Beta decay studies of the N=Z and waiting point nucleus ^{72}Kr

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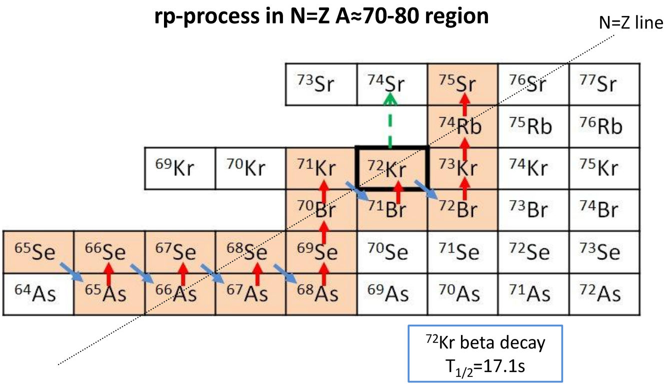
¿Why $^{72}_{36}Kr_{36}$?

- **Nuclear structure:** Phenomena in the mass region such as **shape coexistence** and possibility of study **np pairing** as this region is N=Z.
- **Astrophysical interest:** ^{72}Kr a "waiting point" in rp process. ^{73}Rb is unbound $\longrightarrow \beta$ decay competes with 2p capture.



¿Why β decay studies?

Reasons:

- **Large Q_β** in this mass region → Large energy window in level scheme of daughter nucleus. $Q_{EC}(^{72}Kr)$=5040 keV.
- Comparison of **B(GT) distribution** with theoretical predictions can provide us with information on the deformation of parent nucleus in this mass region.
- **Assignment of J^π=1$^+$** to levels directly fed by allowed transitions as J^π(g.s.)=0^+ for N=Z and even-even nuclei such as $^{72}_{36}Kr_{36}$.
- Only way to **access low spin states** out of Yrast line for nuclei far from stability.

Determination of the deformation through B(GT) distributions

Theoretical calculations predict different B(GT) distributions with respect to excitation energy in daughter nucleus for different deformations of ground state in parent nucleus.

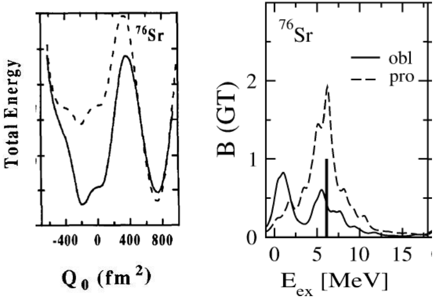


Figura 1: Theoretical predictions on total energy vs. quadrupole moment (Q_0) (left) and accumulated B(GT) vs. Excitacion energy in daughter nucleus for oblate and prolate deformations of ^{76}Sr (right) from [Sarr99] y [Sarr01]

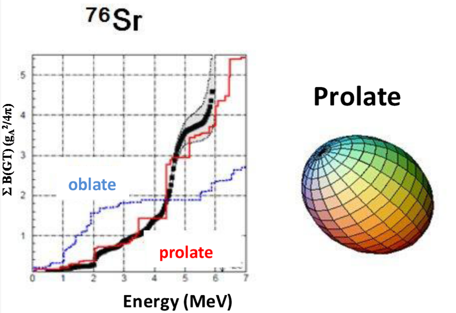
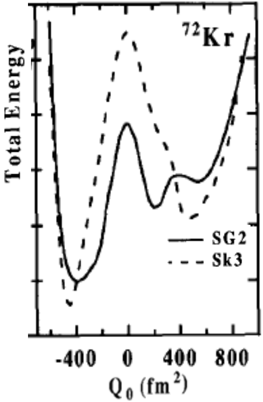


Figura 2: Comparison of experimental results for accumulated B(GT) vs. Excitacion enery in daughter nucleus for ^{76}Sr with theoretical calculations for oblate deformation (blue line) and prolate (red line). [Nac04]

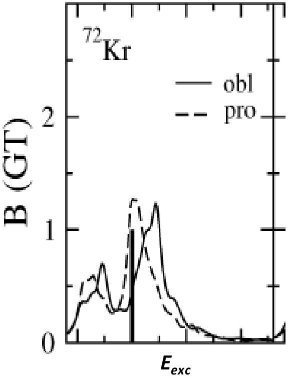
[Sarr99] P. Sarriguren et al., Nucl. Phys. A658, 13 (1999)
[Sarr01] P. Sarriguren et al., Nucl. Phys. A691 631 (2001)
[Nac04] E. Nácher et al., PRL 92 232501 (2004)

