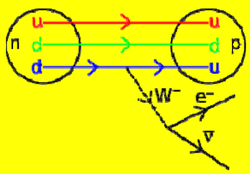
I.N.Borzov *

Beta-decay data from microscopic models



Joint Institute of Heavy Ion Research, ORNL

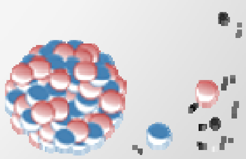
Self-consistent approach to nuclear beta-decay based on DFT

- UNEDF PROGRAM: www.unedf.org
  A quest for universal nuclear density functional.

Aim

- describe existing beta-decay data with well quantified uncertainties;
- provide reliable extrapolation to unknowns,
- large-scale calculations of beta-decay data for applications.

*) NDC IPPE, Obninsk and BLTP JINR, Dubna



Applications:

RIB experiments

T1/2 and Pn-s predictions for recent RIB experiments in ORNL, GSI, IPN.
Nuclear structure models are guided by RIB experiments on short-lived nuclei.
(New data vs. existing global approaches: DFT, FRDM+RPA, Gr. theory.)

Beta-decay data for astrophysics

(Collaborations with ULB and GSI).
Beta-strength functions →TALYS→T1/2, Pn, bn-spectra→R-process abundances.

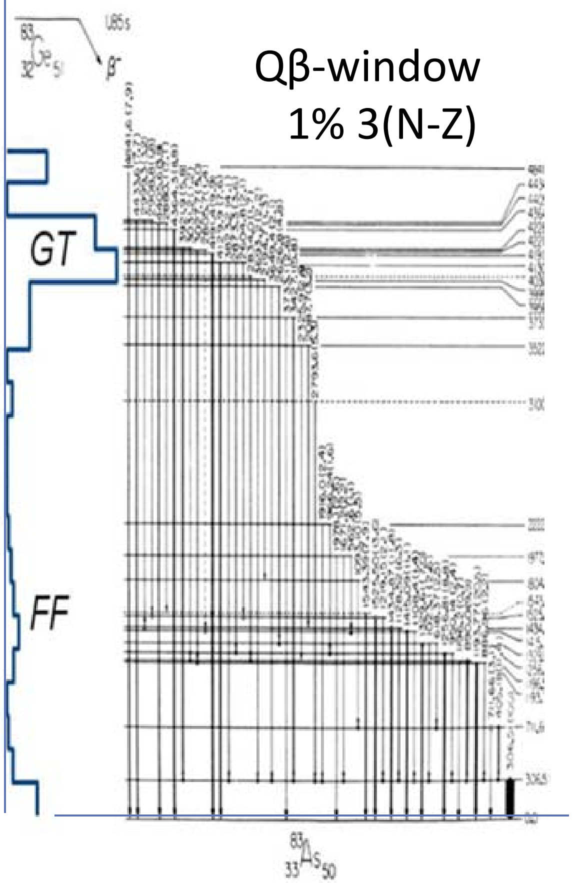
Reactor applications

NDC IPPE, Obninsk
Theoretical nuclear data: Qb, Sn, T1/2, Pn .
Table for fission products and r-process nuclei (I. Spherical nuclei).
Re-evaluation of ν_D for actinides.

Beta decay of very neutron-rich nuclei

GT Resonance
99% 3(N-Z)

Qβ-window
1% 3(N-Z)



Beta-decay rates for the r-process

The most unreliable data-base.
Experimental data are incomplete.
Theoretical predictions are complicated .

- 1-2% of the GT sum rule within the Qβ-window .
  Energy distribution of this tiny strength defines the total half life;
- sensitivity to nuclear g.s. properties: high;
- sensitivity to effective NN-interaction: high;
  (repulsion vs. attraction; finite-range vs. contact)
- competition from the FF decays: complicates theoretical analysis;
- Temperature dependence: rather low (Kajino et al. , 2009).

Different approaches give deviating extrapolations far from stability.

Comparing them one has to clearly realize the main assumptions and restrictions of the models.

Gamow-Teller (GT) vs. first-forbidden (ff).
New effects predicted near the closed shells

The ff decays are suppressed cf. GT

$M^2_{ff} \sim (1/qR\times L)\, M^2_{GT}$

(if the same phase-space is assumed).

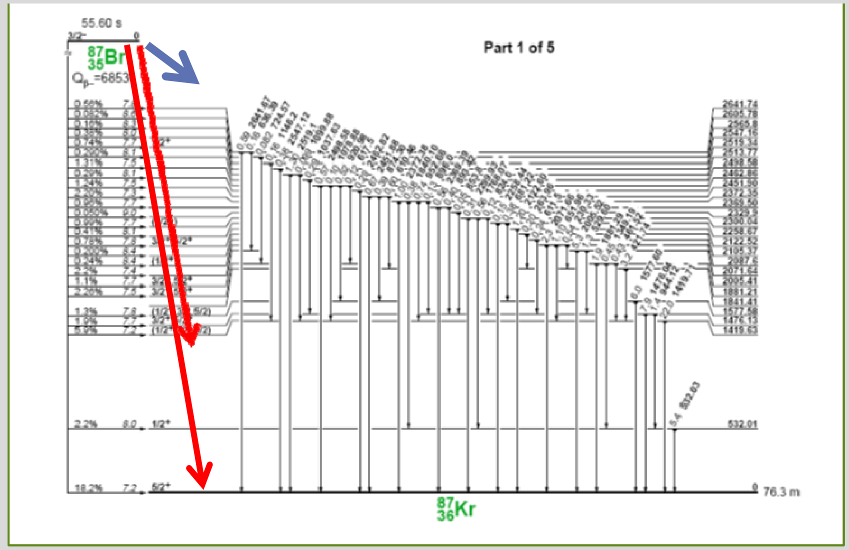
* * *

Below and above the shell closures Nmag=50,82:

a) $N < Nmag$ $\qquad Q_{ff} \leq Q_{GT}$

b) $N > Nmag$ $\qquad Q_{ff} >> Q_{GT}$

The impact of high-energy ff-decays on $S_{JLS}(Q)$, T1/2, Pn-s depends on detail of the shell-sequence



N>50 High-energy FF decay and low-energy GT

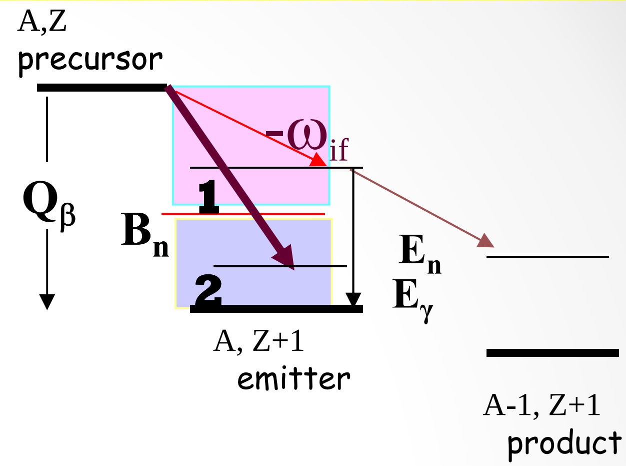
SHELL EFFECTS FAR FOM STABILITY:

- ***Crossing the major N=50,82,126 shells .***
  High-energy ff transitions reduce the half lives and Pn-branchings.
- ***Near Z~28, N~50.***
  Sensitivity of the beta-decay rates to the J/π of the g.s.
  Stabilization of the half-lives near new emerging subshell at N=58.

Half-life, Pn-value

Key ingredient is the ***beta-strength function*** $\boldsymbol{S_{JLS}(\omega)}$***:*** *spectral distribution of beta-decay matrix elements. Its resonance character reflects non-statistical nature of beta-decay.*

(See e.g. I.N. Izosimov , PEPAN 30(2),131,1999.)



$$T_{1/2} = \frac{D}{\left(G_A/G_V\right)^2 \int_0^{Q\beta} S_L(\omega)\ f_0(Z,\omega)\ d\omega}$$

$S_L(\omega) -\ \beta - strength\ \ function$

$$D = 2\pi^3 \ln 2 / G_V{}^2 m_e{}^5 = 6163s$$

$$G_A / G_V = 1.26$$

$$f_0(Z, A, \omega) = \int_0^{\omega} F(Z, A, \omega) pW(\omega - W)^2 dW$$

$f_0(Z,\omega) \sim\ \omega^5 - amplifies\ \ the$
$high - energy\ \ tail\ of\ \ S_\beta(\omega)!$

$$P_n = \frac{\int_{B_n(Z+1)}^{Q\beta} S_L(\omega)\ f_0(Z,\omega) P_{if}(j_{if}, E_n) d\omega}{\int_0^{Q\beta} S_L(\omega)\ f_0(Z,\omega) d\omega}$$

$$P_{if} = \Gamma_n / (\Gamma_n + \Gamma_\gamma),$$

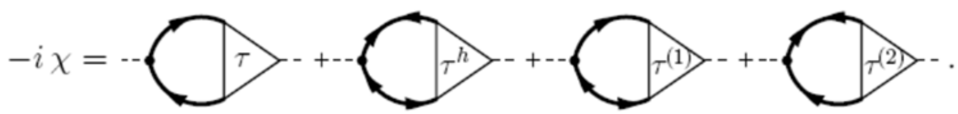
$$\Gamma_\gamma << \Gamma_n \quad \Rightarrow \quad P_{if} \approx 1$$

Beta-strength function

Finite Fermi system theory (FFST):

Beta-decay strength function can be defined through polarization operator of 2-component superfluid Fermi system

Migdal, A.B., Theory of Finite Fermi Systems, Moscow: Nauka, 1983, 2nd ed. (in Russian)



To find the strength function in nuclei with pairing one has to

1. ***constrain the ground state:***

   self-consistent HFB based on DFT (to find Qb and single-quasiparticle basis).

2. ***solve the QRPA-like eqns.:***

   FFST eqns. (to find effective fields $\sim\tau_i$) .

An approach is equivalent to HFB + pnQRPA

Ground State properties : DFT

An upper limit of exact E total:

$$E[\rho,\nu]=Tr\left(\frac{p^2}{2M}\rho\right)+E_{\text{int}}[\rho,\nu]$$

$Kohn-Sham\ quasiparticle\ local\ EDF,\quad M^*=1$

$$E_{\text{int}}=\sum_{main,Coul,sl}\varepsilon_n[\rho]+\frac{1}{2}\ \nu^*\ F^{\xi}[\rho]\nu$$

$F^{\xi}-volume+surface$

$$\boldsymbol{H}=\begin{pmatrix}\boldsymbol{h}-\mu & -\Delta\\ -\Delta & \mu-\boldsymbol{h}\end{pmatrix}$$

$$\boldsymbol{h}=\frac{\boldsymbol{p}^2}{2\boldsymbol{m}}+\frac{\delta E}{\delta\rho}\sim\rho$$

$$\Delta=\frac{\delta E_{\text{int}}}{\delta\nu}$$

$HFB-like\quad iterative\quad procedure$

$\rho_0,\nu_0\Rightarrow h_0,\Delta_0\Rightarrow\rho_1,\nu_1\Rightarrow h_1,\Delta_1$

DF3 functional by S.A. Fayans et al.

S.A. Fayans, S.V. Tolokonnikov,E.Trykov, D. Zawischa, Nucl.Phys. A676 (2000) 49.
I.N. Borzov, S.A. Fayans, E. Kromer, D. Zawischa Z. Phys. A335(1996) 117

Fitted to the masses and (as M=1) it was specially fitted to s.p energies of very neutron-rich doubly-magic 132Sn*

NEW:

DF3a with better spin-orbit splitting; blocking the odd–p in Z and Z+1 isobars

Excited states: CQRPA based on the self-consistent g.s

$$F^{\omega}_{\tau\tau} = \frac{\delta^2 E}{\delta\rho^{\tau}\delta\rho^{\tau}} \qquad F^{\xi}_{\tau\tau} = \frac{\delta^2 E}{\delta\nu^{\tau}\delta\nu^{\tau}}$$

An impact of spin-dependent terms on nuclear masses is of order of 100KeV.
(J. Margueron et al. J.Phys.G 36(2009) 125103)

Approximation:

The spin-isospin (time odd) parts of the effective NN-interaction are defined independently of the scalar (time-even) parts.

