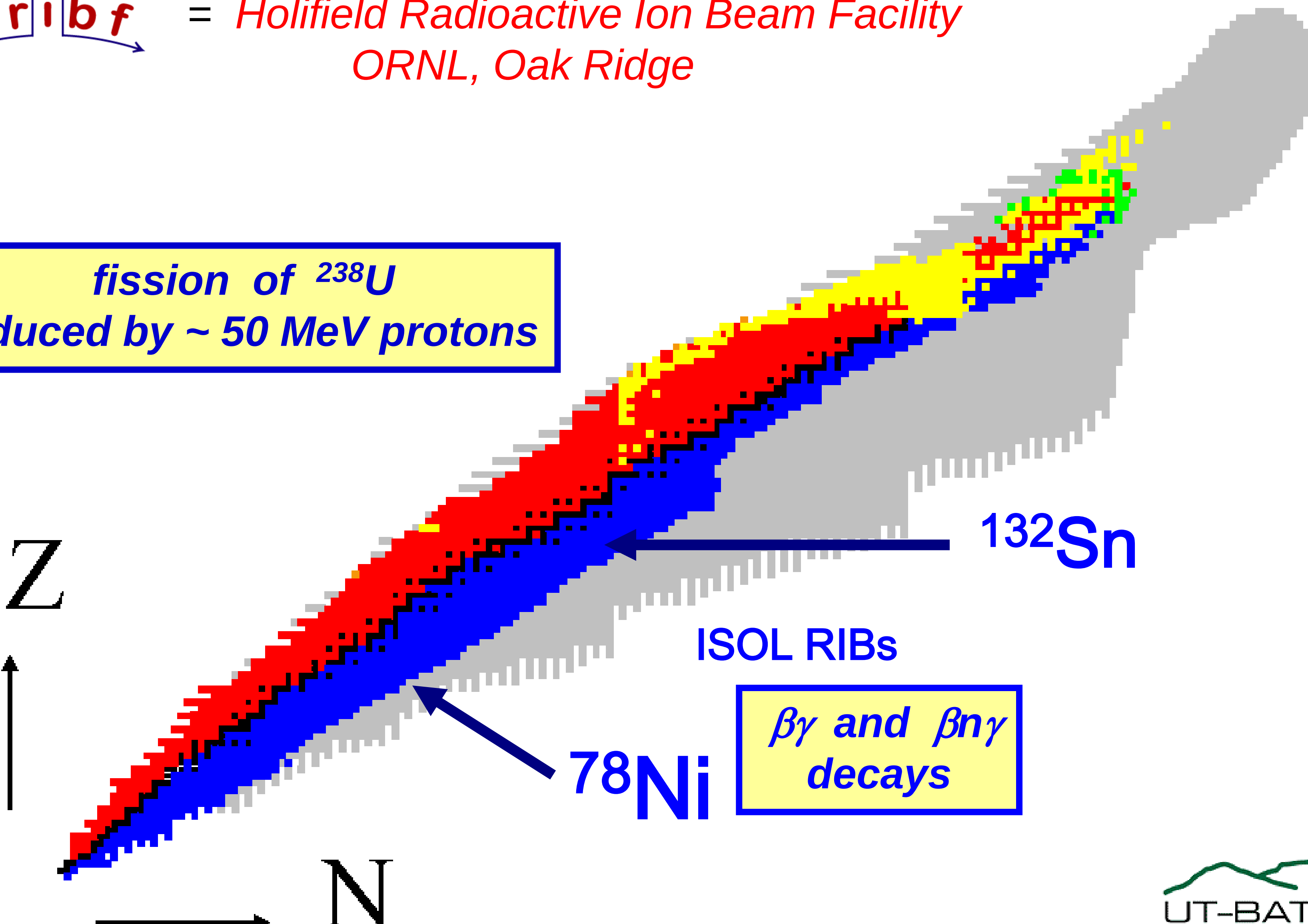
Decay studies including β-delayed neutron emission at the HRIBF

K. P. Rykaczewski (Physics Division, ORNL)

hribf = *Holifield Radioactive Ion Beam Facility*
ORNL, Oak Ridge

fission of ^{238}U
induced by ~ 50 MeV protons



among our motivations :

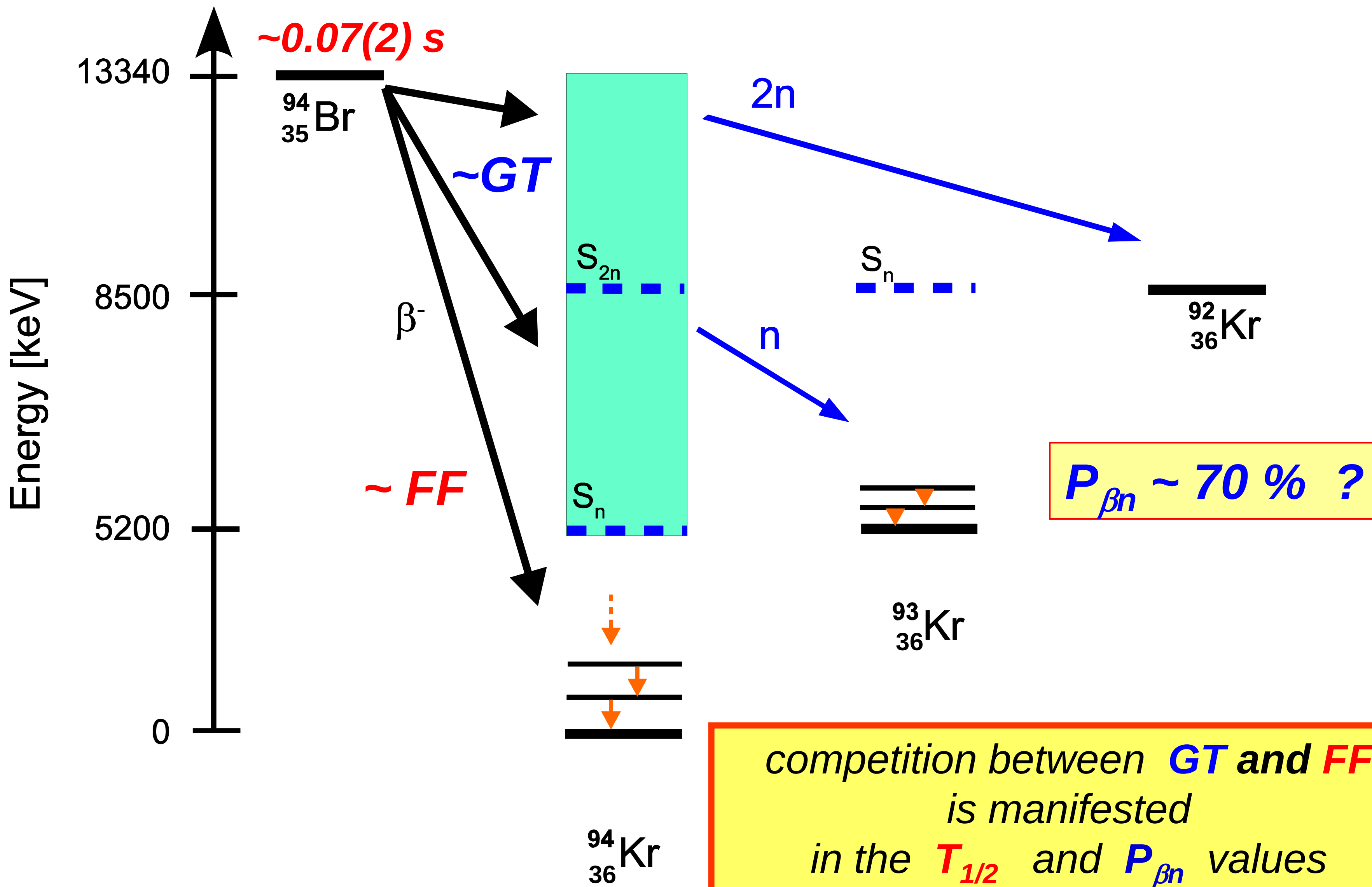
- ***understanding the evolution of nuclear structure***

- *beta-decay properties are needed for the analysis of post r-process isotopic distributions (in particular the data around "waiting-point" nuclei)*
  half-lives, beta-delayed neutron rates, low-energy isomers …

- ***the decay properties of fission products***
  are among the parameters needed for the operation of nuclear reactors,
  e.g., during a shut-down process,
  and for the nuclear spent fuel/nuclear waste handling

