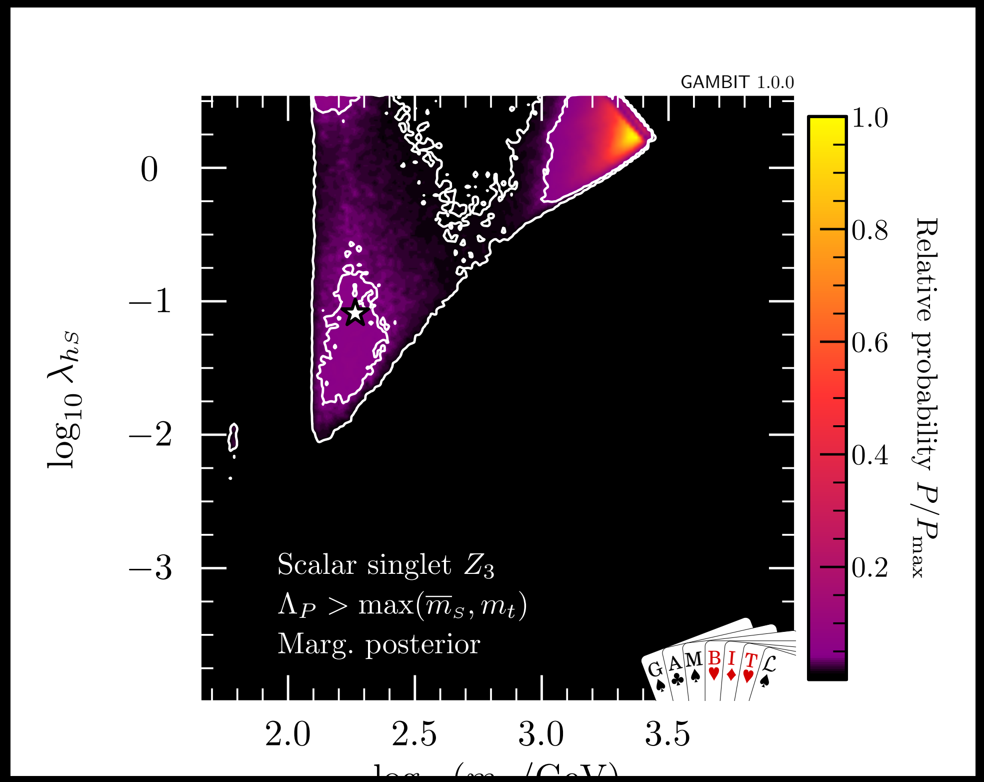
CMSSM/NUHM1/NUMH2
(EPJC, arXiv:1705.07935)



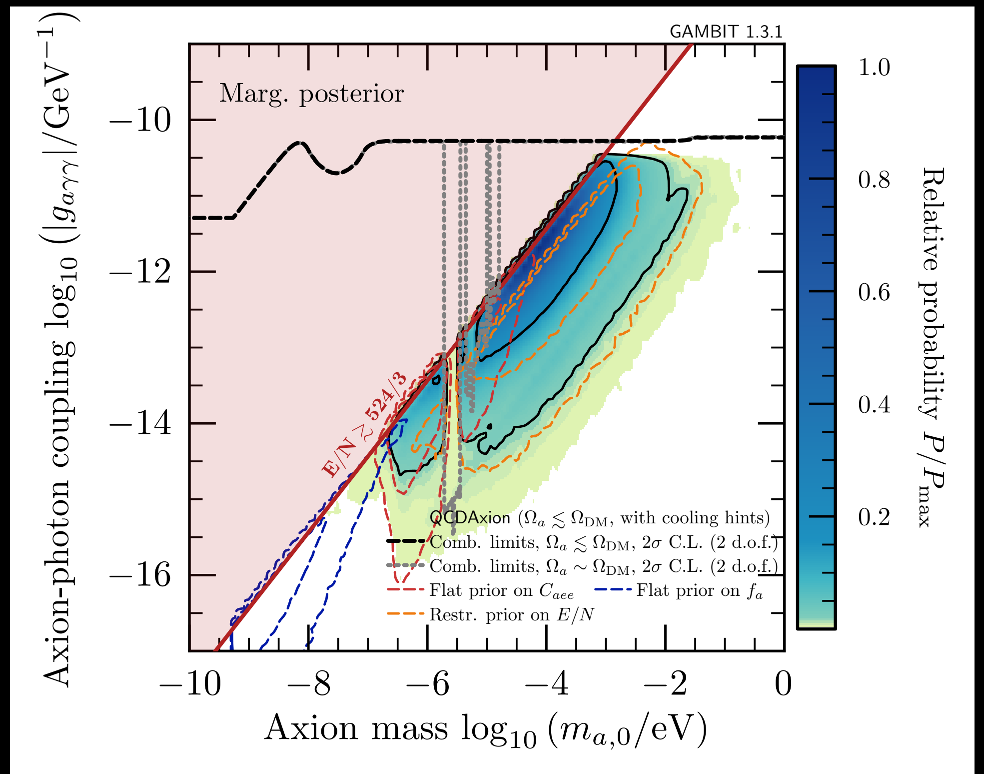
MSSM7
(EPJC, arXiv:1705.07917)



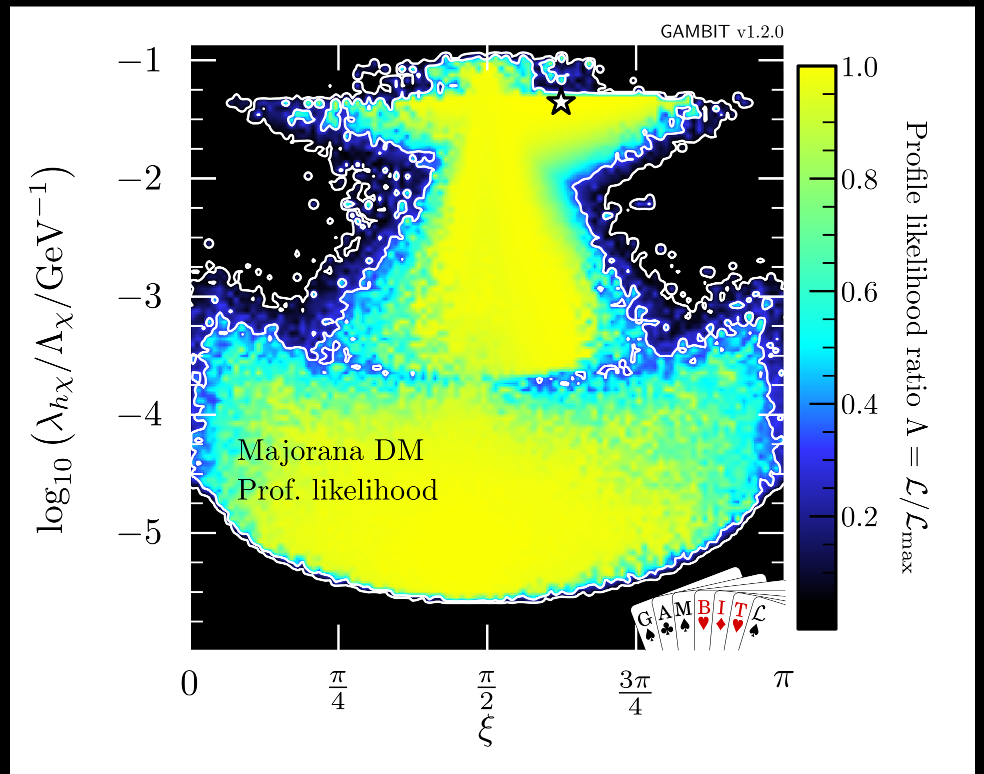
EW MSSM
(EPJC, arXiv:1809.02097)



