Dark Matter Annihilation Cross-Section Bounds from Fermi Observations of Dwarf Galaxies

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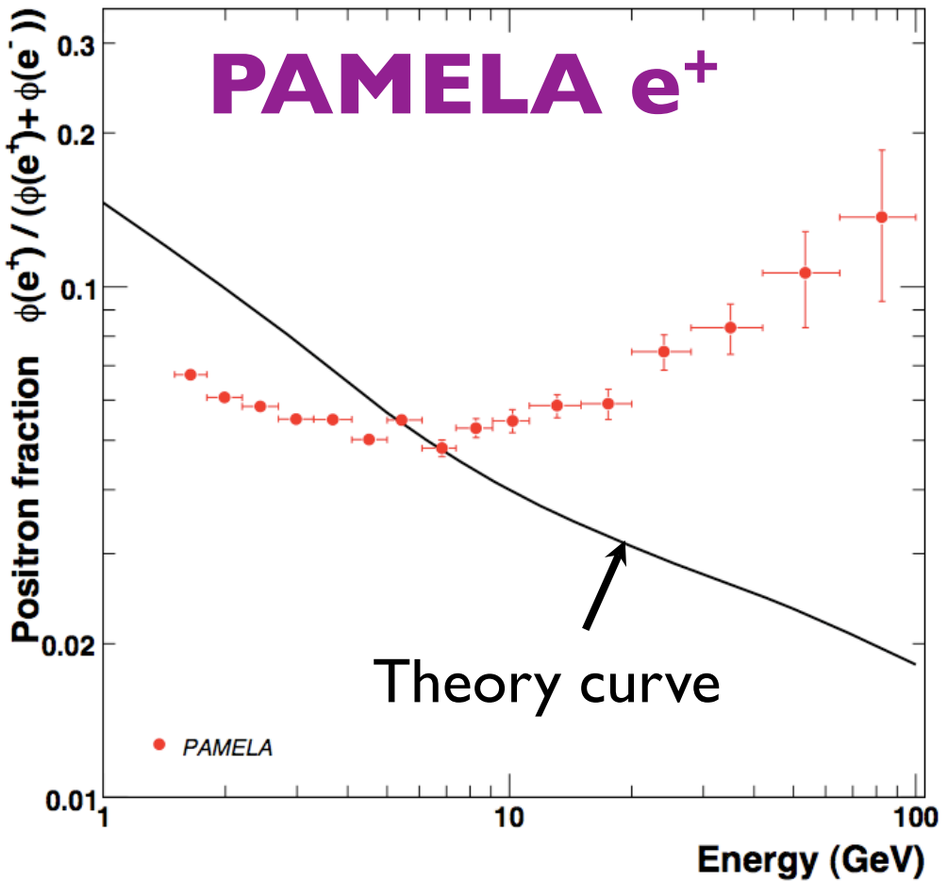
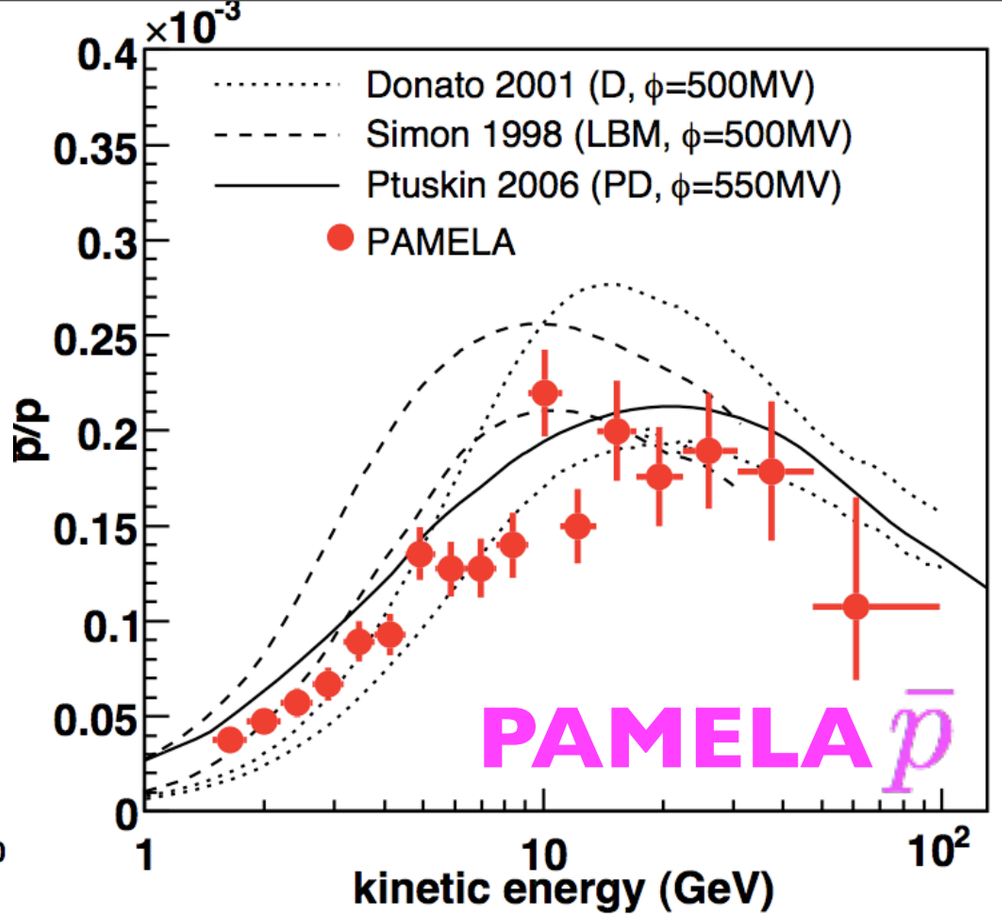
Rouven Essig, NS, Louis Strigari,
arXiv: 0902.4750, PRD 80, 023506 (2009)

