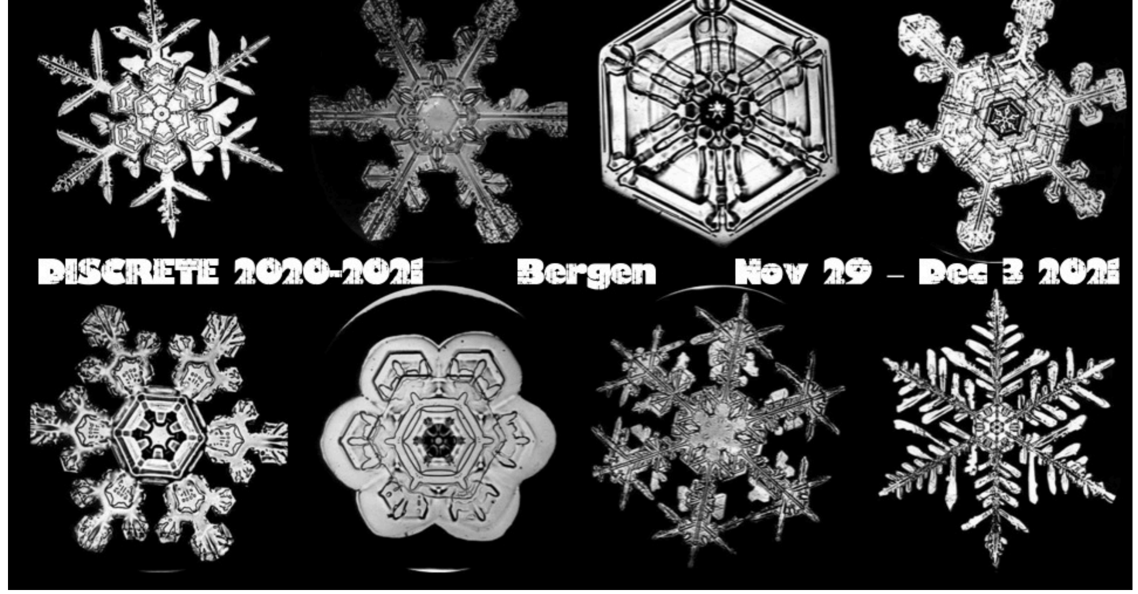

Extending the Reach of Leptophilic Boson Searches at DUNE and MiniBooNE with Bremsstrahlung and Resonant Production

FRANCESCO CAPOZZI

based on arXiv:2108.03262, accepted on PRD

in collaboration with B. Dutta, G. Gurung, W. Jang, I. M. Shoemaker, A. Thompson and J. Yu

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Going beyond the Standard Model

A widely used extension of the SM is an extra $U(1)_X$. A few examples:

$U(1)_D$: dark photon through kinetic mixing $\mathscr{L} = -\dfrac{\epsilon}{2} F_{\alpha\beta} Z'^{\alpha\beta}$

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gauged SM symmetries: $U(1)_{B-L}$, $U(1)_{L_e-L_\mu}$, $U(1)_{L_\mu-L_\tau}$, $U(1)_{L_e-L_\tau}$

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Such a $U(1)_X$ can be a remnant of a larger broken symmetry group

Going beyond the Standard Model

A widely used extension of the SM is an extra $U(1)_X$. A few examples:

Focus on gauged SM symmetries $U(1)_{L_\alpha - L_\beta}$

$$\mathscr{L} = \mathscr{L}_{\rm SM} - \frac{1}{4} Z'^{\delta\eta} Z'_{\delta\eta} + \frac{m^2_{Z'}}{2} Z'_\delta Z'^\delta + Z'_\delta J^\delta_{\alpha-\beta}$$

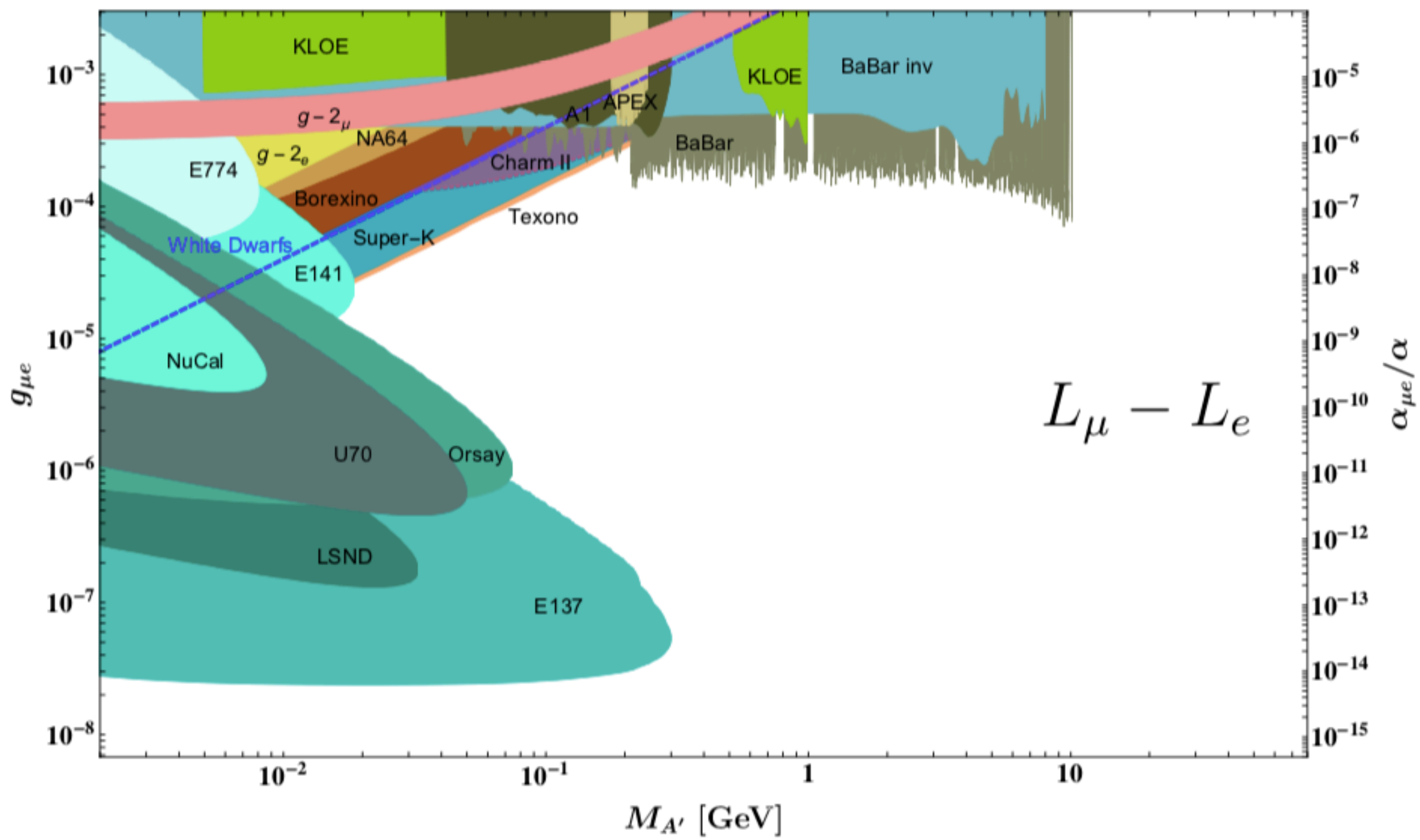
$$J^\delta_{\alpha-\beta} = g_{\alpha\beta} \left(\bar{l}_\alpha \gamma^\delta l_\alpha + \bar{\nu}_\alpha \gamma^\delta P_L \nu_\alpha - \bar{l}_\beta \gamma^\delta l_\beta - \bar{\nu}_\beta \gamma^\delta P_L \nu_\beta \right)$$

Leptons are directly coupled to a new gauge bosons Z’

Current constraints

Effects of Z' from $U(1)_{L_e - L_\mu}$ can be observed in different ways

Bauer, Foldenauer and Jaeckel, JHEP 07 (2018), 094



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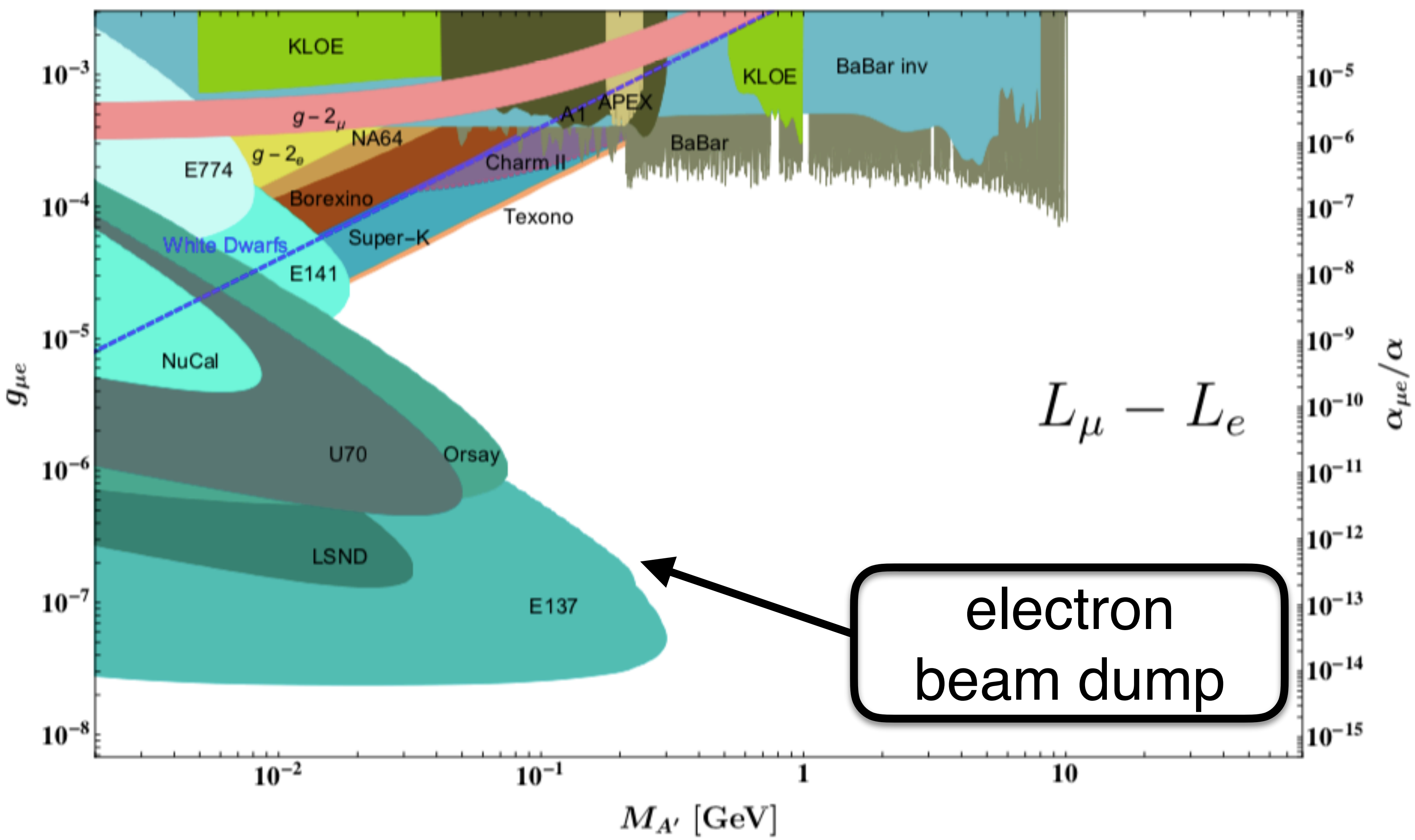

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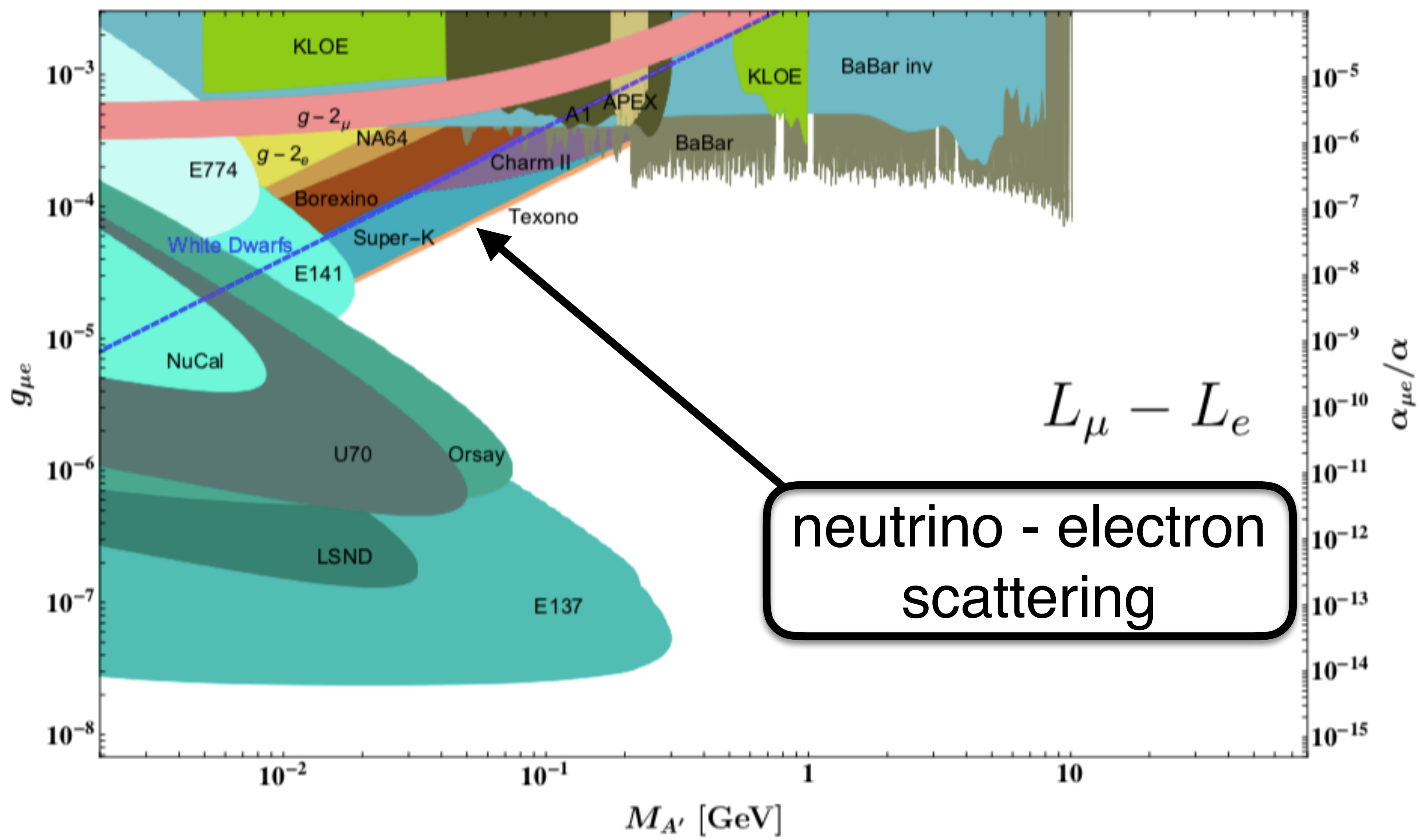

