# Direct Detection and Spallation Experiments to test the Neutrino Dipole Portal

**DAVID ALONSO-GONZÁLEZ**

with D.W.P. Amaral, A. Bariego Quintana, D.G. Cerdeño, P. Coloma & M. de los Ríos

19th MultiDark Consolider Workshop (May 23rd, Miraflores de la Sierra)

Instituto de Física Teórica UAM-CSIC

Universidad Autónoma de Madrid

MultiDark Multimessenger Approach for Dark Matter Detection

Work in **progress!**

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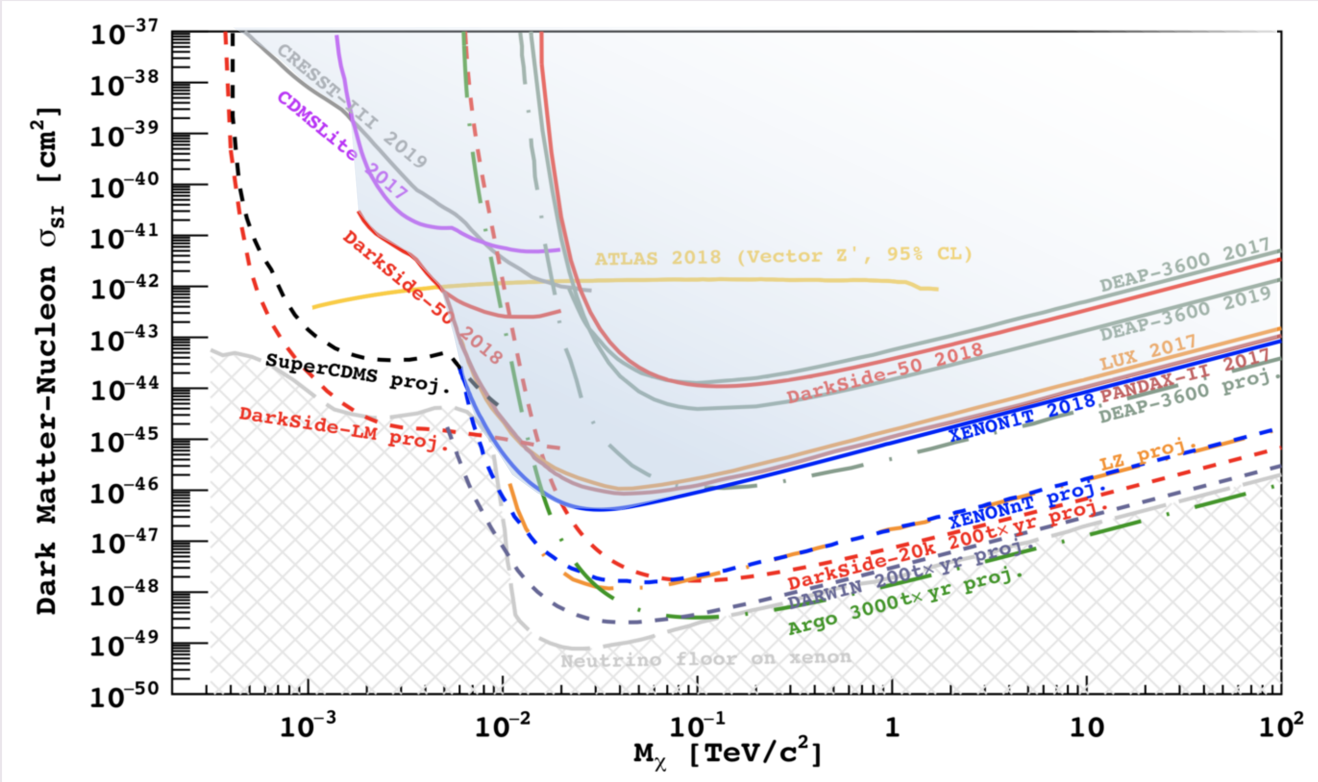

Dark Matter-Nucleon $\sigma_{SI}$ [cm$^2$]
$M_\chi$ [TeV/c$^2$]
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ATLAS 2018 (Vector Z', 95% CL)
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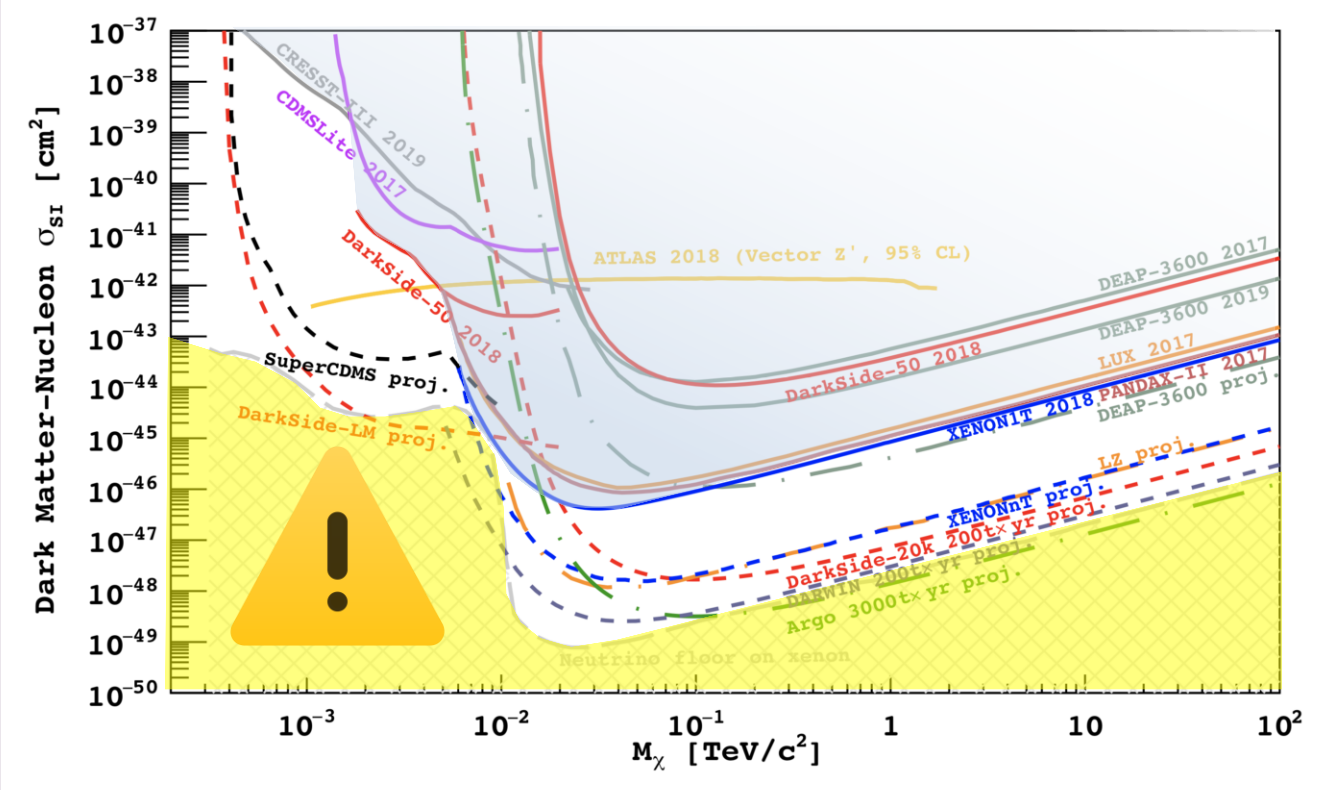
Neutrino floor on xenon



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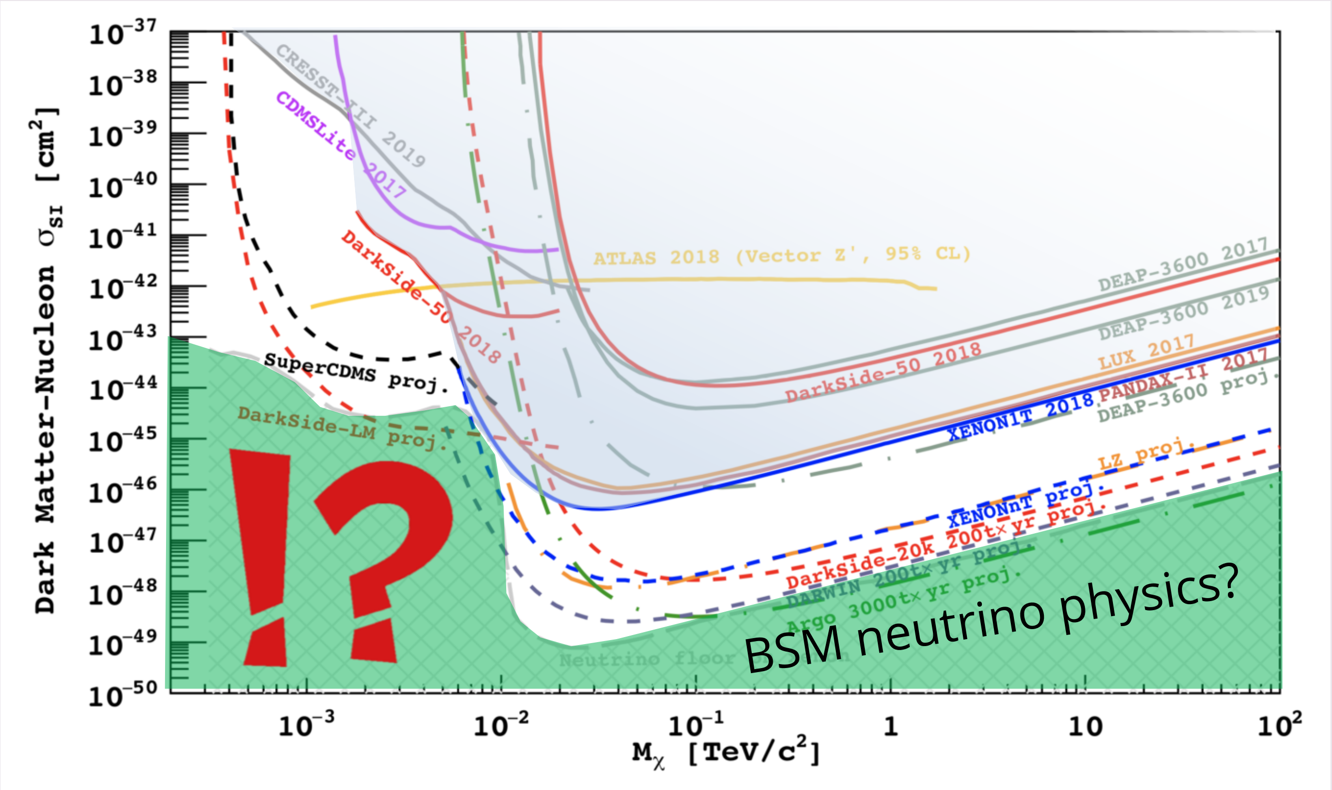
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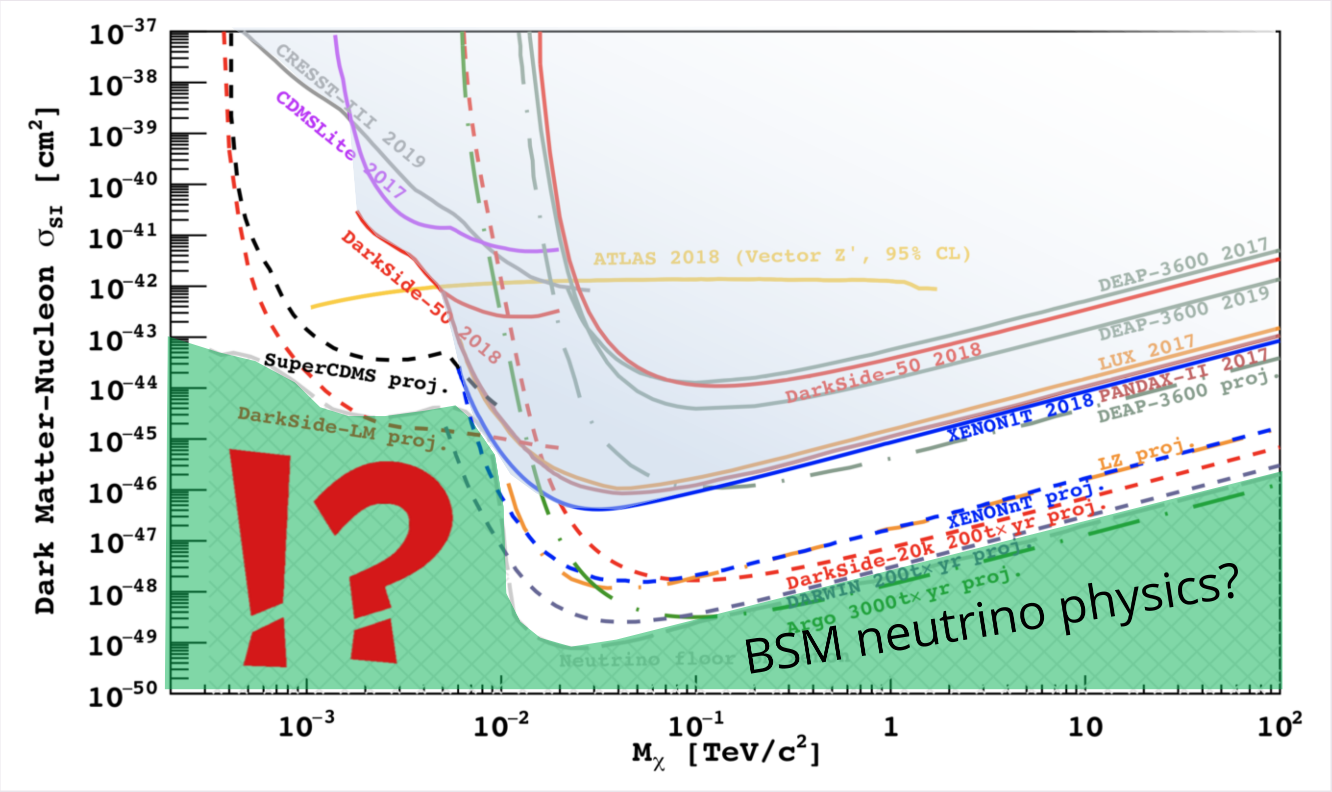
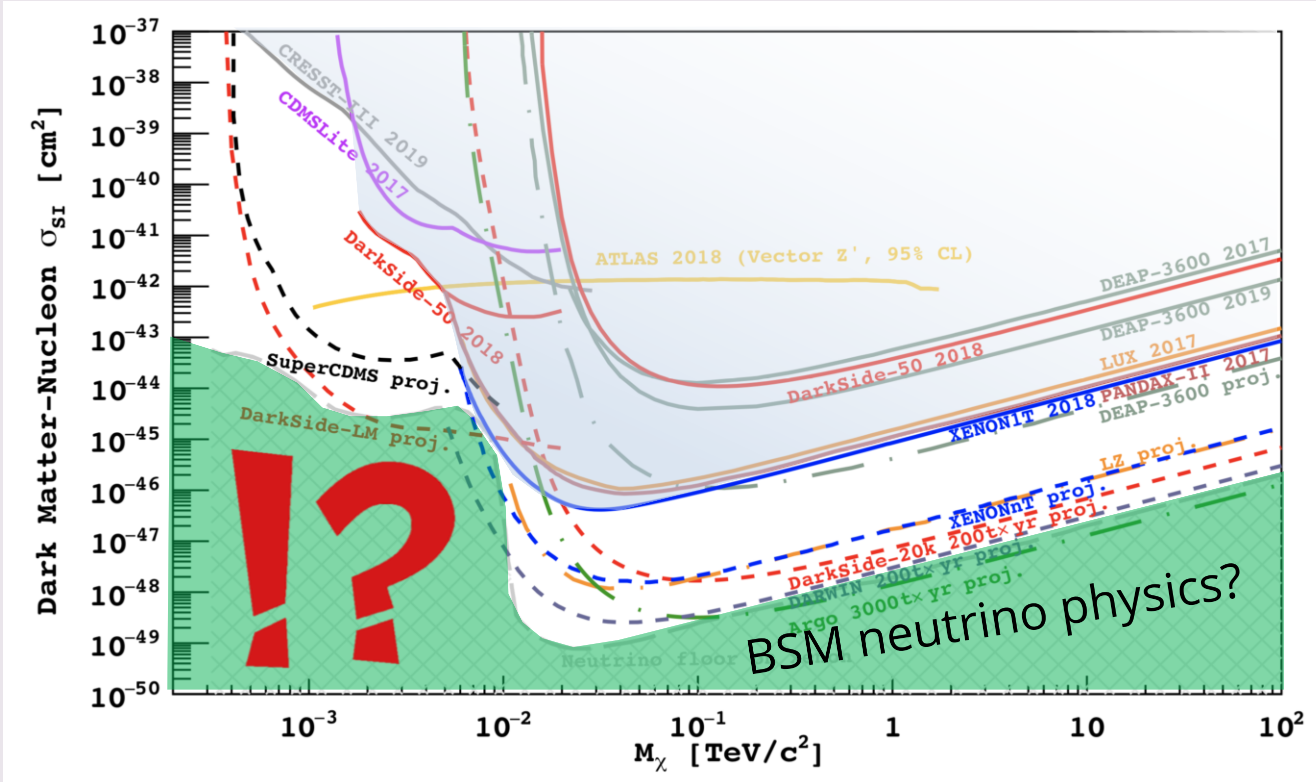
BSM neutrino physics?




