中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

CEPC New Physics

– towards white paper

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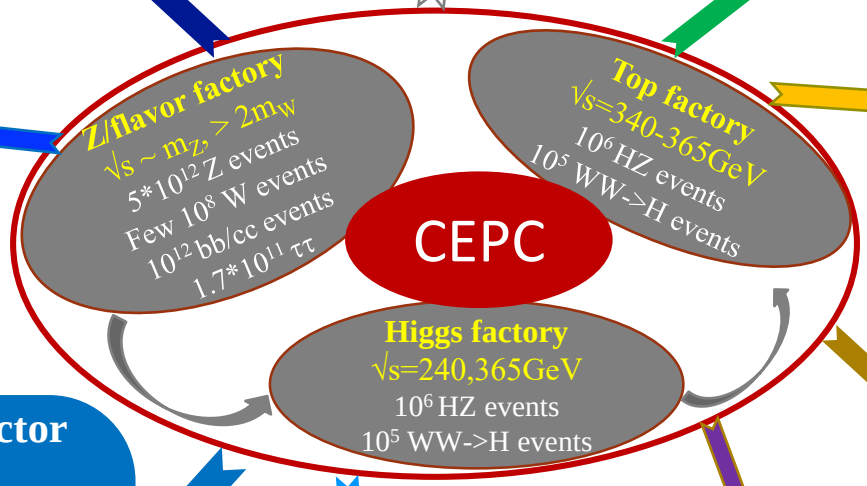
CEPC味物理-新物理和相关探测技术研讨会

Aug. 13-18, 2023

CEPC BSM Physics Program



Exotics of Higgs, W, Z, top
- Exotic Higgs decay
- Exotic W/Z and top decay
- Light higgs
- ……

Indirect searches from SM precision measurements *(not included here)*

Global fits
- Global fit of SUSY
- SMEFT global fit

SUSY
- Light EWKinos
- Light sleptons
- Heavy selectrons
- Axinos
- ……

BSM @ flavor
- Flavor violation
- Flavor anomalies
- ……

Dark Matter & Dark Sector
- Lepton portal DM
- Asymmetric DM
- Dark Sector from exotic Z decay
- Dark Sector-photon interactions
- Millicharged DM, Vector portal DM, DM with EFT interactions
- Mono-gamma
- Dark Fermion in light of Electron Target Absorption
- ……

Long-lived particles
- At both CEPC and it's FAR detector

EWPT & GW

More exotics
- Heavy neutrinos
- Axion-like particles
- Identify CP-odd component in Higgs
- ……

Brief summary of BSM search @CEPC

- BSM working group formed @ 2021.4 Yangzhou WS
- Big updates presented
  - @ 2021.11 CEPC WS (13 talks); @ 2022.5 CEPC WS (17 talks)
  - @ 2022.8 HEP (4-5 Talks); @2022.10 CEPC WS (8 talks)
  - @2023.7 CEPC WS (9 talks)
  - BSM prospects at CEPC are included in CEPC snowmass white paper: arXiv:2205.08553
- BSM white paper is scheduled and going-on smoothly:
  - Timeline: collect inputs and a very brief white paper draft ready by end of 2023; First paper draft is ready by next Jan.-Feb.
  - Preliminary organizers and editors are almost on-boat, just let's know if you would contribute it, thanks!
  - This WS: more inputs and deep discussion towards white paper!

CEPC BSM White Paper (proposal)

Session 1, Executive Summary (Liantao, Xuai, Manqi)

Session 2, Description of CEPC facility, nominal luminosity & Typical Detector Performance (Manqi)

Session 3, Higgs portal & Exotic Higgs/Z/top decays (Yaquan, Zhao LI)

Session 4, SUSY (Lei WU, Tianjun, Xuai)

Session 5, Dark Matter and Dark Sector (Jia LIU, Xiaoping Wang, Yongchao Zhang)

Session 6, Flavor Portal (Lingfeng, Xinqiang LI)

Session 7, EWPT & GW (Kepan XIE, Sai WANG, Fapeng HUANG)

Session 8, LLP (LiangLI, Kechen WANG)

Session 9, More exotics (GaoYu, Zuowei LIU)

Session 10, Global Fits (Jiayin GU, Yang ZHANG)

Session 11, Conclusion (Liantao, Xuai, Manqi)

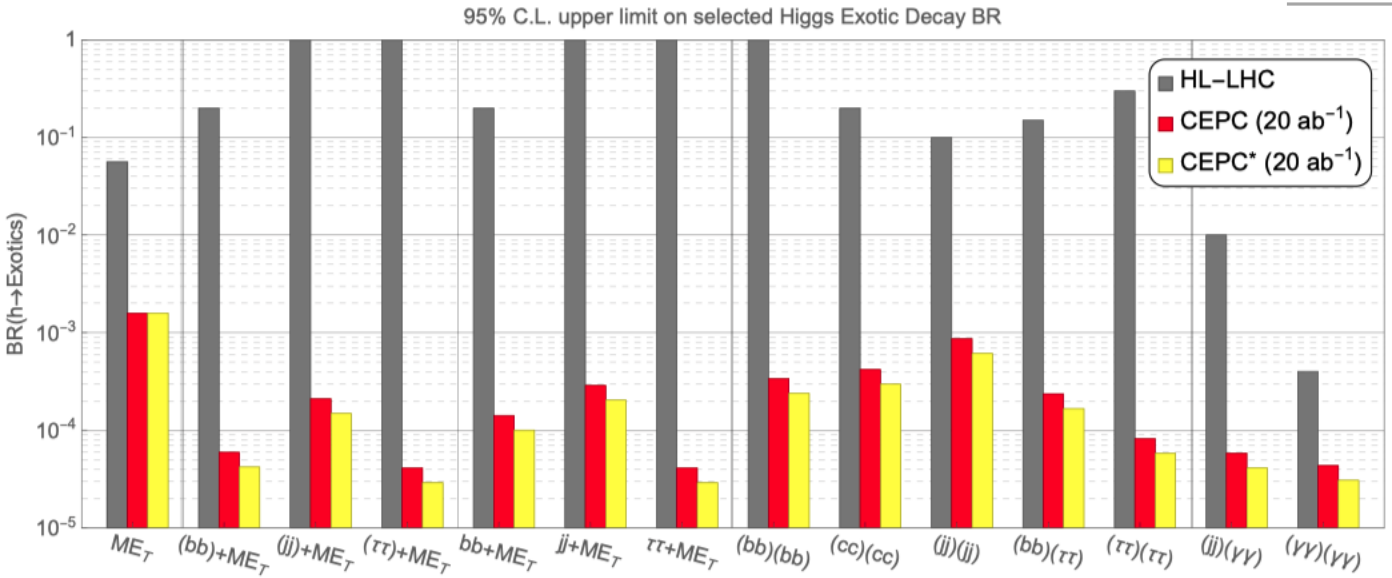
BSM Inputs & Status

- Exotic Decays
  - Higgs exotic decay (1709.06103; 1612.09284,1808.02037; 1912.01431; 2008.05492 ; 2011.04540)
  - Z/W/Top exotic decay
  - Light higgs (Sven's talk)
- SUSY Searches
  - Direct SUSY Searches (CPC46(2022)013106; 2101.12131; 2203.10580;2202.11011, 2211.08132)
  - Indirect search of SUSY (2010.09782)
- Dark Matter and Dark Sector searches
  - Lepton portal DM (JHEP 06 (2021) 149)
  - Asymmetric DM (PRD 104(2021)055008)
  - Dark Sector from exotic Z decay (1712.07237), Dark Sector-photon interactions (2208.08142)
  - DM (Millicharged DM, Vector portal DM, DM with EFT interactions): 1903.1211
  - Mono-gamma (2205.05560) ,
  - Dark Fermion in light of Electron Target Absorption (Kai Ma's talk)
- Long-lived particles (1904.10661, 1911.06576, 2201.08960, Yulei Zhang's Talk, Wei Su's Talk, Cen Mo's Talk;)
- More exotics:
  - Heavy neutrinos (2102.12826, 2201.05831);
  - Axion-like particles (2103.05218, 2204.04702, 2210.09335, J. Phys. G)
  - Electroweak phase transition (1911.10210,1911.10206,2011.04540, 2204.05085)
  - Identify CP-odd component in Higgs (Changlong Xu's talk)
- Global fits:
  - Global fit of SUSY (2203.04828, 2203.07883)
  - SMEFT global fit (2206.08326)

BSM Higgs

- Many BSM models motivate Higgs exotic decay considerations: singlet extensions, 2HDM, SUSY models, Higgs portals, …

