Advances in Nuclear Many-Body Theory, Primosten, Croatia, June 7-10, 2011

# Selected topics of Covariant Density Functional Theory

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# (Deformed) Halos and giant halos

1. Meng, and Ring, Relativisitic Hartree-Bogoliubov description of neutron halo in 11Li, Physical Review Letters 77 (1996) 3963-3966.
2. Meng, and Ring, Giant Halo at the Neutron Drip Line, Physical Review Letters 80 (1998) 460-463.
3. Long, Ring, Meng, Giai, and Bertulani, Nuclear halo structure and pseudospin symmetry, Physical Review C 81, 031302(R) (2010)
4. Zhou, Meng , Ring, Zhao, Neutron halo in deformed nuclei, Physical Review C 82, 011301(R) (2010)
5. Long, Ring, Giai, and Meng, Relativistic Hartree-Fock-Bogoliubov theory with density dependent meson-nucleon couplings, Physical Review C 81, 024308 (2010)

**Li’s talk in the following session!**

# Pseudo-spin symmetry and Spin symmetry

6. Meng, Sugawara-Tanabe, Yamaji, Ring and Arima, Pseudospin symmetry in relativistic mean field theory Physical Review C 58 (1998) R628-R631.
7. Zhou, Meng, and Ring, Spin Symmetry in the Anti-nucleon Spectrum, Physical Review Letters 91, 262501 (2003)
8. Zhou, Meng, and Ring, Spherical relativistic Hartree theory in a Woods-Saxon basis, Physical Review C 68, 034323 (2003)

# Magnetic Moment & Magnetic Rotation

Magnetic Moment

9. Li, Meng, Ring, Yao and Arima, Relativistic description of second-order correction to nuclear magnetic moments with point-coupling residual interaction, Science in China G 54:2 (2011) 204-209

Magnetic Rotation

10. Peng, Meng, Ring, and Zhang, Covariant density functional theory for magnetic rotation, Physical Review C 78 (2008) 024313
11. Zhao, Zhang, Peng, Liang, Ring, Meng, Novel structure for magnetic rotation bands in 60Ni, Physics Letters B699, 181 (2011)
12. Zhao, Peng, Liang, Ring, Meng Antimagnetic rotation band: a microscopic description, arXiv:1105.3622v1 [nucl-th]

**Zhao’s talk on Thursday!**

# Configuration mixing of angular-momentum-projected CDFT

13. Yao, Meng, Ring, and Pena Arteaga, Three-dimensional angular momentum projection in relativistic mean-field theory, Physical Review C 79, 044312 (2009).
14. Yao, Meng, Ring, and Vretenar, Configuration mixing of angular-momentum-projected triaxial relativistic mean-field wave functions, Physical Review C 81, 044311 (2010)
15. Yao, Mei, Chen, Meng , Ring, and Vretenar, Configuration mixing of angular-momentum-projected triaxial relativistic mean-field wave functions. II. Microscopic analysis of low-lying states in magnesium isotopes, Physical Review C 83, 014308 (2011)

**Yao’s talk on Thursday!**

# Collective Hamiltonian based on CEDF

16. Niksic, Li, and Vretenar, Prochniak, Meng Ring, Beyond the relativistic mean-field approximation III. Collective Hamiltonian in five dimensions, Physical Review C 79, 034303 (2009)
17. Li, Niksic, Vretenar, Ring, Meng, Relativistic energy density functionals: Low-energy collective states of Pu-240 and Er-166, Physical Review C 81, 064321 (2010)
18. Li, Niksic, Vretenar, Meng, Lalazissis, Ring, Microscopic analysis of nuclear quantum phase transitions in the N~90 region, Physical Review C 79, 054301 (2009)

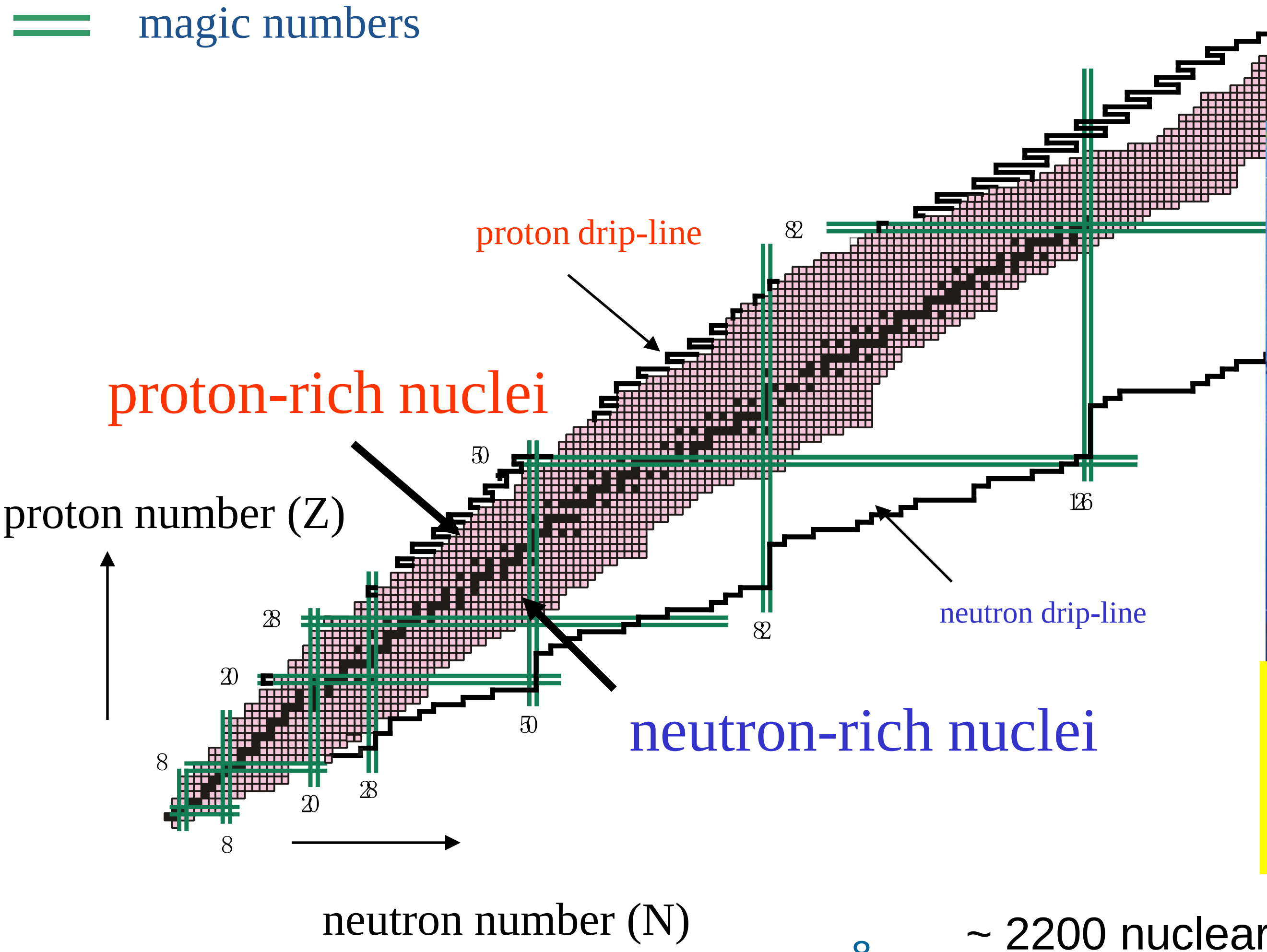
**Niksic’s talk on Thursday!**

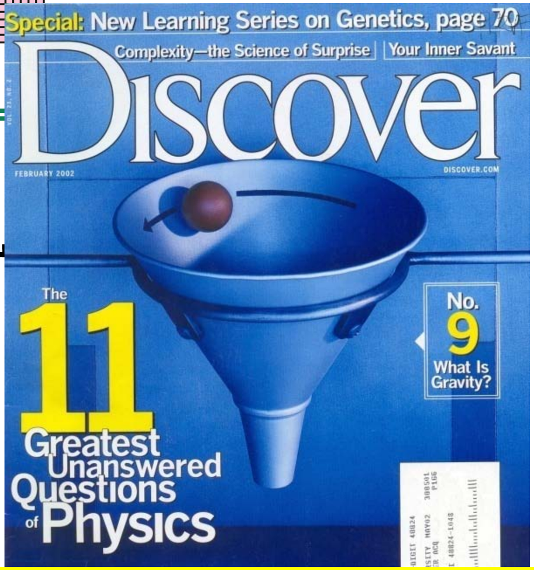
# Outline

- ☐ Introduction
- ☐ (Deformed) Halos and giant halos
- ☐ Pseudo-spin symmetry and Spin symmetry
- ☐ Magnetic Moment &Magnetic Rotation

# Existence Limit of nucleus

| | | |
|---|---|---|
| ■ | stable nuclei | ~300 nuclei |
| ☐ | unstable nuclei observed so far | ~2700 nuclei |
| ▬ | drip-lines (limit of existence)（theoretical predictions) | ~8000 nuclei |
| 〓 | magic numbers | |



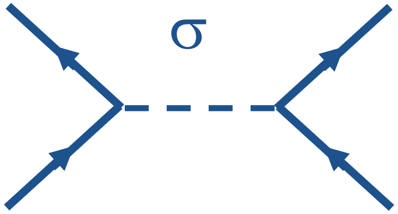


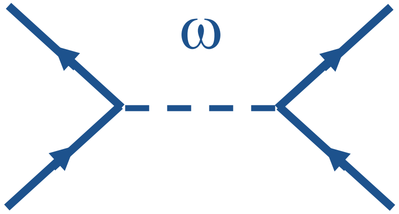
**Question 3**
How were the elements from iron to uranium made ?

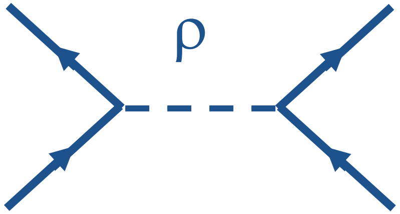
~ 2200 nuclear masses were measured

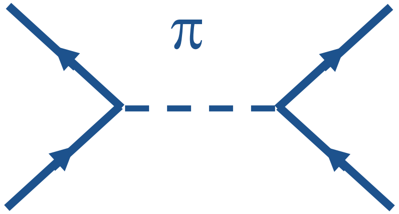
# Starting point of CDFT

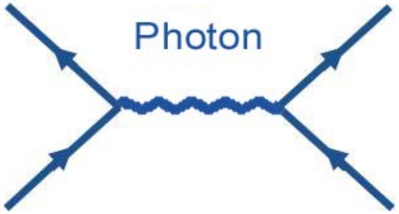
**Nucleons are coupled by exchange of mesons via an effective Lagrangian**







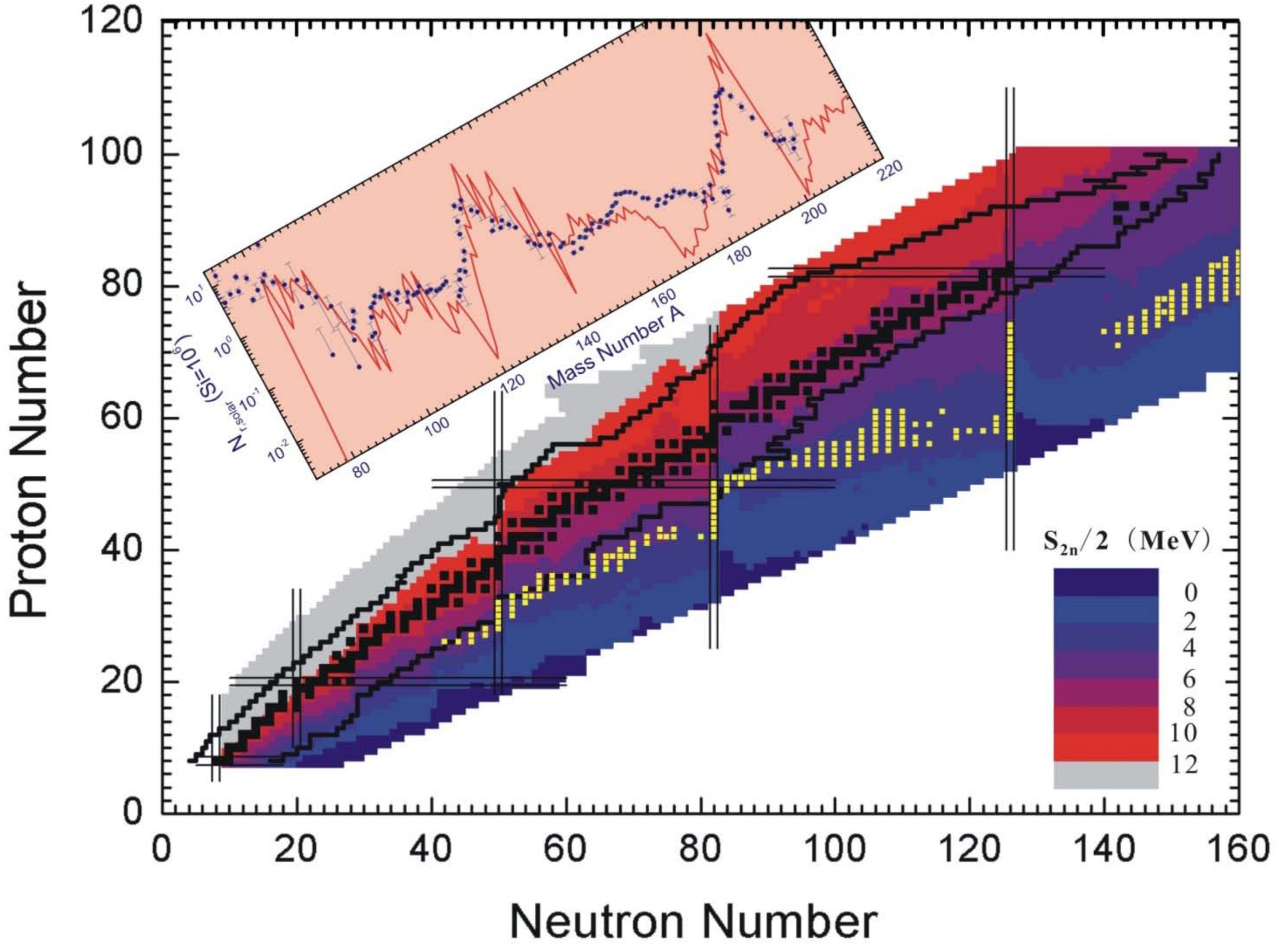




| meson | $J^{\pi}$ | $T$ |
|---|---|---|
| π | $0^-$ | 1 |
| σ | $0^+$ | 0 |
| ω | $1^-$ | 0 |
| ρ | $1^-$ | 1 |

# Classical r-process calculation

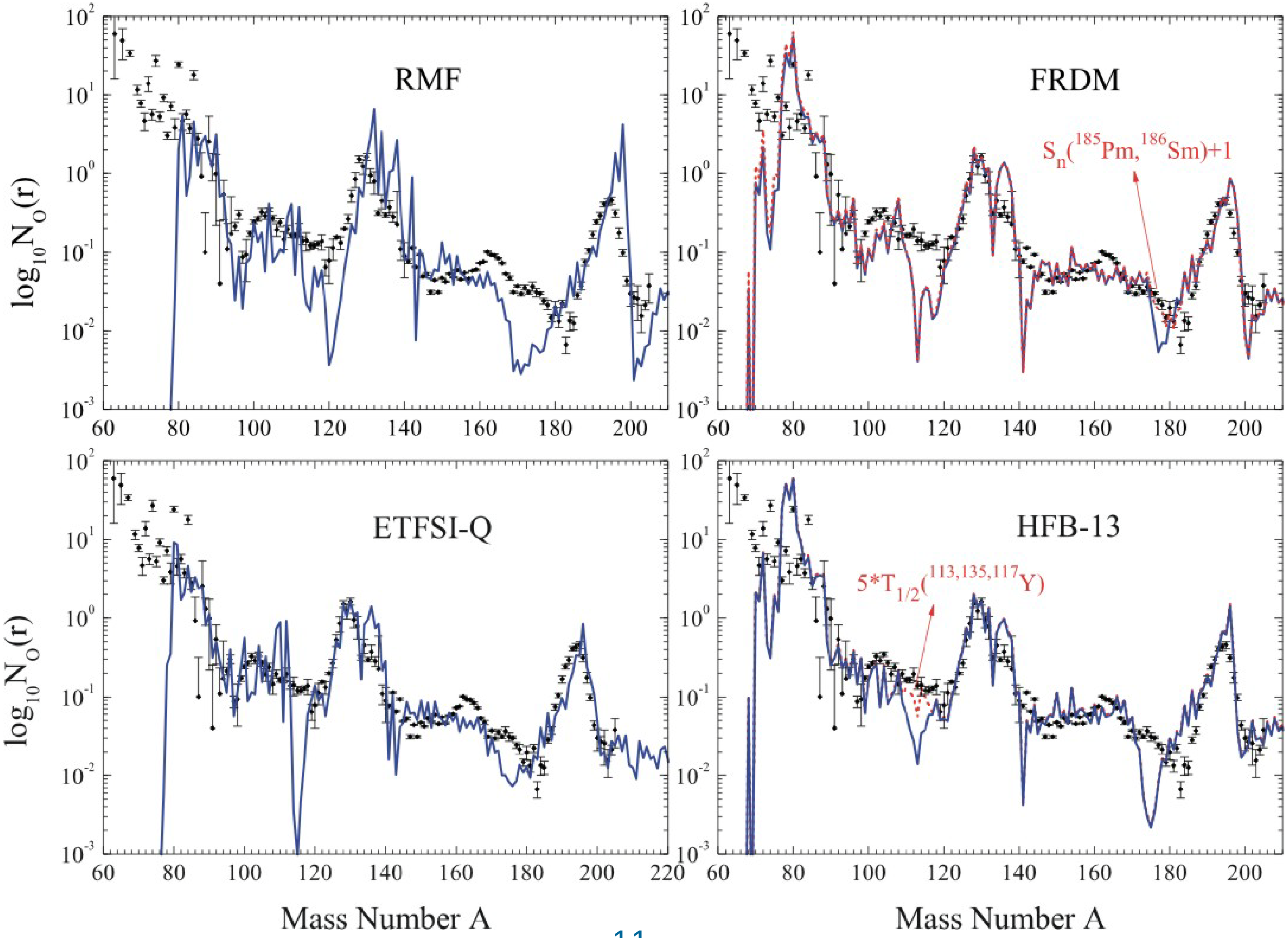
**Nuclear inputs: $S_n$(RMF), $T_{1/2}$(β-decay), $P_{1n}$, $P_{2n}$, $P_{3n}$ (FRDM),**
**Astrophysical parameters: $T_9$=1.5, $n_n$=$10^{20-28}$ , w, t (least-square fit),**



B. Sun et al., PRC 78 025806 (2009)

B. Sun et al., CPL 25 2429 (2008)

# Nuclear Mass Model dependence



# Th/U chronometer

- The age of the universe is one of the most important physical quantities in cosmology.
- The metal-poor star is formed at the early stage of the universe, so its age provides constraint to the age of the universe.
- The age of metal-poor star:

$$\frac{Th}{U}\bigg|_{\text{present}} = \frac{Th}{U}\bigg|_{\text{initial}} e^{-(\lambda_{Th}-\lambda_U)t}$$

- Present abundances: astronomical observations.

