New View of Pulsar and Dark Matter Contributions to the Local Cosmic-Ray Positron Flux

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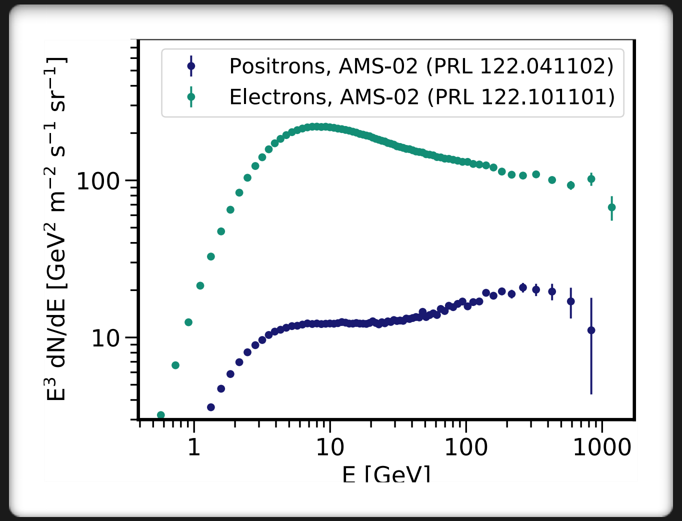
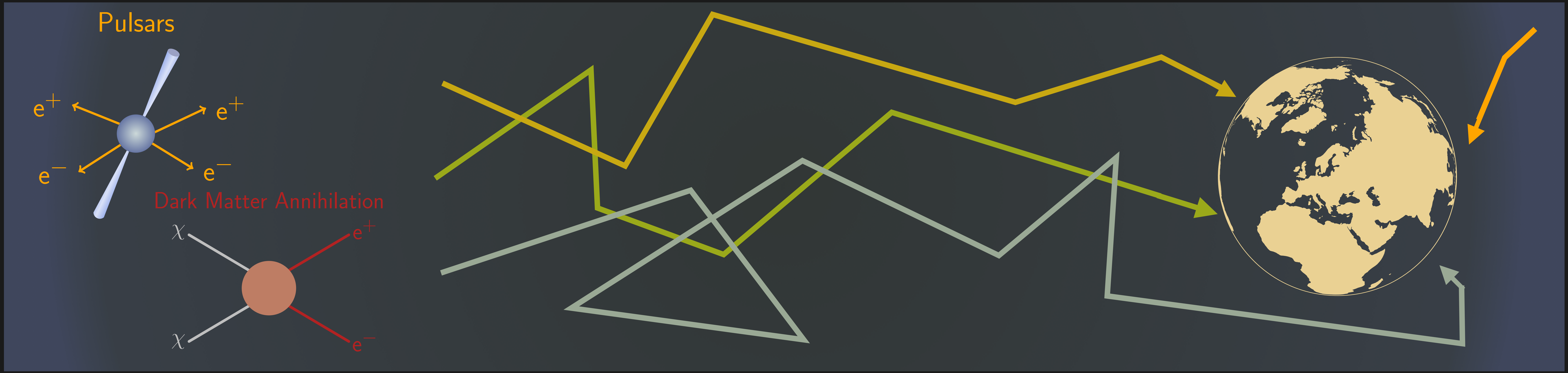
Propagation and Energy Losses

Positron source
e.g. pulsars or
dark matter

Propagation and
energy losses





Synchrotron radiation
in magnetic fields

Inverse-Compton scattering
on ambient photons

Energy Loss Rate

Continuous energy loss rate:

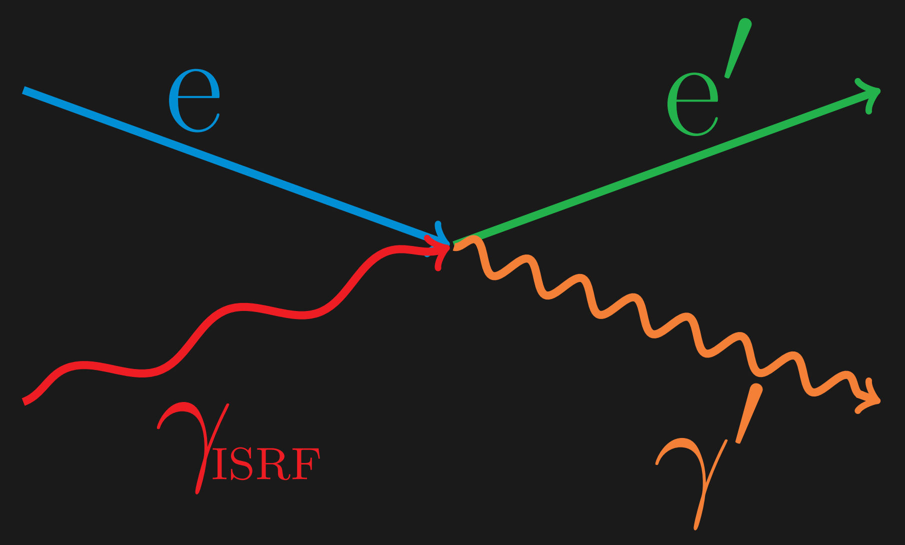
$$\frac{dE}{dt} = -\frac{4}{3}\sigma_T \left(\frac{E}{m_e}\right)^2 \left[\rho_B + \sum_i \rho_i(\nu_i) S(E,\nu_i)\right]$$

σ_T: Thomson cross section
E_e: Electron energy
m_e: Electron mass
u_i: ISRF photon energy density
ν_i: ISRF photon energy
S: Klein–Nishina suppression

