Feeble Sterile Neutrino Portal Dark Matter with Z_2 or Z_3 Symmetry

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[arXiv:2212.10043, 2308.12588]
第十七届TeV工作组学术研讨会

Outline

- **The Model**
- **Relic Density**

Scenario 1: $m_N > m_\phi + m_\chi$ with $m_\phi < 2m_\chi$
Scenario 2: $m_N > m_\phi + m_\chi$ with $m_\phi > 2m_\chi$
Scenario 3: $m_N < m_\phi + m_\chi$ with $m_\phi < 2m_\chi$
Scenario 4: $m_N < m_\phi + m_\chi$ with $m_\phi > 2m_\chi$

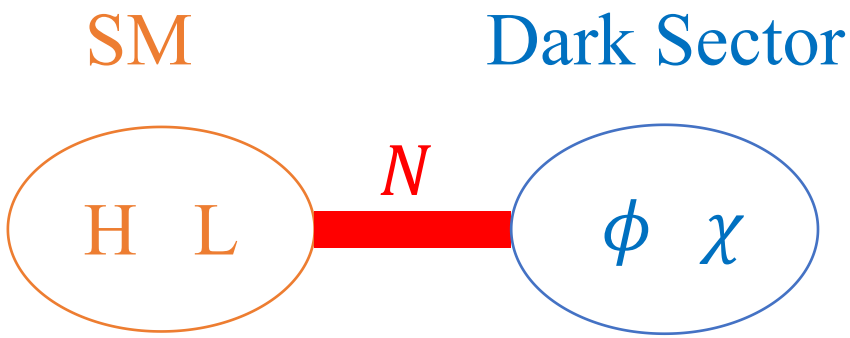
- **Phenomenology**

Detection of N
Cosmological constraints of ϕ
Energetic neutrinos Flux
Effective number of relativistic neutrino species

- **Conclusion**

The Model

- Sterile Neutrino Portal Dark Matter



	L	N	χ	H	ϕ
$SU(2)_L$	2	1	1	2	1
$U(1)_Y$	$-\frac{1}{2}$	0	0	$\frac{1}{2}$	0
$Z_2(Z_3)$	$+(1)$	$+(1)$	$-(\omega)$	$+(1)$	$-(\omega)$

$(\omega = e^{i2\pi/3})$

Transformation

$$\phi \xrightarrow{Z_2} -\phi, \quad \chi \xrightarrow{Z_2} -\chi$$

$$\phi \xrightarrow{Z_3} \omega\phi, \quad \chi \xrightarrow{Z_3} \omega\phi$$

The Model

- Lagrangian

Potential

$$V = -\mu_H^2 H^\dagger H + \mu_\phi^2 \phi^\dagger \phi + \lambda_H (H^\dagger H)^2 + \lambda_\phi (\phi^\dagger \phi)^2 + \lambda_{H\phi} (H^\dagger H)(\phi^\dagger \phi) + \left(\frac{\mu}{2} \phi^3 + h.c. \right)$$

Yukawa

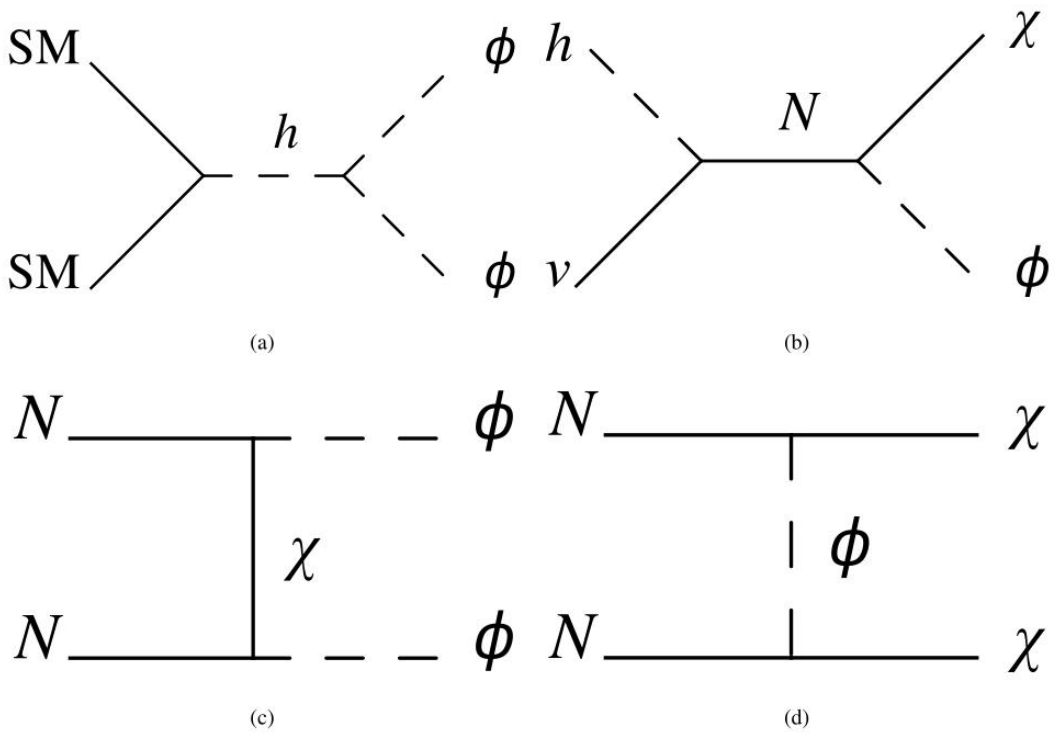
$$-\mathcal{L}_Y \supset \left(y_\nu \overline{L} \widetilde{H} N + y_N \phi \bar{\chi} N + \frac{1}{2} m_N \overline{N^c} N + \text{h.c.} \right) + y_\chi \phi \bar{\chi^c} \chi + m_\chi \bar{\chi} \chi$$

(Z_3 - Additional couplings $\frac{\mu}{2}\phi^3$ and $y_\chi \phi \bar{\chi^c} \chi$)

