Isospin mixing in N=Z nuclei

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Outline

- The Isospin Symmetry
- Isospin Mixing
  - $E^* = 0$
  - $E^* > 0$
- Experimental techniques
- Our work
- Beyond the nuclear structure
- Conclusions

The Isospin Symmetry

- The nuclear interaction is **charge independent**
- Neutrons (**n**) and protons (**p**) are different states of the same particle, the Nucleon (**N**)
- To describe this symmetry Heisemberg introduced a new quantum number, **the Isospin (Isobaric spin) I**.

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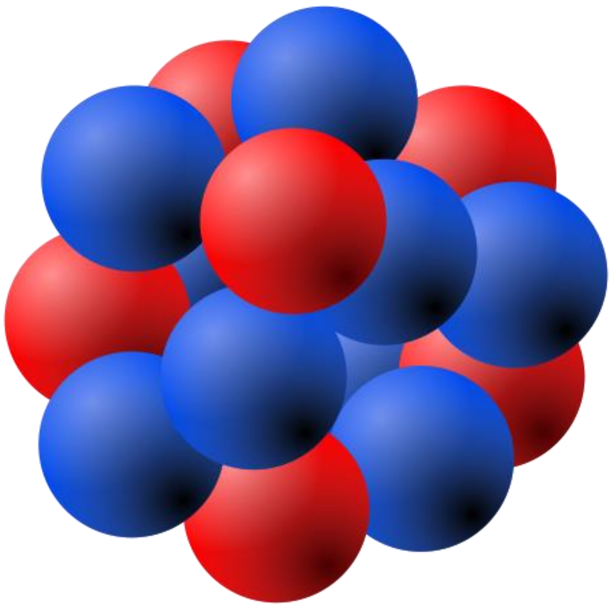
The Isospin Symmetry

For a generic nucleus:



$$I_z = (N - Z)/2$$

$$I_z \leq I \leq |I_z|$$

The nuclear ground state corresponds to the minimum value of isospin $I = I_z$

The Isospin Mixing in the ground state

- The presence of the **Coulomb interaction** inside the nucleus causes a **mixing** between states with different isospin
- The main contribution to the mixing is between states with **ΔI = 1**
- In a perturbative way the mixing probability in the nuclear ground state is defined as:

$$\alpha^2 = \frac{|\langle I=1|H_c|I=0\rangle|^2}{\Delta E^2}$$

The Isospin Mixing in the ground state

NO MIXING

$$|A\rangle = |0\rangle$$

MIXING

$$|A\rangle = \beta|0\rangle + \alpha|1\rangle$$

$$\alpha^2 + \beta^2 = 1$$

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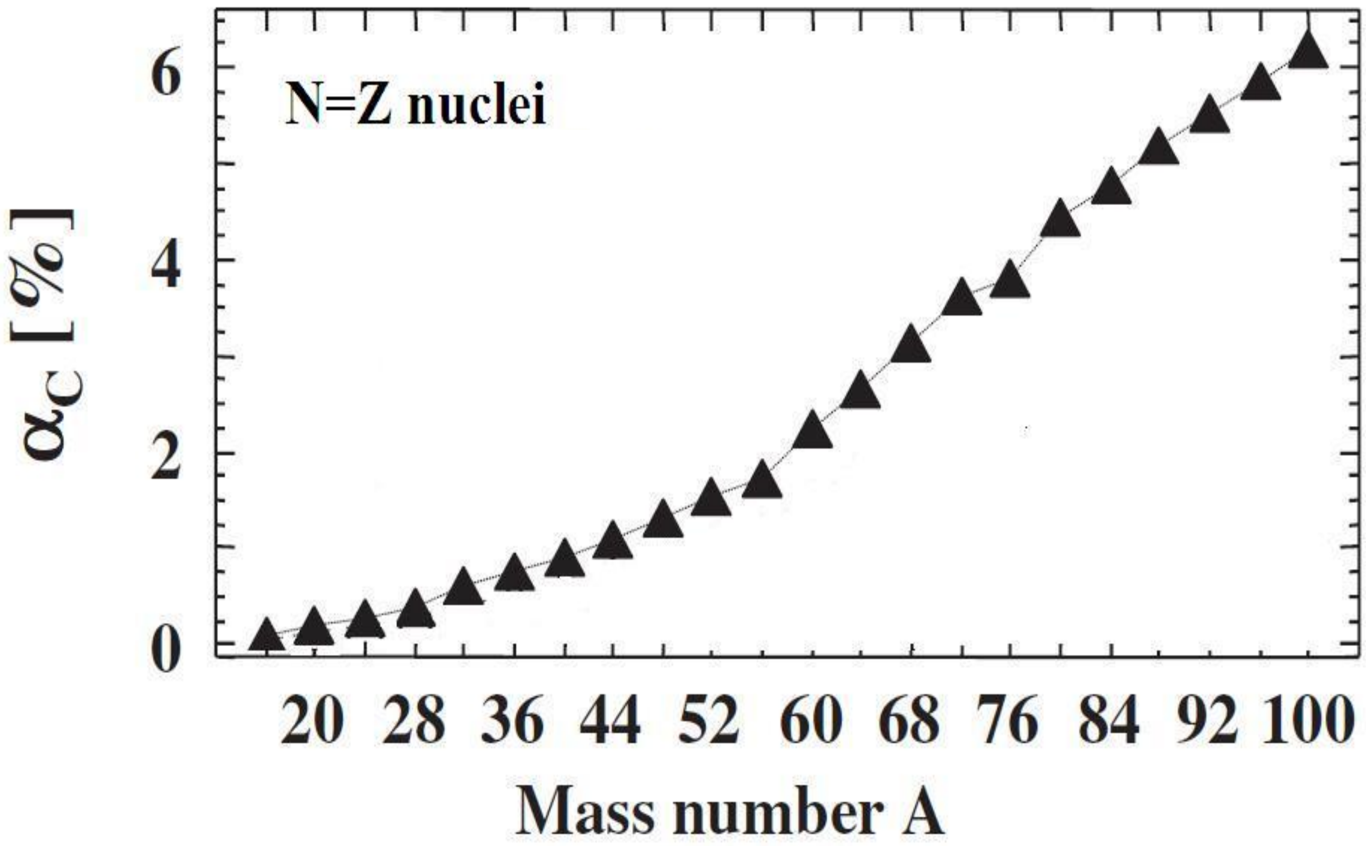
- How much is it?
- α^2 vs Z ?
- α^2 vs E^* ?
- How can we measure it?

