Reverse Direct Detection:
Cosmic Ray Tests of Light Dark Matter Elastic Scattering

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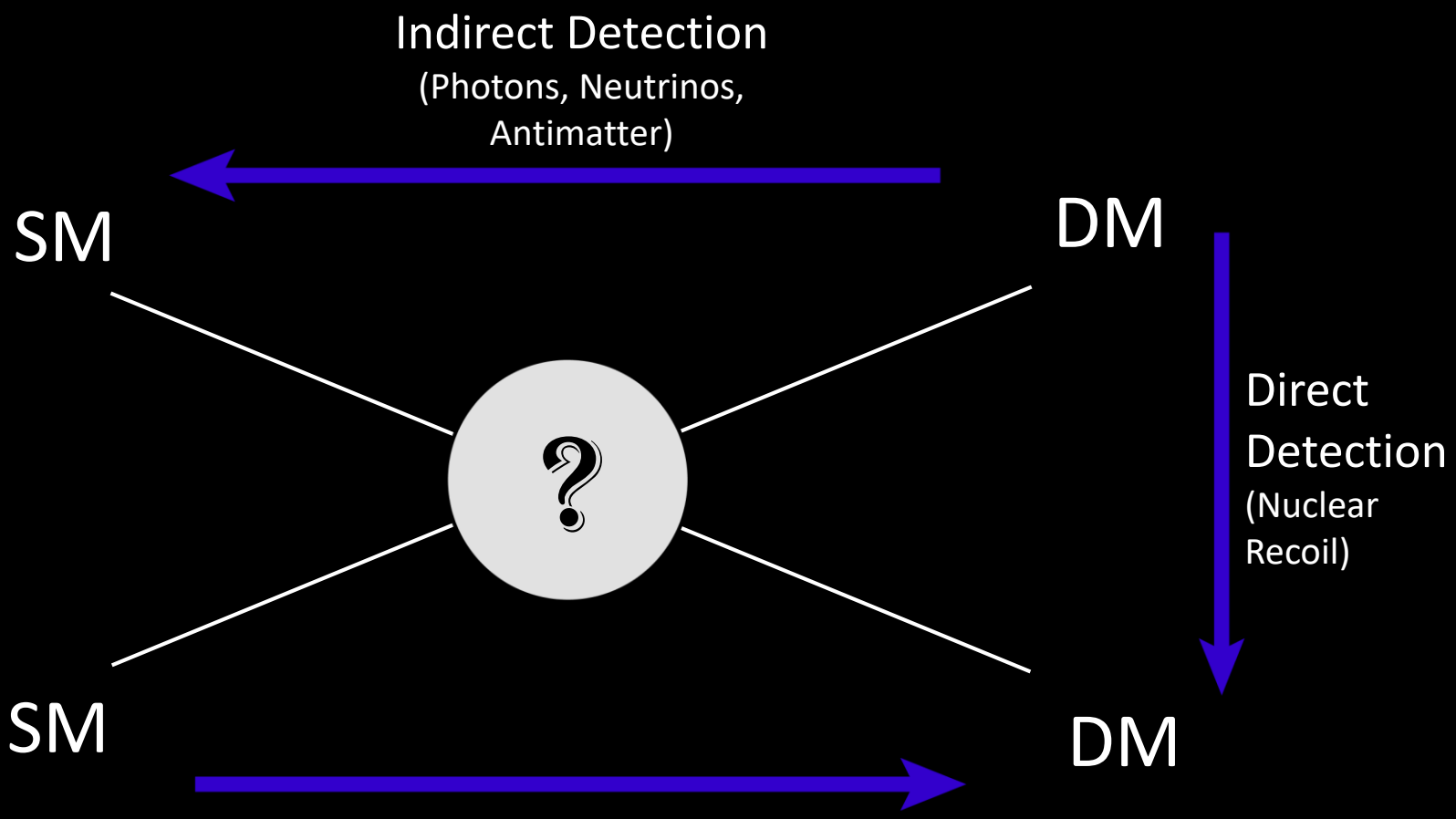
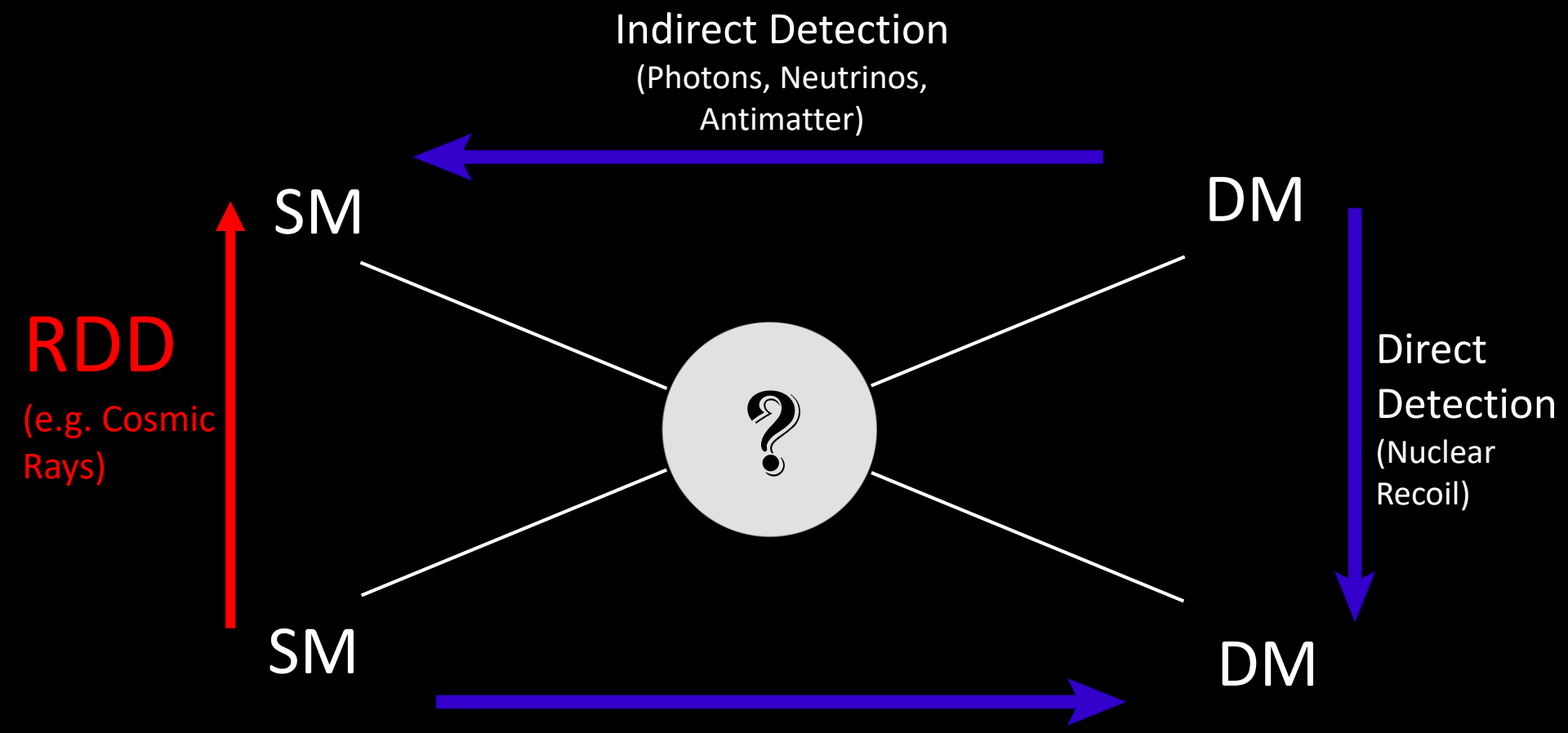
CCAPP

