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INFN Istituto Nazionale di Fisica Nucleare

Isospin Symmetry Breaking in mirror nuclei ^{23}Mg-^{23}Na

Alberto Boso et al.

Mirror Energy Differences

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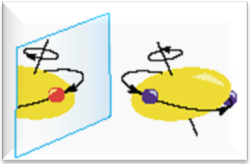
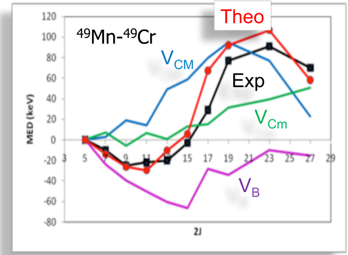
Mirror Energy Differences (MED)

- $\mathrm{MED}_{J,T} = E^*_{J,T,T_z=-T} - E^*_{J,T,T_z=T}$
- If isospin is a good q.n.: **Electromagnetic** origin
- Very sensitive to nuclear **structure**

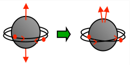




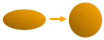
A. P. Zuker et al., PRL 89, 142502 (2002)

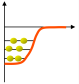
M.A. Bentley and S.M. Lenzi, Prog. Part. Nucl. Phys. 59(2007)

Multipole Term of MED

Protons alignment 

Monopole Term of MED

Radial effect 

Single particle effects 

ISB TERM OF “NUCLEAR” ORIGIN IS NEEDED!

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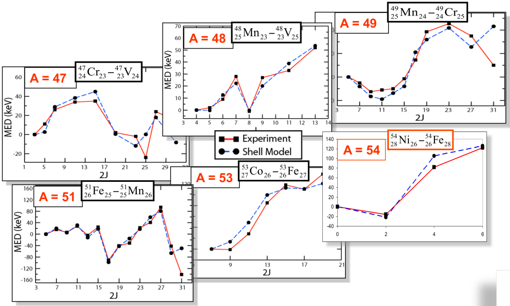
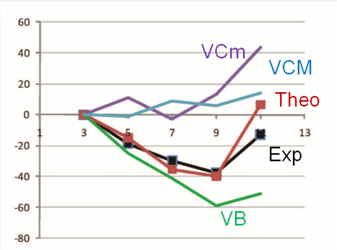


$f_{7/2}$ shell

- V_B term from A=42
- "Nuclear" ISB term is **needed** in all the $f_{7/2}$ shell

Open questions

- Is the V_B term needed also in the *sd* shell??
- Is it a general feature of the effective **N-N** interaction??



SYSTEMATIC STUDIES ARE NEEDED!

The Experiment: MED in mirror nuclei ^{23}Mg $-^{23}$ Na

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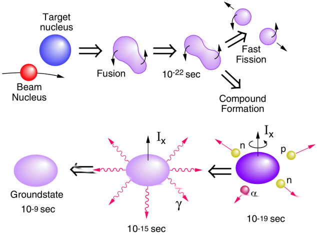
laboratoire commun CEA/DSM spiral2 CNRS/IN2P3

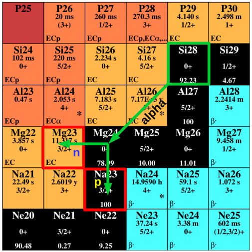
Goal of the Experiment

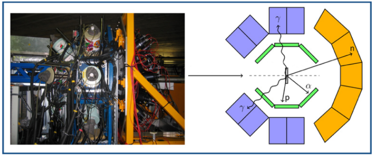
Study of the MED in mirror nuclei ^{23}Mg $-^{23}$ Na up to **high spin**

Fusion Evaporation reaction

$^{16}O \rightarrow ^{12}C$







- EXOGAM: 10 Clover of HPGe
- DIAMANT: 80 CsI
- Neutron Wall: 50 scintillators

The Experiment: Analysis

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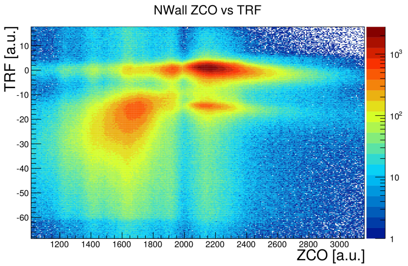
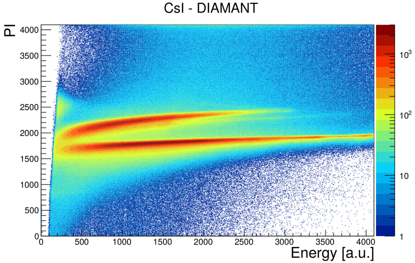
Channel Selection

