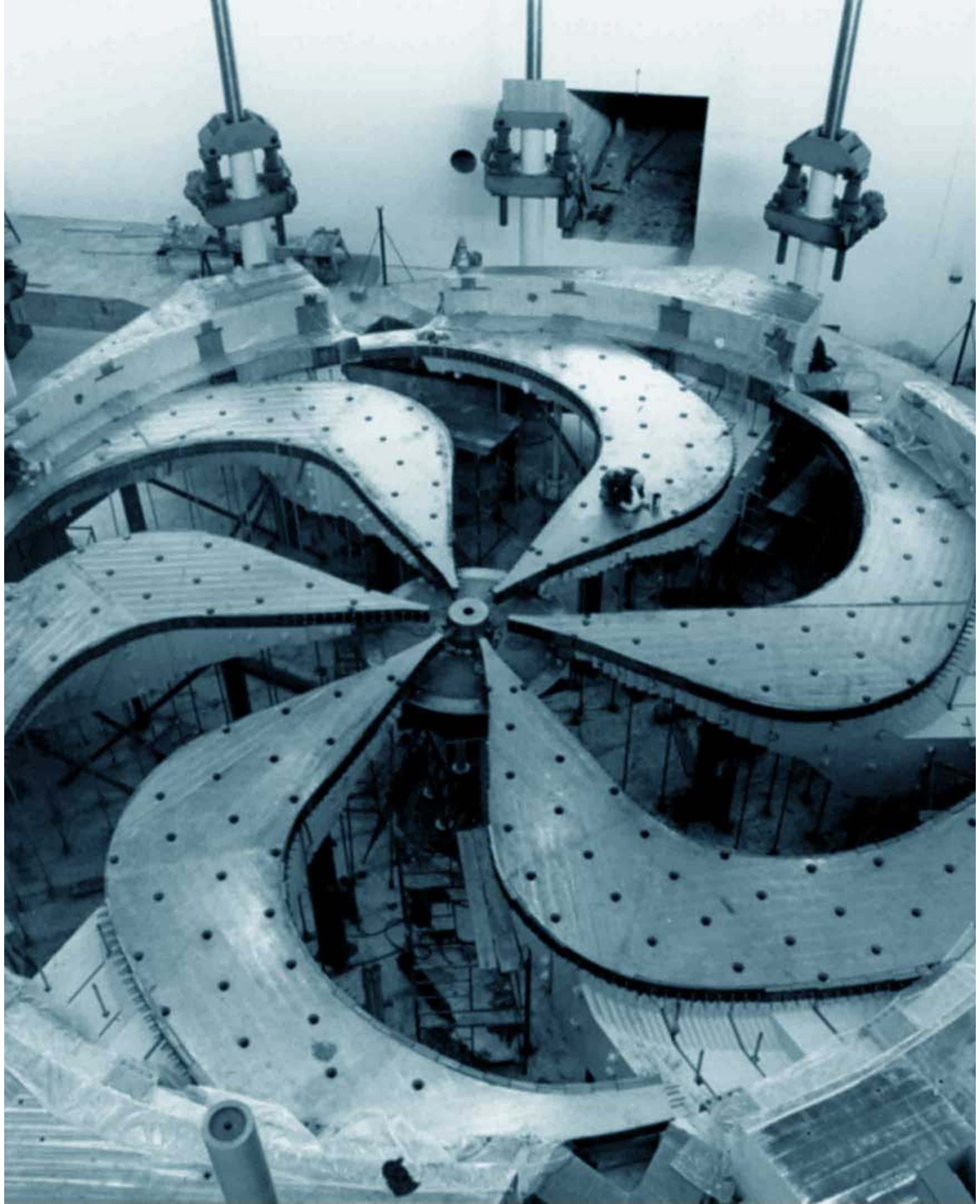
TRIUMF

THE UNIVERSITY OF BRITISH COLUMBIA

Ab initio 0νββ nuclear matrix elements



Antoine Belley

WNPPC 2021

CINP ICPN

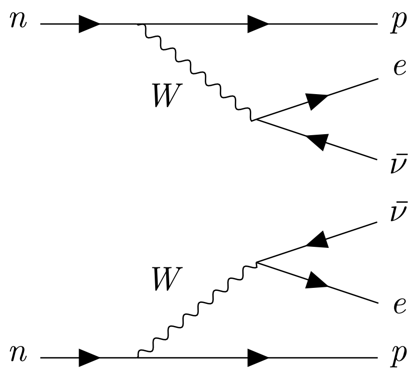
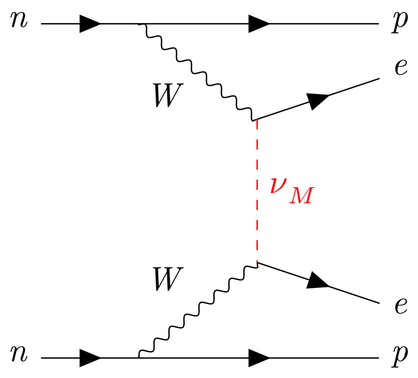
NSERC CRSNG

