Light Dark Sector: Inelastic Exploration

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Outline

- Introduction

- Dark sector models: Light Mediator and sub-GeV DM

- Light DM at beam dump-based neutrino and large neutrino detector experiments using nuclear inelastic processes ➔ *Line signal*
  [**Phys.Rev.D 106 (2022) 11, 113006, Phys.Rev.Lett. 131 (2023) 11, 111801, 2402.04184**]

- Conclusion

Introduction

- New Physics: Dark Matter (DM), Neutrino masses and mixing, various anomalies, e.g., g-2 of muon, MiniBooNE etc

  Are they all correlated? Is there a model?

- Where is the new physics scale?

- Many experiments are probing new physics scales:
  DM direct and indirect detections, LHC,
  neutrino experiments, beam dump experiments, rare decays, etc.

- Scales higher than 1 GeV can be probed with high sensitivities at the LHC

Introduction

This talk: Investigates scales below 1 GeV

- Anomalies, puzzles can be addressed
- There are many new ideas

Models (a lot of ongoing activities):
Light mediators: scalar, pseudo-scalar, vector; sub-GeV DM

This talk will discuss: a few specific well motivated scenarios

- Light DM: Ambient and Laboratory sources

Model 1: $SU(2)_L \times U(1)_Y \times U(1)_{T3R}$

Model with a sub GeV DM and Light mediators

E.g., there may be a new symmetry breaking scale around GeV
➔1st and 2nd generation fermion masses (~MeV to few GeV)

Anomaly free

$SU(2)_L \times U(1)_Y \times U(1)_{T3R}$

field	q_{T3R}
q_R^u	-2
q_R^d	2
ℓ_R	2
ν_R	-2
η_L	1
η_R	-1
ϕ	-2

$U(1)_{T3R}$ is broken at 1-10 GeV down to Z_2

➔Low mass dark matter, gauge and scalar mediators

Predictions are testable at various low energy experiments

Dark matter is made out of η_1, η_2:

$$\eta_1 = -\frac{i}{\sqrt{2}} \begin{pmatrix} \eta_L - \eta_R^c \\ -\eta_L^c + \eta_R \end{pmatrix} \qquad \eta_2 = \frac{1}{\sqrt{2}} \begin{pmatrix} \eta_L + \eta_R^c \\ \eta_L^c + \eta_R \end{pmatrix}$$

Dark Matter (parity odd): $\eta_{1,2}$ and can have small mass gap among η_1, η_2

Dutta, Ghosh, Kumar, 2019

$U(1)_{T3R}$

In SM, the Yukawa couplings are hierarchical:

$\lambda_t^{(SM)} \sim 1$, $\lambda_c^{(SM)} \sim 10^{-2}$, $\lambda_{s,\mu}^{(SM)} \sim 10^{-3}$, $\lambda_{u,d}^{(SM)} \sim 10^{-5}$, $\lambda_e^{(SM)} \sim 10^{-6}$

$$\mathcal{L}_{Yuk} = -\frac{\lambda_u}{\Lambda}\tilde{H}\phi^*\bar{Q}_L q_R^u - \frac{\lambda_d}{\Lambda}H\phi\bar{Q}_L q_R^d - \frac{\lambda_\nu}{\Lambda}\tilde{H}\phi^*\bar{L}_L\nu_R - \frac{\lambda_l}{\Lambda}H\phi\bar{L}_L\ell_R$$
$$- \lambda\phi\bar{\eta}_R\eta_L - \frac{1}{2}\lambda_L\phi\bar{\eta}_L^c\eta_L - \frac{1}{2}\lambda_R\phi^*\bar{\eta}_R^c\eta_R - \mu_\phi^2\phi^*\phi - \lambda_\phi(\phi^*\phi)^2 + H.c.,$$

$$\mathcal{L} = \ldots - \tilde{m}_{\chi_f}\bar{\tilde{\chi}}_f\tilde{\chi}_f - \lambda_{fL}H(\bar{\tilde{\chi}}_f P_L \tilde{f}_L)$$
$$-\lambda_{fR}\phi^*(\bar{\tilde{\chi}}_f P_R \tilde{f}) + h.c.,$$

Dutta, Ghosh, Gurrola, Judson, Kamon, Kumar, JHEP 03 (2023) 164

- Scalar ϕ vev $V = (-\mu_\phi^2/2\lambda_\phi)^{1/2}$ breaks $U(1)_{T3R}$ to Z_2 ,
- vev is around 1-10 GeV

➔ We can have $\lambda_x \sim 0.1 - 1$ since $(\langle H \rangle \langle \phi \rangle)/\Lambda$ helps to fit the fermion masses

U(1)$_{T3R}$

- New scalar and gauge boson: ϕ', A' are light in this model

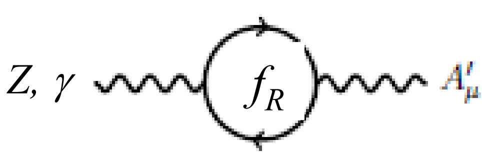
- The couplings of ϕ', A' with quarks and leptons are fixed once we choose the vev of <φ> and the A' mass

$$\mathcal{L}_{Yuk} = -m_u \bar{q}_L^u q_R^u - m_d \bar{q}_L^d q_R^d - m_\nu \bar{\nu}_L \nu_R - m_\ell \bar{\ell}_L \ell_R - \frac{1}{2} m_1 \bar{\eta}_1 \eta_1 - \frac{1}{2} m_2 \bar{\eta}_2 \eta_2$$
$$- \frac{m_u}{V} \bar{q}_L^u q_R^u \phi' - \frac{m_d}{V} \bar{q}_L^d q_R^d \phi' - \frac{m_{\nu D}}{V} \bar{\nu}_L \nu_R \phi' - \frac{m_\ell}{V} \bar{\ell}_L \ell_R \phi' - \frac{1}{2} \frac{m_1}{V} \bar{\eta}_1 \eta_1 \phi' - \frac{1}{2} \frac{m_2}{V} \bar{\eta}_2 \eta_2 \phi' + \ldots.$$

$$D_\mu = \partial_\mu + i \frac{g}{2} \tau_a W_{\mu a} + i g' Y B_\mu + i \frac{g_{T_{3R}}}{2} Q_{T_{3R}} A'_\mu,$$

$$\mathcal{L}_{gauge} = \frac{1}{4} g_{T3R} A'_\mu (\bar{\eta}_1 \gamma^\mu \eta_2 - \bar{\eta}_2 \gamma^\mu \eta_1) + \frac{m_{A'}^2}{V} \phi' A'_\mu A'^\mu + i g_{T3R} A'_\mu (\phi' \partial^\mu \phi'^* - \phi'^* \partial^\mu \phi) - \frac{1}{2} g_{T3R} j^\mu_{A'} A'_\mu,$$

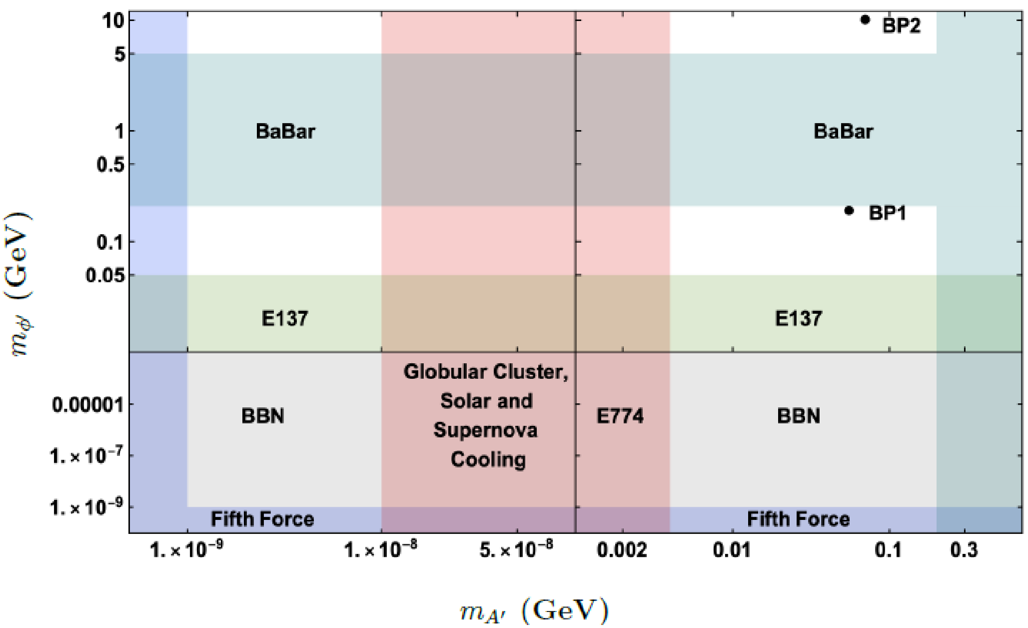
A' also mixes with photon and Z

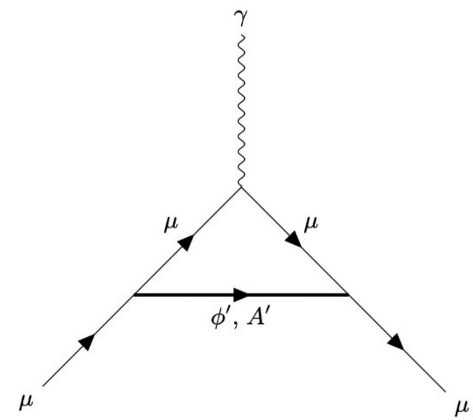


Parameter Space

Various scenarios: Gauge boson (A')-scalar (ϕ') mediators parameter space

- E.g., Muon model: u_R, d_R, ν_R, μ_R





$$\Delta a_\mu = (6.98 \times 10^{-7}) \left(\frac{V}{10\,\mathrm{GeV}}\right)^{-2} (C_{\phi'} - C_{A'}),$$

