On-shell mediator dark matter models and the Xenon1T excess

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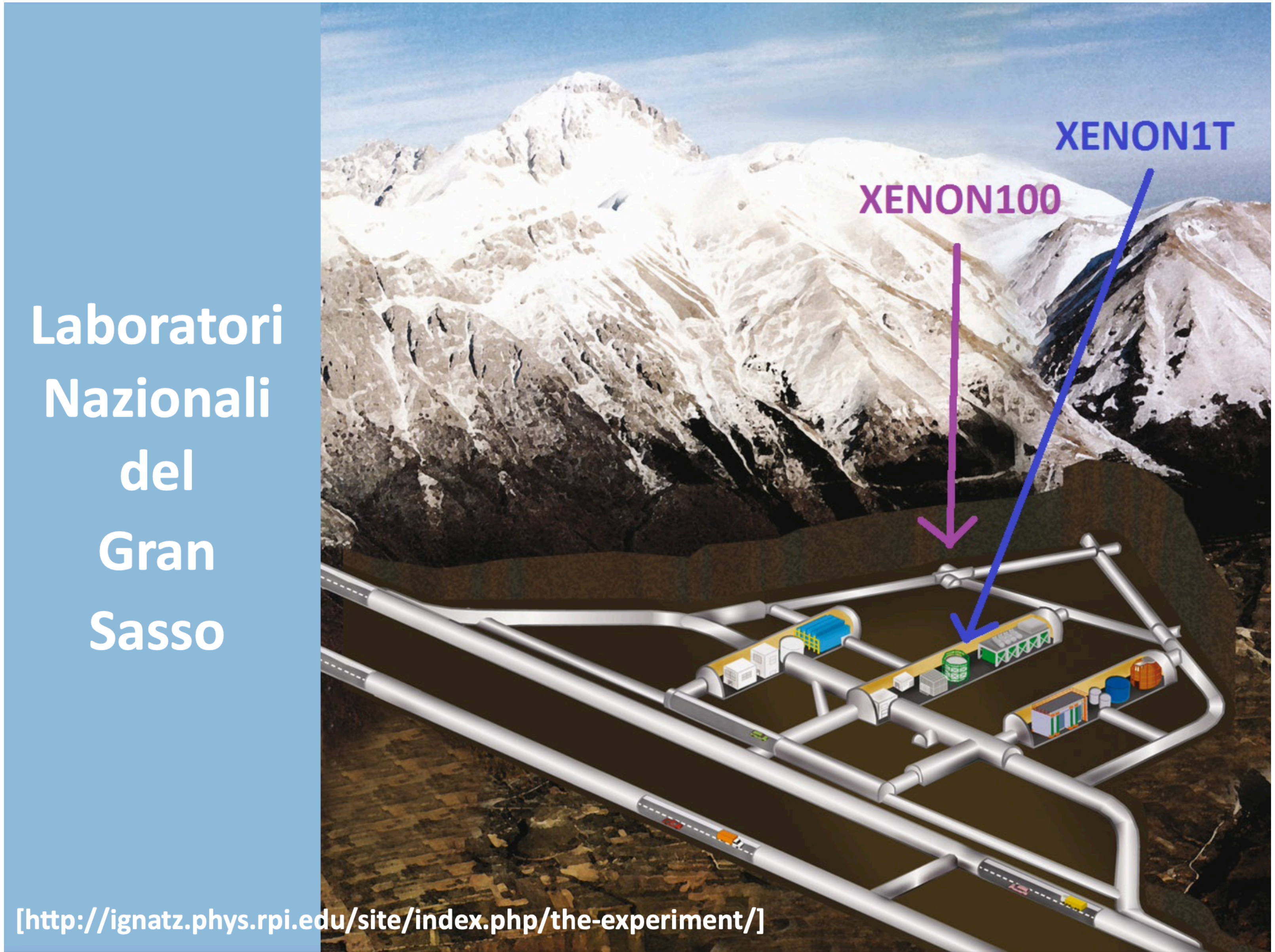
in collaboration with Mingxuan Du, Jinhan Liang, Zuowei Liu and Van Que Tran, arXiv:2006.11949 (Chinese Phys. C 45 013114)