DF+CQRPA

- *Universal (the same for all A) effective NN-interaction*
- *Non-truncated (ph,pp,hh) QRPA matrix.*
  (full ph basis Continuum QRPA)
- *Gamow-Teller and first-forbidden decays*

Spin-isospin NN-interaction

ph:

$$F^{\omega}_{\sigma\tau} = 4N_0^{-1}\left[g'_0\vec{\sigma}_1\cdot\vec{\sigma}_2 + g_\pi e^2_{q\pi}\frac{(\vec{\sigma}_1\cdot\vec{k})(\vec{\sigma}_2\cdot\vec{k})}{k^2+m_\pi^2+P_\Delta(k^2)} + g_\varrho e^2_{q\rho}\frac{[\vec{\sigma}_1\vec{k}][\vec{\sigma}_2\vec{k}]}{k^2+m_\varrho^2}\right]\tau_1\cdot\tau_2\ .$$

$2N_0^{-1} = C_0 =$ 300MeV fm^3, with $C_0 = 2\varepsilon_F/3\rho_0$, and ρ_0=0.0859 fm^{-3}

g'>0 is fixed from GTR position (shifts GT strength to higher Ex↑, as g'$_{\pi,\rho}$ <0 shift it downward)↓

Here, $g_\pi = -2\pi/N_0\ (f_\pi^2/m_\pi^2)$, $g_\varrho = -2\pi/N_0\ (f_\varrho^2/m_\varrho^2)$, where $m_\pi(m_\varrho)$ and $f_\pi(f_\varrho)$ are the bare pion (ϱ-meson) mass and the $\pi NN(\varrho NN)$ coupling constants, respectively. The pion irreducible polarization operator in the nuclear medium $P_\Delta(k^2)$ takes care of the virtual Δ isobar–nucleon hole excitations. The contact part of the effective spin-isospin interaction Eq. (14) is governed by the Landau-Migdal constant g'_0. The operator $e^2_{q\pi} = Q = e_q[\sigma\tau]^2$ is assumed to describe the quenching of the pion-nucleon vertex [18]. The operator $e^2_{q\varrho}$ is defined from the condition that the ϱNN coupling

pp:

$$F\sigma\tau^{\xi}(\boldsymbol{r}_{ij}) = -4N_0^{-1}(g'_\xi + h^\xi x^q)\delta(\boldsymbol{r}_{ij}), \quad (J^\pi = 0^-, 1^+, \ldots)\ .$$

g'$_\xi$ <0 is fixed from (p,n) and (n,p) spectra (shifts the GT strength downward)↓

An increase of g'_ξ leads to shorter β^--decay halflives and softer (p,n) spectra

GT and FF beta-decay driving operators

Gamow-Teller decay

(simple operator)

$$e_q[V_0]_{J=1, L=0, S=1} = 2\sqrt{\pi}(1-2\zeta_s)\vec{\sigma}\vec{\tau}$$

$$\varsigma_s = 0.05 - 0.075 \ \ from \ \ Ward's\ identity$$

$$e_q[\sigma\tau]^2 = (1-2\varsigma_S)^2 = \left(\frac{g_A}{G_A}\right)^2 = 0.9^2$$

eq – GT quenching operator

Migdal, A.B., Theory of Finite Fermi Systems,
Moscow: Nauka, 1983, 2nd ed. (in Russian)
(1st ed. New York: Interscience, 1967).

CQRPA

$$P_{ph}(\omega) = -1/\pi\, \mathrm{Im}(e_q V_0 G_\tau G_{\tau'} V)$$

… + Ppp

First-forbidden decay

(complex operators: contain velocity dependence and interference terms)

$$V_0 = 2\sqrt{\pi}\ e_q[V_0]_{J,L=1,S}\tau_-$$

$$V_{0\ 0,1,1} = (1-2\varsigma_s)\vec{\boldsymbol{\sigma}}*\vec{r} - e_{q5}\ \vec{\boldsymbol{\sigma}}*\vec{P}/2M$$

$$V_{0\ 1,1,0} = \frac{1}{\sqrt{3}}(i\vec{r} - \vec{P}/2M)$$

$$V_{0\ 1,1,1} = (1-2\varsigma_s)\sqrt{2}[\vec{\boldsymbol{\sigma}}\vec{r}]^{(J=1)}$$

$$V_{0\ 2,1,1} = (1-2\varsigma_s)\frac{2}{\sqrt{3}}[\vec{\boldsymbol{\sigma}}\vec{r}]^{(J=2)}$$

Warburton, E.K., Phys. Rev. C, 1991, vol. 44, p. 233.

e_{q5} - FF (J=0) amplification operator

$$\vec{P} \Rightarrow i r, \qquad \vec{\boldsymbol{\sigma}}*\vec{P} \Rightarrow i\vec{\boldsymbol{\sigma}}*\vec{r}$$

$$CVC, PCAC\ reduction$$

I. N. Borzov, Phys. Rev. C 67, 025802 (2003).

Continuum QRPA

Linear eqs. to be solved in coordinate-space

*Each super-matrix has a dimension N*N , where N ~ $4R_{nuc}$/ mesh size*

$$\left[\hat{I} - \begin{pmatrix} F^{\omega} & -F^{\xi} & F^{\omega\xi} & F^{\xi\omega} \\ -F^{\xi} & F^{\omega} & F^{\xi\omega} & F^{\omega\xi} \\ F^{\omega\xi} & F^{\xi\omega} & F^{\xi} & -F^{\omega} \\ F^{\xi\omega} & F^{\omega\xi} & -F^{\omega} & F^{\xi} \end{pmatrix} \begin{pmatrix} L(\omega) & M(\omega) & N^{1}(\omega) & N^{2}(\omega) \\ M(\omega) & L(-\omega) & N^{2}(-\omega) & N^{1}(-\omega) \\ N^{1}(\omega) & N^{2}(-\omega) & K(\omega) & -M(\omega) \\ N^{2}(\omega) & N^{1}(-\omega) & -M(\omega) & K(-\omega) \end{pmatrix}\right] \begin{pmatrix} V \\ V^{h} \\ d^{(1)} \\ d^{(2)} \end{pmatrix} = \begin{pmatrix} e_q V_0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

FRDM:
RPA

Fξ, Fω - effective NN-interactions in ph and pp channels.

L,M,Ni,K - ph ,pp,hh – charge changing propagators p(n)→n(p)

The T=1 ph-propagator with exact account for continuum and pairing

$$L(r,r';\omega) = [illegible](r,r';\omega) + \sum \left[L_{[illegible]} - [illegible] \right] \varphi_{[illegible]}\varphi_{[illegible]}\varphi_{[illegible]}\varphi_{[illegible]}$$

I.N.Borzov, and E.L.Trykov, Sov. J. Nucl. Phys. 52, 52 (1990).
I.N.Borzov, E.L.Trykov, and S.A. Fayans, Sov. J. Nucl. Phys. 52, 627 (1990).

Beta-decay half-life

$$S_\beta^{JLS}(\omega,\gamma) = \frac{(2J+1)}{4\pi}(e_q^{JLS})^2 \int \underline{\hat{V}_0^{JLS}}(r)\underline{\hat{\rho}^{JLS}}(r;\omega,\gamma)r^2dr \ ,$$

$$1/t_{1/2} = D^{-1}(G_A/G_V)^2 \int_{m_ec^2}^{W_{max}} C_\beta(W)F(Z,W)pW(W_{max}-W)^2 \mathrm{d}W,$$

$$1/T_{1/2} = D^{-1}(G_A/G_V)^2 \int_0^{Q_\beta} \mathrm{d}\omega \underline{f_0(Z,\omega)} \sum_{n=1,4} < \kappa_J > \underline{S_{\mathrm{n}}(\omega,\gamma)}$$

Coulomb (ξ) approximation E_{Coul} *=6/5 ξ >> ω* $\xi = Ze^2/2Rm_ec^2$

$$C_\beta = \sum_{J=0,1} B(J) = \sum_{J=0,1} \left| \frac{\sum_{S=0,1} < f|M_{JLS}|i >}{2J+1} \right|^2$$

GT S=1, J=1, L=0 and FF (non-unique) S,J=0,1; L=1

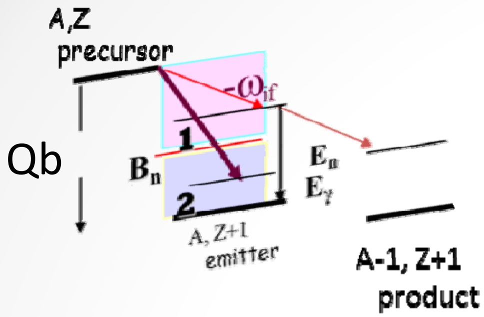
I.N. Borzov Phys.ReV. C67(2003)025802

Near the N=50,82 shells

Beta-decay properties of isotopes near the 78Ni, 132Sn are sensitive to the:

- ***A) competition of high transition energy FF beta-decays and low-energy GT decays at N>Nmag.***
- ***B) interaction induced ground state J-π inversion effects;***
- ***C) Stabilization of the half-lives near new emerging subshell at N=58.***

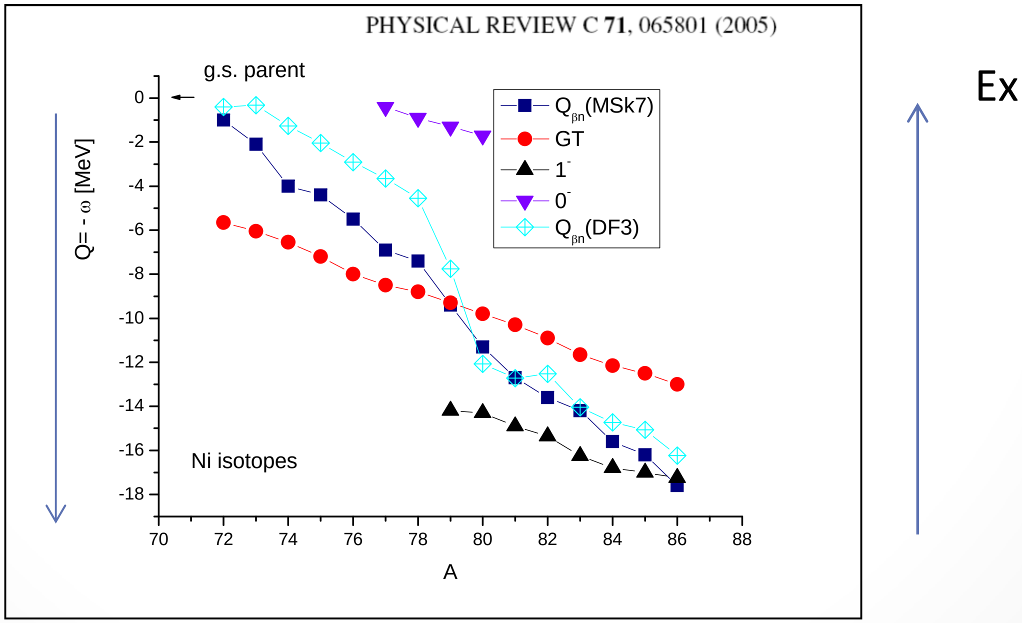
Reduction of Pn-values in Ni isotopes



$$P_n = \frac{\int_{B_n(Z+1)}^{Q\beta} S_L(\omega)\, f_0(Z,\omega) P_n(J_f, E_n)\, d\omega}{\int_0^{Q\beta} S_L(\omega)\, f_0(Z,\omega)\, d\omega}$$

$$P_f = \Gamma_n / (\Gamma_n + \Gamma_\gamma),$$

$$\Gamma_\gamma \ll \Gamma_n \quad \Rightarrow \quad P_f \approx 1$$



*At N>50, the main **GT-decays** undergo to the states located **within the Qbn-window**.*

*At 79Ni (N=50+1), new channel opens: **high energy FF** beta-decay with Q~Qβ **undergo outside the Qbn-window!***

Reduction of Pn-values in Ni isotopes

For neutron excess bigger than a major shell
T1/2 and Pn-values
are reduced compared to pure GT approximation.

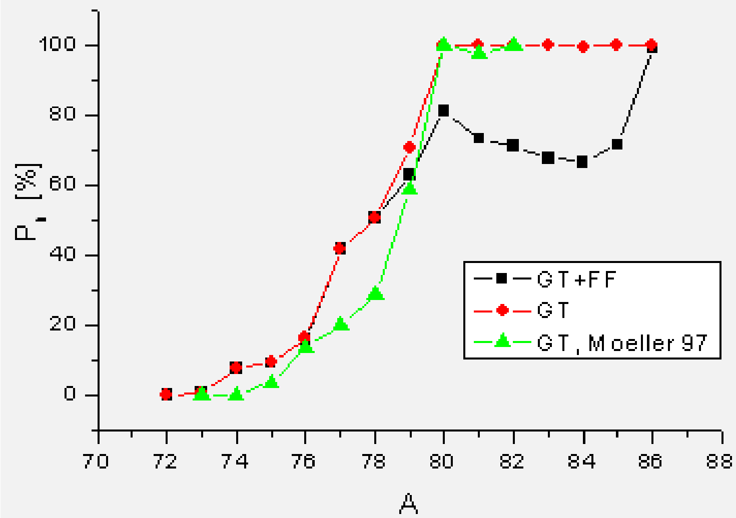
Reason: the high-energy ff decays to the states
outside the Qb-Sn window.

I.N. Borzov Phys.ReV. C71(2005)065801

New experiments at ORNL, 2011.
Isobaric purified beams.
For 82,83Zn Pn<100%

"GT-only" case : Pn tends to 100%.

