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Total muon capture rates from ab-intio NCSM

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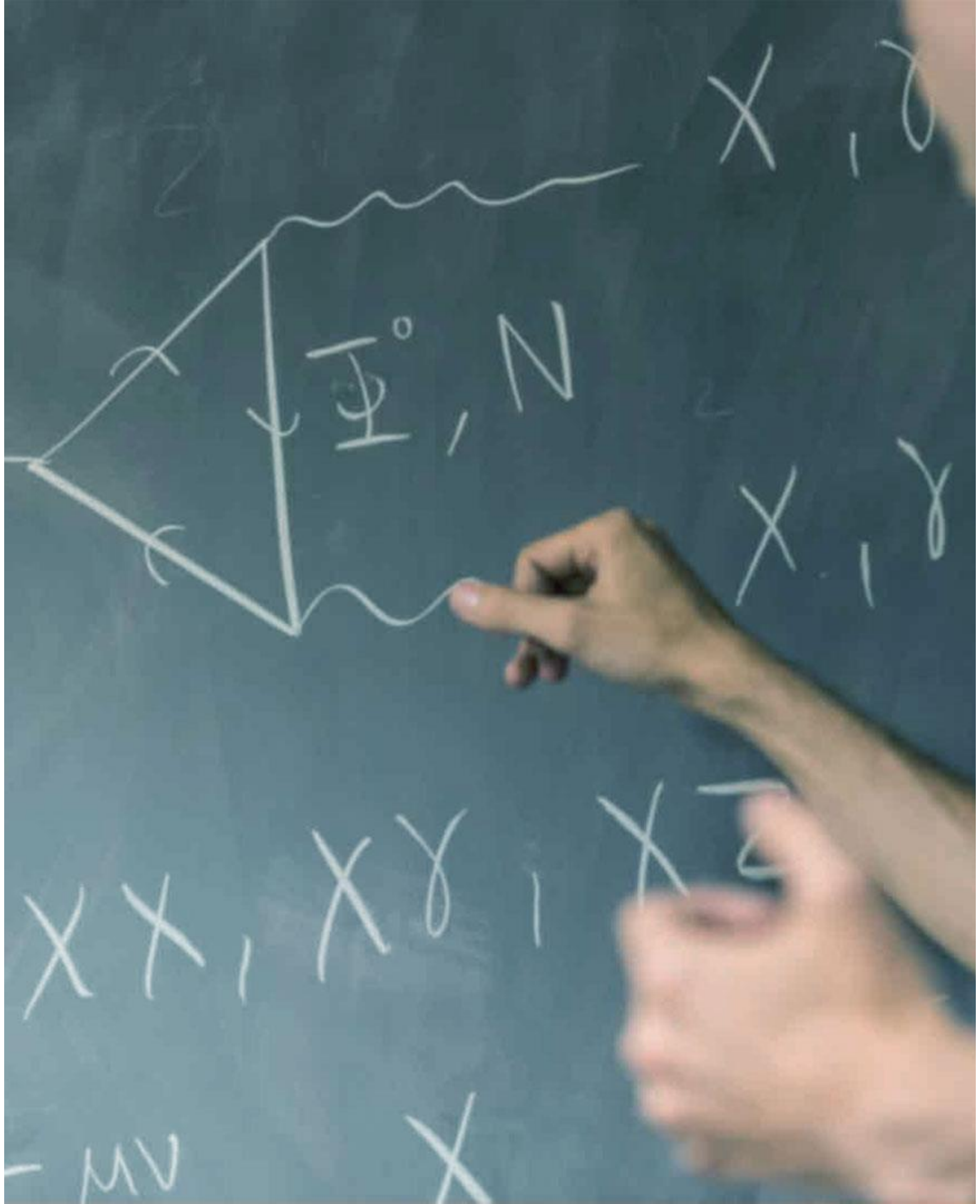

