Probing the general axion – nucleon interaction in water Cherenkov experiments

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based on work w/
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Context

- Water Cherenkov experiments like Hyper Kamiokande designed for detection of ν fluxes from astro sources

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- We investigate this question in a reference case: the most general axion – nucleon interaction

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- Axion emissivities & absorption spectra calculated w/ the consistent EFT framework of Chiral Perturbation Theory

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$\Rightarrow$ well-defined power counting : $\dfrac{\text{pion momenta}}{f_\pi}$

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  - Neutron Star cooling $\Rightarrow$ $C_{aNN} \frac{m_N}{f_a} \lesssim 1.1 \times 10^{-9}$ [Buschmann et al., 2021]
  - Supernova cooling $\Rightarrow$ $L_a \lesssim L_\nu \sim 3 \times 10^{52}$ erg/s (SN 1987A)

Detection on Earth of SN cooling particles

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  $\longrightarrow$ burst of ν

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cooler (↑ α) — Cherenkov parton (↑ X)

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cooler

Cherenkov parton

X number spectrum $\frac{dN_X^{(\alpha)}}{dE_X}$

$\frac{dN_\alpha}{dE_\alpha}$ α number spectrum

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$$\frac{dN_X^{(\alpha)}}{dE_X} = \frac{N_t}{4\pi d^2}\int dE_\alpha \; \frac{\partial \sigma_{\alpha X}}{\partial E_X}\,\frac{dN_\alpha}{dE_\alpha}$$
α number spectrum

number of targets in detector

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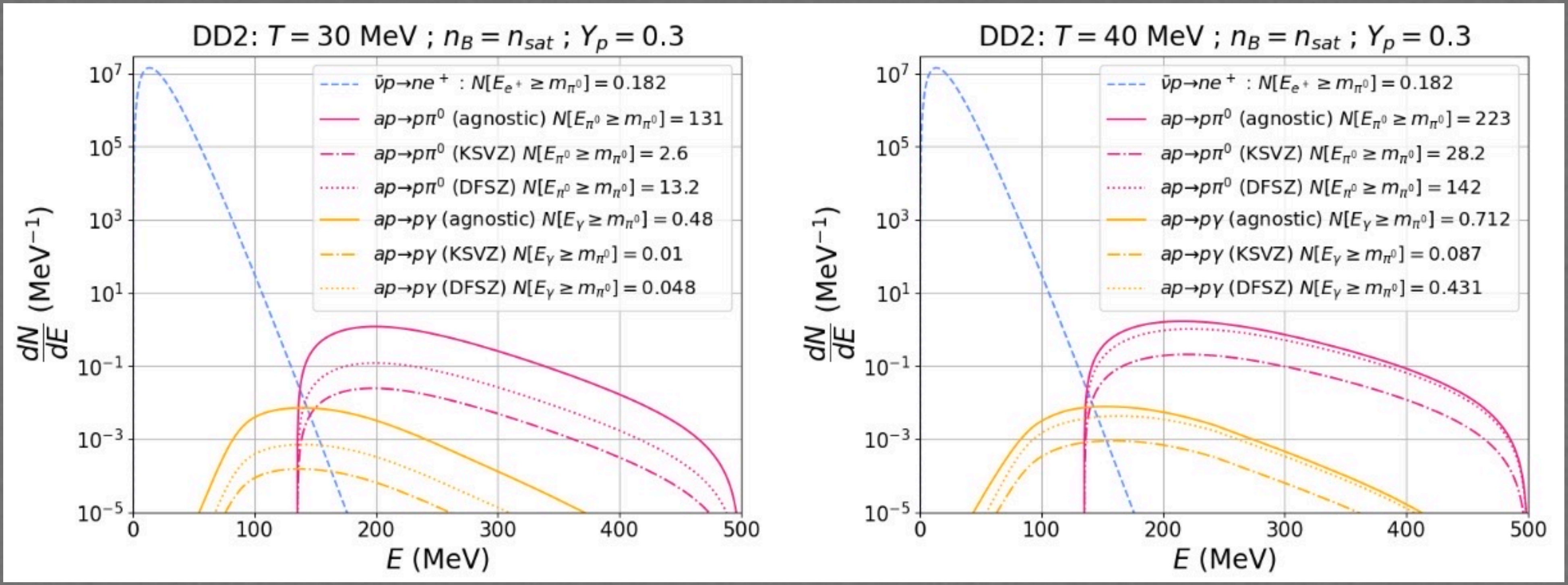
[the Cherenkov parton # spectrum is calculable
in terms of the cooler # spectrum]

