Elastic and quasi-elastic electron scattering off isotopic and isotonic chains

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- Properties of exotic nuclei through electron scattering
- Relativistic model for ground-state observables
- Elastic electron scattering
- Inclusive quasi-elastic electron scattering
- Parity violating asymmetry

- Collaborators

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  P. Finelli (Bologna)

Relativistic model for ground-state observables

- Lagrangian

$$\mathcal{L} = \bar{\psi}(i\gamma^\mu \partial_\mu - M)\psi + \frac{1}{2}\partial^\mu \sigma \partial_\mu \sigma - U(\sigma) - g_\sigma \sigma \bar{\psi}\psi$$
$$- \frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} + \frac{1}{2}m_\omega^2 \omega^\mu \omega_\mu - g_\omega \omega_\mu \bar{\psi}\gamma^\mu \psi$$
$$- \frac{1}{4}\vec{R}^{\mu\nu}\vec{R}_{\mu\nu} + \frac{1}{2}m_\rho^2 \vec{\rho}^\mu \vec{\rho}_\mu - g_\rho \vec{\rho}_\mu \bar{\psi}\gamma^\mu \vec{\tau}\psi$$
$$- \frac{1}{4}F^{\mu\nu}F_{\mu\nu} - eA_\mu \bar{\psi}\gamma^\mu \frac{(\mathbb{I} - \tau_3)}{2}\psi$$

- Nonlinear sigma potential

$$U(\sigma) = \frac{1}{2}m_\sigma^2 + \frac{1}{3}g_2\sigma^3 + \frac{1}{4}g_3\sigma^4$$

- Field tensors

$$\Omega^{\mu\nu} = \partial^\mu \omega^\nu - \partial^\nu \omega^\mu$$
$$\vec{R}^{\mu\nu} = \partial^\mu \vec{\rho}^\nu - \partial^\nu \vec{\rho}^\mu - g_\rho(\vec{\rho}^\mu \times \vec{\rho}^\nu)$$
$$F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu$$

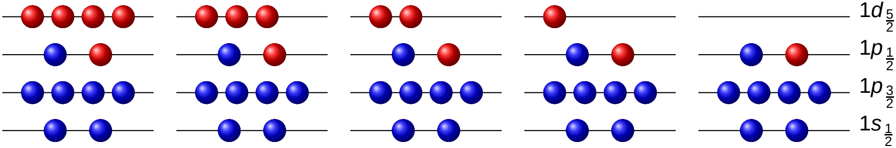
Relativistic model for ground-state observables

- Gap parameter: for open shell nuclei is employed the constant gap approximation with empirical Δ

$$\Delta^{(5)}(N) = -\frac{1}{8}\Big[M(N+2) - 4M(N+1) + 6M(N) - 4M(N-1) + M(N-2)\Big]$$

Five different isotopes

$^{20}_{8}O_{12}$ $^{19}_{8}O_{11}$ $\boxed{^{18}_{8}O_{10}}$ $^{17}_{8}O_{9}$ $^{16}_{8}O_{8}$



Elastic electron scattering

- One photon exchange
- Differential cross section

$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)_{EL} = \sigma_M \left| F_p(q) \right|^2$$

- Charge form factor

$$F_p(q) = \int \mathrm{d}r \, \jmath_0(qr) \rho_p(r)$$

- Coulomb distortion

- Inclusive differential cross section

$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\varepsilon\,\mathrm{d}\Omega}\right)_{QE} = \sigma_M\left[v_L R_L + v_T R_T\right]$$

- Coefficients

$$v_L = \left(\frac{|Q^2|}{|\boldsymbol{q}|^2}\right)^2 \qquad v_T = \tan^2\frac{\theta}{2} - \frac{|Q^2|}{2|\boldsymbol{q}|^2} \qquad Q^2 = |\boldsymbol{q}|^2 - \omega^2$$

- Longitudinal and transverse response functions

$$R_L(q,\omega) = W^{00}(q,\omega) \qquad R_T(q,\omega) = W^{11}(q,\omega) + W^{22}(q,\omega)$$

- Hadron tensor

$$W^{\mu\mu}(q,\omega) = \overline{\sum_i}\;\sum\!\!\!\!\!\!\int_f \left|\langle\Psi_f|\hat{J}^{\mu}(\boldsymbol{q})|\Psi_0\rangle\right|^2 \delta(E_0+\omega-E_f)$$

