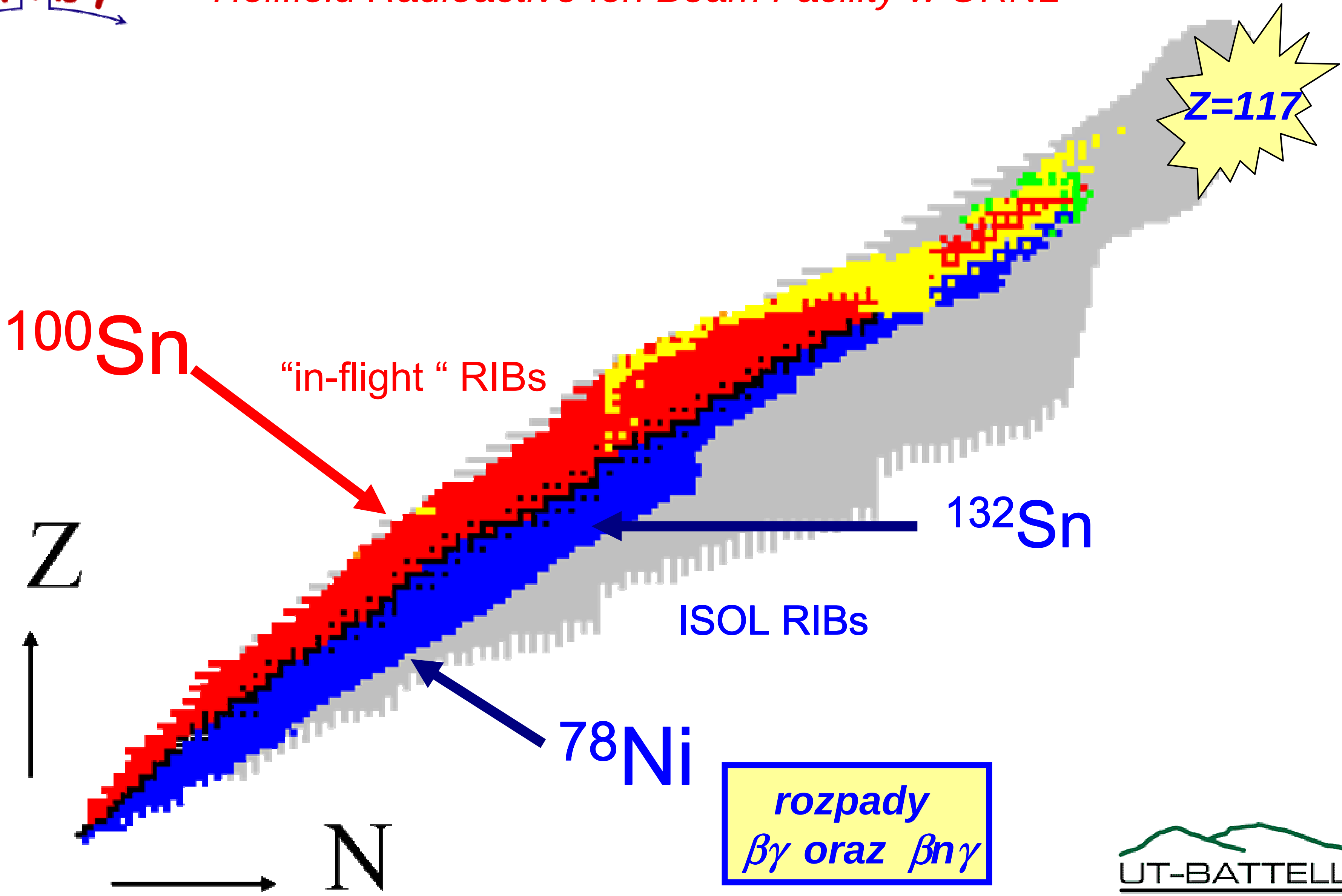
Emisja neutronów po rozpadach beta jąder z obszaru ^{78}Ni

K. P. Rykaczewski (Physics Division, ORNL)

hribf = *Holifield Radioactive Ion Beam Facility w ORNL*



rozpady
$\beta\gamma$ oraz $\beta n\gamma$

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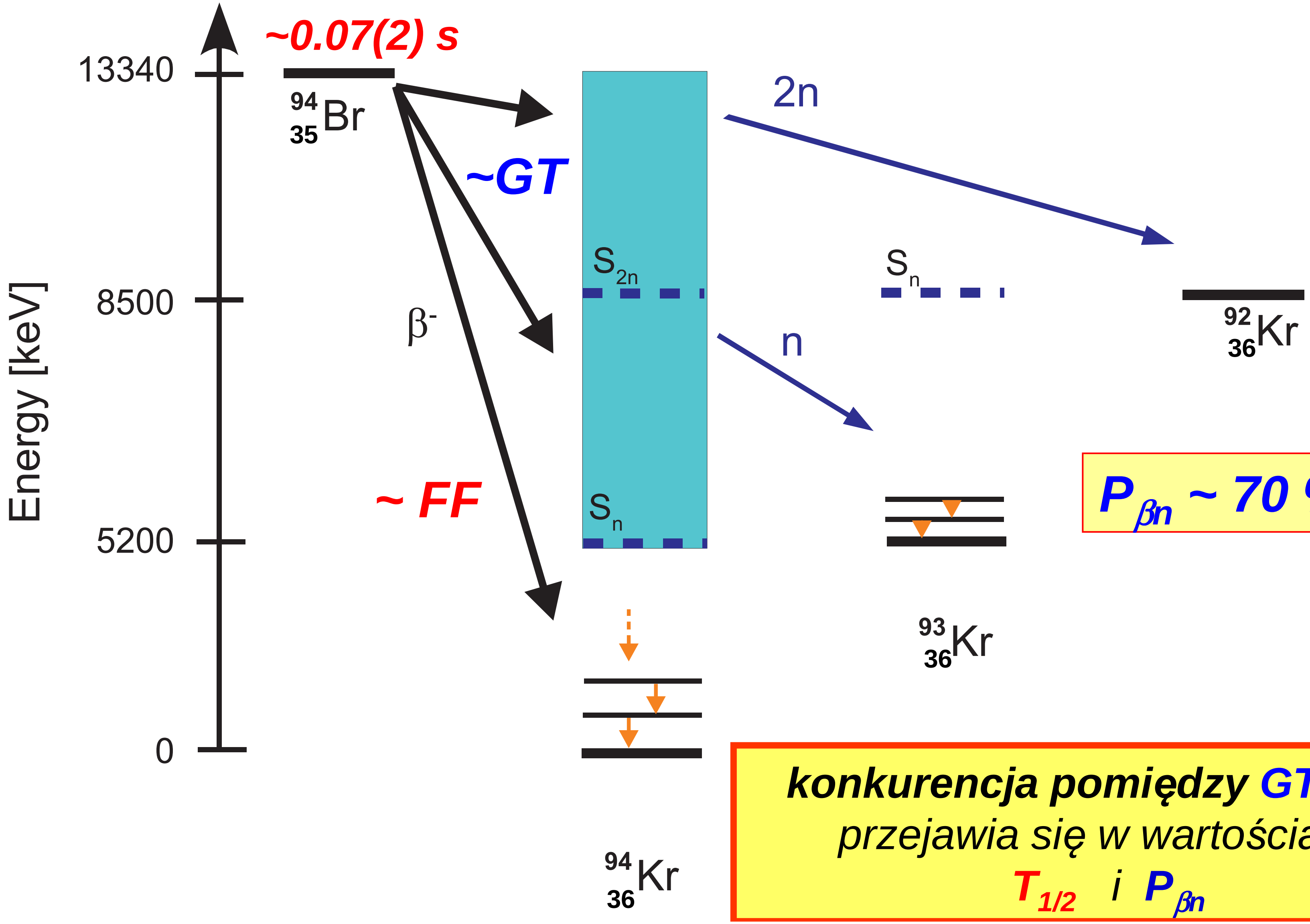
Przykład rozpadu beta z emisją opóźnionych neutronów
S.Liddick et al.,"Gamow-Teller vs First Forbidden β-decays of Br isotopes"

β-delayed 1n and 2n emission from ^{94}Br ***(Z=35)***



P*$_{\beta n}$ *~ 70 % ?

konkurencja pomiędzy GT i FF
przejawia się w wartościach
***T*$_{1/2}$ *i* *P*$_{\beta n}$**

Dlaczego
chcemy badać emisję opóźnionych neutronów ?