# The **Neutrino Dipole Portal (NDP)** [Magill et al. 1803.03262 (2018)]

$$\mathcal{L}_{NDP} \supset \overline{N_R}\left(i\gamma^\mu\partial_\mu - m_4\right)N_R + d\left(\bar{\nu}_L^\alpha\sigma_{\mu\nu}F^{\mu\nu}N_R\right) + h.c.$$

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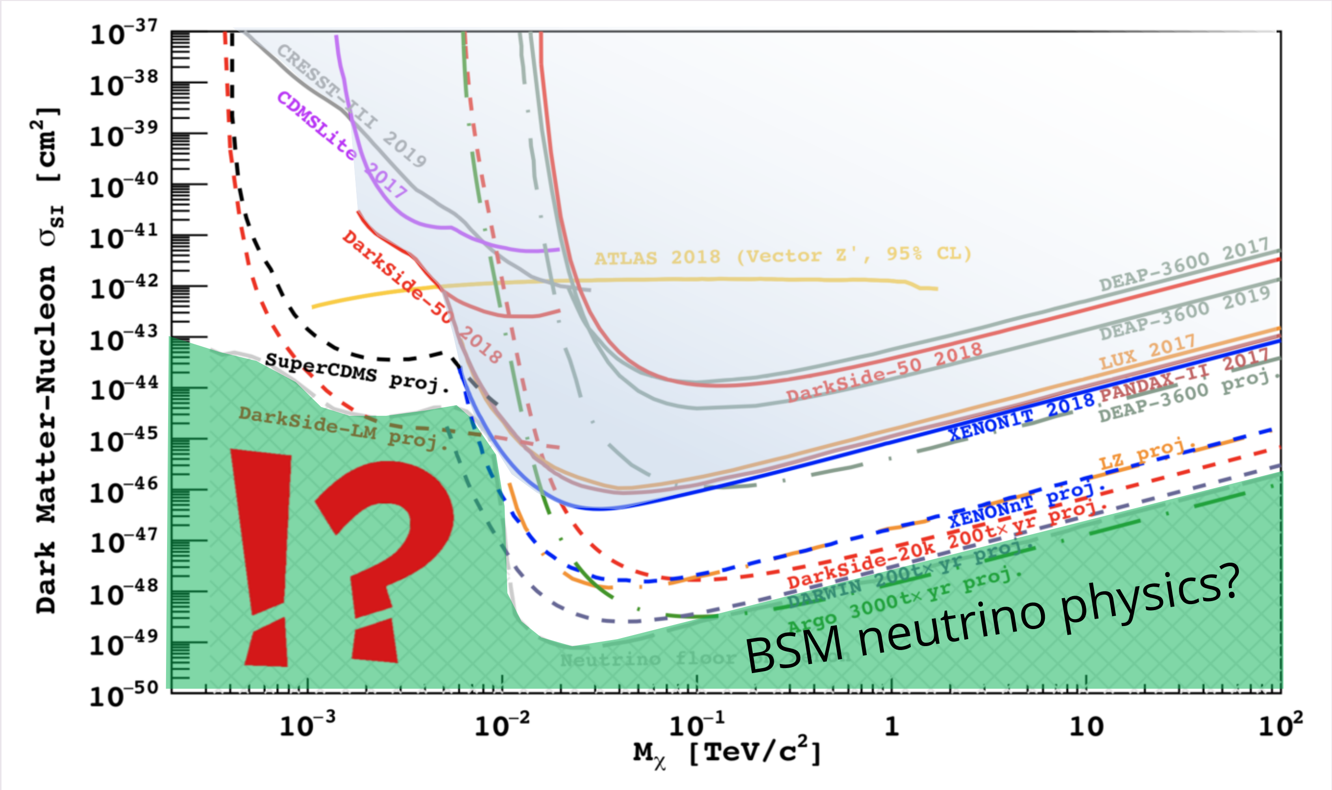


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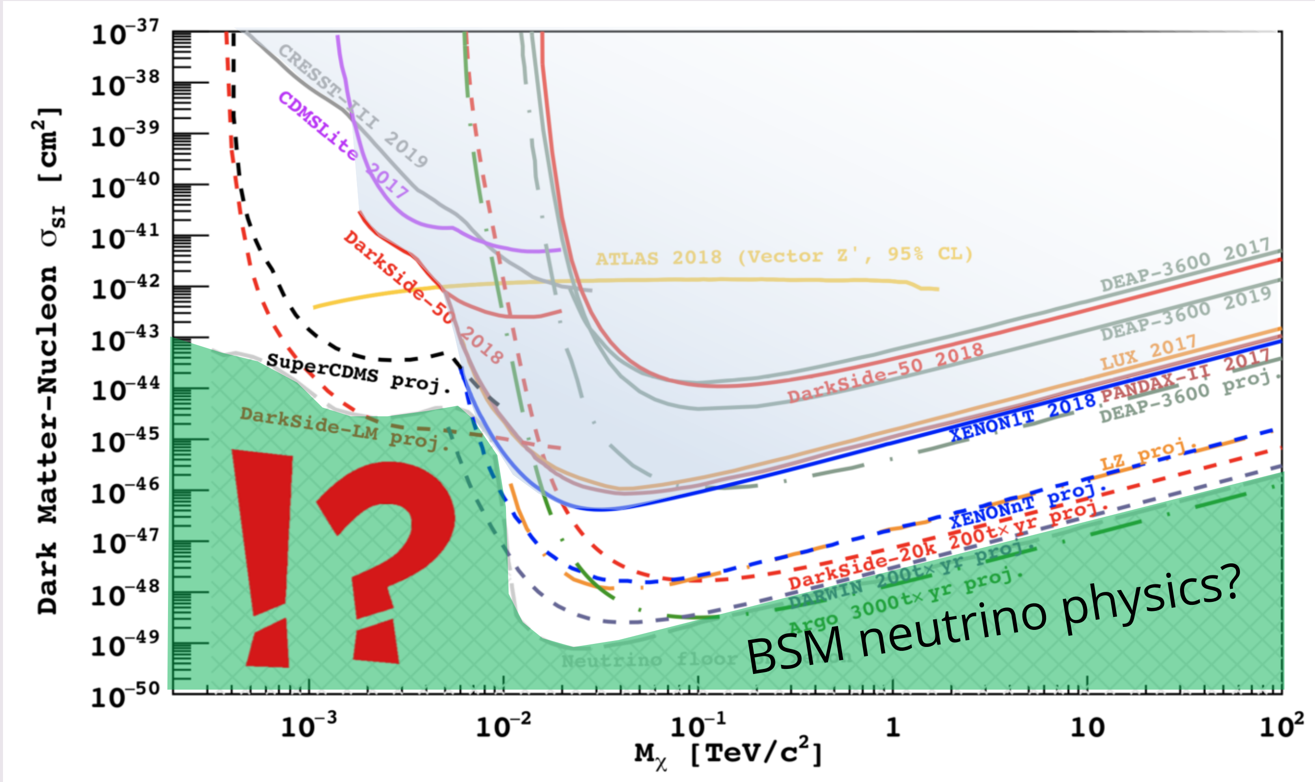