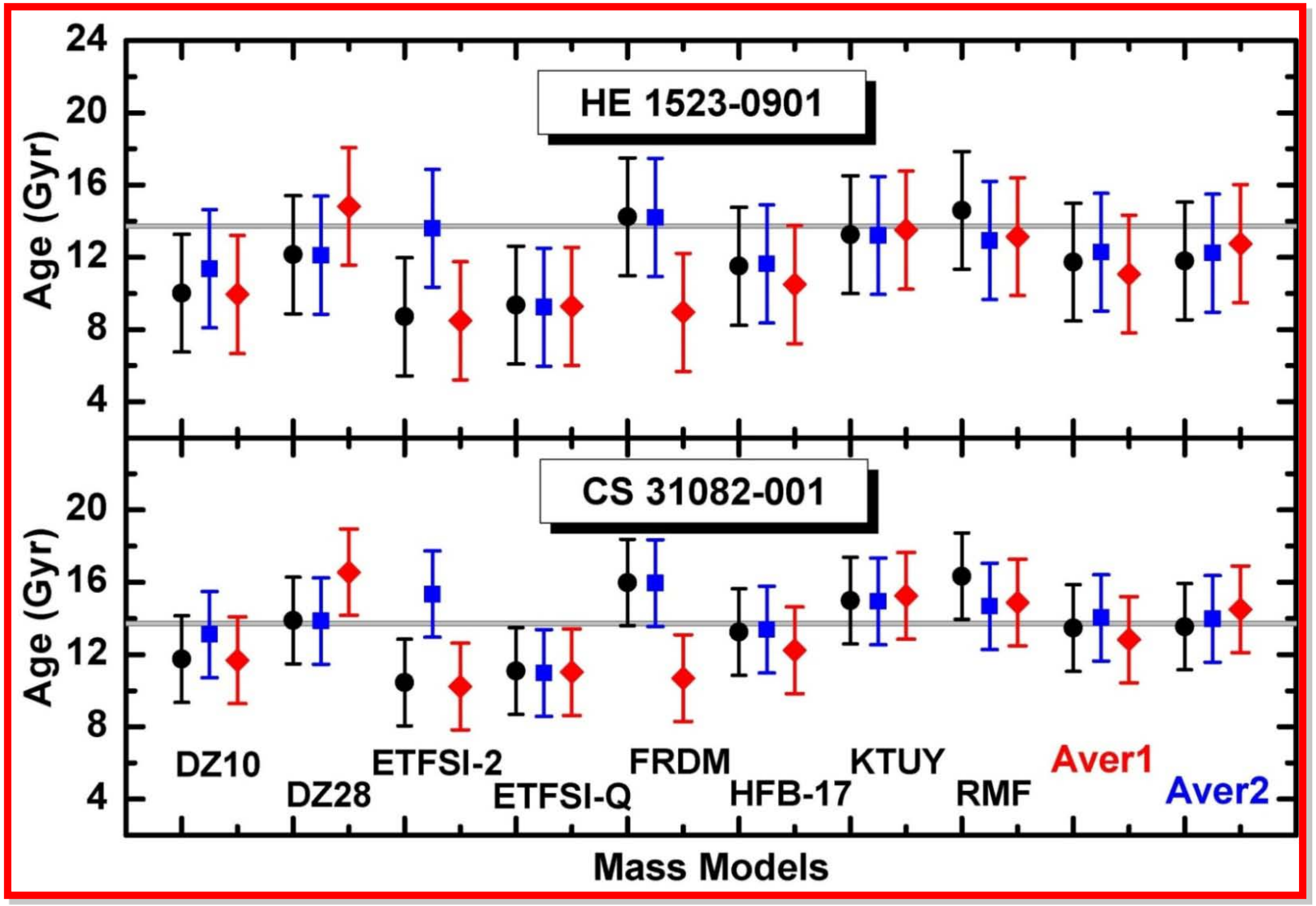
  R. Cayrel, et al., Nature 409, 691 (2001).
  J.J. Cowan, et al., ApJ 572, 861 (2002).
  A. Frebel, et al., ApJ 660, 117 (2007).

- Initial abundances: r-process calculations (Th, U are r-only nuclei).

- The classical r-process model is usually employed in r-process calculations.

  P.A. Seeger, et al., ApJS 11, 121 (1965).
  K.-L. Kratz, et al., ApJ 403, 216 (1993).

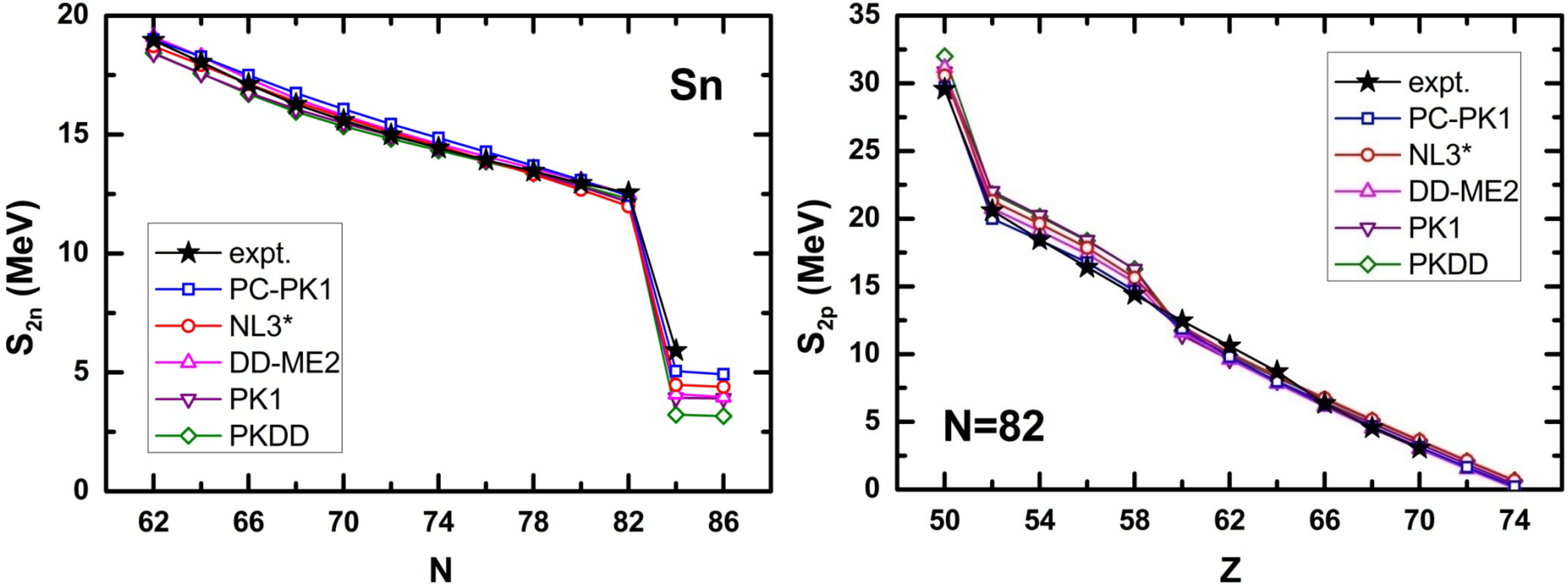
# Ages of metal-poor stars



Age (HE 1523-0901)=11.8 ± 3.7 Gyr   Age (CS 31082-001)=13.5 ± 2.9 Gyr

Z. Niu et al., PRC 80 065806 (2009)

# Radioactive neutron-rich doubly magic nucleus $^{132}$Sn



The two-neutron and two-proton separation energies are well reproduced.

- Sn($\alpha$,$t$) reactions: “Not-so-magic numbers “ D. Warner, Nature 430, 517 (2004).
- $^{132}$Sn(d,p)$^{133}$Sn reaction: revealed for the first time that the spectroscopic factors $S \approx 1$ for the neutron single-particle states outside $N = 82$ *core.*

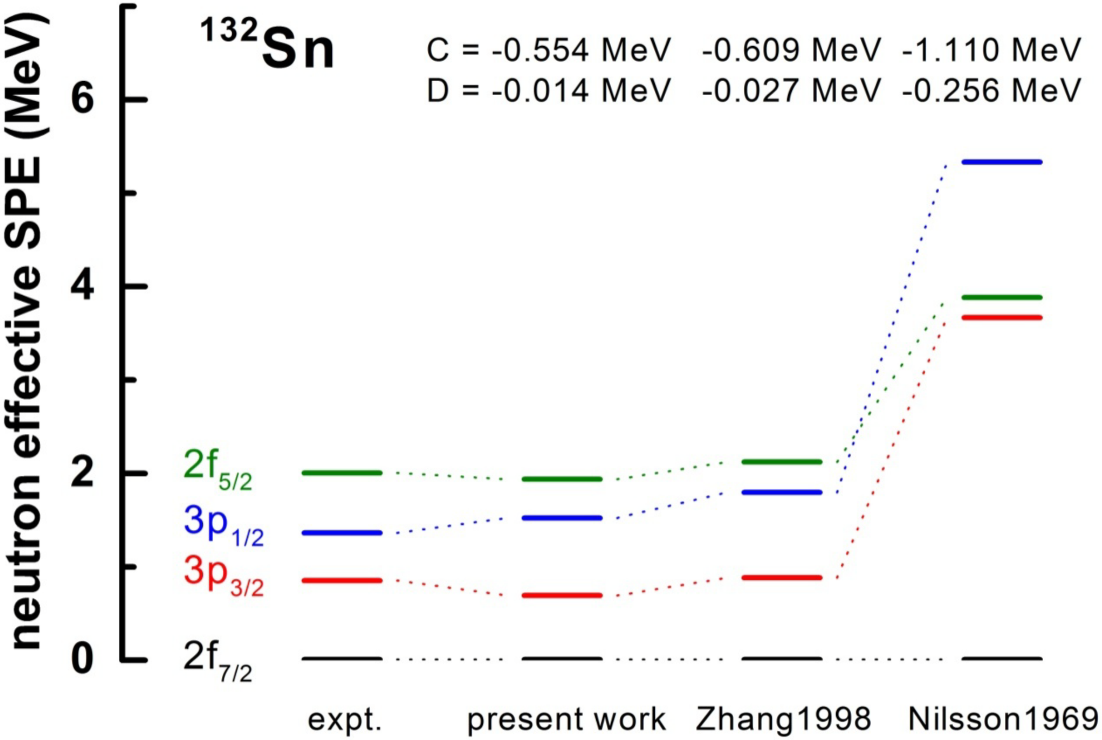
P. Cottle, Nature 465, 430 (2010). B. Schwarzschild, Phys. Today 63, 16 (2010).

# Neutron single-particle spectrum in $^{132}$Sn

- **Nilsson parameters**

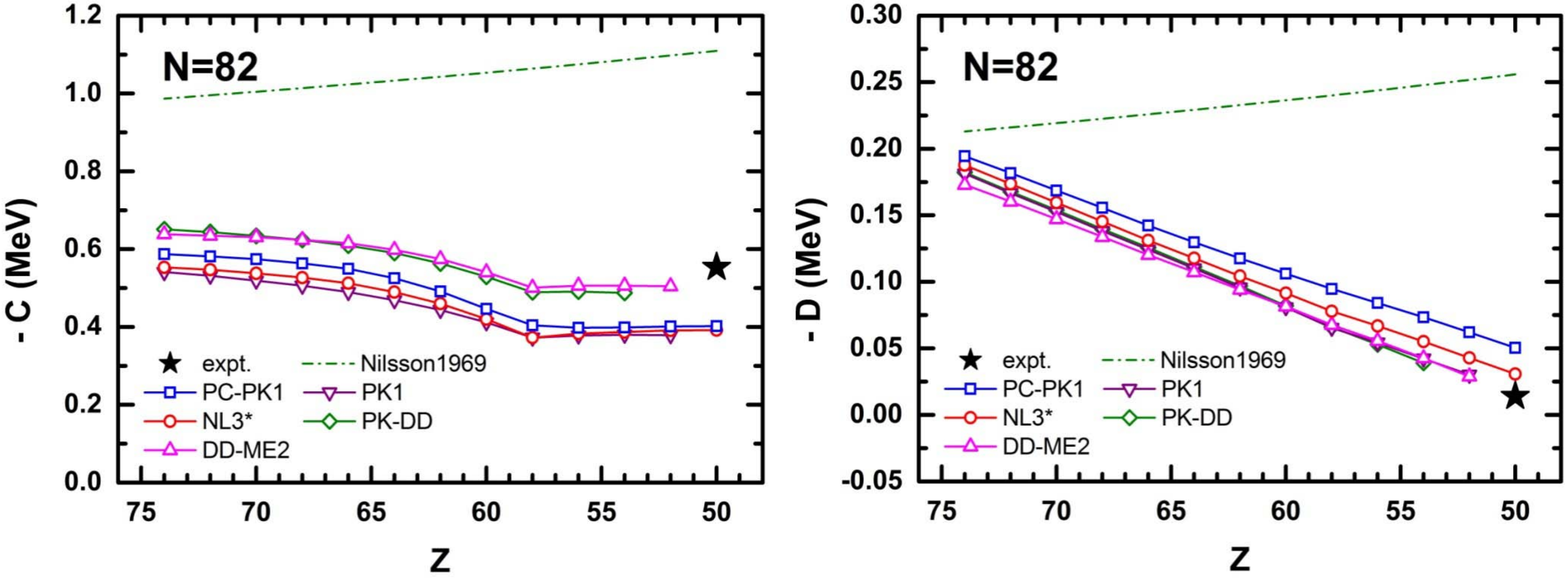
$$V_{s.p.} = -\kappa\hbar\omega_0^{\pm}[2l\cdot s + \mu(l^2 - \langle l^2\rangle_N)], \quad \hbar\omega_0^{\pm} = \hbar\omega_0[1\pm(N-Z)/3A]$$

$$C = -2\kappa\hbar\omega_0^{\pm}, \qquad D = -\kappa\mu\hbar\omega_0^{\pm}$$



K. L. Jones et al., Nature 465, 454 (2010).

# Nilsson parameters for N=82 isotones



- ➢ Nilsson spin-orbit and orbit-orbit parameters for the N=82 isotonic chain.

- ❖ The “experimental” Nilsson spin-orbit parameter C and orbit-orbit parameter D extracted from single-particle spectrum in $^{132}$Sn remarkably differ from the traditional Nilsson parameters but in good agreement with the RMF results.

- ❖ Along the N = 82 isotonic chains, the reduction of both the spin-orbit and orbit-orbit strengths are predicted. The RMF results provide a guideline for the isospin dependence of the Nilsson parameters.

