Probing $0\nu\beta\beta$ Decay in Multiple Isotopes

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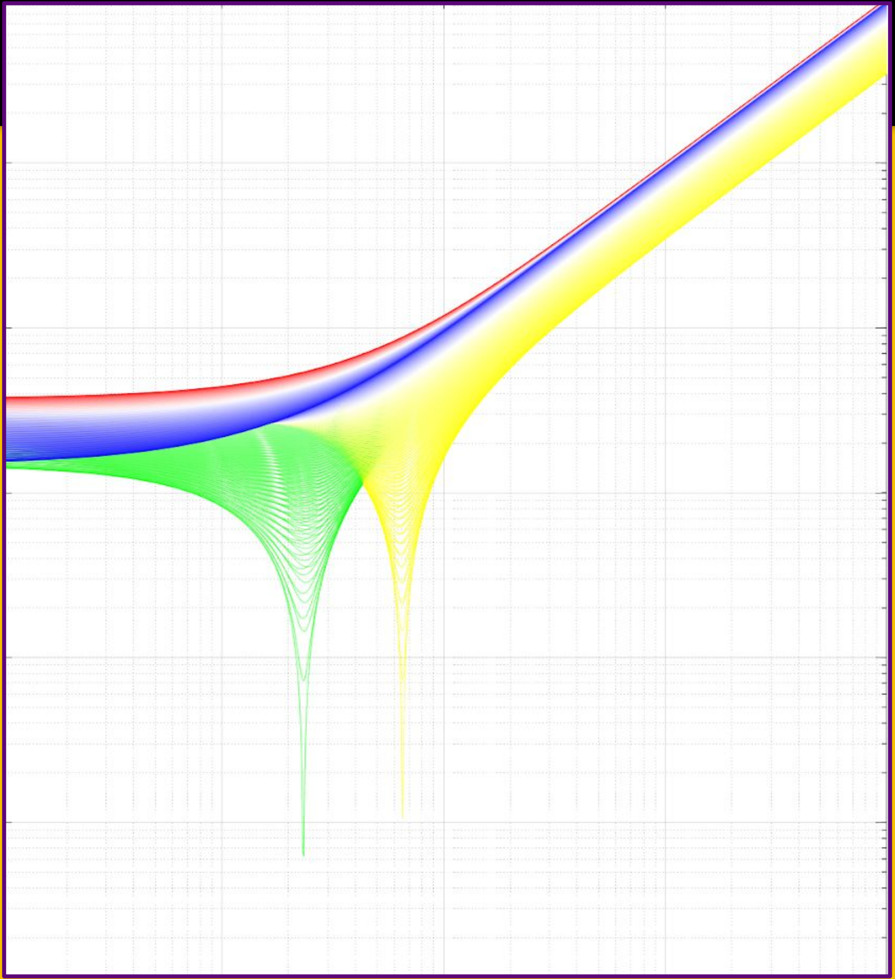
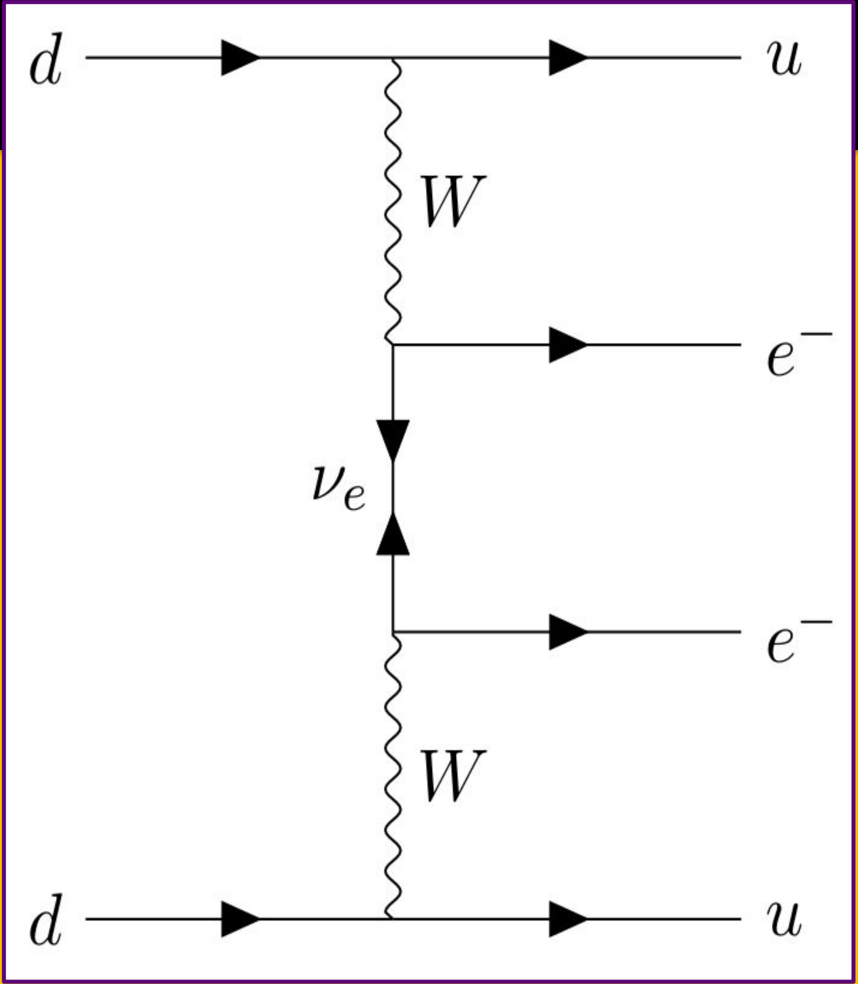


