SMITING NEW PHYSICS AT THE DUNE NEAR DETECTOR

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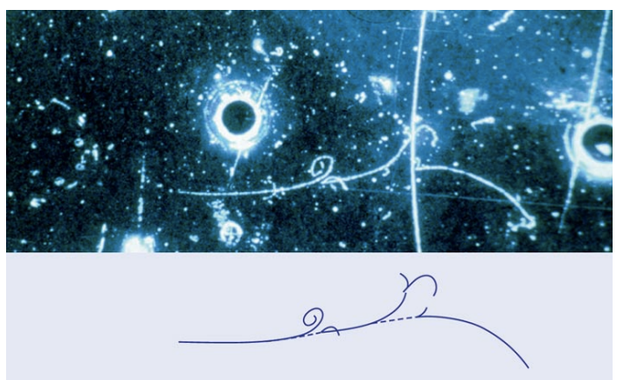
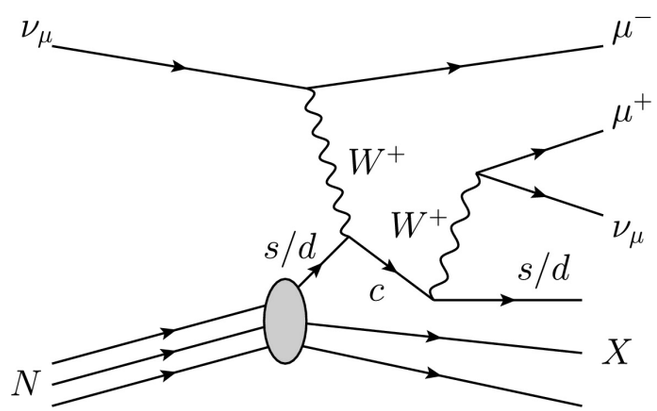
SCIENCE WITHOUT BORDERS

Neutrino scattering

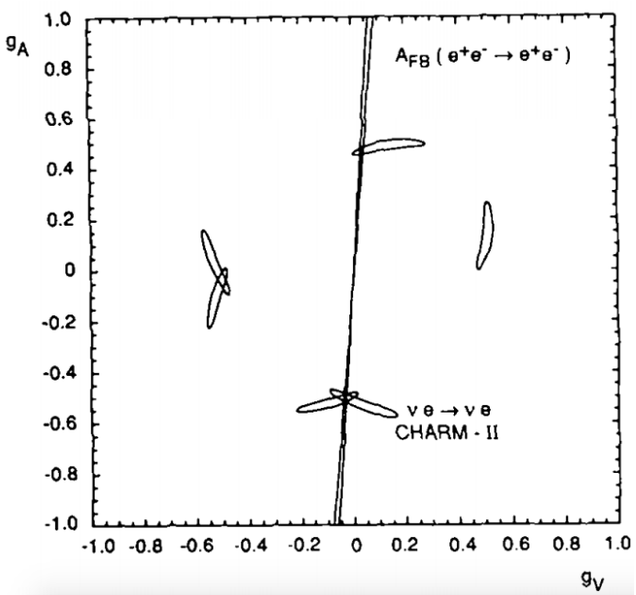
Beyond the exciting oscillation programme, neutrino scattering has taught us a lot of different physics...



First NC measurement at Gargamelle.



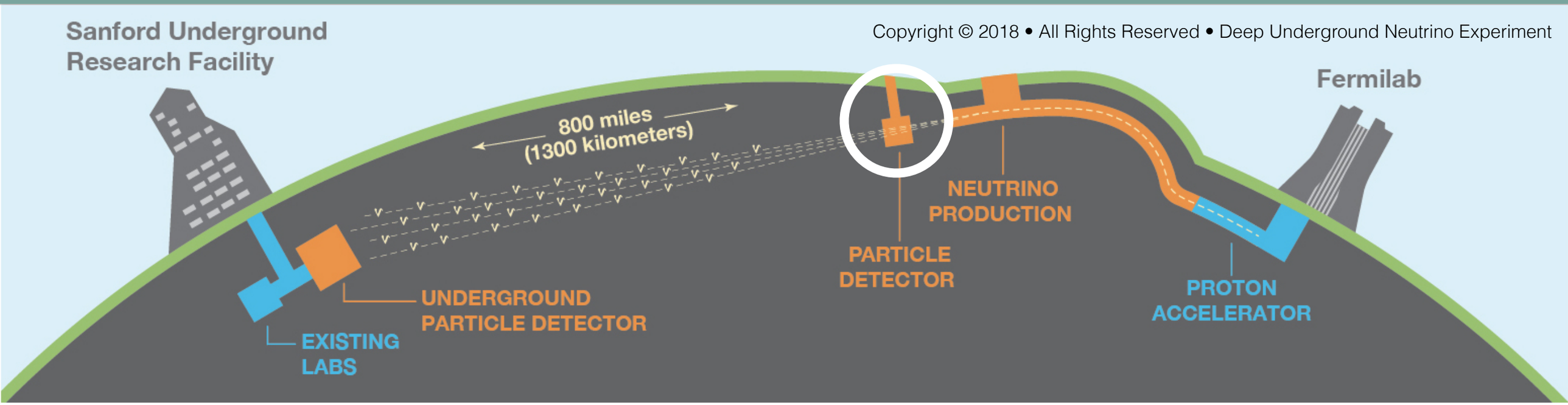
Structure of the nucleons (PDFs, strangeness of nucleon).



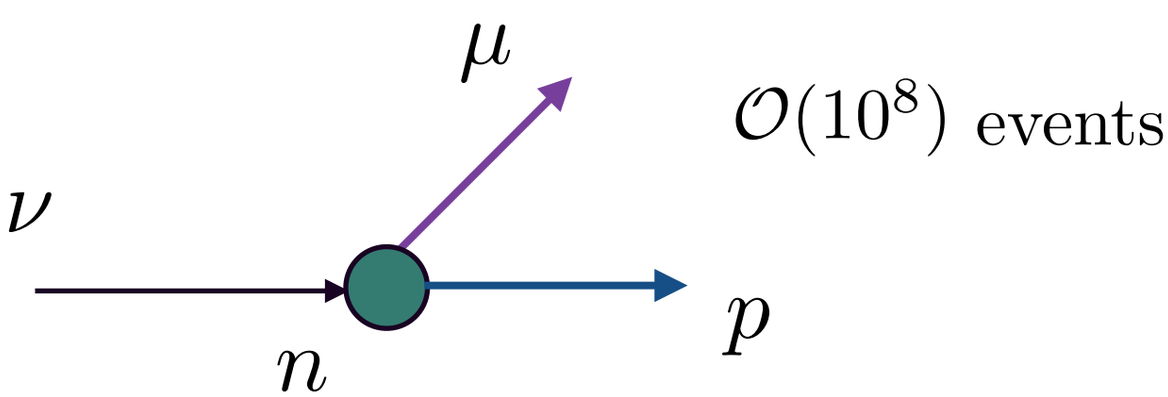
Electroweak measurements

...but novel neutrino interactions remain relatively unexplored.