Theoretical predictions for ^{72}Kr

Sarriguren et al. [Sarr01] using an Skyrme interaction in QRPA approximation predict:



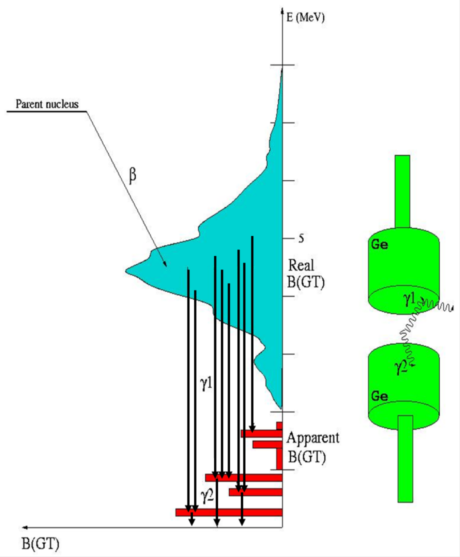
Total energy for ^{72}Kr with respect to masic quadrupole moment (deformation) for 2 different types of forces SG2 and Sk3 [Sarr99]



B(GT) vs. E_{exc} in daughter nucleus [Sarr01]

[Sarr99] P. Sarriguren et al., Nucl. Phys. A658, 13 (1999)
[Sarr01] P. Sarriguren et al., Nucl. Phys. A691 631 (2001)

Feedings from High Resolution measurements: Pandemonium effect

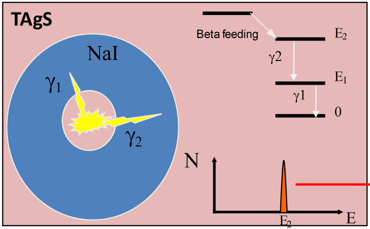


- High density of levels for high excitation energies
- Very fragmented feeding distribution and deexcitation pattern
- Low photopeak efficiency for high energy gammas with HPGe detectors
- Apparent strength is located at lower energies than it is
- **As a result**: overestimated strength at low excitation energies and underestimated for high excitation energies

J.C. Hardy et al, Phys. Lett. 71B (1977)

Total Absorption gamma Spectroscopy (TAgS)

Measurement of B(GT) of each level by measuring the gamma deexcitation intensity, from each excited level directly fed by beta decay, to g.s.



Courtesy B. Rubio

$$B_{GT} = 6147\left(\frac{g_V}{g_A}\right)^2 \frac{I_\beta}{fT_{1/2}} = 6147\left(\frac{g_V}{g_A}\right)^2 \frac{1}{ft_{1/2}}$$

In order to obtain B(GT) we measure experimentally

I_β

$T_{1/2}$

$$t_{1/2} = \frac{T_{1/2}}{I_\beta(E)}$$

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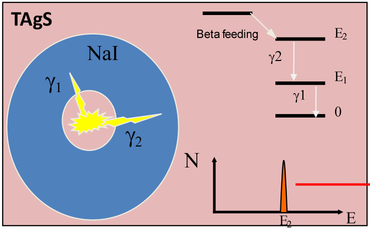

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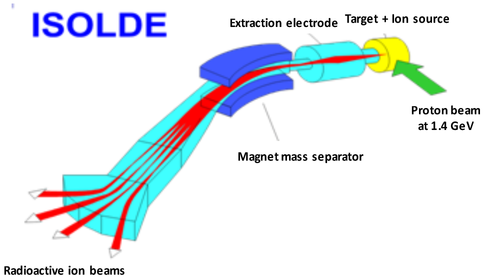
To be taken into account:

1. **Internal conversion:** Deexcitation from each level not always via gamma emission → internal conversion emission.
   Specially relevant for low energy transitions. TAS is not sensitive to low-energy electrons.
   In order to quantify the proportion → conversion coefficients: $\alpha = \frac{I_e}{I_\gamma}$.
2. **Isomeric states** (half-life > 1 ns): Deexcitation intensity is not properly measured because gamma radiation is out of the coincidence window of our DAQ system.



