Quasifree (e,e'p) Reactions on Nuclei with Neutron Excess

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MOTIVATION

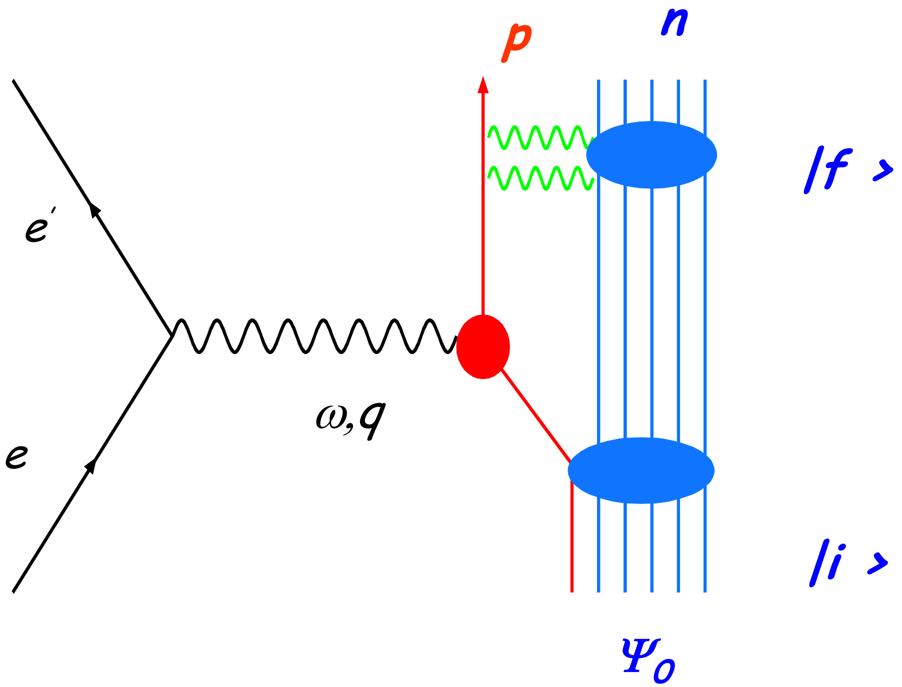
- understanding the evolution of nuclear properties as a function of N/Z
- nuclear reactions main source of information on nuclear properties
- direct reactions give insight into the s.p. properties
- advantages of the elm probe: (e,e'p) preferential tool to study proton-hole states, bound protons, validity and limits of IPSM
- large amount of (e,e'p) data, accurate information on s.p. properties of stable nuclei
- advent of RIB facilities will provide data on unstable nuclei
- electron RIB colliders that use storage rings under construction (GSI, RIKEN) will offer unprecedented opportunities to study exotic nuclei with electron scattering (ELISe at FAIR, SCRIT at RIKEN)
- exclusive (e,e'p) knockout experiments (ELISe at FAIR, SCRIT at RIKEN)

OUTLINE

- DWIA model for (e,e'p)
- NIKHEF data ^{40}Ca ^{48}Ca
- original analysis DWIA
- comparison of different models DWIA, RDWIA, different s.p. wave functions
- calculations performed for Ca isotopes: 40, 48, 52, 60
- evolution of nuclear properties with models of proven reliability in stable isotopes will test the ability of the established nuclear theory in the domain of exotic nuclei

Direct knockout DWIA (e,e′p)

- exclusive reaction: n
- DKO mechanism: the probe interacts through a one-body current with one nucleon that is then emitted the remaining nucleons are spectators



$$\langle f \mid J^{\mu}(\boldsymbol{q}) \mid i \rangle \Rightarrow \lambda_n^{1/2} \langle \chi_{\boldsymbol{p}}^{(-)} \mid j^{\mu}(\boldsymbol{q}) \mid \phi_n \rangle$$

Direct knockout DWIA (e,e′p)

$$\lambda_n^{1/2} \langle \chi^{(-)} \mid j^\mu \mid \phi_n \rangle$$

- j^μ one-body nuclear current
- $\chi^{(-)}$ s.p. scattering w.f. $H^+(\omega+E_m)$
- ϕ_n s.p. bound state overlap function $H(-E_m)$
- λ_n spectroscopic factor
- $\chi^{(-)}$ and ϕ consistently derived as eigenfunctions of a Feshbach optical model Hamiltonian

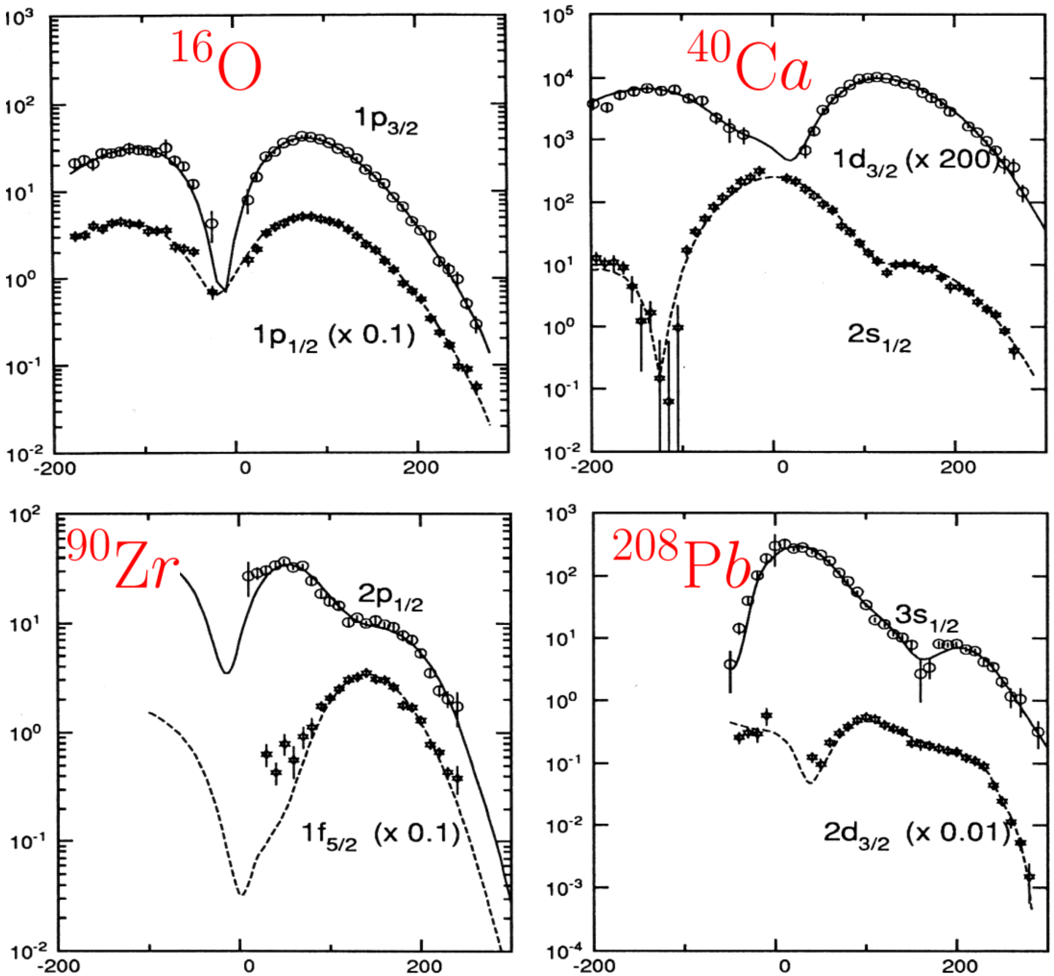
$$\mathcal{H}(E) = PHP + PHQ\frac{1}{E - QHQ + \mathrm{i}\eta}QHP$$

DWIA calculations

- phenomenological ingredients usually adopted
- $\chi^{(-)}$ phenomenological optical potential
- ϕ_n phenomenological s.p. wave functions WS, HF (some calculations including correlations are available)
- λ_n extracted in comparison with data: reduction factor applied to the calculated c.s. to reproduce the magnitude of the experimental c.s.
- DWIA RDWIA calculations with Coulomb distortion excellent description of (e,e′p) data

