Updates On
SUSY Global Fits With CEPC Using GAMBIT

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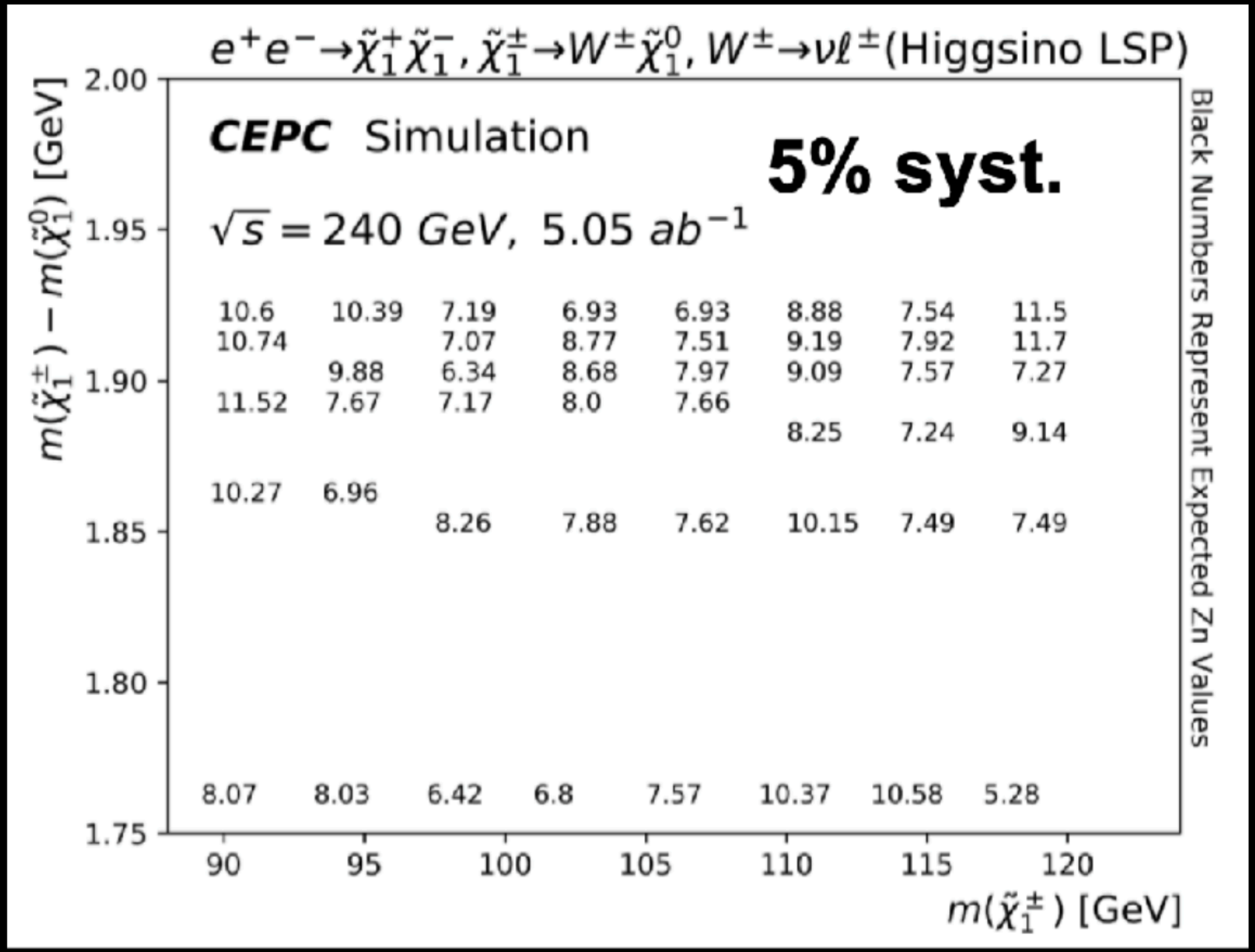
Status of paper

Contents

- The first version is almost ready.
- Now ~ Feb. 1:
  - ✳ Finalize the result section
  - ✳ Add appendix
- Feb. 1 ~ Feb. 20:
  - ✳ Polish the draft
  - ✳ Internal review
- Now ~ Feb. 15:
  - ✳ Rewrite the model section