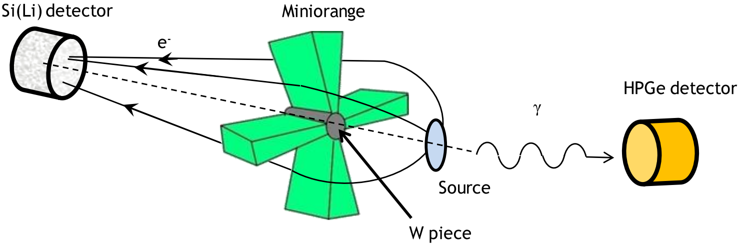
1. **Reaction in target:** Proton beam at 1.4 GeV with a maximum intensity of 2 μA hits a ^{93}Nb target. Spallation reaction produces ^{72}Kr:

$$^{93}_{41}Nb_{52}(p, 16n + 6p)^{72}_{36}Kr_{36}$$

2. **Ion source:** Plasma Ion Source with a cooled transfer line.
   An extraction voltage of ΔV = 60 kV is applied.

3. **Selection of fragments:** ^{72}Kr through the HRS mass separator

Electrons spectrometer: Miniorange



1. Si(Li) cooled detector (300 mm^2 · 4 mm)
2. Set of permanent magnets to stop gamma radiation and improve electron transmission to our Si(Li) detector.

D1/D2/NT	Effective energy range E(keV)
85/8/4B	60-200
110/8/6A	400-1100
125/8/3B	40-170

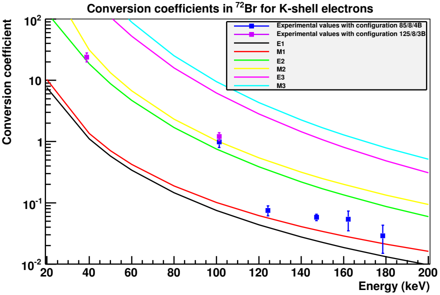
Results on Conversion Coefficients

Núcleus	Minio.	Gamma energy	Electron transition	α(exp)	α(th) [ANU]					Dominant multipolarity
					E1	M1	E2	M2	E3	
^{72}Br	4B	101.3	K	**1.0(2)**	0.072	0.098	0.718	0.987	5.863	
^{72}Br	4B	101.3	(Total-K)	**0.14(3)**	0.00907	0.01271	0.1202	0.1578	1.834	M2
^{72}Br	3B	101.3	K	**1.3(3)**	0.072	0.098	0.718	0.987	5.863	
^{72}Br	4B	124.28	K	**0.08(2)**	0.039	0.056	0.34	0.478	2.424	M1(E2)
^{72}Br	4B	124.28	(Total-K)	**0.010(3)**	0.00492	0.00727	0.053	0.0733	0.623	
^{72}Br	4B	147.2	K	**0.028(8)**	0.02385	0.03578	0.1824	0.2654	1.163	E1 or M1
^{72}Br	4B	162.2	K	**0.055(13)**	0.018	0.028	0.128	0.19	0.763	M1+E2
^{72}Br	4B	162.2	(Total-K)	**0.0064(17)**	0.00222	0.00355	0.0186	0.028	0.1603	
^{72}Br	4B	178.5[a]	K	**0.029(8)**	0.01351	0.02158	0.08999	0.1377	0.5037	M1(E2)
^{72}Br	6A	414.5+415.1	K	**0.0022(6)**	0.00128	0.002649	0.004725	0.00951	0.01534	M1 or ~~E1~~
^{72}Br	6A-125	414.5+415.1	K	**0.0019(5)**	0.00128	0.002649	0.004725	0.00951	0.01534	
^{72}Br	6A-125	310	K	**0.006(2)**	2.79E-03	0.005351	0.01254	0.02304	0.04879	M1(E2)
^{72}Br	6A	576.9	K	**0.0017(6)**	5.68E-04	0.001237	0.001718	0.003699	0.004625	E2
^{72}Br	6A-125	576.9	K	**0.0014(5)**	5.68E-04	0.001237	0.001718	0.003699	0.004625	E2(M1)