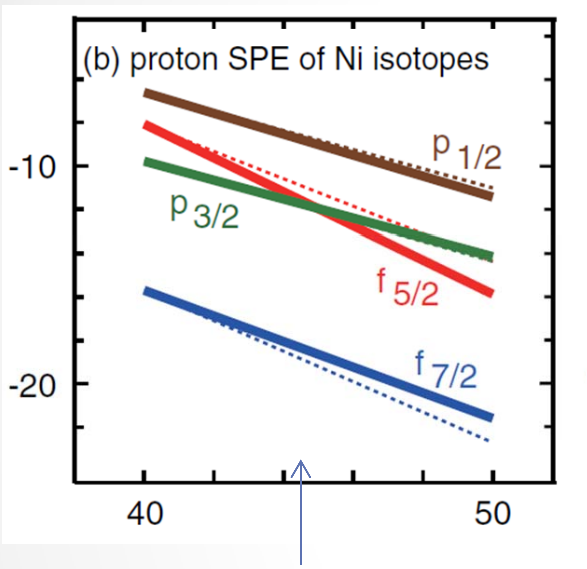
GT+ff : reduction of Pn-values !



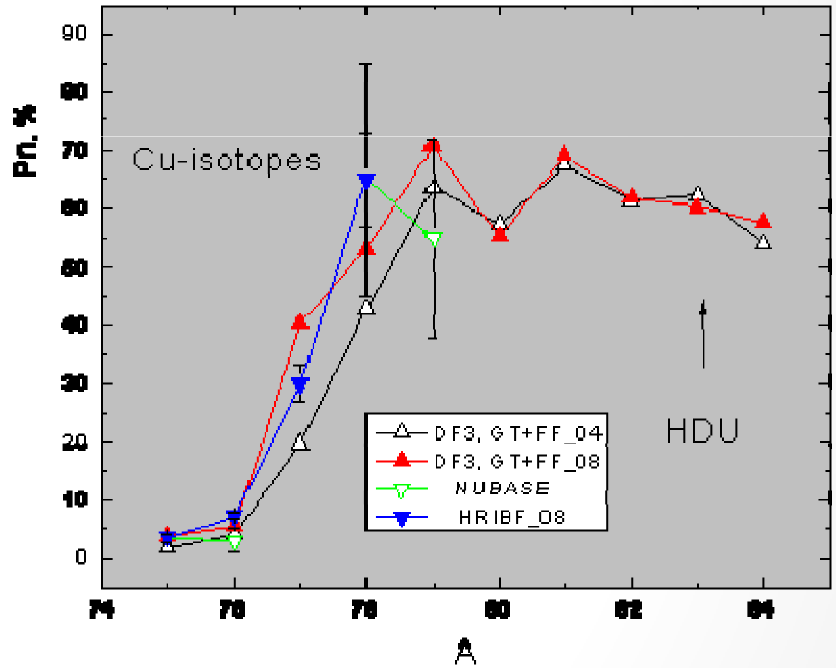
PRL 102, 142502 (2009) PHYSICAL REVIEW LETTERS week ending 10 APRIL 2009

Large β-Delayed Neutron Emission Probabilities in the ^{78}Ni Region

J. A. Winger,[1,*] S. V. Ilyushkin,[1] K. P. Rykaczewski,[2] C. J. Gross,[2] J. C. Batchelder,[3] C. Goodin,[4] R. Grzywacz,[5,2] J. H. Hamilton,[4] A. Korgul,[6,5,4,7] W. Królas,[8,7] S. N. Liddick,[3,5] C. Mazzocchi,[5,9] S. Padgett,[5] A. Piechaczek,[10] M. M. Rajabali,[5] D. Shapira,[2] E. F. Zganjar,[10] and I. N. Borzov[11]



T. Otsuka et al. PRL 104, 012501 (2010)



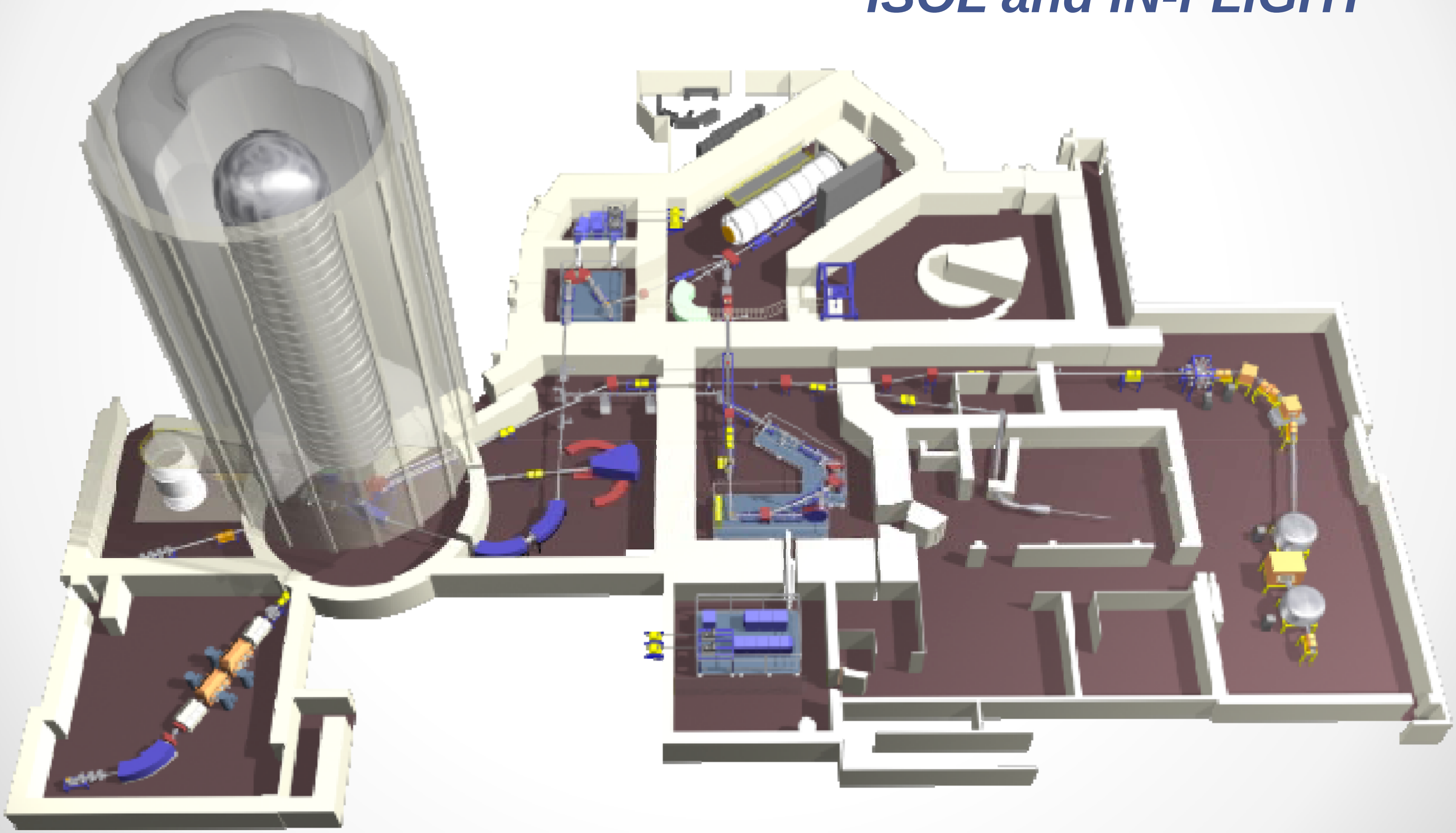
SM : inversion at A=73.
SkP , DF3: at A ~ 79.

Magnetic moments measurements:
in Cu isotopes π2p3/2 →1πf5/2 at A>75.
K. Flanagan et al PRL 103(2010)142501

DF3 with fixing the odd proton at 1πf5/2 in A>75 (blocking).
Pn-s shift in a right direction.

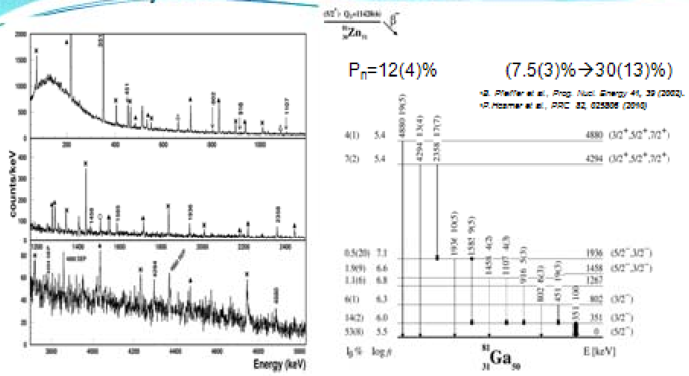
Holifield Radioactive Ion Beam Facility accelerators and separators

ISOL and IN-FLIGHT



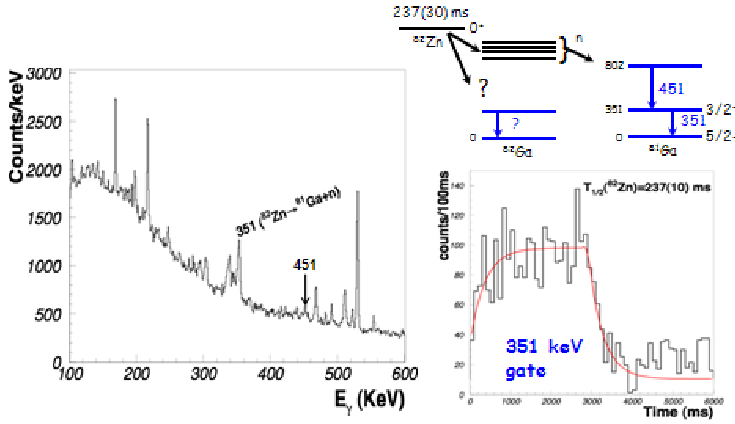
Zn isotopes A=81-83

Summary of ^{81}Zn results



- 11 gamma transitions observed, 9 new ones.
- All placed in level scheme → 5 new states
- Pure ^{81}Zn beam
- 2008 ^{81}Zn rate: 30 pps → 2011: ~300 pps

Decay spectroscopy of ^{82}Zn



S. Padget et al. PRC 82, 064314, 2010

"We consider only exp.data for our evaluation not to be ***contaminated*** *by any theory data…"*

hribf

- ❑ *Isobarically purified beam* ***(no isobaric contamination)***
- ❑ *Tandem post-acceleration (optional)*
- ❑ *LeRIBSS: mass & isobaric separation β, βn, βγ, βnγ*

OAK RIDGE NATIONAL LABORATORY

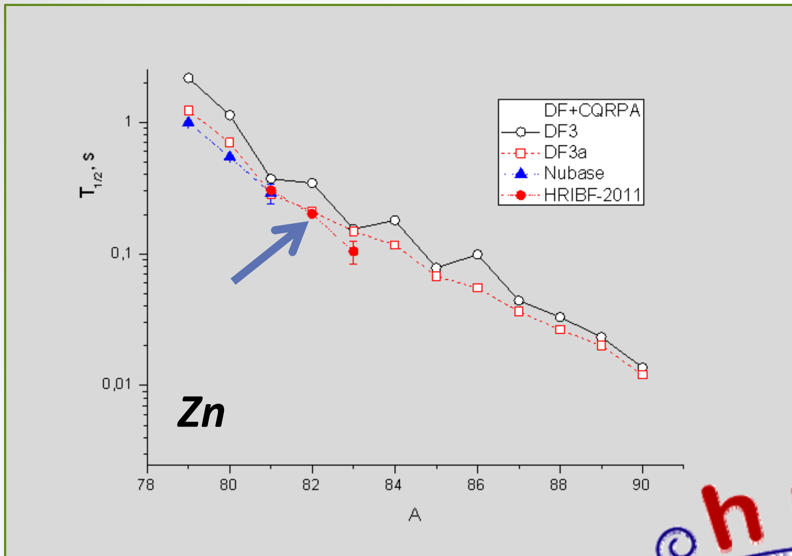
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

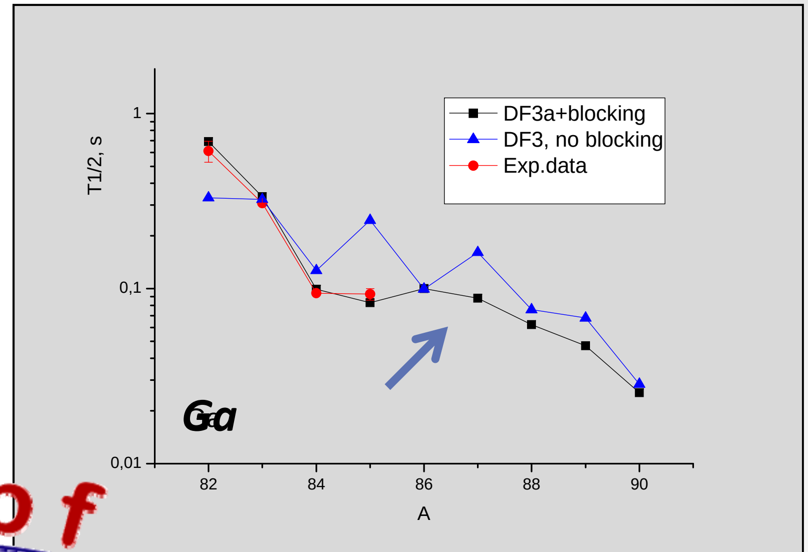
Newly measured half-lives of extremely exotic Zn and Ga isotopes alter calculated isotope abundances

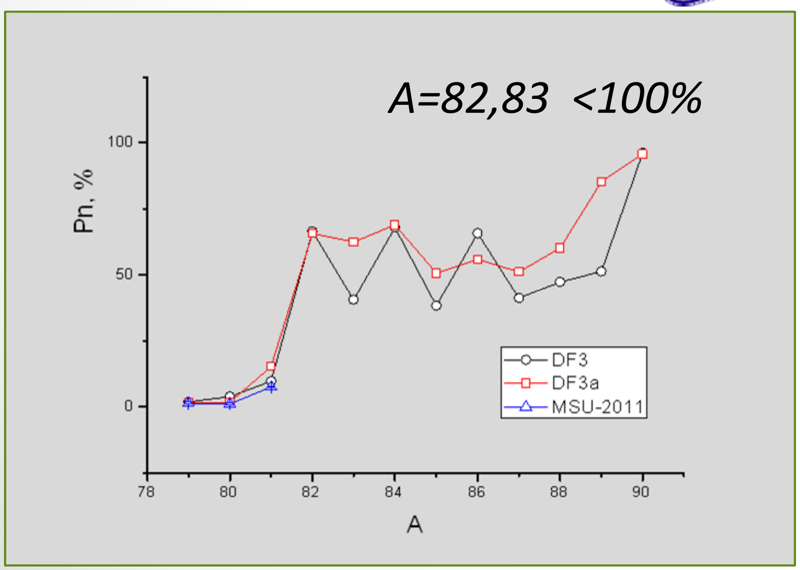
Researchers have, for the first time, identified the β decay of the extremely neutron-rich isotopes ^{82}Zn, $T_{1/2}$=202(7) ms, and ^{83}Zn, $T_{1/2}$=104(20) ms, and measured the β-decay half-life of ^{85}Ga to be 86(5) ms [Madurga2011]. Neutron-rich isotopes occur in environments such as type II supernova explosions believed to be a site of the rapid neutron-capture process and in nuclear reactor fuel. New data contribute to the input for large network calculations leading to better understanding of the abundances of isotopes created in these extreme environments.