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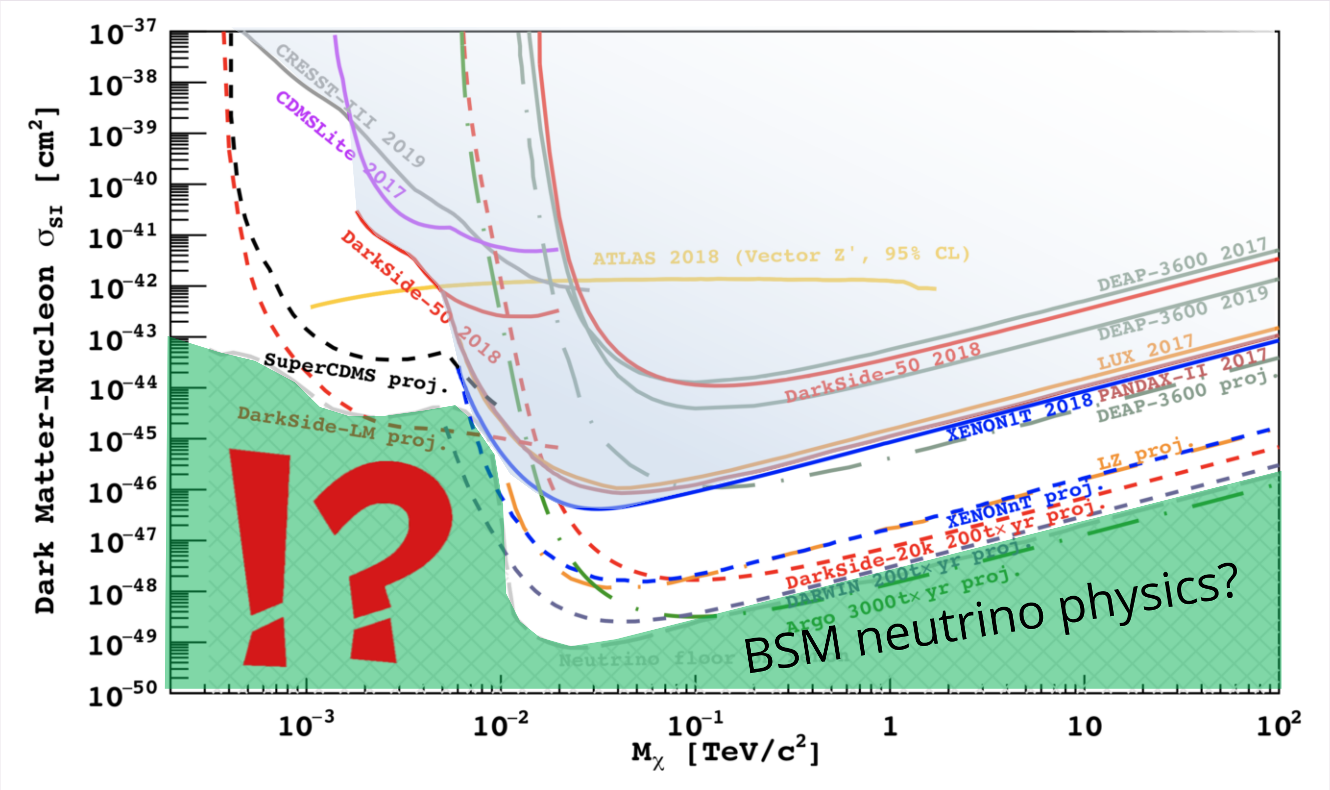


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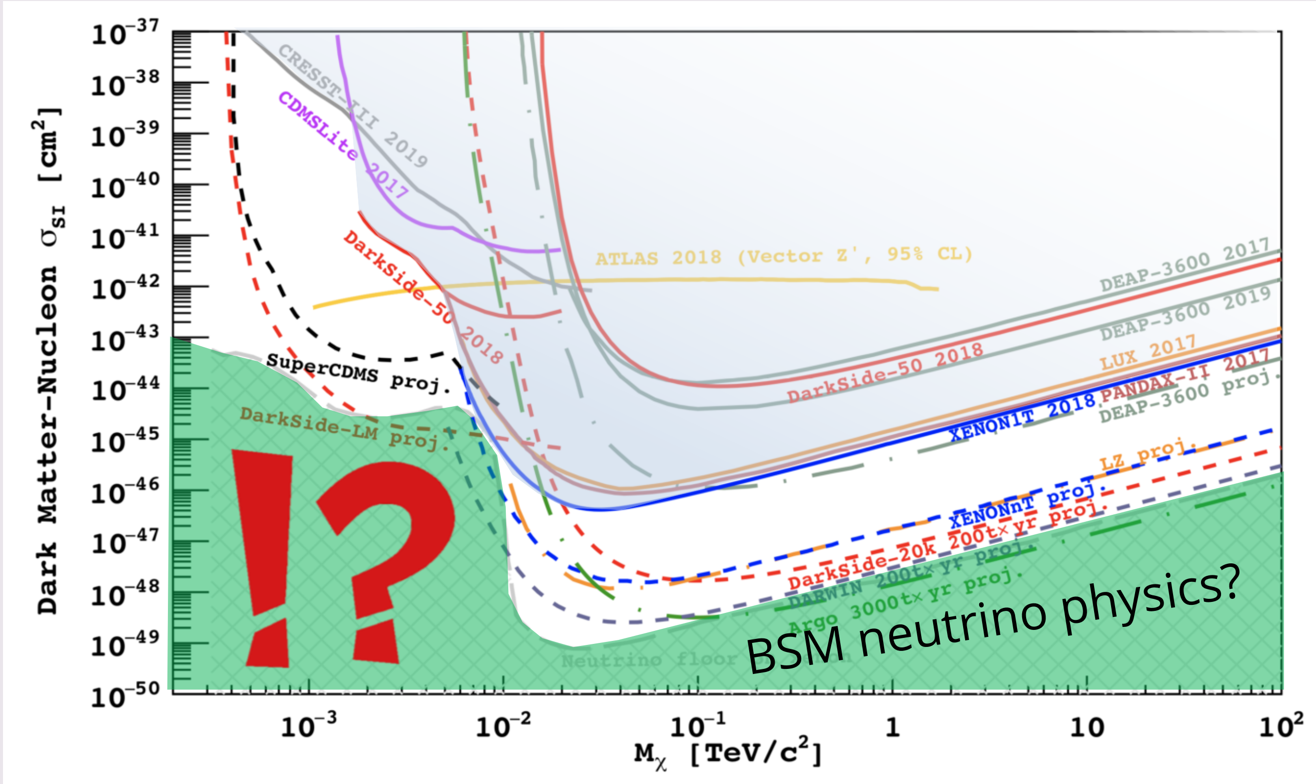


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# Coherent Elastic Neutrino – Nucleus Scattering

…or **CE$\nu$NS** for friends

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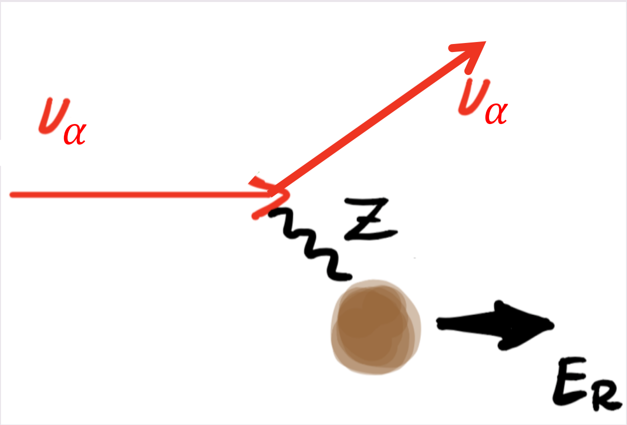

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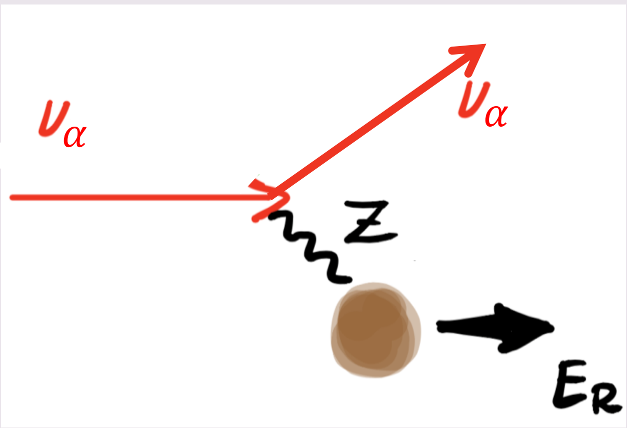


Predicted by the SM…

[Freedman (1974)]

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

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

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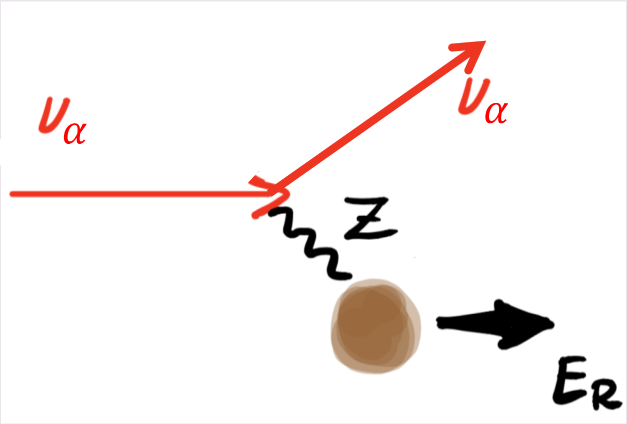


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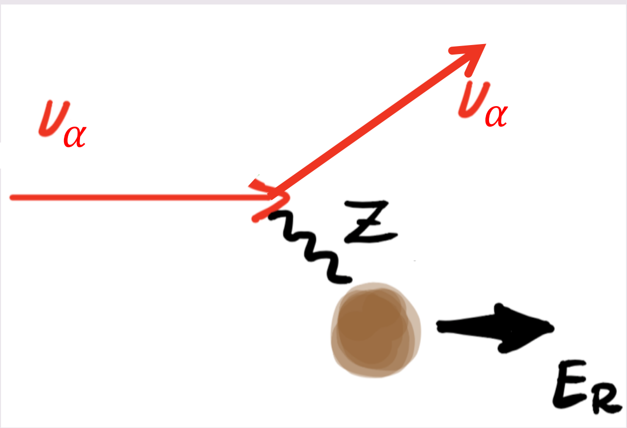


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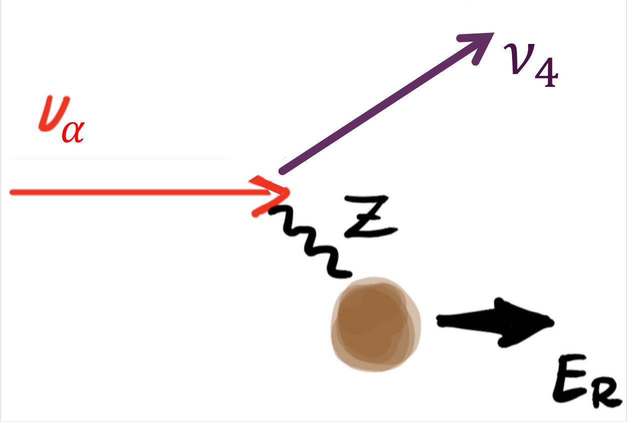


NDP predicts **upscattering** process:

[Shoemaker et al. 1811.12435 (2018)]

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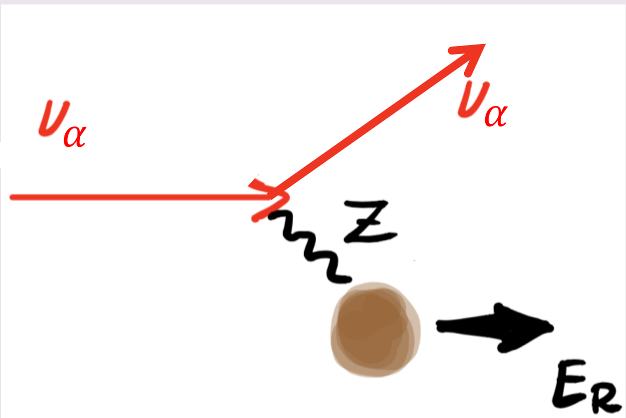


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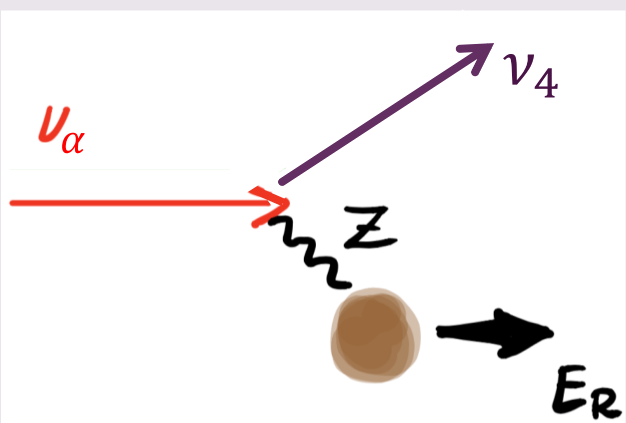