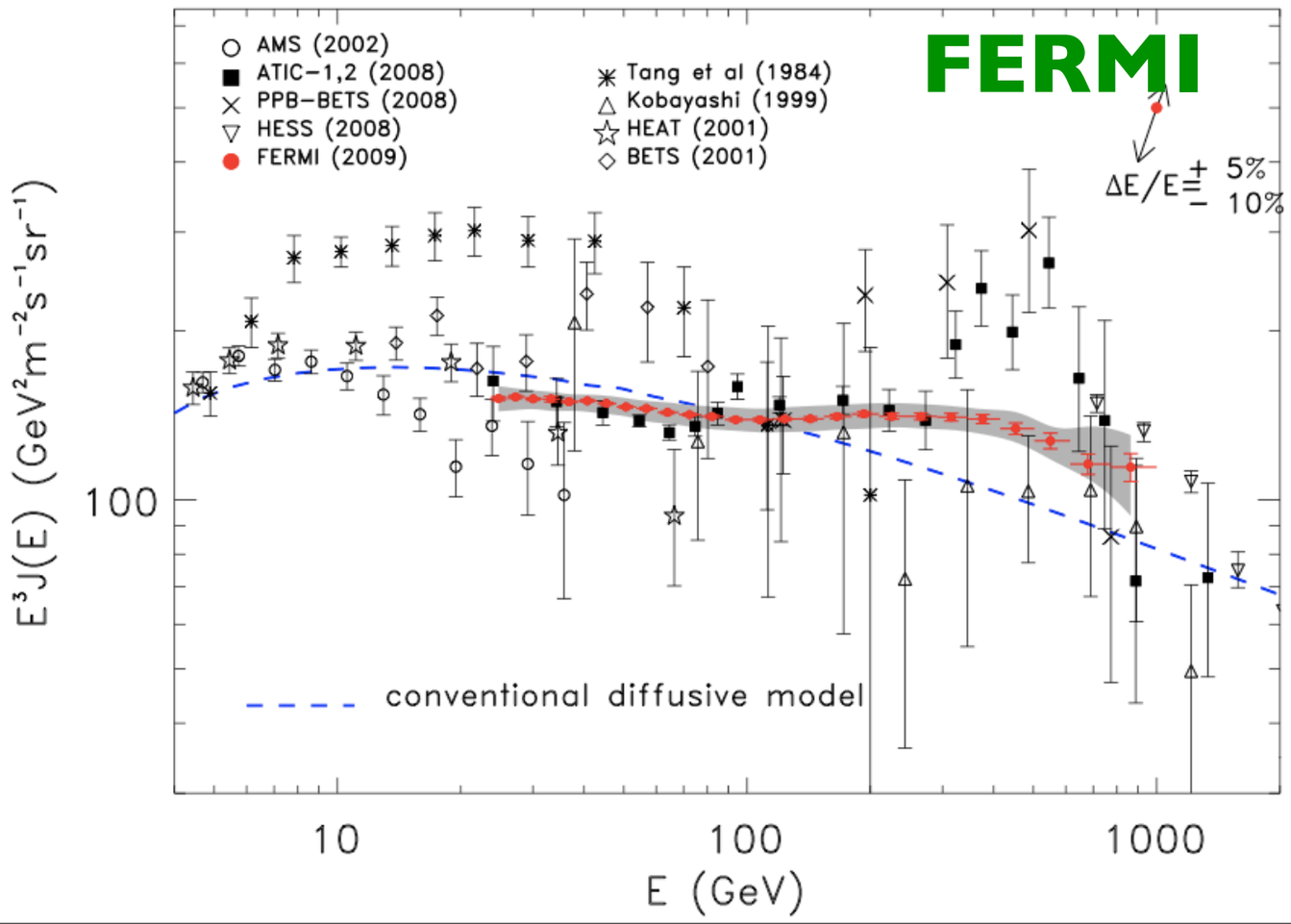
Rouven Essig, NS, Louis Strigari, to appear

