Выездное совещание совета РАН по фундаментальной ядерной физике в ИЯФ СО РАН (г. Новосибирск) 20-21 марта 2023 г.

Перспективы исследований фотоядерных реакций и развитие квазичастично-фононной модели

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Квазичастично-фононная модель: Сферические ядра

$$\Psi_\nu(JM) = \Big(\sum_i R_i(J\nu) Q^+_{JMi} + \sum_{\substack{\lambda_1 i_1 \\ \lambda_2 i_2}} P^{\lambda_1 i_1}_{\lambda_2 i_2}(J\nu) \left[Q^+_{\lambda_1 i_1} Q^+_{\lambda_2 i_2} \right]_{JM} + \sum_{\substack{\lambda_1 i_1 \\ \lambda_2 i_2 \\ \lambda_3 i_3 J'}} T^{\lambda_1 i_1 \lambda_2 i_2}_{J' \lambda_3 i_3}(J\nu) \left[\left[Q^+_{\lambda_1 i_1} Q^+_{\lambda_2 i_2} \right]_{J'} Q^+_{\lambda_3 i_3} \right]_{JM} \Big) |0\rangle$$

$\lambda^\pi = 1^-, 2^+, 3^-$, and 4^+

$$H = \sum_{\lambda\mu i} \omega_{\lambda i} Q^+_{\lambda\mu i} Q_{\lambda\mu i} + \frac{1}{2} \sum_{\substack{\lambda_1 \lambda_2 \lambda_3 \\ i_1 i_2 i_3 \\ \mu_1 \mu_2 \mu_3}} \langle \lambda_1 \mu_1 \, \lambda_2 \mu_2 | \lambda_3 - \mu_3 \rangle \times U^{\lambda_1 i_1}_{\lambda_2 i_2}(\lambda_3 i_3) [Q^+_{\lambda_1 \mu_1 i_1} Q^+_{\lambda_2 \mu_2 i_2} Q_{\lambda_3 - \mu_3 i_3} + h.c.].$$

В.Г. Соловьев, Теория атомного ядра. Квазичастицы и фононы.
В.В. Воронов, В.Г. Соловьев, ТМФ 57, 75 (1983)
V.Yu. Ponomarev, Ch. Stoyanov, N. Tsoneva, M. Grinberg, Nucl. Phys. A 635, 470(1998)

На базе функионала плотности энергии обобщены основные уравнения квазичастично-фононной модели

- Самосогласованное среднее поле
- Гармонические вибрации в пределе малых амплитуд
- Связь простых и сложных конфигураций

Такие расчеты не требуют введения новых параметров, так как остаточное взаимодействие получено самосогласованным образом с тем же самым функционалом плотности энергии как и среднее поле.

Nguyen Van Giai, Ch. Stoyanov, V. V. Voronov, Phys. Rev. C57,1204 (1998).
A.P.S., V.V. Voronov, Nguyen Van Giai, Eur. Phys. J. A22, 397 (2004).

Direct proof of the two-phonon character of the dipole excitations in ^{142}Nd and ^{144}Sm around 3.5 MeV

