Constraints from triple gauge couplings on vectorlike leptons

arXiV:1706.03073

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in collaboration with E. Bertuzzo, Y. Perez-Gonzalez, R. Zukanovich Funchal

Feb/2018

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FCC hh ee he

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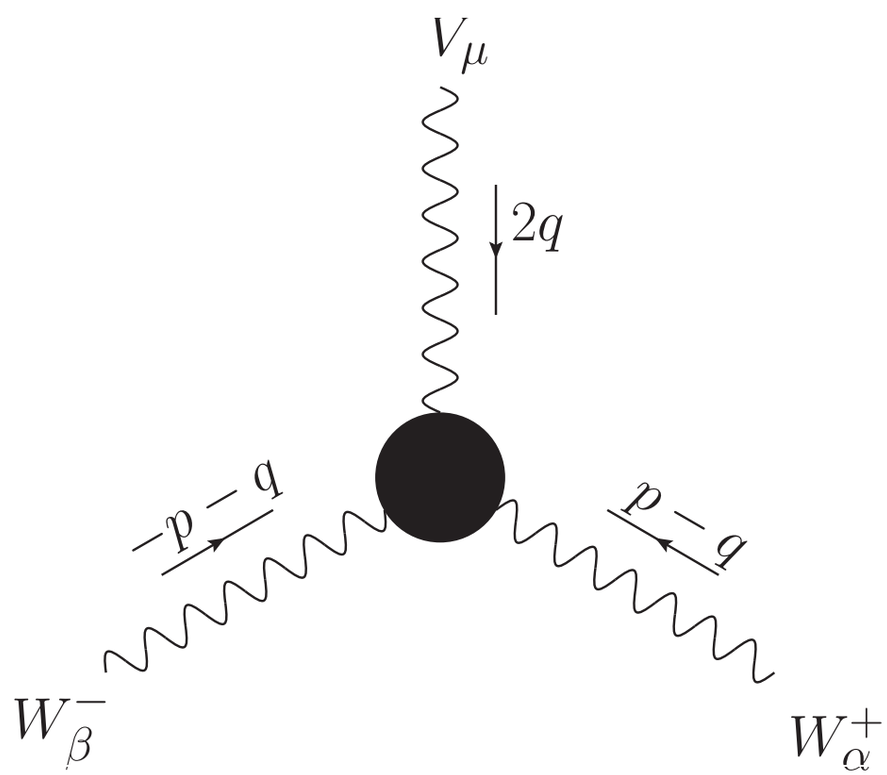
Triple gauge couplings

Triple vector boson interactions are a
direct manifestation of the gauge principle

Deep connection to the SM gauge groups and its particle content

SM has sharp and clean predictions for the TGCs



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Triple gauge couplings

$$\mathcal{L}_{WWV} = -ig_V[(W^\dagger_{\mu\nu}W^\mu V^\nu - W_{\mu\nu}W^{\mu\dagger}V^\nu) + \kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\lambda_V}{M_W^2}W^\dagger_{\mu\tau}W^\tau{}_\nu V^{\nu\mu}$$

$$g_V = \begin{cases} e & \text{for } V = \gamma, \\ e\cot\theta_W & \text{for } V = Z^0 \end{cases}$$

Hagiwara Peccei Zeppenfeld Hikasa 1987

Experimental collaborations work with $\delta\kappa_V = \kappa_V - 1$

TGCs: part of electroweak precision tests - competitive?

1) Case study: vector-like leptons @ FCC-ee, ILC, CLIC
2) Comparison with T parameter (ρ) and Higgs-γγ coupling

Typical sensitivities to TGCs range from about 1~4 x 10^{-4}

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Vectorlike fermions as simplified models

Vectorlike fermions are present in many extensions of the SM

UV complete extensions are typically complex
(SUSY, composite Higgs, twin Higgs, …)

Simplified model approach

Complementary to EFT approach

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Case 1: Unmixed colorless VL fermion

$$SU(2)_L \times U(1)_Y$$

$$\Psi \sim (\mathbf{2j+1}, Y)$$

j=0: singlet
j=1/2: doublet
j=1: triplet
…

$$\Psi = \{\psi_{j,m}\} = \begin{pmatrix} \psi_{j,j} \\ \psi_{j,j-1} \\ \vdots \\ \psi_{j,-j+1} \\ \psi_{j,-j} \end{pmatrix}$$

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$$\mathcal{L} = i\overline{\Psi}\gamma^\mu(\partial_\mu - igW_\mu^a T^a - ig'YB_\mu)\Psi - m_\Psi\overline{\Psi}\Psi$$

SU(2) generators in 2j+1 dimensional rep

Contribution only depend on hypercharge and SU(2) rep

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SU(2) generators in 2j+1 dimensional rep

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$$\delta\kappa_V^\Psi \propto F_j I(m_\Psi) \qquad F_j \equiv N_F\, Y\, \frac{2}{3} j(j+1)(2j+1)$$

$W^+ W^- W^3$ cancel out!
$W^+ W^- B$ is non-zero

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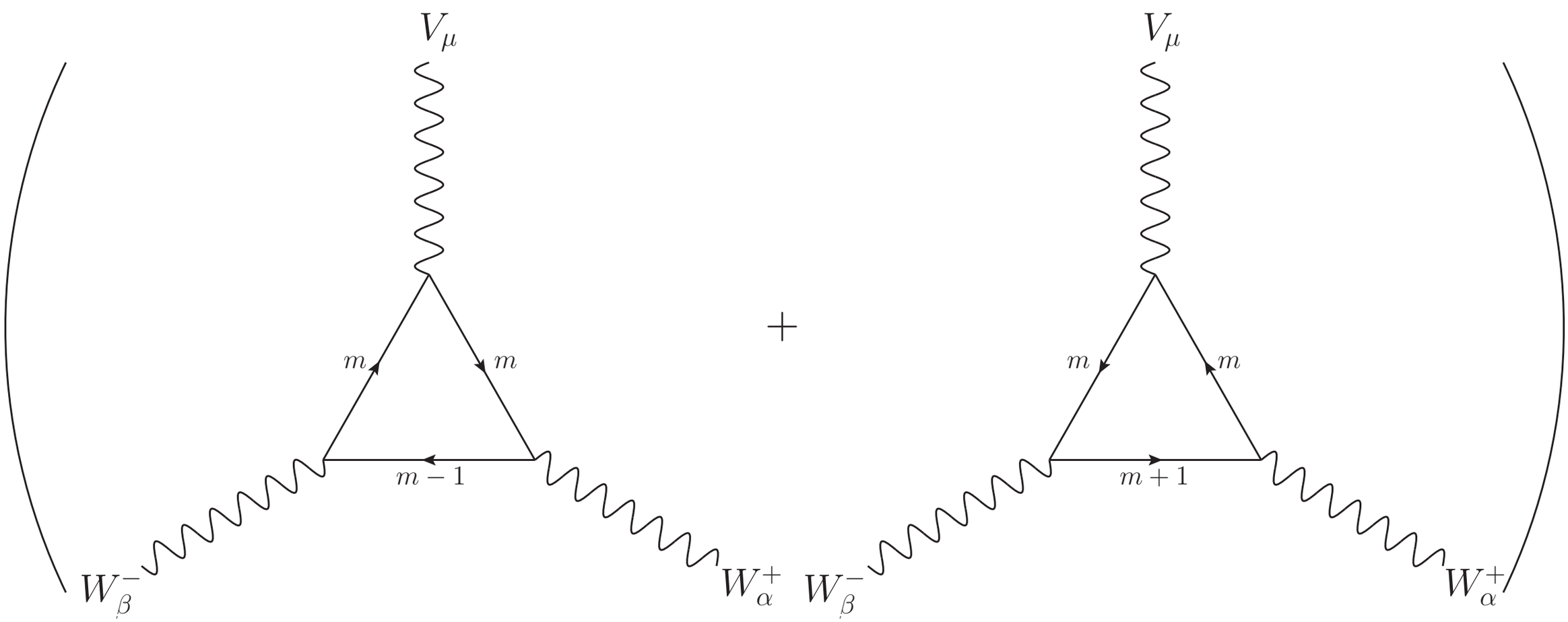
$$\sum_{m=-j}^{j}$$



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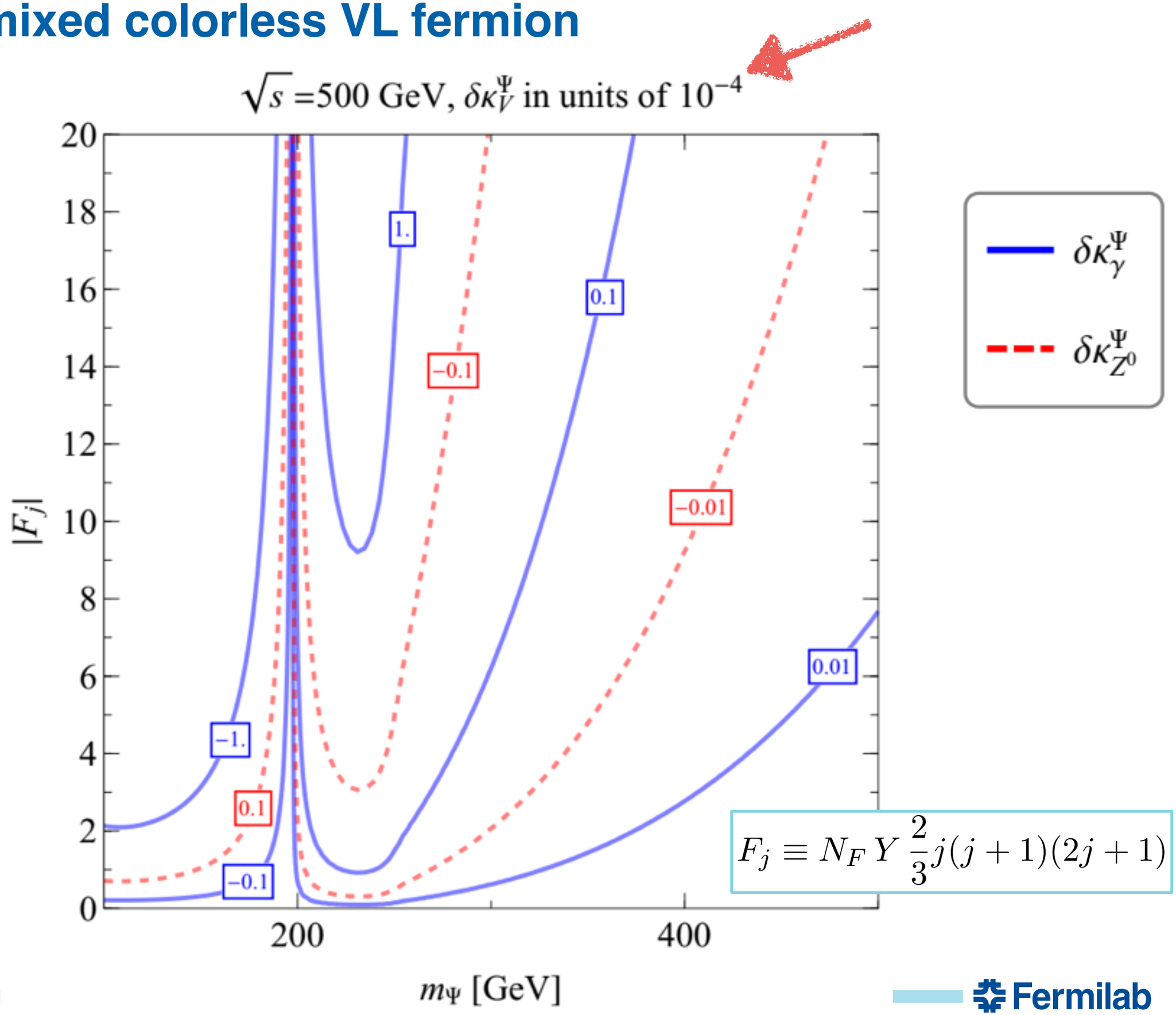

