Loop Effects of an Effective Dark Matter Model on Dilepton Production

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Trajectory

Interference effects

Motivation for model

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The Effective Model

LHC phenomenology

↓

WIMP behavior

Experimental constraints

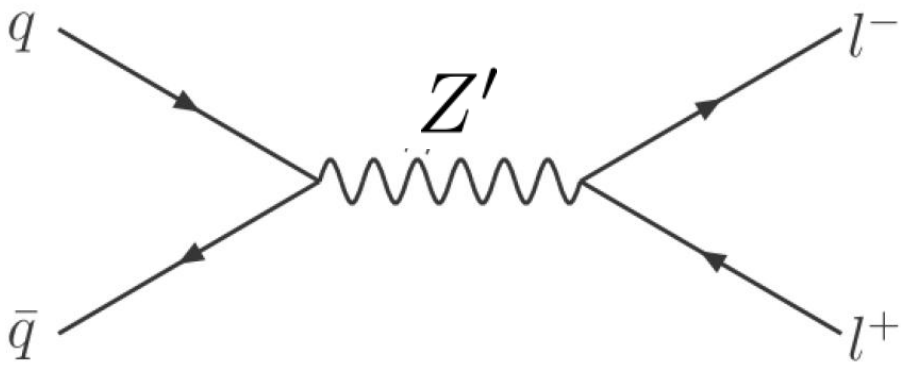
Cosmology, direct detection, collider

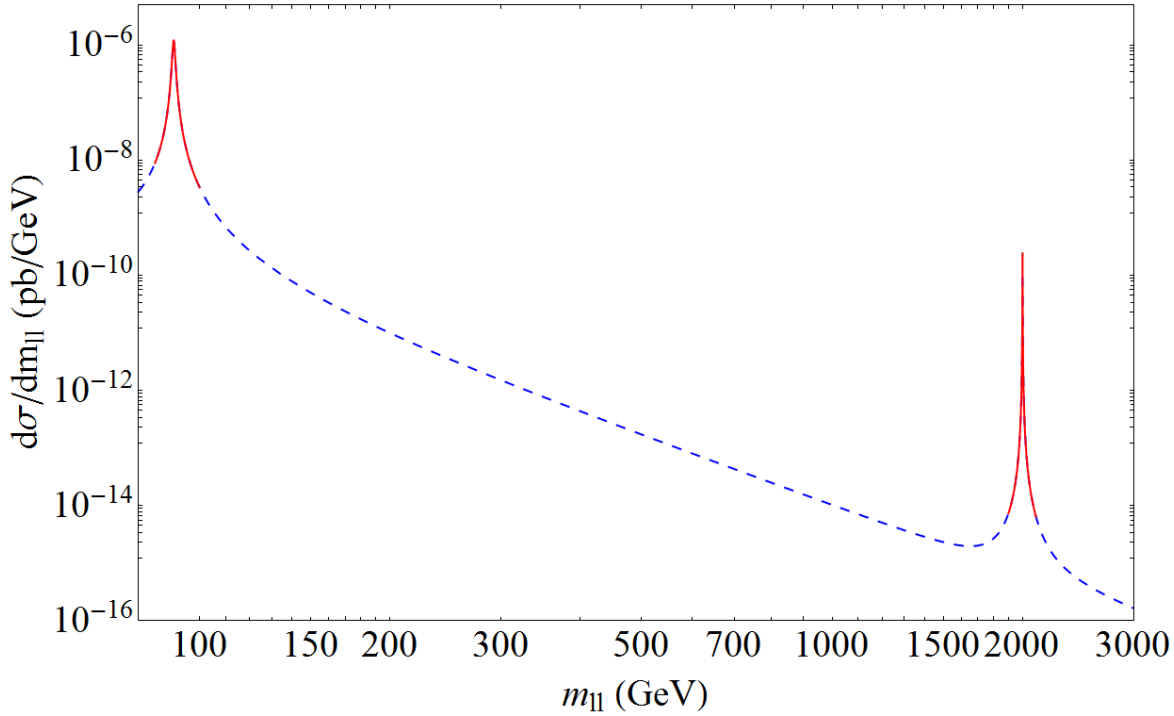
↓

Conclusions

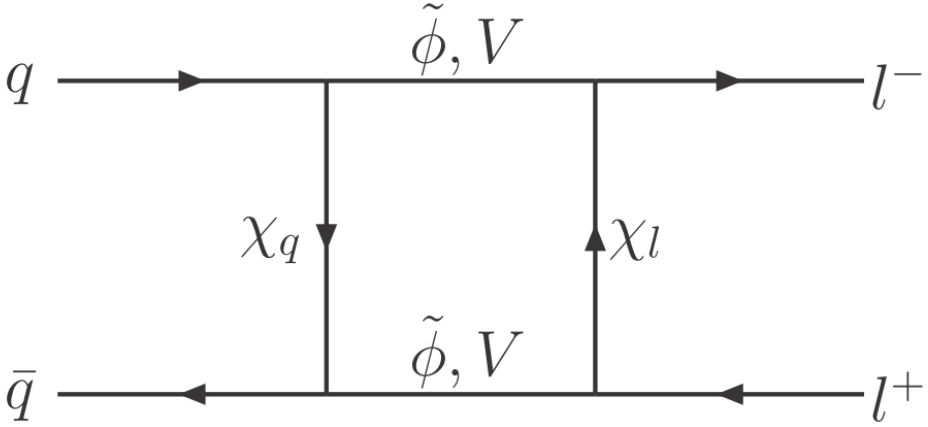
Future programs

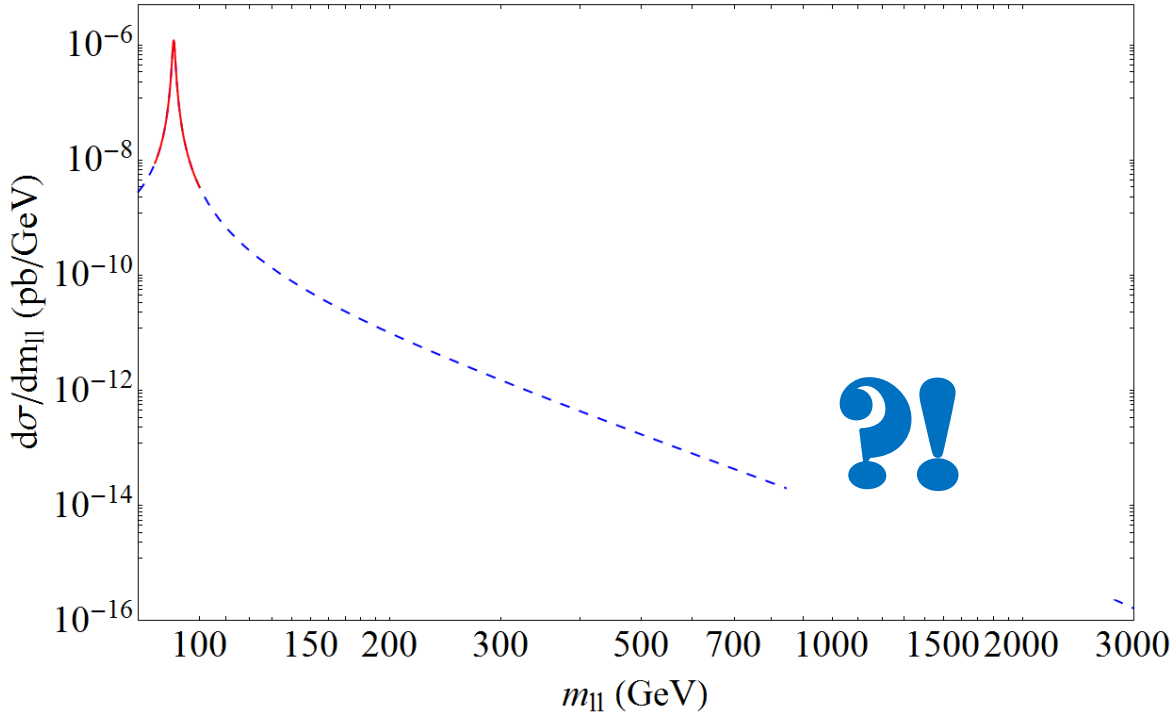
Neutral Current Drell–Yan



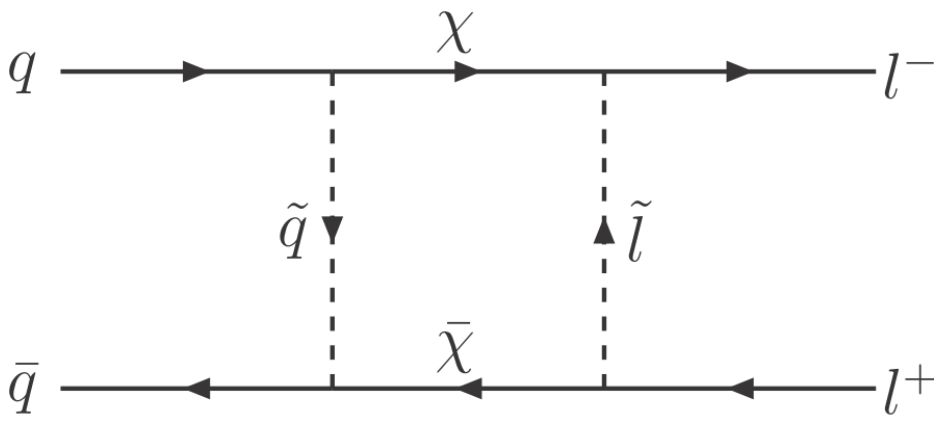


Neutral Current Drell–Yan





Compelling scenario