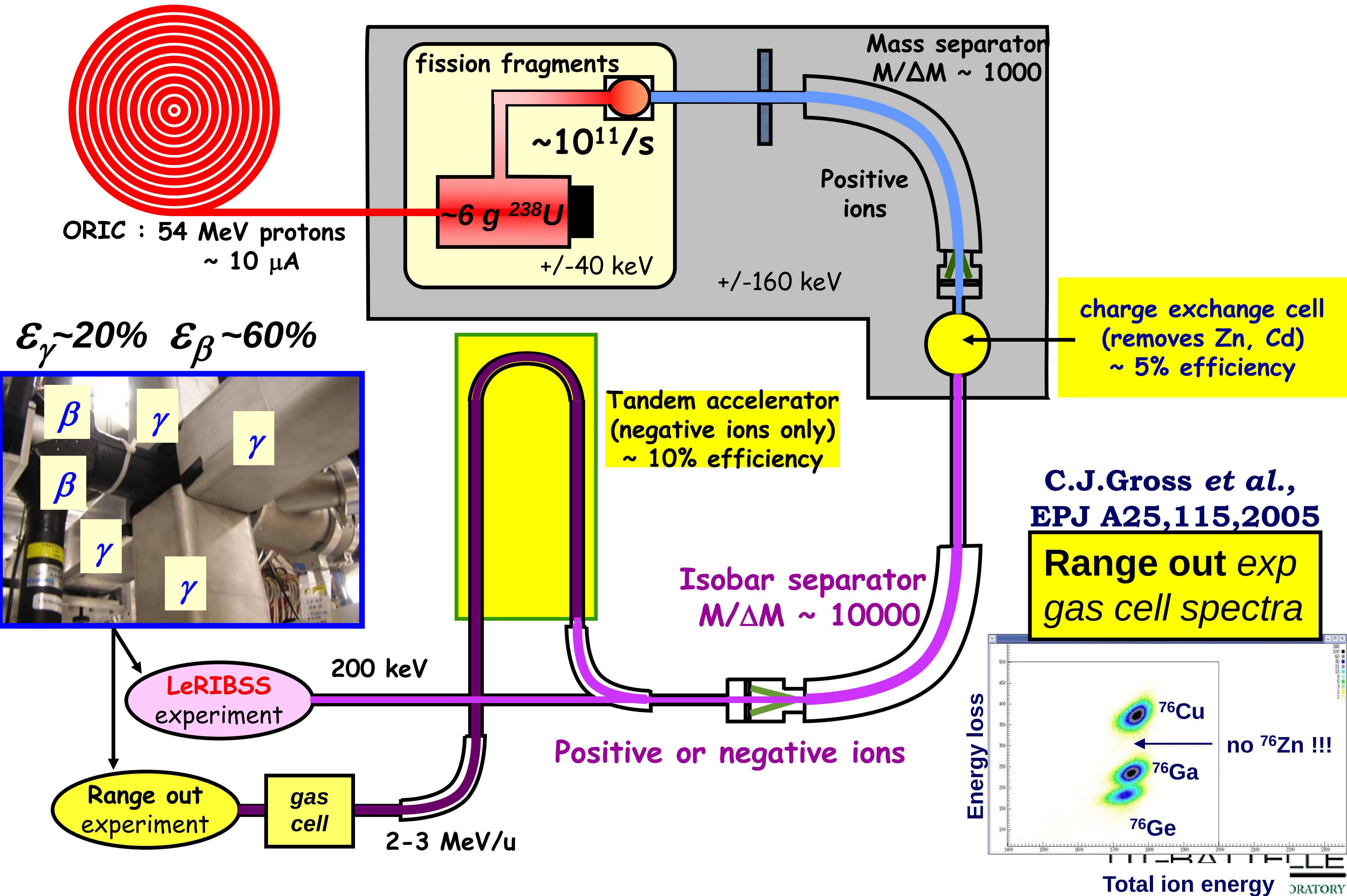
*an example of a complex decay for neutron-rich isotope, from HRIBF proposal by S.Liddick et al.,"**G**amow-**T**eller vs **F**irst **F**orbidden β-decays of Br isotopes"*

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



competition between GT and FF is manifested in the $T_{1/2}$ and $P_{\beta n}$ values

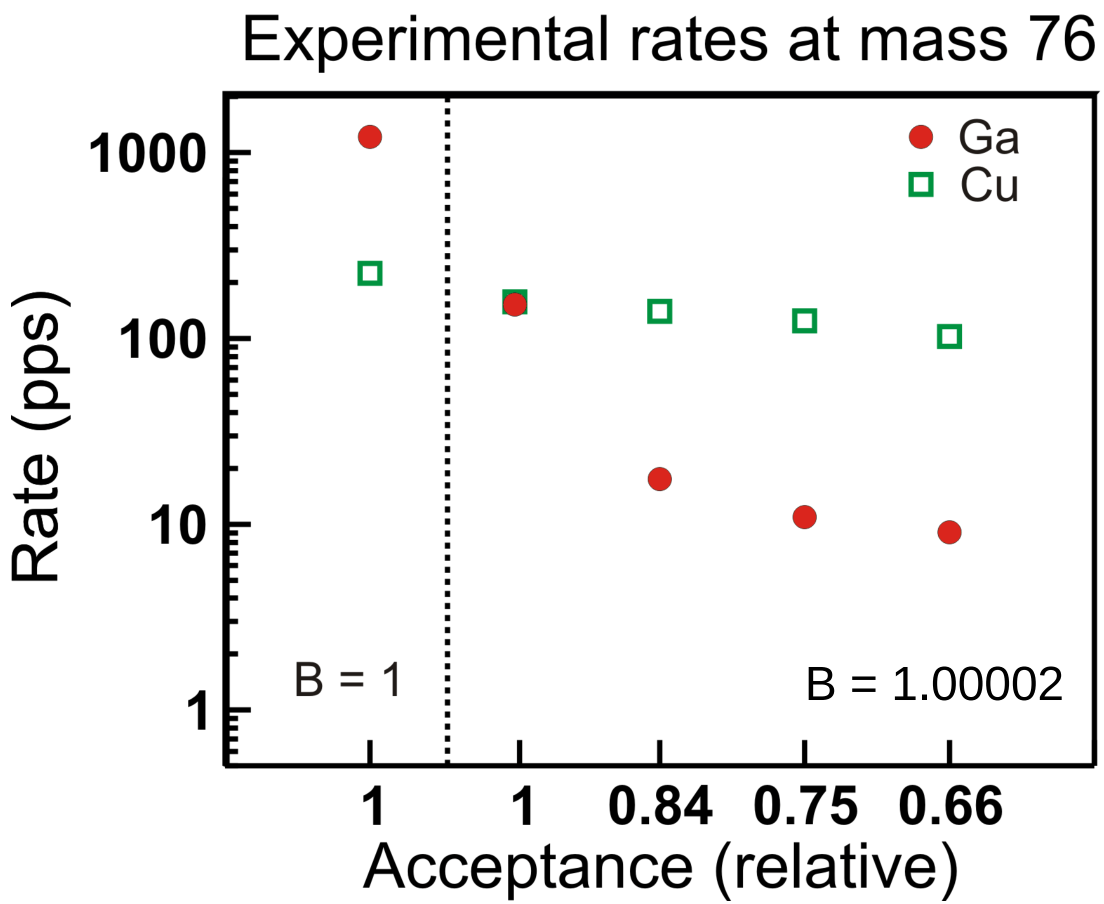
Decay studies of neutron-rich nuclei at hribf *(Oak Ridge)*



HRIBF high-resolution RIB injector magnet ($\Delta M/M \sim 1:10^4$)

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 $\Delta M/M \sim 1:4600$

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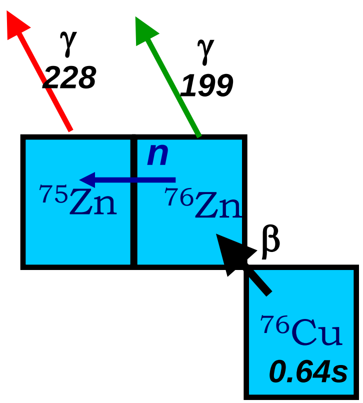
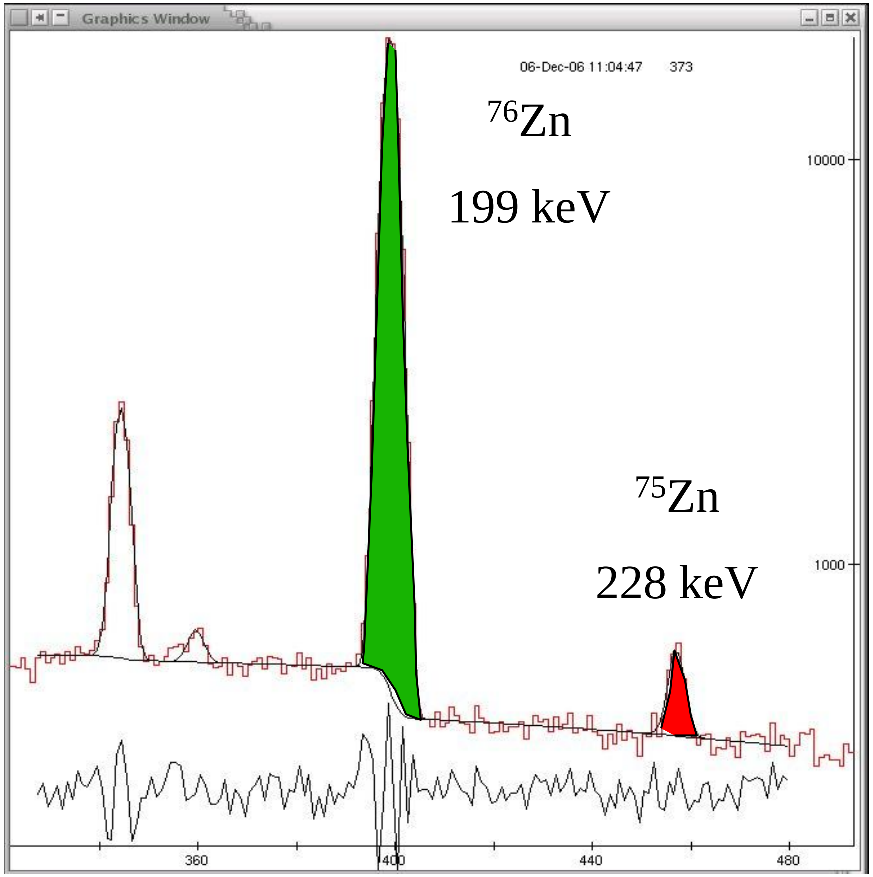
J.A. Winger *et al.*, *Phys. Rev. Letters, 102, 142502, 2009*

