SUSY, Dark Matter and Dark Sector at future e^+e^- collider (CEPC/FCC-ee)

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Peking University

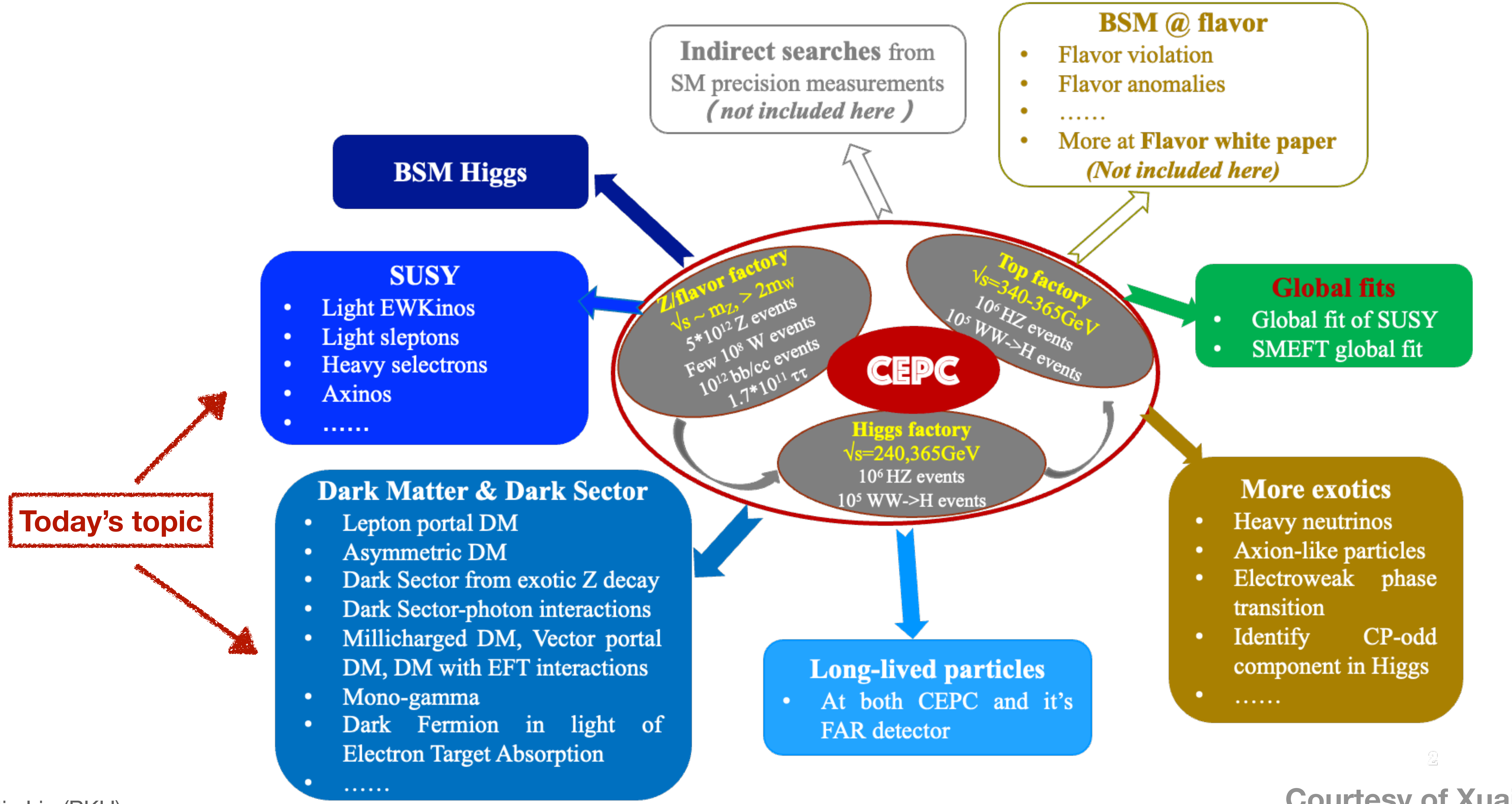
Bias warning: mostly on recent findings of the CEPC study, but work for FCC-ee as well.
Apologize for omitting papers, can not cover all…

The 2023 international workshop on the Circular Electron Positron Collider
@ the University of Edinburgh
2023-07-04

Outline

- CEPC and New Physics Searches
  - SUSY
  - Dark Matter and Dark Sector
    - Fermion portal — lepton portal
    - Higgs portal
    - Vector portal
    - EFT models
- Summary

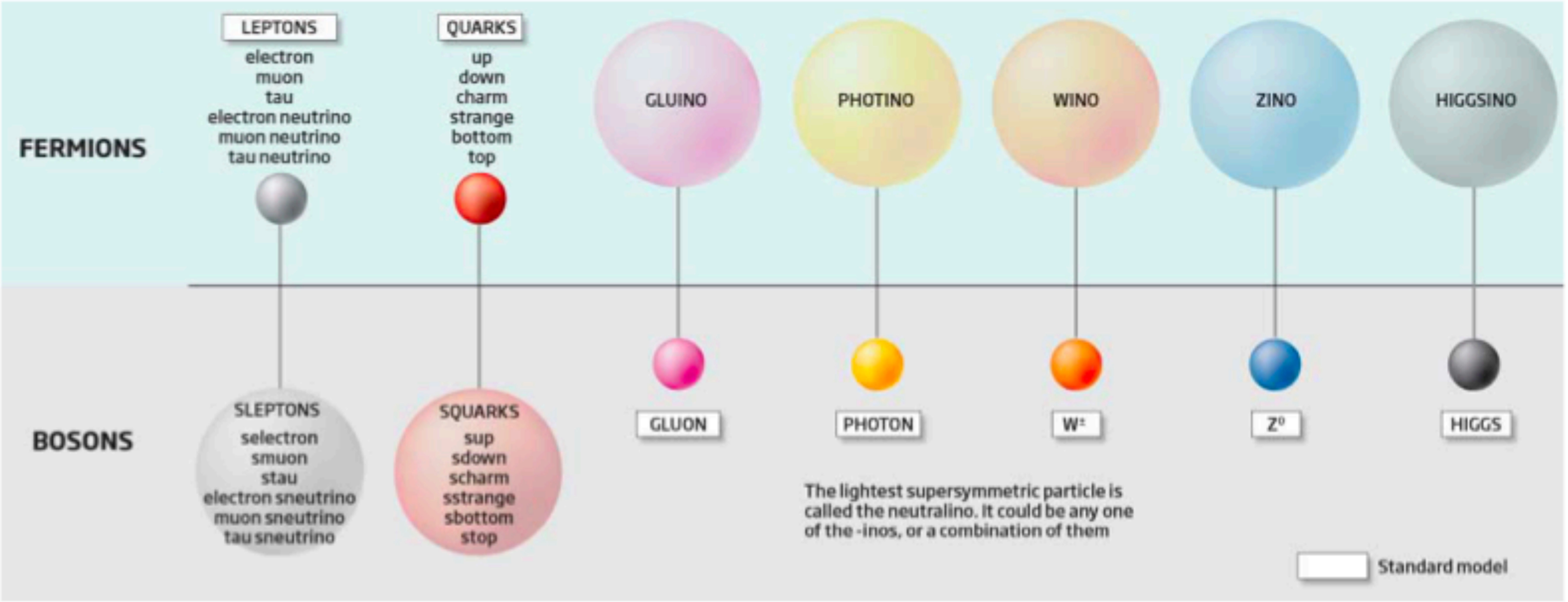
CEPC BSM Physics Program



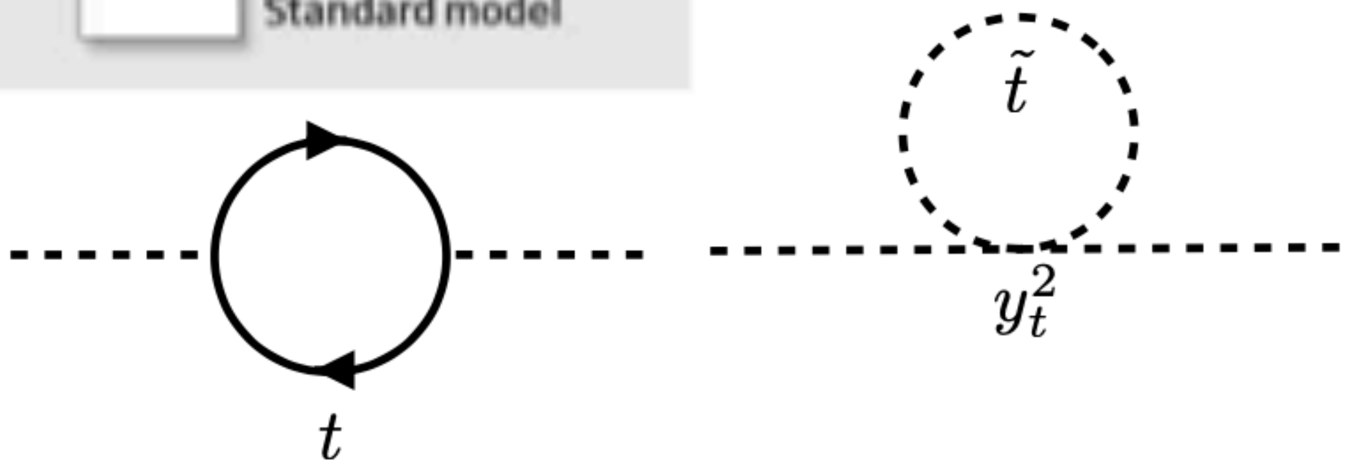
BSM inputs and status

- 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, 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)
  - DM (Millicharged DM, Vector portal DM, DM with EFT interactions): 1903.1211
  - Mono-gamma (2205.05560), Dark Sector-photon interactions (2208.08142)
  - Dark Fermion in light of Electron Target Absorption (2306.00657)
- Long-lived particles (1904.10661, 1911.06576, 2201.08960)
- 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 study (2212.05390)
  - ……
- Global fits:
  - Global fit of SUSY (2203.04828, 2203.07883)
  - SMEFT global fit (2206.08326)

The motivation for SUSY



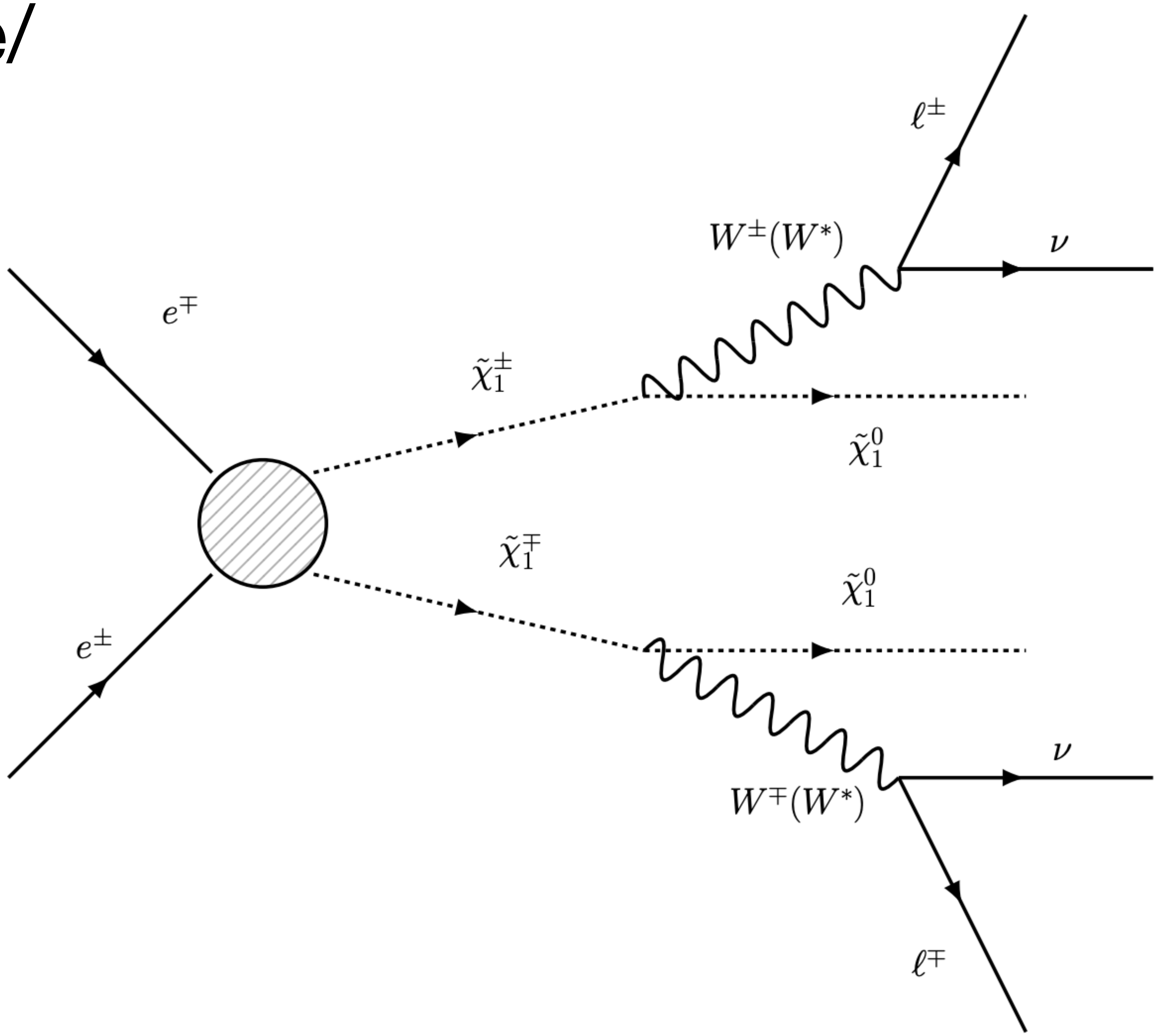
Credit:
New Scientist



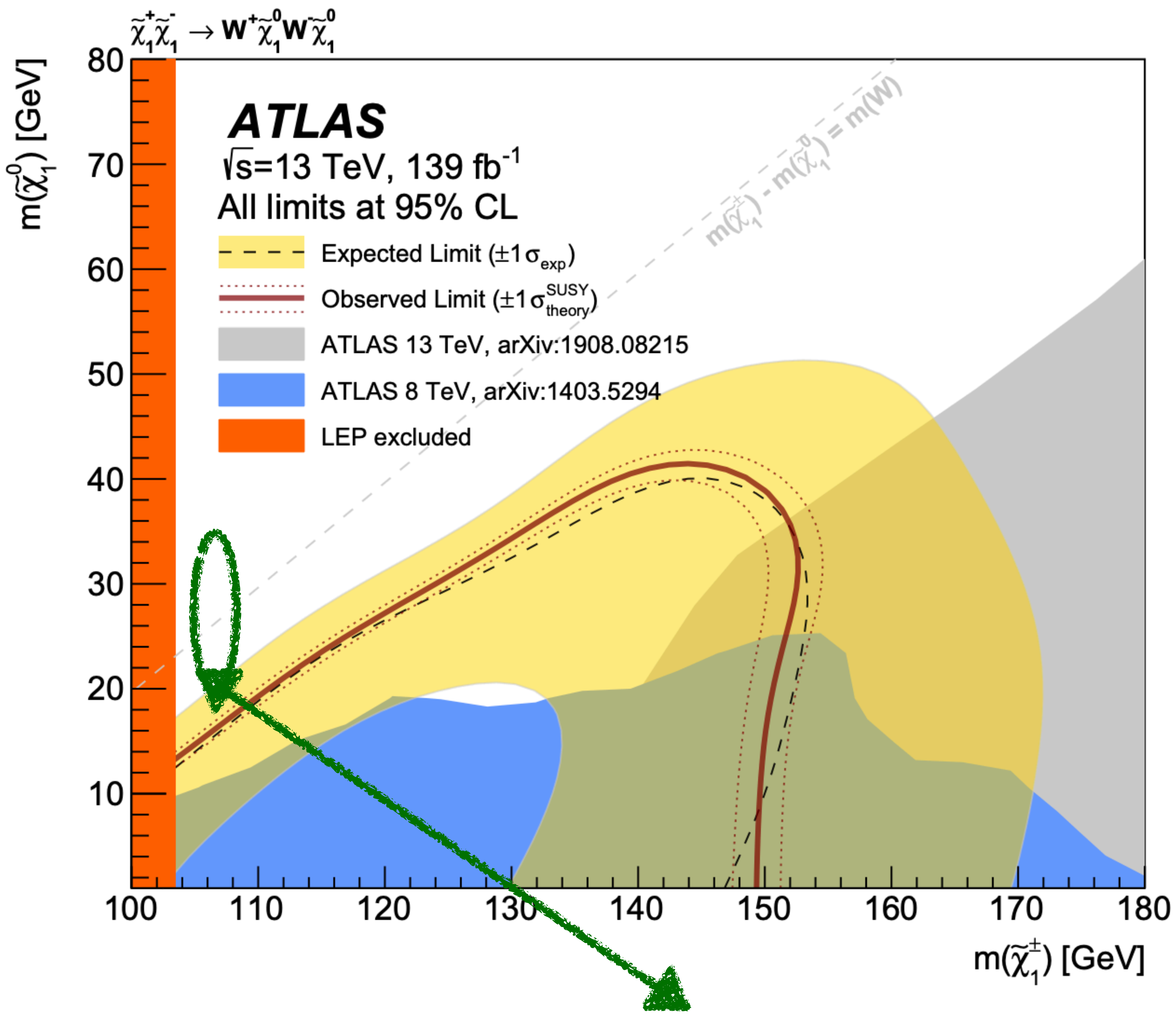
- Stabilize the weak scale from Planck scale via a new space-time symmetry
- MSSM leads to unification of gauge couplings
- EW breaking is induced radiatively
- Neutralino as an excellent candidate for cold dark matter

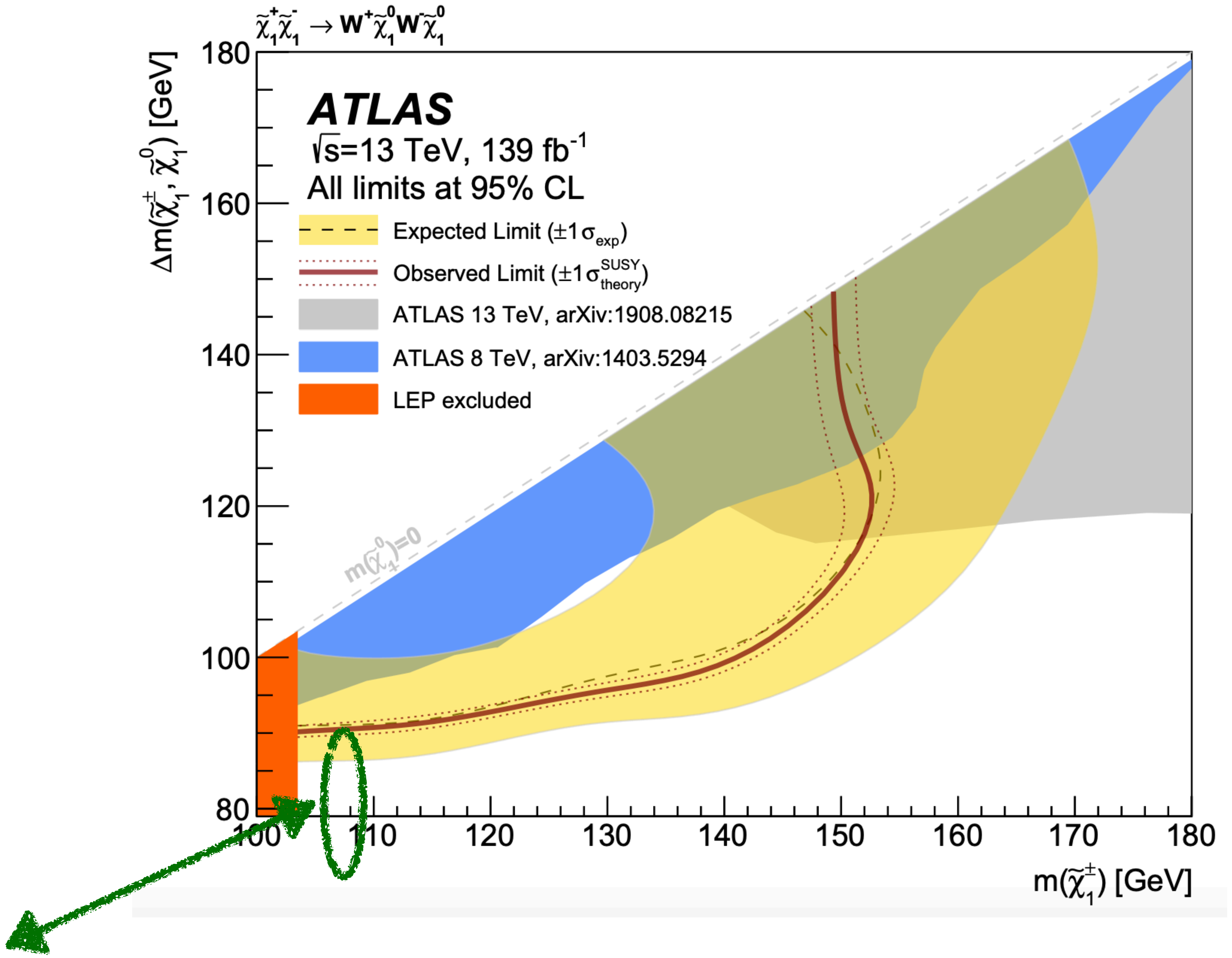
SUSY at future e^+e^- collider

- Why future e^+e^- collider CEPC/FCC-ee/ILC?
- Could be complementary with LHC:
  - Soft energy region
  - Lower mass region
- Study light EWKinos, sleptons
- Indirect searches through precision measurements



