Exotic shapes in exotic nuclei: Shape coexistence in unstable nuclei studied by Coulomb excitation

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CERN-PH/IS

CERN EP Seminar Monday 12 March 2007

Plan

- Nucleus, shape, deformation, shape coexistence ??
- How to measure the shape of the nucleus ?
- Radioactive ions beams
- Coulomb excitation of radioactive Kr beams
- Shape coexistence in light Kr isotopes
- Coulomb excitation of radioactive Se beams
- Shape coexistence at CERN-ISOLDE

Nuclear deformation

- The shape is a fundamental property of the nucleus

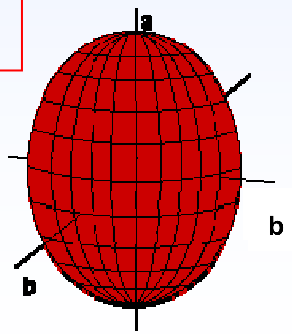
> Quantic system composed by A nucleons and driven by the nuclear interaction and the electromagnetic interaction
>
> $\Rightarrow$ Minimum of the potential energy for a non-spherical shape (shell effect)

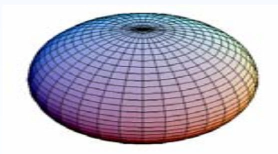
- The sphere is not the most common shape for a nucleus !!!
  $\Rightarrow$ Most of the nuclei are "deformed"

Picture of the ellipsoid : a, b, c, semi-axes

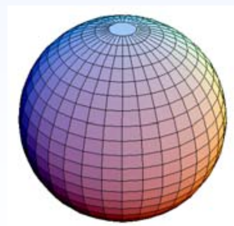
Axial symmetry b=c :
Pure quadrupole deformation

$$\beta = \frac{4}{3}\sqrt{\frac{\pi}{5}}\left(\frac{a-b}{R}\right)$$

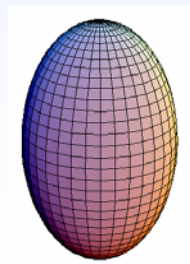




a < b
β < 0 : oblate



a = b
β = 0 : sphère



a > b
β >0 : prolate

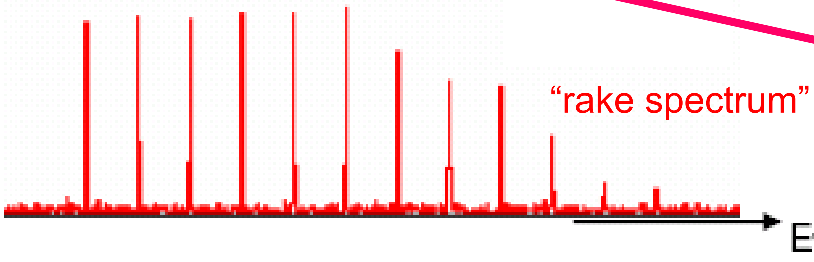
Rotation of a deformed nucleus

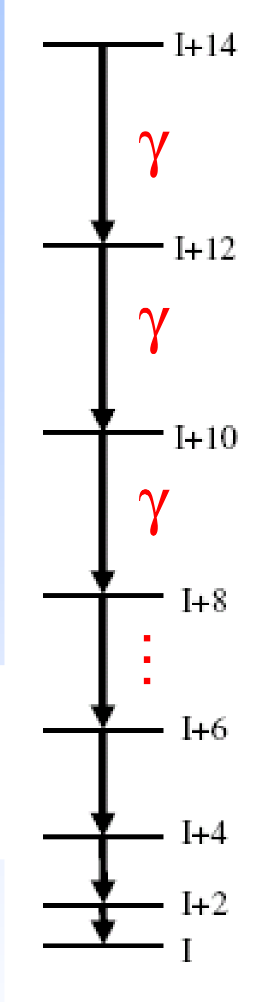
- A deformed nucleus has a rotational spectra

$$E(I) = \frac{\hbar^2}{2\mathcal{J}^{(0)}} I(I+1)$$

Rotor energy sequence

Static moment of inertia





$$\mathcal{J}^{(2)} = \left(\frac{\partial^2 E}{\partial I^2}\right)^{-1} = \frac{\partial I}{\hbar \partial \omega} \approx \frac{(\Delta I)^2}{\Delta E_\gamma}$$

dynamic moment of inertia : variation of the rigid rotor

CONSTANT

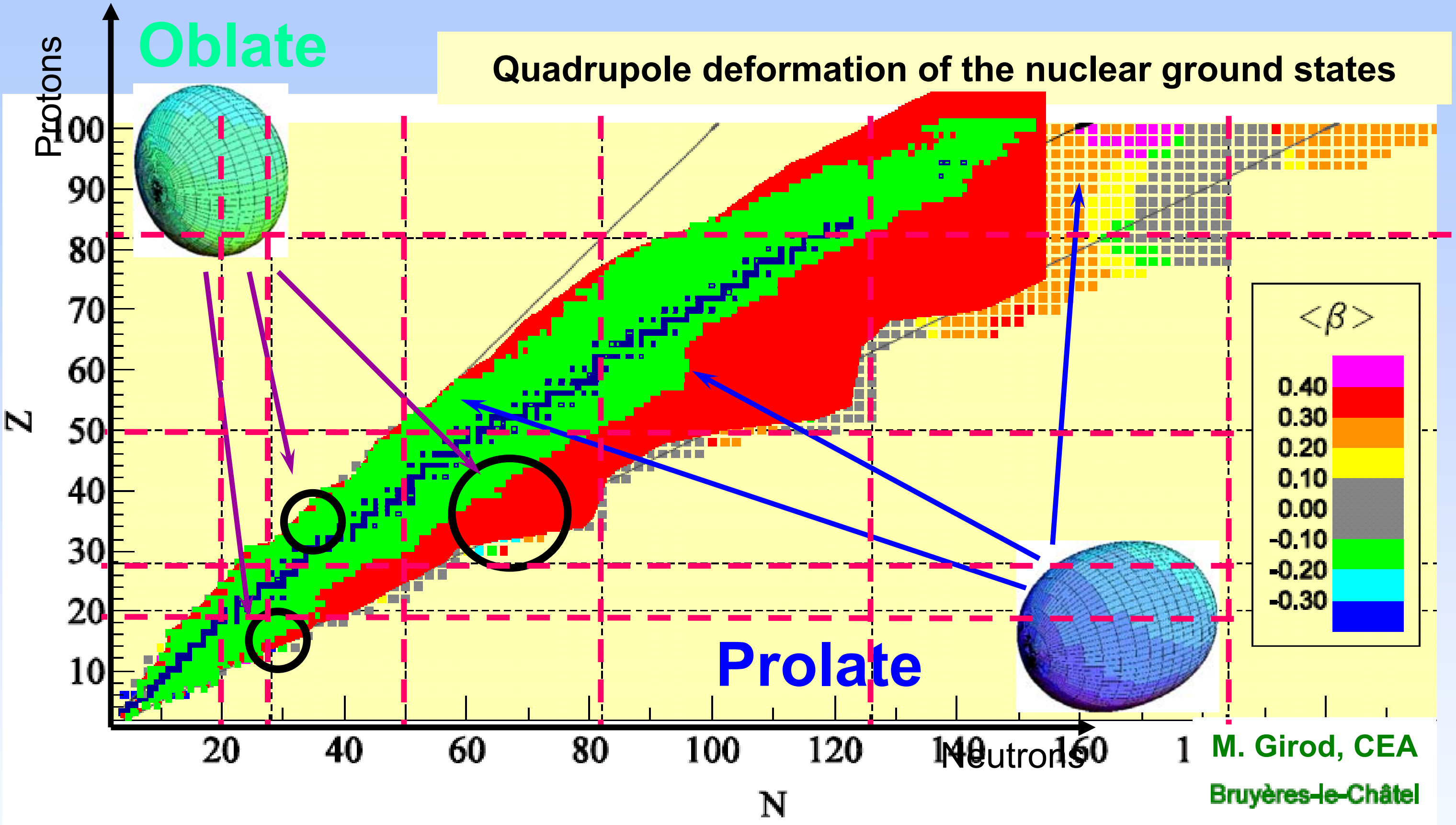
$$B(E\lambda, I_i \rightarrow I_f) = \frac{|\langle I_f \,||\, M(E\lambda) \,||\, I_i \rangle|^2}{2I_i + 1}$$

Reduced transition probability (collectivity)

$$eQ_0 = \sqrt{\frac{16\pi}{5}} \frac{1}{\sqrt{2I_i+1}} \frac{\langle I_f \| M(E2) \| I_i \rangle}{\langle I_i K 2 0 | I_f 0 \rangle}$$

Quadrupole moment (intrinsic properties)

The deformed world …

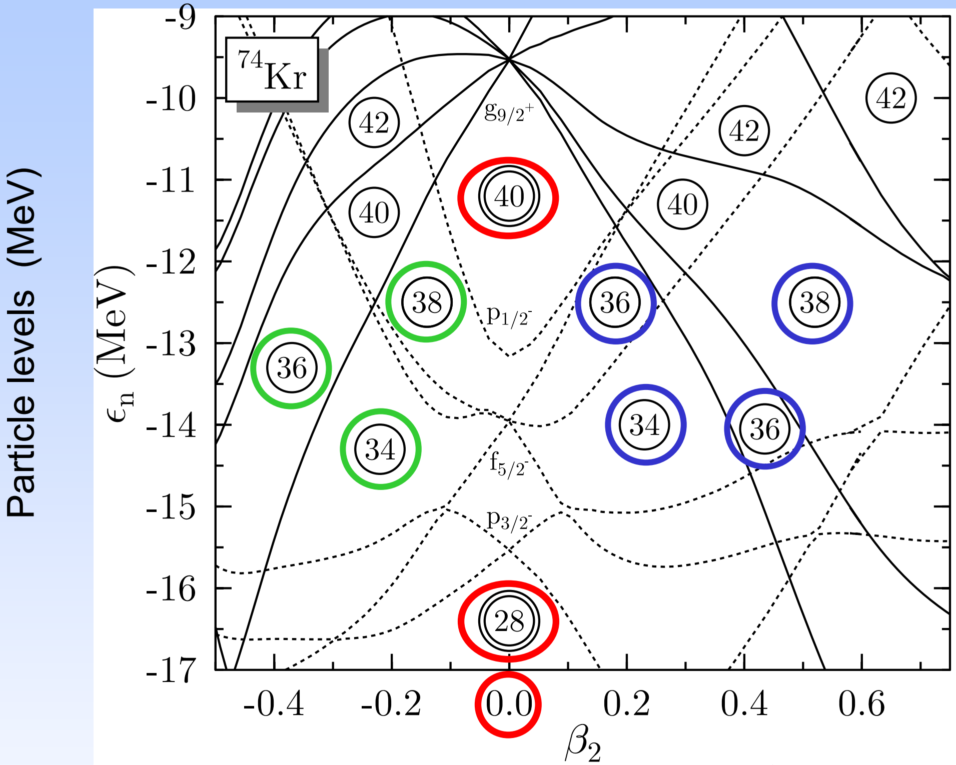


- For the magic numbers of the nuclear physic, the nucleus is spherical
- Between the magic number the nucleus is deformed

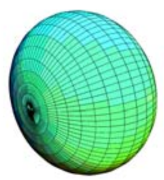
Deformation describe in term of magnetic dipole and quadrupole moments which are very sensitive to all types of correlations

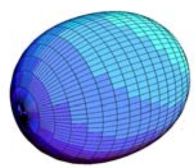
⇨ **Important benchmarks for nuclear models / theory**

The mass region A=70-80 close to N=Z line



Deformation parameter β





One particle level scheme in a phenomenological potential

→ Nilsson scheme

The nucleus chooses a configuration which minimizes its energy and presents a maximal gap with the next orbital

→ energy gap

- Spherical nuclei

➡ Magic number

For nucleons number 34,36,38

- Gap for prolate deformation
- Gap for oblate deformation

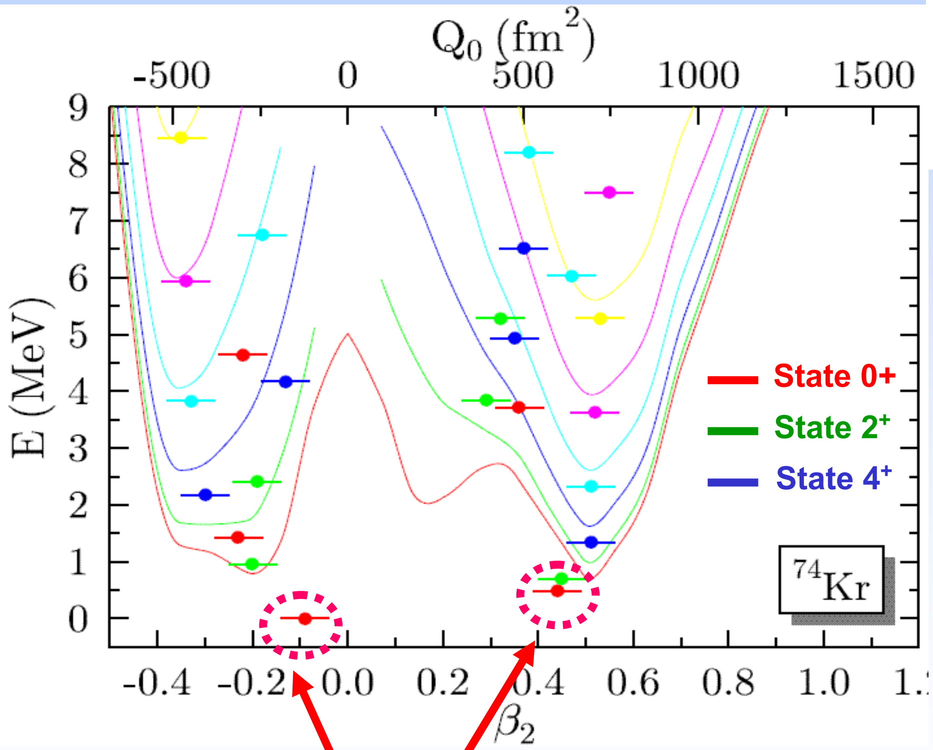
✓ **Shape coexistence** expected in nuclei Z = **34, 36, 38**

$^{72}_{36}Kr_{36}$ $^{74}_{36}Kr_{38}$ $^{68}_{34}Se_{34}$ $^{70}_{34}Se_{36}$

✓ Possibility to study the **oblate deformation**

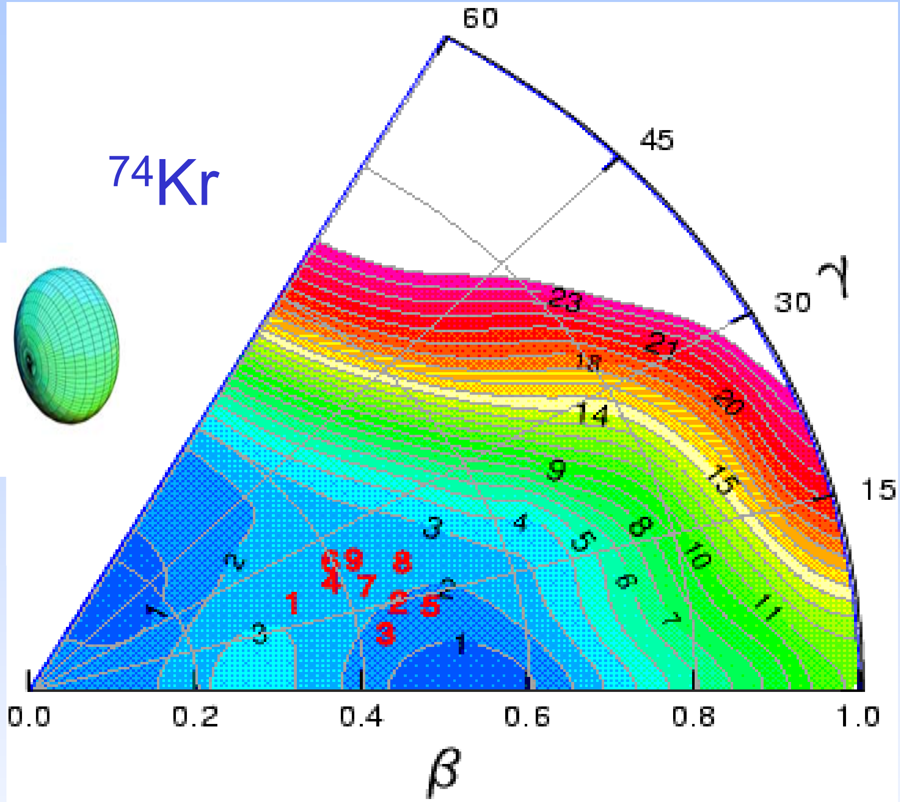
Shape coexistence in the light krypton

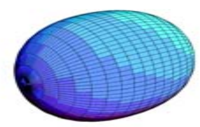
HFB+Gogny D1S
M. Girod *et al.*



oblate

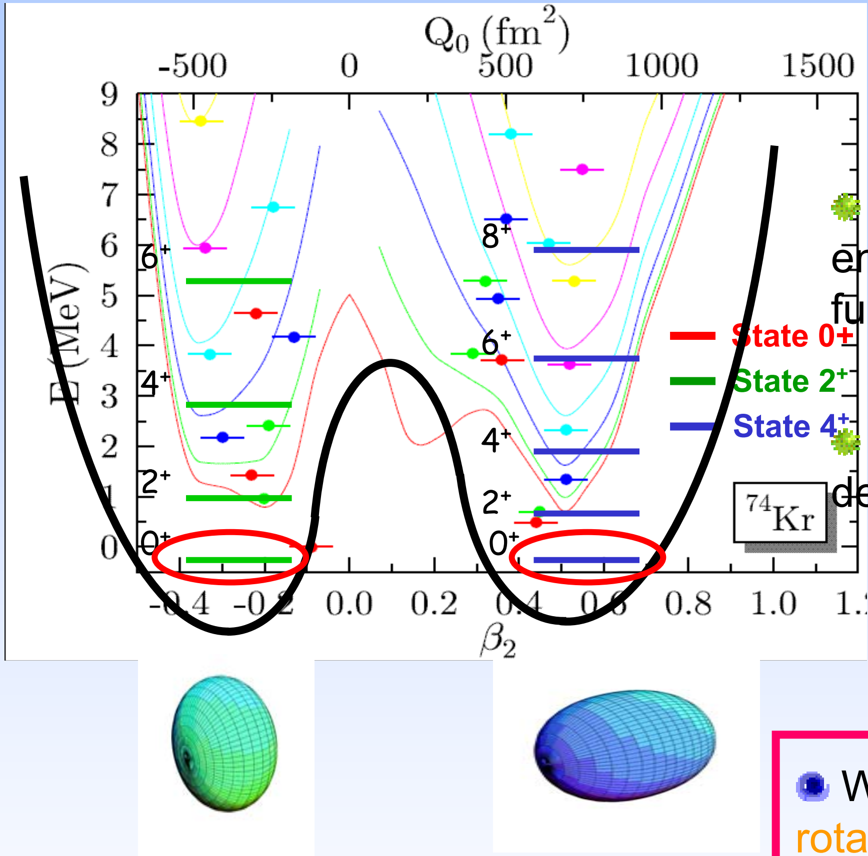
prolate





GCM-HFB (SLy6)
M. Bender, P. Bonche et P.H. Heenen,

The mass region A=70-80 close to N=Z line



GCM-HFB (SLy6)

M. Bender, P. Bonche et P.-H. Heenen,

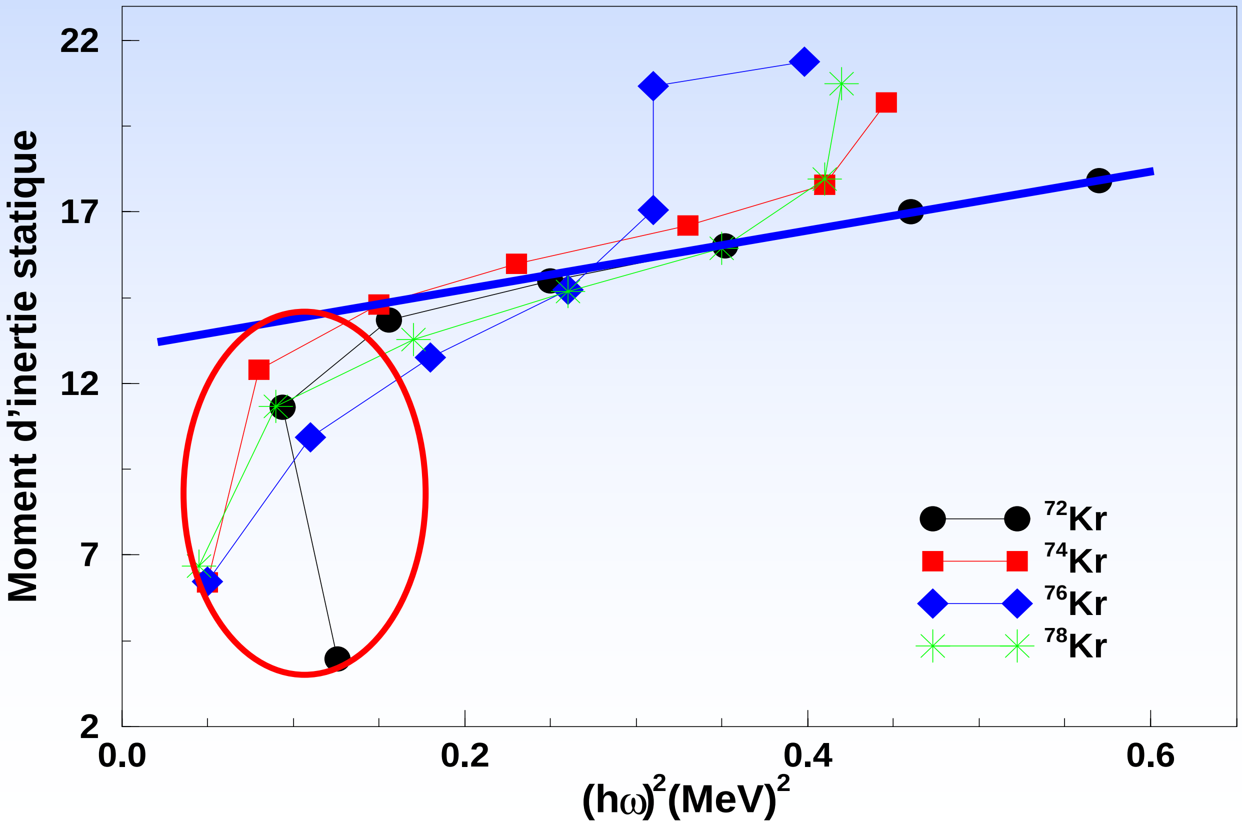
- A low lying 0^+ state is expected at low energy, with a high mixing of the wave function
- 2 rotational bands with an opposite deformation built on each 0^+ state

- What is the relative position of the rotational states ?
- Low lying 0^+_2 state ?
- Deformation of the rotational band ?
- Mixing of the wave function ?

First studies on Shape Coexistence in Kr isotopes

- High spins studies populated by fusion-evaporation reaction
  - Measure of the static moment of inertia of : ^{72}Kr,^{74}Kr, ^{76}Kr et ^{78}Kr

S. M. Fischer et *al.*, Phys. Rev. Lett. **87**, (2001)
N. S. Kelsall et *al.*, Phys. Rev. *C* **64**, (2001)
D. Rudolph et *al.*, Phys. Rev. *C* **56**, (1998)
C. J. Gross et *al.*, Nucl. Phys. *A* **501**, (1989)



Static moment of inertia for a **rotor = constant**

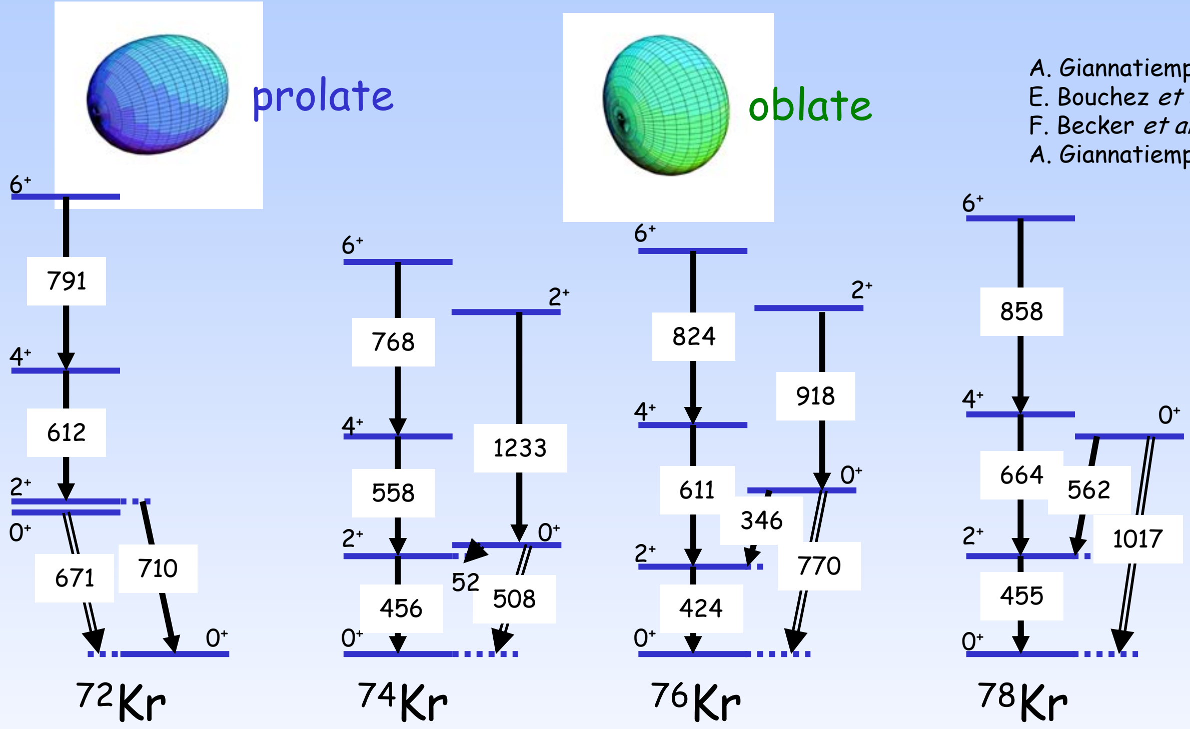
In a normal nucleus :
~ a + b $(\hbar\omega)^2$

Perturbation of the collectivity at low spins

First studies on Shape Coexistence in Kr isotopes

- Identification of the low lying 0^+ state, possible candidate for the shape isomer.