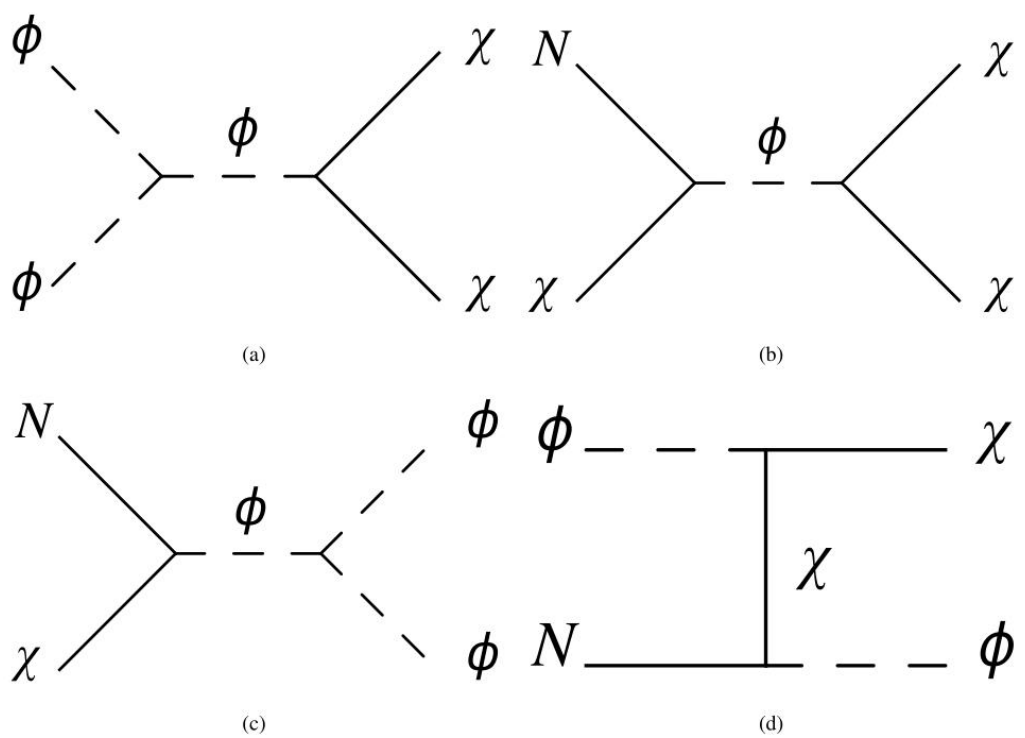
Relic Density

- Feynman diagrams (partial dominant)

Generation



Conversion



Relic Density

- Scenario 1 ($m_N > m_\phi + m_\chi$ with $m_\phi < 2m_\chi$)

Scenario 1	m_χ	m_ϕ	m_N	y_N	y_χ	y_ν	$\lambda_{H\phi}$	μ
a	10	15	50	10^{-13}	10^{-12}	4×10^{-5}	6.7×10^{-12}	15
b	10	15	50	10^{-13}	2×10^{-3}	2×10^{-6}	6.7×10^{-12}	15
c	10	15	50	3.7×10^{-12}	10^{-12}	3×10^{-6}	10^{-14}	15
d	10	15	50	3.7×10^{-12}	2×10^{-3}	10^{-6}	10^{-14}	15

- Scenario 1

Generation

(a) and (b)

$\mathrm{SMSM} \to \phi\phi$

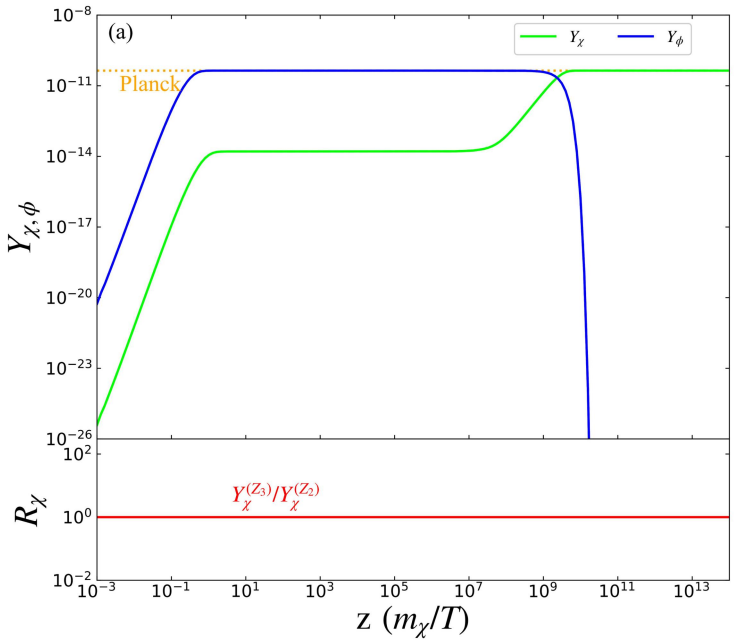
(c) and (d)