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# (Deformed) Halos and giant halos

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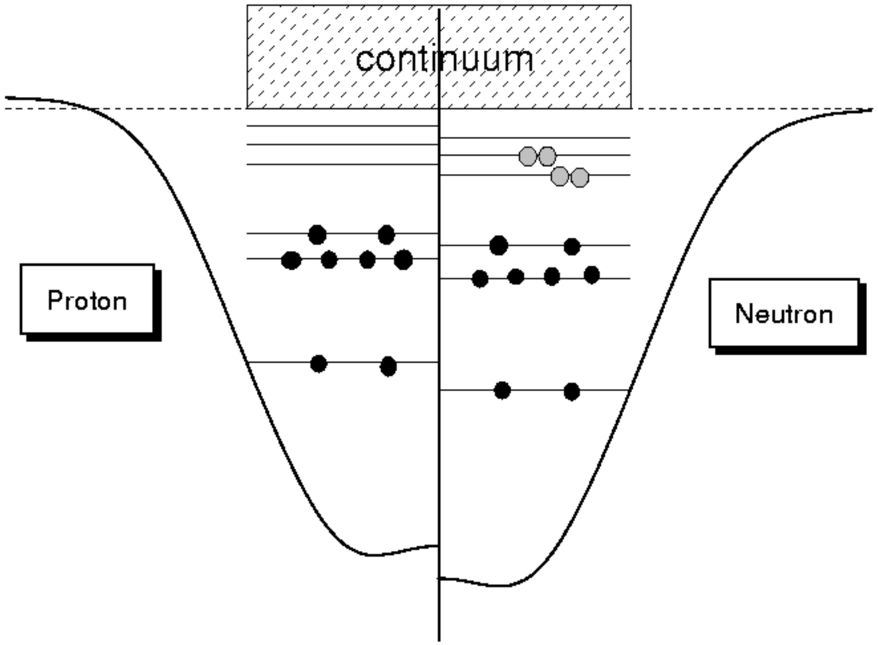
5. Long, Ring, Giai, and Meng, Relativistic Hartree-Fock-Bogoliubov theory with density dependent meson-nucleon couplings, Physical Review C 81, 024308 (2010)

**Li’s talk in the following session!**

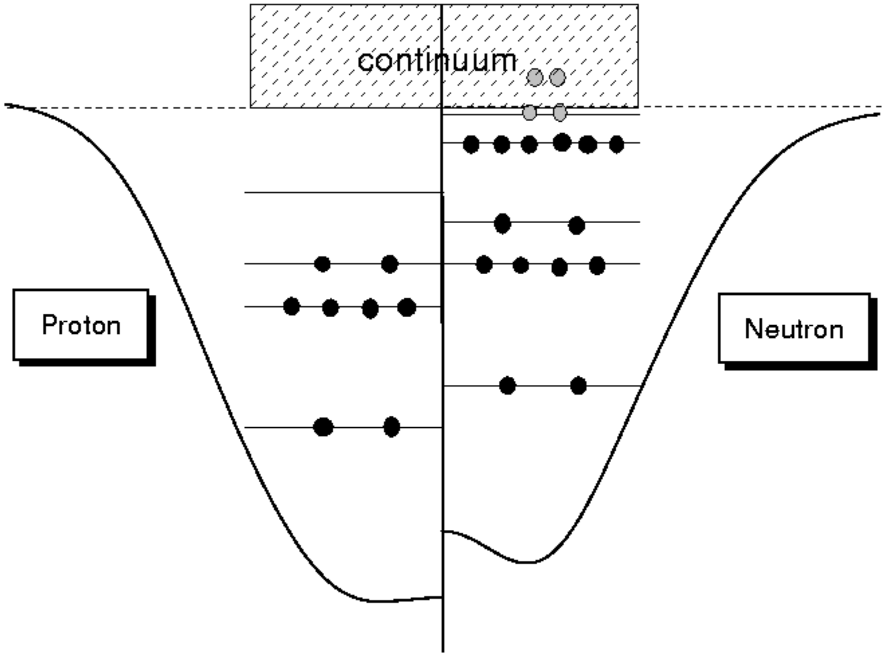
# Contributions from the continuum

- Weakly bound; large spatial extension
- Continuum contribution can not be ignored

连续谱



正常核



奇特核

# Exotic Phenomena

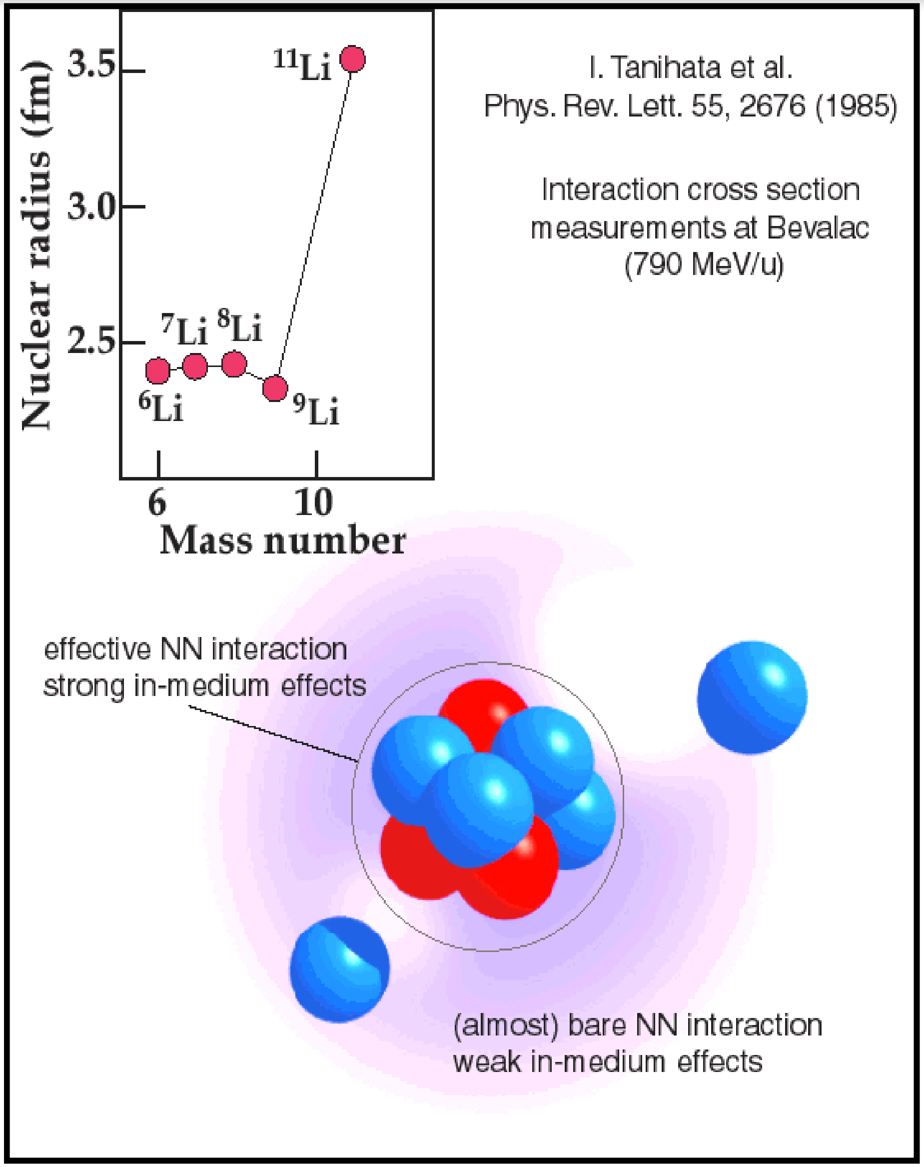
**Relativistic Hartree+Bogoliubov in coordinate space**

**J. Meng and P. Ring, PRL 77, 3963 (1996), PRL 80, 460 (1998)**

**New explanation for halo；**

**Prediction for giant hao：**

**N≥82 $Zr_{40}$**



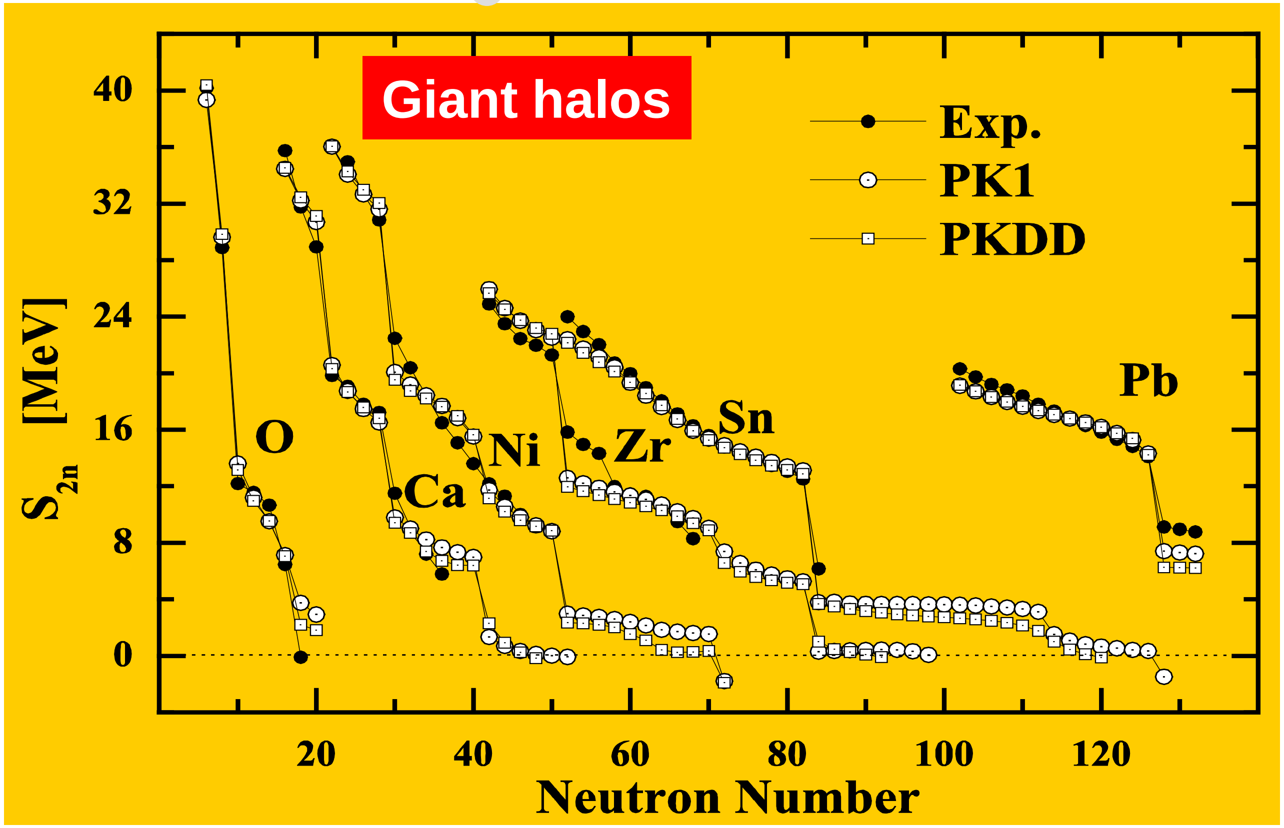
I. Tanihata et al.
Phys. Rev. Lett. 55, 2676 (1985)

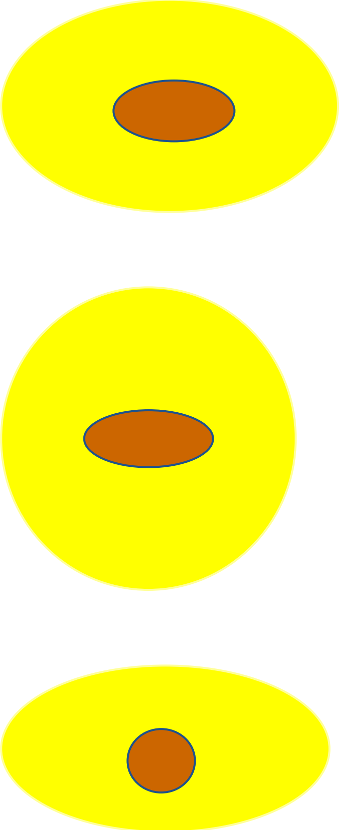
Interaction cross section measurements at Bevalac (790 MeV/u)

# Halo and giant halo

**Meng & Ring, PRL77,3963 (1996)**
**Meng & Ring, PRL80,460 (1998)**
**Meng, NPA 635,3(98)**

**Meng,Tanihata, Yamaji, PLB, 419 (1998) 1**
**Meng, Toki, Zeng, Zhang & Zhou, PRC65,041302R (2002)**
**Meng, Zhou, Tanihata, PLB 532 (2002) 209**
**Terasaki, Zhang, Zhou, Meng, PRC 74（2006） 054318**

