NTN NSI Workshop Summary

also known as "Bhupal's workshop"

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May 2019

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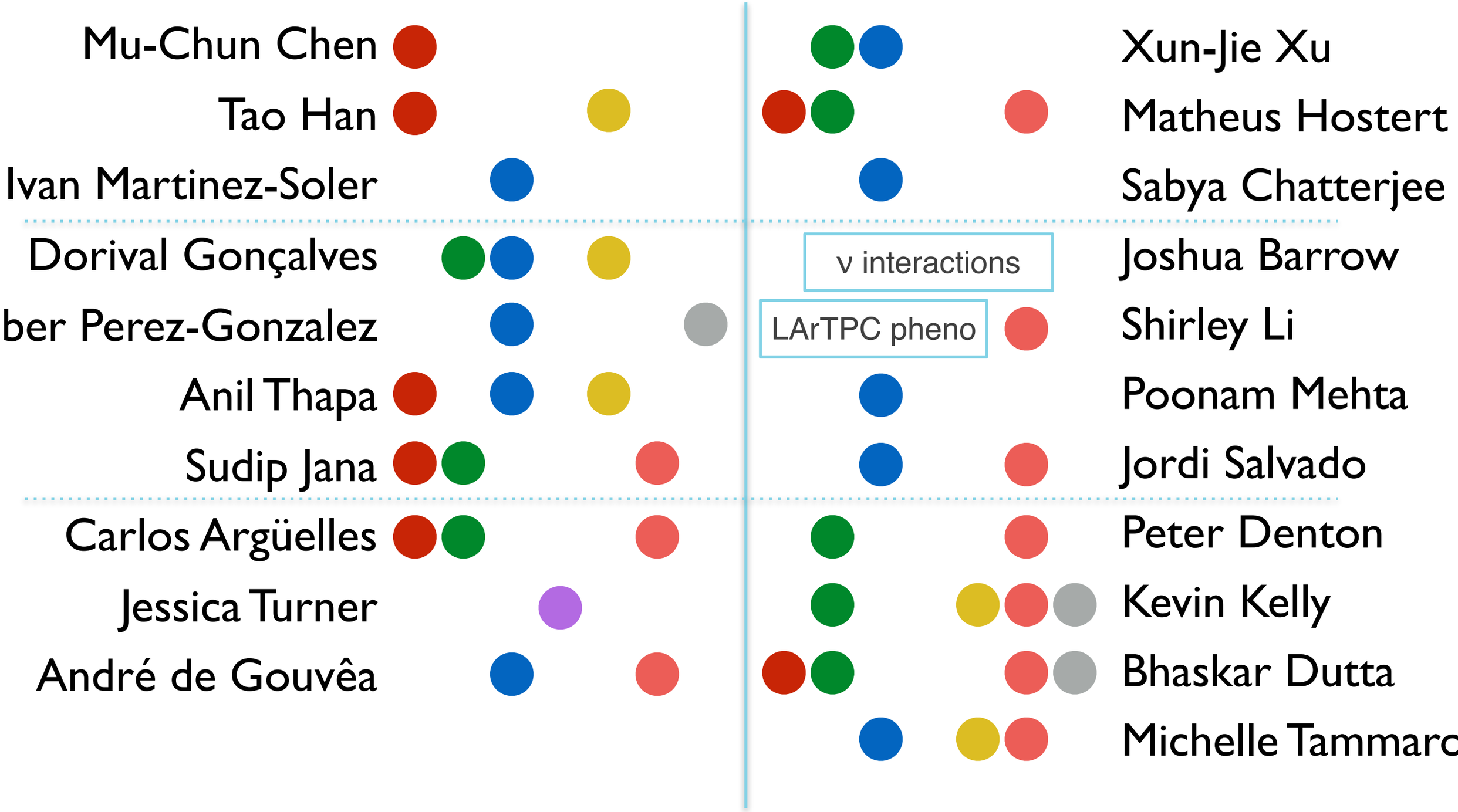
Mass and flavor **Traditional NSI** **Colliders** **Dark matter**

Light mediators **Leptogenesis** **New signatures**



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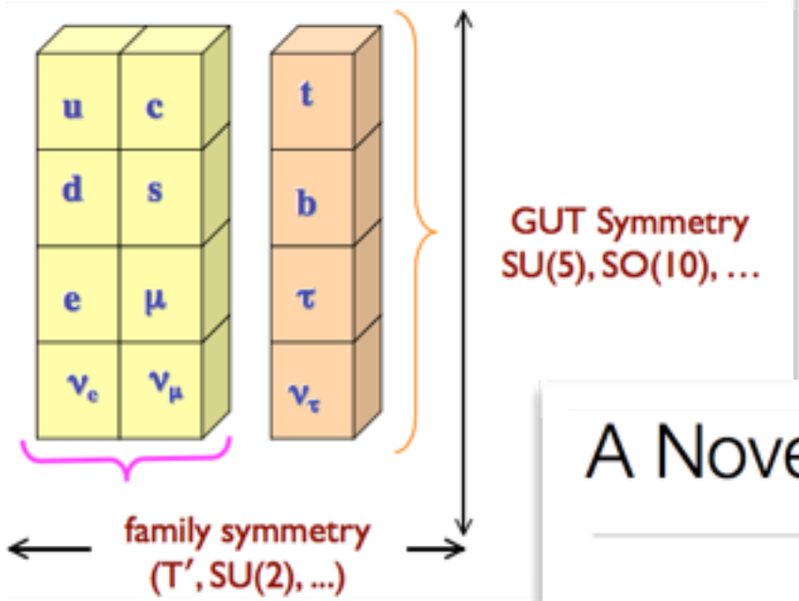
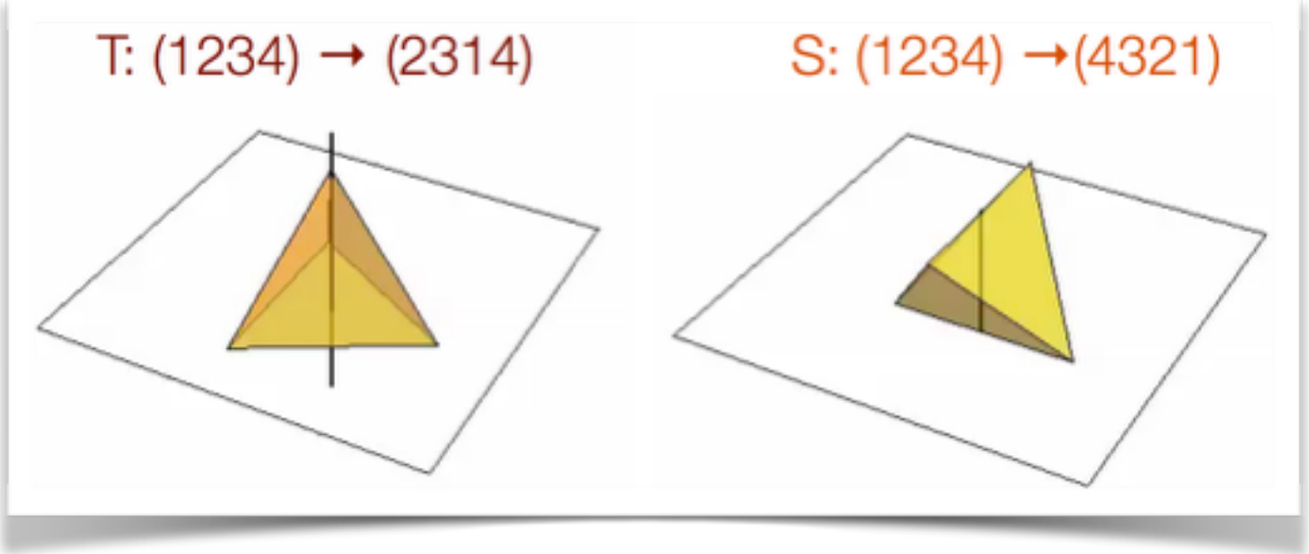
Mass and flavor

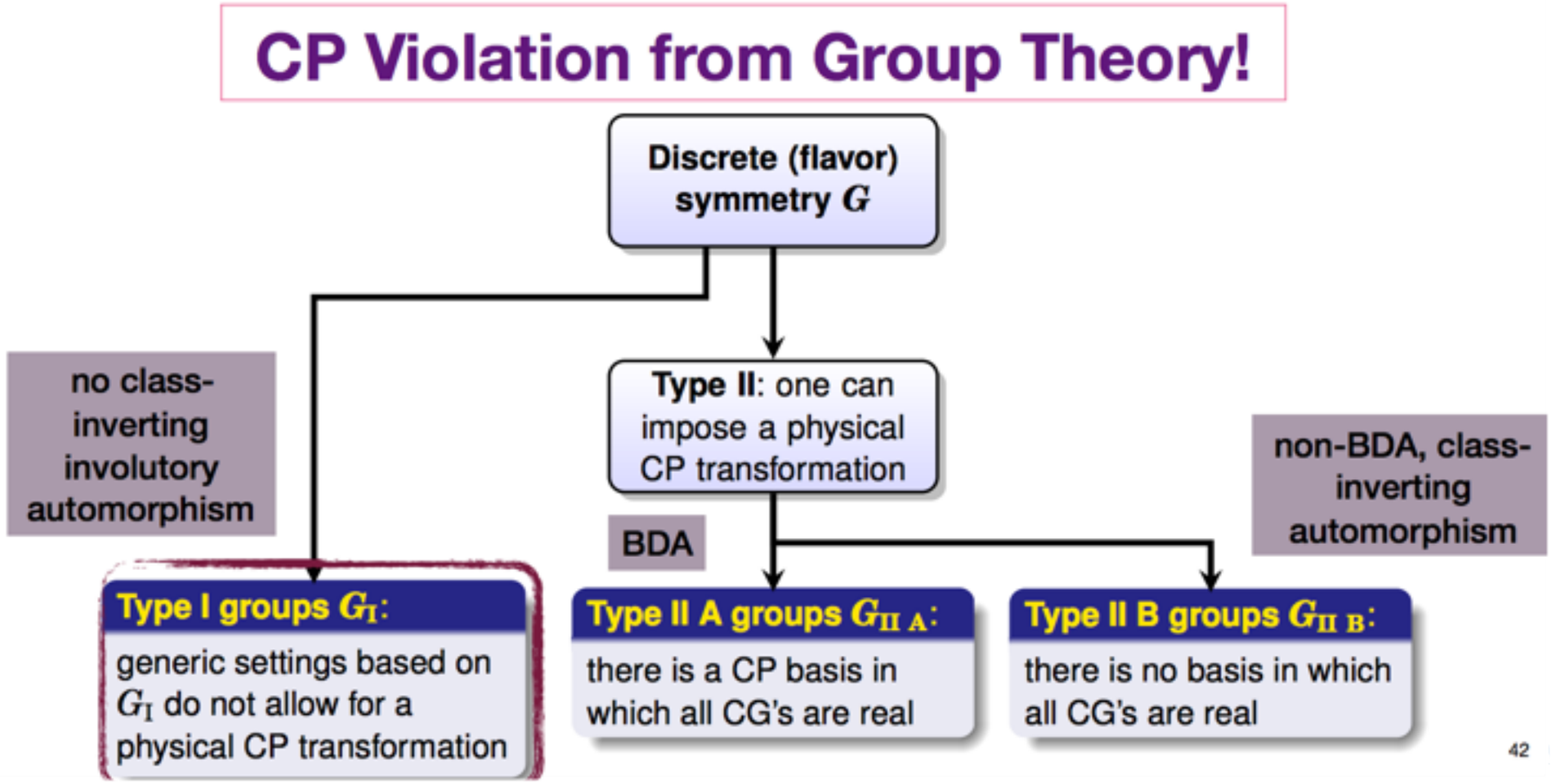




A Novel Origin of CP Violation

M.-C.C, M. Fallbacher, K.T. Mahanthappa, M. Ratz, A. Trautner, NPB (2014)

- **For discrete groups that do not have class-inverting, involutory automorphism, CP is generically broken by complex CG coefficients (Type I Group)**
- **Non-existence of such automorphism ⇔ Physical CP violation**

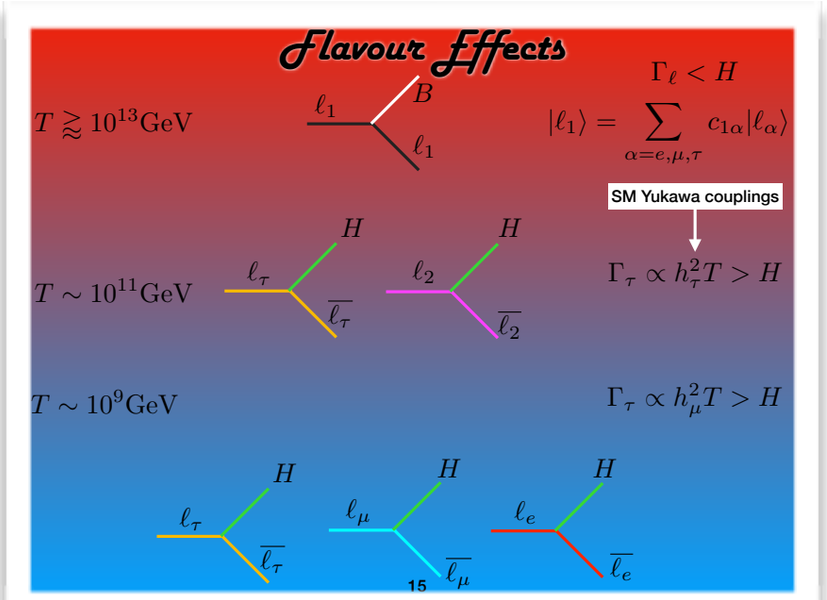


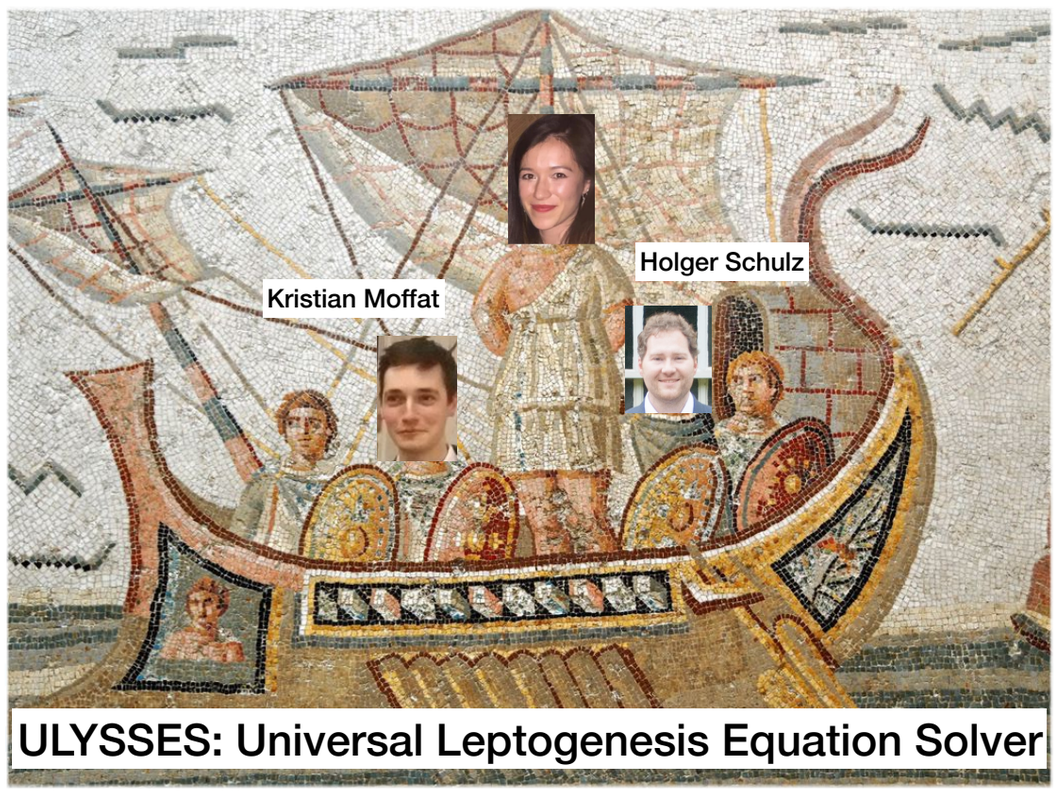
Leptogenesis

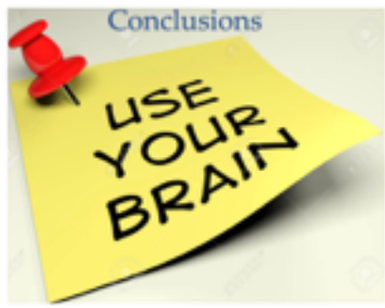
Intermediate Scale Leptogenesis

Leptogenesis via low energy CPV

Mini summary: **non-resonant thermal leptogenesis can explain BAU using only low scale phases at $M_1 \sim 10^6$ GeV**







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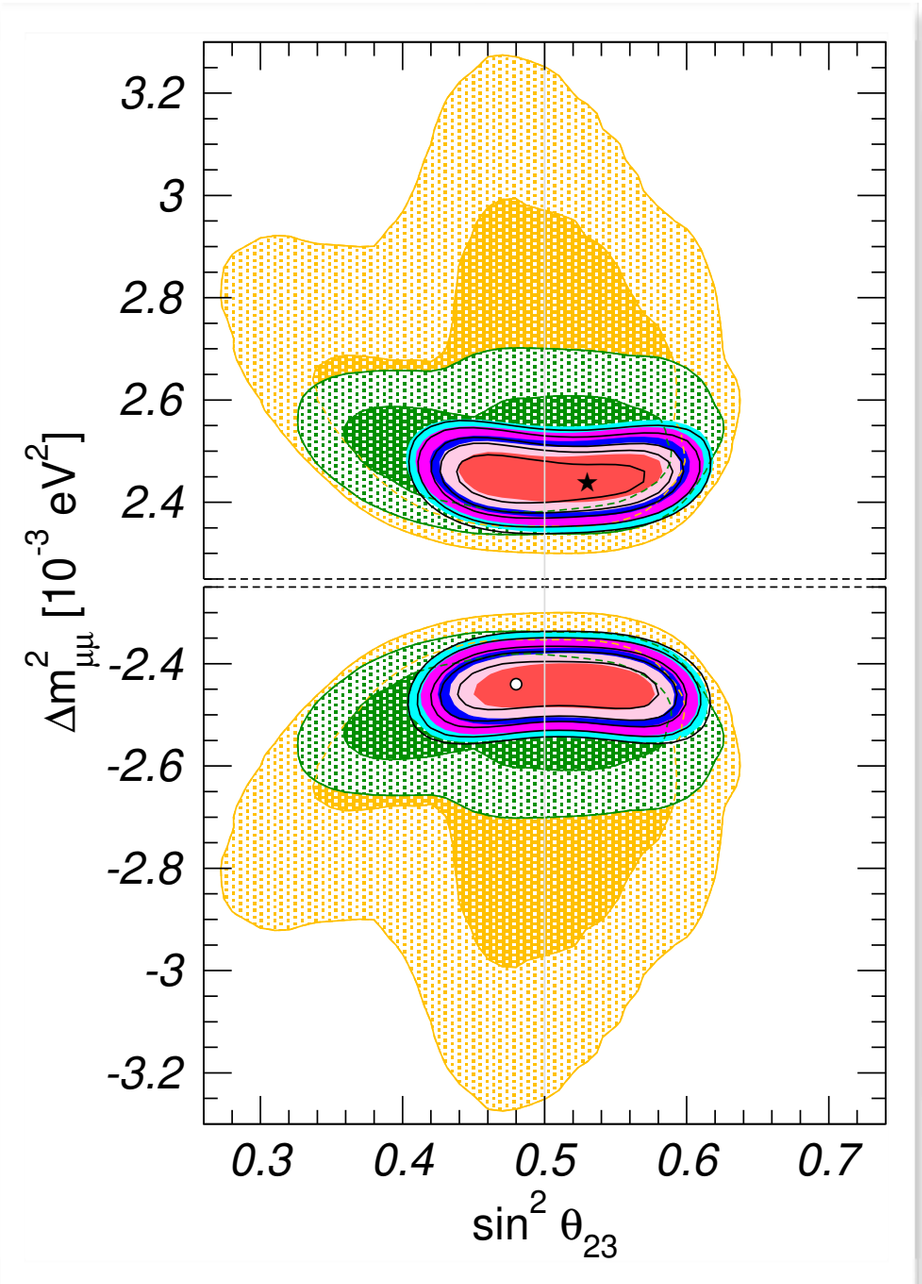
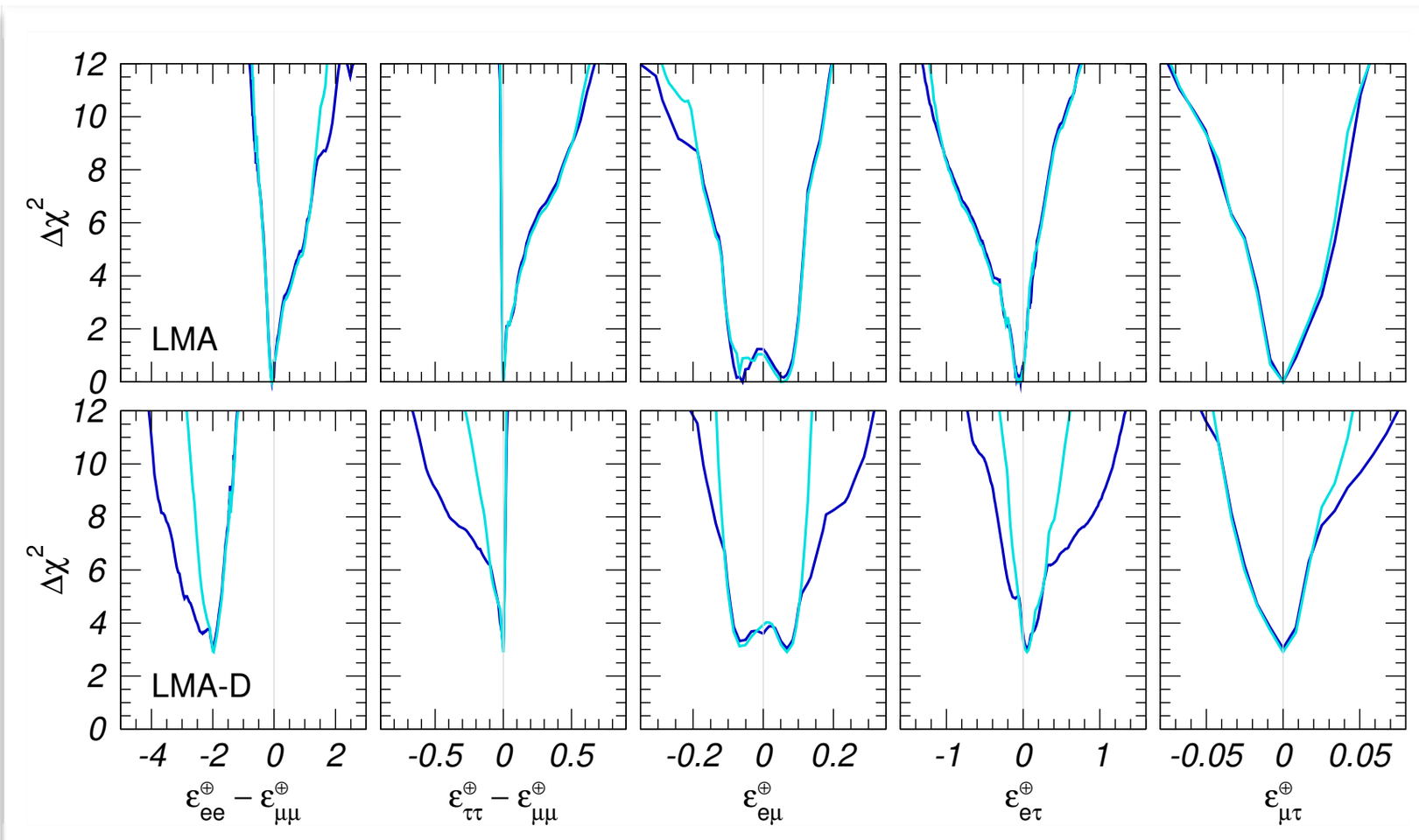
Traditional NSI