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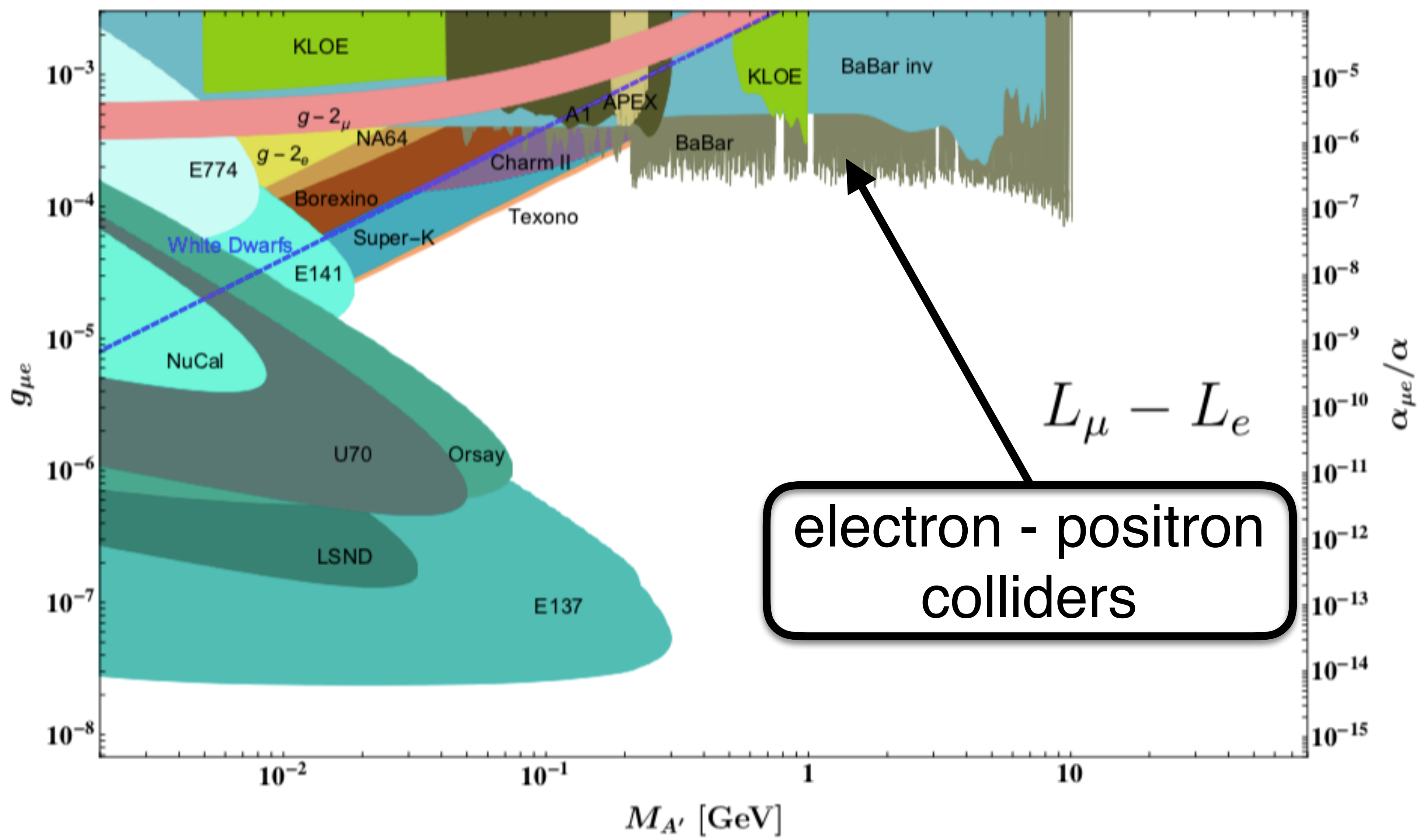

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Effects of Z' from $U(1)_{L_\mu - L_\tau}$ can be observed in different ways

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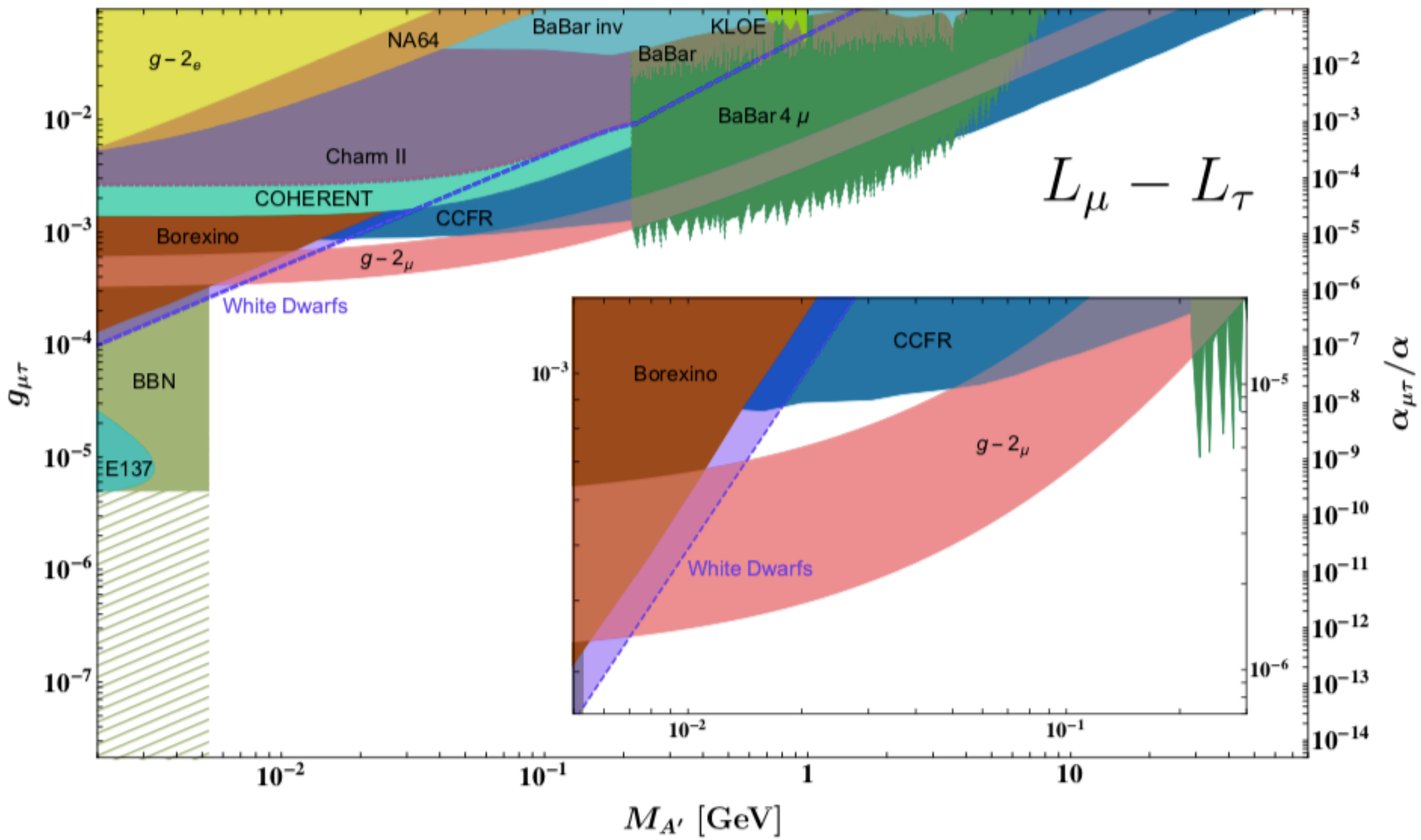
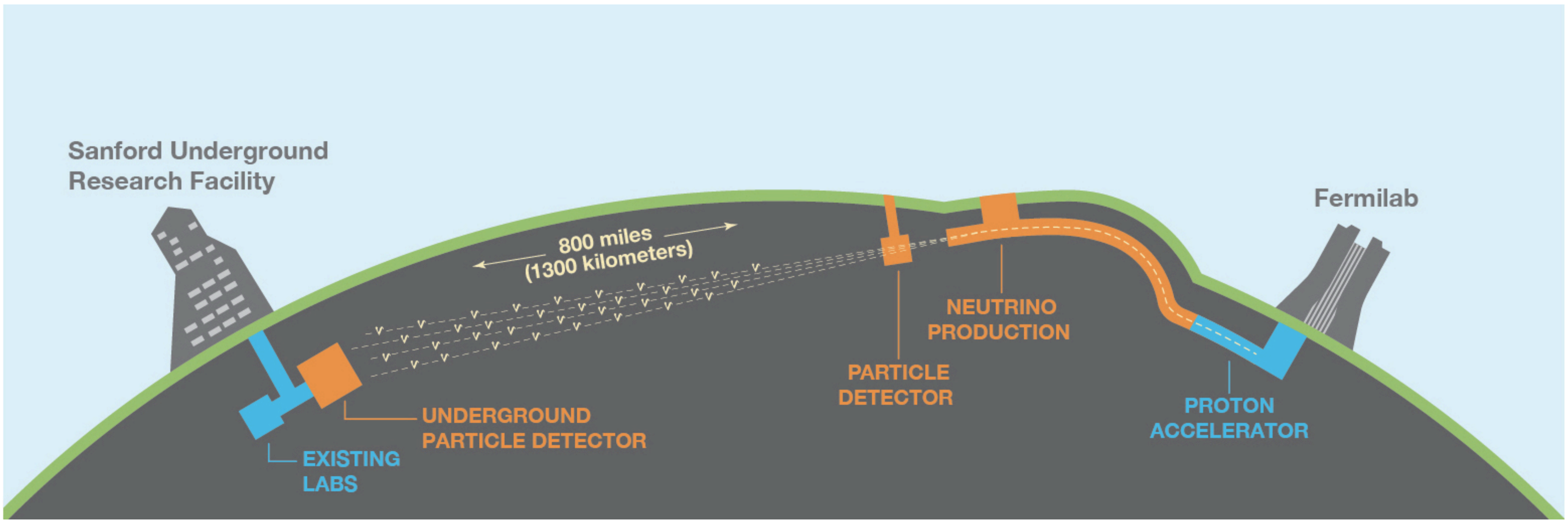
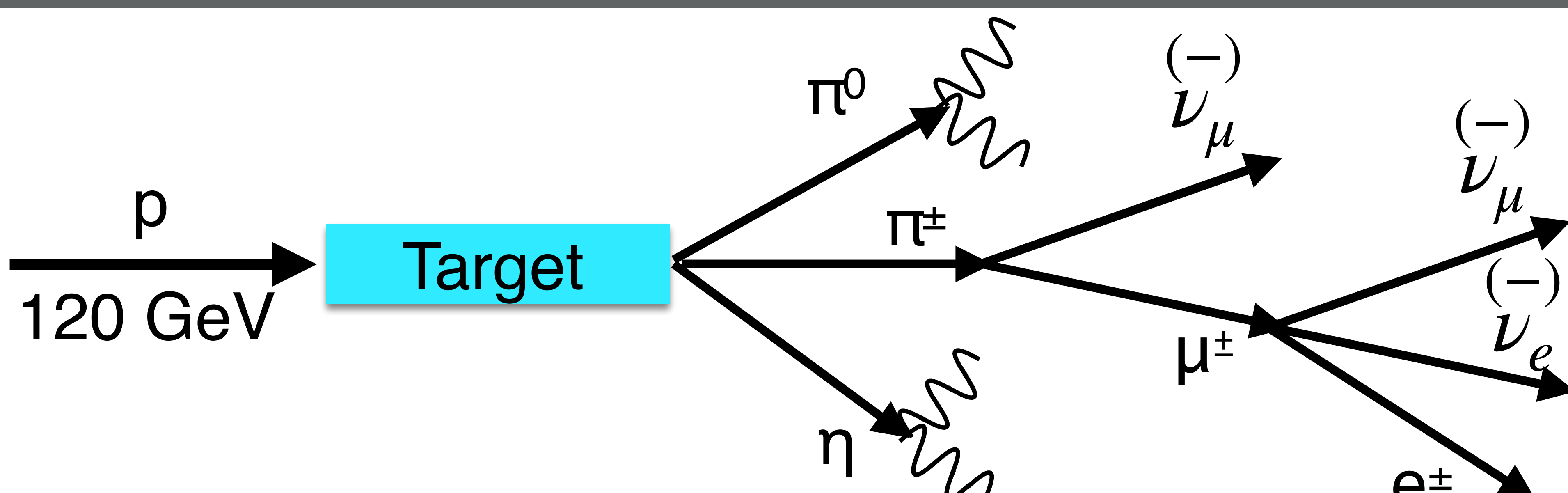


What about future constraints?

Future constraints

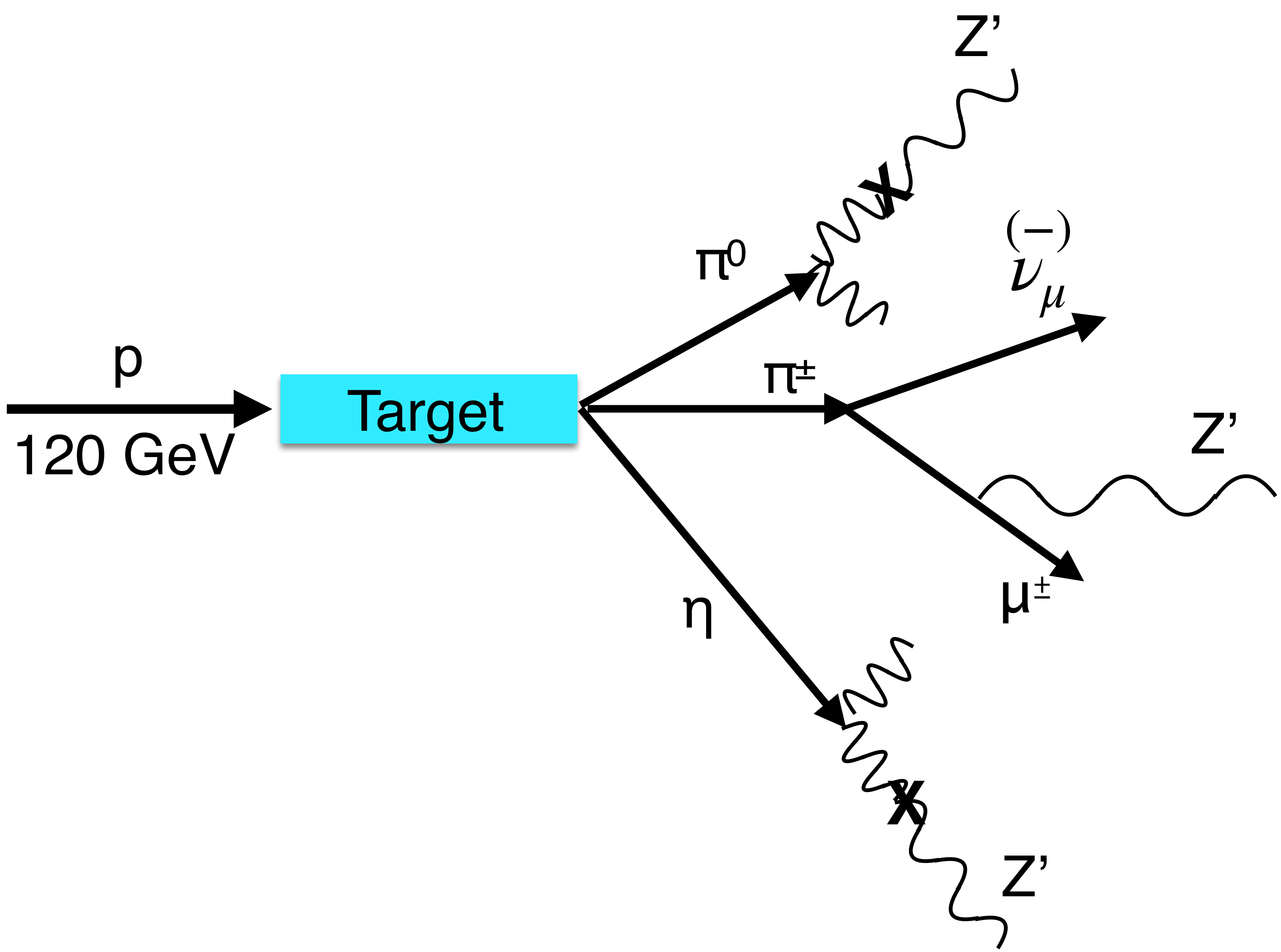
DUNE studies oscillations of ν_μ produced by protons impinging on a target





Future constraints

In the context of $U(1)_{L_\alpha - L_\beta}$ Z's can be produced together with neutrinos