Fixes M_ϕ=10-100 MeV

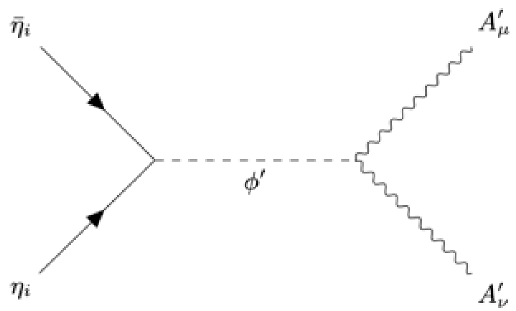
- Electron model: u_R, d_R, ν_R, e_R

- Similarly, models with second generation quarks

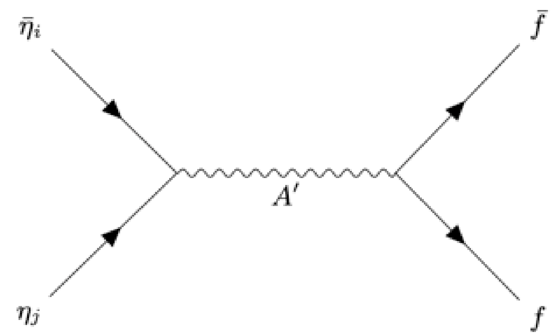
DM Abundance in U(1)T3R

Thermal relic is easier to satisfy due to the existence of two mediators

Various two-body final states:



P-wave



S-wave

+ …

Resonance/non-resonance:

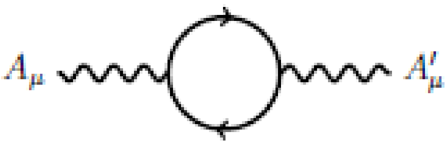
$m_{A'}$ (MeV)	$m_{\phi'}$ (MeV)	m_η (MeV)	m_{ν_s}(MeV)	$m_{\nu D}$(MeV)	$\langle\sigma v\rangle$ (cm^3/sec)	$\sigma_{\rm SI}^{scalar}$(pb)	$\sigma_{\rm SI}^{vector}$(pb)
150	80	40	10	10^{-3}	3×10^{-26}	0.58	1.17
180	76	38	10	10^{-3}	3×10^{-26}	0.58	1.06

Similar Models…

Similar models of light gauge mediators:
$L_\mu - L_\tau$, $U(1)_B$, $U(1)_L$, $U(1)_{B\text{-}L}$.

Battel, Niverville, Pospelov, Ritz, 2014, Kaplan, Luty, Zurek, 2009, Bi, He. Yuan, 2009, Park Kim Park, 2016, Foldenauer, 2019, Dutta, Ghosh, Kumar, 2019

- Photons and new gauge boson mix via $\varepsilon F^{\mu\nu} F'_{\mu\nu}$



[These models have constraints from beam dump, low energy accelerators, g-2, astrophysical and cosmological constraints]

- These light mediators can decay into ν's, DM and various SM particles

Another example: Model 2

One can utilize the Higgs- sector based new physics to have a light scalar (1GeV)

- Higgs sector is extended (No additional gauge symmetry)
- In various models, we can have a larger Higgs sector, e.g., LR, grand-unified models etc.
- We extend the Higgs sector most generally by a doublet, triplet, and a singlet

$$\phi_1 : \left(2, \frac{1}{2}\right), \qquad \phi_2 : \left(2, \frac{1}{2}\right), \qquad \phi_S : (1, 0), \qquad \Delta : (3, 1),$$

Higgs Potential

We choose the Higgs basis from the minimization condition, where only one of the Higgs doublets get a non zero vev, the triplet VEV is constrained by the ρ parameter, singlet VEV is unconstrained

Physical particles	Mass values and descriptions
Neutral scalars: h, h_1, h_2 and h_3	$m_h = 125.5$ GeV, this is the SM Higgs; $m_{h_1} = 0.001$ GeV, very light scalar, neccessary for our analysis; $m_{h_2} = 500$ GeV, $m_{h_3} = 600$ GeV they satisfy the LHC bounds.
Neutral pseudo-scalars: s_1, s_2 and s_3	$m_{s_1} = 500$ GeV, $m_{s_2} = 500$ GeV, $m_{s_3} = 600$ GeV, they satisfy LHC bounds.
Single charged scalars: $h_1^{\pm}$, $h_2^{\pm}$	$m_{h_1^{\pm}} = 500$ GeV, $m_{h_2^{\pm}} = 600$ GeV, in agreement with LHC bounds.
Double charged scalars: $h_3^{\pm\pm}$	$m_{h_3^{\pm\pm}} = 500$ GeV, satisfying LHC limits.

$$-\mathcal{L}_{Yukawa} \supset \bar{\nu^c}_i (y_\nu)_{ij} \Gamma \nu_j h_k + \bar{f}_i (y_f)_{ij} \Gamma f_j h_k$$

i, j: flavor indices: 1, 2, 3

f: u, d, e

h_k: h, h_1, h_2, h_3, s_1, s_2, s_3

There can be additional heavy neutrinos (N) in this model with $y_{NN\phi}$ couplings

Dutta, Ghosh, Li, Thompson, Verma, JHEP 03 (2023) 163, Phys.Rev.D 100 (2019) 11, 115006

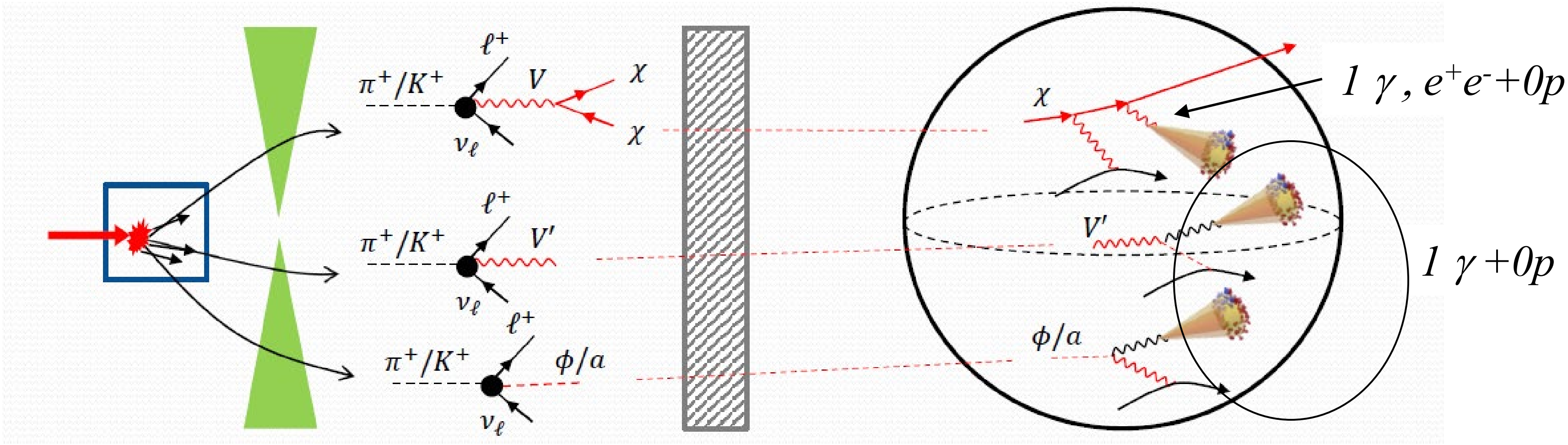
Light DM in Model 1 and 2

- Both Models have light DM and light mediators
- Address various anomalies, g-2, MiniBooNE (heavy neutrino, dark sector)

Dutta, Ghosh, Kumar, PRD 2022; Dutta, Kim, Remington, Thomson, Van de Water, PRL, 2022

- Contains NSIs and associated phenomenologies

Dutta, Ghosh, Li, Thompson, Verma; JHEP, 2023; Dutta, Ghosh, Kelly, Li, Thompson, Verma, 2024; Dutta, Goswami, Karthikeyan, Kelly, To appear



Light DM in Model 1 and 2

Model 1: New particles: ϕ', A', light DM, Mediators couple to first generation quarks and second generation leptons

Model 2: neutrino interactions, light scalars/pseudo-scalars, light DM (N), NSI interactions, mediator coupling to fermions are arbitrary

Both light DM and mediators can be probed in various low energy experiments, Electron, proton beam-dump based experiments and large scale neutrino detectors

- We will explore light DM at neutrino experiments (using mesons etc. to produce light mediators ➔ DM), COHERENT, CCM, JSNS^2
- Ambient DM in large neutrino detector, e.g., JUNO, Borexino, DUNE, HyperK

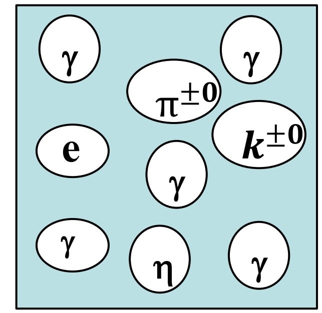
Light Mediators at SBL ν Expts.