Probing new physics

$$V_{mat} = \sqrt{2} G_F N_e(x) \begin{pmatrix} 1+\epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon^*_{e\mu} & \epsilon_{\mu\mu} & \epsilon_{\tau\mu} \\ \epsilon^*_{e\tau} & \epsilon^*_{\mu\tau} & \epsilon_{\tau\tau} \end{pmatrix}$$





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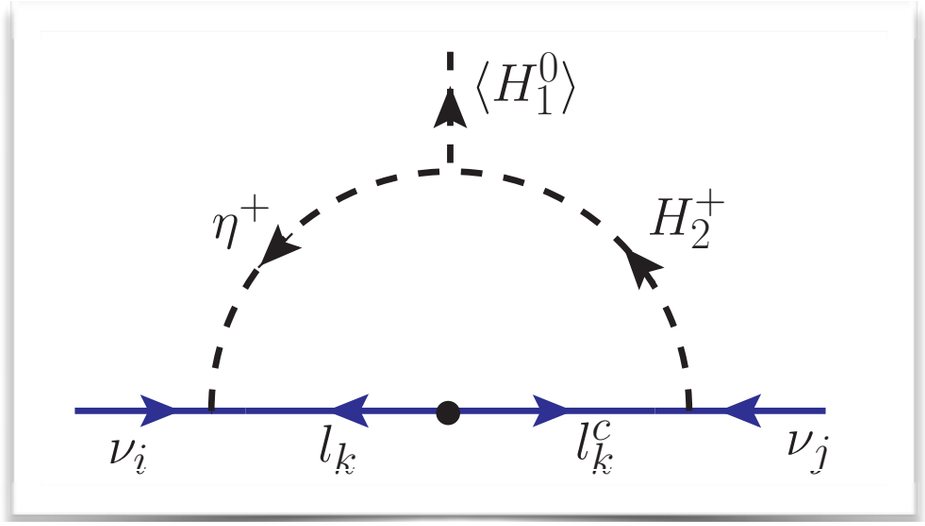
Mass and flavor Traditional NSI

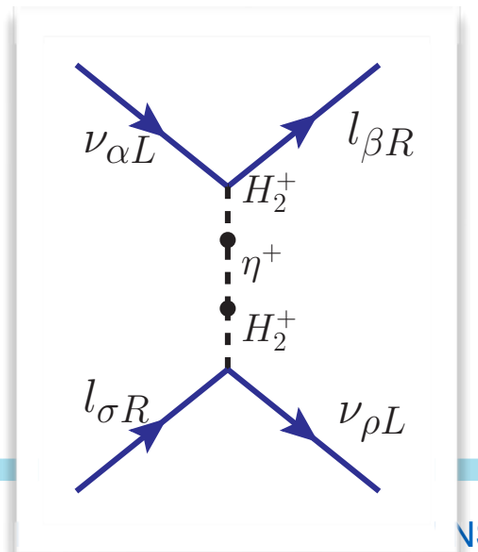


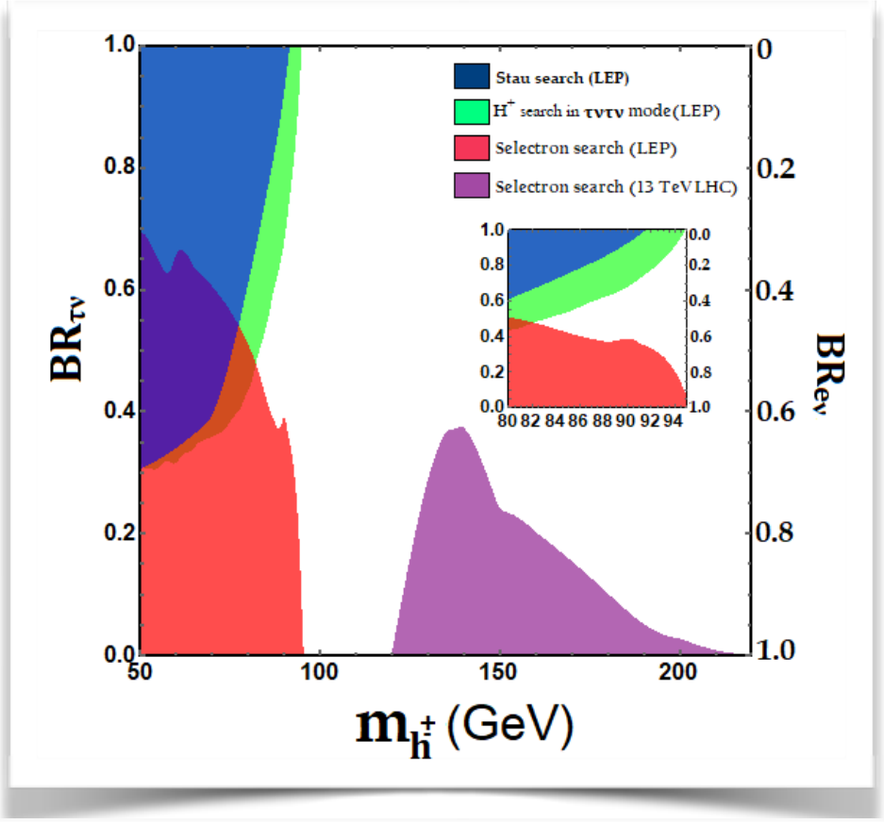
$$\mathcal{L}_Y = f^{ab}(\psi^i_{aL}\, C\, \psi^j_{bL})\, \epsilon_{ij}\, \eta^+ + \overline{\psi}_L \tilde{y} H_1 e_R + \overline{\psi}_L y H_2 e_R + h.c.$$

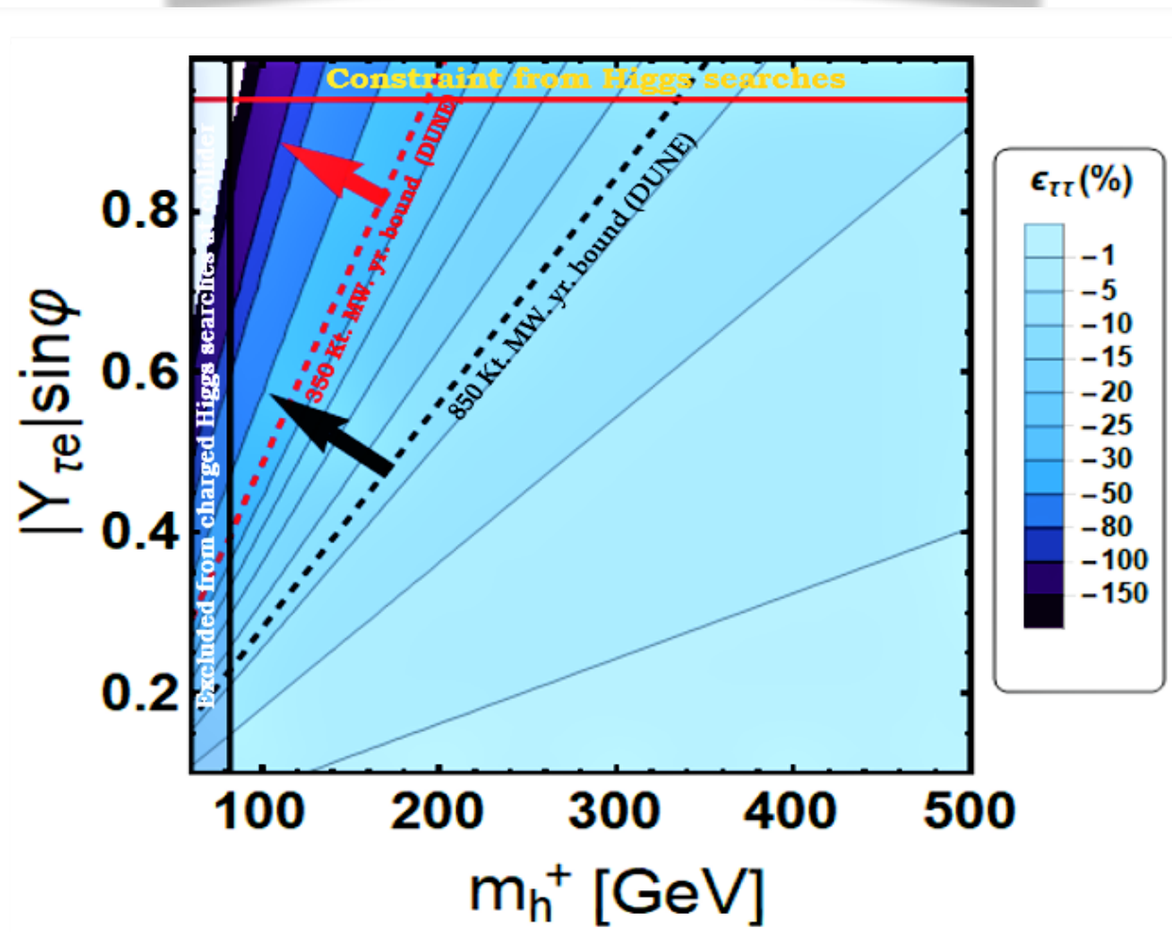
$$V = \mu H_1^i H_2^j \eta^- + h.c. + ...$$

$$y = \begin{pmatrix} y_{ee} & 0 & y_{e\tau} \\ 0 & y_{\mu\mu} & y_{\mu\tau} \\ 0 & 0 & y_{\tau\tau} \end{pmatrix}$$

- The singly-charged scalars η^+ and H_2^+ induce NSI at tree level:

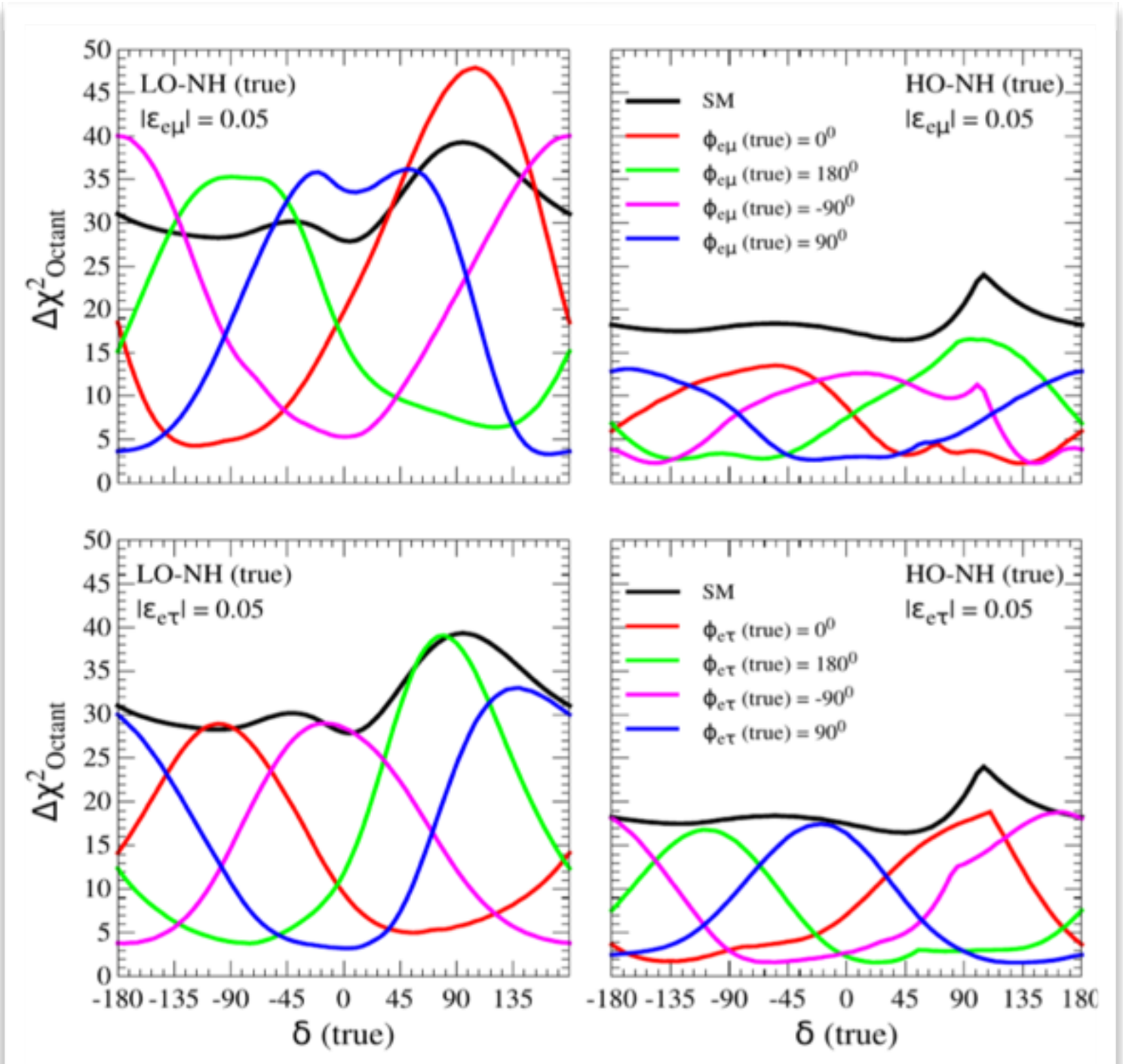






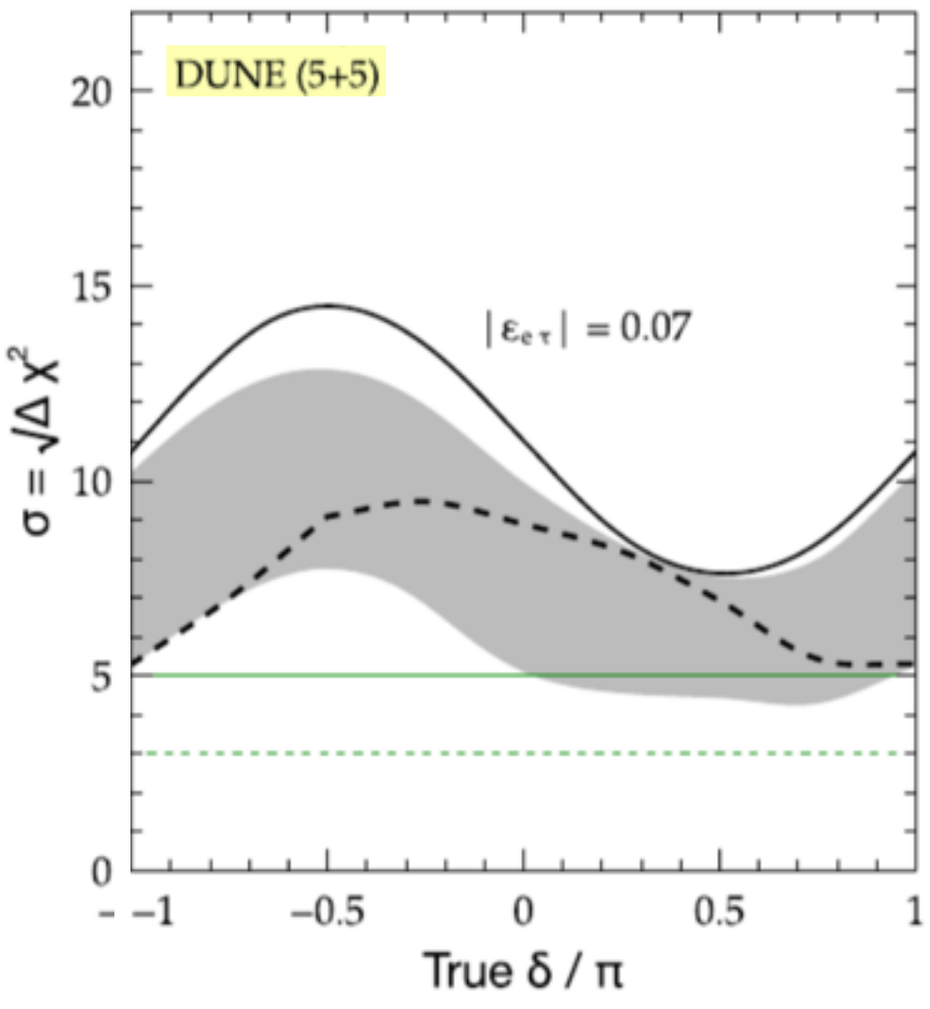
$$\varepsilon^{\max}_{\tau\tau} \approx 150\%$$

Traditional NSI



$$\Delta\chi^2_{\text{octant}} = \chi^2_{\text{test octant}} - \chi^2_{\text{true octant}}$$

