Nuclear structure-based optical potential for predictive calculations

FRIB-TA Topical Program: Theoretical Justifications and Motivations for Early High-Profile FRIB Experiments

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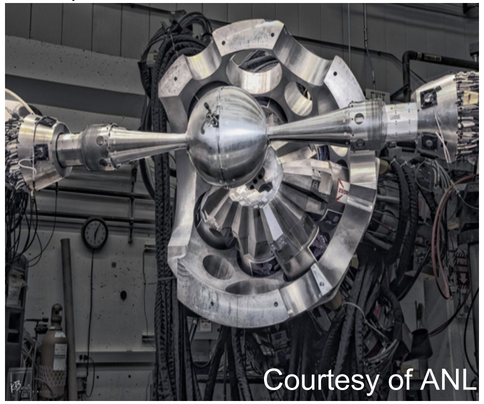
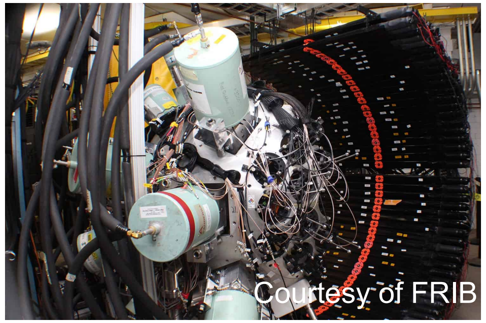
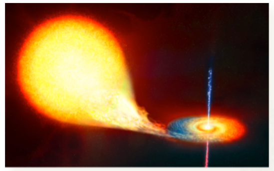
The era of rare isotope beams

