
Studying the Sterile Baryonic Neutrino Using Direct Detection and Spallation Source Experiments

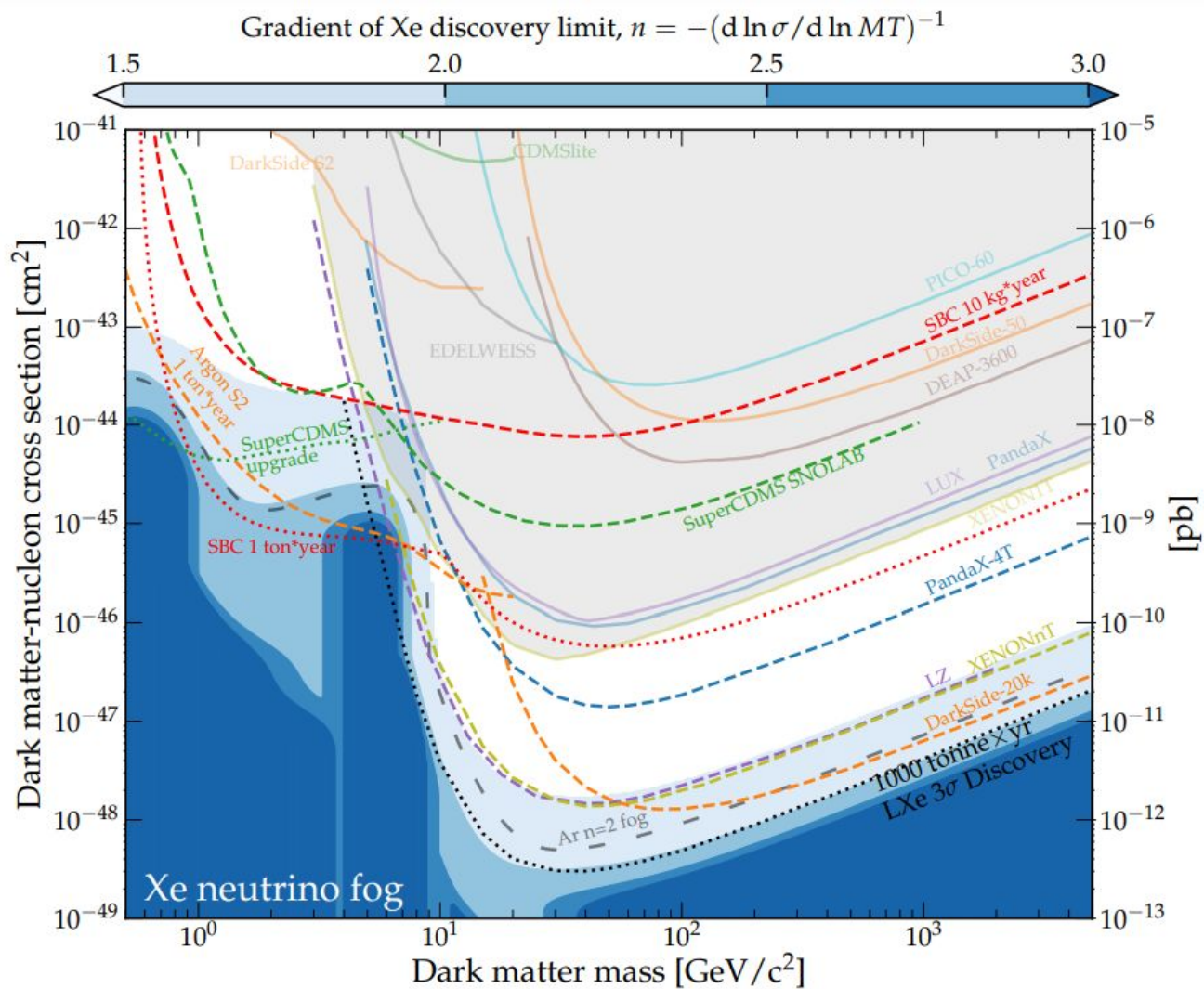
David Alonso-González, Dorian Amaral, Adriana Bariego-Quintana,
David Cerdeño & **Martín de los Ríos***



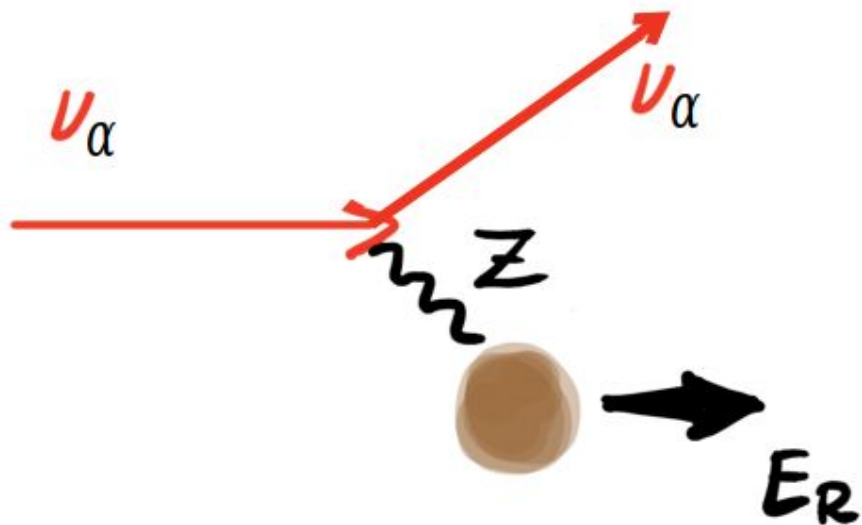
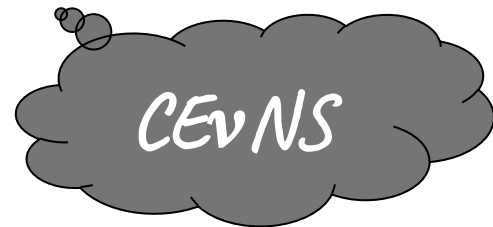
*martindelosrios13@gmail.com

Introduction

- Introduction
 - Coherent elastic neutrino-nucleus scattering
 - Spallation-Source experiments
 - Dark Matter Direct Detection Experiments