$$F_j \equiv N_F\, Y\, \frac{2}{3} j(j+1)(2j+1)$$

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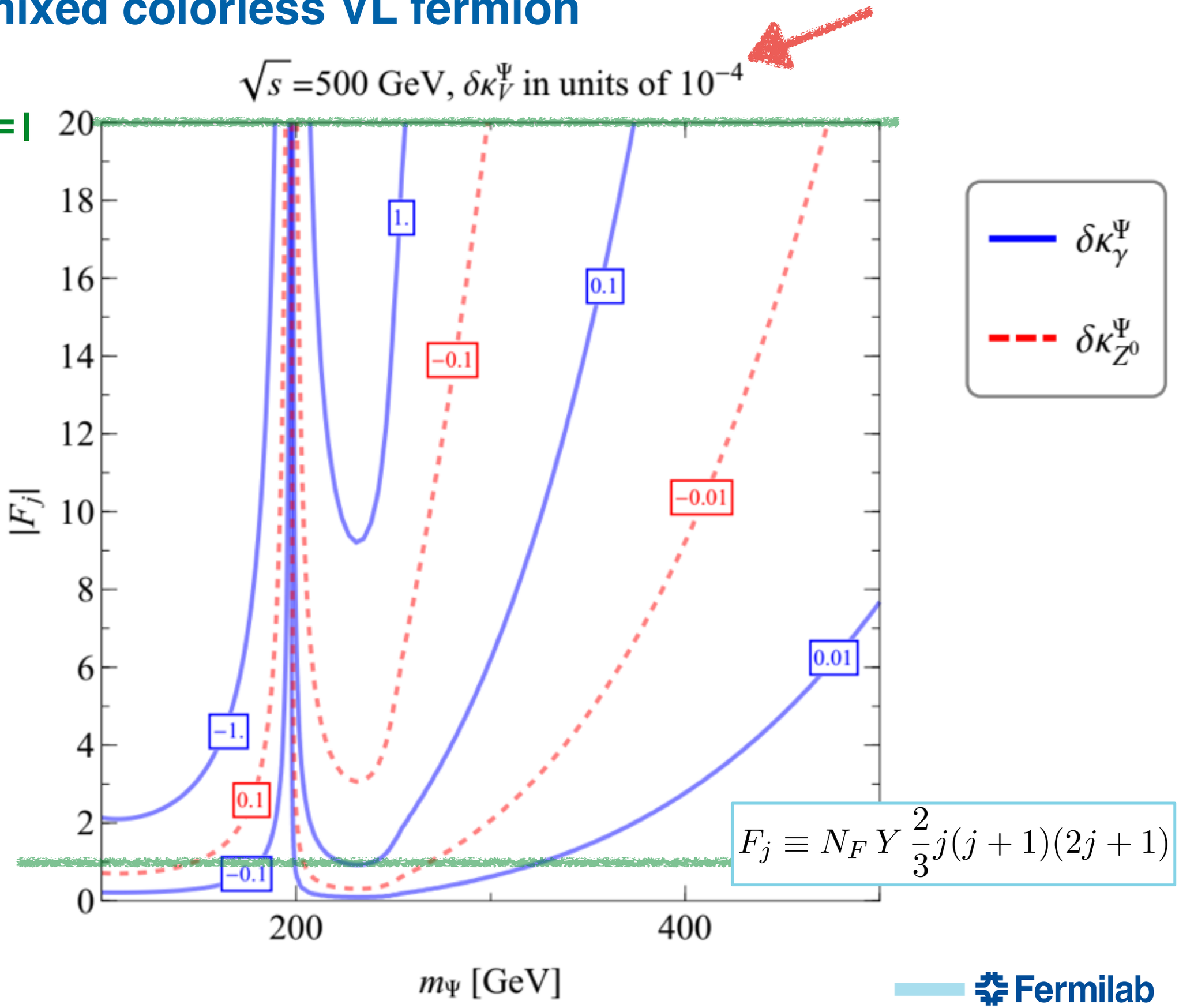
Case 1: Unmixed colorless VL fermion

5-plet, Y=1

doublet, Y=1



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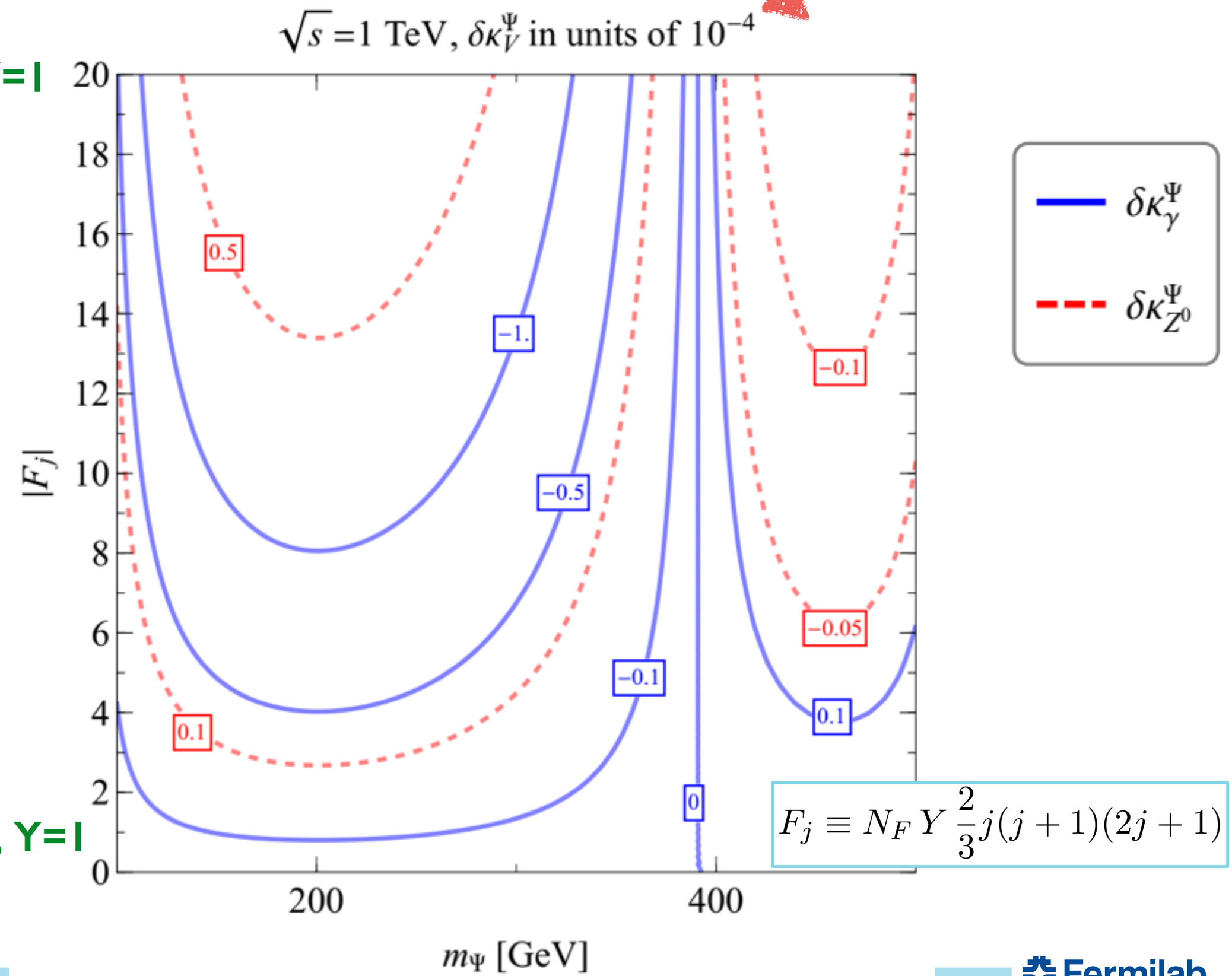