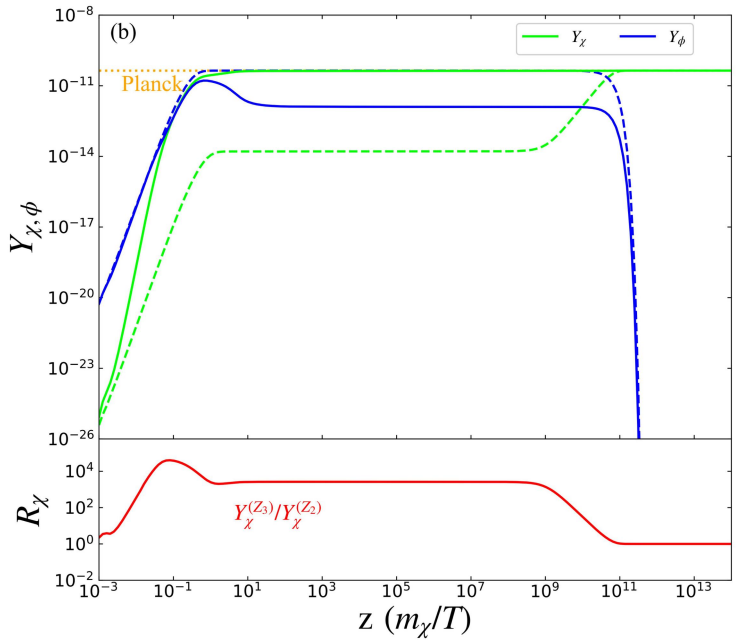
$N \to \phi\chi$

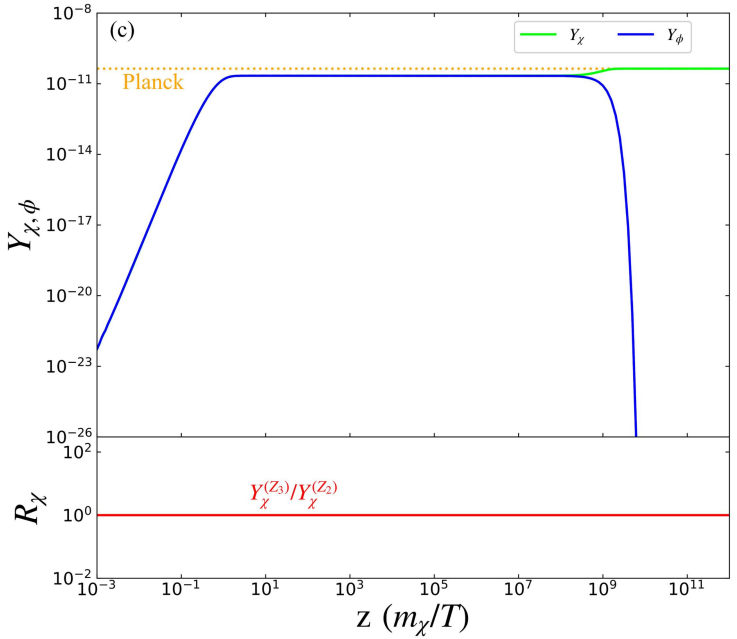
Conversion

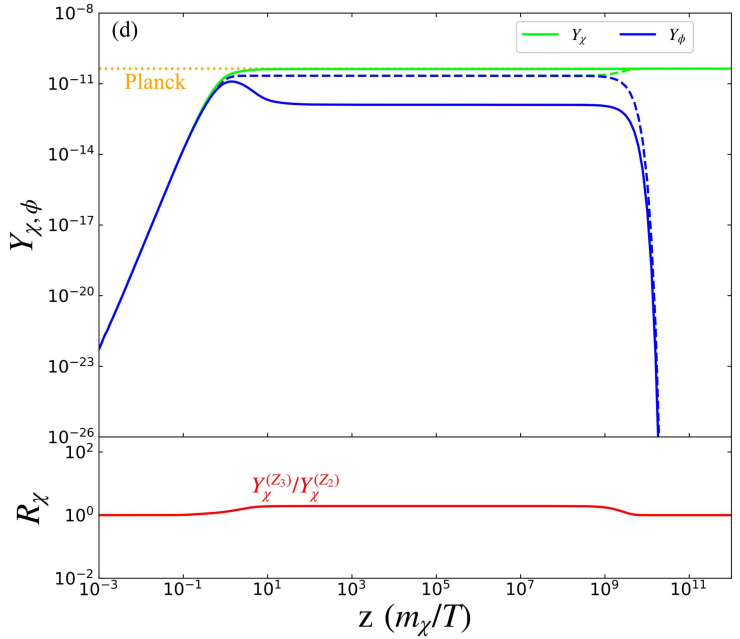
(b) and (d)

$\phi\phi \to \chi\chi$









Relic Density

- Scenario 2 ($m_N > m_\phi + m_\chi$ with $m_\phi > 2m_\chi$)

Scenario 2	m_χ	m_ϕ	m_N	y_N	y_χ	y_ν	$\lambda_{H\phi}$	μ
a	10	25	40	10^{-13}	10^{-12}	7×10^{-7}	4.8×10^{-12}	25
b	10	25	40	10^{-13}	1.2×10^{-4}	5×10^{-6}	3.9×10^{-12}	25
c	10	25	40	3.7×10^{-12}	10^{-12}	10^{-6}	10^{-14}	25
d	10	25	40	3.7×10^{-12}	1.2×10^{-4}	8×10^{-7}	10^{-14}	25

- Scenario 2

Generation

Same as Scenario 1

Conversion

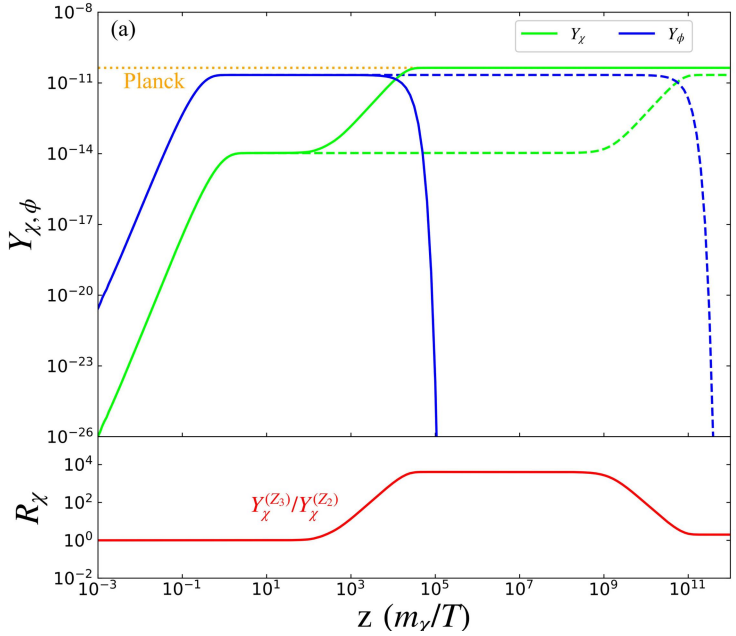
(a) and (b)