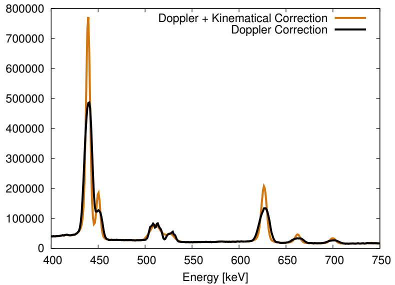
NWALL:
n-γ: ZCO vs TRF

DIAMANT:
α-p: PI vs Energy

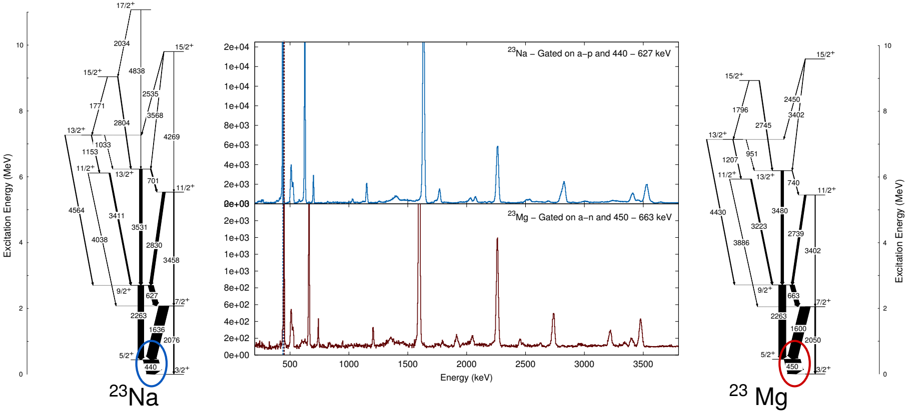
Kinematical Correction







^{23}Mg-^{23}Na Level Scheme



^{23}Na; 440 keV: $\frac{5}{2}^{+} \rightarrow \frac{3}{2}^{+}$

^{23}Mg; 450 keV: $\frac{5}{2}^{+} \rightarrow \frac{3}{2}^{+}$

^{23}Mg-^{23}Na Level Scheme

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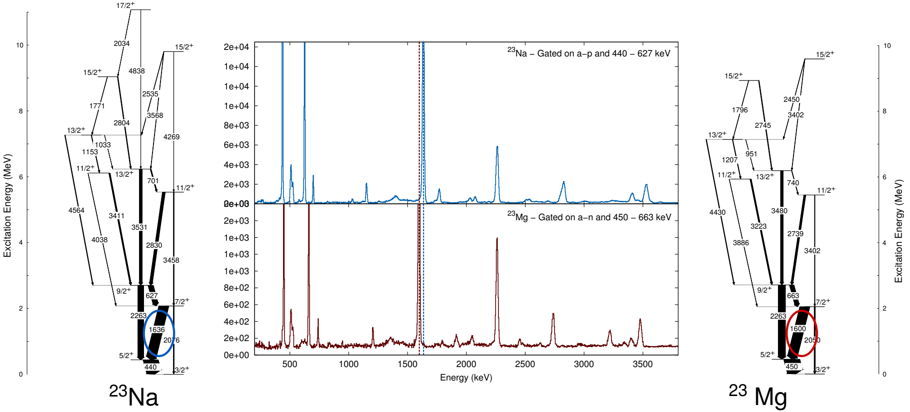
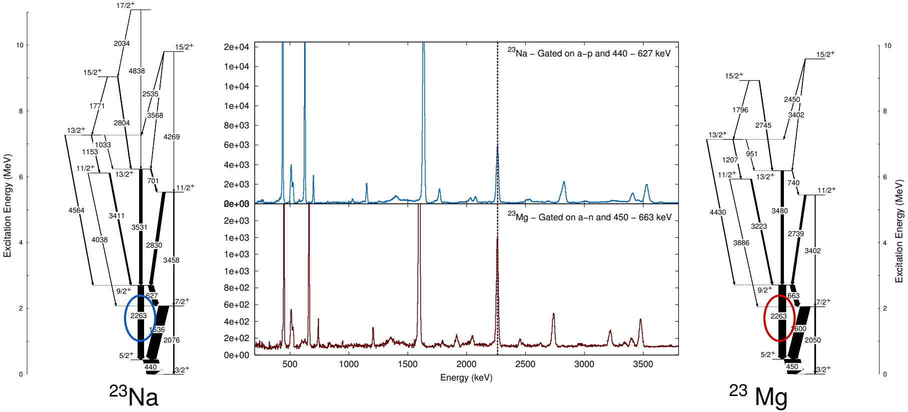