Experiments at RIB facilities





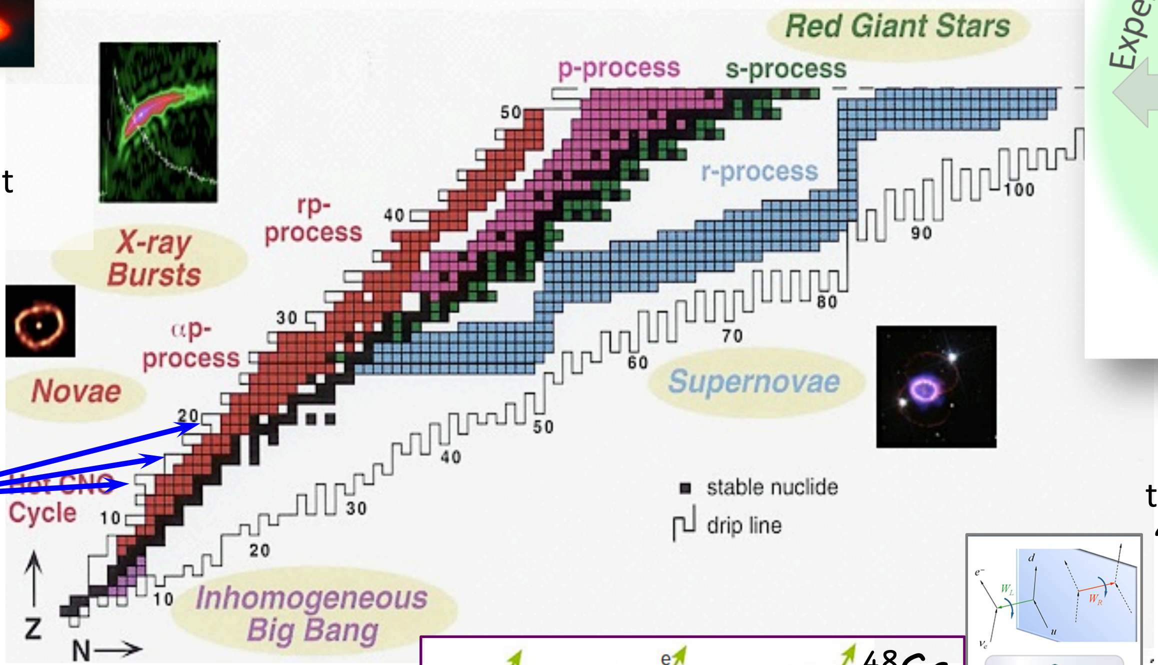


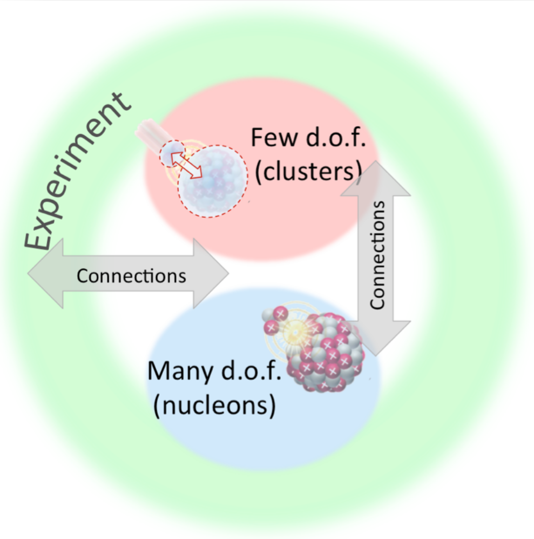
X-ray burst nucleosynthesis

Alpha widths

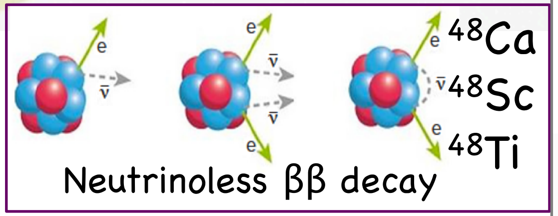
Reaction rates at low energies

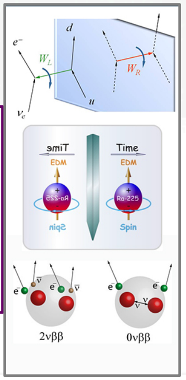
Close proximity of the drip lines





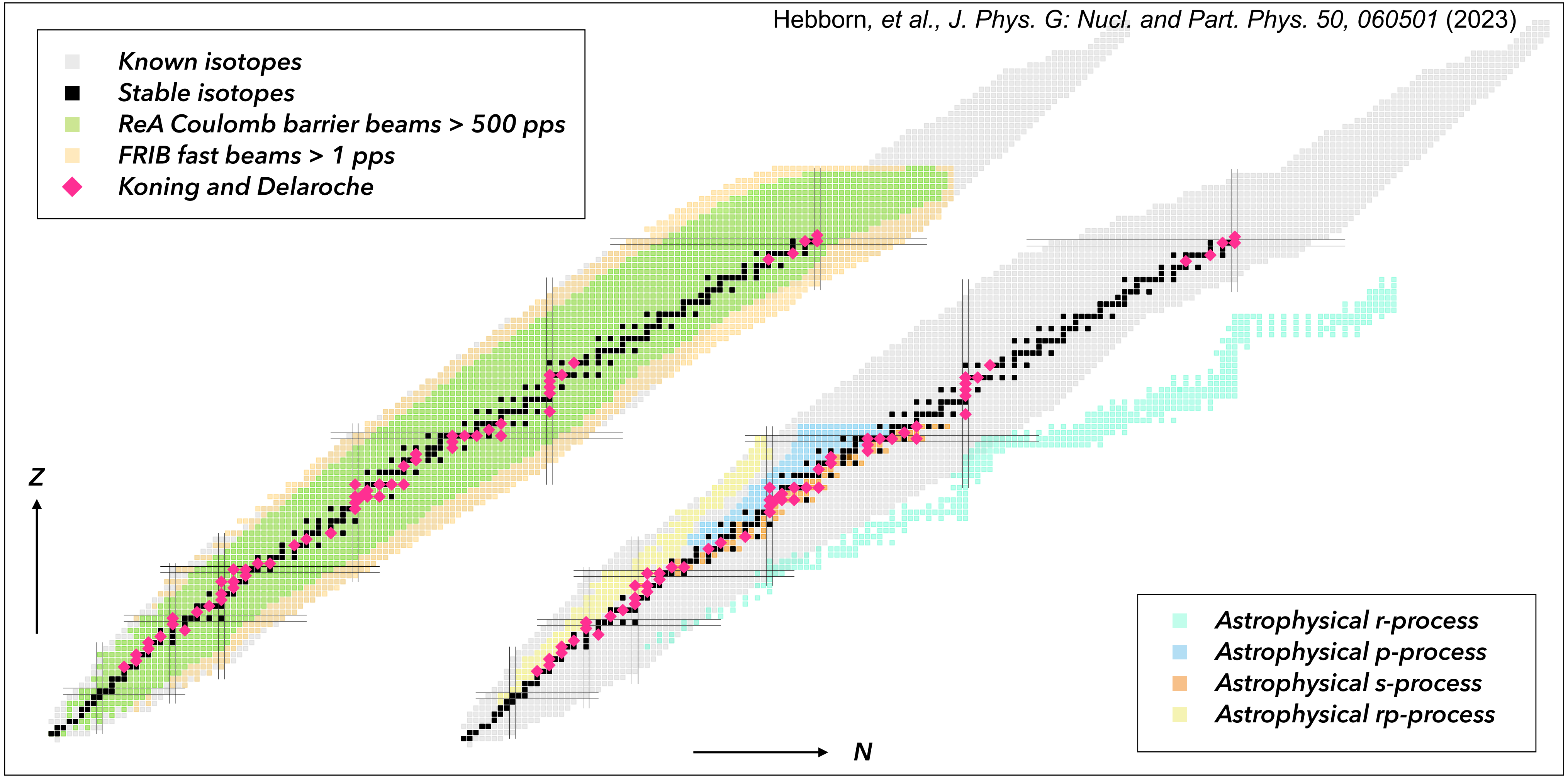
FRIB Theory Alliance topical program (2018) “From bound states to the continuum“ (C. Johnson et al.)

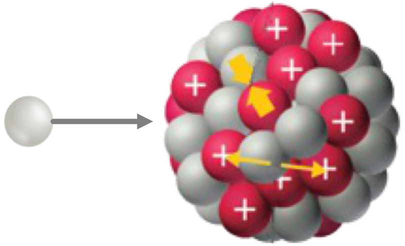




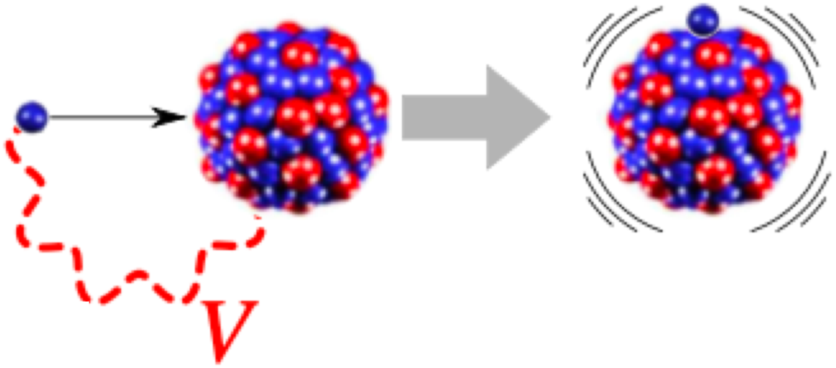
Fundamental symmetries

Our current knowledge of optical potentials (OP) is very limited





Embedding nuclear structure information within the optical potential (OP)



Feshbach formalism

$$V(\boldsymbol{r},\boldsymbol{r}',E) = V_{00}(\boldsymbol{r},E) + V_{PO}(\boldsymbol{r},\boldsymbol{r}',E)$$

$$= V_{00}(\boldsymbol{r},E) + \underbrace{\sum_i V_{0i}(\boldsymbol{r})G_i(\boldsymbol{r},\boldsymbol{r}',E)V_{0i}(\boldsymbol{r}')}$$

