中国科学院高能物理研究所
Institute of High Energy Physics
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BSM Search Potential at CEPC

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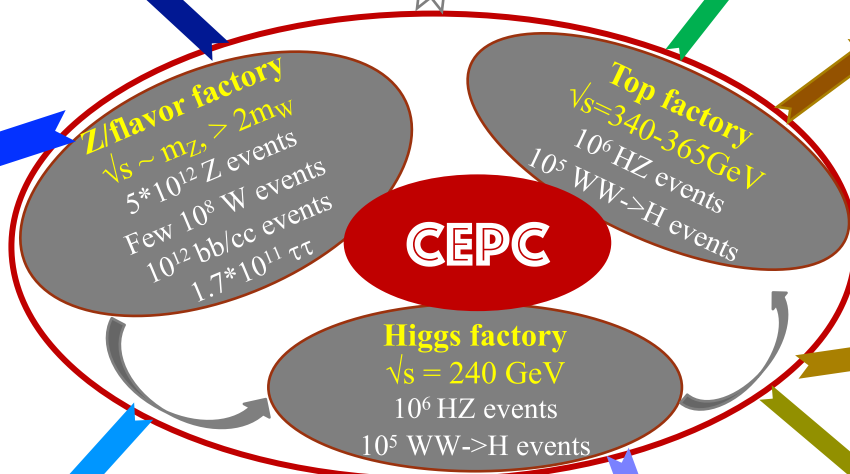
CEPC BSM Physics Program

1: Exotics of Higgs, W, Z, top
- Higgs exotic decay (SUSY, LLP, DS, invisible)
- Light higgs
- Z exotic decay
- Top exotic decay

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

9: Global fits
- Global fit of SUSY
- 2HDM global fit
- SMEFT global fit

2: Dark Matter & Dark Sector
- SUSY DM
- Higgs portal DM
- Vector boson portal DM
- Fermion portal DM
- EFT
- ……



8: More exotics
- Axion-like particles
- Lepton form factors
- Emergent Hadron Mass
- Exotic lepton mass
- ……

7: Neutrino
- Heavy neutrinos
- Active-sterile neutrino
- Non-standard neutrino interactions

3: LLP
- At both CEPC and it's FAR detector
- H/Z decay
- SUSY LLP
- VLL, ALP, …

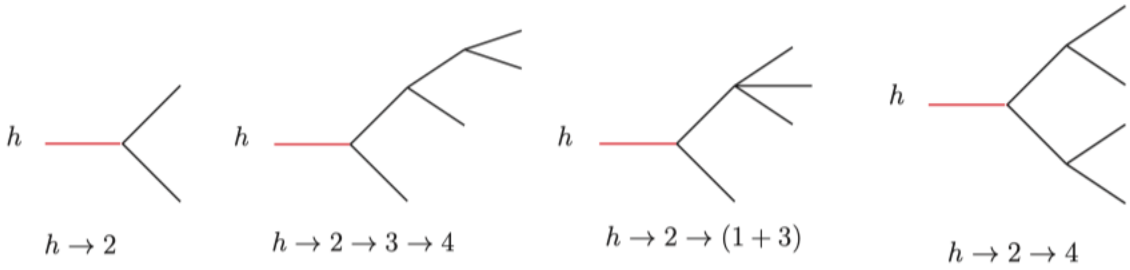
4: SUSY
- Light EWKinos
- Light sleptons
- Heavy selectrons
- ……

5: Flavor portal NP
- cLFV processes
- Decays of b and c hadrons
- ……

6: EWPT & GW
- Probe nature EWPT
- Higgs precision
- Higgs exotic decay

1. Exotic Higgs/Z/top decays

- *Higgs exotic decay* motivated by a large class of BSM physics, such as singlet extensions, two Higgs-doublet-models (2HDM), SUSY models, Higgs portals, gauge extensions of the SM …

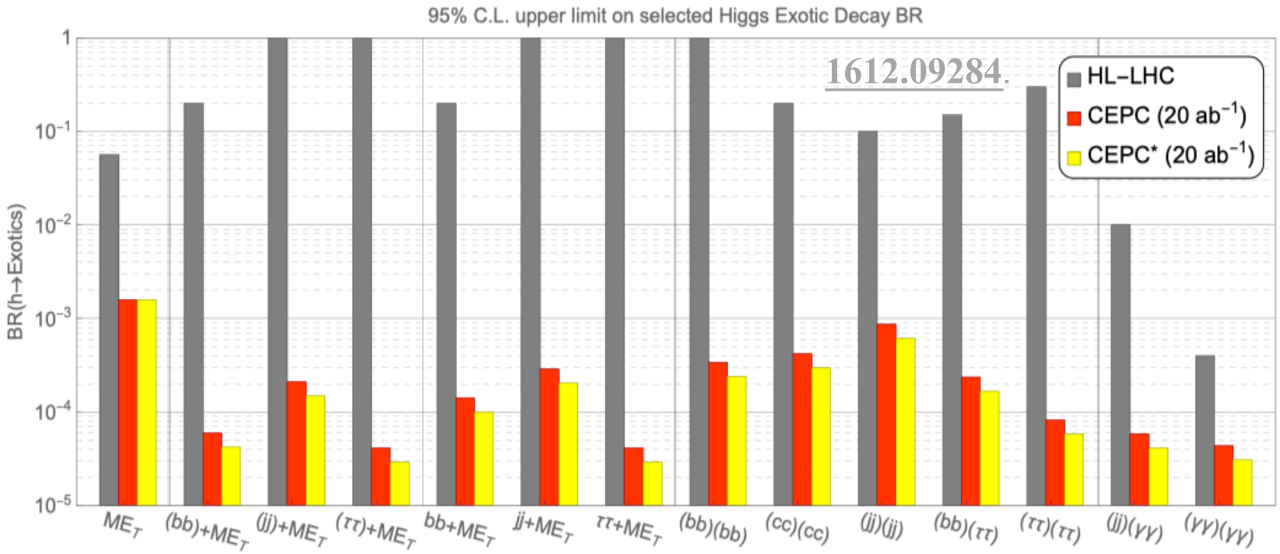


Representative topologies of the Higgs exotic decays

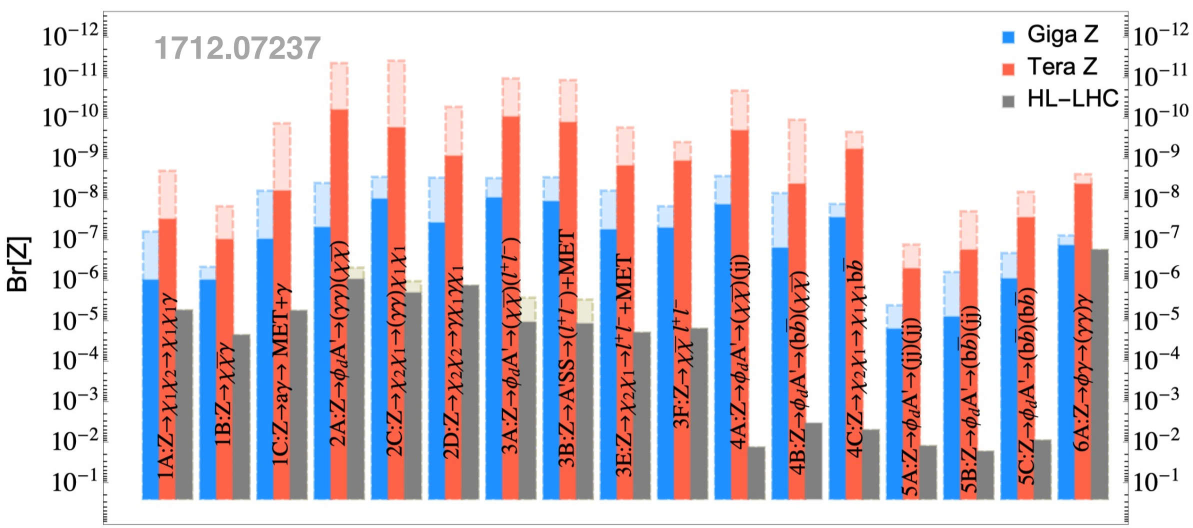
- ***Exotic Z or top decays*** are also motivated by many BSM models (ED, **Heavy Vector Triplet** , …) and can also be searched at CEPC

- ***Light Higgs*** **are motivated by 2HDM and Axion-like particle models, which can be searched at CEPC well if they exist.**

Exotic Higgs/Z/top decays



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

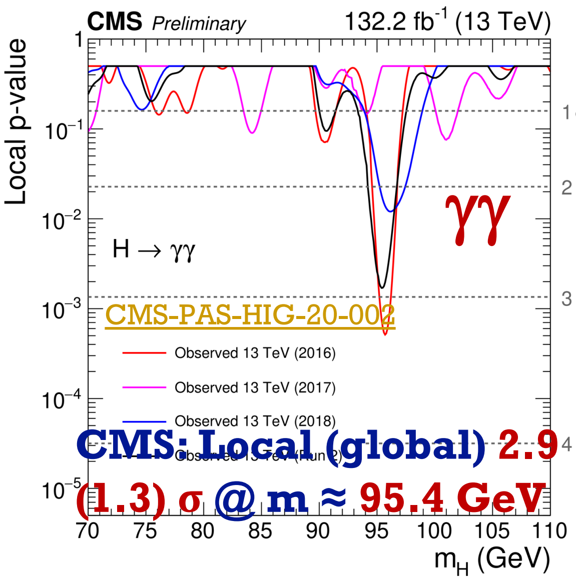


The reach for the branching ratio of various exotic Z decay modes

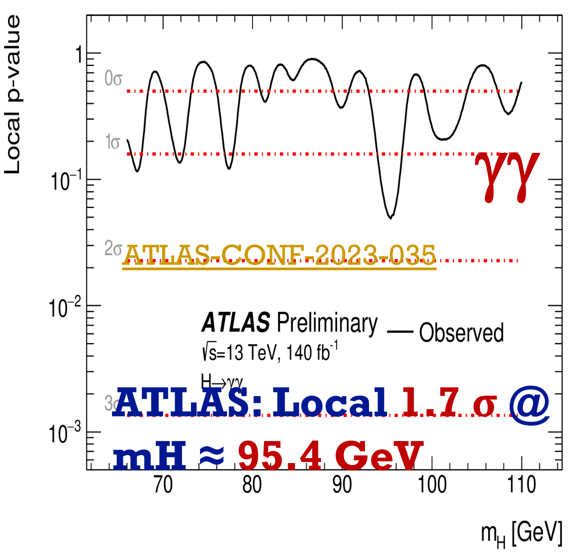
→ Good sensitivity of exotic Higgs/Z decay from CEPC