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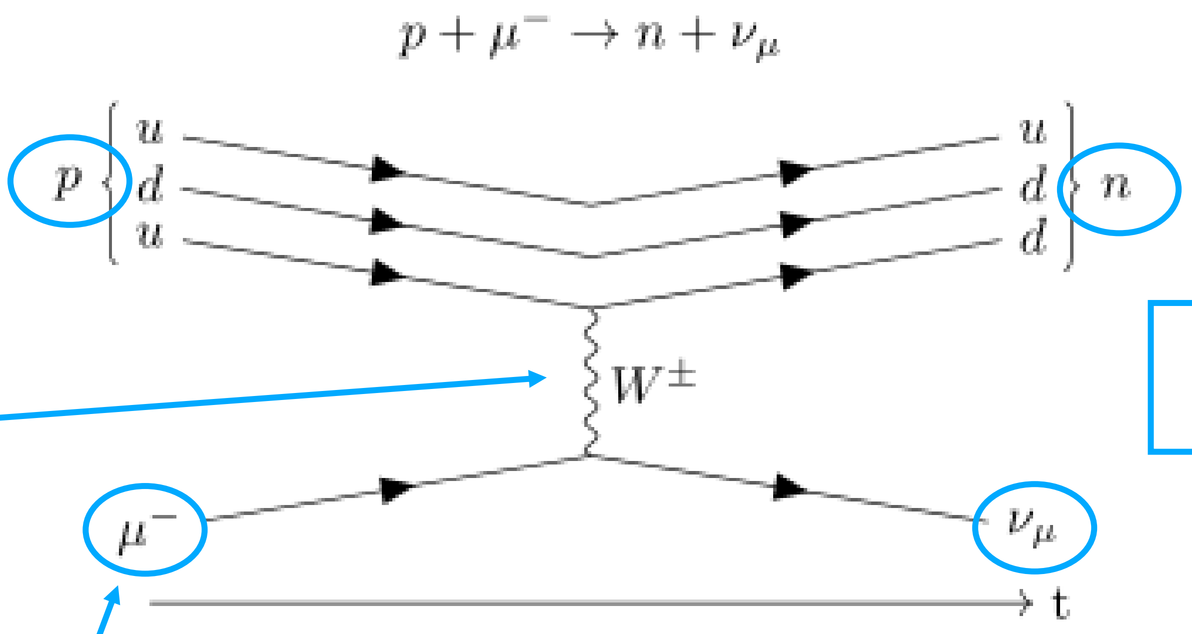
Discovery, accelerated

What is muon capture?



Proton-muon interact through weak force

Results in neutron + neutrino

Muon is bound in the 1s orbital

Fig 1. Feynman diagram for muon capture

Motivation

- Muon capture can probe physics similar to $0\nu\beta\beta$ (see Lotta's presentation tomorrow)
- Total rates are well known experimentally; ab-initio approaches that **explicitly** compute final states are computationally expensive

- Direct summation over final states only results in around 80% of experimental value (Jokiniemi et al. 2024)

