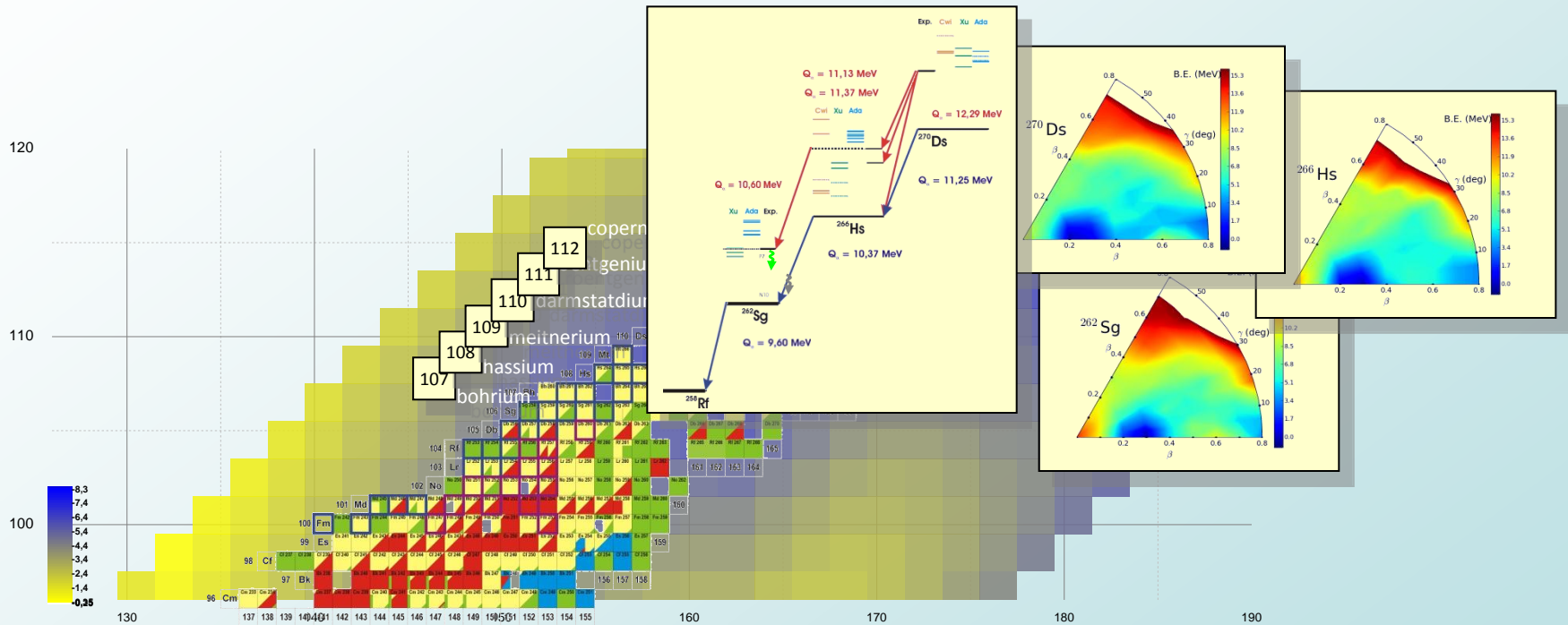


## Nuclear Structure Features as a Guide to SHE



Dieter Ackermann

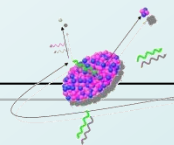


Helmholtzzentrum für Schwerionenforschung GmbH

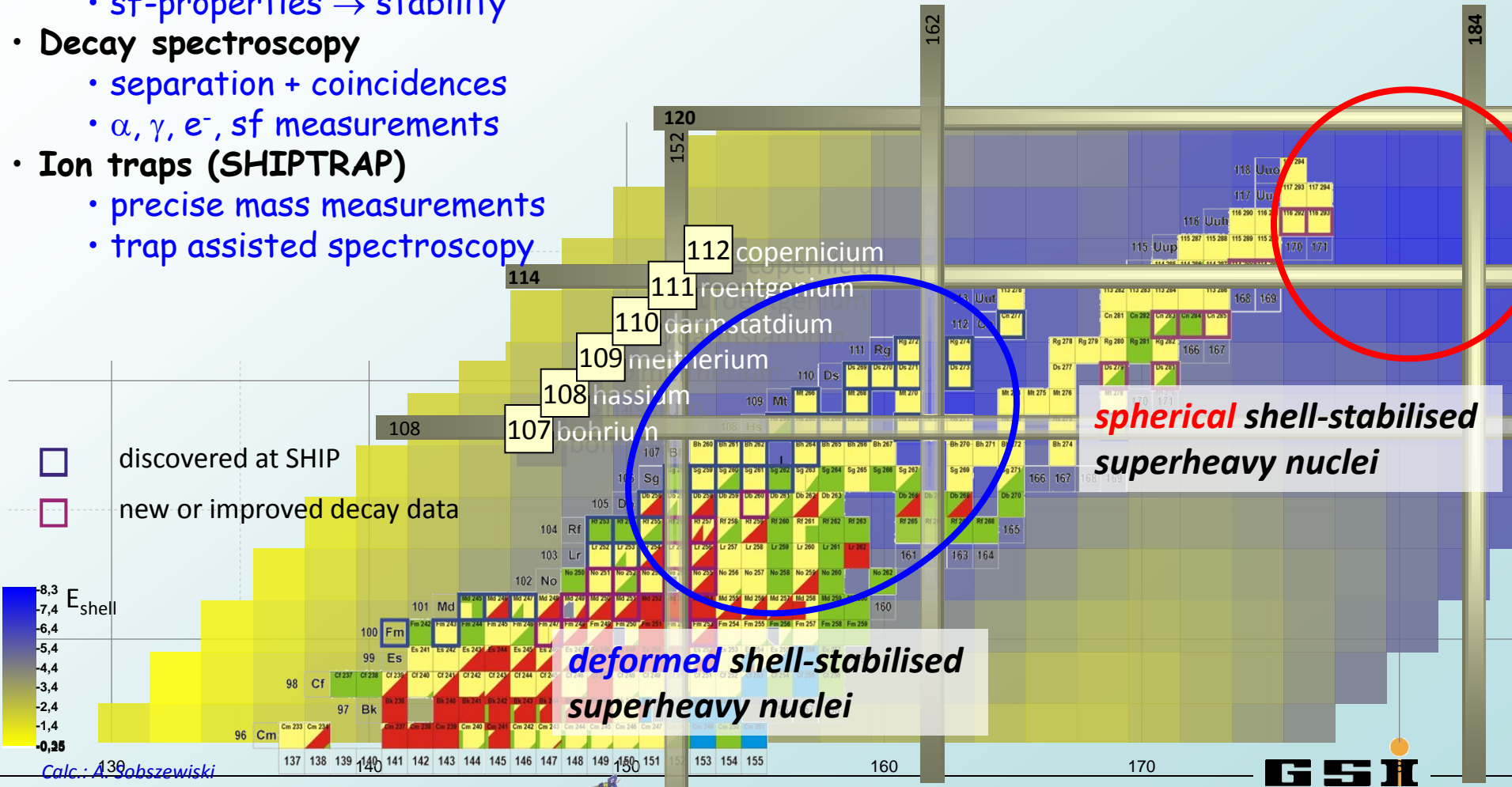
Darmstadt, March 1<sup>st</sup> 2013

# Nuclear Structure studies at SHIP

## - outline



- Nuclear structure features of superheavy nuclei
  - single particle levels → towards the shell gap (trends along isotone/isotope chains)
  - quasiparticle excitations → deformation/K-isomers
  - sf-properties → stability
- Decay spectroscopy
  - separation + coincidences
  - $\alpha, \gamma, e^-, sf$  measurements
- Ion traps (SHIPTRAP)
  - precise mass measurements
  - trap assisted spectroscopy

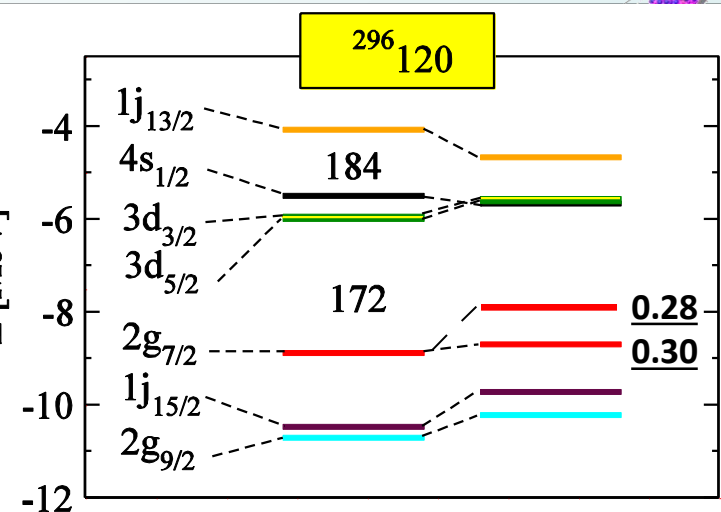
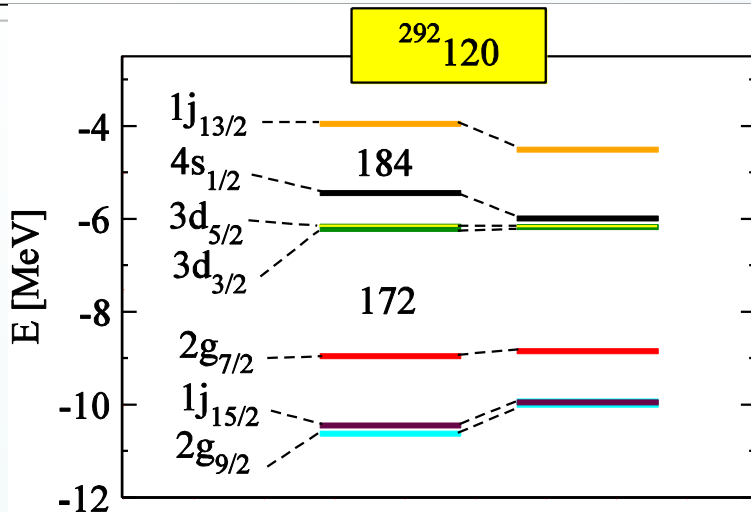


**spherical shell-stabilised superheavy nuclei**

**deformed shell-stabilised superheavy nuclei**

Calc.: A. Sobiczewski

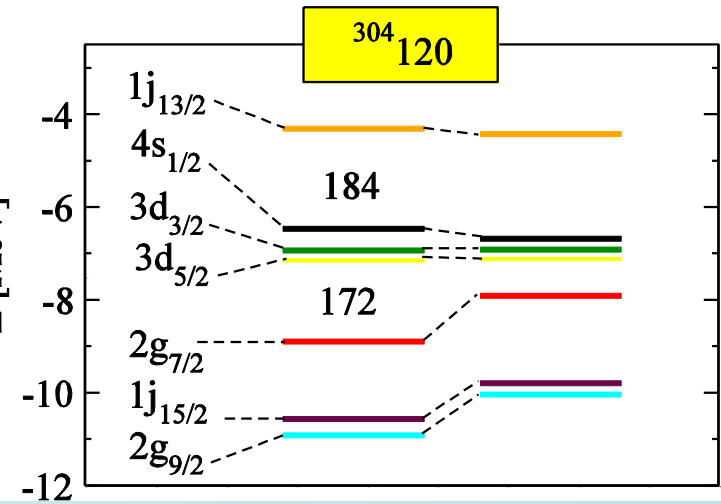
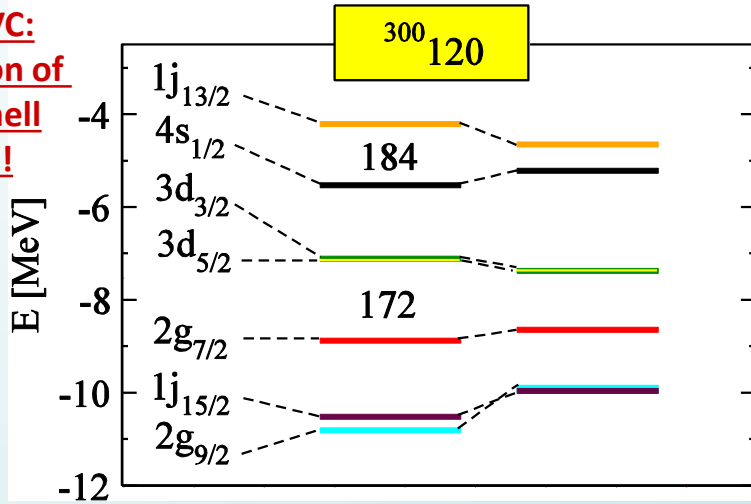


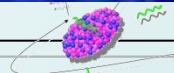


Comparable Spectroscopic strengths

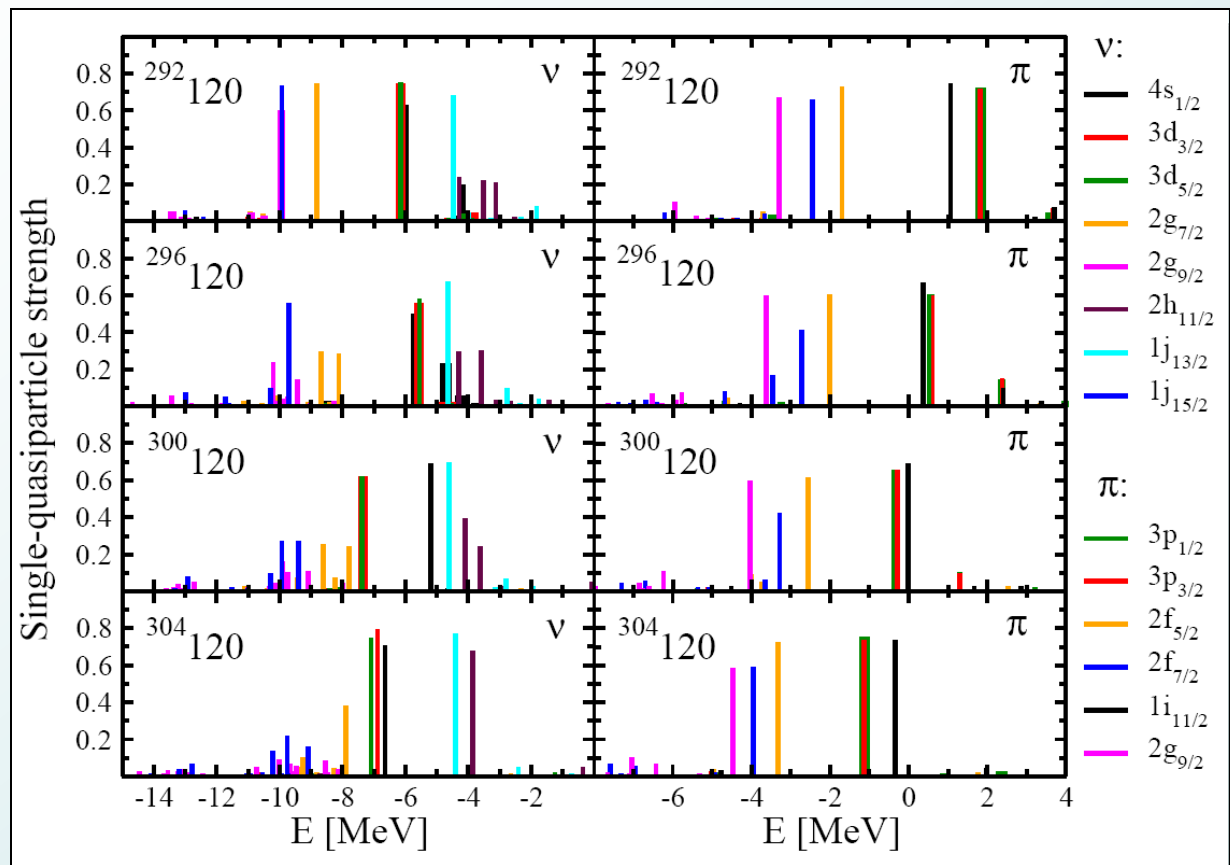


PC+QVC:  
 Formation of the „shell gap“ !

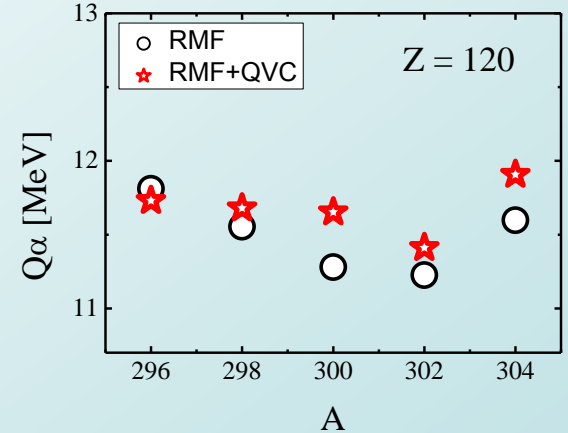




1. Relativistic Mean Field: spherical minima
2. Small amplitude vibrations: RQRPA
3. Very soft nuclei: large amount of low-lying collective vibrational modes ( $\sim 100$  phonons below 15 MeV)



Vibration corrections to alpha decay energies  $Q_\alpha$  [MeV]



- Vibrational corrections:
1. Impact on the shell gaps
  2. Smearing of the shell effects

Shell stabilization & vibration stabilization/destabilization (?)

