LEON MG DE LA VEGA

DARK MATTER AND NEUTRINO PHYSICS WITH CEVNS

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DARK MATTER AND NEUTRINO PHYSICS WITH CEVNS

- CEvNS experiments
- Light Z′ models
- U(1)′ anomalies
- Experimental probes of a light Z′
- Dark Matter
- Z′ portal to dark matter
- CEvNS - Direct Detection Complementarity

COHERENT ELASTIC NEUTRINO NUCLEUS SCATTERING (CEVNS)

- CEvNS - Neutral current process
- Coherent process - Q R <<1
- $E_\nu \leq \sim 50 MeV$ for medium sized nuclei
- SM Z-mediated cs dominated by neutrons:
- $\sigma \propto Q_W^2 \propto (N - (1 - 4\sin^2\theta_W)Z)^2 \sim N^2$

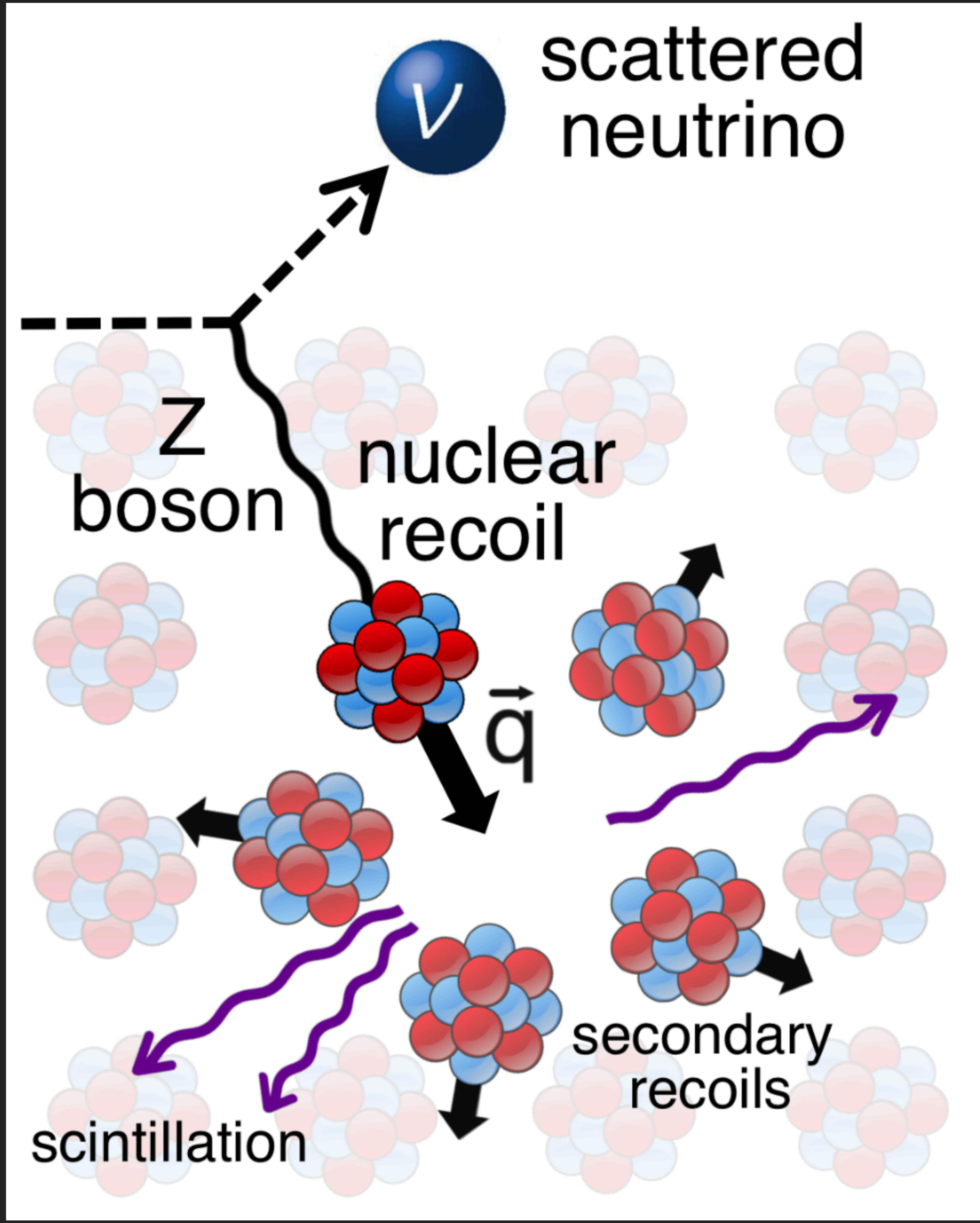
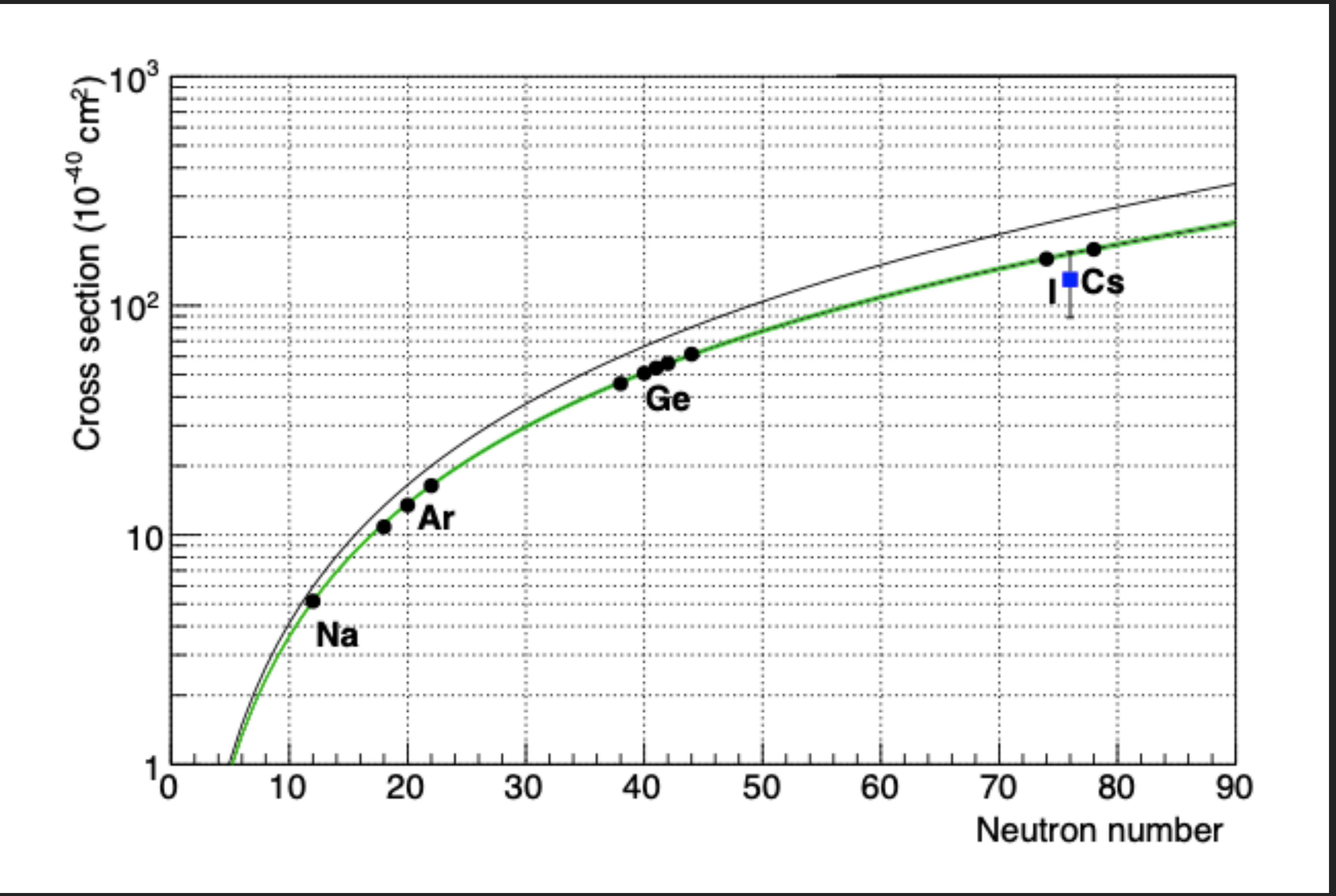


Image: COHERENT collab.

COHERENT ELASTIC NEUTRINO NUCLEUS SCATTERING (CEVNS)



N^2 dependence of CEvNS cross section, for stopped-pion neutrinos. Scholberg, Kate , COHERENT, *PoS* NuFact2017 (2018) 020.

- Nuclear recoils are hard to measure:
  - $T_N^{max} \sim 2E_\nu^2/M_N$
- E.g. : $E^\nu = 30$ MeV -> $T_\nu^{max} \sim 25$ keV in Germanium (Z=32, N=42,40,38)

COHERENT ELASTIC NEUTRINO NUCLEUS SCATTERING (CEVNS)

- In the SM the process is mediated by W,Z boson exchange:

$$\frac{d\sigma}{dT}_{coh} = \frac{G_F^2 M}{2\pi}\left[(G_V+G_A)^2+(G_V-G_A)^2\left(1-\frac{T}{E_\nu}\right)^2-(G_V^2-G_A^2)\frac{MT}{E_\nu^2}\right]$$

$$G_V = (g_V^p Z + g_V^n N)F_{\rm nucl}^V(Q^2)$$

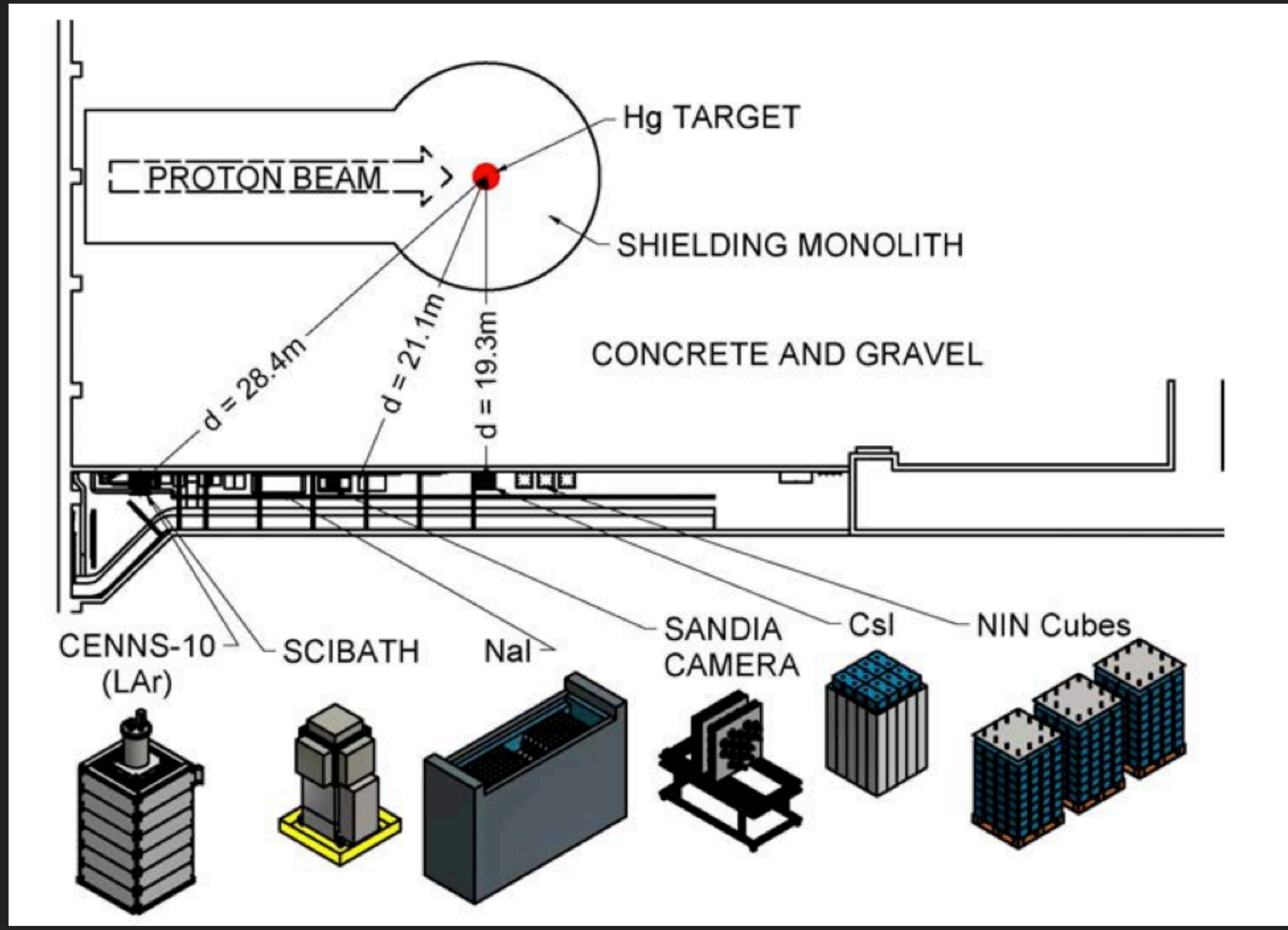
$$G_A = (g_A^p(Z_+ - Z_-) + g_A^n(N_+ - N_-))F_{\rm nucl}^A(Q^2).$$

