Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Sterile neutrino theory overview

Pedro A. N. Machado

September 29th 2021

The short baseline anomalies are largely unexplained

LSND

IBD signature is hard to mimic

MiniBooNE

Cannot distinguish electrons from photons

Δ to γ background relies on theoretical estimate

Reactor and gallium anomalies

Theoretical calculation is very challenging

Error bars are crucial

Difficult to find consistent interpretation that is not ruled out

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The short baseline anomalies are largely unexplained

In this talk, I will go through some interpretations of the anomalies in a critical manner

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Standard physics

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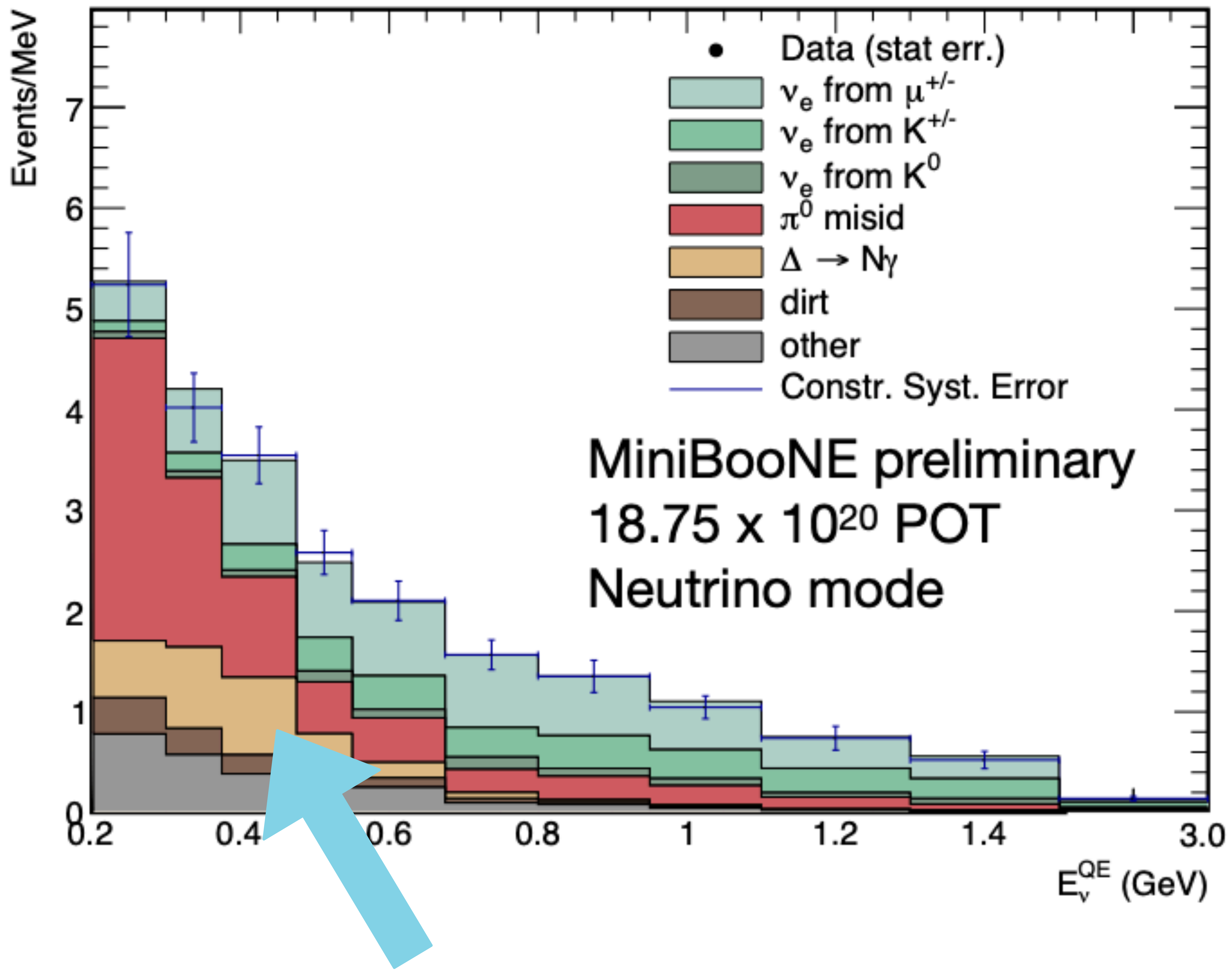

Δ background is mainly theory driven

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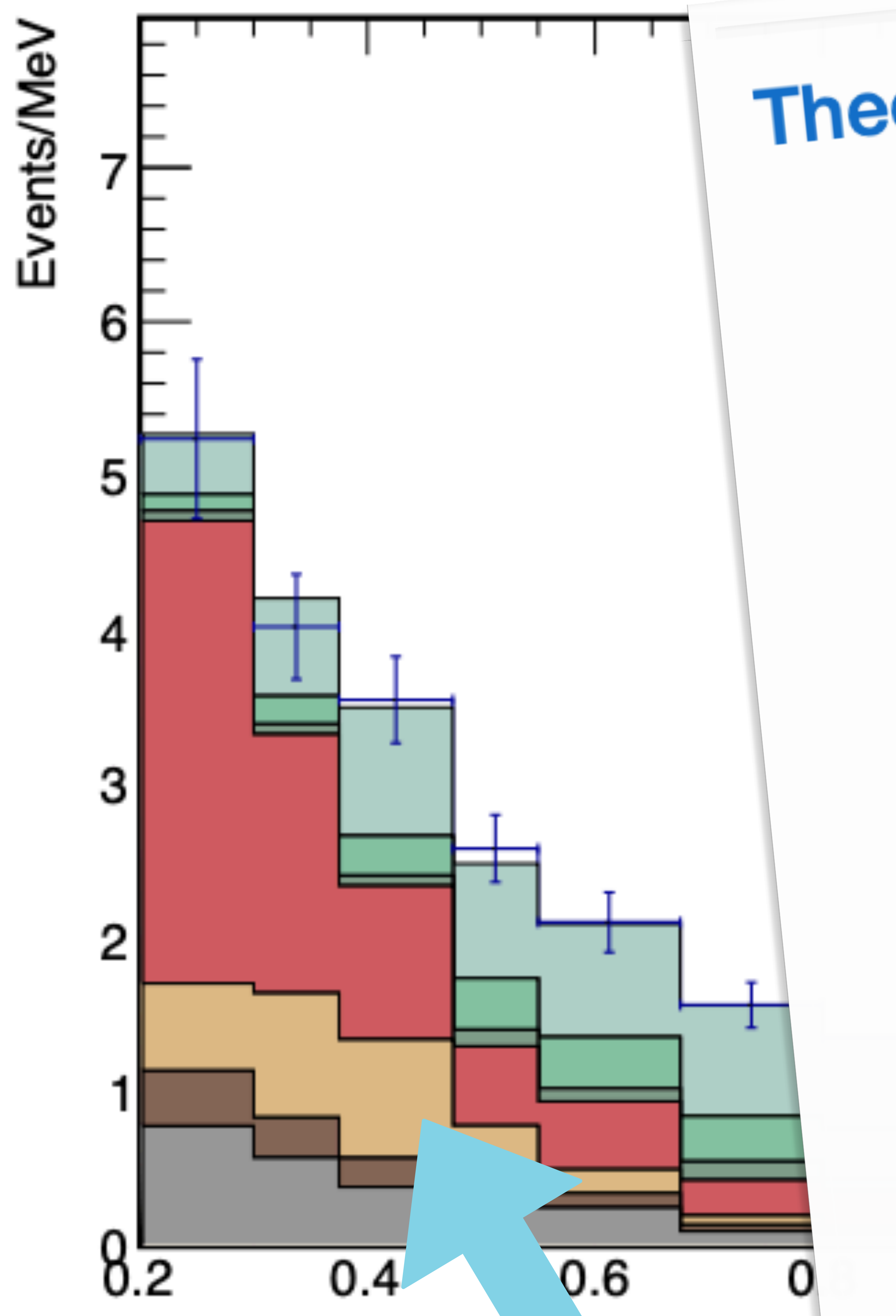