Light Higgs

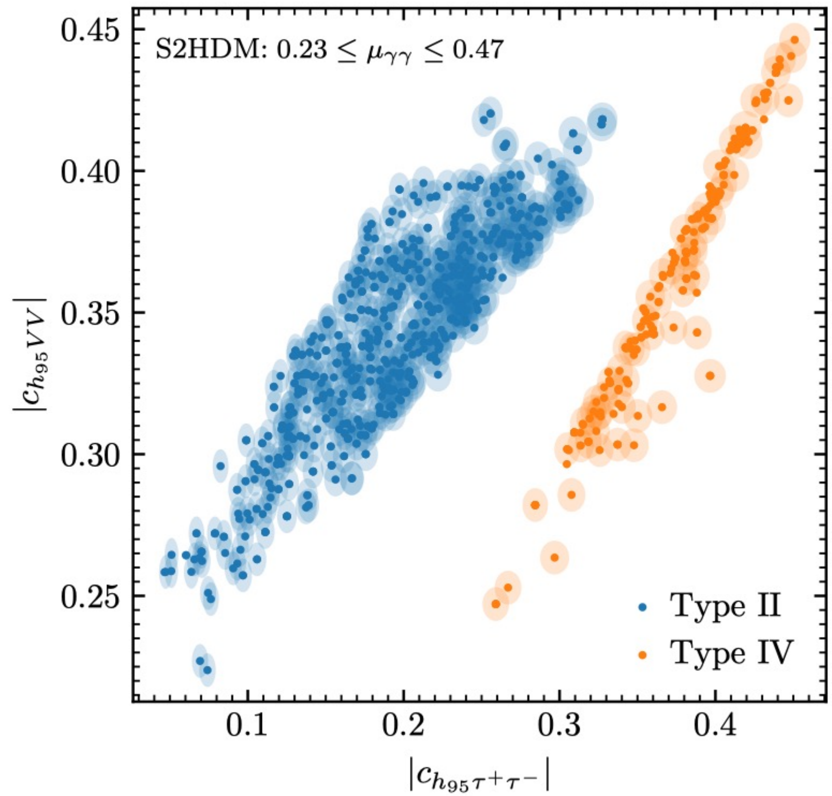
- **Light Higgs are motivated by 2HDM and Axion-like particle models**



CMS: Local (global) 2.9 (1.3) σ @ m ≈ 95.4 GeV



ATLAS: Local 1.7 σ @ mH ≈ 95.4 GeV



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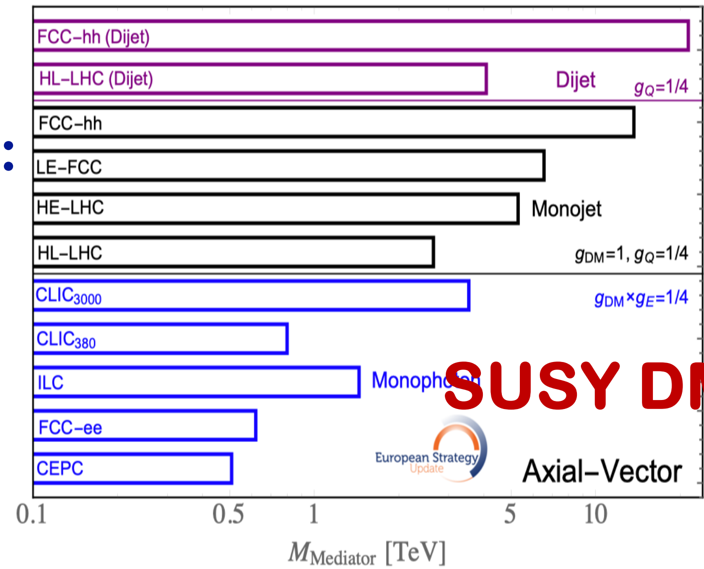
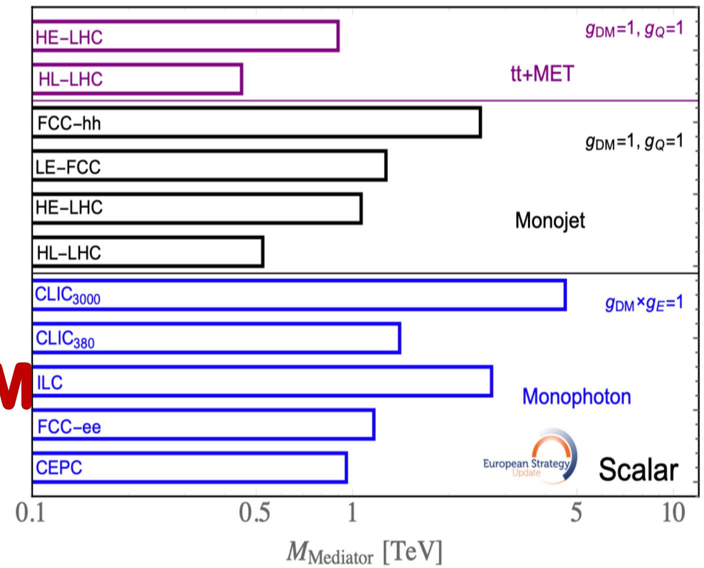
S2HDM parameter points passing the applied constraints for the di-photon signal strengths.

Light higgs can be searched at CEPC very well if exists.

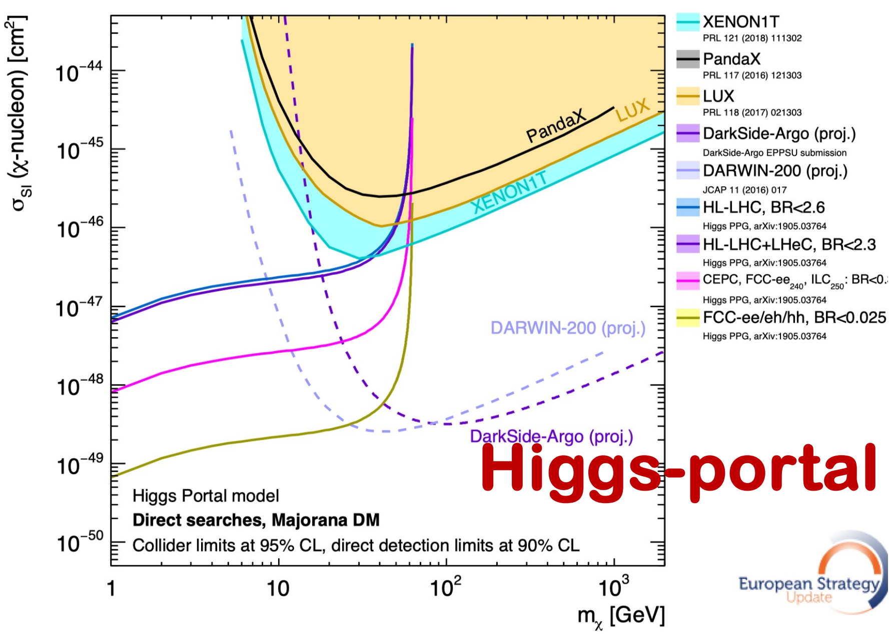
2. Dark Matter and Dark Sector

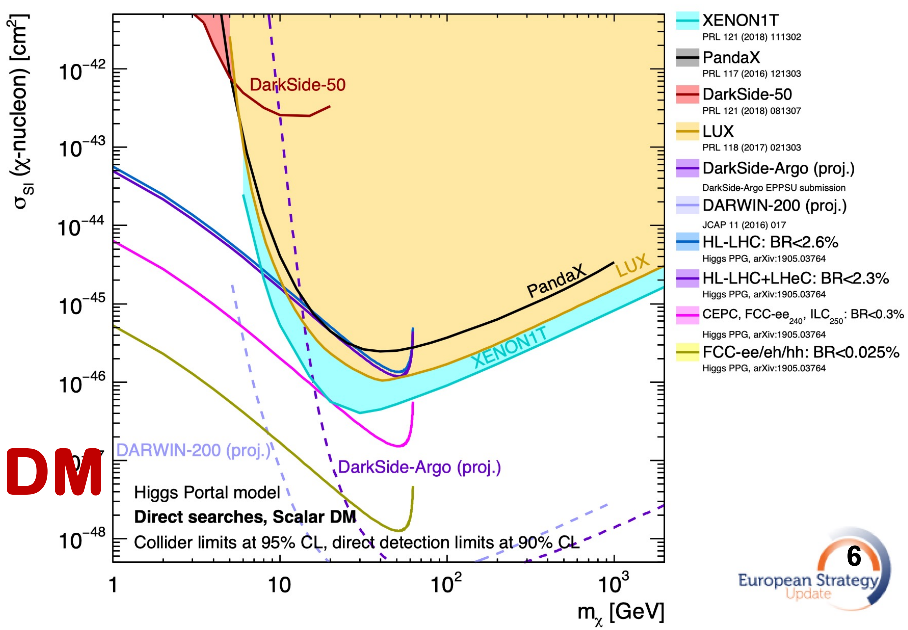
- **SUSY DM**
- **Non-SUSY DM:**
  - Higgs portal
  - Fermion portal
  - Vector portal
  - EFT





SUSY DM

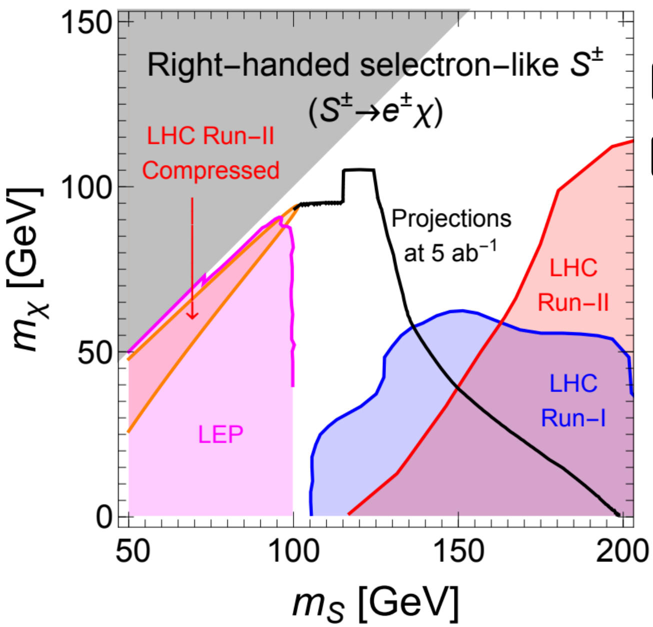




Higgs-portal DM

2. Dark Matter and Dark Sector

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



Lepton-portal DM

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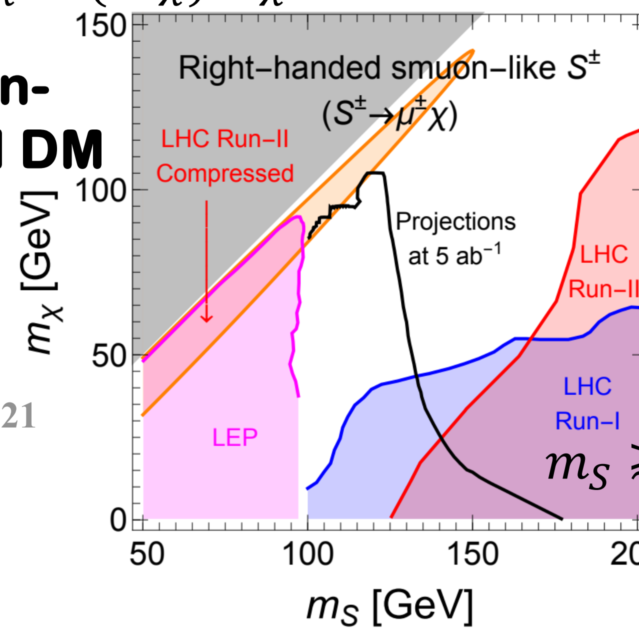
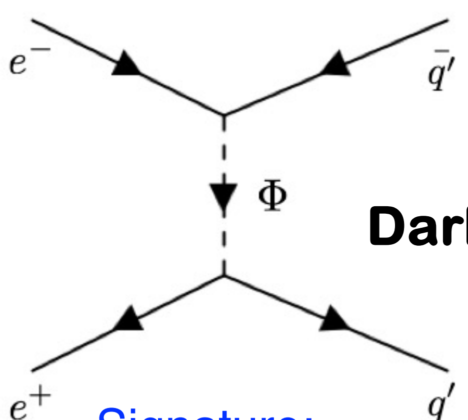