Z. Liu et al 1612.09284.



The 95% C.L. upper limit on selected Higgs exotic decay BR

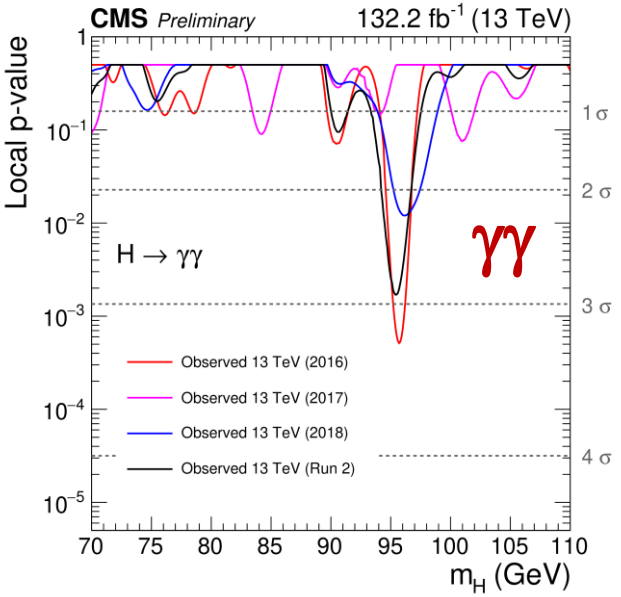
→ Good sensitivity of exotic Higgs decay from CEPC

- Exotic Z or top decays are also motivated by many BSM models (ED, **Heavy Vector Triplet** , …) and can also be searched at CEPC

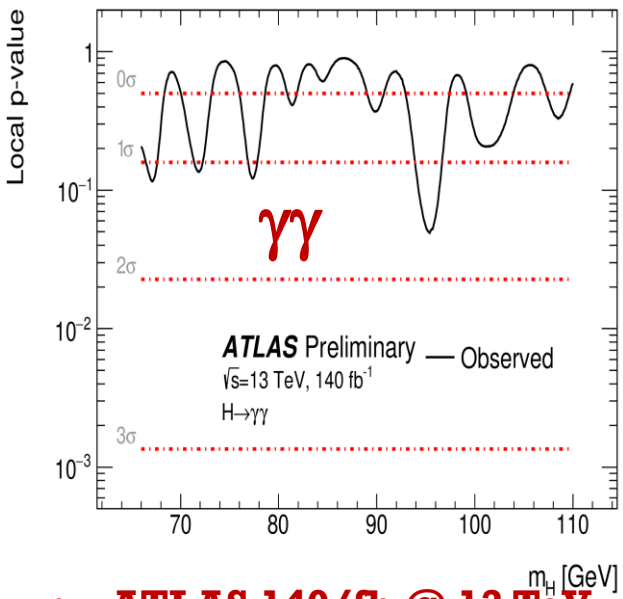
Light Higgs

- Light Higgs are motivated by 2HDM and Axion-like particle models

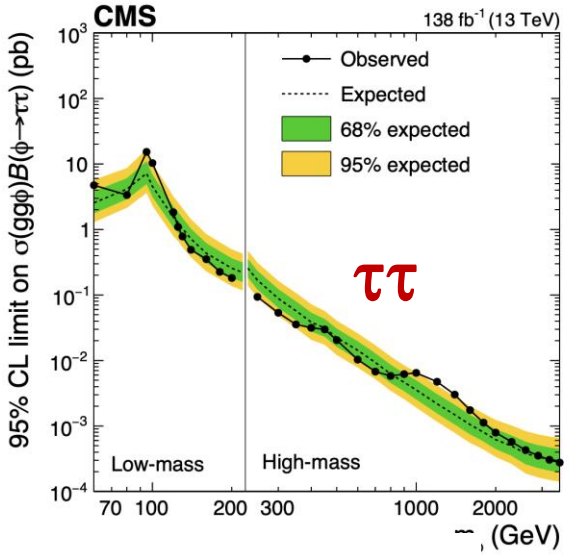
CMS-PAS-HIG-20-002



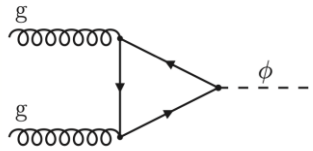
ATLAS-CONF-2023-035



arXiv:2208.02717



- **ATLAS 140/fb @ 13 TeV:**
  Local 1.7 σ @ mH ≈ 95.4 GeV



- **CMS 132.2/fb @ 13 TeV:**
  Local (global) 2.9 (1.3) σ @ m ≈ 95.4 GeV
- **Previous CMS result 20+36/fb@ 8+13 TeV:**
  Local (global) 2.8 (1.3) σ @ m ≈ 95.3 GeV

- **CMS 132.2/fb @ 13 TeV: ggϕ (ϕ–>ττ)**
  Local (global) 3.1 (2.7) σ @ m ≈ 100 GeV
  Local (global) 2.8 (2.2) σ @ m ≈ 1200 GeV

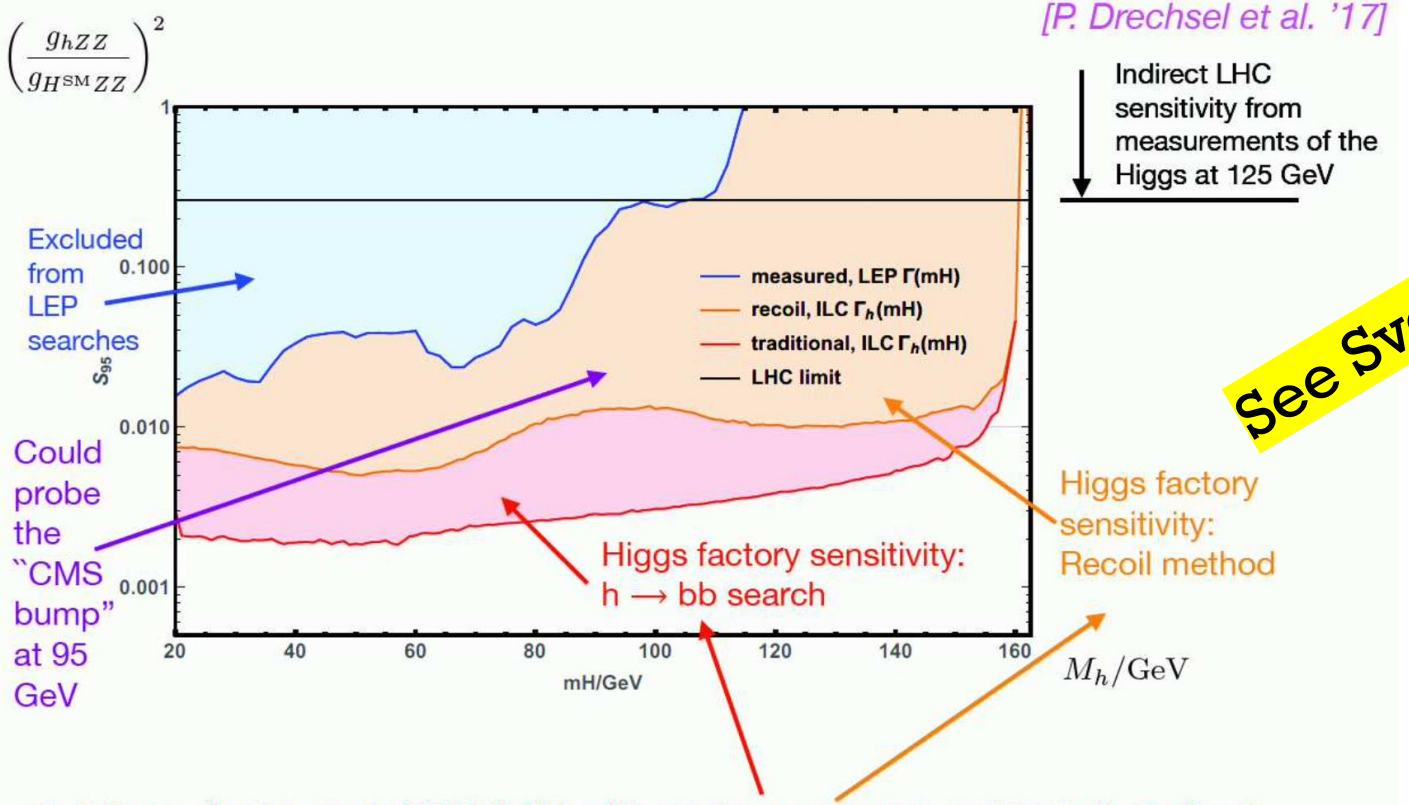
The excess did not grow with luminosity, but remains intriguing, which can be searched at CEPC very well if exists.

