Charged Lepton Flavor Violation in IceCube

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with

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Q-EYES 2025

December 9, 2025

wpi

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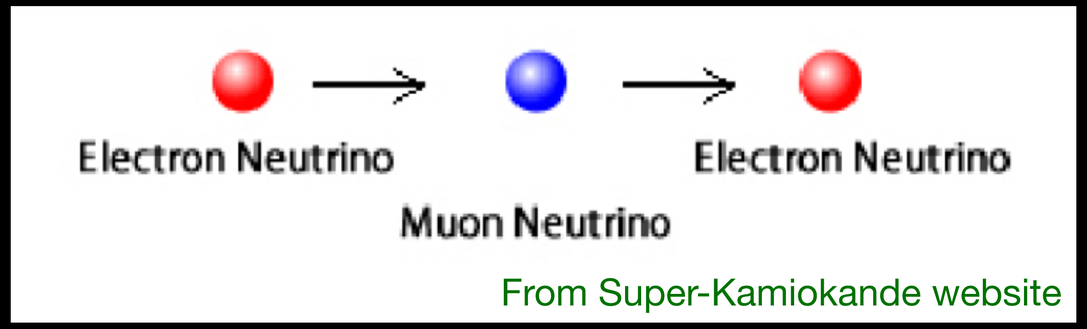
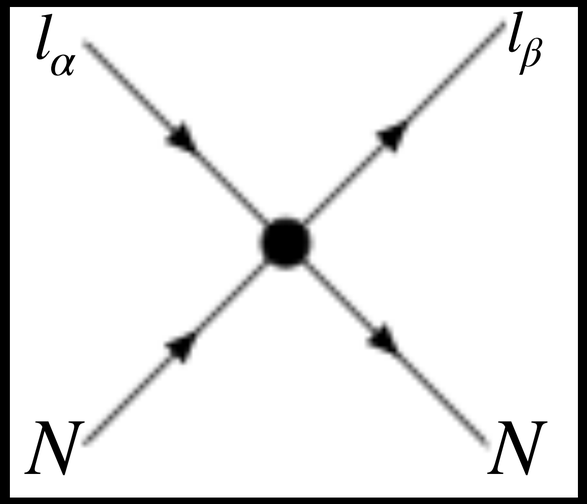
Charged Lepton Flavor Violation (CLFV)

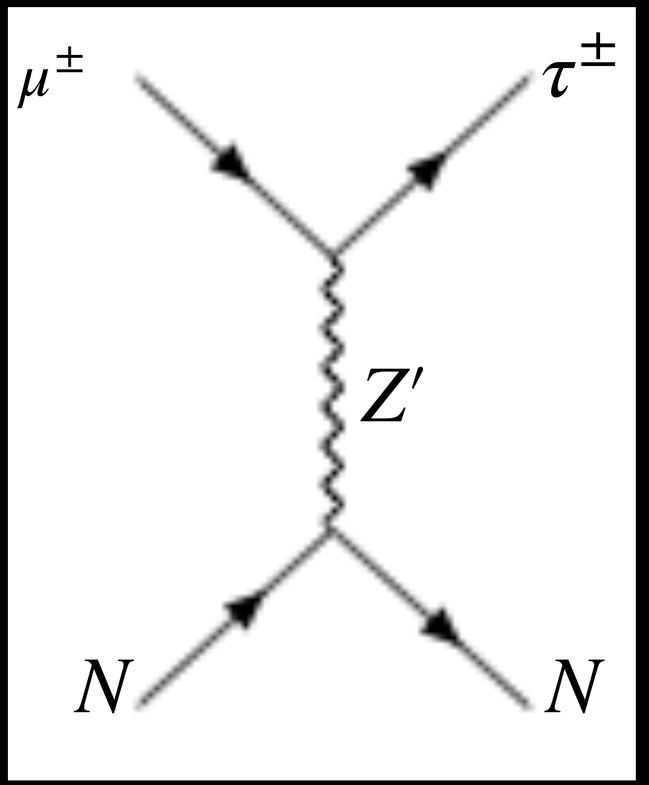
Evidence of LFV



From Super-Kamiokande website

Can we expect the same in the charged lepton sector?





