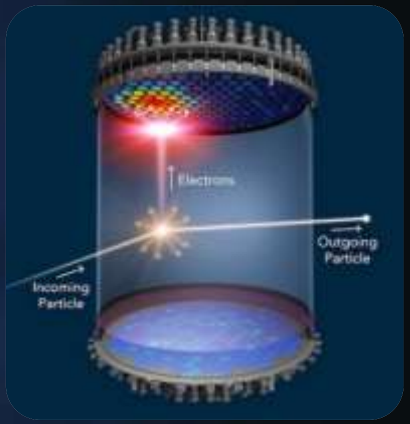
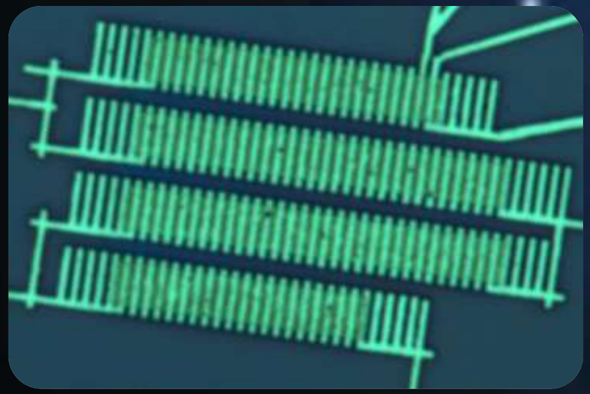
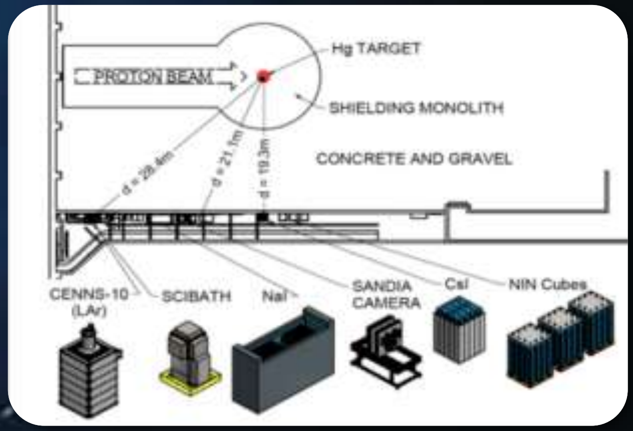
Search for Light New Particles







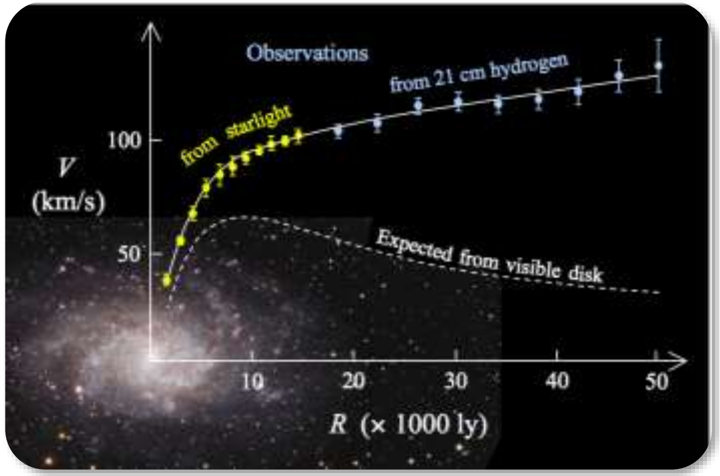
Jong-Chul Park

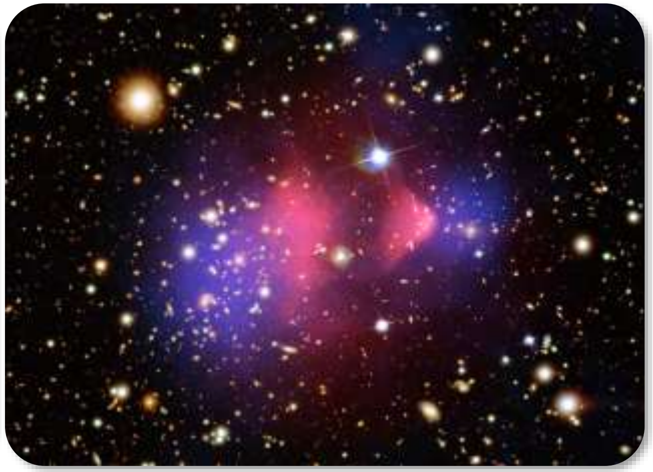
CNU 충남대학교
CHUNGNAM NATIONAL UNIVERSITY

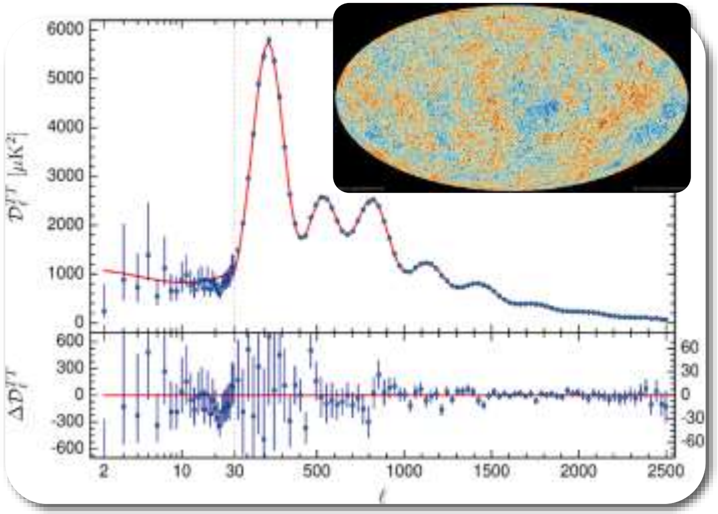
2022 KPS Spring Pioneer Symposium

2022.02.22

Message from Cosmology: Dark Matter (DM)



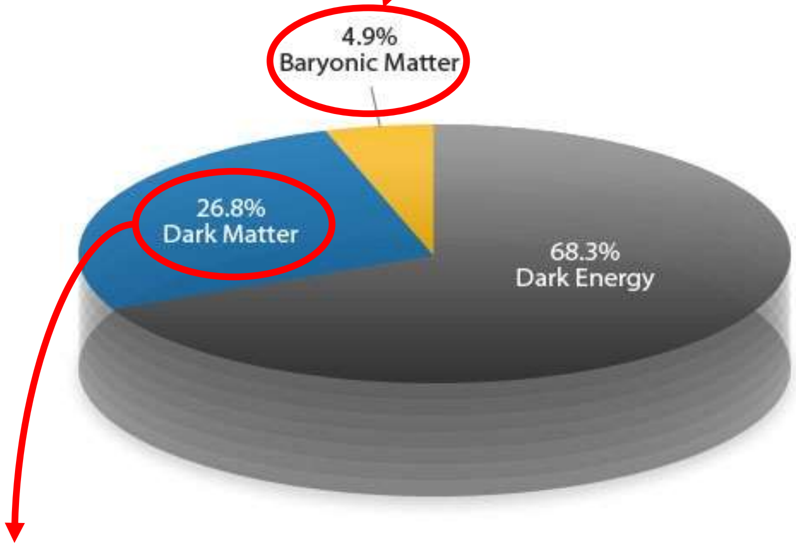




❖ **Evidence**: Galactic rotation curve, Bullet cluster, Coma cluster, Gravitational lensing, Structure formation, CMB, …

❖ **Modern cosmology**:

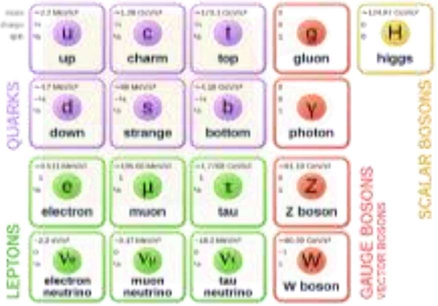
The Standard Model



❖ **Compelling paradigm**:

- ✓ Massive,
- ✓ Non-relativistic ($v \ll c$),
- ✓ Non-luminous (no/tiny EM interaction),
- ✓ Stable particles

Dark Sector: Dark Particles & Portals



$\chi_1, \chi_2, \chi_3, \ldots$

$\phi_1, \phi_2, \phi_3, \ldots$

$X_1, X_2, X_3, \ldots$

❖ **Portals**: <u>mediators</u>

- ✓ Vector portal (kinetic mixing): $\frac{\sin\epsilon}{2} B_{\mu\nu} X^{\mu\nu}$
- ✓ Scalar (Higgs) portal: $\lambda_{H\phi} |H|^2 |\phi|^2$
- ✓ Fermion (neutrino) portal: $\lambda_\chi H L \chi$
- ✓ Pseudo-scalar (axion) portal: $\frac{1}{f_{a\gamma/ag}} a F_{\mu\nu} \tilde{F}^{\mu\nu}$

  $\frac{1}{f_{af}} \partial_\mu a (\bar{\psi} \gamma^\mu \gamma^5 \psi)$
- ✓ Gauged SM global #: B-L, L_μ-L_τ, …
- ✓ Dark axion portal: $G_{a\gamma\gamma'} a F_{\mu\nu} \tilde{X}^{\mu\nu}$
- ✓ Double portal: a combination of ≥ 2 portals
- ✓ ???

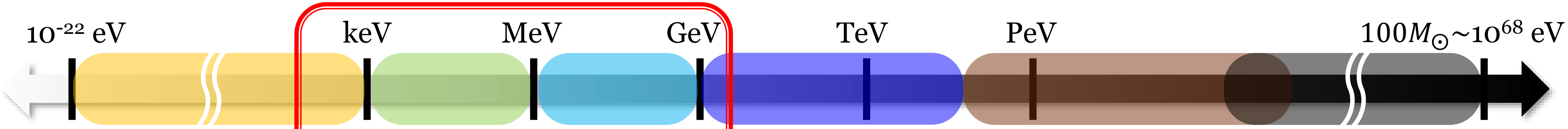
❖ **Dark sector particles**

- ✓ DM spin: fermion, scalar, vector
- ✓ DM species: single-/two-/multi-component
- ✓ DM mass: light, heavy, light & heavy
- ✓ DM interaction: flavor-conserving (elastic),

  flavor-changing (inelastic)
- ✓ ???

Not WIMP: Other Scales?

DM Landscape: A Very Wide Mass Range



Ultralight

(QCD) axion,
hidden photon,
scalar field,
fuzzy,
non-thermal

Superlight

sterile ν,
axino,
warm DM,
can be
thermal

Light

SIMP,
ELDER,
can be
thermal

WIMP

well-motivated,
extensively
studied,
thermal
No firm signal yet!

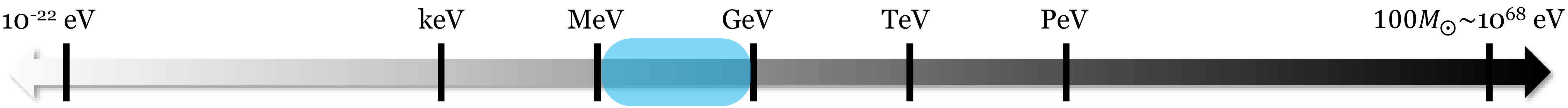
Superheavy

composite,
WIMPzilla,
Q-ball,
Fermi-ball,
dark-quark
nugget,
non-thermal

Astrophysical object

MACHO, PBH,
non-particle

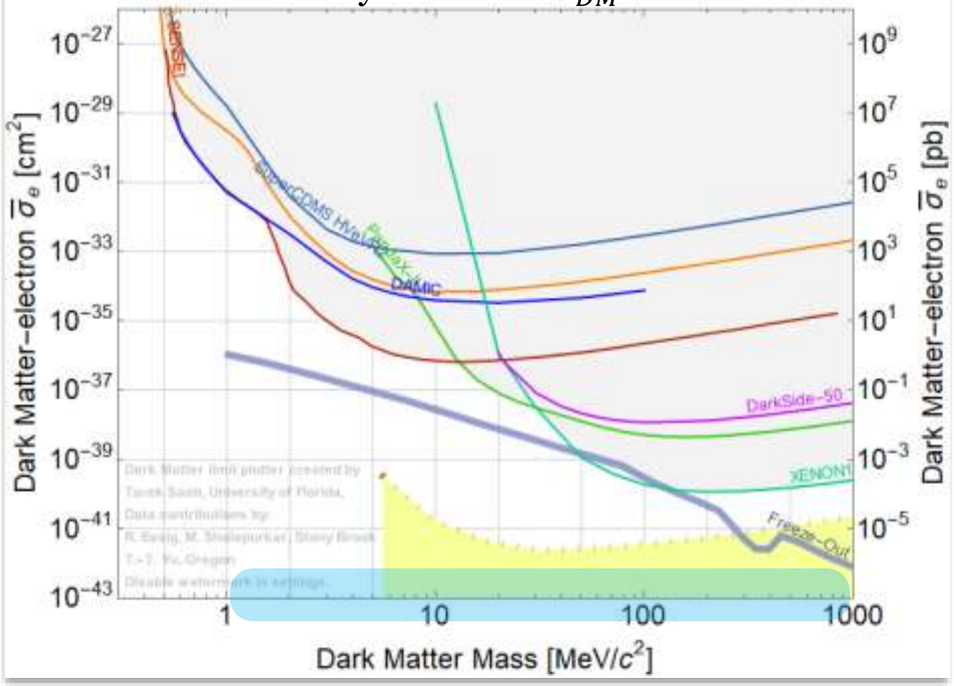
Light DM Direct Search



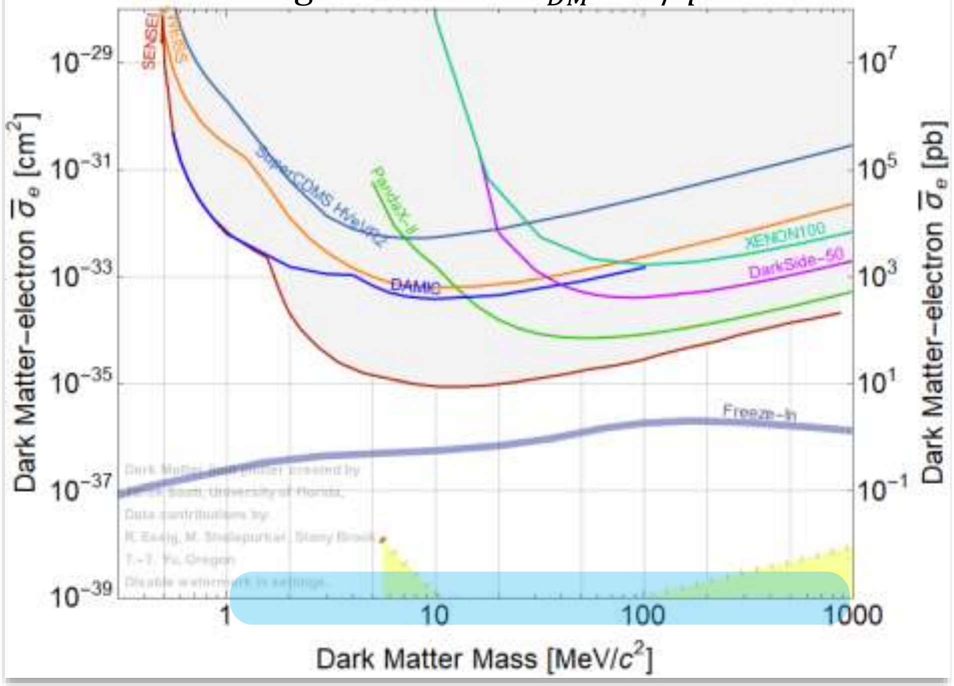
- $E_k \sim mv^2$, $\Phi_\chi = n_\chi v_{rel}$ & $n_\chi = \rho_\chi / m_\chi$ ➔ lighter DM: **smaller E_r** but **lager flux** (**lighter** target particle)

