Cosmology constrains on LDM

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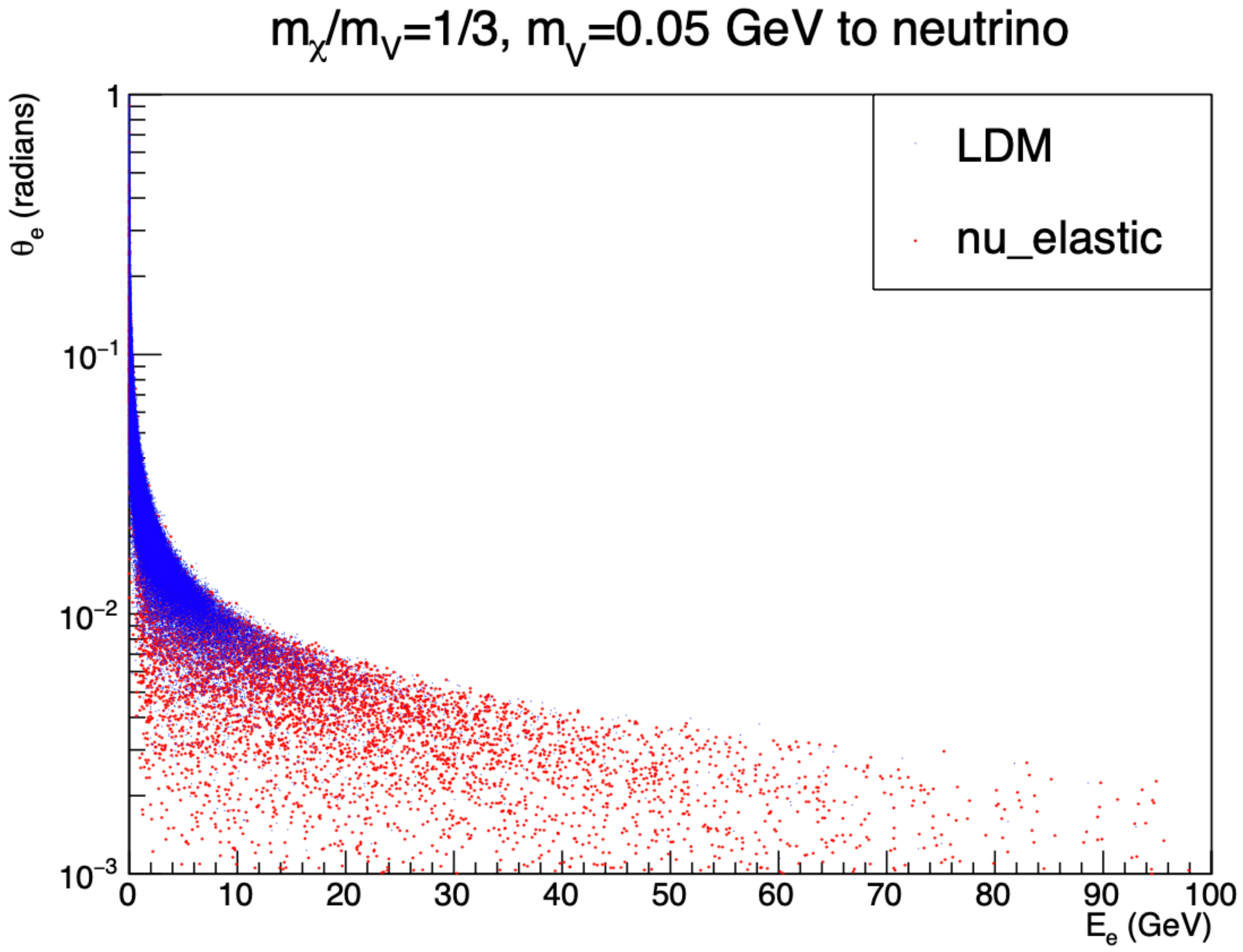
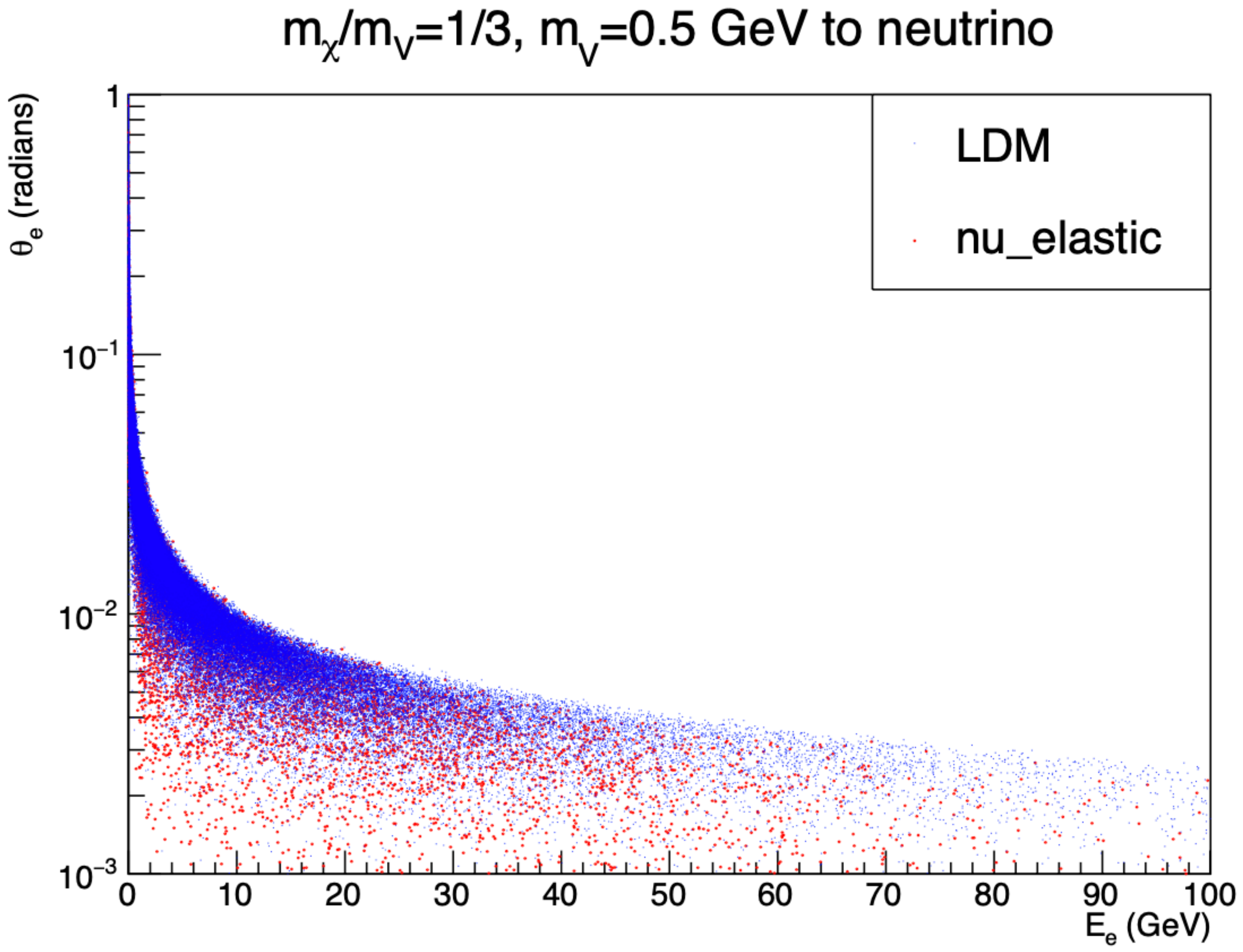
GOAL: differentiate Light Dark Matter (LDM) interactions from neutrino-induced events