Coherent elastic Neutrino-Nucleus scattering



Predicted by the SM: [Freedman (1974)]

$$\frac{d\sigma_{\nu N}}{dE_R} = \frac{G_F^2}{4\pi} Q_v^2 m_N \left(1 - \frac{m_N E_R}{2E_\nu^2} \right) F^2(E_R)$$

$$Q_v = N - (1 - 4\sin^2\theta_W)Z$$

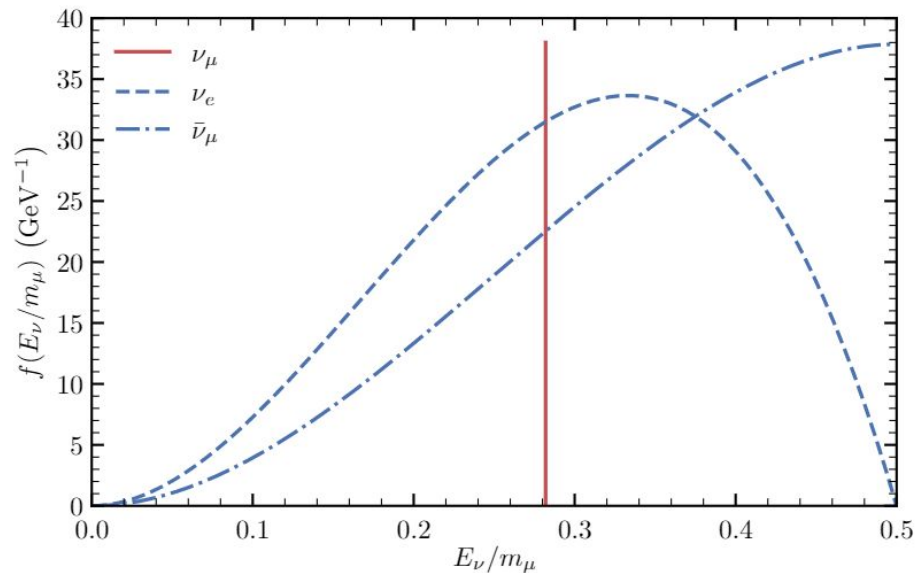
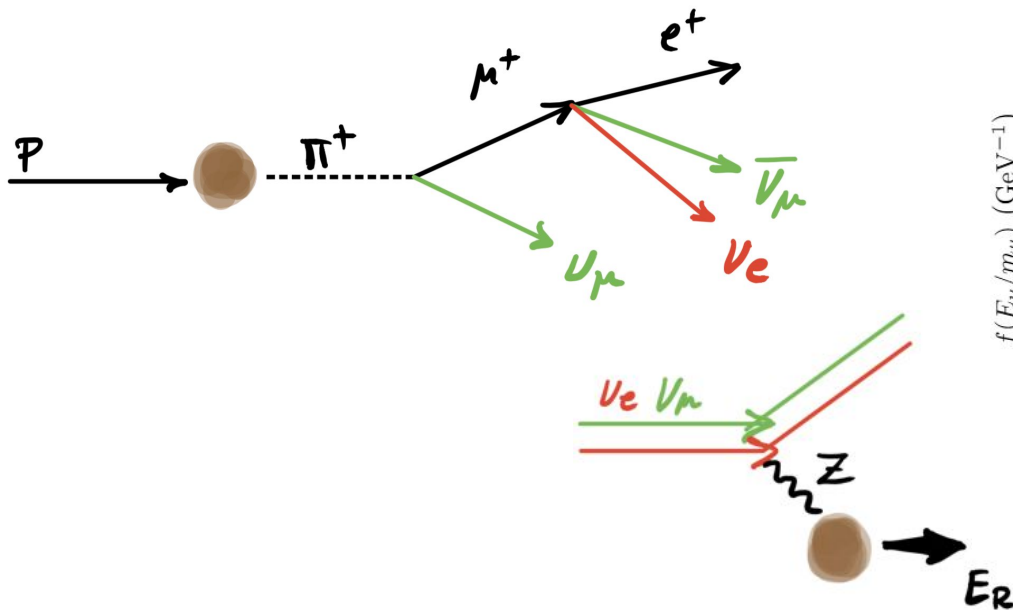
... And detected by the
COHERENT collaboration!!

[Akimov et al. 1708.01294 (2017)]

CE ν NS @ Spallation Source Experiments

$$N_{\text{CE}\nu\text{NS}} = \sum_{\nu_\alpha} N_{\text{targ}} \int_{E_{\text{th}}}^{E_R^{\text{max}}} \int_{E_\nu^{\text{min}}}^{E_\nu^{\text{max}}} \frac{dN_{\nu_\alpha}}{dE_\nu} \epsilon(E_R) \frac{d\sigma_{\nu_\alpha N}}{dE_R} dE_\nu dE_R.$$

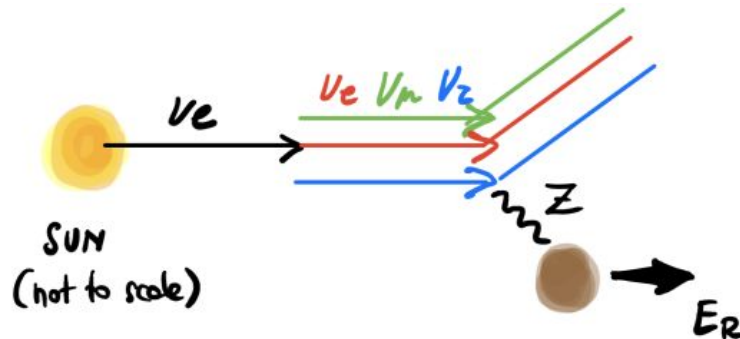
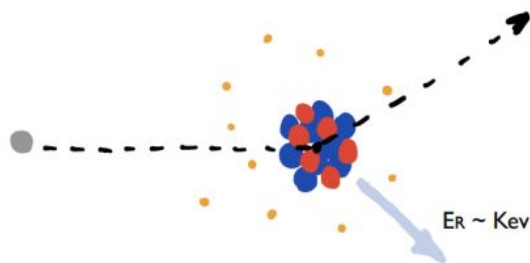
COHERENT



CE ν NS @ DM Direct Detection Experiments

$$\frac{dR}{dE_R} = n_T \sum_{\nu_\alpha} \int_{E_\nu^{\min}} \frac{d\phi_{\nu_e}}{dE_\nu} P(\nu_e \rightarrow \nu_\alpha) \frac{d\sigma_{\nu_\alpha T}}{dE_R} dE_\nu$$

Xenon, LZ,
SuperCDM, etc..