A. Giannatiempo *et al.*, Phys. Rev. C **72** (2005)
E. Bouchez *et al.* Phys. Rev. Lett., **90** *(2003)*
F. Becker *et al.*, Eur. Phys. J. A **4** (1999)
A. Giannatiempo *et al.*, Phys. Rev. C **52** (1995)



72(6) 84(18) 79(11) 47(13) Transition strenght : $\rho^2(E_0).10^{-3}$

- **Shape inversion** for ^{72}Kr

- **^{74}Kr is a transitional nucleus** where the mixing of the wave function is maximal

Complete measure of reduced transition probability B(E2) and static quadrupole moment → **Coulomb excitation**

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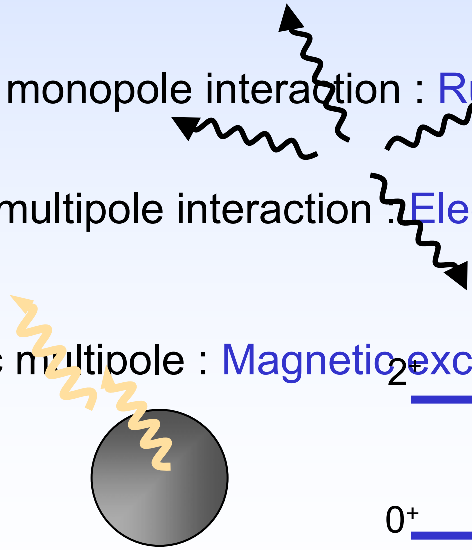
How to measure the shape of the nucleus ?

.... by Coulomb excitation

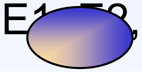
- The electric quadrupole moment of a nucleus is measured through its interaction with an electromagnetic field created by a probe nucleus

- The electromagnetic interaction is the only forces involved in the collision

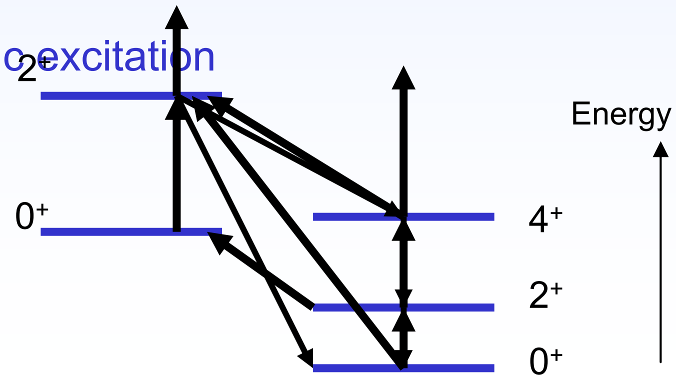
NO nuclear reaction



- Electric monopole – Electric monopole interaction : Rutherford scattering
- Electric monopole – Electric multipole interaction : Electric excitation E1, E2, … ,Eλ

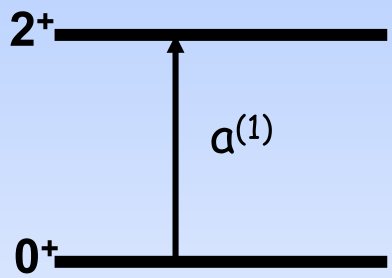


- Electric monopole – Magnetic multipole : Magnetic excitation M1, M2, … ,Mλ



Coulomb excitation et re-orientation effect

1er order:



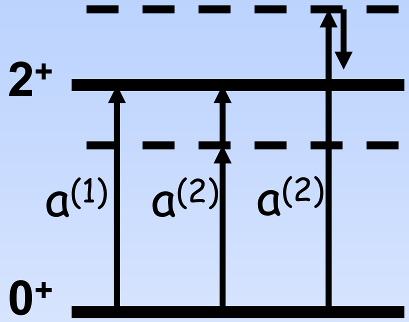
$$a^{(1)} \propto \langle I_f \| \mathrm{M}(E2) \| I_i \rangle$$

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_{Ruth}}{d\Omega} P_{i \to f}$$

$\propto B(E2) \propto \beta^2$

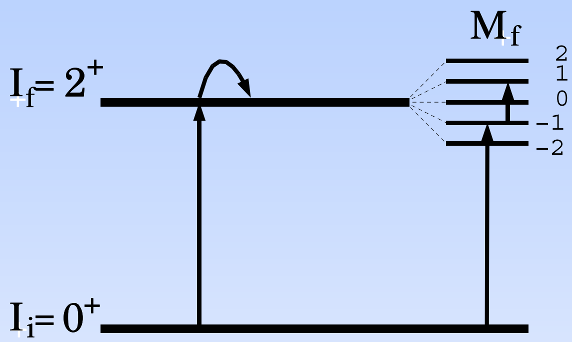
absolute deformation !

2nd order:



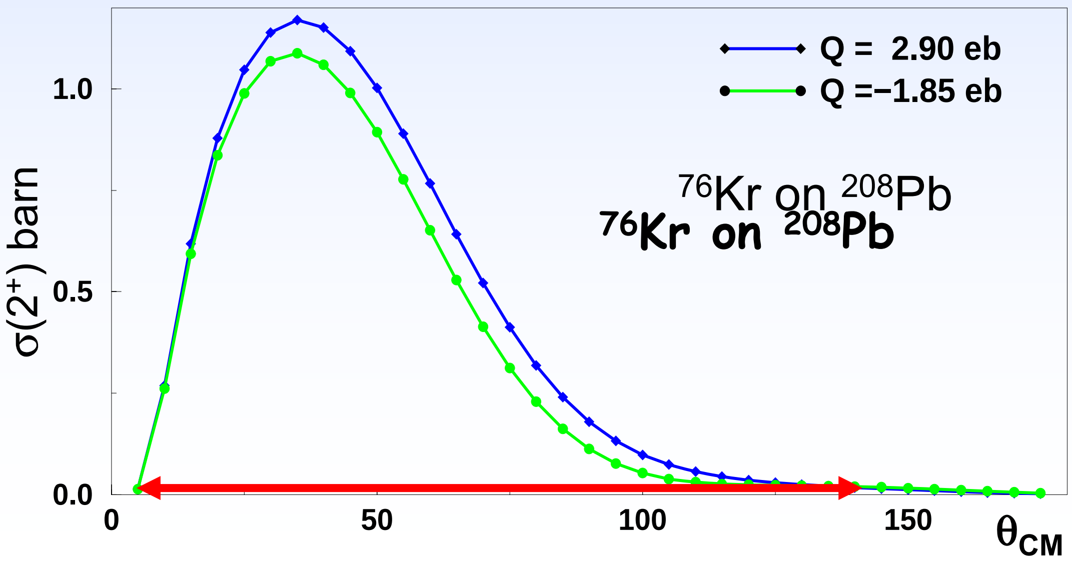
$$a^{(2)} \propto \sum_j \langle I_f \| \mathrm{M}(E2) \| I_j \rangle \langle I_j \| \mathrm{M}(E2) \| I_i \rangle$$

Re-orientation effect



$$a^{(2)} \propto \langle I_f \| \mathrm{M}(E2) \| I_f \rangle \langle I_f \| \mathrm{M}(E2) \| I_i \rangle$$

Cross section → Q_0



- Particle detector covering a large range in scattering angle
- High efficiency and selectivity

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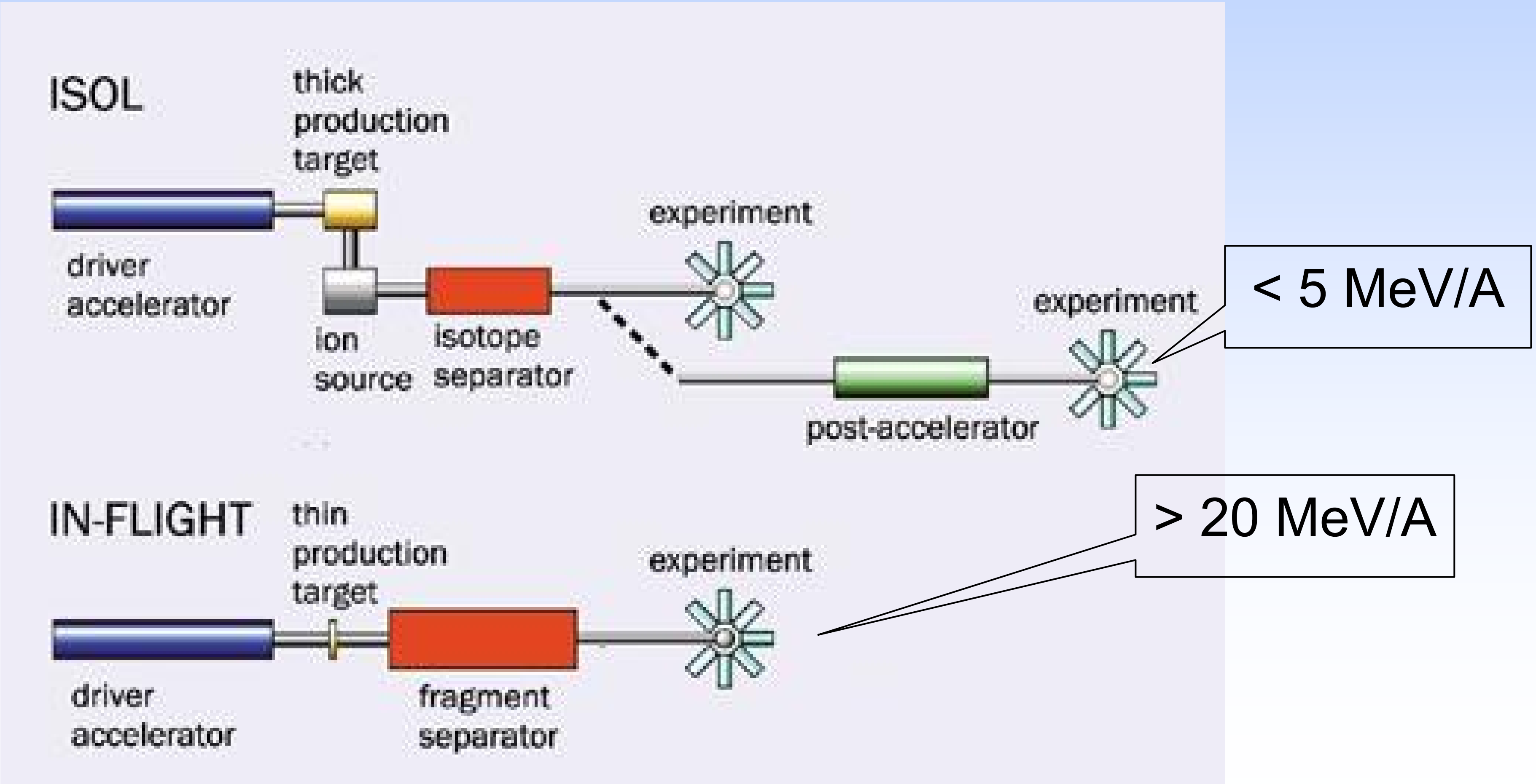
Radioactive ions beam

radioactive target in not possible so we need a
radioactive ions beams bellow the coulomb barrier

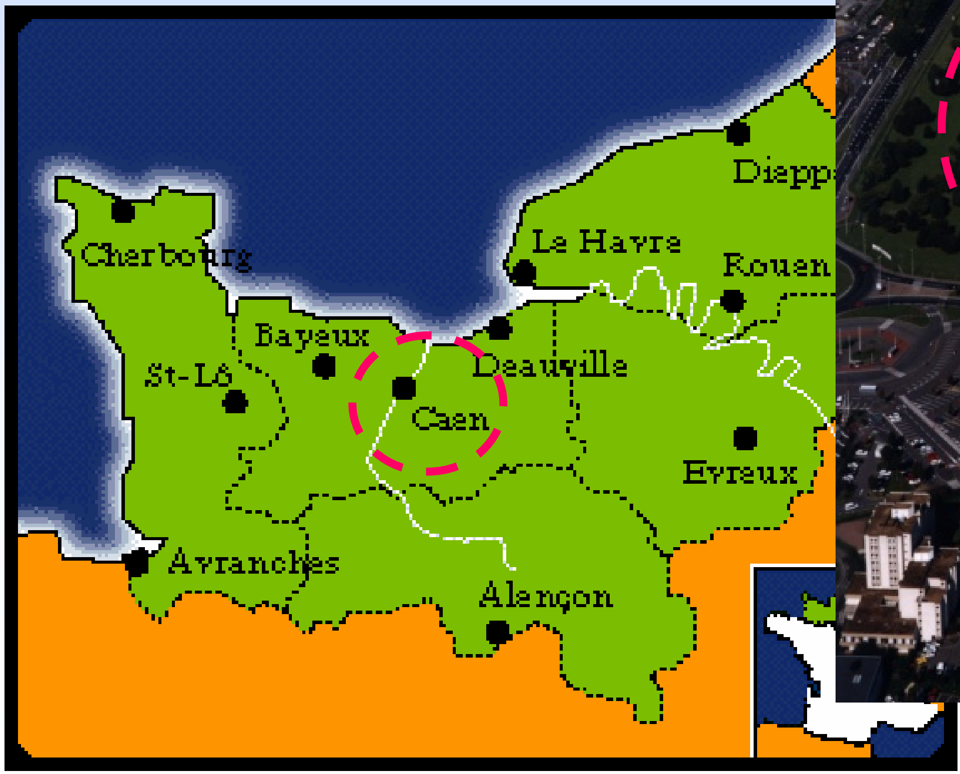


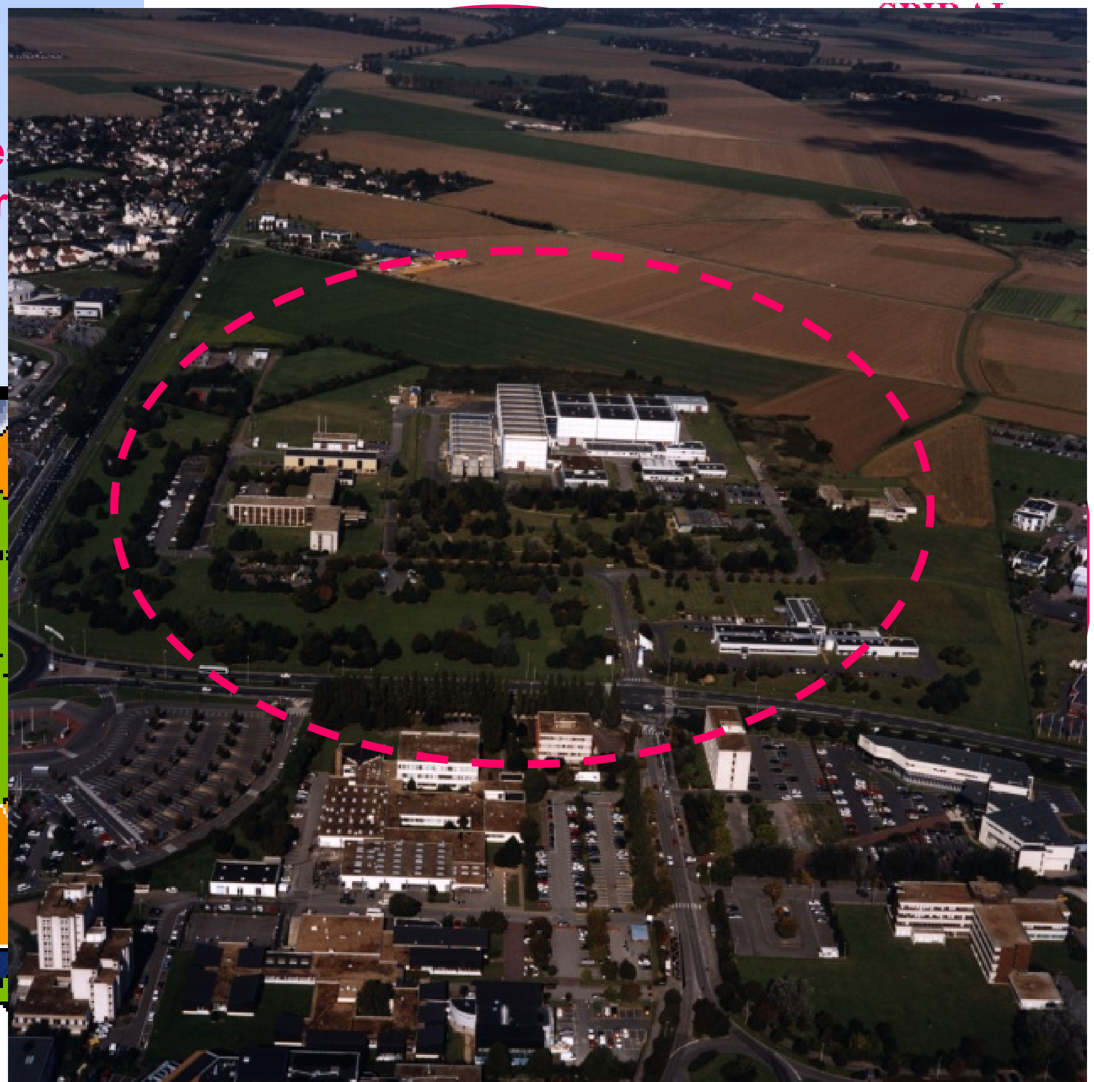
ISOL beam @ SPIRAL –GANIL France

ISOL beam production and post-acceleration

Primary beam acceleration

Ions source and injector





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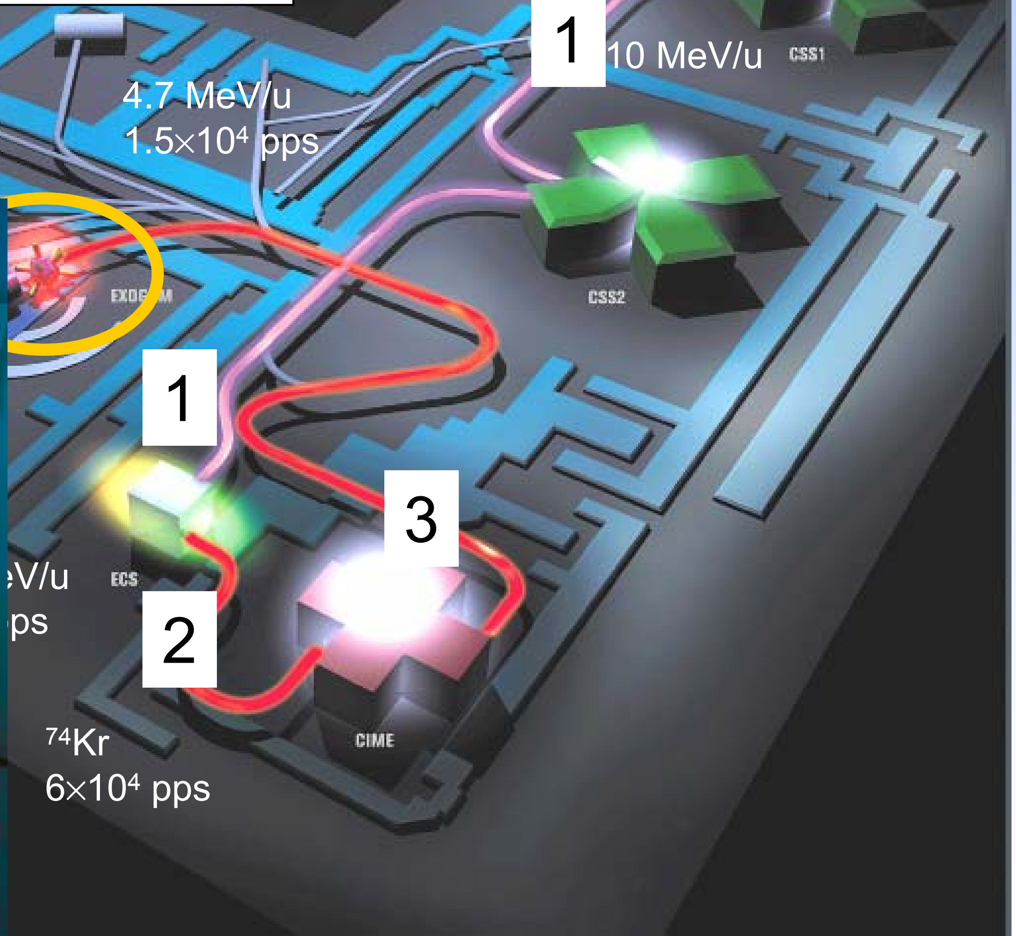
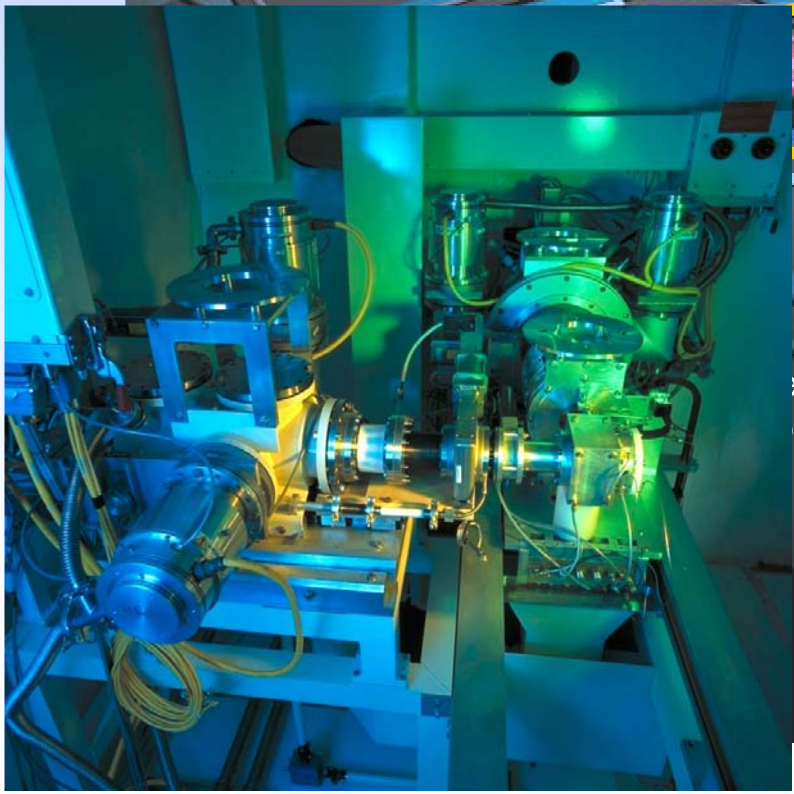
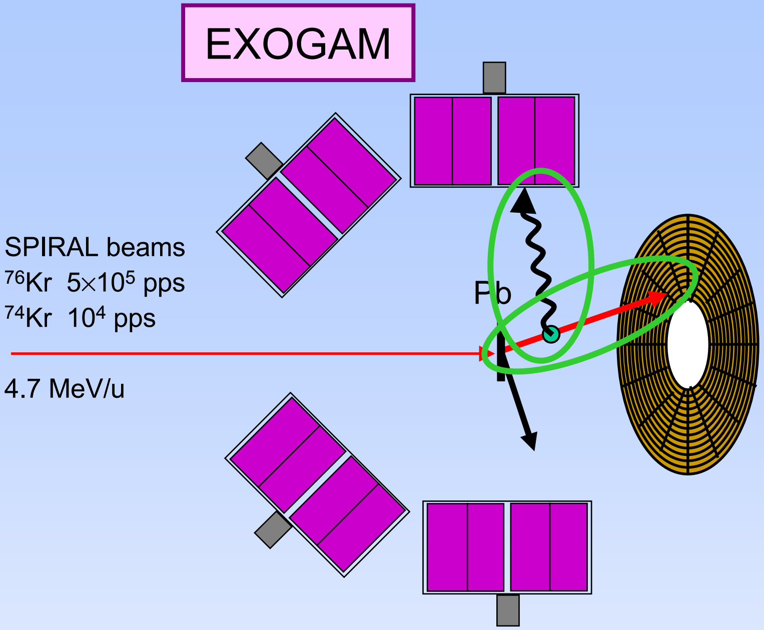
^{74}Kr and ^{76}Kr beam @ SPIRAL

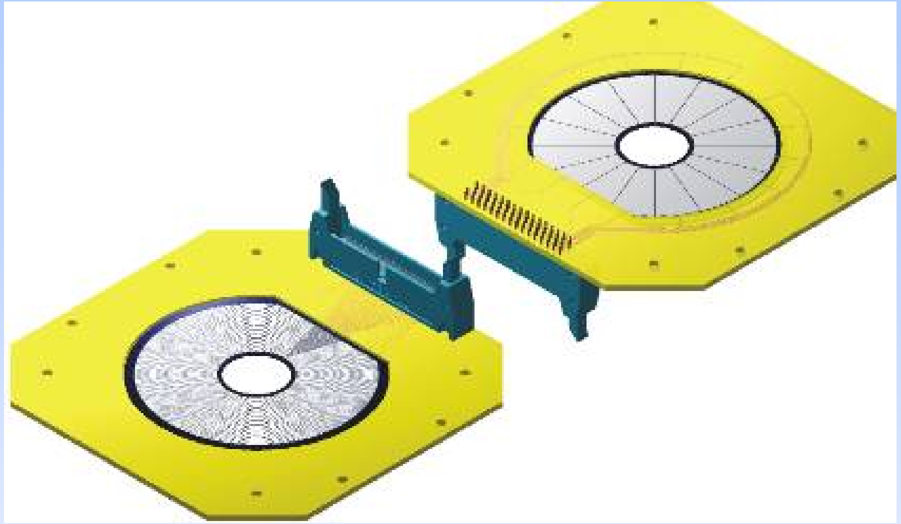
1. The radioactive ^{74}Kr ions beam is produced by the fragmentation of a high energy beam of ^{78}Kr on a carbon target.





