# **BSM prospects at the CEPC**

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### Introduction

- Besides as a higgs factory, CEPC has a good potential to search for the direct production of new physics states
- With a very clean collision background, CEPC has the discovery advantage in many scenarios which are challenging at hadron colliders (large Bgs, large pile-up, trigger constraints from high energy objects, and difficulties in obj. Rec and ID).
  - ✓ Exotic Higgs
  - ✓ SUSY
  - ✓ Dark Matter or Dark sector
  - ✓ Long-lived particles
  - ✓ More exotics: Heavy neutrinos, Axion-like particles, EW phase transition, ...



### **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)
  - BSM white paper is scheduled and going-on smoothly:
    - Preliminary organizers: Liantao Wang, Bruce Mellado, Xuai Zhuang, Jia Liu
      - ✓ More to be invited, strong support from Prof. Jinmin Yang, Tianjun Li, Junjie Cao and other theorists in China
    - Timeline (TBD): collect inputs and a very brief white paper draft ready by end of 2022; First paper draft is ready by next Spring?
- BSM prospects at CEPC are included in CEPC snowmass white paper: <u>arXiv:2205.08553</u>

This talk is based on above white paper and CEPC WS @ May 2022.

### **BSM Inputs & Status**

- BSM Higgs (1709.06103; 1808.02037; 1912.01431; 2008.05492; 2011.04540)
   SUSY Searches
  - Direct SUSY Searches (CPC46(2022)013106; 2101.12131; 2203.10580; 2202.11011)
  - Indirect search of SUSY (2010.09782)
  - Global fit of SUSY (2203.04828)
  - 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)
    - DM (Millicharged DM, Vector portal DM, DM with EFT interactions): 1903.1211
    - Mono-gamma (2205.05560)
    - Long-lived particles (1904.10661, 1911.06576, 2201.08960)
    - More exotics:
      - Heavy neutrinos (2102.12826);
      - Axion-like particles (2103.05218, 2204.04702, Jia Liu's talk)
      - Electroweak phase transition (1911.10210,1911.10206,2011.04540)
      - .....

# **BSM Higgs**

A large class of BSM physics, such as singlet extensions, two Higgs-doublet-models (2HDM), SUSY models, Higgs portals, gauge extensions of the SM, motivates these exotic decay considerations.



Representative topologies of the Higgs exotic decays

#### Reference:

- 2HDM searches: 1709.06103; 1808.02037; 1912.01431; 2008.05492; 2011.04540
- Exotic higgs decay: 1612.09284, 2110.13225, 2203.08206, 2002.05554, 2003.01662, 2006.03527...
- Summarized at <u>2205.08553</u>.

## **Exotic Higgs decay**

- Exotic decays of the 125 GeV Higgs boson at future e +e lepton colliders, Z. Liu, L.-T. Wang, and H. Zhang, <u>1612.09284</u>
- Exotic Higgs Decays to Four Taus at Future Electron-Positron Colliders, J. Shelton and D. Xu, 2110.13225
- CEPC is very sensitive for signals with jets, heavy quarks and taus, which is challenge at LHC



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

### **SUSY Searches at CEPC**

#### Reference: mainly light EWKino and slepton for CEPC

• Electroweakino (wino, higgsino) search: CPC46(2022)013106

Higgsino-like EWK processes

- Bino NLSP at CEP: 2101.12131
- Slepton search: 2203.10580

 $\rightarrow$  Z(\*)  $\widetilde{\chi}_{1}^{0}$  and  $\widetilde{\chi}_{2}^{\pm} \rightarrow$  W(\*)  $\widetilde{\chi}_{1}^{0}$ 

- Heavy selectron search: 2202.11011
- Indirect search of SUSY (2010.09782)
- Global fit of SUSY (2203.04828)





ILC 500/CEPC240: discovery in all scenarios up to kinematic limit:  $\sqrt{s/2}$ 

### Wino & higgsino

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



### **Bino NLSP at CEPC**

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



### **Slepton search**

#### Prospects for slepton pair production at CEPC, Jia-Rong Yuan, Hua-Jie Cheng, Xu-Ai Zhuang, arXiv: 2203.10580



### Heavy selectron search

- Probing relatively heavier right-handed selectron in the GmSUGRA, by Waqas Ahmed, Imtiaz Khan, Tianjun Li, Shabbar Raza and Wenxing Zhang, arXiv: 2202.11011
- There two types of light neutralinos that achieve the correct relic density by Z-resonance and h-resonance.