Different experimental setups

Spallation Source Experiments

ν_e ν_μ $\bar{\nu}_\mu$

DM Direct Detection Experiments

ν_e $\bar{\nu}_e$ ν_μ $\bar{\nu}_\mu$ ν_τ $\bar{\nu}_\tau$

Different experimental setups

Spallation Source Experiments

ν_e ν_μ $\bar{\nu}_\mu$

Neutrinos up to ~50 MeV

DM Direct Detection Experiments

ν_e ν_e ν_μ ν_μ ν_τ ν_τ

Neutrinos up to ~20 MeV

Different experimental setups

Spallation Source Experiments

$$\nu_e \quad \nu_\mu \quad \bar{\nu}_\mu$$

Neutrinos up to ~50 MeV

Not very small energy
thresholds

DM Direct Detection Experiments

$$\nu_e \quad \nu_e \quad \nu_\mu \quad \nu_\mu \quad \nu_\tau \quad \nu_\tau$$

Neutrinos up to ~20 MeV

Very small recoil energy
thresholds

Different experimental setups

Spallation Source Experiments

ν_e ν_μ $\bar{\nu}_\mu$

Neutrinos up to ~50 MeV

Not very small energy
thresholds

DM Direct Detection Experiments

ν_e ν_e ν_μ ν_μ ν_τ ν_τ

Neutrinos up to ~20 MeV

Very small recoil energy
thresholds

*So, why not to
combine them??*

Sterile Baryonic Neutrino Model

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Sterile Baryonic Neutrino (SBN)

Pospelov 1103.3261 (2011)]

$$\mathcal{L} \supset \frac{m_{Z'}^2}{2} Z'^\mu Z'_\mu + g_b Z'^\mu \bar{\nu}_b \gamma_\mu \nu_b + \frac{1}{3} g_q Z'^\mu \sum_q \bar{q} \gamma_\mu q .$$

PARAMETER SPACE

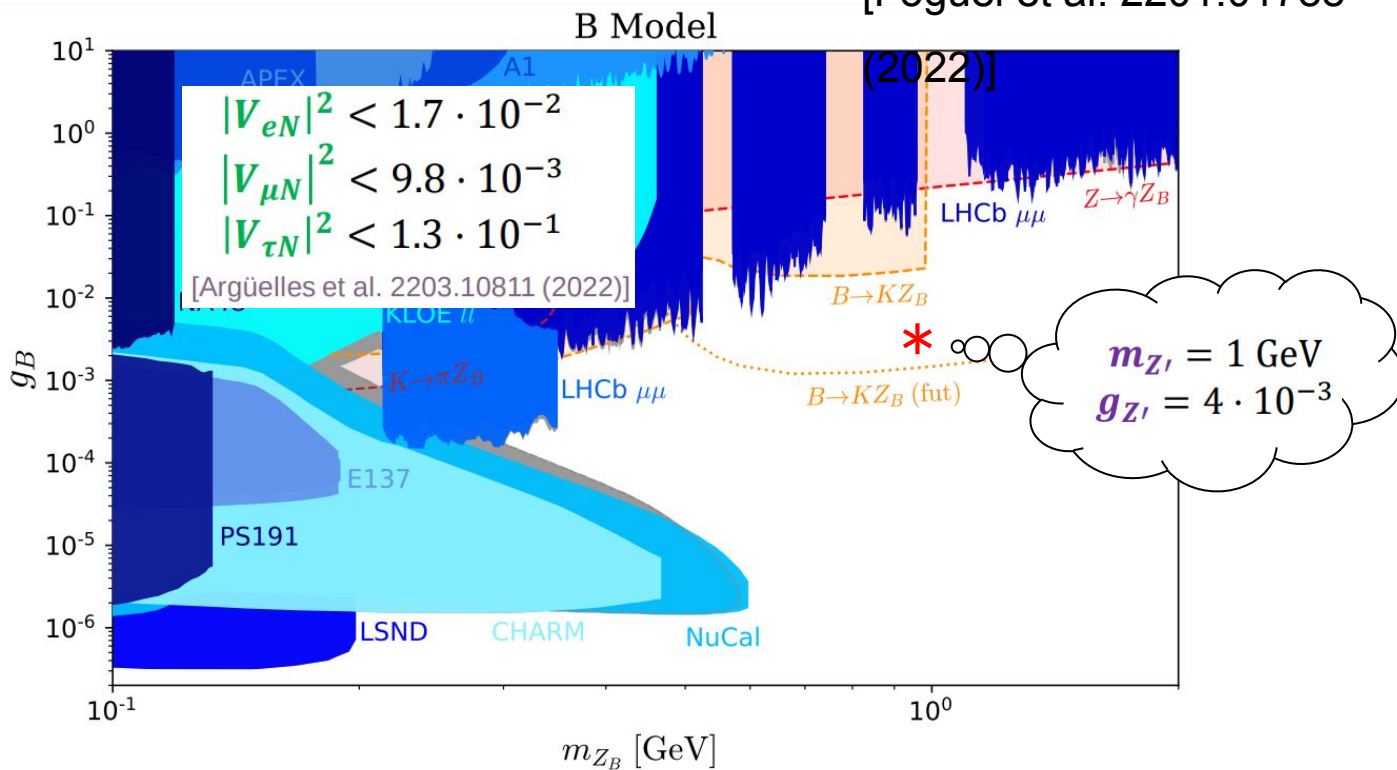
$$g_{Z'}, m_{Z'}$$

$$m_N, |V_{eN}|, |V_{\mu N}|, |V_{\tau N}|$$

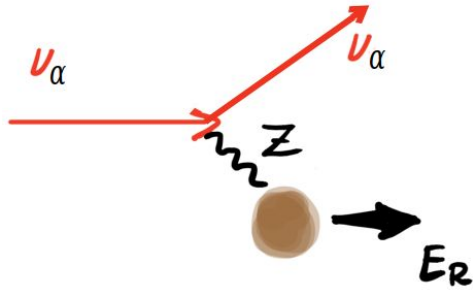
Sterile Baryonic Neutrino (SBN)

$$\mathcal{L} \supset \frac{m_{Z'}^2}{2} Z'^\mu Z'_\mu + g_b Z'^\mu \bar{\nu}_b \gamma_\mu \nu_b + \frac{1}{3} g_q Z'^\mu \sum_q \bar{q} \gamma_\mu q.$$

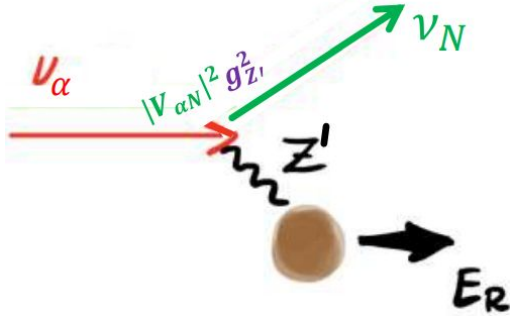
[Foguel et al. 2201.01788]



Predicted by the SM: [Freedman (1974)]