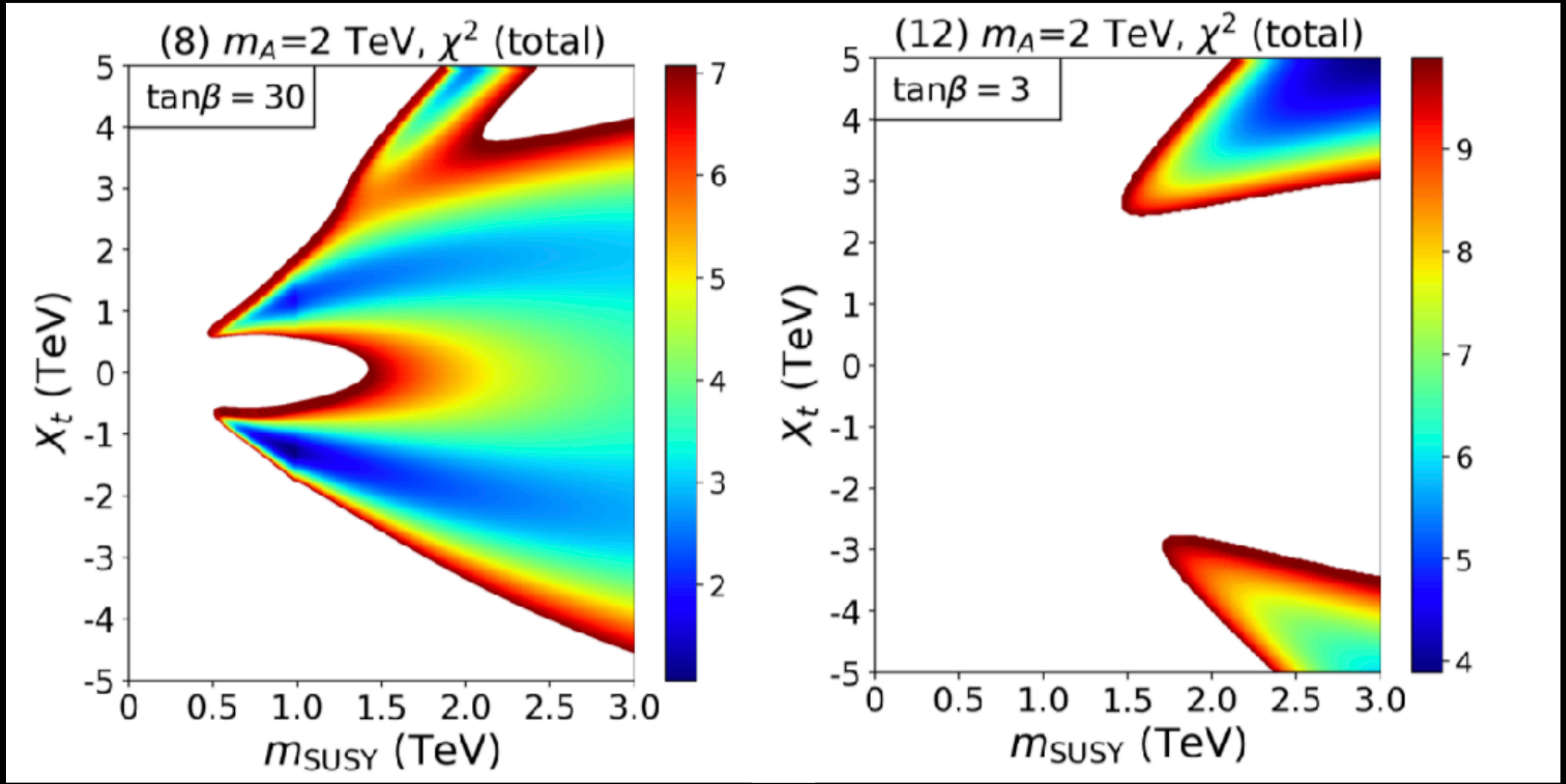
Motivation

Direct searches



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

Indirect searches



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

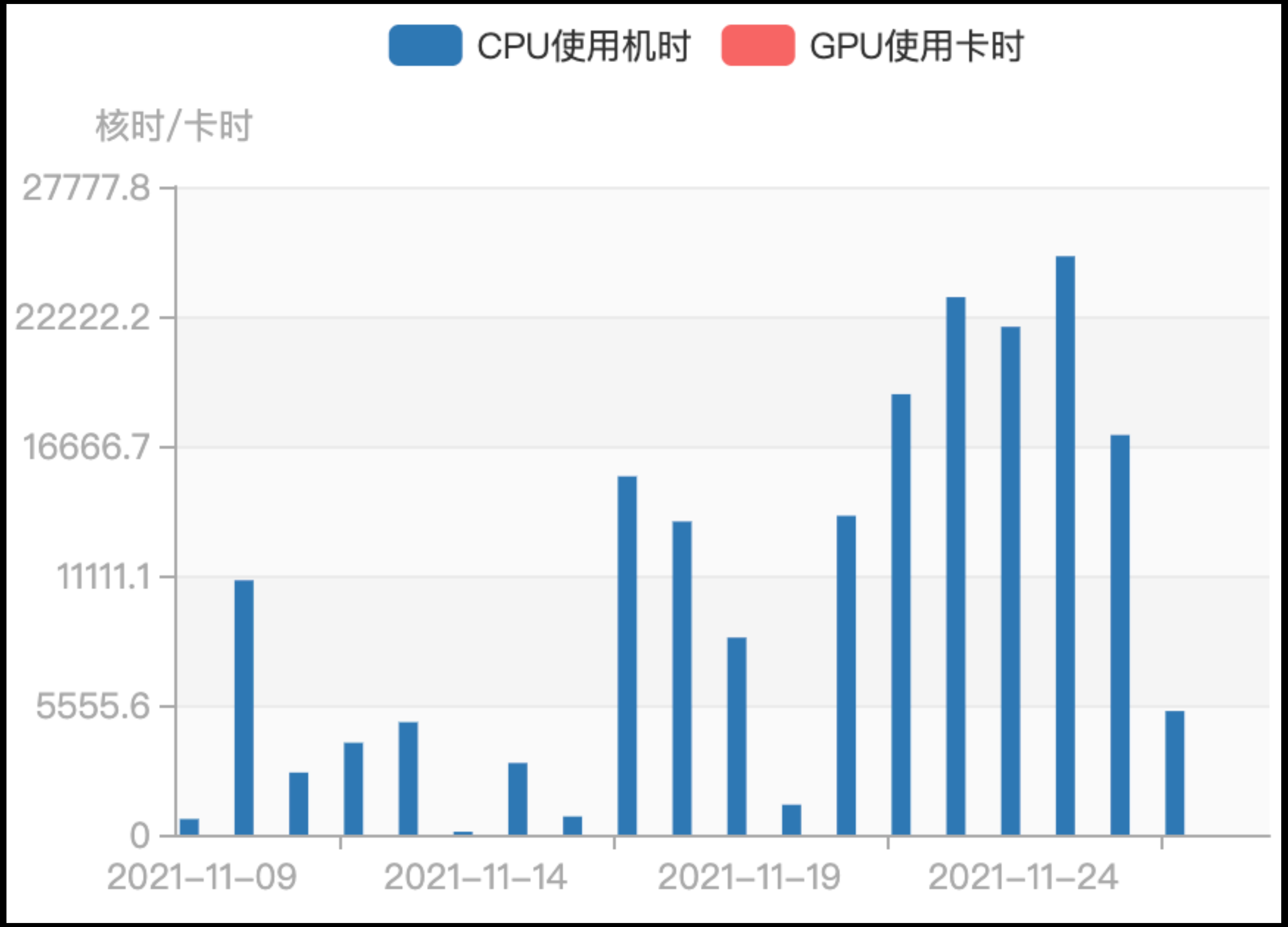
Study Strategy

- We post-process the publicly available data for global fits of SUSY models with additional likelihoods for the proposed Higgs factories.

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

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

- This is extremely time consuming.
- In total, we pose-processed 7.1×10^7 viable samples for CMSSM, 9.4×10^7samples for NUHM1, 1.2×10^8 samples for NUHM1, and 1.8×10^8 samples for MSSM7. Each of the model took on the order of a few days to run on 1280 supercomputer cores.

