29TH INTERNATIONAL SCIENTIFIC CONFERENCE
OF YOUNG SCIENTISTS AND SPECIALISTS

Neutron-proton correlations in macro- and microscopic nuclear models

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Local mass relations (LMR)

Local mass relations:

– based on currently accurately measured nuclear data: the nuclear masses

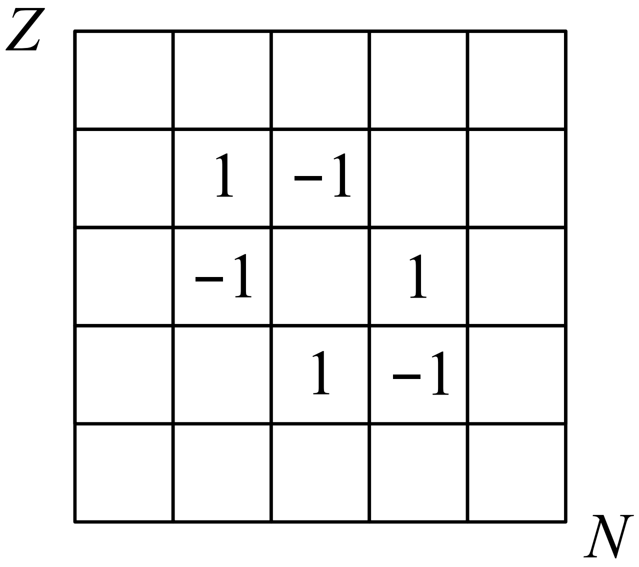
– have a relatively simple physical interpretation

– convenient for verifying the adequacy of theoretical models

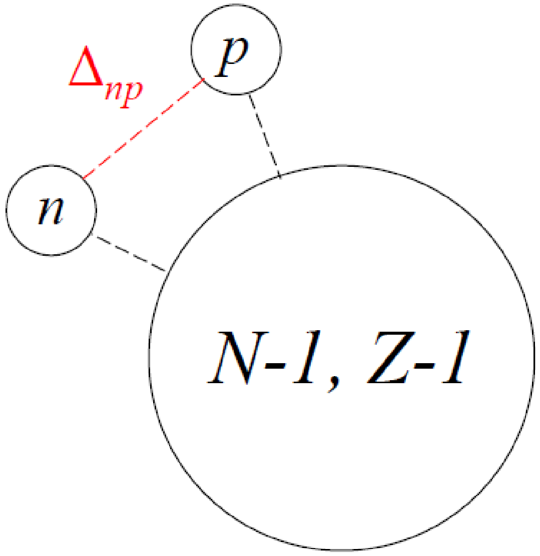
Example: the Garvey-Kelson relation

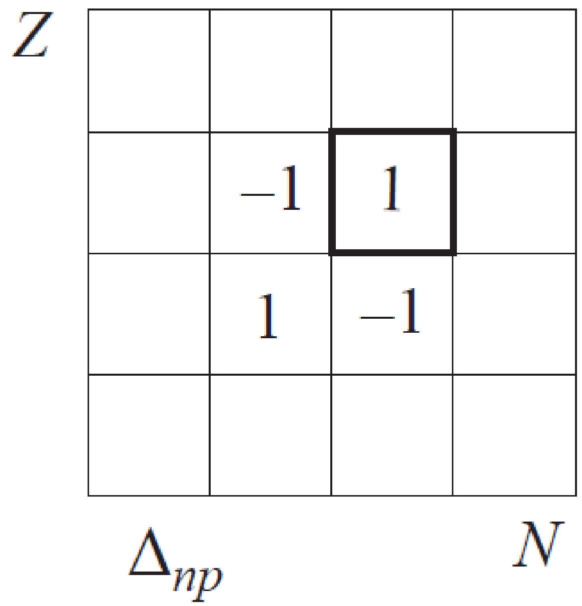
$$B(N+1,Z) - B(N+1,Z-1) + B(N,Z-1)$$
$$-B(N-1,Z) + B(N-1,Z+1) - B(N,Z+1) \approx 0$$