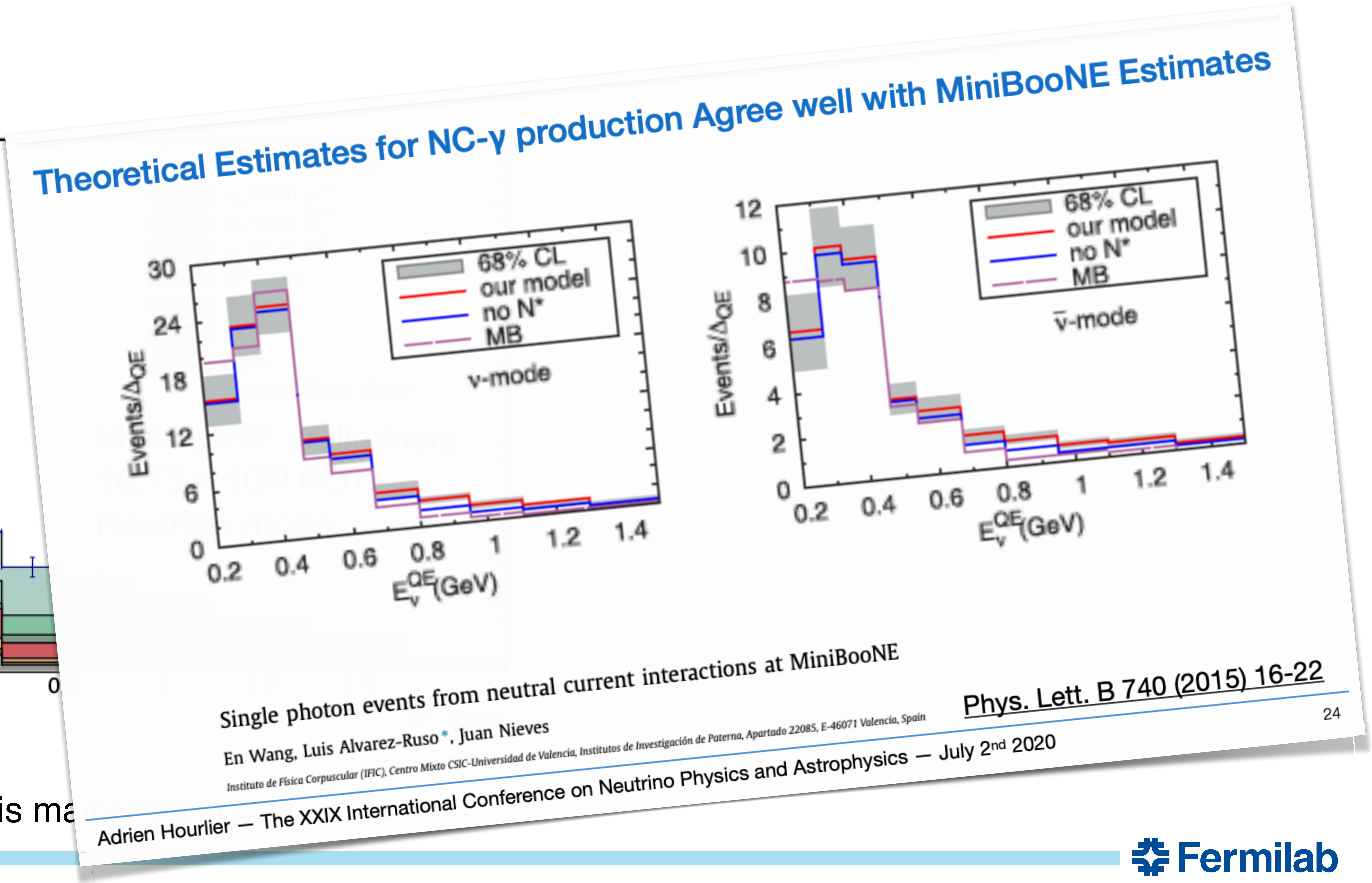

Δ background is ma

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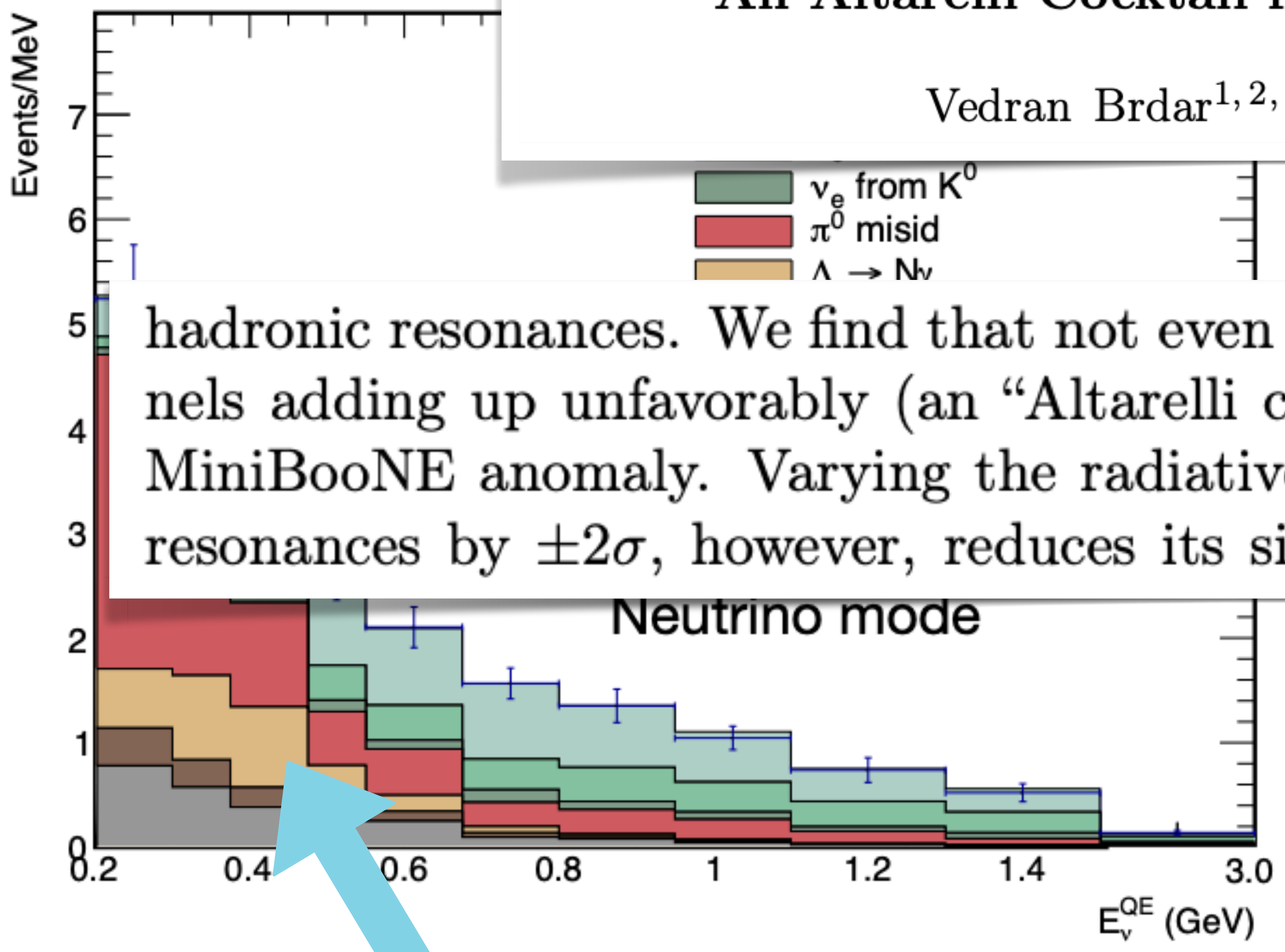
An Altarelli Cocktail for the MiniBooNE Anomaly?

Vedran Brdar[1,2,a] and Joachim Kopp[3,4,b]



hadronic resonances. We find that not even a combination of uncertainties in different channels adding up unfavorably (an "Altarelli cocktail") appears to be sufficient to resolve the MiniBooNE anomaly. Varying the radiative branching ratios of the $\Delta(1232)$ and $N(1440)$ resonances by $\pm 2\sigma$, however, reduces its significance from 4σ to less than 3σ. We finally

Δ background is mainly theory driven

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Standard physics:

+ Theoretical calculations for Δ decays are still under discussion

– Not clear there is a common standard origin for LSND and MiniBooNE

– Uncertainties on Δ do not allow for such large effect (needs factor of 3)

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Light sterile neutrinos

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Oscillations via sterile neutrinos don't really work

$$P_{\alpha\beta} \simeq \delta_{\alpha\beta} - 4|U_{\alpha\beta}|^2(\delta_{\alpha\beta} - |U_{\alpha\beta}|^2)\sin^2\left(\frac{\Delta m_{41}^2 L}{4E}\right)$$

$\nu_\mu \to \nu_e : \ \sin^2 2\theta_{\mu e} \equiv 4|U_{\mu 4}|^2|U_{e4}|^2$ → LSND, MiniBooNE, OPERA, …

$\nu_e \to \nu_e : \ \sin^2 2\theta_{ee} \equiv 4|U_{e4}|^2(1 - |U_{e4}|^2)$ → Reactors, solar, Gallium, …

$\nu_\mu \to \nu_\mu : \ \sin^2 2\theta_{\mu\mu} \equiv 4|U_{\mu 4}|^2(1 - |U_{\mu 4}|^2)$ → MiniBooNE, MINOS, IceCube, …

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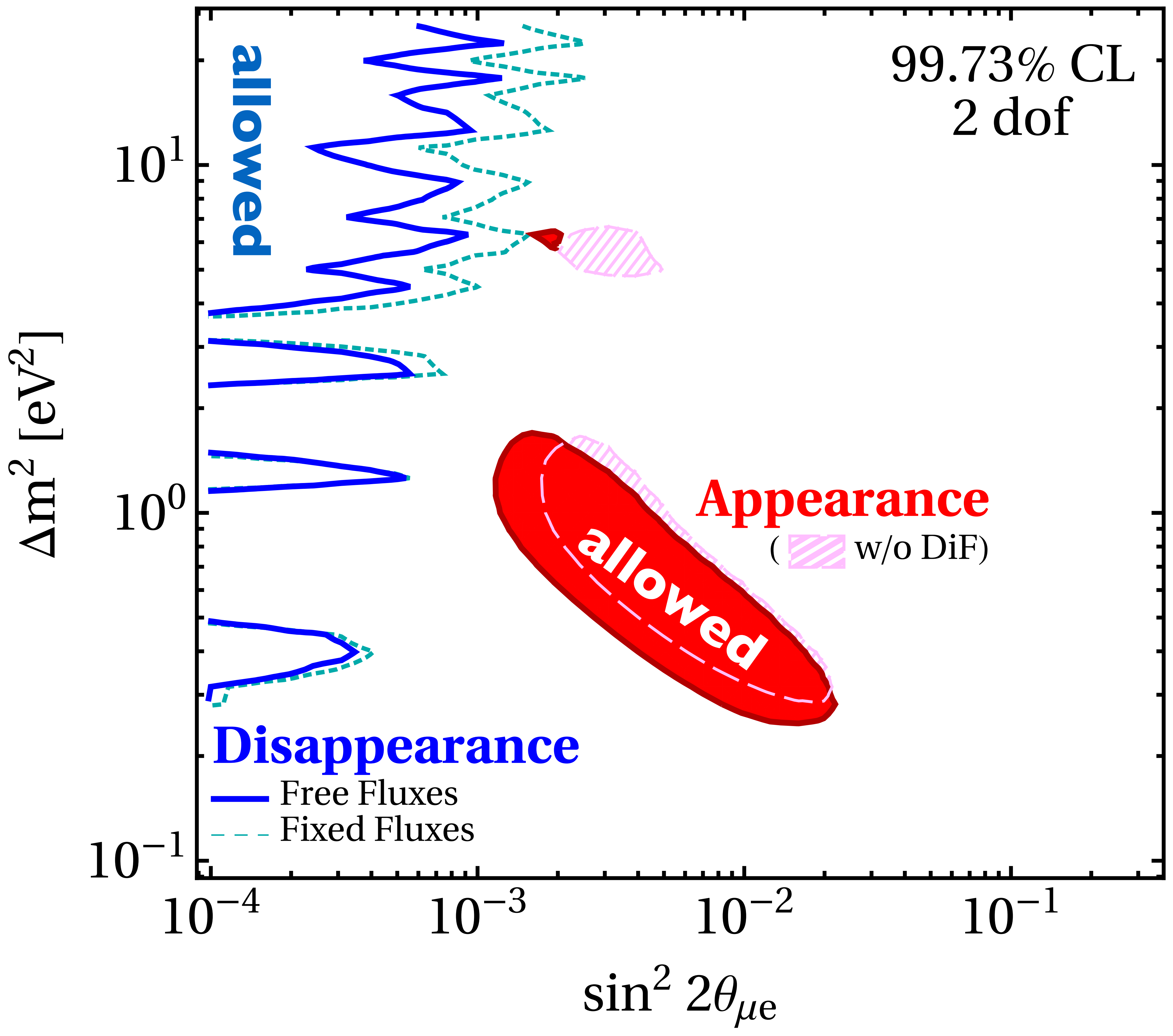
Oscillations via sterile neutrinos don't really work



ν_μ to ν_e appearance

$$\sin^2 2\theta_{\mu e} = 4\, |U_{e4}|^2 |U_{\mu 4}|^2$$

ν_e disappearance $\quad$ ν_μ disappearance

Data sets:

ν_e and ν_μ disappearance

vs.

ν_e appearance

4.7 σ tension

between DISAPP and APP data sets under eV sterile interpretation

Exercise: remove each experiment and see if agreement improves

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Light sterile neutrinos:

+ Explain LSND and MiniBooNE, as well as the reactor and Gallium anomalies

– Exhibit a gigantic tension with disappearance experiments

– Not accommodated by standard cosmology

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Sterile neutrino decay

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Sterile neutrino decay

Decays of sterile neutrinos

Dentler Esteban Kopp M 1911.01427

see also Bai, de Gouvea, Moulai, Pasquini, Salvado, Stenico, …

$$\mathcal{L} \supset -g\,\bar{\nu}_s \nu_s \phi - \sum_{a=e,\mu,\tau,s} m_{\alpha\beta}\,\bar{\nu}_\alpha \nu_\beta$$

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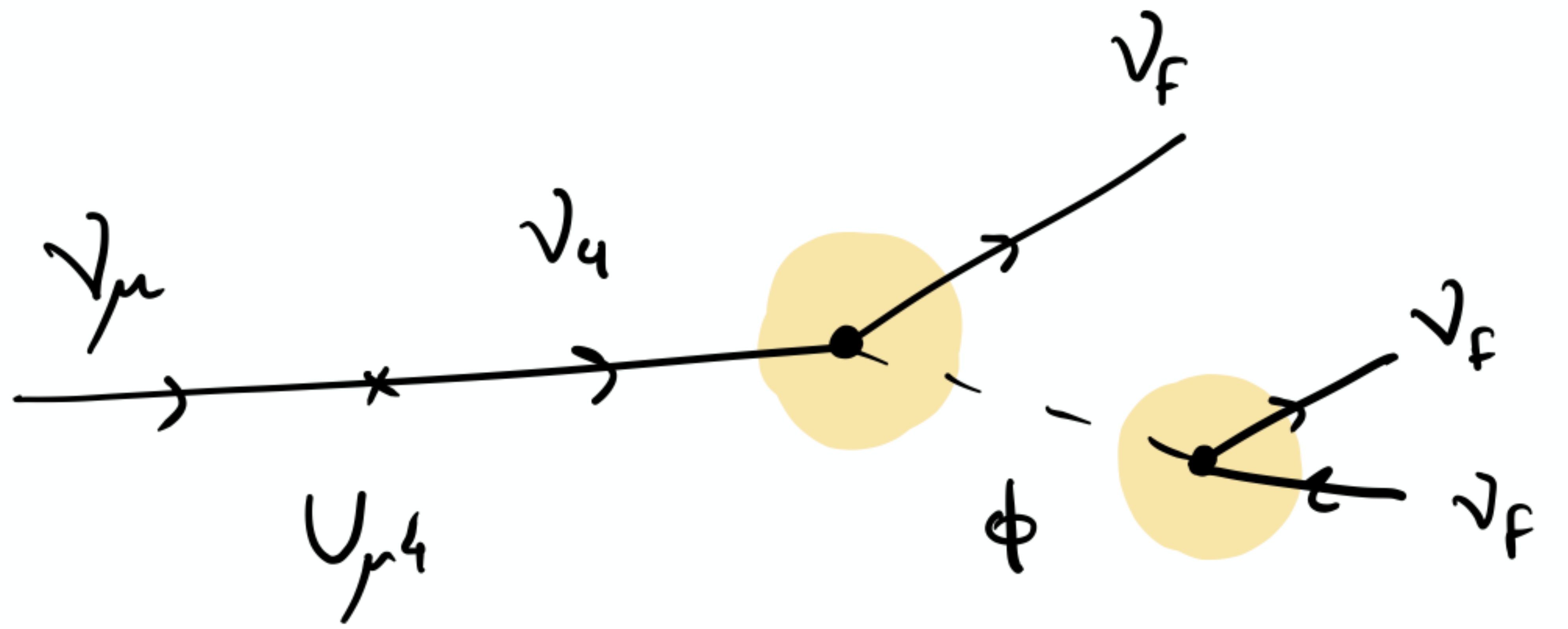
$$\nu_F \equiv \sum_{i=1}^{3} U_{si}\nu_i$$

$$-g\,\bar{\nu}_F \nu_F \phi - g\,|U_{s4}|^2 \bar{\nu}_4 \nu_4 \phi - (g\,U^*_{s4}\bar{\nu}_4 \nu_F \phi + h.c.)$$