Experimental setup

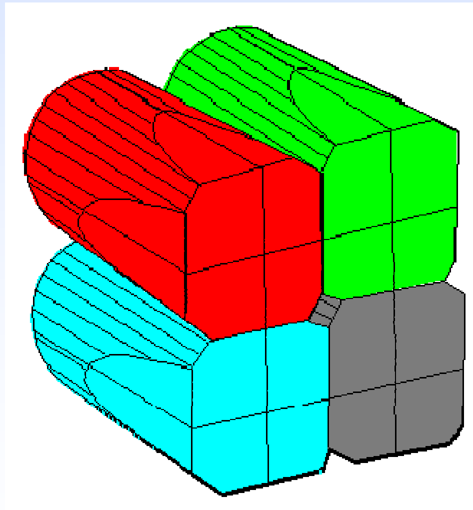




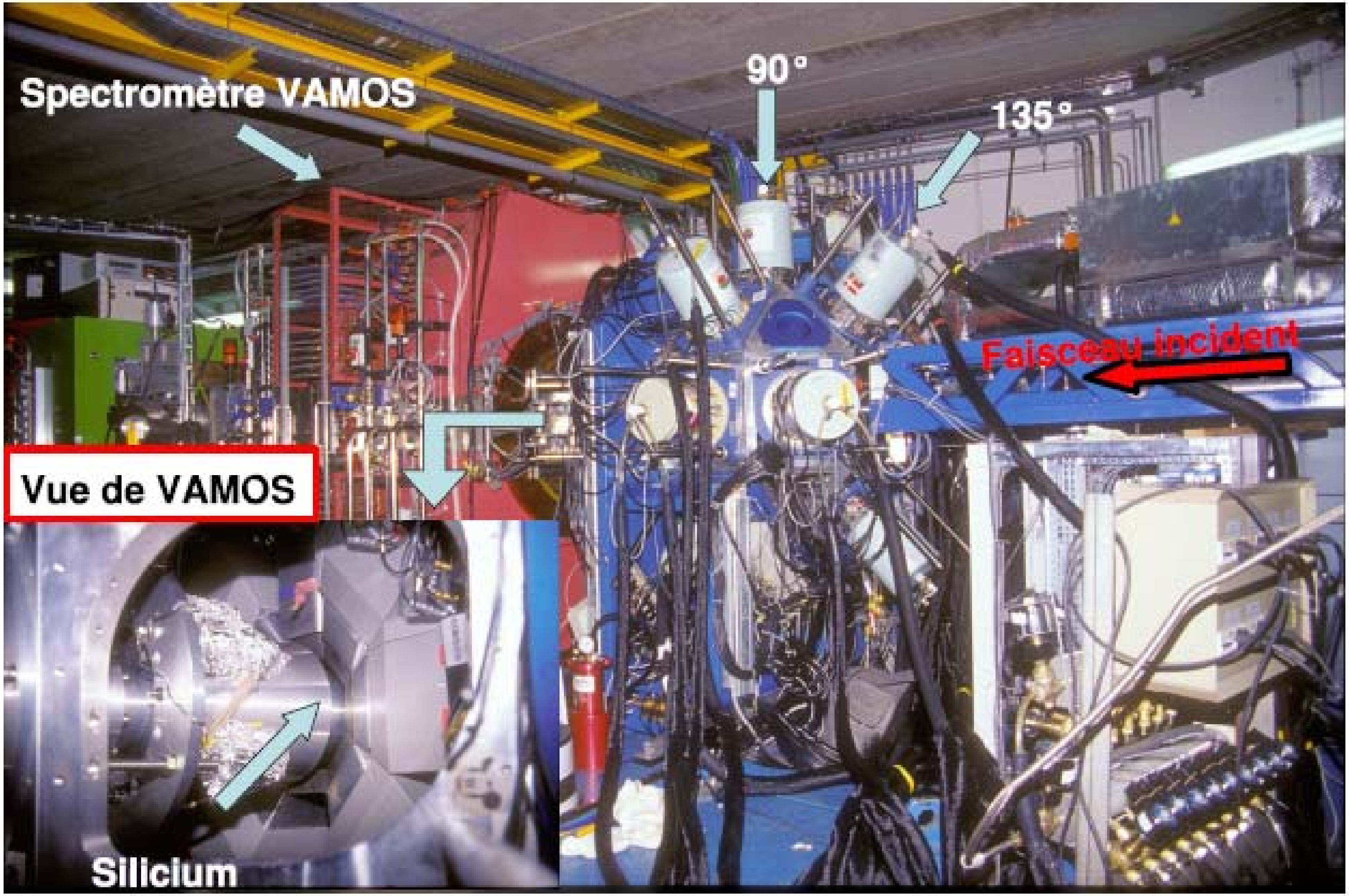
- Highly segmented particle detector 16 concentric ring and 16 sector :

- Segmentation of the Silicon + Segmentation of EXOGAM
  → Doppler Correction

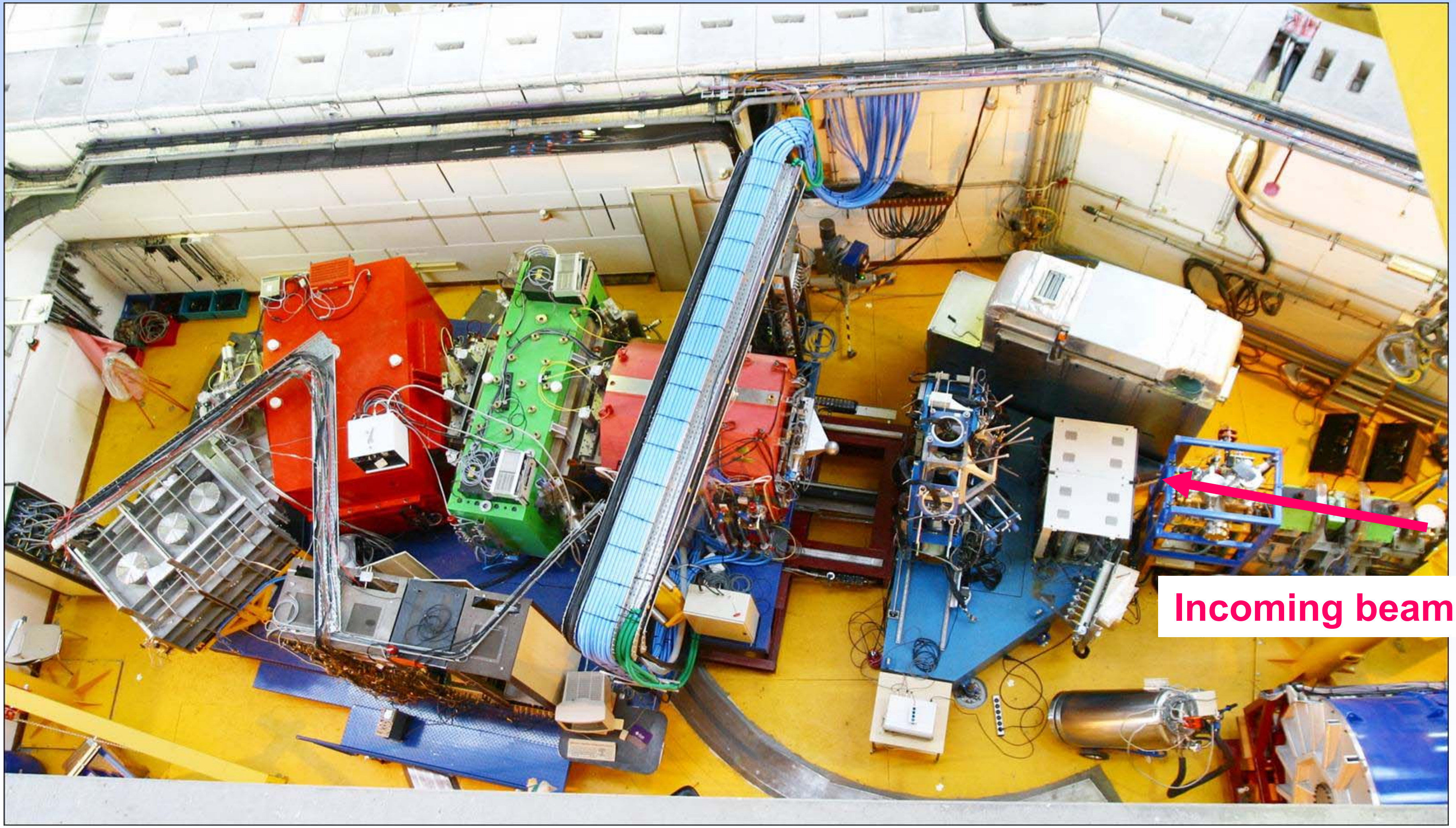
- Differential cross section



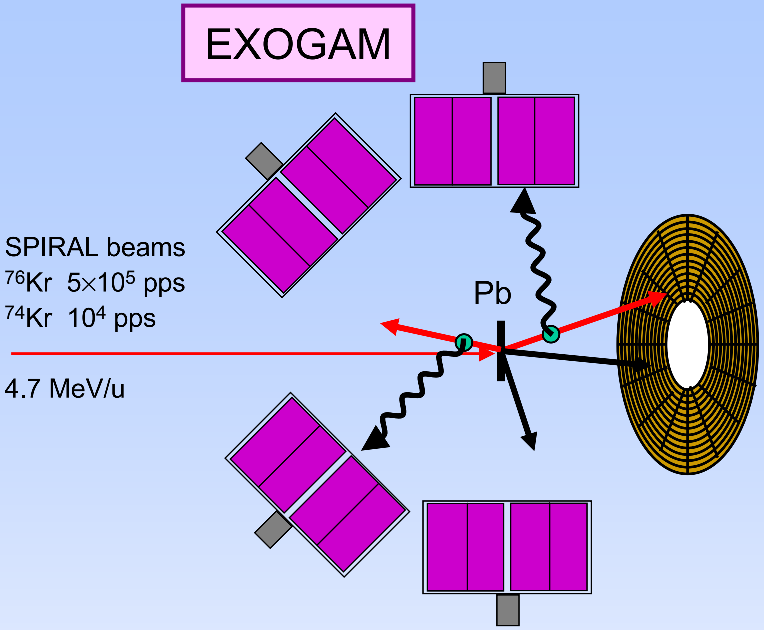
Experimental setup



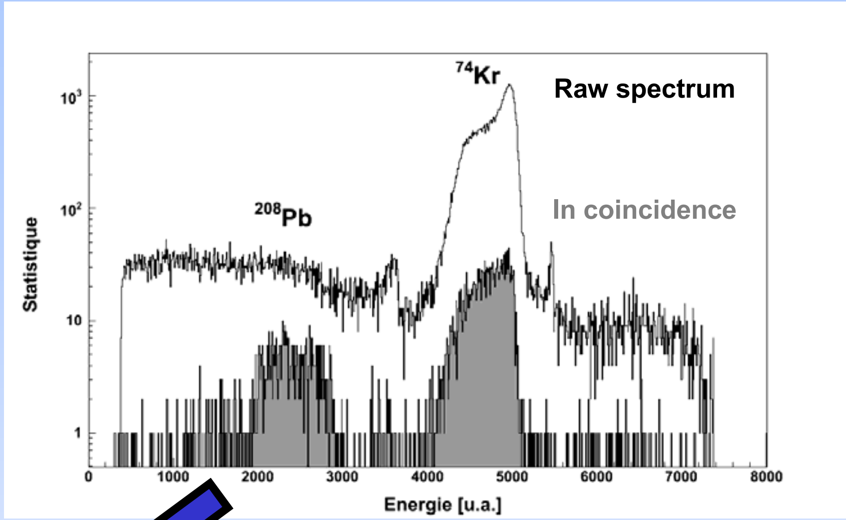
Experimental setup



Experimental results

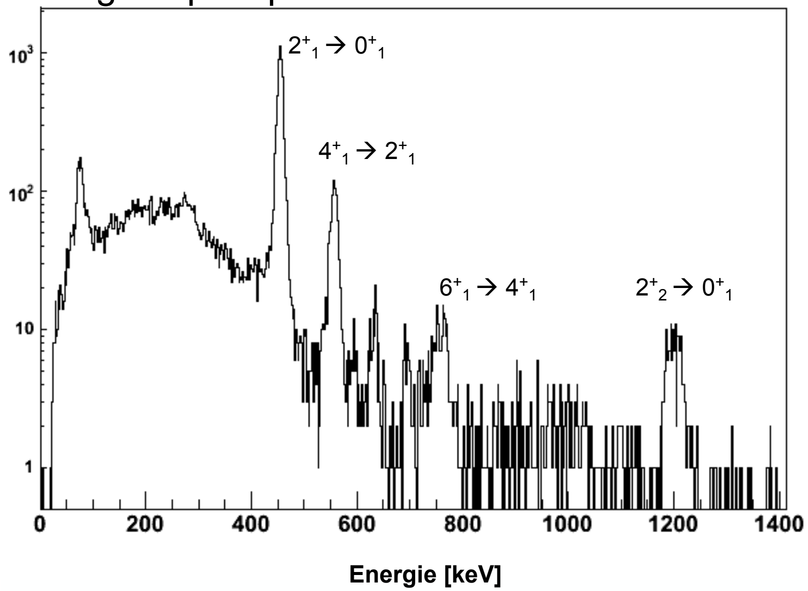


Silicon spectrum



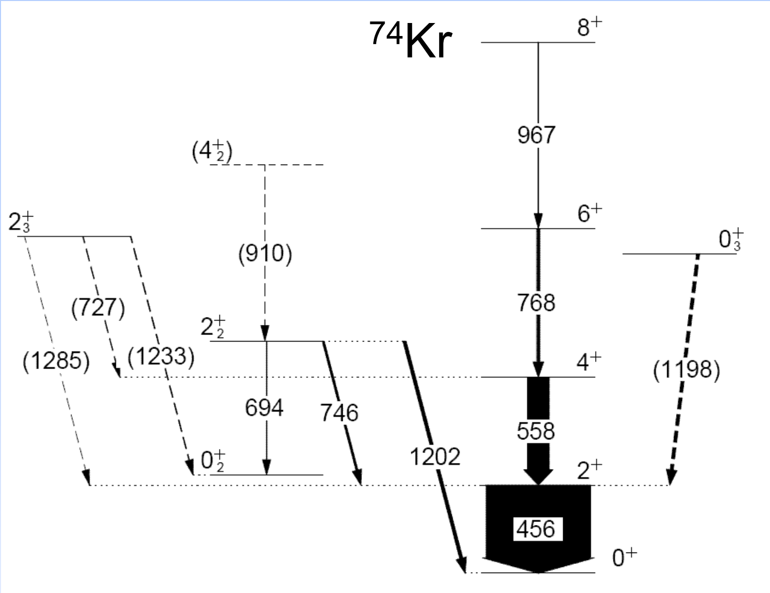
Small impact parameter → Pb detected

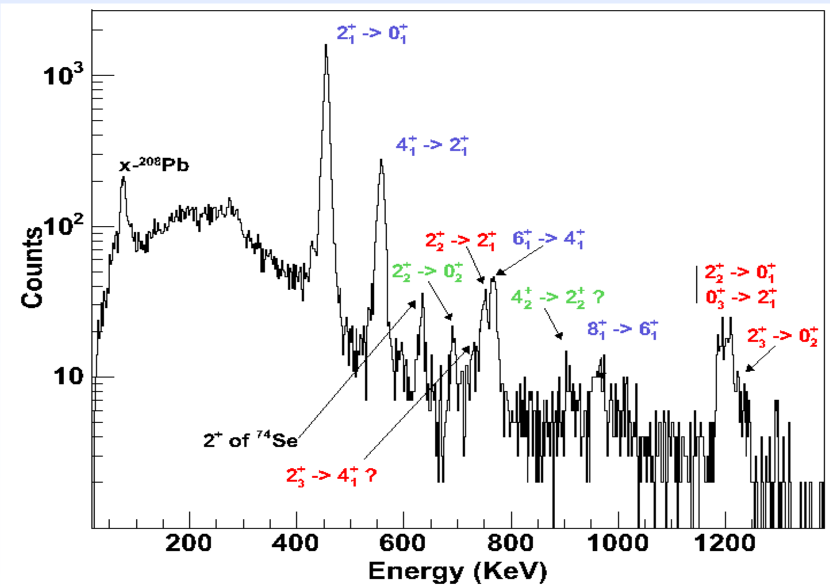
Large impact parameter → Kr detected



Coulomb excitation analysis with GOSIA*

*D. Cline, C.Y. Wu, T. Czosnyka; Univ. of Rochester





Matrix elements adjustment (transitional and diagonal) in order to reproduce the experimental data : $I_\gamma(\theta_{Kr})$

- $I_\gamma(\theta_{Kr})$: differential cross section

  θ_{cm} → [24 ,144.5] degrees

➡ Weak constraint due to the limited statistic

- Additional constraints :

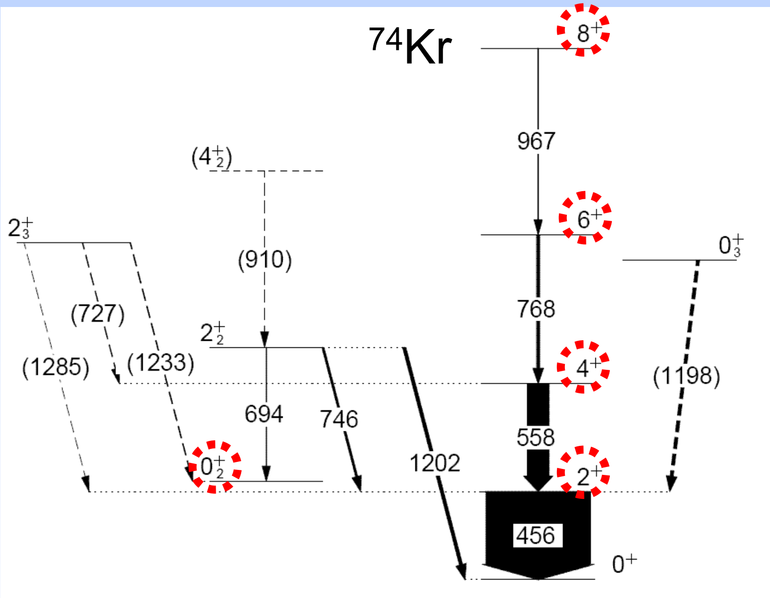
  spectroscopic data

  - Lifetime
  - Branching ratio
  - Mixing E2/M1

Coulomb excitation analysis with GOSIA*

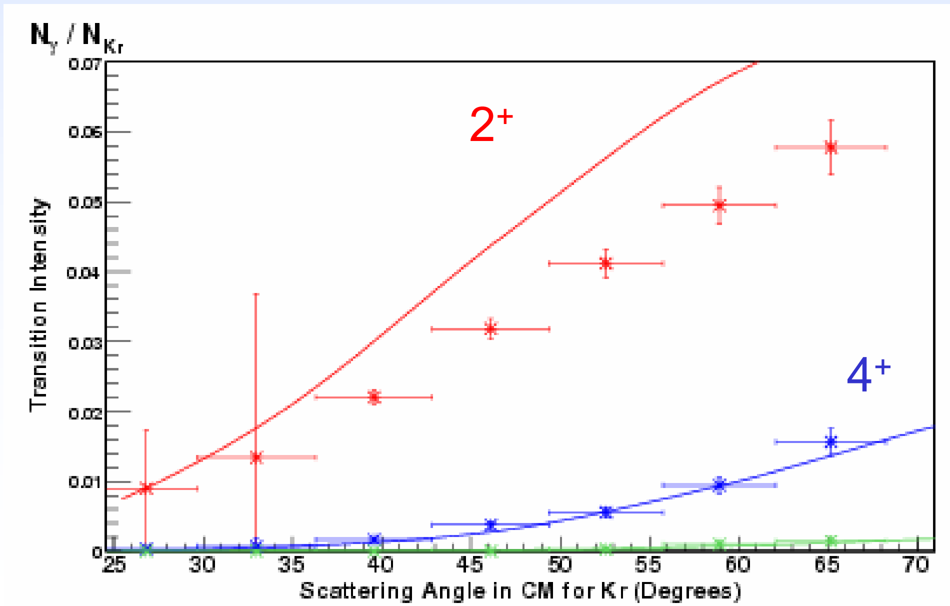
*D. Cline, C.Y. Wu, T. Czosnyka; Univ. of Rochester

- Lifetime are the strongest constraints because directly linked to the transitional matrix elements (transition probability)



☞ 5 lifetime involving populated states were already measured

→ compatible with our measure ?



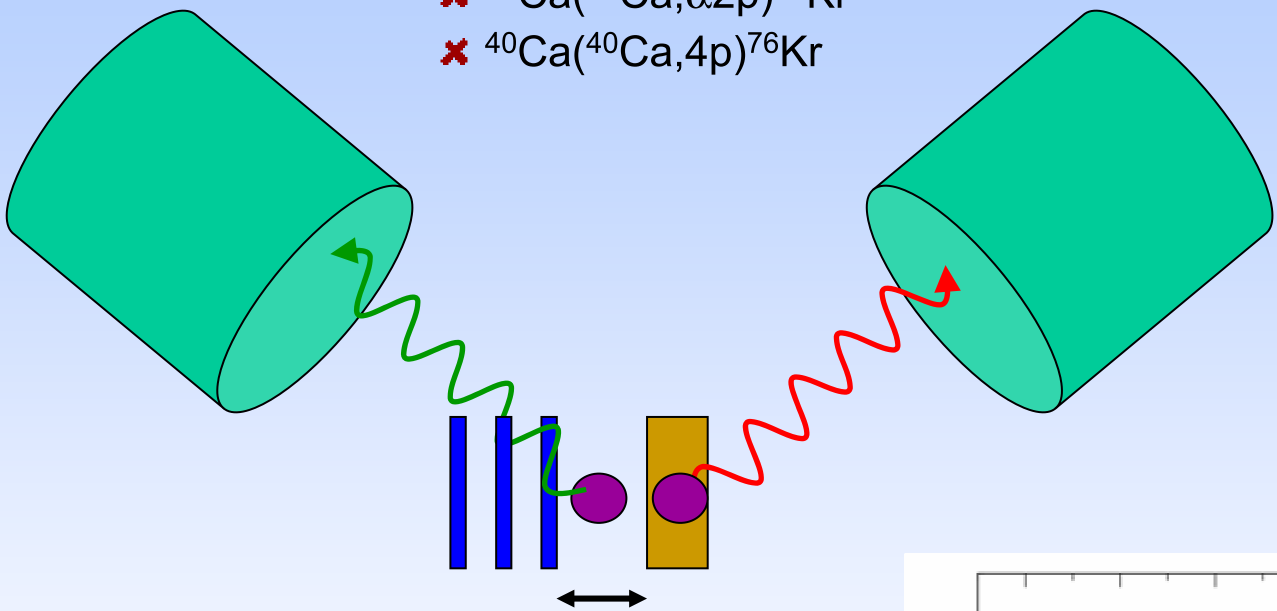
Published lifetime are incompatible with our data

Pico-second lifetime measurement using RDDS

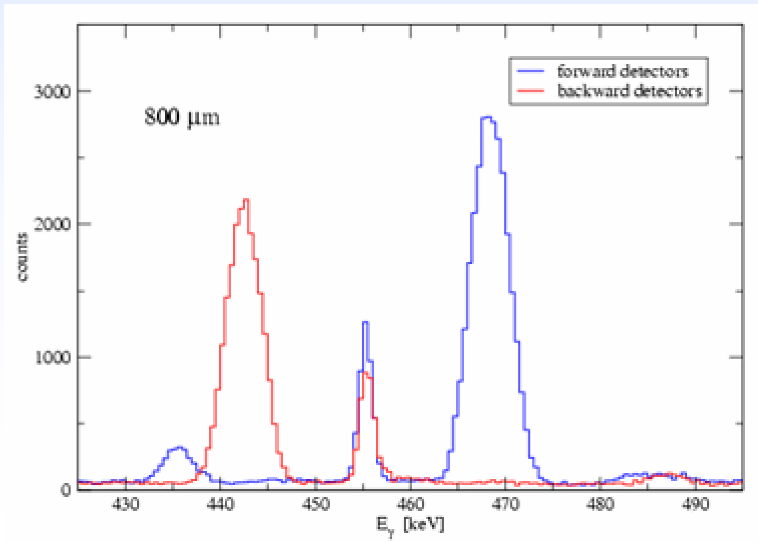
Recoil Distance Doppler Shift

The ^{74}Kr and ^{76}Kr nuclei are populated at high spins by a fusion-evaporation reaction :

- $^{40}Ca(^{40}Ca,\alpha 2p)^{74}Kr$
- $^{40}Ca(^{40}Ca,4p)^{76}Kr$



Target and stopper separated by a fix distance



γ rays of desexcitation emitted :

- In flight $\Rightarrow$ shifted by the Doppler effect
- Stopped $\Rightarrow$ Energy E_0

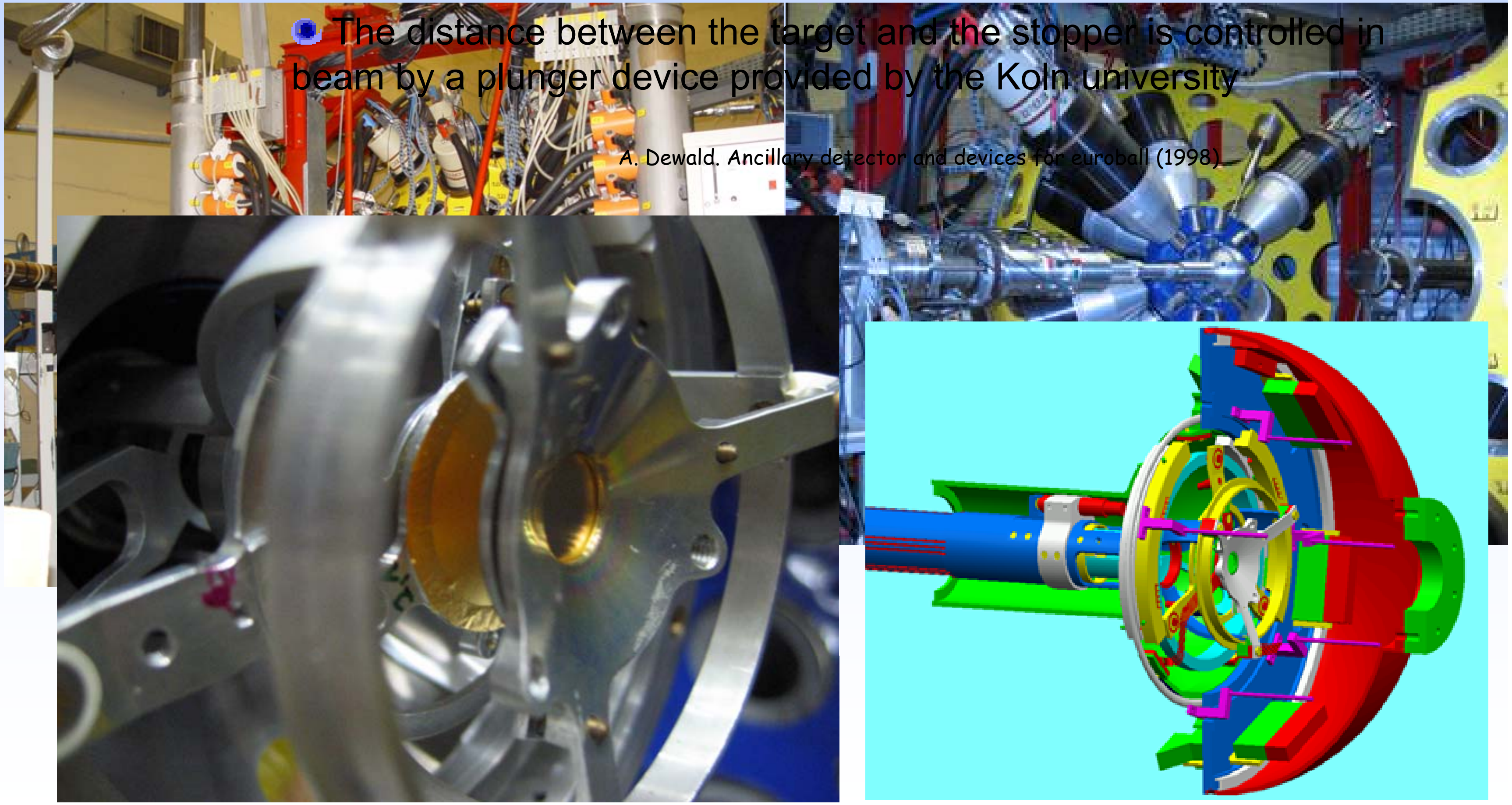
Pico-second lifetime measurement using RDDS