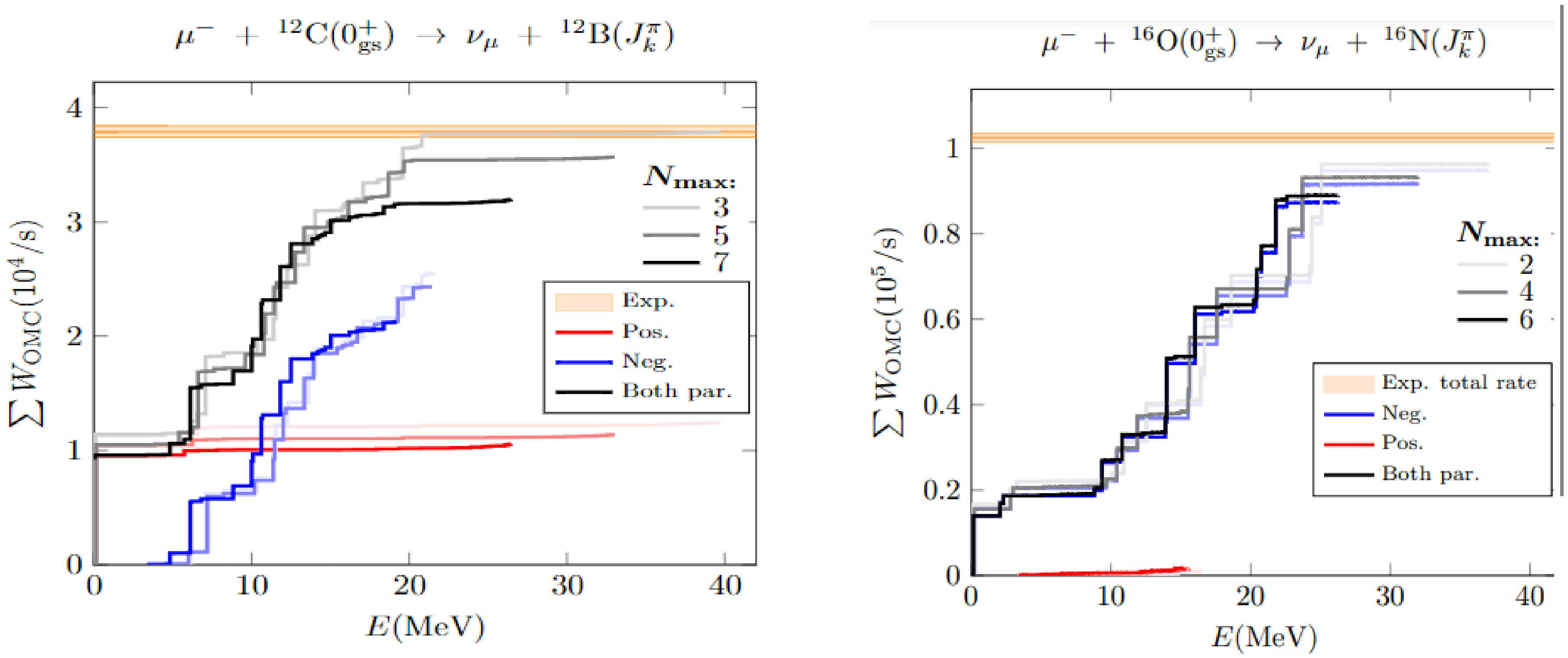


Fig 2. Summed OMC rates to final states in ^{12}B (left) and ^{16}N (right)

Jokiniemi, Navratil, Kotila, Kravvaris *(in preparation, 2024)*

Total muon capture rate

$$\omega_{tot} = \sum_f \omega(i \rightarrow f) + \delta$$

Hyperfine correction

$$\omega(i \rightarrow f) = \frac{G^2 \nu^2}{2\pi(1+\mu/M_t)} \frac{4\pi \langle \phi_{1s}^2 \rangle}{2J_i + 1} \left(\sum_{J \geq 1} \| \langle J_F || \mathcal{T}_J^{el}(\nu) - \mathcal{T}_J^{mag}(\nu) || J_i \rangle \|^2 + \sum_{J \geq 0} \| \langle J_F || \mathcal{L}_J(\nu) - \mathcal{M}_J(\nu) || J_i \rangle \|^2 \right)$$

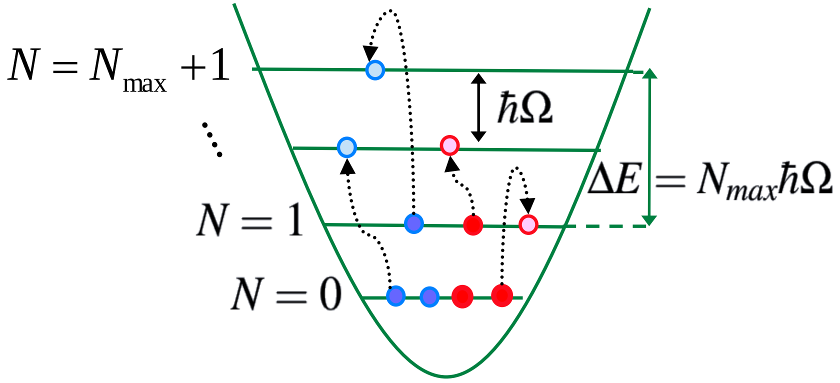
$$\langle \phi_{1s}^2 \rangle = \int \|\phi_{1s}\|^2 \rho(\mathbf{r}) r^2 \, \mathrm{d}r$$