+



$$\frac{d\sigma_{\alpha 4}}{dE_R} = \frac{g_{Z'}^4 A^2 |U_{\alpha 4}|^2 M_N}{2\pi E_\nu^2 (2M_N E_R + m_{Z'}^2)^2} \left[4E_\nu^2 - 2E_R (M_N - E_R + 2E_\nu) - \frac{m_4^2}{M_N} (M_N - E_R - E_\nu) \right] F^2(E_R)$$

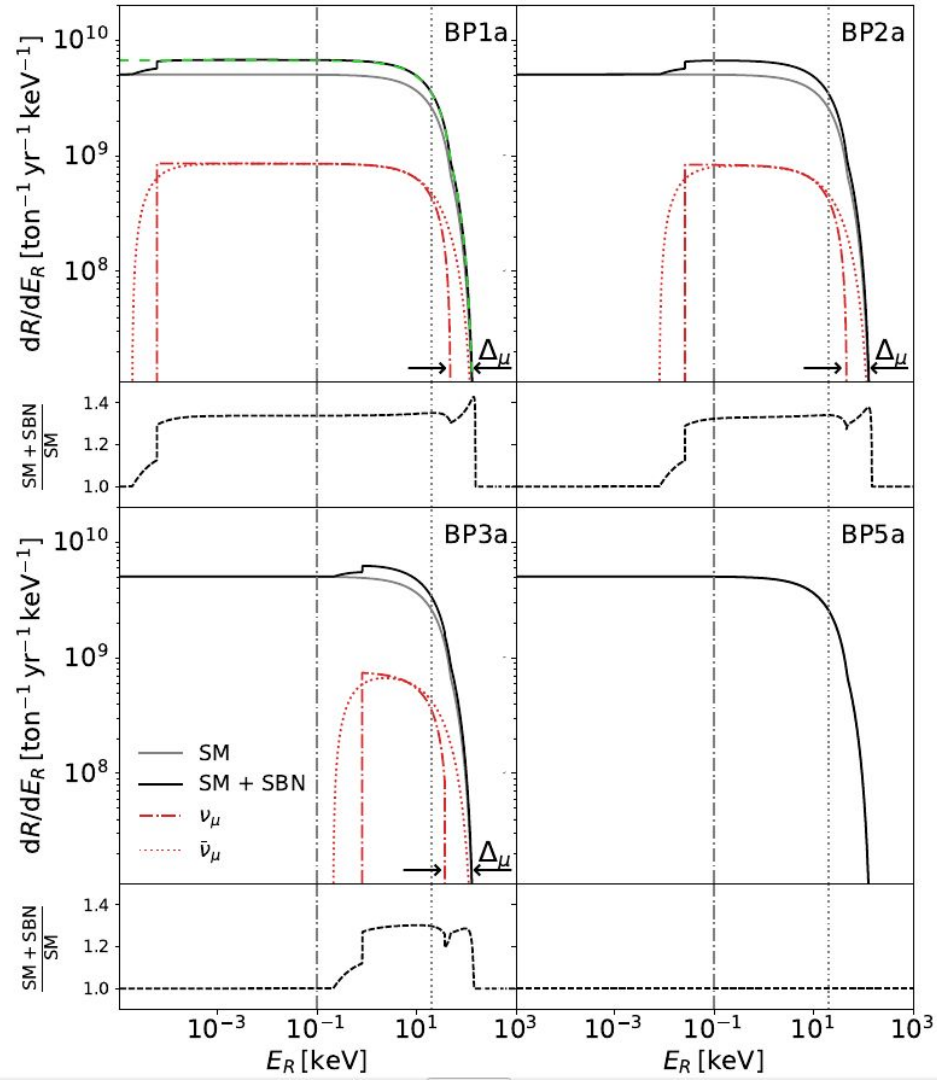
Results

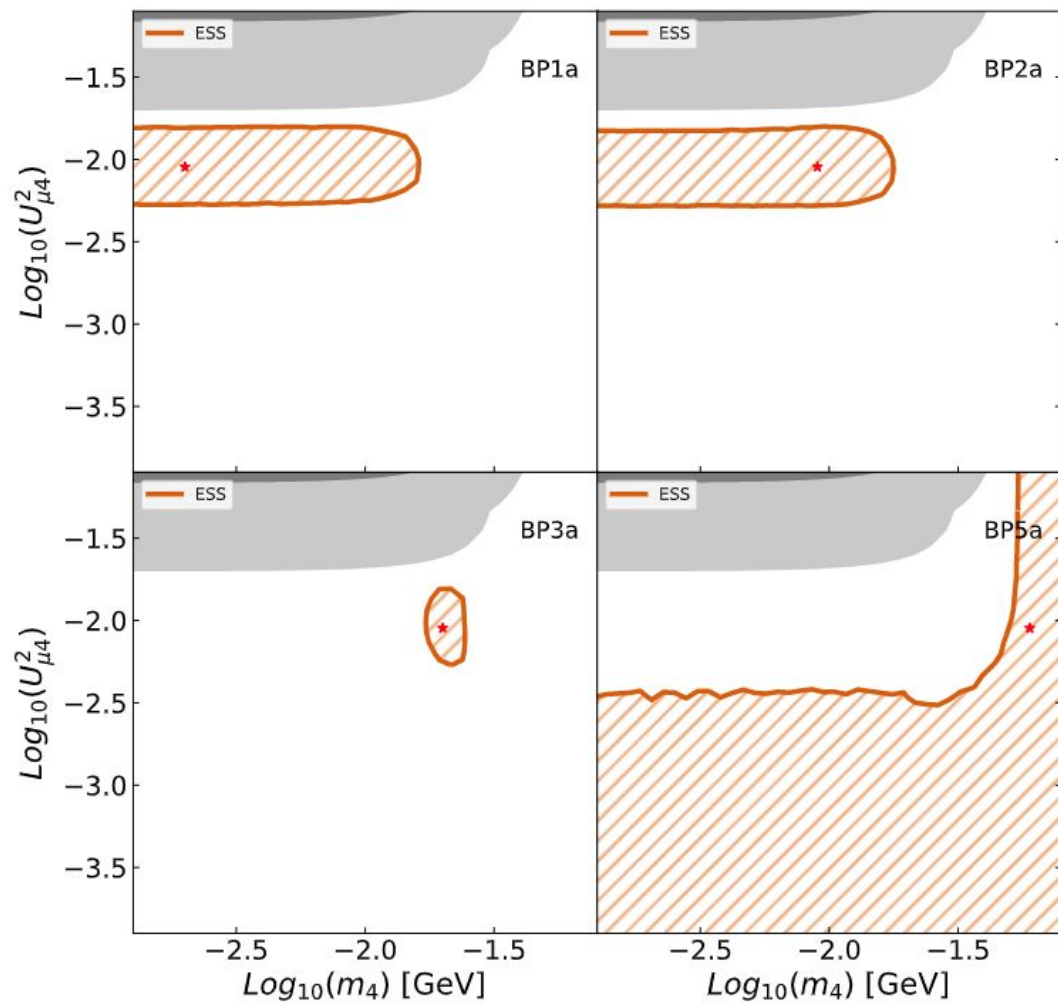
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- Sterile Baryonic Neutrino Model
- Results