- ***zrozumienie ewolucji struktury jąder neutrono-nadmiarowych***
  (np. $T_{1/2}$ vs P_n zawiera infomacje o rozkładzie funkcji nasilenia beta)

- *własności rozpadów beta są niezbędne do analizy rozpowszechnienia izotopów pierwiastków tworzonych* ***w procesie szybkiego wychwytu neutronów w gwiazdach*** *(w szczególności ważne są dane wokoło tzw. "punktów oczekiwania", dane dotyczące czasów zaniku, prawdopodobieństwa emisji opóźnionych neutronów, nisko-wzbudzone stany jądrowe, izomery..)*

- ***własności rozpadów beta produktów rozszczepienia sa ważne dla działania reaktorów jądrowych, (np. dla procesu wyłączania reaktora i dla działań związanych z procesowaniem zużytego paliwa jądrowego)***

hribf

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from Akito Arima, JUSTIPEN meeting, Oak Ridge, February 2009 :

Energy Security is also an Issue, because Fossil Fuel will not last very long.

	Oil	Natural Gas	Coal	Uranium
Proven Reserves (R)	**1,208 billion barrel**	**181 trillion m^3**	**909 billion ton**	**5.47 million ton**
Annual Production (P)	**29.8 billion barrel**	**2.87 trillion m^3**	**6.2 billion ton**	**67* thousand ton**
Reserves Production Ratio (R/P)	**~ 40 years**	**~ 60 years**	**~ 150 years**	**~ 80 years**

*Annual demand (Annual production is 40 thousand ton.)

Source : BP Statistics, 2007 and Uranium 2007, OECD/NEA/IAEA

oil and gas burns completely, but we use only a small fraction of nuclear fuel !!

American Physics Society, Division of Nuclear Physics, Oct. 2008
mini-symposium "Nuclear Research and Connections to Nuclear Energy"

Tony Hill (Los Alamos)
"Basic Nuclear Physics Research Needs for Nuclear Energy"

435 nuclear reactors operating worldwide
28 under construction
222 planned to built

today : ~ 100 GW of US power is generated in nuclear reactors (~ 20%)
ambitious goal for 2050 : about ~300 GW of nuclear power (~ 30%)
[see ORNL Review, vol. 41, no 3, 2008]

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Decay spectroscopy data are important , e.g., for :

- *for the reactor shut-down process*

few percent increase in the total "decay heat" means one more day needed for the reactor shutdown

(motivation for Total Absorption Spectroscopy, ANL and ORNL)

- *for the repository (reprocessing and storing) of used nuclear fuel*

- *for fast reactor core sensitivity estimation*

several (new) funding programs foreseen in US (Oct. 2008) :

Nuclear Power 2010
Advanced Fuel Cycle
Generation IV Nuclear Energy Systems

Nuclear Energy Research : ~ 20 % funds for Universities

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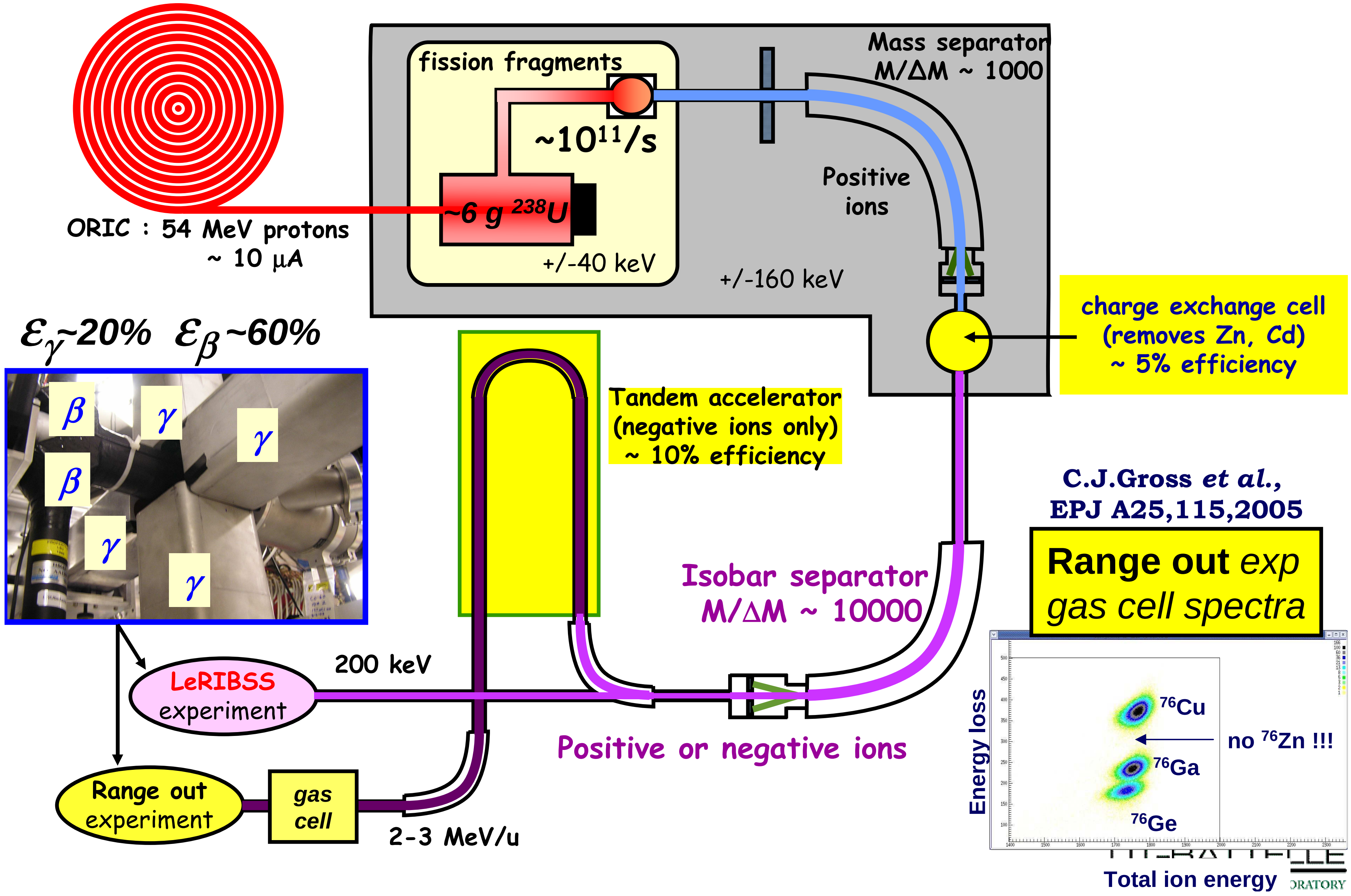
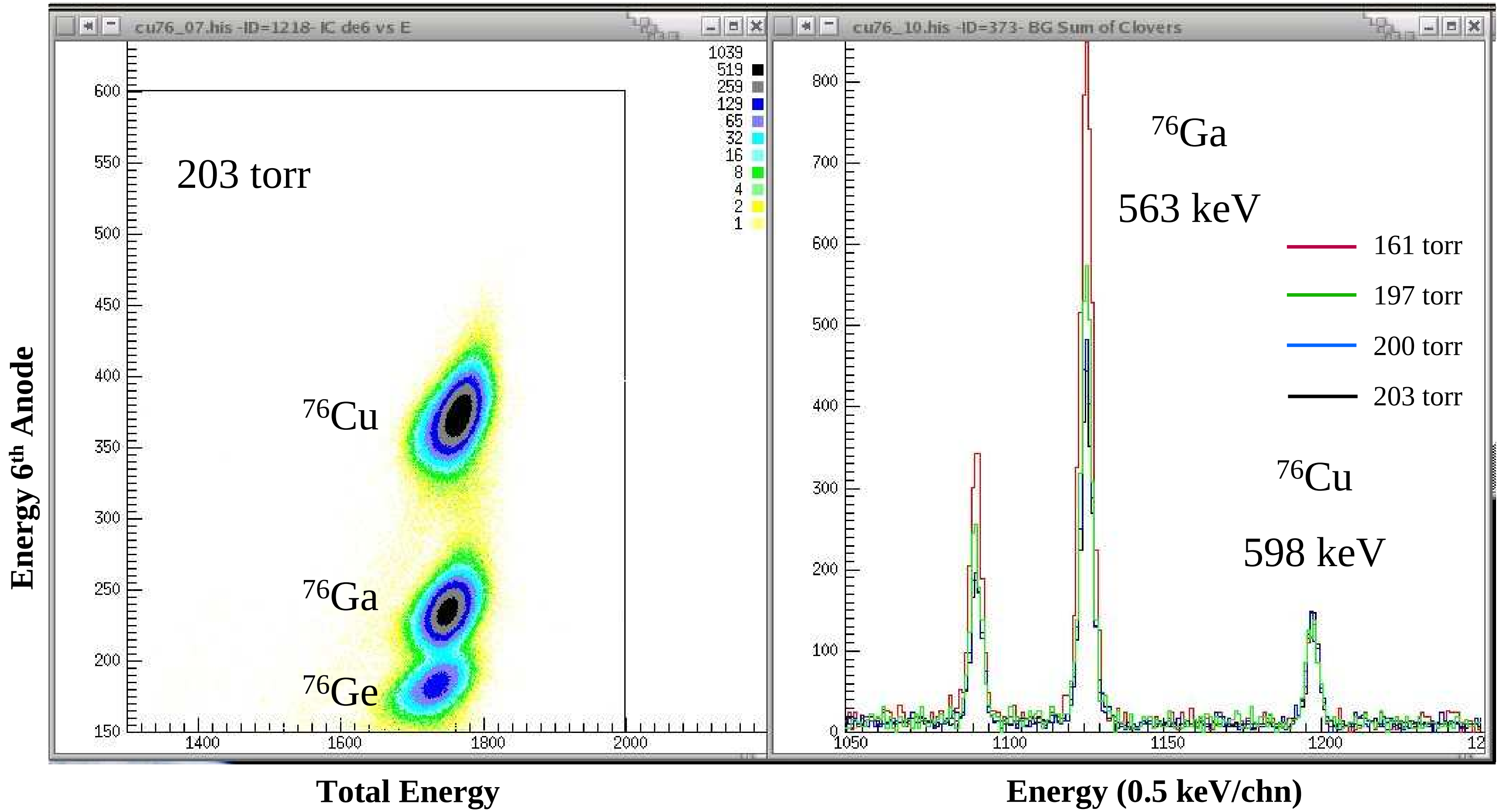
Decay studies of neutron-rich nuclei at hribf (Oak Ridge)