Neutrinos and $0\nu\beta\beta$

- **Flavour oscillation ⇒ massive neutrinos**
- Cosmology, oscillations, β-decay provide partial answers and constraints.
- $0\nu\beta\beta$ -- just another probe? No!
  - Sensitive to LNV
  - May differentiate mass mechanisms
- Current bounds (@90%)
  - GERDA: $T_{1/2} > 1.8 \cdot 10^{26}$ y [1]
  - KamLAND-Zen: $T_{1/2} > 1.1 \cdot 10^{26}$ y [2]

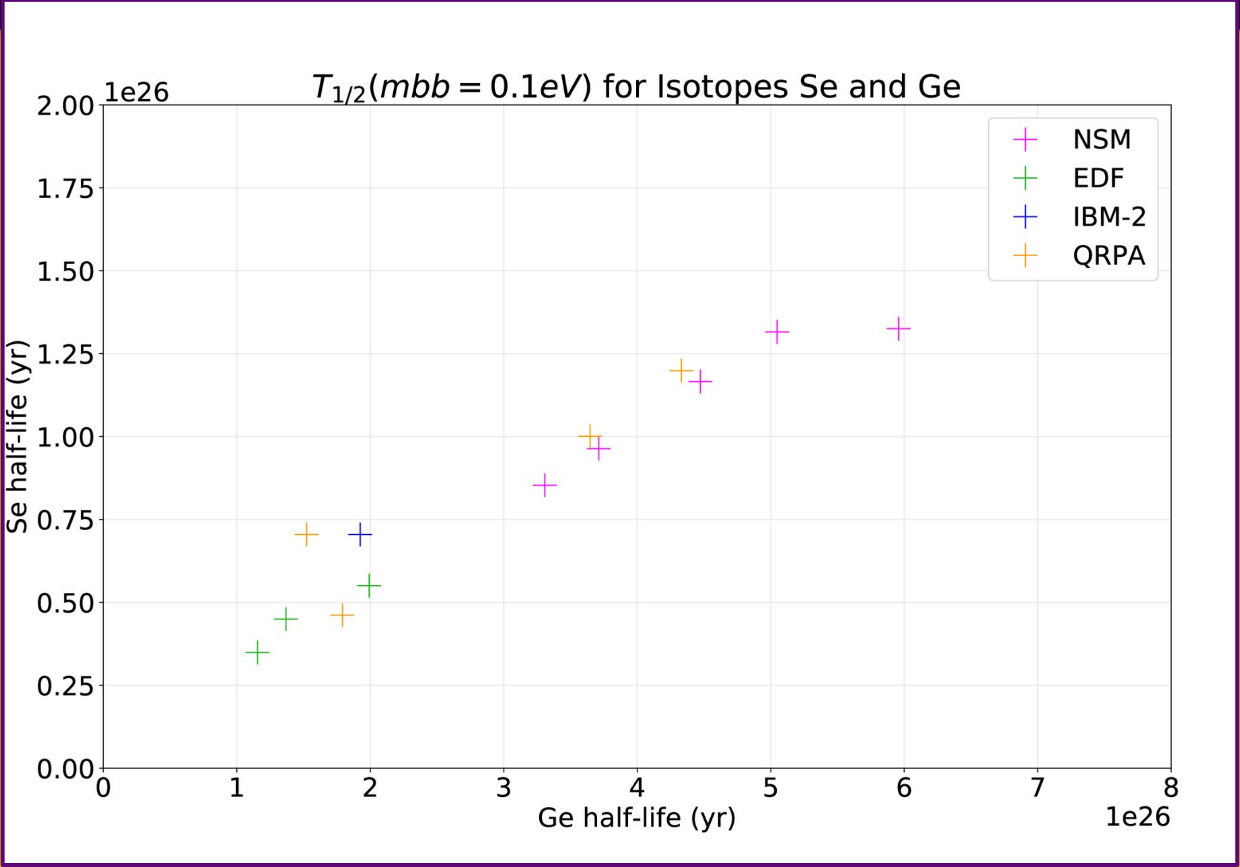


Nuclear Matrix Elements (NMEs)

- Observable $m_{\beta\beta}$ related to decay half-life: [3]

$$T_{1/2}^{-1} = G_{0\nu}|\mathbb{M}|^2 m_{\beta\beta}^2$$

- NMEs are key source of error for $0\nu\beta\beta$ theory.
- However, discrepancies are correlated for (some) pairs of isotopes.