Dark Matter Search Strategies



inspirehep.net/record/1400608

Dark Matter Search Strategies



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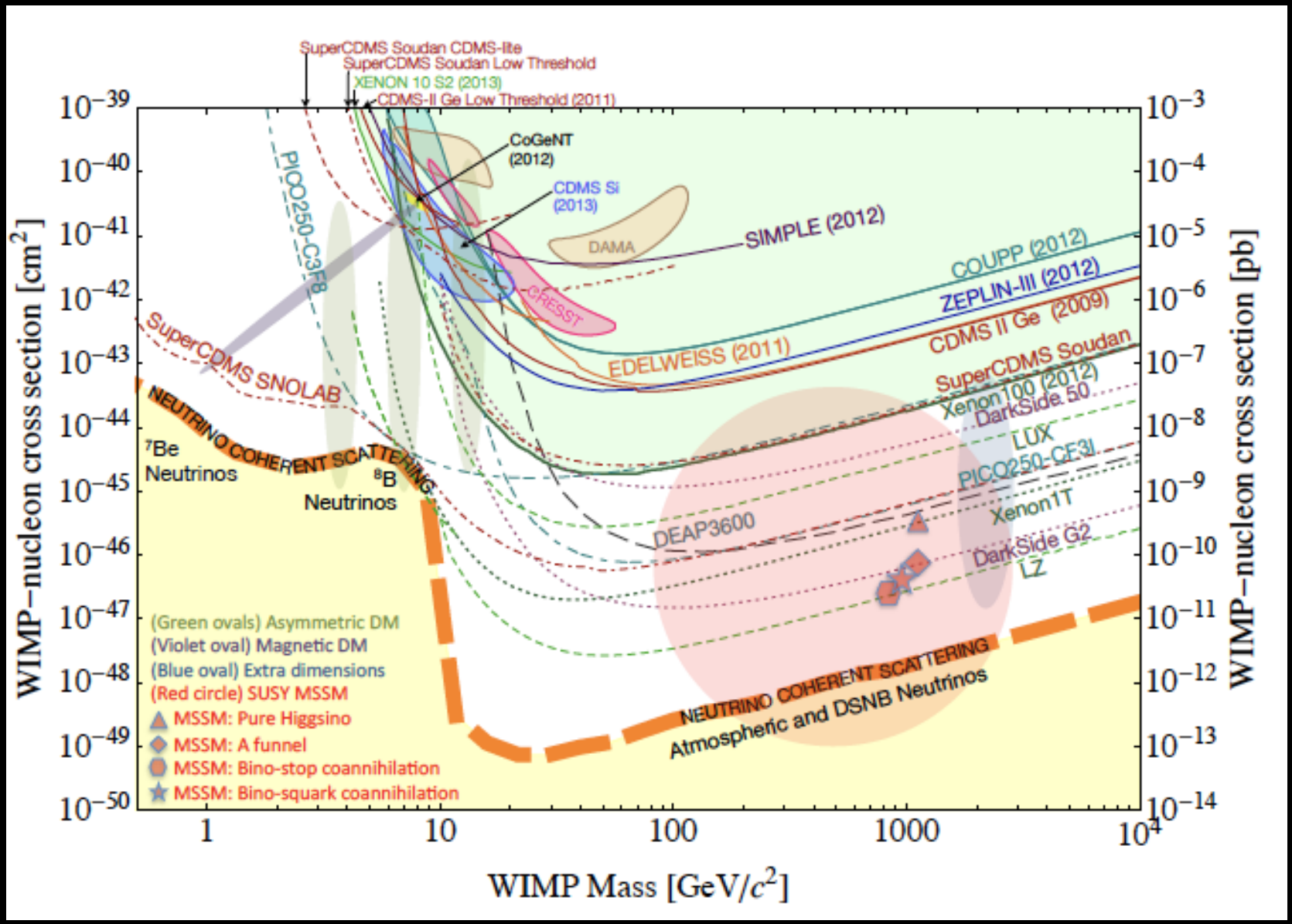
Why RDD?


SuperCDMS Soudan CDMS-lite
SuperCDMS Soudan Low Threshold
XENON 10 S2 (2013)
CDMS-II Ge Low Threshold (2011)
CoGeNT (2012)
CDMS Si (2013)
DAMA
SIMPLE (2012)
CRESST
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
EDELWEISS (2011)
SuperCDMS Soudan
Xenon100 (2012)
DarkSide 50
LUX
PICO250-CF3I
Xenon1T
DarkSide G2
LZ
DEAP3600
PICO250-C3F8
SuperCDMS SNOLAB
NEUTRINO COHERENT SCATTERING
^{7}Be Neutrinos
^{8}B Neutrinos
NEUTRINO COHERENT SCATTERING
Atmospheric and DSNB Neutrinos
(Green ovals) Asymmetric DM
(Violet oval) Magnetic DM
(Blue oval) Extra dimensions
(Red circle) SUSY MSSM
MSSM: Pure Higgsino
MSSM: A funnel
MSSM: Bino-stop coannihilation
MSSM: Bino-squark coannihilation
WIMP–nucleon cross section [cm^2]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c^2]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-50}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
1
10
100
1000
10^4

