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Nuclear excitation by electron capture with electron vortex beams for isomer depletion

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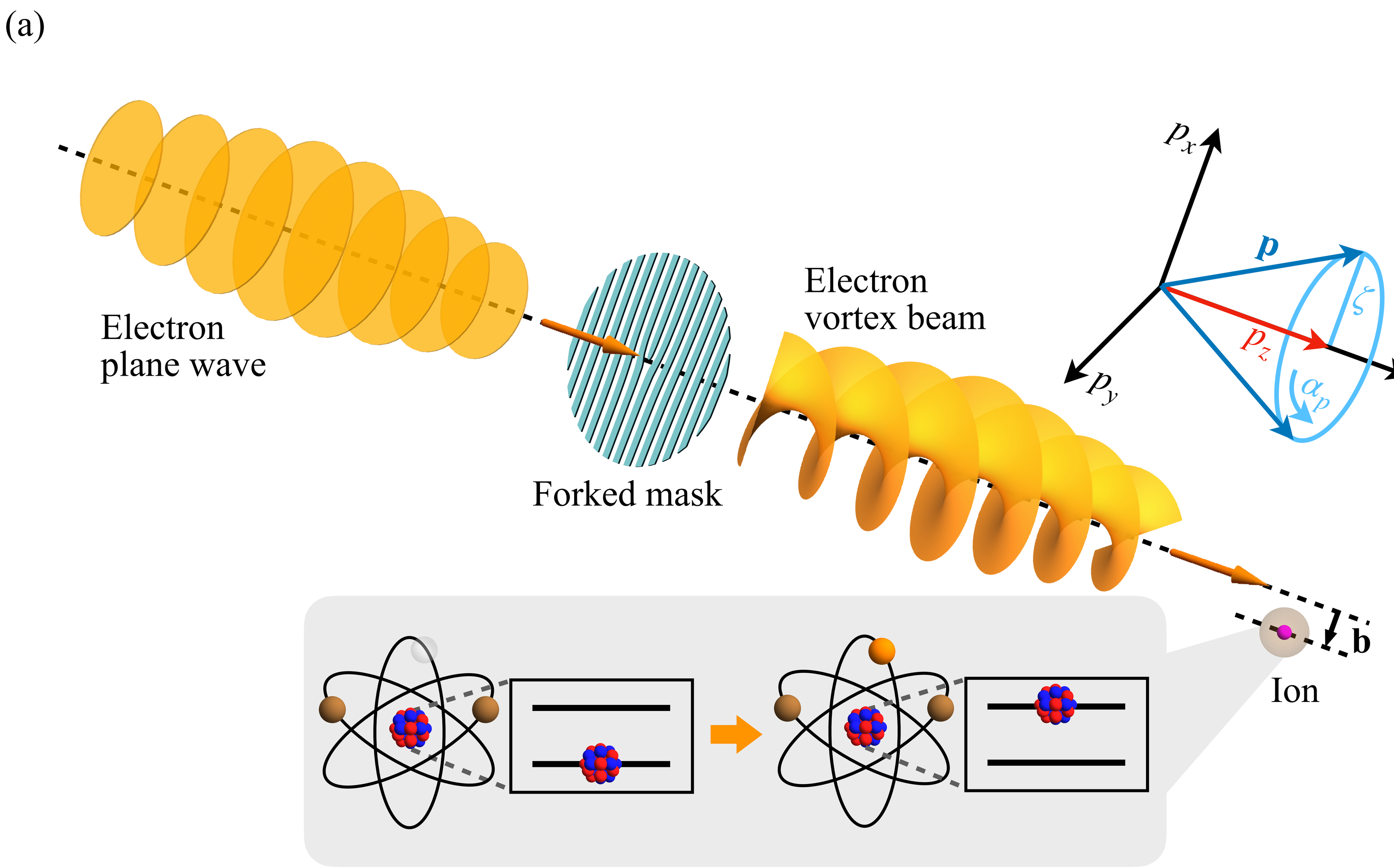
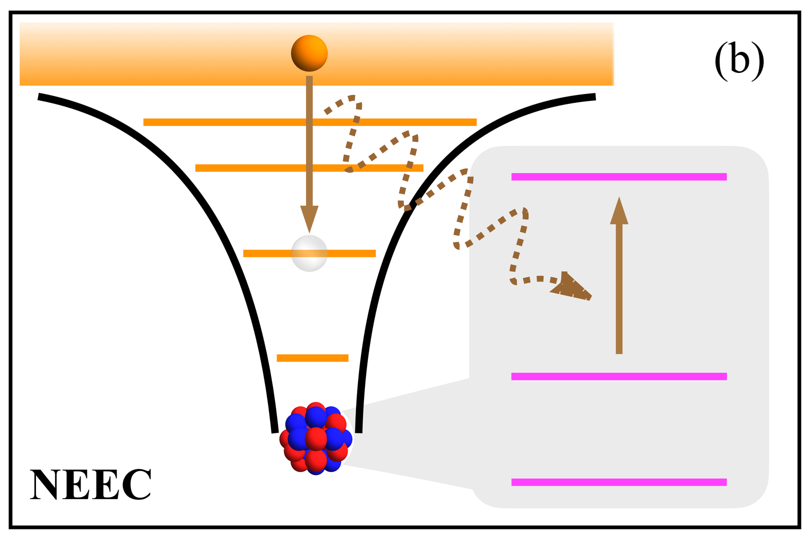
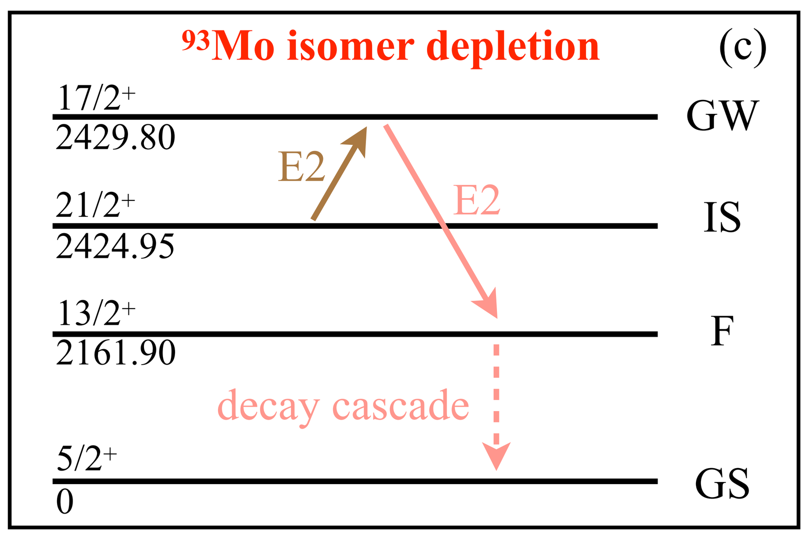






