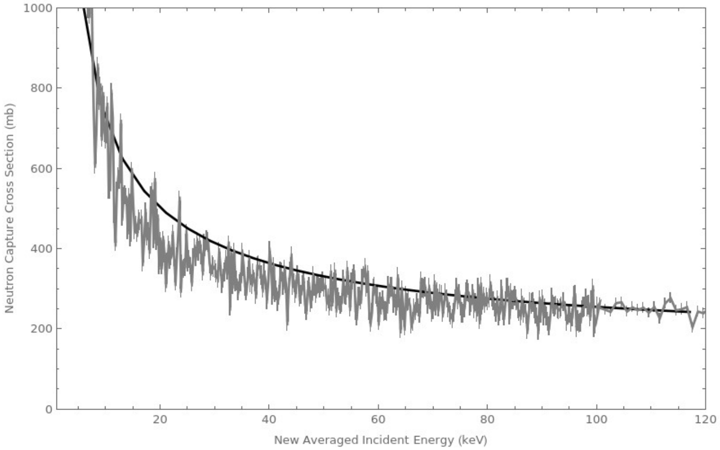
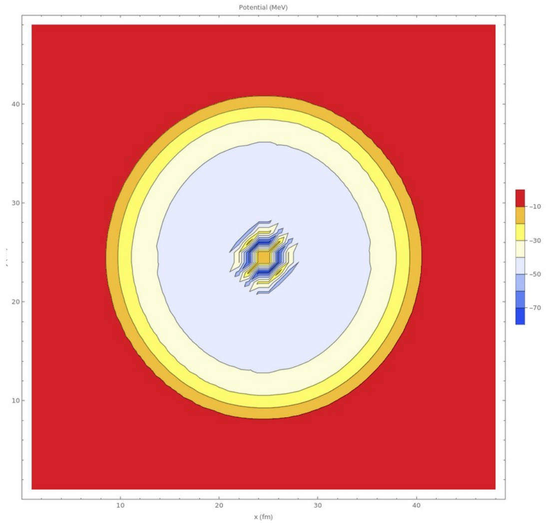
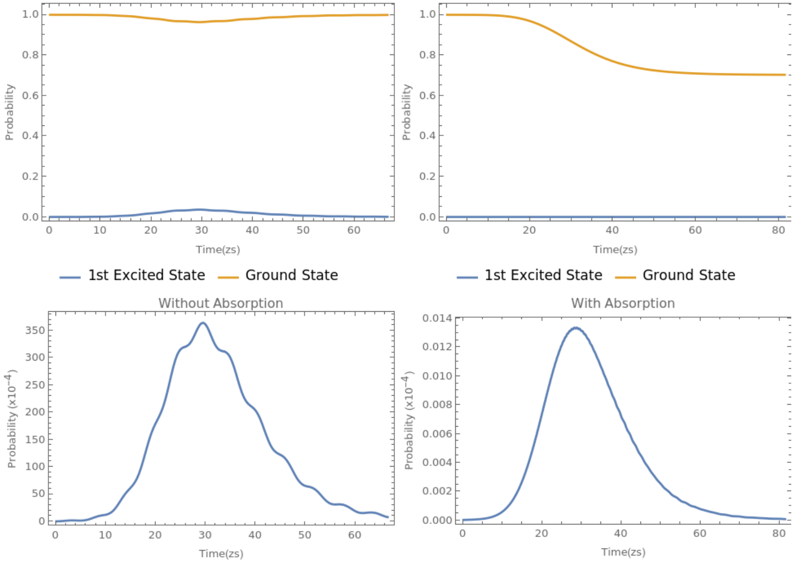
A time dependent many body description of the neutron capture reaction in Osmium-188





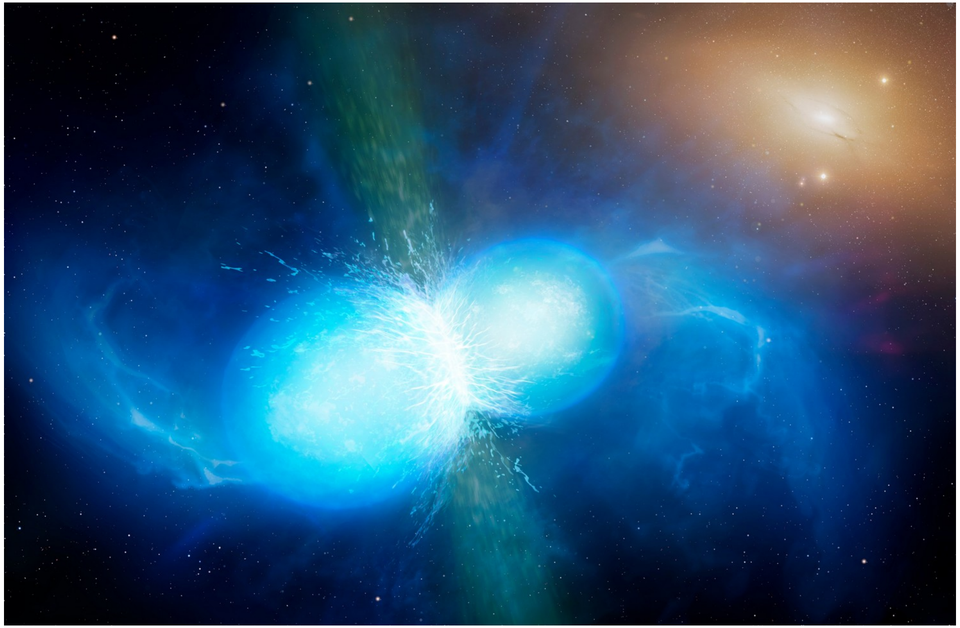


By: Nick Lightfoot
Supervisors: Alexis Diaz-Torres and Paul Stevenson

Introduction-Outline

Outline

- Basic reaction theory
    - Potentials
    - Time evolution
- Single Channel
- Coupled Channels