Polarization potential:
Requires input from
nuclear structure

Can be applied to any mass range as long as nuclear structure calculations are available

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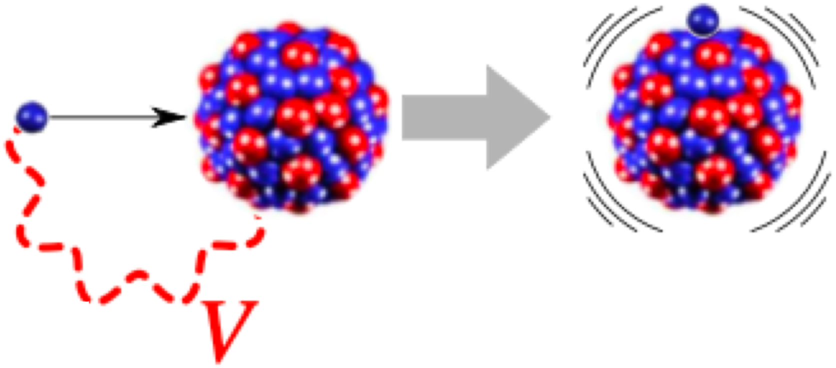

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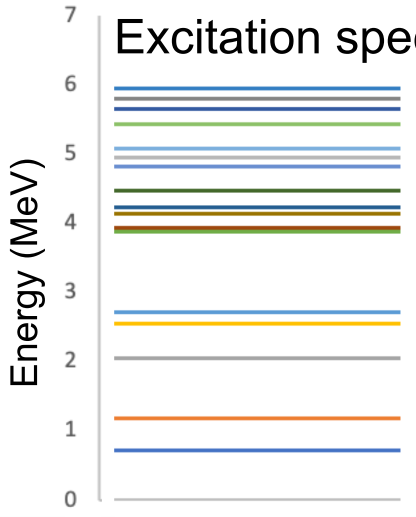
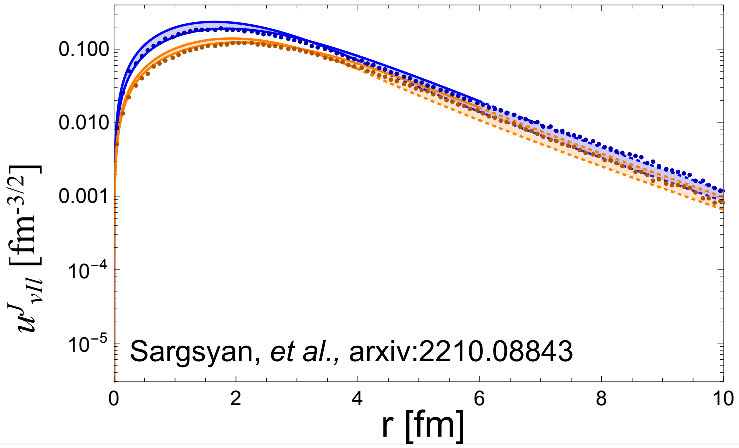
Polarization potential: Requires input from nuclear structure

Excitation spectrum



Single-nucleon overlaps



Various nuclear structure models can be employed, such as **shell model, RPA, ab initio models, ...**

Iterative scheme for self consistent V_{PO}

$$\mathcal{V}^{(0)} = V_{00},$$

$$\mathcal{V}^{(1)} = V_{00} + \lim_{\eta\to 0}\sum_i V_{0i}(r_n)\left(E - T - \mathcal{V}^{(0)}(E_i; \mathbf{r}_n, \mathbf{r}'_n) + i\eta\right)^{-1} V_{i0}(r'_n),$$

$$\ldots$$

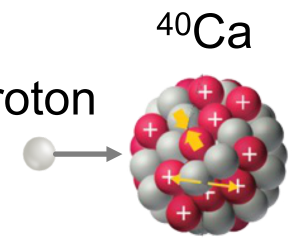
$$\mathcal{V}^{(n+1)} = V_{00} + \lim_{\eta\to 0}\sum_i V_{0i}(r_n)\left(E - T - \mathcal{V}^{(n)}(E_i; \mathbf{r}_n, \mathbf{r}'_n) + i\eta\right)^{-1} V_{i0}(r'_n),$$

$$J^{(n)} = \int \mathcal{V}^{(n)}(\mathbf{r}_n, \mathbf{r}'_n)\, d\mathbf{r}\, d\mathbf{r}',$$

$$\varepsilon = \left|\frac{J^{(n+1)} - J^{(n)}}{J^{(n+1)} + J^{(n)}}\right| \ll 1.$$

← Volume integral convergence condition

^{40}Ca + p elastic scattering with 10 states



Parameters for levels in ^{40}Ca

λ_n^π	1^-	2^+	2^+	2^+	3^-	3^-	4^+	4^+	5^-	5^-
E_n (MeV)	18.0	3.9	8.0	16.0	3.73	15.73	8.0	20.0	4.48	16.48
$\beta_\lambda(n)$	0.087	0.143	0.309	0.250	0.354	0.380	0.254	0.457	0.192	0.653

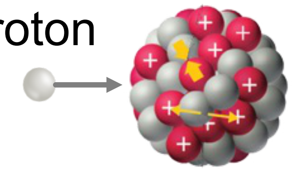
Rao, et al., Nuclear Physics A207 (1973) 182-208.