Experiment performed at the tandem accelerator of Legnaro in November 2004

- The γ rays are detected in the GASP spectrometer (32 HPGe germanium detectors)

- The distance between the target and the stopper is controlled in beam by a plunger device provided by the Koln university

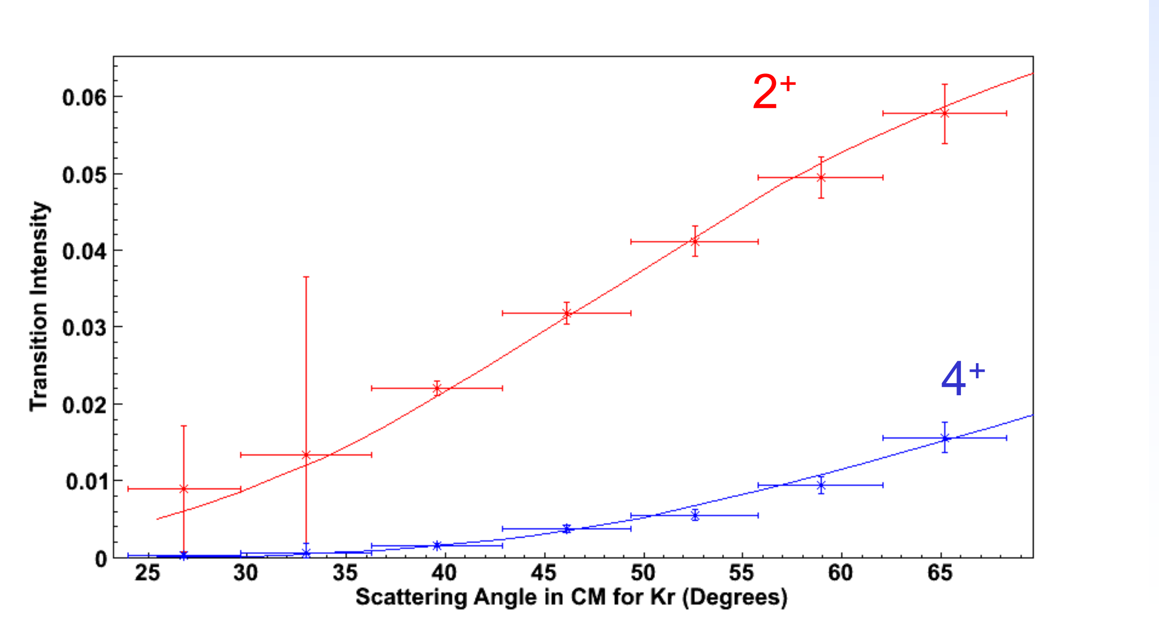
A. Dewald. Ancillary detector and devices for euroball (1998)



Pico-second lifetime measurement using RDDS

	$\tau_{Nucl.Data.}$	$\tau_{Paramètre\ libre\ GOSIA}$	$\tau_{Plunger}$
^{76}Kr			
2_1^+	35.9(10)	38	41.5(8)
4_1^+	4.8(4)	4.4	3.67(9)
6_1^+	0.86(10)	0.8	0.97(29)
^{74}Kr			
2_1^+	23.5(2.0)	29.6	33.8(6)
4_1^+	13.2(7)	5.9	5.2(2)
6_1^+	1.08(14)	1.4	1.09(23)

A. Görgen, E. Clément *et al*., EPJA **26** (2005)



- The measured lifetime are compatible with the coulomb excitation data

The high precision provides strong constraints on the GOSIA minimization

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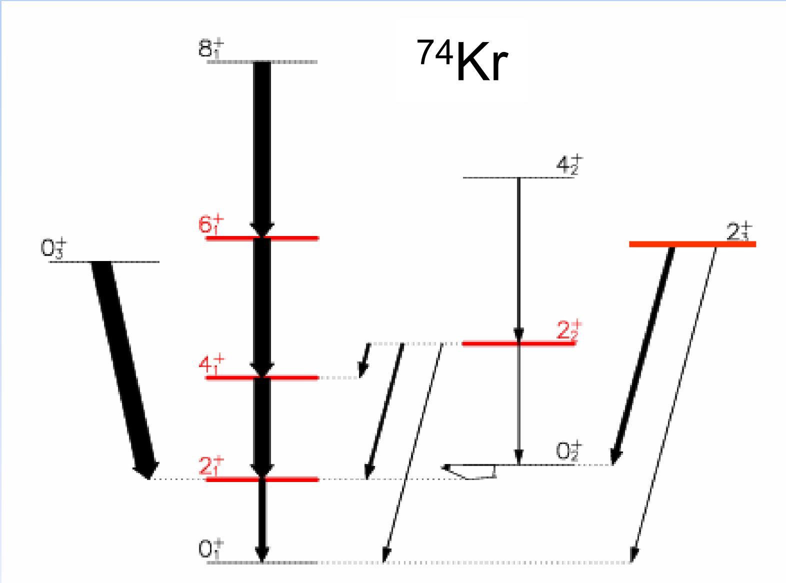
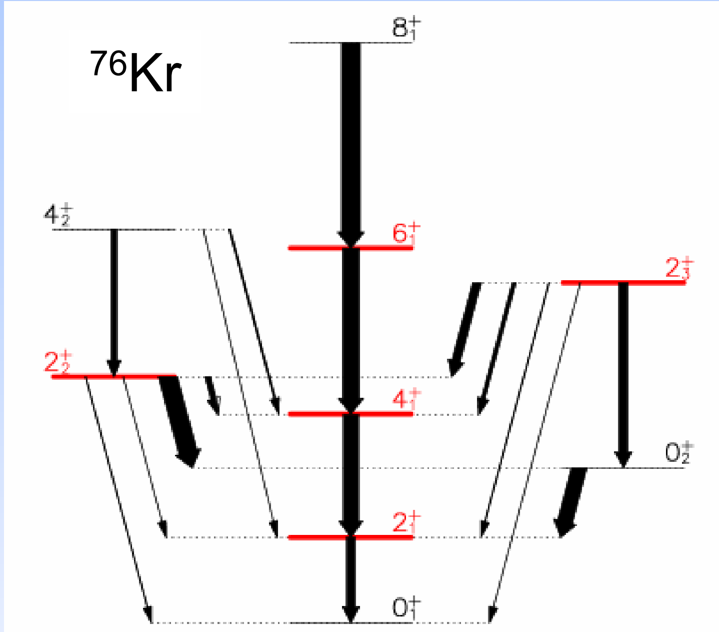
Coulomb excitation analysis with GOSIA





- 14 E2 transitional matrix elements
- 18 E2 transitional matrix elements

In ^{74}Kr and ^{76}Kr, a prolate ground state coexists with an oblate excited configuration

Transition probability : describe the coupling between states

- 5 E2 diagonal matrix element
- 5 E2 diagonal matrix element

First direct experimental proof of the shape coexistence in light Kr isotopes

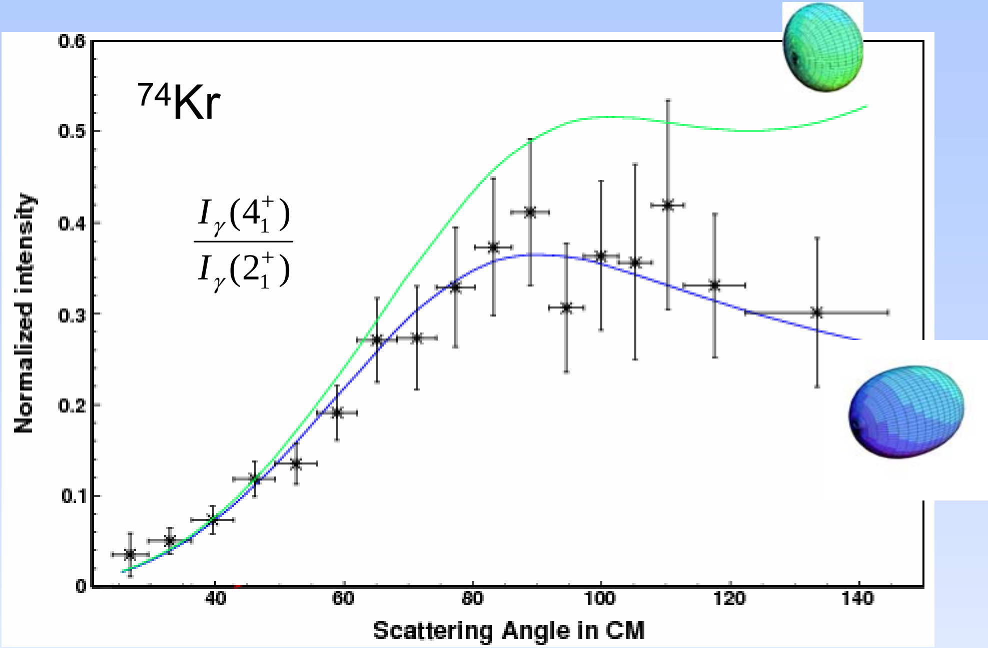
Spectroscopic quadrupole moment : intrinsic properties of the nucleus

E. Bouchez These SPhN 2003

E. Clément These SPhN 2006

E. Clément et al. Submitted to PRC

Sensitivity to the static quadrupole moment



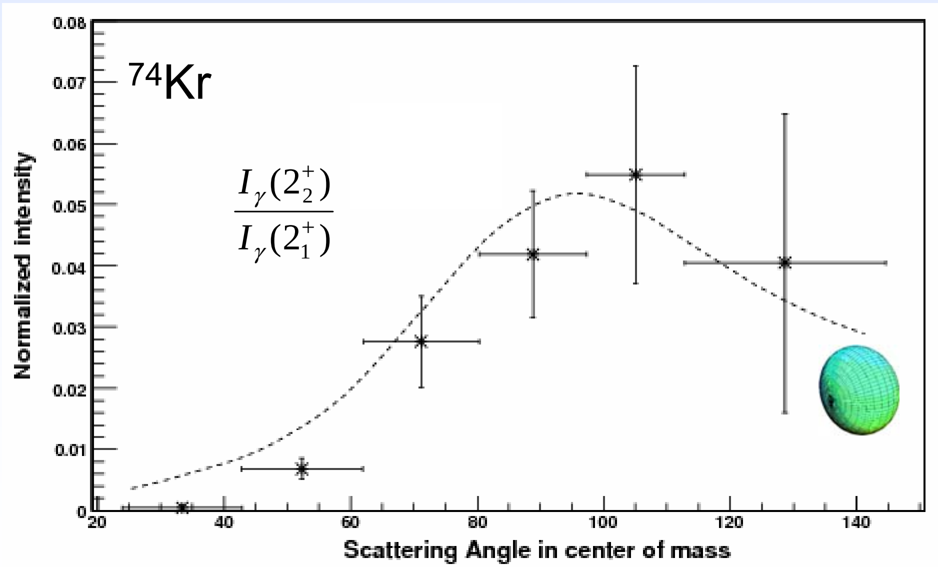
χ^2 minimization:

$$\langle 2_1^+ \| \mathrm{M}(E2) \| 2_1^+ \rangle = -0.70^{+0.33}_{-0.30}$$

$$\langle 4_1^+ \| \mathrm{M}(E2) \| 4_1^+ \rangle = -1.02^{+0.59}_{-0.21}$$

Negative matrix element
(positive quadrupole moment Q_0)

$\Rightarrow$ prolate deformation



$$\langle 2_2^+ \| \mathrm{M}(E2) \| 2_2^+ \rangle = +0.33^{+0.28}_{-0.23}$$

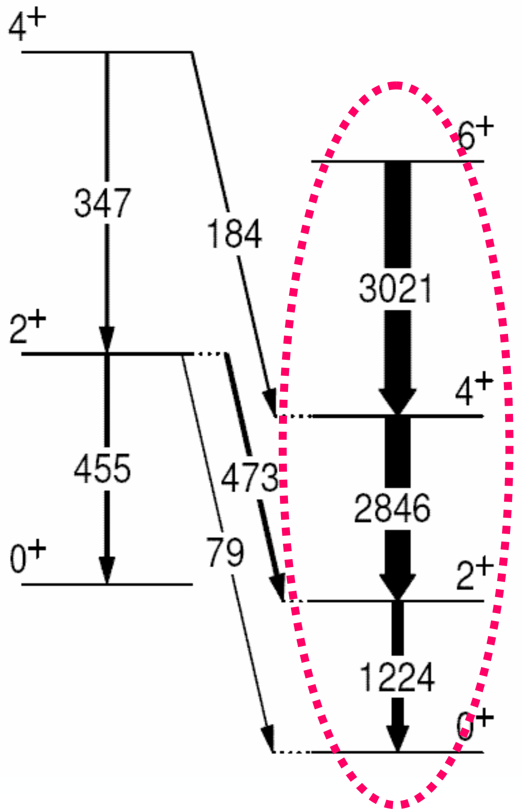
Positive matrix element
(negative quadrupole moment Q_0)

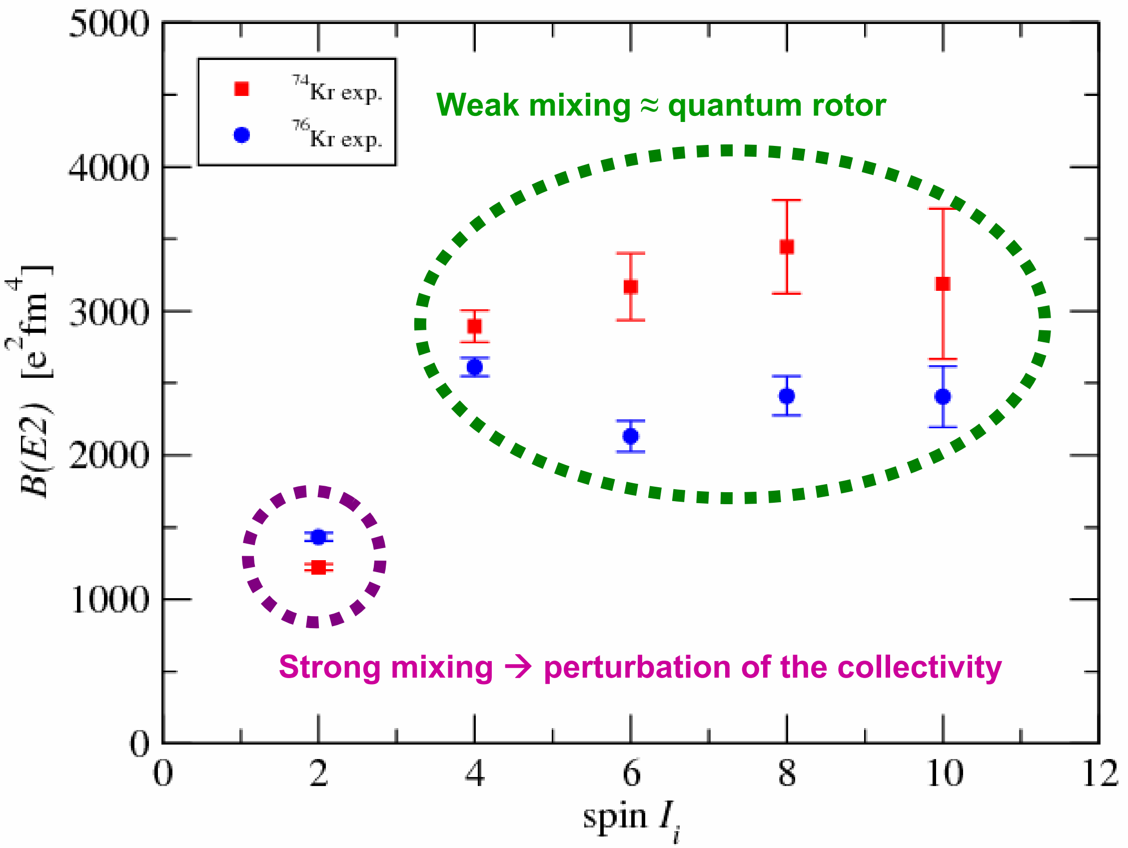
$\Rightarrow$ oblate deformation

Configurations mixing (1)

➡ **For the shape-coexisting states, prolate and oblate wave functions are highly mixed**

$$B(E\lambda, I_i \rightarrow I_f) = \frac{|\langle I_f \,||\, M(E\lambda) \,||\, I_i \rangle|^2}{2I_i + 1}$$ **CONSTANT**





Configurations mixing (2)

Shape coexistence in a two-state mixing model

$$|I_1\rangle = +\cos\theta_I |I_{\rm pr}\rangle + \sin\theta_I |I_{\rm ob}\rangle$$
$$|I_2\rangle = -\sin\theta_I |I_{\rm pr}\rangle + \cos\theta_I |I_{\rm ob}\rangle$$

Pure states

Perturbed states

Extract mixing and shape parameters from set of experimental matrix elements.

		^{76}Kr	^{74}Kr	^{72}Kr
Energy perturbation of 0^+_2 states E. Bouchez *et al.* Phys. Rev. Lett., ***90*** *(2003)*	$\cos^2\theta_0$	0.73(1)	0.48(1)	0.10(1)
Full set of matrix elements : E. Clément, A. Görgen, W. Korten *el al.* Submitted to PRC	$\cos^2\theta_0$	0.69(4)	0.48(2)	

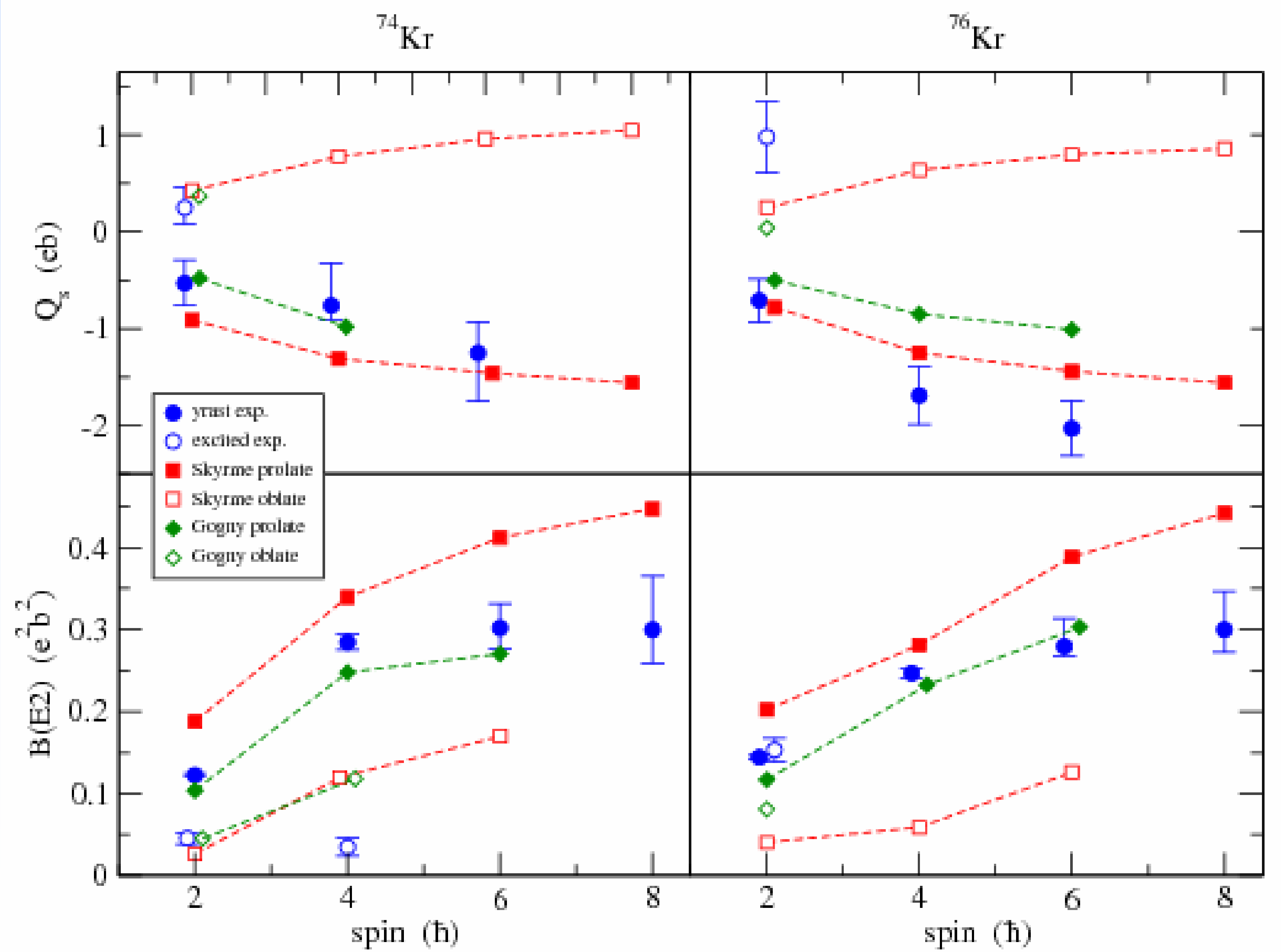
Model describes mixing of 0^+ states well, but ambiguities remain for higher-lying states.
Two-band mixing of prolate and oblate configurations is too simple.

Shape coexistence in mean-field models (1)

- In-band reduced transition probability and spectroscopic quadrupole moments

GCM-HFB (SLy6) M. Bender, P. Bonche et P.H. Heenen, Phys. Rev. C 74, 024312 (2006)

GCM-HFB (Gogny-D1S)
E. Clément *et al.*,
submitted to PRC
J-P. Delaroche *et al.*
In preparation

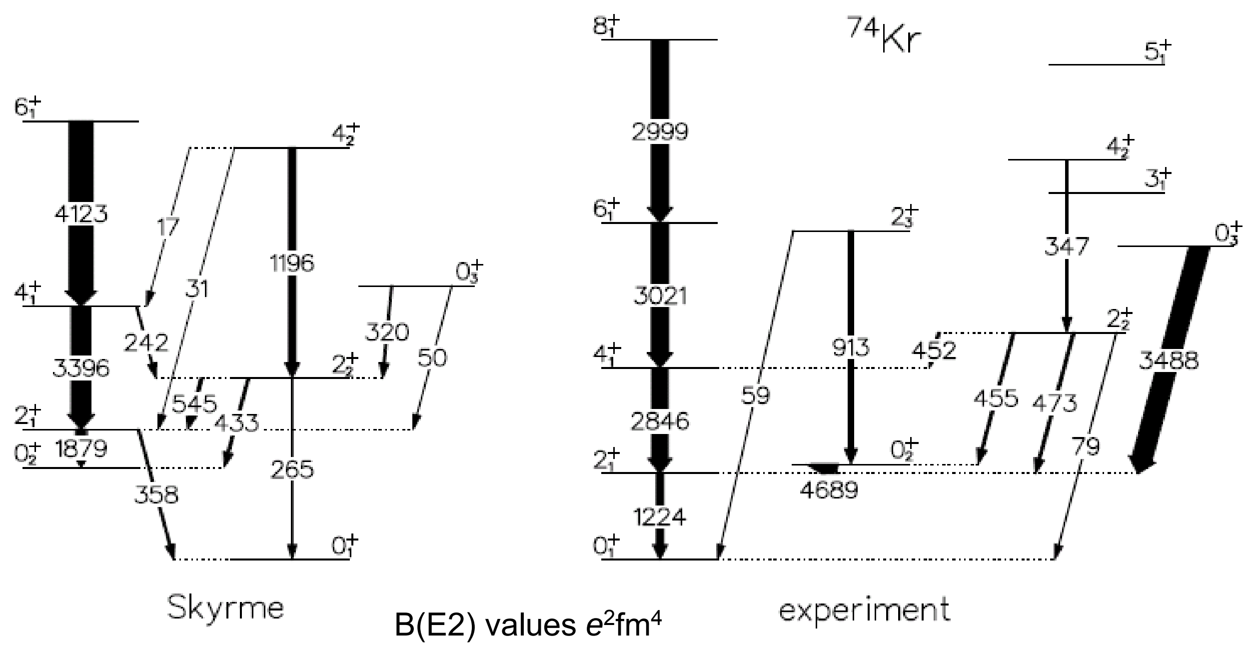


Shape coexistence in mean-field models (2) Skyrme

GCM-HFB (SLy6)
M. Bender, P. Bonche et P.H. Heenen,
Phys. Rev. C 74, 024312 (2006)

HFB+GCM method
Skyrme SLy6 force
density dependent pairing interaction

Restricted to axial symmetry : no K=2 states



- **Inversion of oblate and prolate states**
- **Collectivity of the prolate rotational band is correctly reproduced**
- **Interband B(E2) are under estimated**