Neutrino experiments can be versatile

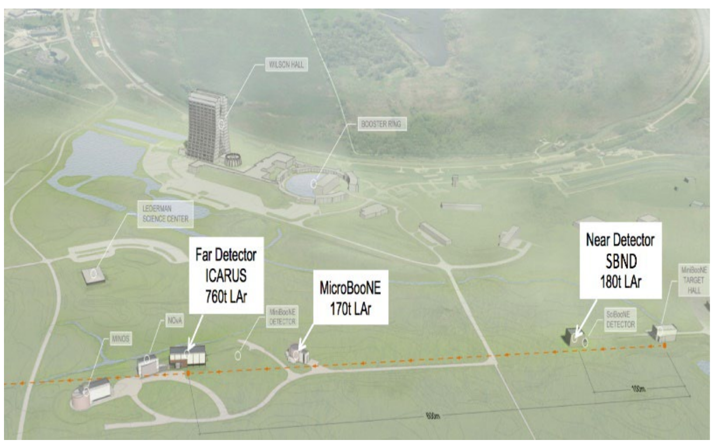
Beam dump-based (proton beam)
[ongoing]: 800 MeV-3 GeV: COHERENT (Oakridge), CCM (LANL), JSNS2(JPARC)
Detectors, CsI, LAr, NaI, Ge

Proton (p)

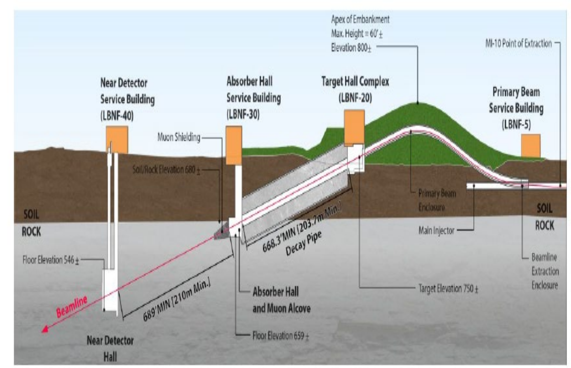
High Intensity
~ $10^{21\text{-}23}$ POT



Fermilab SBN program: 120 GeV NUMI, 8 GeV BNB beams (ongoing)



DUNE (120 GeV)



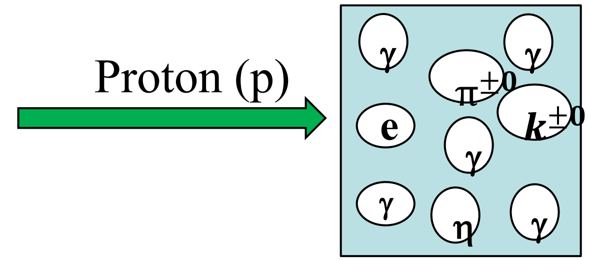
- Many experiments with proton beams have different beam energies using various detectors at different locations
- FASER, FASERν, SND are ongoing

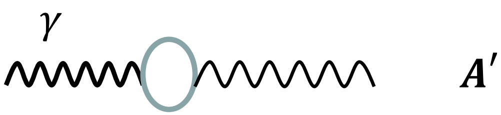
New physics at ν experiments

For example,

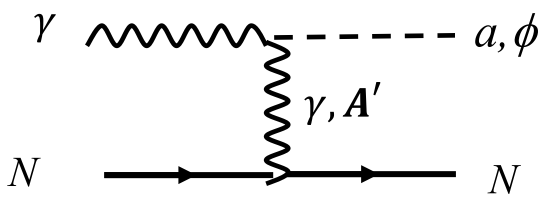
From γ:

A': Vector
ϕ=scalar
a=pseudo-scalar





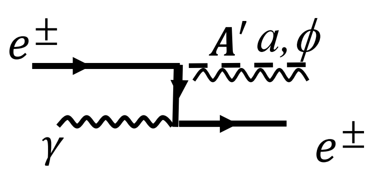
$$L \supset -\frac{\varepsilon}{4} F^{\mu\nu} F_{\mu\nu}^{(\prime)} - g_{a,\phi\gamma(Z')} \frac{(a,\phi)}{4} F^{\mu\nu} \tilde{F}_{\mu\nu}^{(\prime)}$$

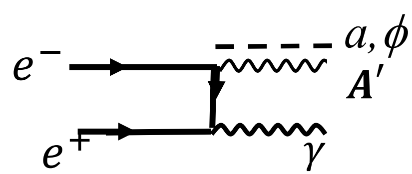


Primakoff

From $e^{\pm}$: $L \supset -g_{\phi(a)ee} \bar{e}\,(i\gamma^5) e\,\phi(a) - g_{A'ee} \bar{e}\,\gamma^\mu e\,A'$

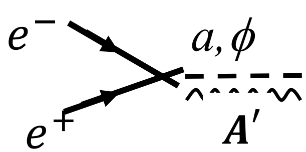
Compton

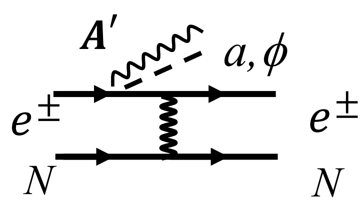




Associated

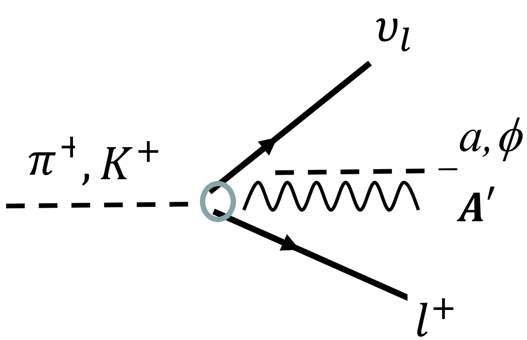
Resonance





Bremsstrahlung

New physics at ν experiments



$$L \supset -g_{\phi(a)ff}\bar{f}(i\gamma^5)f\,\phi(a) - g_{A'ee}\bar{f}\,\gamma^\mu f\,A'_\mu$$

- *Charged meson decay: quarks and lepton couplings*

  - Not helicity suppressed ➔ both electron and muon final states contribute
  - Needs to include all the internal bremsstrahlung diagrams $\mathrm{IB_i}$ (i=1,23)

PHYSICS REPORTS No. 3 (1962) 151-21)5.
Bandyopadhyay, Ghosh, Roy, PRD 105 (2022) 11, 115039.

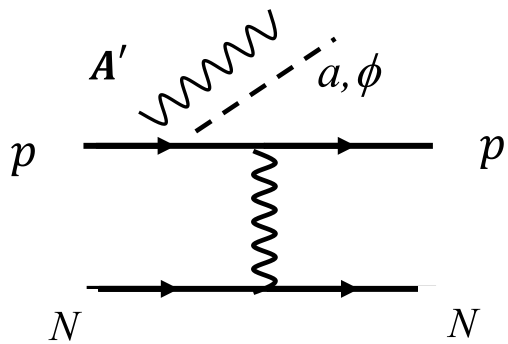
- Satisfy the experimental constraint from **PIENU** (pions) and **NA62**(Kaons)

$\eta^0,\ \pi^0 \rightarrow \gamma A'_\mu$ *Neutral meson decays*

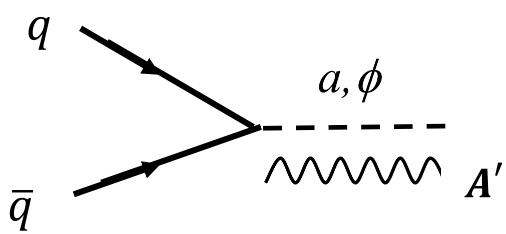
- Charged pion contribution can be larger than the neutral pion even without the focusing horns

- Important for stopped pion and mesons decay-in-flight experiments

New physics



Proton bremsstrahlung



Parton interactions

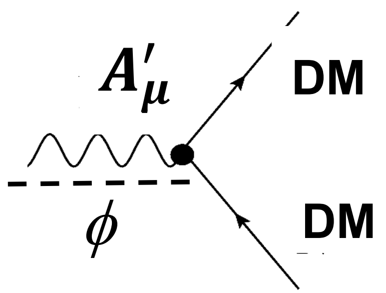
- There can be more production processes, e.g., $\nu + N \to \nu_s + N$ (coherently enhanced) using $\bar{\nu}_s \sigma_{\mu\nu} F^{\mu\nu} \nu$
- Nuclear de-excitation lines at lower mass target (lower beam energy)
- Neutrons can be used: Bremsstrahlung, neutrons on target, etc. to produce light mediators

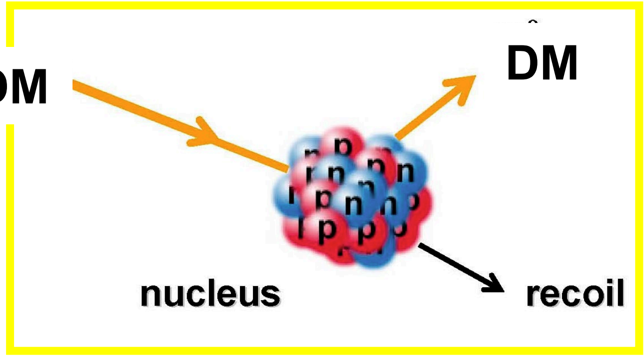
Dev, Dutta, Han, Karthikeyan, Kim, 2311.10078

Low mass DM at ν experiments

Dark matter particles can be produced in the lab

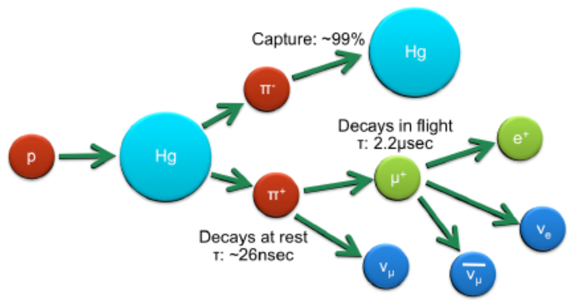
➔ Dark gauge bosons, scalars decay into dark matter





- Low threshold detectors would be useful
- Lot more dark matter particles compared to direct detection experiments
- Low mass dark matter can be investigated
- Problem: Neutrinos also produce same signals ➔ Neutrino floor?

