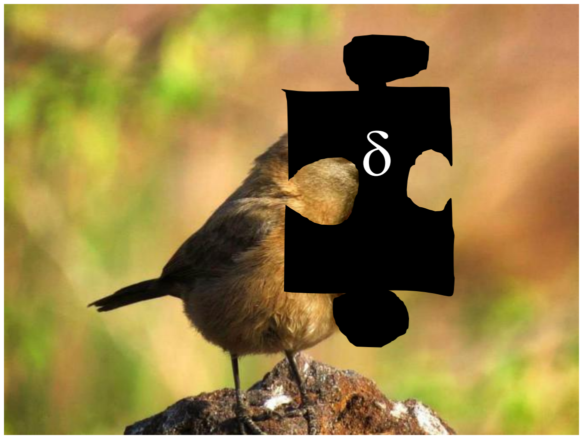
Seesaw mechanism in ν oscillations

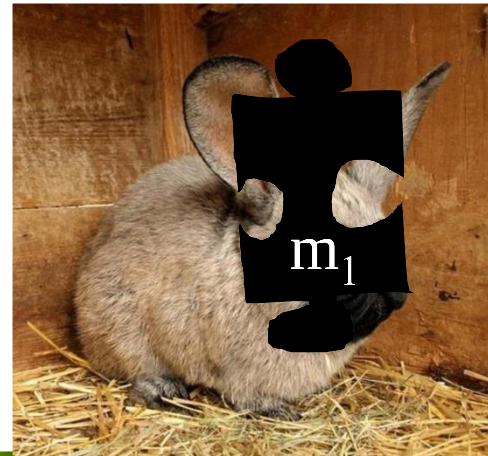
Enrique Fernández Martínez

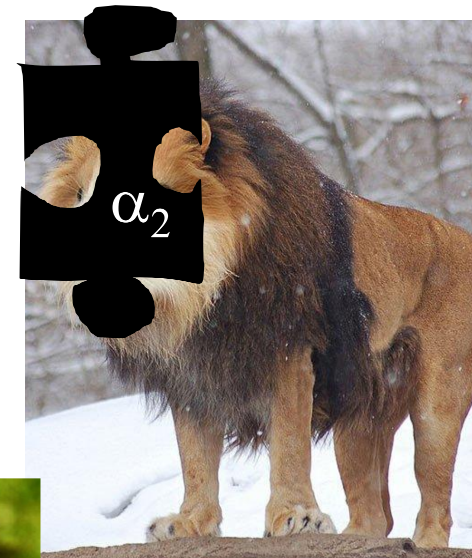
νProbes

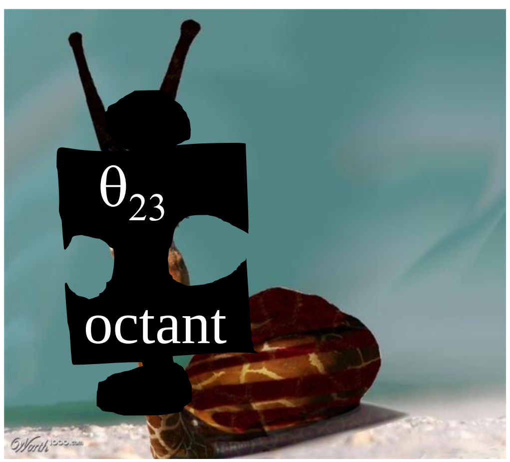
invisiblesPlus elusives

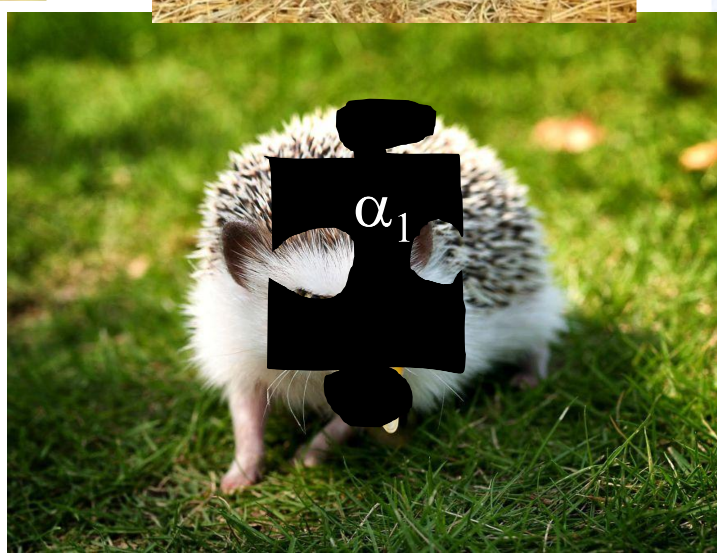
Neutrino physics missing pieces

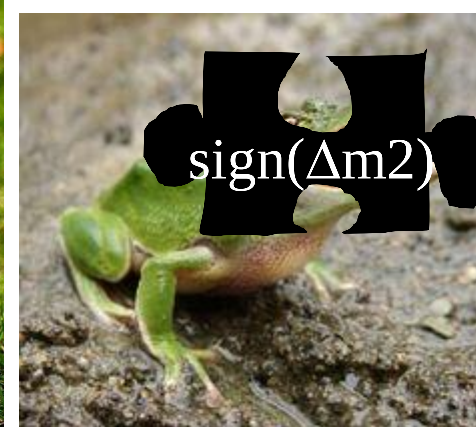












Neutrino physics missing pieces






Neutrino masses beyond the SM

All SM fermions acquire Dirac masses via Yukawa couplings

$$Y_f \, \overline{f_L} \phi f_R$$

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$$M_N \overline{N}_R^C N_R$$

A new physics scale

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→ To be sought for at experiments!!

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$$m_\nu = \begin{pmatrix} 0 & m_D \\ m_D^t & M_N \end{pmatrix} \xrightarrow[\text{Seesaw}]{} U^T \begin{pmatrix} 0 & m_D \\ m_D^t & M_N \end{pmatrix} U = \begin{pmatrix} m & 0 \\ 0 & M \end{pmatrix}$$

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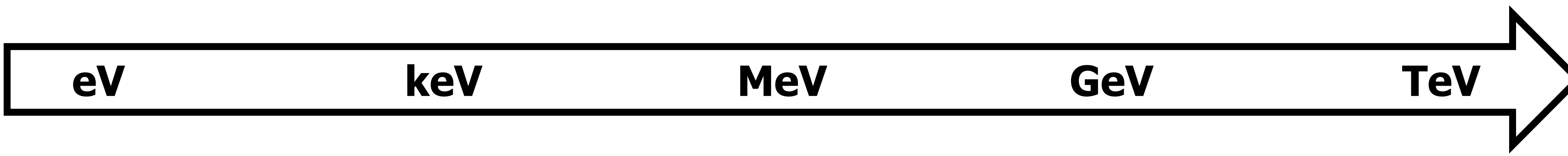

M_N could be anywhere…

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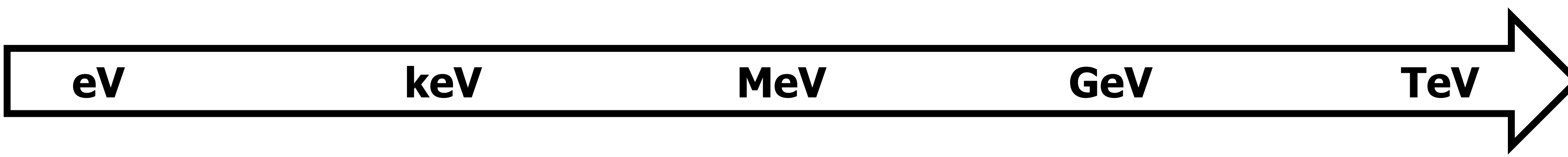

