Mapping shape transitions in neutron-rich A~190 nuclei from isomeric fragments of ^{198}Pt

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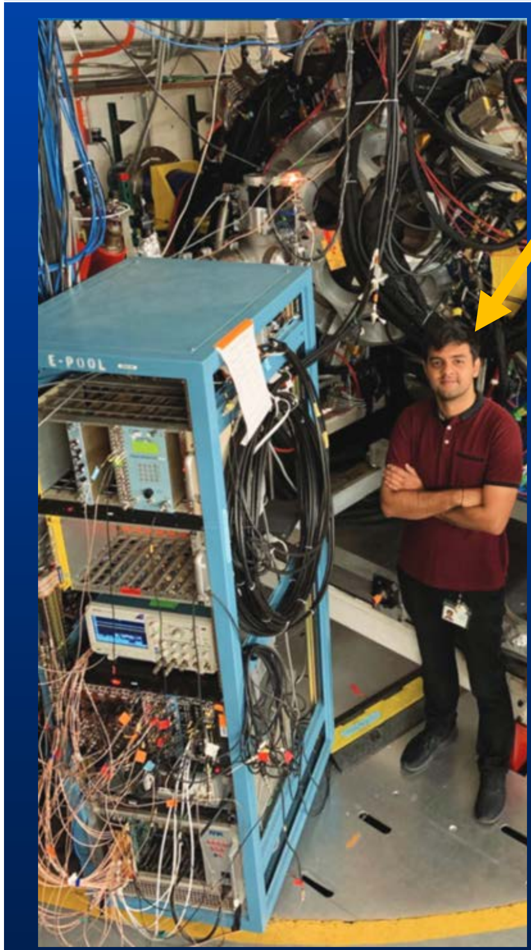
University of Massachusetts Lowell

Work supported by U.S. Department of Energy
and the National Science Foundation

Collaboration



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[7]*RIKEN Nishi* *0198, Japan*
[8]*Department of Ch* *igan 48824, USA*
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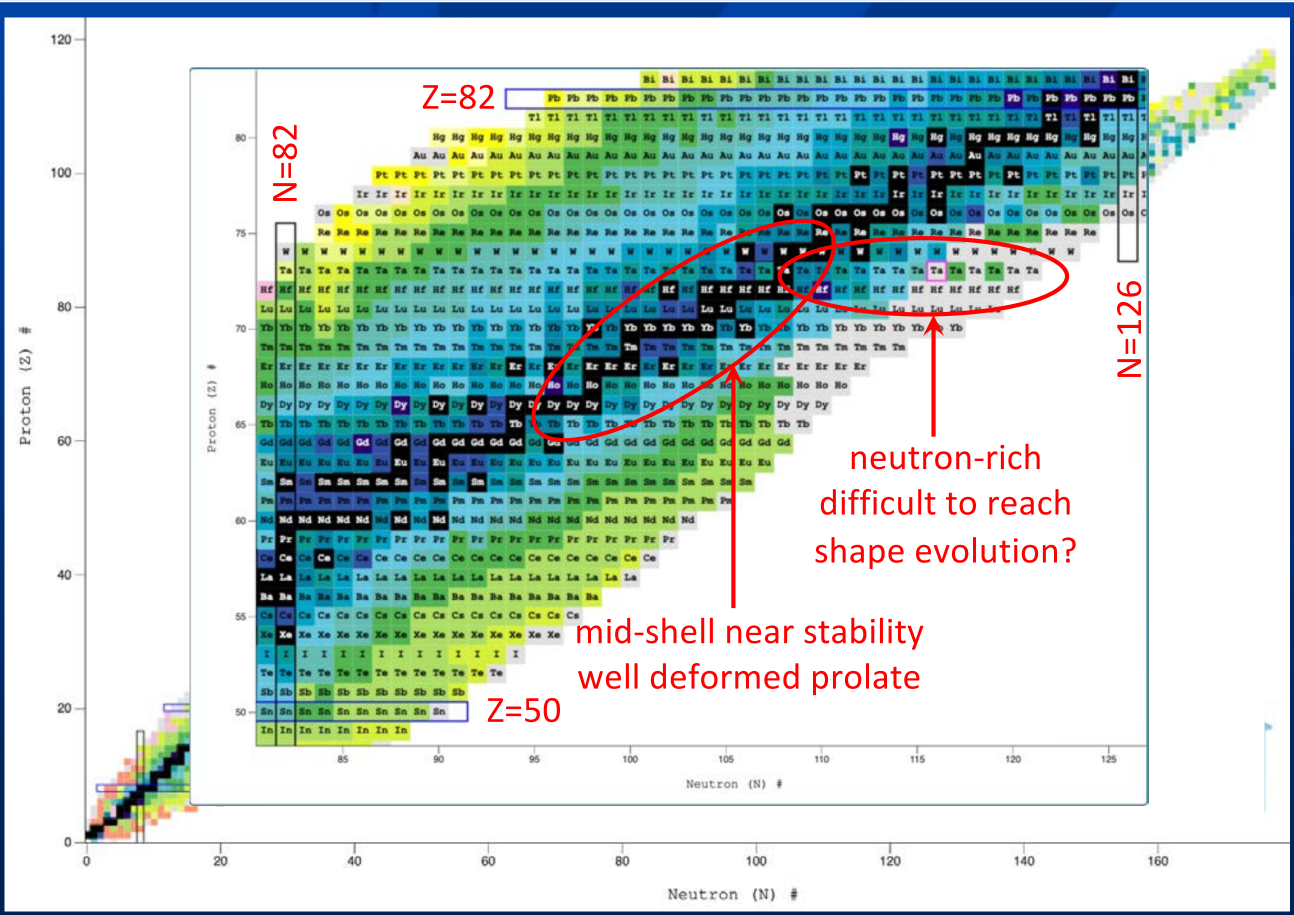
[10]*National Nuclear D* *w York 11973, USA*

- Motivation
  - Nuclear Structure
  - Isotope Discovery
  - Reaction Dynamics
- Experiment
- Results
  - Overviews (Hf-Ta-W)
  - ^{189}Ta
- Summary and Outlook

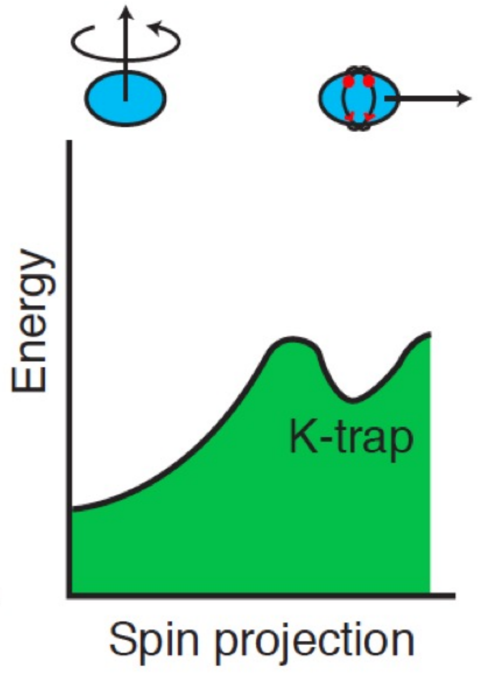
Motivation: Shapes and Symmetries



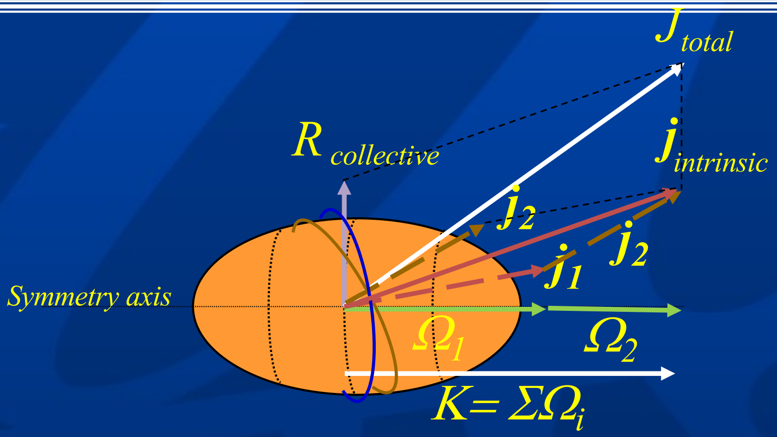
neutron-rich
difficult to reach
shape evolution?

mid-shell near stability
well deformed prolate

Axial Symmetry: K quantum number and K-Isomers

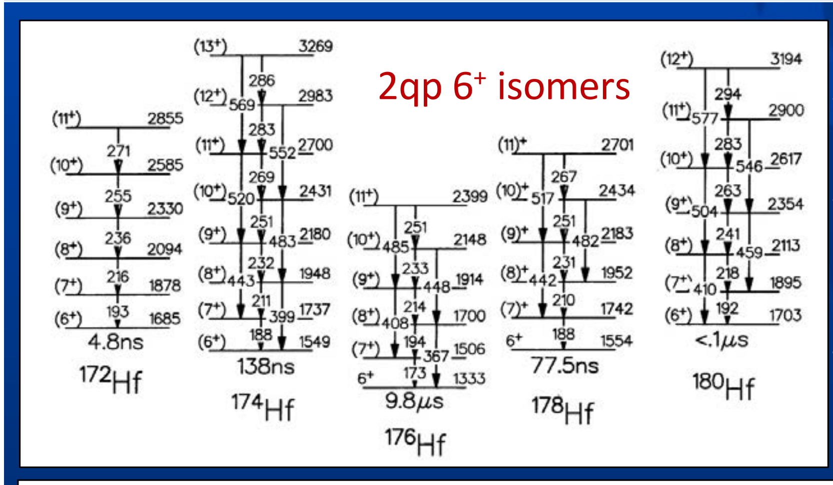

Energy
K-trap
Spin projection

Walker & Dracoulis, Nature 399, 35 (1999)

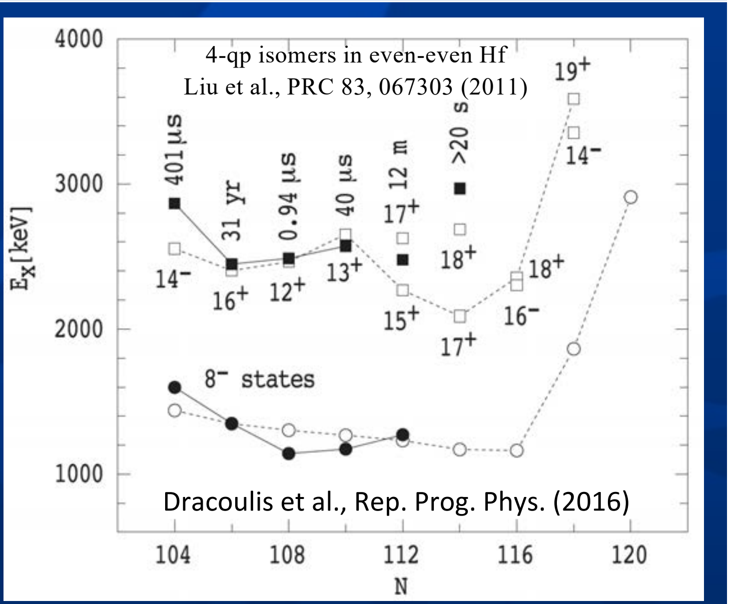

J_{total}
$R_{collective}$
$j_{intrinsic}$
j_2
j_1
j_2
Symmetry axis
Ω_1
Ω_2
$K = \Sigma\Omega_i$