Degeneracies



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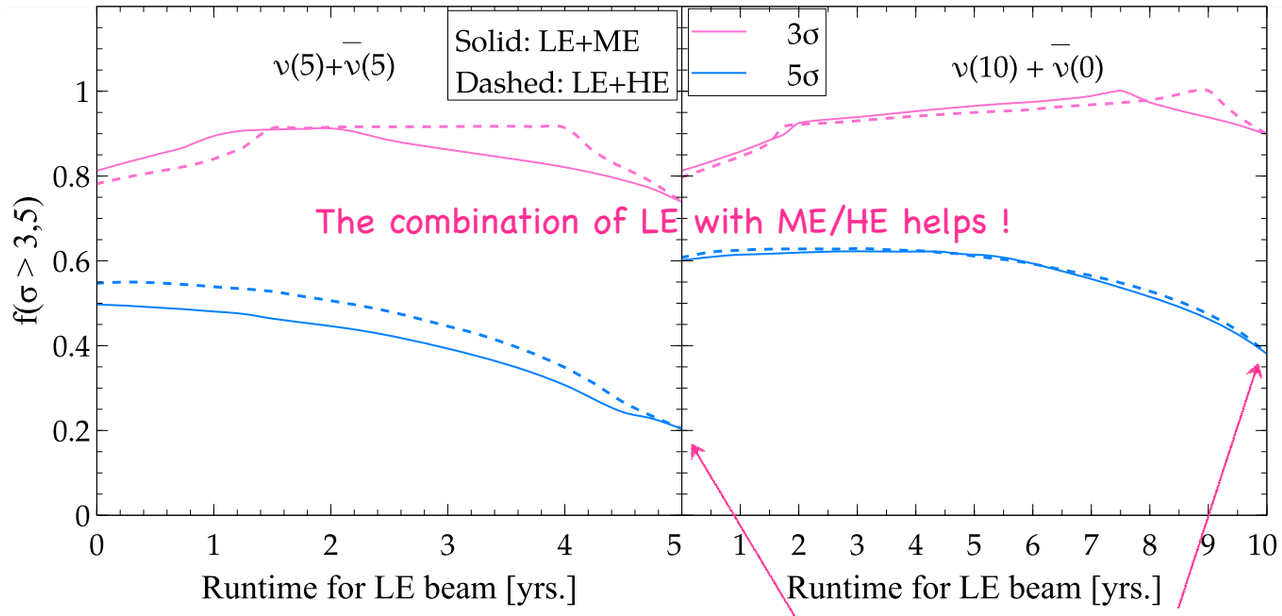
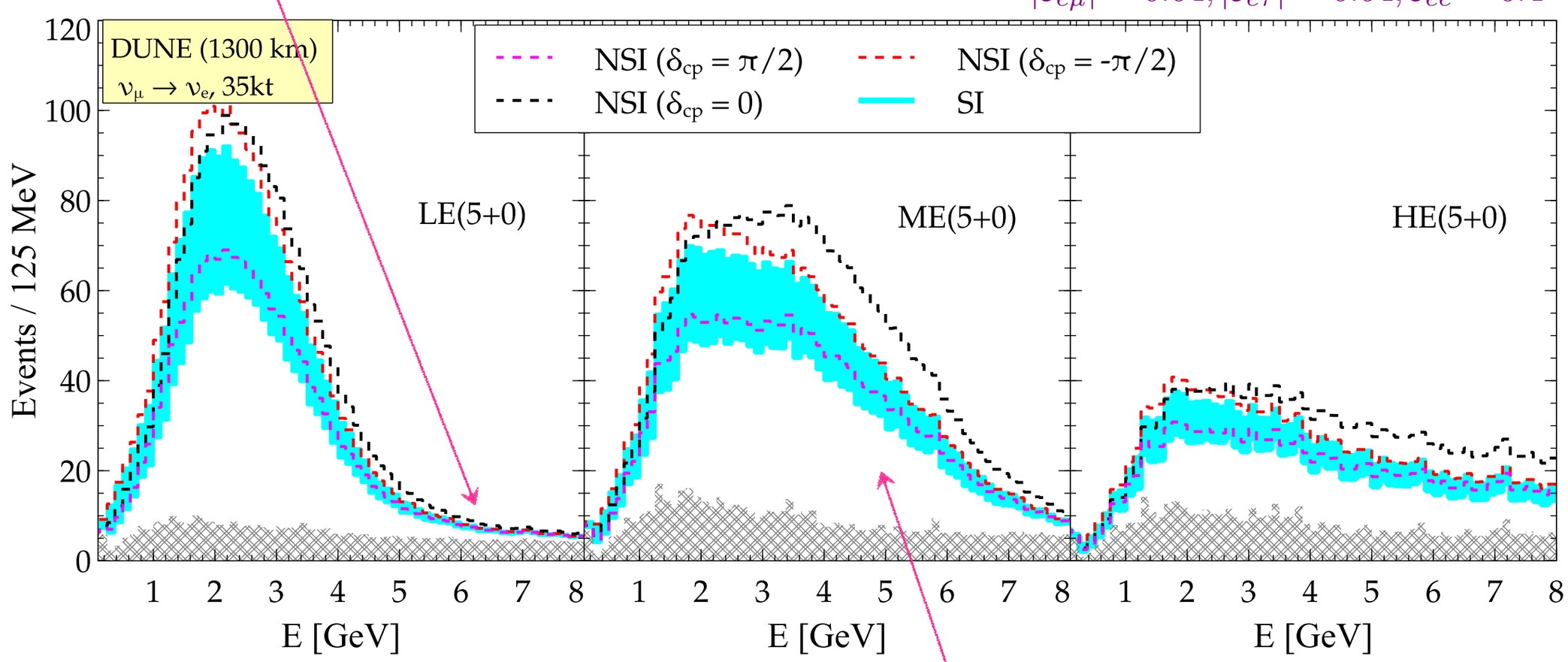
Traditional NSI

III. Can we separate new physics scenarios from the standard ?
IV. Correlations and degeneracies of NSI parameters with high energy beam tunes...



Falling flux kills the large asymmetry at large E

$$|\varepsilon_{e\mu}| = 0.04, |\varepsilon_{e\tau}| = 0.04, \varepsilon_{ee} = 0.4$$



Better ability to separate black curve from cyan band

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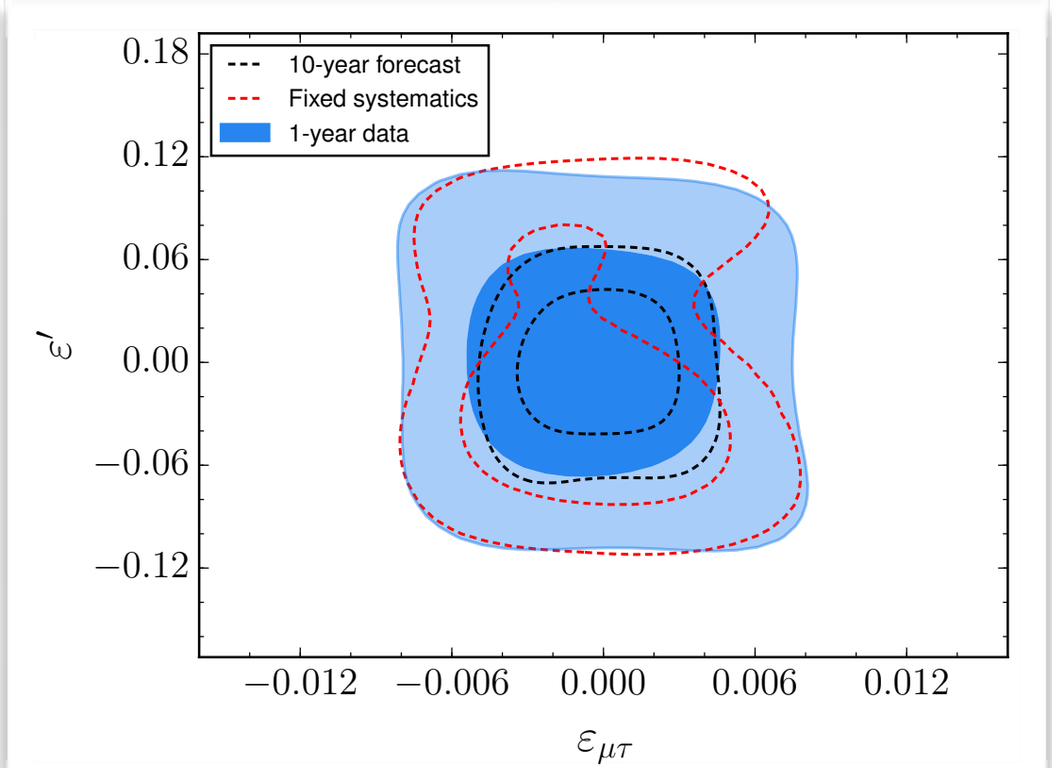
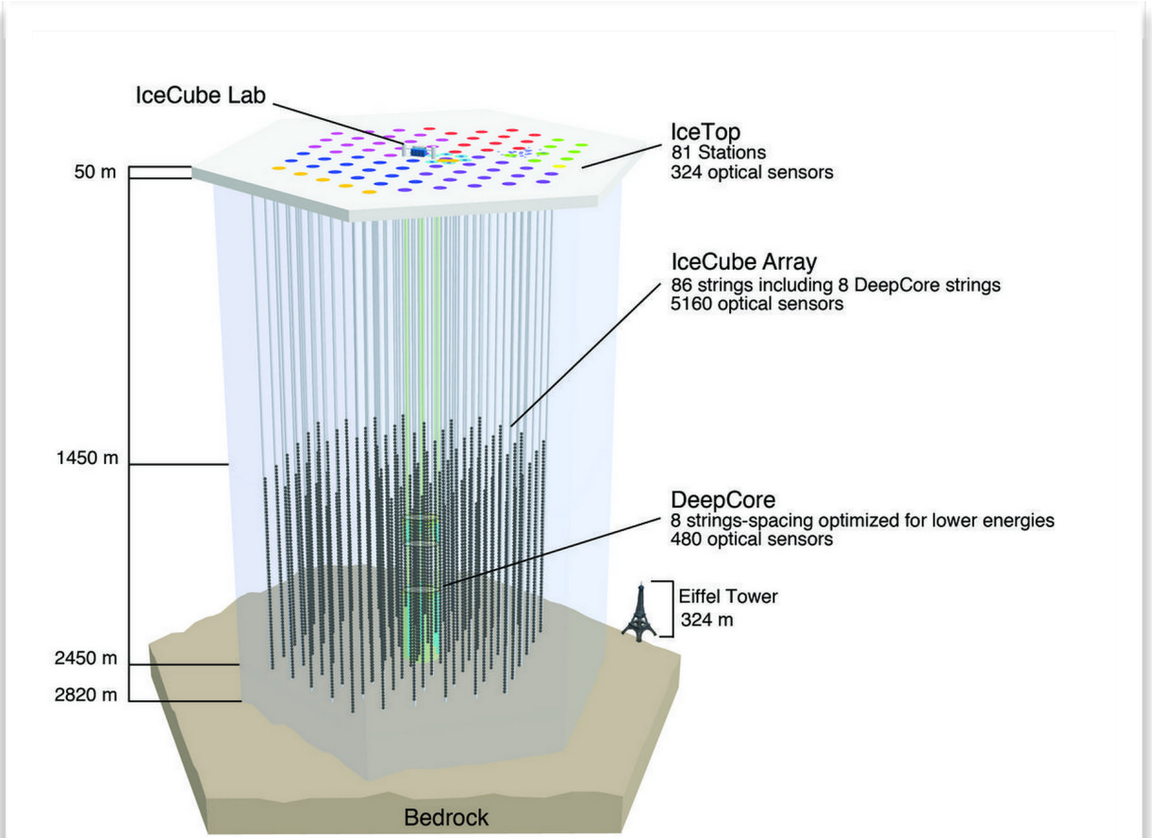
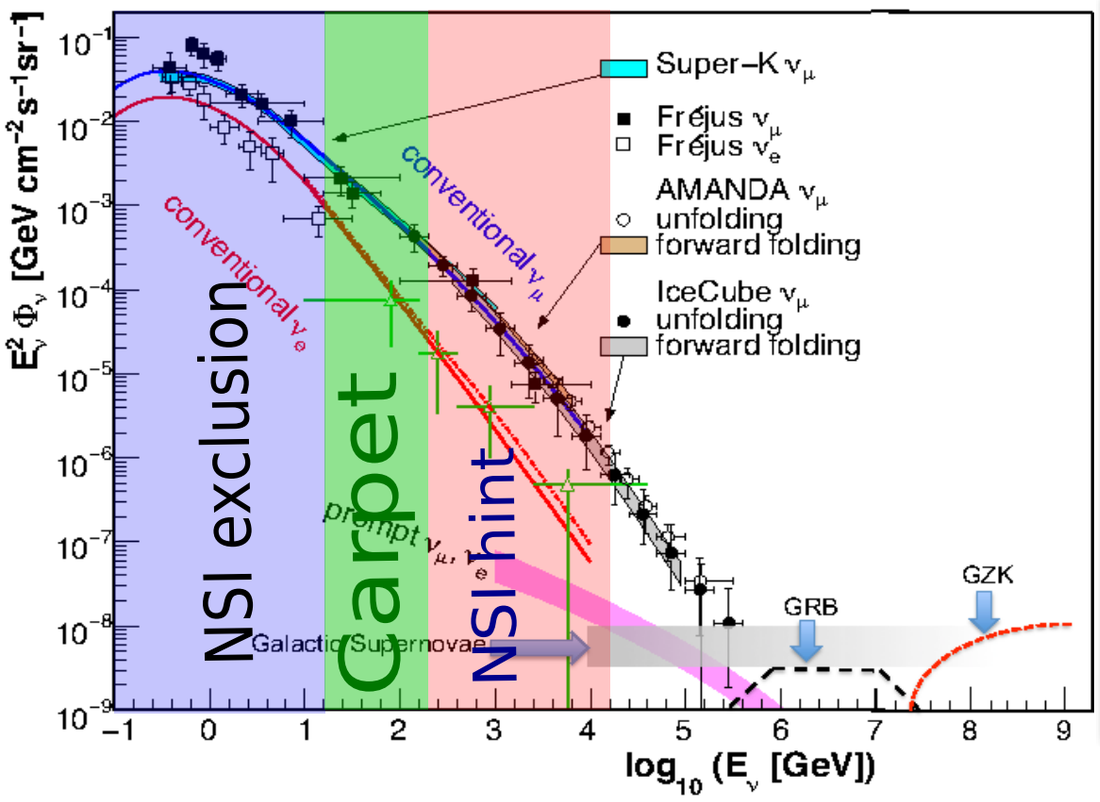
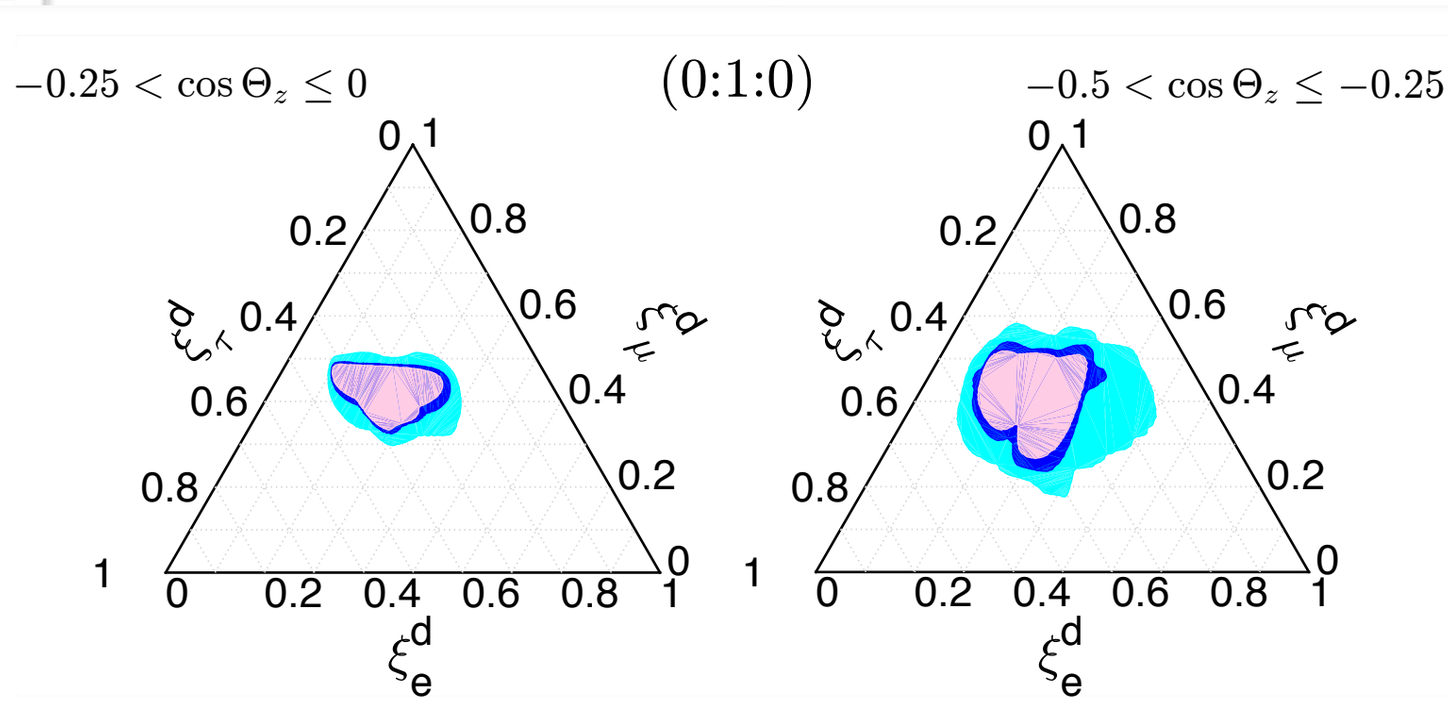
Traditional NSI









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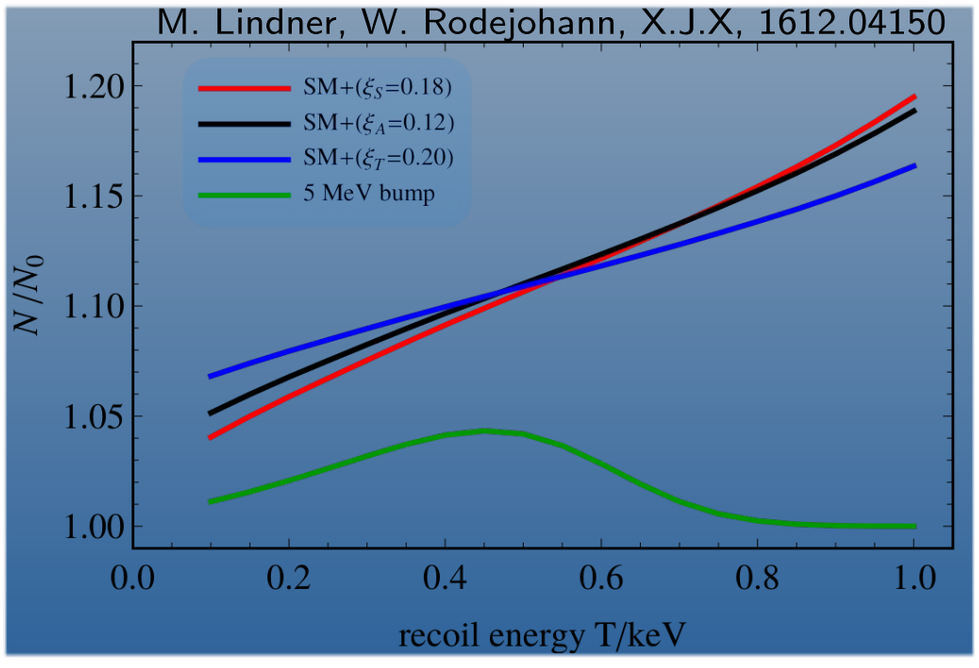
Traditional NSI

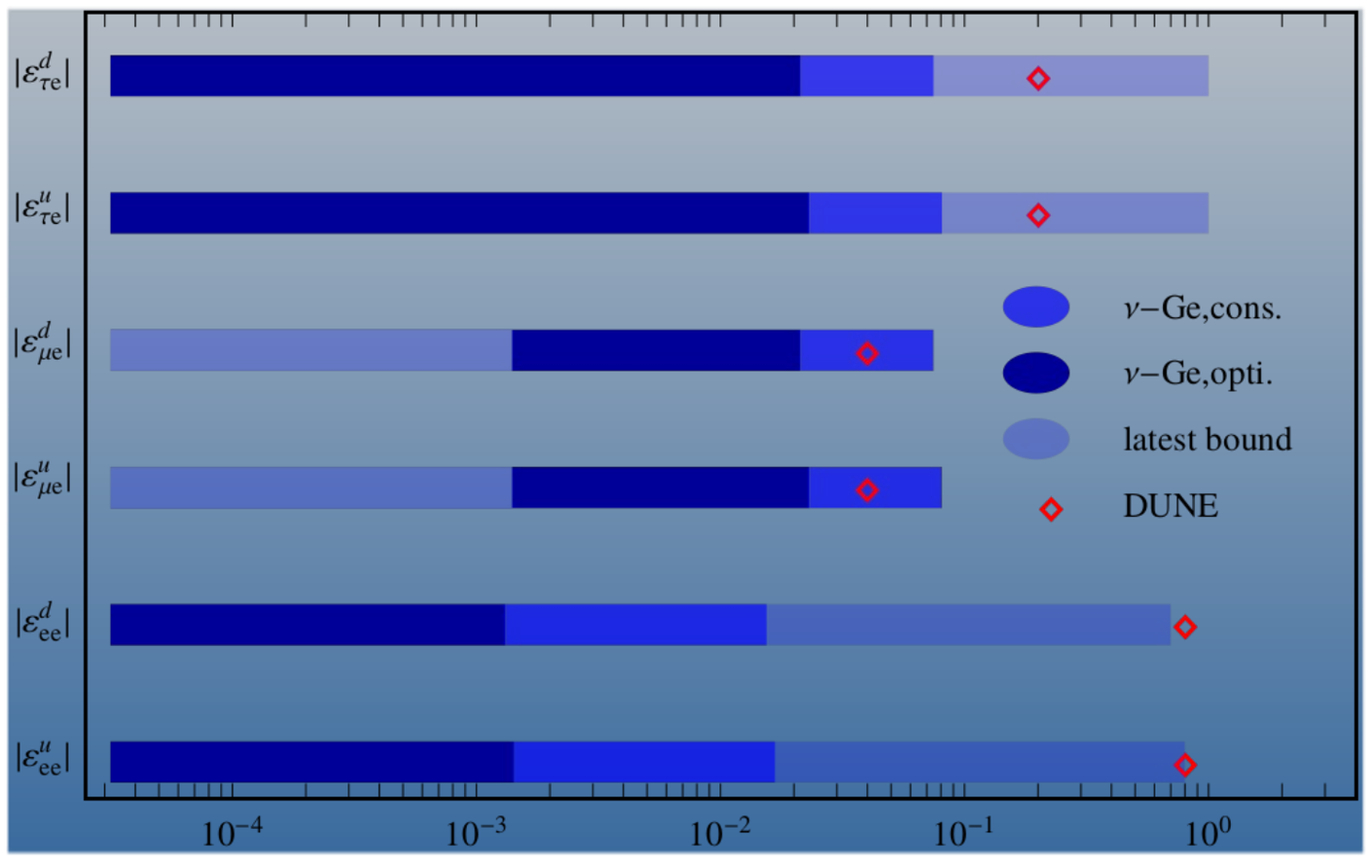
SPVAT (Scalar, Pseudo-S, Vector, Axial-V, Tensor

$$\mathcal{L} \supset \frac{G_F}{\sqrt{2}} \sum_{a=S,P,V,A,T} \overline{\nu}\Gamma^a\nu \left[\overline{\psi}\Gamma^a(C_a + D_a i\gamma^5)\psi\right],$$

$$\Gamma^a = \{1,\, i\gamma^5,\, \gamma^\mu,\, \gamma^\mu\gamma^5,\, \sigma^{\mu\nu} \equiv \frac{i}{2}[\gamma^\mu, \gamma^\nu]\}.$$