The Isospin Mixing in the ground state

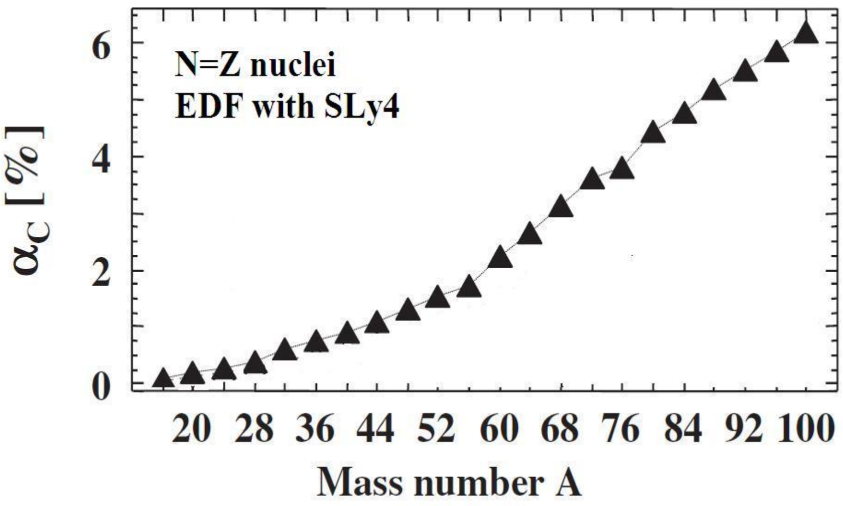
Satula et al., PRL 103 (2009)



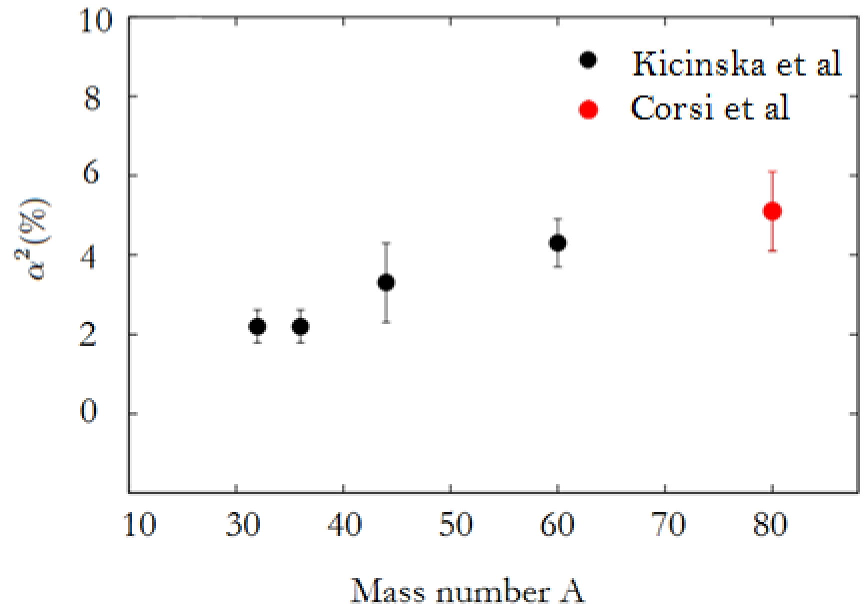
- The **mixing increases** due to the increase of the **Coulomb potential** with Z

The Isospin Mixing in the ground state

Theoretical Data for nuclei in the ground state



Experimental Data for nuclei with $E^{*}>0$



Kicinska et al., Nucl. Phys. A 36 (2005)

Corsi et al., PRC 84 (2011)

Behr et al., PRL 70 (1993)

