Common origin of dark matter and leptogenesis in $U(1)_{B-L}$

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Outline

Motivation

Solving simultaneously three sharp BSM questions:

- Baryon asymmetry
- Dark matter
- Neutrino mass

Who can connect them together? $\rightarrow$ sterile neutrinos N
What is the mass scale of connector? $\rightarrow$ TeV (colliders favor)
What symmetry do they follow? $\rightarrow$ $U(1)_{B-L}$
What is the corresponding mechanism?

- Resonant leptogenesis
- Sterile neutrino portal WIMP
- Type-I seesaw

The Model

Extending $\phi = (v_\phi + \tilde{\rho} + i\eta)/\sqrt{2}$, Majorana sterile neutrinos N and DM χ

	q_L	u_R	d_R	L_L	e_R	N	χ	H	ϕ
$SU(2)_L$	2	1	1	2	1	1	1	2	1
$U(1)_Y$	$+\frac{1}{6}$	$+\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{2}$	-1	0	0	$\frac{1}{2}$	0
$U(1)_{B-L}$	$+\frac{1}{3}$	$+\frac{1}{3}$	$+\frac{1}{3}$	-1	-1	-1	-1	0	2
Z_2	$+$	$+$	$+$	$+$	$+$	$+$	$-$	$+$	$+$

Table: Relevant particle contents and corresponding charge assignments.

The relevant Yukawa interaction:

$$\mathcal{L} \supset -\frac{\lambda_N}{\sqrt{2}}\phi N^T C N - \frac{\lambda_\chi}{\sqrt{2}}\phi \chi^T C \chi - y_\nu \bar{L}_L H P_R N + h.c.. \quad (1)$$

The free parameters are $\{m_\rho, m_{\eta,Z'}, m_N, m_\chi, \tilde{m}, v_\phi, \theta, \varepsilon_{\rm CP}\}$

Fixing $\tilde{m} = 5 \times 10^{-11}$ GeV.

The Model

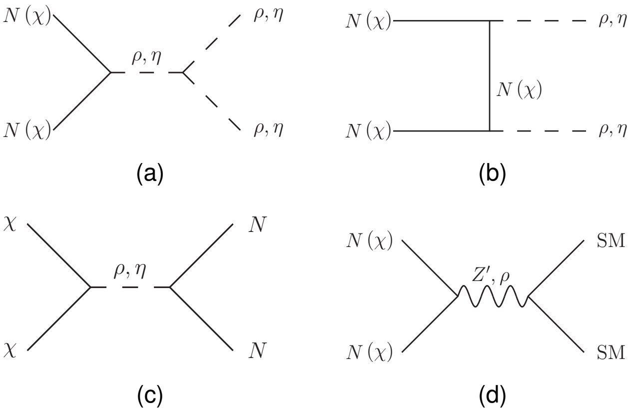


Figure: The dominant Feynman diagrams for N and χ annihilation. (a)-(c) are universal for the global and the local scenarios. In (d), Z' mediated$\rightarrow$ local, ρ mediated$\rightarrow$ global

The global $U(1)_{B-L}$ scenario

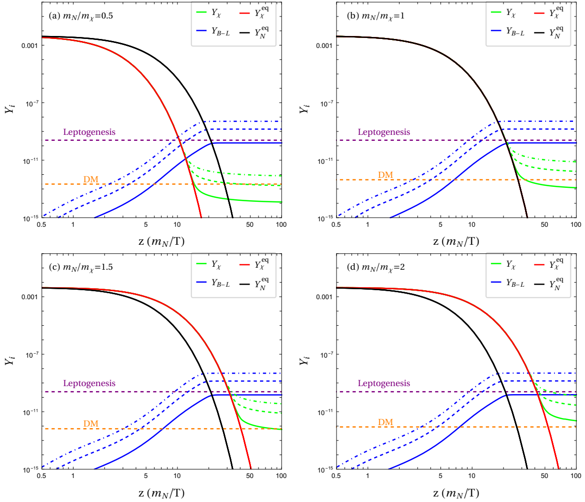
The relevant Boltzmann equations in global scenario:

$$\begin{aligned}
\frac{dY_N}{dz} &= -\frac{z}{sH(m_N)}\left(\frac{Y_N}{Y_N^{\rm eq}}-1\right)\left(\gamma_{N\to HL}+2\gamma_{NL\to qt}+4\gamma_{Nt\to qL}\right) \\
&- \frac{z}{sH(m_N)}\left(\left(\frac{Y_N}{Y_N^{\rm eq}}\right)^2-1\right)\left(2\gamma_{NN\to\rho\rho,\eta\eta}+2\gamma_{NN\to\rho\eta,h\eta}+2\gamma_{NN\to VV}\right) \\
&+ \frac{z}{sH(m_N)}\left(\left(\frac{Y_\chi}{Y_\chi^{\rm eq}}\right)^2-\left(\frac{Y_N}{Y_N^{\rm eq}}\right)^2\right)2\gamma_{\chi\chi\to NN},
\end{aligned} \tag{2}$$

$$\begin{aligned}
\frac{dY_\chi}{dz} &= -\frac{z}{sH(m_N)}\left(\left(\frac{Y_\chi}{Y_\chi^{\rm eq}}\right)^2-1\right)\left(2\gamma_{\chi\chi\to\rho\rho,\eta\eta}+2\gamma_{\chi\chi\to\rho\eta,h\eta}+2\gamma_{\chi\chi\to VV}\right) \\
&- \frac{z}{sH(m_N)}\left(\left(\frac{Y_\chi}{Y_\chi^{\rm eq}}\right)^2-\left(\frac{Y_N}{Y_N^{\rm eq}}\right)^2\right)2\gamma_{\chi\chi\to NN},
\end{aligned} \tag{3}$$

$$\begin{aligned}
\frac{dY_{B-L}}{dz} &= \frac{z}{sH(m_N)}\left(\varepsilon_{\rm CP}\left(\frac{Y_N}{Y_N^{\rm eq}}-1\right)-\frac{Y_{B-L}}{2Y_L^{\rm eq}}\right)\gamma_{N\to HL} \\
&- \frac{z}{sH(m_N)}\frac{Y_{B-L}}{Y_L^{\rm eq}}\left(\frac{Y_N}{Y_N^{\rm eq}}\gamma_{NL\to qt}+2\gamma_{Nt\to qL}\right),
\end{aligned} \tag{4}$$

The global $U(1)_{B-L}$ scenario



Fixing
$m_N = 1000$, $m_\rho = 500$
$\varepsilon_{\rm CP} = 0.1, \theta = 0.05$

Solid$\rightarrow v_\phi = 1000$
Dashed$\rightarrow v_\phi = 2000$
Dot-dashed$\rightarrow v_\phi = 3000$

$v_\phi \simeq 1000$

$m_N/m_\chi \simeq 1.5$

Figure: The evolutions of various abundances Y_i.

The global $U(1)_{B-L}$ scenario

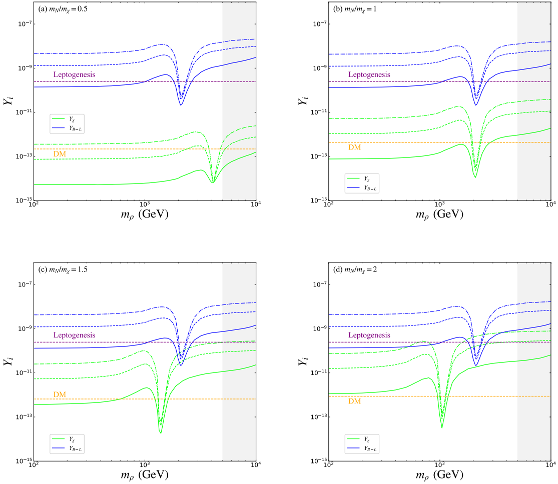


Figure: Y_i as a function of m_ρ at present.

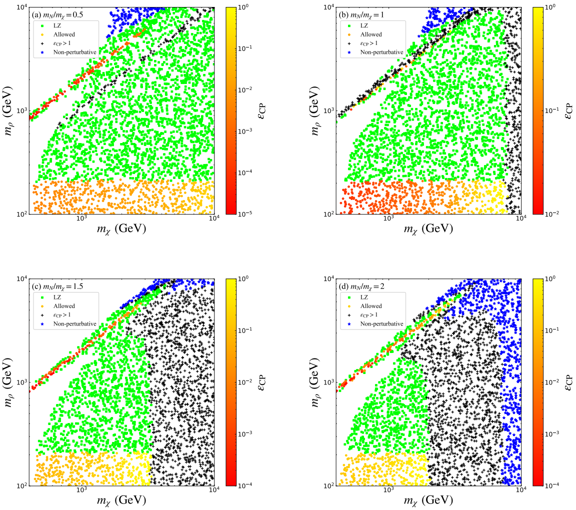
Fixing
$m_N = 1000$
$\varepsilon_{\rm CP} = 0.1, \theta = 0.05$