Use coherent ν-N scattering





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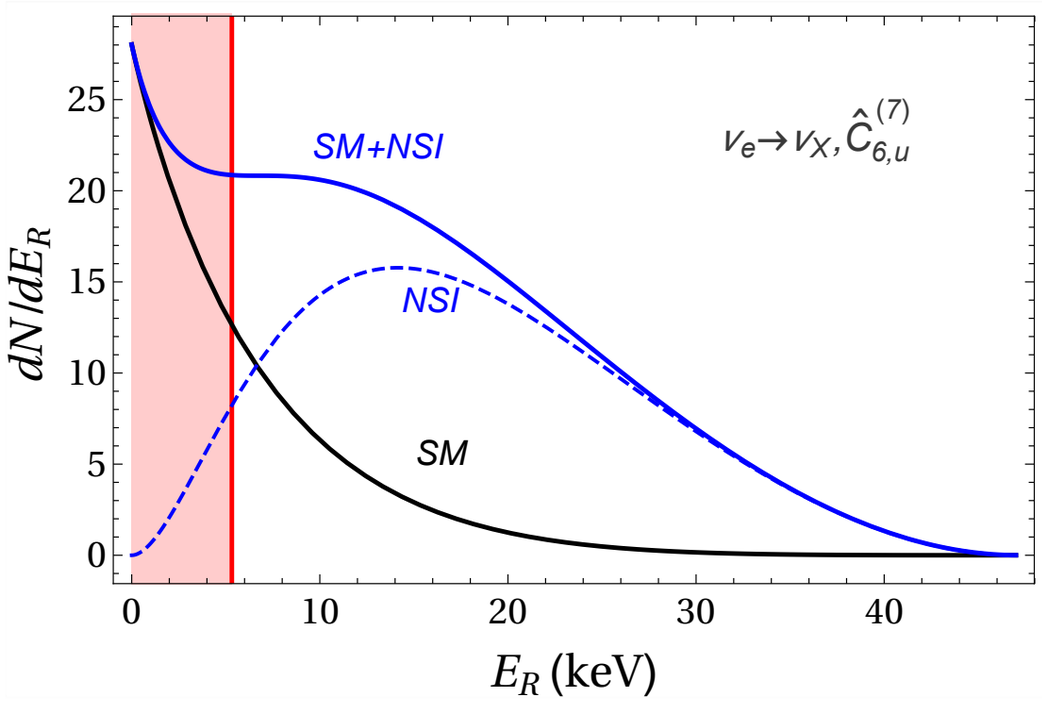
Traditional NSI and more



NSI complete operator basis

3 - Flavors basis ($\mu \sim 2$ GeV): $f = e, \mu, u, d, s$

Dimension five:

$$\mathcal{Q}_1^{(5)} = \frac{e}{8\pi^2}(\bar{\nu}_\beta \sigma^{\mu\nu} P_L \nu_\alpha) F_{\mu\nu}\,,$$

Dimension six:

$$\mathcal{Q}_{1,f}^{(6)} = (\bar{\nu}_\beta \gamma_\mu P_L \nu_\alpha)(\bar{f}\gamma^\mu f), \qquad \mathcal{Q}_{2,f}^{(6)} = (\bar{\nu}_\beta \gamma_\mu P_L \nu_\alpha)(\bar{f}\gamma^\mu \gamma_5 f)\,,$$

Dimension seven:

$$\mathcal{Q}_1^{(7)} = \frac{\alpha}{12\pi}(\bar{\nu}_\beta P_L \nu_\alpha) F^{\mu\nu} F_{\mu\nu}, \qquad \mathcal{Q}_2^{(7)} = \frac{\alpha}{8\pi}(\bar{\nu}_\beta P_L \nu_\alpha) F^{\mu\nu} \widetilde{F}_{\mu\nu},$$

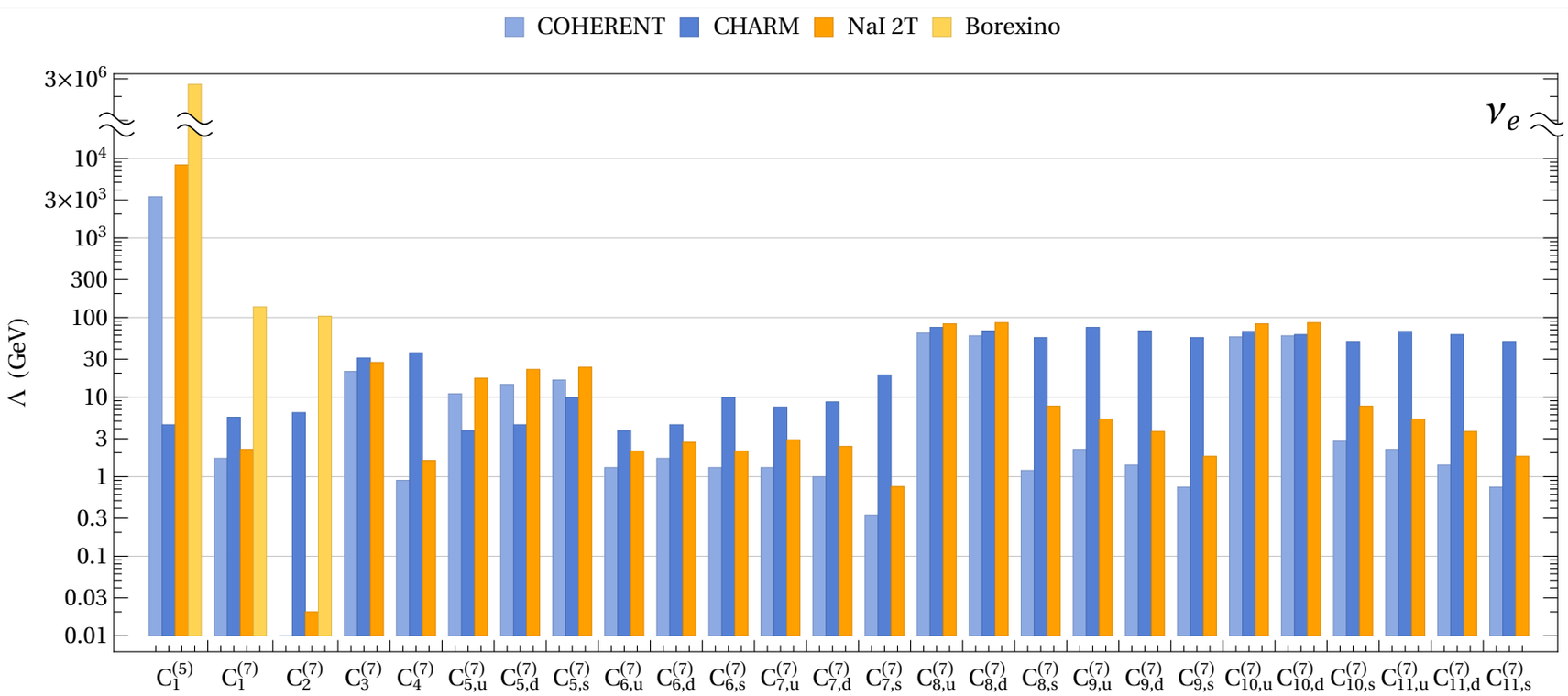
$$\mathcal{Q}_3^{(7)} = \frac{\alpha_s}{12\pi}(\bar{\nu}_\beta P_L \nu_\alpha) G^{a\mu\nu} G^a_{\mu\nu}, \qquad \mathcal{Q}_4^{(7)} = \frac{\alpha_s}{8\pi}(\bar{\nu}_\beta P_L \nu_\alpha) G^{a\mu\nu} \widetilde{G}^a_{\mu\nu}\,,$$

$$\mathcal{Q}_{5,f}^{(7)} = m_f(\bar{\nu}_\beta P_L \nu_\alpha)(\bar{f} f)\,, \qquad \mathcal{Q}_{6,f}^{(7)} = m_f(\bar{\nu}_\beta P_L \nu_\alpha)(\bar{f} i\gamma_5 f)\,,$$

$$\mathcal{Q}_{7,f}^{(7)} = m_f(\bar{\nu}_\beta \sigma^{\mu\nu} P_L \nu_\alpha)(\bar{f}\sigma_{\mu\nu} f)\,, \qquad \mathcal{Q}_{8,f}^{(7)} = (\bar{\nu}_\beta i\overleftrightarrow{\partial}_\mu P_L \nu_\alpha)(\bar{f}\gamma^\mu f)\,,$$

$$\mathcal{Q}_{9,f}^{(7)} = (\bar{\nu}_\beta i\overleftrightarrow{\partial}_\mu P_L \nu_\alpha)(\bar{f}\gamma^\mu \gamma_5 f)\,, \qquad \mathcal{Q}_{10,f}^{(7)} = \partial_\mu(\bar{\nu}_\beta \sigma^{\mu\nu} P_L \nu_\alpha)(\bar{f}\gamma_\nu f)\,,$$

$$\mathcal{Q}_{11,f}^{(7)} = \partial_\mu(\bar{\nu}_\beta \sigma^{\mu\nu} P_L \nu_\alpha)(\bar{f}\gamma_\nu \gamma_5 f)\,.$$



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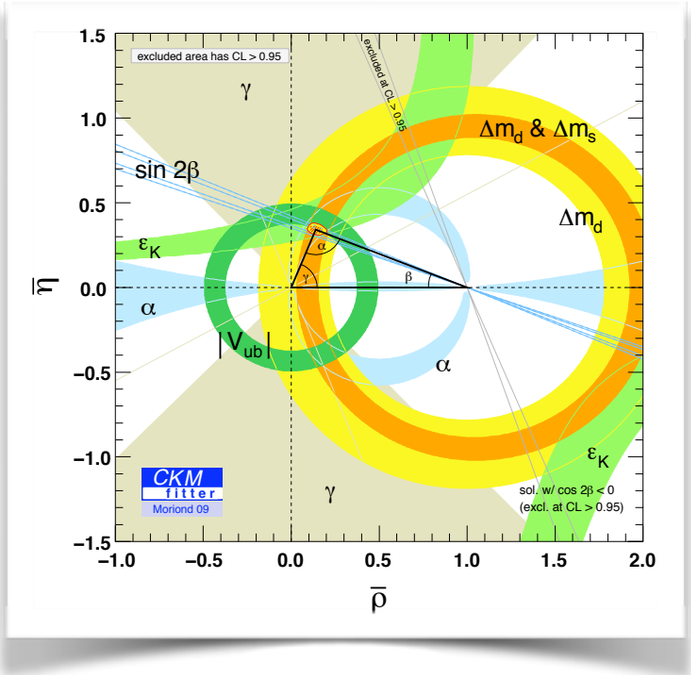
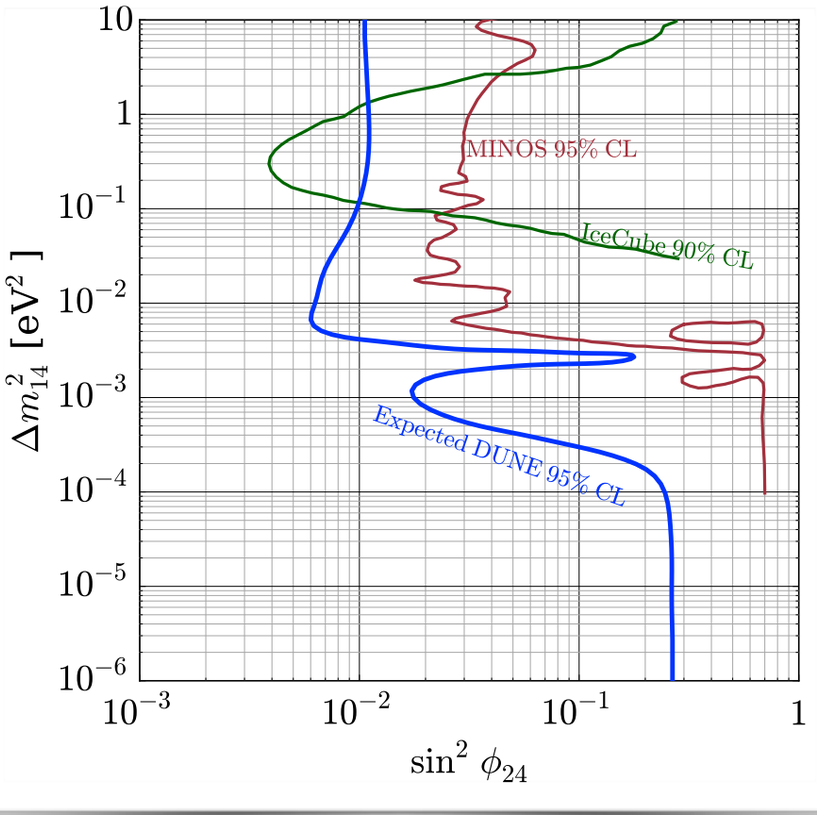
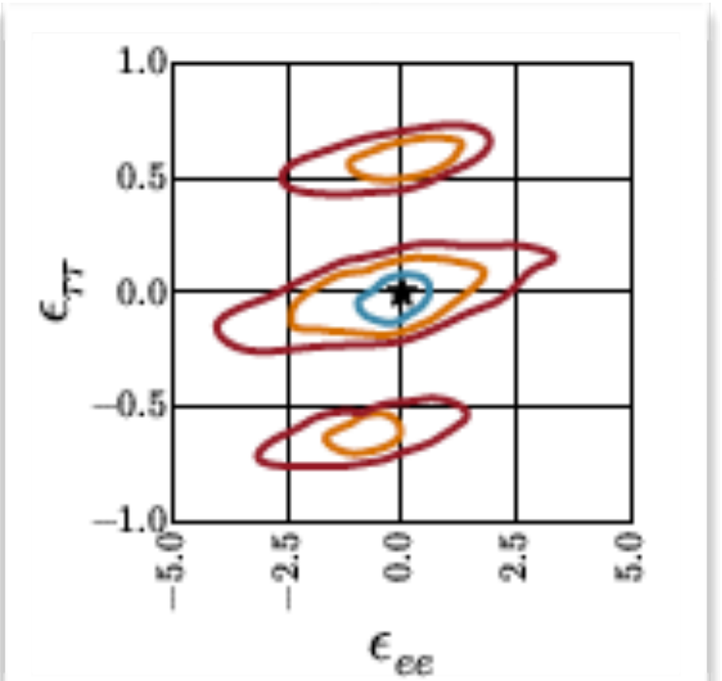
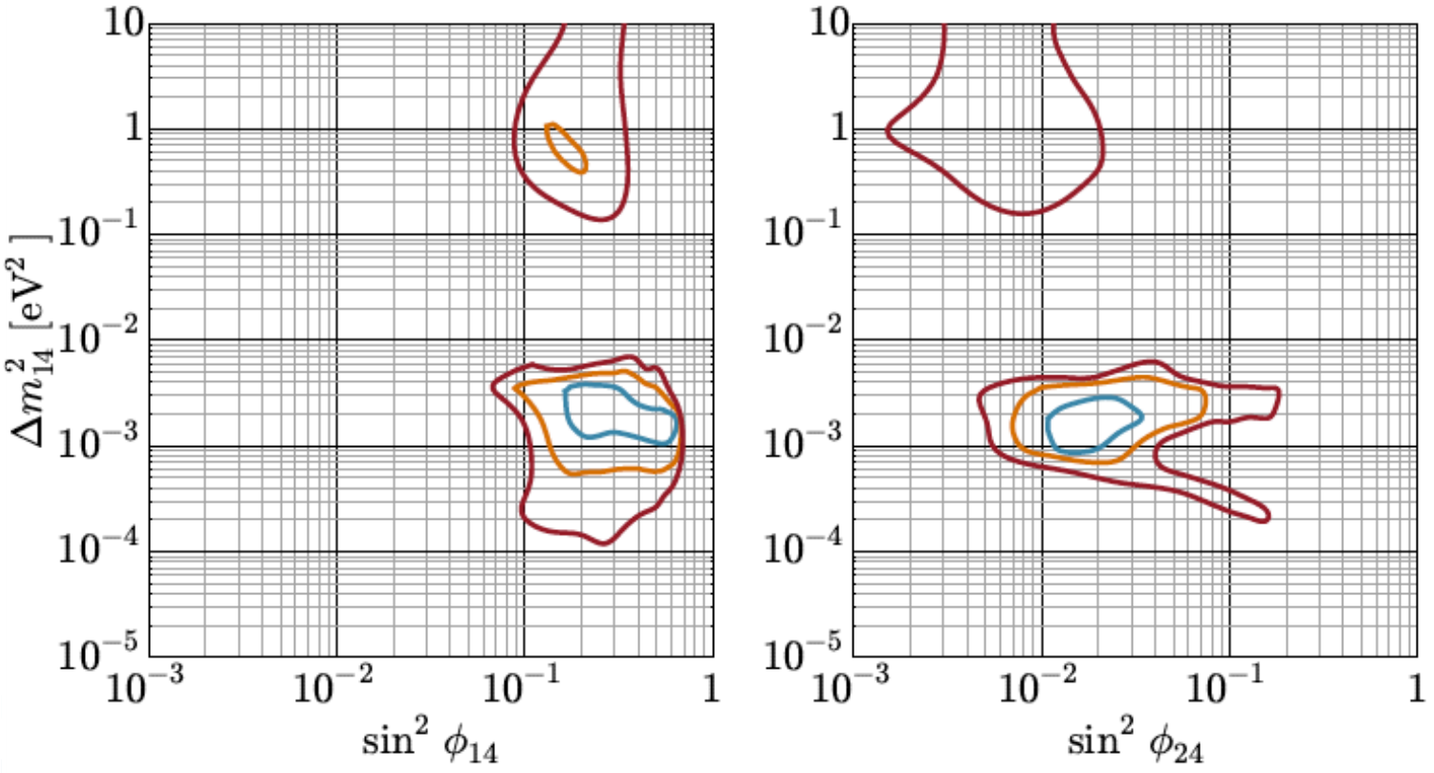
Traditional NSI and more

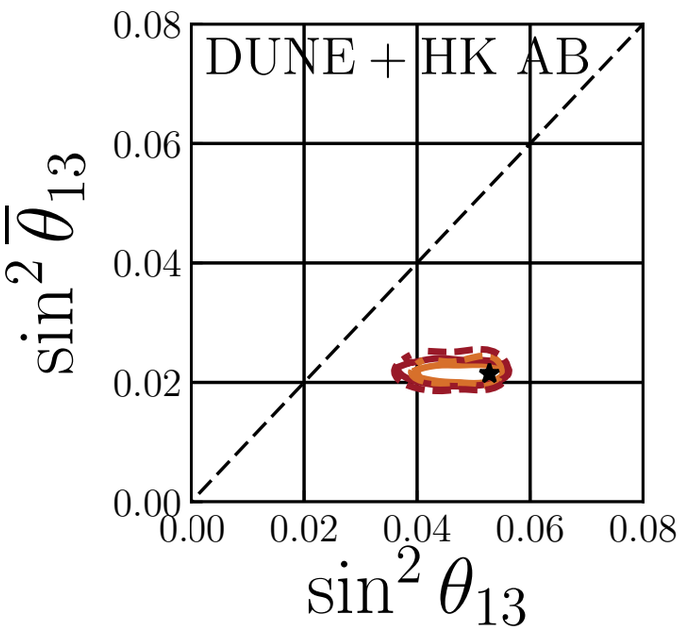






Telling Different Scenarios Apart:





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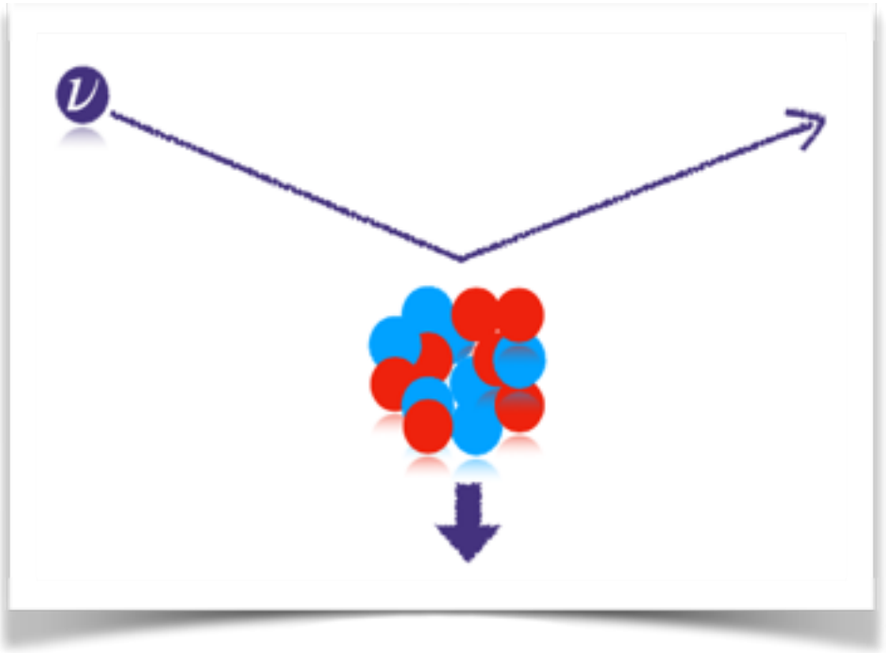
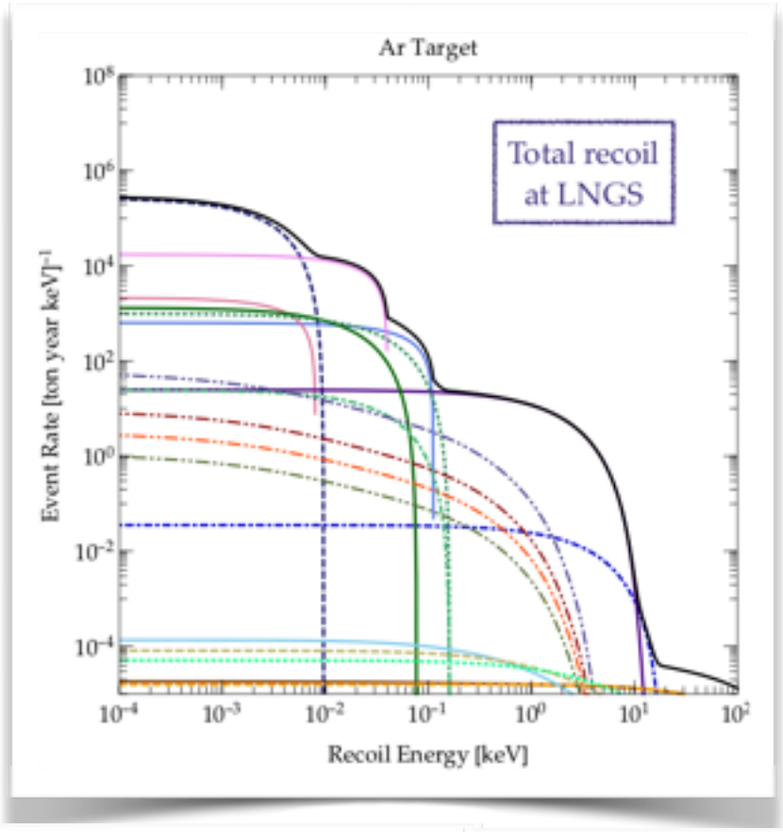
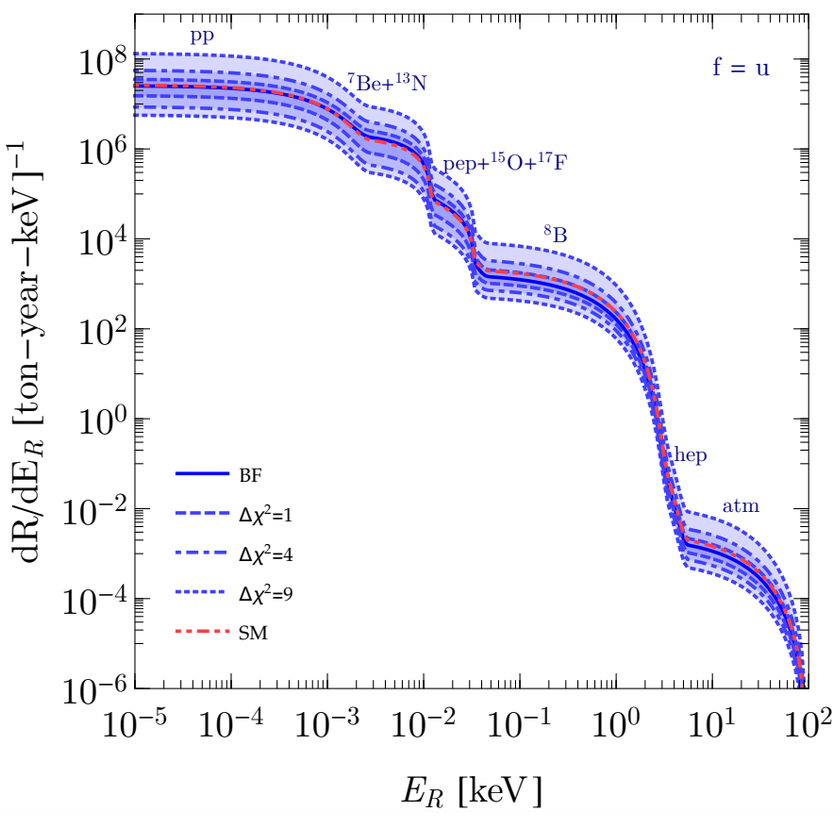
Dark matter **Traditional NSI**

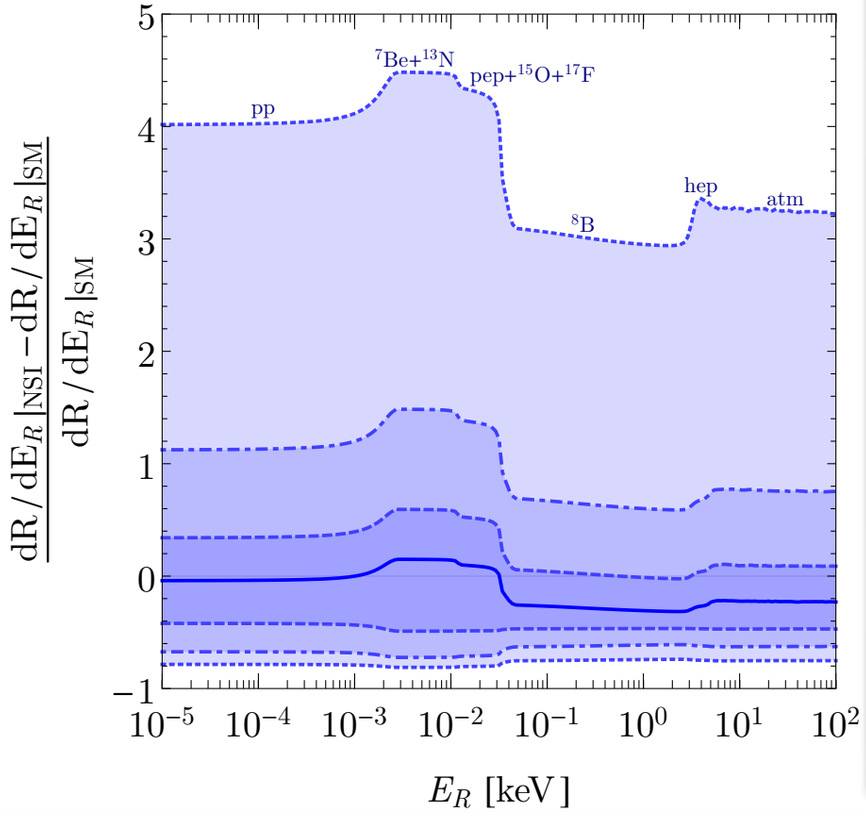




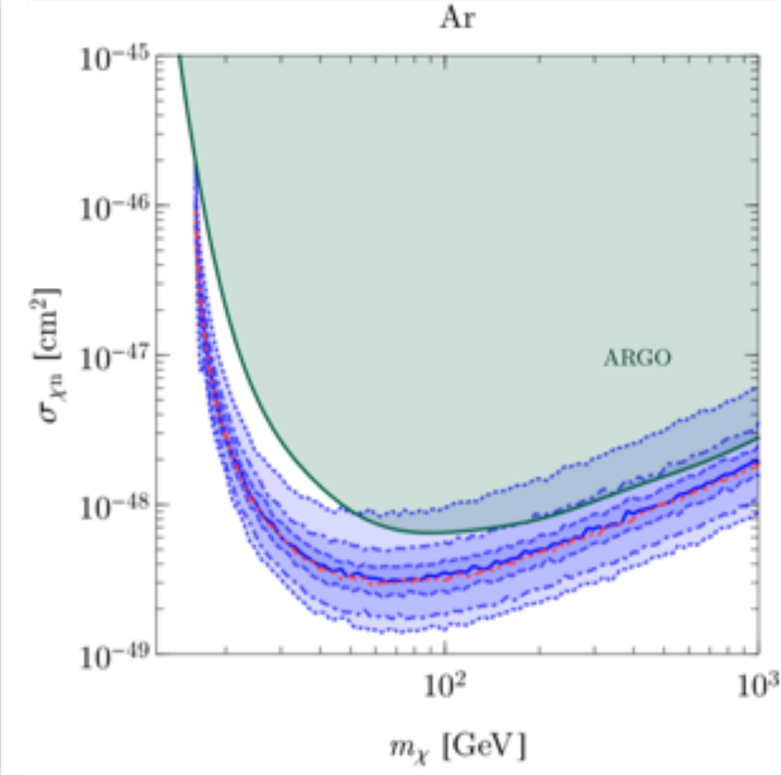
Xe



Xe



Ar



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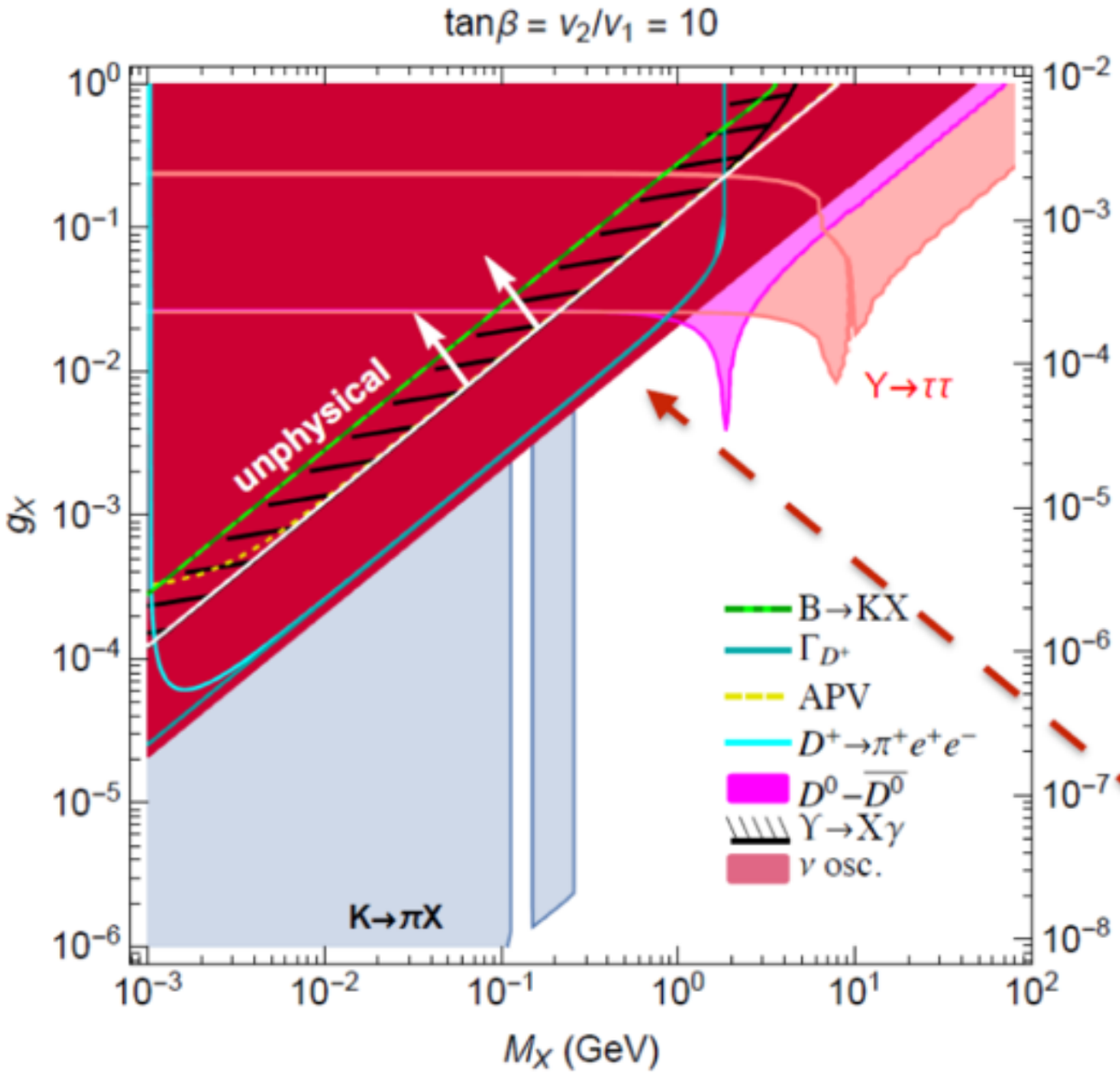
Light mediators

B-L for the 3rd generation

Neutrinos and low scale new Physics

Can there be a flavor mediators at low scale???



U(1) B – L of the third family

Complete model, including scalar sector and CKM generation

Vast phenomenology:
Z-X mixing (s_X)
D oscillations
Atomic Parity Violation
Upsilon, B, D, and K decays
Higgs, top, Z, and W decays
Neutrino oscillations
…

Babu Friedland Machado Mocioiu 1705.01822

Light mediators

UV complete models

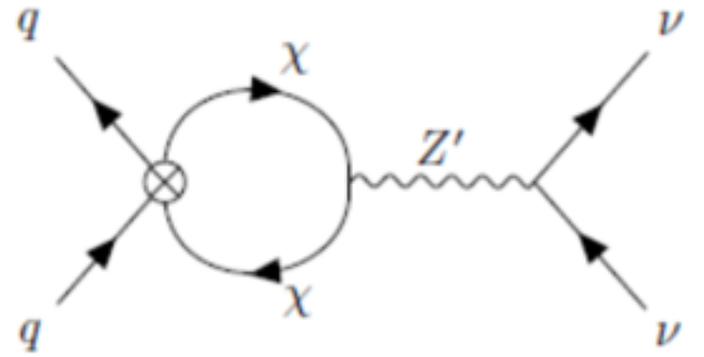
$$DM{:}SU(2)_L \times U(1)_Y \times U(1)_{T3R}$$

Anomaly free

field	q_{T3R}
q_R^u	-2
q_R^d	2
ℓ_R	2
ν_R	-2
η_L	1
η_R	-1
ϕ	-2

New form factors

Datta, Duraisamy, Ghosh'13,
Datta, Kumar, Liao, Marfatia, '17
Elor, Liu, Slatyer, Soreq, '18



New DM phenomenology

Migdal effect (Ionization and excitation of electron)

Ibe, Nakano, Shoji, Sujuki, 2018
Dolan, Kahlhoefer, McCabe, 2018

Cosmic ray scattered

Bringmann, Pospelov, 2018

Ema, Sala, Sato, 2018

Dent, Dutta, Newstead, Shoemaker, to appear

1. Flavor Puzzle is a much^{n} harder problem

→ Scale and couplings wide open in theory space.

Will search for ANYTHING

new states of mass M, new couplings/mixings k, V_{ij} …

Will search EVERY WHERE

low-energy & high-energy regimes.

	$0\nu2\beta$	μ-e conversion $\mu \to e\gamma$ etc.	rare decays τ, K, D, B	colliders e^+e^-, pp	features
Type-I	√	√	√	√	N
Type-II	√	√	√	√	$H^{\pm\pm}$, $W_R^{\pm}$
Type-III	√	√	?	√	$T^{\pm}$
Zee-Babu	?	√	?	√	$k^{\pm\pm}$, $h^{\pm}$
Ma models	?	√	?	√	scalars, DM
RPV/leptoquarks	?	√	√	√	ℓ_q
extra-dim	?	?	√	√	KK states
Inverse/linear	?	?	√	√	
Pseudo Dirac	?	?	√	√	
NSI	?	?	?	√	mediators
… …					

It is of fundamental importance to test the Majorana nature of ν's.

IF lucky, hadron colliders may serve

as the discovery machine for Majorana nature of ν's.

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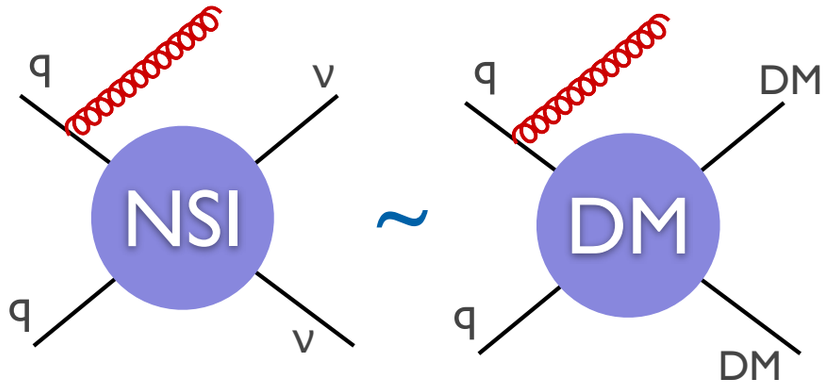
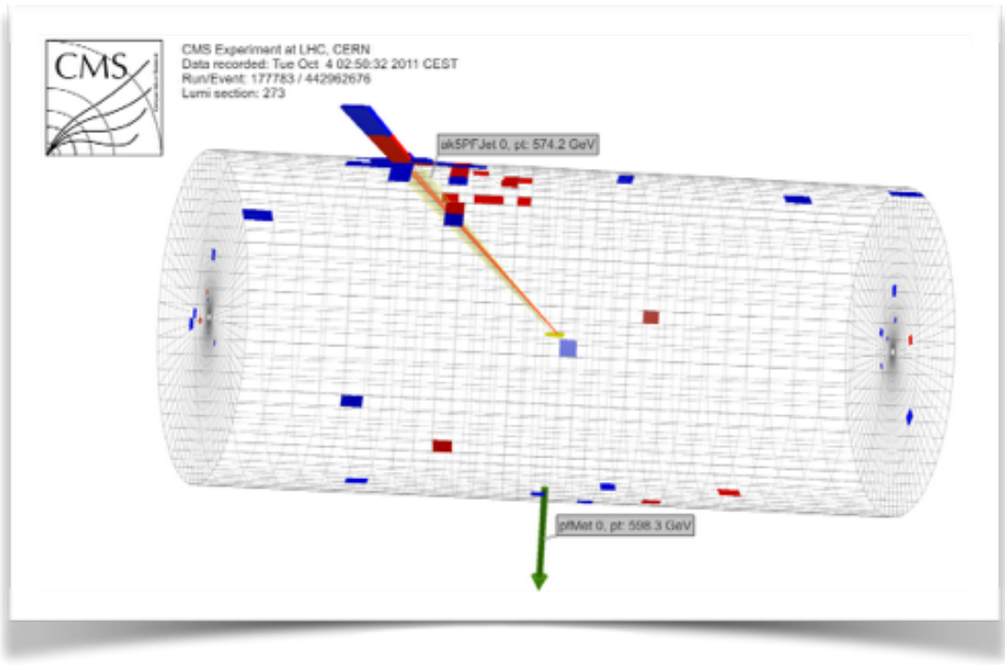
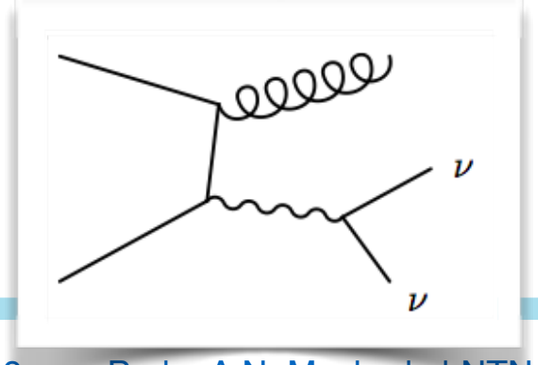
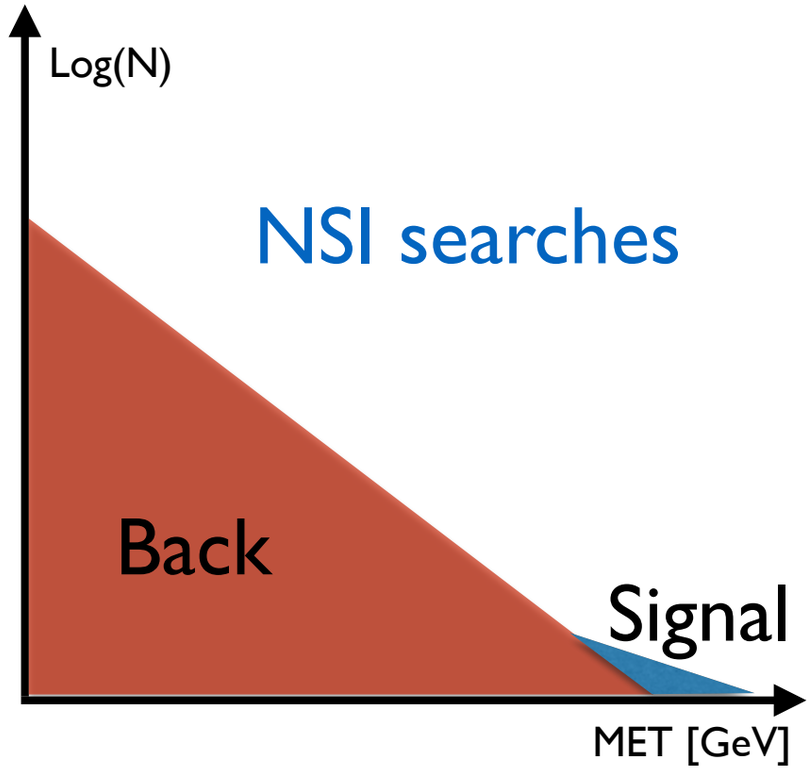
Colliders