Nuclear temperature

We can describe the nucleus at high excitation energy in a thermodynamical way and we can define the ***nuclear temperature*** as:

$$T = \sqrt{\frac{E_{int}}{a}}$$

Isospin mixing depends also on the nuclear temperature

The Isospin Mixing T>0

- A nucleus in a excited state has a **finite lifetime τ**
- The lifetime can be so short to not allow a complete mixing
- At high excitation energy (E^*) the isospin symmetry is **restored**
- We have a **dynamical behavior** of the isospin mixing phenomenon

The Isospin Mixing T>0

As a **first approximation** we can describe the dynamical behavior of the mixing as:

$$\alpha^2 \simeq \frac{\Gamma^{\downarrow}}{\Gamma_{CN}} \simeq \frac{\tau_{CN}}{\tau_{MIX}}$$

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Coulomb spreading width

Compound nucleus decay width

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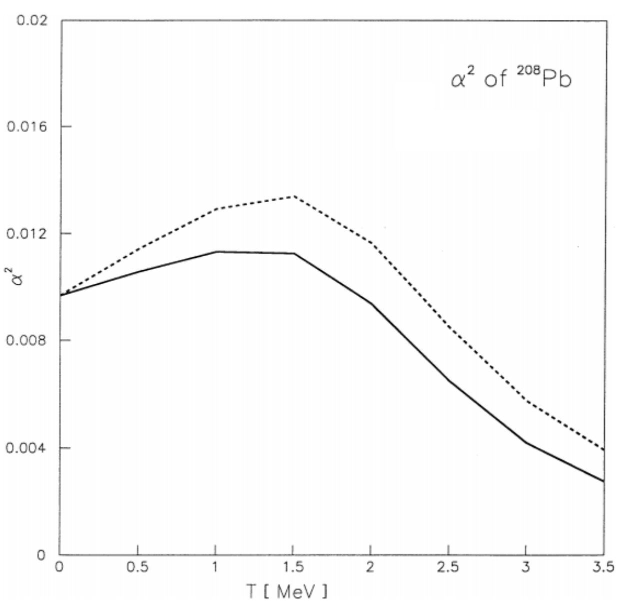
Sagawa, Bortignon, Colò PLB 444 (1998)



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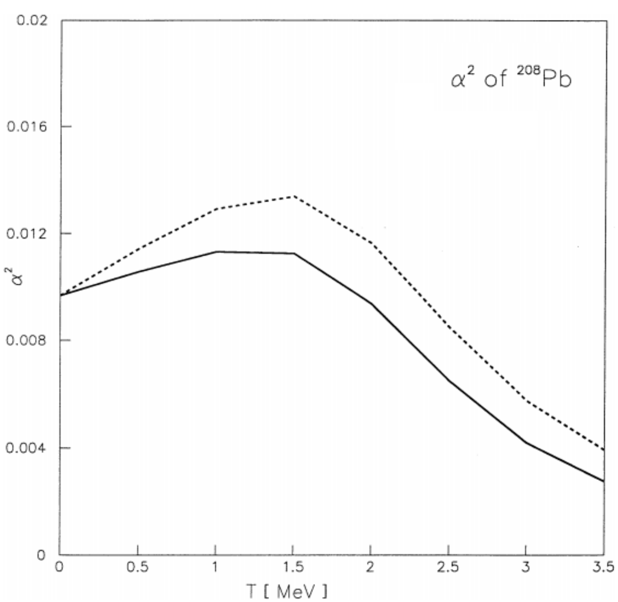
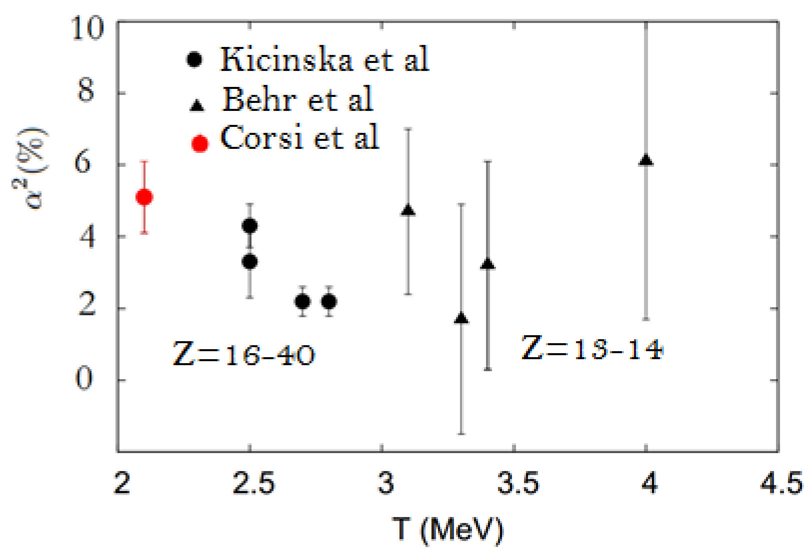


Experimental Data with different Z



Experimental techniques

T= 0

- Study of Fermi **β transitions** ($\Delta J=0$, $\Delta I=0$, $\pi_i \pi_f=+$)
- Measurement of the **β-particles** anisotropy emission
- Possible for **all nuclei**
- Difficult for very **unstable nuclei**

- Study of a **forbidden** E1 decay
- Measurement of the strength of the **E1 gamma-decay**
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Saverijns at al., PRC 71 (2005)
Farnea et al., PLB 551 (2003)