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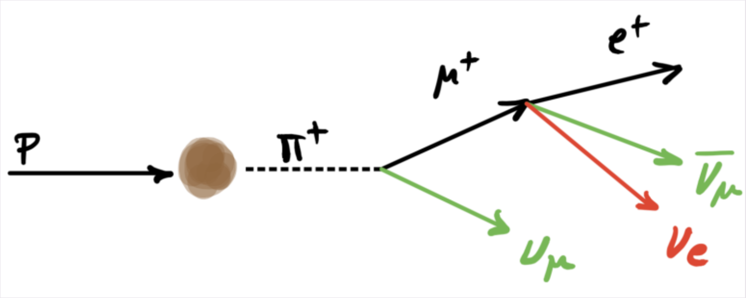
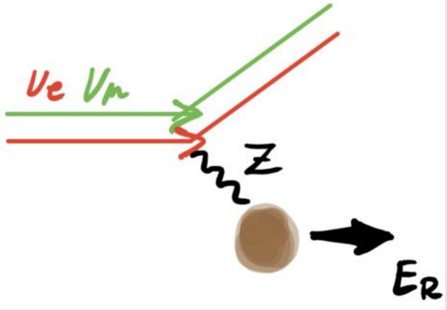
that may **modify** the expected **recoil spectrum!**

# **CE$\nu$NS** at Spallation Sources

## like **COHERENT**




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

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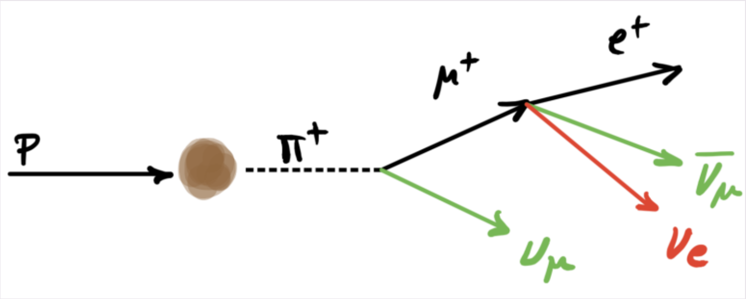


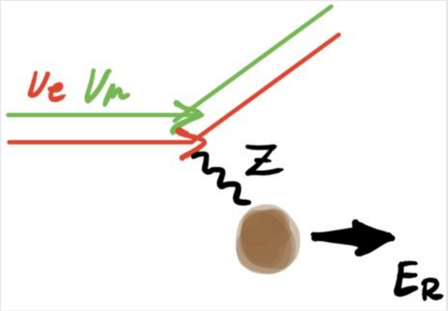


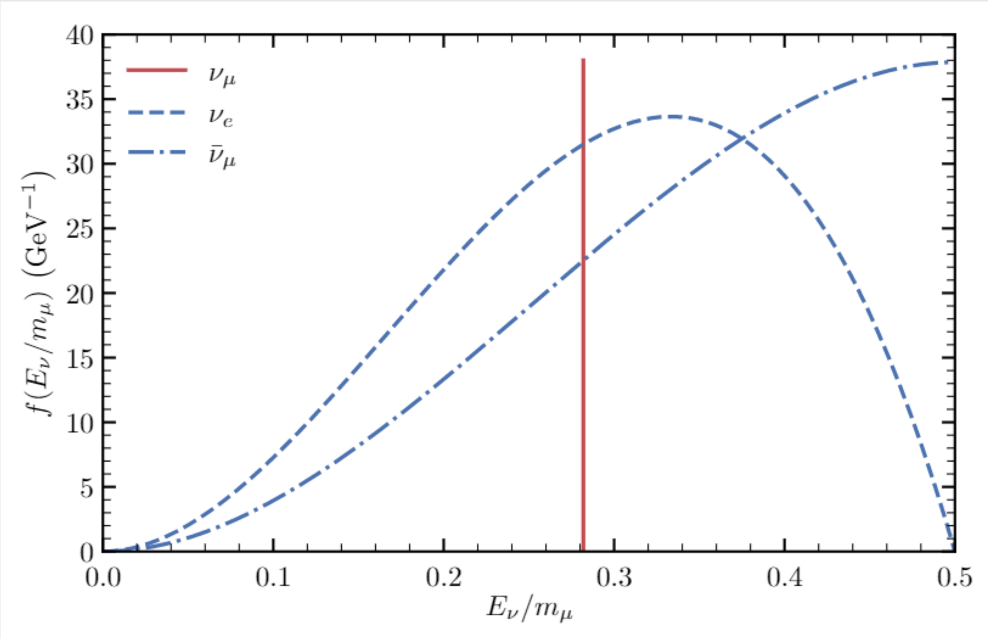


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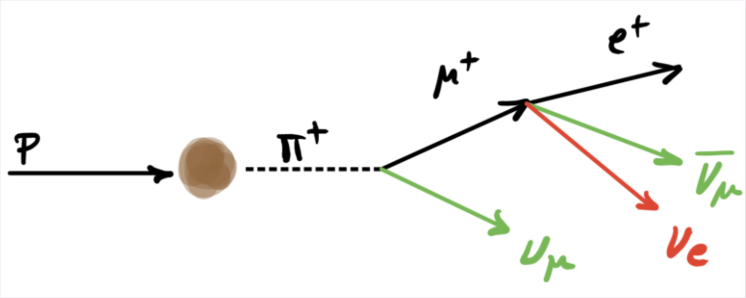


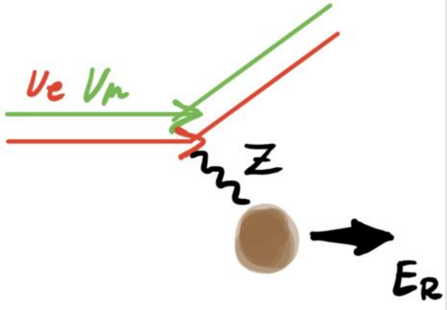


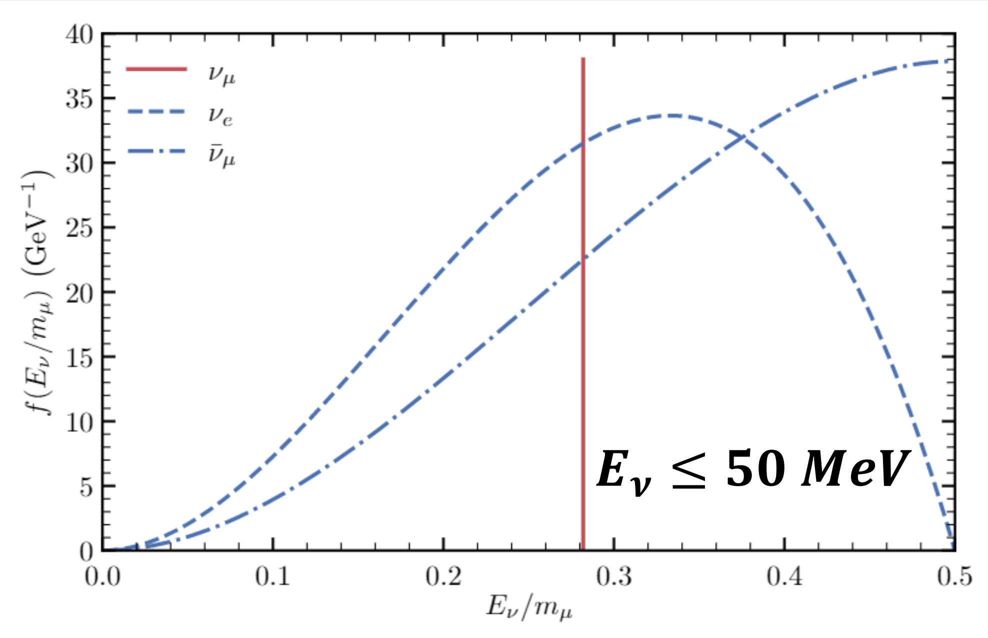


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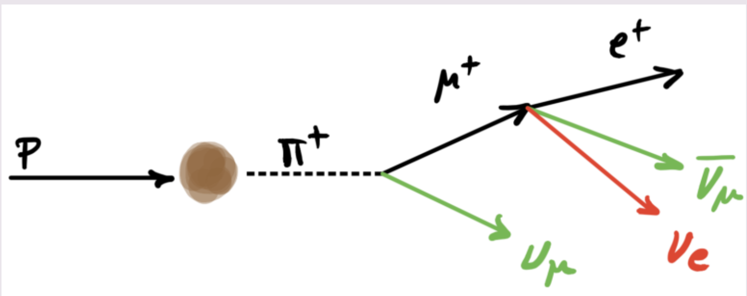
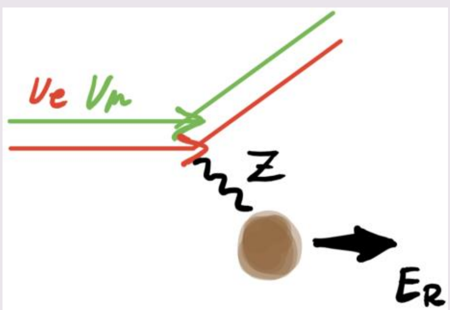
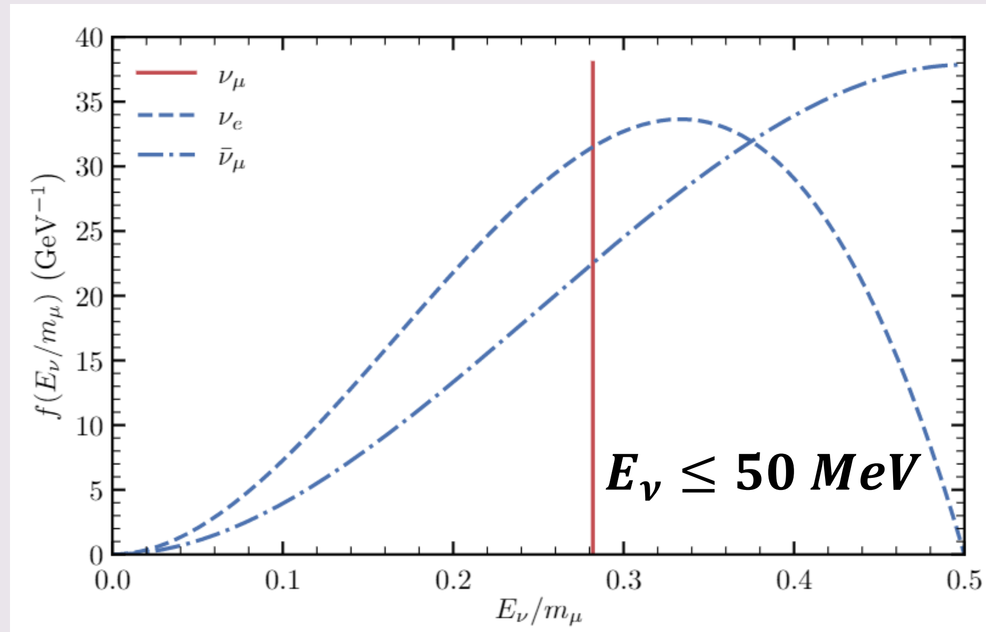


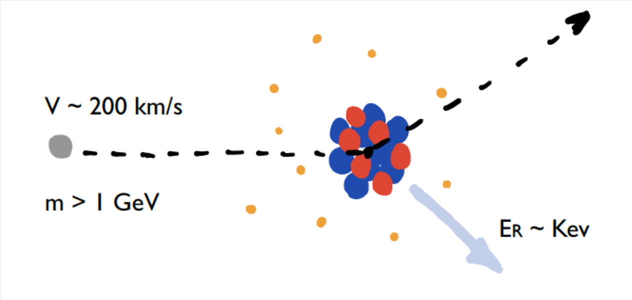

[Miranda et al. 2008.02759 (2020)]

| Experiment | Mass [ton] | $E_{th}$ [keV$_{nr}$] | NPOT [$10^{23}$/yr] | r | $L$ [$m$] | $\sigma_{sys}$ |
|---|---|---|---|---|---|---|
| CENNS610 | 0.61 | $\sim 20$ | 1.5 | 0.08 | 28.4 | 8.5% |
| ESS10 | 0.01 | 0.1 | 2.8 | 0.3 | 20 | 5% |
| CCM | 7 | 10 | 0.177 | 0.0425 | 20 | 5% |
| ESS | 1 | 20 | 2.8 | 0.3 | 20 | 5% |

not low enough thresholds

# **CE$\nu$NS** at Direct Detection

$$\frac{\mathrm{d}R}{\mathrm{d}E_R} = n_T \sum_{\nu_\alpha} \int_{E_\nu^{\min}} \frac{\mathrm{d}\phi_{\nu_e}}{\mathrm{d}E_\nu} \, P(\nu_e \to \nu_\alpha) \, \frac{\mathrm{d}\sigma_{\nu_\alpha T}}{\mathrm{d}E_R} \, \mathrm{d}E_\nu$$