- Todays talk focus on:
  - LDM production via different mechanisms
  - Analysis of event rates under varying mass and energy conditions
  - Consideration of cosmological constraints, specifically relic density

$$\sigma/\sqrt{E} \sim 30\%/\sqrt{E}$$

LDM Production Channels:

1609.01770

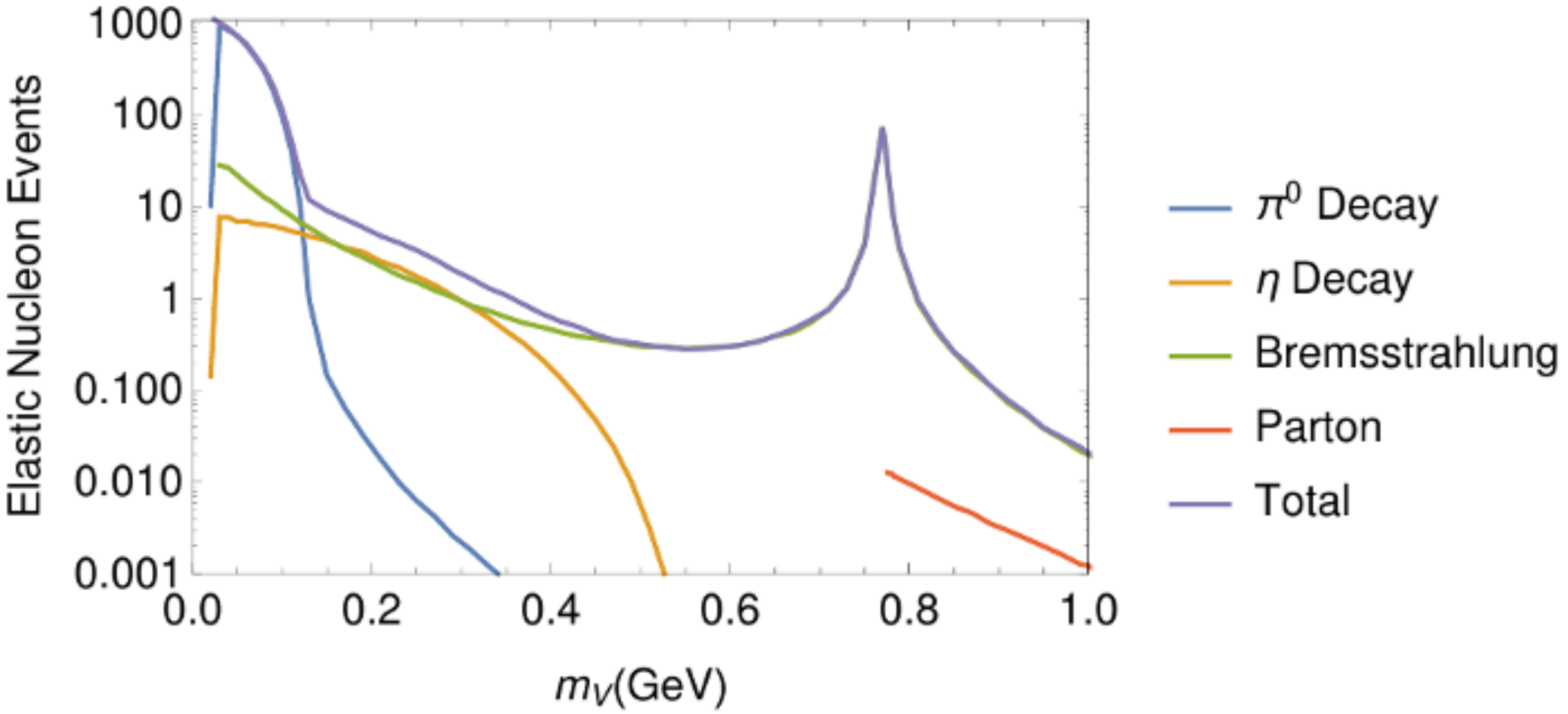


FIG. 1. A plot illustrating the distinct contributions to DM production (coupled through the vector portal), as discussed in the text, using the 9 GeV proton beam at MiniBooNE as an example. The rate of elastic scattering events on nucleons is plotted versus the vector mediator mass. From smaller to larger values of m_V, the dominant channels are π^0 decays, η decay, bremsstrahlung, which becomes resonant near the ρ/ω mass region, and finally direct parton-level production. The plot uses $m_\chi = 0.01$ GeV, $\epsilon = 10^{-3}$ and $\alpha' = 0.1$.

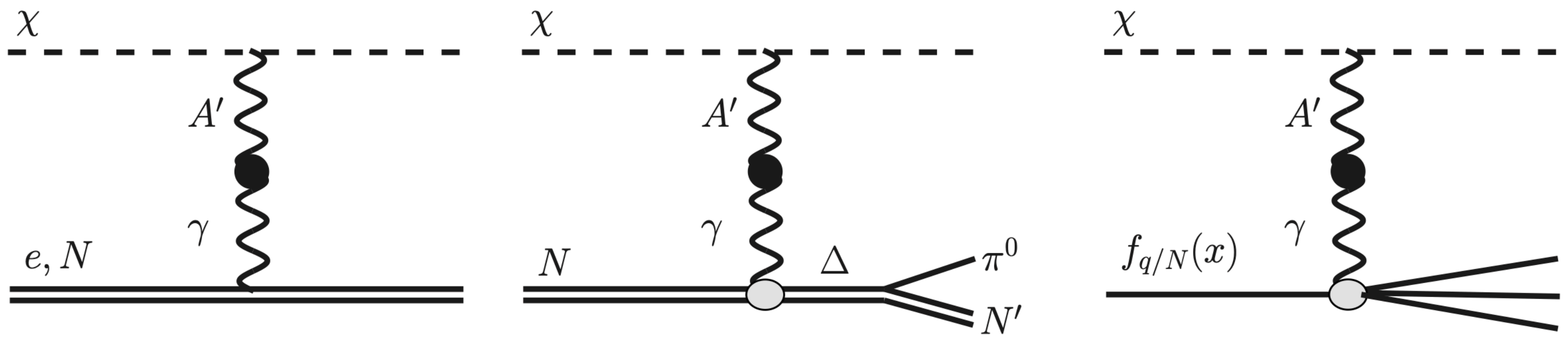
LDM models suggest that dark matter particles have masses below the GeV scale.

Several theoretical frameworks support the possibility of LDM:

1. **Axion-Like Particles (ALPs):** Originally proposed to solve the strong CP problem in quantum chromodynamics, axions are light particles that could also account for dark matter.
2. **Dark Photons:** In models with an additional U(1) gauge symmetry, dark photons mediate interactions between dark matter and ordinary matter, allowing for LDM candidates.
3. **Sterile Neutrinos:** Right-handed neutrinos that do not participate in weak interactions could have keV-scale masses.

Both Scalar and Vector LDM:

SHiP's high-intensity beam and dedicated detector systems make it well-suited to explore a wide parameter space for both scalar and vector LDM, leveraging distinct signatures to differentiate between the two.



Dominant Channels by Mediator Mass:

- **Low Mass:**
  π^0 decay
- **Intermediate Mass**:
  η decay and Bremsstrahlung (Bremsstrahlung dominates in the intermediate mass range (~100 MeV and above)
- **High Mass**:
  Bremsstrahlung

Cosmological Constraints for LDM

Dark matter (DM) can be produced in the early universe via two primary mechanisms:

1. Freeze-Out Mechanism
2. Freeze-In Mechanism

The Planck satellite measured the anisotropies in the Cosmic Microwave Background (CMB) with exceptional precision, allowing determination of the matter density of the universe.