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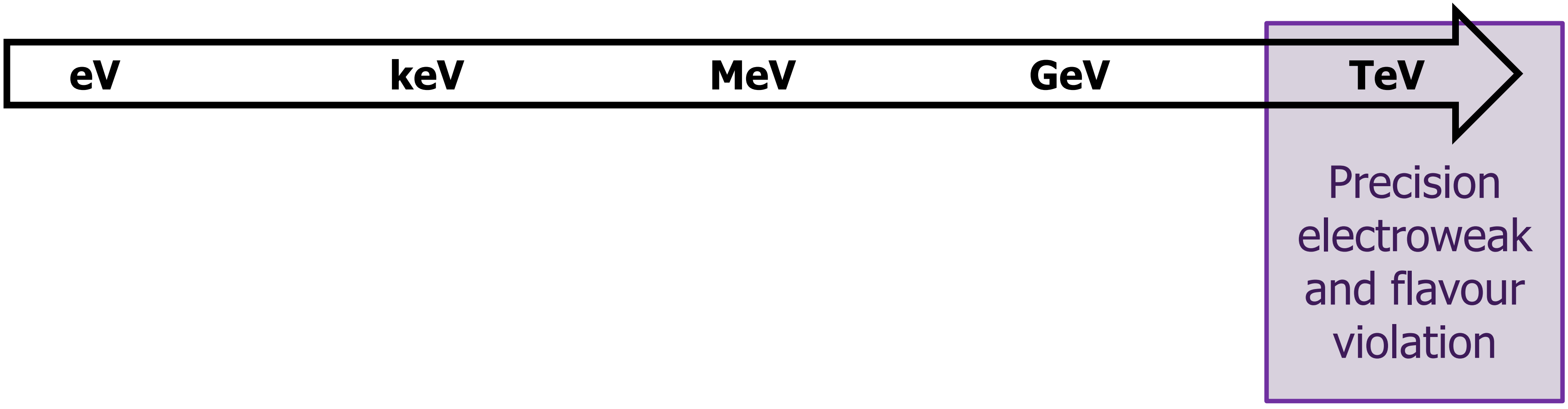
Very different phenomenology at different scales

A new physics scale



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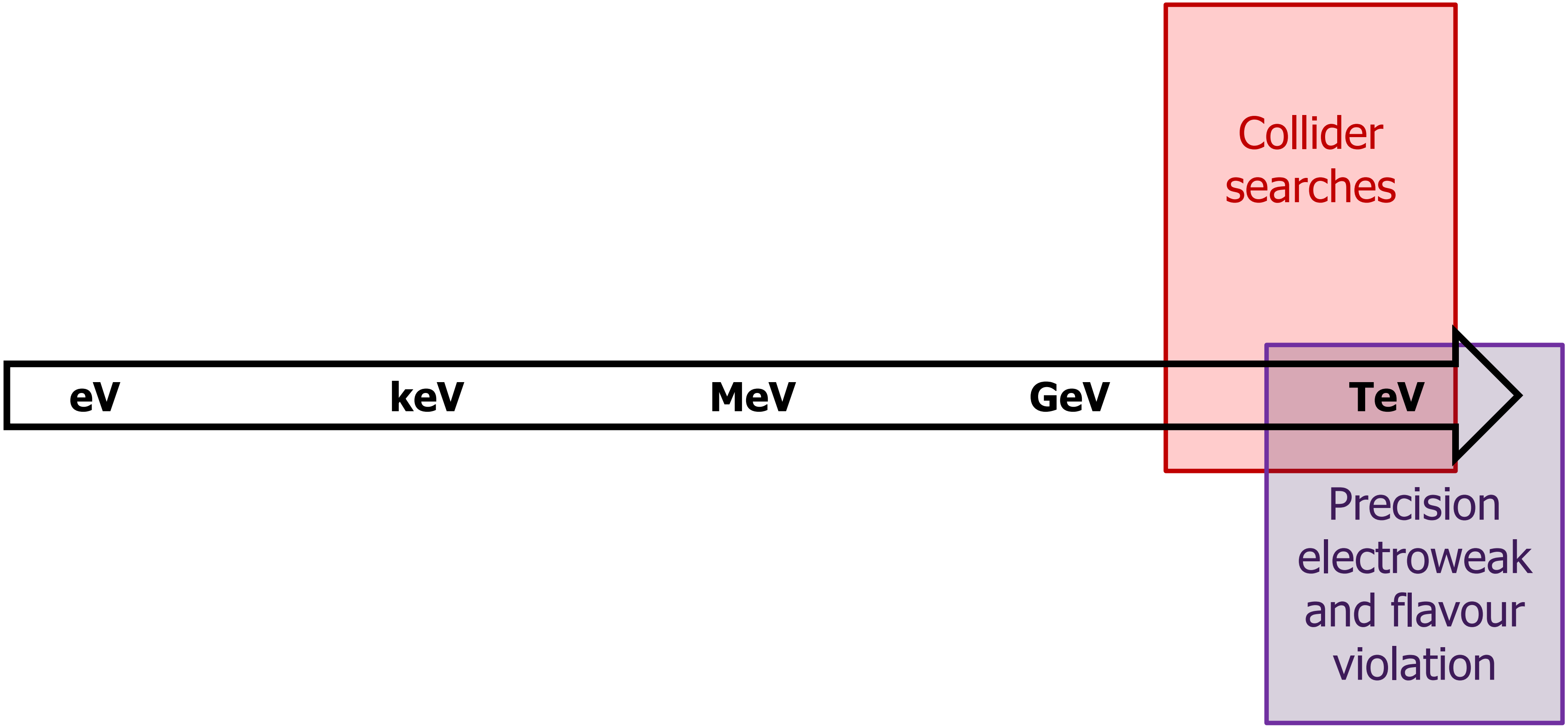

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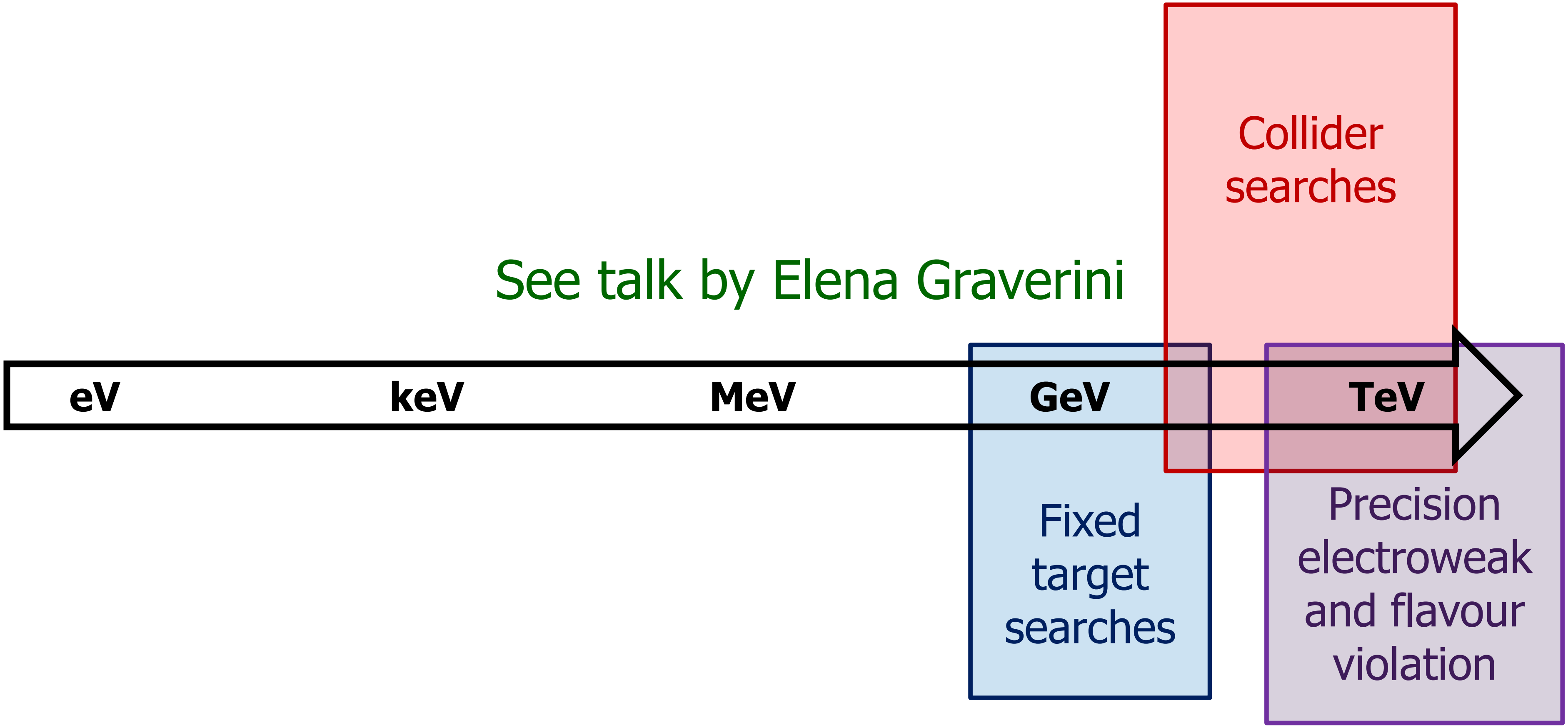