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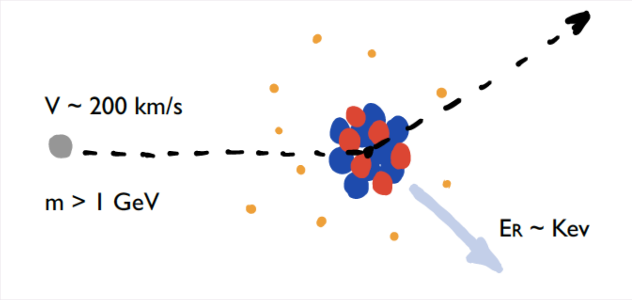


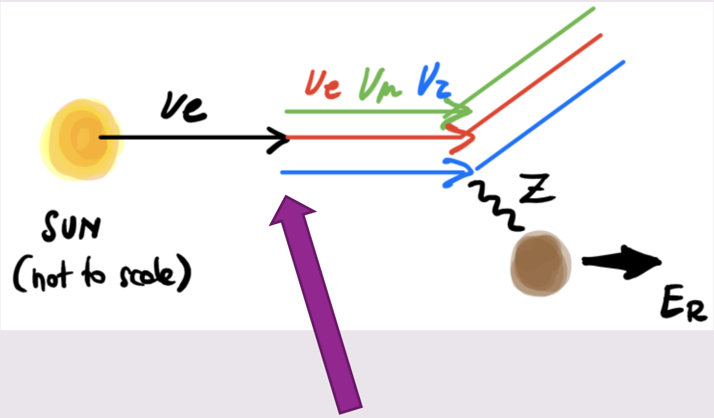


Neutrino oscillations

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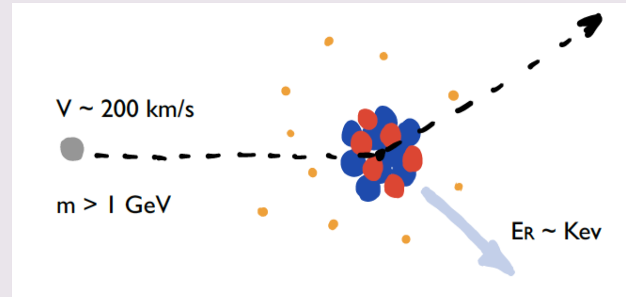


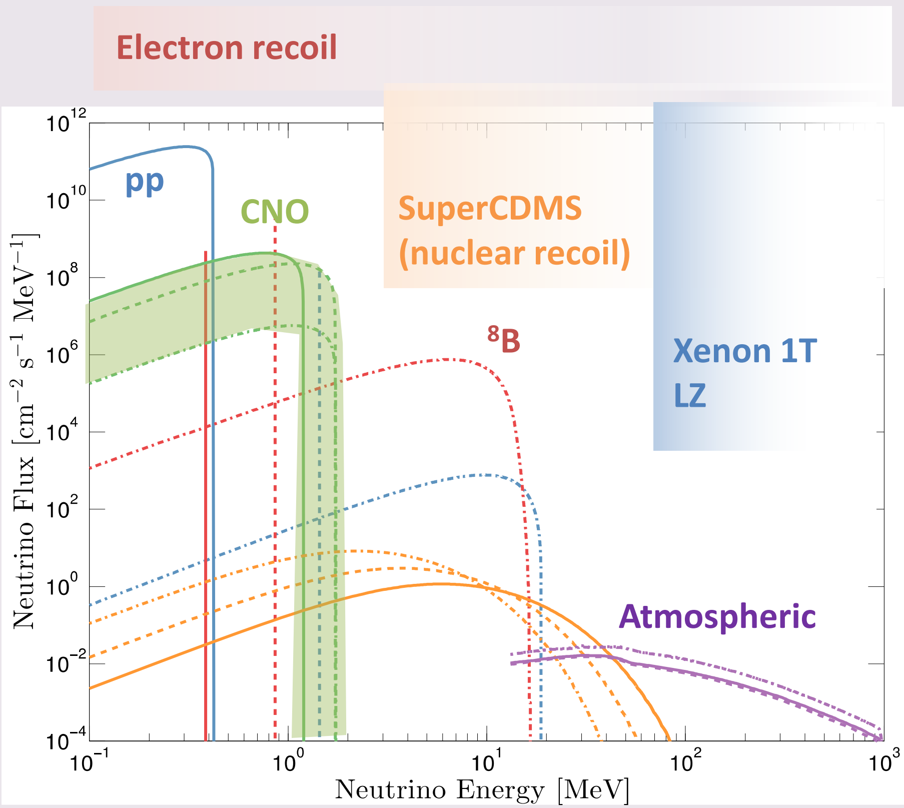


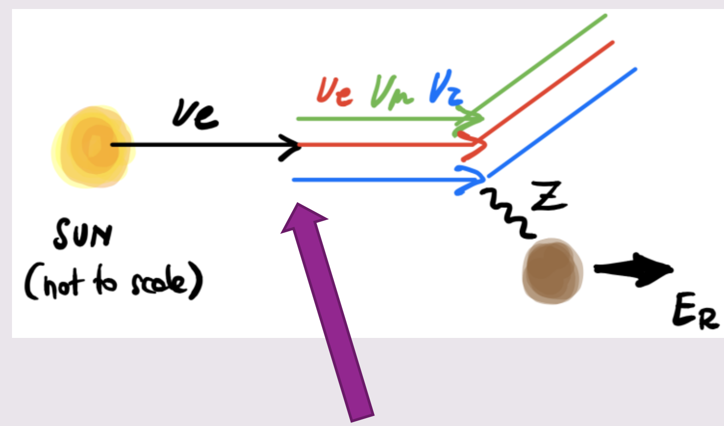


**Neutrino oscillations**

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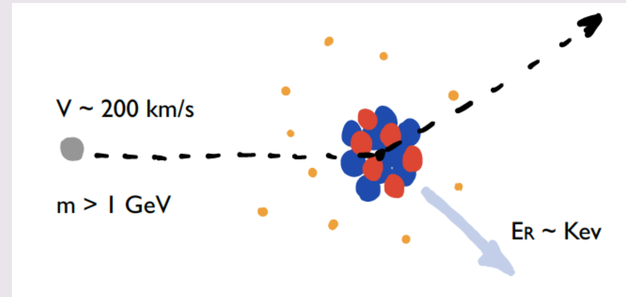


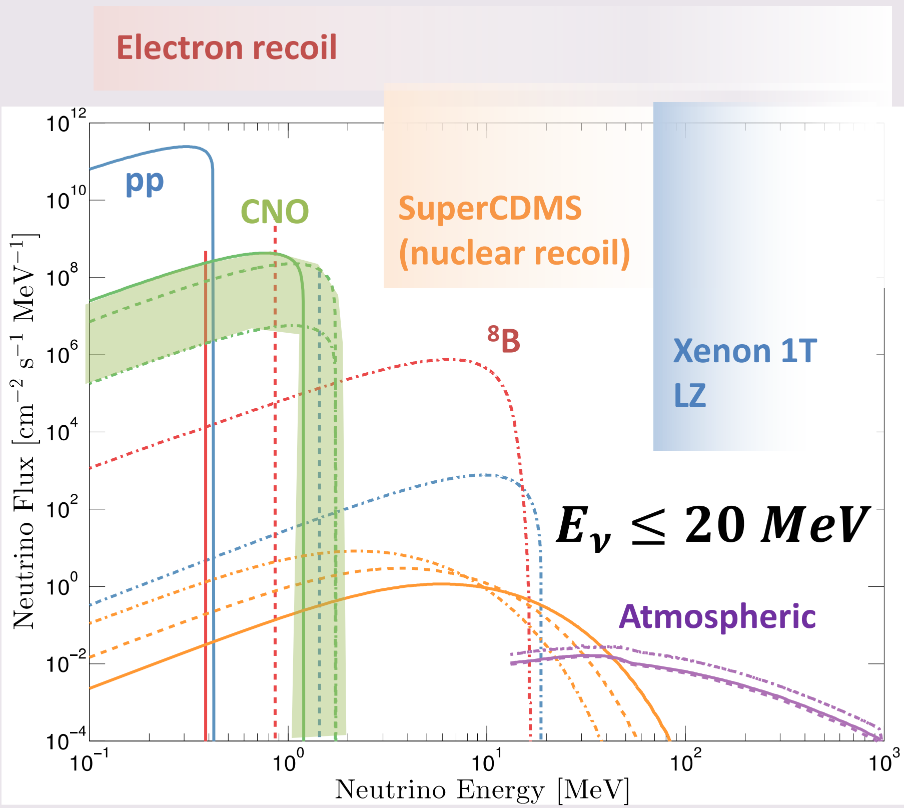


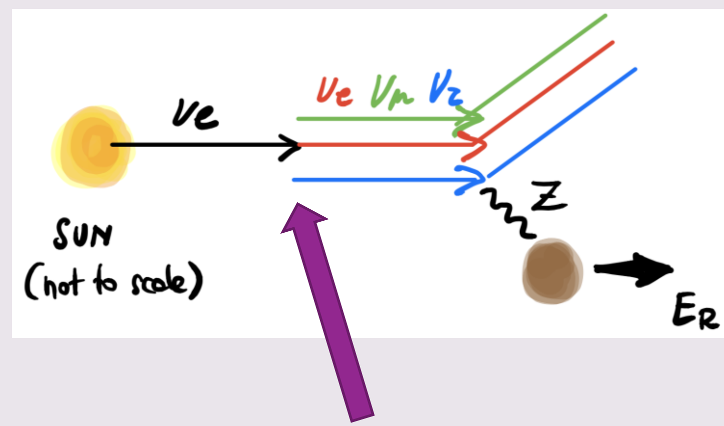


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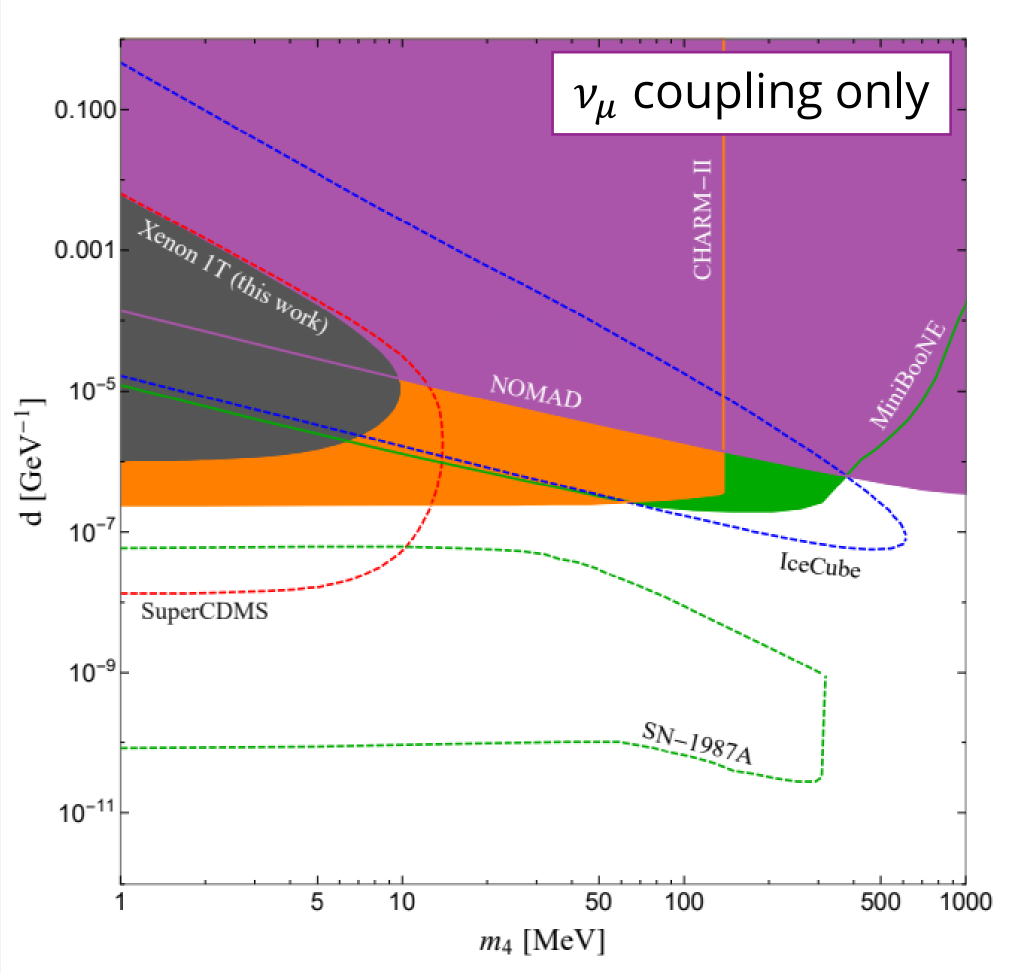