Arthur B. McDonald Canadian Astroparticle Physics Research Institute

NRC·CNRC

Discovery, accelerated

2νββ vs 0νββ

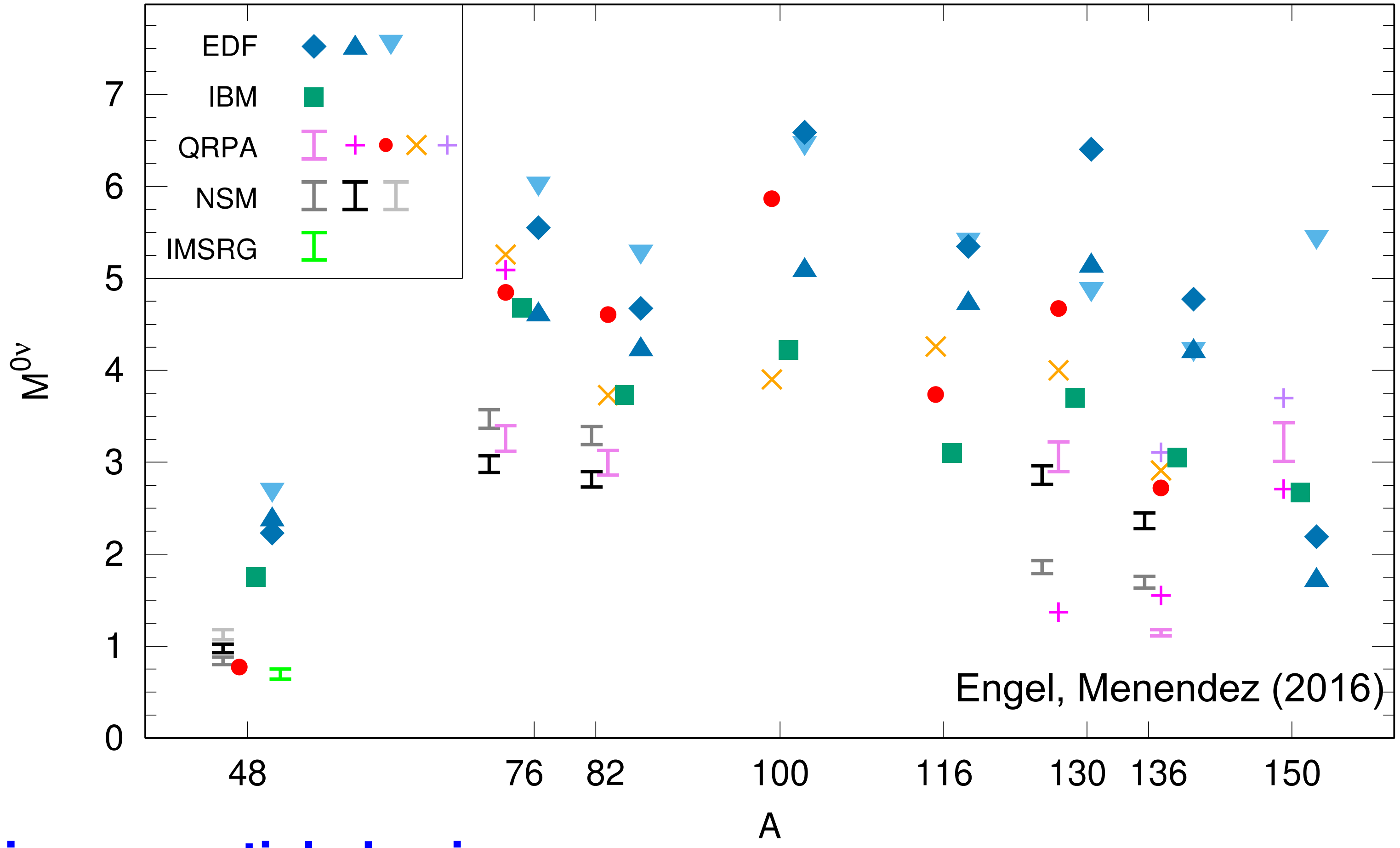
Decay	$2\nu\beta\beta$	$0\nu\beta\beta$
Diagram		
Half-life Formula	$[T^{2\nu}_{1/2}]^{-1} = G^{2\nu}\|M^{2\nu}\|^2$	$[T^{0\nu}_{1/2}]^{-1} = G^{0\nu}\|M^{0\nu}\|^2 \left(\frac{\langle m_{\beta\beta}\rangle}{m_e}\right)^2$
*NME Formula	$M^{2\nu} \approx M^{2\nu}_{GT}$	$M^{0\nu} = M^{0\nu}_{GT} - (\frac{g_v}{g_a})^2 M^{0\nu}_F + M^{0\nu}_T$
**LNV	No	Yes!!!
Observed	Yes (extremely rare)	No

*NME : Nuclear matrix elements
**LNV : Lepton number violation

TRIUMF

Status of 0νββ-decay Matrix Elements

Current calculations from phenomenological models have large spread in results.



All models missing essential physics

Impossible to assign rigorous uncertainties

Nuclear matrix elements

$$NME = \sum_n \sum_m \langle n | \hat{O} | m \rangle$$

$| n \rangle$ are the eigenstates of the nuclear hamiltonian involved in the transition.

$\hat{O}$ is the operator we wish to find the NME of.