M. Wilhelm,[1] E. Radermacher,[1] A. Zilges,[2] and P. von Brentano[1]

PHYSICAL REVIEW C AUGUST 1996

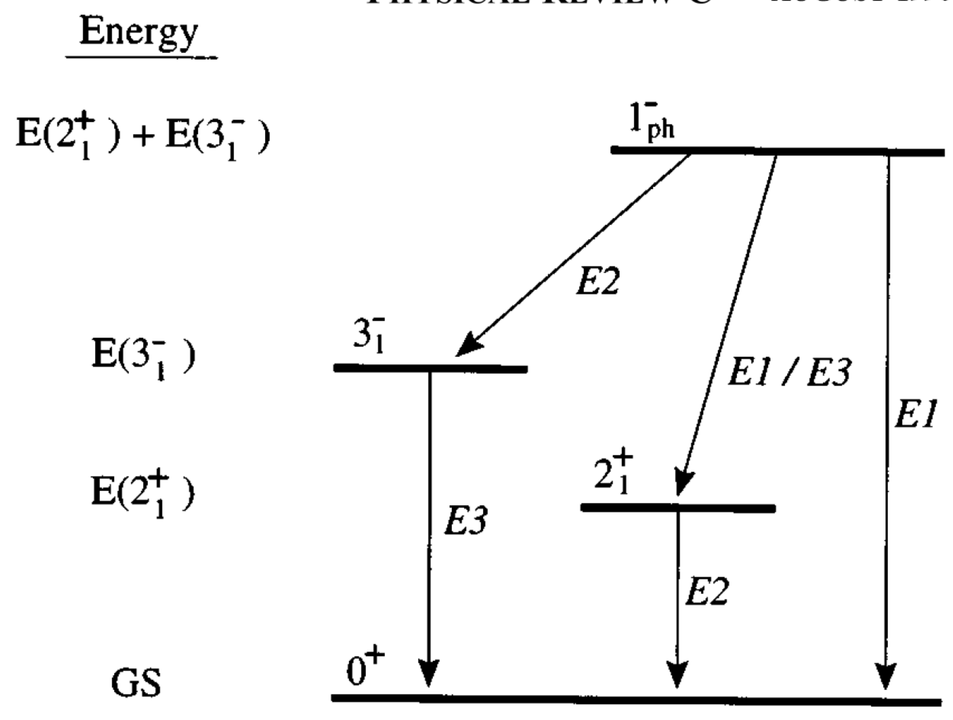


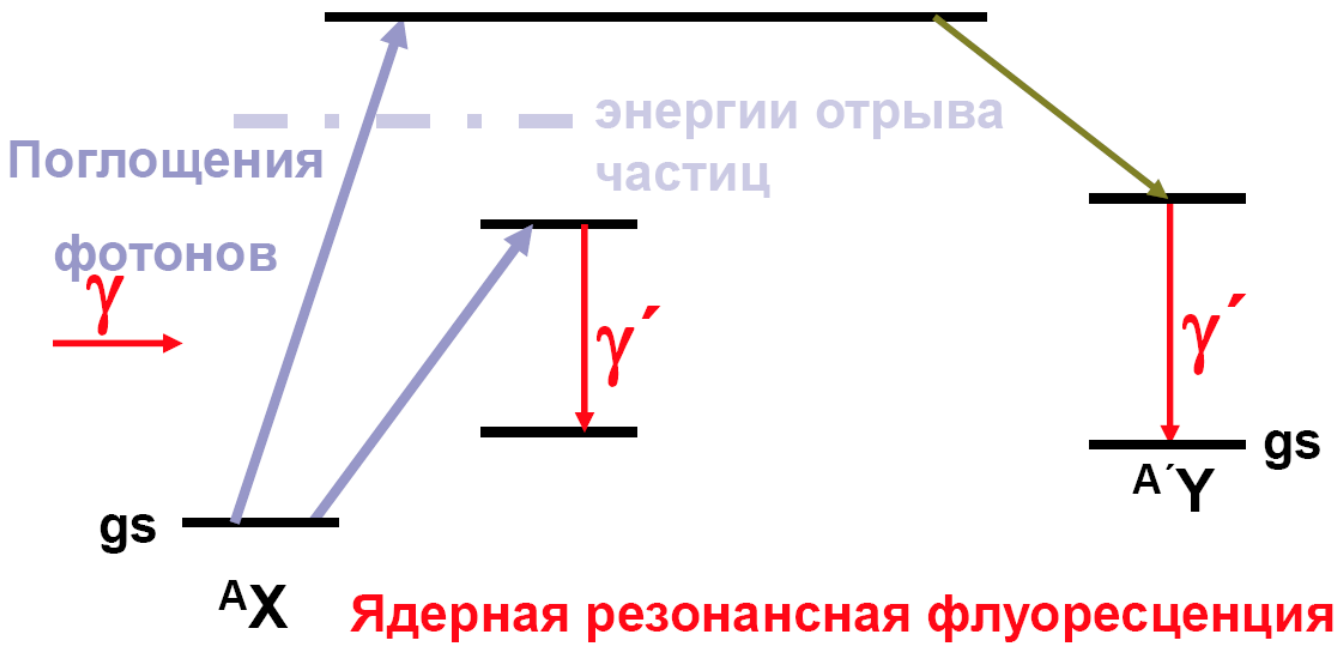
FIG. 1. Decay pattern expected from the γ decay of a two-phonon 1^-_{ph} state.

Предсказание КФМ

V. V. Voronov, D. T. Khoa, and V. Yu. Ponomarev, Bull. Acad. Sci. USSR, Phys. Ser. **48**, 190 (1984).

Перспективы исследований
$E_x < 10$ МэВ

Фотоядерные реакции



Возбуждение дипольных альфа-кластерных состояний?
Пример: состояние 1^- E_x~7.6МэВ изотопа кислорода ^{18}O

$S_n \sim 8.0$МэВ

$S_\alpha \sim 6.2$МэВ

Применить к изучению свойств двойного гамма-распада?

Nuclear Physics **A474** (1987) 412–450

NUCLEAR TWO-PHOTON DECAY IN $0^+ \to 0^+$ TRANSITIONS

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J. SCHIRMER and D. SCHWALM

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C. BROUDE

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Abstract: The two-photon decay of the first excited 0^+ state of ^{16}O has been measured using the Heidelberg-Darmstadt crystal ball. A branching ratio of $\Gamma_{\gamma\gamma}/\Gamma_{tot} = (6.6 \pm 0.5) \cdot 10^{-4}$ was obtained. As in the cases of ^{40}Ca and ^{90}Zr previous
E1 and M1 transitions of similar strengt
angular correlation. The ratio of the matr
values (-6.2 ± 1.5) or (-0.16 ± 0.04).

An interpretation of 2γ matrix elemen
polarizabilities and magnetic susceptibil
decay mode.

Experimental matrix elements and properties of the 0_1^+ and 0_2^+ states in ^{16}O, ^{40}Ca and ^{90}Zr

Nucleus	^{16}O	^{40}Ca	^{90}Zr
$\Delta E_{12} = E_2 - E_1$[MeV]	6.049	3.352	1.761
$T_{1/2}$[ns]	0.067	2.1	61
$(\Gamma_{\gamma\gamma}/\Gamma_{tot}) \cdot 10^{-4}$	6.6 ± 0.5	4.5 ± 1.0 [a]	1.8 ± 0.3 [a]
$\alpha_{E1}^{12}[10^{-3}\ fm^3]$	16.9 ± 4.3 (2.7 ± 0.7)	7.8 ± 1.9	20.1 ± 10.9
$\chi^{12}[10^{-3}\ fm^3]$	-2.7 ± 0.7 (-16.9 ± 4.3)	-18.3 ± 4.5	-10.4 ± 5.7
$\alpha_{E2}^{12}[fm^5]$	≤ 120	≤ 670	≤ 4000
$\lvert\langle 0_1^+ \lvert \bar{r}^2 \rvert 0_2^+ \rangle\rvert$ [fm^2]	3.55 ± 0.21 [b]	2.6 ± 0.1 [c]	1.71 ± 0.06 [d]
$\alpha_{E1}^{11}[10^{-3}\ fm^3]$	585 [e]	2230 [e]	6330 [e]
$\chi_P^{11}[10^{-3}\ fm^3]$	1.78 [f]	5.65 [f]	14.5 [f]
$\bar{E}_{E1} - E_1$[MeV]	24 [e]	20.2 [e]	16.7 [g]
$\bar{E}_{M1} - E_1$[MeV]	17 [h]	10 [i]	9 [j]

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LETTER

doi:10.1038/nature15543

Observation of the competitive double-gamma nuclear decay

C. Walz[1], H. Scheit[1], N. Pietralla[1], T. Aumann[1], R. Lefol[1,2] & V. Yu. Ponomarev[1]

The double-gamma ($\gamma\gamma$)-decay of a quantum system in an excited state is a fundamental second-order process of quantum electrodynamics. In contrast to the well-known single-gamma (γ)-decay, the $\gamma\gamma$-decay is characterized by the simultaneous emission of two γ quanta, each with a continuous energy spectrum. In nuclear physics, this exotic decay mode has only been observed for transitions between states with spin-parity quantum numbers $J^\pi = 0^+$ (refs 1–3). Single-gamma decays—the main experimental obstacle to observing the $\gamma\gamma$-decay—are strictly forbidden for these $0^+ \rightarrow 0^+$ transitions. Here we report the observation of the $\gamma\gamma$-decay of an excited nuclear state ($J^\pi = 11/2^-$) that is directly competing with an allowed γ-decay (to ground state $J^\pi = 3/2^+$). The branching ratio of the competitive $\gamma\gamma$-decay of the $11/2^-$ isomer of ^{137}Ba to the ground state relative to its single γ-decay was determined to be $(2.05 \pm 0.37) \times 10^{-6}$. From the measured angular correlation and the shape of the energy spectra of the individual γ-rays, the contributing combinations of multipolarities of the γ radiation were determined. Transition matrix elements calculated using the quasiparticle–phonon model reproduce our measurements well. The $\gamma\gamma$-decay rate gives access to so far unexplored important nuclear structure information, such as the generalized (off-diagonal) nuclear electric polarizabilities and magnetic susceptibilities[3].