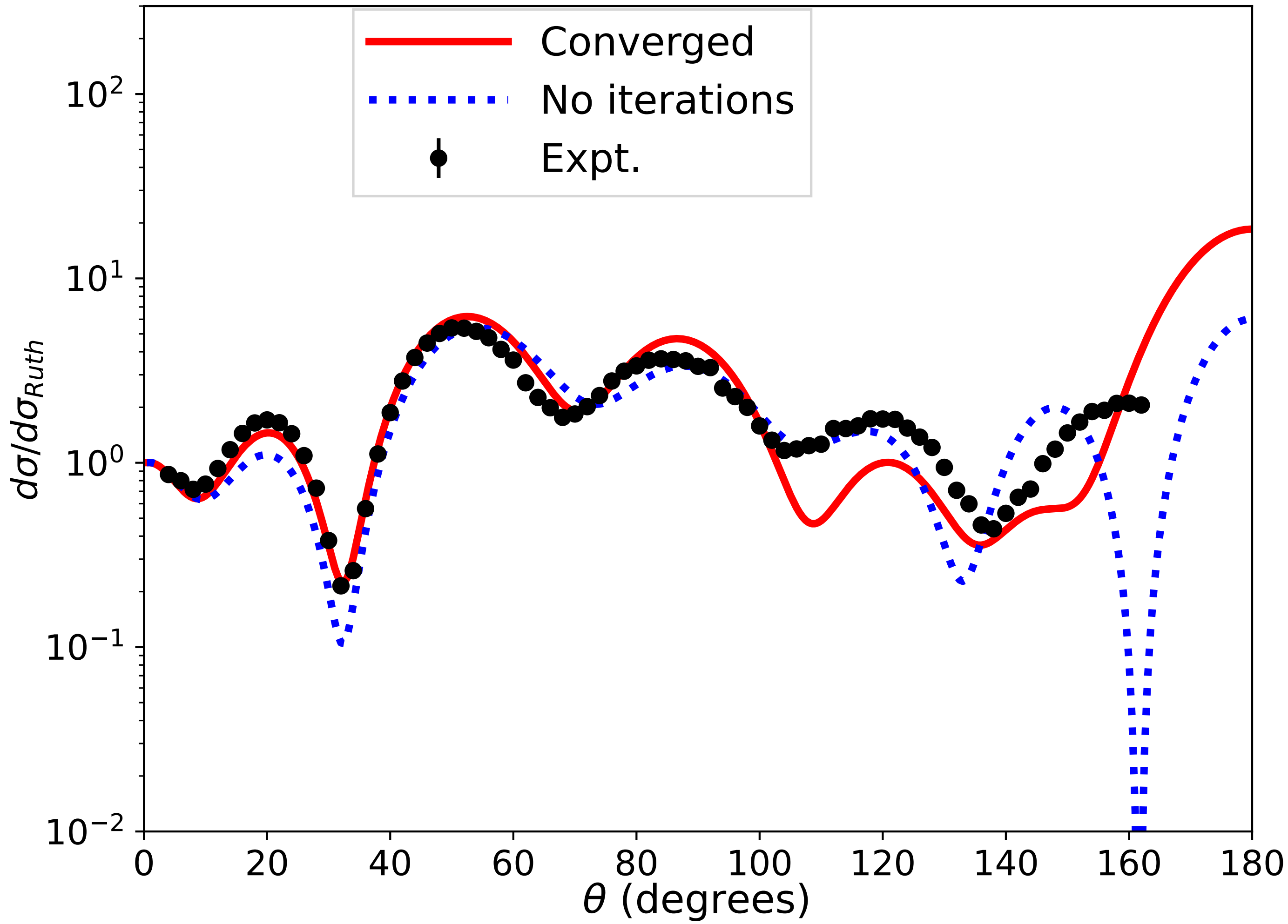
$$V(\boldsymbol{r},\boldsymbol{r}',E) = V_{00}(\boldsymbol{r},E) + V_{PO}(\boldsymbol{r},\boldsymbol{r}',E)$$

Woods-Saxon:
V_0 = -50 MeV
$R_0 = 1.2A^{1/3}$
a = 0.65

10 intrinsic states

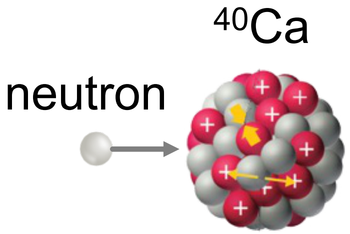
^{40}Ca + p elastic scattering at 30 MeV