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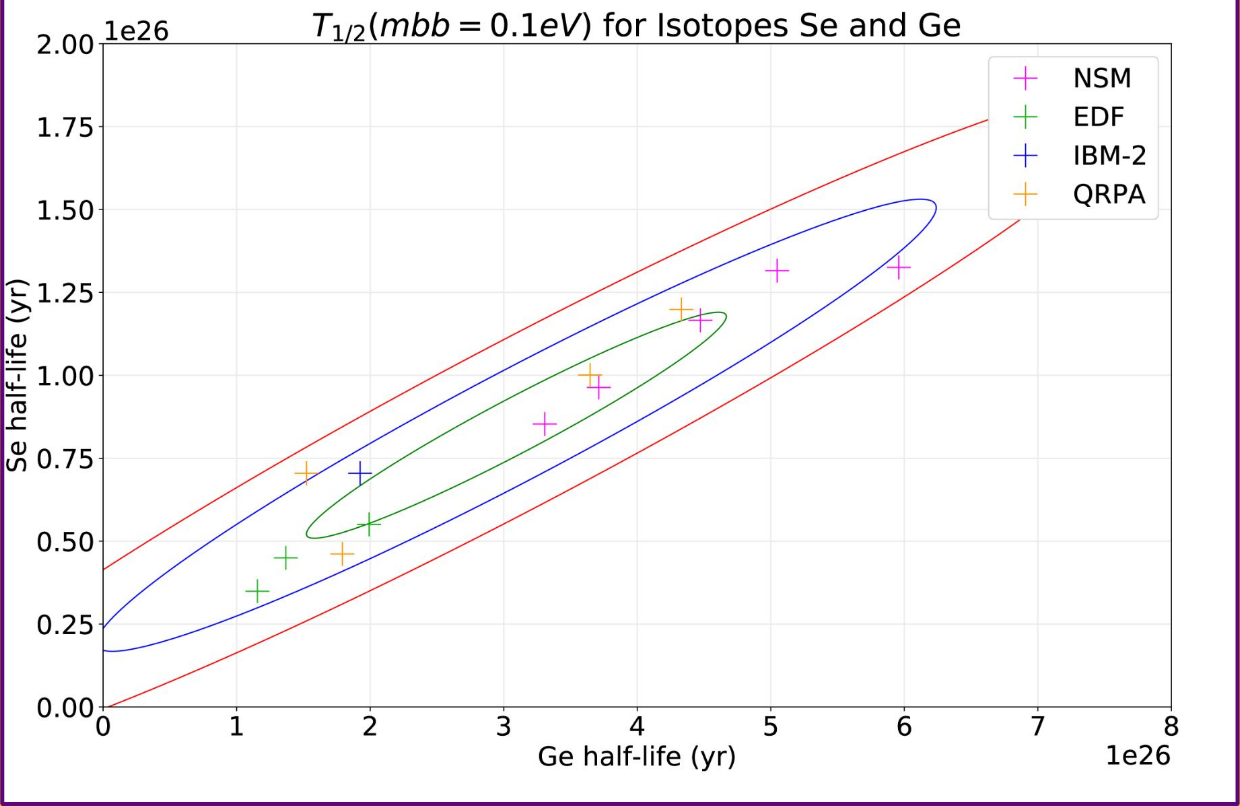


Searching for Short-Range Mechanisms

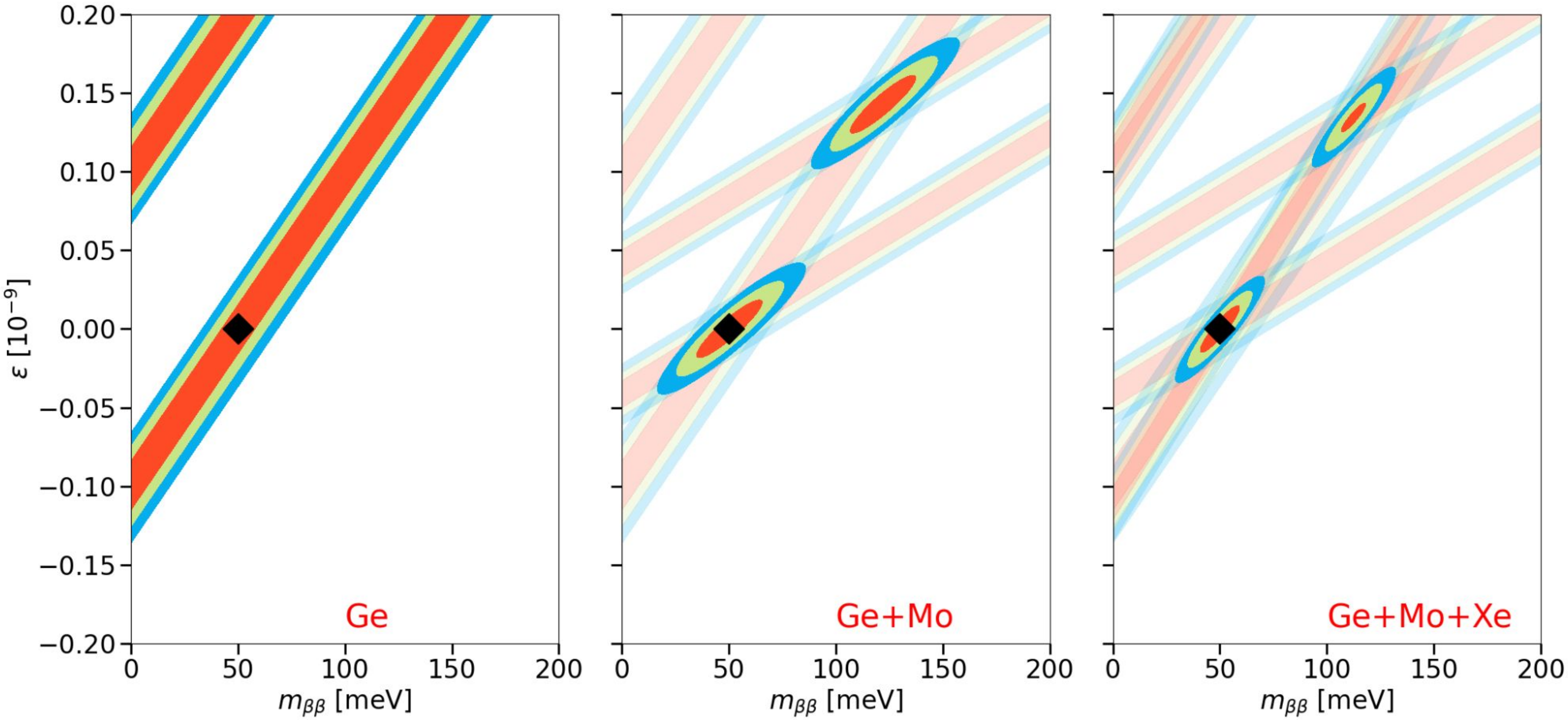
- **Question:** To what extent can multi-isotope observations constrain exotic mechanisms?
  - Can correlations in NME error improve the strength of inferences?