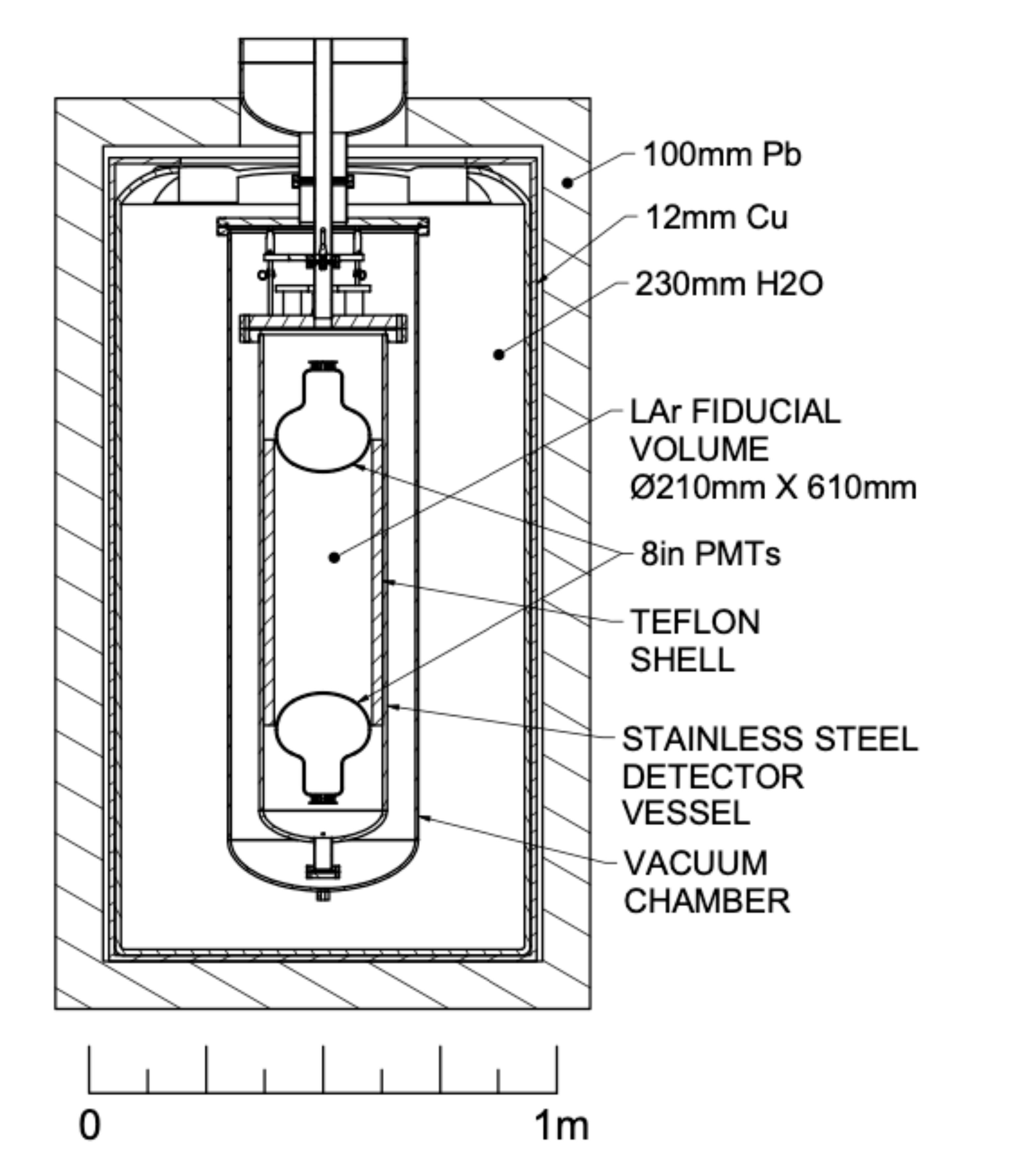
COHERENT ELASTIC NEUTRINO NUCLEUS SCATTERING (CEVNS)

- What can CEvNS tell us:
  - BSM quark-lepton interactions
  - CEvNS is the neutrino floor of dark matter direct detection
  - CEvNS can help determine nuclear structure
  - CEvNS may be used to monitor nuclear reactor activity

COHERENT EXPERIMENT

- Spallation neutron source neutrinos:
- 2017 Cs I
- 2021 Ar



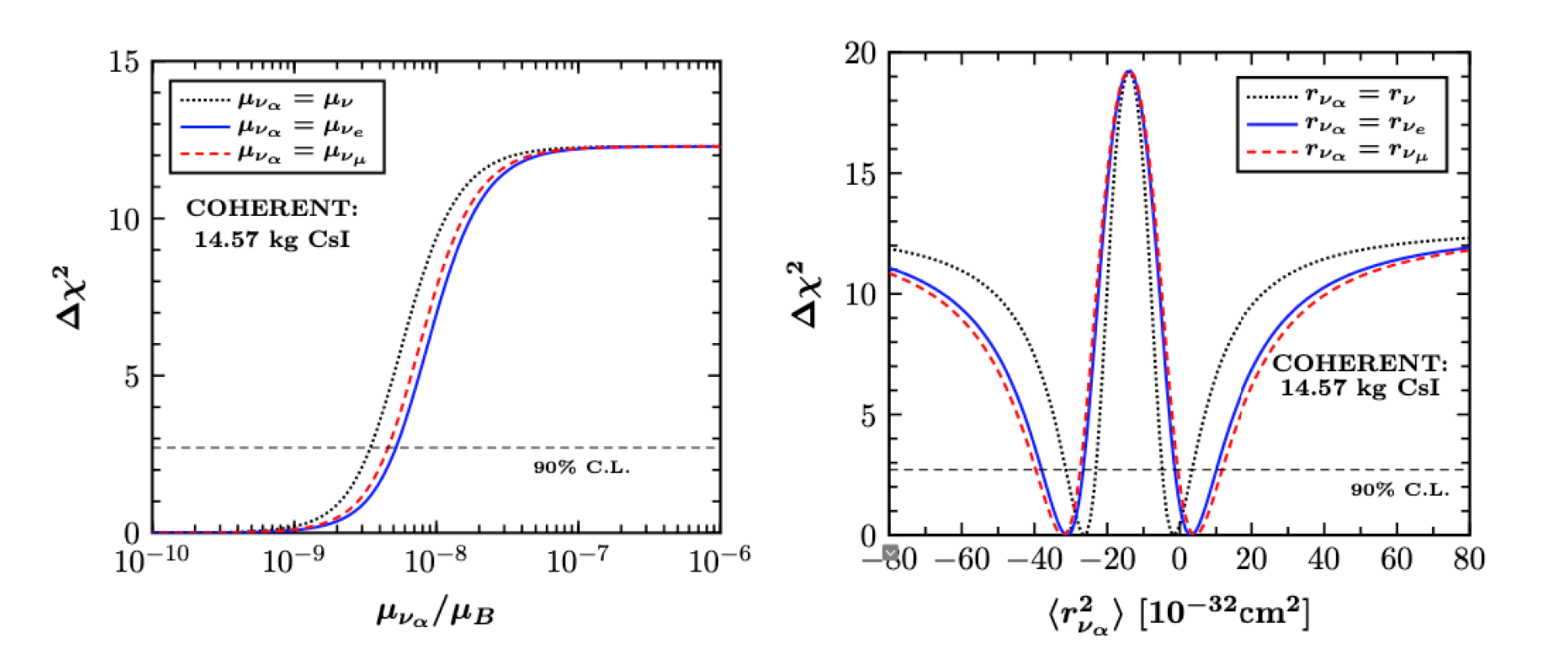


COHERENT EXPERIMENT

- Limits on BSM physics
  - BSM models (scalar, vector mediators, etc…)
  - SMEFT
  - EM couplings of neutrinos

$$\Gamma^{\mu} = F_1 \gamma^{\mu} - \frac{F_2}{2m_\nu} \sigma^{\mu\nu} q_\nu$$

$$F_1 = \tfrac{1}{6} q^2 \langle r^2 \rangle, \quad F_2 = \mu_\nu \frac{m_\nu}{m_e}$$



Papoulias, Kosmas, *Phys.Rev.D* 97 (2018) 3, 033003

Z' MODELS

- Massive neutral vector boson
- Inspired by
  - GUT (e.g. E6 (London,Rosner Phys. Rev. D **34**, 1530,…))
  - Extra dimensions (e.g. Masip, Pomarol, Phys. Rev. D **60**, 096005,…)
  - String theory (e.g. Cvetič, Langacker, Phys. Rev. D **54**, 3570,…)
  - …

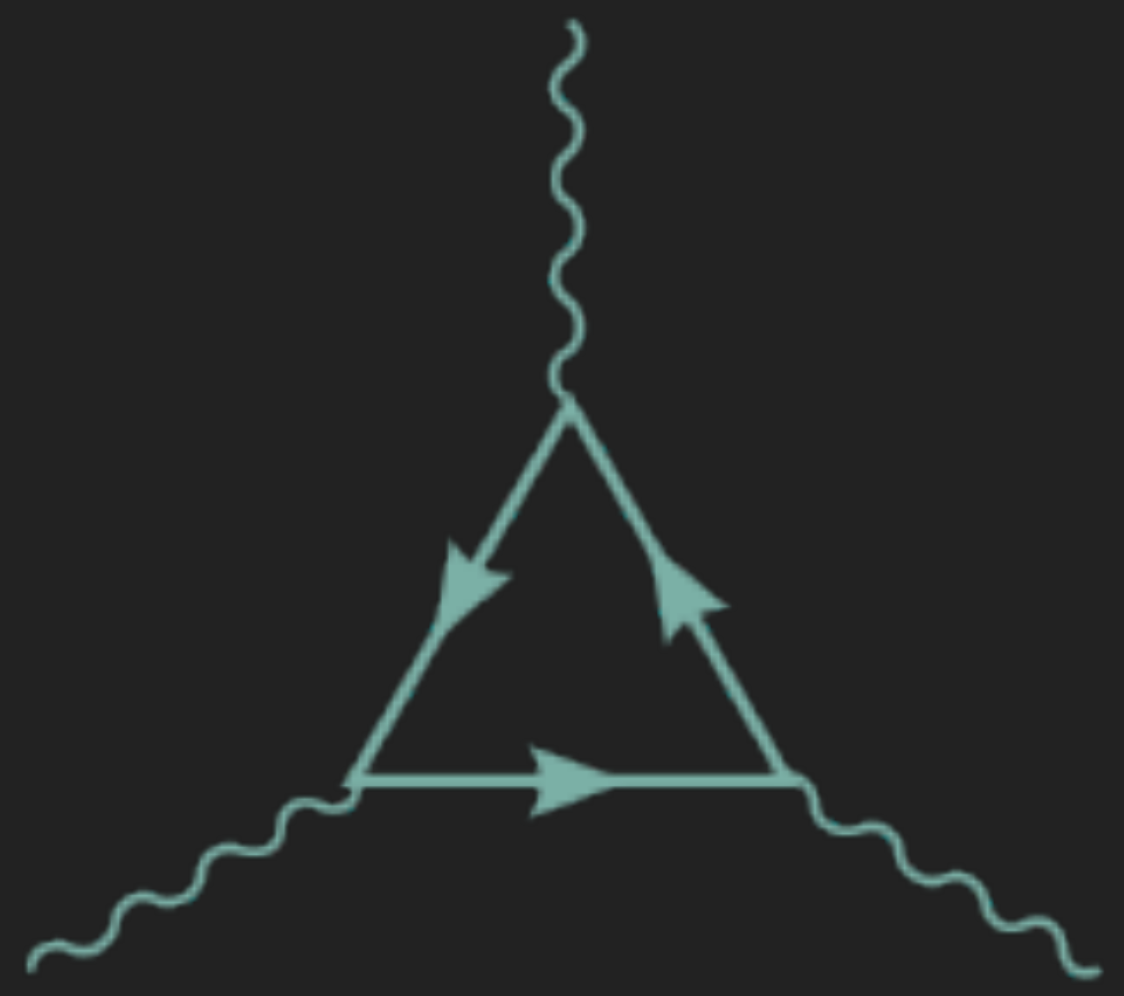
$$\mathscr{L}^{int}_{Z'} = Z'_\mu (g^{f_L}_{Z'} \bar{f}_L \gamma^\mu f_L + g^{f_R}_{Z'} \bar{f}_R \gamma^\mu f_R) = Z'_\mu \bar{f} \gamma^\mu (g^{f_V}_{Z'} - \gamma_5 g^{f_A}_{Z'}) f$$