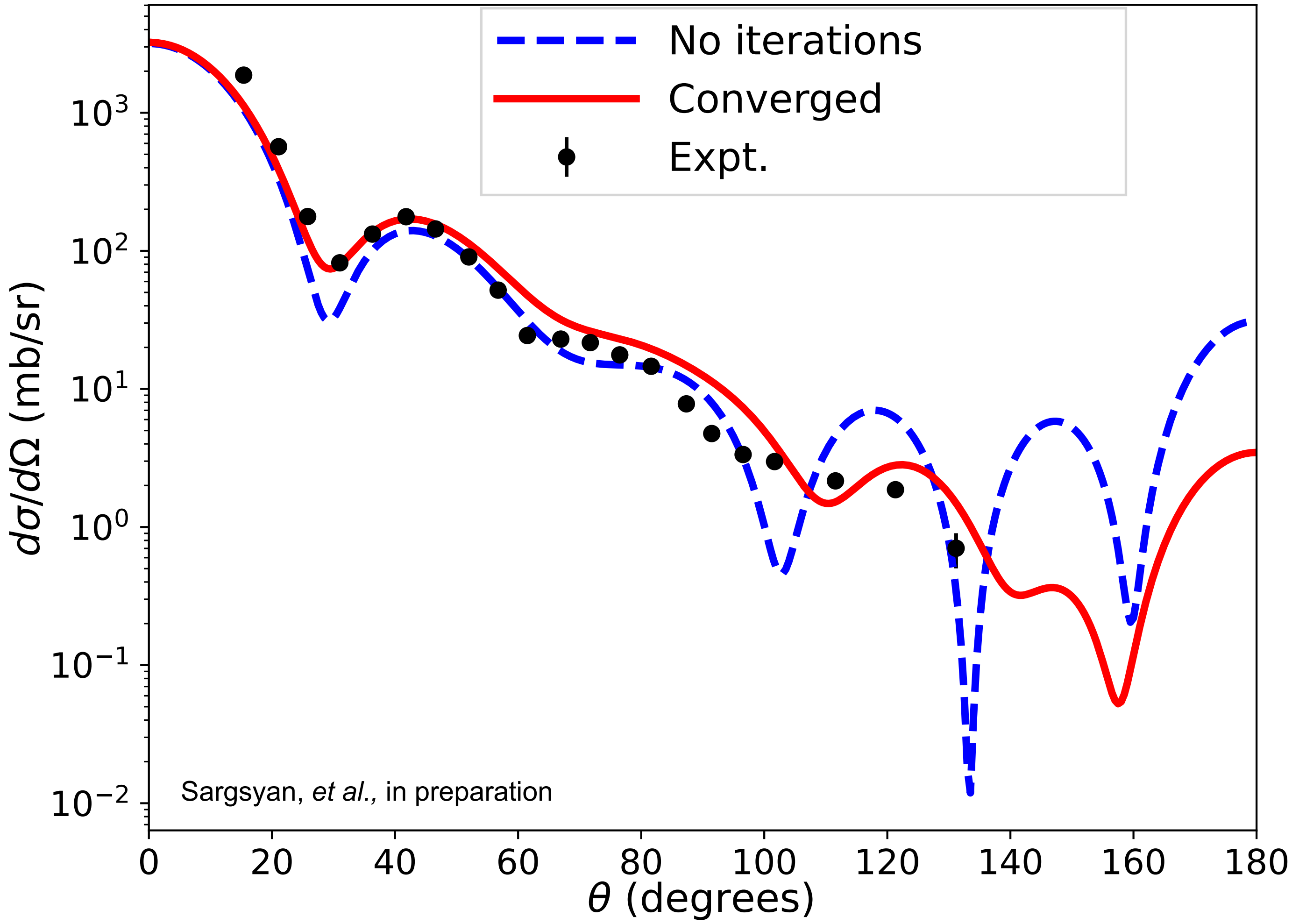




10 intrinsic states

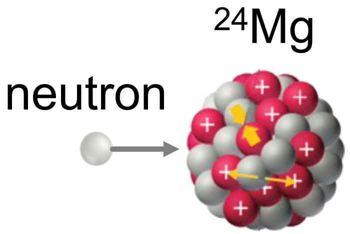
Neutron elastic scattering over ^{40}Ca at 30 MeV

