BSM Prospect at the CEPC

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The 7th China LHC Physics Workshop, 2021.11.27

CEPC BSM White Paper: ToC

BSM working group formed @ 2021.4 Yangzhou WS

BSM prospect at the CEPC

Contributions to Snowmass2021:

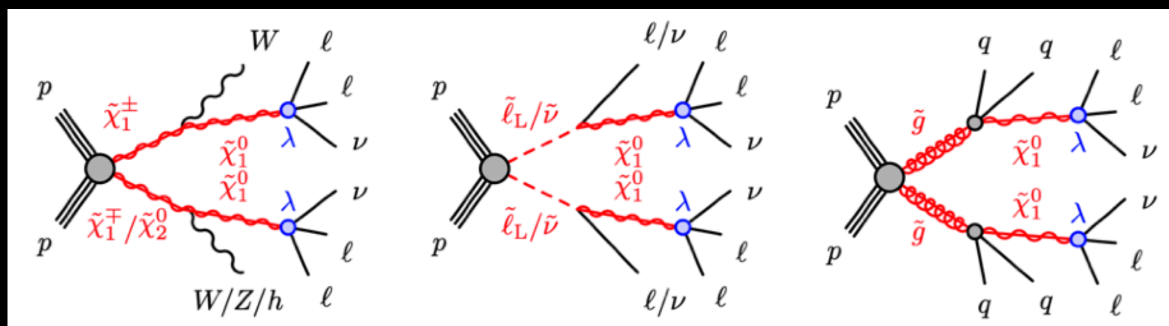
- Supersymmetry searches
  - Direct searches for sleptons and electroweakinos
  - Global fit of SUSY
- Two Higgs doublet model searches
- Dark Matter searches
  - Axion-like particles
  - Asymmetric DM
  - Lepton portal DM
- Electroweak phase transition
- … …

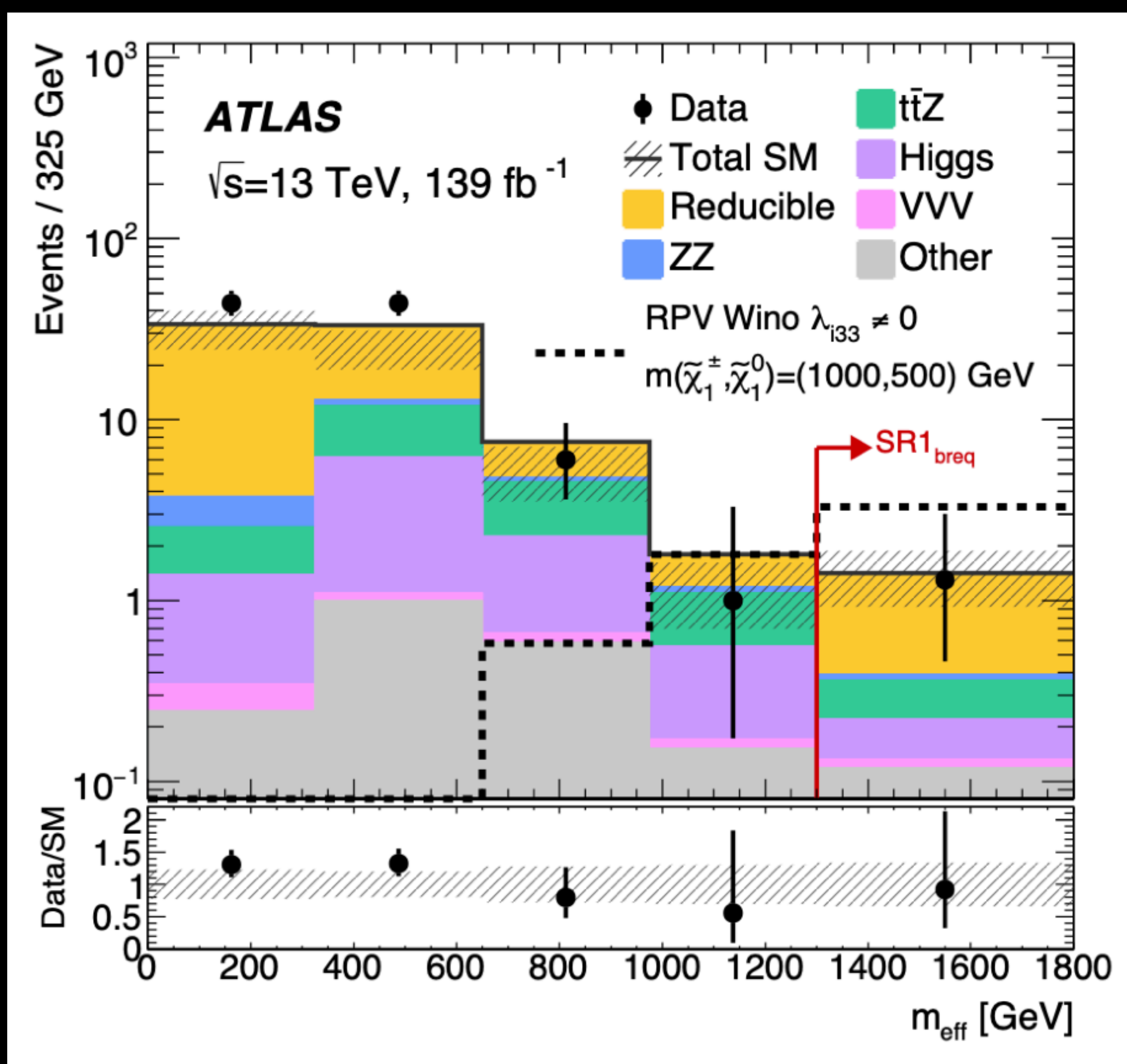
Supersymmetry searches at CEPC

References:

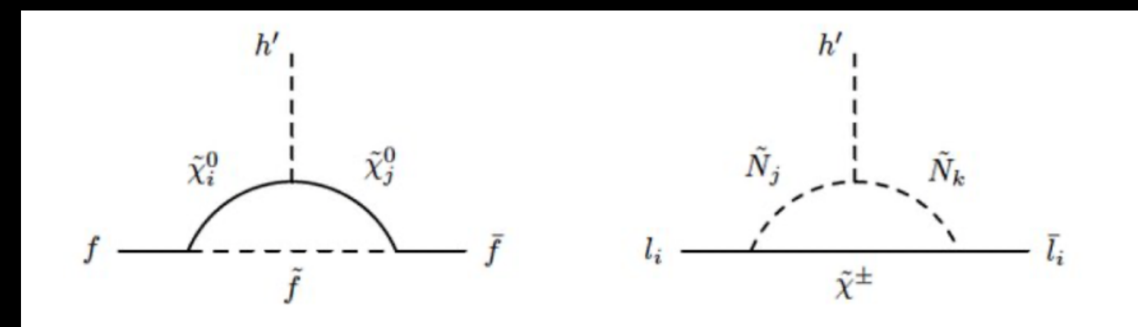
https://arxiv.org/pdf/2105.06135.pdf
https://arxiv.org/pdf/2101.12131.pdf
https://arxiv.org/pdf/2010.09782.pdf
https://indico.ihep.ac.cn/event/14938/session/13/contribution/99/material/slides/0.pdf
https://indico.ihep.ac.cn/event/14938/session/13/contribution/138/material/slides/0.pdf
https://indico.fnal.gov/event/50140/contributions/220054/attachments/145453/185187/20210722Snowmass.pdf

