Heating of Neutron Stars With Inelastic Dark Matter

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Work With :
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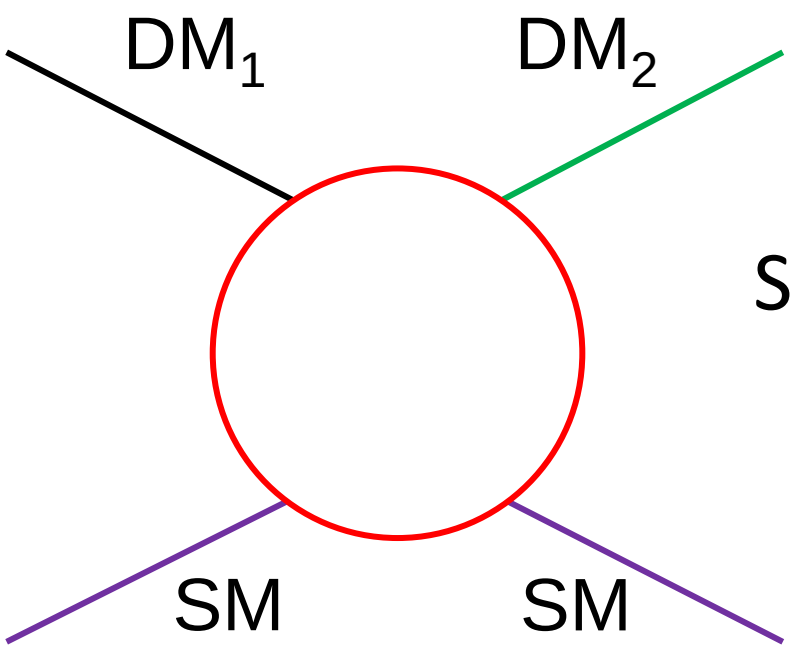
Inelastic Dark Matter



Initially proposed to explain DAMA anomaly

Tucker-Smith, Weiner Phys. Rev. D64 (2001) 043502

Small velocity ⇨ Kinematically suppressed

DM can escape terrestrial direct detection

$$\delta = \frac{\Delta m}{m_1}$$

Vector Portal

Broken $U(1)_D$ ⇨ Massive dark photon

$$-\mathcal{L} \supset m_d \theta \xi + \frac{\Delta_\theta}{2}\theta^2 + \frac{\Delta_\xi}{2}\xi^2$$

Broken $U(1)_D$ ⇨ Majorana mass terms

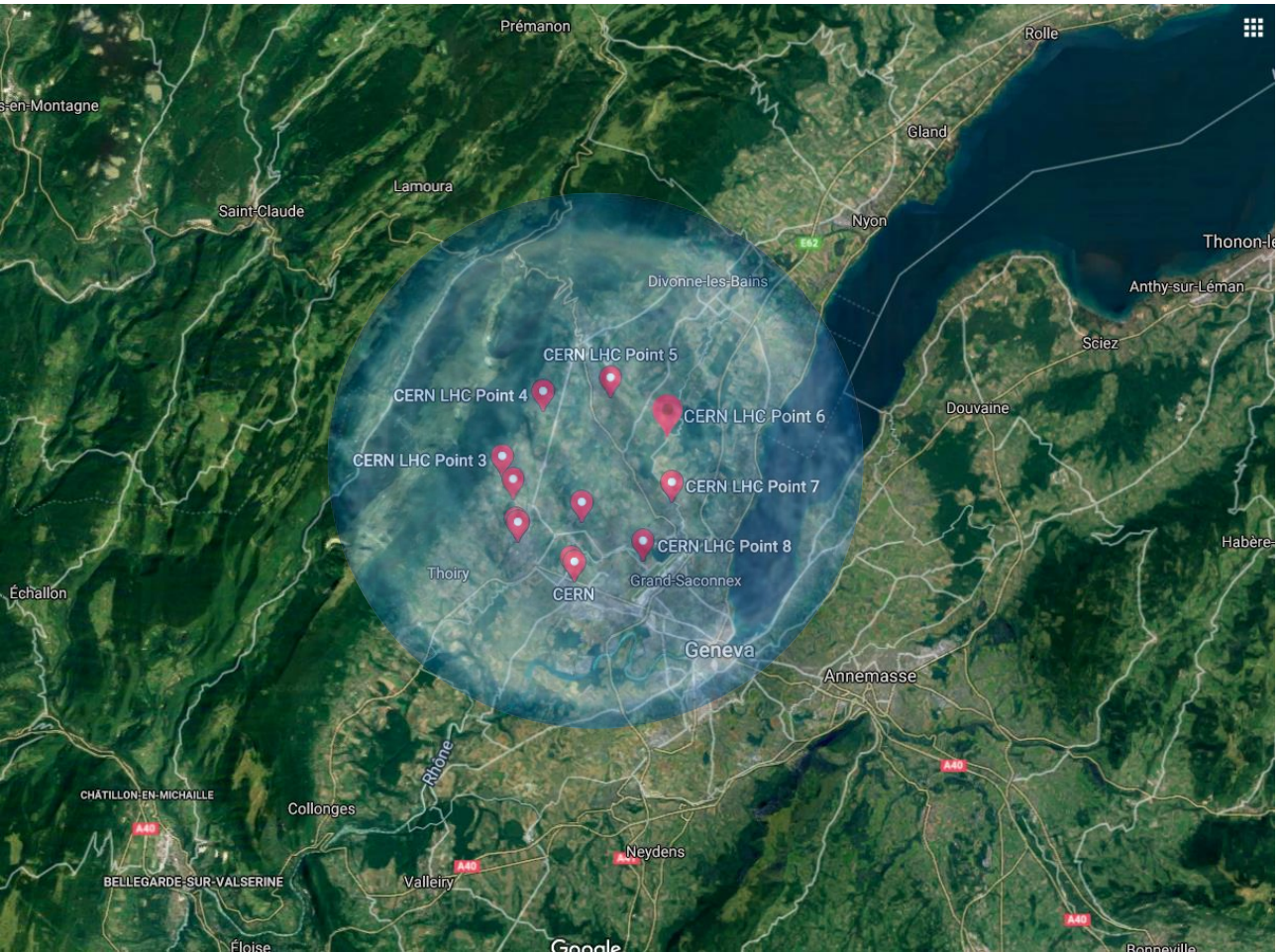
Mass Gap $\sim \Delta_\theta + \Delta_\xi$

$$\mathcal{L} \supset g_D A'_\mu \bar{\chi_1} \gamma^\mu \chi_2 + e\epsilon A'_\mu J^\mu_{\mathrm{EM}}$$