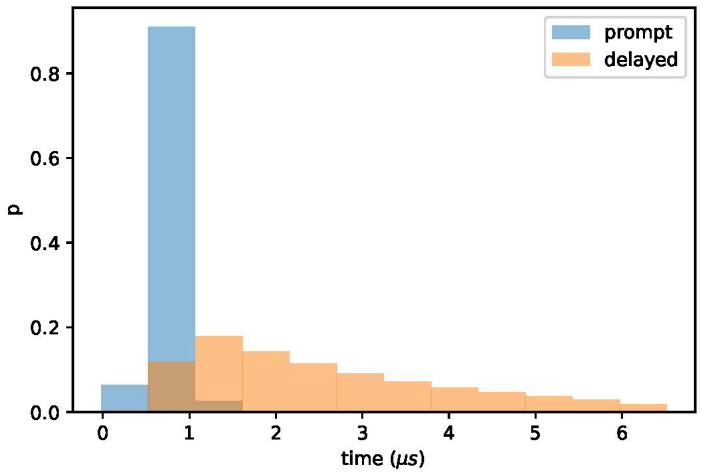
Ex. KeV signal at COHERENT, CCM

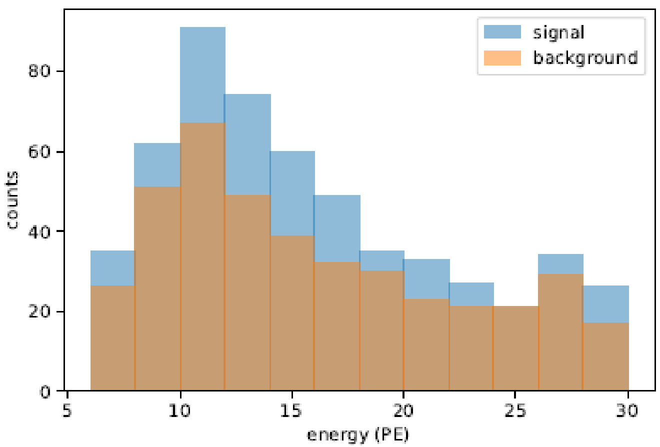


$$\textit{Prompt:} \quad \pi^+ \to \mu^+ + \nu_\mu$$

$$\textit{Delayed:} \quad \mu^+ \to e^+ + \overline{\nu_\mu} + \nu_e$$

COHERENT: CsI data:2018





COHERENT (2017) **No CEvNS rejected at 6.7σ: CsI (2020): 11.6σ**

COHERENT (2020) **No CEvNS rejected at 3.8σ : LAr**

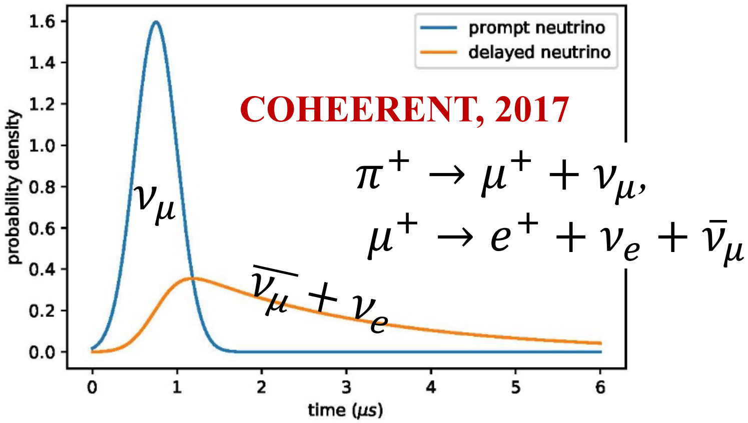
- ***New results using Ge [2024]: 3.9σ***

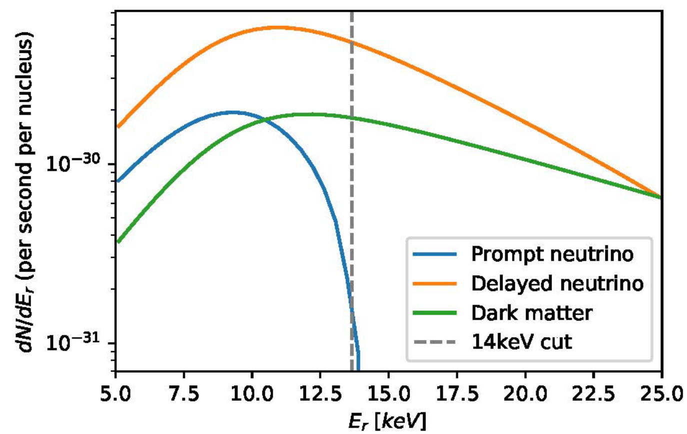
Light DM at COHERENT, CCM

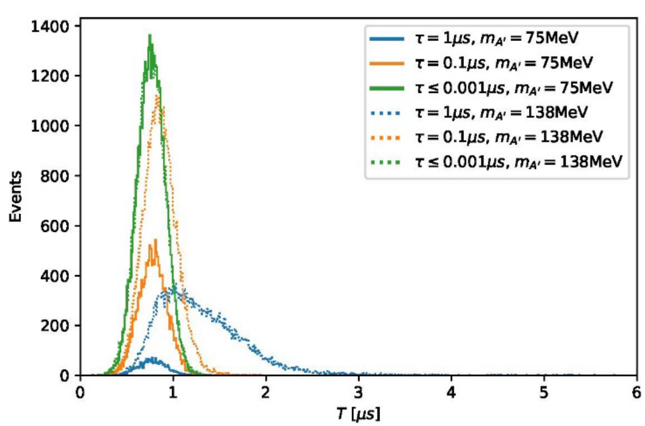
The ongoing CEνNS experiments, COHERENT, CCM etc. are probing DM

Deniverville, Pospelov, Ritz, PRD, 2015, Ge, Shoemaker, JHEP, 2018, Dutta, Kim, Liao, Park, Shin, Strigari, PRL, 2020

- Both neutrinos, DM produce nuclear/electron recoils: how to distinguish them?
- The timing and energy recoil measurement at COHERENT, CCM, JSNS^2 can be used







- For $t < 1.5\mu$ s, we have mostly prompt ν
- For E_r >14 KeV (CsI) we remove the prompt ν

➔ We can remove the SM/NSI ν backgrounds

➔ We need to do the same thing for CCM, JSNS^2

Light DM at COHERENT, CCM

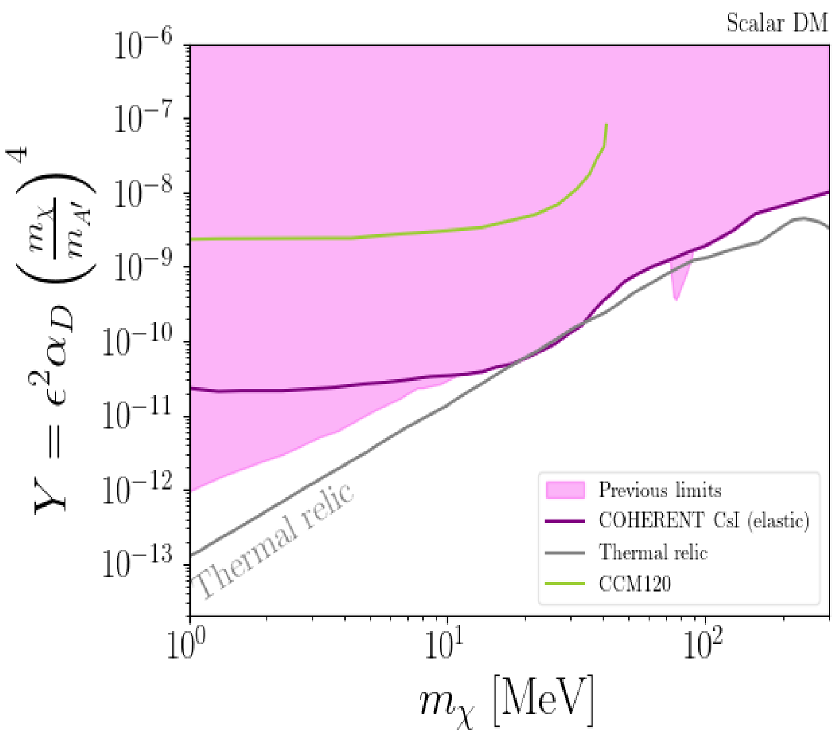
Another method:

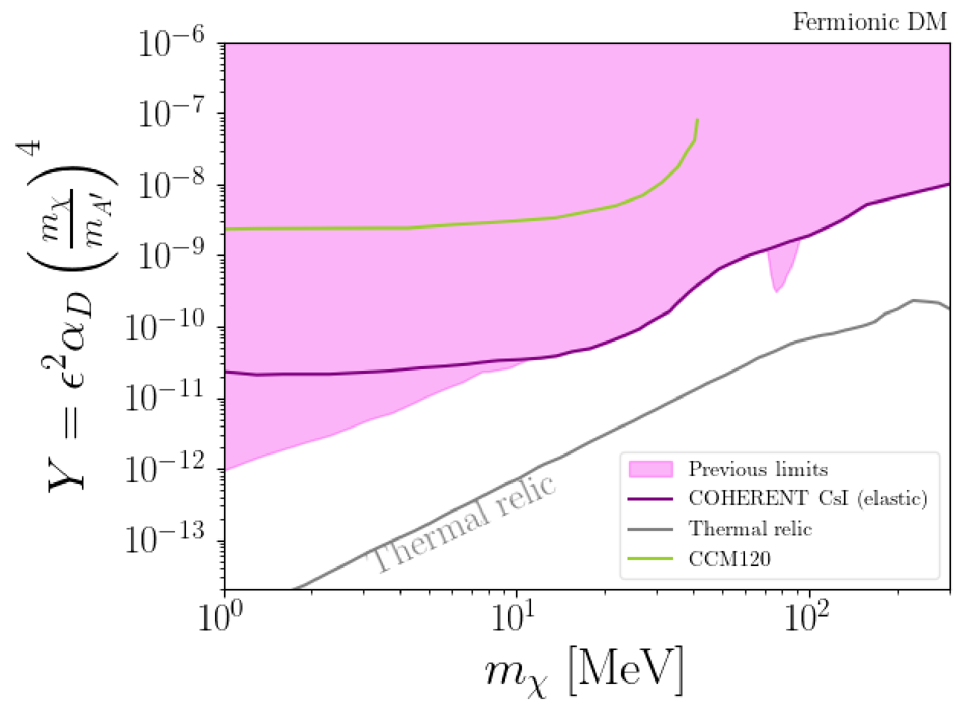
Use the delayed neutrinos ($T>2.2\mu s$) to determine the background-related uncertainties➔ predict the backgrounds in the prompt window

- The first method needs to know the time t_0 very well
- The second method assumes no NSI in the neutrino spectra