Z' MODELS

- SM fermions may be charged under the new gauge symmetry, or acquire couplings through the Z-Z′-photon mixing (Babu,Kolda,March-Russell, Phys. Rev. D **57**, 6788)
- Z′ may acquire mass through spontaneous symmetry breaking or through the Stueckelberg mechanism (e.g. Feldman,Liu,Nath, Phys. Rev. D **75**, 115001)

U(1)' ANOMALIES

- Gauged U(1)′ -> Anomaly cancellation
- Top-down approach : U(1)′ from GUTs have no anomalies (e.g. SM obtained from SU(5), SO(10),…)
- Bottom-up : U(1)′ anomaly cancellation conditions define possible models



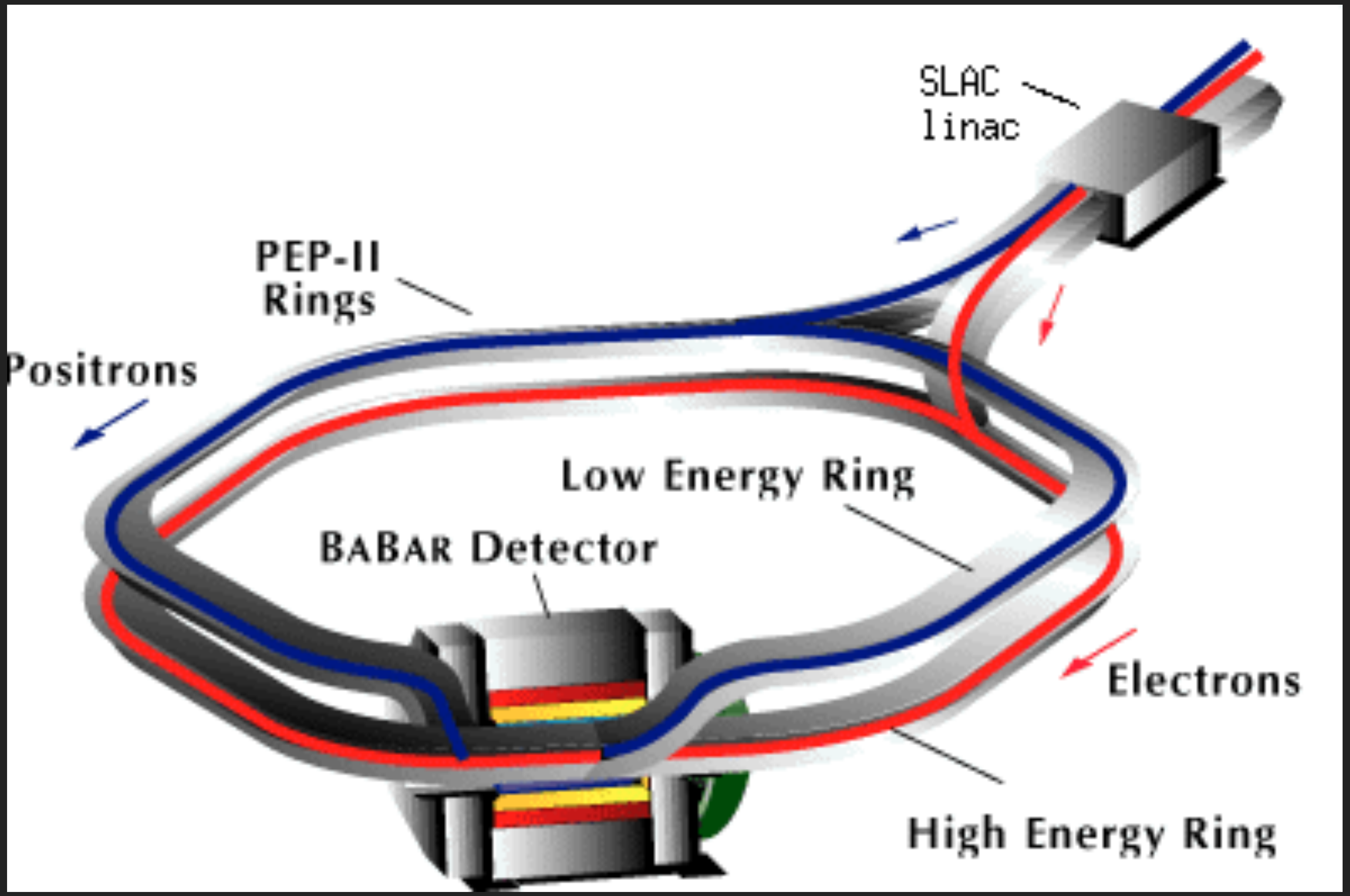
U(1)' ANOMALIES

- Some anomaly free charge assignments:

  - $B - L$
  - $B - 2L_\alpha - L_\beta$
  - $B - 3L_\alpha$
  - $L_\alpha - L_\beta$

EXPERIMENTAL EFFECTS OF A Z'

- BaBar (BaBar collaboration, J. P. Lees et al., Phys. Rev. Lett. 113 (2014) 201801)
- $e^-e^+ \to \gamma Z' (\to e^-e^+/\mu^-\mu^+)$
- $g^e_{Z'} \neq 0$, $g^\mu_{Z'} \neq 0$ (for muon final state channel)



EXPERIMENTAL EFFECTS OF A Z'

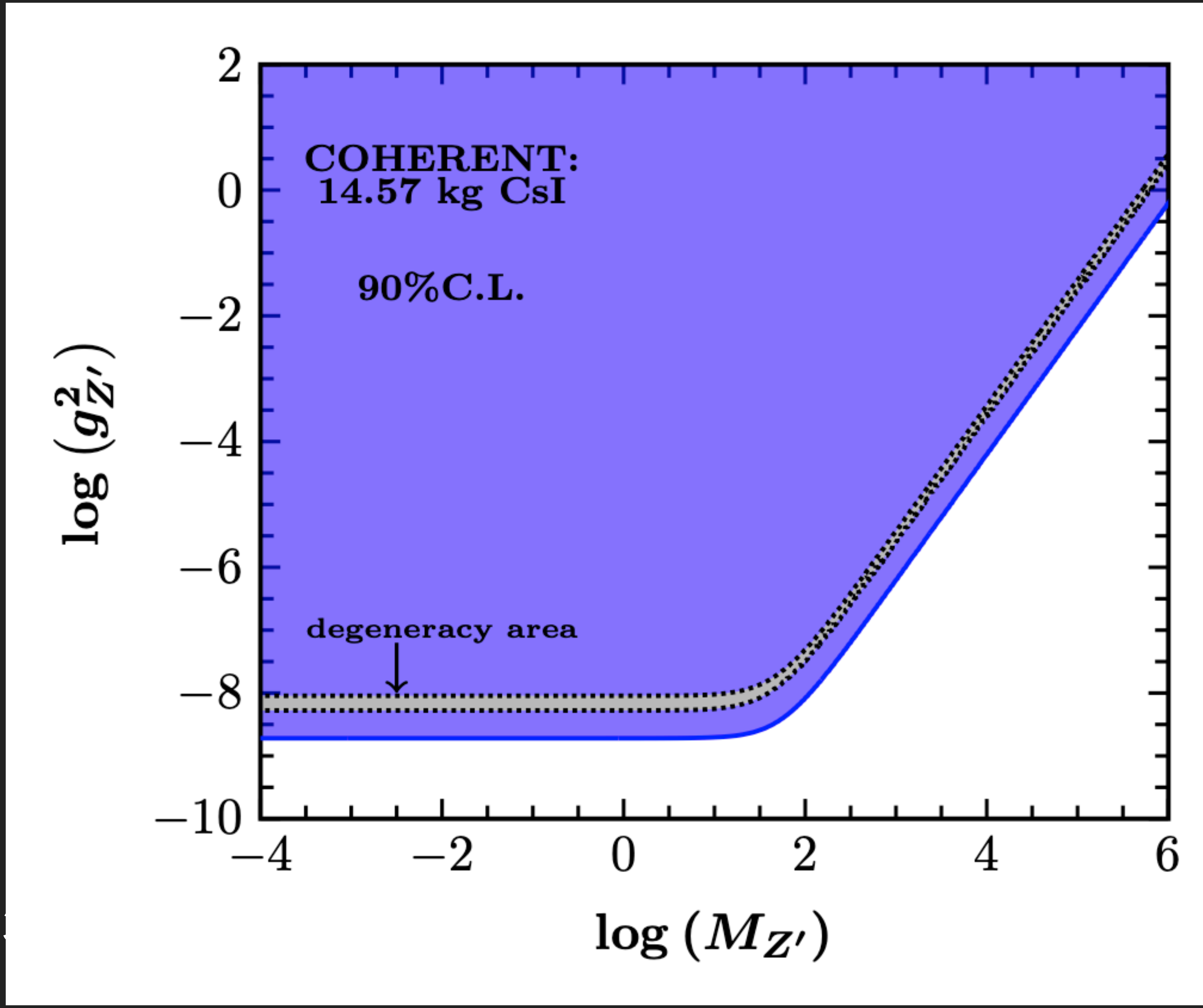
- LHCb (LHCb collaboration, R. Aaij et al., Phys. Rev. Lett. 120, 061801 (2018))
- $pp \to \ldots (Z' \to \mu^- \mu^+)$
- $(g^u_{Z'} \neq 0$ and/or $g^d_{Z'} \neq 0$) and $g^\mu_{Z'} \neq 0$

EXPERIMENTAL EFFECTS OF A Z'

- Beam dumps
  - Electrons: $e^- N_Z \to e^- N_Z Z' (\to e^- e^+)$
  - $(g_{Z'}^u \neq 0$ and/or $g_{Z'}^d \neq 0$) and $g_{Z'}^e \neq 0$
  - E141,E137,E774,NA64, KEK,...
  - Protons: $\pi^0 \to \gamma Z' (\to e^+ e^-)$
  - $(g_{Z'}^u \neq 0$ and/or $g_{Z'}^d \neq 0)$ and $g_{Z'}^e \neq 0$
  - ν-CAL I , NOMAD

EXPERIMENTAL EFFECTS OF A Z'

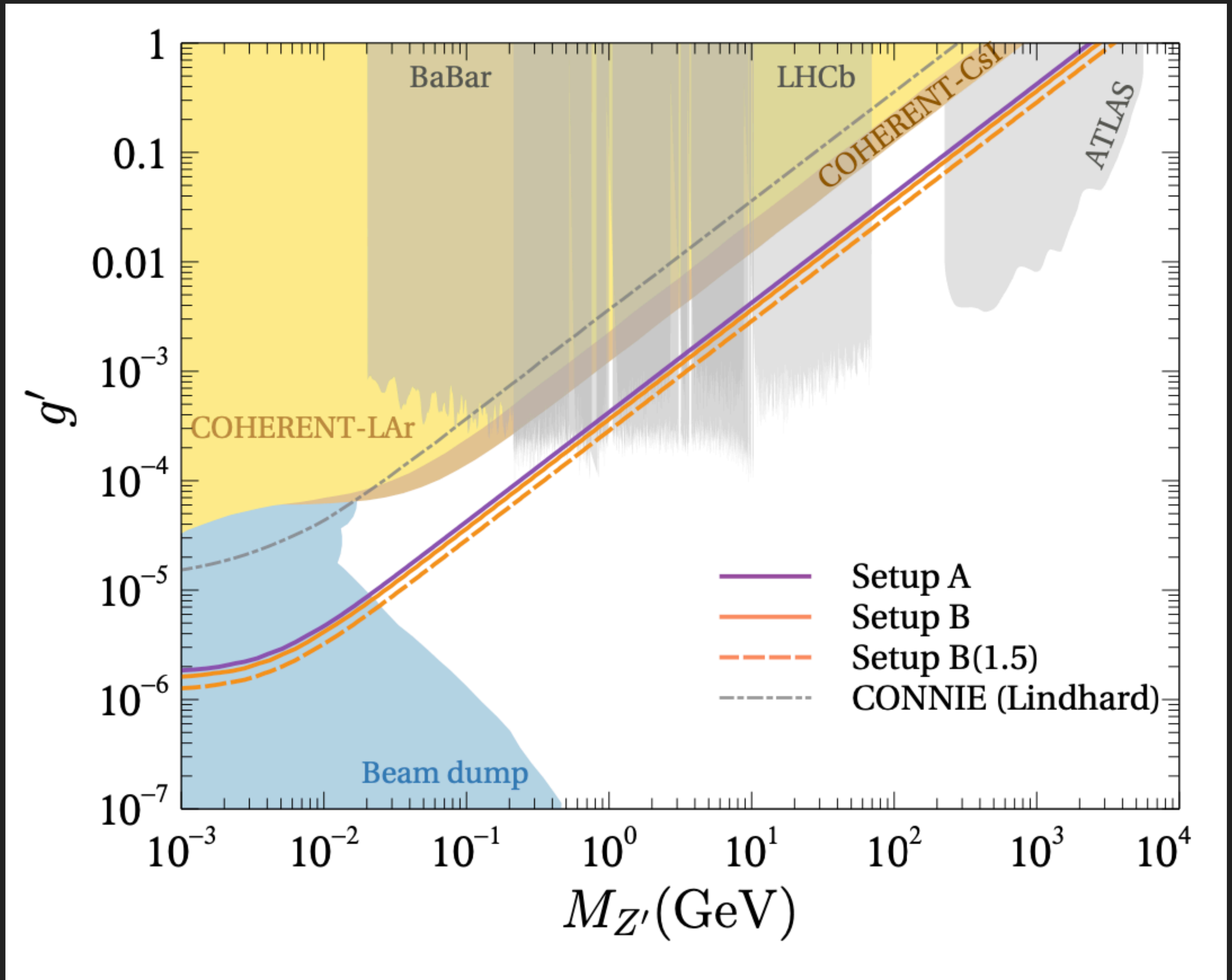
- CEvNS
  - Z′ coupling to quark and left-handed lepton doublets affects the CEvNS cross section
  - COHERENT
  - $\nu_\mu, \bar{\nu}_\mu, \nu_e$
  - ($g^{\mu}_{Z'} \neq 0$ and/or $g^{e}_{Z'} \neq 0$) and ($g^{u}_{Z'} \neq 0$ y/o $g^{d}_{Z'} \neq 0$)