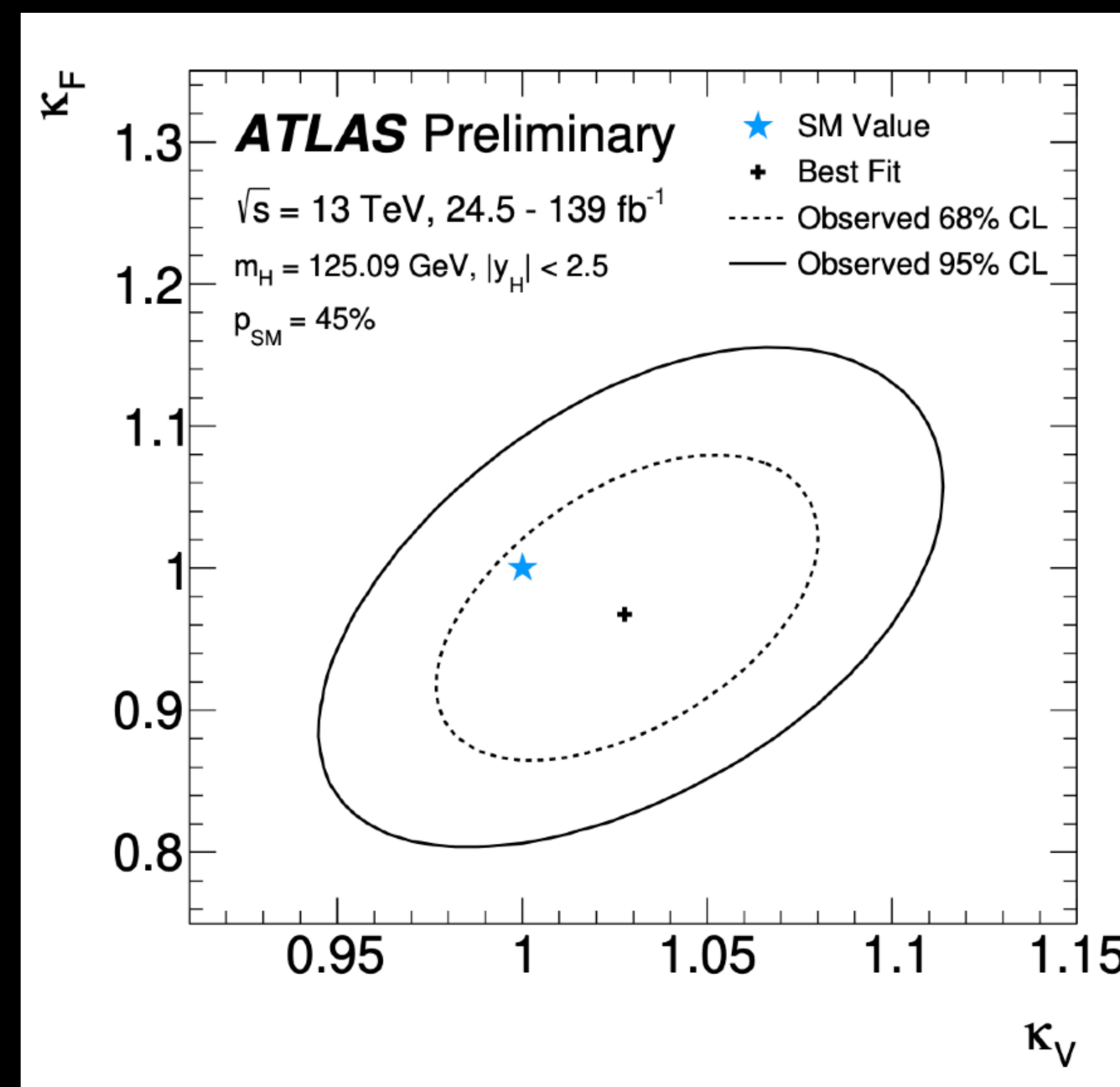
Direct searches





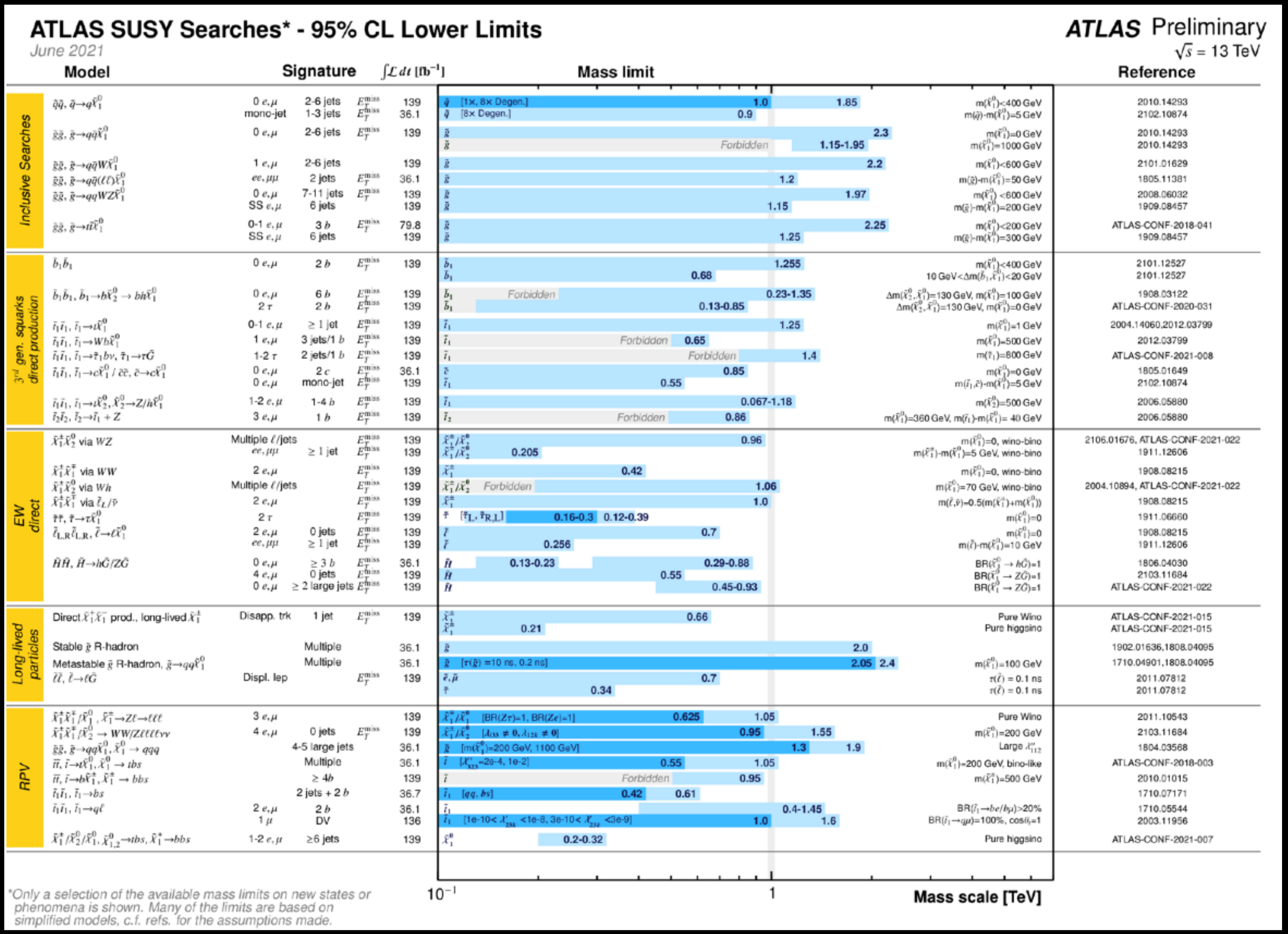
Indirect searches





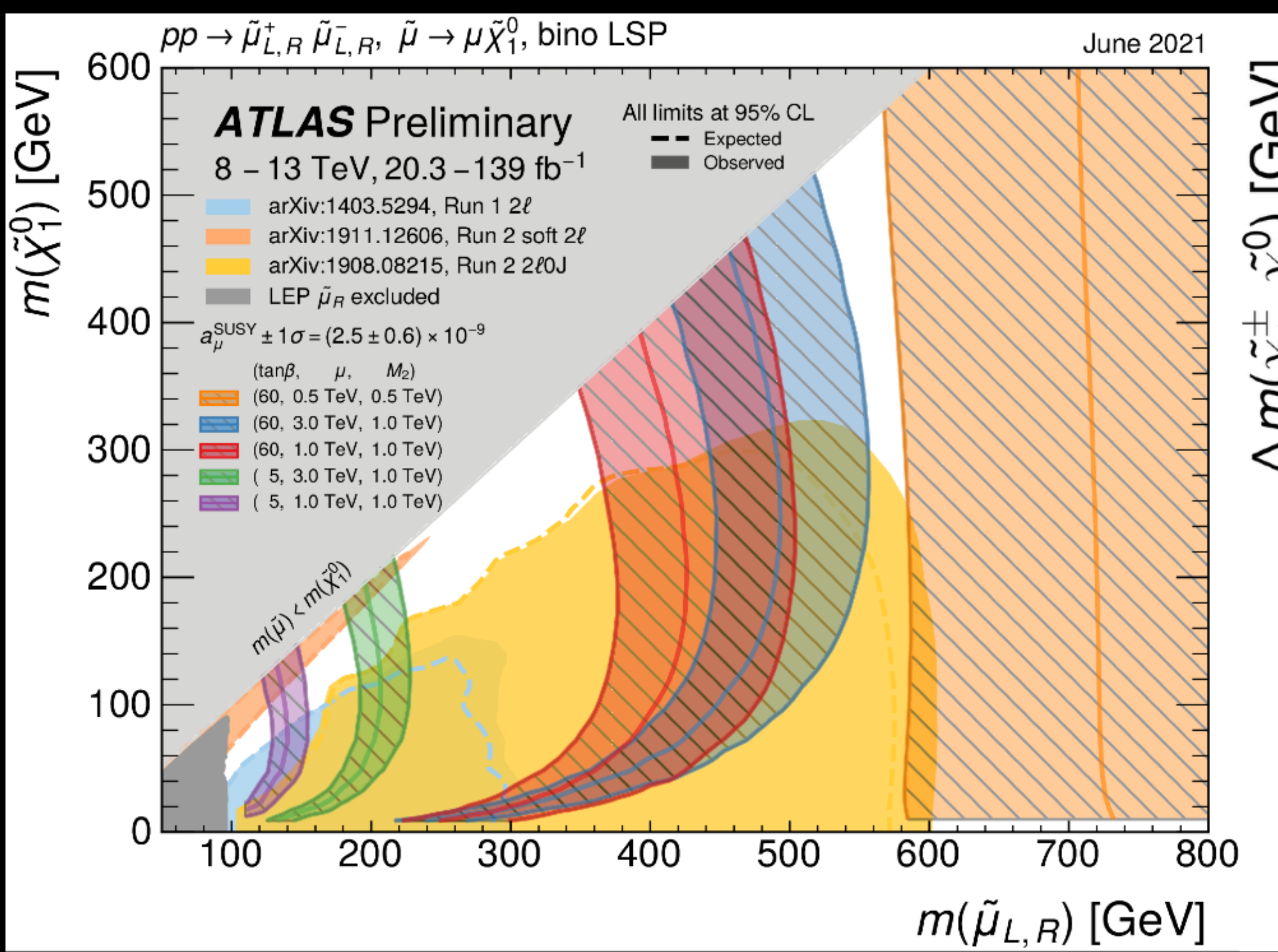
LHC direct searches

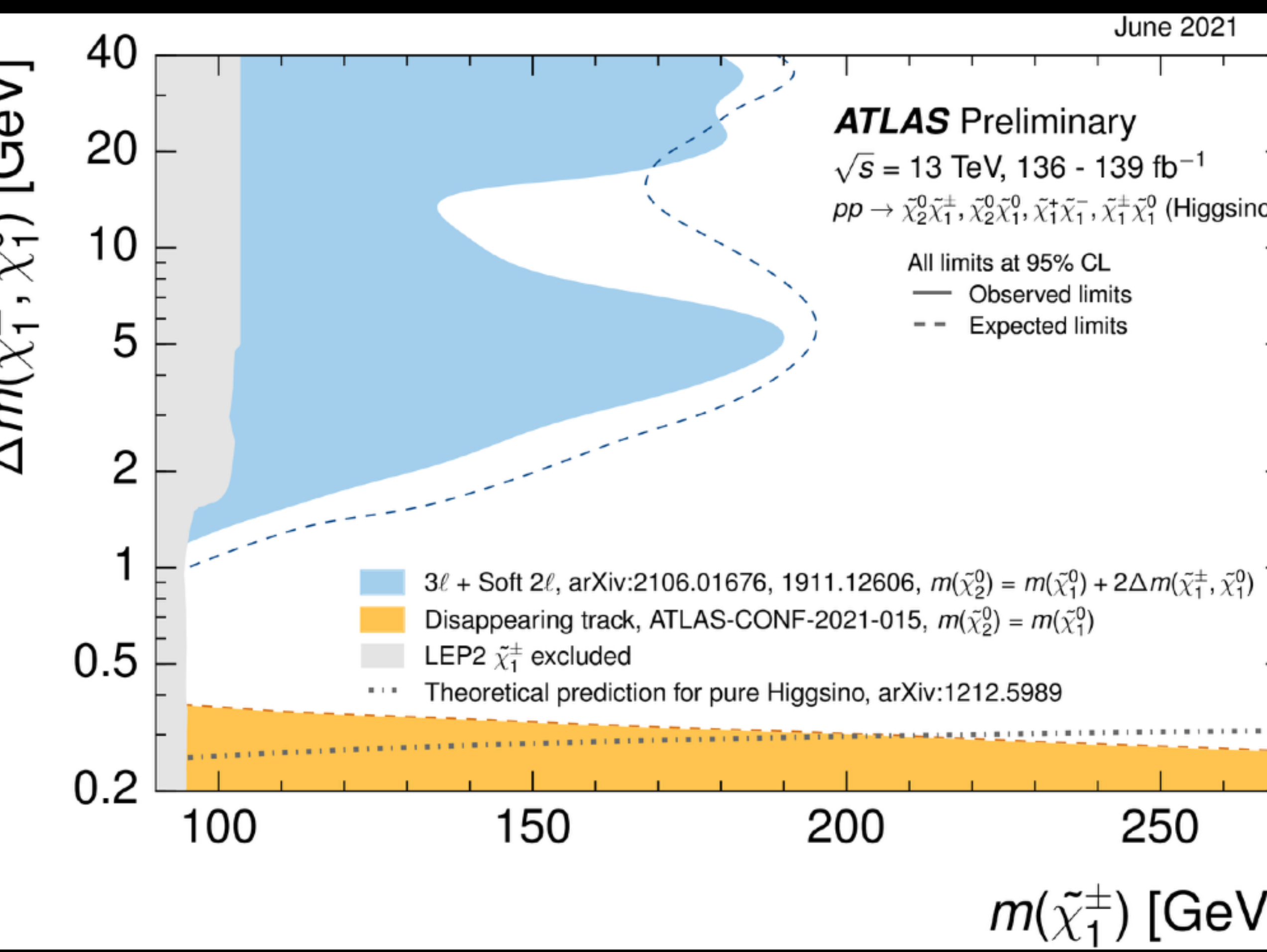
- In most of the SUSY parameter spaces, the mass bounds from LHC have reached TeV scale.
- They are way beyond the center-of-mass energy of CEPC.



LHC direct searches

- However, due to large backgrounds, the compressed spectrum are very difficult to be covered for LHC and even HL-LHC.