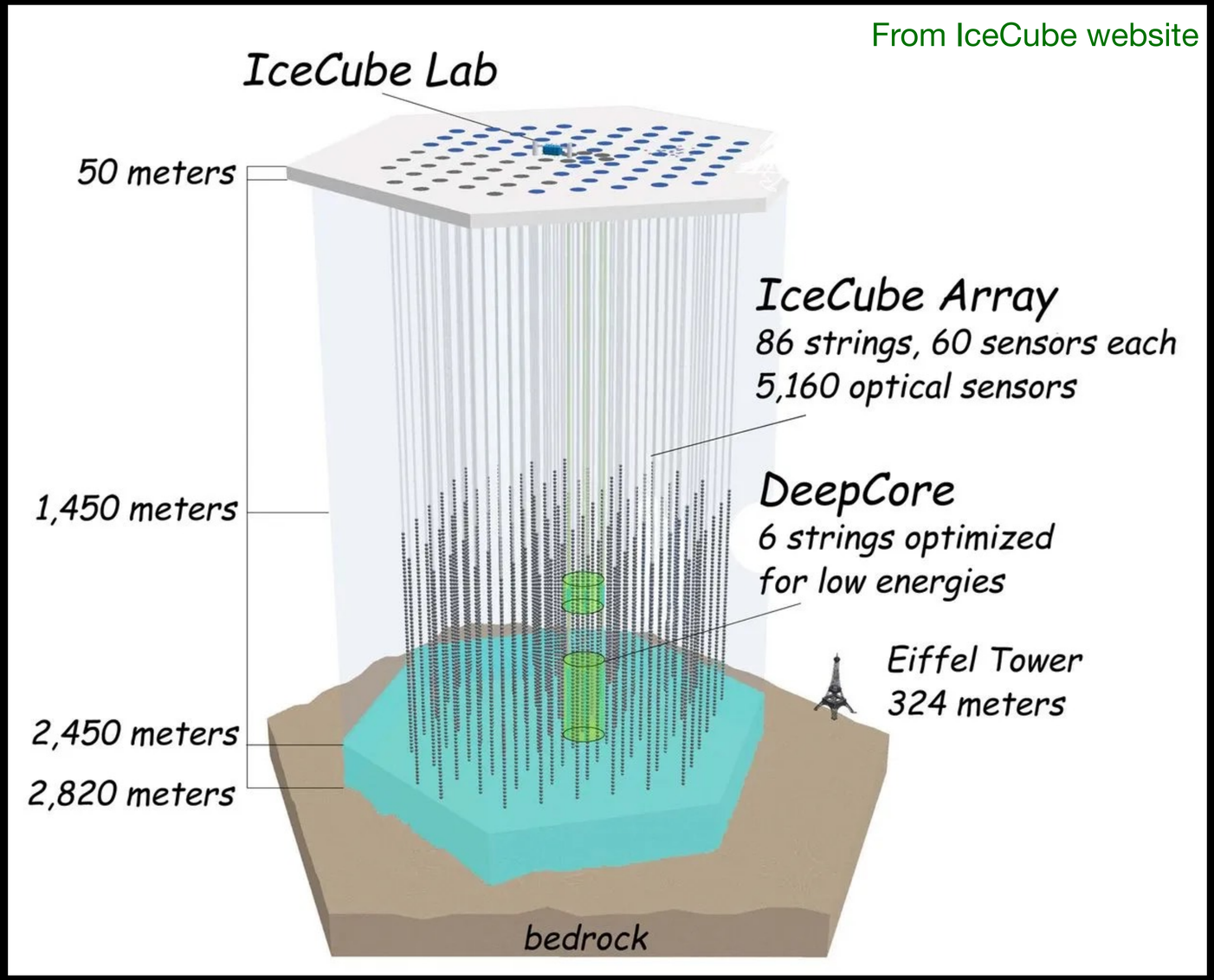
$\mu^\pm N \to \tau^\pm N$

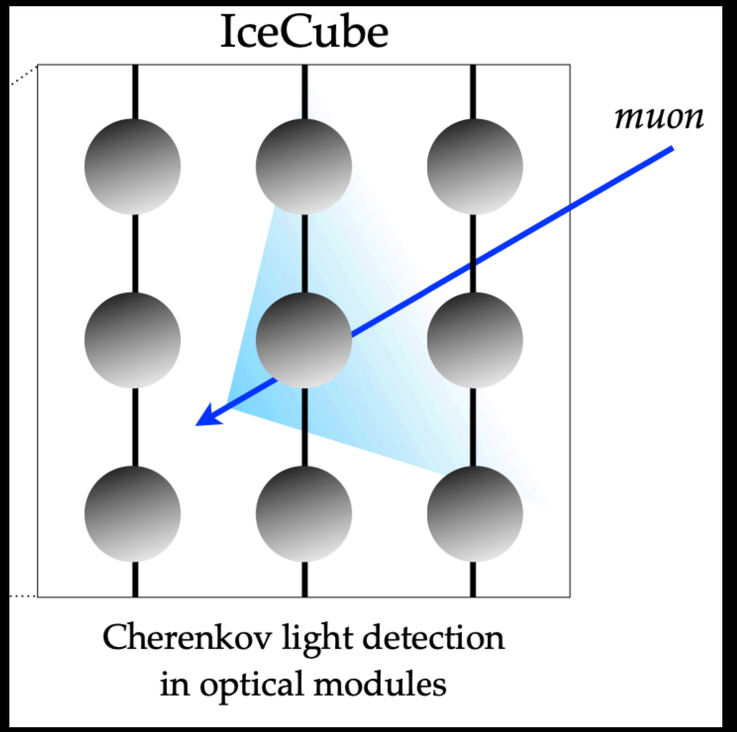
(Mediated by vector boson, Z')

Detecting CLFV will clearly indicate new physics!!