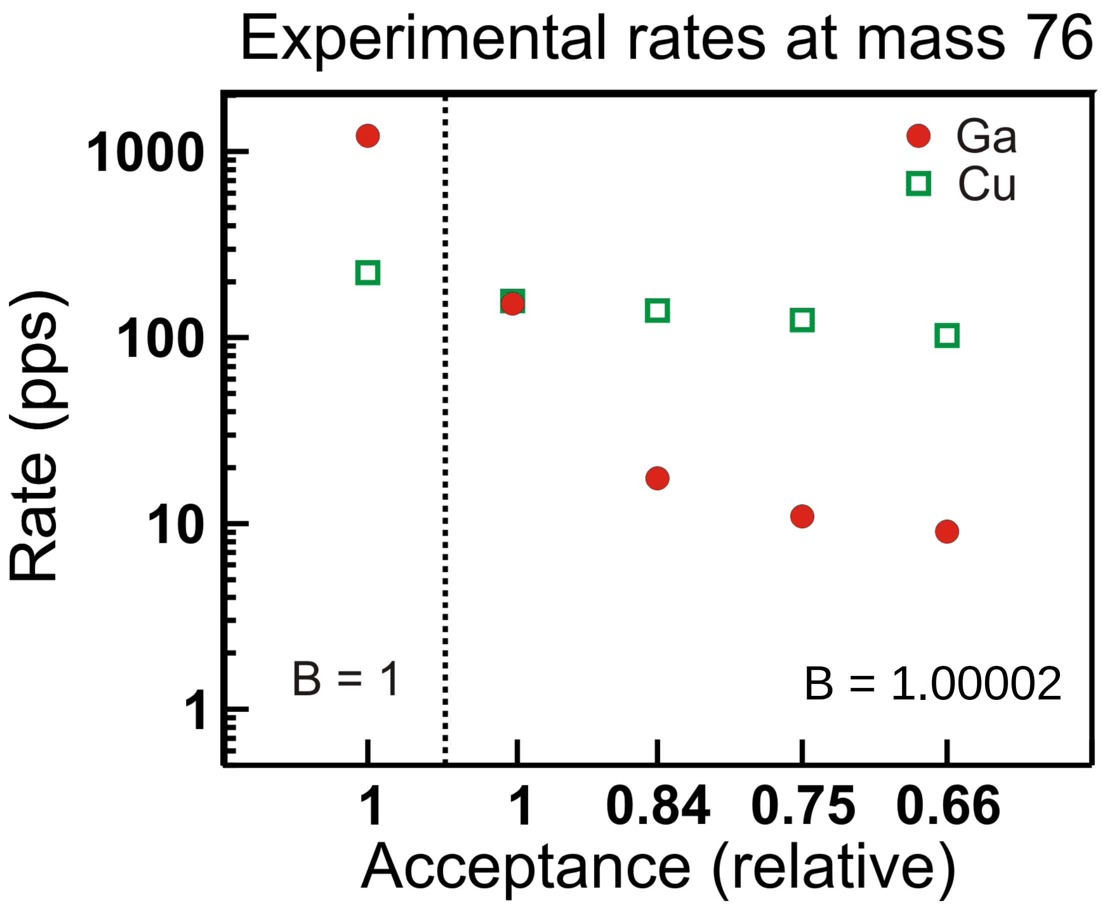
Ranging Out $^{76}Cu/^{76}Ga$ Beam



MTC Cycle: 19.2-0.52 second

HRIBF high-resolution RIB injector magnet (ΔM/M ~ 1 : 10^4)

from initial rate of post-accelerated A=76 isobars ~ 10^5 pps
to " $\vec{B}$-optimized" rate of ~ pure $^{76}Cu^-$ ~ 220 pps