- Numerous parameterised mechanisms [Deppisch et al. Phys. Rev. D 102, 095016 (2020)]
- We consider a single exotic $0\nu\beta\beta$ mechanism with its own "heavy NME" (a la RPV SUSY):

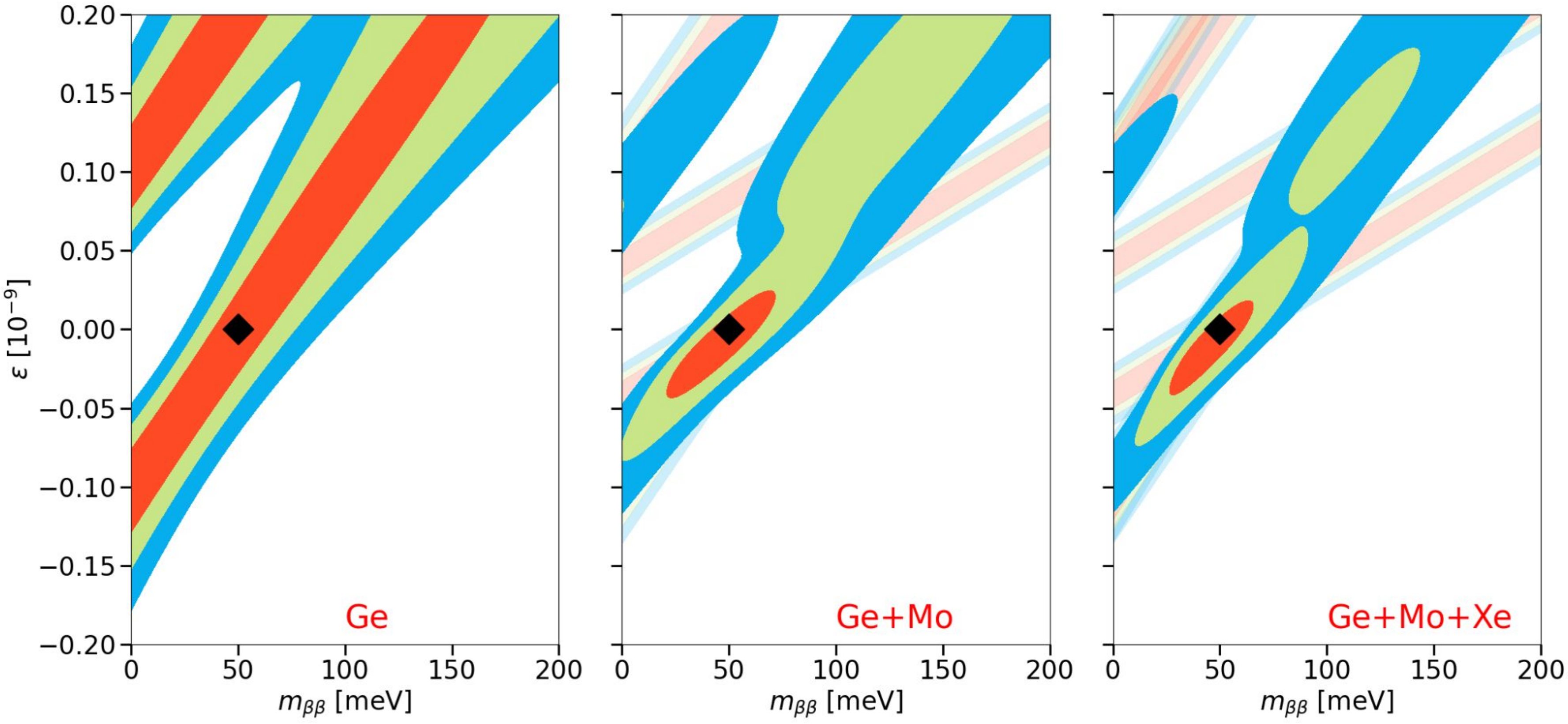
$$T_{1/2}^{-1} = G_{iso} \left| \frac{m_{\beta\beta}}{m_e} M_{\nu,iso} + \epsilon M_{H,iso} \right|^2$$