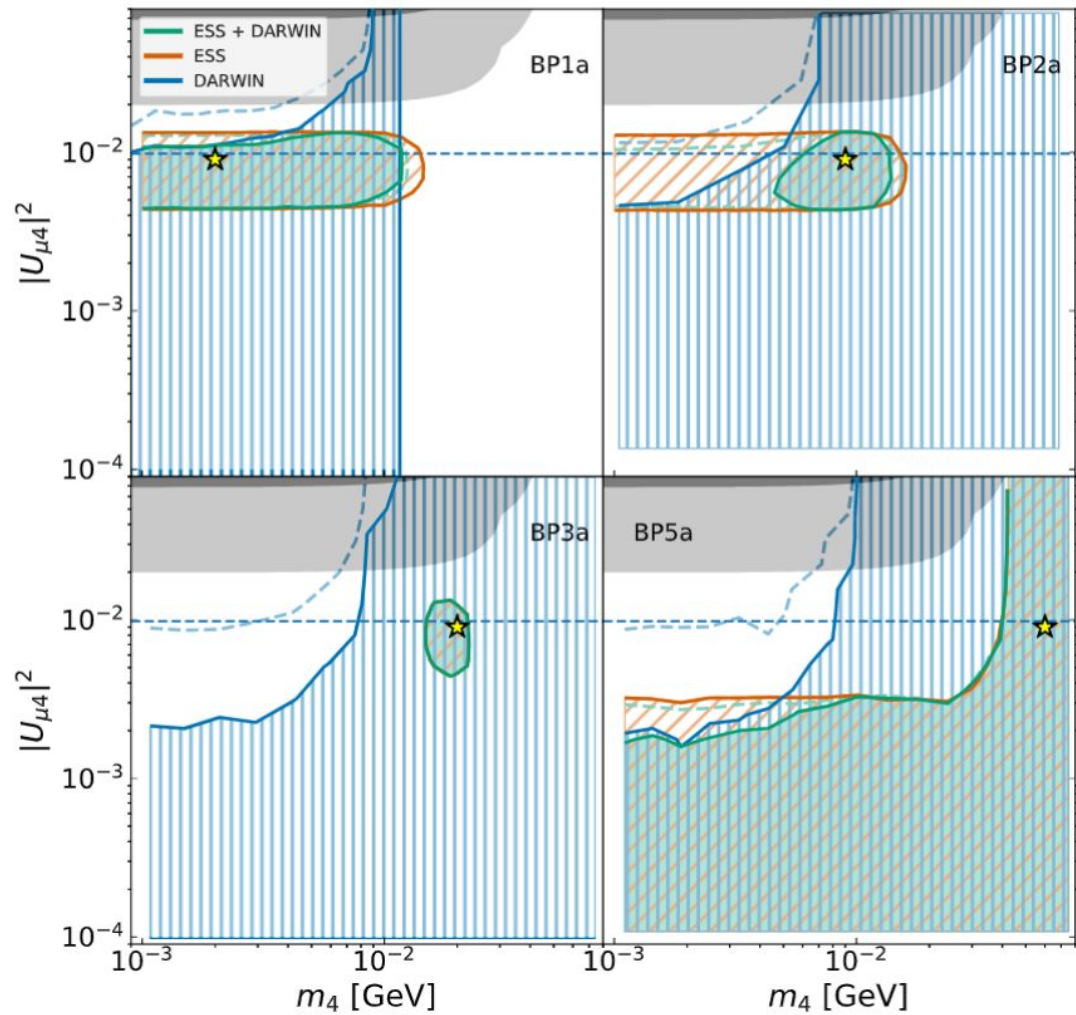
Let's study some
benchmark
points

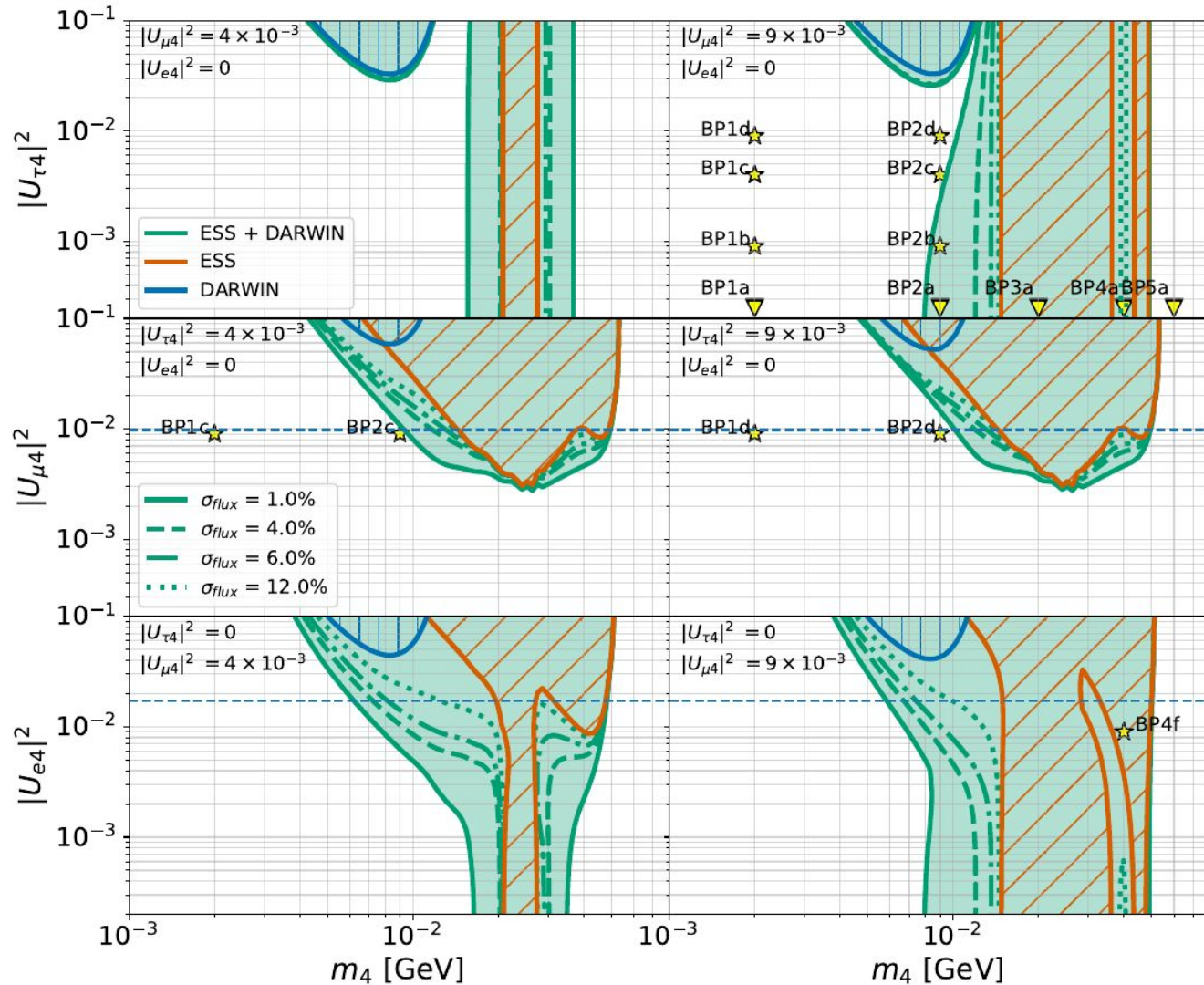
	m_4 [GeV]	$ U_{e4} ^2$	$ U_{\mu 4} ^2$	$ U_{\tau 4} ^2$
BP1a	2×10^{-3}	0	9×10^{-3}	0
BP1b	2×10^{-3}	0	9×10^{-3}	9×10^{-4}
BP1c	2×10^{-3}	0	9×10^{-3}	4×10^{-3}
BP1d	2×10^{-3}	0	9×10^{-3}	9×10^{-3}
BP1e	2×10^{-3}	9×10^{-3}	0	0
BP2a	9×10^{-3}	0	9×10^{-3}	0
BP2b	9×10^{-3}	0	9×10^{-3}	9×10^{-4}
BP2c	9×10^{-3}	0	9×10^{-3}	4×10^{-3}
BP2d	9×10^{-3}	0	9×10^{-3}	9×10^{-3}
BP3a	20×10^{-3}	0	9×10^{-3}	0
BP4a	40×10^{-3}	0	9×10^{-3}	0
BP4f	40×10^{-3}	9×10^{-3}	9×10^{-3}	0
BP5a	60×10^{-3}	0	9×10^{-3}	0

	m_4 [GeV]	$ U_{e4} ^2$	$ U_{\mu 4} ^2$	$ U_{\tau 4} ^2$
BP1a	2×10^{-3}	0	9×10^{-3}	0
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BP1e	2×10^{-3}	9×10^{-3}	0	0
BP2a	9×10^{-3}	0	9×10^{-3}	0
BP2b	9×10^{-3}	0	9×10^{-3}	9×10^{-4}
BP2c	9×10^{-3}	0	9×10^{-3}	4×10^{-3}