Higgs-pole  $\rightarrow m_{\tilde{\chi}_1^0} \approx \frac{1}{2} m_h$  and Z-pole  $\rightarrow m_{\tilde{\chi}_1^0} \approx \frac{1}{2} m_Z$ .





### 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, such as CMSSM, NUHM1, NUHM2 and pMSSM-7, Yang Zhang etc, arXiv: 2203.04828
- CEPC can further test the currently allowed parameter space of these models, advance our understanding of the mass spectrum





### **Dark Matter and Dark Sector searches**

#### Reference:

- Lepton portal DM (JHEP 06 (2021) 149)
- Asymmetric DM (PRD 104(2021)055008)
- Dark Sector from exotic Z decay (1712.07237)
- DM (Millicharged DM, Vector portal DM, DM with EFT interactions): 1903.1211
- Mono-gamma (2205.05560)

| FCC-hh (Dijet)<br>HL-LHC (Dijet) Dijet g <sub>Q</sub> =1/4   | HE-LHC<br>HL-LHC            | g <sub>DM</sub> =1, g <sub>Q</sub> =1<br>tt+MET | E 2000 110-44<br>E 2000 1100 1100 1100 1100 1100 1100 110  |
|--|-----------------------------|---|--|
| FCC-hh<br>LE-FCC   | FCC-hh<br>LE-FCC            | g <sub>DM</sub> =1, g <sub>Q</sub> =1           | DarkSide-Argo (proj.)<br>DarkSide-Argo (proj.)<br>DARWIN-200 (proj.)   |
| HE-LHC Monojet   | HE-LHC                      | Monojet   | 10 <sup>-46</sup>  |
| CLIC <sub>3000</sub> g <sub>DM</sub> ×g <sub>E</sub> =1/4  | CLIC <sub>3000</sub>        | g <sub>DM</sub> ×g <sub>E</sub> =1              | 10 <sup>-47</sup> DARWIN-200 (proj.)   |
| ILC Monophoton   | ILC<br>FCC-ee               | Monophoton                                      | 10 <sup>-49</sup><br>Hings Portal model  |
| CEPC         European Strategy         Axial-Vector           0.1         0.5         1         5         10 | 0.1 0.5 1                   | European Strategy Scalar<br>5 10                | Direct searches, Majorana DM<br>10 <sup>-50</sup> Collider limits at 95% CL, direct detection limits at 90% CL<br>1 10 10 <sup>2</sup> 10 <sup>3</sup> European Strategy |
| $M_{ m Mediator}$ [TeV]  | M <sub>Mediator</sub> [TeV] |   | m <sub>x</sub> [GeV]   |

- Searching for lepton portal dark matter with colliders and interplay with the gravitational wave (GW) astronomy, Jia Liu, Xiao-Ping Wang, KePan Xie, 2104.06421, JHEP 06 (2021) 149
- The phase transition GWs can also be a probe of the model.

 $e^+e^- \to S^{\pm(*)}S^{\mp} \to \ell^+\chi\ell'^-\chi \quad h/Z \to S^{\pm(*)}S^{\mp(*)} \to \ell^+\chi\ell'^-\chi \text{ and } h \to \chi\chi_{\Xi}$ 



FIG. 10. Figure from Ref. [168], the interplay between GW detection and future  $e^+e^-$  collider searches. The gray shaded region is the LISA detectable parameter space. From left to right, the sensitivities for  $\lambda_{HS}$  are shown from future CEPC precision measurements, in which the region above a given  $m_{\chi}$  (corresponding to a colored line) can be probed.



- Searching for asymmetric Dark Matter (ADM) at CEPC, Mengchao Zhang, 2104.06988, PRD 104, 055008 (2021)
- It is possible to generate dark quark pair through a t-channel process, dark quark q' will be a jet-like object in detector.