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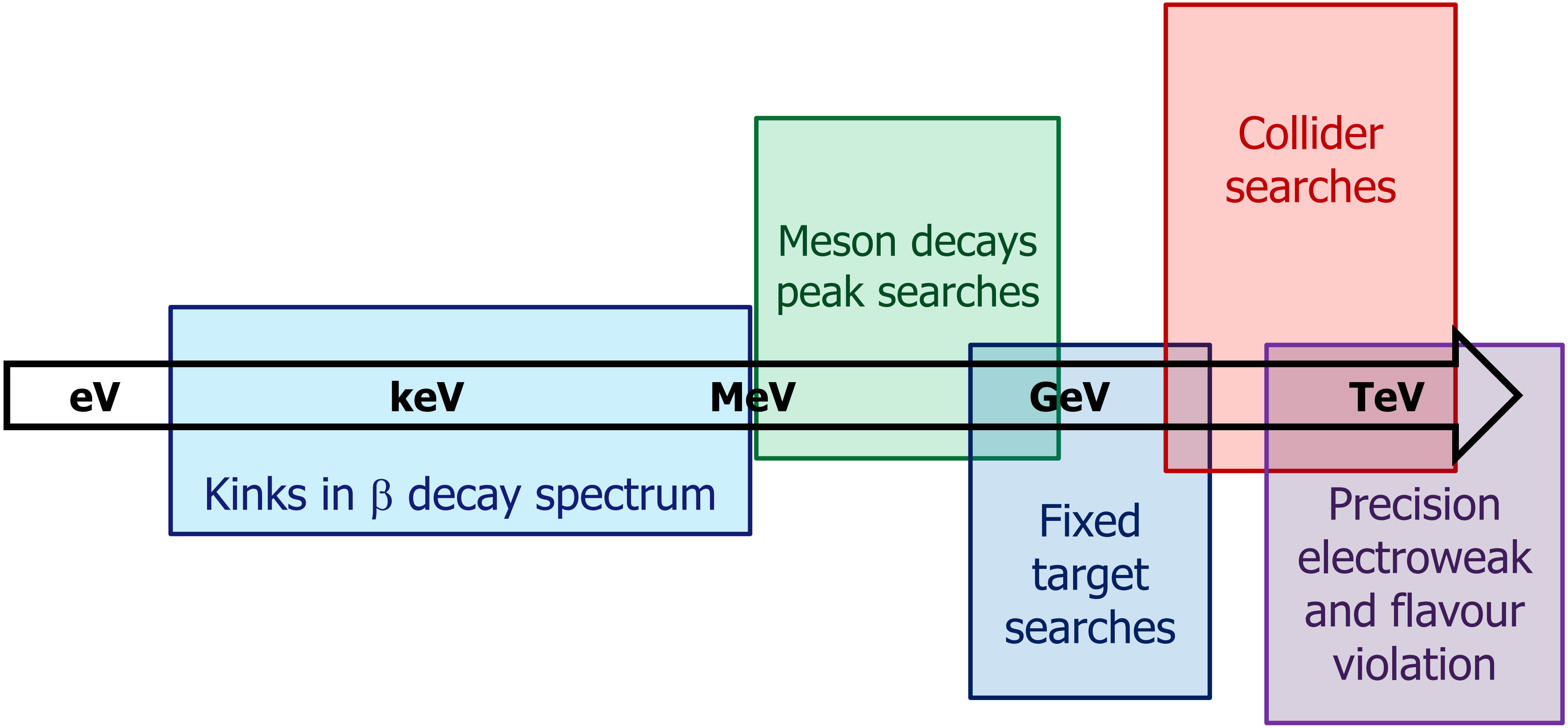

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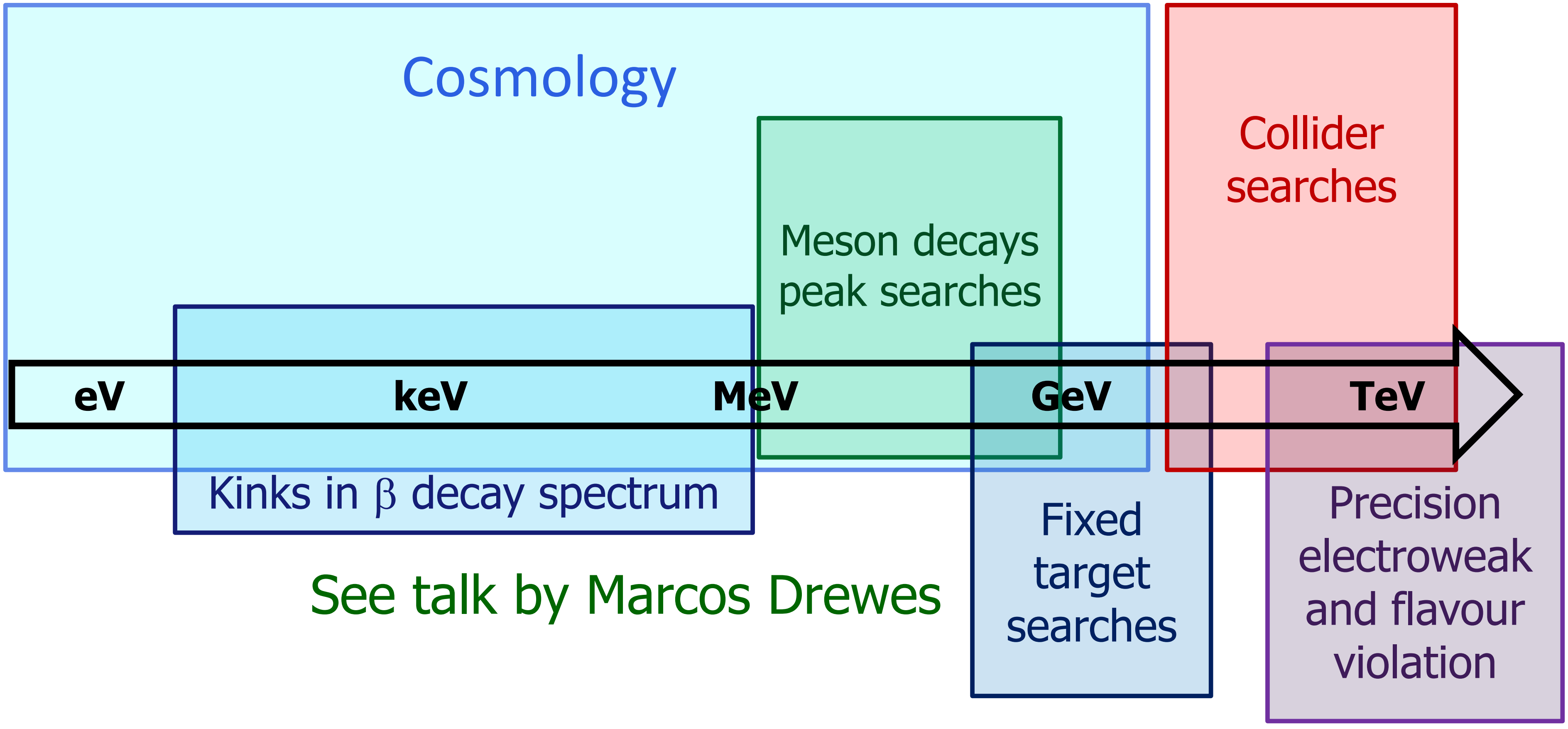
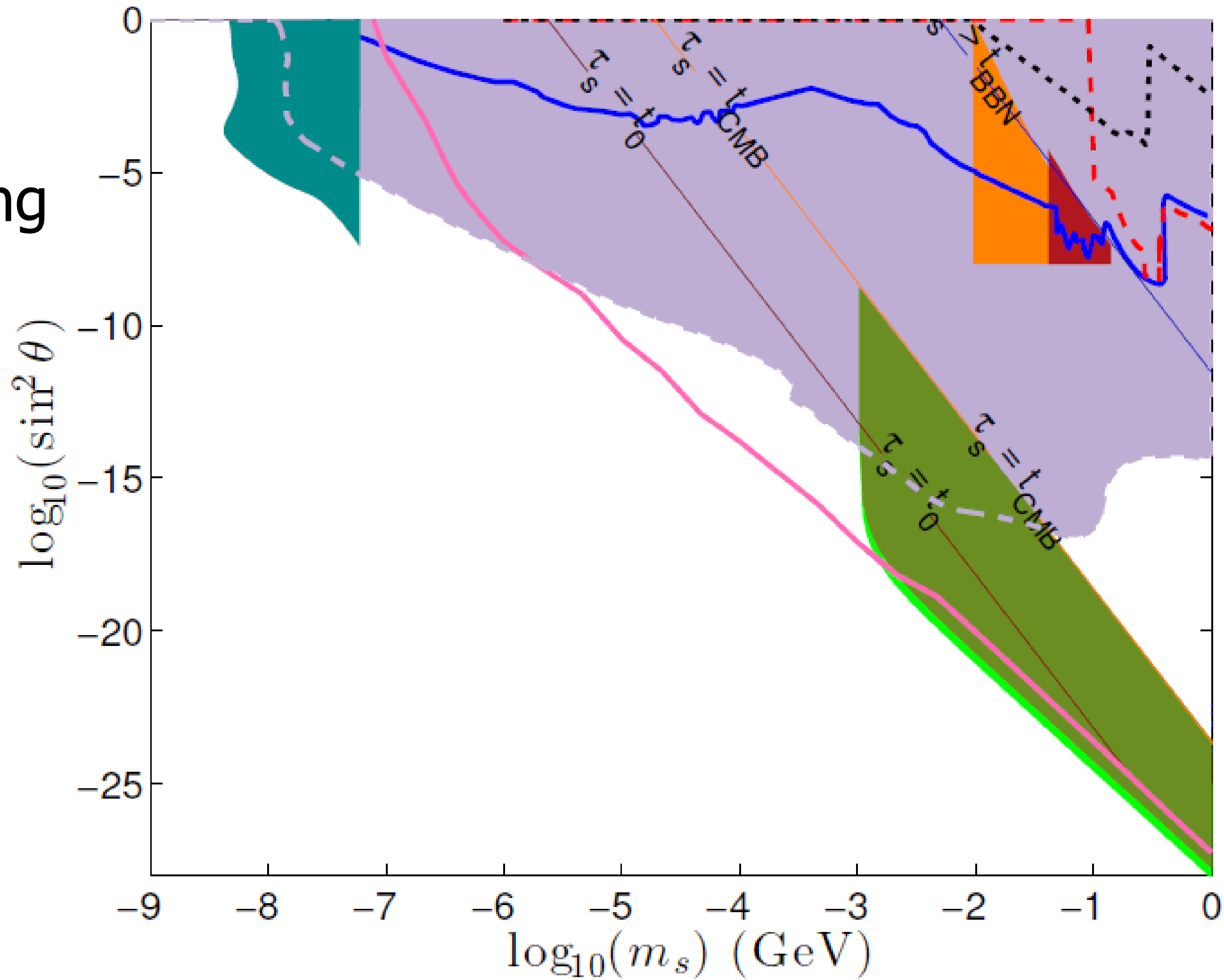