The observed value is: $\Omega h^2 \approx 0.120 \pm 0.001$ 1807.06209v4

This sets the amount of dark matter in the universe today. For LDM, this relic density depends on the production mechanism (e.g., freeze-out or freeze-in).

Cosmological Constraints for LDM

The evolution of the number density of dark matter particles n_χ is governed by the Boltzmann equation:

$$\frac{dn_\chi}{dt} + 3Hn_\chi = -\langle \sigma v \rangle \left(n_\chi^2 - n_\chi^{\text{eq}2} \right)$$

where:

- n_χ: Number density of dark matter particles
- H : Hubble parameter, $H = \sqrt{\frac{8\pi G}{3}\rho}$, where ρ is the total energy density
- $\langle \sigma v \rangle$: Thermally averaged annihilation cross-section
- n_χ^{eq}: Equilibrium number density of dark matter particles at temperature T

The abundance Y_χ is defined as the ratio of the number density to the entropy density s: $Y_\chi = \frac{n_\chi}{s}$, $s = \frac{2\pi^2}{45} g_{*S} T^3$

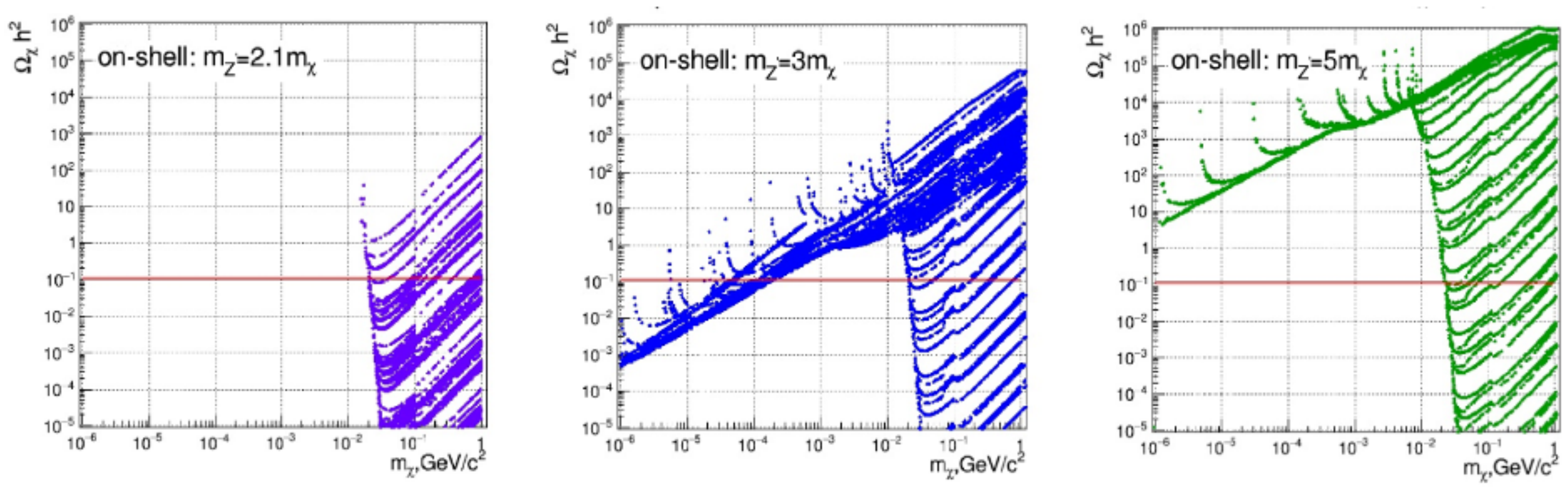
After freeze-out, the abundance Y_∞ becomes constant. The relic density is then given by: $\Omega_{\text{DM}} h^2 = \frac{m_\chi s_0 Y_\infty}{\rho_{\text{crit}}}$

where:

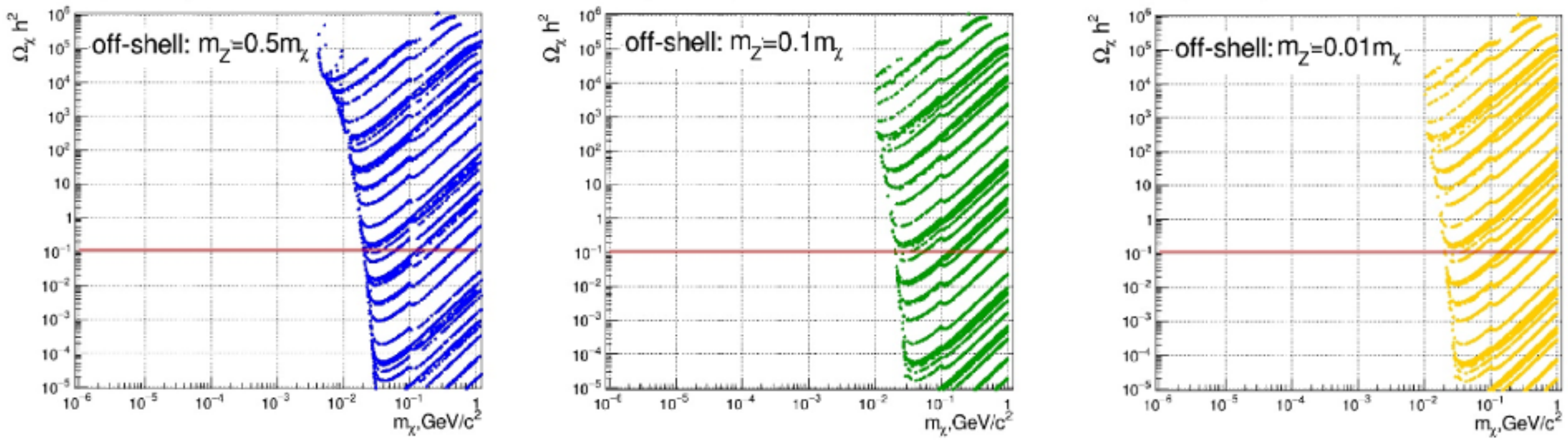
- m_χ Mass of the dark matter particle
- s_0: Current entropy density of the universe
- ρ_{crit}: Critical density of the universe, $\rho_{\text{crit}} = \frac{3H_0^2}{8\pi G}$, with H_0 being the Hubble constant

Cosmological Constraints for LDM

Dark matter relic density (Ωh^2) in on-shell regimes. The red lines indicate the area nearby Ωh^2 = 0.12



Dark matter relic density (Ωh^2) in off-shell regimes. The red lines indicate the area nearby Ωh^2 = 0.12



micrOMEGAs is used to assess models meeting relic density

$\Omega h^2 \approx$ 0.120 ± 0.001

(The Planck collaboration)

On-Shell Regime:

- Mediator mass $m_{Z'} > 2m_{DM}$
- Mediator can be a real particle
- $m_V = 2.1m_\chi$, $m_V = 3m_\chi$, $m_V = 5m_\chi$