Synchrotron radiation
in magnetic fields

Inverse–Compton scattering
on ambient ISRF photons

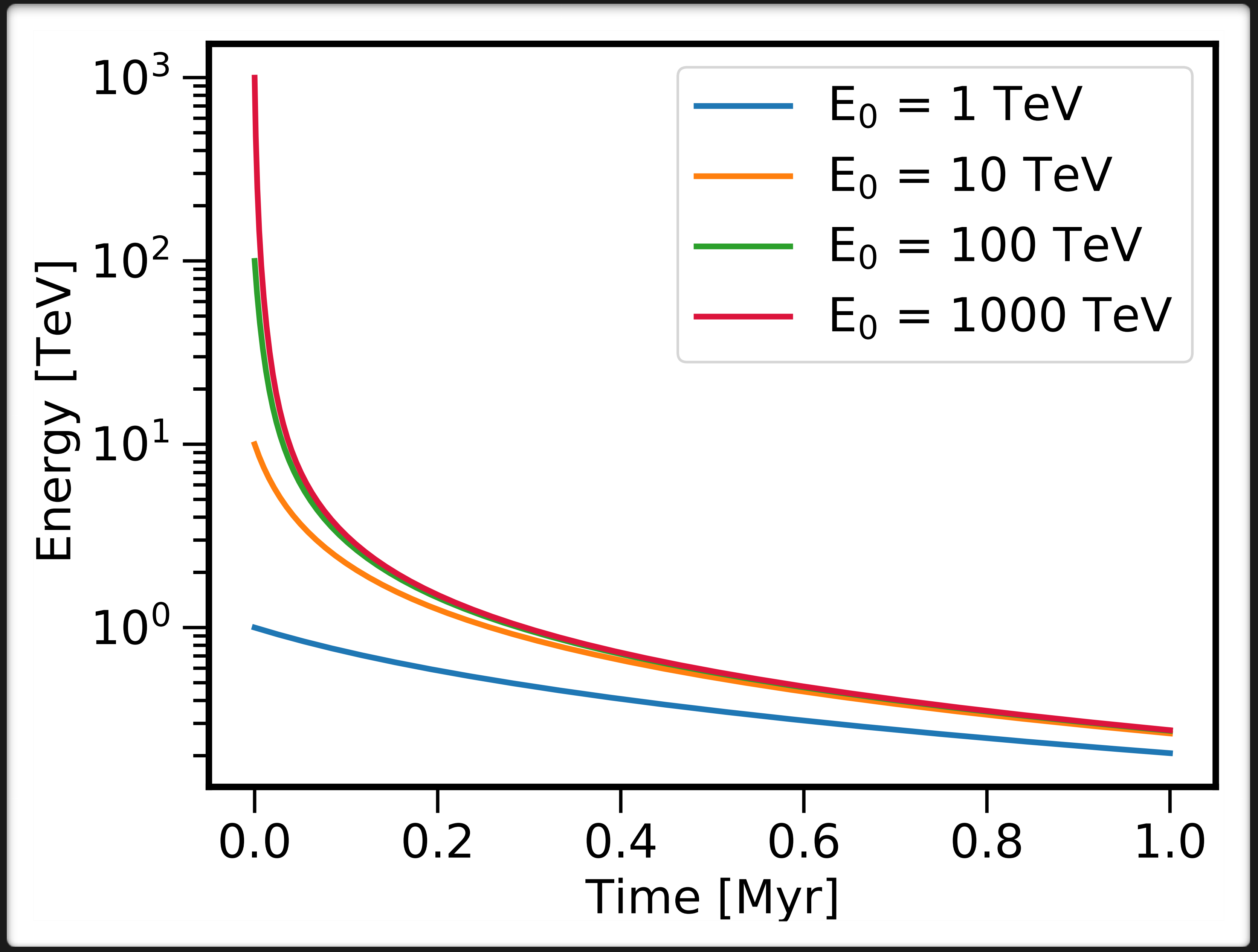
ICS is a stochastic process.



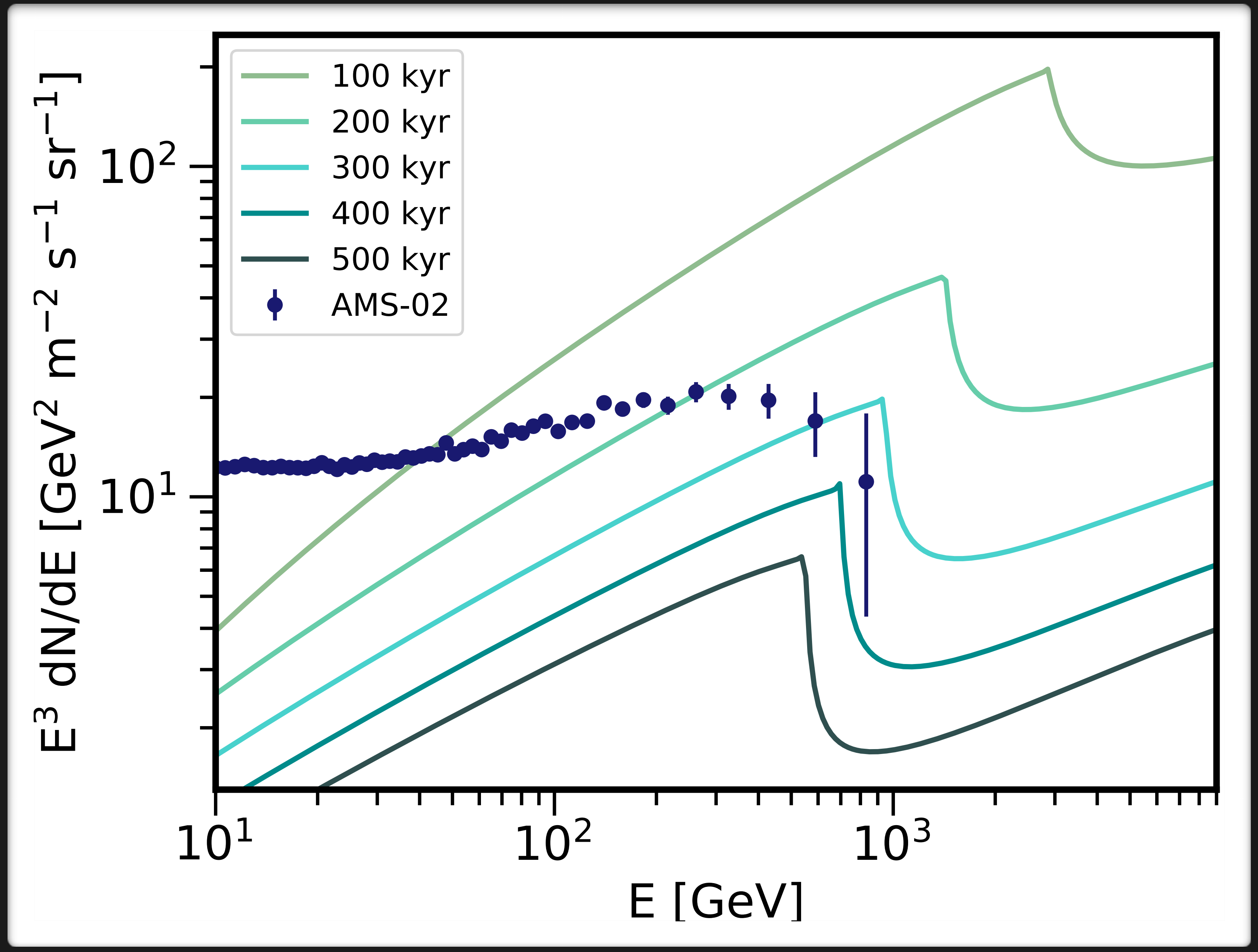
Spectral Features From Pulsars

1. Large fraction of positrons are produced when pulsar is very young

2. High-energy positrons lose energy faster than low-energy positrons



3. These initial positrons build up sharp feature in positron spectrum over time



Stochastic Inverse-Compton Scattering Model

[I. John & T. Linden, arXiv:2107.10261]

1. Create positron with some initial energy
2. Evolve in time steps:
    - Calculate synchrotron energy losses
    - Based on positron energy, determine if inverse-Compton scattering happens and at what photon energy
    - If ICS: Calculate energy loss and new positron energy
3. Repeat until desired cooling time is reached