Sub-GeV Dark Matter

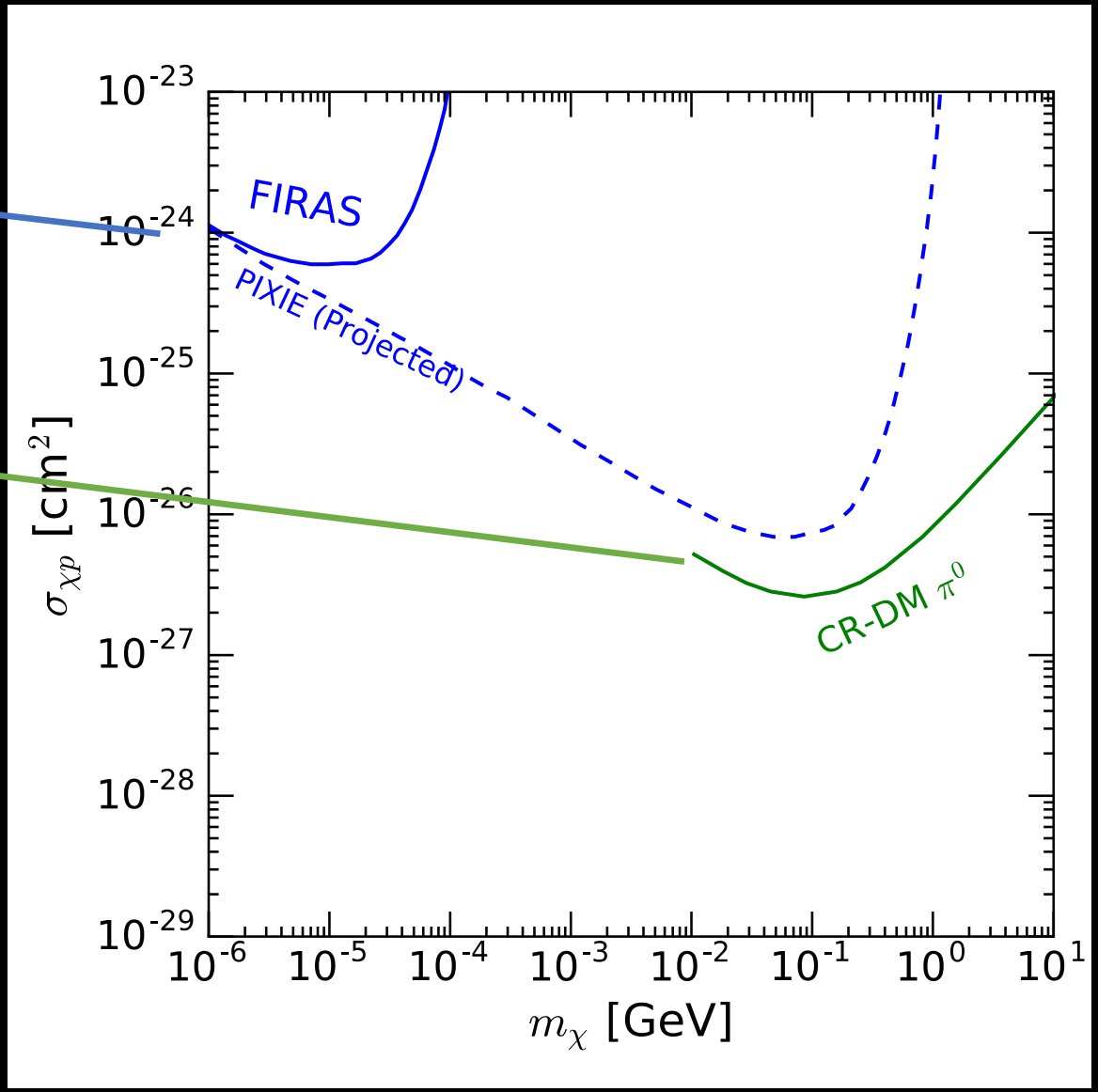
CMB spectral distortion

Ali-Haïmoud,Chluba, Kamionkowski
1506.04745

CR-DM Inelastic

Scattering->Pions->Gammas

Cyburt, Fields, Pavlidou, Wandelt