University of Warwick/Mark Garlick, https://www.eso.org/public/images/eso1733s/

Basic Problem-Wave packet In Space

Wave packet

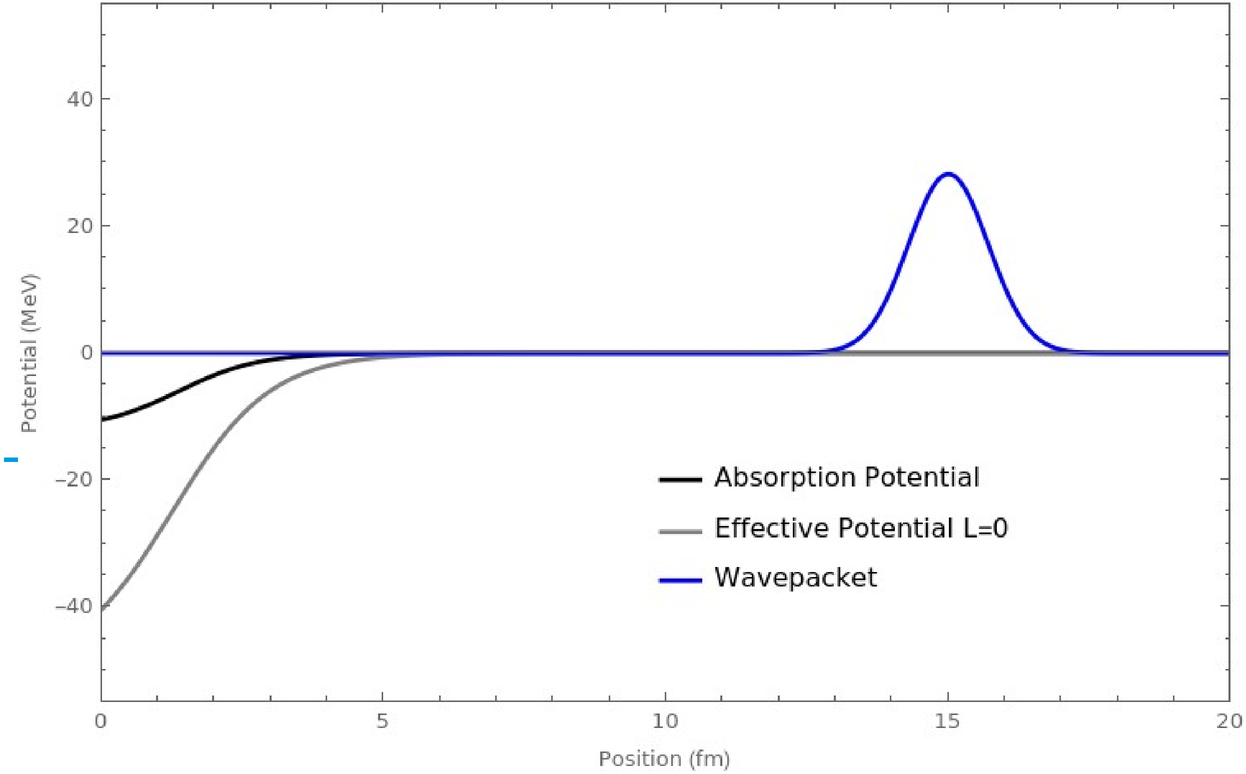
- Initial position
- Large width

Effective Potential

- Time Dependent Hartree-Fock (TDHF)
- Centrifugal component

Absorption

- Imaginary Potential



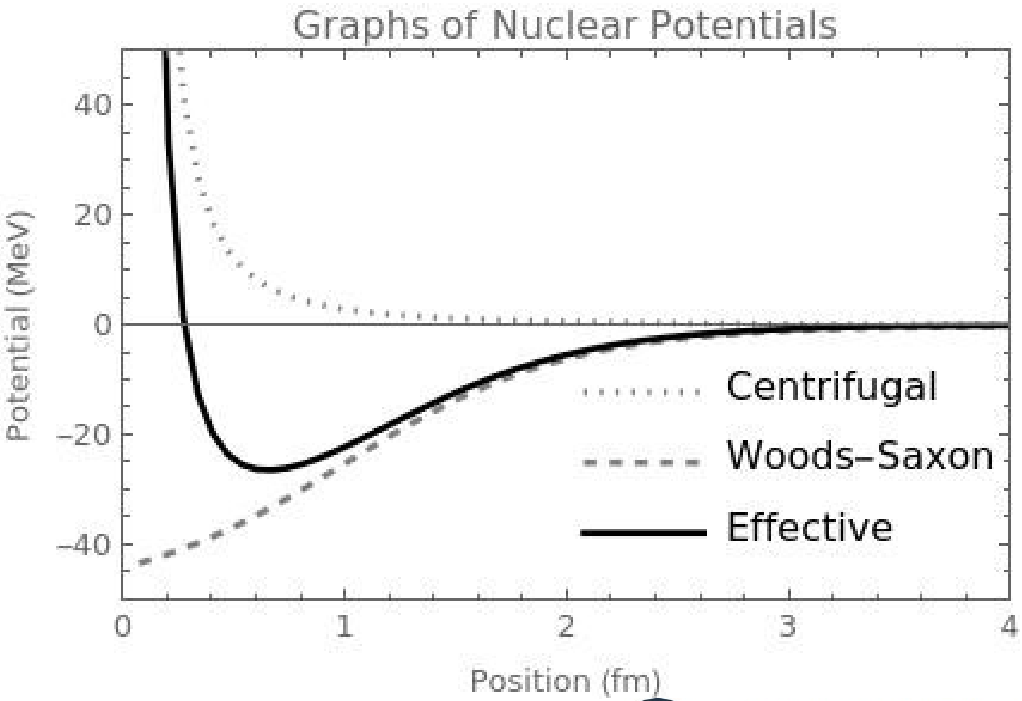
Basic Problem-Potential

- Internal Potential

$$V_{WS} = -\frac{U_{WS}}{1 + \exp\frac{r - r_{ws}}{a_{WS}}}$$

- Centrifugal Potential

$$V_C = \frac{\hbar^2 l(l+1)}{2\mu r^2}$$



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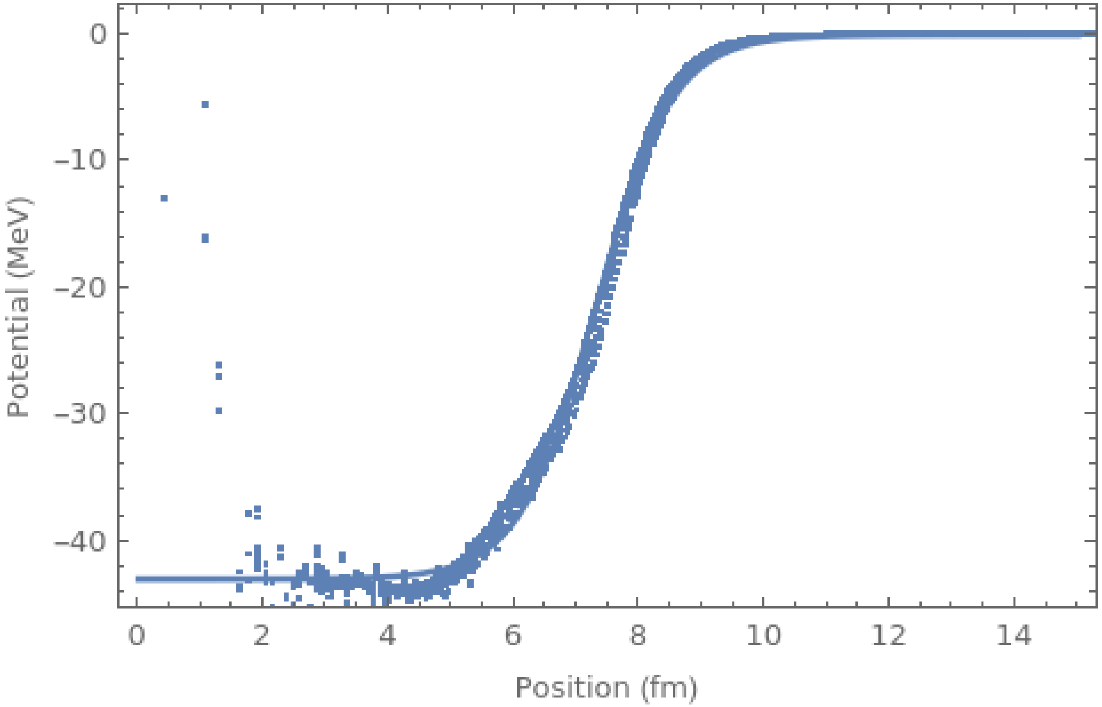
Basic Problem-TDHF

- Static TDHF
  - Many internal wavepackets
  - Allowing them to evolve
  - Mapping x,y,z into radial.
- Least Squares
  - Effective Woods Saxon
  - Excludes internal potential



Basic Problem-Time Evolution

- Chebyshev Polynomials
  - Time Evolution
  - Extending into a set of polynomials
  - Recurrence Relation

$$\psi(r,t) = e^{-i\frac{Ht}{\hbar}}\psi(r,0).$$

$$\exp^{-iH\Delta t} = J_0(\tau)\sum_{n=1}^{\infty} J_n(\tau)T_n(H)$$

$$\psi_0(t) = \psi(t)$$

$$\psi_1(t) = H\psi_0(t)$$

$$\psi_n(t) = 2H\psi_{n-1}(t) - \psi_{n-2}(t)$$

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Basic Problem-Absorption

- Absorption Potential
- Modified Chebyshev Polynomials
- Woods Saxon Shaped Potential

$$\psi_0(t) = \psi(t)$$
$$\psi_1(t) = H\psi_0(t)$$
$$\psi_n(t) = 2H\psi_{n-1}(t) - \psi_{n-2}(t)$$