If (a) $M_\chi < M_\varphi$,

(b) stability of χ insured by a discrete symmetry,

an effective dark matter model

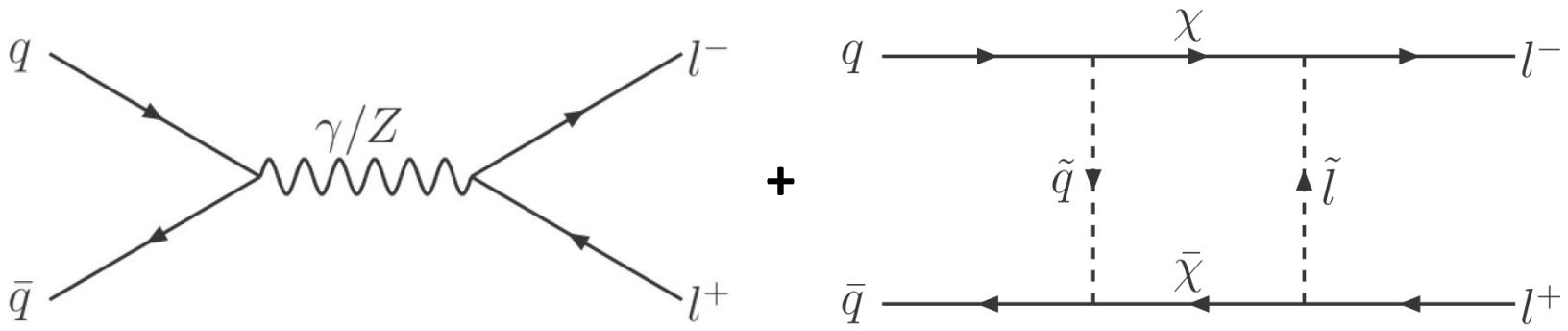
B and L conservation

∴ first place to study at the LHC

Inspired by SUSY, but couplings undetermined

Splitting the Amplitude – Dirac Case

"Toy example"



$$|A_{\text{tree}} + A_{\text{box}}|^2$$

$$\sigma_{\text{tree}} + \sigma_{\text{int}} + \sigma_{\text{box}}$$

$$|A_{\text{tree}} + A_{\text{box}}^{\text{real}} + iA_{\text{box}}^{\text{imag}}|^2$$

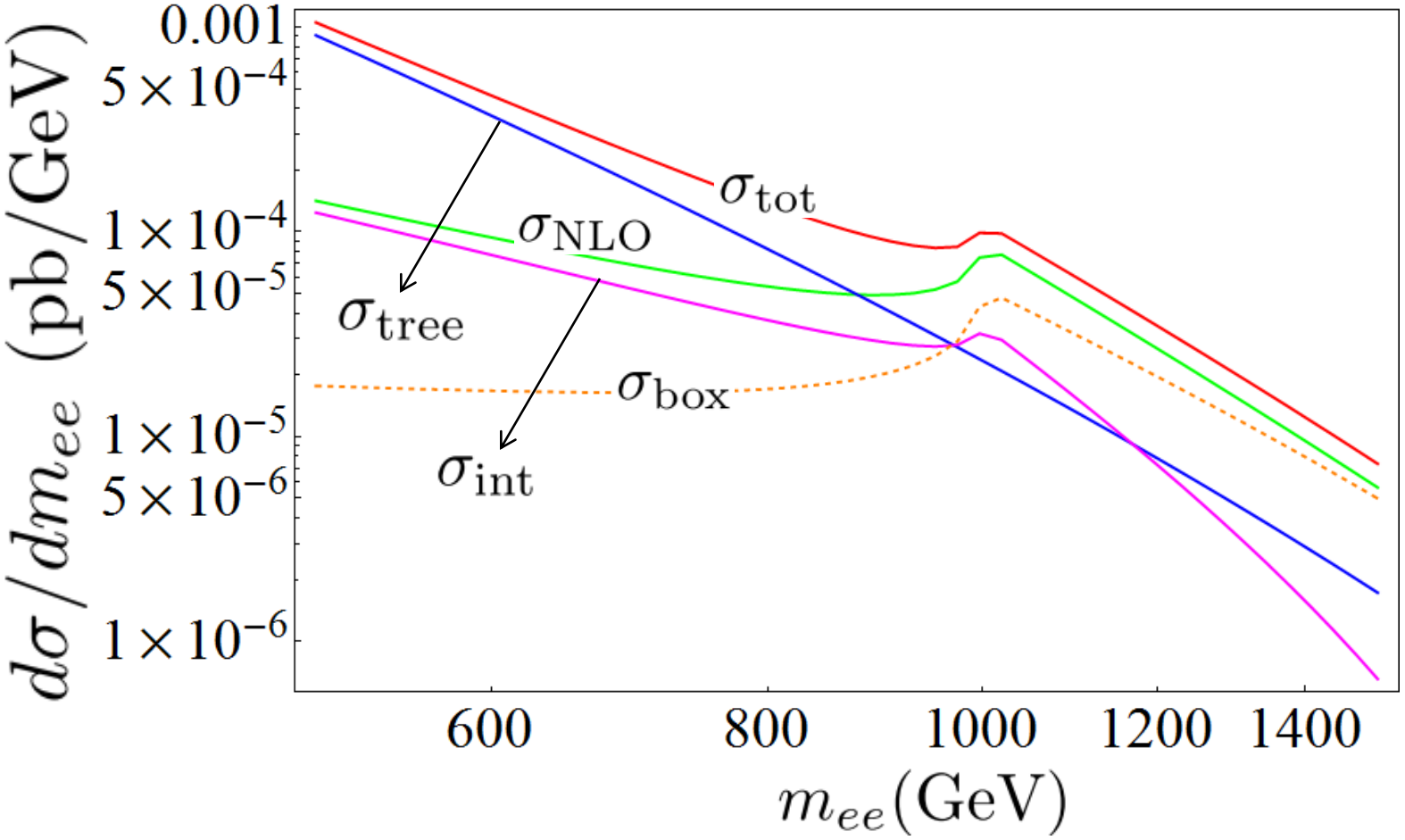
from Optical Theorem

$$\sigma_{\text{tree}} + \sigma_{\text{int}} + \sigma_{\text{box}}^{\text{real}} + \sigma_{\text{box}}^{\text{imag}}$$