for ^{76}Cu - ^{76}Ga ΔM/M ~ 1 : 4600

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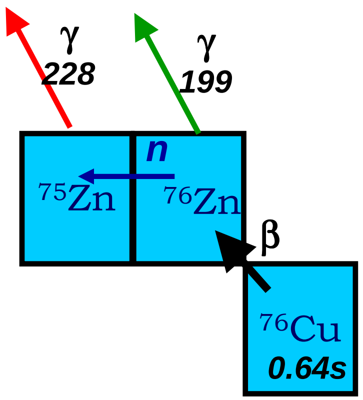
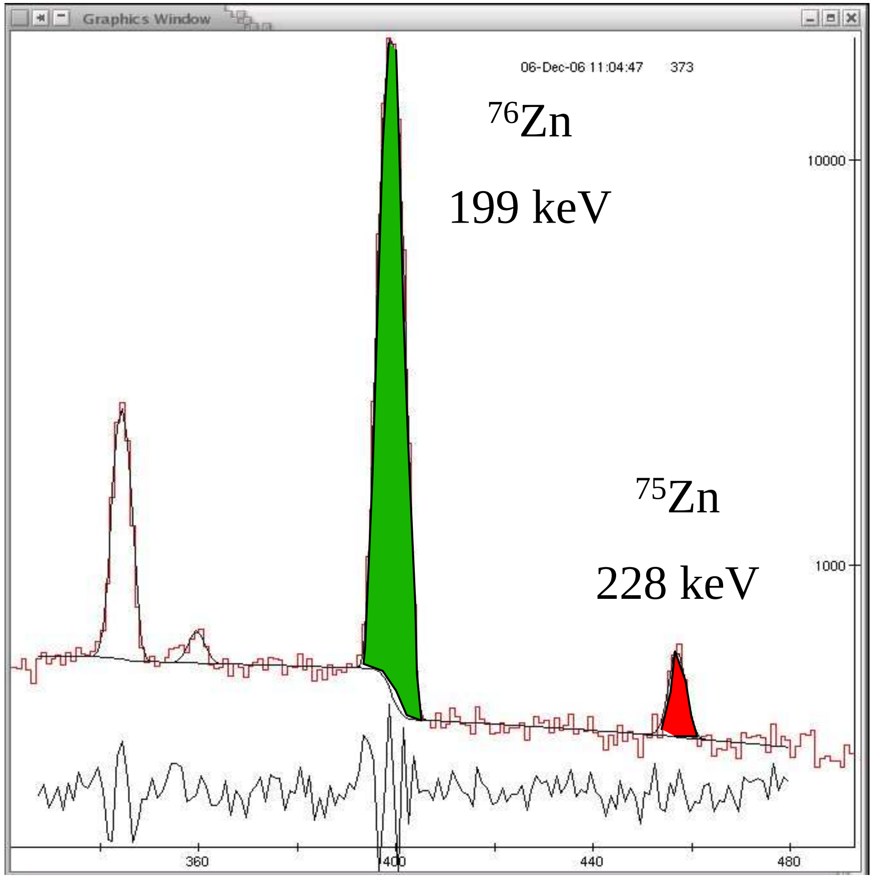
J.A. Winger.. KR,.. R. Grzywacz, A. Korgul, W. Królas *et al.*,
Phys. Rev. Letters, 2009, in press

P_n=7.2(5)%





e.g., recent ISOLDE measurement did not detect bn-branch
compare **Van Roosbroeck et al., Phys. Rev. C 71, 054307 (2005)**

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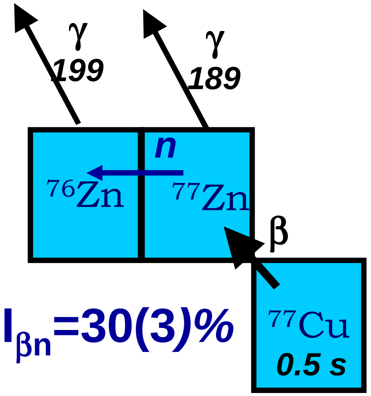
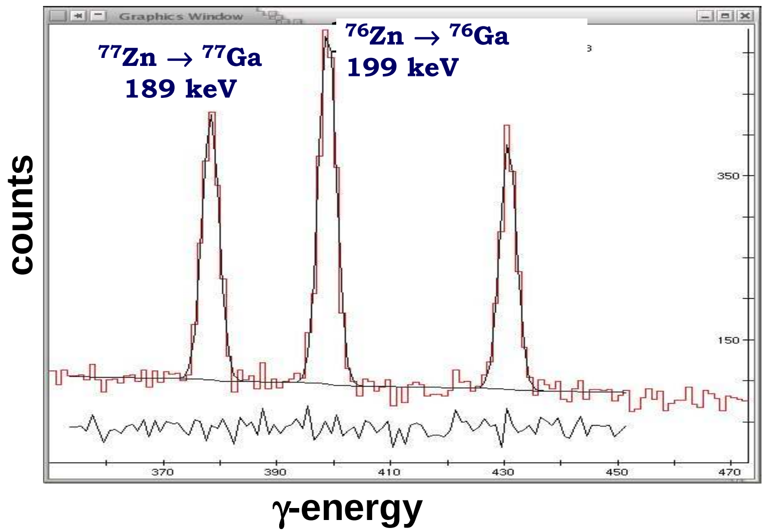
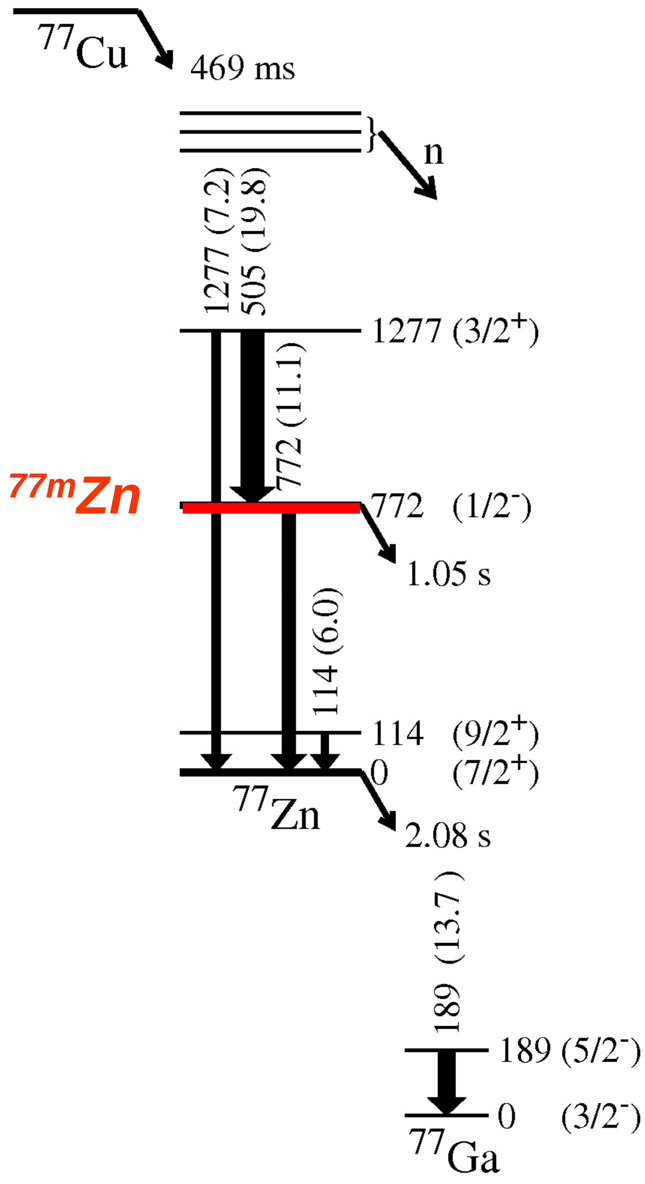
^{77}Cu : 18 hours of "ranging-out" exp with 15 pps