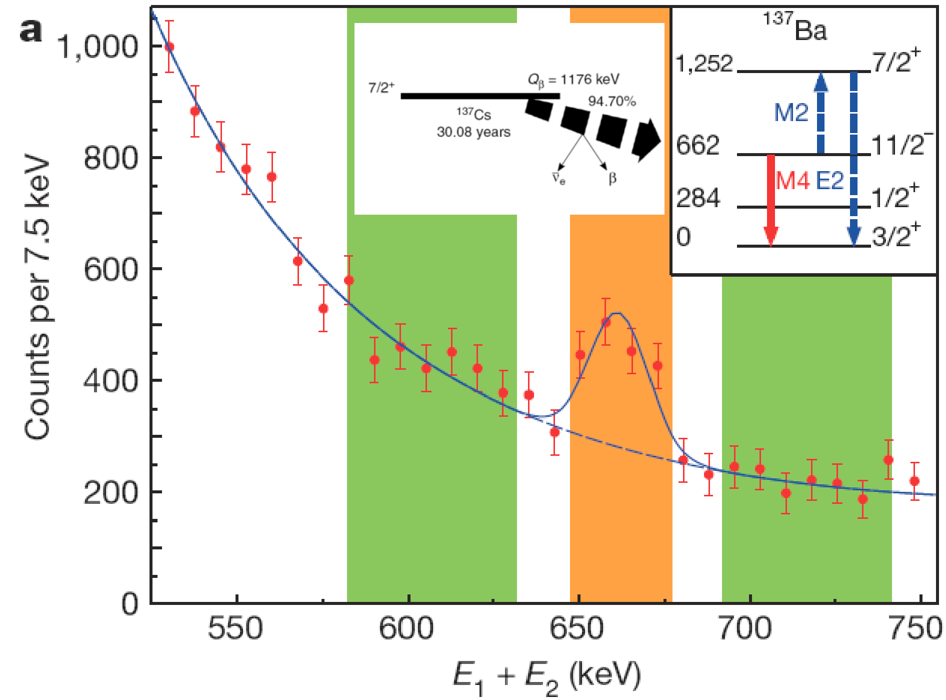

Figure 2 | Energy-sum spectrum and energy-gated time spectra of the 72°-group. a, Energy-sum spectrum $E_1 + E_2$ after subtraction of the random coincidences (requiring the energy condition $|E_1 - E_2| < 300$ keV). The spectrum is fitted with a superposition of a Gaussian and an exponential function to describe the peak and the background, respectively. The orange (647 keV $< E_1 + E_2 <$ 677 keV) and green areas (582 keV $< E_1 + E_2 <$ 632 keV and 692 keV $< E_1 + E_2 <$ 742 keV) represent the energy conditions employed

Published: 26 June 2020

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ARTICLE

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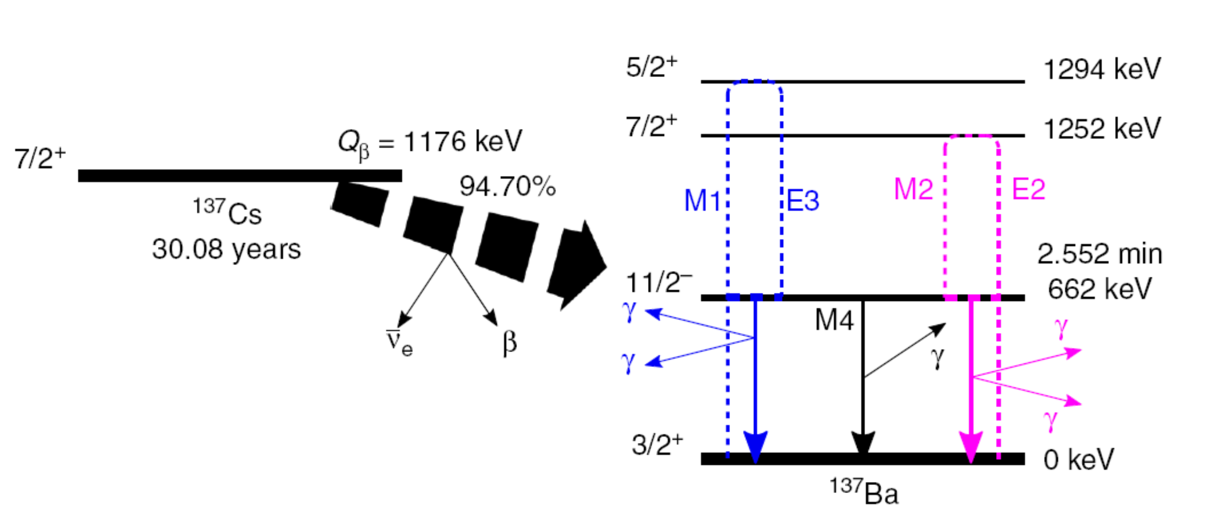
https://doi.org/10.1038/s41467-020-16787-4 OPEN