$$\nu \propto m_\mu + E_i - E_f$$

J.D. Walecka, Nucl. Phys. A **256**, 397-416 (1976)

Ab-initio NCSM with Lanczos method

- *Ab-initio* approach to solving many-body Schrödinger equation



$$H \left| \Psi_A^{J^\pi T} \right\rangle = E^{J^\pi T} \left| \Psi_A^{J^\pi T} \right\rangle$$

$$\left| \Psi_A^{J^\pi T} \right\rangle = \sum_{N=0}^{N_{max}} \sum_{\alpha} c_{N\alpha}^{J^\pi T} \left| \Phi_{N\alpha}^{J^\pi T} \right\rangle$$

- Expand in harmonic oscillator basis
- N_{max} fixes the size of basis, <u>truncation parameter</u>

Slide adapted from M.Gennari (2023)

Ab-initio NCSM with Lanczos

- Use Lanczos method to calculate ω and δ. **Implicitly** include contributions from final states:

$$\left|\phi_0^{(i)}\right\rangle = \frac{\mathbf{O_1}\,|J_i\rangle}{\|\mathbf{O_1}\,|J_i\rangle\|} \qquad \left|\phi_0^{(F)}\right\rangle = \frac{\mathbf{O_2}\,|J_F\rangle}{\|\mathbf{O_2}\,|J_F\rangle\|}$$

Pivots for Lanczos basis

$$\langle J_n|\mathbf{O_1}|J_i\rangle\ \langle J_i|\mathbf{O_2}|J_n\rangle$$

Linear combinations of multipoles

$$\langle J_n|\mathbf{O_1}|J_i\rangle = (\mathbf{P}^{(i)})^{\dagger}_{0n}\|\mathbf{O_1}\,|J_i\rangle\| \qquad \langle J_i|\mathbf{O_2}|J_n\rangle = \|\mathbf{O_2}\,|J_F\rangle\|\sum_m \left(\mathbf{P}^{(i)}\right)_{mn}\left\langle\phi_0^{(f)}\middle|\phi_0^{(i)}\right\rangle$$