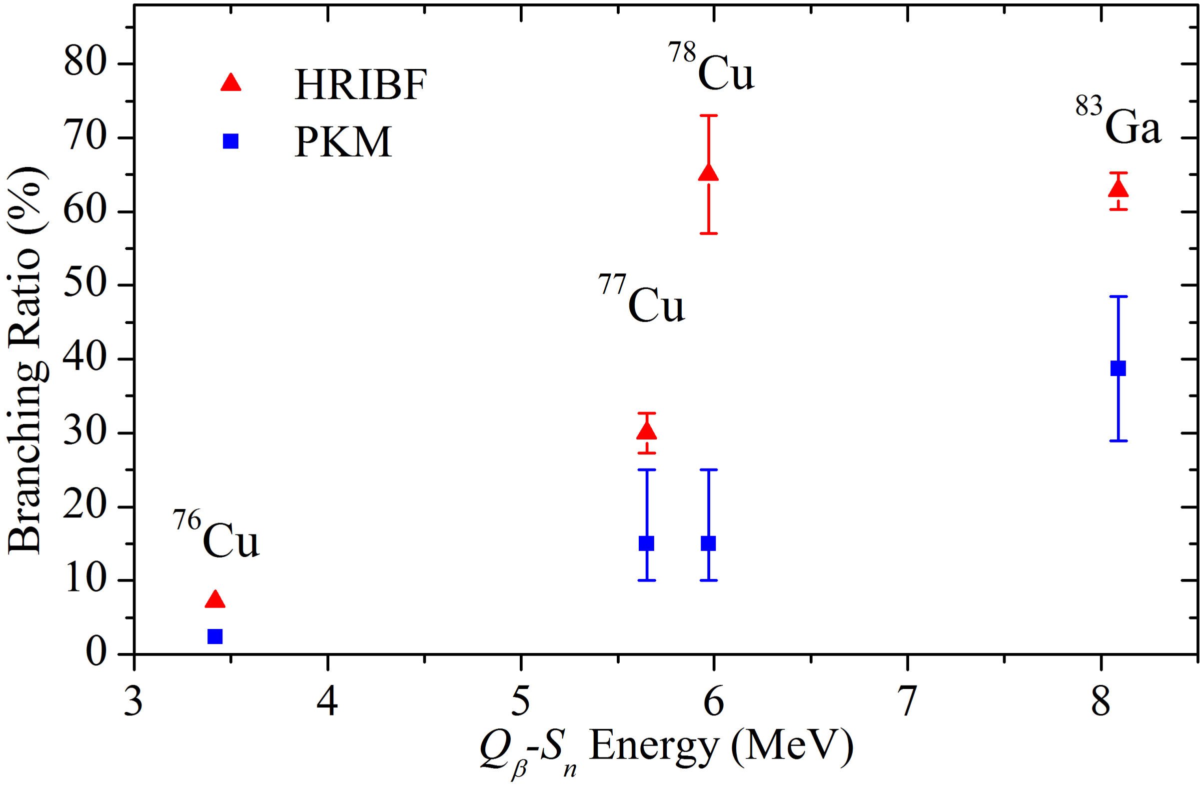
$I_{\beta n}$=30(3)%



no Zn in separated beam,
***Cu** ions **identified** and **counted** !*

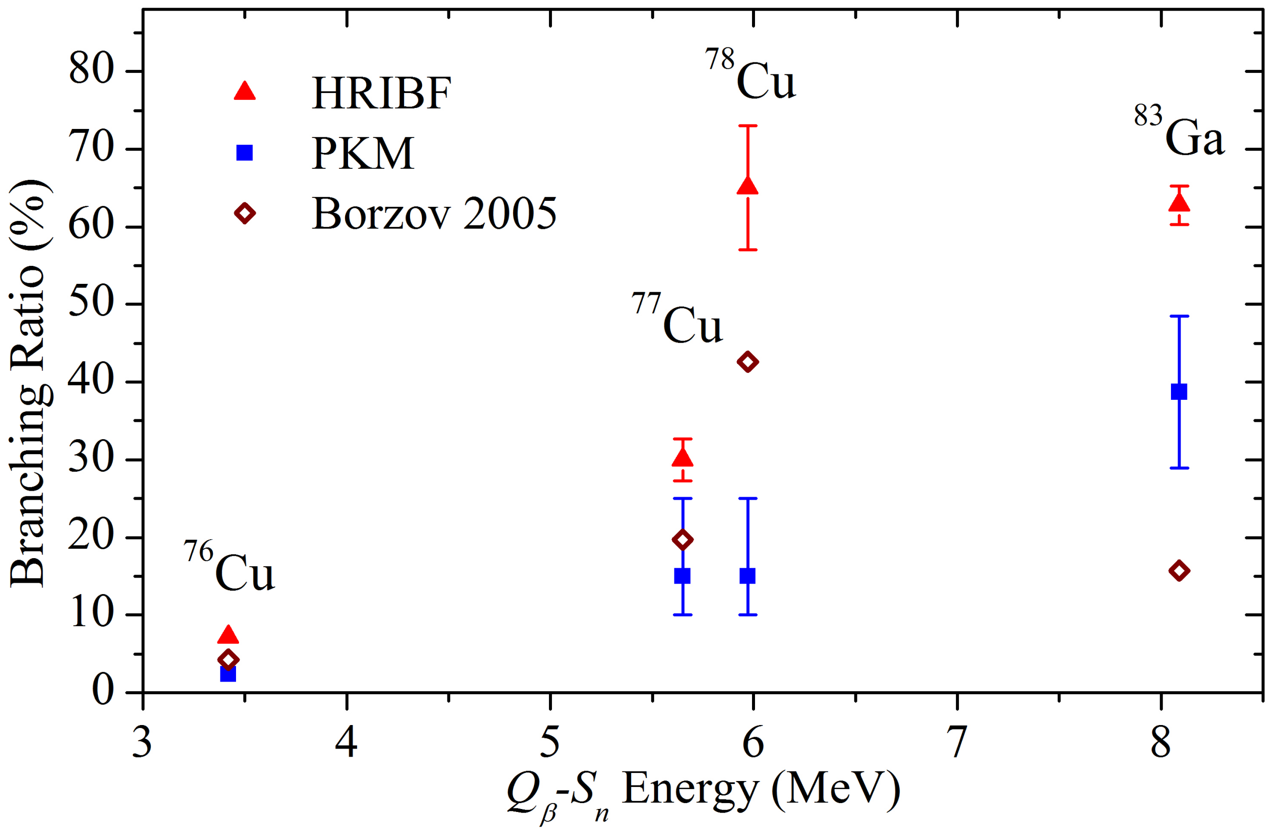


watch out :
^{77}Cu→^{77m}Zn→^{77gs}Ga



factor 2 to 4 higher P_n values
in comparison
to the "current βn-reference"
B. Pfeiffer, K.-L. Kratz, P. Möller **(PKM)**
Prog. Nucl. Energy, 41, 5 (2002)

J.A. Winger,…, KR, R. Grzywacz, .., A. Korgul, W. Królas,.. *et al., Phys. Rev. Letters, 2009*