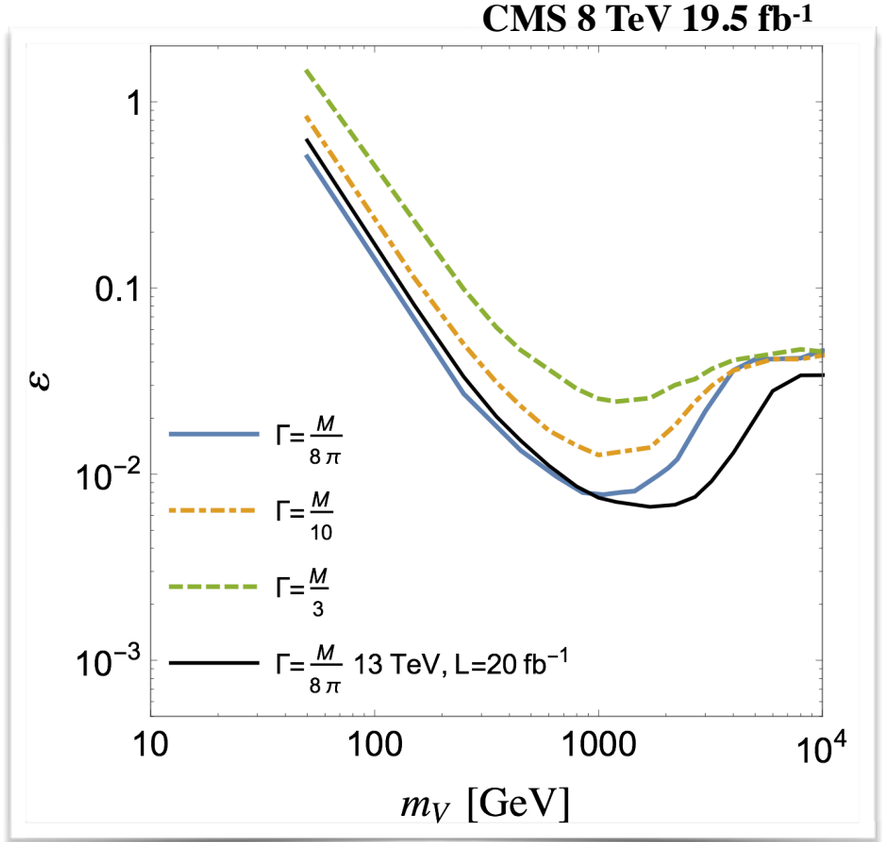


EFT vs simplified models?





Systematic uncertainties are dominant



Diogo, Frandsen, Shoemaker '15

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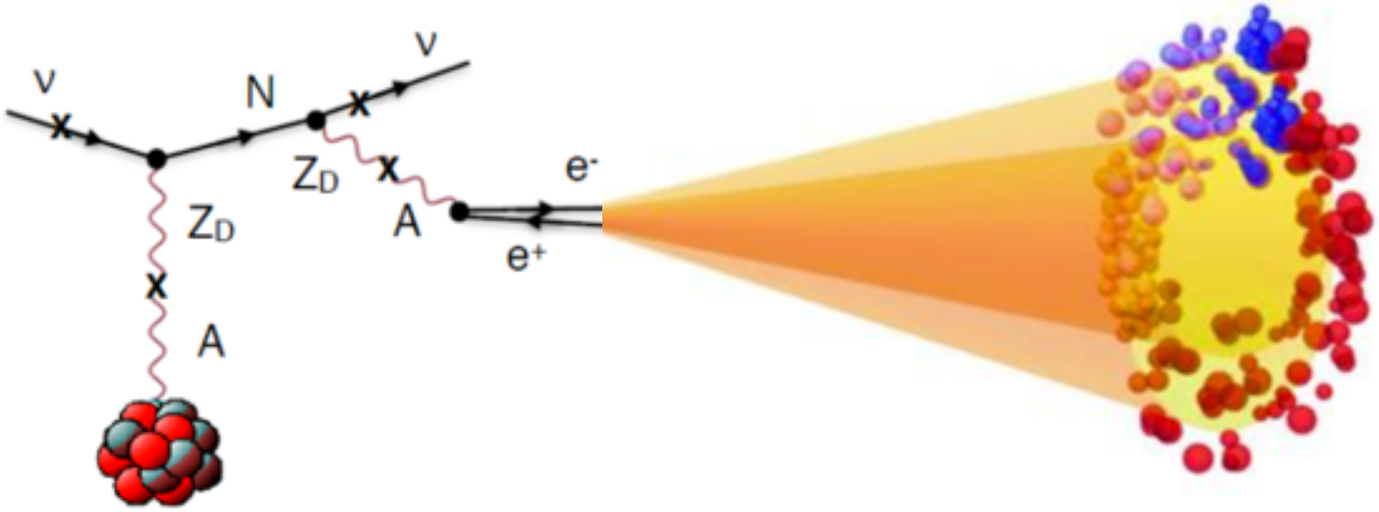
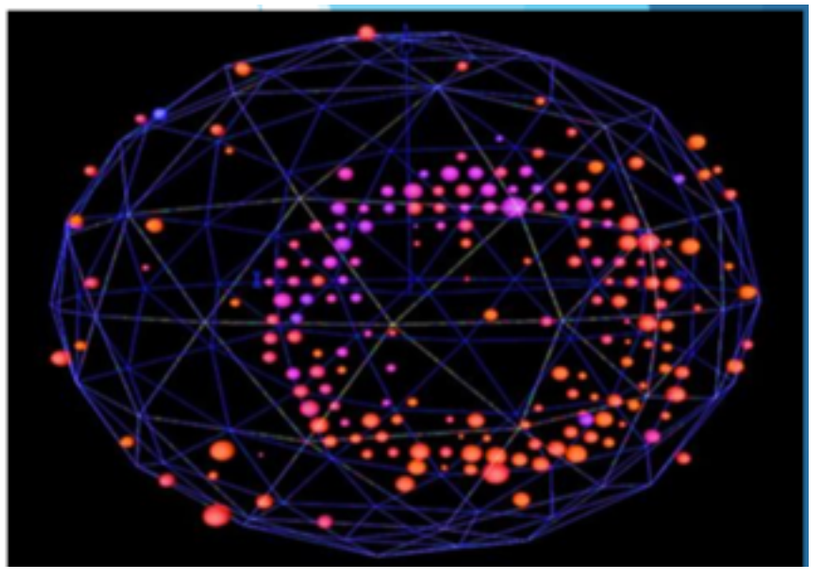
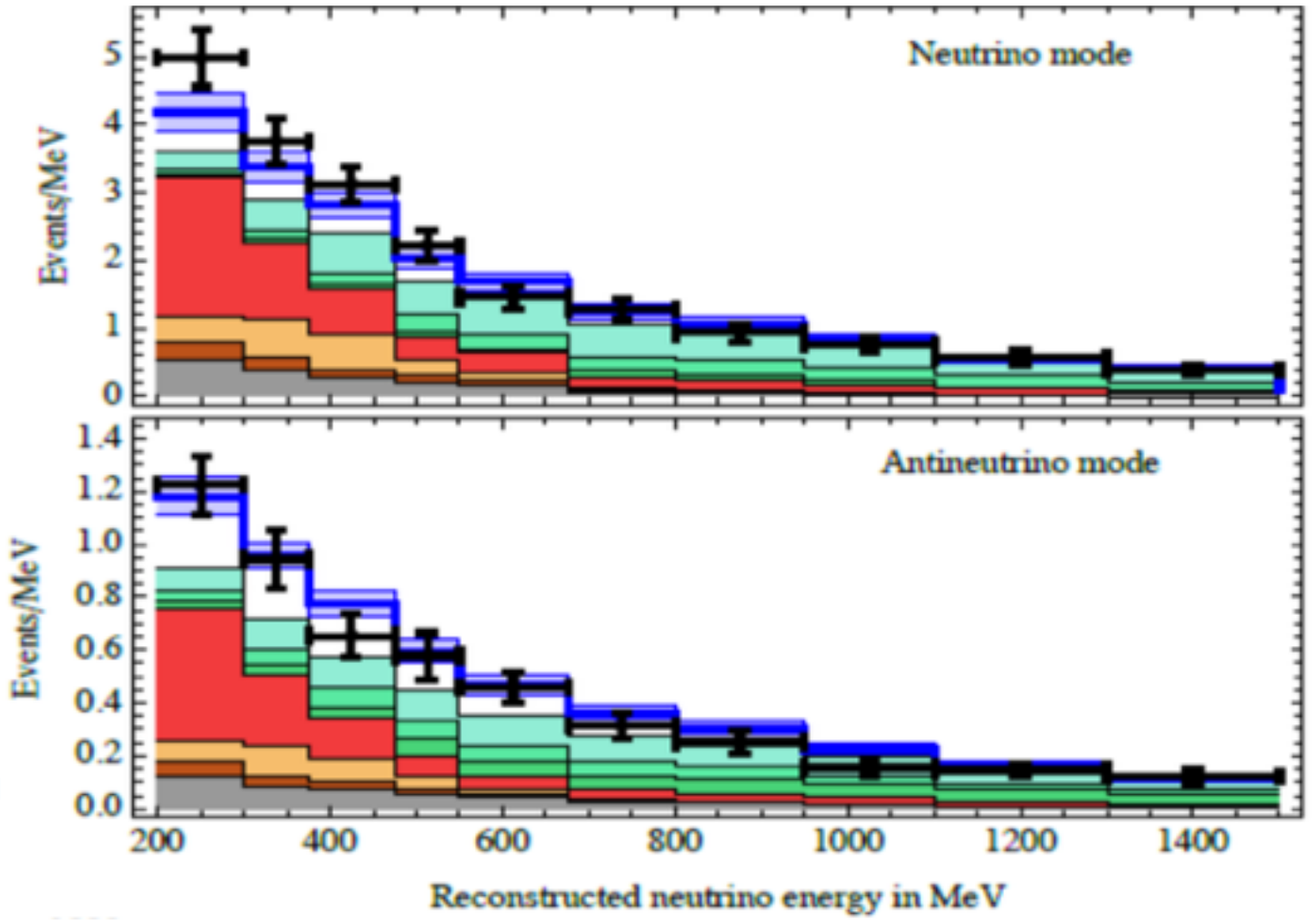
Light mediators

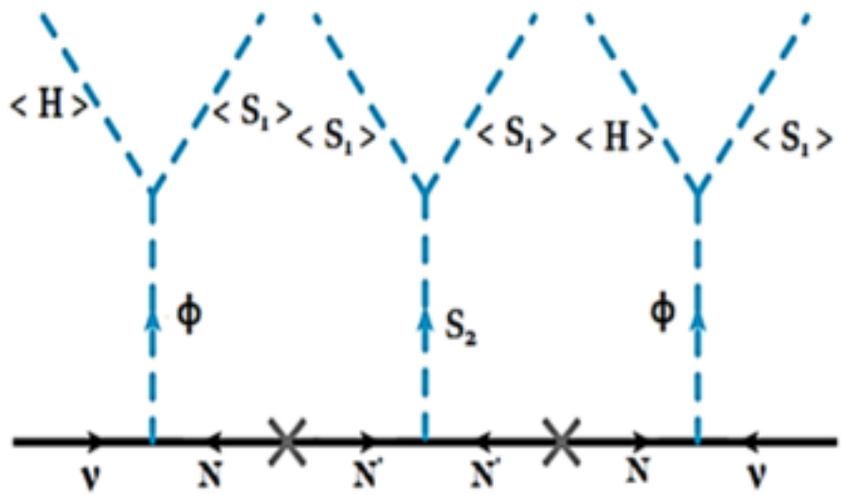
❖ *Explanation of MiniBooNE's low energy excess*

A LIGHT DARK SECTOR – THE IDEA









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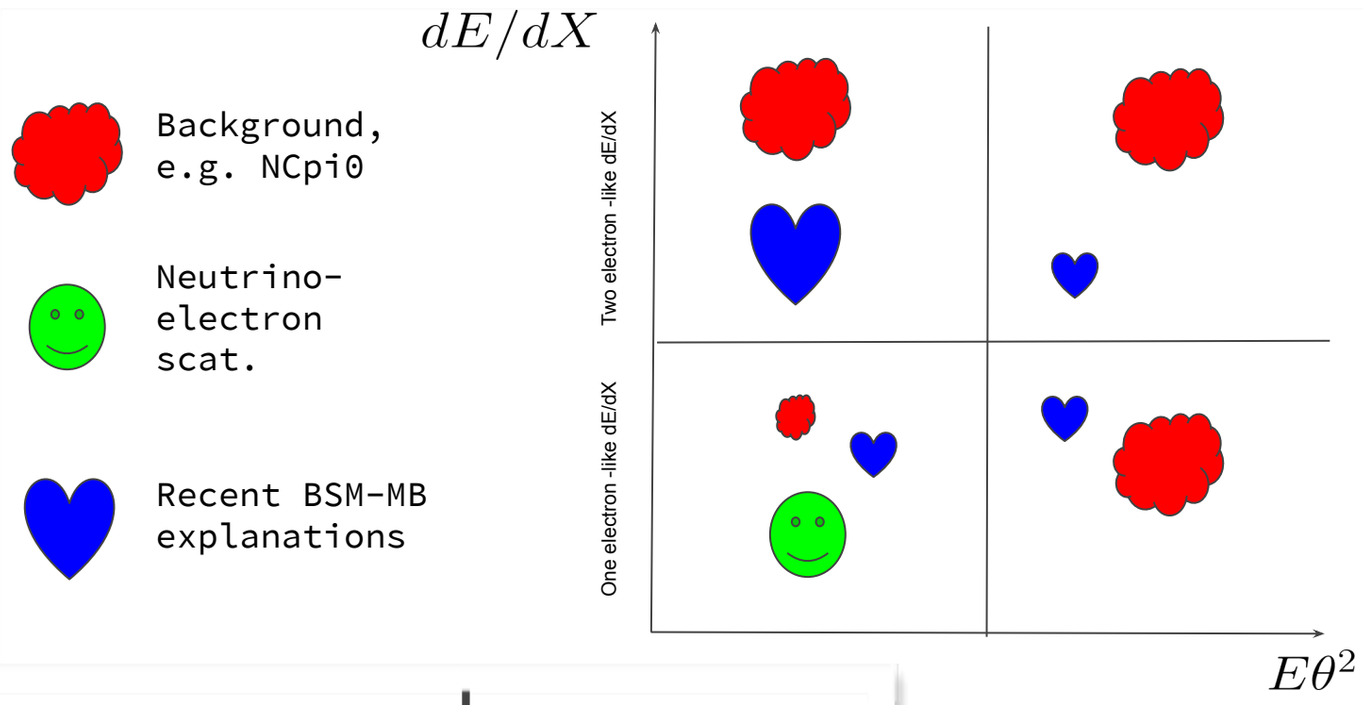