digital data acquisition – XIA DGFs and Pixie16

P_n=7.2(5)%





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

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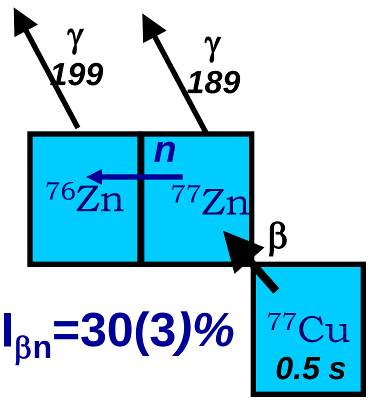
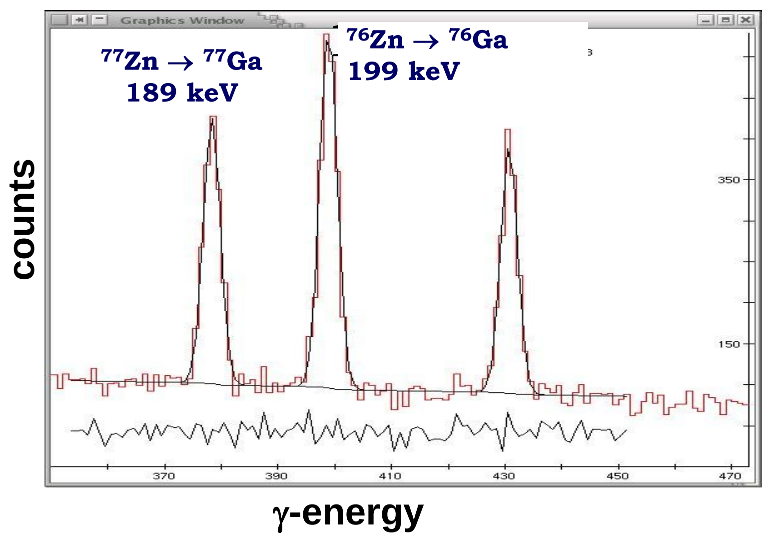
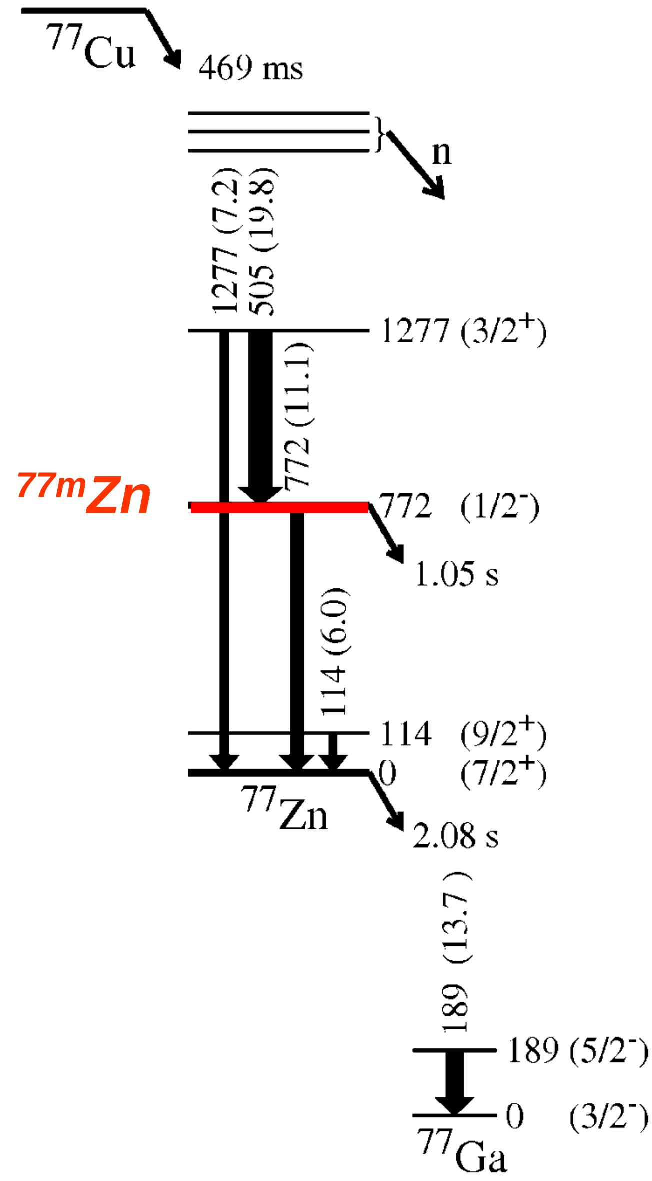
^{77}Cu : 18 hours of "ranging-out" exp with 15 pps