Fermion-portal DM

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

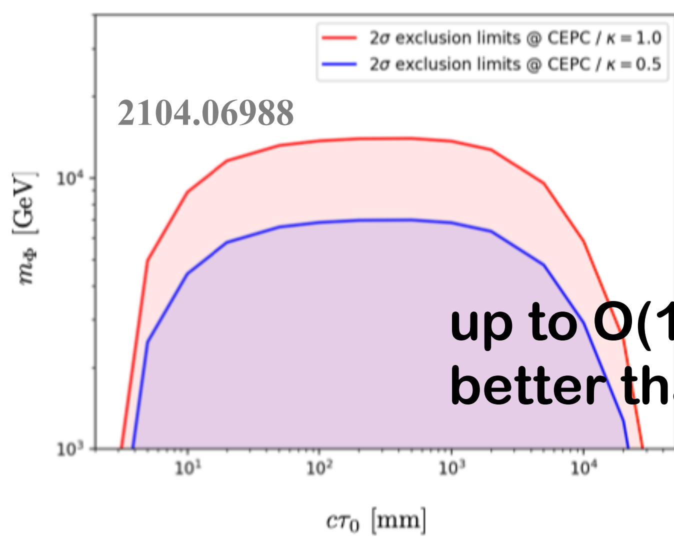


Decay to leptons

Dark quark q′

Jet-like

Signature:
Lepton + jet + MET



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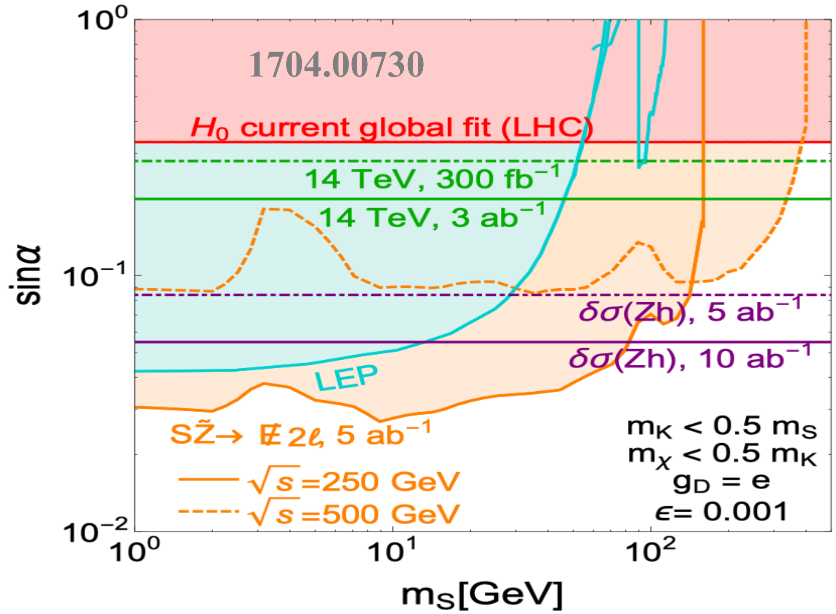
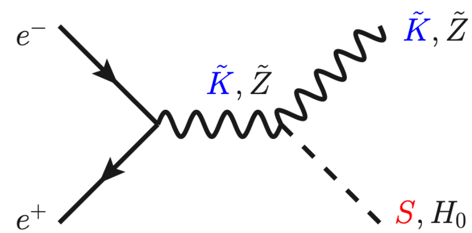
up to O(10) TeV, better than LHC

2. Dark Matter and Dark Sector

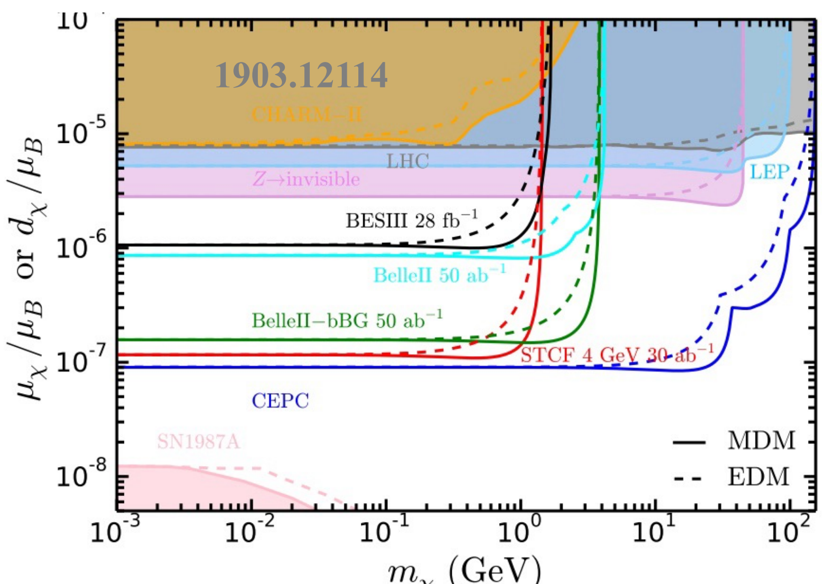


Dark Sector from Z/H associate production

Double Dark Portal model

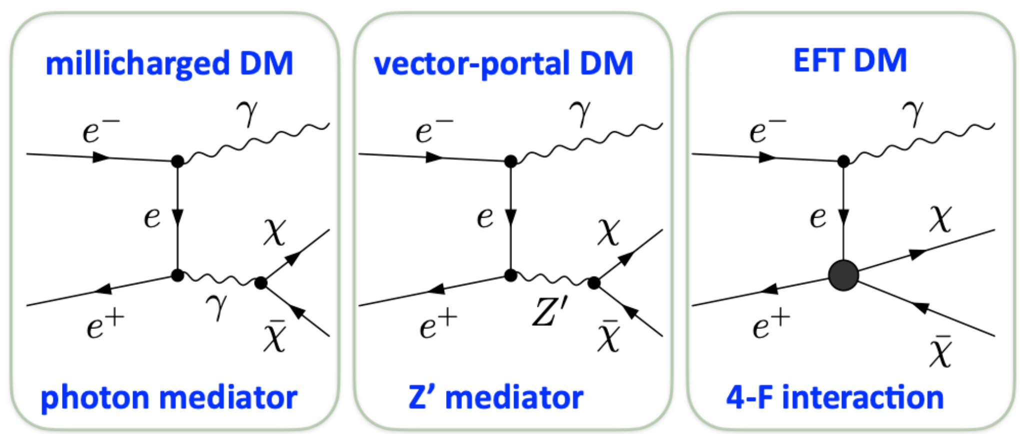


Vector-portal DM



EFT DM

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

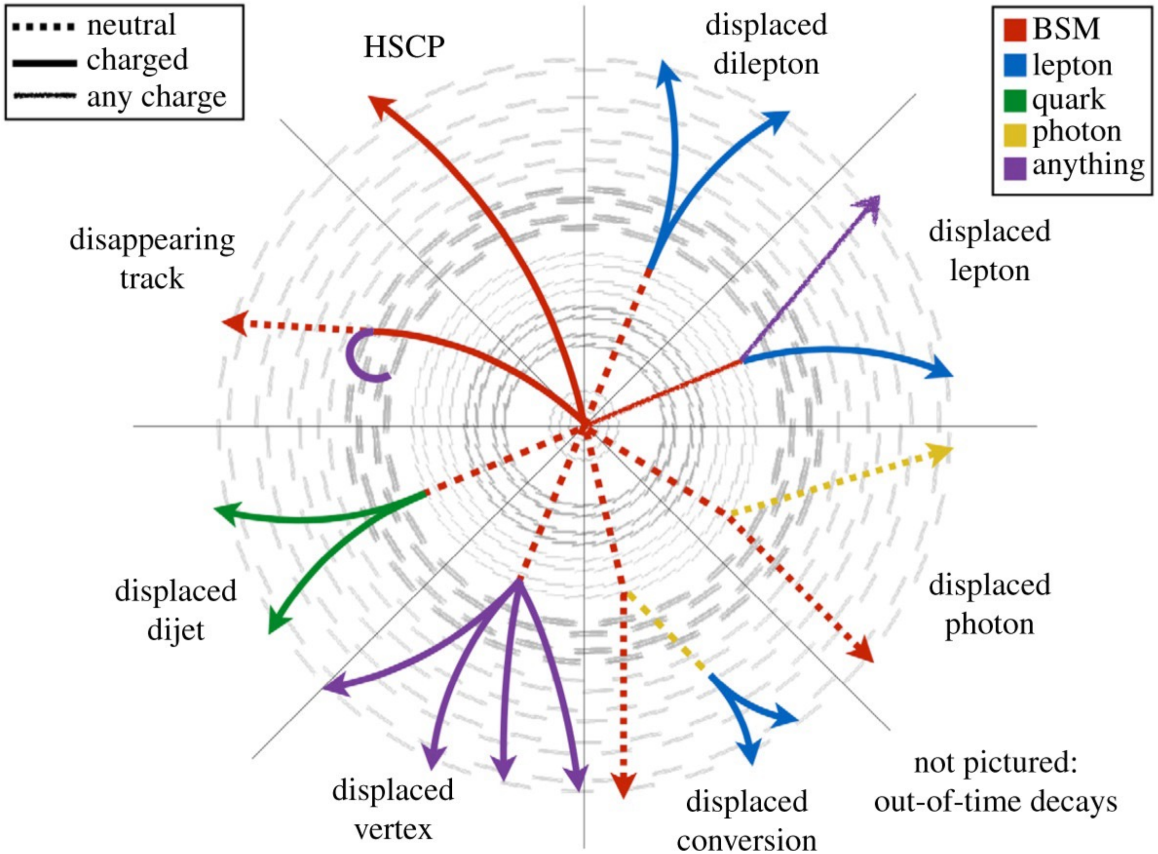


→ CEPC can probe low-mass light dark states.