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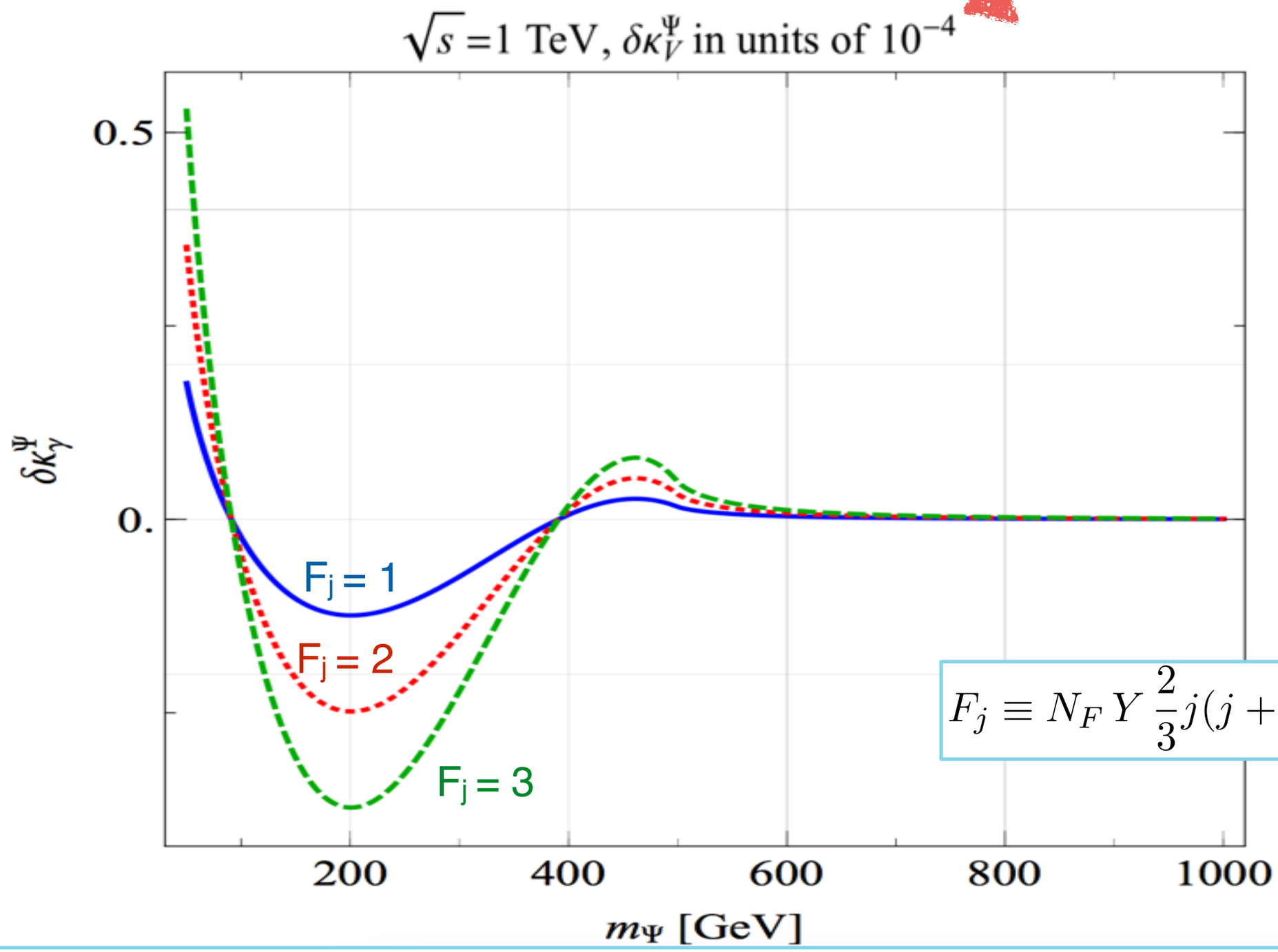

$$F_j \equiv N_F\, Y\, \frac{2}{3} j(j+1)(2j+1)$$

Canonical effective field theory not valid for this example
Possible cancellations
Sign of contribution depends on the mass

Case 2: Mixed colorless VL fermion

$$\mathcal{L}_{2+1} = i\overline{L}\not{D}L + i\overline{N}\not{D}N - \underbrace{M_N\overline{N_R}N_L - M_L\overline{L_R}L_L}_{\text{vectorlike masses}} - \underbrace{c\,\overline{N_R}HL_L - c'\,\overline{N_L}HL_R}_{\text{mixing}} + h.c.$$

$L = (N_0, E)^T$ with hypercharge $Y - \frac{1}{2}$ and N with hypercharge Y

Larger hypercharge leads to larger electric charge and stronger couplings to the Z: larger deviations on TGCs

Case study: doublet-singlet with Y = 1
(like heavy VL lepton and neutrino)
take c = c' and $M_L = M_N$ for simplicity

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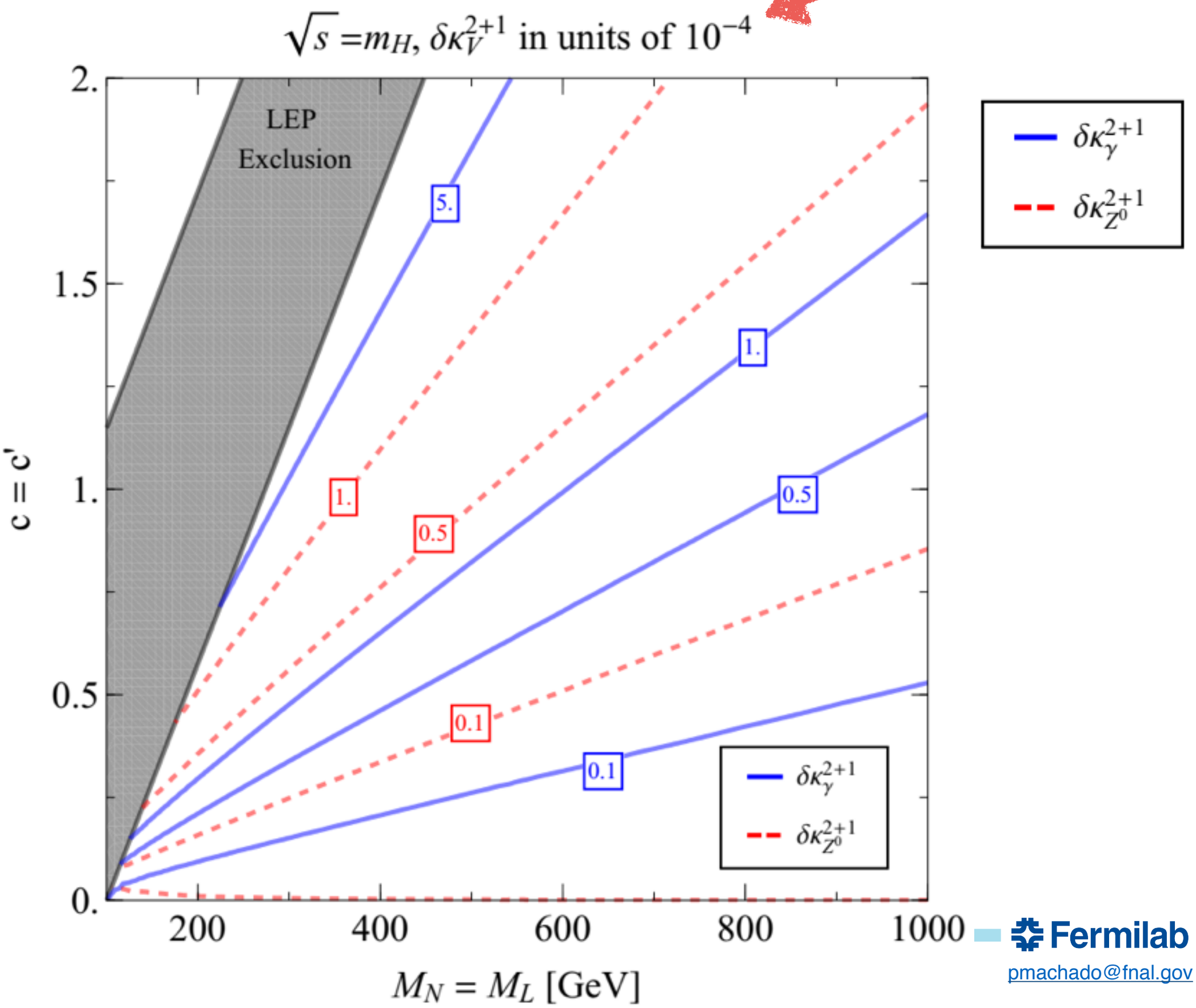
Case 2: Mixed colorless VL fermion: doublet-singlet



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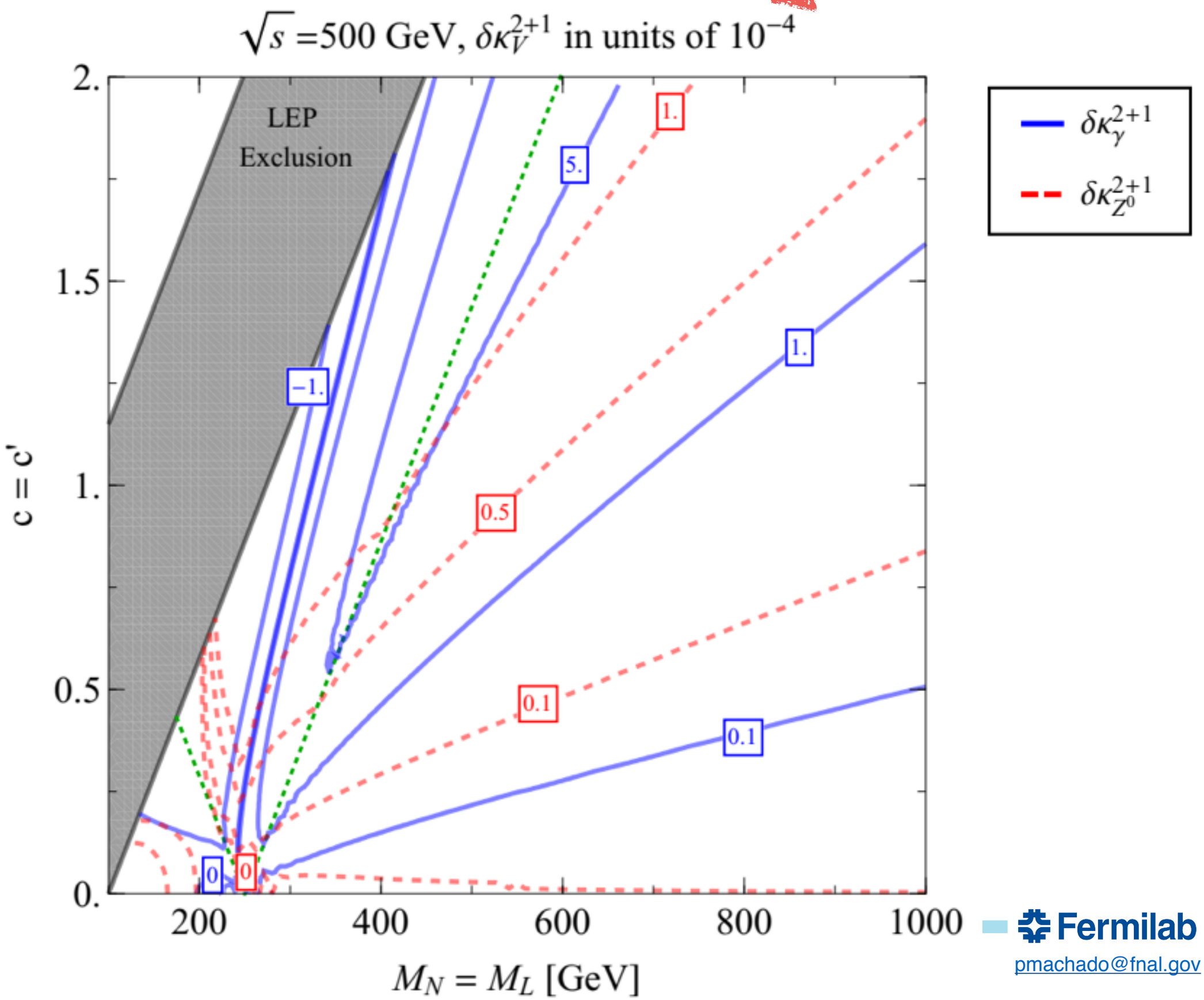