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

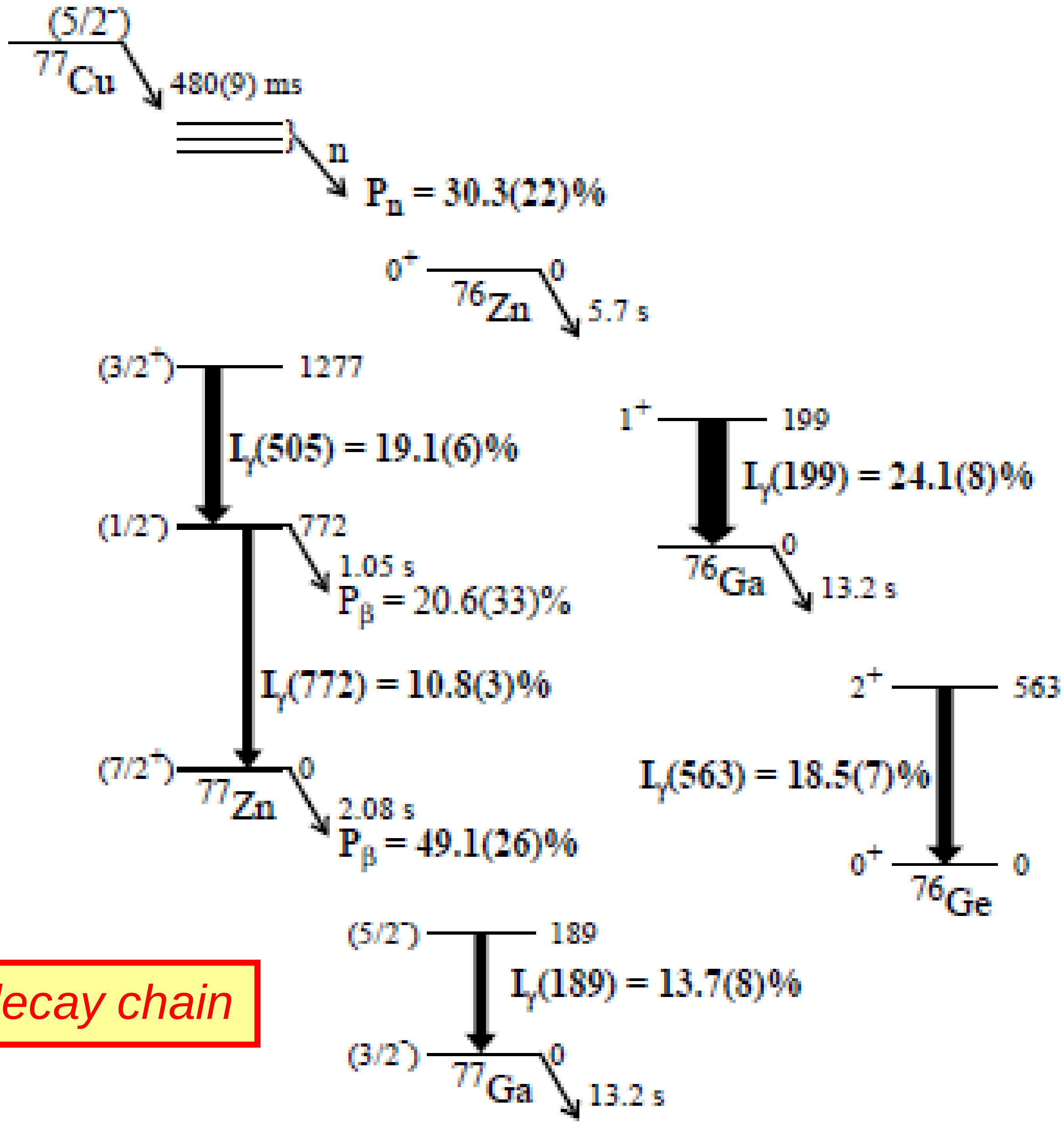




no Zn in separated beam,
***Cu** ions **identified** and **counted** !*

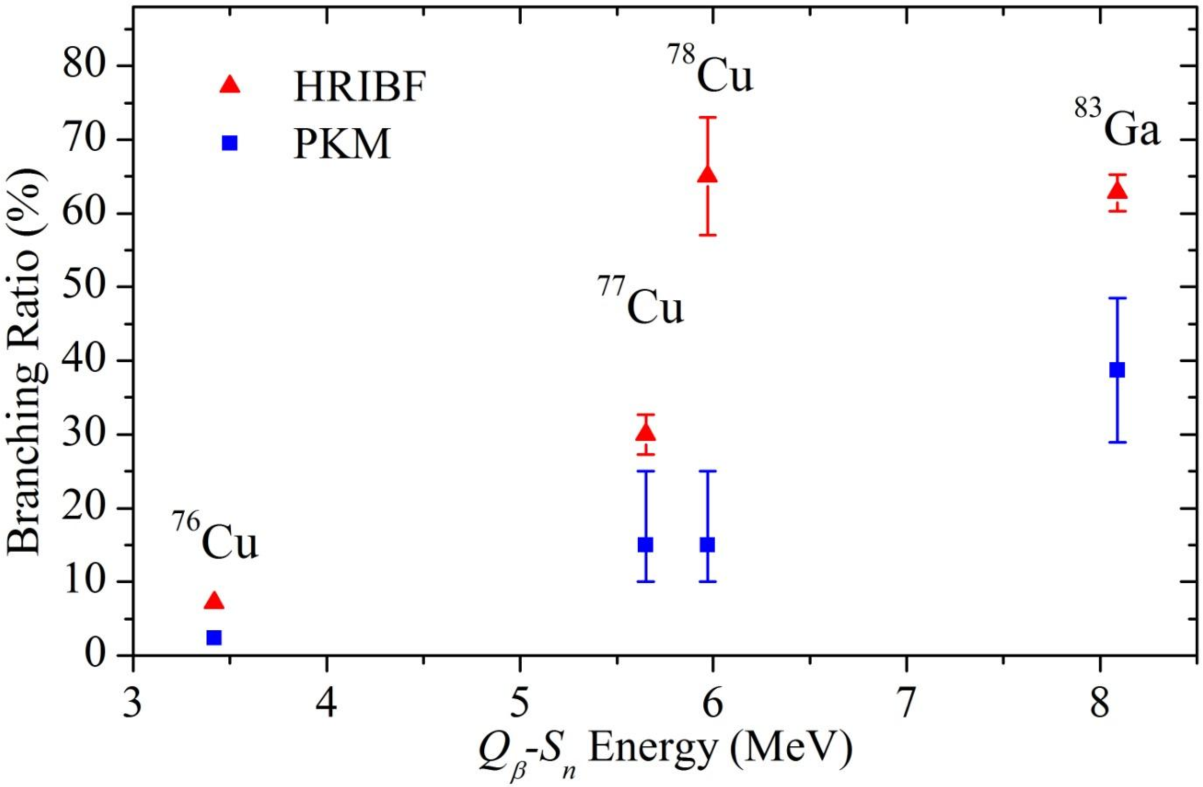
watch out :
^{77}Cu→^{77m}Zn→^{77gs}Ga

S. Ilyushkin et al., Phys. Rev. C, 2009, in press



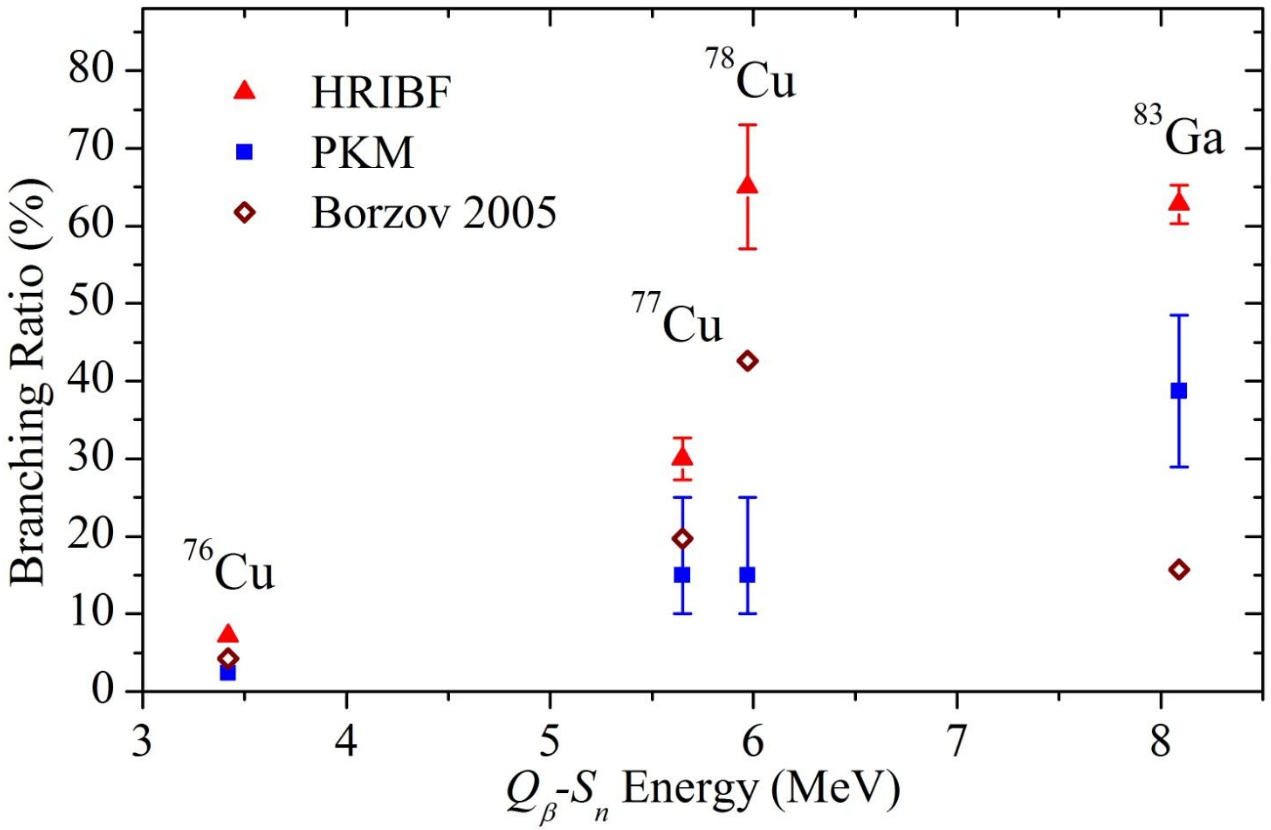
A=76 decay chain

A=77 decay chain



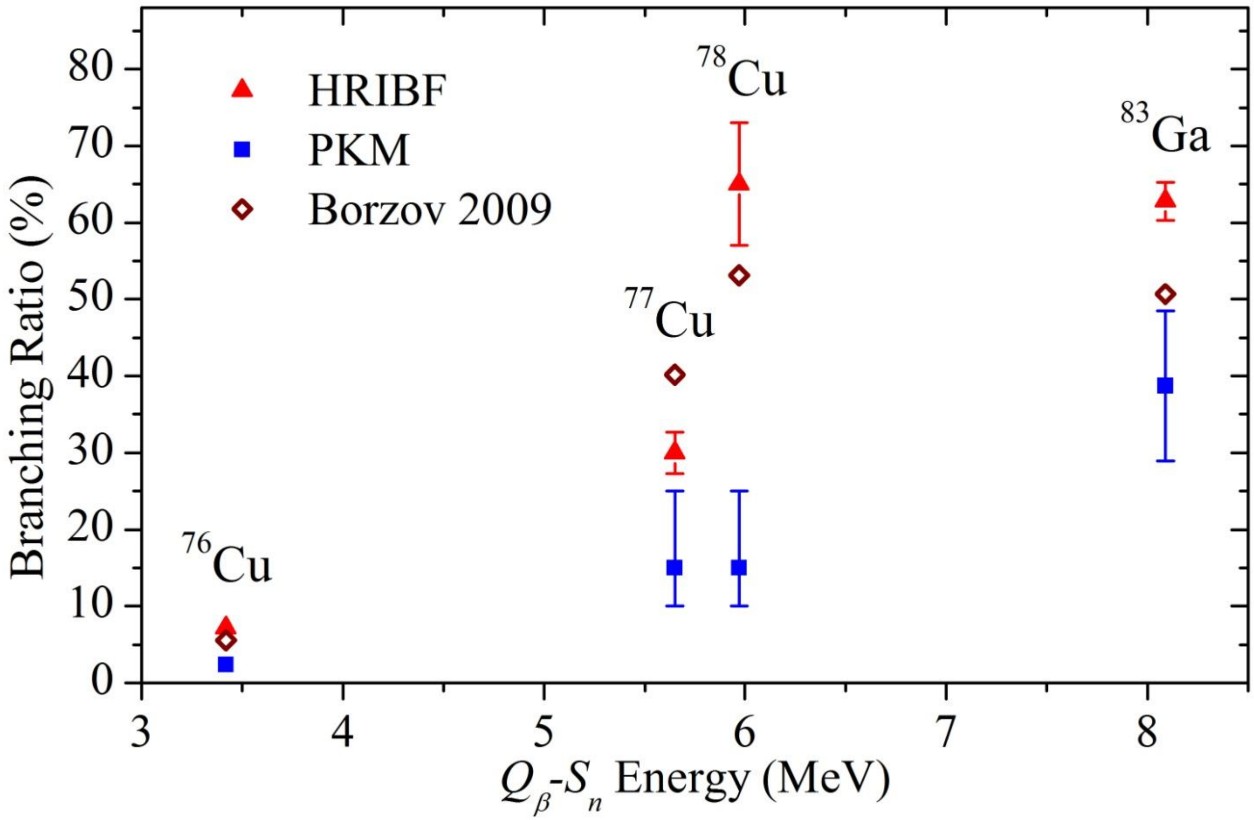
factor 2 to 5 higher P_n values
in comparison
to the "current βn-references"
e.g., B. Pfeiffer, K.-L. Kratz, P. Möller **(PKM)**
Prog. Nucl. Energy, 41, 5 (2002)

J.A. Winger et al., ***Phys. Rev. Letters, 102, 142502, 2009***



HRIBF exp : ***factor 2 to 5 higher P_n values** in comparison to the "current βn-references"*
e.g., 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
(interesting ^{83}Ga story !)