Papoulias, Kosmas, *Phys.Rev.D* 97 (2018) 3, 03300

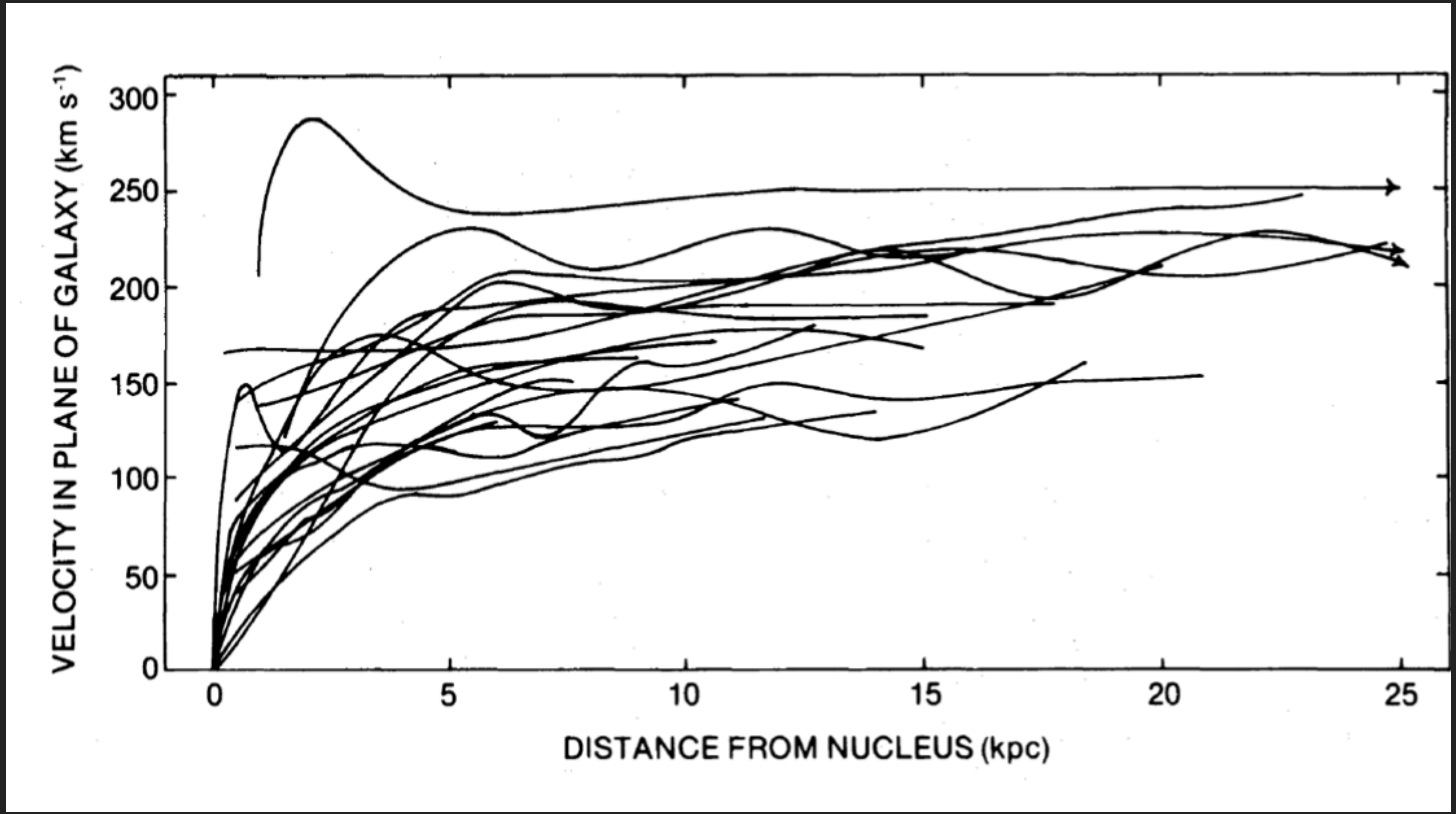
EXPERIMENTAL EFFECTS OF A Z'

- CEvNS
  - Z′ coupling to quark and left-handed lepton doublets affects the CEvNS cross section
  - νs from reactors($\bar{\nu}_e$)
  - $g^e_{Z'} \neq 0$ and ($g^u_{Z'} \neq 0$ and/or $g^d_{Z'} \neq 0$)



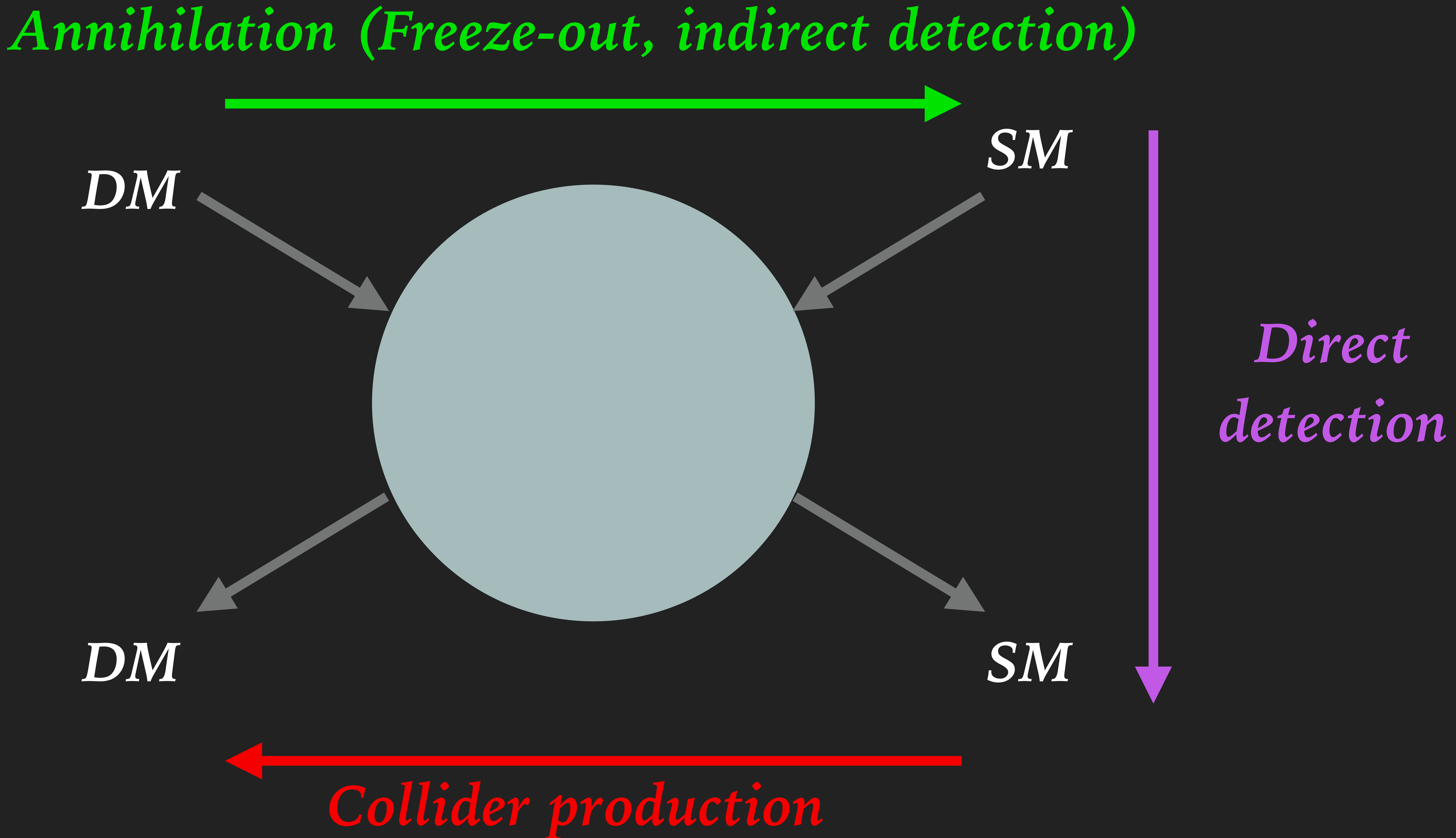
DARK MATTER

- $\sim 27\ \%$ of Universe content is nonbaryonic matter
- We have only observed DM gravitationally
- Early Universe production mechanism?
- Short-range interaction with Baryonic Matter?



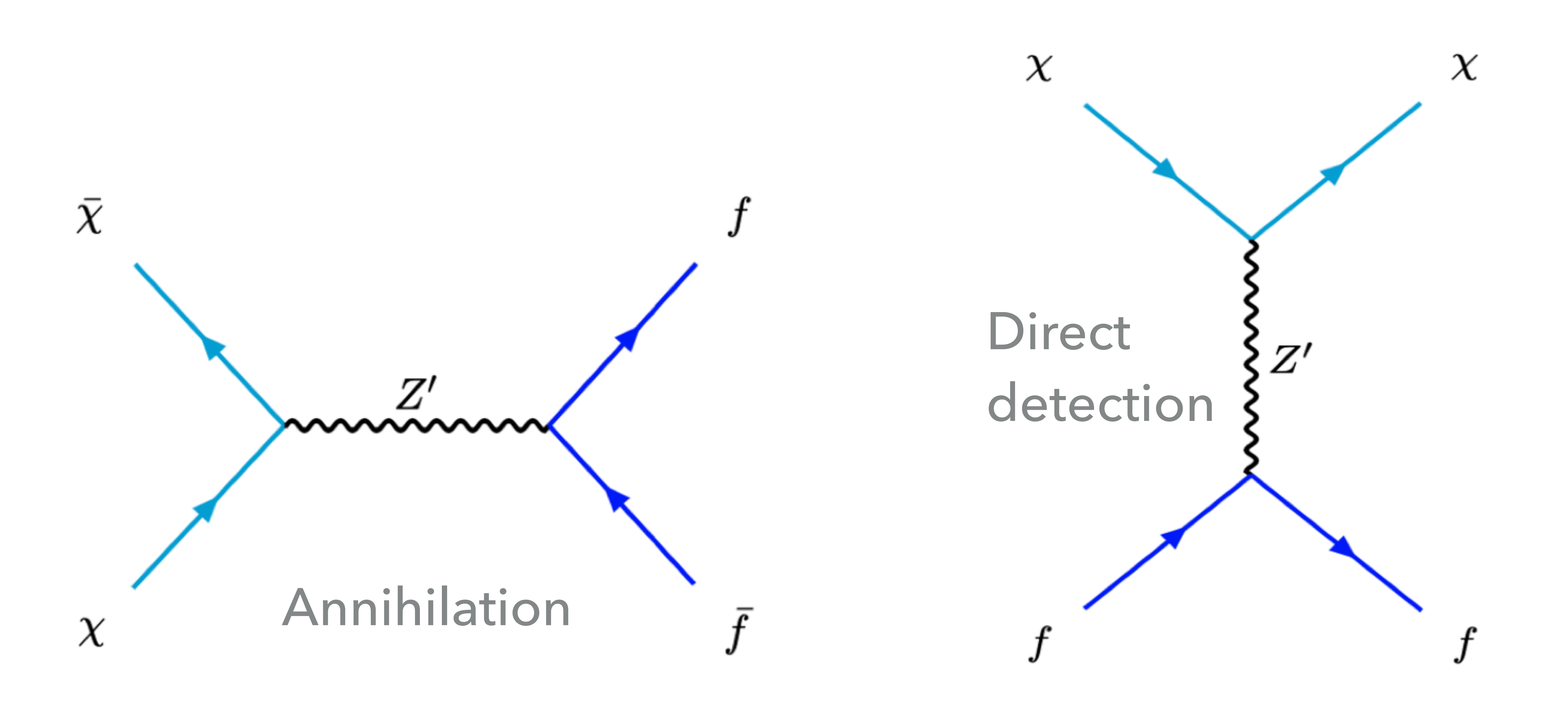
- V. C. Rubin, et. al., Astrophys. J., 238:471, 1980.