^{23}**Na; 1636 keV:** $\frac{7}{2}^{+} \rightarrow \frac{5}{2}^{+}$

^{23}**Mg; 1600 keV:** $\frac{7}{2}^{+} \rightarrow \frac{5}{2}^{+}$

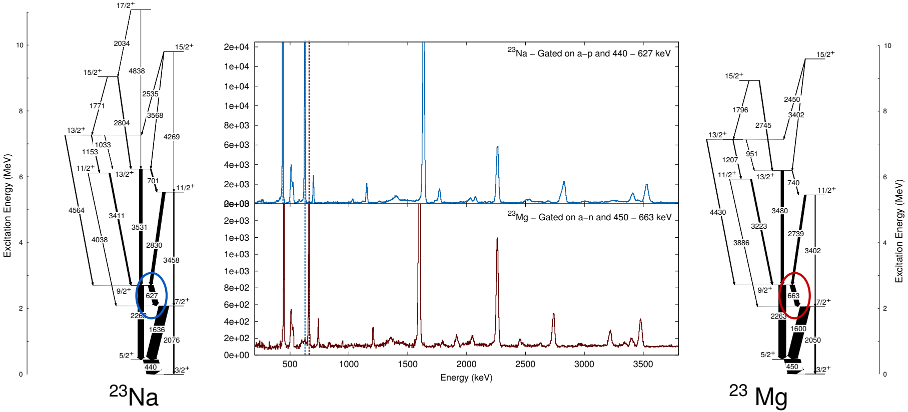
^{23}Mg-^{23}Na Level Scheme



^{23}**Na; 2263 keV:** $\frac{7}{2}^{+} \rightarrow \frac{5}{2}^{+}$

^{23}**Mg; 2263 keV:** $\frac{7}{2}^{+} \rightarrow \frac{5}{2}^{+}$

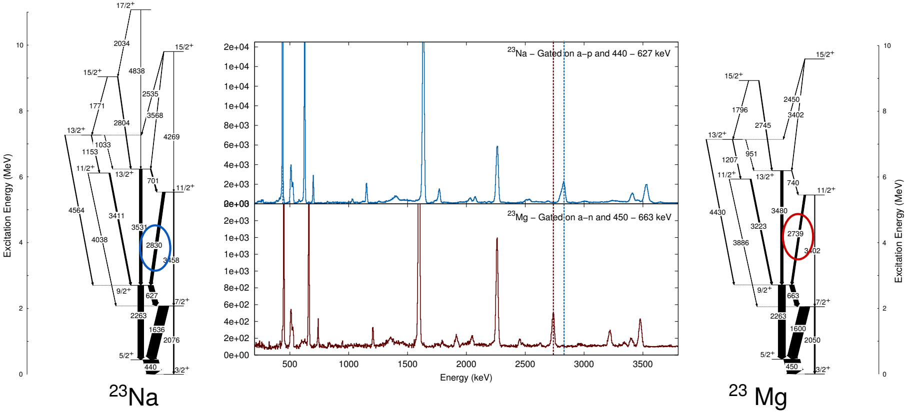
^{23}Mg-^{23}Na Level Scheme