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

New modeling accounts for :

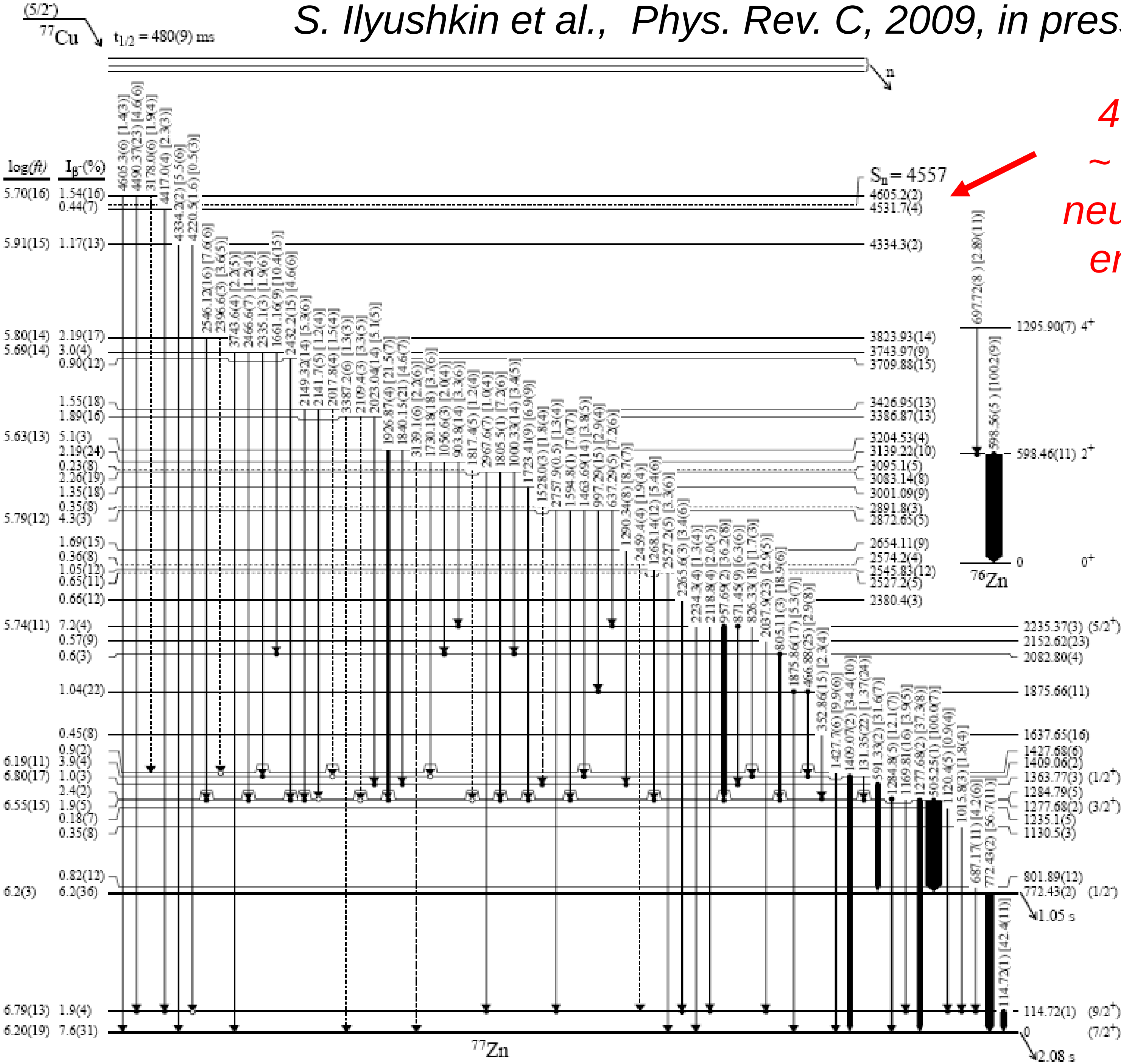
- ***new mass measurements Hakala et al., PRL 101, 052502, 2008***
- ***an inversion of proton orbitals occurring near ^{78}Ni, from $2p_{3/2}$ to $1f_{5/2}$ (Z=29 ^{76,77,78}Cu and Z=31 ^{83}Ga), see K. Flanagan et al, Phys. Rev. Lett., 103, 142501, 2009***

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!

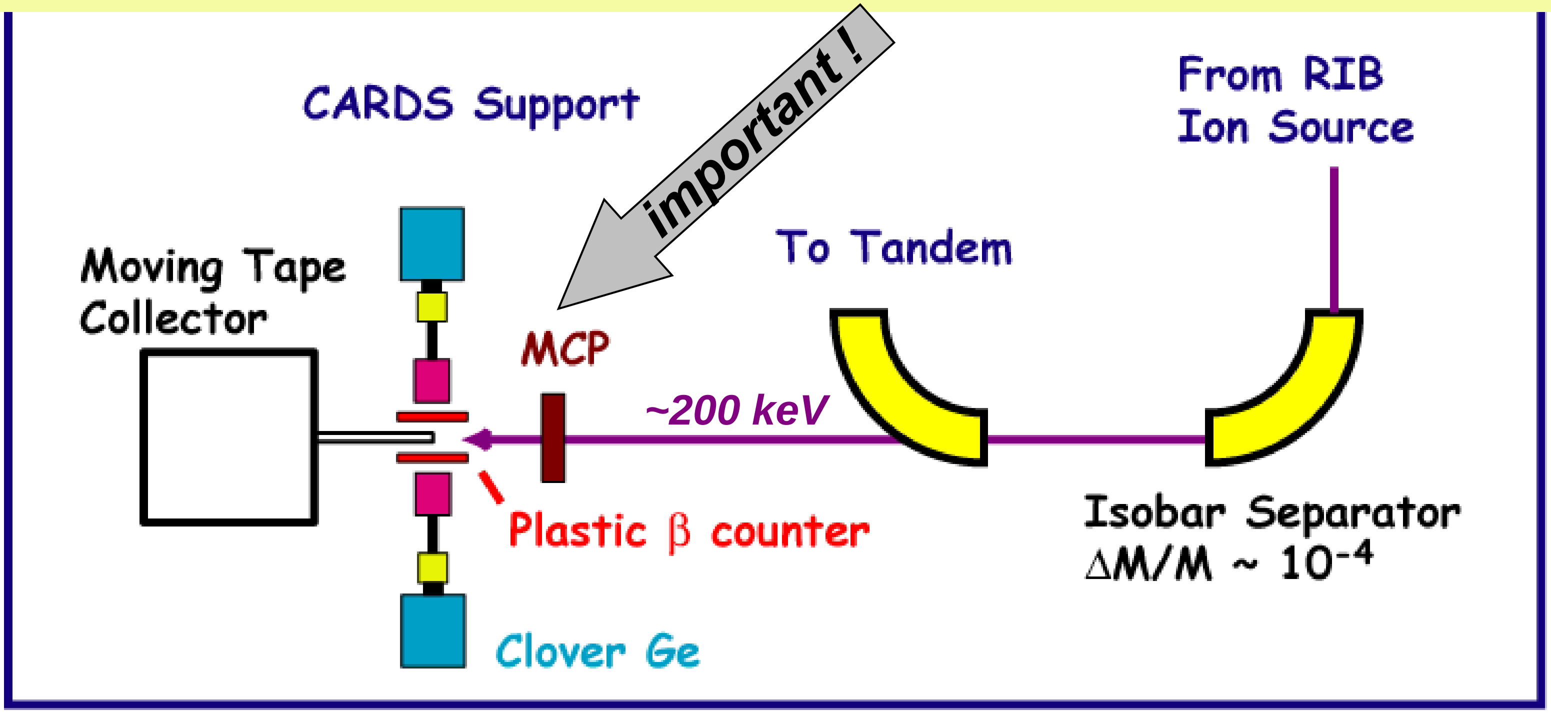
S. Ilyushkin et al., Phys. Rev. C, 2009, in press



4.6 MeV level :
~ 50 keV ***above***
neutron separation energy value S_n

Low-energy Radioactive Ion Beam Spectroscopy Station LeRIBSS

Factor 20 to 1000 improvement in RIBs intensity
in comparison to "ranging-out" experiments with postaccelerated beams
[no Tandem – 10, no Charge Exchange – 2++ for Cu, Ga – 10x20=200)]
negative AND positive ~ 200 keV ions from IRIS-1 and 250 keV from IRIS-2
profiting from all HRIBF beam purification methods (except "ranging-out")
ultra-thin foil MCP : time correlations with implanted ions (D.Shapira,C.J Gross..)