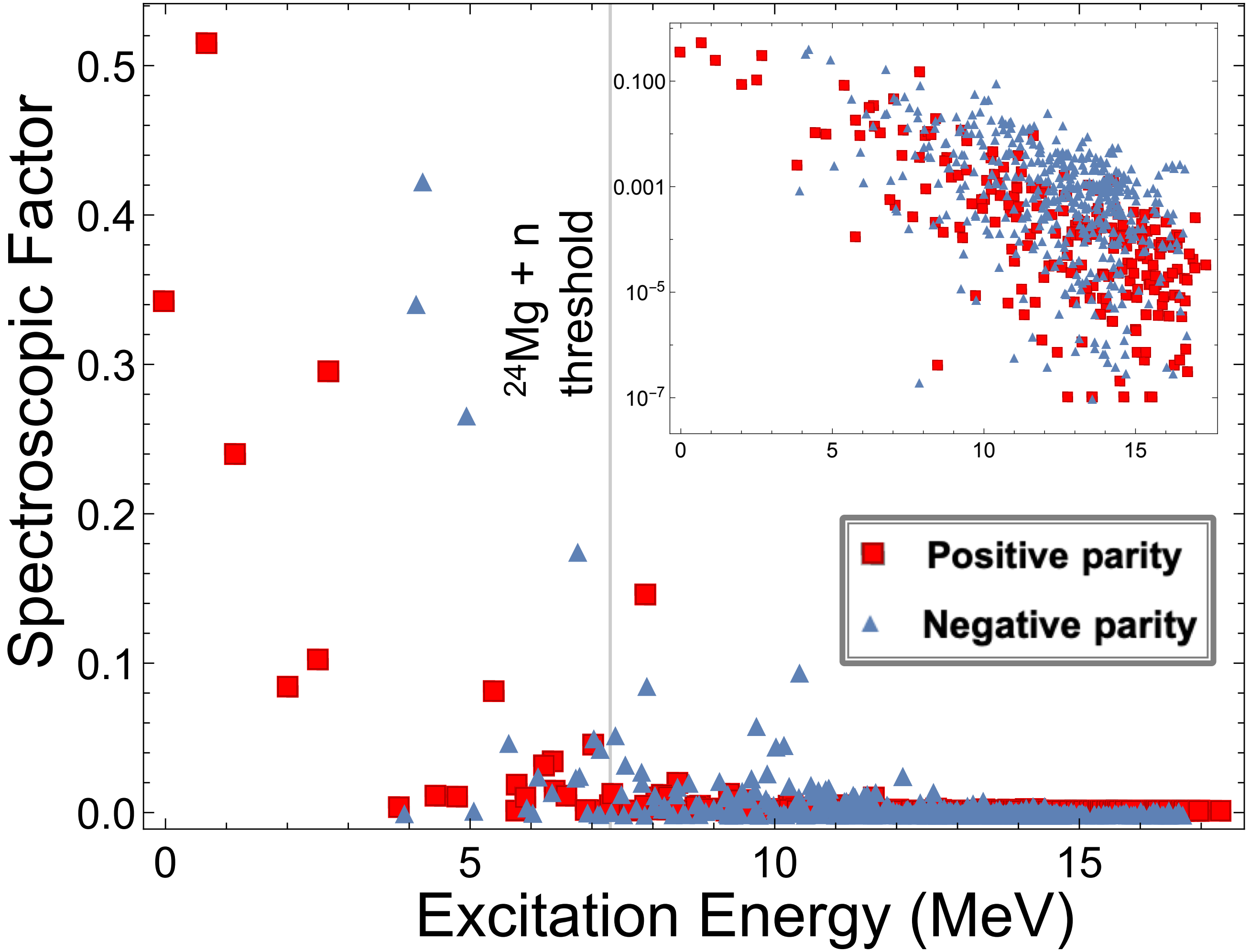




10 intrinsic states

Ingredients for constructing neutron+^{24}Mg OP



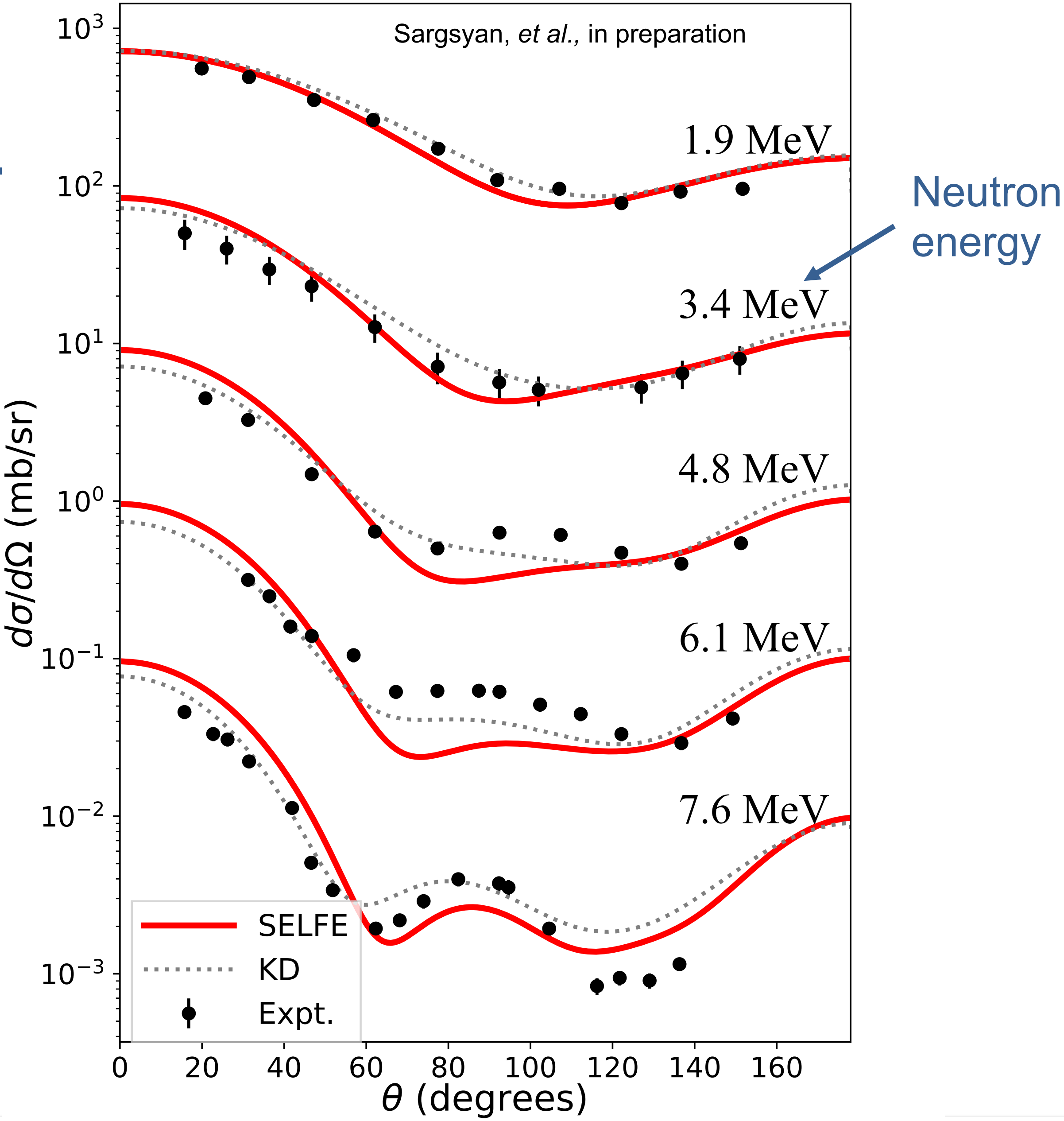


Around 600 intrinsic states

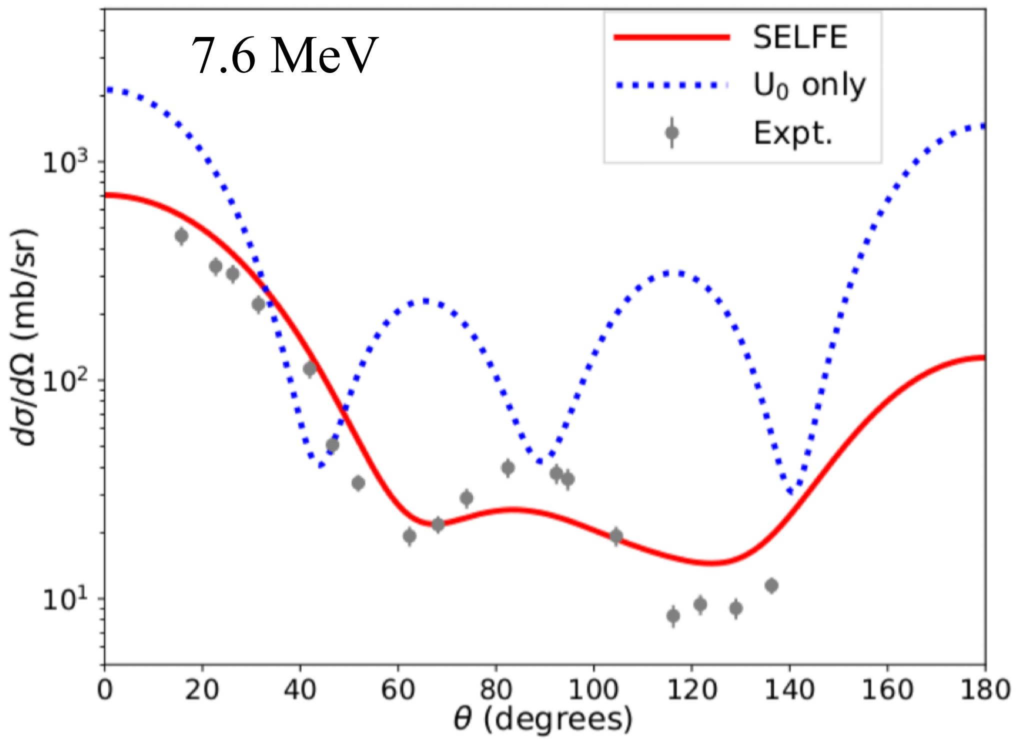
Shell model calculations with PSDPF potential M Bouhelal, *et al.*, Nucl. Phys. A 864 (2011)