SUSY 2021

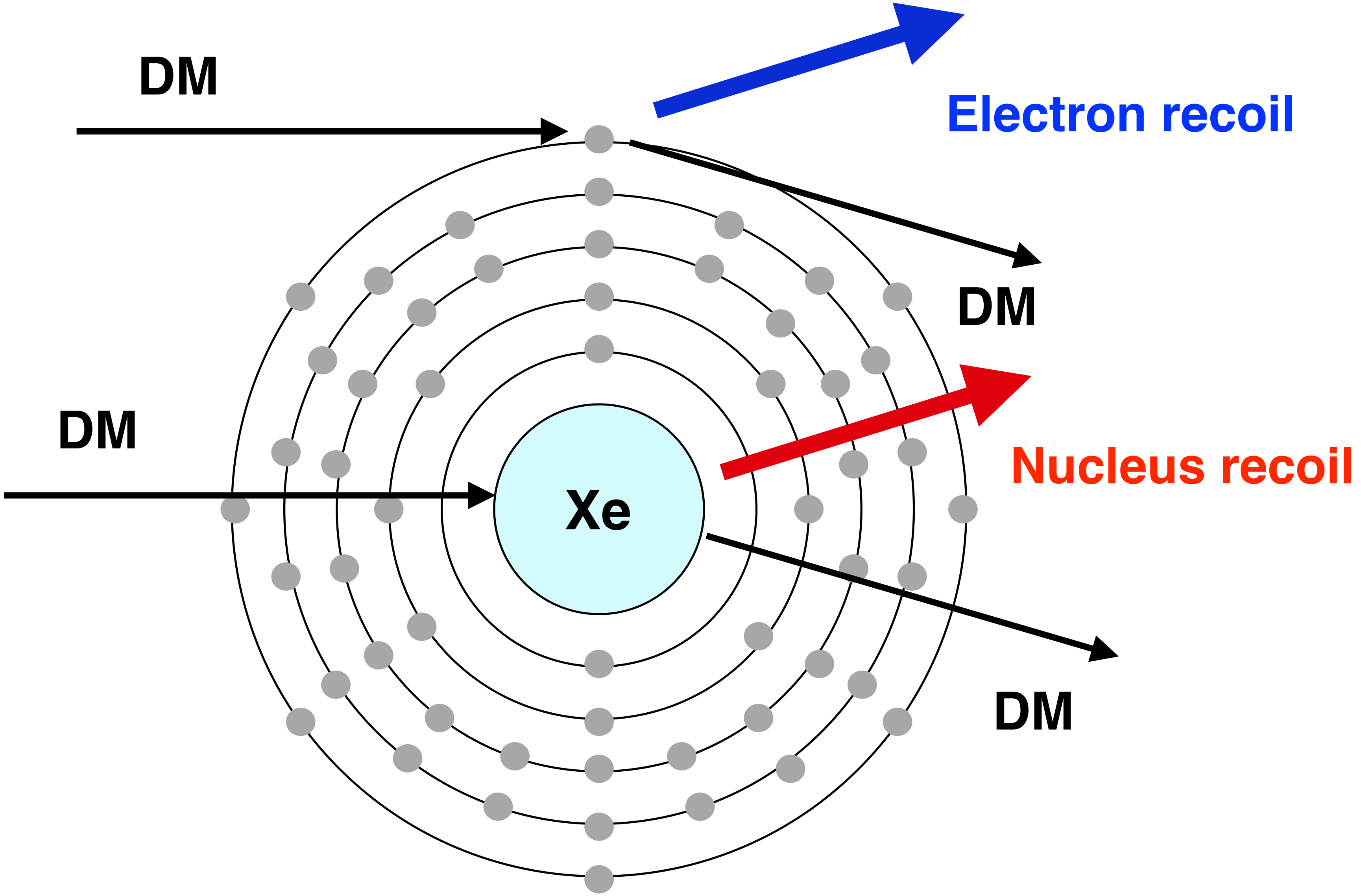
Outline

- Xenon-1T experiment and electron recoil excess
- On-shell mediator DM model
- Velocity distribution
- Particle flux & cross section
- Constraints