LeRIBSS successfully commissioned in July 2008

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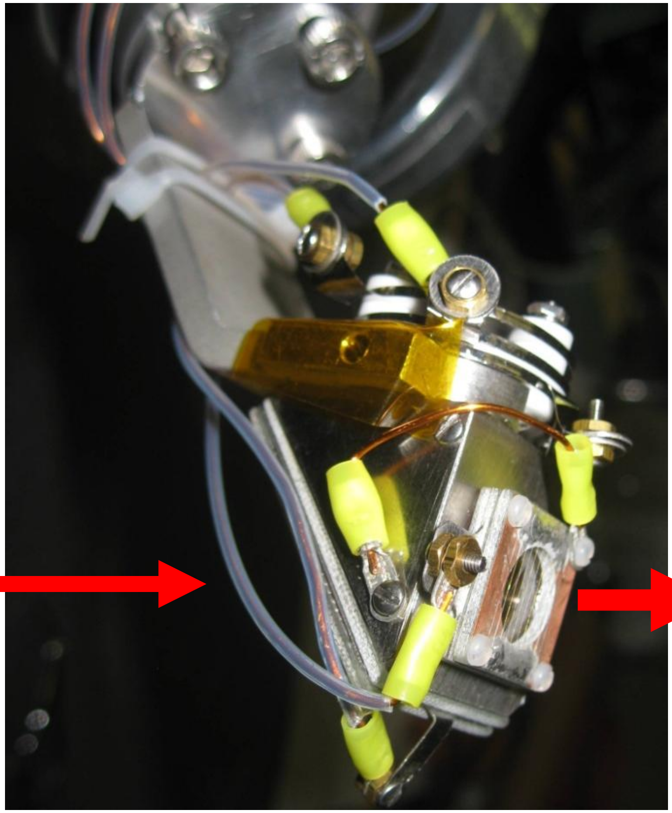
Oak Ridge has a unique ISOL facility :
high-resolution isobar separator operating with 200 keV beams and Micro-Channel Plate (MCP) detector allowing for ion tagging and counting

single isobar ion beam



movable tape collector surrounded by radiation detectors
β,γ, electron, neutron ..

5 μg/cm^2, 8 mm diameter Carbon foil plus small MCP detector

***Dan Shapira** (ORNL), Steven Padgett (UTK) et al.,*

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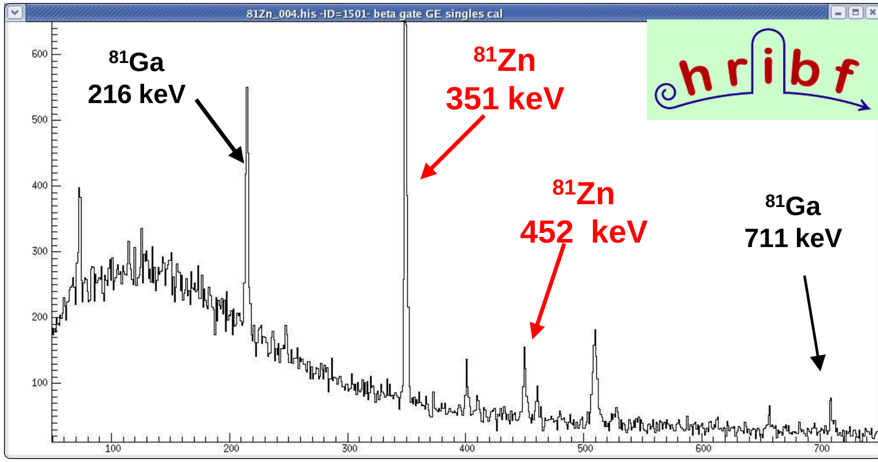
HRIBF exp by S. Liddick (UTK), S. Padgett (UTK,PhD) et al.,

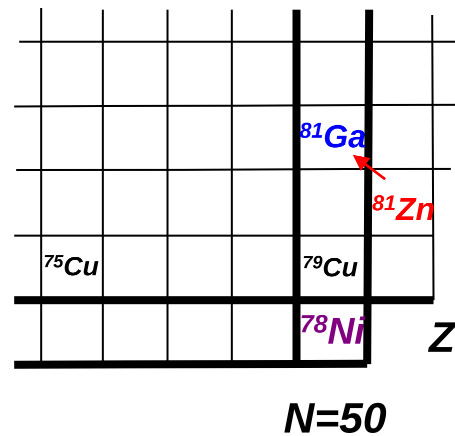
Decays of ^{79}Zn, ^{80}Zn and ^{81}Zn *positive ions* were studied at LeRIBSS at the end of July 2008.

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)

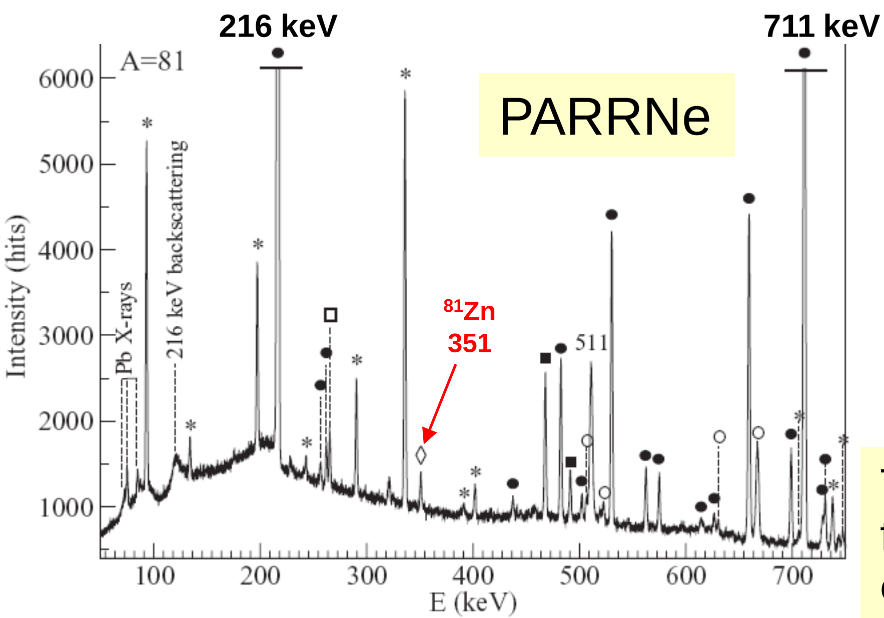
~ 5 hours measurement at LeRIBSS with nearly pure ^{81}Zn ($T_{1/2}$ ~ 0.3 s) 30 pps beam
Initially, Z=31 ^{81}Ga rate was about ~ 5 orders of magnitude higher than Z=30 ^{81}Zn.
here M/ΔM ~ 6400



Physics ~ N=50

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

^{80}Zn (n,γ) ^{81}Zn

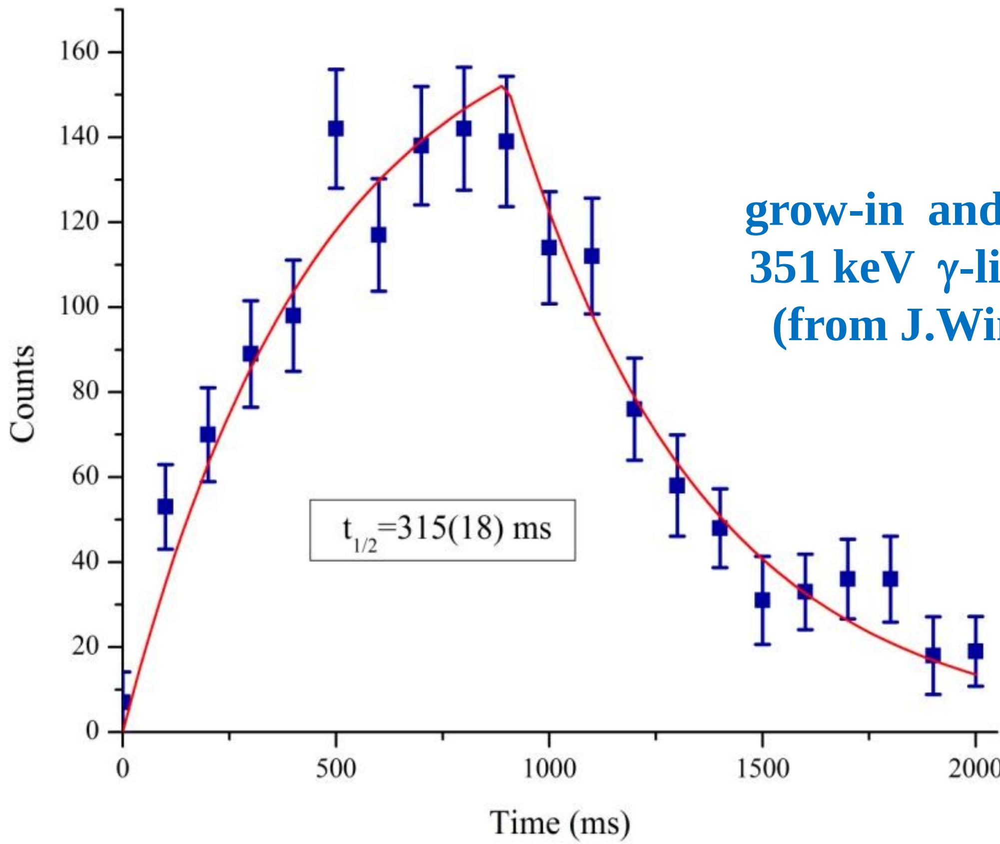


The experiment at **PARRNe** on **^{81}Zn** suffered from **orders of magnitude higher isobaric contamination** of **^{81}Ga (•), ^{81}Ge(*) and ^{81}As( ).**

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 (RIB-181), and hopefully for even more exotic ones (beyond ~ ^{81}Zn, ^{88}As, ^{94}Br…)