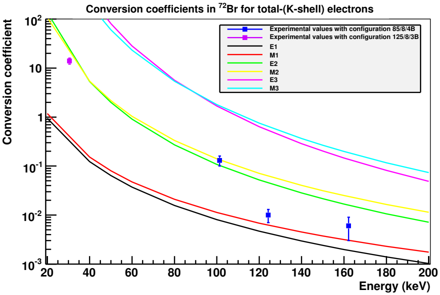
[ANU] ANU - NNDC - Petersburg - ORNL collaboration for the International Network of Nuclear Structure and Decay Data (NSDD) Evaluators.

http://physics.anu.edu.au/nuclear/bricc

Results on Conversion Coefficients

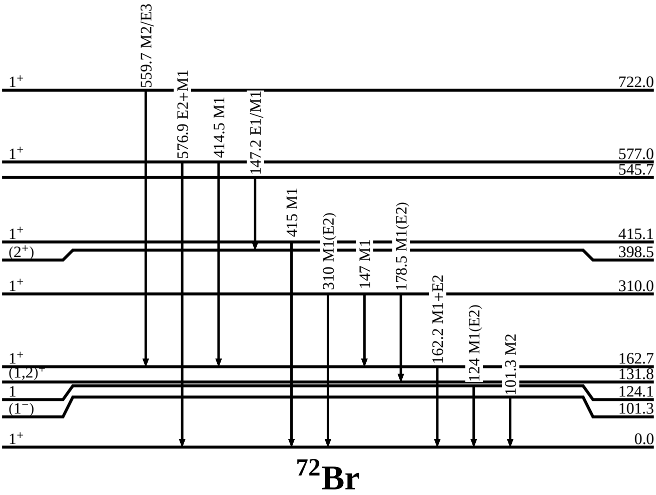


(a)

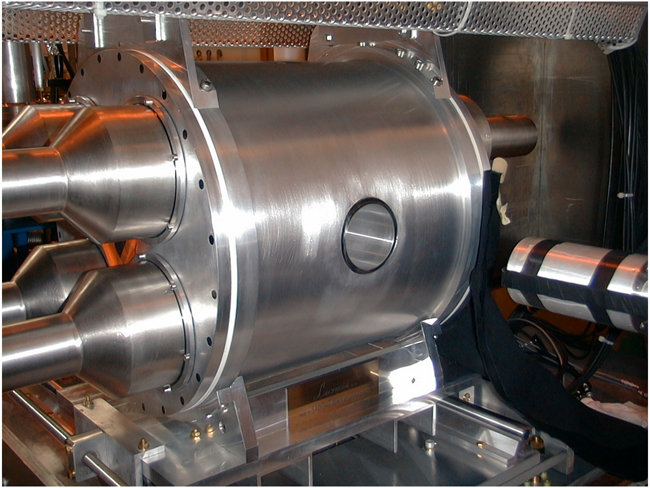


(b)

^{72}Br level scheme

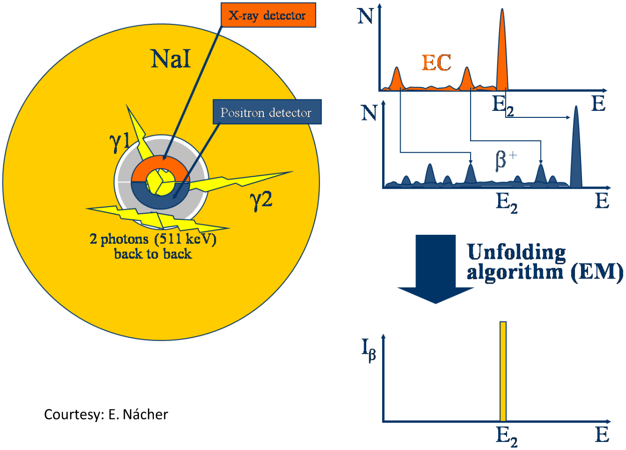


Total Absorption Spectroscopy



"Lucrecia"spectrometer installed at ISOLDE

Total Absorption Spectroscopy: Real conditions for EC/β^+ decay



Courtesy: E. Nácher

Deconvolution of data

- **Experimental data (d)** is influenced by the **Response function (R)** of our detector to the **feeding at a certain level (f)**:

$$d = R \otimes f \quad (1)$$

Or in matrix formalism:

$$d(i) = \sum_j R(i,j) \otimes f(j) \quad (2)$$

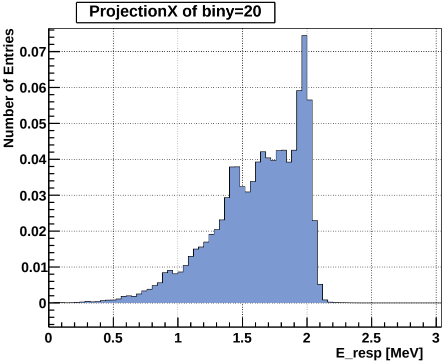
- Solve the **Inverse problem** with the *Expectation-Maximization Algorithm [Dem77]*:

$$f_k(j) = \frac{1}{\sum_i R(i,j)} \sum_i \frac{R(i,j) f_{k-1}(j) d(i)}{\sum_j R(i,j) f_{k-1}(j)} \quad (3)$$

- **RESPONSE MATRIX (R)** has to be obtained.
  - **Impossible to measure the experimental response** for all the possible monoenergetic gamma rays and betas in our beta decay scheme (up to Q_{EC}=5040 keV).
  - **Solution**: Use Monte-Carlo simulations in order to obtain the Response Function but we have to crosscheck it against experiment for radioactive sources.

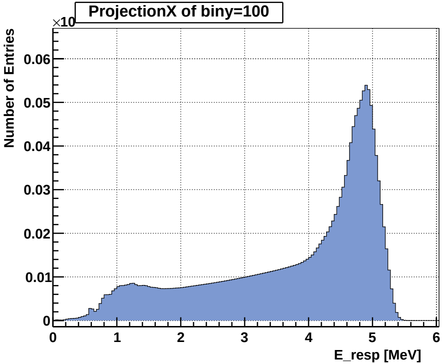
[Dem77] A. P. Dempster et al. J. R. Statist. Soc. B 39 (1977) 1

Feeding to a level at E_{exc}= 800 keV



$R(e^+, Q_{\beta+}\text{-800 keV}) + R(\gamma, \text{800 keV} \rightarrow \text{g.s.})$

Feeding to a level at E_{exc}= 4000 keV



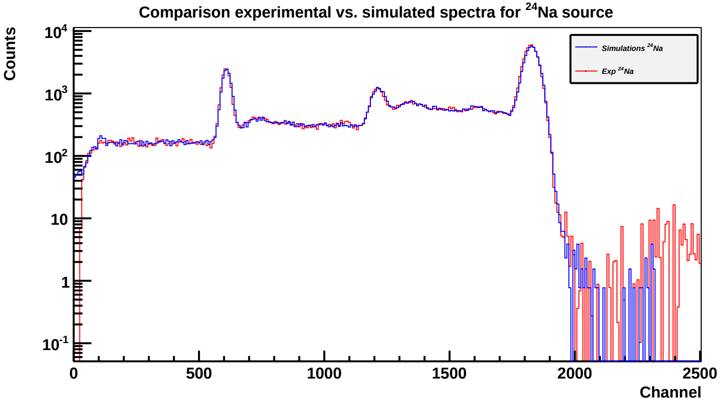
$R(e^+, Q_{\beta+}\text{-4000 keV}) + R(\gamma, \text{4000 keV} \rightarrow \text{g.s.})$

$Q_{\beta+} = Q_{EC}$ - 1022 keV = 4018 keV

Response function for gamma radiation takes into account Branching Ratios in the deexcitation

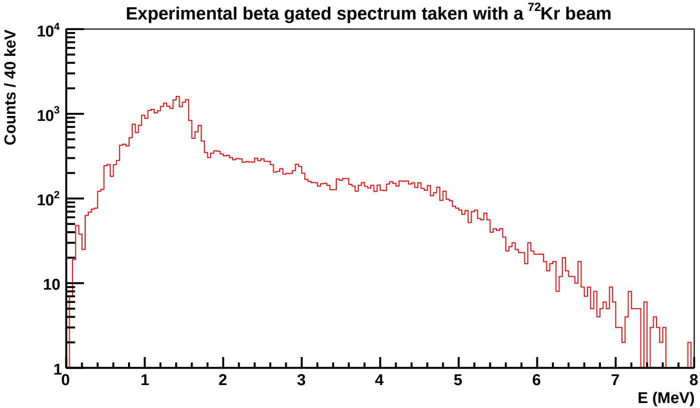
TAS Response Function: Validation of simulations

Comparison between the experimental and simulated response for a ^{24}Na source to validate our simulations.