DUNE near detector

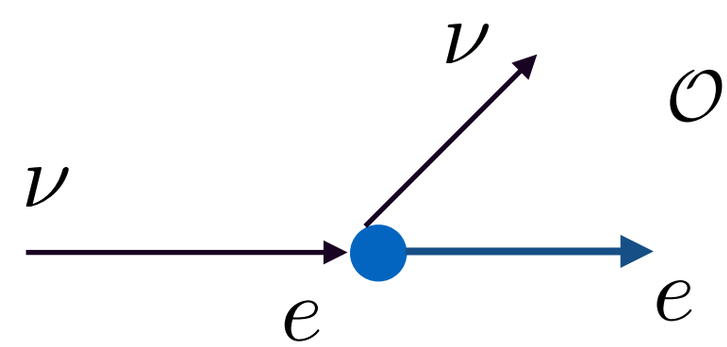


Neutrino-hadron scattering



$\mathcal{O}(10^8)$ events

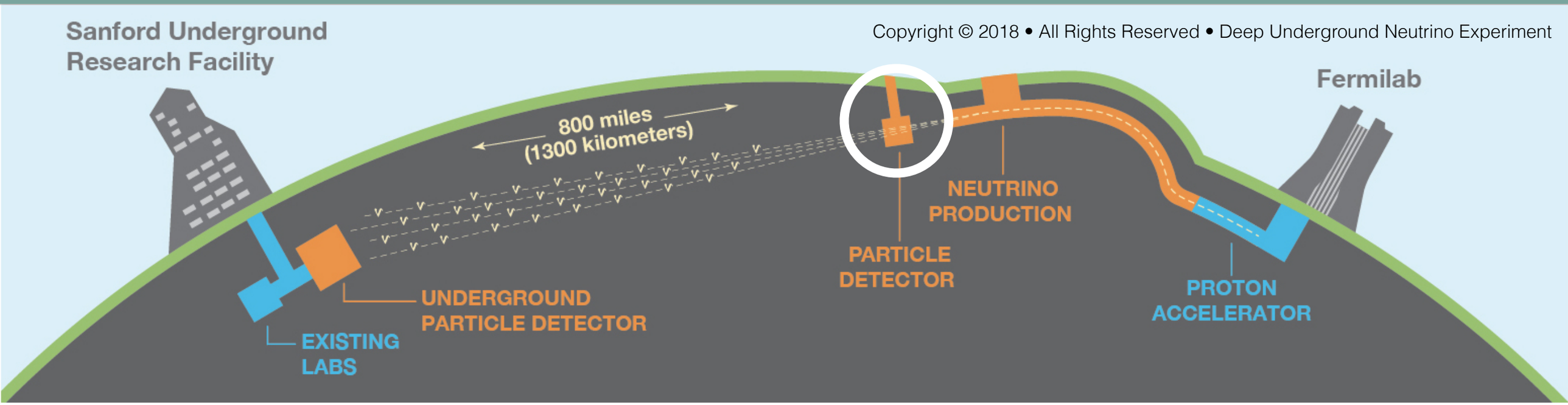
Neutrino-electron scattering



$\mathcal{O}(10^5)$ events

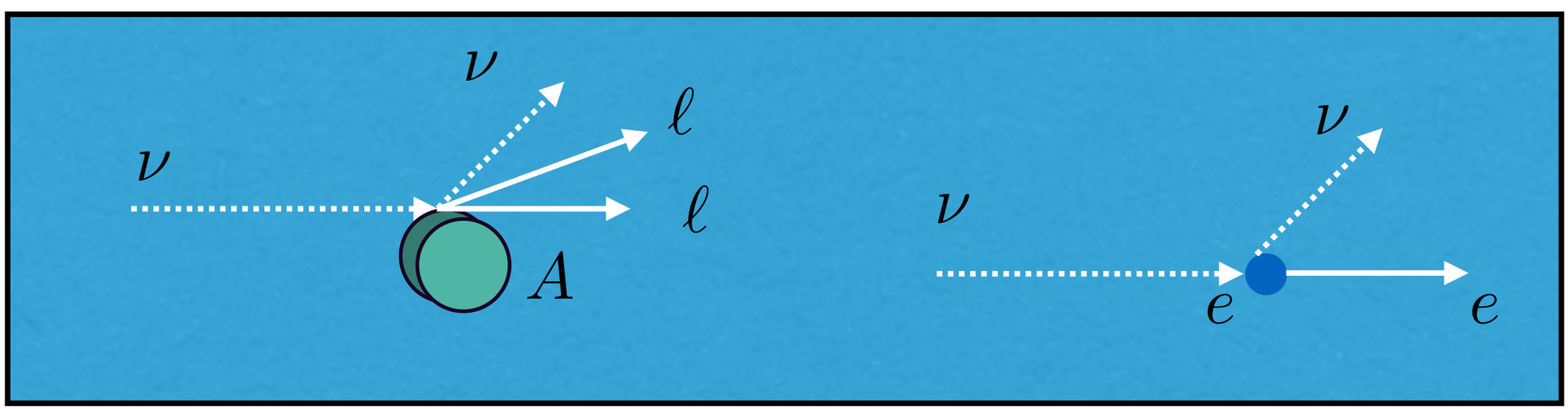
DUNE ND expects $\mathcal{O}(10^8)$ nu events /12.81e21 P.O.T./ 35 t of LAr

DUNE near detector



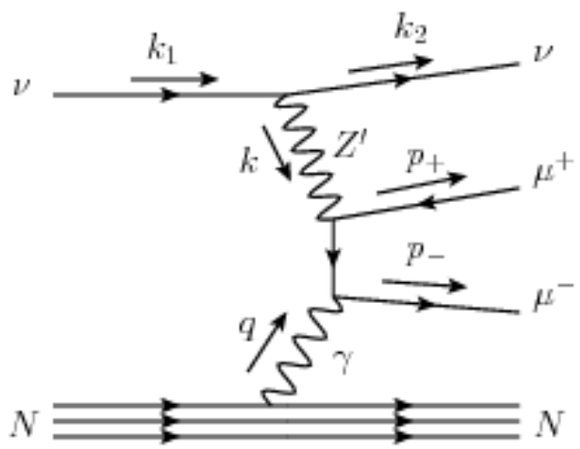
In this talk:

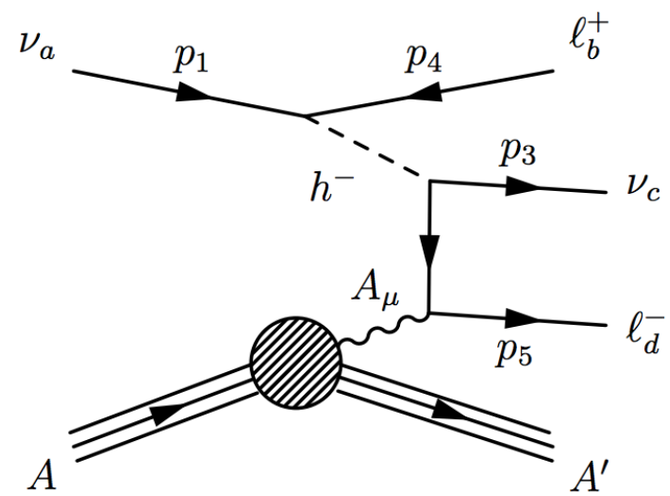
Neutrino trident production



Neutrino-electron scattering

Renewed interest





Renewed interest, leading bound in $U(1)_{L_\mu - L_\tau}$ model. **[W. Altmannshoffer et al, 2014]**

High rates for DUNE ND and SHiP for unobserved channels. **[G. Magill et al, 2016]**

Atmospheric neutrino trident production. **[SF Ge et al, 2017]**

Charged scalars influence on CC channels. **[G. Magill et al, 2017]**

Trident constraints on EFT. **[A. Falkowski et al, 2018]**

Light new forces — additional $U(1)$

Economical/likely: extend the SM by an extra abelian gauge group.

Dark photons — below EW scale, generates couplings mainly to electric charge:

$$\mathcal{L}_{\text{mix}} = -\frac{\varepsilon}{2} F_{\kappa\rho} F'^{\,\kappa\rho}$$

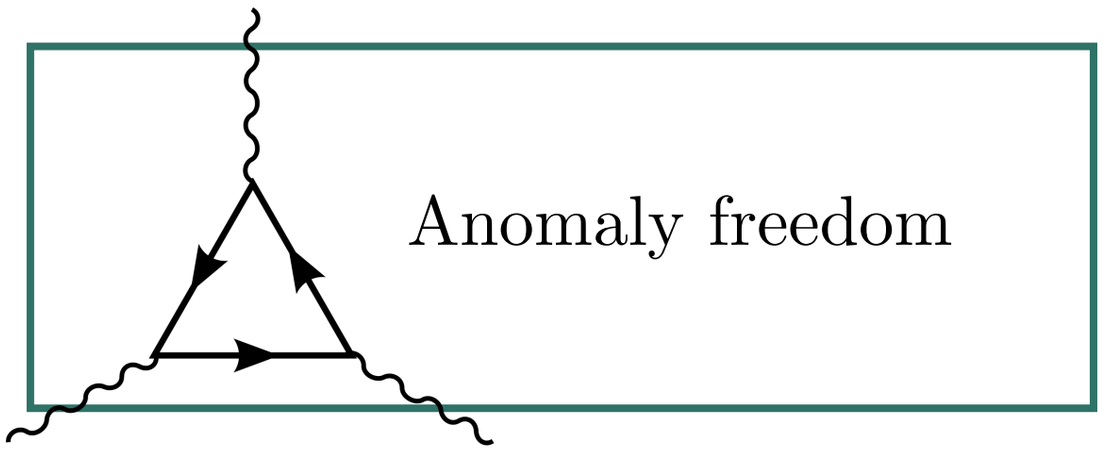
Far from being the only possibility. The SM gives us global symmetries which we can gauge

$$B, \quad L_e, \quad L_\mu, \quad L_\tau$$

Accident tree-level symmetries of the SM
(L_α, approx symmetry with massive neutrinos)

See [M. Bauer, 2018]

Goodybag



No extra particle content.

$$L_\alpha - L_\beta$$

Promote it to an abelian gauge symmetry

$$L_e - L_\mu$$

$$L_\mu - L_\tau$$

If right-handed neutrinos are added.

$$\varrho(L_\alpha - L_\beta) + \vartheta(L_\beta - L_\gamma)$$

$$B - L$$

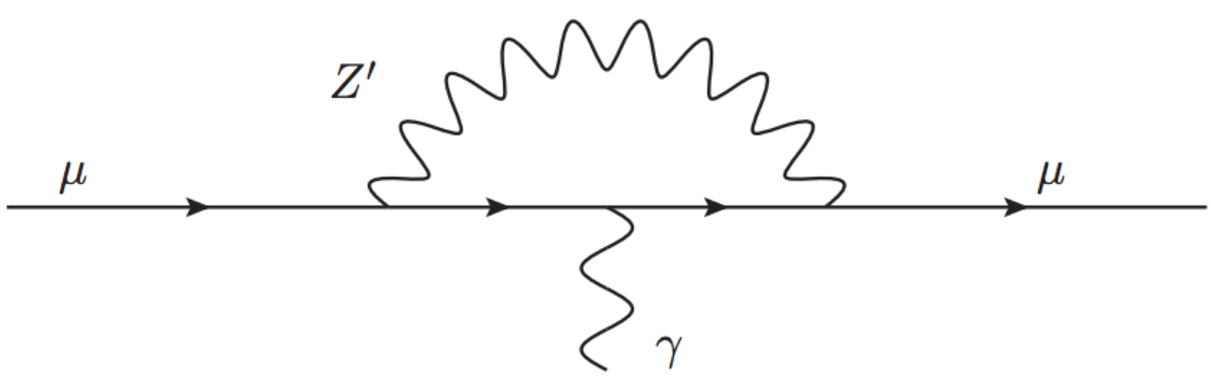
$$\mathrm{SU}(3)_c \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y \times \mathrm{U}(1)_{L_\alpha - L_\beta}$$

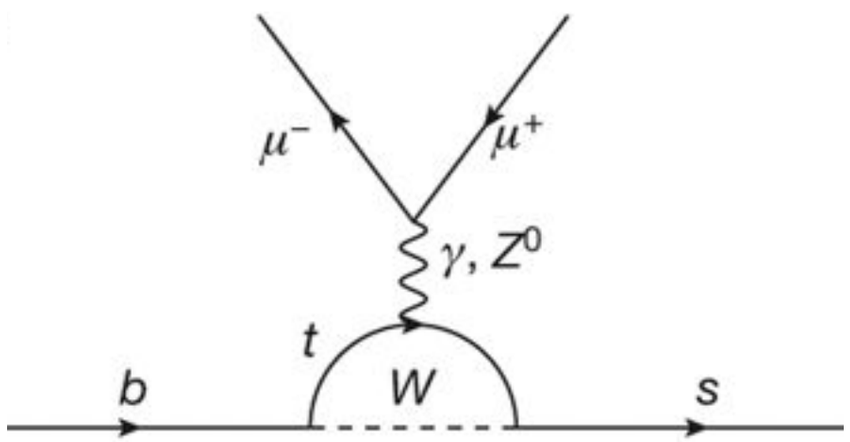
$L_\mu - L_\tau$ gauge

$$\mathscr{L}_{\rm int} \supset g' Z'_\alpha \left(\overline{L}_\mu \gamma^\alpha L_\mu - \overline{L}_\tau \gamma^\alpha L_\tau + \overline{\mu}_R \gamma^\alpha \mu_R - \overline{\tau}_R \gamma^\alpha \tau_R \right)$$