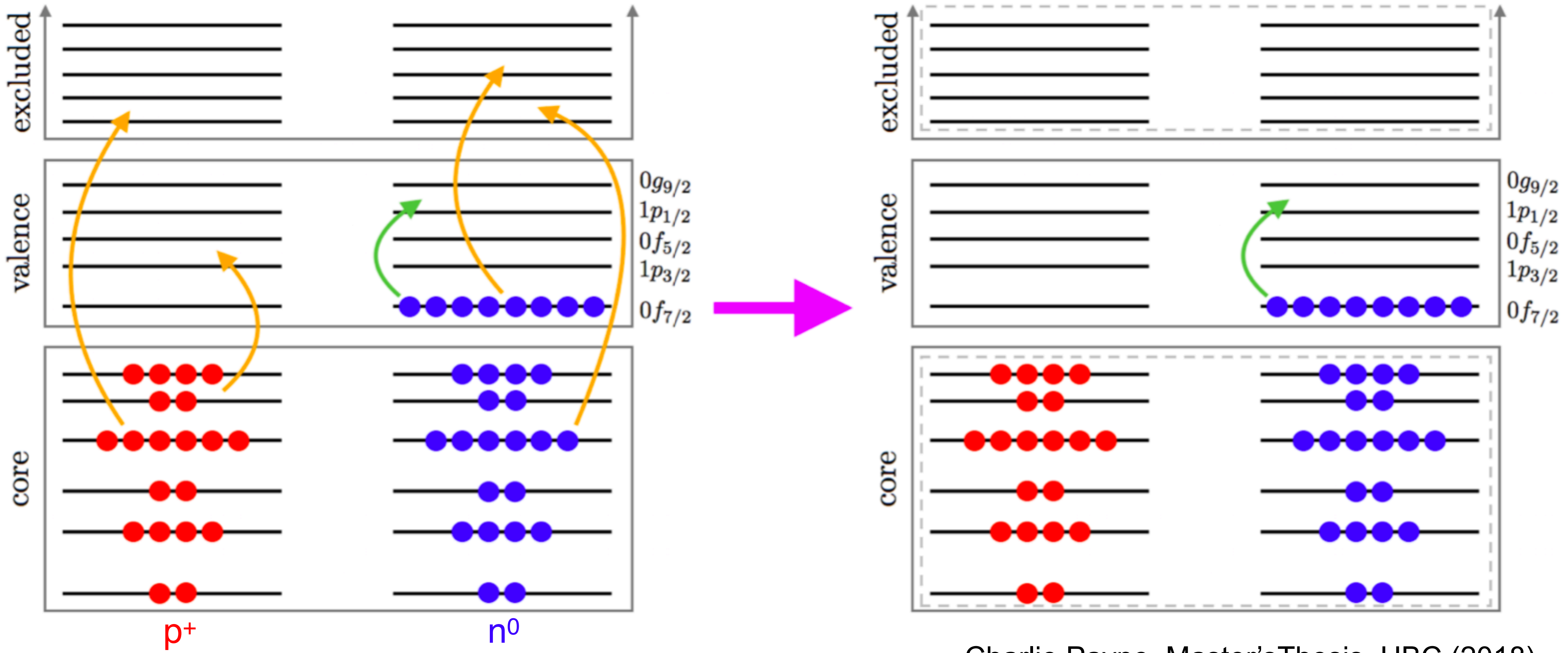
Nuclear matrix elements

$$NME = \sum_n \sum_m \langle n | \hat{O} | m \rangle$$

$| n \rangle$ are the eigenstates of the nuclear hamiltonian involved in the transition.
$\hat{O}$ is the operator we wish to find the NME of.

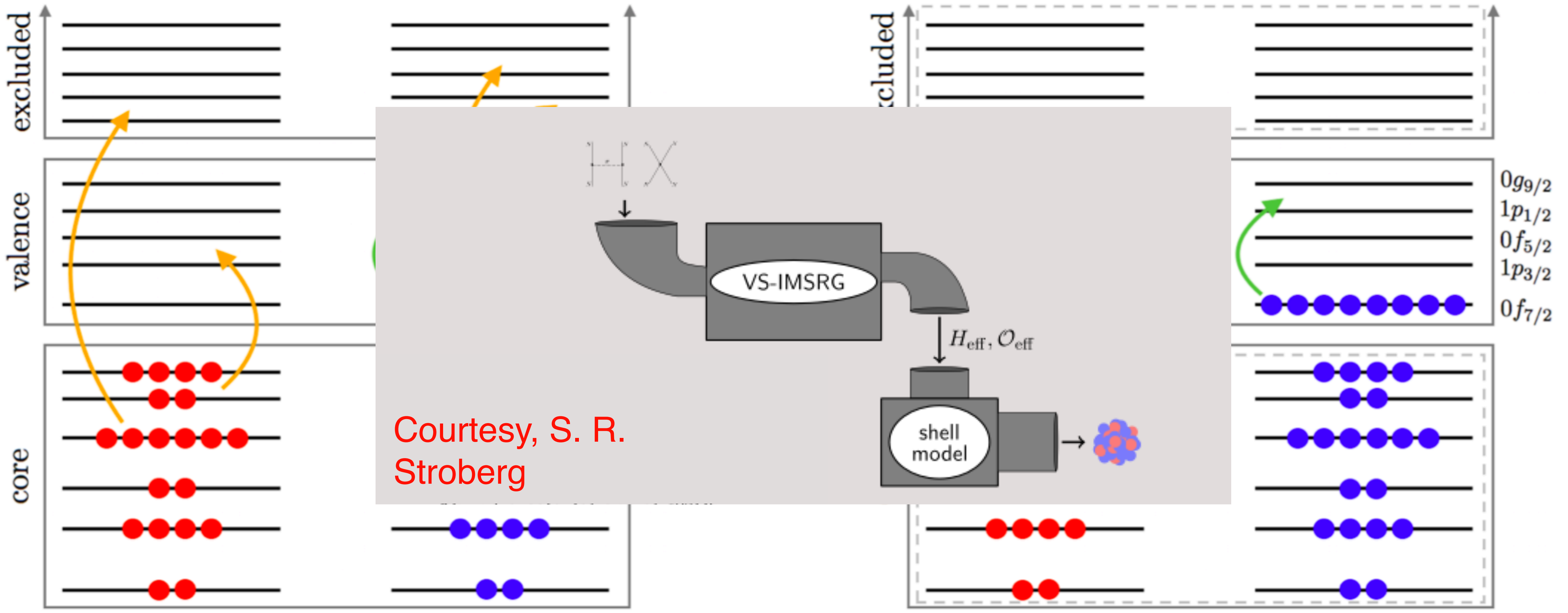
$\Rightarrow$ We need the nuclei wave functions!