[Shoemaker et al. 1811.12435 (2018)]

# CURRENT BOUNDS:

- NOMAD [(1998)]
- CHARM [(1989)]
- MiniBooNE [0704.1500 (2007)]
- IceCube [Coloma et al. 1707.08573 (2017)]
- SN-1987A [Magill et al. 1803.03262 (2018)]

# EXPECTED SENSITIVITY:

- SuperCDMS
- XENON1T

# Different experimental setups...

| Spallation Sources | Direct Detection |
| --- | --- |

# Different experimental setups…

| Spallation Sources | Direct Detection |
|---|---|
| Source: Spallation | Source: Sun |

# Different experimental setups…

## Spallation Sources

Source: Spallation

$\nu_\mu, \overline{\nu_\mu}, \nu_e$

## Direct Detection

Source: Sun

$\nu_e, \overline{\nu_e}, \nu_\mu, \overline{\nu_\mu}, \nu_\tau, \overline{\nu_\tau}$

# Different experimental setups…

| Spallation Sources | Direct Detection |
|---|---|
| Source: Spallation | Source: Sun |
| $\nu_\mu, \overline{\nu_\mu}, \nu_e$ | $\nu_e, \overline{\nu_e}, \nu_\mu, \overline{\nu_\mu}, \nu_\tau, \overline{\nu_\tau}$ |
| Neutrinos up to 50 MeV | Neutrinos up to 20 MeV |

# Different experimental setups…

**Spallation Sources**

Source: Spallation

$\nu_\mu, \overline{\nu_\mu}, \nu_e$

Neutrinos up to 50 MeV

$m_4 \leq 50$ MeV

**Direct Detection**

Source: Sun

$\nu_e, \overline{\nu_e}, \nu_\mu, \overline{\nu_\mu}, \nu_\tau, \overline{\nu_\tau}$

Neutrinos up to 20 MeV

$m_4 \leq 20$ MeV

# Different experimental setups…

| **Spallation Sources** | **Direct Detection** |
| --- | --- |
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| Not small enough thresholds | Very small thresholds |

...so why not **combine** them?

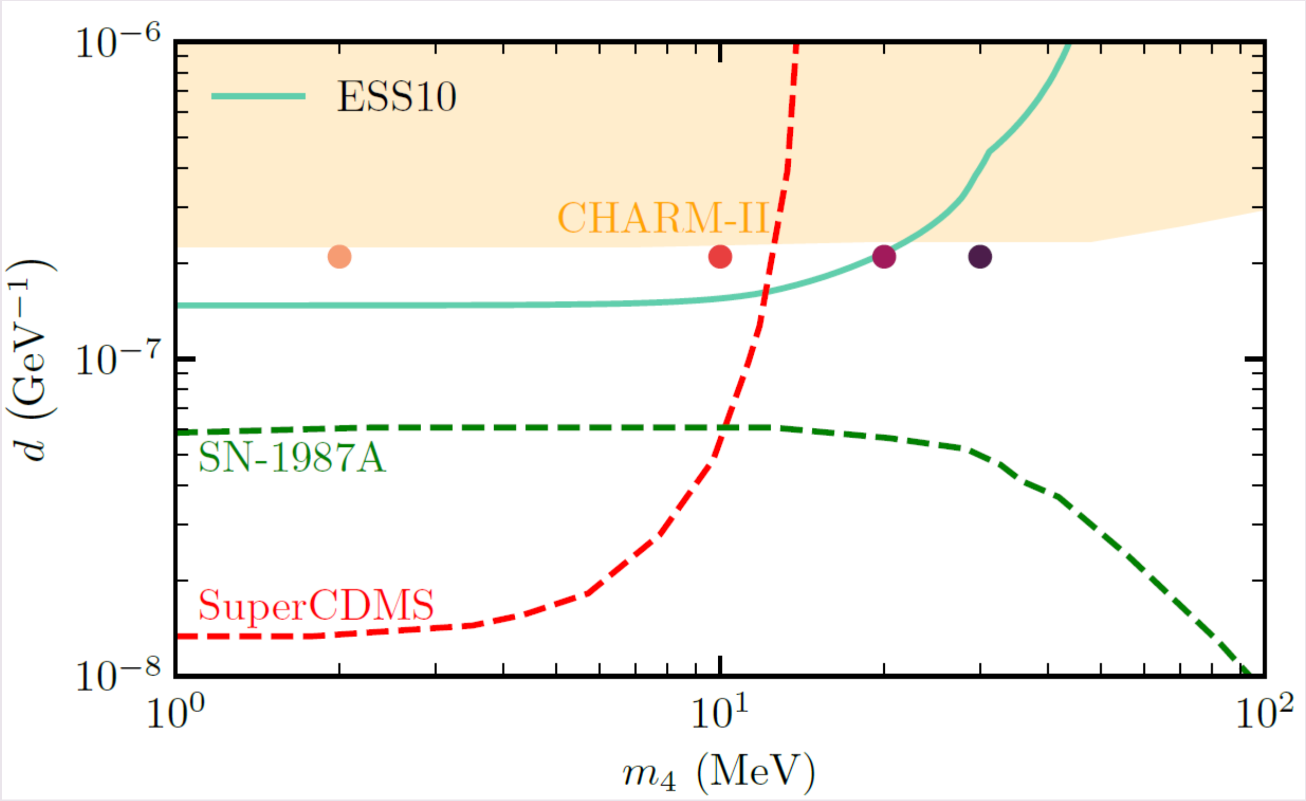
# **DD + Spallation:** why it’s a good idea

1. Increase the **statistical significance** of a prospective discovery.
2. Improve the **parameter reconstruction** of the model.
3. Allow to **discriminate** between NDP and other **models** that can give similar experimental evidence.

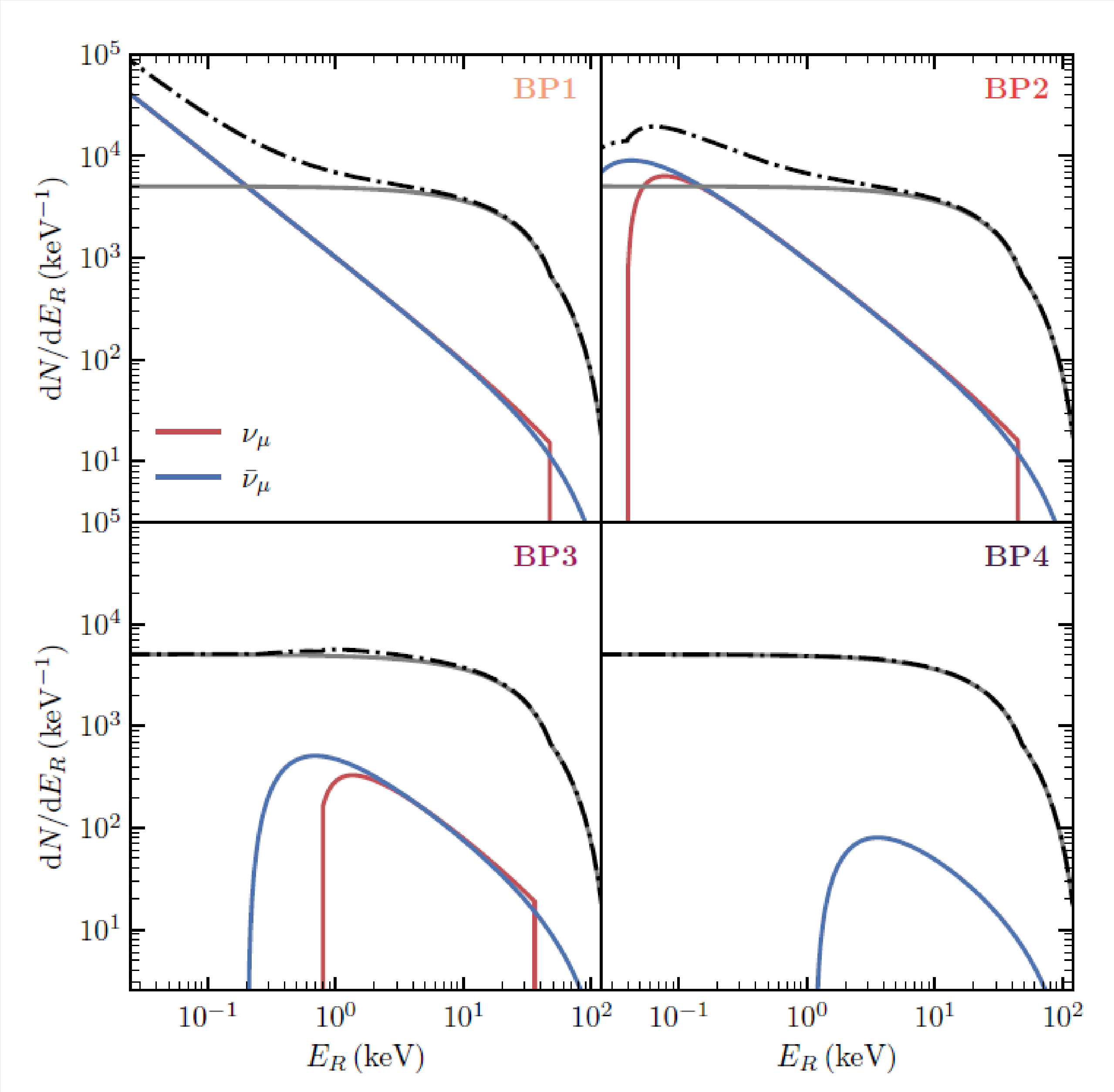
# What can we expect from **future** Spallation Experiments?

# What can we expect from **future** Spallation Experiments?

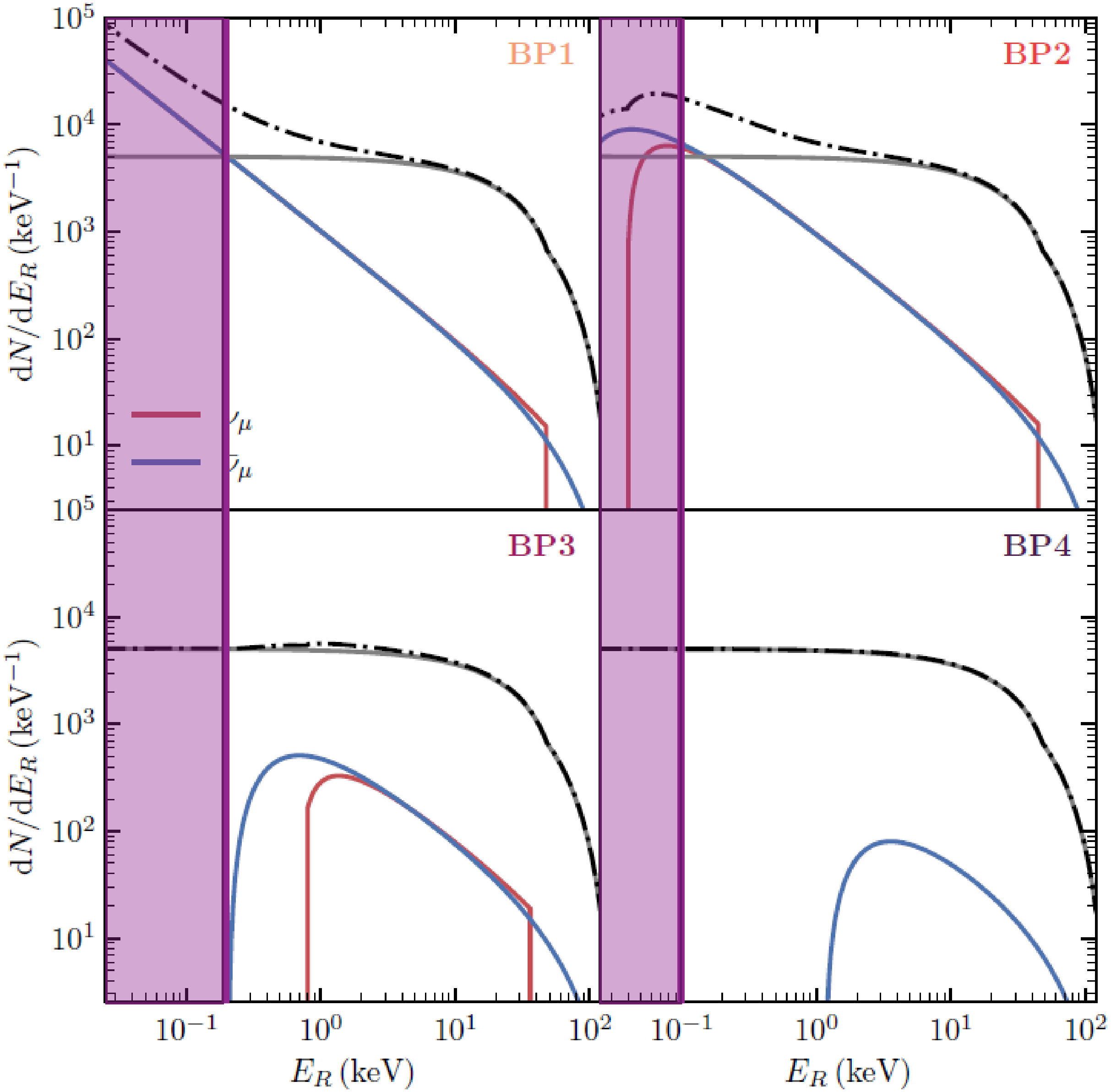
[Preliminary]




| BP | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $d\ (GeV^{-1})$ | $2.1 \cdot 10^{-7}$ | $2.1 \cdot 10^{-7}$ | $2.1 \cdot 10^{-7}$ | $2.1 \cdot 10^{-7}$ |
| $m_4\ (MeV)$ | 2 | 10 | 20 | 30 |