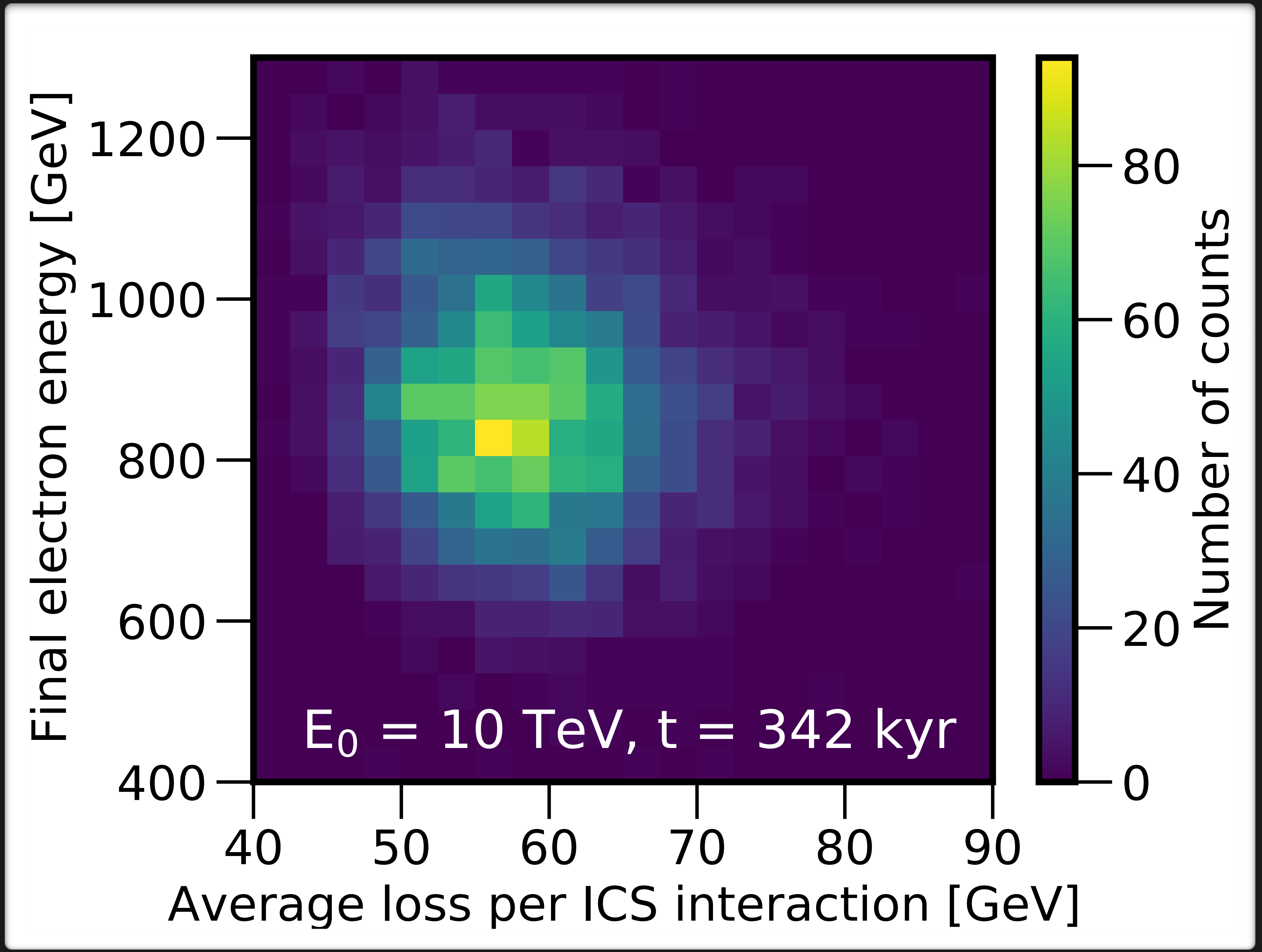
Stochasticity of Inverse–Compton Scattering

Continuous calculation:

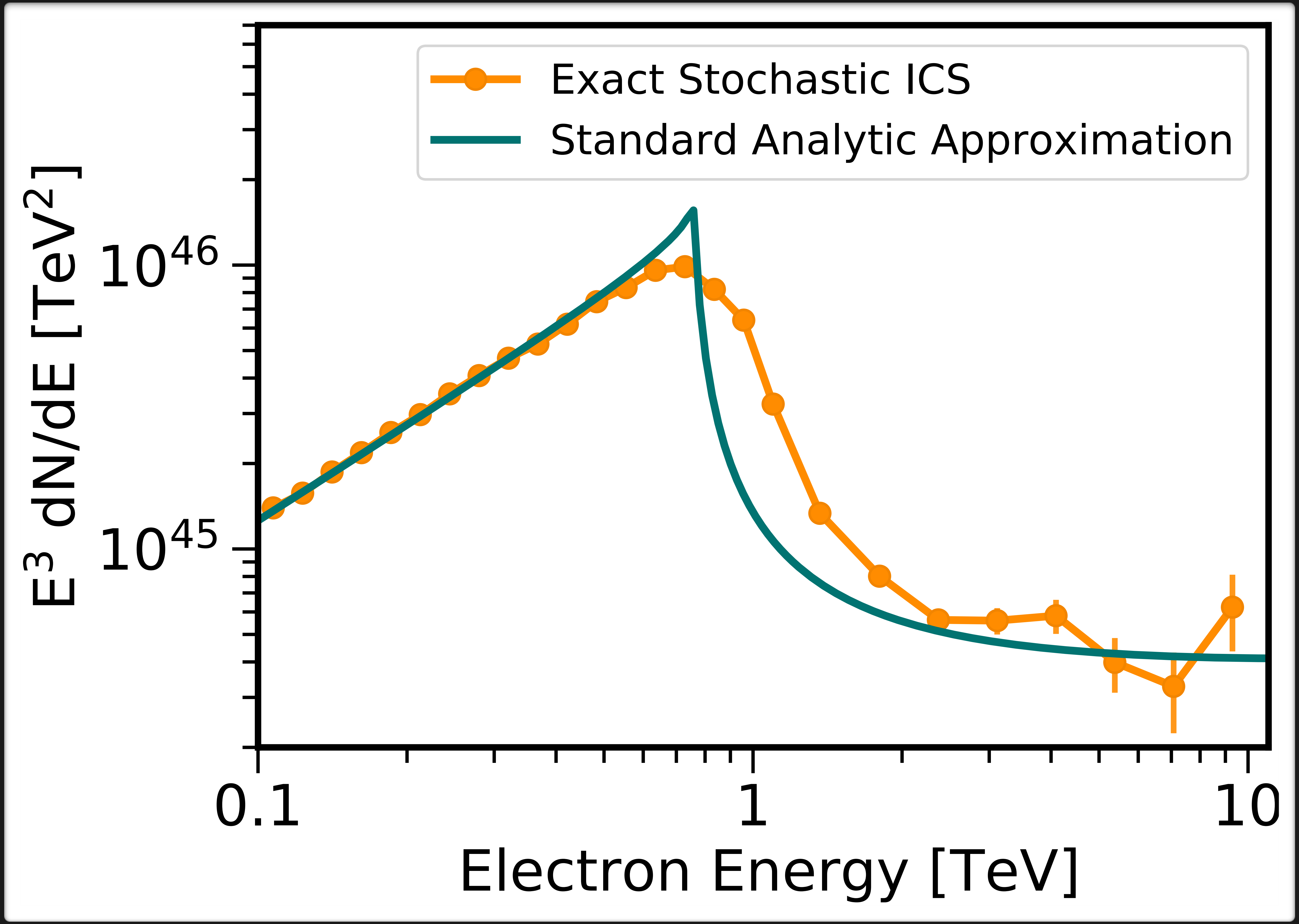
- All positrons are treated the same way, cool down to exactly the same energy

Stochastic ICS:

- ICS interactions are rare (~120 interactions in 342 kyr)
- Catastrophic energy losses (~10–100% of energy lost)
- ~30% spread in final positron energy distribution



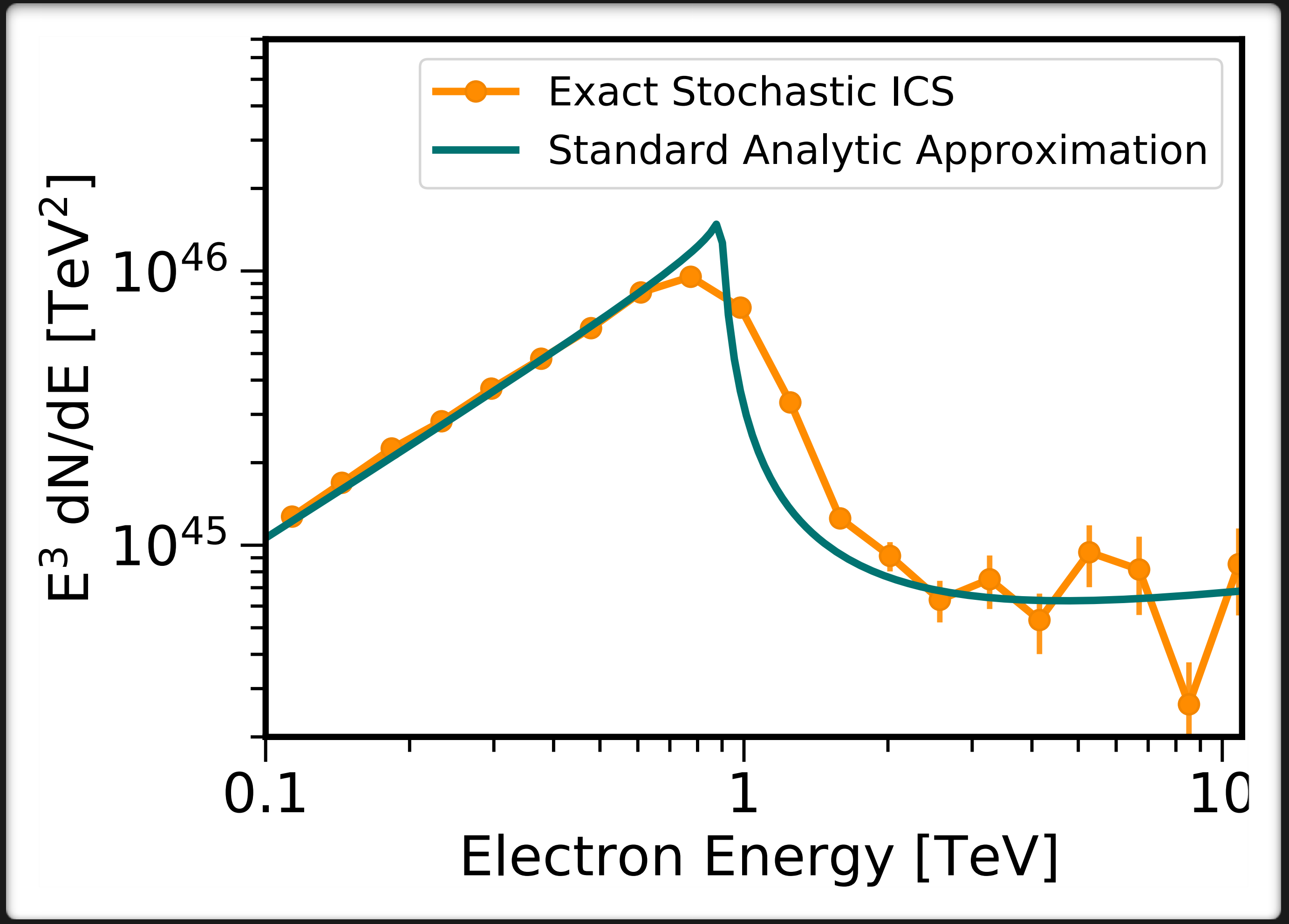
Positron Spectrum of Individual Pulsars

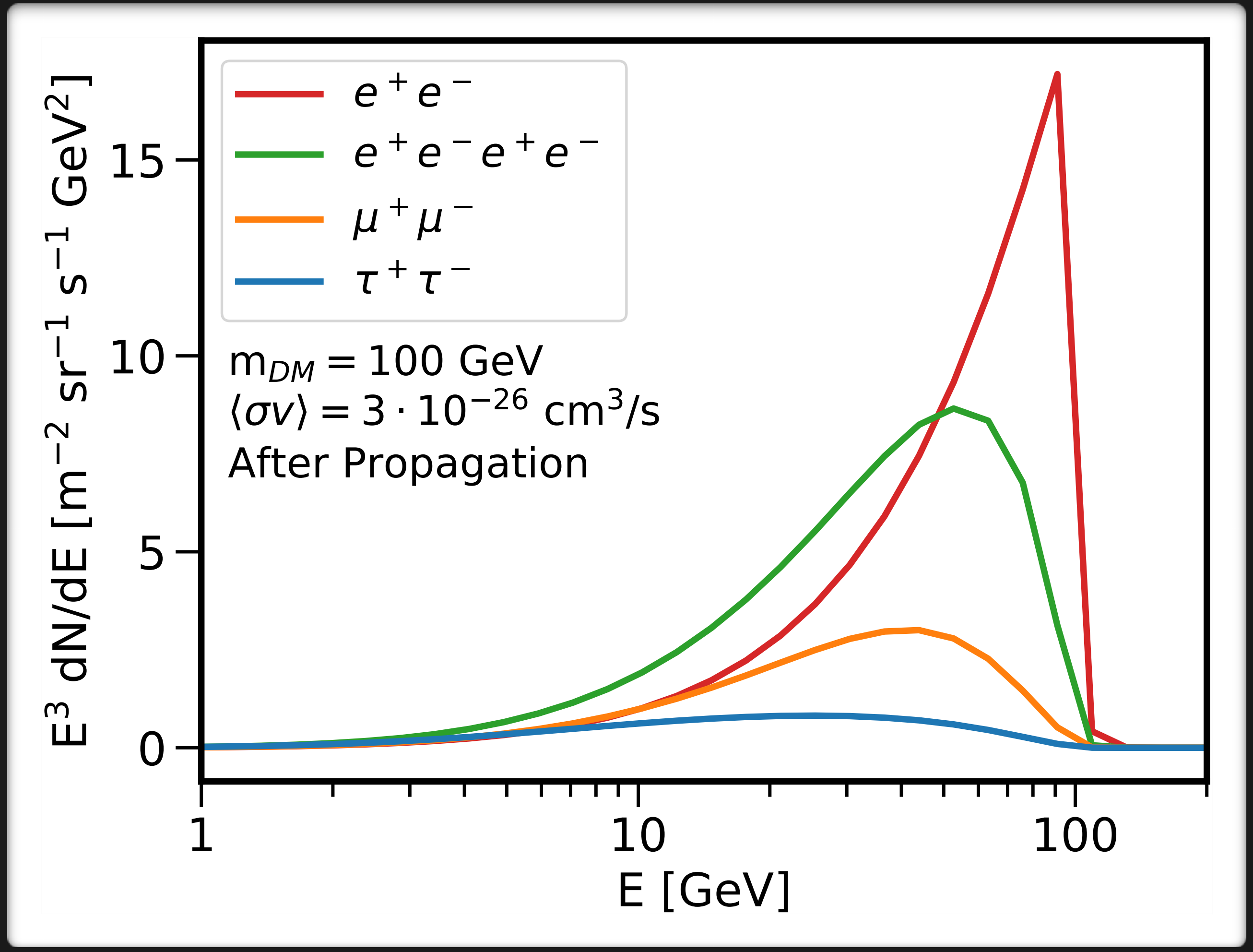


Sharp spectral features introduced by continuous approximation are smoothened out by ~50% when correctly treating inverse-Compton scattering stochastically