3Hen

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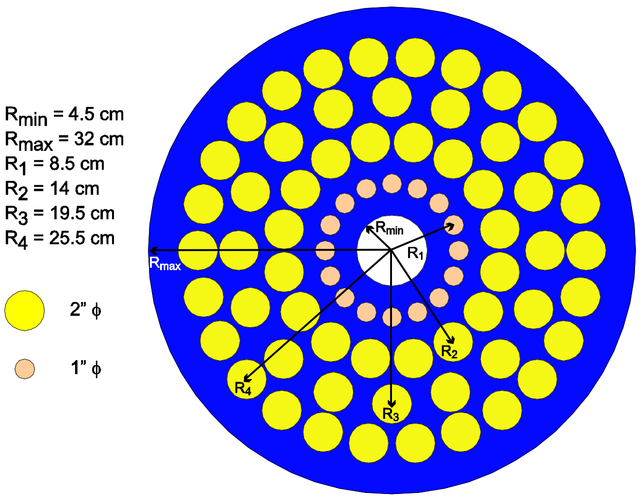
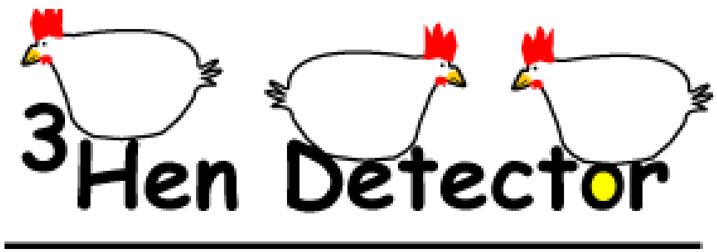
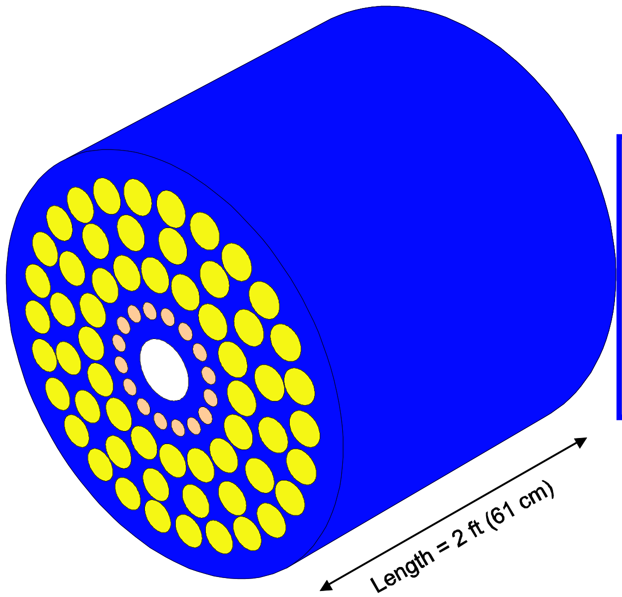
Digital beta-delayed neutron detector ^{3}Hen





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

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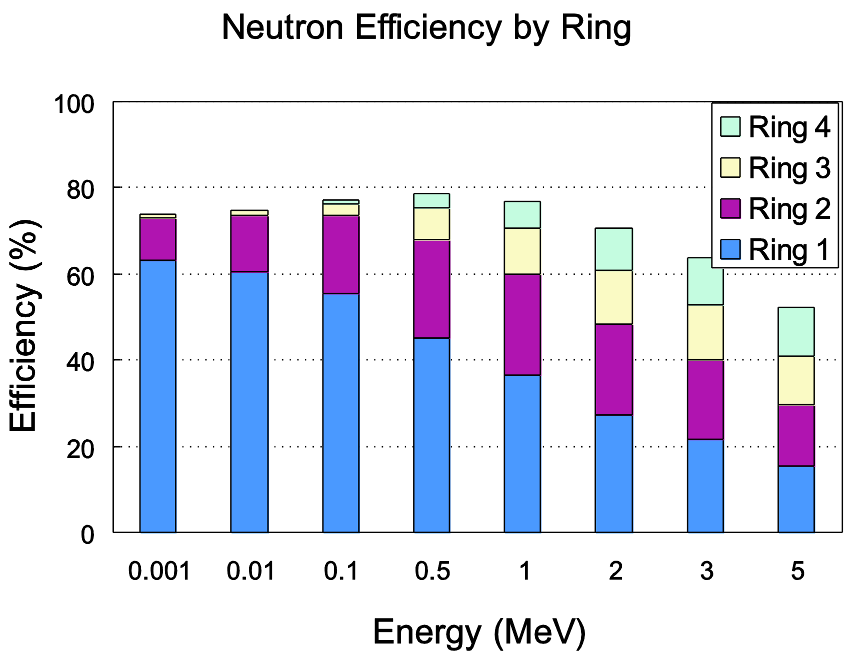
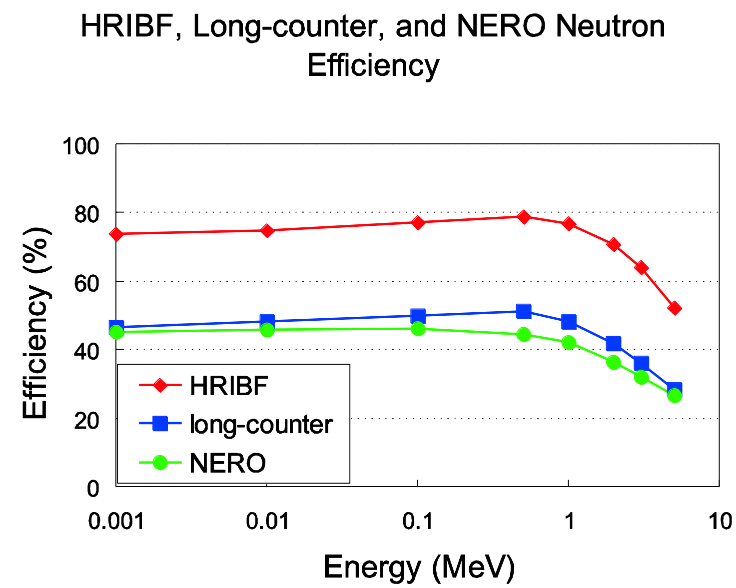
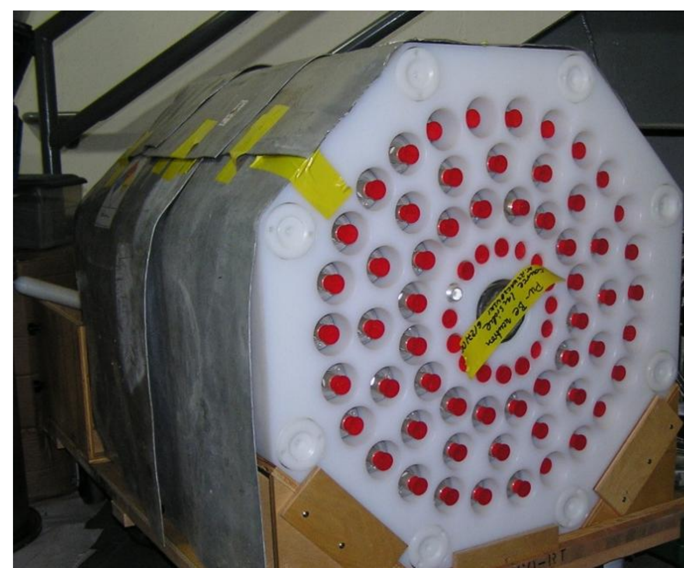
new equipment enhancing our LeRIBSS and "ranging-out" capabilitities

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



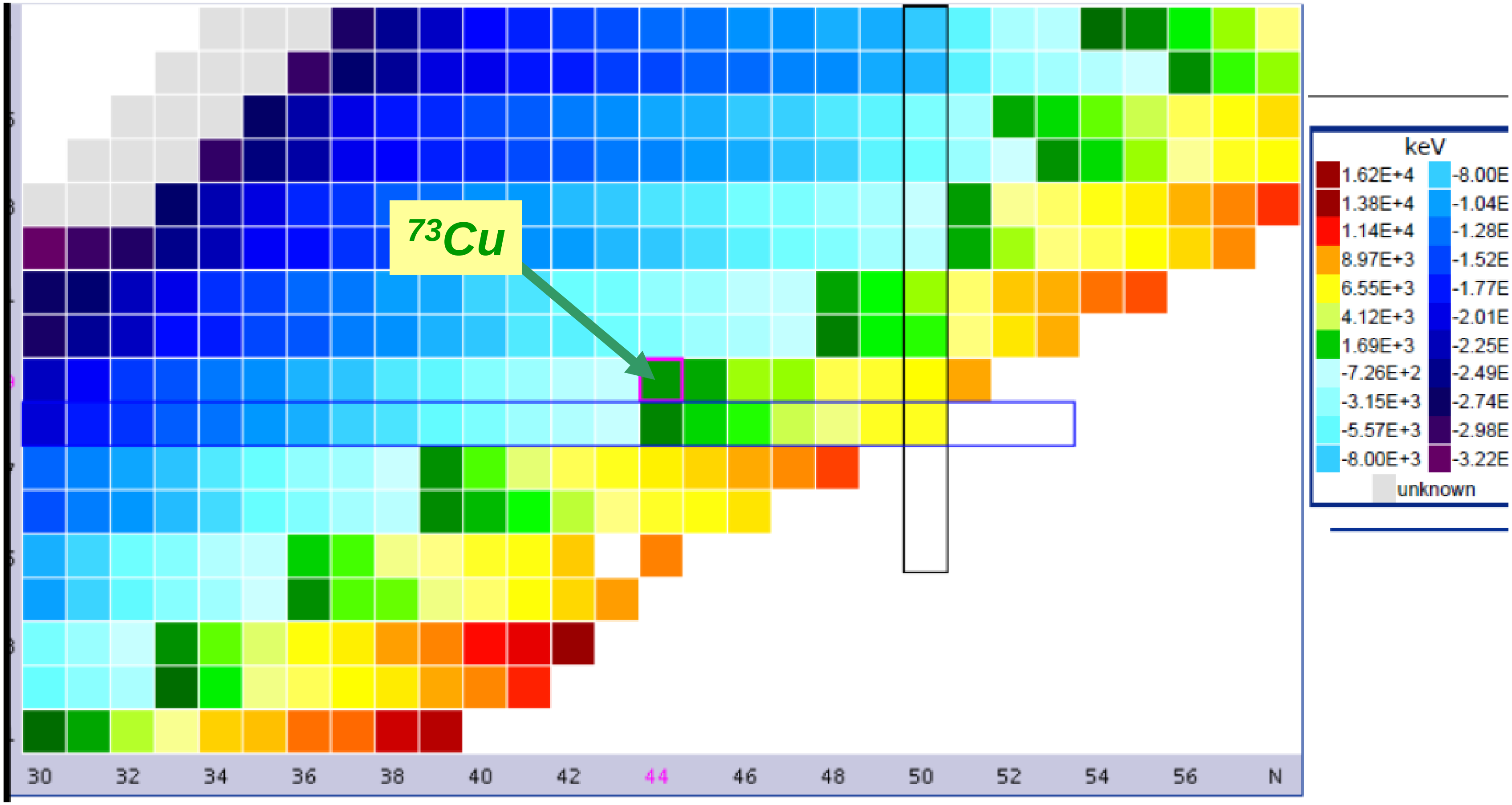


ORNL
LSU , Mississippi
UTK, UNIRIB



from NNDC :