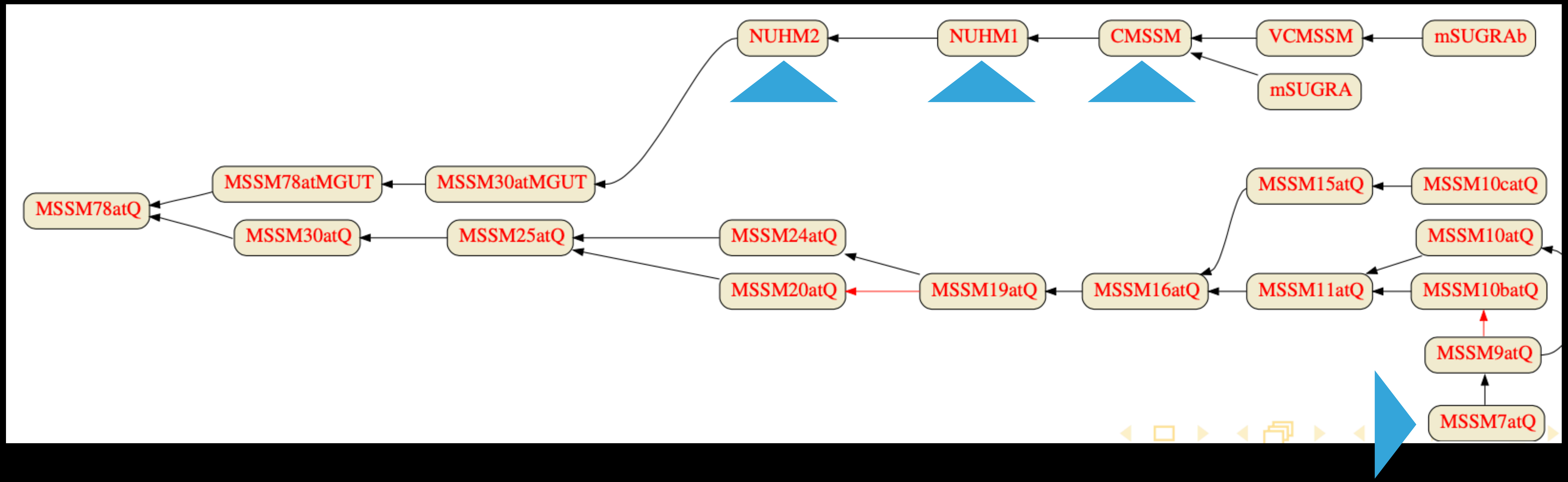


CMSSM, NHUM1, NUHM2 and MSSM7

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

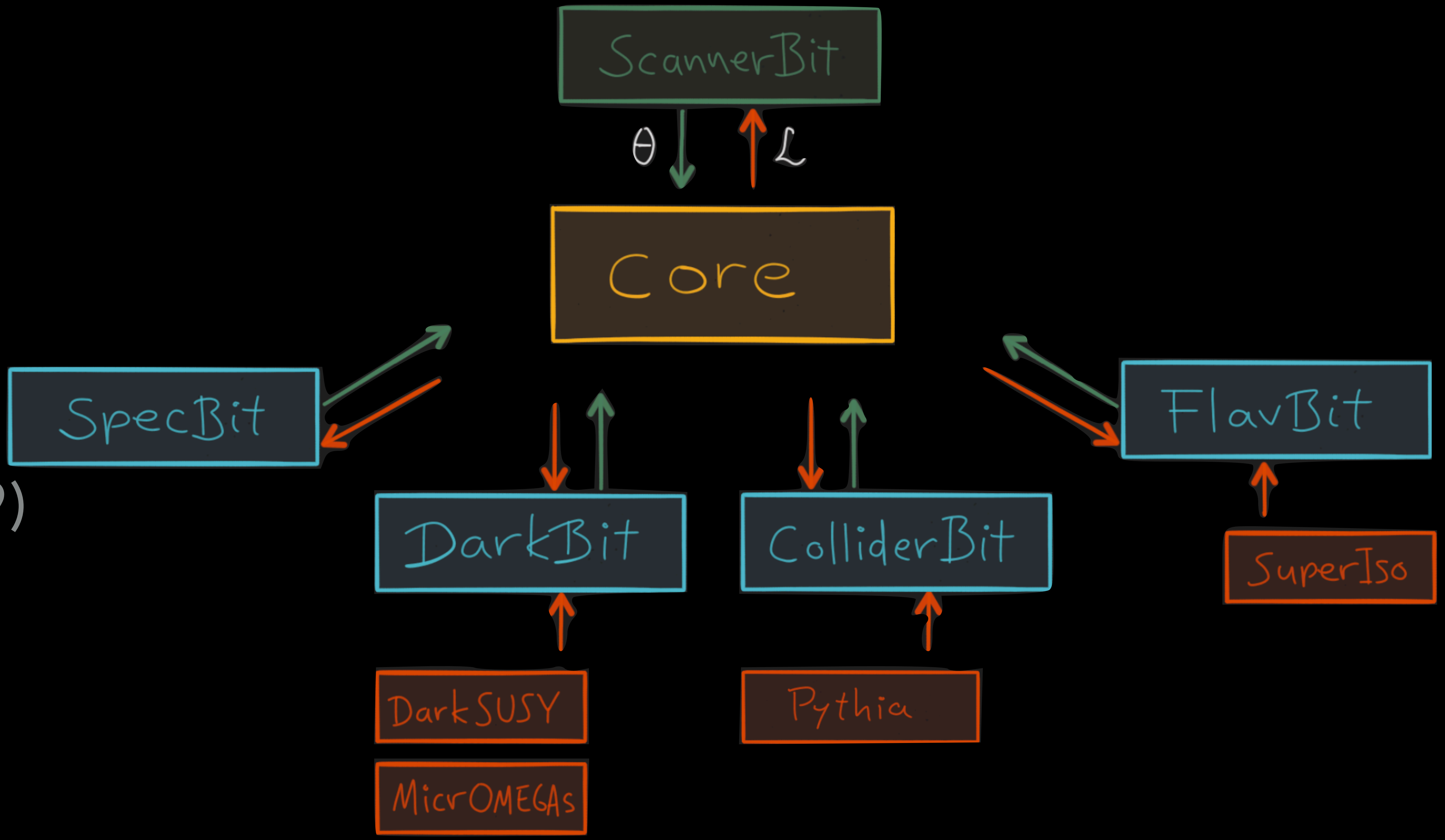


- Weak scale

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

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

Present 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, …

✳ 5 nuisances:

  - local DM density, nuclear physics parameters, top mass, strong coupling

Higgs likelihood for the proposed Higgs factories

$$-2\ln\mathscr{L} = \frac{(m_h - m_h^{\rm obs})^2}{\sigma^2_{\mu_h}} + \sum \frac{(\mu_i - \mu_i^{\rm obs})^2}{\sigma^2_{\mu_i}}$$

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}

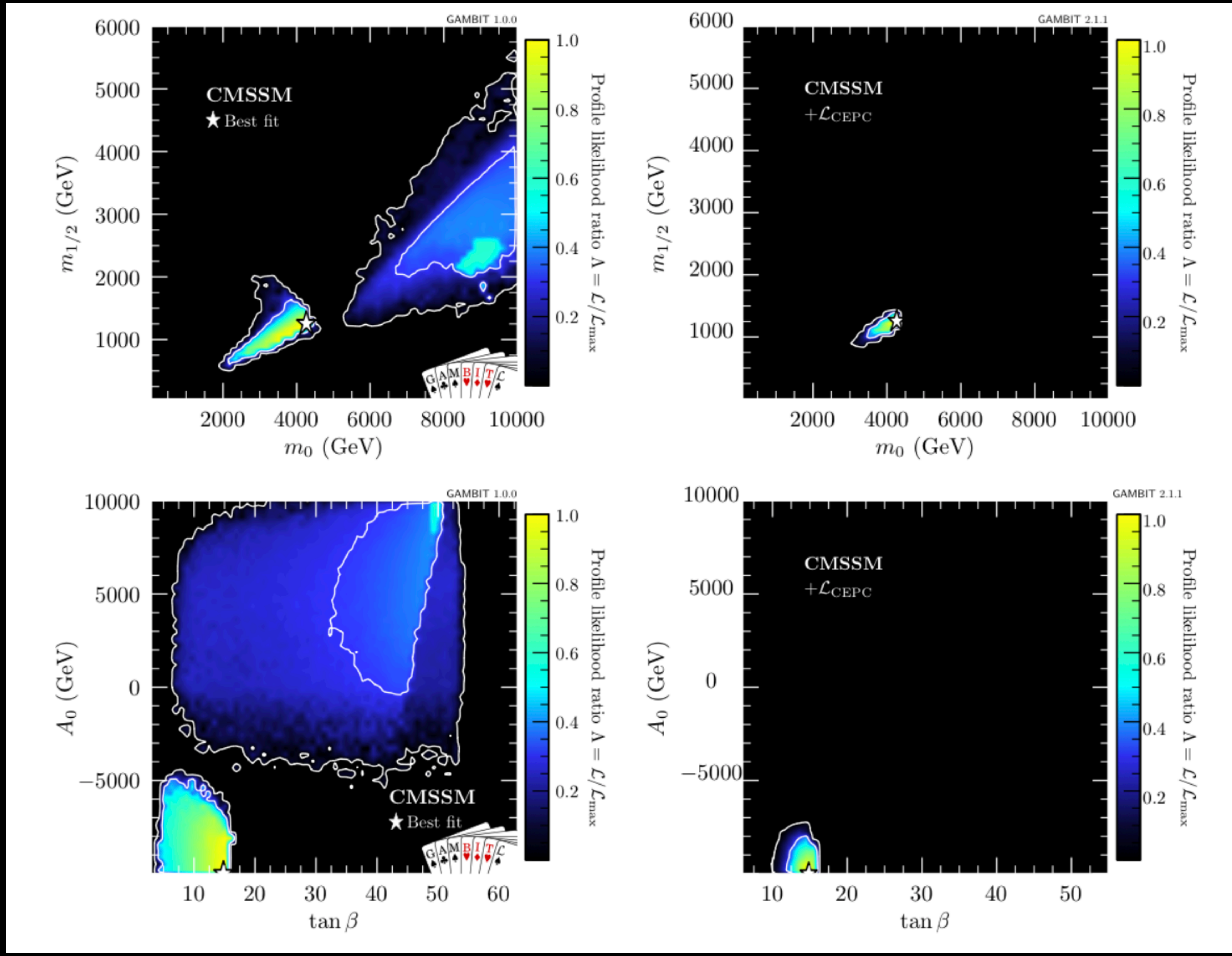
- Two assumptions:
  - $\mu_i^{\rm obs}$, central values of signal strength at future facilities,
  - $\sigma_{\mu_i}^{\rm the}$, theoretical uncertainties.