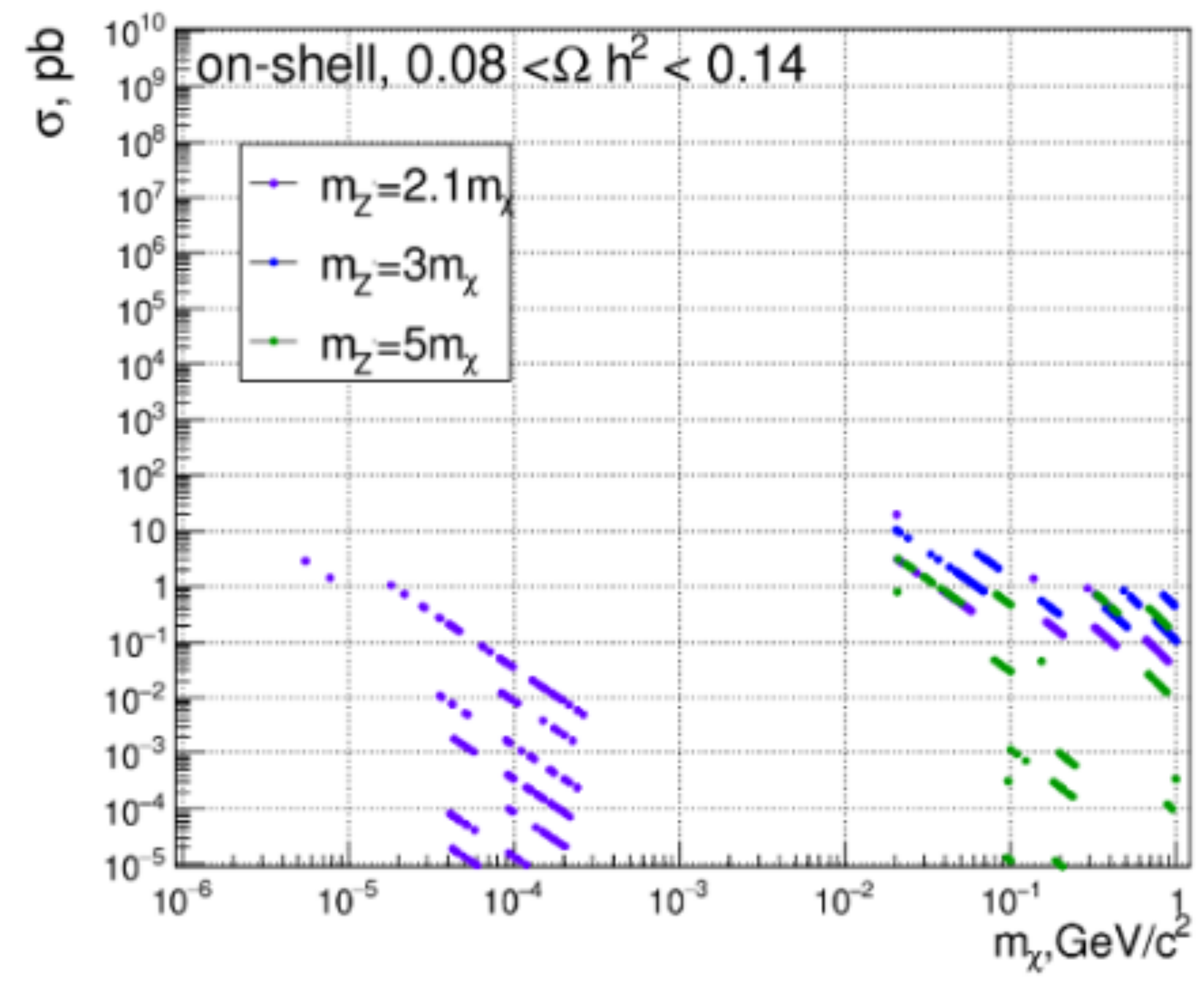
Off-Shell Regime:

- Mediator mass $m_{Z'} < 2m_{DM}$
- Mediator is virtual
- $m_V = 0.5m_\chi$, $m_V = 0.1m_\chi$, $m_V = 0.01m_\chi$

Cross-section:

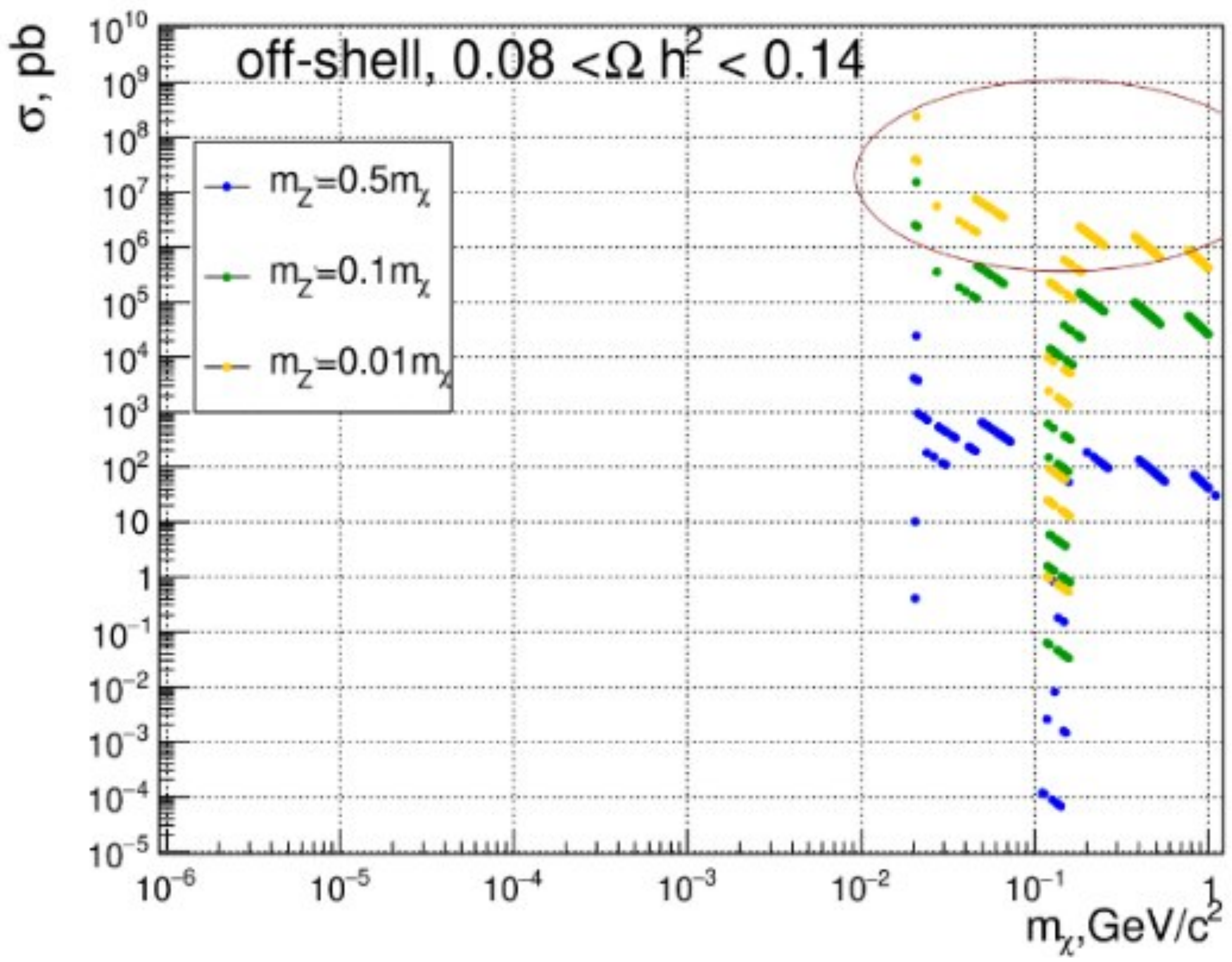
Choose model points where the calculated relic density (Ωh^2) is close to the observed value of 0.12

!Ensures that selected DM models are consistent with cosmological observations of dark matter abundance in the universe.



On-shell regime.