^{23}Na; 627 keV: $\frac{9}{2}^+ \rightarrow \frac{7}{2}^+$

^{23}Mg; 663 keV: $\frac{9}{2}^+ \rightarrow \frac{7}{2}^+$

^{23}Mg-^{23}Na Level Scheme



^{23}**Na; 2830 keV:** $\frac{11}{2}^+ \rightarrow \frac{9}{2}^+$

^{23}**Mg; 2739 keV:** $\frac{11}{2}^+ \rightarrow \frac{9}{2}^+$

^{23}Mg-^{23}Na Level Scheme

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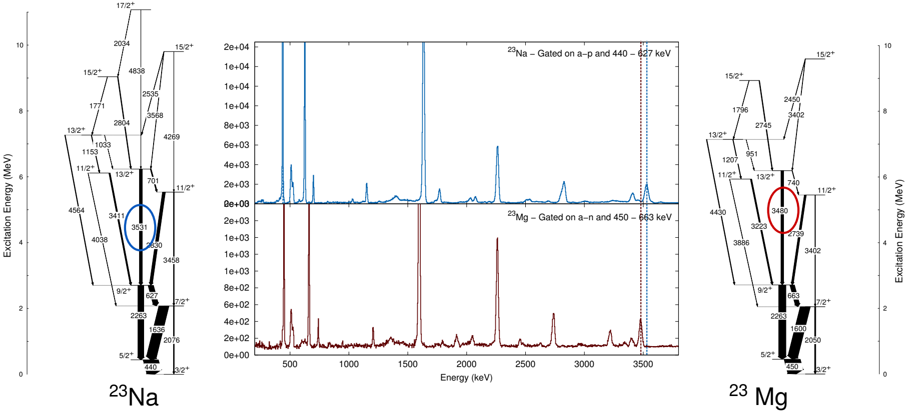
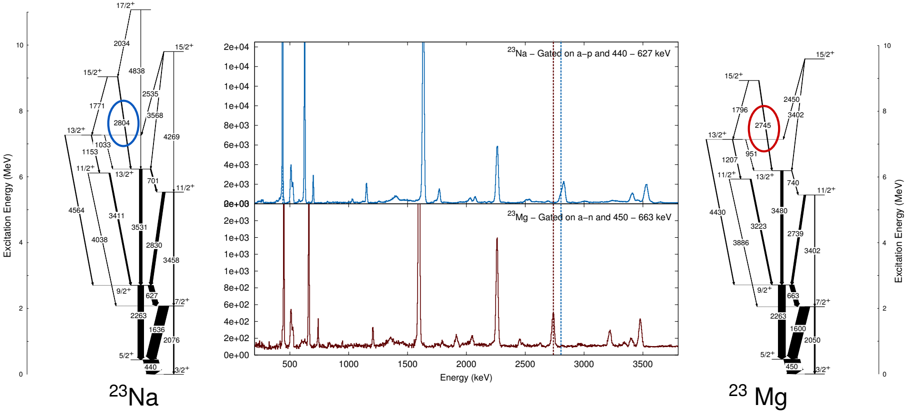