Positrons Injection from Pulsars and Dark Matter

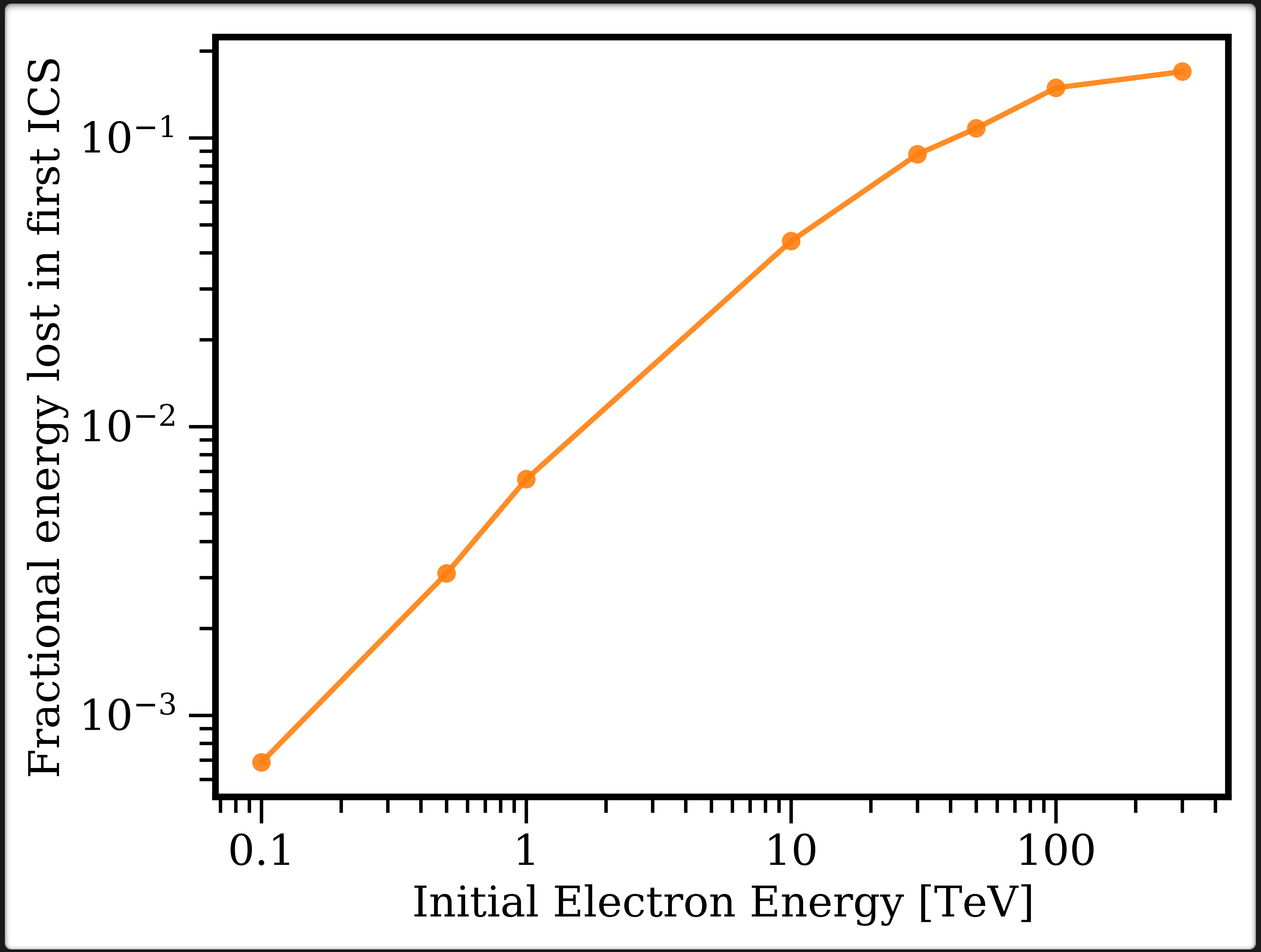
Pulsars		Dark matter
Distribution of e^+e^- injection energies (power law)	⟷	Single e^+e^- injection energy (corresponding to dark matter mass)
Burst-like injection of e^+e^-	⟷	Continuous injection of e^+e^-