→

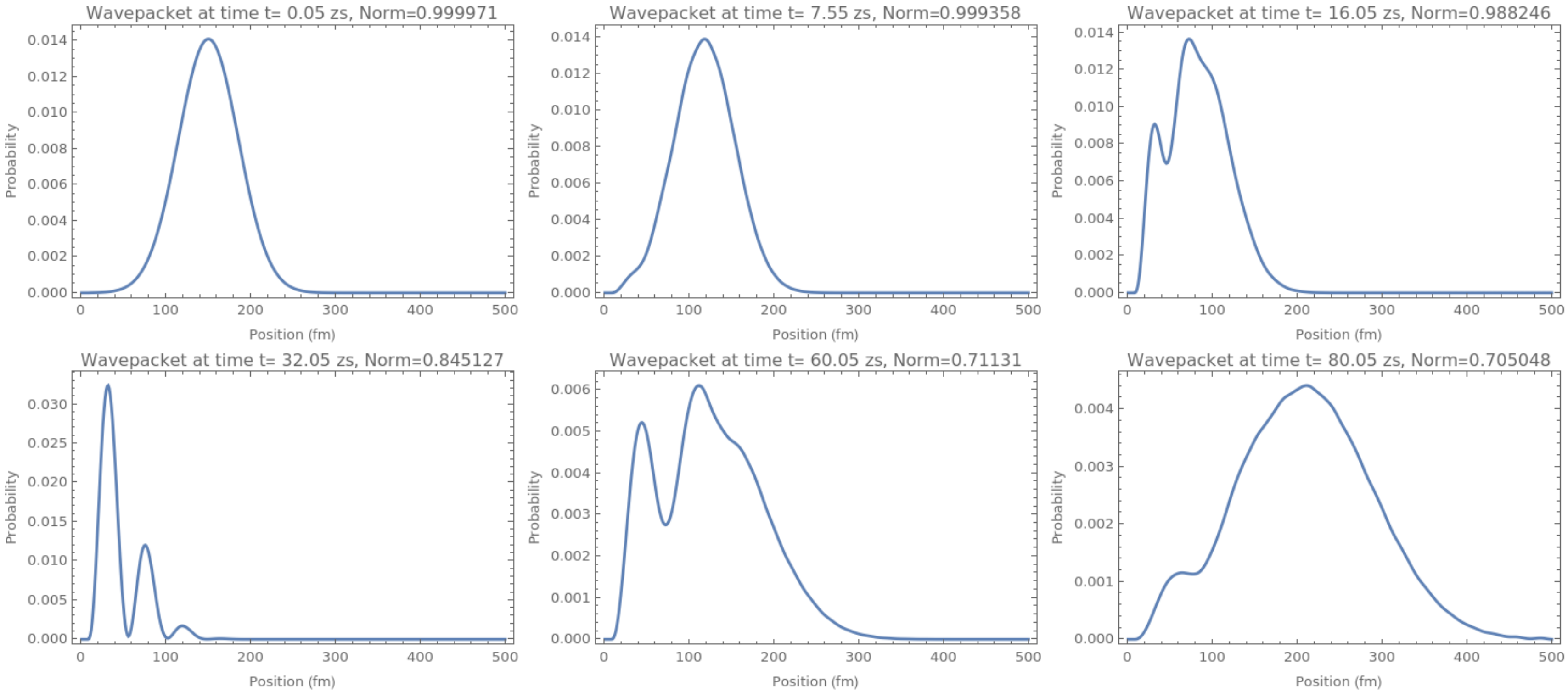
$$\psi_0(t) = \psi(t)$$
$$\psi_1(t) = e^{-\gamma}H\psi_0(t)$$
$$\psi_n(t) = 2e^{-\gamma}H\psi_{n-1}(t) - e^{-2\gamma}\psi_{n-2}(t).$$

$$W = \Delta H[\cos\xi(1 - \cosh\gamma - i\sin\xi\sinh\gamma]$$

→

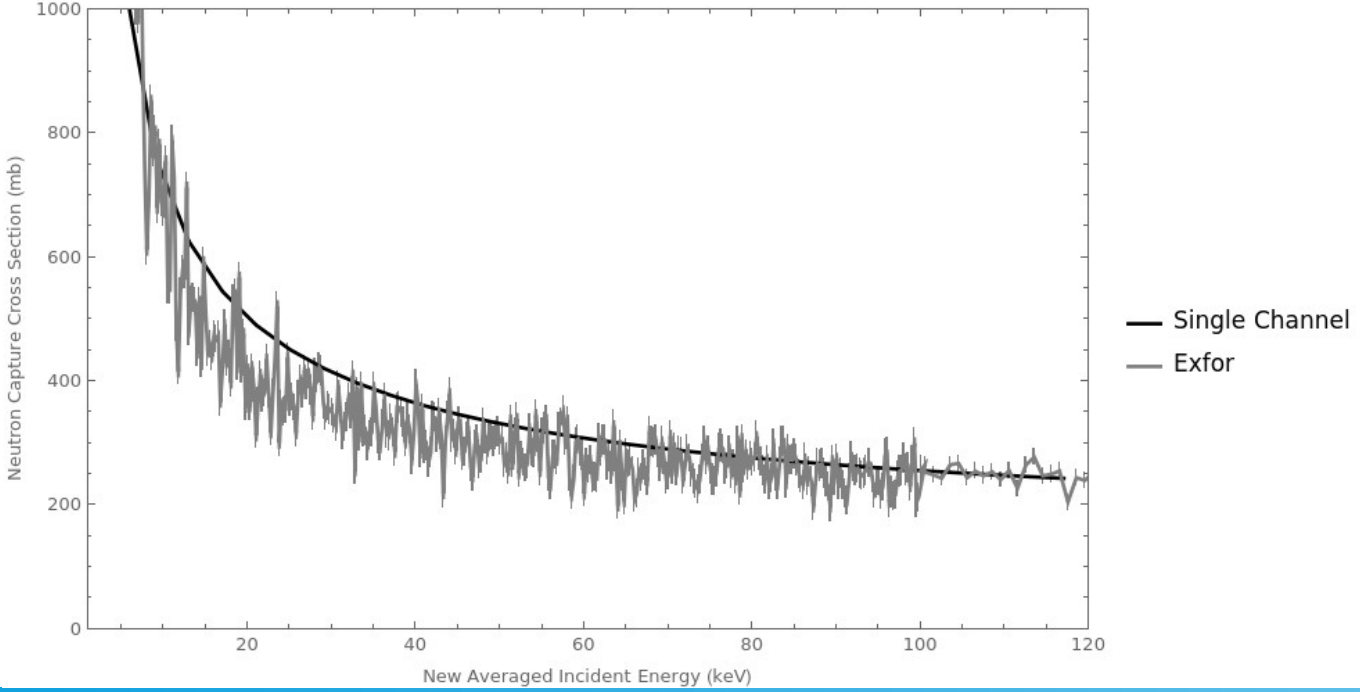
$$\gamma = \text{arcsinh}(-\frac{W}{\Delta H\sin\xi}).$$