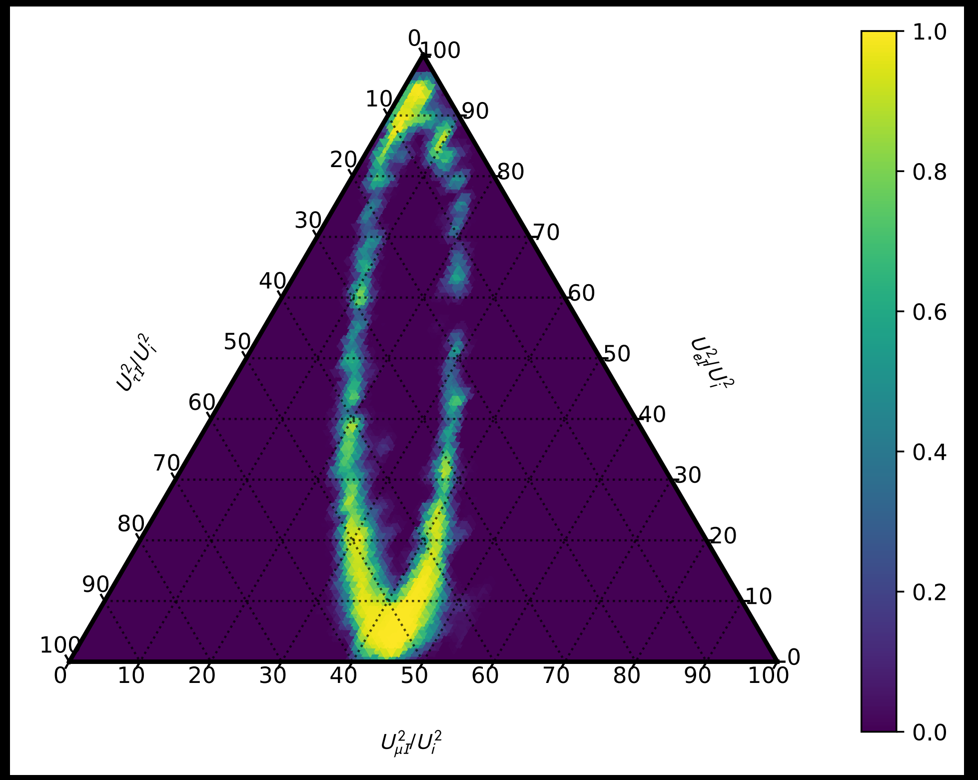
Scalar singlet dark matter
(EPJC, arXiv:1705.07931)



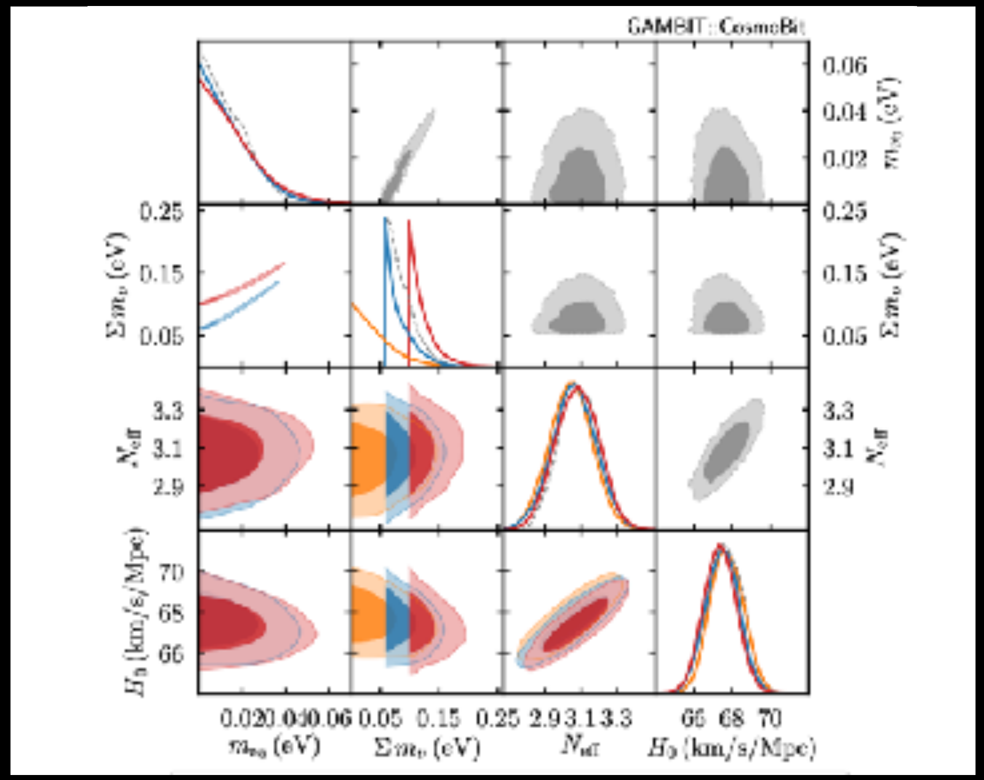
Axions & ALPs
(EPJC, arXiv:1810.07192)



Fermion/vector Higgs portal
(EPJC, arXiv:1808.10465)



Right-handed neutrinos
(EPJC / arXiv:1908.02302)



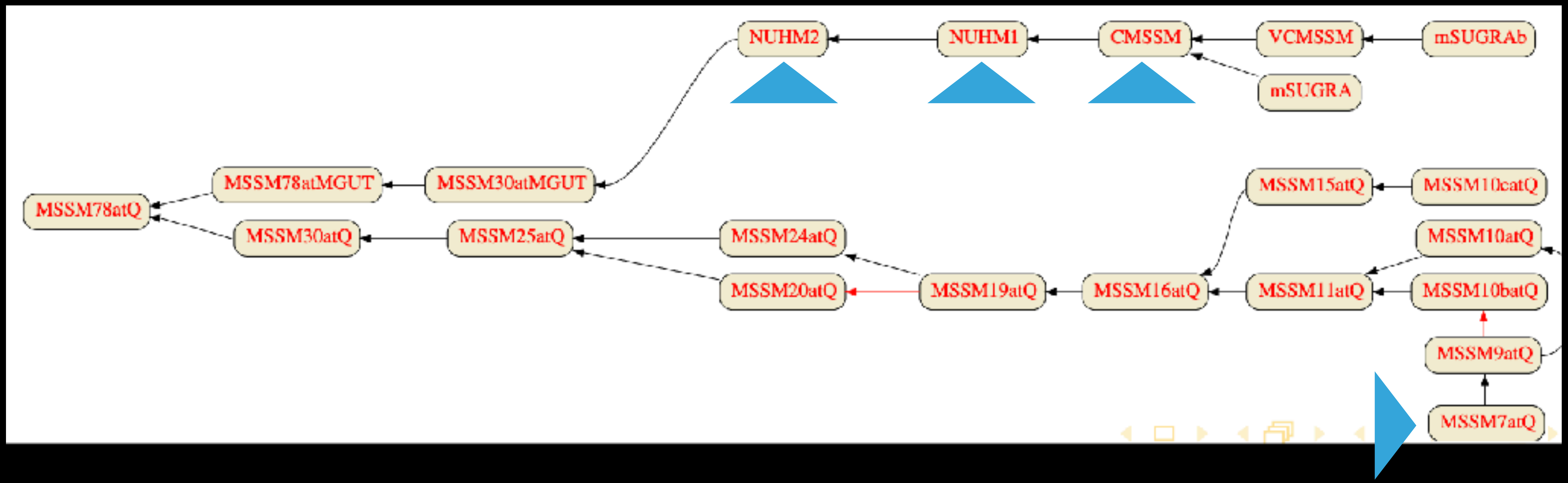
Neutrino masses
(PRD, arXiv:2009.03287)