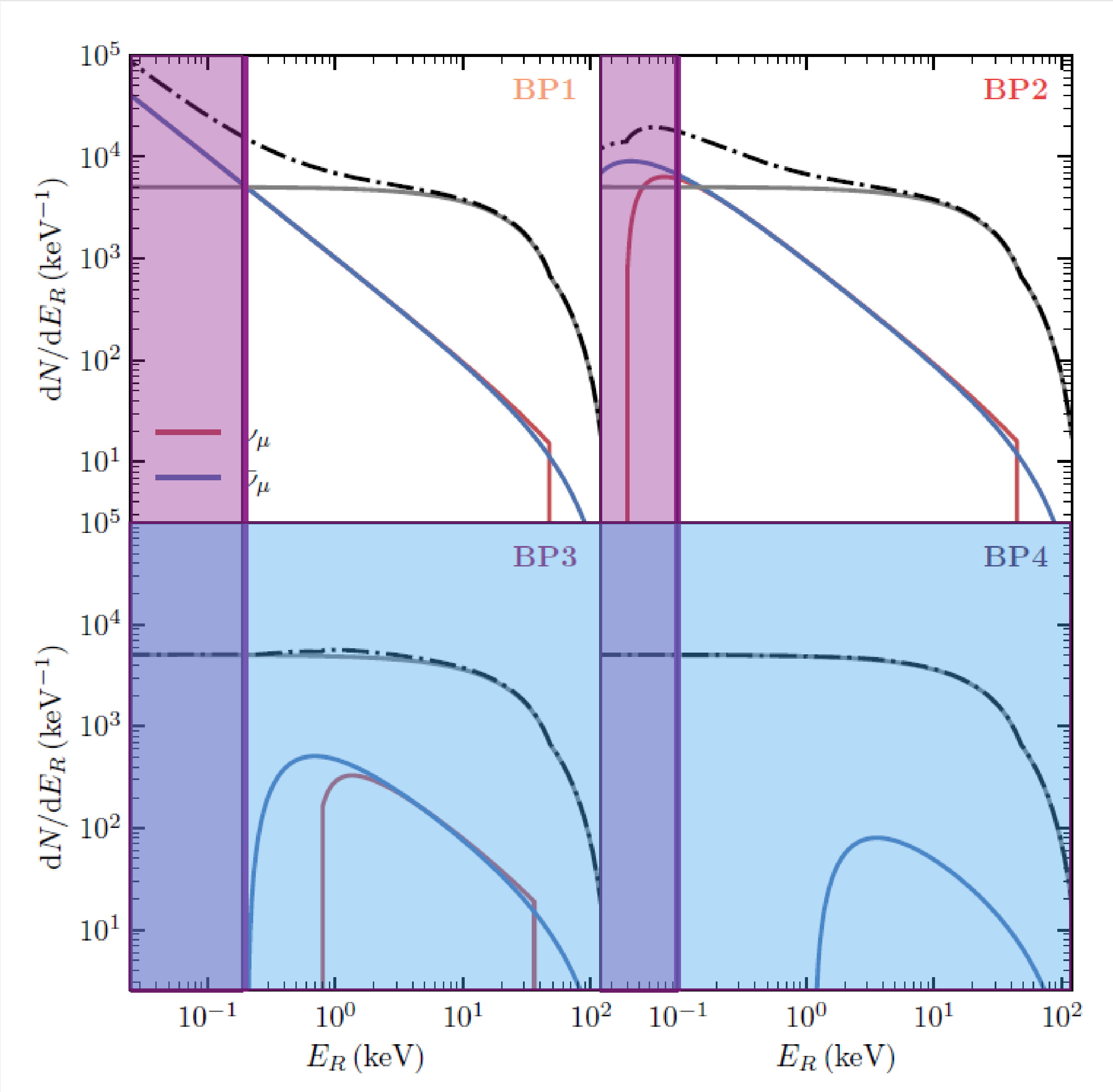



[Preliminary]




**Spallation** cannot see small energy recoils!

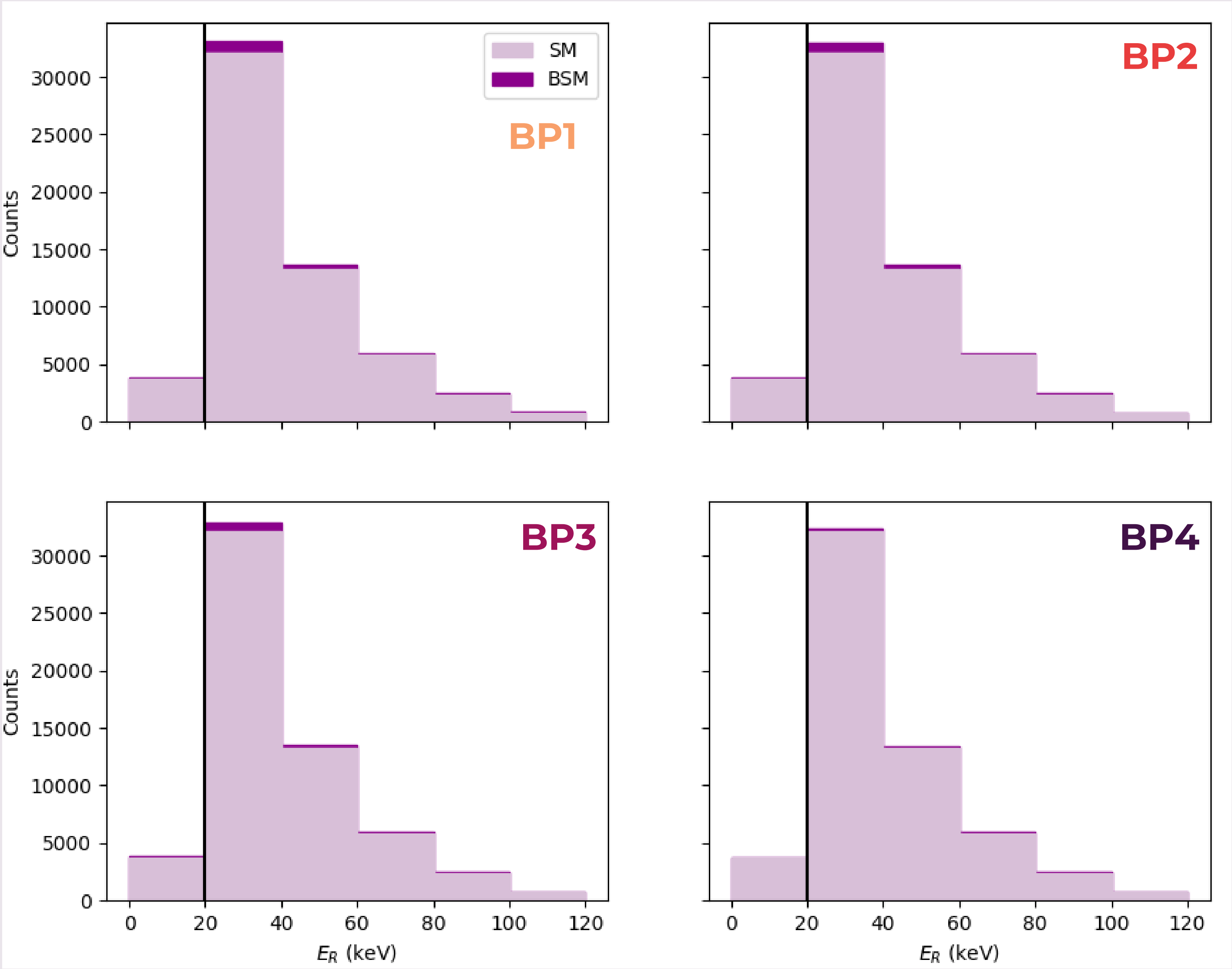
[Preliminary]




**Spallation** cannot see small energy recoils!

**DD** cannot see larger sterile neutrino masses!

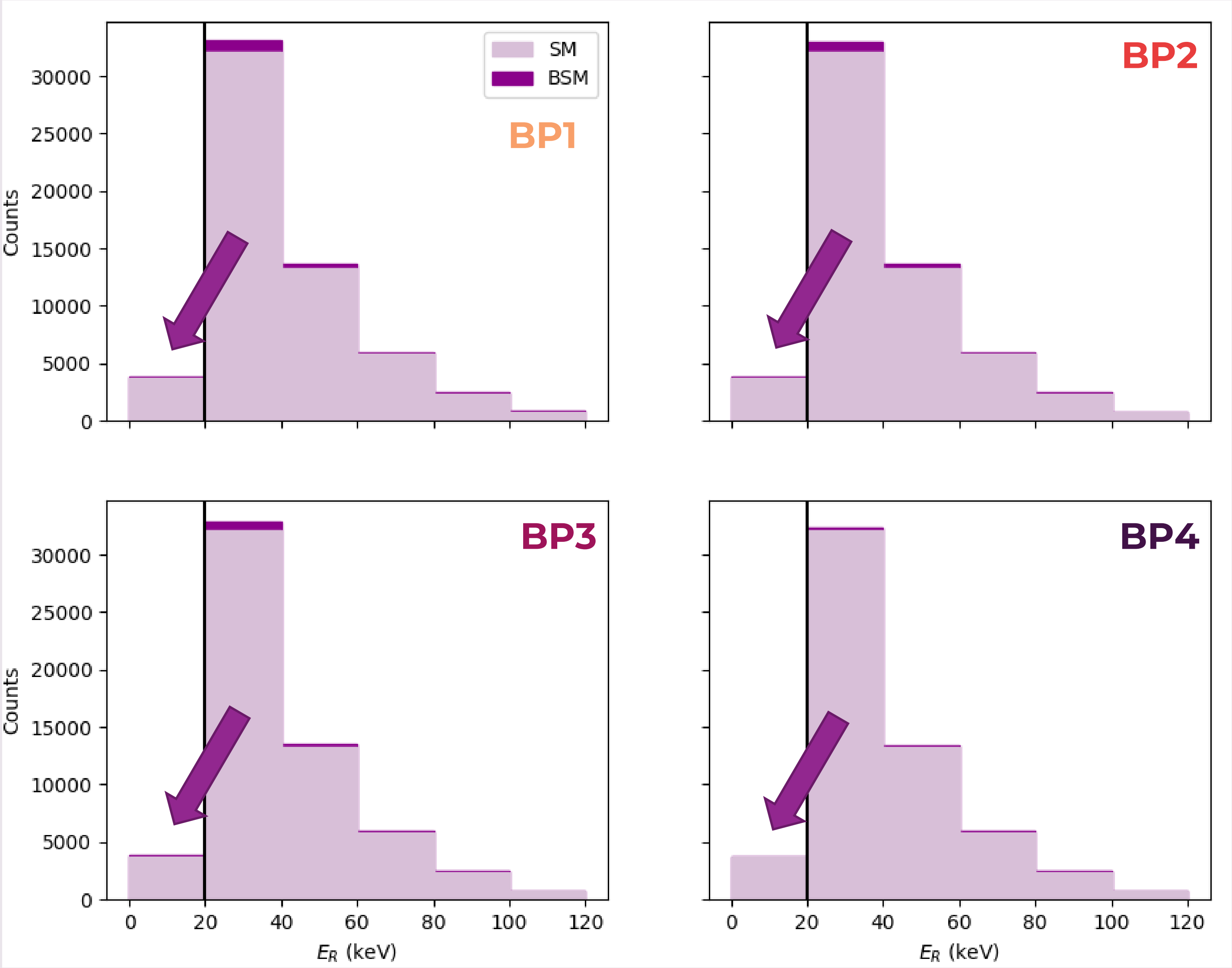
[Preliminary]