- Any fixed $0\nu\beta\beta$ half-life corresponds to two parallel-line solutions in $\{m_{\beta\beta}, \varepsilon\}$

χ^2 Likelihoods for Ge, Ge/Mo, Ge/Mo/Xe



χ^2 Likelihoods with Uncorrelated NME Errors



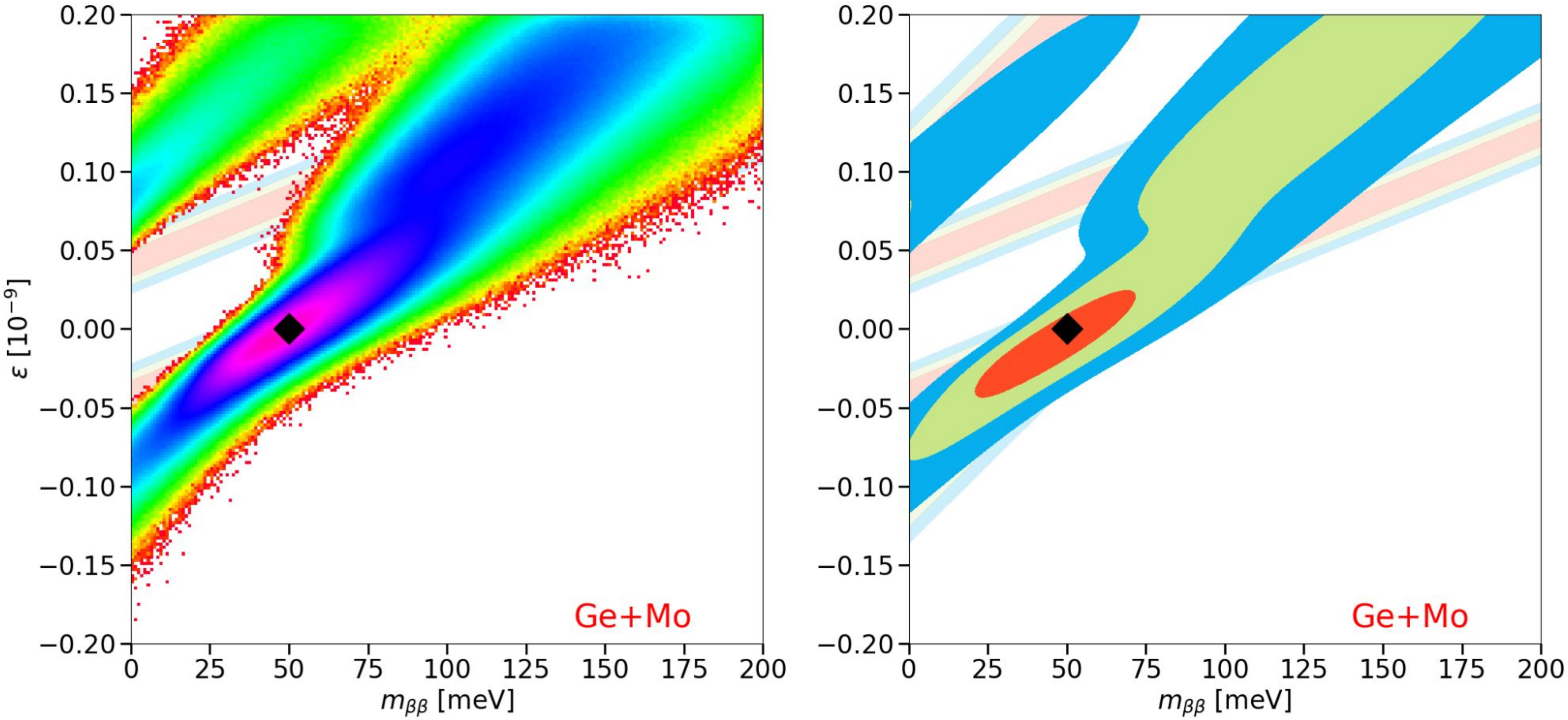
Bayesian Inference

- Update prior knowledge $\pi(\theta)$ with likelihood $L_X(\theta)$ to obtain posterior knowledge $p(\theta)$.