Results-Wavepacket Propagation



Results-Neutron Capture Cross Sections

$$\sigma_{nc}(E_i) = \frac{\pi\hbar^2}{2\mu E_i} \sum_{l=0} (2l+1) T(E_i, l)$$



Coupled Channels-Theory

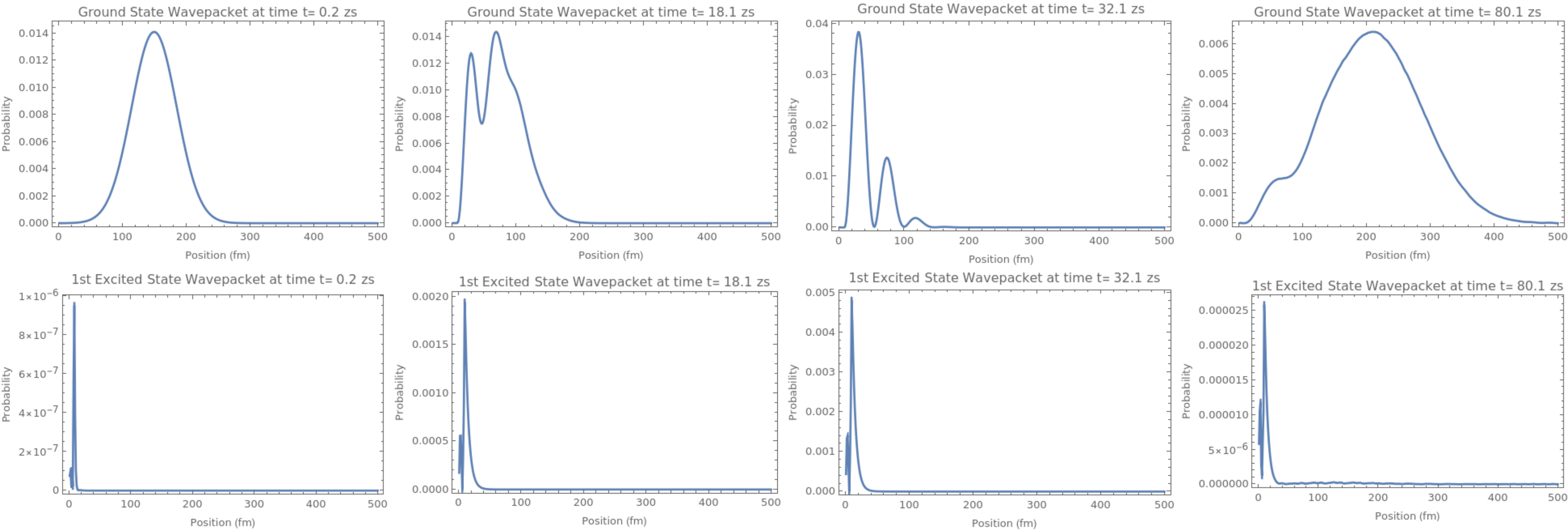
- Shifted Woods-Saxon
- $$V_{CC} = -\frac{U_{WS}}{1+\exp((r - r_{WS} - \hat{r}_{cc})/a_{WS})}$$
- Generate and Diagonalise the Coupling Matrix
- $$\langle I_n|\hat{r}_{cc}|I_{n'}\rangle = r_{coup}\beta_2 F(2, I_n, I'_n)$$
- Generate a full coupled channels Hamiltonian
- $$H = \begin{pmatrix} 0-0 & 0-2 \\ 2-0 & 2-2 \end{pmatrix} \begin{pmatrix} |\psi_1\rangle \\ |\psi_2\rangle \end{pmatrix}$$
- Diagonal Entries