NEEC — fundamental process at the nuclear-atomic interface

- First proposed theoretically in 1976

  Phys. Lett. B **62**, 393 (1976)
- First experimental observation claimed in 2018

  Nature **554**, 216 (2018)

- Population mechanisms of excited nuclear levels
- Atomic vacancy effects on nuclear lifetime
- Dense astrophysical plasmas
- Isomer depletion

NEEC with electron vortex beams

- Key points for NEEC:

  Vacancies of atomic levels

  Free electrons

☑ Shaping electron wave functions to manipulate nuclei?

Vortex beam

$$\psi_s(\mathbf{r}) = \int \frac{d^2\mathbf{p}_\perp}{(2\pi)^2} a_{\zeta m}(\mathbf{p}_\perp) u_{\mathbf{p}s} e^{i\mathbf{p}\cdot\mathbf{r}}, \quad a_{\zeta m}(\mathbf{p}_\perp) = (-i)^m e^{im\alpha_p}\delta(|\mathbf{p}_\perp| - \zeta)/\zeta$$

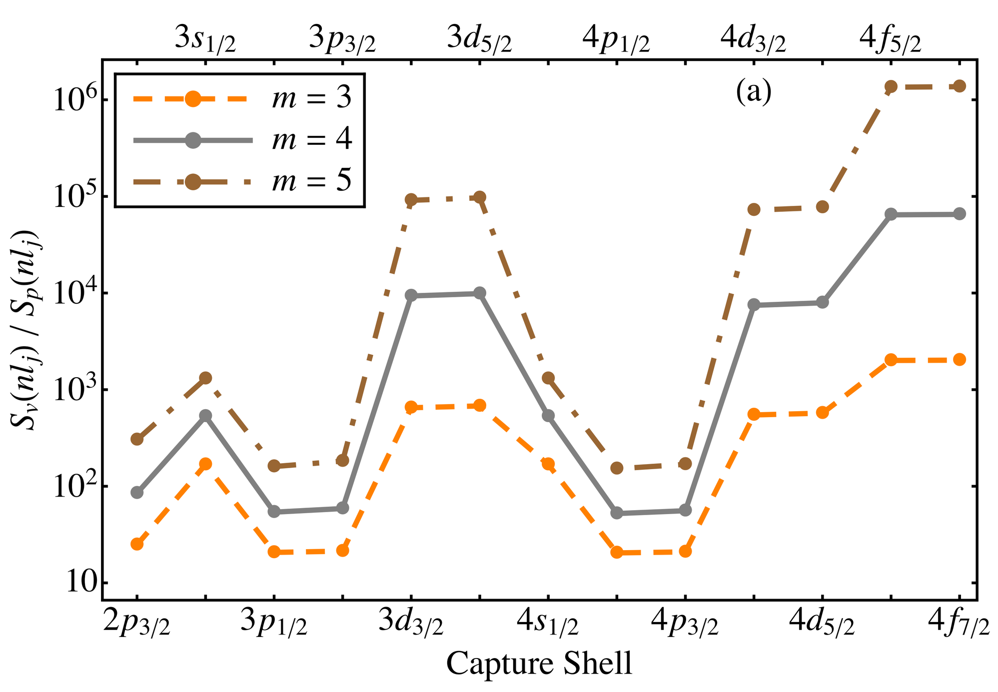
Theoretical formalism

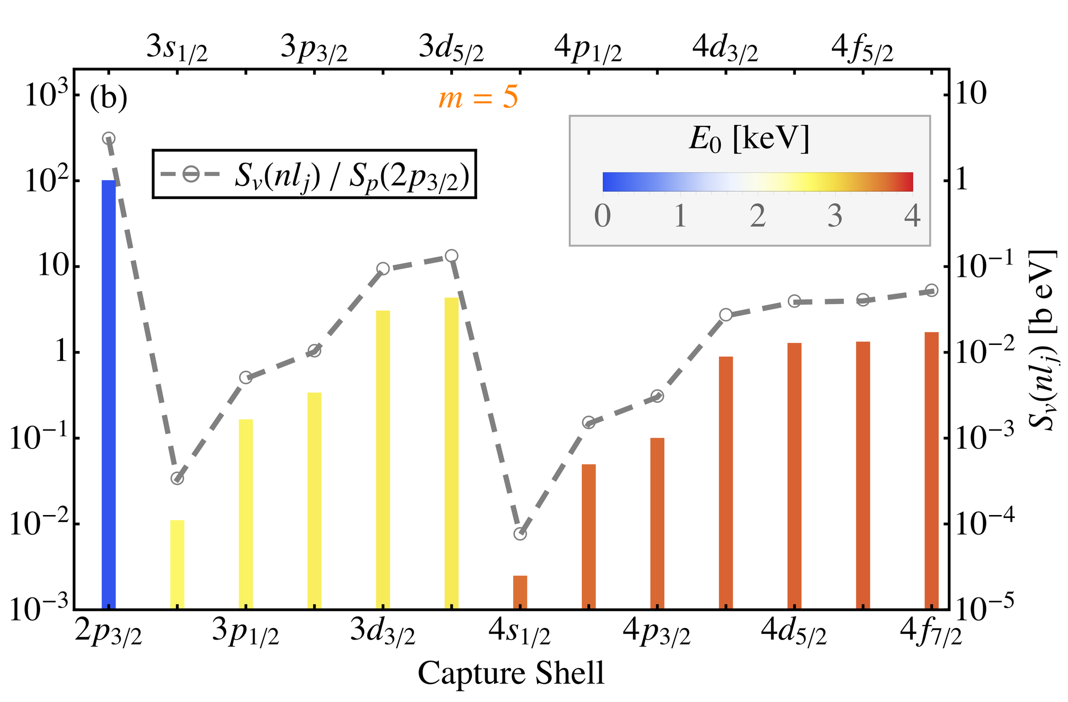
$$\sigma^{i\to g}_{neec}(E) = \frac{4\pi^2}{pJ_z} Y^{i\to g}_{neec}\mathscr{L}(E - E_0), \quad Y^{i\to g}_{neec} \propto |\langle\Psi^N_g|\langle\Psi^e_g|H_N|\Psi^e_i, \psi_s\rangle|\Psi^N_i\rangle|^2$$