Comparing with recent LHC results: where to go

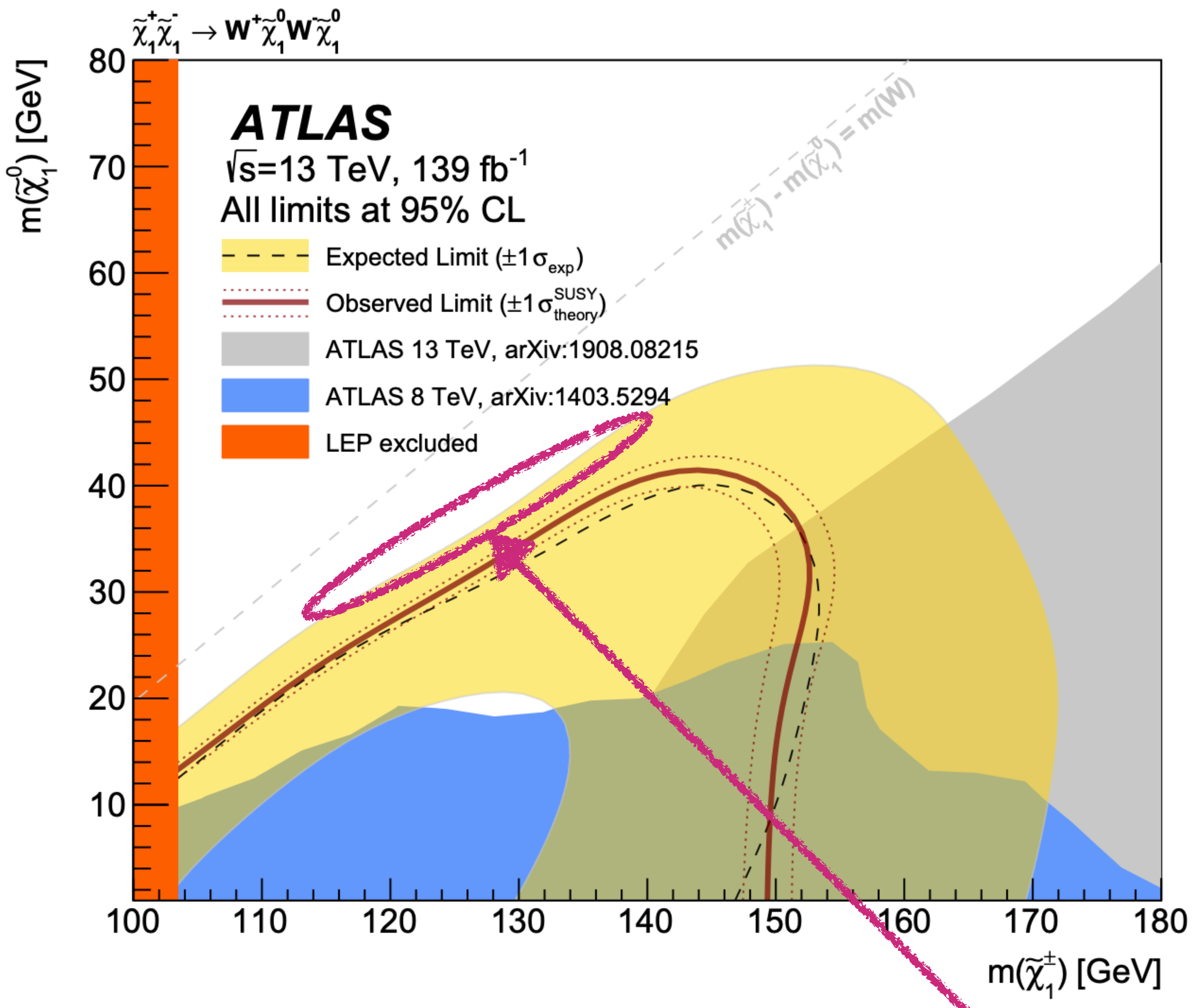


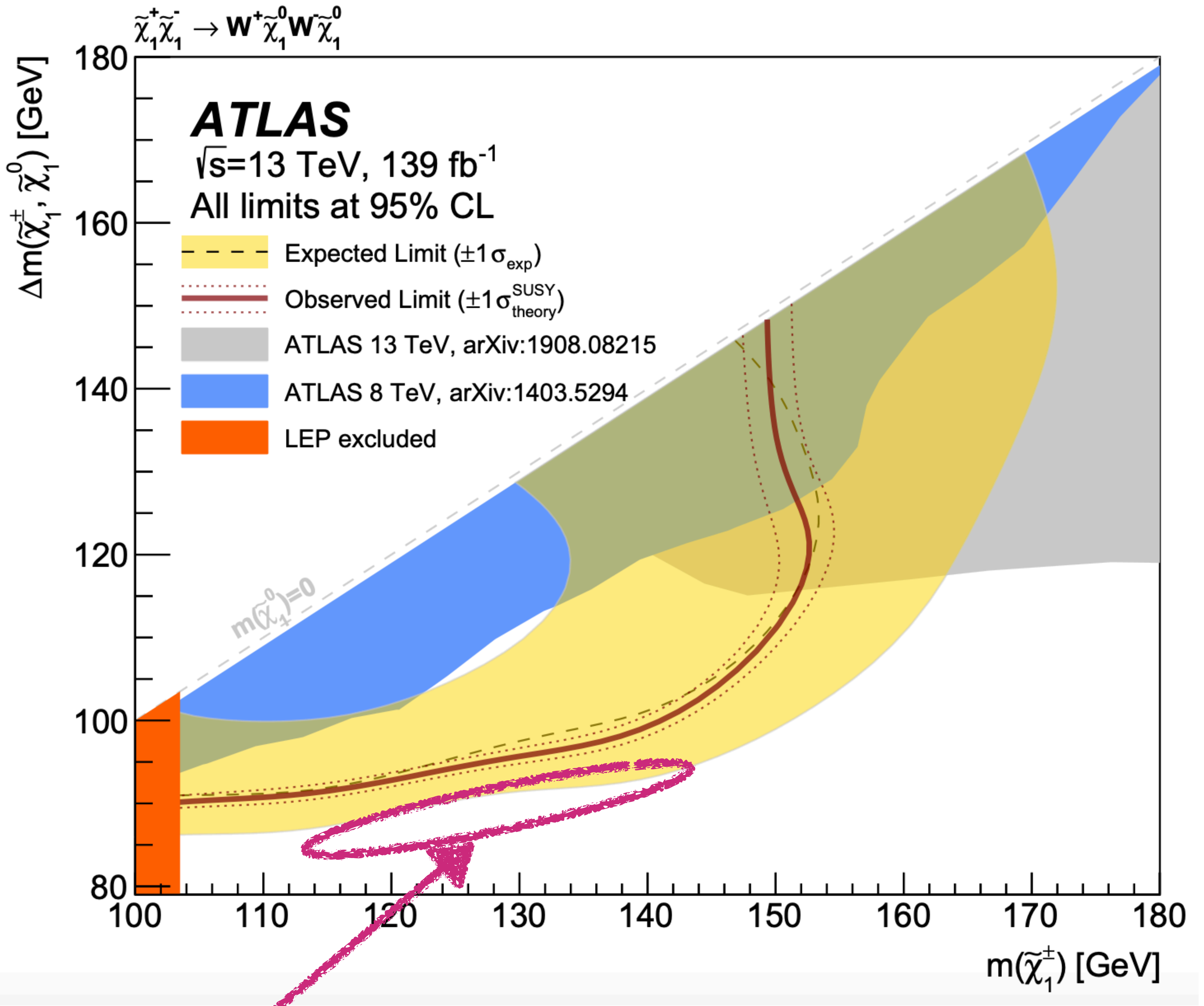


- Improving low mass boundary: naively up to $\sqrt{s}/2$, but can be better than that

- Improving the soft lepton region

Comparing with recent LHC results: where to go





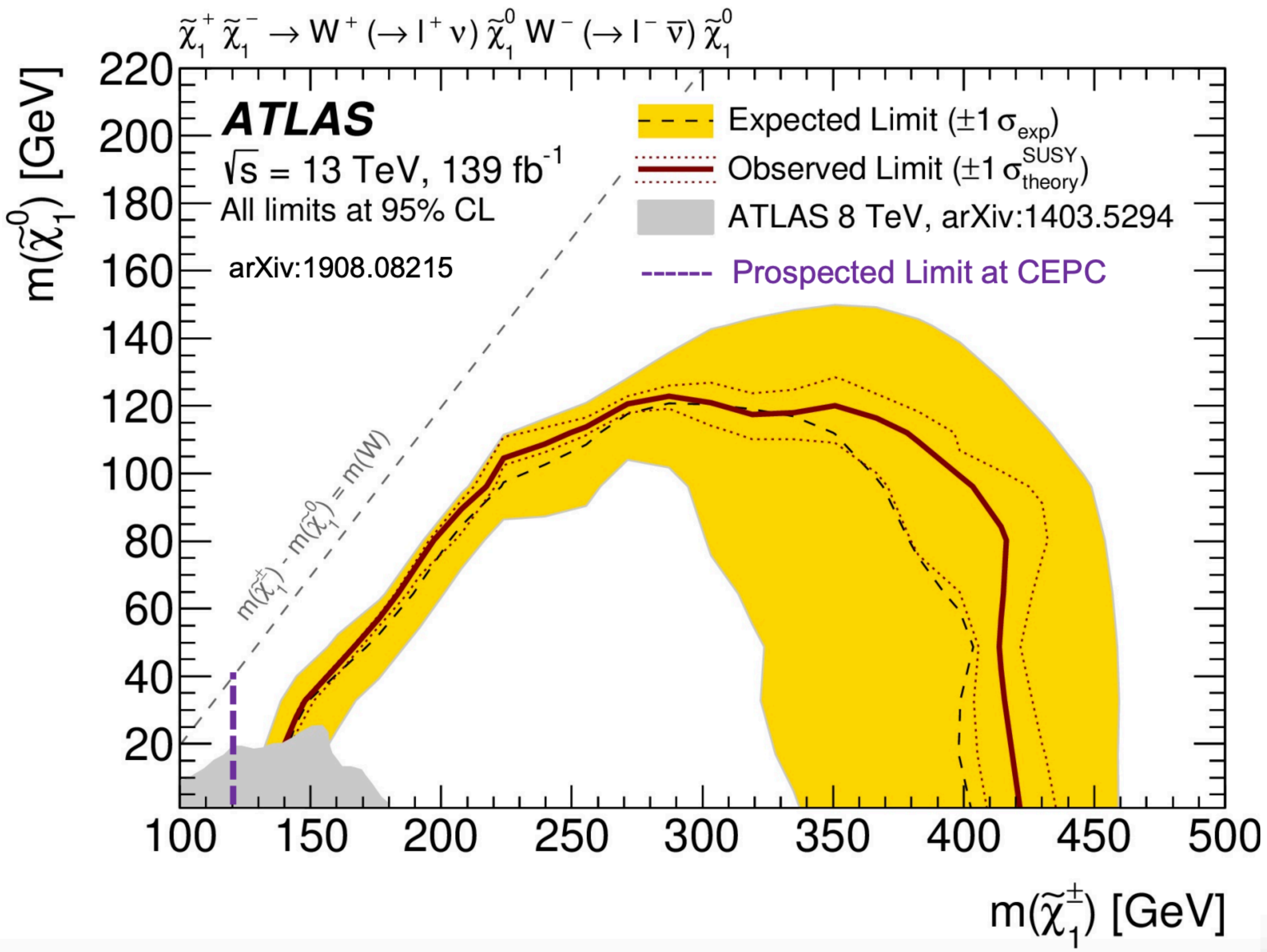
- Improving low mass boundary
- Improving the soft lepton region

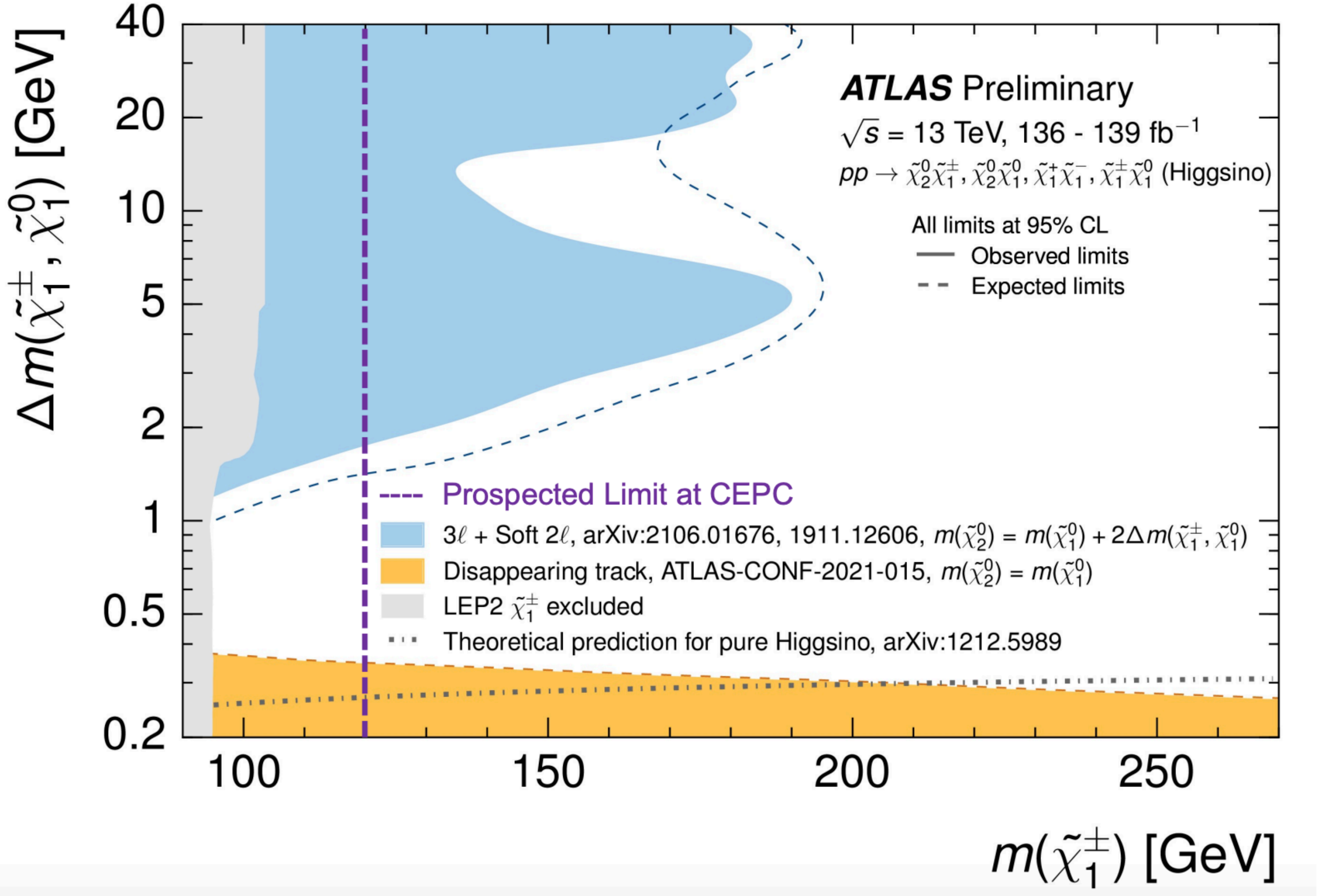
Dilepton + Missing energy signal region

- Focus on opposite-sign dimuon
- Large recoil mass ~ Large missing energy
- Up to mass = $\sqrt{s}/2$

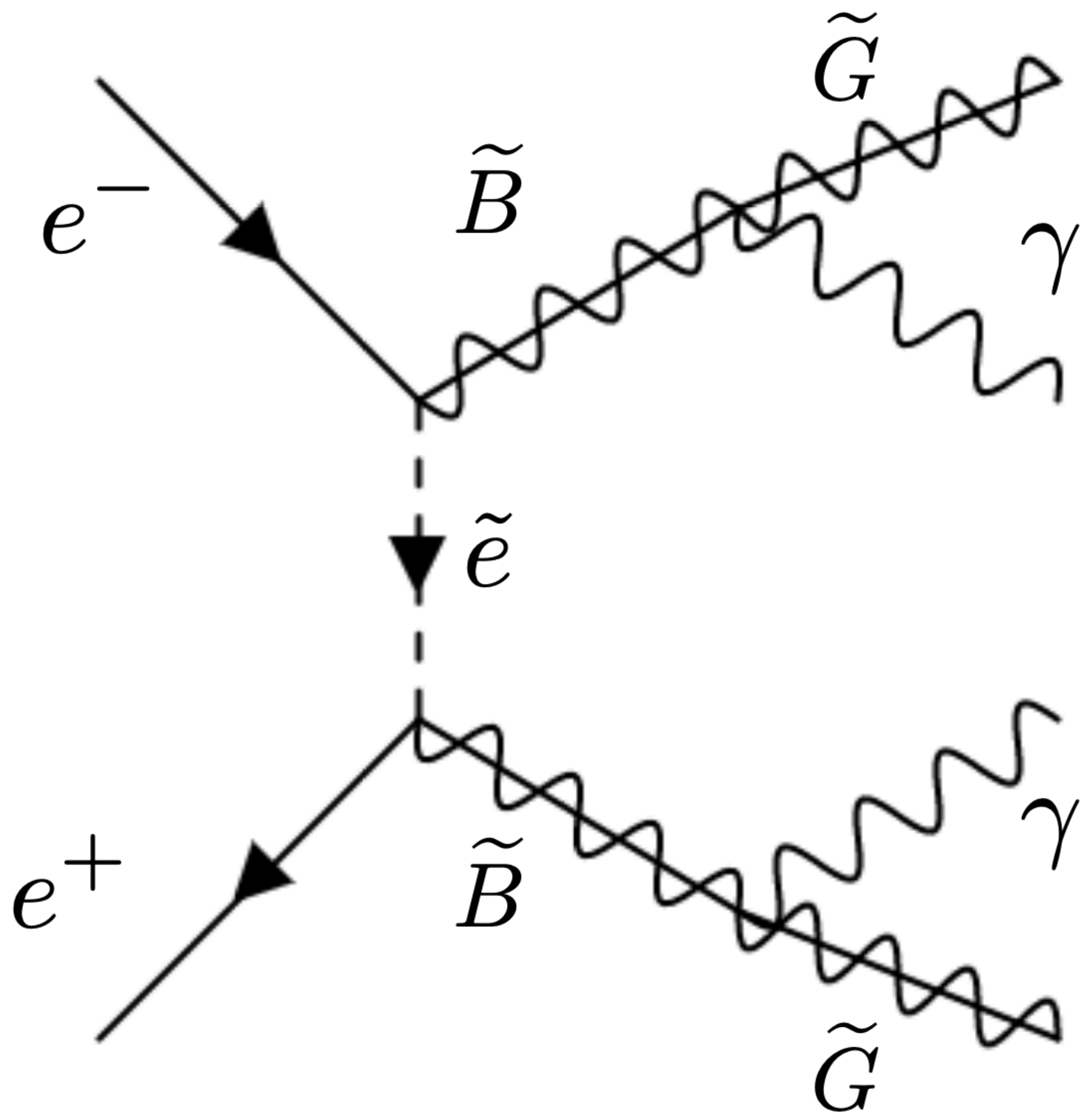
Xuai Zhuang et al, 2105.06135 (CPC)

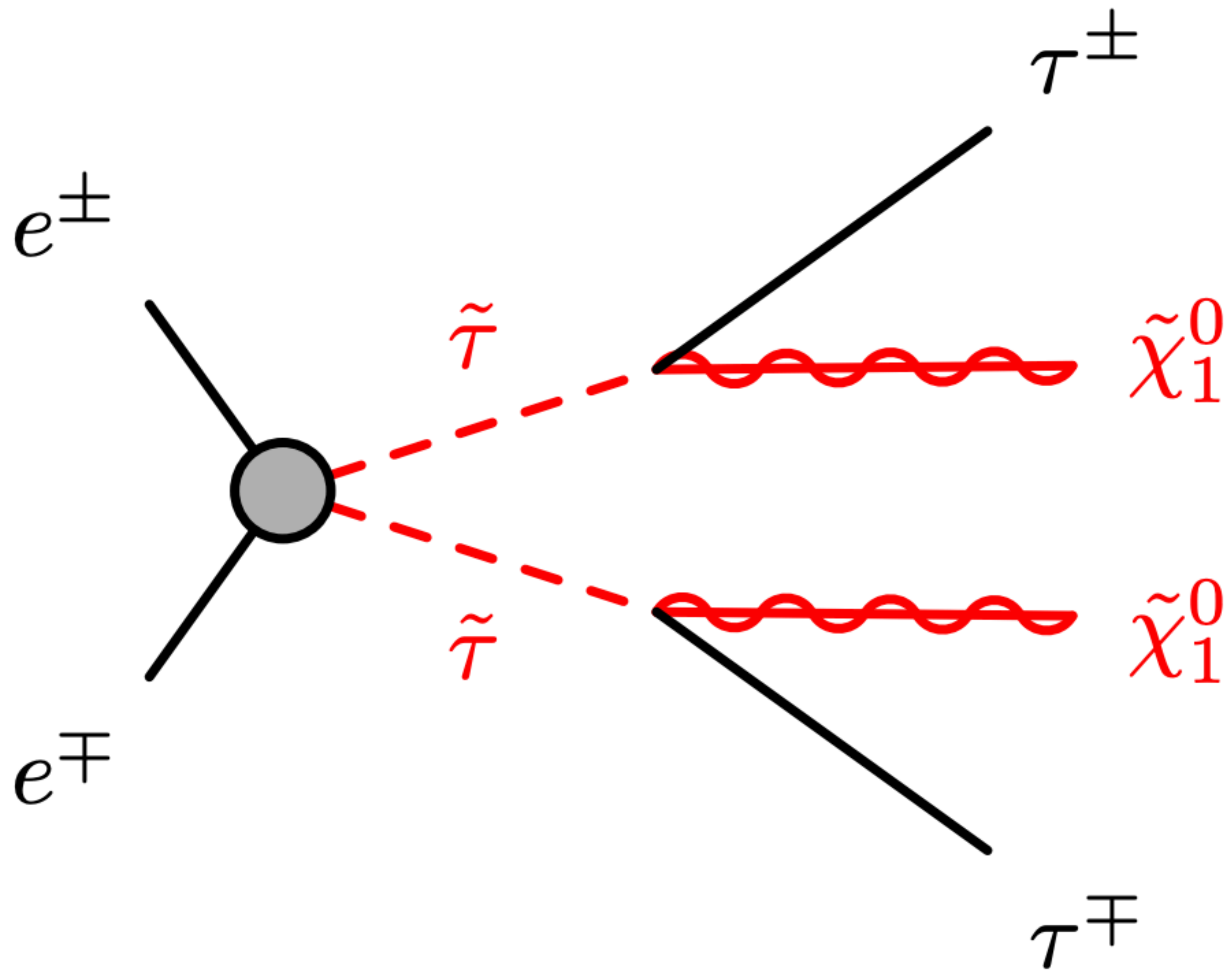
Signal Region
== 2 muons (OS)
$E_{\mu^\pm} > 10$ GeV
$0.4 < \Delta R(\mu^+, \mu^-) < 1.6$
$P_T^{\mu^\pm} > 30$ GeV
$M_{recoil} > 130$ GeV





Other possible complementary searches





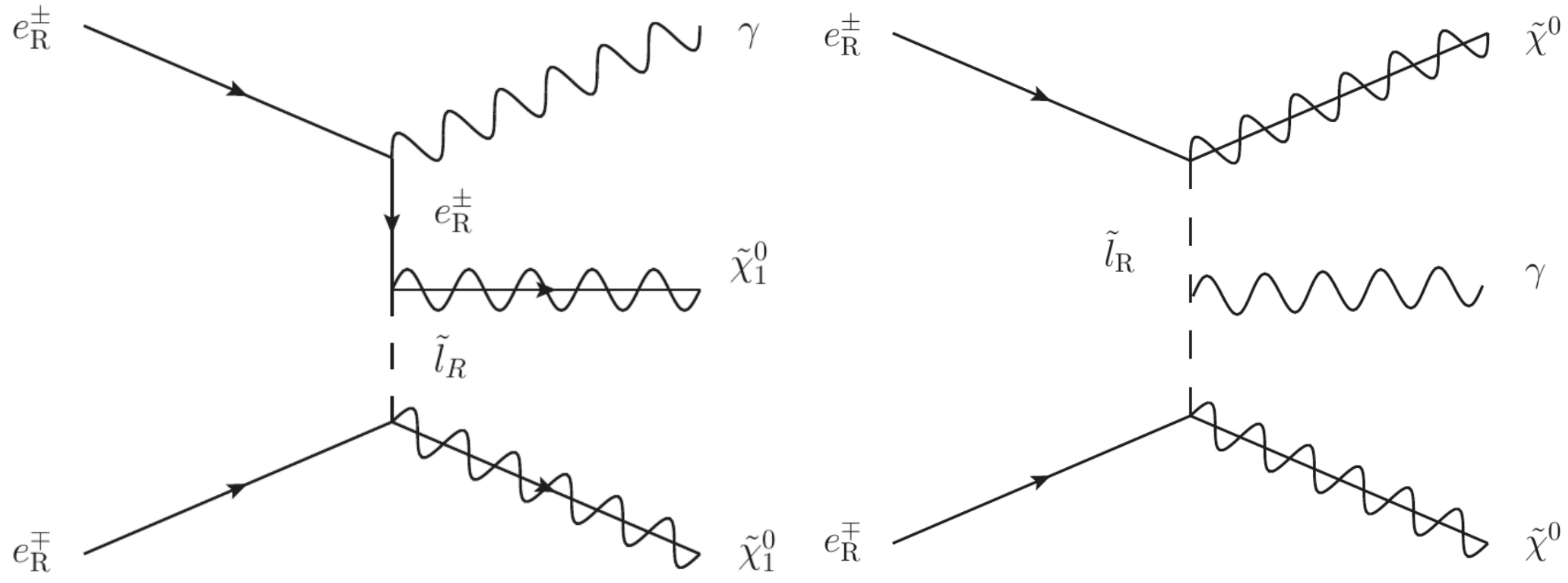
- Low mass Bino decay ~ O(100) GeV: $\tilde{B} \to \tilde{G} + \gamma$

Junmou Chen et al, 2101.12131 (PRD)

- Low mass stau/smuon ~ O(100) GeV: $\tilde{\tau} \to \tilde{\chi}_1^0 + \tau$
- Cleaner background for tau final states comparing with LHC

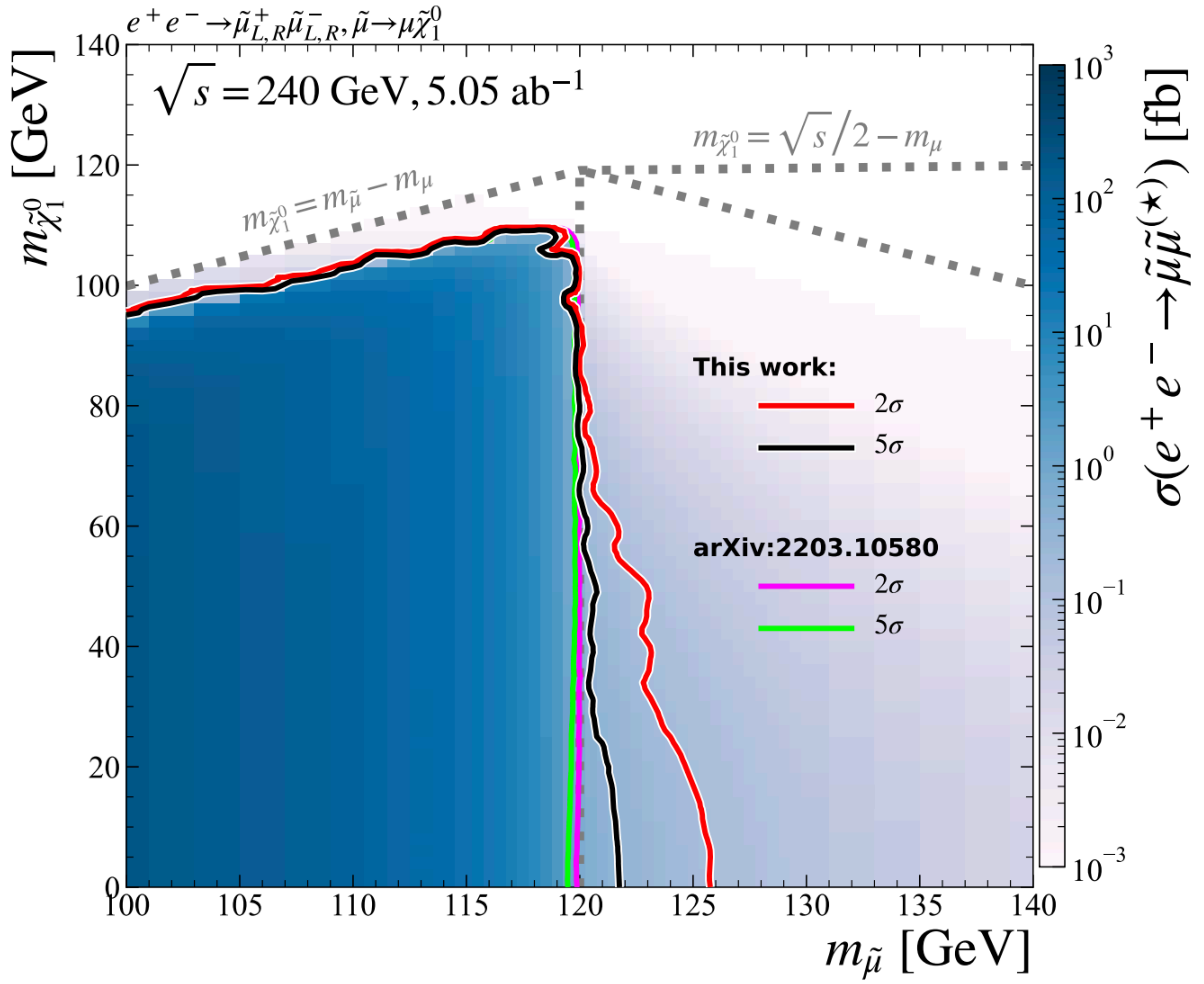
Xuai Zhuang et al, 2203.10580

Other possible complementary searches



- Mono-photon search: $\gamma\tilde{\chi}_0^1\tilde{\chi}_0^1$
- Cleaner background comparing with LHC

