Inelastic Dark Matter at Neutrino Experiments

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HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

DESY Summer Student Talks,
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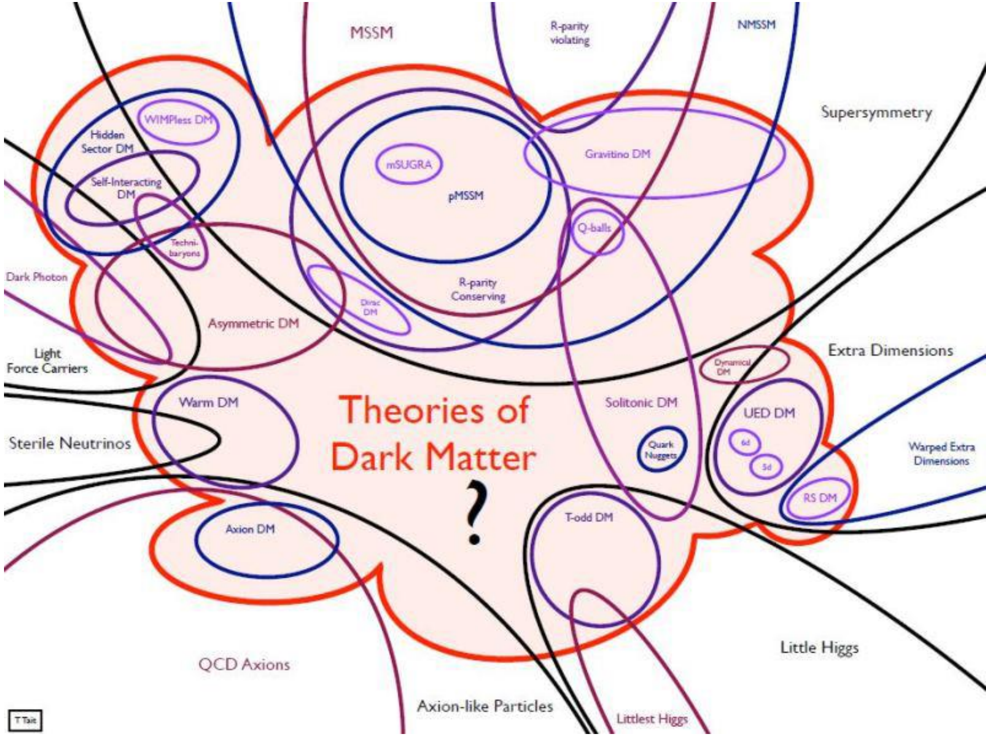
DESY.

Outline

- Introduction
- Physical Motivations
- Model
- Results

Dark Matter is complicated

- Multitude of candidates
- Bottom-Up vs Top-Down approach
- Need to study phenomenology of models to predict observation



T.Tait/University of California,Irvine

Our starting point

DESY 18-194
KEK-TH 2085

Light Dark Matter at Neutrino Experiments

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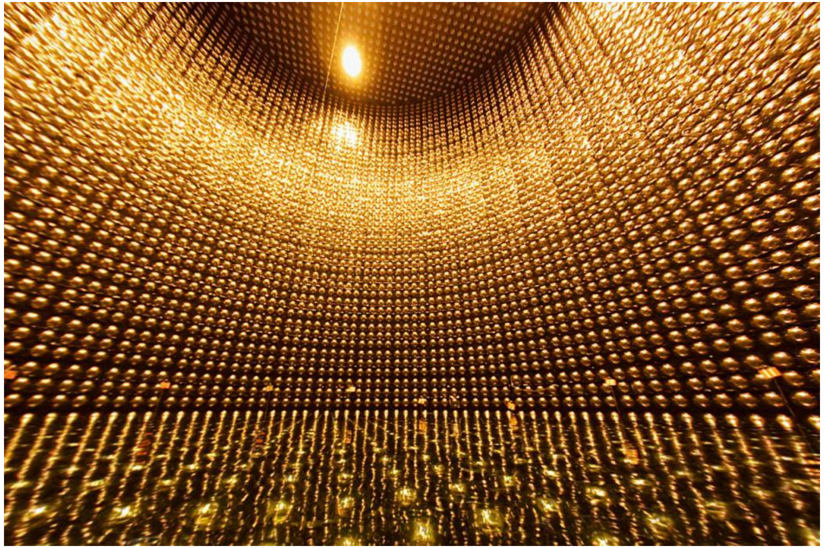
Sub-GeV Dark Matter particles upscattered by cosmic rays gain enough kinetic energy to pass the thresholds of large volume detectors on Earth. We then use public Super-Kamiokande and MiniBooNE data to derive a novel limit on the scattering cross section of Dark Matter with electrons that extends down to sub-keV masses, closing a previously allowed wide region of parameter space. We finally discuss search strategies and prospects at existing and planned neutrino facilities.