LHC direct searches

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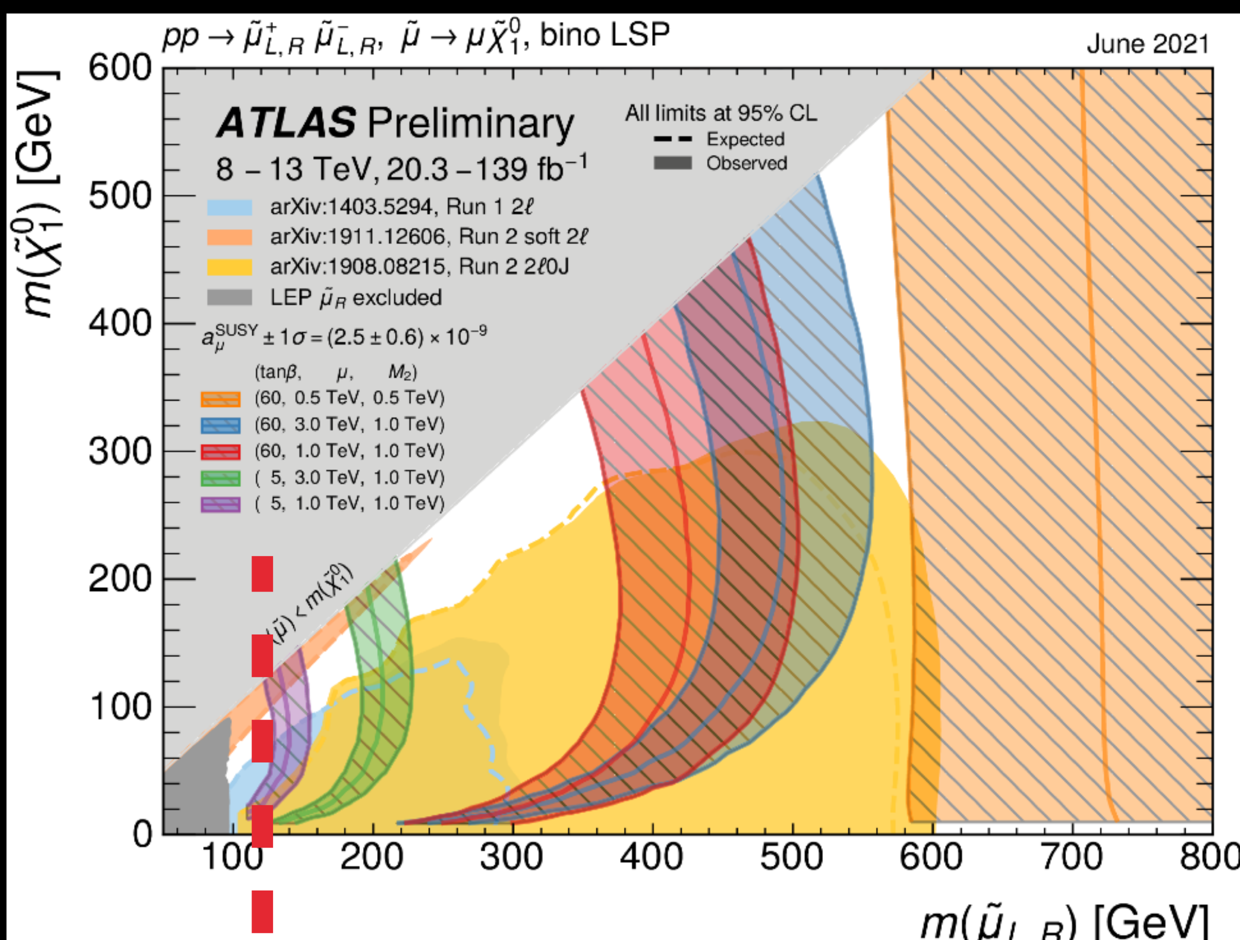
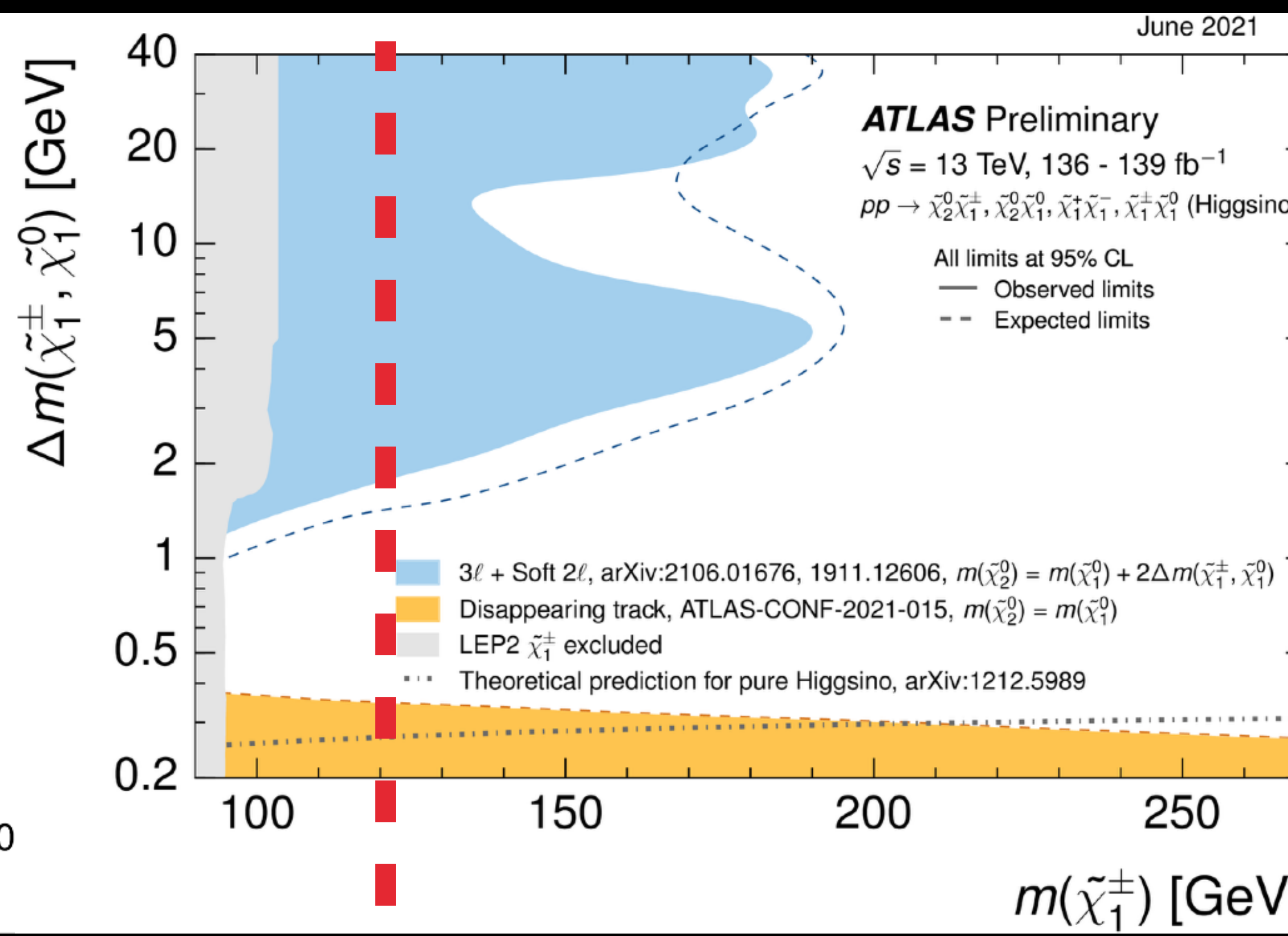
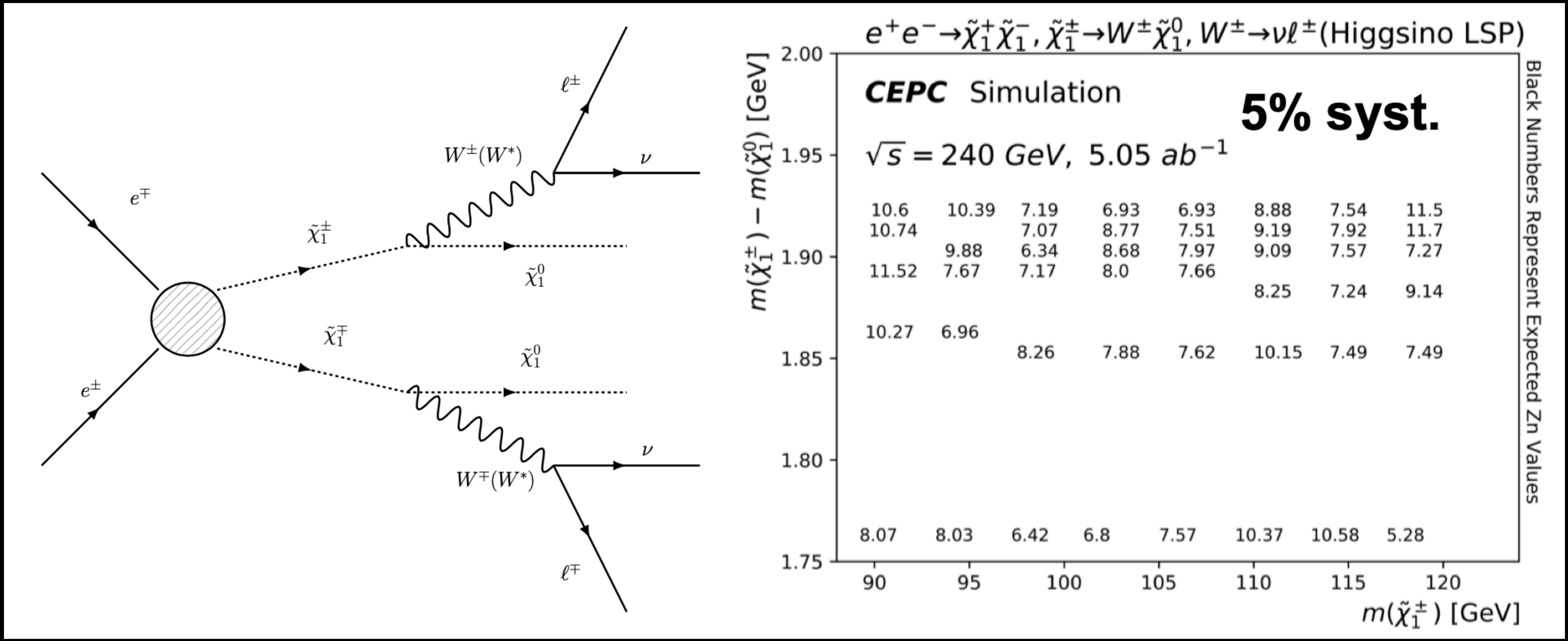