Only off diagonal couplings to the mediator

Neutron Stars

Neutron star : Dense, strong gravity



Typical Neutron star :

$$M_\star \sim 1.5\, M_\odot$$

$$R_\star \sim 10\,\mathrm{km}$$

Accelerates DM to high velocities

- Overcomes velocity suppression
- Can help to increase energy deposition

NS Kinetic Heating

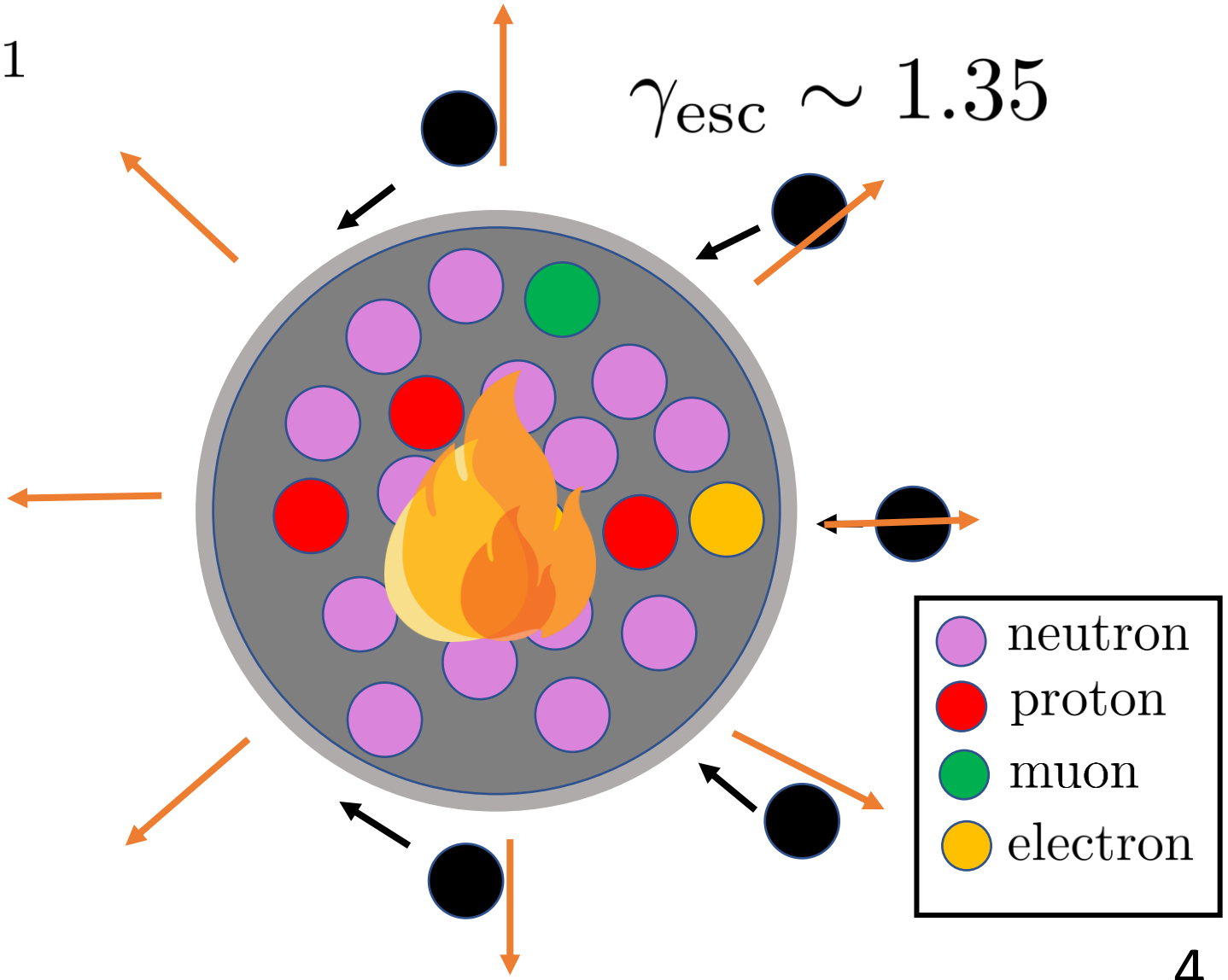
$$\dot{E} = f \times (\gamma - 1) \times 25\,\mathrm{g}\,s^{-1}$$

$$\gamma_{\mathrm{esc}} \sim 1.35$$

Stephan-Boltzmann Law

$$\dot{E} = 4\pi R_\star^2 \sigma_{\mathrm{SB}} T^4$$

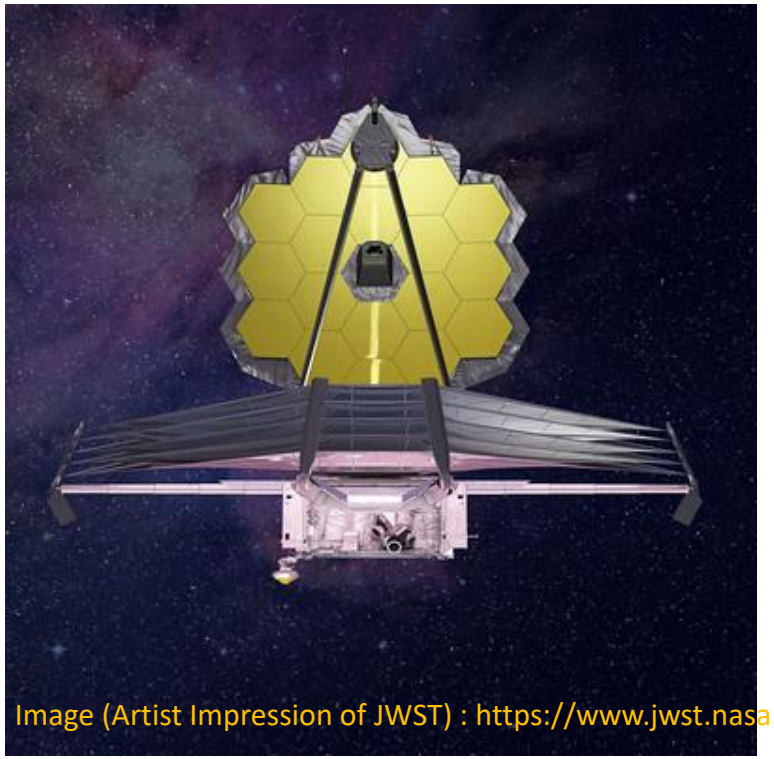
$$T \sim 1600 f^{1/4}\, K$$



How to Detect Heated NS?

FAST

New generation of radio telescopes can see an old neutron star with expected temperatures of O(10-100) K without DM



JWST

Upcoming infrared telescopes like JWST, TMT, ELT can see if it is heated to O(1000) K

Baryakhter, Bramante, Li, Linden, Raj 1704.01577 *Phys.Rev.Lett.* 119 (2017) 13, 131801