^{23}**Na; 3531 keV:** $\frac{13}{2}^{+} \rightarrow \frac{9}{2}^{+}$

^{23}**Mg; 3480 keV:** $\frac{13}{2}^{+} \rightarrow \frac{9}{2}^{+}$

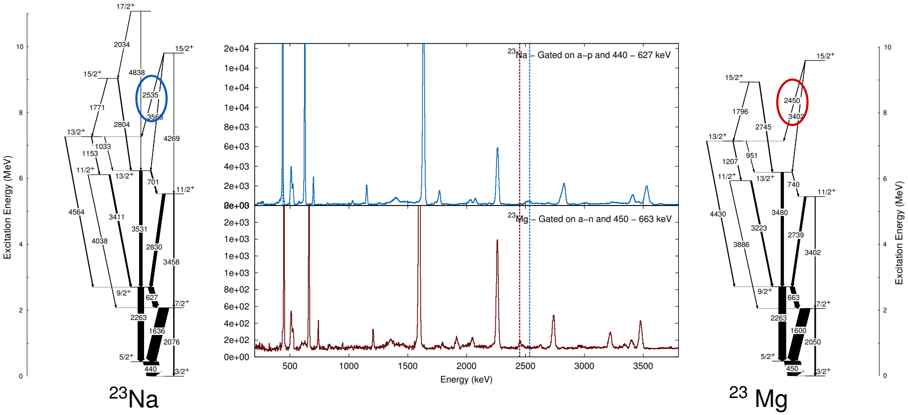
^{23}Mg-^{23}Na Level Scheme



^{23}Na; 2804 keV: $\frac{15}{2}^{+} \rightarrow \frac{13}{2}^{+}$

^{23}Mg; 2745 keV: $\frac{15}{2}^{+} \rightarrow \frac{13}{2}^{+}$

^{23}Mg-^{23}Na Level Scheme



^{23}Na; 2535 keV: $\frac{15}{2}^{+}_{2} \rightarrow \frac{13}{2}^{+}_{2}$

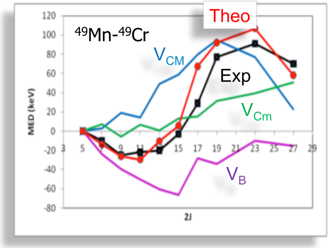
^{23}Mg; 2450 keV: $\frac{15}{2}^{+}_{2} \rightarrow \frac{13}{2}^{+}_{2}$

Shell Model calculations: the "standard" approach

MED terms

$f_{7/2}$ prescription:

- **Multipole Coulomb** Term
- **Single particle** corrections
- **"Nuclear"** ISB: $V_B(J=2)$
- **Radial** Term



A. P. Zuker et al., PRL 89, 142502 (2002); M.A. Bentley and S.M. Lenzi, Prog. Part. Nucl. Phys. 59(2007)

The Radial Term V_R

Coulomb monopole Term

Charged sphere:

$$E_C = \frac{3}{5}\frac{Z(Z-1)e^2}{R_C}$$

It amounts to tens of MeV...
...but the MED are **normalized** to ground state!

Bulk effect **vanishes**!!

Radius variation with J

Related to **orbitals radii**:

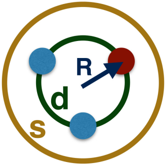
- $l < \rightarrow$ r>

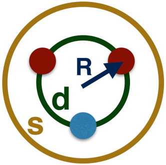
fp shell: p orbitals **bigger** than $f_{7/2}$
sd shell: $s_{1/2}$ **bigger** than d orbitals

$$r_s - r_d \sim 1.5 \text{ fm}$$

Sensitive to **difference** in occ numbers

$$V_r \propto \left(\frac{m_\pi(0)+m_\nu(0)}{2} - \frac{m_\pi(J)+m_\nu(J)}{2}\right)$$





Ground State:
$V_r = 0$

J. Bonnard, A. Zuker, arXiv:1606.03345v1

The Radial Term V_R

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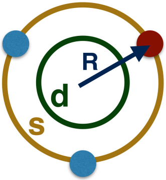
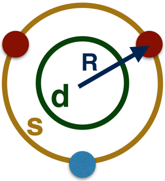




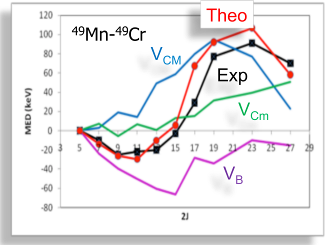
Excited State:
$V_r < 0$

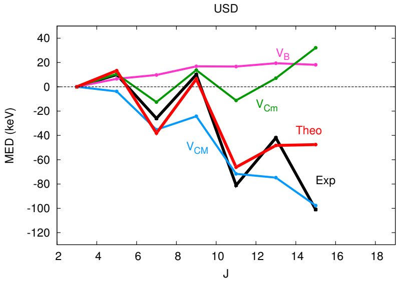
J. Bonnard, A. Zuker, arXiv:1606.03345v1