Light Higgs

3. Physics opportunities at CEPC (originally for ILC, but equivalent!)

Example for discovery potential for new light states:
Sensitivity at 250 GeV with 500 fb^{-1} to a new light Higgs

[P. Drechsel et al. '17]



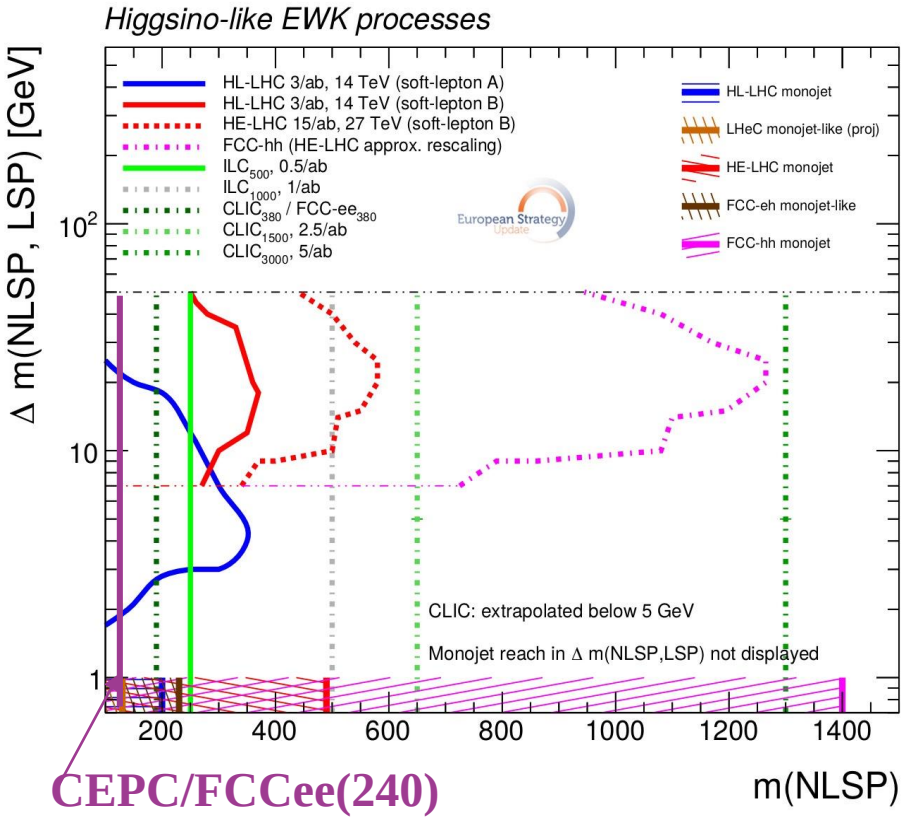
See Sven's talk

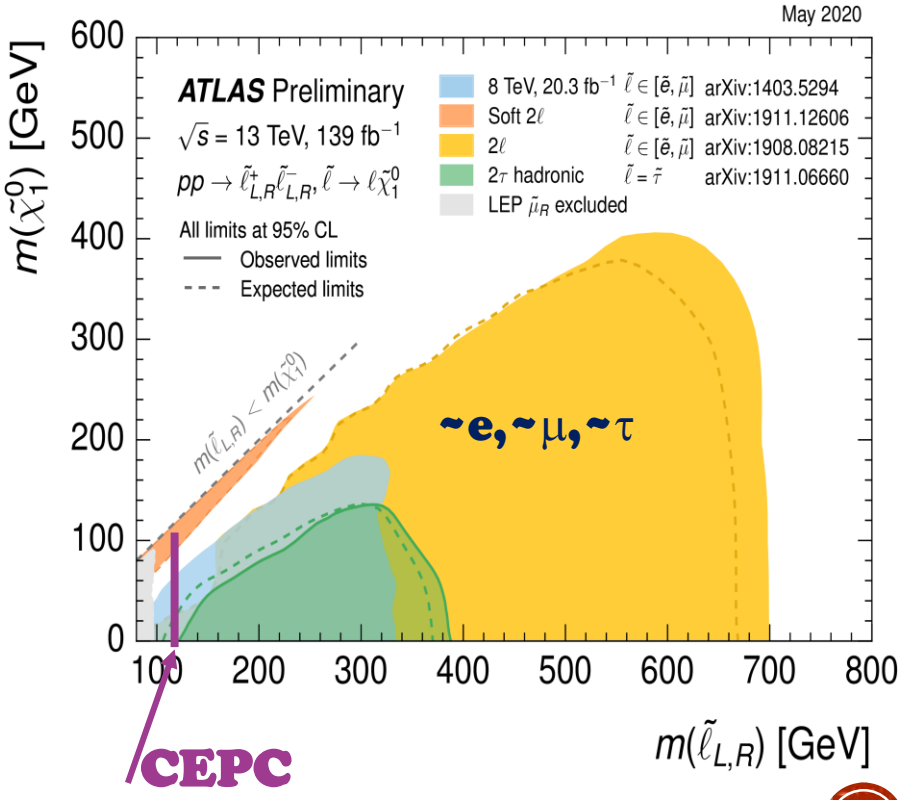
[Taken from G. Weiglein '18]

The excess did not grow with luminosity, but remains intriguing, which can be searched at CEPC very well if exists.

SUSY Searches at CEPC

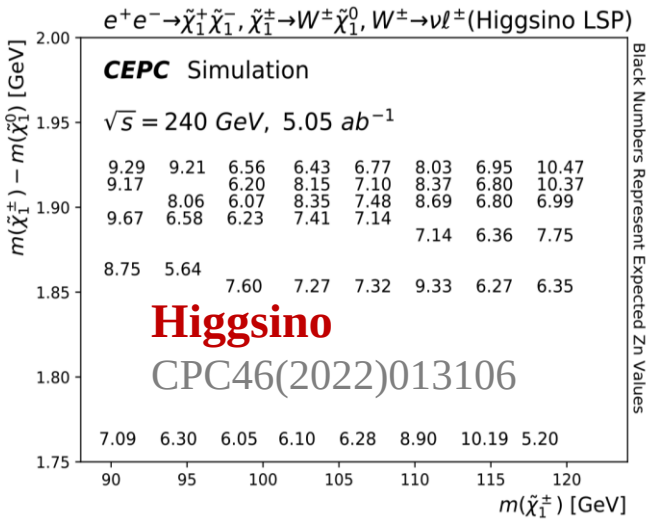
- **SUSY: establishes a symmetry between fermions and bosons, solve many big questions: unification, DM, Hierarchy, ……**
- **Complementary with LHC: lower mass/soft energy region**
  - ✓ **Mainly light EWKino and slepton for CEPC**





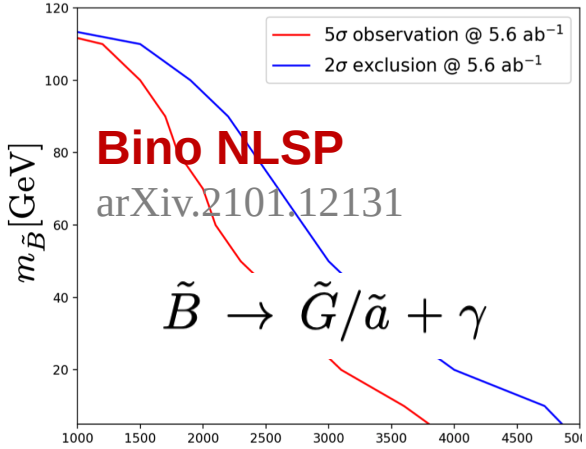
Lepton collider: discovery in all scenarios up to kinematic limit: √s/2