A bit on IceCube

From IceCube website



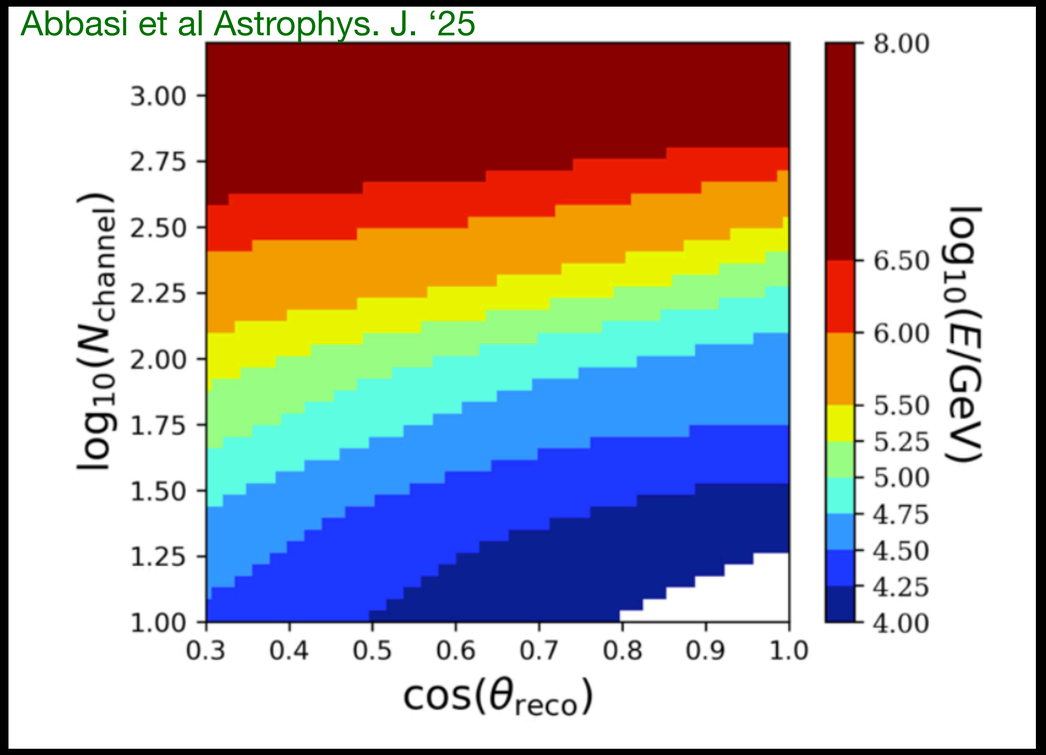


IceCube can be a hub of all these ν-induced muons & hence can used to look for CLFV.