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%

SM predictions for a 125 GeV Higgs boson

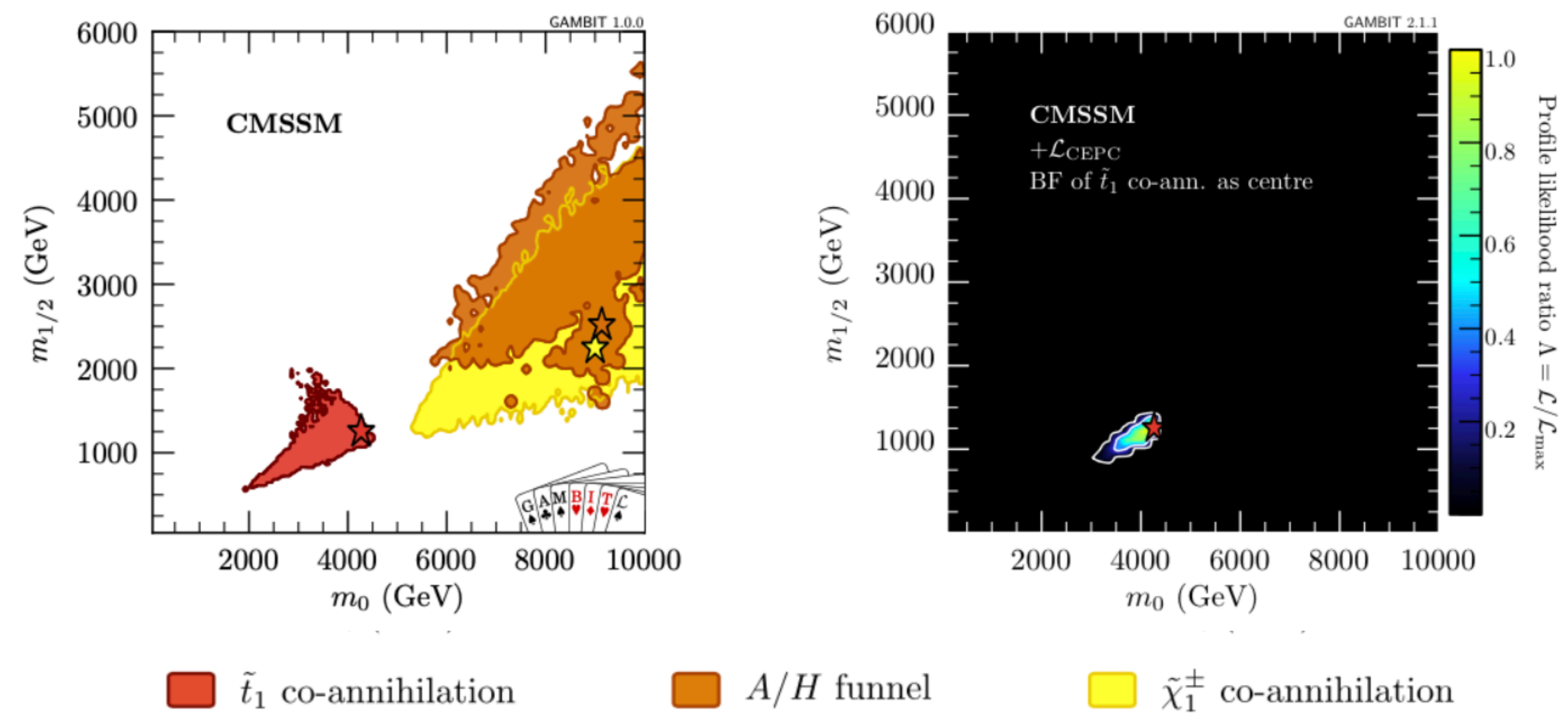
collider	CEPC	FCC-ee			ILC				
$\sqrt{s}$ / $\int \mathcal{L}dt$	240 GeV, 5.6 ab^{-1}	240 GeV, 5 ab^{-1}	365 GeV, 1.5 ab^{-1}		250 GeV, 2 ab^{-1}	350 GeV, 200 fb^{-1}		500 GeV, 4 ab^{-1}	
production	Zh	Zh	Zh	$\nu\bar{\nu}h$	Zh	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$
$\Delta\sigma/\sigma$	0.5%	0.5%	0.9%	−	0.71%	2.0%	−	1.05	−
decay	$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$								
$h \to b\bar{b}$	0.27%	0.3%	0.5%	0.9%	0.46%	1.7%	2.0%	0.63%	0.23%
$h \to c\bar{c}$	3.3%	2.2%	6.5%	10%	2.9%	12.3%	21.2%	4.5%	2.2%
$h \to gg$	1.3%	1.9%	3.5%	4.5%	2.5%	9.4%	8.6%	3.8%	1.5%
$h \to WW^*$	1.0%	1.2%	2.6%	3.0%	1.6%	6.3%	6.4%	1.9%	0.85%
$h \to \tau^+\tau^-$	0.8%	0.9%	1.8%	8.0%	1.1%	4.5%	17.9%	1.5%	2.5%
$h \to ZZ^*$	5.1%	4.4%	12%	10%	6.4%	28.0%	22.4%	8.8%	3.0%
$h \to \gamma\gamma$	6.8%	9.0%	18%	22%	12.0%	43.6%	50.3%	12.0%	6.8%
$h \to \mu^+\mu^-$	17%	19%	40%	−	25.5%	97.3%	178.9%	30.0%	25.0%
$(\nu\bar{\nu})h \to b\bar{b}$	2.8%	3.1%	−	−	3.7%	−	−	−	−

Profile likelihood ratio in CMSSM



- Profile likelihood ratio in planes of the CMSSM parameters
- Left panels: present likelihood
- Right panels: present likelihood + $\mathscr{L}_{\mathrm{CEPC}}$
- The central values of measurements at CEPC are values of the best-fit point, and the theoretical uncertainties are $k=1/5$ times smaller than the current SM value.
- The position of the best-fit point holds still, and the preferred regions shrink significantly towards the the best-fit point.