SUSY Searches at CEPC



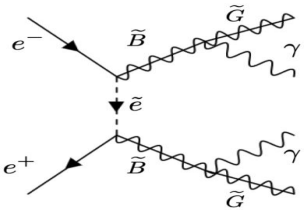
Higgsino

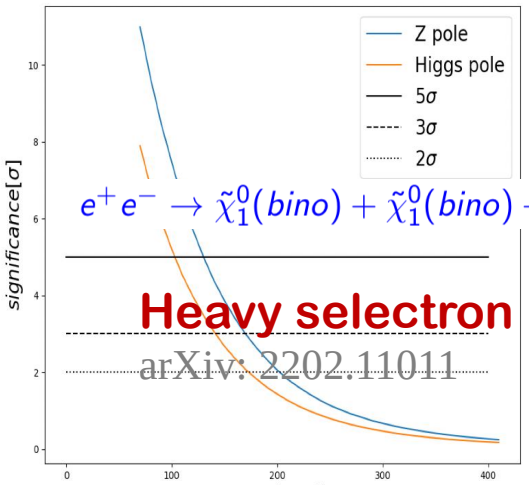
CPC46(2022)013106



Bino NLSP

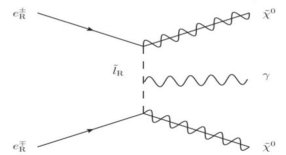
arXiv.2101.12131

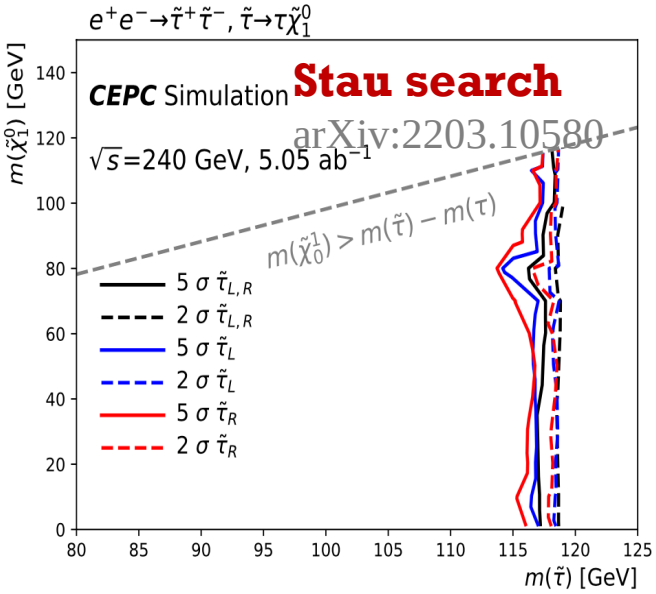




Heavy selectron

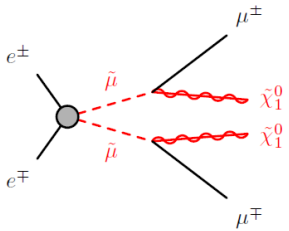
arXiv: 2202.11011

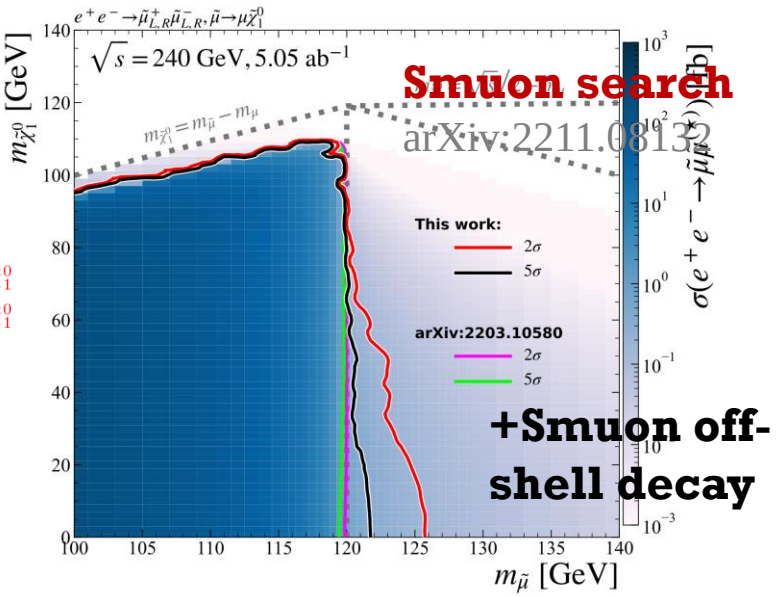




Stau search

arXiv:2203.10580





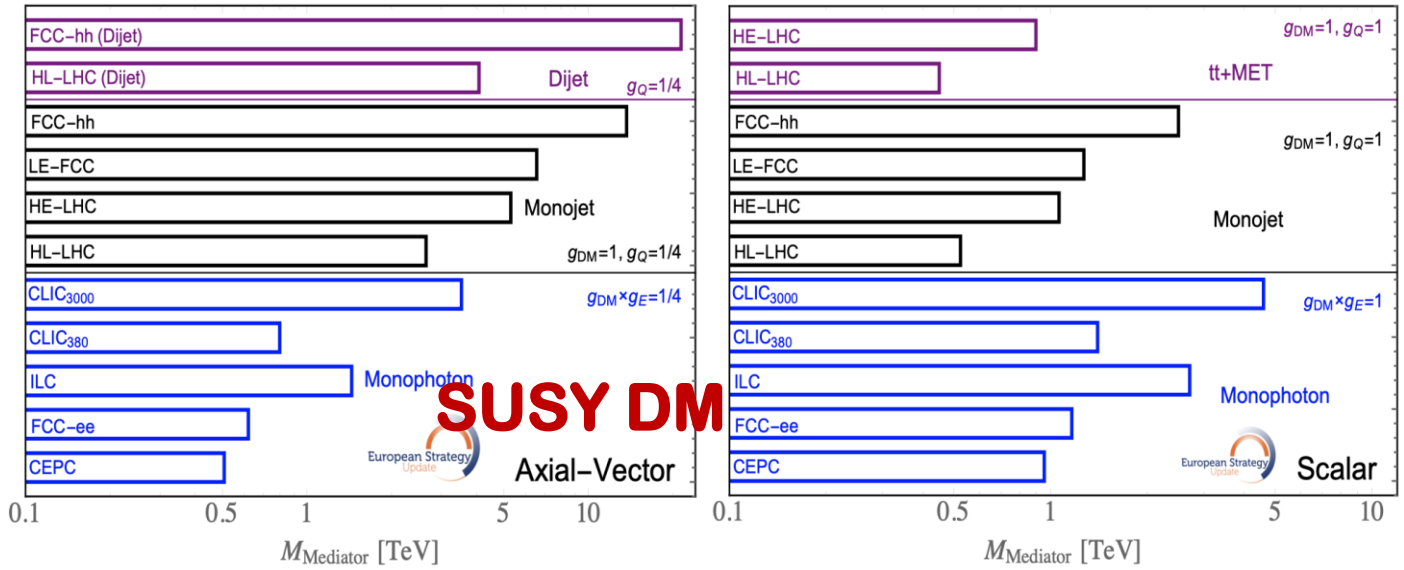
Smuon search

arXiv:2211.08132

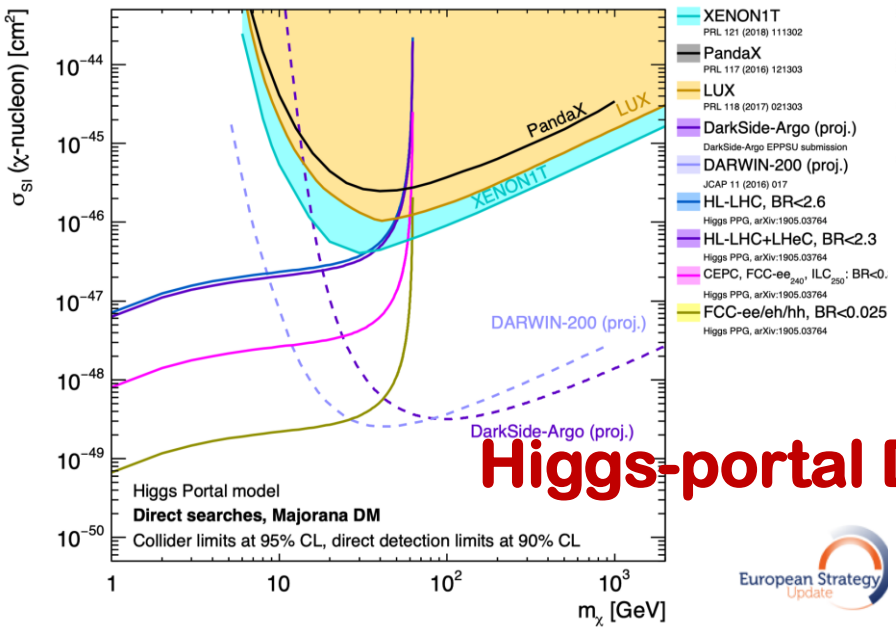
+Smuon off-shell decay

Dark Matter and Dark Sector searches

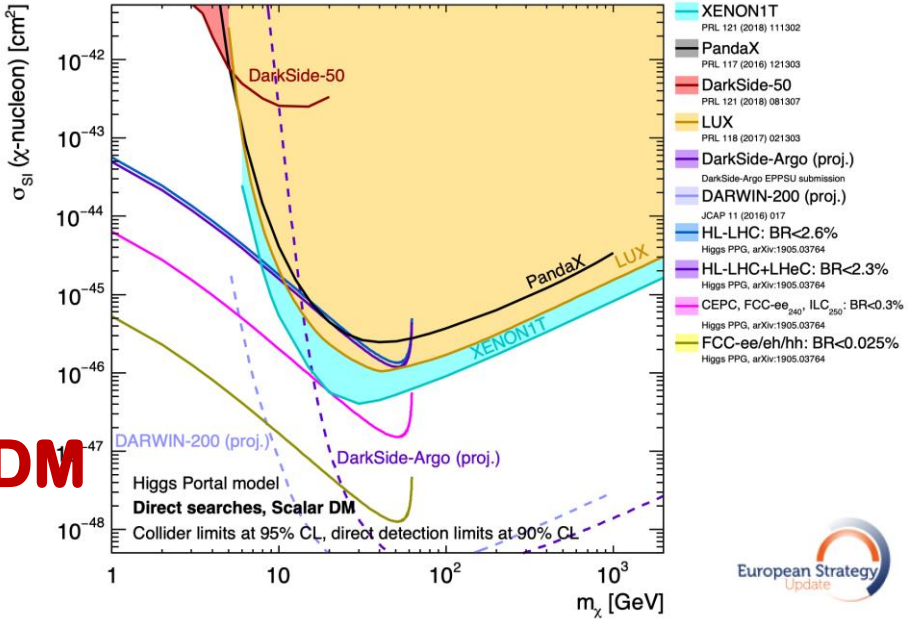
- **SUSY DM**
- **Non-SUSY DM:**
  - Higgs portal
  - Fermion portal
  - Vector portal
  - EFT