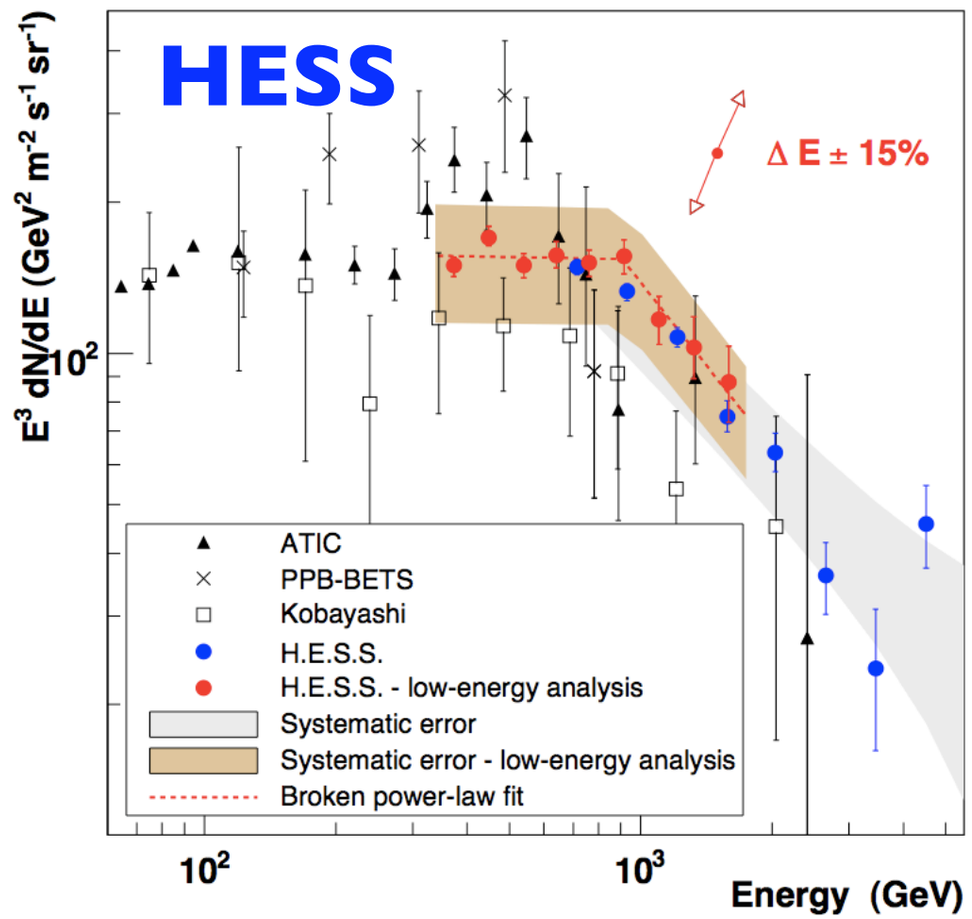




e^+, e^- excess

No $\bar{p}$ excess



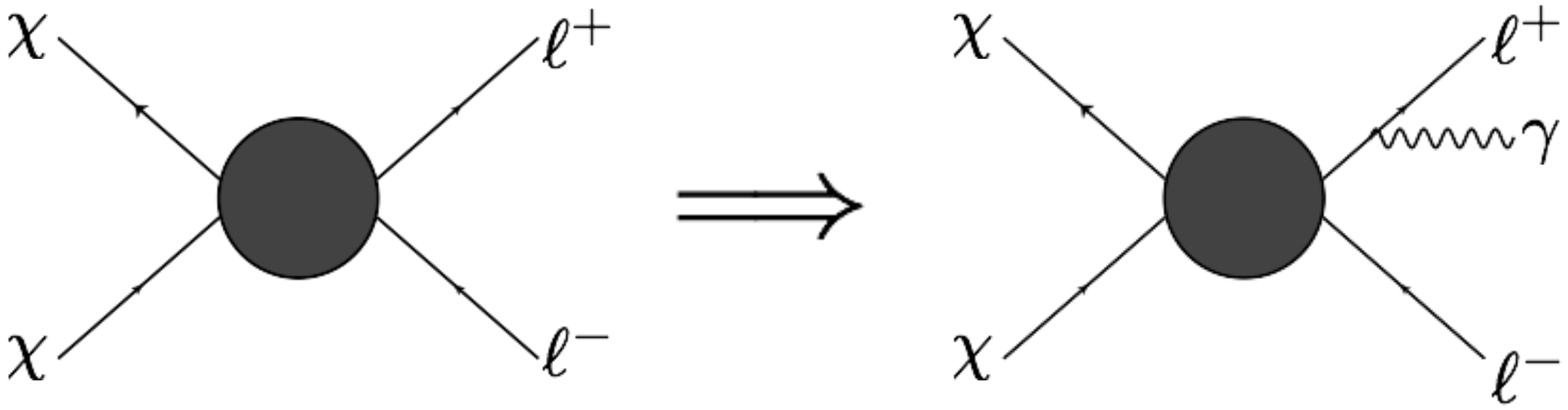


Implications for DM *annihilations*

- DM mass > 1 TeV
- Annihilation only into charged leptons, NOT $\bar{p}$
- Cross-section ~1000 times larger than during thermal freeze-out

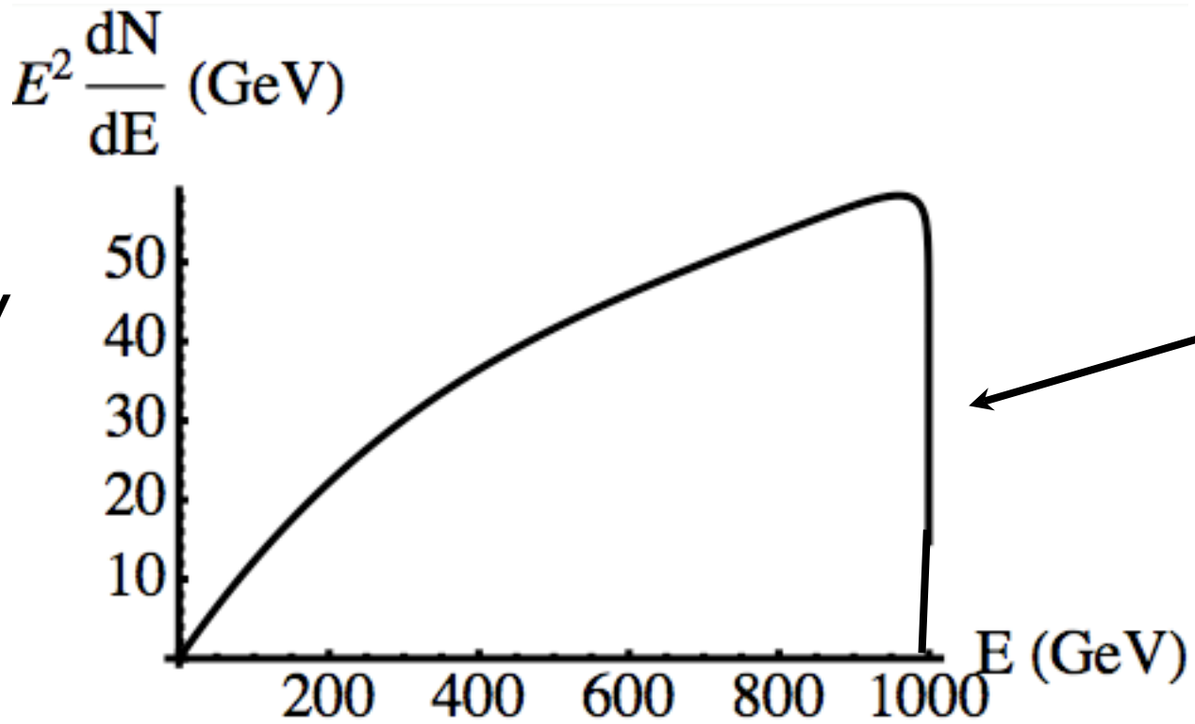
How can we test if anomalies are from DM?

Gamma Rays from Final State Radiation (FSR)



(Birkedal, Matchev, Perelstein, Spray, 2005)

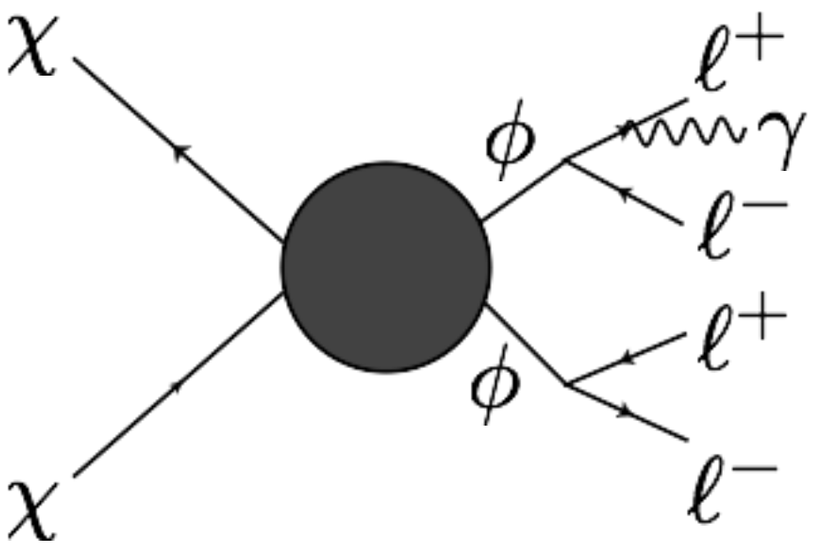
Gamma-ray Energy spectrum



Edge at DM mass

$m_\chi = 1\,\mathrm{TeV}$

A compelling scenario: new particle ϕ

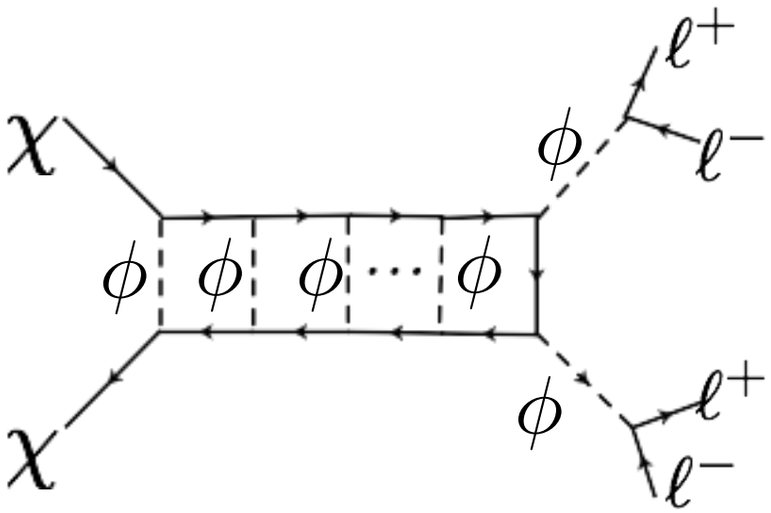


$m_\phi \sim 1$ GeV

- $\bar{p}$ kinematically forbidden
- cross-section large due to Sommerfeld enhancement