  ➔ **low E_{th}** (**e-recoil**) preferred even with **small target mass**

Heavy mediator: $F_{DM} = 1$

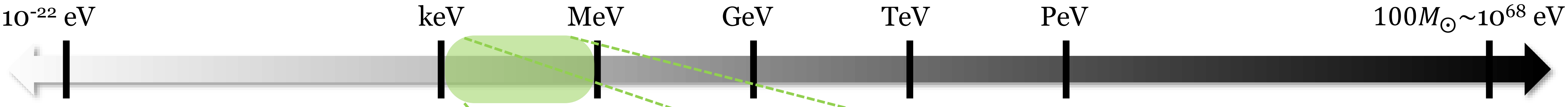


Light mediator: $F_{DM} \propto 1/q^2$

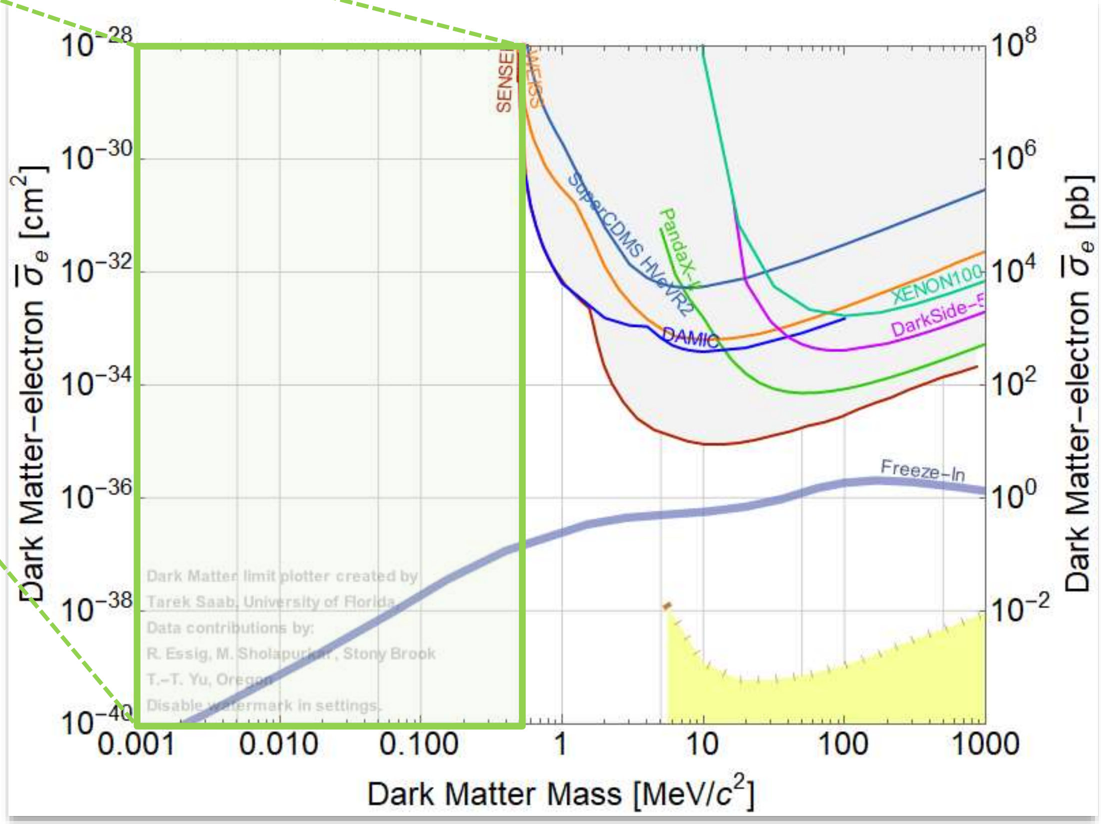


Dark Matter Limit Plotter v5.17, updated December 21, 2021

Super-Light DM Direct Search



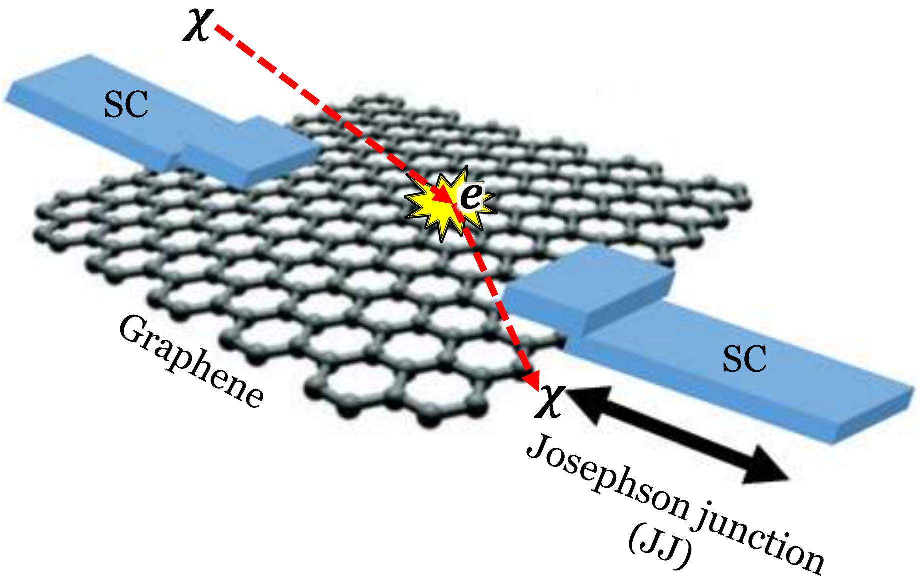
- ❖ $\boldsymbol{E_k} \sim mv^2 \sim \boldsymbol{O(\mathrm{meV})}$ with $m\sim$keV & $v\sim 10^{-3}$
- ❖ **New approaches** are required!
  - ✓ Superconductor [PRL (2016)]
  - ✓ Superfluid He [PRL (2016)]
  - ✓ 3D Dirac material [PRD (2018)]
  - ✓ Polar material [PLB (2018)]
  - ✓ Superconducting-nanowire [PRL (2019)]
  - ✓ Graphene Josephson junction (GJJ) [**JCP** et al. 2002.07821 & In preparation]
  - ✓ ...
- ❖ **World race** to prove **super-light DM**.
- ❖ **No experiment** for **O(keV) DM** so far.



Dark Matter Limit Plotter v5.17, updated December 21, 2021

Detection Principle with GJJ

D. Kim, **JCP**, K. C. Fong & G.-H. Lee,
[2002.07821 & In preparation]



I. **DM scatters off (π-bond) free electrons**, transferring some fraction of its incoming E_k.

II. **The recoiling e heats up & thermalizes** with nearby e's rapidly via e-e interactions.

III. **The JJ is triggered**: the temperature rise switches the zero-voltage (non-resistive) of JJ to a **non-zero-voltage (resistive) state**.

- **GJJ**: sensitivity to ~0.1 meV E deposit demonstrated experimentally [Nature (2020)]
- $E_k \sim mv^2$ & $v \sim 10^{-3}$ ➔ **GJJ detector: sensitivity** to the signal even by **sub-keV DM**.

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D. Kim, **JCP**, K. C. Fong & G.-H. Lee,
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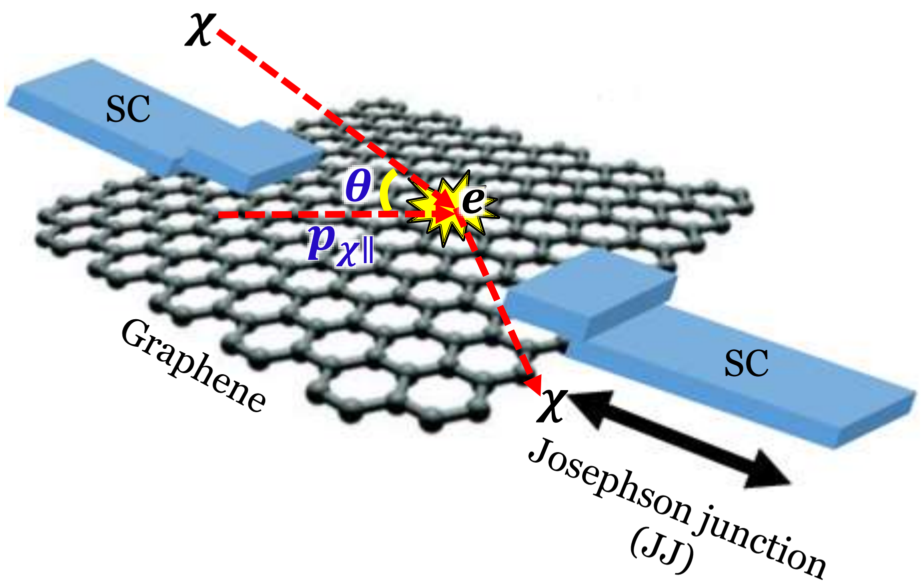

- ✓ **Scattering** between DM traveling in 3D & electrons **confined** in the 2D graphene ➔ No significant momentum change along the surface normal direction
- ✓ **Prediction**: the signal rate depends on the **DM flux direction**.

  ➔ Applicable to background rejection

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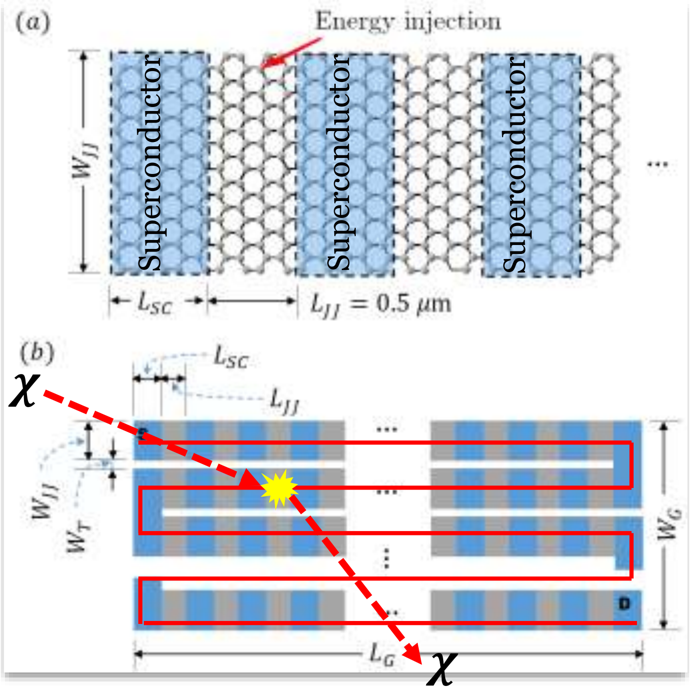
Super-Light DM Direct Search Using GJJ

D. Kim, **JCP**, K. C. Fong & G.-H. Lee,
[2002.07821 & In preparation]

- ❖ Detector using graphene Josephson junction



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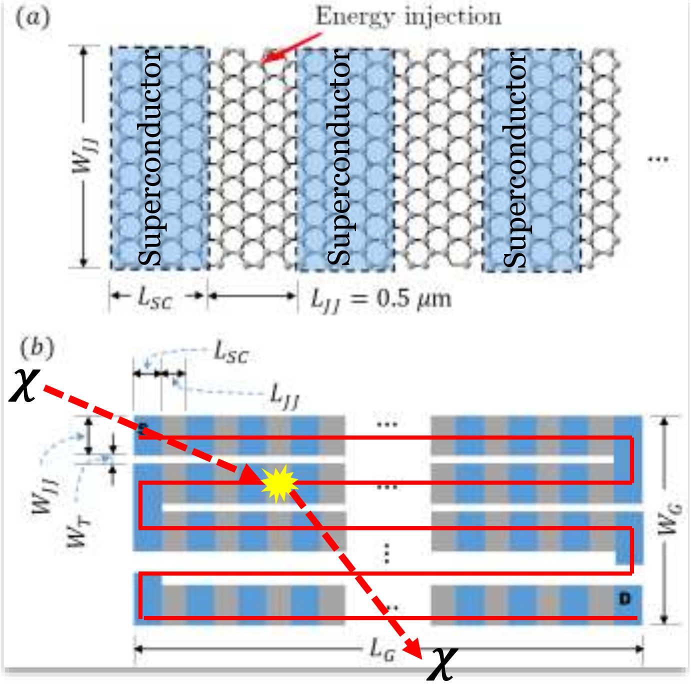
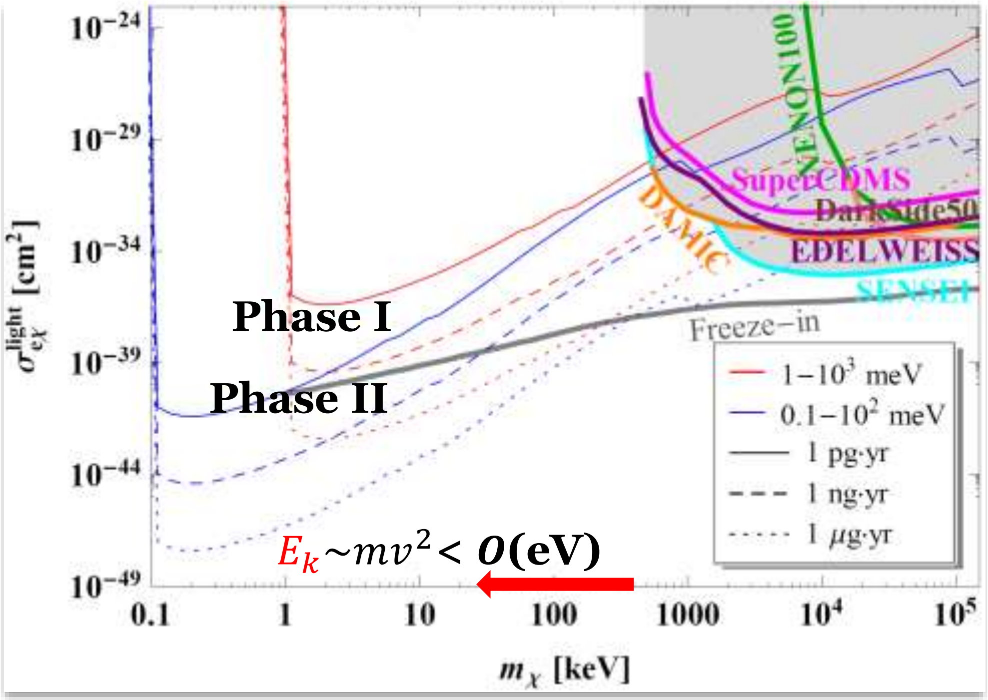


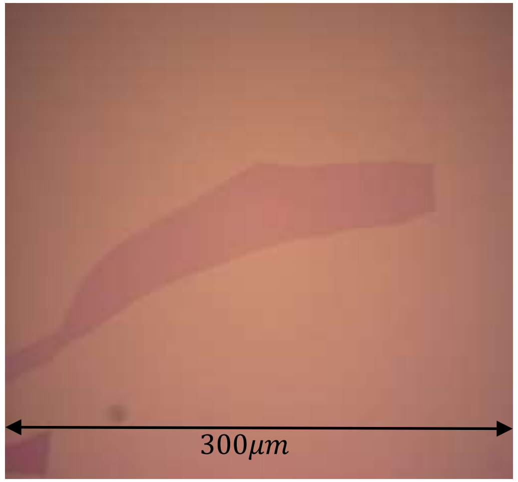


Light mediator: $F_{DM} \propto 1/q^2$ with $q_{\rm ref} = \alpha_e m_e$

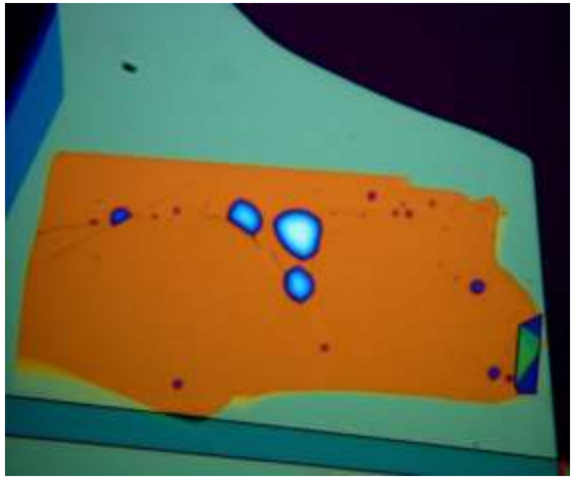
✓ The **proposed detector** can improve the minimum detectable DM mass (**$m_{DM} \sim 0.1$ keV**) by more than 2-3 orders of magnitude over the ongoing/existing experiments.