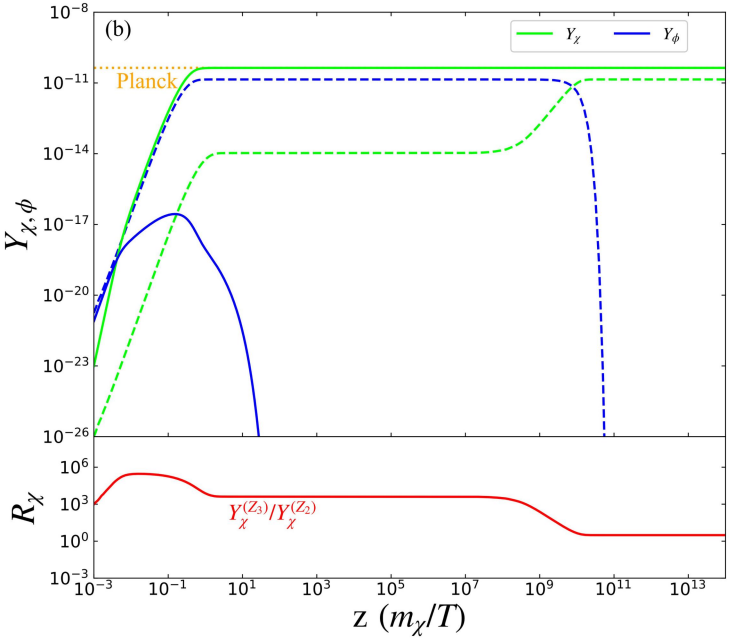
$\phi \to \chi\chi$

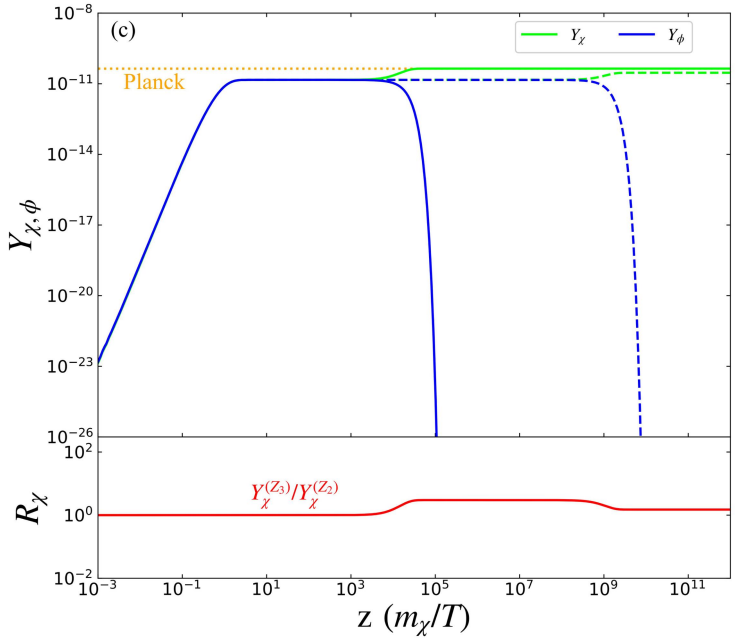
(c) and (d)

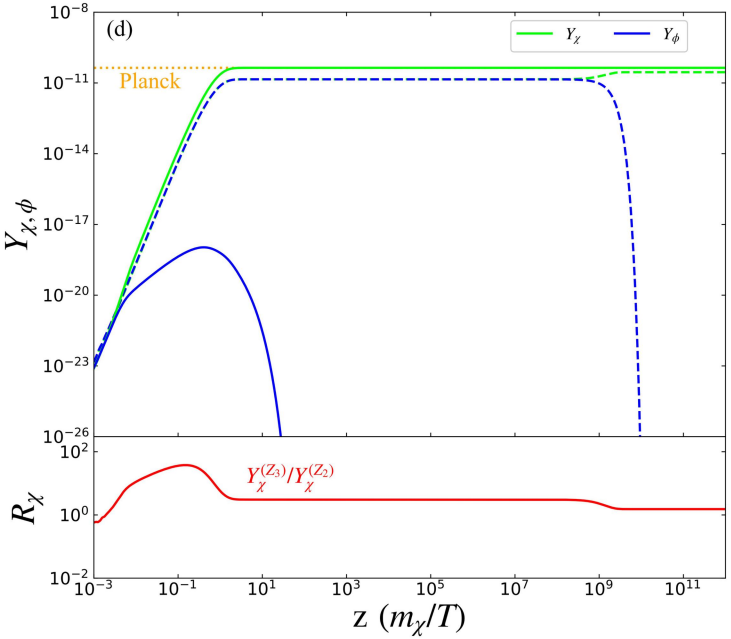
$\phi \to \chi\chi$

$\phi\phi \to \chi\chi$









Relic Density

- Scenario 3 ($m_N < m_\phi + m_\chi$ with $m_\phi < 2m_\chi$)

Scenario 3	m_χ	m_ϕ	m_N	y_N	y_χ	y_ν	$\lambda_{H\phi}$	μ
a	10	14	20	10^{-13}	10^{-12}	3×10^{-5}	6.6×10^{-12}	14
b	10	14	20	10^{-13}	2×10^{-3}	10^{-6}	6.6×10^{-12}	14
c	10	14	20	1.6×10^{-7}	10^{-12}	7×10^{-7}	10^{-14}	14
d	10	14	20	6×10^{-8}	5.7×10^{-1}	8×10^{-7}	10^{-14}	14

- Scenario 3

Generation

(a) and (b)

$$\mathrm{SMSM} \rightarrow \phi\phi$$

(c) and (d)