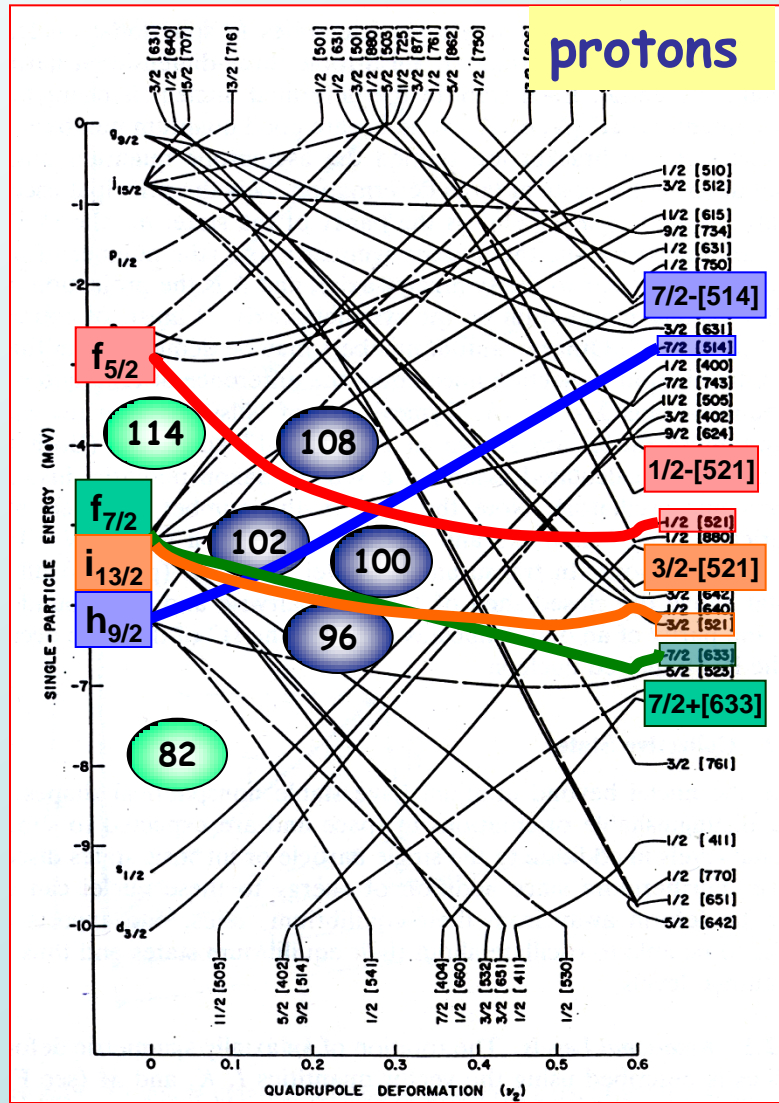
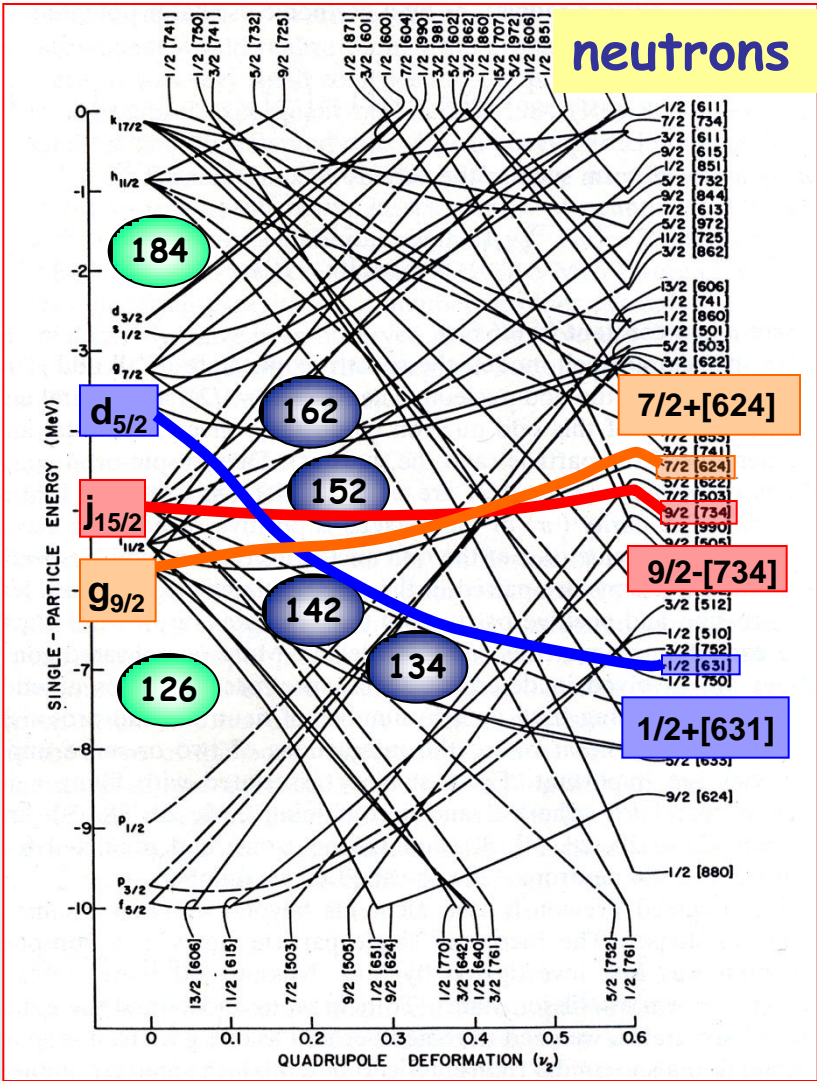
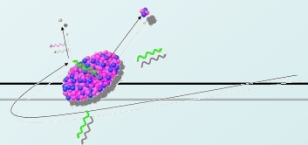
E.L., arXiv:1108.3508





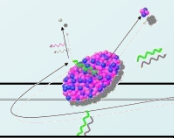
# Nuclear Structure of Heavy Nuclei

## - Single Particle Levels and Deformation



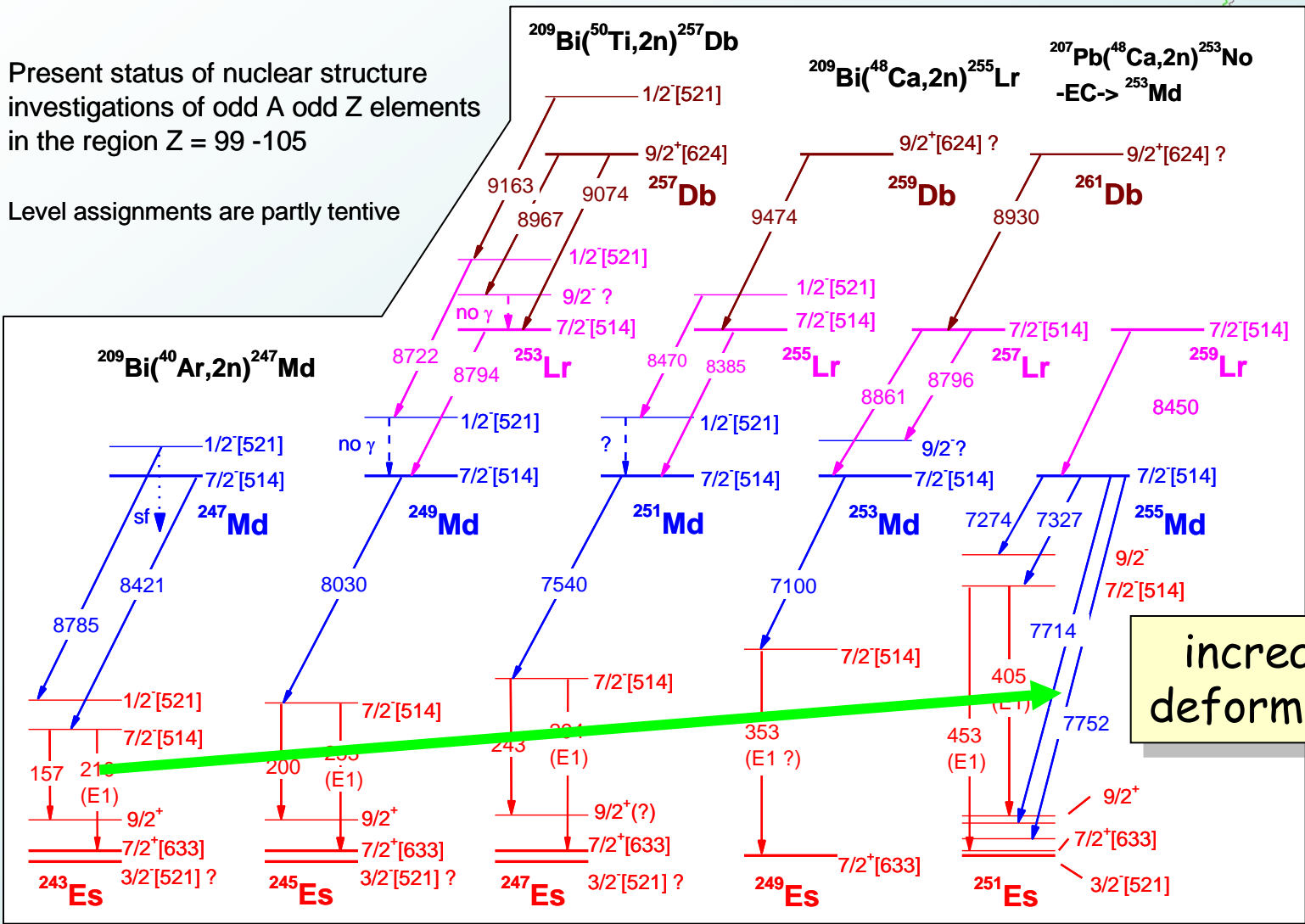
# Nuclear Structure of the Heaviest Nuclei:

## - odd-A odd-Z Istopes for Z = 99 - 105



Present status of nuclear structure investigations of odd A odd Z elements in the region Z = 99 - 105

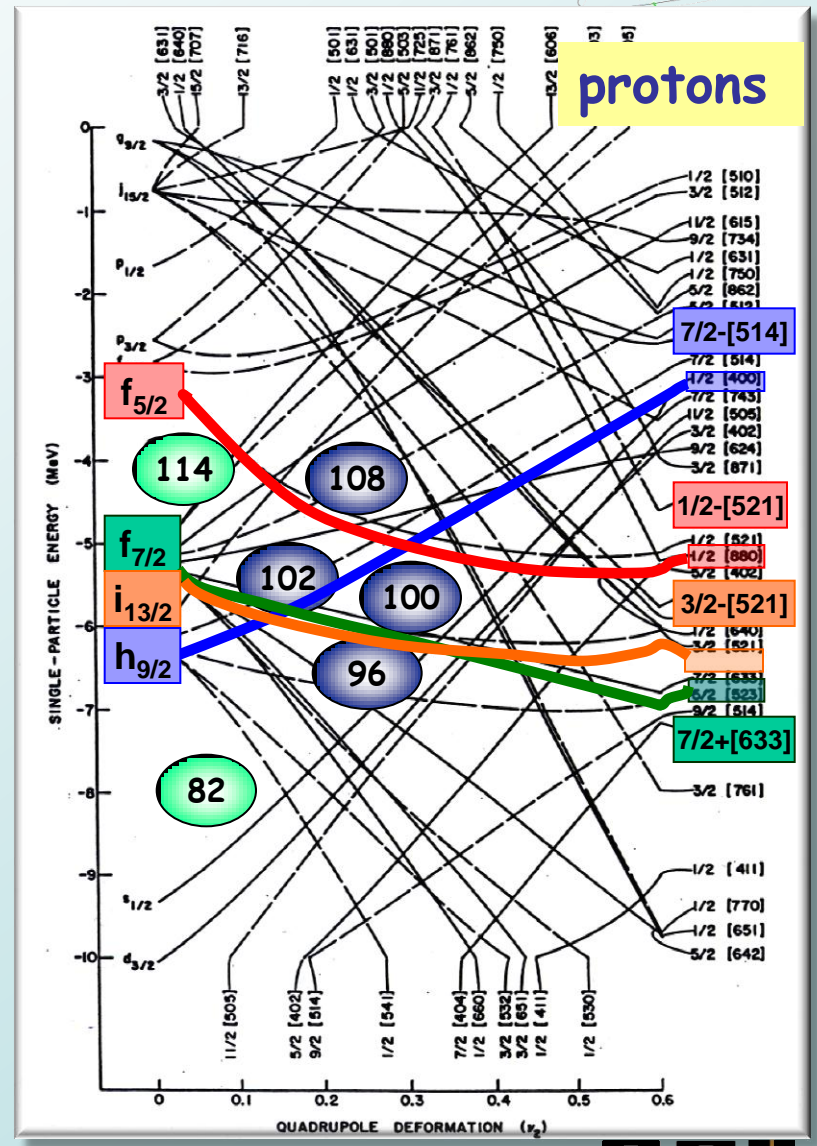
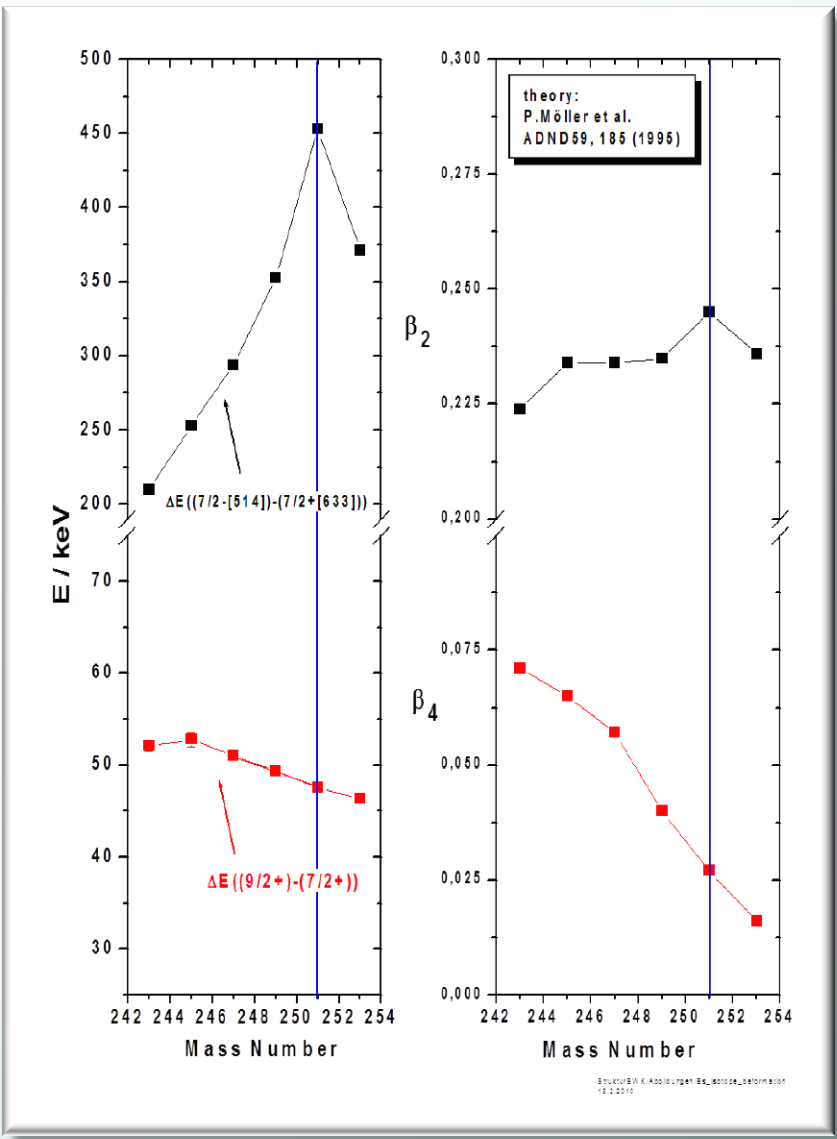
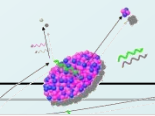
Level assignments are partly tentative



increasing deformation

# Deformation of odd-mass Es-isotopes as function of mass number

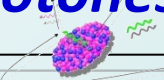
## - Relation between energy of 7/2-[514] level and deformation