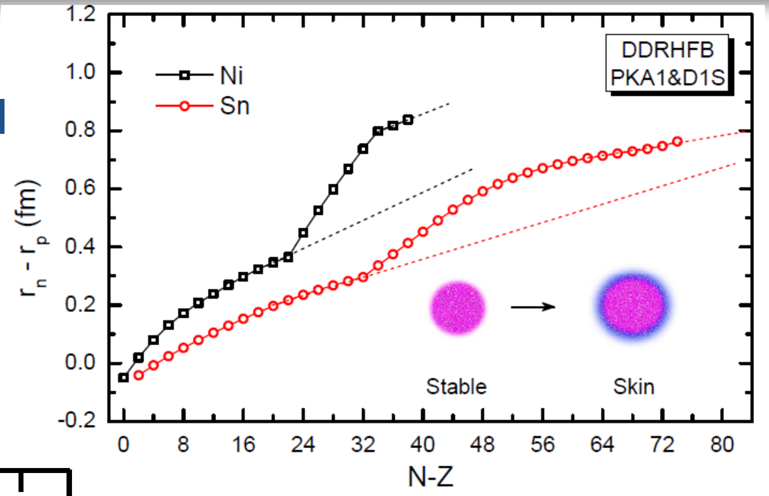


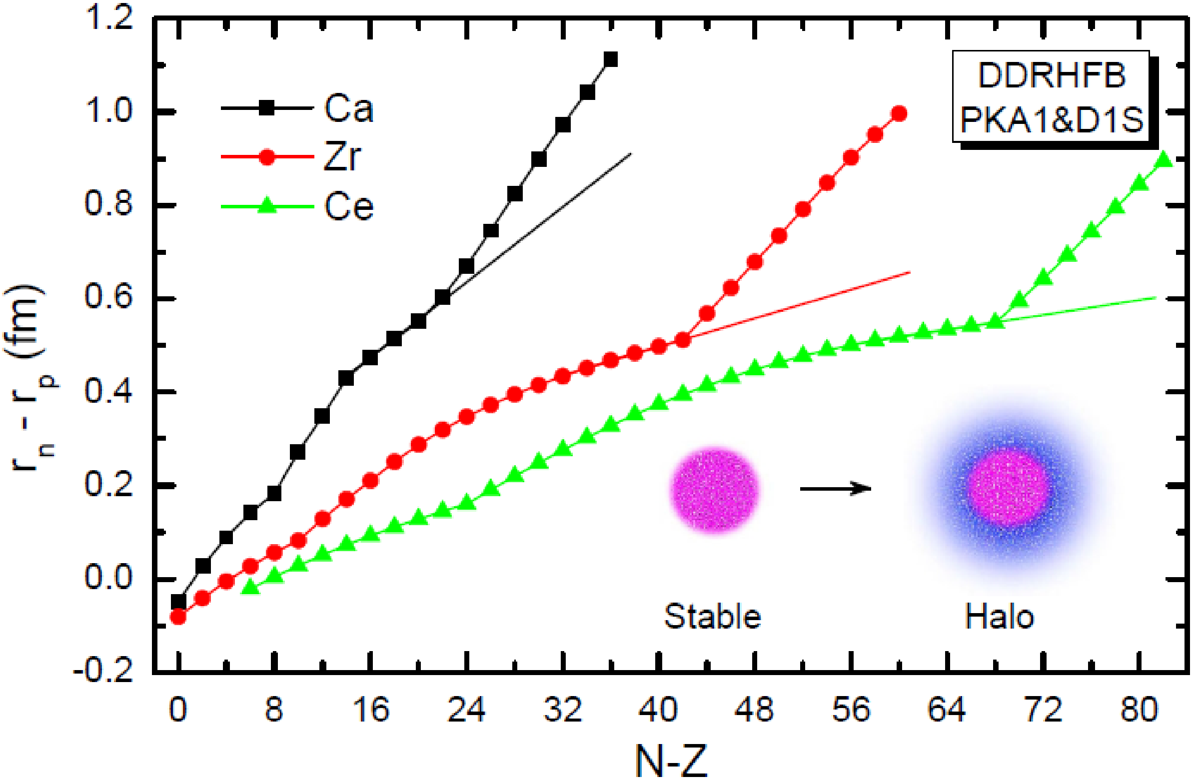


Meng, Toki, Zhou, Zhang, Long & Geng, Prog. Part. Nucl. Phys. 57(2006) 470-563

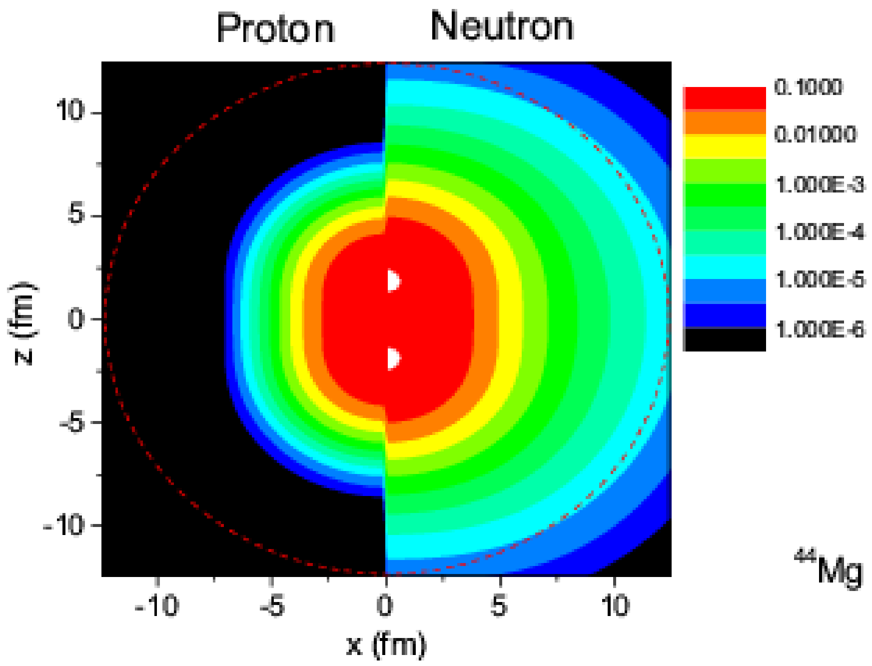
# Halo and giant halo in DDRHFB

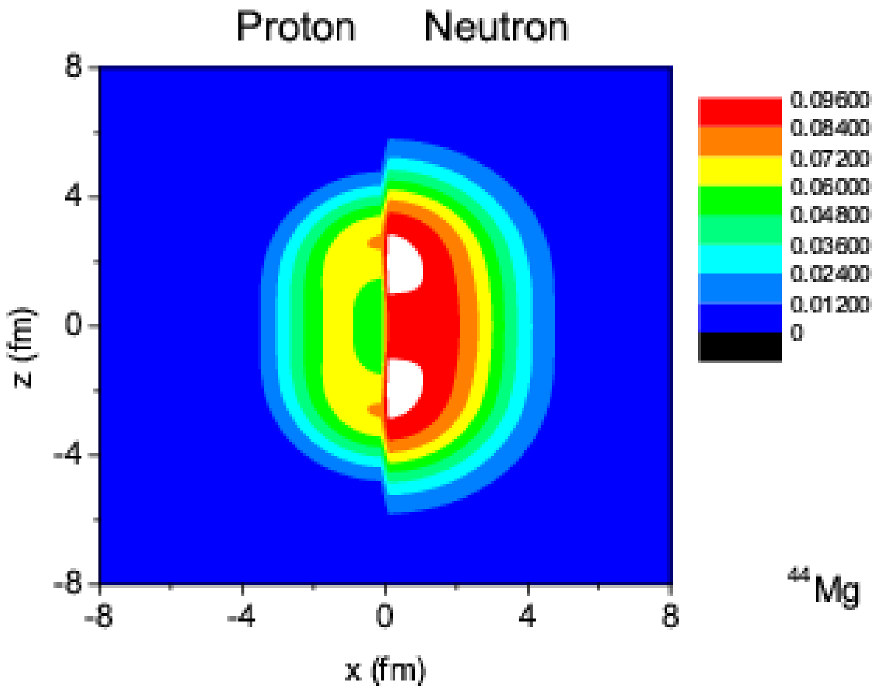
1. Long, Ring, Meng, Giai, and Bertulani, Nuclear halo structure and pseudospin symmetry, Physical Review C 81, 031302(R) (2010)
2. Long, Ring, Giai, and Meng, Relativistic Hartree-Fock-Bogoliubov theory with density dependent meson-nucleon couplings, Physical Review C 81, 024308 (2010)





# Deformation effects in Halo nuclei

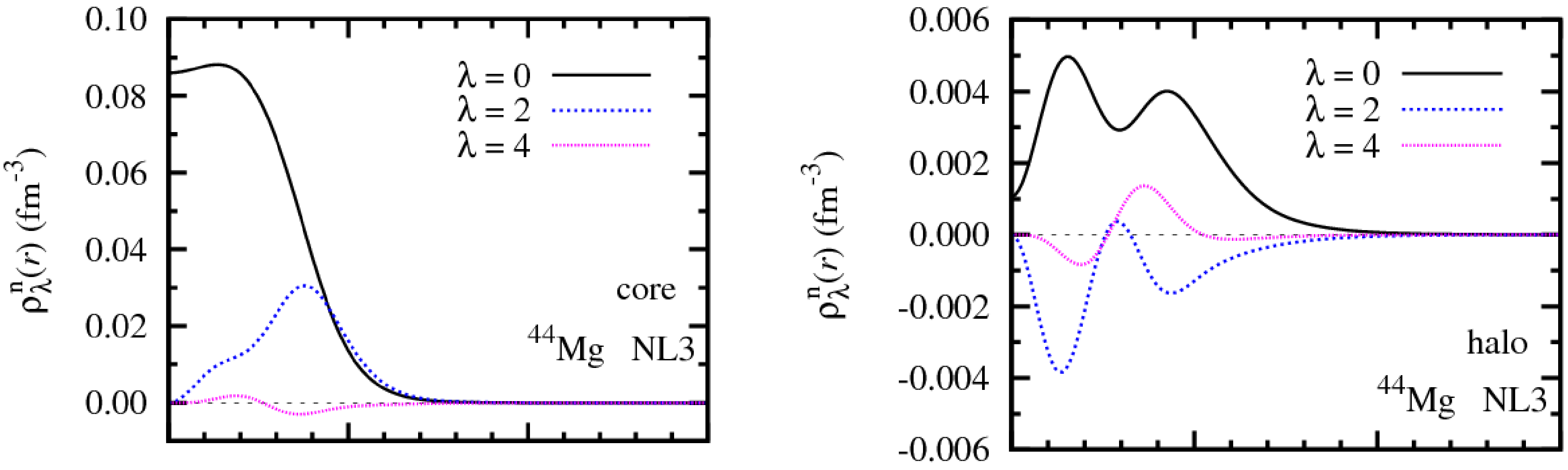


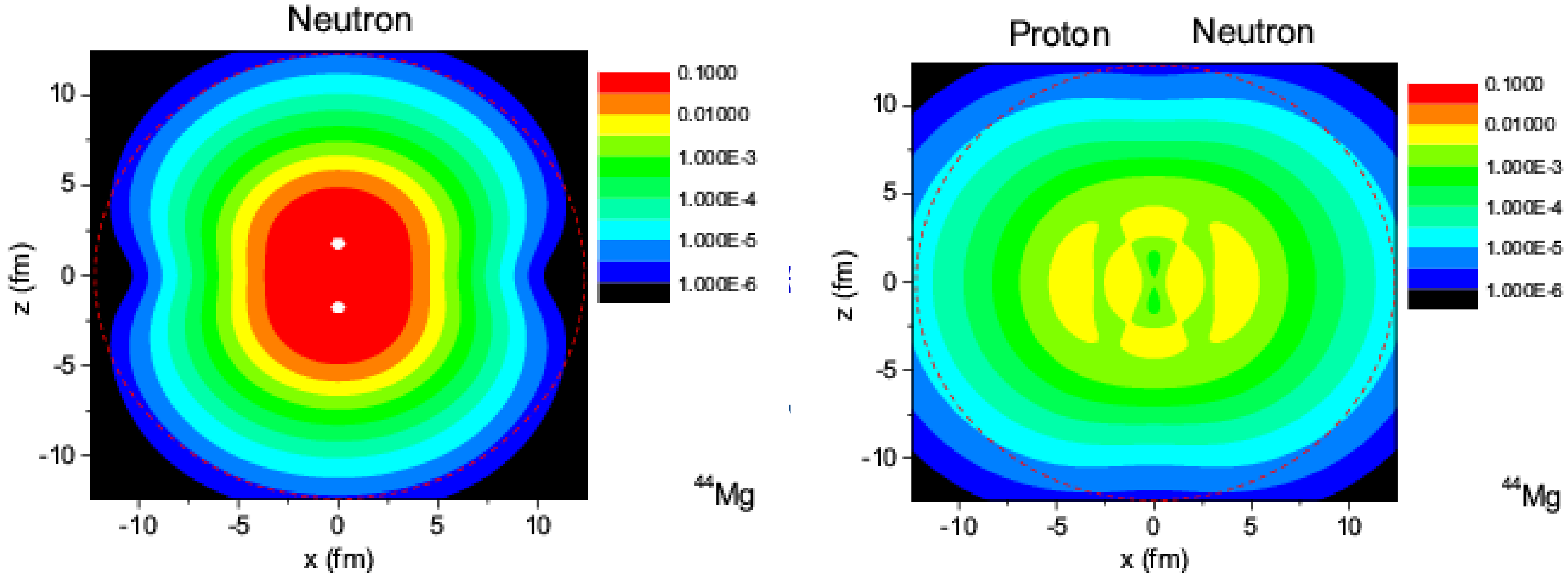


Zhou, Meng, Ring, Zhao, Phys. Rev. C 82 (2010) 011301R

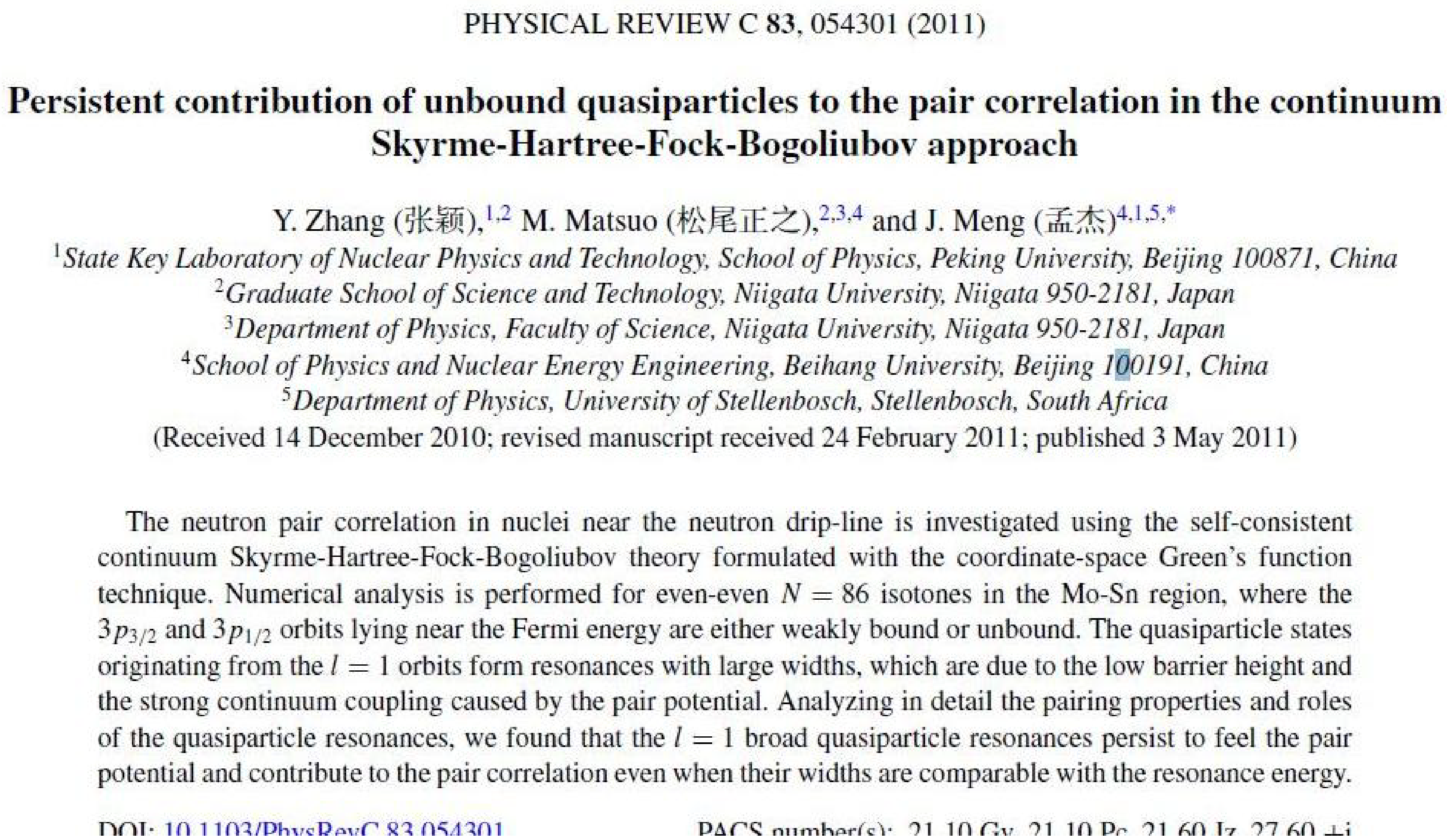
- Prolate deformation
- Large spatial extension in neutron density distribution

# Density of core & halo





# Persistent contribution of unbound quasiparticles to the pair correlation in the continuum



PHYSICAL REVIEW C **83**, 054301 (2011)

## Persistent contribution of unbound quasiparticles to the pair correlation in the continuum Skyrme-Hartree-Fock-Bogoliubov approach

Y. Zhang (张颖),[1,2] M. Matsuo (松尾正之),[2,3,4] and J. Meng (孟杰)[4,1,5,*]
[1]*State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China*
[2]*Graduate School of Science and Technology, Niigata University, Niigata 950-2181, Japan*
[3]*Department of Physics, Faculty of Science, Niigata University, Niigata 950-2181, Japan*
[4]*School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China*
[5]*Department of Physics, University of Stellenbosch, Stellenbosch, South Africa*

(Received 14 December 2010; revised manuscript received 24 February 2011; published 3 May 2011)

The neutron pair correlation in nuclei near the neutron drip-line is investigated using the self-consistent continuum Skyrme-Hartree-Fock-Bogoliubov theory formulated with the coordinate-space Green's function technique. Numerical analysis is performed for even-even $N = 86$ isotones in the Mo-Sn region, where the $3p_{3/2}$ and $3p_{1/2}$ orbits lying near the Fermi energy are either weakly bound or unbound. The quasiparticle states originating from the $l = 1$ orbits form resonances with large widths, which are due to the low barrier height and the strong continuum coupling caused by the pair potential. Analyzing in detail the pairing properties and roles of the quasiparticle resonances, we found that the $l = 1$ broad quasiparticle resonances persist to feel the pair potential and contribute to the pair correlation even when their widths are comparable with the resonance energy.

DOI: 10.1103/PhysRevC.83.054301 PACS number(s): 21.10.Gv, 21.10.Pc, 21.60.Jz, 27.60.+j

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8. Zhou, Meng, and Ring, Spherical relativistic Hartree theory in a Woods-Saxon basis, Physical Review C 68, 034323 (2003)

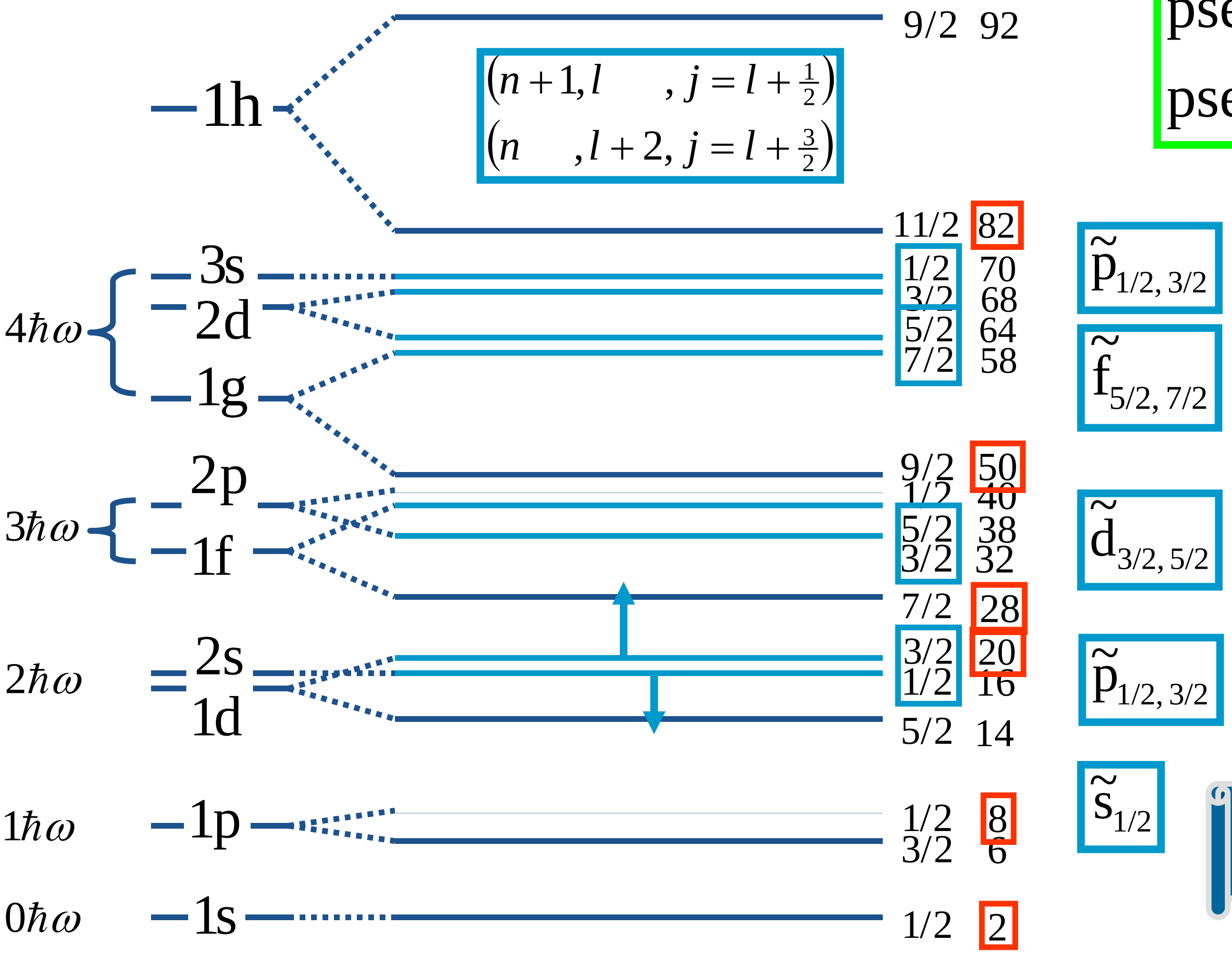
# Spin and pseudospin symmetry in atomic nuclei