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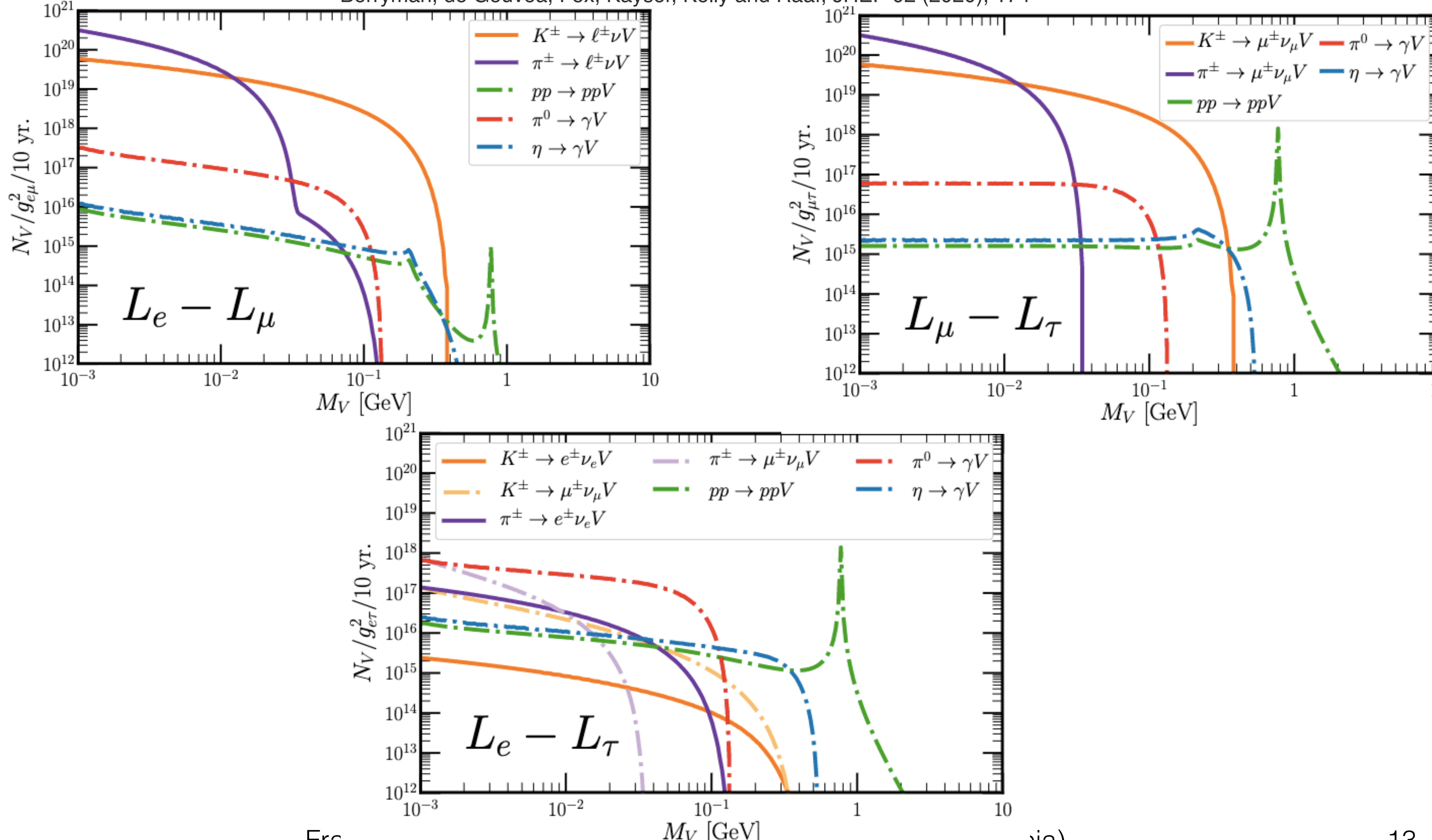

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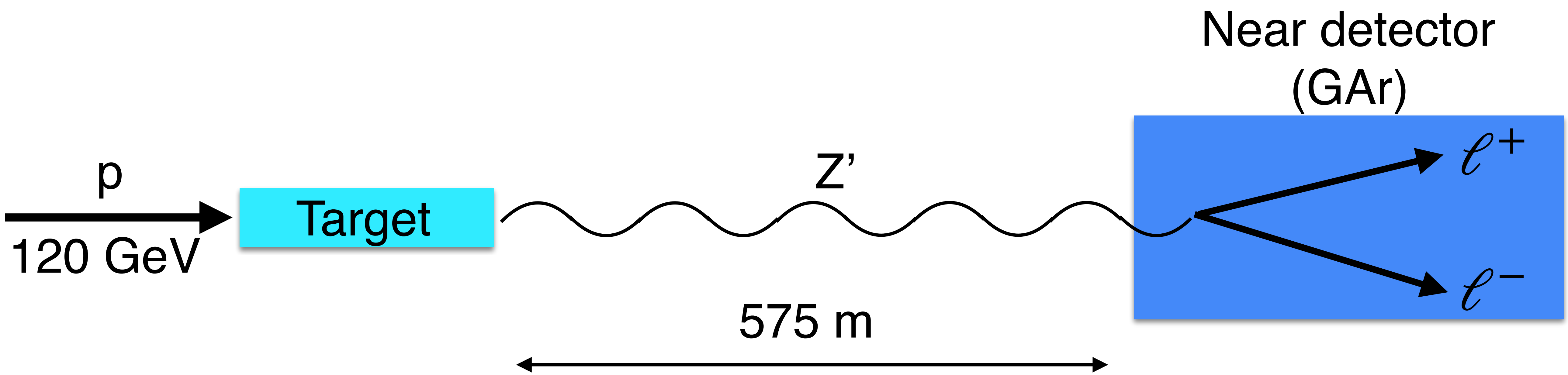


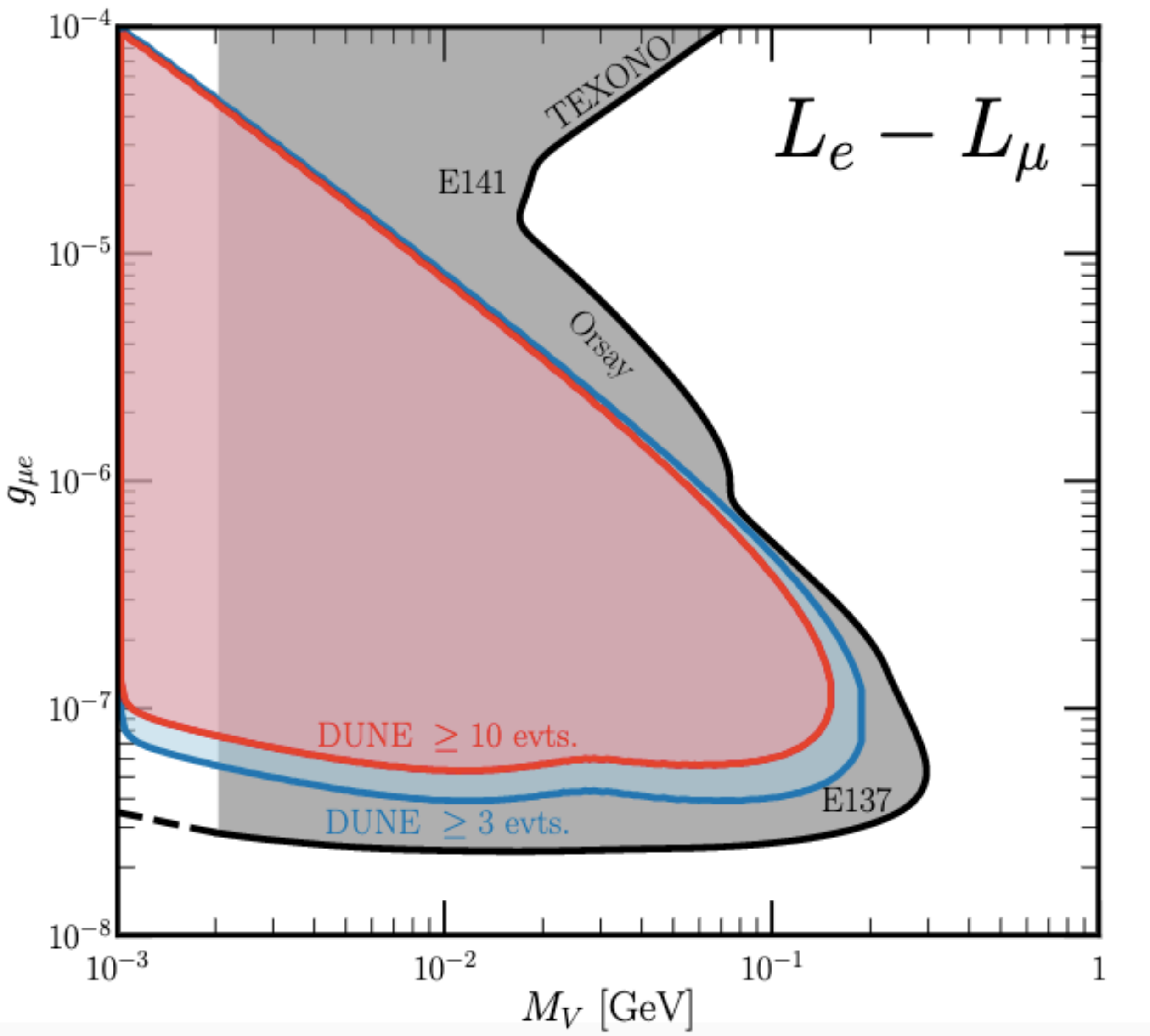
$$\Gamma(Z' \to \ell^+\ell^-) = \frac{g_l^2 m_{Z'}}{12\pi}\sqrt{1 - 4\left(\frac{m_l}{m_{Z'}}\right)^2}\left[1 + 2\left(\frac{m_l}{m_{Z'}}\right)^2\right]$$

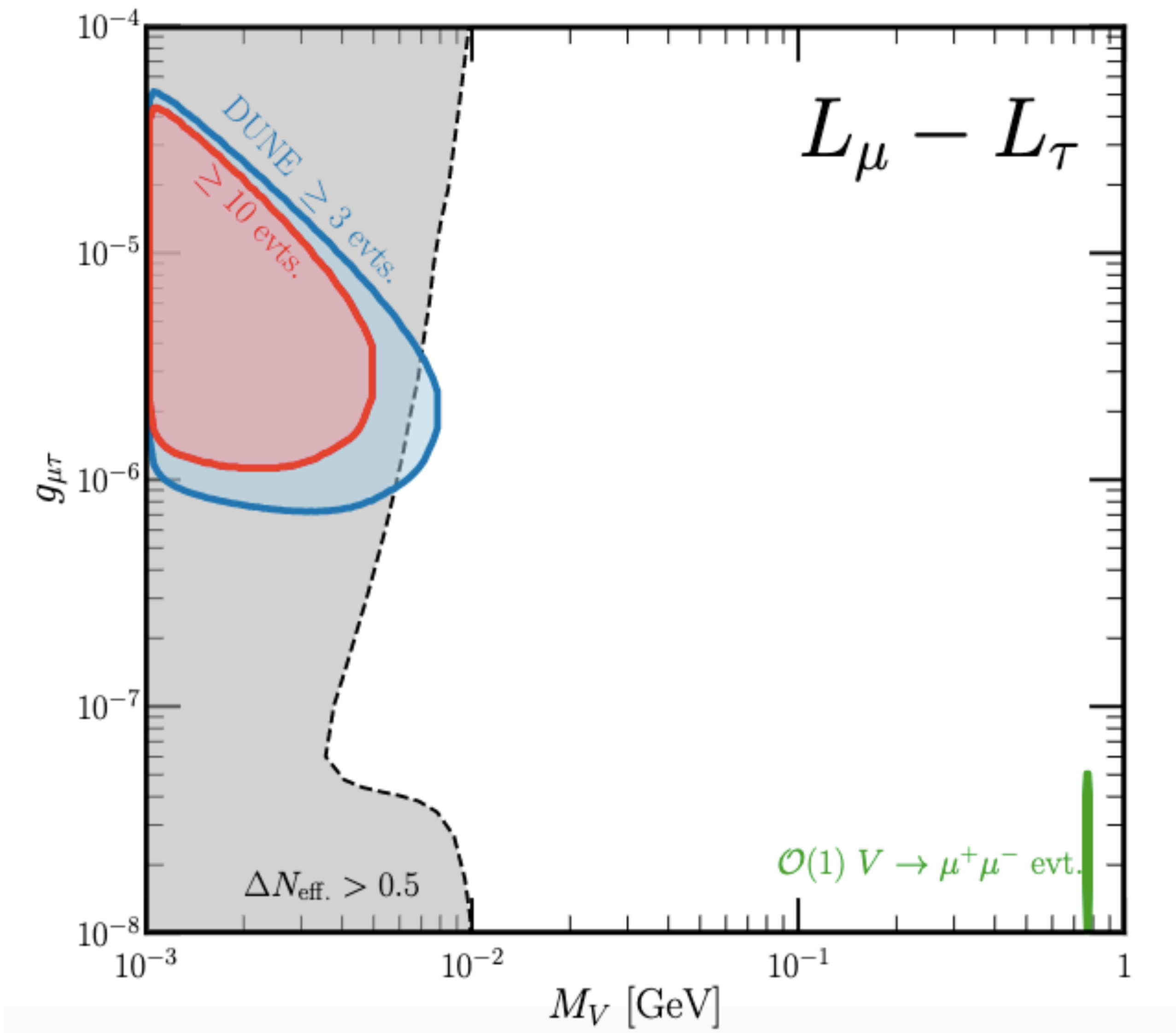
Experimental signature: pair of leptons production in the GAr