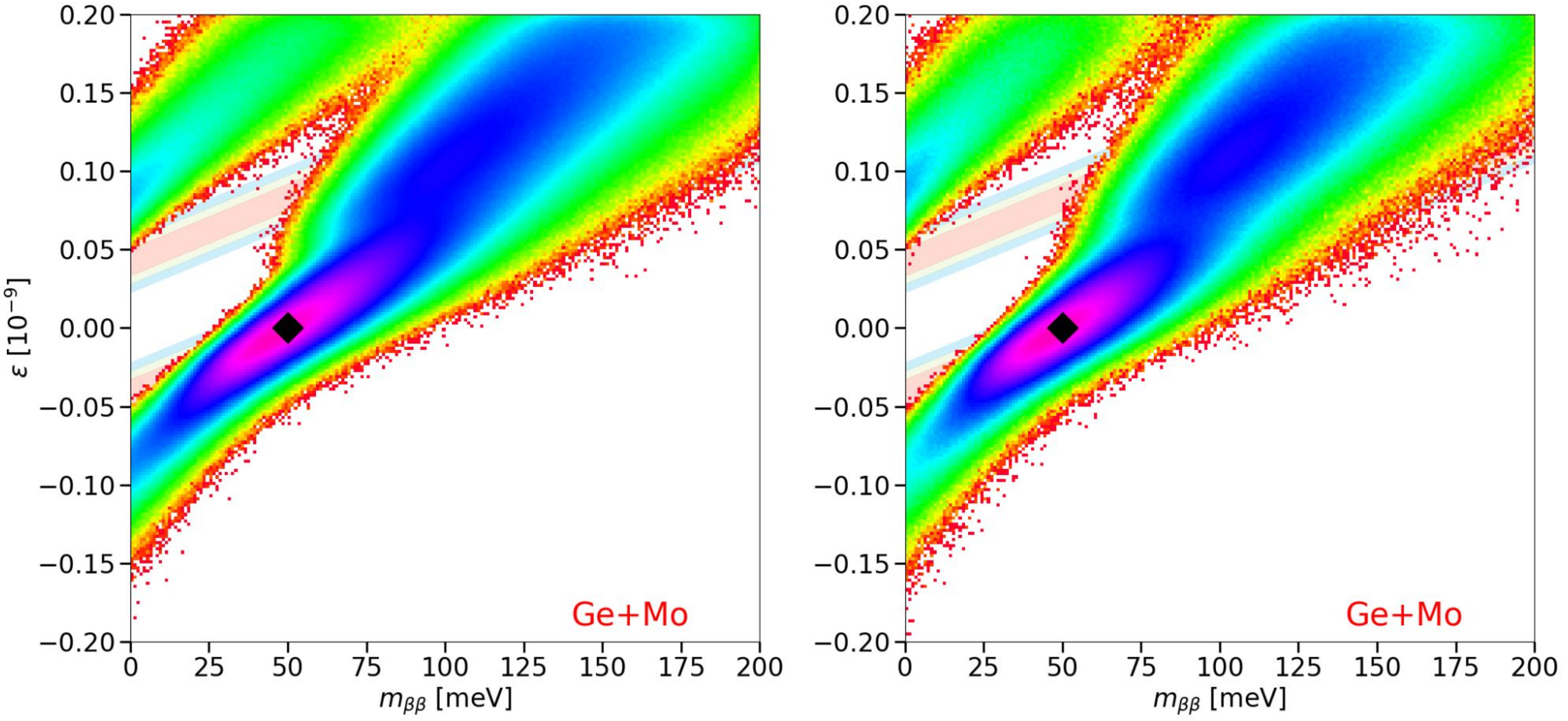
$$p(\boldsymbol{\theta}) = \frac{L_X(\boldsymbol{\theta})\pi(\boldsymbol{\theta})}{\int L_{\mathbf{X}}(\boldsymbol{\theta}')\pi(\boldsymbol{\theta}')d\boldsymbol{\theta}'_H} \equiv \frac{L_{\mathbf{X}}(\boldsymbol{\theta})\pi(\boldsymbol{\theta})}{M^H_{\mathbf{X}}}$$

- Markov Chain Monte Carlo (MCMC) samples $p(\theta)$ using only local distributions.
  - Locality helps to combat MC rejection problems at high-dimensionalities.
- Our parameter space: $\{m_{\beta\beta}, \varepsilon\}$ + $\{M_\nu, M_H\}$ for each isotope
  - Flat priors on $m_{\beta\beta}$, ε – see [Deppisch, Van Goffrier Phys. Rev. D 104, 055040 (2021)]
  - Careful tuning of the proposal width needed to achieve heuristic 25% acceptance.