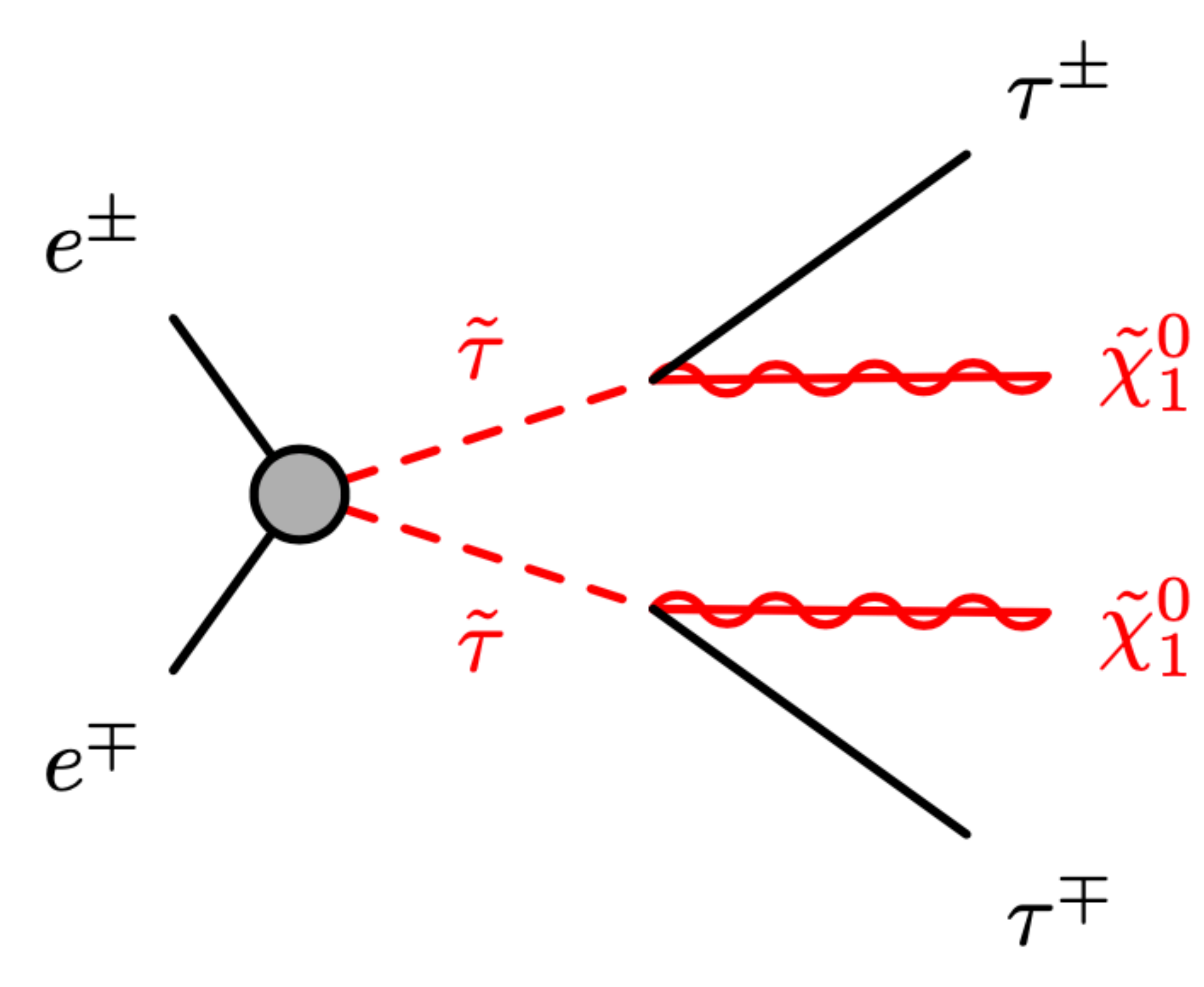
Chargino search at CEPC

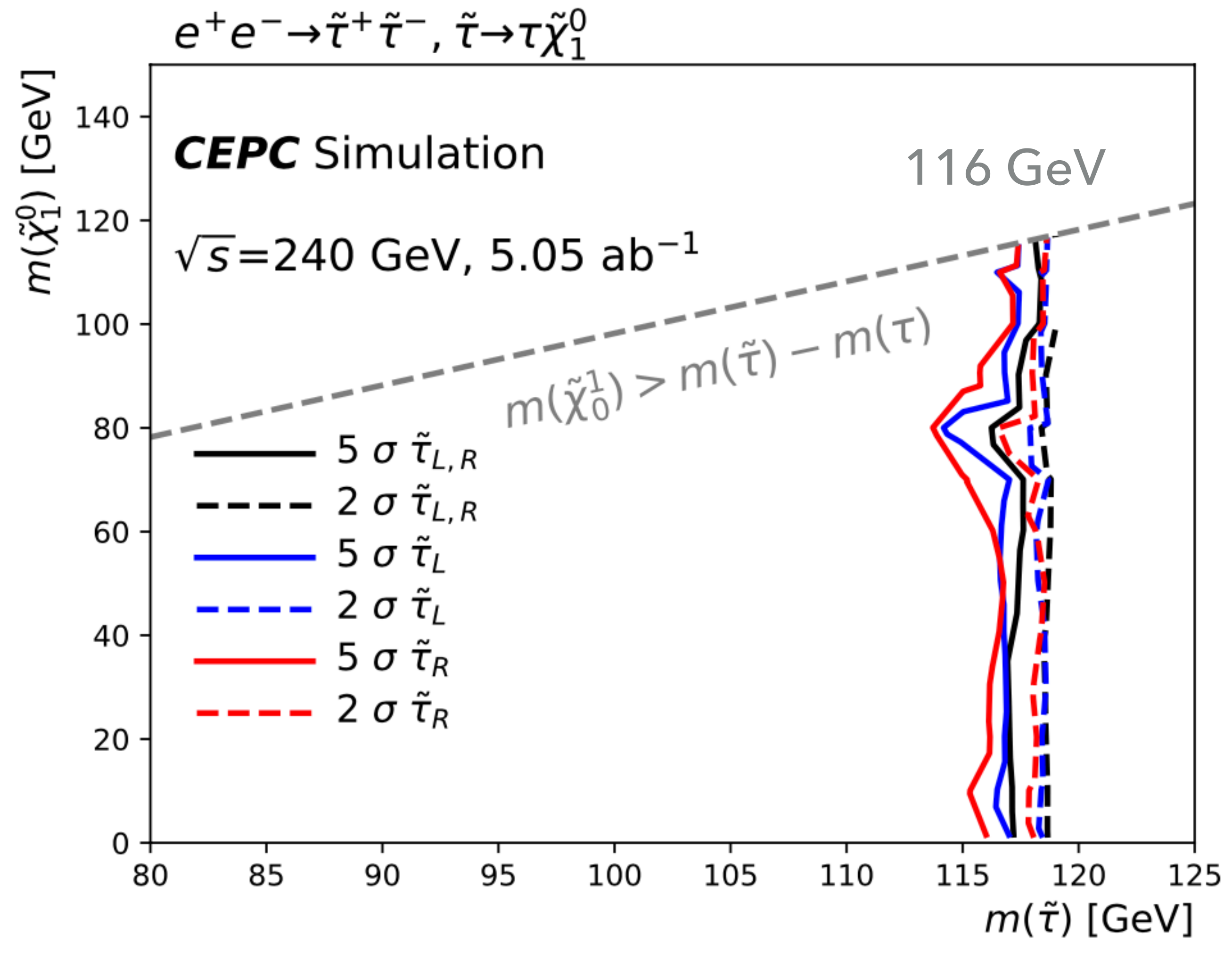
- Prospects for chargino pair production at CEPC, Jia-Rong Yuan, Hua-Jie Cheng, Xu-Ai Zhuang, arXiv:2105.06135.



Slepton search at CEPC

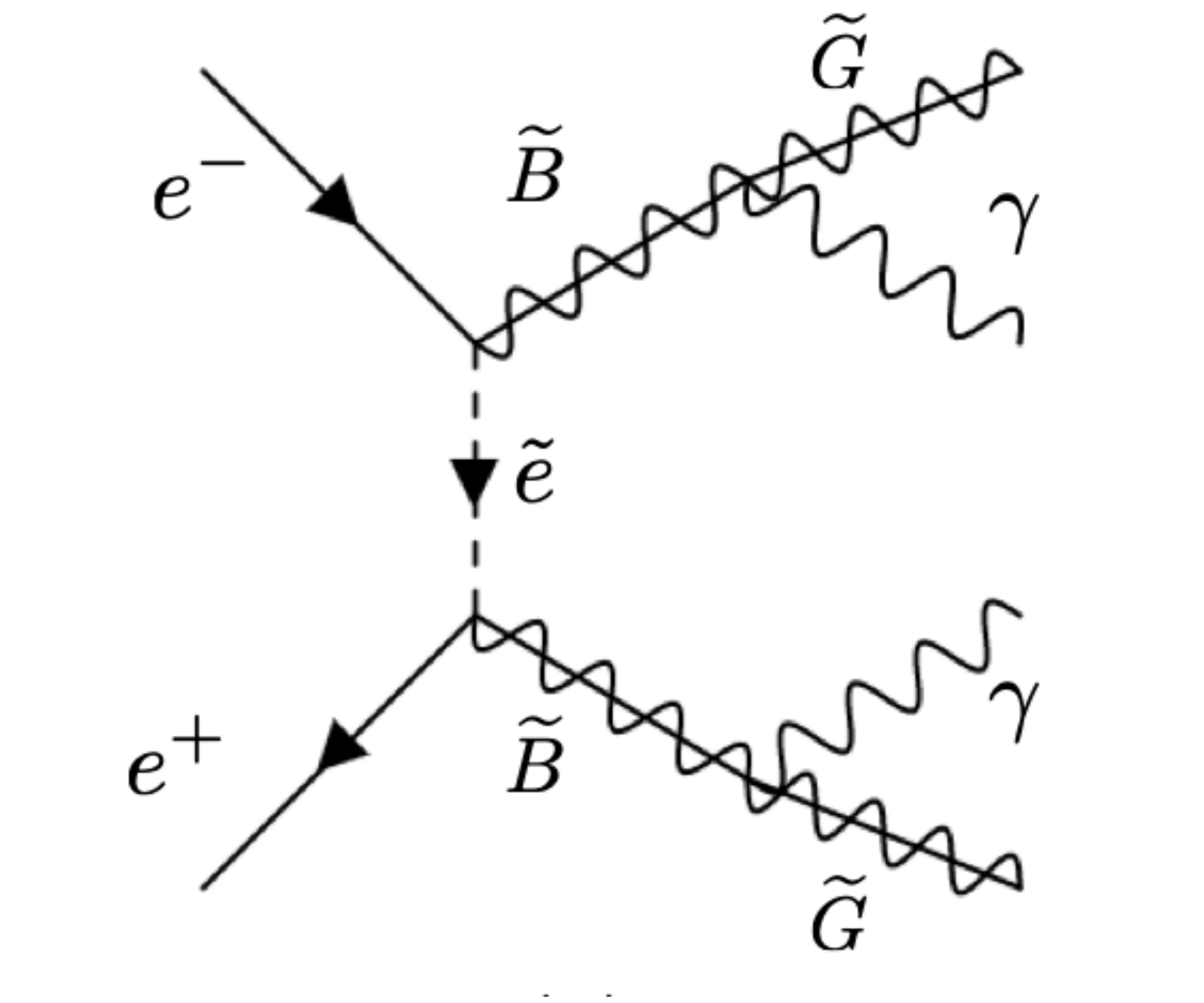
- Prospects for slepton pair production in the future e^+e^- Higgs factories, Jia-Rong Yuan, Hua-Jie Cheng, Xu-Ai Zhuang.

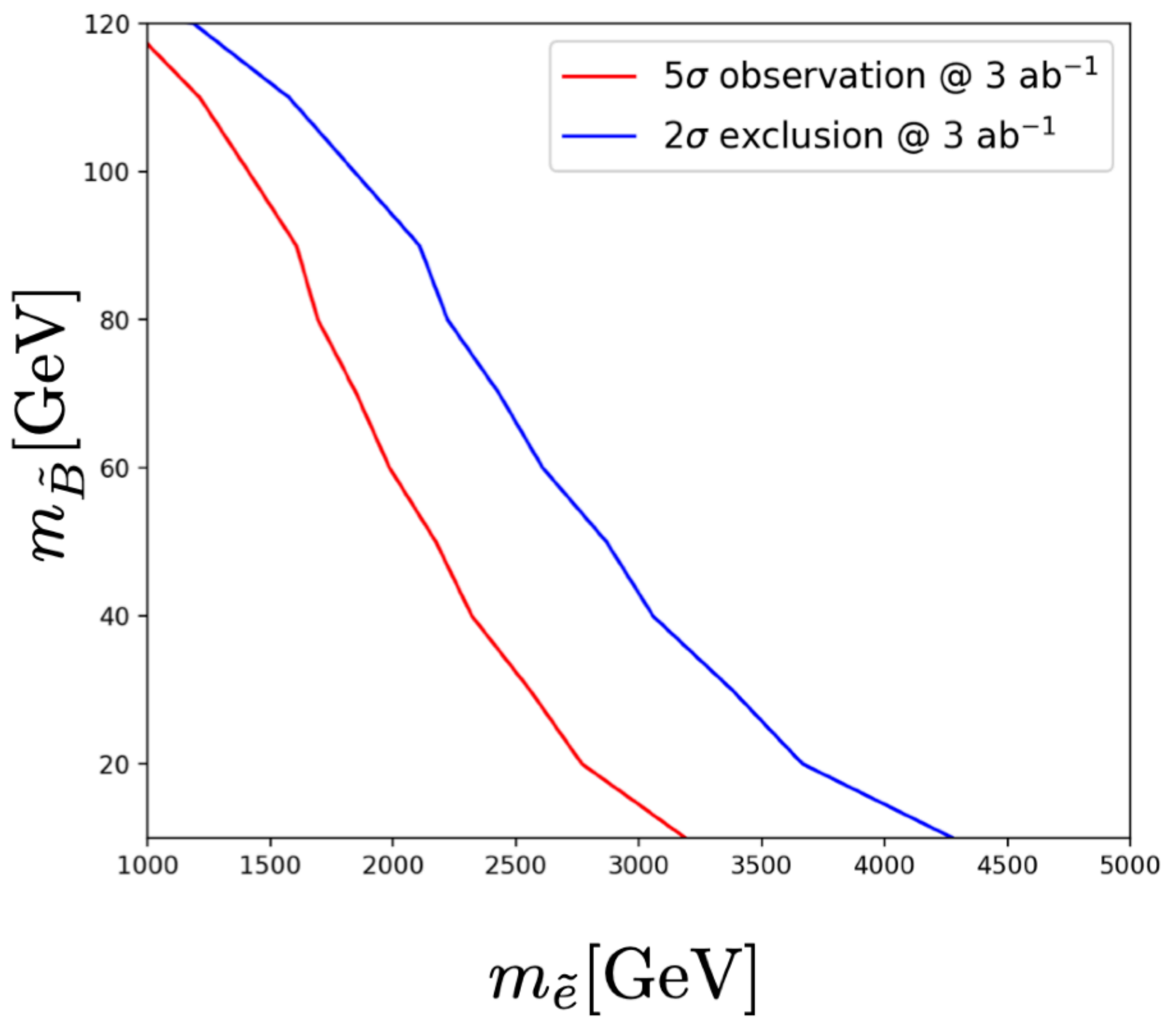




Neutralino search at CEPC

- Probing bino NLSP at lepton colliders, Junmou Chen, Chengcheng Han, Jin Min Yang, Mengchao Zhang, arXiv:2101.12131.





Neutralino search at CEPC

- Probing relatively heavier selectron in the GmSUGRA, by Waqas Ahmed, Imtiaz Khan, Tianjun Li, Shabbar Raza and Wenxing Zhang.
- There two types of light neutralinos that achieve the correct relic density by Z-resonance and h-resonance.