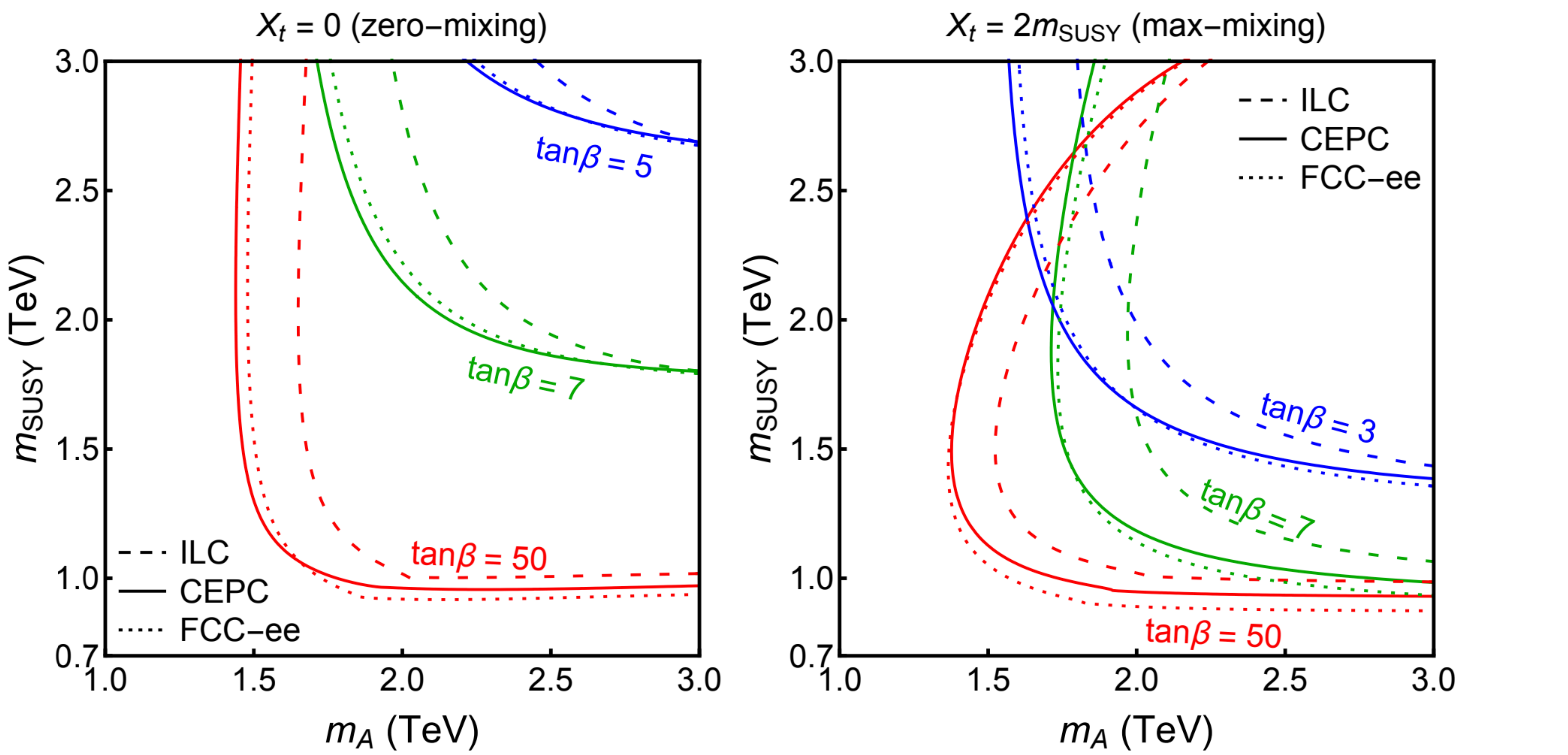
Waqas Ahmed et al, 2202.11011 (PLB)



- Trying to cover higher slepton mass as best as one could

Jinmin Yang et al, 2211.08132

Other possible complementary searches



- Probing SUSY parameters without producing SUSY particles
- Indirect search at Higgs factories through Higgs precision measurements

Honglei Li et al, 2010.09782 (CPC)

Other possible complementary searches

- Probing SUSY parameters without producing SUSY particles
- Indirect search at Higgs factories through Higgs precision measurements

Physics potential of CEPC, 2205.08553 (snowmass 2021)

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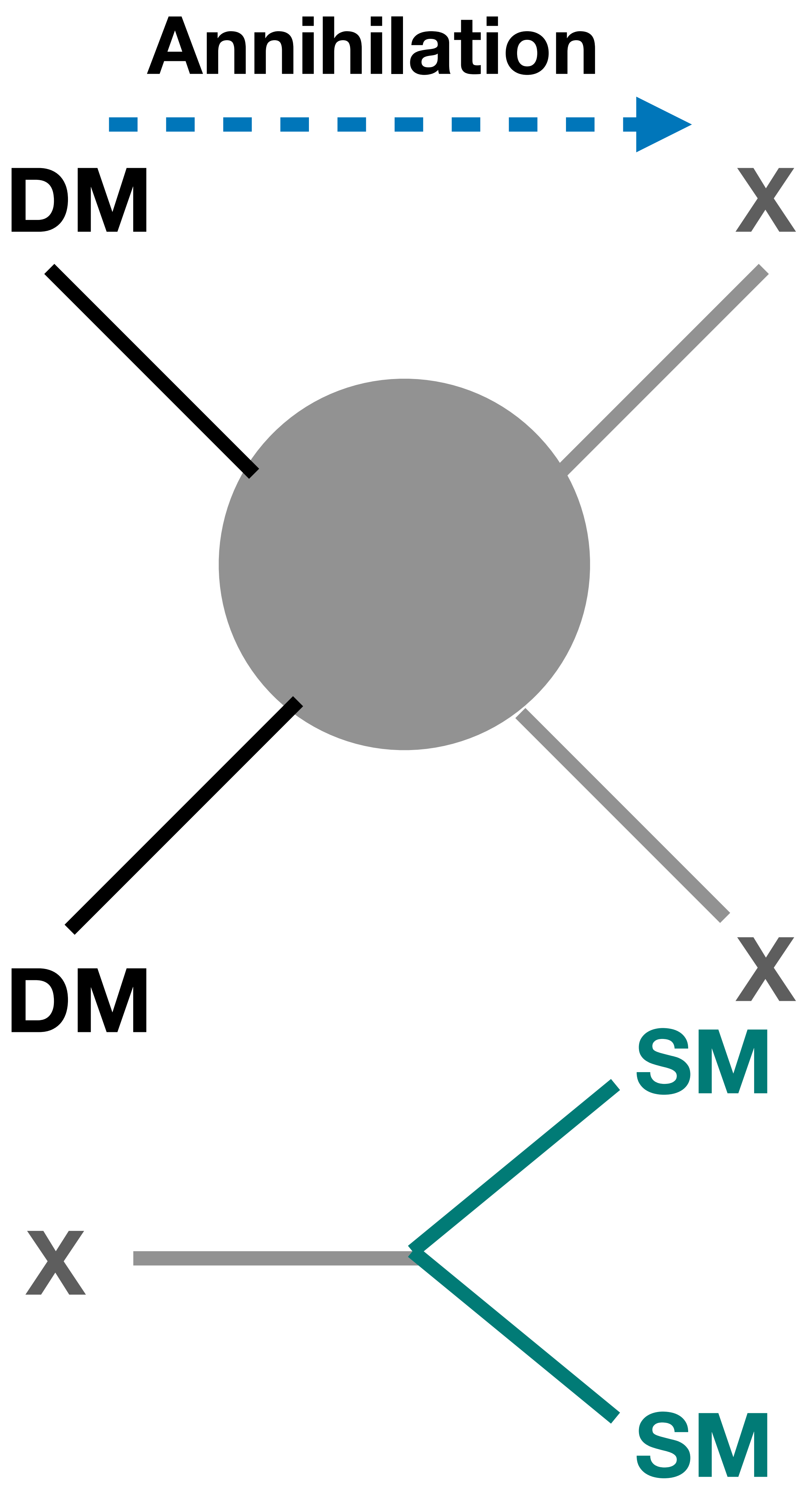

Dark mediator X
with small coupling to SM

Fermion portal

JL, S. Brian, N. Weiner, I. Yavin, 1303.4404 (JHEP)
Y. Bai, J. Berger, 1308.0612 (JHEP)

- The Fermion portal to DM
  - The Interaction: $\lambda\bar{\psi}\phi f_{\rm SM}$
  - Dark Matter and Dark Sector
    - Fermion portal — lepton portal
    - f can be quark/lepton, L/R-handed

	DM	SM charge	Z_2
ψ	Yes	No	-1
ϕ	No	Yes	-1
$f_{\rm SM}$	No	Yes	1

ϕ can be DM as well!

Searching lepton portal dark sector at CEPC

$$\mathcal{L}_\chi = \frac{1}{2}\bar{\chi}i\partial\!\!\!/\chi - \frac{1}{2}m_\chi\bar{\chi}\chi + y_\ell\left(\bar{\chi}_L S^\dagger \ell_R + \text{h.c.}\right),$$

$$\mathcal{L}_S = \left(D^\mu S\right)^\dagger D_\mu S - V(H,S),$$

$$V(H,S) = \mu_H^2|H|^2 + \mu_S^2|S|^2 + \lambda_H|H|^4 + \lambda_S|S|^4 + 2\lambda_{HS}|H|^2|S|^2$$

JL, XP Wang, KP Xie, 2104.06421 (JHEP)

- DM (χ) couples to SM via the lepton portal
- Mediated by charged particle (S), similar to slepton
  - DM thermal relic requirements
  - Lepton collider production of dark sector particle S
  - Higgs precision test on the model
  - Gravitational Wave signal and its complementary with ee collider

Searching lepton portal dark sector at CEPC

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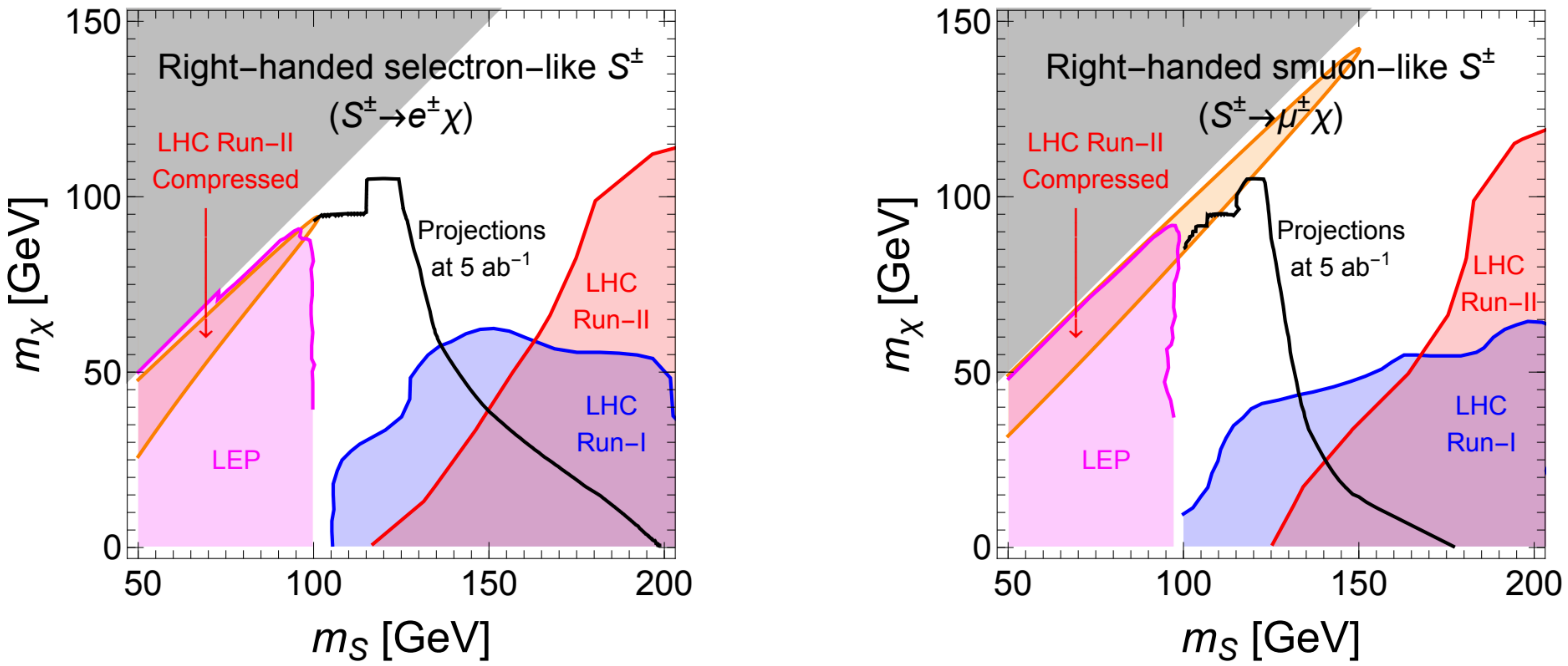
- DM (χ) couples to SM via the lepton portal
- Mediated by charged particle (S), similar to slepton
  - DM thermal relic requirements — $\chi\chi \to \ell^+\ell^-$, p-wave annihilation, less constrained by indirect detection
  - Lepton collider production of dark sector particle S
  - Higgs precision test on the model
  - Gravitational Wave signal and its complementary with ee collider

Dark sector particle production in 3-body final state

- 3-body final state: $e^+e^- \to S^+S^{-*} \to S^+\ell^-\chi \to (\ell^+\chi)\ell^-\chi$

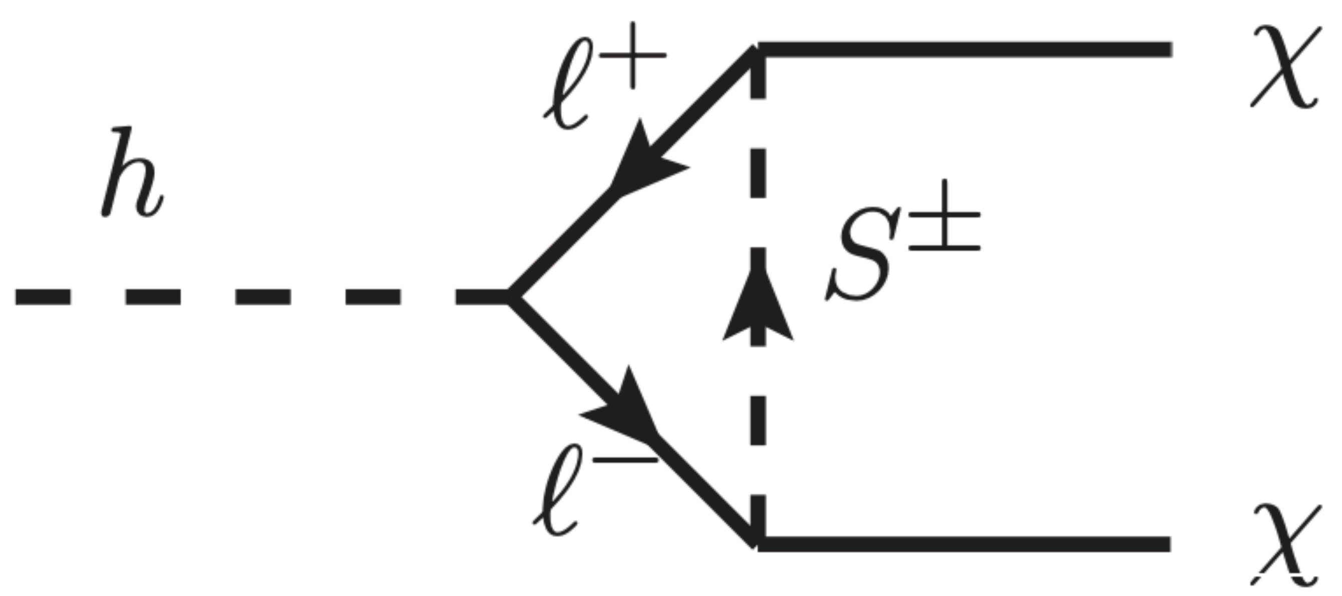
JL, XP Wang, KP Xie, 2104.06421 (JHEP)

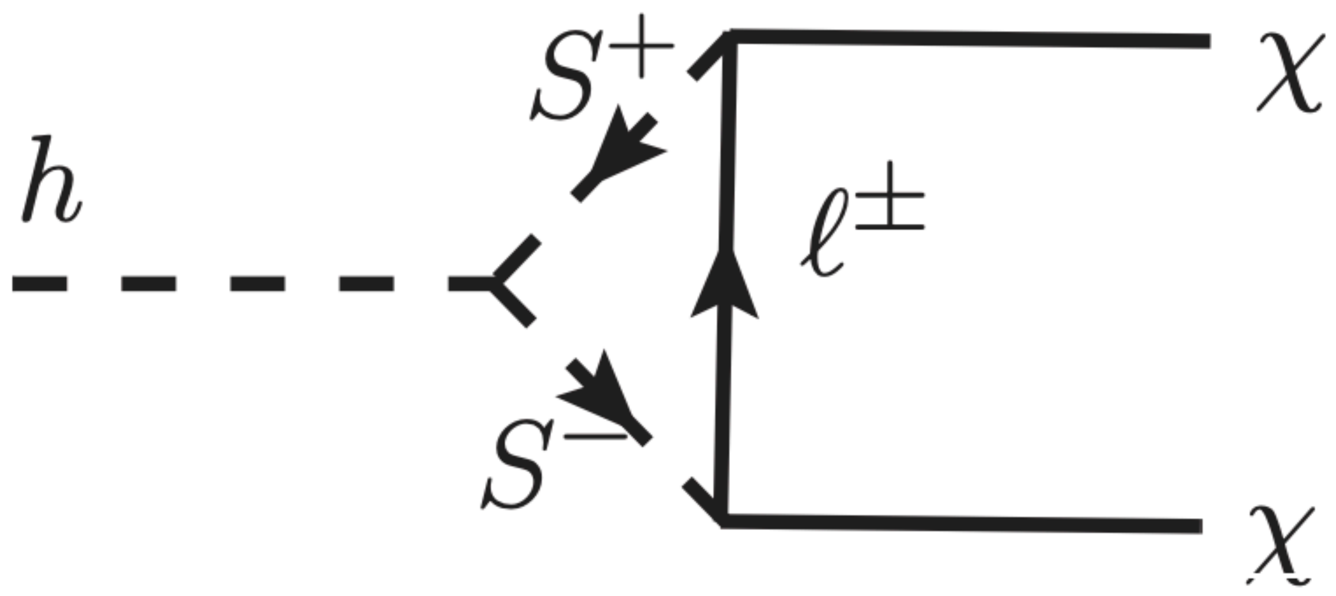
- Reaching higher mass: $m_S \gtrsim \sqrt{s}/2 = 120$ GeV



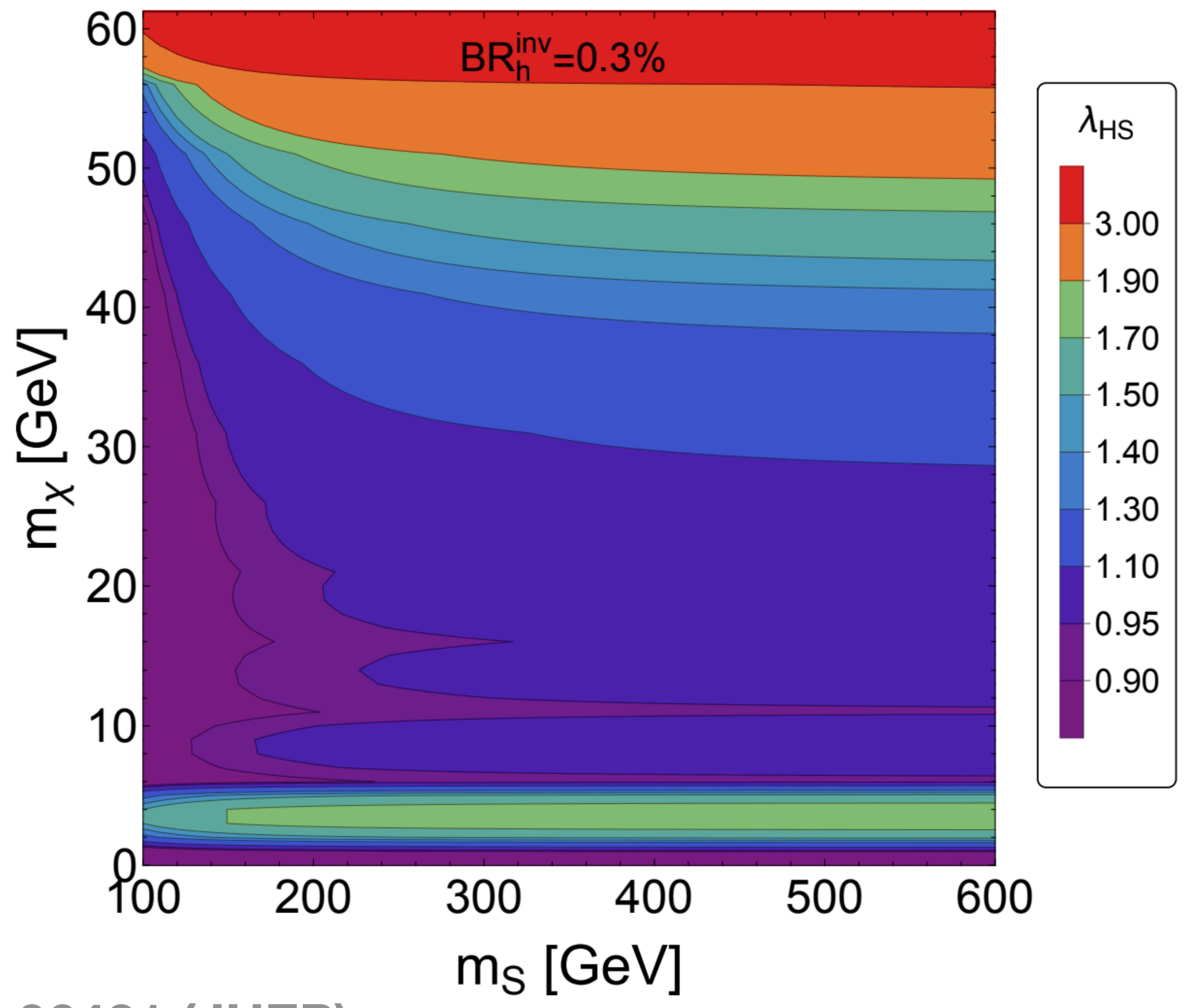
Exotic Higgs decay constraints

- Invisible Higgs decay at 1-loop





- The Higgs-dark sector coupling is constrained

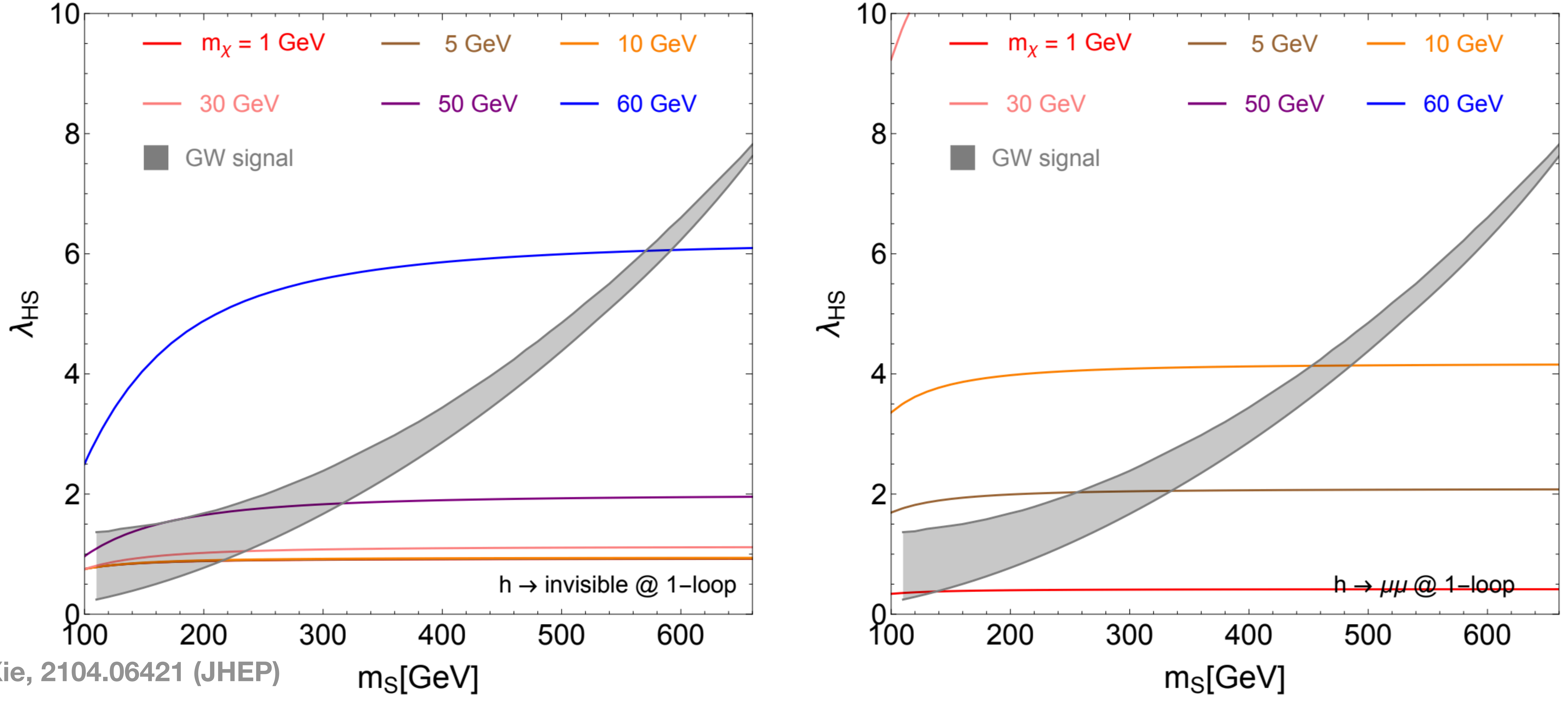


JL, XP Wang, KP Xie, 2104.06421 (JHEP)