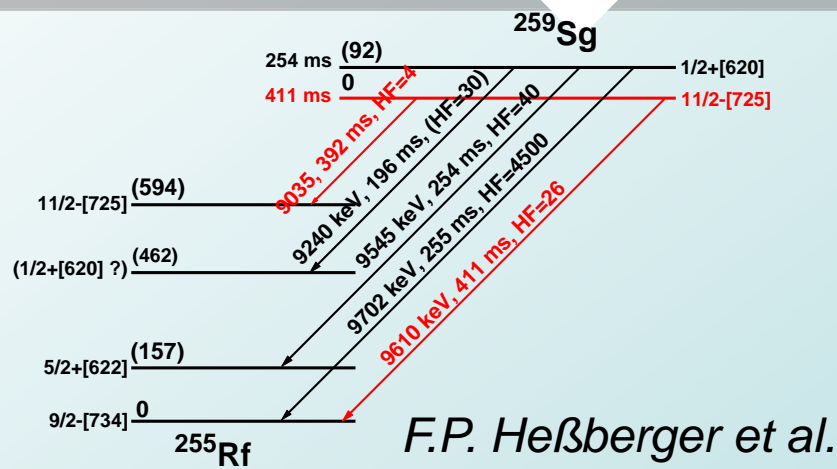
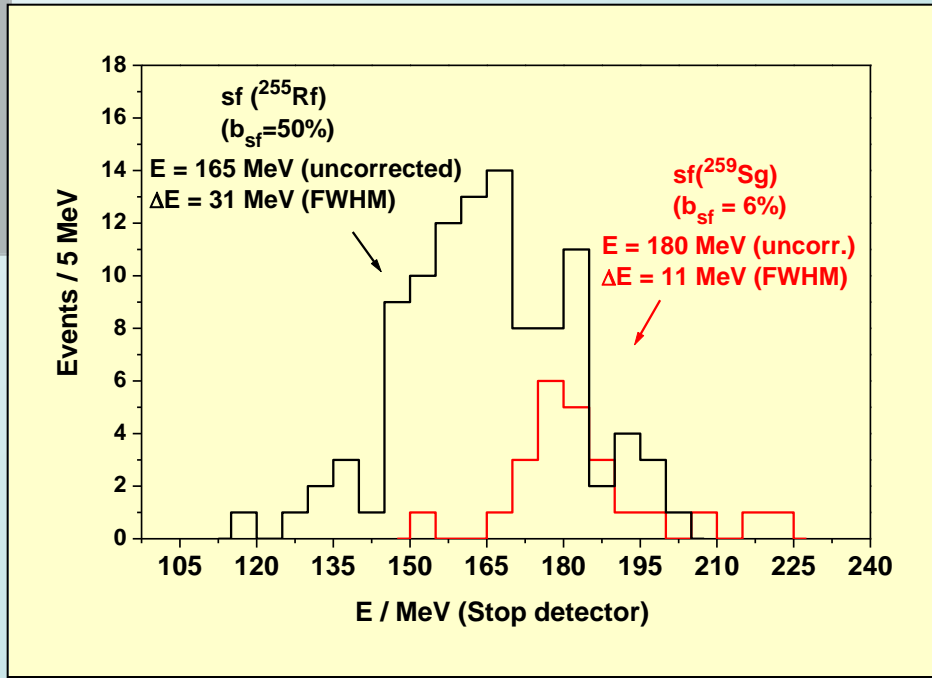
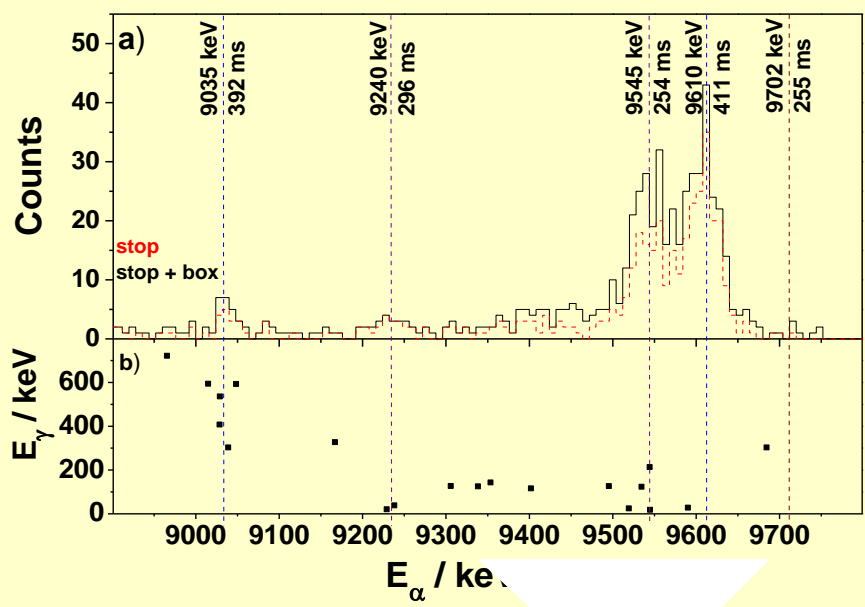


# Decay Study of $^{259}\text{Sg}$ ( $Z=106$ )

## - sf Properties, Low Lying States and Trend for $N=153$ Totonones



- Production:  $^{206}\text{Pb}(^{54}\text{Cr}, 1n)^{259}\text{Sg}$ ,  $\sigma \approx 1$  nb
- $\alpha$ -decay from two low lying levels
- TKE(sf) of  $^{259}\text{Sg} > 15$  MeV higher than for  $^{255}\text{Rf}$ ; change from asymmetric to symmetric fission
- $T_{1/2}(\text{sf}, ^{259}\text{Sg}) \approx 235$  ms; sf from  $1/2^+[620]$
- change of gs – configuration within  $N = 153$  isotones from  $1/2^+[620]$  to  $11/2^-[725]$



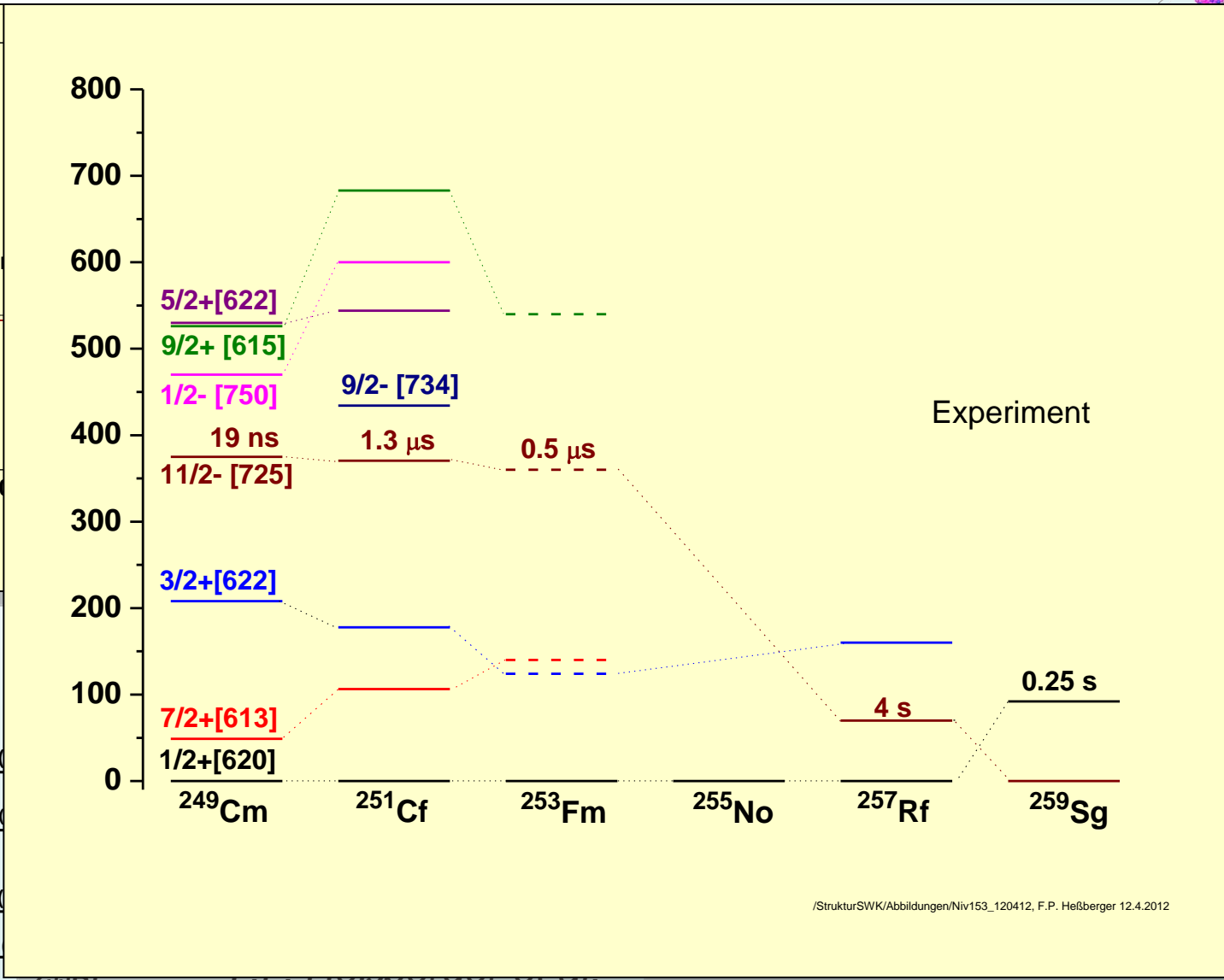
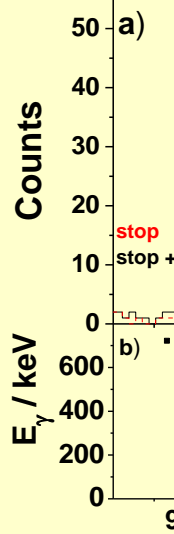
F.P. Heßberger et al.





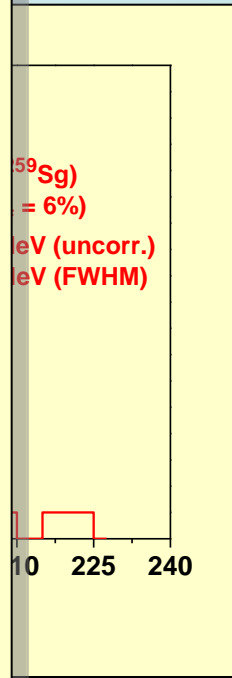
# Decay Study of $^{259}\text{Sg}$ (Z=106)

## - sf Properties, Low Lying States and Trend for N=153 Tsootones



Experiment

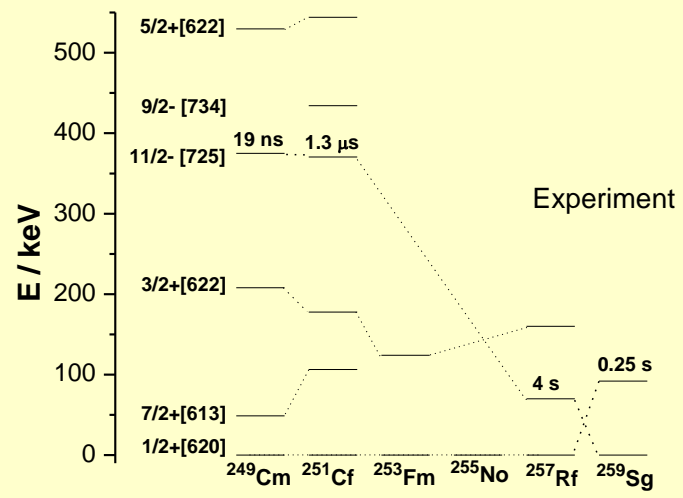
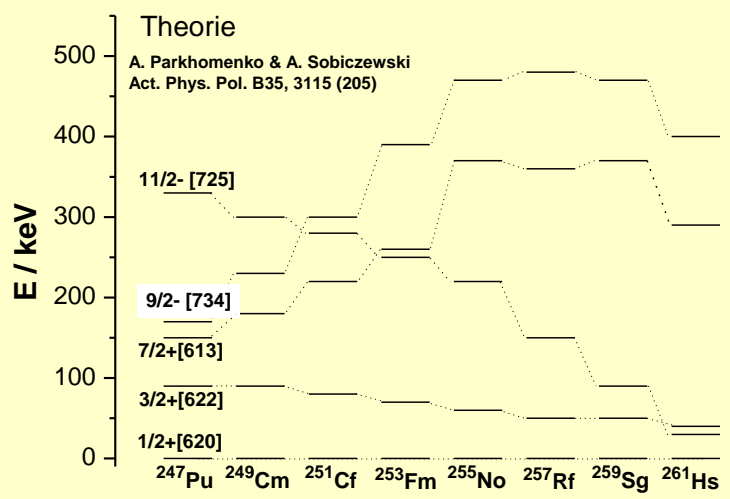
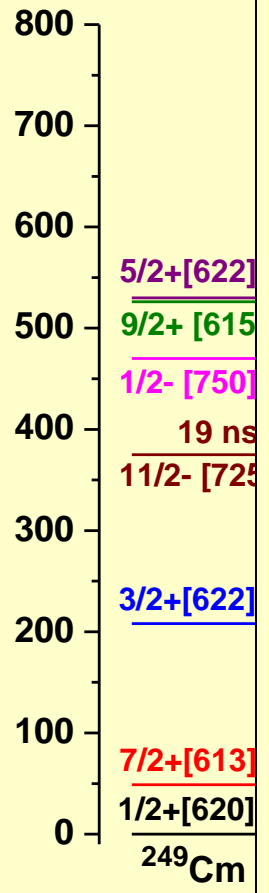
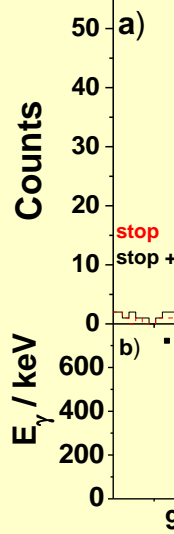
nb  
for  
metric  
20]  
= 153



/StrukturSWK/Abbildungen/Niv153\_120412, F.P. Heßberger 12.4.2012

# Decay Study of $^{259}\text{Sg}$ (Z=106)

## - sf Properties, Low Lying States and Trend for N=153 Tsotones



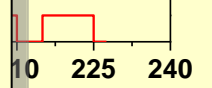
Experiment

0.25 s

$^{259}\text{Sg}$

nb  
for  
nmetric  
20]  
= 153

$^{259}\text{Sg}$   
= 6%)  
eV (uncorr.)  
eV (FWHM)



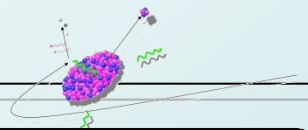
53\_120412, F.P. Heßberger 12.4.2012

graph/niv\_schem\_ssk/Niv153\_120412  
F.P.Heßberger 12.4.2012

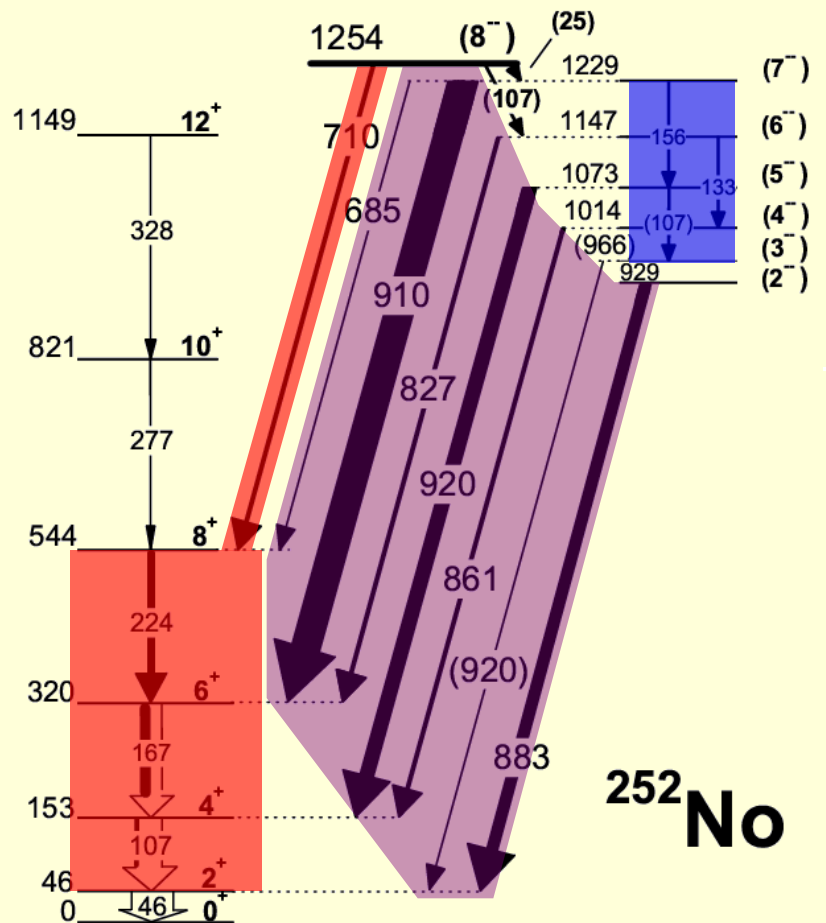


# Nuclear Structure of the Heaviest Nuclei:

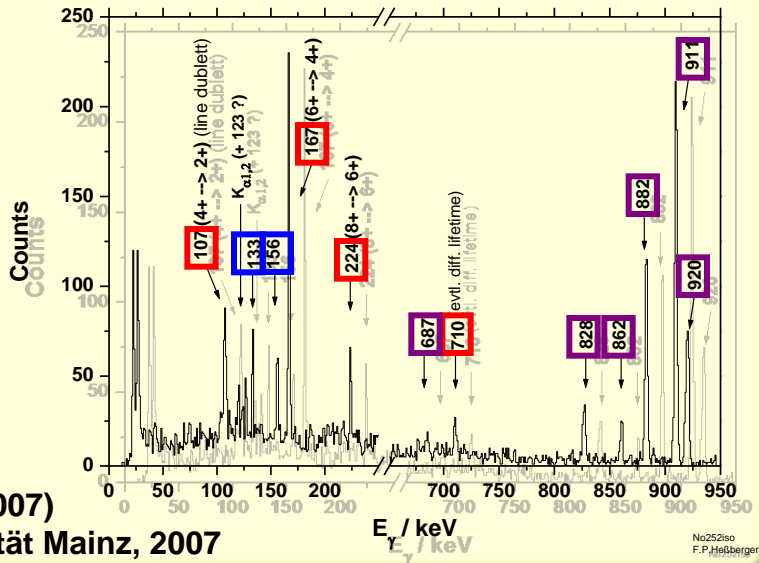
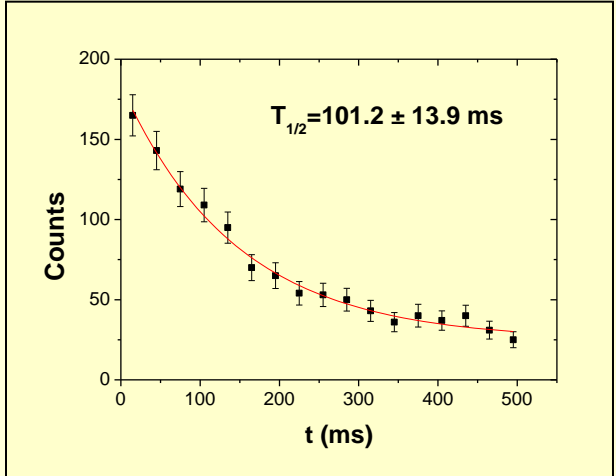
- Isomeric states:  $^{252}\text{No}$