- deformation and axial symmetry
- high-Ω orbitals near Fermi surface
- interplay of intrinsic and collective excitations
- *K*-selection rule $\Delta K \leq \lambda$ (transition multipolarity)
- transitions hindered if selection rule violated (*K*-isomers)
- spectroscopic tool
- sensitive probe of nuclear structure

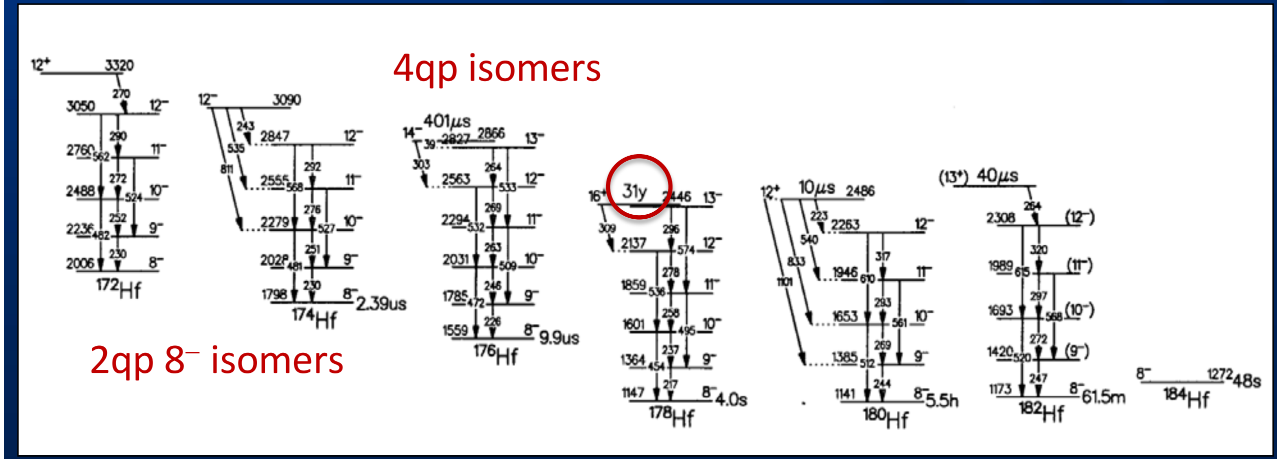
High-K Isomers: Hf isotopes


2qp 6+ isomers
(6+) 1685 4.8ns 172Hf
(6+) 1549 138ns 174Hf
6+ 1333 9.8µs 176Hf
6+ 1554 77.5ns 178Hf
(6+) 1703 <.1µs 180Hf

- Rigid axial quadrupole deformation
- Multiple high-Ω *n* and *p* orbitals near Fermi surface
- Yrast traps predicted in neutron-rich Hf



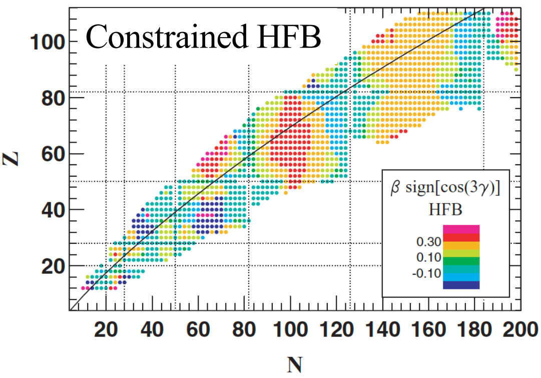
Dracoulis et al., Rep. Prog. Phys. (2016)


4qp isomers
2qp 8− isomers
12+ 3320
172Hf
174Hf 2.39us
401µs
176Hf 9.9us
31y
178Hf 4.0s
10µs
180Hf 5.5h
(13+) 40µs
182Hf 61.5m
8− 1272 48s
184Hf

Questions and challenges:

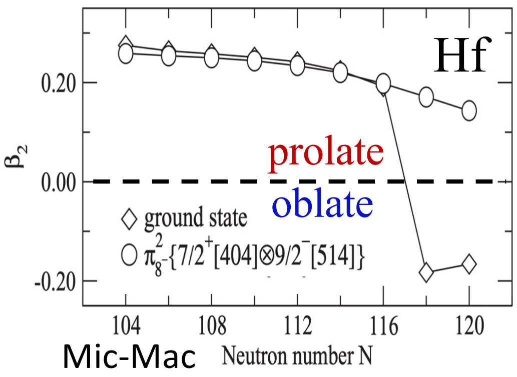
- Nature of shape evolution
- Impact on approximate symmetries
- Accessing the neutron-rich region at moderate angular momenta

Model Predictions: Shape Evolution



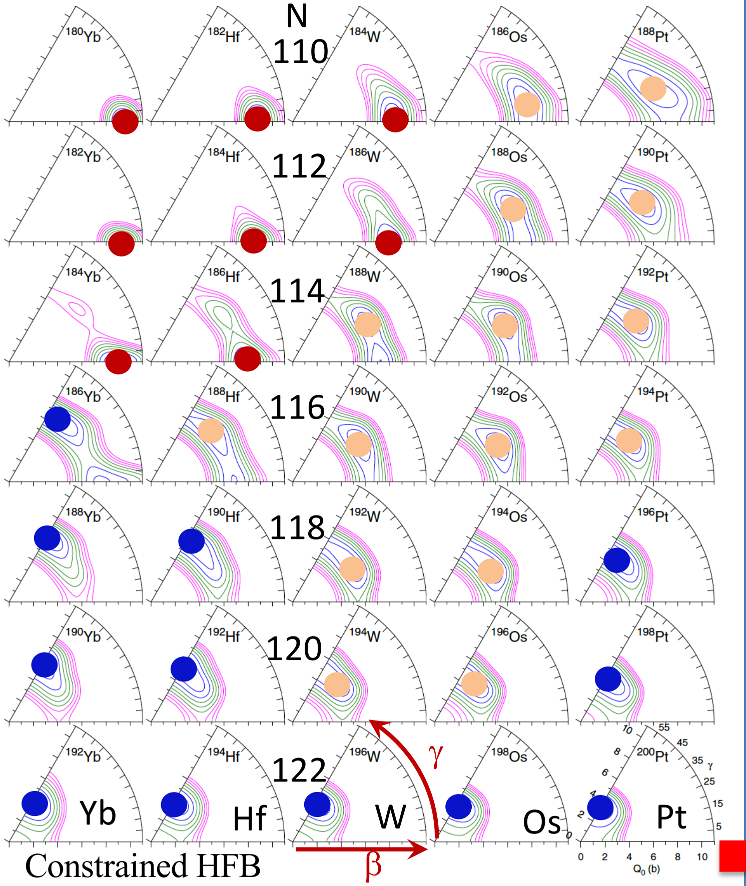
Delaroche et al., *PRC 81, 014303 (2010)*

Configuration constrained WS + pairing

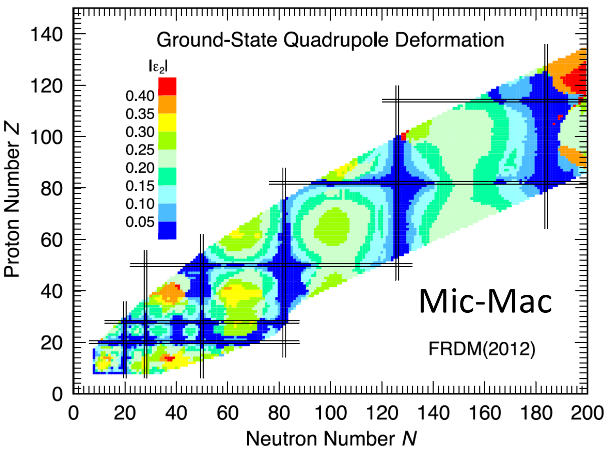


Liu, Xu et al., *PRC 83, 067303 (2011)*

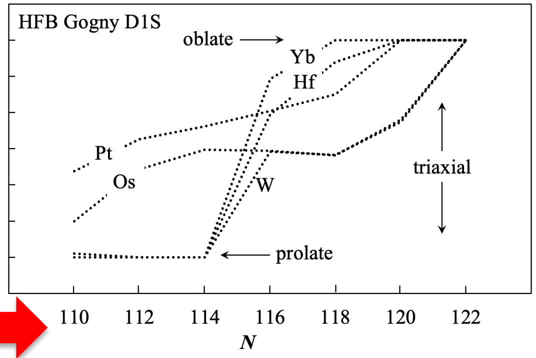
Robledo et al., J. Phys. G 36, 115104 (2009)