- **P** is the unitary matrix that diagonalizes the already tri-diagonal **H**

Preliminary results

$$^{12}C(0^+_{gs}) + \mu^- \longrightarrow ^{12}B(1^+_{gs}) + \nu_\mu$$

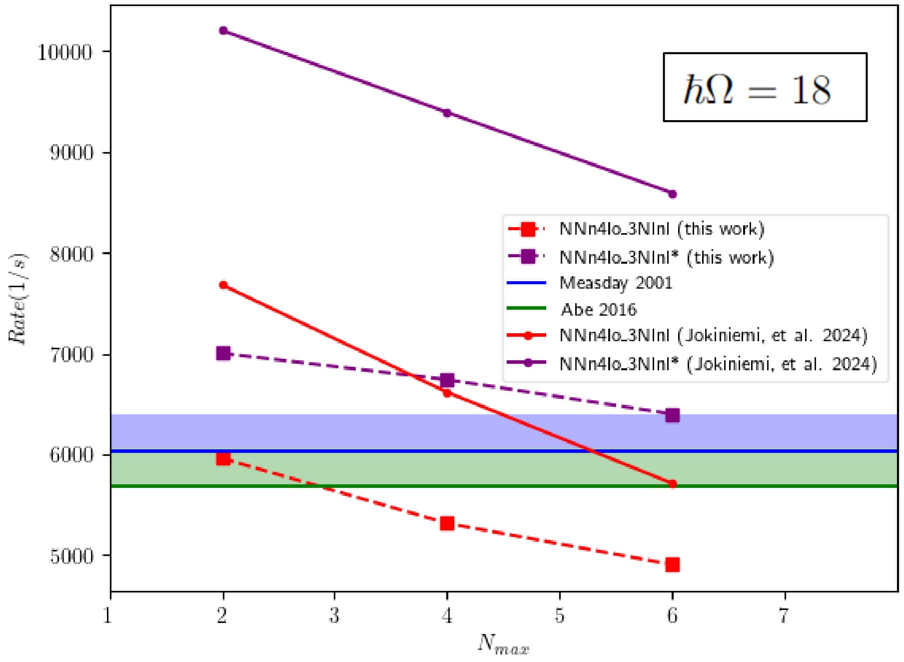


Fig 3. Partial muon capture rate from ground state of ^{12}C to ground state of ^{12}B

$$^{16}O(0^+_{gs}) + \mu^- \longrightarrow ^{16}N(3^-_1) + \nu_\mu$$

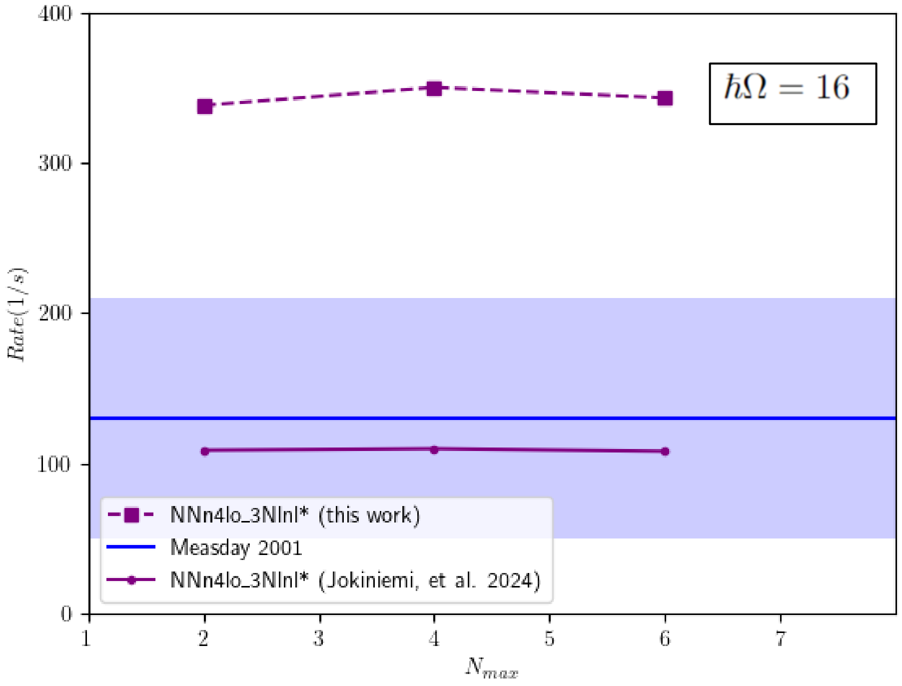


Fig 4. Partial muon capture rate from ground state ^{16}O to 3^- of ^{16}N

- Differences due to simplified treatment of muon wavefunction

Jokiniemi, Navratil, Kotila, Kravvaris *(in preparation, 2024)*
D.F. Measday, Phys. Rep. **354**, 243 (2001)
Abe, *et al,* Phys. Rev. C **93** 054608 (2016)

Summary and outlook

- We are calculating total muon capture rates using ab-initio NCSM with Lanczos method to overcome computational complexity due to contributions of final states.
- Aim to implement a better and more exact treatment of the bound muon wavefunction in the capture rate expression.

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Thank you
Merci

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