$T_{1/2} = 110 \pm 10$  ms  $^{206}\text{Pb}(^{48}\text{Ca}, 2n)^{252}\text{No}$



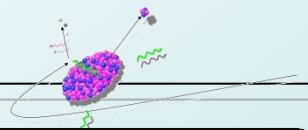
**$^{252}\text{No}$**



B. Sulignano et al. EPJ A33, 327 (2007)  
 B. Sulignano, PHD thesis, Universität Mainz, 2007

# Nuclear Structure of the Heaviest Nuclei:

## - Isomeric states: $^{252}\text{No}$



inbeam studies at JUROGAM  
 B. Sulignano et al.  
*Phys. Rev. C 86, 044318 (2012)*

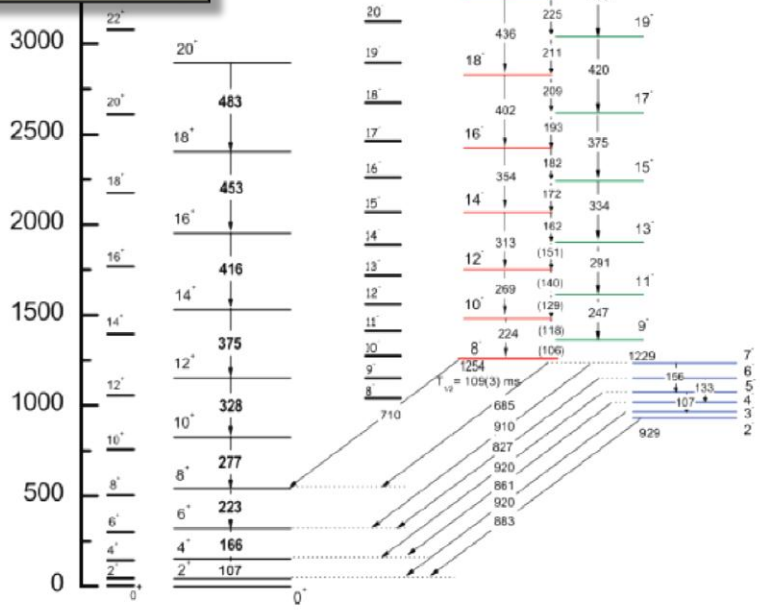
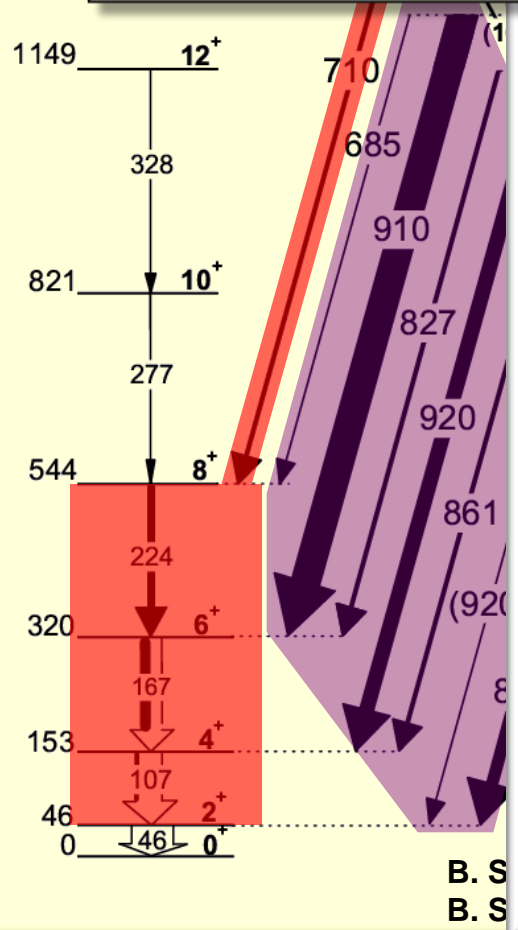
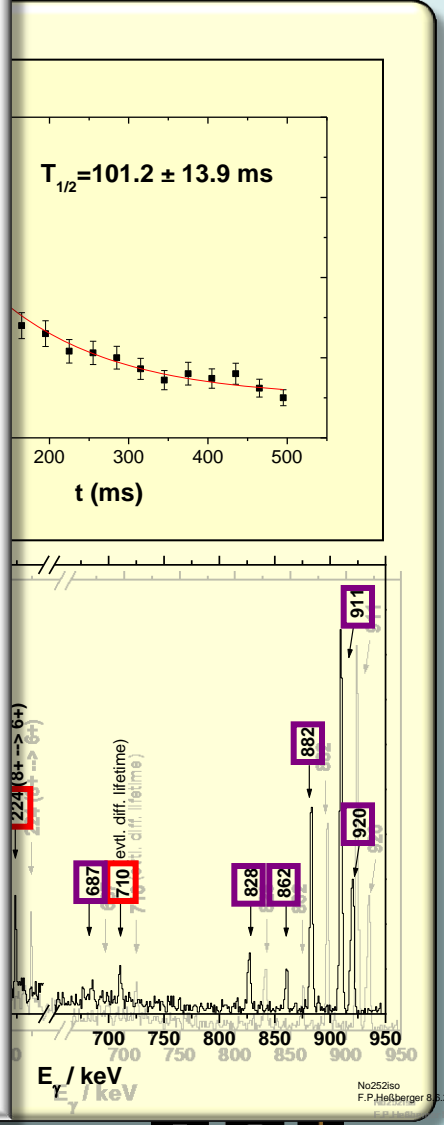


FIG. 4. (Color online)  $^{252}\text{No}$  level scheme. Ground-state band measured up to spin  $I^\pi = 20^+$  and comparison to HFB predictions to spin  $24^+$  (gray box) are shown on the left-hand side. The rotational band measured on top of the  $K^\pi = 8^-$  neutron isomer is shown (up to spin  $I^\pi = 22^-$ ) in red and green colors for even and odd spin sequences, respectively. HFB level predictions for this band to spin  $I^\pi = 23^-$  are shown inside the gray box. The  $K^\pi = 2^-$  collective band observed at lower excitation energy is marked in blue.





# $^{270}\text{Ds}$ and its Decay Products

- 1<sup>st</sup> experiment in 2000 (S. Hofmann et al., Eur. Phys. J. A 10, 5 (2001))

$^{270}\text{Ds} \rightarrow ^{266}\text{Hs}$  (6 chains)

chain# 1, 3 and 5

chain# 2

chain# 8

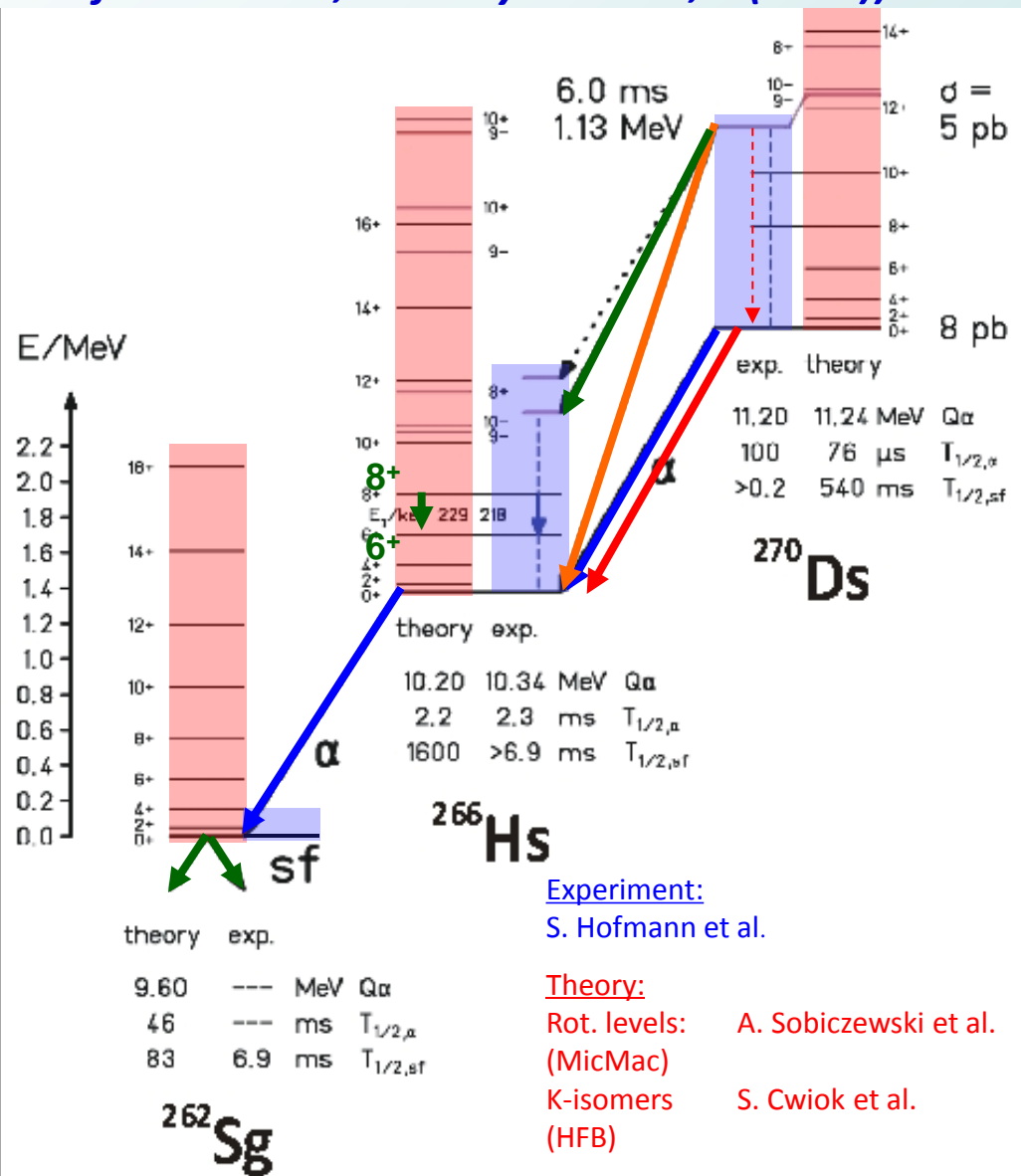
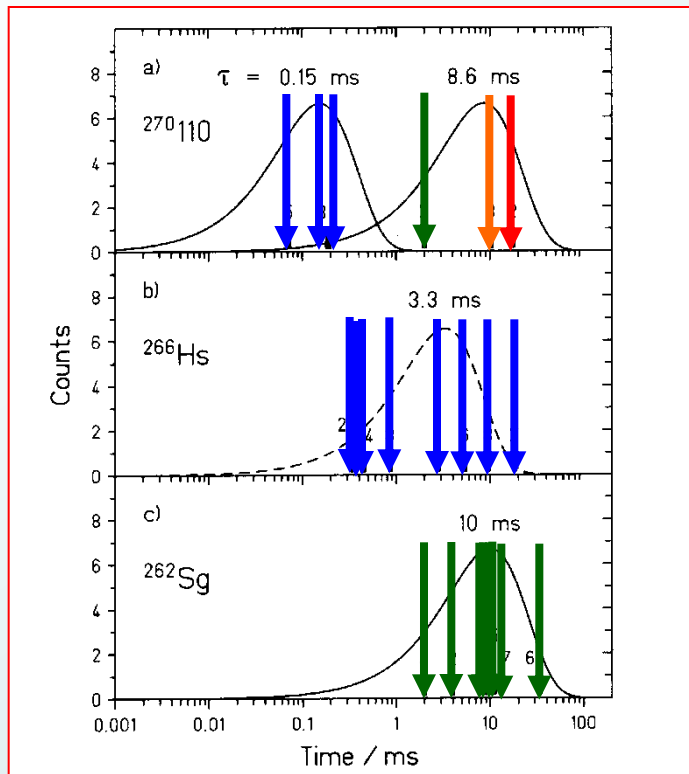
chain# 7

$^{266}\text{Hs} \rightarrow ^{262}\text{Sg}$  (8 chains)

chain# 1-8

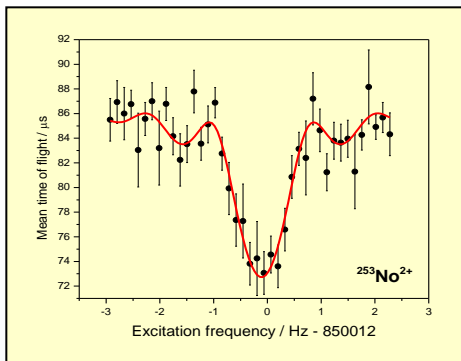
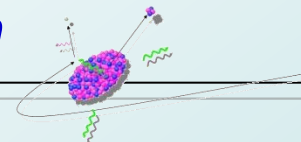
$^{262}\text{Sg}$  decay (8 chains)

chain# 1-8

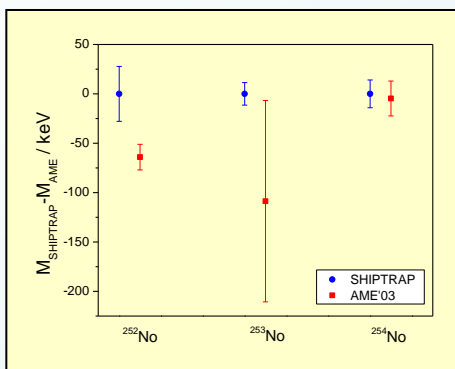


# Decay Chain of $^{270}\text{Ds}$ from $^{64}\text{Ni}+^{207}\text{Pb}$

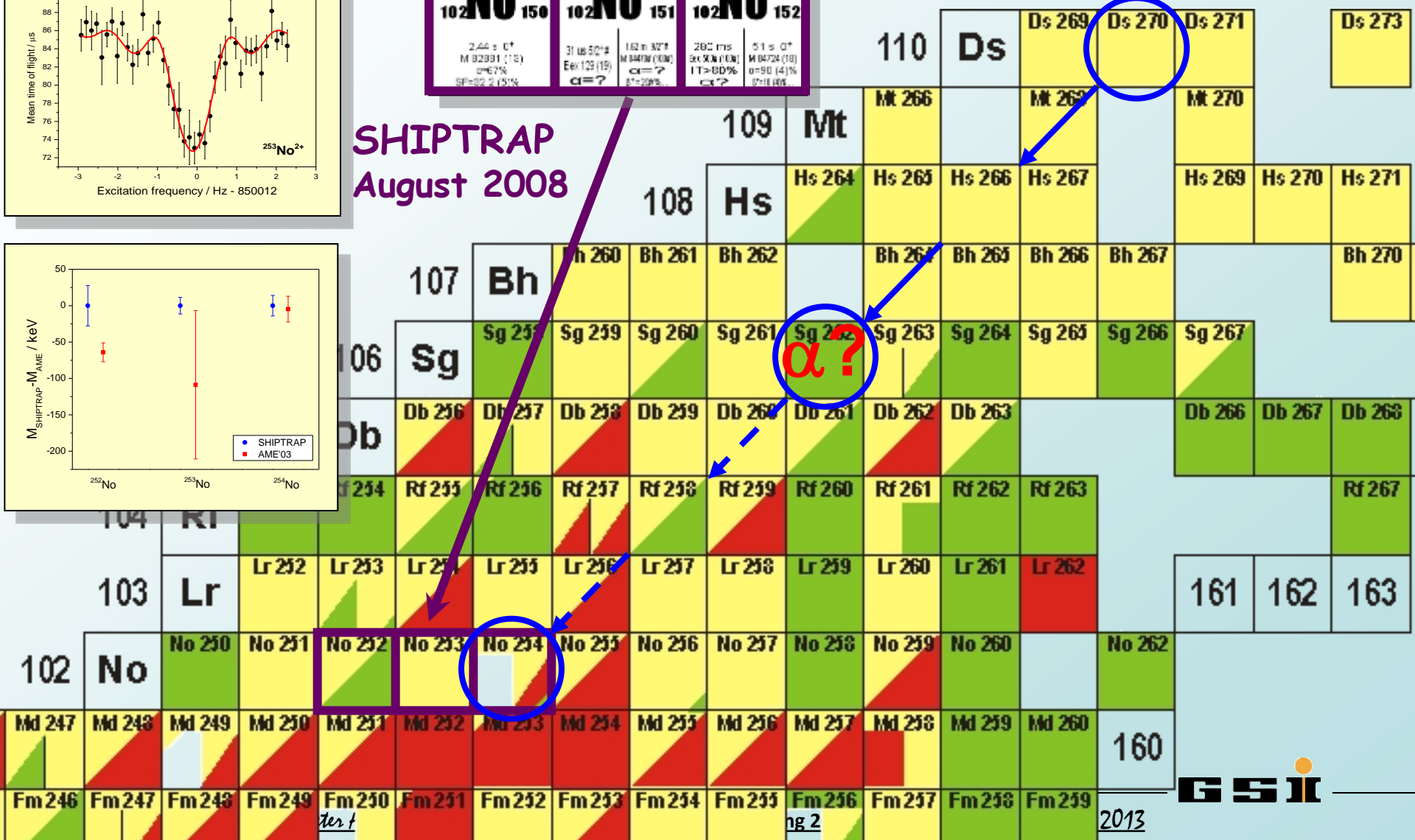
## - Results from October 2000 and Possible Extension