Pay only $|U_{\mu 4}|$, decays can easily produce ν_e

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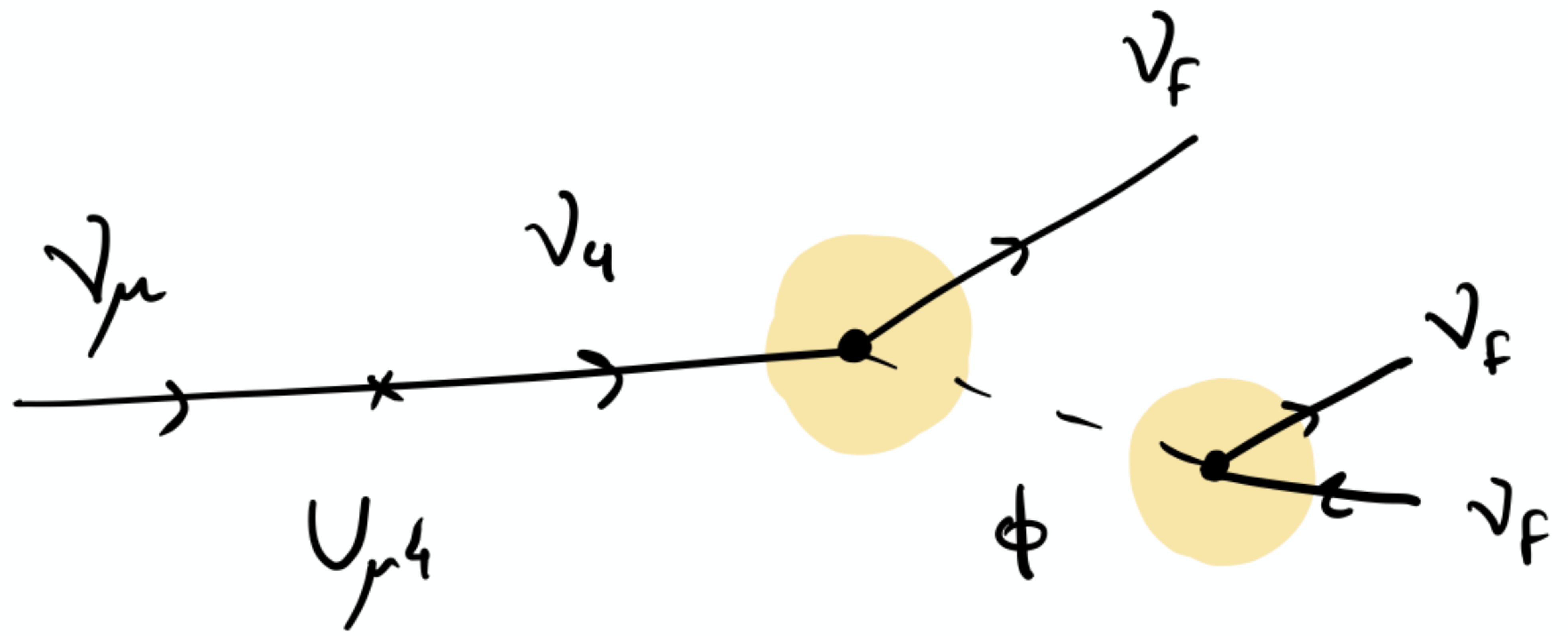

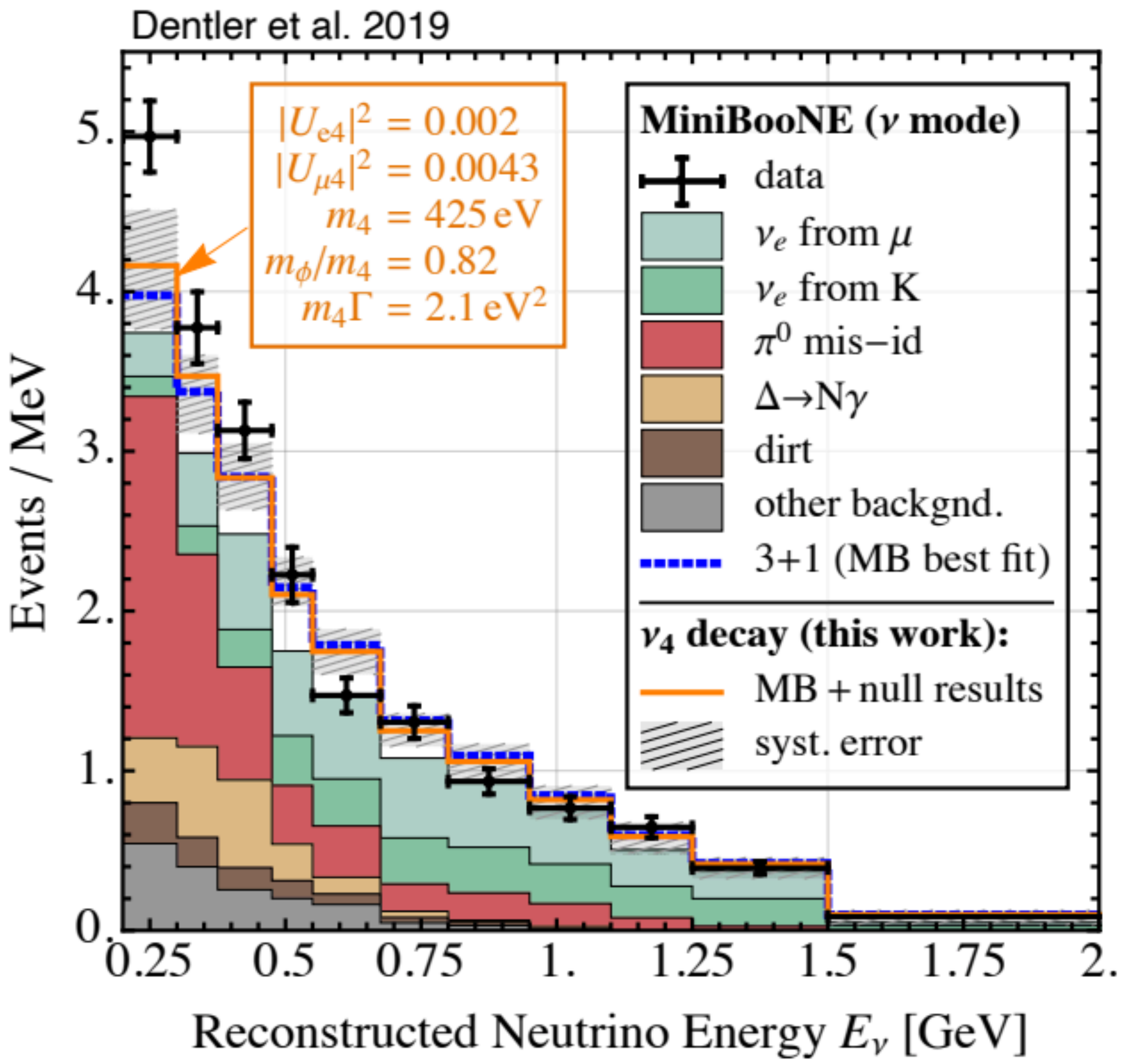

Pay only $|U_{\mu 4}|$, decays can easily produce ν_e

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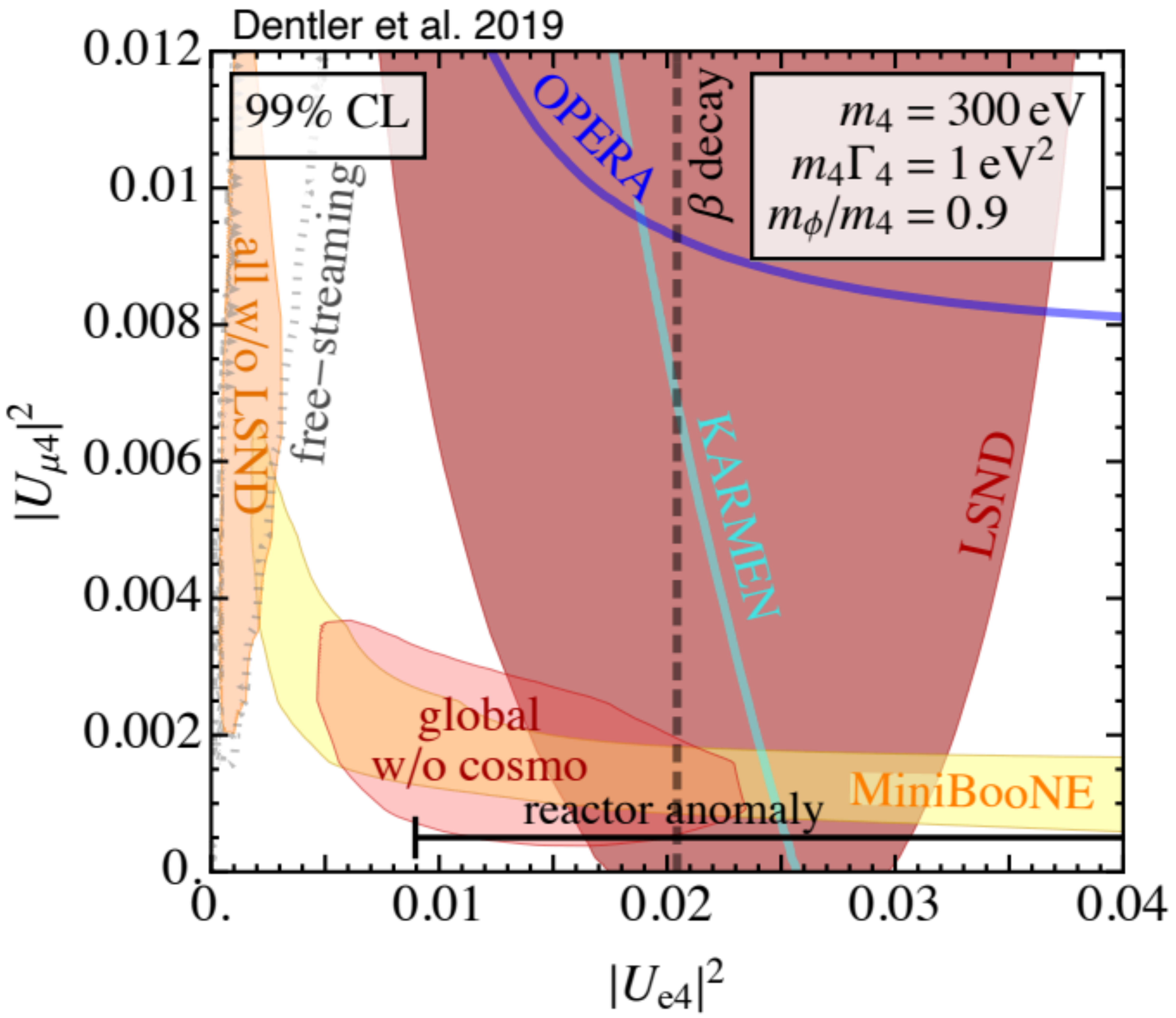
Sterile neutrino decay