Motivation!!

IceCube Data Analysis (without CLFV)

Abbasi et al Astrophys. J. ‘25



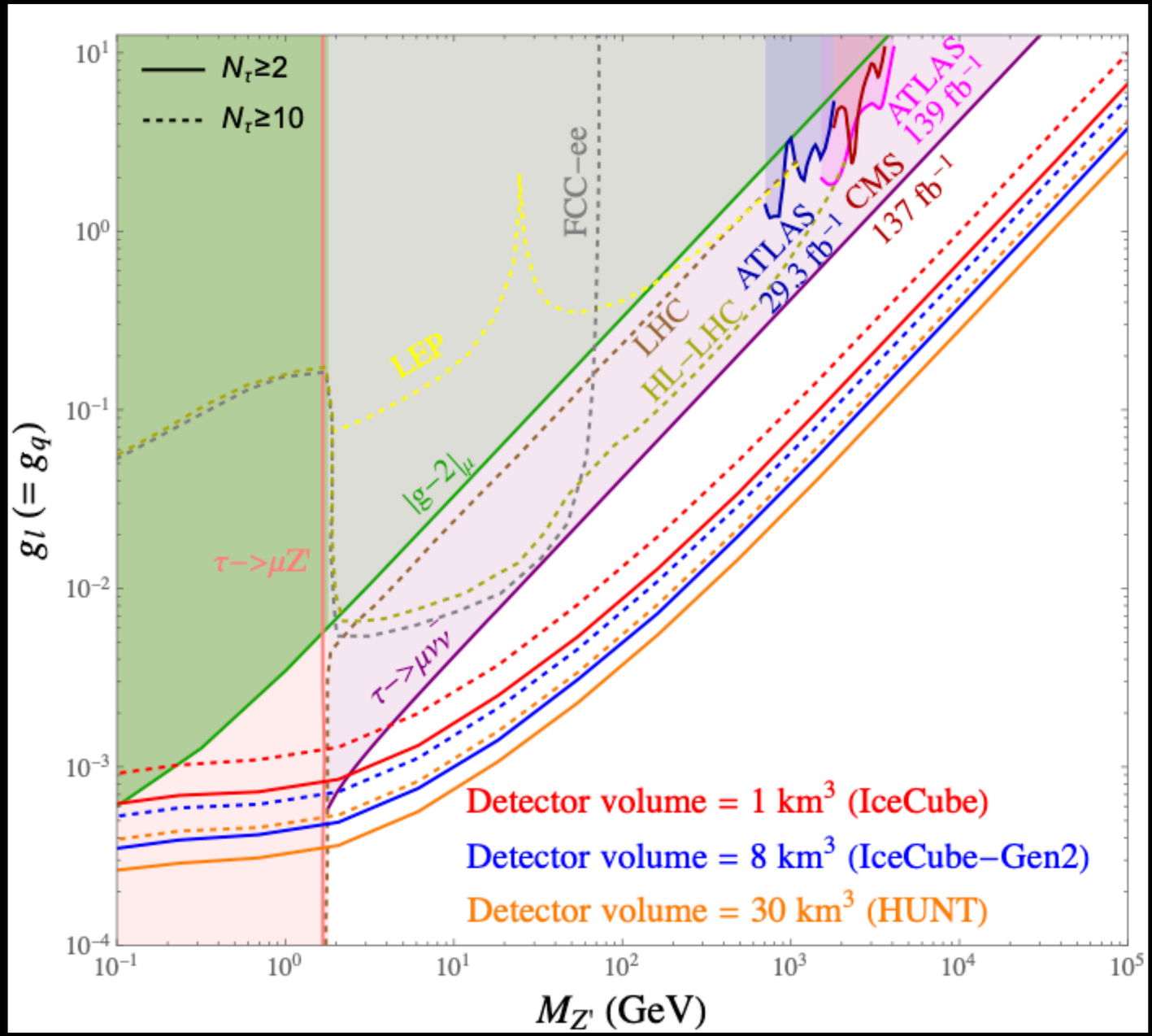
Energy, E_i (TeV)	N_{events} $(\times 10^9)$
13	330.40
24	197.15
42	89.74
67	22.17
130	6.32
240	2.13
470	1.0147
1500	0.1019
5300	0.0128