SHIPTRAP  
August 2008

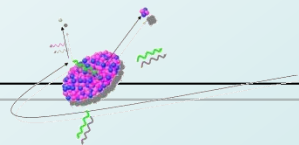


<b>252</b> 102 <b>No</b> 150	<b>253</b> 102 <b>No</b> 151	<b>254</b> 102 <b>No</b> 152
$2.44 \pm 0^+$ M 92391 (18) $\alpha = 67\%$ SF=92.2(51%)	$31.16 \pm 0^+$ E $\alpha$ 129 (19) $\alpha = ?$	$1.62 \pm 0^+$ M 94409 (100) $\alpha = ?$ SF=200%
$280 \text{ ms}$ SF=80%	$51 \text{ s } 0^+$ M 94724 (18) $\alpha = 90(4)\%$ SF=14%	

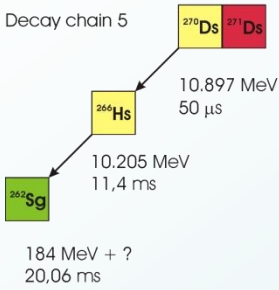


# 2010: Observed types of decay chains

## - ER- $\alpha$ - $\alpha$ - $\alpha$ -sf



### a) ER- $\alpha$ - $\alpha$ -sf



ER:  
Time: 761391.182  
MP: 1531  
Strip#: 11  
E: 38.72 MeV  
Posyt: 14.75 mm  
Posyb: 18.41 mm  
ToF: 1409

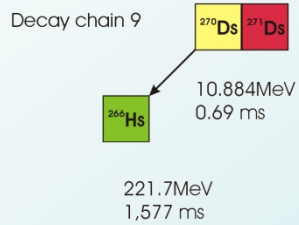
270Ds:  
Time: 761391.182  
MP: 1581  
Strip#: 11  
Estop: 10897 keV  
Posyt: 15.36 mm  
Posyb: 20.45 mm  
Posyb(HE): 18.32 mm  
Egamma1: 1126.9 keV

266Hs:  
Time: 761391.193  
MP: 12976  
Strip#: 11  
Estop: 10205.4 keV  
Posyt: 15.29 mm  
Posyb: 20.57 mm  
Posyt(HE): 10.25 mm

262Sg:  
Time: 761391.213  
MP: 13036  
Strip#: 11  
Estop: 184.58 MeV  
Posyt: 14.70 mm  
Posyb: 18.85 mm  
Box#: 20  
Ebox: --- MeV  
Egamma3: 678.8 keV

15 chains

### b) ER- $\alpha$ -sf



ER:  
Time: 1281611.582  
MP: 1547  
Strip#: 9  
E: 47.65 MeV  
Posyt: 17.63 mm  
Posyb: 15.95 mm  
ToF: 1417

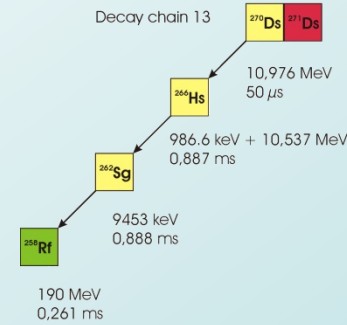
270Ds:  
Time: 1281611.582  
MP: 2235  
Strip#: 9  
Estop: 10883.9 keV  
Posyt: 18.10 mm  
Posyb: 16.50 mm  
Posyt(HE): 18.18 mm  
Posyb(HE): 16.09 mm  
Box#: 21  
Ebox: 12047.2 keV

266Hs:  
Time: 1281611.584  
MP: 3812  
Strip#: 13  
Estop: 221.71 MeV  
Posyt: 17.74 mm  
Posyb: 16.03 mm  
Box#: ---  
Ebox: --- MeV  
Egamma: --- keV

8 chains

$\Rightarrow sf(^{266}\text{Hs}) = 24\%$

### c) ER- $\alpha$ - $\alpha$ - $\alpha$ -sf



ER:  
Time: 1960630.182  
MP: 1940  
Strip#: 10  
E: 40.79 MeV  
Posyt: 18.36 mm  
Posyb: 17.83 mm  
ToF: 1413

270Ds:  
Time: 1960630.182  
MP: 1990  
Strip#: 10  
Estop: 10975.9 keV  
Posyt: 15.23 mm  
Posyb: 18.55 mm  
Posyt(HE): 19.43 mm  
Posyb(HE): 15.66 mm

266Hs:  
Time: 1960630.183  
MP: 2867  
Strip#: 10  
Estop: 986.6 keV  
Posyt: 15.04 mm  
Posyb: 17.53 mm  
Box#: 4  
Ebox: 10536.8 keV

262Sg:  
Time: 1960630.184  
MP: 3755  
Strip#: 10  
Estop: 9453.1 keV  
Posyt: 15.17 mm  
Posyb: 18.60 mm  
Posyt(HE): 20.43 mm  
Posyb(HE): 15.62 mm

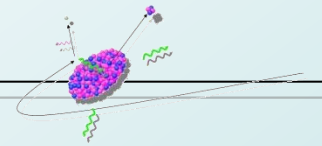
258Rf:  
Time: 1960630.184  
MP: 4016  
Strip#: 9  
Estop: 189.78 MeV  
Posyt: 18.14 mm  
Posyb: 18.65 mm  
Egamma2: 309.7 keV  
Egamma3: 1055.3 keV  
Egamma4: 1095.5 keV

2 chains

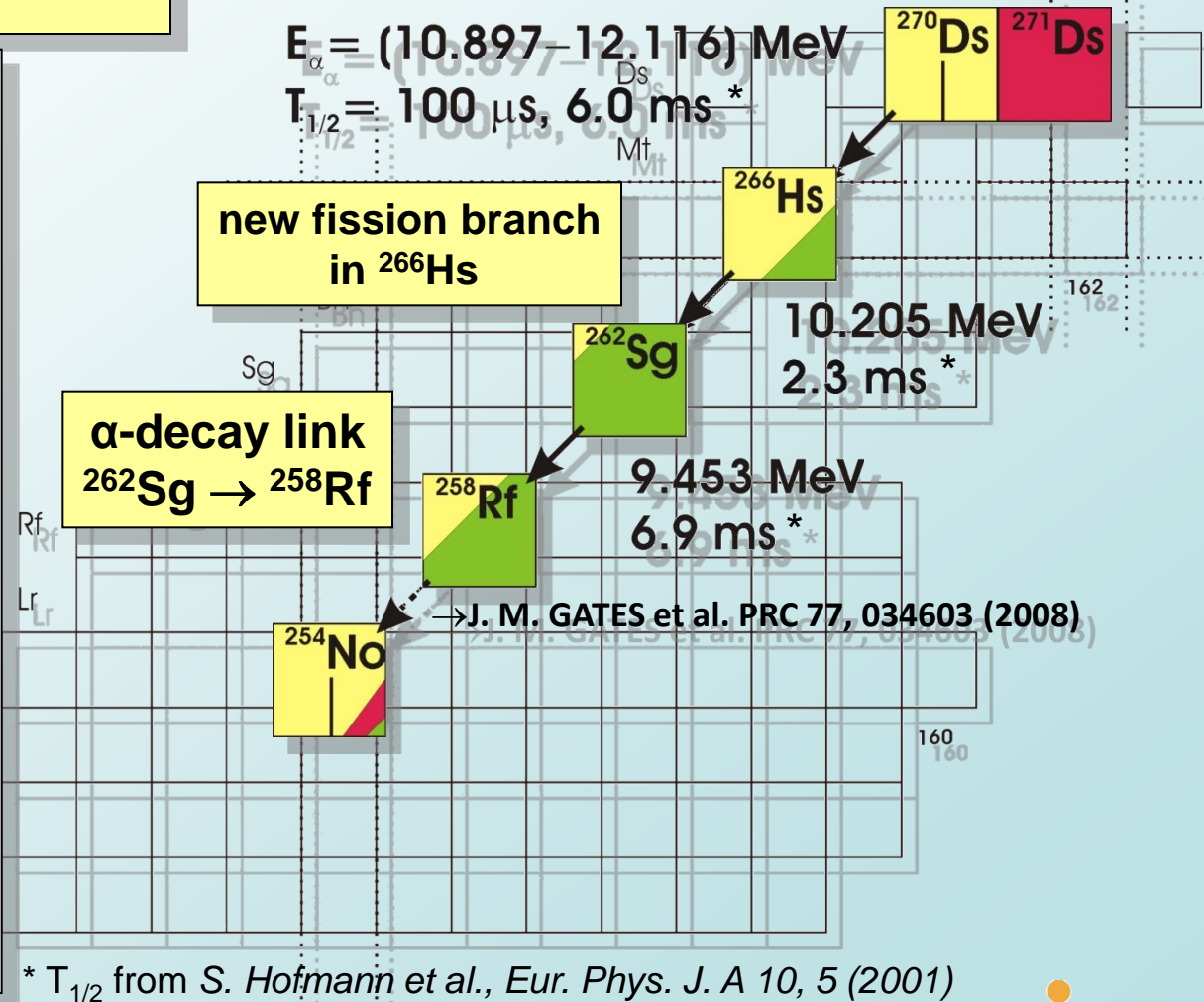
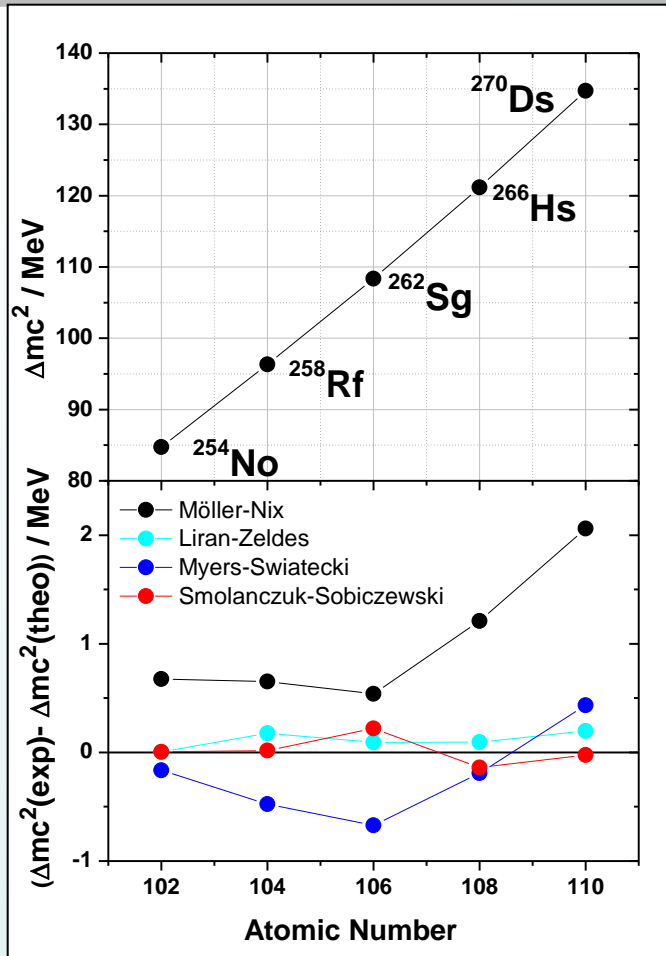
$\Rightarrow \alpha(^{262}\text{Sg}) = 6\%$



## - News III - $^{262}\text{Sg}$ $\alpha$ -branch $\rightarrow$ link to $^{254}\text{No}$



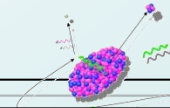
- 26 decay chains ( $^{270}\text{Ds}$ : 25,  $^{271}\text{Ds}$ :1)
- new spectroscopic data