Future ee collider search and GW complementarity

- Higgs precision measurement can cover 1st order phase transition region, m_S, up to hundred of GeV

$$\mathcal{L}_\chi = \frac{1}{2}\bar{\chi}i\partial\!\!\!/\chi - \frac{1}{2}m_\chi\bar{\chi}\chi + y_\ell\left(\bar{\chi}_L S^\dagger \ell_R + \text{h.c.}\right),$$
$$\mathcal{L}_S = (D^\mu S)^\dagger D_\mu S - V(H,S),$$
$$V(H,S) = \mu_H^2|H|^2 + \mu_S^2|S|^2 + \lambda_H|H|^4 + \lambda_S|S|^4 + 2\lambda_{HS}|H|^2|S|^2$$



JL, XP Wang, KP Xie, 2104.06421 (JHEP)

Asymmetric dark matter connecting to lepton portal

Mengchao Zhang, 2104.06988 (PRD)

- A model for (dark) baryogengesis via leptogenesis
- The dark matter is dark baryon and asymmetric

Right-handed nu/Leptogenesis → N_1/N_2

Dark mediators/ Fermion-portal type → Φ, χ

Dark quark/ DM is dark baryon → q'

	$SU(3)'$	$SU(3)$	$U_Y(1)$	Spin	L	B	B'
N_1/N_2	1	1	0	1/2	0	0	0
Φ	3	1	1	0	-1	0	1/3
χ	3	1	1	1/2	-1	0	1/3
q'	3	1	0	1/2	0	0	1/3
l_R	1	1	-1	1/2	1	0	0
d_R	1	3	-1/3	1/2	0	1/3	0
u_R	1	3	2/3	1/2	0	1/3	0

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{2}\sum_{i=1,2} M_{N_i}\overline{N}_i N_i^C - m_\Phi^2 \Phi^\dagger\Phi - m_\chi \bar{\chi}\chi - m_{q'}\bar{q}'q' + \mathcal{L}_{\rm kinetic}$$

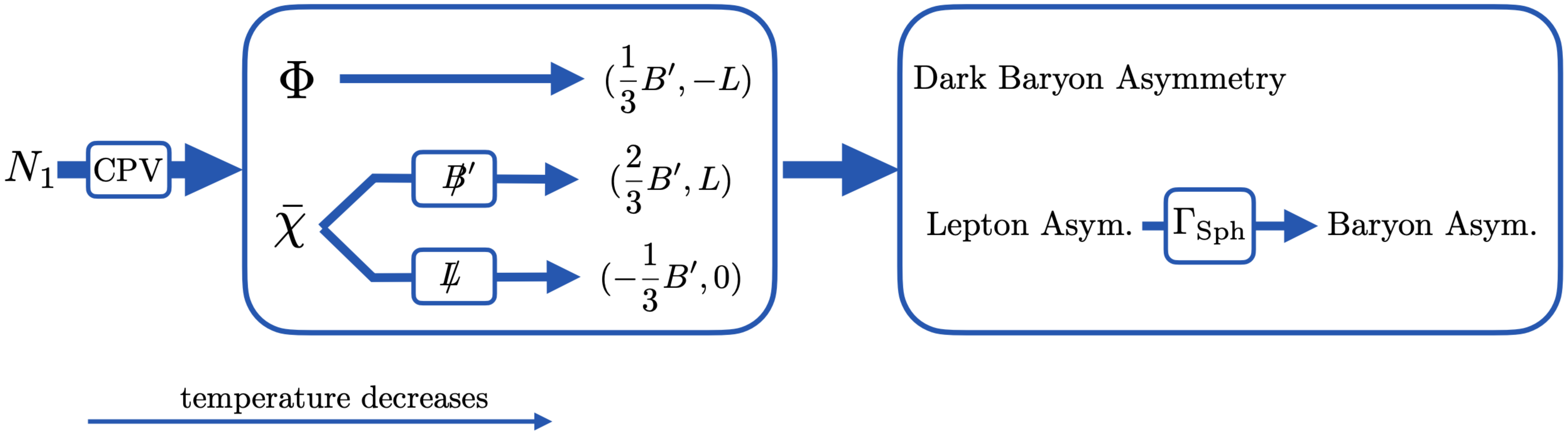
$$- \sum_{i=1,2}\lambda_i \overline{N}_i \chi \Phi^\dagger - \kappa \Phi \bar{q}'_L l_R - \frac{1}{\Lambda_1^2}\left(\bar{q}'^C \chi\right)\left(\bar{q}'^C_L l_R\right) - \frac{1}{\Lambda_2^2}\left(\bar{\chi}\gamma^\mu q'\right)\left(\bar{d}_R \gamma_\mu u_R\right) + h.c.$$

Dark matter and Baryon asymmetry

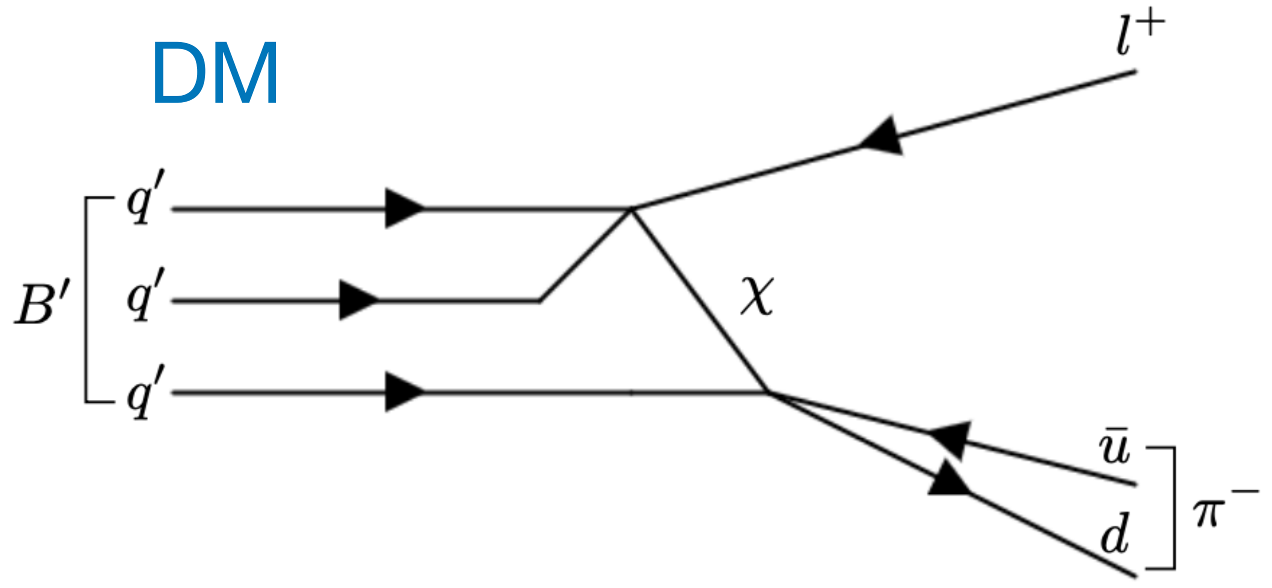
$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{2}\sum_{i=1,2} M_{N_i}\overline{N}_i N_i^C - m_\Phi^2 \Phi^\dagger\Phi - m_\chi \bar{\chi}\chi - m_{q'}\bar{q}'q' + \mathcal{L}_{\rm kinetic}$$
$$- \sum_{i=1,2}\lambda_i \overline{N}_i\chi\Phi^\dagger - \kappa\Phi\bar{q}'_L l_R - \frac{1}{\Lambda_1^2}\left(\bar{q}'^C\chi\right)\left(\bar{q}'^C_L l_R\right) - \frac{1}{\Lambda_2^2}\left(\bar{\chi}\gamma^\mu q'\right)\left(\bar{d}_R\gamma_\mu u_R\right) + h.c.$$

$\Delta B' \neq 0$ $\Delta L \neq 0$

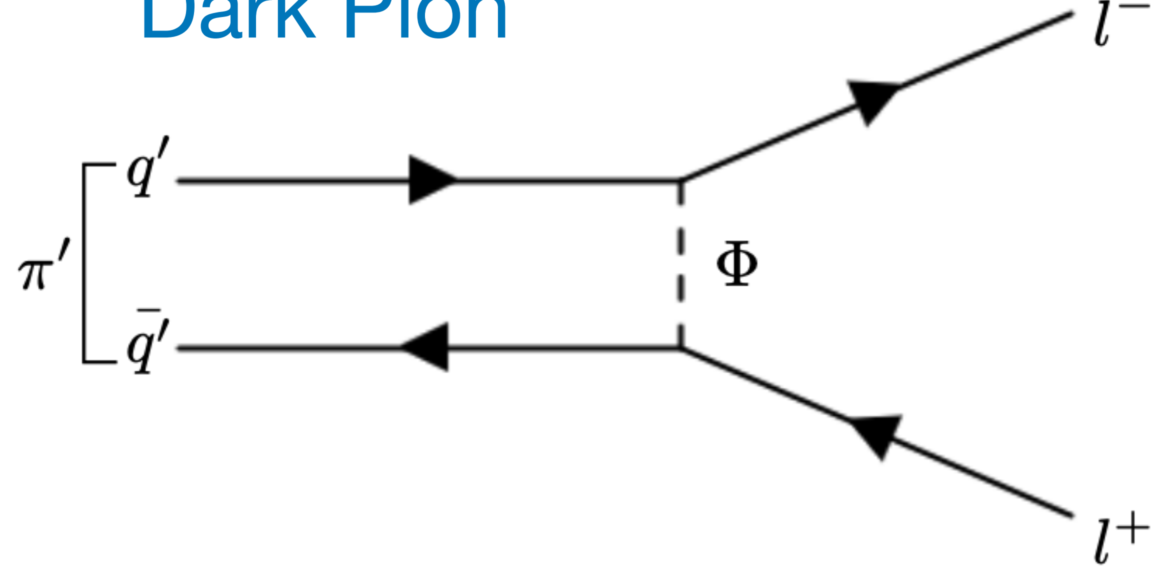
	$SU(3)'$	$SU(3)$	$U_Y(1)$	Spin	L	B	B'
N_1/N_2	1	1	0	1/2	0	0	0
Φ	3	1	1	0	-1	0	1/3
χ	3	1	1	1/2	-1	0	1/3
q'	3	1	0	1/2	0	0	1/3
l_R	1	1	-1	1/2	1	0	0
d_R	1	3	-1/3	1/2	0	1/3	0
u_R	1	3	2/3	1/2	0	1/3	0



DM



Dark Pion



Mengchao Zhang, 2104.06988 (PRD)

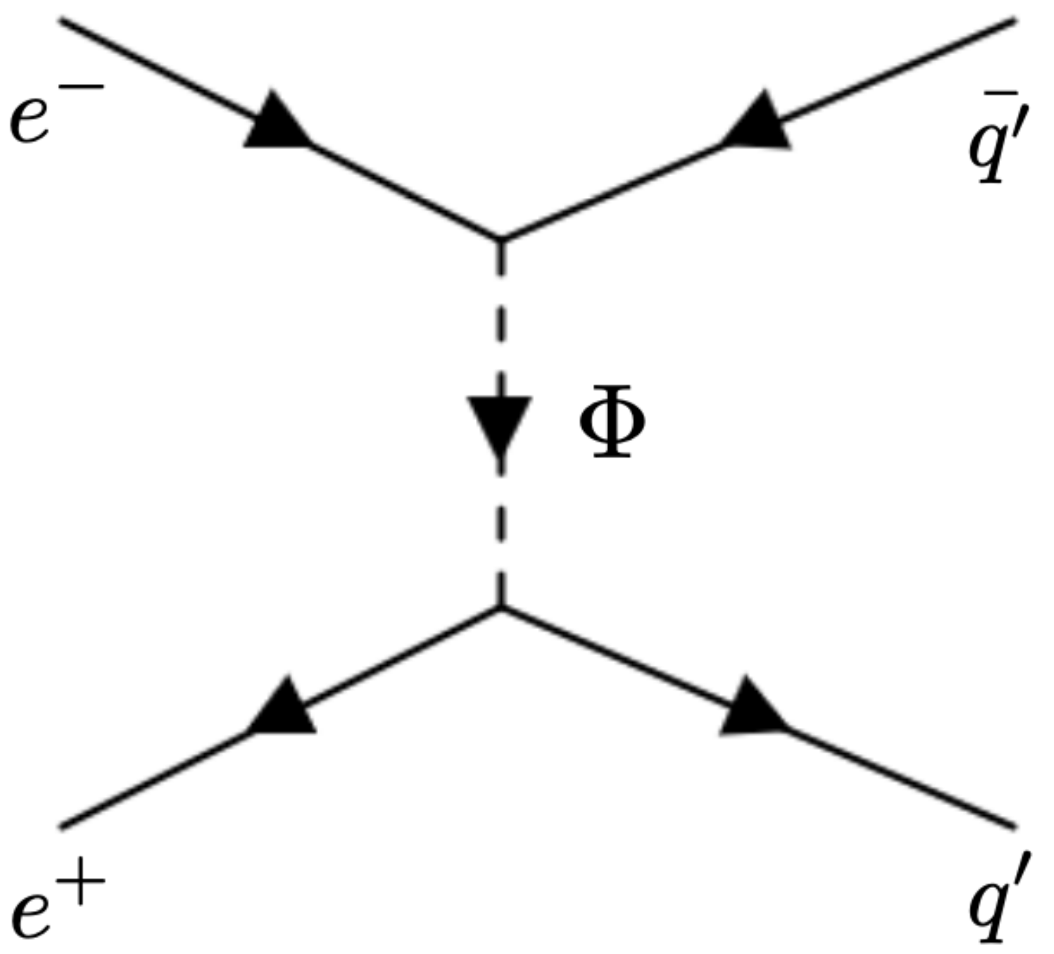
Dark jets at ee collider

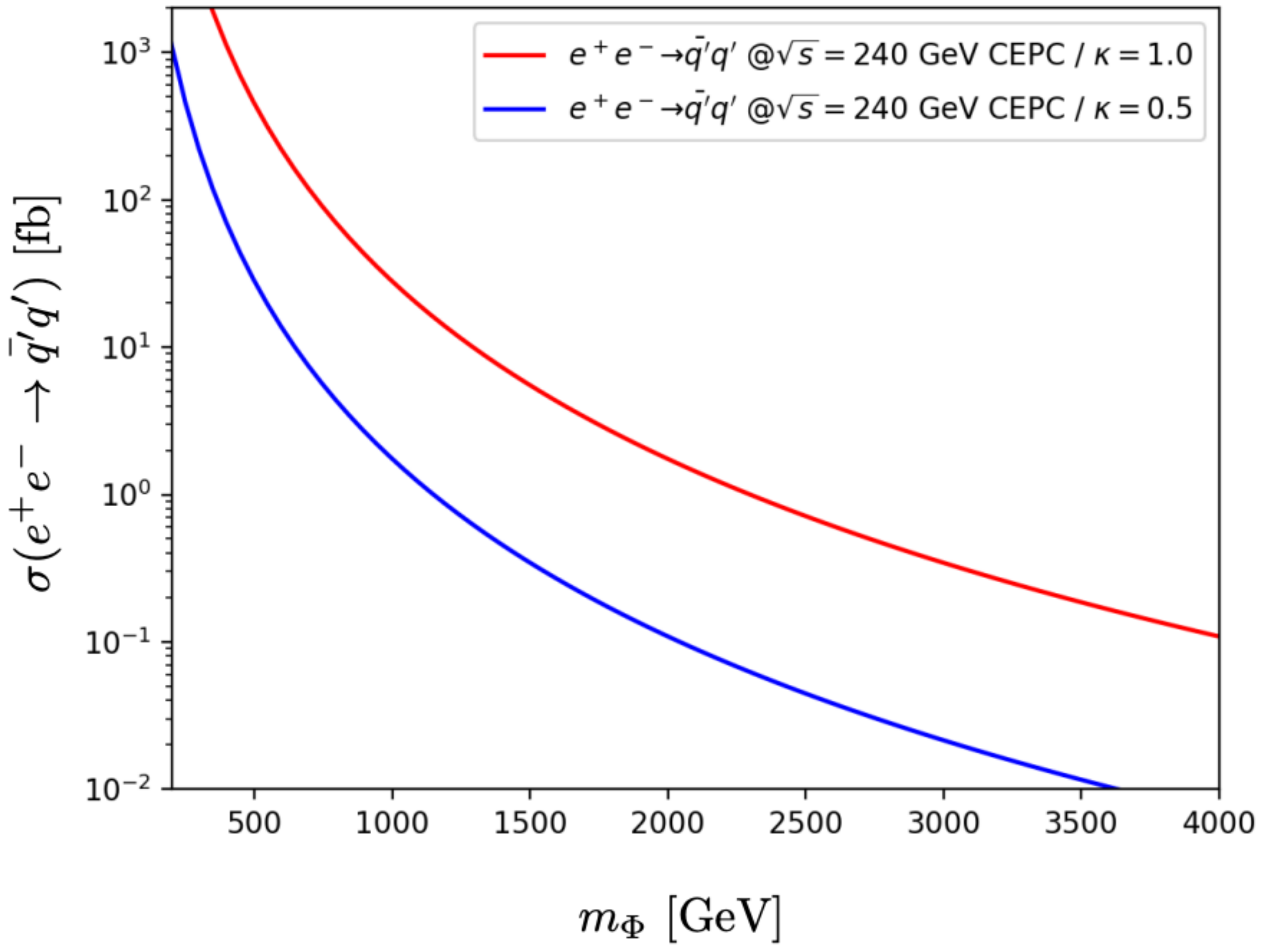
$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{2}\sum_{i=1,2} M_{N_i}\overline{N}_i N_i^C - m_\Phi^2 \Phi^\dagger\Phi - m_\chi \bar{\chi}\chi - m_{q'}\bar{q}'q' + \mathcal{L}_{\rm kinetic}$$
$$- \sum_{i=1,2}\lambda_i \overline{N}_i \chi \Phi^\dagger - \kappa\Phi\bar{q}'_L l_R - \frac{1}{\Lambda_1^2}\left(\bar{q}'^C\chi\right)\left(\bar{q}'^C_L l_R\right) - \frac{1}{\Lambda_2^2}\left(\bar{\chi}\gamma^\mu q'\right)\left(\bar{d}_R\gamma_\mu u_R\right) + h.c.$$

- Relevant Lagrangian

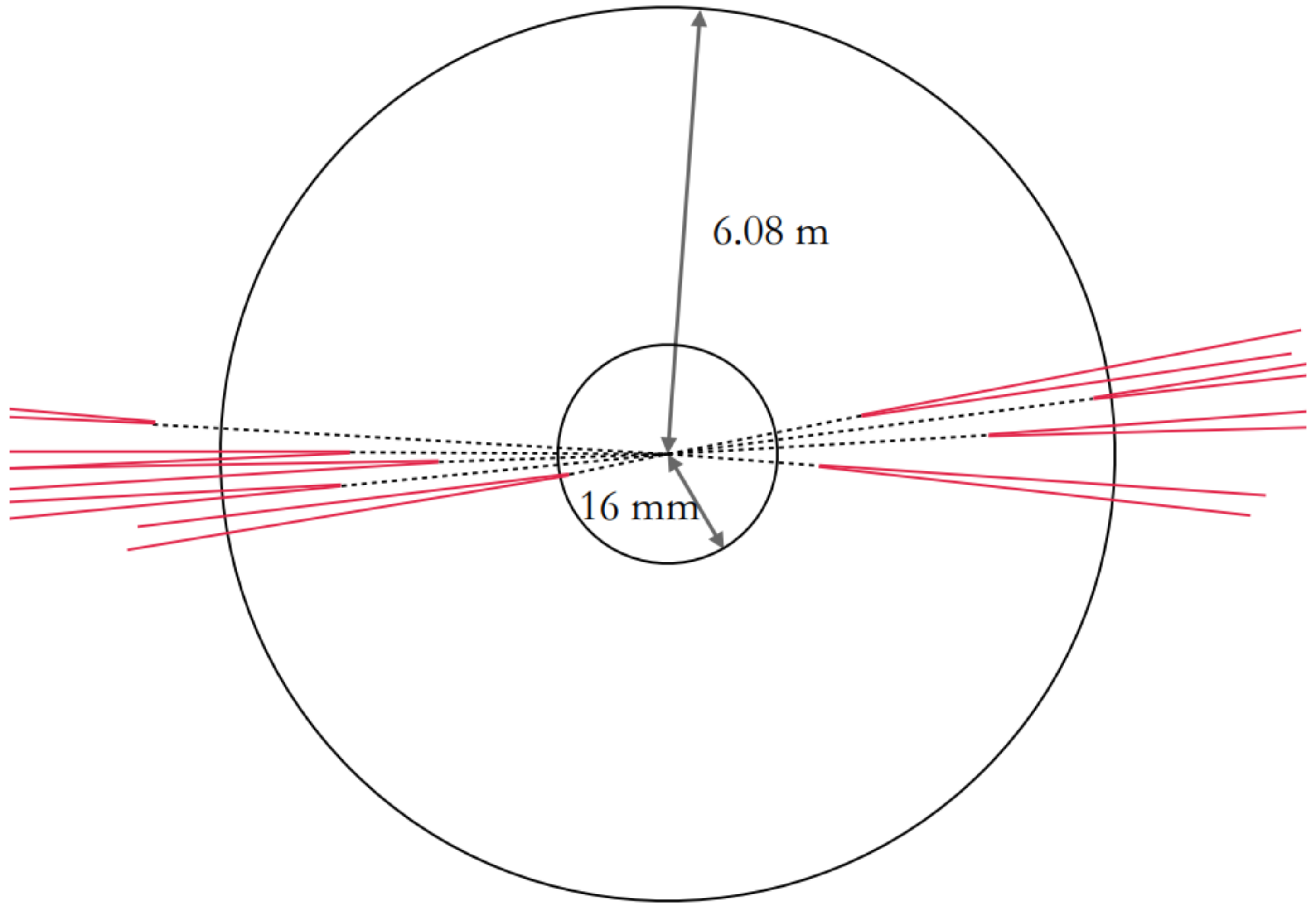
P. Schwaller et al, 1502.05409 (JHEP)

$$\mathcal{L} \supset \bar{q}'(\not{D} - m_{q'})q' + (D_\mu\Phi)^\dagger(D^\mu\Phi) - m_\Phi^2\Phi^\dagger\Phi - \frac{1}{4}G'^{\mu\nu}G'_{\mu\nu} - (\kappa\Phi\bar{q}'_L l_R + h.c.)$$





- $e^+e^- \to \bar{q}'q'$ followed by dark hadronization
- Displaced dark meson decay $\pi_d = (\bar{q}'q')$



Mengchao Zhang, 2104.06988 (PRD)