✓ **Capable of probing** the prediction of **freeze-in** scenarios even with a pg-scale detector.

Progress in Fabrication: ~100 GJJs in Series



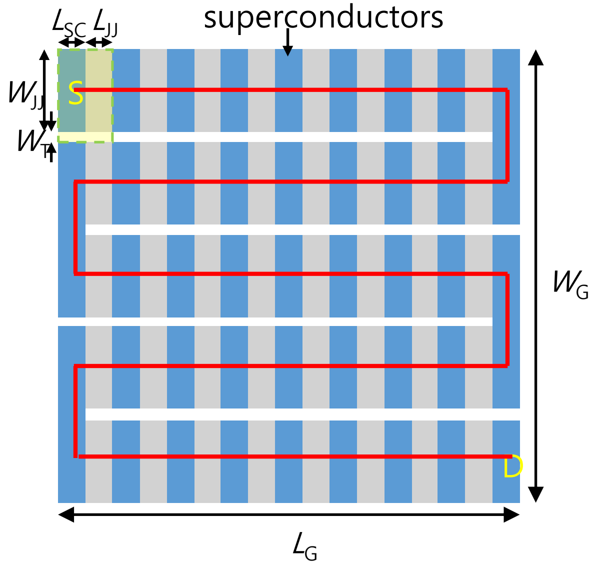
Large piece of graphene



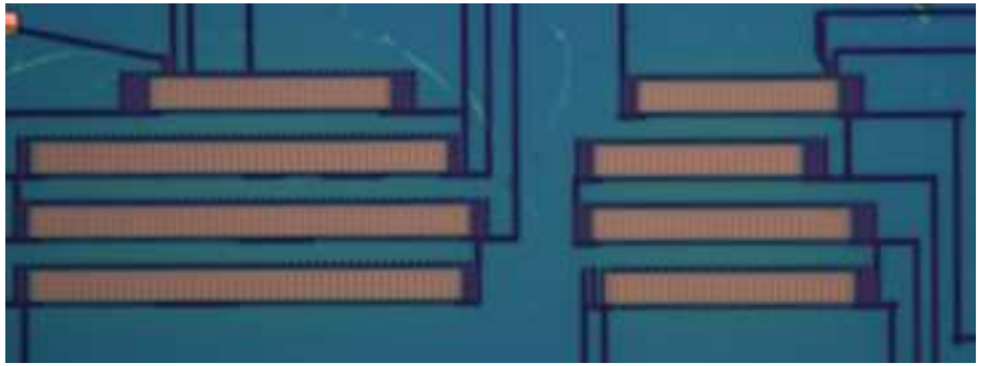
hBN-encapsulated graphene

Etched hBN/Graphene/hBN stack

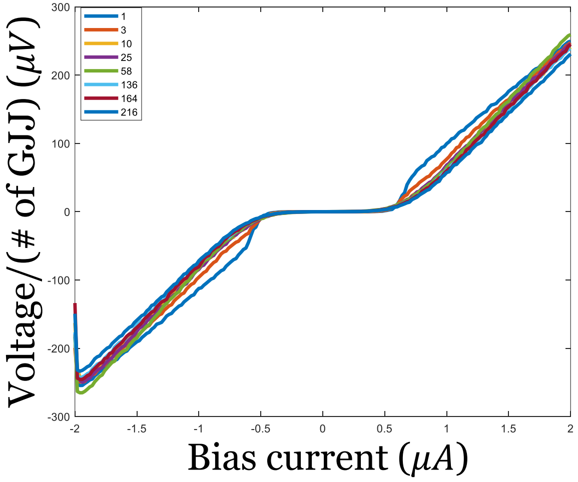
Schematics



216 GJJs connected in series



T=5 K

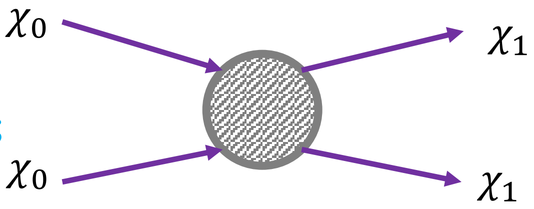


Boosting Light DM

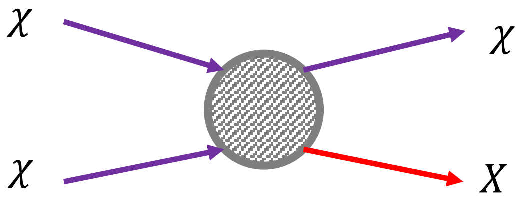
DM Boosting Mechanisms: Dark Sector


Boosted DM (BDM) coming from the Universe

[Belanger & **JCP**, JCAP (2012);
Agashe et al., JCAP (2014);
Kong, Mohlabeng, **JCP**, PLB (2015);
Berger et al., JCAP (2015);
Kim, **JCP**, Shin, PRL (2017);
more]



✓ Multi-component model
$m_0 \gg m_1$

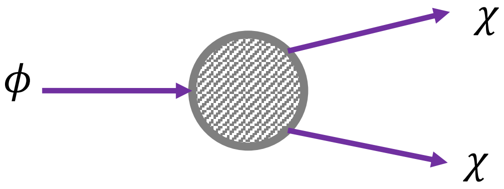


✓ Semi-annihilation model
$m_\chi \gg m_X$

[D'Eramo & Thaler, JHEP (2010);
Berger et al., JCAP (2015)]

Large E_k^{DM} (monochromatic) due to **mass gap**

- Relic component DM: non-relativistic!
- BDM signal: detectable at large Vol. DM & neutrino detectors
- Need extension of dark sector



✓ Decaying multi-component DM
$m_\phi \gg m_\chi$

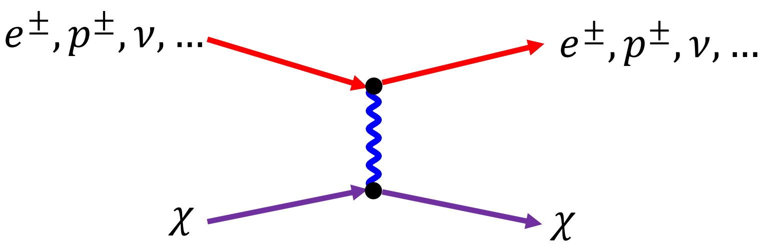
[Bhattacharya et al., JCAP (2015);
Kopp et al., JHEP (2015);
Cline et al., PRD (2019);
Heurtier, Kim, **JCP**, Shin, PRD (2019);
more]

- Heating via sizable self-scattering (natural for LDM) ➔ affect the thermal evolution of DM

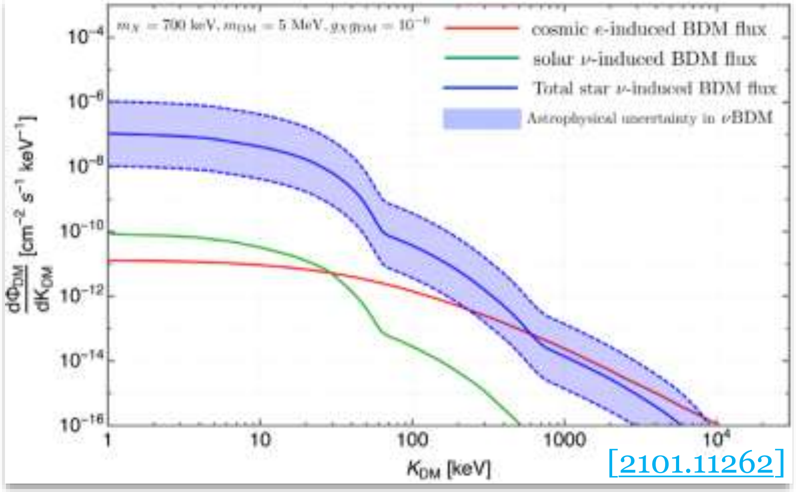
[Kamada, Kim, Kim & Sekiguchi, PRL (2018); Kamada, Kim, **JCP** & Shin, 2111.06808]

DM Boosting Mechanisms: Cosmic-Ray

Cosmic-Ray-Induced BDM



- ✓ Charged cosmic-ray: [Bringmann & Pospelov, PRL (2019); Ema et al., PRL (2019); Cappiello & Beacom, PRD (2019); Dent et al., PRD (2020); Jho, **JCP**, Park & Tseng, PLB (2020); Cho, Choi & Yoo, PRd (2020); more]
- ✓ Cosmic- ν (νBDM): [Jho, **JCP**, Park & Tseng, 2101.11262 & In preparation; Das & Sen, 2104.00027; Chao, Li, Liao, 2108.05608; more]



[2101.11262]

❖ Energetic cosmic-ray-induced BDM: energetic cosmic-rays kick DM (large $E_{e^{\pm},p^{\pm},\nu,\ldots}$ ➔ large E_χ)

➔ Efficient for Light DM

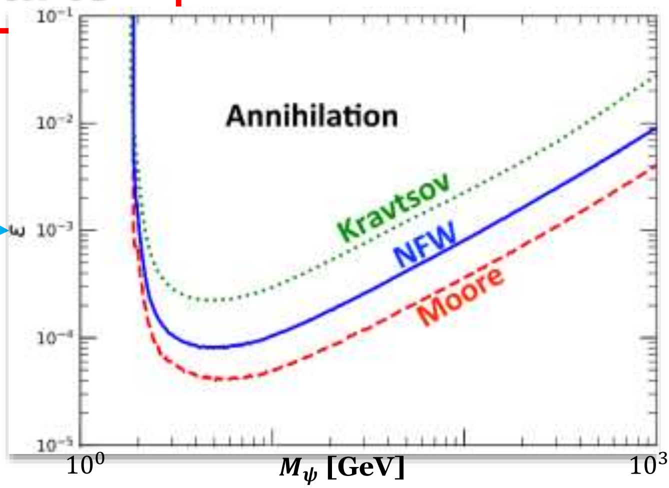
BDM Searches @ Neutrino Experiments

Boosted DM (BDM) models:
Receiving rising attention as an alternative scenario

PHYSICAL REVIEW LETTERS **120,** 221301 (2018)

Editors' Suggestion

Search for Boosted Dark Matter Interacting with Electrons in Super-Kamiokande



Eur. Phys. J. C (2021) 81:322
https://doi.org/10.1140/epjc/s10052-021-09007-w

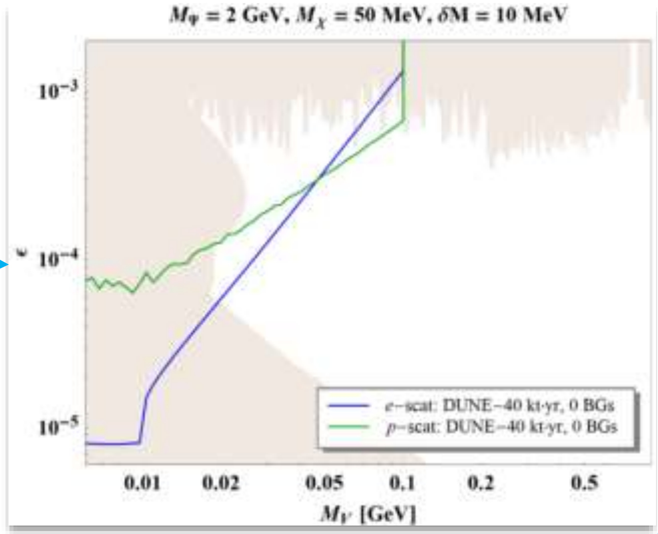
THE EUROPEAN PHYSICAL JOURNAL C

Check for updates

Regular Article - Experimental Physics

Prospects for beyond the Standard Model physics searches at the Deep Underground Neutrino Experiment

DUNE Collaboration



- ✓ Not restricted to primary physics goals
- ✓ Opened to other (unplanned) physics opportunities

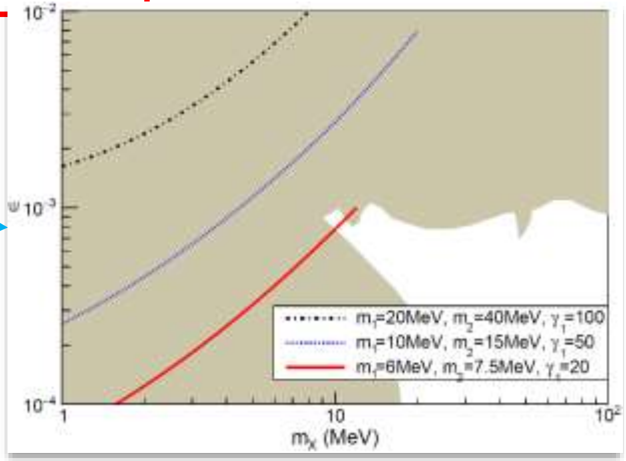
BDM Searches @ DM Experiments

Boosted DM (BDM) models:
Receiving rising attention as an alternative scenario

PHYSICAL REVIEW LETTERS **122,** 131802 (2019)