Valence-Space In Medium Similarity Renormalization Group

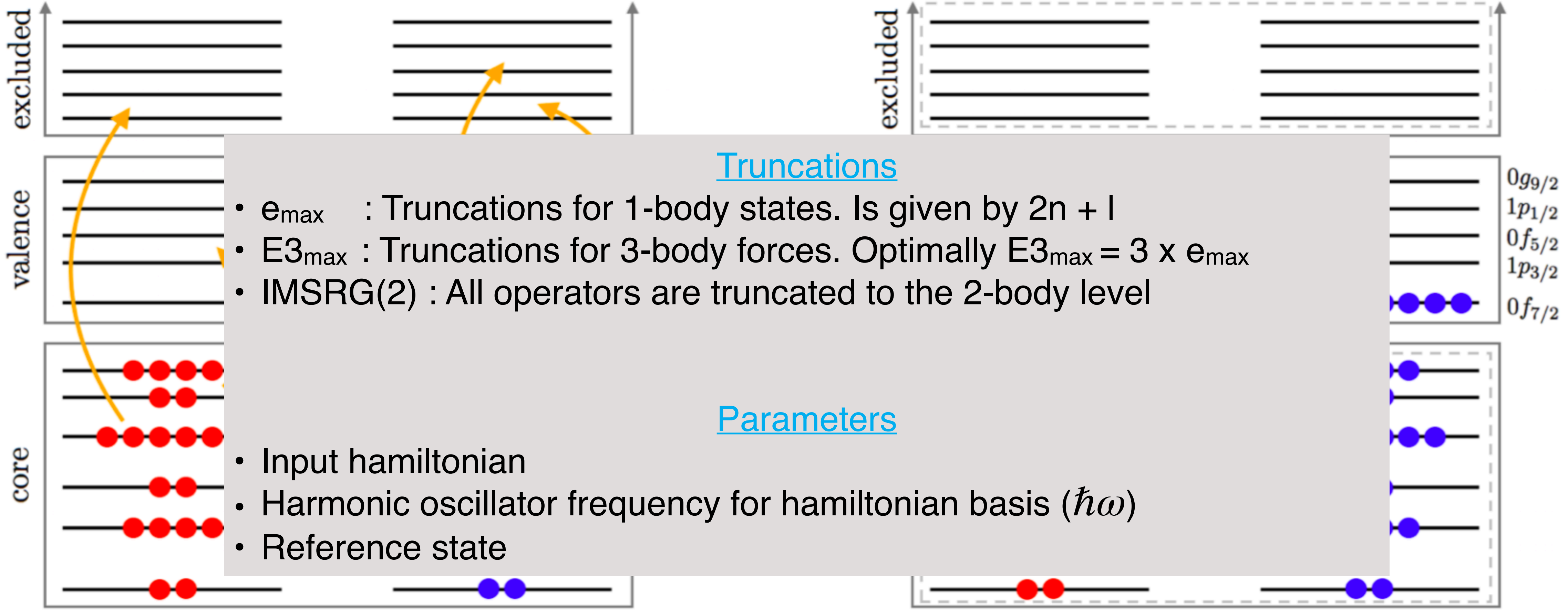


Charlie Payne, Master'sThesis, UBC (2018)

Valence-Space In Medium Similarity Renormalization Group



Valence-Space In Medium Similarity Renormalization Group



Truncations

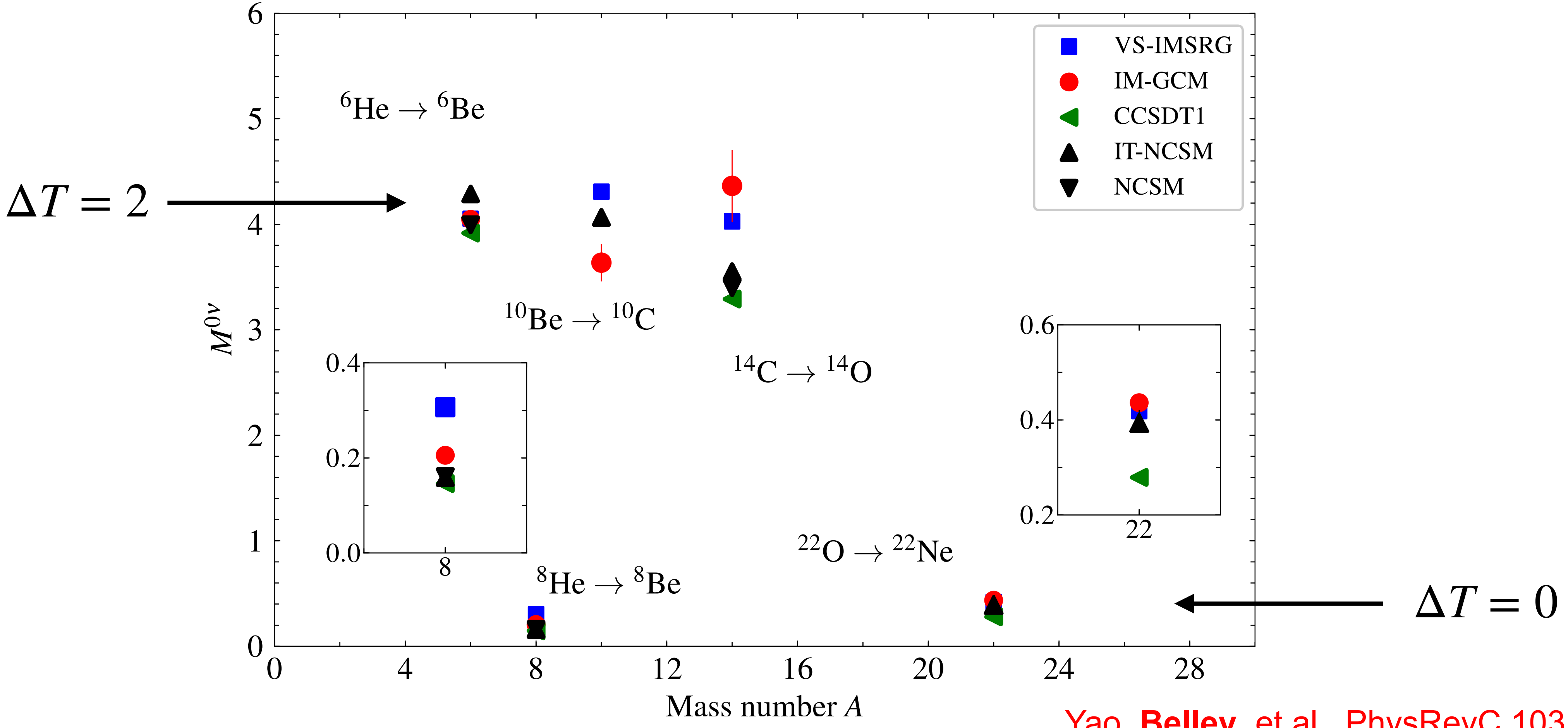
- e_{max} : Truncations for 1-body states. Is given by 2n + l
- $E3_{max}$: Truncations for 3-body forces. Optimally $E3_{max} = 3 \times e_{max}$
- IMSRG(2) : All operators are truncated to the 2-body level