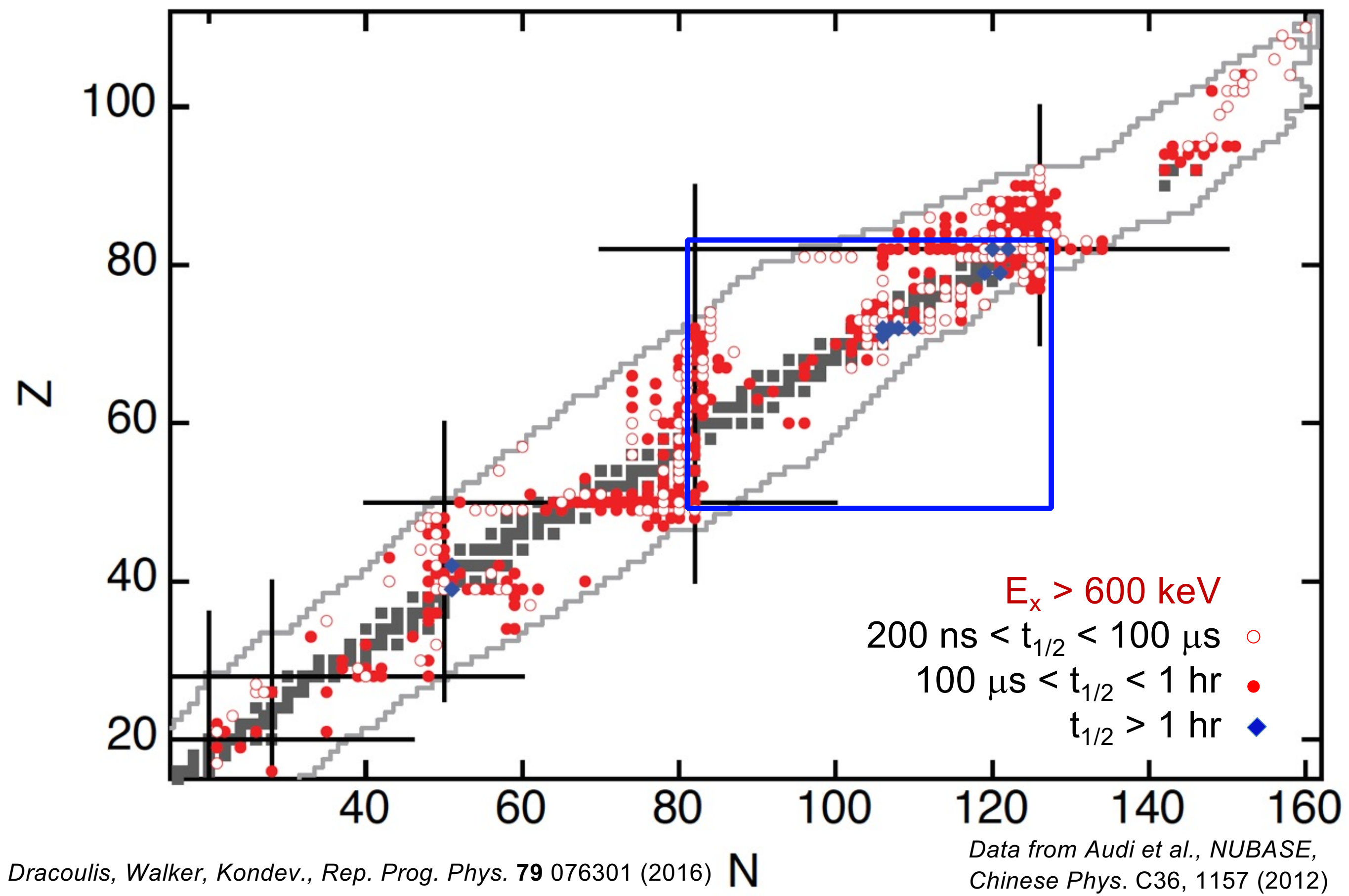
Constrained HFB



Moller et al., *At. Data. Nucl. Data Tables, 109-110, 1 (2016)*



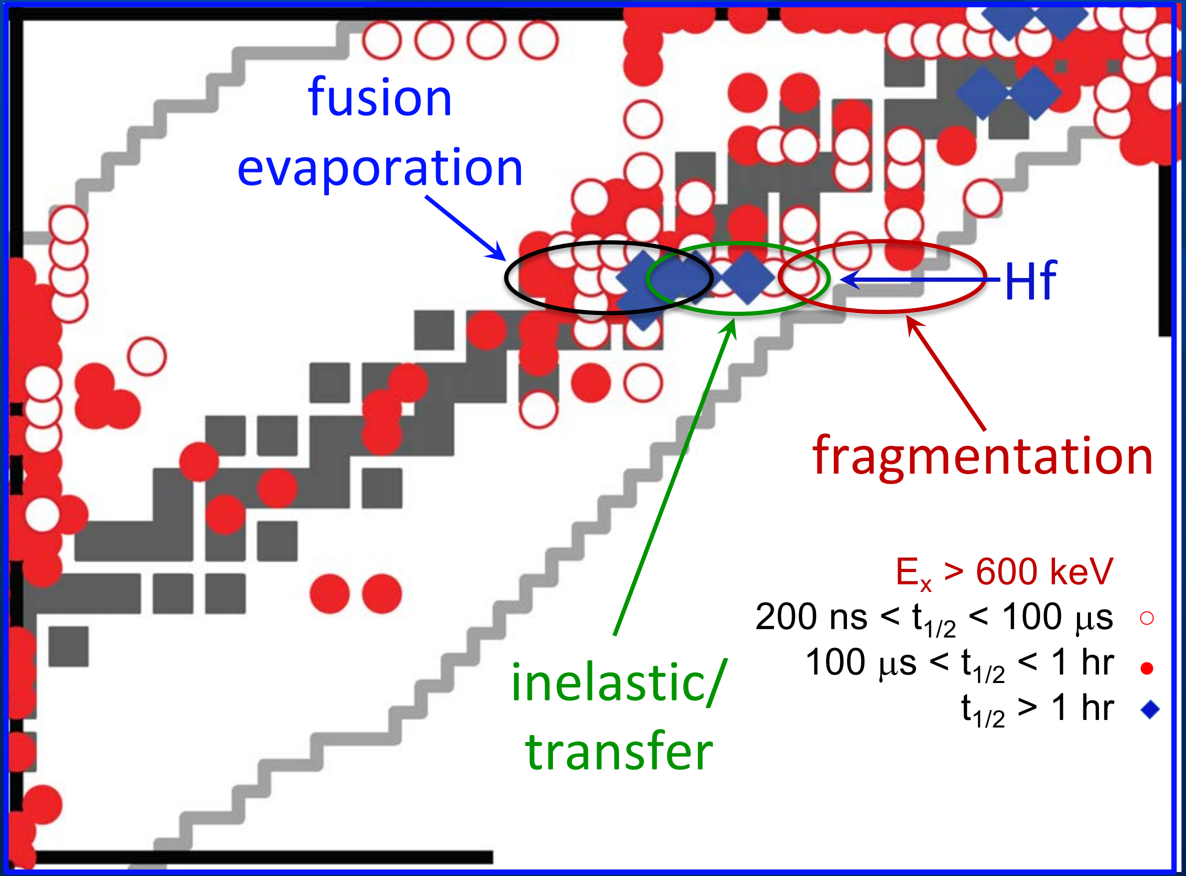
Isomers for Structure Studies



Dracoulis, Walker, Kondev., Rep. Prog. Phys. **79** 076301 (2016)

Data from Audi et al., NUBASE, Chinese Phys. C36, 1157 (2012)

Population Mechanisms

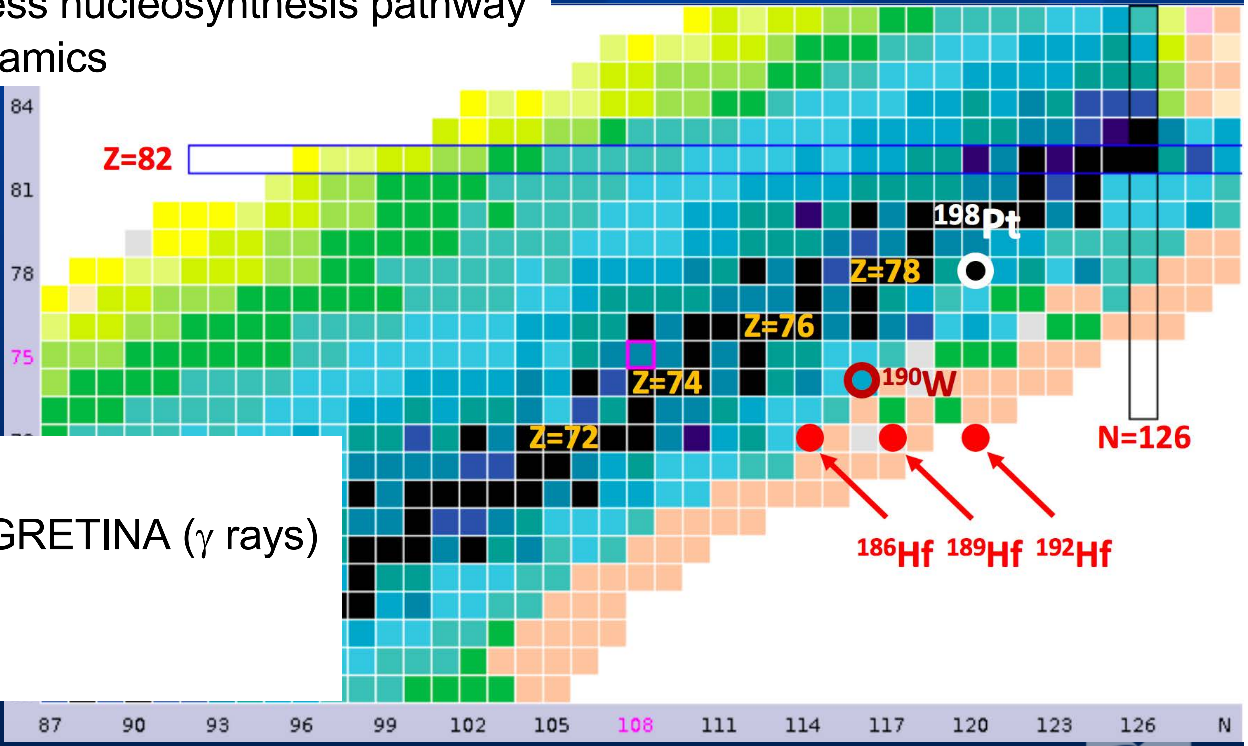


^{198}Pt Fragmentation at NSCL: Overview

- Nuclear structure: K-isomers in neutron-rich Hf-W region
- Astrophysics: A=190 region r-process nucleosynthesis pathway
- Isotope discovery and reaction dynamics

