PAST, PRESENT and FUTURE studies of proton emission at the HRIBF

K.P. Rykaczewski

multi-user program !

PAST = our results after 5 years

new proton radioactivities (μs !), RDT

fine structure in p-emission: ^{141}Ho, ^{145}Tm

neutron orbitals from ^{146gs,m}Tm decay

digital signal processing

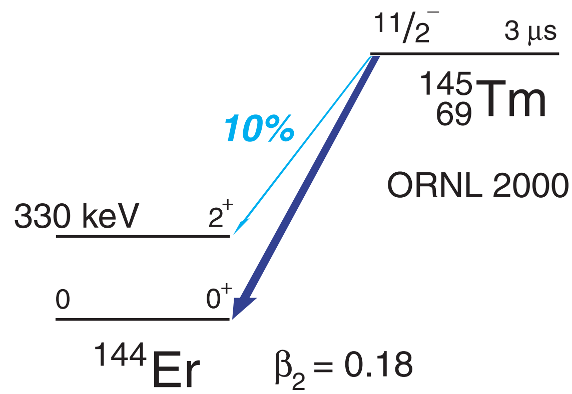
2p-radioactivity ^{45}Fe (GSI)

R. F. Casten, Phys. Rev. C33, 1819 (1986)
R. F. Casten, N. V. Zamfir, J. Phys. G22, 1521 (1996)
R. F. Casten "Nuclear Structure from a Simple Perspective", 2nd Edition, 2000, p. 297-330

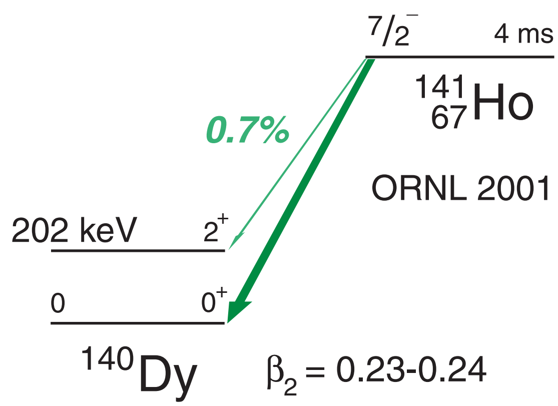
Valence Correlation Scheme

Np Nn

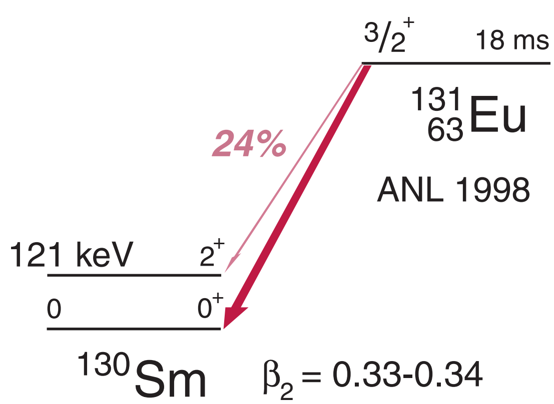
~ 344 keV



160(20) keV



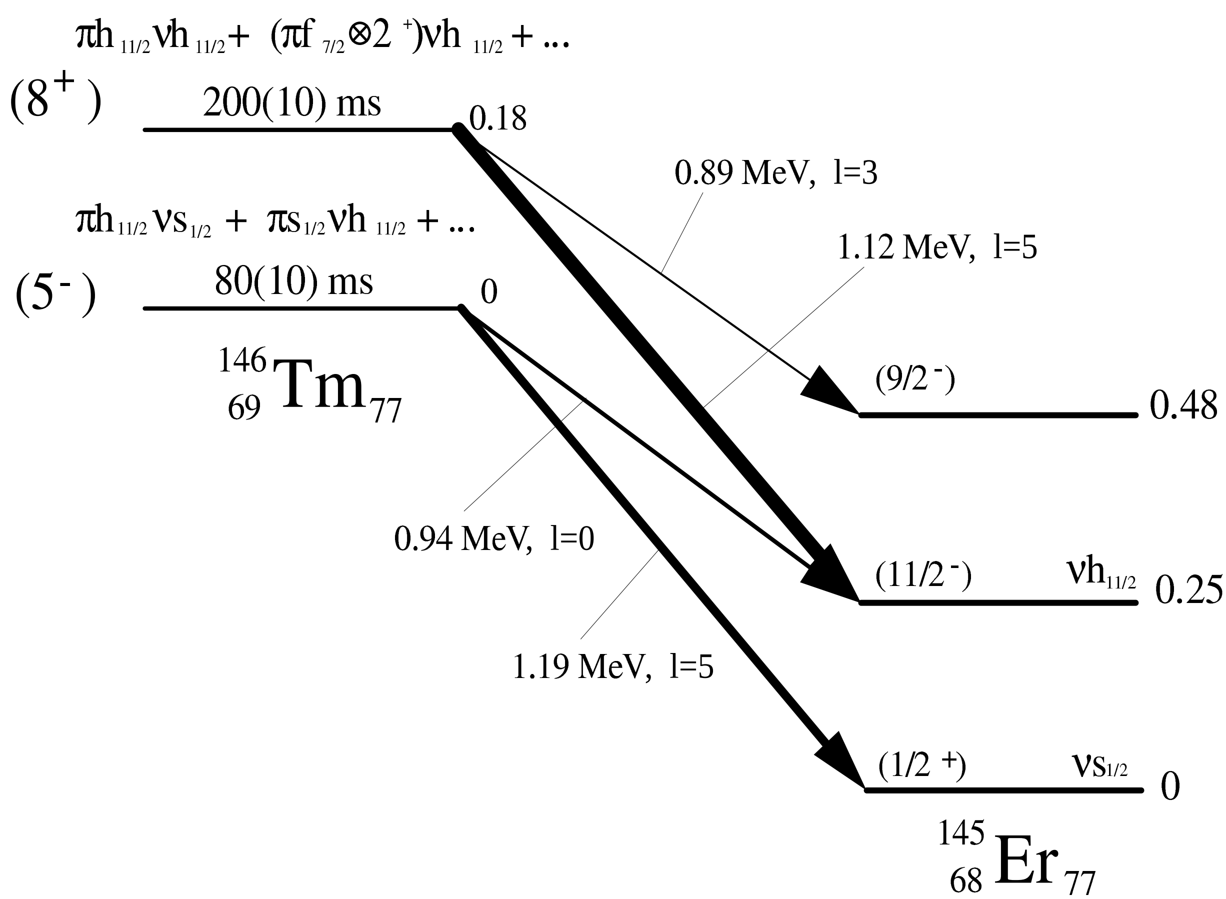
120(20) keV



β_2 from $E(2^+)$:

L. Grodzins, Phys. Lett. 2, 438 (1972)
S. Raman, C. W. Nestor, P. Tikkanen, At. Data Nucl. Data Tables 78, 1 (2001)

T. Ginter et al., Phys. Rev. C68, 2003, 0343XX



Partial decay scheme illustrating the proton emission from ^{146gs,m}Tm.

neutron = influential spectator !