Cherenkov light spectra



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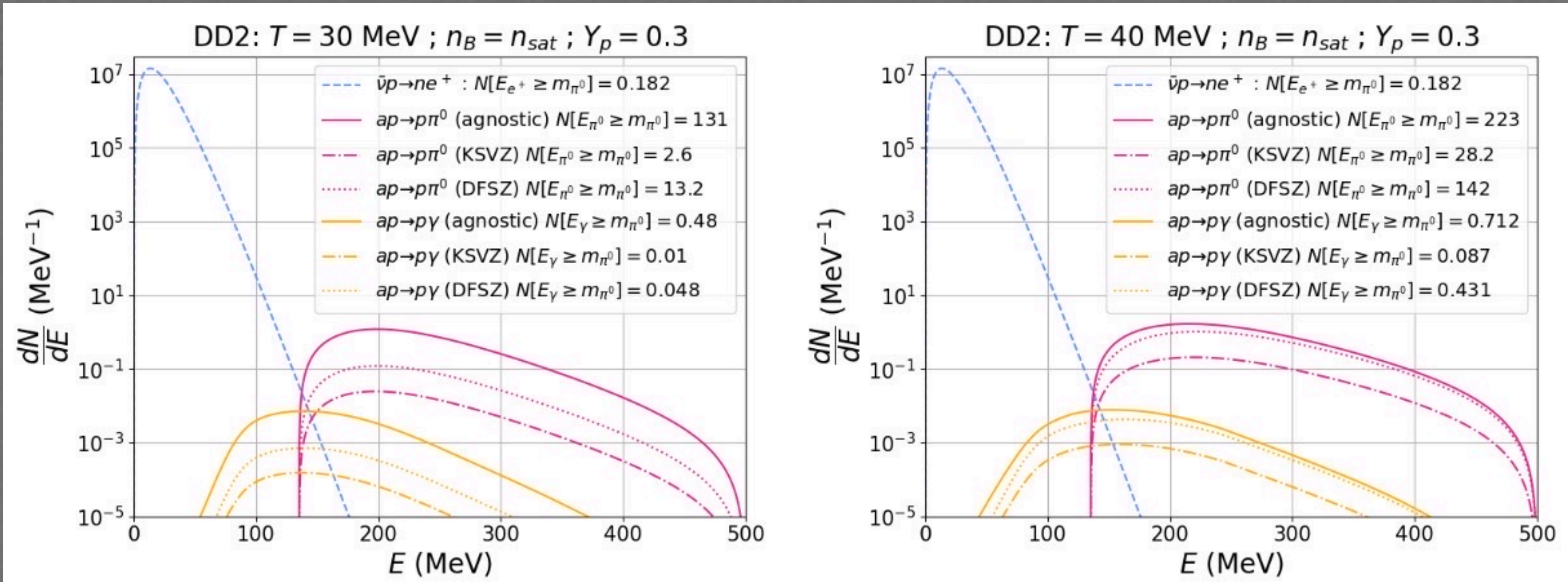

= The Cherenkov-light spectra induced by ν vs. a absorption peak at well separated energies