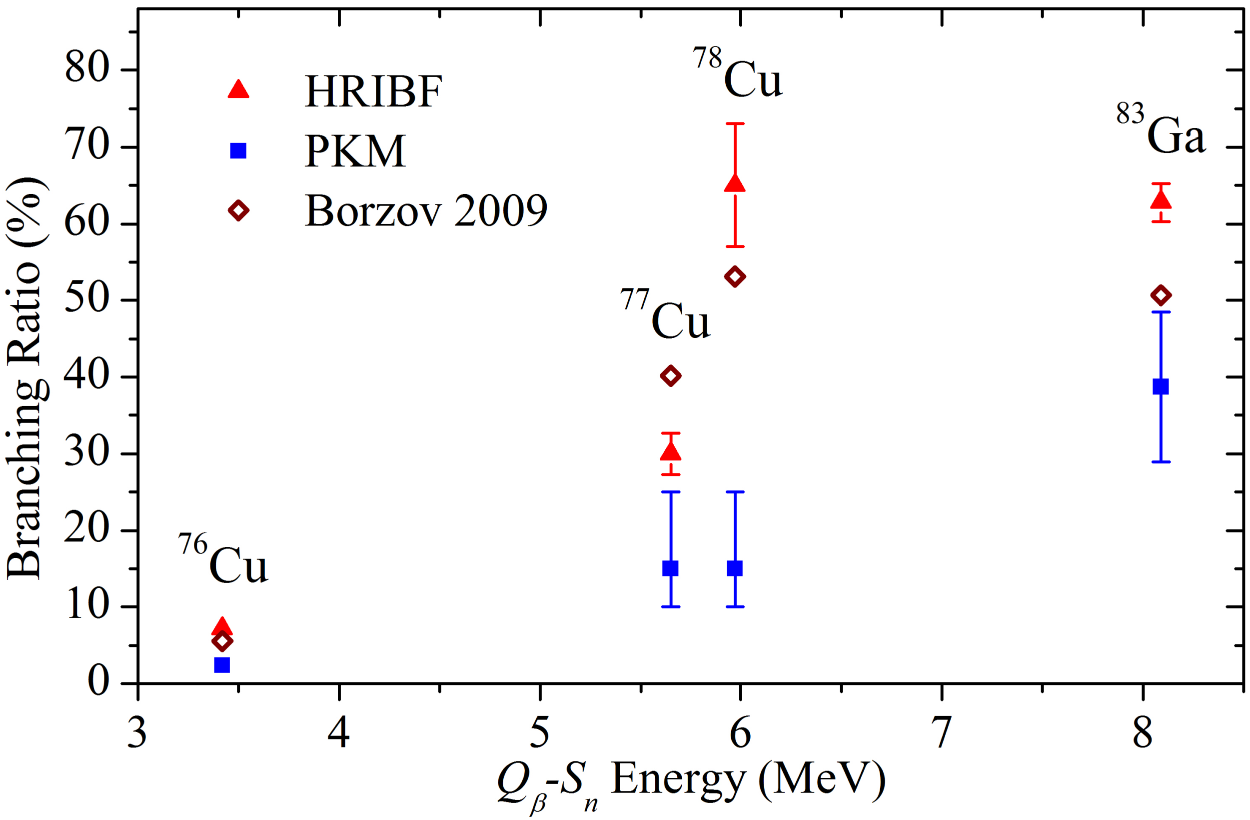


HRIBF exp : ***factor 2 to 4 higher P_n values** in comparison to the "current βn-reference"*

B. Pfeiffer, K.-L. Kratz, P. Möller **(PKM)** ***Prog. Nucl. Energy, 41, 5 (2002)***

HRIBF exp : ***well above the calculated βn-values***

I.N. Borzov, Phys.Rev. C71, 065801, 2005



New βn-calculations of Borzov closer to the HRIBF "reference values" !

New modeling accounts for :

- *new mass measurements Hakala et al., PRL 101, 052502, 2008*
- *an inversion of proton orbitals occurring near ^{78}Ni, from $2p_{3/2}$ to $1f_{5/2}$ (Z=29 ^{76,77,78}Cu and Z=31 ^{83}Ga)*

I.N. Borzov, Phys.Rev. C71, 065801, 2005

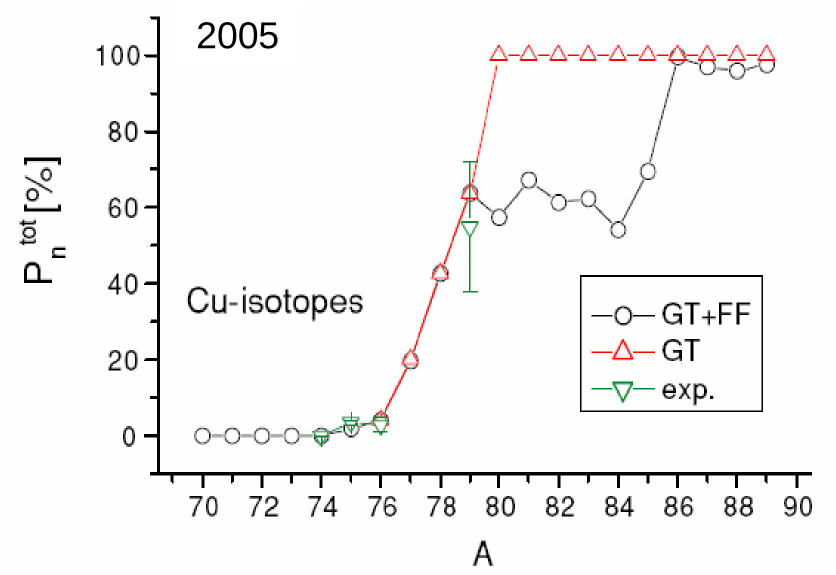
what are the differences in $Q_\beta - S_n$ values "NEW" – OLD (AME2003) ?

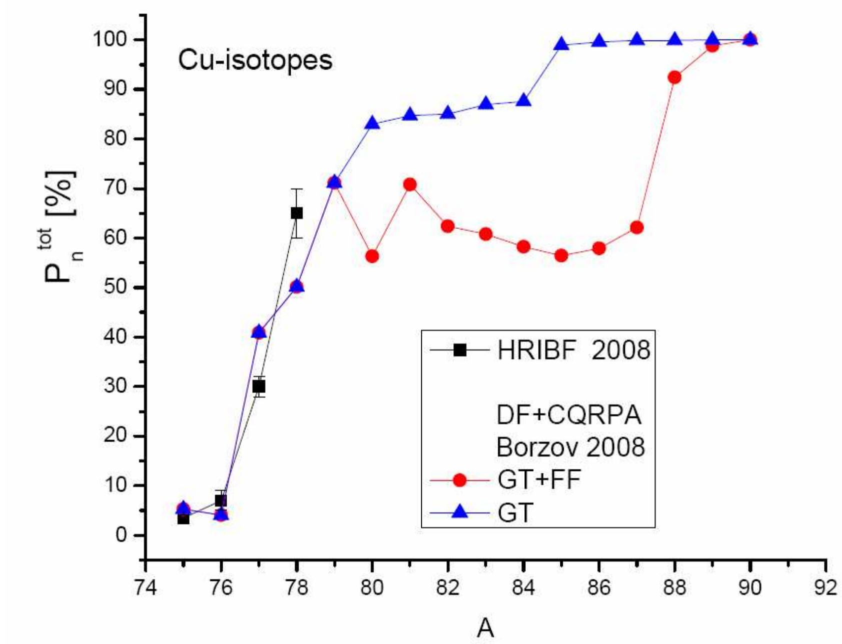
^{76}Cu : +2.7 keV　^{77}Cu : +163 keV　^{78}Cu : + 68 keV　^{83}Ga : – 73 keV

proton orbital inversion plays an important role in Borzov's calculations!

Borzov's predictions of beta-delayed neutron branching ratios for Cu isotopes are including the First-Forbidden (FF) beta-transitions in addition to allowed Gamow-Teller (GT) beta decay

I.N. Borzov, Phys.Rev. C71, 065801, 2005 *and* 2008/2009





we can experimentally verify the models
"GT-only" vs "GT+First Forbidden"
only by measuring P_n values beyond N=50 ^{79}Cu !

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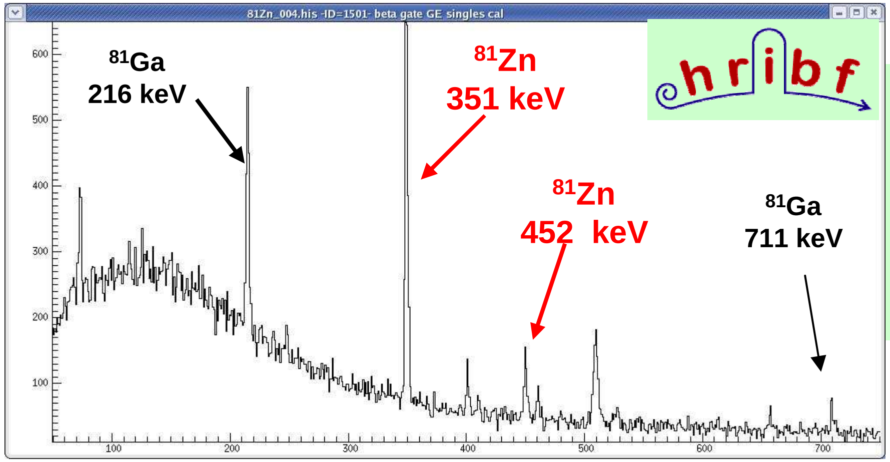
HRIBF exp by S. Liddick (UTK), S. Padgett (UTK,PhD) et al.,

Decays of ^{79}Zn, ^{80}Zn and ^{81}Zn *positive ions* were studied at LeRIBSS at the end of July 2008.