Right quantum charges to explain e/mu non-universality:

- Measurement of muon (g-2).
- Flavour anomalies in $b \to s\,\ell^+\,\ell^-$ measurements (w/ extra minimal model building). **[Altmannshofer et al, 1406.2332]**
- Neutrino mixing data (maximal mixing). **[J. Heeck et al, 1107.5238]**





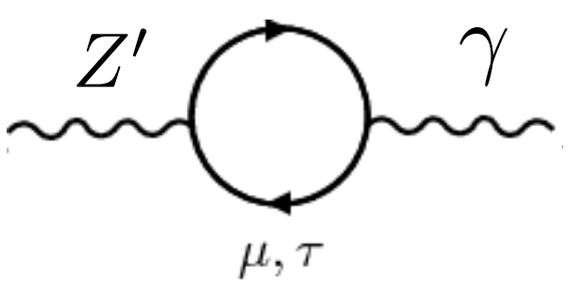
Kinetic Mixing

Kinetic mixing term allowed by the symmetries

$$\mathcal{L}_{\text{mix}} = -\frac{\varepsilon}{2} F_{\kappa\rho} F'^{\,\kappa\rho}$$

We assume this term is **not present at tree level**

but always generate it, even if at 1-loop:



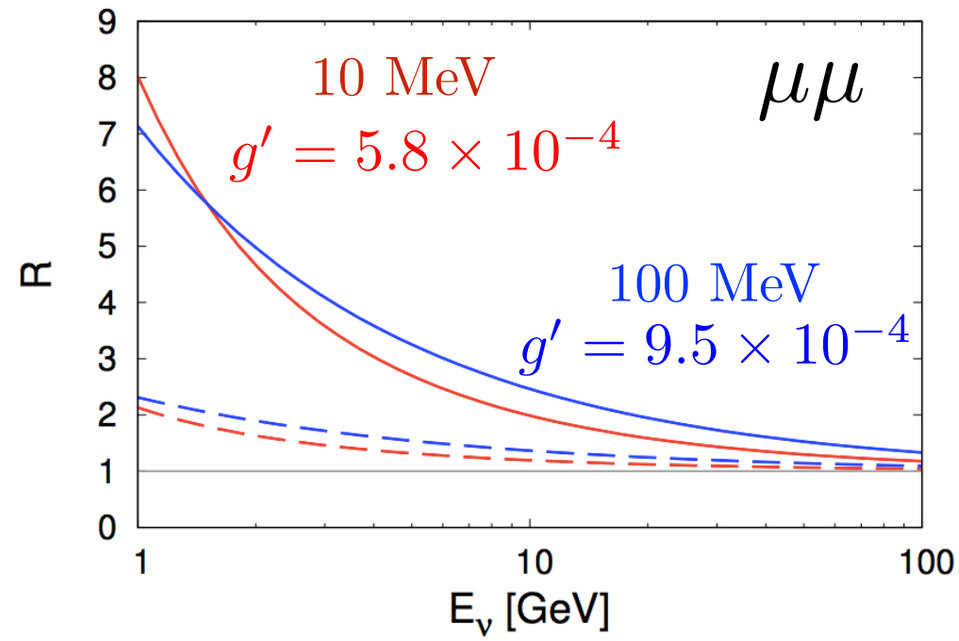
$$\varepsilon(q^2) = -\frac{eg'}{2\pi^2} \int_0^1 \mathrm{d}x\, x(1-x) \ln \frac{m_\mu^2 - x(1-x)q^2}{m_\tau^2 - x(1-x)q^2}$$

Additional method to constrain these models!

Strategy at DUNE

Measure neutral current channels of neutrino trident production

— benefit from lower energy of the experiment.

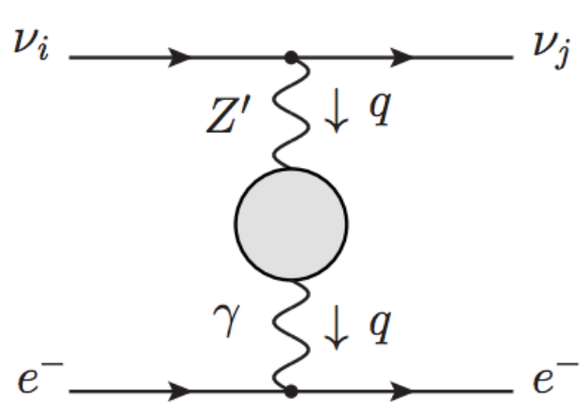


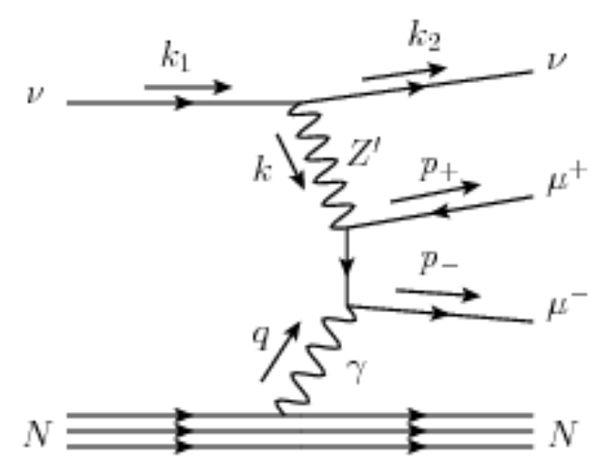
[Y. Kaneta et al, 2017]

Measure neutrino-electron scattering

—benefit from the large statistics.

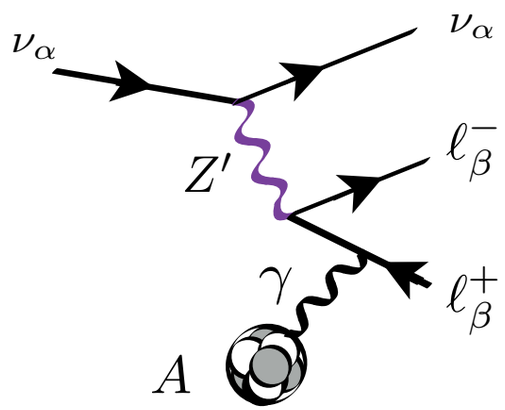
[T. Araki et al, 2017]



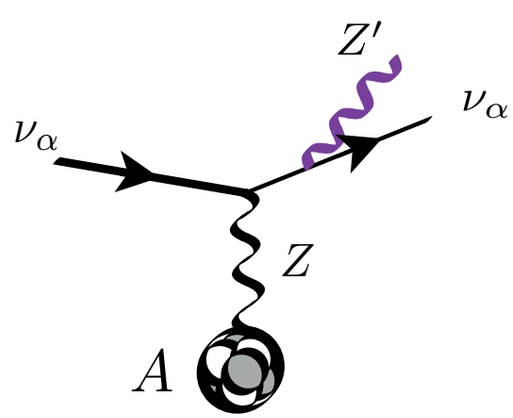


[W. Altmannshoffer et al, 2014]

BSM tridents @ DUNE

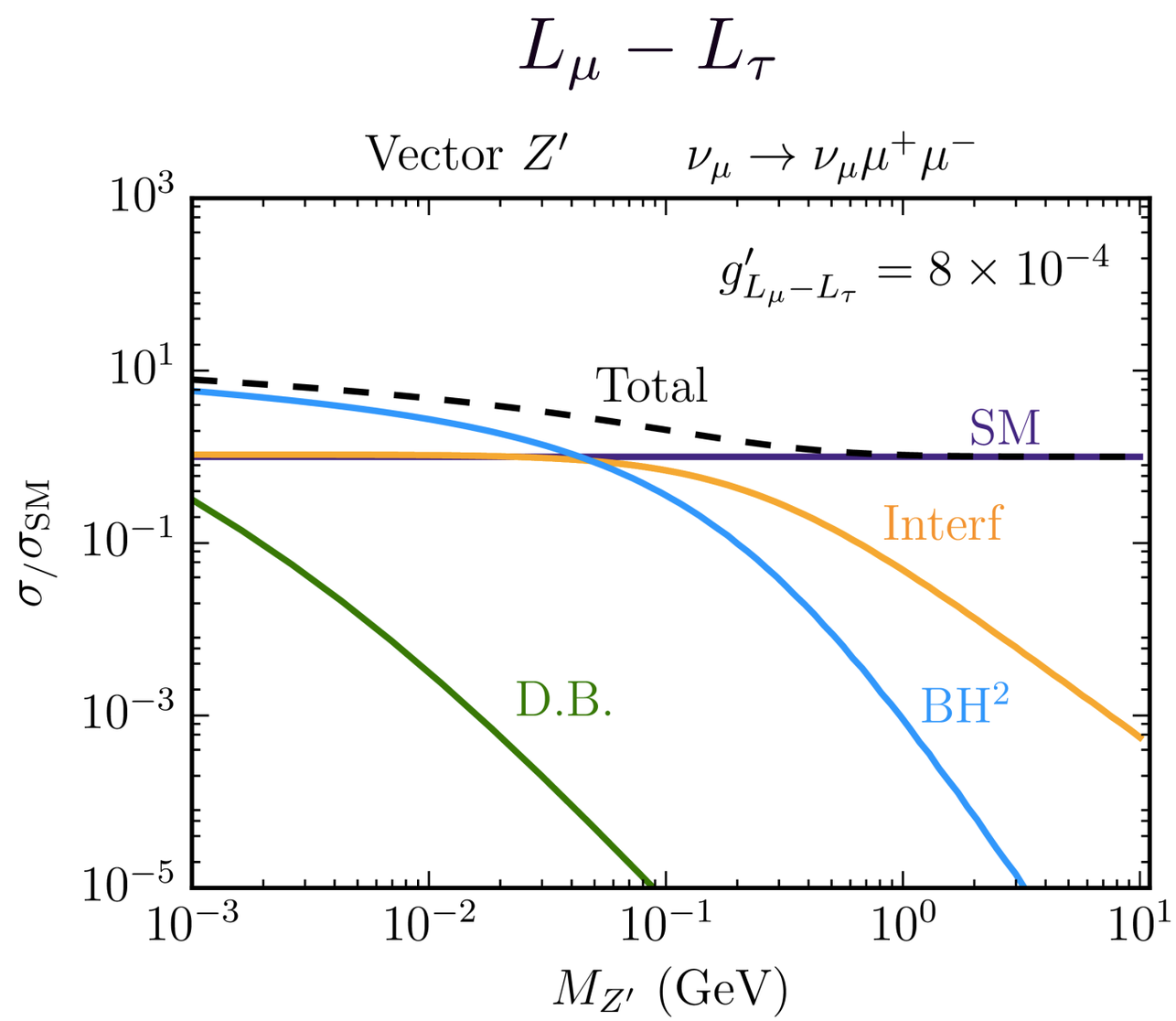


Bethe-Heitler (BH)