792 billion events in total

$$N_\tau(E_i) = \int_{E_{\min}}^{E_{\max}} dE \int_{-1}^{1} d\cos\theta \frac{d^2 N_\mu}{dE d\cos\theta}(E, E_i)$$

IceCube Data Analysis (with CLFV)

$$N_\tau(E_i) = \int_{E_{\min}}^{E_{\max}} dE \int_{-1}^{1} d\cos\theta \left(1 - e^{-L(\theta)/\lambda_{\mathrm{CLFV}}(E)}\right) \frac{d^2 N_\mu}{dE\, d\cos\theta}(E, E_i)$$



IceCube Data Analysis (with CLFV)

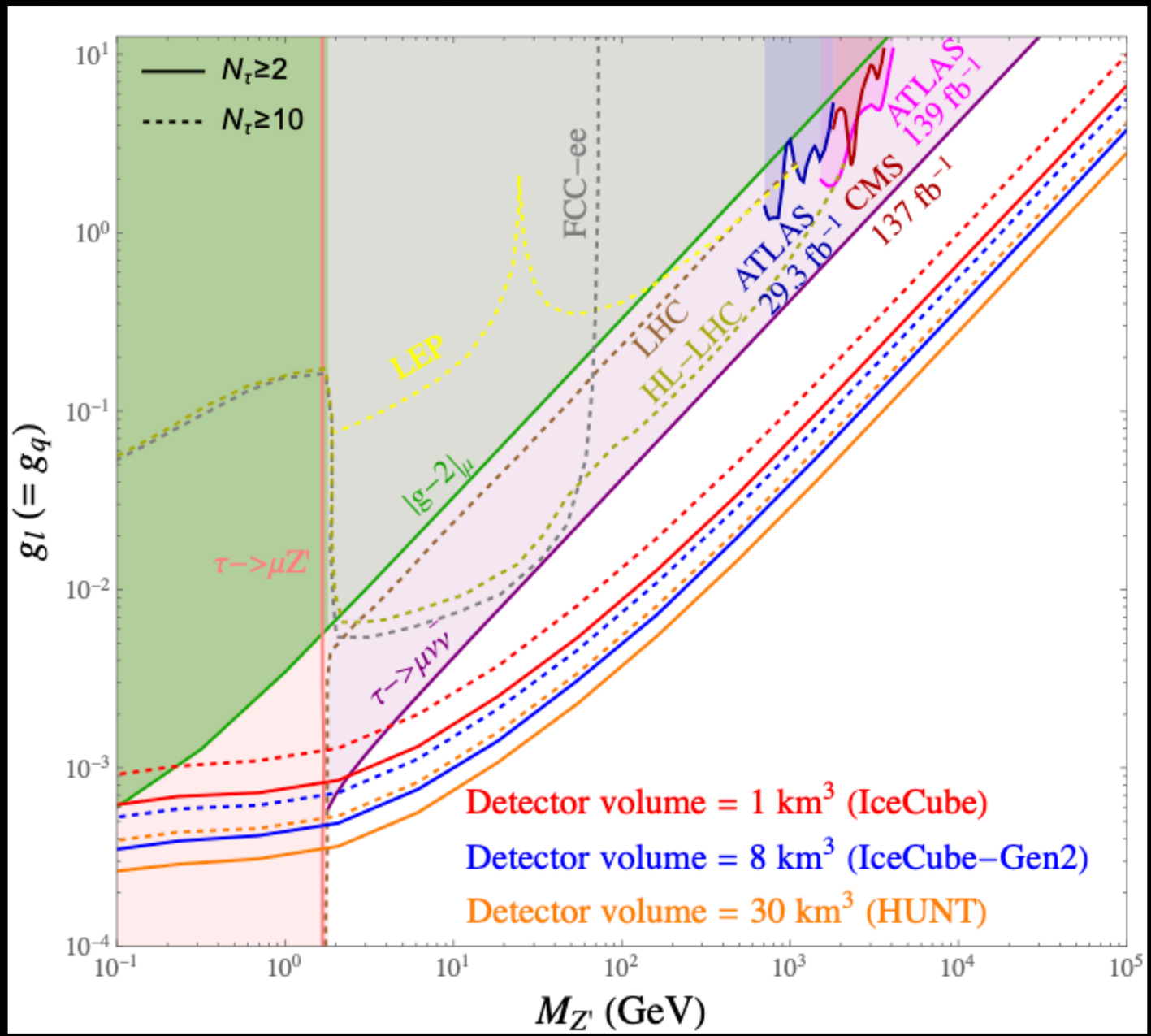
Existing constraints: [Altmannshofer et al PLB'16] [Dobrescu et al, PRD'24]