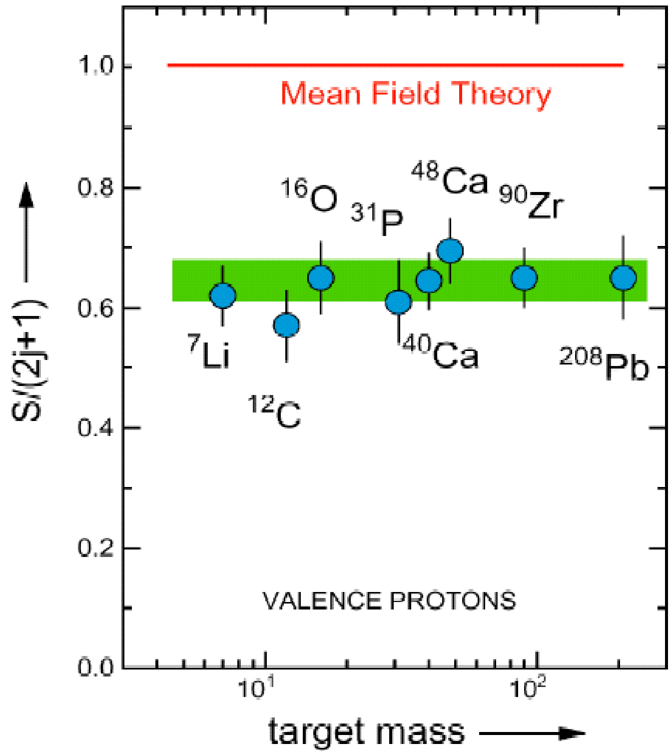
Experimental data: E_m and p_m distributions

Experimental data: p_m distributions



reduction factors applied: spectroscopic factors

0.6 - 0.7

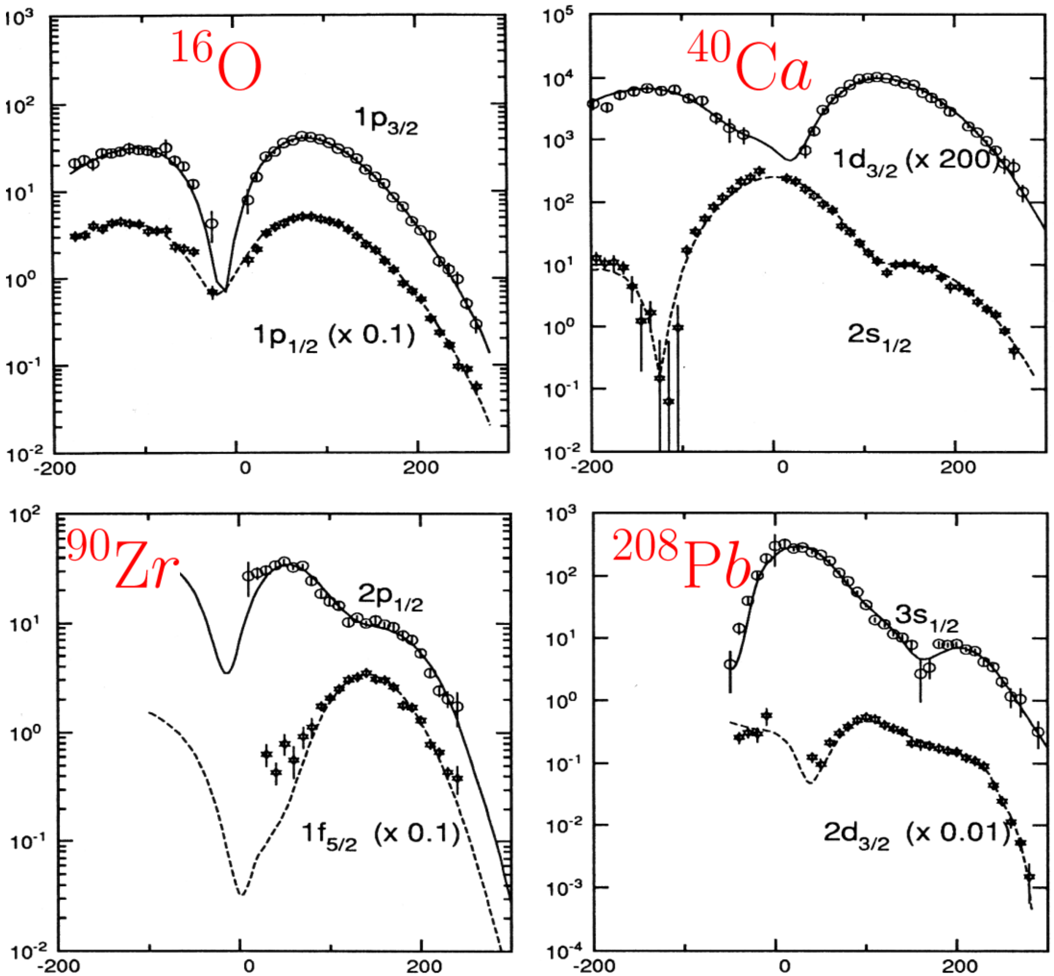


NIKHEF data & CDWIA calculations

NIKHEF data: $^{40}Ca(e,e'p)$, $^{48}Ca(e,e'p)$

- NIKHEF data ^{40}Ca ^{48}Ca
- original analysis: DWIA with phenomenological WS bound state w.f., depth of the WS well adjusted to give the experimentally observed separation energy, rms radius determined to fit the experimental momentum distribution