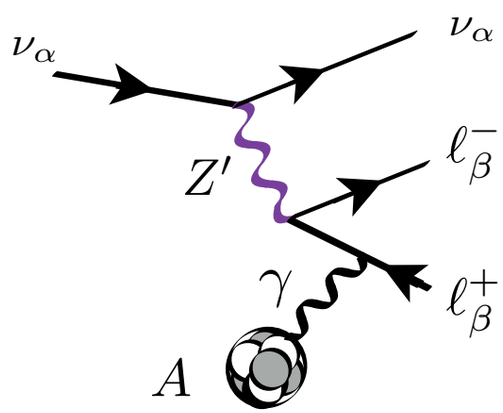


Dark-Bremsstrahlung (DB)

Calculation using NWA (negligible!)



BSM tridents @ DUNE



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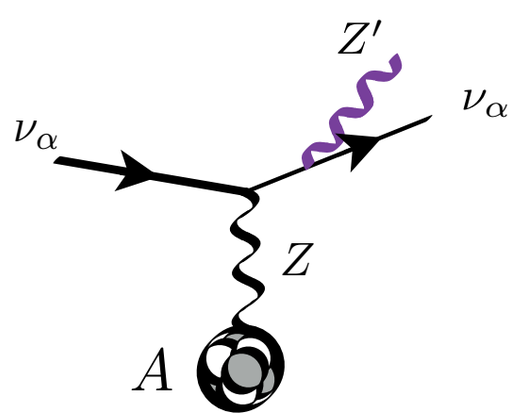
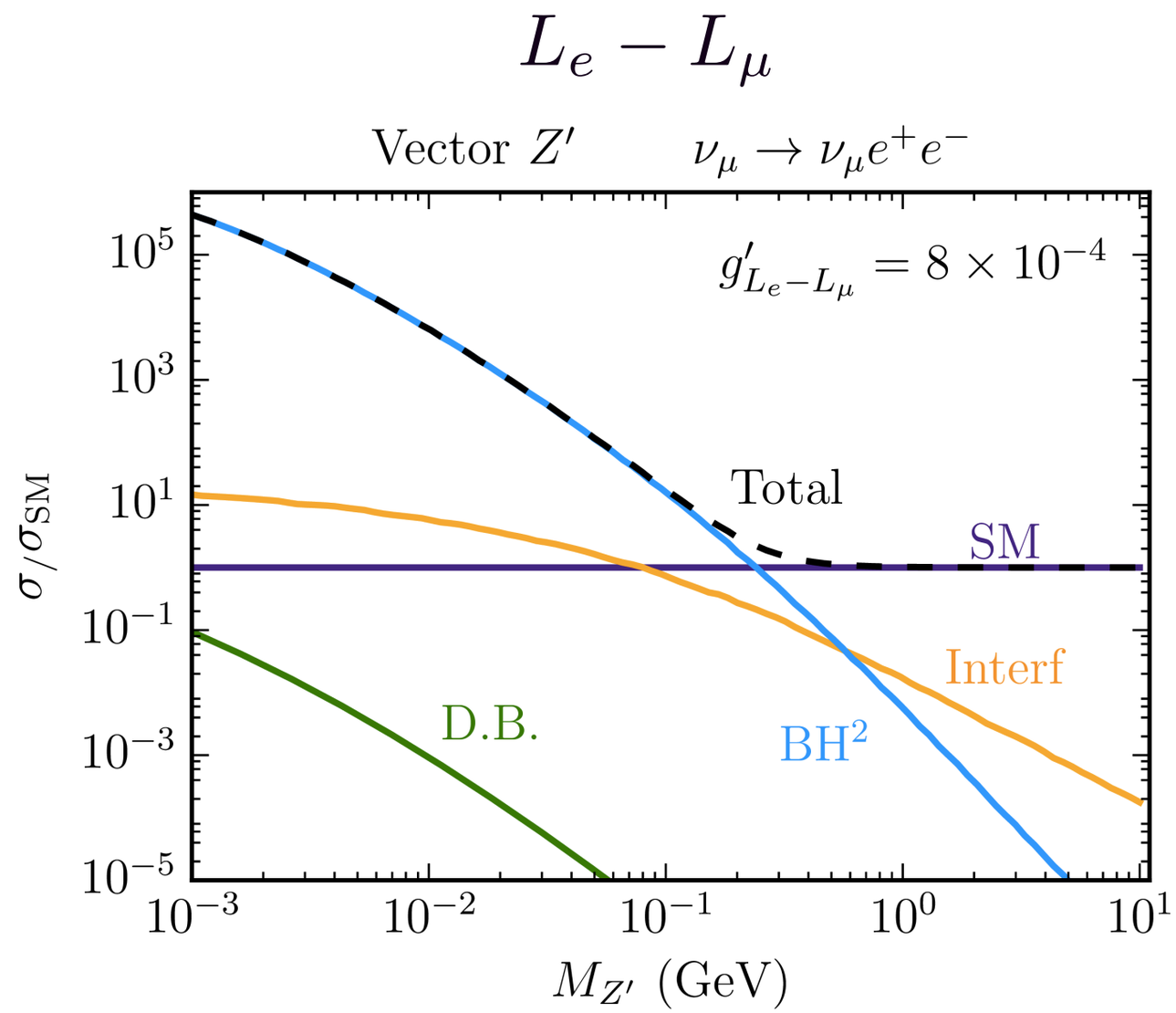


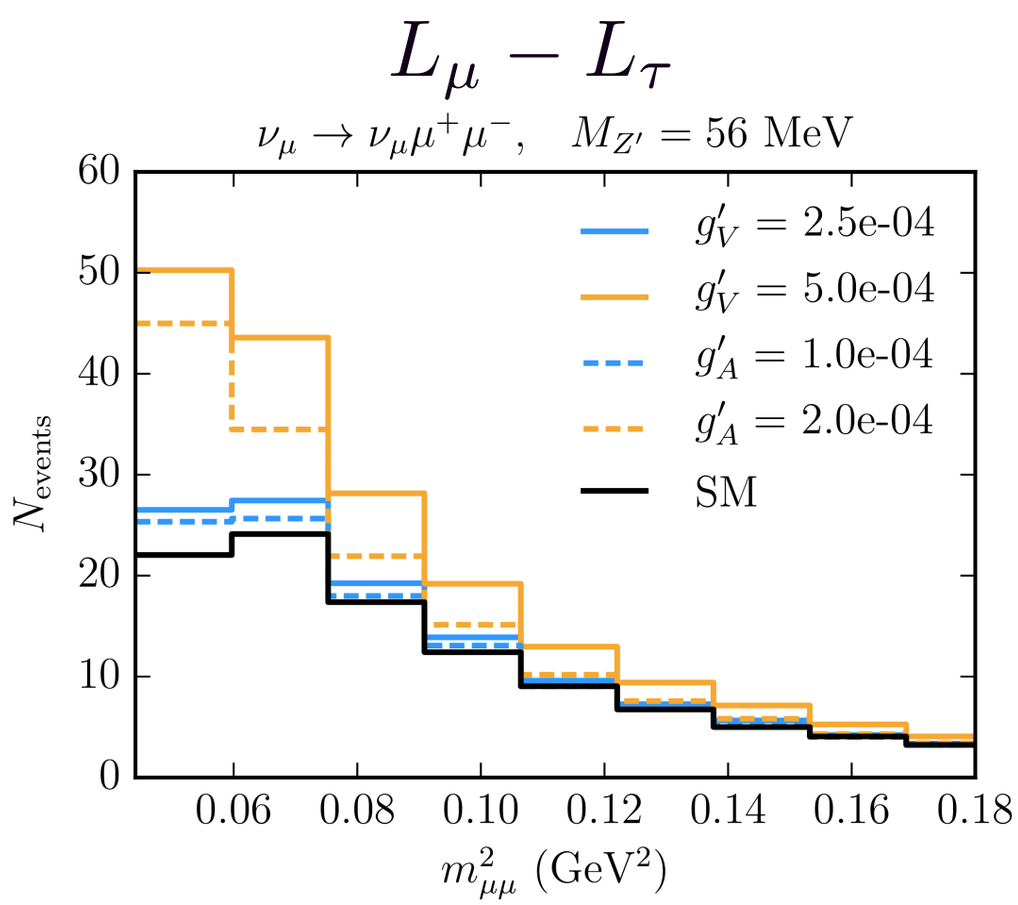
Dark-Bremsstrahlung (DB)
Calculation using NWA (negligible!)