First experiment with newly developed ^{198}Pt beam at NSCL

Isomers in 180<A<190 region

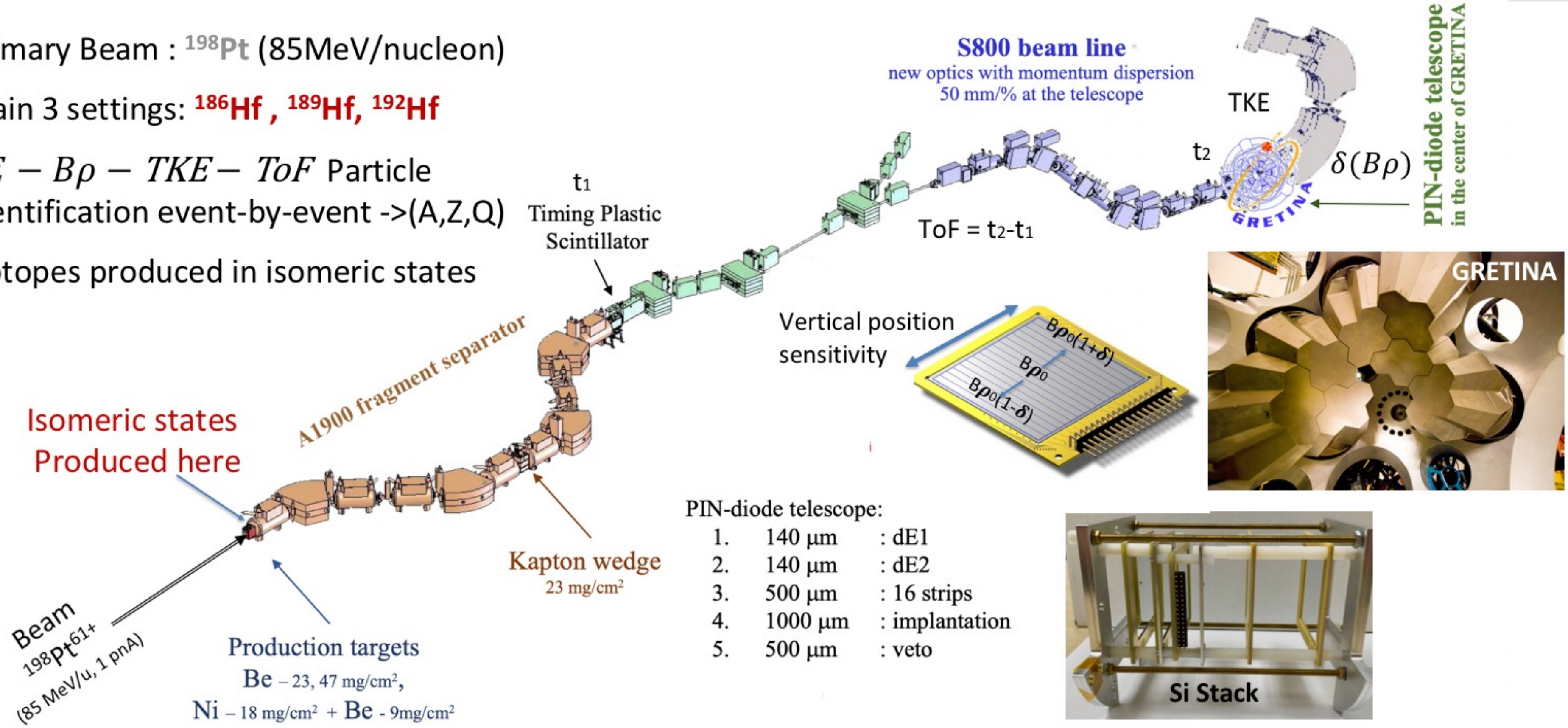


Stopped beam experiment:

- Si stack (implants) surrounded by GRETINA (γ rays)
- Implant-γ coincidences
- Half-lives and level schemes

A1900@NSCL: e15130 Experimental Setup

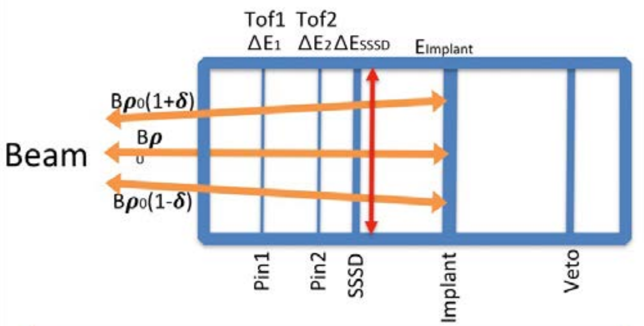
- Primary Beam : ^{198}Pt (85MeV/nucleon)
- Main 3 settings: **^{186}Hf , ^{189}Hf, ^{192}Hf**
- $\Delta E - B\rho - TKE - ToF$ Particle Identification event-by-event ->(A,Z,Q)
- Isotopes produced in isomeric states


S800 beam line
new optics with momentum dispersion
50 mm/% at the telescope
TKE
t_2
$\delta(B\rho)$
PIN-diode telescope
in the center of GRETINA
GRETINA
t_1
Timing Plastic
Scintillator
ToF = t_2-t_1
A1900 fragment separator
Vertical position
sensitivity
$B\rho_0(1+\delta)$
$B\rho_0$
$B\rho_0(1-\delta)$
GRETINA
Isomeric states
Produced here
Kapton wedge
23 mg/cm^2
Beam
^{198}Pt^{61+}
(85 MeV/u, 1 pnA)
Production targets
Be – 23, 47 mg/cm^2,
Ni – 18 mg/cm^2 + Be - 9mg/cm^2
Si Stack

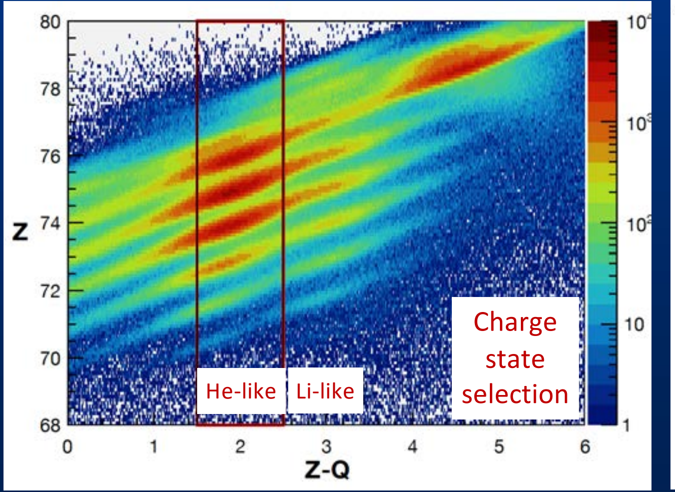
PIN-diode telescope:

1. 140 µm : dE1
2. 140 µm : dE2
3. 500 µm : 16 strips
4. 1000 µm : implantation
5. 500 µm : veto

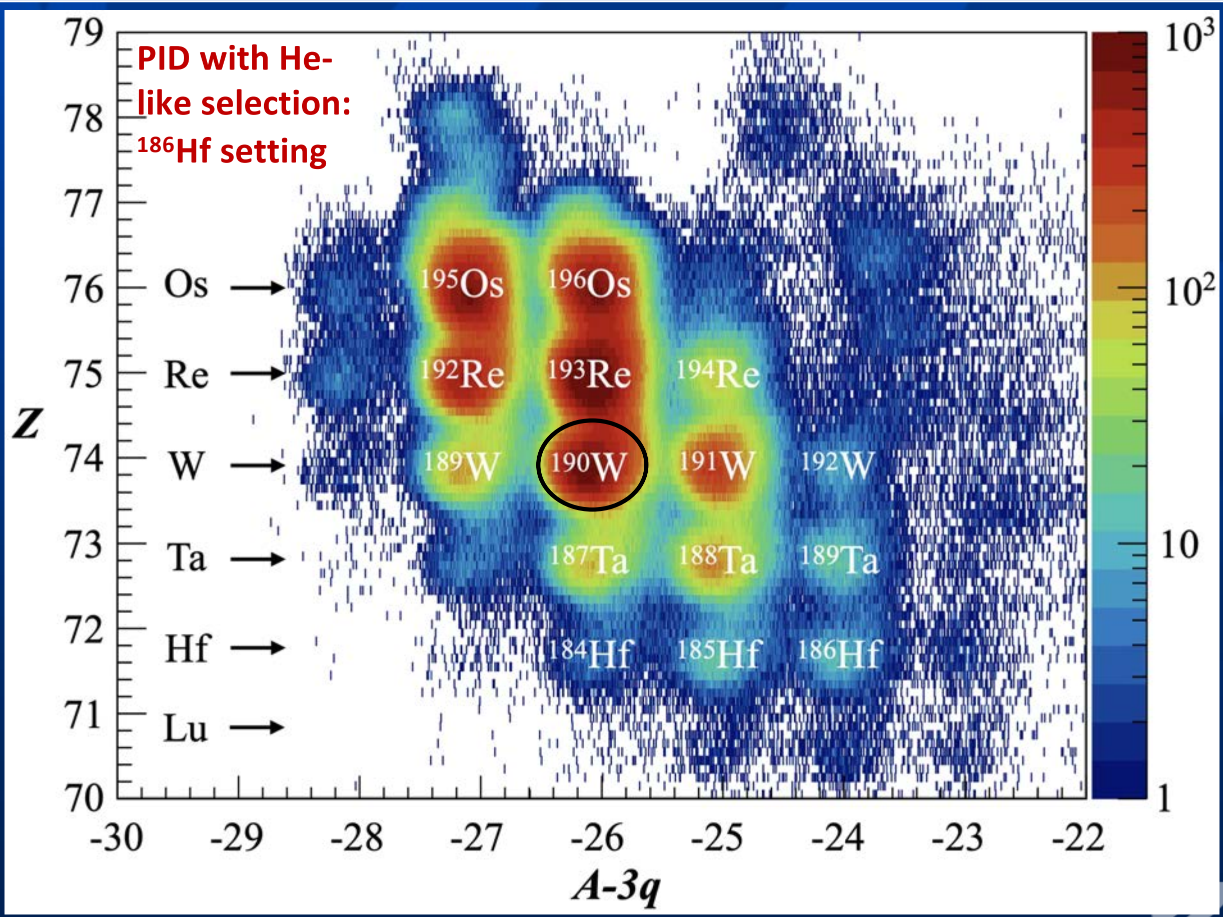
^{198}Pt Fragmentation at NSCL: Particle Identification


Tof1
Tof2
ΔE1
ΔE2
ΔESSSD
EImplant
Bρ0(1+δ)
Bρ0
Beam
Bρ0(1-δ)
Pin1
Pin2
SSSD
Implant
Veto