Parameters

- Input hamiltonian
- Harmonic oscillator frequency for hamiltonian basis ($\hbar\omega$)
- Reference state

Benchmarking $0\nu\beta\beta$ Decay in Light Nuclei: Summary

Benchmark with other ab initio method for fictitious decays in light nuclei

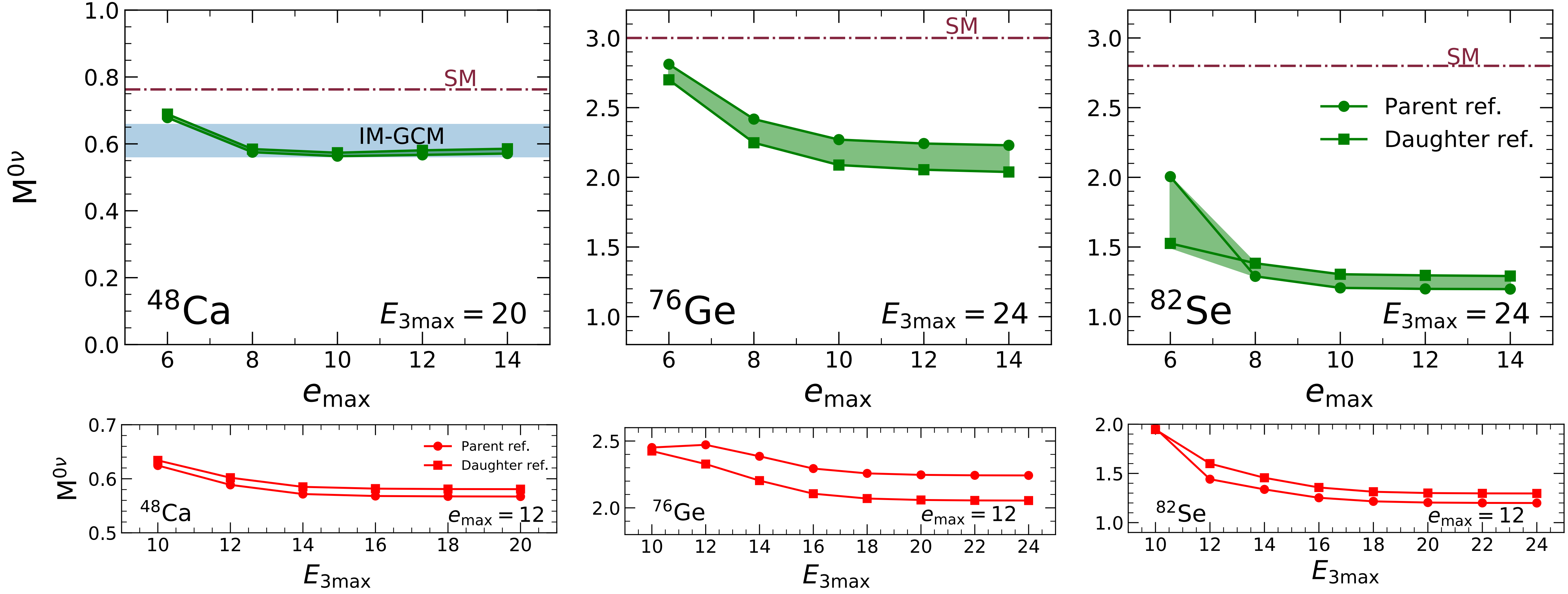


Yao, **Belley**, et al., PhysRevC.103.014315

Reasonable to good agreement in all cases

Ab Initio $0\nu\beta\beta$ Decay: ^{48}Ca, ^{76}Ge and ^{82}Se