BP2d	9×10^{-3}	0	9×10^{-3}	9×10^{-3}
BP3a	20×10^{-3}	0	9×10^{-3}	0
BP4a	40×10^{-3}	0	9×10^{-3}	0
BP4f	40×10^{-3}	9×10^{-3}	9×10^{-3}	0
BP5a	60×10^{-3}	0	9×10^{-3}	0









Conclusions

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- Results
- Conclusions

- Sterile neutrino models can be probed with Spallation Source (SS) and Direct Detection (DD) experiments.
- DD will be able to access to very low recoil energies, all the neutrino flavours but not big masses.
- SS will be able to access to heavier sterile neutrinos but not to all neutrino flavours.
- Combining DD and SS may help...
 - improving the significance,
 - constraining the parameter space
 - allowing parameter reconstruction (especially in the couplings),
 - and allowing model discrimination (Sterile Baryonic Neutrino).



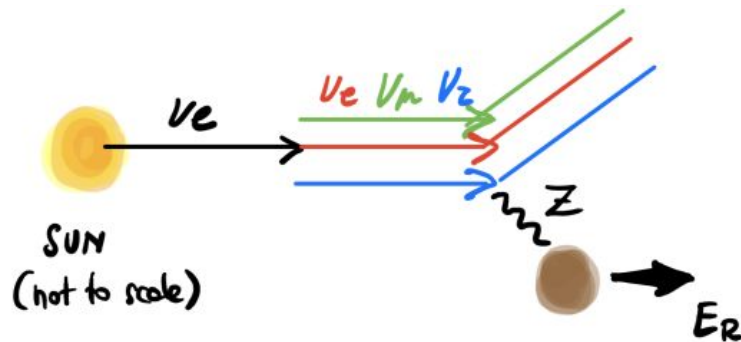
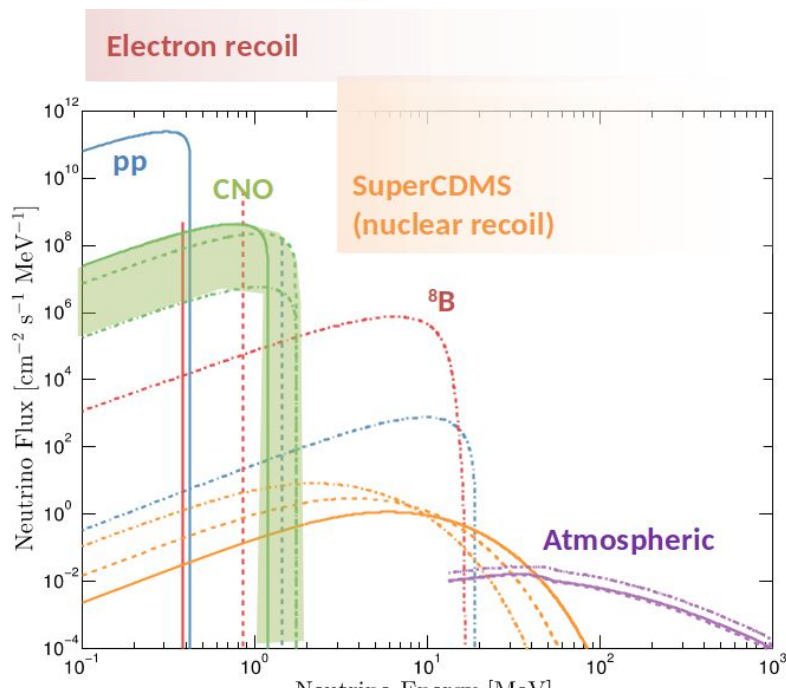
THANK YOU