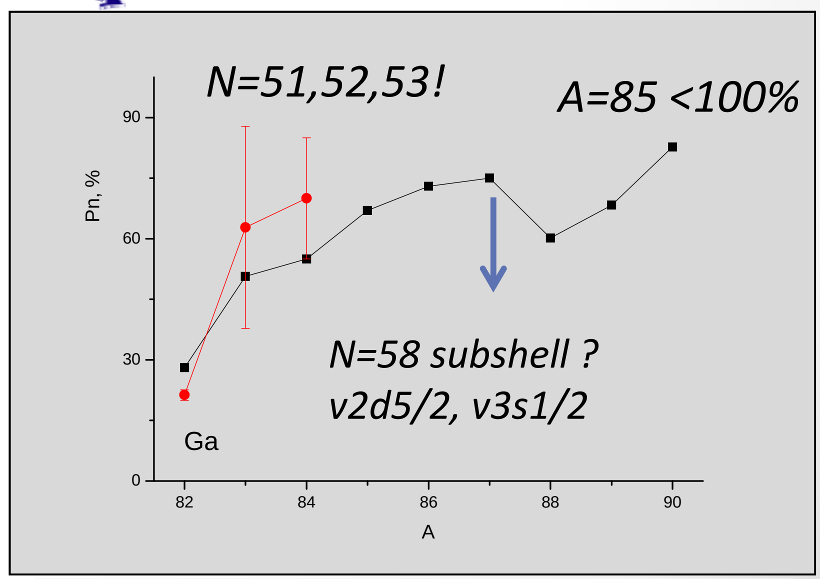
The Holifield Radioactive Ion Beam Facility (HRIBF) produces very neutron-rich nuclei using proton-induced fission of ^{238}U and is able to produce radioactive samples with enhanced isotopic purity. Zinc-82 is among "r-process waiting-point" isotopes, where β-decay is more likely to occur than neutron-capture. Zinc-83 and ^{85}Ga are now the most neutron-rich Zn and Ga isotopes with known β-decay properties, see Fig. 1. The measured half-lives indicate β-decay probability larger than estimated earlier. The half-life and nuclear structure information obtained from HRIBF experiments have been used to refine the theoretical modeling of the β-decay process within the continuum quasi-particle random phase approximation [Borzov2005, Winger2009]. The experimental half-lives and resulting changes in theoretical extrapolations have been used to re-analyze the post r-process isobaric distribution [Surman2011], see Fig. 1. This new analysis includes accelerated r-process decay rates and shows a redistribution of isotopic abundances for heavy nuclei.

DF-CQRPA vs. ORNL HRIBF 2011 measurements in Zn and Ga









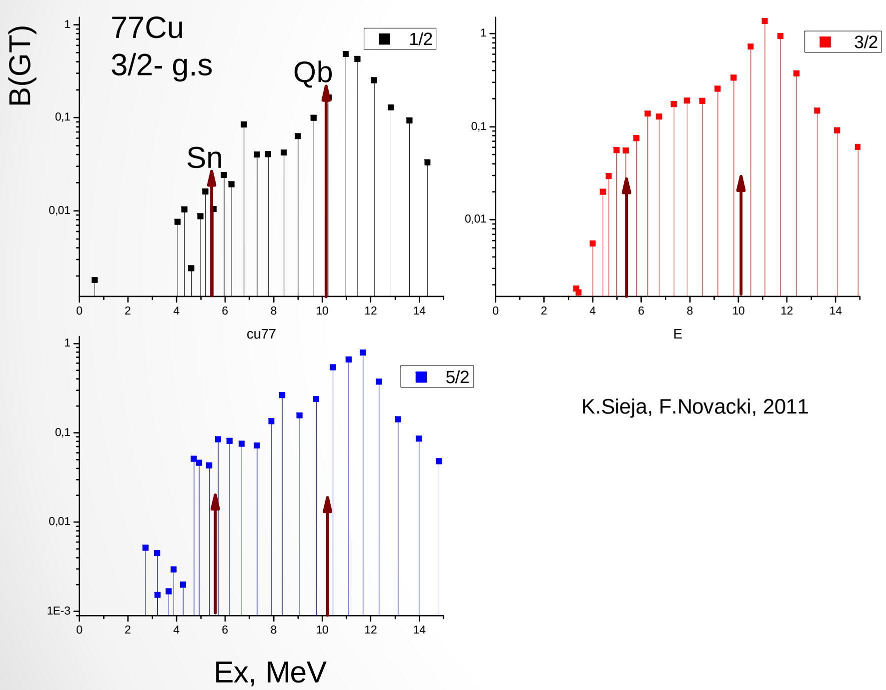
S. Padget et al. PRC 82, 064314, 2010

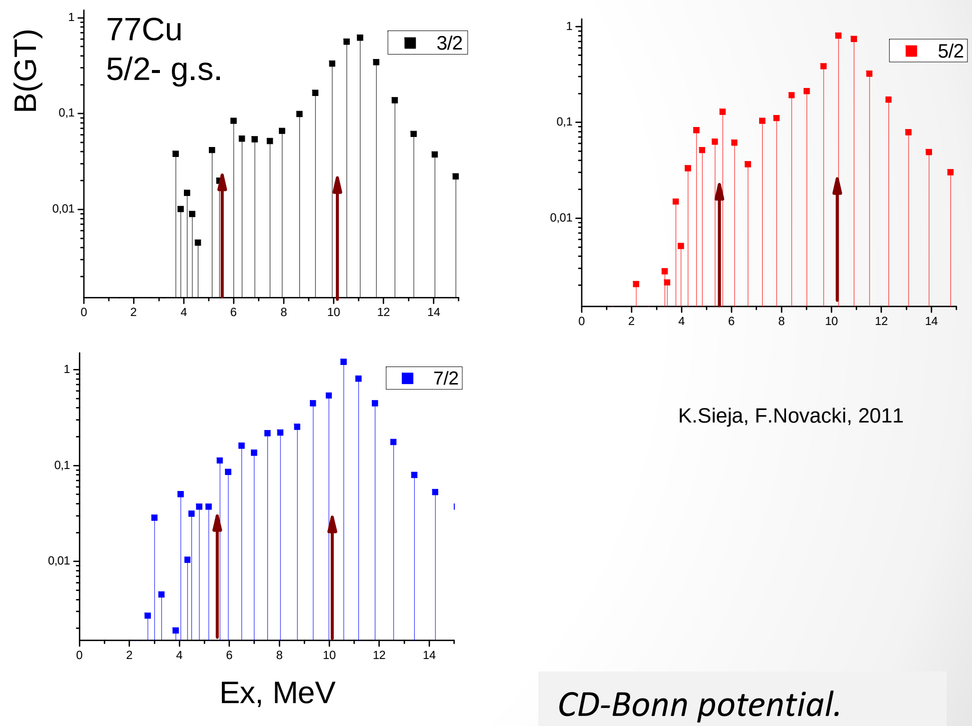
J. Winger et al. PRC 81, 044303, 2010
M. Madurga et al. , to be published 2011

Partial beta-strength functions. (K. Sieja, F. Novacki, 2010, p.c.)

~~Parent 3/2$^-$ g.s~~

Parent 5/2$^-$ g.s.



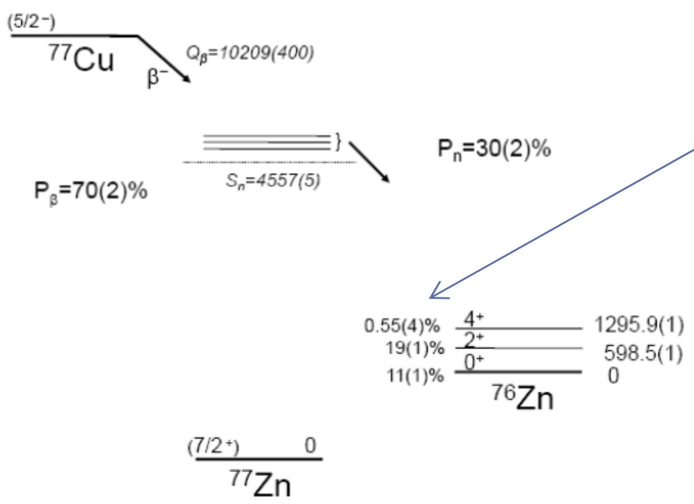


Sensitivity to the 77Cu g.s. J/ π
At least GT-distributions
*for **j_f=1/2 and 7/2** differ.*

CD-Bonn potential.
48Ca core.
p: f7/2, f5/2, p3/2, p1/2
n: f5/2, p3/2, p1/2,g9/2
*→ fp / **up to 8p8h***
*N=40 / **7*10(8)***

Fine structure of delayed neutron Pn-s.

A. Korgul et al. , to be published 2011



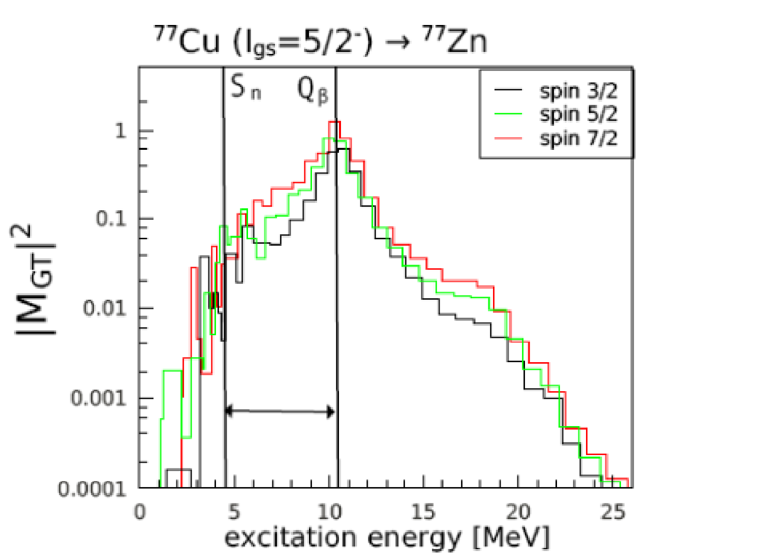


FIG. 6. Partial decay schemes of ^{77}Cu and [comment icon]. Partial and total branching ratios for βn emission are shown as well as the branching ratios for β-decay. The values for branching ratio of ^{77}Cu and ^{79}Cu are deduced from data published in [8], [14] and our work. Excited states in ^{76,78}Zn are not in energy scale. All energies are in keV. The values of Q_β and S_n energies are taken from [33, 34]. See text for more details.