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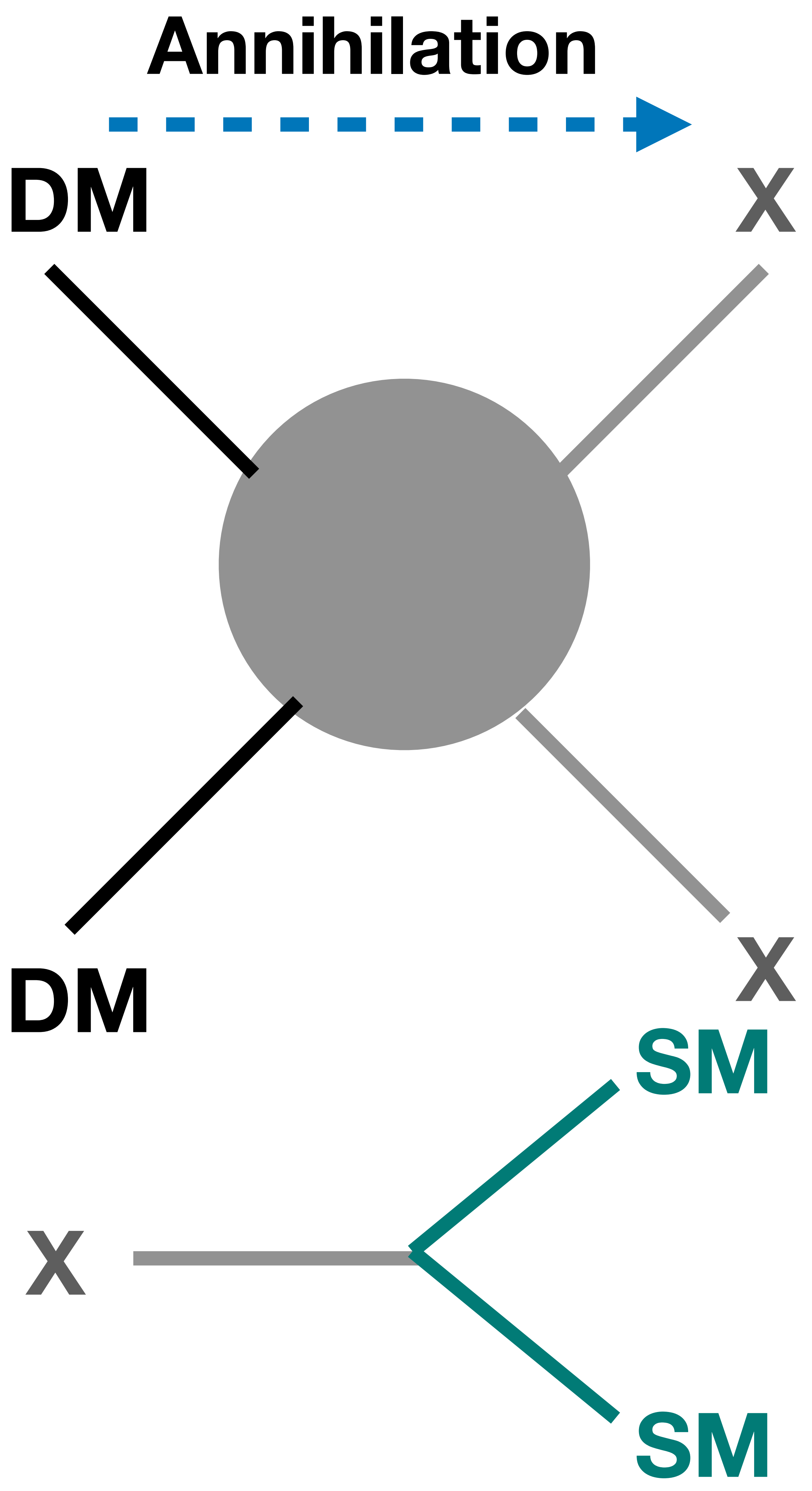
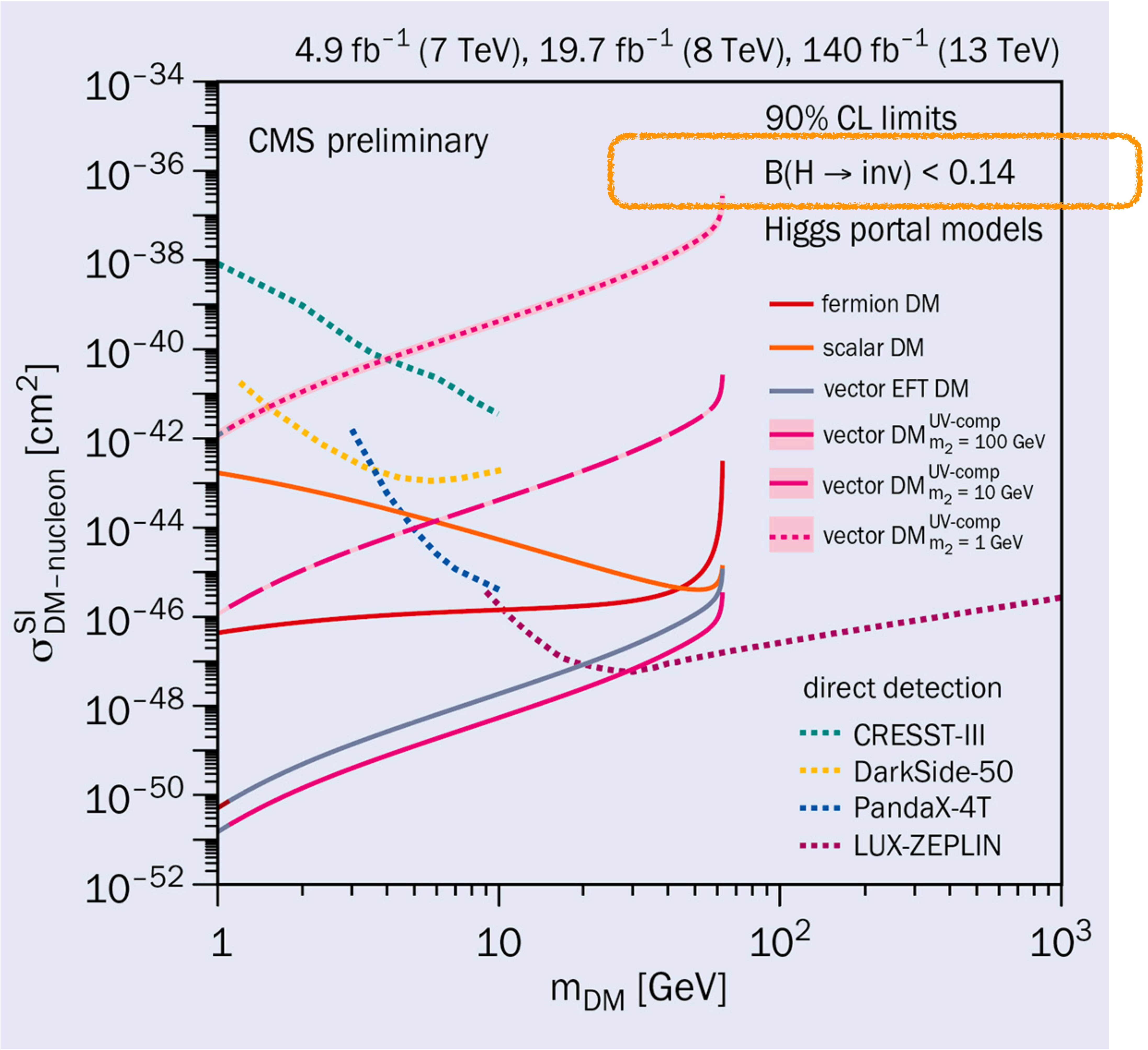


Dark mediator X with small coupling to SM

Higgs portal DM: invisible Higgs decay

- Precision measurement of Higgs
  - Invisible Higgs test to 0.07%@CEPC

	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	vvH	ZH	vvH	eeH
inclusive	**0.26%**		**1.40%**	\	\
H→bb	**0.14%**	**1.59%**	**0.90%**	**1.10%**	**4.30%**
H→cc	**2.02%**		**8.80%**	**16%**	**20%**
H→gg	**0.81%**		**3.40%**	**4.50%**	**12%**
H→WW	**0.53%**		**2.80%**	**4.40%**	**6.50%**
H→ZZ	**4.17%**		**20%**	**21%**	
$H\to\tau\tau$	**0.42%**		**2.10%**	**4.20%**	**7.50%**
$H\to\gamma\gamma$	**3.02%**		**11%**	**16%**	
$H\to\mu\mu$	**6.36%**		**41%**	**57%**	
$H\to Z\gamma$	**8.50%**		**35%**		
$Br_{upper}(H\to inv.)$	**0.07%**				
Γ_H	**1.65%**		**1.10%**		



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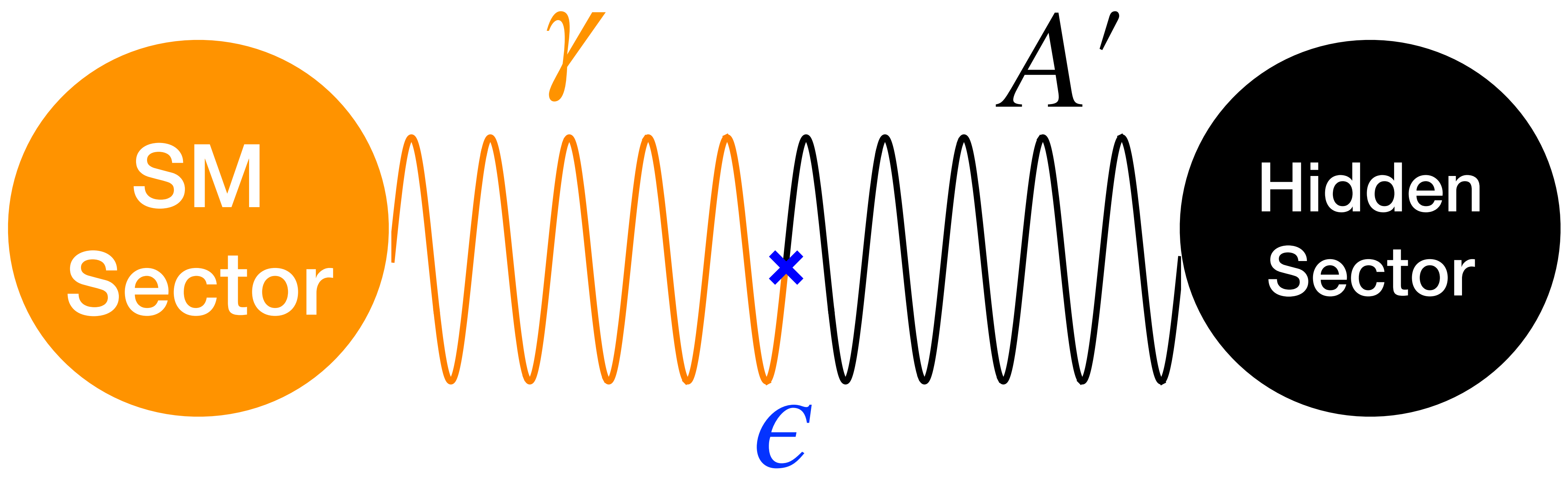
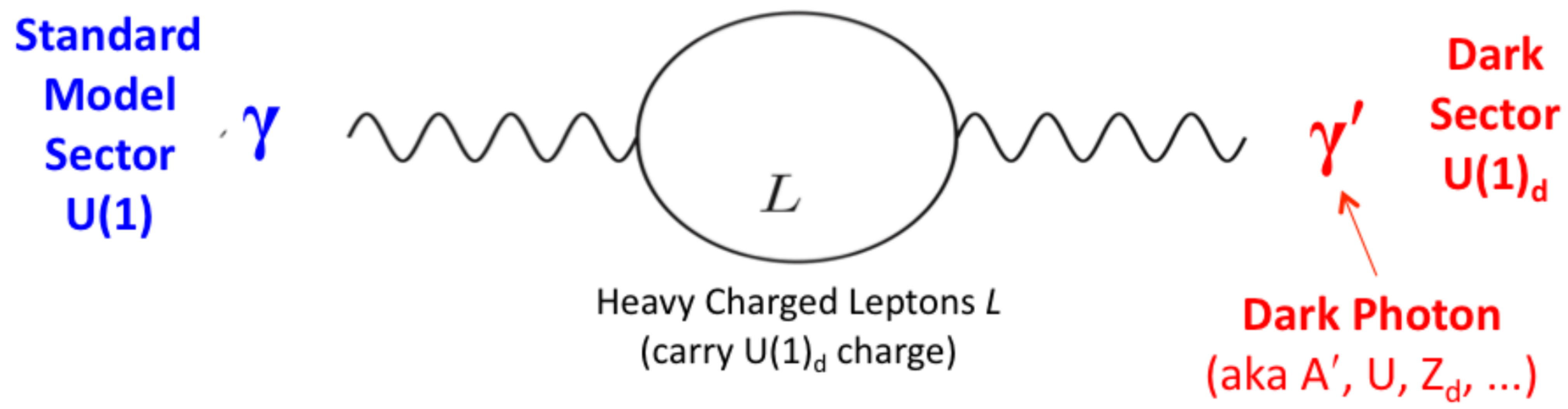
Vector portal

- The vector portal to DM
  - The Interaction: $g' \bar{\chi} \gamma^\mu \chi Z'_\mu$
    - Millicharged DM: EM with ϵe
    - Kinetic mixing portal
    - Effective Z' through fermion mass mixing





$$\epsilon \sim -\frac{g g'}{16\pi^2} \log\left(\frac{m_L^2}{\mu^2}\right)$$

$$\mathscr{L} = -\frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} + \frac{1}{2} m_{A'}{}^2 A'^\mu A'_\mu - \frac{1}{2} \epsilon F'_{\mu\nu} F^{\mu\nu}$$

Vector portal

- The vector portal to DM
  - The Interaction: $g'\bar{\chi}\gamma^\mu\chi Z'_\mu$
    - Millicharged DM: EM with ϵe
    - Kinetic mixing portal
    - Effective Z' through fermion mass mixing $(\psi/f_{\rm SM})$ $g'\bar{f}\gamma^\mu f Z'_\mu$

DM χ is charged under U(1)'

	U(1)'	SM charge
ψ	1	Yes
ϕ	1	No
$f_{\rm SM}$	0	Yes

$$\mathscr{L} \supset m_\psi \bar{\psi}\psi + \lambda\bar{\psi}\langle\phi\rangle f_{\rm SM}$$

P. Fox, JL, D.T. Smith, N. Weiner, 1104.4127 (JHEP)

Searching DM via mono-photon at CEPC

- DM searches via mono-photon final states

Millicharged DM

$$\mathcal{L} = e\varepsilon A_\mu \bar{\chi}\gamma^\mu \chi,$$

Z' portal DM

$$\mathcal{L} = Z'_\mu \bar{\chi}\gamma^\mu (g_V^\chi - g_A^\chi \gamma_5)\chi + Z'_\mu \bar{f}\gamma^\mu (g_V^f - g_A^f \gamma_5) f,$$

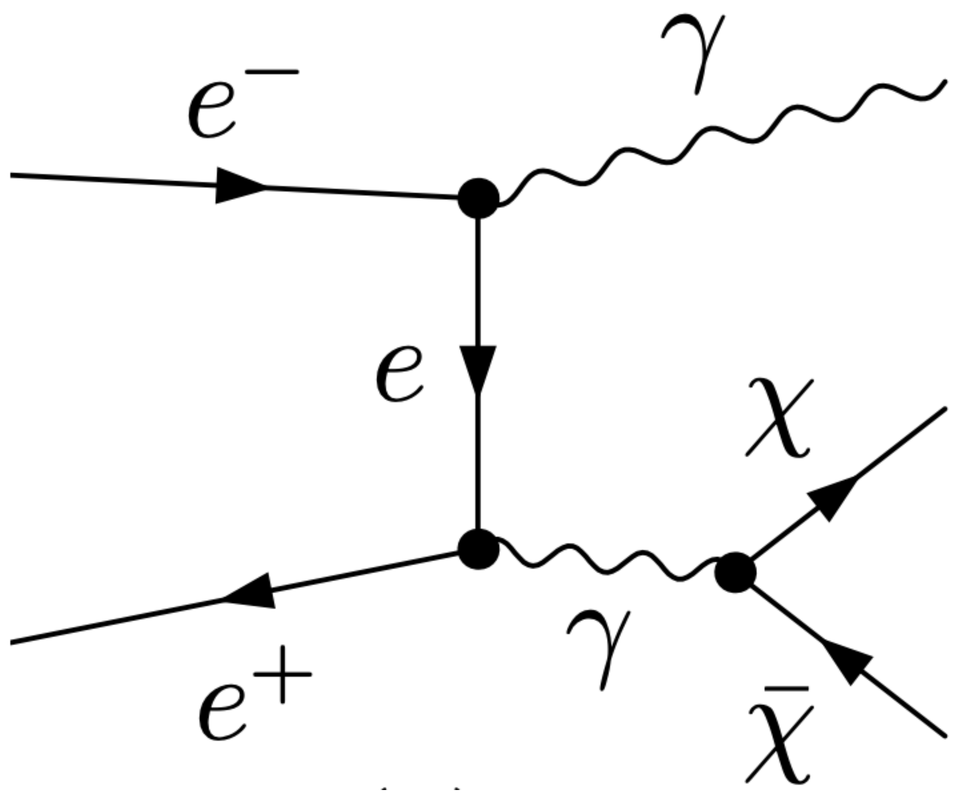
DM EFTs

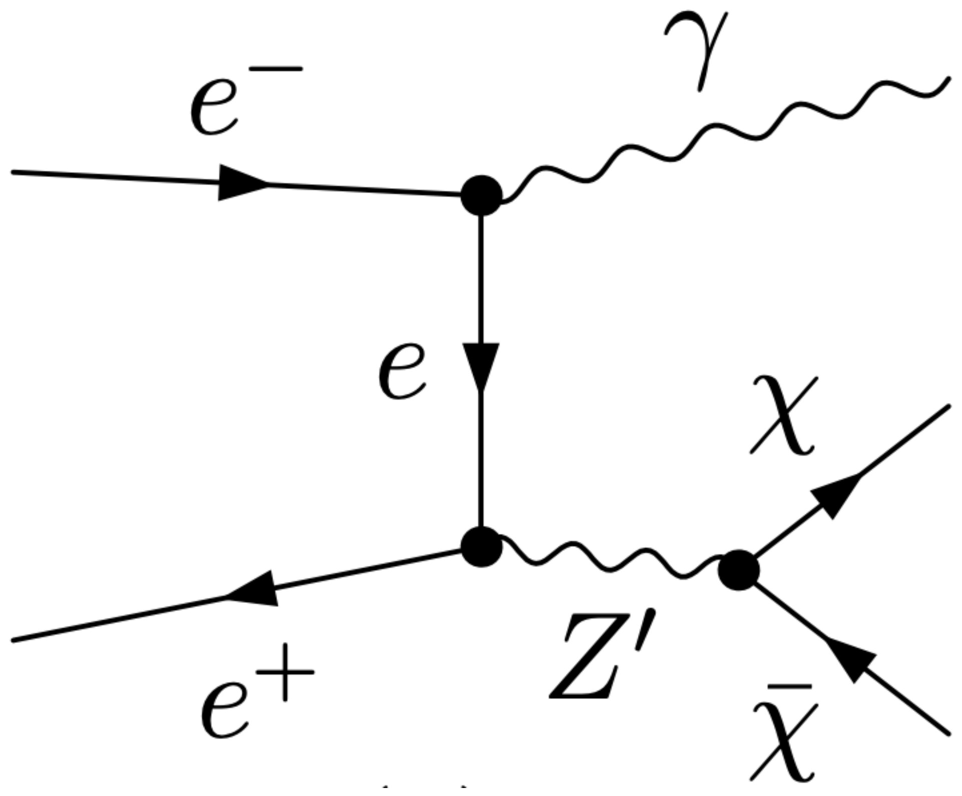
$$\mathcal{L} = \frac{1}{\Lambda_V^2}\bar{\chi}\gamma_\mu\chi\bar{\ell}\gamma^\mu\ell,$$

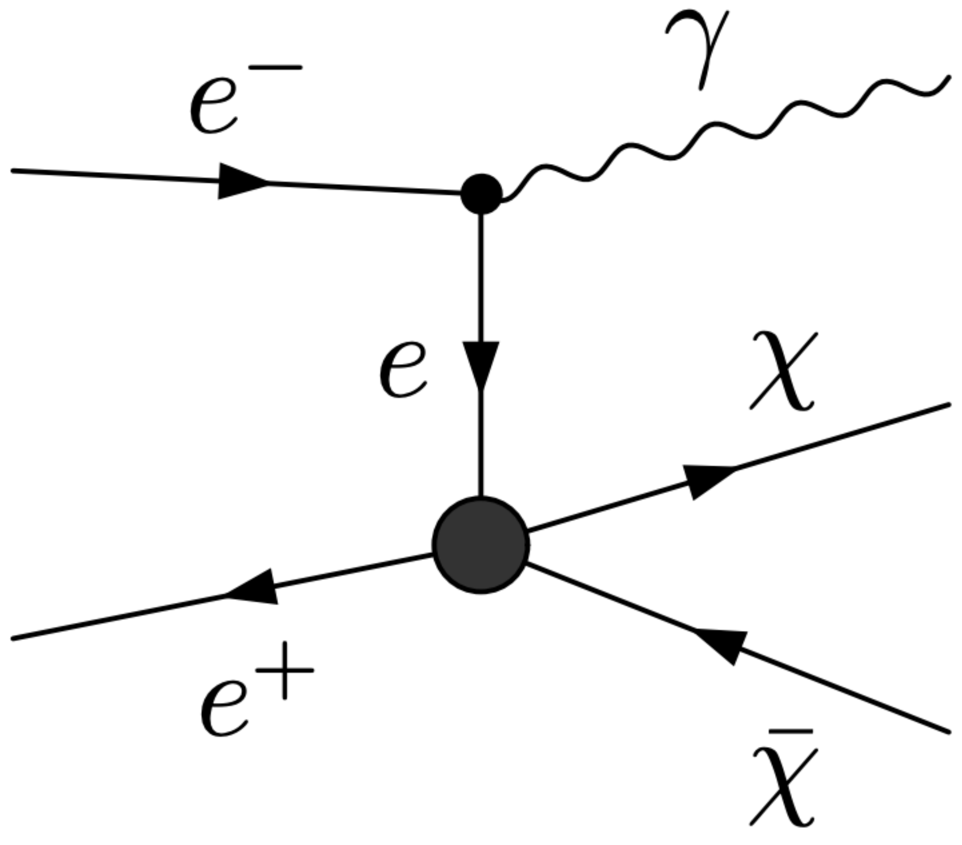
$$\mathcal{L} = \frac{1}{\Lambda_s^2}\bar{\chi}\chi\bar{\ell}\ell,$$

$$\mathcal{L} = \frac{1}{\Lambda_A^2}\bar{\chi}\gamma_\mu\gamma_5\chi\bar{\ell}\gamma^\mu\gamma_5\ell,$$

$$\mathcal{L} = \frac{1}{\Lambda_t^2}\bar{\chi}\ell\bar{\ell}\chi$$



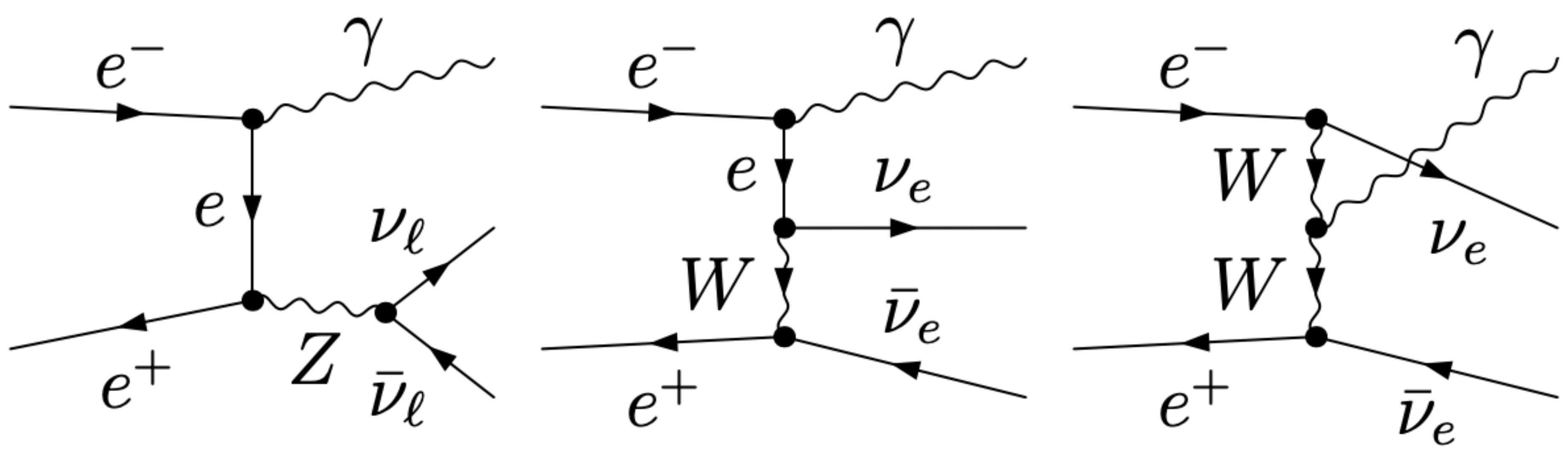




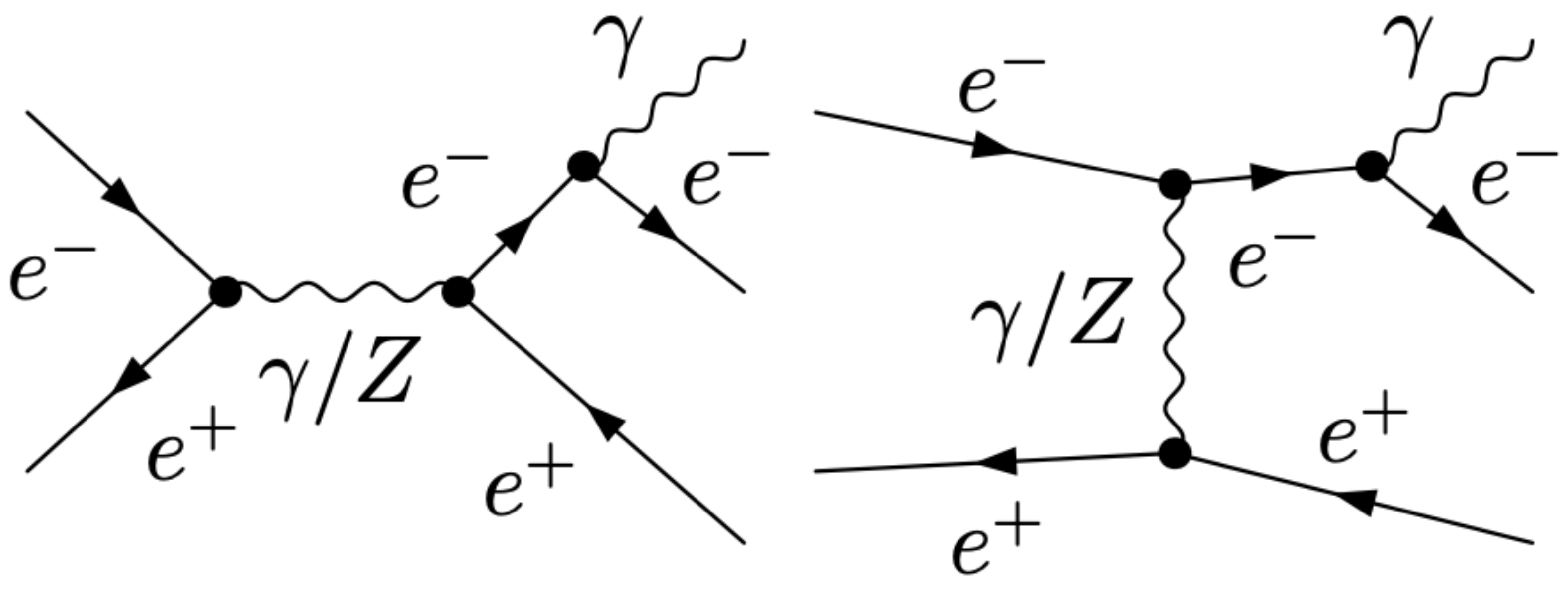
Zuowei Liu et al, 1903.12114 (JHEP)