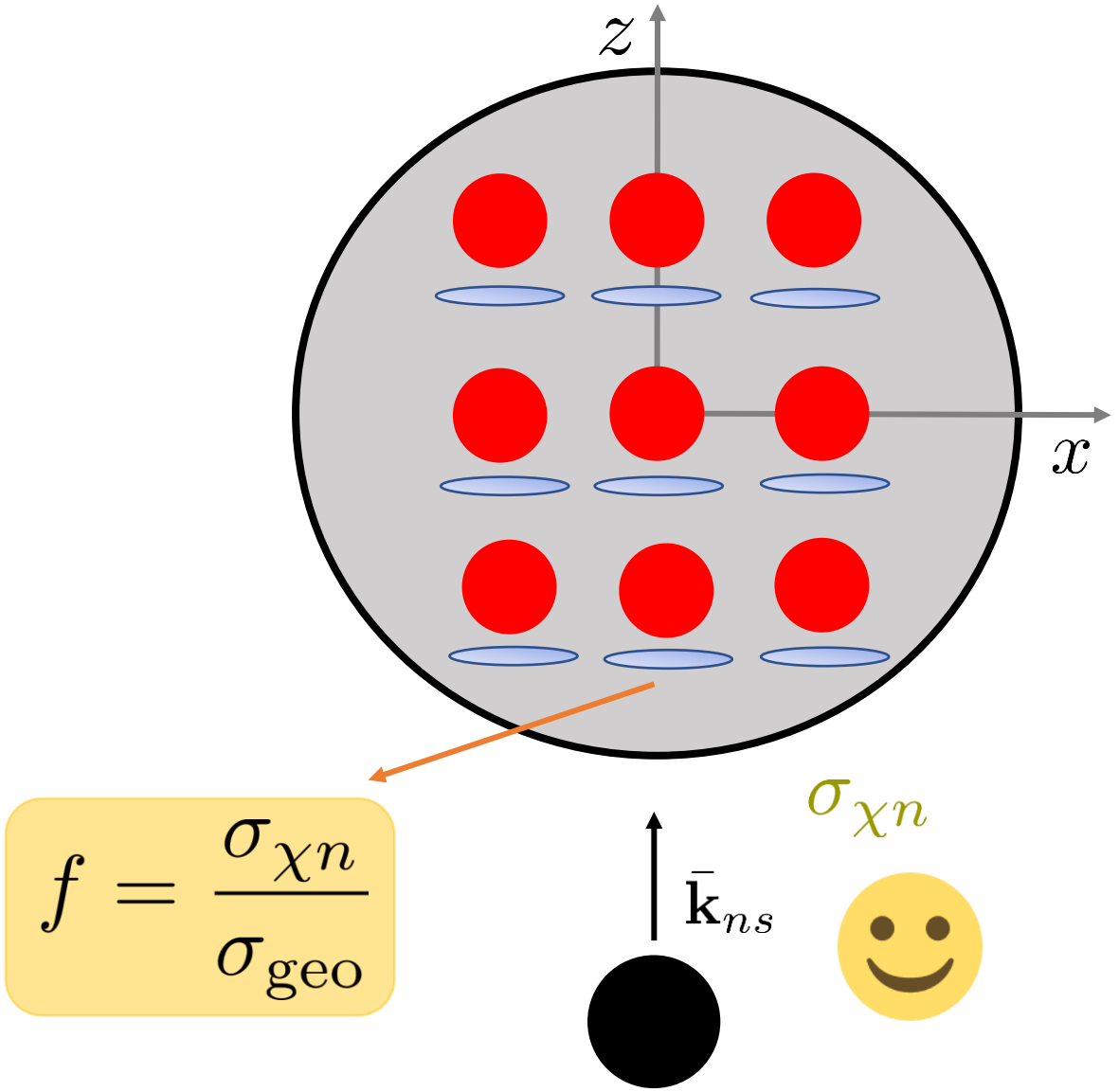
How Efficient is the Capture?

$$T \sim 1600\, f^{1/4}\, \mathrm{K}$$

For non relativistic targets

$$\sigma_{\rm geo} = \frac{\text{Cross section of star}}{\text{Number of targets}}$$

$$\approx \frac{\pi R_\star^2 m_n}{M_\star}$$



$$f = \frac{\sigma_{\chi n}}{\sigma_{\rm geo}}$$

Baryakhter, Bramante, Li, Linden, Raj P*hys.Rev.Lett.* 119 (2017) 13, 131801

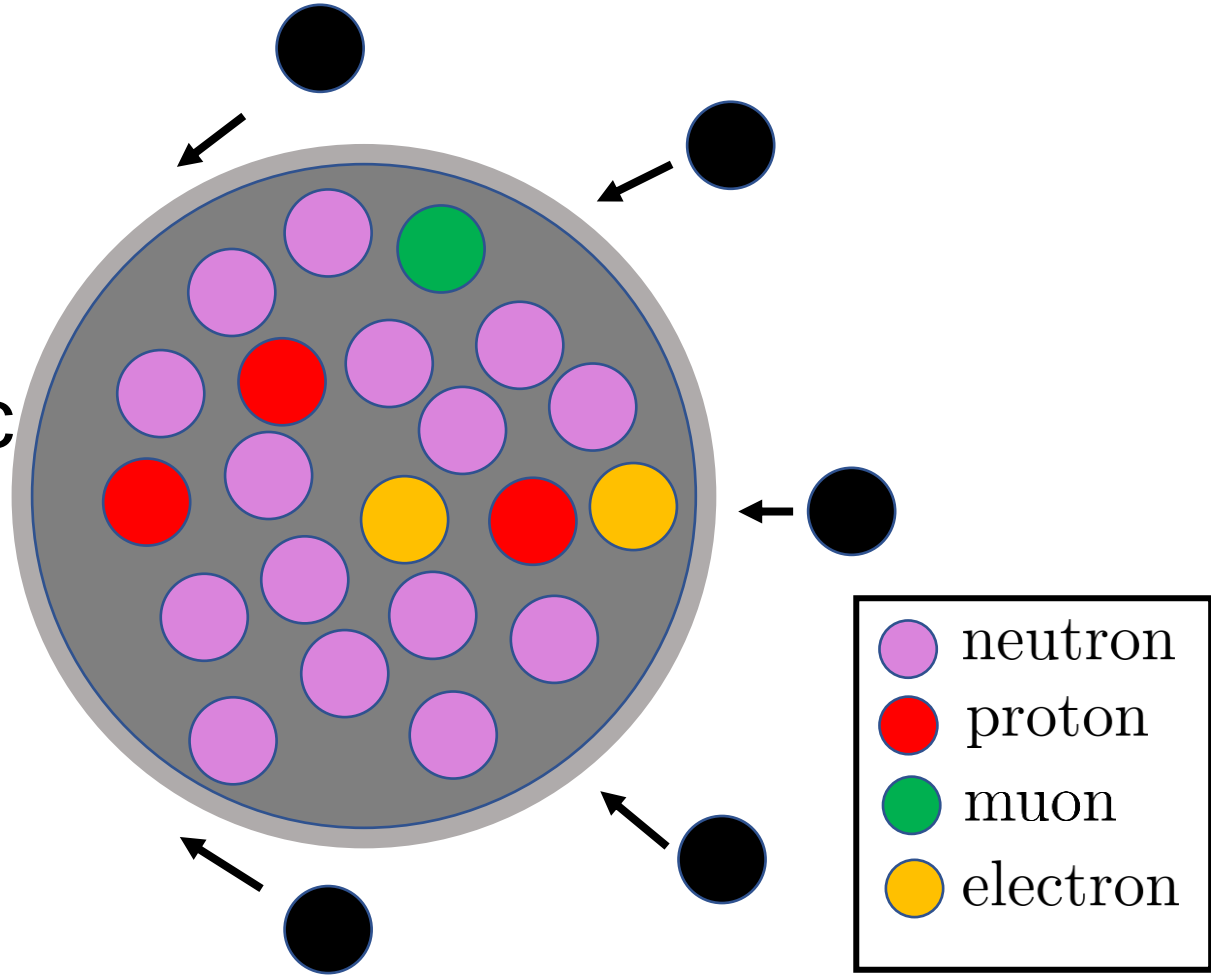
Raj, Tanedo, Yu *Phys.Rev.D* 97 (2018) 4, 043006