DARK MATTER

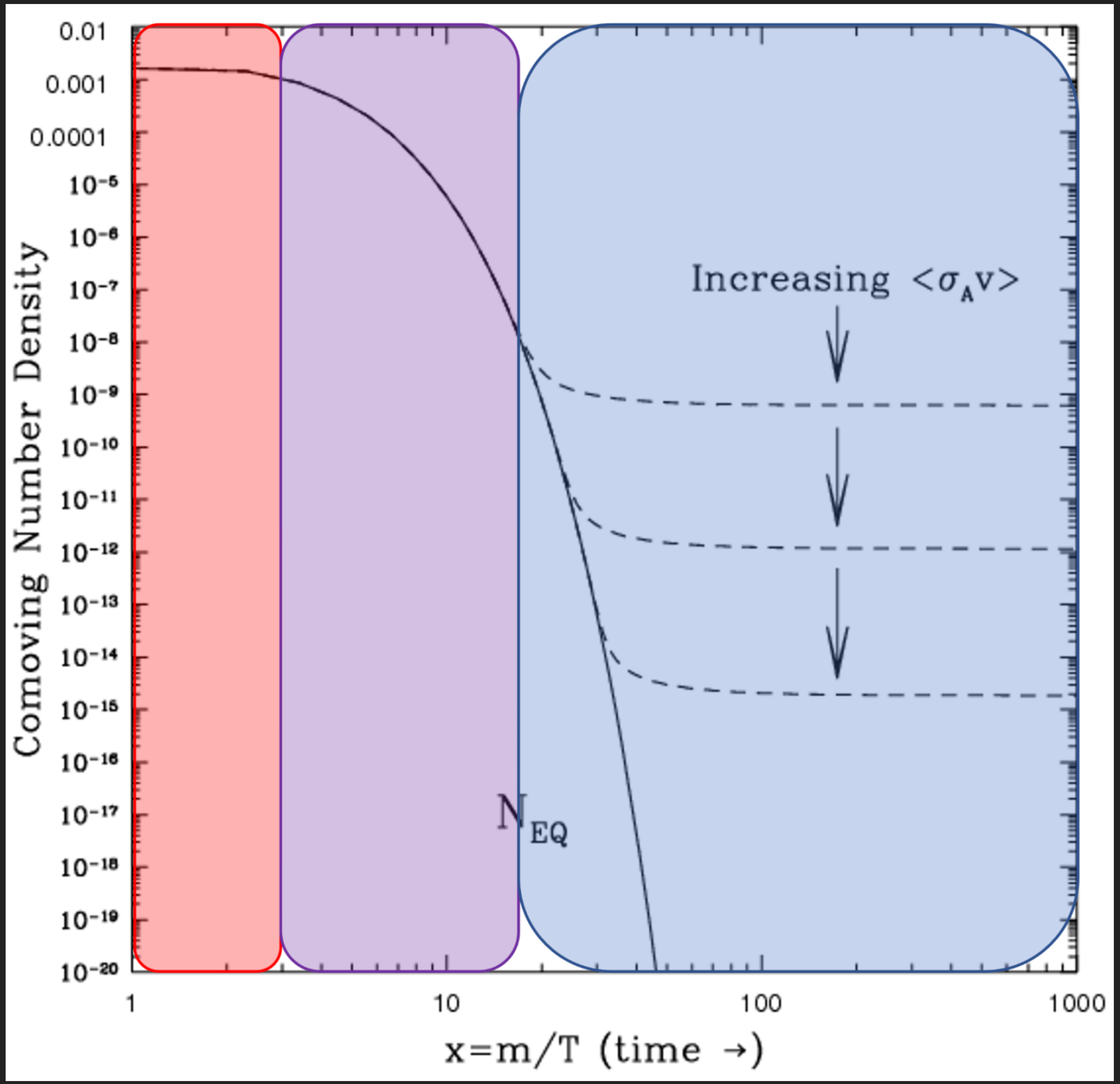

Annihilation (Freeze-out, indirect detection)
DM
SM
Direct detection
DM
SM
Collider production

Z' PORTAL DARK MATTER

$$\mathscr{L}_{Z'}^{dark} = Z'_\mu(g_{Z'}^{\chi_L}\bar{\chi}_L\gamma^\mu\chi_L + g_{Z'}^{\chi_R}\bar{\chi}_R\gamma^\mu\chi_R) = Z'_\mu\bar{\chi}\gamma^\mu(g_{Z'}^{\chi_V} - \gamma_5 g_{Z'}^{\chi_A})\chi$$



DARK MATTER FREEZE OUT

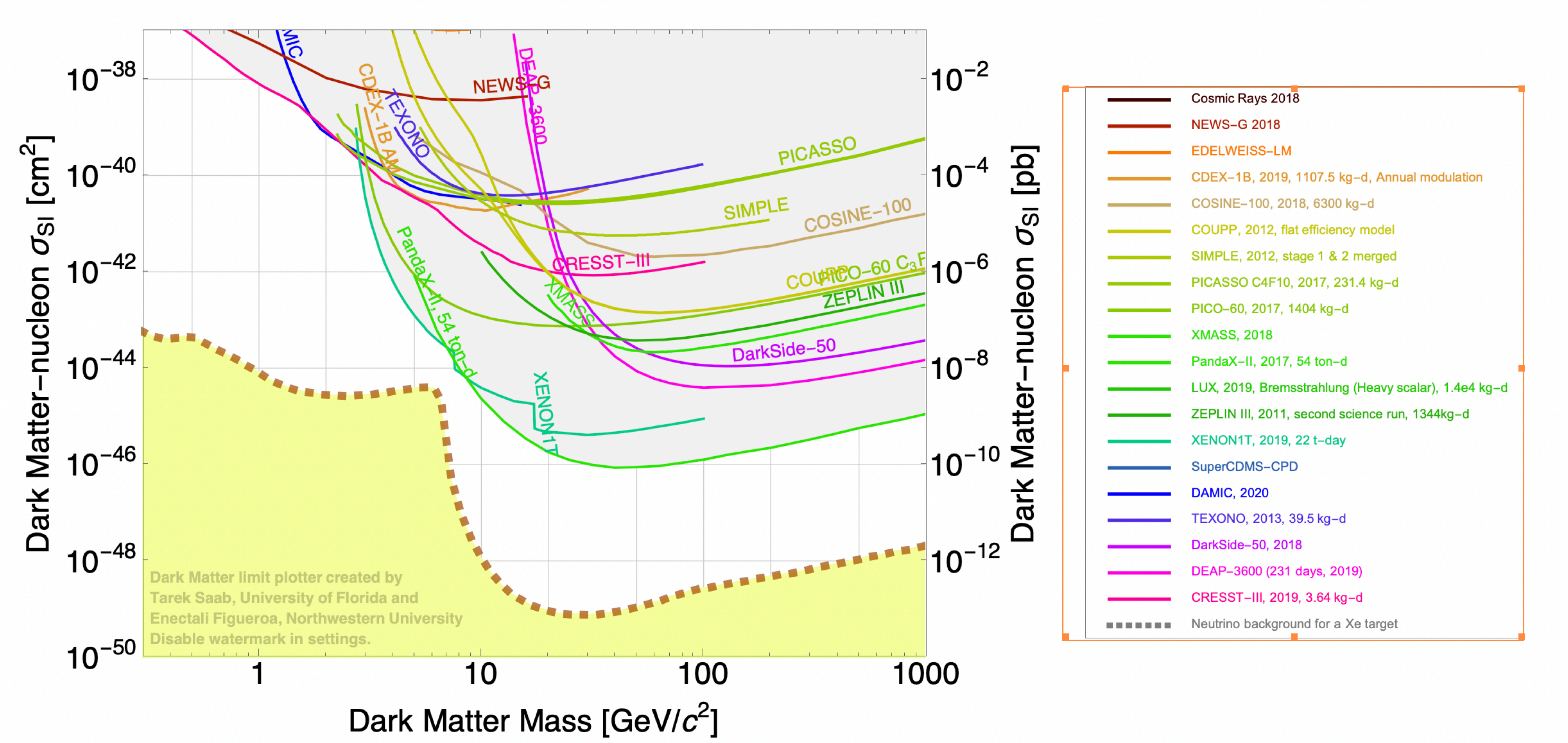


- To obtain $\Omega_{DM} \sim 0.2$, $\sigma_{an} \sim 10^{-8} GeV^2$ is needed
- For $M_{Z'} \sim 1 GeV$, $(g^f_{Z'} g^\chi_{Z'})^2 \sim 10^{-8}$
- If $g^f_{Z'}$ is close to $g^\chi_{Z'}$,CEvNS excludes Z′ portal DM
- We can enhance DM annihilation CS $M_{Z'} \sim 2M_\chi$, while keeping CEvNS CS low

Kolb, Adam Green (particlebites.com)

DM DIRECT DETECTION

- E
- N



Dark matter limit plotter, https://supercdms.slac.stanford.edu/dark-matter-limit-plotter

CEνNS measurements and SBC

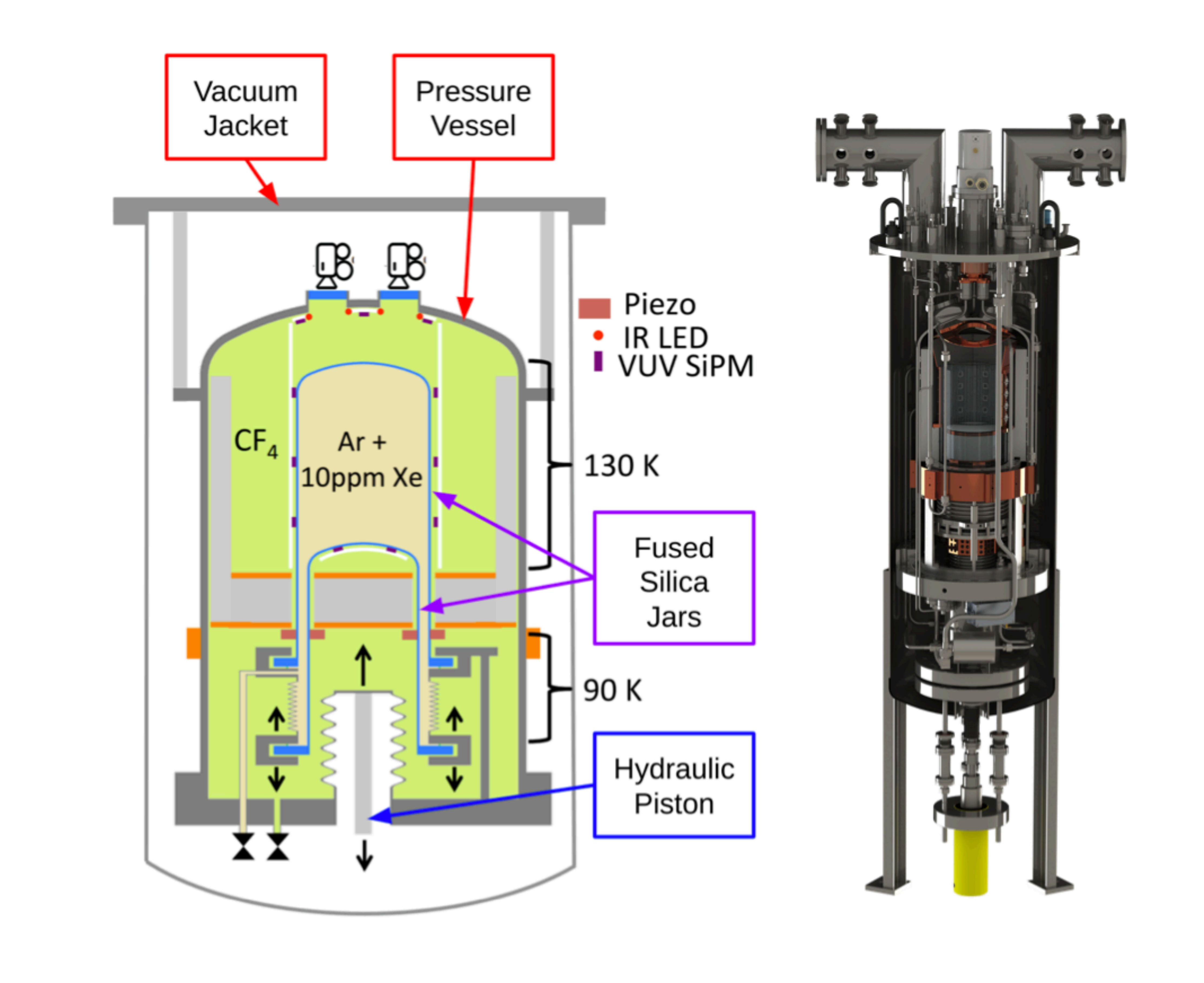


Image from : Giampa, *PoS* ICHEP2020 (2021) 632

Superheated argon scintillating bubble chamber (SBC)