SUSY DM

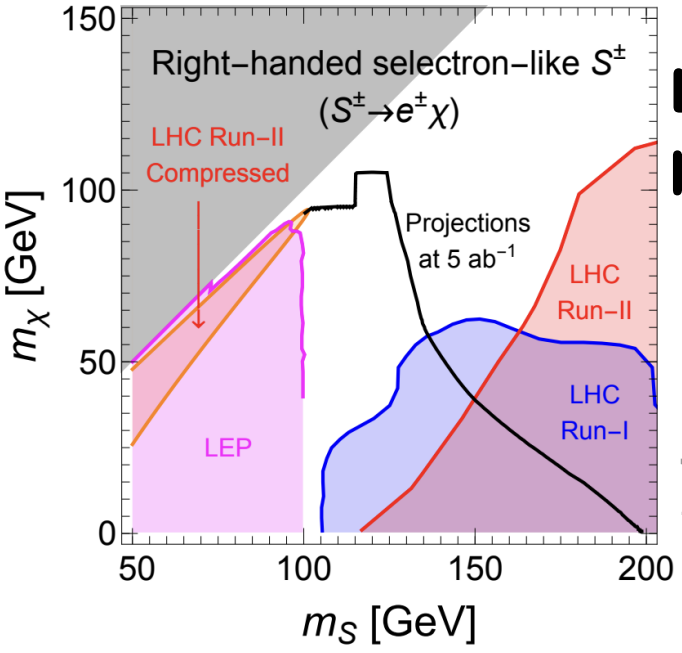


Higgs-portal DM

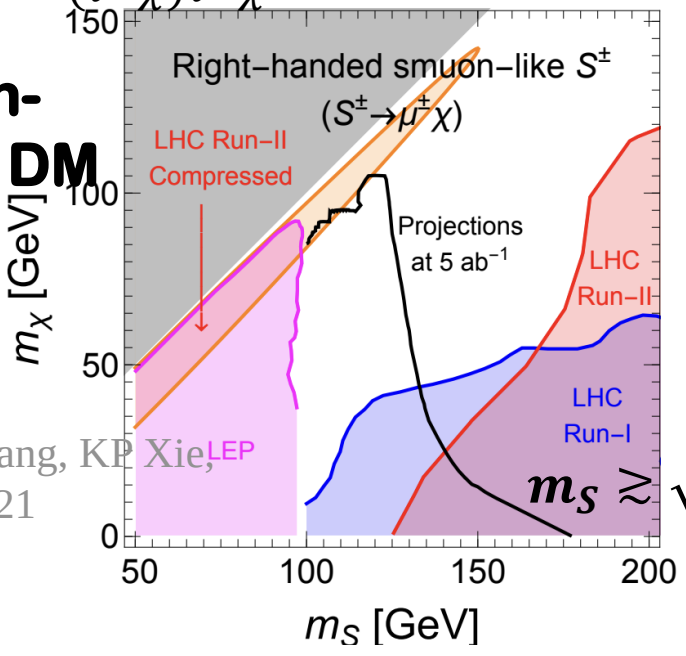


Dark Matter and Dark Sector searches

$$e^+e^- \to S^+S^{-*} \to S^+\ell^-\chi \to (\ell^+\chi)\ell^-\chi$$



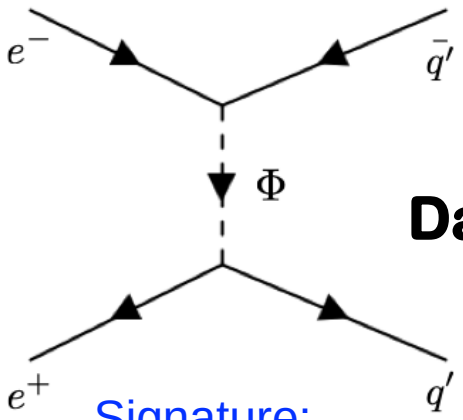
Lepton-portal DM



Fermion-portal DM

JL, XP Wang, KP Xie, 2104.06421

$$m_S \gtrsim \sqrt{s}/2 = 120GeV$$

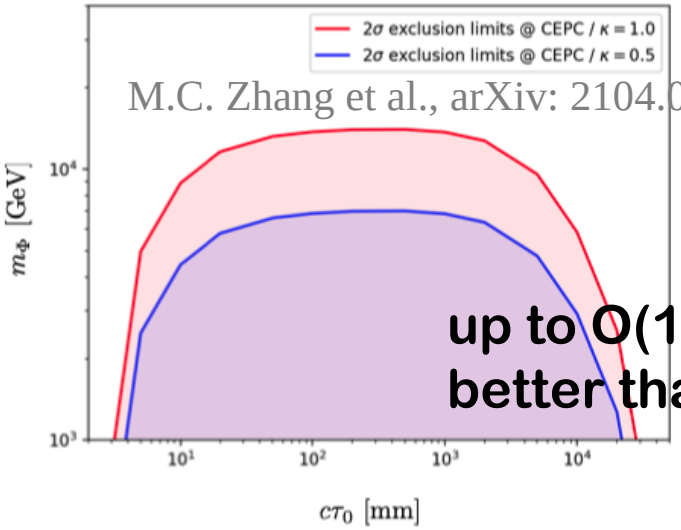


Decay to leptons

Dark jets

Jet-like

Signature:
Lepton + jet + MET



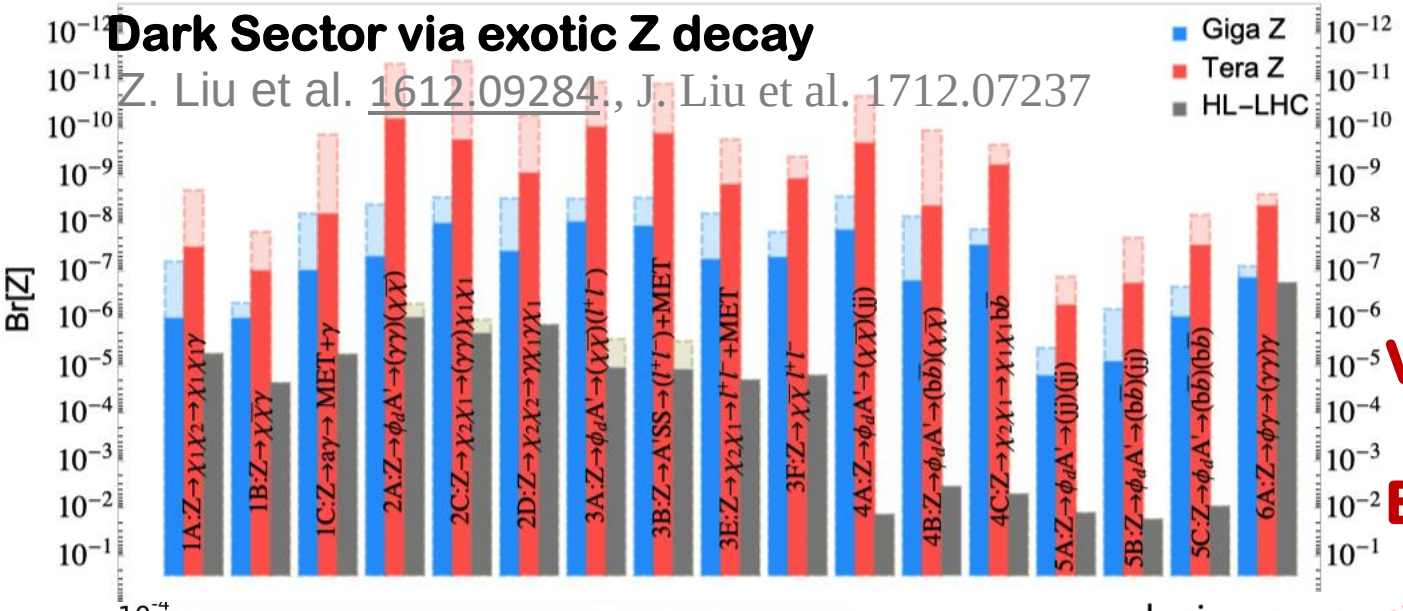
M.C. Zhang et al., arXiv: 2104.06988

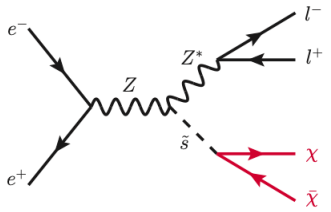
up to O(10) TeV, better than LHC

Dark Matter and Dark Sector searches