energy window (Q_β - S_n) for β-delayed neutron emission precursors



blue color – *βn emission not possible*

green color – *3Hen* ***$I_{\beta n}$*** *measurements of low energy βn's*

Collaborators :

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

UT Knoxville : **R.K.Grzywacz**, C.R.Bingham, S. Liddick, I. Darby, L. Cartegni, M. Rajabali, S. Padgett, M. Madurga, D. Miller, S.Paulaskas

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

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

Lousiana (LSU) : **Ed Zganjar**, A. Piechaczek *UNIRIB :* J.C. Batchelder

Nashville (Vanderbilt) : J.H. Hamilton, S. Liu et al.,

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

Milano : **Ch. Mazzocchi**

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

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Beta-decay (β-delayed neutrons) studies at the HRIBF

*1. High energy-resolution studies with **pure beams of known intensities***

ranging-out technique plus gamma-beta-conversion electron detectors

***reliable** basic decay scheme + βn-branching ratio*

*2. Measurements with **3Hen** neutron detector array and ranging-out*

- measurements of βn-branching-ratio for low energy neutron emitters

(0.01 MeV to ~ 1 MeV neutrons, βn branching ratio below 1 %, e.g., ^{73}Cu, ^{74}Cu)

- discovery experiments for short-lived (~ 50 ms) nearly 100% βn-emitters

3. measurements with VANDLE time-of-flight neutron detector

neutron energy vs intensity spectrum

4. Total Gamma Absorption Spectroscopy with Modular TAS

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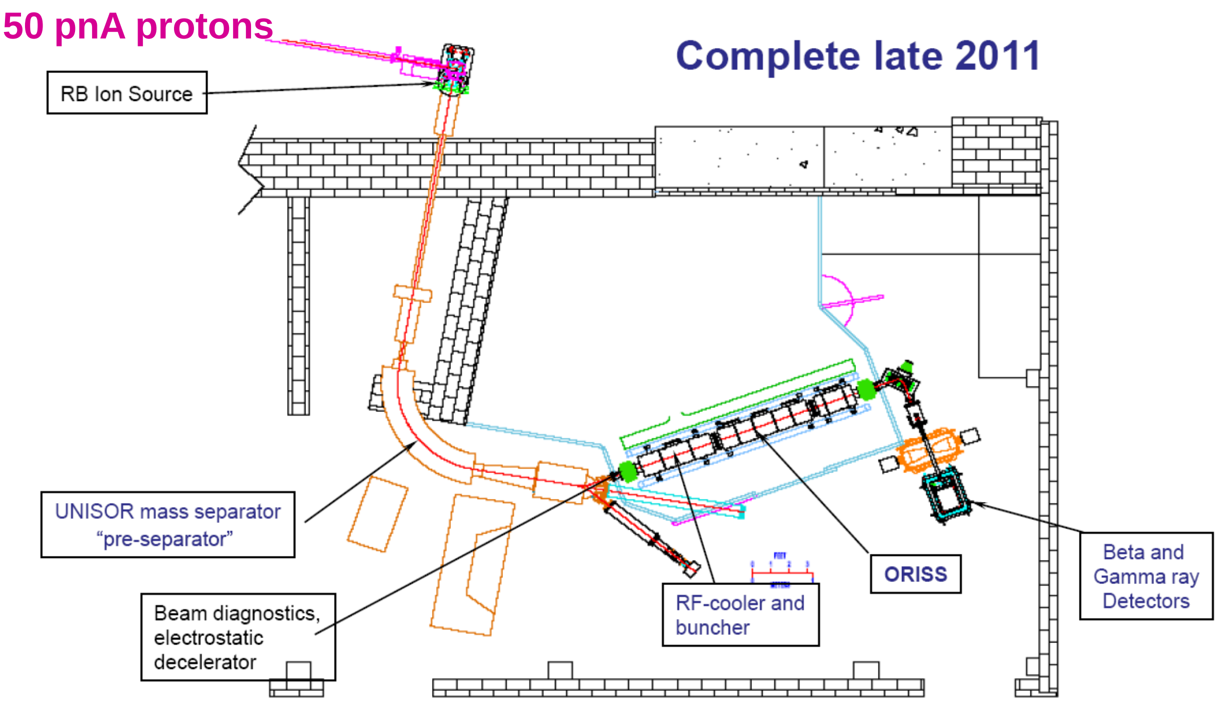
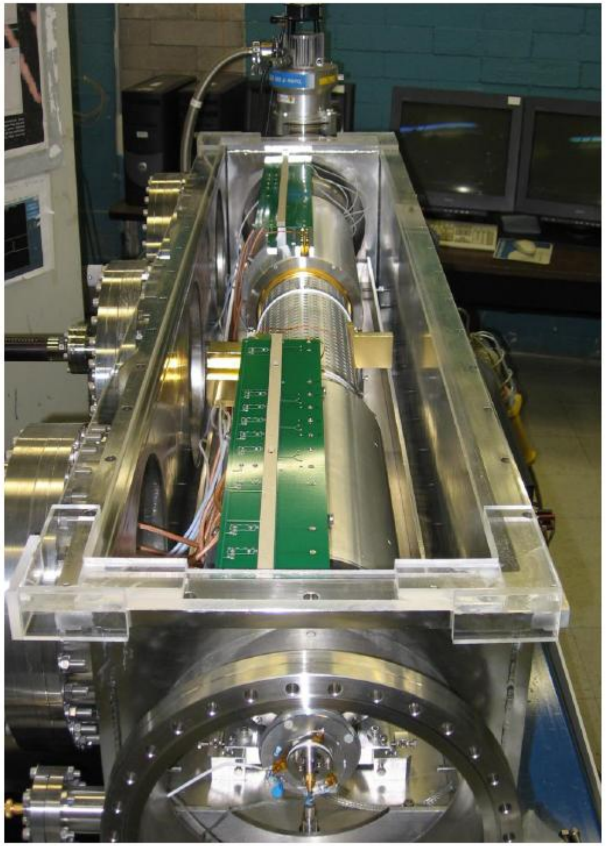
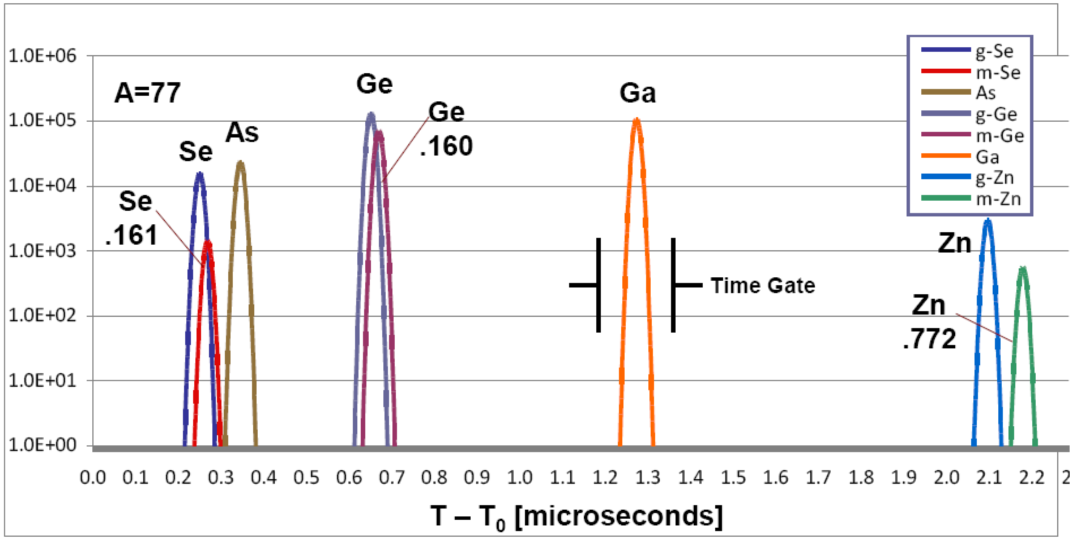
new project : Oak Ridge Isomer Separator and Spectrometer (ORISS)

K.Carter, A.Piechaczek,E.F.Zganjar,J.C.Batchelder and UNIRIB



based on the Multi-pass Time of Flight principle





ΔM/M ~ 1: 400,000 !!

efficiency ~ 50%