(e.g. Arkani-Hamed, Finkbeiner, Slatyer, Weiner)

Sommerfeld enhancement:



$$\sigma v \propto \frac{1}{v} \Longrightarrow$$

Cross-section:
large today
small at freeze-out

Dwarf galaxies: Excellent Targets

Large Signal

- relatively nearby (~20 kpc to a few 100 kpc)
- DM dominated: high mass-to-light ratio (M/L~100-1000)
- velocity dispersion ~10-30 lower than Milky Way halo

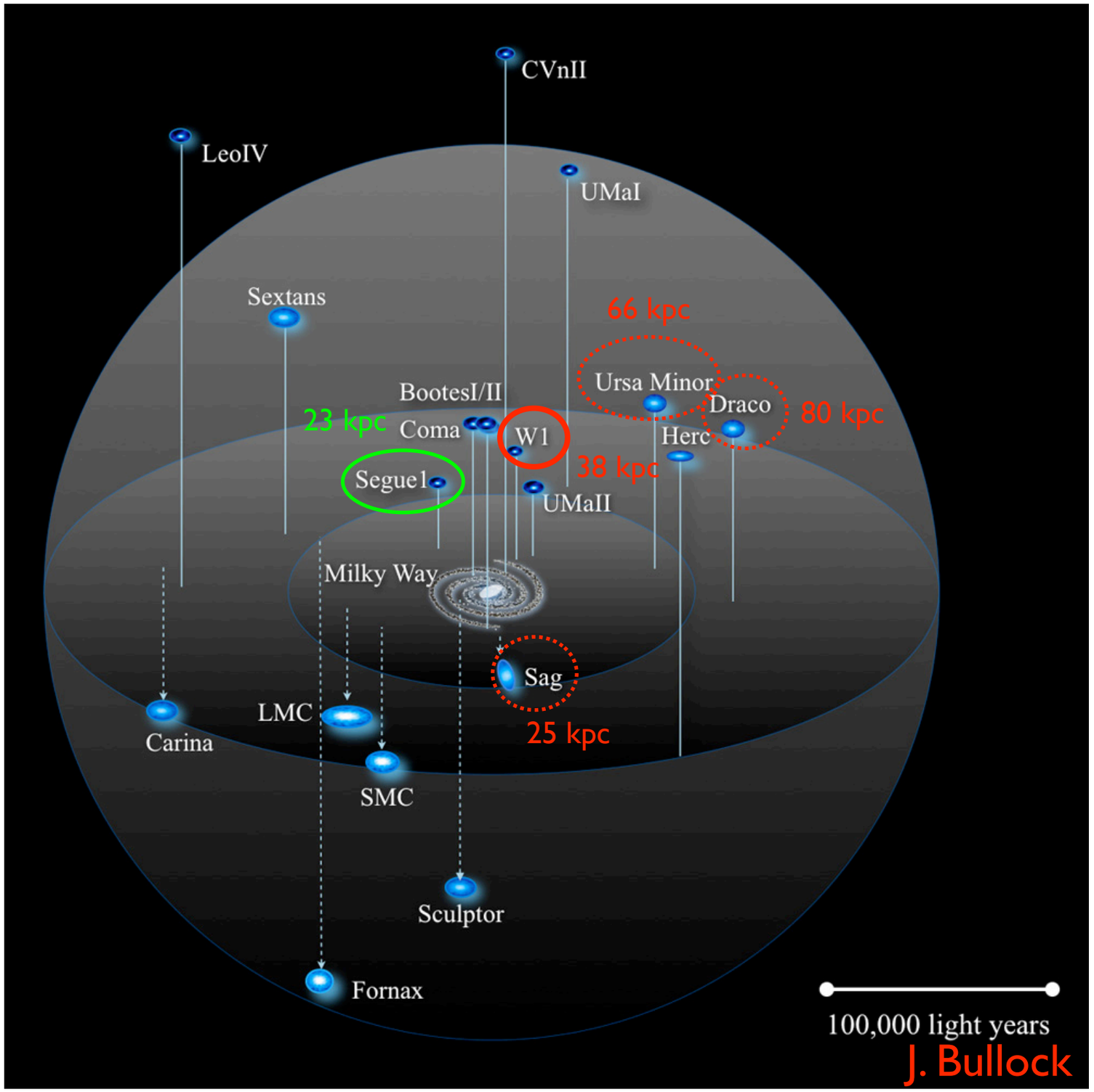
$\Longrightarrow$ additional Sommerfeld enhancement can give

~10-30 times larger annihilation cross-section!

Low Background

- high galactic latitude
- small magnetic fields and little gas
- use stellar kinematics to determine dark matter distribution better than galactic center

Focus on these Dwarf Galaxies:



Solid red: Willman 1
strongest ACT constraints on DM annihilation

Dashed red:
weaker ACT constraints than from Willman 1

Green: Segue 1
- recently discovered
- very nearby
- Excellent prospects for Fermi & ACTs

Gamma-ray flux = (Astrophysics) x (Particle Physics)

$\int \rho^2$

$\langle \sigma v \rangle, \frac{dN_\gamma}{dE_\gamma}, m_\chi$

stellar line-of-sight velocities
constrain integrals rather well

DWARF	$\int \rho^2$
Draco	$10^{18.63 \pm 0.73}$
Willman 1	$10^{19.55 \pm 1.19}$
Segue 1	$10^{19.88 \pm 0.82}$
Galactic center (Einasto)	$10^{20.84}$