MED terms

$f_{7/2}$ prescription:

- **Multipole Coulomb** Term
- **Single particle** corrections
- **“Nuclear”** ISB: $V_B(J=2)$
- **Radial** Term





MED in A=23

- USD interaction
- Coulomb terms reproduce the experimental trend
- V_B term makes things **worse**

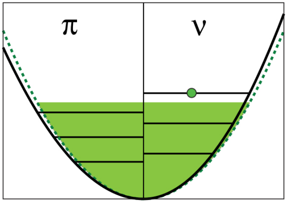
A. P. Zuker et al., PRL 89, 142502 (2002); M.A. Bentley and S.M. Lenzi, Prog. Part. Nucl. Phys. 59(2007)

Shell Model calculations: alternative approach

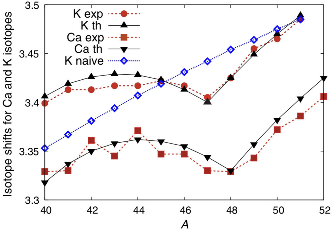
MED terms

- Realistic NN interaction **N3LO**
- Coulomb interaction: **included**
- EMSO term: **included**
- Nuclear ISB term: **included**
- **Different** $\hbar\omega$ for protons and neutrons

J. Bonnard et al., PRL 116, 212501(2016)



Extra particle polarizes both fluids



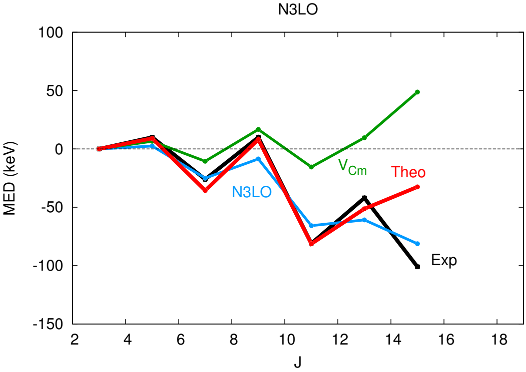
r_π increases filling $p_{3/2}$ with ν
IV monopole polarizability

Potential Wells

- r_p from experiment
- IS: $r_p(Z > N) = r_n(Z < N)$
- From MDE we get $r_n(Z > N)$
- $r \rightarrow \hbar\omega$
- **Different** $\hbar\omega$ for each **nucleus**
- Valid for **ground states**

V_r in MED treated in the usual way

Application to ^{23}Mg-^{23}Na mirror nuclei



Results

- N3LO reproduce the MED trend
- Radial term is **needed**
- $V_r(J = \frac{15}{2}^+)$ needs clarification

Next Steps

- Different $\hbar\omega$ for each **state** to account for changes in the radius with J
- MED of **yrare** and **negative** parity states

The Collaboration

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[13] *Aksaray Universitesi, Department of Physics, Aksaray, Turkey*

Thank you for your attention !!

Duflo-Zuker approach

Proton radii

$$\sqrt{\langle r_\pi^2 \rangle} = \rho_\pi = A^{1/3}\left(\rho_0 - \frac{\zeta}{2}\frac{t}{A^{4/3}} - \frac{\upsilon}{2}\left(\frac{t}{A}\right)^2\right)e^{(g/A)}$$

$$+\lambda[z(D_\pi - z)/D_\pi^2 \times n(D_\nu - n)/D_\nu^2]A^{-1/3},$$

Related to $\hbar\omega$ by:

$$\hbar\omega_\pi = \frac{41.47}{\langle r_\pi^2 \rangle}\sum_i z_i(p_i + 3/2)/Z.$$

To take into account shell effect

$$\langle r_\pi^2 \rangle = \frac{41.47}{\hbar\omega_\pi}\sum_i z_i(p_i + 3/2 + \delta_i)/Z.$$

where $\delta \neq 0$ only for $s_{1/2}$

$$\delta = \begin{cases} \delta_< & \text{if } N \text{ and } Z < 14 \\ \delta_> & \text{if } N \text{ or } Z \geq 14. \end{cases}$$

J. Bonnard et al., PRL 116, 212501(2016)