Solid$\rightarrow v_\phi = 1000$
Dashed$\rightarrow v_\phi = 2000$
Dot-dashed$\rightarrow v_\phi = 3000$

$m_\rho \simeq 2 m_{N,\chi}$
$m_N / m_\chi \simeq 1$

★ Varying $\varepsilon_{\rm CP}$

The global $U(1)_{B-L}$ scenario



Perturbation limits:

$\lambda_{N,\chi} < \sqrt{4\pi}$

$\lambda_\phi < 4\pi$

Exceeding ε_{CP}:

$\varepsilon_{CP} > 1$

Resonance (red)

Non resonance (yellow):

$m_\rho \lesssim 200$ GeV

Figure: Perturbation constraints and exceeding ε_{CP}.

The global $U(1)_{B-L}$ scenario

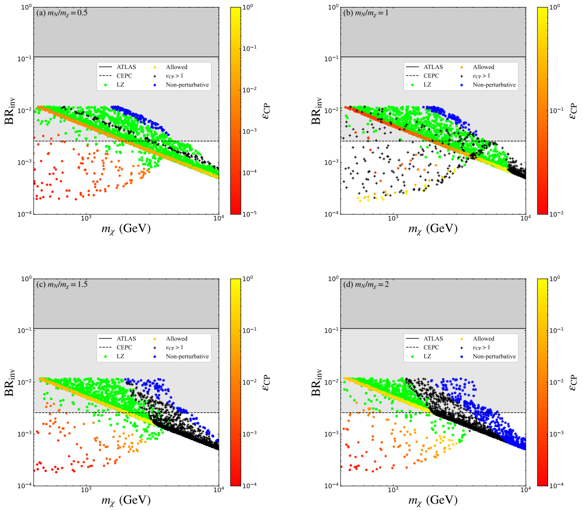


Figure: Branching ratio of Higgs invisible decay.

$$\Gamma_{h\to\eta\eta} = \frac{\sin^2\theta\, m_h^3}{32\pi v_\phi^2}. \quad (5)$$

θ=0.05 throughout

ATLAS limit:
$BR_{\rm inv} < 0.11$

CEPC limit:
$BR_{\rm inv} < 2.6 \times 10^{-3}$

CEPC: Non resonance

The global $U(1)_{B-L}$ scenario

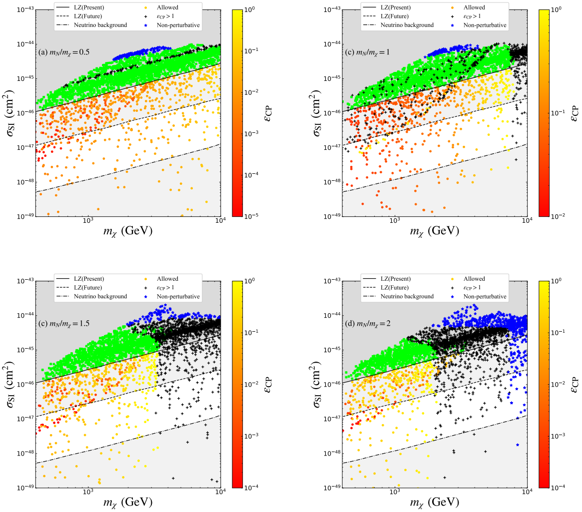


Figure: Spin-independent scattering cross section.