3. Long-lived particles (LLP)

Long lifetimes result from a few simple physical mechanisms:

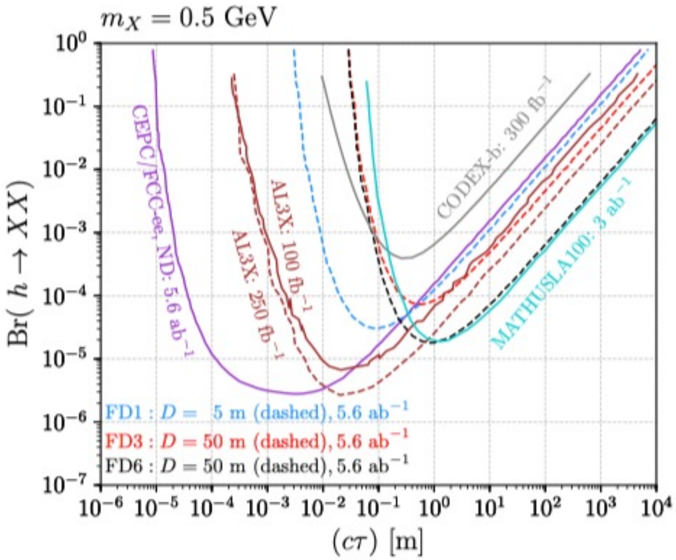
- Small couplings (ex. RPV SUSY)
- Limited phase space: small mass splitting (ex. compressed SUSY, …)
- Heavy intermediate states
- ……



- Higgs boson decays
- Z-boson decays
- SUSY LLP
- Vector-like leptons with scalar
- …

→ Far Detector can help a lot!

3. LLP at Far Detector (FD)



Light Scalars from Exotic Higgs Decays

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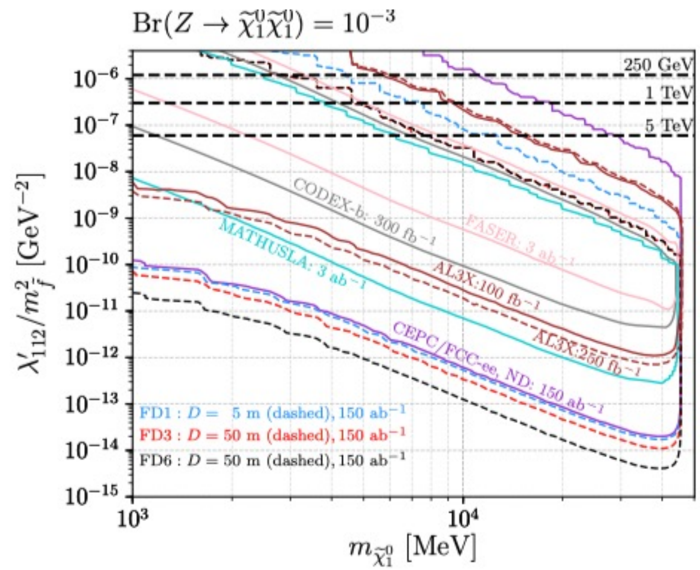
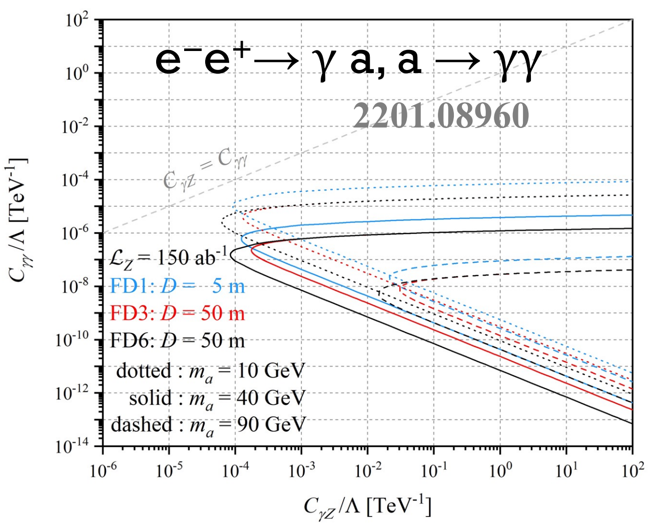


Light Neutralinos from Z Decays

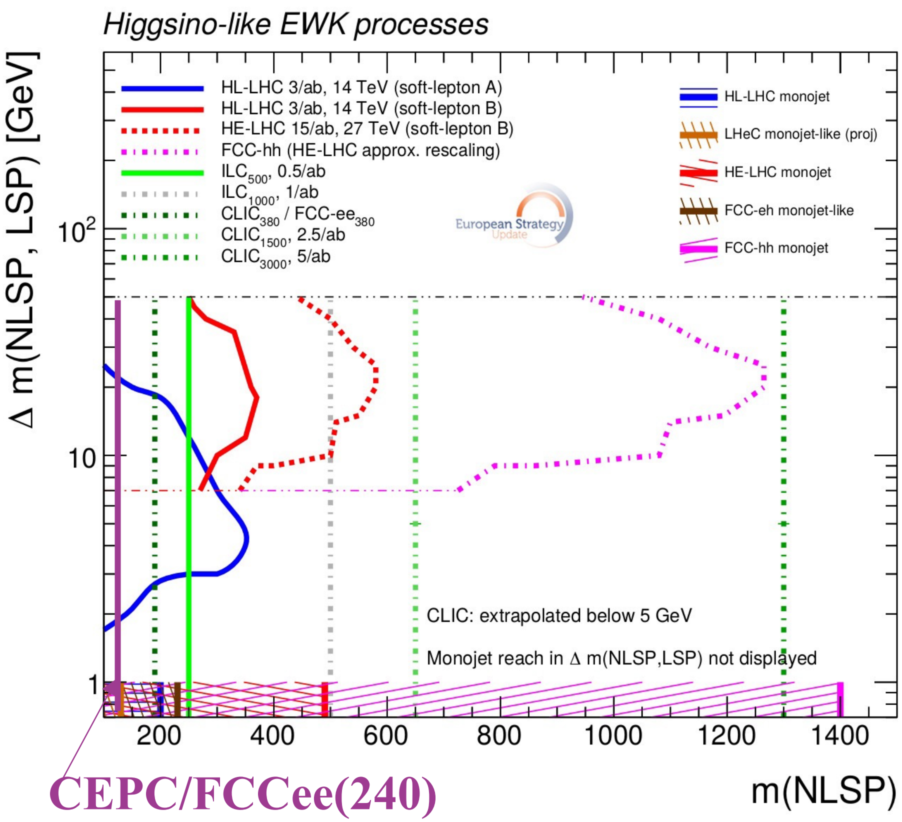


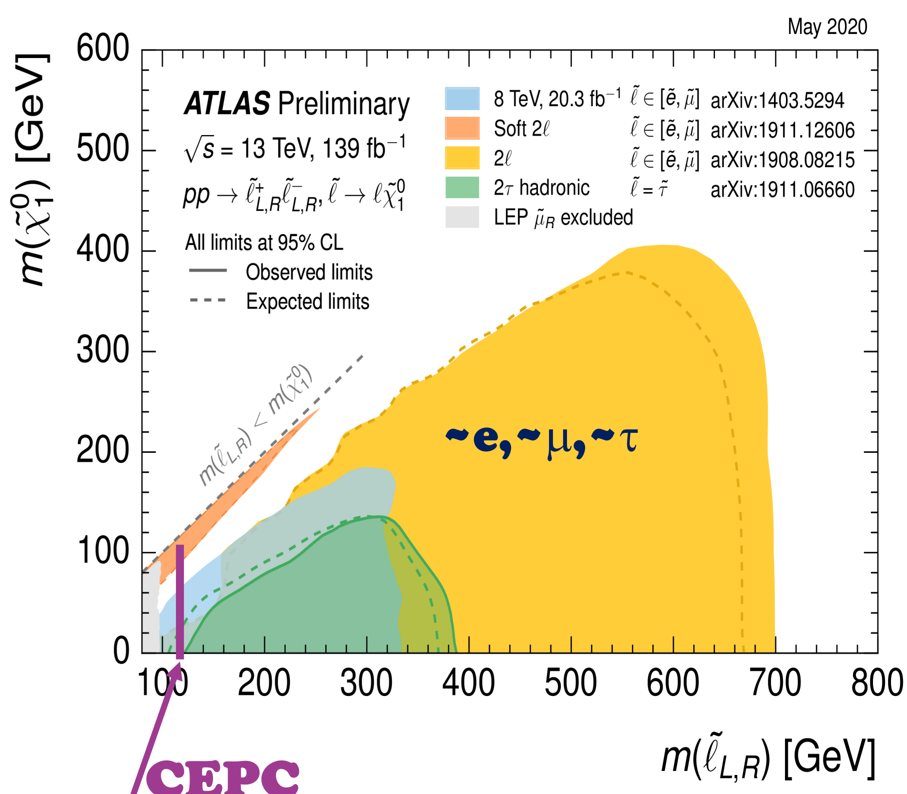
Axion-like Particles

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

4. SUSY Searches at CEPC

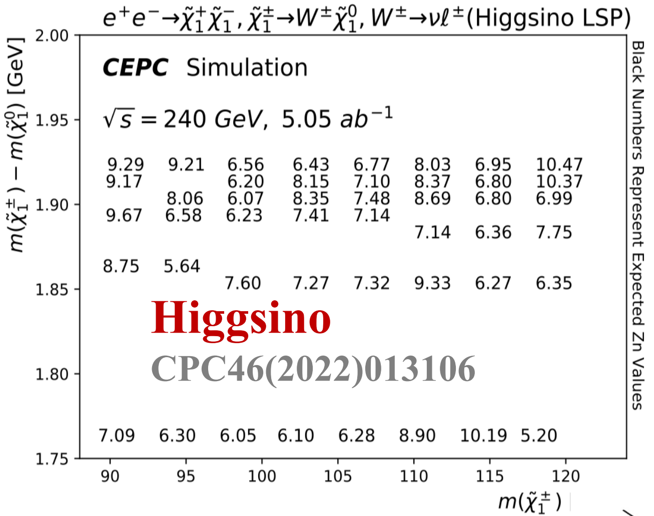
- **SUSY: establishes a symmetry between fermions and bosons, solve many big questions: unification, DM, Hierarchy, ……**
- **Complementary with LHC: lower mass/soft energy region**
  - ✓ **Mainly light EWKino and slepton for CEPC**

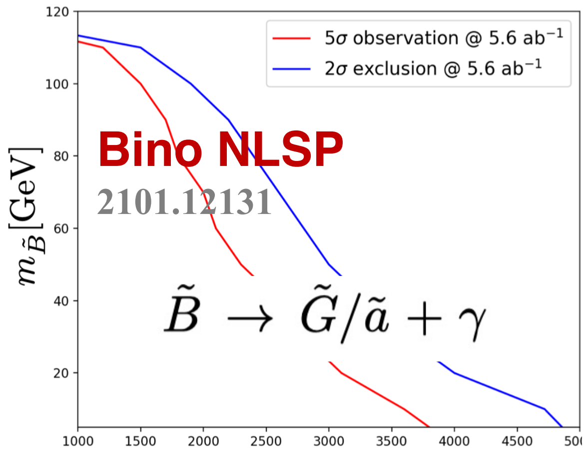


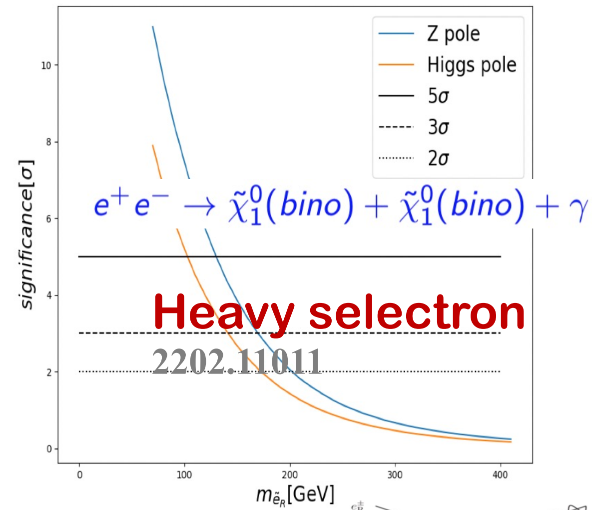


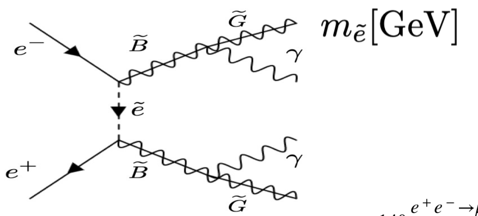
Lepton collider: discovery in all scenarios up to kinematic limit: √s/2