Experimental data: p_m distributions



$1d_{3/2}$

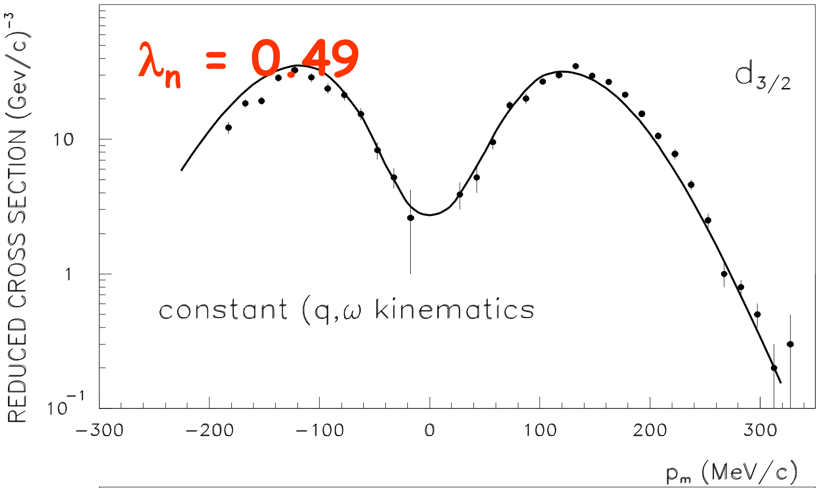
$2s_{1/2}$

NIKHEF data + CDWIA calculations

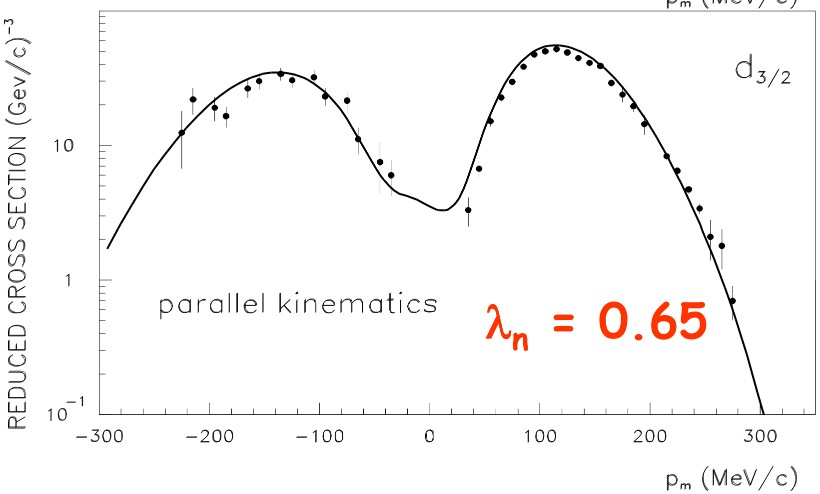
$^{40}Ca(e,e'p)$

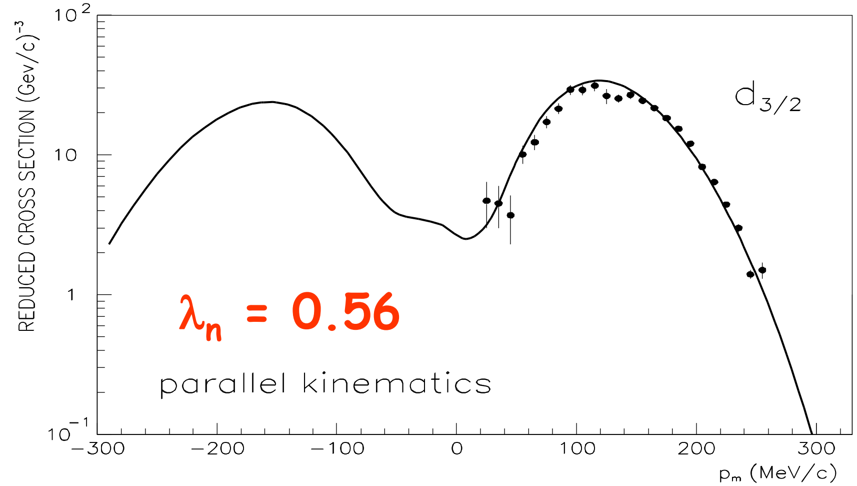
DWIA WS wave function

$^{48}Ca(e,e'p)$



$1d_{3/2}$





(ω,q) const: E_0=483.2 MeV θ =61.52 deg. q=450 MeV/c T_p=100 MeV

parallel kin: E_0=483.2 MeV T_p=100 MeV

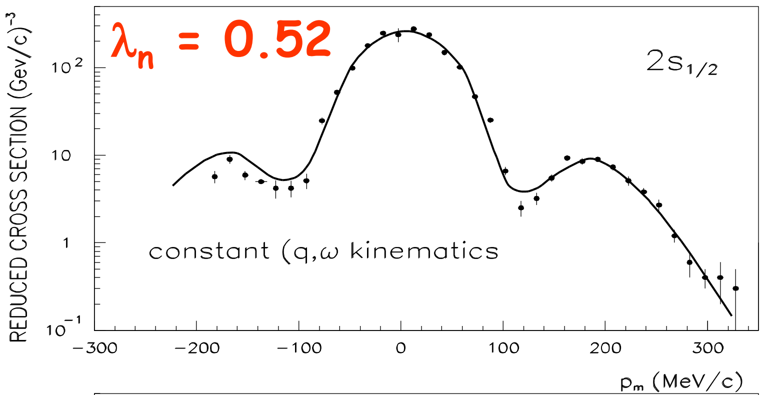
NIKHEF data G.J. Kramer Ph. D. Thesis (1990)

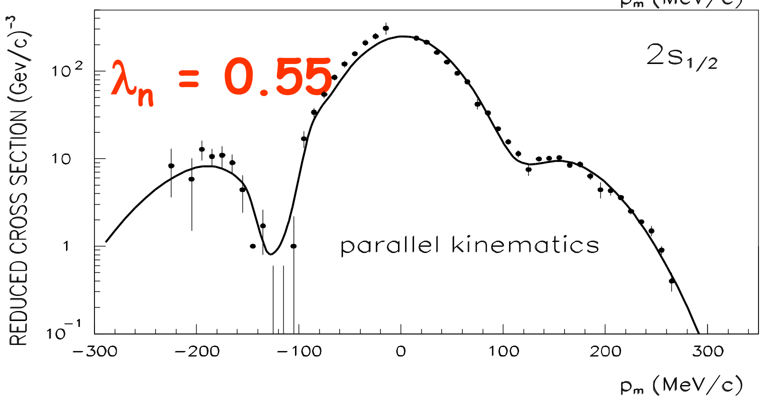
$^{40}Ca(e,e'p)$

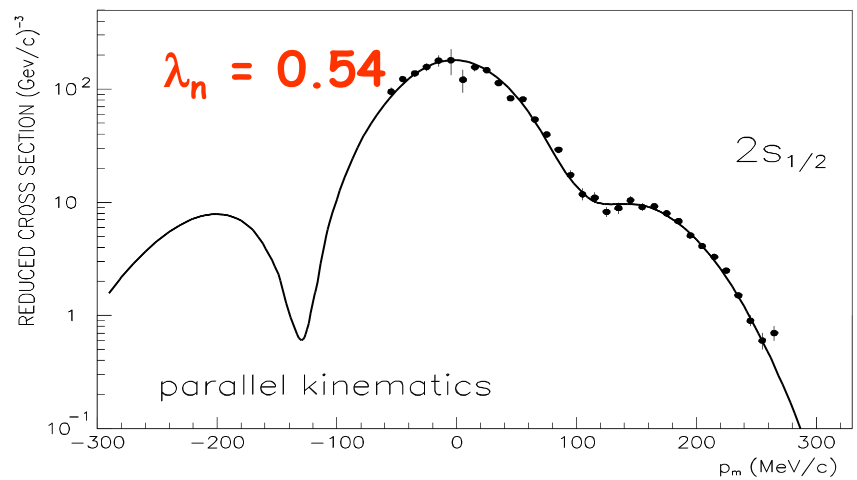
$^{48}Ca(e,e'p)$

DWIA WS wave function

$2s_{1/2}$







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parallel kin: E_0=483.2 MeV T_p=100 MeV

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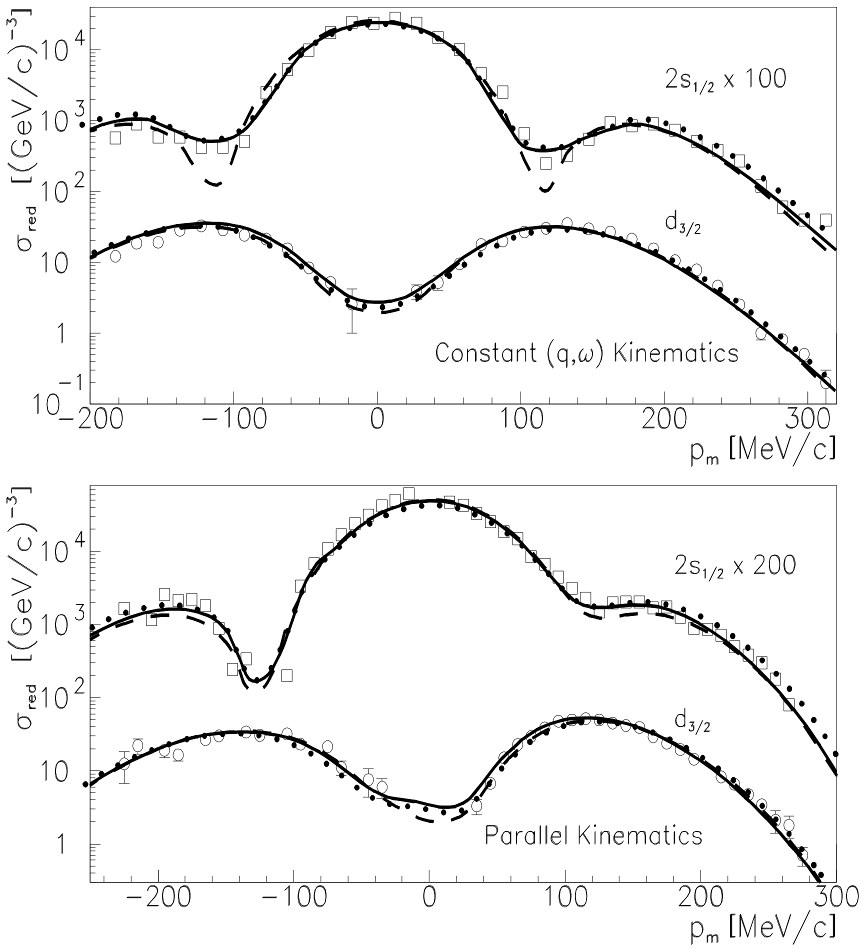
Comparison of different models