Profile likelihood ratio in CMSSM

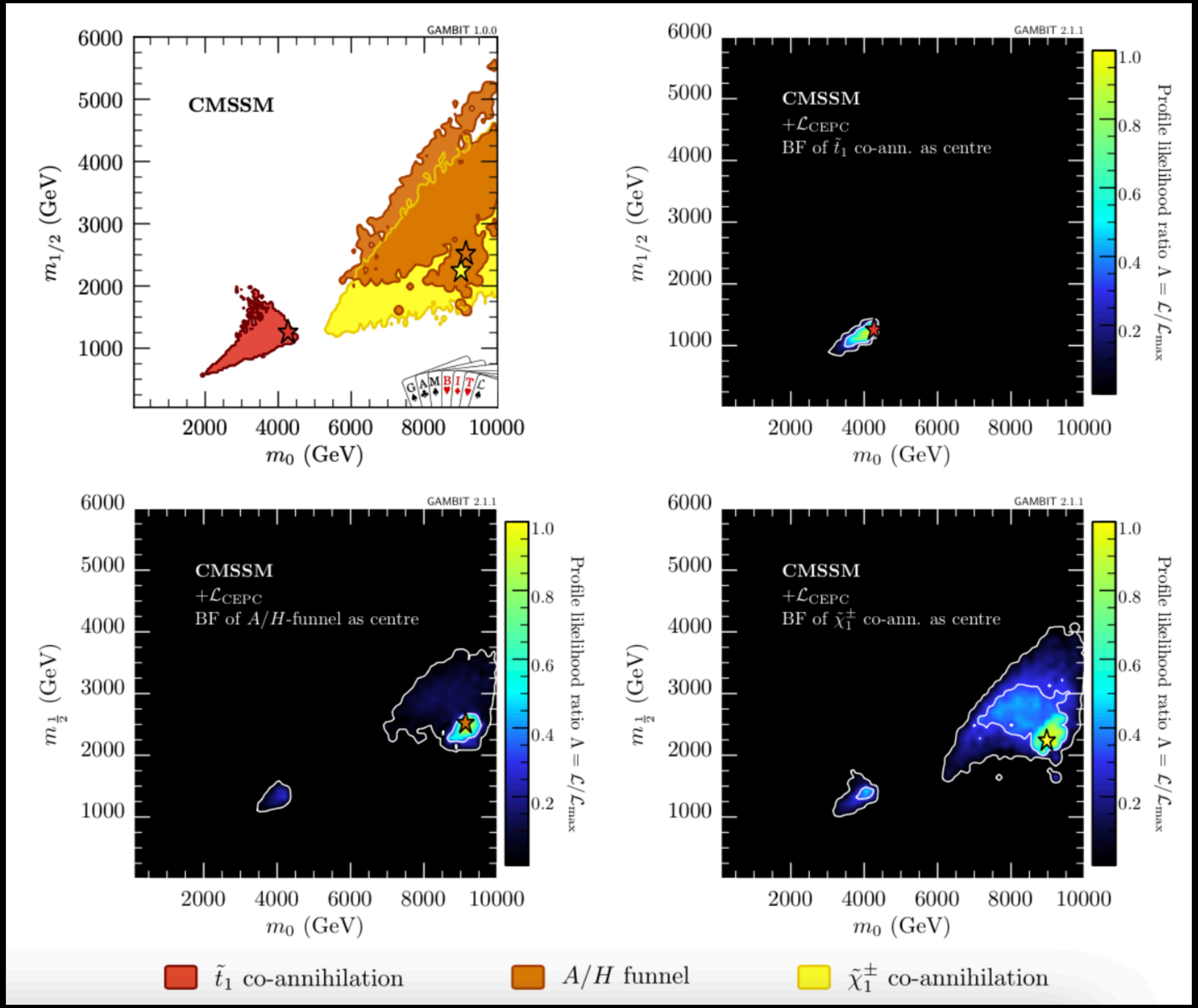


Decay mode	A/H-funnel	$\tilde{\chi}_1^{\pm}$ co-ann.	$\tilde{t}$ co-ann.	Abs. error
$h \to b\bar{b}$	60.29%	60.87%	58.89%	0.98%
$h \to c\bar{c}$	3.39%	3.35%	3.44%	0.24%
$h \to gg$	6.81%	6.74%	6.55%	0.34%
$h \to WW^*$	20.14%	19.80%	21.48%	0.51%
$h \to ZZ^*$	2.53%	2.48%	2.72%	0.15%
$h \to \gamma\gamma$	2.64×10^{-3}	2.60×10^{-3}	2.76×10^{-3}	0.20×10^{-3}
$h \to \tau^+\tau^-$	6.37%	6.32%	6.44%	0.19%
$h \to \mu^+\mu^-$	2.26×10^{-4}	2.24×10^{-4}	2.28×10^{-4}	0.39×10^{-4}

- stop co-annihilation: $m_{\tilde{t}_1} \leq 1.2\, m_{\tilde{\chi}_1^0}$,
- A/H-funnel: $1.6\, m_{\tilde{\chi}_1^0} \leq m_{\rm heavy} \leq 2.4\, m_{\tilde{\chi}_1^0}$,
- chargino co-annihilation: $\tilde{\chi}_1^0 \geq 50\%$ Higgsino,