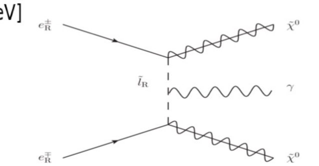
4. SUSY Searches at CEPC

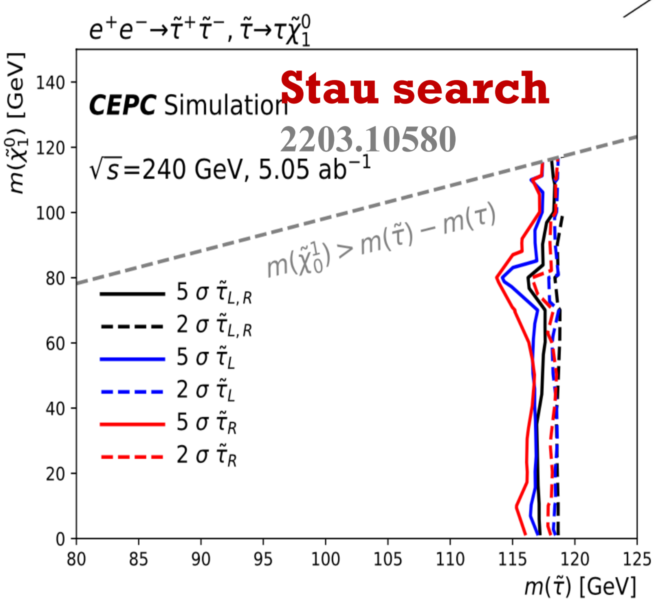


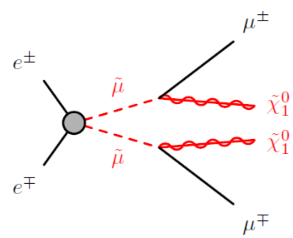


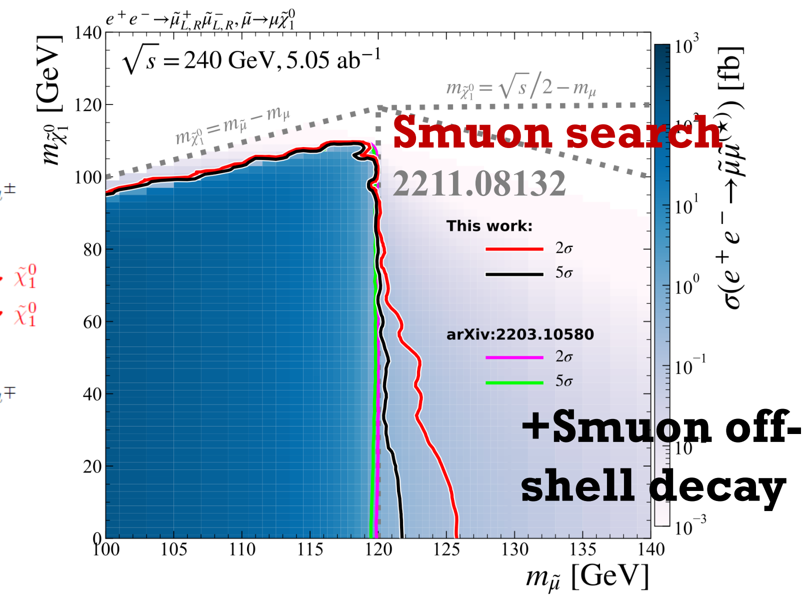












5. Flavor portal NP

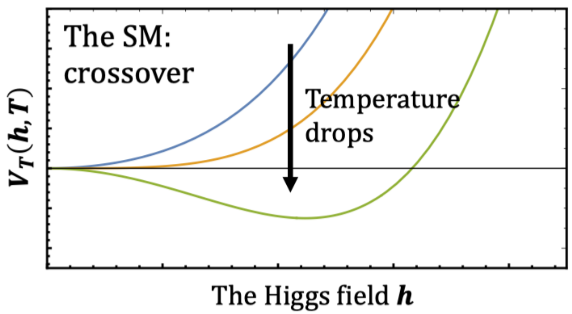
- CEPC is also a flavor factory (b,c,tau) when running at Z pole, which has a unique sensitivity for some rare processes due to suppression in SM
- The sensitivity of the flavor sector to new physics is underscored by several factors:
  - cLFV processes
  - Decays of b and c hadrons
  - Light BSM degrees of freedom from flavor transitions (cLFV or quark FCNC processes) with inv. BSM states or LLP

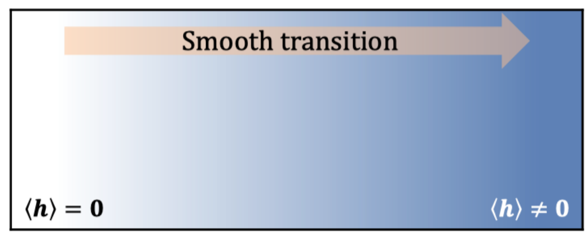
Measurement	Current Limit	CEPC [272]
$\mathrm{BR}(Z \to \tau\mu)$	$< 6.5 \times 10^{-6}$	$\mathcal{O}(10^{-9})$
$\mathrm{BR}(Z \to \tau e)$	$< 5.0 \times 10^{-6}$	$\mathcal{O}(10^{-9})$
$\mathrm{BR}(Z \to \mu e)$	$< 7.5 \times 10^{-7}$	$10^{-8} - 10^{-10}$
$\mathrm{BR}(\tau \to \mu\mu\mu)$	$< 2.1 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to eee)$	$< 2.7 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to e\mu\mu)$	$< 2.7 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to \mu ee)$	$< 1.8 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to \mu\gamma)$	$< 4.4 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(\tau \to e\gamma)$	$< 3.3 \times 10^{-8}$	$\mathcal{O}(10^{-10})$
$\mathrm{BR}(B_s \to \phi\nu\bar{\nu})$	$< 5.4 \times 10^{-3}$	$\lesssim 1\%$ (relative)
$\mathrm{BR}(B^0 \to K^{*0}\tau^+\tau^-)$	-	$\lesssim \mathcal{O}(10^{-6})$
$\mathrm{BR}(B_s \to \phi\tau^+\tau^-)$	-	$\lesssim \mathcal{O}(10^{-6})$
$\mathrm{BR}(B^+ \to K^+\tau^+\tau^-)$	$< 2.25 \times 10^{-3}$	$\lesssim \mathcal{O}(10^{-6})$
$\mathrm{BR}(B_s \to \tau^+\tau^-)$	$< 6.8 \times 10^{-3}$	$\lesssim \mathcal{O}(10^{-5})$
$\mathrm{BR}(B^0 \to 2\pi^0)$	$\pm 16\%$ (relative)	$\pm 0.25\%$ (relative)
$C_{CP}(B^0 \to 2\pi^0)$	± 0.22 (relative)	± 0.01 (relative)
$\mathrm{BR}(B_c \to \tau\nu)$	$\lesssim 30\%$	$\pm$ 0.5% (relative)
$\mathrm{BR}(B_c \to J/\psi\tau\nu)/\mathrm{BR}(B_c \to J/\psi\mu\nu)$	$\pm 0.17 \pm 0.18$	$\pm 2.5\%$ (relative)
$\mathrm{BR}(B_s \to D_s^{(*)}\tau\nu)/\mathrm{BR}(B_s \to D_s^{(*)}\mu\nu)$	-	$\pm 0.2\%$ (relative)
$\mathrm{BR}(\Lambda_b \to \Lambda_c\tau\nu)/\mathrm{BR}(B_c \to \Lambda_c\mu\nu)$	$\pm$ 0.076	$\pm 0.05\%$ (relative)
$\mathrm{BR}(\tau \to \mu X_{\mathrm{inv.}})$	7×10^{-4}	(3-5)$\times 10^{-6}$
$\mathrm{BR}(B \to \mu X_{\mathrm{LLP}}(\to \mu\mu))$	-	$\mathcal{O}(10^{-10})$ (optimal)

Preliminary sensitivities of BSM flavor physics probes at CEPC
> two orders of magnitude improv.

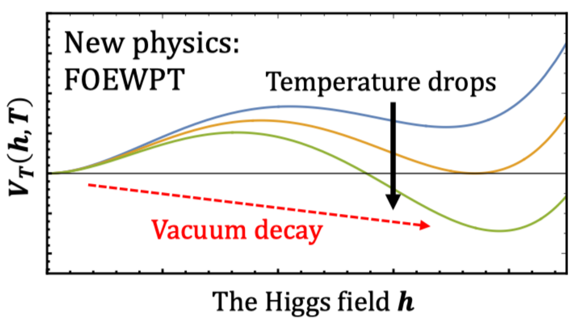
6. EWPT at CEPC

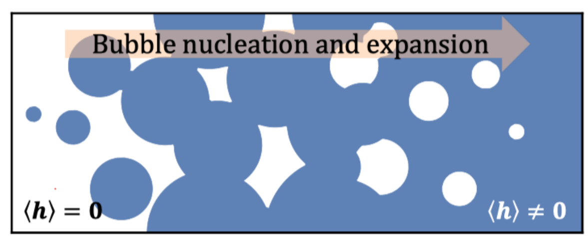
- The nature of Electroweak Phase Transition (EWPT) deeply impacts the thermal history of the Universe, closely linked to puzzles of DM, matter-antimatter asymmetry
  - Probing the nature of EWPT at colliders