Dark Sector via exotic Z decay

Z. Liu et al. 1612.09284., J. Liu et al. 1712.07237

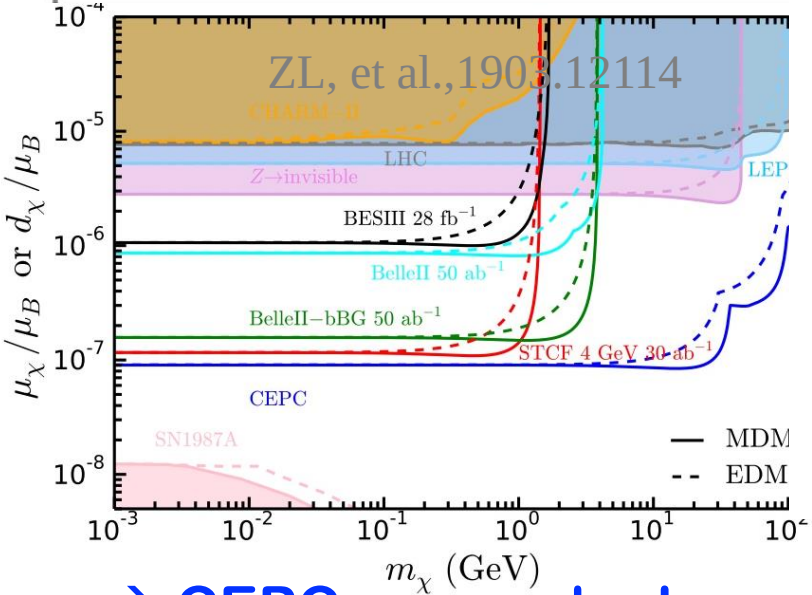


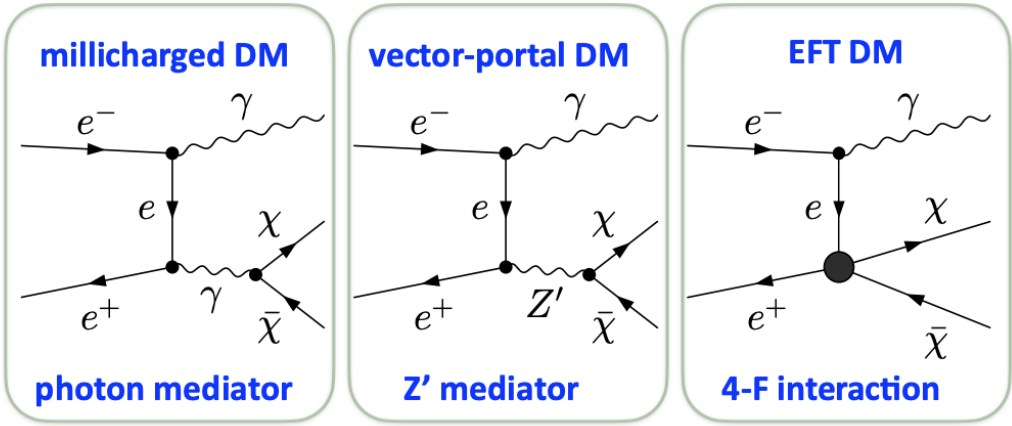


Vector-portal DM

EFT DM

new physics process: $e^+e^- \to \bar{\chi}\chi\gamma$



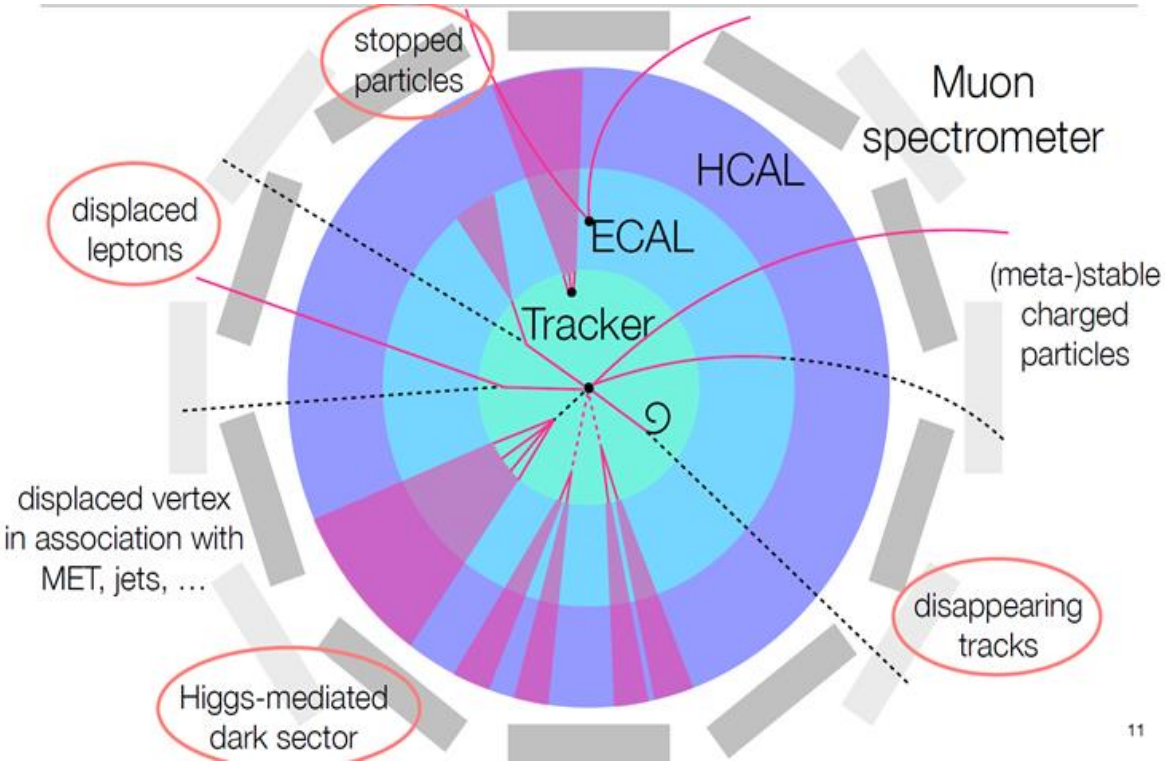


→ CEPC can probe low-mass light dark states.

Long-lived particles (LLP)

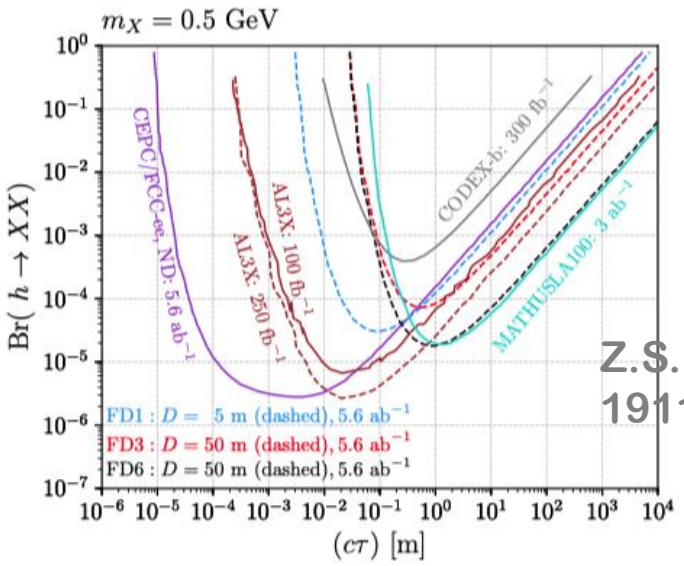
Long lifetimes result from a few simple physical mechanisms:

- Small couplings (ex. RPV SUSY)
- Limited phase space: small mass splitting (ex. compressed SUSY, …)
- Heavy intermediate states
- ……

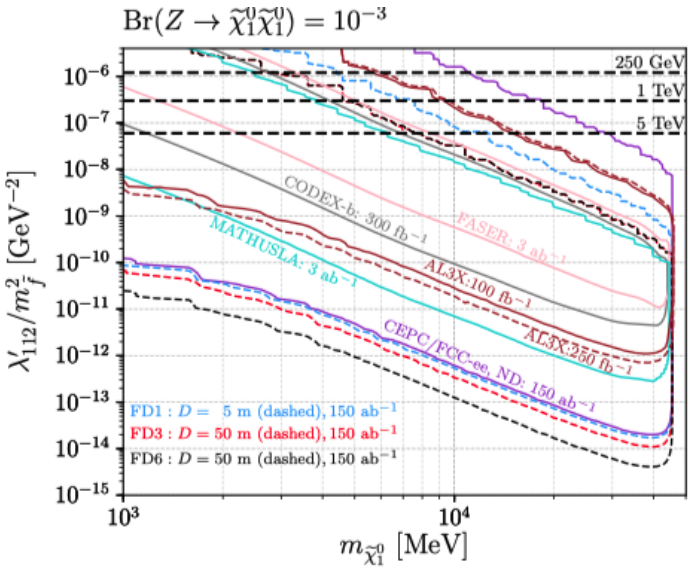


Far Detector can help a lot!