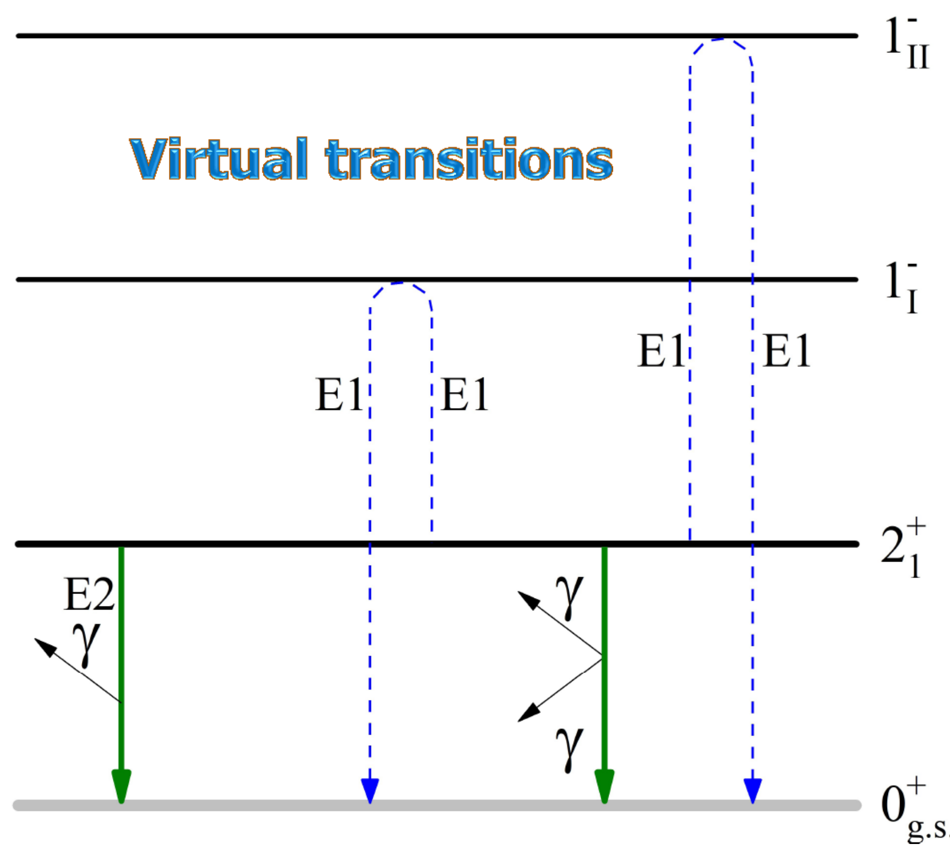
Electromagnetic character of the competitive $\gamma\gamma/\gamma$-decay from ^{137m}Ba

P.-A. Söderström[1✉], L. Capponi[1], E. Açıksöz[1], T. Otsuka[2,3,4], N. Tsoneva[1], Y. Tsunoda[2], D. L. Balabanski[1], N. Pietralla[5], G. L. Guardo[1,6], D. Lattuada[1,6,7], H. Lenske[8], C. Matei[1], D. Nichita[1,9], A. Pappalardo[1] & T. Petruse[1,9]

Second-order processes in physics is a research topic focusing attention from several fields worldwide including, for example, non-linear quantum electrodynamics with high-power lasers, neutrinoless double-β decay, and stimulated atomic two-photon transitions. For the electromagnetic nuclear interaction, the observation of the competitive double-γ decay from ^{137m}Ba has opened up the nuclear structure field for detaile
processes through the manifestation of off-diagonal nuclear
this observation with an 8.7σ significance, and an improv
versus single-photon branching ratio as $2.62 \times 10^{-6}(30)$. Our
conclusions from the original experiment, where the decay w
by a quadrupole-quadrupole component. Here, we find a s
energy distribution consistent with a dominating octupole-dip
quadrupole-quadrupole component in the decay, hindered du
nuclear structure. The implied strongly hindered double-phot
the possibility of the double-photon branching as a feasible t
on off-diagonal polarisability in nuclei where this hindrance