PACS numbers: 95.35.+d (Dark matter), 95.55.Vj (Neutrino, muon, pion, and other elementary particle detectors; cosmic ray detectors)

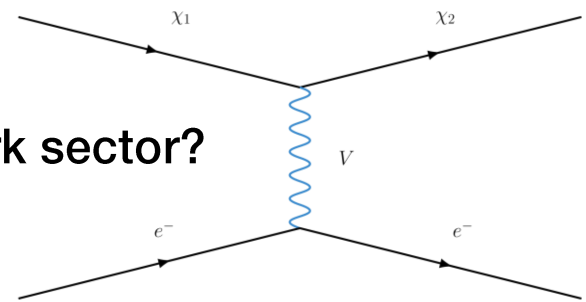
Our starting point (2)

- Light dark matter = Sub-GeV
- Up-scattered by cosmic rays
- Scatters with electrons in Super-K tank
- Momentum high enough to be detected by Super-K

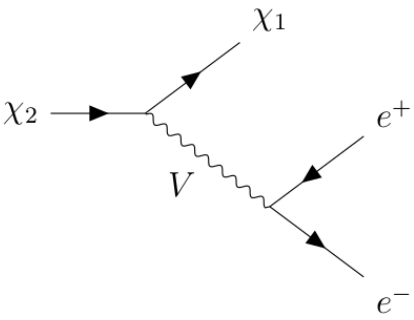


ABC News: Jake Sturmer

Our starting point (3)

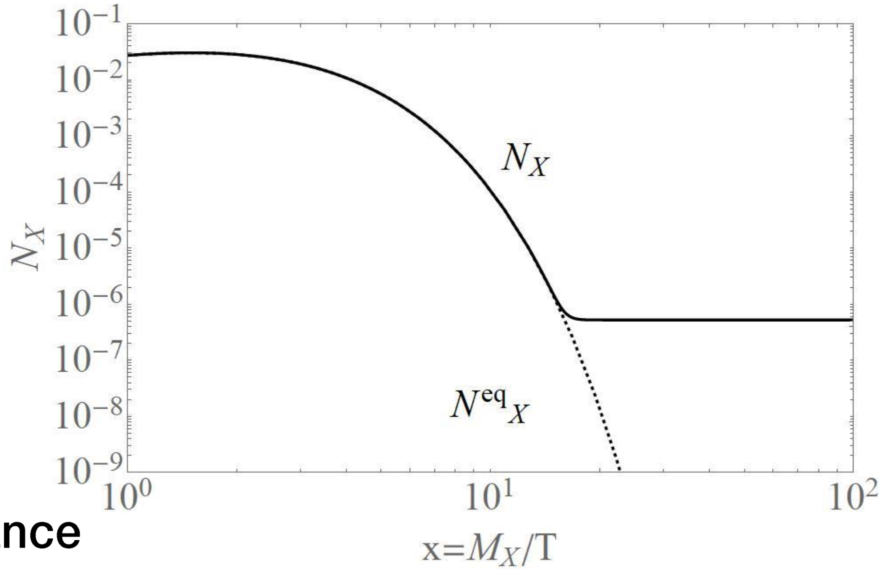


- What happens if there are two particles in the dark sector?
- χ_2 is heavier than χ_1 => χ_2 can decay into χ_1
- Detection motivations
- Cosmology motivations