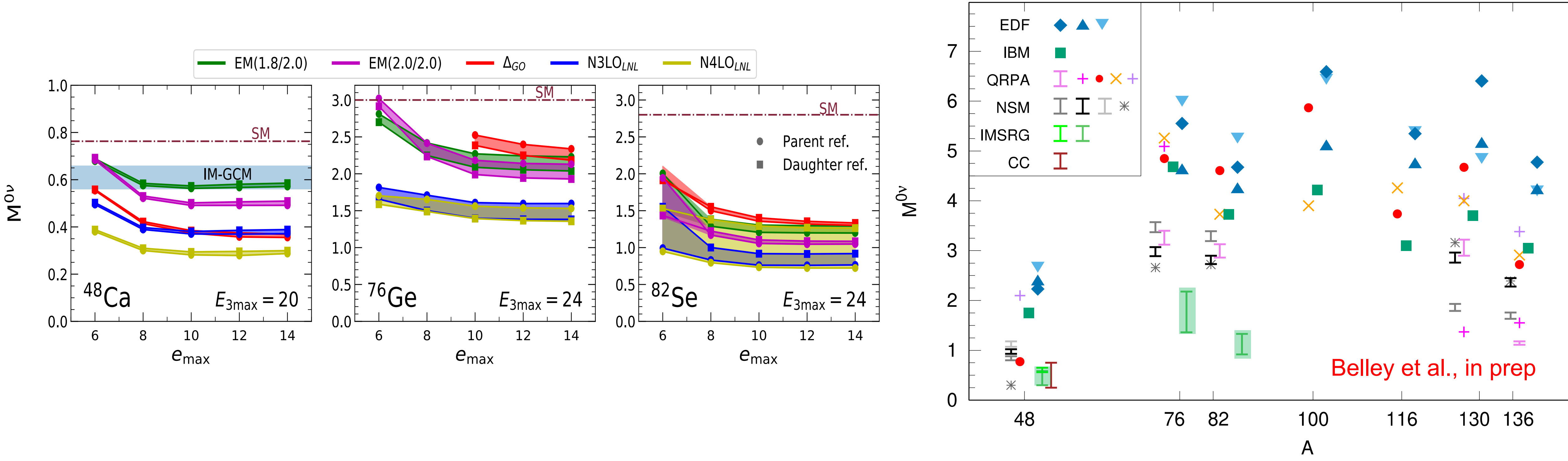
Well converged results both in e_{max} and E_{3max} for the "magic" interaction (EM1.8/2.0)



Belley et al., PhysRevLett.126.042502

Ab Initio 0νββ Decay: ^{48}Ca, ^{76}Ge and ^{82}Se

Results with 5 different input hamiltonians to study uncertainty from interaction choice.



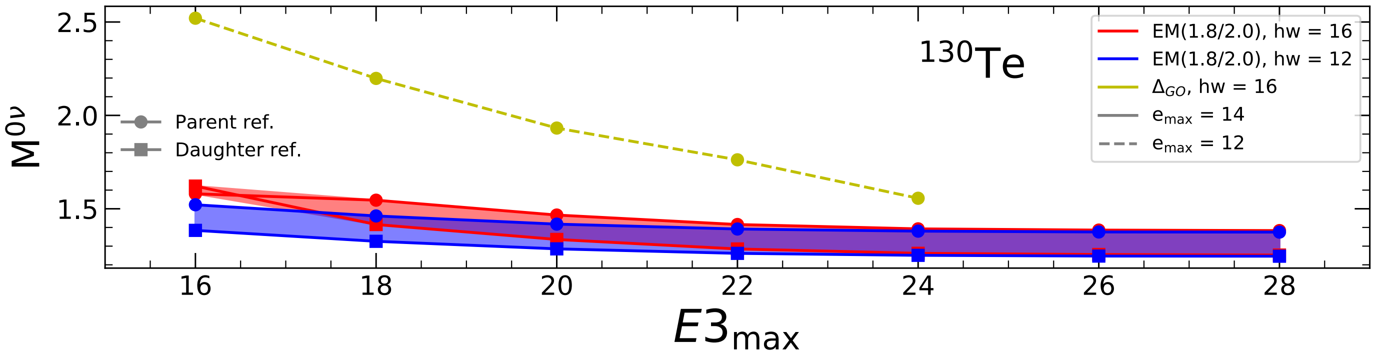
Things to add: valence space variation, two-body currents, IMSRG(3), …