Future constraints

DUNE is sensitive to a region similar to the one of electron beam dumps

Berryman, de Gouvea, Fox, Kayser, Kelly and Raaf, JHEP 02 (2020), 174





Not enough to get constraints beyond those from E137

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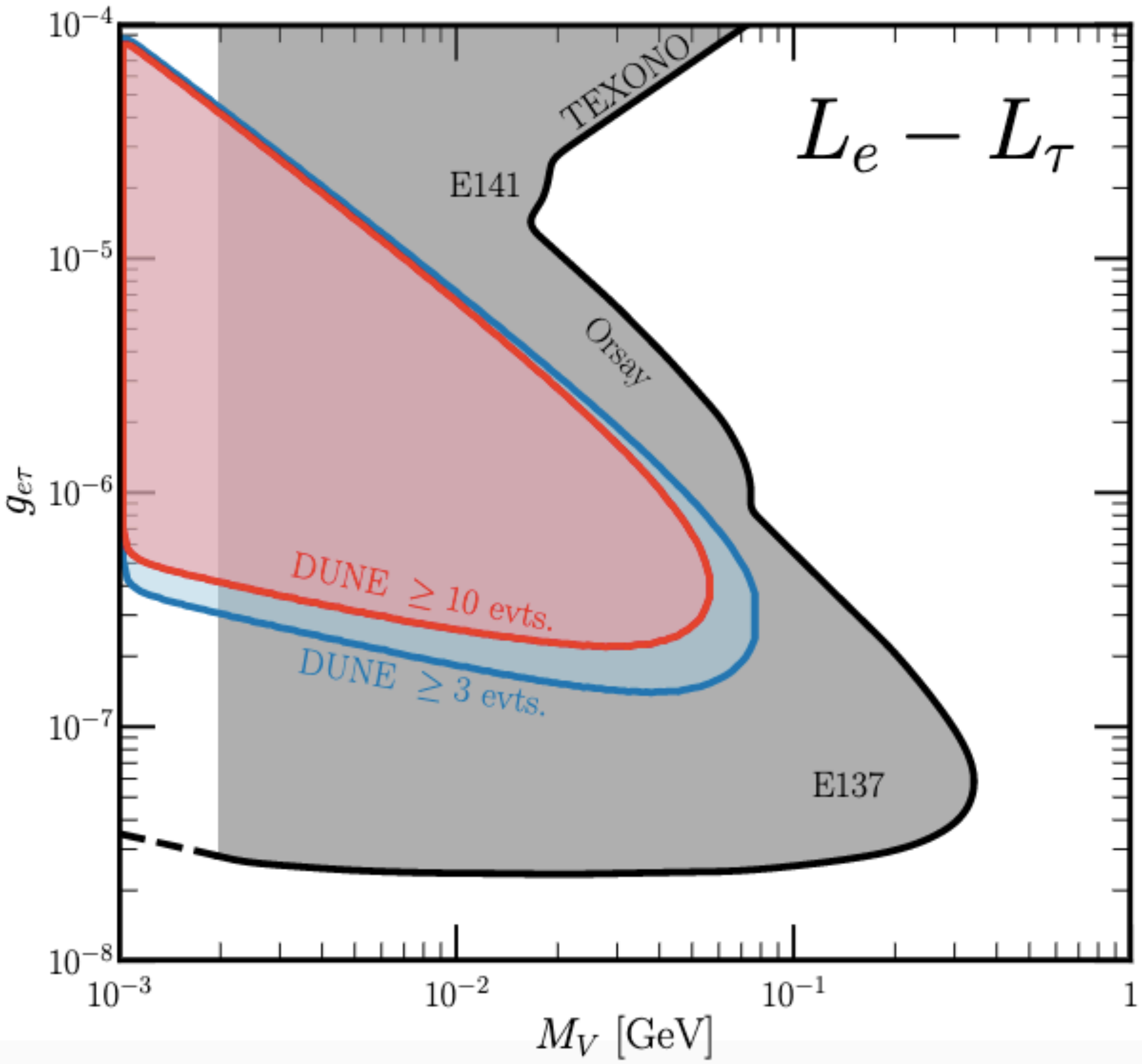
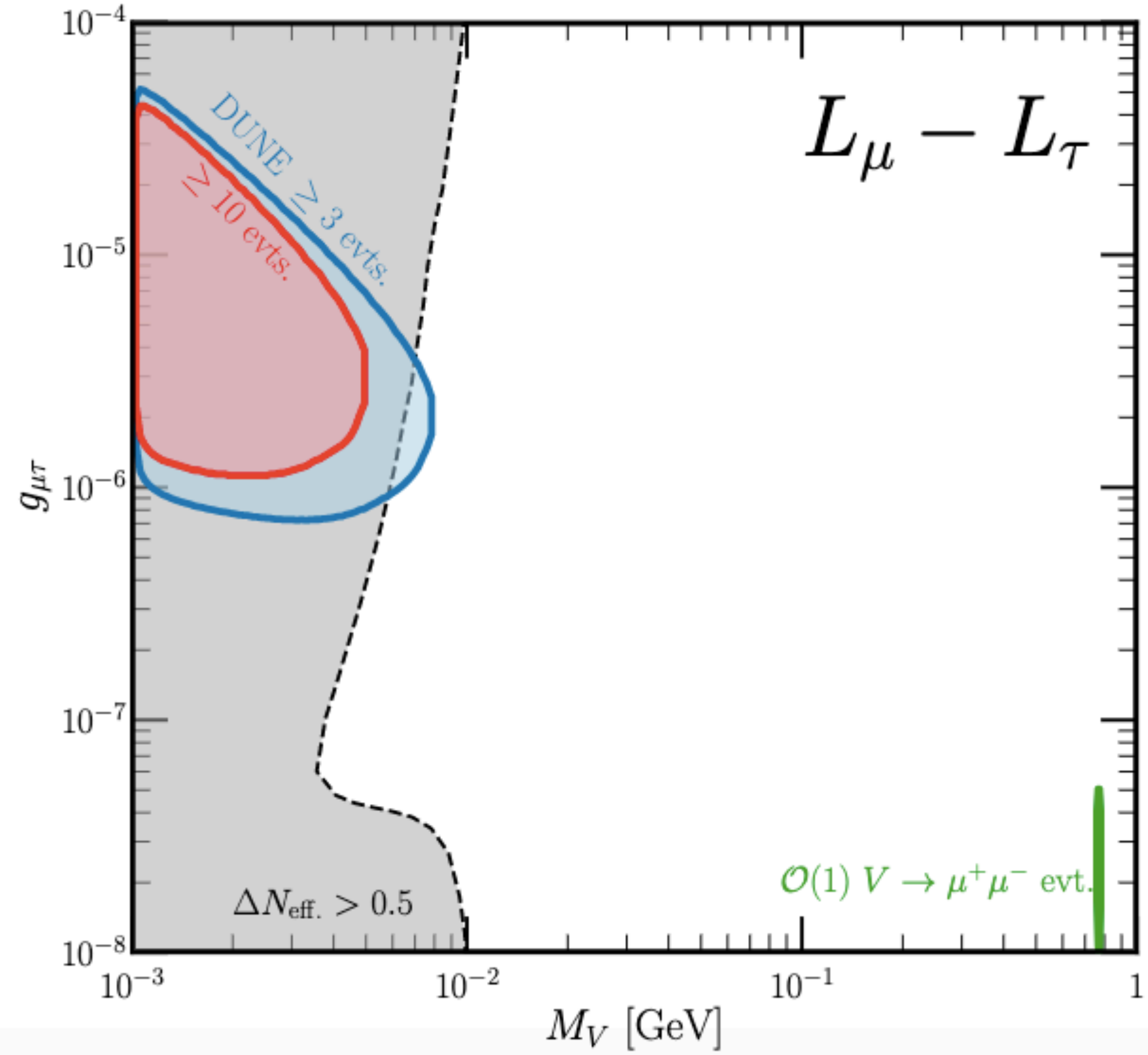
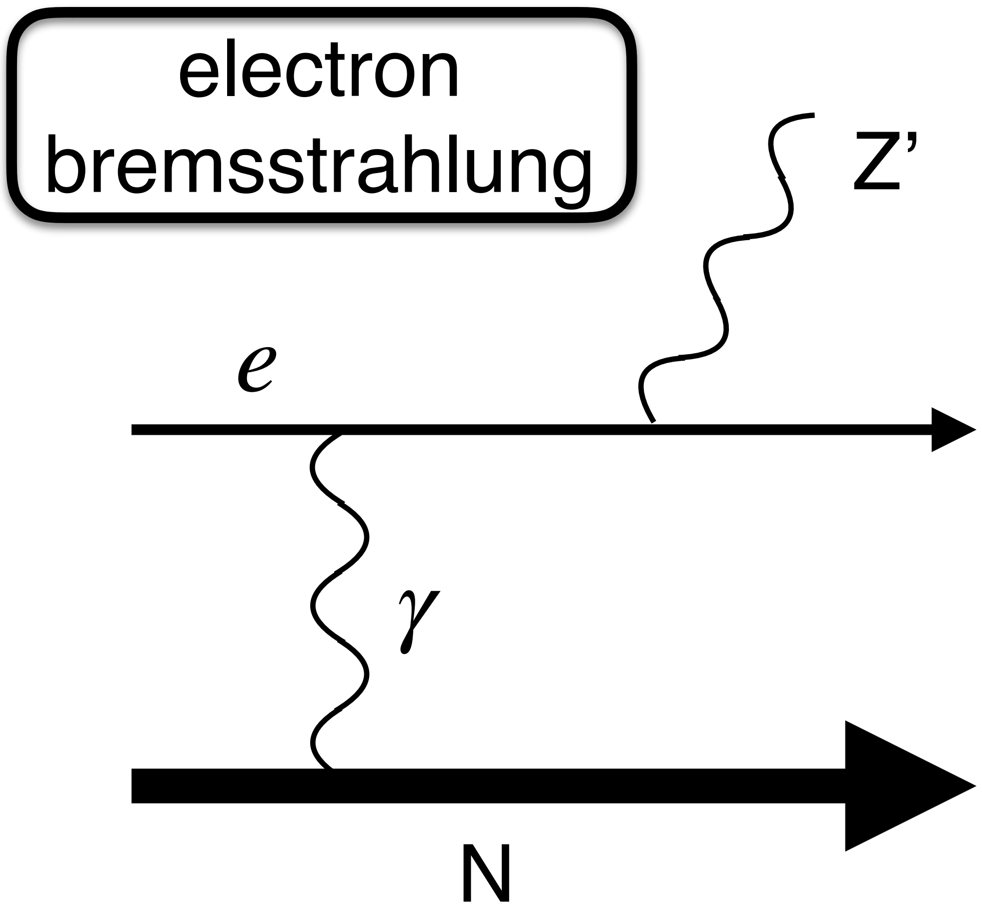


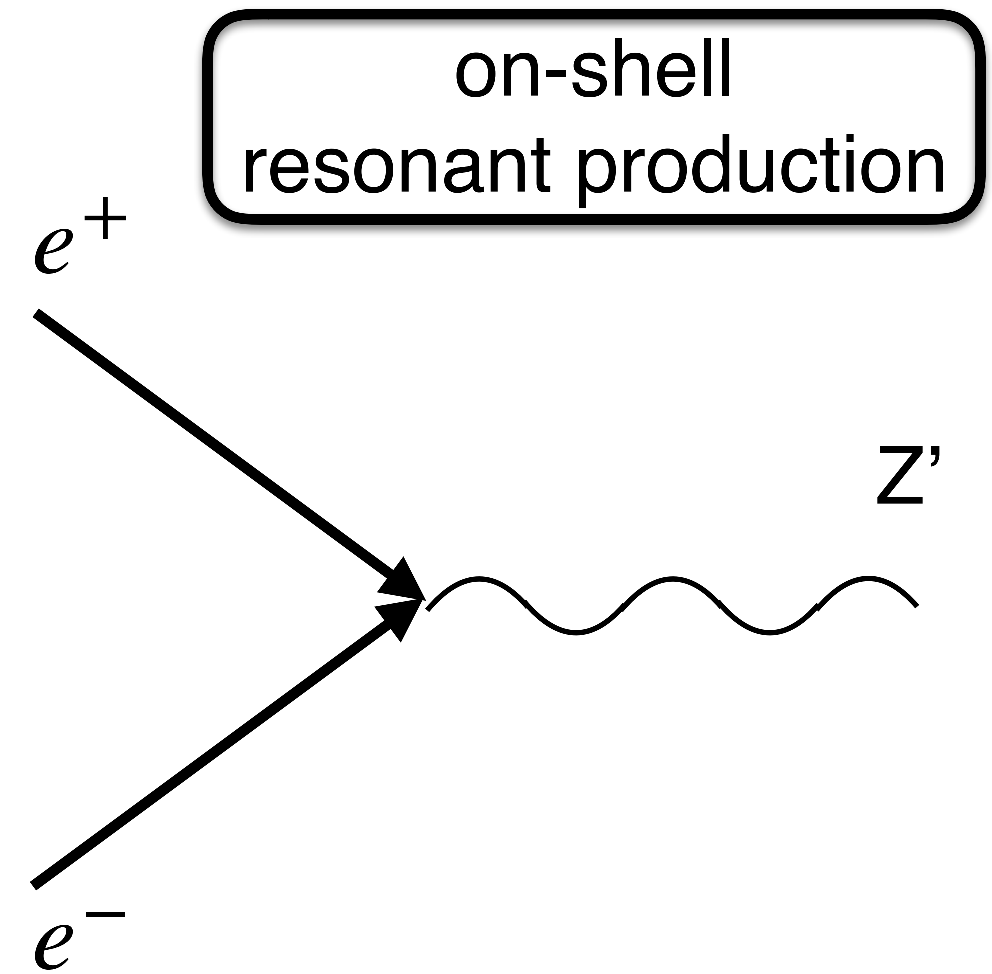


Not enough to get constraints beyond those from E137

Extra production channels

If Z' is couple to electrons, then two other production channels are available



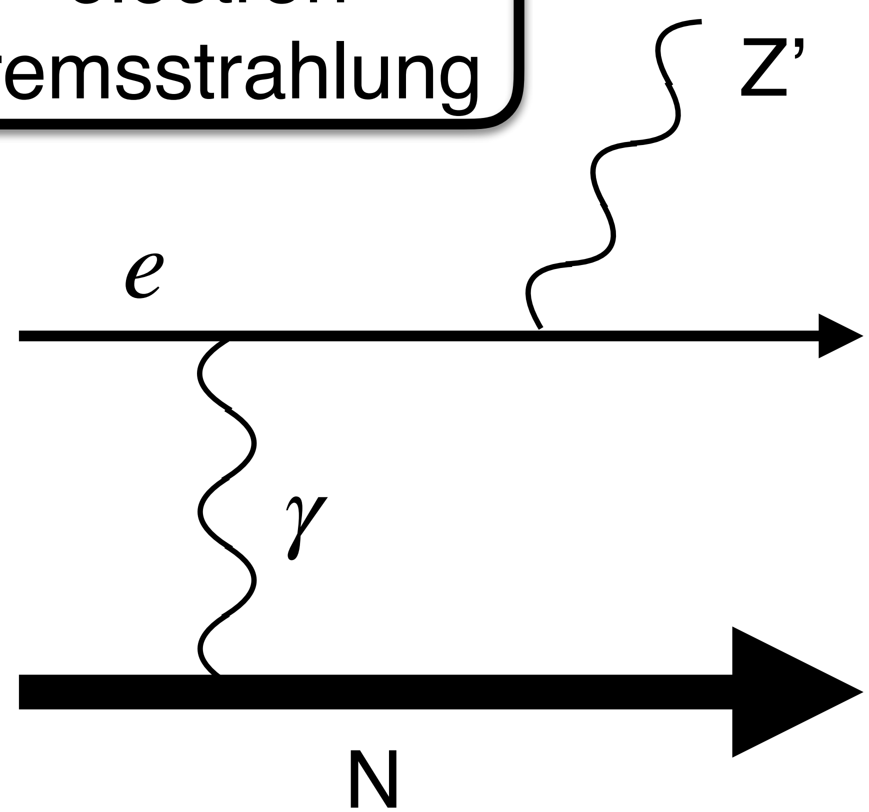


How do we compute the contribution from these channels?