$$h\nu \rightarrow \chi\phi$$

$$NN \rightarrow \chi\chi, \phi\phi$$

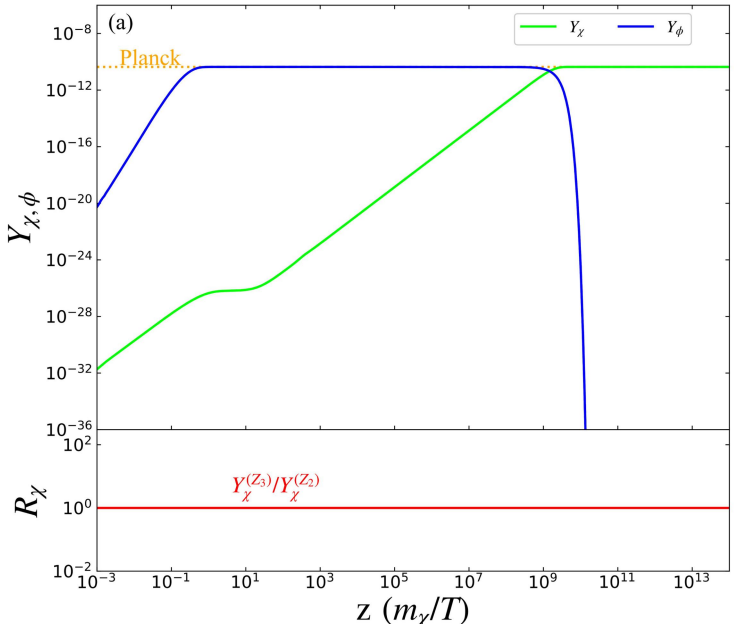
Conversion

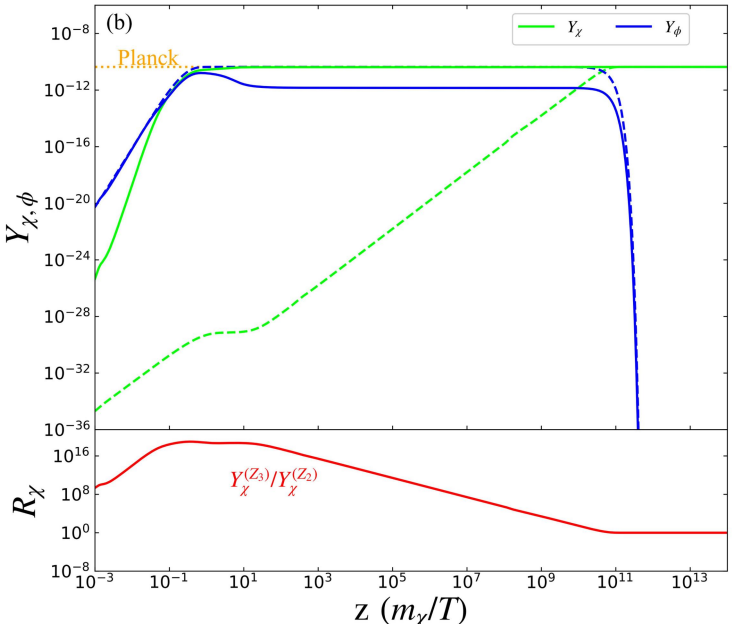
(b) → $\phi\phi \rightarrow \chi\chi$

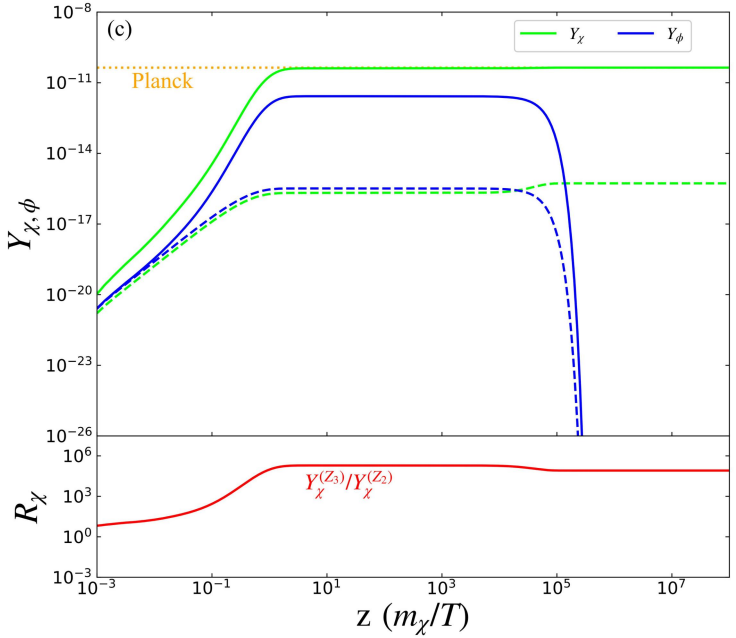
(c) and (d) → **Semi-Production**

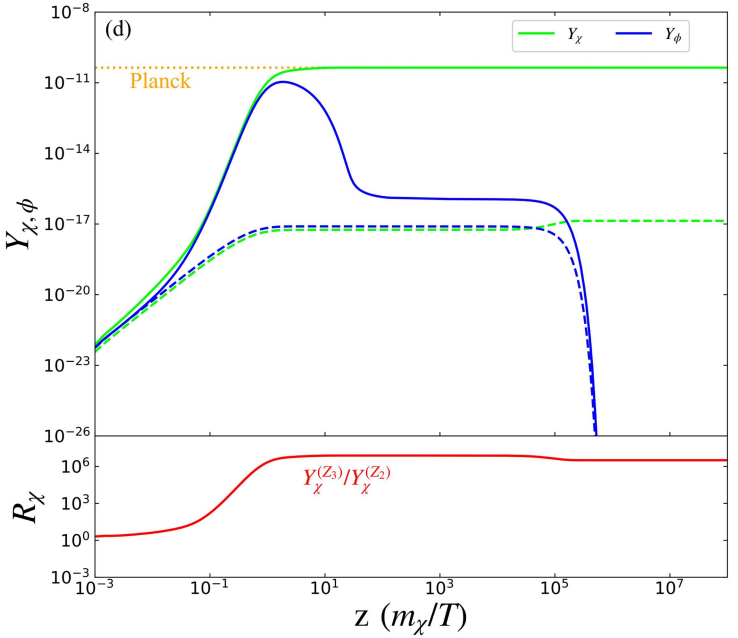
$$N\chi \rightarrow \chi\chi, \phi\phi$$

$$\phi N \rightarrow \chi\phi$$









Relic Density

- Scenario 4 ($m_N < m_\phi + m_\chi$ with $m_\phi > 2m_\chi$)

Scenario 4	m_χ	m_ϕ	m_N	y_N	y_χ	y_ν	$\lambda_{H\phi}$	μ
a	10	25	30	10^{-13}	10^{-12}	7×10^{-7}	4.8×10^{-12}	25
b	10	25	30	10^{-13}	1.2×10^{-4}	5×10^{-6}	3.9×10^{-12}	25
c	10	25	30	1.2×10^{-7}	10^{-12}	8×10^{-7}	10^{-14}	25
d	10	25	30	1.7×10^{-7}	1.2×10^{-4}	10^{-6}	10^{-14}	25

- Scenario 4

Generation

Same as Scenario 3

Conversion

(a) and (b)