- DWIA with phenomenological WS wave functions (DWIA-WS)
- DWIA with HF wave functions from two different parametrizations of the finite-range Gogny interactions D1S and D1M. Results presented for the new D1M force (DWIA-HF)
- RDWIA relativistic model, ROP for the scattering state, the bound states are obtained in the context of the RMF approach solving the Dirac-Hartree equations. The nucleon interaction is derived from a relativistic Lagrangian containing σ, ω, ρ meson fields and also the photon field
- E- and A-dependent optical potentials contain central, spin-orbit, Coulomb terms and a term dependent on the (N-Z)/A asymmetry
- comparison with NIKHEF data on ^{40}Ca ^{48}Ca

$^{40}Ca(e,e'p)$

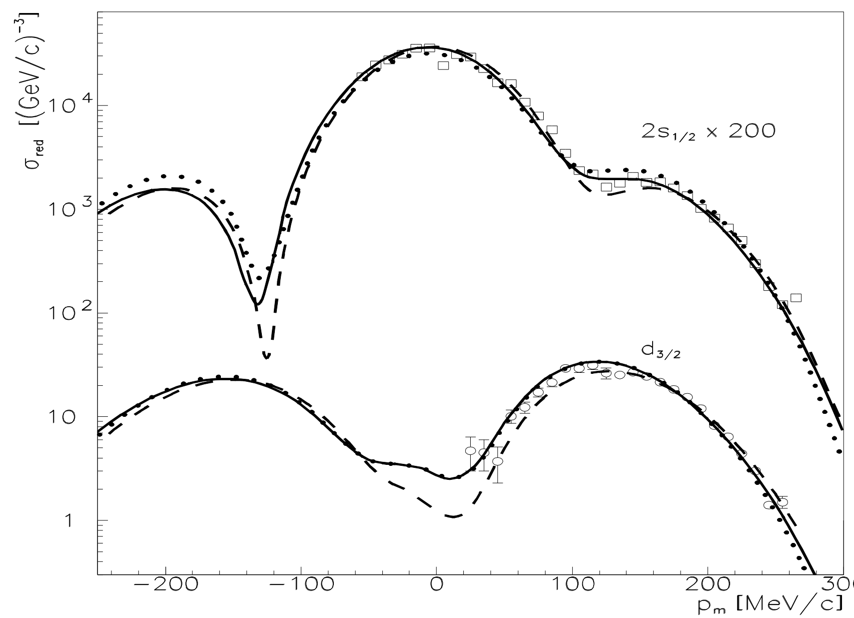
$^{48}Ca(e,e'p)$



DWIA-WS

DWIA-HF

RDWIA



$^{40}Ca(e,e'p)$ | $1d_{3/2}$ | $^{48}Ca(e,e'p)$

λ_n = 0.49 DWIA-WS

0.51 DWIA-HF

0.49 RDWIA

(ω,q) const kin

λ_n = 0.65 DWIA-WS

0.64 DWIA-HF

0.69 RDWIA

parallel kin

λ_n = 0.56 DWIA-WS

0.55 DWIA-HF

0.52 RDWIA

$^{40}Ca(e,e'p)$

$2s_{1/2}$

$^{48}Ca(e,e'p)$

λ_n = 0.55 DWIA-WS

0.62 DWIA-HF

0.51 RDWIA

(ω,q) const kin

λ_n = 0.56 DWIA-WS

0.55 DWIA-HF

0.52 RDWIA

parallel kin

λ_n = 0.54 DWIA-WS

0.58 DWIA-HF

0.55 RDWIA

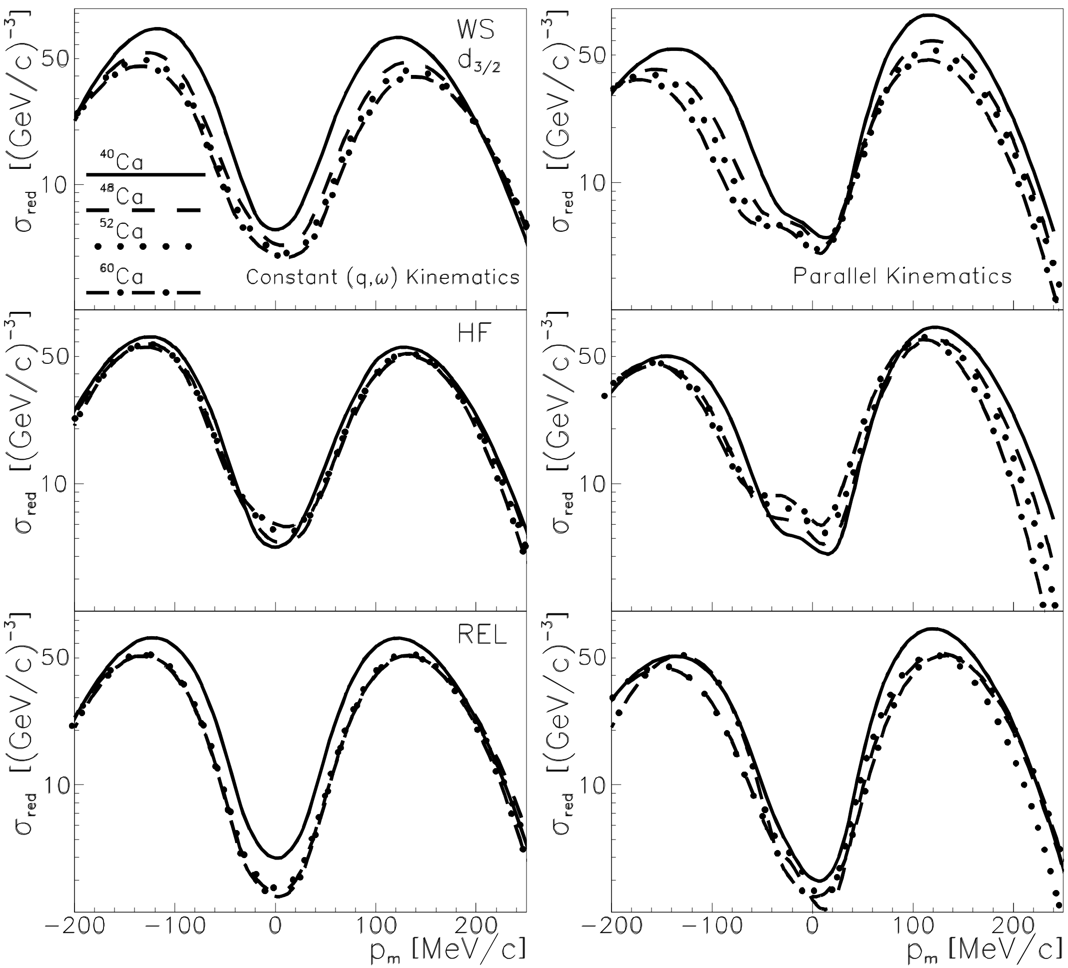
$^{40,48,52,60}Ca(e,e'p)$

- DWIA-WS DWIA-HF and RDWIA for Ca isotopes
- even-even isotopes, spherical nuclei where the s.p. level are fully occupied and pairing effects should be minimized