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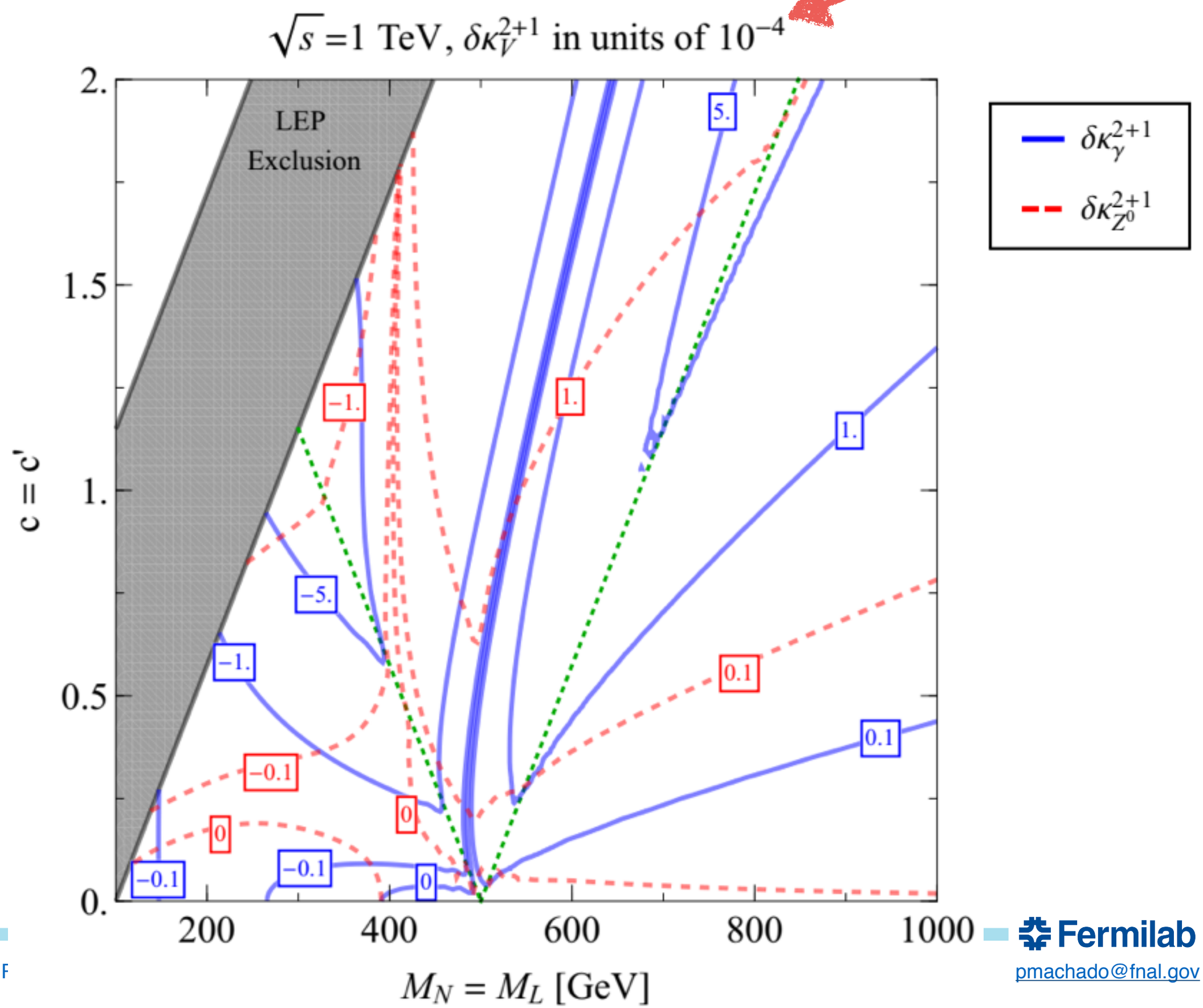

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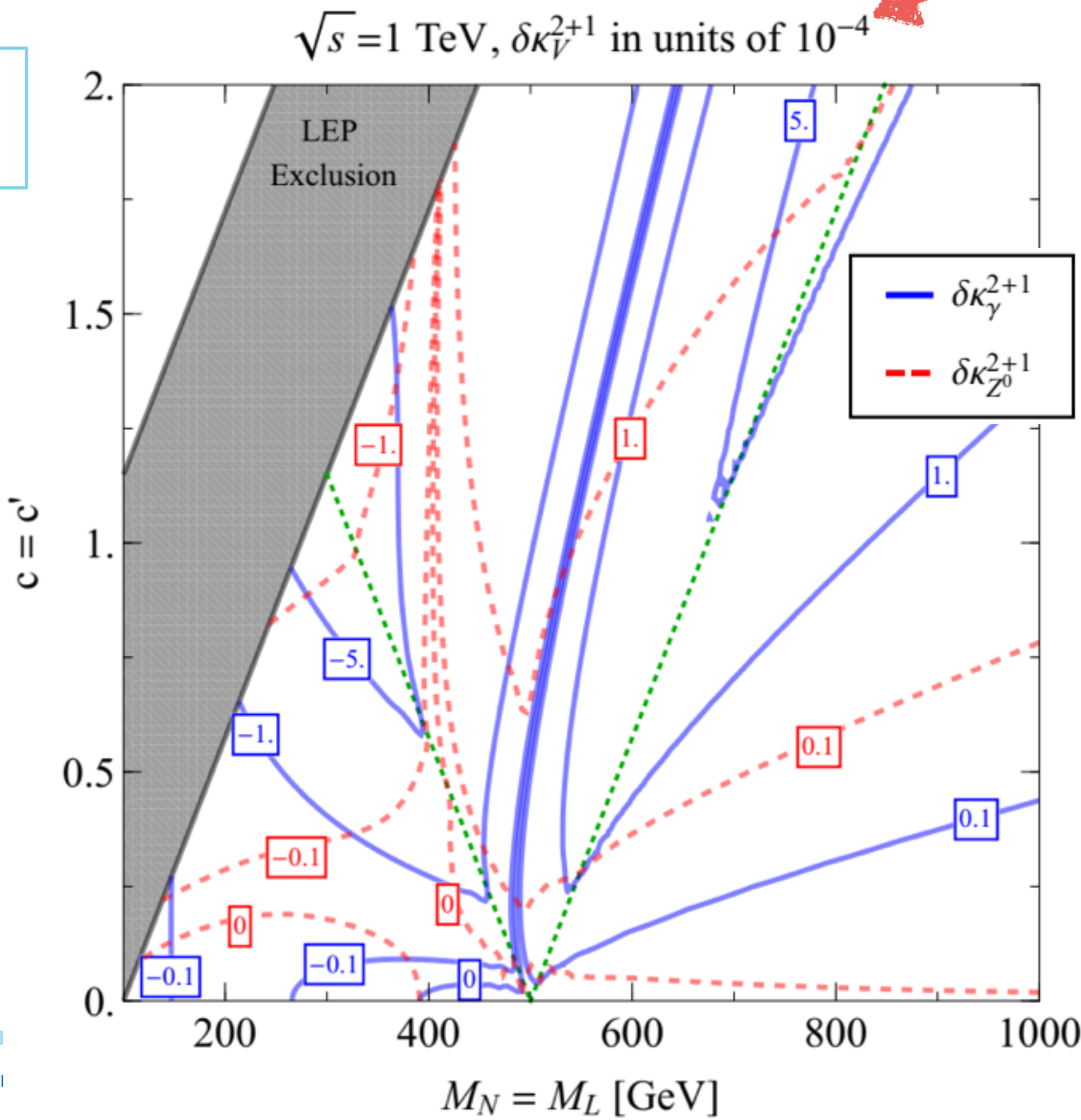
Case 2: Mixed colorless VL fermion: doublet-singlet