CMSSM, NHUM1, NUHM2 and MSSM7

- GUT scale

$$\mathcal{L}_{soft} \sim M^2_{H_{u,d}}|H_{u,d}|^2 + m_0^2 \tilde{F}_i^\dagger \tilde{F}_i + \frac{1}{2} m_{1/2} \tilde{G}_j \tilde{G}_j + A_0 \tilde{F}_i^c H_{u,d} \tilde{F}_i + \cdots$$

  - CMSSM: $m_0^2 = M^2_{H_{u,d}}$
  - NUHM1: $m_0^2 \neq M^2_{H_{u,d}}$, $M^2_{H_u} = M^2_{H_d}$
  - NUHM2: $m_0^2 \neq M^2_{H_{u,d}}$, $M^2_{H_u} \neq M^2_{H_d}$

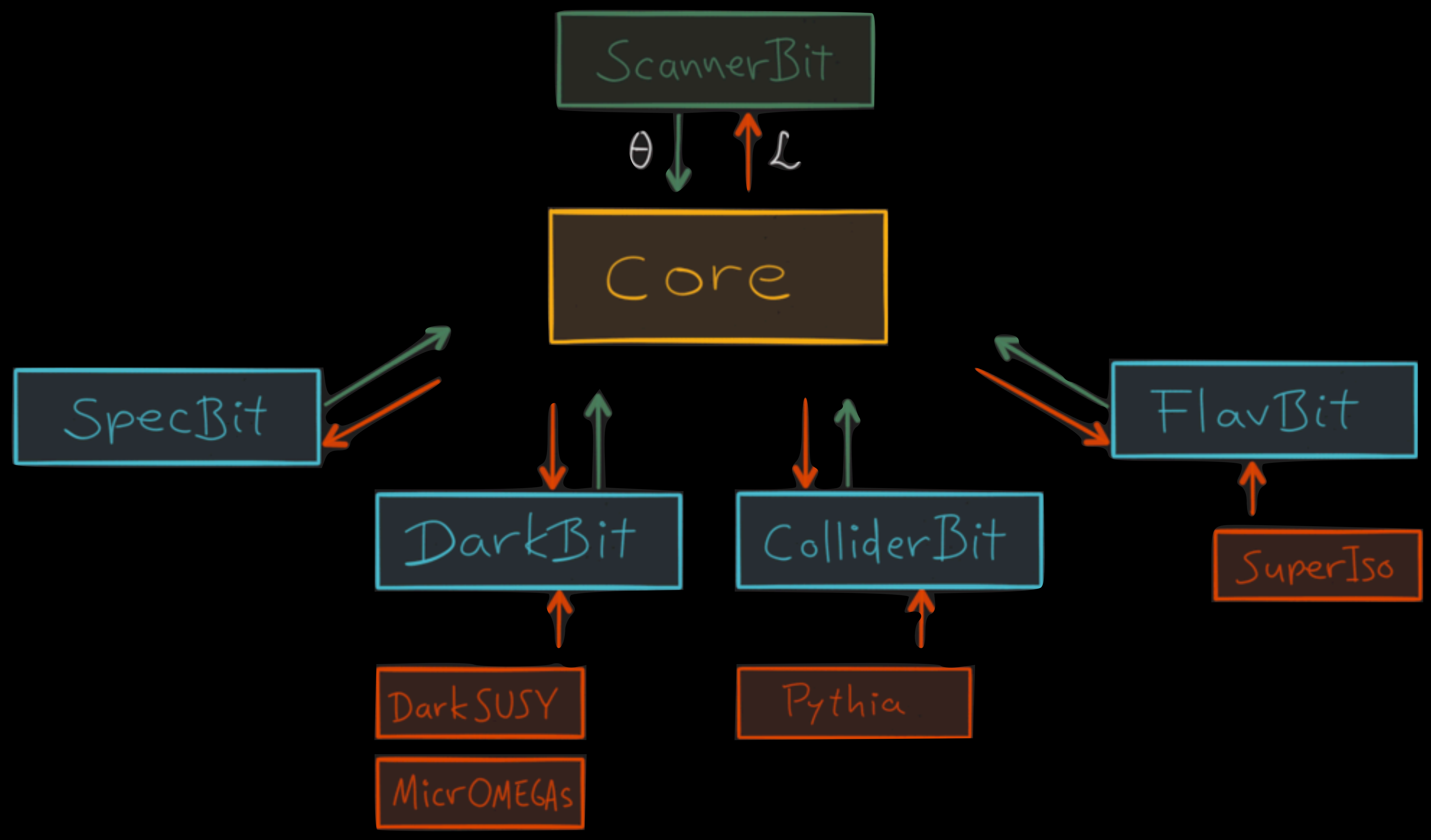


- Weak scale

$$\mathcal{L}_{soft} \sim M^2_{H_{u,d}}|H_{u,d}|^2 + m^2_{\tilde{f}_i} \tilde{F}_i^\dagger \tilde{F}_i + \frac{1}{2} M_j \tilde{G}_j \tilde{G}_j + A_{f_i} \tilde{F}_i^c H_{u,d} \tilde{F}_i + \cdots$$

  - MSSM7: $\tan\beta, A_u = A_d = A_e = 0$, except for $(A_u)_{33} = A_{u3}, (A_d)_{33} = A_{d3}$.

Constraints



- DM abundance (upper bound)
- DM direct det. (8 experiments)
- DM indirect det. (Fermi-LAT, IceCube79)
- EW precision (W mass, muon g-2, …)
- 59 flavor observables
- LHC Higgs data, SUSY searches, …

✳ Uncertainties, nuisances:

- local DM density, nuclear physics parameters, Higgs and quark masses, gauge couplings

✳ about 280 million valid samples for the three models

CEPC Higgs likelihood

$$-2\ln\mathscr{L}_{\rm CEPC} = \frac{(m_h^{\rm SUSY}-m_h^{\rm obs})^2}{(\Delta m_h)^2} + \sum_{i=f,V,\ldots}\frac{(\mu_i^{\rm SUSY}-\mu_i^{\rm obs})^2}{(\Delta\mu_i)^2}, \quad \mu_i = \frac{(\sigma_i\times{\rm Br}_i)}{(\sigma_i\times{\rm Br}_i)^{\rm SM}}.$$

- $m_h^{\rm obs} = 125.25$ GeV, $\Delta m_h = \sqrt{0.17^2+2^2} =$ 2.007 GeV

Decay mode	SM BR	Best-fit BR
$H\to b\bar{b}$	57.5	59.0%
$H\to c\bar{c}$	2.91%	3.45%
$H\to gg$	8.57%	6.57%
$H\to WW^*$	21.5%	21.3%
$H\to ZZ^*$	2.64%	2.69%
$H\to\gamma\gamma$	2.28×10^{-3}	2.69×10^{-3}
$H\to\tau^+\tau^-$	6.32%	6.45%
$H\to\mu^+\mu^-$	2.19×10^{-4}	2.28×10^{-3}