Xenon-1T experiment



Nucleus recoil VS electron recoil



Electron configuration

$1s^2$

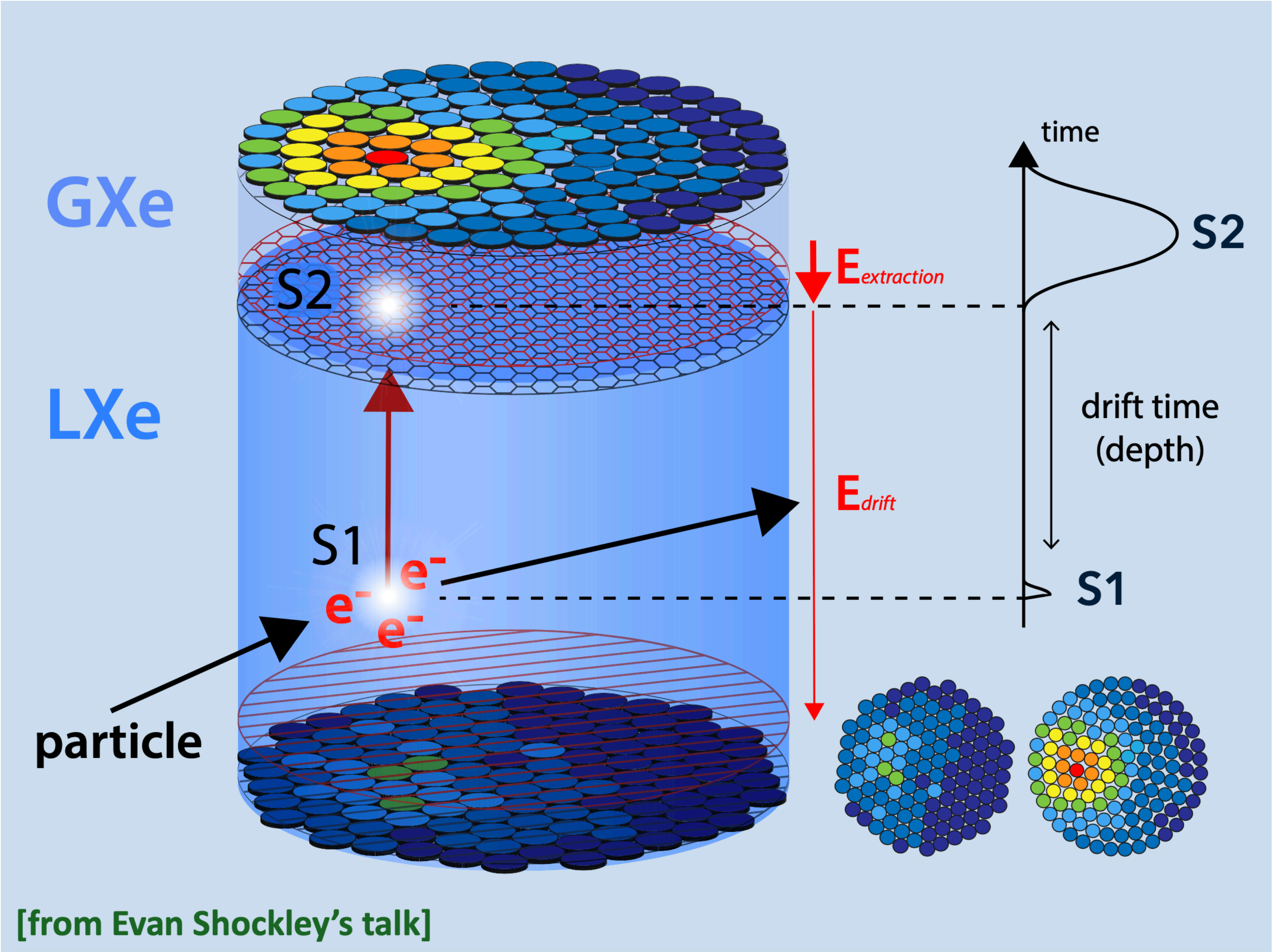
$2s^2 2p^6$

$3s^2 3p^6 3d^{10}$

$4s^2 4p^6 4d^{10}$

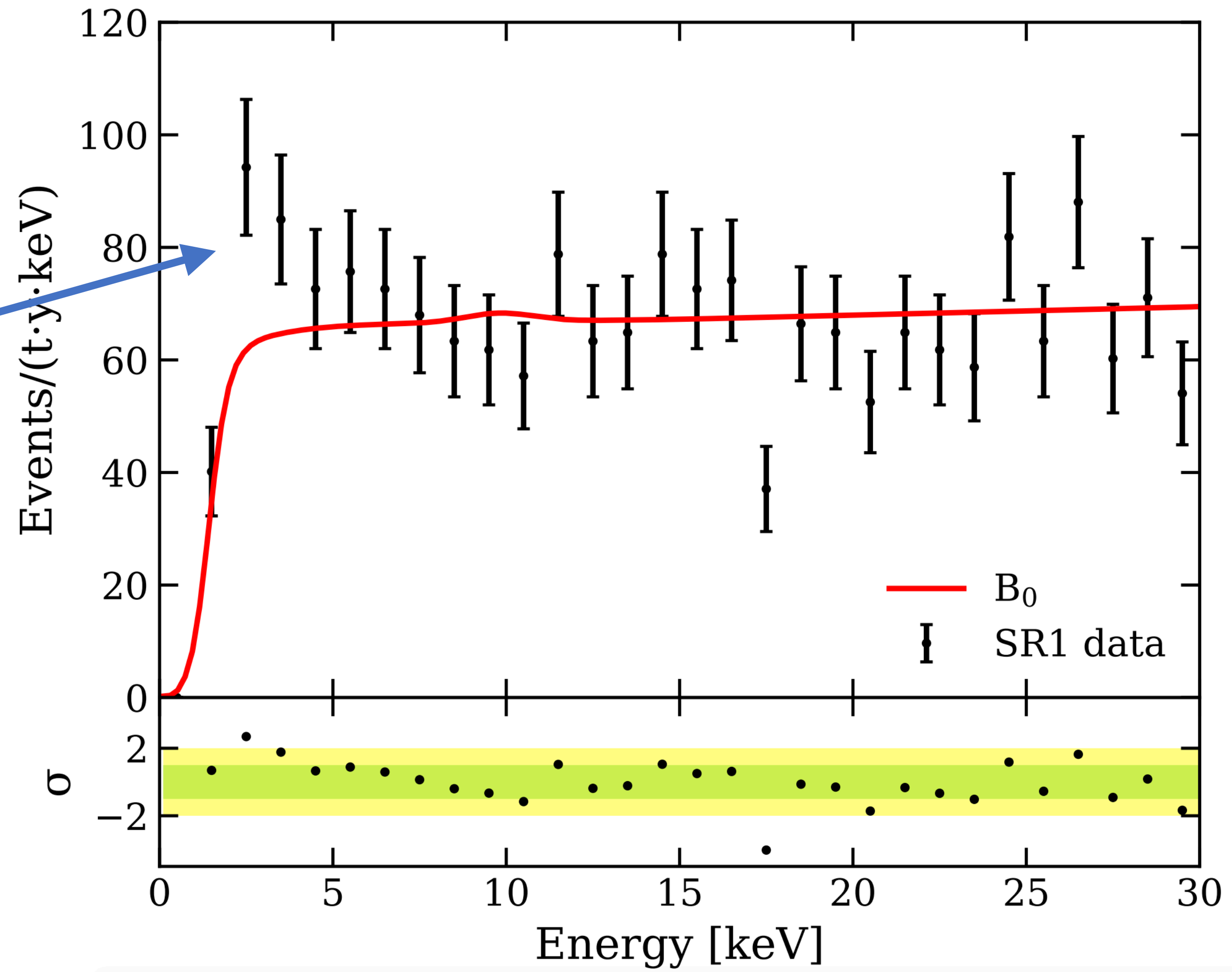
$5s^2 5p^6$

Xenon-1T experiment