Extra production channels

We extract spectrum and direction of $e^{\pm}$ from a GEANT4 simulation

electron bremsstrahlung



$$N_{Z'}^{\text{brem},ij} = N_{\gamma}^{\text{brem},ij} \left(\frac{g}{e}\right)^2 f\left(\frac{m_{Z'}}{\langle E_e \rangle}\right)$$

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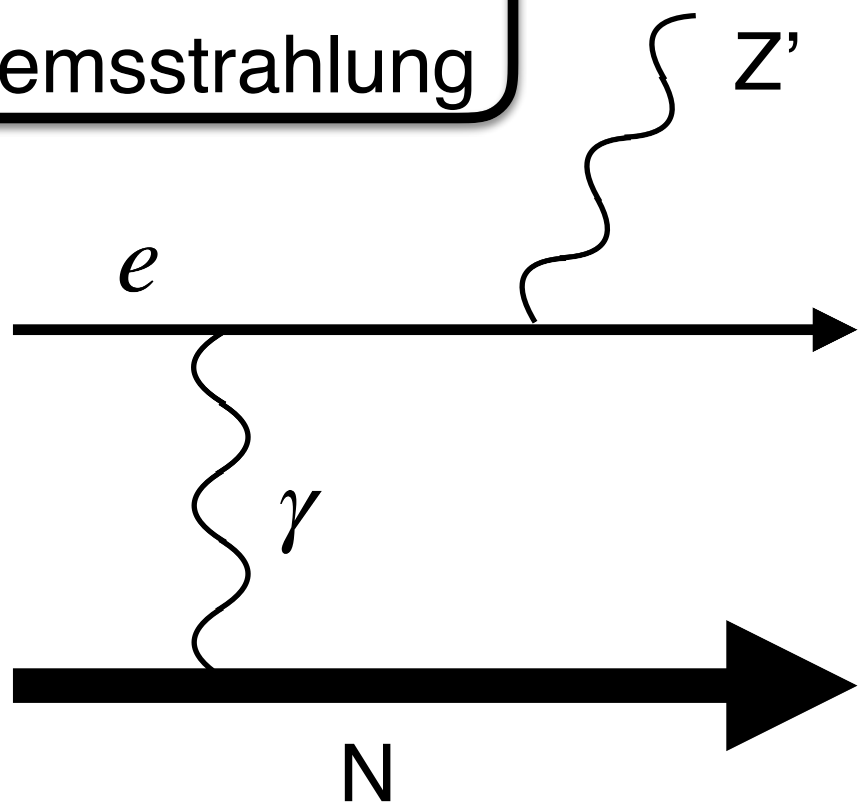

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photon energy (i) and angle (j) distribution from GEANT4

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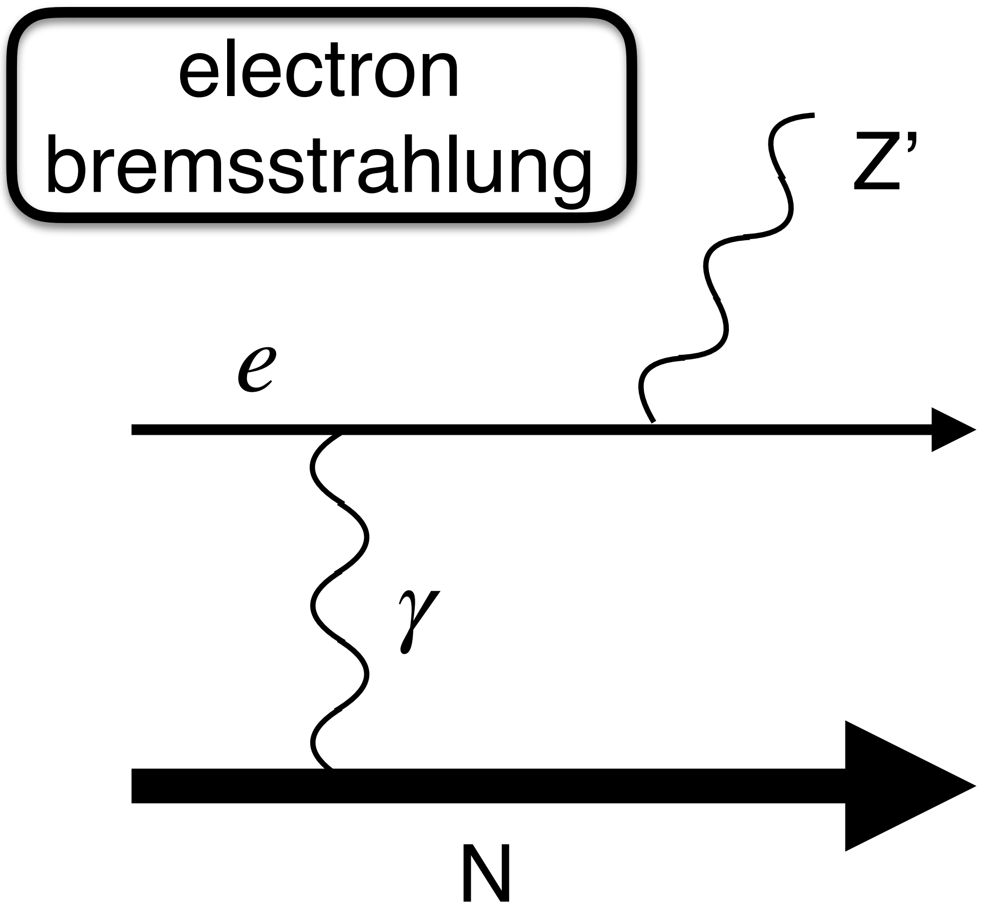

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rescaling of the coupling with respect to standard brem

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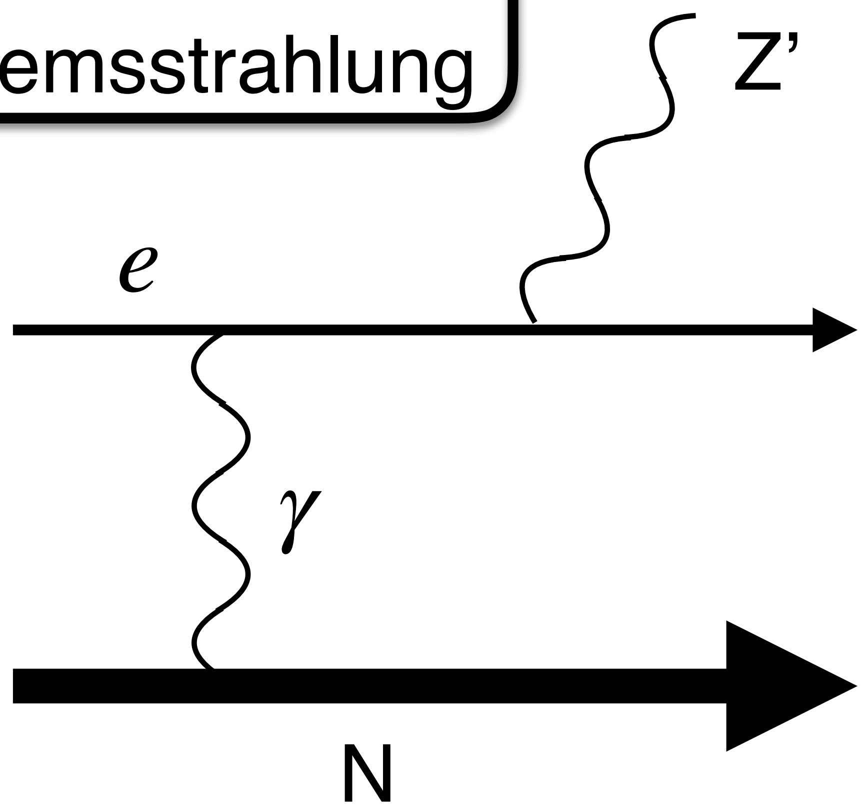

Dutta, Kim, Liao, Park, Shin, Strigari and Thompson, arXiv:2006.09386

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phase space factor

Extra production channels

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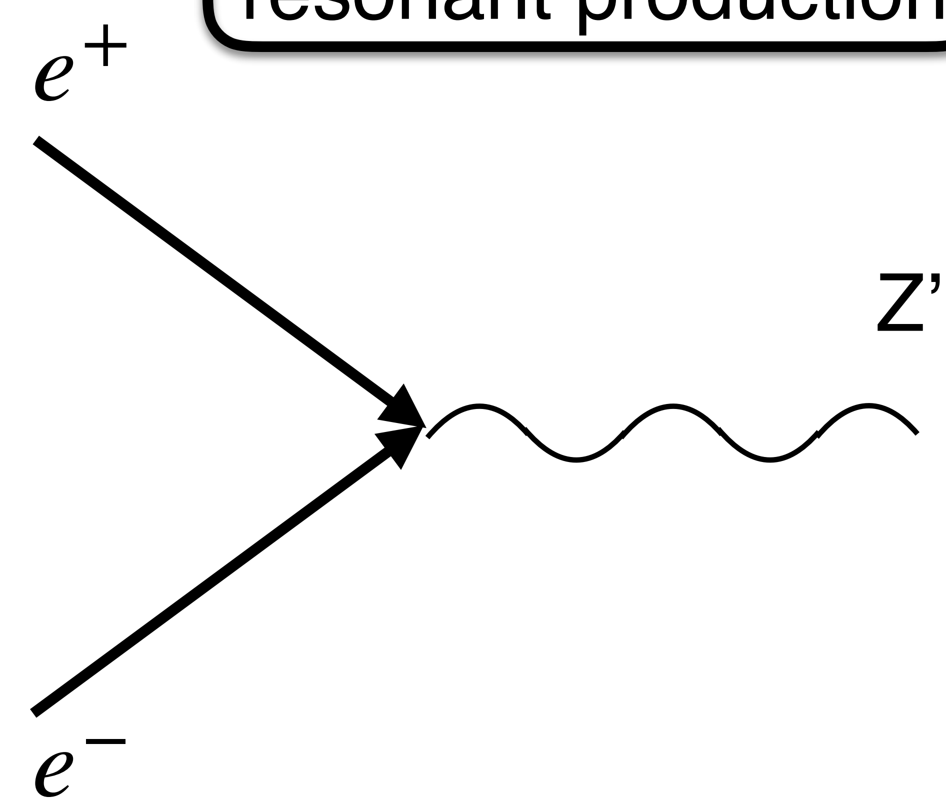
$$N_{Z'}^{\text{res},j} = \frac{ZX_0}{m_p A} \sum_i \int_0^{t_{\max}} dt\, N_{e^+}^{ij}\, I(E_i, E_{e^+}^{\text{res}}, t)\, \sigma_{\text{res}}$$

on-shell
resonant production



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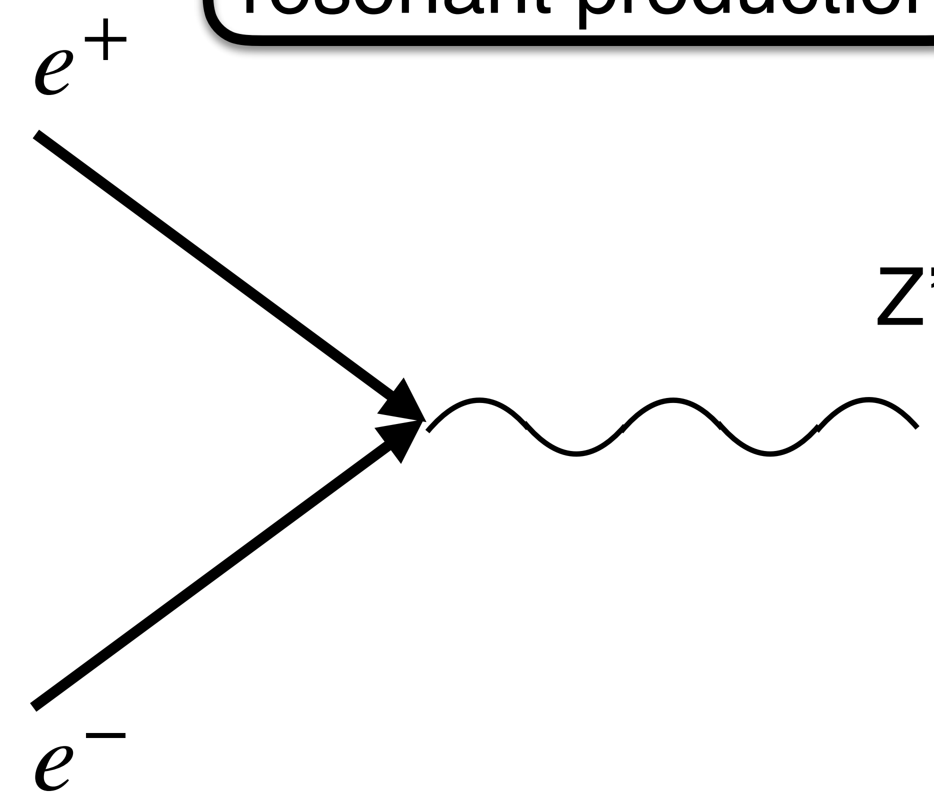
sum over all initial energies of e^+

on-shell resonant production



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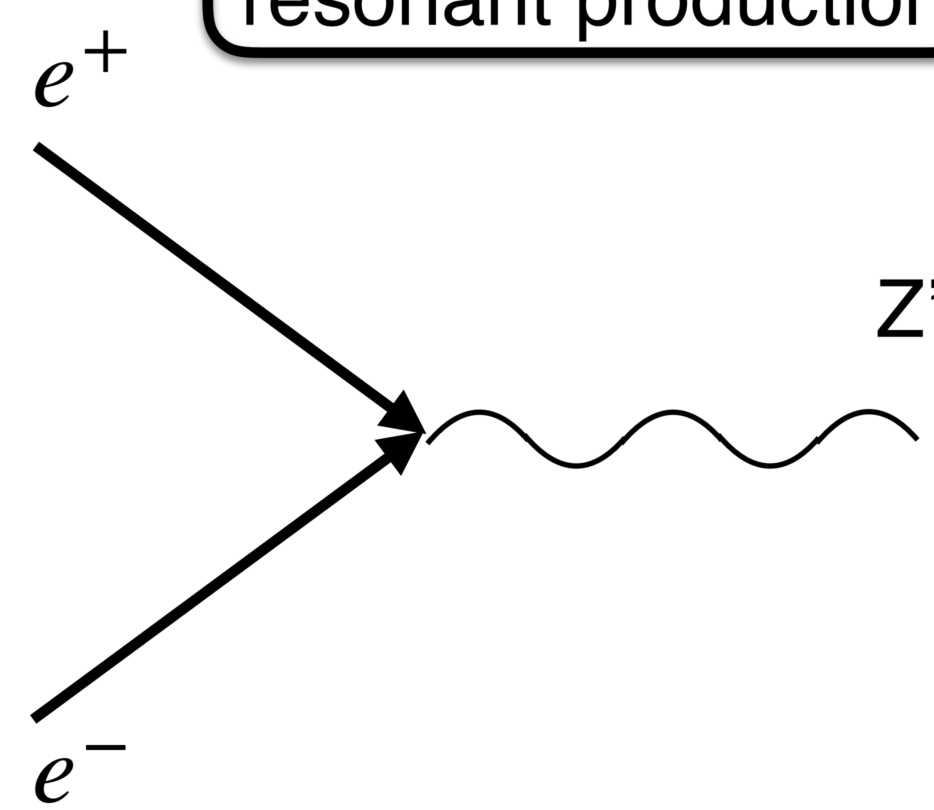
$$N_{Z'}^{\mathrm{res},j} = \frac{Z X_0}{m_p A} \sum_i \int_0^{t_{\max}} dt \, N_{e^+}^{ij} \, I(E_i, E_{e^+}^{\mathrm{res}}, t) \, \sigma_{\mathrm{res}}$$

integral over the amount of radiation lengths travelled by e^+

on-shell resonant production



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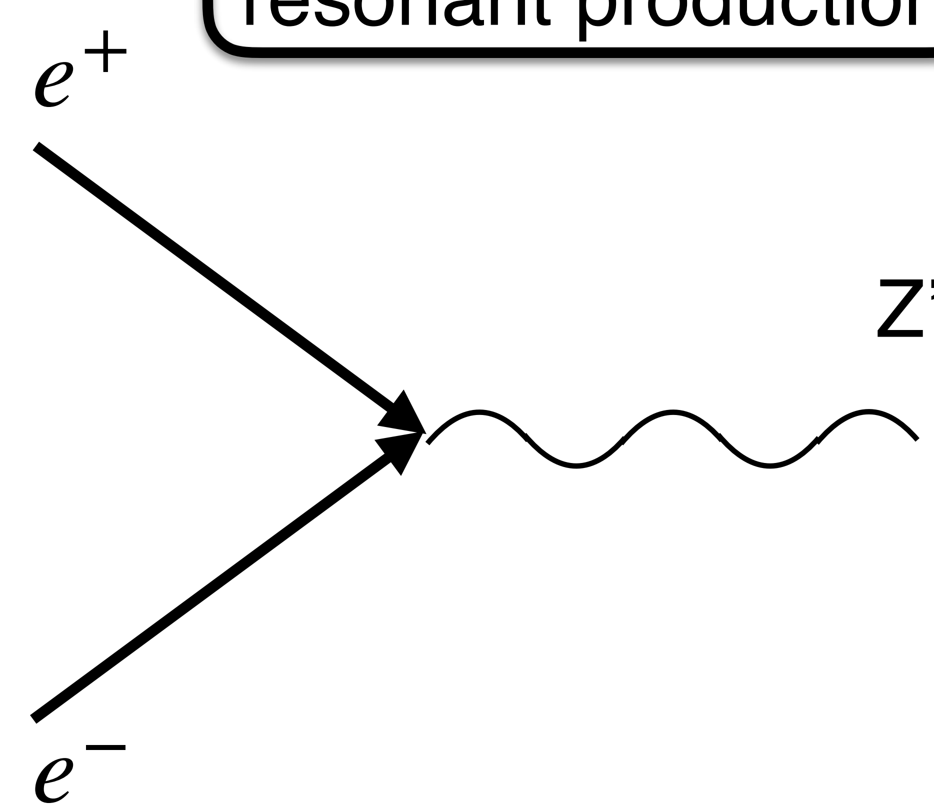
e^+ energy (i) and angle (j) distribution from GEANT4