astro-ph/0203240



Sub-GeV Dark Matter

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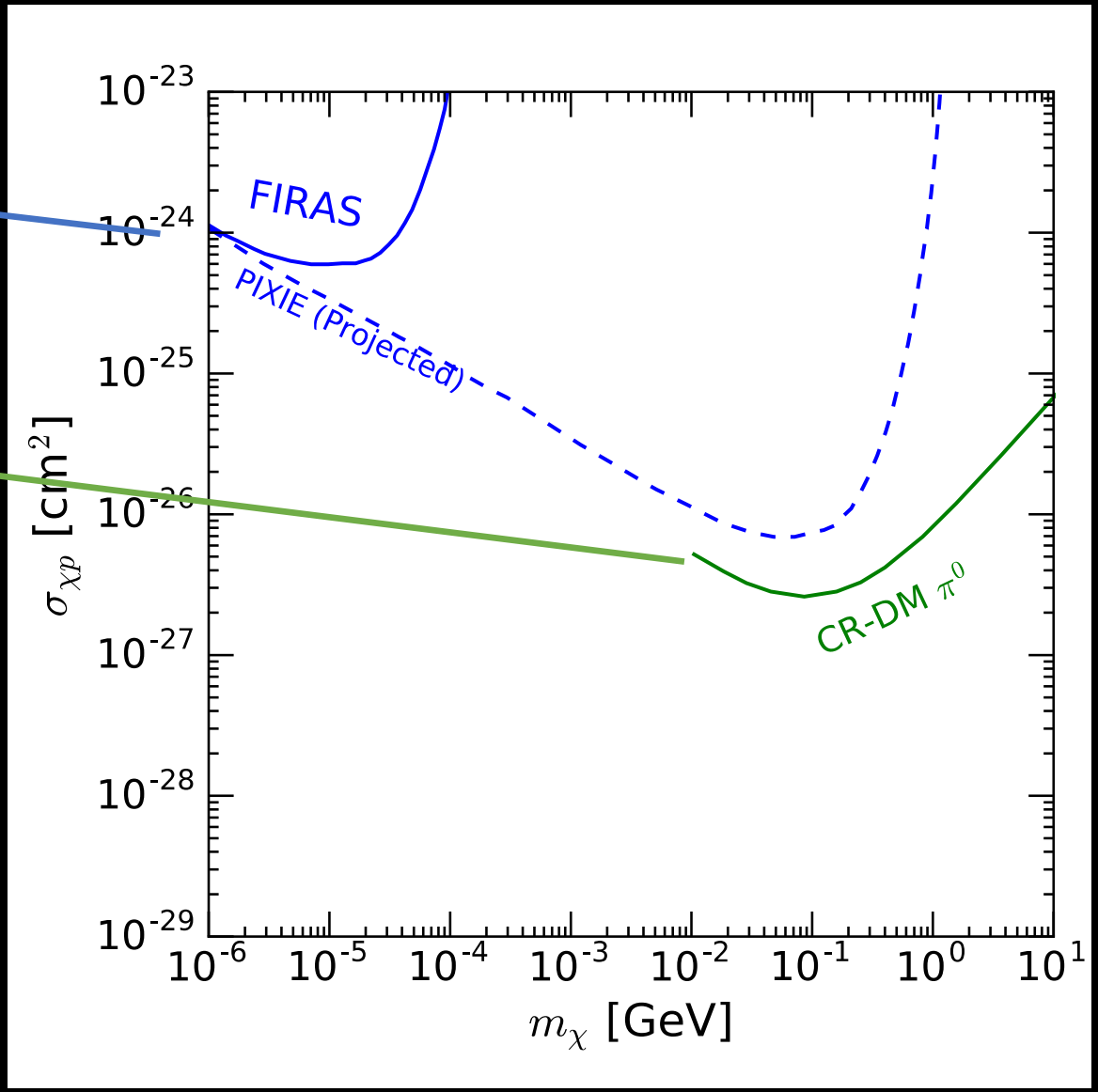
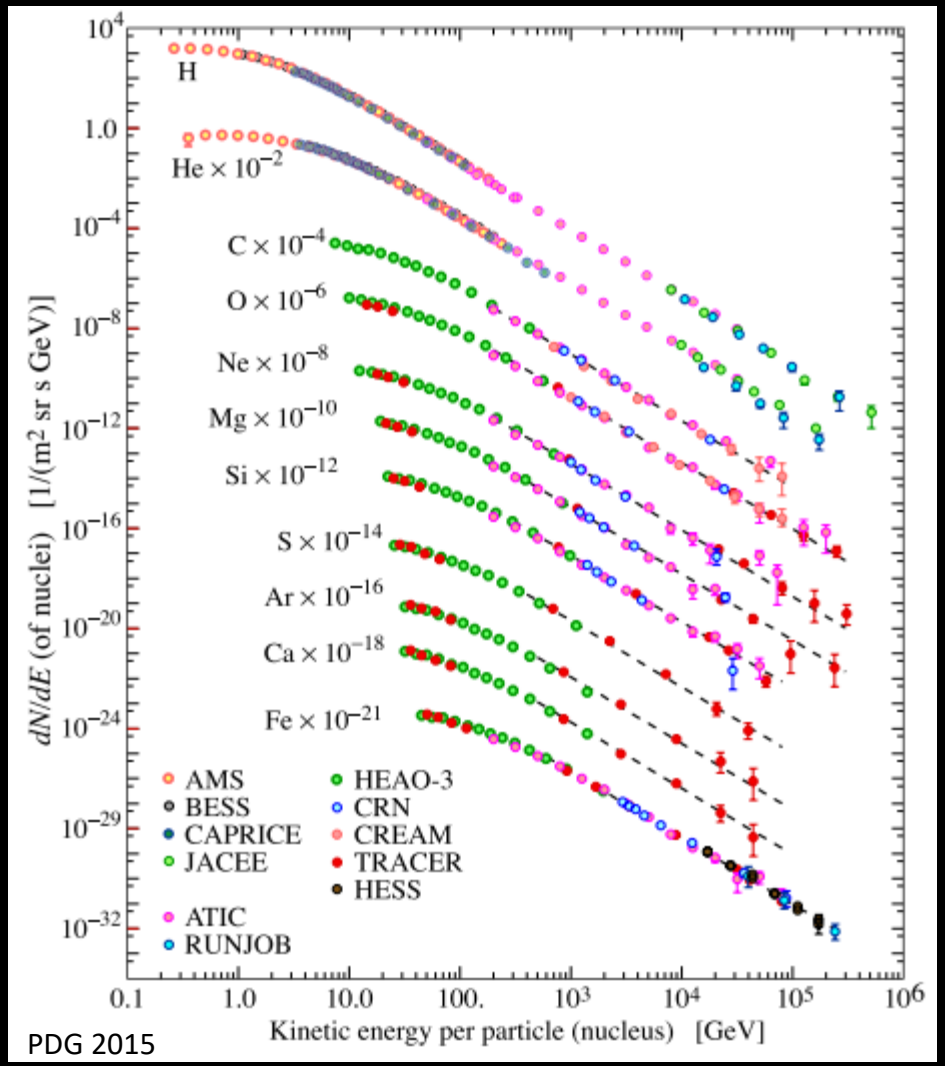
CR-DM Elastic Scattering?