Xenon-1T experiment

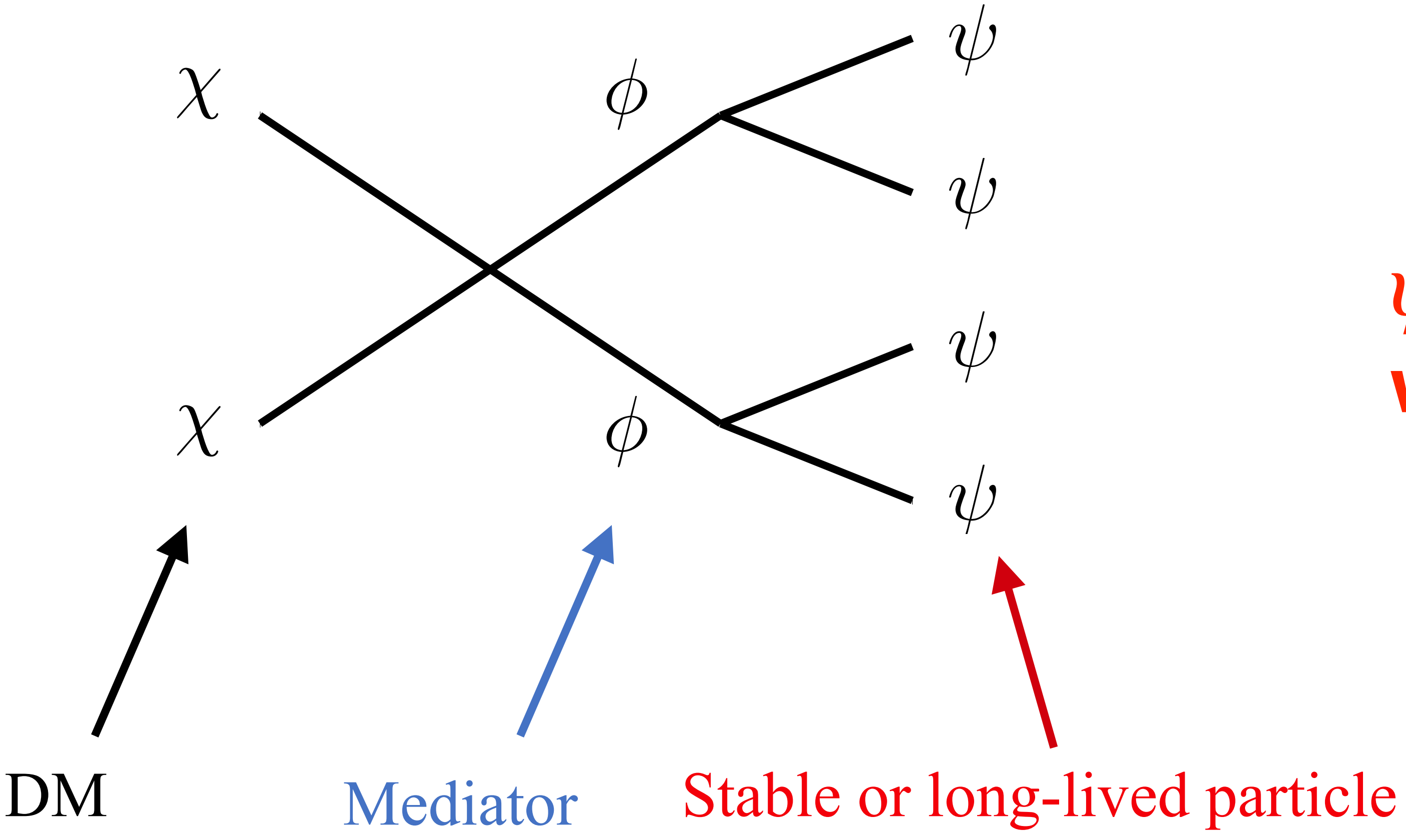
Low energy electron recoil excess



Axion?
or
DM with large velocity?

E. Aprile et al. [XENON Collaboration], arXiv:2006.09721 [hep-ex].

On shell mediator DM Models



ψ interacts with electron

$$m_\chi > m_\phi > 2m_\psi$$

Energy spectrum of ψ

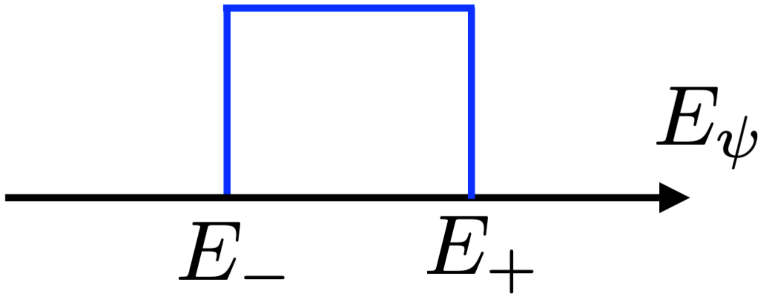
$$x = \sqrt{1 - m_\phi^2/m_\chi^2}$$

$$y = \sqrt{1 - 4m_\psi^2/m_\phi^2}$$

two mass parameters

$$E_- < E_\psi < E_+$$

$$E_\pm = \frac{m_\chi}{2}(1 \pm xy)$$



Energy of ψ :