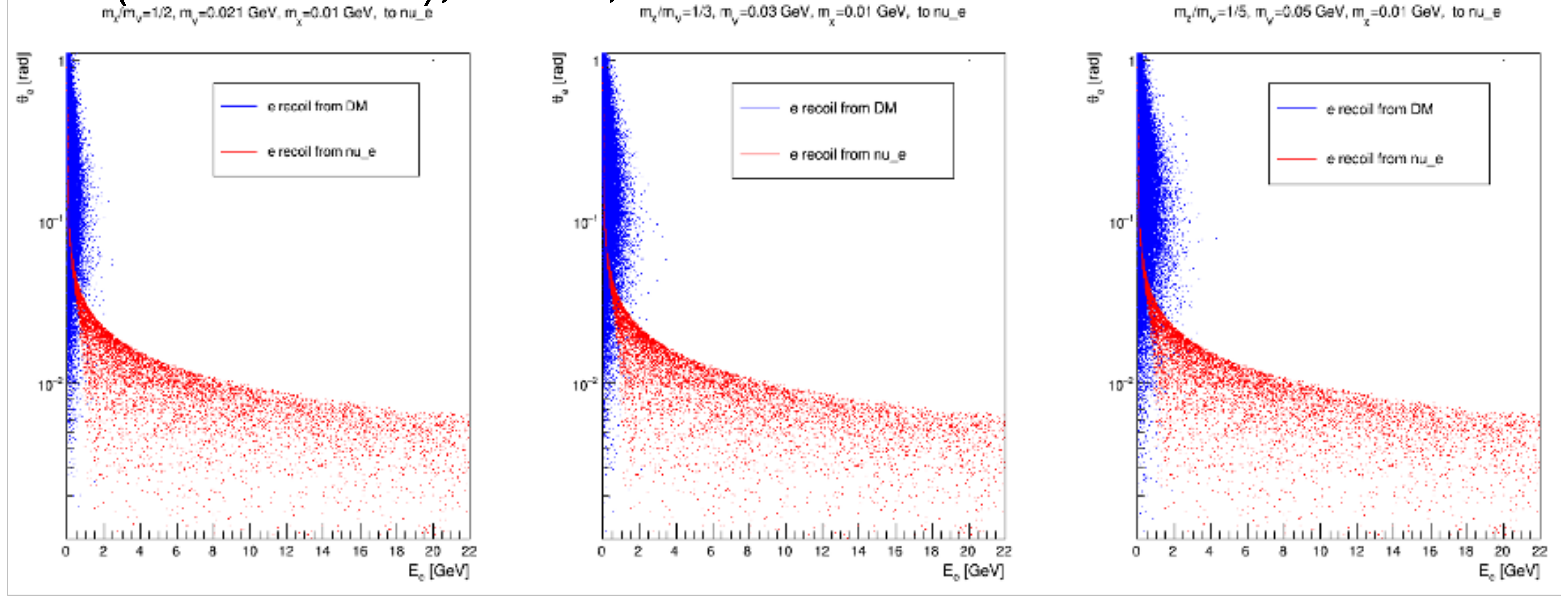
Quasi elastic cross section values for Z' model space parameters in the close vicinity of the Ωh^2 = 0.12



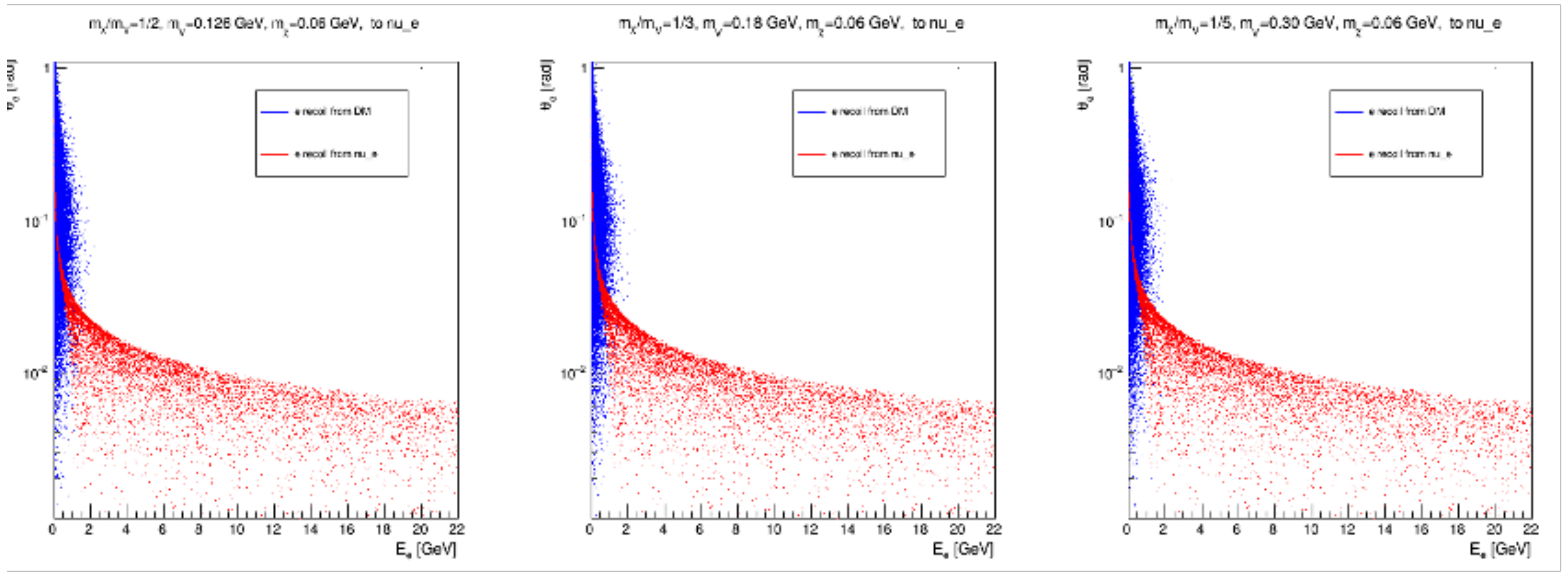
Off-shell regime.

Quasi elastic cross section values for Z' model space parameters in the close vicinity of the Ωh^2 = 0.12