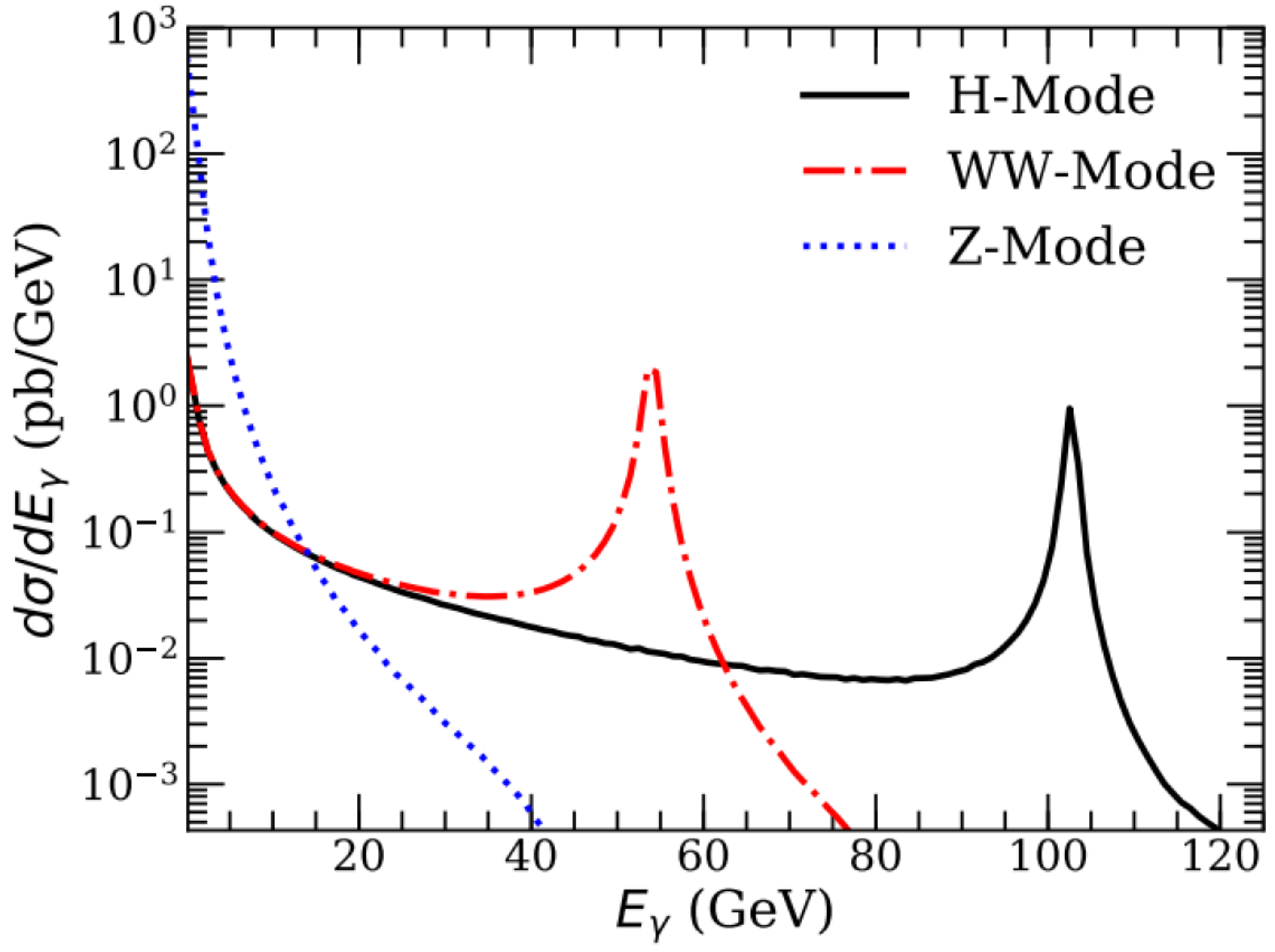
Mono-photon background at CEPC

- Irreducible background
  $e^+e^- \to \gamma\nu\bar{\nu}$

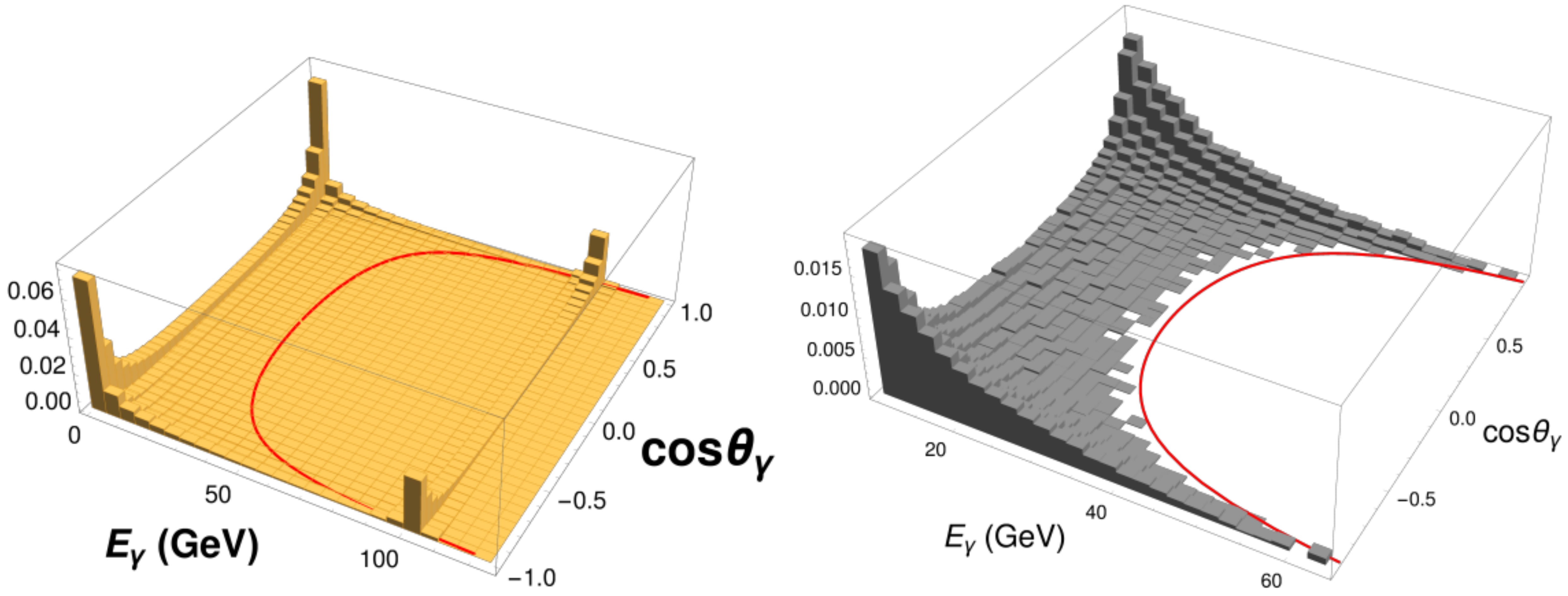


- Reducible background
  $e^+e^- \to \gamma e^+e^-$





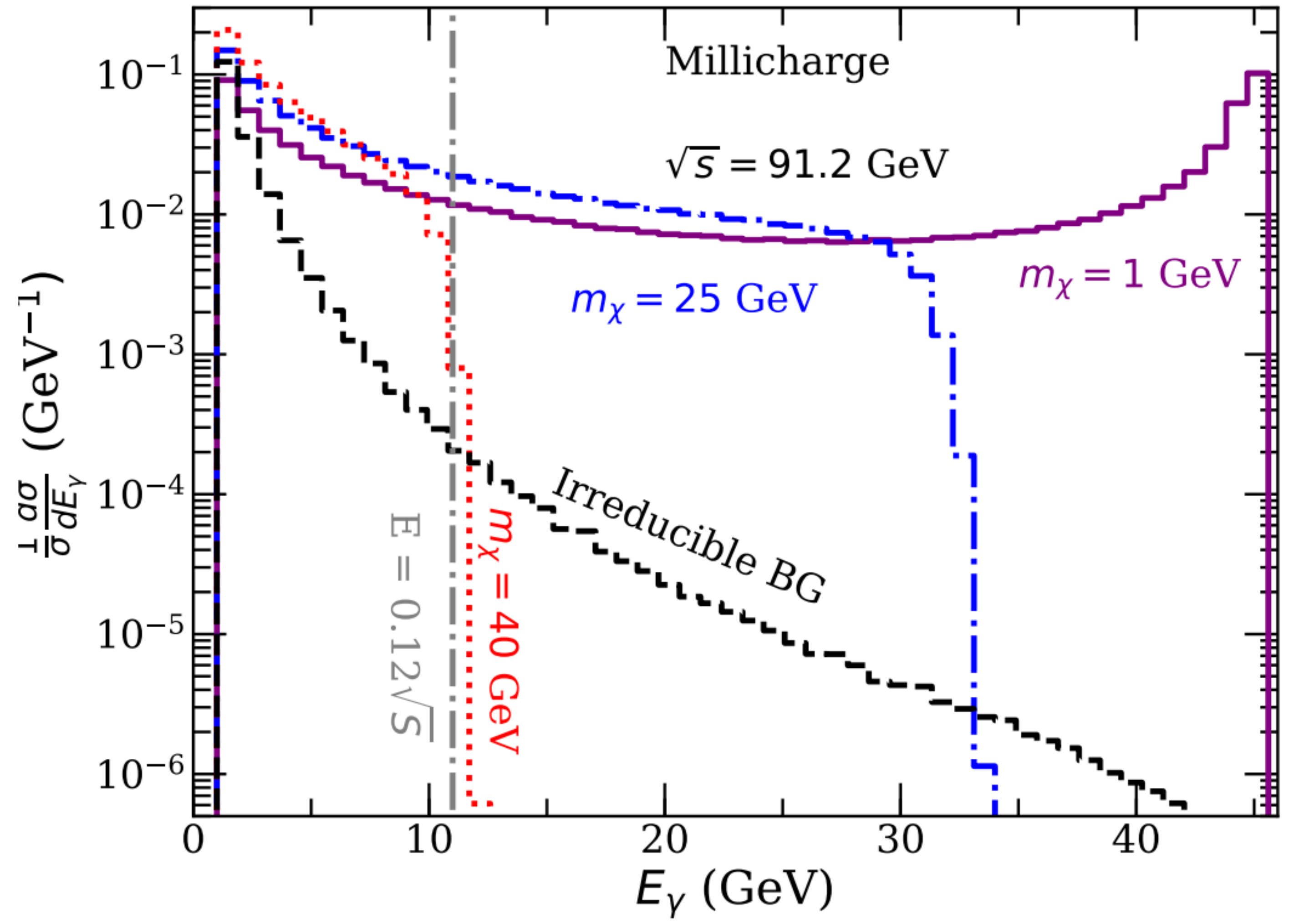
- Red curve shows the signal region

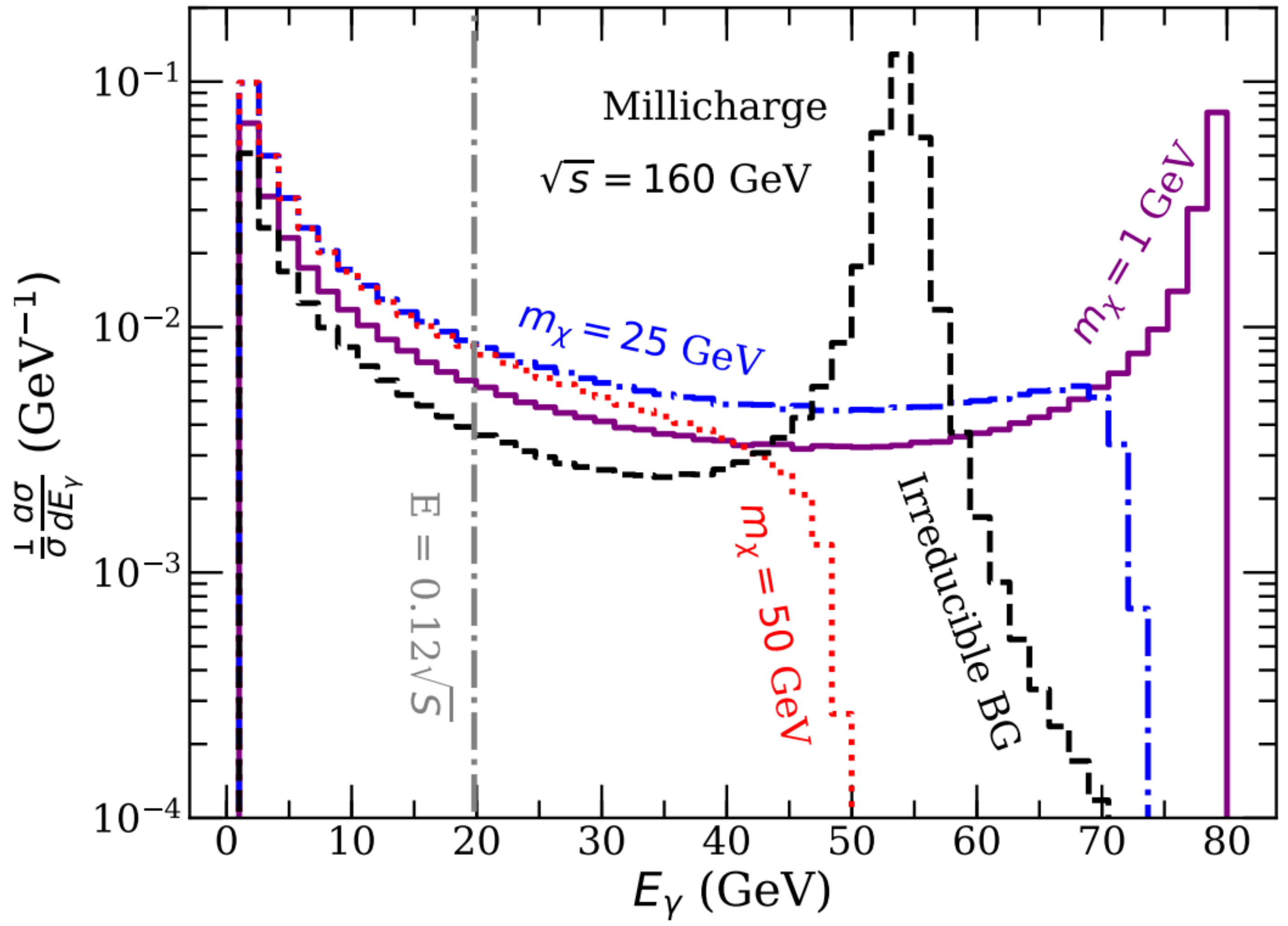


Zuowei Liu et al, 1903.12114 (JHEP)

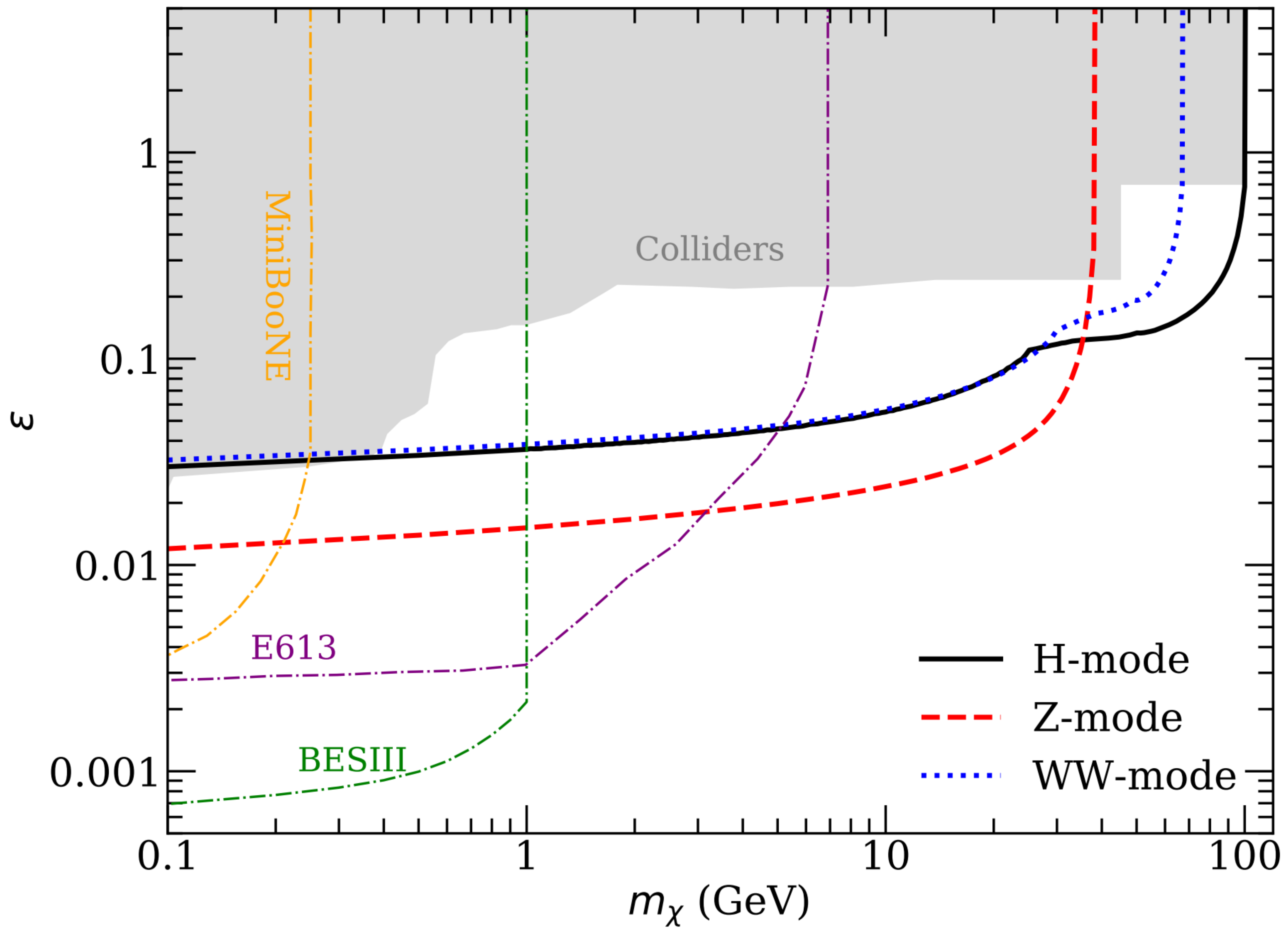
Constraints on millicharged DM

- The signal distribution at Z $(2.6\ \mathrm{ab}^{-1})$, H $(5.6\ \mathrm{ab}^{-1})$, WW modes $(16\ \mathrm{ab}^{-1})$





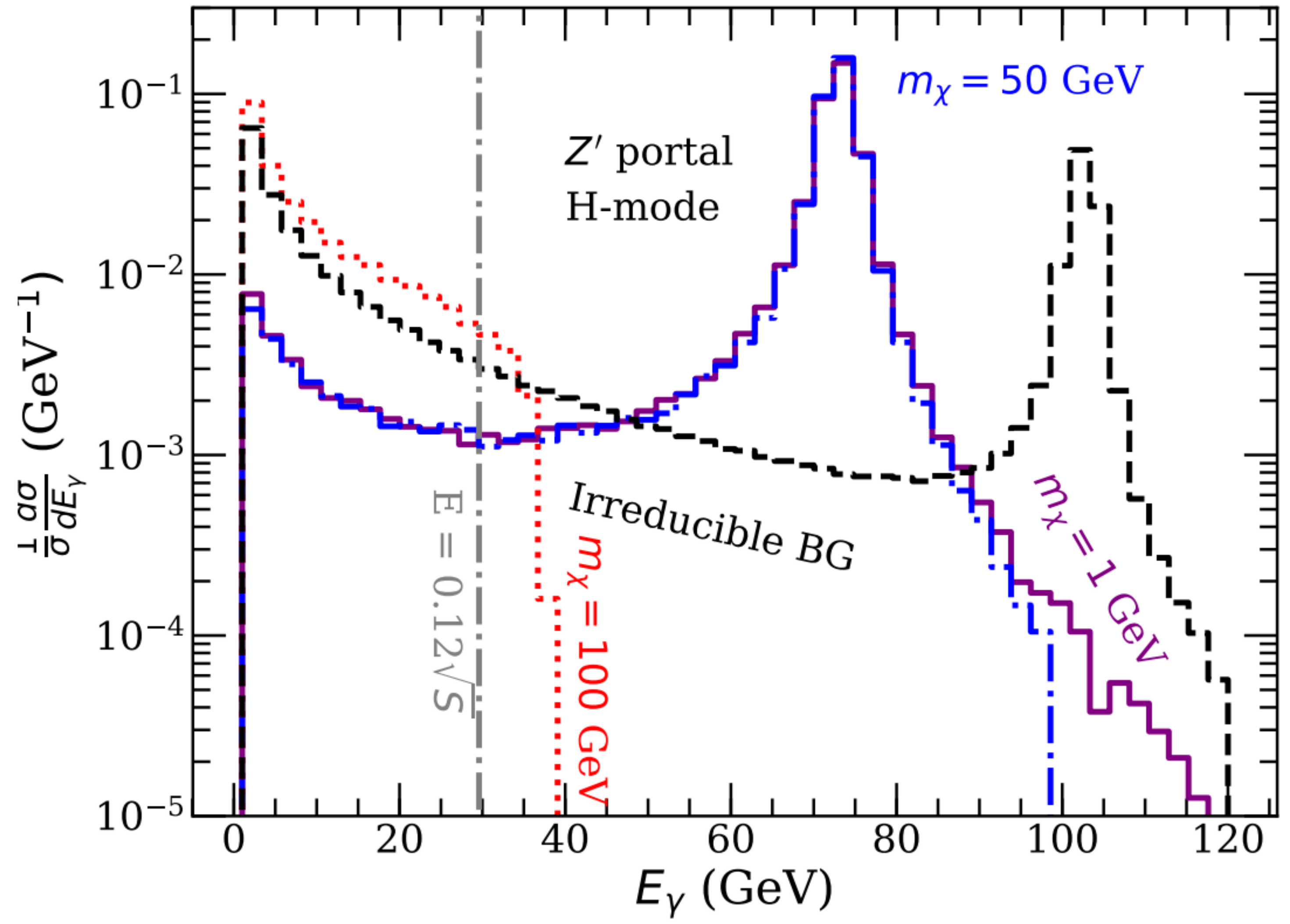
Zuowei Liu et al, 1903.12114 (JHEP)