Property	Estimated Precision	
Decay mode	$\sigma(ZH)\times$ BR	BR
$H\to b\bar{b}$	0.27%	0.56%
$H\to c\bar{c}$	3.3%	3.3%
$H\to gg$	1.3%	1.4%
$H\to WW^*$	1.0%	1.1%
$H\to ZZ^*$	5.1%	5.1%
$H\to\gamma\gamma$	6.8%	6.9%
$H\to Z\gamma$	15%	15%
$H\to\tau^+\tau^-$	0.8%	1.0%
$H\to\mu^+\mu^-$	17%	17%
$H\to$ inv	–	$<0.30\%$

Estimated precision of CEPC

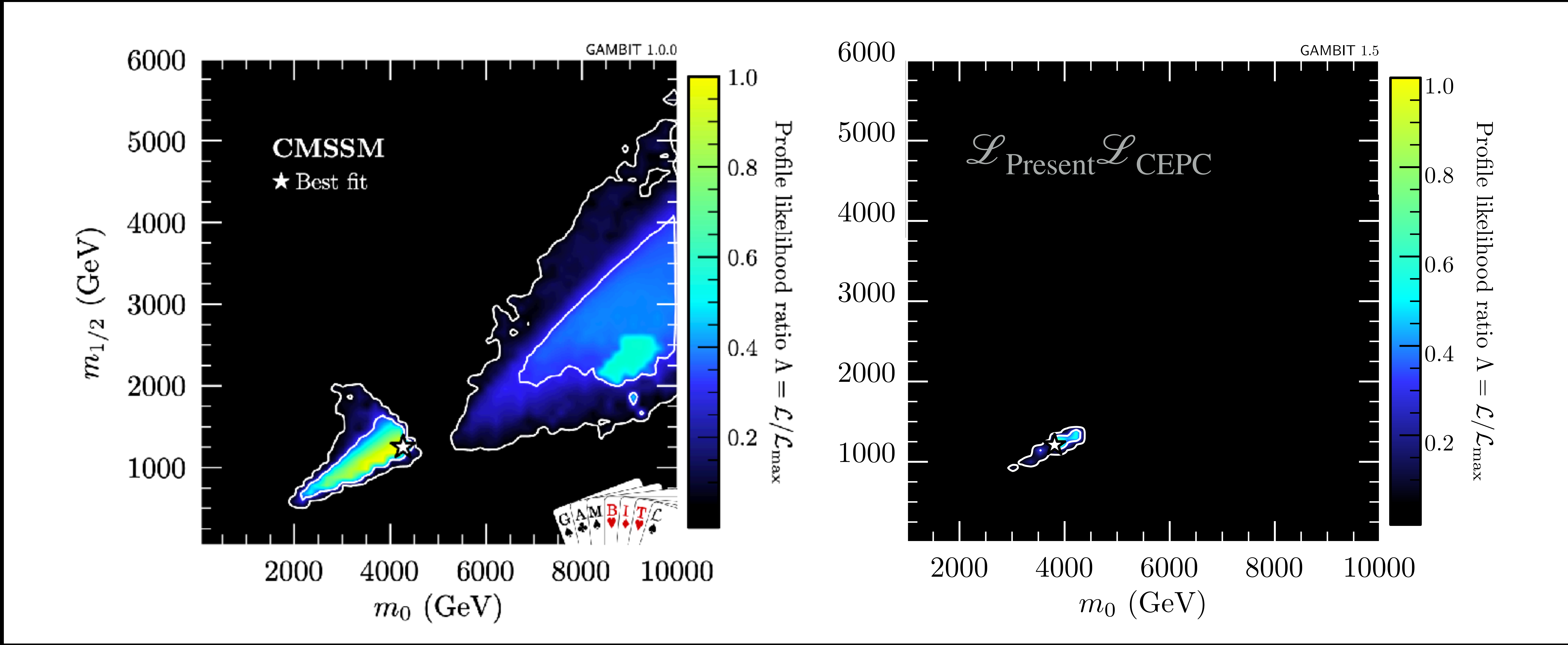
Decay mode	Branching ratio	Relative uncertainty
$H\to b\bar{b}$	57.7%	+3.2%, −3.3%
$H\to c\bar{c}$	2.91%	+12%, −12%
$H\to gg$	8.57%	+10%, −10%
$H\to\tau^+\tau^-$	6.32%	+5.7%, −5.7%
$H\to\mu^+\mu^-$	2.19×10^{-4}	+6.0%, −5.9%
$H\to WW^*$	21.5%	+4.3%, −4.2%
$H\to ZZ^*$	2.64%	+4.3%, −4.2%
$H\to\gamma\gamma$	2.28×10^{-3}	+5.0%, −4.9%
$H\to Z\gamma$	1.53×10^{-3}	+9.0%, −8.8%
Γ_H	4.07 MeV	+4.0%, −4.0%

$\times\frac{1}{5}$

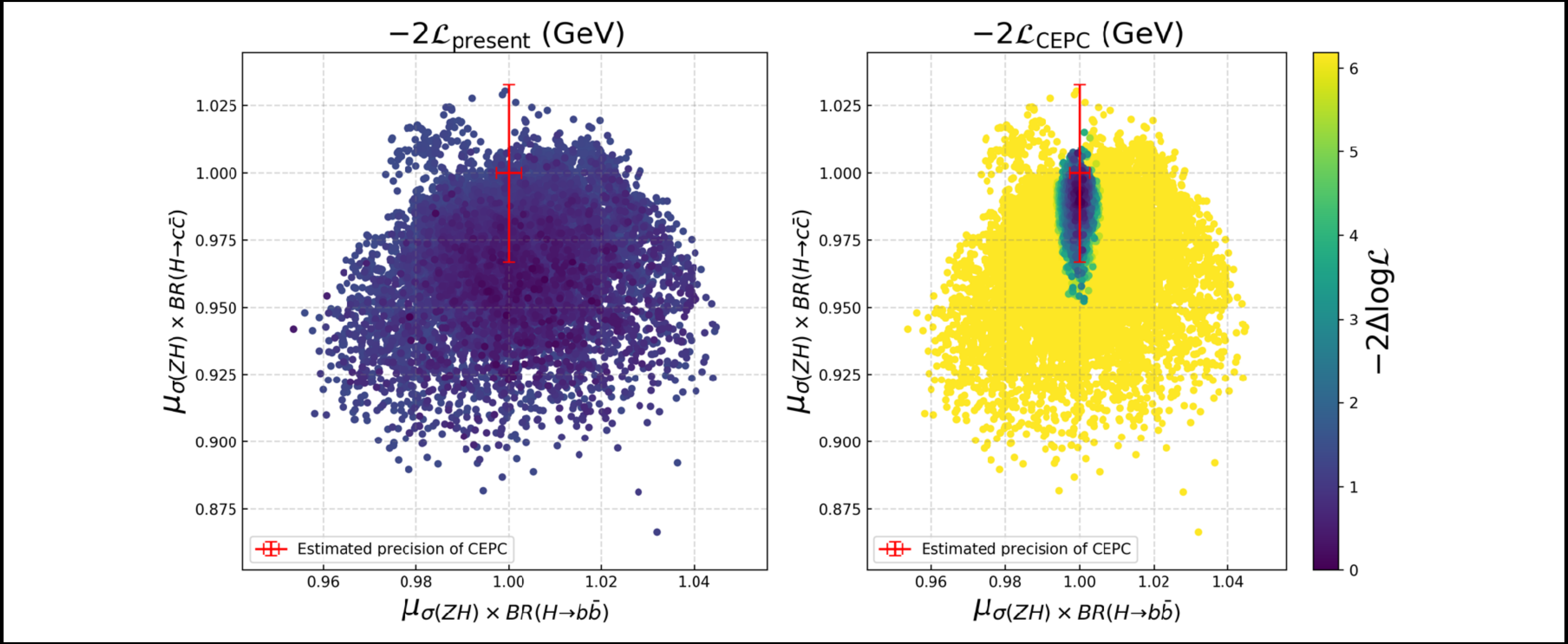
SM predictions for a 125 GeV Higgs boson

CMSSM global fit with CEPC results

- The preferred regions are visibly shrunk by adding CEPC Higgs likelihood.