T> 0

- Study of a **forbidden** E1 decay
- Measurement of the strength of the E1 gamma decay of the **Giant Dipole Resonance** (GDR)
- Possible only in **N=Z** nuclei
- It's easier to produce a N=Z nucleus at T>0
- Possible to **reach very unstable nuclei** with heavy ions fusion

Harakeh et al., PLB 176 (1986)
Behr at al., PRL 70 (1993)

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Our work in ^{80}Zr

Harakeh et al., PLB 176 (1986)
Behr at al., PRL 70 (1993)

Our work

We form a I=0 Compound Nucleus with

a heavy ion fusion reaction

$$^{40}\mathrm{Ca} + {}^{40}\mathrm{Ca} \Rightarrow {}^{80}\mathrm{Zr}^{*}$$

We measure the γ-rays yield from the E1

decay of the GDR built on the CN (first step)

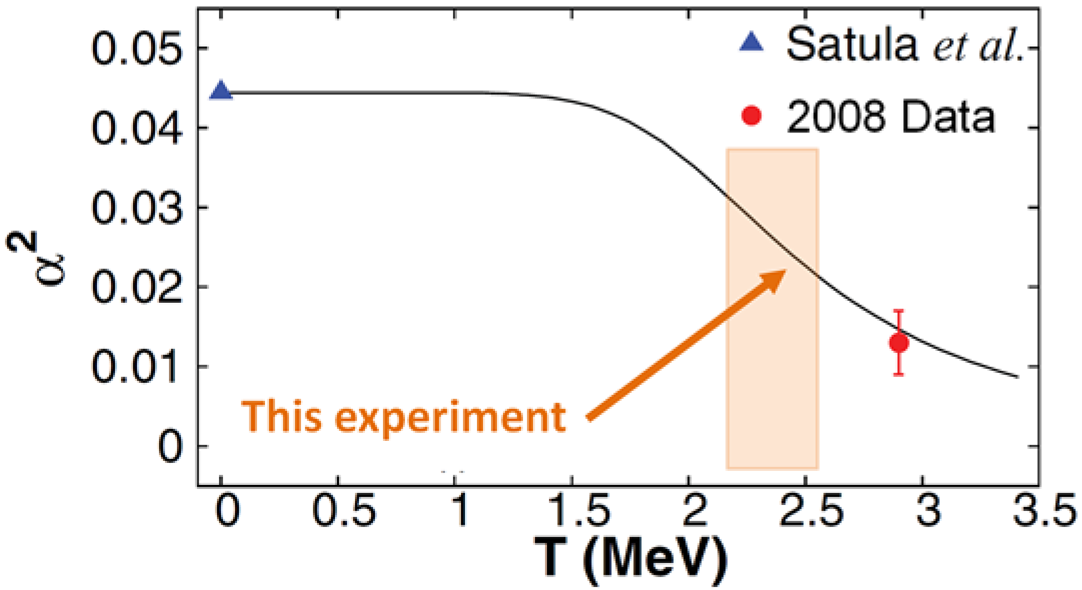
$I=0 \Rightarrow I=0$	$I=0 \Rightarrow I=1$	$I=1 \Rightarrow I=0$
E1 Transition are forbidden	E1 Transitions are allowed	E1 Transition are allowed
	Few I=1 states	If $\alpha^2 > 0$

This results in a strong inhibition of the GDR γ-decay from the hot ^{80}Zr compound

mixing increases the GDR γ yield

From the data fit we can extract Γ↓

Our work



- With **two or more experimental** points on the same nuclear system we can extract the isospin mixing at **T=0**.
- **For ^{80}Zr we have only a theoretical value at T=0**.
- With this technique **we can extract the value of isospin mixing at T=0** for N=Z unstable nuclei (**vary short lifetime**)

Conclusions

- The isospin mixing is a phenomenon known for a long time as it enter in beta decay, ….
- **BUT** there are few data available for testing the models
  - There isn't a systematical experimental study
  - Experimental techniques are very complicated
- We aim to extract the value of the T = 0 isospin mixing from data on nuclei at T>0
- This is a nuclear structure problem but …..

Beyond the nuclear structure

In the Standard Model (SM) the Cabibbo-Kobayashi-Maskawa matrix (CKM) is a unitary matrix. Its elements satisfy:

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$$

- Usually the $\boldsymbol{V_{ud}}$ element is derived from superallowed nuclear β-decay measuring the ***ft*** value:

$$\boldsymbol{ft} \Longrightarrow \boldsymbol{G_v} \Longrightarrow \boldsymbol{V_{ud}}$$

  - ***ft*** value is affected to isospin mixing
  - We have to correct the data in order to extract a value of $\boldsymbol{G_V}$ nucleus independent

$$\boldsymbol{ft} \Longrightarrow \boldsymbol{Ft} \Longrightarrow \boldsymbol{G_v} \Longrightarrow \boldsymbol{V_{ud}}$$

$$Ft \equiv ft(1+\delta_R)(1-\delta_C)$$

$$\delta_C = 4(I+1)\frac{V_1}{41\xi A^{2/3}}\alpha^2$$

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How can I test it?