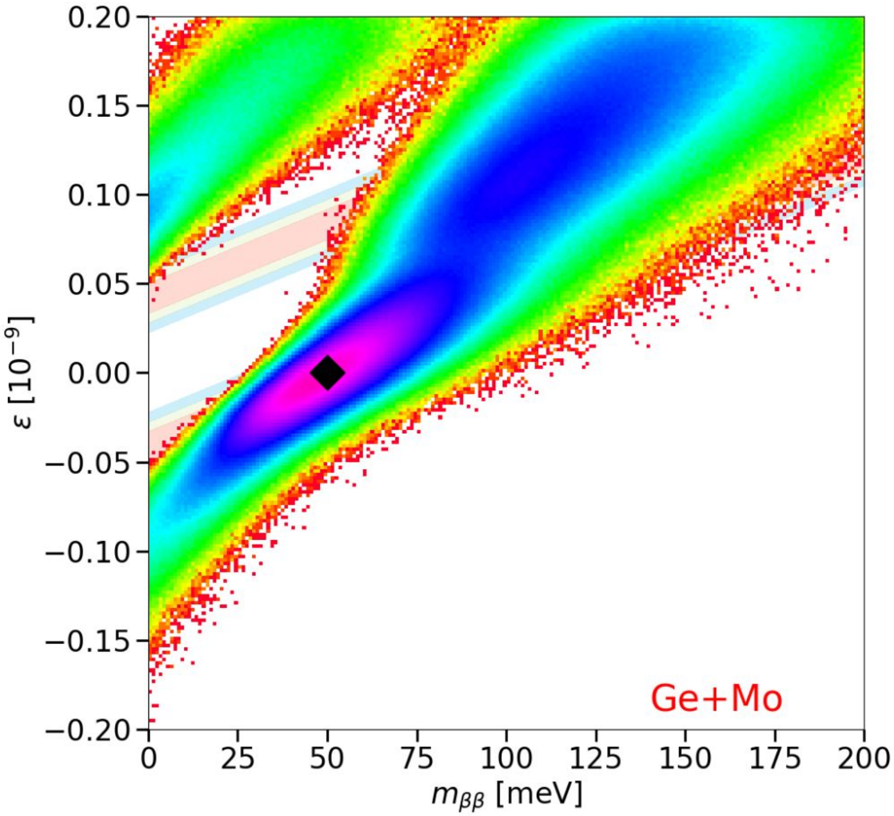
MCMC with Uncorrelated NME Errors

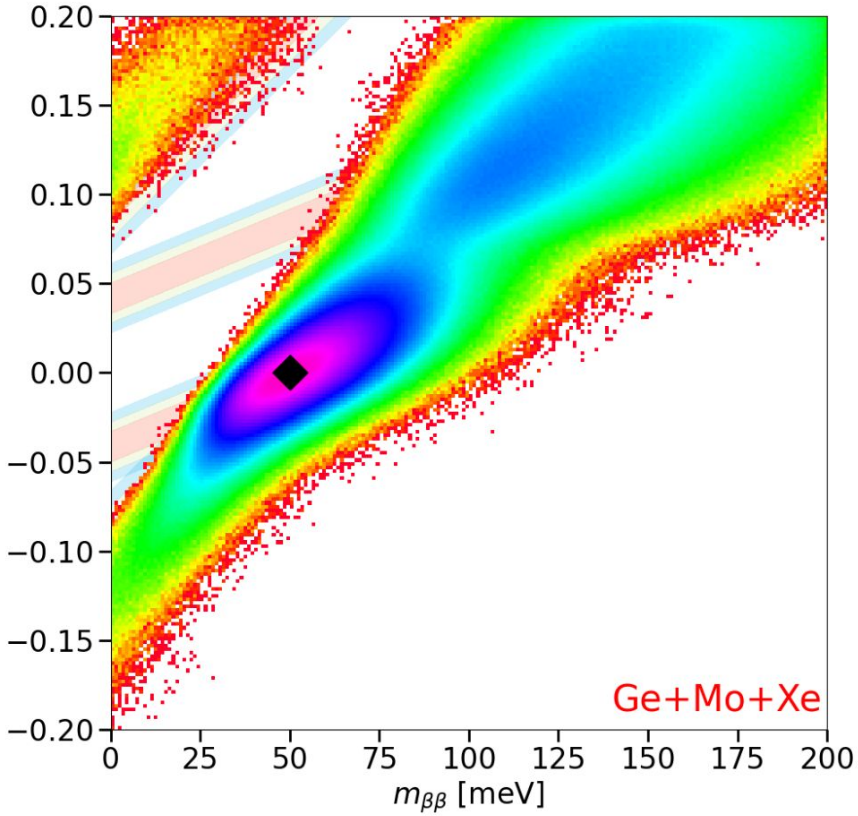


Uncorrelated vs. Correlated



Ge+Mo vs. Ge+Mo+Xe





Conclusions

- Multi-isotope observations put multi-mechanism constraints within reach!
    - We have examined representative next-gen Ge, Mo, Xe experiments in coalition.

- Two-isotope combinations suffer from anomalous "secondary peaks" in $\{m_{\beta\beta}, \varepsilon\}$.
    - A third isotope can suppress the extra peaks, contingent on its slope.
    - Extra peaks also excluded by cosmology in many scenarios. [3]

- These results hold even when taking account of current NME errors.
    - NME correlations indeed improve inference, but more weakly than a third isotope.

THANK YOU FOR LISTENING!

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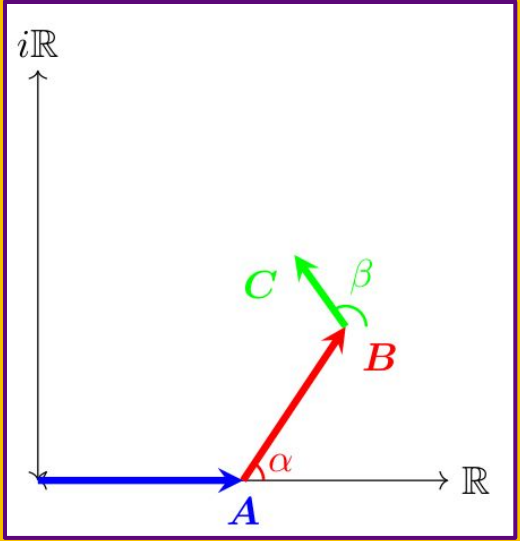
HUGE thank you to my supervisors at UCL: Prof. Frank Deppisch, Dr. Matteo Agostini