$^{40,48,52,60}Ca(e,e'p)$

$1d_{3/2}$

40
48
52
60



DWIA-WS

DWIA-HF

RDWIA

constant (q,ω)

parallel

$^{40,48,52,60}Ca(e,e'p)$

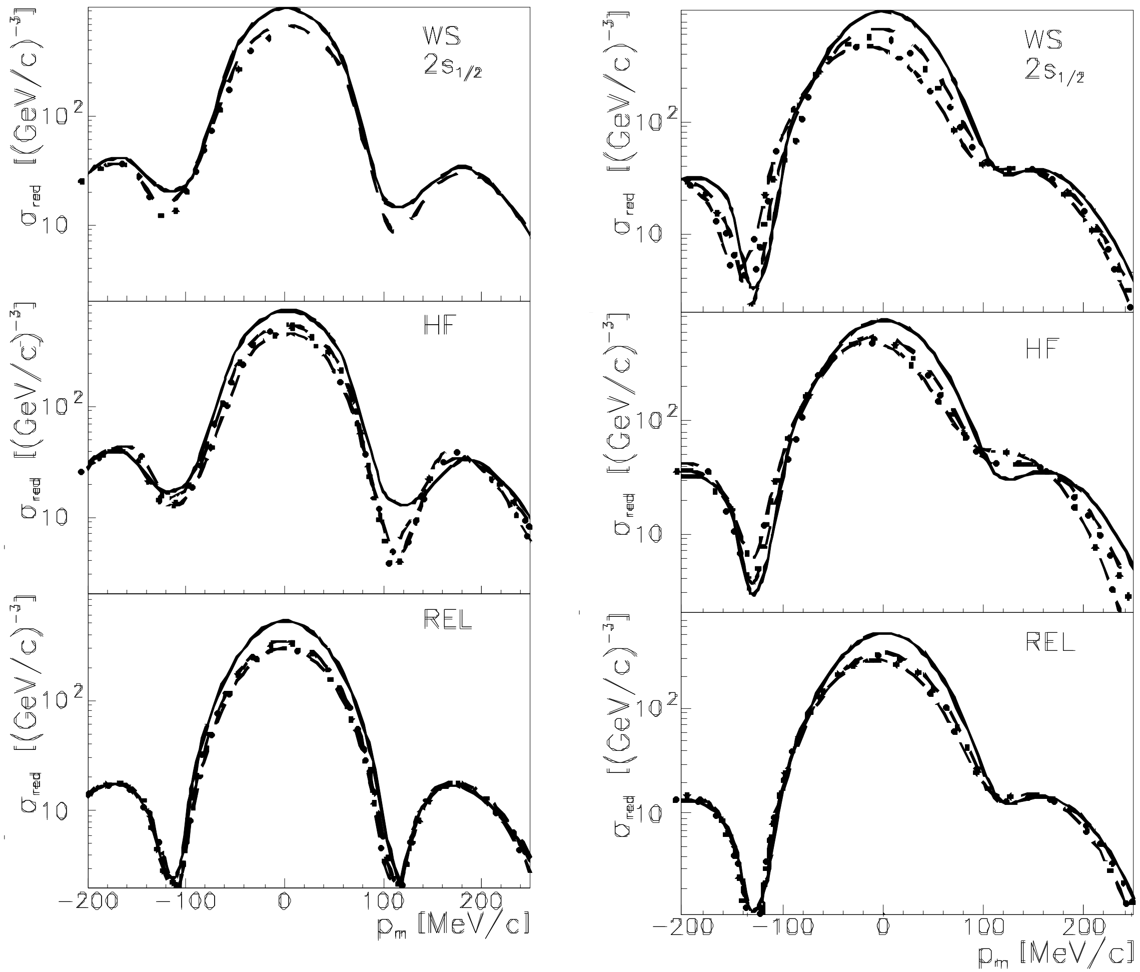
$2s_{1/2}$

40

48

52

60



DWIA-WS

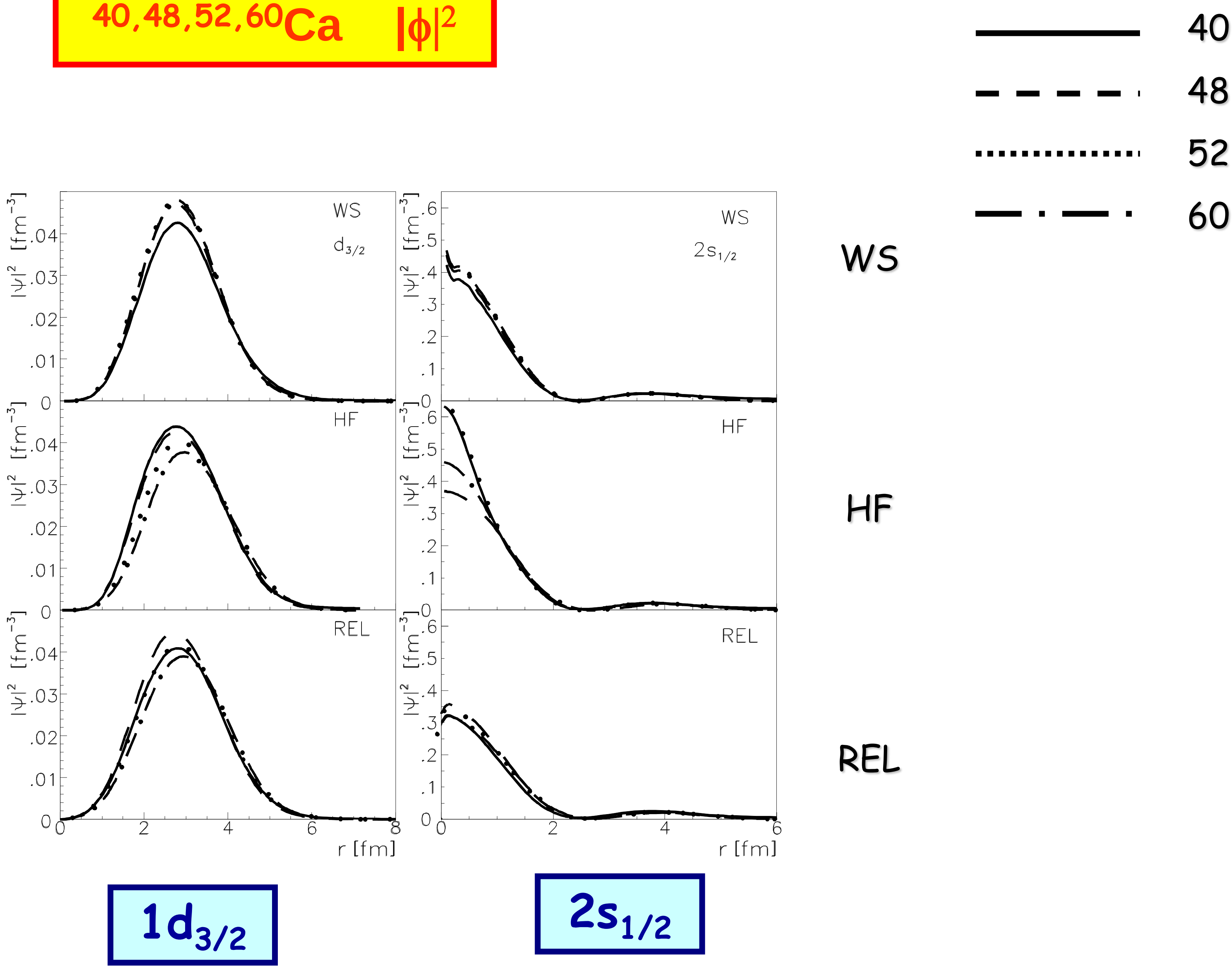
DWIA-HF

RDWIA

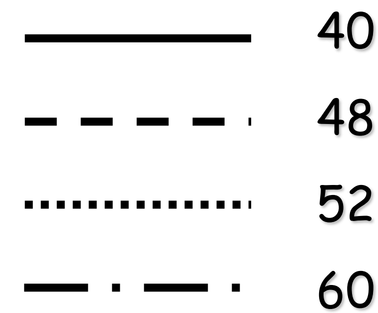
constant (q,ω)