Двойной гамма-распад квадрупольного состояния

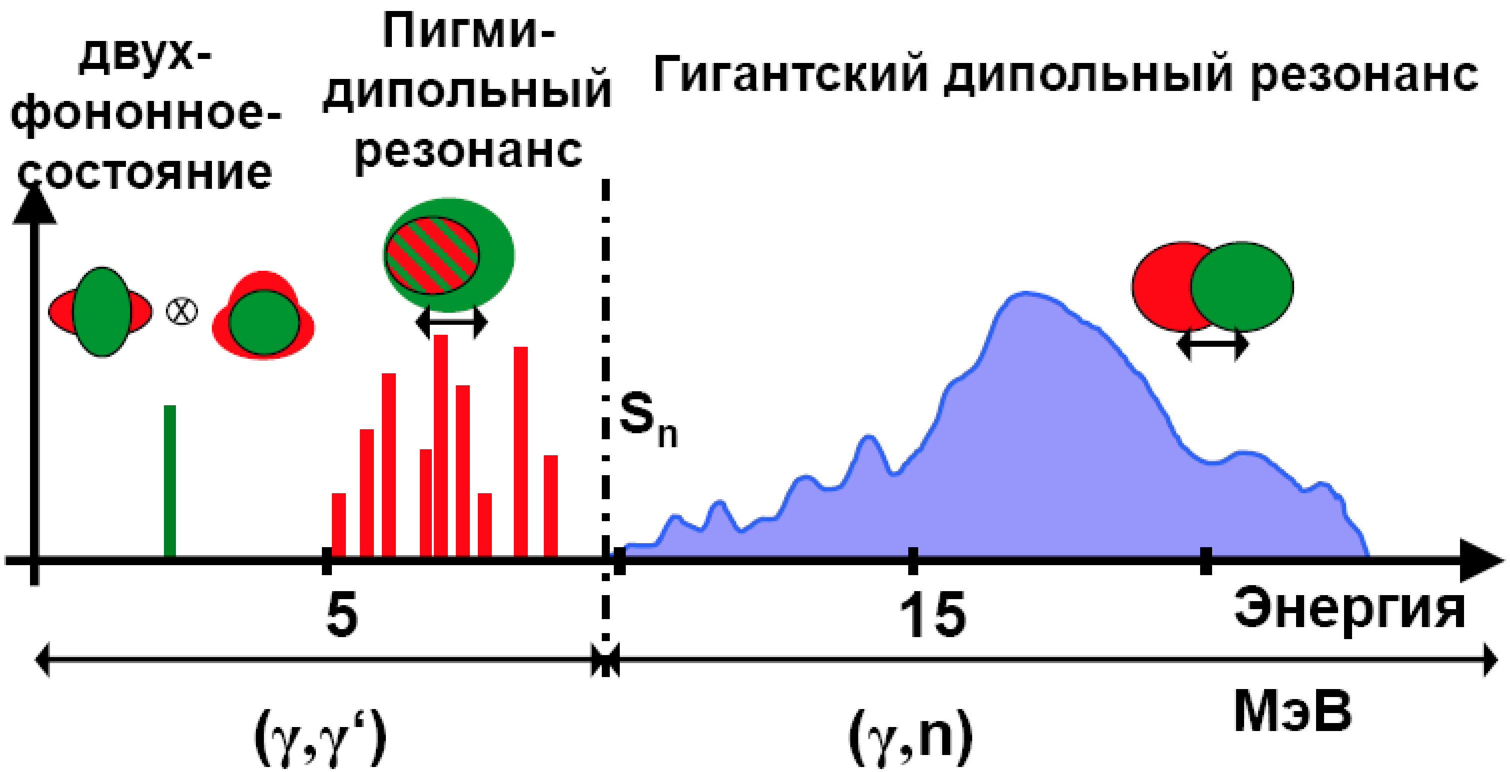


We construct a two-state mixing scheme by considering the GDR state, the coupled $GDR \otimes 2_1^+$ state, and the interaction V between them. The relative phases of amplitudes are opposite in the perturbed states I and II, i.e.,

$$|1_I^-\rangle = \alpha|GDR\rangle + \beta|GDR \otimes 2_1^+\rangle,$$
$$|1_{II}^-\rangle = -\beta|GDR\rangle + \alpha|GDR \otimes 2_1^+\rangle.$$

A.P.S., N.N. Arsenyev, N. Pietralla, Phys. Rev. C. 104, 024310 (2021).

Распределение силы E1-переходов



Учет пигми резонанса в расчете r-процесса

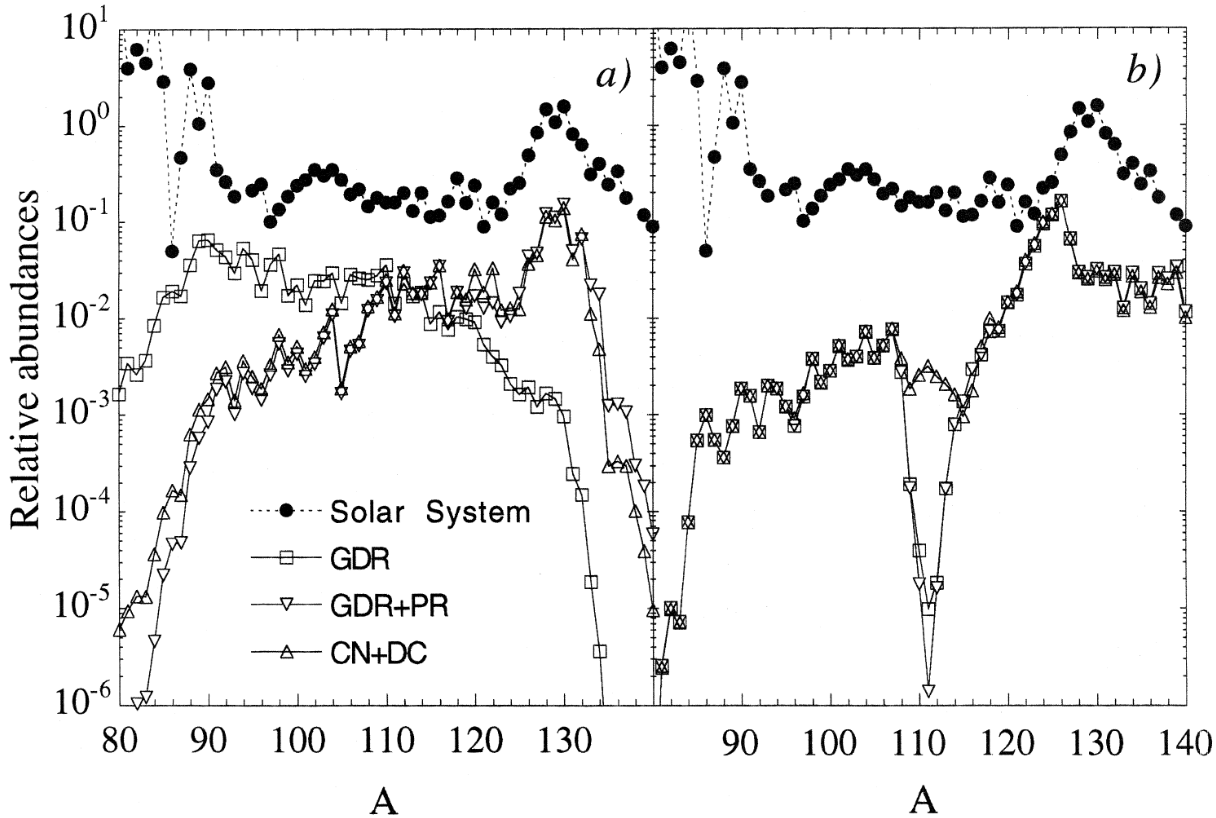
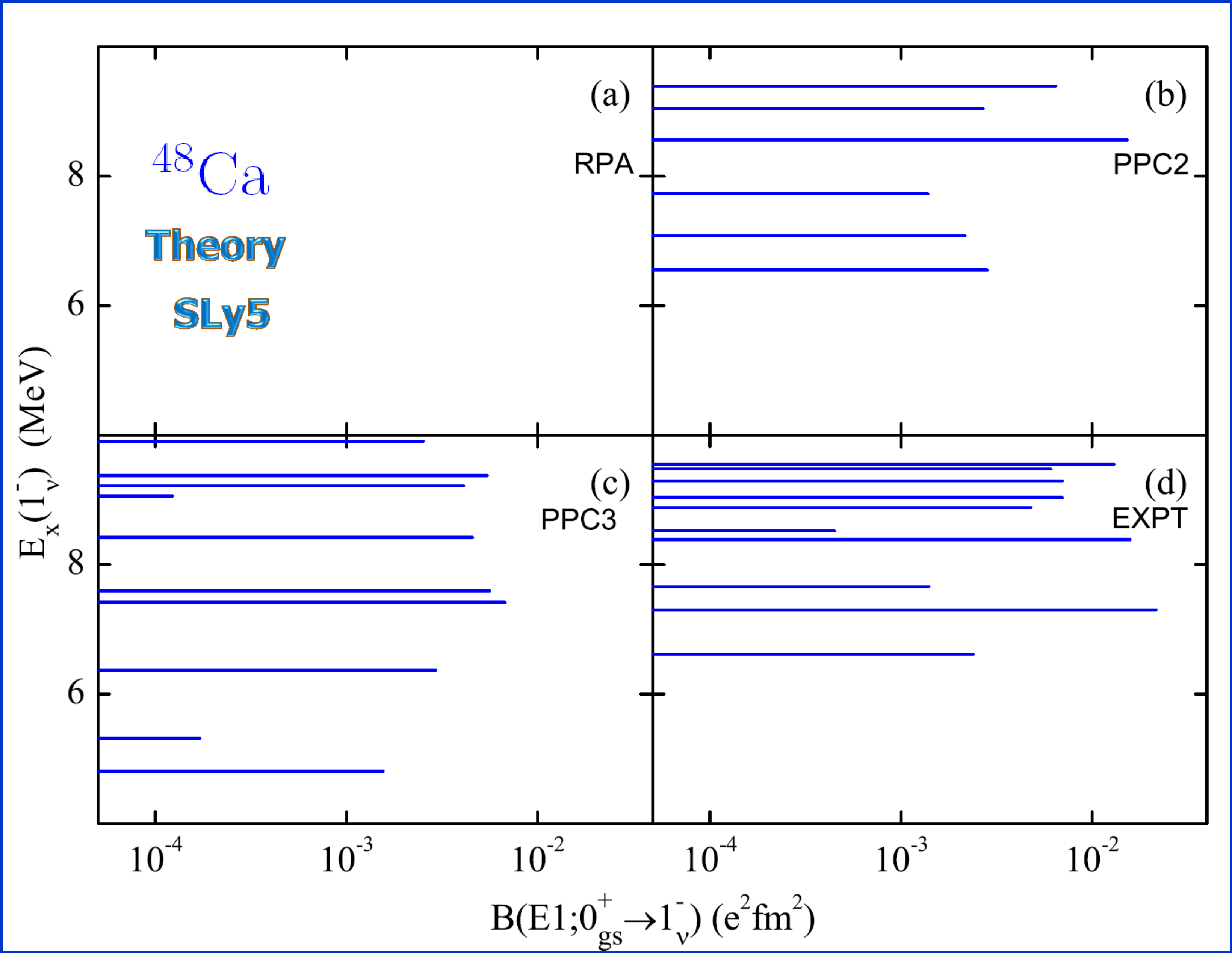