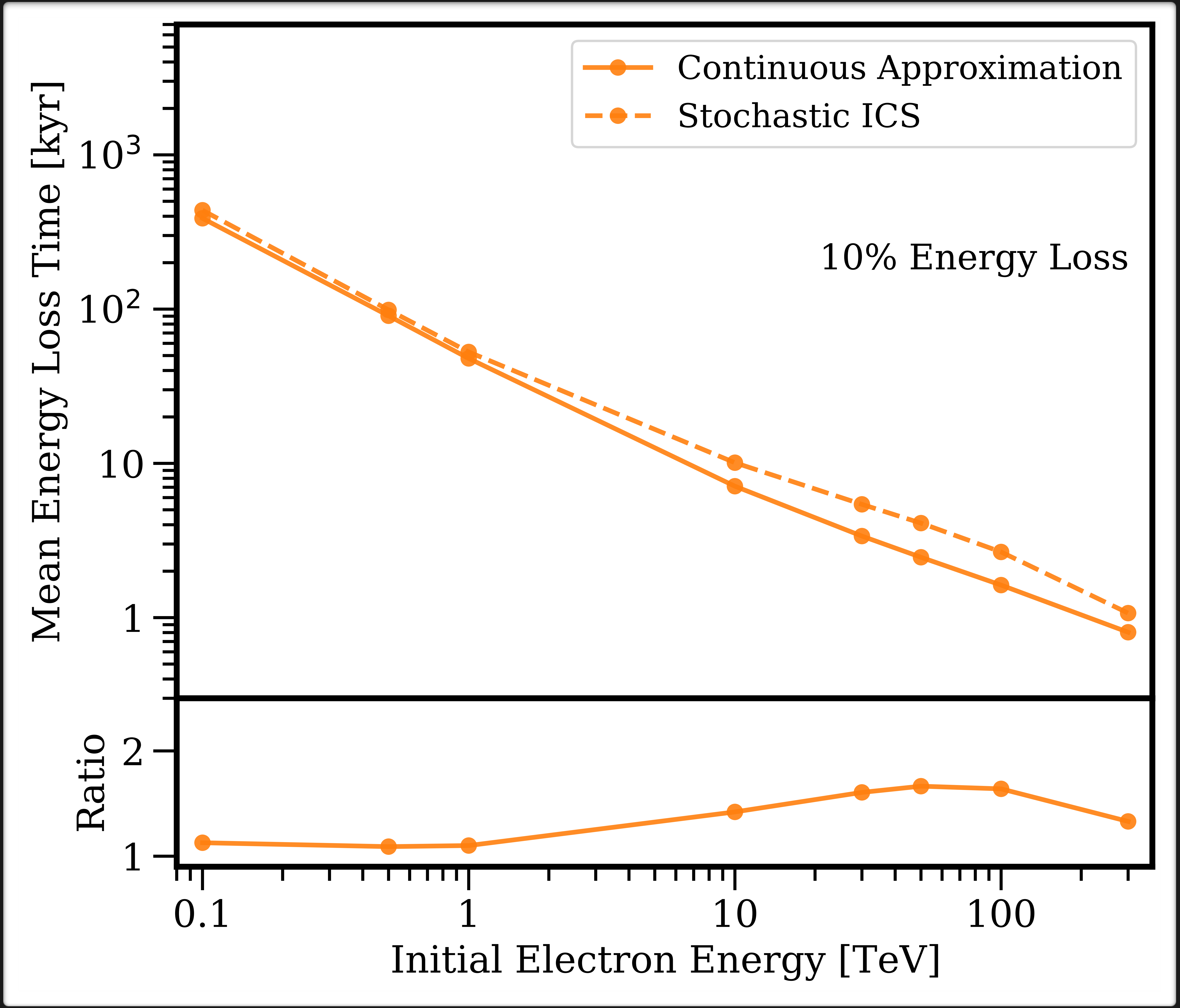
TeV-Scale Dark Matter Signals

[I. John & T. Linden, arXiv:2304.07317]



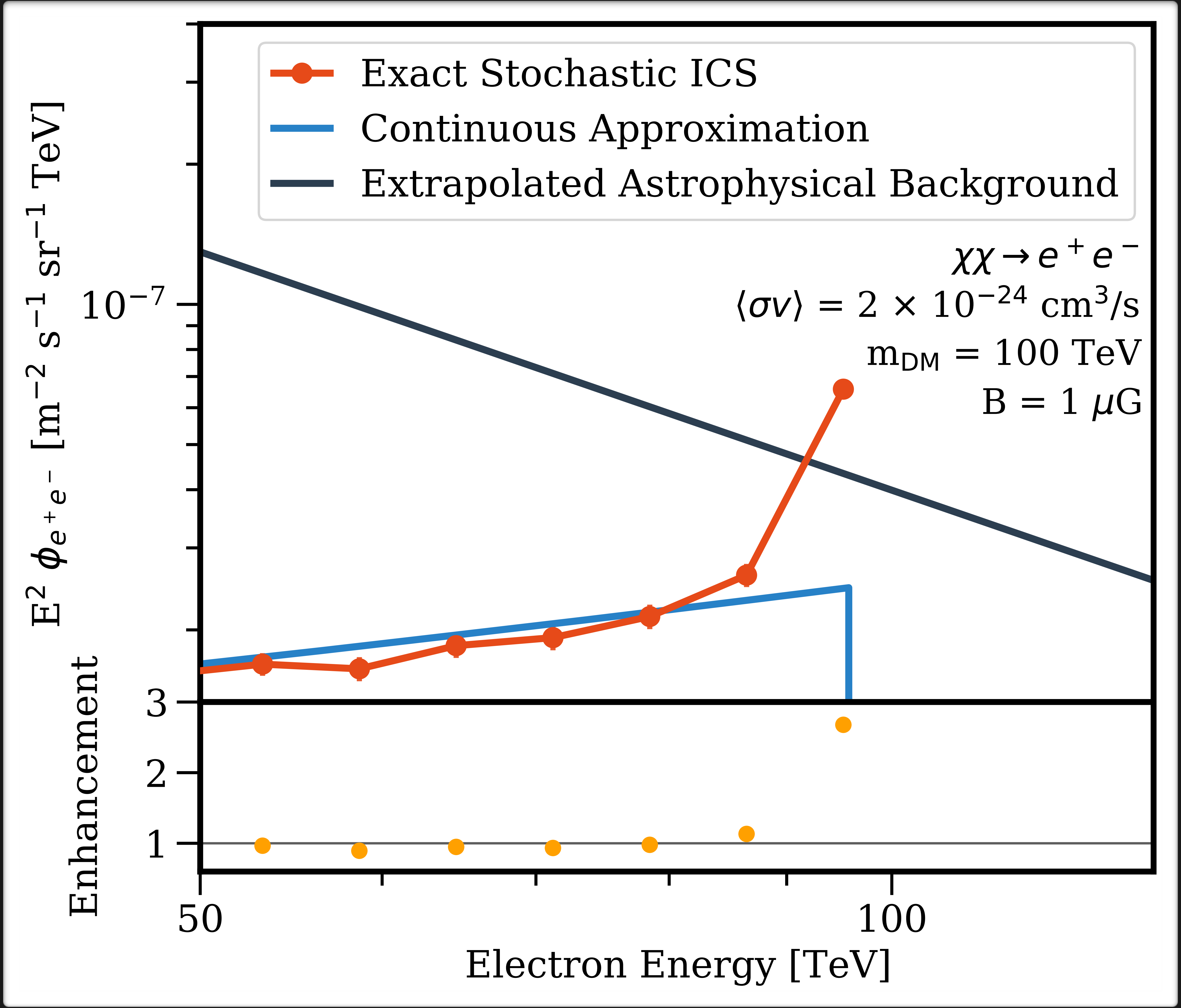
At high energies, ICS interactions are rare, but take a large fraction of the energy in a single interaction

Mean Energy Loss Times



At 10% energy loss, energy losses happen slower in stochastic model compared to continuous model