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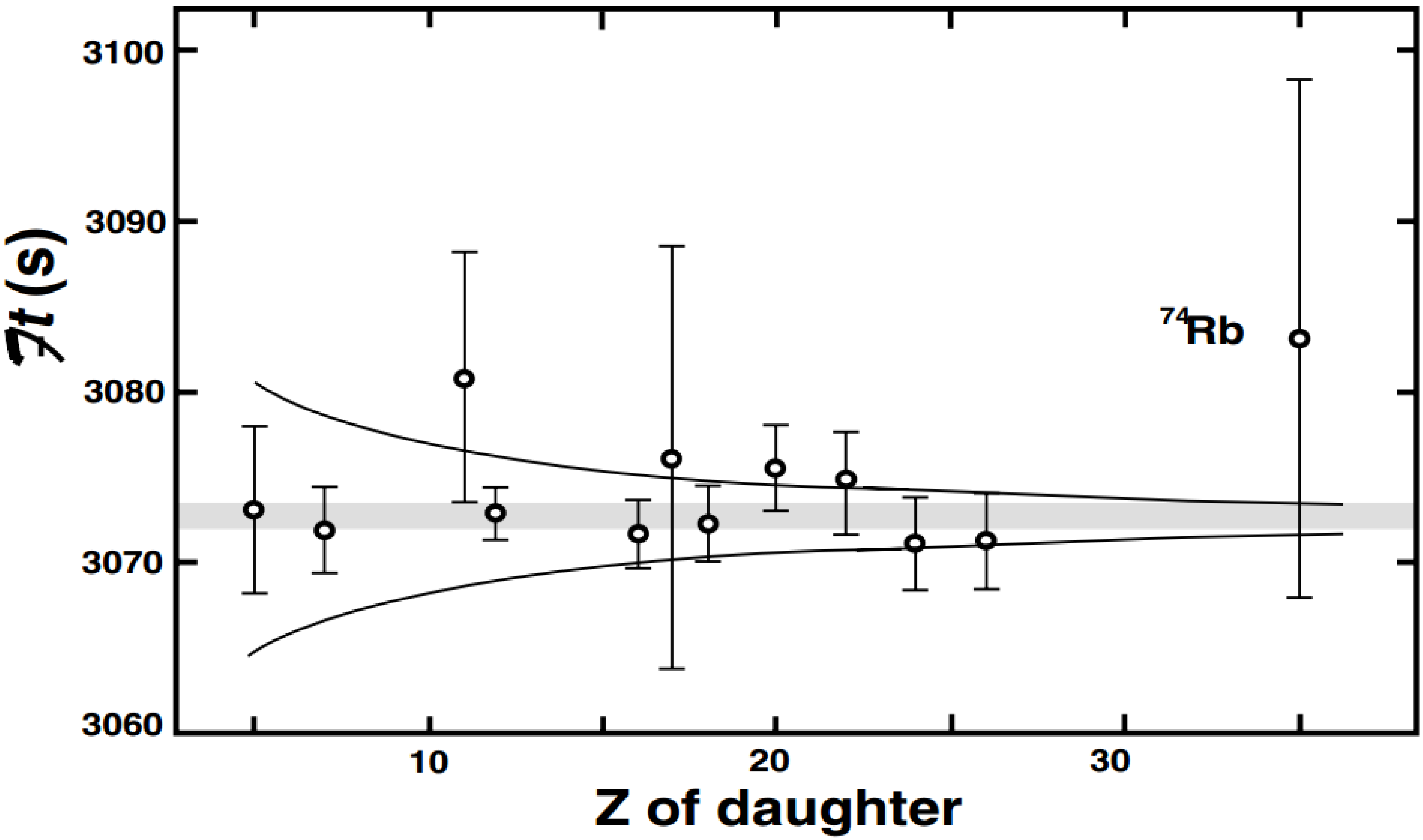
$$|V_{ud}| = 0.9738(4)$$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9966 \pm 0.0014$$

Hardy, PRL 94 (2005)

Beyond the nuclear structure



Hardy, PRL 94 (2005)
Kellerbauer, PRL 93 (2004)