- Equivalent expression for the hadron tensor

$$W^{\mu\mu}(q,\omega) = -\frac{1}{\pi}\mathrm{Im}\langle\Psi_0|J^{\mu\dagger}(\boldsymbol{q})G(E_f)J^{\mu}(\boldsymbol{q})|\Psi_0\rangle$$

- Final expression for the hadron tensor

$$\begin{aligned} W^{\mu\mu}(q,\omega) = \sum_n \Bigg[& \mathrm{Re}\, T_n^{\mu\mu}(E_f-\varepsilon_n, E_f-\varepsilon_n) \\ & - \frac{1}{\pi}\mathcal{P}\int_M^\infty \mathrm{d}\mathcal{E}\, \frac{1}{E_f-\varepsilon_n-\mathcal{E}}\, \mathrm{Im}\, T_n^{\mu\mu}(\mathcal{E}, E_f-\varepsilon_n) \Bigg] \end{aligned}$$

$$\begin{aligned} T_n^{\mu\mu}(\mathcal{E},E) = {} & \lambda_n \langle\varphi_n|j^{\mu\dagger}(\boldsymbol{q})\sqrt{1-\mathcal{V}'(E)}|\tilde{\chi}_{\mathcal{E}}^{(-)}(E)\rangle \\ & \times \langle\chi_{\mathcal{E}}^{(-)}(E)|\sqrt{1-\mathcal{V}'(E)}j^{\mu}(\boldsymbol{q})|\varphi_n\rangle \end{aligned}$$

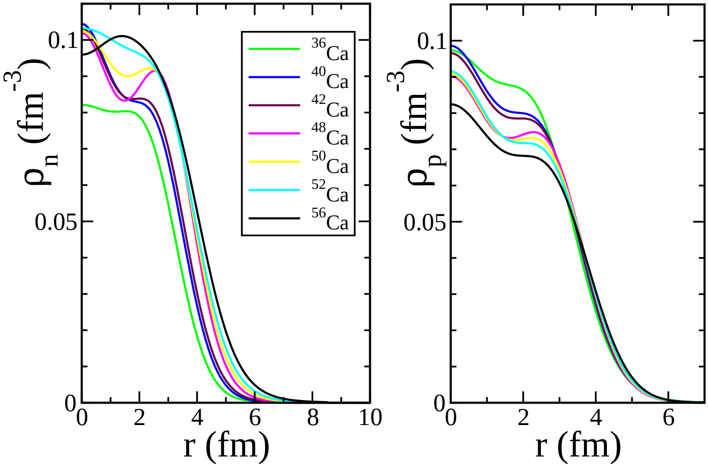
- Dirac equation $$[\boldsymbol{\alpha} \cdot \mathbf{p} + U_{\pm}(r)]\Psi_{\pm} = E\Psi_{\pm}$$
- Total potential $$U(r)_{\pm} = V(r) \pm \gamma_5 A(r)$$
- Axial potential $$A(r) = \frac{G_F}{2\sqrt{2}} \rho_W(r)$$
- Weak charge density

$$\rho_W(r) = \int \mathrm{d}\mathbf{r}' \, G_E\left(|\mathbf{r} - \mathbf{r}'|\right) \times \left[-\rho_n(r') + (1 - 4\sin^2\Theta_W)\rho_p(r')\right]$$

- Electric form factor $$G_E(r) \approx \frac{\Lambda^3}{8\pi} e^{-\Lambda r} \qquad \Lambda = 4.27 \text{ fm}^{-1}$$
- Parity-violating asymmetry in Born approximation

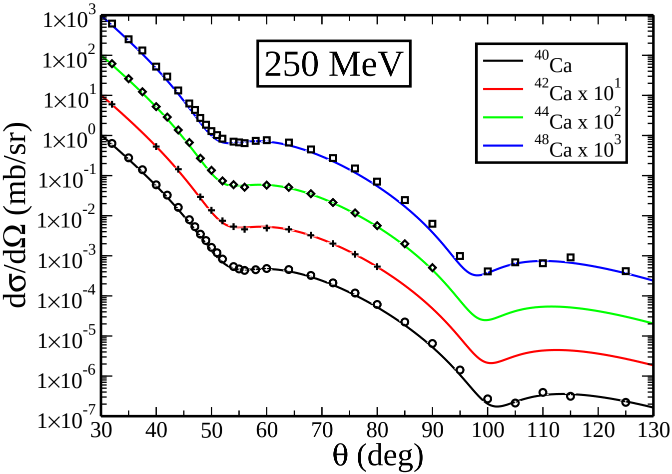
$$A_{pv} = \frac{\frac{d\sigma_+}{d\Omega} - \frac{d\sigma_-}{d\Omega}}{\frac{d\sigma_+}{d\Omega} + \frac{d\sigma_-}{d\Omega}} = \frac{G_F\, Q^2}{4\sqrt{2}\,\pi\alpha}\left[4\sin^2\Theta_W - 1 + \frac{F_n(q)}{F_p(q)}\right]$$