Affects both $d\sigma/dm_{ll}$ **and** $d\sigma/d\cos\theta$

Dilepton Spectrum – Dirac Case

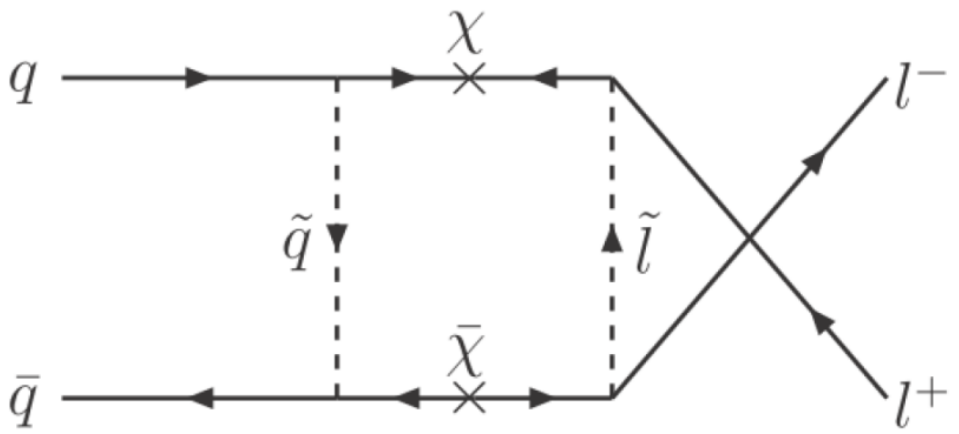
$$\lambda_u = 1.8, M_\chi = M_\phi = 500 \text{ GeV}$$



$\tilde{q}\ (3, 1, \frac{2}{3})$ $\quad$ $\tilde{l}\ (1, 1, -1)$ $\quad$ $\chi\ (1, 1, 0)$

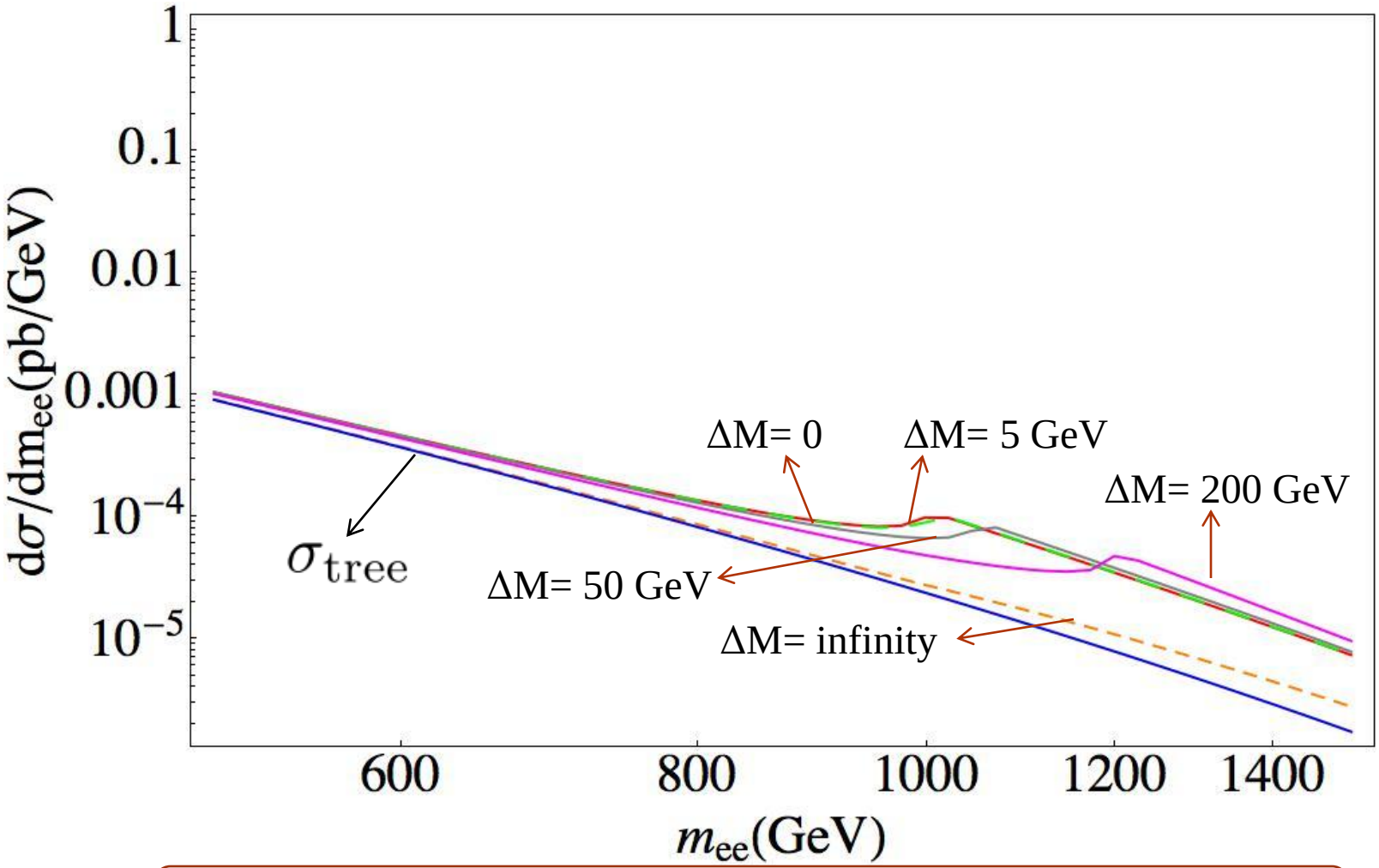
Dark matter?

	Dirac	Majorana	Pseudo-Dirac
Direct detection	✗ Vector–vector operator	✓ Quark twist–2 or spin–dependent	✓ Majorana–like
Dilepton signature	✓ Distinct feature	✗ Suppressed effect	✓ Dirac–like