Electrons in Neutron Stars

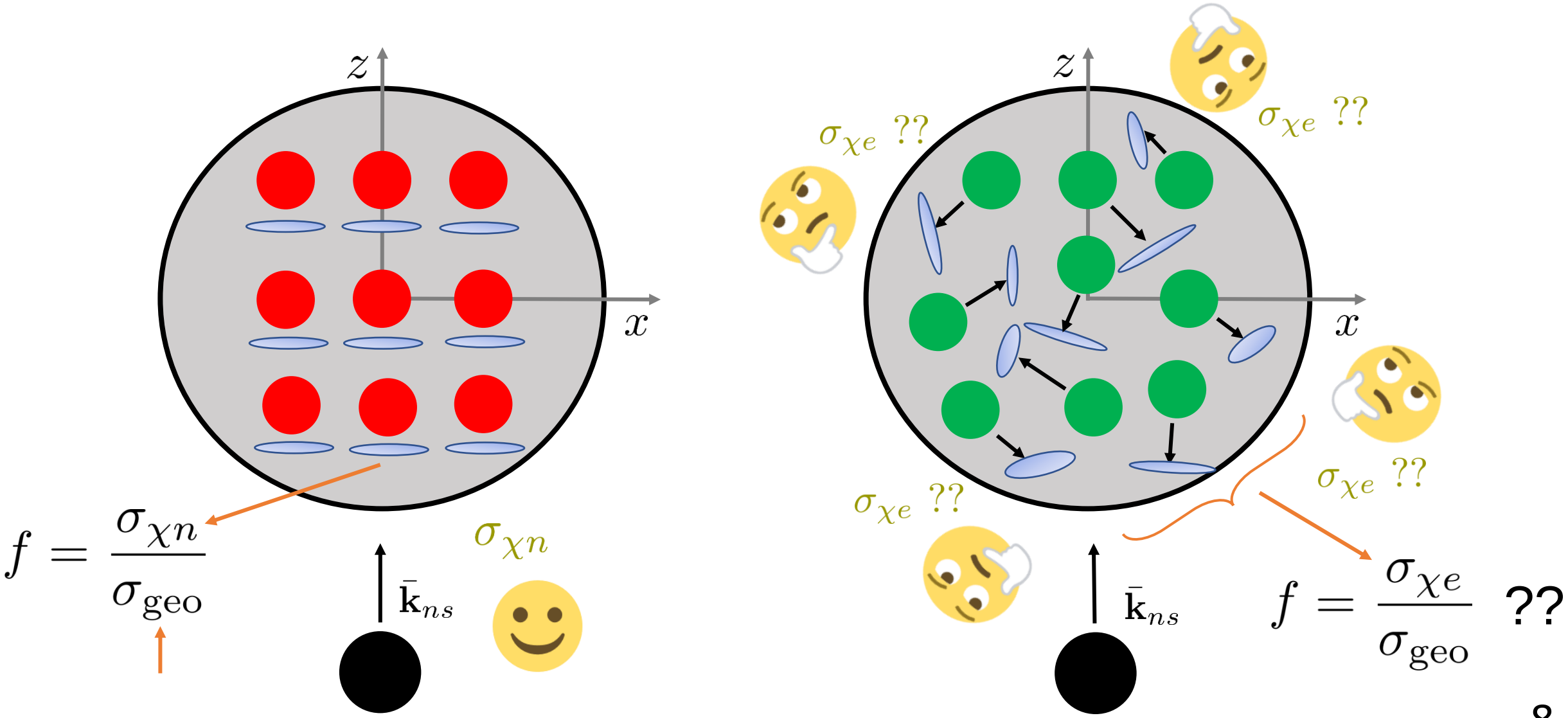
~ 5-10% leptons by number

Leptophilic DM detection

Beta equilibrium ⇨ Ultra-relativistic
Fermi energy ~ 150 MeV



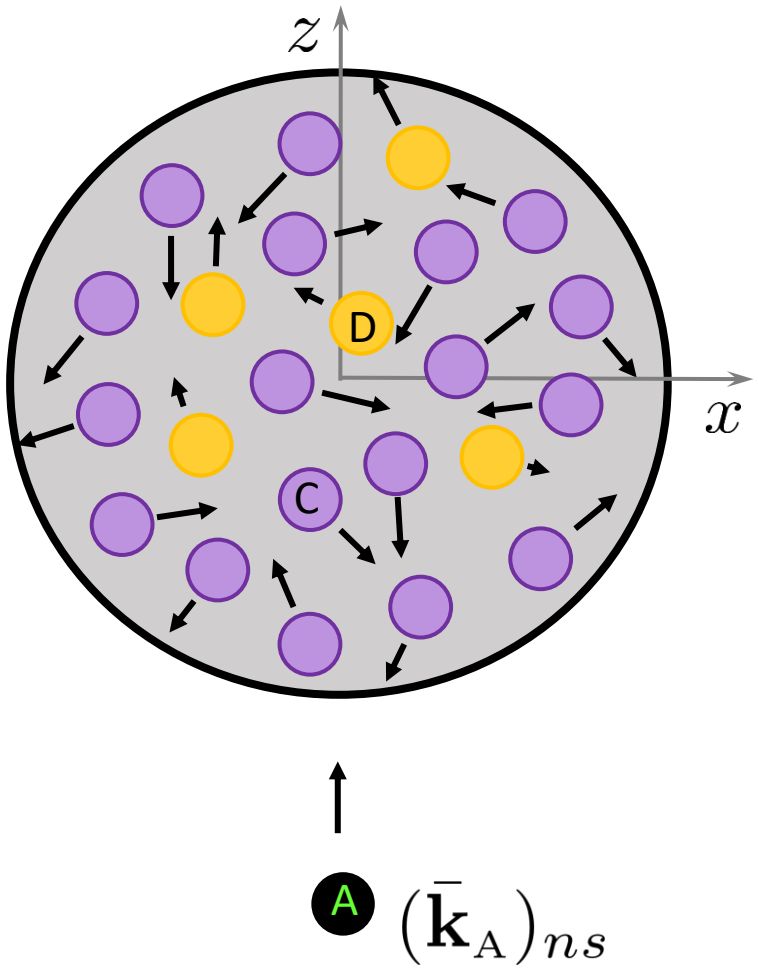
Relativistic Capture Efficiency



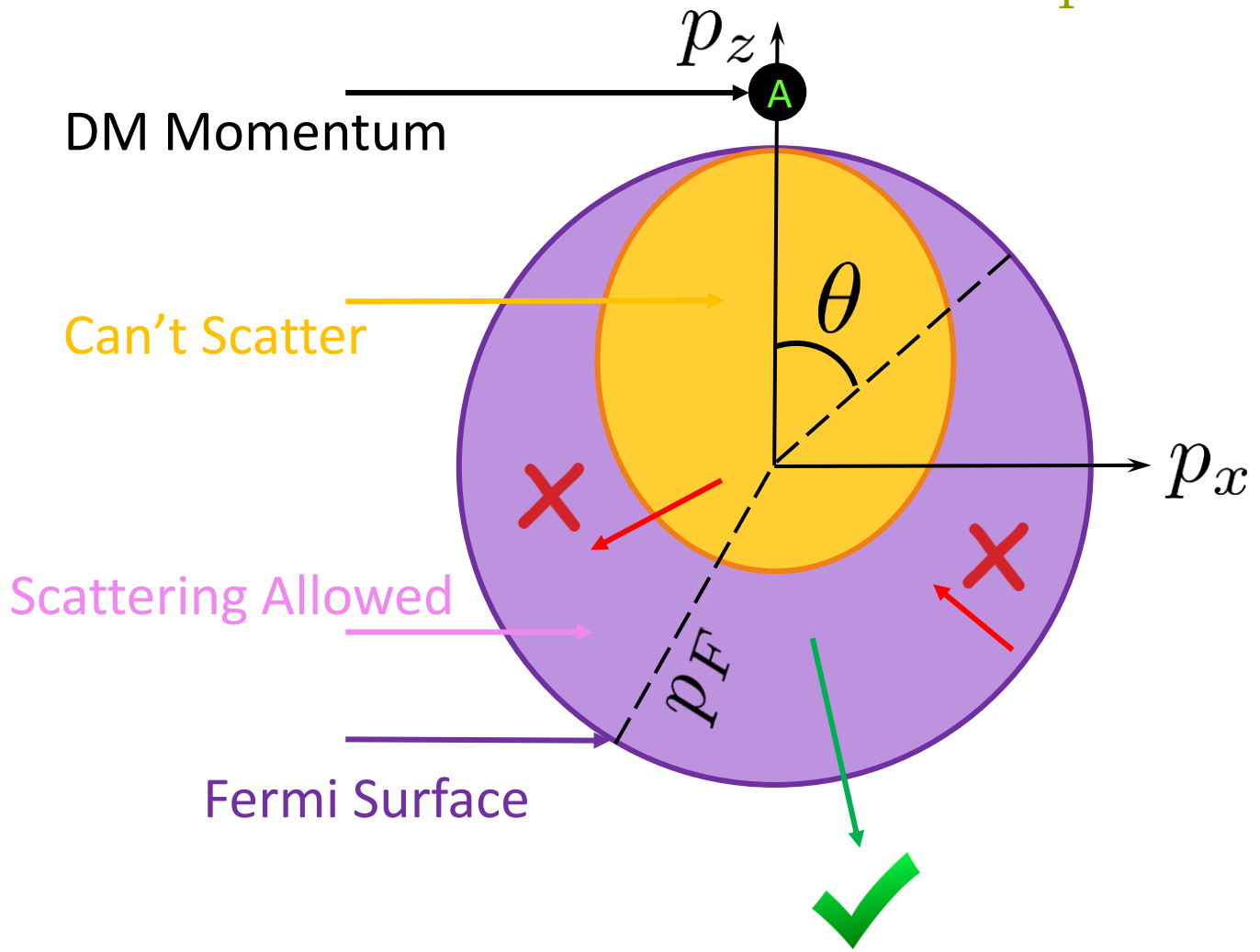
AJ, Raj, Tanedo, Yu *Phys.Lett.* B (2020) 135767, **AJ**, Raj, Tanedo, Yu *Phys.Rev.D* 102 (2020) 12, 123002

Pauli Blocking

NS Frame: Position Space



NS Frame: Momentum Space



AJ, Raj, Tanedo, Yu *Phys.Lett.* B (2020) 135767, **AJ**, Raj, Tanedo, Yu *Phys.Rev.D* 102 (2020) 12, 123002