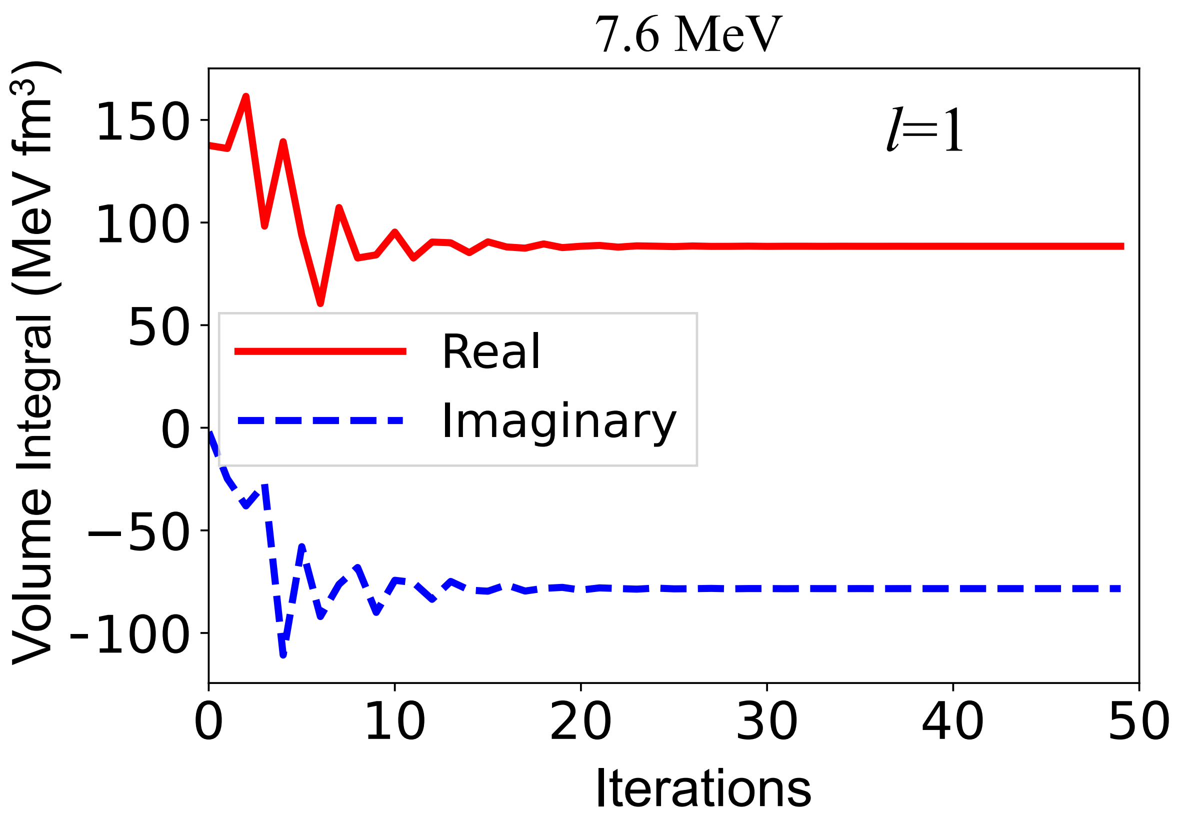
First shell model-based OP for n+^{24}Mg

- Almost 600 states from microscopic nuclear shell model calculations
- No parameters fitted to experimental scattering data
- All the absorption comes from shell model states
- Compound nucleus contribution added incoherently