$TKE = \Delta E_1 + \Delta E_2 + \Delta E_{SSSD} + E_{Implant}$

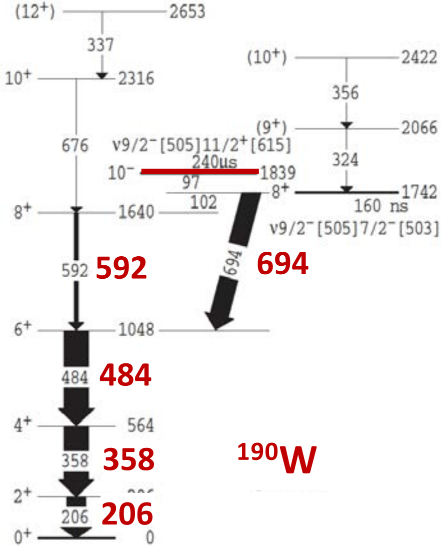


Charge state selection



PID with He-like selection: ^{186}Hf setting

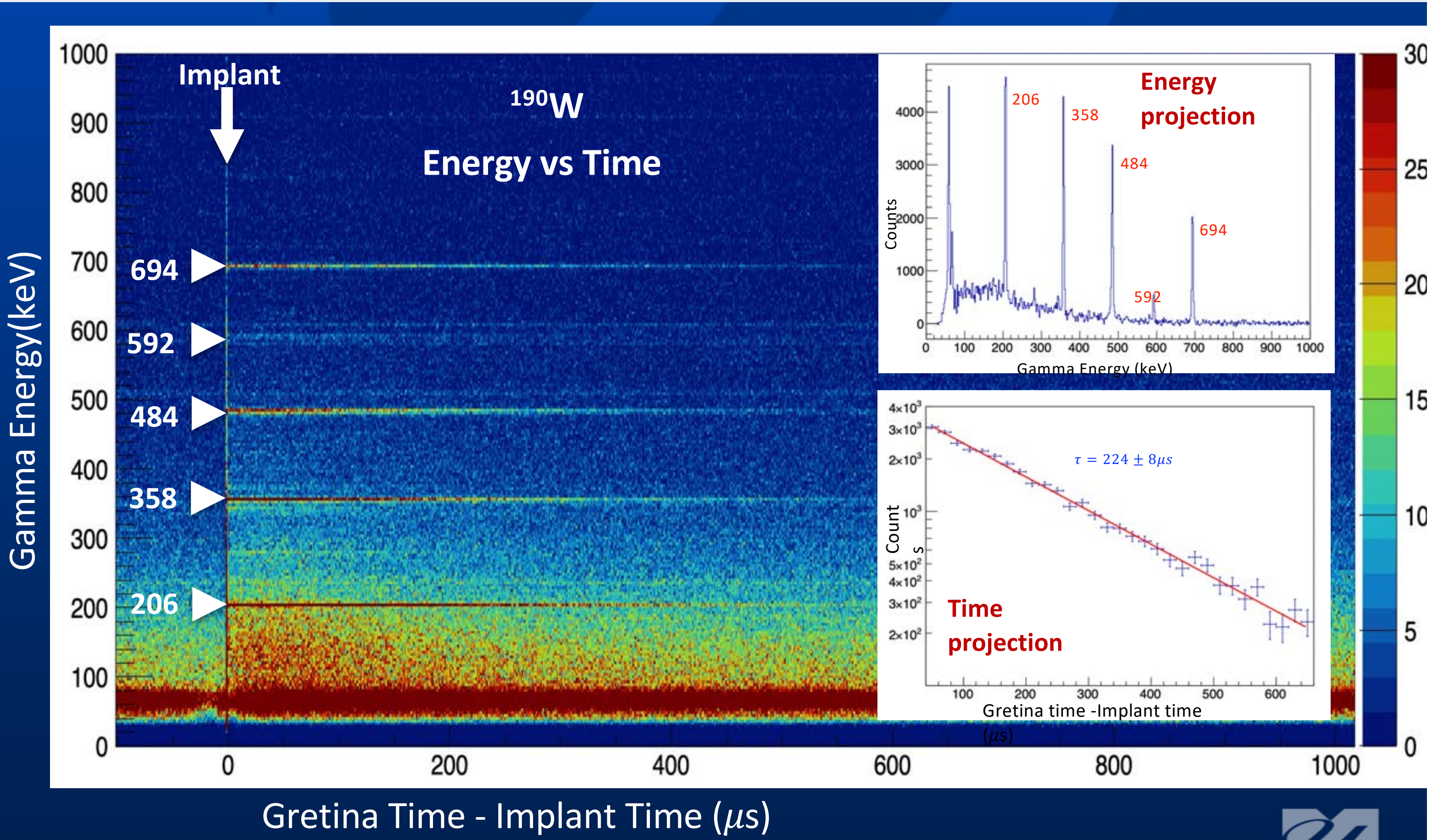
^{190}W: Implant-Decay Correlation



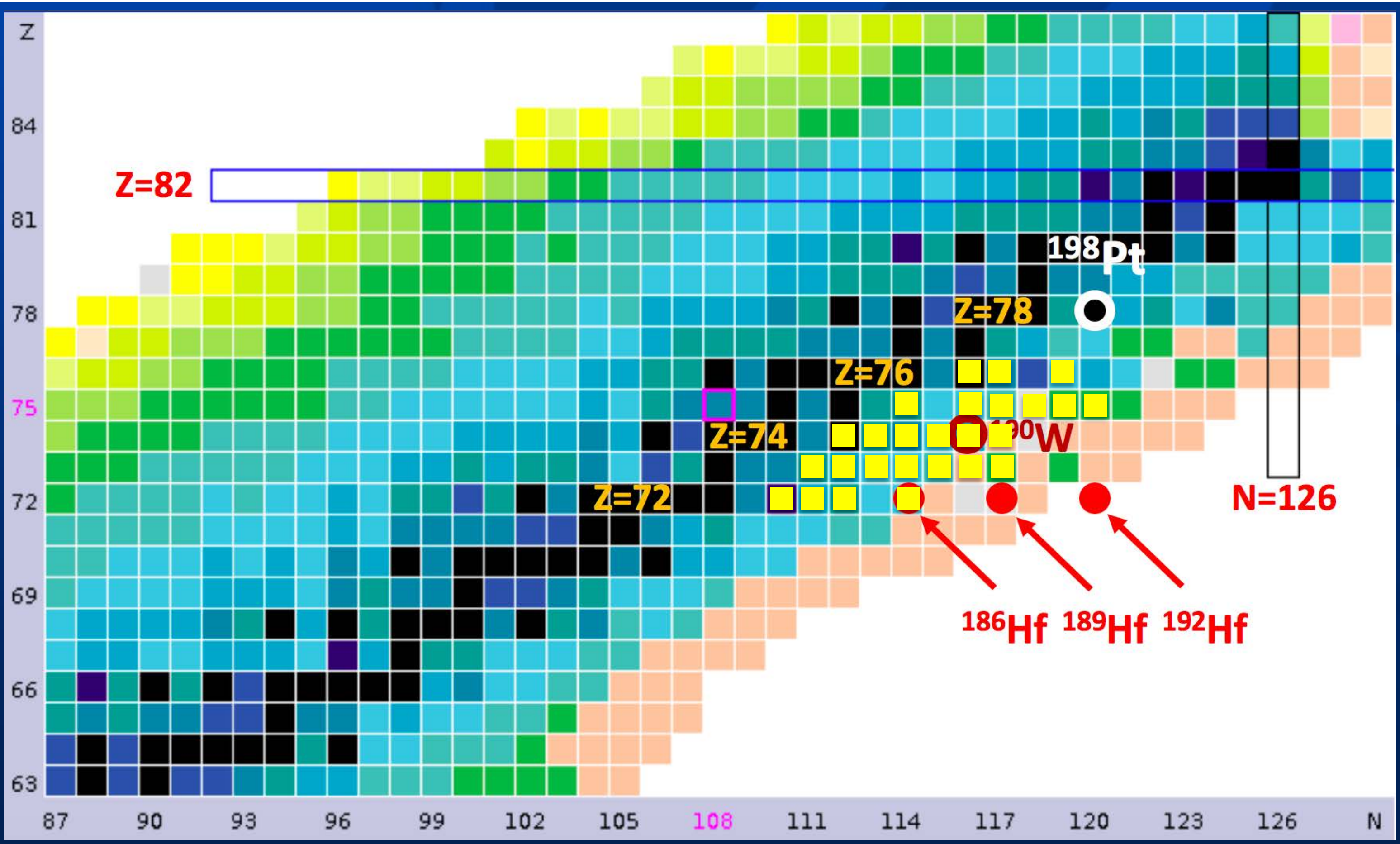
(12⁺) 2653
337
10⁺ 2316
(10⁺) 2422
356
(9⁺) 2066
676
ν9/2⁻[505]11/2⁺[615]
10⁻ 240us 1839
97
102
324
8⁺ 1742
160 ns
8⁺ 1640
ν9/2⁻[505]7/2⁻[503]
592 592
694 694
6⁺ 1048
484 484
4⁺ 564
358 358
2⁺
206 206
0⁺ 0
190W