Box-shape

Energy spectrum

$$x = \sqrt{1 - m_\phi^2/m_\chi^2}$$

$$y = \sqrt{1 - 4m_\psi^2/m_\phi^2}$$

two mass parameters

$$E_- < E_\psi < E_+$$

$$E_\pm = \frac{m_\chi}{2}(1 \pm xy)$$

Energy of ψ

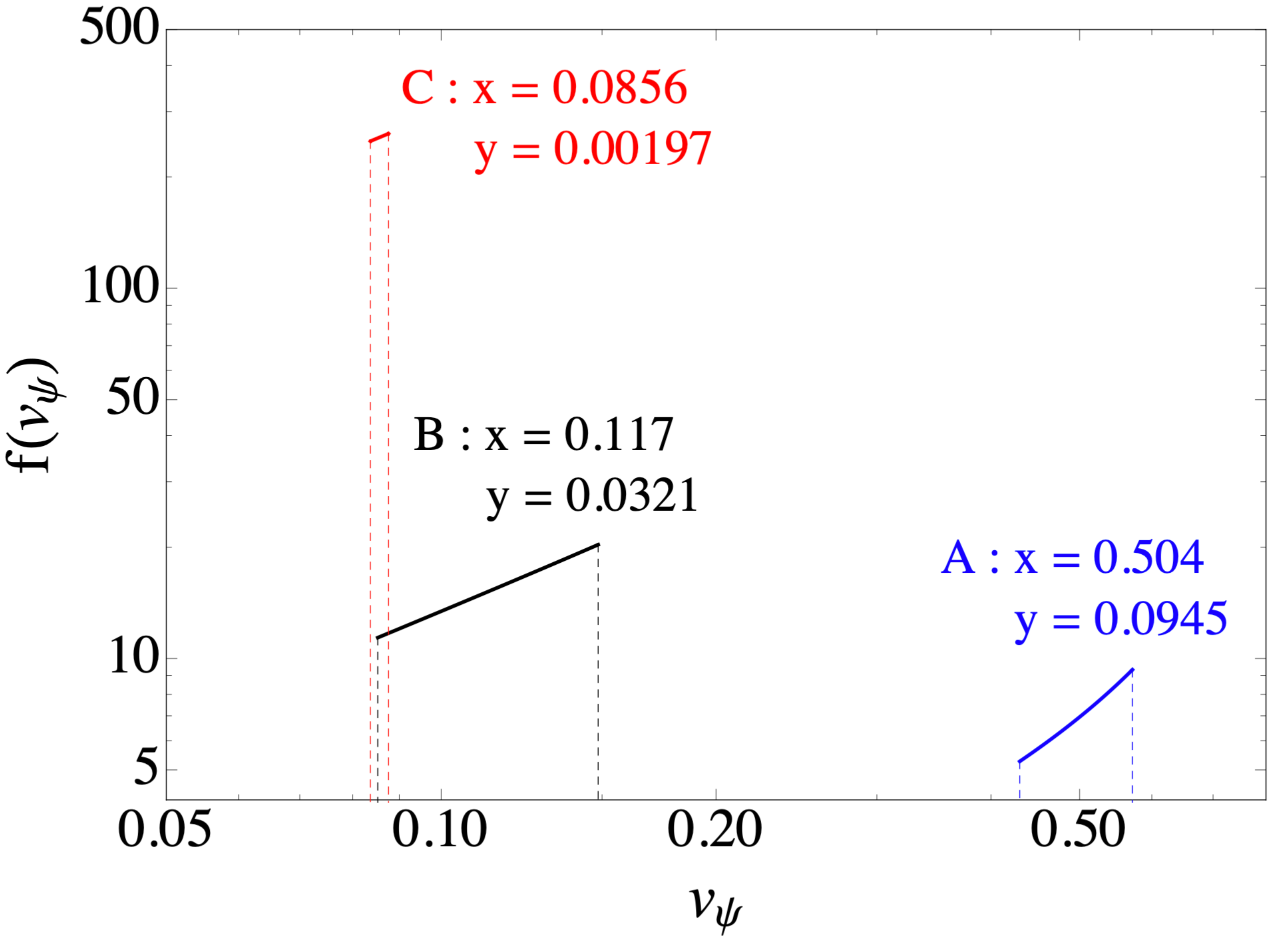
Box-shape

$$v_\psi\left(E_\psi\right) = \sqrt{1 - m_\psi^2/E_\psi^2}$$

$$v_\pm = \frac{|x \pm y|}{1 \pm xy}$$

Velocity of ψ

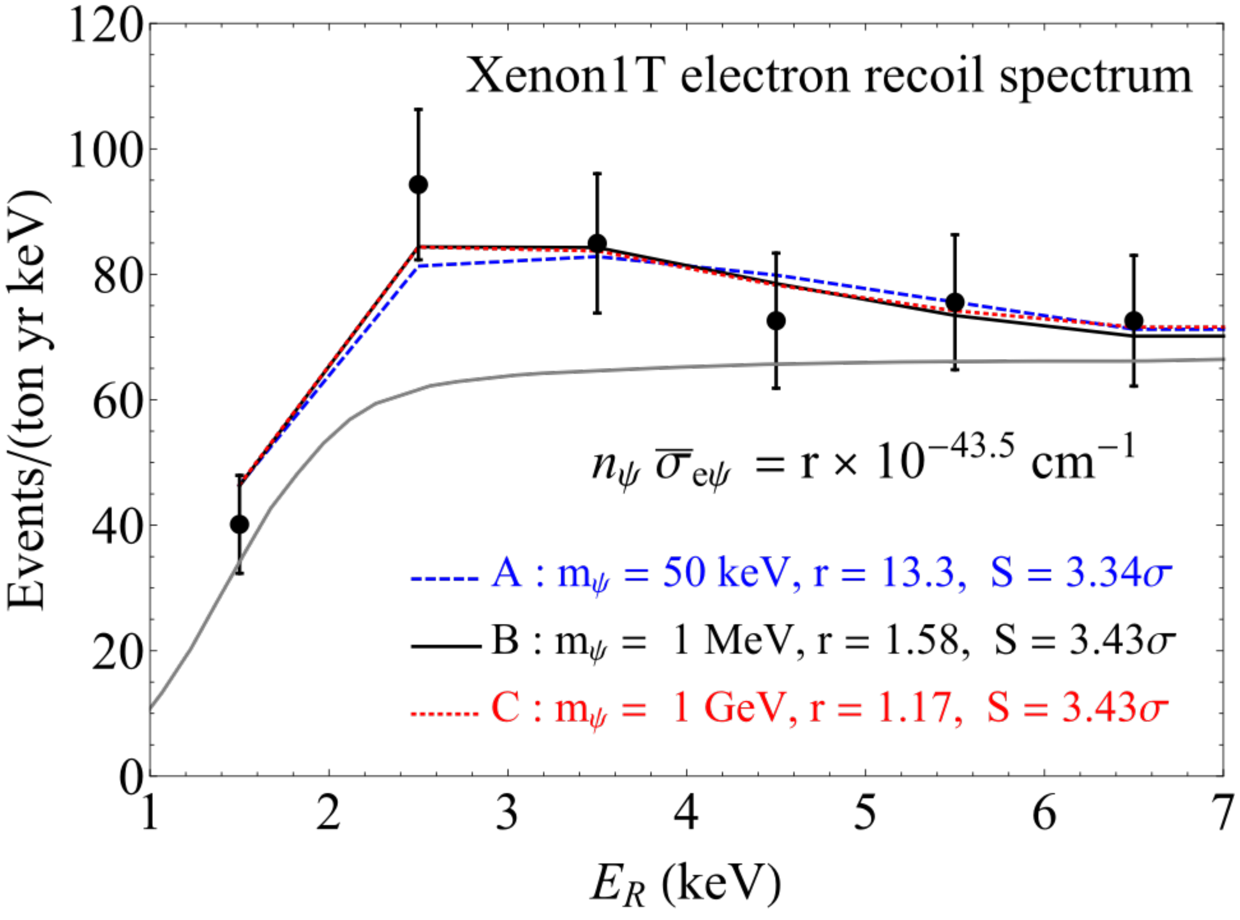
Velocity distribution



$$\int_{v_-}^{v_+} dv_\psi f\left(v_\psi\right) = \int_{v_-}^{v_+} dv_\psi \frac{v_\psi \sqrt{1-x^2}\sqrt{1-y^2}}{2\left(1-v_\psi^2\right)^{3/2} xy}$$

velocity depends on x&y, but not on any mass scale

ER spectrum



$$N_S = \text{ exposure } \int_{E_1}^{E_2} dE_R \frac{dR}{dE_R} \epsilon\left(E_R\right)$$

$$\frac{dR}{dE_R} = N_T \frac{n_\psi \bar{\sigma}_{e\psi}}{2m_e} \int \frac{dv_\psi f\left(v_\psi\right)}{v_\psi} \int_{q_-}^{q_+} a_0^2 q dq \, |F(q)|^2 K\left(E_R, q\right)$$