In the SM, the transition is a smooth crossover

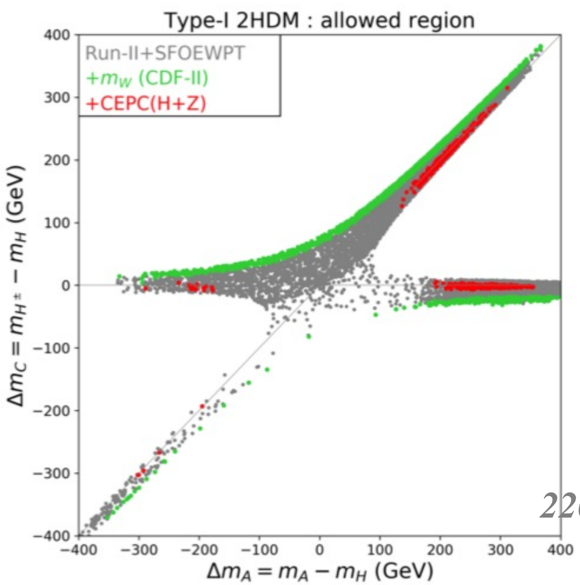


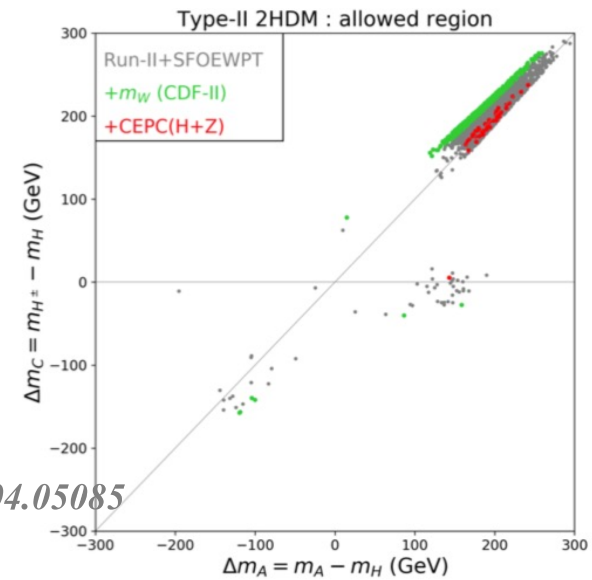


In NP, the scalar potential exhibits a barrier, allowing for a FOEWPT with bubble nucleation and expansion

  - Higgs precision measurements
  - Higgs exotic decay

6. EWPT at CEPC





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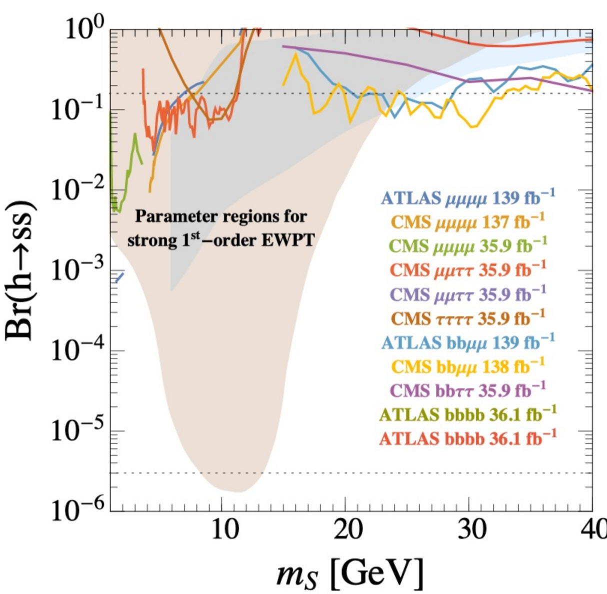
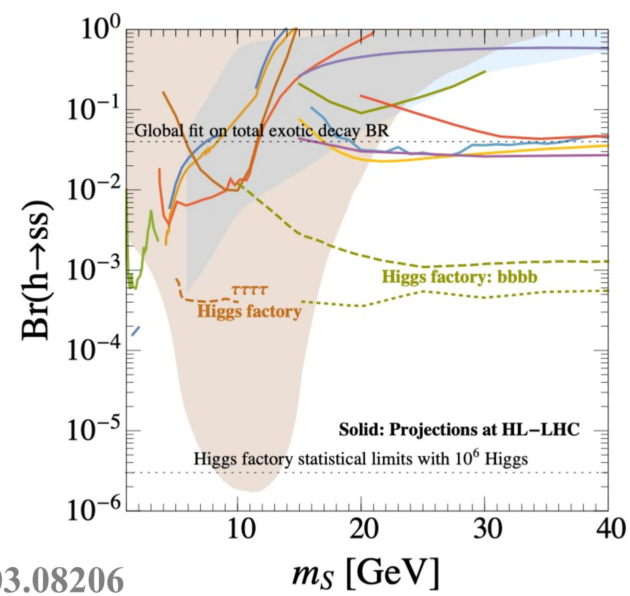
Under current constraints, both Type-I and Type-II 2HDM can explain the SFOEWPT, Z-pole, **Higgs precision measurements** and mW precision measurement of CDF-II at same time.





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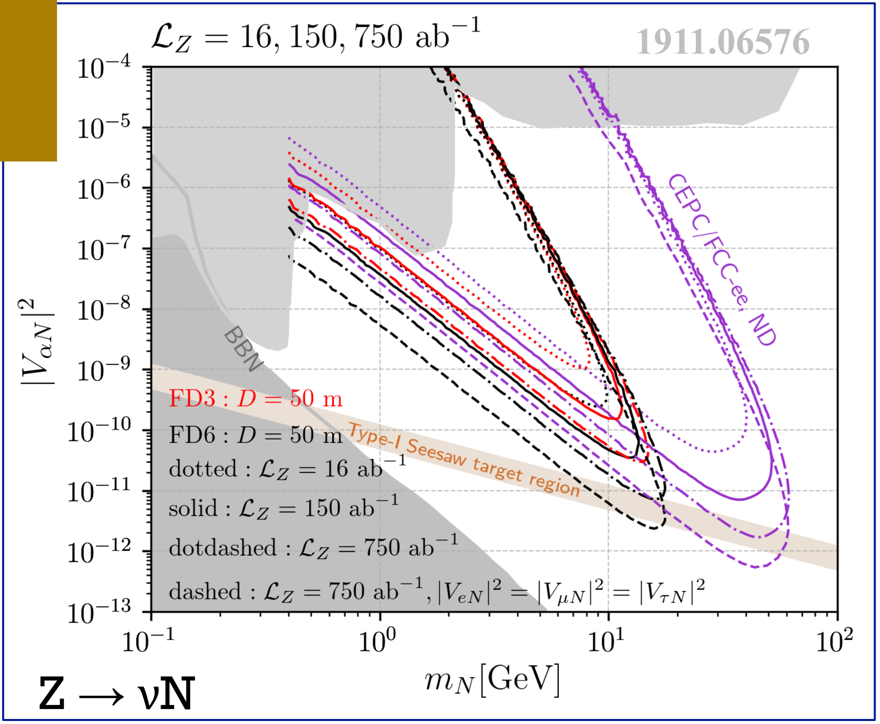
Higgs exotic decay

h→ss→XXYY as a probe for the FOEWPT：

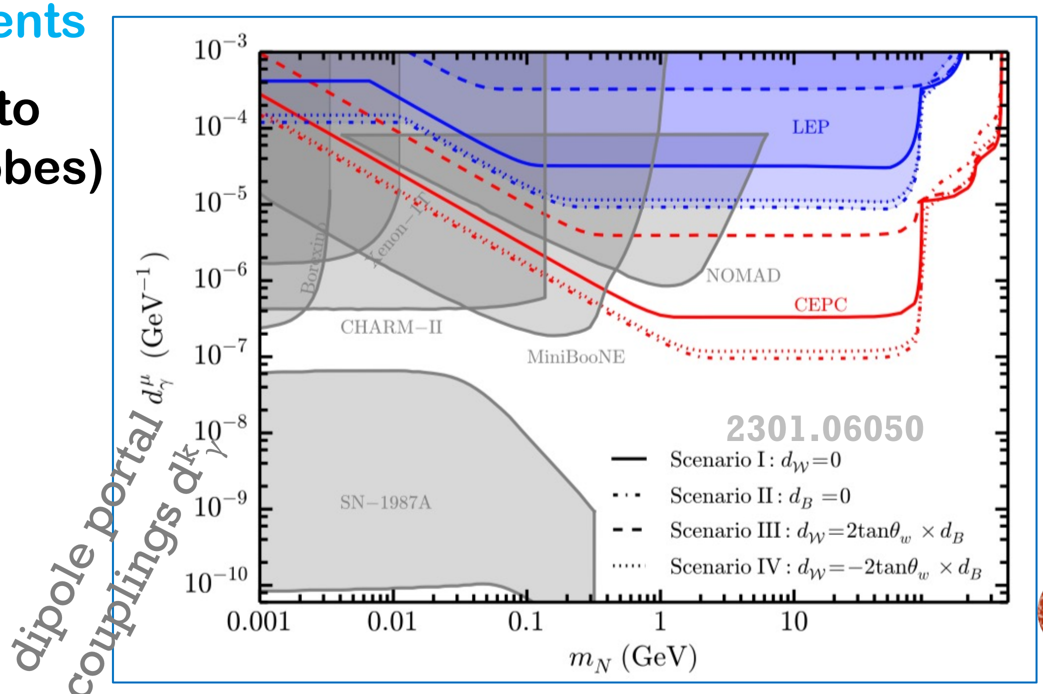
CEPC has the potential to probe almost the entire FOEWPT parameter space for 4b and 4tau channels

7. Neutrino physics



BSM related neutrino physics from neutrino mass mechanism, new messengers and interactions at EW scale:

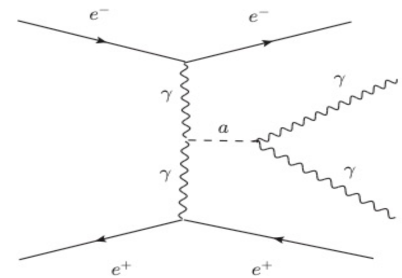
- **Heavy neutrino (@ND, FD)**
- **Active-sterile neutrino transition magnetic moments**
- **Possibility of connecting to leptogenesis (collider probes) and dark matter (sterile neutrino in the νMSM)**
- **Non-standard neutrino interactions**



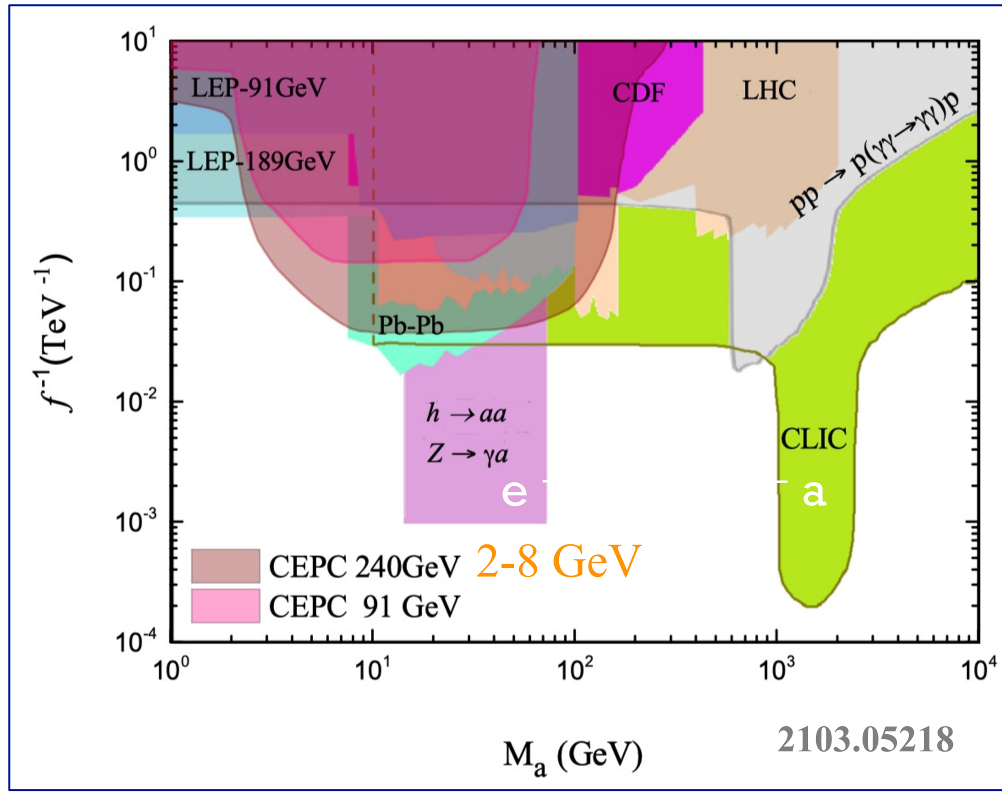
8. More exotics

High precision of Z, h width offers power test of exotics process of Lepton number/flavor violation, Sterile states, Axion-like particles …