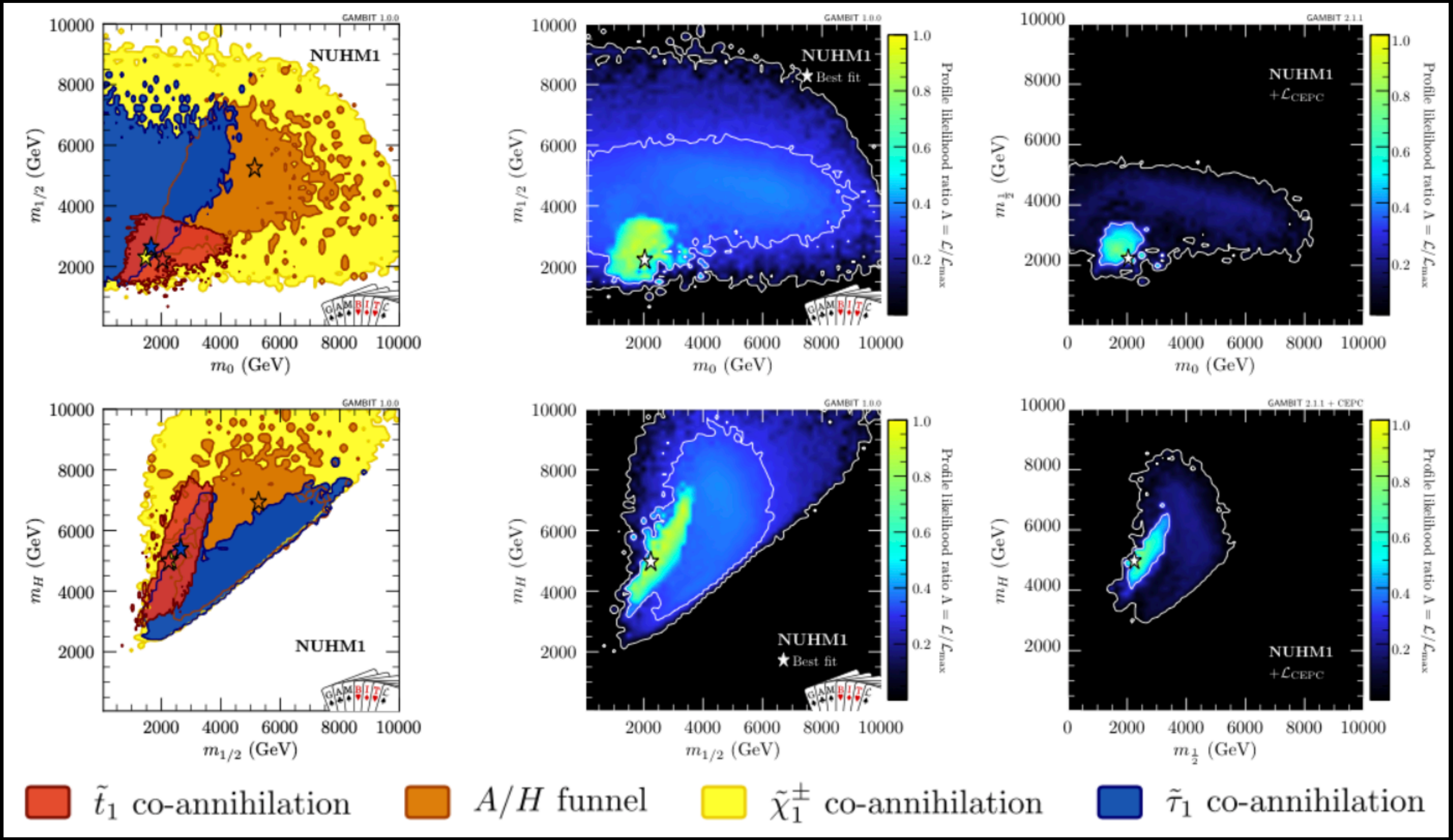
- The differences of BR($h \to b\bar{b}$), BR($h \to WW^*$) and BR($h \to ZZ^*$) between the best fit point of the stop co-annihilation region and the A/H-funnel region or the $\tilde{\chi}_1^{\pm}$ co-annihilation region are obviously larger than the corresponding total absolute uncertainties.
- The sign of μ in the remaining stop co-annihilation regions is always negative.
- In CMSSM, the precision of CEPC can distinguish possible DM annihilation mechanisms and sign of μ parameter.

Assumption about central values of Higgs measurements at CEPC



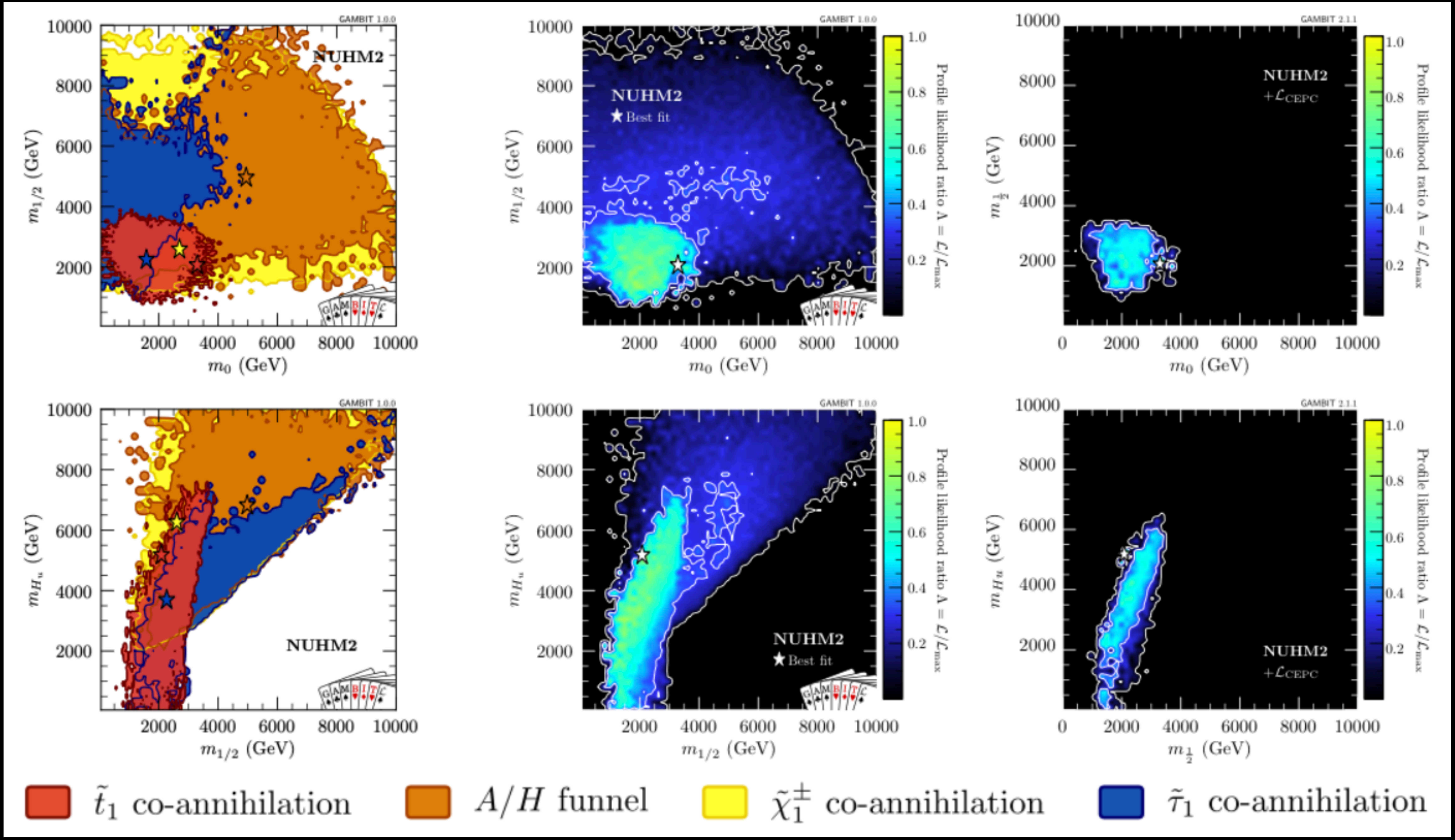
- It is obvious that the results depend on the assumptions about central values of Higgs measurements at CEPC.
- We display the 2D profile likelihoods assuming the central values of CEPC to be values of best fit point in each DM annihilation region.
- The favored regions change dramatically, and are not shrunk as much as before.
- In all cases, the μ parameter is negative in the whole favored regions.

Profile likelihood ratio in NUHM1 and NUHM2



- There is a stau co-annihilation region in results of NUHM1 and NUHM2.
- The μ parameters decouples from the m_0, leading to arbitrarily light Higgsino.
- The best fit points in both the NUHM1 and NUHM2 result are also located in the stop co-annihilation region, with $\mathscr{L}$ slightly larger the best fit point of CMSSM.