Very low threshold (100 eV)

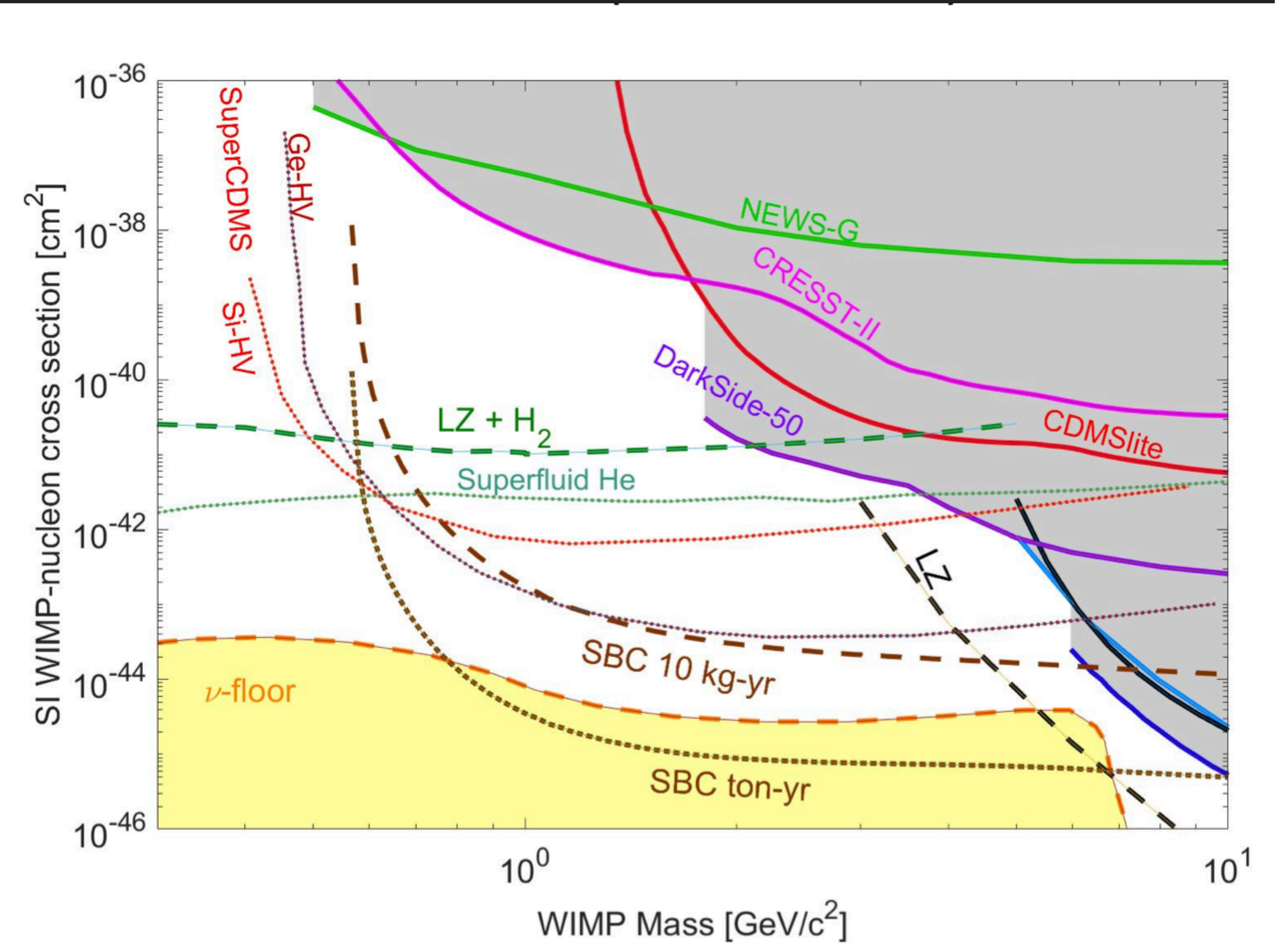
10 kg detector material

DM direct detection @ SNOLAB

CEνNS measurement @ reactor

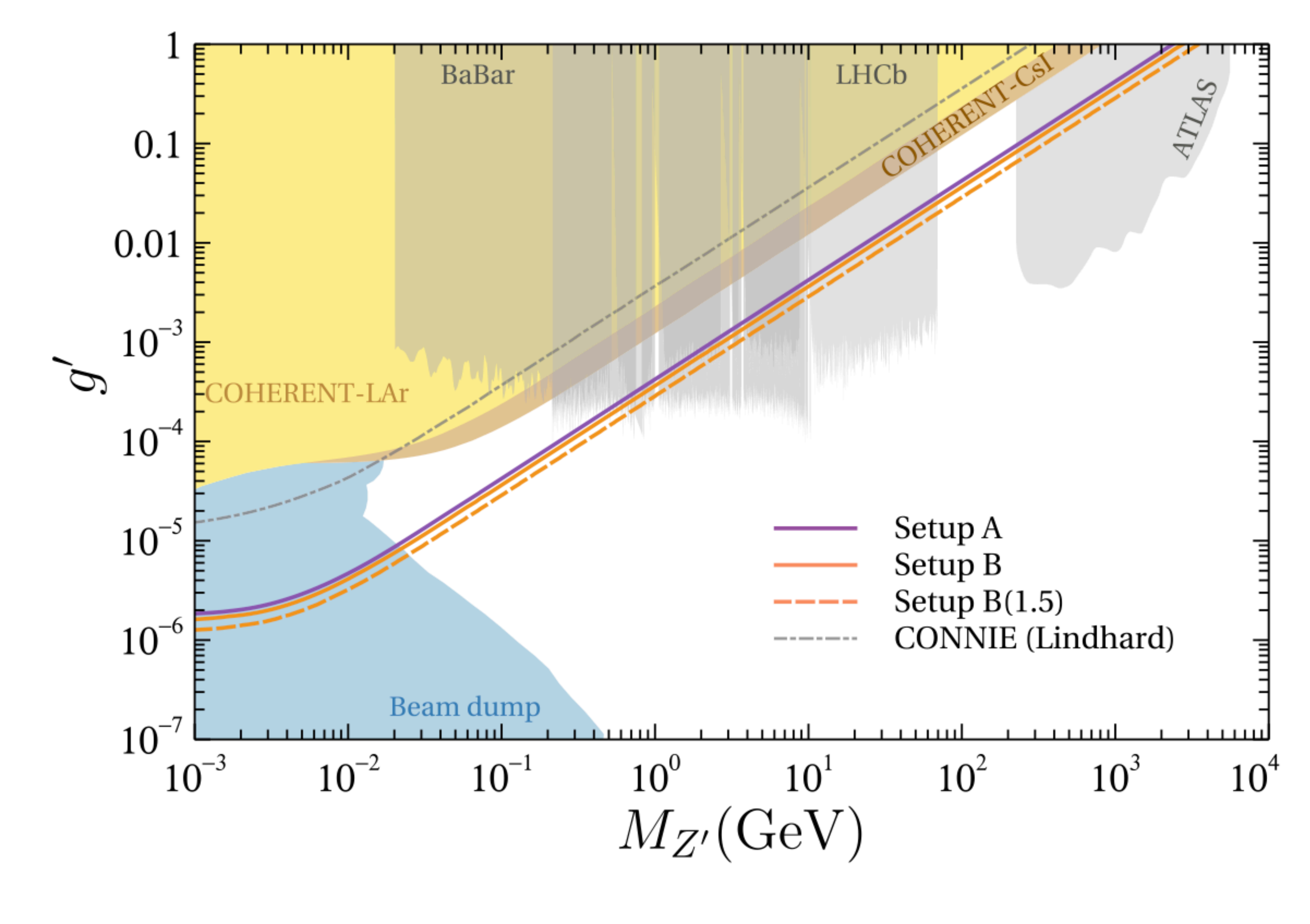
Future tonne-scale DM detector

DM DIRECT DETECTION & CEVNS AT SBC



SBC @ SNOLAB

Giampa, *PoS* ICHEP2020 (2021) 632



SBC @ ININ/Laguna Verde

Flores et. al., SBC collaboration, PRD 103, L091301 (2021)

DMDD & CEVNS

- Let's look at concrete U(1)' models with DM
- Defining $g_{Z'}^{f_V} = \dfrac{g_{Z'}^{f_L} + g_{Z'}^{f_R}}{2} = g' Q_f$
  - $Q_{u/d} \neq 0$, $Q_L \neq 0$ for CEvNS
  - $Q_L \neq 0$ for some, or all neutrino flavors
  - Anomalies define models
    - Leon MG de la Vega, L.J. Flores, Newton Nath & Eduardo Peinado, Journal of High Energy Physics, 2021, Article number: 146 (2021)

	U(1)′ models
MI	$U(1)_{B-L}$
MII	$U(1)_{B-2L_\alpha-L_\beta}$
MIII	$U(1)'_{B-2L_\alpha-L_\beta}$
MIV	$U(1)_{B-3L_\alpha}$

DMDD & CEVNS

- For DM we introduce a vector-like pair χ_L, χ_R with identical U(1)′ such that
- $\chi = \chi_L + \chi_R$
- $Q_{\chi_L} = Q_{\chi_R} = 1/3$
- This way, DM does not contribute to anomalies
- DM is stable thanks to a residual symmetry from U(1)′ breaking

- Leon MG de la Vega, L.J. Flores, Newton Nath & Eduardo Peinado, Journal of High Energy Physics, 2021, 146 (2021)

DMDD & CEVNS

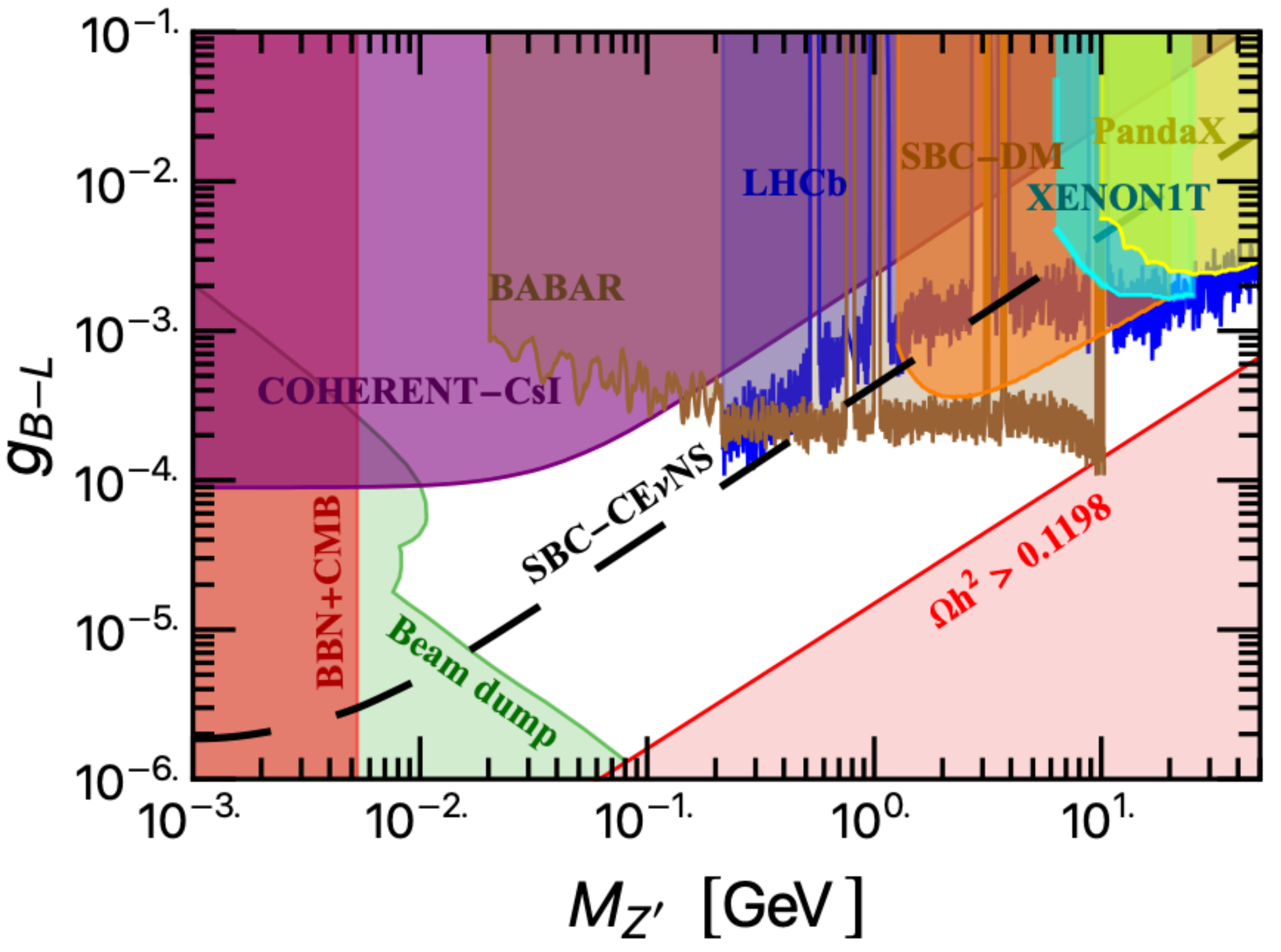
	U(1)′ models	Scalar Fields
MI	$U(1)_{B-L}$	ϕ_2
MII	$U(1)_{B-2L_\alpha-L_\beta}$	ϕ_1, ϕ_2
MIII	$U(1)'_{B-2L_\alpha-L_\beta}$	ϕ_1, ϕ_2, ϕ_4
MIV	$U(1)_{B-3L_\alpha}$	ϕ_3, ϕ_6