77Cu – βn → 76Zn (HRIBF)

0.55(4)% 4+

19(1)% 2+ (5,7/2- + ln=1)

11(1)% 0+ (3/2- + ln=1)

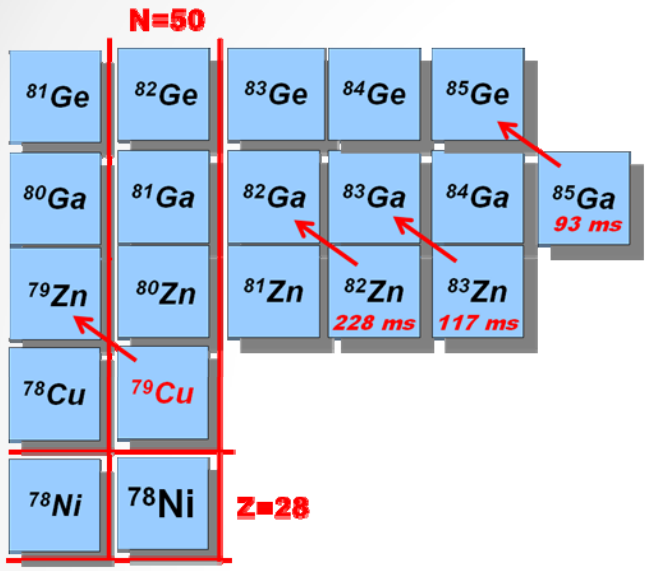
Fine structure of Pn(En) in (Z+1,N-2) products is affected by

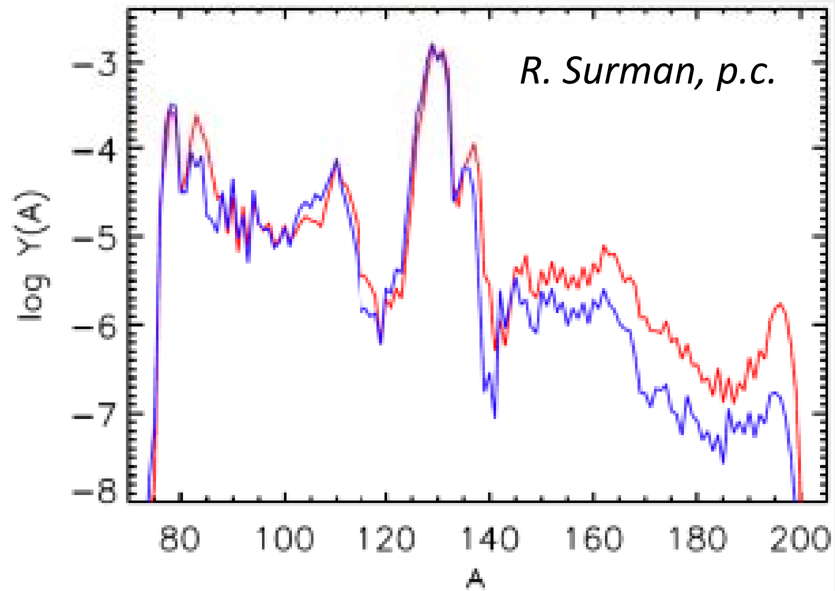
distribution of the partial GT strengths near S_n and l_n ;

structure of the wave functions of GT de-excitations in77Zn

(different 1qp and 3qp decay rates to the g.s. and excited states).

Newly measured half-lives of extremely exotic Zn and Ga alter calculated isotope abundances





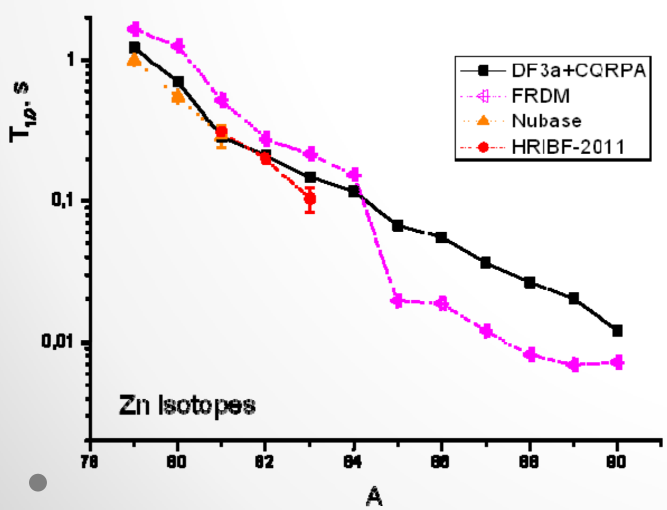


Fig. 1. (left) Section of the chart of nuclei near doubly magic 78Ni is shown. Marked isotopes above 78Ni are among the nuclei studied at the HRIBF [Winger2010, Padgett2010]. Newly measured half-lives for 82Zn, 83Zn and 85Ga isotopes are given in red. (right) The r-process abundances (note logarithmic scale) ***calculated using new experimental and theoretical half-lives (red curve)*** *are compared to previous simulations* ***(blue curve).***

M. Madurga et al. , to be published 2011

How good are "first-principle" nuclear structure models in extrapolating beta-decay data?

Theoretical models give deviating extrapolations far from stability.
DF+CQRPA extrapolation is supported by recent data for WP-nuclei.

NB! *T1/2, Pn-s are functionals of Gamow-Teller strength distribution.*
Different beta-strength functions may result in close T1/2, Pn-s.

Георгий (George) А. Гамов (Gamow)

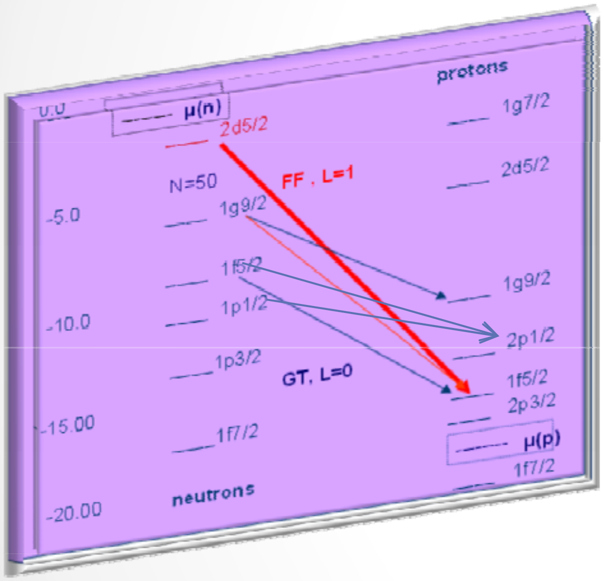
Teller (Edward) Ede

As FF decays across the major shell are not expected at N<50, DF+CQRPA gives no impact of FF decays for N=50,82 isotones

A comparison with quantum-statistical description of FRDM:

RPA for GT + Gr.Th. for FF decays … gives a

strong impact of the FF decays: see the last two columns of Table.



		DF3+CQRPA		FRDM	
Nucleus	Expt.	GT [22]	GT + FF [22]	GT [14]	GT + FF [15]
^{78}Ni	$0.110^{+0.100}_{-0.060}$ [26]	0.102	0.102	0.477	0.224
^{79}Cu	$0.257^{+0.29}_{-0.26}$ [26]	0.266	0.257	0.430	0.157
	0.188 ± 0.25				
^{80}Zn	0.578 ± 0.21 [26]	0.865	0.839	3.068	1.259
	0.545 ± 0.16				
^{129}Ag	$0.046^{+0.05}_{-0.09}$	0.061	0.056	0.047	0.0317
^{130}Cd	0.162 ± 0.007	0.15	0.14	1.123	0.502
^{131}In	0.280 ± 0.030	0.35	0.34	0.147	0.139

ЯДЕРНАЯ ФИЗИКА, 2011, том 74, № 10, с. 1–11

ЯДРА

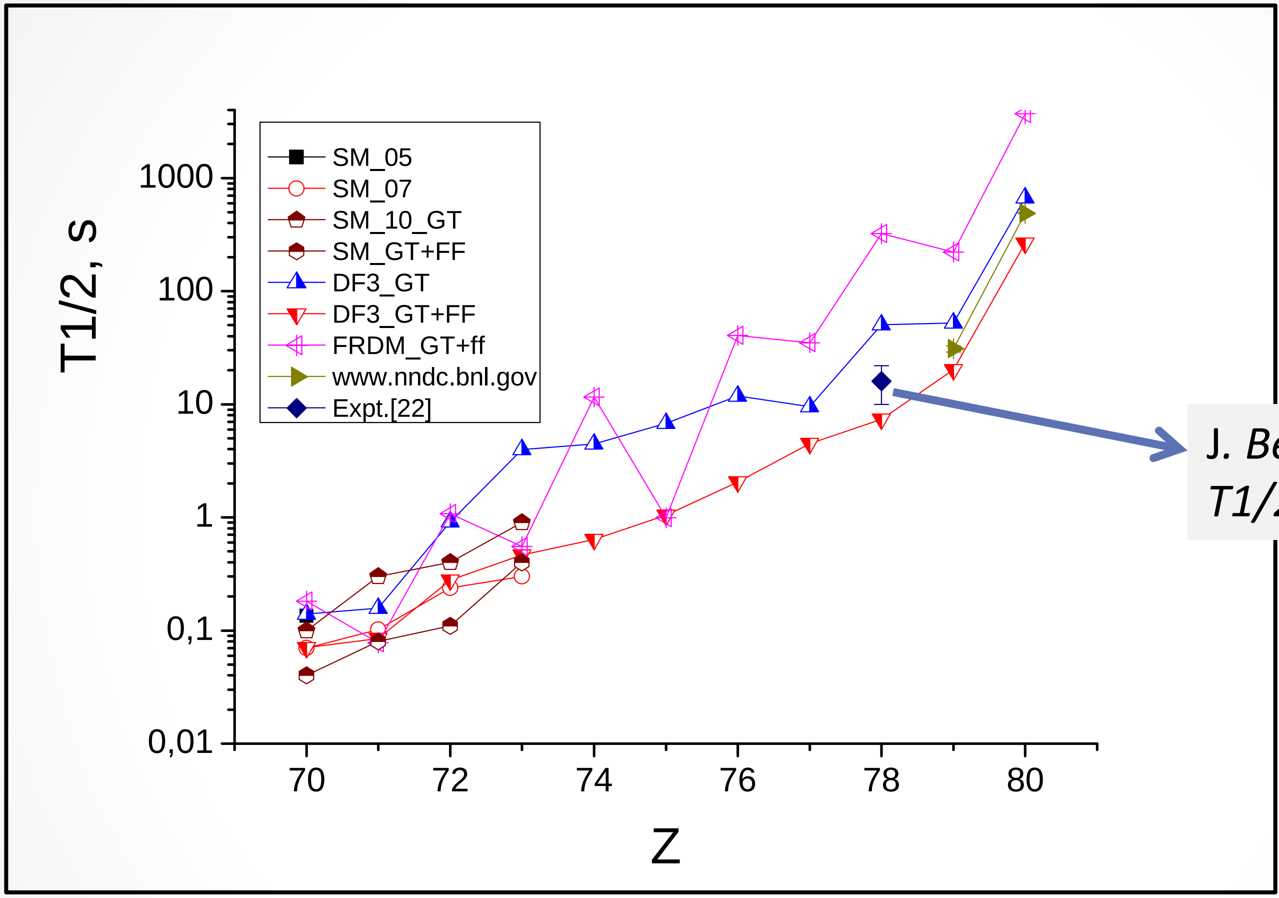
BETA-DECAY OF NUCLEI NEAR THE NEUTRON SHELL $N = 126$

© 2011 I. N. Borzov*
Joint Institute of Heavy Ion Research, Oak Ridge, USA

Received December 23, 2010; in final form, April 26, 2011

In DF+CQRPA
fast decays at N=50,82
are due to GT transitions

N=126 isotones: FF decays are important



J. Benliure e a. 2010,
T1/2 (204Pt) =16+6-5 s

Taking off the T=0 pp-effective NN-interaction leads to SO(8)-symmetry violation of QRPA.
An odd-even effect in FRDM at N=126 is not supported by the existing data.

SM10 (GT+FF)
T. Suzuki et al.
Non-standard J=0 operator

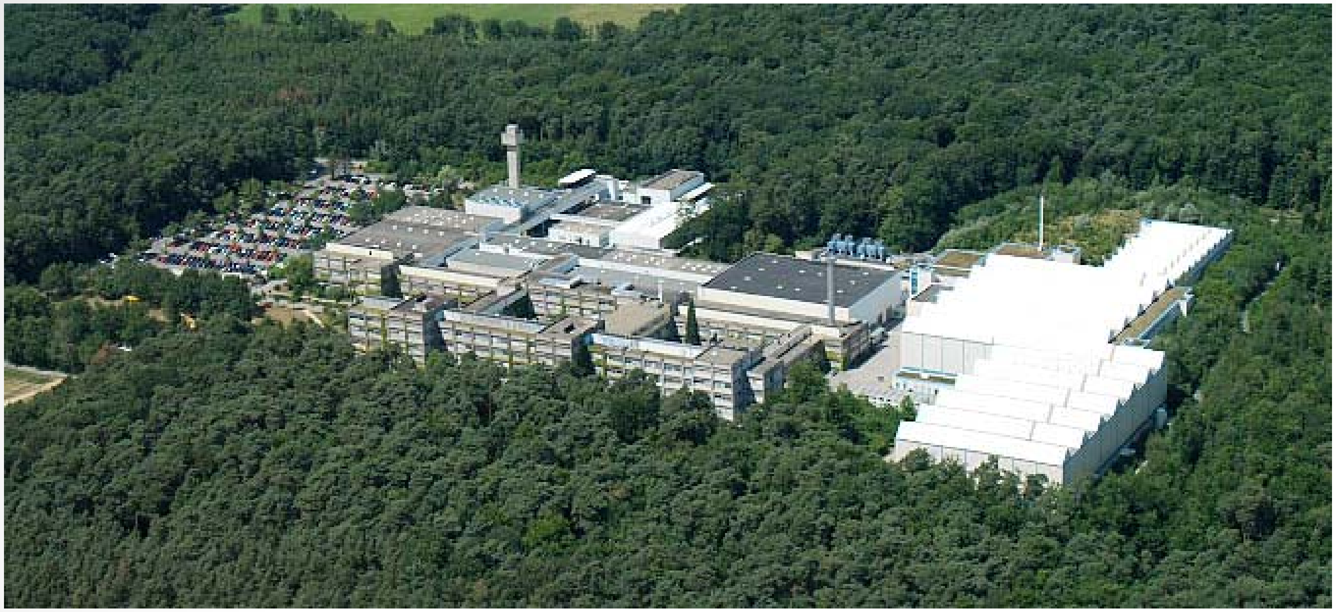
Near the N=126 shell

Recent experiments GSI , USC …

2007-2010 K.-H. Schmidt, J. Benlliure et al.
2011 S410 I. Dillmann et al.