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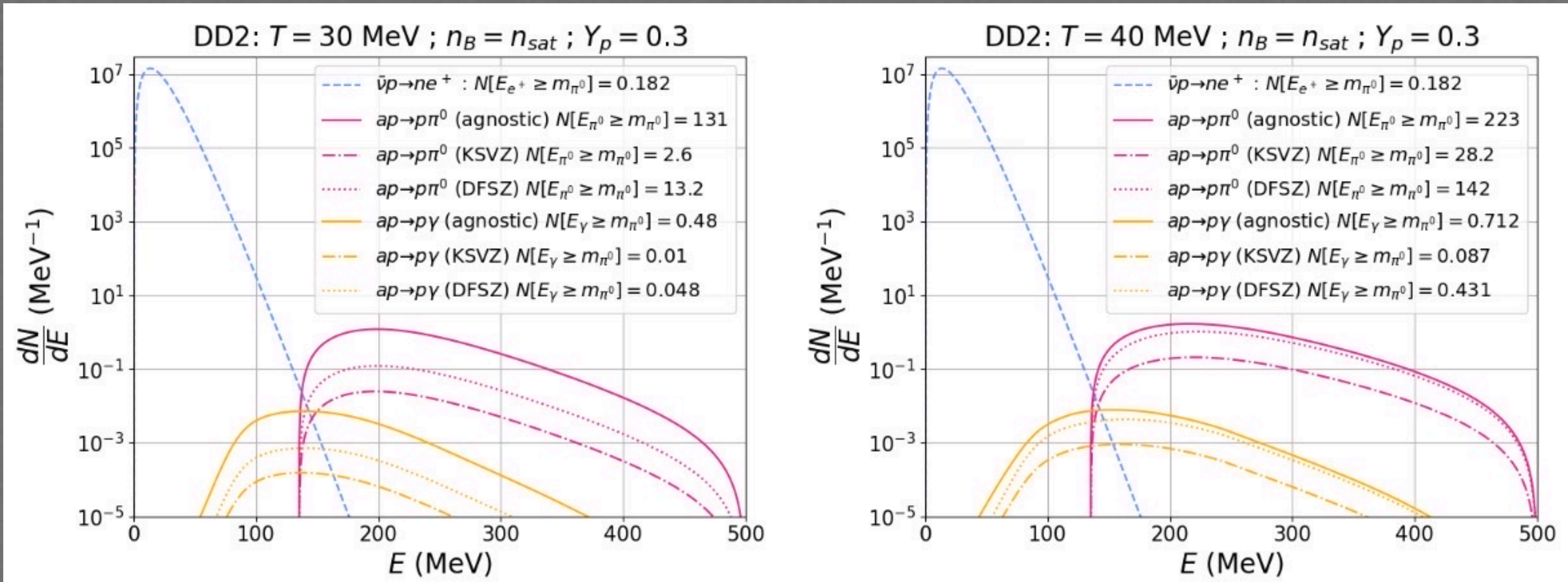
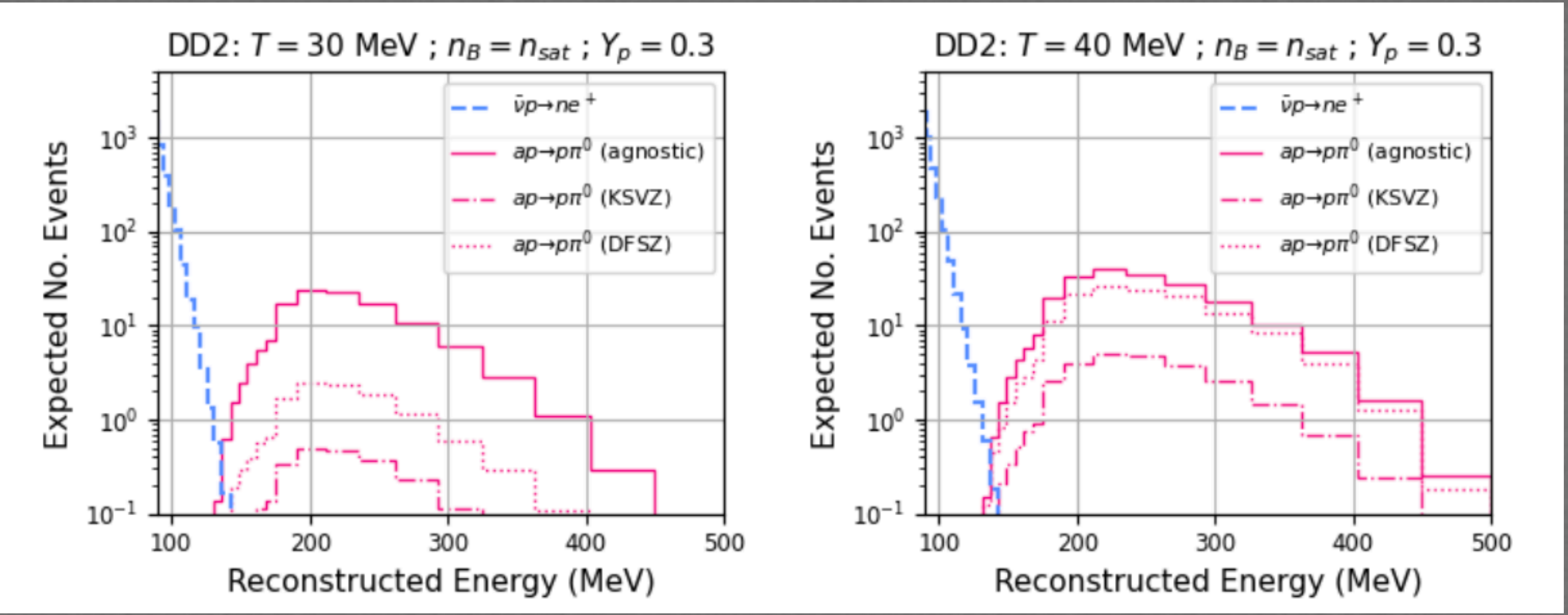