PHYSICS

complex structure of the exotic wave function

spherical emitters

TPA, WKB : ^{145}Tm, ^{151}Lu

transitional emitters

particle-core excitation model : ^{151m}Lu, ^{145}Tm

deformed emitters

adiabatic approach: ^{141m}Ho vs ^{141gs}Ho

non-adiabatic approach: ^{140m}Dy and ^{141gs,m}Ho

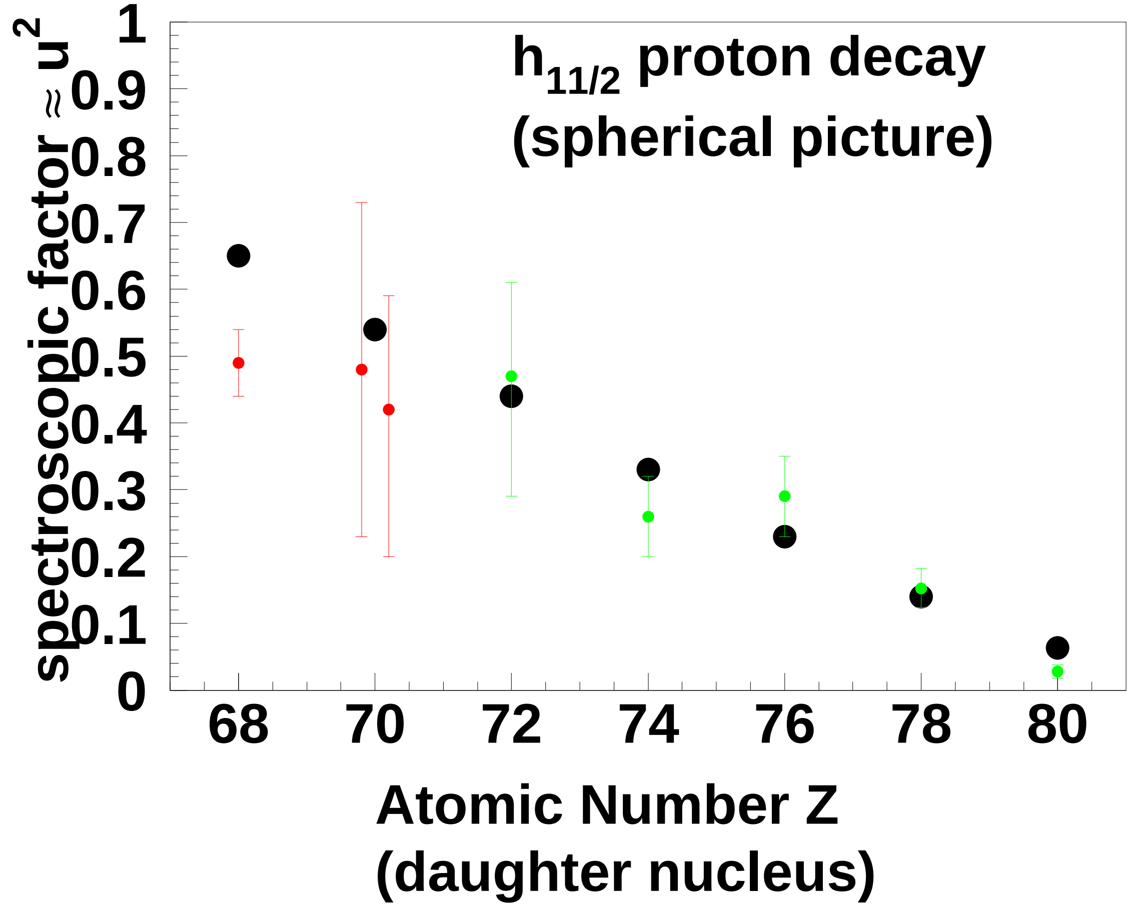
γ-vibration coupling : fine structure ^{141gs}Ho

Spherical Proton Emitters

S.Aberg, P.Semmes and W.Nazarewicz

Phys. Rev. C56(97)1762 and Phys. Rev. C58(98)3011

"good" odd-Z even-N l=5 emitters

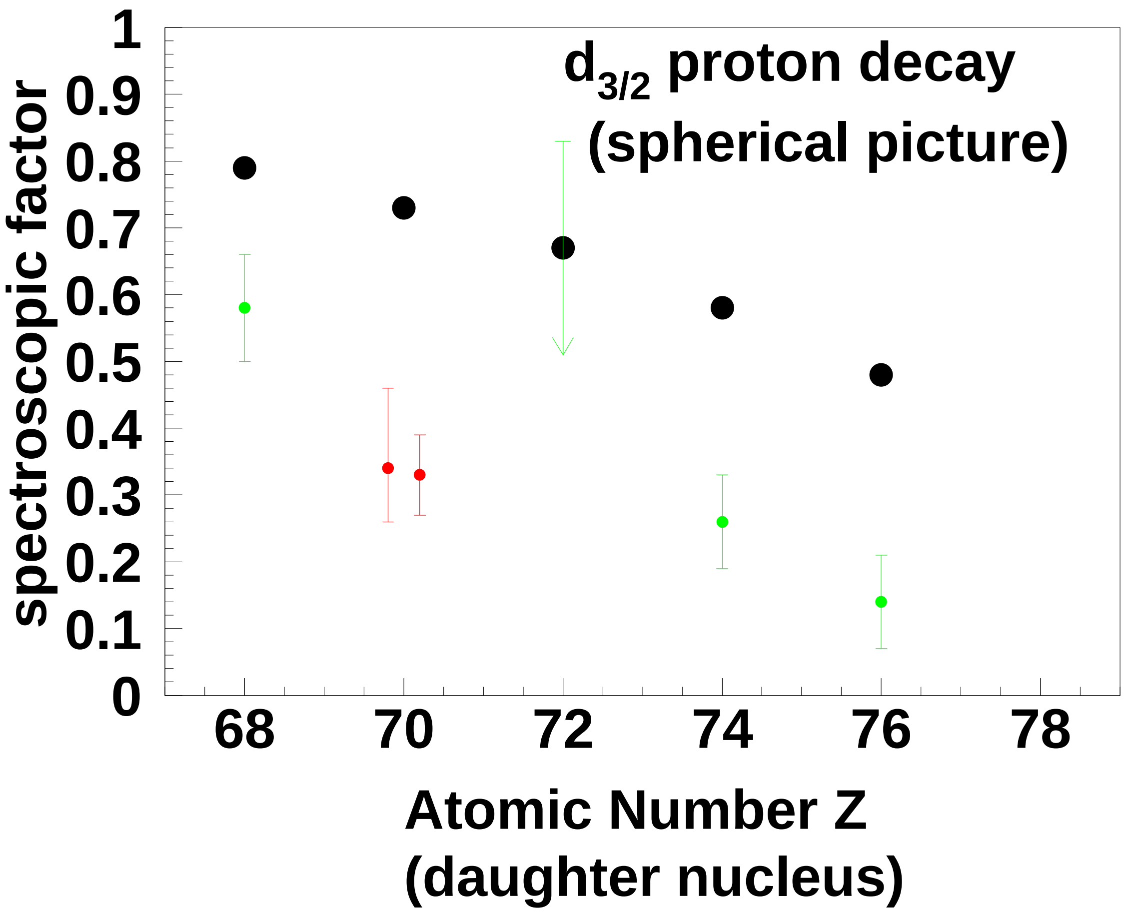


pure $h_{11/2}$ states

spectroscopic factor $\approx$ u^2

^{145}Tm ???

l=2 emitters ($d_{3/2}$)



$$3/2^{+} \approx \alpha \{ d_{3/2} \otimes 0^{+} \} + \beta \{ s_{1/2} \otimes 2^{+} \} + \gamma \{ d_{3/2} \otimes 2^{+} \}$$

configuration mixing:

$\pi d_{3/2} \otimes 0^{+}$, $\pi d_{3/2} \otimes 2^{+}$ and $\pi s_{1/2} \otimes 2^{+}$

spectroscopic factor $\approx \alpha^{2} \times u^{2}$

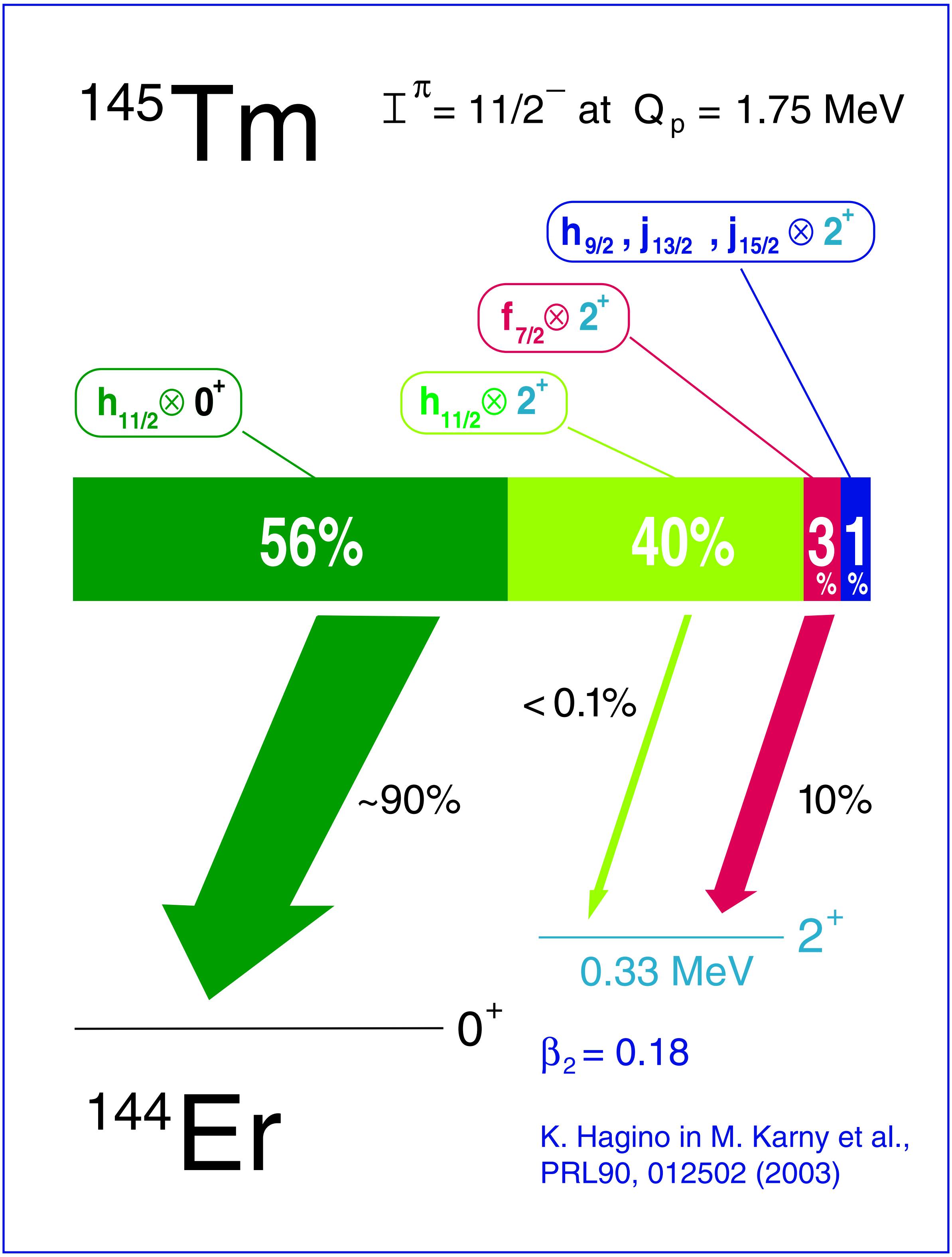
C.H.Yu et al., Phys.Rev. **C58**,*1998, R3042*

C.Bingham et al., Phys. Rev. **C59**,*1999, R2984*

KR et al, Acta Phys. Pol. **B30**,*1999, 565*

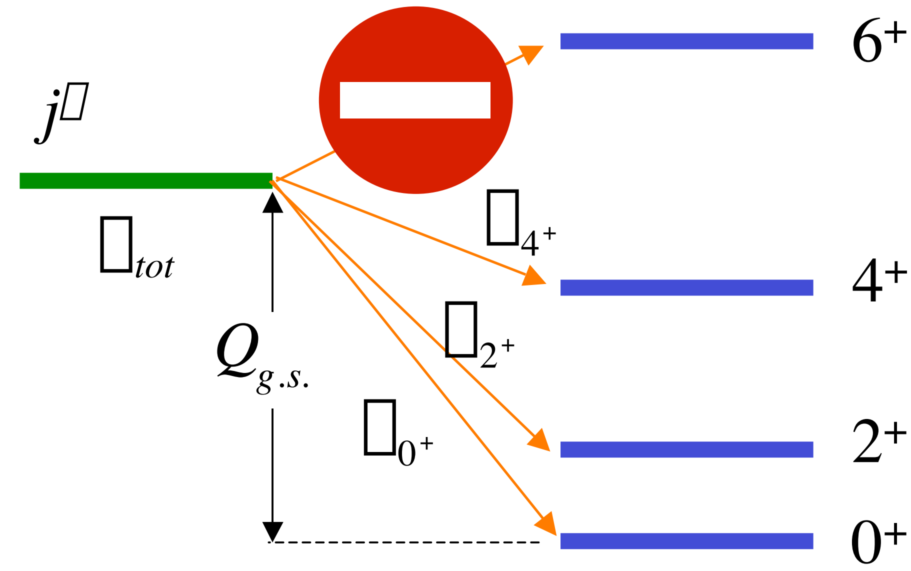
T.N. Ginter et al.,Phys. Rev. **C61**, *2000, 014308*

P.Semmes, Nucl.Phys. A682,2001,239c



145Tm
Iπ = 11/2− at Qp = 1.75 MeV
h9/2 , j13/2 , j15/2 ⊗ 2+
f7/2 ⊗ 2+
h11/2 ⊗ 0+
h11/2 ⊗ 2+
56%
40%
3 %
1 %
< 0.1%
~90%
10%
2+
0.33 MeV
0+
β2 = 0.18
144Er
K. Hagino in M. Karny et al.,
PRL90, 012502 (2003)