Non-trivial dependence on VLL masses and s

$$m_\chi = M$$
$$m_{\omega_1,\omega_2} = |M \pm 2cv|$$



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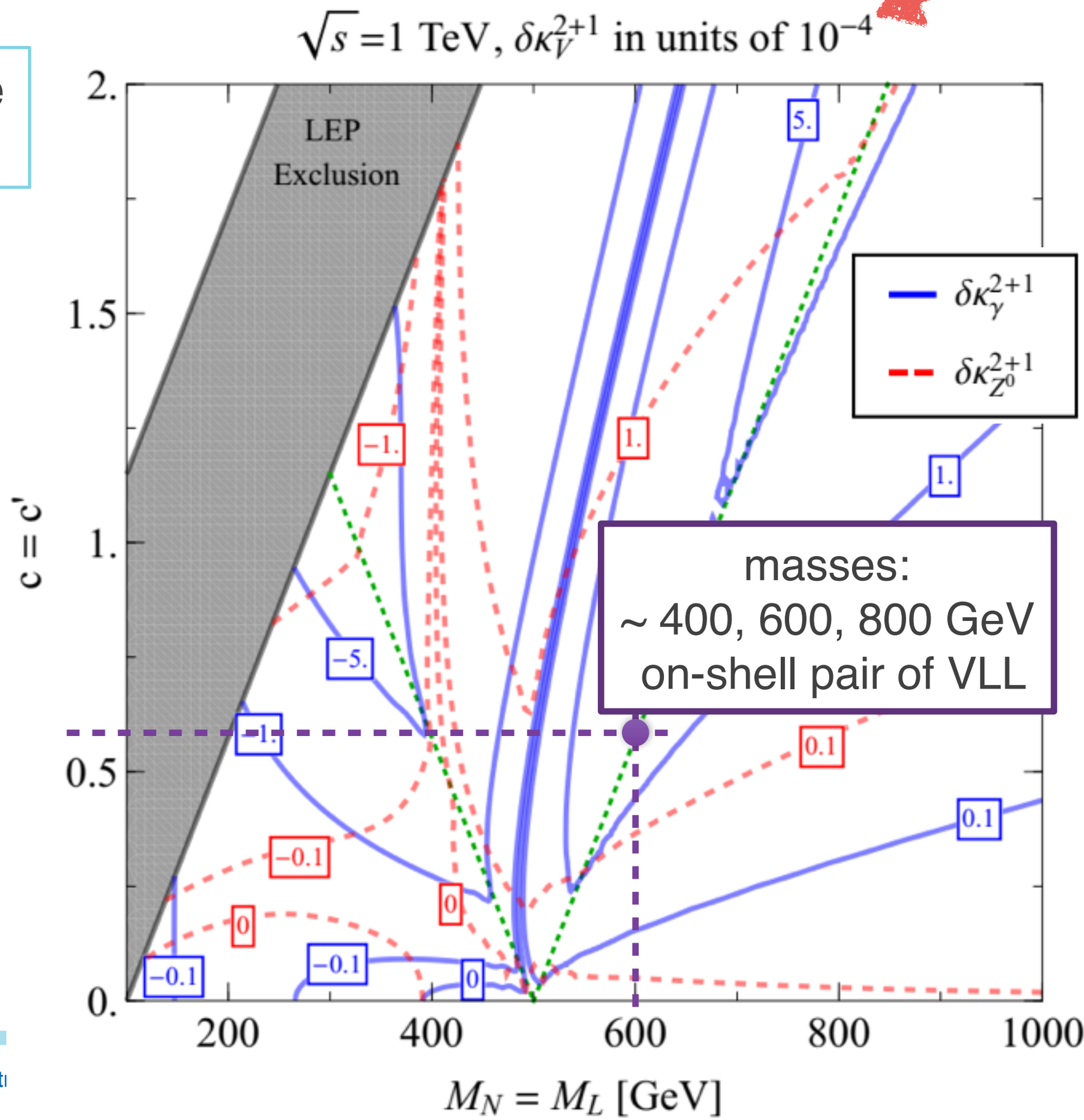

masses:
~ 400, 600, 800 GeV
on-shell pair of VLL

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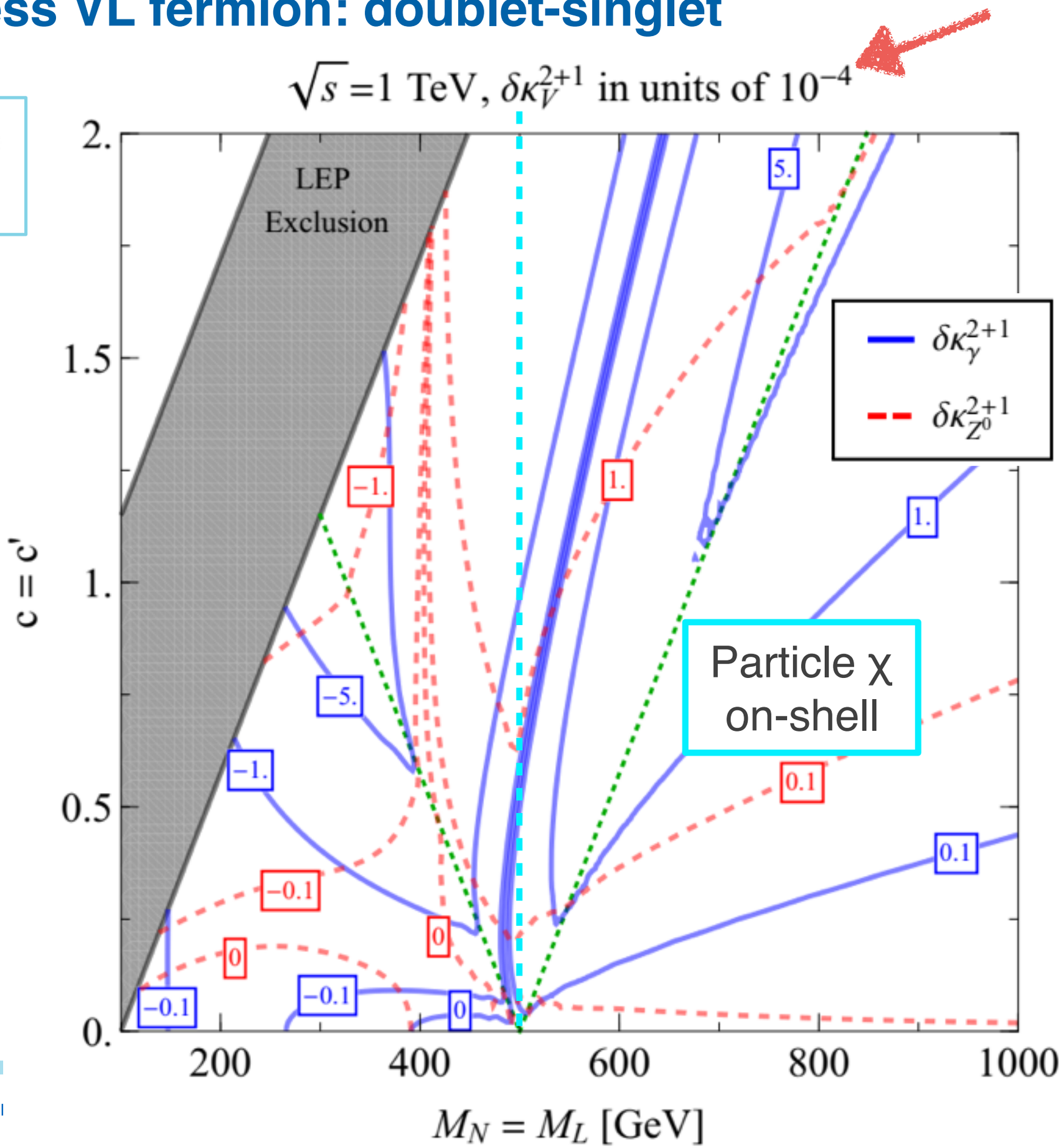

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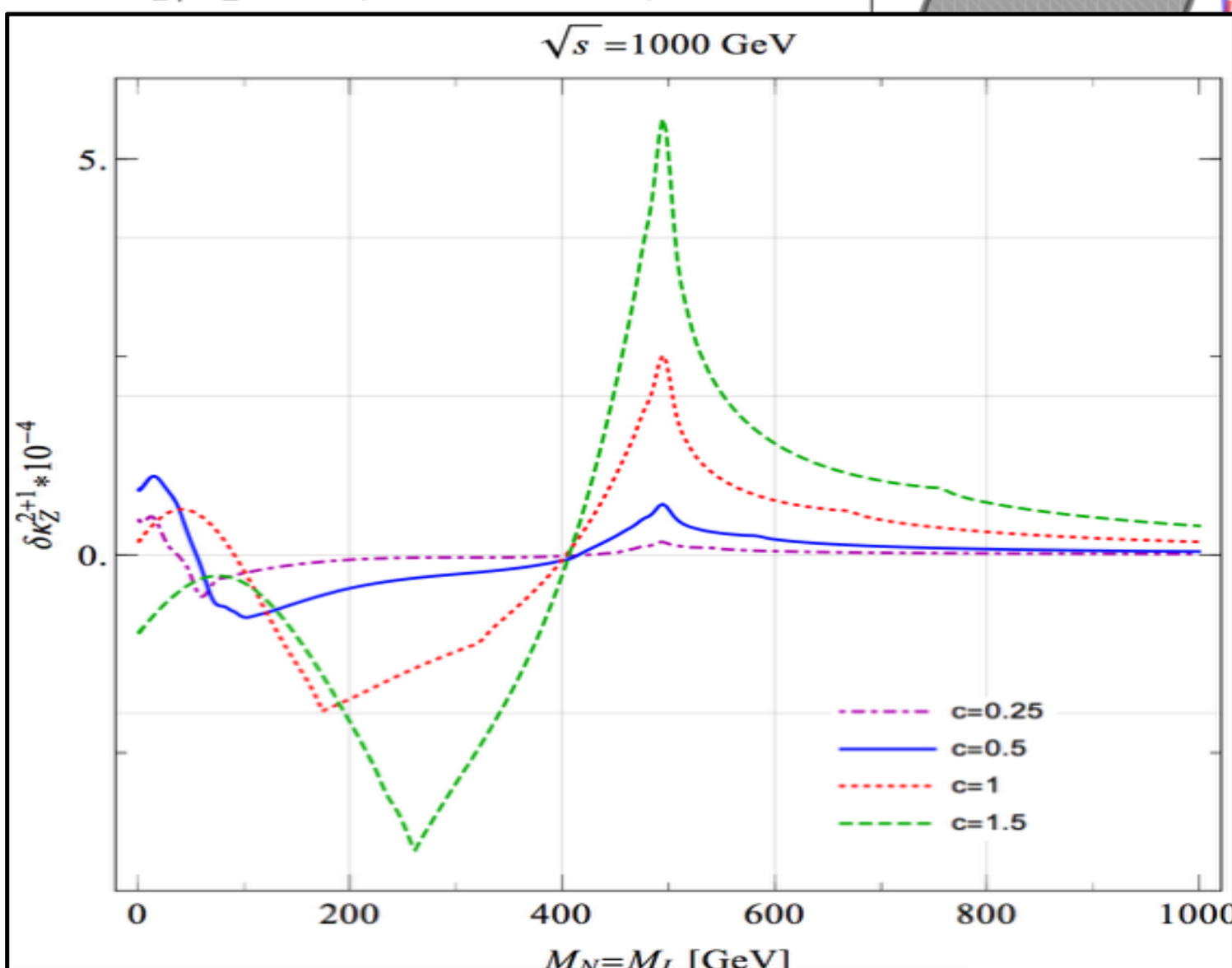