Pseudo-Dirac: Dilepton Spectrum

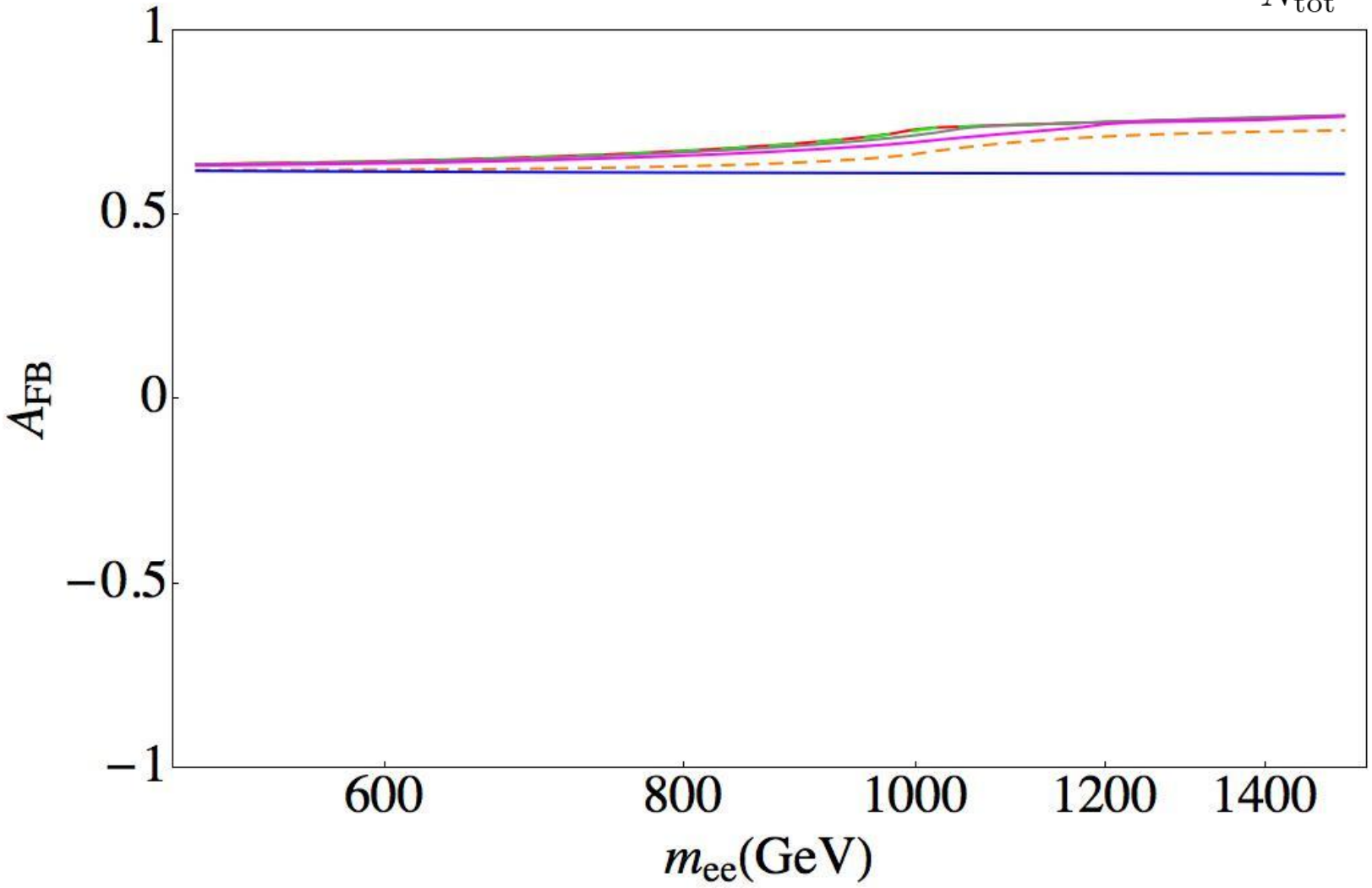
$$\lambda_u = 1.8, M_\chi = M_\phi = 500 \text{ GeV}$$



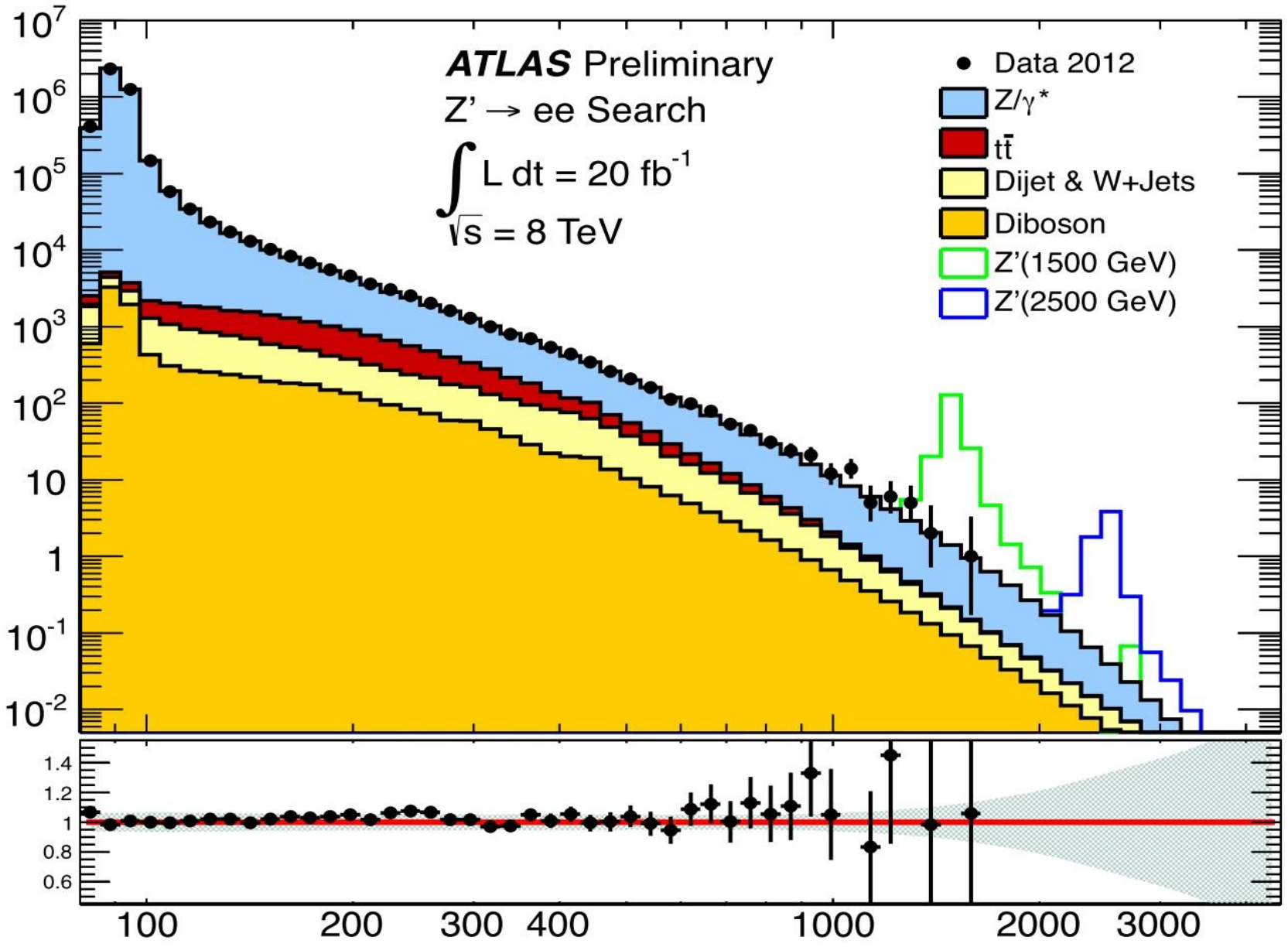
$\tilde{q}\ (3, 1, \frac{2}{3})$ $\tilde{l}\ (1, 1, -1)$ $\chi\ (1, 1, 0)$