on-shell resonant production



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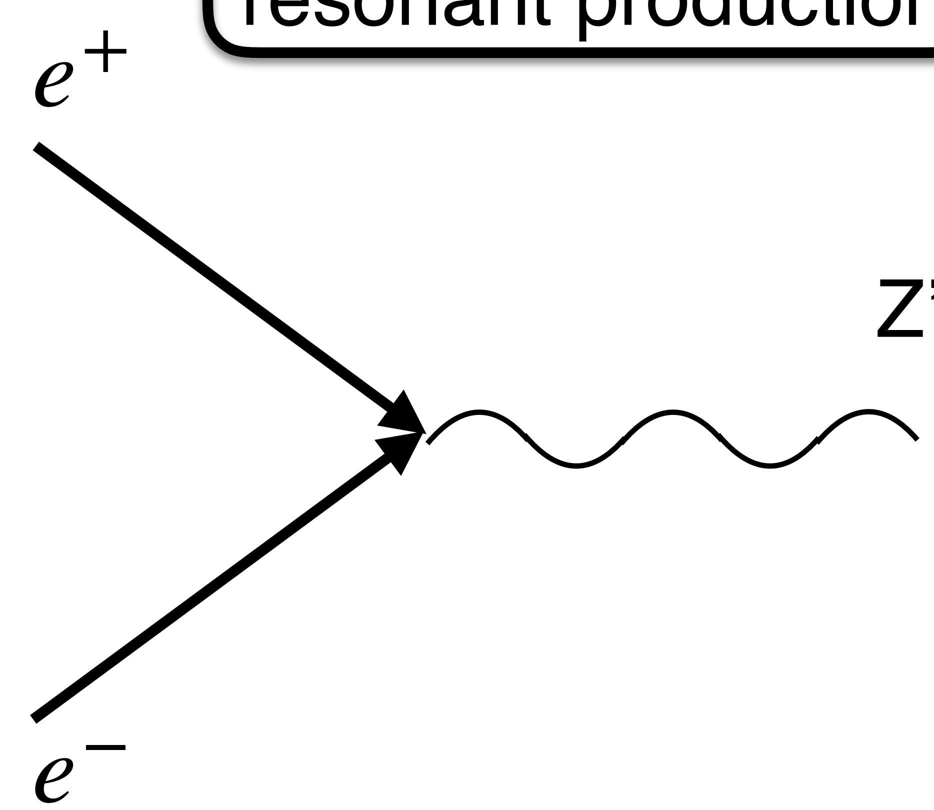
probability that a e^+ with Ei ends up with E^{res} after t radiation lengths

on-shell resonant production



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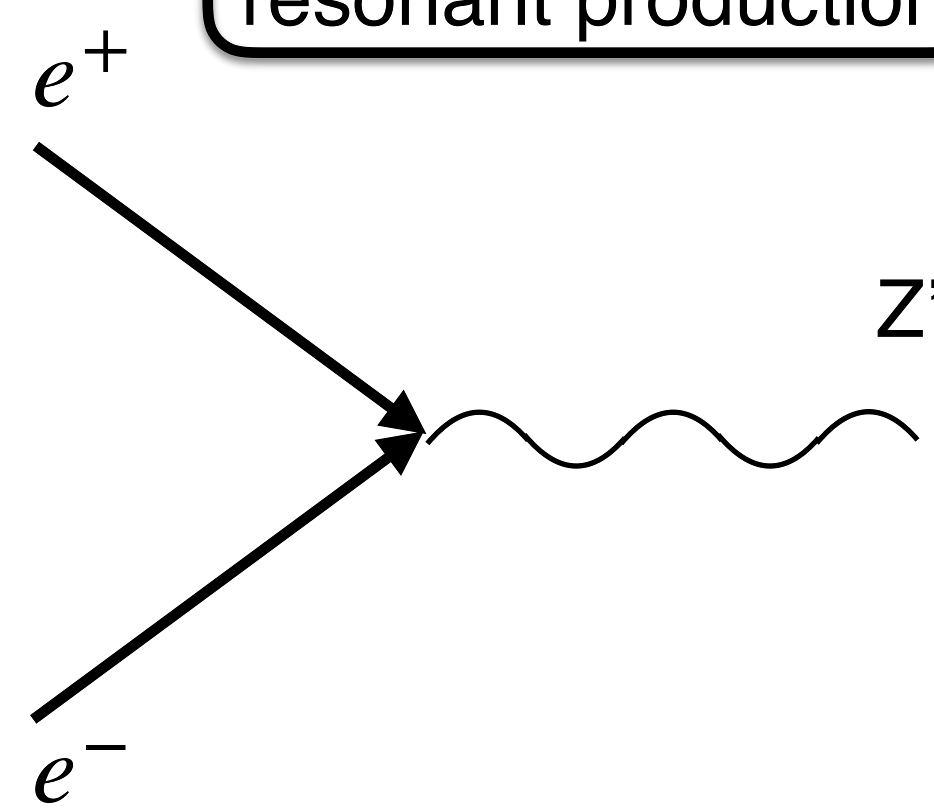
$$\sigma_{\mathrm{res}} = \frac{\pi g^2}{2m_e} \delta\left(E_{e^+} - \frac{m_{Z'}^2}{2m_e}\right)$$

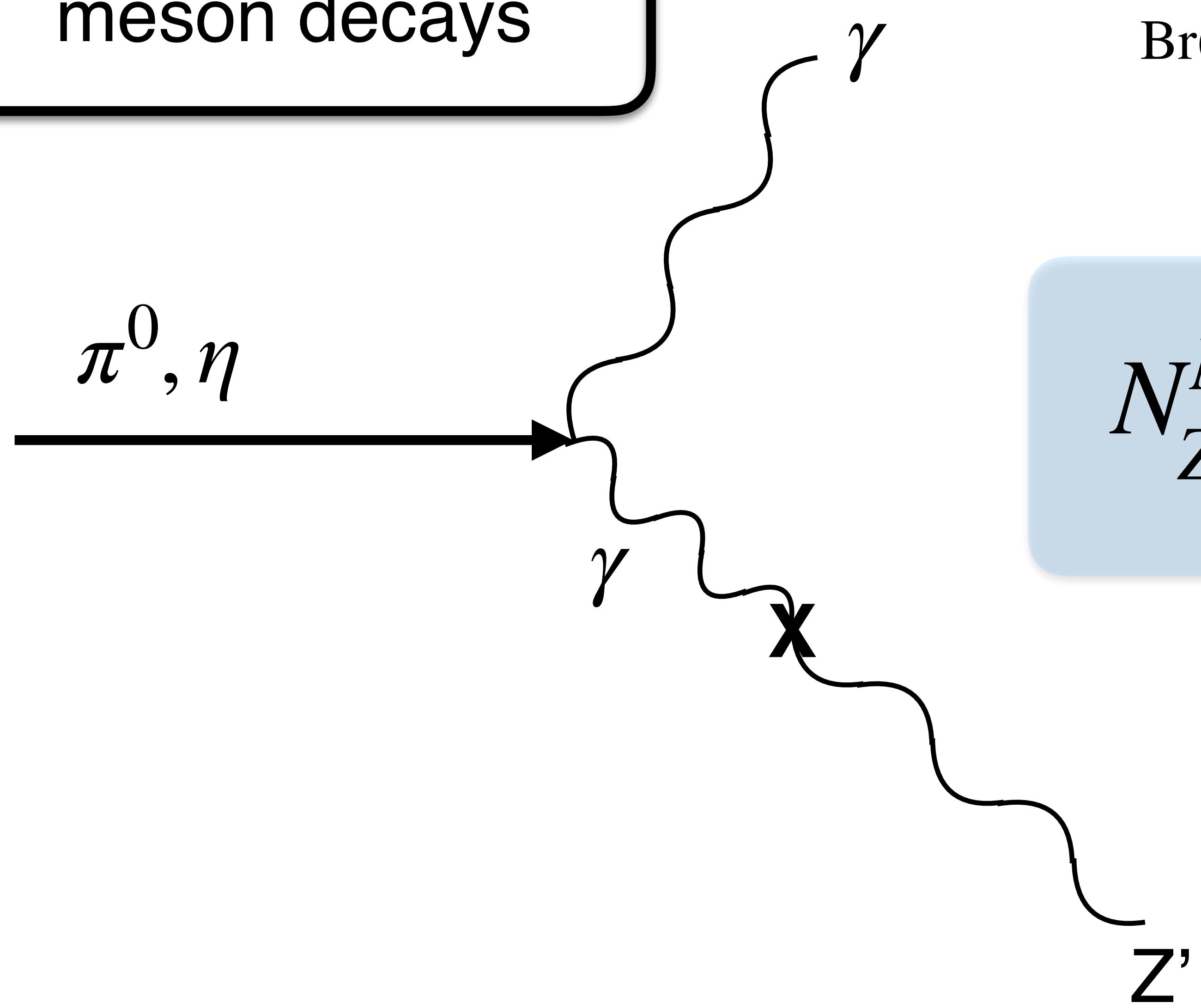
on-shell resonant production



Extra production channels

To compare our GEANT4 simulation with literature, we include meson decays

meson decays

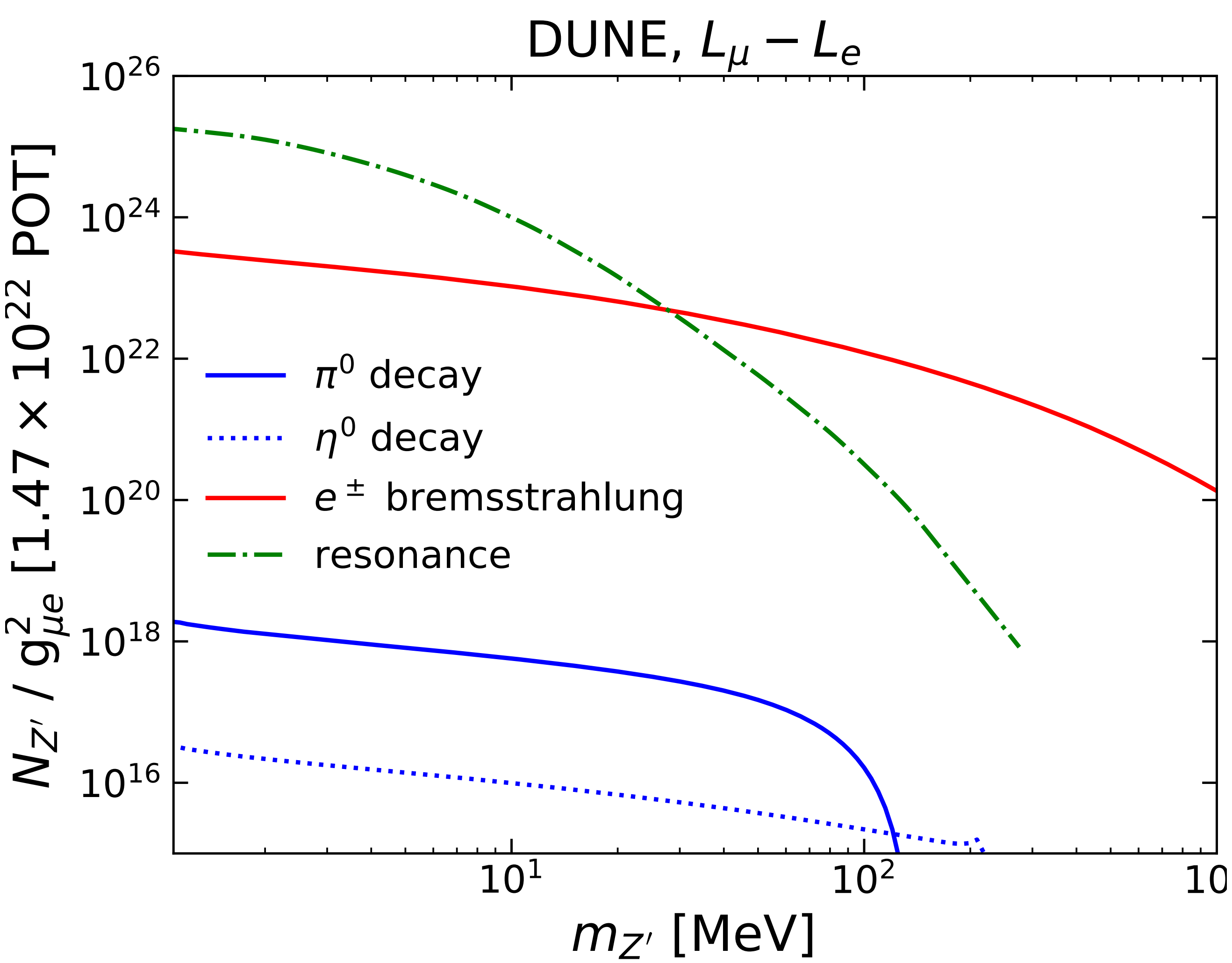


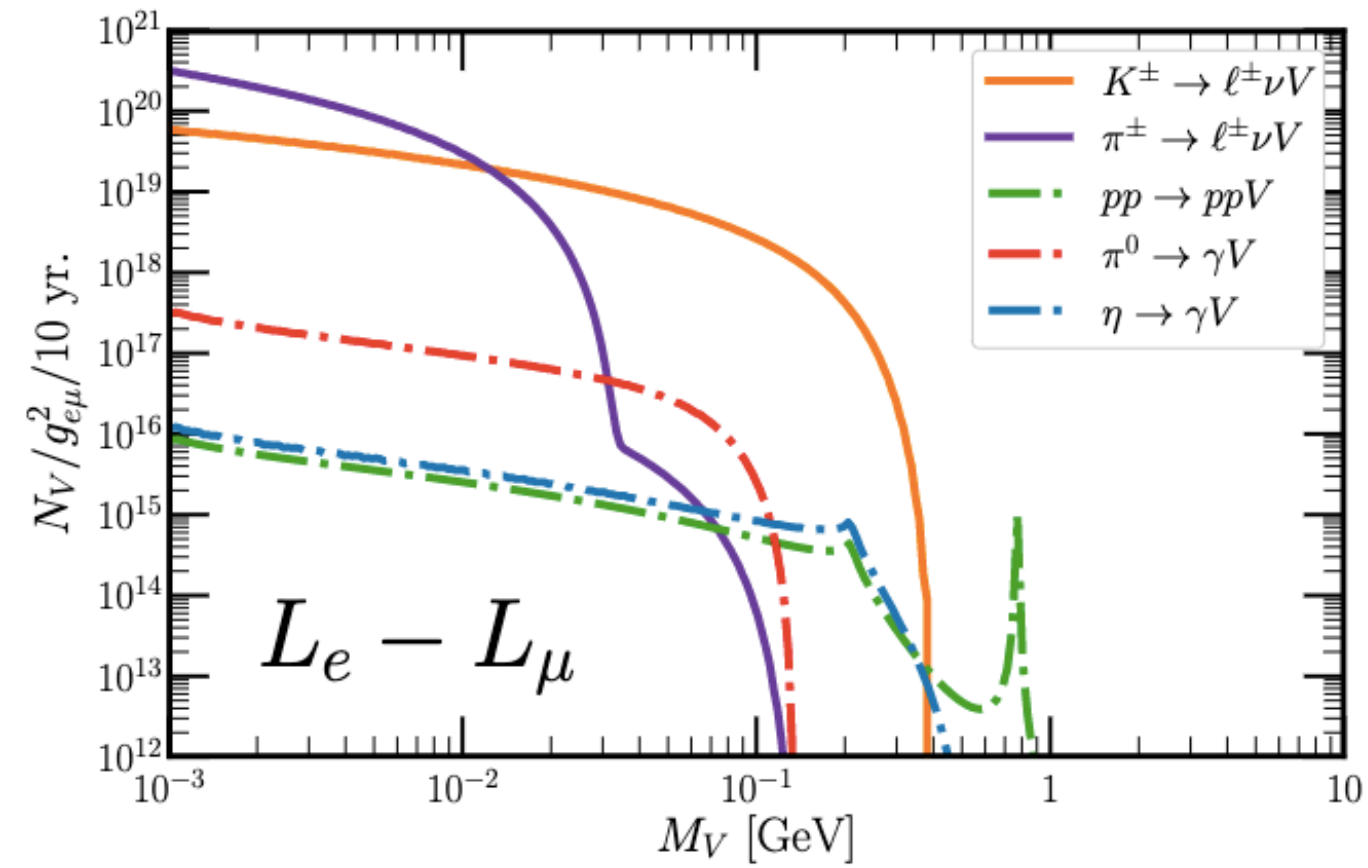
$$\mathrm{Br}(M \to \gamma Z') = 2\epsilon^2(m_{Z'}^2)\left(1 - \frac{m_{Z'}^2}{m_M^2}\right)^3 \mathrm{Br}(M \to \gamma\gamma)$$

$$N_{Z'}^{M,ij} = N_{\gamma}^{M,ij}\frac{\mathrm{Br}(M \to \gamma Z')}{2\mathrm{Br}(M \to \gamma\gamma)}$$