COHERENT uses the second method while CCM uses the first method

Light DM at COHERENT, CCM



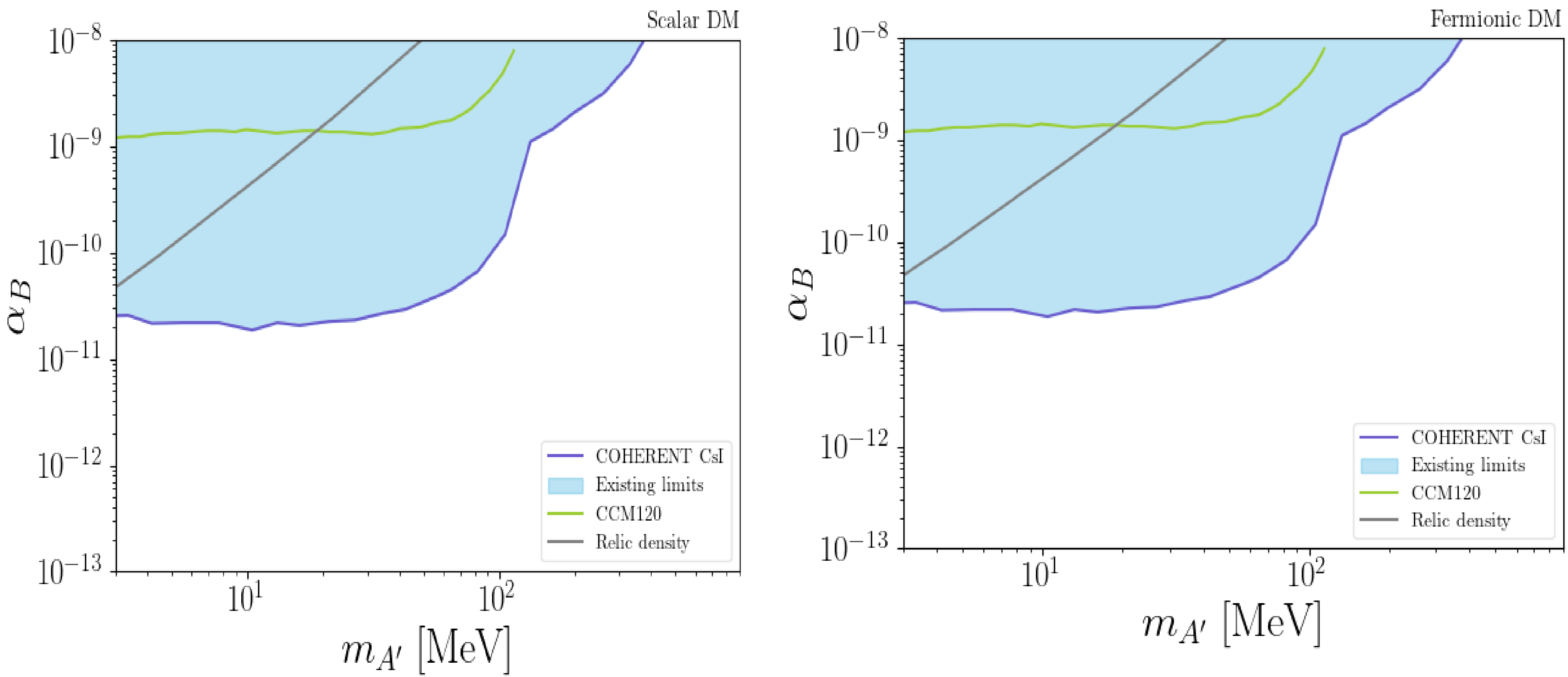


COHERENT: CsI (14.6 kg): 3.2 x10^{23} POT,

CCM 120: LAr (7ton): 1.79 x10^{20} POT (Engineering run)

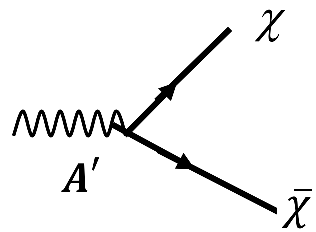
Here the mediators do not need electron interactions

Light DM at COHERENT, CCM

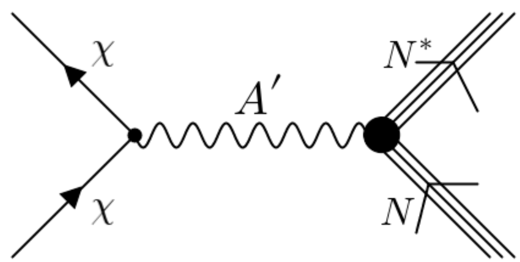


MeV signal – Light DM

$$\begin{aligned}\pi^- + p &\rightarrow n + A' \\ \pi^0 &\rightarrow \gamma + A' \\ \eta^0 &\rightarrow \gamma + A' \\ e^{\pm *} &\rightarrow e^{\pm} + A'\end{aligned}$$



DM (χ) can be scalar/fermion



$N^* \rightarrow N\gamma$

MeV

We use Bigstick: Shell Model code for this calculation

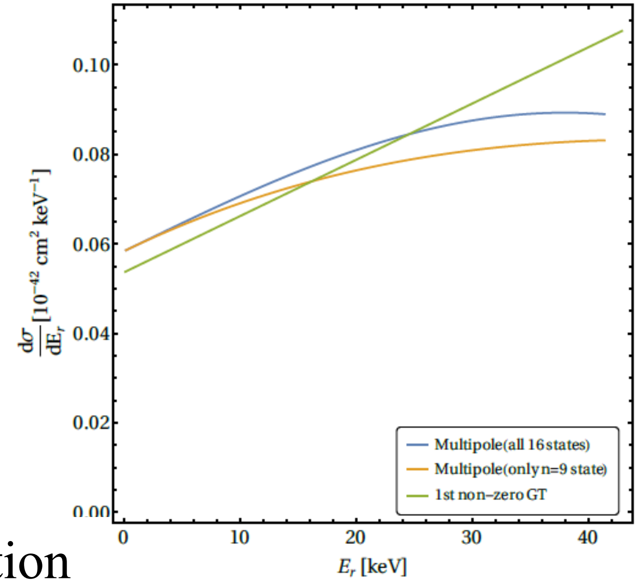
B. Dutta, Wei-Chih. Huang, J. Newstead, V. Pandey, Phys.Rev.D 106 (2022) 11, 113006

MeV signal - DM

$$\frac{d\sigma^{DM}_{\text{inel}}}{dE_r} = \frac{2e^2\epsilon^2 g_D^2 E'^2_\chi}{p_\chi p'_\chi (2m_N E_r + m_{A'}^2)^2}\frac{m_N}{2\pi}\frac{4\pi}{2J+1}\Bigg\{\sum_{J\geqslant 1, spin}\left[\frac{1}{2}(\vec{l}\cdot\vec{l}^* - l_3 l_3^*)\left(|\langle J_f||\hat{\mathcal{T}}_J^{mag}||J_i\rangle|^2 + |\langle J_f||\hat{\mathcal{T}}_J^{el}||J_i\rangle|^2\right)\right]$$

$$+\sum_{J\geqslant 0, spin}\left[l_0 l_0^*\,|\langle J_f||\hat{\mathcal{M}}_J||J_i\rangle|^2 + l_3 l_3^*\,|\langle J_f||\hat{\mathcal{L}}_J||J_i\rangle|^2 - 2\,l_3 l_0^* Re\left(\langle J_f||\hat{\mathcal{L}}_J||J_i\rangle\langle J_f||\hat{\mathcal{M}}_J||J_i\rangle^*\right)\right]\Bigg\}$$

$$\begin{aligned}\frac{d\sigma^{GT}_{DM}}{dE_r} &= \frac{2e^2\epsilon^2 g_D^2 E'^2_\chi}{p_\chi p'_\chi (2m_N E_r + m_{A'}^2)^2}\frac{m_N}{2\pi}\frac{4\pi}{2J+1} \\ &\times\left[\frac{(\vec{l}\cdot\vec{l}^* - l_3 l_3^*)}{2}|\langle J_f||\hat{\mathcal{T}}_J^{el5}||J_i\rangle|^2\right. \\ &\left.+\, l_3 l_3^*\,|\langle J_f||\hat{\mathcal{L}}_J||J_i\rangle|^2\right]. \\ &= \frac{2e^2\epsilon^2 g_D^2 E'^2_\chi}{p_\chi p'_\chi (2m_N E_r + m_{A'}^2)^2}\frac{m_N}{2\pi}\frac{4\pi}{2J+1} \\ &\times\frac{\vec{l}\cdot\vec{l}^*}{2}\frac{g_A^2}{6\pi}|\langle J_f||\sum_{i=1}^{A}\frac{1}{2}\hat{\sigma}_i\hat{\tau}_0||J_i\rangle|^2.\end{aligned}$$



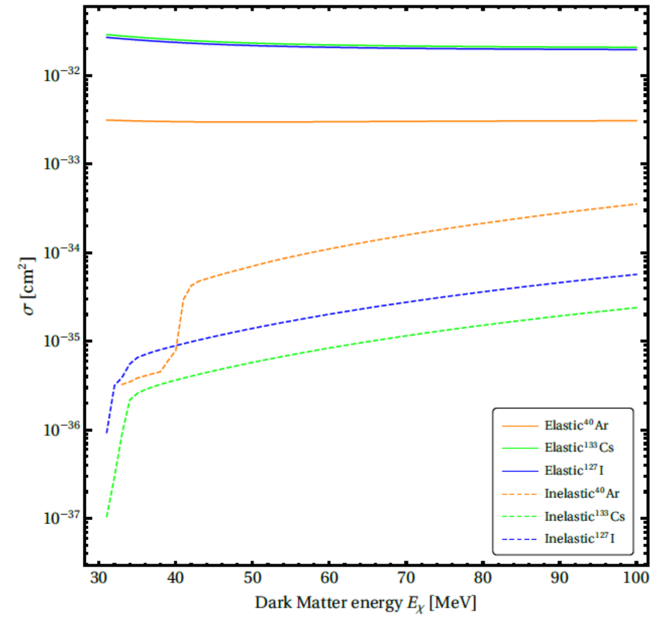
For ν-DM scattering with E_ν=30 MeV

- GT: dominates the cross-section
- Cross-section can be calculated:
  Using shell model code, e.g., BIGSTICK,
  Experimental measurements

B. Dutta, W. Huang, J. Newstead, V. Pandey, Phys.Rev.D 106 (2022) 11, 113006

MeV Signal - DM

We use BIGSTICK: SDPF-NR interaction for Ar



For elastic scattering:

$$\frac{d\sigma_{\mathrm{el}}^{DM}}{dE_r} = \frac{e^2\epsilon^2 g_D^2 Z^2}{4\pi(E_\chi^2 - m_\chi^2)(2m_N E_r + m_{A'}^2)^2} F^2(q^2) \times \left[2E_\chi^2 m_N \left(1 - \frac{E_r}{E_\chi} - \frac{m_N E_r}{2E_\chi^2}\right) + E_r^2 m_N\right]$$