LLP at Far Detector (FD)

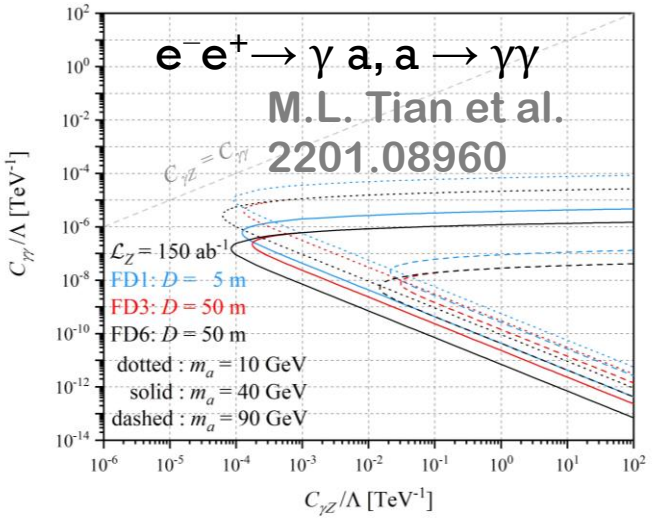


Z.S. Wang, et al.,
1911.06576



Light Scalars from Exotic Higgs Decays

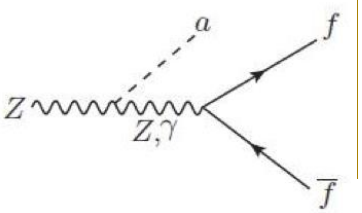
Light Neutralinos from Z Decays

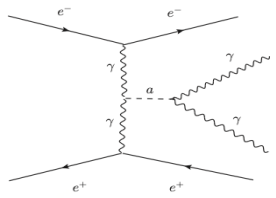


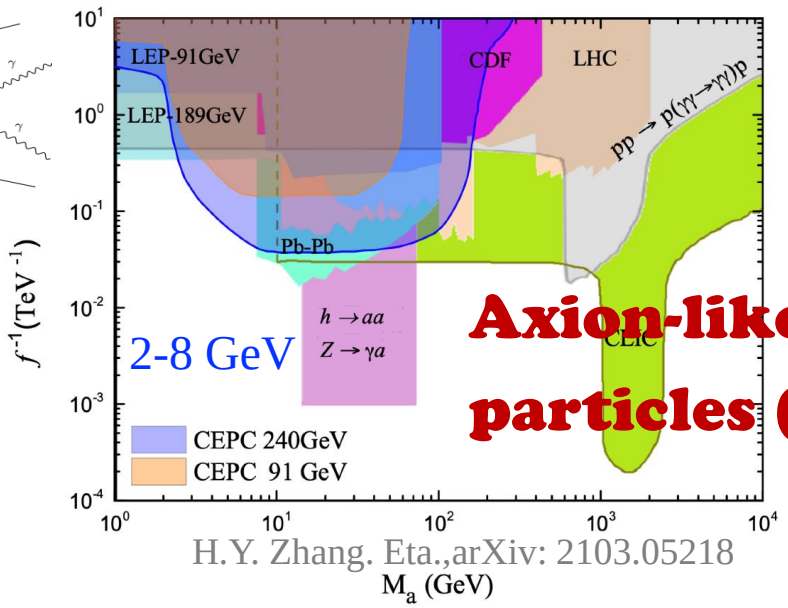
Axion-like Particles

→ FD can extend and complement the sensitivity to the LLPs compared with Near Detector

More exotics

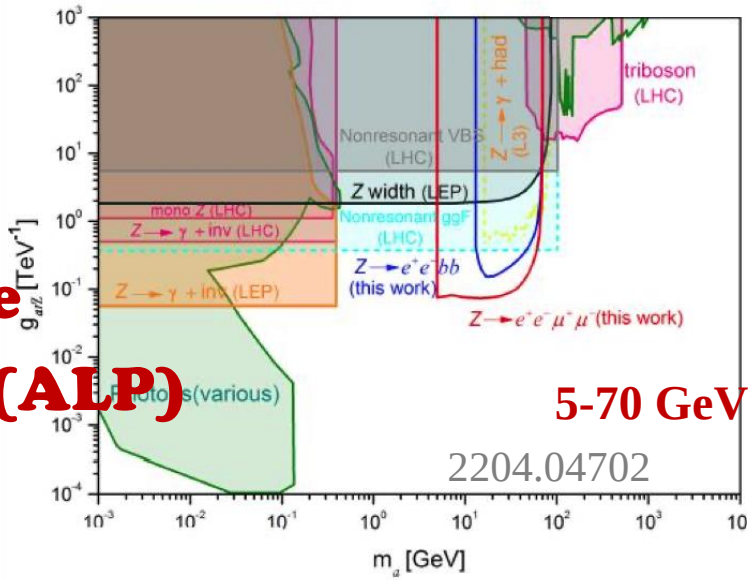






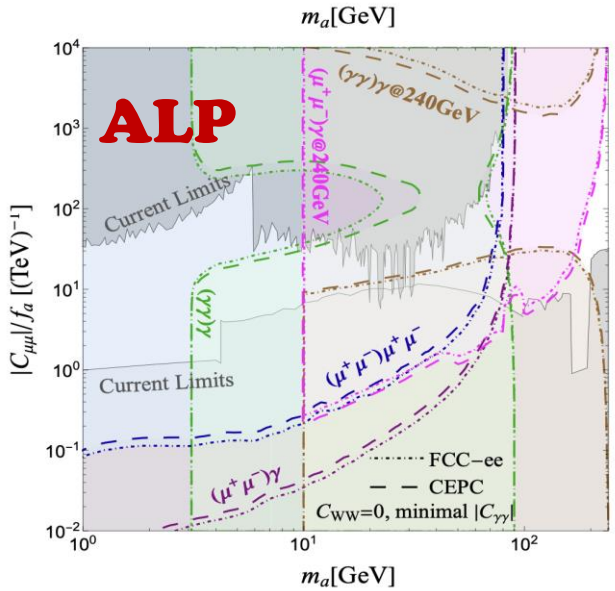
Axion-like particles (ALP)