See talk by Marcos Drewes

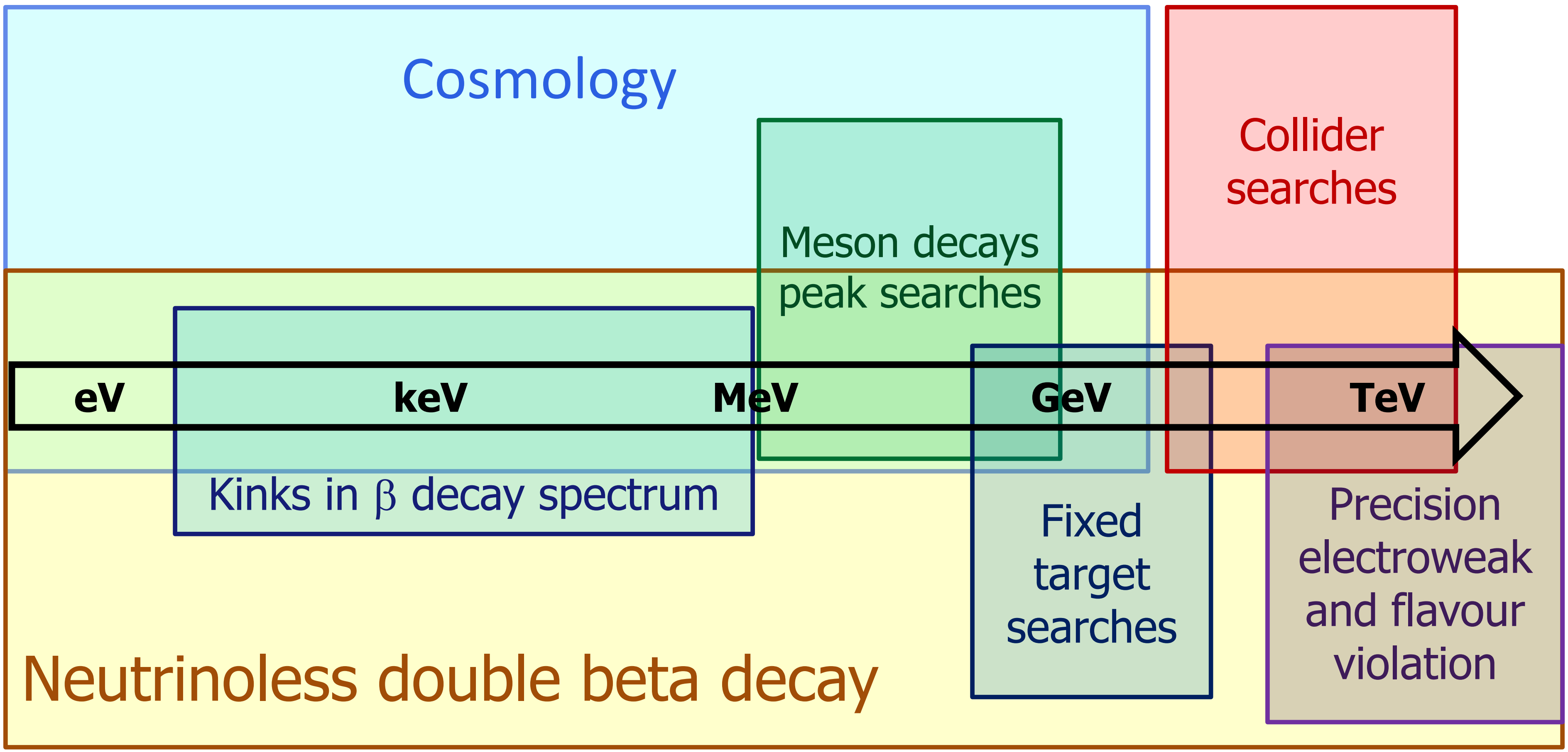
Cosmology and lab constraints

At intermediate scales very strong constraints from direct searches and cosmology