G. Lane et al., PRC 82, 051304 (R), 2010

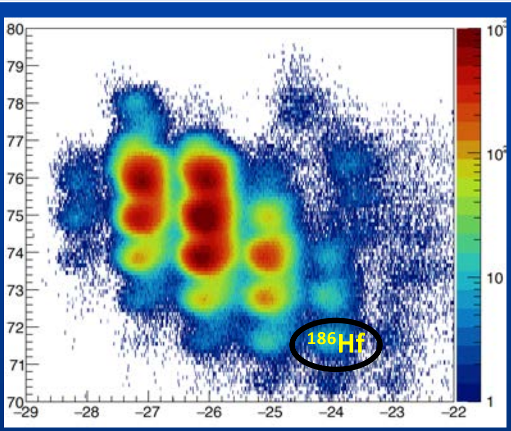
via multi-nucleon transfer

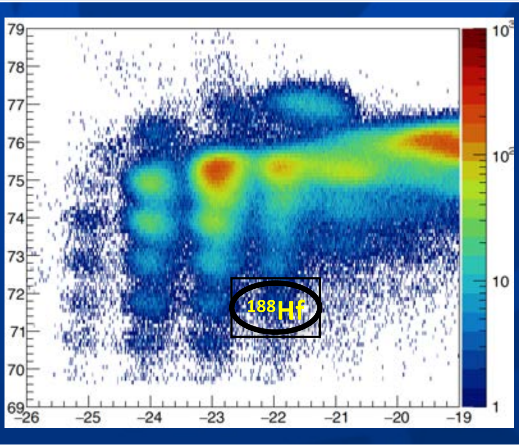


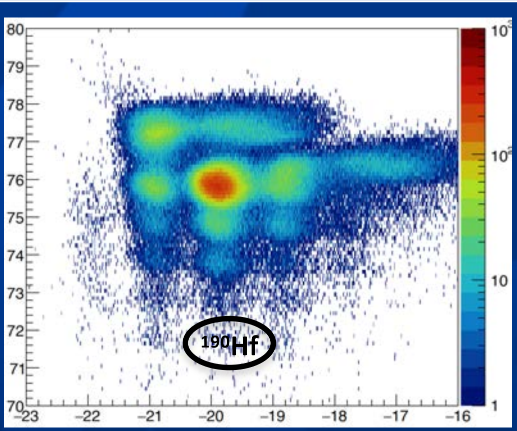
Isomer Landscape

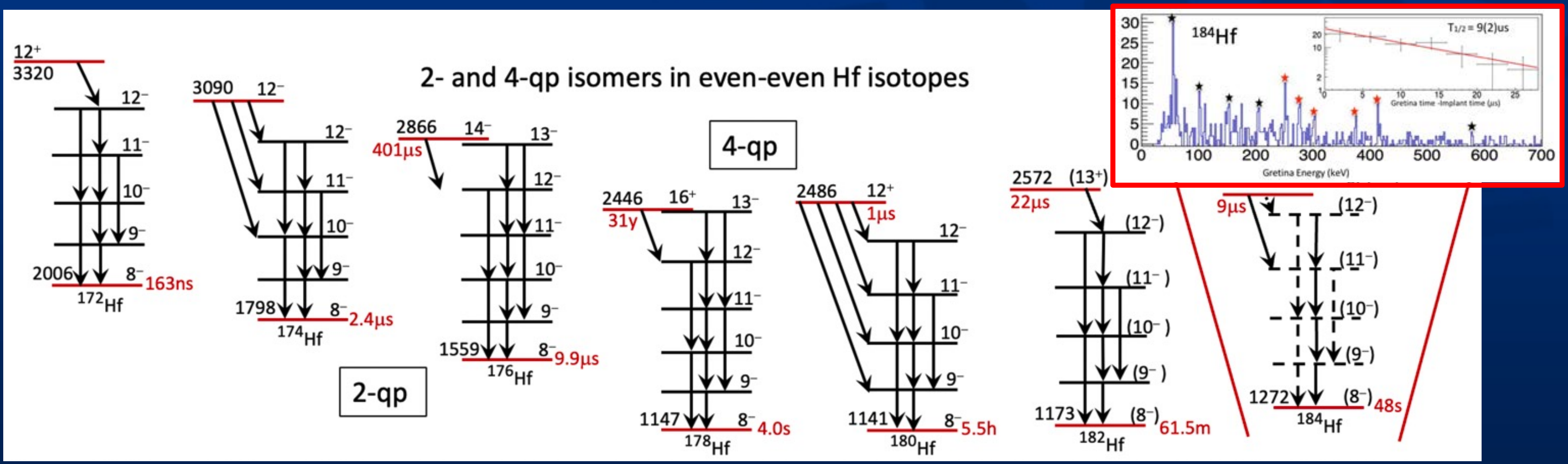


Neutron-rich terra incognita - Even-Even Hf









2- and 4-qp isomers in even-even Hf isotopes
2-qp
4-qp
12+
3320
12−
11−
10−
9−
2006
8−
163ns
^{172}Hf
3090
12−
12−
11−
10−
9−
1798
8−
2.4μs
^{174}Hf
2866
14−
401μs
13−
12−
11−
10−
9−
1559
8−
9.9μs
^{176}Hf
2446
16+
31y
13−
12−
11−
10−
9−
1147
8−
4.0s
^{178}Hf
2486
12+
1μs
12−
11−
10−
9−
1141
8−
5.5h
^{180}Hf
2572
(13+)
22μs
(12−)
(11−)
(10−)
(9−)
1173
(8−)
61.5m
^{182}Hf
9μs
(12−)
(11−)
(10−)
(9−)
1272
(8−)
48s
^{184}Hf
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
Gretina Energy (keV)
$T_{1/2}$ = 9(2)us
20
10
2
1
0
5
10
15
20
25
Gretina time -Implant time (μs)

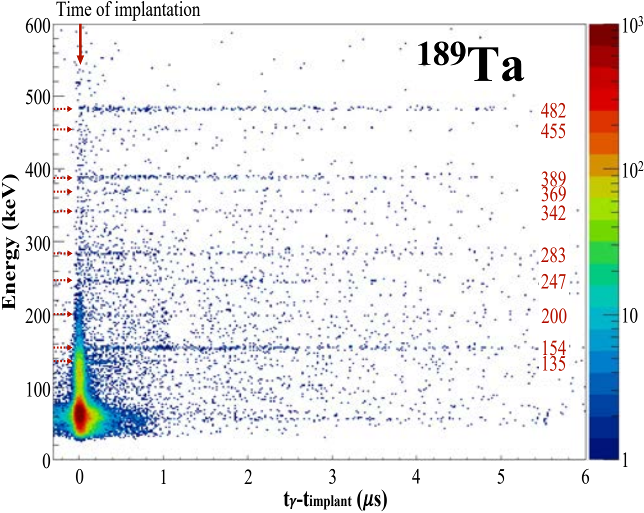
Learning with Purpose

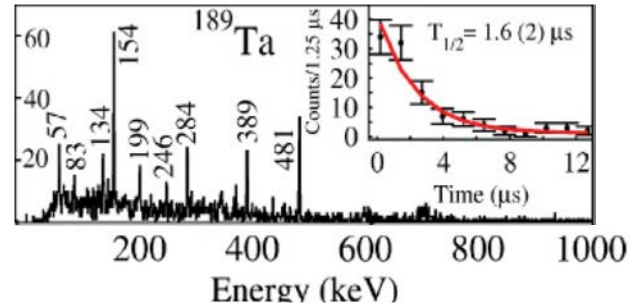
Chowdhury

SSNET 2024, Orsay

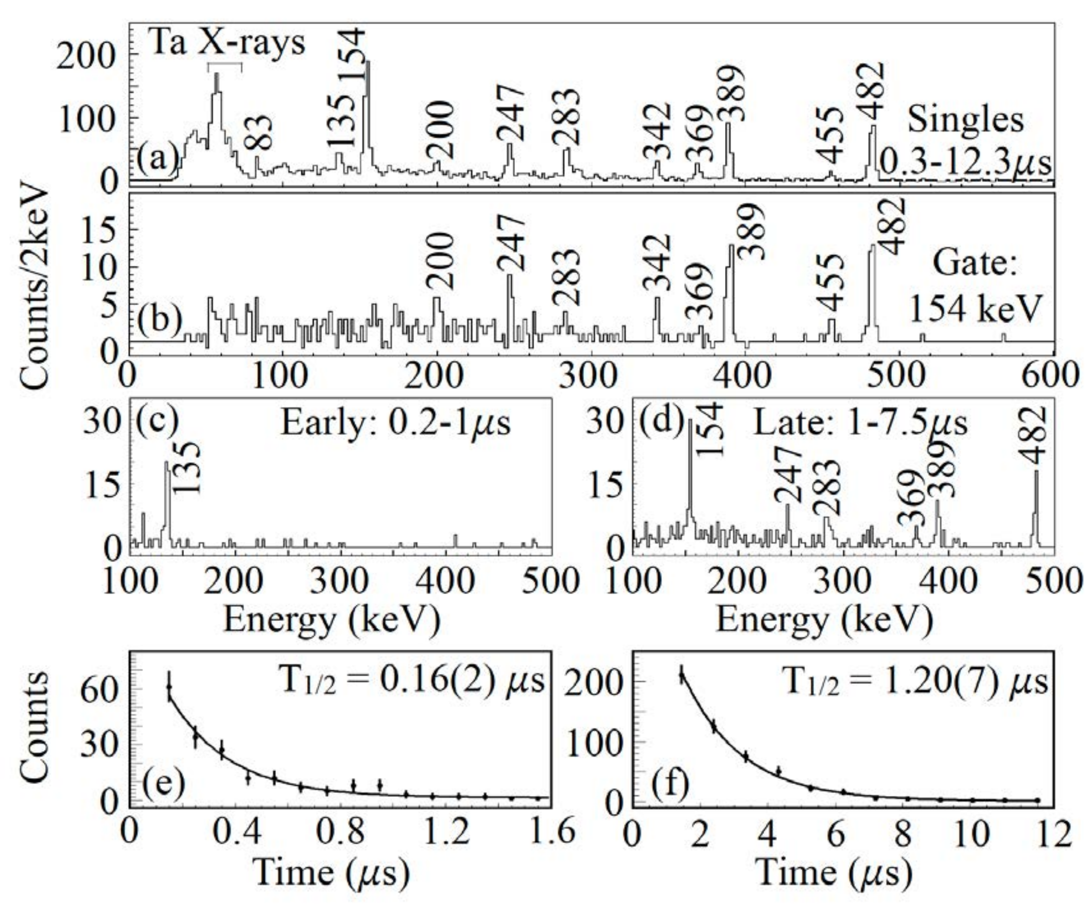
Nov 6, 2024

^{189}Ta Spectroscopy: Fragmentation + GRETINA

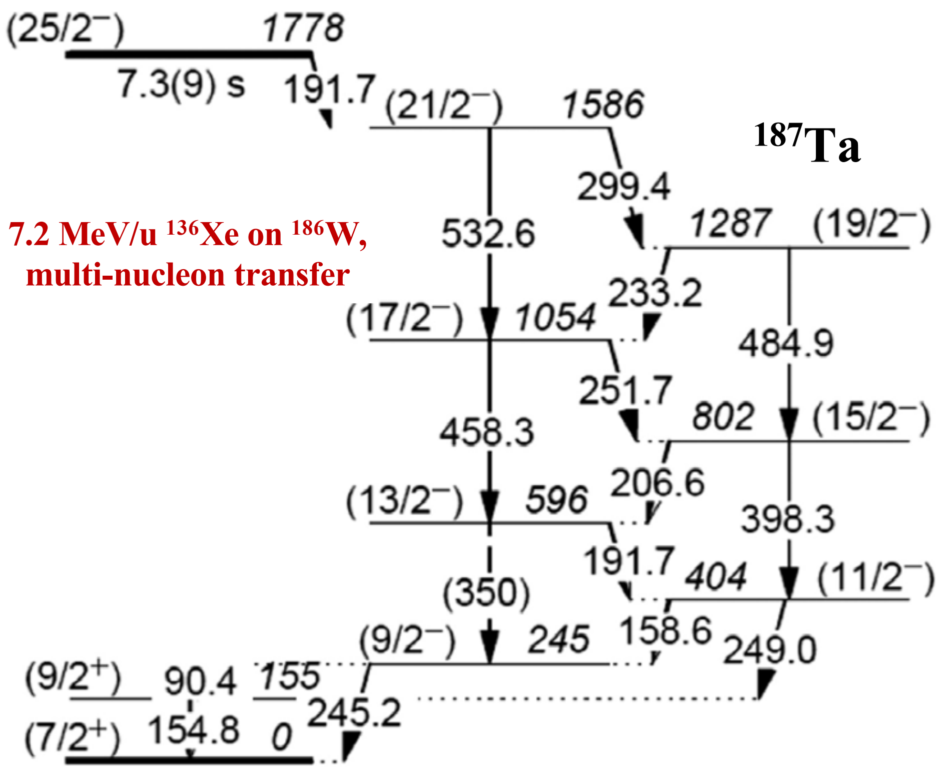




N. Alkhomashi et al., PRC 80, 064308 (2009)



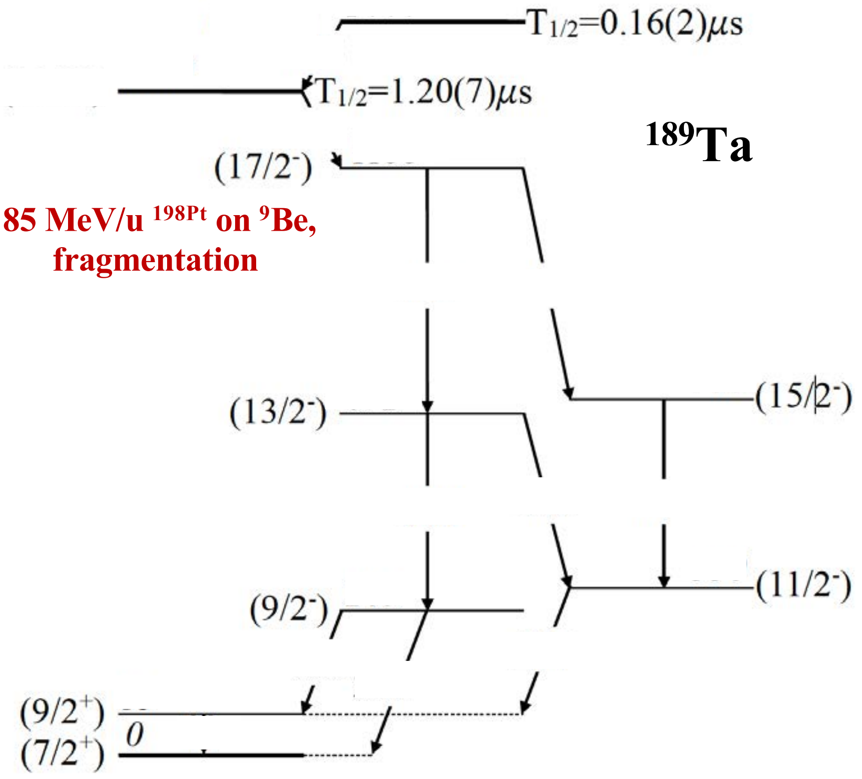
First Level Scheme of ^{189}Ta : 8 neutrons beyond stability


