Neutrinoless Double Beta Decay Nuclear Matrix Elements

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BNL's NSAC Town Hall

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Speaking from Setauket land

Neutrinos have mass[1]!

One of the biggest open questions in particle physics[2]

$$\boxed{\text{Neutrino mass} = \text{Dirac mass } (+ \text{ Majorana mass?})}$$

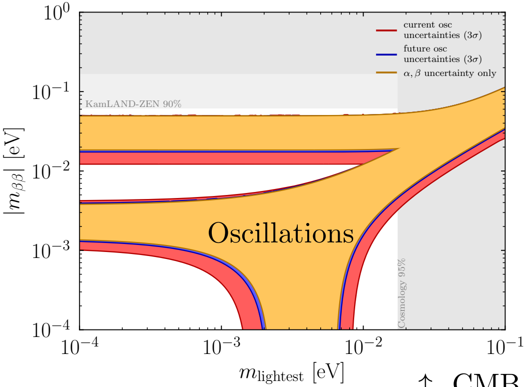
UV completing and diagonalizing this leads to many options
No obvious choice

[1] Technically first observed by BNL's Ray Davis Jr. ⇒ Nobel Prize 2002
Second Nobel prize in 2015

[2] Recommendations I, II of '15 NSAC report
one of the five science drivers in the '14 US P5 report,
one of two major developments for the European strategy update '20,

Allowed space for Majorana mass term

Searches for $0\nu\beta\beta$ constrain $|m_{\beta\beta}| \longrightarrow$



$\uparrow$ CMB and LSS constrain $\sum_i m_i$

$$(T_{1/2})^{-1} = G_{01}|\mathcal{M}(A,Z)|^2|m_{\beta\beta}|^2$$

Rate	Phase space	Matrix element	Effective mass
Measured/ constrained	Known	Uncertain	Determined

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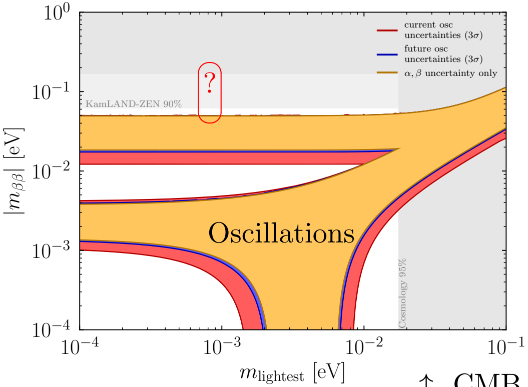

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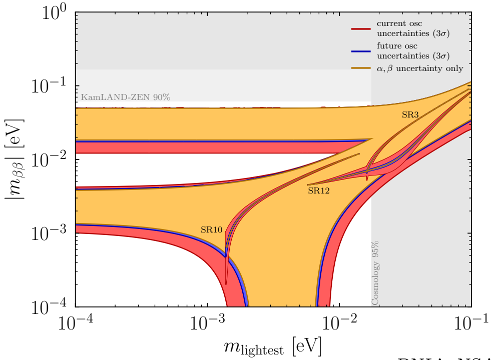
Getting it right matters

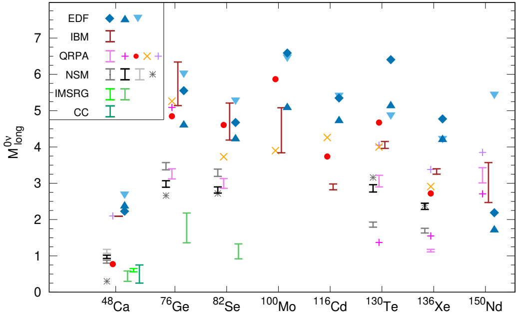
1. Backgrounds and energy resolution are hard; we have to *know* we have $0\nu\beta\beta$
2. Current plan is to compare two detections
3. Need to be consistent with oscillations and cosmology

Even more new physics?

4. Flavor models predict Majorana phases α, β



Neutrinoless double beta decay nuclear matrix element



LEGEND
GERDA
MAJORANA

CUPID

SNO+

KamLAND-Zen
EXO/nEXO

M. Agostini, et al 2202.01787
$0\nu\beta\beta$ Whitepaper 2203.12169

Where's the problem?

Nuclear matrix elements for this process for large elements are *hard*

1. Pheno methods include:
   - shell model
   - quasiparticle random-phase approximation
   - interacting boson model
   - generator coordinate method
2. No data exists so uncertainties are very uncertain
3. Recently, has been a shift from pheno to ab initio for "lighter" elements
   - in-medium generator-coordinate method
   - valence space
   - coupled cluster
4. Some level of compatability for ^{48}Ca
5. Improvements required in code and computational resources
6. Lattice QCD also helps connect to EFT understanding

Conclusions

- Measuring $0\nu\beta\beta$ is a major discovery opportunity
- Nuclear matrix element uncertainty is quite large
- Current plan:
  1. Discover $0\nu\beta\beta$
  2. Confirm it with different element
  3. "Solve" matrix element problem by comparing
- Would be better to have better calculations