Relation between non-adiabatic and adiabatic formalism



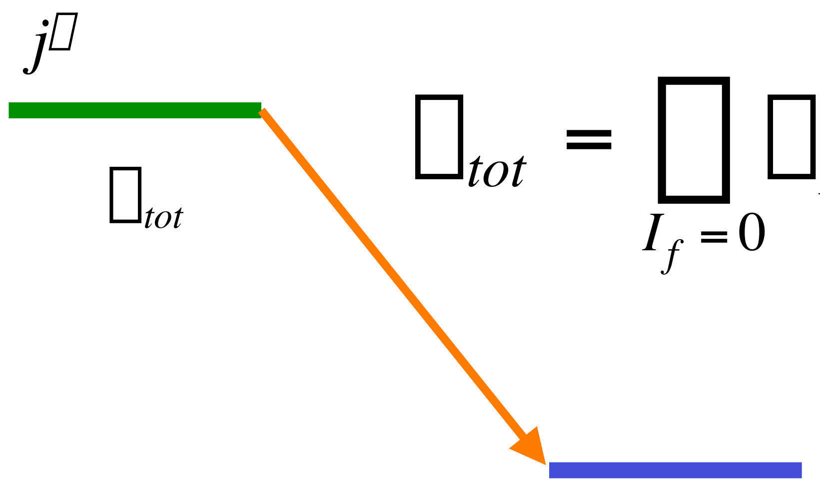
non-adiabatic

- only few channels open
- lab-system description
- Coriolis coupling

$$□_{tot} = □_{0^+} + □_{2^+} + □_{4^+}$$

$$E_f^{□} □ □ I_f(I_f + 1)$$

$$Q_f = Q_{g.s.} □ E_f^{□}$$



$$□_{tot} = \sum_{I_f = 0} □_{I_f^+}$$

adiabatic

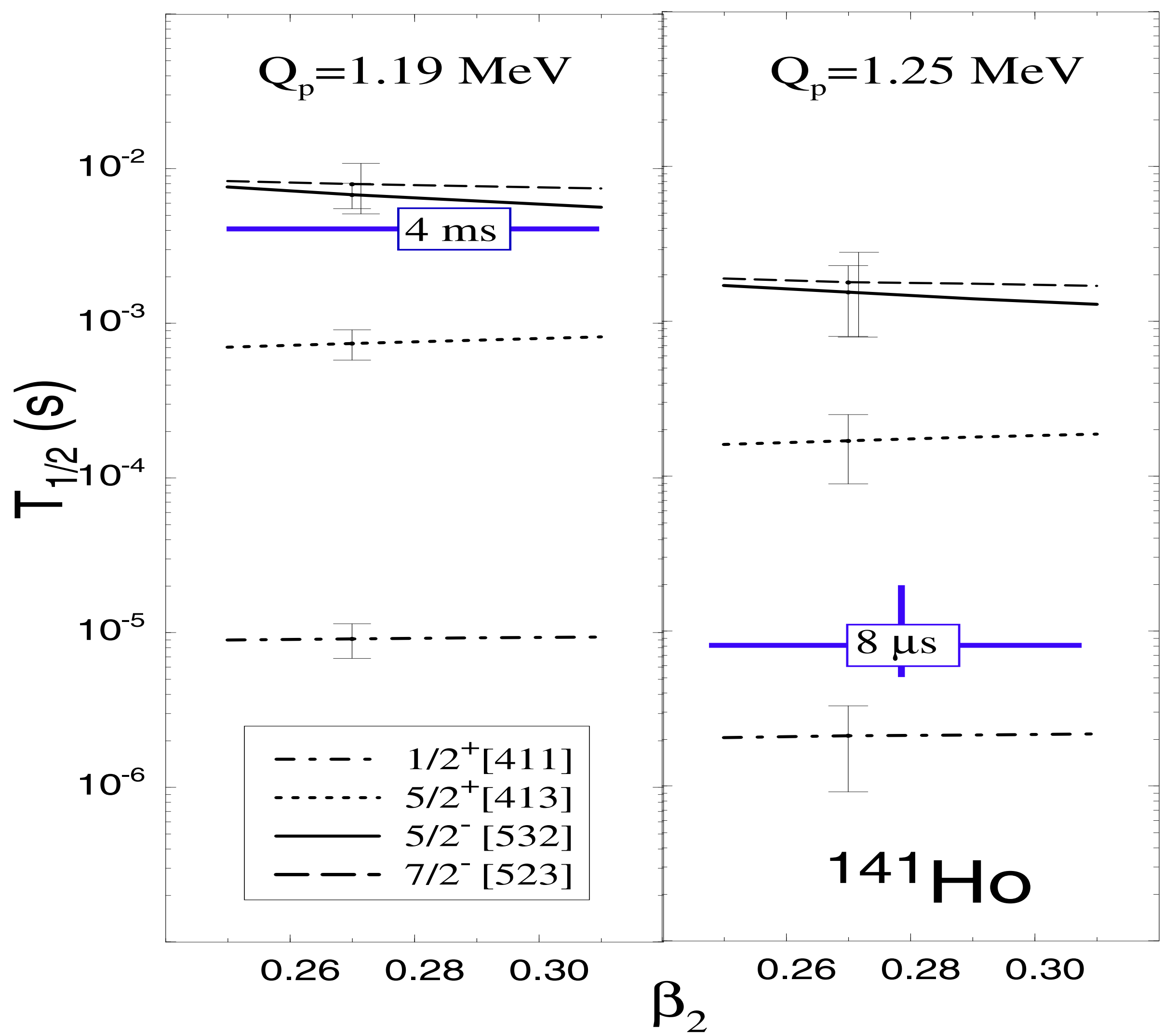
- all channels open
- intrinsic-system description
- no Coriolis coupling

$0^+, 2^+, 4^+, 6^+ \ldots \quad □ = 0$

KR et al., Phys. Rev. **C60**, *1999, 011301R*

“ADIABATIC APPROACH”

Barmore, Ixaru, Kruppa, Nazarewicz, Rizea, Vertse



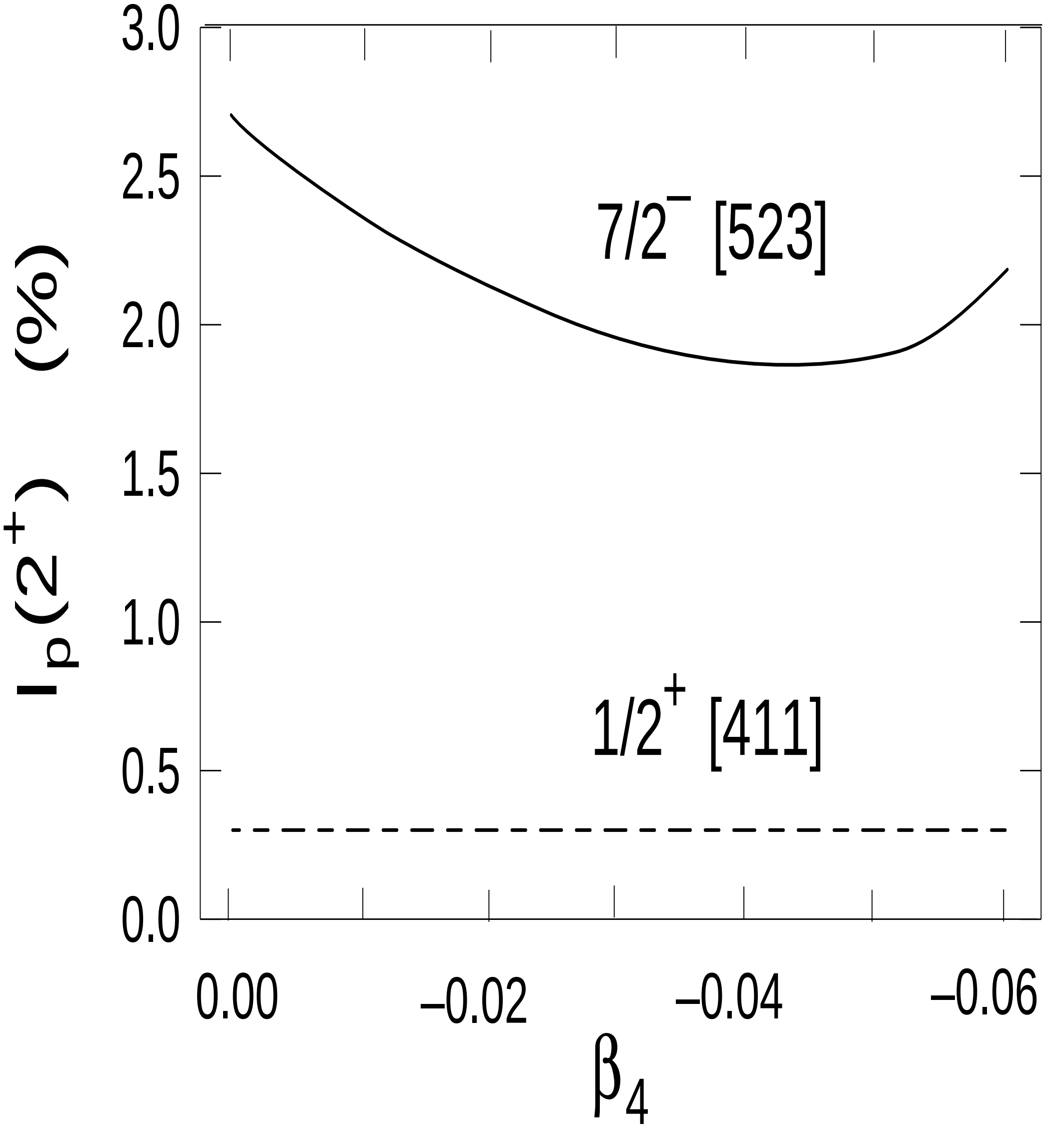
Calculated half-lives for the $1/2^+[411]$, $7/2^-[523]$, $5/2^-[532]$, and $5/2^+[413]$ resonances in ^{141}Ho as functions of quadrupole deformation β_2 (β_4=–0.06) assuming Q_p=1.19 MeV (^{141gs}Ho) and 1.25 MeV (^{141m}Ho).