The Qb-values of reachable isotopes south-west of 208Pb are relatively low. Nevertheless, their b-decay properties reflect a competition of high transition energy FF beta-decays and low-energy GT decays at N~Nmag.

GSI, Darmstadt



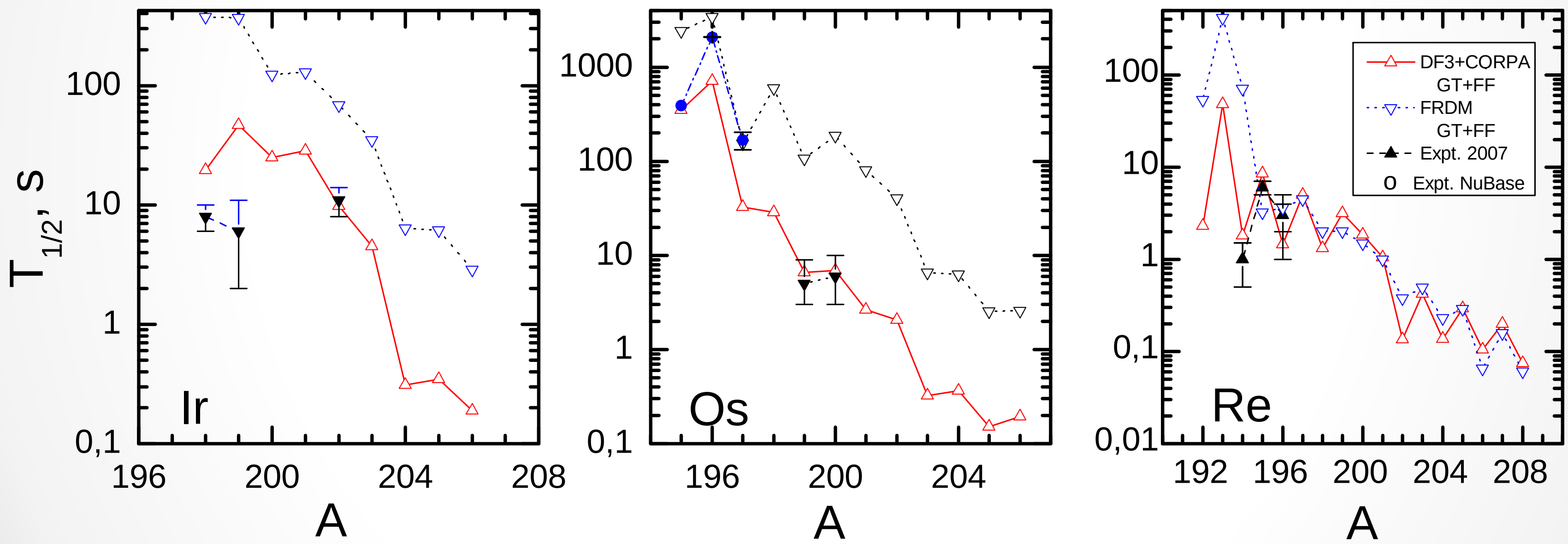
The experiment, which aimed at measuring the β half-lives of heavy neutron-rich nuclei close to the neutron closed shell $N = 126$ was performed at the fragment separator FRS [9] at the Gesellschaft für Schwerionenforschung (GSI) in Darmstadt, Germany. A ^{208}Pb primary beam of 1 A GeV, delivered by the SIS18 heavy-ion synchrotron, was directed to a beryllium target at the entrance of the FRS. The reaction residues were identified by determining both their atomic number Z and their mass-over-charge ratio A/Z by means of the measurements of the energy loss, the magnetic rigidities, and the time of flight (ToF).

First access to β-decay half-lives approaching the r-process path near N=126

T. Kurtukian-Nieto[a,1], J. Benlliure[a], K.-H. Schmidt[b], L. Audouin[c], F. Becker[b], B. Blank[d], I.N. Borzov[b,2], E. Casarejos[a], M. Fernández-Ordóñez[a,3], J. Giovinazzo[d], D. Henzlova[b,4], B. Jurado[d], K. Langanke[b,e], G. Martínez-Pinedo[b], J. Pereira[a,4], F. Rejmund[f], O. Yordanov[b,5]

GSI FRS- Collaboration 2007

T.Kurtukian-Nieto et al. *nucl-ex.0711.0101v1, 2007;*
Nucl.Instr.Meth. A589,472,2008.
Nucl. Phys. A 589,472c, 2008.

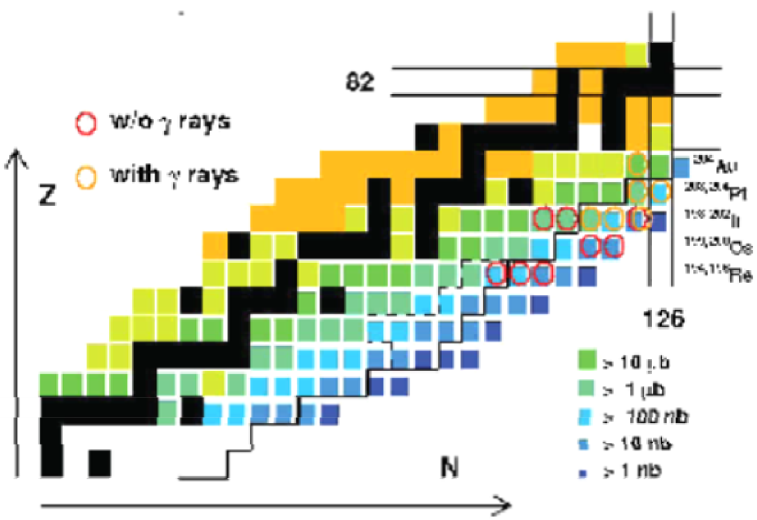


From a theory side global predictions based on self-consistent microscopic models may facilitate the choice of appropriate experimental conditions.

The prospects for extending this experimental approach to more neutron-rich isotopes of elements below lead are very promising, in particular when higher beam intensities will become available in new-generation in-flight secondary-beam facilities, like FAIR at GSI, the RI Beam Factory of RIKEN, FRIB at MSU or HRIBF at ORNL.

β half lives

Results



The β half lives of 13 heavy neutron-rich nuclei have been determined, 11 of them for the first time.

Nuclei	w/o γ	with γ	other works	FRDM+ QRPA[1]	DF3+ QRPA[2]
^{204}Au		37±0.8 s	39.8±0.9 s		
^{204}Pt		16^{+6}_{-5} s		321.8 s	7.4 s
^{203}Pt		22±4 s		654.0 s	12.7 s
^{202}Ir	11±3 s	15±3 s		68.4 s	9.8 s
^{201}Ir		21±5 s		130.0 s	28.4 s
^{200}Ir		43^{+6}_{-5} s		124.1 s	25.0 s
^{199}Ir	6^{+5}_{-4} s			370.6 s	46.7 s
^{198}Ir	8±2 s		8±1 s	377.1 s	19.1 s
^{200}Os	6^{+4}_{-3} s			187.1 s	6.9 s
^{199}Os	5^{+4}_{-2} s			106.8 s	6.6 s
^{196}Re	3^{+1}_{-2} s			3.6 s	1.4 s
^{195}Re	6±1 s			3.3 s	8.5 s
^{194}Re	1±0.5 s			70.8 s	2.1 s

[1] P. Möller, et al. PRC 67, 055802 (2003)
[2] I. N. Borzov PRC 67, 025802 (2003)

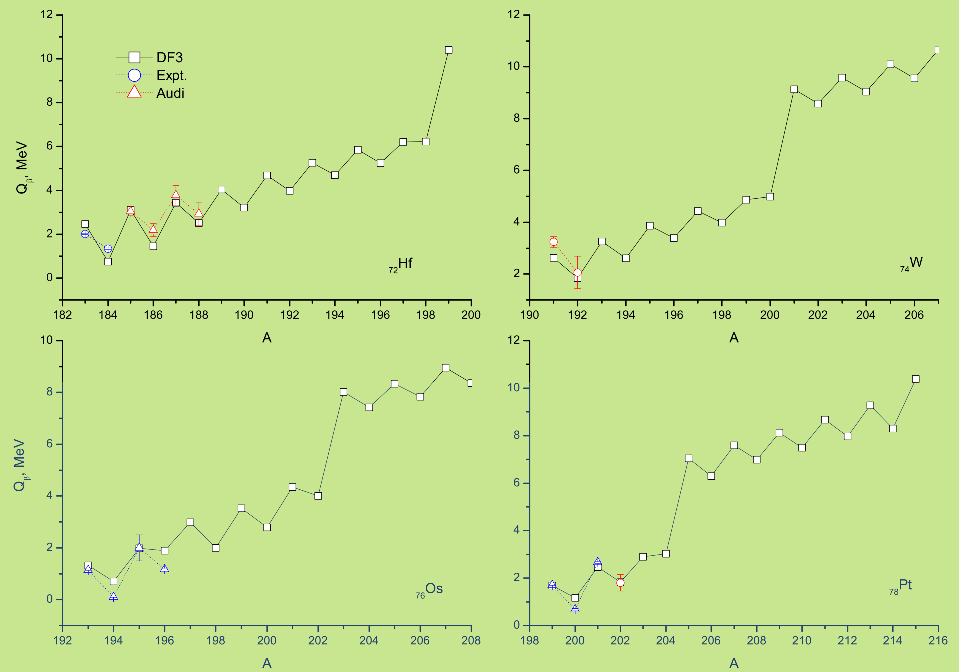
Systematic study of Q_β – values in Z=70-80, N=126 region.

Accurate description of the Q_β-values is crucial for beta-decay studies.
Q_β is correlated with the qp-energies, as both are obtained from the same DF framework.

DFs with m*/M~1 reproduce Q_β–values well enough :

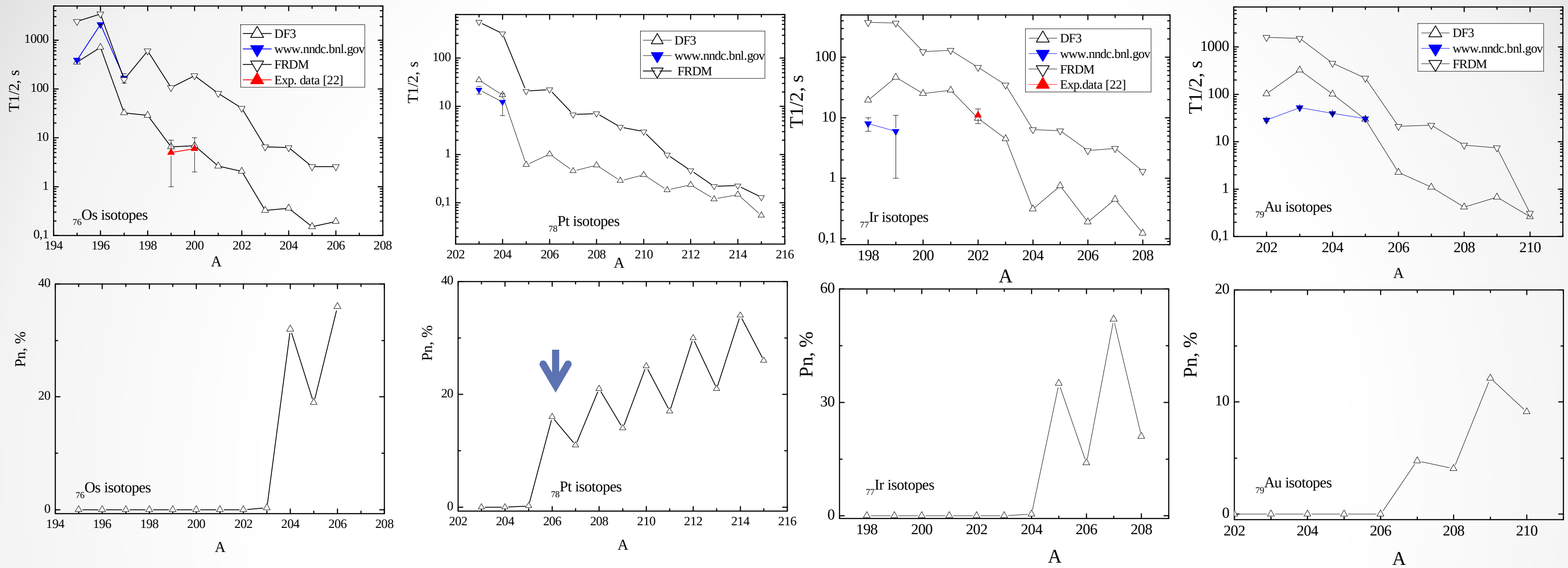
For N=50,82:
Typical deviation from the data is 0.5 - 1.5 MeV