Enhancement of Dark Matter Signal

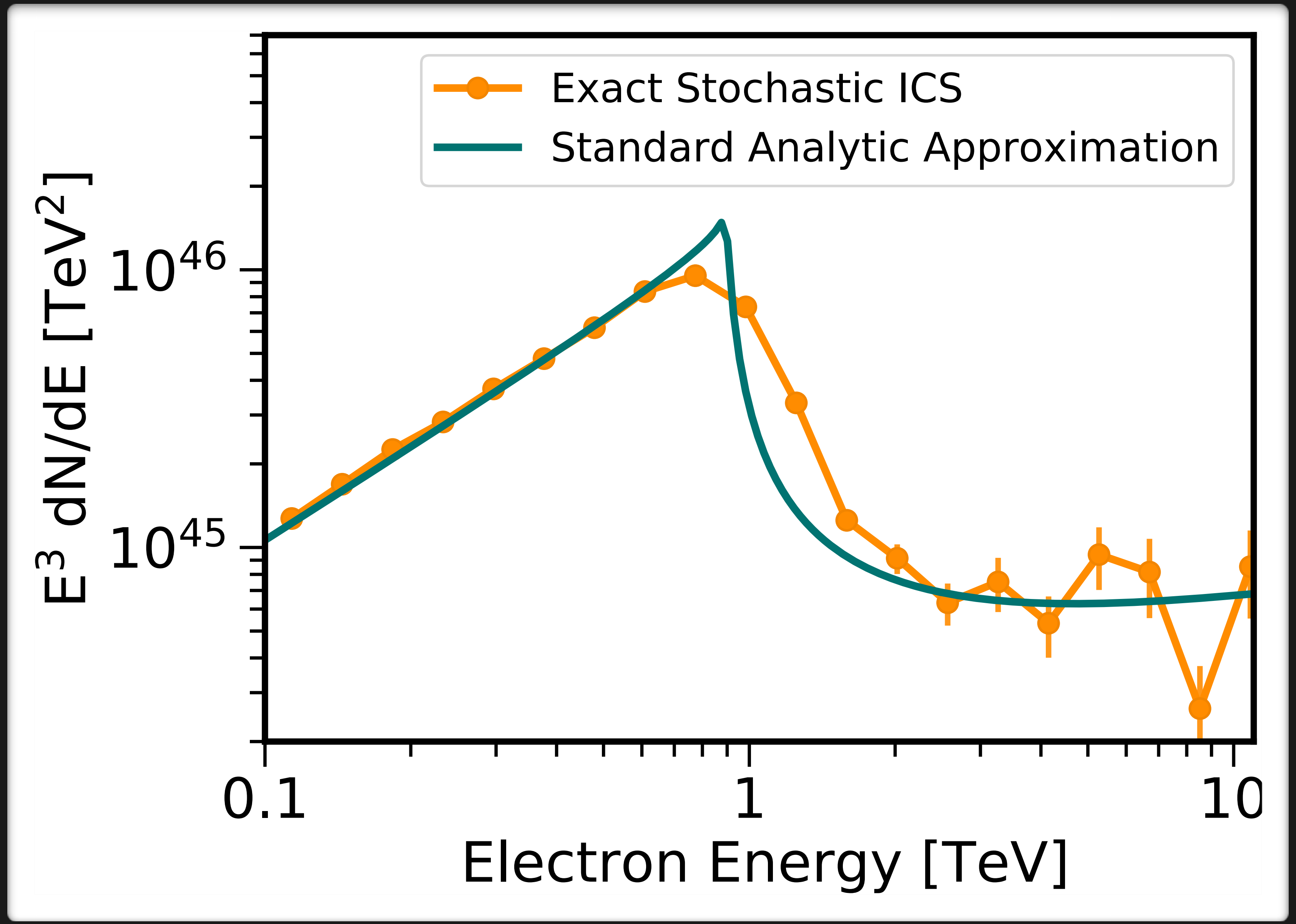


- Near the dark matter mass, the spectral cutoff is enhanced by about a factor of 2.6

- Greatly improves detectability of dark matter signals

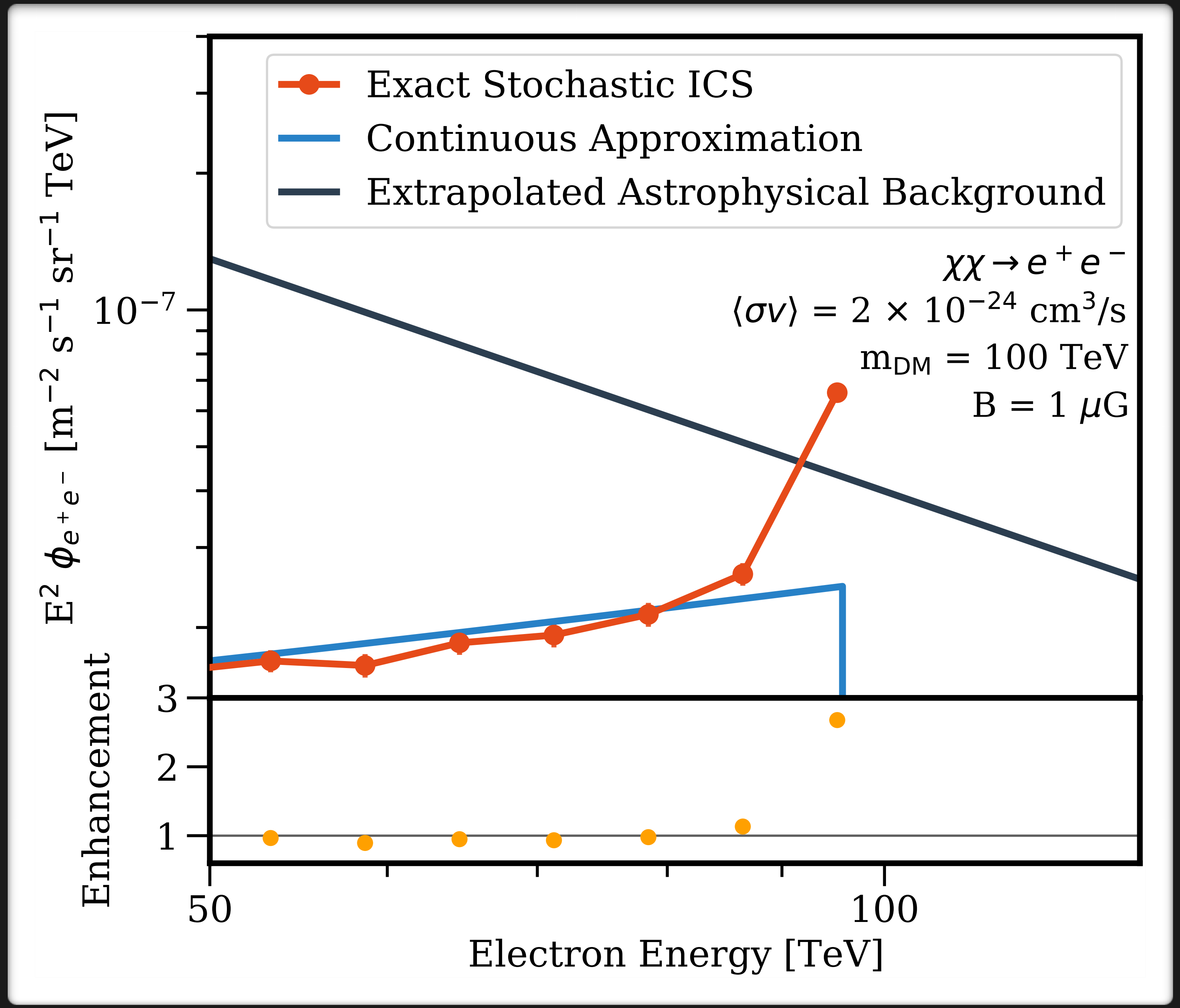
Implications of Stochastic ICS

Pulsars do not produce sharp spectral features



[arXiv:2107.10261]