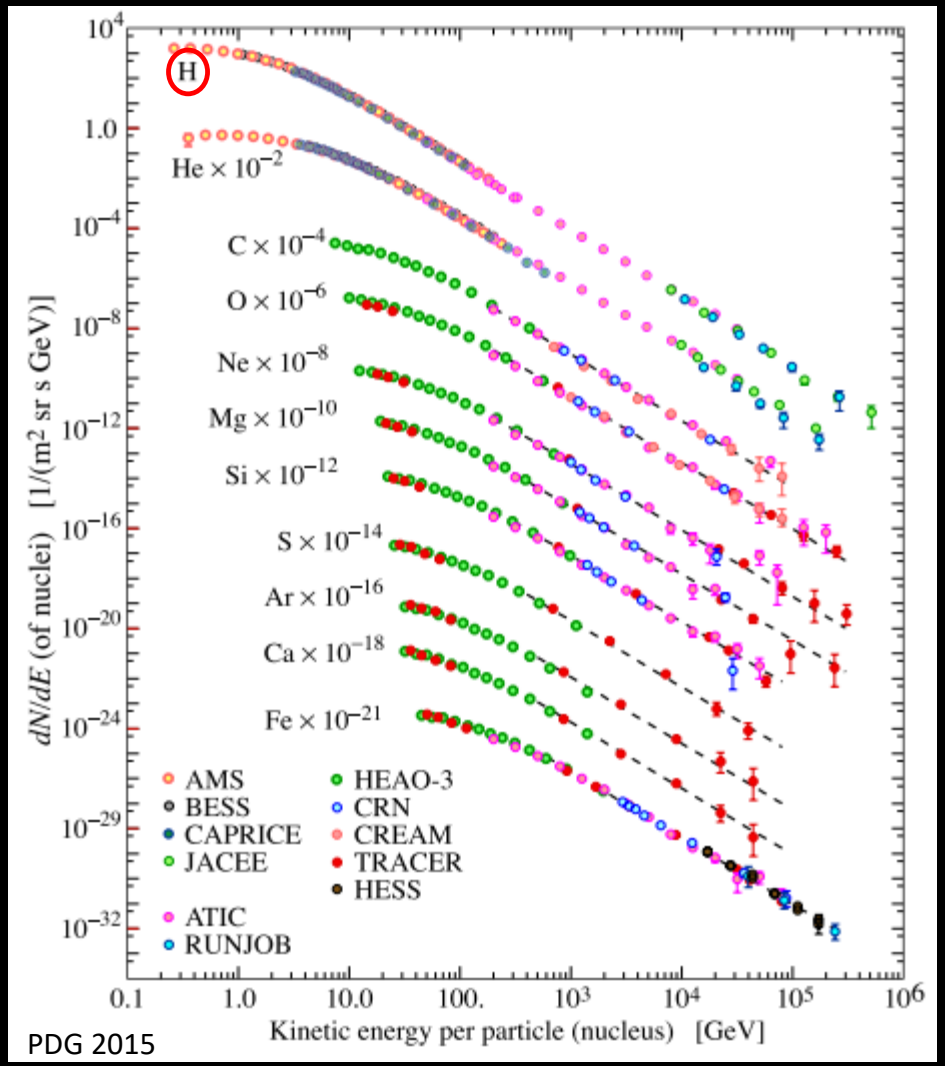
Cosmic Rays in the Galaxy

- Acceleration: SNR
- Propagation: Magnetic Fields -> Diffusion-Like Propagation
- Loss Processes: Spallation, Decay, dE/dt, Escape



Cosmic Ray Protons

- Acceleration: SNR
- Propagation: Magnetic Fields -> Diffusion-Like Propagation
- Loss Processes: Spallation, Decay, dE/dt, Escape



Leaky Box Model: Protons

- Acceleration: Q(ε)
- Diffusion -> T_{esc}
- Energy Loss?

$$\frac{N(\mathcal{E})}{T_{\mathrm{esc}}} + \frac{d}{d\mathcal{E}}\left[\frac{d\mathcal{E}}{dt}N(\mathcal{E})\right] = Q(\mathcal{E})$$

Leaky Box Model: Protons

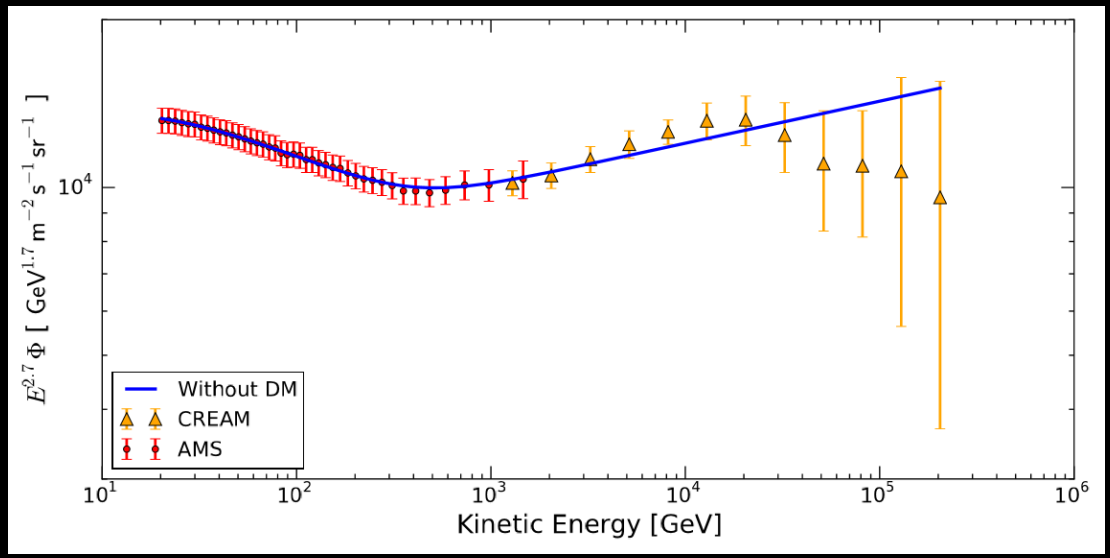
- Acceleration: Q(ε)
- Diffusion -> T_{esc}
- Energy Loss: negligible

$$\frac{N(\mathcal{E})}{T_{\mathrm{esc}}} + \frac{d}{d\mathcal{E}}\left[\frac{d\mathcal{E}}{dt}N(\mathcal{E})\right] = Q(\mathcal{E})$$

Leaky Box Model: Protons

- Acceleration: Q(ε)
  - Broken Power Law
- Diffusion -> T_{esc}
  - Energy Power Law
- Energy Loss: negligible

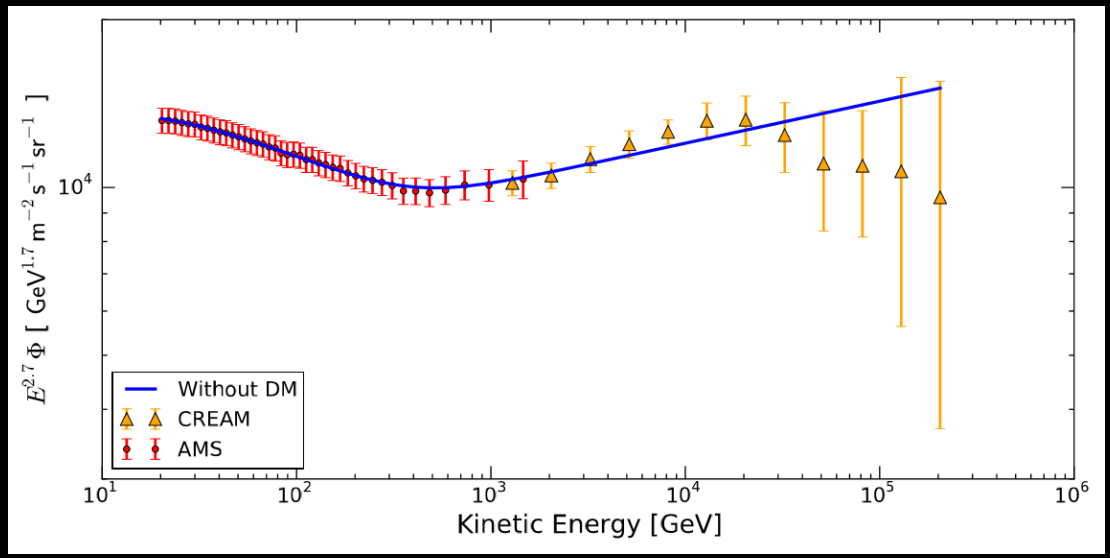
$$\frac{N(\mathcal{E})}{T_{\mathrm{esc}}} + \frac{d}{d\mathcal{E}}\left[\frac{d\mathcal{E}}{dt}N(\mathcal{E})\right] = Q(\mathcal{E})$$



Leaky Box Model: Protons

- Acceleration: Q(ε)
  - Broken Power Law
- Diffusion -> T_{esc}
  - Energy Power Law
- Energy Loss: negligible
  - BUT: Dark Matter?