W. Królas et al., Phys. Rev. C65, 2002, 031303R

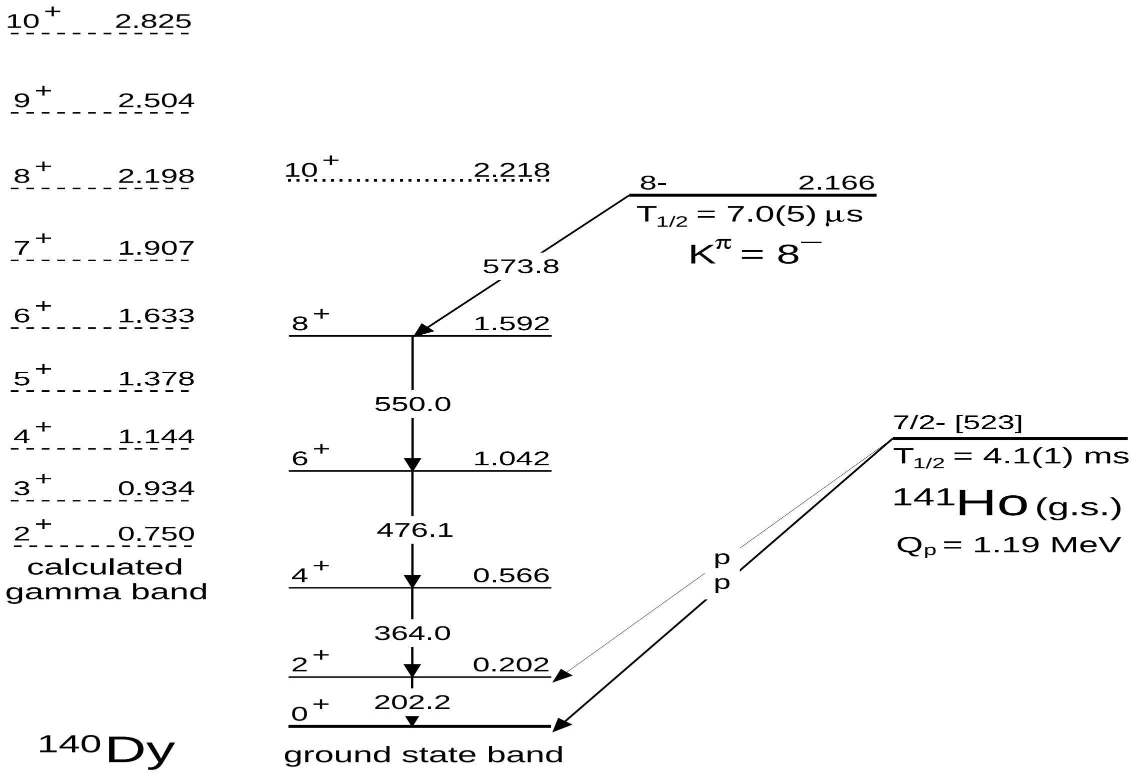
“NON-ADIABATIC APPROACH”

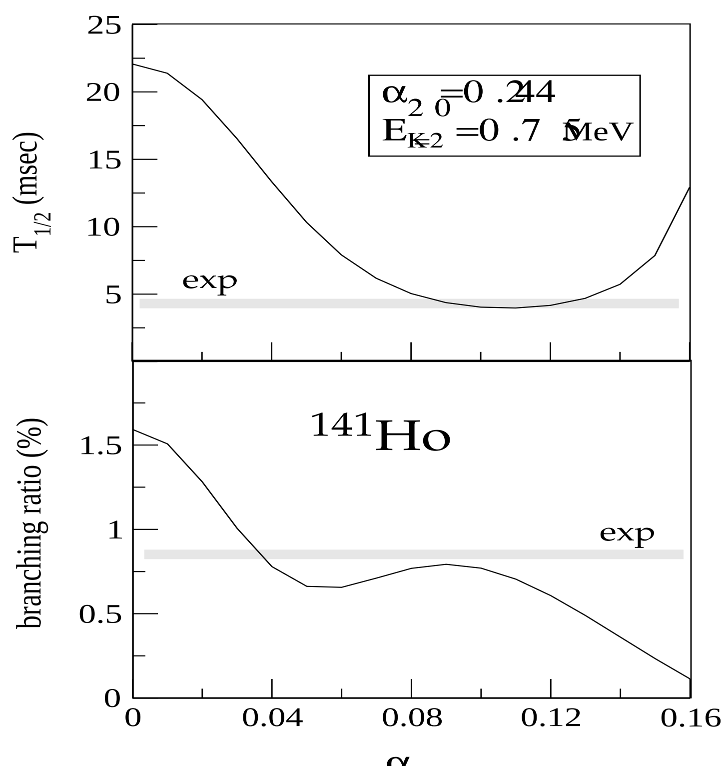
Barmore, Kruppa, Nazarewicz, Vertse

PRL **84***, 2000, 4549 and Phys.Rev.* **C62***, 2000, 054315*



Proton branching ratio $I_p(2^+)$ to the 2^+ level in ^{140}Dy in the proton decay of ^{141}Ho calculated as a function of β_4 deformation with a fixed value of $\beta_2 = 0.244$ for two deformed resonances: the $7/2^-[523]$ (^{141gs}Ho; solid line) and $1/2^+[411]$ (^{141m}Ho; dashed line).





coupling between γ-band and gs-band included !
A.Kruppa and W.Nazarewicz, PROCON 2003, Padova, Italy (2003)

PRESENT studies

experimental upgrades

DETECTORS :

large MCP - Si-box - DSSD - SiLi set-up

ELECTRONICS :

DSP modules 40 MHz/12 bit DGF :

- clock repeater (reliability !)

- JTEC-Xport readout (few Mb/s)