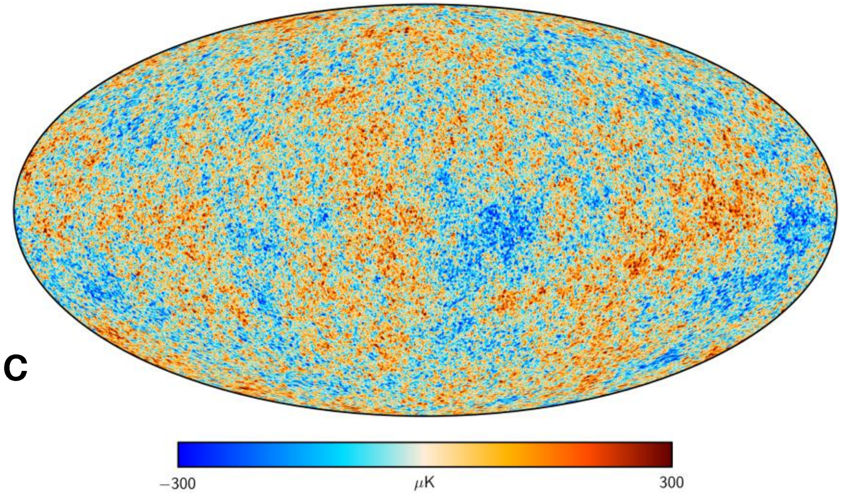
Freeze-out

- DM in thermal eq. with SM in early Universe
- Around $\Gamma \approx H$, rate of interaction (Γ) is slower than expansion rate (H)
- Dark matter freezes out
- Can then calculate current days abundance



Relic abundance

- Know from CMB measurements that $\Omega_{DM} h^2 \approx 0.11$
- Model has five free parameters
- Which combinations yield the correct relic abundance?



ESA and the Planck collaboration

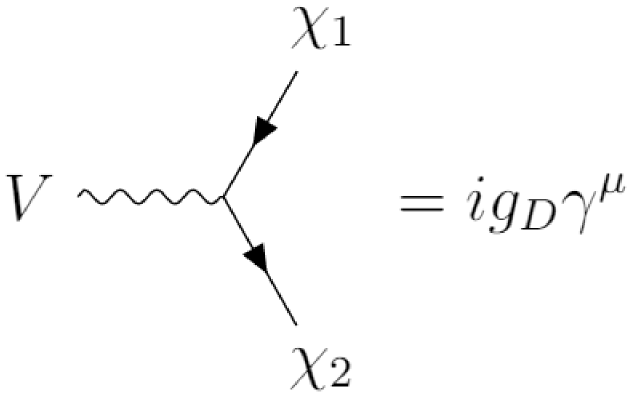
Boltzmann equation

- Calculate number of particles at freeze-out: $$\frac{dN_X}{dx} = -\frac{\lambda}{x^2}[N_X^2 - (N_X^{eq})^2]$$
- Where: $\lambda \equiv \frac{2\pi^2}{45} g_{*S} \frac{M_X^3 \langle \sigma v \rangle}{H(M_X)}$, hence why we calculated the c-s!
- Need to solve numerically
- From there, straightforward to calculate relic abundance

Dark sector interactions

$$\mathcal{L}_{Dint} = -i\bar{\chi_1}\gamma^5\gamma^\mu V_\mu g_D \chi_2 - i\bar{\chi_2}\gamma^5\gamma^\mu V_\mu g_D \chi_1$$

- Majorana Dark Matter
- Couples only to dark photon



Kinetic Mixing: New vertices

$$\mathcal{L} \supset -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{1}{4}F_D^{\mu\nu}F_{D\mu\nu} - \frac{\epsilon}{2}F^{\mu\nu}F_{D\mu\nu} - \frac{m_v^2}{2}V^{\mu}V_{\mu} - iqJ^{\mu}A_{\mu}$$