Calcium neutron and proton densities



A. Meucci, M. Vorabbi, C. Giusti, F. D. Pacati and P. Finelli, Phys. Rev. C**87**, (2013) 054620.

Experimental elastic differential cross sections



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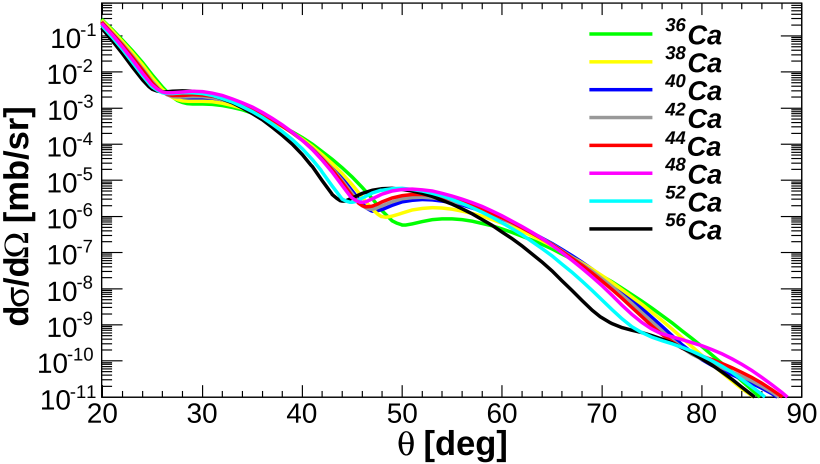
$\varepsilon = 496.8$ MeV



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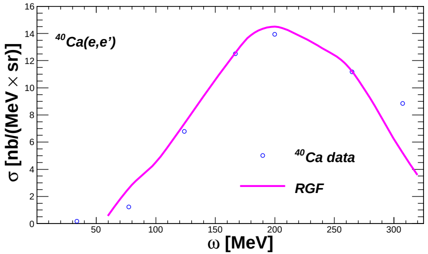
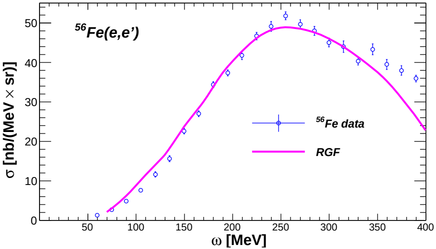
Experimental inclusive QE differential cross sections



^{40}Ca
$\varepsilon = 841$ MeV
$\theta = 45°$



^{56}Fe
$\varepsilon = 2020$ MeV
$\theta = 20°$

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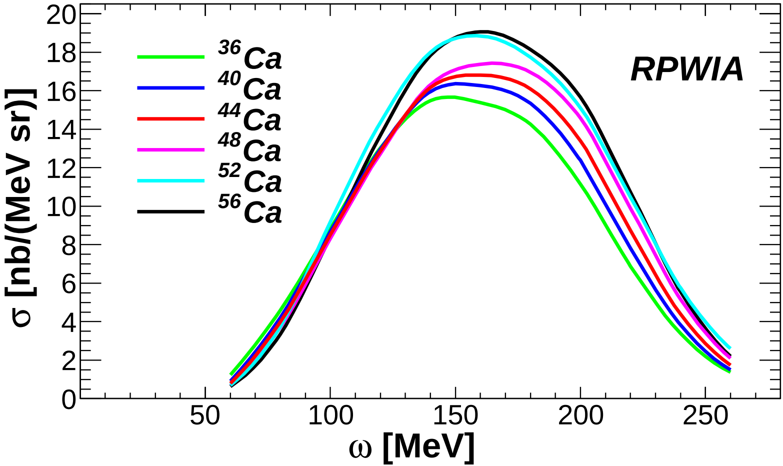
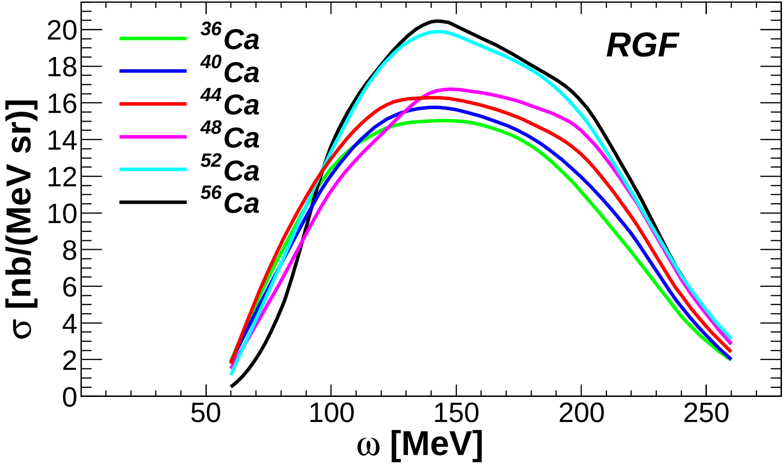
$\varepsilon = 560\,\mathrm{MeV} \qquad \theta = 60^{o}$