The quality of our data is illustrated below by comparing our on-line ^{81}Zn results to the measurement done at PARRNe facility at Orsay (France) by Verney et al, PRC76, 054312, 2007

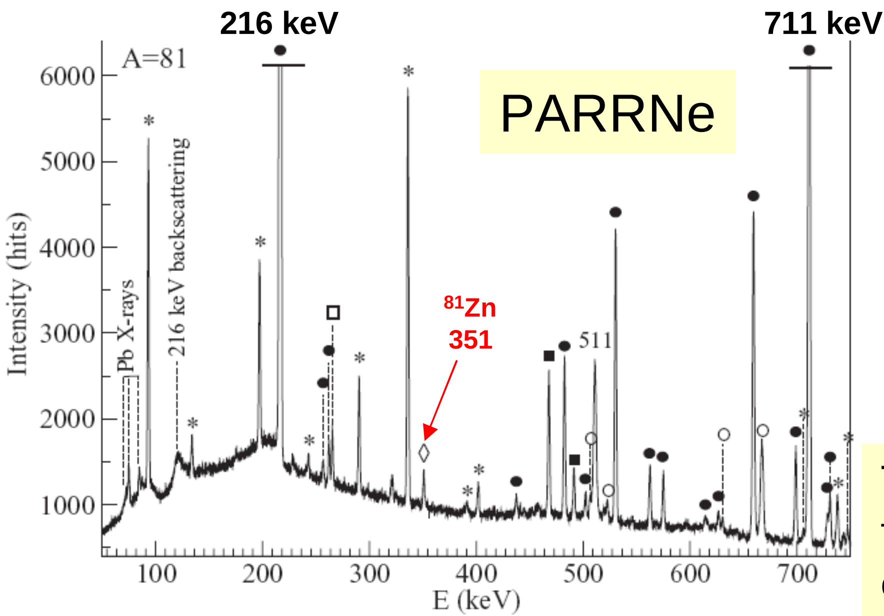


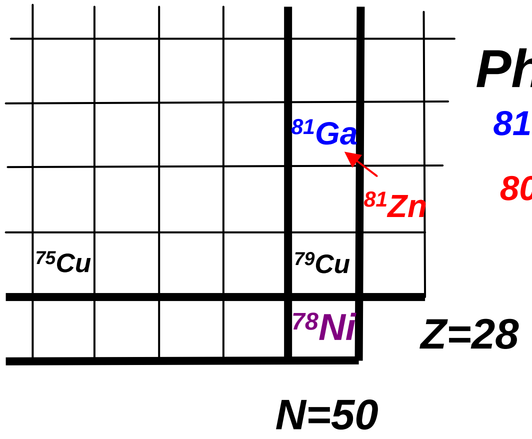
β-gated γ-energy spectrum (keV)

~ 5 hours measurement at LeRIBSS with nearly pure ^{81}Zn ($T_{1/2}$ ~ 0.3 s) 10 pps beam

Initially, Z=31 ^{81}Ga rate was about ~ 5 orders of magnitude higher than Z=30 ^{81}Zn.

here M/ΔM ~ 6400





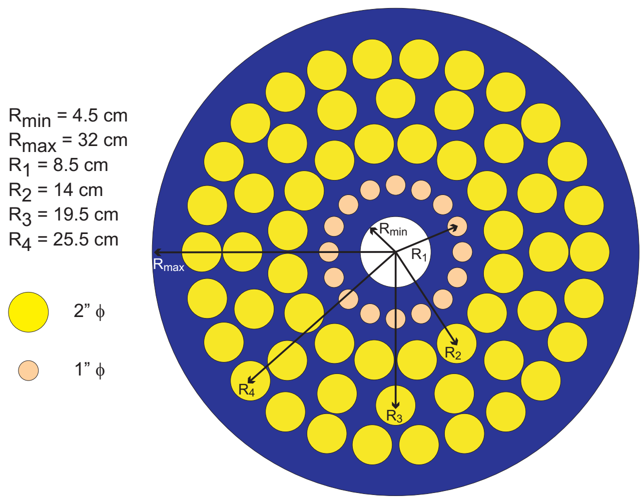
Physics ~ N=50

^{81}Ga = ^{78}Ni+3p

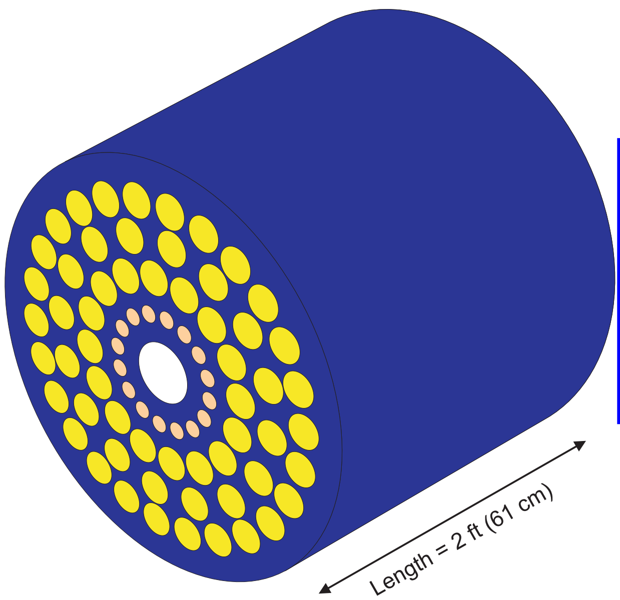
^{80}Zn (n,γ) ^{81}Zn

The experiment at **PARRNe** on **^{81}Zn** suffered from **orders of magnitude higher isobaric contamination** of **^{81}Ga (•), ^{81}Ge(*) and ^{81}As(■).**

Digital beta-delayed neutron detector ^{3}Hen



art by Carl Gross



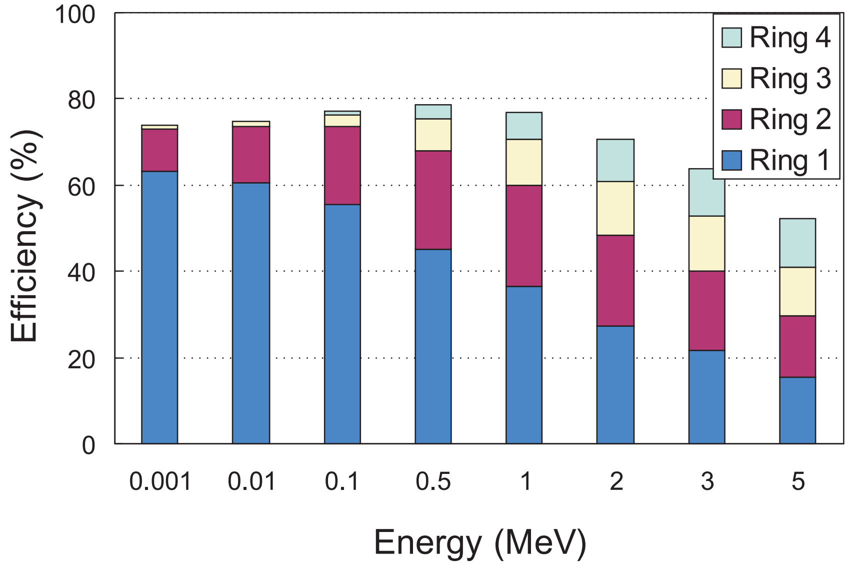
seventy four neutron detecting ^{3}*He tubes*
in a High-Density Polyethylen (HDPE)
moderator structure