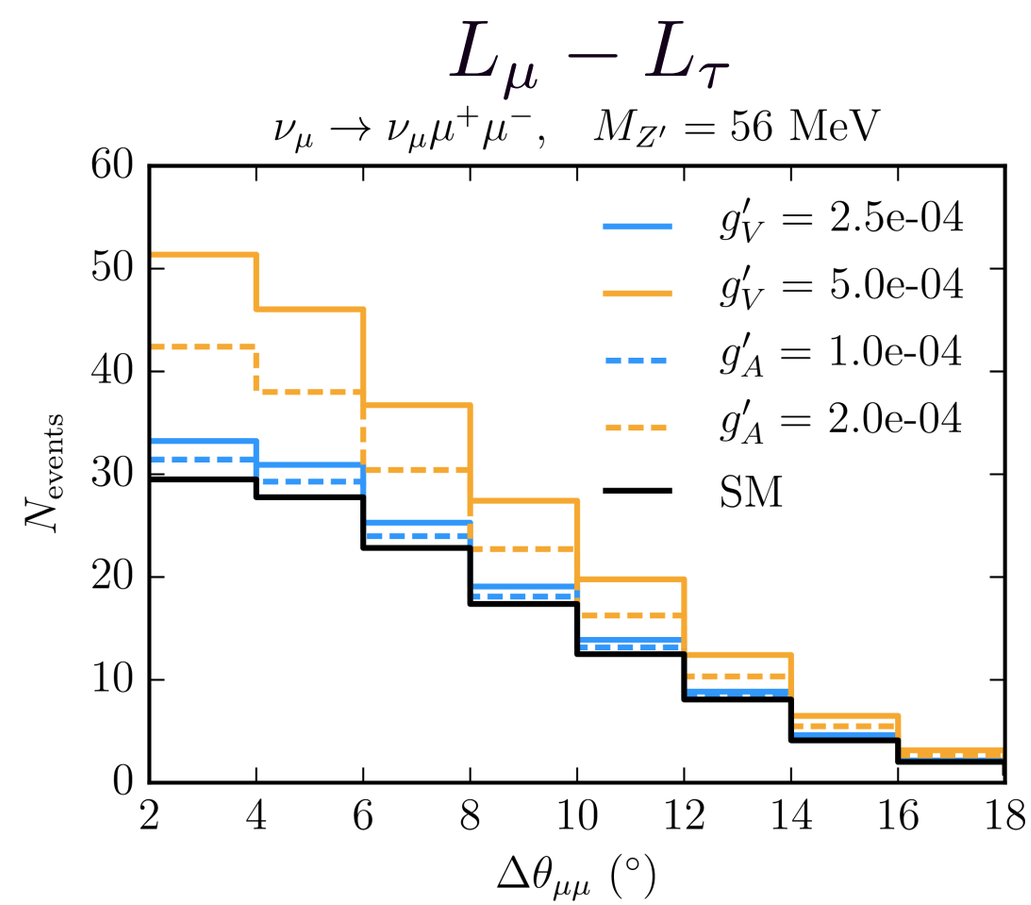
Dielectron tridents scale very differently!

BSM tridents @ DUNE

Generated events with dedicated MC, Gaussian smeared them and applied **background reduction cuts**.



Smaller invariant masses

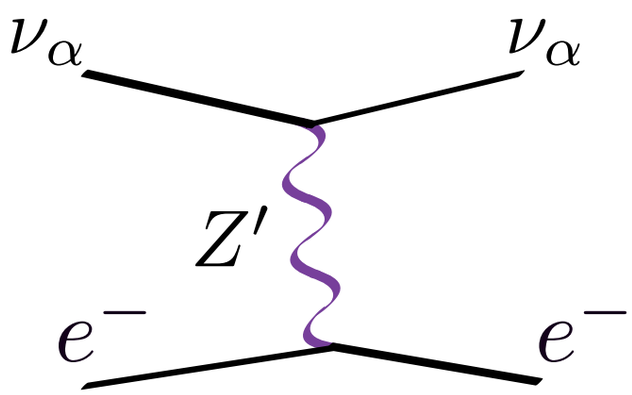


More collimated signals.

BSM $\nu - e$ scattering @ DUNE

Analytical expressions available.

Destructive interference depending on polarity and the sign of the charges.



$$\frac{d\sigma_{\nu_\alpha - e}}{dT_e} = \frac{2m_e G_F^2}{\pi}\left[\left(C_\alpha^{\mathrm{L}}\right)^2 + \left(C_\alpha^{\mathrm{R}}\right)^2\left(1 - \frac{T_e}{E_\nu}\right)^2 - C_\alpha^{\mathrm{L}} C_\alpha^{\mathrm{R}}\, m_e \frac{T_e}{E_\nu^2}\right]$$

$$C_\alpha^{\mathrm{V}} = C_{\mathrm{SM}}^{\mathrm{V}} + \frac{Q_e^{\mathrm{V}} Q_\alpha^{\mathrm{L}}}{2\sqrt{2}G_F}\frac{(g')^2}{M_{Z'}^2 + 2m_e T_e}$$

$$T_{\mathrm{th}} \leq T_e \leq \frac{2E_\nu^2}{m_e + 2E_\nu}$$

Optimistic threshold at 30 MeV.
More realistic choice to suppress backgrounds: 400 MeV

Experimental Sensitivity

Systematics are very important for neutrino-electron scattering
(large statistics — sys. limited)

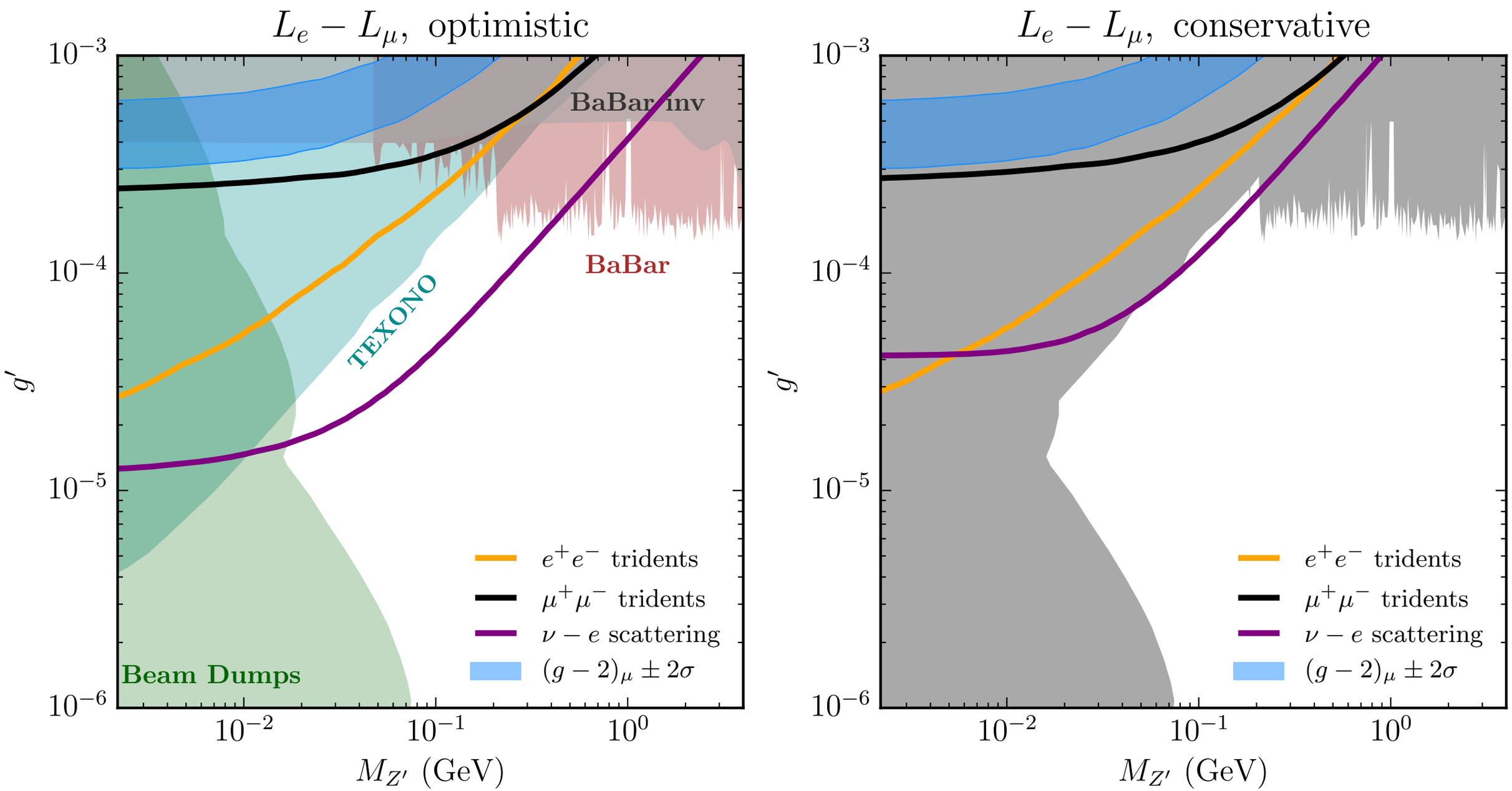
$$\chi^2 = \min_{\alpha} \left[\frac{(N_{\mathrm{BSM}} - (1+\alpha)N_{\mathrm{SM}})^2}{N_{\mathrm{BSM}}} + \left(\frac{\alpha}{\sigma_\alpha} \right)^2 \right]$$

Optimistic	**Conservative**
$\sigma_\alpha = 1\%$	$\sigma_\alpha = 10\%$
$T_{\mathrm{th}} = 30$ MeV	$T_{\mathrm{th}} = 400$ MeV