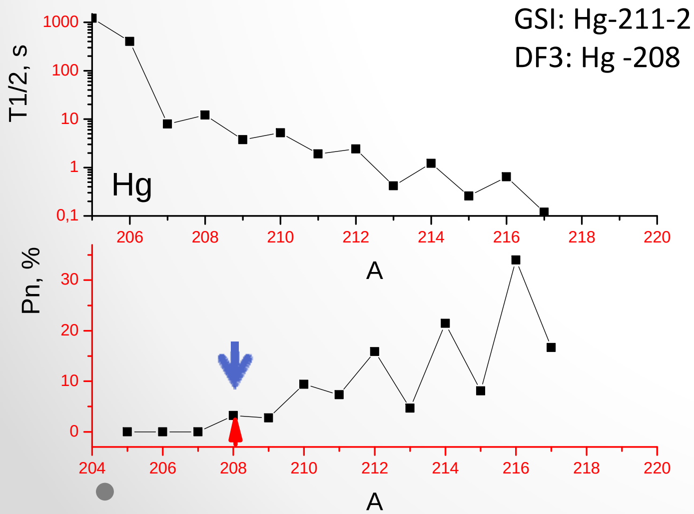
For N~126:
Higher accuracy, as deviation ~ 1/A 0.5 - 0.8 MeV



NB! Approaching N=126 : further from stability , larger is N-Z, closer we are to the r-process paths. Qβ-values increase, as well as relative probability of the FF transitions. Favorable conditions for competition of the GT & FF decays…
(The usual nomenclature of log(ft)-values should not be taken too literally in this case.)

Systematic study of half-lives and Pn-s in Z=70-80, N=126 region





GSI: Hg-211-213
DF3: Hg -208 3.4%

I.N.B. Phys.At.Nucl.74,2011, 1435.

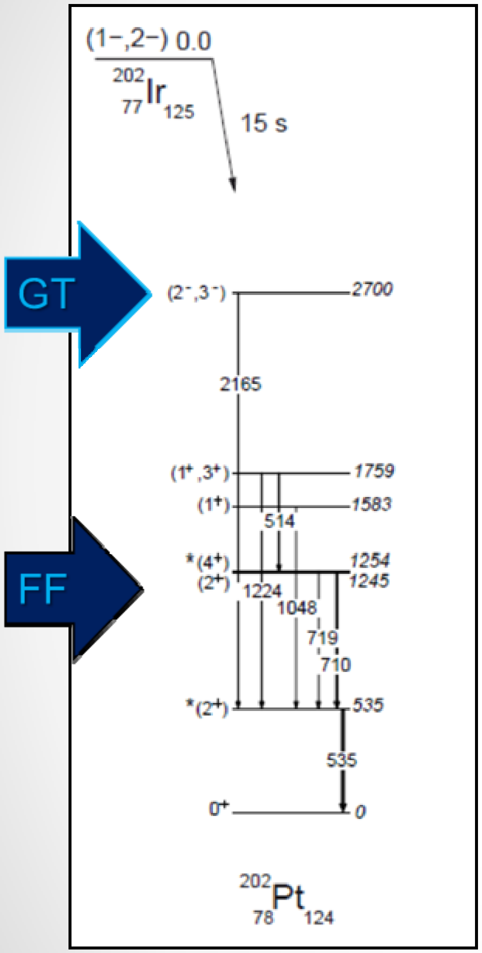
GSI S410 (September, 2011)

… isotopes with Pn-s to be measured are
Ir-204-206 Pt-208-209, Au-207-211
Hg-211-213   Tl-213-216.

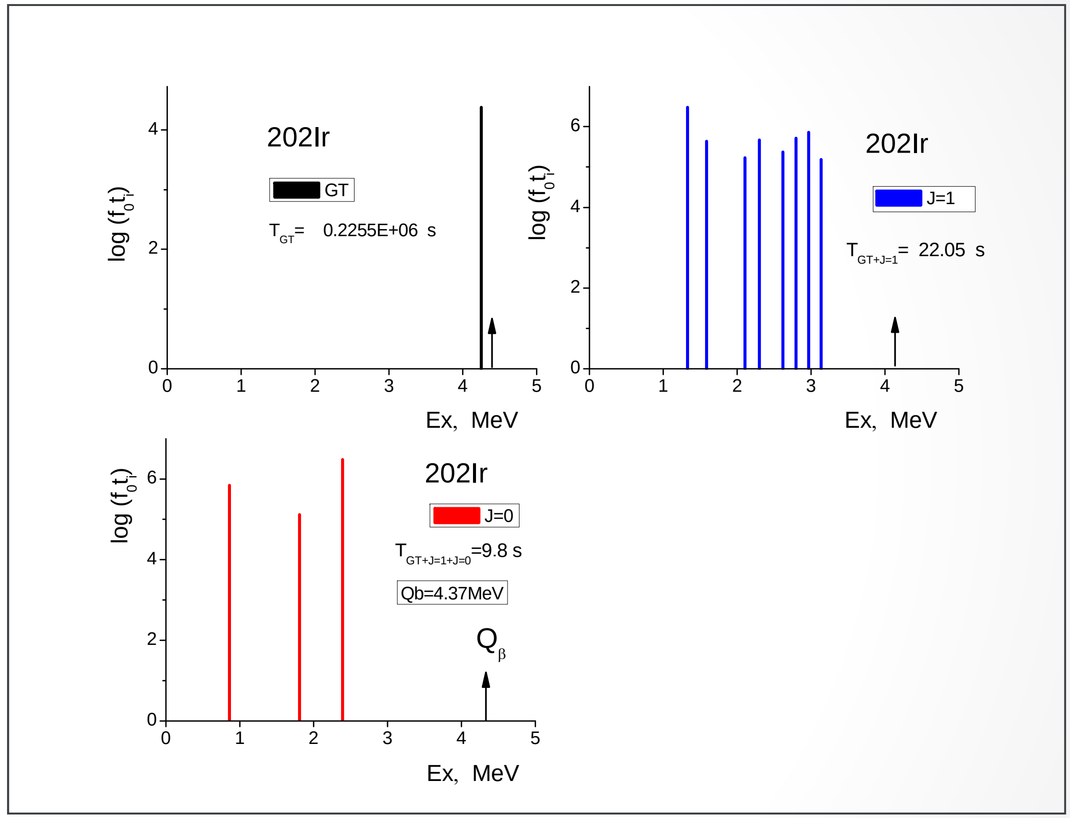
(From calculations already ***Pt-206 and 207*** *could be measured!)*

Microscopic origin of accelerated beta-decays at N=126. Beta-strength functions: GT vs. J=0, J=1.

I.N.B Phys.At.Nucl .74 (2011) 1435



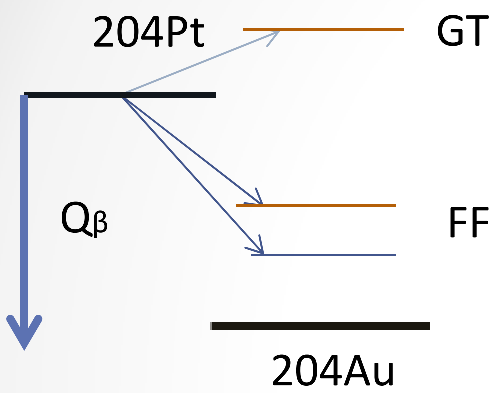
A. Morales, USC thesis, 2010



Very low transition energy (high-excitation energy) GT: n1h9/2→p1h11/2 : retarded by low phase-space"factor f(Qb-Ex) and high occupancy factor of proton orbital u^2(p1h11/2).

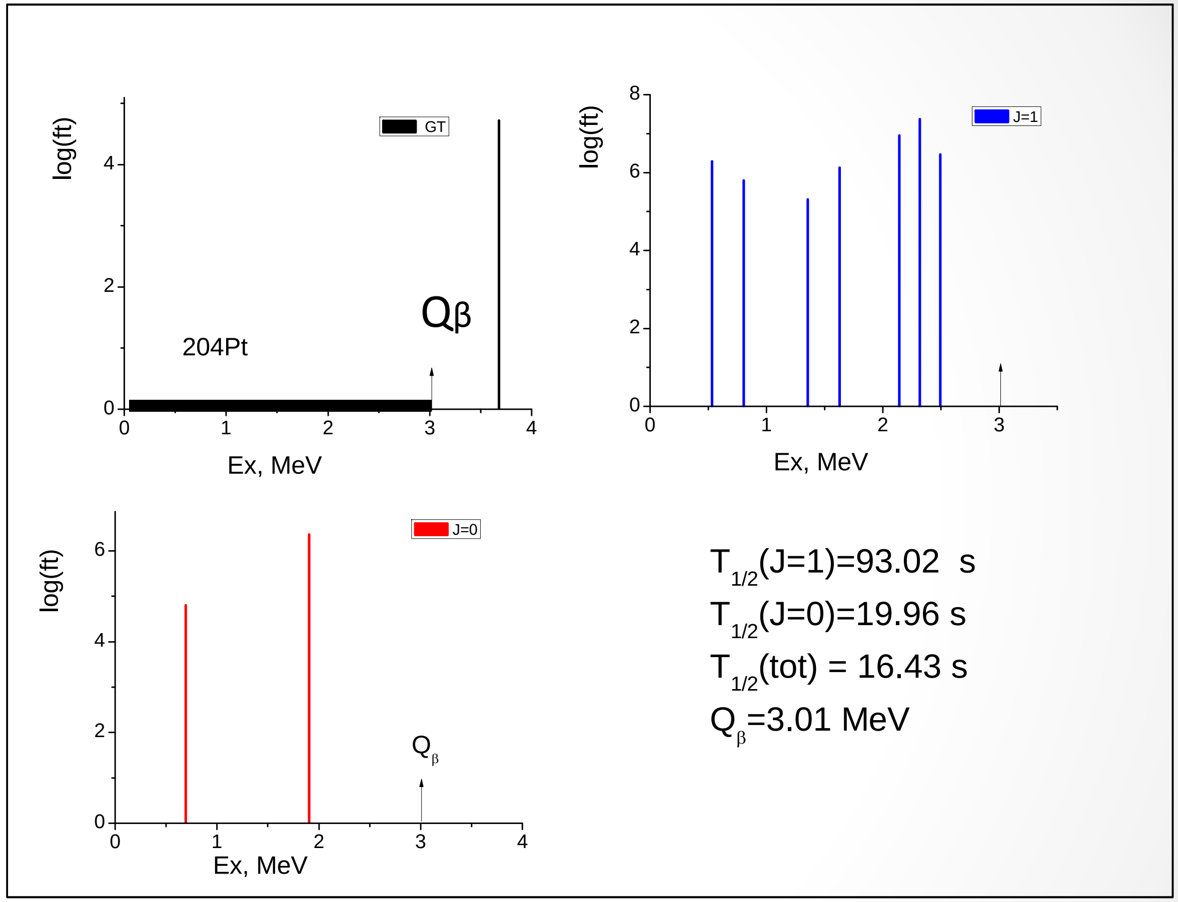
A bunch of higher transition energy FF-s "built" on n1i13/2→p1h11/2 reduce the half-life drastically: T1/2(GT)=0.23(+06)s → T1/2(tot)=9.8s!