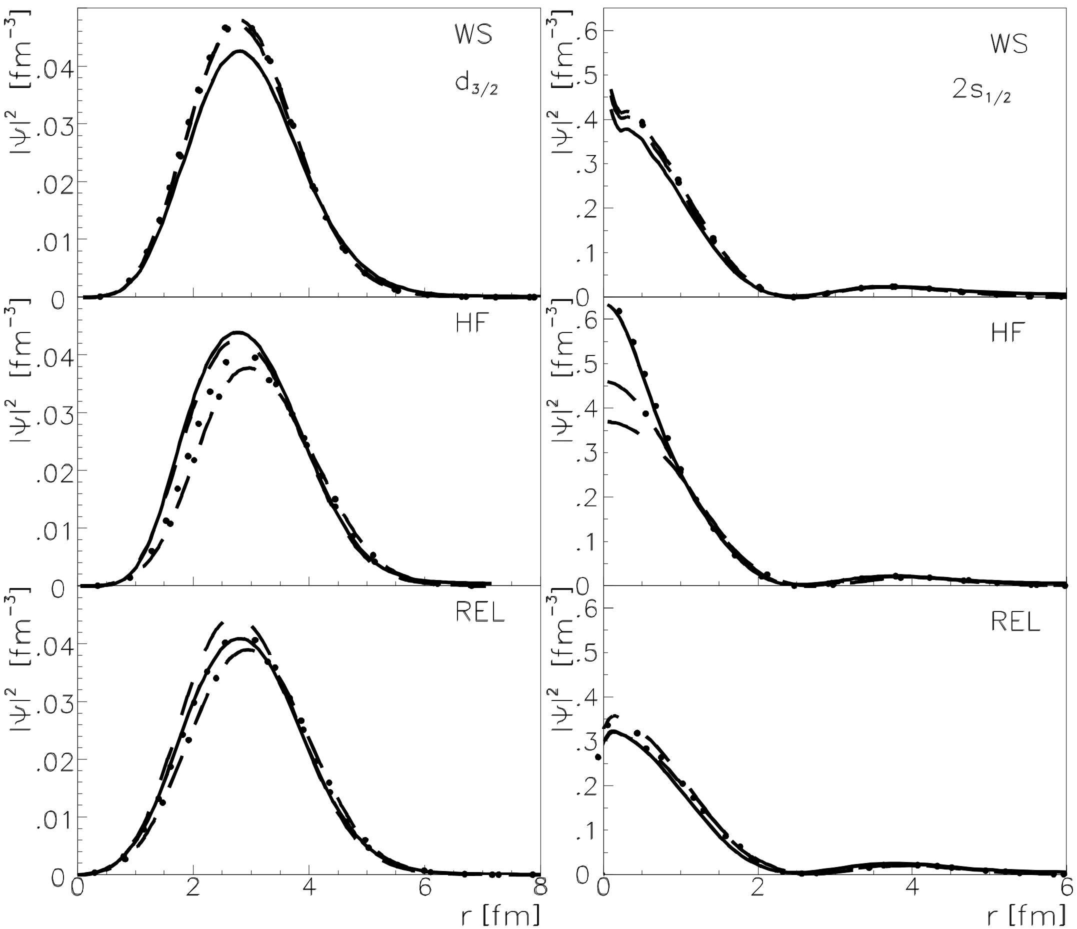
parallel

$^{40,48,52,60}Ca \quad |\phi|^2$



$^{40,48,52,60}Ca$ $|\phi|^2$





WS

HF

increasing N/Z different behavior for the wave functions and the cross sections: FSI

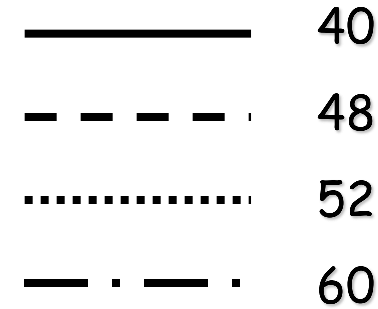
REL

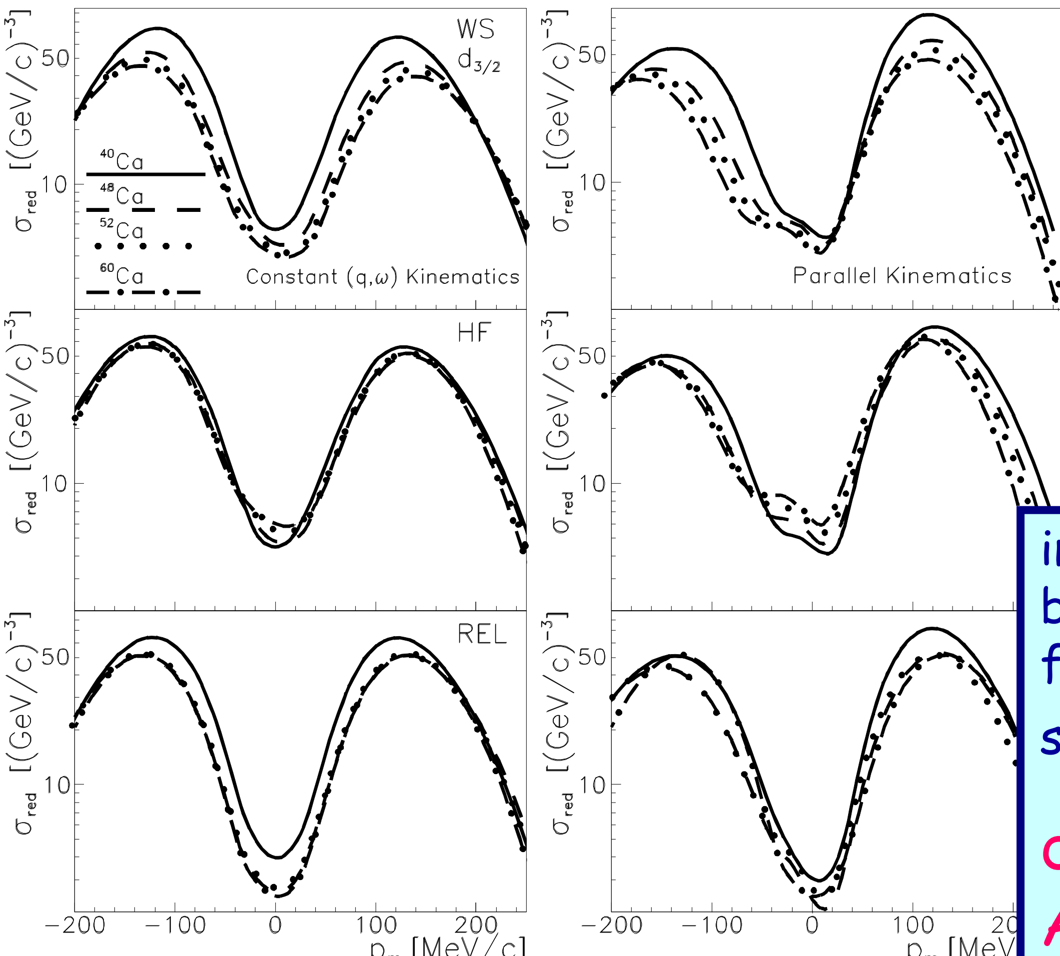
$d_{3/2}$

$2s_{1/2}$

$^{40,48,52,60}Ca(e,e'p)$

$1d_{3/2}$





DWIA-WS

DWIA-HF

constant (q,ω)