- The Cherenkov-light spectra induced by ν vs. a absorption peak at well separated energies
- This is especially true of the $ap \to p\pi^0$ process whose peak energy $\sim 10^2$ larger than for $ap \to p\gamma$

☒ Detector-response corrected spectra



(injected spectra are those in previous figure)

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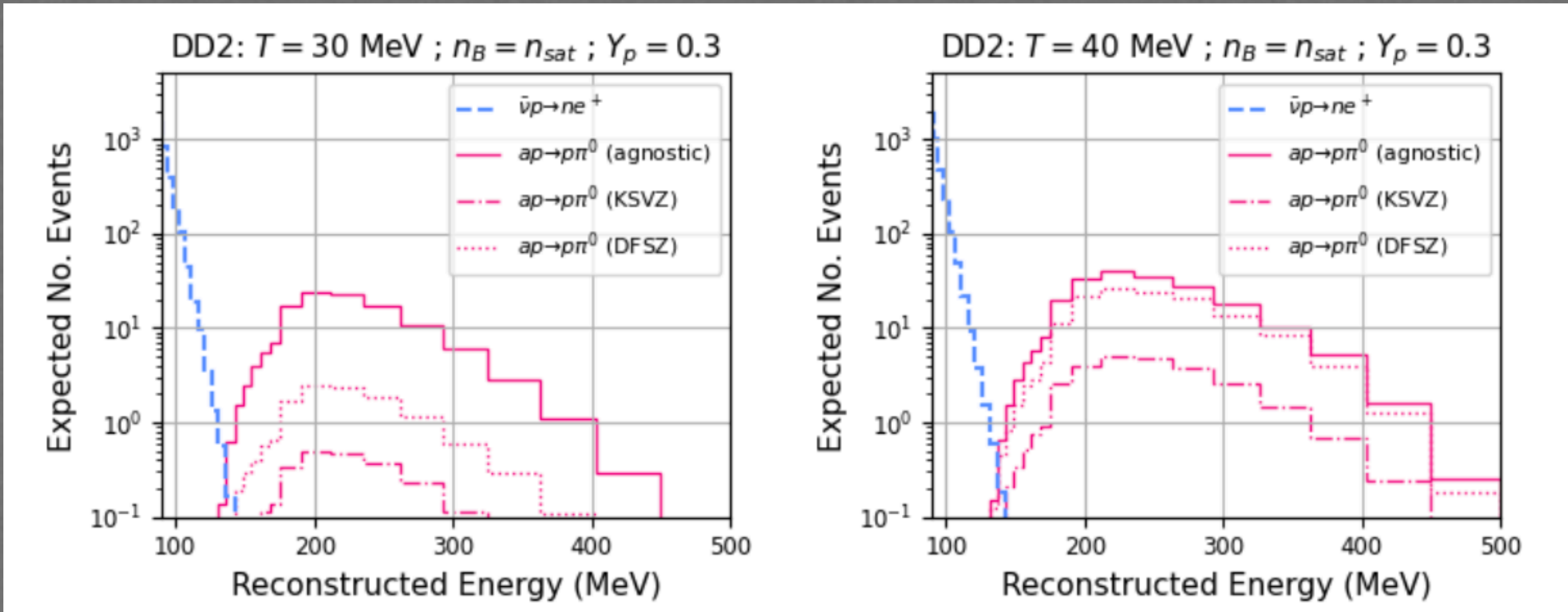

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- Main features remain unchanged as expected:
  - peak positions
  - relative peak heights

Couplings dependence of expected # of events

$$\langle N_{\pi^0}^{(R)} \rangle \equiv \lambda_{\pi^0}(C_{app}, C_{ann}) = \int_R dE_{\pi^0} \, \frac{dN_{\pi^0}^{(R)}(C_{app}, C_{ann})}{dE_{\pi^0}}$$