$$\phi \to \chi\chi$$

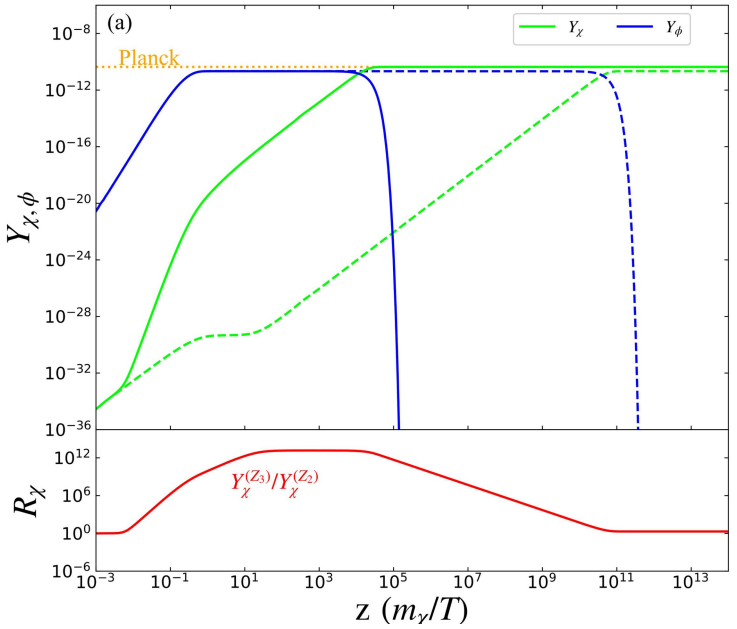
$$\phi\phi \to \chi\chi$$

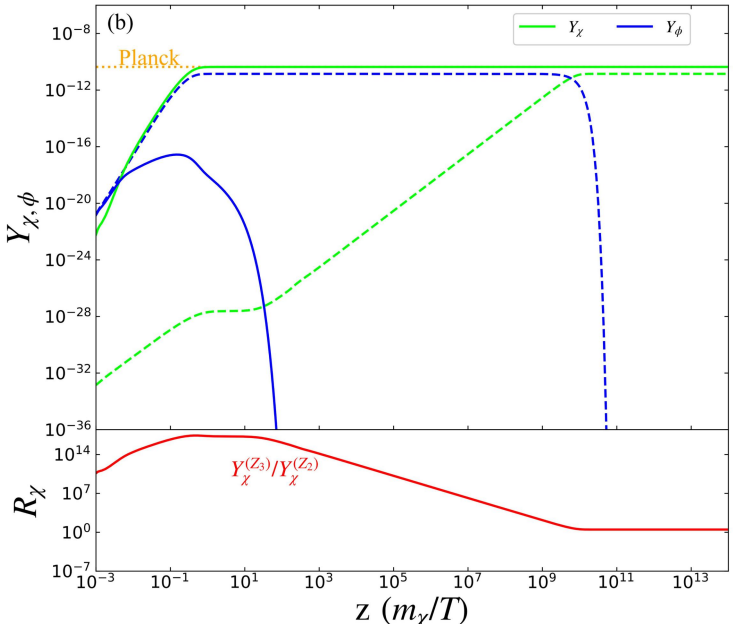
(c) and (d) → **Semi-Production**

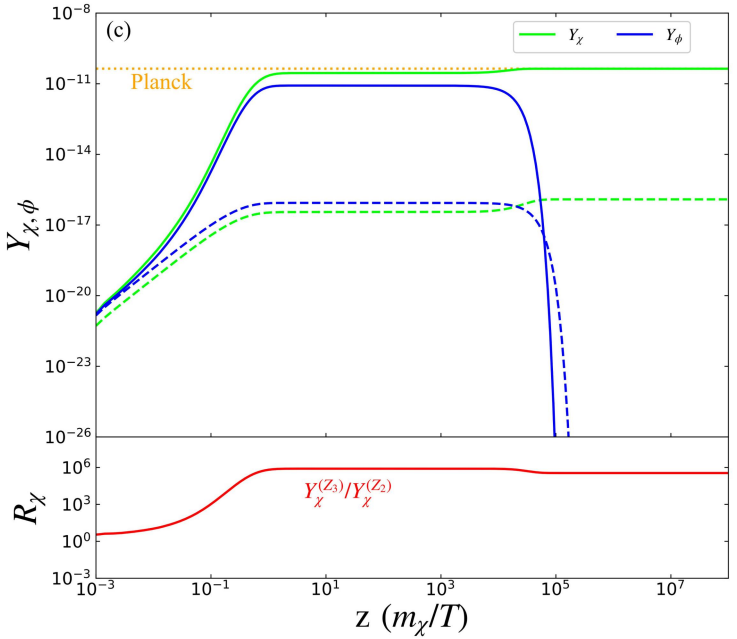
$$N\chi \to \chi\chi, \phi\phi$$

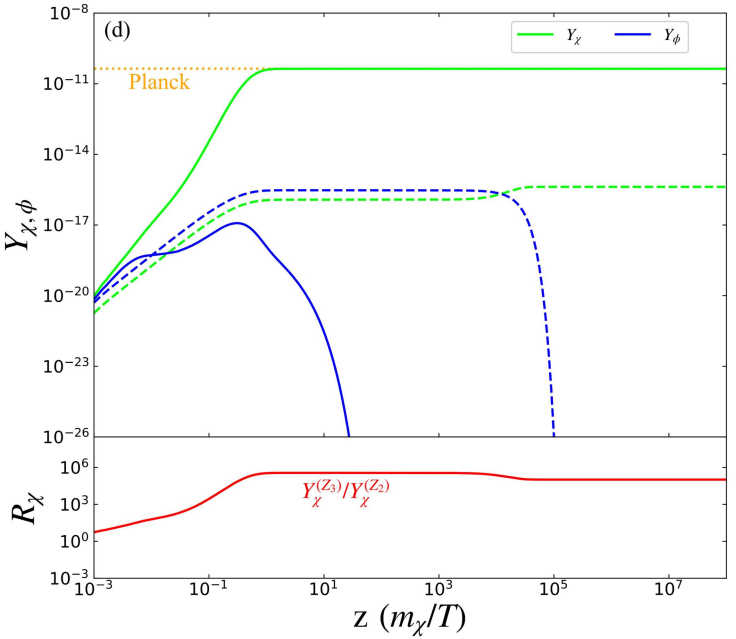
$$\phi N \to \chi\phi$$

$$\phi \to \chi\chi$$









Phenomenology

Detection of N

Cosmological constraints of ϕ