A. C Vincent, EFM, P. Hernandez, M. Lattanzi and O. Mena arXiv:1408.1956

A new physics scale



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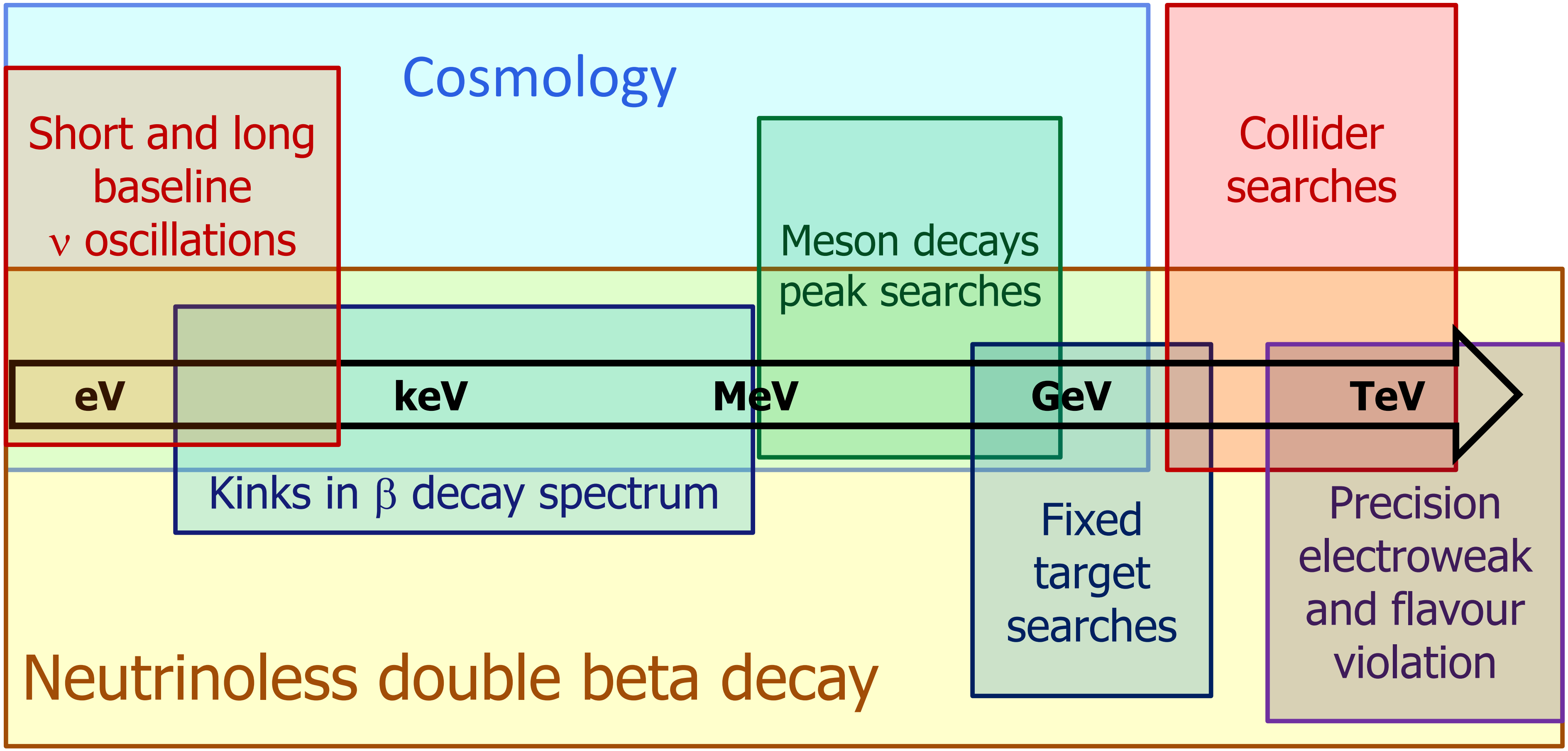


A new physics scale

Short and long baseline ν oscillations

eV keV MeV GeV TeV

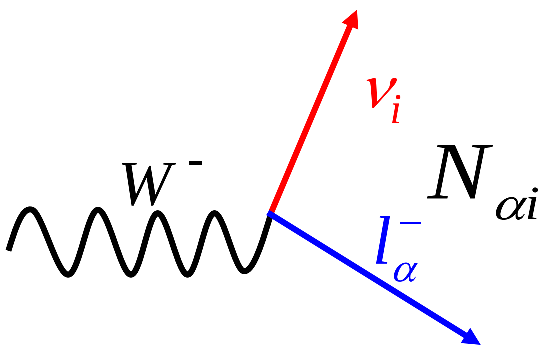
Precision electroweak and flavour violation

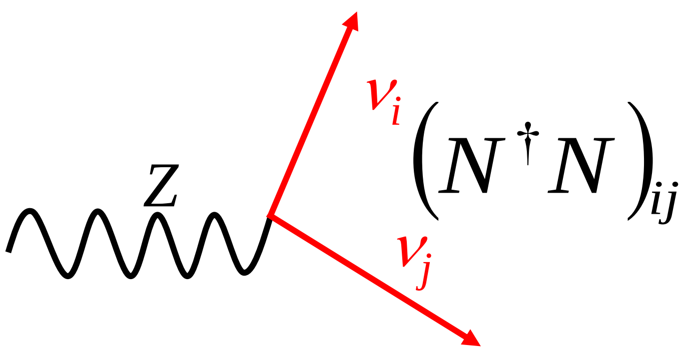
I will concentrate in the very high ($M_N > 100$ GeV) and very low ($M_N < 1$ keV) limits of potential interest for ν oscillations

Probing the Seesaw: Non-Unitarity

$$U^T \begin{pmatrix} 0 & m_D \\ m_D^t & M_N \end{pmatrix} U = \begin{pmatrix} m & 0 \\ 0 & M \end{pmatrix}$$

The 3×3 submatrix N of active neutrinos will not be unitary





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$$\Gamma = \Gamma_{SM} \sum_i \left|N_{\alpha i}\right|^2 = \Gamma_{SM} \left(N N^\dagger\right)_{\alpha\alpha}$$

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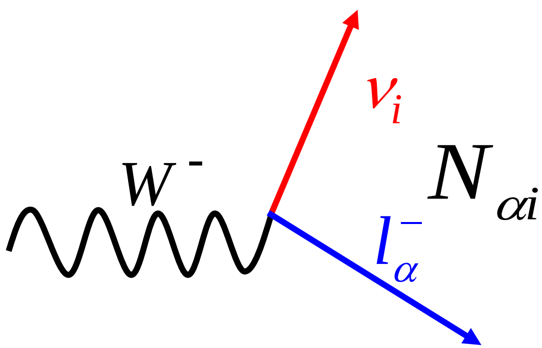

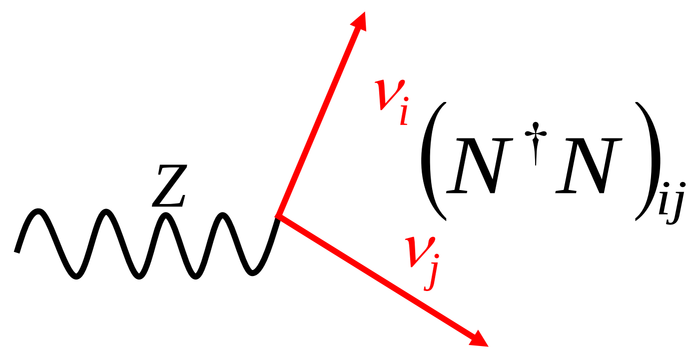

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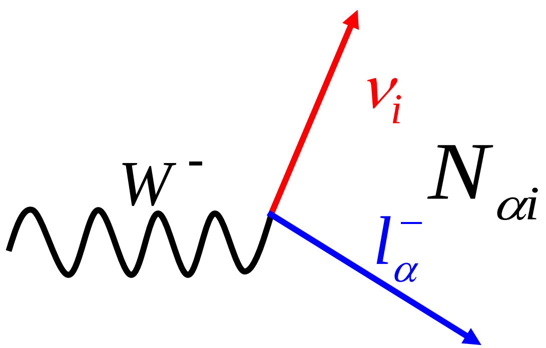

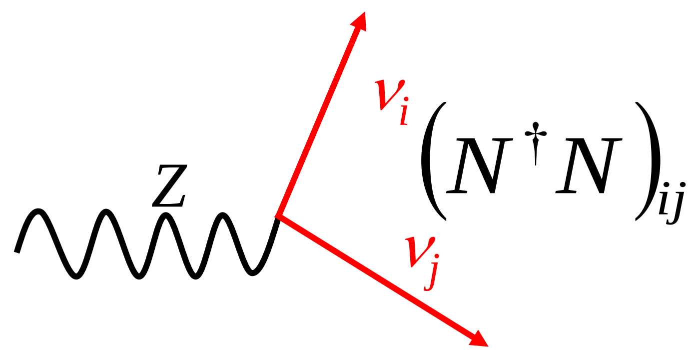

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Zero-distance effect:

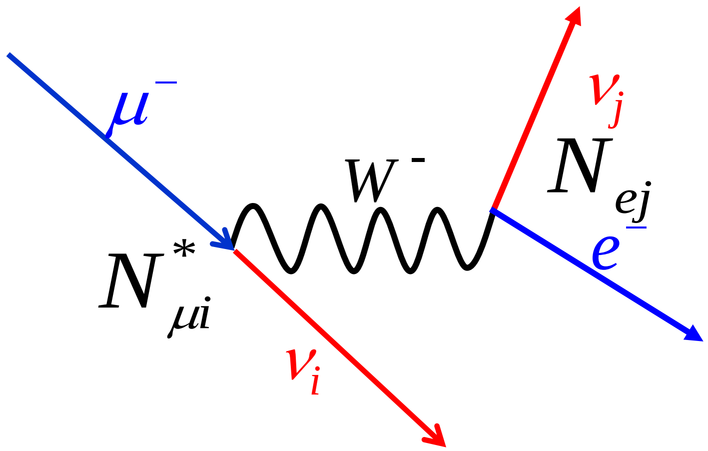
$$P\left(\nu_\alpha \to \nu_\beta; 0\right) \propto \left|\sum_i N_{\alpha i}^* N_{\beta i}\right|^2 \neq \delta_{\alpha\beta}$$

Probing the Seesaw: Non-Unitarity

In general $N = (1-\eta)\cdot U$ with η Hermitian and U Unitary

For a Seesaw $\eta = \frac{\Theta\Theta^\dagger}{2}$ with $\Theta \approx m_{\mathrm{D}}^\dagger M_N^{-1}$ the heavy-active mixing

G_F from μ decay is affected!