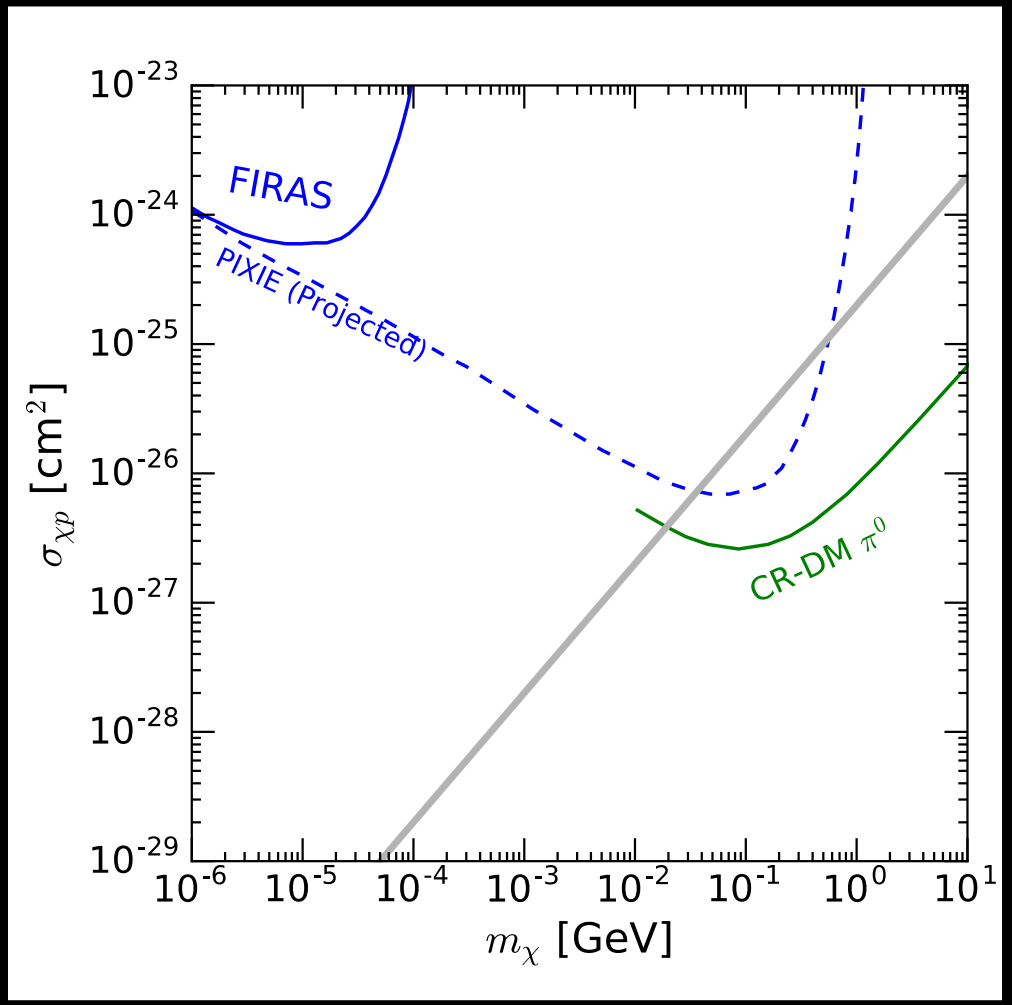
$$\frac{N(\mathcal{E})}{T_{\mathrm{esc}}} + \frac{d}{d\mathcal{E}}\left[\frac{d\mathcal{E}}{dt}N(\mathcal{E})\right] = Q(\mathcal{E})$$



DM-Cosmic Ray Scattering

- Grammage ~10 g/cm^2
- Gray: 1 scattering/particle
  - "Best possible" sensitivity
- Energy loss per collision
  - Assume elastic scattering

$$|\Delta\mathcal{E}| = \frac{4m_p(1+\frac{\mathcal{E}}{2m_p})\frac{\mathcal{E}}{m_\chi}}{(1+\frac{m_p}{m_\chi})^2+\frac{2\mathcal{E}}{m_\chi}}\frac{(1-\cos\theta)}{2}$$

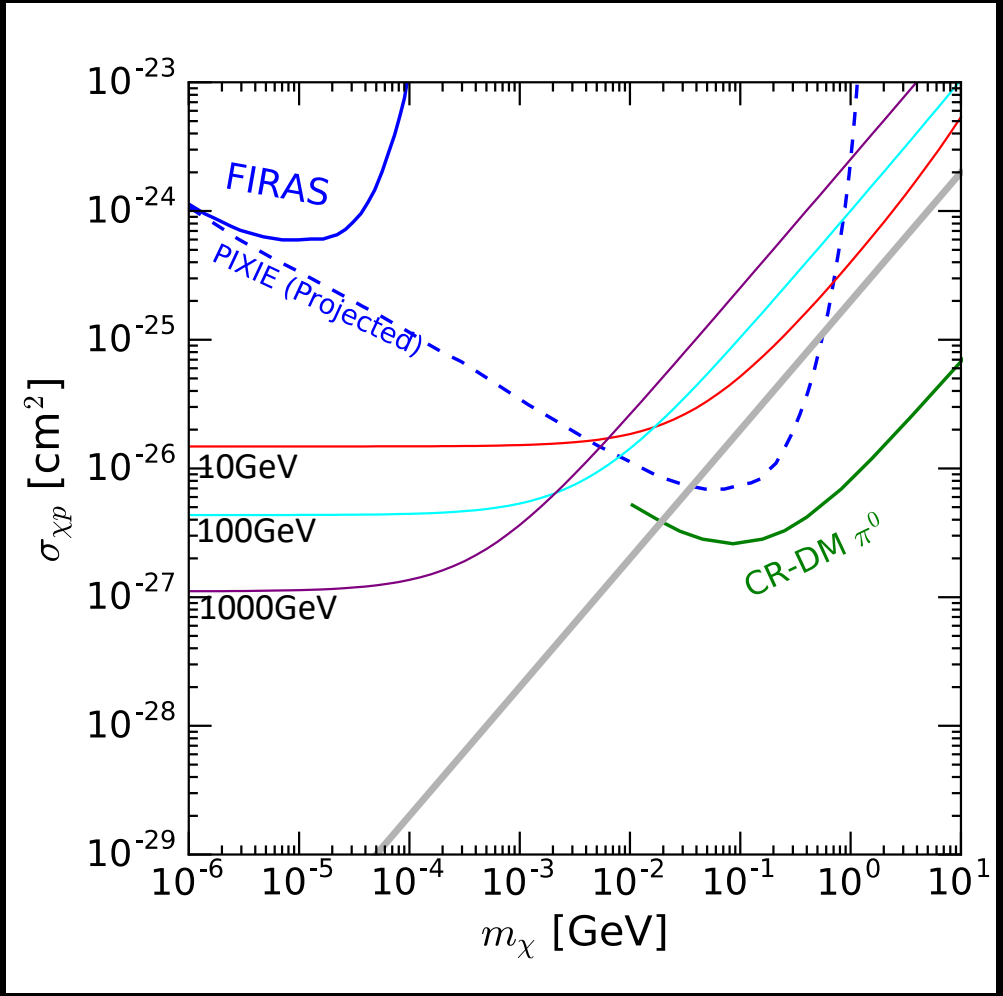


DM-Induced Energy Loss

- Simplified Energy Loss Model:
  - Elastic Scattering
  - Energy-Independent Cross Section
- Colored Curves: $\frac{d\varepsilon}{dt} Tesc = \varepsilon$