(with $\sigma \approx 0.7$ MeV) as of AME2020

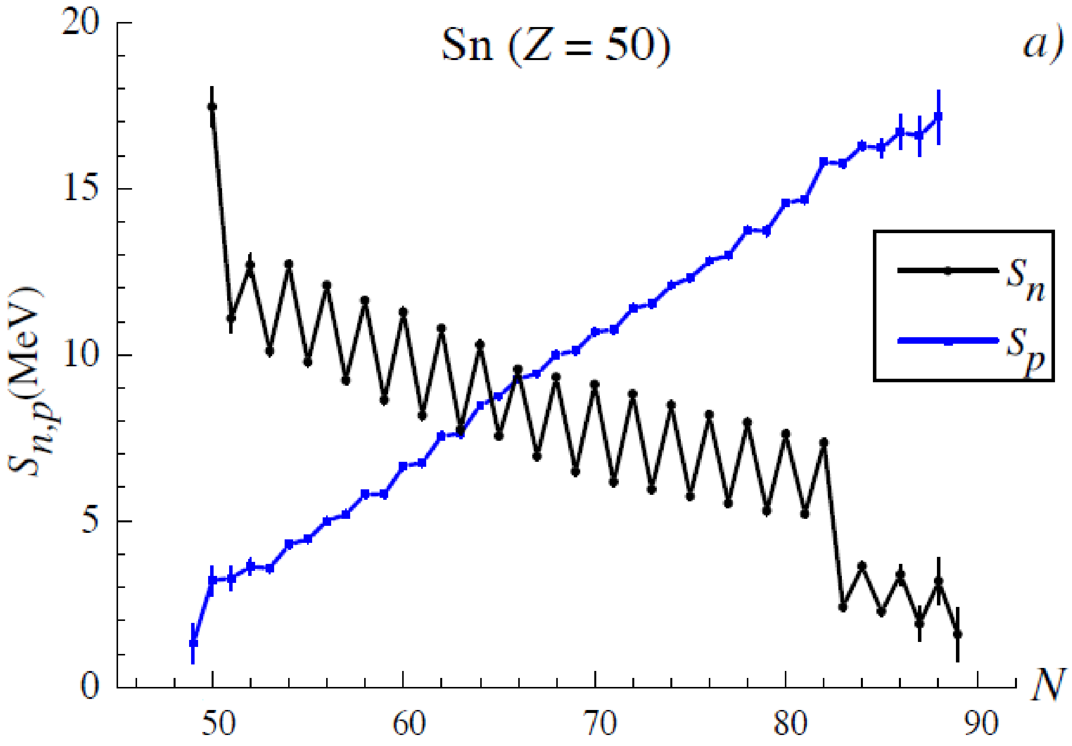


Commonly used *np*-pairing LMRs



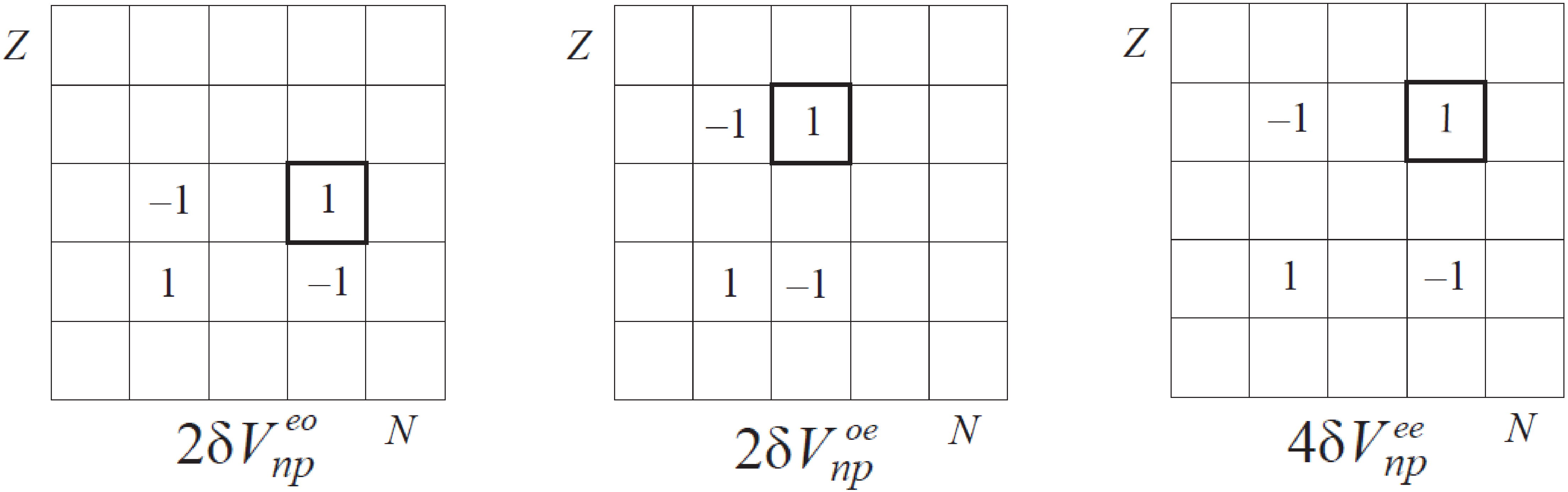


V.A. Kravtsov, Sov. Phys. JETP 36(9): 871 (1959)



$$\Delta_{np} = S_{np}(N,Z) - S_n(N,Z-1) - S_p(N-1,Z) =$$
$$= B(N,Z) - B(N,Z-1) - B(N-1,Z) + B(N-1,Z-1)$$
$$= S_p(N,Z) - S_p(N-1,Z)$$