The mass of mediator can be excluded up to O(10) TeV, better than LHC



- Exposing Dark Sector via exotic Z-boson decay with Future Z-Factories, Jia Liu, Lian-Tao Wang, Xiao-Ping Wang, Wei Xue, 1712.07237, PRD 97, 095044 (2018)
- Four models include: Higgs/Vector portal DM, inelastic dark matter and axion like particles.
- Compared with HL-LHC, the reach for the BR of various exotic Z decay modes at Z-factories is sensitive for many decay modes.



- Probing DM particles at CEPC (Millicharged DM, Vector portal DM, DM with EFT interactions): ZL, Yong-Heng Xu, Yu Zhang ,1903.1211
  - ✓ CEPC can probe millicharged DM that is currently unexplored
  - ✓ CEPC can probe the parameter space of vector-portal DM models and EFT DM models that are unconstrained by DMDD
- Mono-γ Production of a Vector Dark Matter at CEPC, K Ma, 2205.05560





# Long-lived particles (LLP)

#### Reference:

- LLP at near Detector:1904.10661
- LLP at Far Detector: 1911.06576, 2201.0896
- LL Dark Hadrons: 2110.10691
- On-going: Yulei Zhang: Talk





# LLP at near Detector (ND)

- Long-lived light neutralinos at future Z-factories (RPV SUSY), Zeren Simon Wang, Kechen Wang, 1904.10661, PRD 101, 115018 (2020)
- The model parameter λ'<sub>112</sub>/m<sup>2</sup><sub>f</sub> can be discovered down to as low as ~1.5×10<sup>-14</sup> (3.9×10<sup>-14</sup>) GeV<sup>-2</sup> at the FCC-ee (CEPC)



#### arXiv: 1904.10661



# LLP at Far Detector (FD)

- Physics with Far Detectors at Future Lepton Colliders, Zeren Simon Wang, Kechen Wang, 1911.06576, PRD 101, 075046 (2020)
- Search for long-lived axions with far detectors at future lepton colliders, Minglun Tian, Kechen Wang, Zeren Simon Wang, 2201.08960
- FD can extend and complement the sensitivity to the LLPs compared with Near Detector



### LL Dark Hadrons

- A theory of Dark Pions, Hsin-Chia Cheng, Lingfeng Li, Ennio Salvioni, 2110.10691, JHEP 01 (2022) 122, see Lingfeng's <u>talk</u>
- The dark quarks couple to the SM via irrelevant Z- and Higgsportal operators. The dark pions, behave as either composite axion-like particles (ALPs) mixing with Z or h
  arXiv: 2110.10691



### **More exotics**

#### Reference:

- Heavy neutrinos (2102.12826);
- Axion-like particles (2103.05218, 2204.04702, Jia Liu's <u>talk</u>)
- Electroweak phase transition (1911.10210,1911.10206,2011.04540,)
- •

# Axion-like particles (ALP)

Searching for ALP at future electron-positron colliders, H. Y. Zhang, C.X. Yue, Y.C. Guo, and S. Yang, 2103.05218, PRD104 (2021) 096008

 $\rightarrow$  CEPC is more sensitive to the ALPs couplings  $g_{a\gamma\gamma}$  with mass 2-8 GeV than LHC and CLIC.

• Searching for ALP via decay  $Z \rightarrow aff$  at future Z factories, 2204.04702

Axion-like particle solution to muon g-2 and its test at Z-factory, Jia Liu's talk



### **Summary and Outlook**

- CEPC has good discovery potential for NP at many scenarios which are challenge for LHC
  - BSM prospects study at CEPC is going on well, many of the analyses are already public
- Plan to organize a workshop by end of this year to collect inputs for CEPC BSM white paper
  - **BSM physics white paper for CEPC at next Spring?**

#### **Thanks for your attention!**





https://indico.cern.ch/event/687651/contributions/3400865/attachme nts/1850992/3038683/Wagner-LHCP2019.pdf

#### **Muon Anomalous Magnetic Moment**



Here  $\tilde{m}$  represents the weakly interacting supersymmetric particle masses.

For tan  $\beta \simeq 10$  (50), values of  $\tilde{m} \simeq 230$  (510) GeV would be preferred.

Masses of the order of the weak scale lead to a natural explanation of the observed anomaly !