Fig. 6. a) r-abundance distributions for $T = 10^9$ K, $N_n = 10^{20}$ cm^{-3} and $\tau_{irr} = 2.4$ s with 3 different estimates of the neutron capture rates: the standard GDR component, the GDR + PR strength and the damped statistical (CN) plus DC contribution. The top curve corresponds to the solar r-abundances arbitrarily normalized. b) same as a) for $T = 1.5 \times 10^9$ K, $N_n = 10^{28}$ cm^{-3} and $\tau_{irr} = 0.3$ s.

S. Goriely / Physics Letters B 436 (1998) 10–18



A.P.S., N.N. Arsenyev, N. Pietralla, Phys. Rev. C. 104, 024310 (2021).

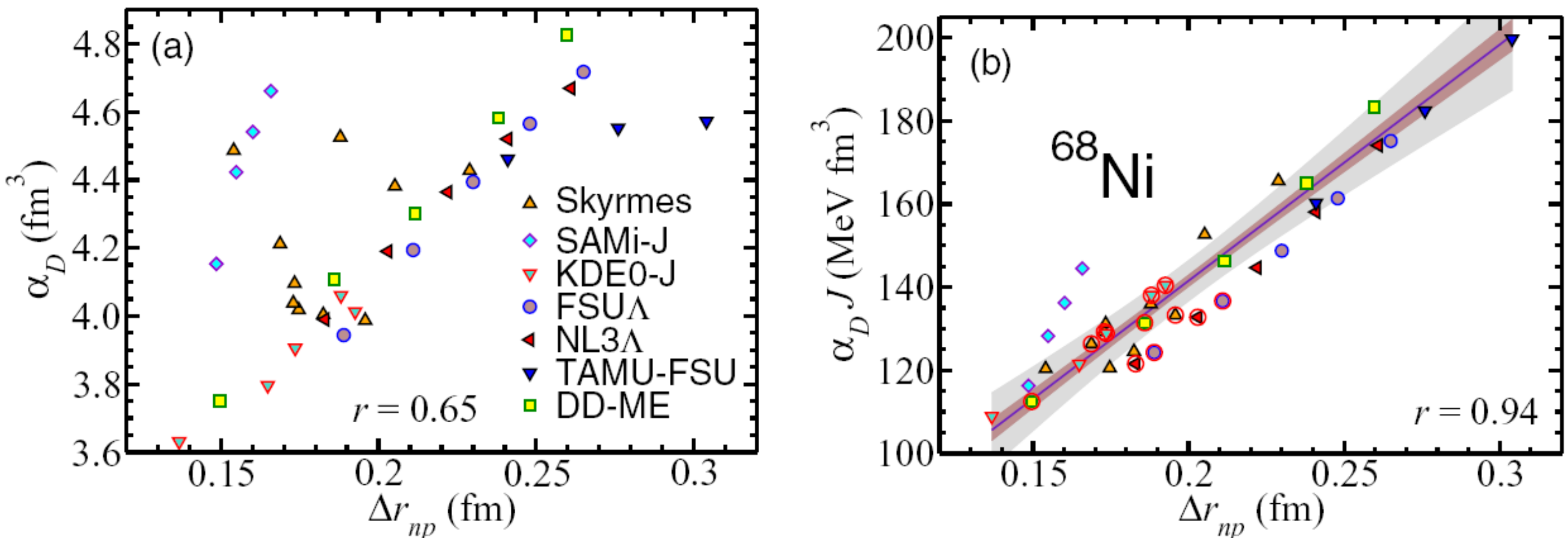
Перспективы исследований
10 МэВ $< E_x <$ 60 МэВ