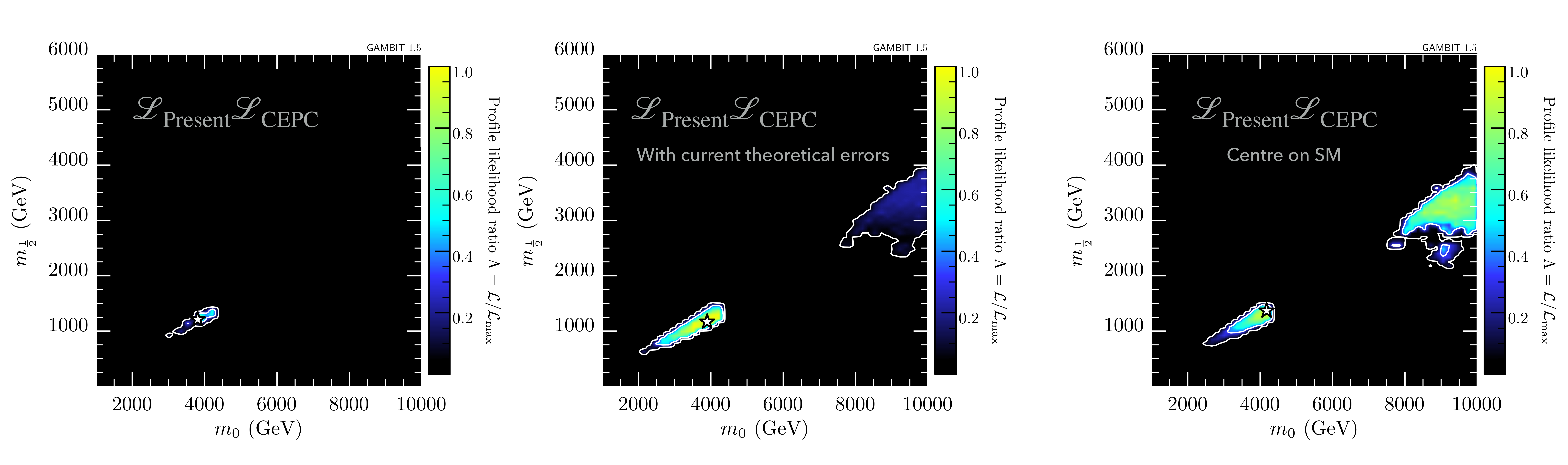


CMSSM global fit with CEPC results



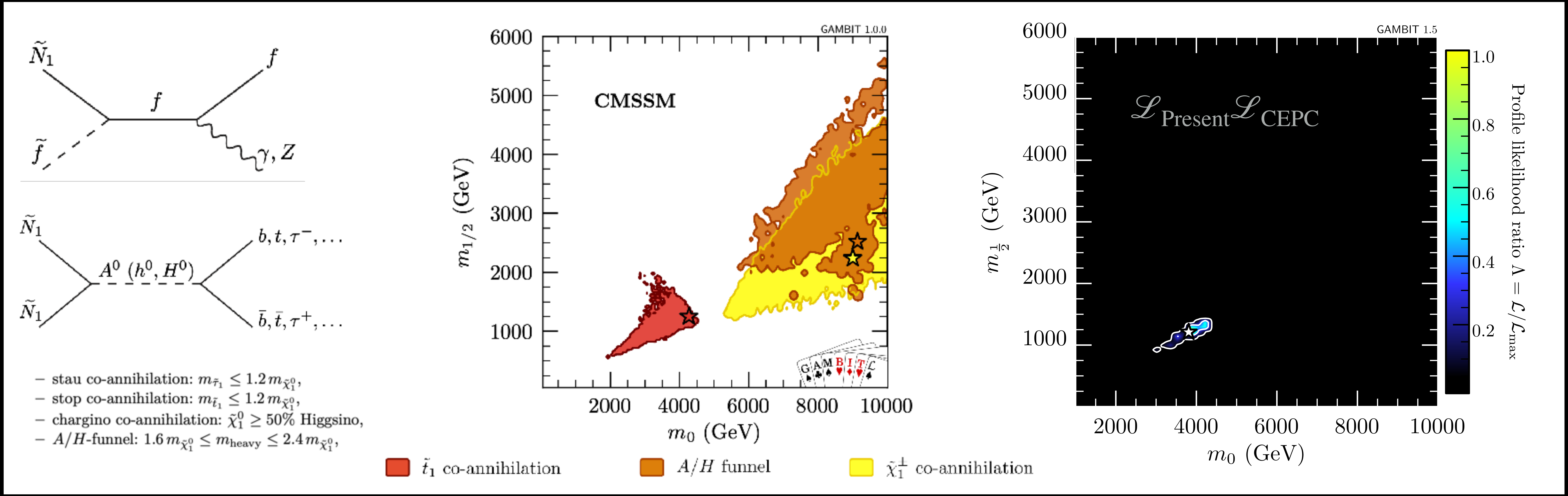
CMSSM global fit with CEPC results

- The results are highly dependent on the assumptions about the central values of CEPC measurements and theoretical errors.



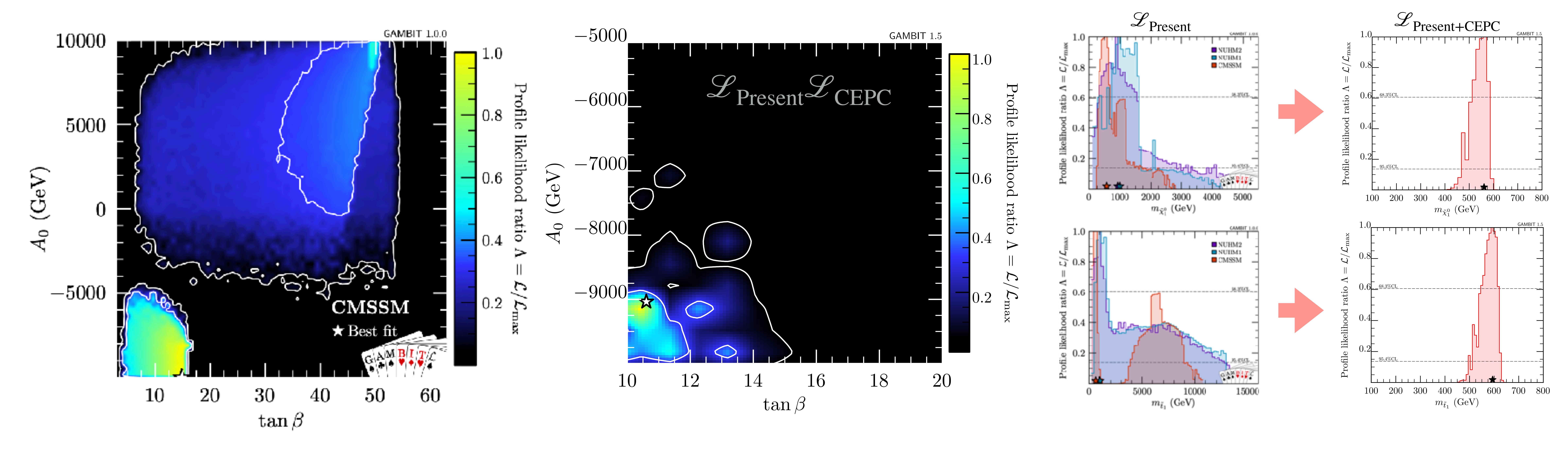
CMSSM global fit with CEPC results

- The parameter space can be classified by the different DM annihilation mechanisms.