The EWSSUY from General minimal Supergravity (GmSUGRA) Model

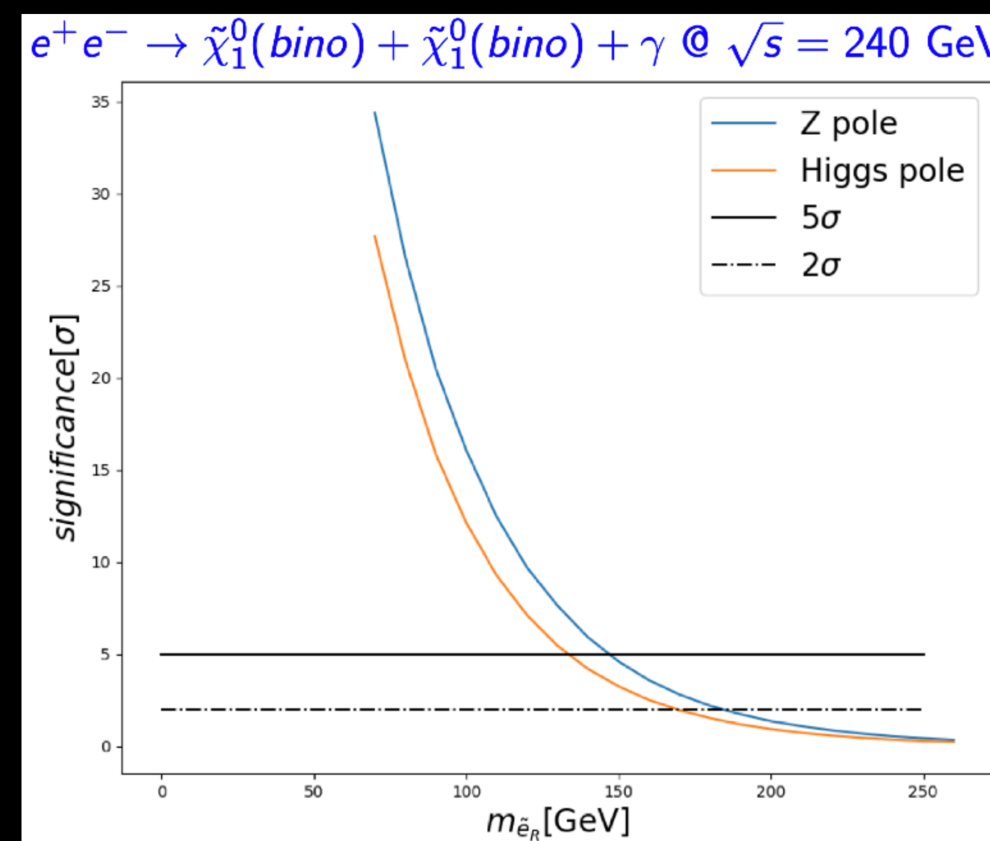
$$M_3 = \frac{5}{2}\,M_1 - \frac{3}{2}\,M_2 \ .$$

$$m^2_{\tilde{Q}_i} = \frac{5}{6}(m_0^U)^2 + \frac{1}{6}m^2_{\tilde{E}_i^c} \ ,$$

$$m^2_{\tilde{U}_i^c} = \frac{5}{3}(m_0^U)^2 - \frac{2}{3}m^2_{\tilde{E}_i^c} \ ,$$

$$m^2_{\tilde{D}_i^c} = \frac{5}{3}(m_0^U)^2 - \frac{2}{3}m^2_{\tilde{L}_i} \ .$$

In addition, the Higgs soft masses m_{H_u} and m_{H_d}, and the trilinear soft terms A_U, A_D and A_E can all be free parameters



Indirect searches of SUSY at CEPC

- MSSM at future Higgs factories, Honglei Li, Huayang Song, Shufang Su, Wei Su, Jin Min Yang, arXiv:2010.09782.

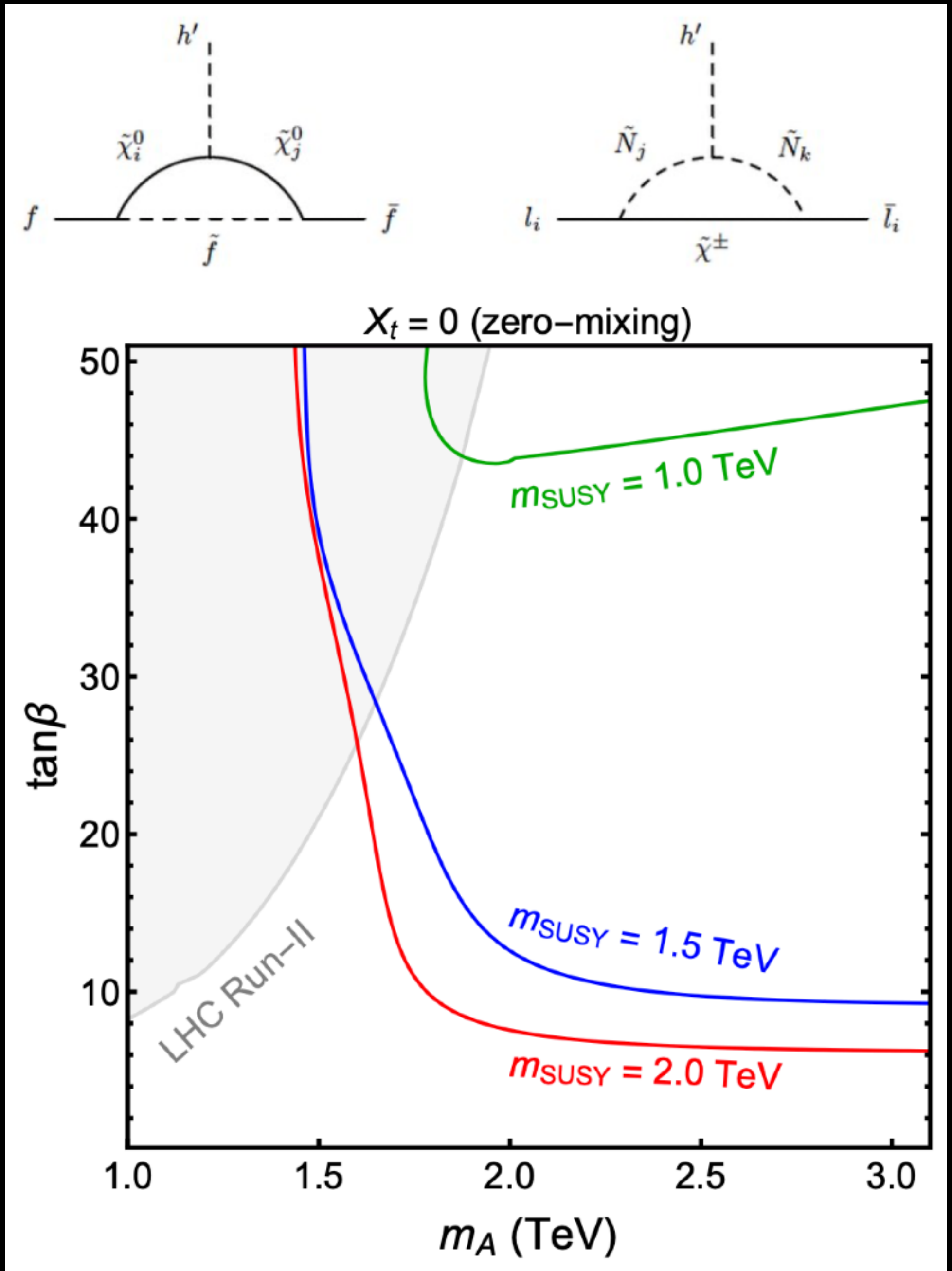
- MSSM contribution to κ_b, the Higgs coupling normalized to the SM value, is

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

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

- The loop contribution of the stop sector is

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



SUSY global fit with CEPC results

- Global fits with present likelihood:

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

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

- 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 $(A_u)_{33} = A_{u3}$, $(A_d)_{33} = A_{d3}$.

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

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
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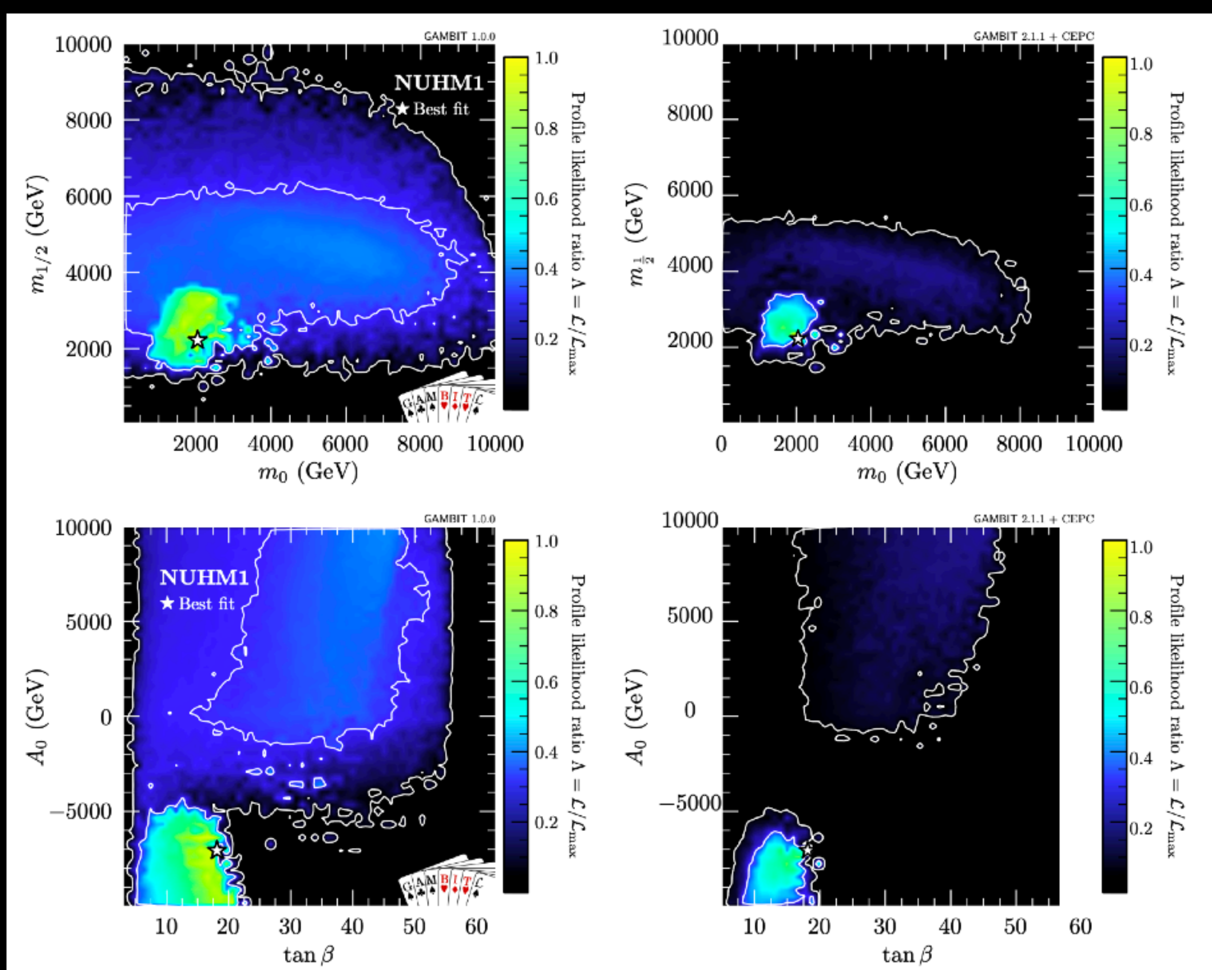
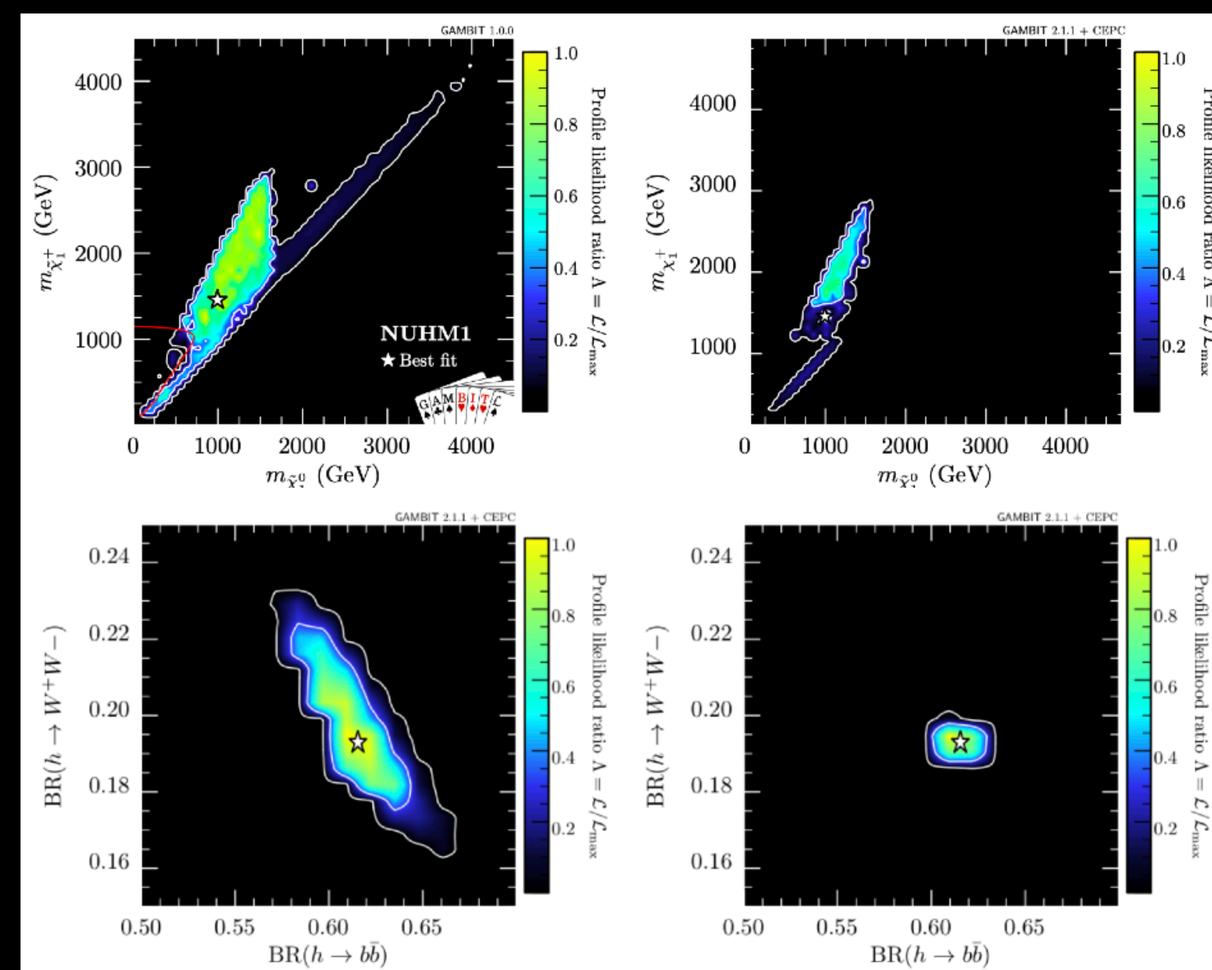
ATLAS_13TeV_3b_discoverySR_36invfb
ATLAS_13TeV_HtoPhotons_139invfb
ATLAS_13TeV_PhotonGGM_36invfb
ATLAS_13TeV_ZGammaGrav_CONFNOTE_80invfb
ATLAS_13TeV_MONOJET_36invfb