Two issues

Problem 1: Self-interaction is too strong, neutrinos do not free-stream
Solution: Add more light, thermalized degrees of freedom in the early universe

Problem 2: Solar neutrinos also decay, leading to electron antineutrinos
Solution: Neglect LSND



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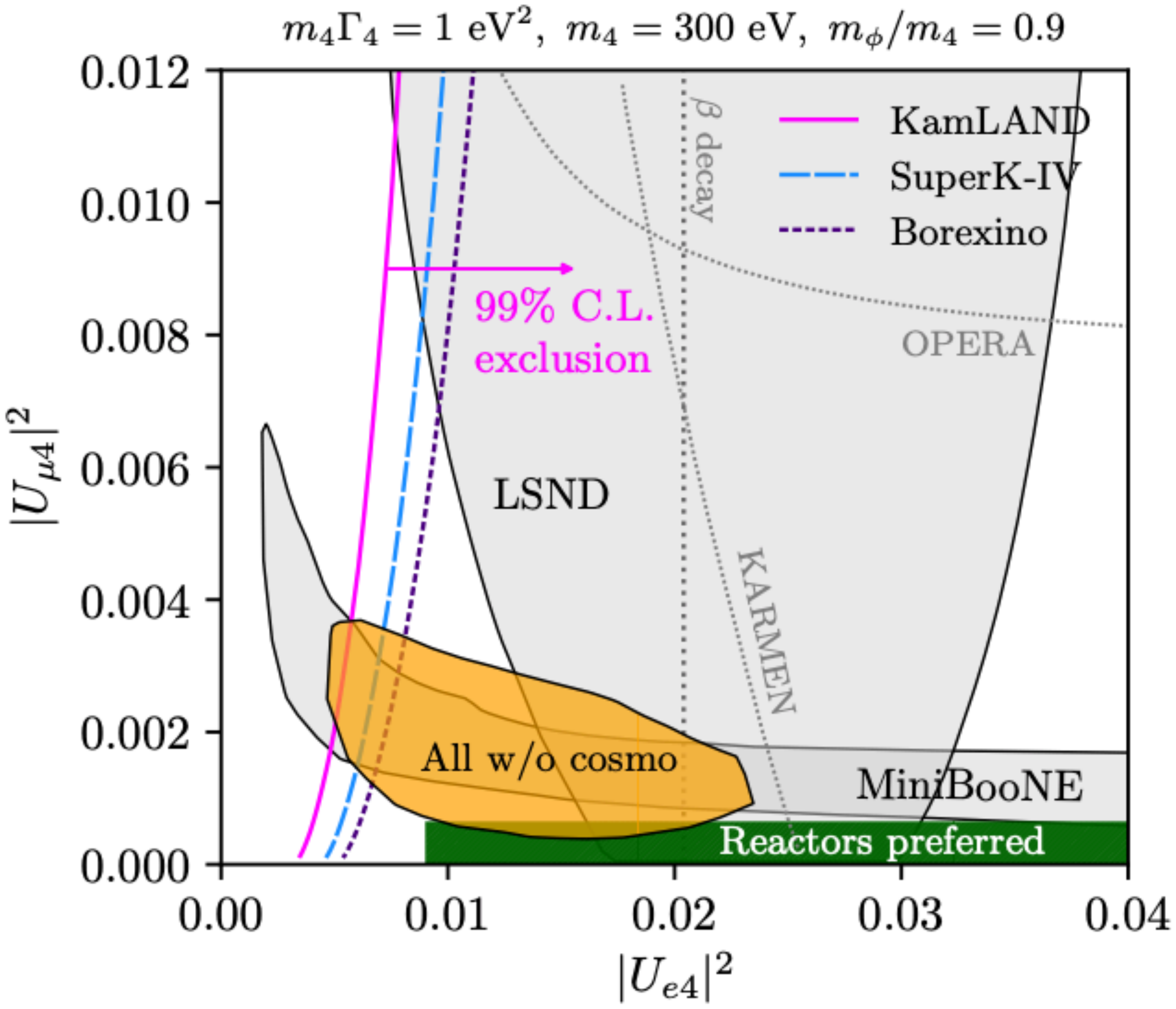
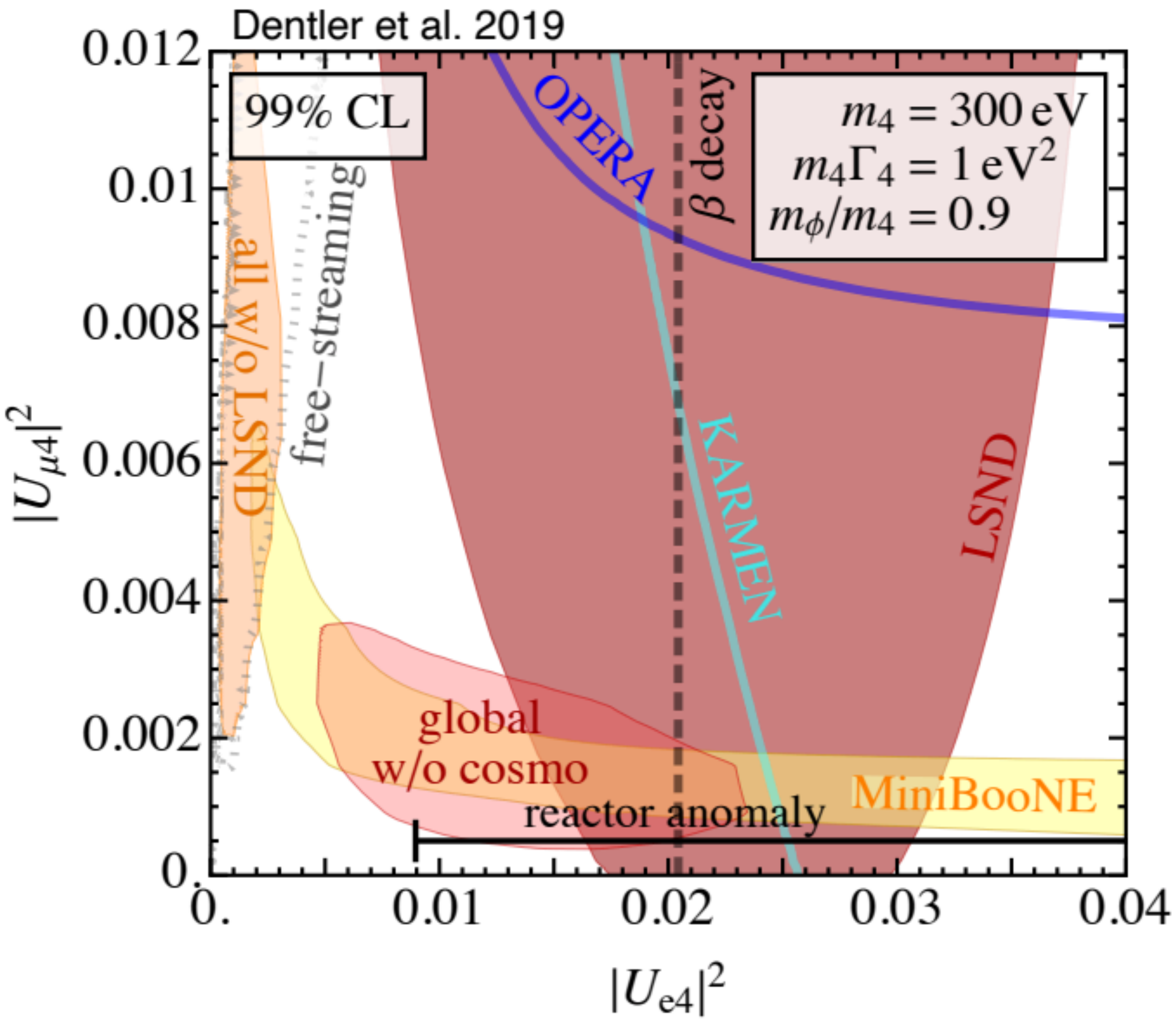
Sterile neutrino decay

Hostert Pospelov 2008.11851





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Sterile neutrino decay:

+ Model independent: explains all anomalies, no tension

• Simple models may present cosmological issues, easy to evade though

•UV inspired: explains MiniBooNE but accommodating LSND creates a tension with solar antineutrino searches

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Dark neutrinos

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Dark Neutrinos

Dark neutrinos

Bertuzzo Jana M Zukanovich 1807.09877, 1808.02500

see Abdullahi, Arguelles, Ballett, Hostert, Pascoli, Ross, Tsai

1. Neutrino mass is protected by gauge symmetry on the sterile neutrino sector
2. Breaking happens at low scale

$$\mathcal{L}_\nu = - y_\nu \overline{L}\widetilde{\phi} N + y_N S_2 \overline{N} N^c + y_{N'} S_2^* \overline{N'} N'^c + m \overline{N'} N^c + \text{h.c.} ,$$

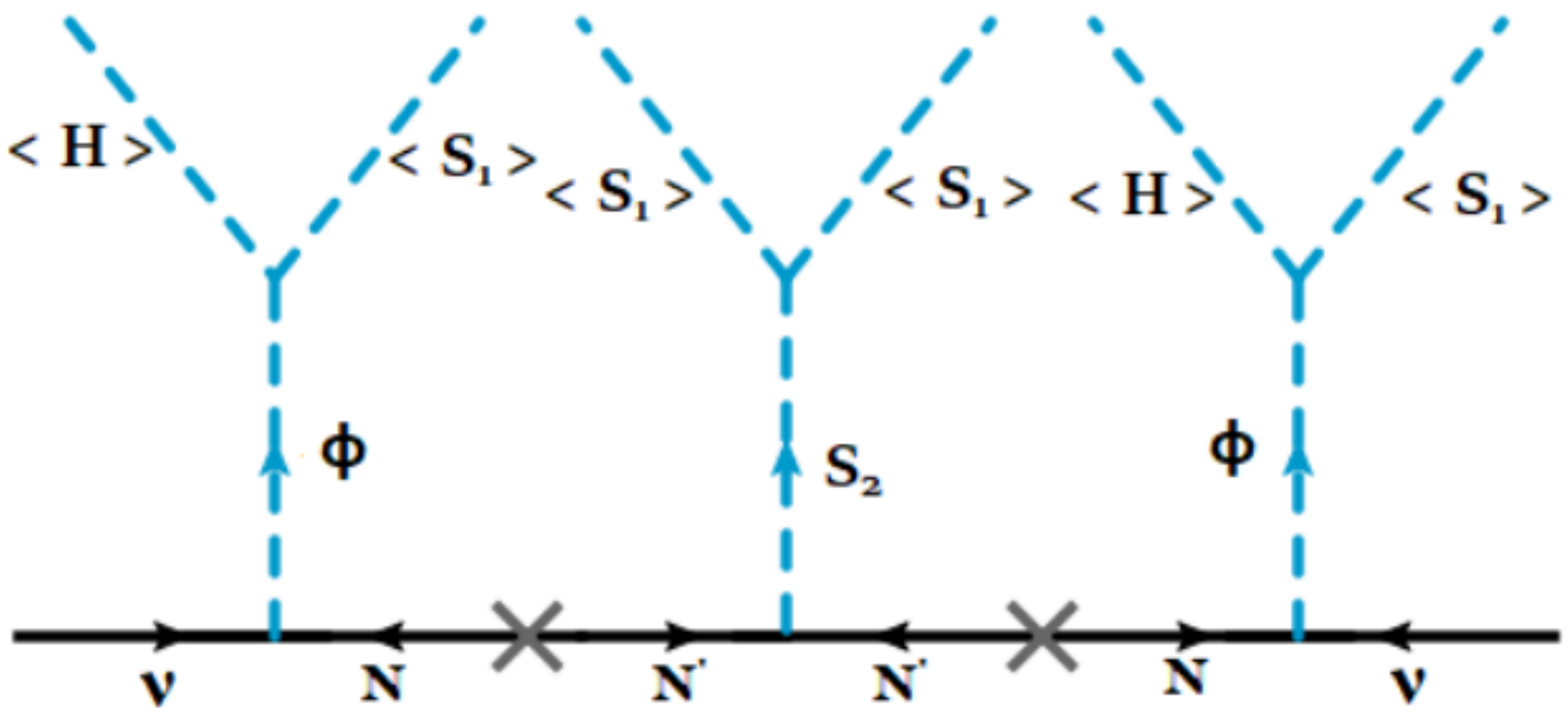
Φ: scalar doublet (+1)