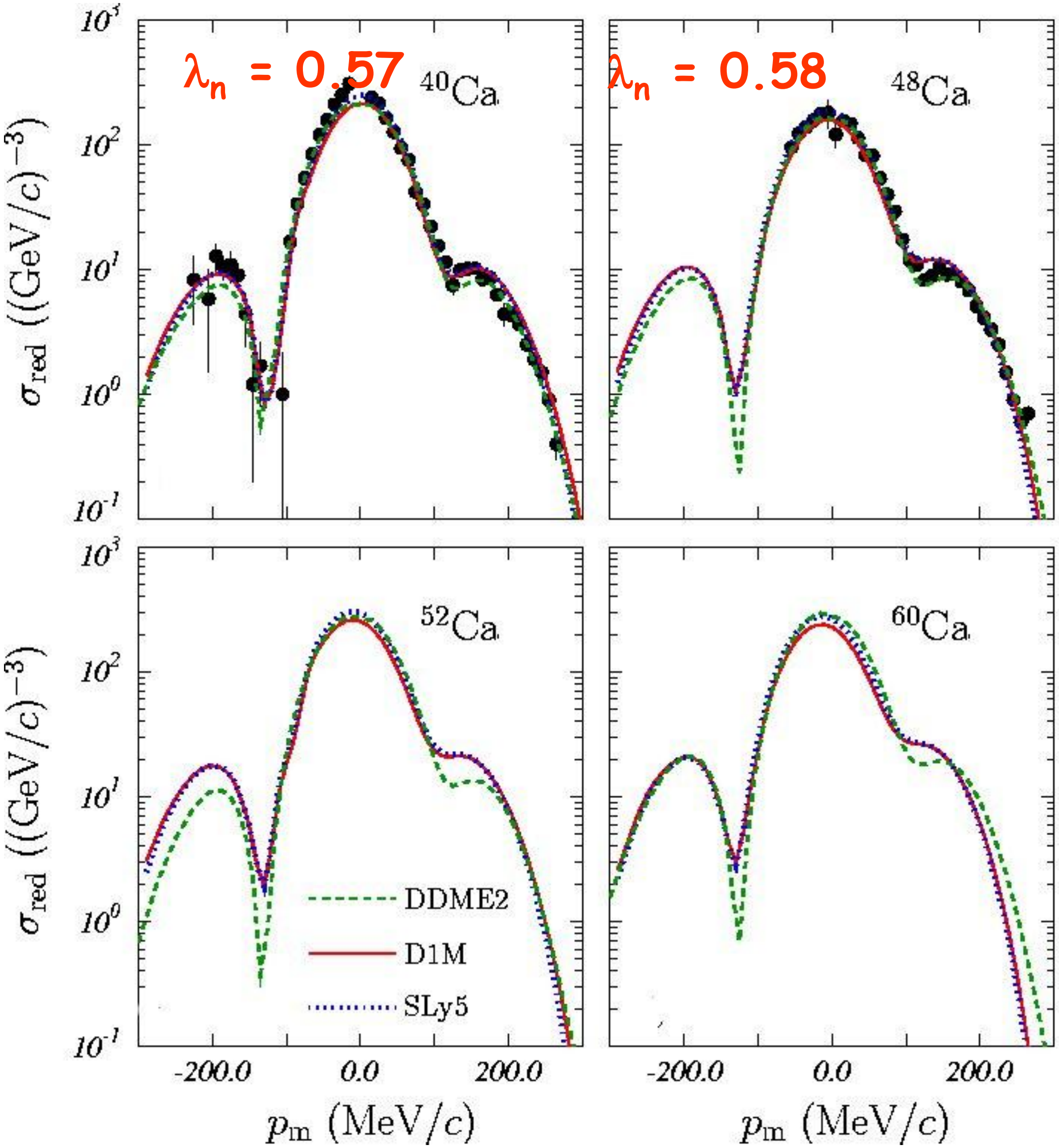
parallel

increasing N/Z different behavior for the wave functions and the cross sections: FSI

difference due to the A- dependence of the optical potential

$^{40,48,52,60}Ca(e,e'p)$

$2s_{1/2}$



D1M HF finite-range DWIA

SLy5 HF zero range DWIA

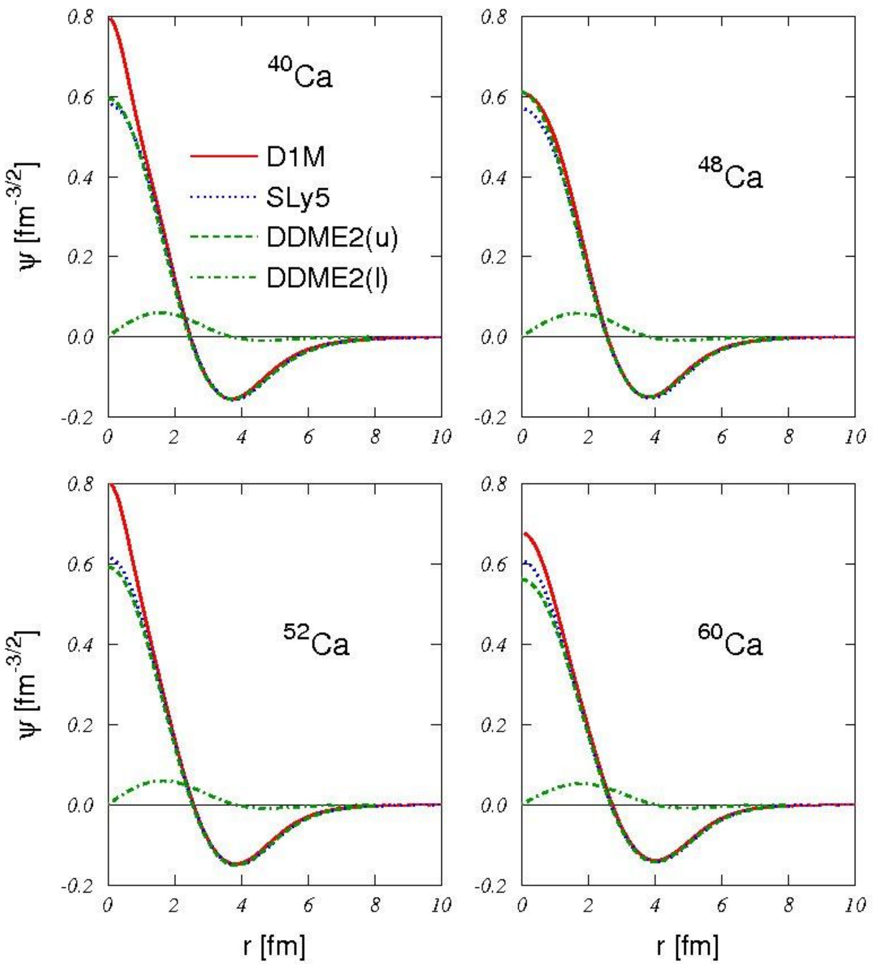
DDME2 relativistic density dependent meson-nucleon couplings

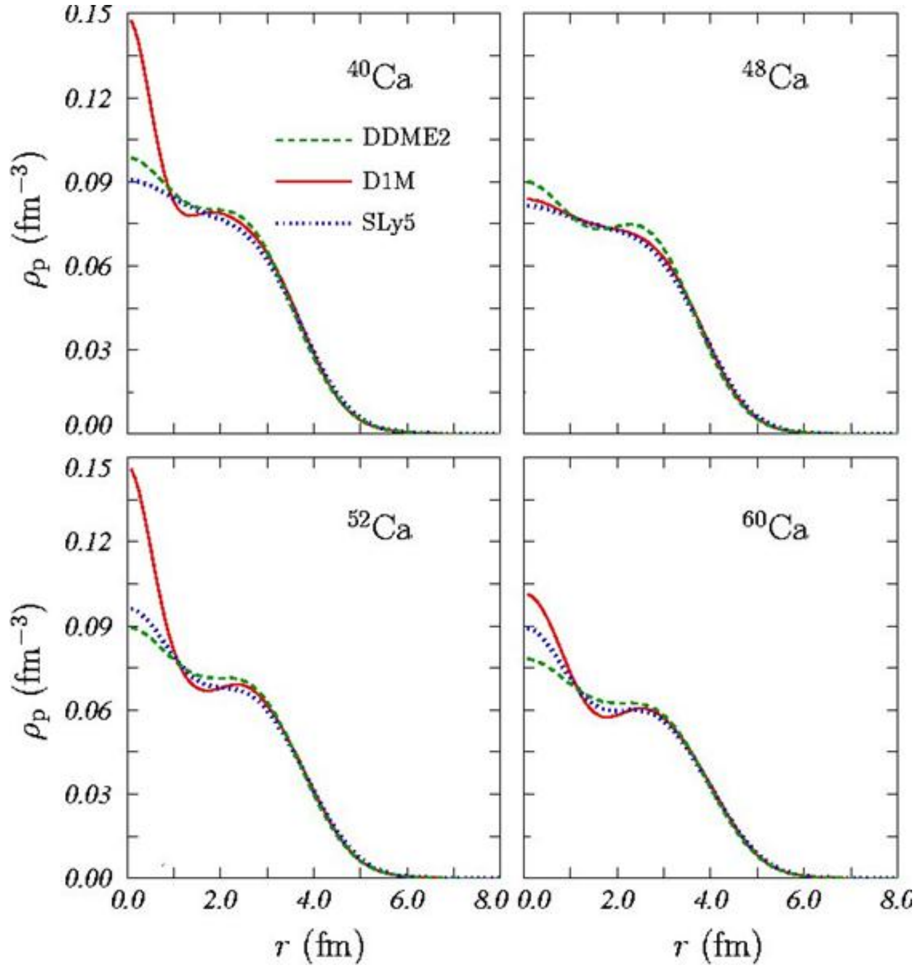
parallel kin.