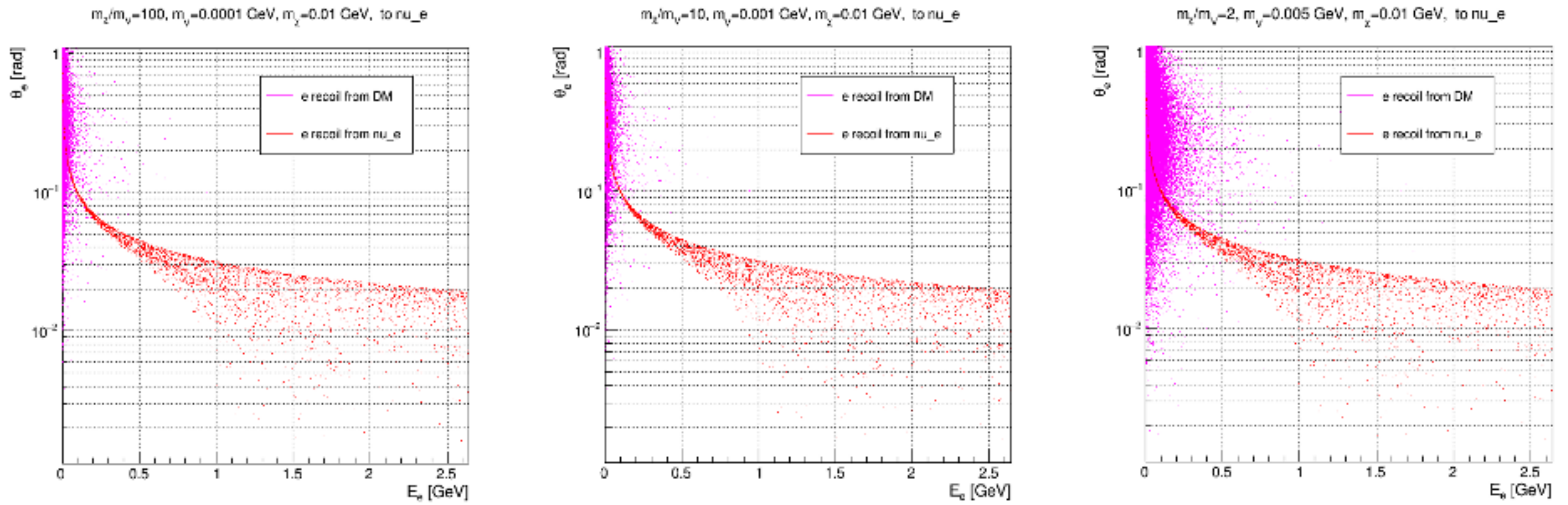
DM (m=0.01 GeV), scalar, on shell



DM (m=0.06 GeV), scalar, on shell



DM (m=0.01 GeV), scalar, off shell



π0 decay: Main channel for low mediator masses, effective for low-energy LDM detection.

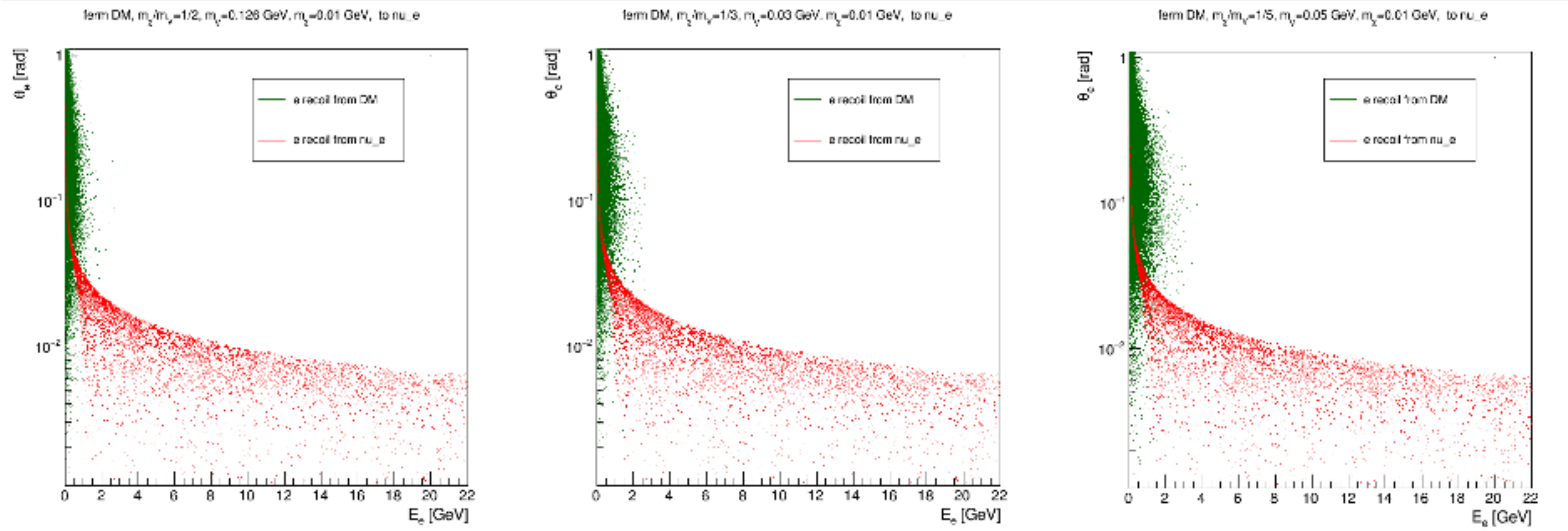
on shell
#dark_matter_mass 0.01 #dark_photon_mass 0.03
#dark_matter_mass 0.01 #dark_photon_mass 0.05
#dark_matter_mass 0.01 #dark_photon_mass 0.021

off shell
#dark_matter_mass 0.01 #dark_photon_mass 0.005
#dark_matter_mass 0.01 #dark_photon_mass 0.001
#dark_matter_mass 0.01 #dark_photon_mass 0.0001

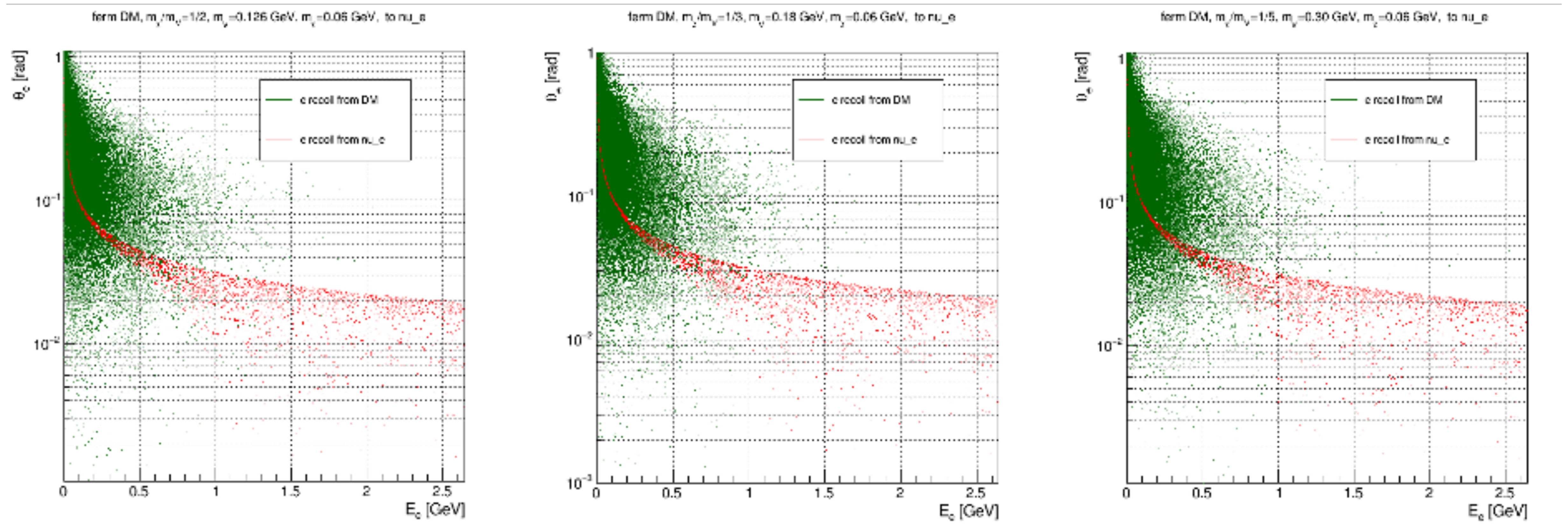
#dark_matter_mass 0.06 #dark_photon_mass 0.03
#dark_matter_mass 0.06 #dark_photon_mass 0.006
#dark_matter_mass 0.06 #dark_photon_mass 0.0006