(25/2⁻) 1778
7.3(9) s
191.7
(21/2⁻) 1586
299.4
532.6
1287 (19/2⁻)
233.2
(17/2⁻) 1054
484.9
251.7
458.3
802 (15/2⁻)
206.6
(13/2⁻) 596
398.3
191.7
404 (11/2⁻)
(350)
(9/2⁻) 245
158.6
249.0
(9/2⁺) 90.4 155
245.2
(7/2⁺) 154.8 0

^{187}Ta

7.2 MeV/u ^{136}Xe on ^{186}W, multi-nucleon transfer

P.M. Walker et al., PRL 125, 192505 (2020)

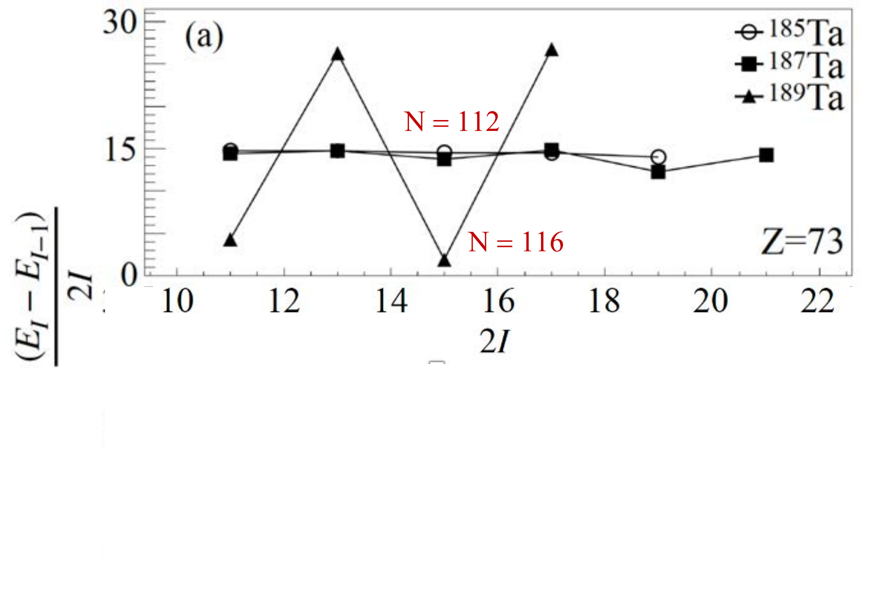

T1/2=0.16(2)μs
T1/2=1.20(7)μs
(17/2⁻)
(13/2⁻)
(15/2⁻)
(9/2⁻)
(11/2⁻)
(9/2⁺)
(7/2⁺)
0

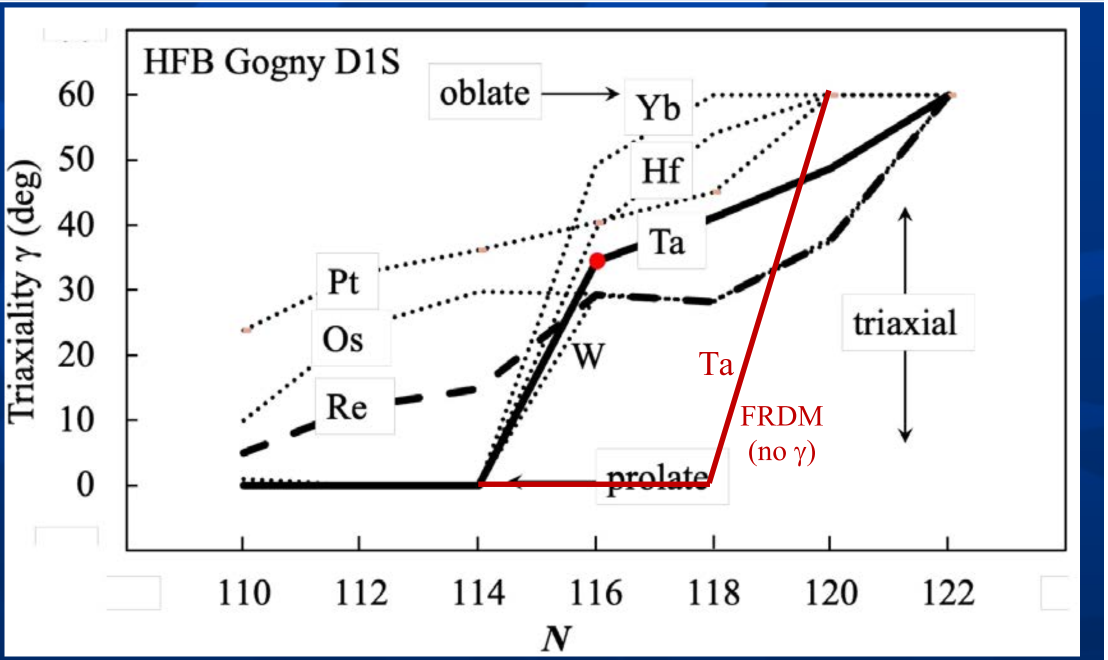
^{189}Ta

85 MeV/u ^{198}Pt on ^{9}Be, fragmentation

K. Sharma et al., submitted to PRL (2024)

Reaching the Prolate-Oblate Boundary





Large staggering (signature splitting) in ^{189}Ta rotational band

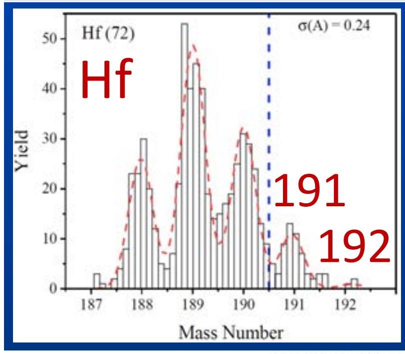
Sharp transition to strong triaxial shapes in ^{189}Ta (N=116) at the prolate-oblate boundary

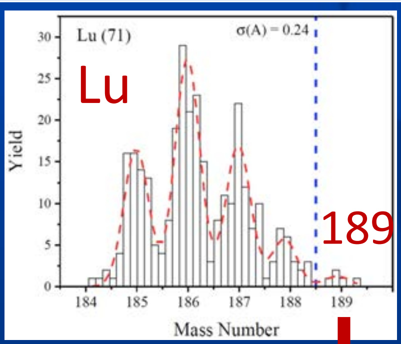
Agrees with HFB predictions but not with FRDM

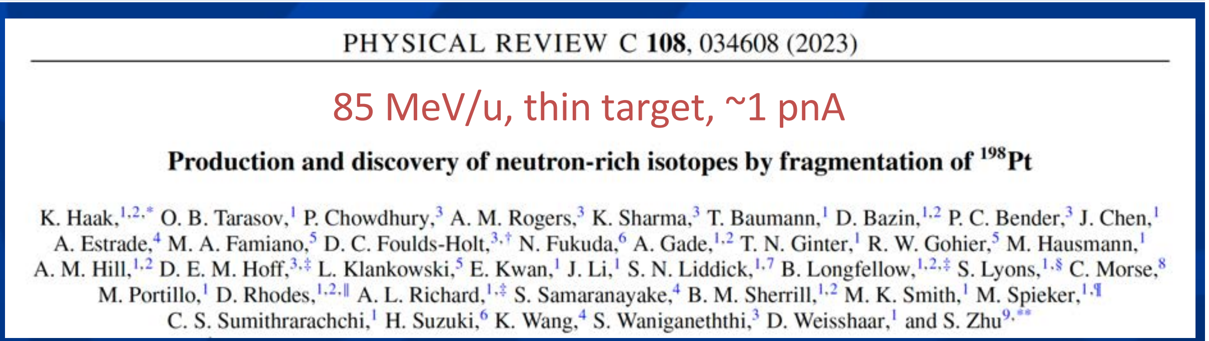
Decrease in *K*-hindrance consistent with loss of axial symmetry

K. Sharma et al., submitted to PRL

Isotope Discovery





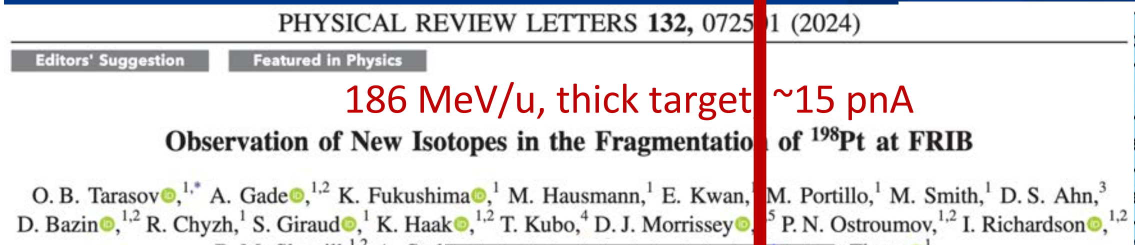


PHYSICAL REVIEW C **108**, 034608 (2023)

85 MeV/u, thin target, ~1 pnA

Production and discovery of neutron-rich isotopes by fragmentation of ^{198}Pt

K. Haak,[1,2,*] O. B. Tarasov,[1] P. Chowdhury,[3] A. M. Rogers,[3] K. Sharma,[3] T. Baumann,[1] D. Bazin,[1,2] P. C. Bender,[3] J. Chen,[1] A. Estrade,[4] M. A. Famiano,[5] D. C. Foulds-Holt,[3,†] N. Fukuda,[6] A. Gade,[1,2] T. N. Ginter,[1] R. W. Gohier,[5] M. Hausmann,[1] A. M. Hill,[1,2] D. E. M. Hoff,[3,‡] L. Klankowski,[5] E. Kwan,[1] J. Li,[1] S. N. Liddick,[1,7] B. Longfellow,[1,2,‡] S. Lyons,[1,§] C. Morse,[8] M. Portillo,[1] D. Rhodes,[1,2,‖] A. L. Richard,[1,‡] S. Samaranayake,[4] B. M. Sherrill,[1,2] M. K. Smith,[1] M. Spieker,[1,¶] C. S. Sumithrarachchi,[1] H. Suzuki,[6] K. Wang,[4] S. Waniganeththi,[3] D. Weisshaar,[1] and S. Zhu[9,**]