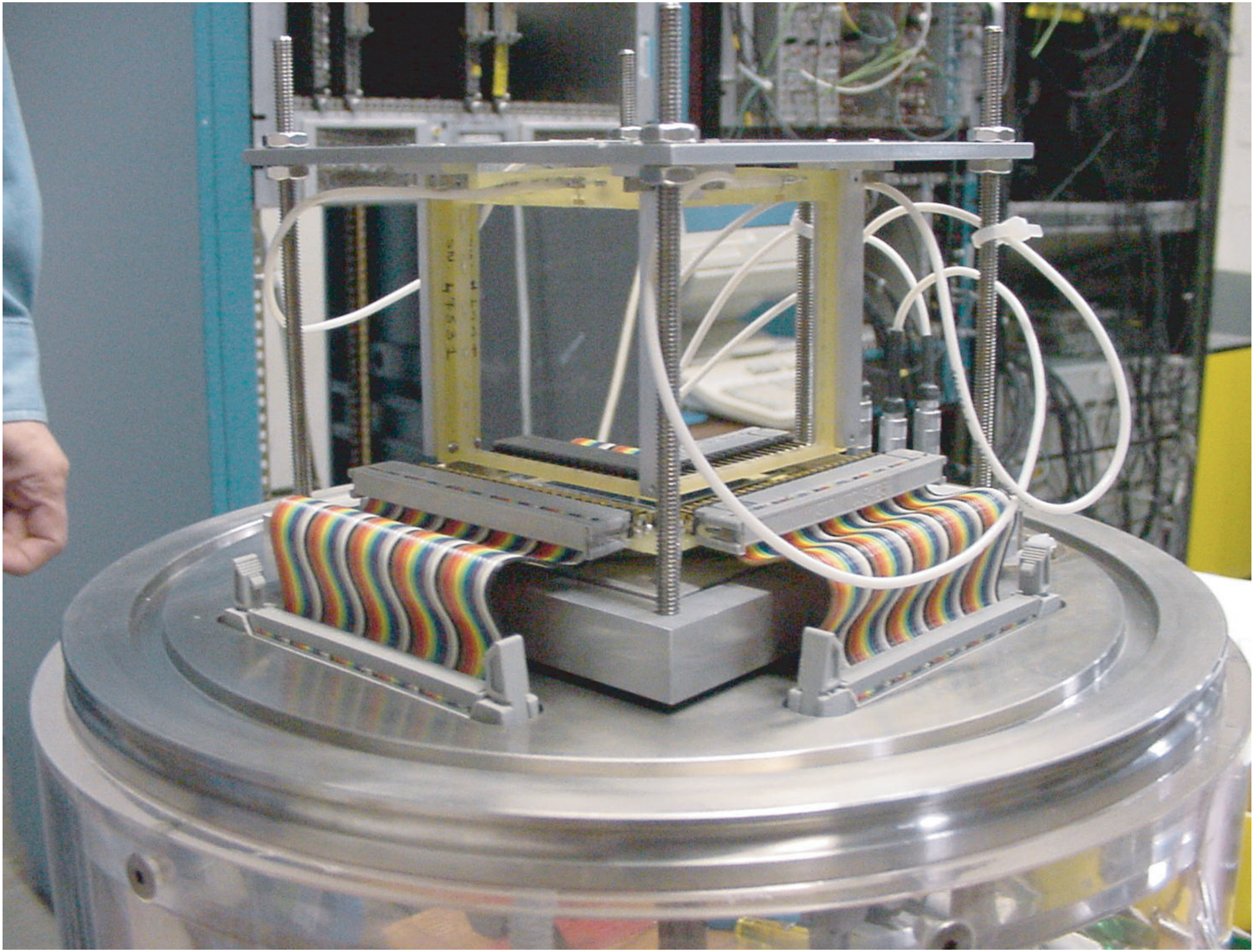
- 100 μs traces (6μs ^{141m}Ho !)

- 100 channels

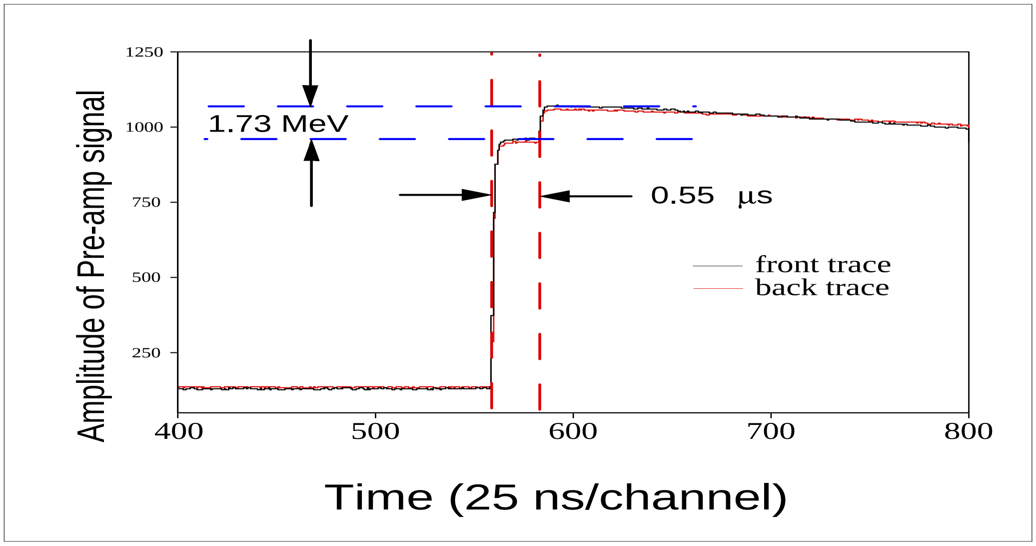
100 MHz/12 bit Pixie-16 coming !

spectroscopy at ENGE spectrometer

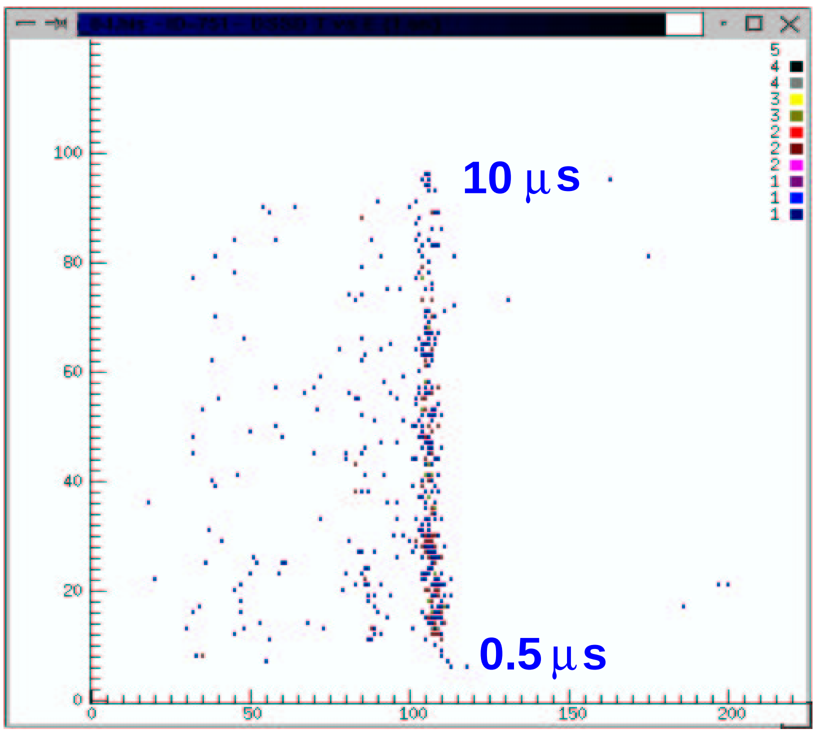
stable ^{58}Ni vs radioactive ^{56}Ni beam