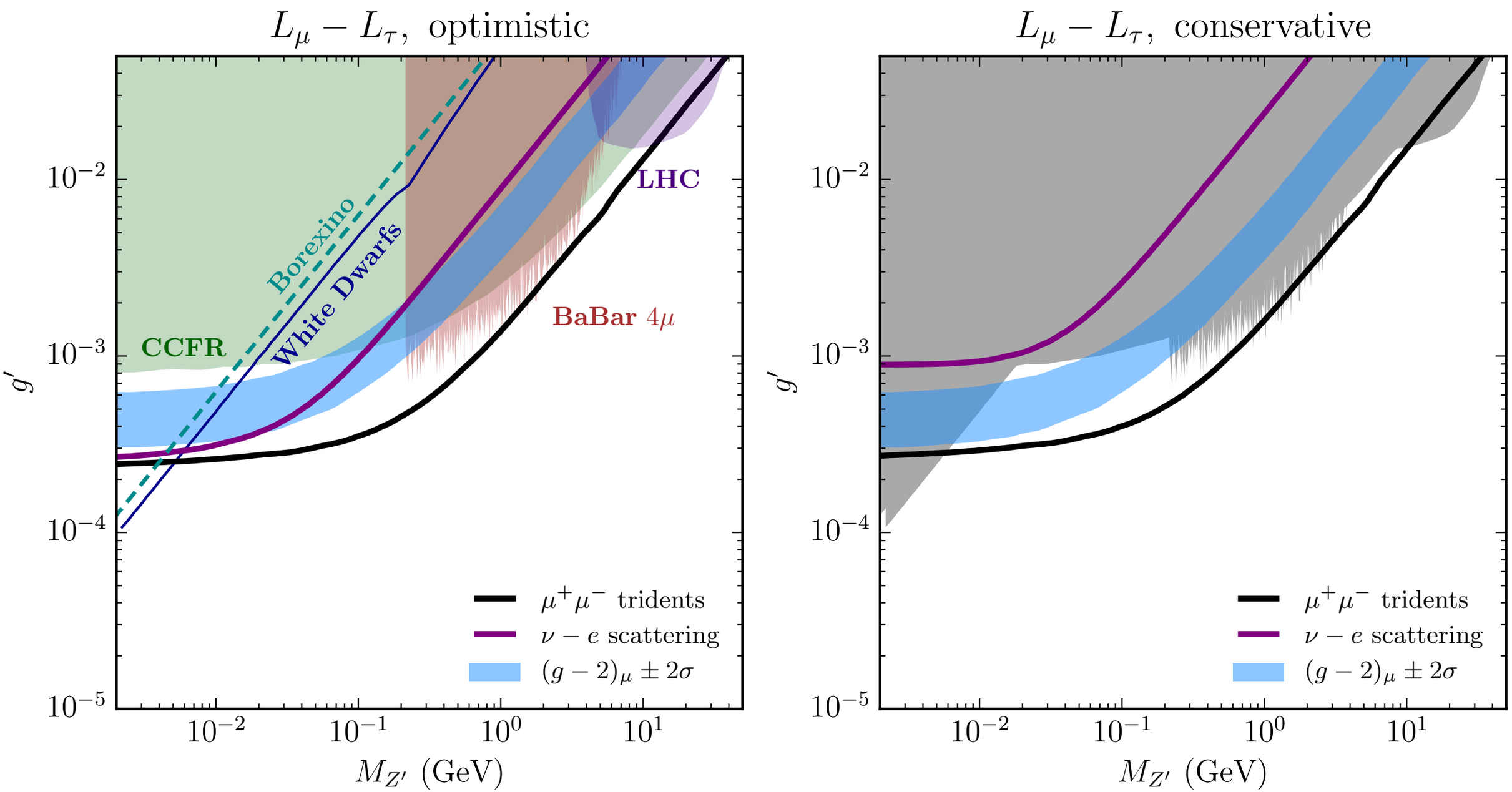
Change thresholds only for nu-e scattering.

Assuming systematics comes mainly from flux uncertainties.
Flux cannot be constrained by nu-e scattering measurement for this analysis.

$L_e - L_\mu$ sensitivity

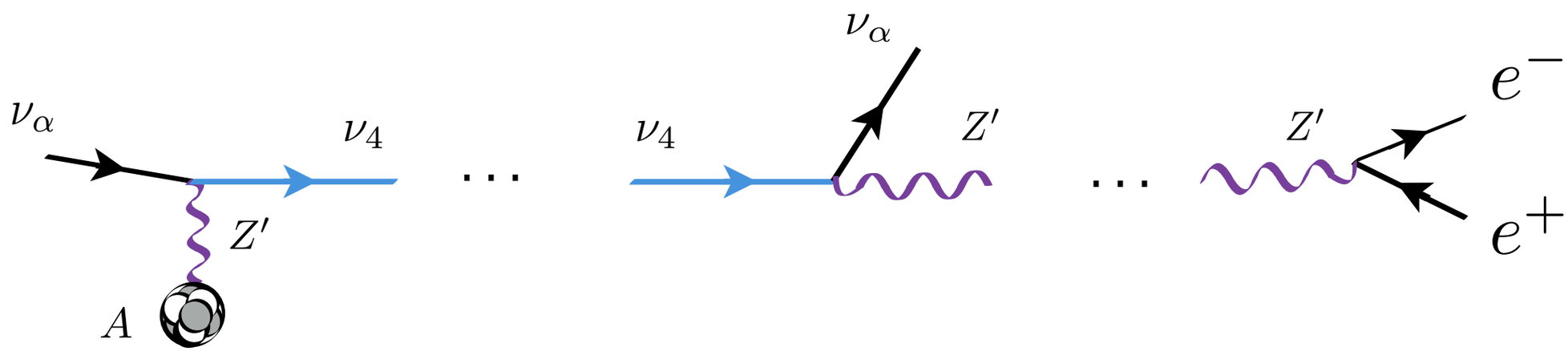


$L_\mu - L_\tau$ sensitivity



Double electron signatures

See upcoming talks on MiniBooNE LEE explanations by **M. Ross-Lonergan, S. Jana and C. Arguelles**.



For $M_4 = 420$ MeV and $M_{Z'} = 30$ MeV we have **30%** of events with $\Delta\theta_{ee} > 8^\circ$

How many more BSM models could we constrain if we had this measurement?

MORE DATA is always better.

Conclusions

Measuring neutrino trident scattering is certainly an **attainable goal for DUNE**, and possibly for other current and future experiments.

Neutrino-electron scattering can also be a valuable tool for new physics searches, even for $L_\mu - L_\tau$.

DUNE can confirm or rule out the $L_\mu - L_\tau$ explanation of the muon (g-2) discrepancy.

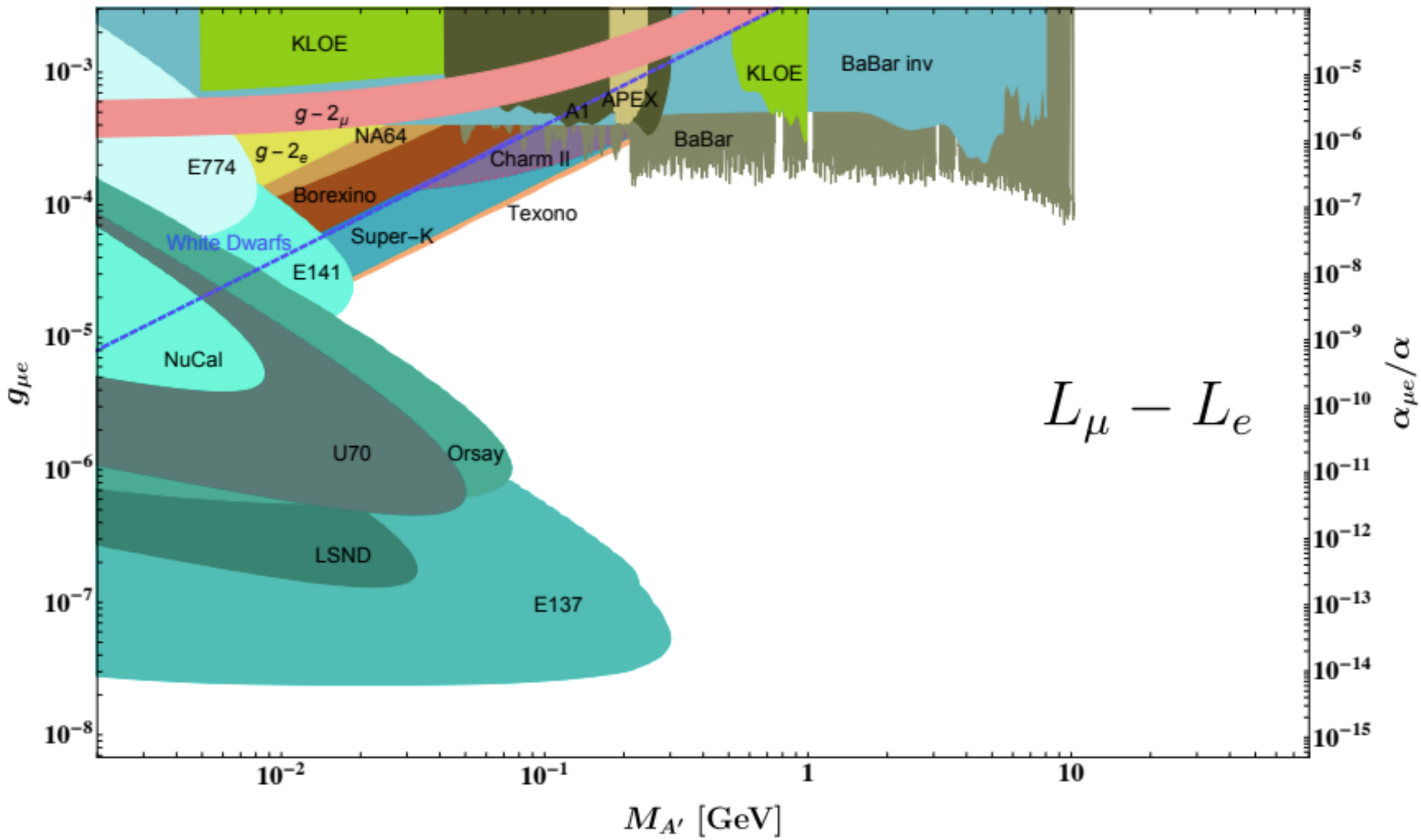
New fundamental forces not the only type of new physics that generate trident signatures at neutrino experiments. **Many ideas yet to be explore here.**

THANK YOU

APPENDIX

Other constraints

[M. Bauer, 2018]