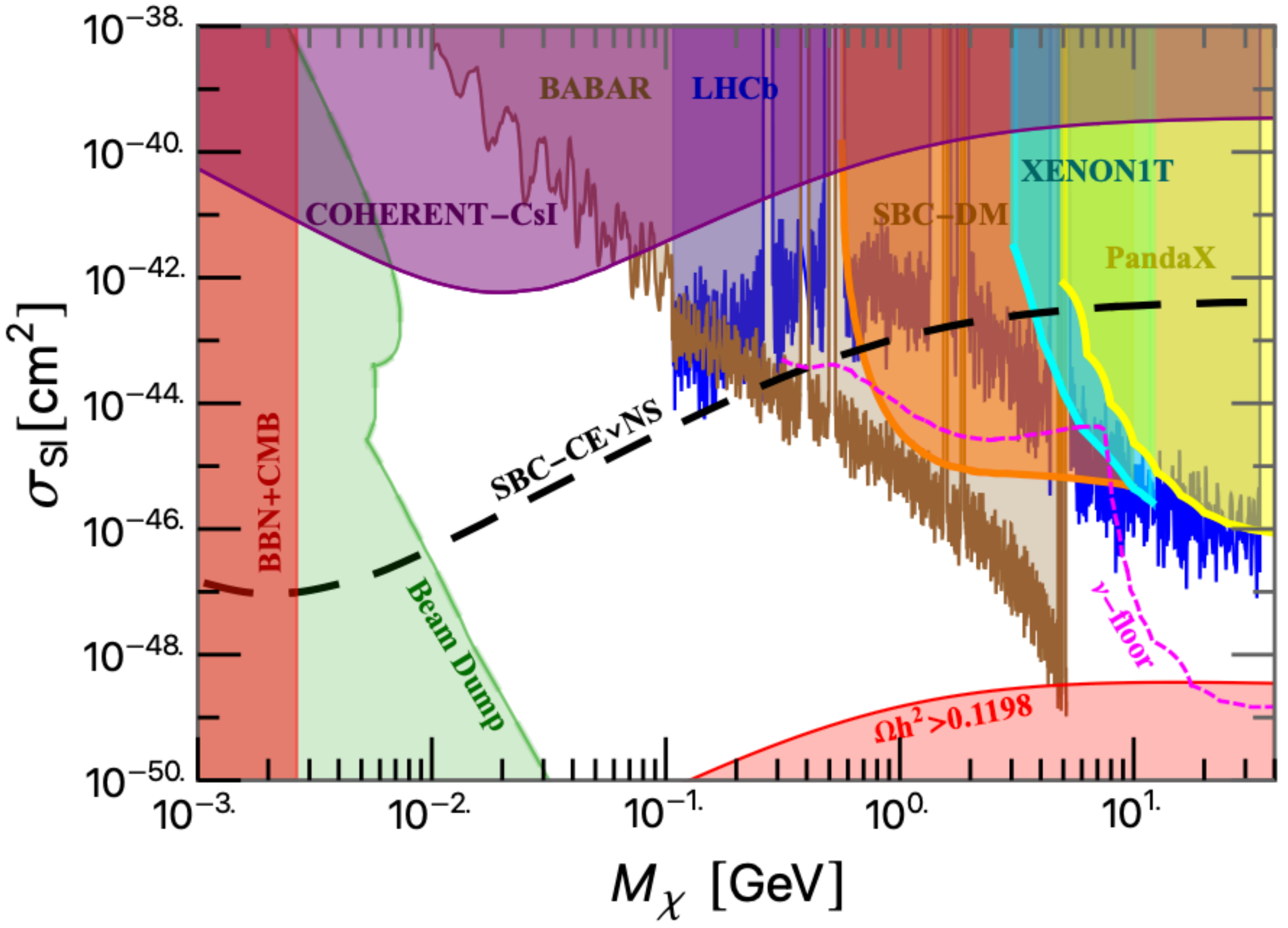
- Majorana masses from type-I seesaw
- Non-universal lepton charges -> Structured neutrino mass matrices, texture zeroes or correlations

- Leon MG de la Vega, L.J. Flores, Newton Nath & Eduardo Peinado, Journal of High Energy Physics, 2021, Article number: 146 (2021)