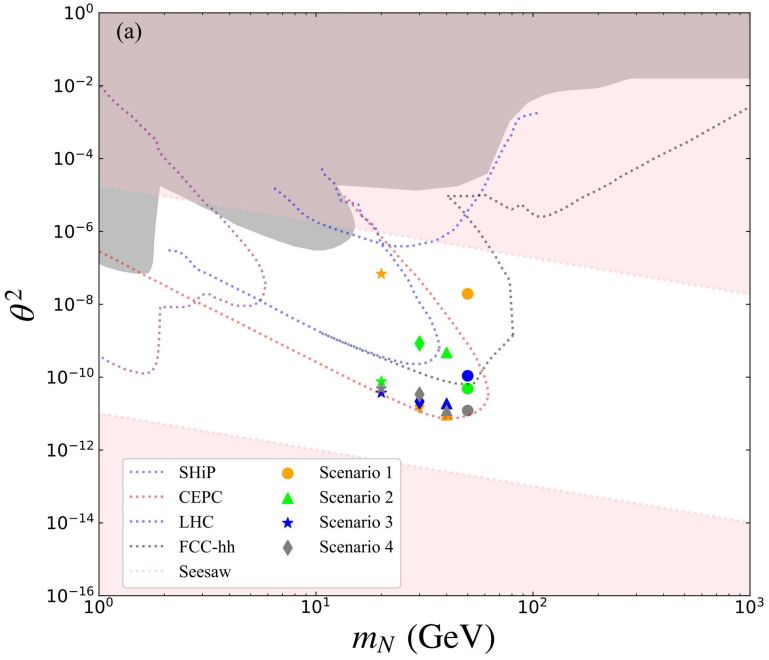
Future

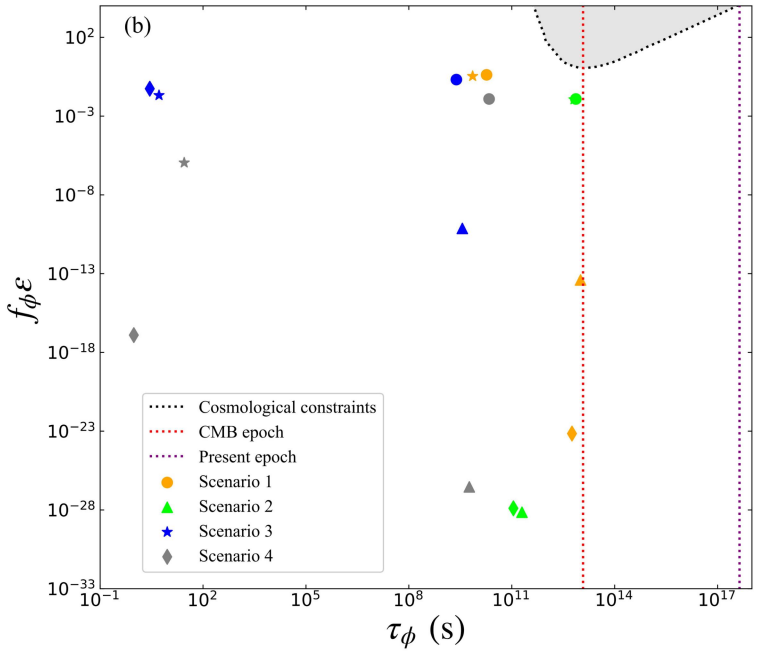
↓

CEPC

LHC

FCC-hh





Allowed

↓

Bound

($m_\phi = 10$ GeV)

Phenomenology

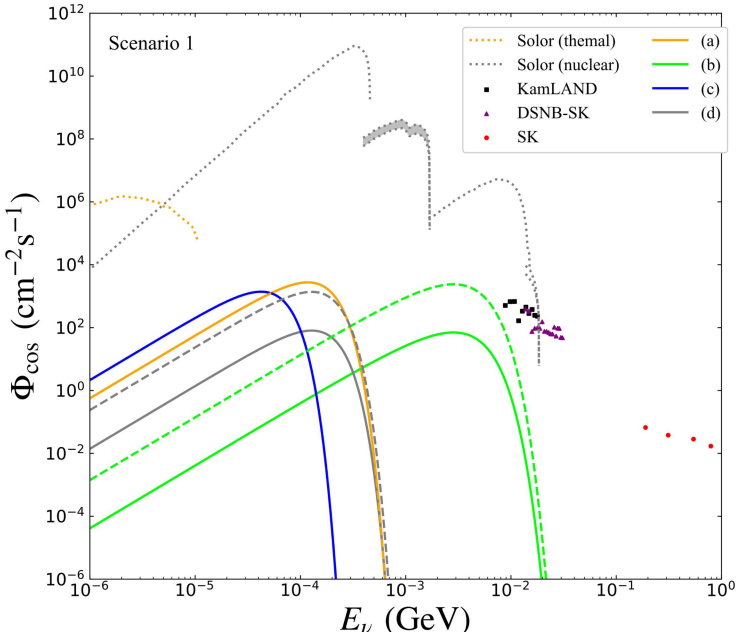
Energetic Neutrinos

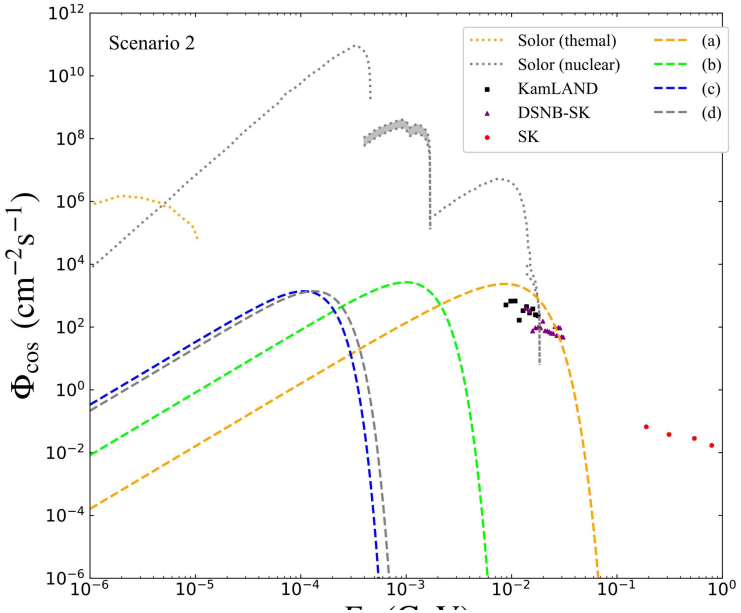
Difference → (Z_2 and Z_3)

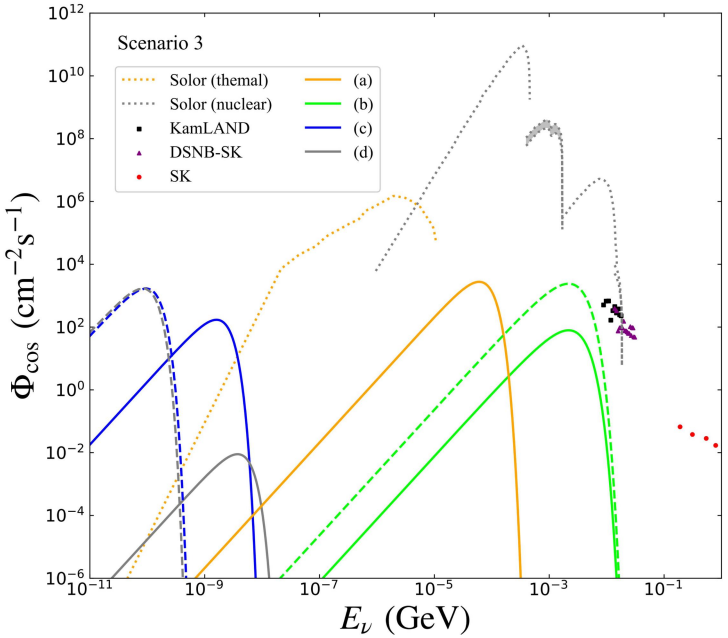
- Scenario 1 (b) and (d)
- Scenario 2 (a)-(d)
- Scenario 3 (b)-(d)
- Scenario 4 (a)-(d)