# ESS

$$E_{th} \sim 20 \text{ keV}$$
$$E_{bin} = 20 \text{ keV}$$

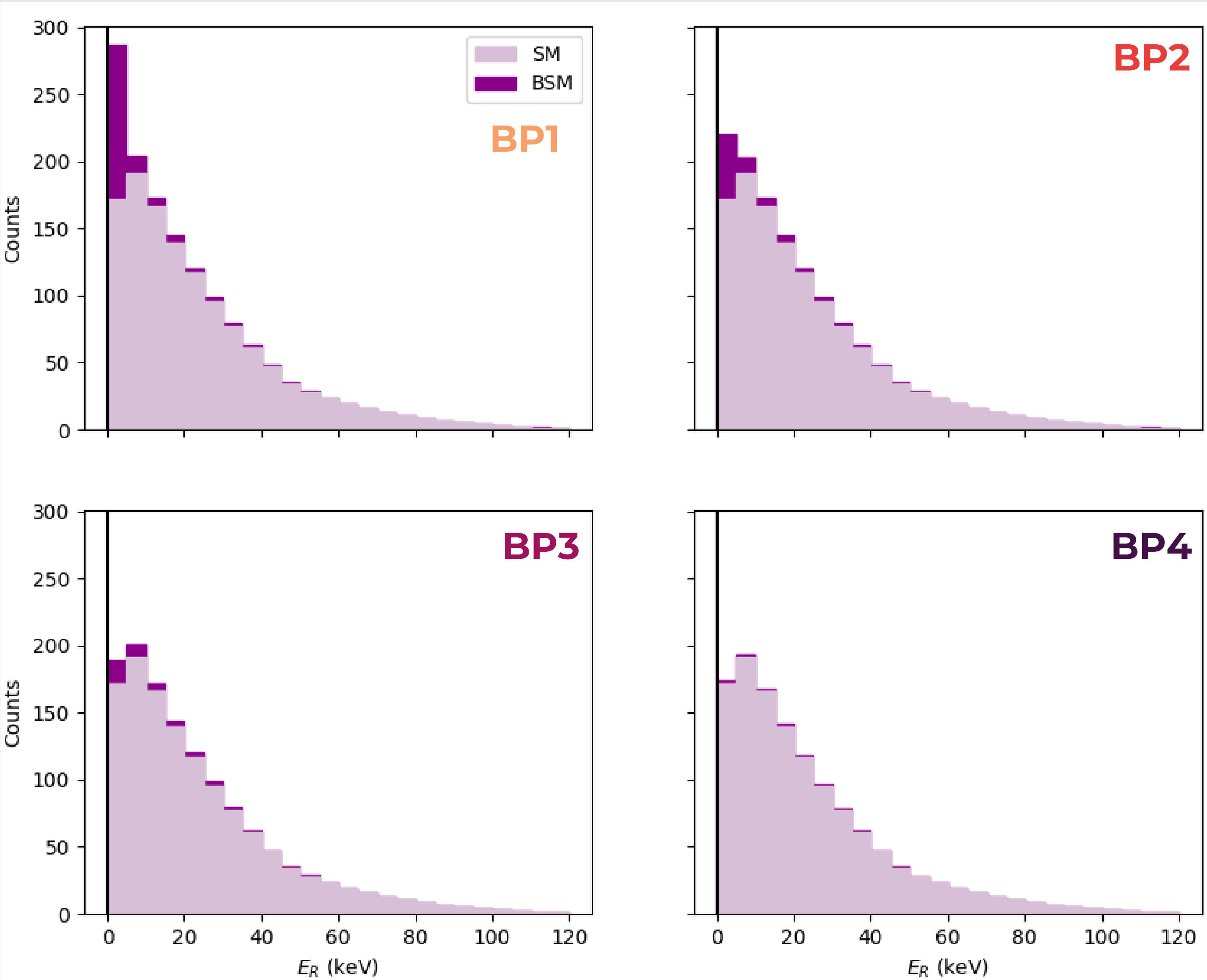
[Preliminary]




[Preliminary]

# ESS

$E_{th} \sim 20$ keV
$E_{bin} = 20$ keV




# ESS10

$$E_{th} \sim 0.1 \text{ keV}$$
$$E_{bin} = 5 \text{ keV}$$

[Preliminary]

# **Parameter** reconstruction in **SS**

$$\chi^2(d, m_4) = \min_a \left[ \sum_i \frac{\left(N^i_{\rm obs} - N^i_{\rm th}(d, m_4)\,[1+a]\right)^2}{\left(\sigma^i_{\rm stat}\right)^2} + \left(\frac{a}{\sigma_{\rm sys}}\right)^2 \right]$$

[Miranda et al. 2008.02759 (2020)]

# **Parameter** reconstruction in **SS**

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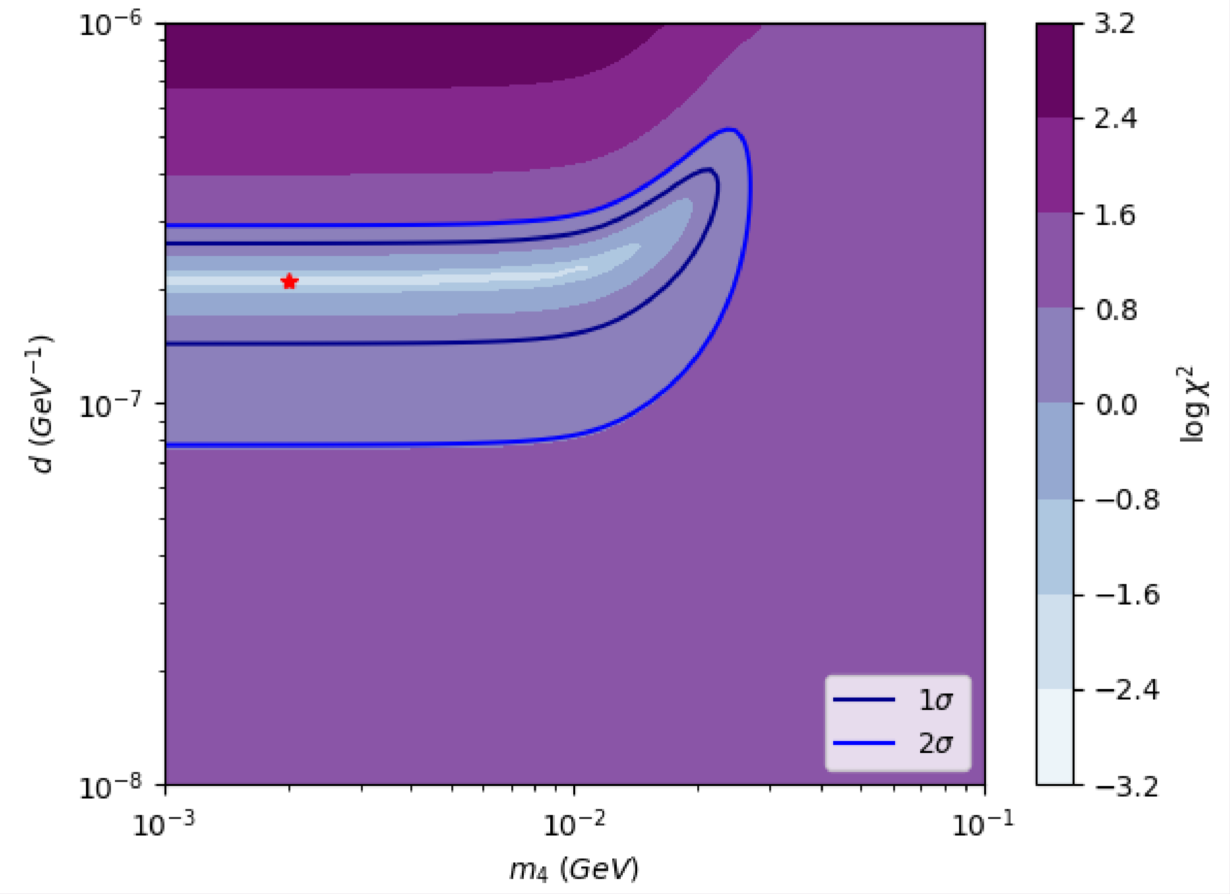
[Miranda et al. 2008.02759 (2020)]

For **BP1** ....

[Preliminary]



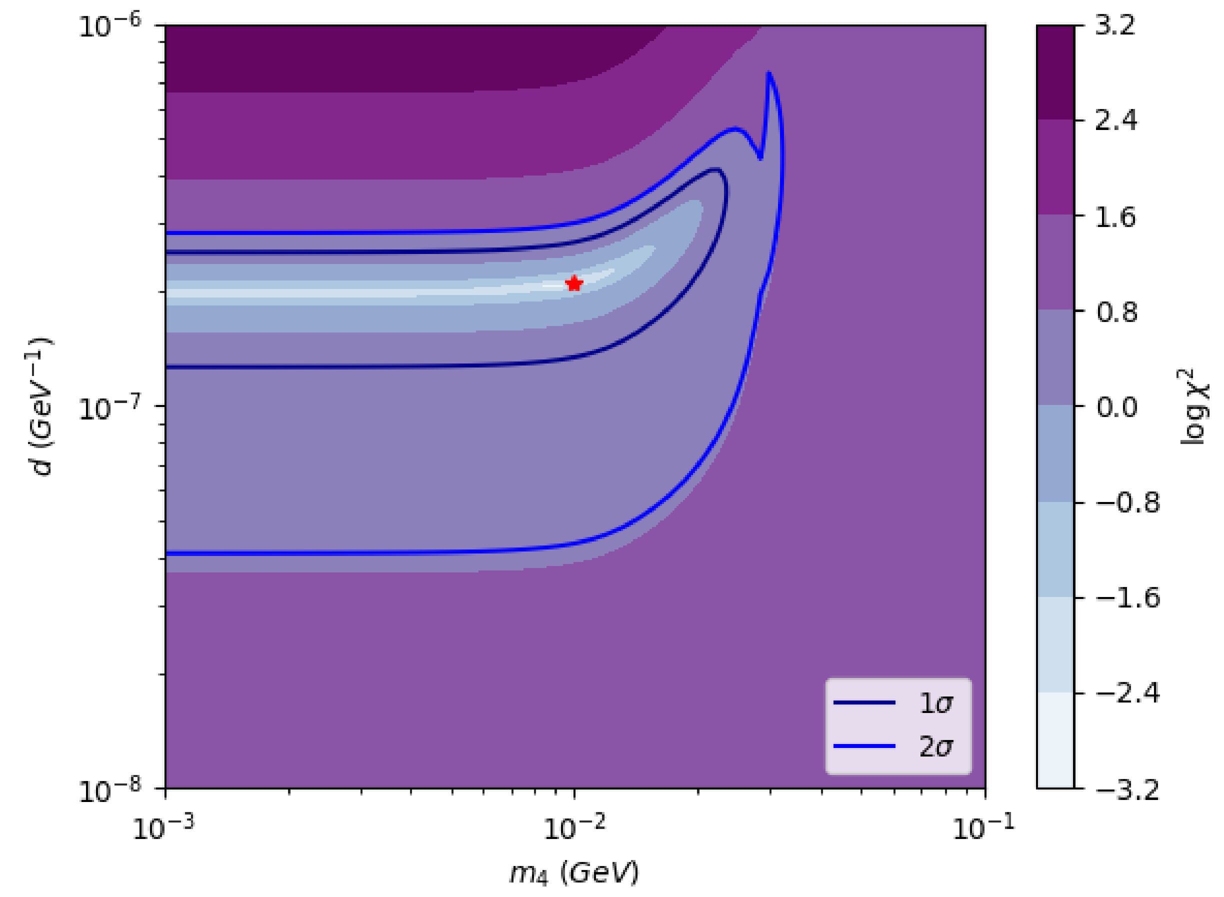
# **Parameter** reconstruction in **SS**

$$\chi^2(d, m_4) = \min_a \left[ \sum_i \frac{\left(N^i_{\rm obs} - N^i_{\rm th}(d, m_4)\,[1+a]\right)^2}{\left(\sigma^i_{\rm stat}\right)^2} + \left(\frac{a}{\sigma_{\rm sys}}\right)^2 \right]$$

[Miranda et al. 2008.02759 (2020)]

and for **BP2** ....

[Preliminary]



# Conclusions…

- Neutrino Dipole Portal (**NDP**) models can be **proven** with Spallation Source (**SS**) and Direct Detection (**DD**) experiments.
- **DD** will be able to access to very **low recoil energies** thanks to its low threshold.
- **SS** will be able to access to **heavier sterile neutrinos**.
- **SS** experiments by themselves may not have **sufficient statistics** to reconstruct parameters of TMM models.
- **Combining** DD and SS may help constraining the parameter space, **improving the significance** and allowing **parameter reconstruction** and **model discrimination**.