N_T: # of Xe atom $\simeq 4.2 \times 10^{27}$/ton

n_ψ: # density of ψ particle

$\bar{\sigma}_{e\psi}$: cross section at $q = \dfrac{1}{a_0}$

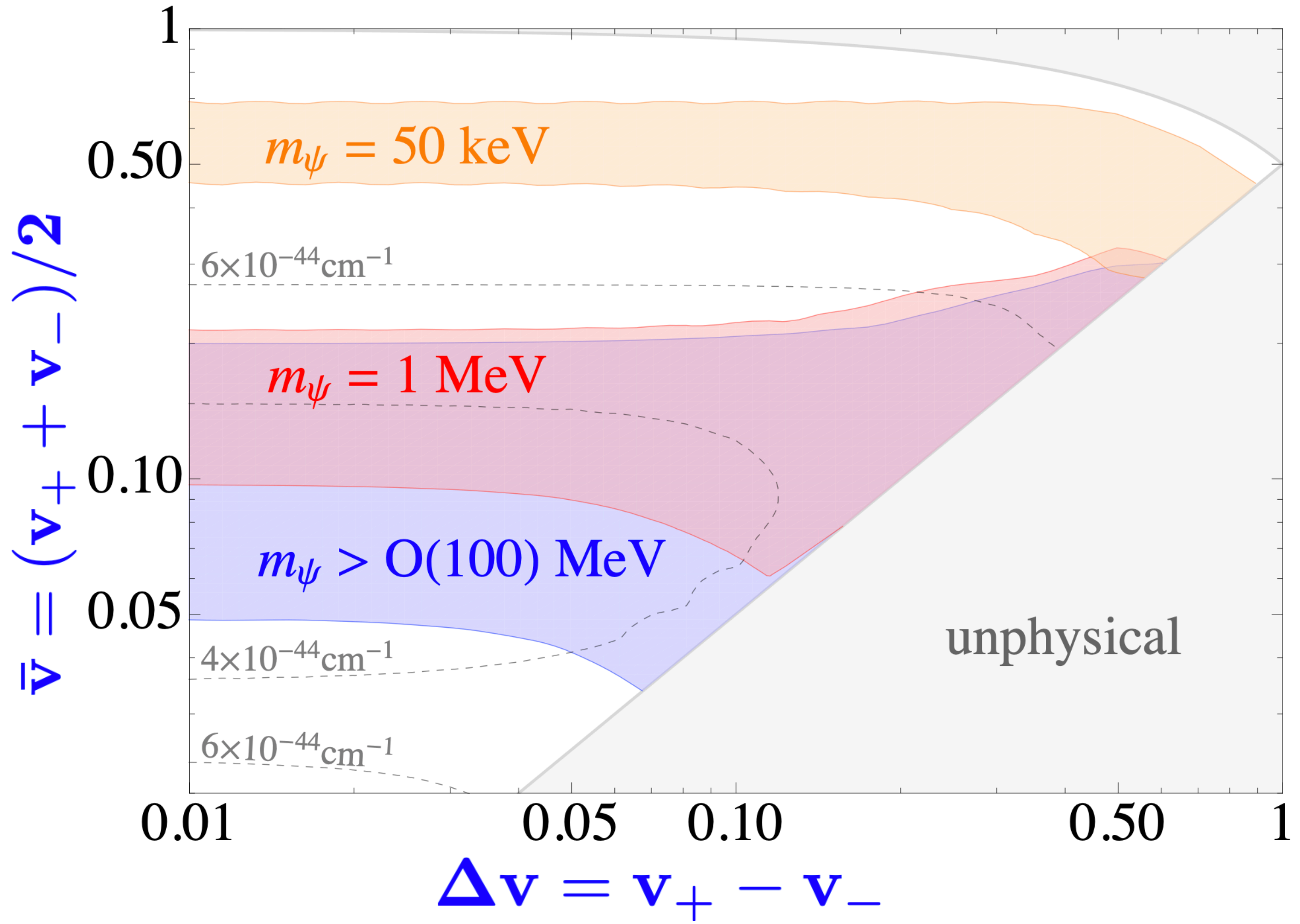
$|F(q)|^2$: DM form factor

$K\left(E_R, q\right)$: atomic function

$\epsilon\left(E_R\right)$: efficiency

[see e.g. Essig+ 1108.5383, Roberts+ 1904.07127]

1σ region parameter space



$\Delta\chi^2 \leq 2.3$

$\chi^2_{\rm min} = 1.656$ w/$\left(m_\psi, \bar{v}, \Delta v\right) = (117.5\text{MeV},0.086,0.011)$

$n_\psi \bar{\sigma}_{e\psi} = 3.73 \times 10^{-44}$ cm^{-1}

Particle flux of ψ

DM density profile: $\rho_\chi(r) = \rho_s \frac{(r/r_s)^{-\gamma}}{(1+r/r_s)^{3-\gamma}}$

$$\gamma = 1$$
$$\rho_s = 0.31\ \mathrm{GeV/cm^3}$$
$$r_s = 21\ \mathrm{kpc}$$

Flux of ψ : $\Phi_\psi = 4\frac{\langle\sigma v\rangle}{8\pi m_\chi^2} J$

$$J = \int d\Omega \int ds \rho_\chi^2 \simeq 10^{23} \mathrm{GeV^2/cm^5}$$

$\Phi_\psi \simeq 10^{-4}\ (10^2)\ \mathrm{cm^{-2}\ s^{-1}}$ for $m_\psi \simeq \mathrm{GeV\ (MeV)}$

Constraints

DM direct detection $\sigma_{e-DM} \lesssim 10^{-38}\ \mathrm{cm}^2$

Model	m_ψ	x	y	$n_\psi \bar{\sigma}_{e\psi}\ (\mathrm{cm}^{-1})$	$\bar{\sigma}_{e\psi}\ (\mathrm{cm}^2)$
A	50 keV	0.504	0.0945	$13.3 \times 10^{-43.5}$	$\mathcal{O}(10^{-37})$
B	1 MeV	0.117	0.0321	$1.58 \times 10^{-43.5}$	$\mathcal{O}(10^{-36})$
C	1 GeV	0.0856	0.00197	$1.17 \times 10^{-43.5}$	$\mathcal{O}(10^{-30})$

much larger than DMDD

Constraints

DM direct detection

$$\sigma_{e-DM} \lesssim 10^{-38}\ \mathrm{cm}^2$$

Local DM flux in DM direct detection

$$\Phi_\chi \simeq 10^5\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$$

Which is smaller than flux of ψ

$$\Phi_\psi \simeq 10^{-4}\left(10^2\right) \mathrm{cm}^{-2}\ \mathrm{s}^{-1} \text{ for } m_\psi \simeq \mathrm{GeV}(\mathrm{MeV})$$

Constraints

Stopped by rock (2 km)

$$\sigma_{e\psi} \gtrsim 10^{-24}\ \mathrm{cm}^2 \text{ for } m_\psi \simeq \mathcal{O}(\mathrm{MeV})$$

Larger cross section for higher mass

[Emken+, 1905.06348]

LEP constraints

$$\frac{1}{\Lambda^2}\bar{\psi}\psi\bar{e}e \quad \text{for} \quad \Lambda \gtrsim 440\mathrm{GeV} \longrightarrow \bar{\sigma}_{e\psi} \lesssim 1 \times 10^{-45}\ \mathrm{cm}^2$$

[Fox+,1103.0204]

Summary

- On-shell mediator DM model can generate a high velocity particle that can explain the Xenon-1T excess

- Flux and the cross section of ψ particle are consistent with canonical thermal annihilation cross section

- Constraints from DMDD, rock and LEP