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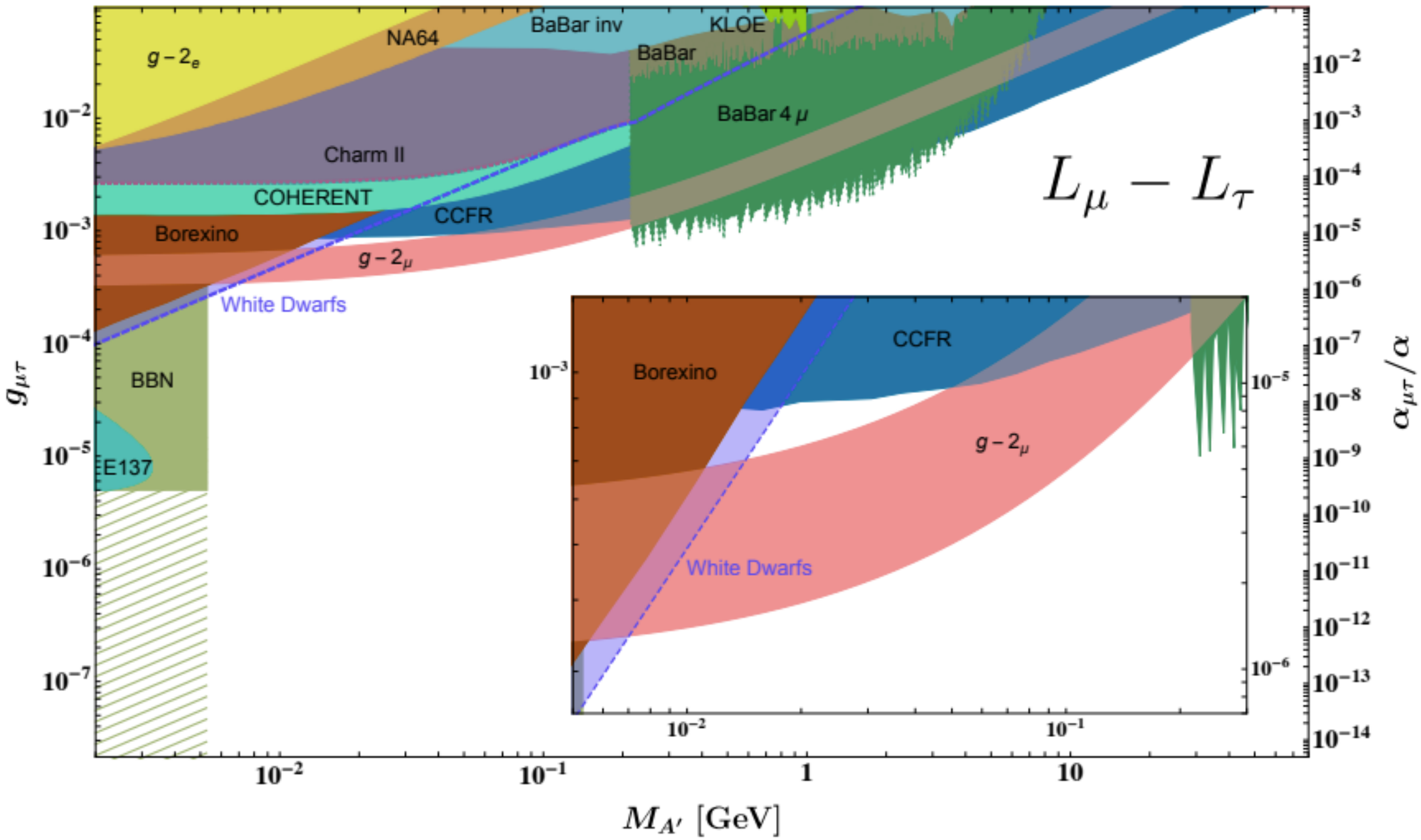

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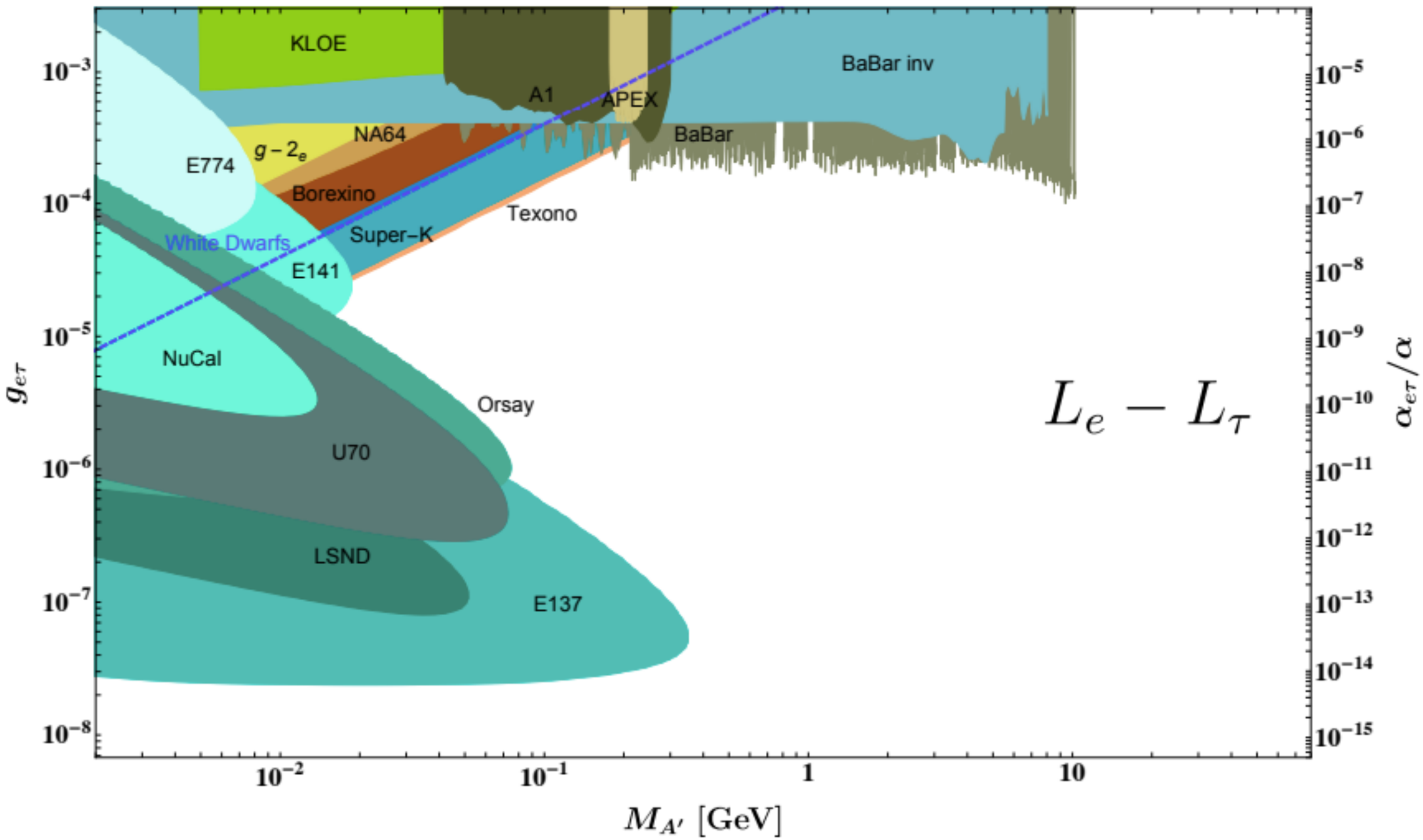
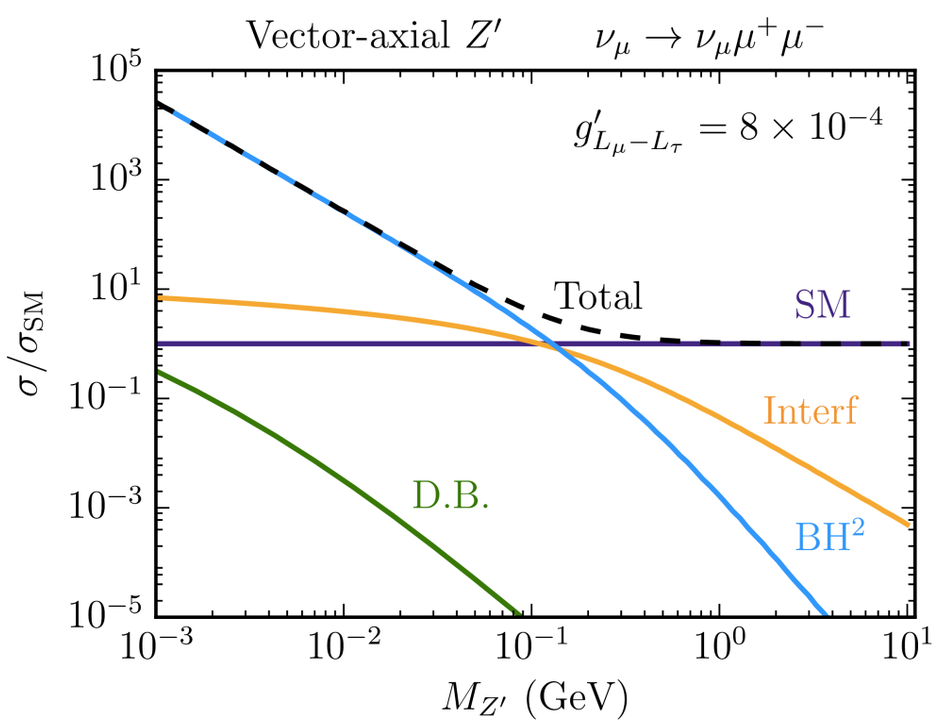
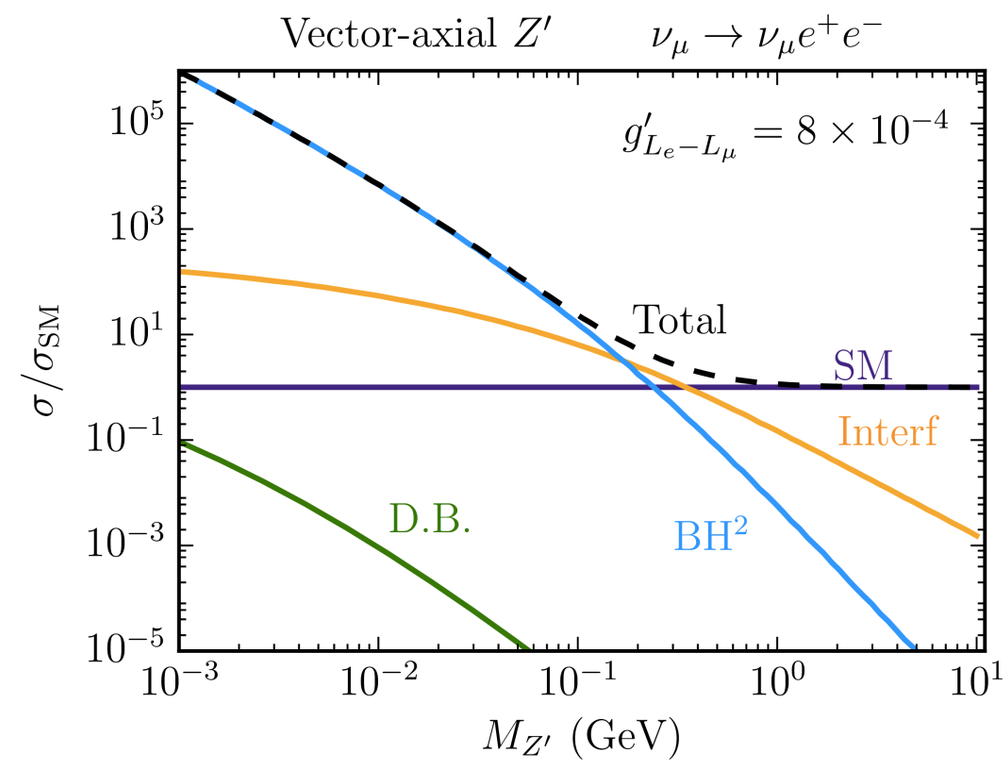