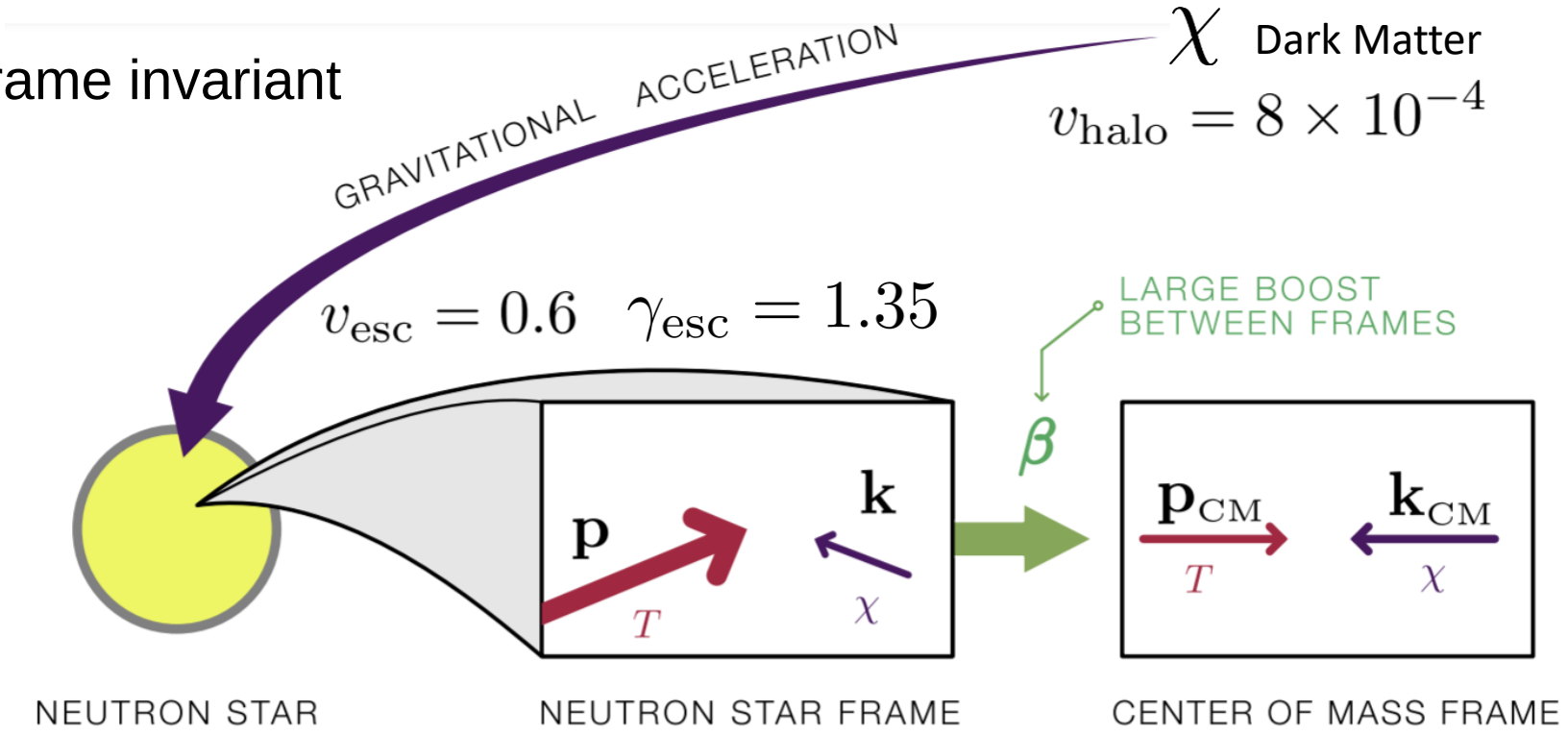
Frames, Moving Parts

Target mom distribution : NS frame

Total KE deposited : NS frame

f needs to be frame invariant

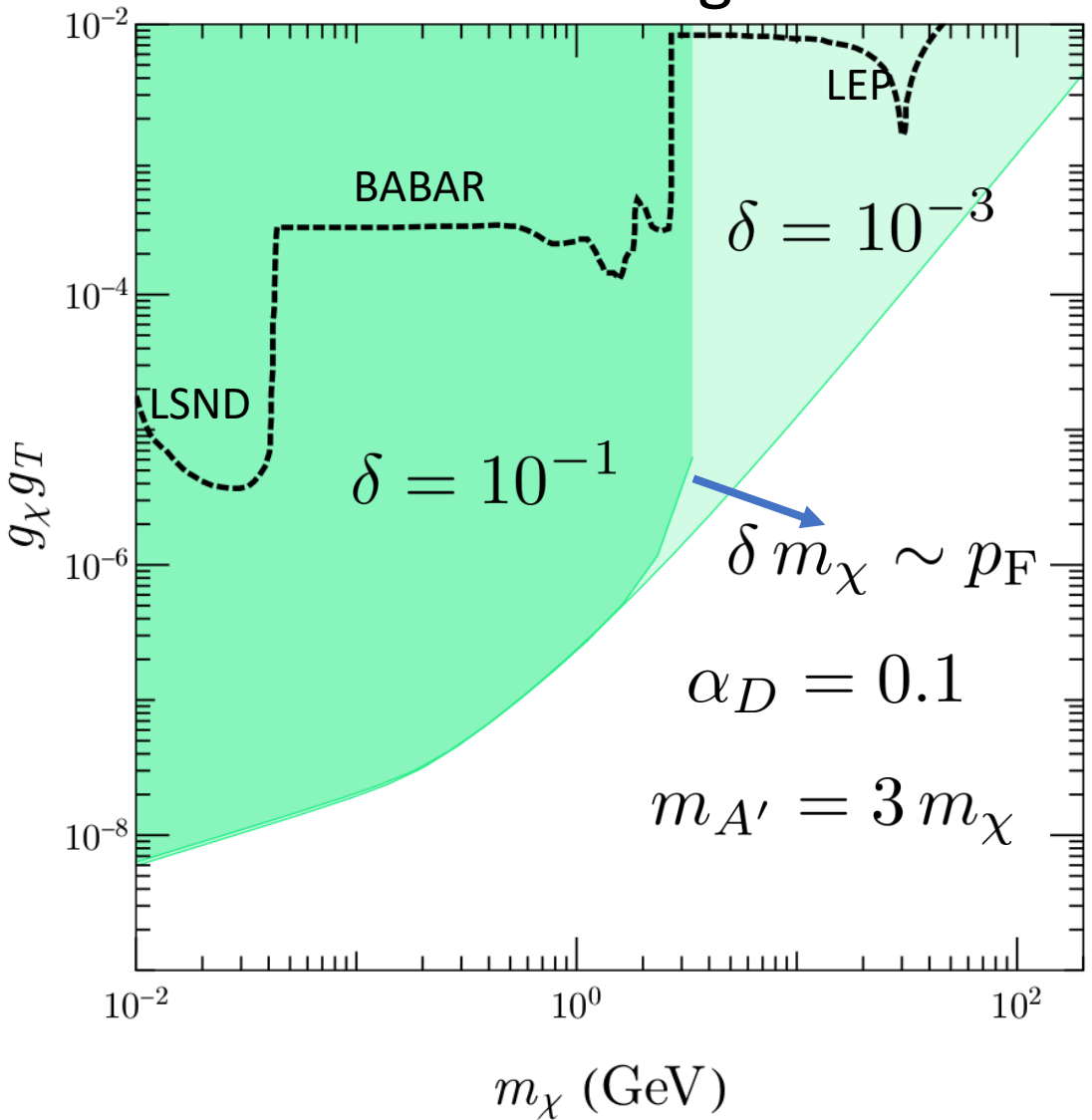