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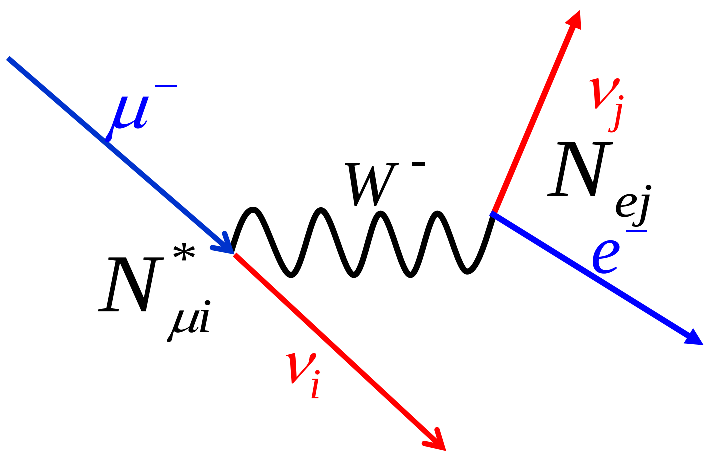

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Agree at the ~per mille level

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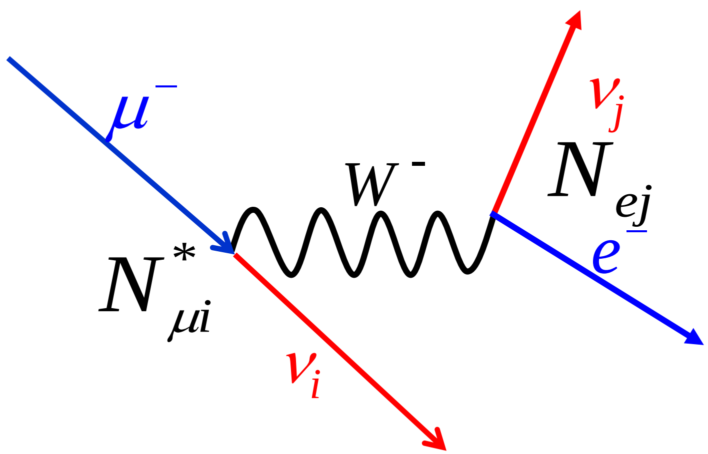

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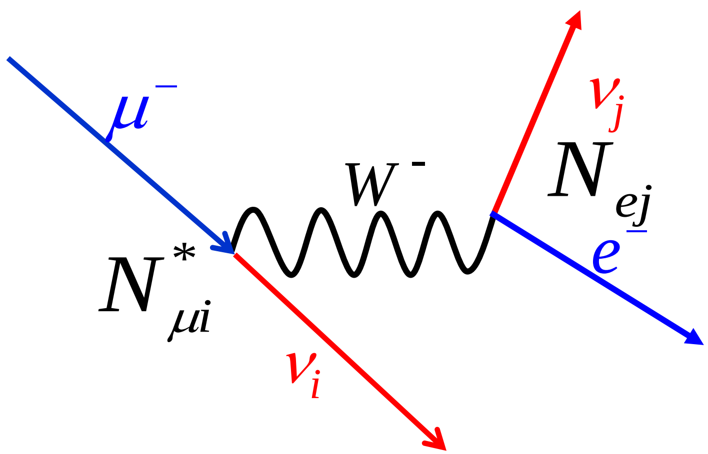

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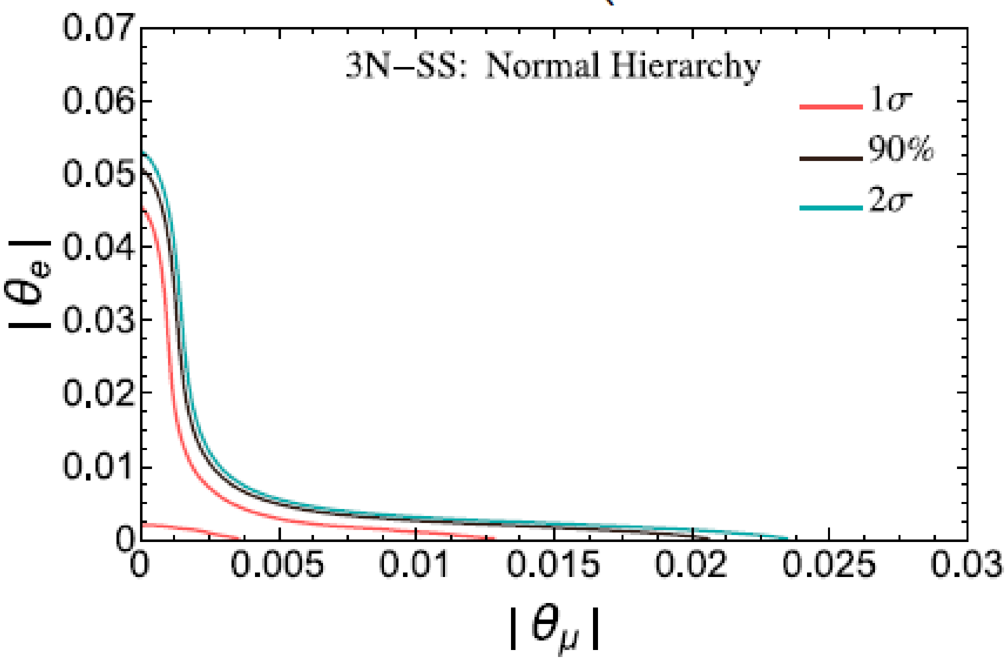
Lepton weak universality from π, K and τ decay ratios

LVF processes from the loss of the GIM cancellation...

Probing the Seesaw: Non-Unitarity

Recent bounds from a global fit to flavour and Electroweak precision data (28 observables considered) EFM, J. Hernandez-Garcia and J. Lopez-Pavon arXiv:1605.08774

$$|\eta_{\alpha\beta}| \leq \begin{pmatrix} 1.3\cdot 10^{-3} & 1.2\cdot 10^{-5} & 1.4\cdot 10^{-3} \\ 1.2\cdot 10^{-5} & 2.0\cdot 10^{-4} & 6.0\cdot 10^{-4} \\ 1.4\cdot 10^{-3} & 6.0\cdot 10^{-4} & 2.8\cdot 10^{-3} \end{pmatrix}$$



$$N = (1-\eta)U_{PMNS} \qquad \eta = \frac{\Theta\Theta^\dagger}{2}$$

$$\Theta = m_D M_N^{-1}$$

See talk by Josu Hernandez
Thursday 15:30 WG4+5

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Despite some confusion in present literature non-unitarity from heavy ν mixing is beyond the reach of present and near future facilities (given the 10^{-3}-10^{-4} bounds)