N: Sterile (+1)

N’: Sterile (-1)

S_2: scalar singlet (+2)

S_1: scalar singlet (+1)



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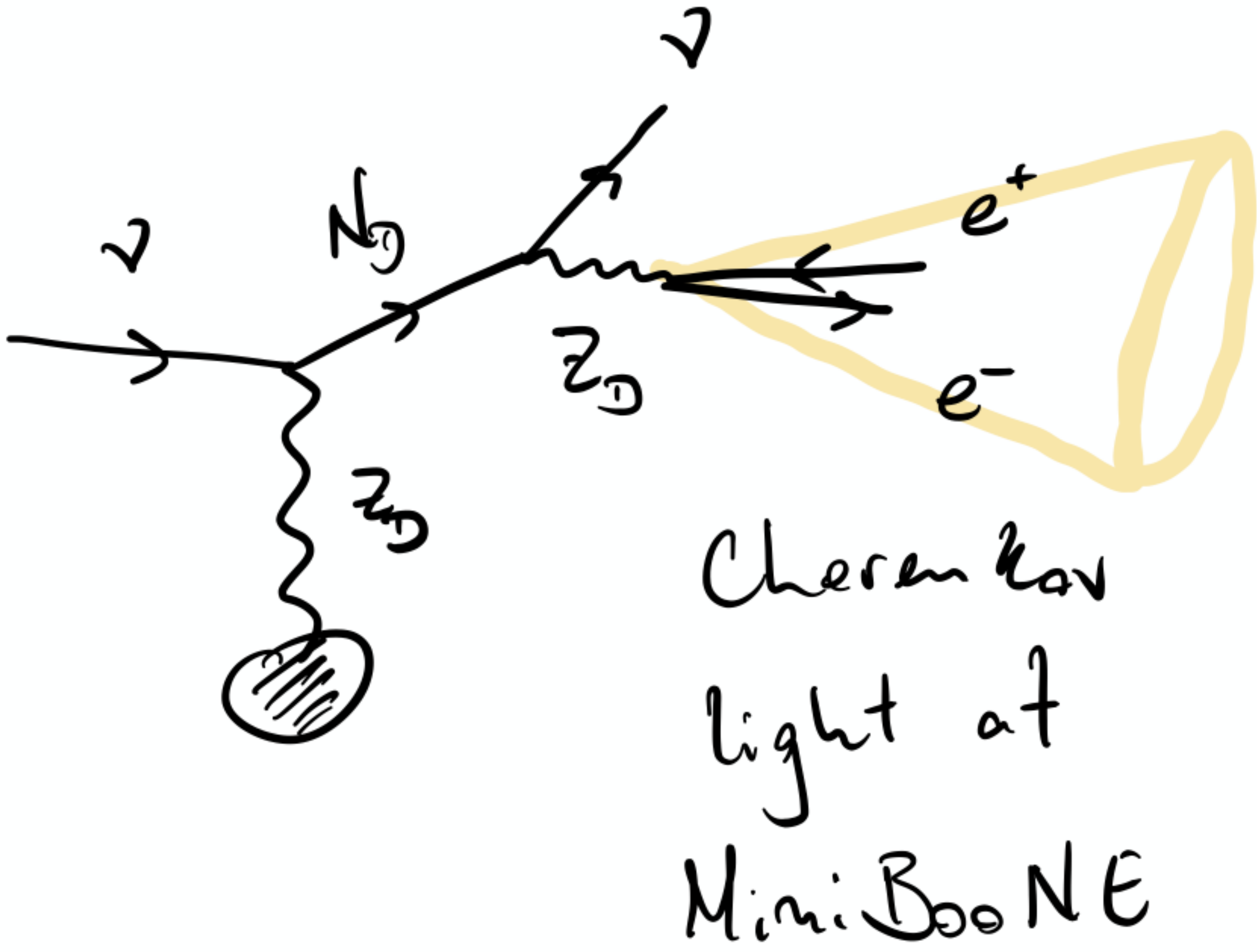

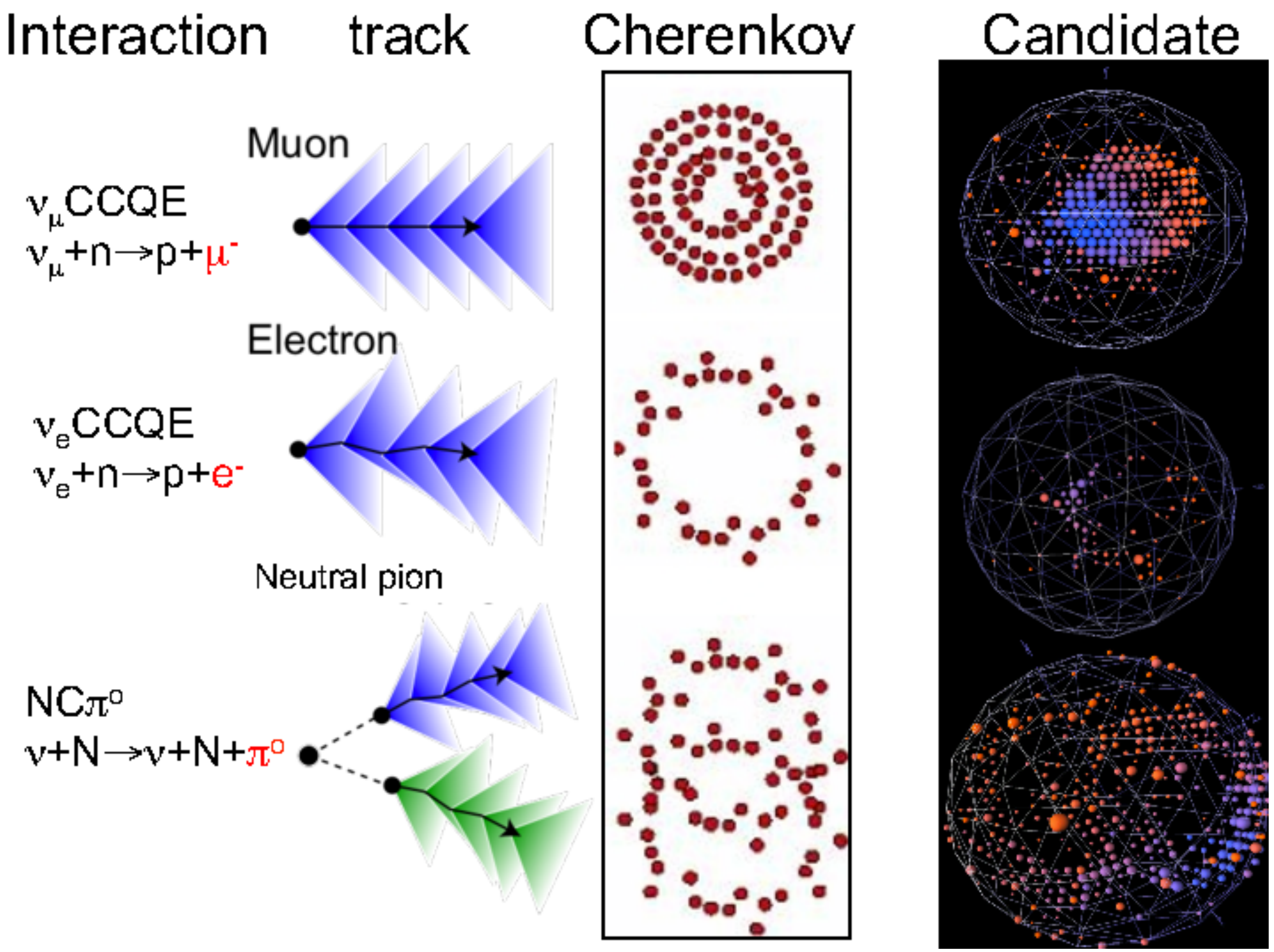

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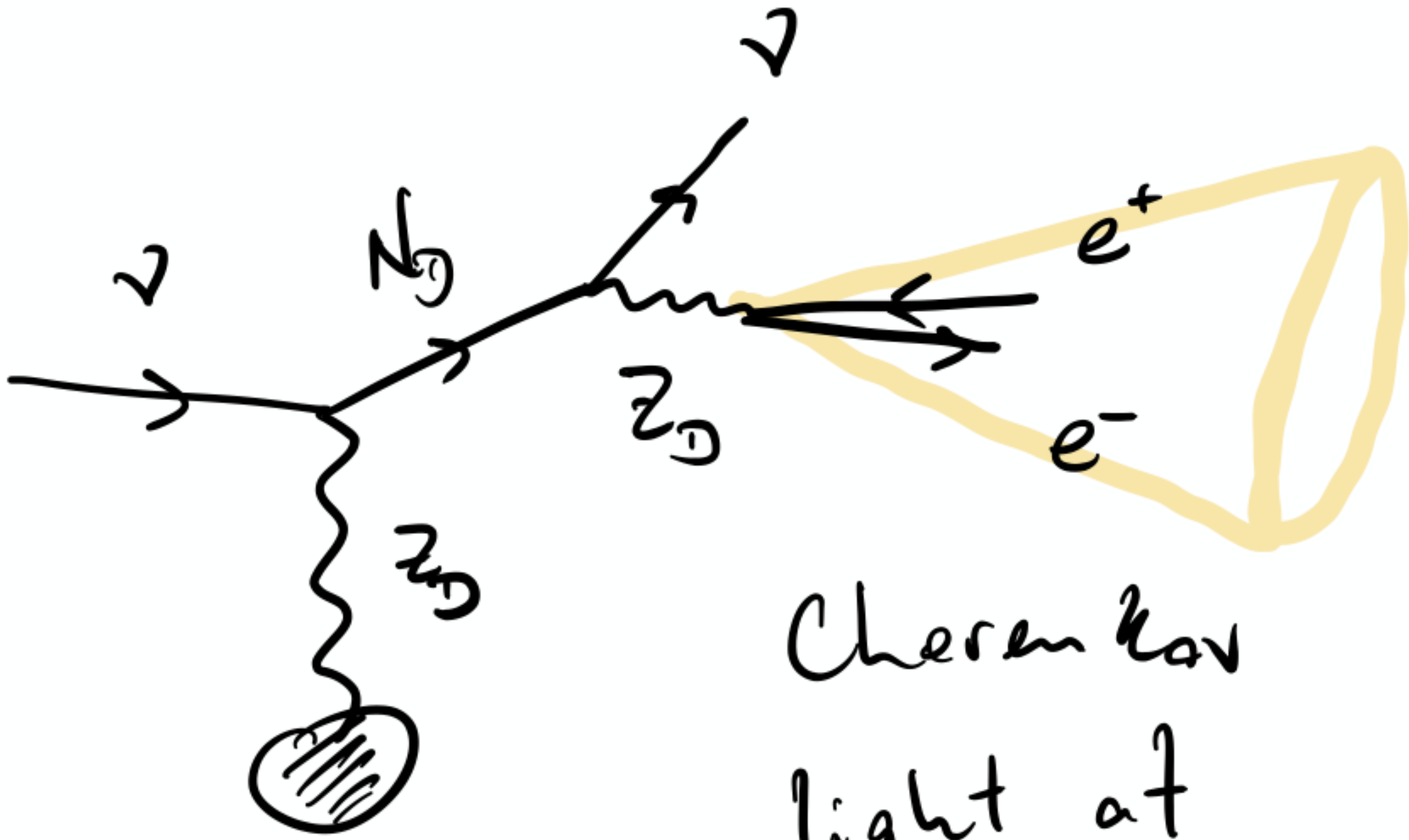
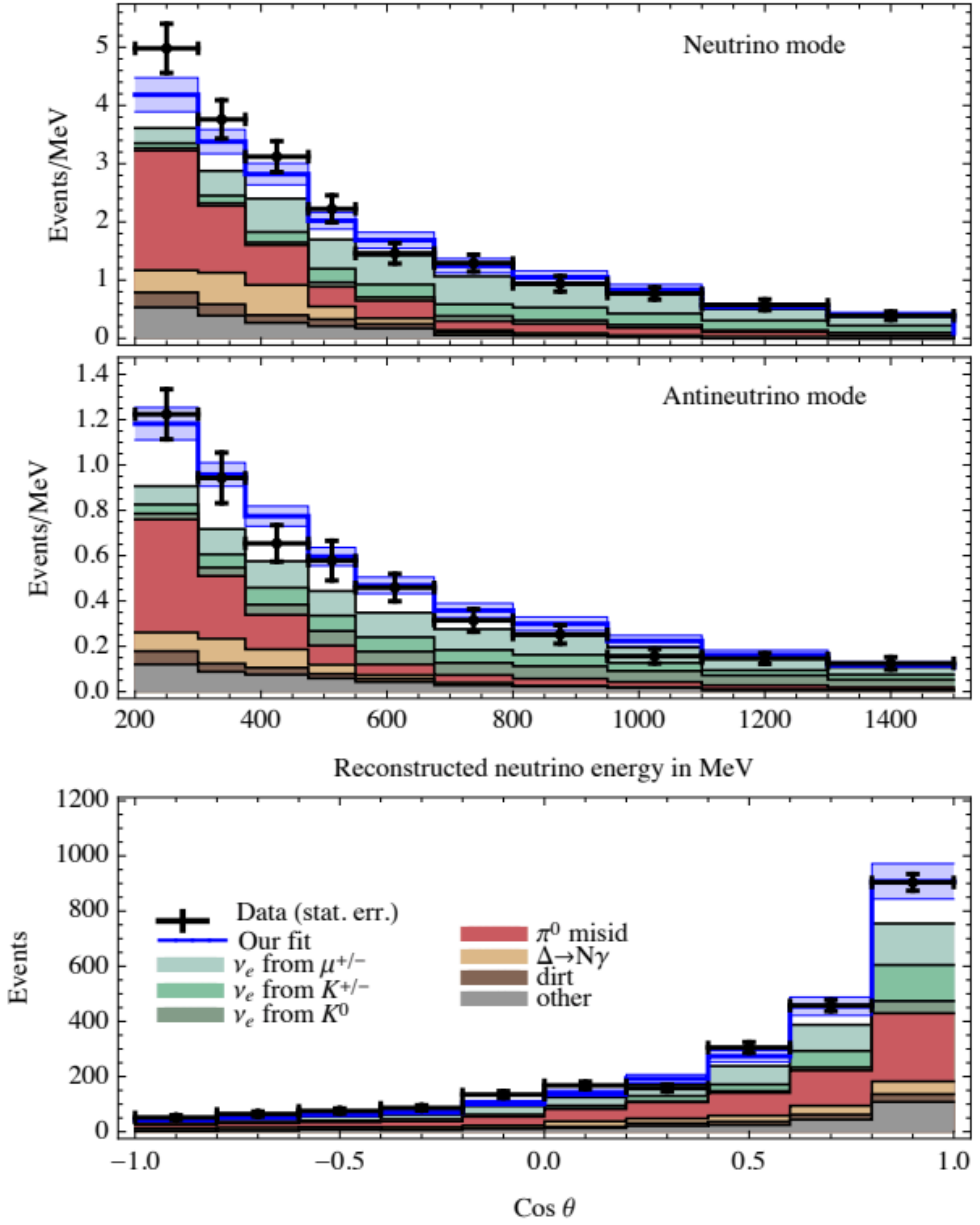