Error bars are 2σ

Data from: Willman et al., to appear

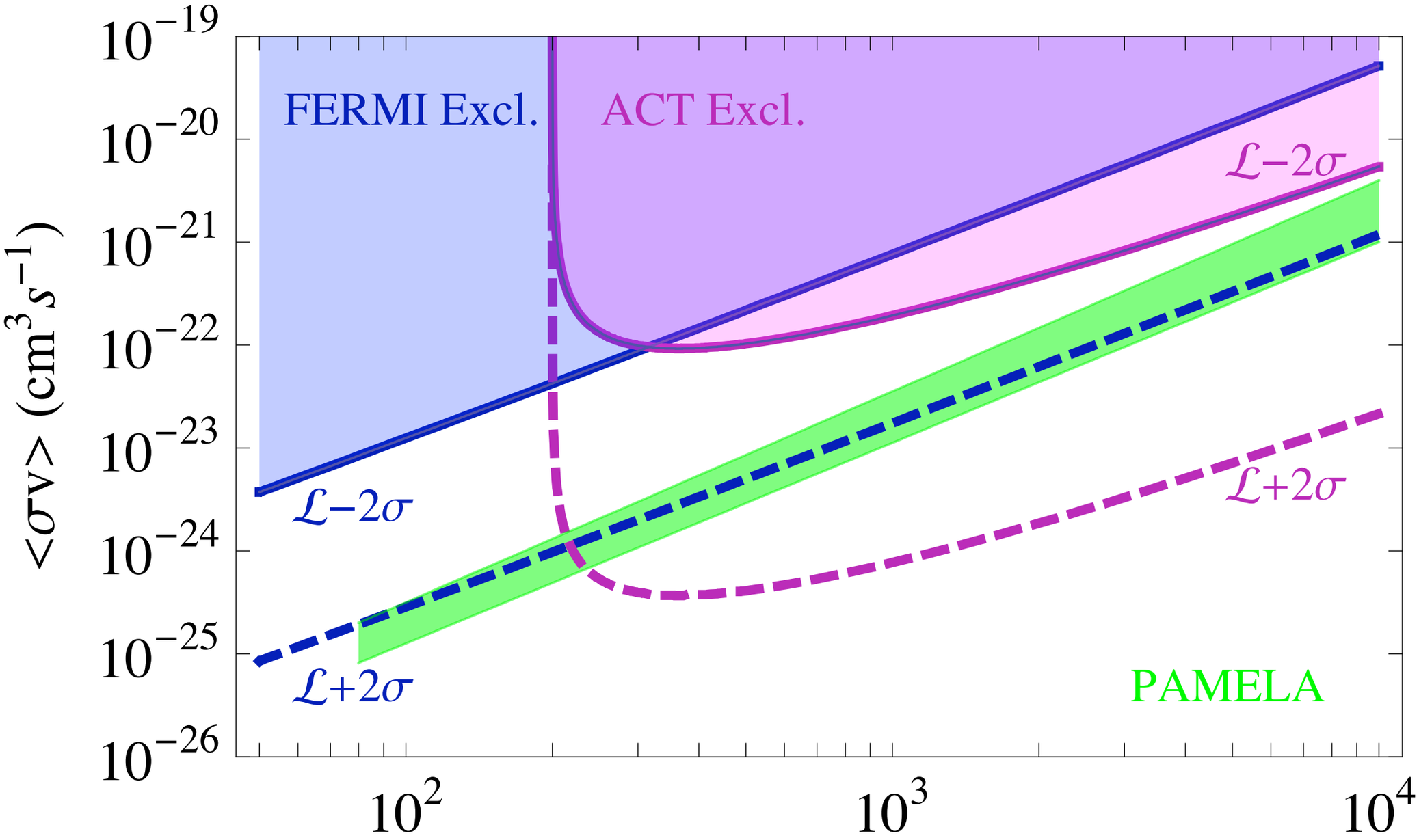
Data from: Geha et al.; Simon et al., to appear

observational uncertainty ($\sim 10^3$-10^4)

Dark Matter Annihilation into Electron/Positrons

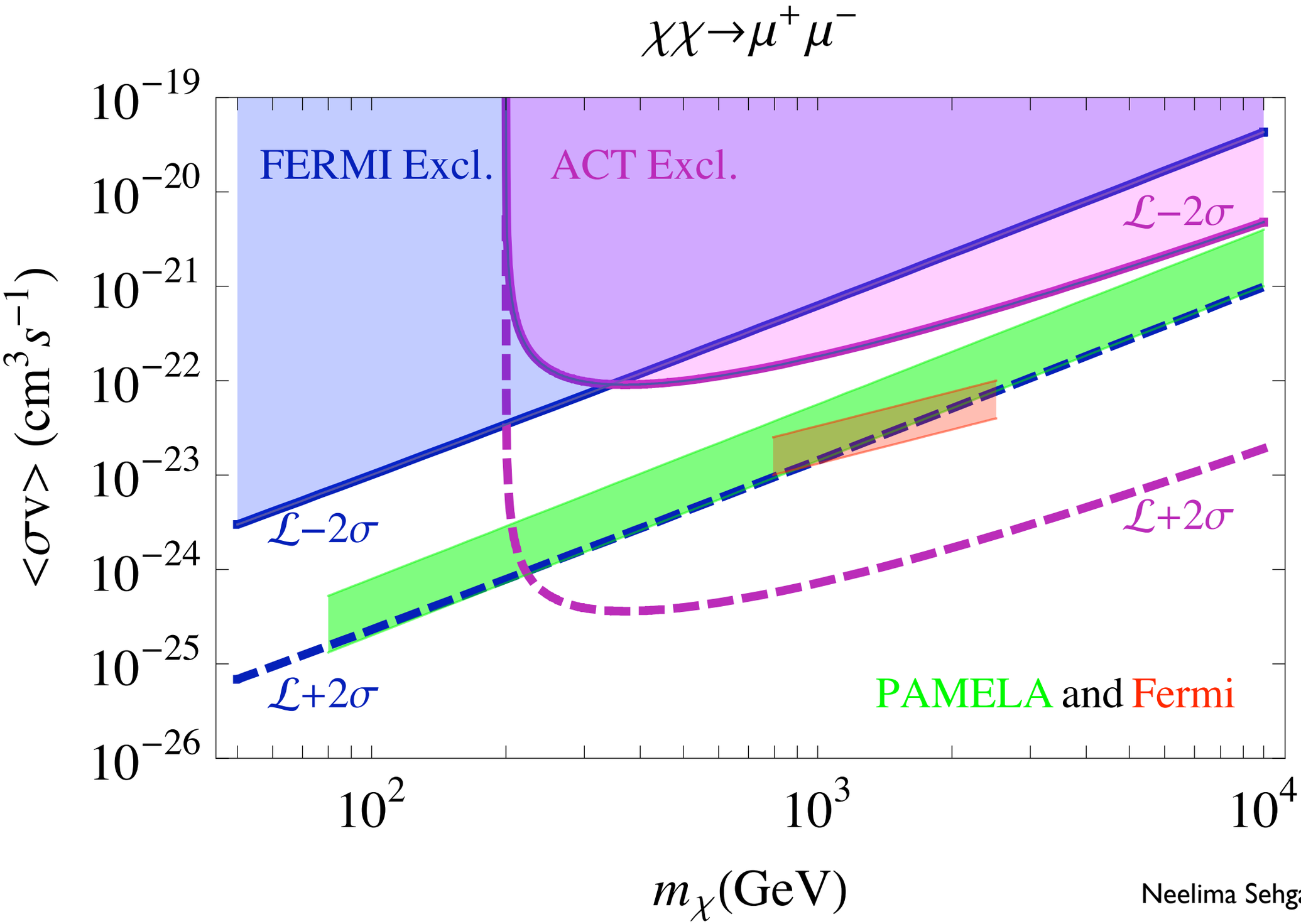
Fermi data: observation of Segue 1 over 3 months (see e.g. Ping Wang's talk at CINC09)
(9 months data factor of ~2 better due to statistics - see TeVPA talks by Simona Murgia and Tesla Jeltema)
ACT data: Veritas observation of Willman 1

$$\chi\chi \to e^+ e^-$$



Best-fit PAMELA/Fermi regions from Meade, Papucci, Strumia, Volansky arXiv:0905.0480