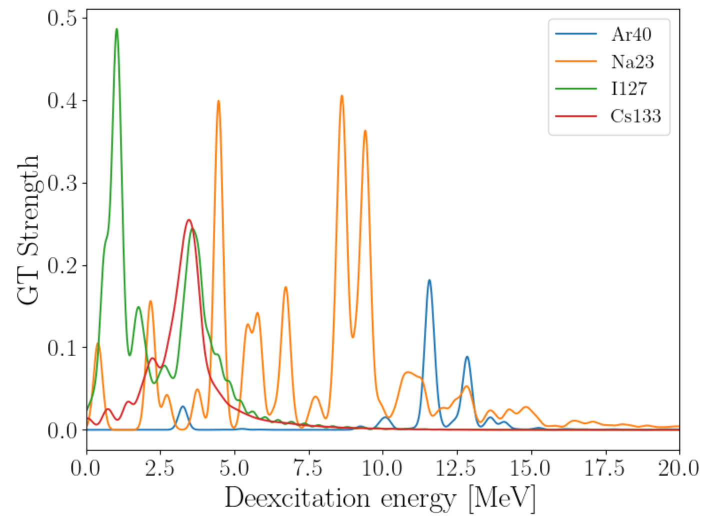
- Inelastic to elastic Cross-section ratio ~ 10^{-1}-10^{-3}
- The signal is now in the MeV Region (not KeV), neutrino background is easy to overcome
- The signal is a line signal
- Impact of threshold is different

Scattering	Experiment	Elastic	Inelastic	Ratio
ν-^{40}Ar	COHERENT	2.27×10^2	3.15	7.21×10
ν-^{40}Ar	CCM	1.91×10^4	2.65×10^2	7.21×10
ν-^{133}Cs	COHERENT	1.16×10^3	1.52×10^{-2}	7.65×10^3
ν-^{127}I	COHERENT	1.06×10^3	3.75×10^{-1}	2.81×10^3
χ-^{40}Ar	COHERENT	1.18	1.13×10^{-1}	1.04×10
χ-^{40}Ar	CCM	9.92×10	9.52	1.04×10
χ-^{133}Cs	COHERENT	4.11	4.91×10^{-3}	8.38×10^2
χ-^{127}I	COHERENT	3.87	1.16×10^{-2}	3.33×10^2

MeV signal-Light DM

- The cross-section for the line signal is smaller compared to the elastic signal
- The background is small
- threshold requirement is ~ 0.5-10 MeV

➔ Better sensitivity of the parameter space



Experiment	E_{beam} [GeV]	POT [yr^{-1}]	Target	Detector: material	mass	distance	angle	runtime	E_r^{th}
KARMEN	0.8	1.16×10^{22}	Ta	CH_2	56 t	17.7 m	100°	4 years	10 MeV
COHERENT†	1	6.0×10^{23}	Hg	NaI[Tl]	3.5 t	22 m	120°	3 year	~few keV
CCM†	0.8	7.5×10^{21}	W	Ar	7 t	20 m	90°	3 years	25 keV
PIP2-BD†	2	9.9×10^{22}	C	Ar	100 t	15 m	N/A	5 years	20 keV

- For Carbon, we use the measurement (KARMEN) of the 15.1 MeV line (in the neutral current data),
- We use the BIGSTICK calculations

MeV signal-Light DM

KARMEN:

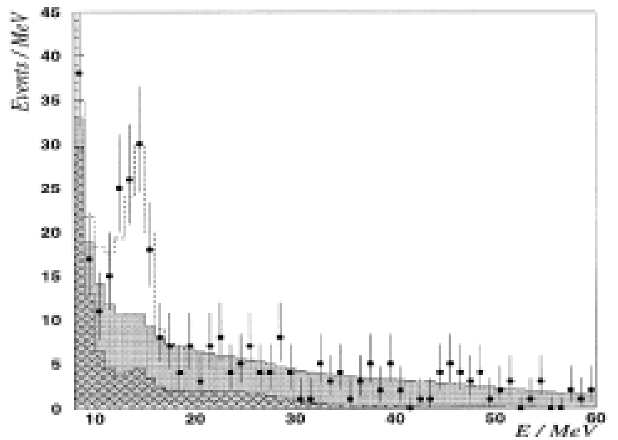
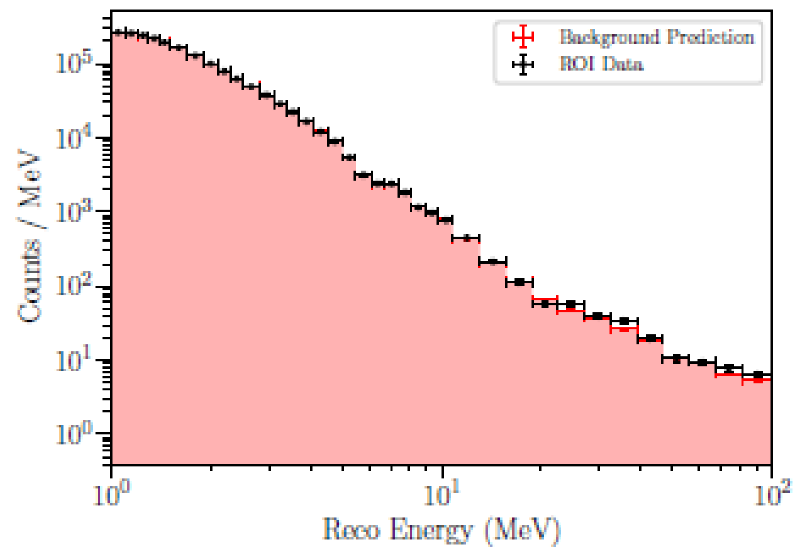


Fig. 3 Energy distribution of neutrino (white area) and back-

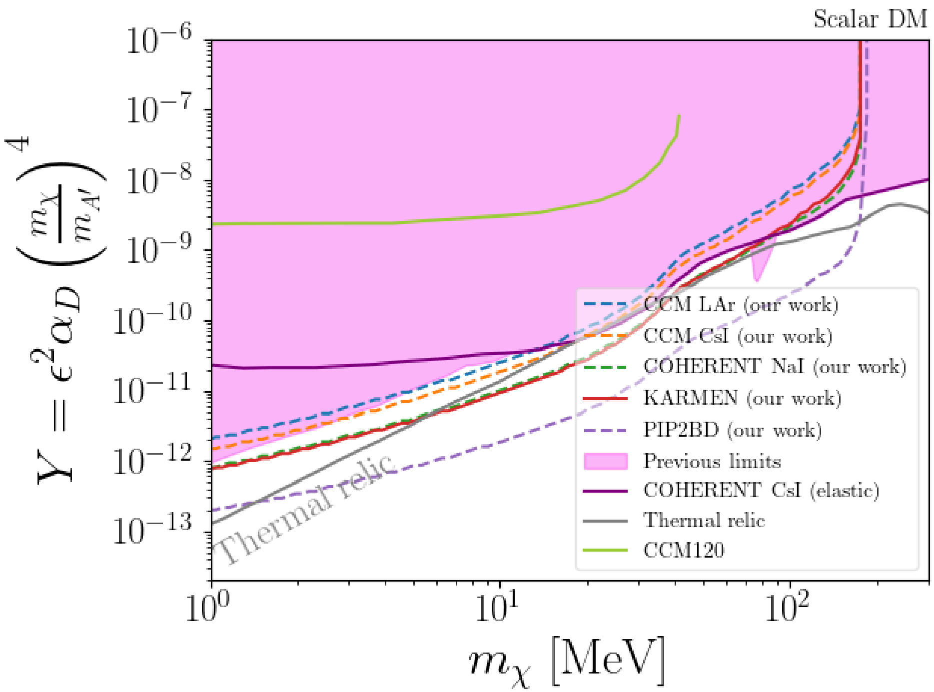
$$^{12}C(\nu_\mu \nu_\mu')\,^{12}C^*(1^+,1;15.1\ \mathrm{MeV})$$