N=126 waiting-point nucleus 204Pt



T1/2$_{exp}$=16+6-5 s

J. Benlliure,
Talk at NIC-XI, 2010

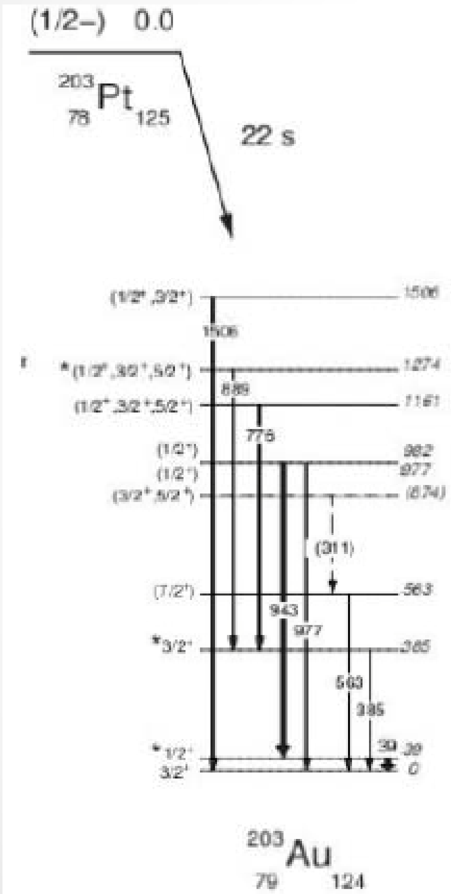


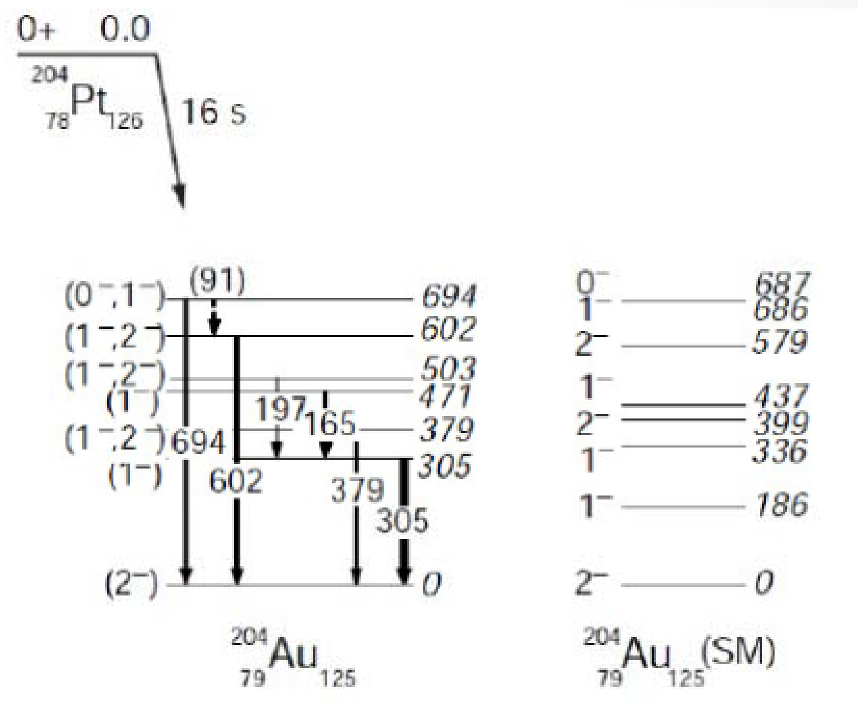
- ***No GT-states within (rather small) Q-window according to our 1ph-QRPA prediction.***
- *Interesing case: total half-life is solely due to the FF-decays!*

I.N.B. Phys.At.Nucl.74,2011, 1435.

Recent USC experiment in 203,204Pt:

evidence for high-energy FF transitions



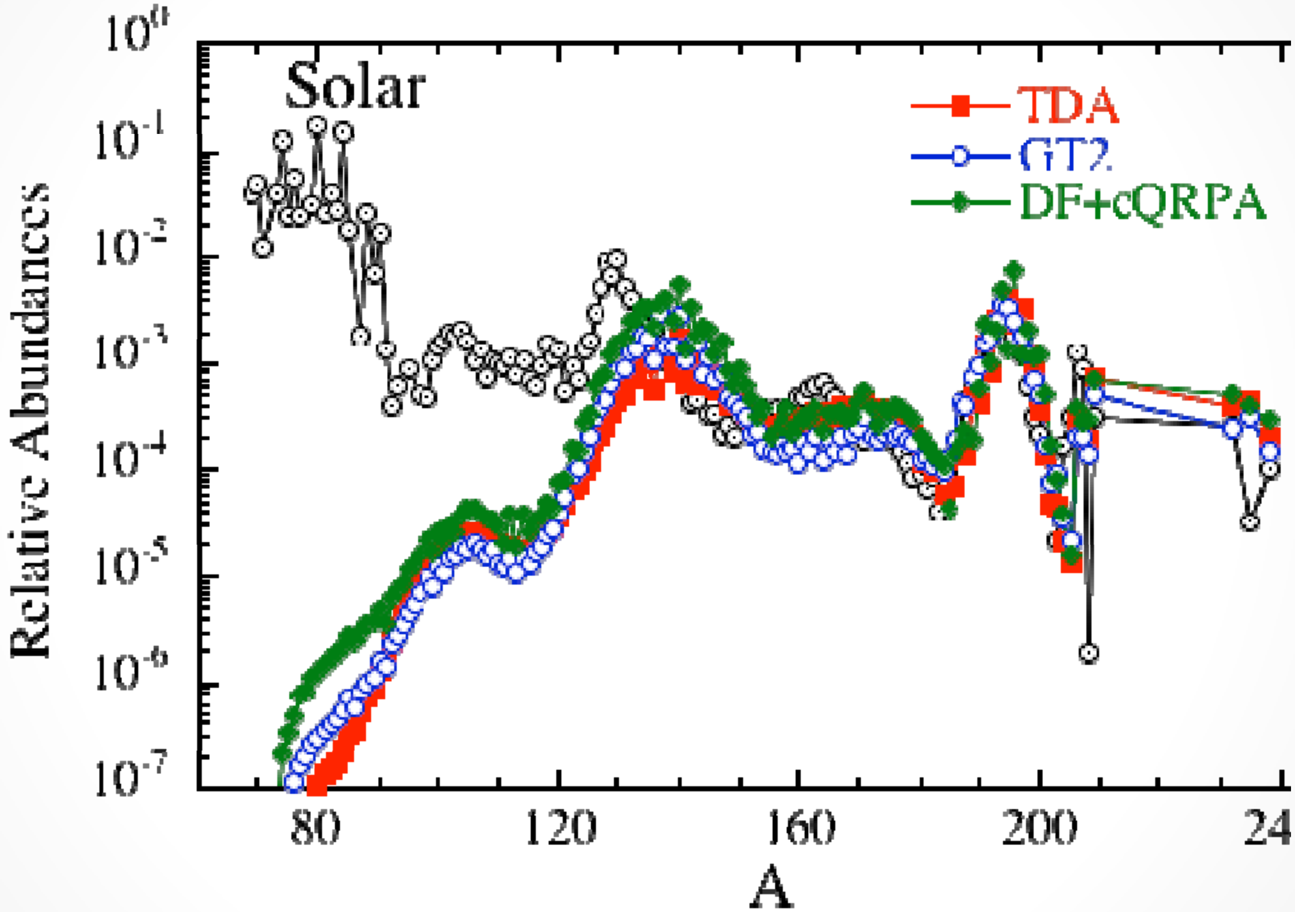


A. Morales, USC thesis, 2010

Waiting for S-410 GSI results !

Astrophysical r-process nucleosynthesis

Abundances with DF3 beta-rates for Z>24 up to Z=84



TDA- H.-V.Klapdor-Kleingrothaus et al.
GT2- T.Tachibana et. al.

INB, S. Goriely, preliminary, June-011.

"We will consider only experimental data …
for our evaluation not to be ***contaminated*** *by any theoretical data…"*

1. *"…in most cases, the βn-measurements were performed with radioactive beams* ***containing more than one isotopes****. However the Pn-values can be determined reliably with an* ***isobarically purified beam*** *of bn-precursor of known intensity and subsequent measurements of ϒ-radiation properties along the mass A and A-1 chains with efficiency calibrated ϒ-detectors."* *(HRIBF ORNL report, 2011)*

2. *Theoretical extrapolation is unavoidable!*
   The best observable to compare with data is ***beta-decay strength function****.*
   Constrains the theoretical model especially if taken together with other quantities :
   - *J/π g.s., charge-density, single –particle levels, magnetic moments, radii… .*

Data for Beta-delayed neutron precursors selected as "Standards"
Balraj Singh (McMaster University) and Daniel Abriola (IAEA-NDS), Nov 10, 2011.

At the IAEA Consultants' meeting Oct 10-12, 2011, the following beta-delayed neutron precursors were selected as "standards" for the purpose of data evaluation and measurements:

Precursor	Jπ (g.s.)	**Half-life (s)**	**%P(n)**	Q(β-) (keV)	S(n) (keV)	Q(β-n) (keV)
Li-9	3/2-	0.1783(4) s	50.8(2)	13606.47(11)	1664.55(8)	11941.92(9)
N-17	1/2-	4.173(4) s	95.1(7)	8679(15)	4143.08(01)	4536(15)
Br-87	(5/2-) *	55.65(13) s	2.60(4)	6818(3)	5515.17(25)	1303(3)
Br-88	(2-)	16.29(6) s	6.58(18)	8975(4)	7053.1(26)	1922(3)
Rb-94	3(-)	2.702(15) s	10.5(4)	10281(8)	6828(10)	3453(8)
Rb-95	5/2-	0.3777(8) s	8.73(20)	9229(20)	4352(9)	4877(21)
I-137	(7/2+)	24.5(2) s	7.14(23)	5877(27)	4025.53(11)	1851(27)
I-138	(2-)	6.23(3) s	5.56(22)	8070(100)SY	5663(3)	2410(100) SY

	DF3		NuBase				FRDM+GrTh		
Br87	47,7	**0,15**	/55,65	0,13	/ 0,2	0,04/	7.34507	**0.9975**	0.0025
Br88	16,55	**2,9**	/16,36	0,07	/ 6,72	0,27/	4.92517	**0.9864**	0.0136
I-137	29.28	**11.85**	/24.13	0.12	/ 7.14	0.23/	18.12382	**0.9734**	0.0266

Conclusions

- *Microscopic self-consistent DF3+CQRPA approach is capable to reliably predicts beta-decay half-lives and Pn-branchings for important fission products and r-process nuclei near the closed shells.*

- *RESULTS :*

1. *Above the N=50, (82,126) closed shells DF+CQRPA predicts reduction of the T1/2 and Pn-values.*

2. *Sensitivity of the T1/2 and Pn-s to the g.s. J/π inversion.*

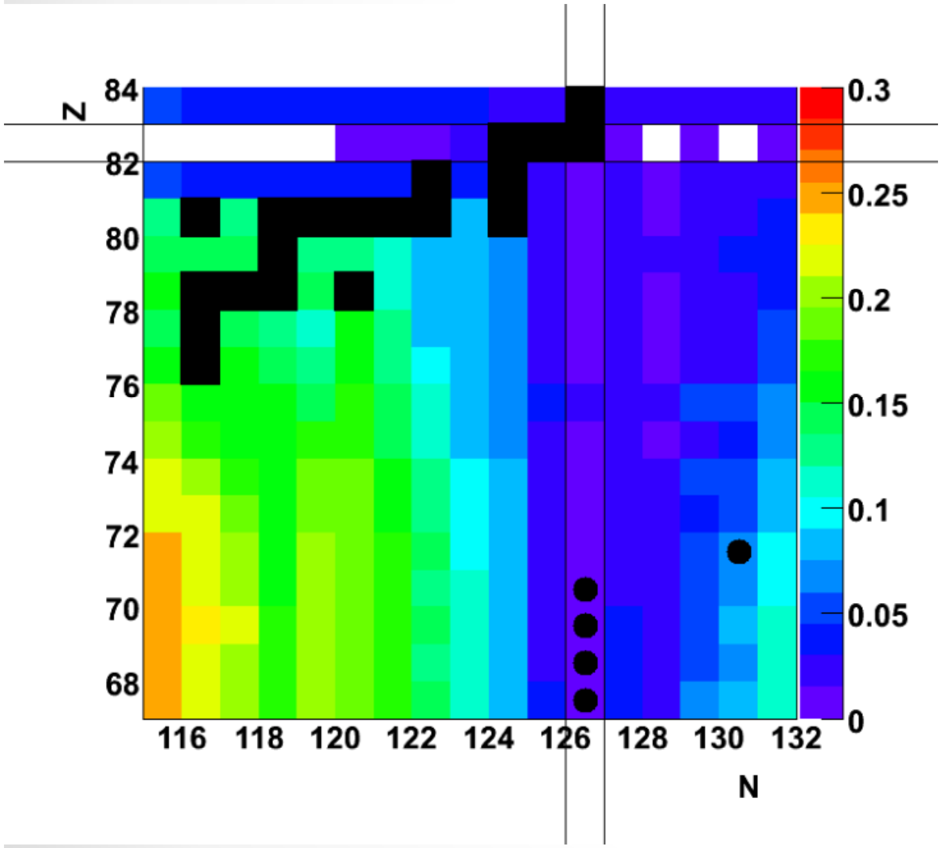
Agree with recent ORNL and GSI-USC experiments for new short-lived nuclides.

These robust effects have to be taken care of in evaluations of beta-decay data.

- *The DFT based approaches to beta-decay strength function are valuable alternative to empirical and semi-microscopical schemes.*

Outlook

FRDM deformation near N=126



- ***1. Systematical calculations of the g.s. deformation and paring properties in Z~28, N~50 region:***
- ***Include DF3, DF3a within HFBTHO***

  M.V. Stoitsov, J. Dobaczewski, W. Nazarewicz, P. Ring

  Computer Physics Communications

  Vol. 167, 2005, 43-63.

  Deformation effects at N=40 -50 -58

- ***2. Detailed study of the g.s. deformation and paring properties above N=126.***

  Deformation effects at N>126

- ***3. A challenge:***

  FAM for pnQRPA in deformed nuclei

  P. Avogadro, T. Nakatsukasa PRC 84,014314 (2011)

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W. Nazarewicz, K.Rykaczewski , R. Grzywacz (ORNL, UTK) .

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under IN2P3-RFBR agreement No.~110291054.

New mass and beta-decay data in a wider region near @ N ~ 50, 82, 126
are very important for further elaborating
the universal nuclear energy-density functional.