Extra production channels

Comparison between meson decays and (bremsstrahlung + resonance)





Huge improvement in the case of $U(1)_{L_\mu - L_e}$

Extra production channels

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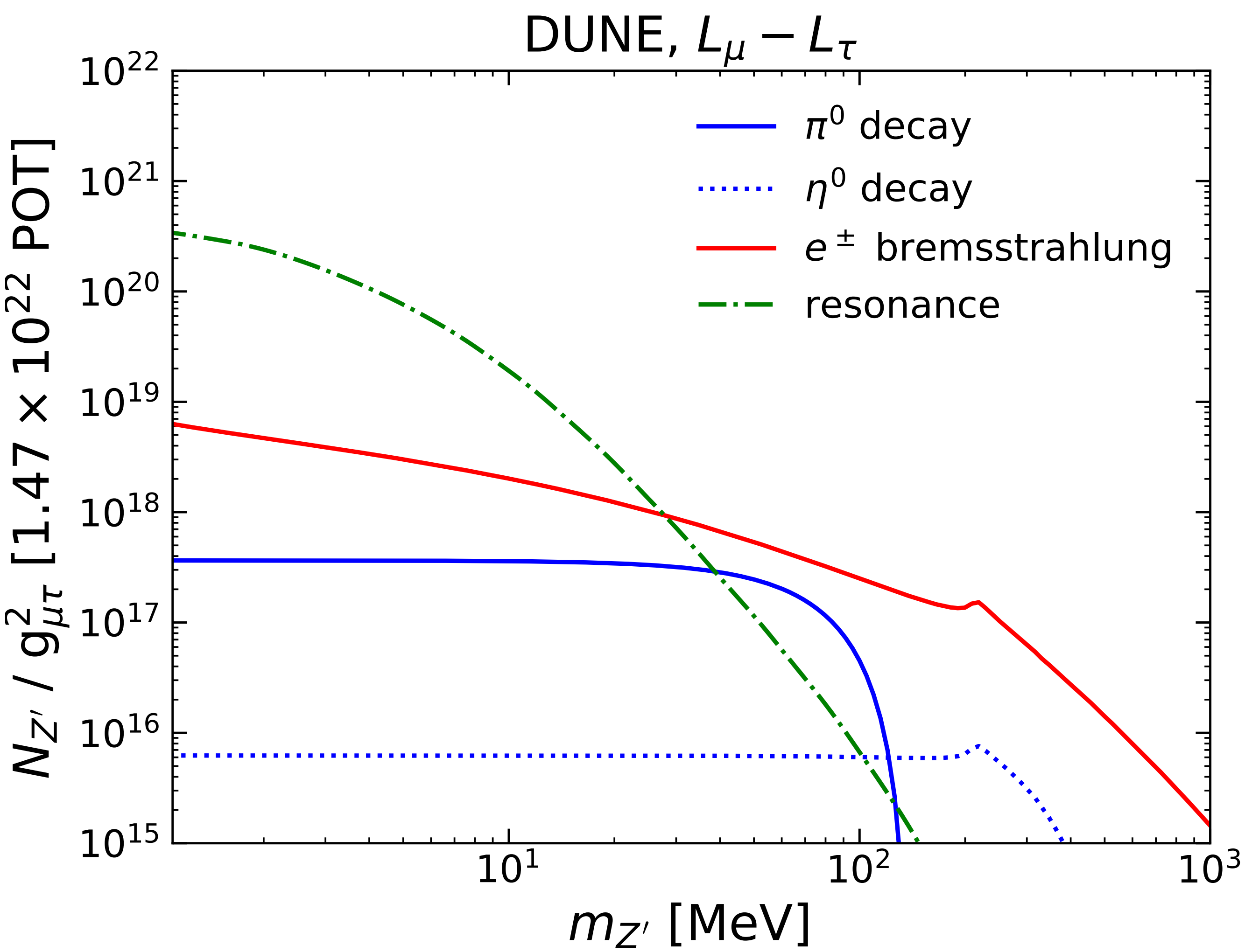
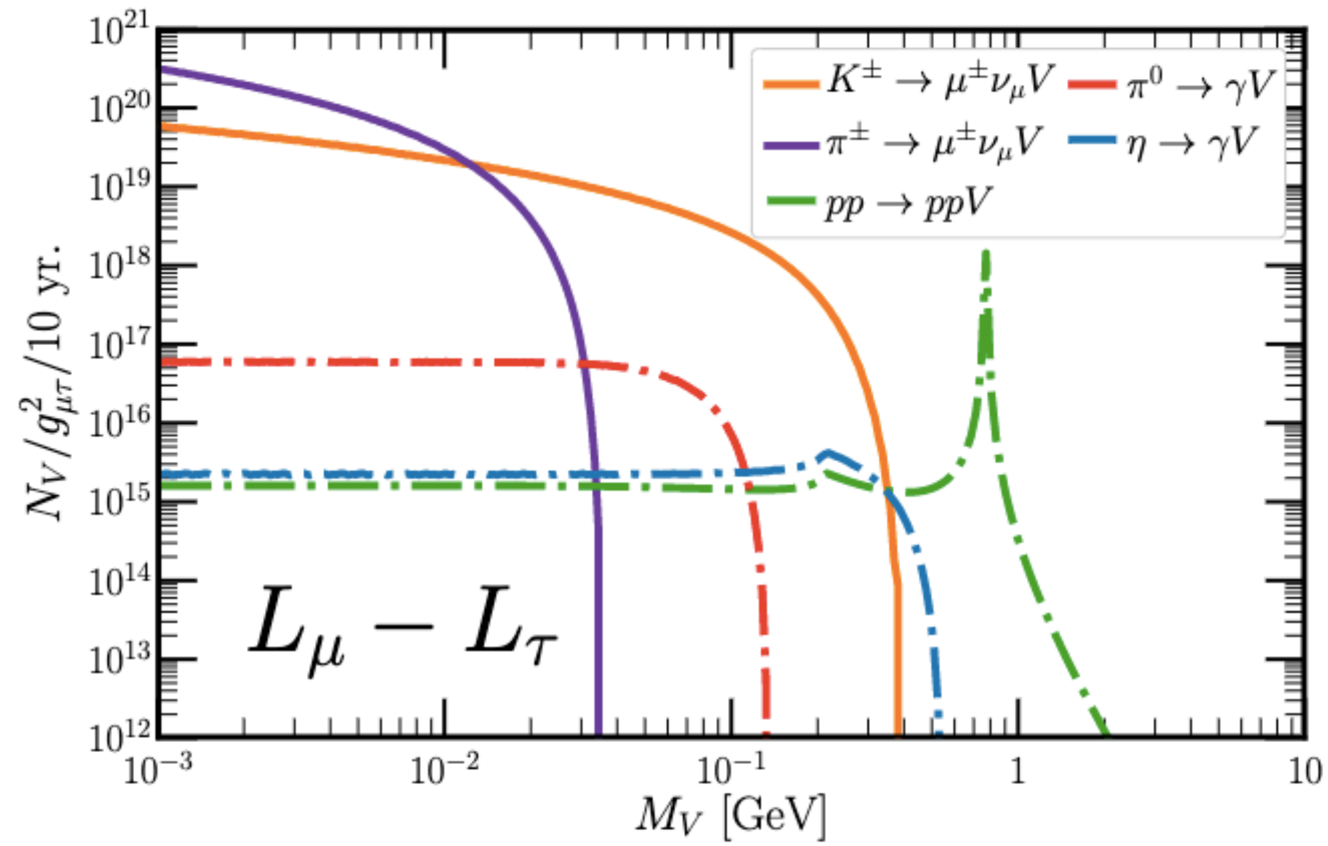


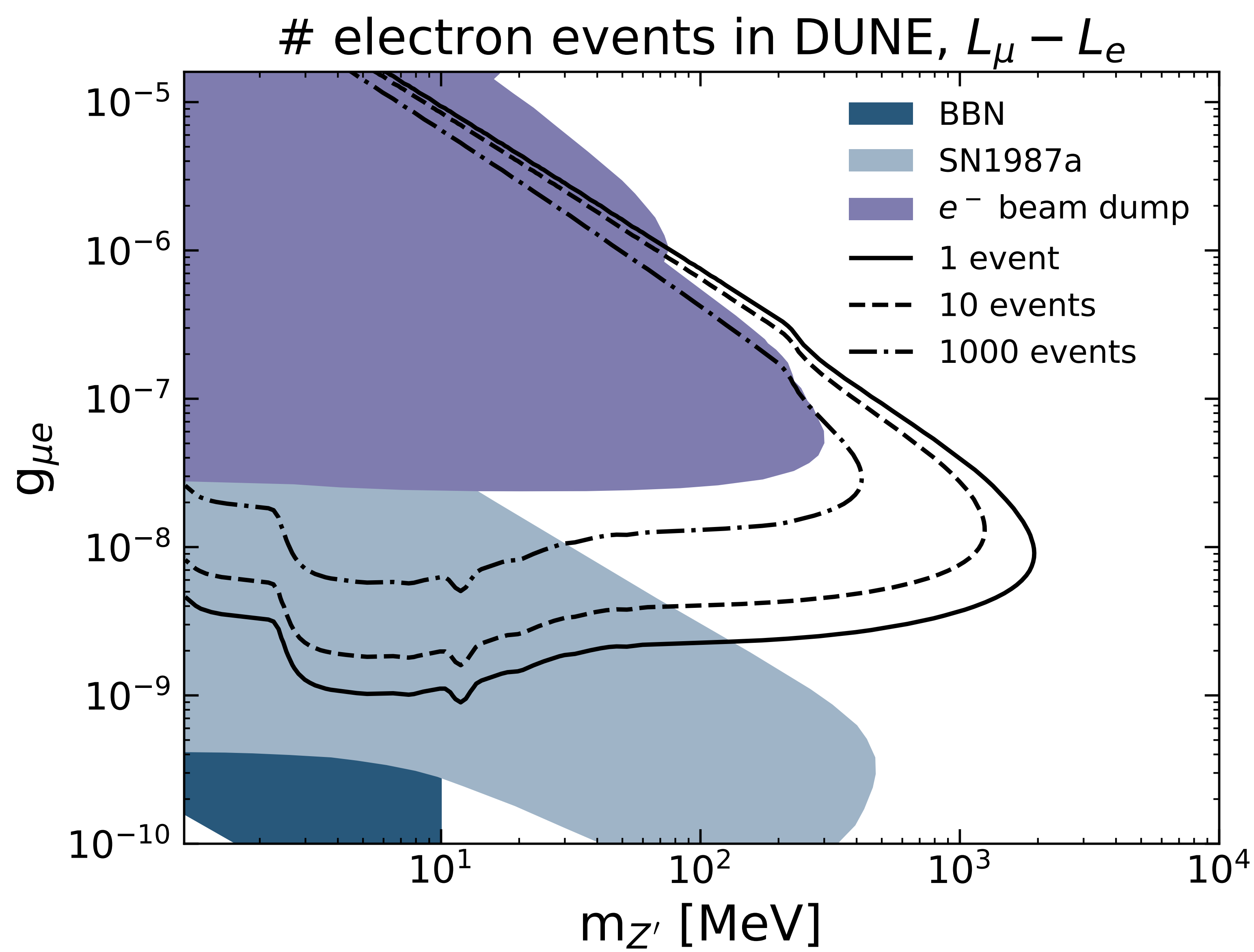
Berryman, de Gouvea, Fox, Kayser, Kelly and Raaf, JHEP 02 (2020), 174



Similar contributions in the case of $U(1)_{L_\mu - L_\tau}$

Future constraints

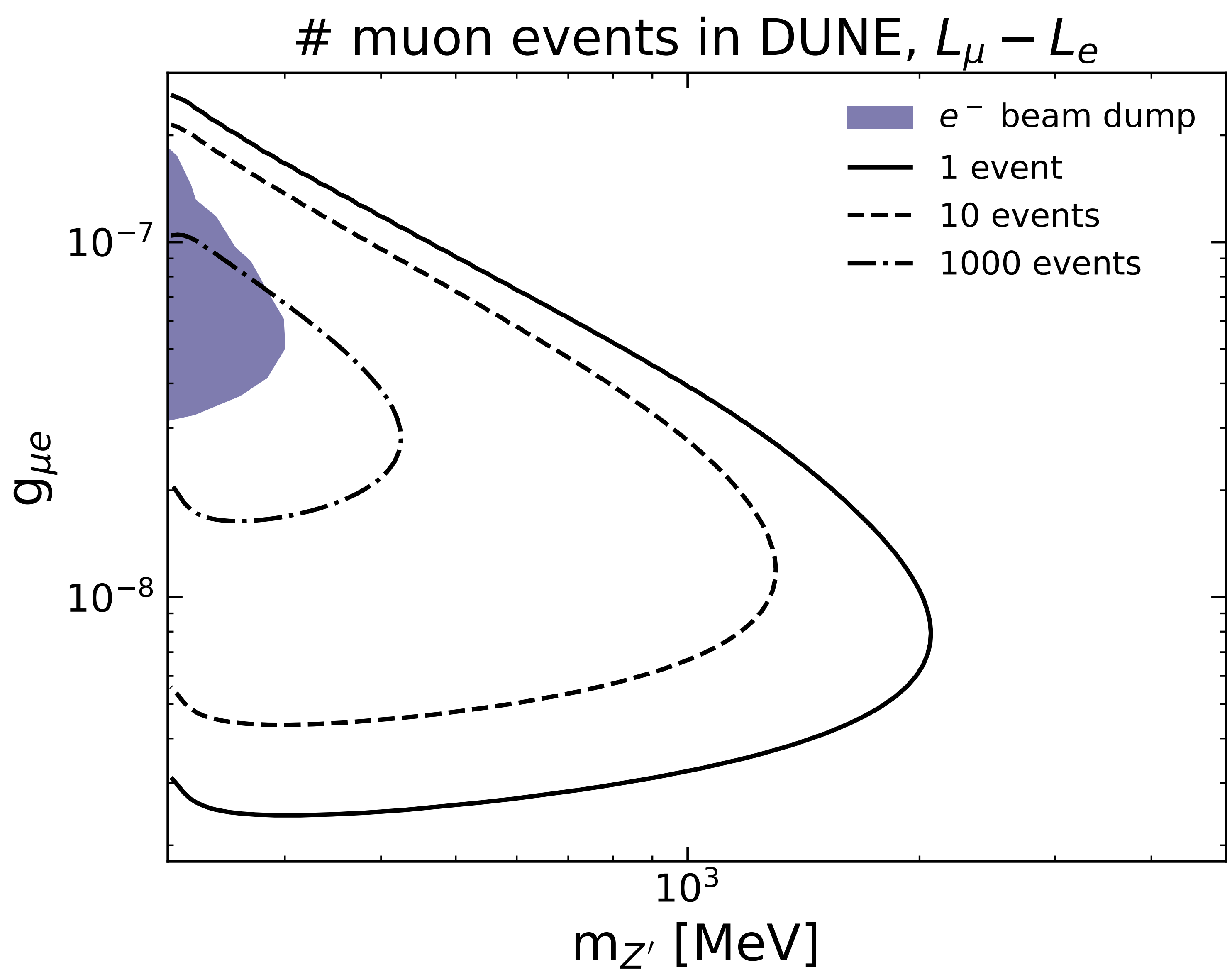
How many $e^{\pm}$ do we see in the DUNE GAr near detector?