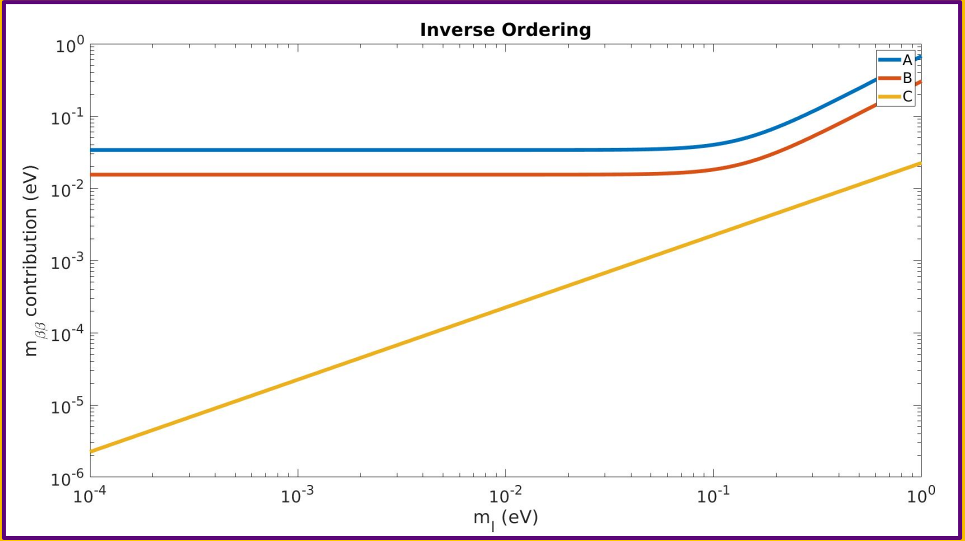
Backup I: Neutrinos and $0\nu\beta\beta$

- $m_{\beta\beta}$ dependent on neutrino masses and two Majorana phases α and β:

$$m_{\beta\beta} = \left| c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 m_2 e^{i\alpha} + s_{13}^2 m_3 e^{i\beta} \right| = \left| A + B e^{i\alpha} + C e^{i\beta} \right|$$

- With IO hierarchy, small m_3 causes C << A, B.





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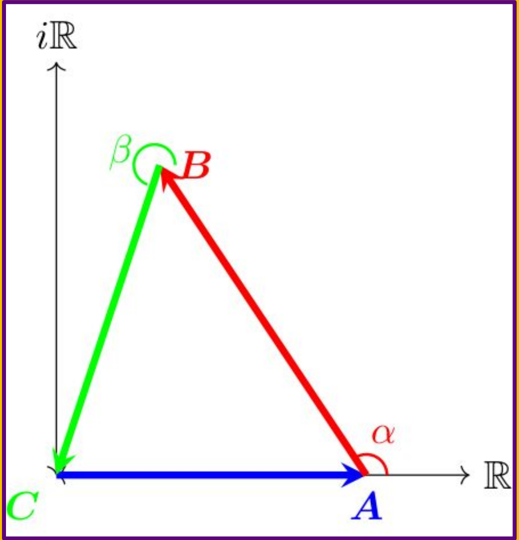
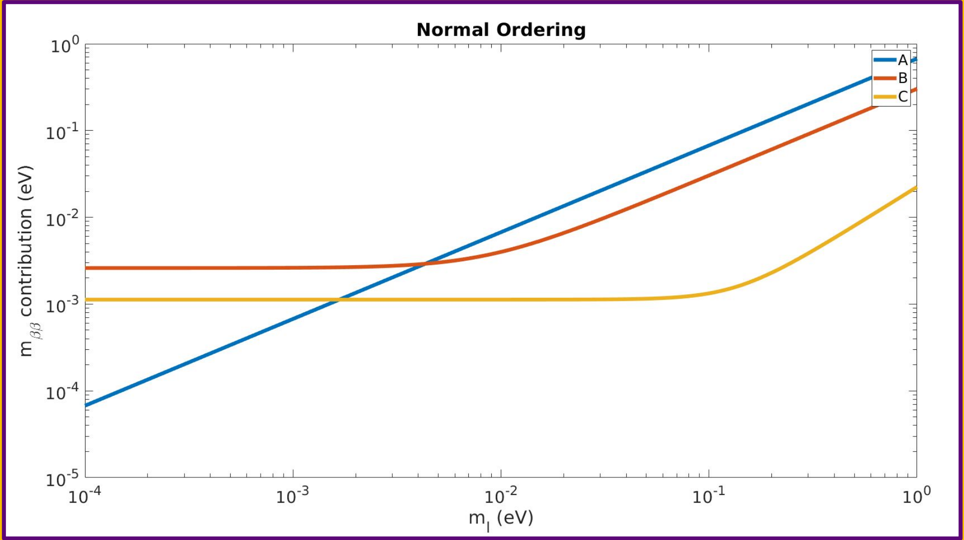
- With NO hierarchy, possible to tune parameters and drive $m_{\beta\beta} \rightarrow 0$.





Backup II: Least-Informative Priors

- **Information theory:** we want posterior to arise from experiment, not our prior biases.
- Information gain from prior to posterior captured in the Kullback-Leibler divergence.
- Define Least-Informative Prior (LIP) as prior which maximises expected information gain.

$$\langle D_{KL}(p|\pi)\rangle_{data} = \int dX \int d\theta \; p(\theta|X) \log\left(\frac{p(\theta|X)}{\pi(\theta)}\right)$$

- No prior is bias-free, but the LIP can serve as a reference with which to compare others.