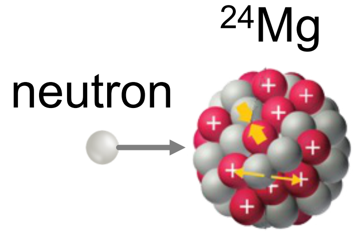
No phenomenological imaginary terms

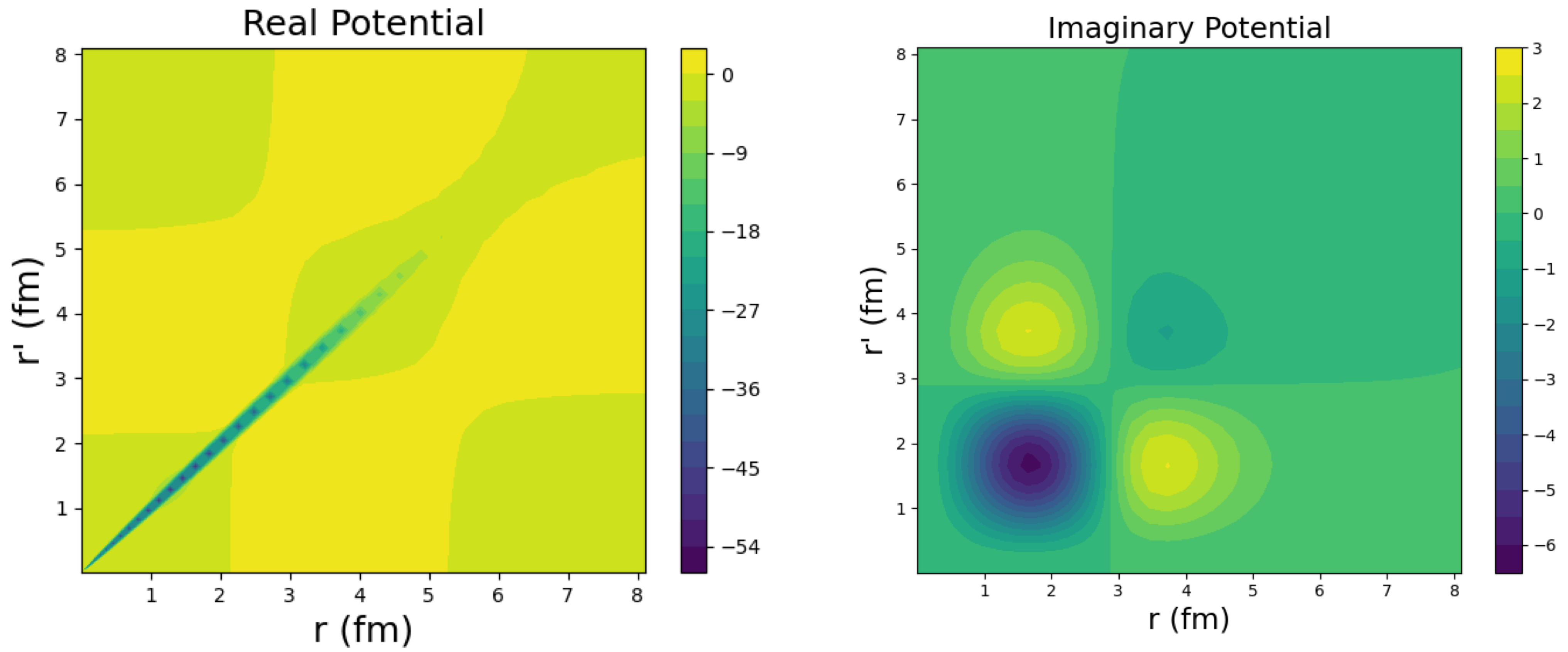




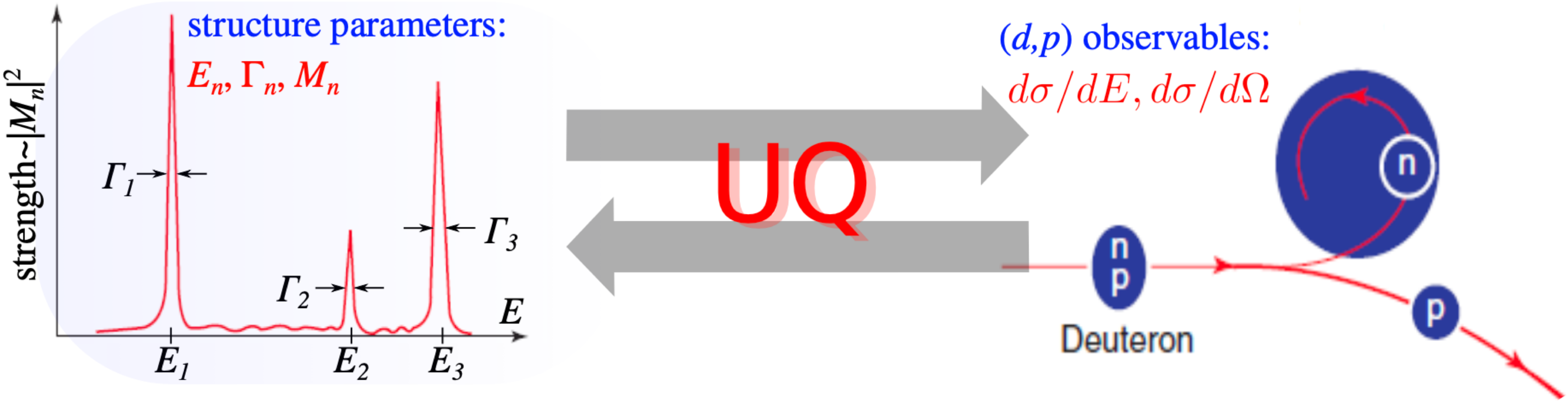
$$V(\boldsymbol{r},\boldsymbol{r}',E) = U_0(\boldsymbol{r},E) + V_{PO}(\boldsymbol{r},\boldsymbol{r}',E) = U_0(\boldsymbol{r},E) + \sum_i U_{0i}(\boldsymbol{r})G_i(\boldsymbol{r},\boldsymbol{r}',E)U_{0i}(\boldsymbol{r}')$$

Potential profiles for 3.4 MeV



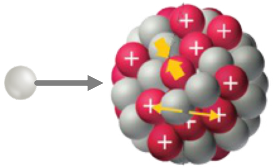


Quantify uncertainties in the structure parameters that define V



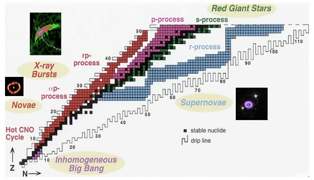
Summary

- We develop a new code to build nucleon-nucleus optical potentials for reliable calculations of nuclear reactions

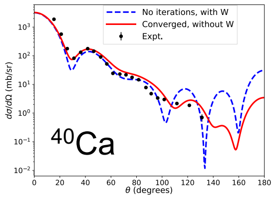


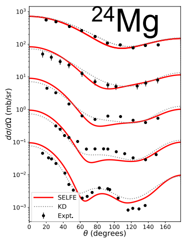
- Nuclear shell model calculations allow us to account for the intrinsic microscopic structure of the reacting nuclei, adding predictive power to the method

- The method can be applied to any mass range of nuclei as long as structure calculations are available



- First results for ^{40}Ca and ^{24}Mg target nuclei are in good agreement with measurements





Thank you!