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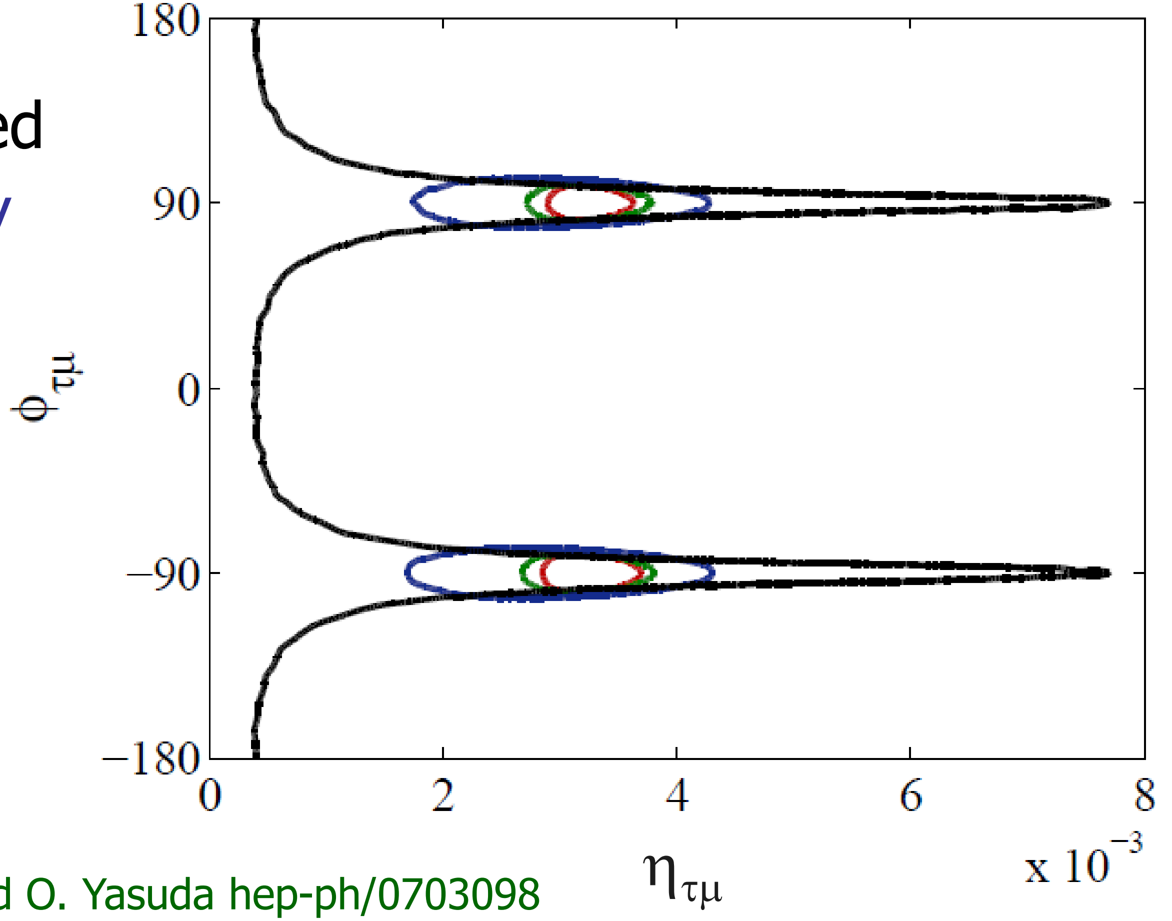
But it could be probed at a Neutrino Factory



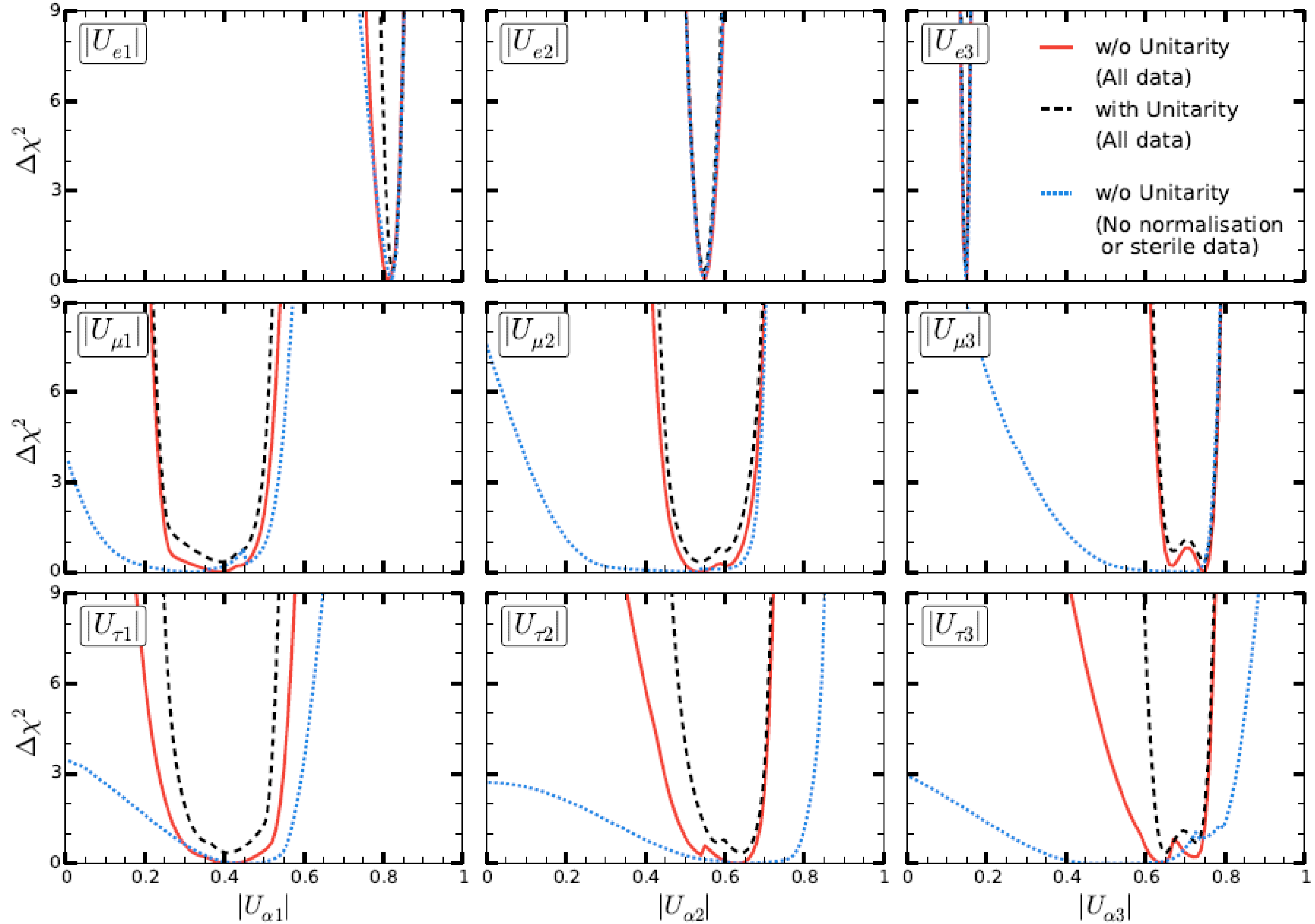
EFM, B. Gavela, J. Lopez-Pavon and O. Yasuda hep-ph/0703098
S. Antusch, M. Blennow, EFM and J. Lopez-Pavon arXiv:0903.3986

Probing the Seesaw: Steriles

For very light (< keV) extra neutrinos these strong constraints are lost and ν oscillations are our best probe of this scale.

See talk by Mark Ross-Lonergan and sterile ν talks

Friday WG1+5



S. Parke and M. Ross-Lonergan arXiv:1508.05095

Probing the Seesaw: Steriles vs NU

Non-unitarity (from heavy ν mixing) constraints from precision EW and flavour observables

$$|\eta_{\alpha\beta}| \leq \begin{pmatrix} 1.3\cdot 10^{-3} & 1.2\cdot 10^{-5} & 1.4\cdot 10^{-3} \\ 1.2\cdot 10^{-5} & 2.0\cdot 10^{-4} & 6.0\cdot 10^{-4} \\ 1.4\cdot 10^{-3} & 6.0\cdot 10^{-4} & 2.8\cdot 10^{-3} \end{pmatrix}$$