$$Y^{i\to g}_{neec} = \frac{b^2}{4\pi}\int_0^{2\pi}\int_0^{2\pi}\frac{d\alpha_p}{2\pi}\frac{d\alpha_k}{2\pi} e^{im(\alpha_p-\alpha_k)}\mathscr{Y}^{i\to g}_{neec}(\mathbf{p},\mathbf{k})\,{}_0F_1(2;u)$$

$$\mathscr{Y}^{i\to g}_{neec}(\mathbf{p},\mathbf{k}) = \frac{16\pi^3(2J_g+1)}{(2J_i+1)(2L+1)^2}\mathscr{B}\uparrow(\lambda L)\rho_i\sum_{\kappa,m_l}\frac{\mathscr{Y}_b}{2l+1}Y^*_{lm_l}(\theta_k,\varphi_k)Y_{lm_l}(\theta_p,\varphi_p)$$

^{93m}Mo isomer depletion E2 transition





^{152m}Eu isomer depletion M1 transition

nlj	E_d [keV]	S_p [b eV]	S_v [b eV] $m = 3$	S_v [b eV] $m = 5$
$2s_{1/2}$	5.20	8.05×10^{-4}	1.14×10^{-3}	1.14×10^{-3}
$2p_{1/2}$	5.19	7.85×10^{-5}	1.35×10^{-3}	3.34×10^{-3}
$2p_{3/2}$	6.02	1.25×10^{-5}	4.21×10^{-4}	7.61×10^{-3}

- The choice of impact parameter **b** is crucial $\quad \zeta = p_z; \quad \zeta b = 1$

☑ Introduce the theory for NEEC with an electron vortex beam

☑ 2 orders of magnitude enhancement for NEEC cross section for ^{93m}Mo isomer depletion

☑ 6 orders of magnitude enhancement for higher shells

☑ Control nuclear excitations by shaping electron wave functions

Reference:
Y. Wu, S. Gargiulo, F. Carbone, C. H. Keitel, and A. Pálffy, *Phys. Rev. Lett.* **128**, 162501 (2022).

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