- Тонкая структура гигантского резонанса
- Электрическая дипольная поляризуемость ядра

The electric dipole polarizability,

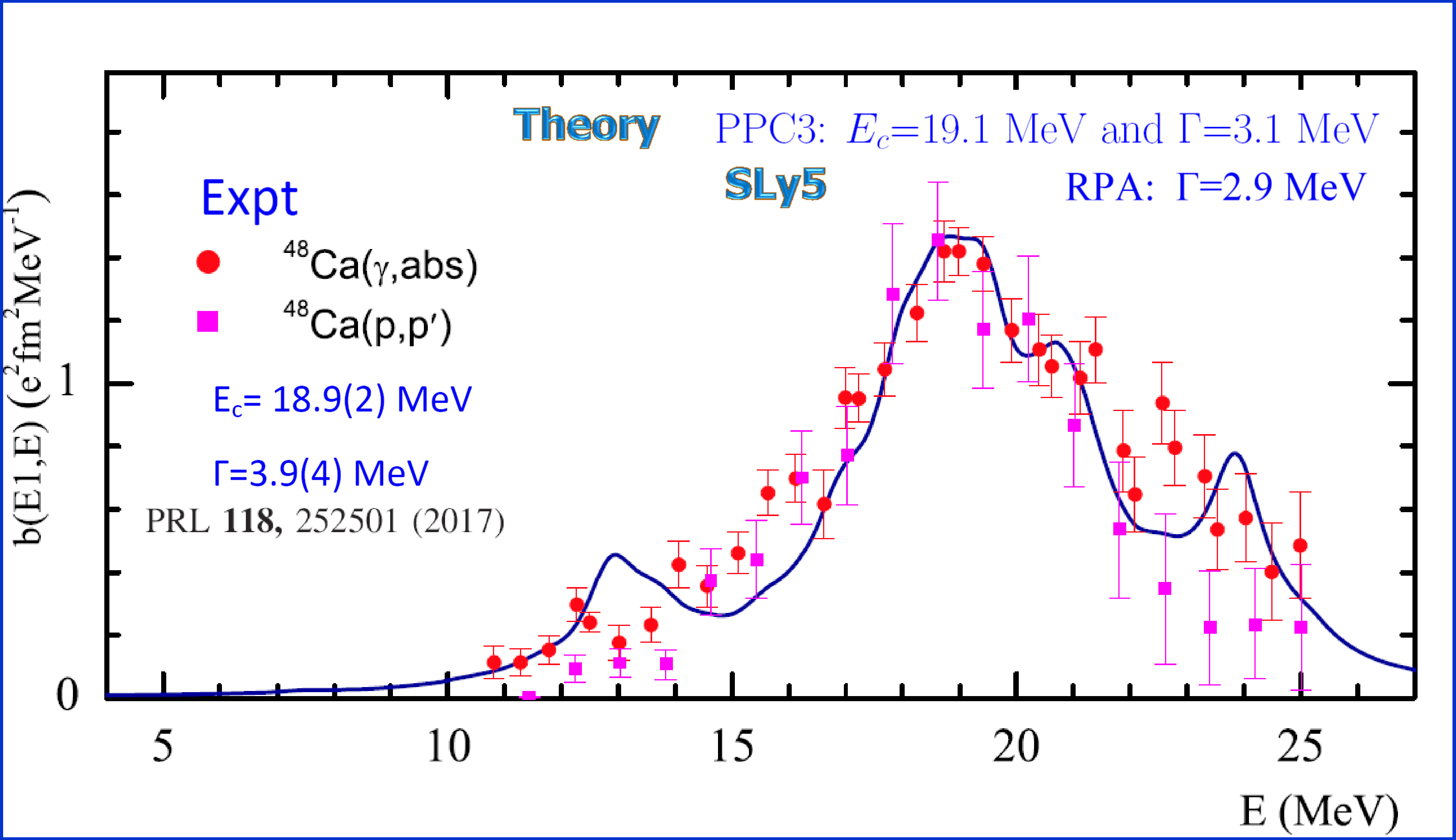
$$\alpha_D = \frac{8\pi}{9} \sum_i \frac{\langle 0^+_{gs} || M(E1) || 1^-_i \rangle \langle 1^-_i || M(E1) || 0^+_{gs} \rangle}{E_{1^-_i}},$$

have played an important role, in particular, its value has strong implications in constraining the symmetry energy J as well as its density dependence and slope parameter L. The symmetry energy also plays an important role in nuclei, where it contributes to the formation of neutron skins in the presence of a neutron excess.