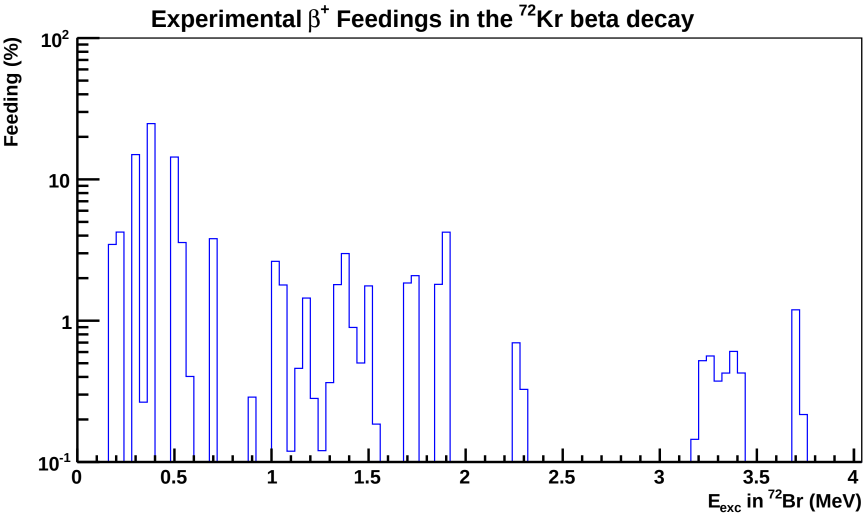


Beta gated analysis: experimental spectrum from *"Lucrecia"*

- Beta gated analysis in order to extract the β^+ component of ^{72}Kr EC/β^+ decay.

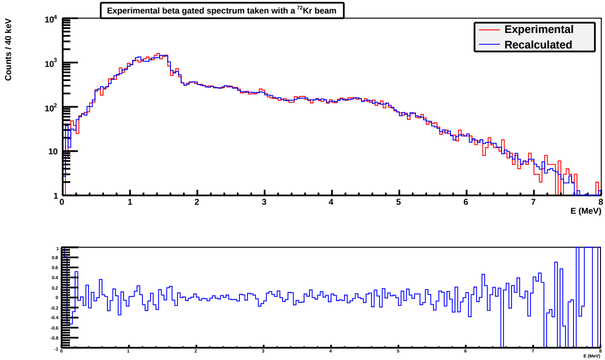


^{72}Kr β^+ decay feedings



Beta gated analysis: Check for the goodness of our results

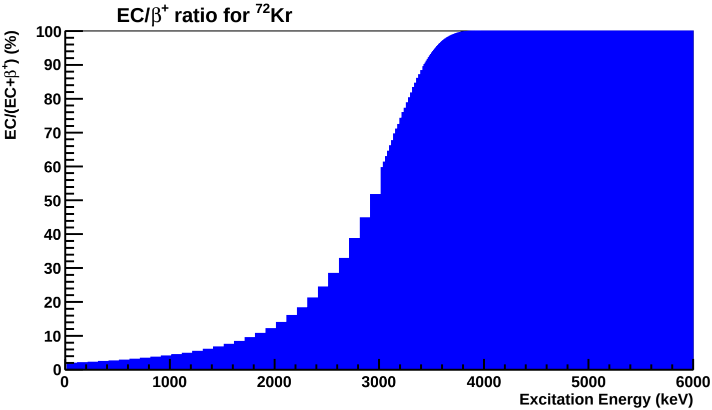
- Comparison: **experimental data** and **recalculated** from $d = R \otimes f$
- As well recalculated spectrum matches experimental one as reliable our analysis is.