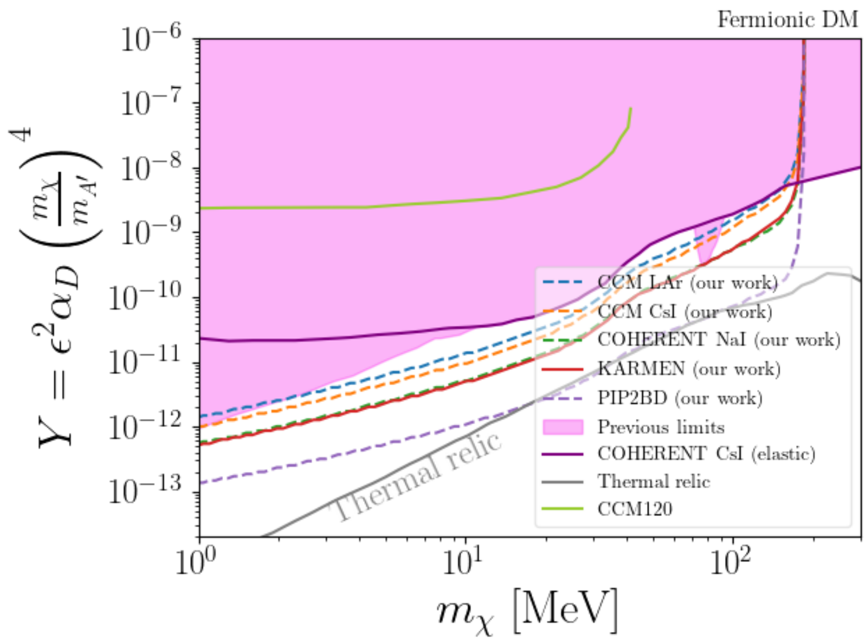
CCM 120



The background will be reduced
by 1/100 in CCM200 for the same POT

MeV signal – DM: COHERENT & CCM



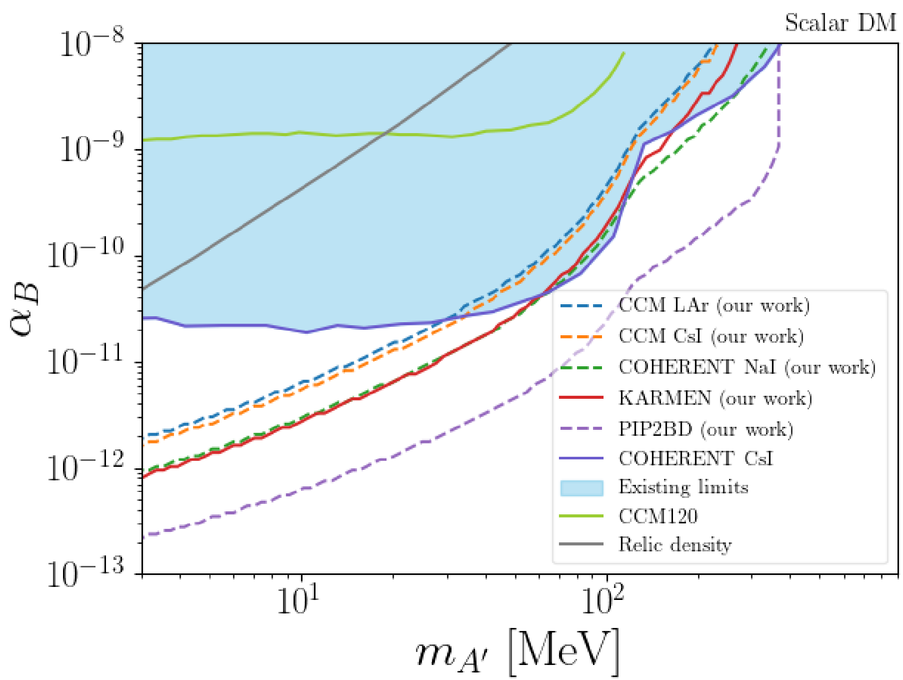


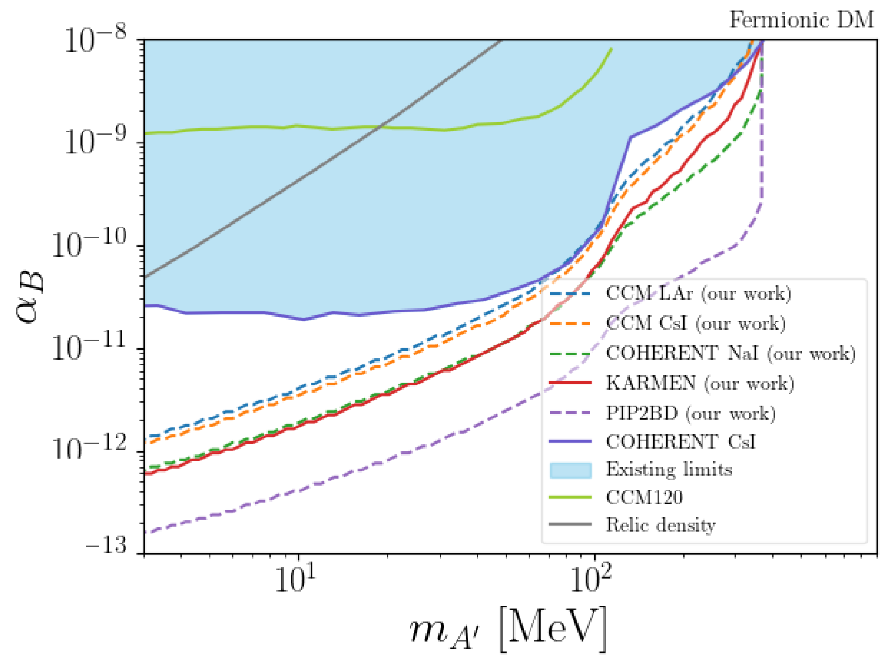
$g_D = \sqrt{2\pi}$, $\quad \frac{M_{A'}}{M_\chi} = 3$

- We use CCM 120 background measurements and projections for CCM 200 (for MeV region)
- t < 200 ns, prompt window reduces the neutrino background down to O(1) events
- Rescale the shell model prediction to be consistent with the experiment, **W. Tornow et al., 2210.14316**
- A lower threshold detector will help to improve the sensitivity in the elastic channel

B. Dutta, W. Huang, J. Newstead, Phys.Rev.Lett. 131 (2023) 11, 111801

MeV signal – Light DM: COEHERNT & CCM





$U(1)_B$ Model

$$m_{A'}/m_\chi \approx 2$$

- Karmen seems to be providing the best limit with the observation
  Is the neutron background correctly estimated?
- CCM 200 is measuring the MeV scale electromagnetic signal

Direct Detection: Light DM&Med

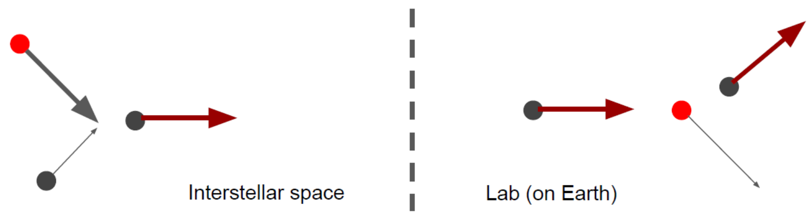
Various ways of probing Sub-GeV DM:

Cosmic ray scattered

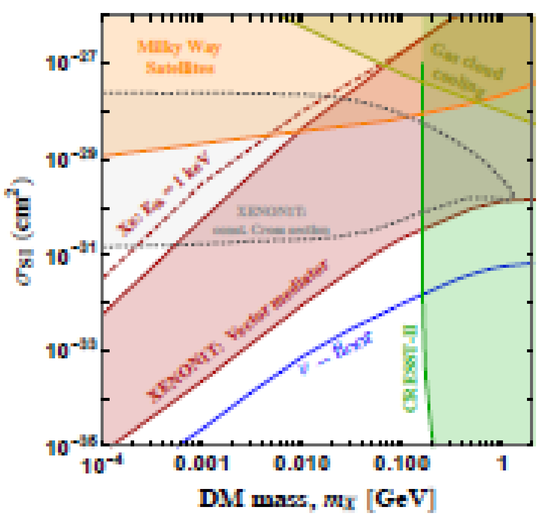
Bringmann, Pospelov, 2018

Ema, Sala, Sato, 2018

Dent, Dutta, Newstead, Shoemaker, 2019



Low mass DM (up to 10 GeV)
becomes energetic ➔ detection becomes easier



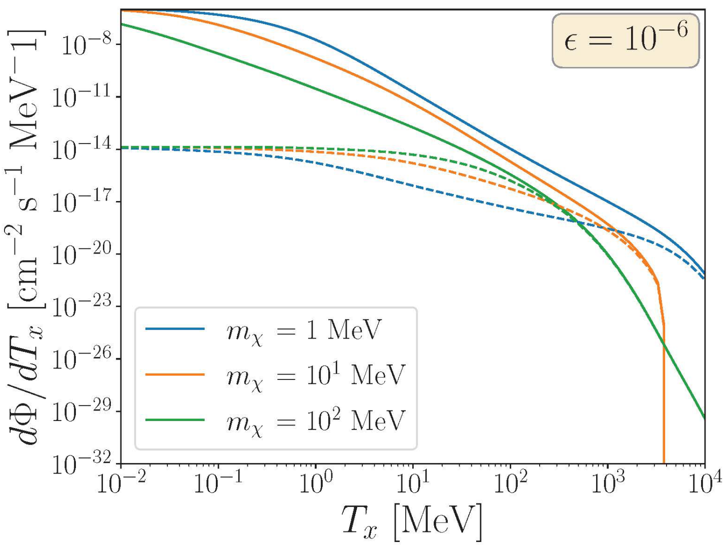
- Since light DM comes to the detector with higher energy, threshold does not matter