**Woods-Saxon**

$\kappa \vec{l} \cdot \vec{s}$

$$\text{pseudo}-\text{orbit}: \quad \tilde{l} = l+1$$

$$\text{pseudo}-\text{spin} \ : \quad \tilde{s} = 1/2$$



$$\left(n+1, l \quad , j=l+\tfrac{1}{2}\right)$$
$$\left(n \quad , l+2, j=l+\tfrac{3}{2}\right)$$

Hecht & Adler
NPA137(1969)129

Arima, Harvey & Shimizu
PLB30(1969)517

# Pseudo quantum numbers

$$\psi^{N}_{n\kappa m}(\boldsymbol{r}) = \frac{1}{r}\begin{pmatrix} i\; G_{n\kappa}(r)\, Y^{l}_{jm}(\Omega) \\ -\,F_{\tilde{n}\kappa}(r)\, Y^{\tilde{l}}_{jm}(\Omega) \end{pmatrix}$$

$$\begin{cases} j = l \pm 1/2 \\ \kappa = (-)^{j+l+1/2}(j+1/2) \\ \tilde{l} = l + (-)^{j+l-1/2} \end{cases}$$

$$n = \text{node number} + 1$$

$$\left(2\mathrm{s}_{1/2},\, 1\mathrm{d}_{3/2}\right) \Rightarrow \left(\tilde{\mathrm{p}}_{1/2,\,3/2}\right)$$

$$(\tilde{n} = 2)\, \tilde{\mathrm{p}}_{1/2,3/2}$$

$$2\mathrm{s}_{1/2} = \begin{pmatrix} n = 2,\; l = 0,\;\; j = l + \tfrac{1}{2} \\ \tilde{n} = 2,\, \tilde{l} = 1,\; j = \tilde{l} - \tfrac{1}{2} \end{pmatrix}$$

$$1\mathrm{d}_{3/2} = \begin{pmatrix} n = 1,\; l = 2,\;\; j = l - \tfrac{1}{2} \\ \tilde{n} = 2,\, \tilde{l} = 1,\; j = \tilde{l} + \tfrac{1}{2} \end{pmatrix}$$

Pseudo quantum numbers are nothing
but the quantum numbers of the lower component.

Ginocchio
PRL78(97)436

# Origin of the symmetry - Nucleons

$$V_\pm(r) = V(r) \pm S(r)$$

$$M_\pm(\varepsilon_N, r) = M \pm \varepsilon_N \mp V_\mp(r)$$

$$\psi^N_{n\kappa m}(\mathbf{r}) = \frac{1}{r}\begin{pmatrix} i\; G_{n\kappa}(r)\, Y^{l}_{jm}(\Omega) \\ -F_{\tilde{n}\kappa}(r)\, Y^{\tilde{l}}_{jm}(\Omega) \end{pmatrix}$$

$$\left[-\frac{1}{2M_+}\left(\frac{d^2}{dr^2}+\frac{1}{2M_+}\frac{dV_-}{dr}\frac{d}{dr}-\frac{l(l+1)}{r^2}\right)-\frac{1}{4M_+^2}\frac{\kappa}{r}\frac{dV_-}{dr}+M-V_+\right]G=+\varepsilon_N G$$

$$\left[-\frac{1}{2M_-}\left(\frac{d^2}{dr^2}-\frac{1}{2M_-}\frac{dV_+}{dr}\frac{d}{dr}+\frac{\tilde{l}(\tilde{l}+1)}{r^2}\right)+\frac{1}{4M_-^2}\frac{\tilde{\kappa}}{r}\frac{dV_+}{dr}+M-V_-\right]F=-\varepsilon_N F$$

For nucleons,

✖ $V(r)-S(r)=0 \Rightarrow$ spin symmetry

✓ $V(r)+S(r)=0 \Rightarrow$ pseudo-spin symmetry

# Origin of the symmetry - Anti-nucleons

$$V_{\pm}(r) = V(r) \pm S(r)$$

$$M_{\pm}(\varepsilon_A, r) = M \mp \varepsilon_A \mp V_{\mp}(r)$$

$$\psi^{A}_{n\kappa m}(\boldsymbol{r}) = \frac{1}{r}\begin{pmatrix} -F_{n\kappa}(r)\,Y^{l}_{jm}(\Omega) \\ i\;G_{\tilde{n}\kappa}(r)\,Y^{\tilde{l}}_{jm}(\Omega) \end{pmatrix}$$

$$\left[-\frac{1}{2M_-}\left(\frac{d^2}{dr^2}-\frac{1}{2M_-}\frac{dV_+}{dr}\frac{d}{dr}+\frac{l(l+1)}{r^2}\right)+\frac{1}{4M_-^2}\frac{\kappa}{r}\frac{dV_+}{dr}+M-V_-\right]F=-\varepsilon F$$

$$\left[-\frac{1}{2M_+}\left(\frac{d^2}{dr^2}+\frac{1}{2M_+}\frac{dV_-}{dr}\frac{d}{dr}-\frac{\tilde{l}(\tilde{l}+1)}{r^2}\right)-\frac{1}{4M_+^2}\frac{\tilde{\kappa}}{r}\frac{dV_-}{dr}+M-V_+\right]G=+\varepsilon G$$

For anti-nucleons,

✖ $V(r)-S(r)=0 \Rightarrow$ pseudo-spin symmetry

✓ $V(r)+S(r)=0 \Rightarrow$ spin symmetry

Zhou,Meng&Ring
PRL92(03)262501

# Origin of the symmetry

Zhou,Meng&Ring
PRL92(03)262501

For nucleons, the smaller component *F*

$$\left[-\frac{\vec{\nabla}^2}{2M_-^*}-[V(r)-S(r)]+\frac{1}{4M_-^2}\frac{1}{r}\frac{d}{dr}\boxed{[V(r)+S(r)]}\left(1+\tilde{\vec{l}}\cdot\tilde{\vec{\sigma}}\right)+M\right]F=-\varepsilon_N F$$

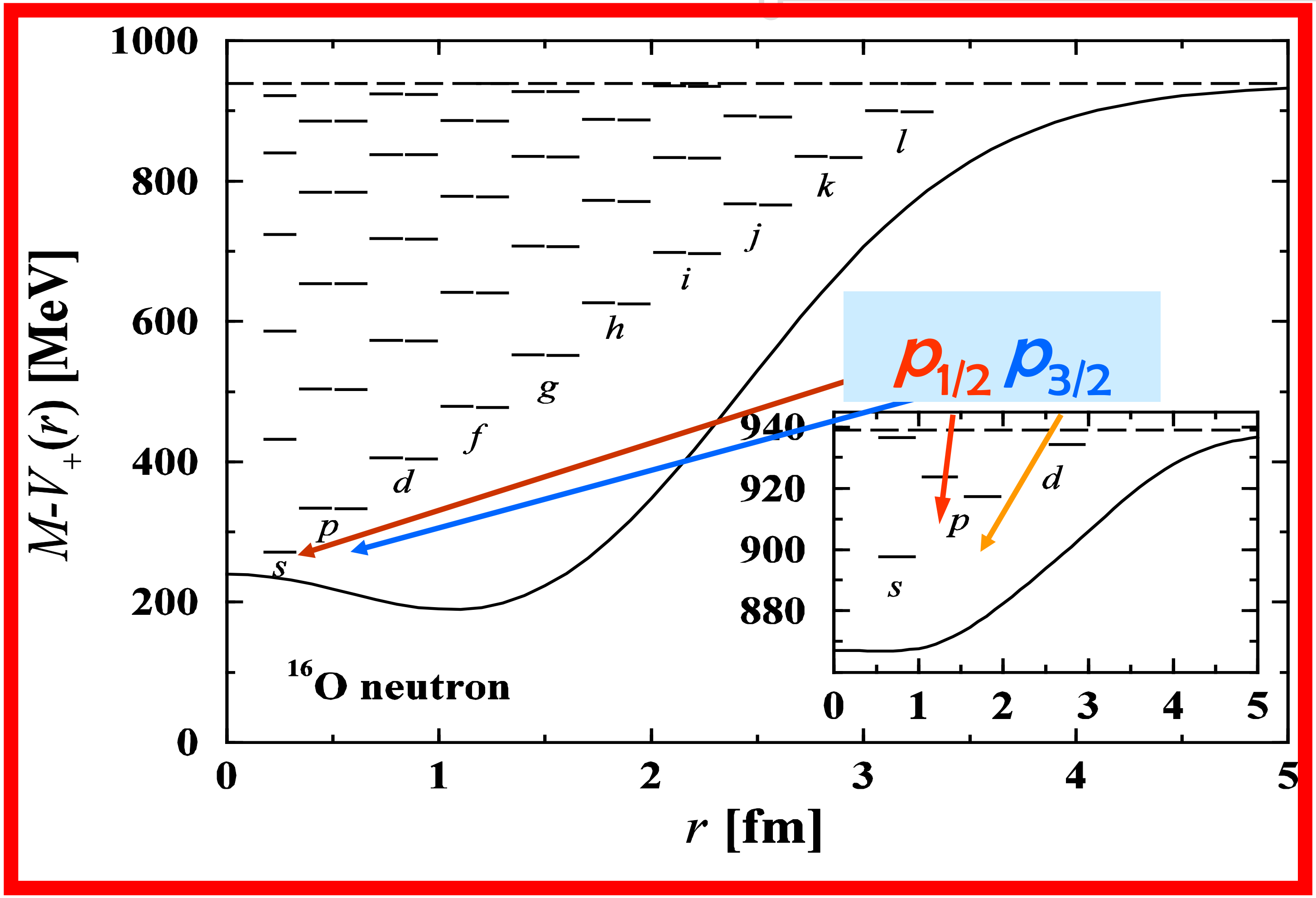
For anti-nucleons, the larger component *F*

$$\left[-\frac{\vec{\nabla}^2}{2M_-^*}-[V(r)-S(r)]+\frac{1}{4M_-^2}\frac{1}{r}\frac{d}{dr}\boxed{[V(r)+S(r)]}\left(1+\vec{l}\cdot\vec{\sigma}\right)+M\right]F=+\varepsilon_A F$$

The factor $^{1}\!/_{4M_-^2}$ is ~400 times smaller for anti nucleons!

# Origin of the symmetry - Anti-nucleons

Zhou, Meng & Ring, PRL92(03)262501



# Outline

- ☐ Introduction
- ☐ (Deformed) Halos and giant halos
- ☐ Pseudo-spin symmetry and Spin symmetry
- ☐ Magnetic Moment &Magnetic Rotation

# Magnetic Moment &Magnetic Rotation

Magnetic Moment

9. Li, Meng, Ring, Yao and Arima, Relativistic description of second-order correction to nuclear magnetic moments with point-coupling residual interaction, Science in China G 54:2 (2011) 204-209

Magnetic Rotation

10. Peng, Meng, Ring, and Zhang, Covariant density functional theory for magnetic rotation, Physical Review C 78 (2008) 024313
11. Zhao, Zhang, Peng, Liang, Ring, Meng, Novel structure for magnetic rotation bands in 60Ni, Physics Letters B699, 181 (2011)
12. Zhao, Peng, Liang, Ring, Meng Antimagnetic rotation band: a microscopic description, arXiv:1105.3622v1 [nucl-th]

**Zhao's talk on Thursday!**

# Relativistic description of magnetic moment

- Nuclear magnetic moment is ontained from the effective electromagnetic current

$$j_i^{\mu}(x)=\underset{\substack{\big\downarrow\\ \boldsymbol{j_D}}}{Q\bar{\psi}_i\gamma^{\mu}\psi_i}+\underset{\substack{\big\downarrow\\ \boldsymbol{j_A}}}{\frac{\lambda_a}{2M}\partial_{\nu}(\bar{\psi}_i\sigma^{\mu\nu}\psi_i)}$$

- Static magnetic dipole moment is determined by

$$\vec{\mu}=\sum_i\frac{1}{2}\int d^3r[\vec{r}\times\vec{j}_i]$$

- Nuclear magnetic moment can naturally be divided into the **Dirac** and **anomalous** parts,

$$\mu=\begin{cases}\mu_D, & \text{for a relativistic point particle}\\ \mu_A, & \text{from intrinsic structure}\end{cases}$$

It was always assumed that the relativistic single-particle model could not reproduce the corresponding Schmidt values.

# Isoscalar magnetic moment

**Agreement can be improved by the introduction of vertex corrections:**

I. The **renormalized** single-particle currents

J. A. McNeil, et. al., PRC1986; S. Ichii, et. al., PLB1987;
A. Arima et al, Advan. Nucl. Phys. 1987 J. R. Shepard et. al., PRC1988

II. The consideration of space-like components of vector meson in the **self-consistent** deformed RMF theory

U. Hofmann and P. Ring, PLB 1988; R. J. Furnstahl et al., PRC1989;
**Yao et. al., Phys. Rev. C 74, 024307(2006)**

**Isoscalar magnetic moment**

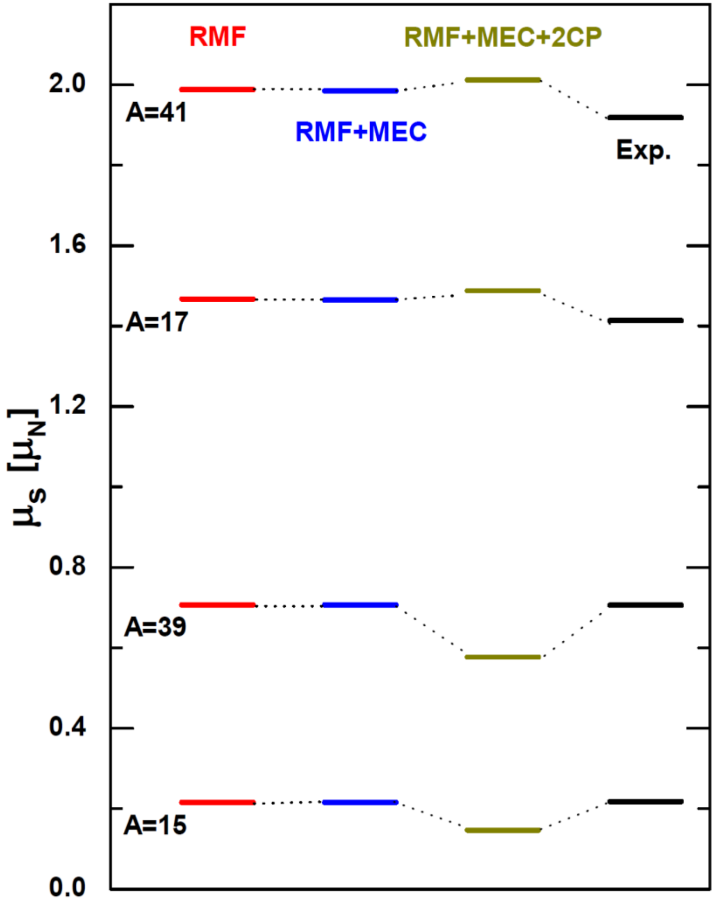
$$\mu_s = [\mu(Z,N) + \mu(Z+1, N-1)]/2$$

**_LS_ closed-shell nuclei ±1 nucleon around $^{16}$O and $^{40}$Ca**

| A | Exp. | Tri. | Axi. | Sph. | Sch. |
|---|---|---|---|---|---|
| 15 | 0.22 | 0.19 | 0.18 | 0.32 | 0.19 |
| 17 | 1.41 | 1.45 | 1.48 | 1.57 | 1.44 |
| 39 | 0.71 | 0.67 | 0.64 | 0.94 | 0.64 |
| 41 | 1.92 | 1.96 | 1.97 | 2.21 | 1.94 |

# Isoscalar magnetic moment (ISMM)

***LS*** **closed-shell nuclei ±1 nucleon around $^{16}$O and $^{40}$Ca**



$$\boxed{\mu_s = \frac{1}{2}(\mu_p + \mu_n)}$$

- ◆ one-pion exchange current (**MEC**)
  Li, et al., Prog. Theor. Phys. (2011)
- ◆ second-order core polarization (**2CP**)
  Li, et al., Sci China Phys Mech Astro, (2011)

✓ **RMF:** already excellent descritpion

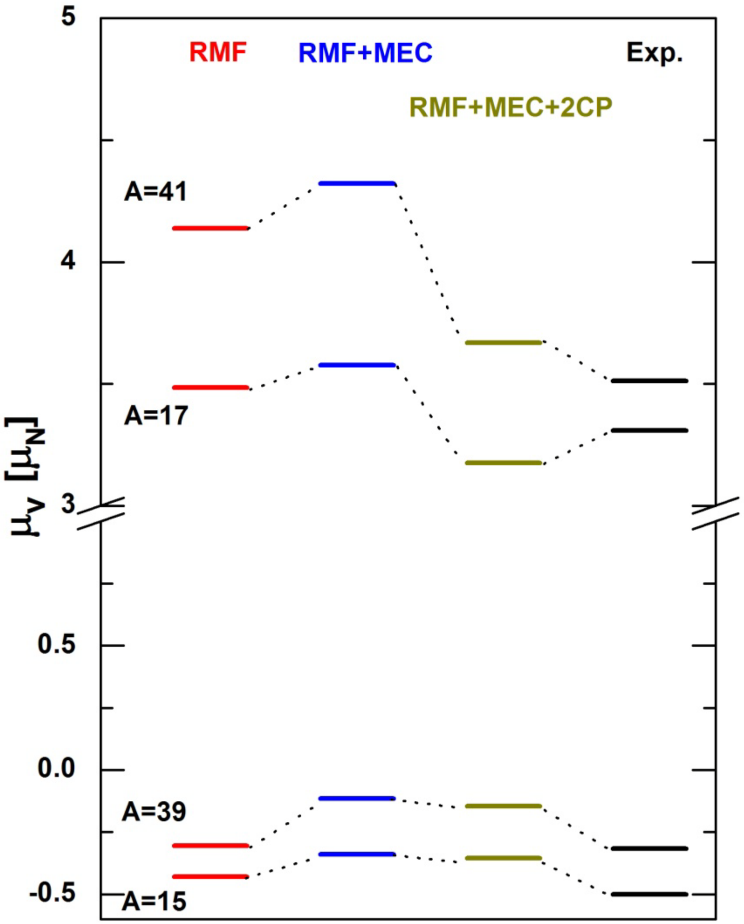
✓ **MEC:** Negligible

✓ **2CP:** small influence on A=17 and 41, relatively large corrections for A=15 and 39.