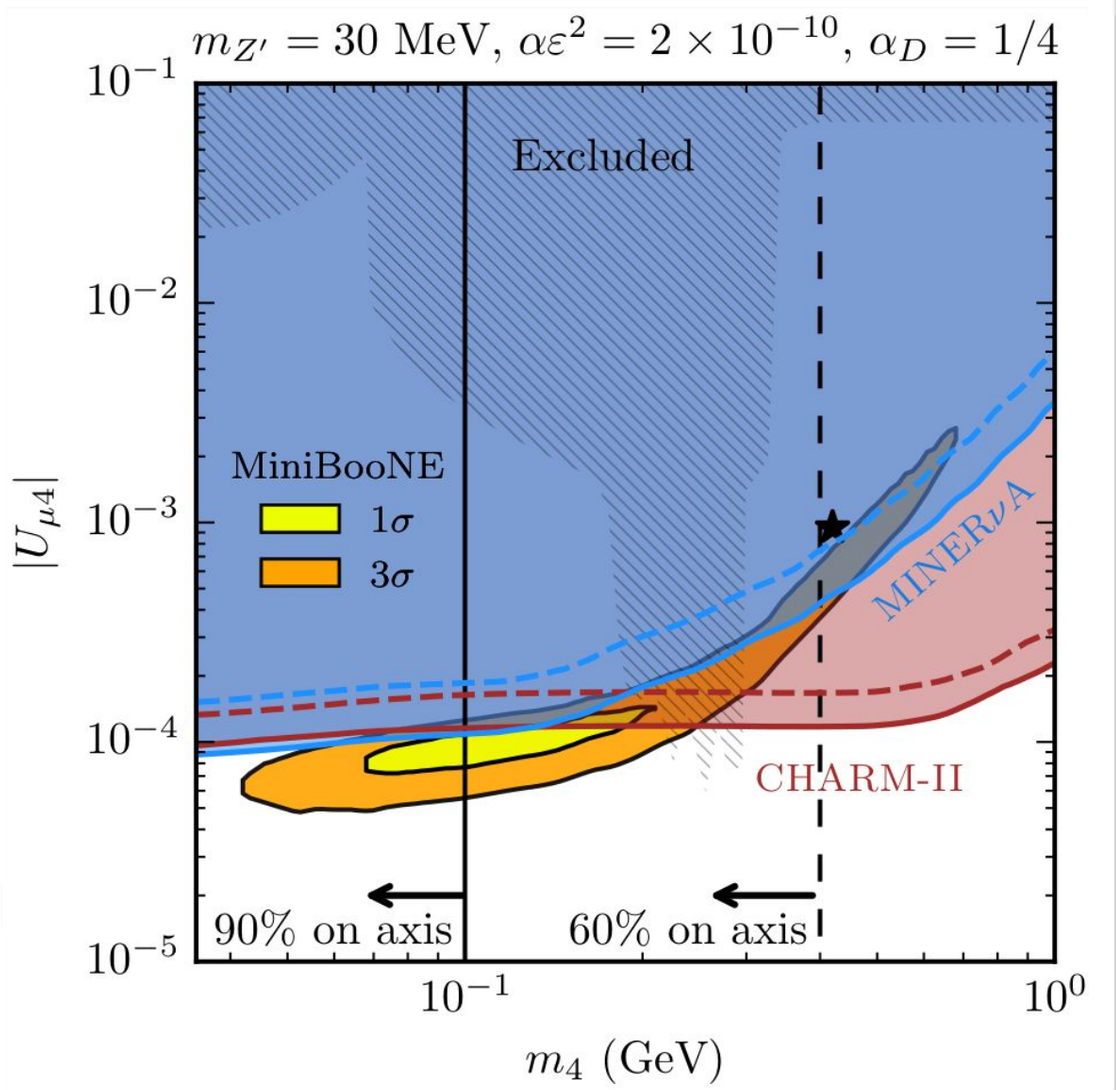

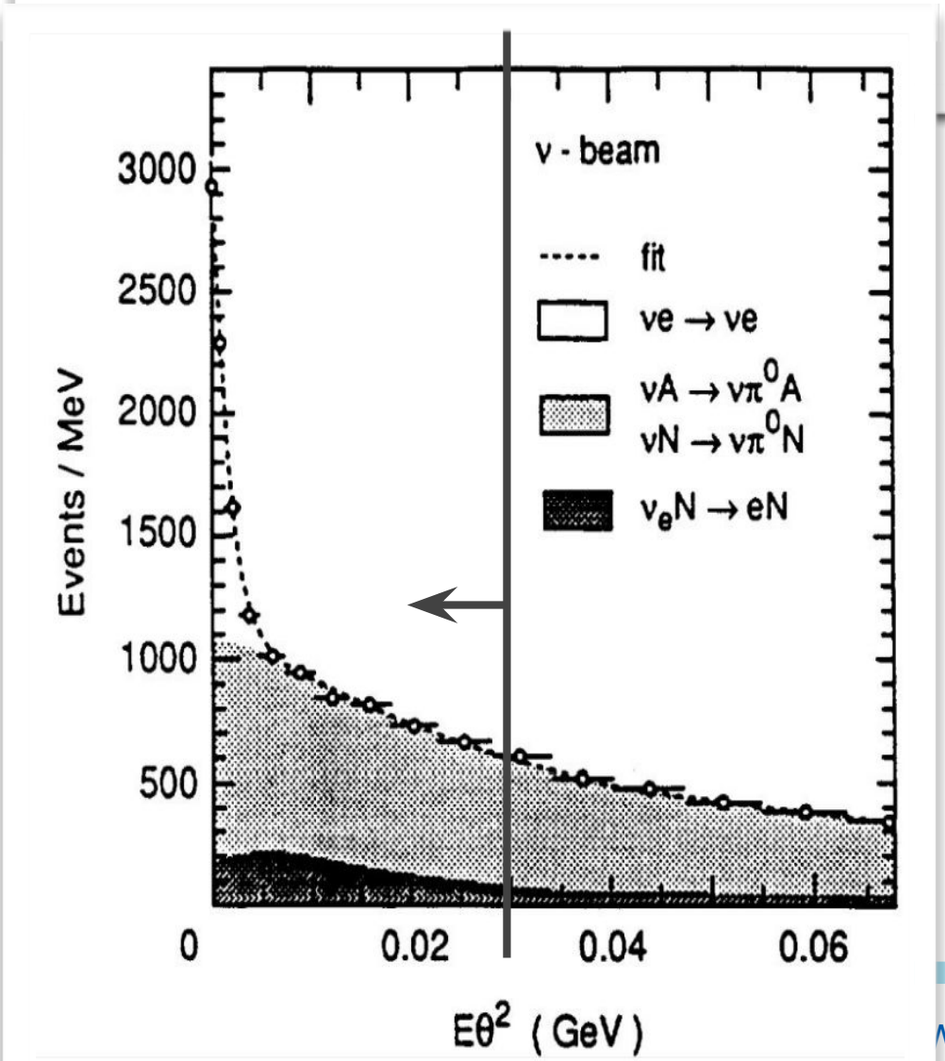

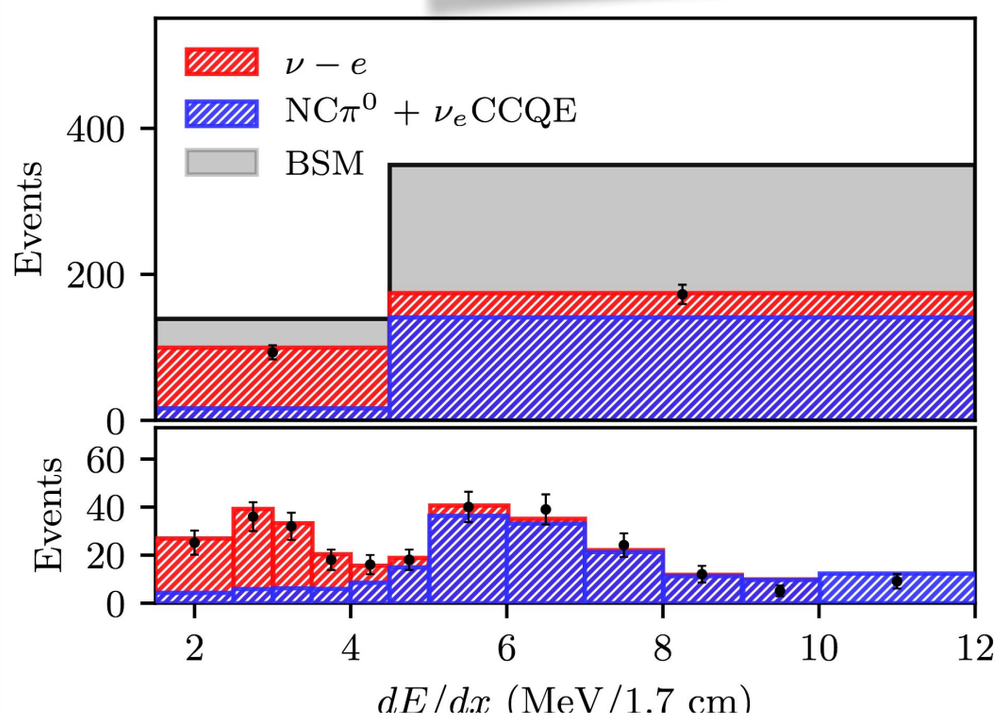

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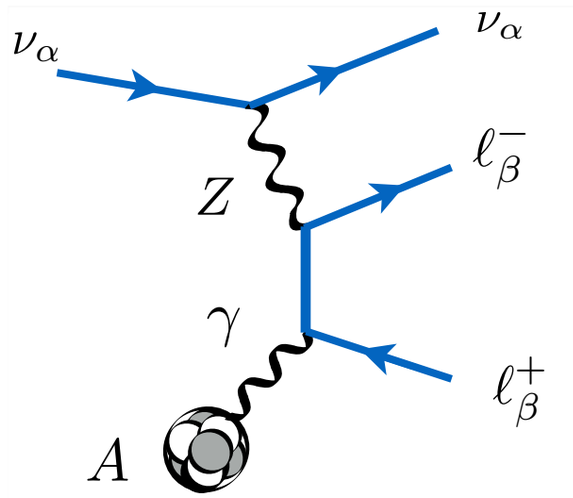
New signatures Light mediators

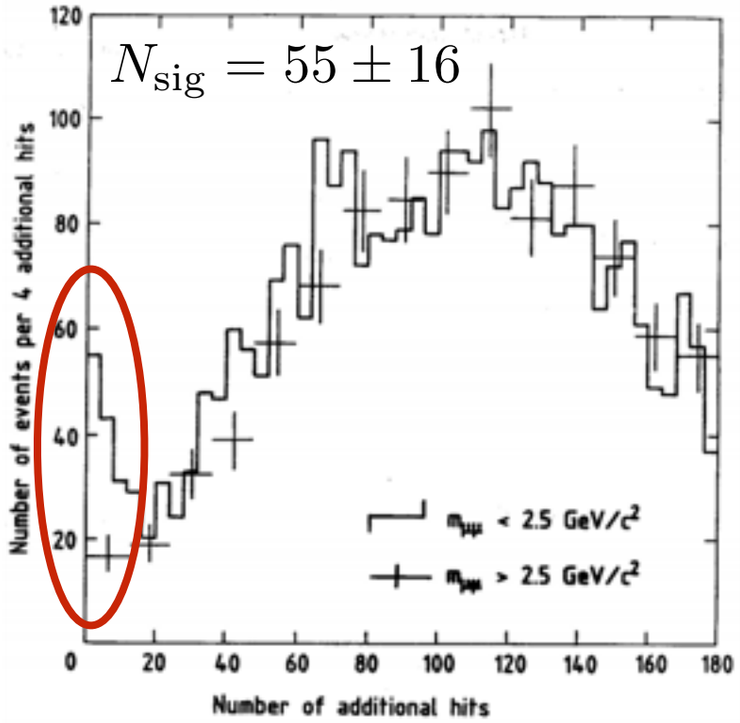


Neutrino trident production

e^+e^- $\mu^\pm e^\mp$

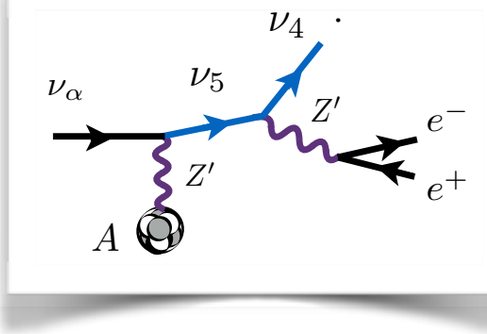
Not yet observed or even searched for!

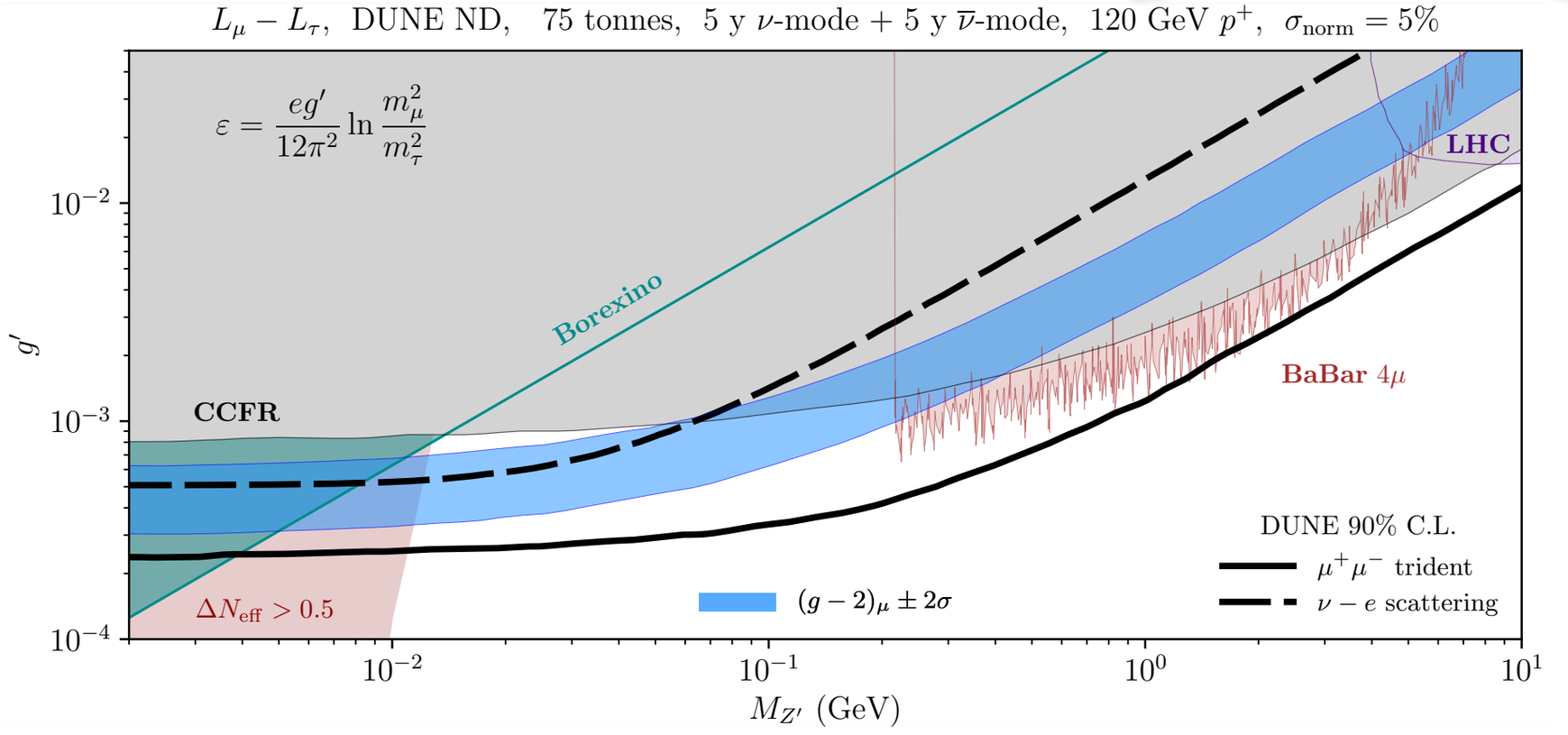
CHARM-II
WANF beam (CERN)
$\langle E_\nu \rangle = 25$ GeV



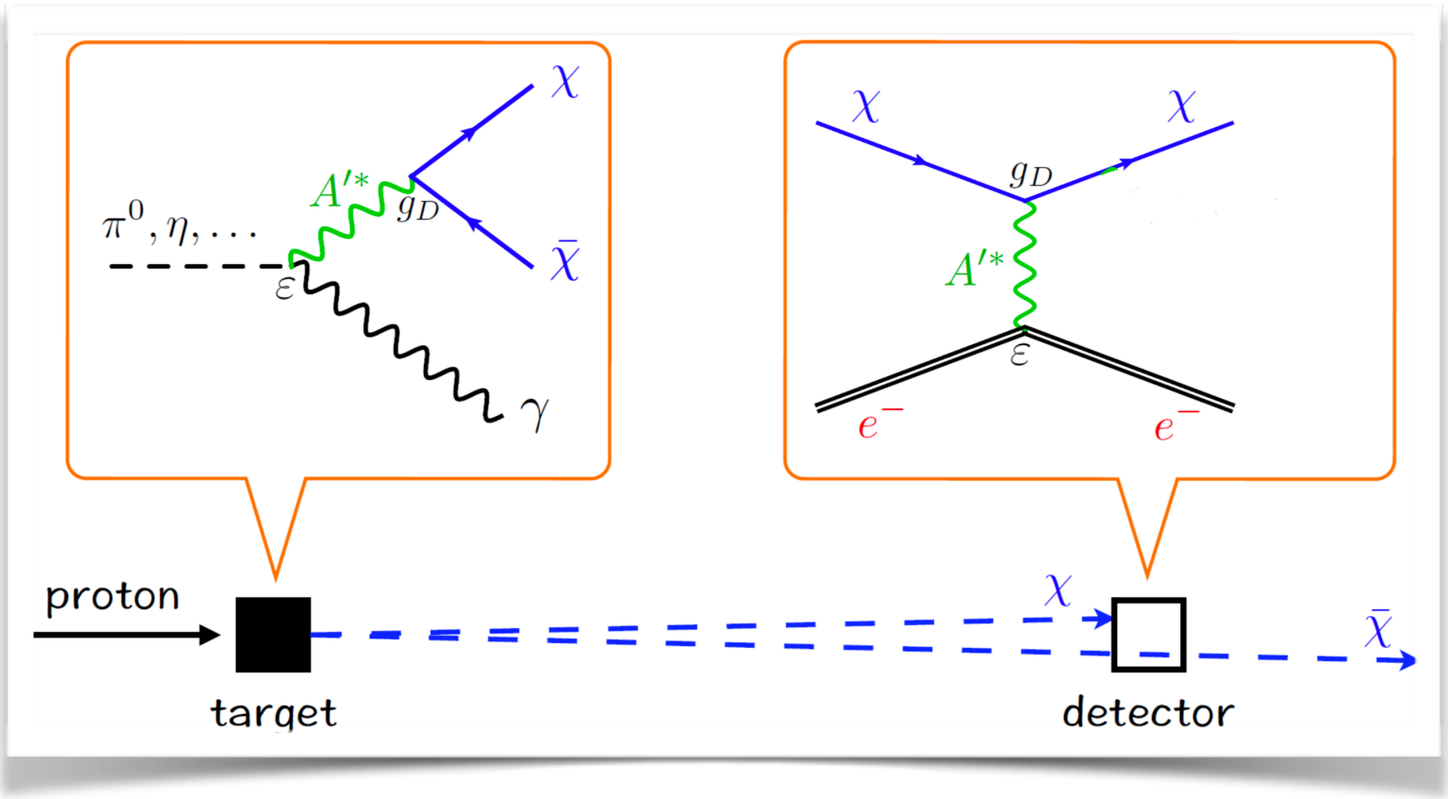
$$\frac{\sigma_{\rm CHARM-II}}{\sigma_{\rm SM}} = 1.58 \pm 0.57$$