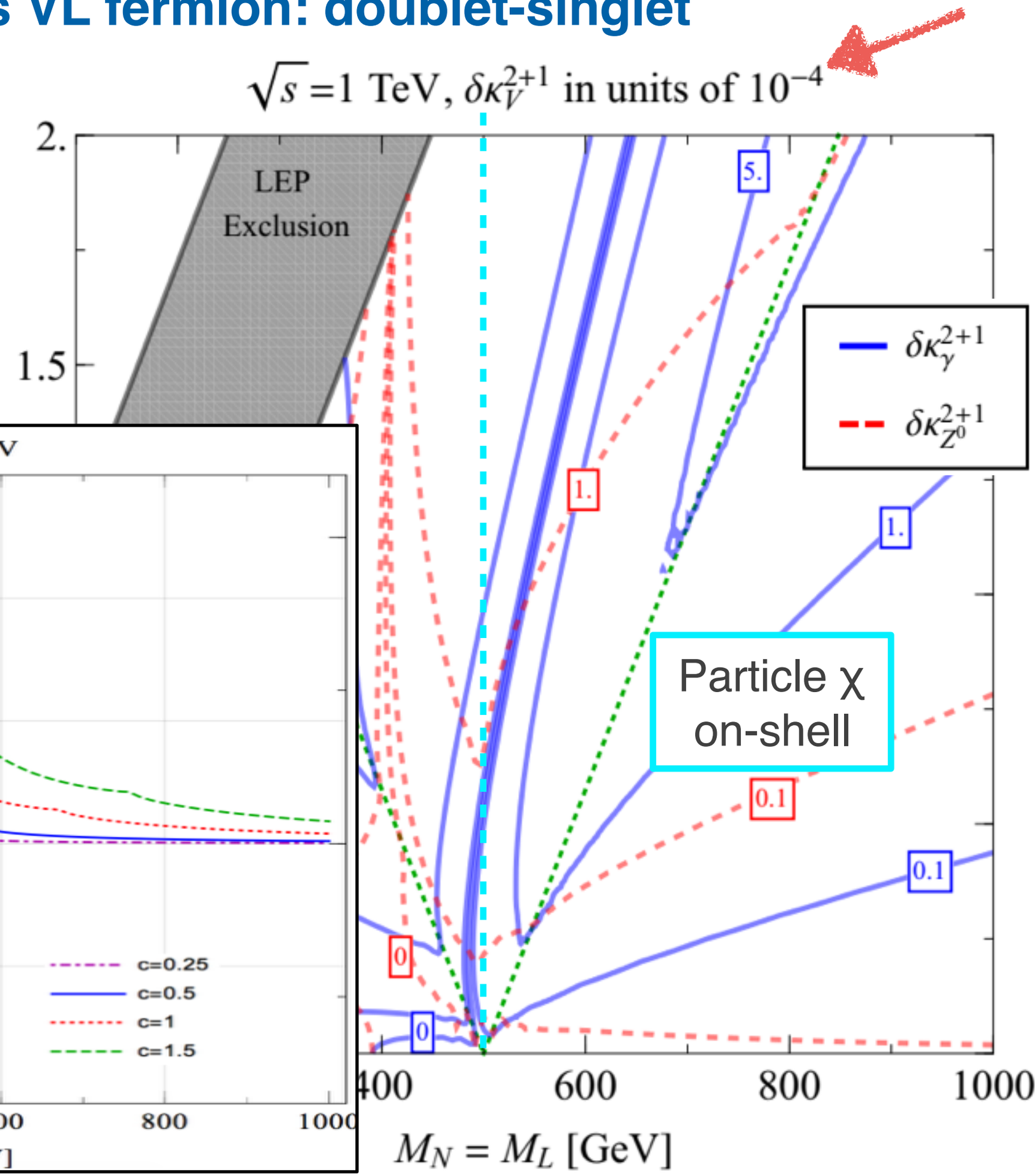

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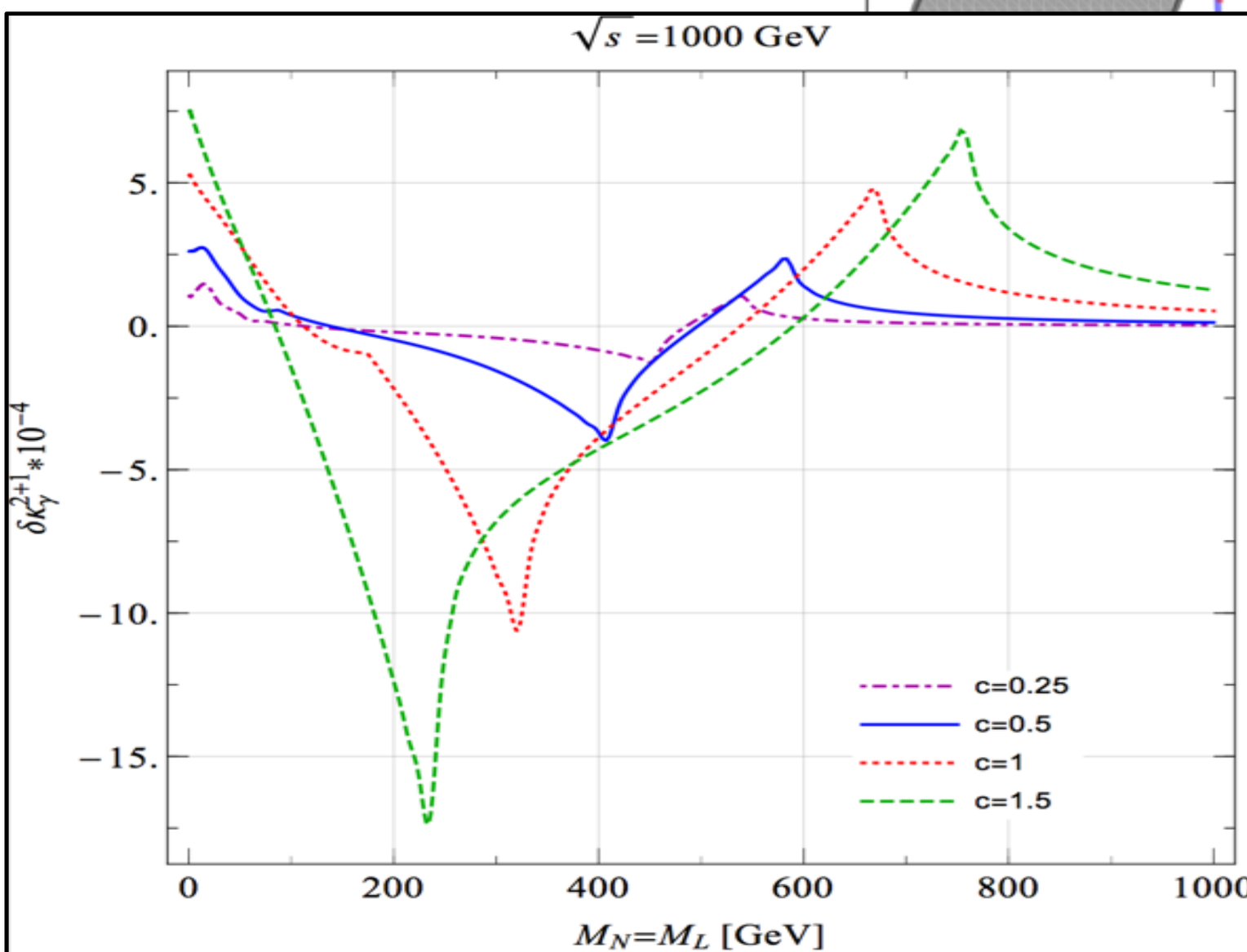

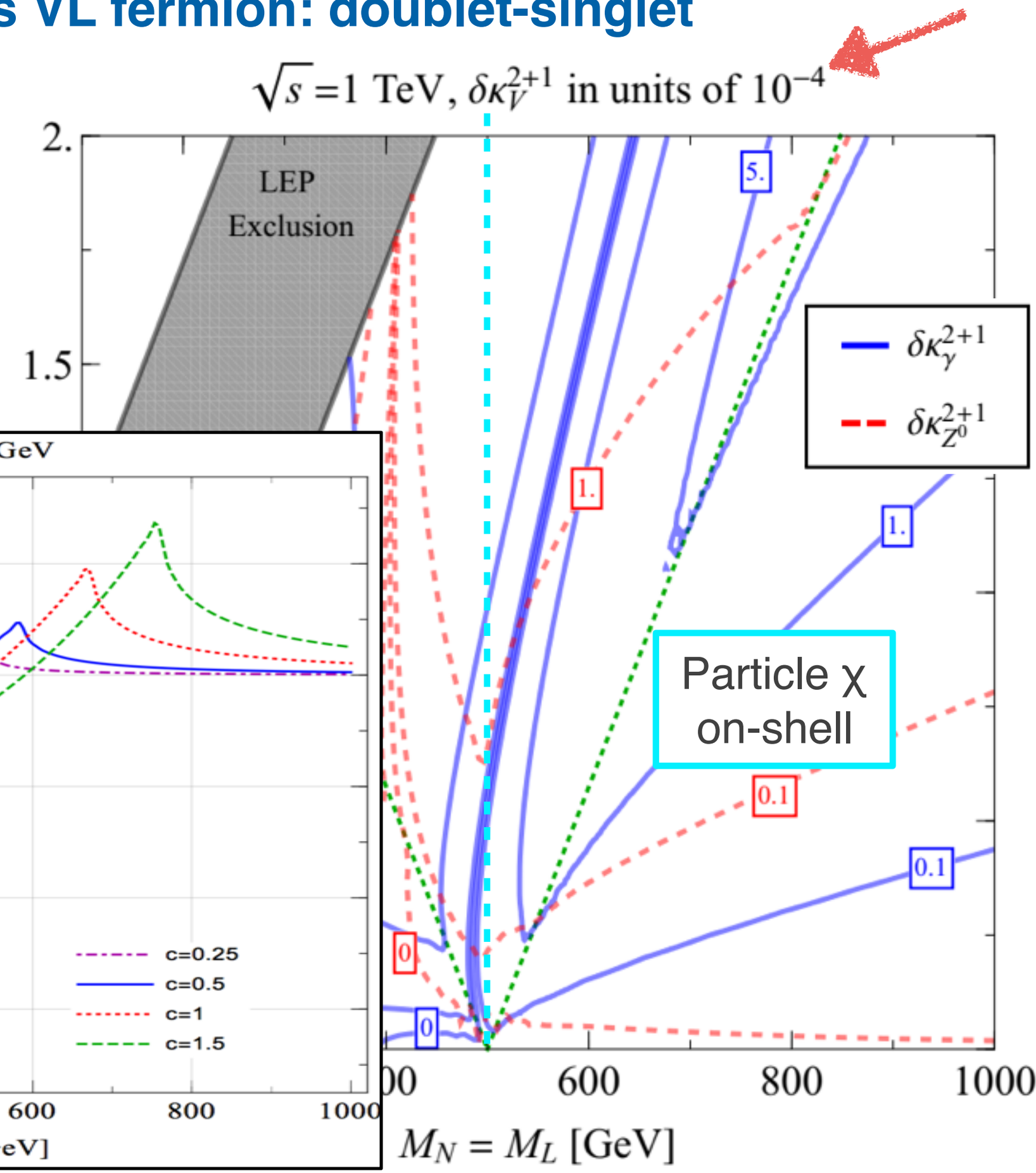

Experimental sensitivity

FCC-ee	*M_Z = 91 GeV* *M_H = 125 GeV* *$2M_Z$ = 182 GeV* *$2M_{top}$ = 350 GeV*
ILC	*500 GeV* *800 GeV* *1000 GeV*
CLIC	*500 GeV* *1400 GeV* *3000 GeV*