Commonly used np-pairing LMRs: δV_{np}



Interaction of multiple nucleons in nuclei with *N* and *Z* of various parity

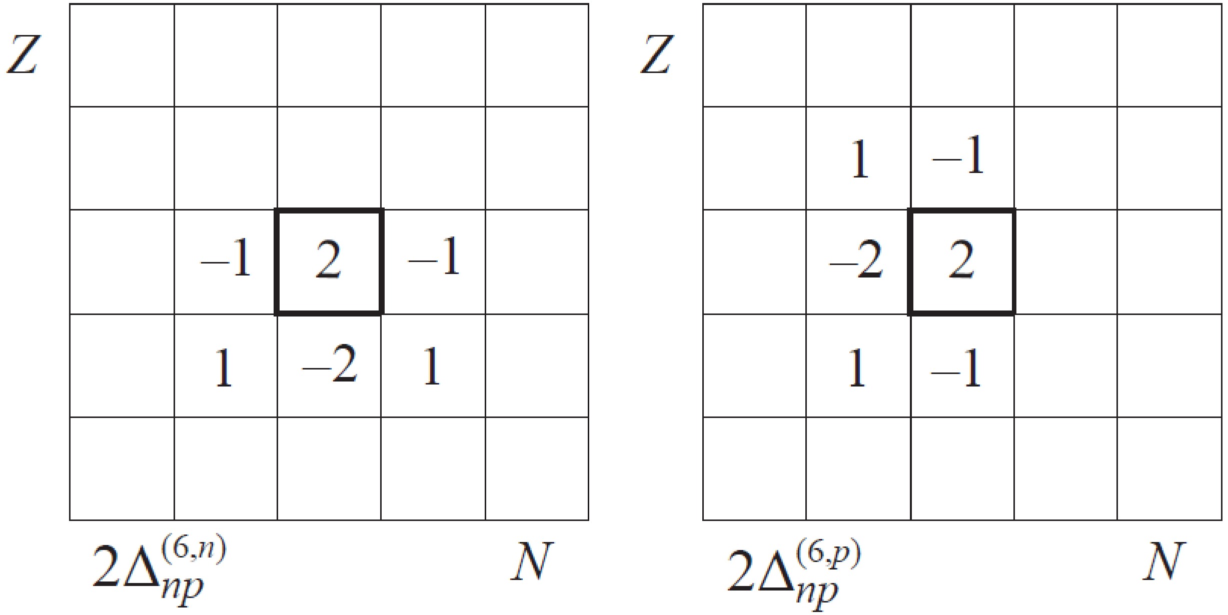
Zhang, Casten, Brenner, Phys. Lett. B (1989)

Commonly used np-pairing LMRs

Averaging of Δ_{np} over two neighbouring nuclei:

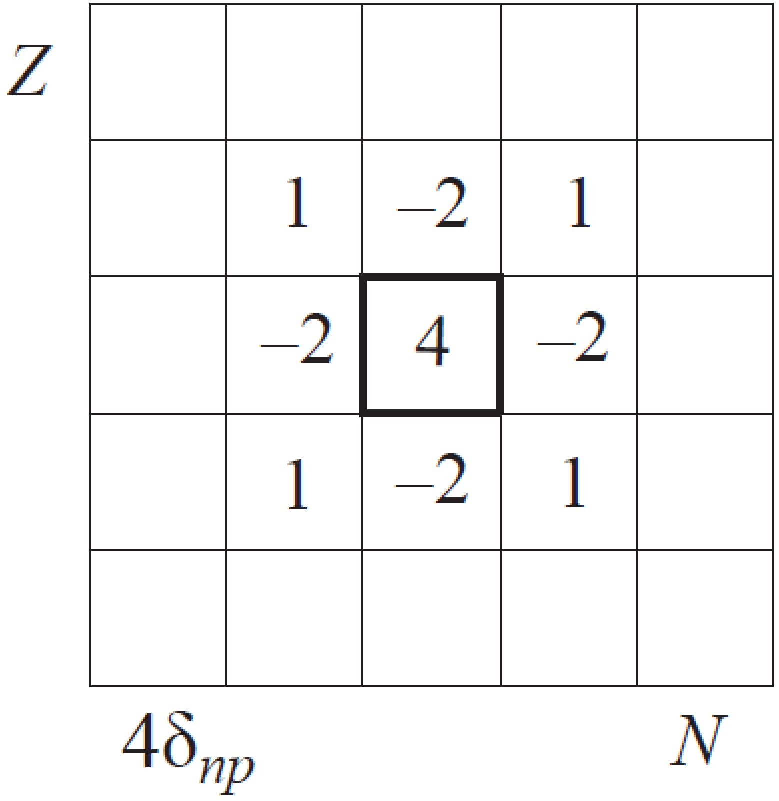
$$\Delta_{np}^{(6,n)}(N,Z) = \frac{\Delta_{np}(N,Z)-\Delta_{np}(N+1,Z)}{2}$$