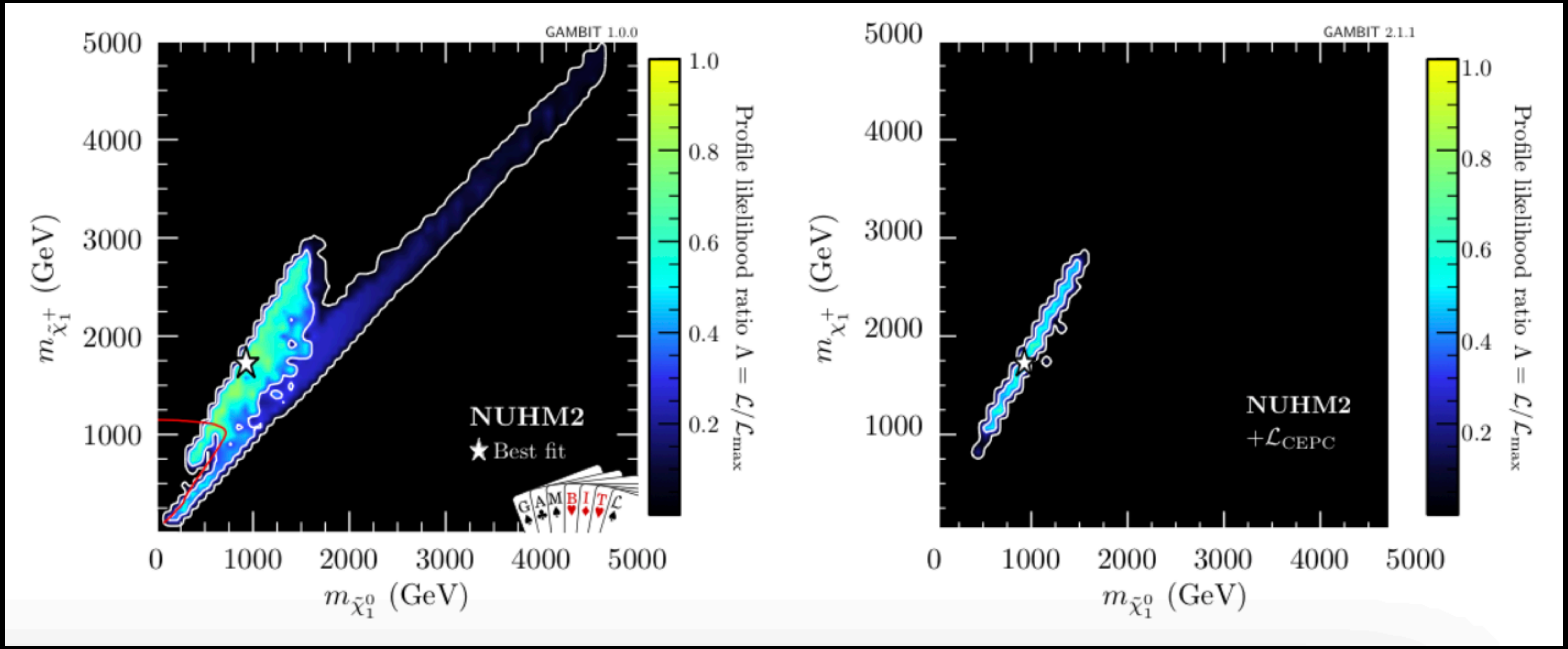
Profile likelihood ratio in NUHM1 and NUHM2



- The result are similar to CMSSM, but with larger favored regions, as expected.
- In comparison to the NUHM1 results, NUHM2 has larger 68% CL region, but smaller 95% CL region.
- It is because $\Delta\mathscr{L}$ between the overall best fit point and the best fit point in other regions is larger in NUHM2 than in NUHM1.

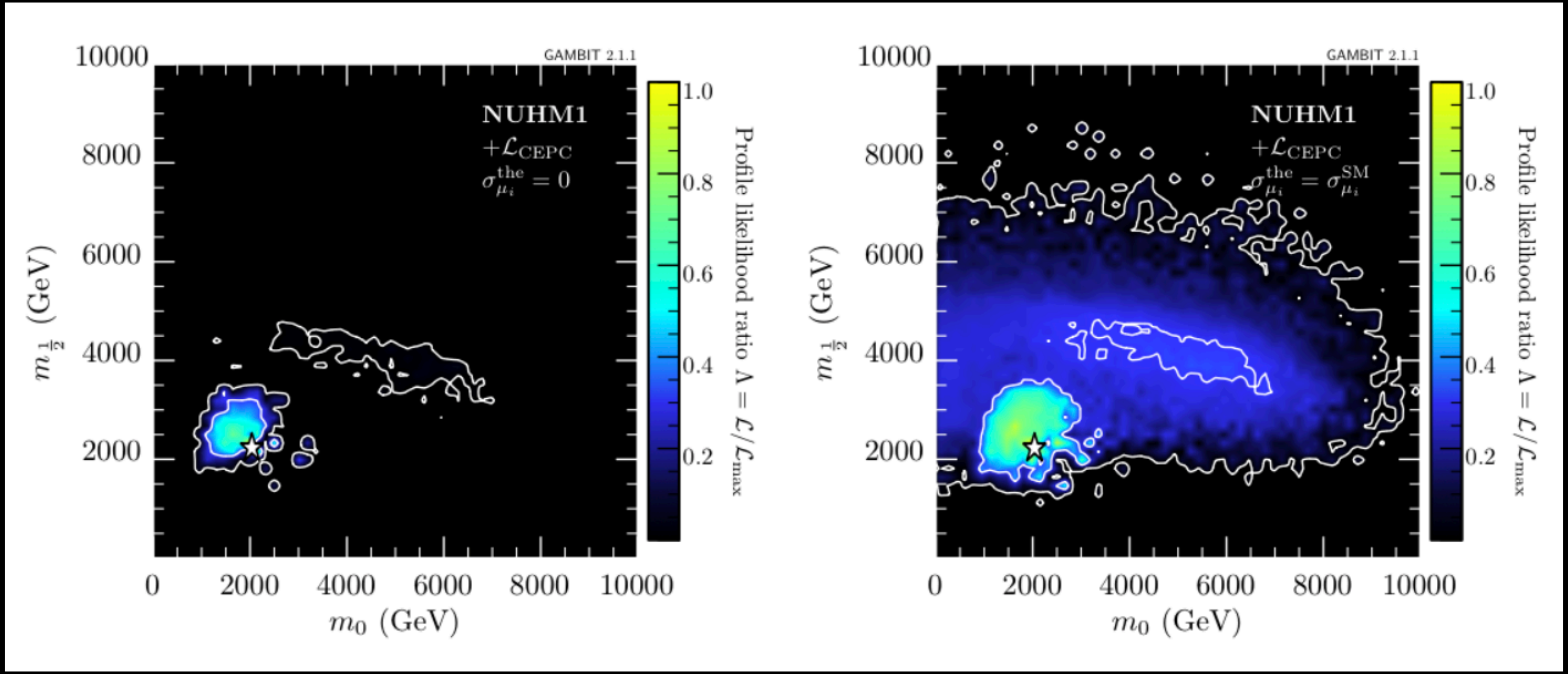
Profile likelihood ratio in NUHM1 and NUHM2

- As the DM annihilation mechanisms instruct relationship between sparticle masses, the masses of sparticle can be restricted into limited ranges.