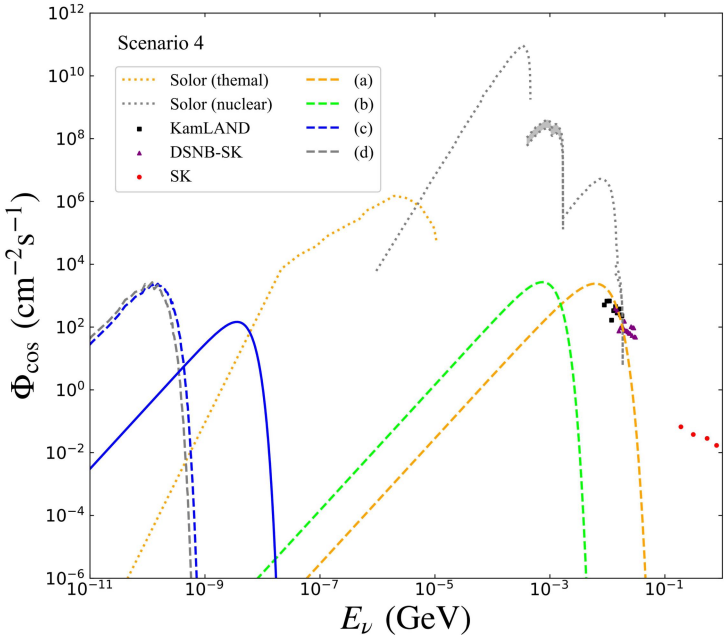
Excluded → (Z_2)

- Scenario 2 (a)
- Scenario 4 (a)









Phenomenology

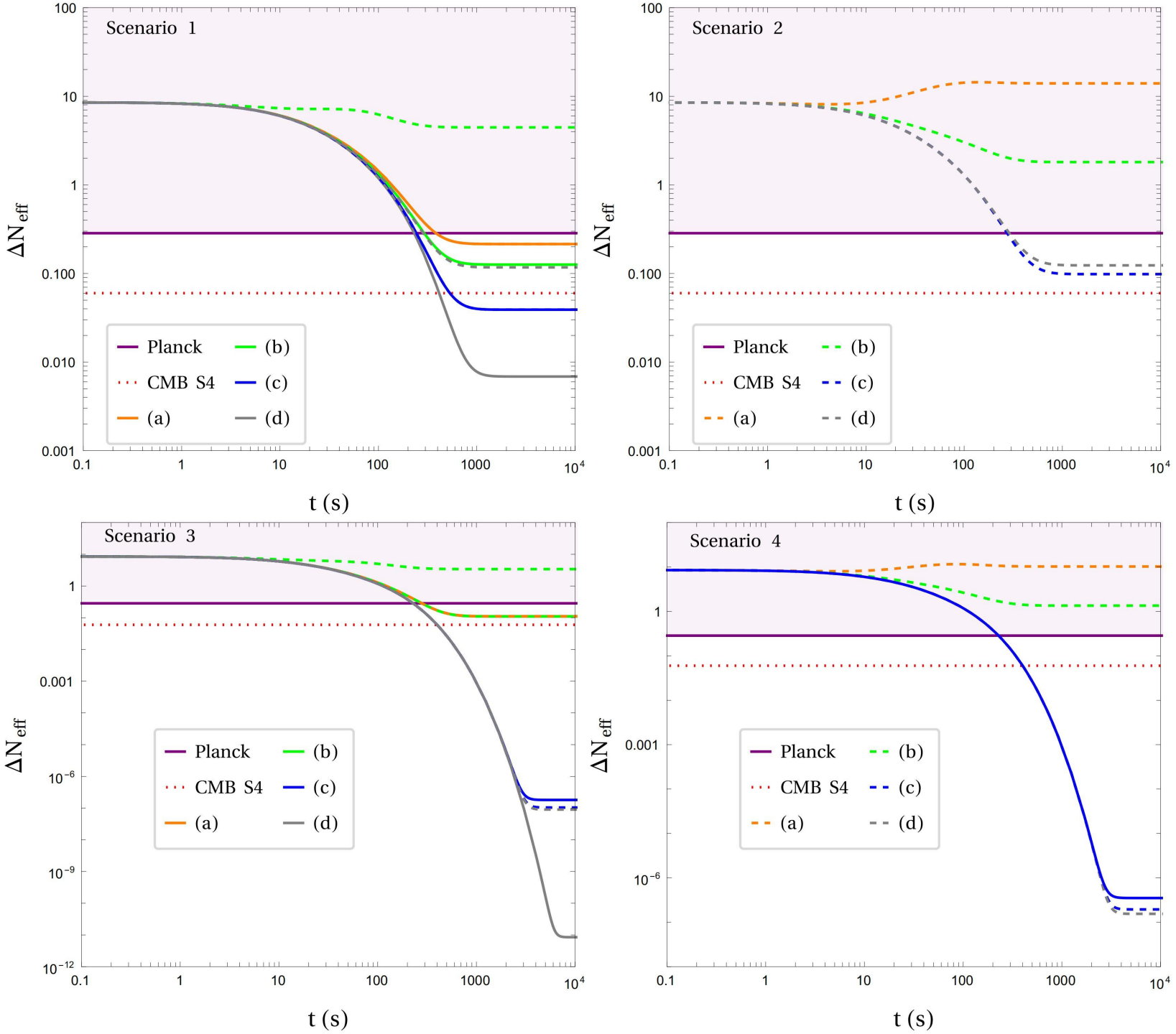
Effective Number

Difference → (Z_2 and Z_3)

- Scenario 1 (b) and (d)
- Scenario 2 (a)-(d)
- Scenario 3 (b)-(d)
- Scenario 4 (a)-(d)

Excluded → (Z_2)

- Scenario 1 (a)
- Scenario 2 (a) and (b)
- Scenario 3 (a)
- Scenario 4 (a) and (b)



Conclusion

Discrepancy

Relic Density Ω_{DM}: Scenario 2-4

Detection of N : No

Cosmological constraints CC: No

Neutrino Fluxes Φ_{cos}: Scenario 2,4

Effective Number N_{eff}: Scenario 1-4

✗ → Excluded by current experiments

Symmetry	Phenomenology	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Z_2	Ω_{DM}	✓✓✓✓	✗✗✗✗	✓✓✗✗	✗✗✗✗
	Collider	✓✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓
	CC	✓✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓
	Φ_{cos}	✓✓✓✓	✗✓✓✓	✓✓✓✓	✗✓✓✓
	N_{eff}	✓✗✓✓	✗✗✓✓	✓✗✓✓	✗✗✓✓
Z_3	Ω_{DM}	✓✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓
	Collider	✓✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓
	CC	✓✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓
	Φ_{cos}	✓✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓
	N_{eff}	✓✓✓✓	✓✓✓✓	✓✓✓✓	✓✓✓✓