A. Meucci, M. Vorabbi, C. Giusti, F. D. Pacati and P. Finelli, Phys. Rev. C**87**, (2013) 054620.

Inclusive QE differential RGF cross sections

$$\varepsilon = 560\,\mathrm{MeV} \qquad \theta = 60^{\mathrm{o}}$$



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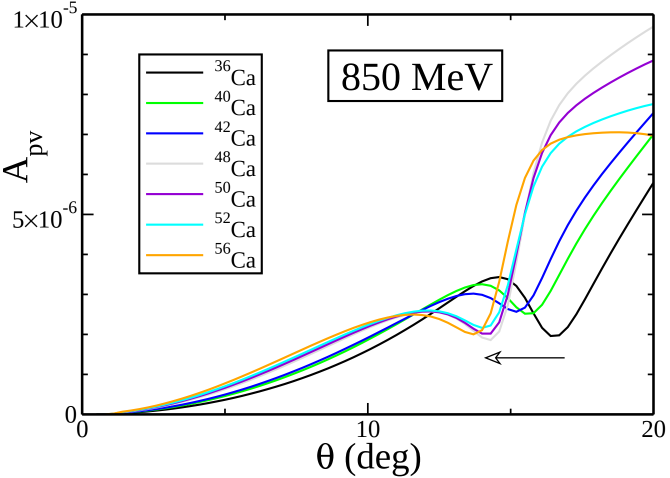

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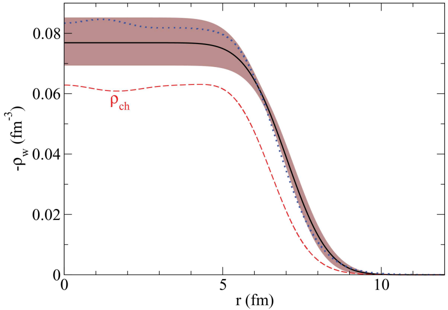
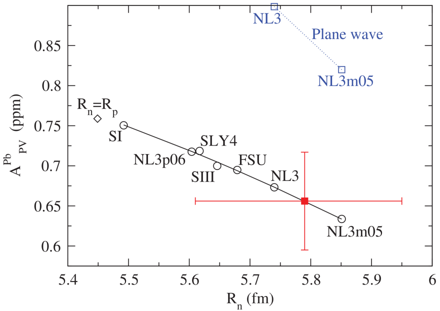
Physical Review C **85**, 032501(R) (2012)



Physical Review Lett. **108**, 112502 (2012)

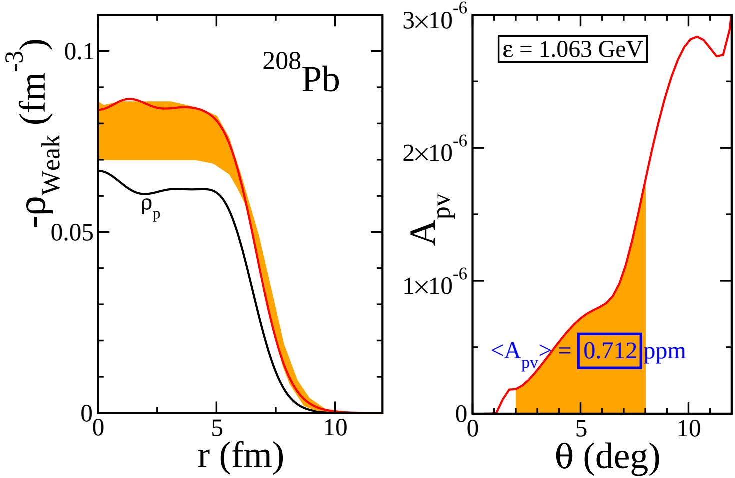


- Asymmetry averaged over the acceptance

$$\langle A_{pv} \rangle = \frac{\int d\theta \ \ \sin\theta A_{pv}(\theta) \frac{d\sigma}{d\Omega} \ \ \epsilon(\theta)}{\int d\theta \ \ \sin\theta \ \ \frac{d\sigma}{d\Omega} \ \ \epsilon(\theta)}$$