Dark Matter Annihilation into Muons



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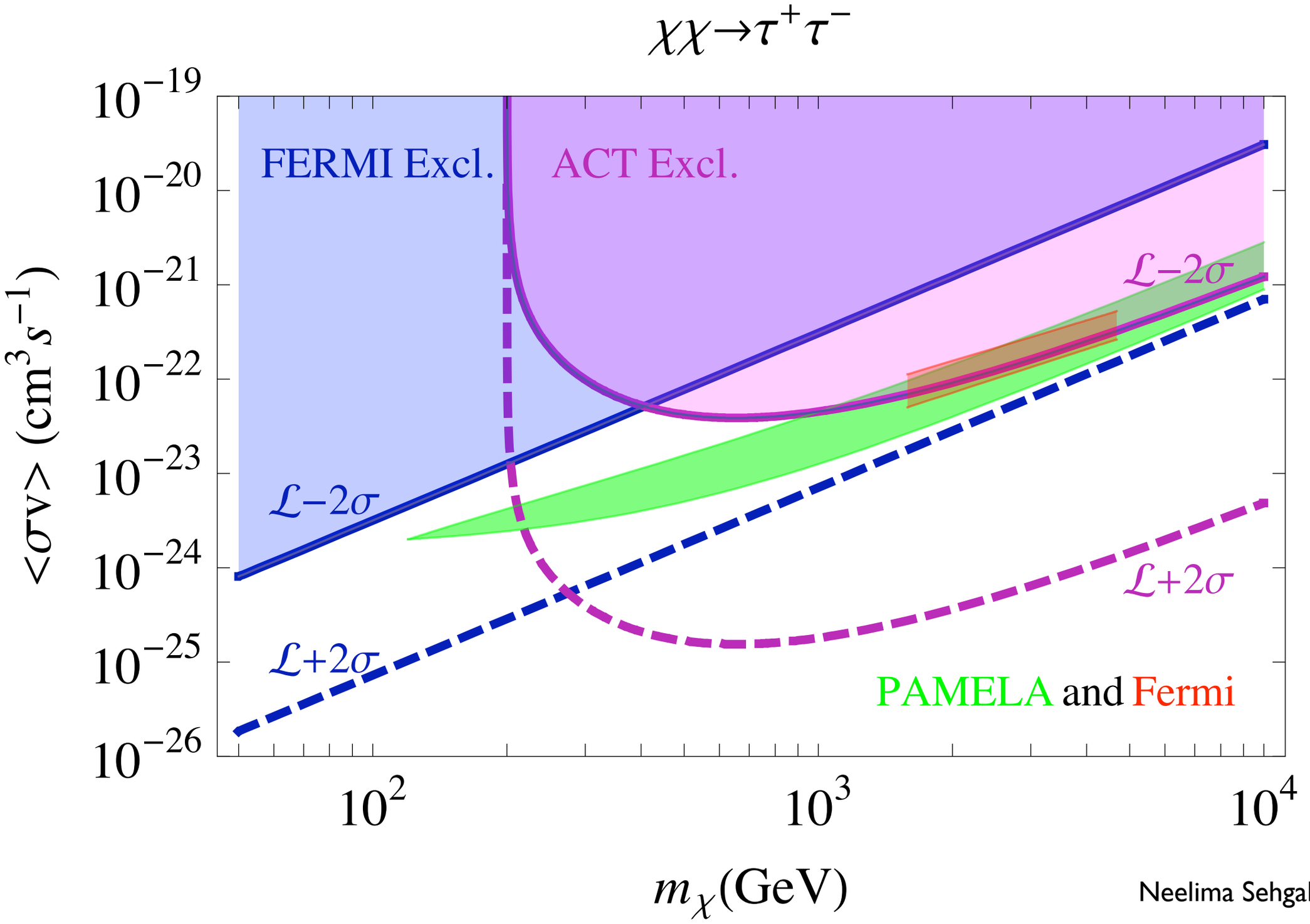
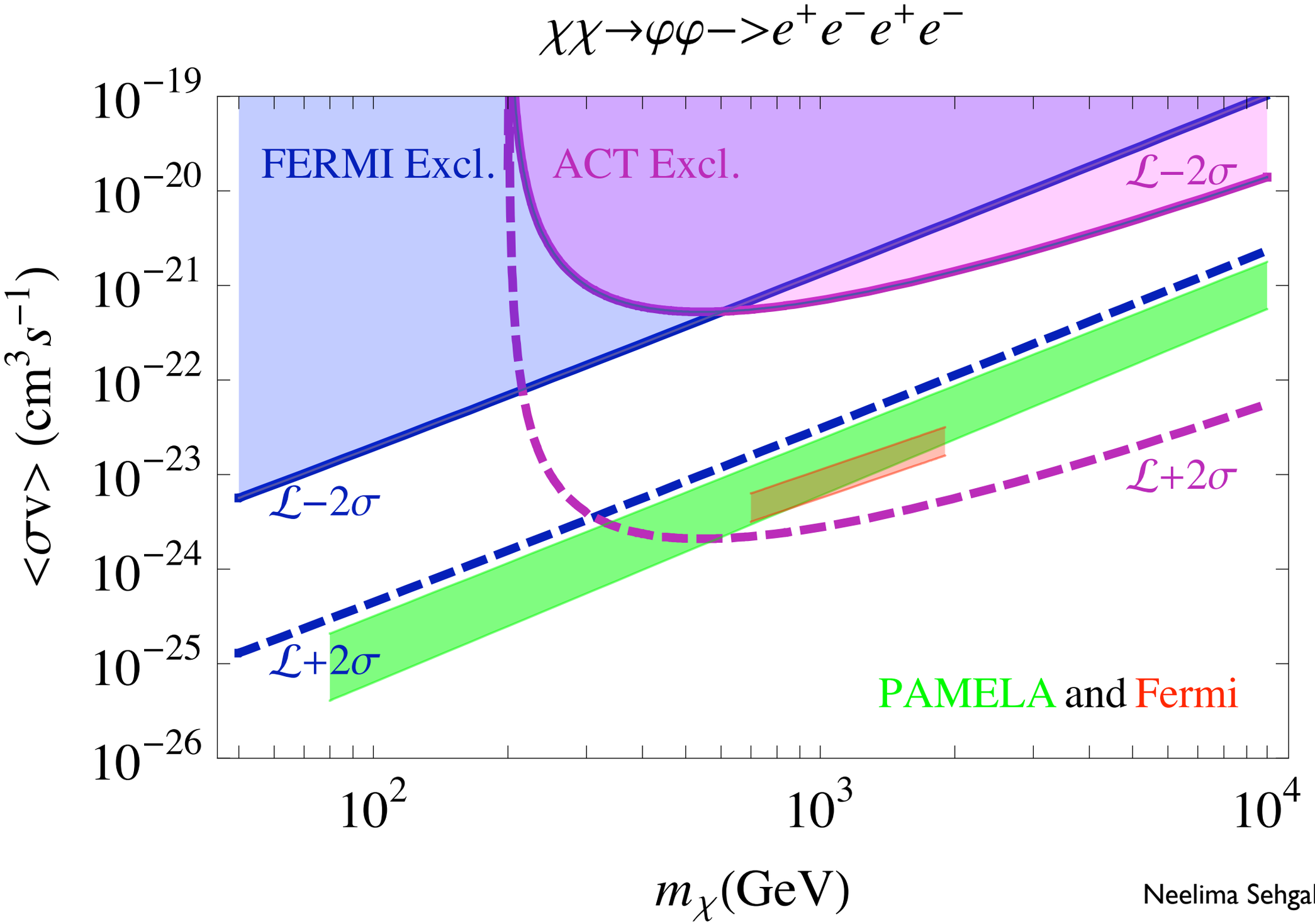
Dark Matter Annihilation into Taus