- **Axion-like particles (solve "strong-CP" problem)**
- Lepton form factors (μ /e g-2, μ /e dipole moments in SUSY, τ weak-electric dipole moments)
- Emergent Hadron Mass
- Exotic lepton mass models
- ……



$e^+e^- \to \gamma\gamma e^+e^-$



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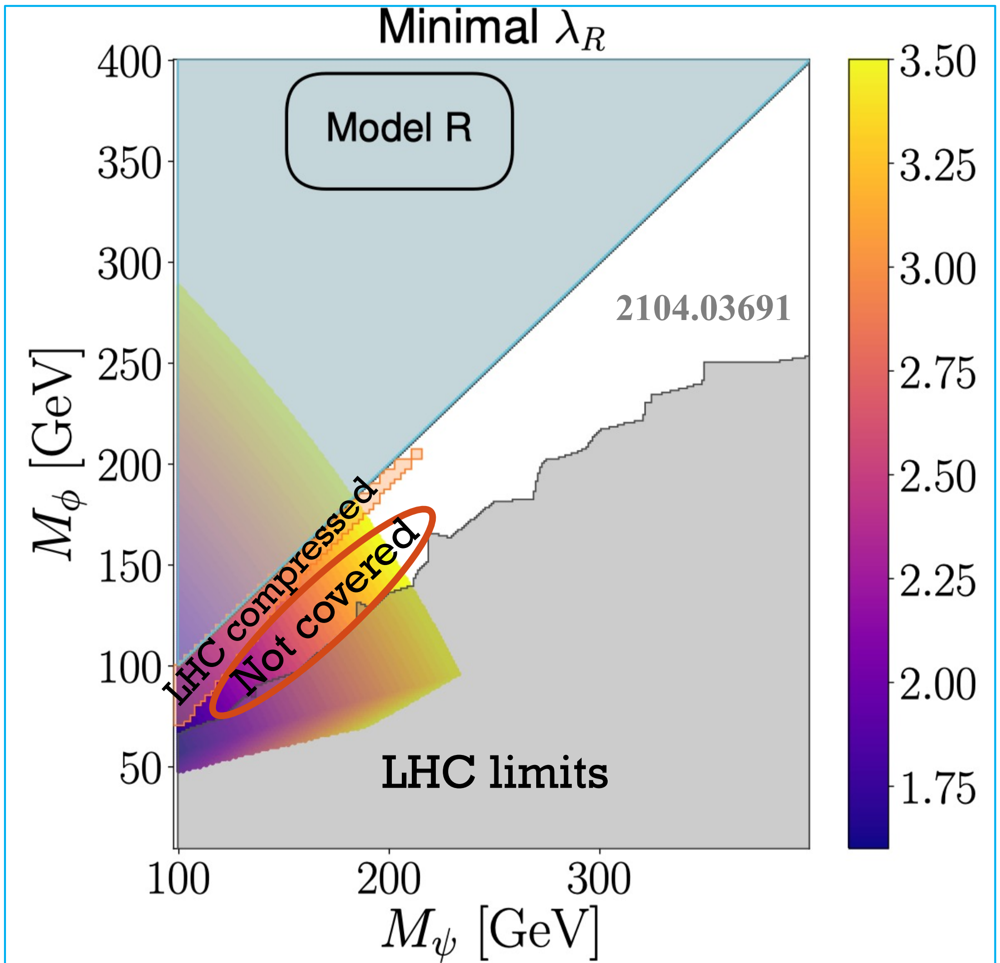

- Light EWKinos, smuon, stau co-annihilation can explain mu g-2 excess
- Gaps from LHC, can cover by CEPC

A simple model with a new scalar and and a new fermion

9. Global fits

Global fits: an essential tool to obtaining a thorough understanding of a NP model, and the implications and predictions of the models for future searches and experiments.

- SUSY global fits
- 2HDM
- SMEFT

CEPC has the potential to greatly enhance our understanding of the parameter space and mass spectrum in the MSSM.

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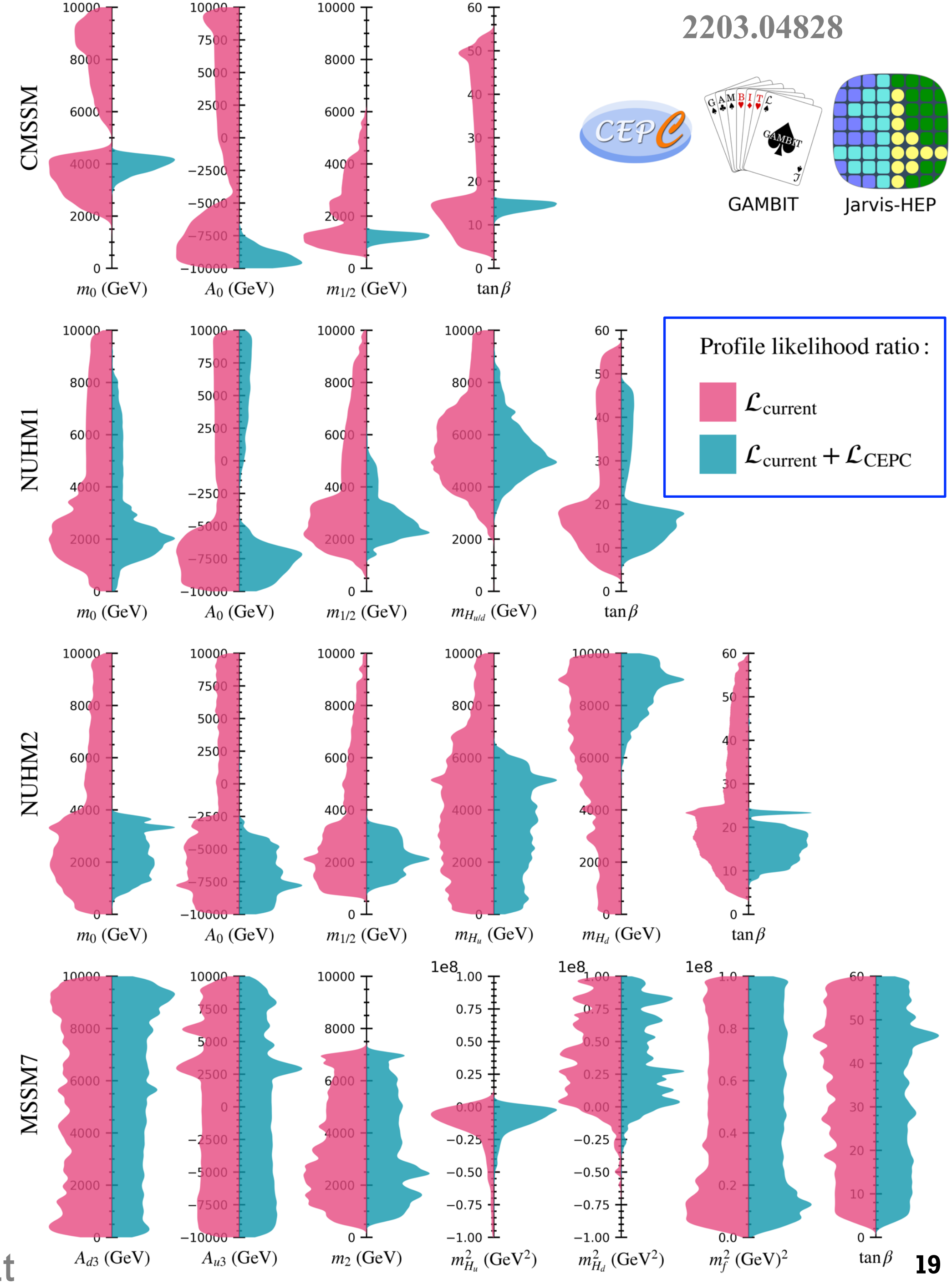
GAMBIT