$^{3}He + n = p + t + 0.75$ MeV

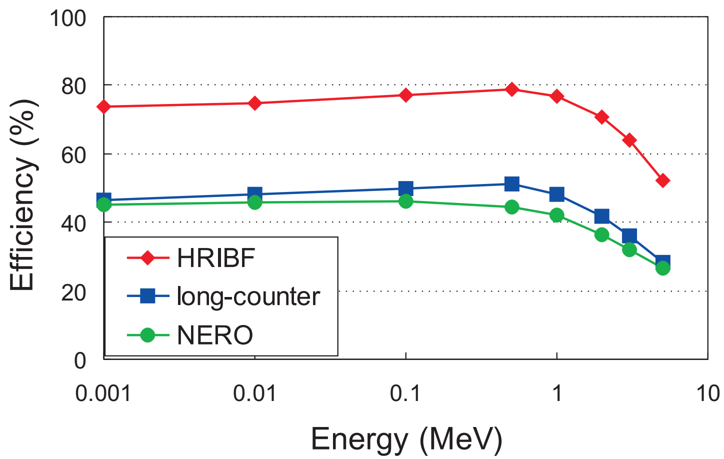
new equipment enhancing our LeRIBSS and “ranging-out” capabilitities

nearly 80% efficient and segmented ^{3}Hen neutron counter

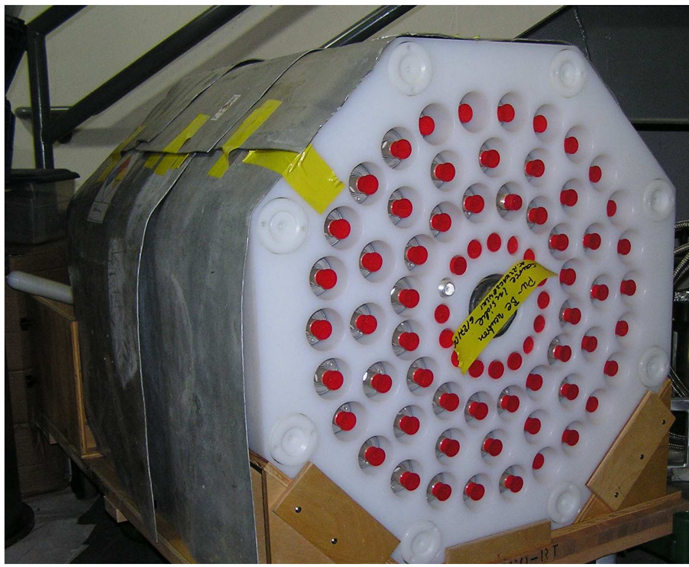
Neutron Efficiency by Ring



HRIBF, Long-counter, and NERO Neutron Efficiency

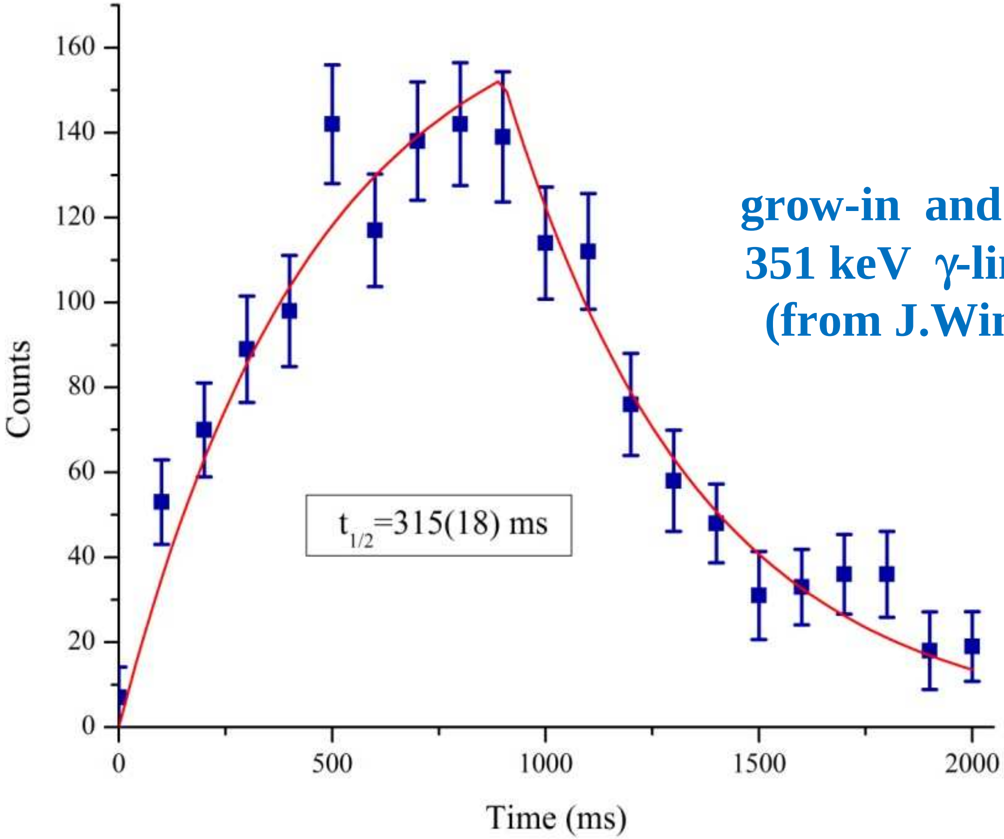


ORNL
LSU , Mississippi
UTK, UNIRIB



pure ^{81}Zn beam → $T_{1/2}$ (^{81}Zn)= 315(18) ms

***$T_{1/2}$=290(50) ms**, β-delayed neutrons, K.-L. Kratz et al, Zeit. Phys. A340, 419, 1991*
***$T_{1/2}$ = 391(65) ms**, 351 keV γ-line, D. Verney et al., Phys. ReV. C76, 054312, 2007*



grow-in and decay pattern
351 keV γ-line , ^{81}Zn decay
(from J.Winger, 10/2008)

we will use this beam on-off technique for the identification of βn-decay pattern for most n-rich nuclei : ^{81,82}Cu (RIB-180), ^{86}Ge (RIB-128) and ^{87}Ga (A.Korgul et al., RIB-181), and hopefully for even more exotic ones (beyond ~ ^{81}Zn, ^{88}As, ^{94}Br…)

3Hen

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Współpracownicy :

ORNL : **C.J. Gross, D. Shapira**

UT Knoxville : **R.K.Grzywacz**, C.R.Bingham,
S. Liddick, I. Darby, L. Cartegni, M. Rajabali, S. Padgett, E. Freeman

Warszawa : **A. Korgul,** M .Karny

Mississippi : **J. A. Winger, S.Ilyushkin**

Luizjana : **Ed Zganjar**, A. Piechaczek *UNIRIB :* J.C. Batchelder

Vanderbilt : J.H. Hamilton, S. Liu et al.,

Kraków : W. Królas, *Łódz:* J. Perkowski

Mediolan : **Ch. Mazzocchi** *et al.,*

LeRIBSS : *T.Mendez, C.Reed, Ed Zganjar, R.Juras, D.Dowling, J.Johnson*

HRIBF (Oak Ridge) :

badamy (= zmierzyć i zrozumieć)

strukturę i własności jąder najbardziej odległych od ścieżki stabilności beta

W badaniach jąder neutrono-nadmiarowych z okolicy ^{78}Ni
zmierzyliśmy duże wartości
prawdopodobieństw emisji neutronów po rozpadach beta

duże = 2 do 5 razy większe niż raportowano poprzednio
(i zmierzyliśmy dobrze !!)

nowa analiza teoretyczna (I.Borzov) pokazuje, że zmiana stanu podstawowego, czyli proton $1f_{5/2}$ zamiast $2p_{3/2}$ dla neutrononadmiarowych Z=29 Cu i Z=31 Ga, może spowodować zwiększenie
emisji βn !

Rozwój nowych technik detekcji opartych na cyfrowej analizie sygnałów może znaleźć zastosowanie w innych eksperymentach, np. poszukiwaniu nowych pierwiastków superciężkich