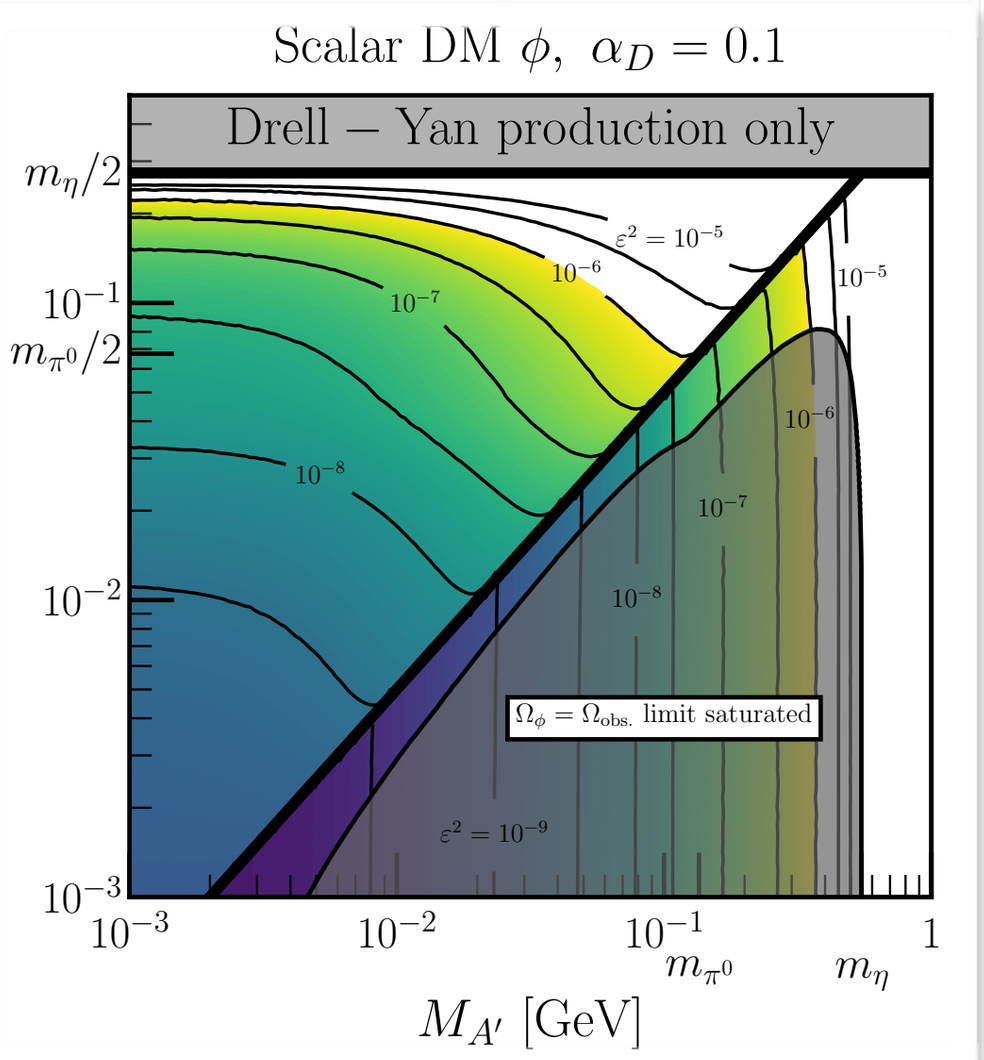
Smiting New Physics

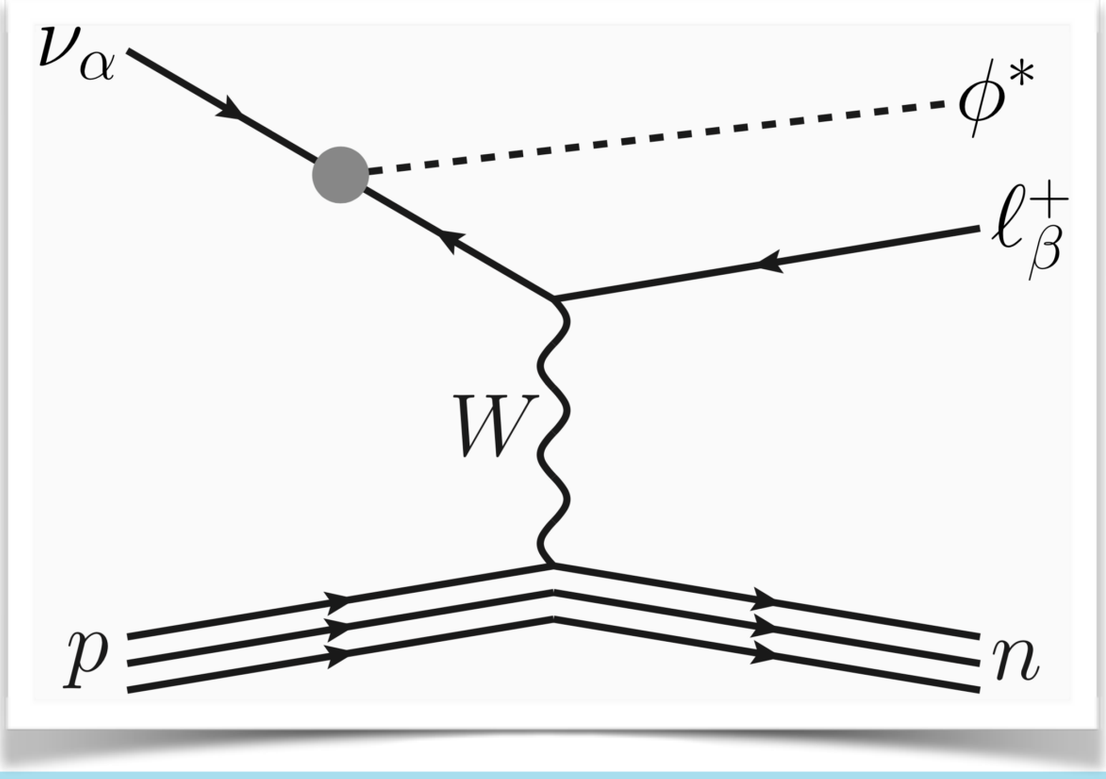


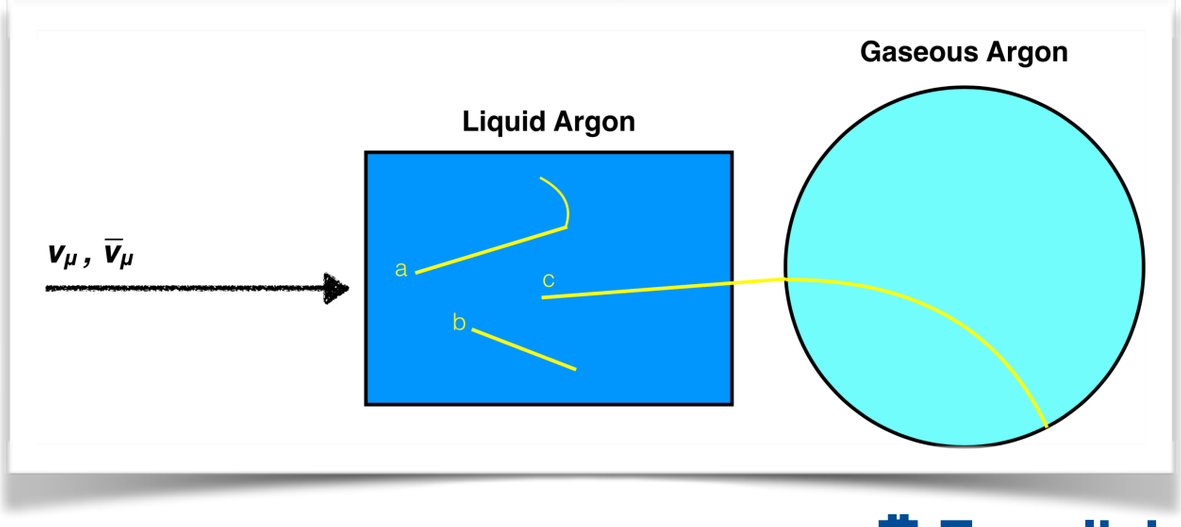


New signatures Dark matter









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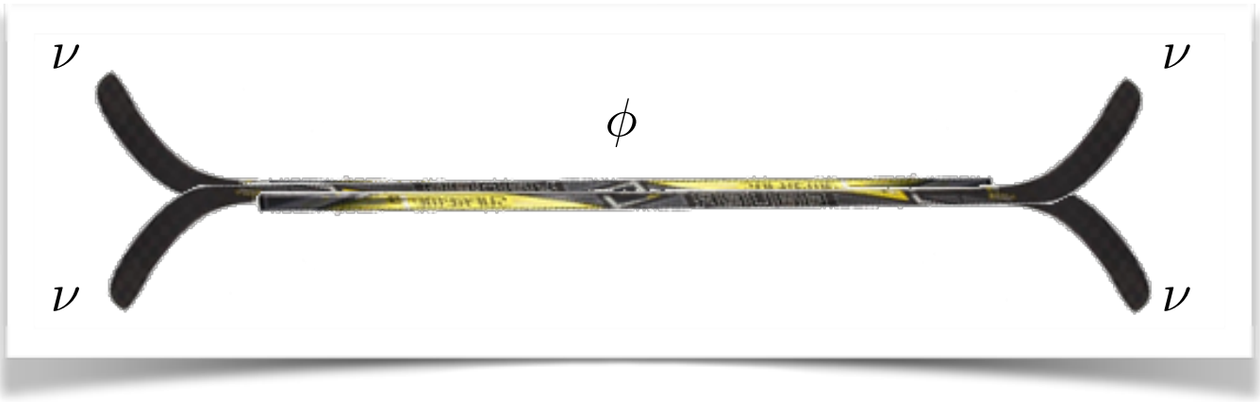
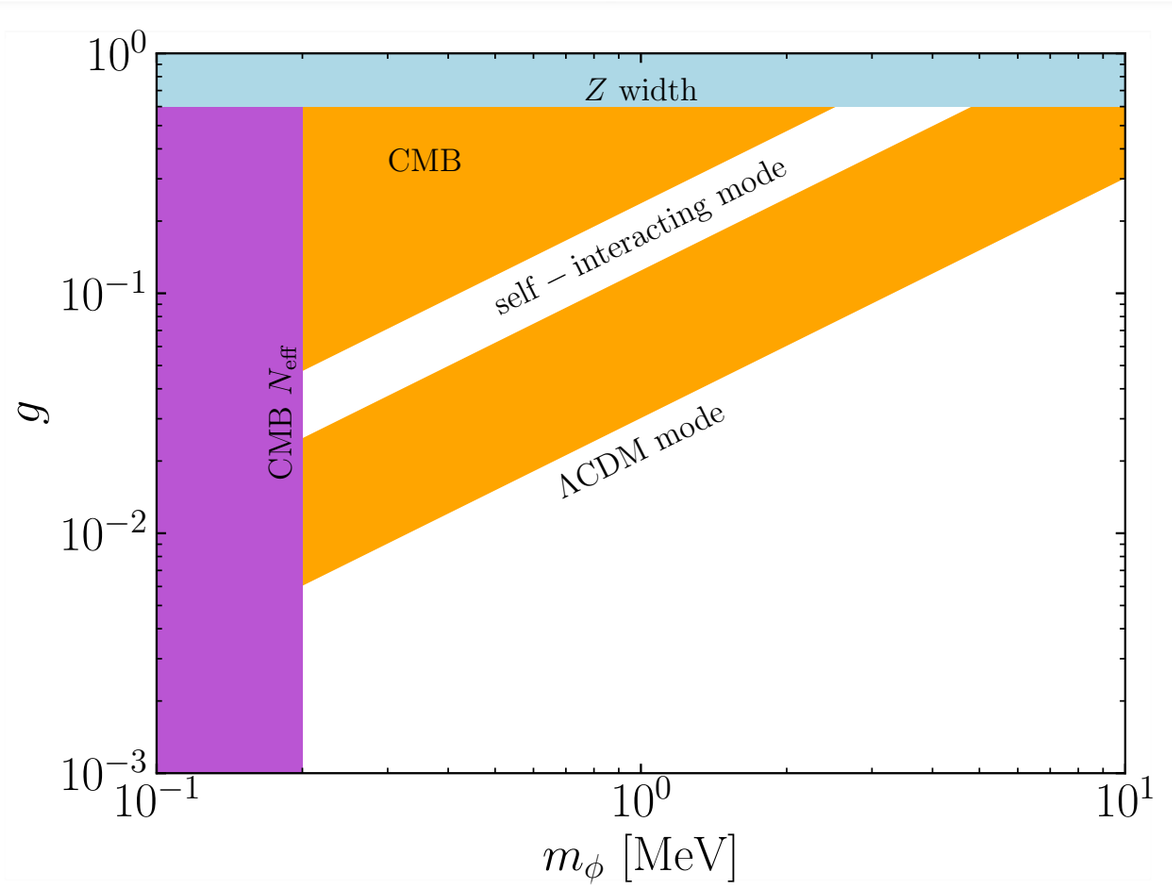
Light mediators and more





Early Universe Physics
Inflation Models: Natural Inflation
CνB Scattering
H_0 Tension

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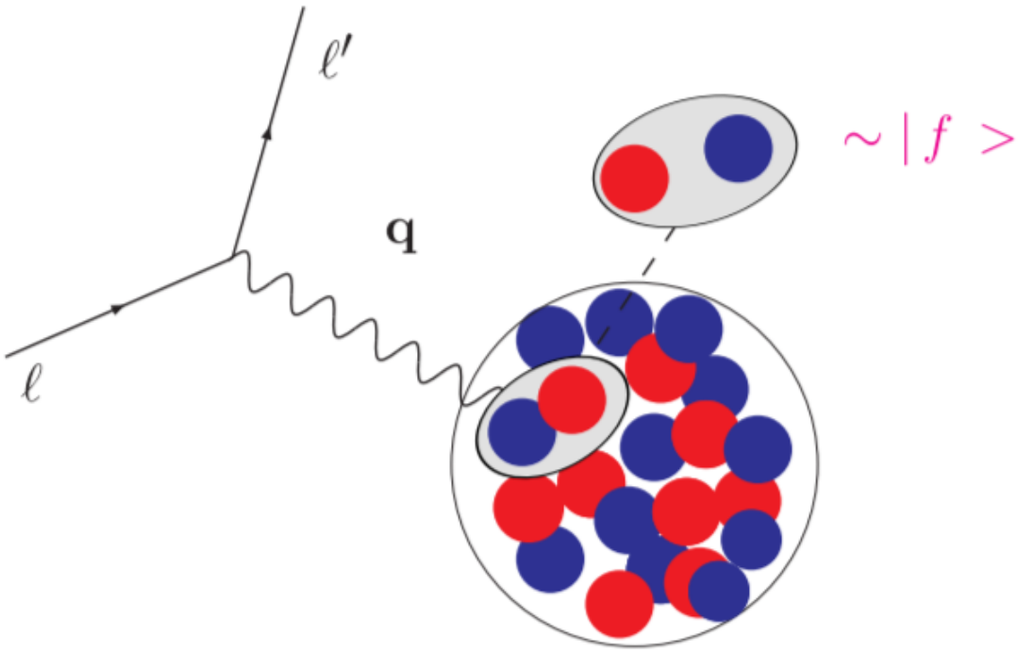
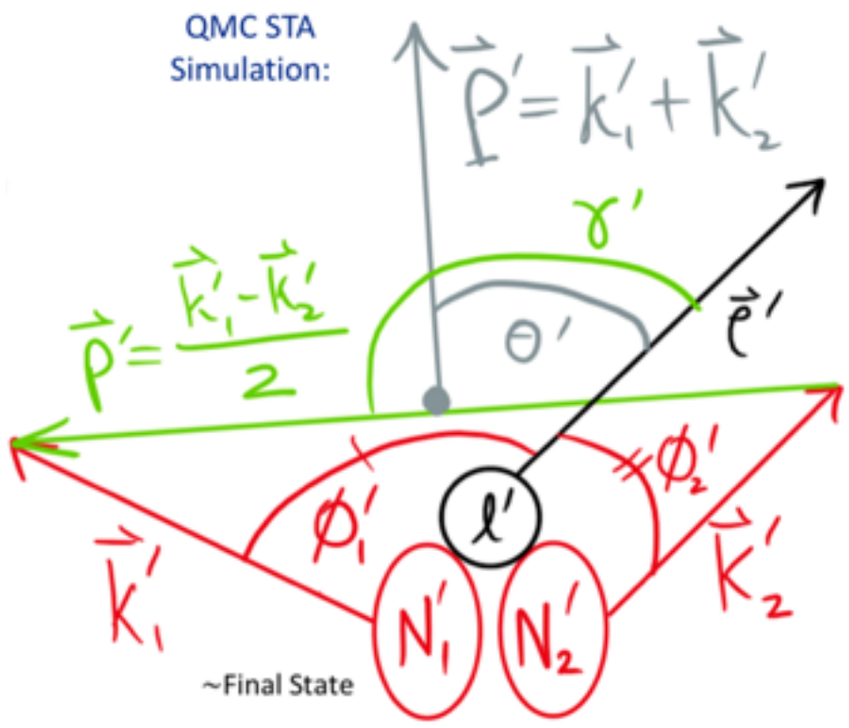
And much more

The Inclusion of Two-Body Physics: Nuclear Response

- The second order correction to a Hamiltonian describing a system of bound nucleons comes from two-body interaction terms in a high-order expansion:





UNIVERSAL NEUTRINO GENERATOR & GLOBAL FIT

Future Generator Validation

- Ample amounts of data are available for e^4_2He and e^{12}_6C scattering
- Once the generator is complete, tested, and validated on e data, we will proceed to ν generation
- Publication will follow soon after

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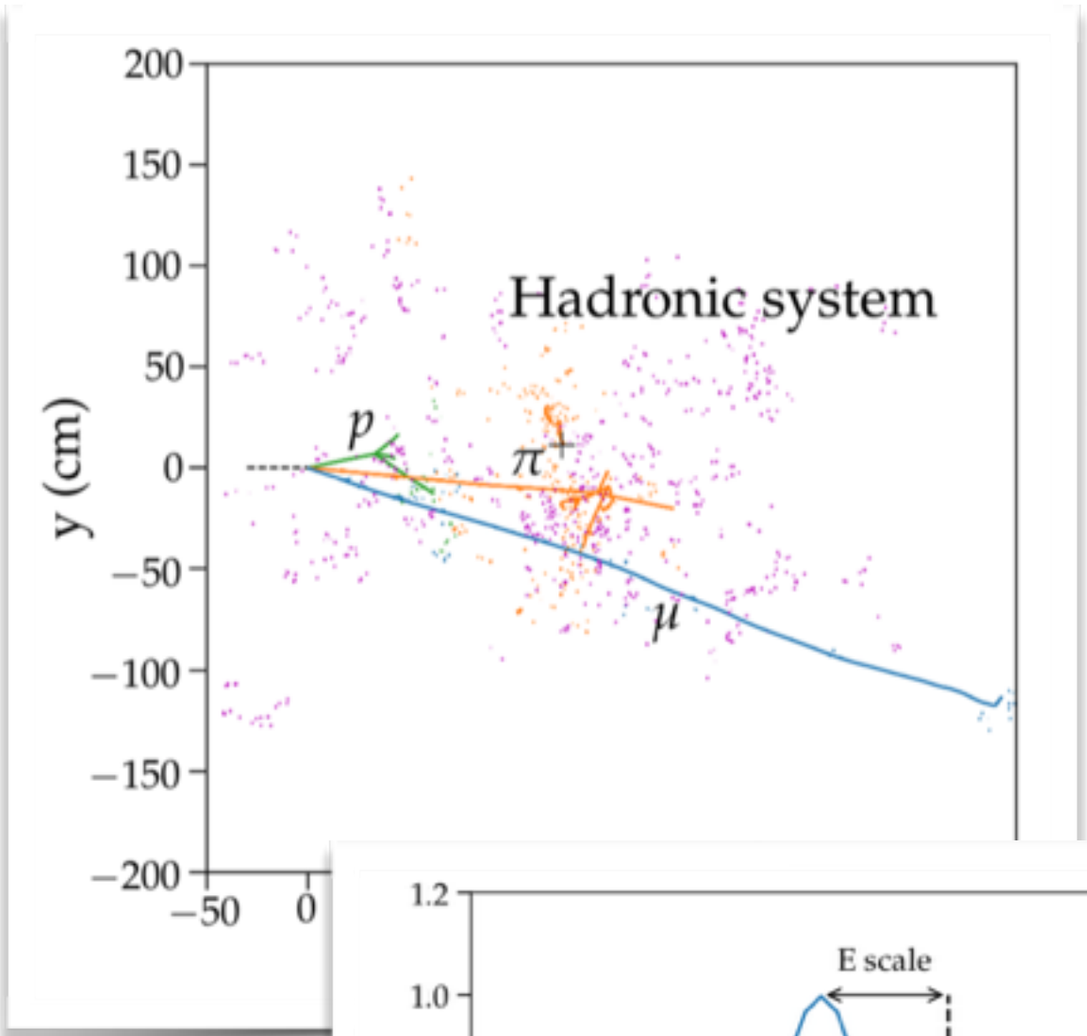
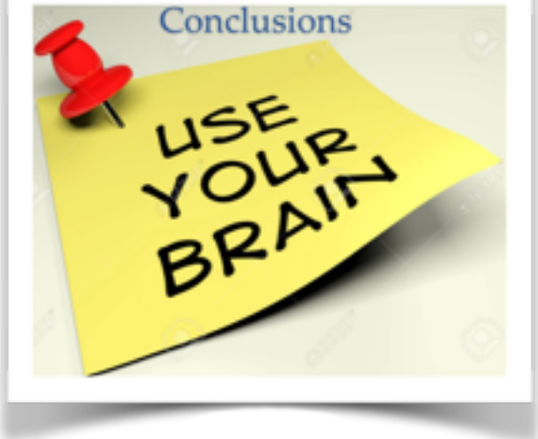
And much more

What do particles do

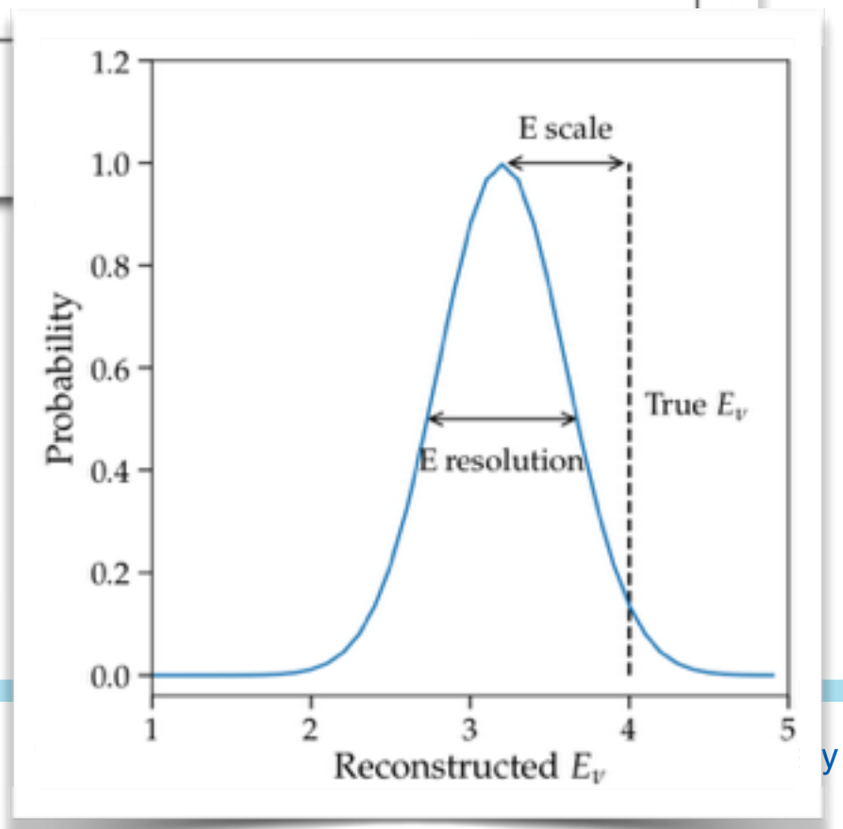


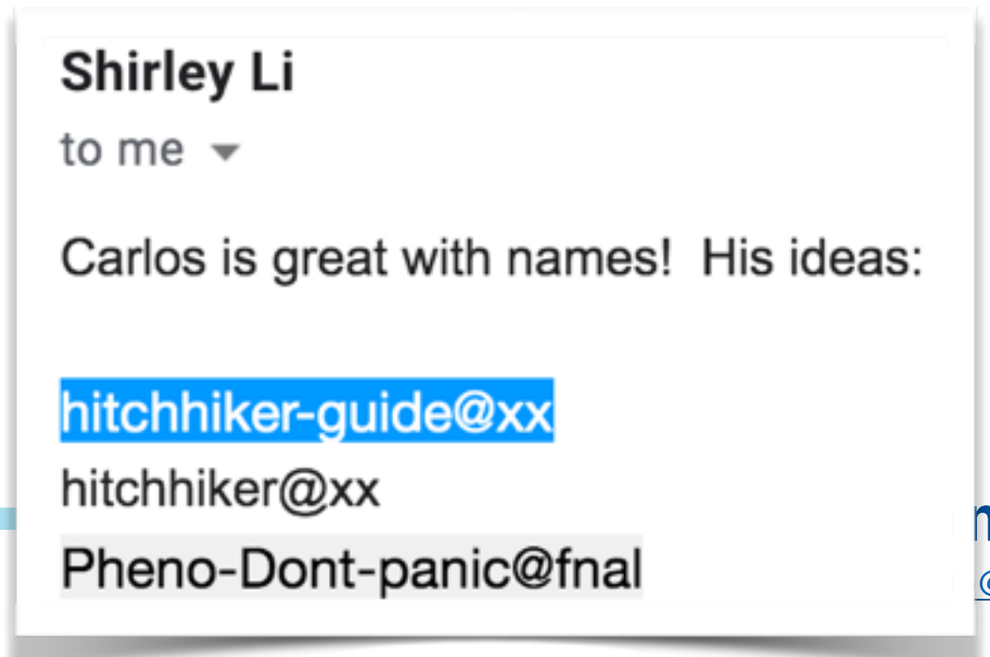
Particle type	Detection Threshold (KE)
$\mu^{\pm}$	30 MeV
$\pi^{\pm}$	100 MeV
$e^{\pm}/\gamma$	30 MeV
p	50 MeV
n	50 MeV
other	50 MeV



Mailing list:

Help with neutrino generators and propagation in liquid argon





Few questions and comments

Traditional EFT NSI below weak scale: Are we happy with it?

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UV complete models for NSI: proof of principle or should we focus on them?

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What do we need from EXPs to perform better analysis and propose new searches?

We plan on writing a report about this workshop.

Background: NSI community is changing. Several efforts on more coherent framework, new observables, UV complete models, complementarity with other experiments, greater precision, …

Goal: Write a report to identify the recent progress we achieved and the new directions we are pursuing.

Each of you should write a 3 pages (maximum) summary related to your talk (including refs). We will put this all together, edit, and write intro and conclusions. You will get a more detailed email soon.

Deadline: June 15th

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What a great workshop!
Thanks to all of you for coming here!

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