**The ISMM are in reasonable agreement with data.**

# Isovector magnetic moment (IVMM)

***LS*** **closed-shell nuclei ±1 nucleon around $^{16}$O and $^{40}$Ca**



$$\mu_v = \frac{1}{2}(\mu_p - \mu_n)$$

- ◆ one-pion exchange current (**MEC**)
  Li, et al., Prog. Theor. Phys. (2011)
- ◆ second-order core polarization (**2CP**)
  Li, et al., Sci China Phys Mech Astro, (2011)

✓ **MEC:**

Positive correction to IVMM

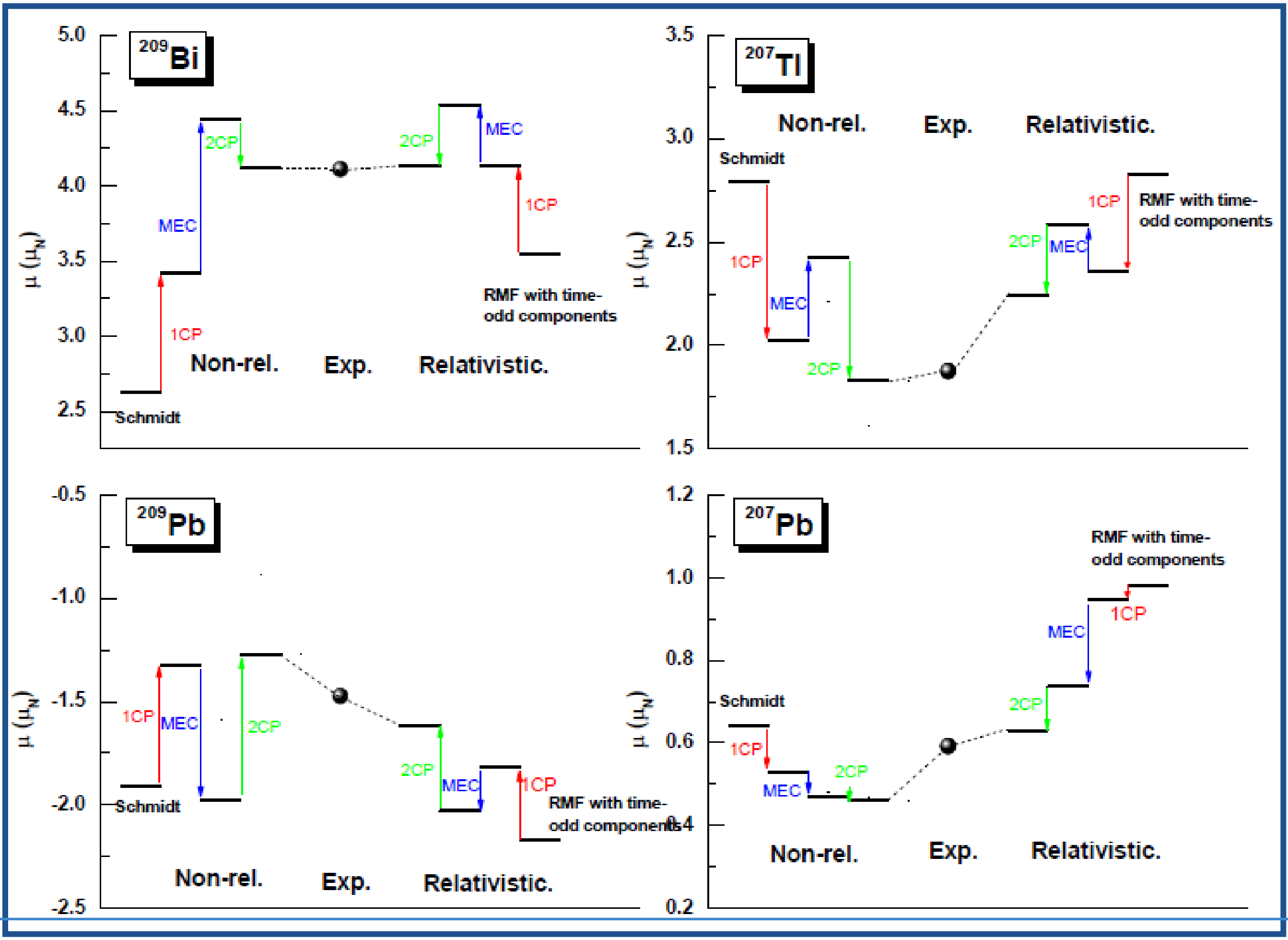
✓ **2CP:**

Negative correction to IVMM

**The net effect between MEC and 2CP well reproduce the IVMM, especially for A=17 and A=41.**

# Magnetic moments: $^{209}$Bi, $^{207}$Tl, $^{209}$Pb and $^{207}$Pb

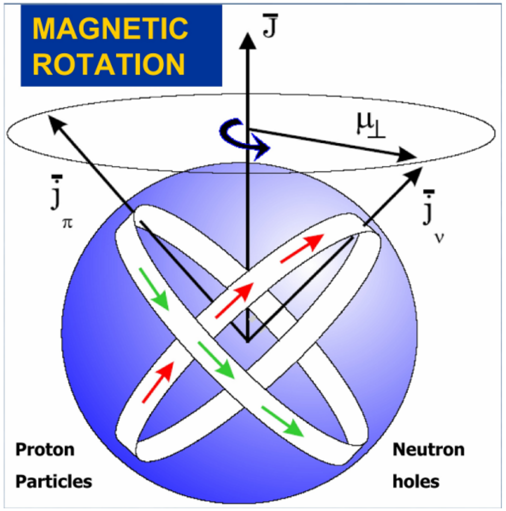
*j-j* closed-shell nuclei ±1 nucleon: $^{209}$Bi, $^{207}$Tl, $^{209}$Pb and $^{207}$Pb

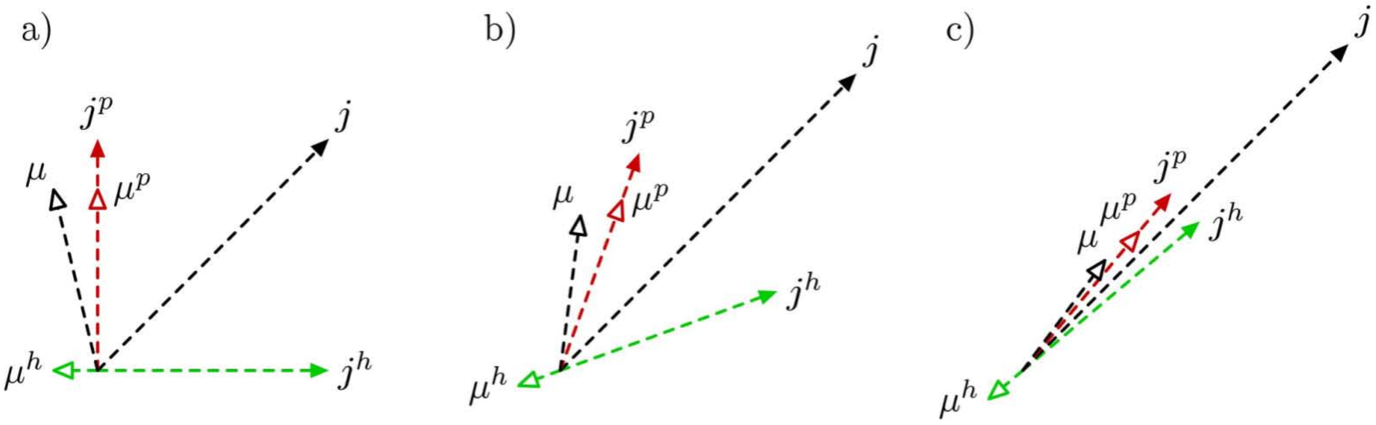


- ✓ In the 1cp and 2cp, including the residual interaction by π
- ✓ Results greatly improved by including 1cp, MEC and 2cp

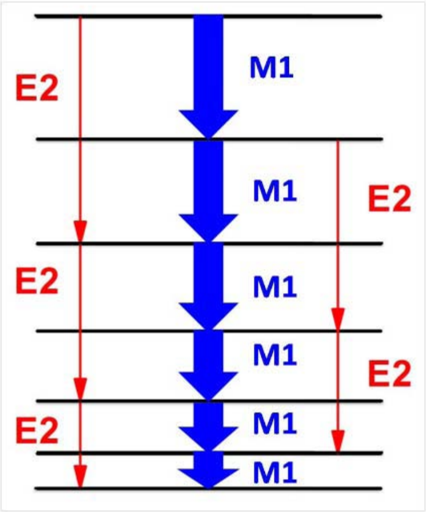
# Magnetic Rotation(MR)

- ✓ Almost spherical or weakly deformed nuclei
- ✓ Rotational bands with ΔI=1
- ✓ Strong M1 transition and weak E2 transition
- ✓ Shears mechanism



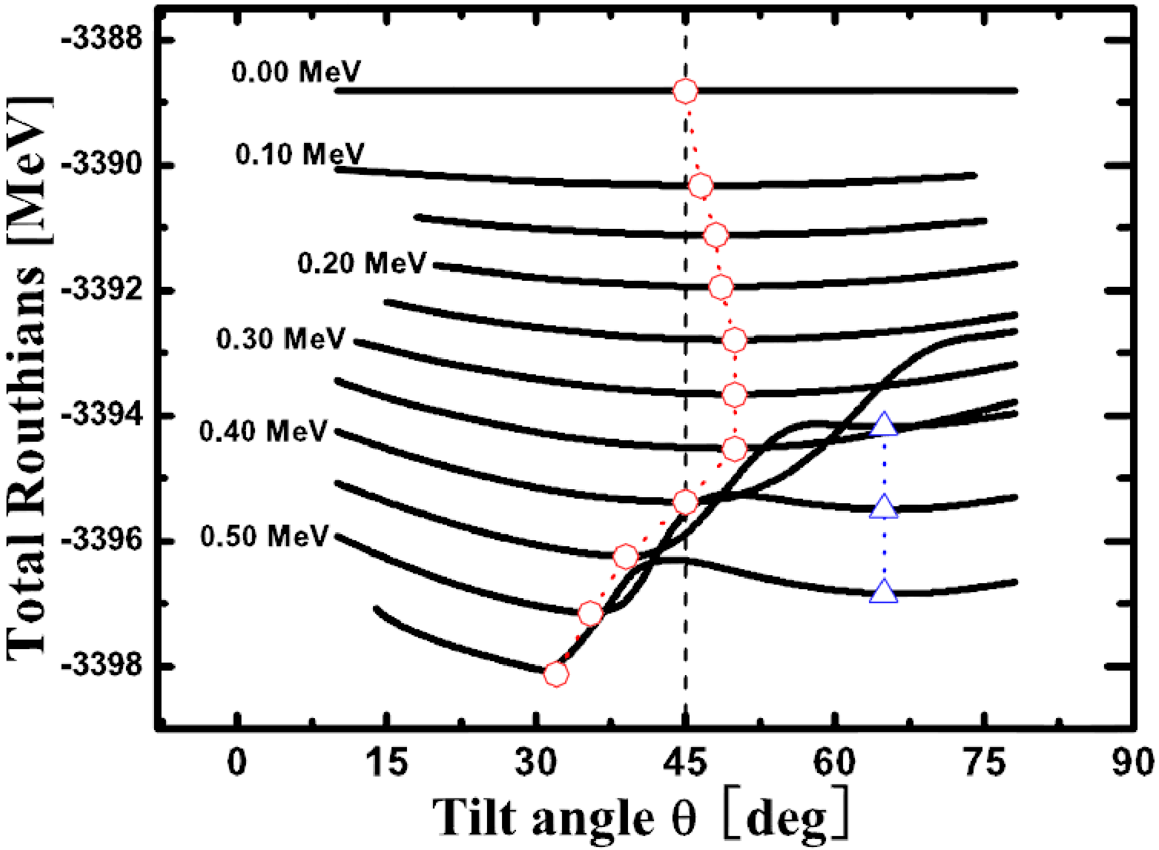


Madokoro, Meng, Matsuzaki, Yamaji 2000



# MR: $^{142}$Gd $\pi h^{2}_{11/2}\otimes\nu h^{-2}_{11/2}$

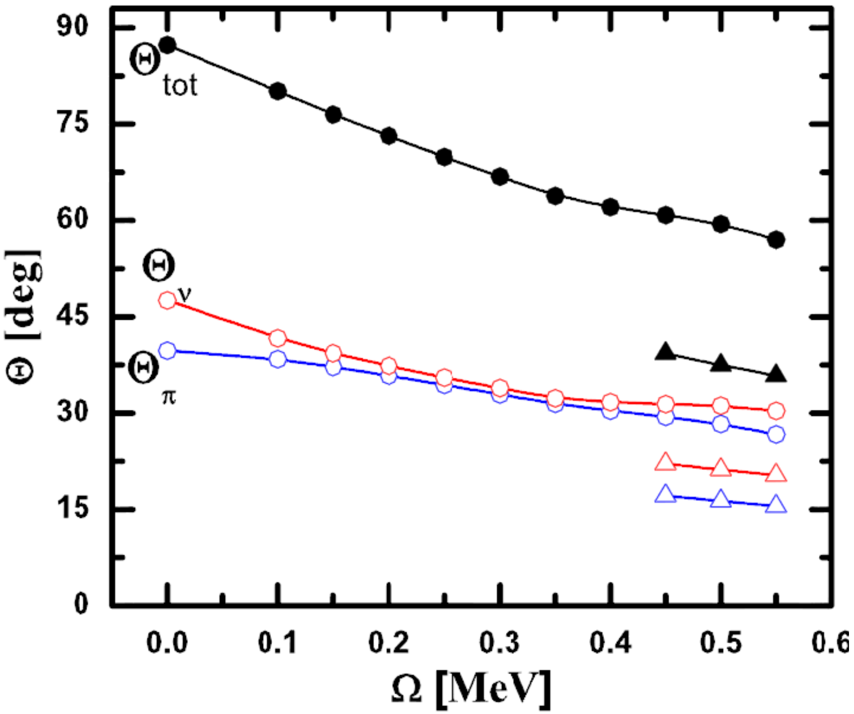
## Total Routhians as function of tilted angle $\theta$