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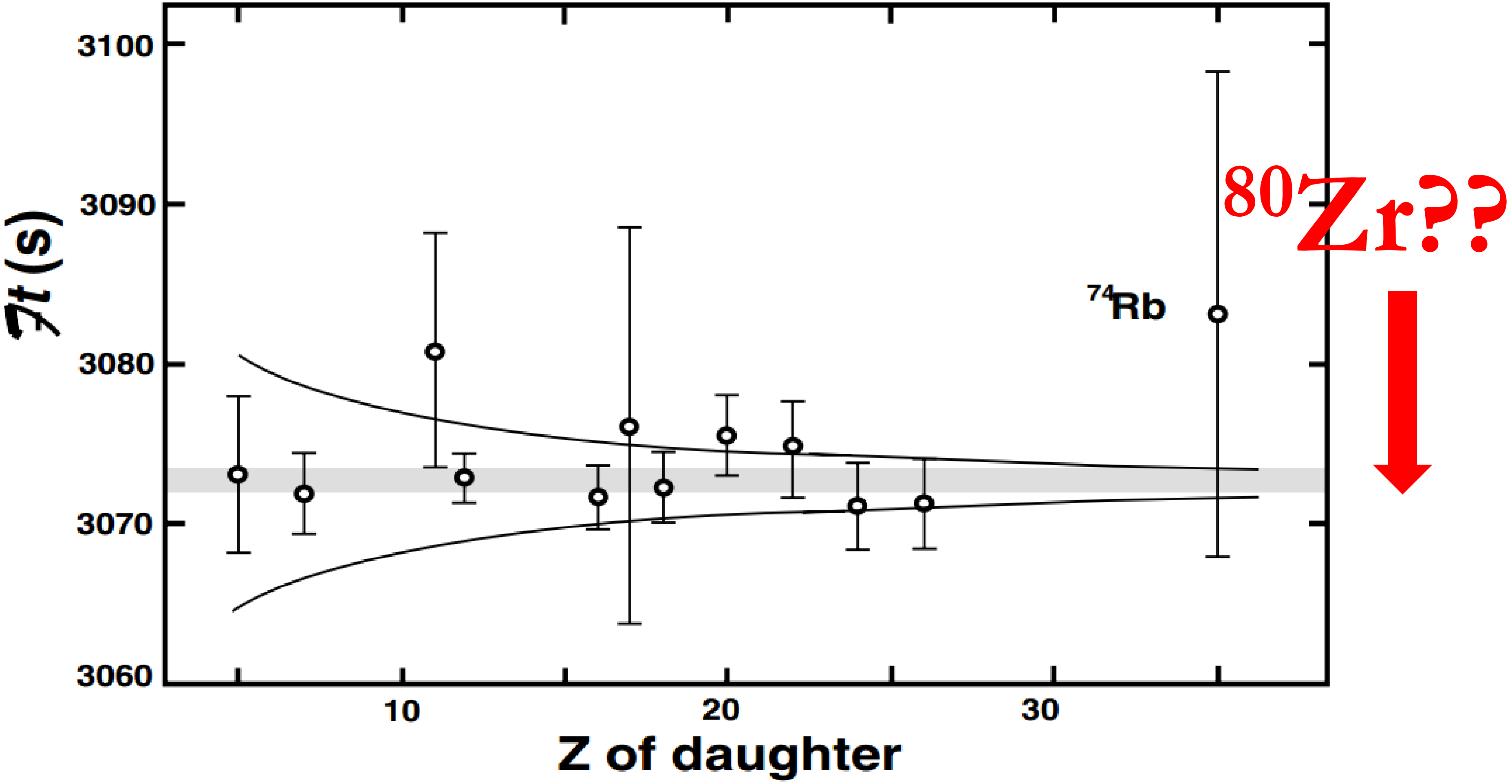


Hardy, PRL 94 (2005)
Kellerbauer, PRL 93 (2004)

Thank you for your attention

Isospin mixing

$$Q = \frac{e}{2}(1 - \tau_3) \qquad V_C = \sum_{i>j} \frac{1}{4}(1 - \tau_3^{(i)})(1 - \tau_3^{(j)})\frac{e^2}{r_{ij}}$$

$$V_C^{(0)} = \sum_{i>j} \frac{1}{4}\frac{e^2}{r_{ij}}\left(1 + \frac{1}{3}\vec{\tau}_{(i)} \cdot \vec{\tau}_{(j)}\right)$$

$$V_C^{(1)} = -\sum_{i>j} \frac{1}{4}\frac{e^2}{r_{ij}}(\tau_3^{(i)} + \tau_3^{(j)})$$

$$V_C^{(2)} = \sum_{i>j} \frac{1}{4}\frac{e^2}{r_{ij}}\left(\tau_3^{(i)}\tau_3^{(j)} - \frac{1}{3}\vec{\tau}_{(i)} \cdot \vec{\tau}_{(j)}\right)$$

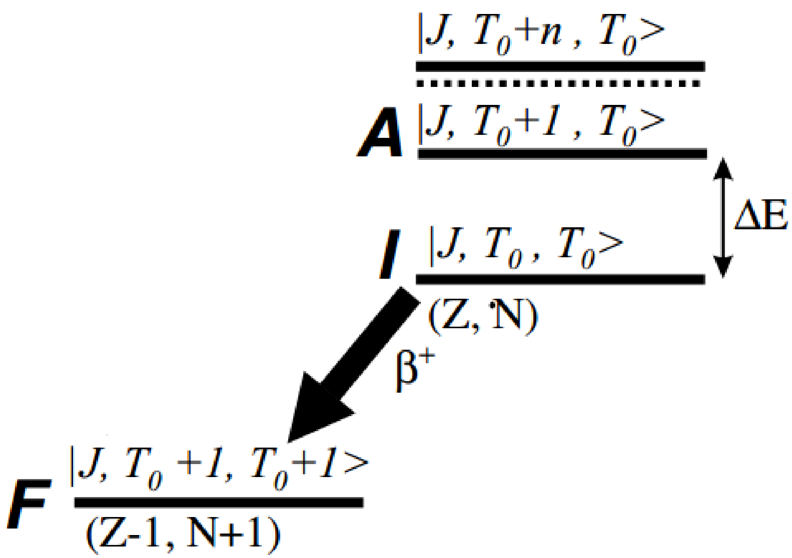
Beyond the nuclear structure

In a superallowed β-decay ($0^+ \rightarrow 0^+$)