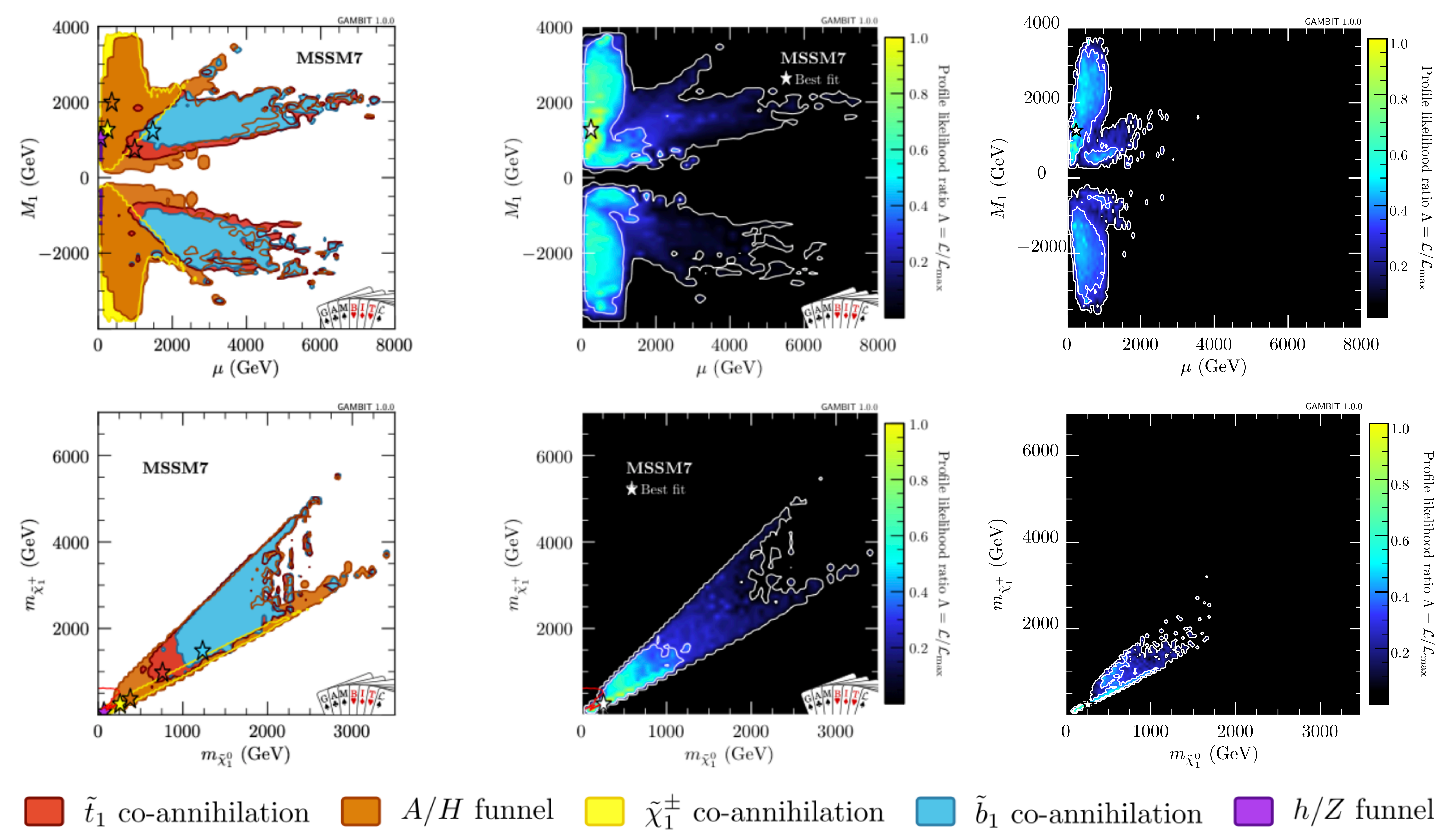


Assumption about theoretical uncertainty

- Left: no no theoretical uncertainties
- Right: equal to current theoretical uncertainties of SM Higgs



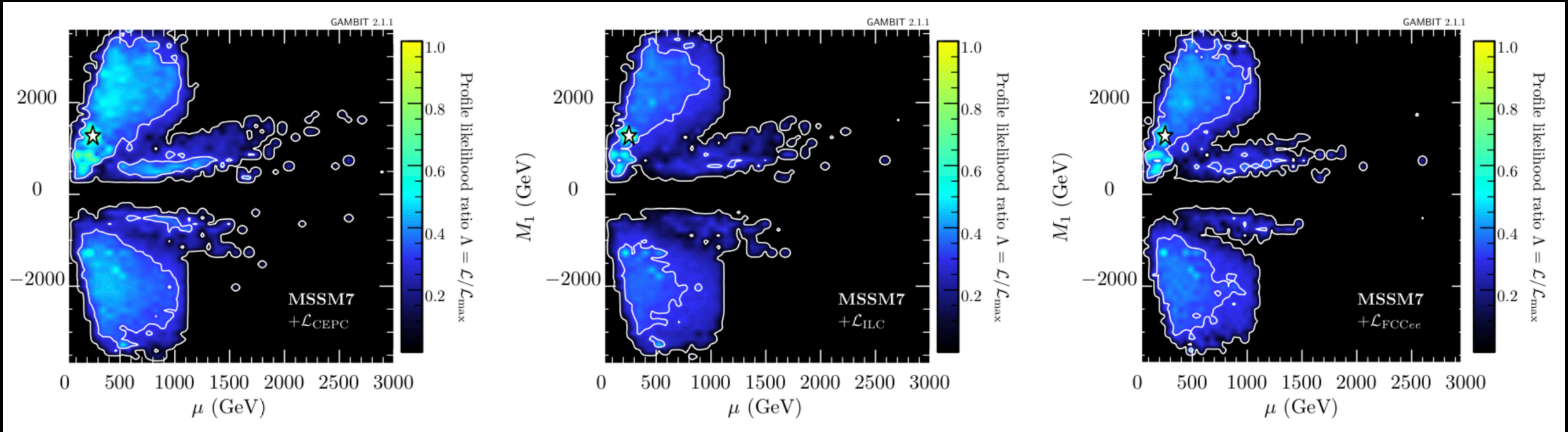
Profile likelihood ratio in MSSM7



- Two new regions, sbottom co-annihilation region and light higgs funnel region, appears.
- The best fit point is located in chargino co-annihilation region.
- It is hard to distinguish between chargino co-annihilation region and A/H funnel region by Higgs measurements.
- Moreover, both negative and positive mu are found in the 95% CL region.

Comparison between different Higgs factories

- The preferred regions for ILC is smaller than for FCCee and CEPC, mainly because of better precisions on BR($h \to b\bar{b}$), BR($h \to WW^*$), given the various center of mass energy options. The main change in the preferred regions is 1σ A/H funnel region, while seemed to vanish in results for ILC.



Summary

- The first version is almost ready. Plan to finish it before Feb. 15.
- We compare profile likelihoods with and without the additional likelihood for Higgs measurements at future electron-positron colliders, by taking CEPC as representative, in CMSSM, NUHM1, NUHM2 and MSSM7, respectively.
- We find that precision of future Higgs factories may distinguish possible DM annihilation mechanisms and sign of μ parameter.
- Moreover, the dependence of the results on assumptions about central values of Higgs measurements at future facilities and theoretical uncertainties are investigated.
- We also compare the sensitivity of CEPC FCC-ee and ILC.

THANK YOU.