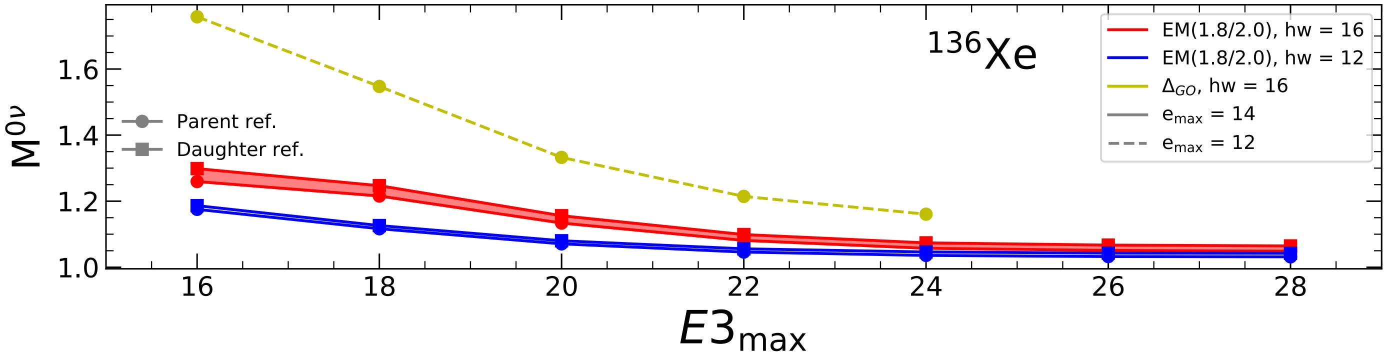
TRIUMF

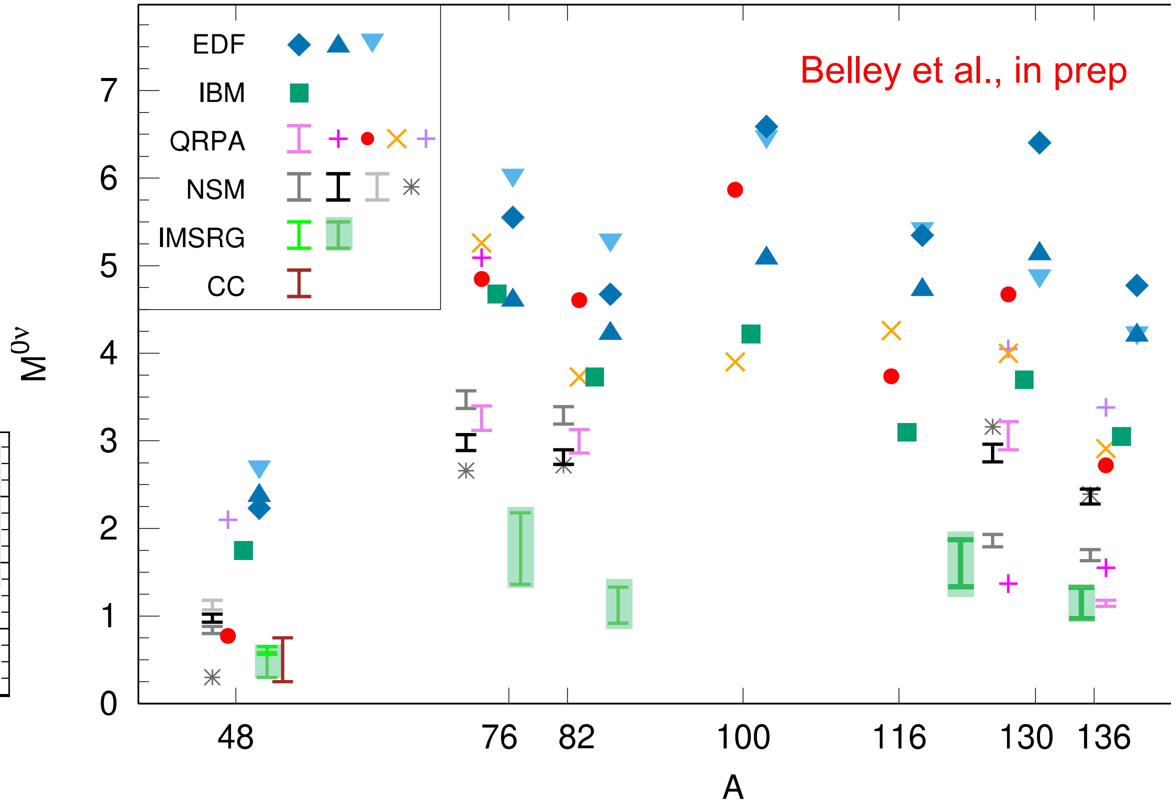
Ab Initio $0\nu\beta\beta$ Decay: ^{130}Te, ^{136}Xe

^{130}Te, ^{136}Xe major players in global searches with SNO+ and nEXO

Increased E_{3max} capabilities allow first converged ab initio calculations [EM1.8/2.0, Δ_{GO}]







TRIUMF

Summary…

1)Computed first ever ab-initio NMEs of isotopes of experimental interest, which is a first step towards computing NME with reliable theoretical uncertainties.

2) Method has been benchmarked with exact methods in fictitious light decays.

3) Computed NME with multiple interactions for ^{48}Ca, ^{76}Ge and ^{82}Se.

4) Computed preliminary results for ^{130}Te and ^{136}Xe.

… and outlook

1)Finish calculations with different interactions for ^{130}Te and ^{136}Xe

2) Analysis of undetermined leading order contact (and finite momentum 2bc)

3) Correlations with other operators: eg, double Gamow-Teller

4) Large scale ab initio uncertainty analysis with other methods for 'final' NMEs

5) Study other exotic mechanism proposed for $0\nu\beta\beta$.

Discovery, accelerated

TRIUMF

Questions?

Discovery, accelerated

0νββ operators

$$O_{GT} = \frac{2R}{\pi}\int_0^\infty \frac{q * j_o(qr) * h_{GT}(q)}{E_c + q}(\boldsymbol{\sigma_1}\cdot\boldsymbol{\sigma_2})\tau_1^+\tau_2^+$$