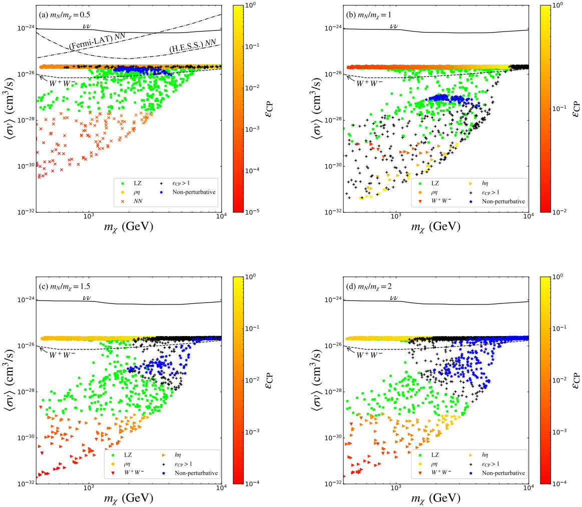
$$\sigma_{\rm SI} = \frac{C^2(\sin 2\theta)^2 m_n^4 m_\chi^4}{4\pi v_H^2 v_\phi^2 (m_n + m_\chi)^2} \times \left(\frac{1}{m_h^2} - \frac{1}{m_\rho^2}\right)^2, \quad (6)$$

LZ (present) limit:
$\sigma_{\rm SI} \gtrsim 10^{-46}{\rm cm}^2$

LZ (future) limit::
$\sigma_{\rm SI} \gtrsim 10^{-47}{\rm cm}^2$

LZ (future): Most allowed samples.

The global $U(1)_{B-L}$ scenario



Resonance: p wave
$\langle\sigma v\rangle \lesssim 10^{-28}\ \mathrm{cm}^3/\mathrm{s}$

Non resonance: s wave
$\langle\sigma v\rangle \simeq 2\times10^{-26}\ \mathrm{cm}^3/\mathrm{s}$

Non resonance: $\langle\sigma v\rangle$ of $\chi\chi \to \rho\eta \to W^+W^-\eta$ is around $10^{-27}\mathrm{cm}^3/\mathrm{s}$.

Figure: Constraints from the indirect detections.

The local $U(1)_{B-L}$ scenario

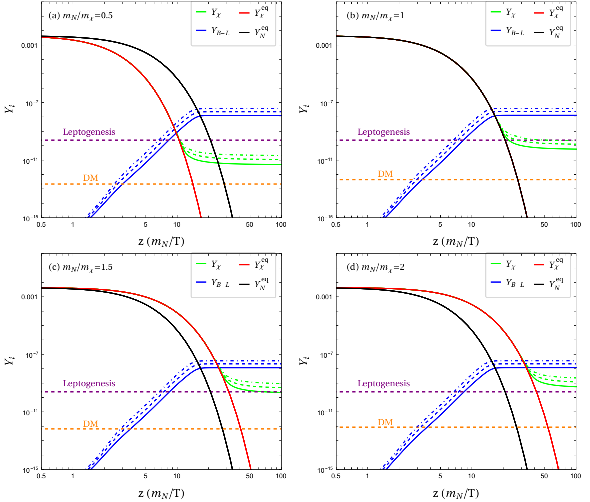
The relevant Boltzmann equations in local scenario:

$$\begin{aligned}
\frac{dY_N}{dz} &= -\frac{z}{sH(m_N)}\left(\frac{Y_N}{Y_N^{\rm eq}}-1\right)(\gamma_{N\to HL}+2\gamma_{NL\to qt}+4\gamma_{Nt\to qL}) \\
&- \frac{z}{sH(m_N)}\left(\left(\frac{Y_N}{Y_N^{\rm eq}}\right)^2-1\right)(2\gamma_{NN\to\rho\rho,Z'Z'}+2\gamma_{NN\to\rho Z',hZ'}+2\gamma_{NN\to{\rm SMSM}}) \\
&+ \frac{z}{sH(m_N)}\left(\left(\frac{Y_\chi}{Y_\chi^{\rm eq}}\right)^2-\left(\frac{Y_N}{Y_N^{\rm eq}}\right)^2\right)2\gamma_{\chi\chi\to NN}, \qquad (8)
\end{aligned}$$

$$\begin{aligned}
\frac{dY_\chi}{dz} &= -\frac{z}{sH(m_N)}\left(\left(\frac{Y_\chi}{Y_\chi^{\rm eq}}\right)^2-1\right)(2\gamma_{\chi\chi\to\rho\rho,Z'Z'}+2\gamma_{\chi\chi\to\rho Z',hZ'}+2\gamma_{\chi\chi\to{\rm SMSM}}) \\
&- \frac{z}{sH(m_N)}\left(\left(\frac{Y_\chi}{Y_\chi^{\rm eq}}\right)^2-\left(\frac{Y_N}{Y_N^{\rm eq}}\right)^2\right)2\gamma_{\chi\chi\to NN}, \qquad (9)
\end{aligned}$$