Same conclusion for ^{76}Kr

Shape coexistence in mean-field models (3) Gogny

GCM-HFB (Gogny-D1S)
J-P. Delaroche *et al.*
In preparation

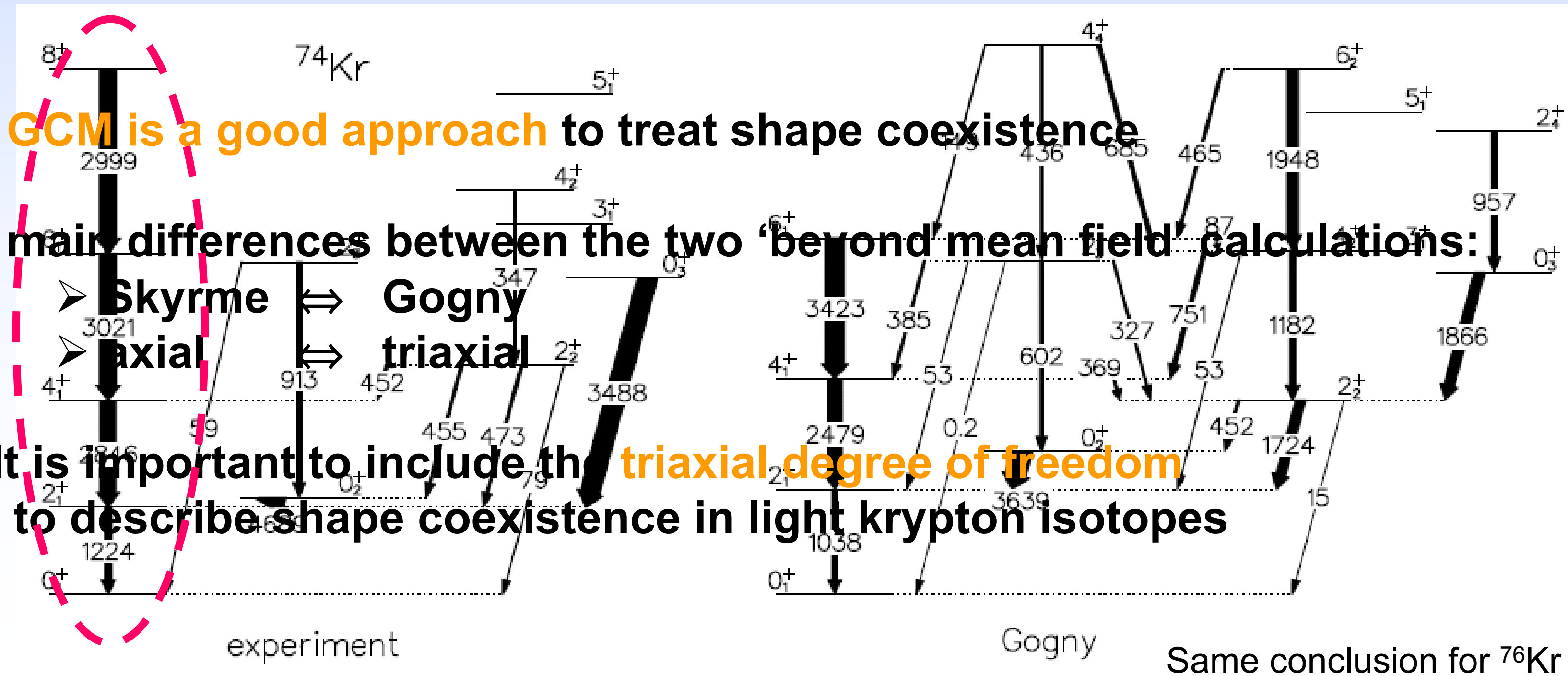
HFB+GCM with Gaussian overlap approximation Gogny D1S force

↓

Axial and triaxial degrees of freedom

The agreement is remarkable for excitation energy and matrix elements

- **K=0 prolate rotational ground state band**
- **K=2 gamma vibrational band**
- **2^+_3 oblate rotational state**
- **Strong mixing of K=0 and K=2 components for 2^+_3 and 2^+_2 states**
- **Grouping the non-yrast states above 0^+_2 state in band structures is not straightforward**

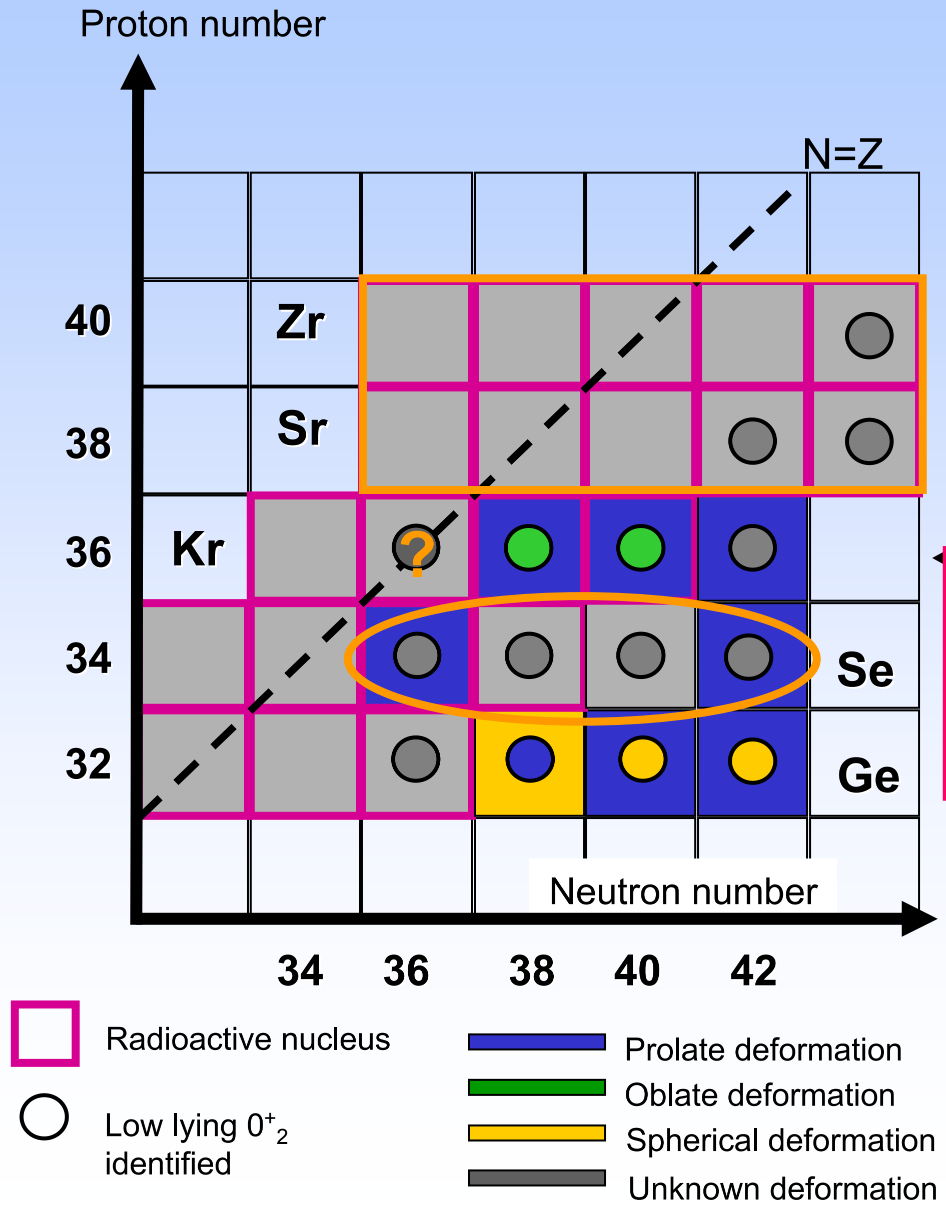


- **GCM is a good approach to treat shape coexistence**
- **main differences between the two 'beyond mean field' calculations:**
  - ➢ **Skyrme ⇔ Gogny**
  - ➢ **axial ⇔ triaxial**

- **It is important to include the triaxial degree of freedom to describe shape coexistence in light krypton isotopes**

Same conclusion for ^{76}Kr

The mass region A=70-80 close to N=Z line



- ✗ Shape inversion in ^{72}Kr ?
- ^{74}Kr and ^{76}Kr : prolate ground state and oblate 0^+_2 with high mixing
- ✗ Shape coexistence in selenium isotopes ?
- The ^{70}Se ground state is purely prolate (Rex-ISOLDE)
- ✗ Shape coexistence in Sr and Zr (sub shell closure at Z=40 ? Spherical shape ?)
- ^{74}Ge and ^{72}Ge : prolate ground state and spherical 0^+_2
  - ^{70}Ge → Shape Inversion
  - ^{72}Ge → maximal mixing

The structure evolves rapidly with the proton and neutron number

→ Strong constraint for modern nuclear t

The ^{72}Kr SPIRAL beam is delivered with a too low intensity (< 100 pps)

The Se, Sr and Zr beam are not available at SPIRAL

Radioactive ions beam of Se and Sr are available at REX-ISOLDE

Plan

- Nucleus, shape, deformation, shape coexistence ??
- How to measure the shape of the nucleus ?
- Radioactive ions beams
- Coulomb excitation of radioactive Kr beams
- Shape coexistence in light Kr isotopes
- Coulomb excitation of radioactive Se beams
- Shape coexistence at CERN ………….;

Coulomb excitation at intermediate energy

For radioactive ions very far from the stability, i.e. very low beam intensity ~ 100 pps, one can take advantage of a higher beam energy (20-40 Mev/A) in order to use thicker target to increase the interaction probability

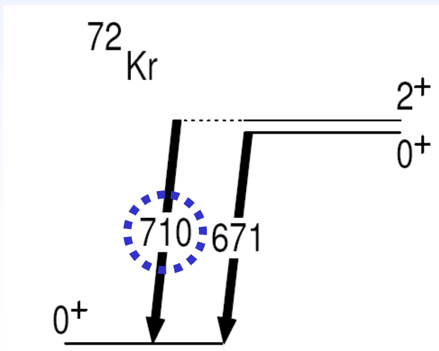
- **One step excitation ($0^+ \rightarrow 2^+_i$)**
- **No sensitivity to the quadrupole moment**
- **Low beam quality (optic, purity, …)**

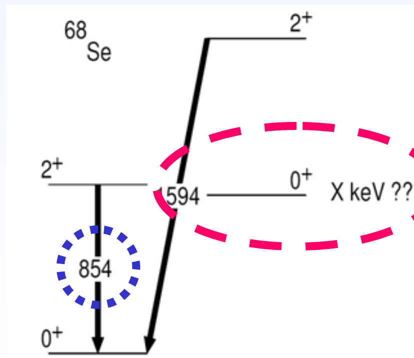
→ However it is a first estimation of the nucleus collectivity

✓ ^{72}Kr collectivity

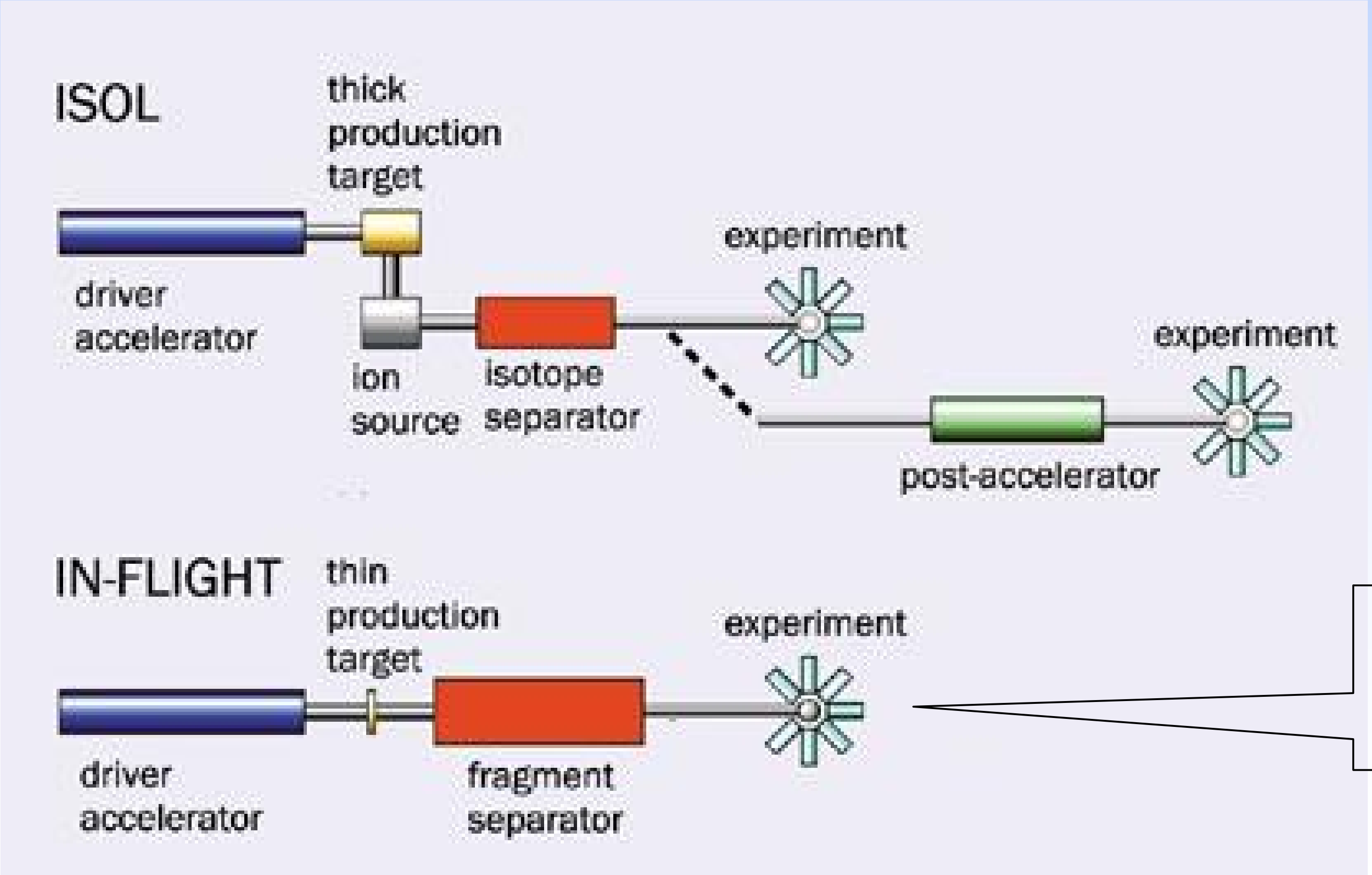
✓ ^{68}Se collectivity

✓ Shape isomer in ^{68}Se



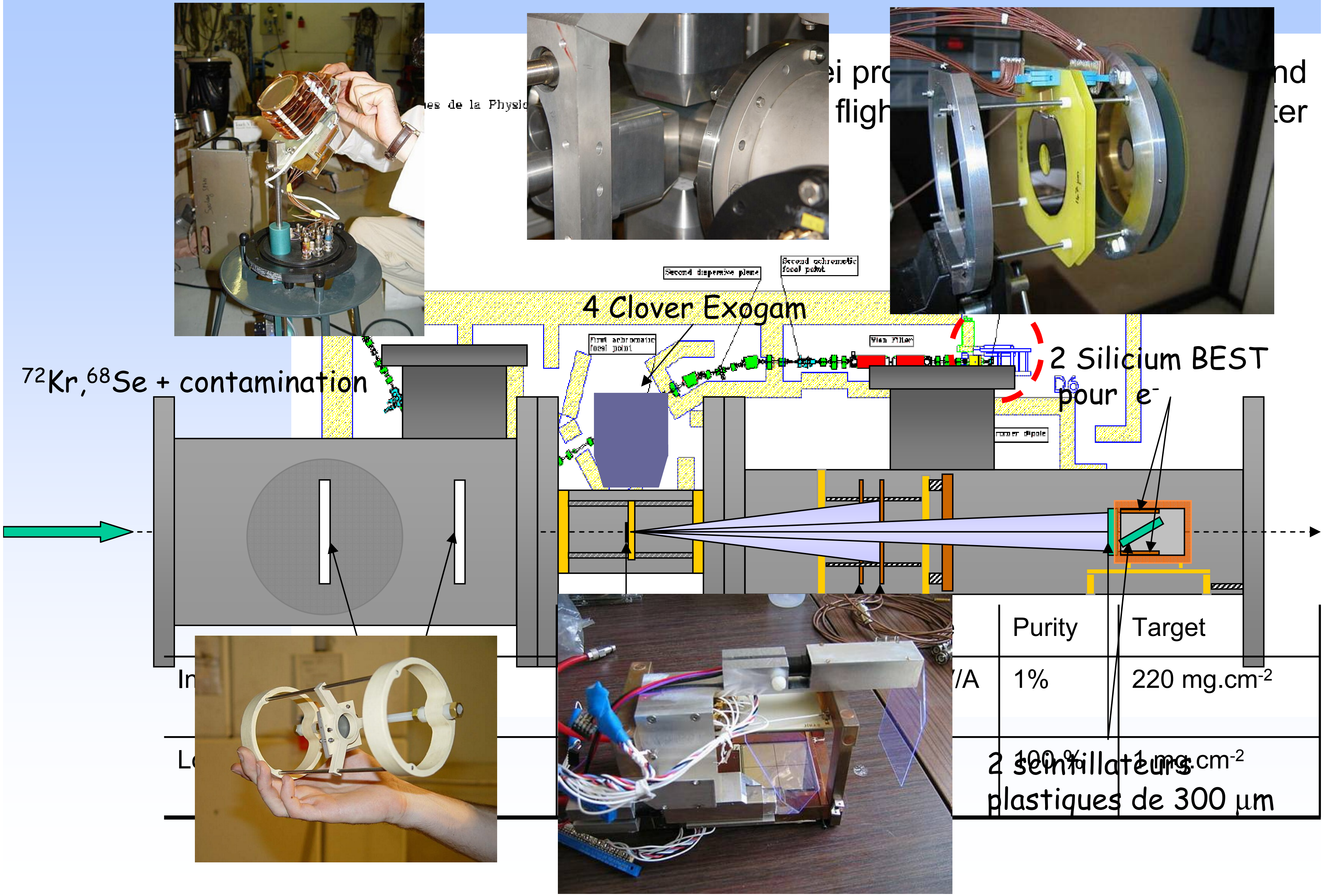


Radioactive ions beam

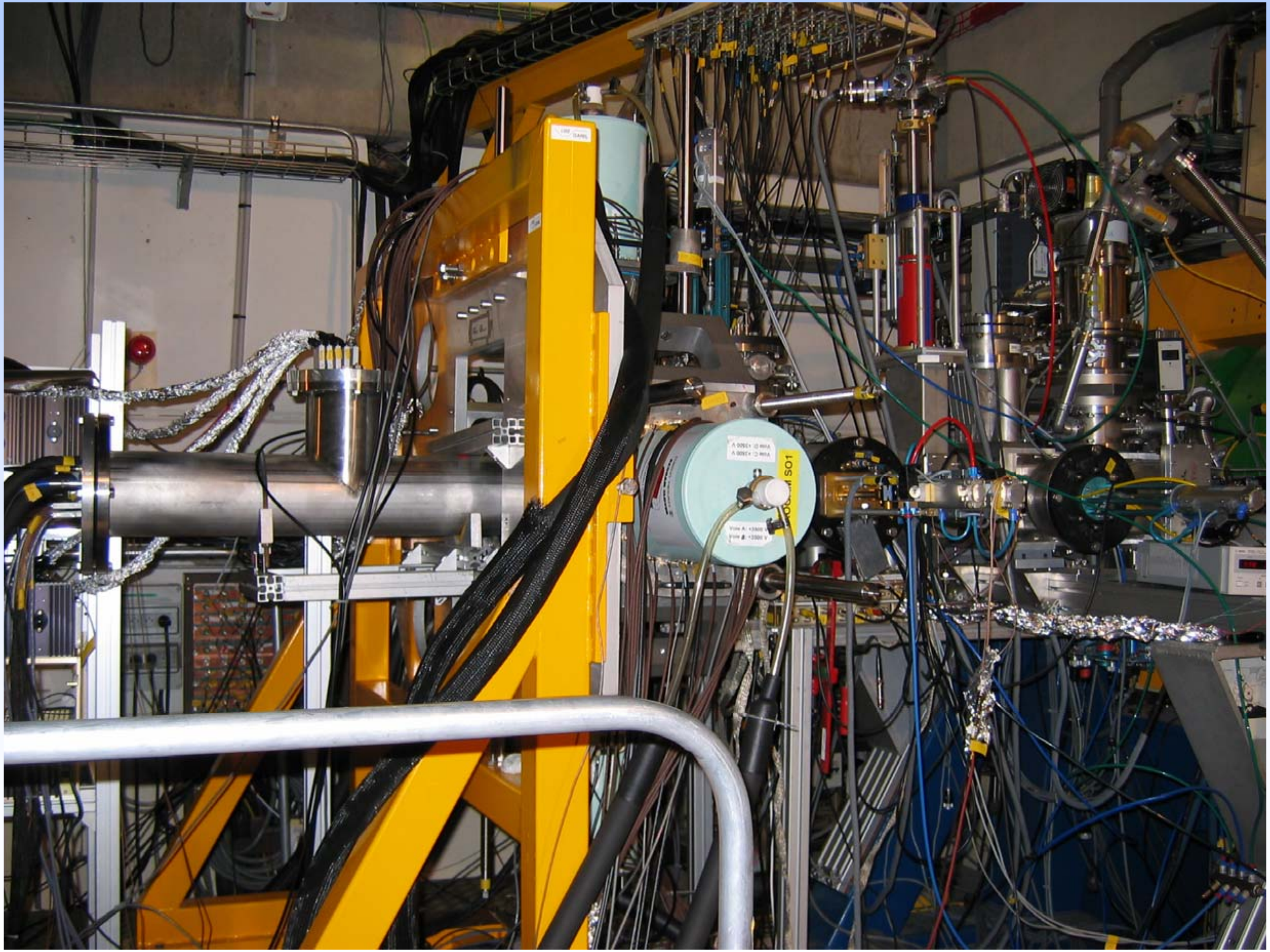


20-30
MeV/A

Experimental setup



Experimental setup



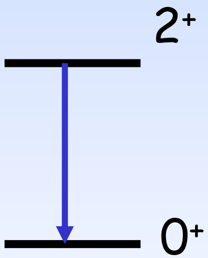
Experimental results

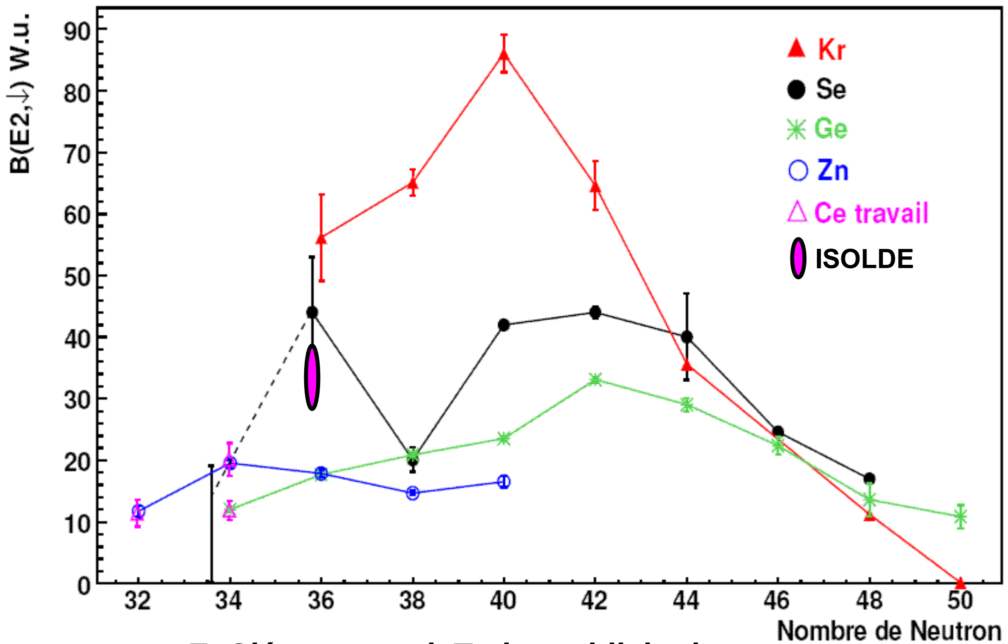
- Coulomb excitation of ^{78}Kr, ^{72}Ge and ^{64}Zn for normalization

- Too low intensity in ^{72}Kr case (< 54 pps)

- Coulomb excitation of ^{62}Zn, ^{66}Ge and ^{68}Se radioactive ions

Noyau	B(E2) Référence	B(E2) déduit [W.u]
^{66}Ge	12.0 (23)	11.7 (1.5)
^{62}Zn	11.7 (9)	10.2 (2.1)
^{68}Se		$\leq$19
^{64}Zn	19.5 (6)	21.7 (2.8)





E. Clément et al. To be published

- No electron or γ transition corresponding to the decay of an isomeric 0^+_2 observed

⇨ No low lying 0^+_2 state

Plan

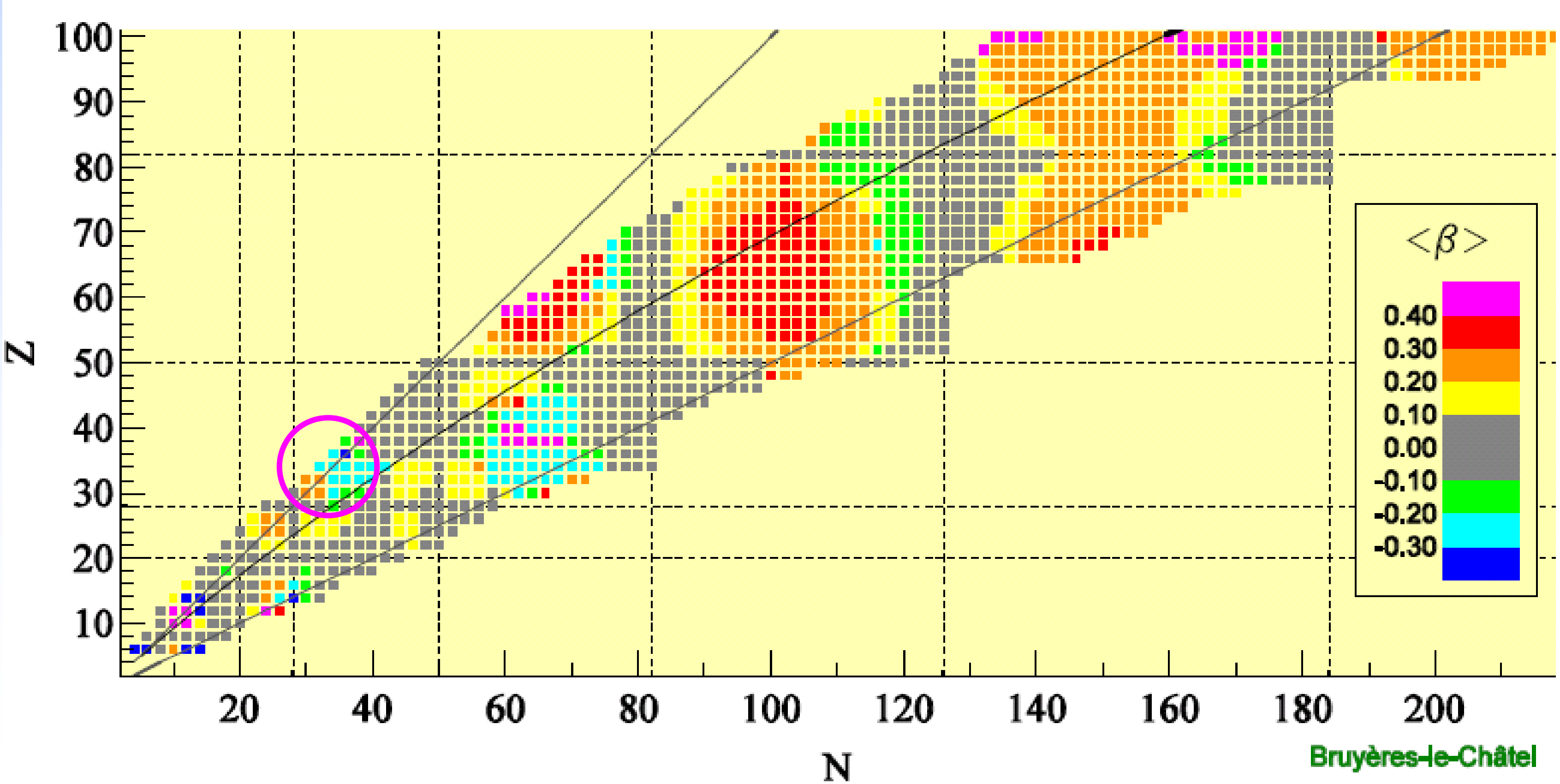
- Nucleus, shape, deformation, shape coexistence ??
- How to measure the shape of the nucleus ?
- Radioactive ions beams
- Coulomb excitation of radioactive Kr beams
- Shape coexistence in light Kr isotopes
- Coulomb excitation of radioactive Se beams
- Shape coexistence at CERN ………….