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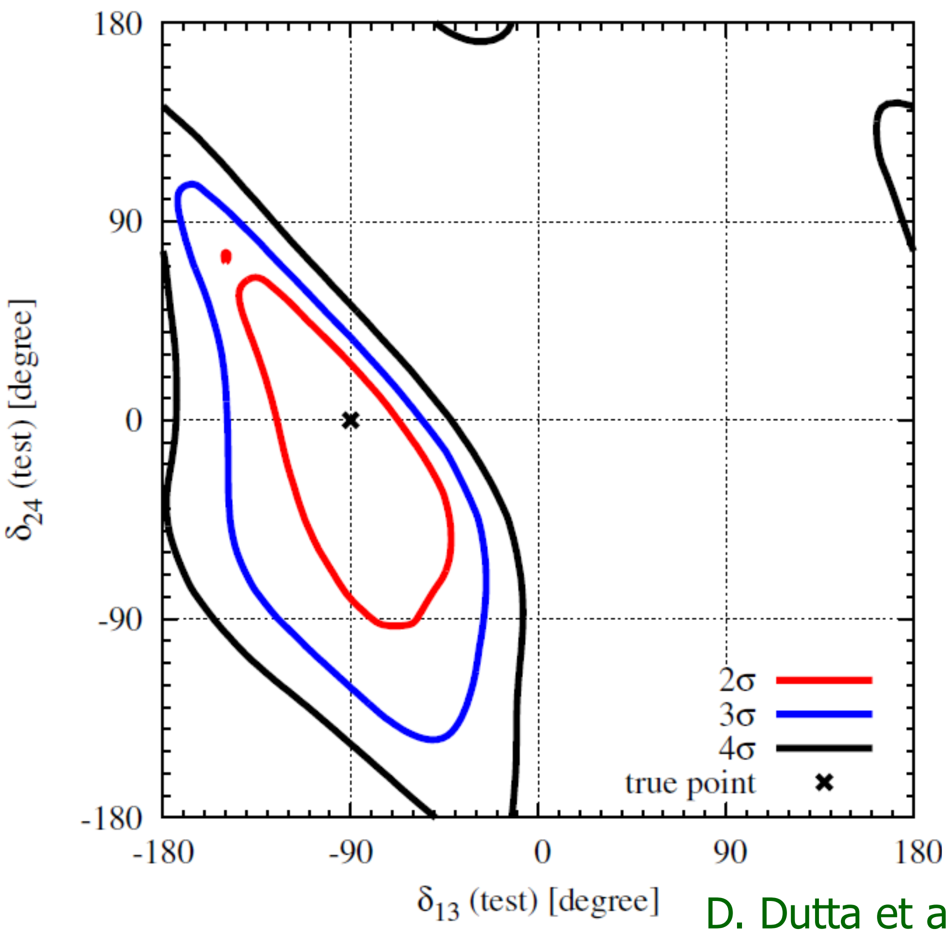
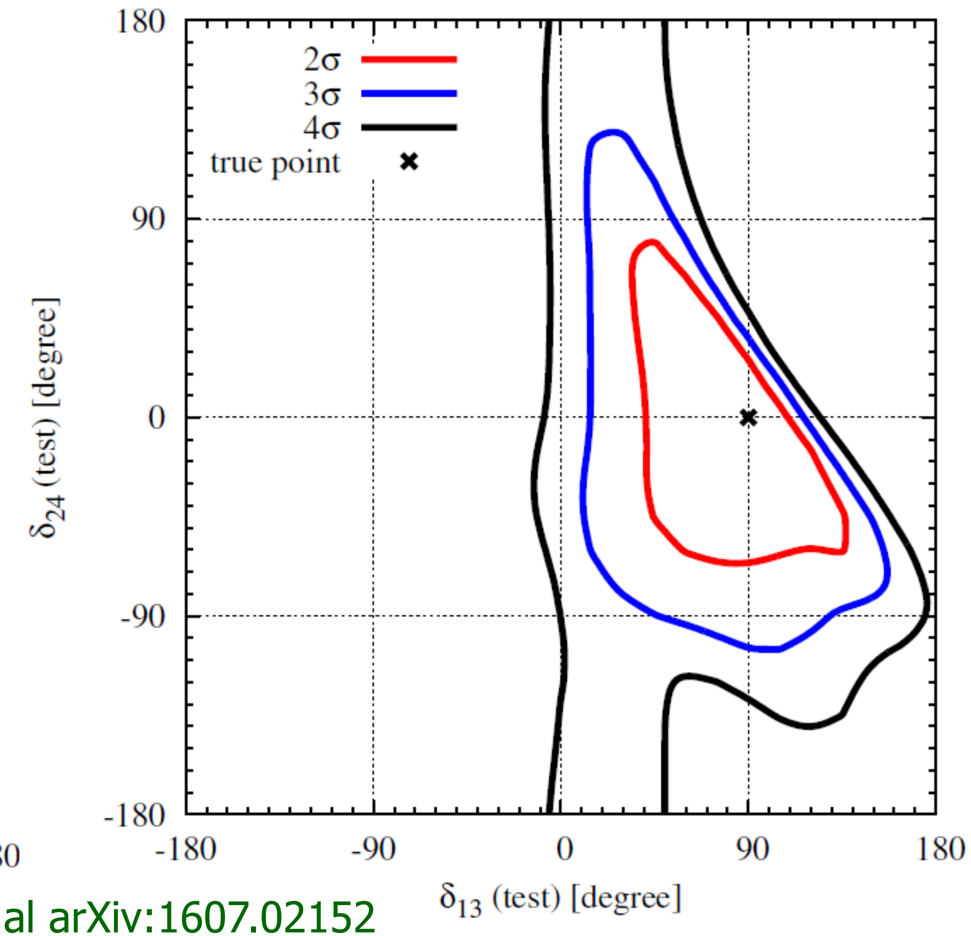
@ 95% CL

$$|\eta_{\alpha\beta}| \leq \begin{pmatrix} 2.6\cdot 10^{-2} & 2.4\cdot 10^{-2} & 3.6\cdot 10^{-2} \\ 2.4\cdot 10^{-2} & 4.5\cdot 10^{-2} & 4.8\cdot 10^{-2} \\ 3.6\cdot 10^{-2} & 4.8\cdot 10^{-2} & 0.10 \end{pmatrix}$$

Non-unitarity (from light ν mixing) constraints from oscillation searches

Steriles and CPV at DUNE far detector



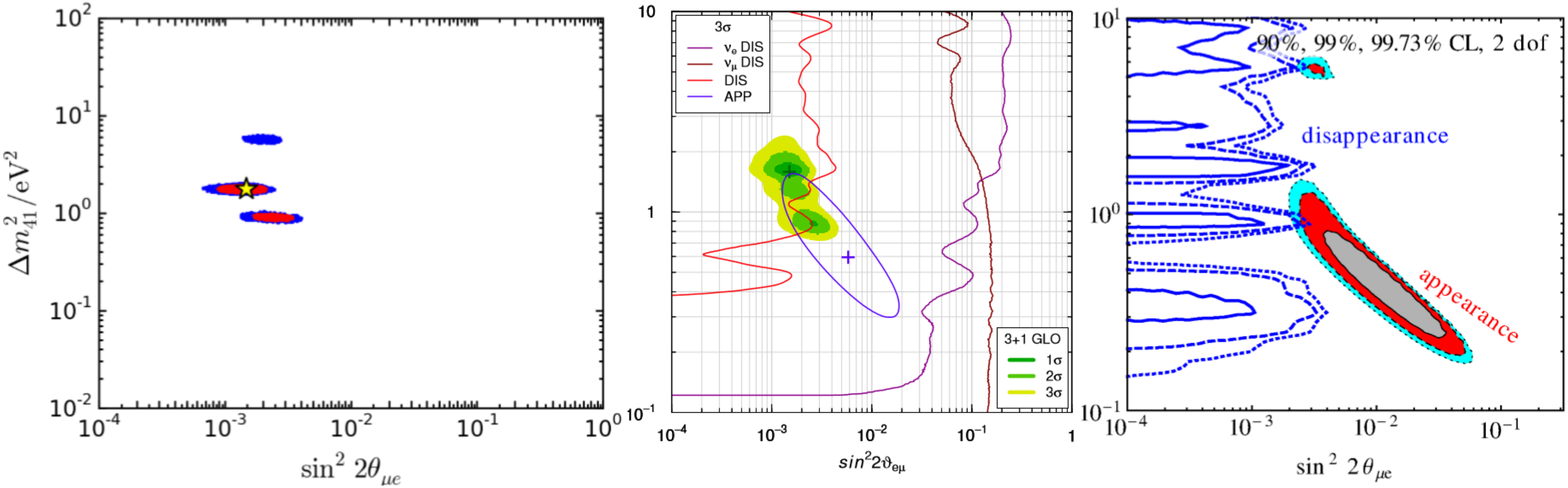


D. Dutta et al arXiv:1607.02152

See also talk by Sanjib Agarwalla Friday WG1+5

Probing the Seesaw: Steriles

Present sterile neutrino anomalies



G. H. Collin et al arXiv:1602.00671; S. Gariazzo et al arXiv:1507.08204; J. Kopp et al arXiv:1303.3011

Can also be interpretetd in a (really) low scale Seesaw context

A. de Gouvea hep-ph/0501039; A. Donini et al 1106.0064; M. Blennow and EFM 1107.3992
J. Fan and P. Langacker 1201.6662; A. Donini et al 1205.5230

Conclusions

- Neutrino masses and mixings point to a new physics scale where Lepton number is broken
- Different phenomenology depending on the scale
- Present and near future ν oscillation facilities can probe the very low scale (sterile ν) limit
- Neutrino Factory could also explore the very high scale scenario (PMNS non-unitarity)