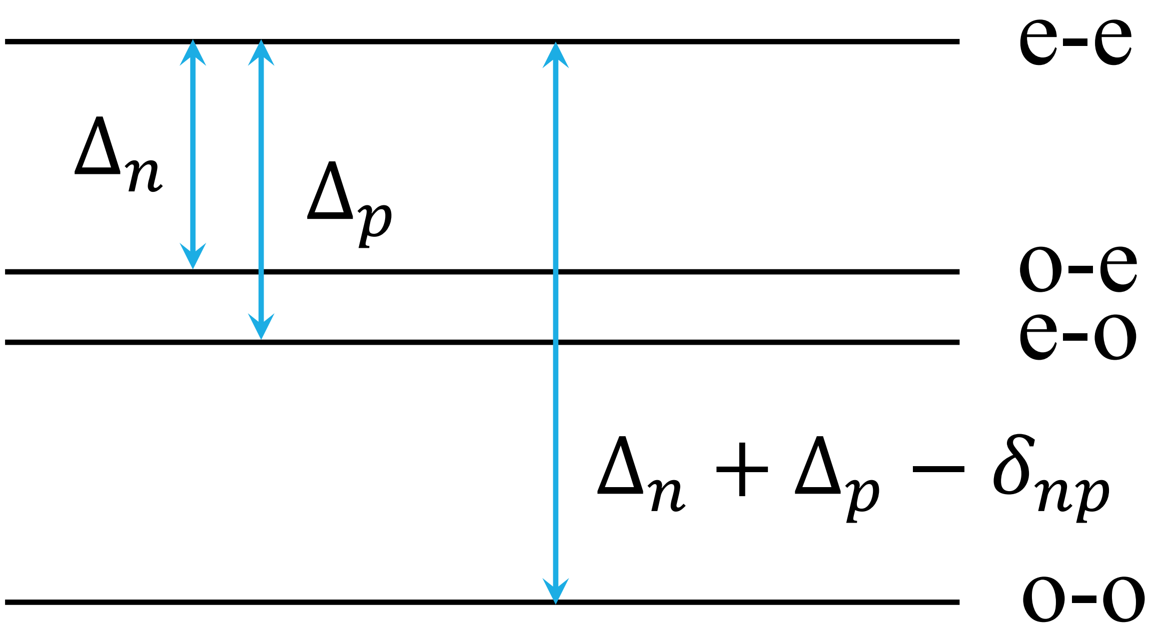
$$\Delta_{np}^{(6,p)}(N,Z) = \frac{\Delta_{np}(N,Z)-\Delta_{np}(N,Z+1)}{2}$$



Jensen, Hansen, Jonson, Nucl. Phys. (1984)