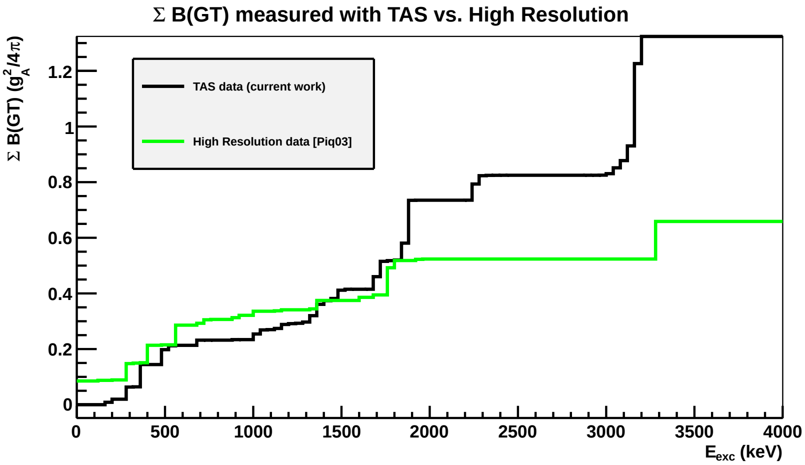
EC/β^+ fraction

To obtain the total EC+β^+ feeding, we multiply β^+ feeding by (1+EC/β^+) [Gov71]

Q_{EC}=5040 (80) keV and $Q_{\beta+}$=4018 keV



[Gov71] N.B. Gove et al., Nuclear Data Tables **10**, 205-317 (1971)



[Piq03] I. Piqueras et al., Eur. Phys. J. A **16**, 313-329 (2003)

Theoretical calculations

- Theoretical calculations shown in [Sarr09] have been performed with 3 different forces but we are going to compare only with the latest paramerization, SLy4:

- In our case the Fermi transitions are forbidden, so B(F)=0 and:

$$B(GT) = K \cdot \left(\frac{g_v}{g_a}\right)^2 \frac{1}{ft_{1/2}} \tag{4}$$

$\frac{g_A}{g_V}$ = -1.2695(29) [Yao06]

- Quenching factor(QF) = 0.77 [Sarr09]
  In order to take into account in an effective way all the correlations.

  Introducing a quenching factor QF:

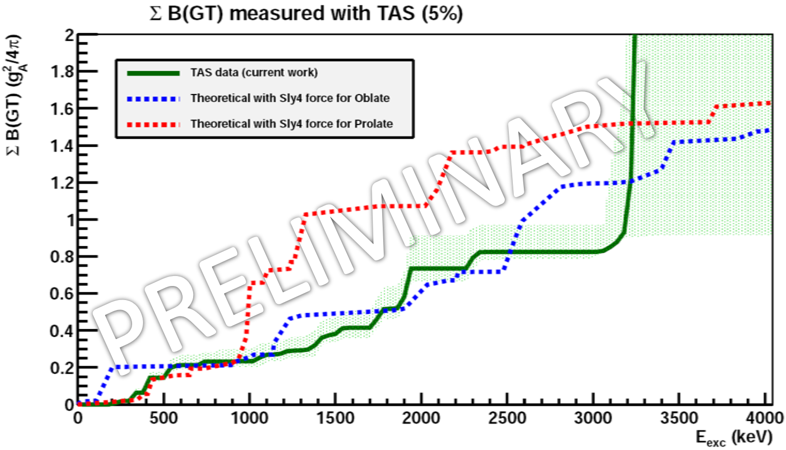
$$B'(GT) = K \cdot \left(QF \times \frac{g_v}{g_a}\right)^2 \frac{1}{ft_{1/2}} = QF^2 \times B(GT) \tag{5}$$

So the theoretical data is multiplied by $0.77^2 \approx 0.6$

[Sarr09] P. Sarriguren, Phys. Rev. C **79**, 044315 (2009)

[Yao06] W.M. Yao et al., J. Phys. G **33**, 1 (2006)

Preliminary Results: Accumulated B(GT)



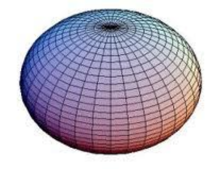
Shaded region shows the uncertainty derived only from the systematic errors due to the subtraction of contaminants. Statistical errors must be derived and added to this plot.

[Sarr09] P. Sarriguren, Phys. Rev. C **79**, 044315 (2009)

Conclusions

Results

1. Beta gated analysis suggests an **Oblate deformation of the ^{72}Kr ground state**.



2. **Conversion coefficients** for low energy transitions in the daughter nucleus ^{72}Br have been obtained.

3. Detailed information on the **low-spin structure** of ^{72}Br was extracted including spin-parities of several levels and multipolarity of some transitions.

To be done

- Perform analysis total (without any condition) to obtain the full B(GT) directly from experiment and to extend the energy window up to the Q_{EC}=5040 keV $\rightarrow$ Harder because of the background contamination

Acknowledgements

Thanks to:

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