$$(In - In) = K + V_C + V_{WS} + V_{cc} + \epsilon_n I.$$

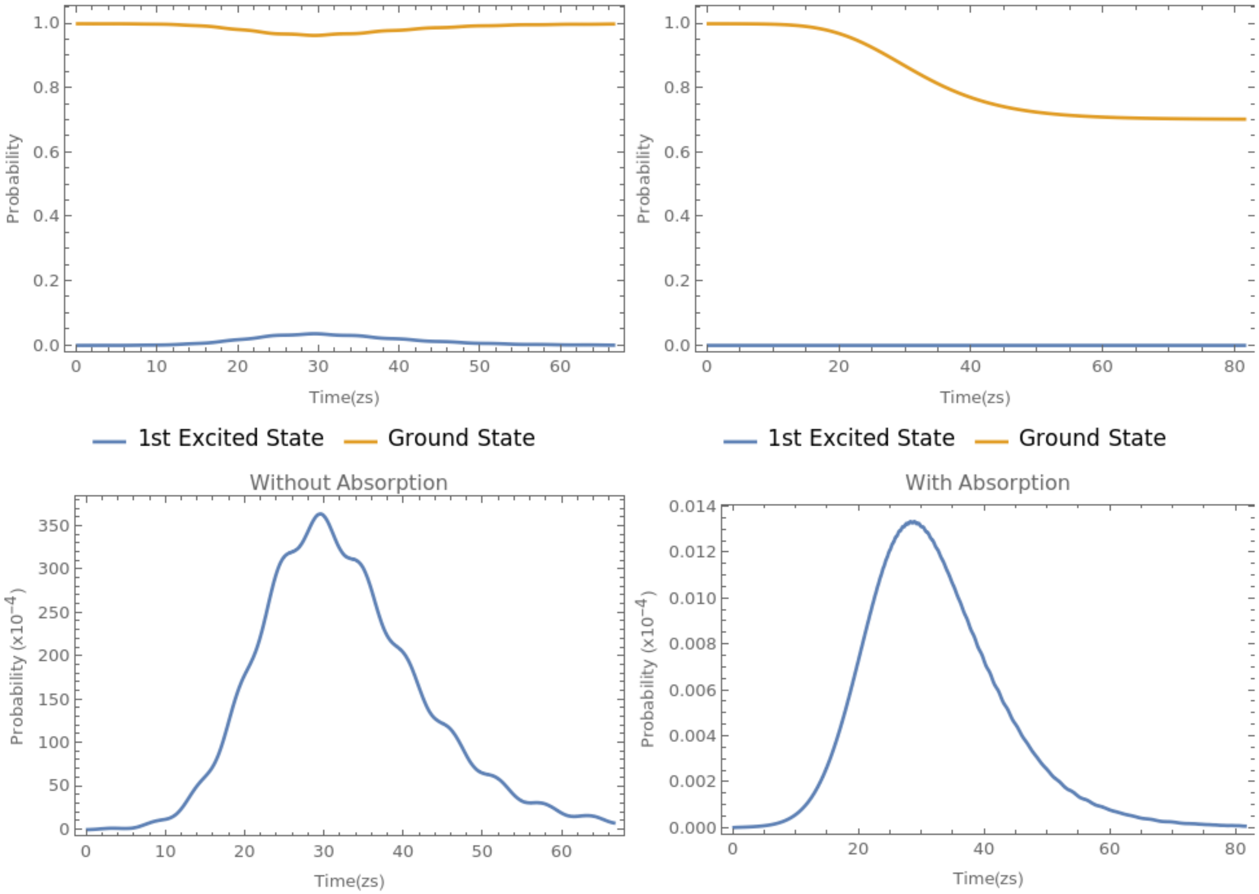
Off-Diagonal Entries

$$(I_n - I_{n'}) = V_{nn'}$$

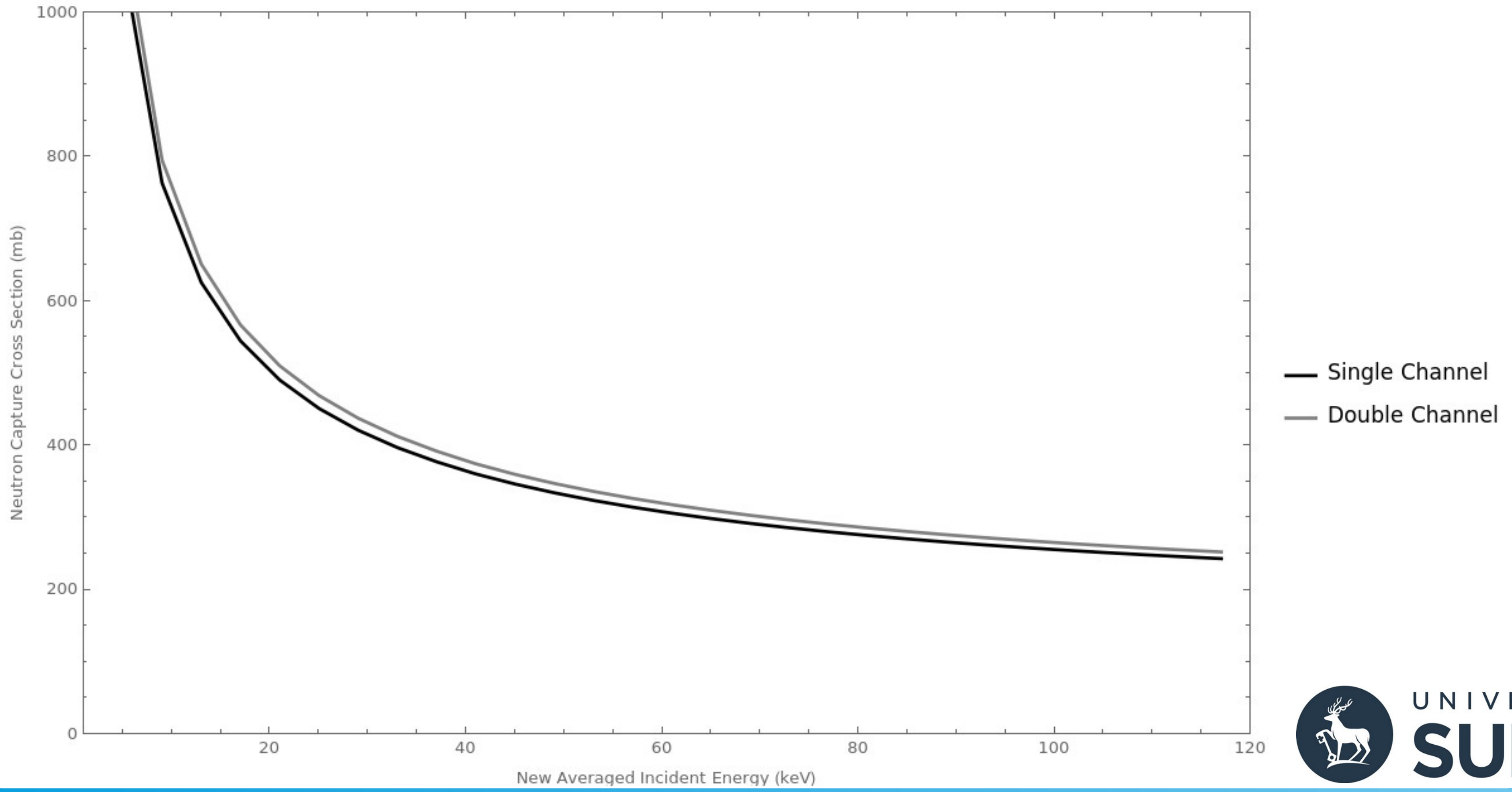
Coupled Channels-Wave packet Propagation