Benchmark: 1, 2, 4 x 10^{-4} determination of $\delta\kappa_Z$ and $\delta\kappa_\gamma$, at each center of mass configuration independently

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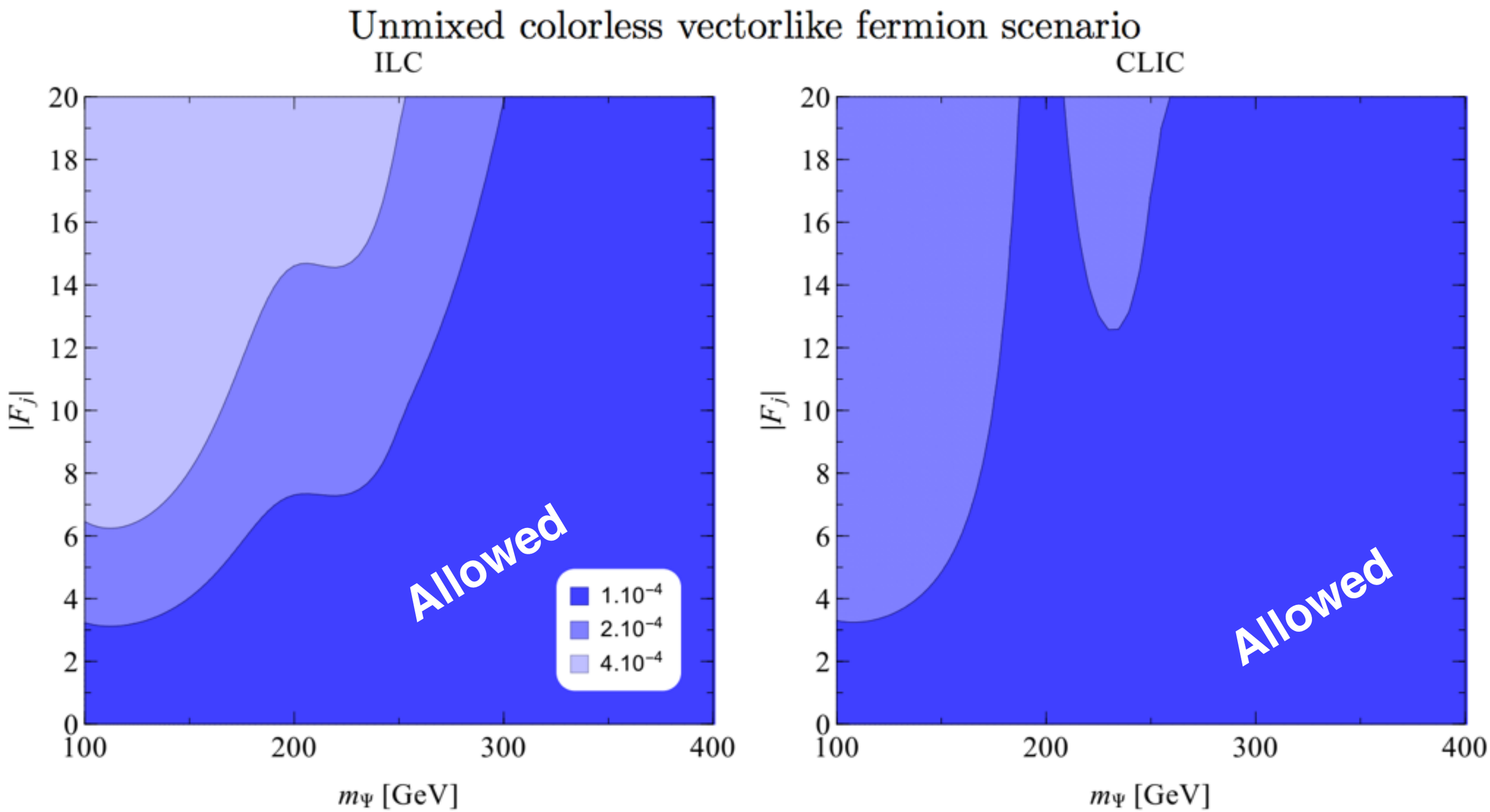
Experimental sensitivity



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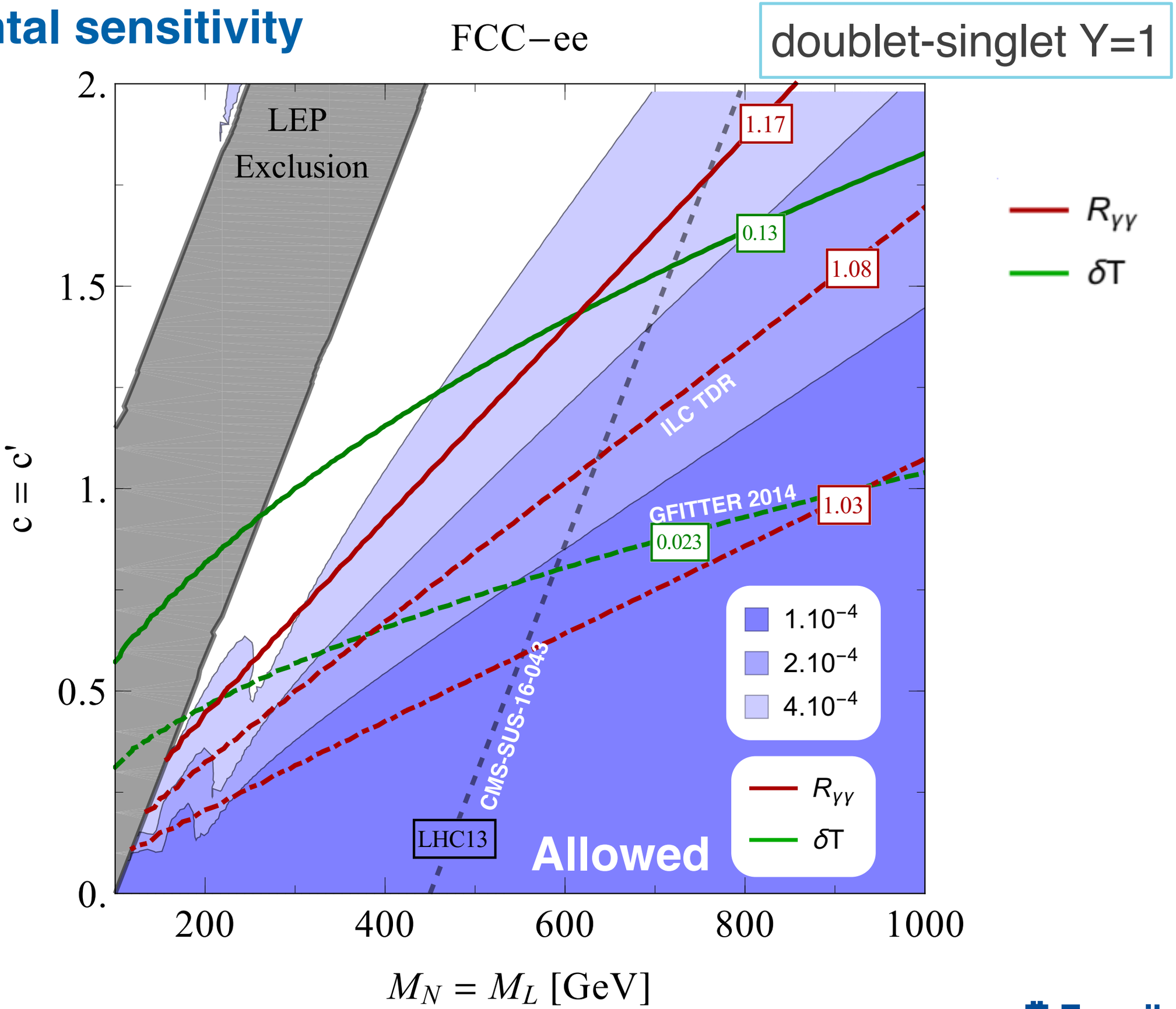