Forward-backward Asymmetry

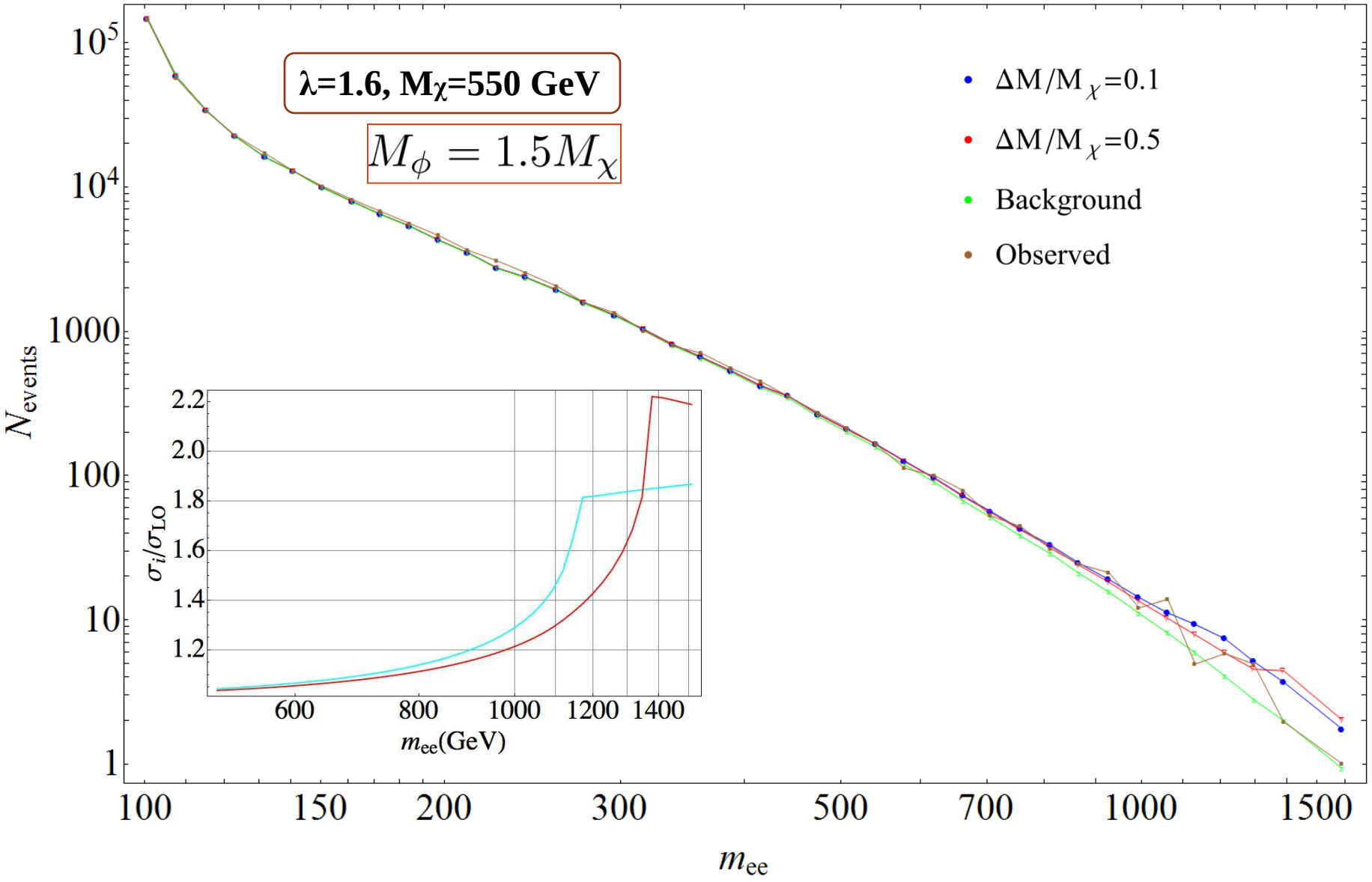
$$A_{FB} = \frac{\int_0^1 dc_\theta (d\sigma/dc_\theta) - \int_{-1}^0 dc_\theta (d\sigma/dc_\theta)}{\int_{-1}^1 dc_\theta (d\sigma/dc_\theta)} = \frac{\sigma_F - \sigma_B}{\sigma_{\rm tot}} = \frac{N_F - N_B}{N_{\rm tot}}$$