- Exp. Result: $\boxed{A^{\mathrm{Pb}}_{\mathrm{pv}} = 0.656 \pm 0.060(\mathrm{stat}) \pm 0.014(\mathrm{syst})\ \mathrm{ppm}}$

Weak charge density and A_{pv} for ^{208}Pb



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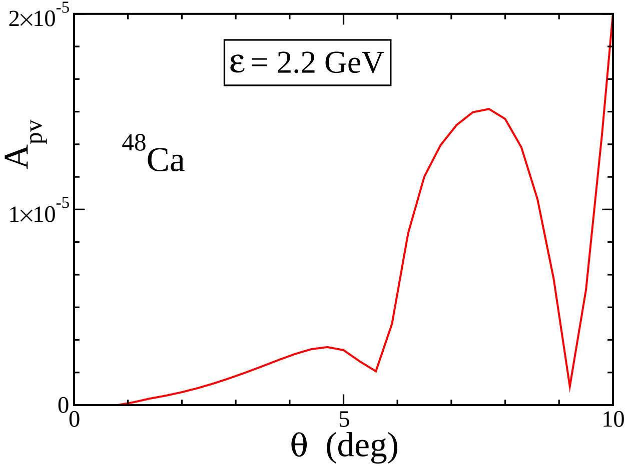
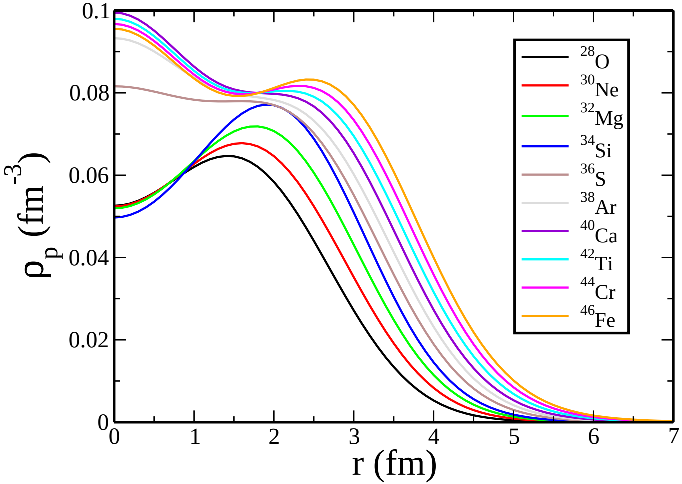
C-REX: Parity-violating measurement of the weak charge distribution of ^{48}Ca at 2.2 GeV



A. Meucci, M. Vorabbi, C. Giusti, F. D. Pacati and P. Finelli, Phys. Rev. C**87**, (2013) 054620.

Proton densities for $\mathrm{N} = 20$ isotones



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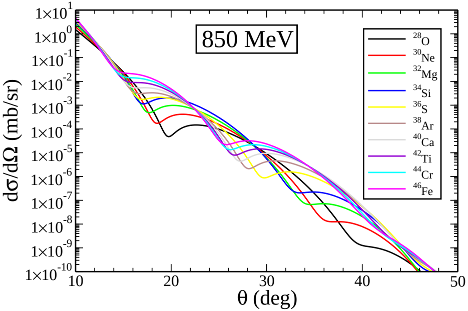

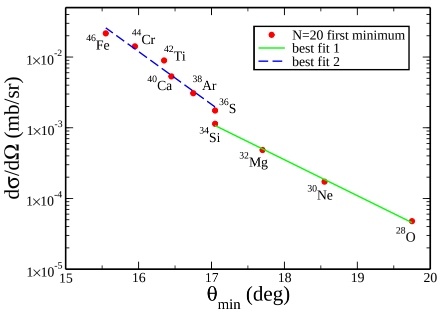

In preparation

Conclusions

- Elastic and quasi-elastic electron scattering give information on the global properties of nuclei and on the single particle aspects of the nucleus
- Isotopic and isotonic chains
- Parity-violating asymmetry parameter investigates the neutron skin
- Good agreement with PREX measurement on ^{208}Pb
- Prediction for the future experiment CREX on ^{48}Ca