Kinetic Mixing: New vertices

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$$\hat{A}^\mu \rightarrow A^\mu + \epsilon V^\mu$$

$$\mathcal{L} \supset -\frac{1}{4}\hat{F}^{\mu\nu}\hat{F}_{\mu\nu} - \frac{1}{4}F_D^{\mu\nu}F_{D\mu\nu} - \frac{m_v^2}{2}V^\mu V_\mu - iqJ^\mu \hat{A}_\mu - iq\epsilon J^\mu V_\mu$$

Kinetic Mixing: New vertices

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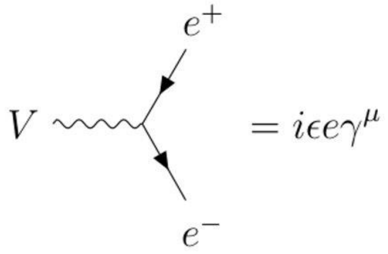
$$\hat{A}^\mu \to A^\mu + \epsilon V^\mu$$

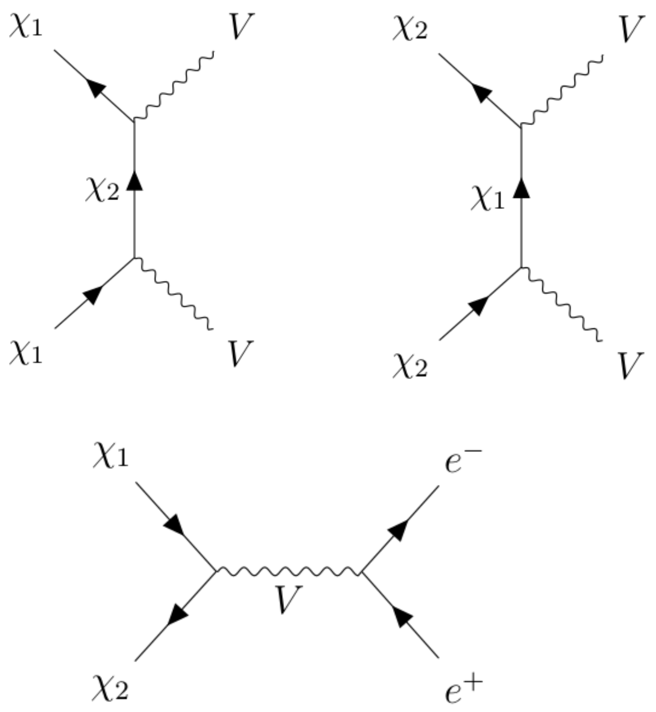


$$\mathcal{L} \supset -\frac{1}{4}\hat{F}^{\mu\nu}\hat{F}_{\mu\nu} - \frac{1}{4}F_D^{\mu\nu}F_{D\mu\nu} - \frac{m_v^2}{2}V^\mu V_\mu - iqJ^\mu \hat{A}_\mu - iq\epsilon J^\mu V_\mu$$