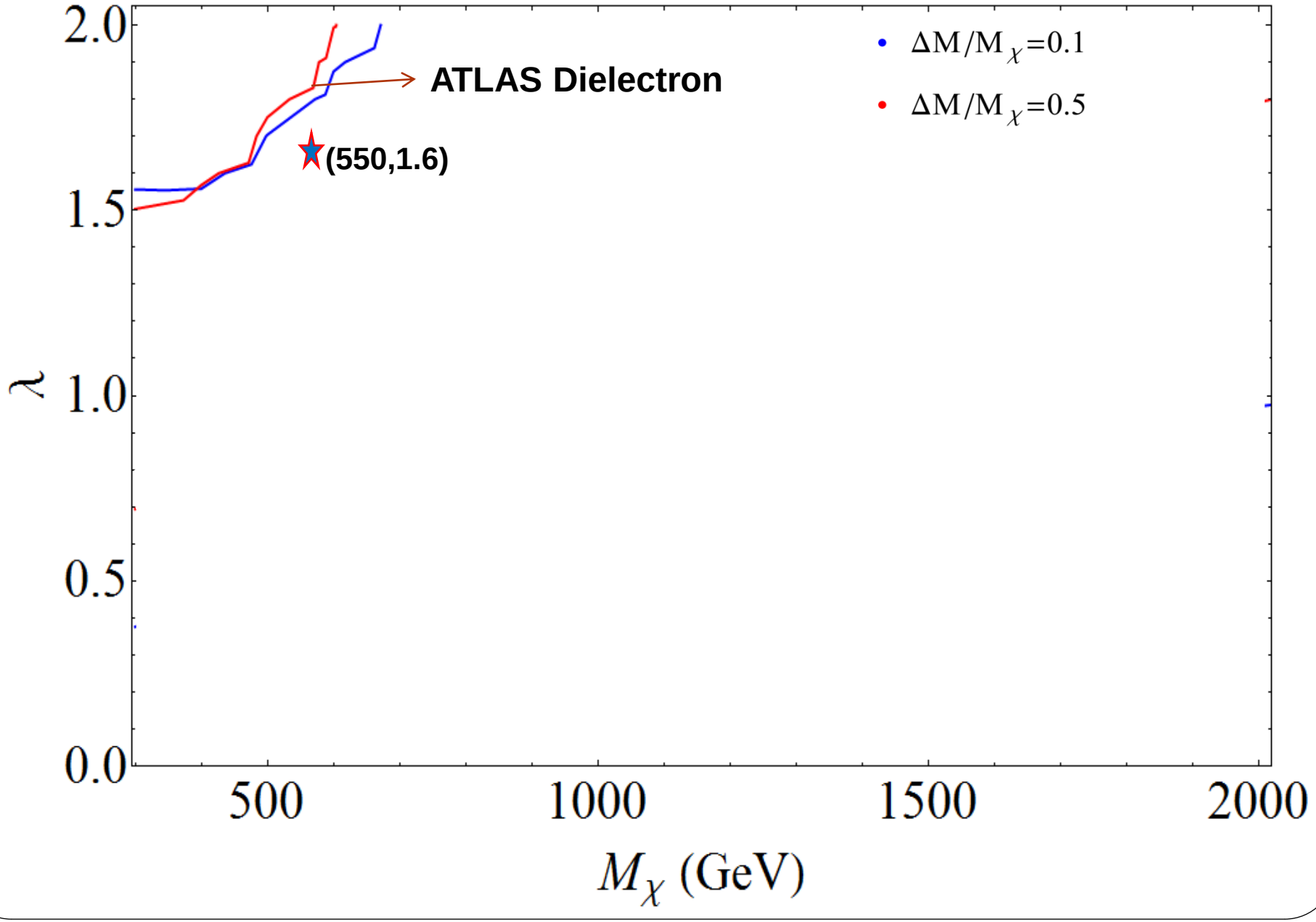
Realistic Signals



Realistic Signals



Constraints: $M_\phi = 1.5 M_\chi$



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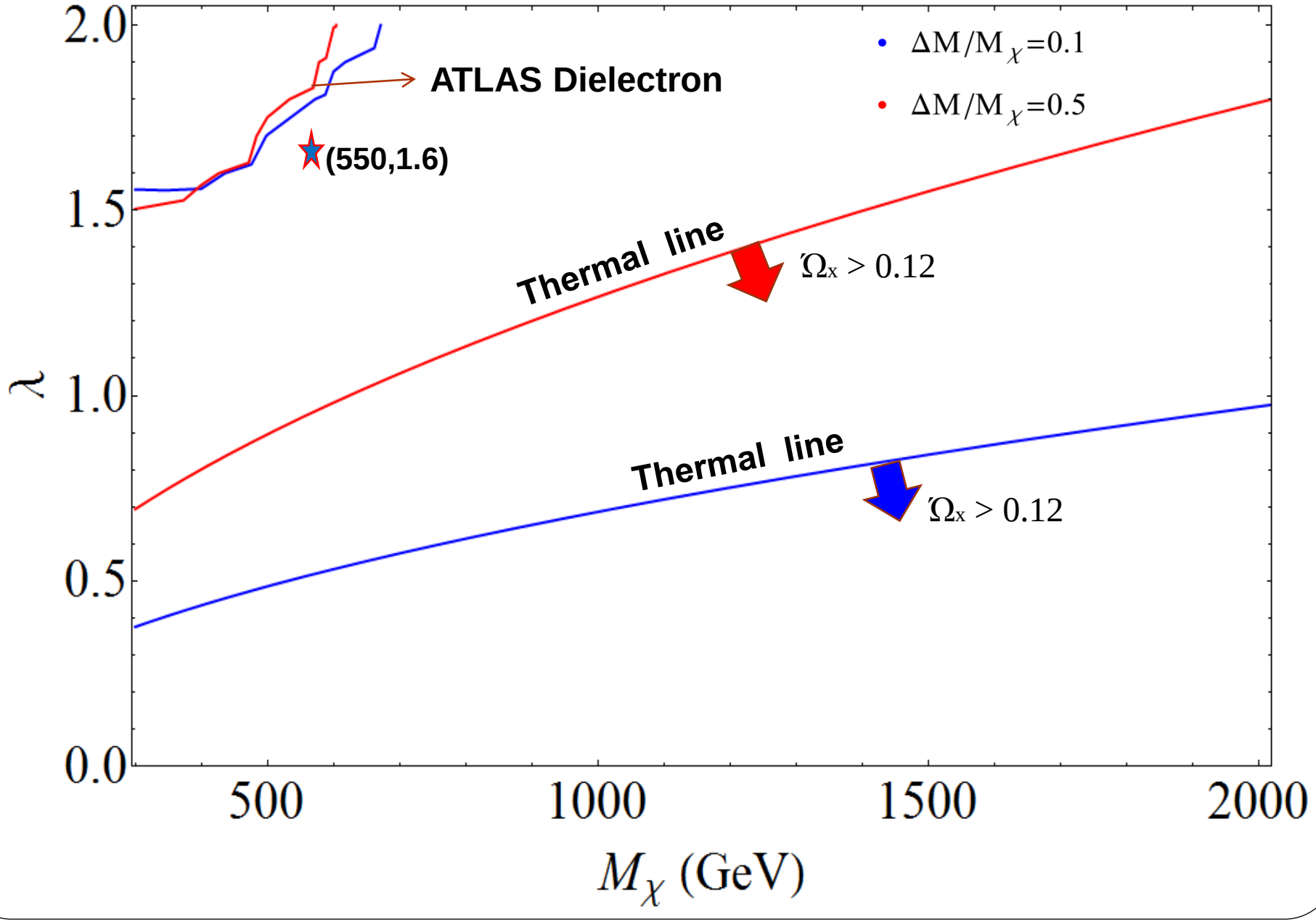

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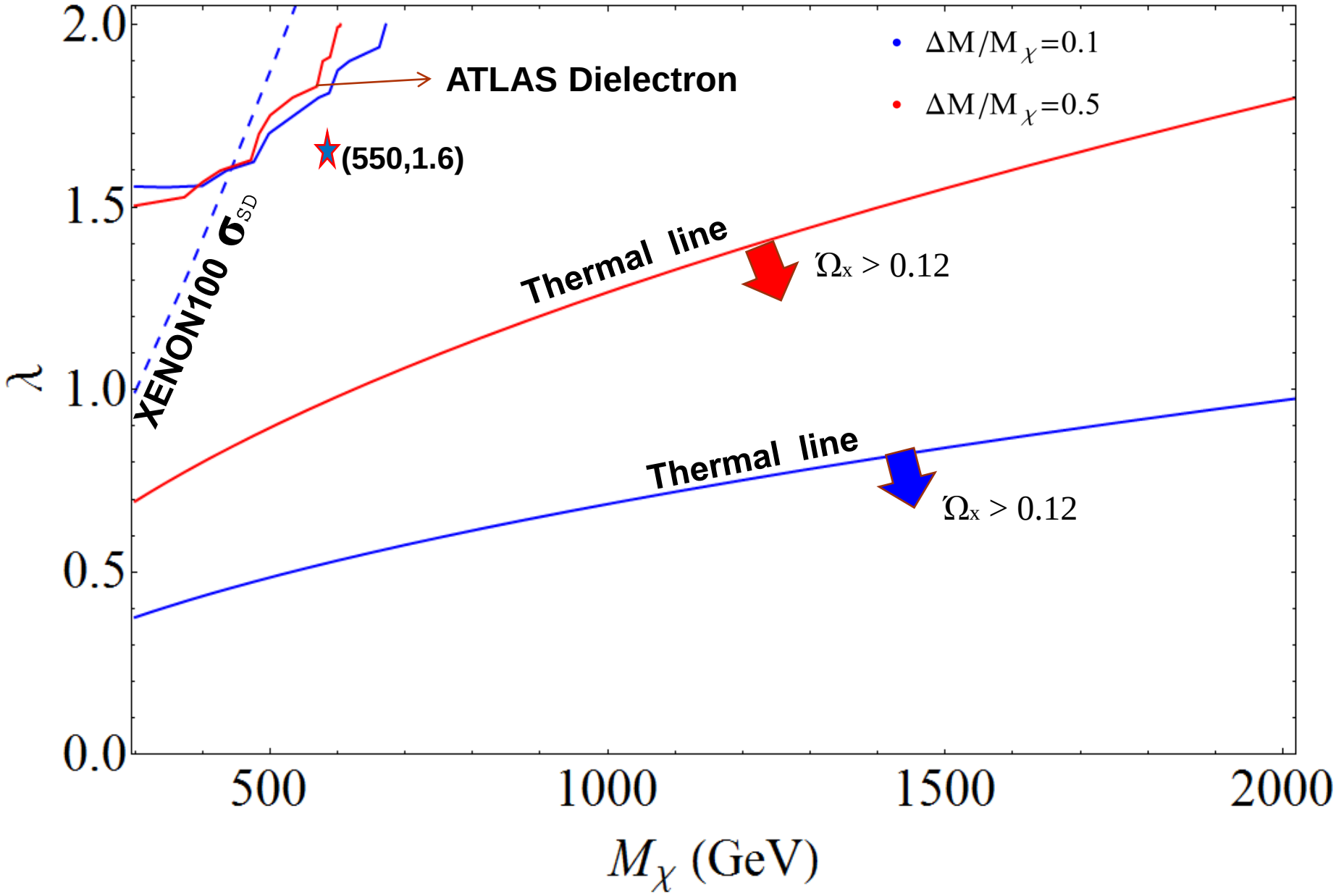