Simulated mass ratios for scalar and fermionic DM, both on-shell and off-shell

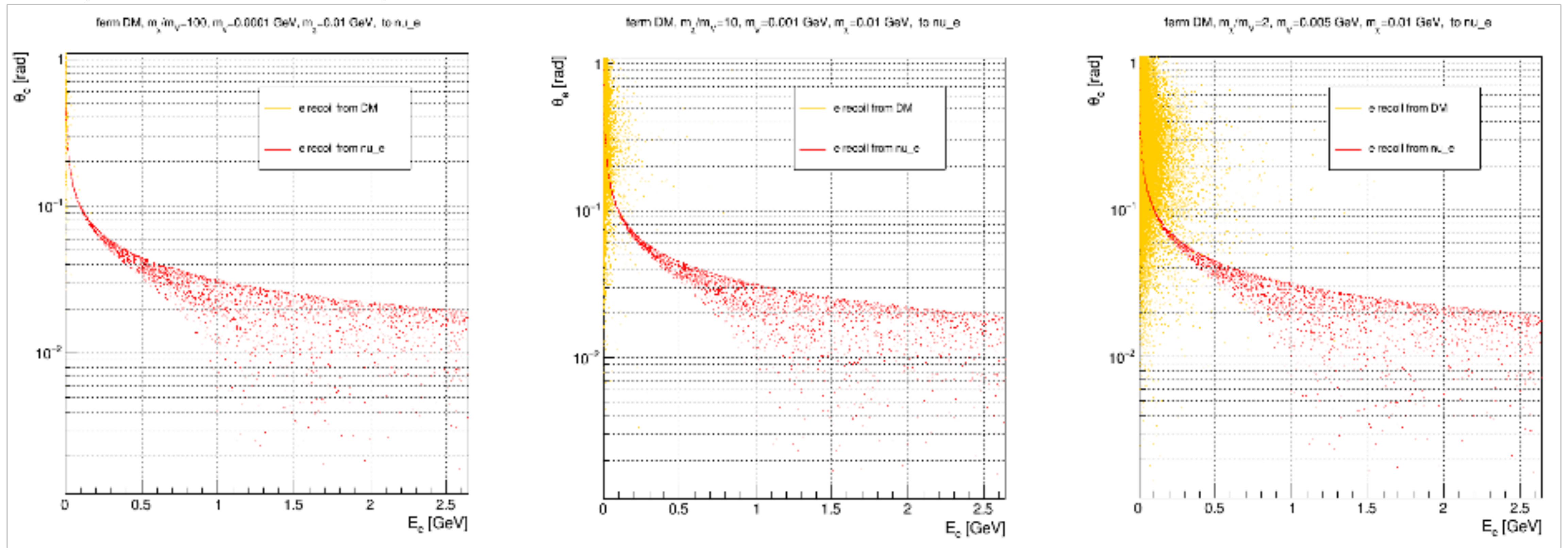
DM (m=0.01 GeV), fermion, on shell



DM (m=0.06 GeV), fermion, on shell



DM (m=0.01 GeV), fermion, off shell



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off shell
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#dark_matter_mass 0.01 #dark_photon_mass 0.001
#dark_matter_mass 0.01 #dark_photon_mass 0.0001

#dark_matter_mass 0.06 #dark_photon_mass 0.03
#dark_matter_mass 0.06 #dark_photon_mass 0.006
#dark_matter_mass 0.06 #dark_photon_mass 0.0006