Editors' Suggestion

First Direct Search for Inelastic Boosted Dark Matter with COSINE-100

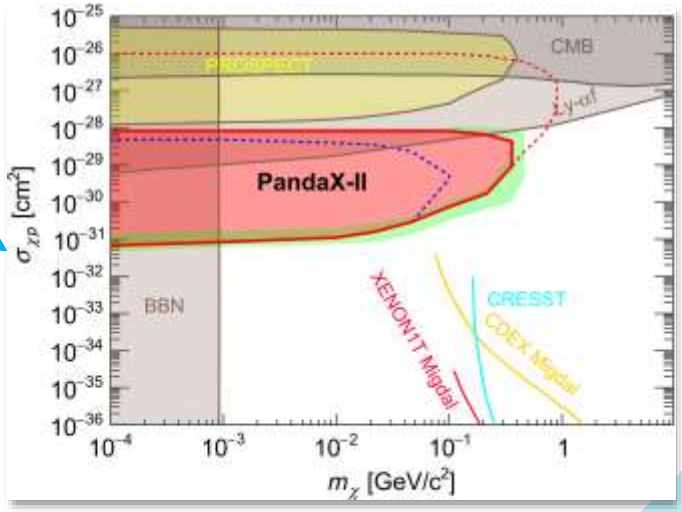


A Search for the Cosmic Ray Boosted Sub-GeV Dark Matter at the PandaX-II Experiment

[PandaX-II, 2112.08957]

Constraints on sub-GeV Dark Matter Boosted by Cosmic Rays from CDEX-10 Experiment at the China Jinping Underground Laboratory

[CDEX, 2201.01704]



- ✓ Not restricted to primary physics goals
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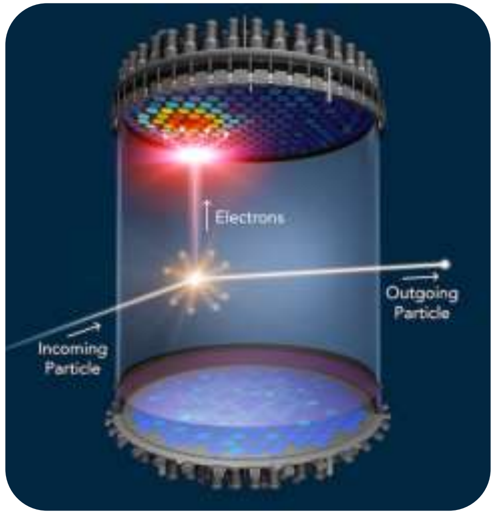
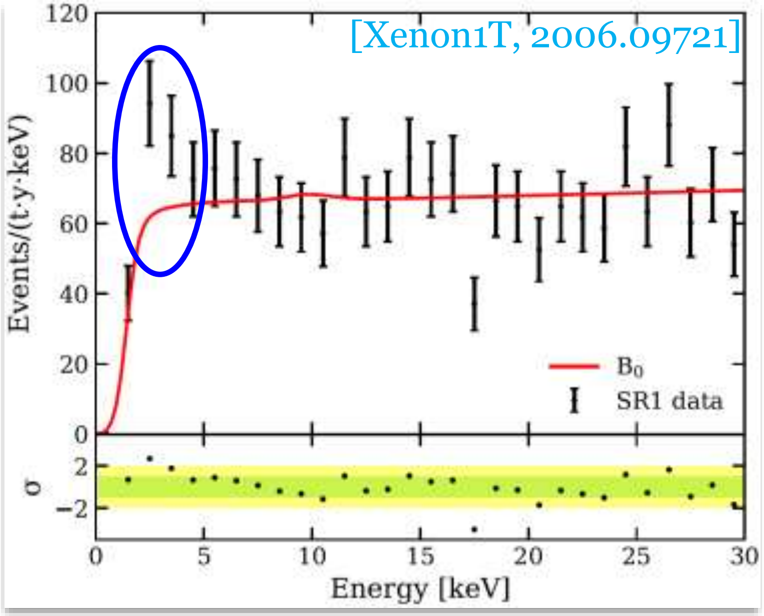
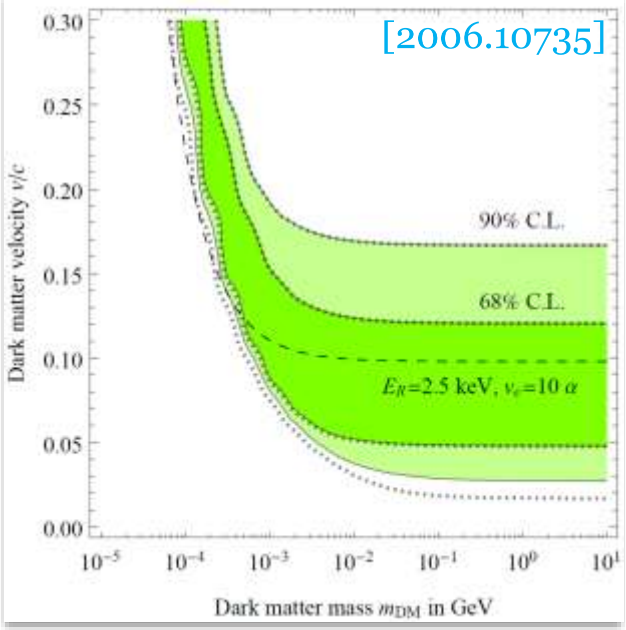
XENON1T Anomaly







- ❖ An excess of **electron recoil** events over known(?) BGs around 2-4 keV.
- ❖ The interpretation with conventional (elastic & $v/c \sim 10^{-3}$) DM is less favored:

  ∵ $\boldsymbol{E_r \sim m_e v^2 \sim O(eV)}$ even for $m_{\mathrm{DM}} \gg m_e$, [Kannike, Raidal, Veermae & Strumia, 2006.10735].

- ❖ This problem may be avoidable with non-conventional dark-sector scenarios:

  e.g., ALP, dark photon, inelastic and/or, $\boldsymbol{v \sim c}$ **(→ BDM!)** etc.

XENON1T Anomaly: BDM & e-Recoil

- DM direct detection experiments including XENON1T would be sensitive enough to energetic e-recoils induced by BDM by pumping up the BDM flux. [G. Giudice, D. Kim, **JCP**, S. Shin, PLB (2018)]
- Fast moving DM, $v/c \gtrsim O(0.1)$, is needed for ~keV electron recoil events. [PRD (2020)]

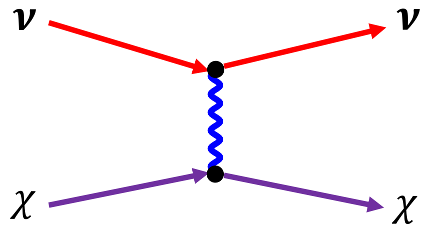
↓

- Various BDM studies for the XENON1T anomaly.
  - ✓ Multi-component model: [Fornal et al., 2006.11264; Alhazmi, Kim, Kong, Mohlabeng, **JCP** & Shin, 2006.16252]
  - ✓ Charged cosmic-ray induced BDM: [Su et al., 2006.11837; Cao, Ding & Xiang 2006.12767; Jho, **JCP**, Park & Tseng, 2006.13910]
  - ✓ Cosmic-Neutrino-Boosted DM (νBDM): [Jho, **JCP**, Park & Tseng, 2101.11262; Das & Sen, 2104.00027; Chao et al., 2108.05608; …]
  - ✓ …

Cosmic-ray-induced BDM: νBDM

[Jho, **JCP**, Park & Tseng 2101.11262 & In preparation]

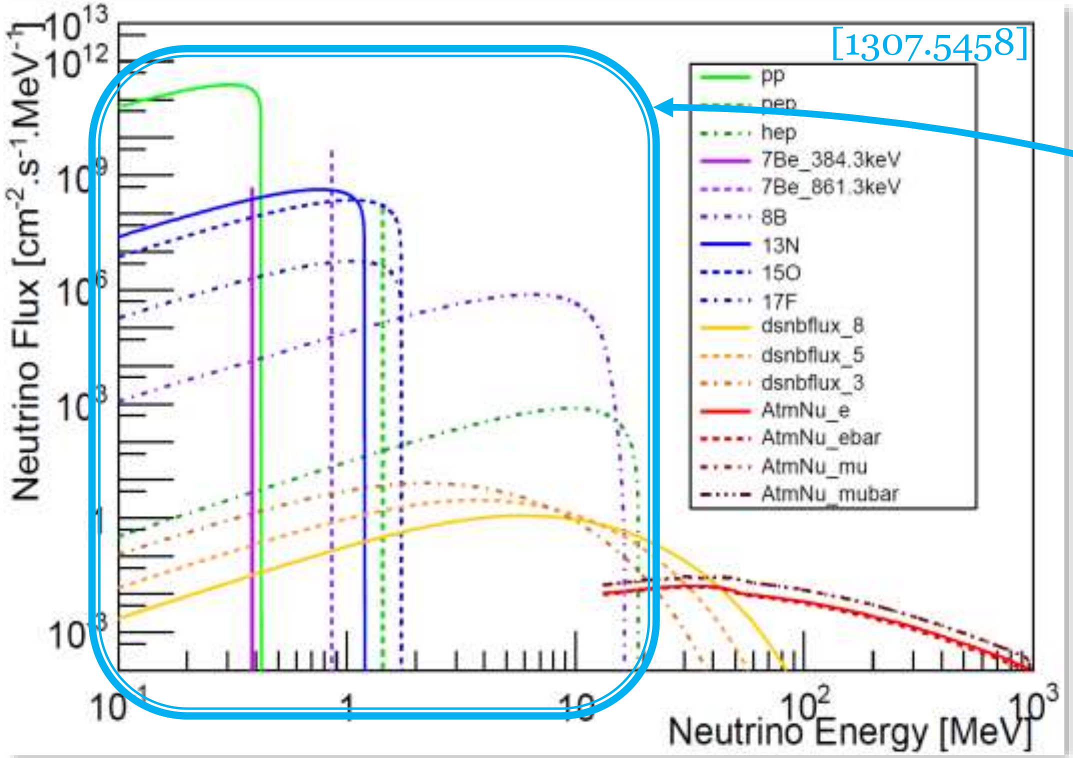
- **Cosmic-ν-induced BDM (νBDM)**: cosmic neutrinos kick DM (large E_ν)

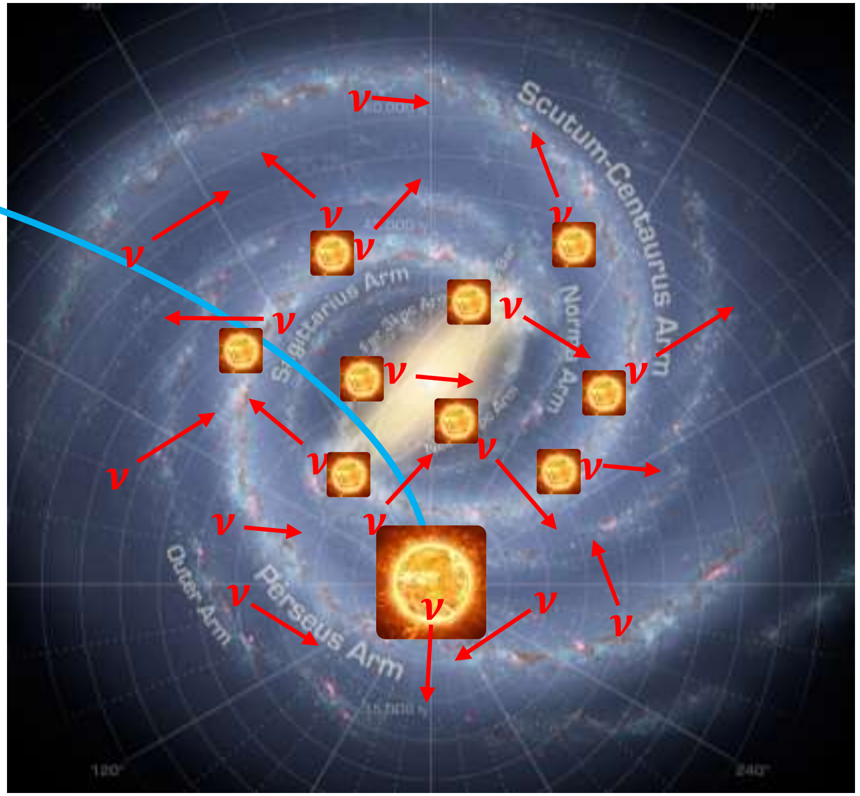


Large E_k^χ due to E_k^ν transfer

- ✓ DM-ν interaction ➔ Non-relativistic halo DM can be boosted by ***ν*'s from stars in the galaxy**.

$\Phi_\nu \gg \Phi_{e,p}$

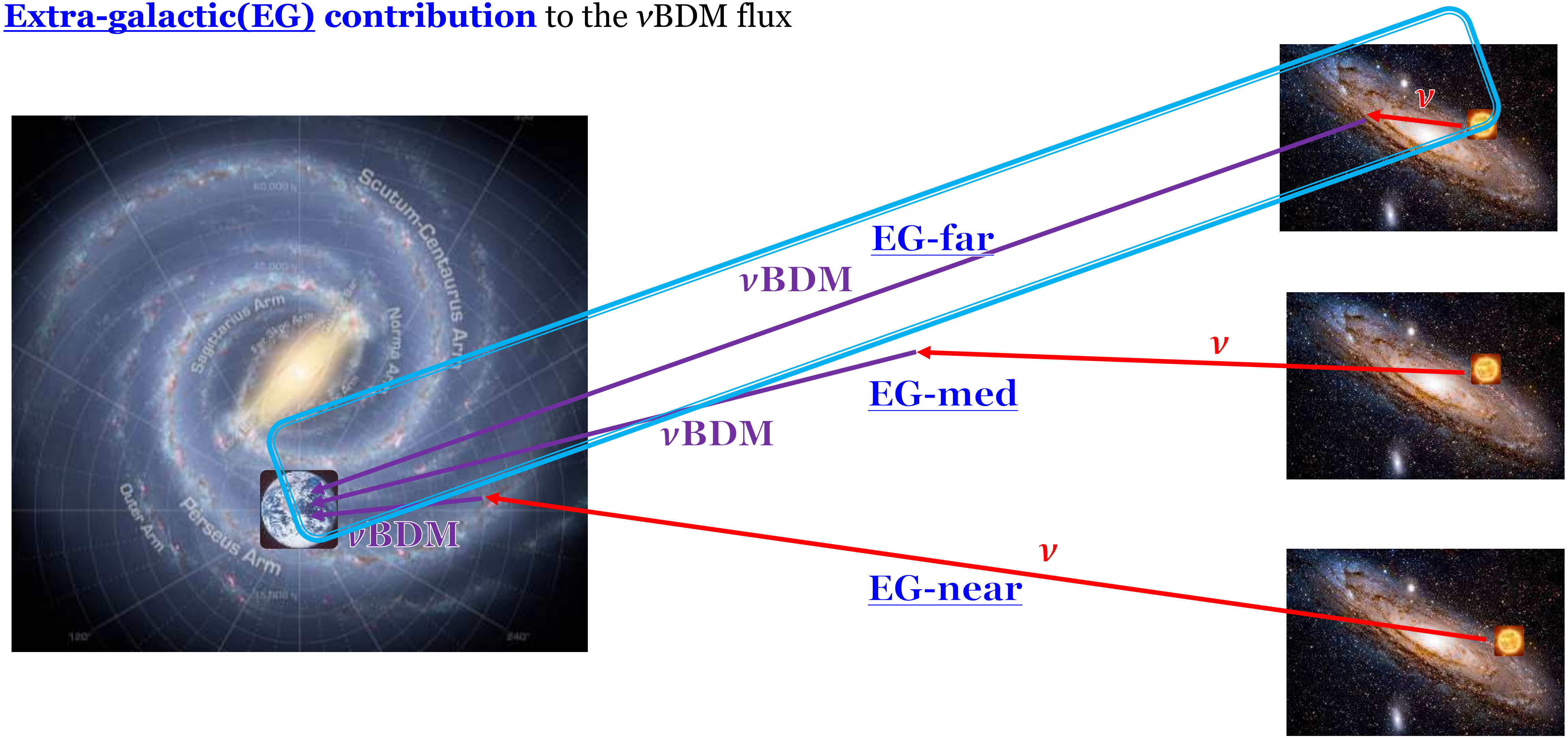




Cosmic-ray-induced BDM: νBDM

[Jho, **JCP**, Park & Tseng
2101.11262 & In preparation]