$$\begin{aligned}
\frac{dY_{B-L}}{dz} &= \frac{z}{sH(m_N)}\left(\varepsilon_{\rm CP}\left(\frac{Y_N}{Y_N^{\rm eq}}-1\right)-\frac{Y_{B-L}}{2Y_L^{\rm eq}}\right)\gamma_{N\to HL} \\
&- \frac{z}{sH(m_N)}\frac{Y_{B-L}}{Y_L^{\rm eq}}\left(\frac{Y_N}{Y_N^{\rm eq}}\gamma_{NL\to qt}+2\gamma_{Nt\to qL}\right), \qquad (10)
\end{aligned}$$

The local $U(1)_{B-L}$ scenario



Fixing
$m_N = 1000$, $m_\rho = 500$
$m_{Z'} = 7000$ $\varepsilon_{\rm CP} = 0.1$

Solid$\rightarrow v_\phi = 4000$
Dashed$\rightarrow v_\phi = 5000$
Dot-dashed$\rightarrow v_\phi = 6000$

Figure: The evolutions of various abundances Y_i.

The local $U(1)_{B-L}$ scenario

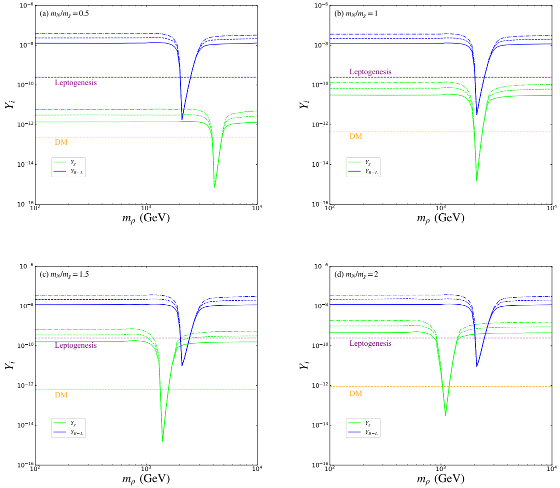


Figure: Y_i as a function of m_ρ at present.

Fixing
$m_N = 1000$, $m_\rho = 500$
$m_{Z'} = 7000$ $\varepsilon_{\rm CP} = 0.1$

Solid$\rightarrow v_\phi = 4000$
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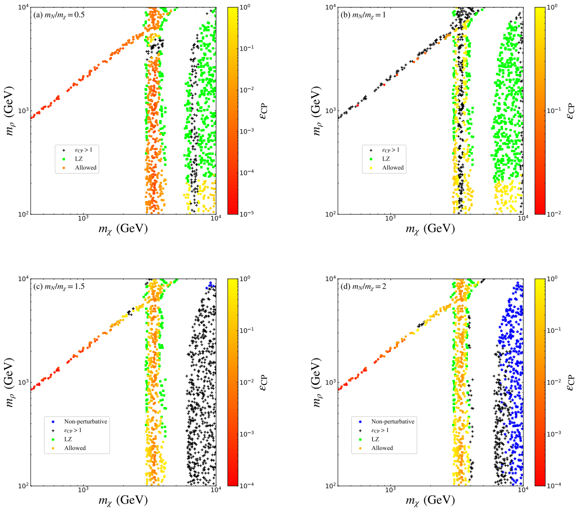
$m_\rho \simeq 2m_{N,\chi}$
$m_N/m_\chi \simeq 1$