➔ Large scale neutrino detectors can be used

- We can use this boosted DM for inelastic nuclear scattering

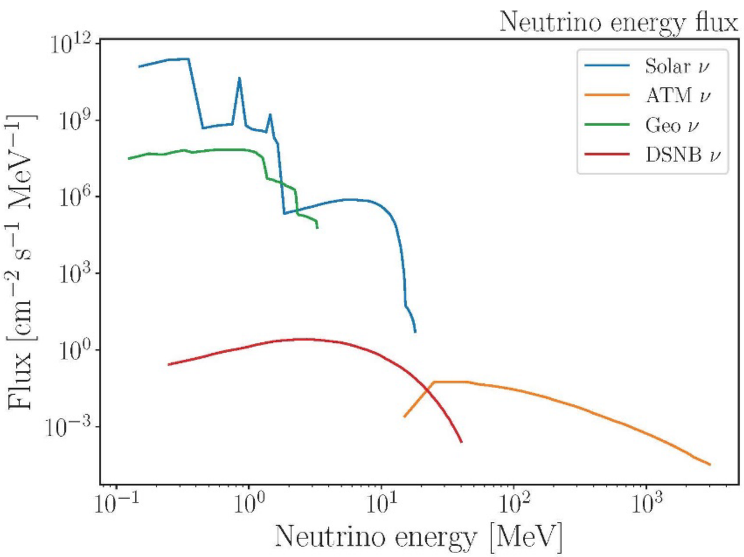
Dent, Dutta, Newstead, Shoemaker, 2019

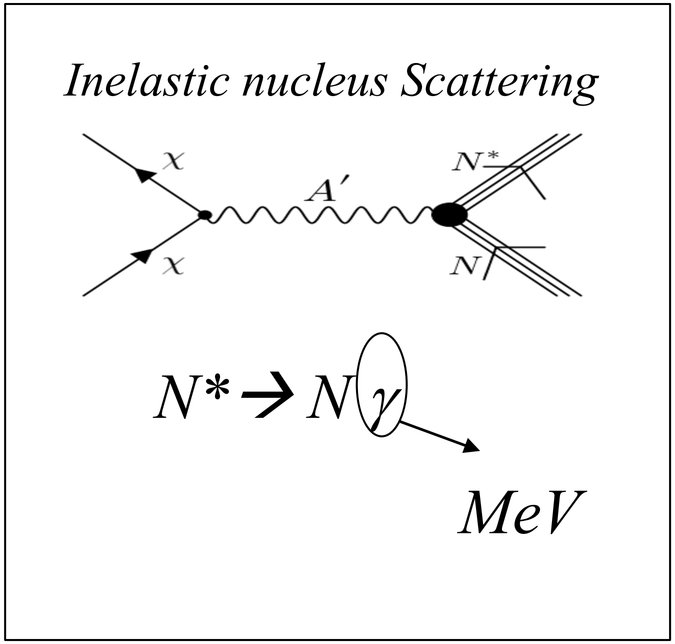
Direct Detection: Light DM



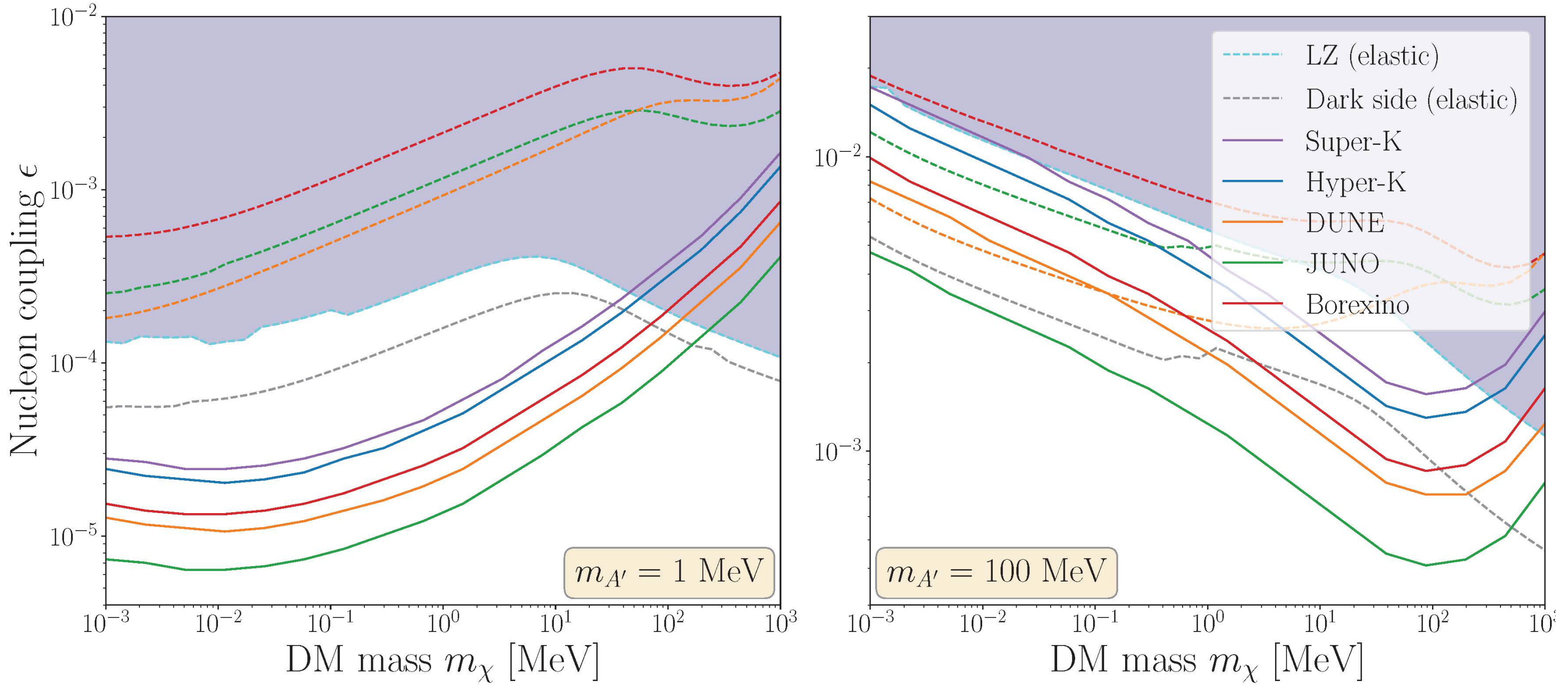
Experiment	Target	Mass (kt)	Time (yr)	$\frac{E_{res}}{MeV}$	$\frac{E_{th}}{MeV}$
Hyper-K	water	188	10	2	4.5
DUNE	Ar	40	10	2	5
JUNO	CH_2	20	10	0.1	0.5
Borexino	CH_2	0.1	5.6	0.2	0.2
DUNE	p,n(Ar)	40	10	-	50
JUNO	p	20	10	-	15
Borexino	p	0.1	1.22	-	12.3
LZ	Xe	0.0055	0.167	-	0.001
DarkSide-20k	Ar	0.02	5	-	0.03

Large ν detectors: Larger threshold compared to the DM detectors

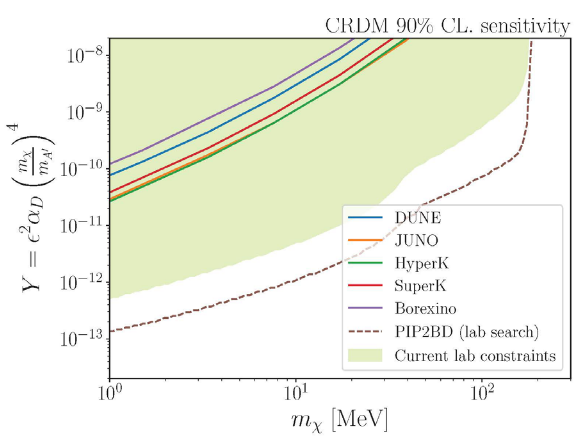




Large ν detectors : Light DM



- Solid lines denote the inelastic channel, while dashed lines are elastic channels.
- We use the hadronic interactions.

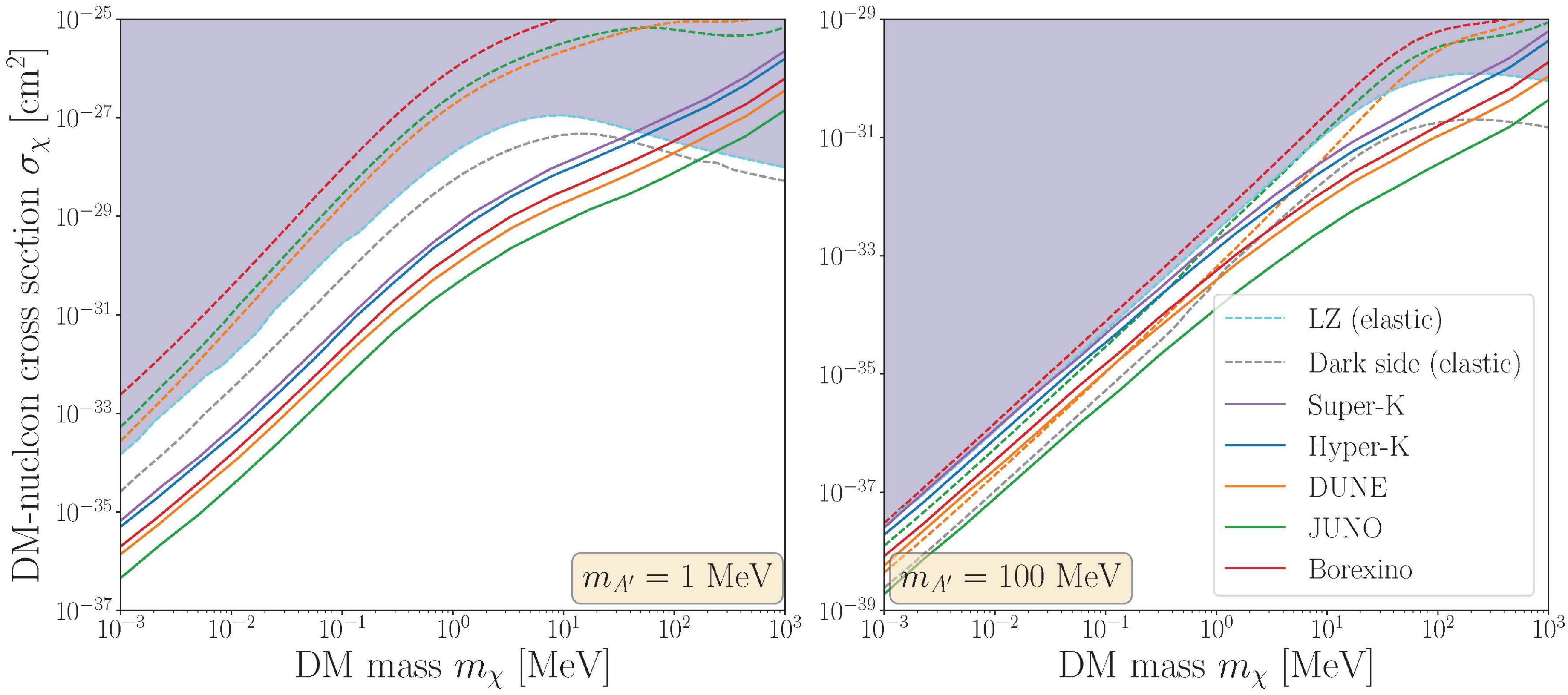


$$\frac{M_{A'}}{M_\chi} = 3$$

← Beam-dump-based DM limit

B. Dutta, W. Huang, D. Kim J. Newstead, J. Park, I. Shaukat Ali, 2402.04184

Large ν detectors : Light DM



Outlook

- Light mediator models can explain various anomalies and puzzles
- Many model possibilities
- M(new physics) < GeV is not easy to probe, e.g., LHC mostly probe M> GeV
- Various experiments provide interesting possibilities for searching low-scale models
- Sub-GeV DM with light mediators is searched via elastic channels in direct detection and beam dump-based experiments
- Inelastic nuclear searches (line measurements) can provide a very good ability to probe light DM in ongoing experiments.

  Also, other processes, e.g., Atomki anomaly, axion/DM absorption at reactors, beam dumps etc.