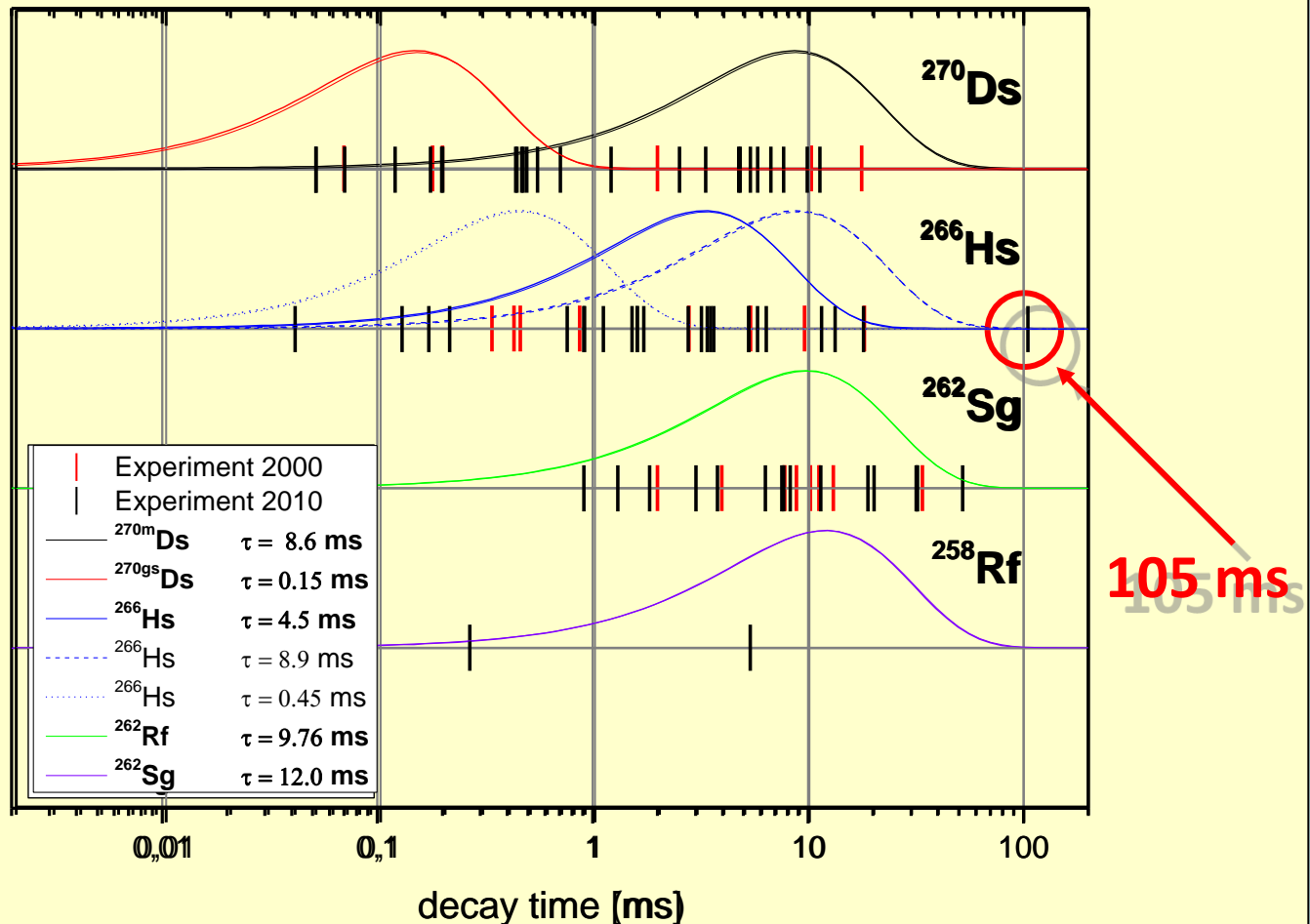
# Decay details

## - time distributions



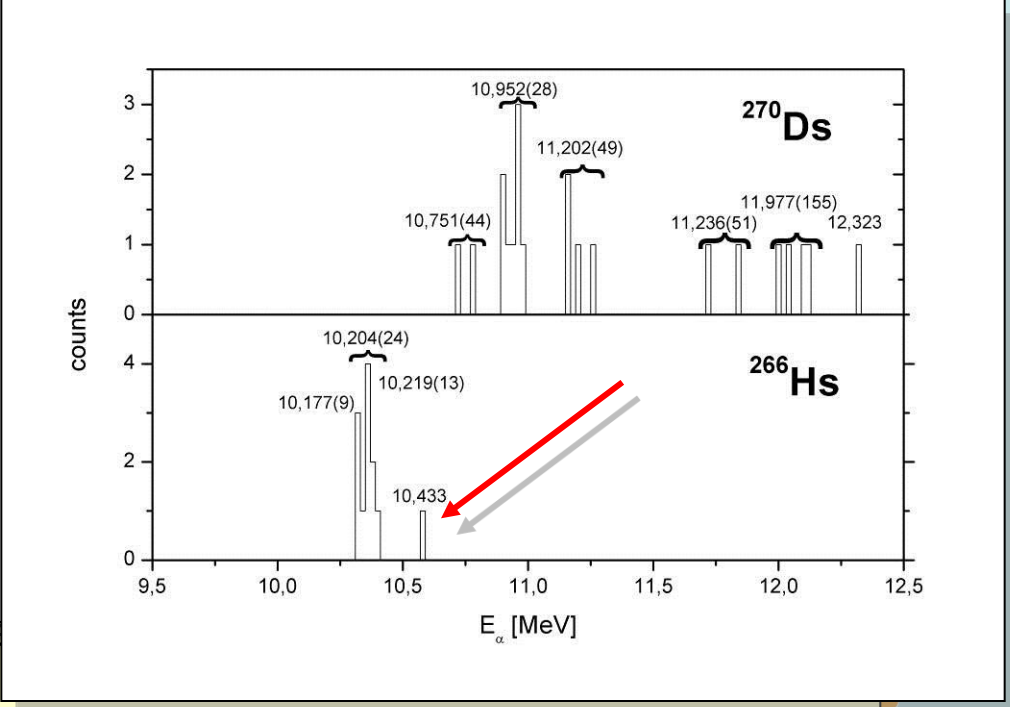
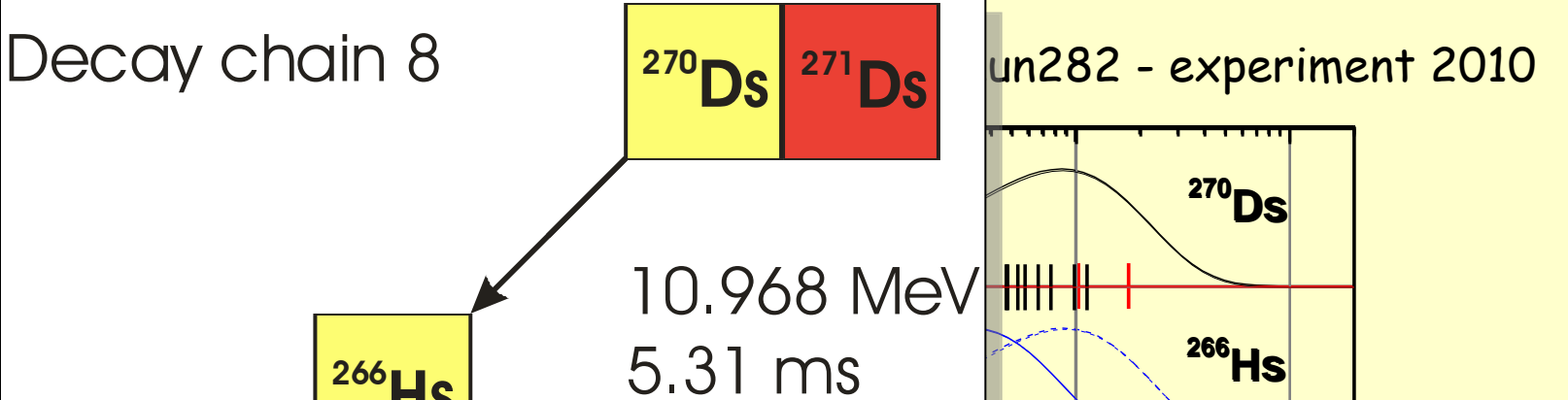
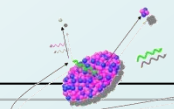
Run 197 - experiment 2000

Run282 - experiment 2010



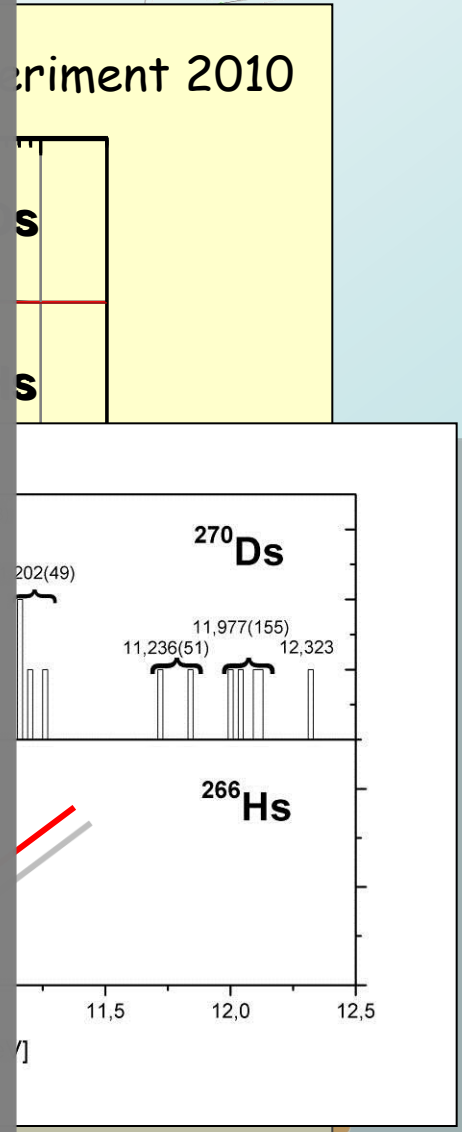
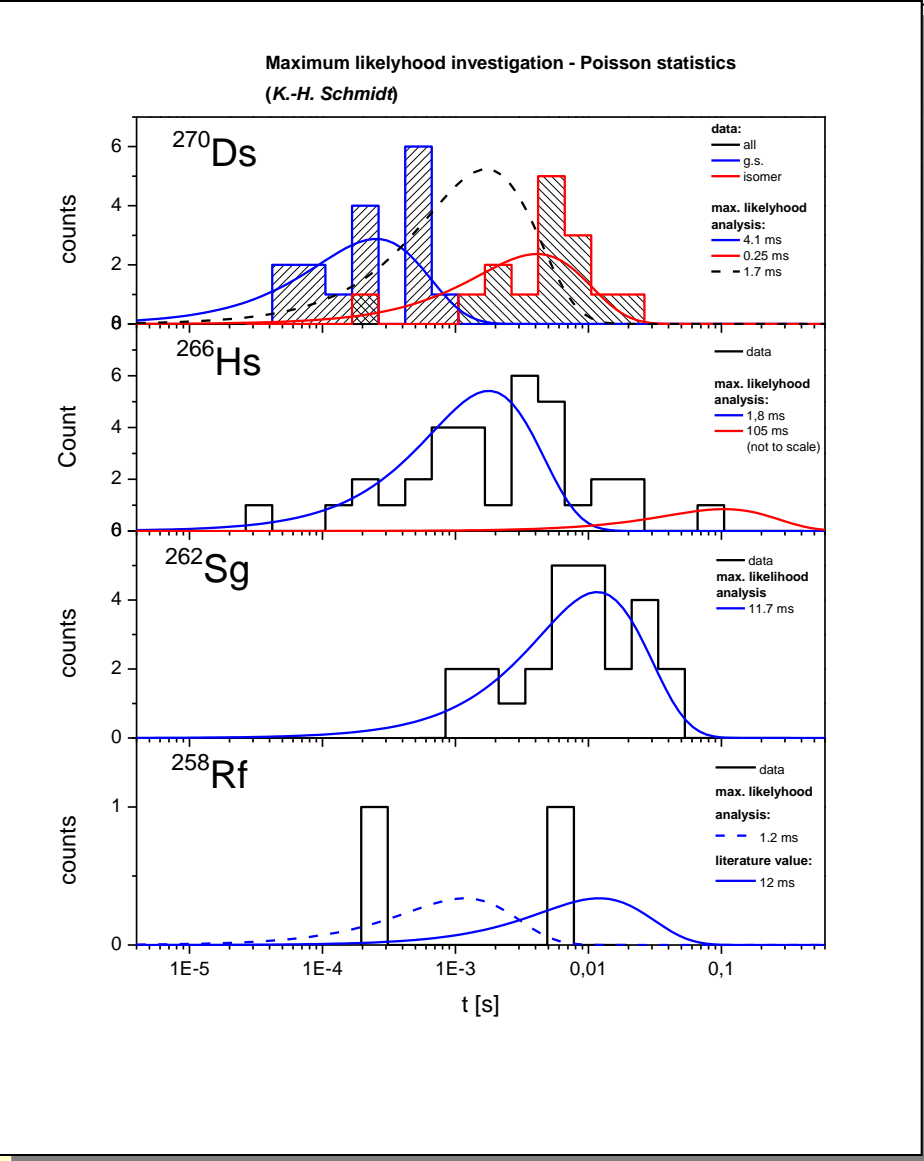
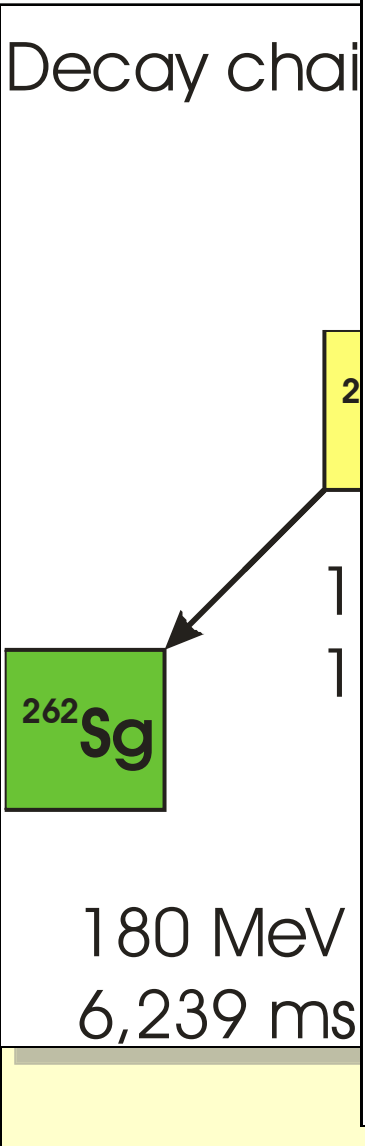
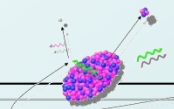
# Decay details

## - time distributions

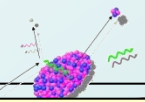


# Decay details

## - time distributions



# $^{270}\text{Ds}$ Decay Scheme



## $^{270}\text{Ds}$ :

12 g.s. decays  
 13 isomer decays - 2  $\gamma$ 's: 175/741 keV  
 (in 2000: 3:3 + 1  $\gamma$ )

chain 8:  
 $E_\alpha$  200-300 keV lower

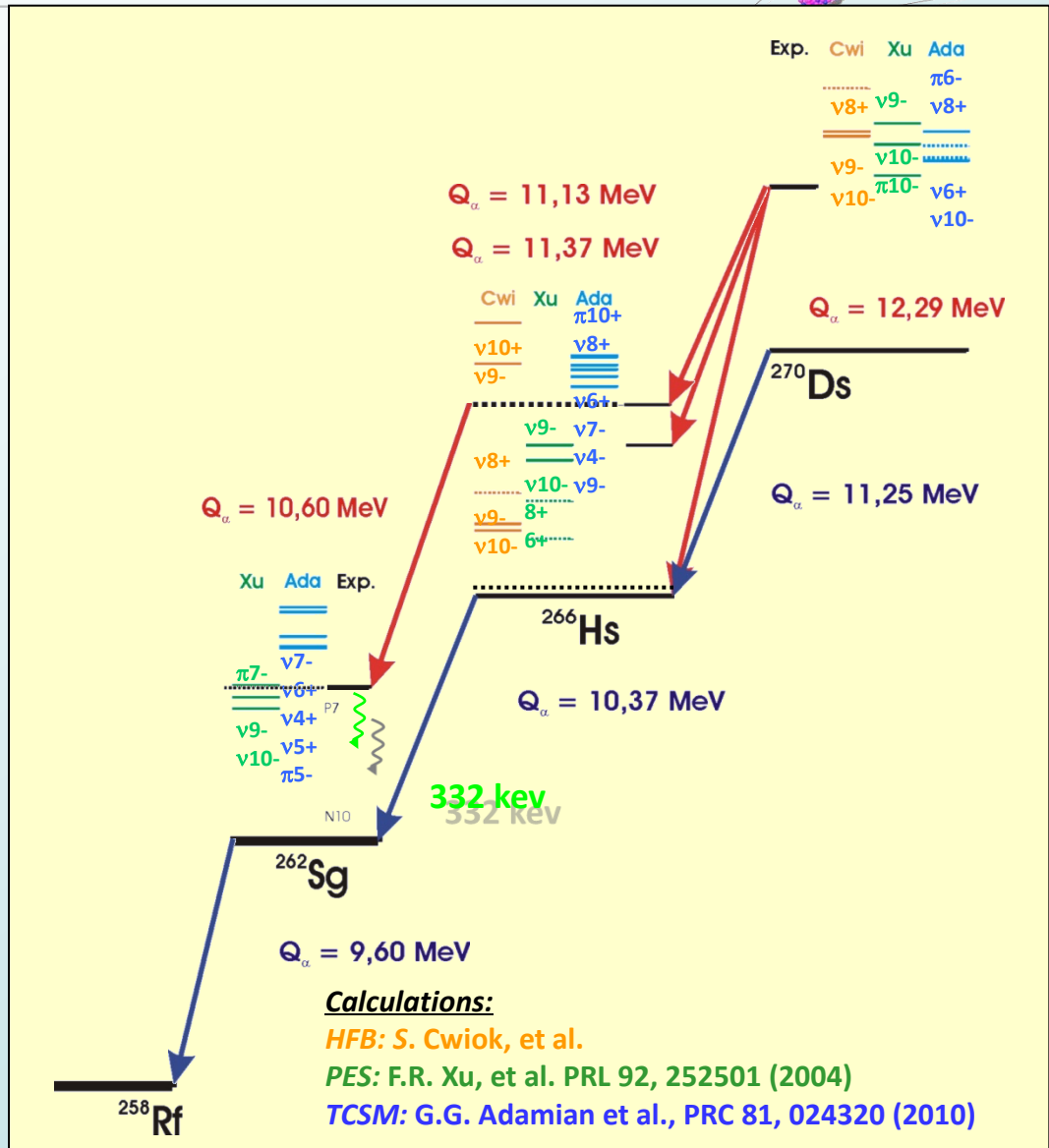
## $^{266}\text{Hs}$ :