Digital Signal Processing



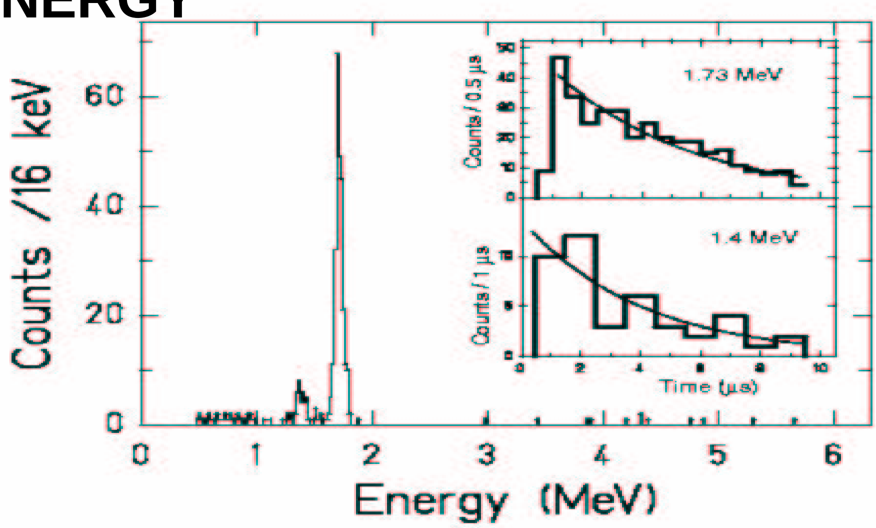
TIME



ENERGY

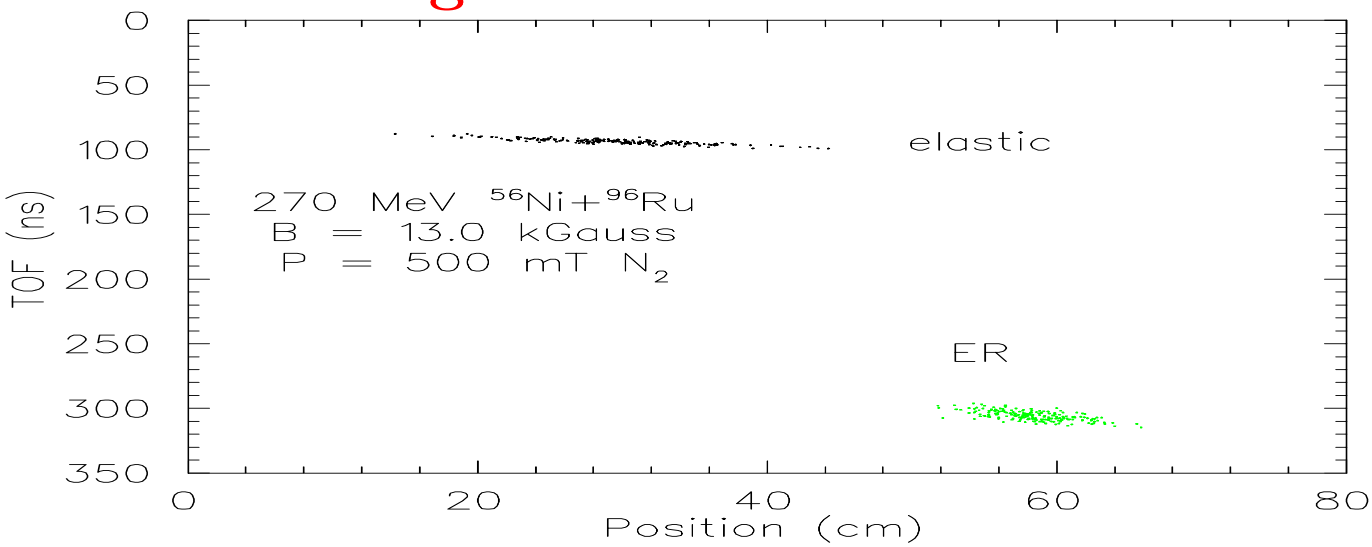
fine structure in proton emission from 3 μs 145Tm

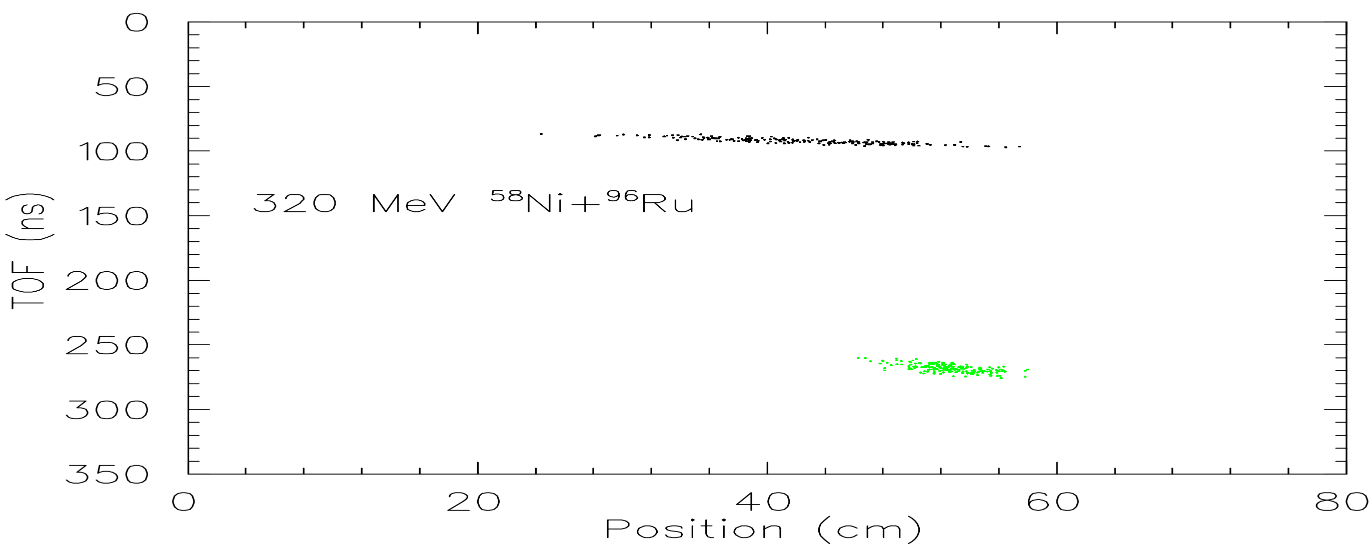
M. Karny et al.
PRL 90 (2003) 012502



proton radioactivity studies
with RIB's at Enge spectrometer (HRIBF)

high recoil transmission
short time-of-flight
higher cross section





no mass selectivity
^{56}Ni : low intensity
^{56}Co contamination

FUTURE :
SEVEN accepted experiments !

ν-orbitals studied via p-radioactivity

N=77 isotones ^{146}Tm and ^{140m}Eu, ^{142m}Tb, ^{144m}Ho
μs activity of ^{144}Tm

particle-core excitation description

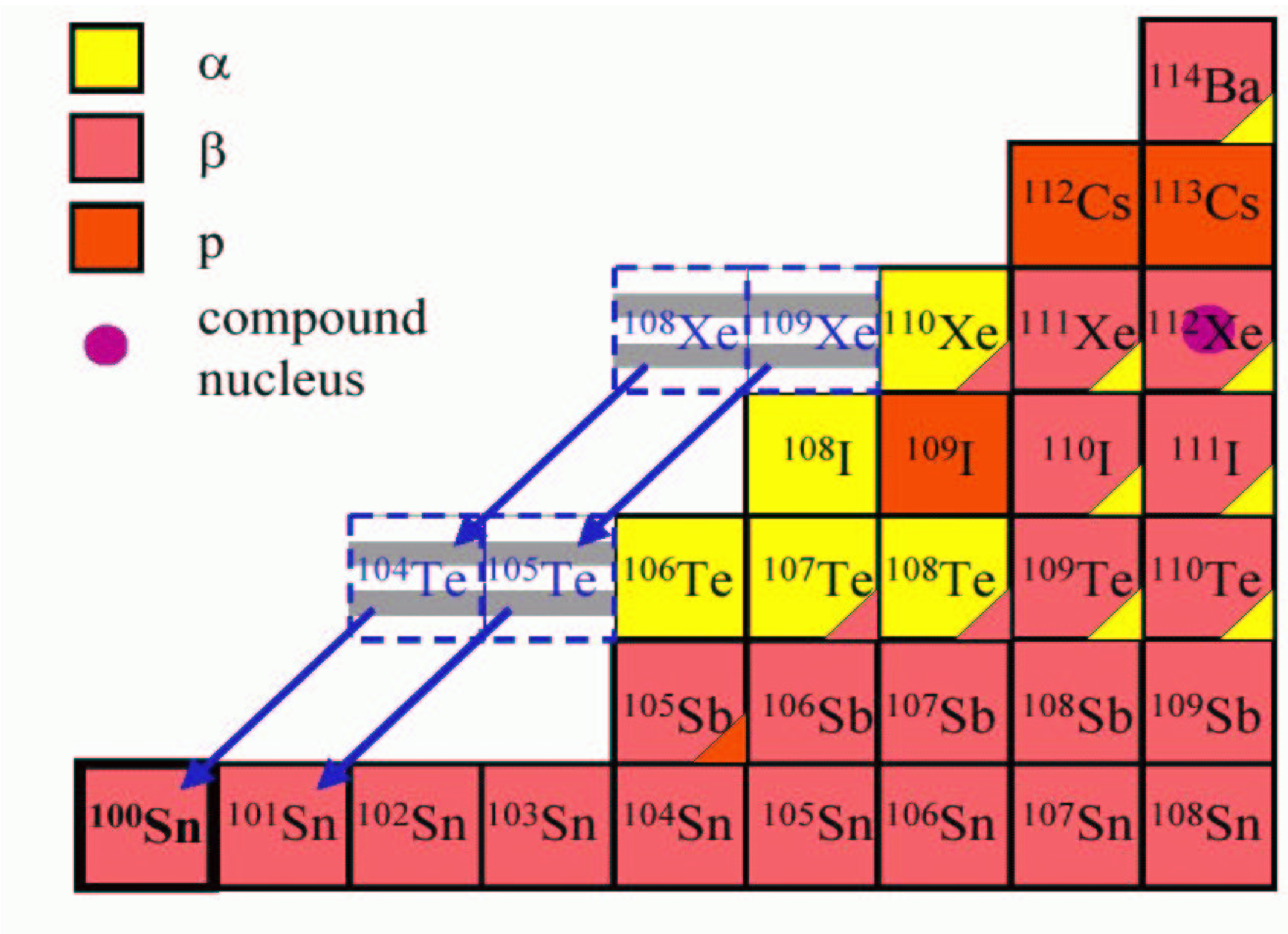
ENGE spectrometer : ^{149}Lu
RDT study of ^{145}Tm