❖ **Extra-galactic(EG) contribution** to the νBDM flux

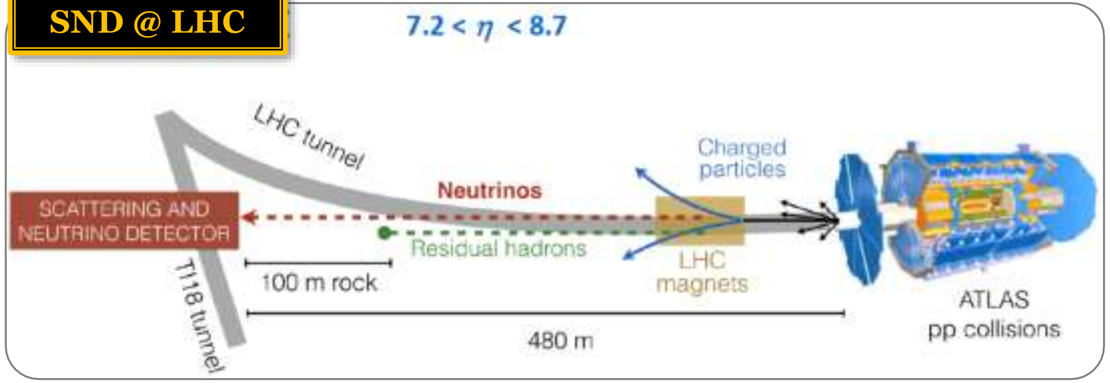


Active Production & Detection

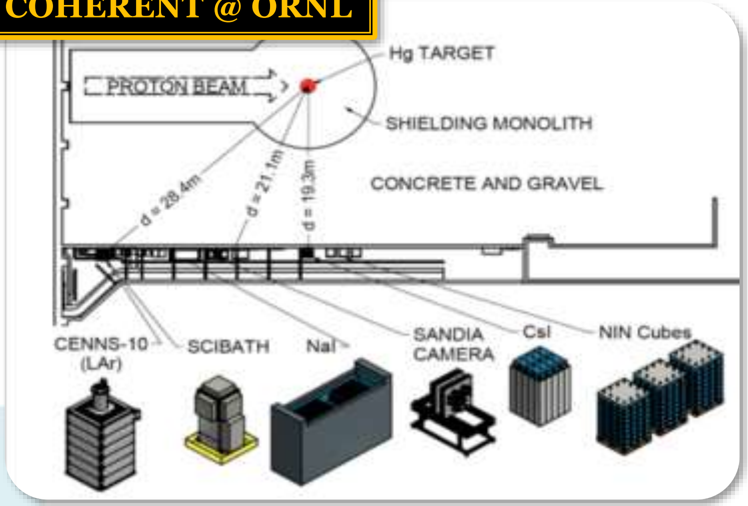
Direct Production & Detection Exps.

- ✓ Various Exps.: beam E, detector type, distance, angle, etc.

SND @ LHC

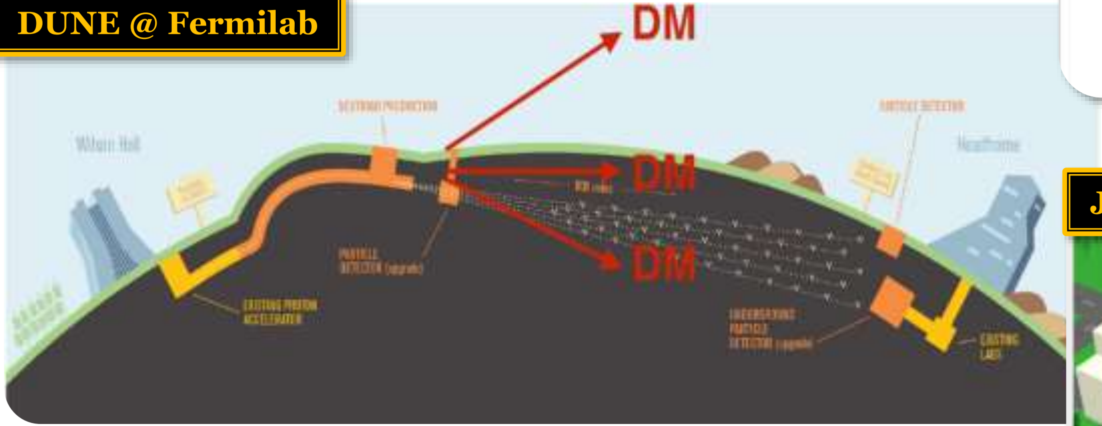


COHERENT @ ORNL

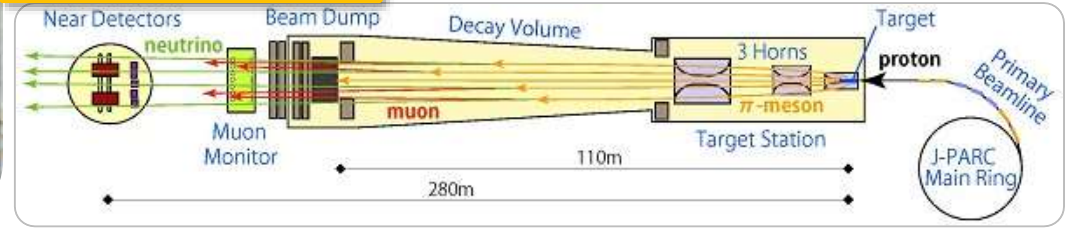


SHiP @ CERN

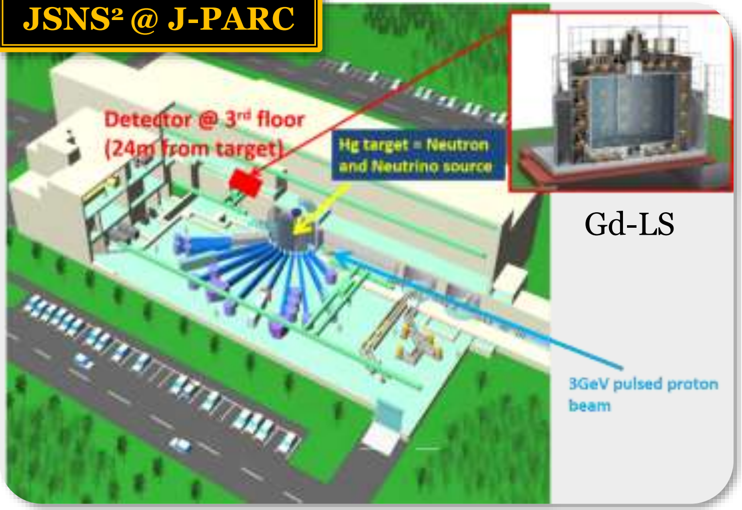
DUNE @ Fermilab



T2SK/HK @ J-PARC

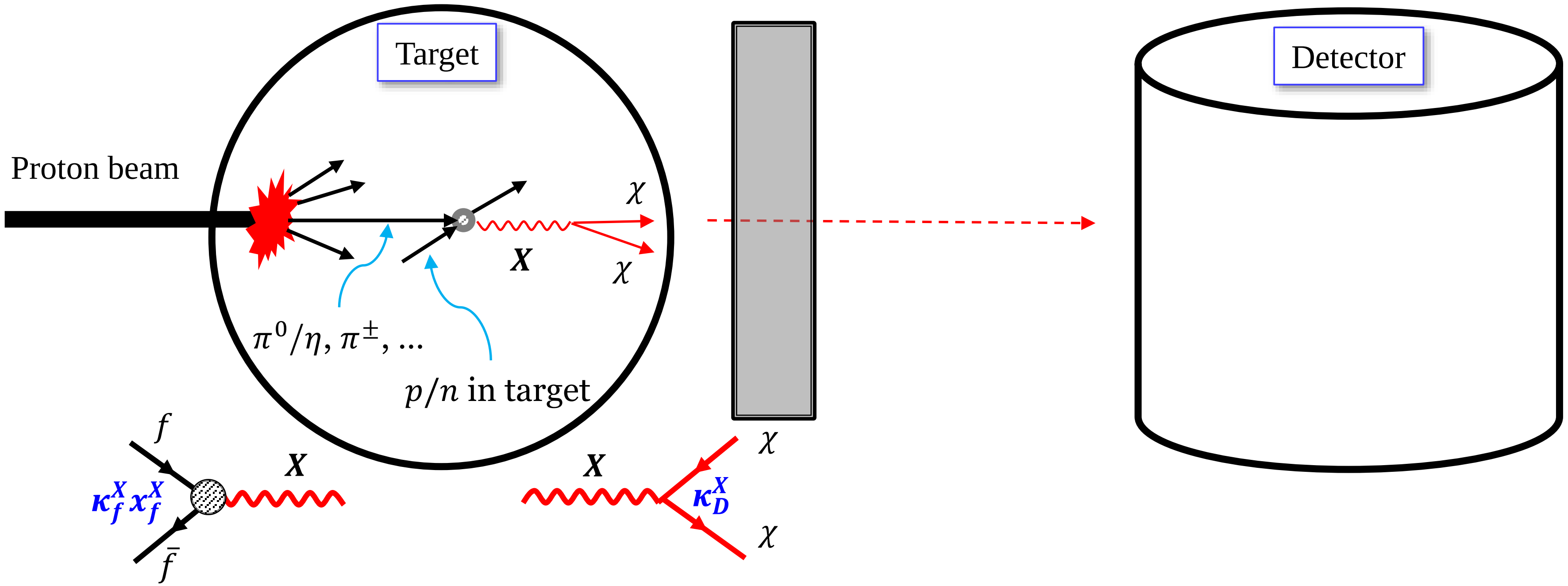


JSNS² @ J-PARC



Passive → Active: Direct Production

Dutta, Kim, Liao, **JCP**, Shin, Strigari, Thompson
PRL (2020) /JHEP (2022)



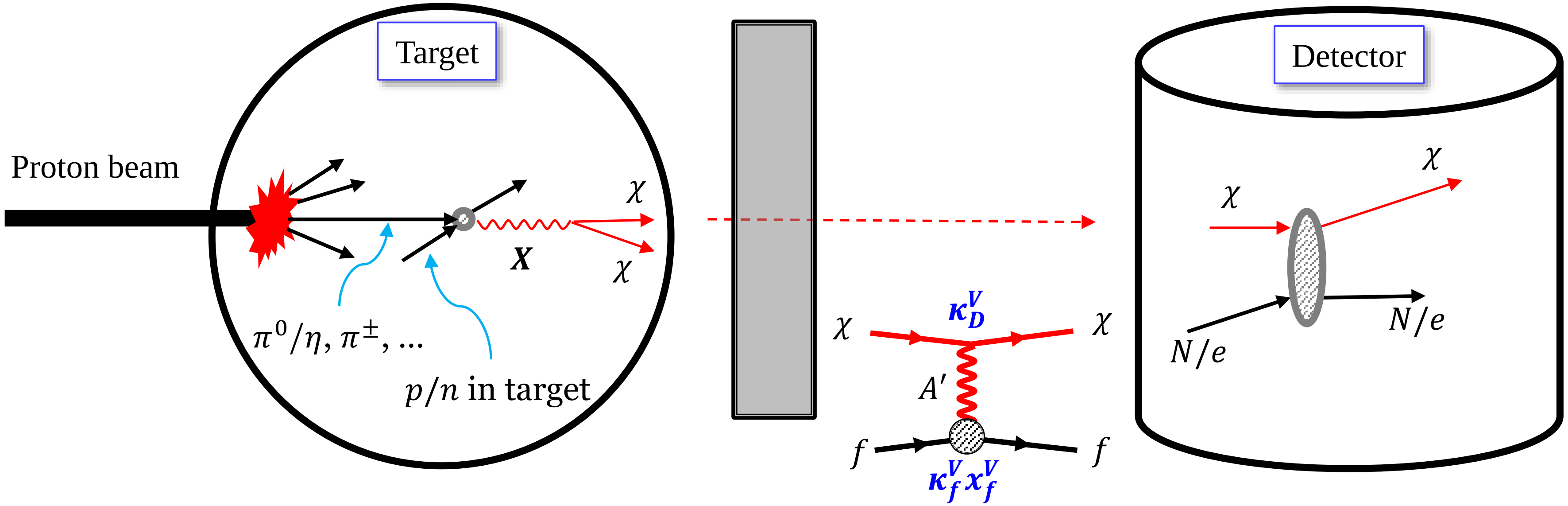
$$\mathcal{L}_{X,\text{prod}} \supset \sum_f \kappa_f^X x_f^X X_\mu \bar{f}\gamma^\mu f + \kappa_D^X X_\mu \bar{\chi}\gamma^\mu \chi$$

- Meson decays (P1): $\pi^0/\eta \to \gamma + \gamma/\boldsymbol{X}$
- π^- absorption (capture) process (P2): $\pi^- + p \to n + \gamma/\boldsymbol{X}$ (X: single-valued E)
- Charge exchange processes (P3): $\pi^{-(+)} + p(n) \to n(p) + \pi^0$ & $\pi^0 \to \gamma + \gamma/\boldsymbol{X}$
- $e^{\pm}$-induced cascade (P4): electromagnetic cascade showering & $\gamma \to \boldsymbol{X}$

Dedicated simulation using e.g. GEANT4 & BdNMC are needed!