$$ft = \frac{K}{|M_V|^2 G_V^2}$$

$$|V_{ud}|^2 = \frac{G_V^2}{G_F^2}$$

Experimental technique



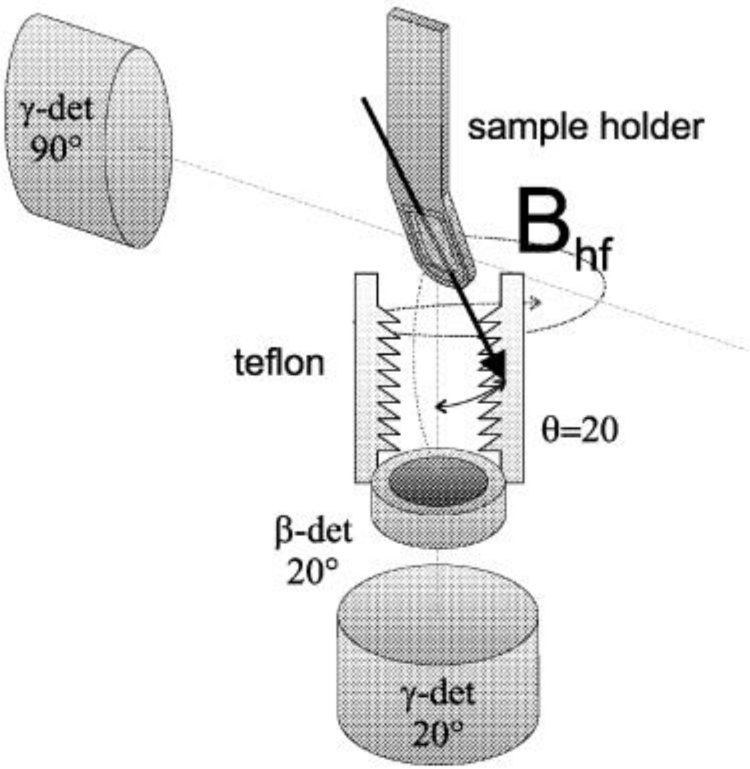
$$ft = \frac{2(G_V)^2 \mathcal{F}t^{0^+\to 0^+}}{(G_V M_F)^2 + (G_A M_{\mathrm{GT}})^2}$$

$$y = \frac{G_V M_F}{G_A M_{\mathrm{GT}}}$$

$$\alpha^2 = \frac{y^2}{(1+y^2)(1+T_0)} \frac{\mathcal{F}t^{0^+\to 0^+}}{ft}$$

Saverijns at al., PRC 71 (2005)