SUSY global fit with CEPC results

- The Higgs precision measurements at the CEPC will visibly shrink the preferred parameter regions. It has the power to rule out some DM annihilation mechanisms in the framework of constrained SUSY.





2HDM searches at CEPC

References:

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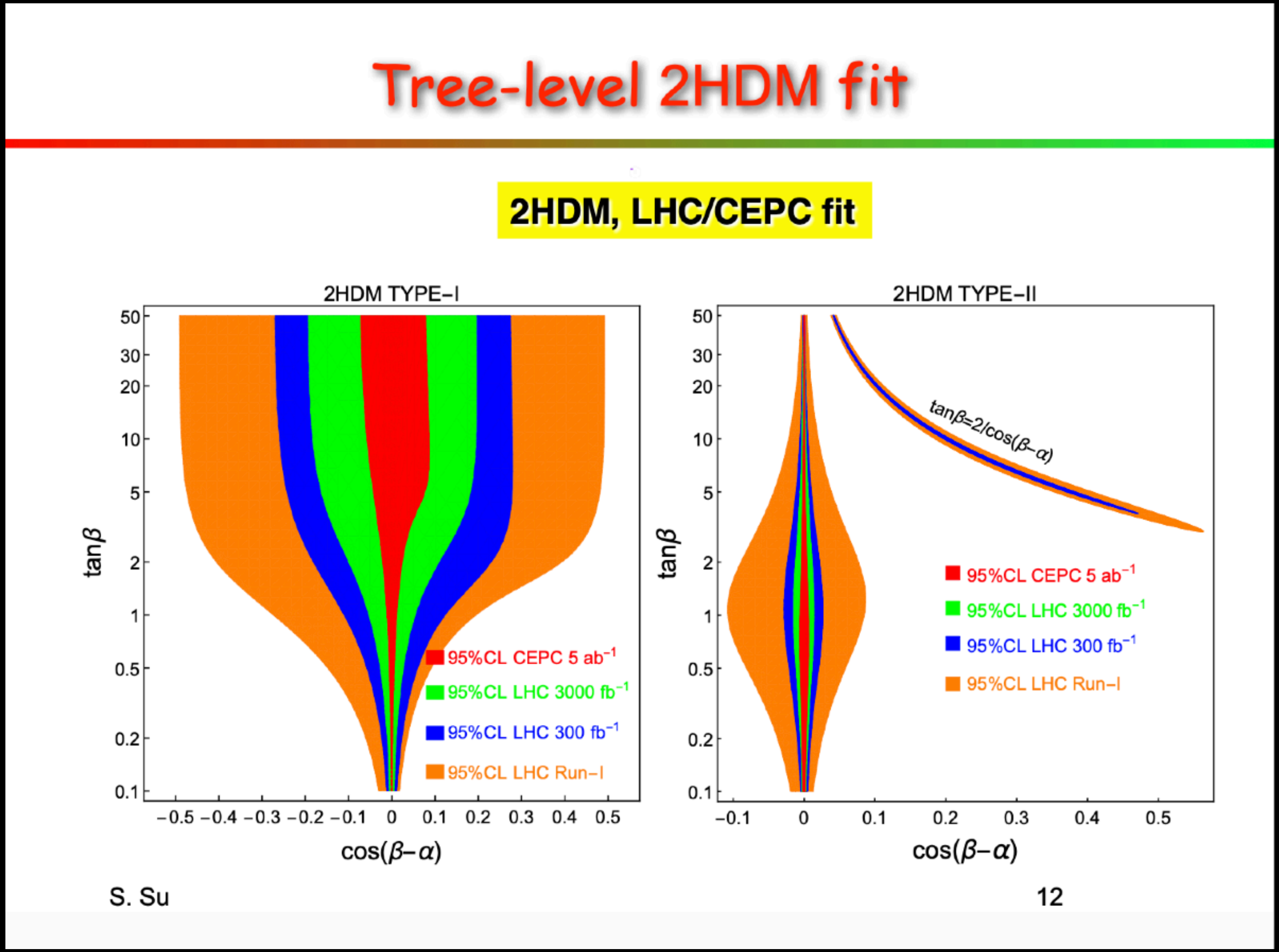
https://arxiv.org/pdf/1808.02037.pdf
https://arxiv.org/pdf/1912.01431.pdf
https://arxiv.org/pdf/2008.05492.pdf
https://indico.ihep.ac.cn/event/13888/session/13/contribution/76/material/slides/0.pdf

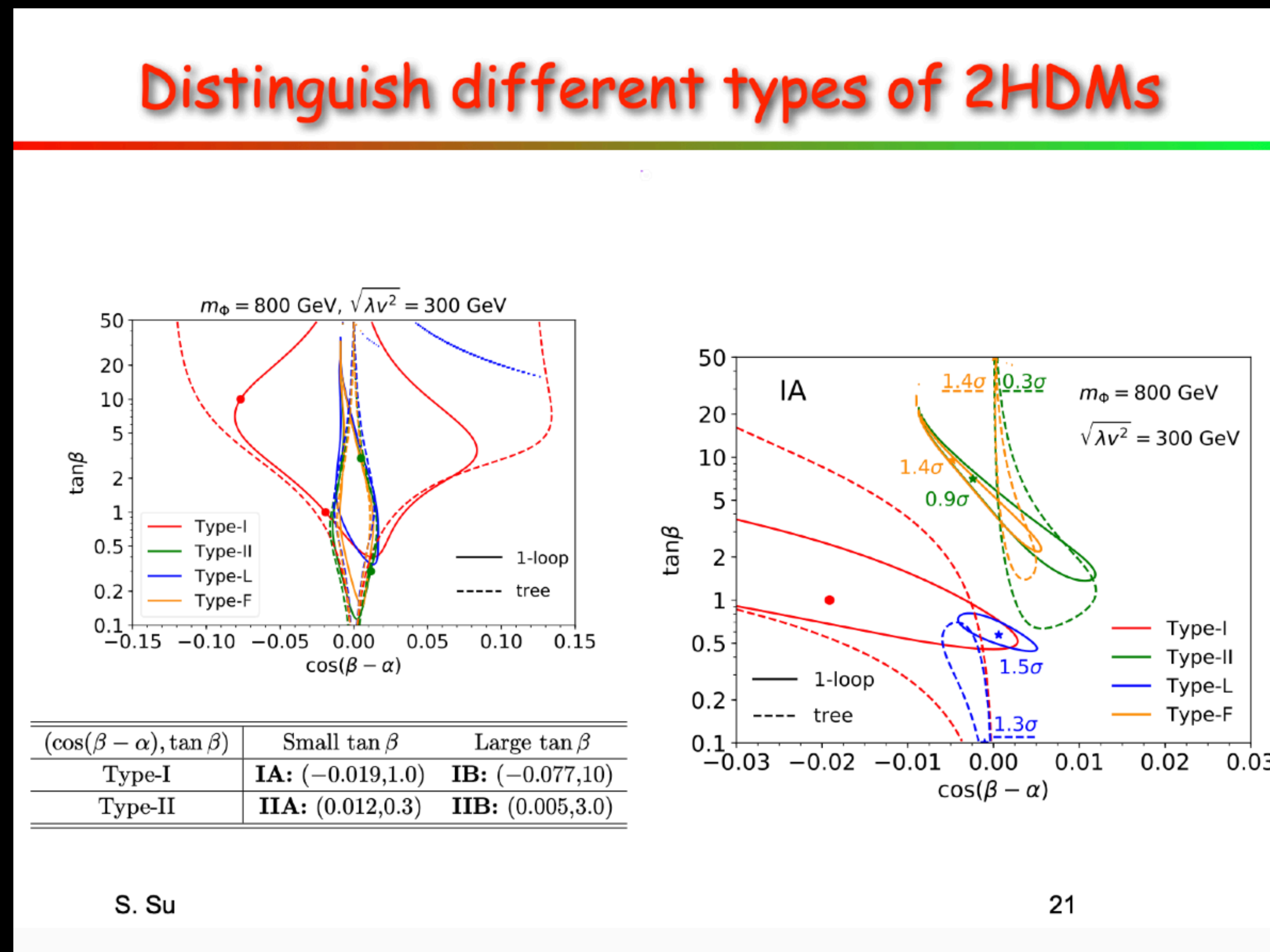
2HDM searches at CEPC

- J. Gu, H. Li, Z. Liu, W. Su, 1709.06103
- N. Chen, T. Han, S. Su, W. Su, Y. Wu, 1808.02037
- N. Chen, T. Han, S. Li, S. Su, W. Su, Y. Wu, 1912.01431
- T. Han, S. Li, S. Su, W. Su, Y. Wu, 2008.05492



2HDM searches at CEPC

- Indirect constraints on new physics models
- Complementary to direct search at 100 TeV Hadron Collider
- Distinguish different types of 2HDMs



$(\cos(\beta-\alpha), \tan\beta)$	Small $\tan\beta$	Large $\tan\beta$
Type-I	**IA:** (−0.019,1.0)	**IB:** (−0.077,10)
Type-II	**IIA:** (0.012,0.3)	**IIB:** (0.005,3.0)