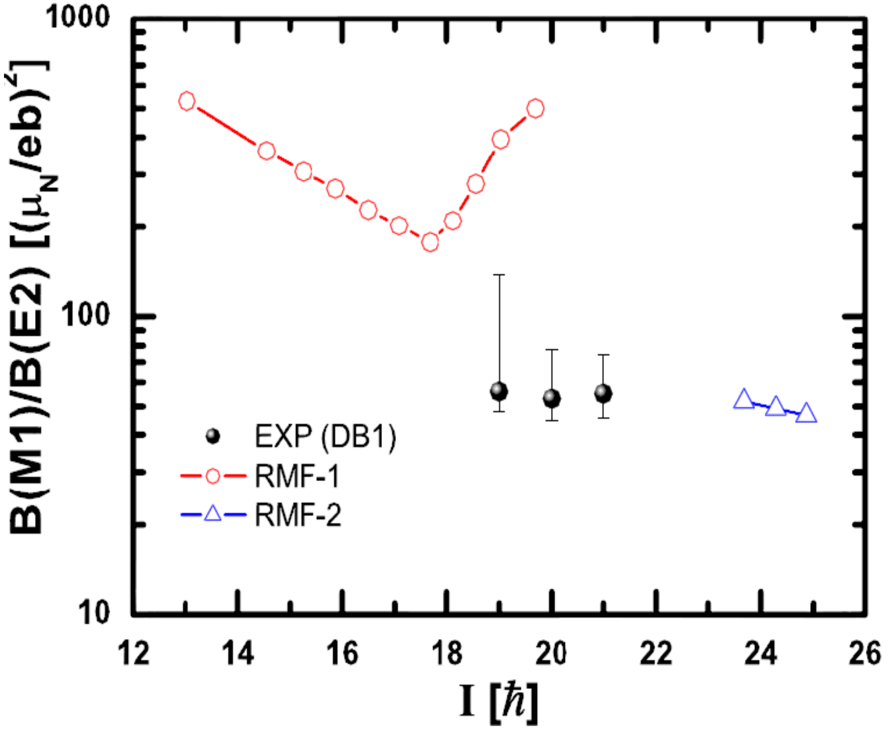
- ✓ Minima with configuration $\pi h^{2}_{11/2}\otimes\nu h^{-2}_{11/2}$ when $\Omega<0.40$
- ✓ level crossing between $1g_{7/2}$ and $2d_{5/2}$
- ✓ second configuration $\pi[h^{2}_{11/2}\, g^{-1}_{7/2}\, d_{5/2}] \otimes \nu h^{-2}_{11/2}$

Phys.Rev.C**78**, 024313 (2008)

# MR: $^{142}$Gd $\pi h^{2}_{11/2} \otimes \nu h^{-2}_{11/2}$



**Shears angle**



**ratios *B(M1)/B(E2)***

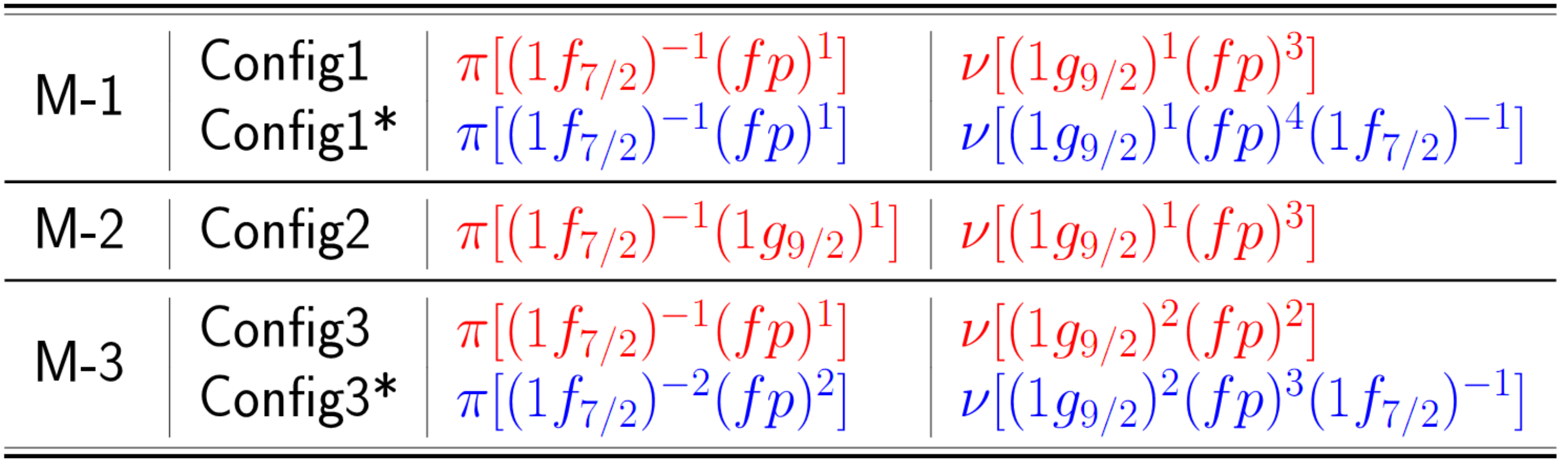
Phys.Rev.C**78**, 024313 (2008)

# MR: $^{60}$Ni

- $^{60}$Ni: the lightest nucleus with magnetic rotation

Torres, et al., PRC 78, 054318 (2008)

- Harmonic oscillator shells: Nf = 10
- Parameter set: PC-PK1
- Configurations:

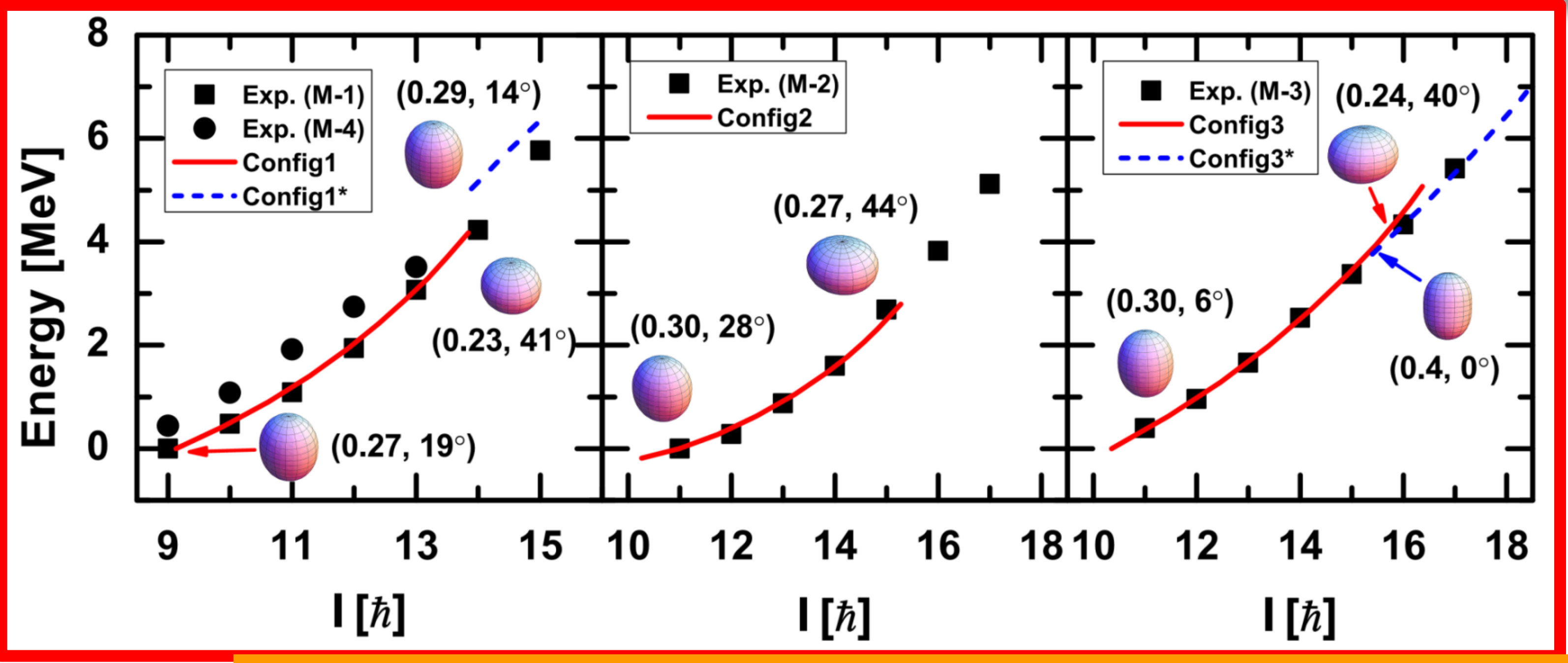


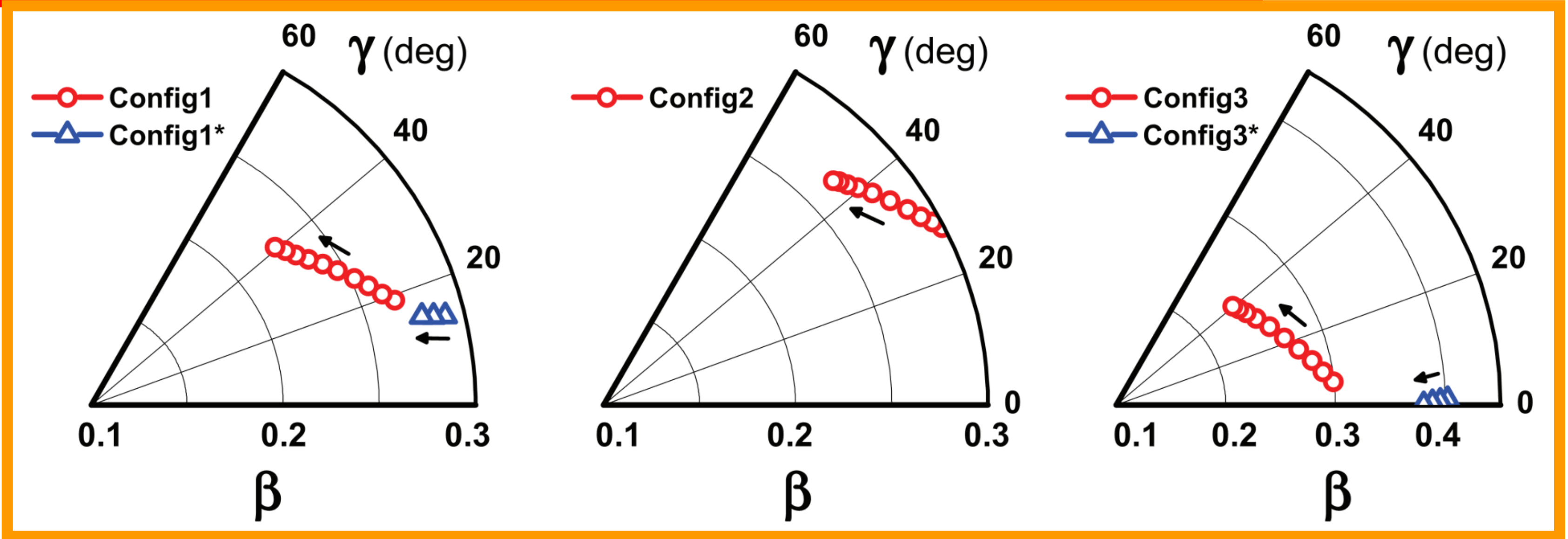
| | | | |
|---|---|---|---|
| M-1 | Config1<br>Config1* | $\pi[(1f_{7/2})^{-1}(fp)^{1}]$<br>$\pi[(1f_{7/2})^{-1}(fp)^{1}]$ | $\nu[(1g_{9/2})^{1}(fp)^{3}]$<br>$\nu[(1g_{9/2})^{1}(fp)^{4}(1f_{7/2})^{-1}]$ |
| M-2 | Config2 | $\pi[(1f_{7/2})^{-1}(1g_{9/2})^{1}]$ | $\nu[(1g_{9/2})^{1}(fp)^{3}]$ |
| M-3 | Config3<br>Config3* | $\pi[(1f_{7/2})^{-1}(fp)^{1}]$<br>$\pi[(1f_{7/2})^{-2}(fp)^{2}]$ | $\nu[(1g_{9/2})^{2}(fp)^{2}]$<br>$\nu[(1g_{9/2})^{2}(fp)^{3}(1f_{7/2})^{-1}]$ |

Zhao, Zhang, Peng, Liang, Ring, Meng, PLB 699, 181 (2011)

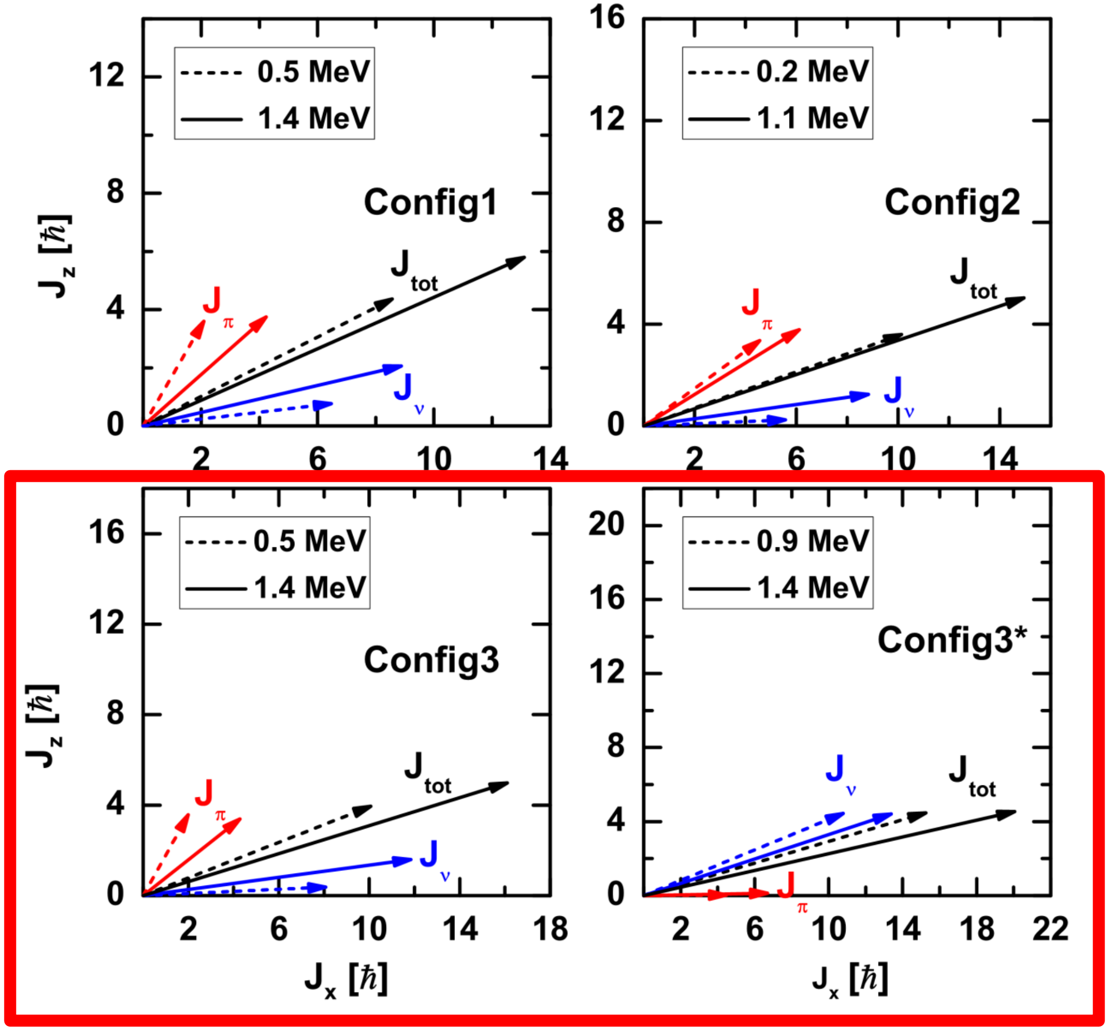
# MR: $^{60}$Ni

Zhao, Zhang, Peng, Liang, Ring, Meng, PLB 699, 181 (2011)