★ Varying $\varepsilon_{\rm CP}$

The local $U(1)_{B-L}$ scenario



Perturbation limits:
$\lambda_{N,\chi} < \sqrt{4\pi}$
$\lambda_\phi < 2\pi$

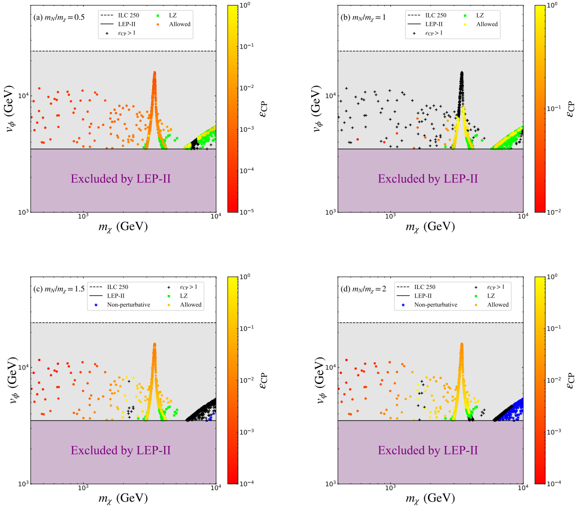
Exceeding $\varepsilon_{\rm CP}$:
$\varepsilon_{\rm CP} > 1$

Resonance (red)

Non resonance (yellow):
$m_\rho \lesssim 200$ GeV

Figure: Perturbation constraints and exceeding $\varepsilon_{\rm CP}$.

The local $U(1)_{B-L}$ scenario



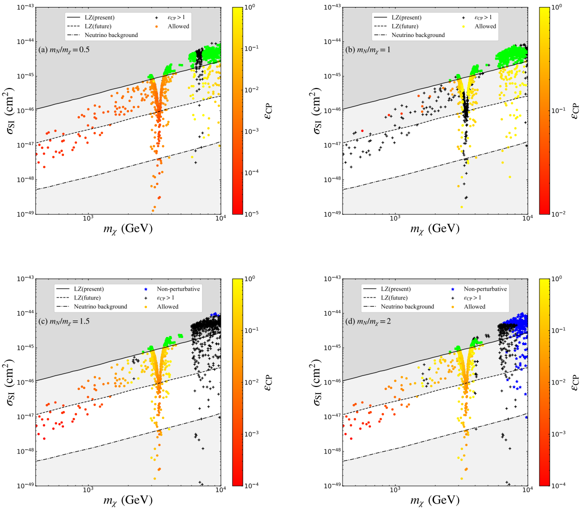
LEP-II limit: $v_\phi \lesssim 3500$ with $m_{Z'} = 7000$

ILC limit: $v_\phi \lesssim 22000$ with $m_{Z'} = 7000$

ILC (future): All allowed samples.

Figure: The current LEP-II and prospective ILC limits

The local $U(1)_{B-L}$ scenario



Dominated: Eq.(6)
ρ mediated process

LZ (future): Some allowed samples.

Figure: Constraints from the direct detection experiment.

The local $U(1)_{B-L}$ scenario

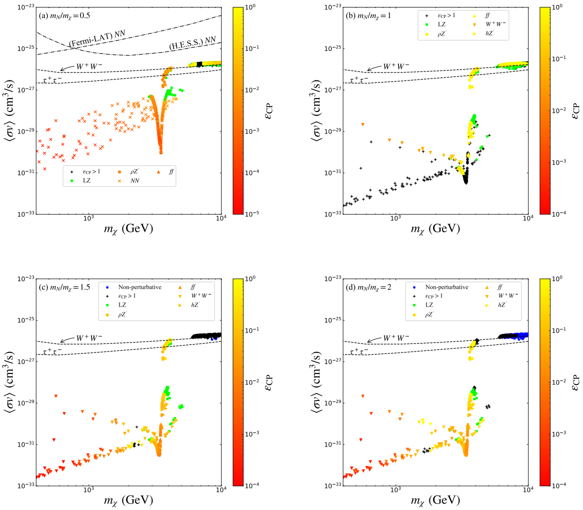


Figure: Constraints from the indirect.

Resonance: p wave
$\langle\sigma v\rangle \lesssim 10^{-27}\ \mathrm{cm}^3/\mathrm{s}$

Non resonance: s wave
$\langle\sigma v\rangle \simeq 2 \times 10^{-26}\ \mathrm{cm}^3/\mathrm{s}$

Promising channel:

$\chi\chi \to \rho Z' \to W^+W^-\bar{f}f$.

(a) and (b) with $m_\chi \gtrsim$ 5800 GeV

Conclusion

- Global scenario
  Relic density: resonance and non resonance
  Higgs invisible decay:future CEPC-non resonance
  Direct detection:current and future LZ
  Indirect detection: unpromising
- Local scenario
  Relic density: resonance and non resonance
  Higgs invisible decay:unpromising
  Direct detection:current and future LZ
  Indirect detection: promising in non resonance in (a) and (b)