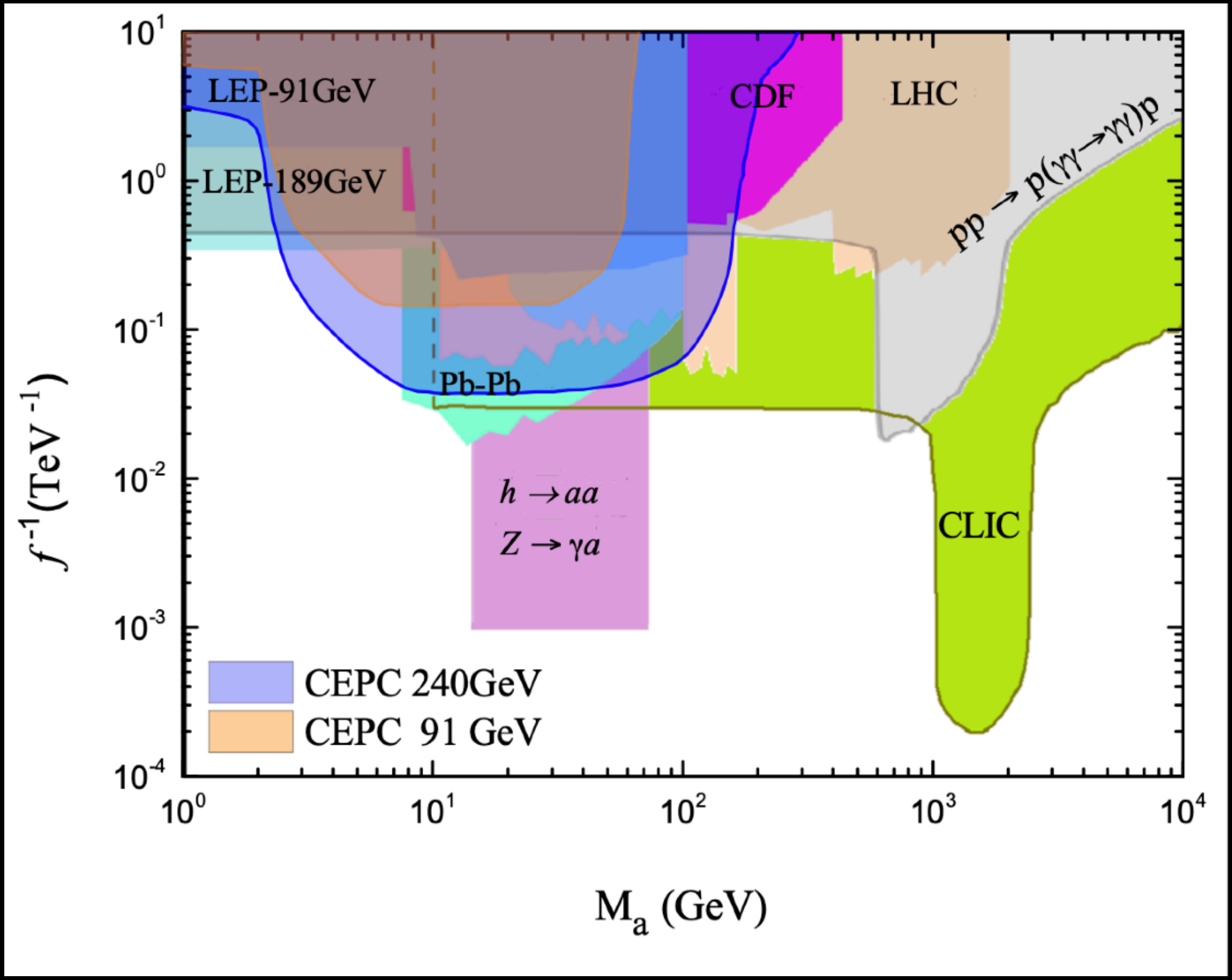
DM searches at CEPC

References:

https://arxiv.org/abs/2103.05218.pdf
https://arxiv.org/pdf/2104.06988.pdf
https://arxiv.org/pdf/2104.06421.pdf

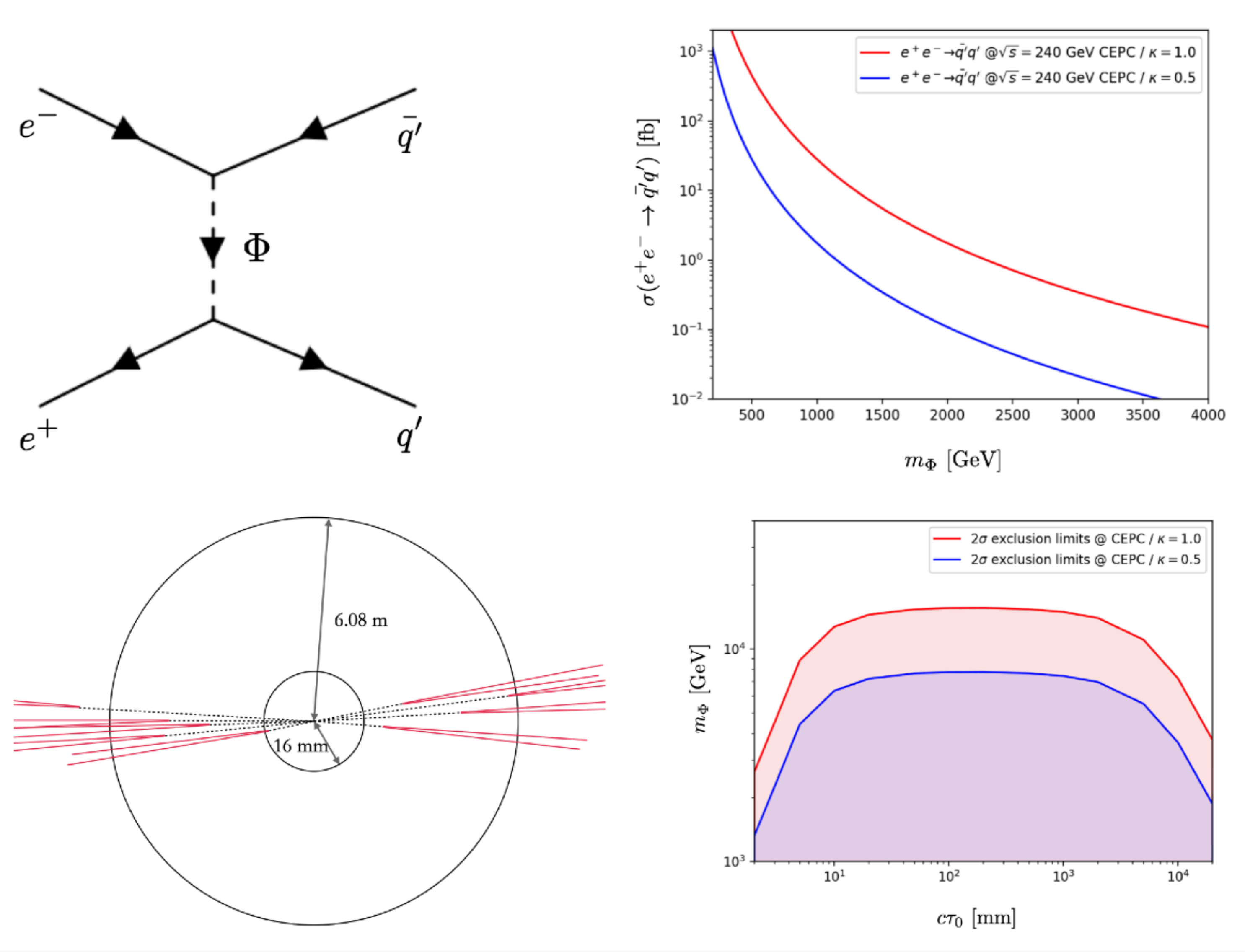
DM searches at CEPC

- Searching for axion-like particles at future electron-positron colliders, by Hua-Ying Zhang, Chong-Xing Yue, Yu-Chen Guo, Shuo Yang, 2103.05218.
- For heavier ALPs, the cosmological and astrophysical limits are less stringent.
- The CEPC might be more sensitive to the ALPs with mass 2 GeV ~ 8 GeV than the LHC and CLIC.



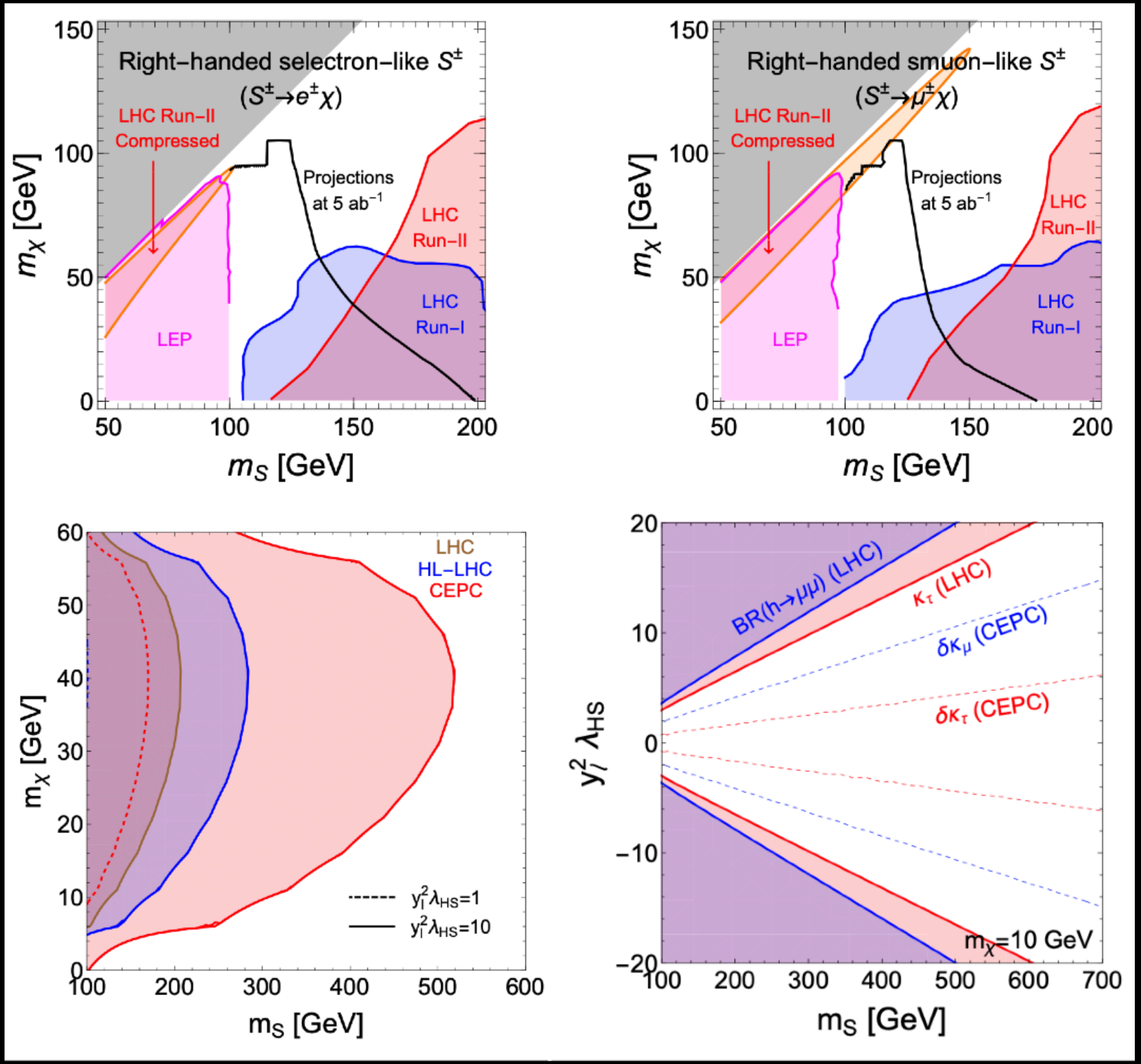
DM searches at CEPC

- Leptophilic Composite Asymmetric Dark Matter and its Detection, Mengchao Zhang, 2104.06988
- On the CEPC, it is possible to directly generate dark quark pair through a t-channel process.
- Dark quark finally evolves to a jet-like object.



DM searches at CEPC

- Searching for lepton portal dark matter with colliders and gravitational waves, Jia Liu, Xiao-Ping Wang, Ke-Pan Xie, 2104.06421.
- The direct and indirect searches are not sensitive to this model.
- The scalar potential triggers a first- order phase transition.