# MR: $^{60}$Ni



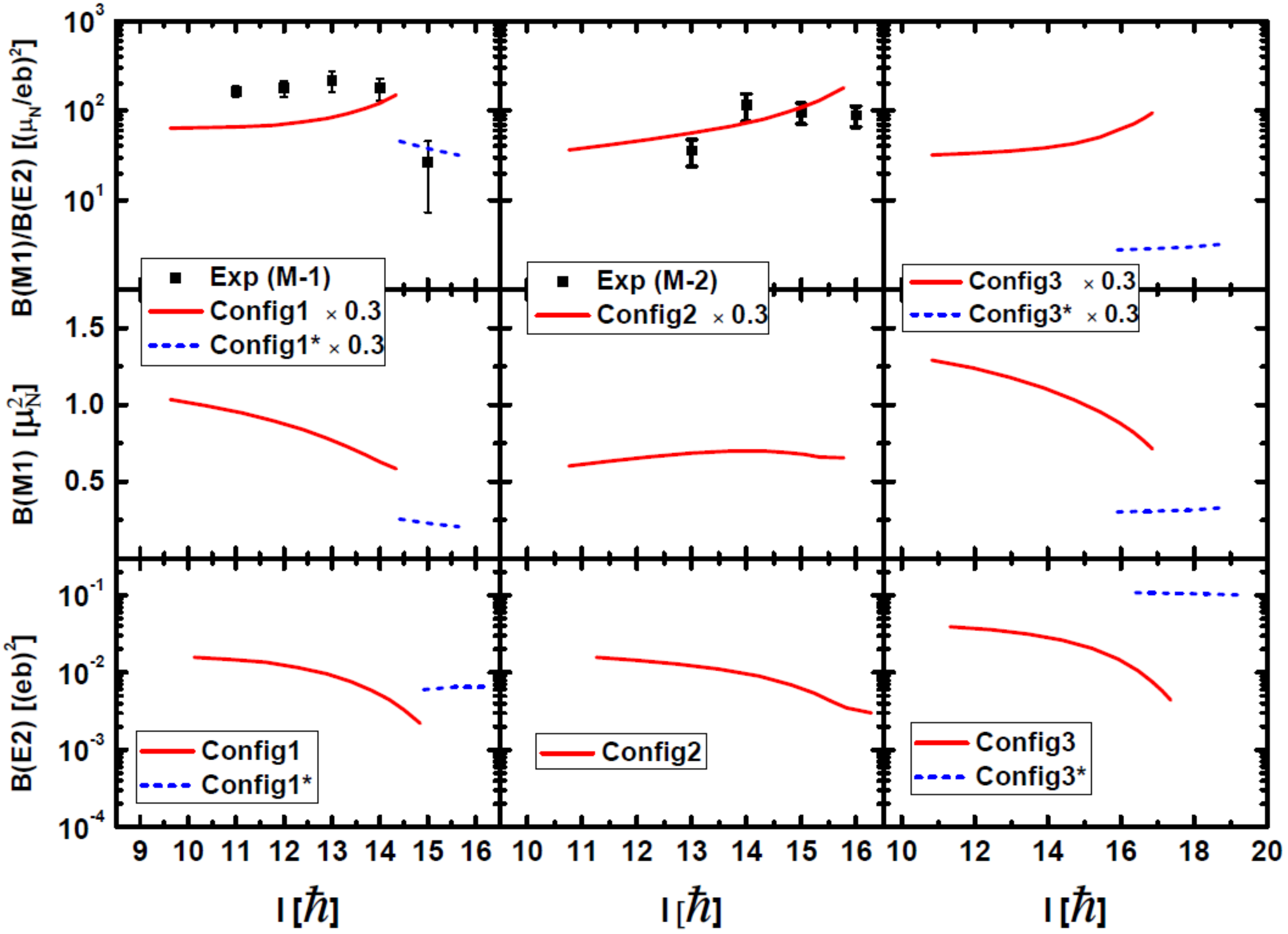
**Magnetic Rotation**

↓

**Electric Rotation**

**Shears mechanism**

# MR: $^{60}$Ni

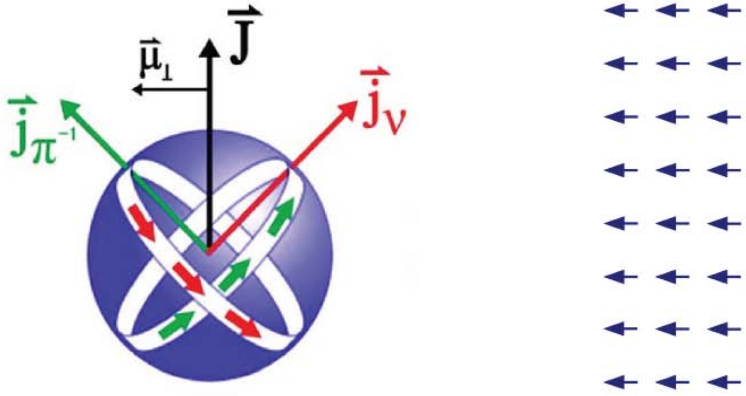


Electromagnetic transition properties

# Antimagnetic Rotation (AMR)

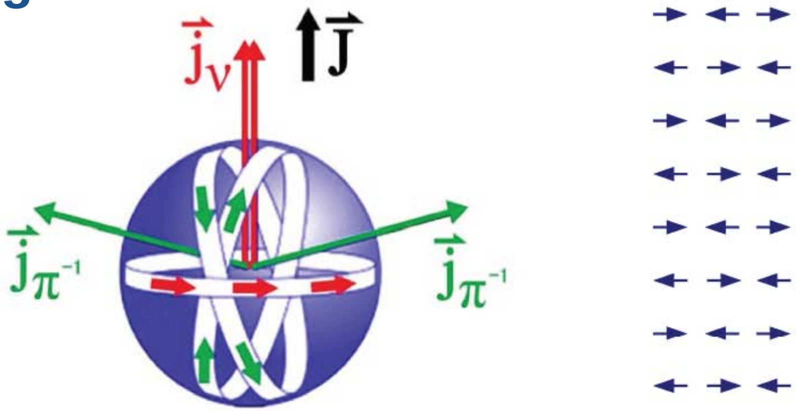
## Magnetic rotation ⟺ Ferromagnet

- ✓ rotational bands with $\Delta I = 1$
- ✓ near spherical nuclei; weak E2 transitions
- ✓ strong M1 transitions
- ✓ B(M1) decrease with spin
- ✓ shears mechanism



## Antimagnetic rotation ⟺ Antiferromagnet

- ✓ rotational bands with $\Delta I = 2$
- ✓ near spherical nuclei; weak E2 transitions
- ✓ no M1 transitions
- ✓ B(E2) decrease with spin
- ✓ two “shears-like” mechanism

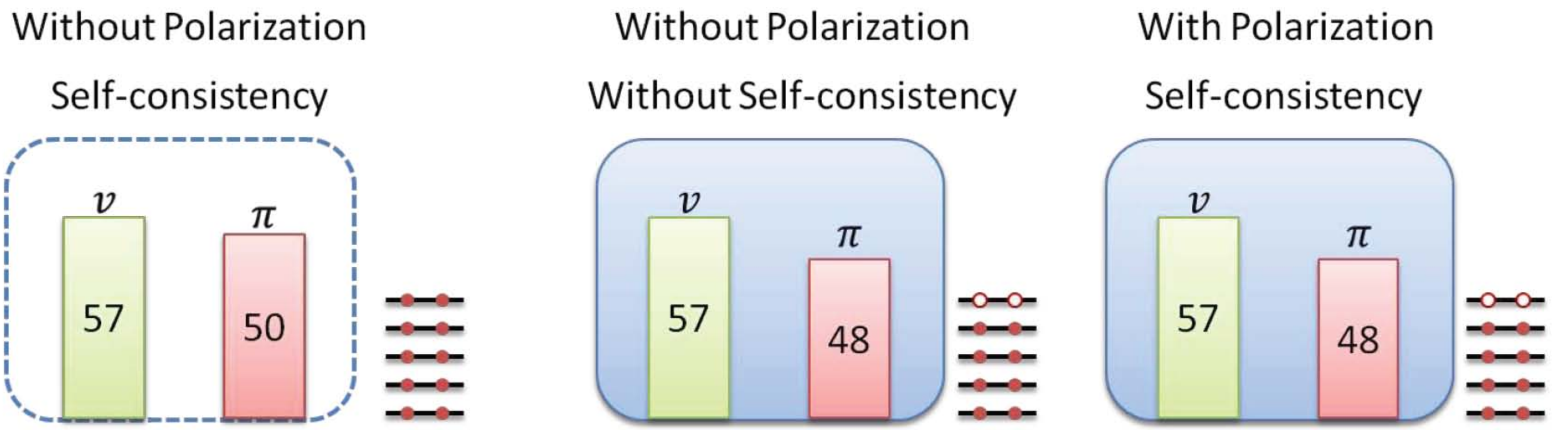


# AMR: $^{105}$Cd

- $^{105}$Cd: the first odd-A nucleus with antimagnetic rotation

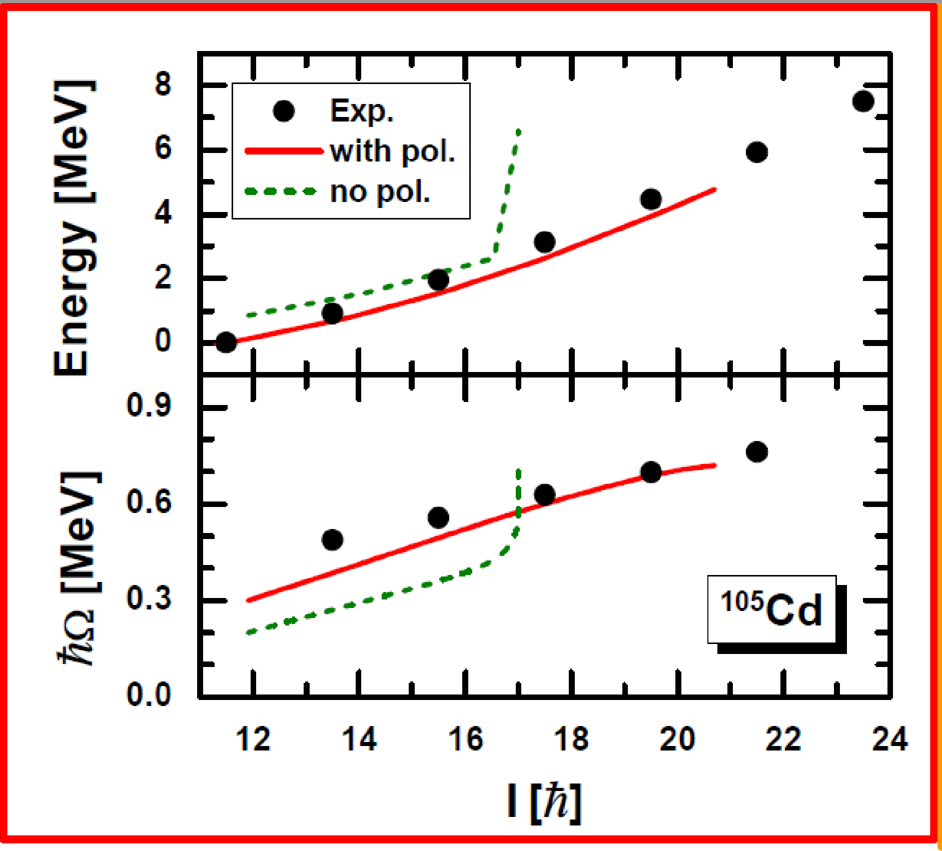
Choudhury, et al., PRC 82, 061308(R) (2010)

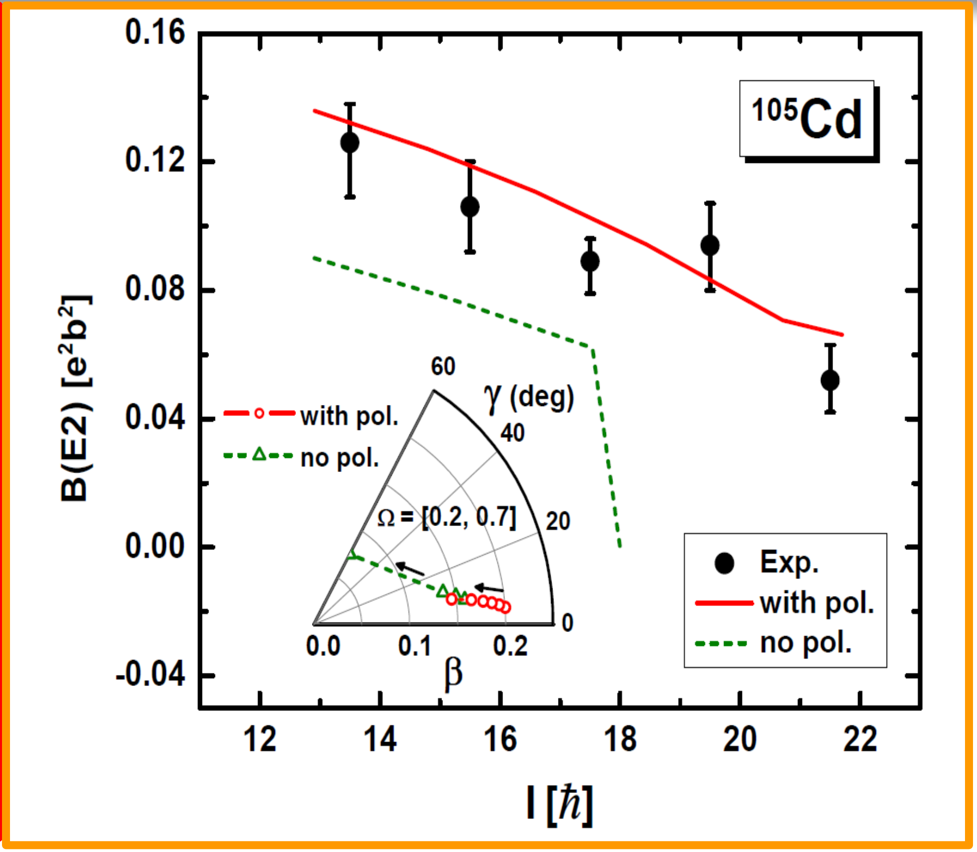
- Harmonic oscillator shells: Nf = 10
- Parameter set: PC-PK1
- Configurations: $\nu[h_{11/2}(g_{7/2})^2] \otimes \pi[(g_{9/2})^{-2}]$
- Polarizations:



Zhao, Peng, Liang, Ring, Meng arXiv:1105.3622v1 [nucl-th]

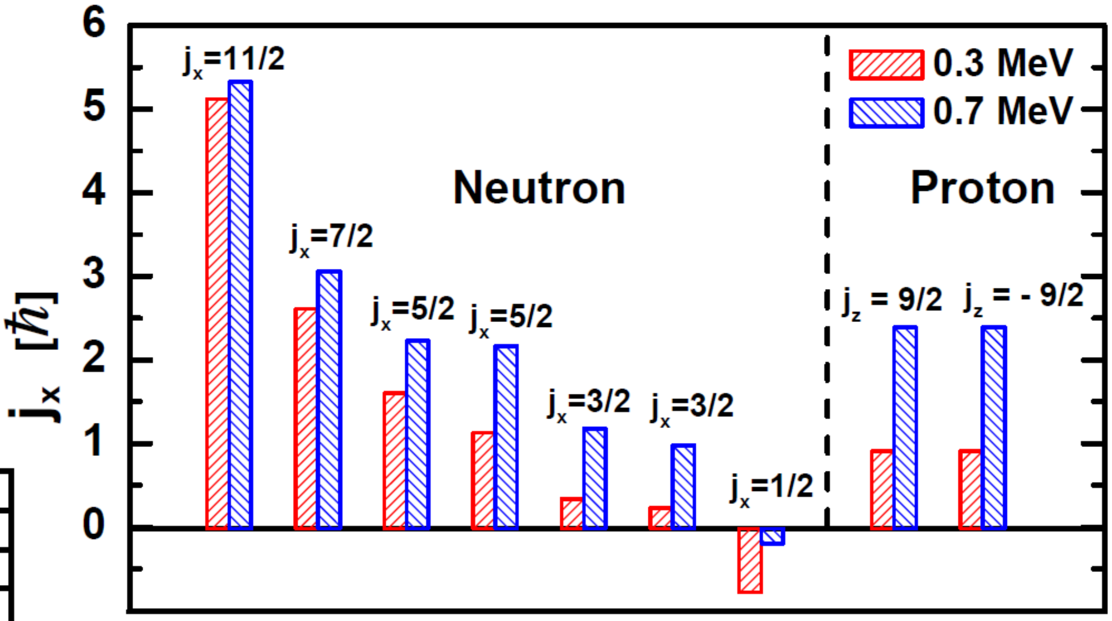
# AMR: $^{105}$Cd



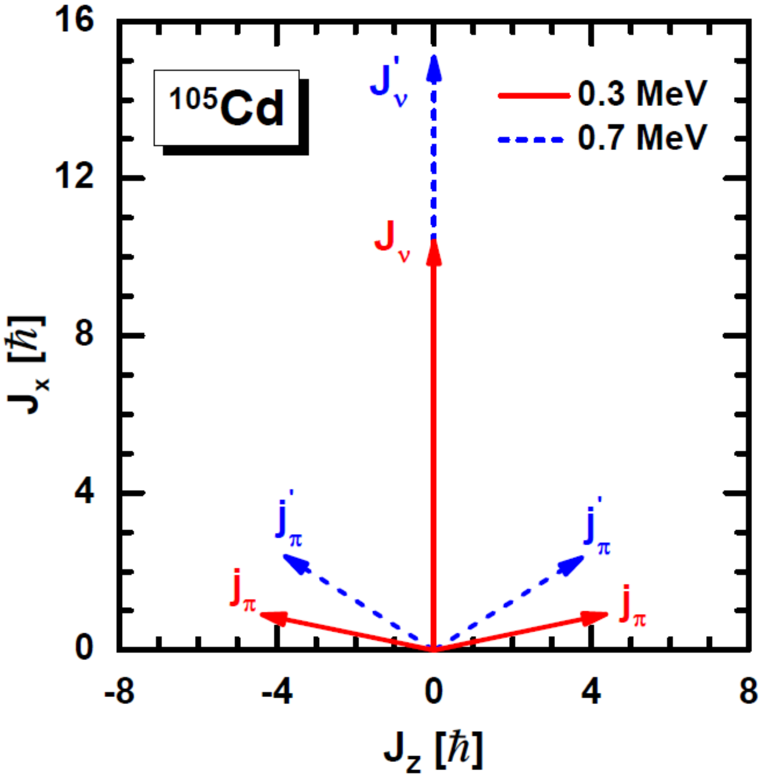


**Polarization effects play a very important role in the self-consistent microscopic description of AMR bands, especially for the E2 transitions.**

# AMR: $^{105}$Cd



Two “shears-like” mechanism



In the microscopic point of view, increasing angular momentum results from the alignment of the proton holes and the mixing within the neutron orbitals.

# Happy Birth day to Peter !