TeV–scale dark matter signal is enhanced



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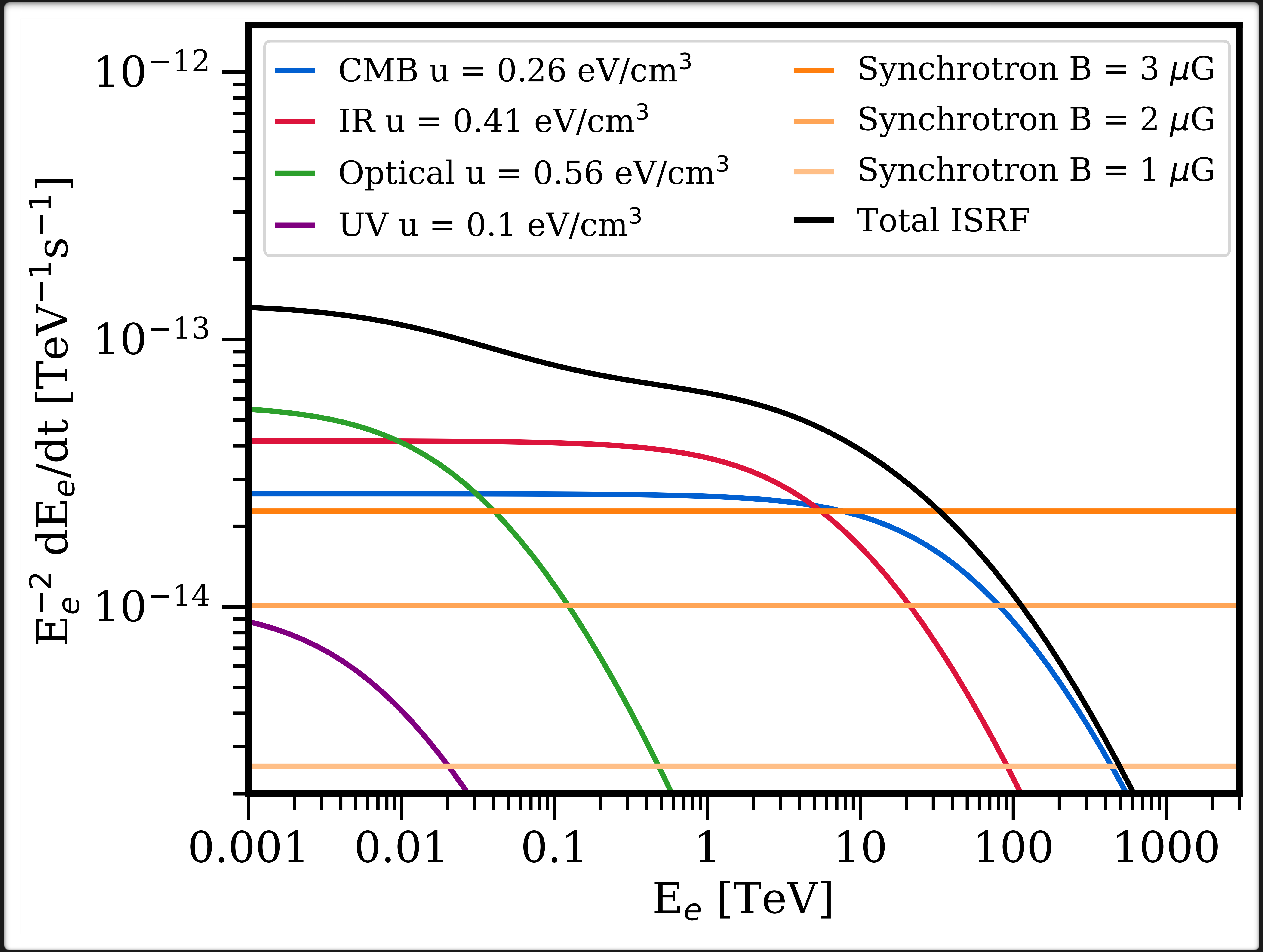
Dark matter is the only known astrophysical mechanism that can produce sharp spectral features in the e^+e^- flux.

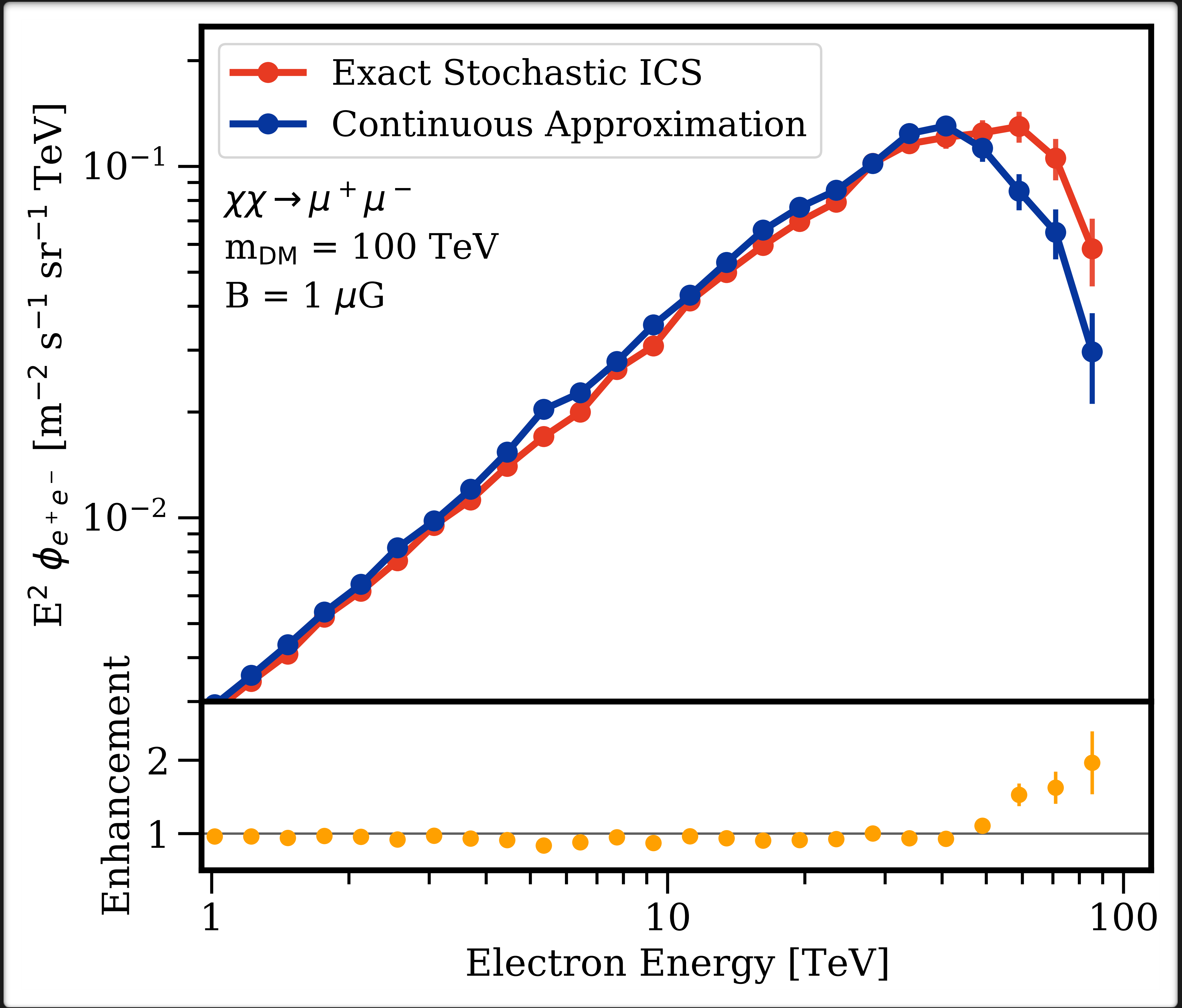
Supplementary Slides

Interstellar Radiation Fields and Magnetic Fields



Dark Matter Annihilation into Muons

- Dark matter annihilates into $\mu^+\mu^-$ that subsequently decay into e^+e^-
- e^+e^- are injected at a distribution of energies
- Enhancement is smaller than in direct e^+e^- case
- Enhancement is further reduced for annihilations into $\tau^+\tau^-$ and other hadronic final states



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