Cherenkov light at MiniBooNE



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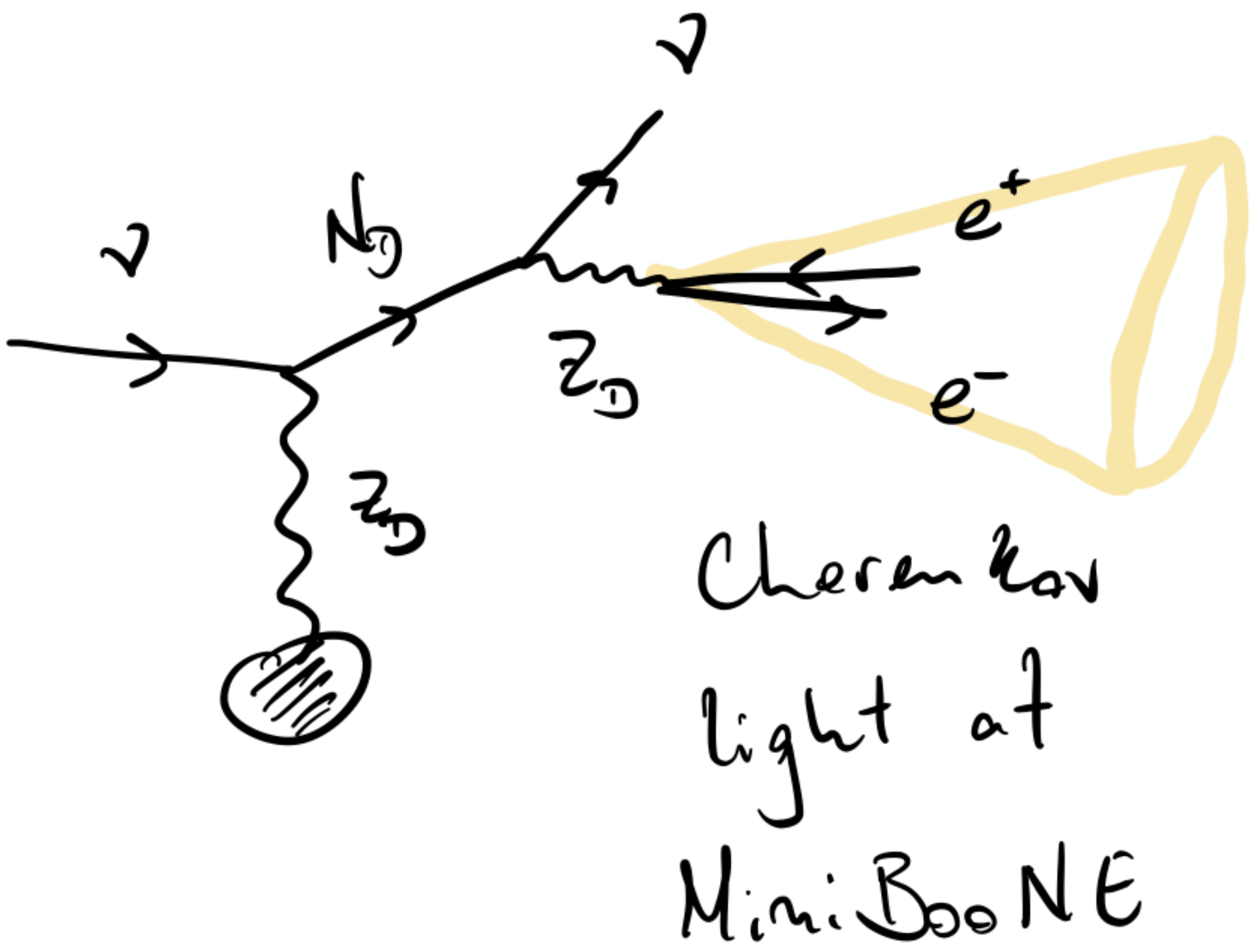