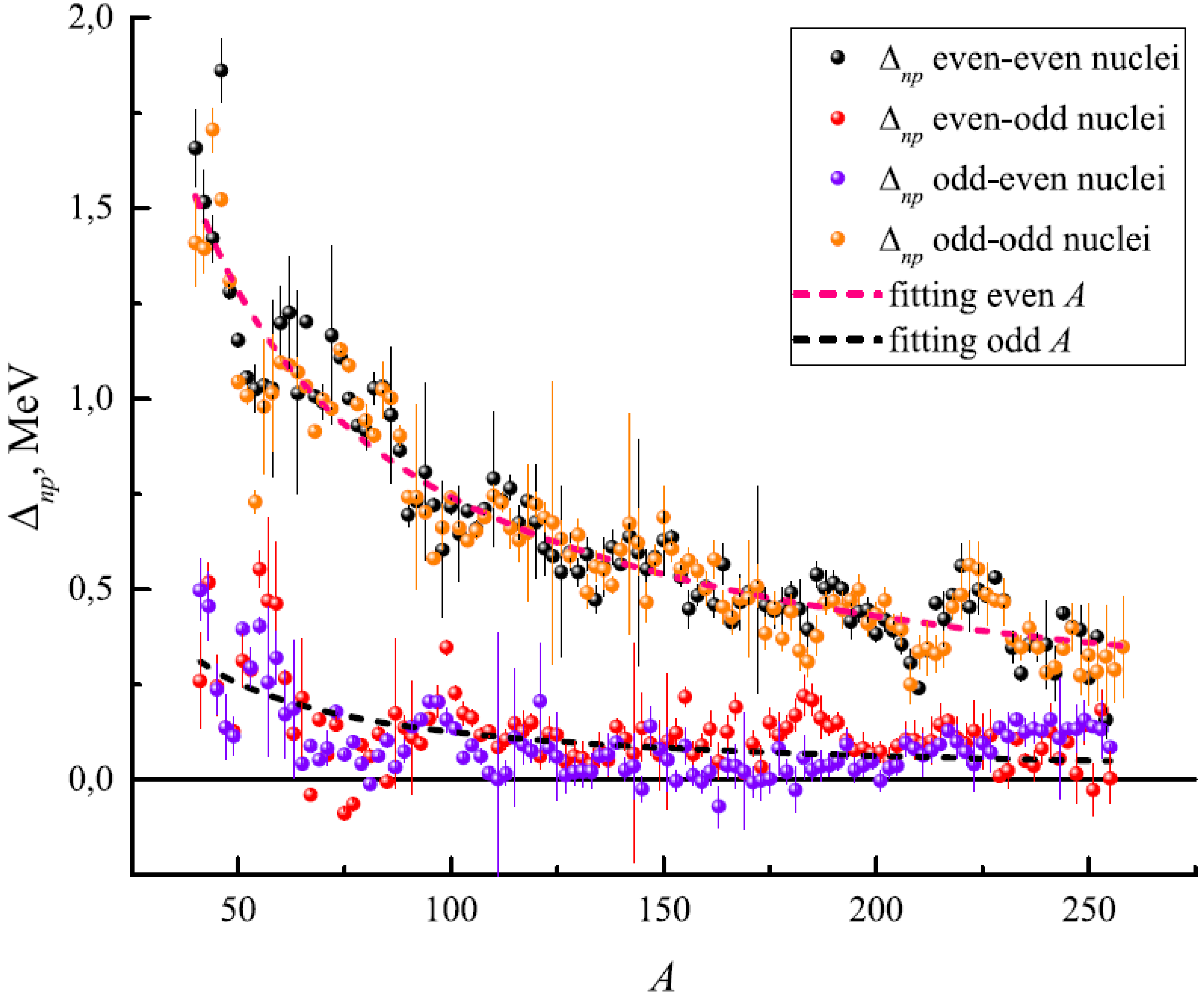
Commonly used np-pairing LMRs





Madland, Nix, Nucl. Phys. (1988)

Δ_{np} in nuclei of all parities by N and Z



Approximations with $y = ax^b$:

- even nuclei:

$$a = 28.2 \pm 2.2$$
$$b = -0.79 \pm 0.02$$

- odd nuclei:

$$a = 13.2 \pm 5.3$$
$$b = -1.01 \pm 0.09$$

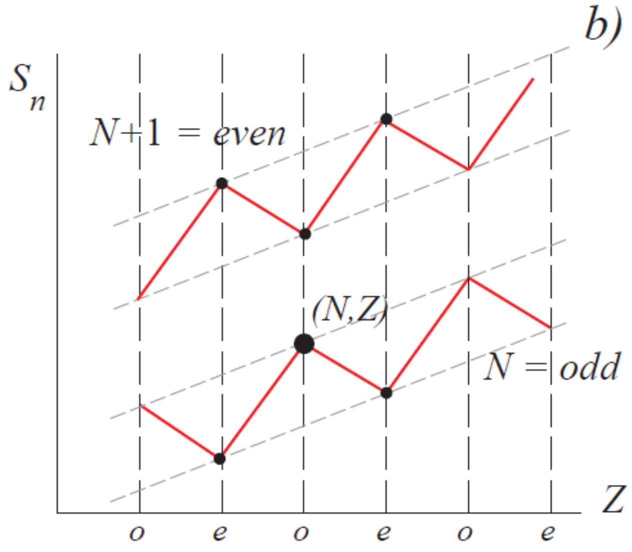
Interpretation of various LMRs

From shell model [Racah, Talmi, 1952] for n neutrons and p protons on shells j_1^n and j_2^p:

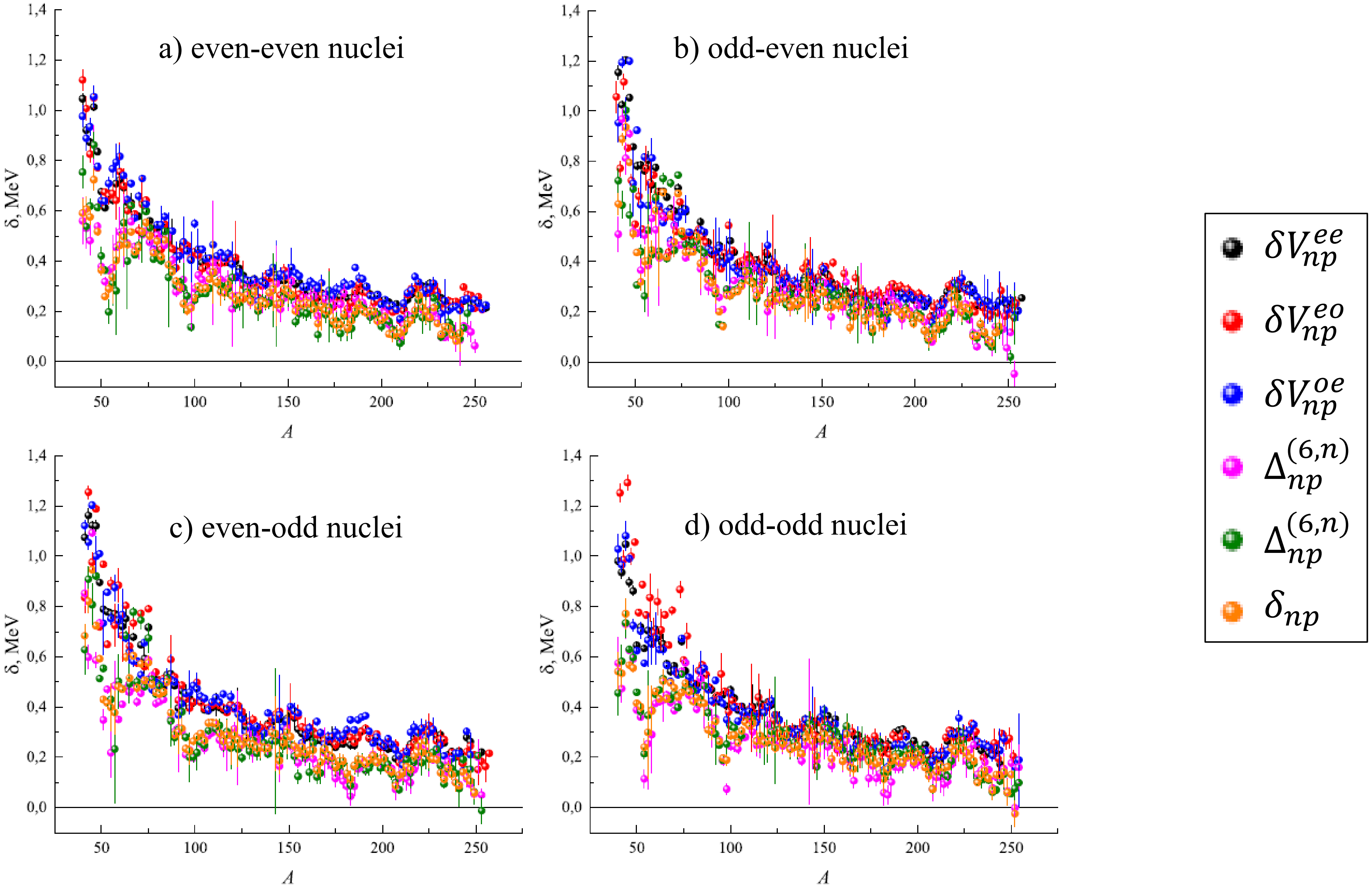
$$I(j_1^n, j_2^p) = npI^0 + \frac{(1-(-1)^n)(1-(-1)^p)}{4} I',$$

where I^0 stands for scalar neutron-proton interaction,
I' represents the pairing part of interaction, present in odd-odd nuclei only.
For different LMR's we get:

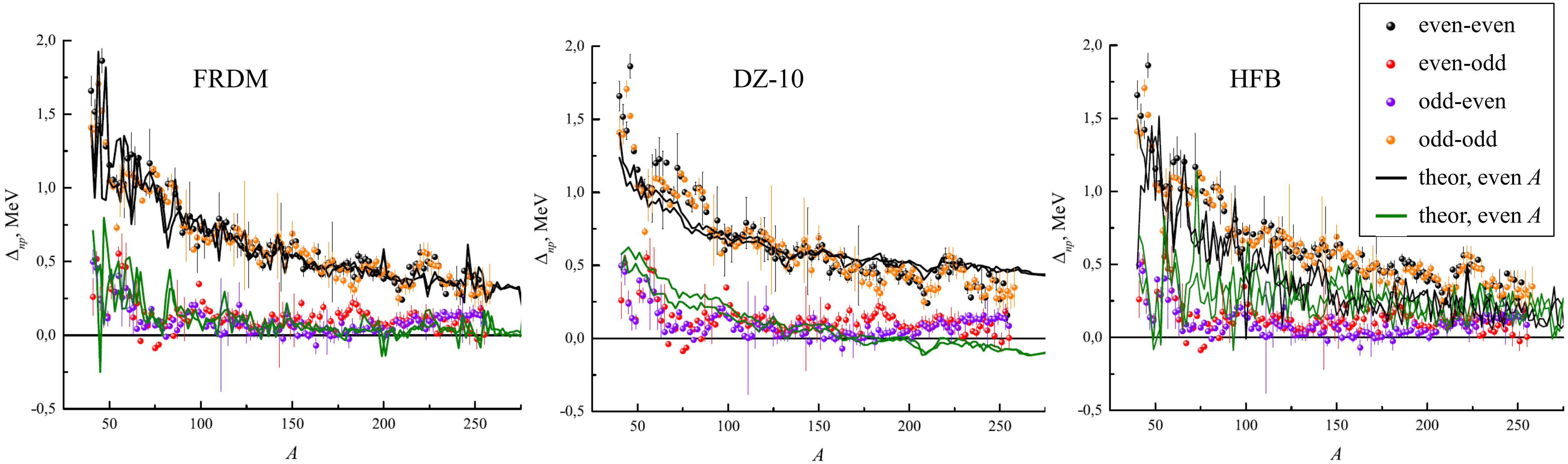
$$\Delta_{np} \equiv \delta V_{np}^{oo} = I' + I^0 \quad \text{for ee and oo nuclei,}$$
$$\Delta_{np} \equiv \delta V_{np}^{oo} = I' - I^0 \quad \text{for eo and oe nuclei,}$$
$$\delta V_{np}^{ee} = \delta V_{np}^{eo} = \delta V_{np}^{oe} = I^0, \quad \text{for all nuclei,}$$
$$\Delta_{np}^{(6,n)}(N,Z) = \Delta_{np}^{(6,p)}(N,Z) = \delta_{np} = I' \quad \text{for all nuclei.}$$