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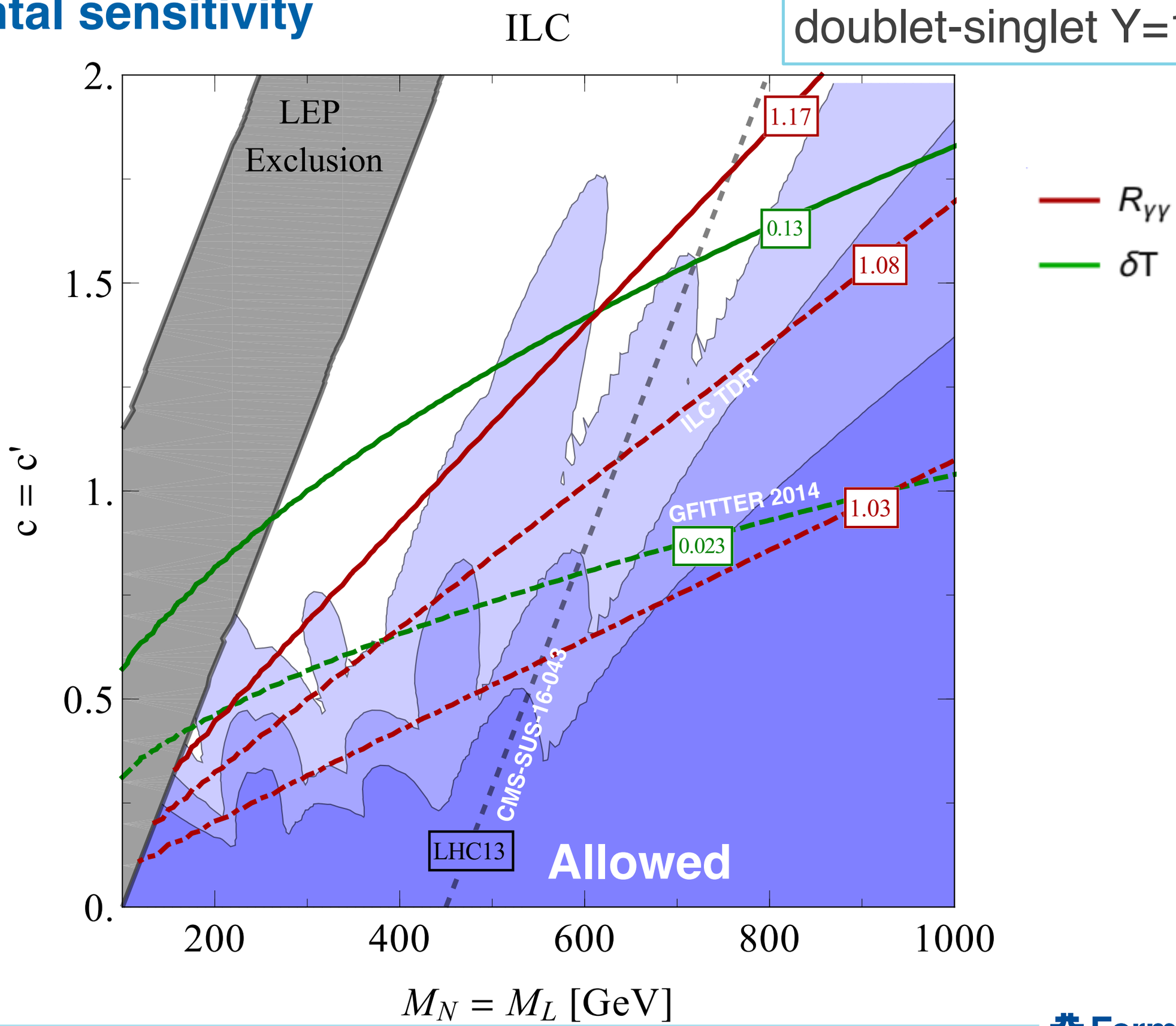
Experimental sensitivity

doublet-singlet Y=1



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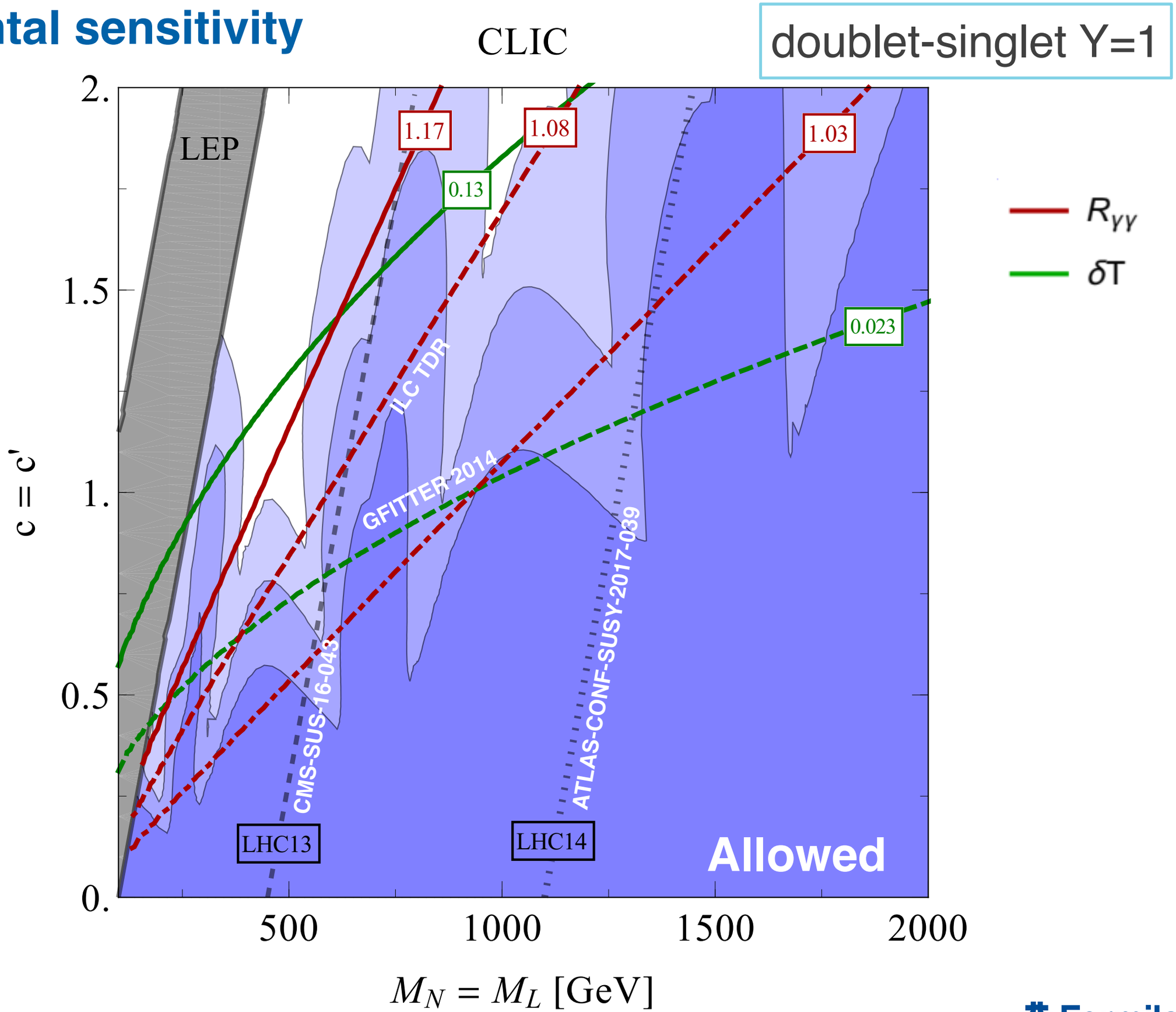
Experimental sensitivity



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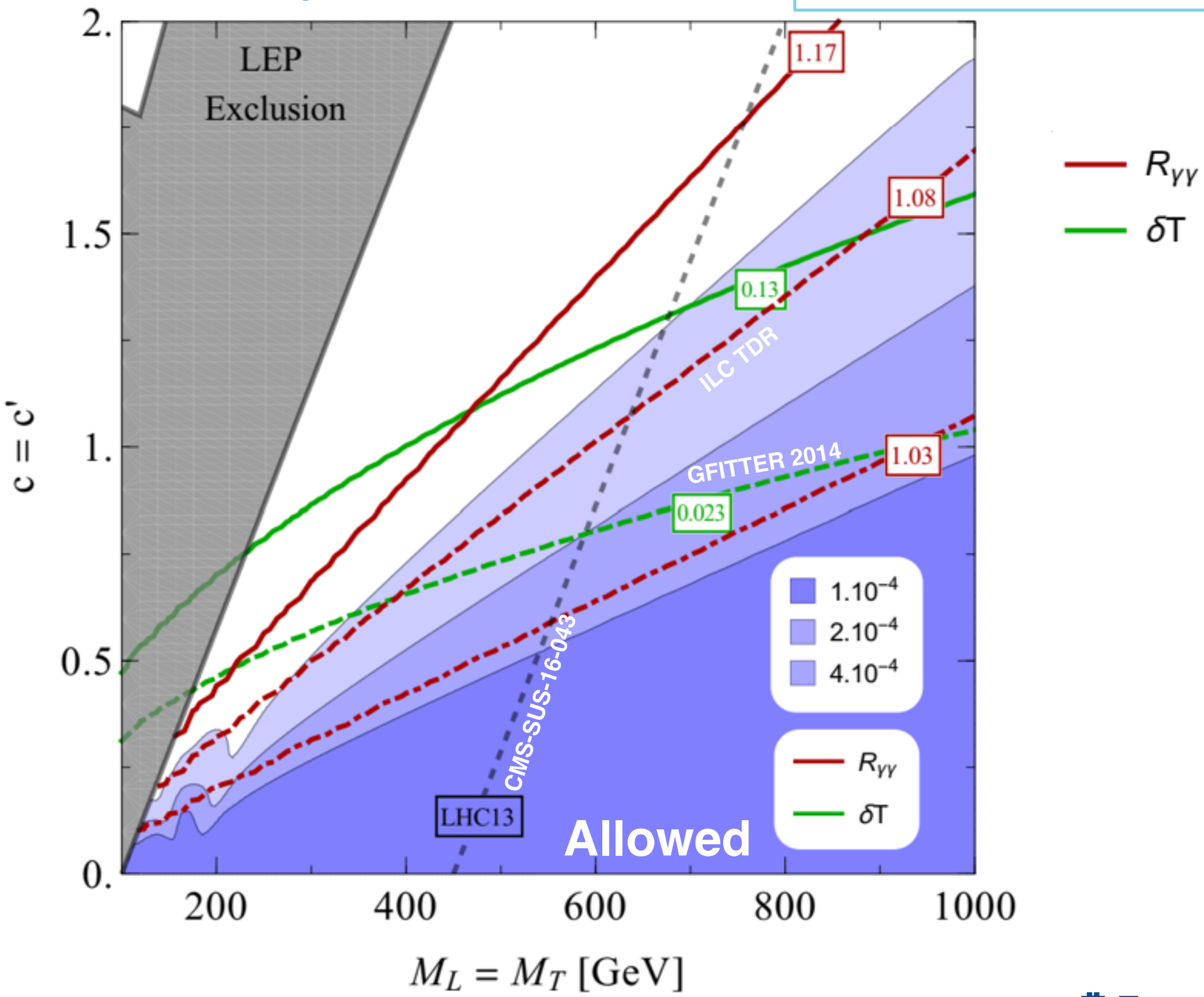
Experimental sensitivity

triplet-doublet Y=1/2



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Take home message

Triple gauge vertices will be an important precision parameter in future e^+e^- colliders

TGC sensitivity to new physics is complementary to other observables like $H\gamma\gamma$ and T parameter

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