New area of investigation

All theoretical calculations predict a sudden onset of quadrupole deformation at the neutron number N=60

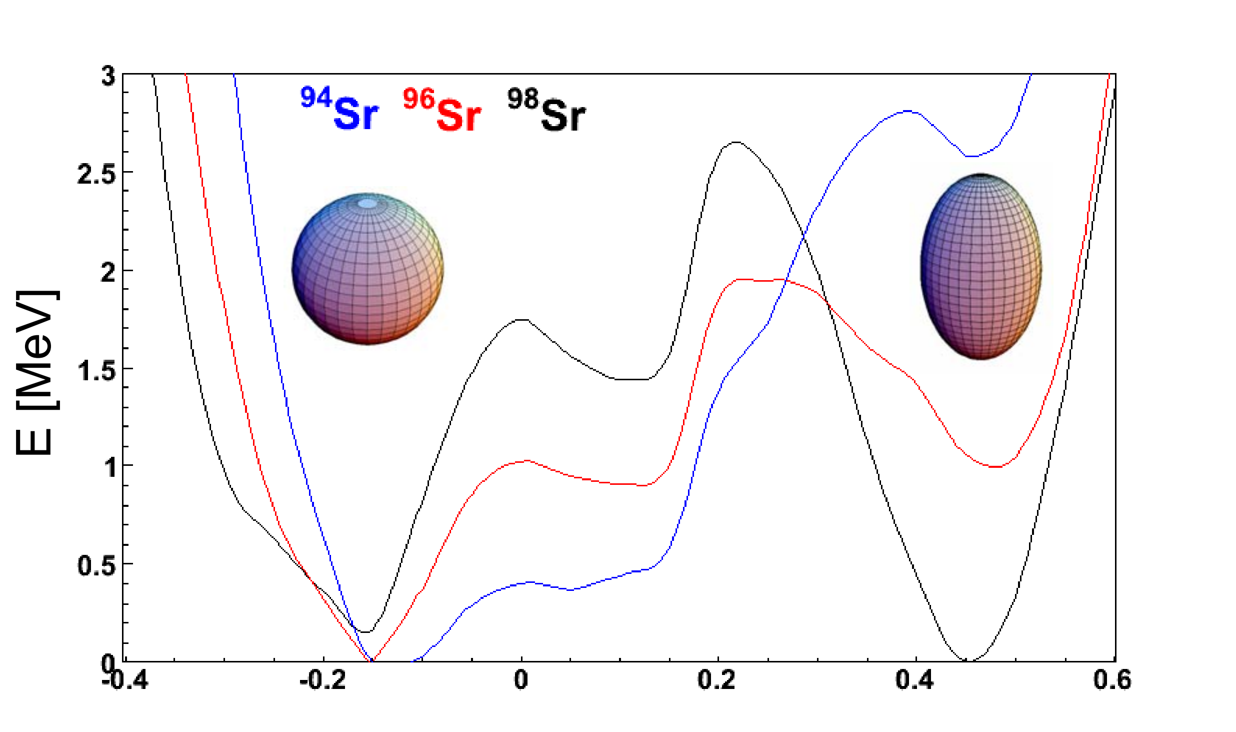
Neutron rich Sr & Zr isotopes are accessible by fission of an UC_x target

Coulomb excitation of such nuclei can be performed at REX-ISOLDE



N-rich Sr and Zr isotopes

Sudden onset of quadrupole deformation at the neutron number N=60



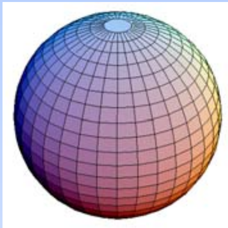
HFB Gogny D1S
M. Girod
CEA Bruyères-le-Châtel

^{96}Sr is a transitional nucleus

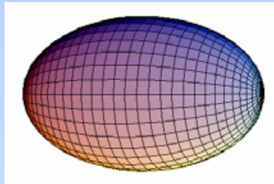
- Both deformations should coexist at low energy
  - Shape coexistence between highly deformed and quasi-spherical shapes
- Important constraints for modern nuclear structure theories :
  - Predicted values of β_2
  - E (0^+_2), ρ^2(E0), B(E2), Q_0 …
  - Mixing of wave function → GCM

N-rich Sr and Zr isotopes

The first evidence is the energy of the 2^+_1 state

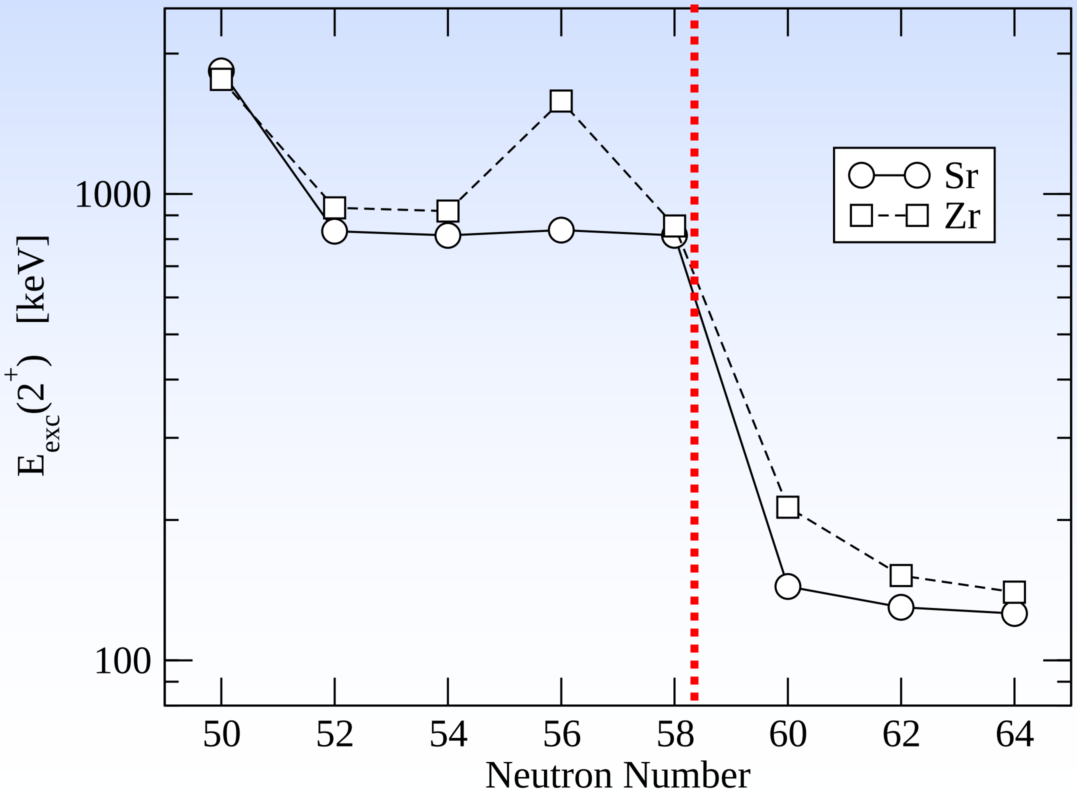


N=58



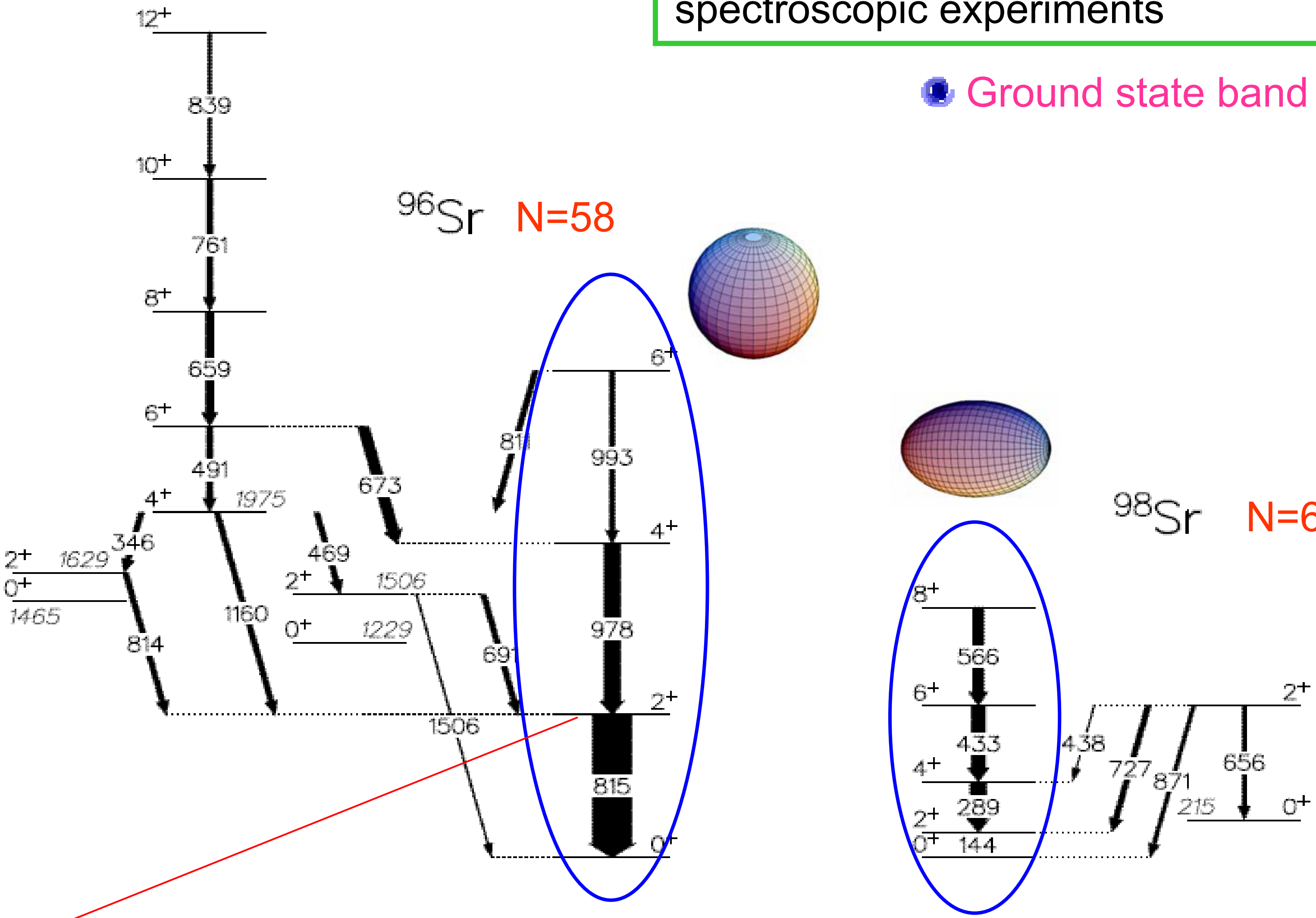
$|\beta| <<1$: Quasi-spherical

$|\beta| >0$: deformed state



N-rich Sr isotopes

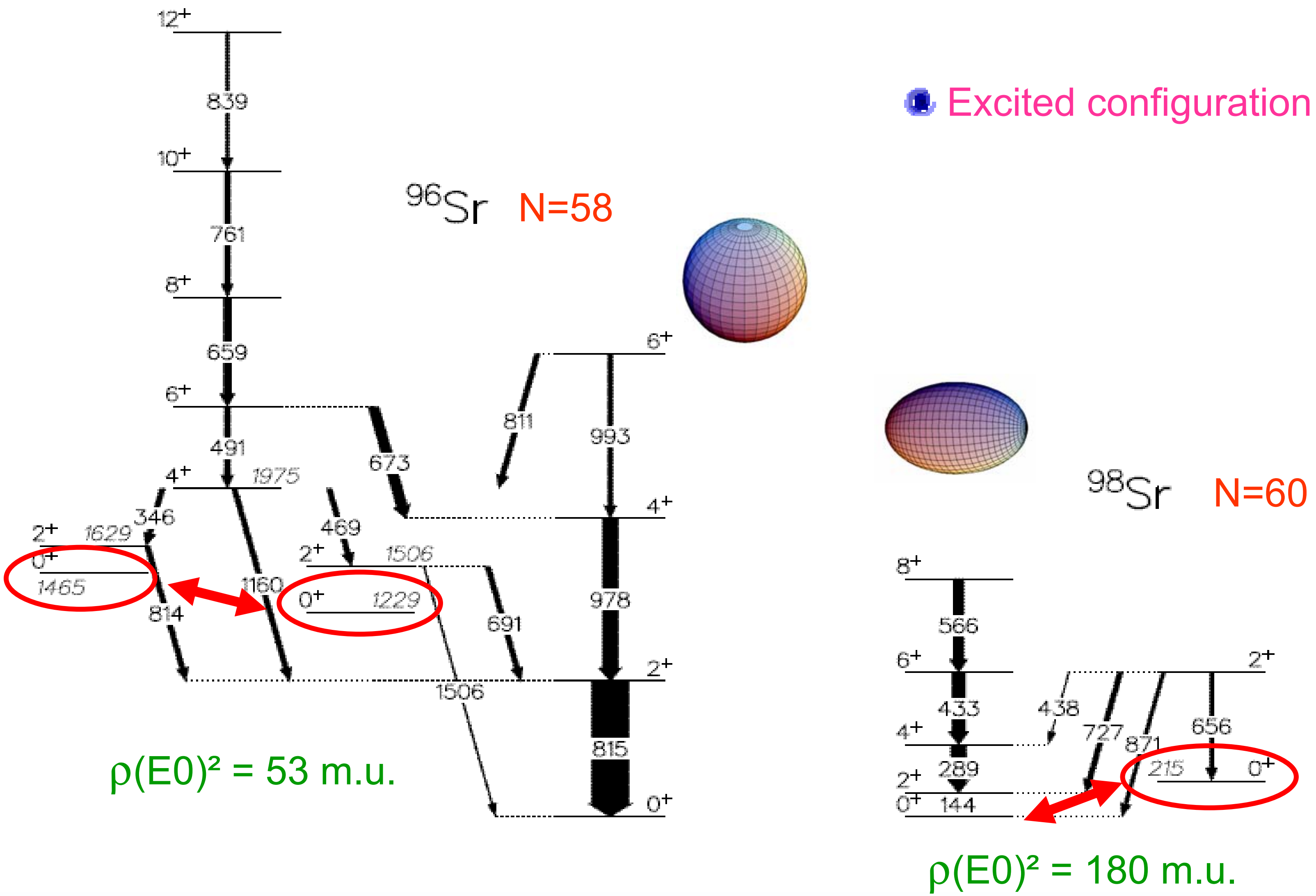
Level scheme established by spectroscopic experiments



τ = 7(4) ps → Nearly spherical ground state

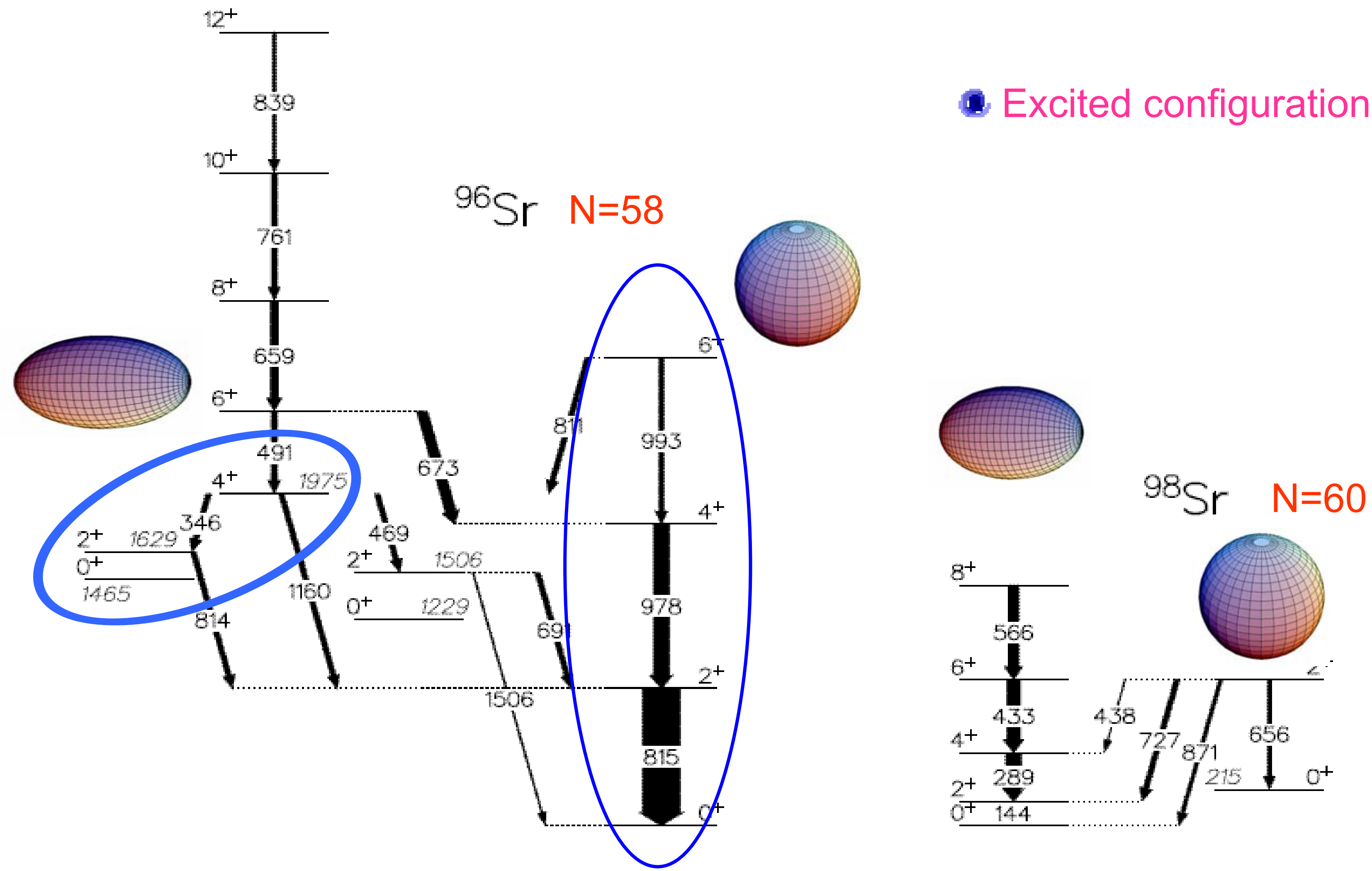
Highly deformed rotational band β ≈ 0.4

N-rich Sr isotopes



ρ(E0)² is directly linked to deformation and mixing configuration

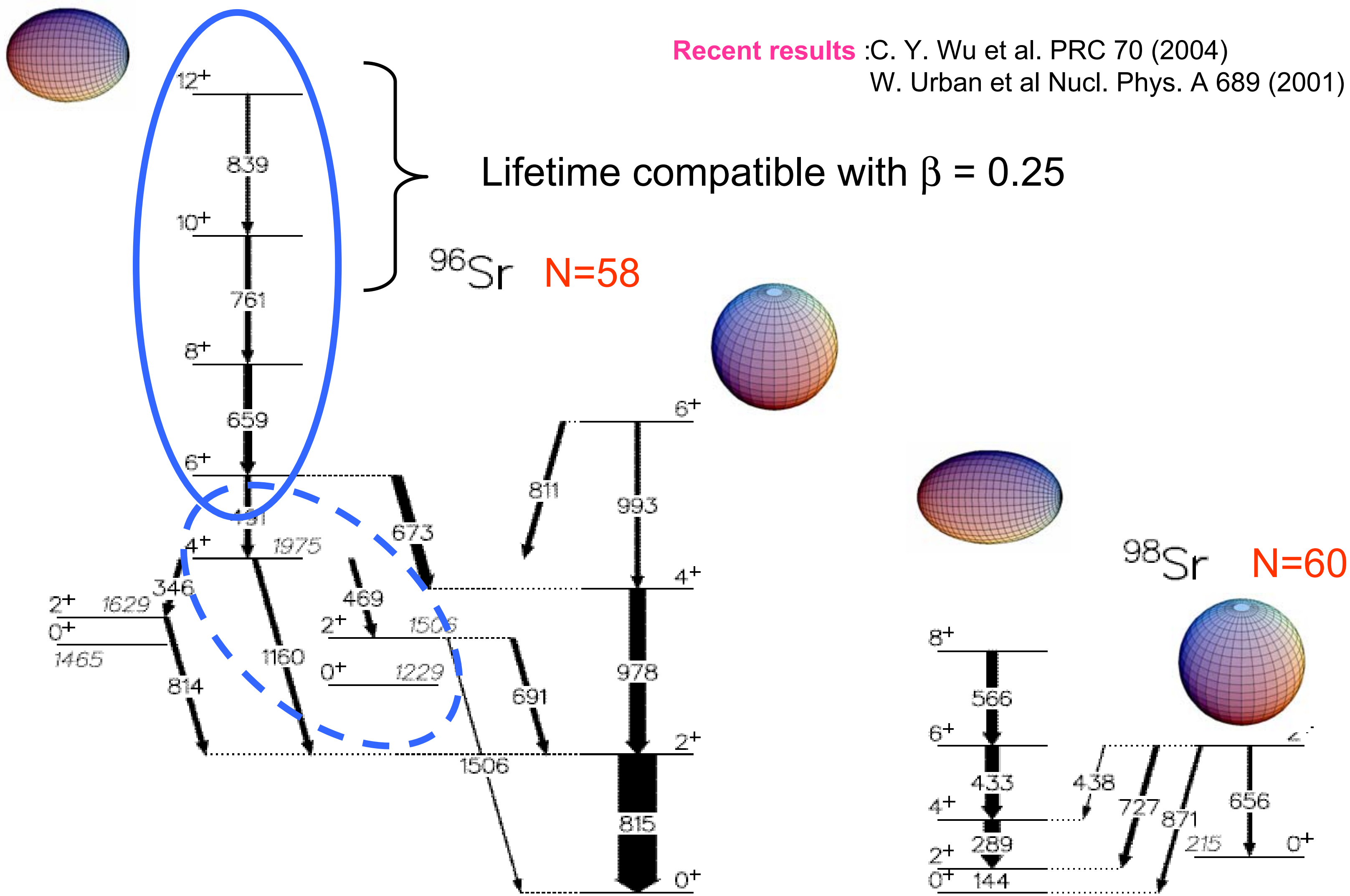
N-rich Sr isotopes



The highly deformed band $0^+_3 \rightarrow 2^+_3 \rightarrow 4^+_2$ becomes the ground state band in ^{98}Sr

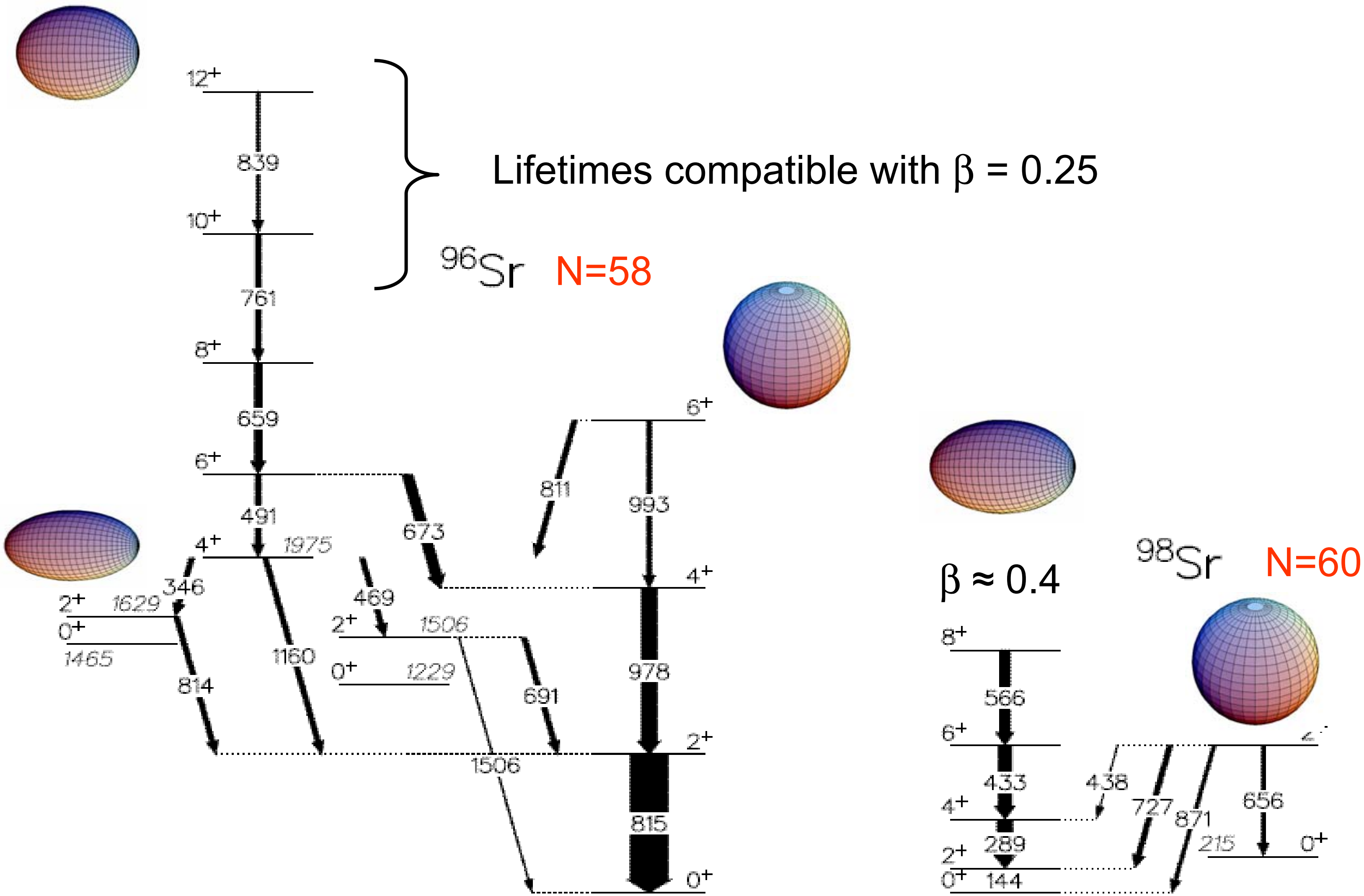
N-rich Sr isotopes

Recent results :C. Y. Wu et al. PRC 70 (2004)
W. Urban et al Nucl. Phys. A 689 (2001)