Passive ➔ Active: Direct Detection

Dutta, Kim, Liao, **JCP**, Shin, Strigari, Thompson
PRL (2020) /JHEP (2022)



$$\mathcal{L}_{V,\text{scatter}} \supset \sum_f \kappa_f^V x_f^V V_\mu \bar{f}\gamma^\mu f + \kappa_D^V V_\mu \bar{\chi}\gamma^\mu \chi$$

❖ Nuclear scattering (D1): (small E_r for light DM)

$$\frac{d\sigma}{dE_{r,N}} = \frac{(\kappa_f^V \kappa_D^V)^2 (Q_{\text{eff}}^V)^2 \cdot |F_V|^2}{4\pi p_\chi^2 (2m_N E_{r,N} + m_V^2)^2} \left\{ 2E_\chi^2 m_N \left(1 - \frac{E_{r,N}}{E_\chi} - \frac{m_N E_{r,N}}{2E_\chi^2}\right) + m_N E_{r,N}^2 \right\}$$

❖ Electron scattering (D2): (large E_r even for light DM)

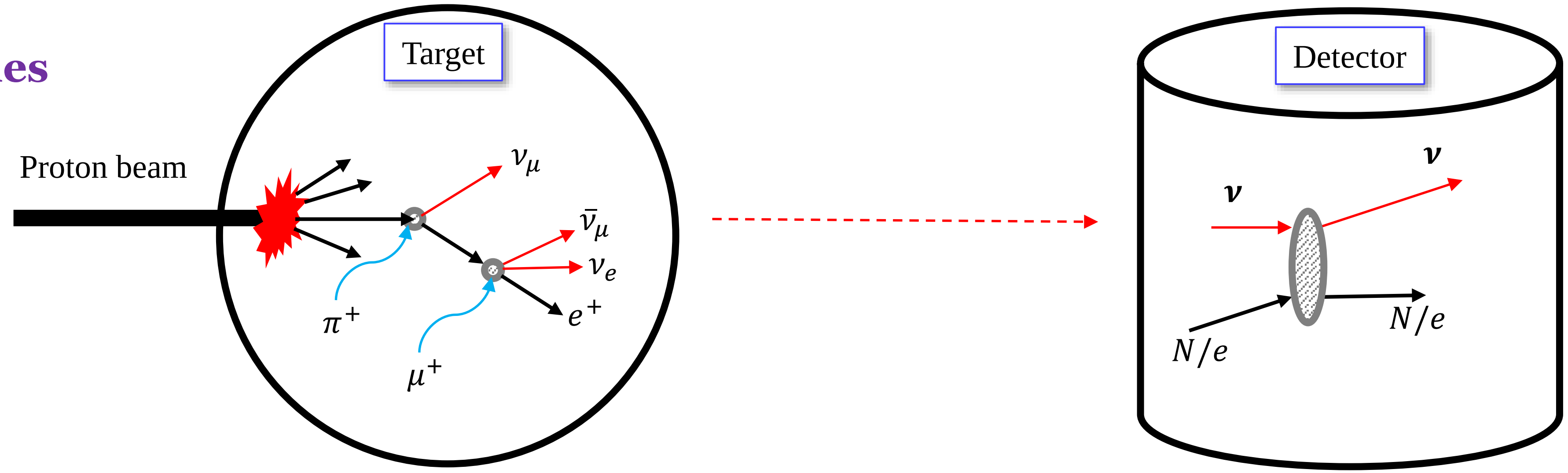
$$\frac{d\sigma}{dE_{r,e}} = \frac{Z (x_f^V \kappa_f^V \kappa_D^V)^2 m_e^2}{\pi \lambda(s, m_e^2, m_\chi^2) \left\{2m_e(m_e - E_{r,e}) - m_V^2\right\}^2} \times \left[m_e \left\{E_\chi^2 + (m_e + E_\chi - E_{r,e})^2\right\} + (m_e^2 + m_\chi^2)(m_e - E_{r,e}) \right]$$

$E_{r,N/e}$: recoil kinetic E of target particle
$m_{N/e}$: mass of target particle
Z: atomic number
$s = m_e^2 + 2E_\chi m_e + m_\chi^2$
$\lambda(x,y,z) = (x-y-z)^2 - 4yz$

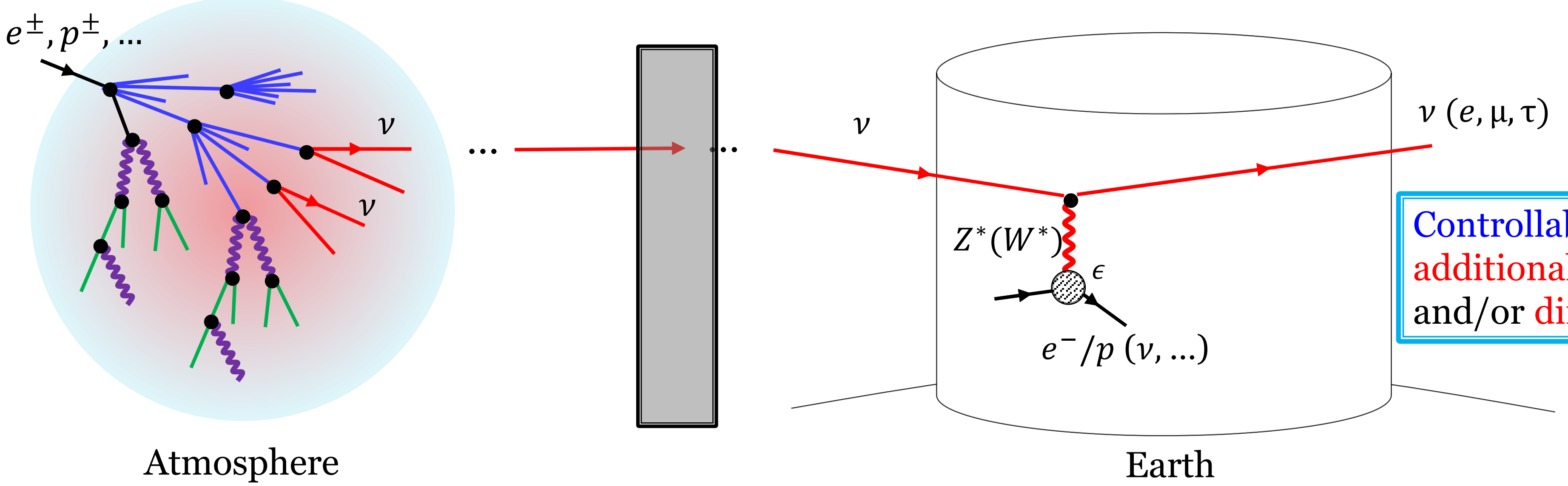
p-scattering dominates over DIS for m_X < O(GeV) [2003.07369]

Background? Neutrinos

Active searches



Passive searches



Controllable via additional signatures and/or directionality

Background? Controllable

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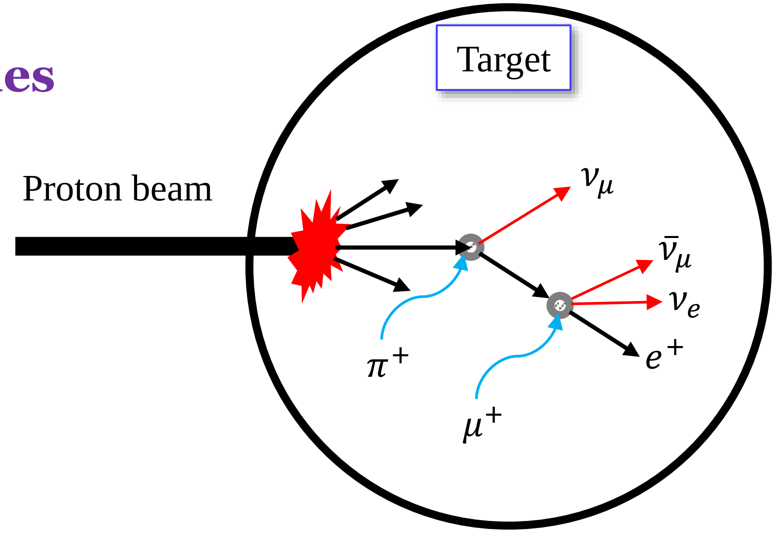
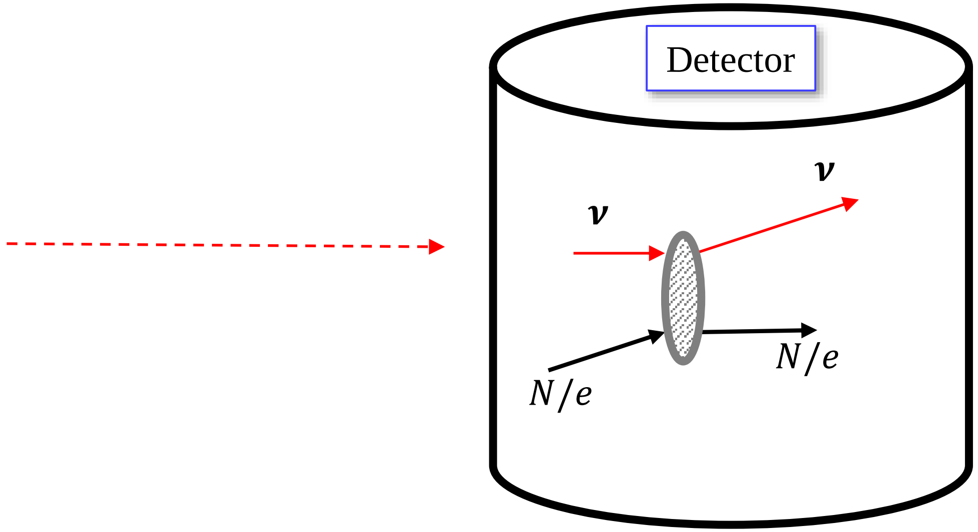
PRL (2020) /JHEP (2022)

Active searches





e.g. Low-energy, High luminosity & Pulsed-beam neutrino experiments

- Prompt neutrinos from the decay of stopped (positively)-charged pions (kaons → minor)
  - ✓ Mean life time of $\pi^+ = 2.6 \times 10^{-8}$s $\ll \mu$s.
  - ✓ Neutrino E is single-valued ($E_\nu = \frac{m_\pi^2 - m_\mu^2}{2m_\pi}$~30 MeV) ➔ ***E*-cut**
- Delayed neutrinos from the decay of stopped muons
  - ✓ Mean life time of $\mu^+ = 2.2 \times 10^{-6}$s $> \mu$s ➔ ***t*-cut**
  - ✓ Neutrinos are more energetic than prompt neutrinos ($E_\nu^{\max} = \frac{m_\mu^2 - m_e^2}{2m_\mu}$~53 MeV).

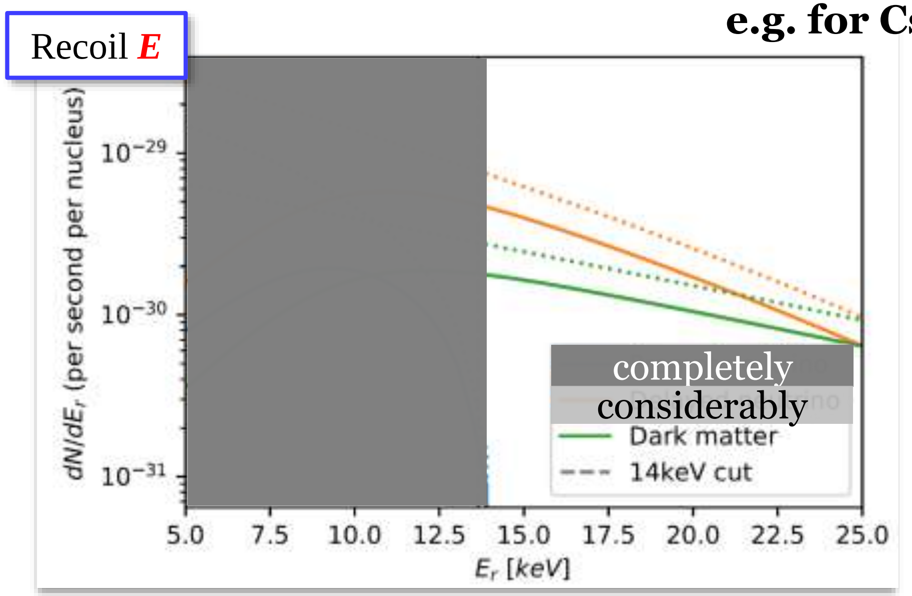
$$E_{r,N}^{\max} = \frac{2E_\nu^2}{m_N + 2E_\nu}$$

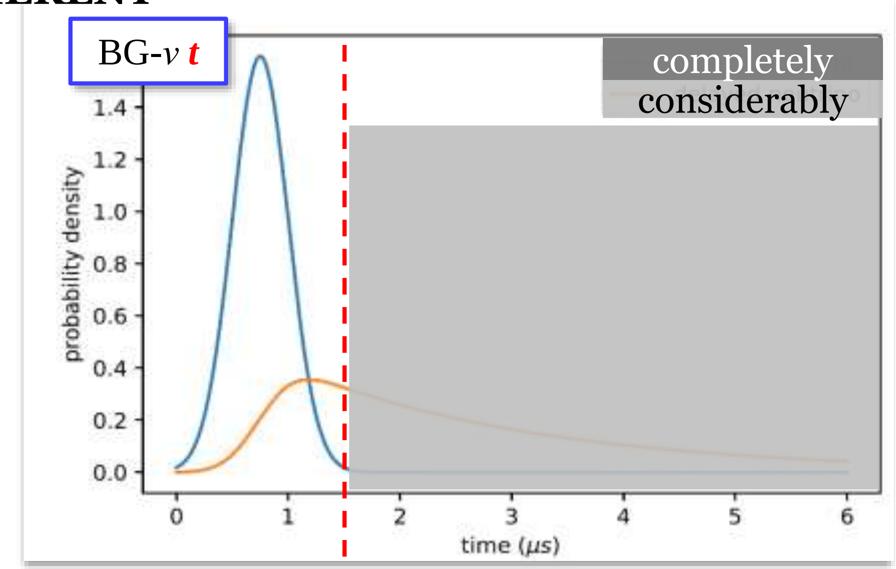
$$E_{r,e}^{\max} = \frac{2E_\nu^2 + 2E_\nu m_e + m_e^2}{m_e + 2E_\nu}$$

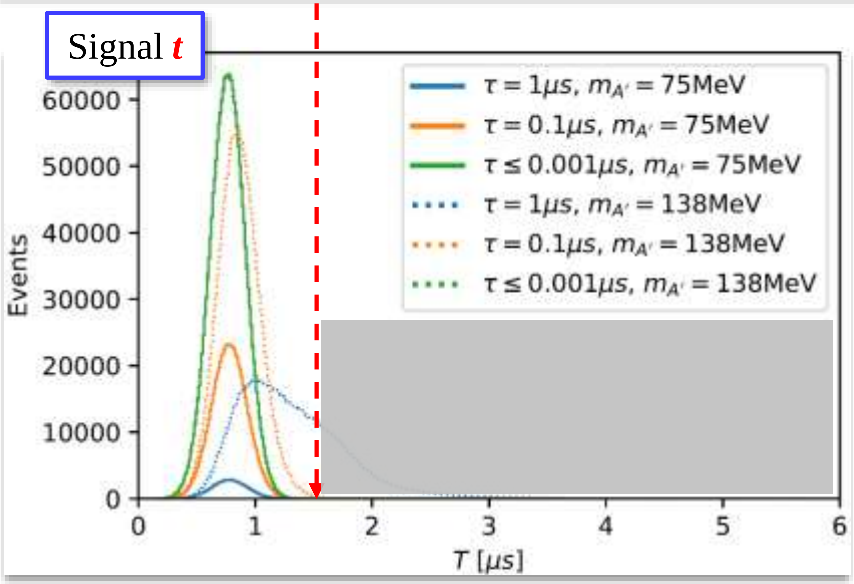
Background? Proposed Search Strategy: E_r- & t-cuts

Dutta, Kim, Liao, **JCP**, Shin, Strigari, Thompson
PRL (2020) /JHEP (2022)

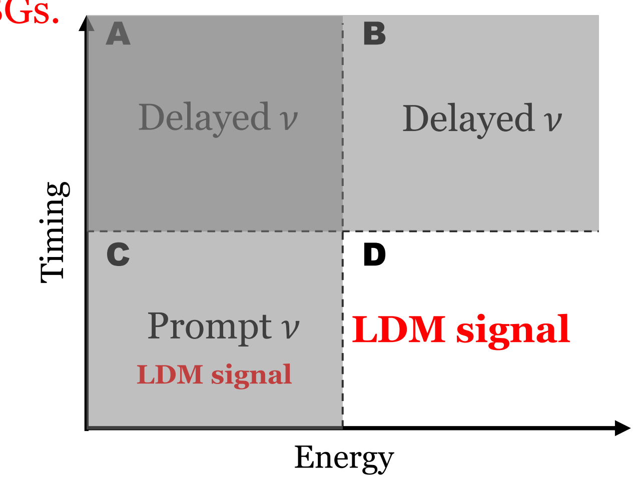
e.g. for CsI at COHERENT







❖ **A combination of *E* & *t* cuts** can remove SM/NSI ν BGs.