Co-annihilation

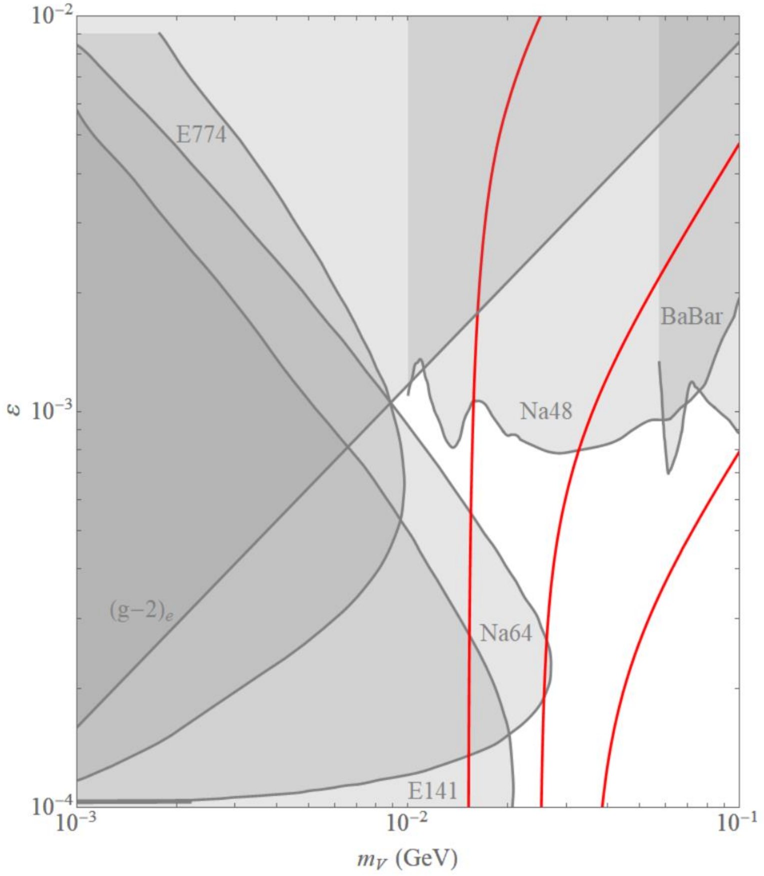
- Forbidden channel: $m_{1,2} < m_V$

- However, exponential tail of distribution still has access.