DUNE can improve current astro and electron beam dump constraints

Future constraints

How many $\mu^{\pm}$ do we see in the DUNE GAr near detector?



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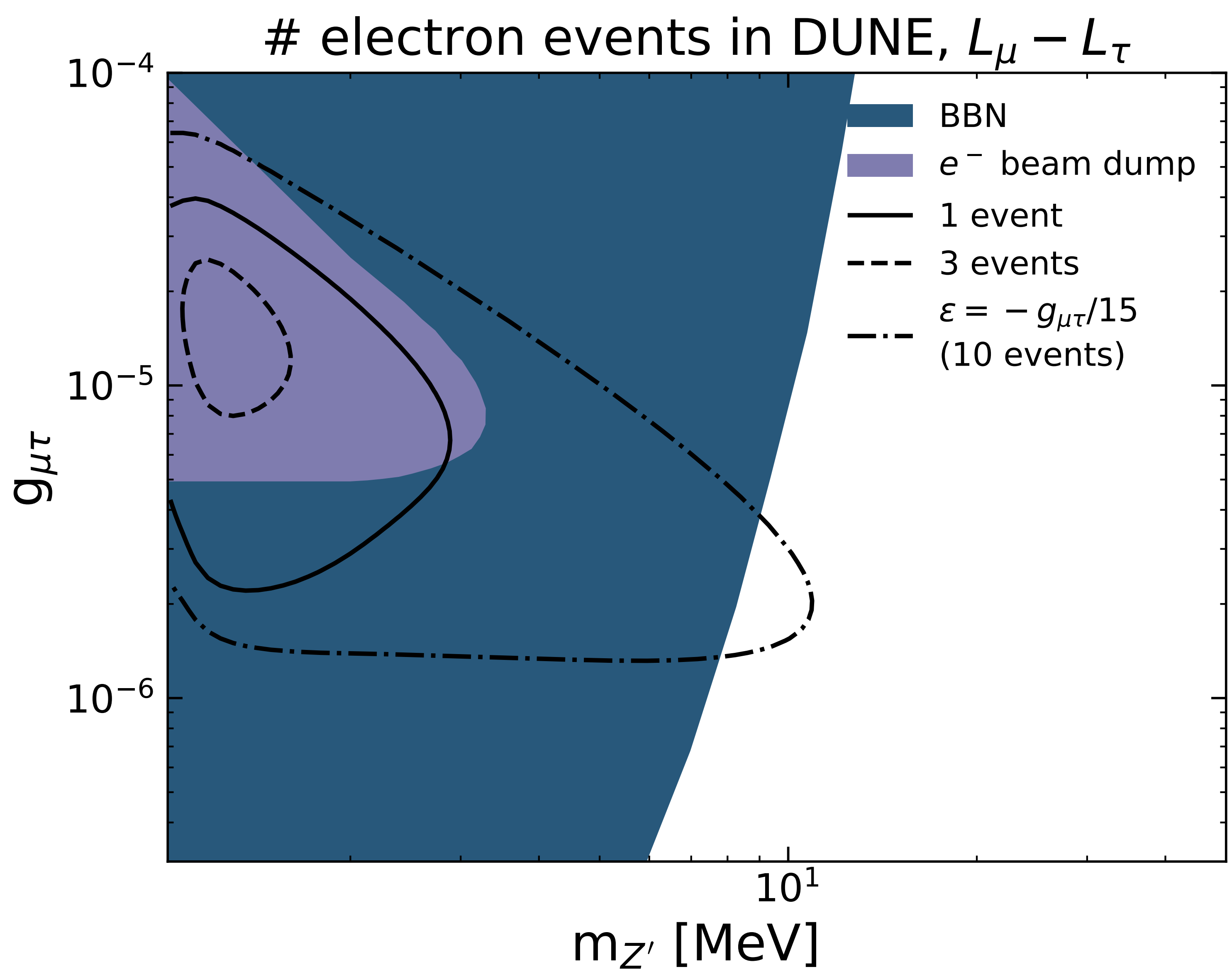
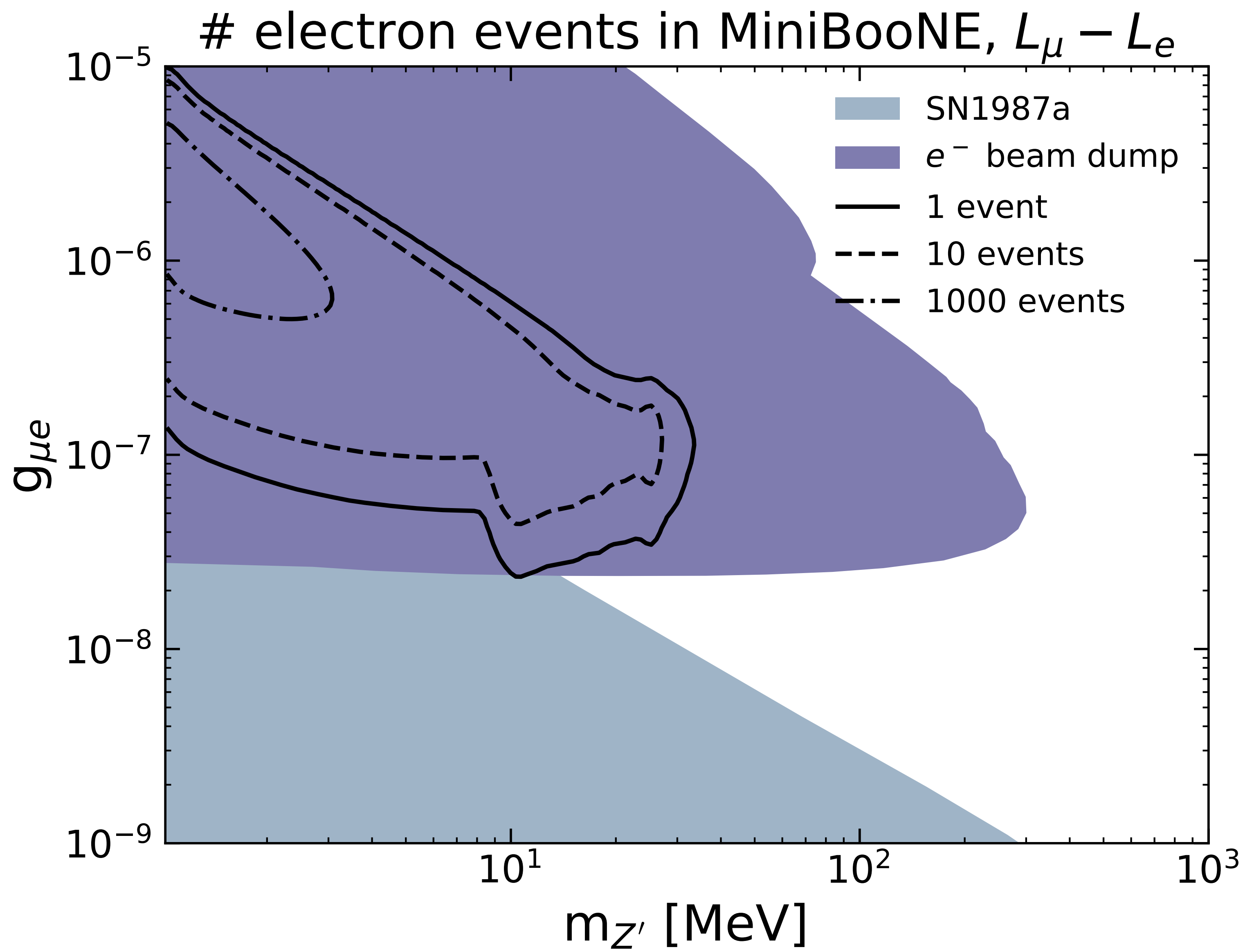


No improvements for $U(1)_{L_\mu - L_\tau}$, unless there is a tree level contribution to ϵ

What about MiniBooNE

How many $e^{\pm}$ do we expect in the MiniBooNE detector?



MiniBooNE can provide nearly competitive constraints

Conclusions

Resonant and especially bremmstrahlung production play an important role in leptophilic gauge boson models

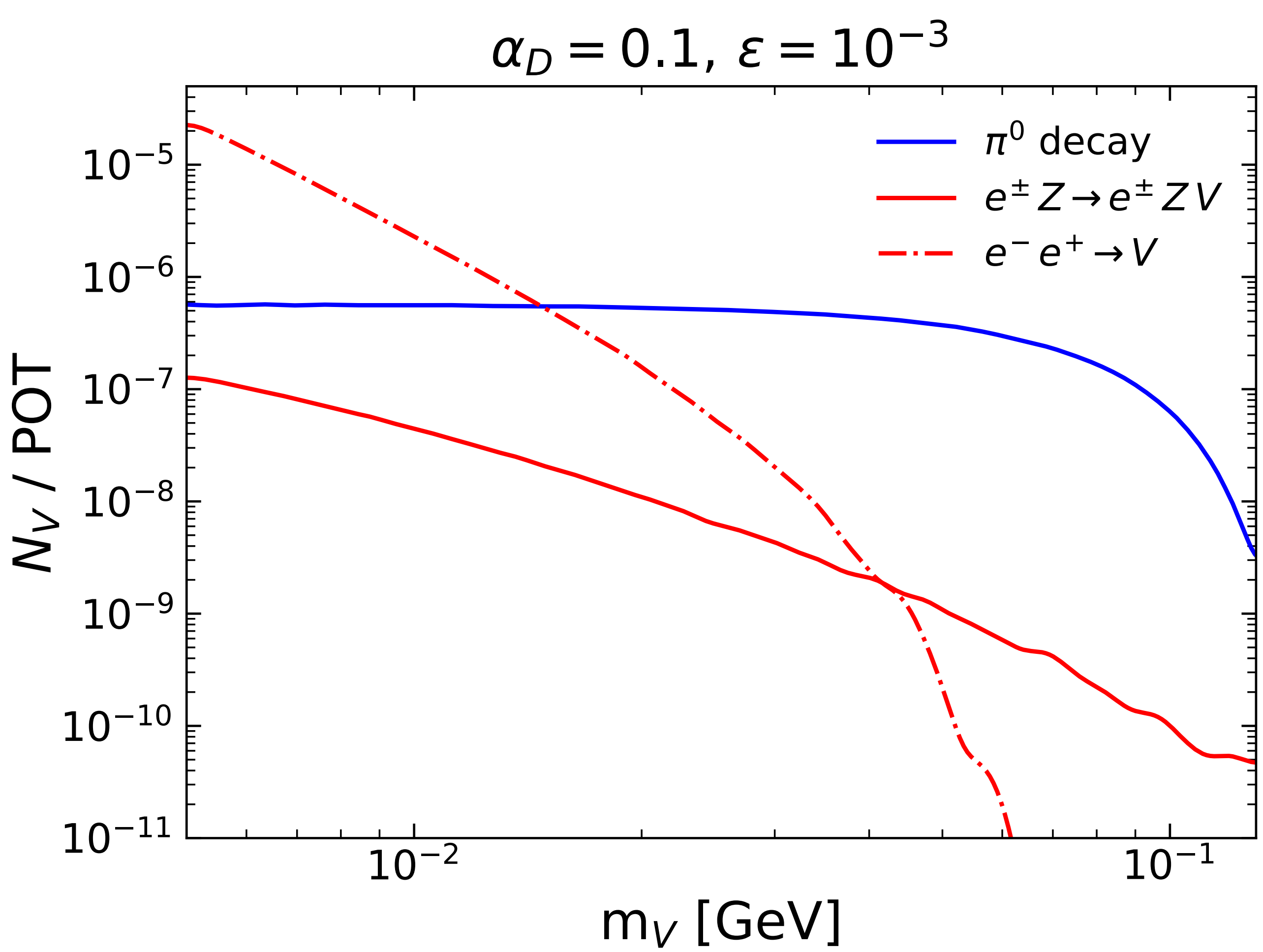
DUNE can improve current constraints on $U(1)_{L_\mu - L_e}$ for $m_{Z'} \in [10, 1000]$ MeV

These results apply also to other models

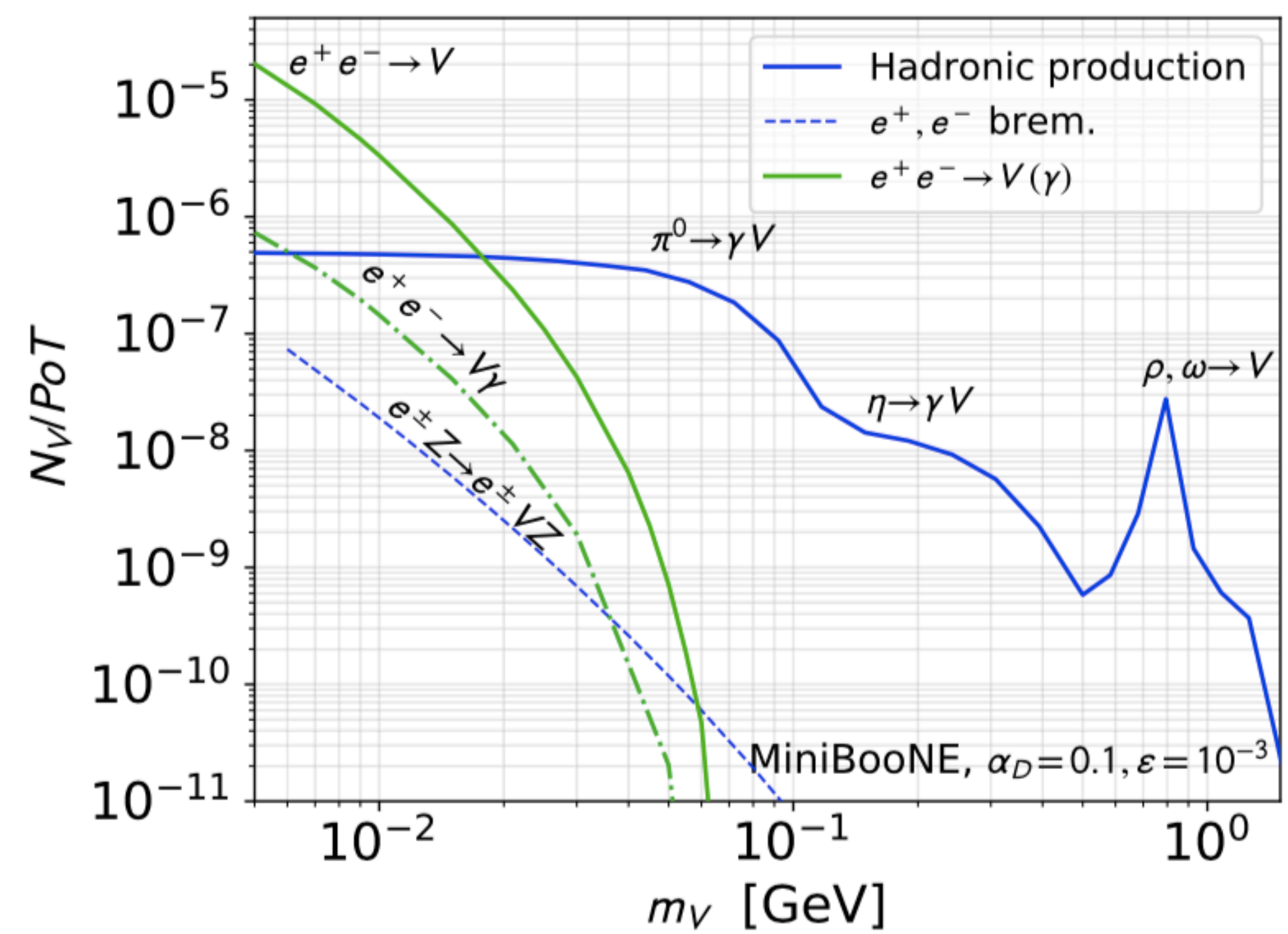
Thank You !!!

Extra production channels

Comparison with other GEANT based calculations, in dark photon models



Celentano, Darmè, Marsicano and Nardi, Phys. Rev. D 102 (2020) no.7, 075026



Relatively good agreement between the two calculations