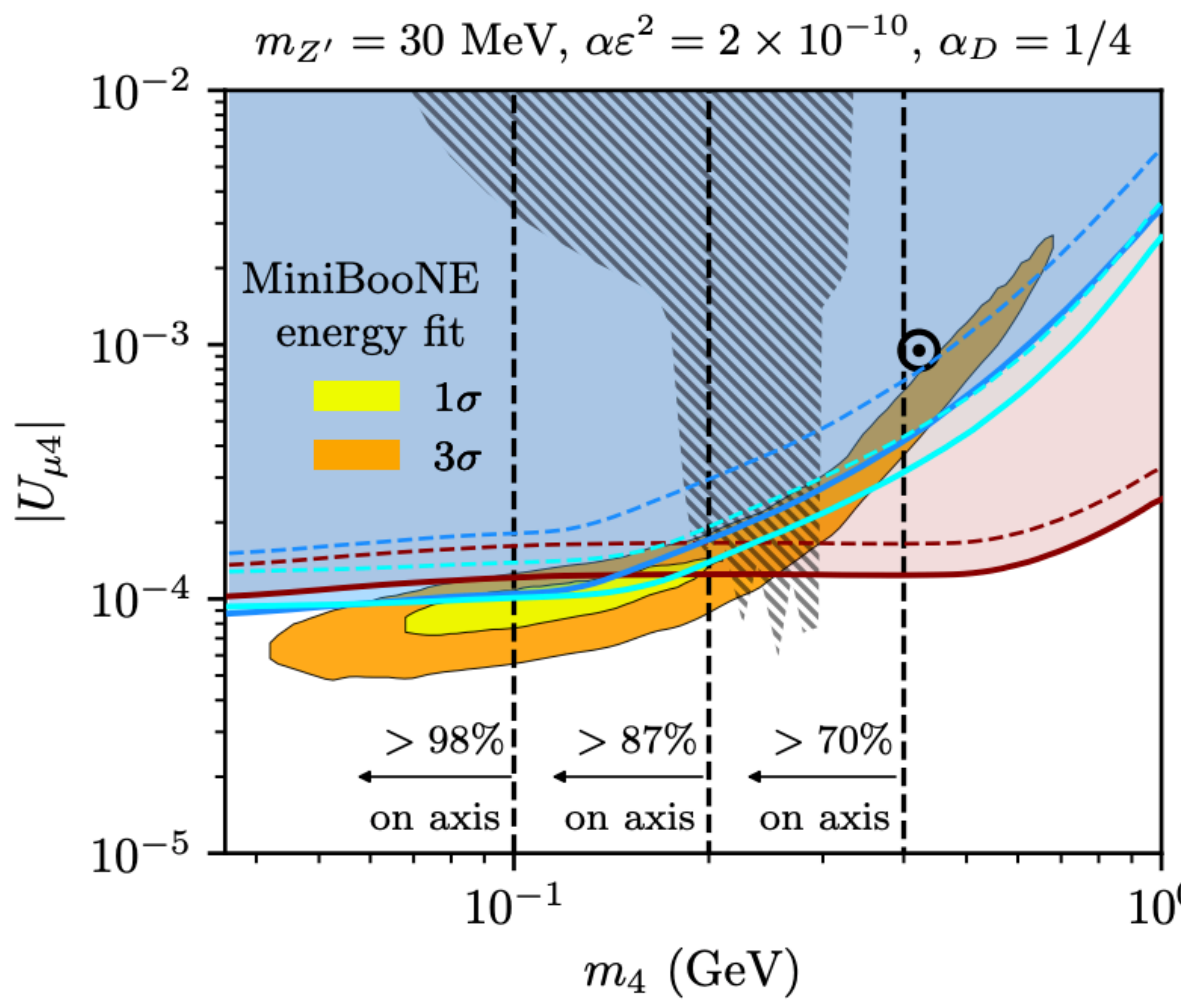

Arguelles Hostert Tsai 1812.08768

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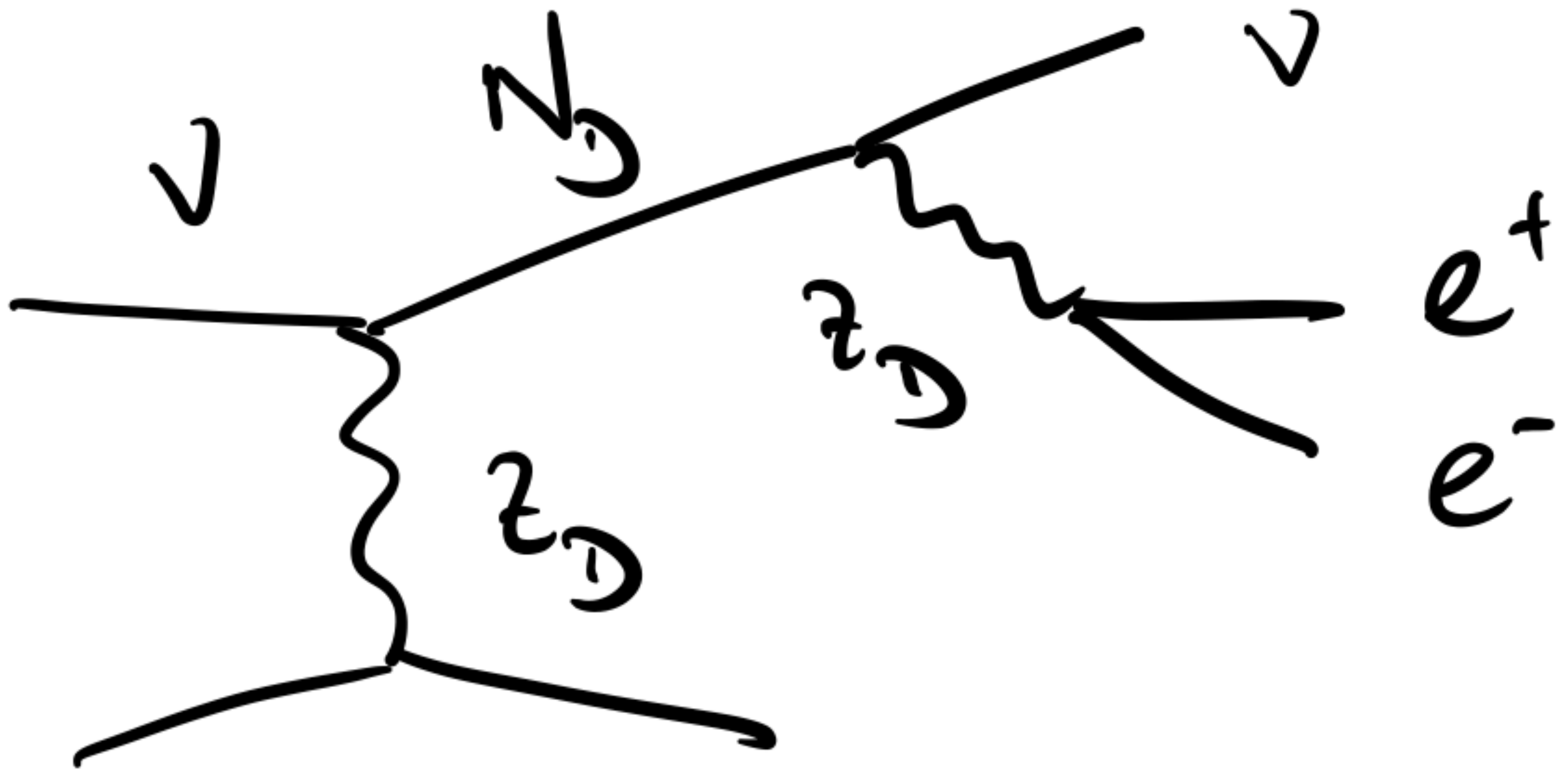

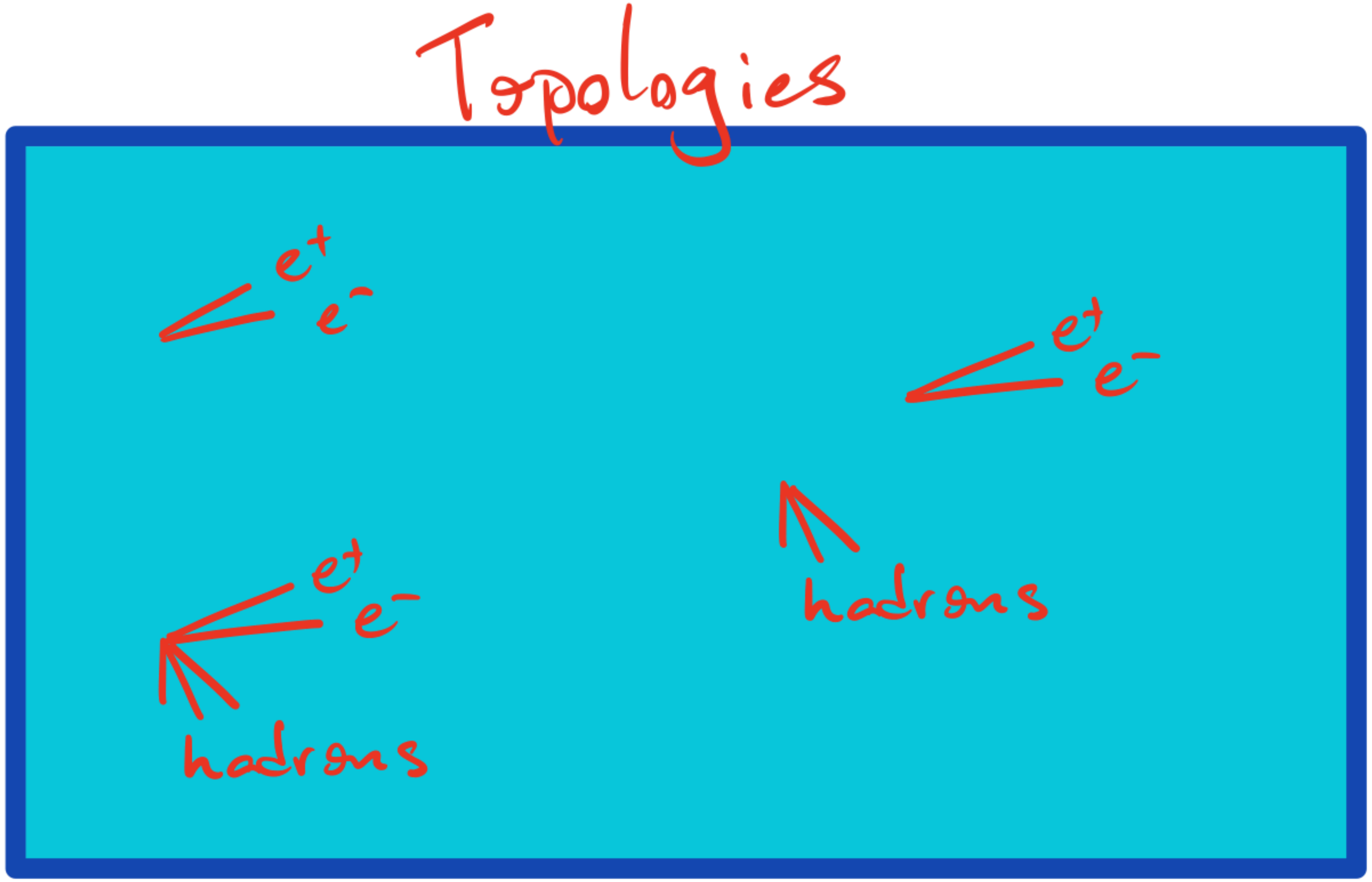

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Dark neutrinos:

+ Consequence of neutrino mass model

+ Better fit to MiniBooNE than sterile neutrinos

+ Novel signatures beyond neutrino interactions

•Constraints from high energy experiments, global analysis/scan needed

– Cannot explain LSND

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Transition magnetic moment

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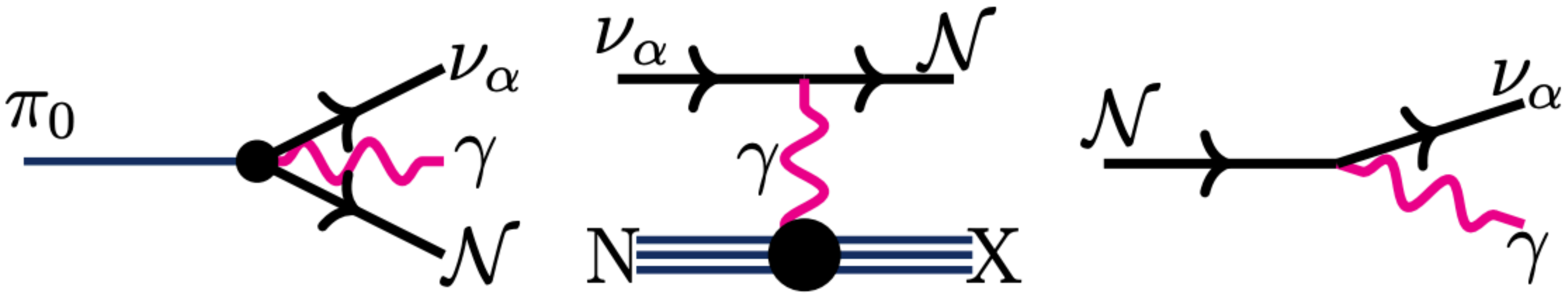
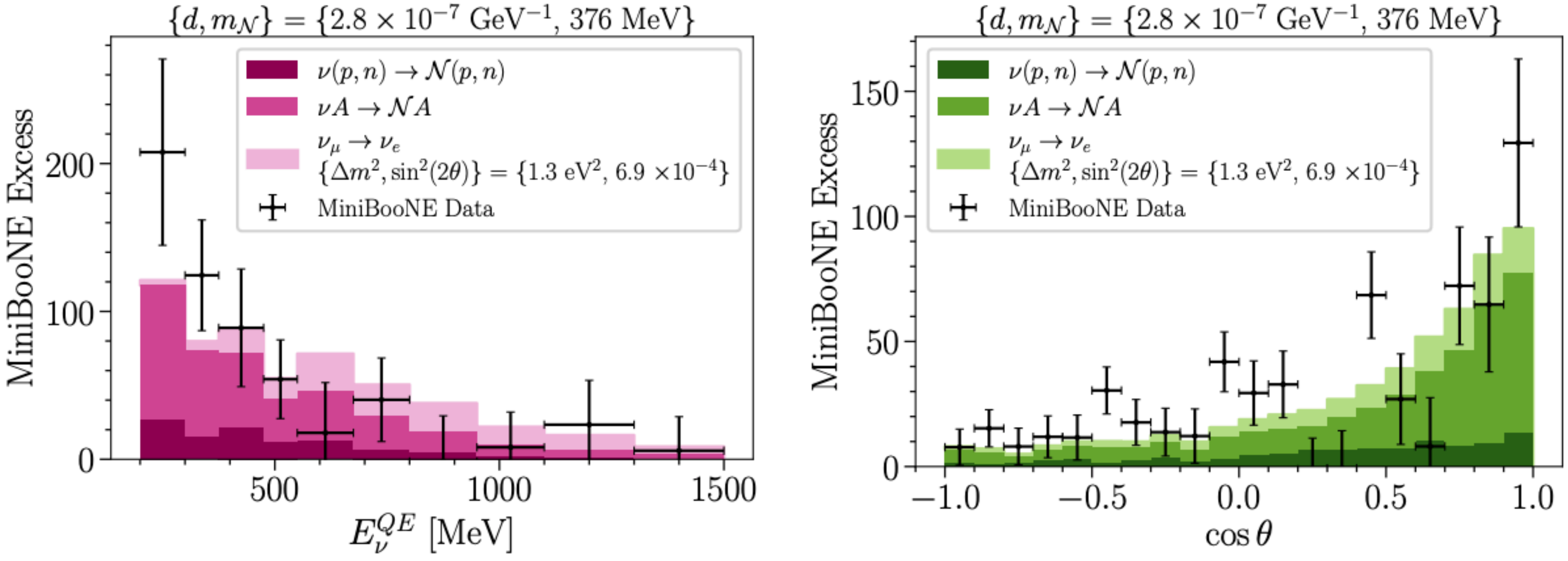
Transition magnetic moment

Vergani et al 2105.06470
see also
Arguelles et al 2109.03831
Ismail et al 2109.05032
Atkinson et al 2105.09357
Brdar et al 2007.15563
Fischer et al 1909.09561
Gninenko 1201.5194, 0902.3802
McKeen Pospelov 1011.3046