Summary of E_r- & t-cuts

Dutta, Kim, Liao, **JCP**, Shin, Strigari, Thompson
PRL (2020) /JHEP (2022)

	Channel	E_r cut	t cut	Background eff. (Remaining events)
COHERENT-CsI	Nucleus	$E_r \in (14, 26)$ keV	$t < 1.5\ \mu s$	AC: 13.4% (138) CEνNS: 37.9% (69)
COHERENT-LAr	Nucleus	$E_r > 10$ keV	$t < 1.5\ \mu s$	AC: 15% (550) CEνNS: 21% (27)
CCM	Nucleus	$E_r > 50$ keV	$t < 0.1\ \mu s$ (Tight WP) $t < 0.4\ \mu s$ (Loose WP)	CEνNS: 0.03% (189) CEνNS: 0.88% (5,970)
JSNS^2	Electron	$E_r > 30$ MeV	$t < 0.25\ \mu s$	CEνNS: 1.17% (107)

Remaining events
COHERENT-CsI: 4466 kg·d,
COHERENT-LAr: 6576 kg·d,
CCM & JSNS^2: 3 year exposures

- ✓ COHERENT & CCM: designed to be sensitive the nucleus recoil [low $E_r \sim O(10\ \text{keV})$]
- ✓ JSNS^2: a good sensitivity to the electron recoil [high $E_r \sim O(10\ \text{MeV})$]
- ✓ COHERENT-CsI: an upper E_r-cut beyond which BG uncertainties are high.
- ✓ CCM: 50 keV is not the optimized cut, only E_r > 50 keV data will be available.
- ✓ CCM: two working points (WP) – a tight cut (the experimental recommendation) & a loose cut (the t-spectrum of the DM signal)
- ✓ JSNS^2: only the duration of the 1st pulse as our baseline timing cut as the t window of the 2nd pulse may be contaminated by delayed neutrinos generated by the 1st pulse.

Application to Experiments

Dutta, Kim, Liao, **JCP**, Shin, Strigari, Thompson
PRL (2020) /JHEP (2022)

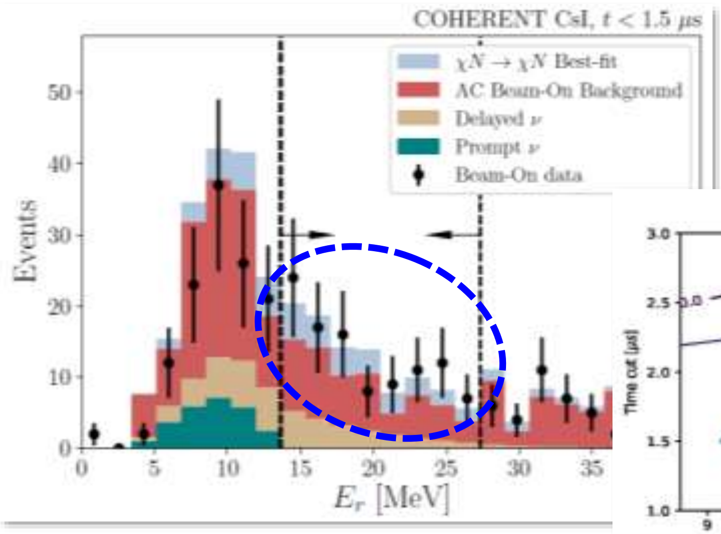
- COHERENT [Science (2017)]: CsI ➔ 14.57×308.1 kg·d
- Cuts: 14 keV < E_r < 28 keV & t < 1.5 μs w/ R_n = 4.7 fm

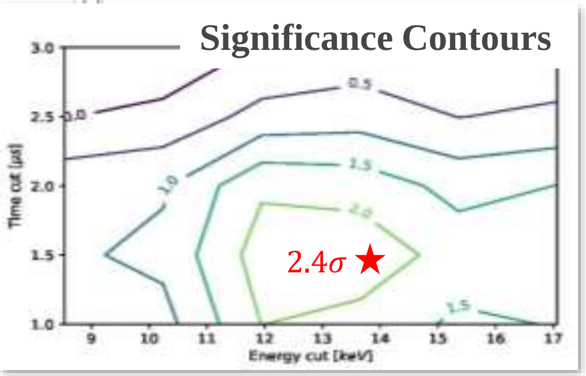
97 : total remaining events
– 49 : classified as steady-state (SS) backgrounds
– 3 : beam-related neutron (BRN) backgrounds
– 19 : identified as delayed (SM) ν events (due to E_r & t-cuts)
– 0 : identified as prompt (SM) ν events (due to E_r-cut)

---

26 : mild excess(?) ➔ can be explained by DM but not NSI

R_n = 4.7 fm: **2.4 σ**
R_n = 5.5 fm: **3.0 σ**
[1801.05546]





Application to Experiments

Dutta, Kim, Liao, **JCP**, Shin, Strigari, Thompson
PRL (2020) /JHEP (2022)

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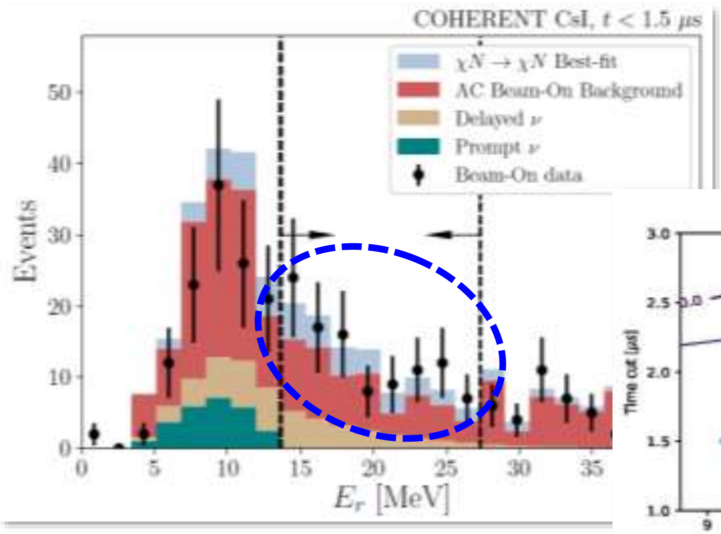

R_n = 4.7 fm: **2.4 σ**
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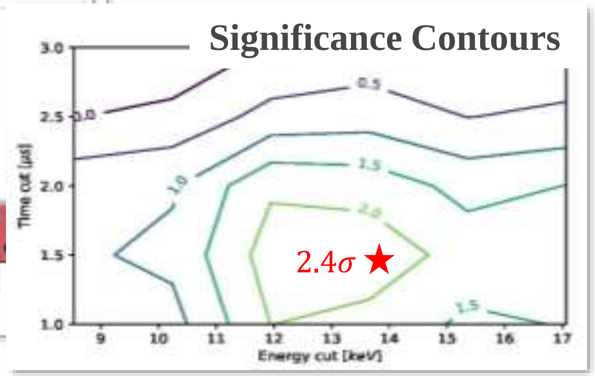
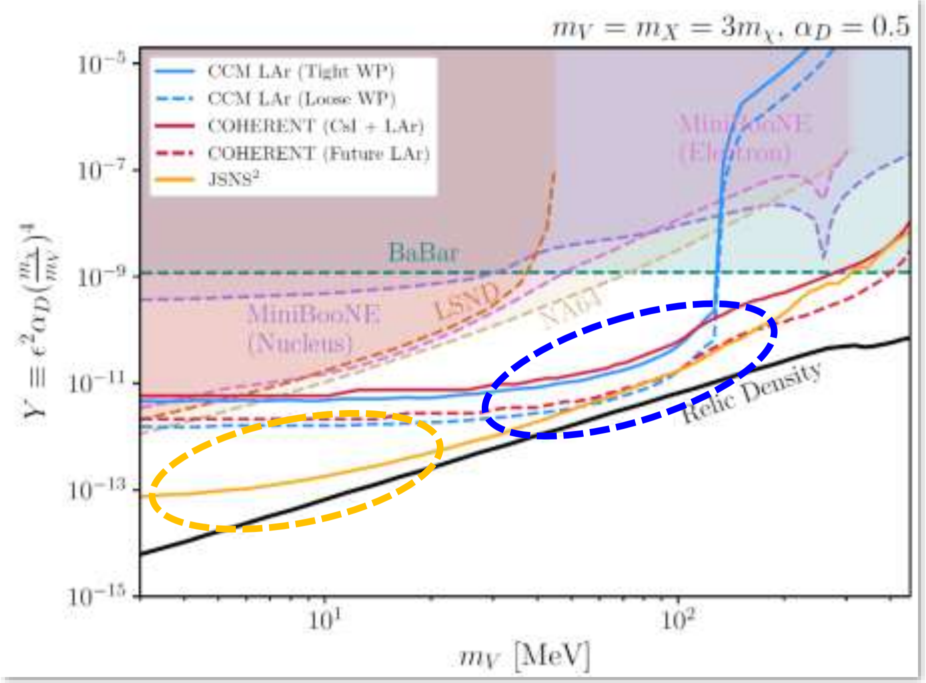
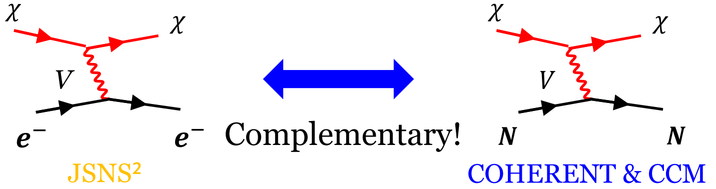
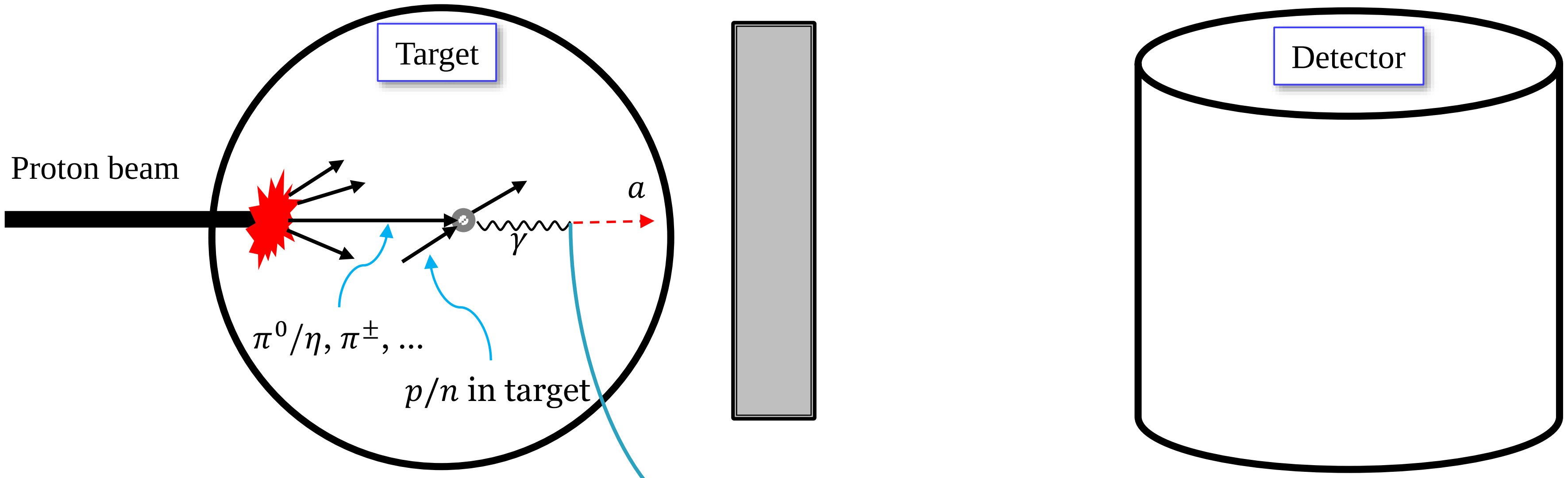


- ❖ Assuming no excess is observed, we can constrain parameter space.
  - ✓ NA64, BaBar: missing E_T

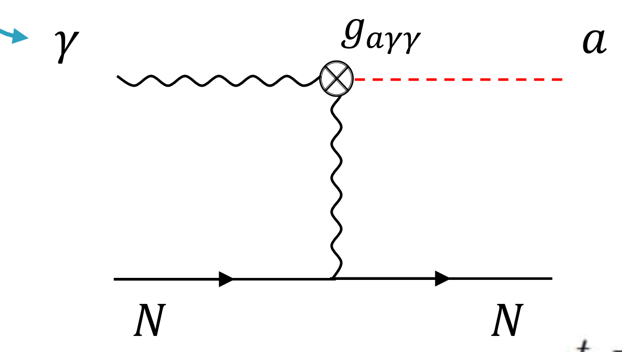




ALP Production: Primakoff Process



Photon production: Dedicated simulation using e.g. GEANT4 is needed!