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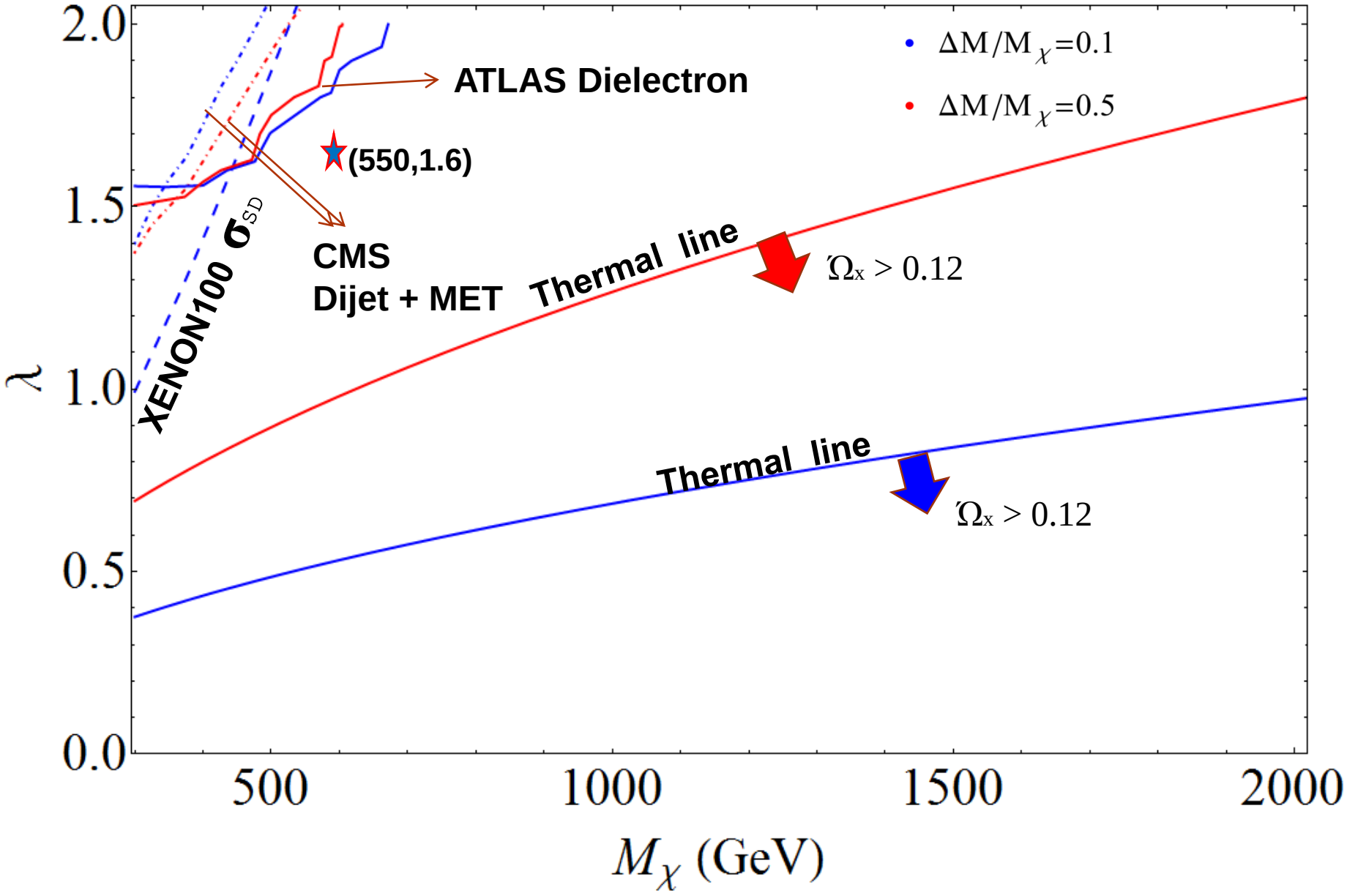
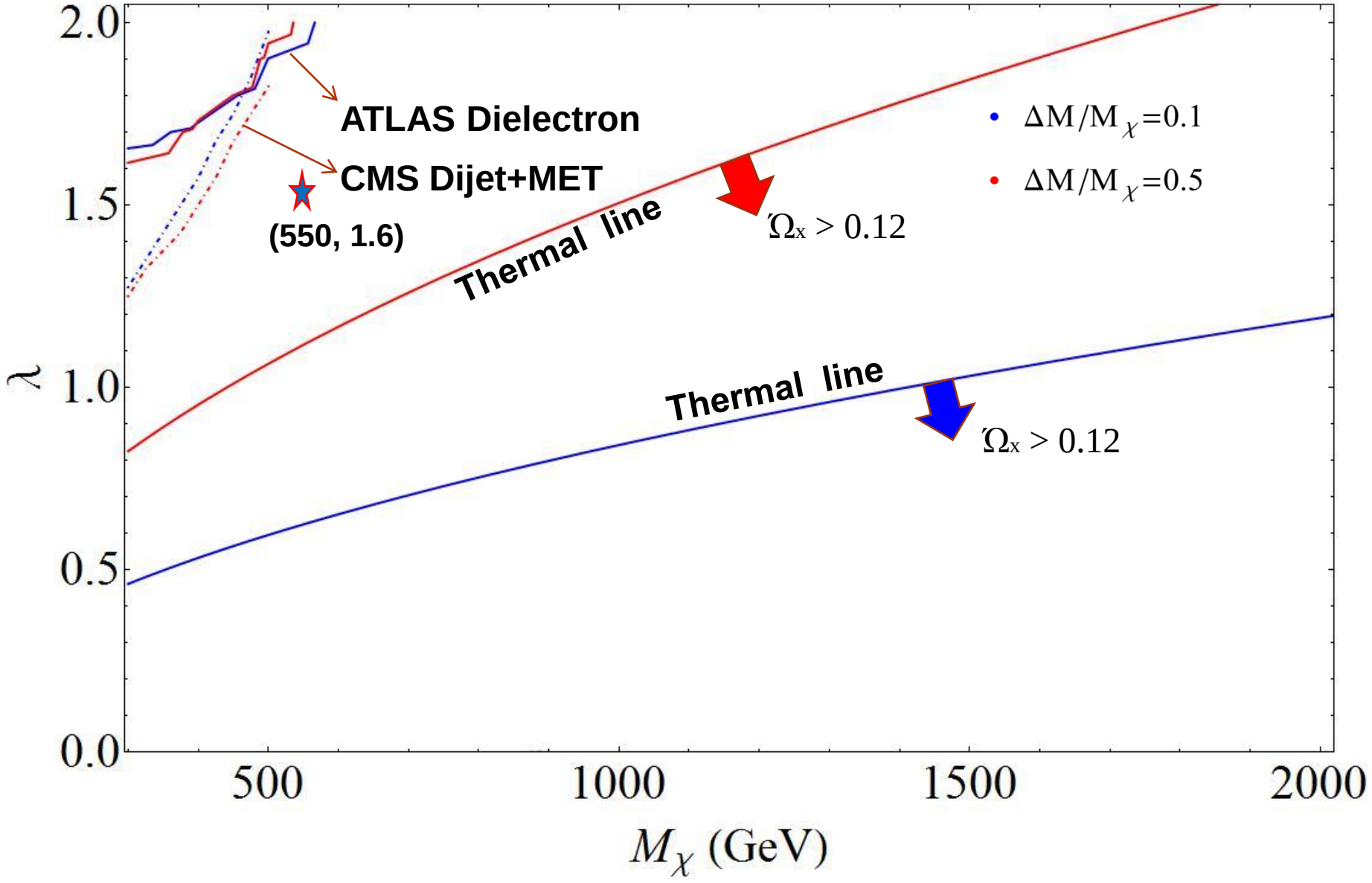


Constraints: $M_\phi = 2M_\chi$



Future directions

UV completion

Non-minimal scenarios

Scalar DM + fermion mediator

More angular observables

Electron direct detection

References

ATLAS Drell-Yan Results

Phys. Lett. B 725, 223 (2013)

CMS Drell-Yan Results

Phys. Lett. B 718 (2013) 752–772

Effective WIMPs

Chang, Edezhath, Hutchinson, Luty: Phys. Rev. D 89, 015011 (2014)