new regions of p-radioactivity

^{105}Te, ^{104}Te and ^{103}Sb
rp-process termination, superallowed α-decay

^{113}Ba $\rightarrow$ ^{113}Cs $\rightarrow$ ^{112}Te
towards ^{112}Ba - the heaviest N=Z nucleus ??
millisec β-emitter $\rightarrow$ μs proton-emitter

HRIBF proposal: Robert Page and Robert Grzywacz



μs and sub-μs particle emitters

superallowed α-decay ^{104}Te$\rightarrow^{100}$Sn

fine structure in α-decay ^{105}Te$\rightarrow^{101}$Sn

relative energy $\nu g_{7/2}$ - $\nu d_{5/2}$

p-emission from ^{103}Sb to ^{102}Sn

$\pi d_{5/2}$ above the closed Z=50 shell

FUTURE directions (proposals)

new regions of p-radioactivity

T_Z= -3/2 βp-emitters
from ^{45}Cr to ^{61}Ge, ^{65}Se and ^{69}Kr

fine structure in p-emission from β-populated IAS

an example :

$^{69}Kr,\beta\text{-}ms \rightarrow {}^{69}Br\ IAS,\ proton \rightarrow {}^{68}Se, 0^+\ and\ 2^+$

$^{69}Kr,\beta\text{-}ms \rightarrow {}^{69gs}Br,\ proton\text{-}nanosec \rightarrow {}^{68}Se, 0^+$

γ-vibrations coupling model (^{141}Ho)

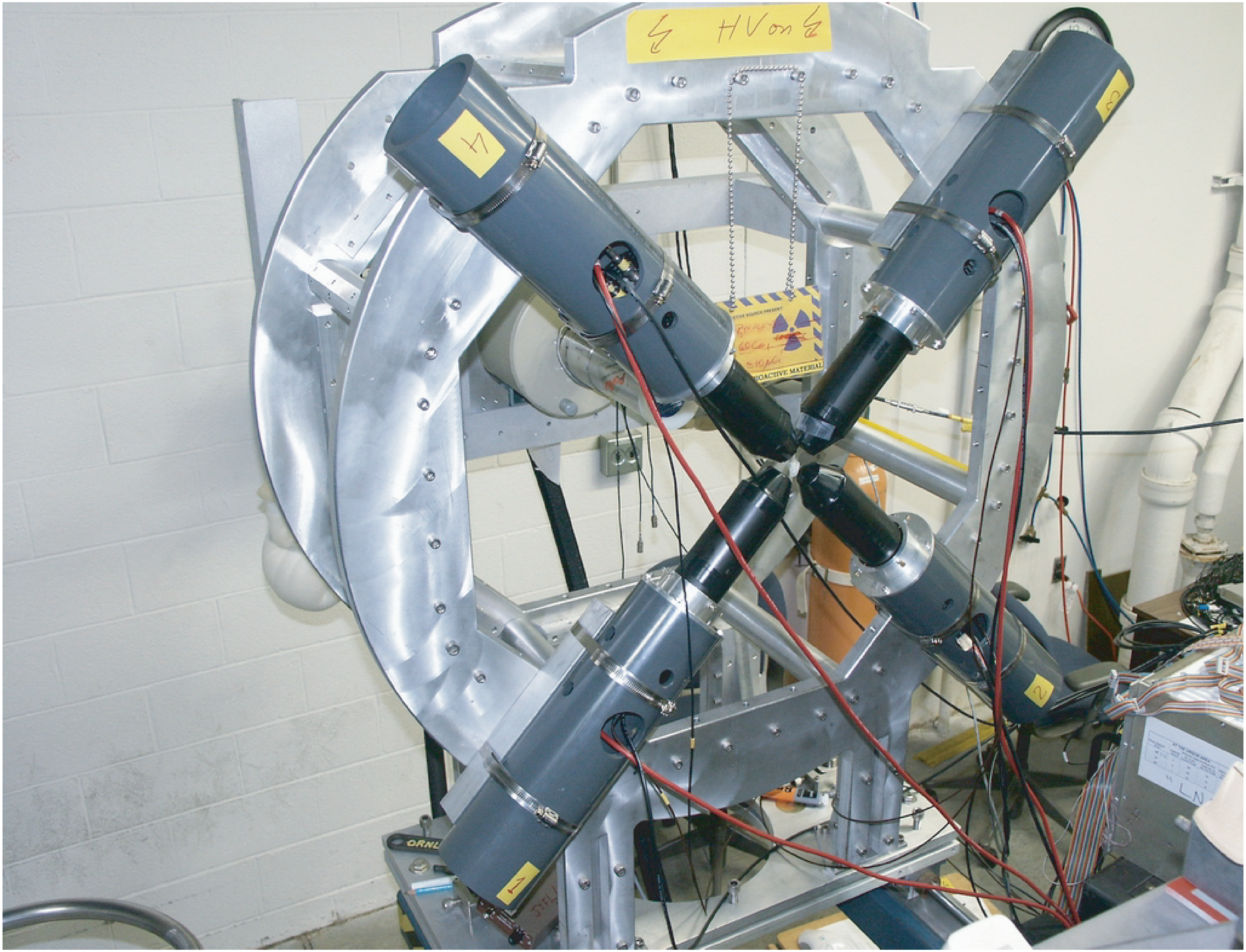
lifetime of 2^+ *level in* ^{140}Dy ($\approx$ *360 ps ?*)

fine structure in p-emission from 6 μs ^{141m}Ho

particle - core vibration model

sub-μs *p-emitter* ^{159}Re

^{58}Ni *beam - RMS or ENGE,* ^{56}Ni *beam at ENGE*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ORNL

SUMMARY

Studies of proton emission at the HRIBF

several important results achieved

new emitters
fine structure
neutron orbitals
2p-radioactivity

technical progress

new detectors
digital electronics
towards ^{56}Ni at ENGE

long list of future studies

odd-odd emitters
new regions of p-emitters