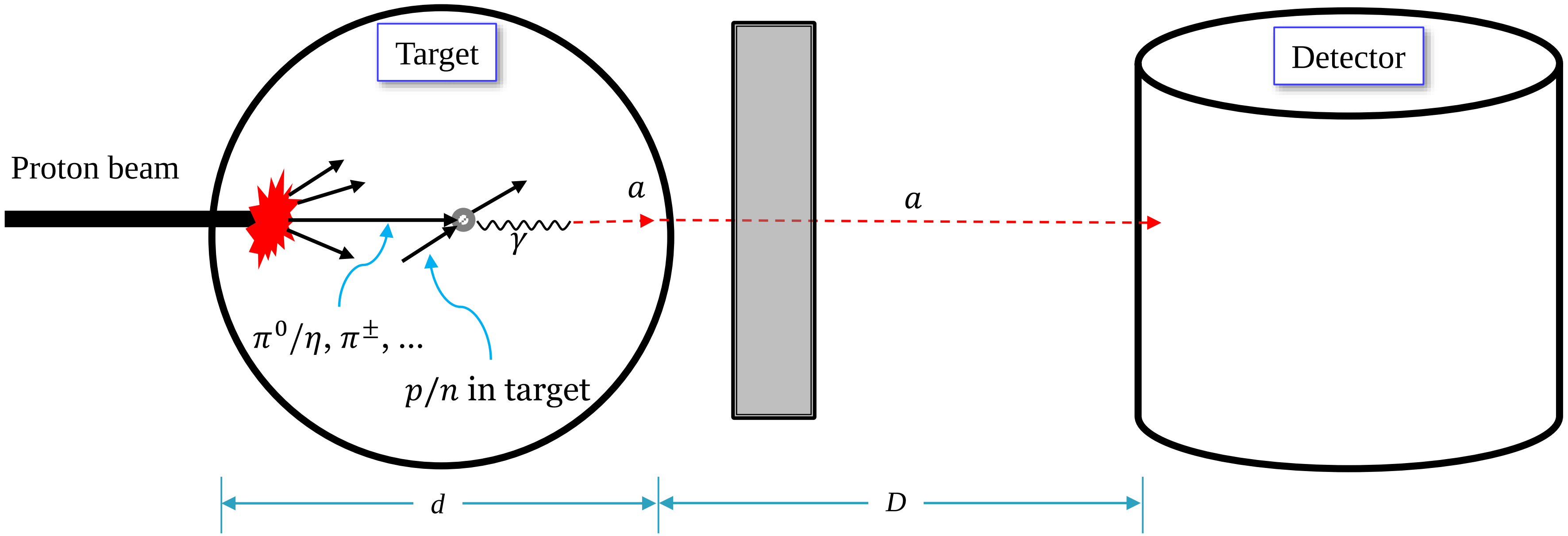
$$\frac{d\sigma_P^p}{d\cos\theta} = \frac{1}{4} g_{a\gamma\gamma}^2 \alpha Z^2 F^2(t) \frac{|\vec{p}_a|^4 \sin^2\theta}{t^2}$$

$$t = (p_1 - k_1)^2 = m_a^2 + E_\gamma (E_a - |\vec{p}_a| \cos\theta)$$

- Meson decays (P1): $\pi^0/\eta \to \gamma + \gamma$
- π^- absorption (capture) process (P2): $\pi^- + p \to n + \gamma$
- Charge exchange processes (P3): $\pi^{-(+)} + p(n) \to n(p) + \pi^0$ & $\pi^0 \to \gamma + \gamma$
- $e^\pm$-induced cascade (P4): γ's from electromagnetic cascade showering

Z: atomic number, α: fine structure constant, $F(t)$: form factor,
E_γ: incident photon energy,
$|\vec{p}_a|$: magnitude of the outgoing three-momentum of the ALP at the angle θ relative to the incident photon momentum

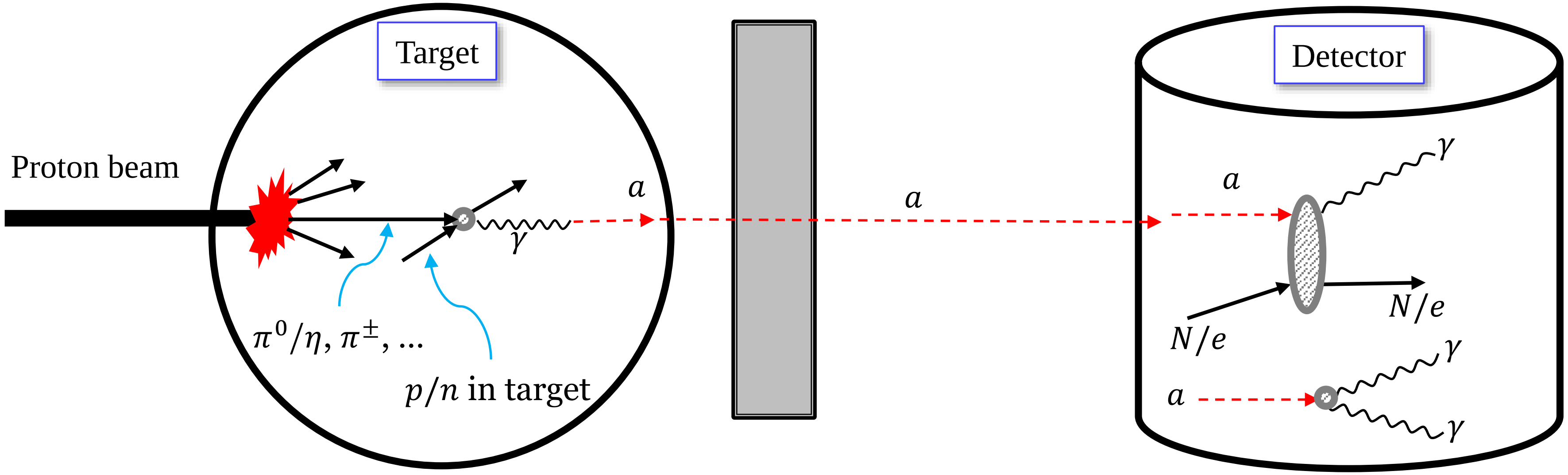
ALP Transportation



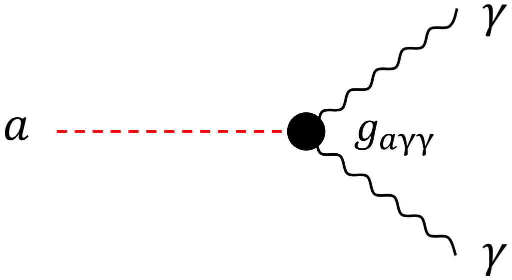
$$P_{\text{tran}} = \underbrace{\exp(-\rho_T\, \sigma_{\text{prod}}^{\text{tot}} d)}_{\approx 1 \text{ in most experiments}} \exp\left(-\frac{D}{\bar{\ell}_a^{\text{lab}}}\right)$$

- ρ_T: scattering target number density in the target/dump or reactor core
- $\sigma_{\text{scat}}^{\text{tot}}$: ALP scattering cross-section in the target/dump or reactor core
- d: thickness of target/dump or reactor core
- D: distance to the detector of interest
- $\bar{\ell}_a^{\text{lab}}$: lab-frame mean decay length of ALP

ALP Detection

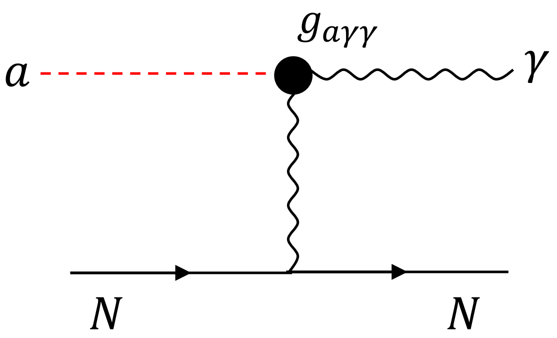


Decay



$$\Gamma(a \to \gamma\gamma) = \frac{g_{a\gamma\gamma}^2 m_a^3}{64\pi}$$

Scattering



$$\frac{d\sigma_P^p}{d\cos\theta} = \frac{1}{4} g_{a\gamma\gamma}^2 \alpha Z^2 F^2(t) \frac{|\vec{p}_a|^4 \sin^2\theta}{t^2}$$

$$P_{\text{det}}^{\text{decay}} = 1 - \exp\left(-\frac{L_{\text{det}}}{\bar{\ell}_a^{\text{lab}}}\right)$$

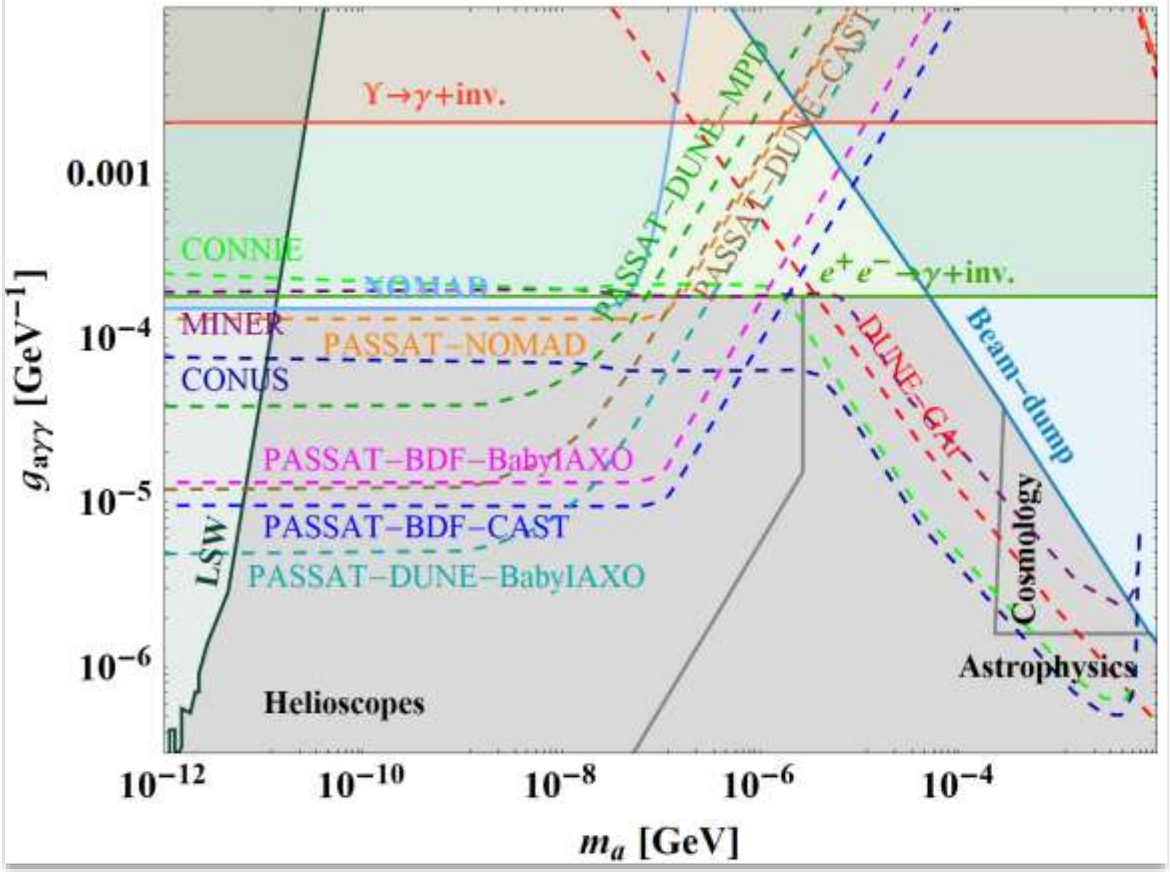
- ✓ $\bar{\ell}_a^{\text{lab}}$: lab-frame mean decay length
- ✓ L_{det}: length of detector

$$P_{\text{det}}^{\text{scat}} = n_T\, \sigma_{\text{det}}^{\text{fid}}\, L_{\text{det}}$$

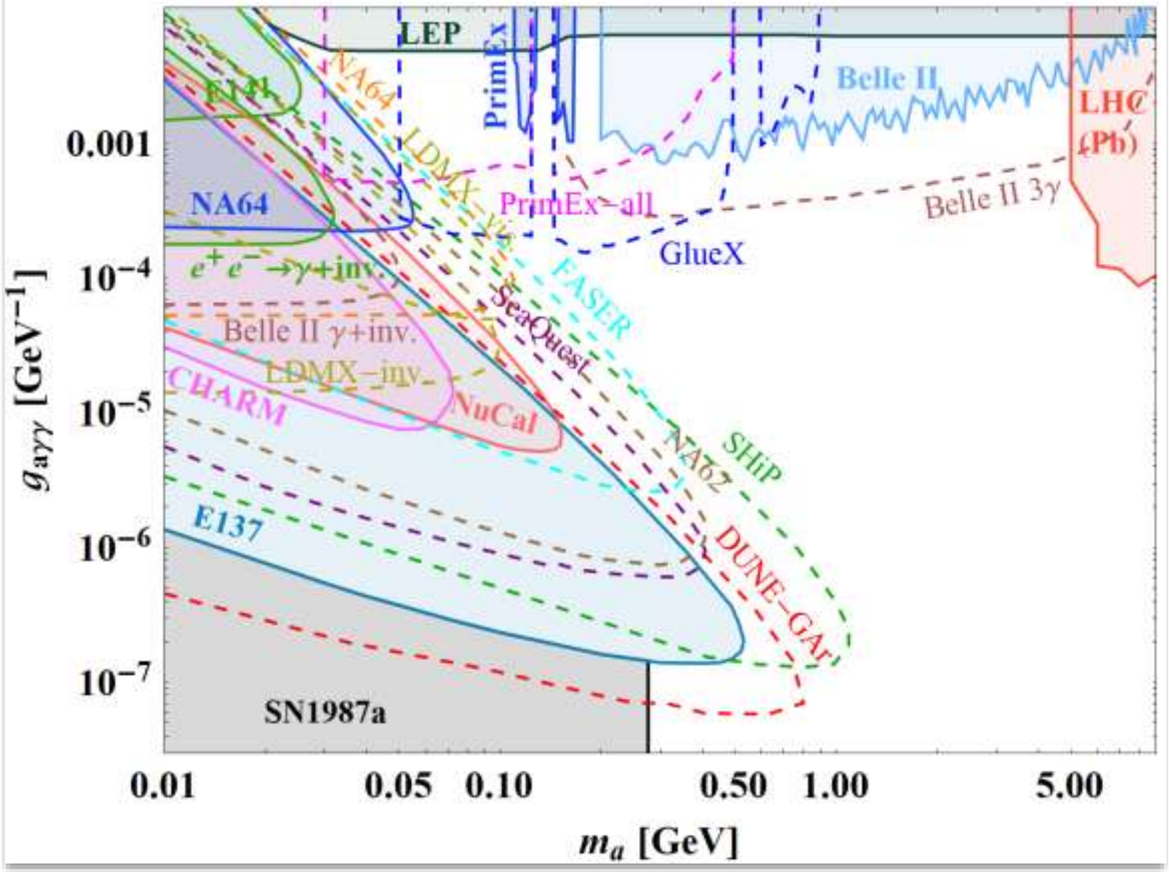
- ✓ n_T: scattering target number density
- ✓ $\sigma_{\text{det}}^{\text{fid}}$: fiducial ALP scattering cross-section
- ✓ L_{det}: length of magnetic field region

ALP Sensitivity Reaches

Scattering & Conversion channels



Decay channels



[Fortin, Guo, Harris, Kim, Sinha, Sun, 2102.12503]

Summary

- Dark world: can be flavorful & secluded ➔ multi-species, masses, spins, interactions, ...

  ➔ Numerous ideas for portals between DM-SM sectors & dark sector particles

- Light new particles: rising interest

  ✓ **Light DM (< MeV) direct detection**: Very low E_{th} detectors are required.

  ✓ **Cosmogenic boosted DM**: ***νBDM*** dominant & enhanced flux for light DM with $K_{\mathrm{DM}} > E_{th}$

  ➔ Even detectable using ordinary DM detectors

  ✓ **Beam-induced energetic production**: new opportunities for DM, dark photon, ALP, ...

Thank you