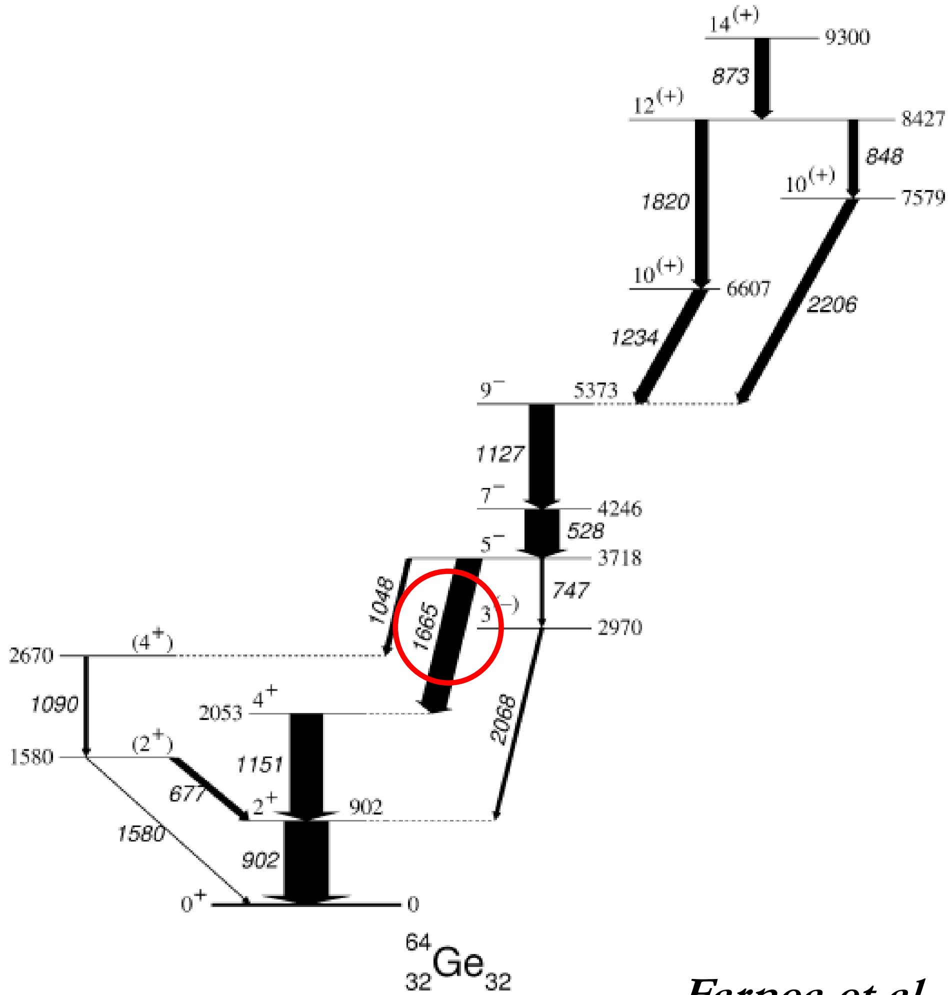
Experimental technique



$$W(\theta) \equiv \frac{N_{\text{cold}}(\theta)}{N_{\text{warm}}(\theta)} = 1 + f\frac{v}{c}A_1 B_1 Q_1 \cos(\theta)$$

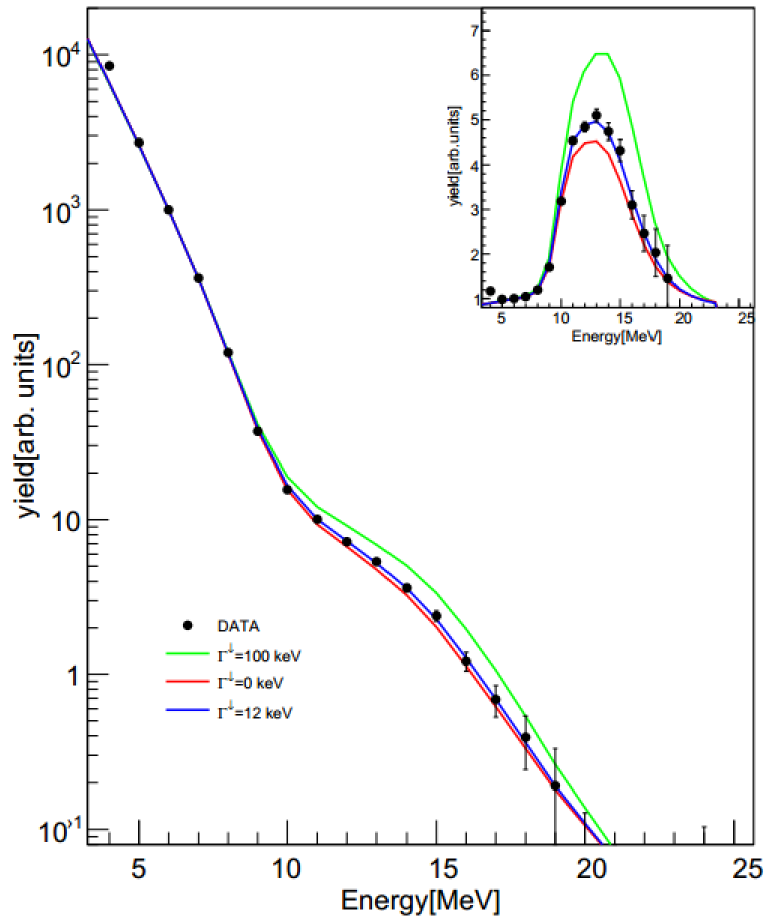
Schuurmans et al., Nuclera Physics A 672 (2000)

Experimental technique



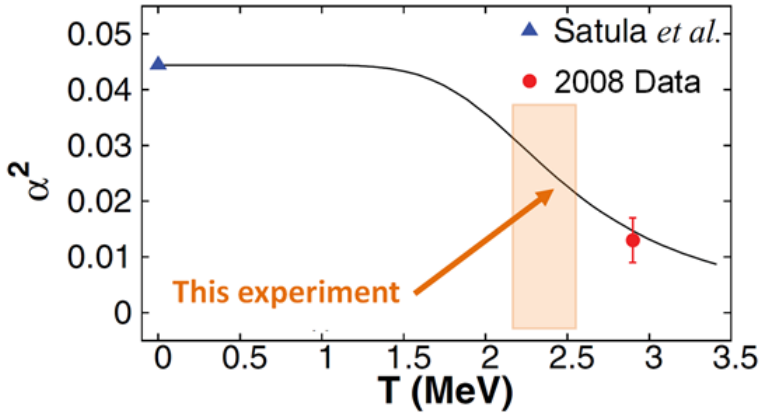
Farnea et al., PLB 551 (2003)

Our work



Fit of gamma-decay spectrum of ^{80}Zr varying the value of the Coulomb Spreading Width

Our work



$$(\alpha^{I_0+1})^2 = \frac{1}{I_0+1}\frac{\tilde{\Gamma}^{\downarrow}_{IAS}(E^*)}{\tilde{\Gamma}_C(E^*)+\Gamma_M(E^*)}$$

- **$\Gamma^{\downarrow}_{IAS}$** is the coulomb spreading width of the Isobaric Analog State. **FROM DATA**
- **Γ_M** is the width of the monopole resonance at the energy of the IAS **PARAMETER**
- **Γ_C** is the decay width of the nucleus. **KNOWN FROM CN DECAY**

Corsi et al., PRC 84 (2011)
Sagawa, Bortignon, Colò PLB 444 (1998)