Pseudo-Dirac Dark Matter Leaves a Trace

De Simone, Sanz, Sato: arxiv:1004.1567v2

XENON100 225-Day Results

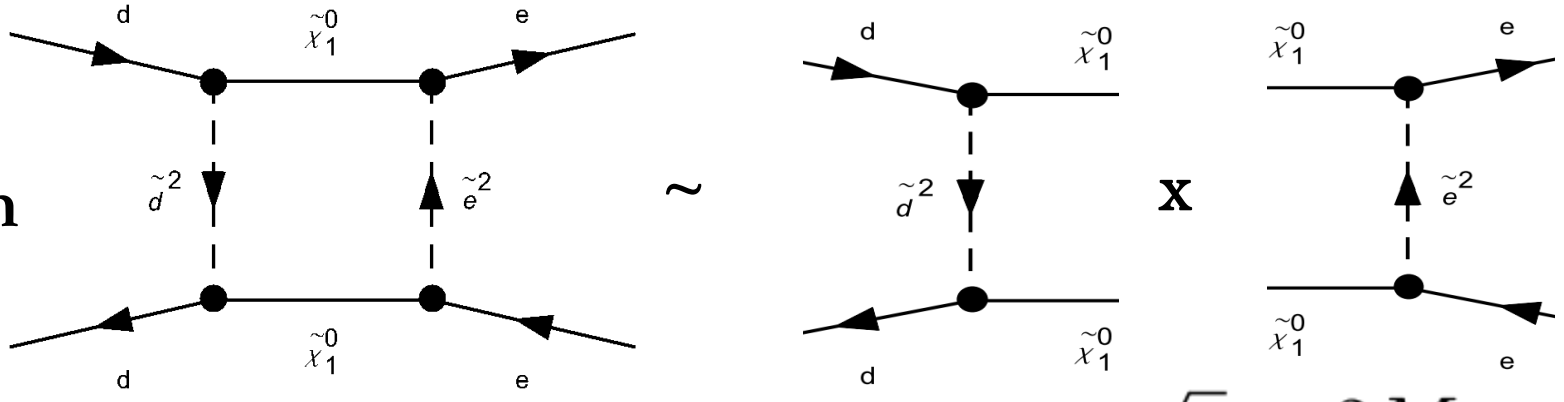
Phys. Rev. Lett. 109, 181301

CMS Multijets + MET Analysis

CMS-PAS-SUS-13-012

Back-up

Dispersion Relations

Im 

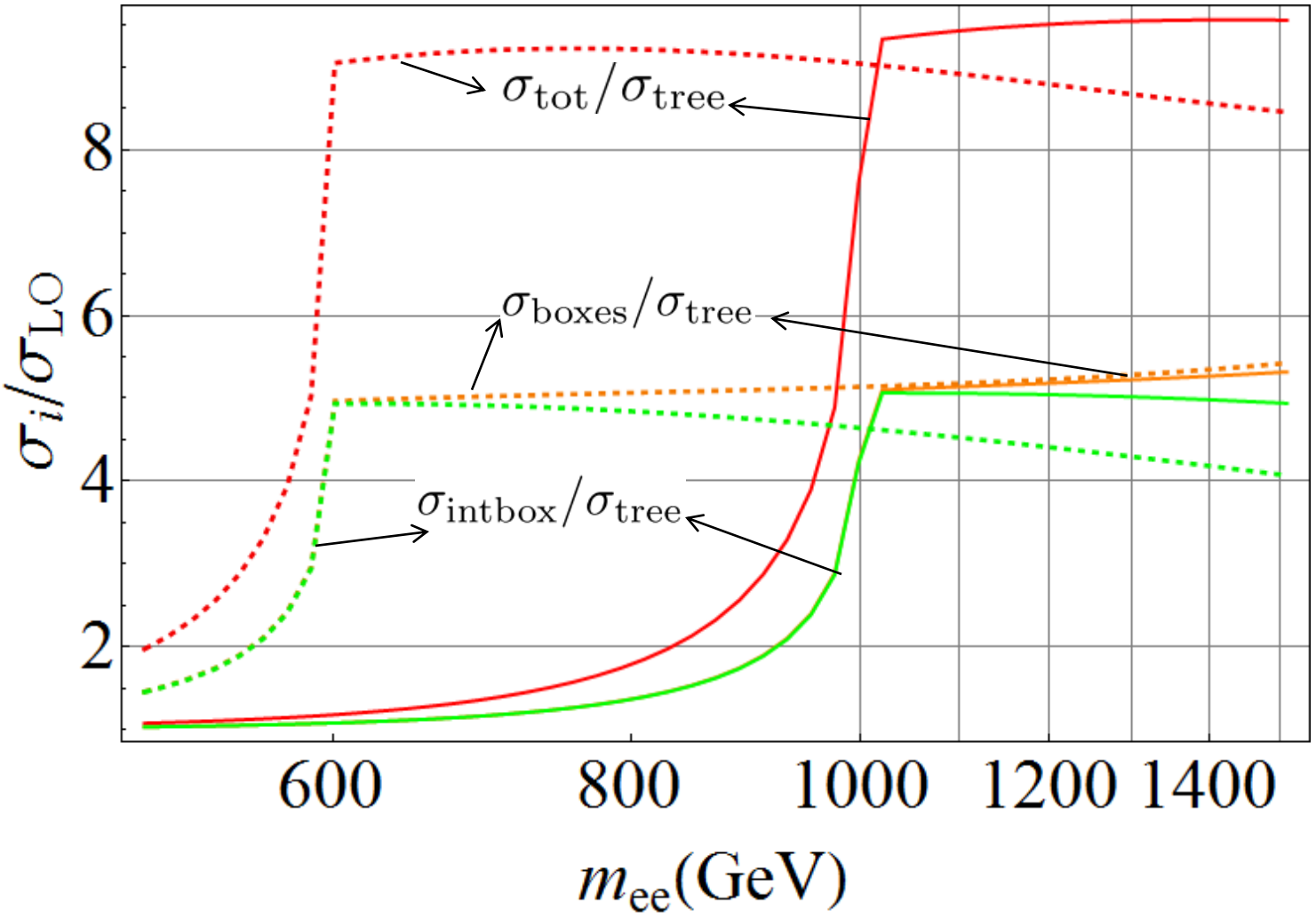
when $\sqrt{s} > 2M_\chi$

OPTICAL THEOREM

$$2\ \mathrm{Im}\ \mathcal{M}(a \to b) = \sum_F \int d\Pi_F \mathcal{M}^*(b \to F)\mathcal{M}(a \to F)$$

$$\mathcal{M}(s_0) = \frac{1}{2\pi i} \int_{4m^2}^{\infty} ds\ 2i\ \frac{\mathrm{Im}(\mathcal{M}(s + i\epsilon))}{s - s_0}$$

Mass-independence



Coupling fixed, mass varied

Dashed: $M_\chi = 300$ GeV
Solid: $M_\chi = 500$ GeV

Collins–Soper Frame

$$\cos\theta^*_{CS} = \frac{Q_z}{|Q_z|}\frac{2(P_1^+P_2^- - P_1^-P_2^+)}{|Q|\sqrt{Q^2+Q_T^2}}, \tag{3}$$

where Q is the four-momentum of the dilepton and Q_T and Q_z are the transverse and longitudinal components of the dilepton momentum with respect to the beam axis; P_1 (P_2) represents the four-momentum of the lepton (antilepton); and $P_i^{\pm} = (P_i^0 \pm P_i^3)/\sqrt{2}$. The quark direction is not determined a priori at the Large Hadron Collider (LHC) [13] because both beams consist of protons. However, because the antiquark is necessarily a sea quark, on average we expect it to carry less momentum than the valence quark, and therefore the dilepton system is usually boosted in the direction of the valence quark [5,14,15]. This assumption is taken into account by including the sign of the longitudinal boost in the definition of $\cos\theta^*_{CS}$. The forward–backward asymmetry is