Back up

CE ν NS @ DM Direct Detection Experiments

$$\frac{dR}{dE_R} = n_T \sum_{\nu_\alpha} \int_{E_\nu^{\min}} \frac{d\phi_{\nu_e}}{dE_\nu} P(\nu_e \rightarrow \nu_\alpha) \frac{d\sigma_{\nu_\alpha T}}{dE_R} dE_\nu$$

Xenon, LZ,
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Sterile Baryonic Neutrino (SBN)

Pospelov 1103.3261 (2011)]

$$\mathcal{L} \supset \frac{m_{Z'}^2}{2} Z'^\mu Z'_\mu + g_b Z'^\mu \bar{\nu}_b \gamma_\mu \nu_b + \frac{1}{3} g_q Z'^\mu \sum_q \bar{q} \gamma_\mu q .$$

Z'^μ : baryonic vector boson $U(1)_B$ ($m_{Z'}$)

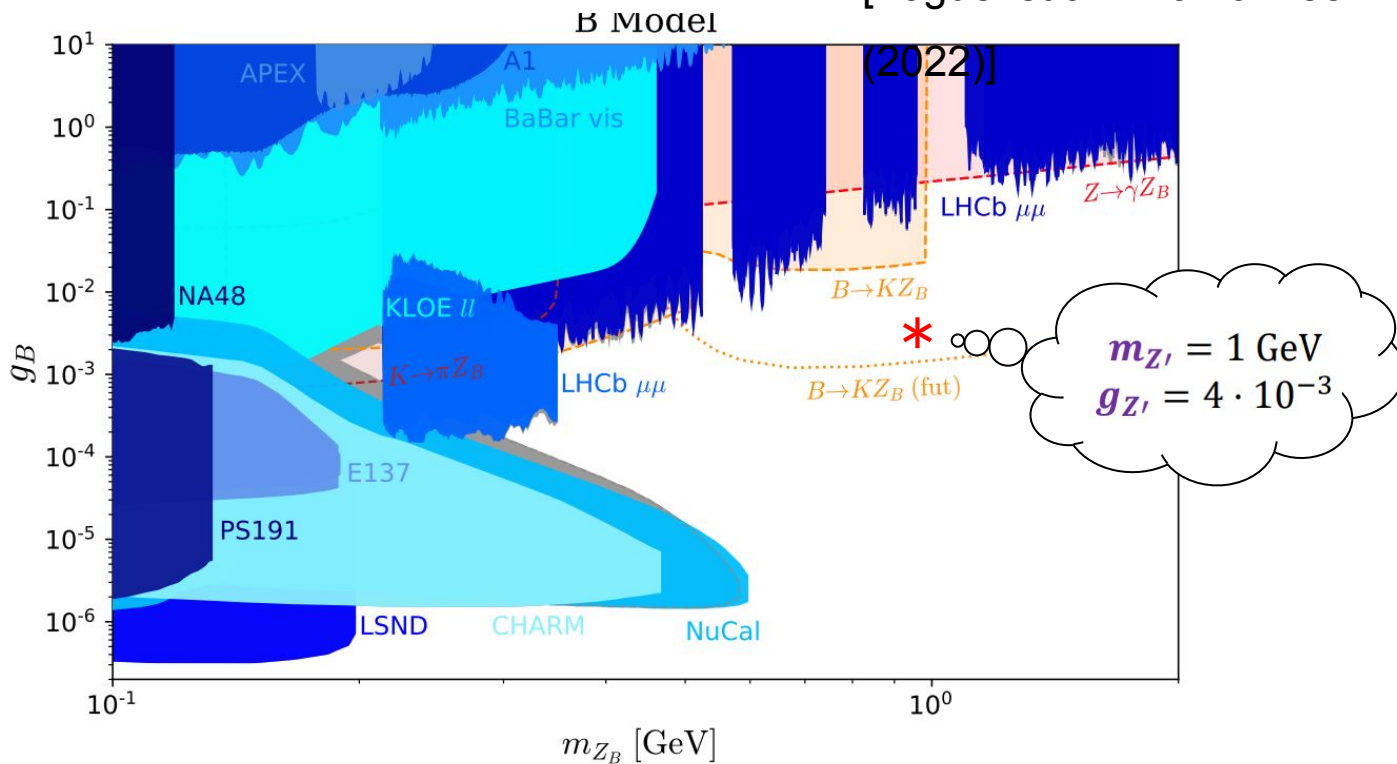
g_b : $U(1)_B$ gauge coupling

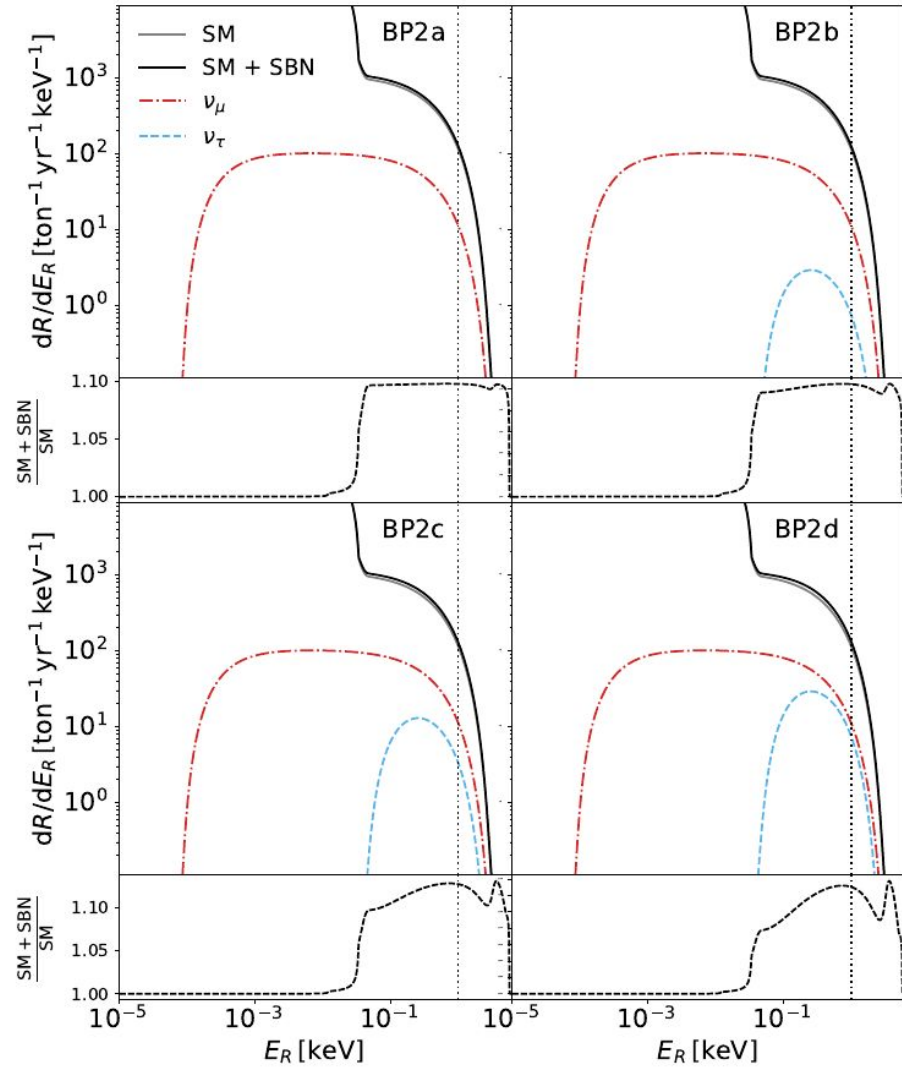
ν_N : sterile baryonic neutrino (m_N)