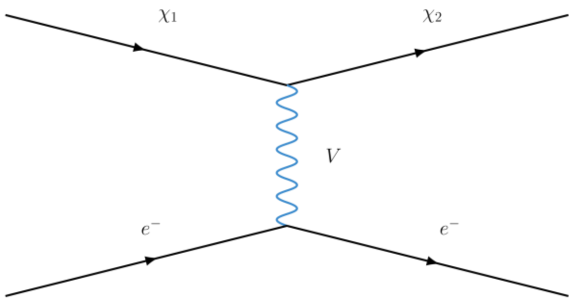


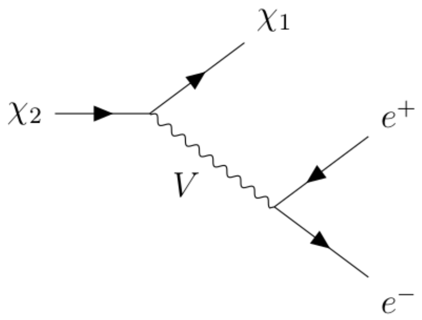
Final results

- Fix α_D and the mass ratios $\frac{m_2}{m_1}, \frac{m_v}{m_1}$
- Vary m_v, ε



Sensitivity



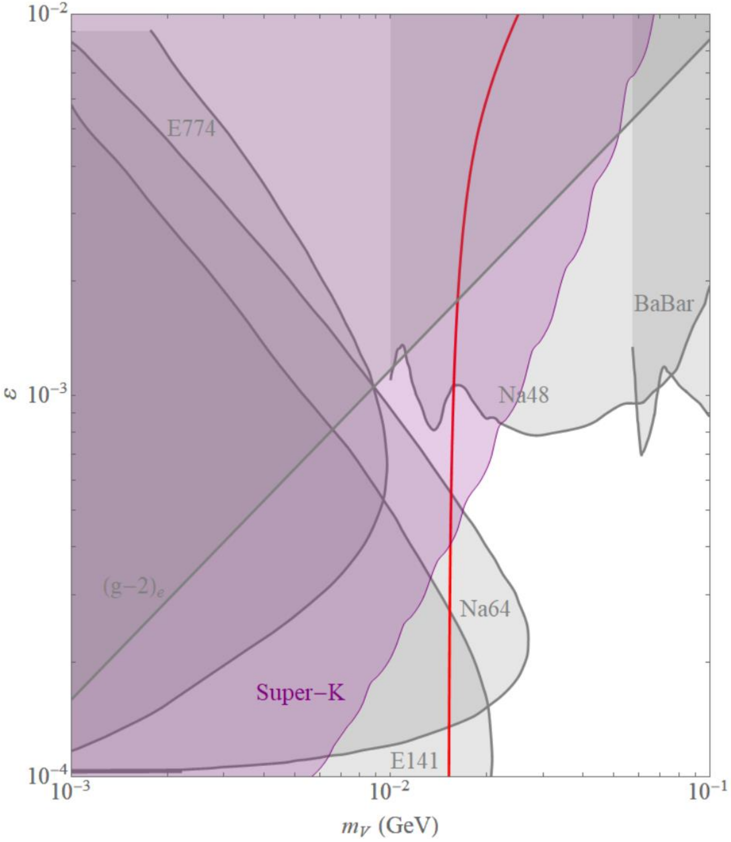


$$N = \int_t^{t+T} dt \int dK_1 \int dK_e \quad \Phi_{(K_1)} \frac{d\sigma}{dK_1 dK_e} P_{(K_1, K_e)} \propto \epsilon^4$$

Expected number of observations, combined with the absence of detections puts a sensitivity bound on epsilon for a given set of dark sector mass parameters

Final results

- $\alpha_D = 1$
- $\frac{m_2}{m_1} = 1.7$
- $\frac{m_v}{m_1} = 1.72$



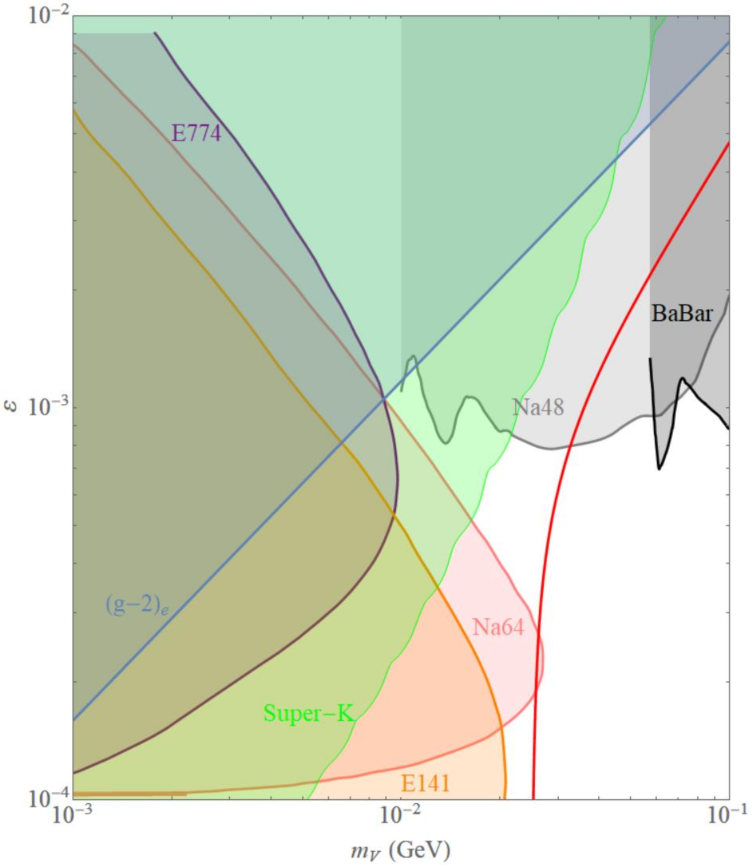
The End.

- Thanks for listening!