$$\frac{d\mathcal{E}}{dt} = c\frac{\rho}{m_\chi}\int_0^{\mathcal{E}_{\max}} T\frac{d\sigma}{dT}dT$$

$$\frac{N(\mathcal{E})}{T_{\rm esc}} + \frac{d}{d\mathcal{E}}\left[\frac{d\mathcal{E}}{dt}N(\mathcal{E})\right] = Q(\mathcal{E})$$

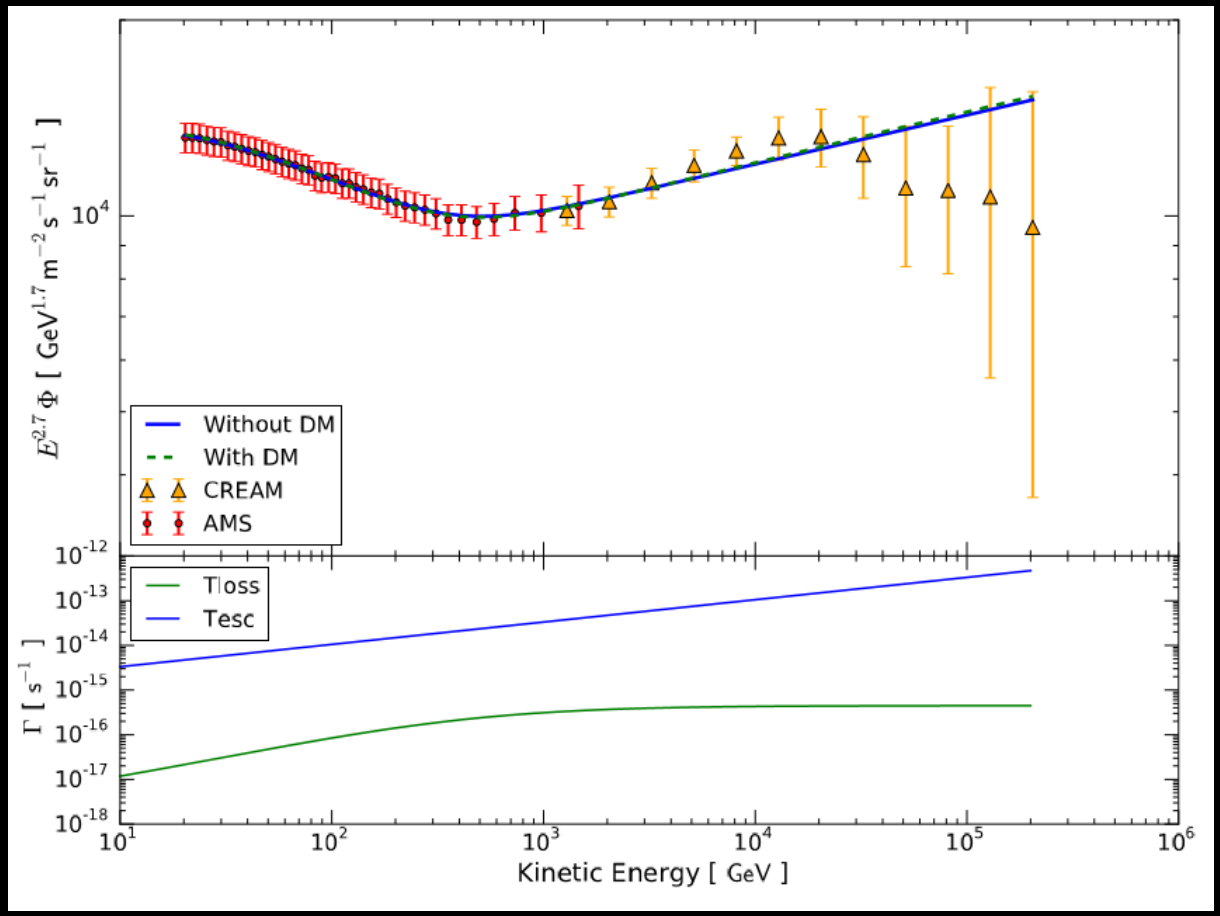


DM-Induced Energy Loss

- Mx = 1e-3 GeV
- σ = 1e-28 cm^2

- Fix:
  - Break energy

- Vary:
  - Injection Indices
  - Injection Normalization
  - Escape Time Index

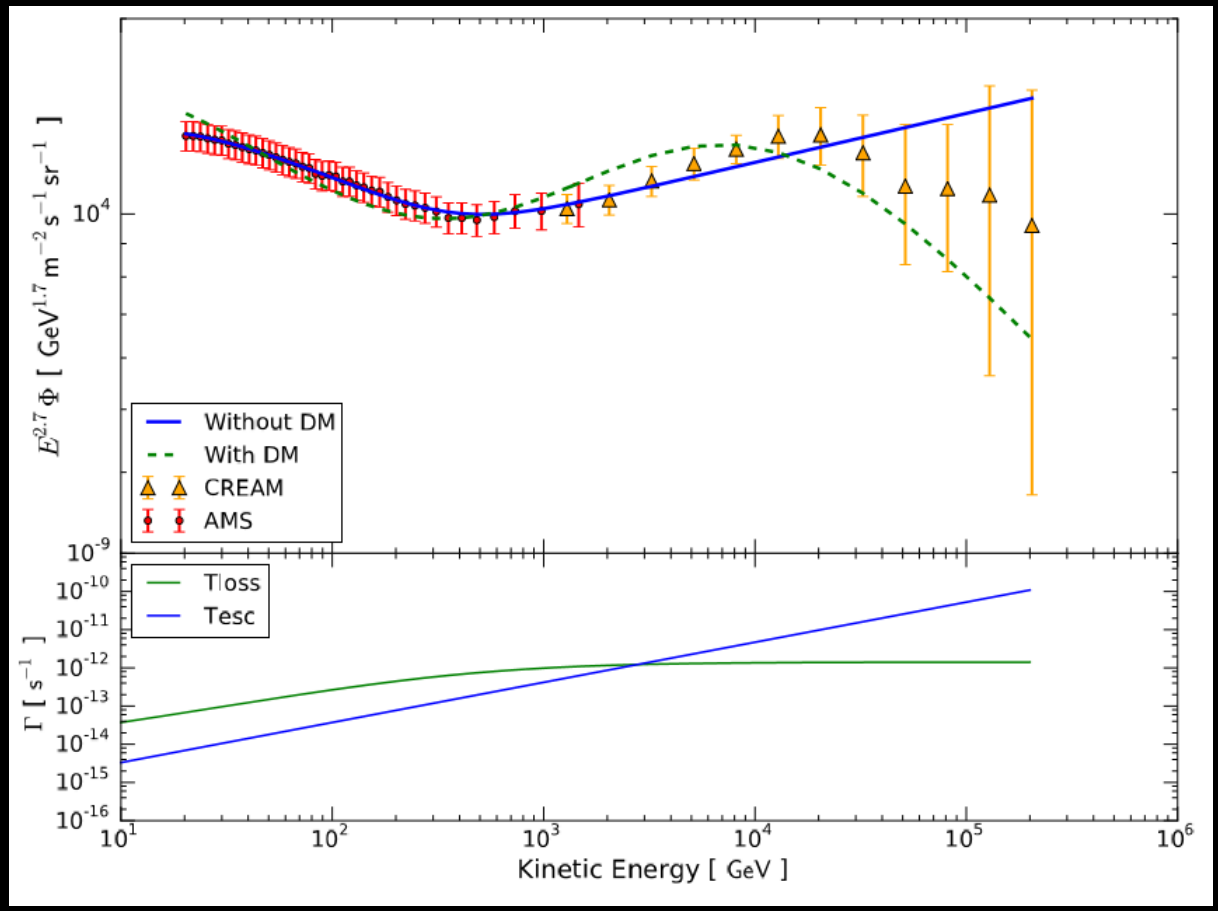


DM-Induced Energy Loss