16 g.s. decays  
 1 isomer decay  
 with a 332 keV  $\gamma$ -ray

chain 8:  
 $E_\alpha \approx 200$  keV higher  
 $E_\gamma = 332$  keV

## $^{262}\text{Sg}$ :

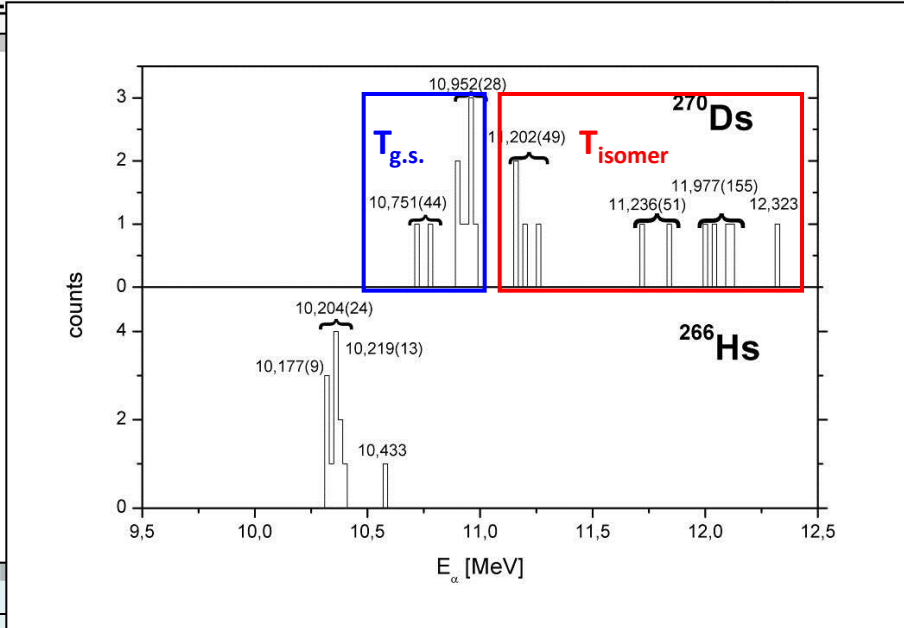
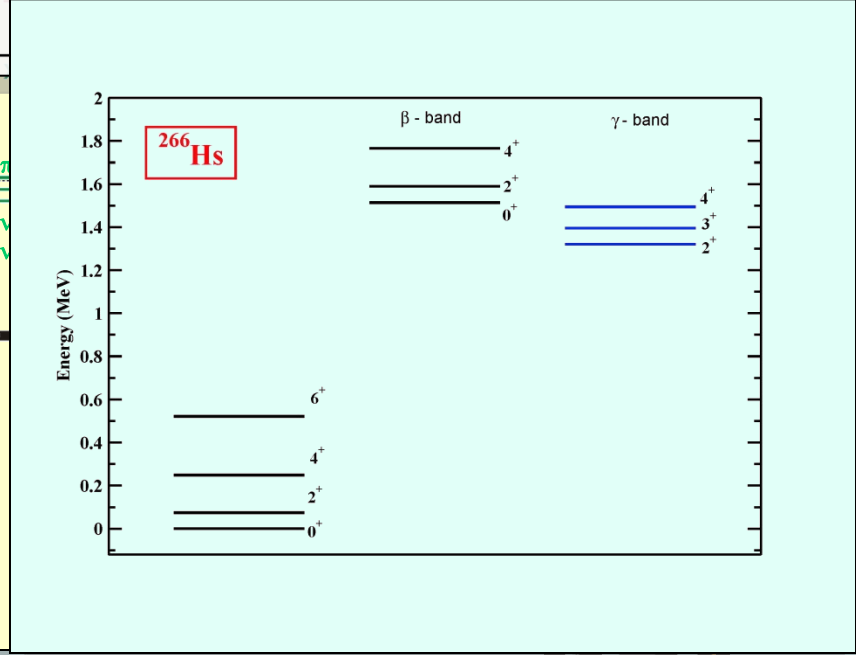
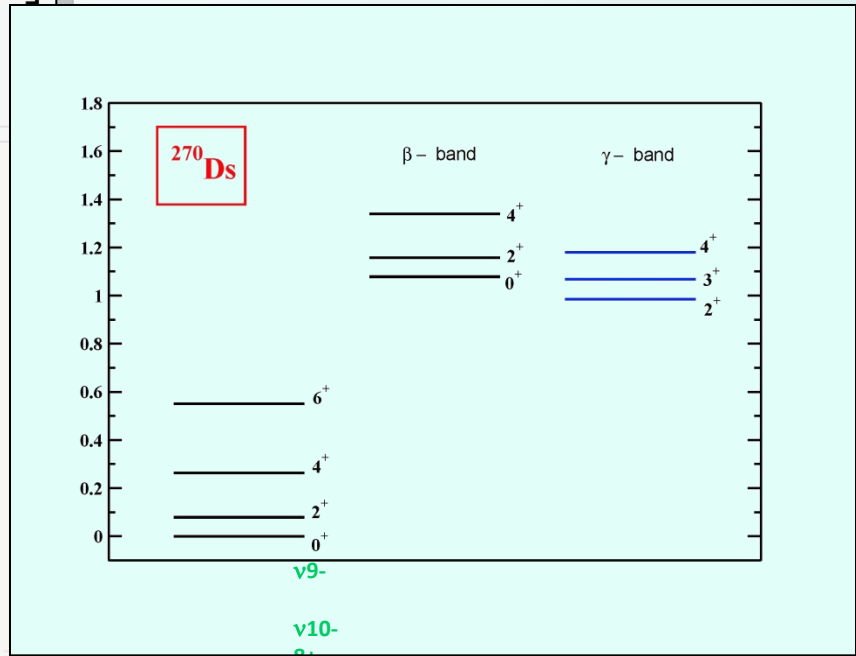
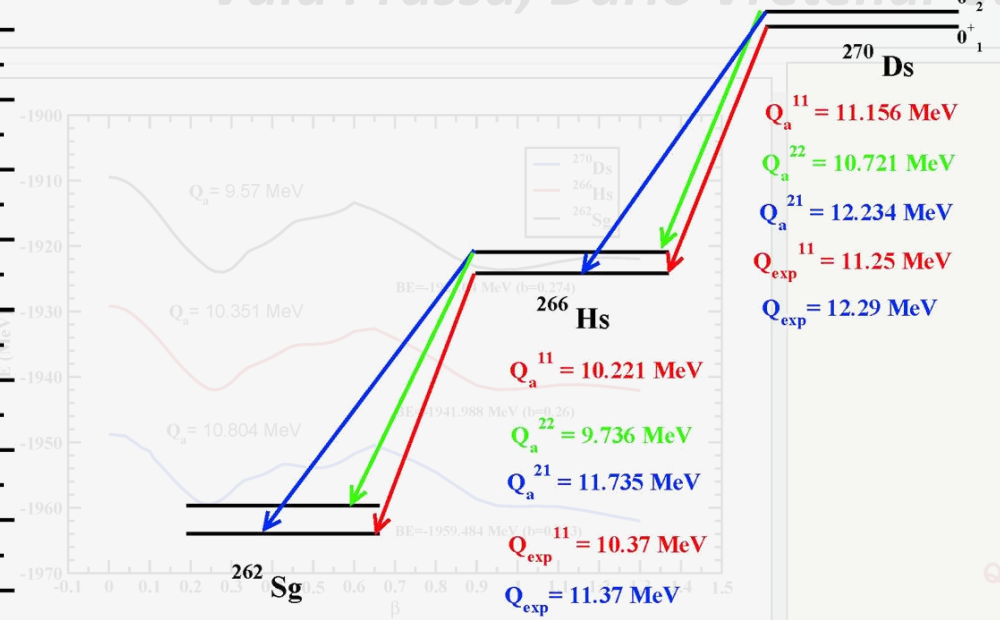
$\alpha$  decay observed for the first time  
 (1 full E, 1 escape)





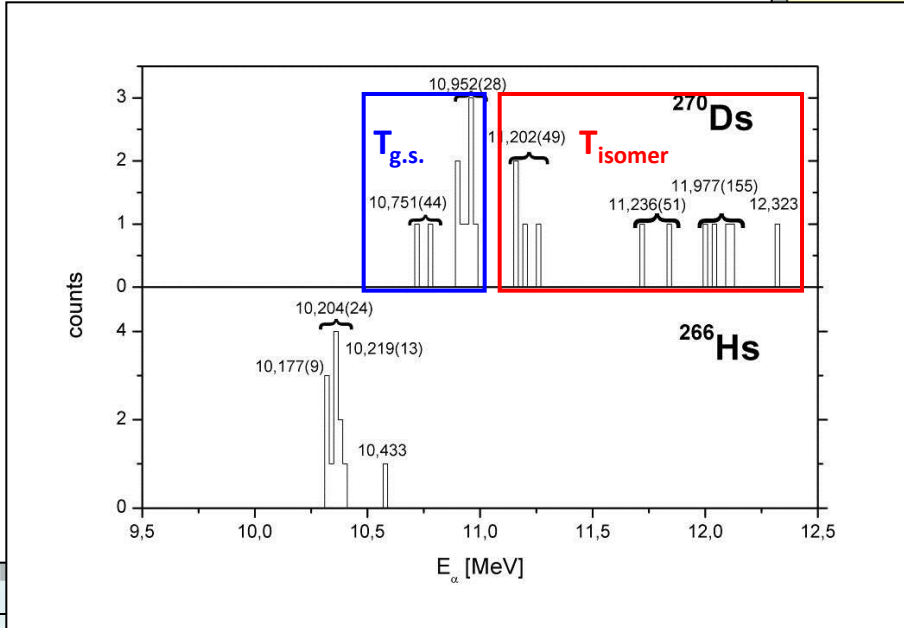
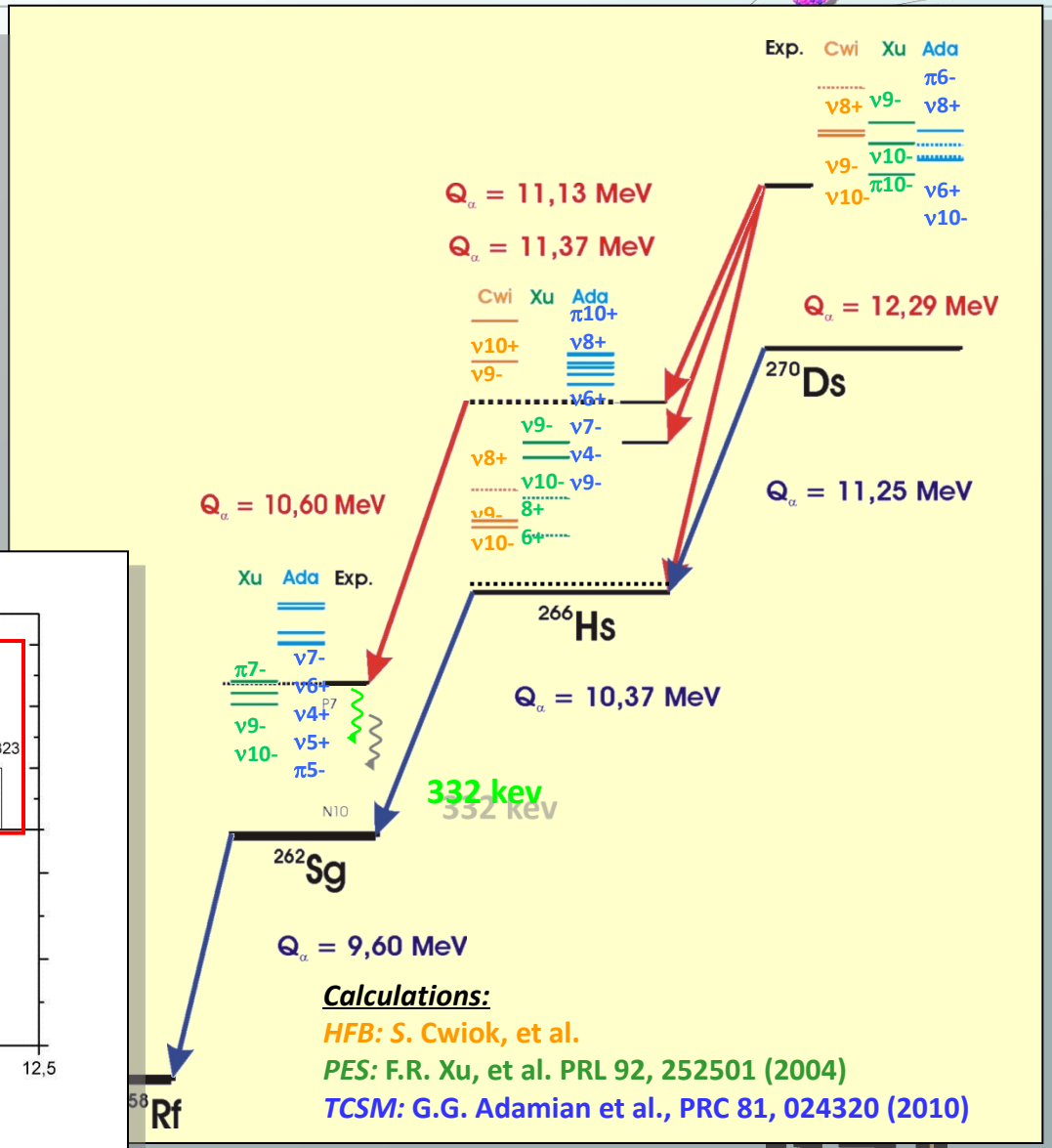
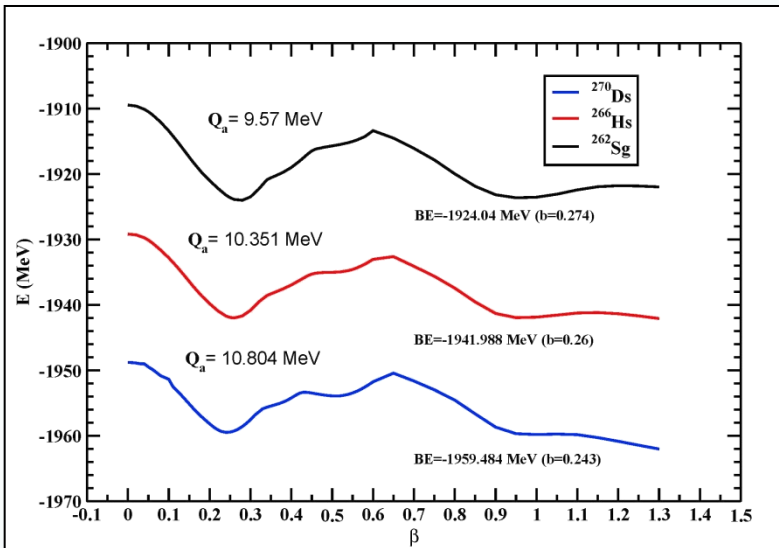
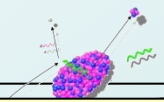
# Energy Density Functional Calculations

- Vaia Prassa, Dario Vretenar et al.



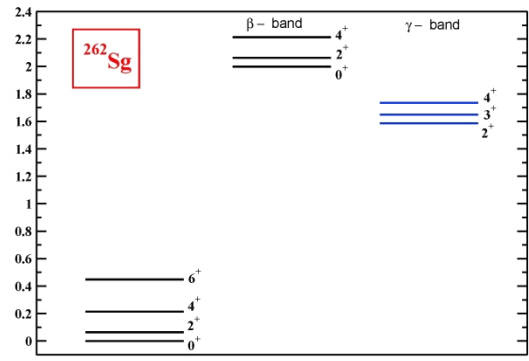
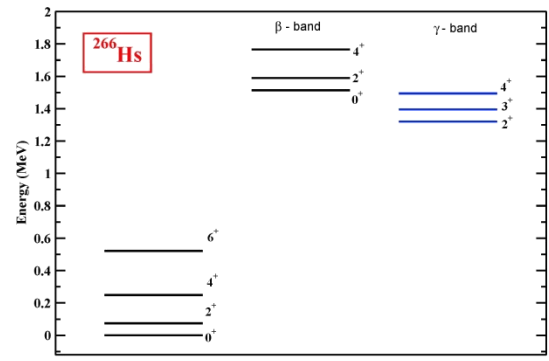
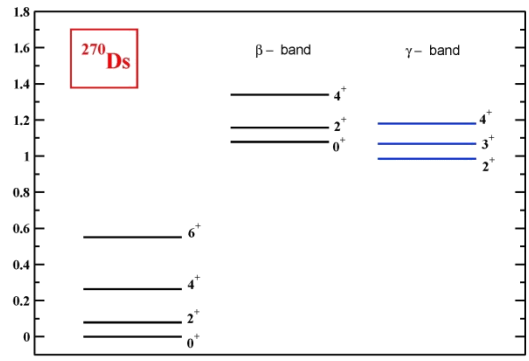
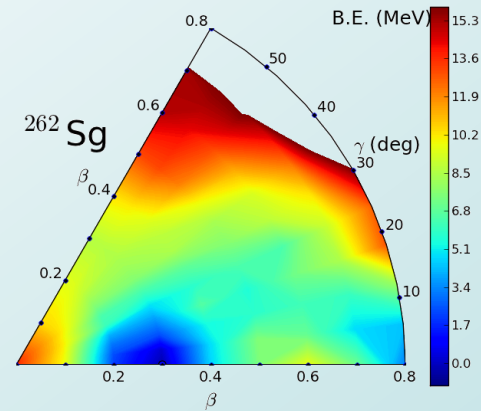
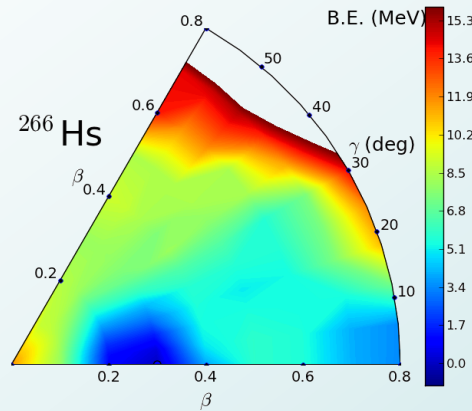
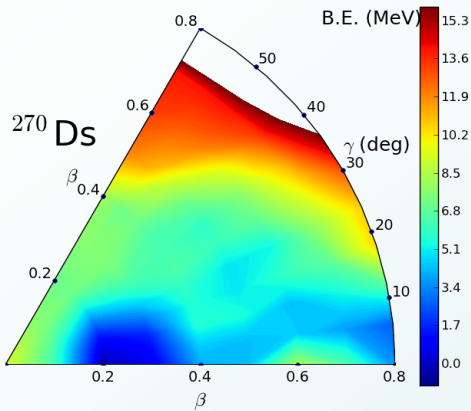
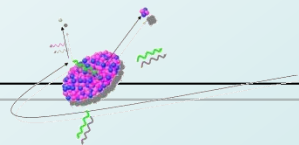
# Energy Density Functional Calculations