- $\tau \to \mu\nu\bar{\nu}$

$$R_{\rm SM} = \frac{\mathrm{BR}(\tau \to \mu\nu_\tau\bar{\nu}_\mu)_{\rm SM}}{\mathrm{BR}(\tau \to e\nu_\tau\bar{\nu}_e)_{\rm SM}}$$

- $\tau \to \mu Z'$

$\tau \to \mu$ + missing energy



Making Analysis More Realistic….

- Muons lose energy in their propagation via ionization, bremsstrahlung, electron-pair production and nuclear interactions.

$$\frac{dE_\mu}{dx} = -a - bE_\mu$$

- Not all produced τ's will create cascade-like signature.

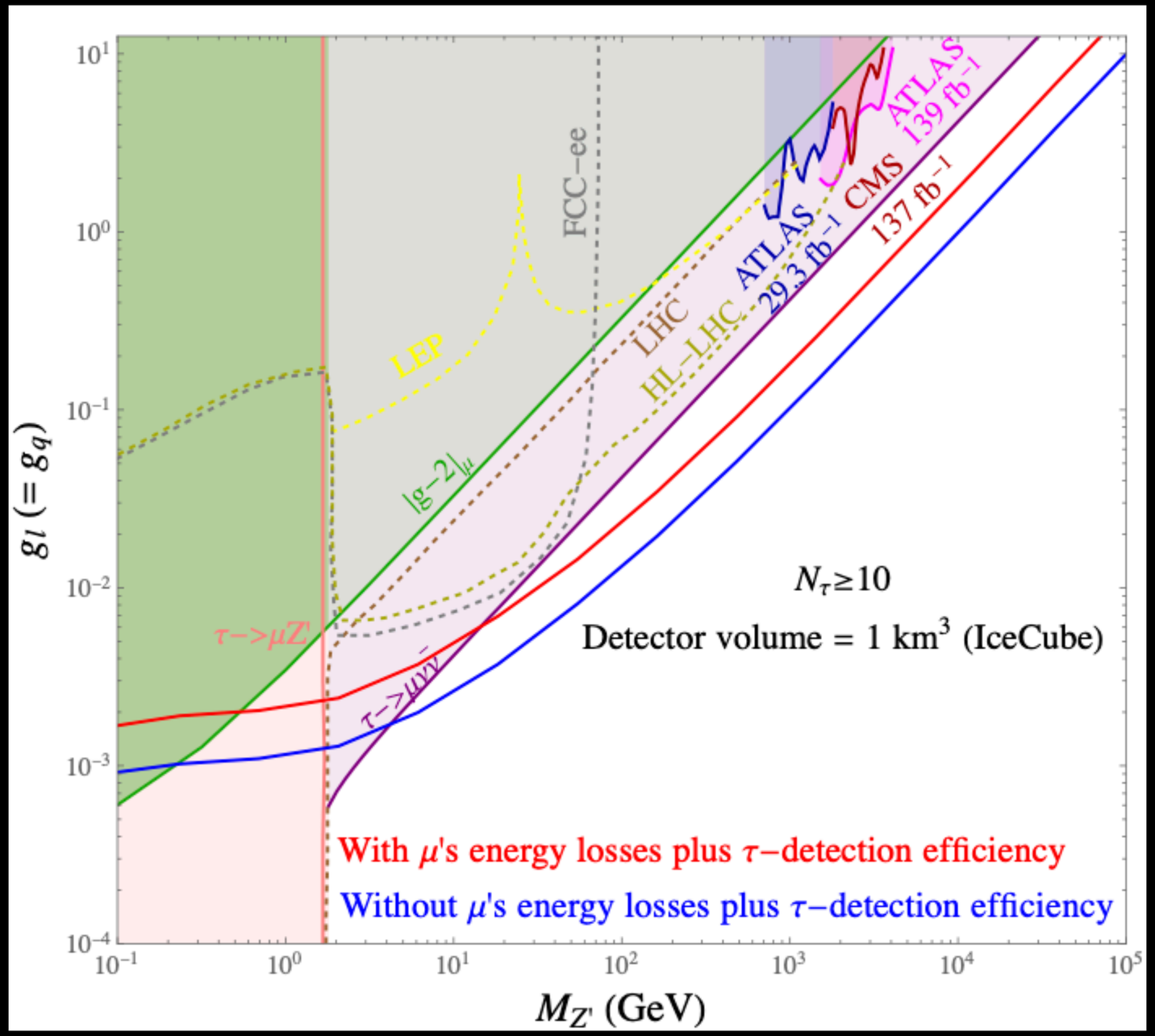
Taking care of muons' energy loss

$$N_\tau(E_i) = \int_{E_{\min}}^{E_{\max}} dE \int_{-1}^{1} d\cos\theta \frac{d^2 N_\mu(E)}{dE d\cos\theta} \int_0^1 d\eta \left(1 - e^{-(L(\theta) - x(E_\mu = E - \eta E))/\lambda(E_\mu = E - \eta E)}\right)$$