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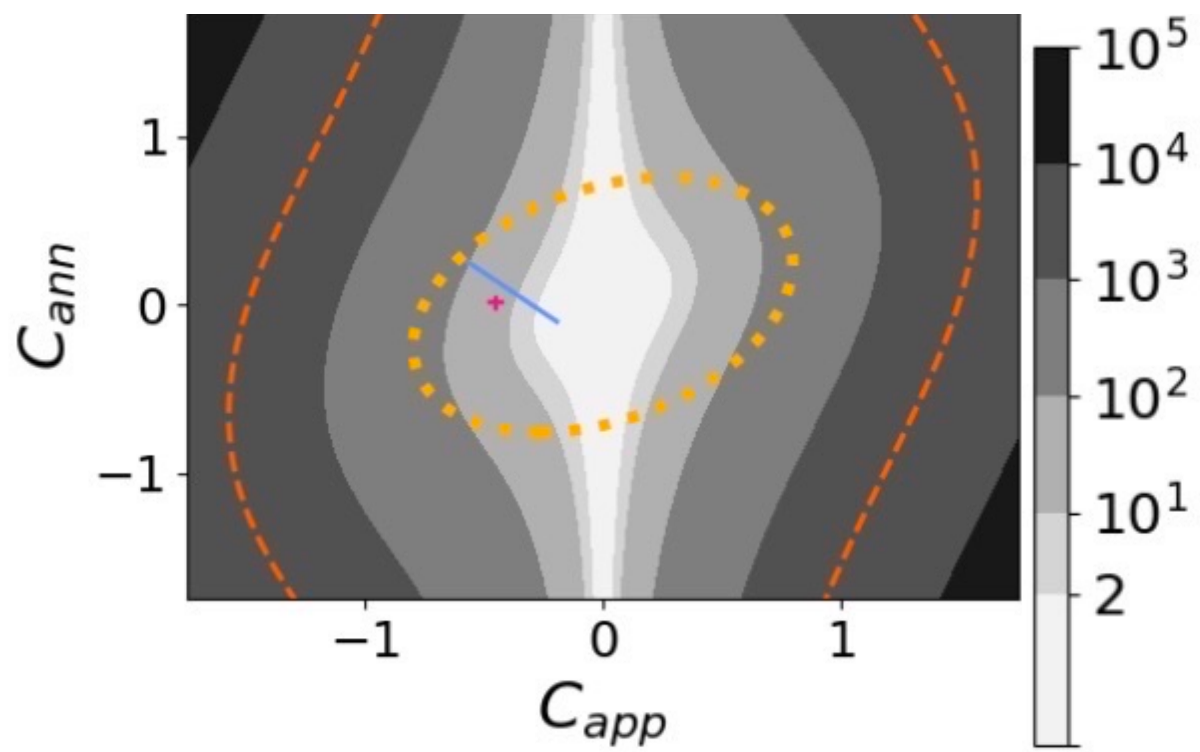
# of events from a SN candidate at 0.2 kpc (like Betelgeuse)