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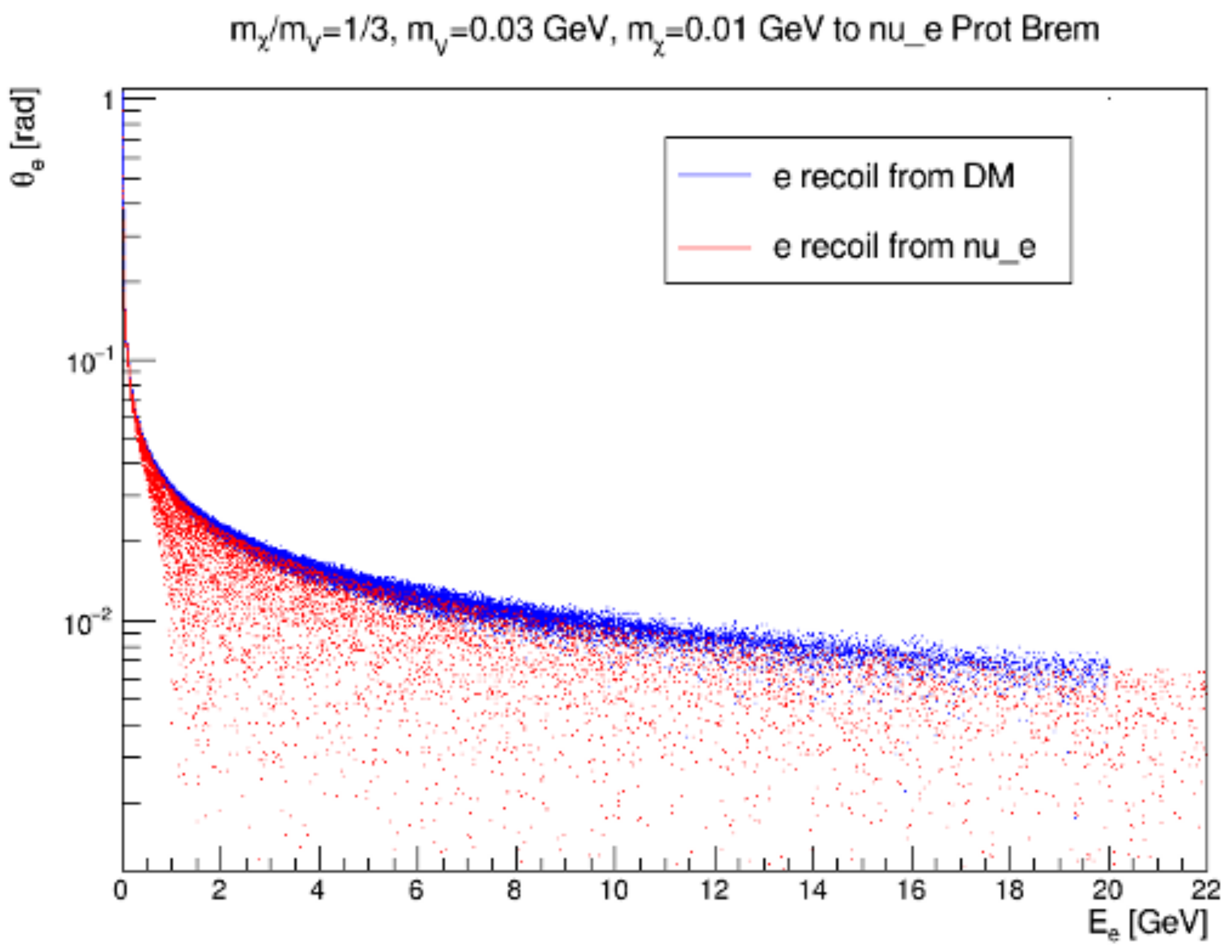
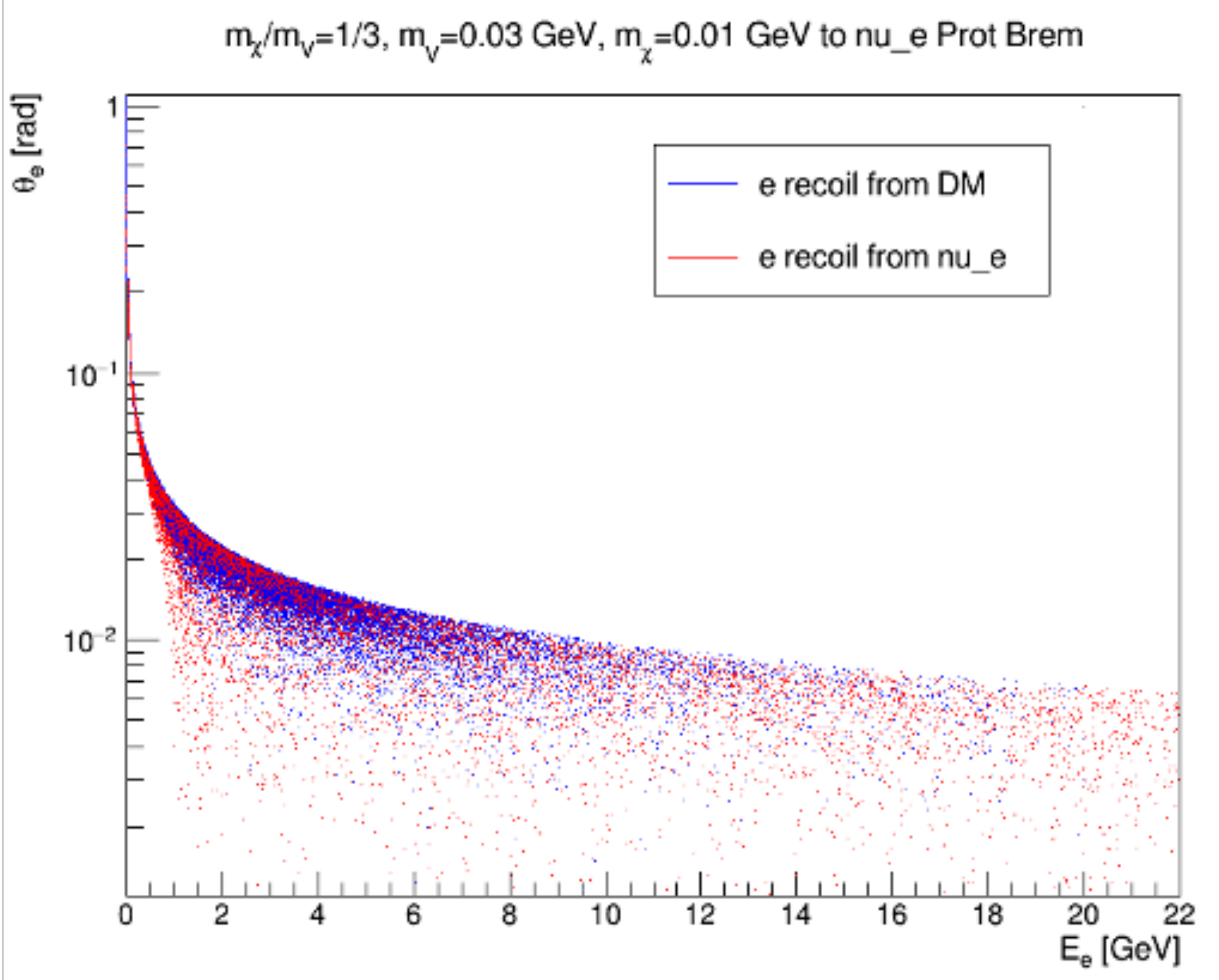
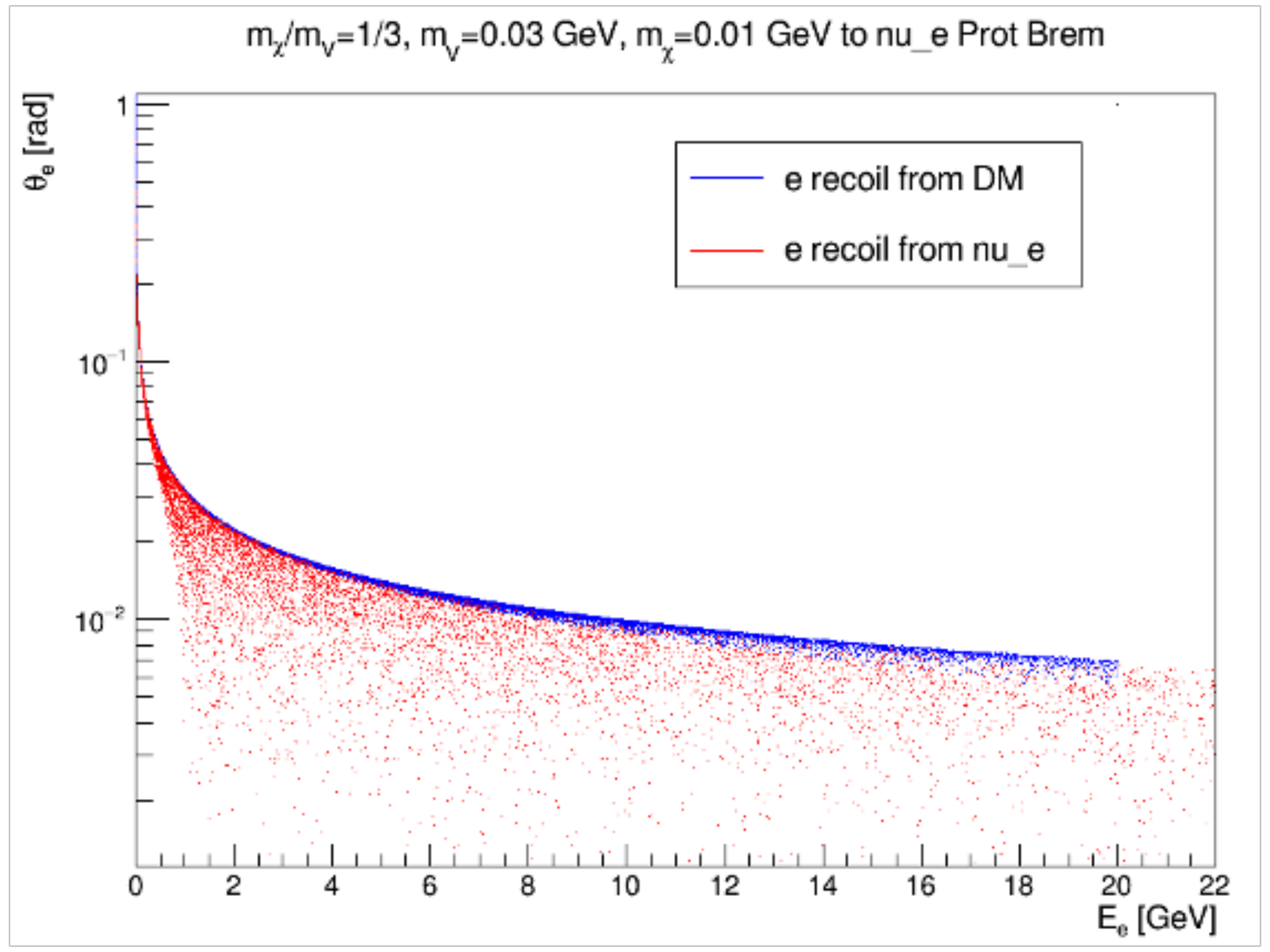


ptmax 0.2
zmin 0.3
zmax 0.7



ptmax 0.02
zmin 0.3
zmax 0.9



ptmax 0.02
zmin 0.8
zmax 0.9

ptmax: The maximum transverse momentum which a produced V mediator may possess. The minimum is assumed to be 0.

zmin: The minimum value of $z = \frac{p_{V,z}}{P}$, where $p_{V,z}$ is the momentum of the V parallel to the z axis, and P is the total momentum of a beam proton incident on the target. See below for further details on choosing these parameters.

zmax: The maximum value of z, defined as in the **zmin**.

For the proton bremsstrahlung channel, we examine how varying parameters such as pTmax , zmin , and zmax affect LDM distribution in the detector
(needs to be checked with Maksym)