Coupled Channels-Absorption effects

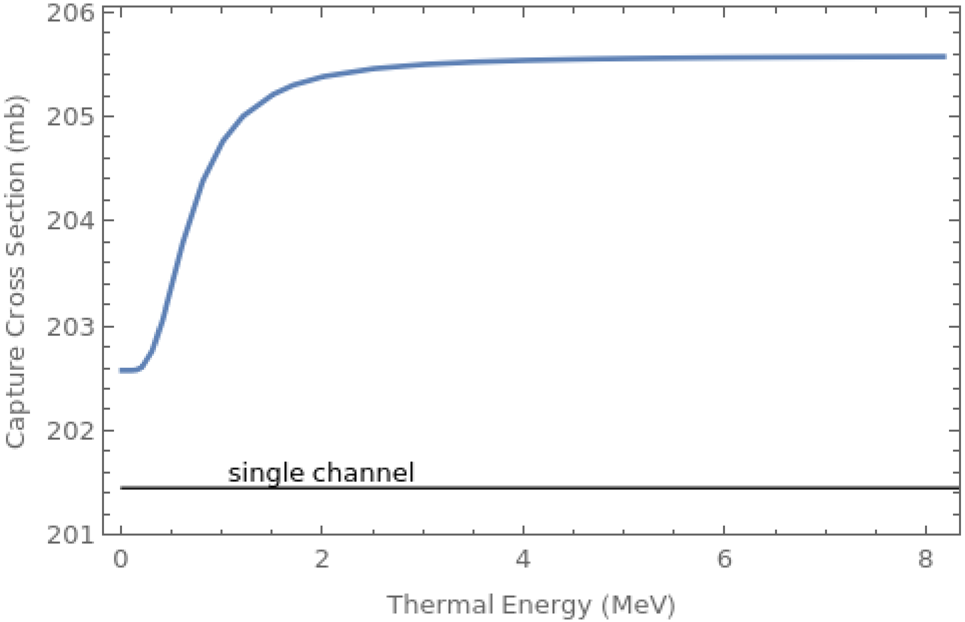


Coupled Channels-Cross Section Comparisons



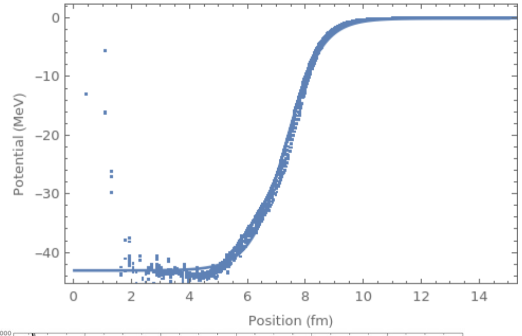
Future Steps

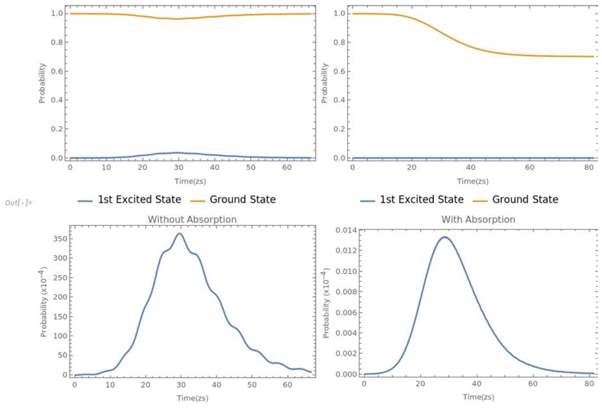
- Thermal Effects
- Reaction Rates
- Comparison to FRESCO,CCFULL, etc.
- 187-Os, 186-Os, etc.