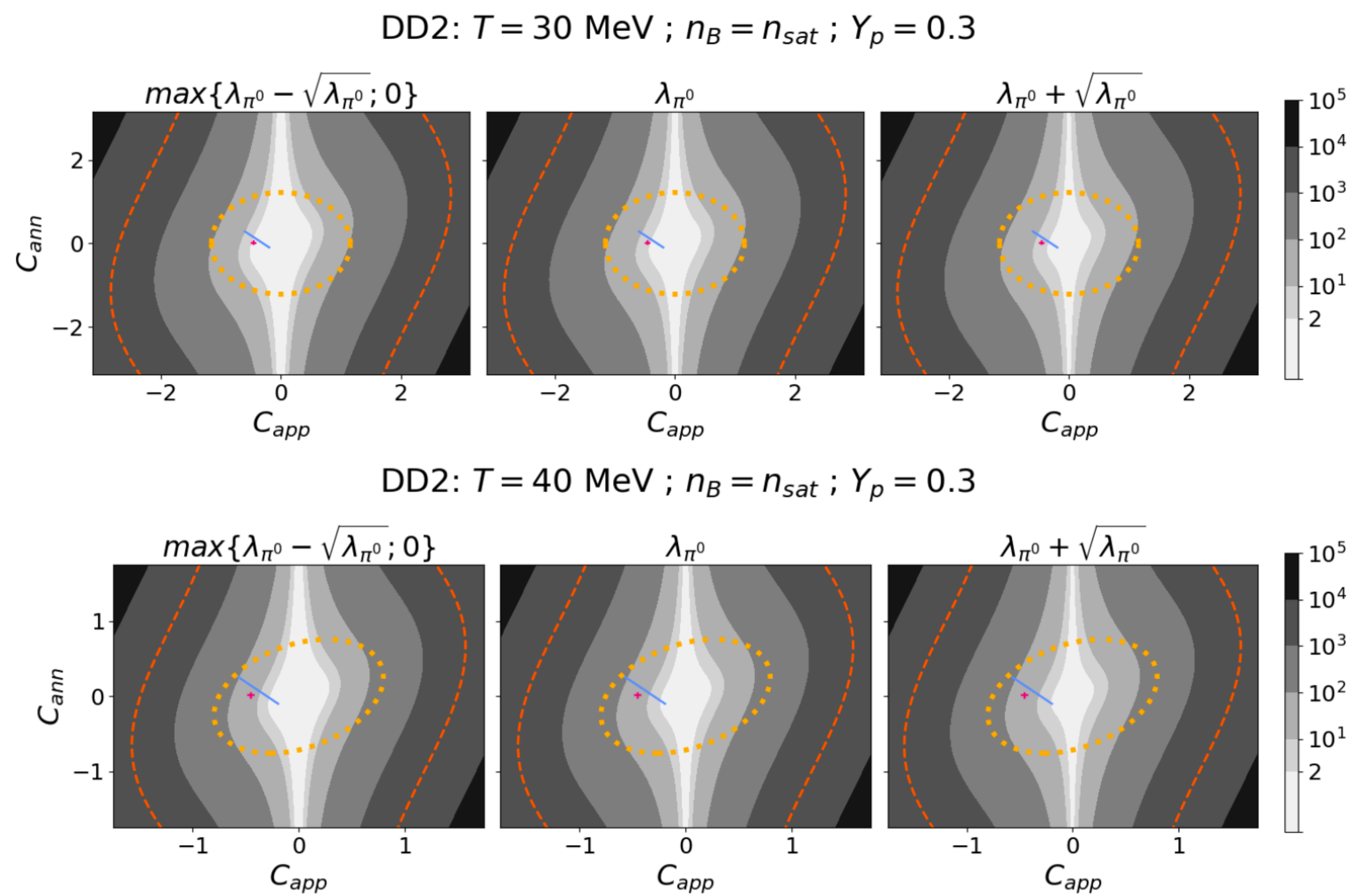
DFSZ w/ $\tan\beta \in [0.25, 170]$

KSVZ

NS & SN constraints

detectability criterion ($\lambda_{\pi^0} \geq 2$) assuming $d = 8.2$ kpc

☒ T dependence



■ # of events vs. # of SN candidates

$$\#\ \text{axion-absorpt. events} \propto \frac{1}{(\text{SN-to-Earth distance})^2} \equiv \frac{1}{d^2}$$

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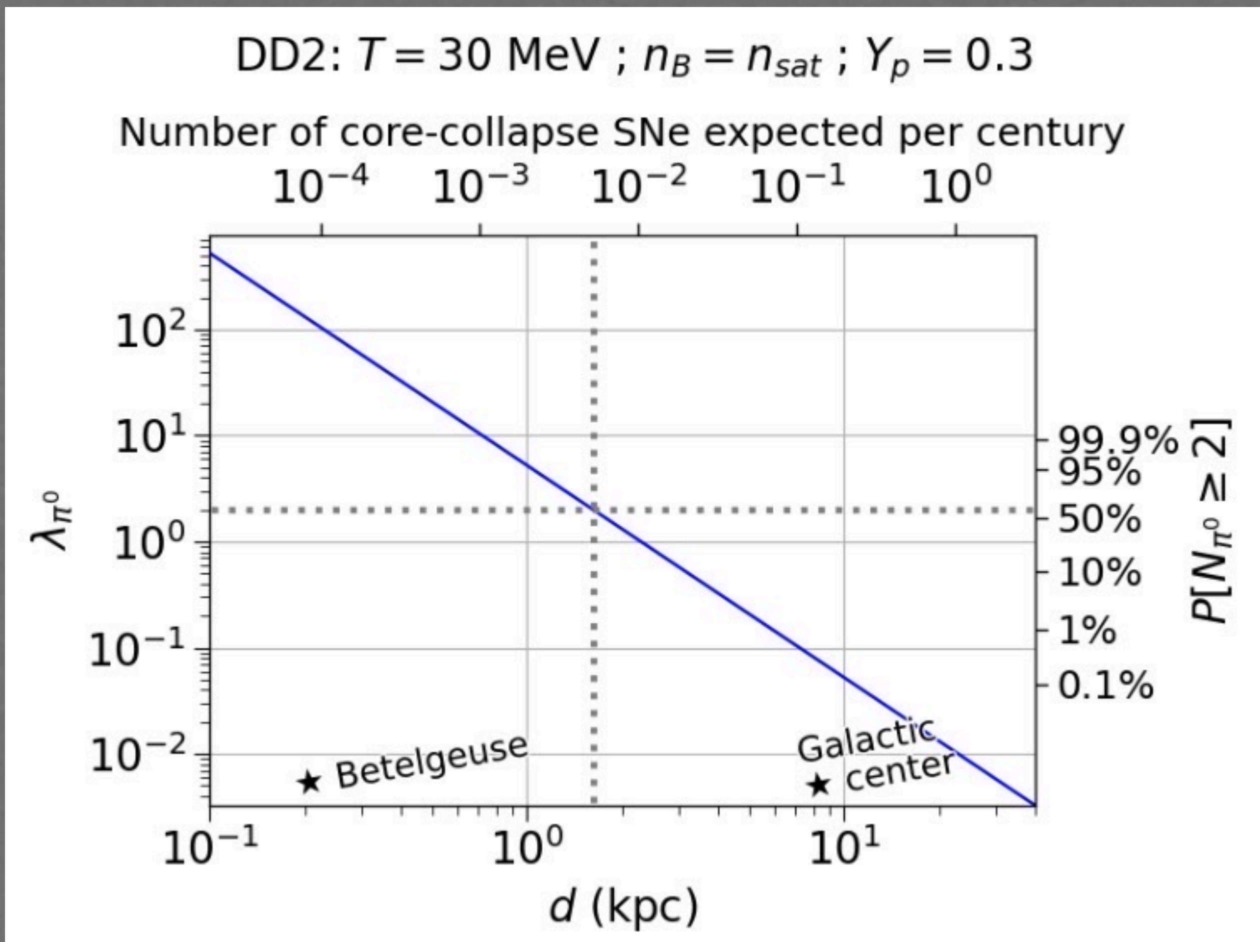