Dark Matter Annihilation into Electron/Positrons through an intermediate particle



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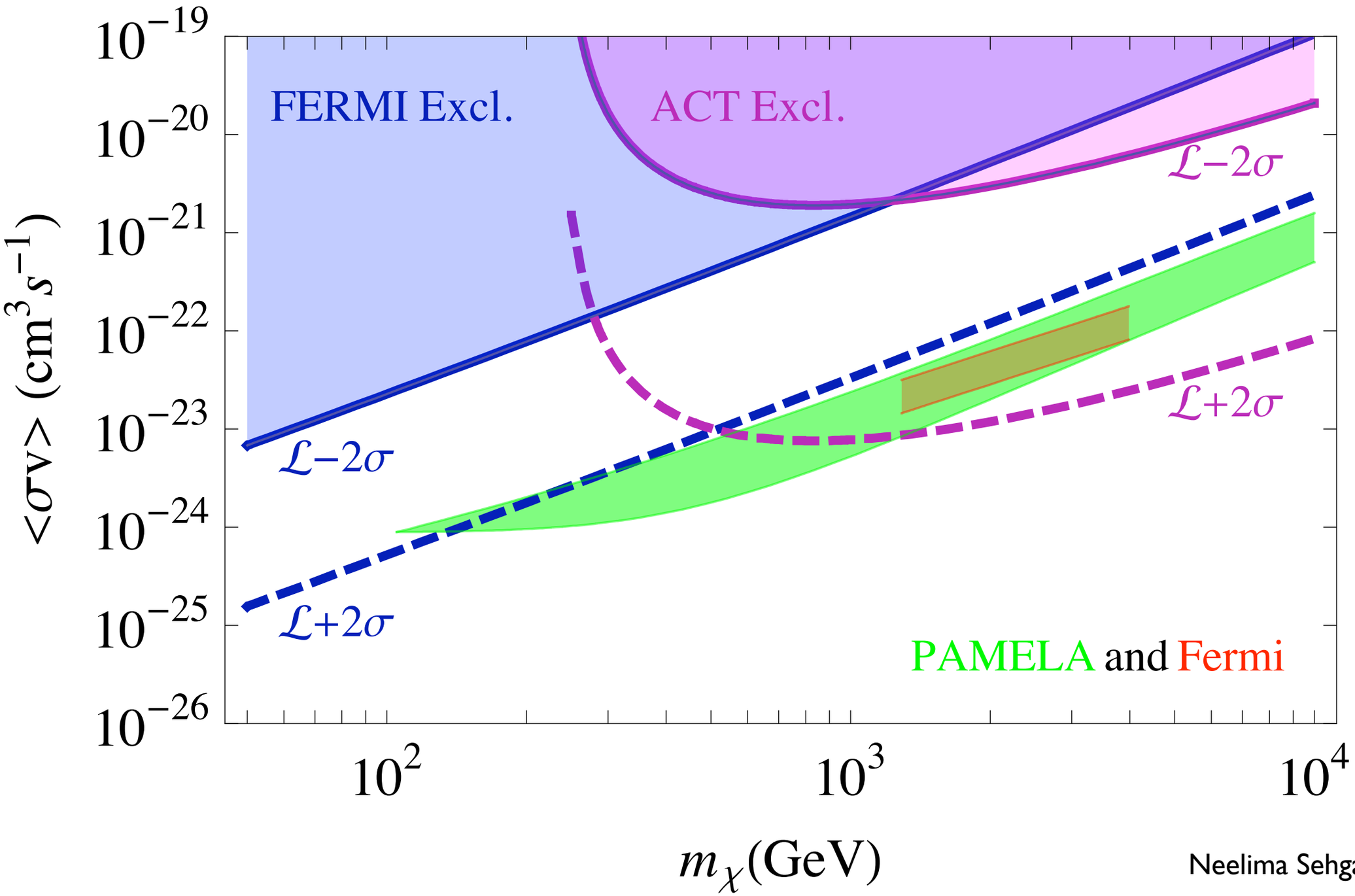
Dark Matter Annihilation into Muons through an intermediate particle