The onset of deformation around N=58 is maybe more gradual

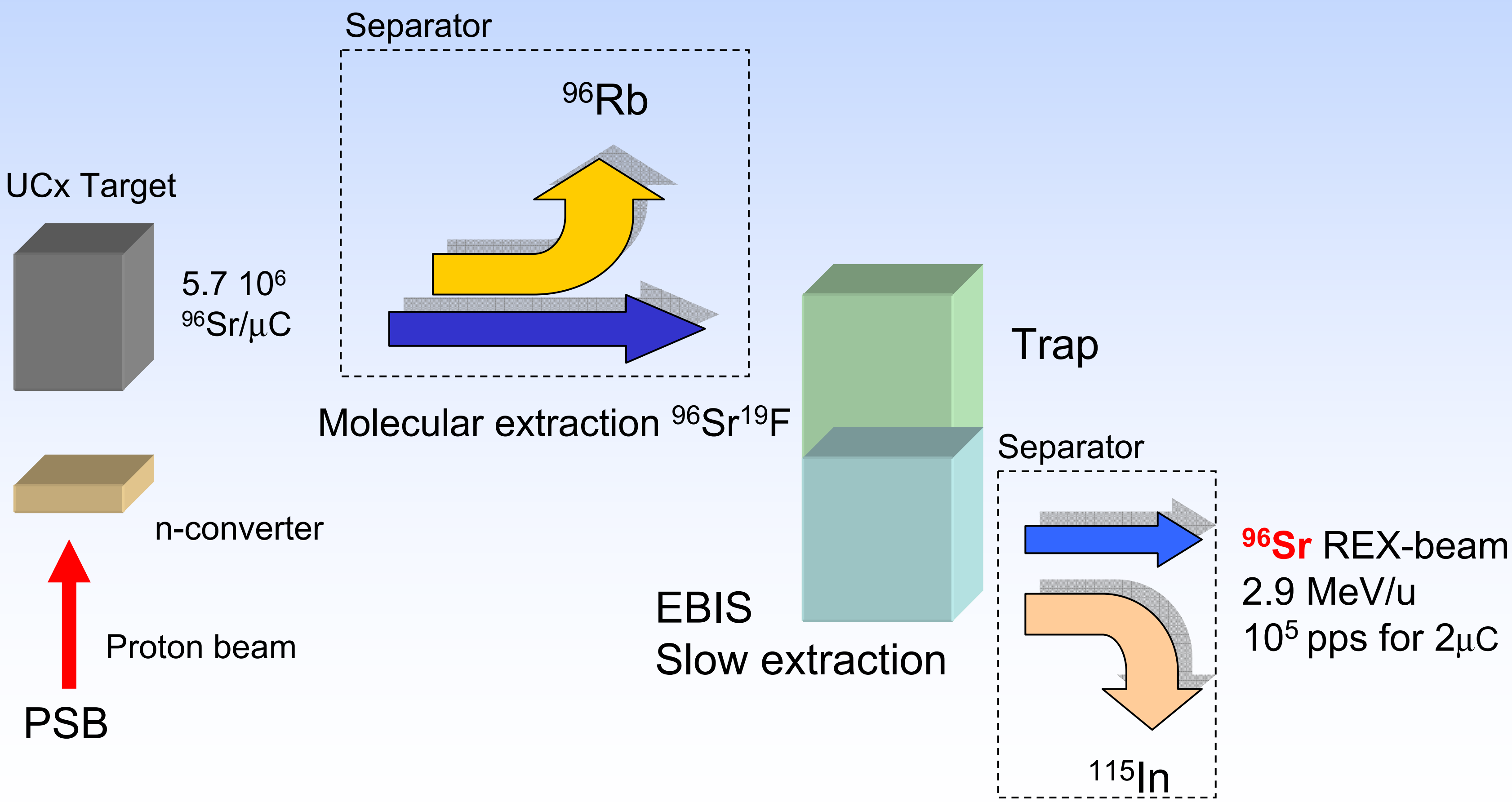
N-rich Sr isotopes



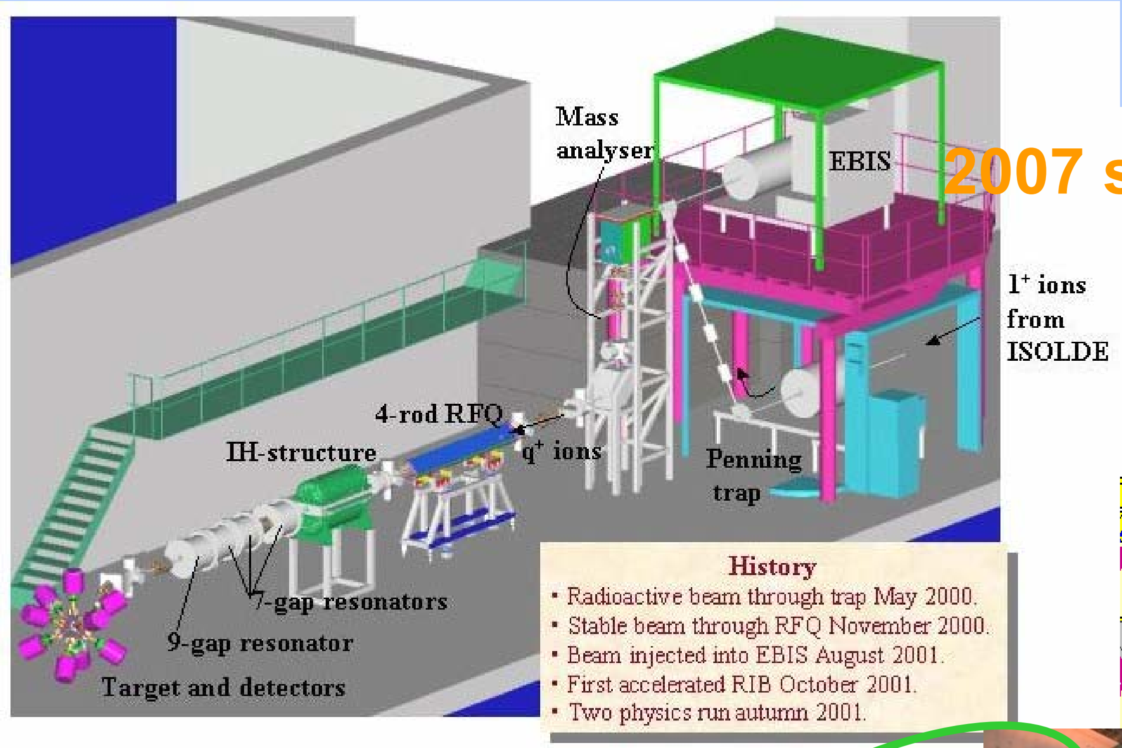
The measure of transition strength and intrinsic quadrupole moments is essential to understand the complex shape coexistence in Sr isotopes → Coulomb excitation

Coulomb excitation of a Sr beam at Rex-ISOLDE

- First Sr beam at REX-ISOLDE → need new development
  - Molecular beam has shown the efficiency of this technique in term of purity and intensity…

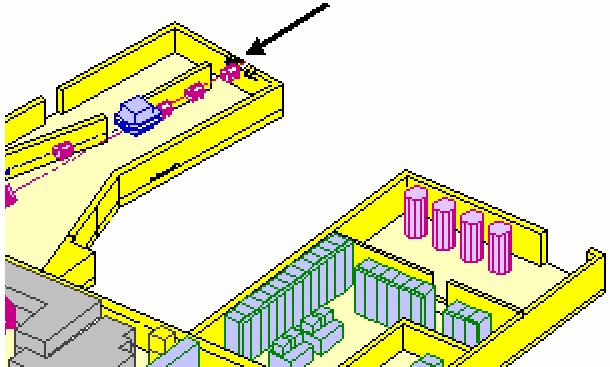


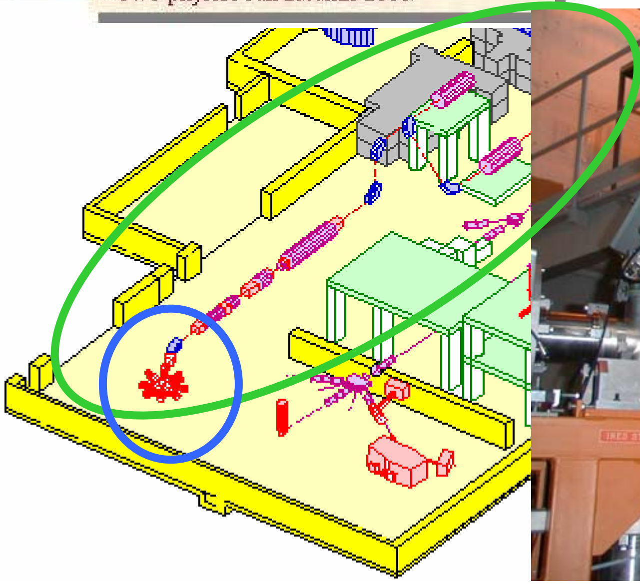
Coulomb excitation of a Sr beam at Rex-ISOLDE

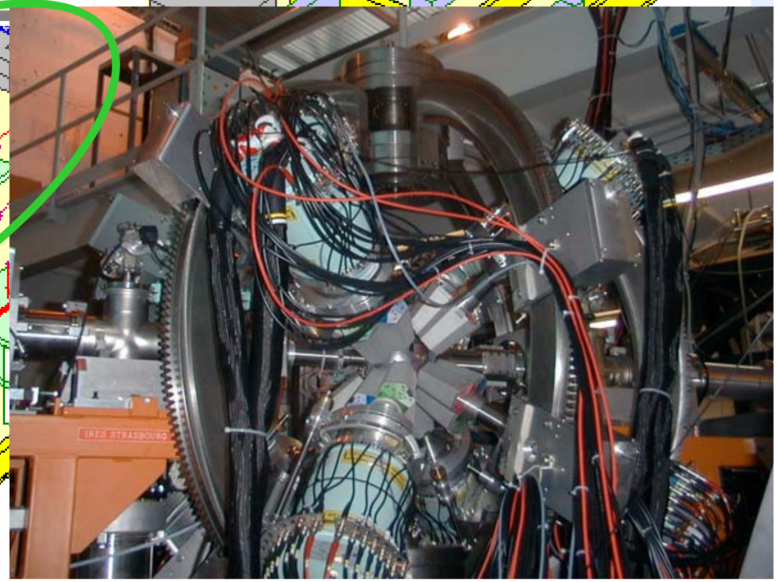


2007 summer campaign

PSB beam







Conclusion

- Coulomb excitation of radioactive ^{74}Kr and ^{76}Kr ions beams
  - Extraction of the diagonal matrix element, 1ère measure of the sign of quadupole moment in radioactive beam
    - ↳ prolate ground state coexists with an oblate excited configuration
  - Extraction transitional matrix element
    - ↳ In contradiction with published lifetime
      - re-measured by plunger
    - ↳ Very complex coupling between all configurations …. Triaxiality
- Coulomb excitation at high energy of ^{68}Se
  - First estimation of the collectivity
    - ↳ $B(E2\ ;\ 2^+_1 \rightarrow 0^+_1) < 19$ W.u (low collectivity)
  - No low-lying 0^+_2 state
    - ↳ Shape coexistence ??
- Coulomb excitation of radioactive ^{96}Sr ions beams at Rex-ISOLDE

Thanks for your attention

Collaboration “E344aS“

E. Clément,[1] A. Görgen,[1] W. Korten,[1] E. Bouchez,[1] A. Chatillon,[1] Y. Le Coz,[1] Ch. Theisen,[1] J.N. Wilson,[1] M. Zielinska,[5,1] C. Andreoiu,[2] F. Becker,[3] J.M. Casandjian,[4] W. Catford,[9] T. Czosnyka,[5] G. de France,[4] J. Gerl,[3] J. Iwanicki,[5] P. Napiorkowski,[5] G. Sletten,[8] C. Timis[9]

Collaboration “temps de vie”

A. Görgen,[1] E. Clément,[1] A. Chatillon,[1] A. Dewald,[6] W. Korten,[1] Y. Le Coz,[1] N. Marginean,[7] B. Melon,[6] R. Menegazzo,[7] O. Möller,[6] Ch. Theisen,[1] D. Tonev,[7] C.A. Ur,[7] K.O. Zell[6]

Collaboration “E410”

E. Clément,[1] A. Bürger,[1,12] A. Chatillon,[1] A. Görgen,[1] W. Korten,[1] Y. Le Coz,[1] Ch. Theisen,[1] M. Zielinska,[5,1] B. Blank,[12] S. Fox,[10] G. Georgiev,[7] S. Grevy,[4] D.G. Jenkins,[10] F. Johnston-Theasby,[10] P. Joshi,[10] I. Matea,[12] P. Napiorkowski,[5] F. de Oliveira Santos,[4] M.G. Pellegriti,[4] R. Wadsworth[10]

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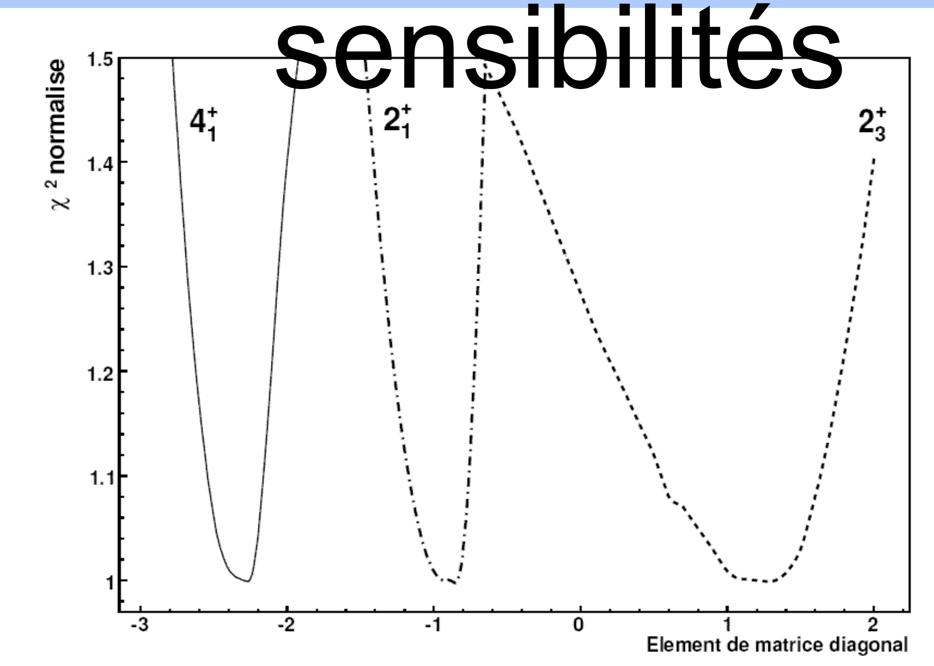
[2]Oliver Lodge Laboratory, University of Liverpool
[3]GSI Darmstadt
[4]GANIL
[5]Heavy Ion Laboratory, Warsaw
[6]Institut für Kernphysik, Universität zu Köln
[7]INFN Legnaro
[8]NBI Copenhagen
[9]University of Surrey
[10]University of York
[11]Universität zu Bonn

Comparaison des sensibilités



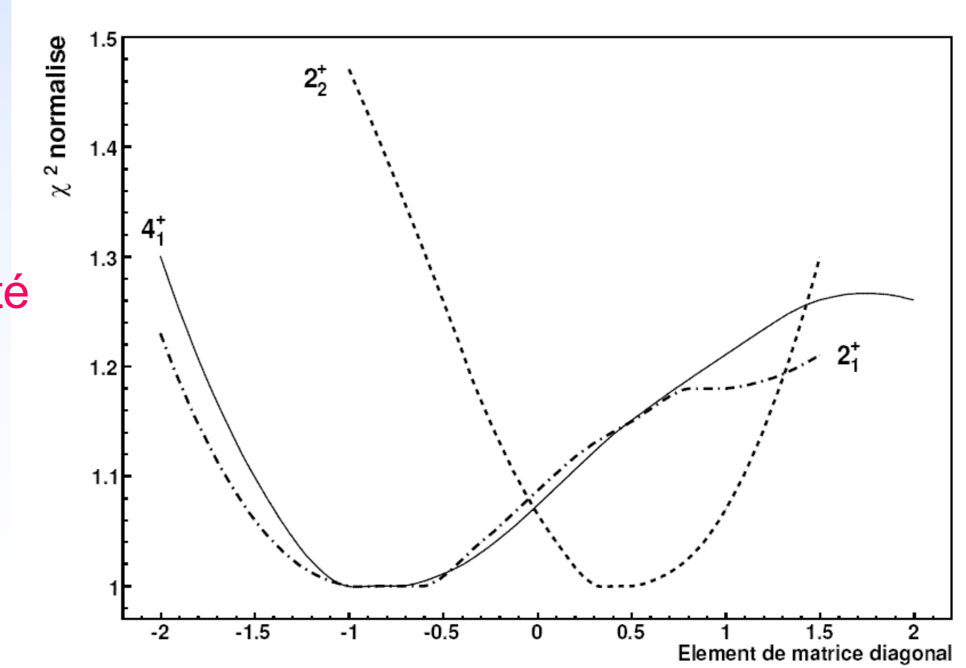
⇦ ^{76}Kr

Plus de statistique dans le ^{76}Kr

→ L'augmentation de la sensibilité

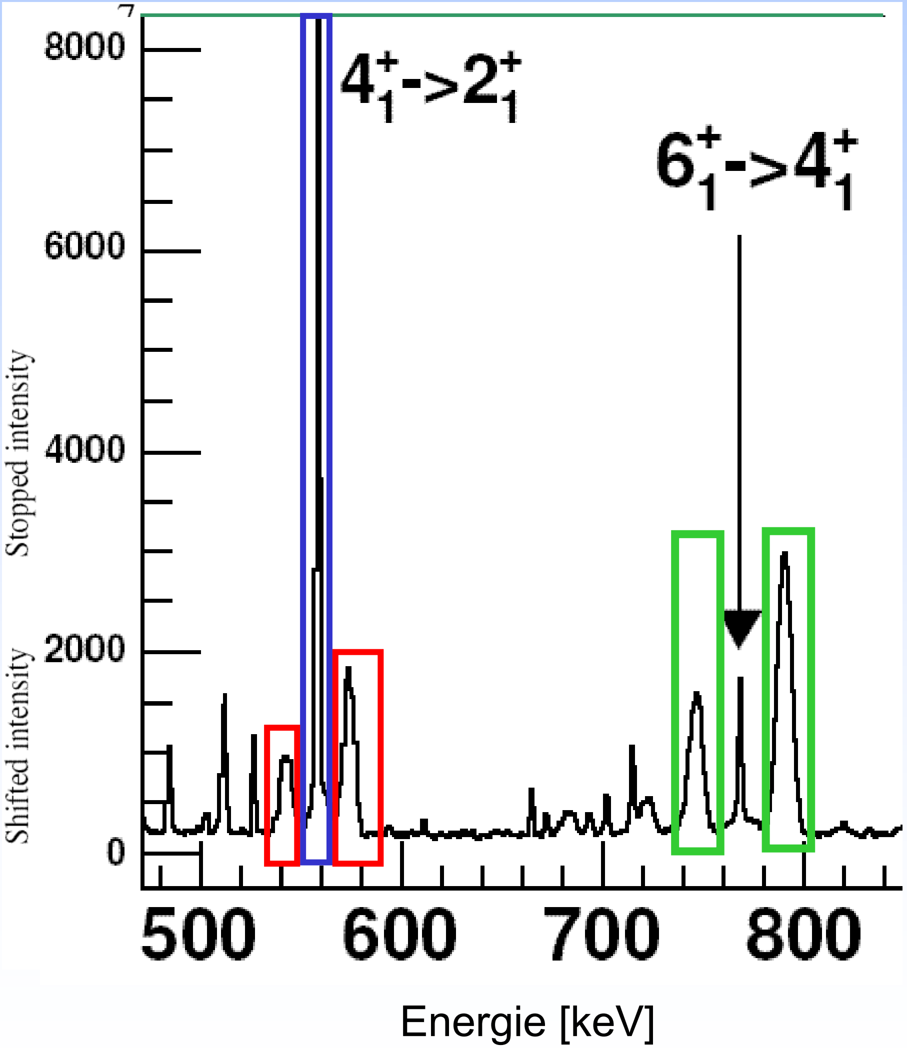
→courbes plus étroites

⇨ ^{74}Kr

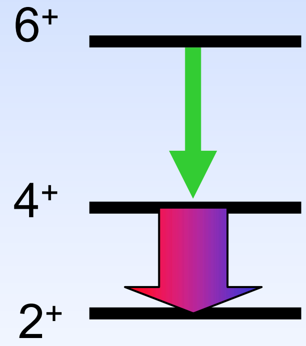


Mesure de temps de vie

Les contaminations et alimentations parallèles sont supprimées par une analyse en coïncidences γ–γ



Extraction du temps de vie :
exemple de l'état 4^+ du ^{74}Kr



$$\tau(x) = \frac{\frac{1}{N(x)} I(\gamma_1^{sh}, \gamma_2^{st}, x)}{v_{Kr} \frac{d}{dx} \frac{I(\gamma_1^{sh}, \gamma_2^{sh}, x)}{N(x)}}.$$

Calcul de la probabilité de transition réduite: B(E2)

Au premier ordre de l'excitation Coulombienne :

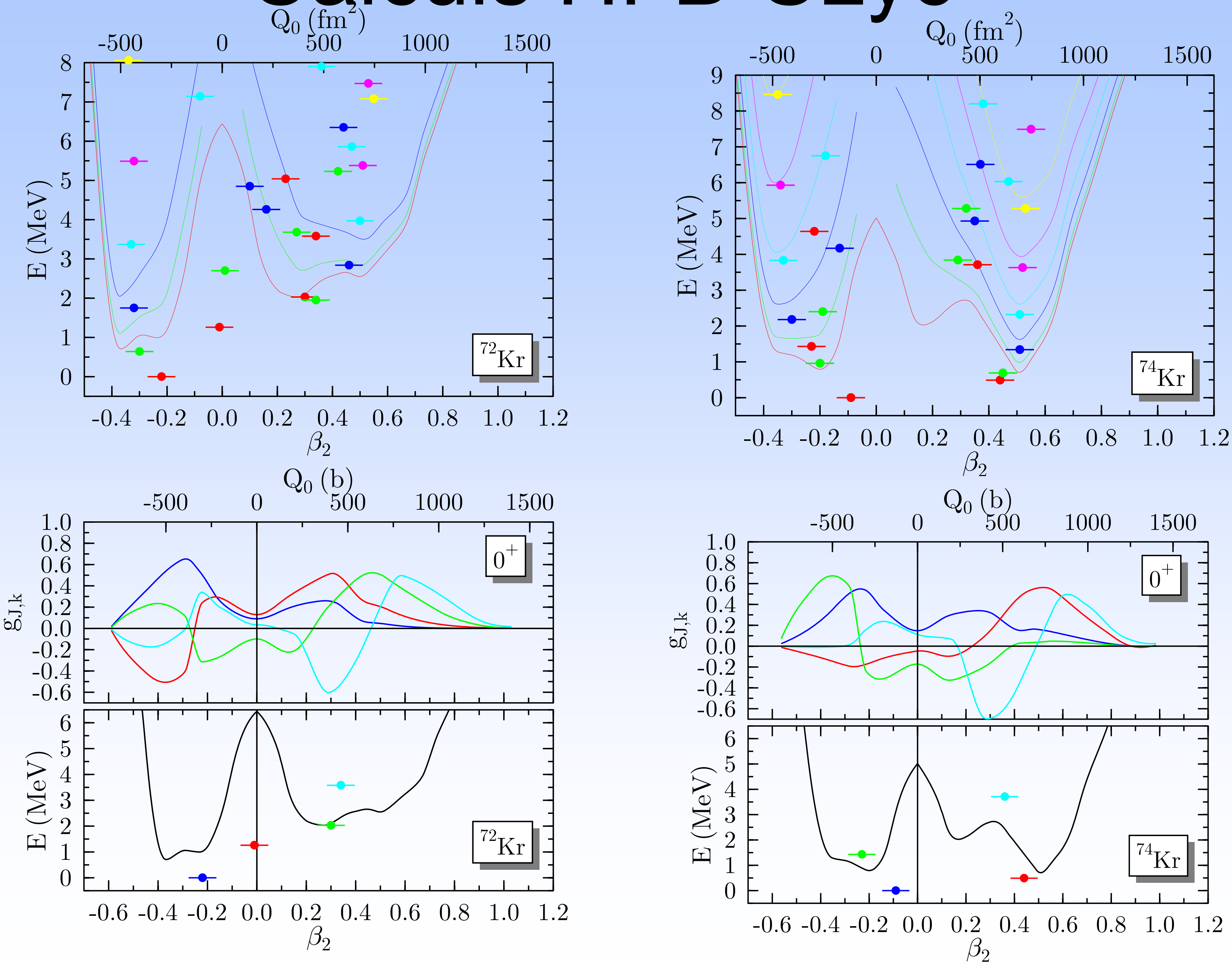
$$\sigma_{E2} \simeq \left(\frac{Z_c e^2}{\hbar c}\right)^2 \frac{\pi}{e^2 b_0^2} B(E2)$$

$$\sigma_{E2} = \frac{N_\gamma^{coulex}}{N_{inc} N_{cible/cm^2}}$$

$$B(E2,X) = B(E2,Ref)\,\frac{\epsilon_{E\gamma}^{rel}(Ref)\; N_{particule}^{Detecte}(Ref)}{N_\gamma^{Det}(Ref)}\;\frac{N_\gamma^{Det}(X)}{\epsilon_{E\gamma}^{rel}(X)\; N_{particule}^{Detecte}(X)}\;\mathcal{F}_{cinematique}$$