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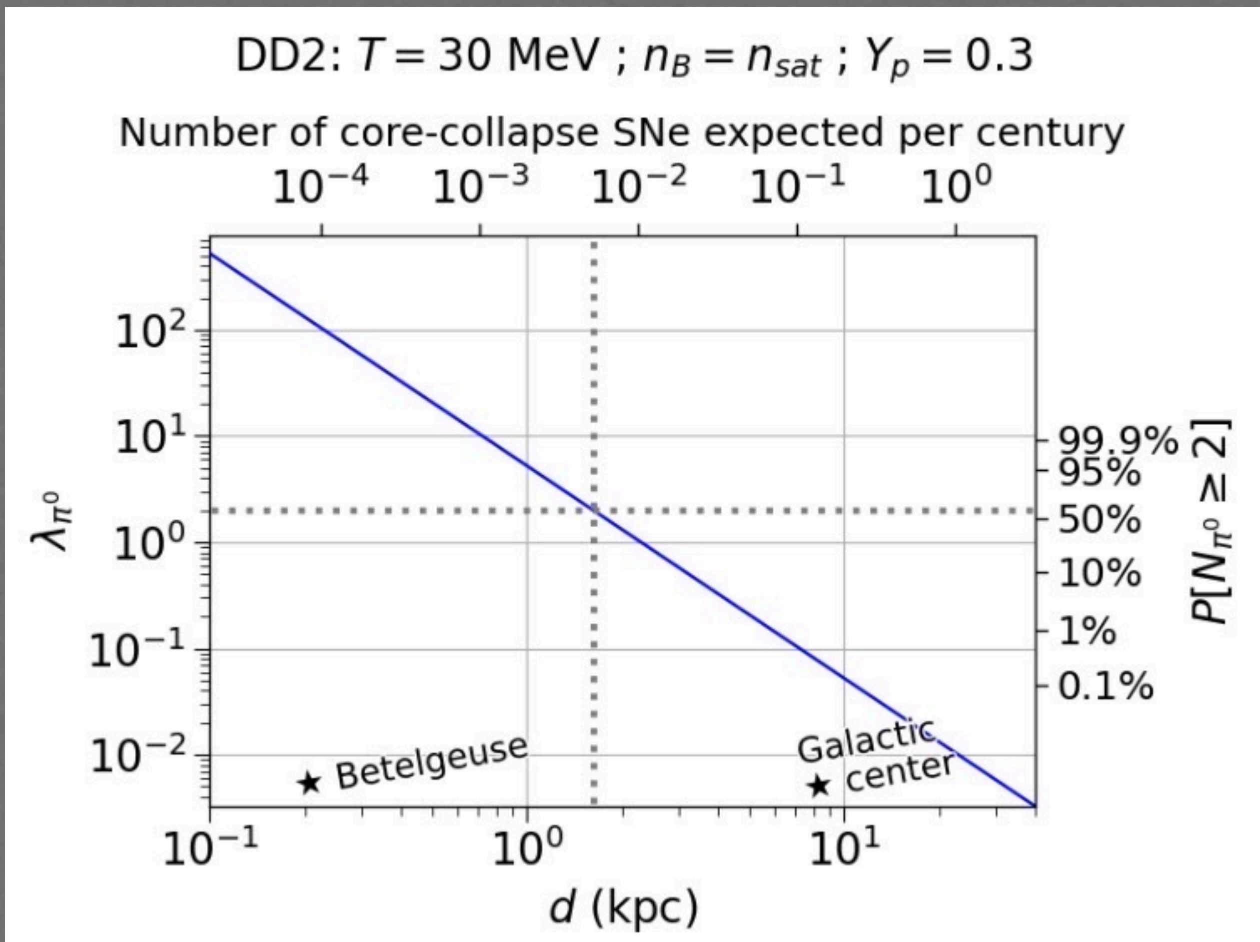