$$\chi\chi \rightarrow \varphi\varphi -> \mu^+\mu^-\mu^+\mu^-$$



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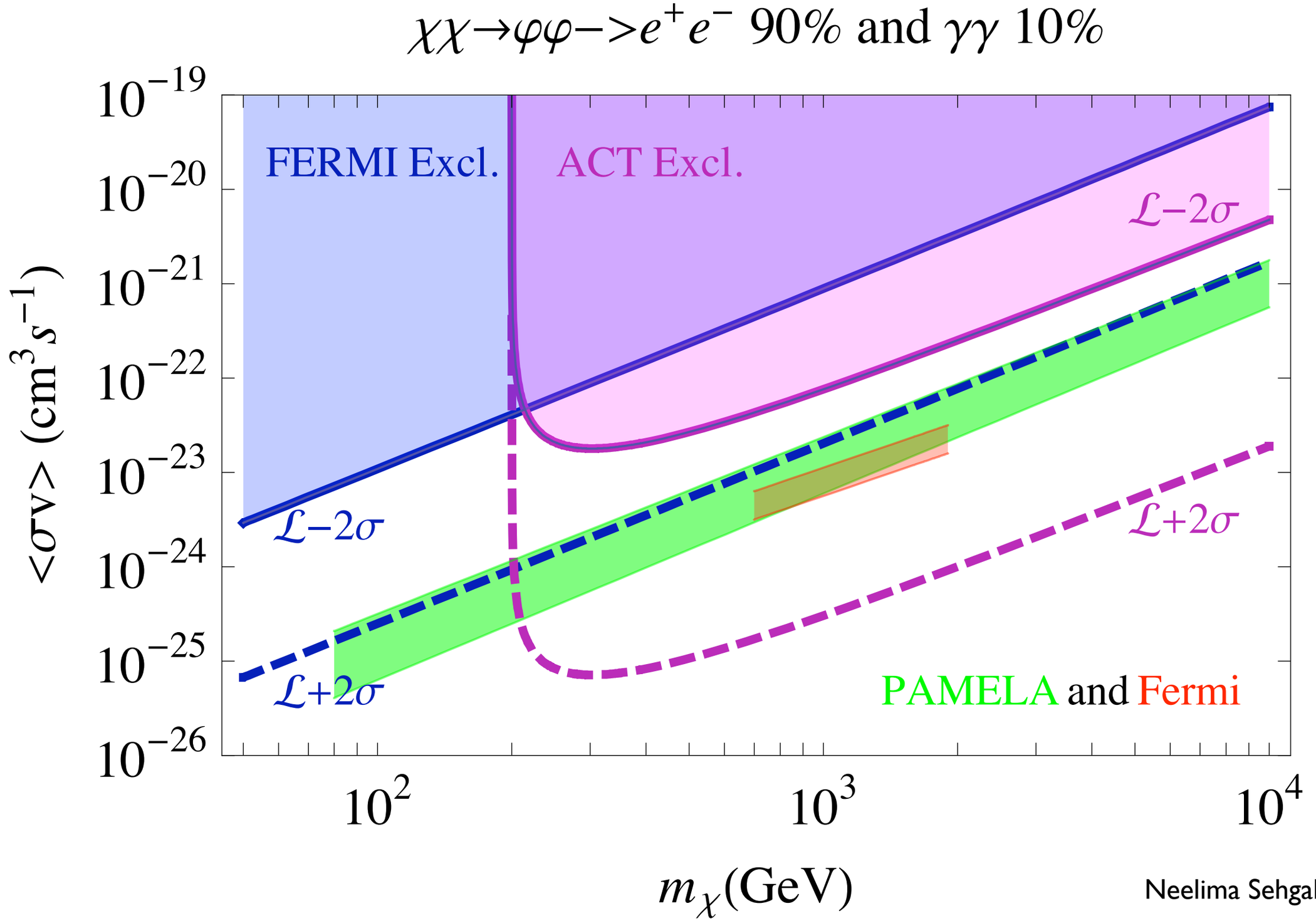
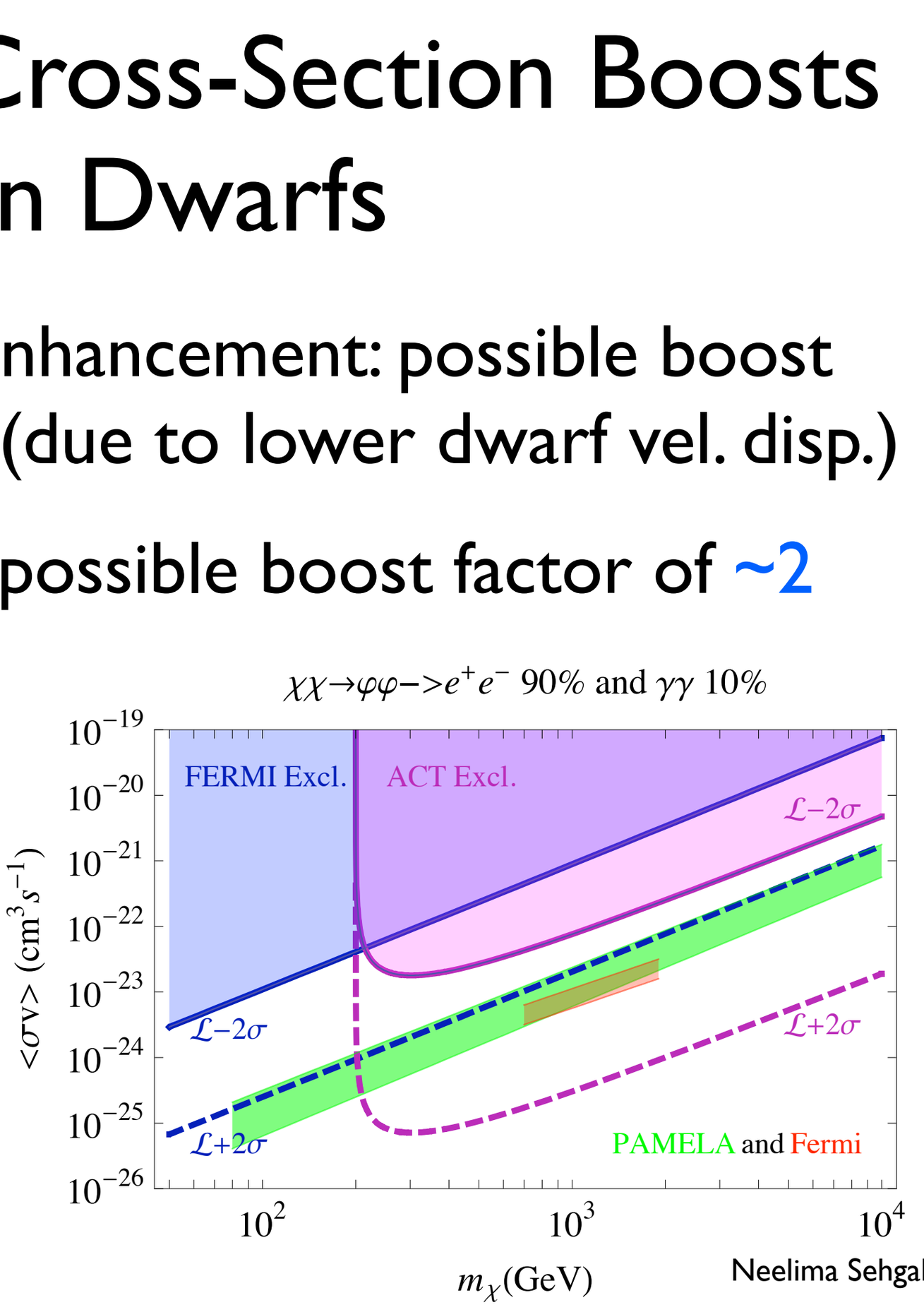
Dark Matter Annihilation into a φ which Decays to Electron/ Positrons with 90% prob. and Gamma-rays with 10% prob.



Additional Cross-Section Boosts in Dwarfs

- Sommerfeld enhancement: possible boost factor of ~30 (due to lower dwarf vel. disp.)
- Substructure: possible boost factor of ~2

With these boost factors, this channel is almost ruled out as an explanation of Fermi excess



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Summary

- Dwarfs are excellent targets to look for gamma-ray signals from DM
- A gamma-ray signal would be *very* suggestive of DM
- Conservative bounds do not rule out DM annihilations as source of Fermi/PAMELA anomalies
- If DM does explain Fermi and/or PAMELA excesses, then Fermi/ACTs have good prospects for DM detection with dwarfs