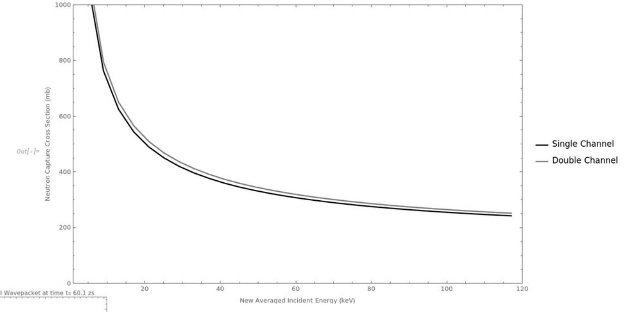


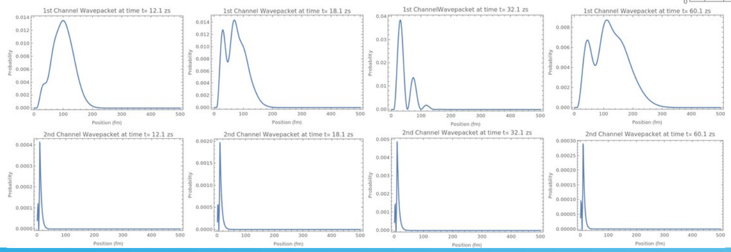
Recap

- Neutron Capture Reaction
- Applying Static HF
- Time Evolving
- Absorption
- Coupled Channels
- Comparison of capture cross sections



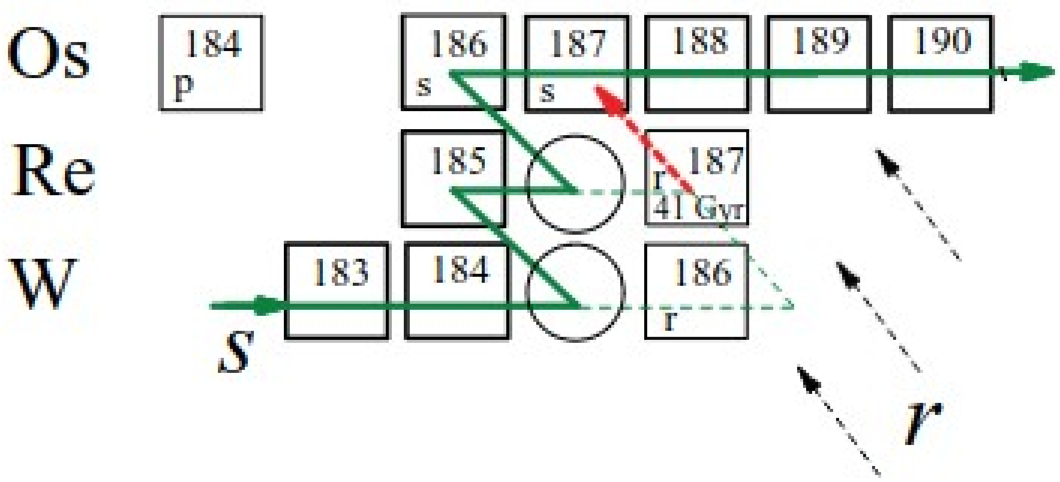






Introduction

- The reaction
  - Os-Re clock
- Progression
  - Basic Problem
  - Single Channel
  - Coupled Channels



Mosconi, M., et al. “Neutron physics of the Re/Os clock. I. Measurement of the (n,gamma) cross sections of Os 186,187,188 at the CERN n_TOF facility.” *Physical Review C-Nuclear Physics 82.1 (2010):015802*

Thermal Effects-Theory I

- Liouville Equation
  - In the case with a pure state
  - Our initial non-thermalised state

$$i\hbar\frac{\delta\rho(x,x',t)}{\delta t} = [\hat{H},\hat{\rho}]_{x,x',t}$$

$$\hat{\rho} = |\psi^*(x,t)\rangle\langle\psi(x',t)|$$

- Lindblad Equation
  - Gives environmental effects
  - Thermalisation of the system

$$i\hbar\frac{\delta\rho(x,x',t)}{\delta t} = [\hat{H},\hat{\rho}]_{x,x',t} + \hat{L}[...].$$

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Coupled Channels-Theory

- Shifted Woods-Saxon

$$V_{CC} = -\frac{U_{WS}}{1+\exp((r - r_{WS} - \hat{r}_{cc})/a_{WS})}$$

- Generate the Coupling Matrix

$$\langle I_n|\hat{r}_{cc}|I_{n'}\rangle = r_{coup}\beta_2 F(2, I_n, I'_n)$$

- Diagonalise

$$\begin{aligned} V_{N,nn'} &= \langle I_n|V_N(r,\hat{r}_{CC})|I_{n'}\rangle - V_N(r,0)\delta_{nn'} \\ &= \sum_{\alpha}\langle I_n|\alpha\rangle V_N(r, r_{cc,\alpha}) - V_N(r,0)\delta_{nn'} \end{aligned}$$

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Form Factor

- Form factor
- Generates using a J-symbol
- Similar to a Glebsch-Gordon coefficient.

$$F(I, I_n, I_{n'}) = \sqrt{\frac{(2I+1)(2I_n+1)(2I_{n'}+1}{4\pi}} \begin{pmatrix} I_n & I & I_{n'} \\ 0 & 0 & 0 \end{pmatrix}^2$$