Electroweak phase transition and CEPC

References:

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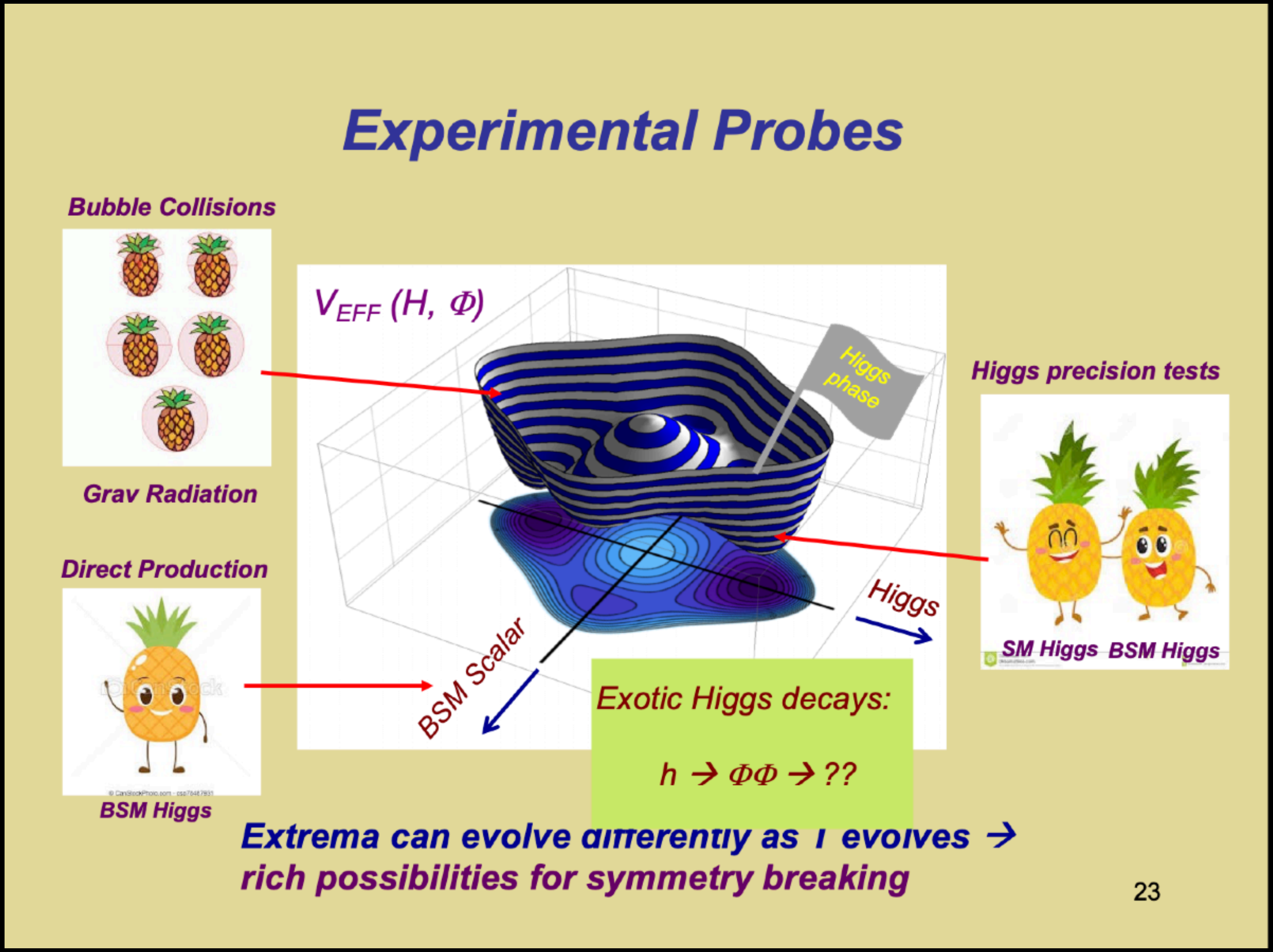
https://arxiv.org/pdf/2011.04540.pdf
https://indico.ihep.ac.cn/event/13888/session/15/contribution/121/material/slides/0.pdf

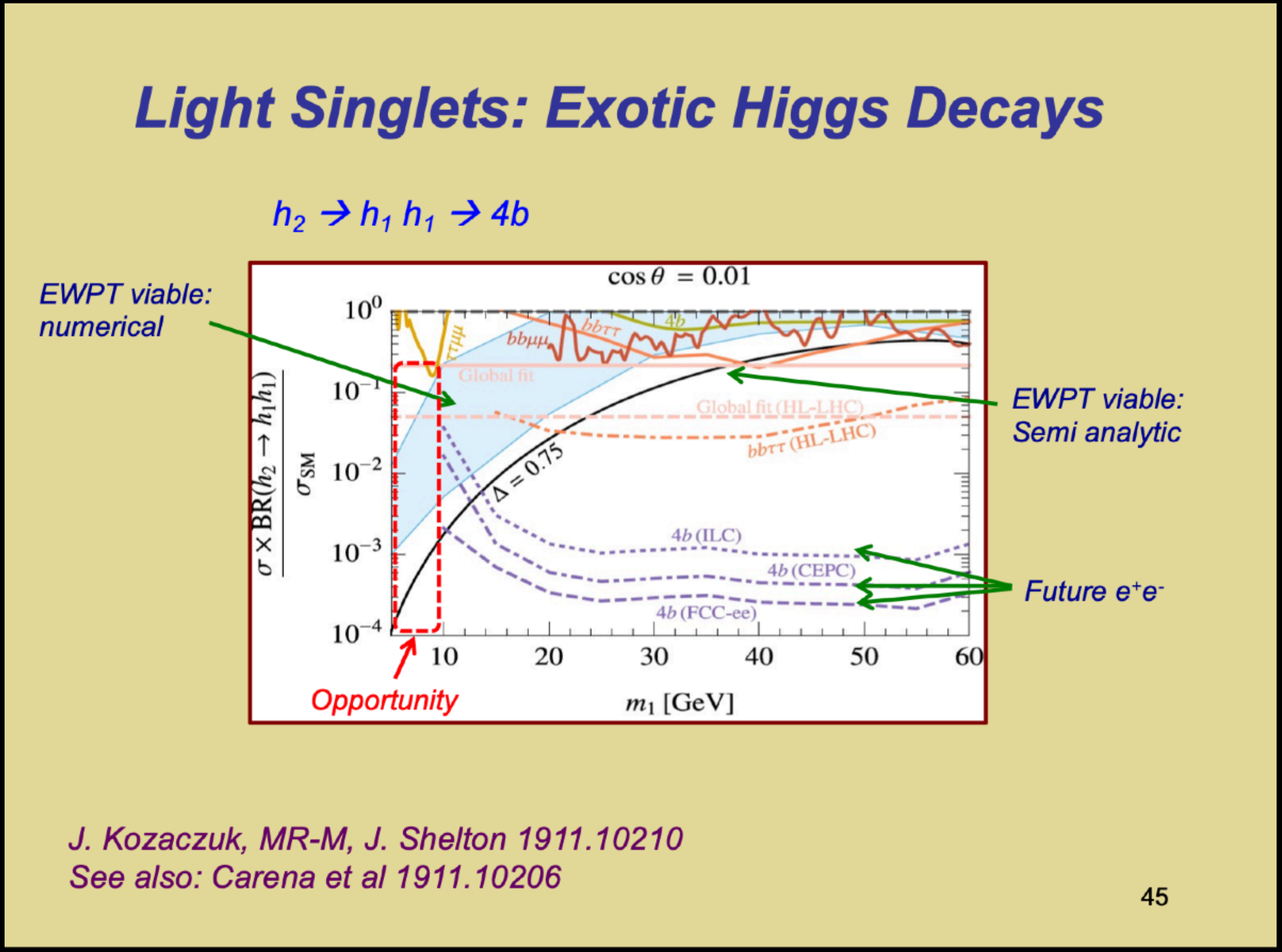
Electroweak phase transition

- M.J. Ramsey-Musolf 1912.07189
- Profumo, MJRM, Shaugnessy 0705.2425
- Kozaczuk, MJRM Shelton 1911.10210
- Carena, Liu, Wang 1911.10206



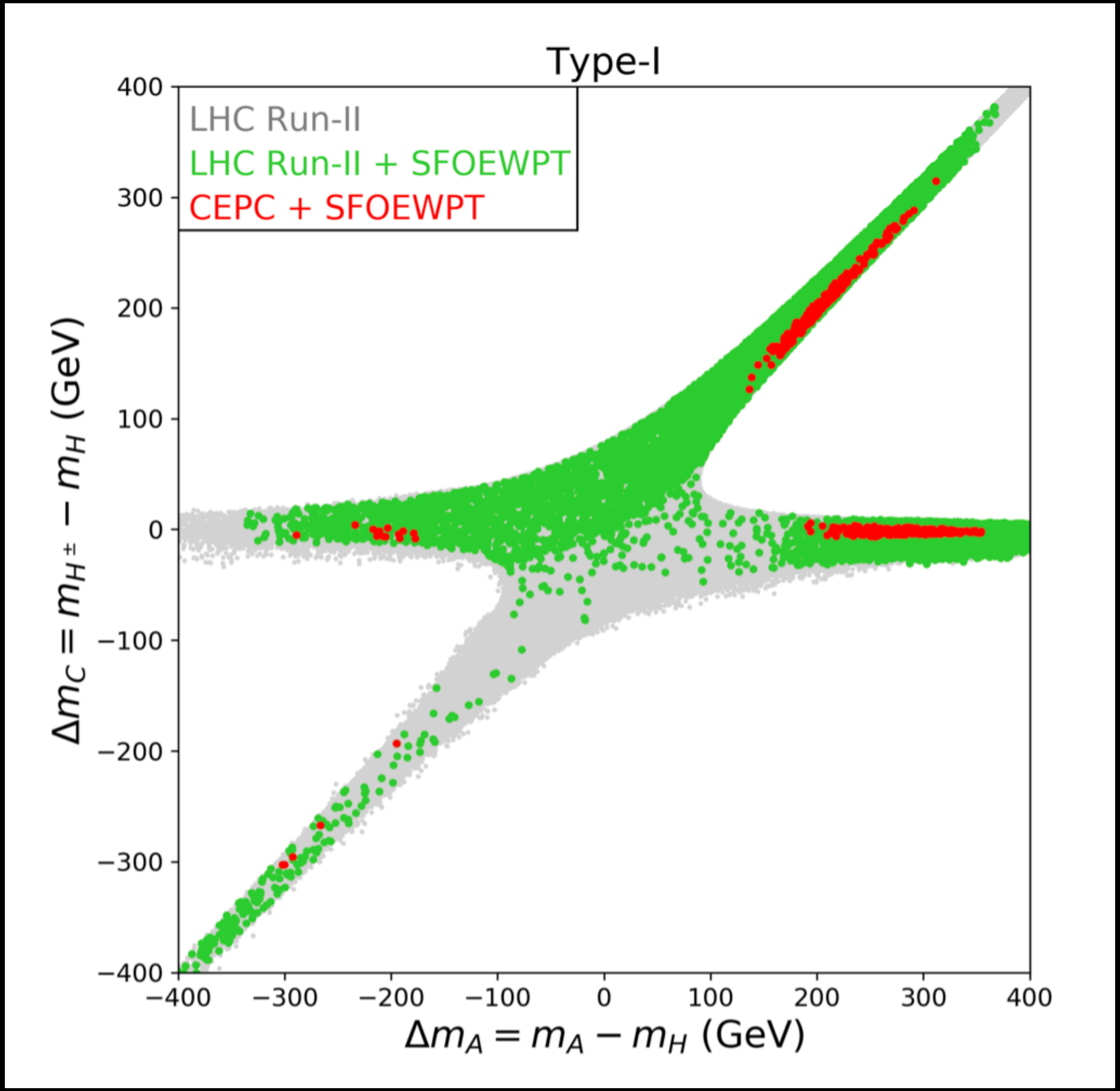
Electroweak phase transition

- The electroweak temperature $T_{\rm EW}$ sets a scale for colliders.
- Exotic Higgs decays provide a unique probe of light scalar-induced thermal history modifications.



Electroweak phase transition

- Strong first order electroweak phase transition in 2HDM confronting future Z & Higgs factories, by Wei Su, Anthony G. Williams, Mengchao Zhang, 2011.04540.
- SFOEWPT suggests upper limits on the masses of heavy Higgs, which is less than 1 TeV.
- The CEPC can further exclude the allowed parameters space because of the one-loop level corrections to the SM-like Higgs couplings.



Summary

- Direct searches of SUSY
  - The CEPC has the potential to discover the chargino up to 120 GeV, the stau up to 113~116 GeV, and smuon up to 117 GeV.
- Indirect searches of SUSY
  - Higgs precision measurements at the CEPC have significant impacts on SUSY global fits. It has the power to rule out some DM annihilation mechanisms in the framework of constrained SUSY.
- Two Higgs doublet models
  - The CEPC can distinguish different types of 2HDMs.
- DM searches
  - The CEPC has great potential to detect a large portion of the model parameter space.
- Electroweak phase transition
  - The CEPC can provide a unique probe of the thermal history of EW symmetry breaking.

THANK YOU.