Differential cross section and scattering angles : CM frame



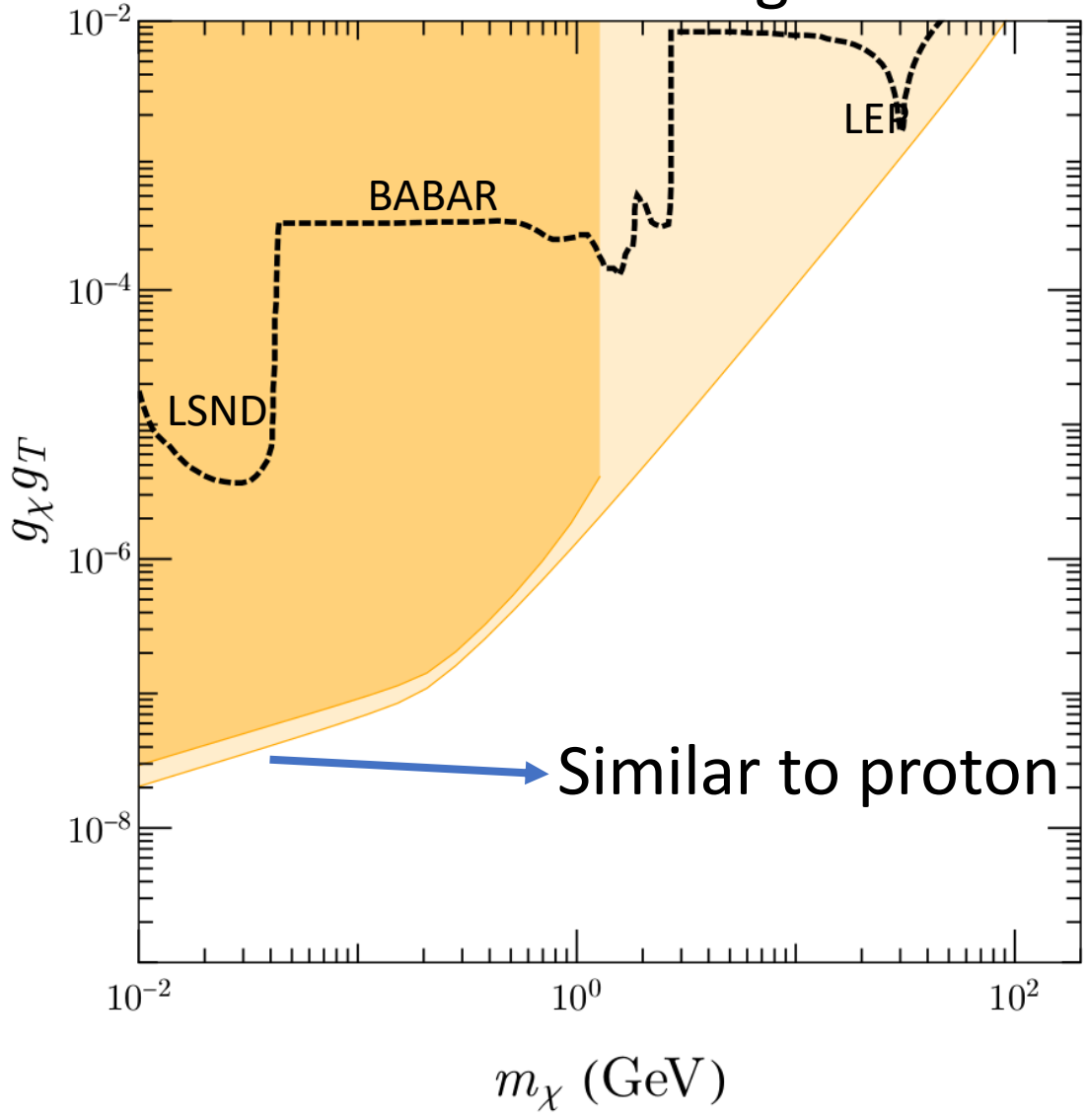
AJ, Raj, Tanedo, Yu *Phys.Lett.* B (2020) 135767, **AJ**, Raj, Tanedo, Yu *Phys.Rev.D* 102 (2020) 12, 123002