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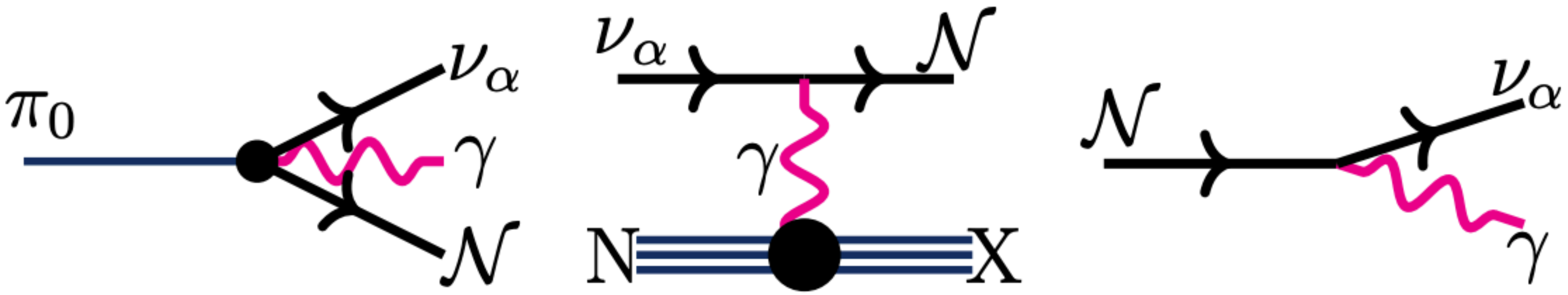
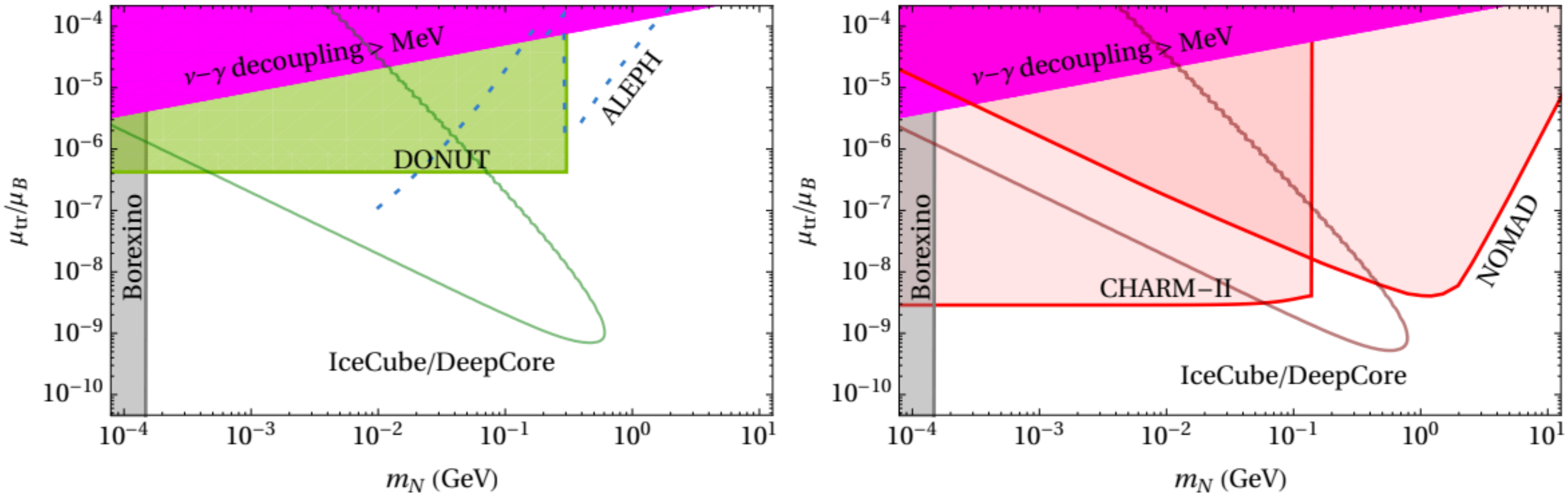


Coloma M Martinez-Soler Shoemaker 1707.08572



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Brdar et al 2007.15563
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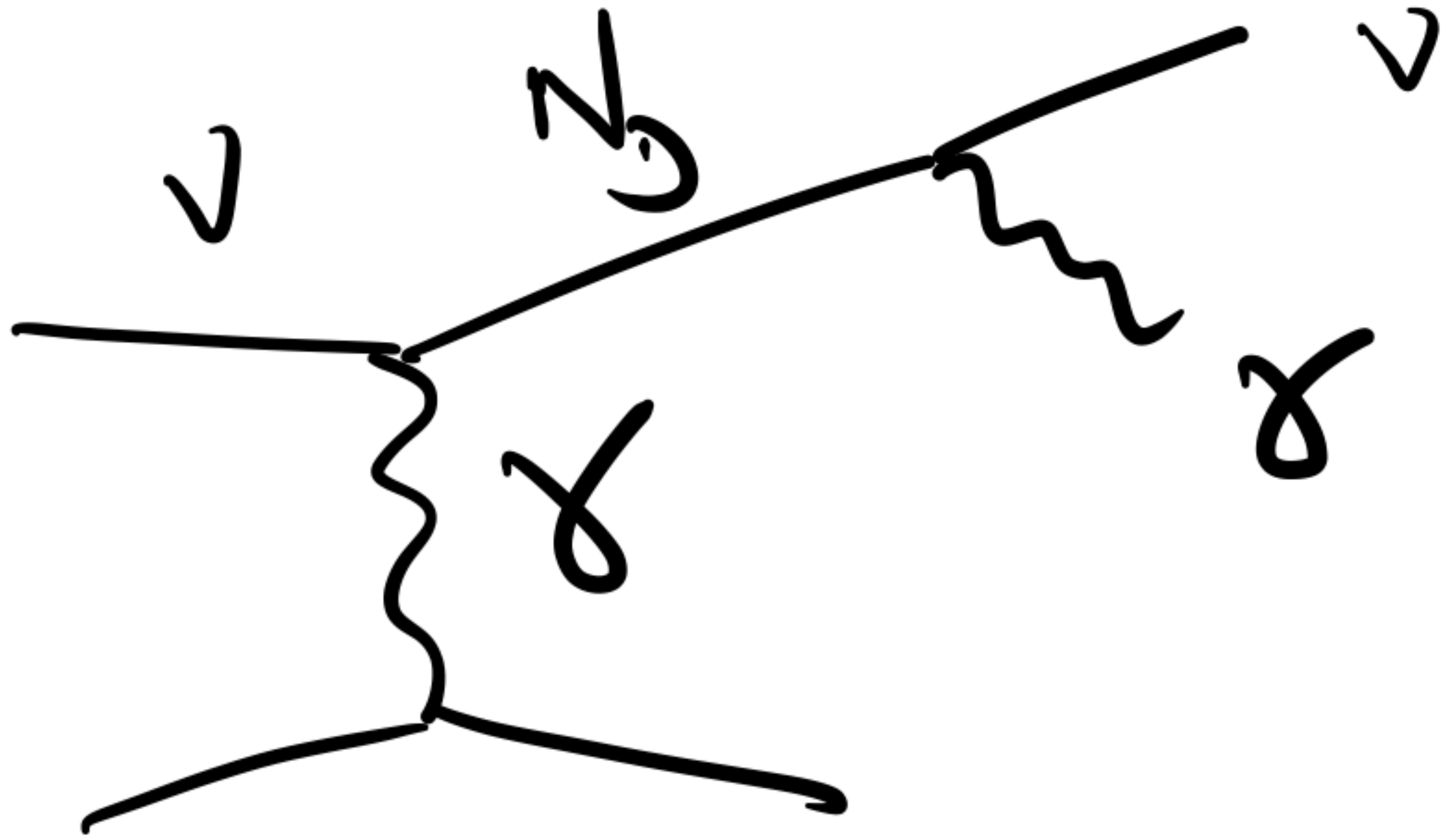

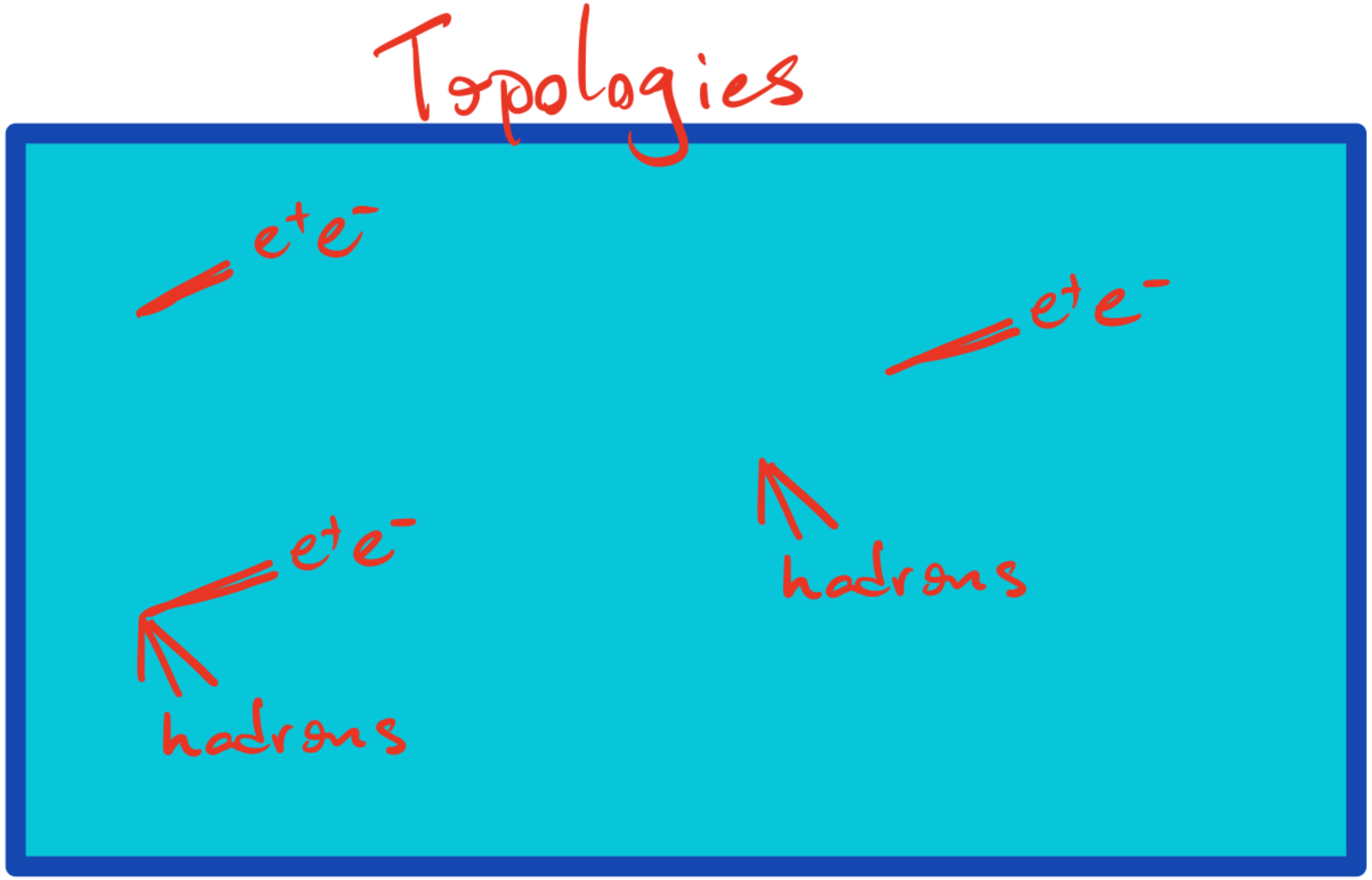

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Transition magnetic moment:

+ Better fit to MiniBooNE than sterile neutrinos

+ Novel signatures beyond neutrino interactions

– Cannot explain LSND

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Other possibilities

Sterile neutrinos and modified dispersion relations (Doring et al 1808.07460, Barenboim et al 1911.02329):

Not clear it works, detailed studies needed

eV steriles + NCNSI + CCNSI (Liao et al 18010.01000):

Works, but very baroque. UV challenge…

Resonant matter effect (Asaadi et al 1712.08019, Smirnov Valera 2108.07202):

Strong constraints from higher energy data

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Conclusions

Short baseline anomalies are still largely unexplained

New theoretical models lead to new experimental observables

MicroBooNE e^- and γ searches will provide invaluable information here

Fermilab’s SBN program will be crucial to pin down the explanation

Very hard to explain everything at the same time with UV complete model

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Backup

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