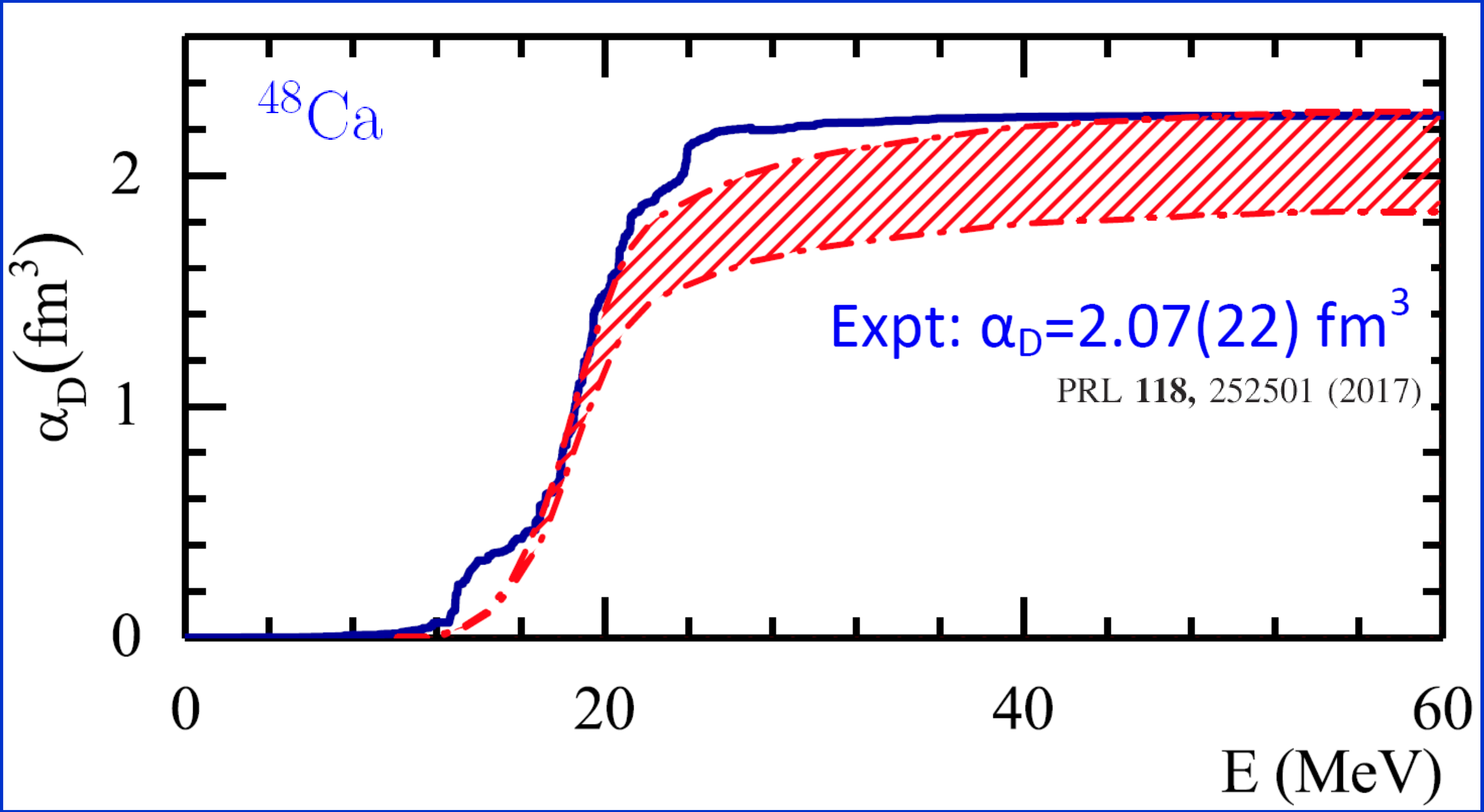


NEUTRON SKIN THICKNESS FROM THE MEASURED ... PHYSICAL REVIEW C **92**, 064304 (2015)

X. Roca-Maza,[1,*] X. Viñas,[2] M. Centelles,[2] B. K. Agrawal,[3] G. Colò,[1] N. Paar,[4,5] J. Piekarewicz,[6] and D. Vretenar[5]



Theory
PPC3: E_c=19.1 MeV and Γ=3.1 MeV
SLy5
RPA: Γ=2.9 MeV
Expt
^{48}Ca(γ,abs)
^{48}Ca(p,p′)
E_c= 18.9(2) MeV
Γ=3.9(4) MeV
PRL **118,** 252501 (2017)
b(E1,E) ($e^2fm^2MeV^{-1}$)
1
0
5
10
15
20
25
E (MeV)



$$\alpha_D = \frac{8\pi}{9} \sum_i \frac{\langle 0^+_{gs} || M(E1) || 1^-_i \rangle \langle 1^-_i || M(E1) || 0^+_{gs} \rangle}{E_{1^-_i}}$$

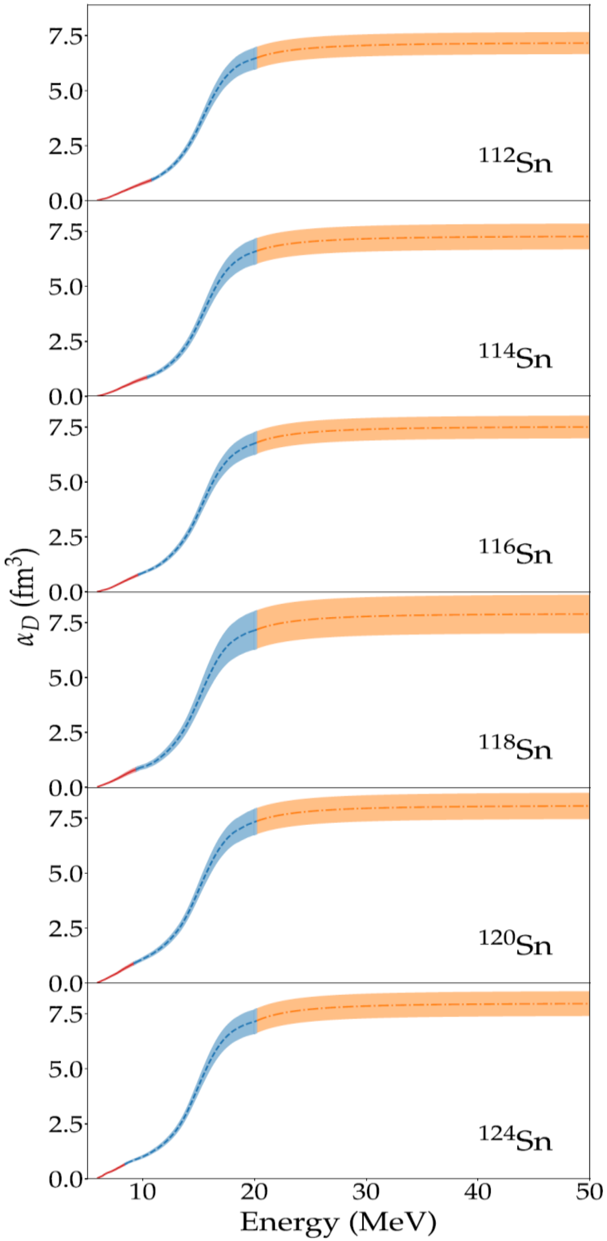


FIG. 20. Running sums of the dipole polarizability deduced from the present (p, p') data. Red: Contribution from 6 MeV to S_n. Blue: Contribution from S_n to 20 MeV. Orange: Contribution above 20 MeV from QPM calculations; see text for details.

Перспективы исследований

20 МэВ< E_x

Идентификация природы дипольных возбуждений

S. BASSAUER *et al.* PHYSICAL REVIEW C **102**, 034327 (2020)

СПАСИБО ЗА ВНИМАНИЕ