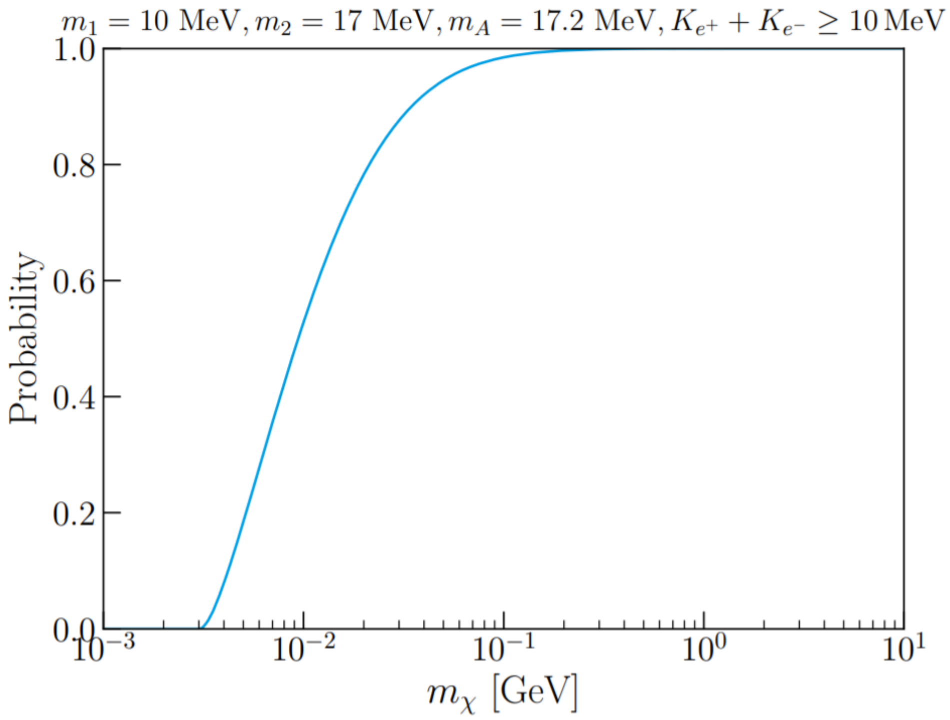
- Questions?

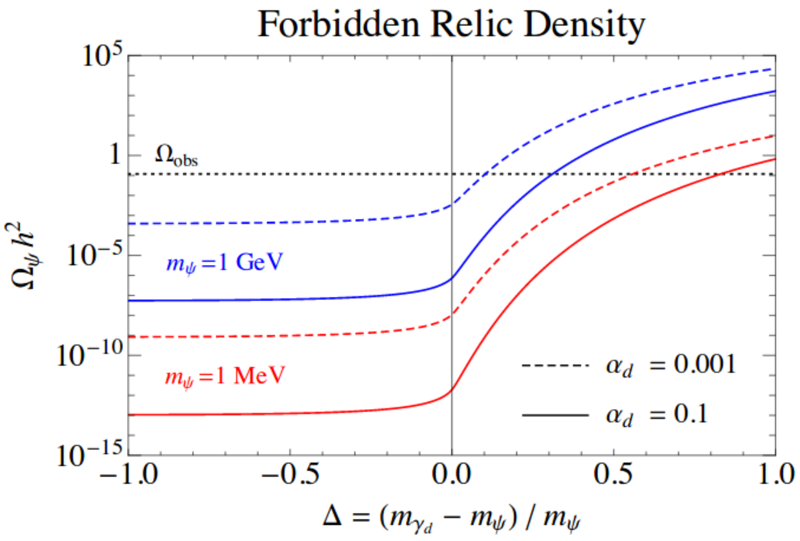
(Too much sun
for Gaspard)

BACK UP SLIDES



E774
BaBar
Na48
$(g-2)_e$
Na64
Super−K
E141
ε
10^{-2}
10^{-3}
10^{-4}
10^{-1}
m_V (GeV)


$m_1 = 10$ MeV, $m_2 = 17$ MeV, $m_A = 17.2$ MeV, $K_{e^+} + K_{e^-} \geq 10$ MeV
Probability
1.0
0.8
0.6
0.4
0.2
0.0
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
m_χ [GeV]



D'Agnolo, Ruderman (2015)

Detection

$$P = \int_0^{K_{max}} \frac{1}{\Gamma} \frac{d\Gamma}{dK_{\chi_1}}$$

K1max=K2-(m1-
m2)-Eth