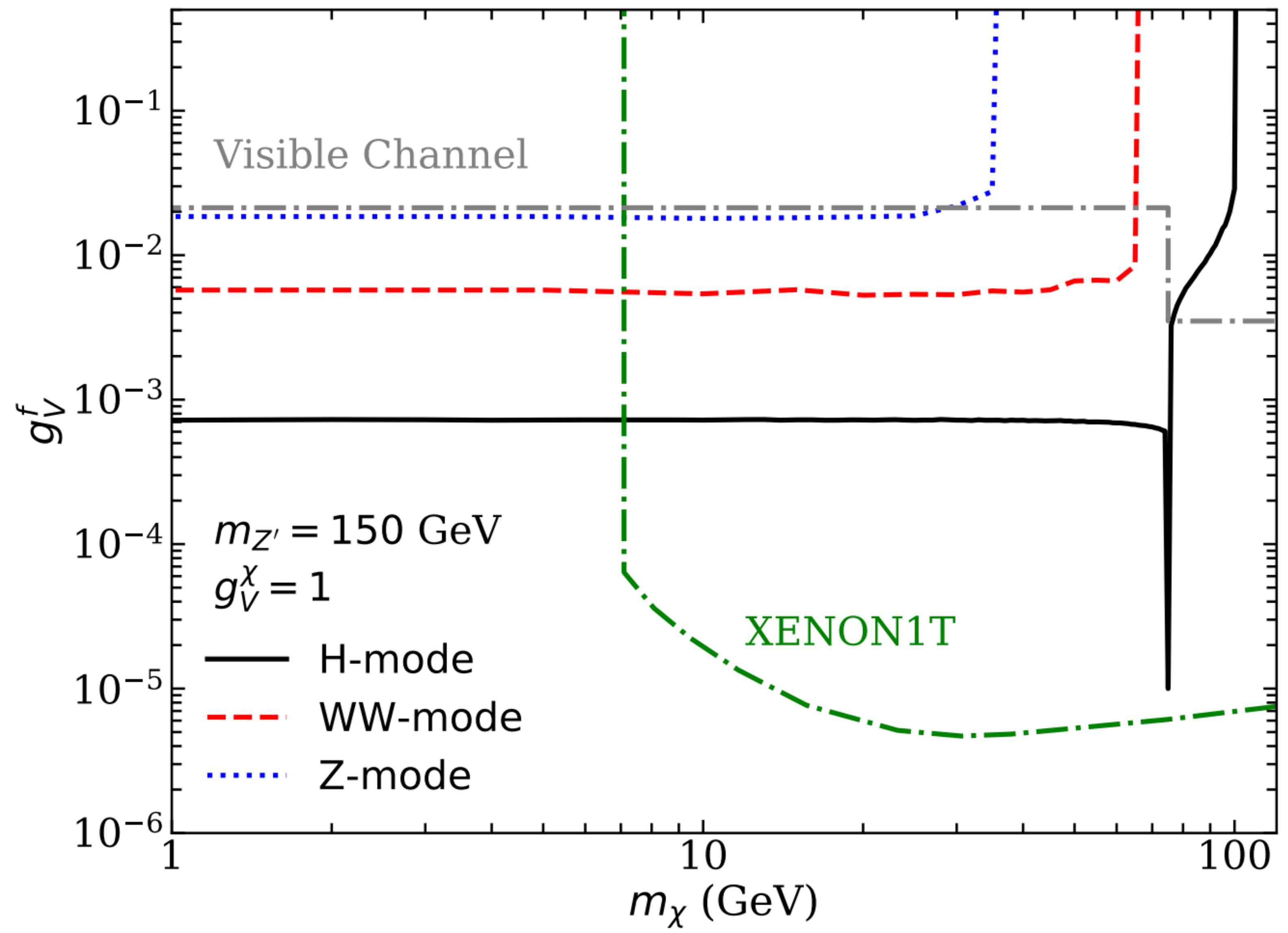


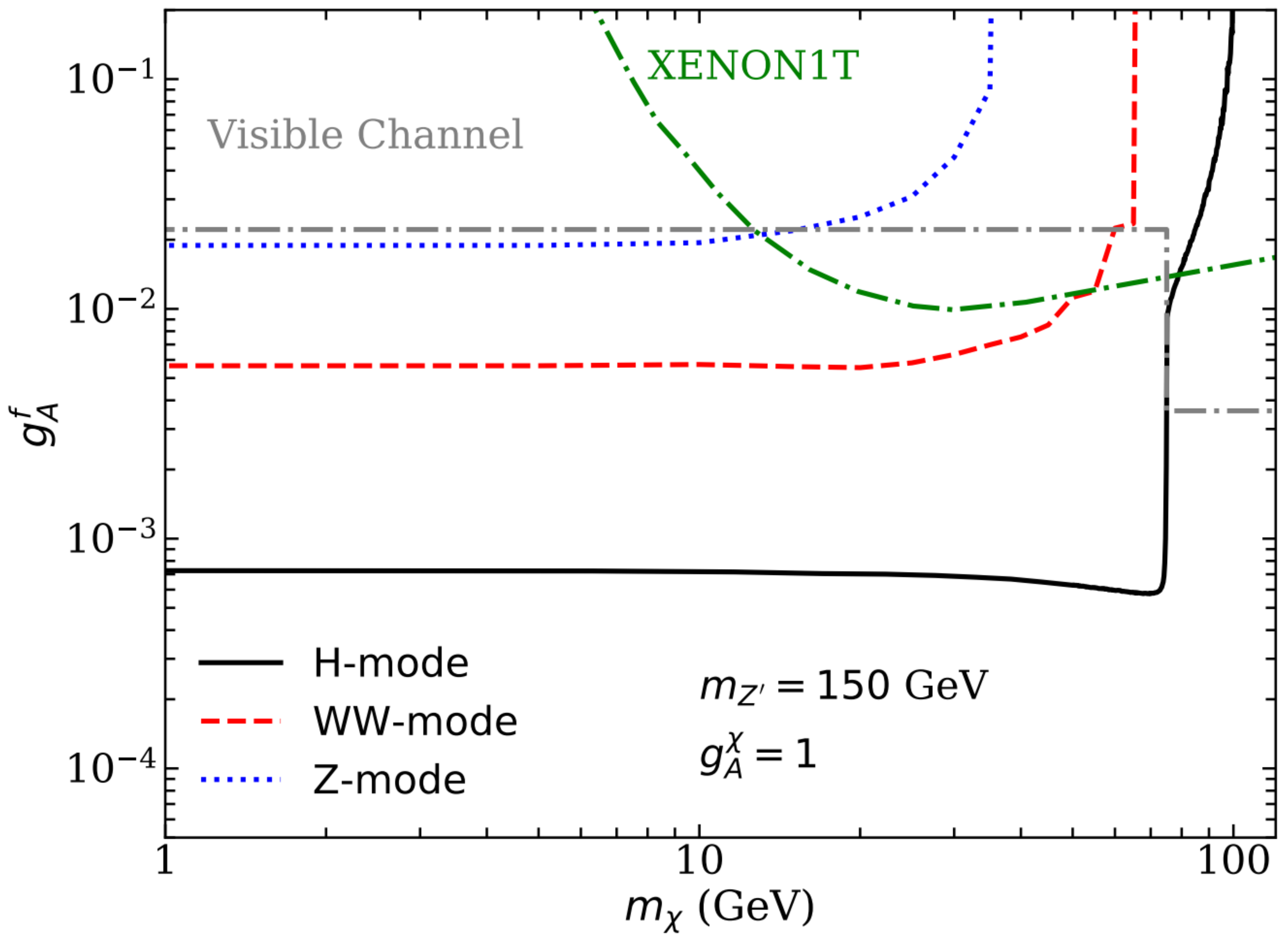
- The Z/Higgs factory modes can provide competitive sensitivity comparing with existing colliders

Constraints on Z’ portal DM model

- The signal distribution at Z $(2.6\ \mathrm{ab}^{-1})$, H $(5.6\ \mathrm{ab}^{-1})$, WW modes $(16\ \mathrm{ab}^{-1})$







- The Z/Higgs factory modes can provide competitive sensitivity comparing with existing colliders and direct detection searches

Zuowei Liu et al, 1903.12114 (JHEP)

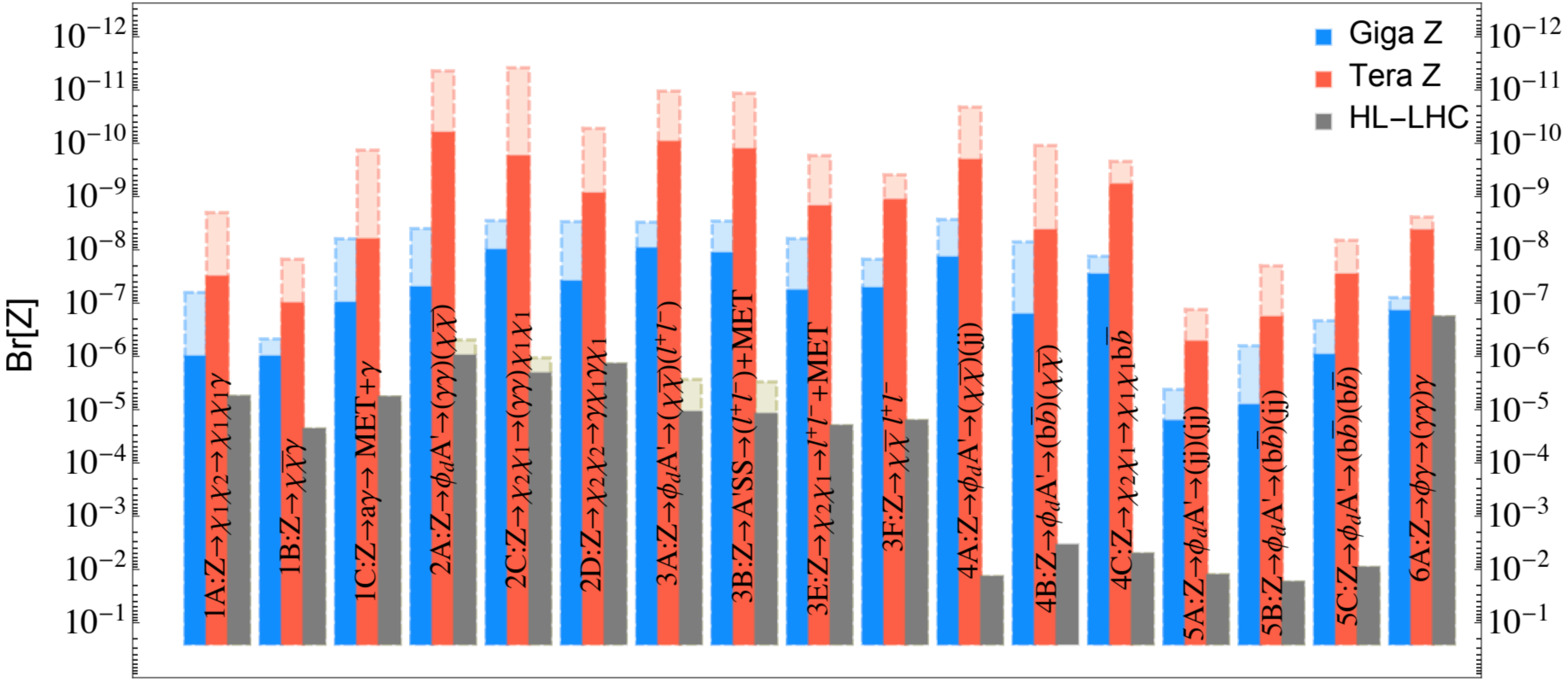
Probing dark sector models at future Z-factory

exotic decays	topologies	n_{res}	models
$Z \to \not{E} + \gamma$	$Z \to \chi_1\chi_2, \chi_2 \to \chi_1\gamma$	0	1A: $\frac{1}{\Lambda_{1A}}\bar{\chi}_2\sigma^{\mu\nu}\chi_1 B_{\mu\nu}$ (MIDM)
	$Z \to \chi\bar{\chi}\gamma$	0	1B: $\frac{1}{\Lambda^3_{1B}}\bar{\chi}\chi B_{\mu\nu}B^{\mu\nu}$ (RayDM)
	$Z \to a\gamma \to (\not{E})\gamma$	1	1C: $\frac{1}{4\Lambda_{1C}} a B_{\mu\nu}\tilde{B}^{\mu\nu}$ (long-lived ALP)
	$Z \to A'\gamma \to (\bar{\chi}\chi)\gamma$	1	1D: $\epsilon^{\mu\nu\rho\sigma}{A'}_\mu B_\nu \partial_\rho B_\sigma$ (WZ terms)
$Z \to \not{E} + \gamma\gamma$	$Z \to \phi_d A', \phi_d \to (\gamma\gamma), A' \to (\bar{\chi}\chi)$	2	2A: Vector portal
	$Z \to \phi_H\phi_A,\ \phi_H \to (\gamma\gamma),\ \phi_A \to (\bar{\chi}\chi)$	2	2B: 2HDM extension
	$Z \to \chi_2\chi_1,\ \chi_2 \to \chi_1\phi,\ \phi \to (\gamma\gamma)$	1	2C: Inelastic DM
	$Z \to \chi_2\chi_2,\ \chi_2 \to \gamma\chi_1$	0	2D: MIDM

$Z \to \not{E} + \ell^+\ell^-$	$Z \to \phi_d A',\ A' \to (\ell^+\ell^-),\ \phi_d \to (\bar{\chi}\chi)$	2	3A: Vector portal
	$Z \to A'SS \to (\ell\ell)SS$	1	3B: Vector portal
	$Z \to \phi(Z^*/\gamma^*) \to \phi\ell^+\ell^-$	1	3C: Long-lived ALP, Higgs portal
	$Z \to \chi_2\chi_1 \to \chi_1 A'\chi_1 \to (\ell^+\ell^-)\not{E}$	1	3D: Vector portal and Inelastic DM
	$Z \to \chi_2\chi_1,\ \chi_2 \to \chi_1\ell^+\ell^-$	0	3E: MIDM, SUSY
	$Z \to \bar{\chi}\chi\ell^+\ell^-$	0	3F: RayDM, slepton, heavy lepton mixing
$Z \to \not{E} + JJ$	$Z \to \phi_d A' \to (\bar{\chi}\chi)(jj)$	2	4A: Vector portal
	$Z \to \phi_d A' \to (bb)(\bar{\chi}\chi)$	2	4B: Vector portal + Higgs portal
	$Z \to \chi_2\chi_1 \to bb\chi_1 + \chi_1 \to bb\not{E}$	0	4C: MIDM
$Z \to (JJ)(JJ)$	$Z \to \phi_d A', \phi_d \to jj, A' \to jj$	2	5A: Vector portal + Higgs portal
	$Z \to \phi_d A', \phi_d \to b\bar{b}, A' \to jj$	2	5B: vector portal + Higgs portal
	$Z \to \phi_d A', \phi_d \to b\bar{b}, A' \to b\bar{b}$	2	5C: vector portal + Higgs portal
$Z \to \gamma\gamma\gamma$	$Z \to \phi\gamma \to (\gamma\gamma)\gamma$	1	6A: ALP, Higgs portal

JL, LT Wang, XP Wang, W. Xue, 1712.07237 (PRD)

Probing dark sector models at future Z-factory



JL, LT Wang, XP Wang, W. Xue, 1712.07237 (PRD)

Outline

- CEPC and New Physics Searches
  - SUSY
  - Dark Matter and Dark Sector
    - Fermion portal — lepton portal
    - Higgs portal
    - Vector portal
    - EFT models
- Summary

Searching DM via mono-photon at CEPC

- DM searches via mono-photon final states

Millicharged DM

$$\mathcal{L} = e\varepsilon A_\mu \bar{\chi}\gamma^\mu \chi,$$

Z' portal DM

$$\mathcal{L} = Z'_\mu \bar{\chi}\gamma^\mu (g_V^\chi - g_A^\chi \gamma_5)\chi + Z'_\mu \bar{f}\gamma^\mu (g_V^f - g_A^f \gamma_5) f,$$

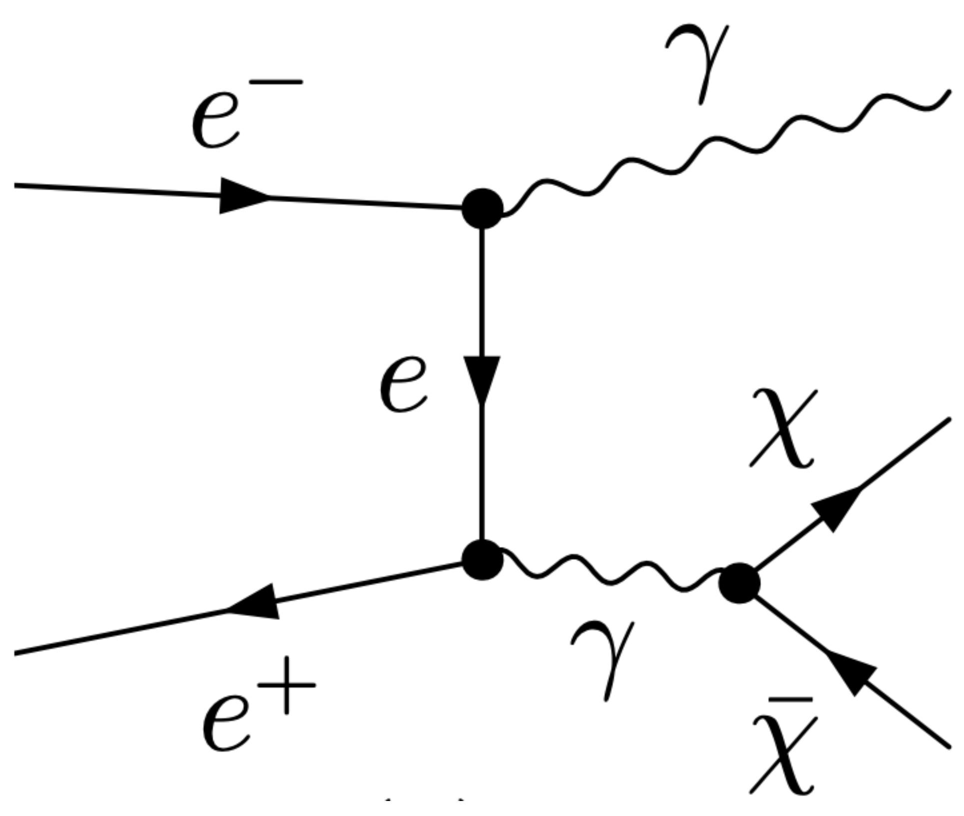
DM EFTs

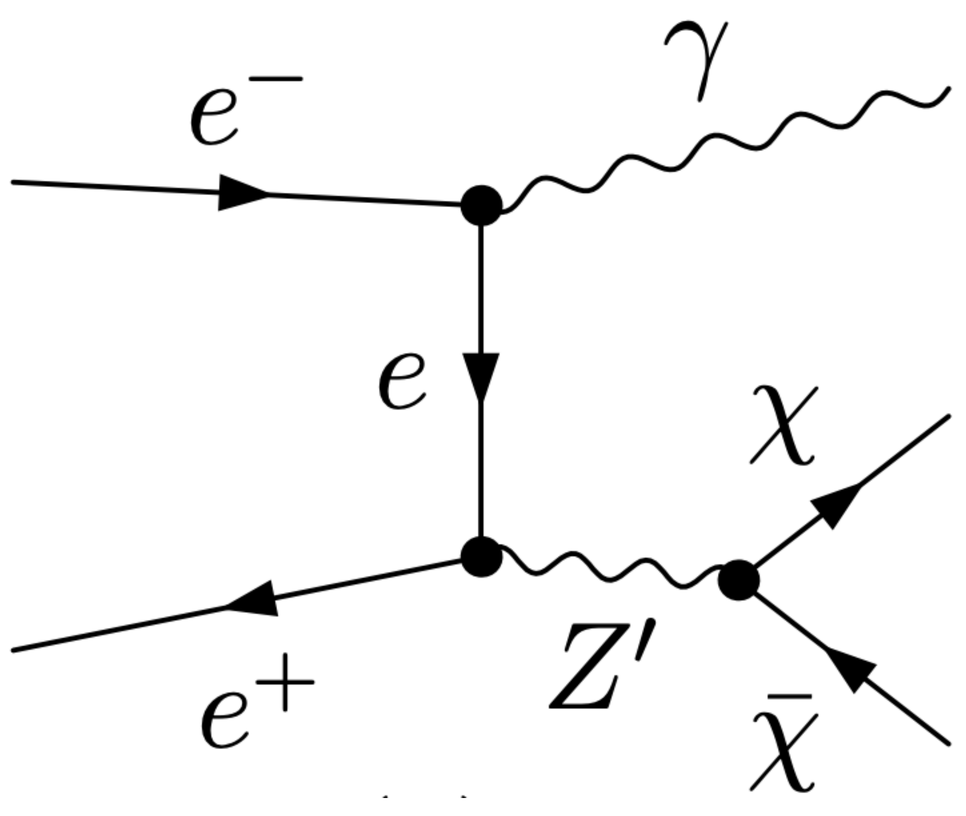
$$\mathcal{L} = \frac{1}{\Lambda_V^2}\bar{\chi}\gamma_\mu\chi\bar{\ell}\gamma^\mu\ell,$$

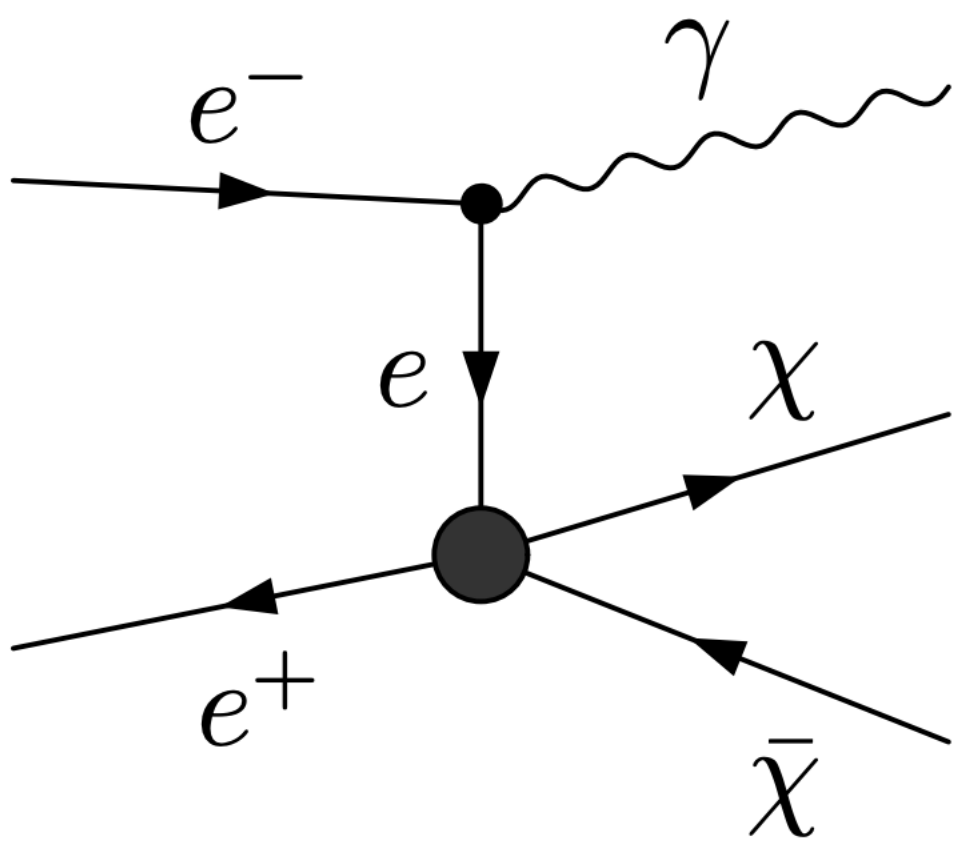
$$\mathcal{L} = \frac{1}{\Lambda_s^2}\bar{\chi}\chi\bar{\ell}\ell,$$

$$\mathcal{L} = \frac{1}{\Lambda_A^2}\bar{\chi}\gamma_\mu\gamma_5\chi\bar{\ell}\gamma^\mu\gamma_5\ell,$$