G.Co', V. De Donno, P. Finelli, M. Grasso, M. Anguiano, A.M. Lallena, C. Giusti, A. Meucci, F.D. Pacati

wave functions $2s_{1/2}$

proton distributions





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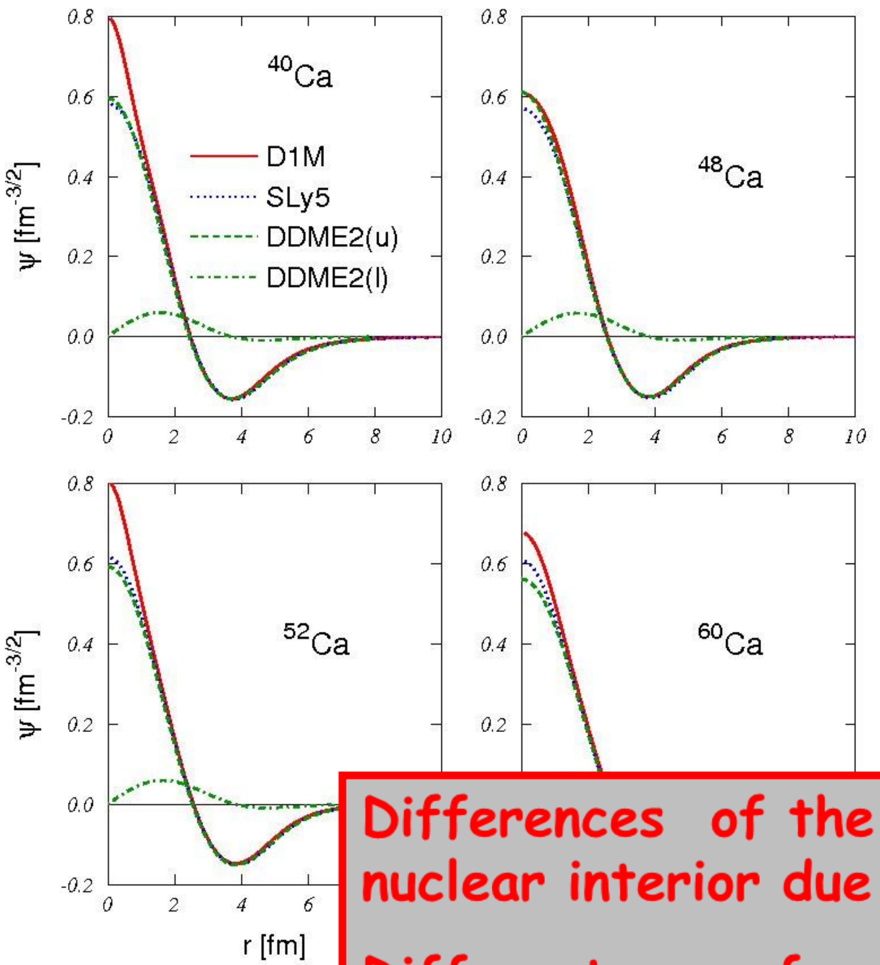

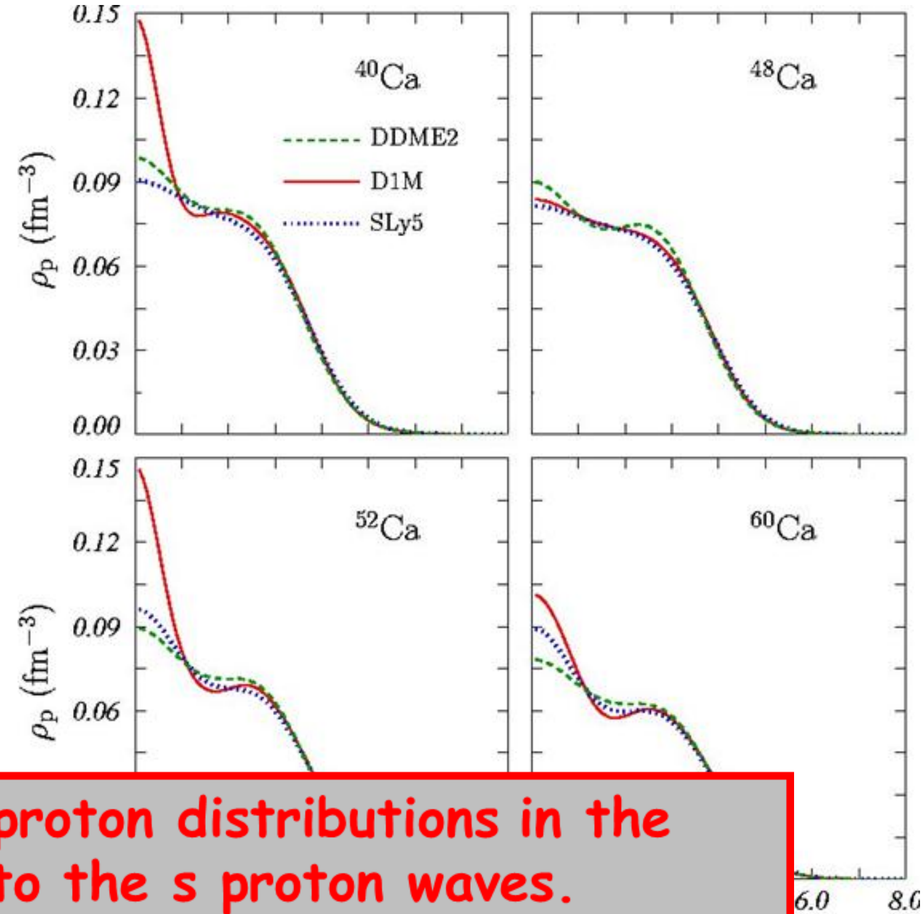

Differences of the proton distributions in the nuclear interior due to the s proton waves.

Different wave functions produce similar (e,e'p) cross sections. The considered kinematics unable to emphasize the differences in the s.p wave functions.

G.Co', V. De ... sti,
A. Meucci, F ...

CONCLUSIONS (I)

- evolution of nuclear properties with models of proven reliability in stable isotopes (DWIA-WS DWIA-HF RDWIA)
- all the considered models give good and similar description of the available (e,e'p) data on ^{40}Ca and ^{48}Ca
- general behavior of the cross sections with respect to the increasing N/Z asymmetry is analogous for all the three models: the reduced cross sections are larger and narrower for the lighter isotopes and evolve by lowering and widening increasing N
- the behavior of the s.p. bound-state wave functions shows different trends for the different models
- the dependence of the w.f. on N/Z is responsible for only a part of the differences in the calculated cross sections, an important and crucial contribution is given also by FSI which are described in the calculations by phenomenological optical potentials
- the optical potential is an important ingredient of the model, affects the size and the shape of the cross section in a way that strongly depends on kinematics
- the dependence of the optical potential on N/Z deserves careful investigation

CONCLUSIONS (II)

- spectroscopic factors and correlations: recent exp. and theor. studies indicate that the s.f. depend on N/Z, in general the quenching of the quasi-hole states becomes stronger increasing the separation energy (increasing N)
- (e,e′p) measurements on nuclei with neutron excess would offer a unique opportunity for studying the dependence of the properties of bound protons on N/Z
- the present results can serve as a useful reference for future experiments
- comparison with data can confirm or invalidate the predictions of the models and will test the ability of the established nuclear theory in the domain of exotic nuclei