- Mx = 1e-3 GeV
- σ = 1e-24.5 cm^2

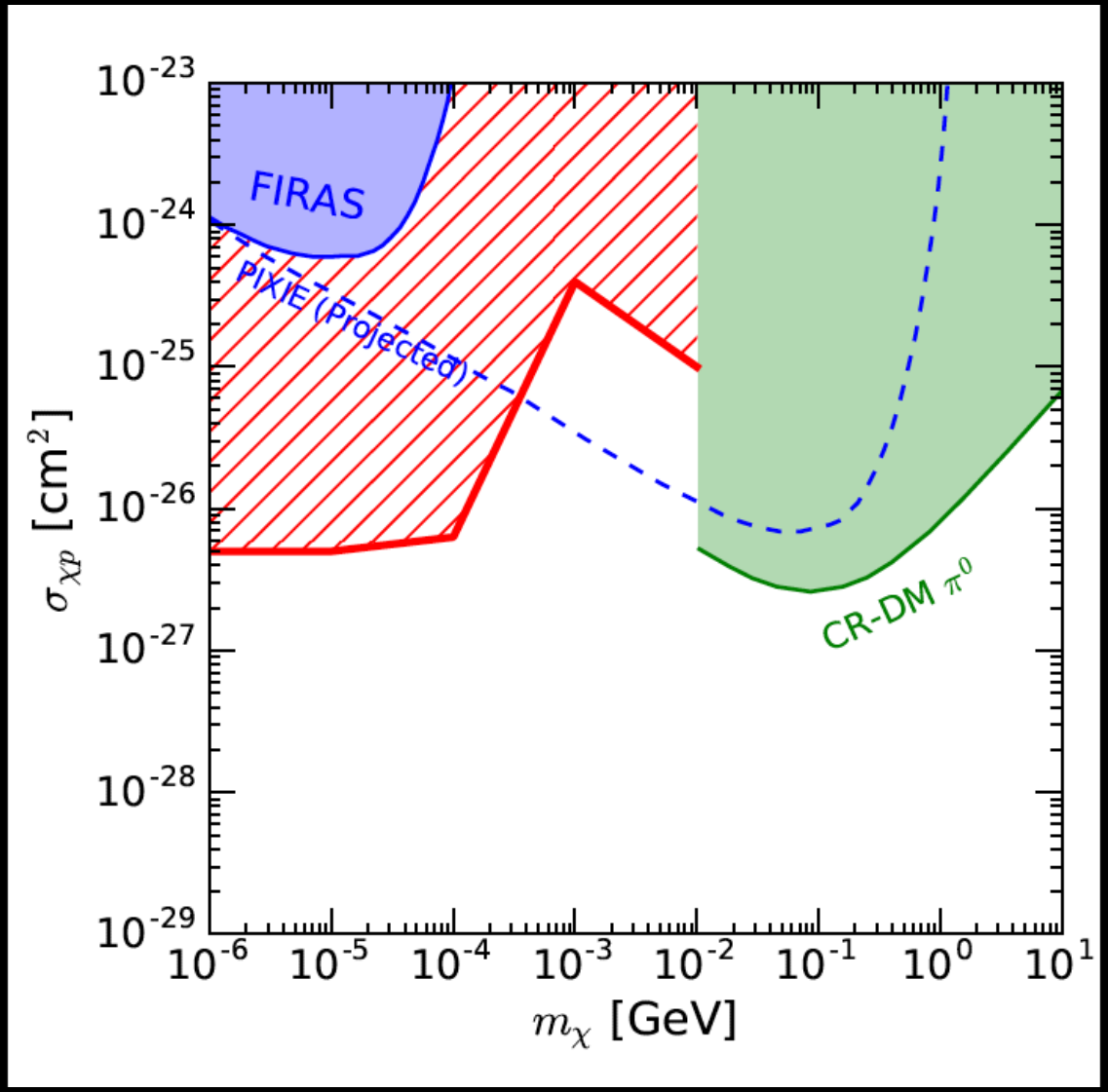
- Fix:
  - Break energy

- Vary:
  - Injection indices
  - Injection Normalization
  - Escape Time Index



Final Constraint

- Fix:
  - Break energy
- Vary:
  - Injection indices
  - Injection Normalization
  - Escape Time Index



Summary

- CR-DM scattering -> Spectral Distortion
- New Probe of Dark Matter
  - Most sensitive to sub-GeV Dark Matter
  - Uses available CR data
- More to come!

Thank You!