COMPLEMENTARIEDAD DE DMDD Y CEVNS

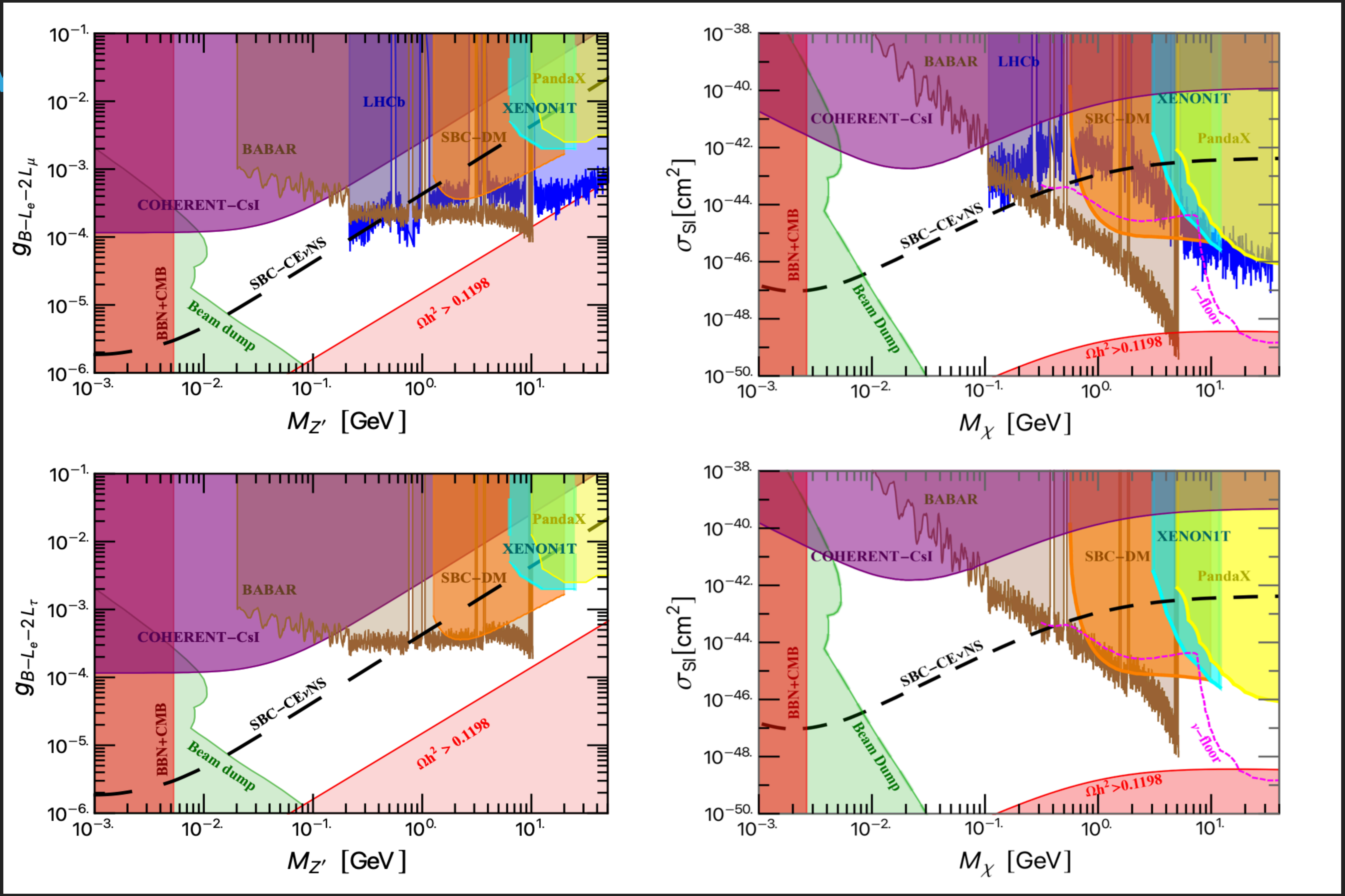
- B - L





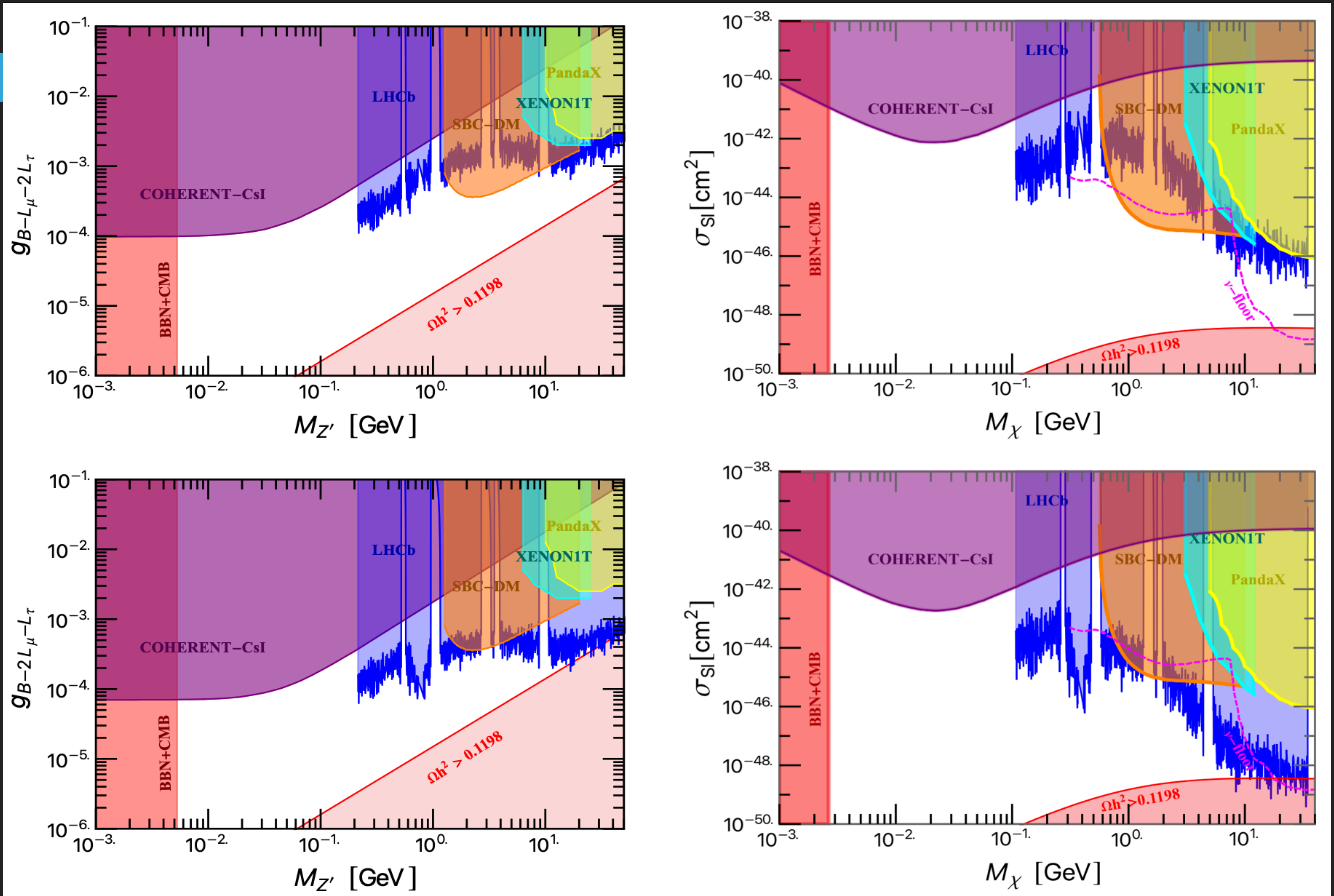
COMPLEM

- $B - 2L_\alpha - L_\beta$

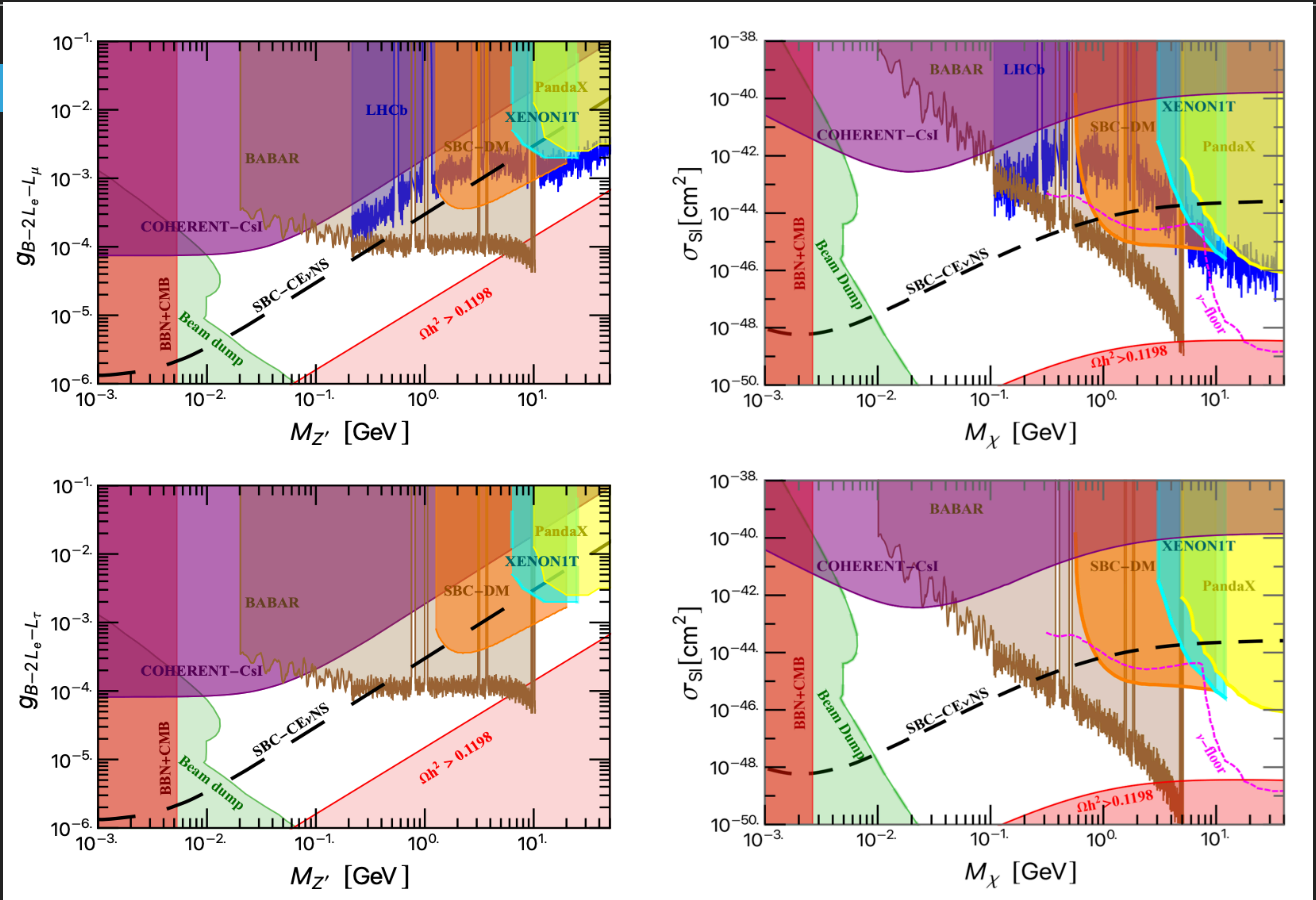


COMPLEI

- Modelos $B - 2L_\alpha - L_\beta$



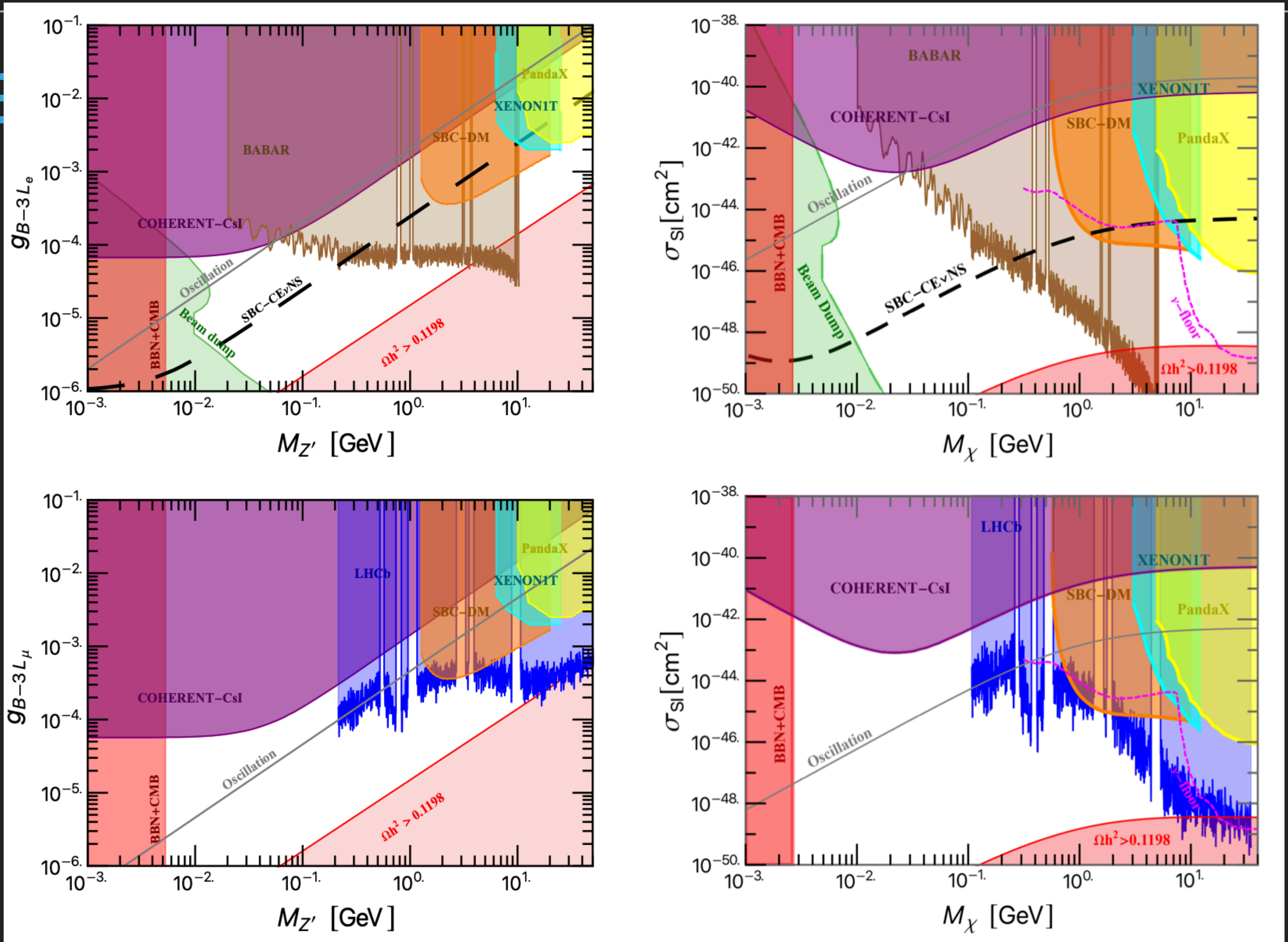
COMPLE



- $B - 2L_\alpha - L_\beta$

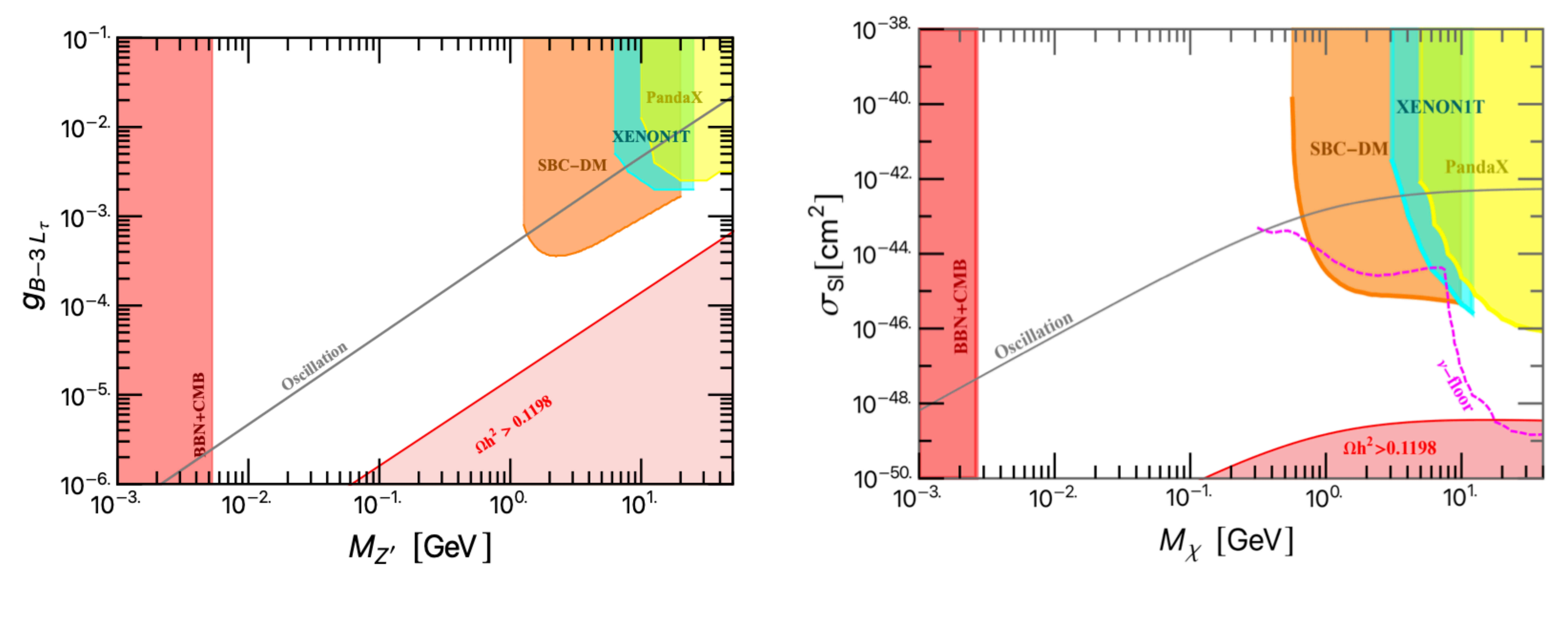
COMPLEME

- $B - 3L_\alpha$



COMPLEMENTARIEDAD DE DMDD Y CEVNS

- Modelos $B - 3L_\alpha$



Oscillation limits: P. Coloma, M.C. Gonzalez-Garcia and M. Maltoni, JHEP 01 (2021) 114

SUMMARY

- CEvNS experimental results constitute a very sensitive probe of BSM physics
- Together with collider, beam dump, and oscillation experiments, CEvNS can tightly constrain quark-neutrino interactions
- CEvNS results can be used together with dark matter direct detection results to probe UV-complete dark matter models
- Future of CEvNS & DMDD experiments is tightly dependent on each other