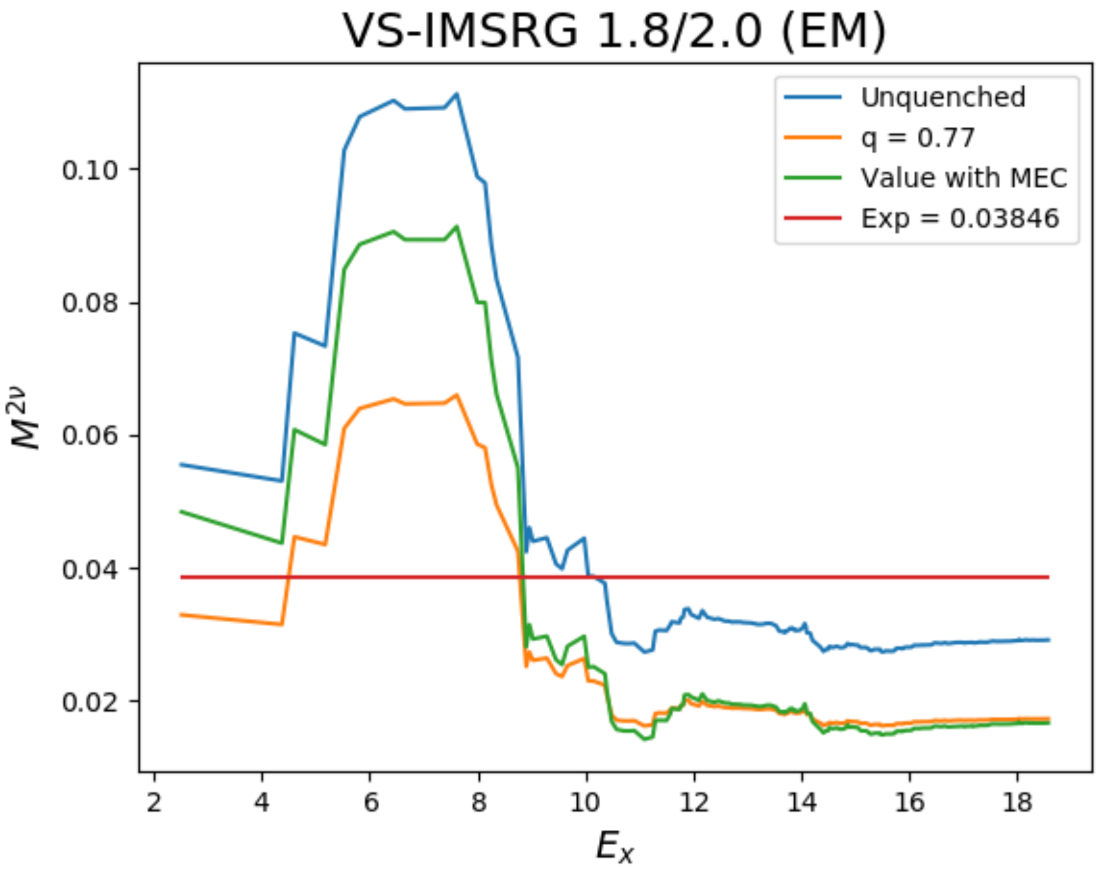
$$O_F = \frac{2R}{\pi}\int_0^\infty \frac{q * j_o(qr) * h_F(q)}{E_c + q}\tau_1^+\tau_2^+$$

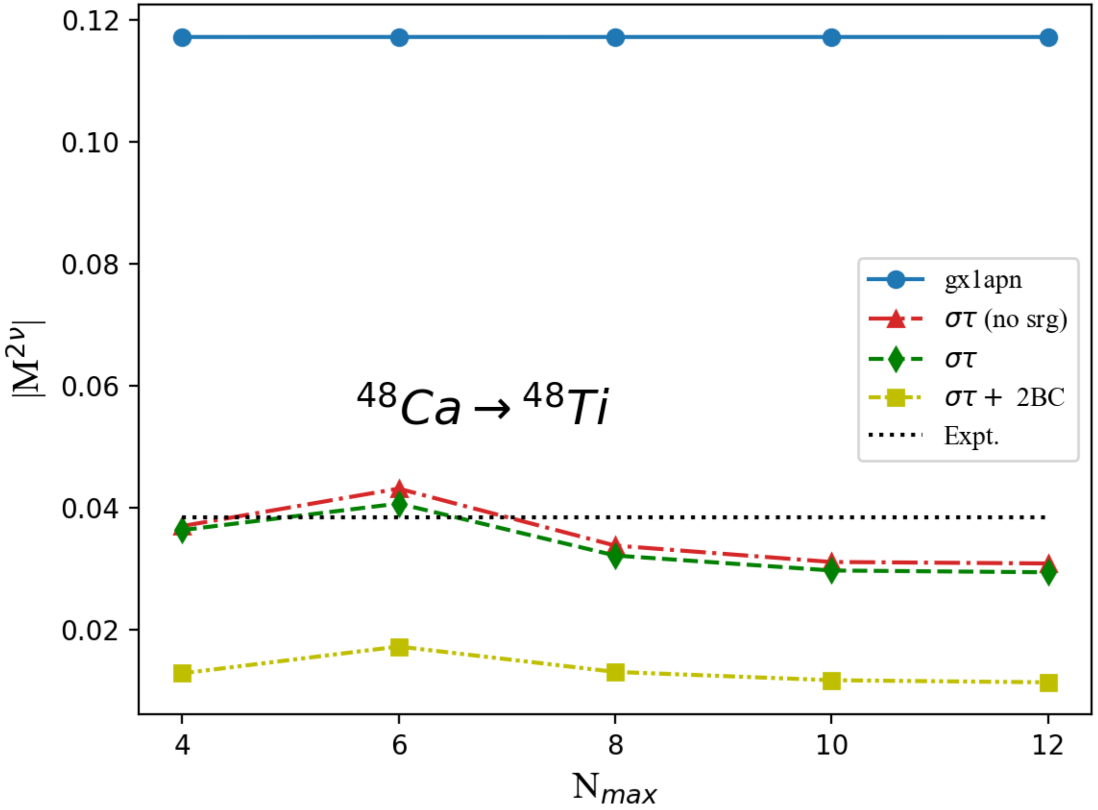
$$O_T = \frac{2R}{\pi}\int_0^\infty \frac{q * j_2(qr) * h_T(q)}{E_c + q}(3(\boldsymbol{\sigma_1}\cdot\hat{\boldsymbol{r}})(\boldsymbol{\sigma_2}\cdot\hat{\boldsymbol{r}}) - (\boldsymbol{\sigma_1}\cdot\boldsymbol{\sigma_2}))\tau_1^+\tau_2^+$$

where the functions h are the neutrino potentials respective to each decay mode and E_C is the closure energy.

TRIUMF

Ab Initio $2\nu\beta\beta$ Decay: ^{48}Ca





VS-IMSRG: decrease in final matrix element

Belley, Payne, Stroberg, JDH, in prep

Potential issues: limited 1+ states, missing IMSRG(3),... Benchmarks with CC underway!