Jarvis-HEP



One-dimensional profiled likelihood ratio for the global fit

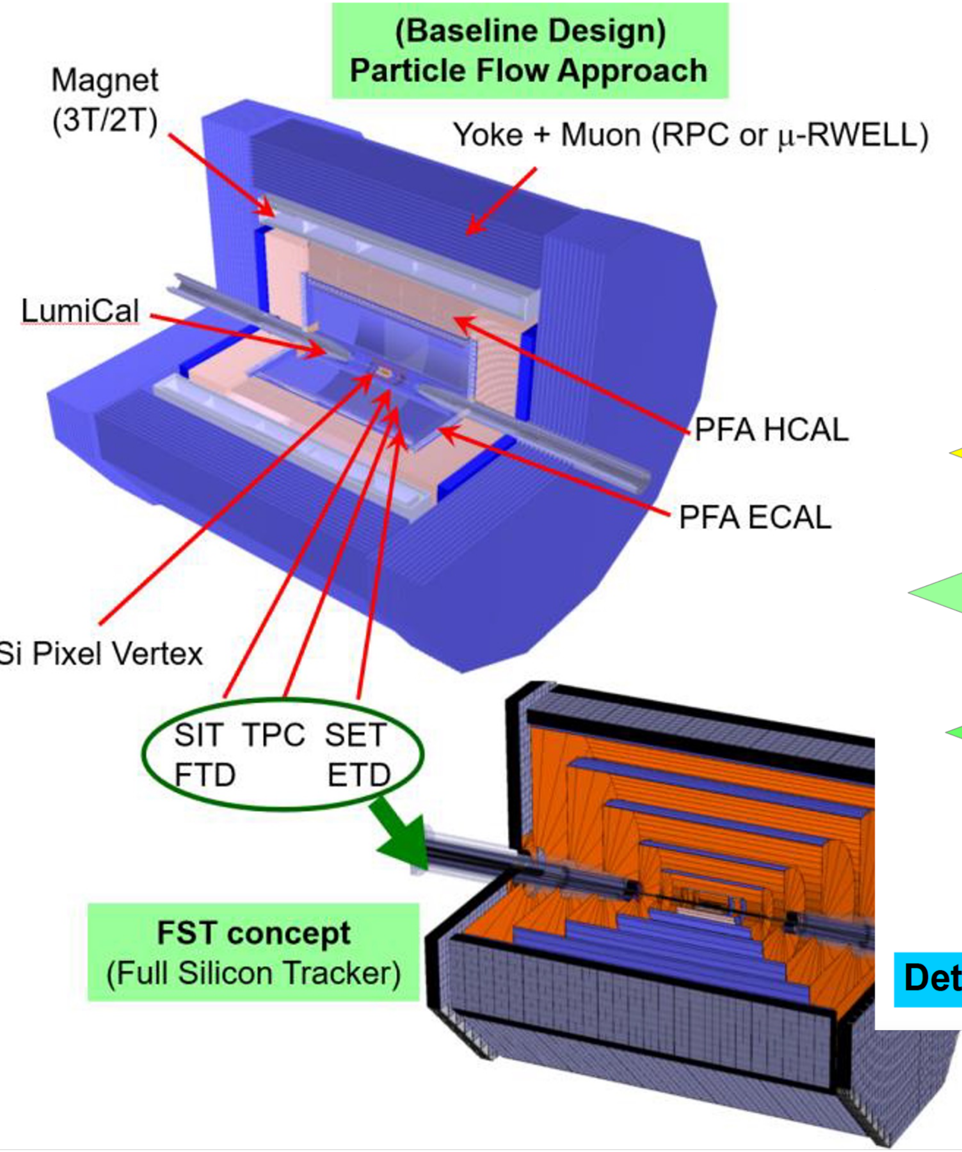
Summary and Outlook

- **CEPC has good discovery potential for NP, which is good complementary to LHC**
- **Partial of BSM prospects at CEPC are included in CEPC snowmass white paper in 2023:** arXiv:2205.08553
- **CEPC BSM white paper is preparing and to be ready for review by this year**
- **Please let us know if you would like to help to polish and review the BSM white paper !**

Thanks for your attention!

Backup

CEPC



- About CEPC

ECM=240GeV, higgs factory, 100 km circumference, 2 interaction points.

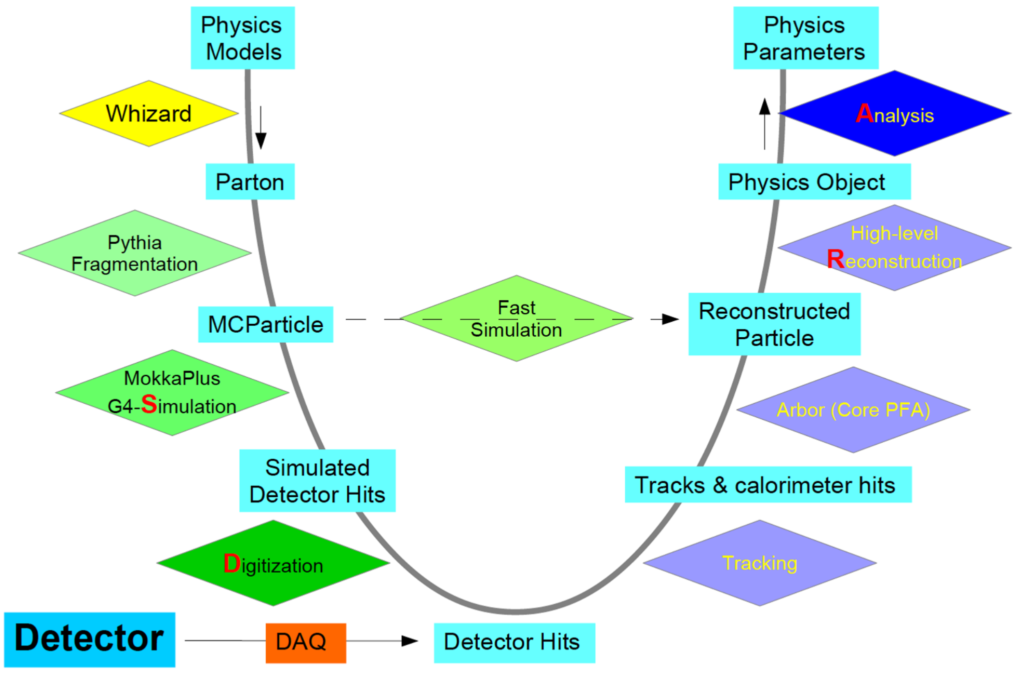
ILD-like detector

- Software

Signal samples: MadGraph+Pythia8

Simulation: Mokka

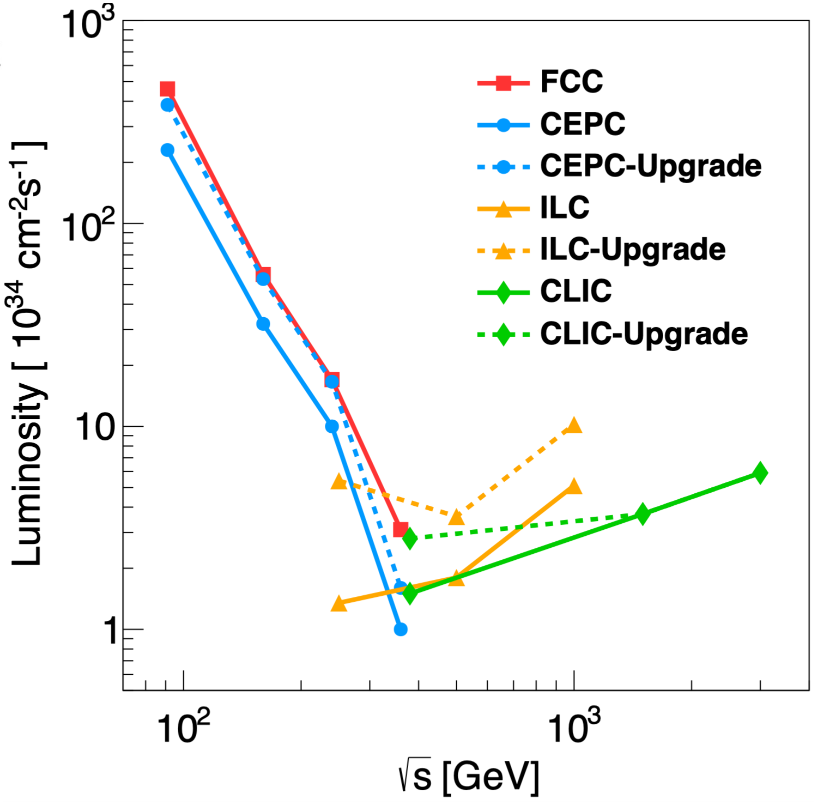
Reconstruction: Marlin



Full simulation reconstruction Chain with Arbor, iterating/validation with hardware studies

Operation mode	Z factory	WW threshold	Higgs factory	$t\bar{t}$
$\sqrt{s}$ (GeV)	91.2	160	240	360
Run time (year)	2	1	10	5
Instantaneous luminosity ($10^{34}cm^{-2}s^{-1}$, per IP)	191.7	26.6	8.3	0.83
Integrated luminosity (ab^{-1}, 2 IPs)	100	6	20	1
Event yields	3×10^{12}	1×10^{8}	4×10^{6}	5×10^{5}

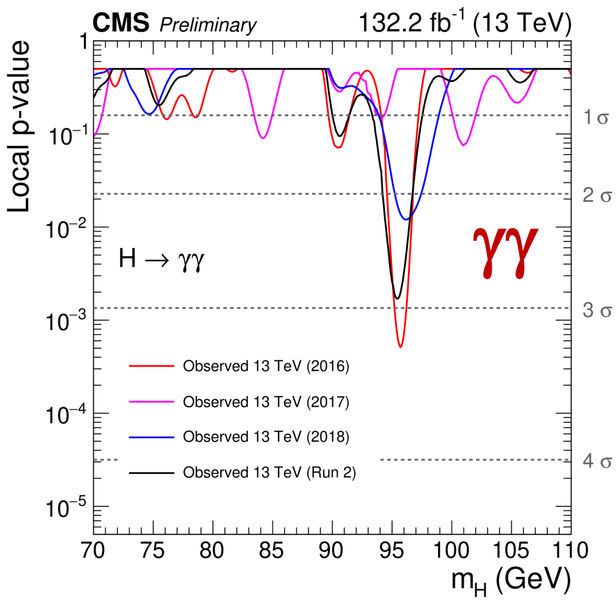
TABLE I: Nominal CEPC operation scheme, and the physics yield

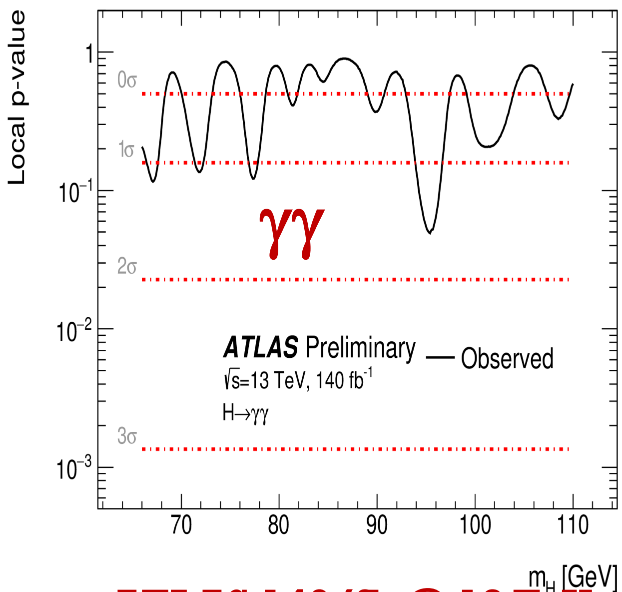


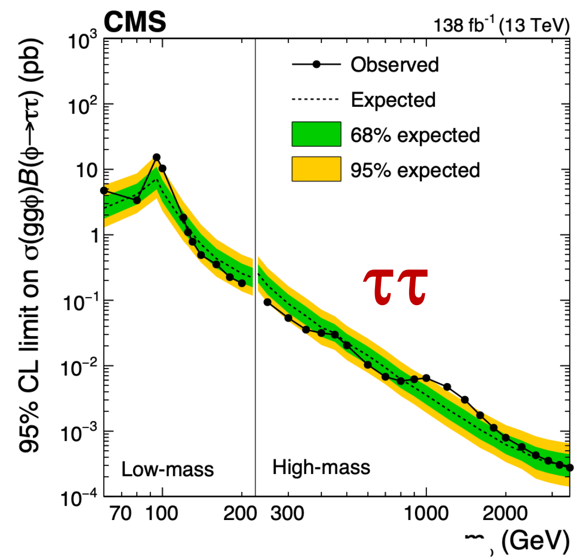
Light Higgs

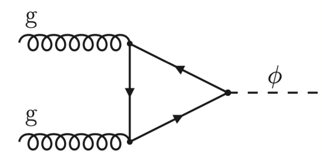
- Light Higgs are motivated by 2HDM and Axion-like particle models

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.

9. Global fits

Global fits: an essential tool to obtaining a thorough understanding of a NP model, and the implications and predictions of the models for future searches and experiments.

- SUSY global fits
- 2HDM
- **SMEFT**

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