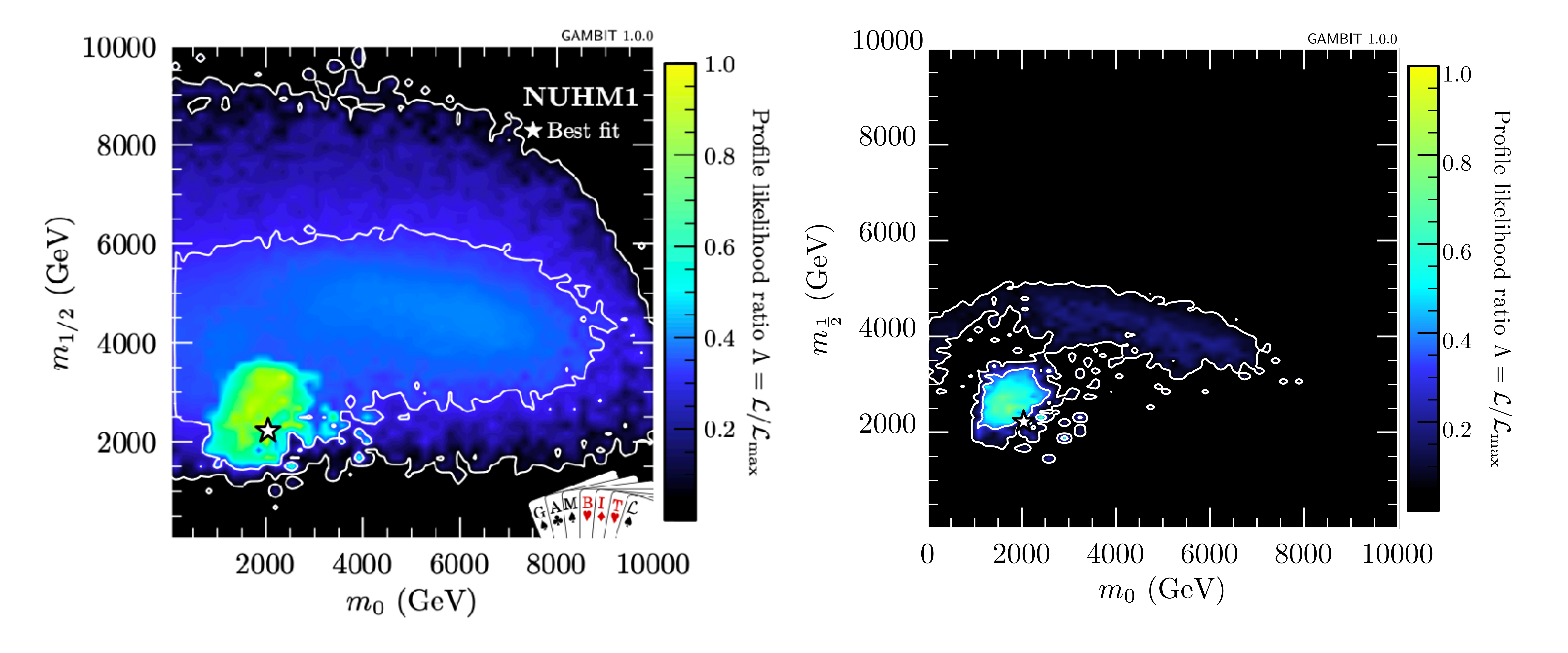
CMSSM global fit with CEPC results

- The stop co-annihilation region needs large stop mixing.



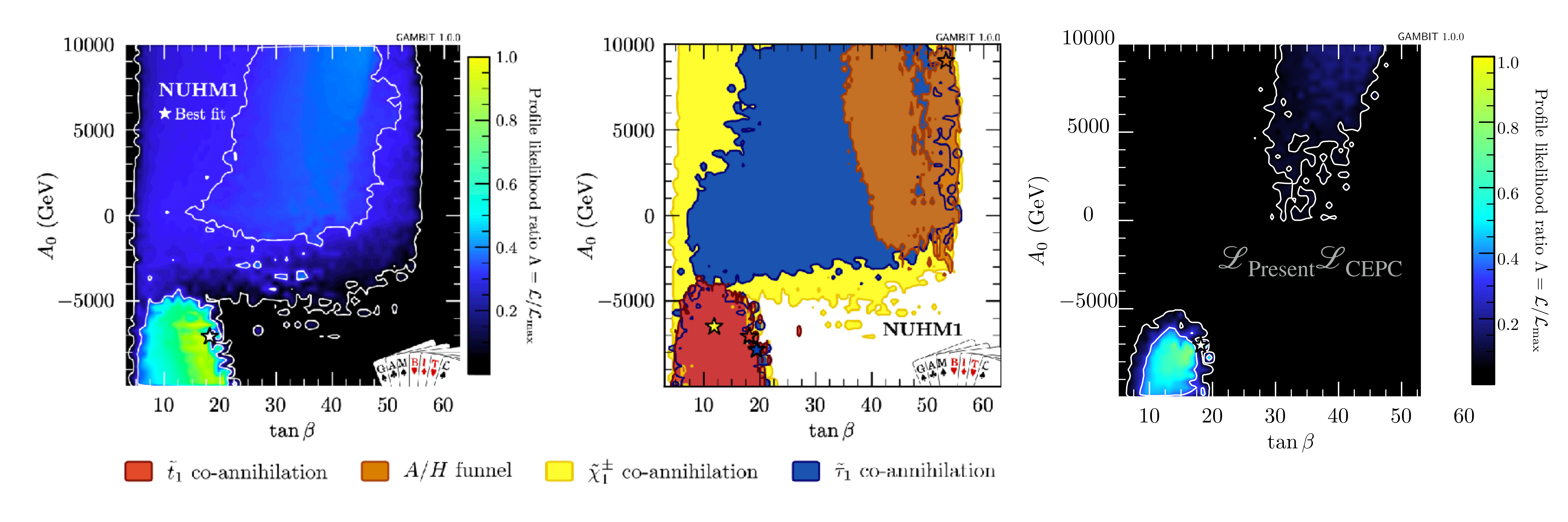
NUHM1 global fit with CEPC results

- Similar to CMSSM, the preferred regions are visibly shrunk.