Results

Proton Targets

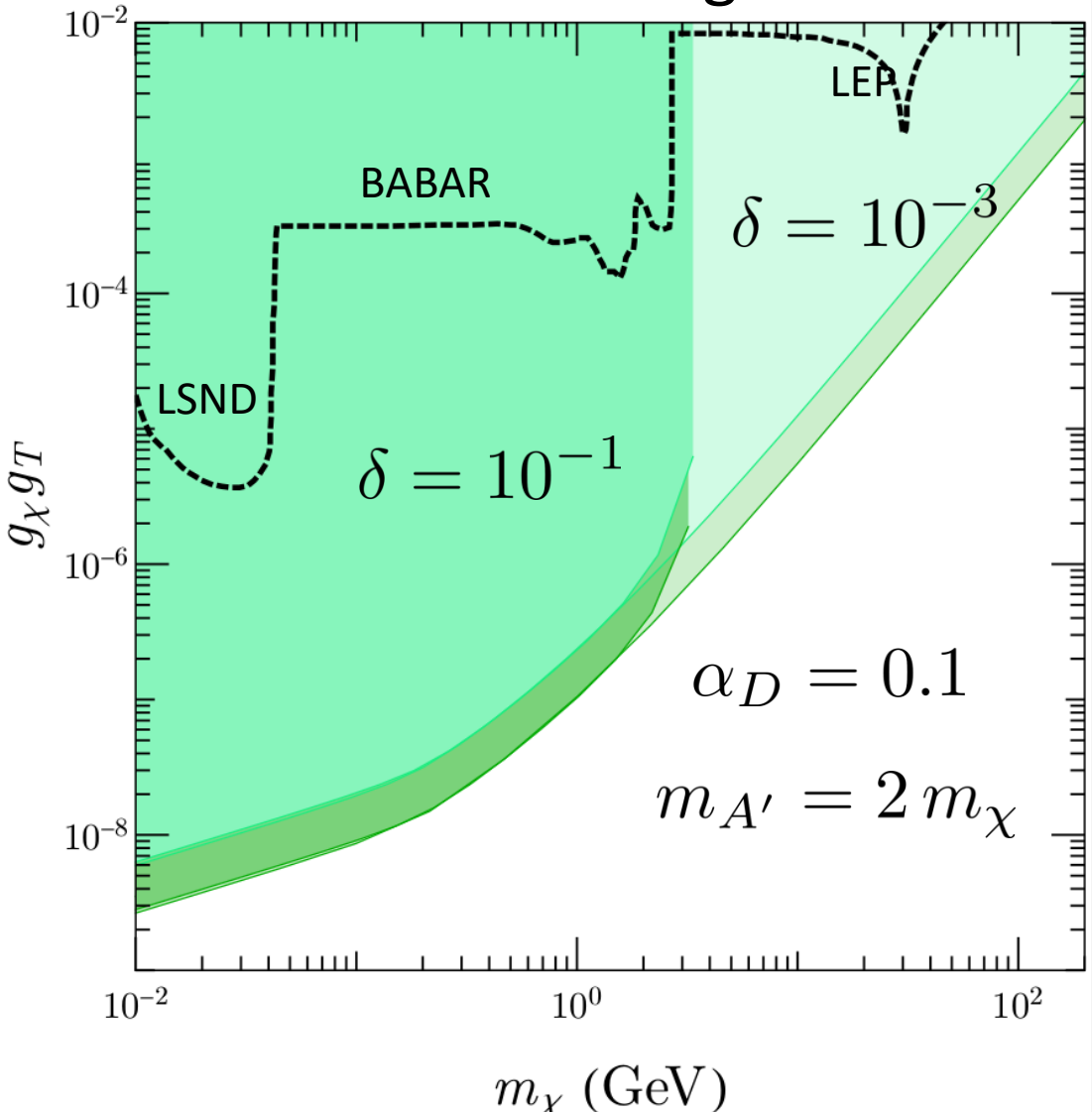


Electron Targets

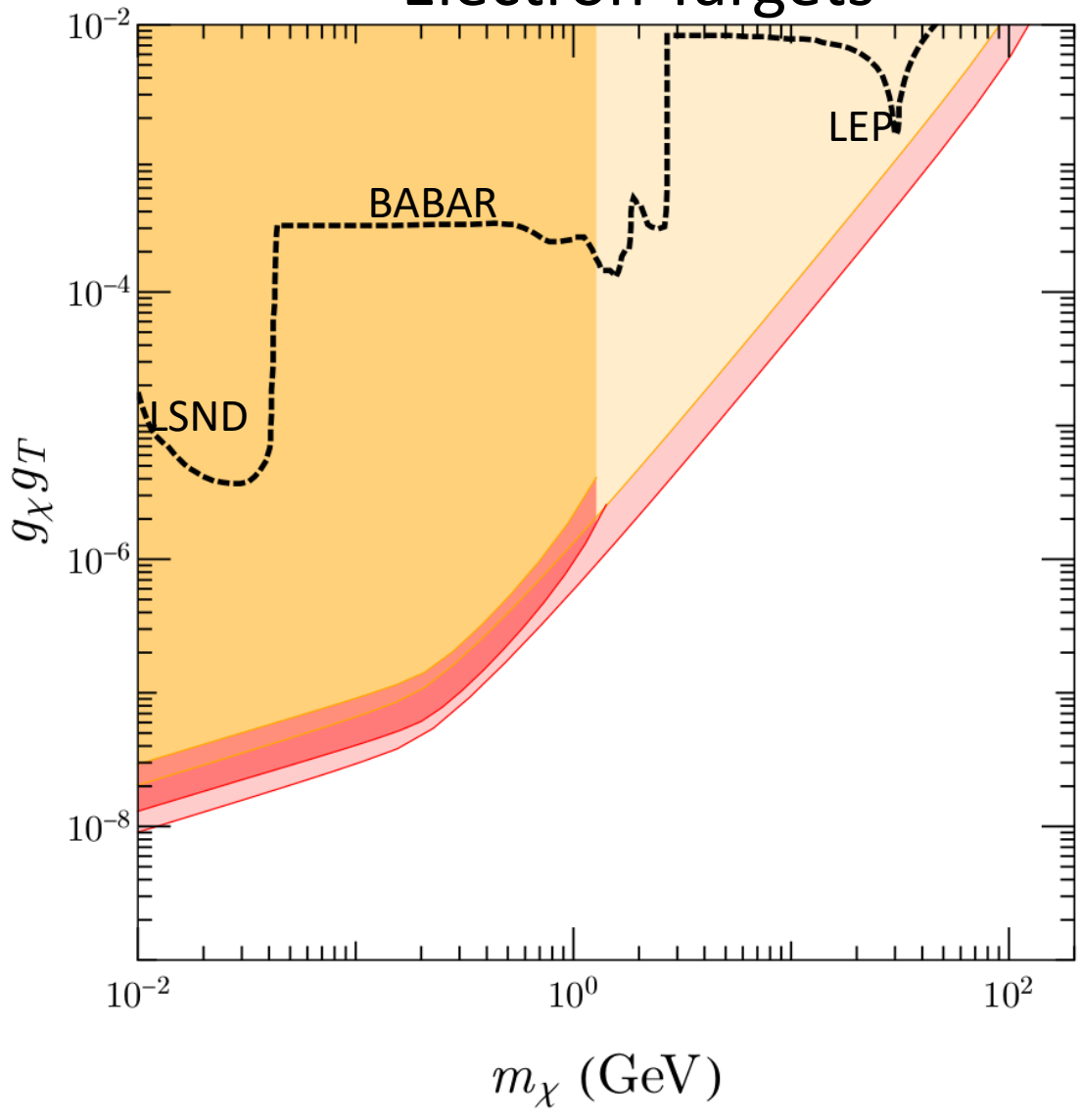


Results

Proton Targets

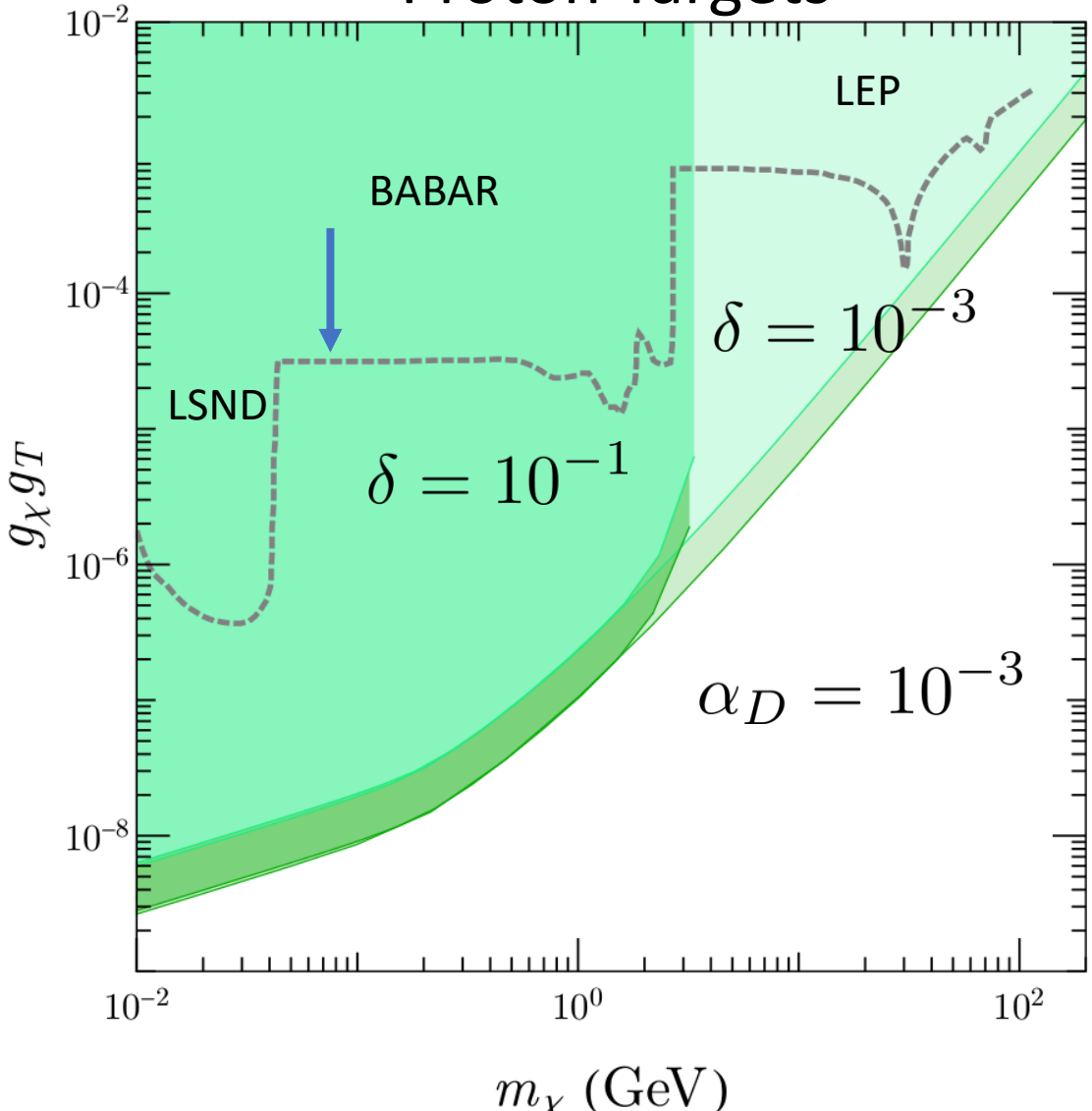


Electron Targets

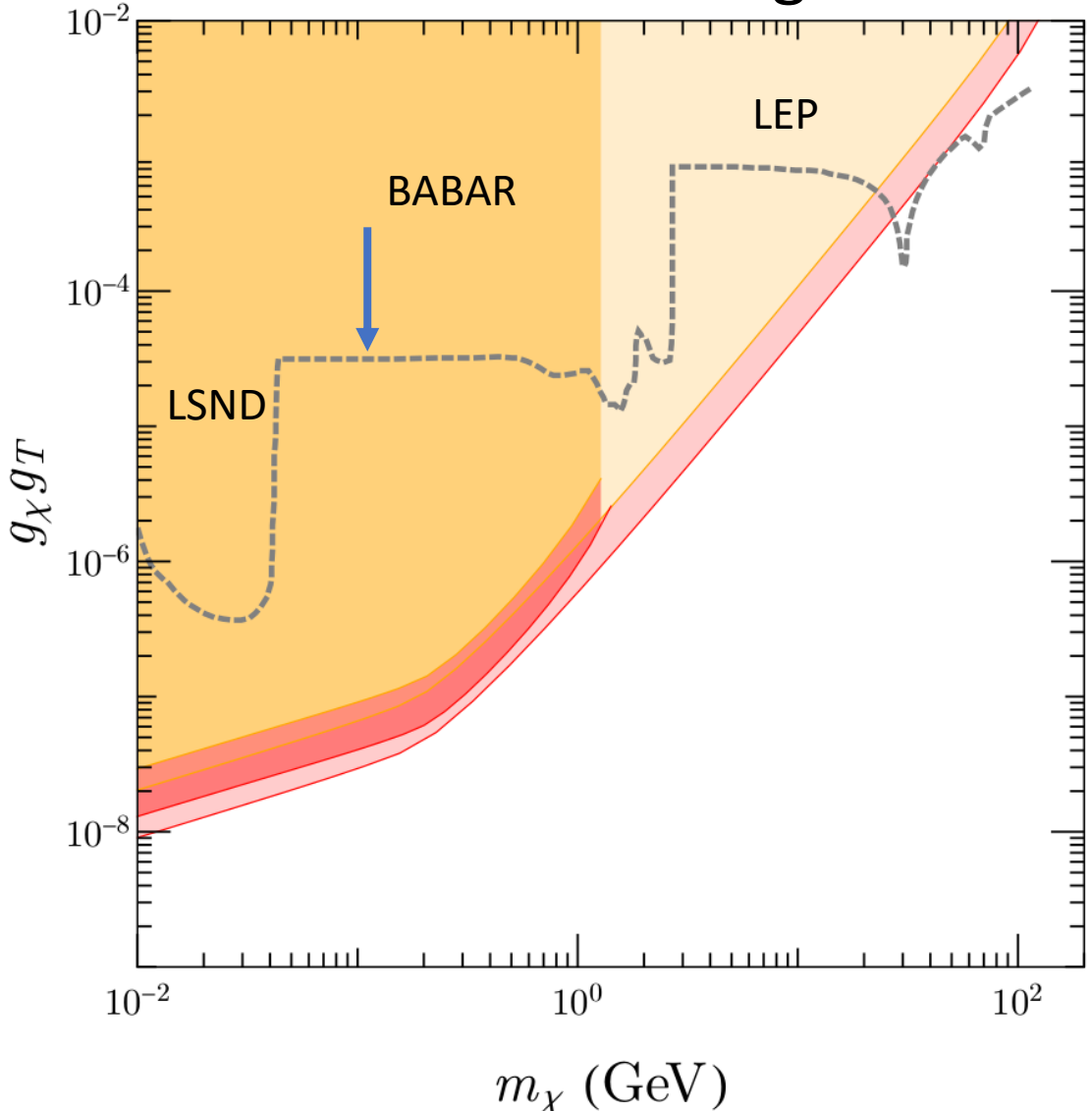


Results

Proton Targets



Electron Targets



Summary

Search for NS kinetic heating can nicely complement existing terrestrial search programs. Advantages in various mass ranges especially could be large

Electrons in NS can be a powerful probe. New relativistic formalism is needed.

Bounds almost as strong as nucleons!

Thank You!