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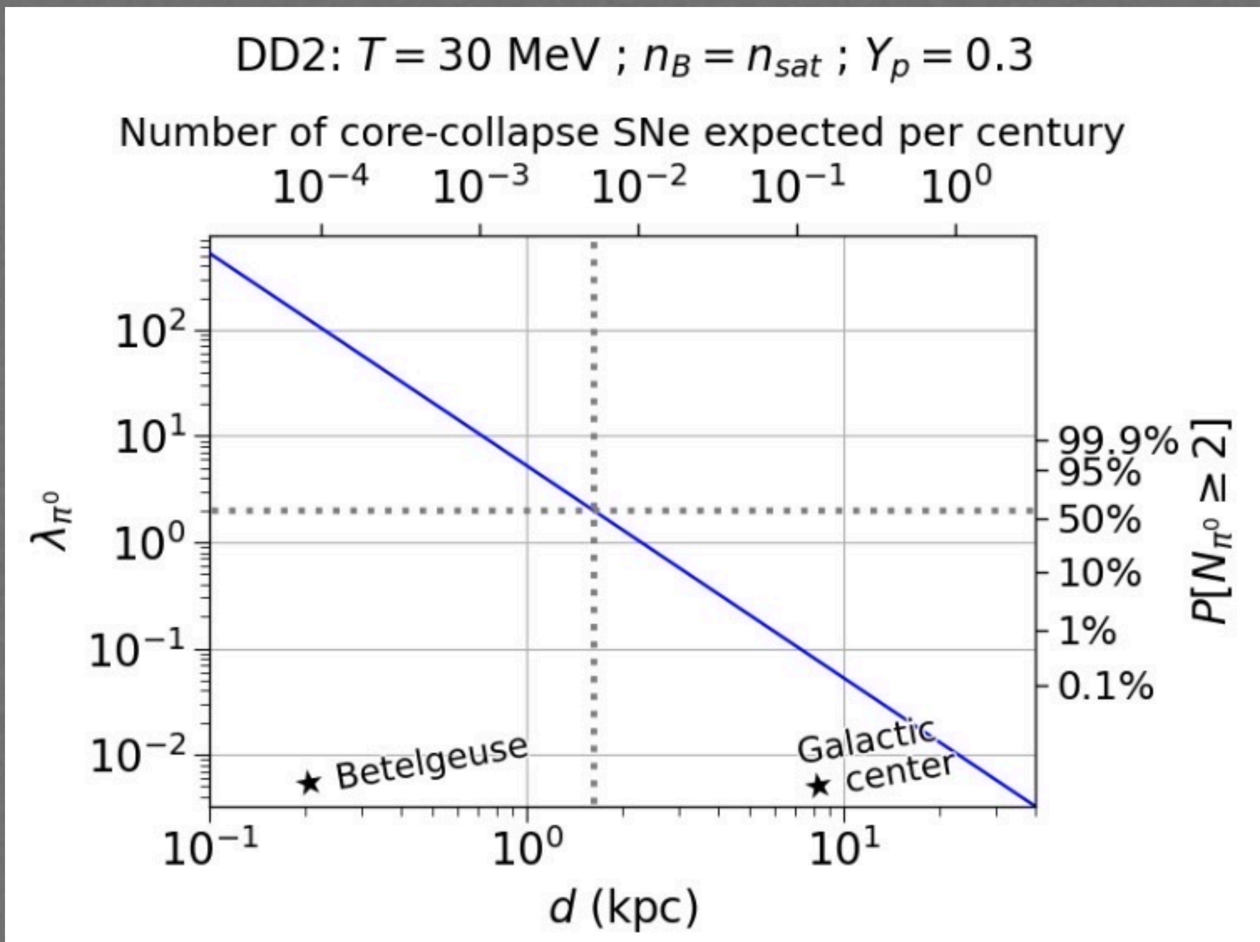

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- λ_{π^0} refers to axion-absorption evts.

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  - TH : inclusion of neutron & oxygen components or alternative absorption processes
  - EXP : scaling up detector volumes