Axial-vector couplings





Combined models

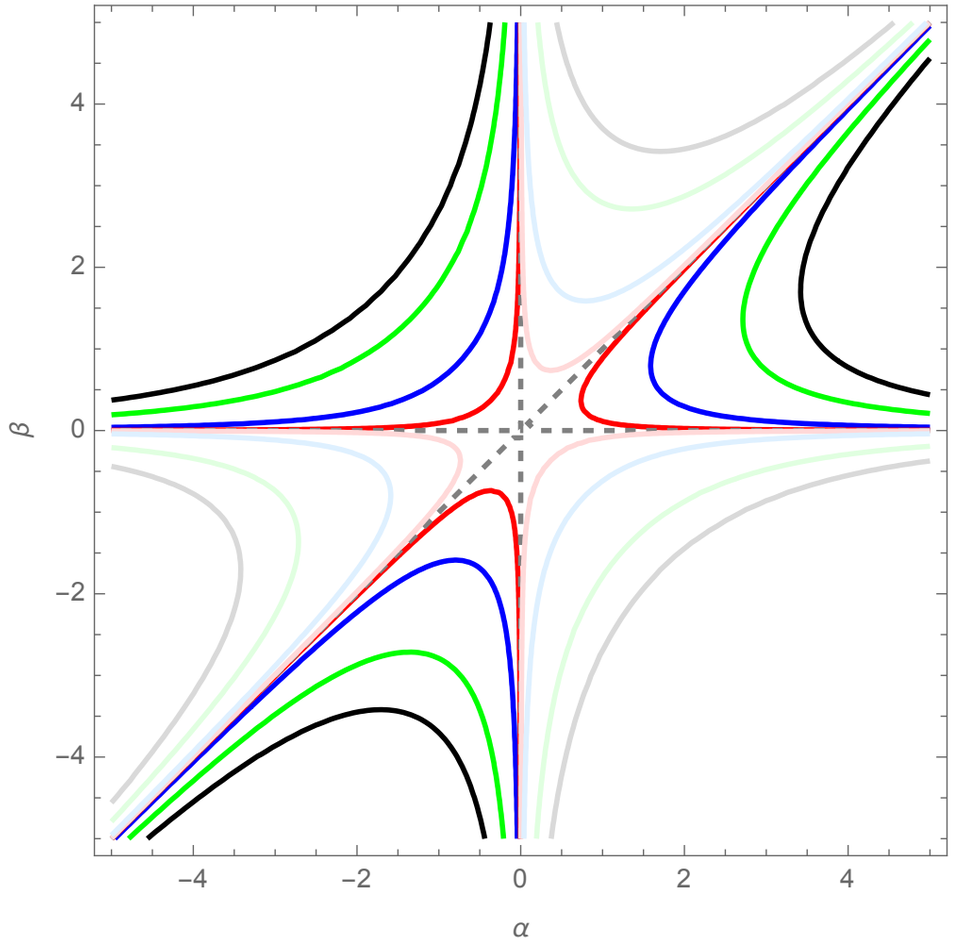
$$\mathrm{SU}(2)^2_{\mathrm{W}} \times \mathrm{U}(1)_{\mathrm{Z}'} \qquad \sum_\alpha Q^{\mathrm{L}}_\alpha = 0,$$

$$\mathrm{U}(1)^2_{\mathrm{Y}} \times \mathrm{U}(1)_{\mathrm{Z}'} \qquad \sum_\alpha \left[\frac{1}{2} Q^{\mathrm{L}}_\alpha - Q^{\mathrm{R}}_\alpha\right] = 0,$$

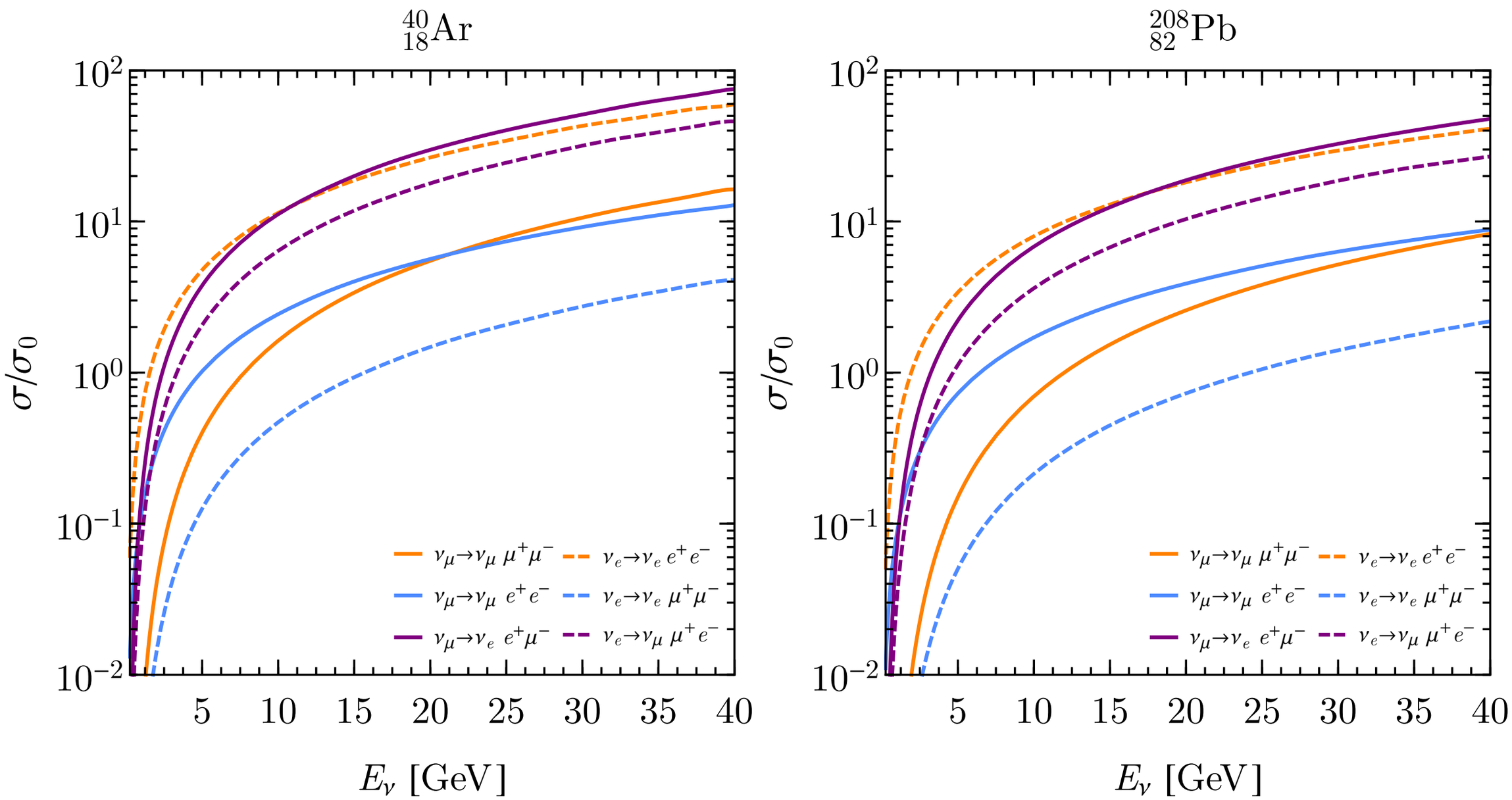
$$\mathrm{U}(1)_{\mathrm{Y}} \times \mathrm{U}(1)^2_{\mathrm{Z}'} \qquad \sum_\alpha \left[Q^{\mathrm{L}\,2}_\alpha - Q^{\mathrm{R}\,2}_\alpha\right] = 0,$$

$$\mathrm{U}(1)^3_{\mathrm{Z}'} \qquad \sum_\alpha \left[2Q^{\mathrm{L}\,3}_\alpha - Q^{\mathrm{R}\,3}_\alpha\right] - \sum_{\mathrm{N}} Q^3_{\mathrm{N}} = 0,$$

$$\text{Gauge-Gravity} \qquad \sum_\alpha \left[2Q^{\mathrm{L}}_\alpha - Q^{\mathrm{R}}_\alpha\right] - \sum_{\mathrm{N}} Q_{\mathrm{N}} = 0.$$



Coherent cross sections



$$\sigma_0 = Z^2\, 10^{-44}\ \mathrm{cm}^2$$