$$\mathcal{L} = \frac{1}{\Lambda_t^2}\bar{\chi}\ell\bar{\ell}\chi$$



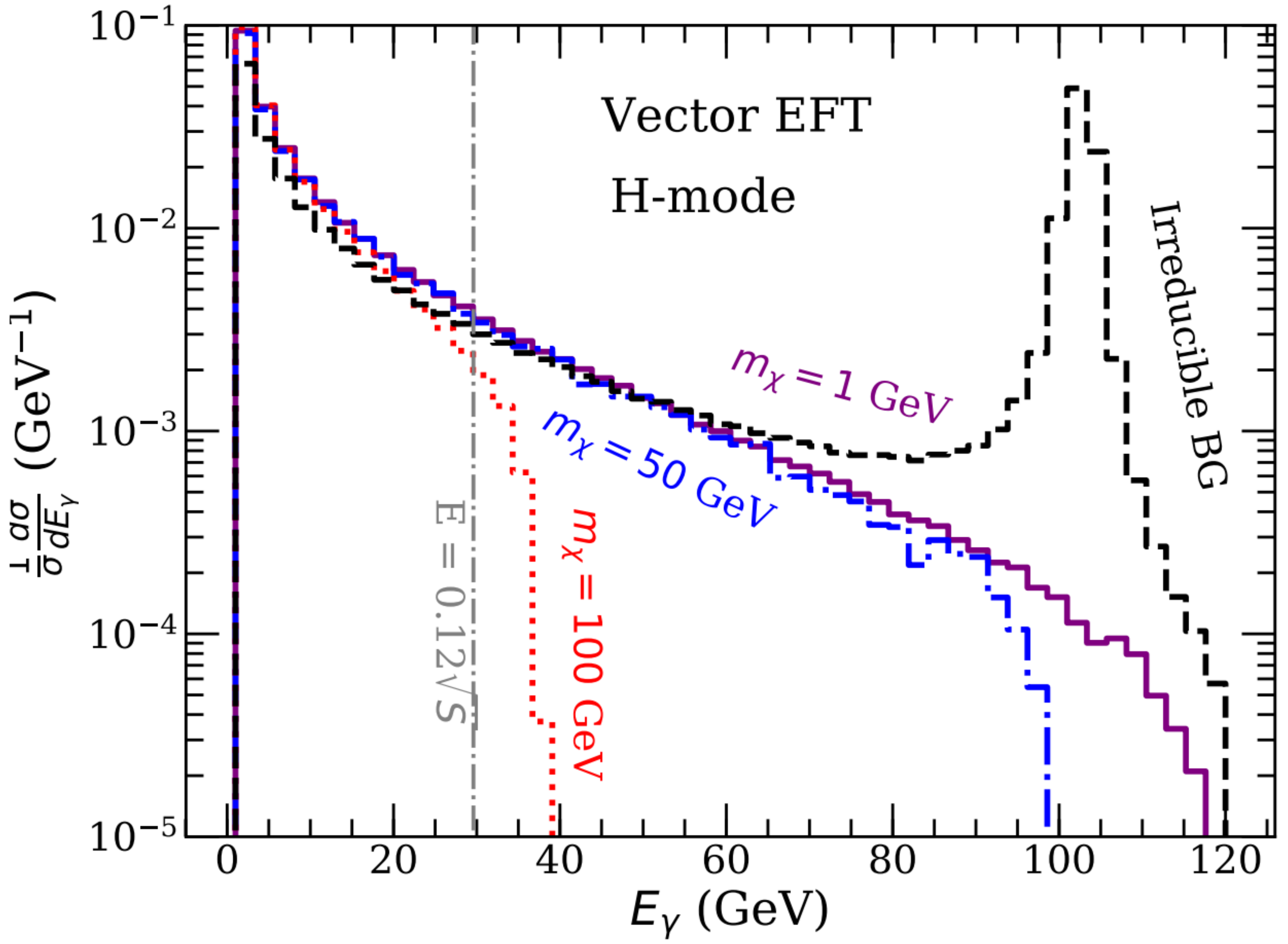


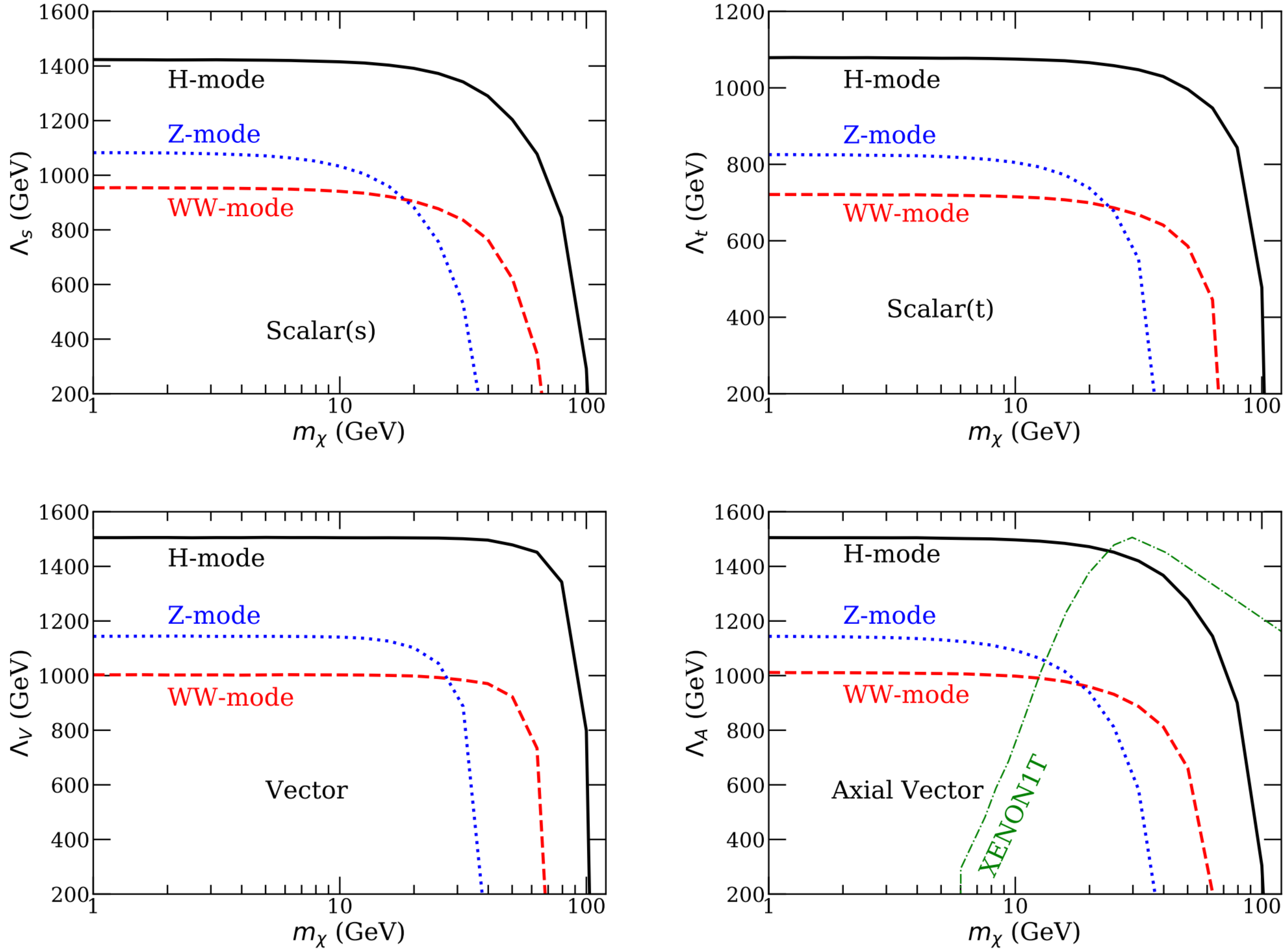


Zuowei Liu et al, 1903.12114 (JHEP)

Constraints on DM EFTs

- The signal distribution at Z $(2.6\ \text{ab}^{-1})$, H $(5.6\ \text{ab}^{-1})$, WW modes $(16\ \text{ab}^{-1})$





- The Z/Higgs factory modes can provide competitive sensitivity comparing with existing colliders and direct detection searches

Zuowei Liu et al, 1903.12114 (JHEP)

Searching fermionic DM absorption at CEPC

- Light DM can provide enough energy to direct detection via down-scattering (fermionic)/absorption (bosonic)
  - Inelastic DM $\chi_2 q \to \chi_1 q$, Luminous DM long-lived $\chi_2 \to \chi_1 \gamma$
  - Fermionic DM down-scattering: $\chi e \to \nu e$, no Z_2 protection

Shaofeng Ge et al, 2201.11497 (JHEP)

$$\mathcal{O}^S_{e\nu\chi} \equiv (\bar{e}e)(\bar{\nu}_L \chi_R),$$
$$\mathcal{O}^P_{e\nu\chi} \equiv (\bar{e}i\gamma_5 e)(\bar{\nu}_L \chi_R),$$
$$\mathcal{O}^V_{e\nu\chi} \equiv (\bar{e}\gamma_\mu e)(\bar{\nu}_L \gamma^\mu \chi_L),$$
$$\mathcal{O}^A_{e\nu\chi} \equiv (\bar{e}\gamma_\mu \gamma_5 e)(\bar{\nu}_L \gamma^\mu \chi_L),$$
$$\mathcal{O}^T_{e\nu\chi} \equiv (\bar{e}\sigma_{\mu\nu} e)(\bar{\nu}_L \sigma^{\mu\nu} \chi_R),$$

- DM is stable, because
  - $m_\chi < 2m_e$
  - Radiative decay to $\nu + \gamma^n$ is small enough

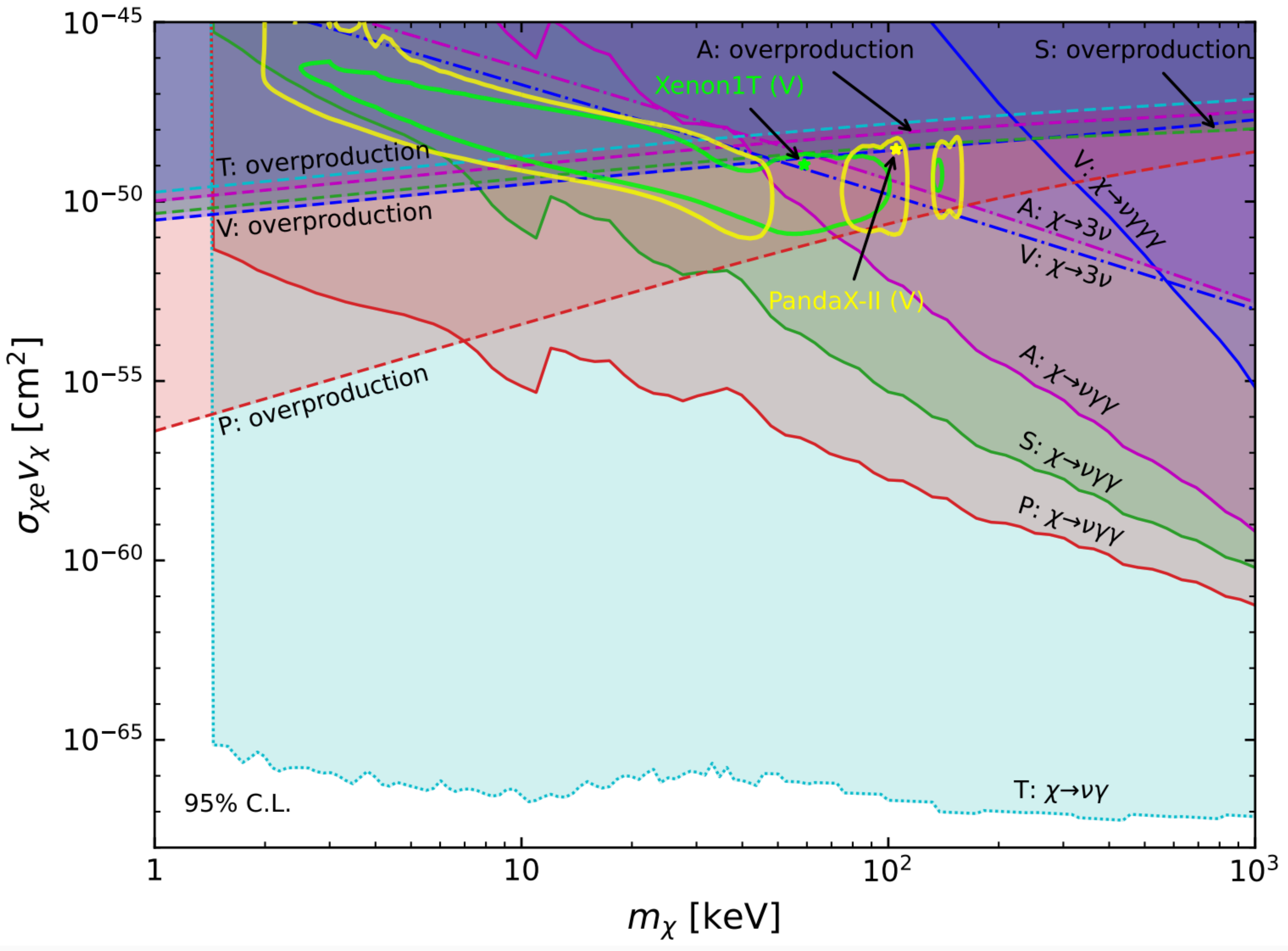
$(\bar{\nu}_L \chi_R)F^2, (\bar{\nu}_L \chi_R)F\tilde{F}$

Operator \ Process	$\chi \to \nu\gamma$	$\chi \to \nu\gamma\gamma$	$\chi \to \nu\gamma\gamma\gamma$	$\chi \to 3\nu$
S: $\mathcal{O}^S_{e\nu\chi}$	×	✓	×	×
P: $\mathcal{O}^P_{e\nu\chi}$	×	✓	×	×
V: $\mathcal{O}^V_{e\nu\chi}$	×	×	✓	✓
A: $\mathcal{O}^A_{e\nu\chi}$	×	✓	×	✓
T: $\mathcal{O}^T_{e\nu\chi}$	✓	×	×!	×!

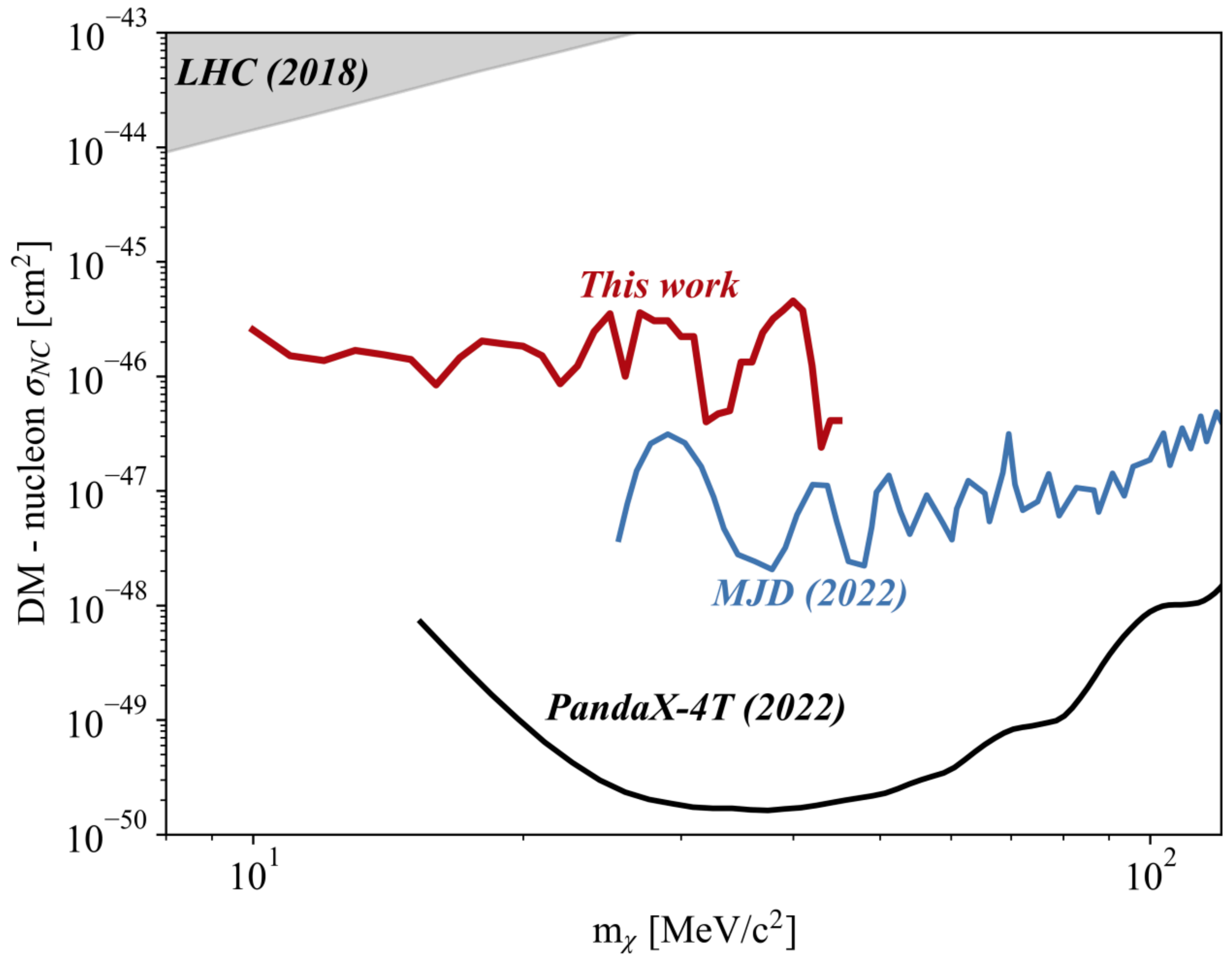
Searching fermionic DM absorption at CEPC

- Light DM can provide enough energy to direct detection via fermionic DM down-scattering: $\chi e \to \nu e$

Shaofeng Ge et al, 2201.11497 (JHEP)



- Actively searched by DM direct detection experiments

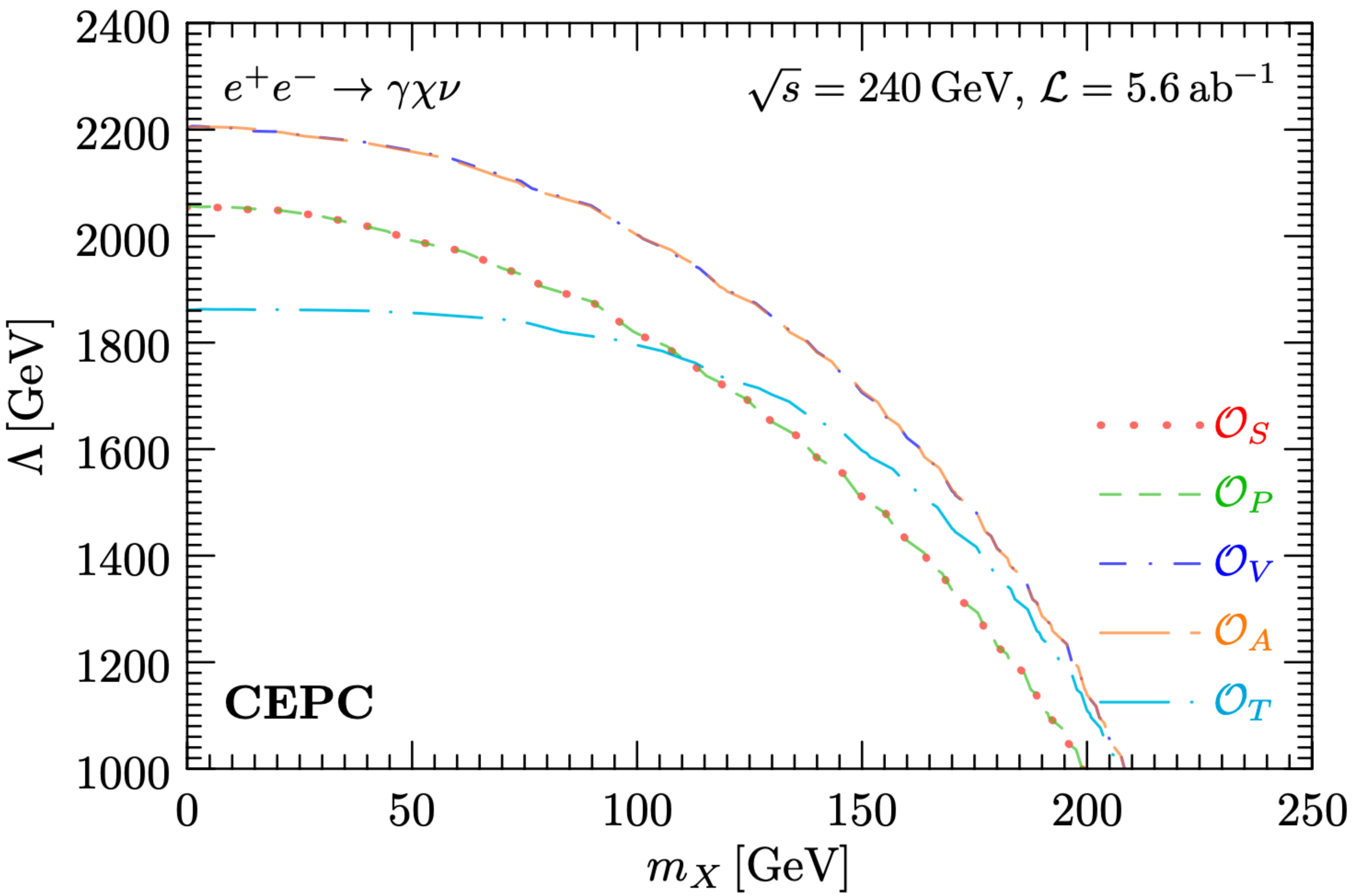


PANDAX 2206.02339 (PRL)
CDEX 2209.00861(PRL)

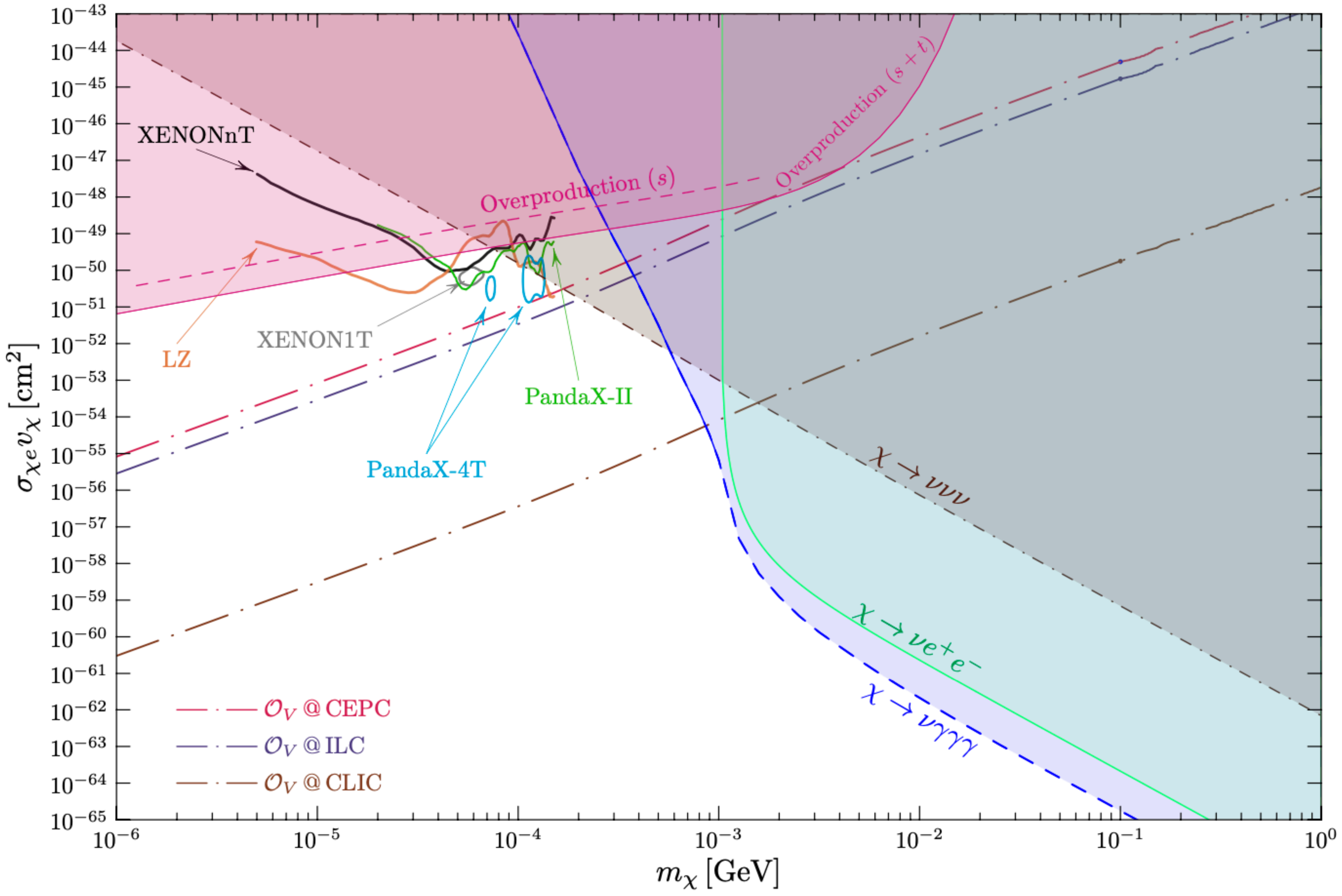
Searching fermionic DM absorption at CEPC

- The future ee collider can also test this scenariom via
  - $e^+e^- \to \gamma\nu\bar{\chi}, e^+e^-\nu\bar{\chi}, e^+e^-\nu\bar{\nu}$, in multi-particle final states

Shaofeng Ge et al, 2306.00657



- Collider complementary between DM direct and indirect experiments



Summary

- Future ee collider (CEPC/FCC-ee etc) provides valuable opportunities to test Beyond the Standard Model physics
    - Interactions with leptons and photons can be generally covered
    - Light particles are covered, even larger than $\sqrt{s}/2$ through 3-body final states
    - Much heavier particle can be tested indirectly through precision measurements
    - Complementarity with other dark matter studies: direct detection, indirect detection
    - Suitable for searching for light dark sector bosons and its complementarity with gravitational wave studies
- CEPC offers a diverse and extensive research program covering various areas of fundamental physics

Thank you!

Backup slides