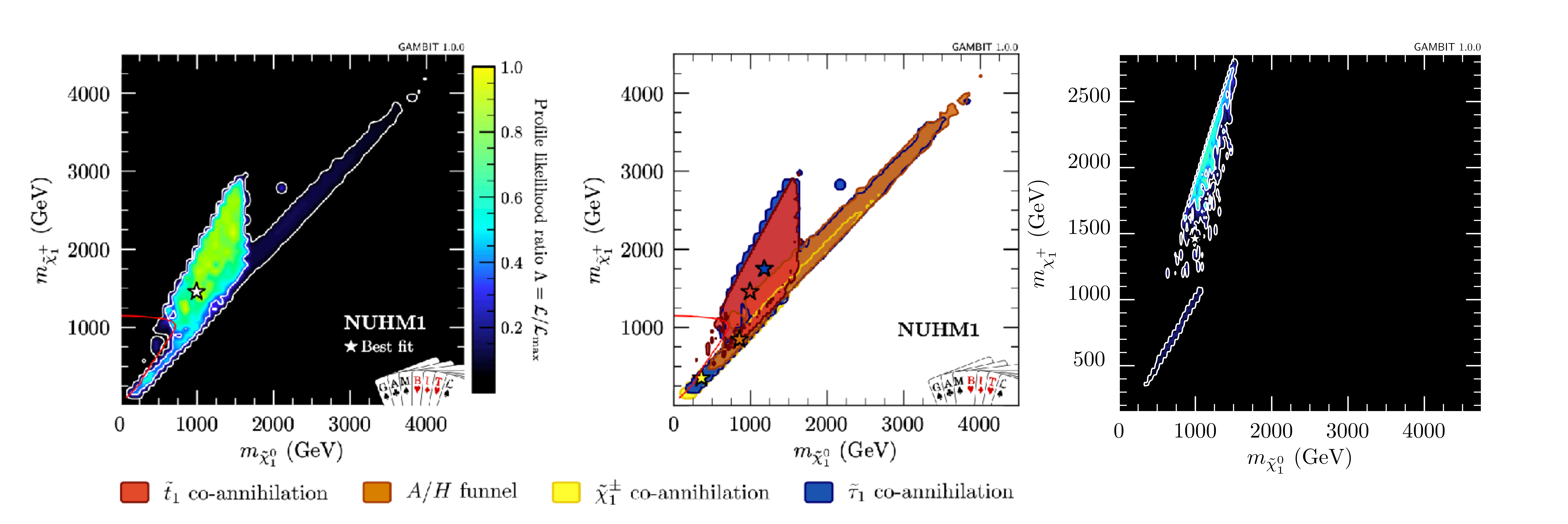
NUHM1 global fit with CEPC results

- The stop co-annihilation regions and chargino co-annihilation regions remain.



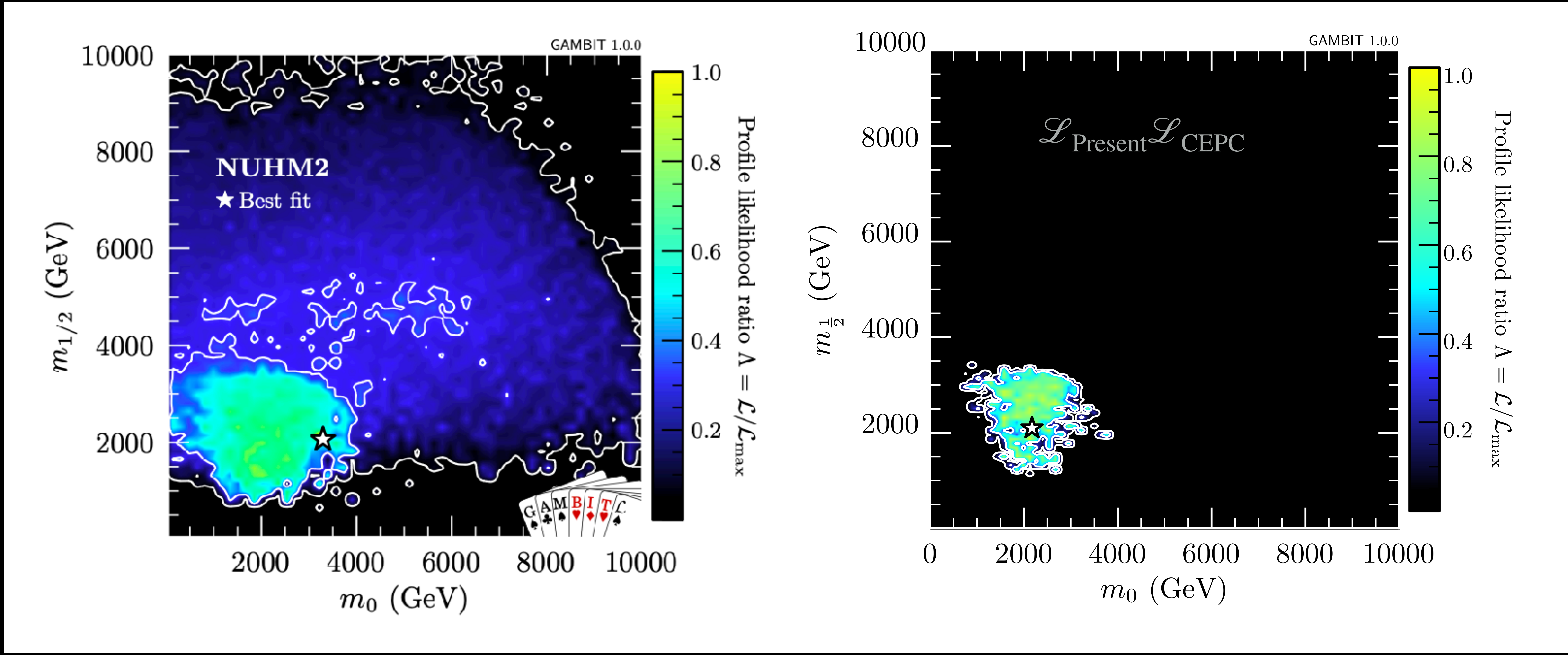
NUHM1 global fit with CEPC results

- The stop co-annihilation regions and chargino co-annihilation regions remain.