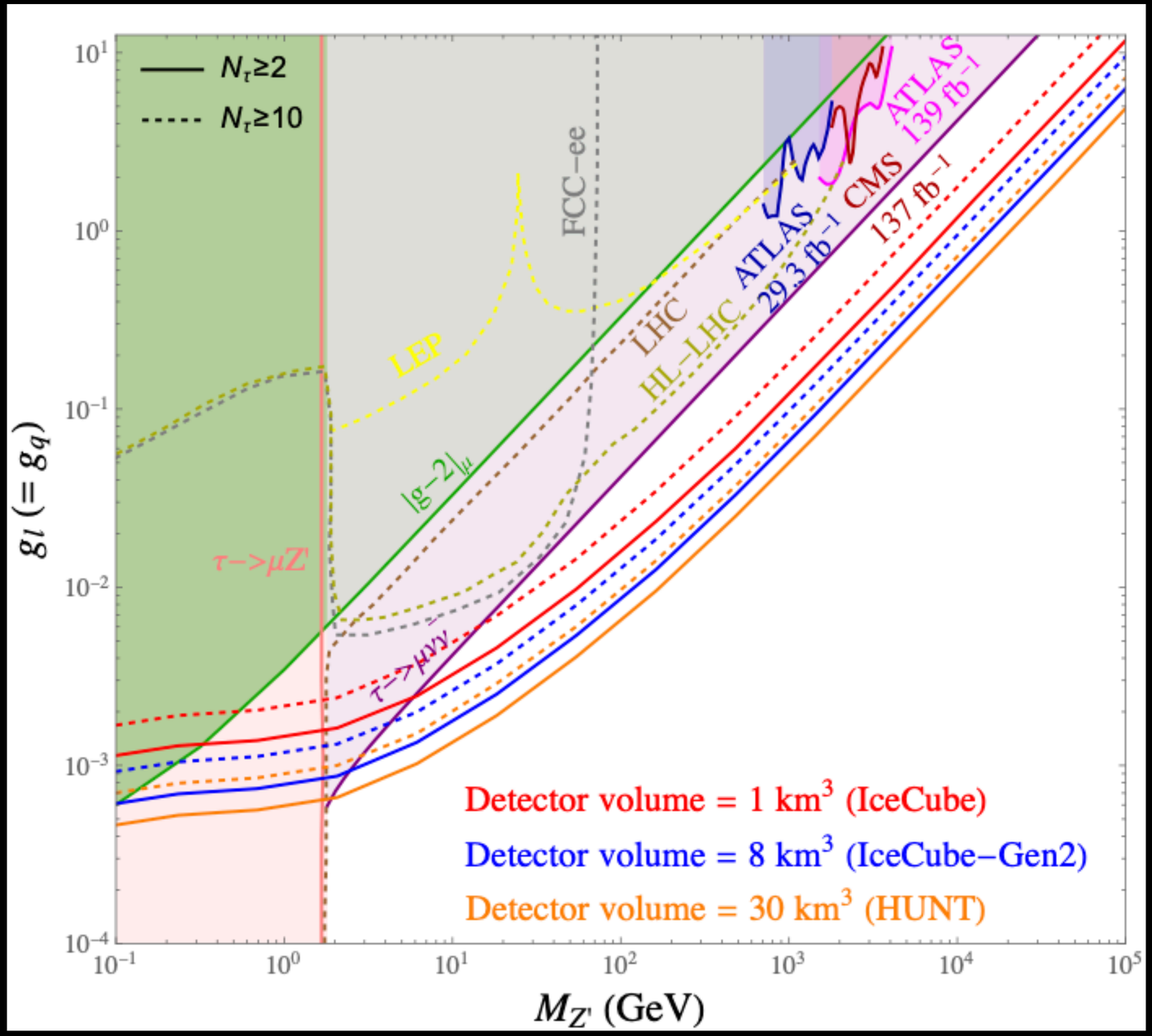
$$\int_0^1 \frac{dy}{\sigma(E_\mu)} \int_0^1 dx \frac{d^2\sigma}{dx dy} e^{-d_\tau / l_\tau(E_\tau = yE_\mu)} \times (1 - P_{\tau \to \mu})$$

Including τ-detection efficiency

Making Analysis More Realistic….

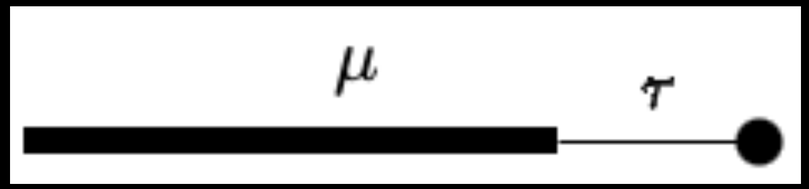


Constraint on CLFV Parameter Space

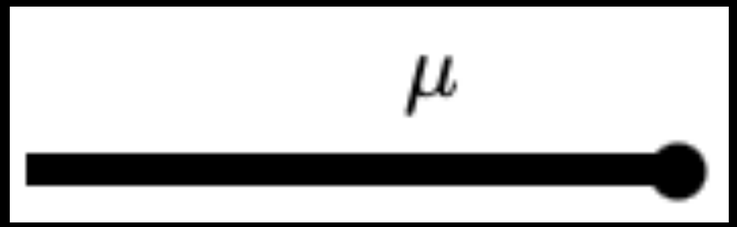


Ongoing Effort…..

Signal we are looking for:



Possible strong background:



Working on estimating the background…….

Summary

- Charged Lepton Flavor Violation (CLFV) can be a telltale signature of BSM physics.
- IceCube can be an ideal place to look for CLFV.
- We have analyzed existing IceCube data to set a constraint on Z′ parameter space and have projected a constraint from future experiments.
- Ongoing effort:- some of the μ's can also give τ-cascade like signature which can be background o our analysis

Thank you!