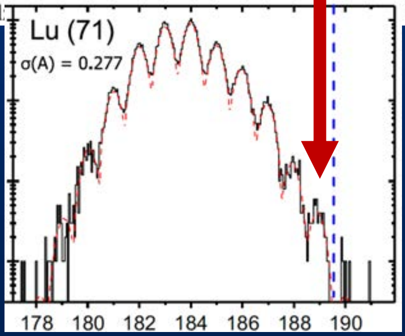
PHYSICAL REVIEW LETTERS **132**, 0725 1 (2024)

Editors' Suggestion Featured in Physics

186 MeV/u, thick target ~15 pnA

Observation of New Isotopes in the Fragmentatio of ^{198}Pt at FRIB

O. B. Tarasov,[1,*] A. Gade,[1,2] K. Fukushima,[1] M. Hausmann,[1] E. Kwan, M. Portillo,[1] M. Smith,[1] D. S. Ahn,[3] D. Bazin,[1,2] R. Chyzh,[1] S. Giraud,[1] K. Haak,[1,2] T. Kubo,[4] D. J. Morrissey,[5] P. N. Ostroumov,[1,2] I. Richardson,[1,2] B. M. Sherrill,[1,2] A. Stol Zhang[1]

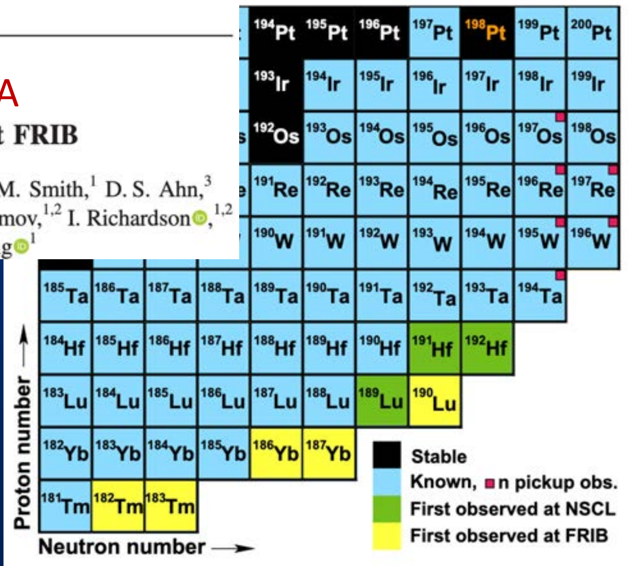


FRIB PAC3

UML, FRIB, Surrey, JYFL, ORNL, ANL +

Z=68-75

Proposal under review



^{194}Pt ^{195}Pt ^{196}Pt ^{197}Pt ^{198}Pt ^{199}Pt ^{200}Pt

^{193}Ir ^{194}Ir ^{195}Ir ^{196}Ir ^{197}Ir ^{198}Ir ^{199}Ir

^{192}Os ^{193}Os ^{194}Os ^{195}Os ^{196}Os ^{197}Os ^{198}Os

^{191}Re ^{192}Re ^{193}Re ^{194}Re ^{195}Re ^{196}Re ^{197}Re

^{190}W ^{191}W ^{192}W ^{193}W ^{194}W ^{195}W ^{196}W

^{185}Ta ^{186}Ta ^{187}Ta ^{188}Ta ^{189}Ta ^{190}Ta ^{191}Ta ^{192}Ta ^{193}Ta ^{194}Ta

^{184}Hf ^{185}Hf ^{186}Hf ^{187}Hf ^{188}Hf ^{189}Hf ^{190}Hf 🟩 ^{191}Hf 🟩 ^{192}Hf

^{183}Lu ^{184}Lu ^{185}Lu ^{186}Lu ^{187}Lu ^{188}Lu 🟩 ^{189}Lu 🟨 ^{190}Lu

^{182}Yb ^{183}Yb ^{184}Yb ^{185}Yb 🟨 ^{186}Yb 🟨 ^{187}Yb

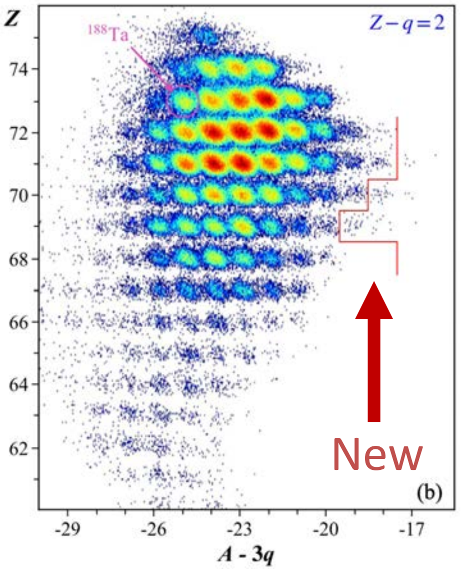
^{181}Tm 🟨 ^{182}Tm 🟨 ^{183}Tm

■ Stable

🟦 Known, ▪ n pickup obs.

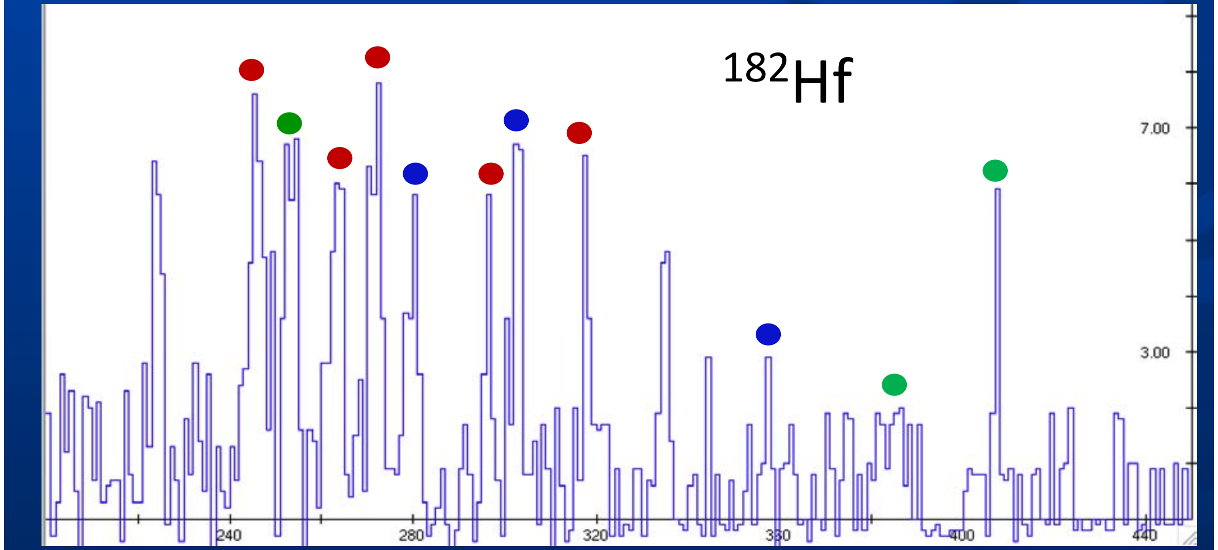
🟩 First observed at NSCL

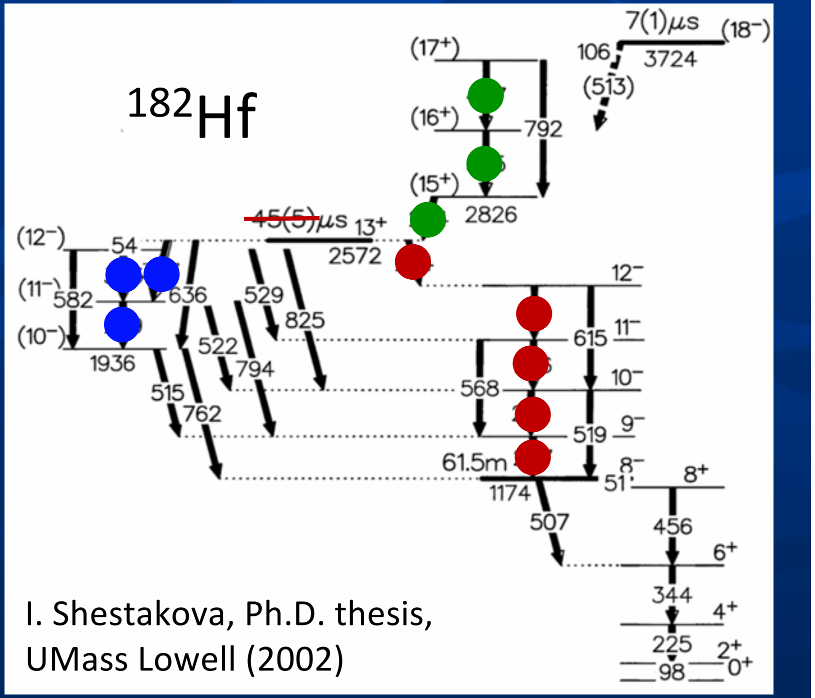
🟨 First observed at FRIB



New

Reaction Dynamics: Angular Momentum in Fragments




^{182}Hf
7(1)μs
(18⁻)
106
3724
(5̄13)
(17⁺)
(16⁺)
792
(15⁺)
2826
~~45(5)~~μs 13⁺
2572
(12⁻)
54
(11⁻)
582
636
529
825
(10⁻)
522
794
1936
515
762
568
12⁻
615
11⁻
10⁻
519
9⁻
61.5m
8⁻
51
8⁺
1174
507
456
6⁺
344
4⁺
225
2⁺
98
0⁺

I. Shestakova, Ph.D. thesis, UMass Lowell (2002)

Populating isomeric states up to I ~ 18ℏ

Summary and Outlook

- First fragmentation of ^{198}Pt beams
- ΔE – Bρ – TKE – TOF → PID Si SSSD → Δ(Bρ) GRETINA → γ–γ coincidence power
- Isotopes implanted in (~10%) isomeric high spin states
- Half-life sensitivity between ~400 ns (flight path) and ~10 ms (implant rate)
- Many isomers identified in neutron-rich landscape (more results in queue)
- Half-life of 2-qp Hf isomers out of range, μs 4-qp isomers identified in ^{184,186}Hf
- First level scheme of ^{189}Ta (N=116) from K-isomer decay - Sharp transition to strong triaxial shapes: Reaching the Prolate-Oblate boundary (submitted to PRL)
- FRIB PAC3 proposal under review, wider scope, larger team, FDSi, 128x128 Si DSSD, increased sensitivity to longer $t_{1/2}$

THANK YOU!