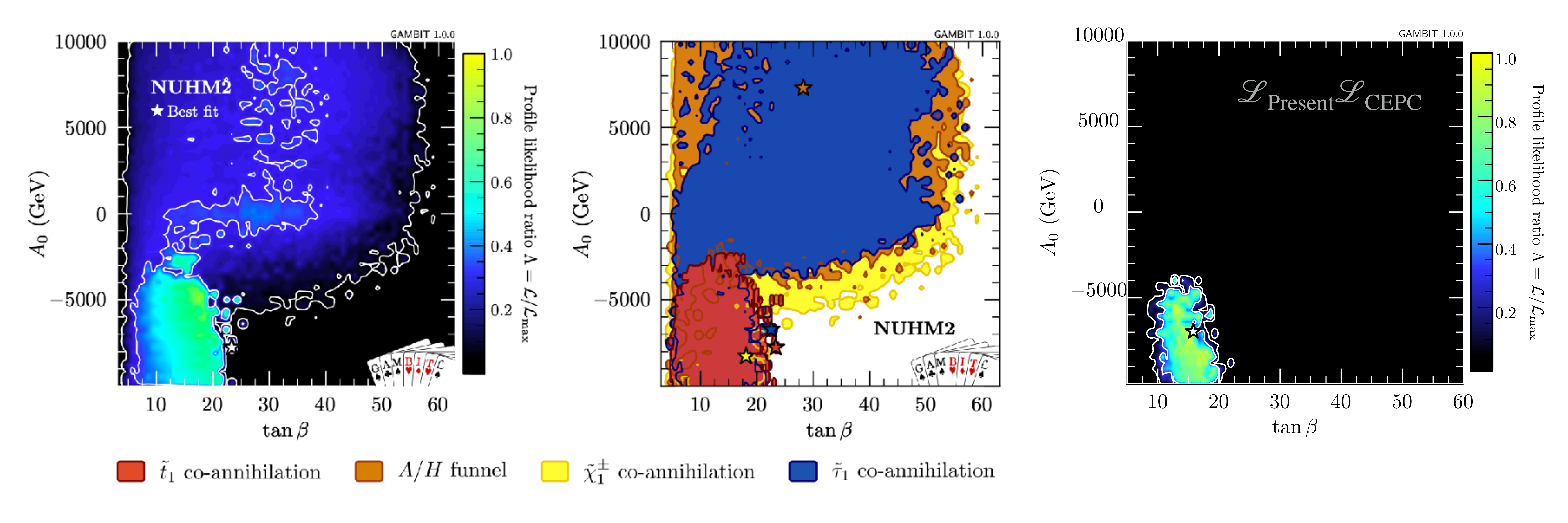
NUHM2 global fit with CEPC results

- Similar to CMSSM, the preferred regions are visibly shrunk



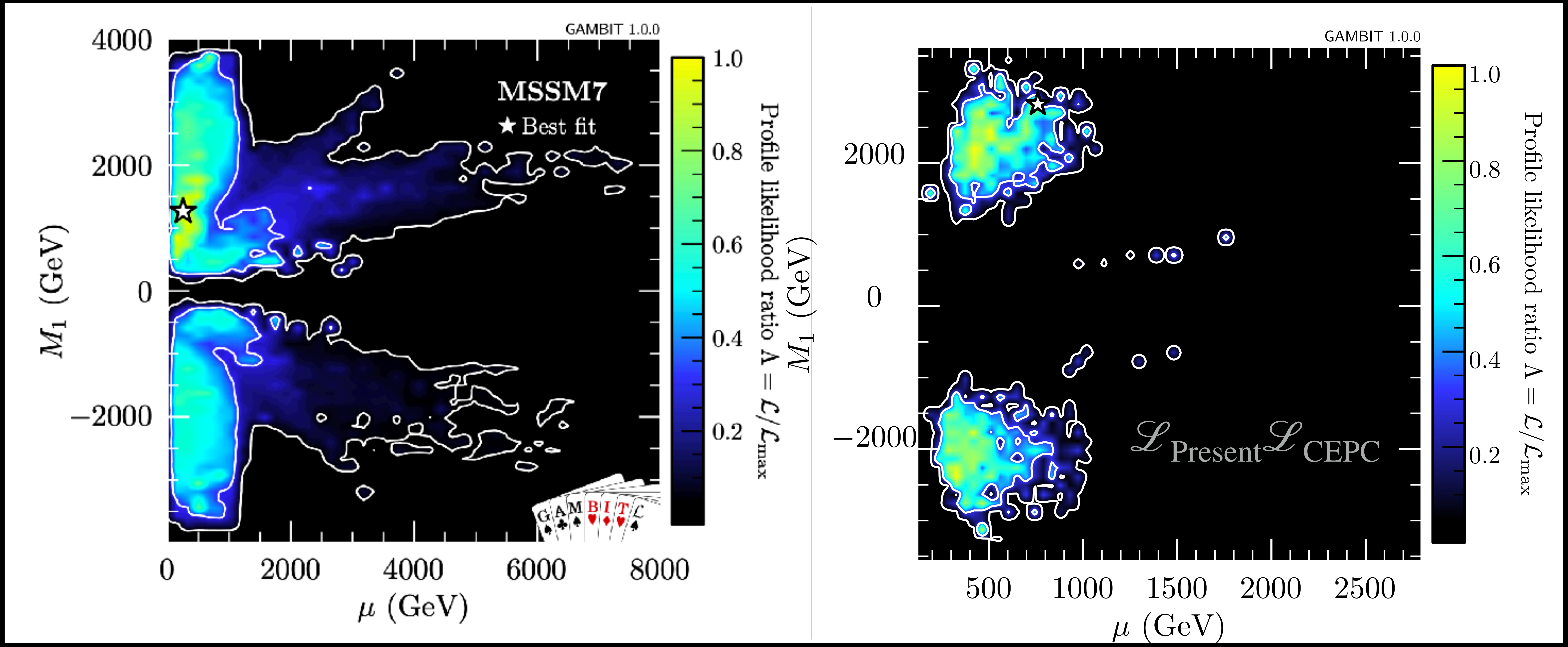
NUHM2 global fit with CEPC results

- Only stop co-annihilation regions remain.



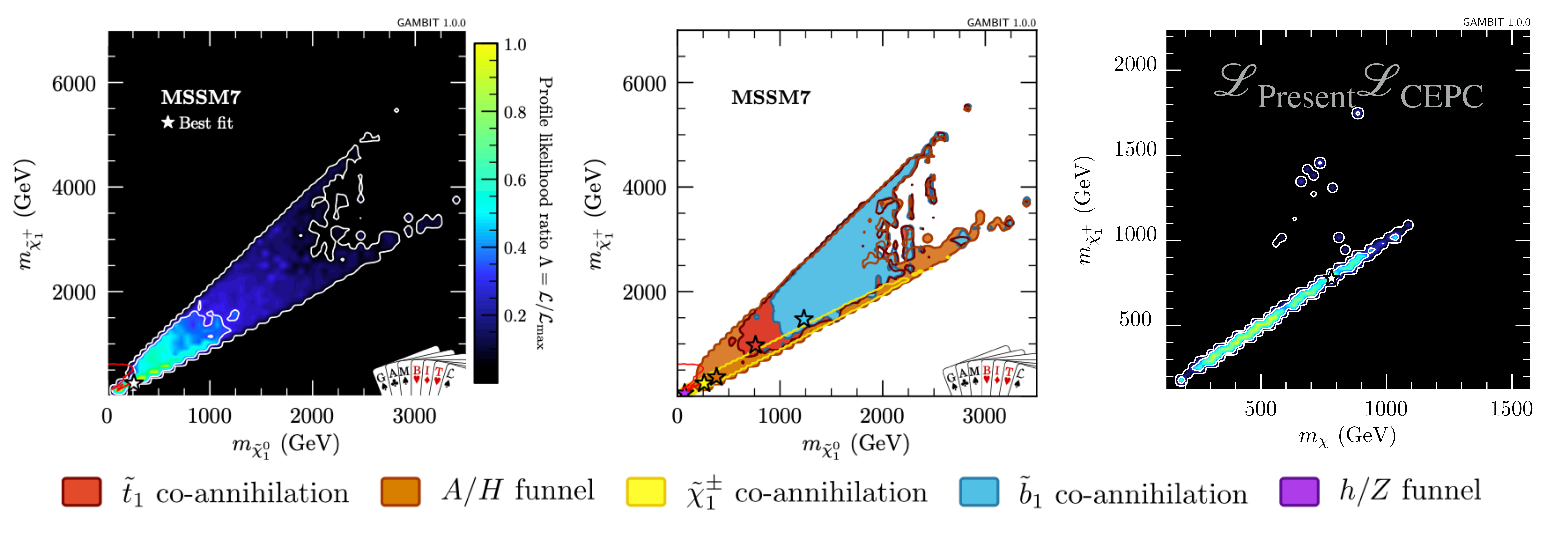
MSSM7 global fit with CEPC results

- The preferred regions of pMSSM-7 do not change dramatically as the CMSSM.



MSSM7 global fit with CEPC results

- Only one of the DM annihilation mechanisms remains.



Summary

- We post-processed the GAMBIT data for CMSSM, NUHM1/2, and MSSM7 with the CEPC predicted results, to study the impact of future colliders on SUSY global fits.
- We find that
  - Higgs precision measurements at the CEPC have significant impacts on the SUSY global fits.
  - It will visibly shrink the preferred parameter regions. The more model parameter are relevant, the more parameters regions are excluded.
  - Note that the remain parameter regions are highly dependent on the assumptions about the central values of CEPC measurements and the theoretical errors.
  - CEPC has the power to rule out some DM annihilation mechanisms in the framework of constrained SUSY.

THANK YOU.