Noyau	B(E2) Référence	B(E2) déduit [W.u]
^{66}Ge	12.0 (23)	11.7 (1.5)
^{62}Zn	11.7 (9)	10.2 (2.1)
^{68}Se		$\leq$19
^{64}Zn	19.5 (6)	21.7 (2.8)

Calculs HFB-SLy6



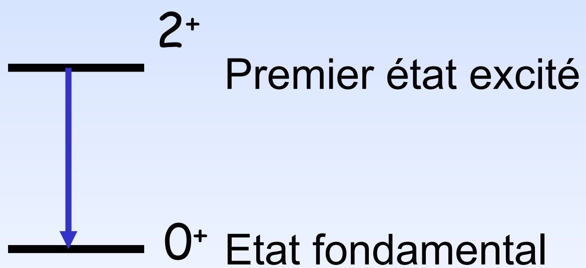
M. Bender et al., communication privée

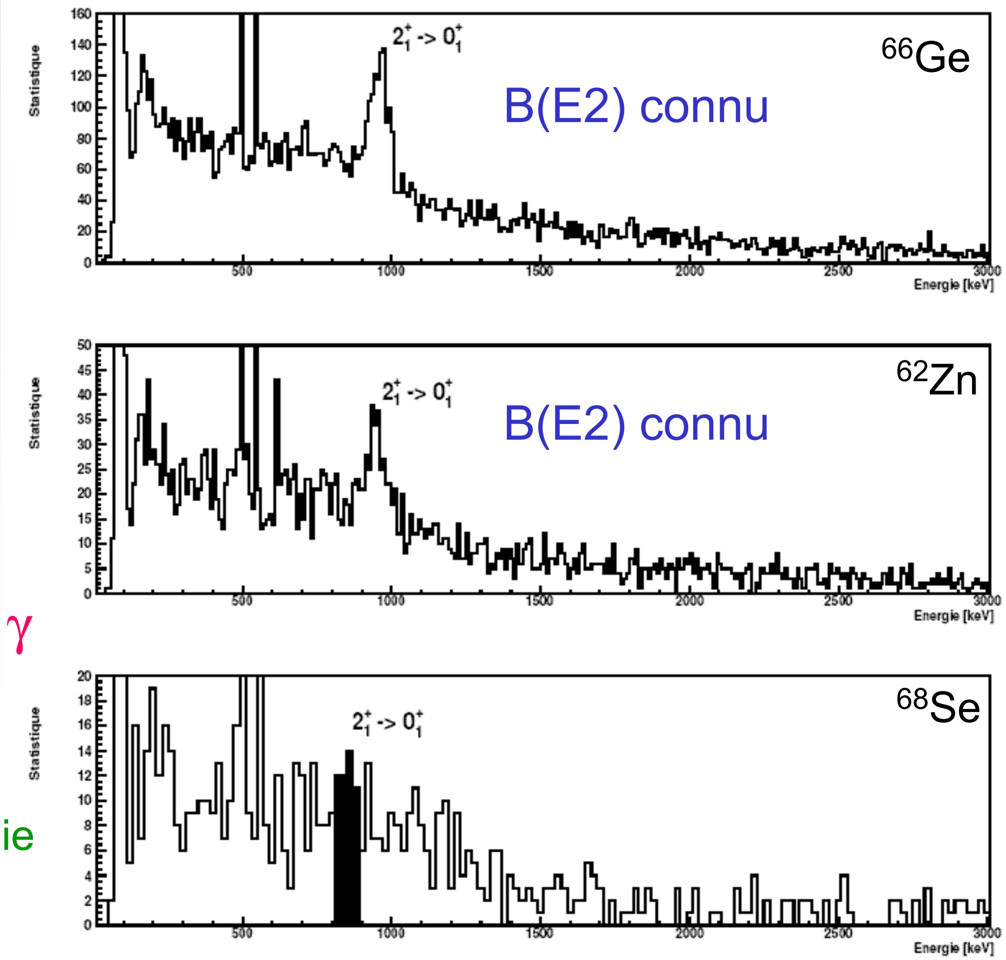
Résultats expérimentaux

- Excitation Coulombienne des noyaux de ^{78}Kr, ^{72}Ge et ^{64}Zn pour la normalisation

- Intensité du ^{72}Kr trop faible (< 54 pps) pour réaliser l'expérience

- Excitation coulombienne des noyaux radioactifs de ^{62}Zn, ^{66}Ge et ^{68}Se





- Aucune transition électron ou γ correspondant à la décroissance de l'état 0^+_2 n'a été observée

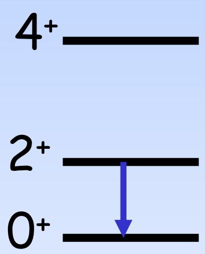
⇨ Pas d'état 0^+_2 à basse énergie

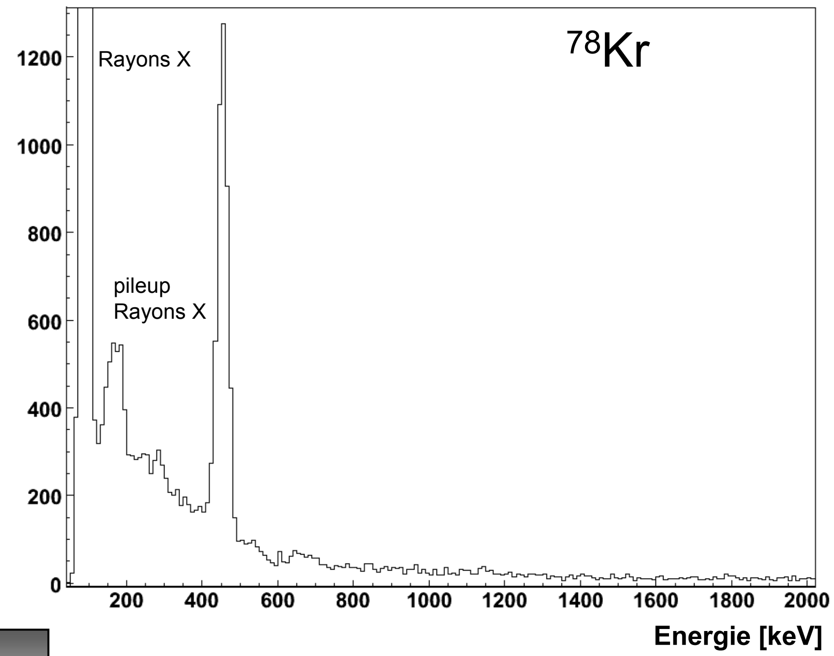
Faisceaux de normalisation

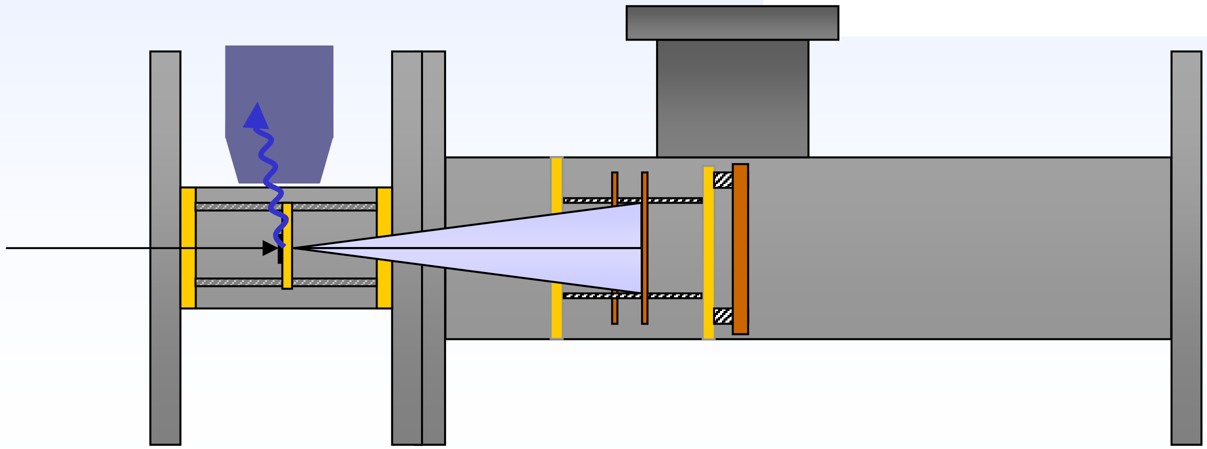
Le B(E2) mesuré est normalisé à une valeur connue

→ « Calibration » du B(E2) en faisceaux stables de ^{78}Kr, ^{72}Ge et ^{64}Zn

Excitation coulombienne

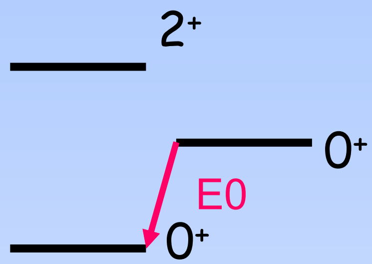






Spectroscopie isomérique

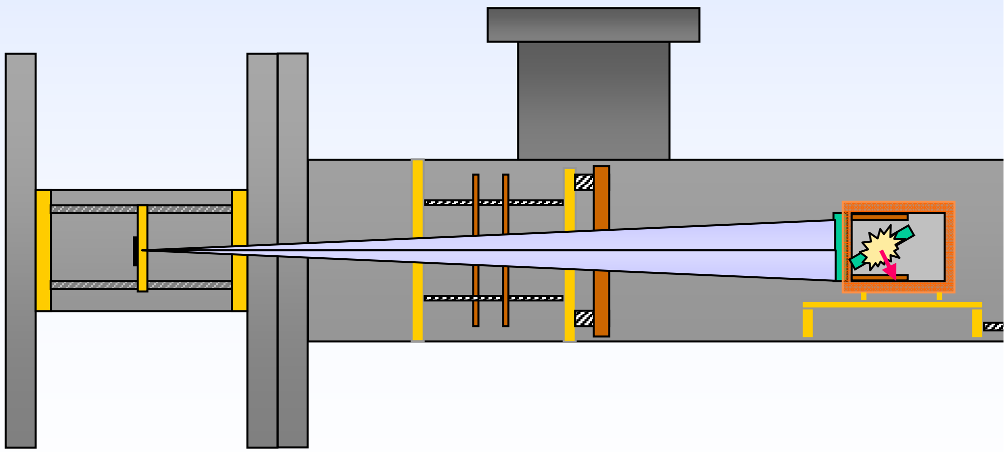
Isomère E_0 du ^{72}Ge

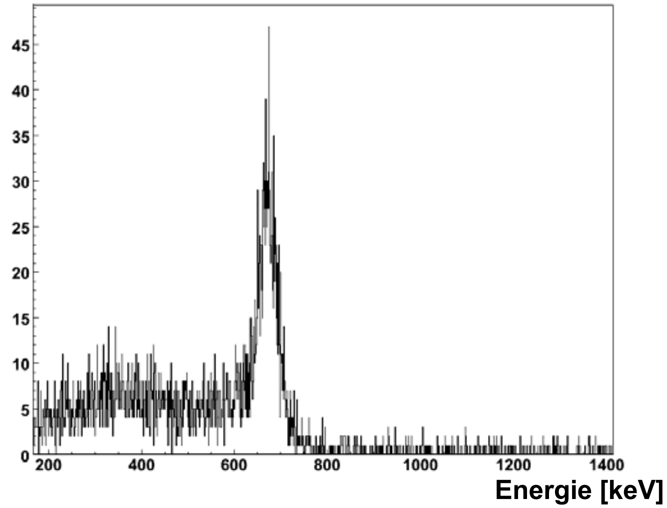


Le premier état excité du ^{72}Ge est un état 0^+,
scénario connu pour le ^{72}Kr et attendu pour le ^{68}Se

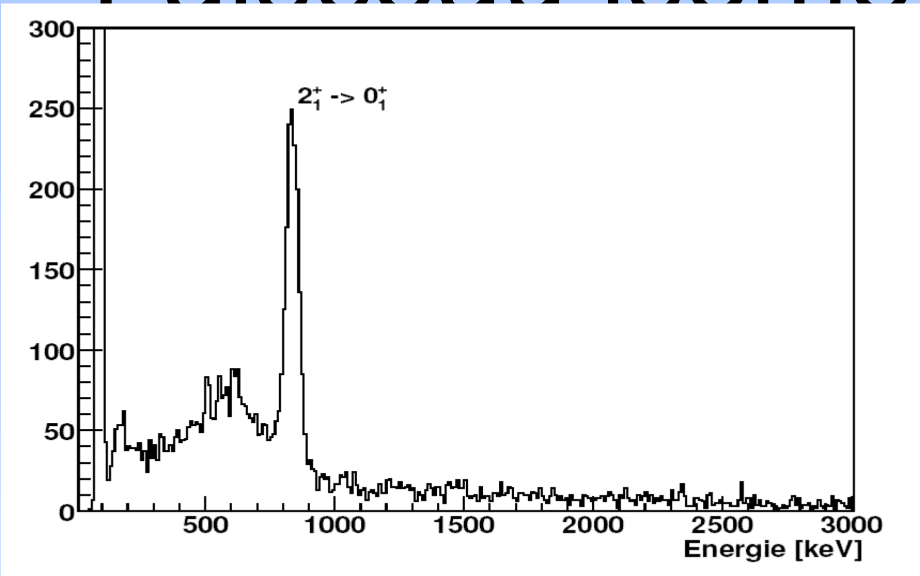
La transition directe entre 2 états 0^+ (E_0) ne peut se faire par γ mais uniquement par électrons de conversion

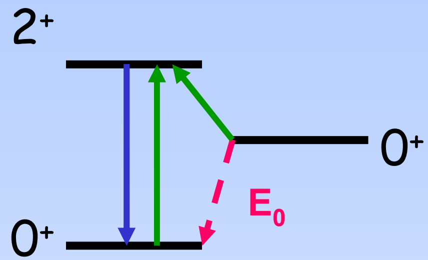
A travers le spectromètre les ions sont compléments épluchés de leurs électrons atomiques:
→ transition E_0 bloquée !



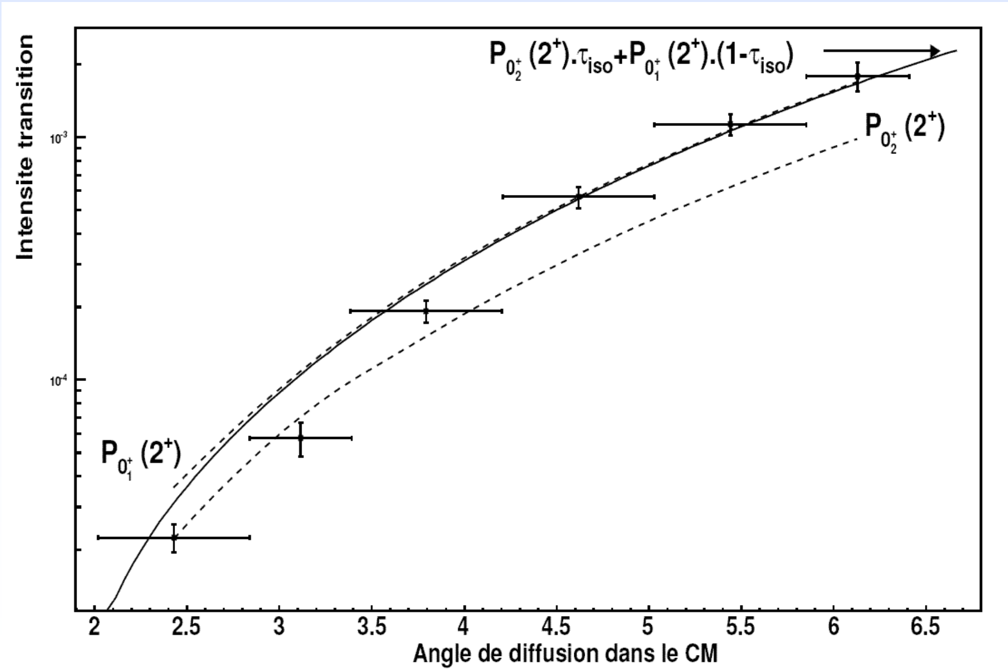


Faisceau isomérique de ^{72}Ge

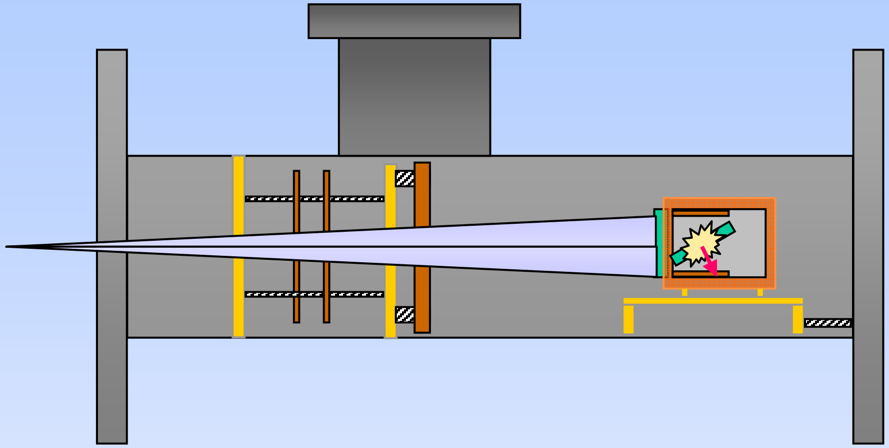


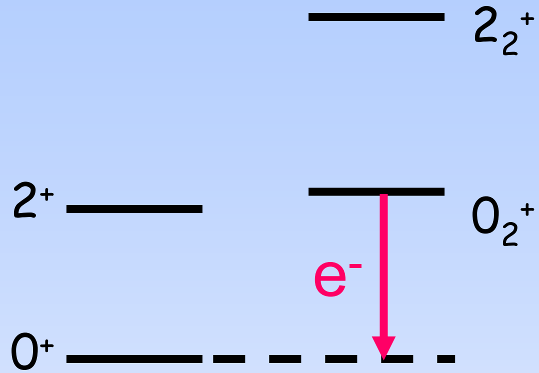


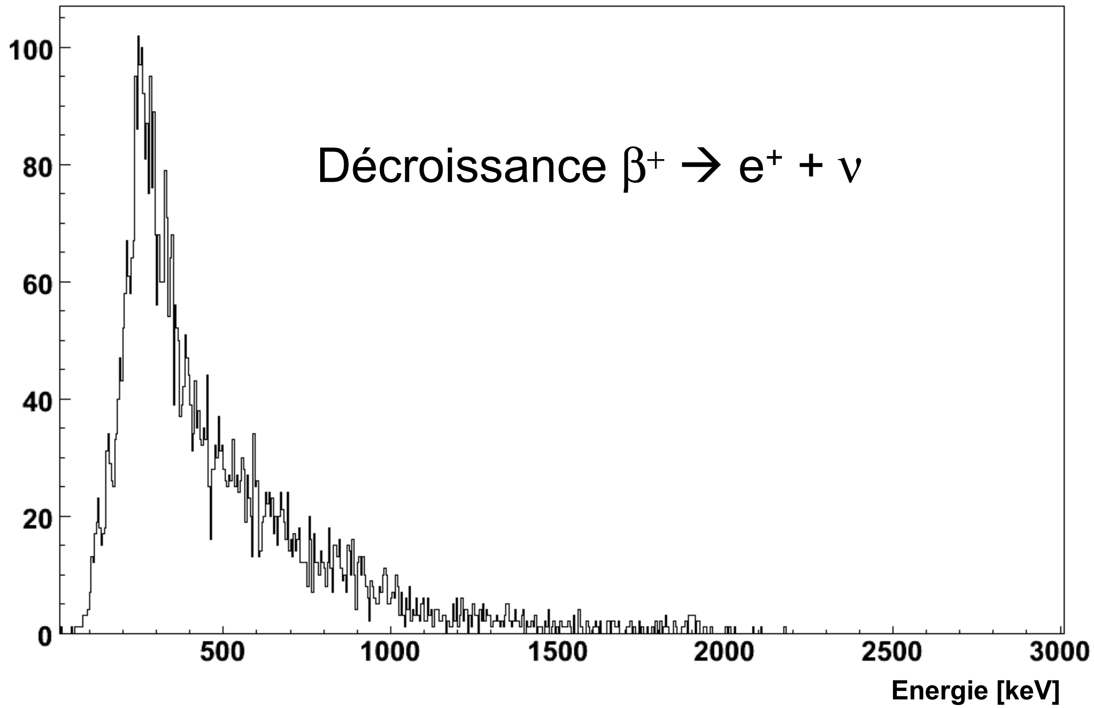
$$\sigma(E2)^{Tot.} = x.\sigma(E2; 0_2^+ \rightarrow 2^+) + (1-x).\sigma(E2; 0_1^+ \rightarrow 2^+)$$



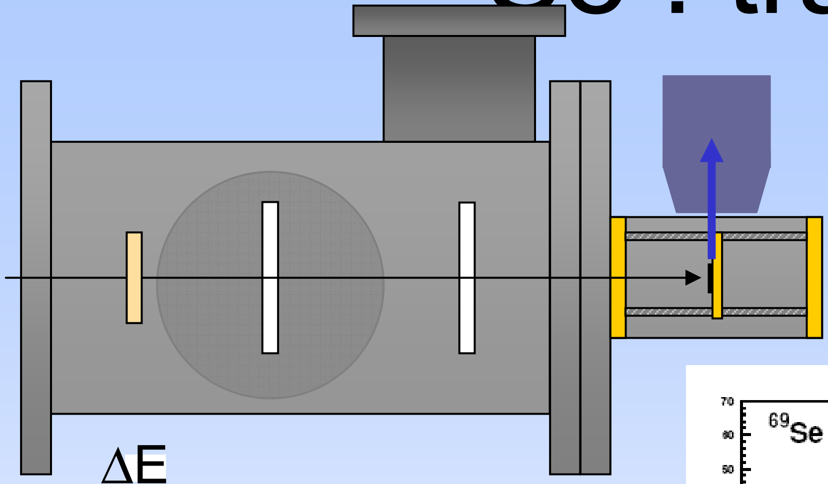
Spectroscopie isomérique du ^{68}Se : transition E_0

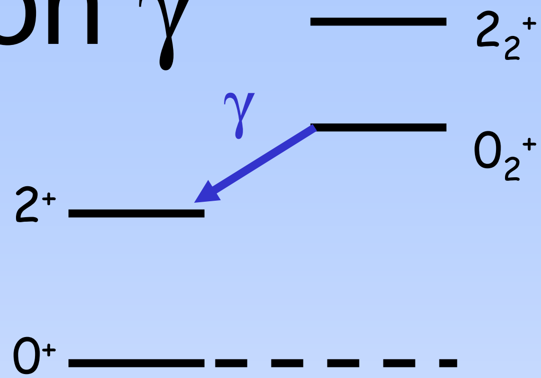




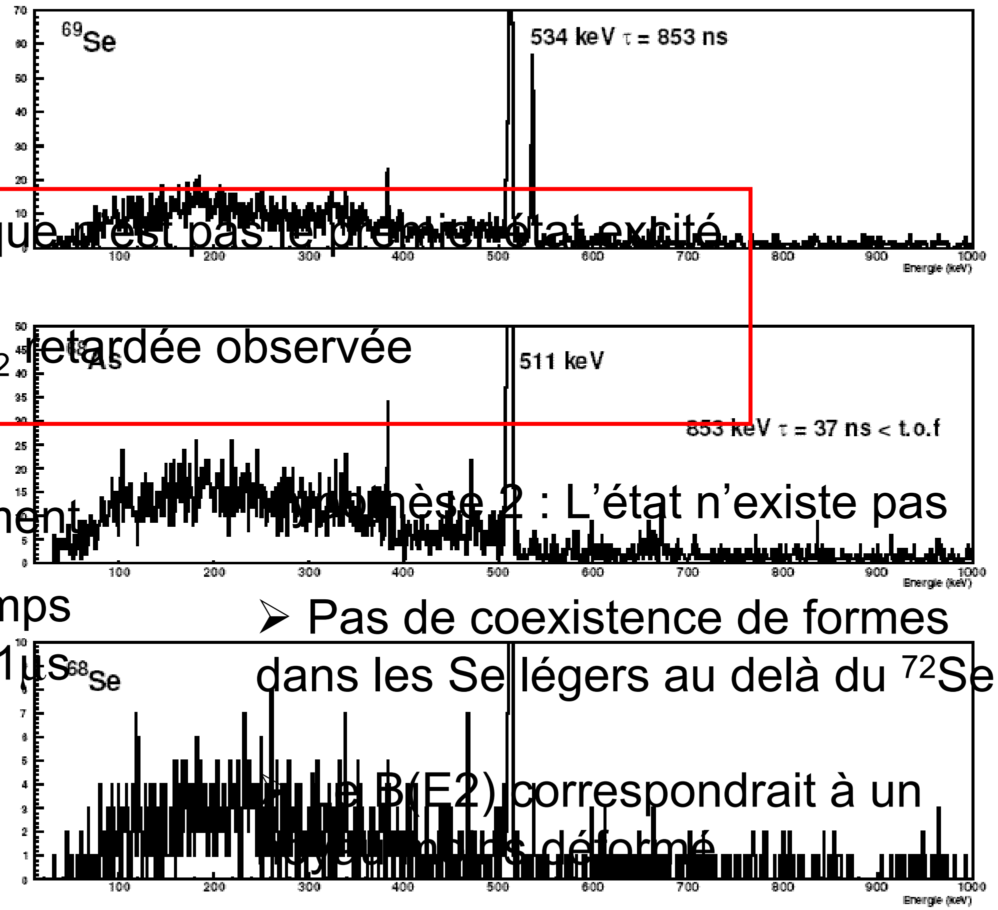


Spectroscopie isomérique du ^{68}Se : transition γ





- L'état 0^+_2 hypothétique n'est pas le premier état excité
- Aucune transition E_2 retardée observée



Hypothèse 1 : L'état existe vraiment

➢ Temps de vie inférieur au temps de vol dans le spectromètre < 1μs

➢ 100 keV au dessus du 2^+_1

Hypothèse 2 : L'état n'existe pas

➢ Pas de coexistence de formes dans les Se légers au delà du ^{72}Se

➢ Le B(E2) correspondrait à un noyau plus déformé