LMRs in nuclei of all parities by *N* and *Z*

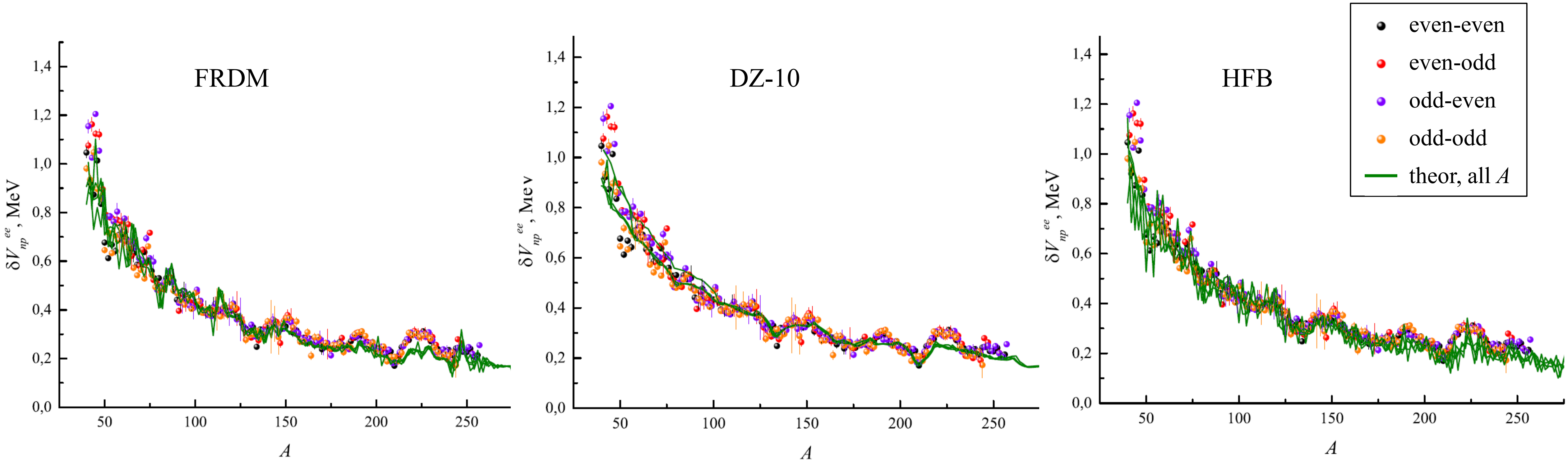


Δ_{np} in nuclei of all parities by N and Z



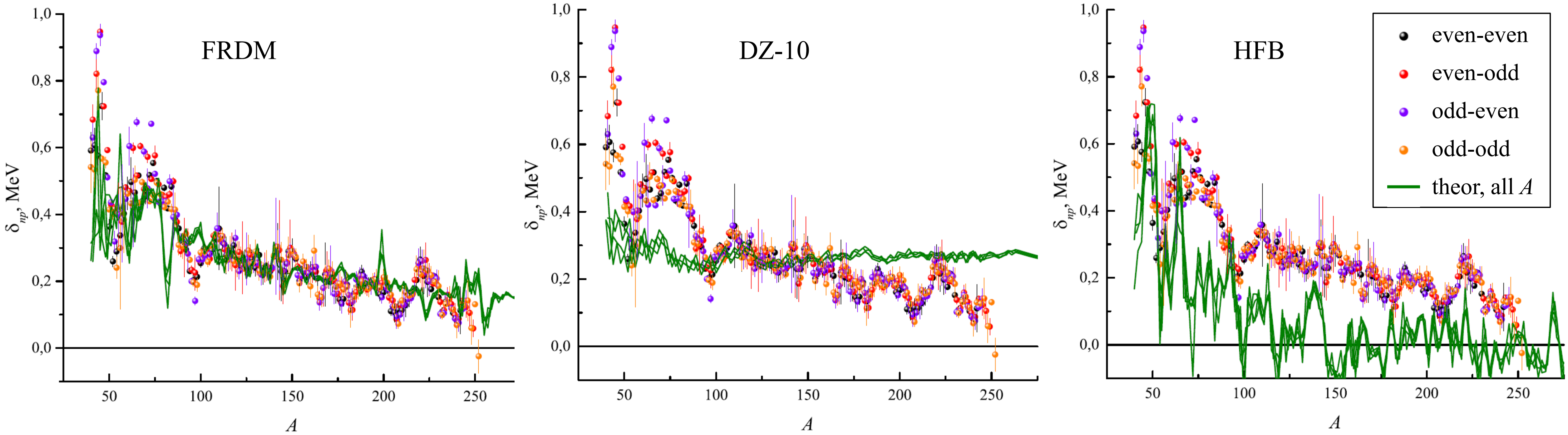
FRDM: Moller, Sierka, Ichikawa, Sagawa, At. Data and Nucl. Data Tables (2016)
Duflo-Zucker 10 (DZ-10): Pastore, Neill, Powell et al., Phys. Rev. C (2020)
HFB: Goriely, Chamel, Pearson, Phys. Rev. Lett., (2009)

$\delta V_{np} = I^0$ in nuclei of all parities by N and Z



- $\delta V_{np}^{ee} = I^0$ is reproduced adequately by all of the models under consideration
- Similar δV_{np}^{ee} for even and odd nuclei in all models

$\delta_{np} = I'$ in nuclei of all parities by N and Z



- $\delta_{np} = I'$ is reproduced adequately only in FRDM
- Similar δ_{np} for even and odd nuclei in all models, but not between different models

Conclusion

Various relations dubbed in literature as related to neutron-proton pairing have, in fact, several different meanings.

- The Δ_{np} relation, while initially introduced as interaction between an odd neutron and odd proton, carries in itself a mix of information pertaining to scalar neutron-proton interaction and pairing effects
- Relations from the δV_{np} family are typically related to the scalar neutron-proton interaction that doesn't depend on parity of *N* or *Z*. This part of *np*-interaction is typically described well in various macro- and microscopic approaches.
- LMR $\Delta_{np}^{(6,n)}$, $\Delta_{np}^{(6,p)}$ and δ_{np} are related to actual np-pairing as an effect contributing to even-odd staggering (EOS). The Finite Liquid Drop Model (FRDM) generally reproduce scale of these effects. On the example of HFB as a microscopic model it is shown that neutron-proton pairing requires explicit introduction in the Hamiltonian, as taking into account the blocking effects arising in odd or odd-odd nuclei is not sufficient for description of EOS.

Thank you for your attention!