Sterile Baryonic Neutrino (SBN)

$$\mathcal{L} \supset \frac{m_{Z'}^2}{2} Z'^\mu Z'_\mu + g_b Z'^\mu \bar{\nu}_b \gamma_\mu \nu_b + \frac{1}{3} g_q Z'^\mu \sum_q \bar{q} \gamma_\mu q.$$

[Foguel et al. 2201.01788





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	m_4 [GeV]	$ U_{e4} ^2$	$ U_{\mu 4} ^2$	$ U_{\tau 4} ^2$
BP1a	2×10^{-3}	0	9×10^{-3}	0
BP1b	2×10^{-3}	0	9×10^{-3}	9×10^{-4}

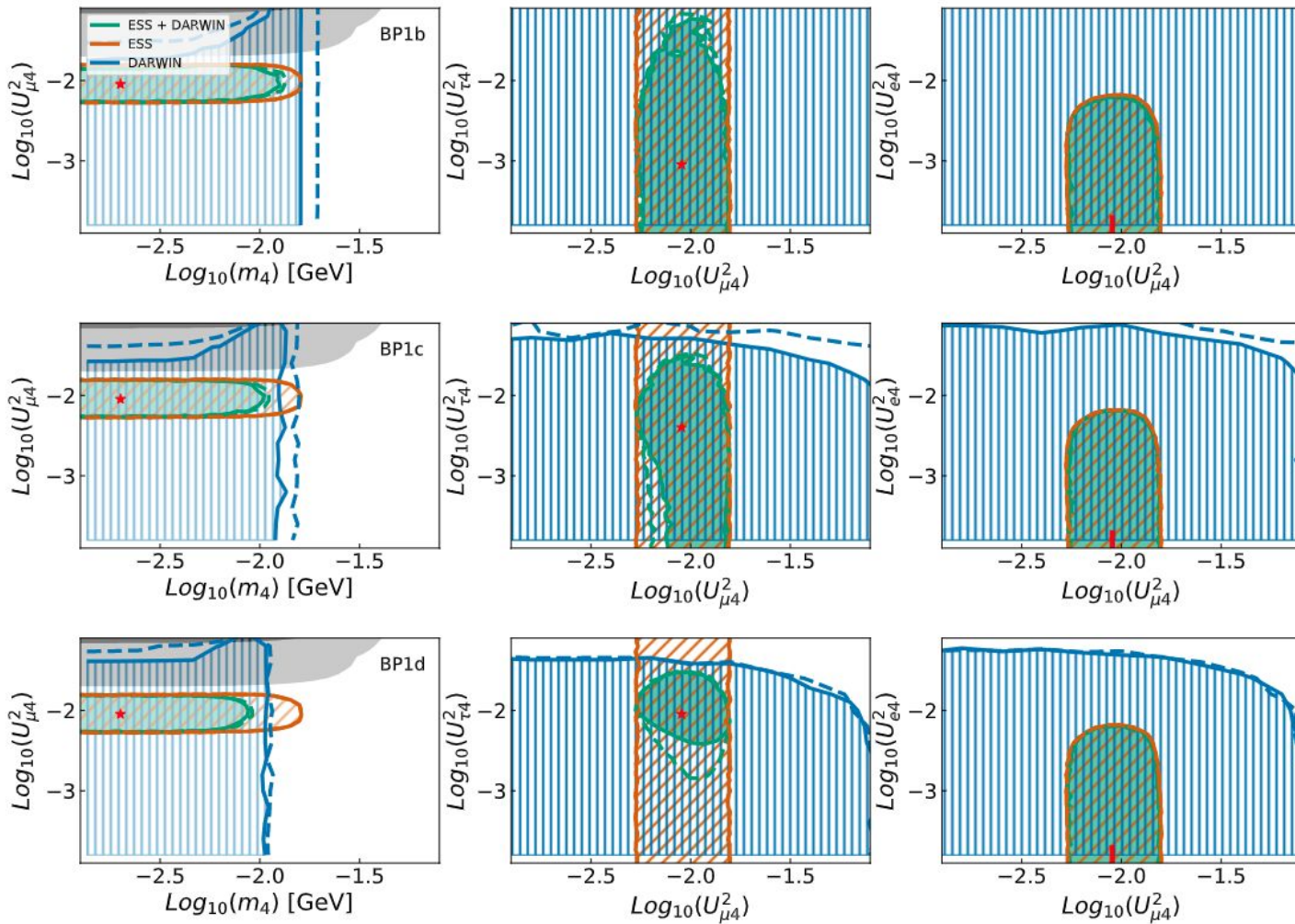
Experiment	M_{det} (ton)	E_{th} (keV _{nr})	N_{POT} ($\times 10^{23}$)	r	L (m)	σ_{sys}
ESS	1	20	2.8	0.3	20	5%

BP2b	9×10^{-3}	0	9×10^{-3}	9×10^{-4}
BP2c	9×10^{-3}	0	9×10^{-3}	4×10^{-3}

Experiment	M_{det} (ton)	E_{th} (keV _{nr})	σ_{8B}
DARWIN	200	1	1(4)%

BP4f	40×10^{-3}	9×10^{-3}	9×10^{-3}	0
BP5a	60×10^{-3}	0	9×10^{-3}	0

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BP1e	2×10^{-3}	9×10^{-3}	0	0
BP2a	9×10^{-3}	0	9×10^{-3}	0
BP2b	9×10^{-3}	0	9×10^{-3}	9×10^{-4}
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