H.Y. Zhang. Eta.,arXiv: 2103.05218

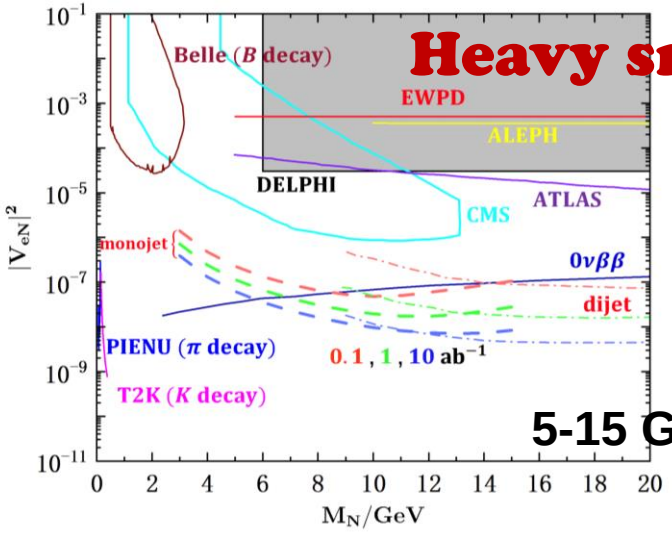


5-70 GeV

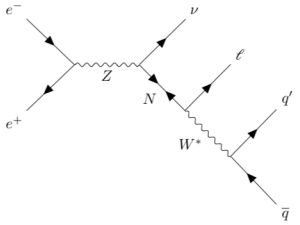
2204.04702



J. Liu et al., arXiv:2210.09335



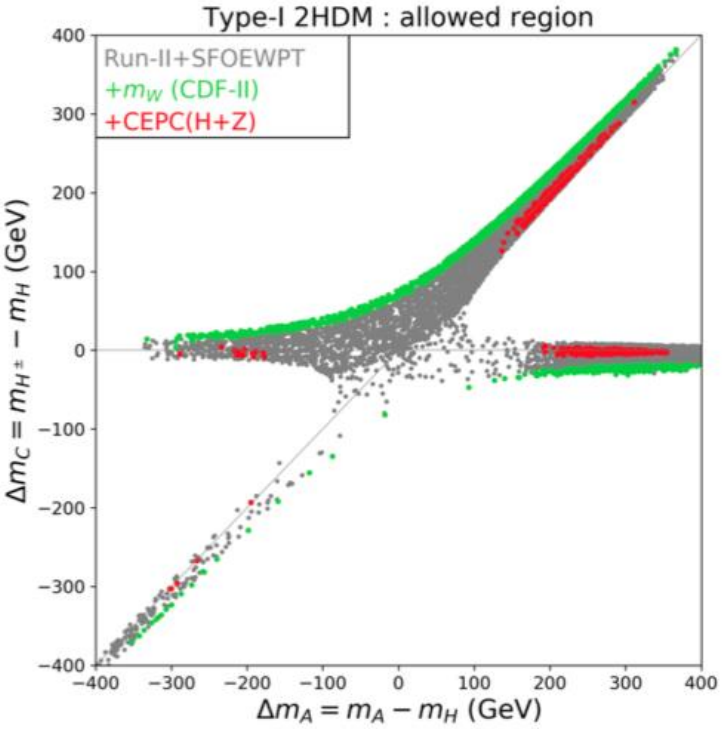
5-15 GeV

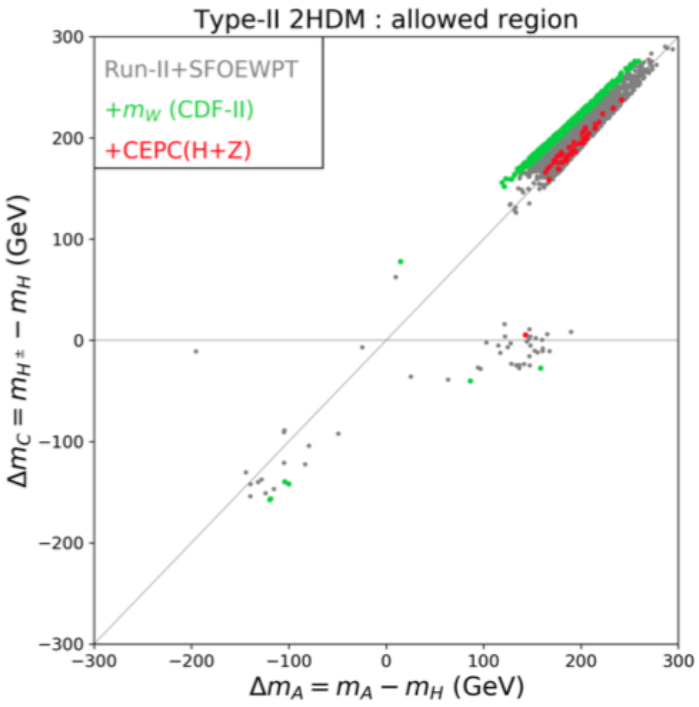


Y.F. Shen et al., arXiv: 2201.05831

EWPT at CEPC

- **Electroweak Phase Transition in 2HDM under Higgs, Z-pole, and W precision measurements**
- Under current constraints, both Type-I and Type-II 2HDM can explain the strong first order electroweak phase transition (SFOEWPT), Z-pole, Higgs precision measurements and mW precision measurement of CDF-II at same time.



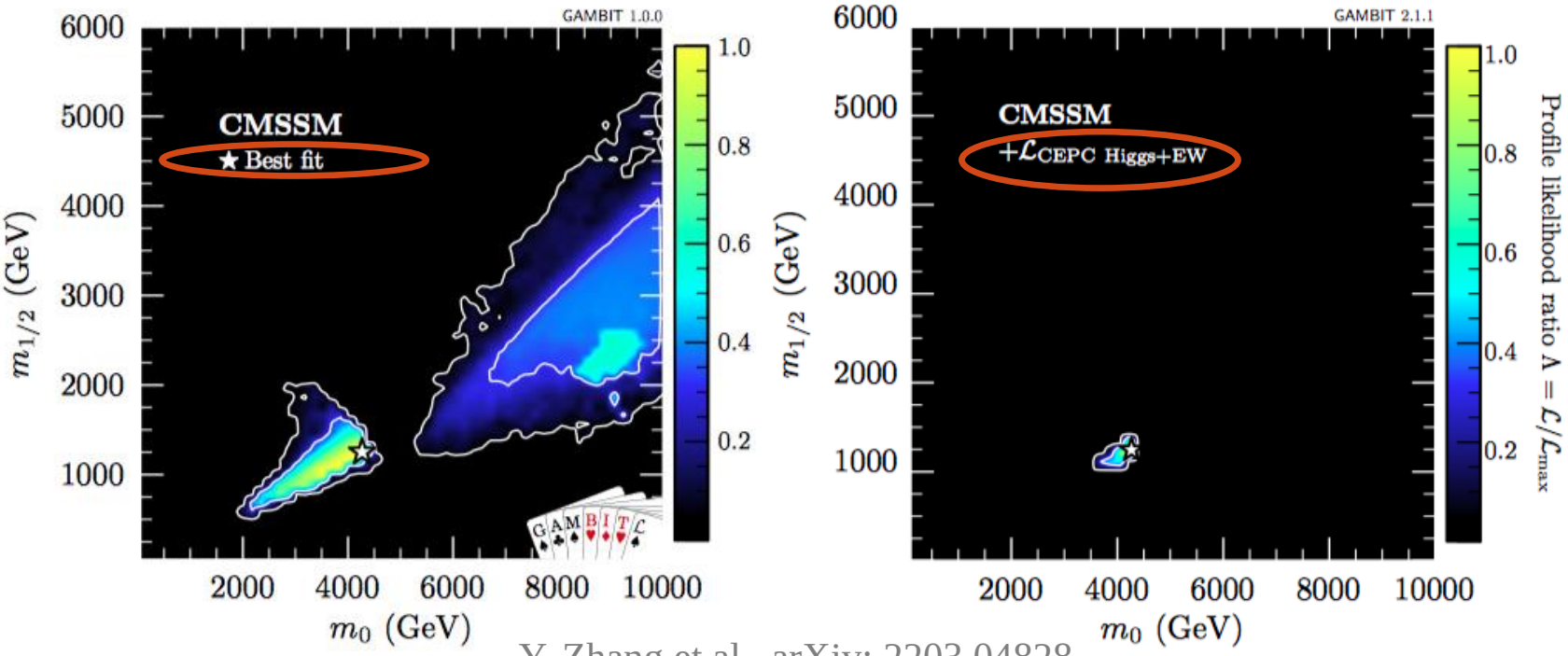


H. Song, et al., *arXiv:2204.05085*

SUSY global fits with CEPC using GAMBIT

- Study of the impact of the Higgs and electroweak precision measurements at the CEPC *with GAMBIT global fits* of the SUSY models

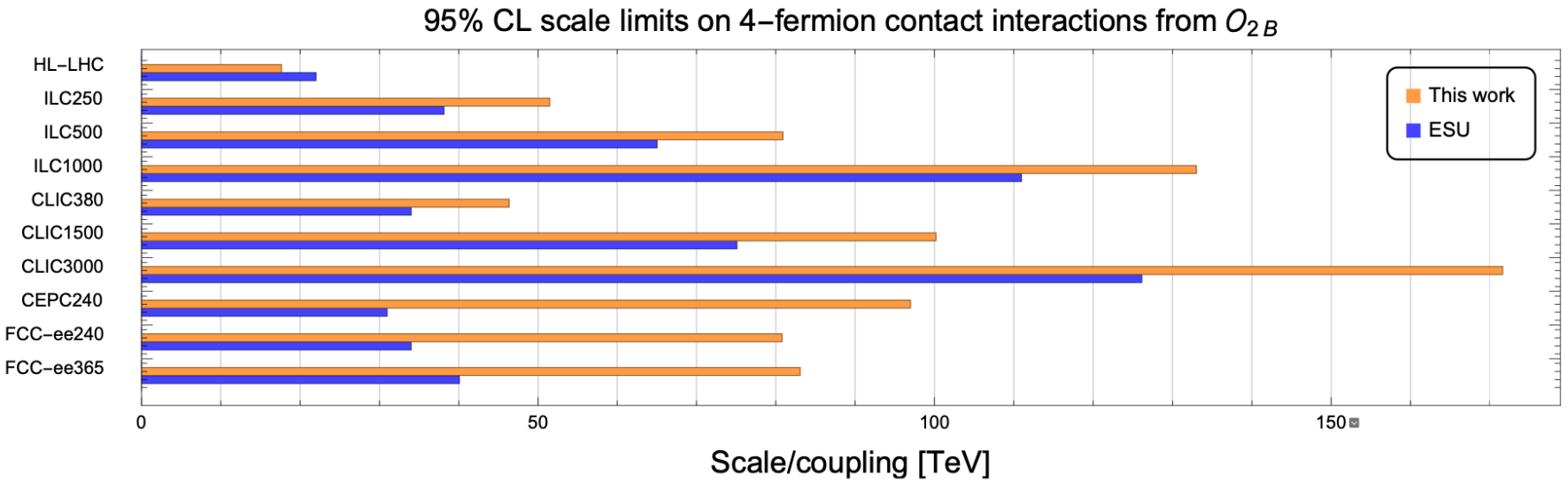
→ CEPC can further test the currently allowed parameter space of these models, advance our understanding of the mass spectrum



Y. Zhang et al., arXiv: 2203.04828

SMEFT global fit

- **SMEFT global fit for 4-fermion and CPV operators at future colliders,**
- The sensitivity to new physics from global fit is significantly enhanced thanks to the high energy/ luminosity/beam polarization of future lepton colliders



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Summary and Outlook

- CEPC has good discovery potential for NP, which is good complementary to LHC
- BSM prospects study at CEPC is going on well, many of the analyses are already public
- CEPC BSM white paper is preparing and to be ready for review by next spring
- Please let us know if you would like to help to the BSM white paper !

Follow more details at each NP session!

Thanks for your attention!

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