## - Vaia Prassa, Dario Vretenar et al.



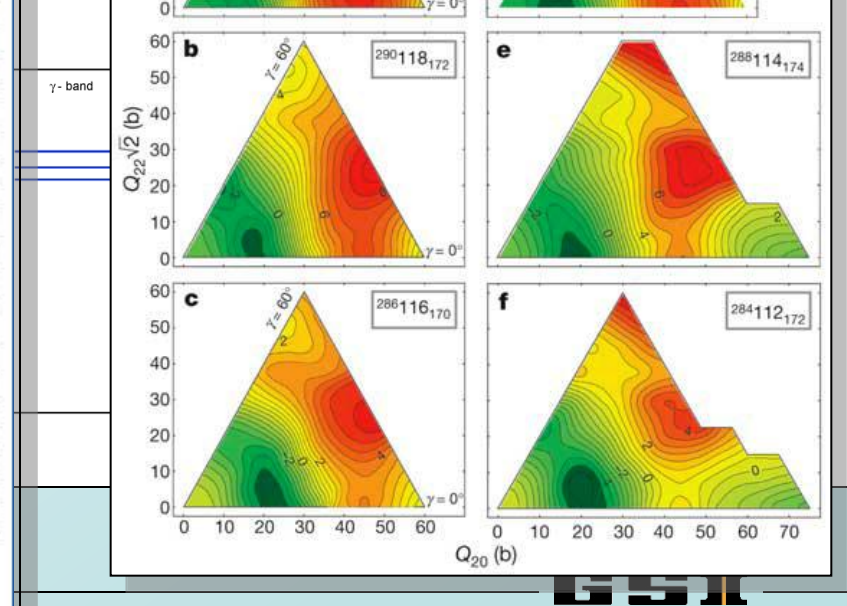
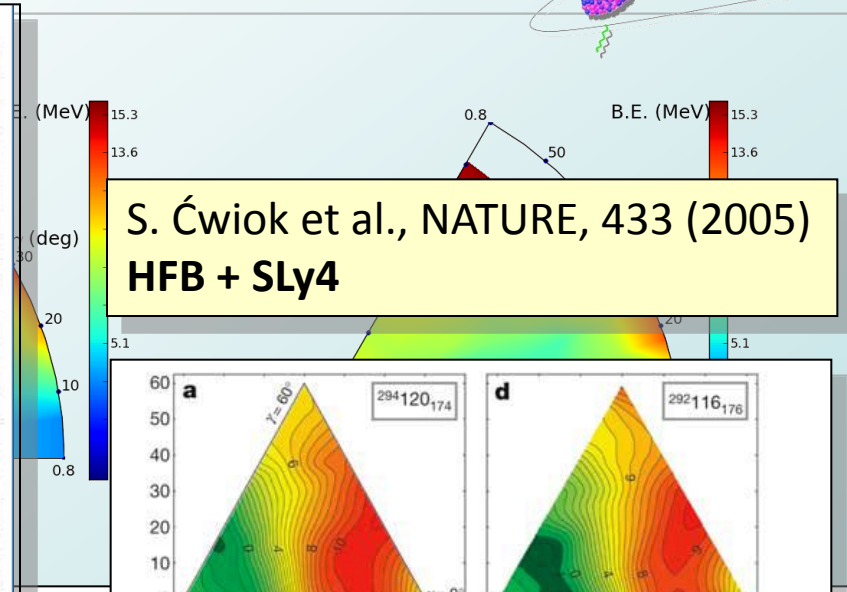
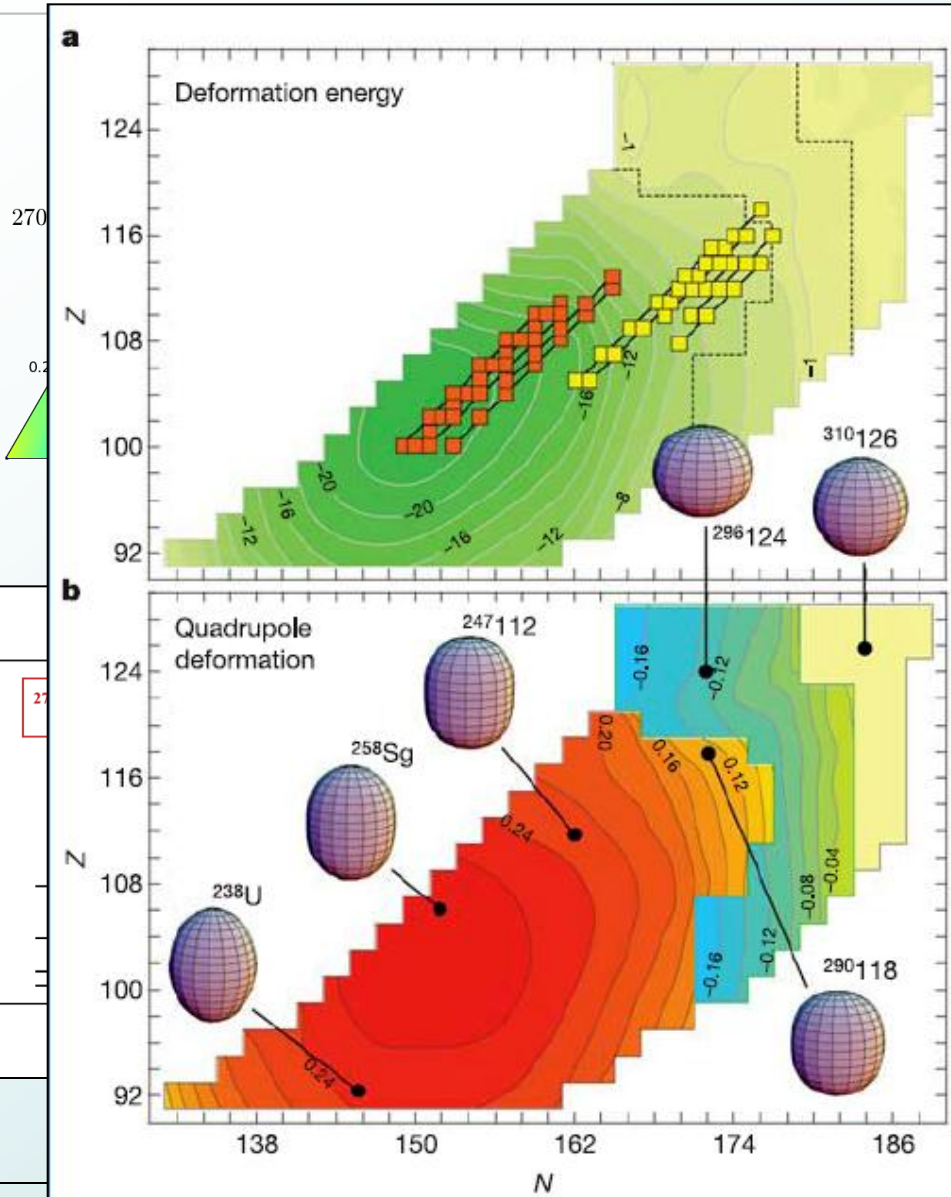
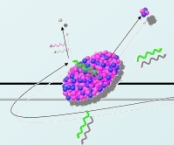
# Energy Density Functional Calculations

- Vaia Prassa, Dario Vretenar et al.



# Energy Density Functional Calculations

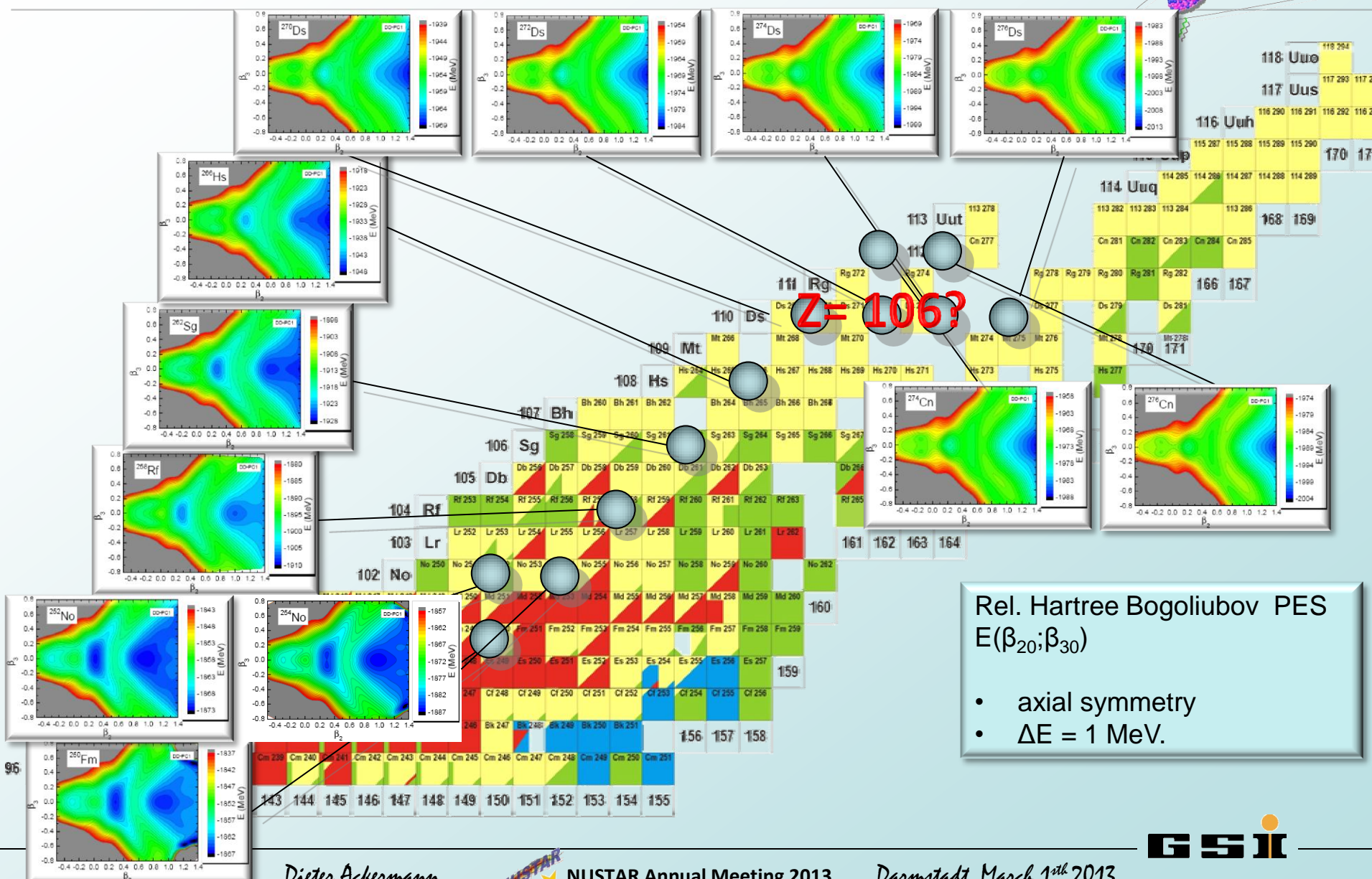
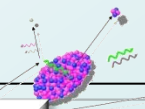
- Vaia Prassa, Dario Vretenar et al.





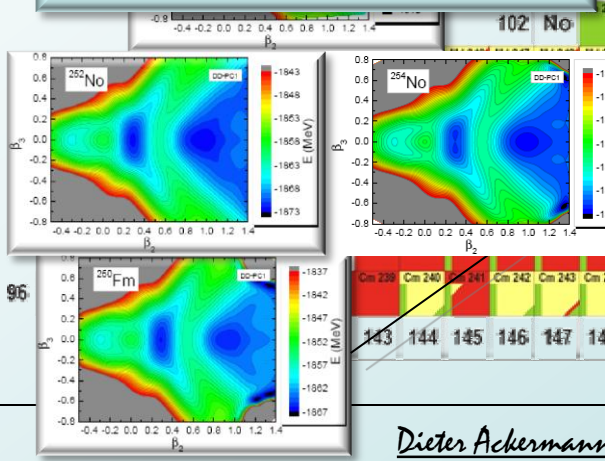
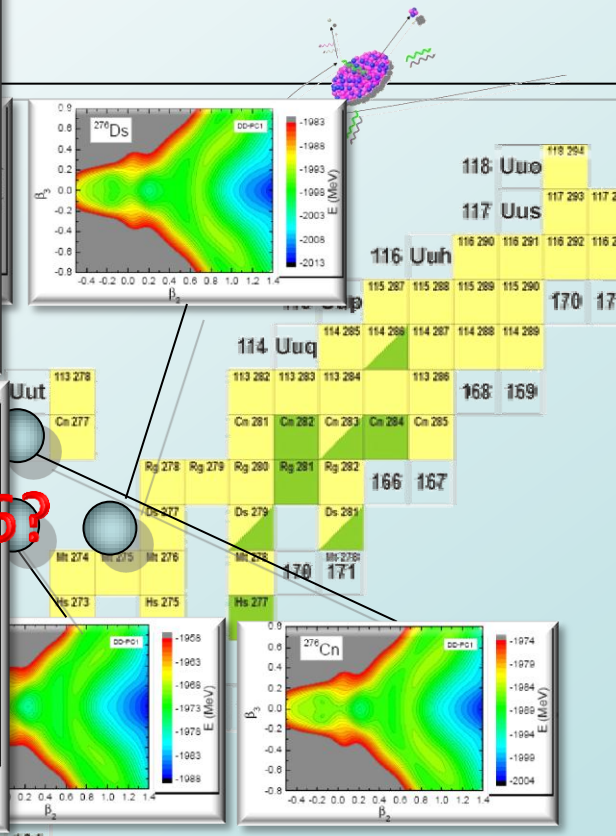
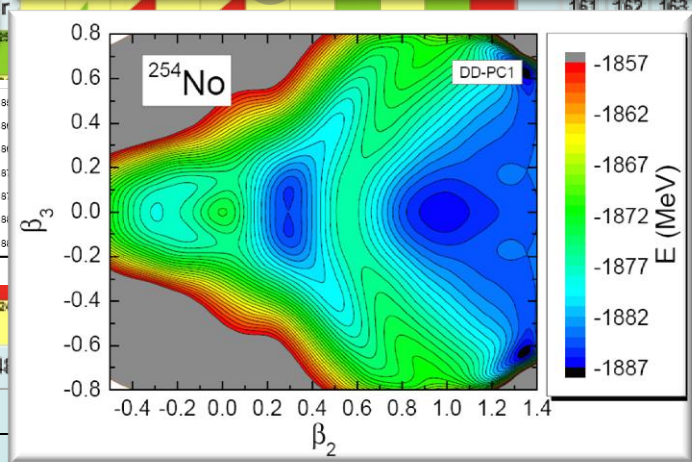
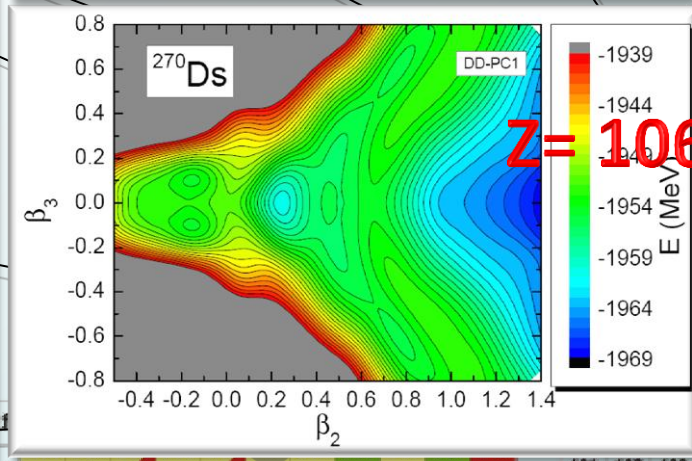
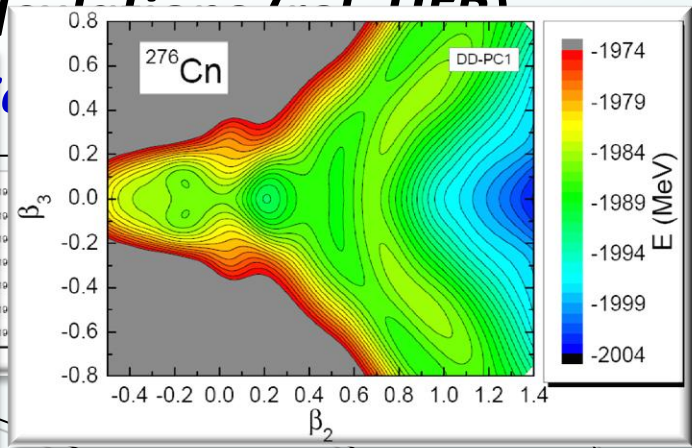
# Potential E surface Calculations (rel. HFB)

- Bingnan Lu, Dario Vretenar et al.



# Potential E surface Cal

- g.s. deformation varies slowly from Z=100 to 112
- wide octupole range for second minimum for Fm and No isotopes
- second minimum decreases → K-isomer in  $^{276}\text{Cn}$ ?
- Z = 112: at the edge of the sperical shell stabilized region - "island of stability"?



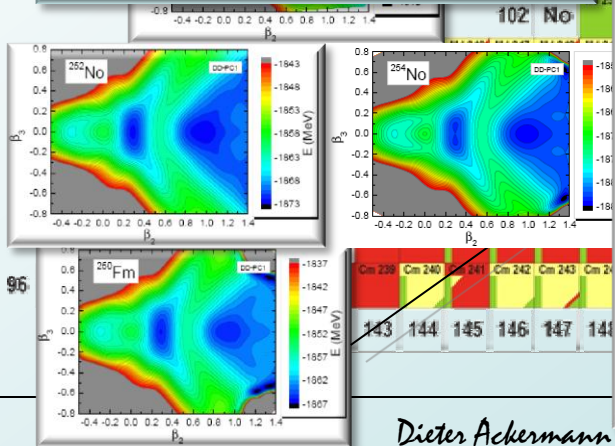
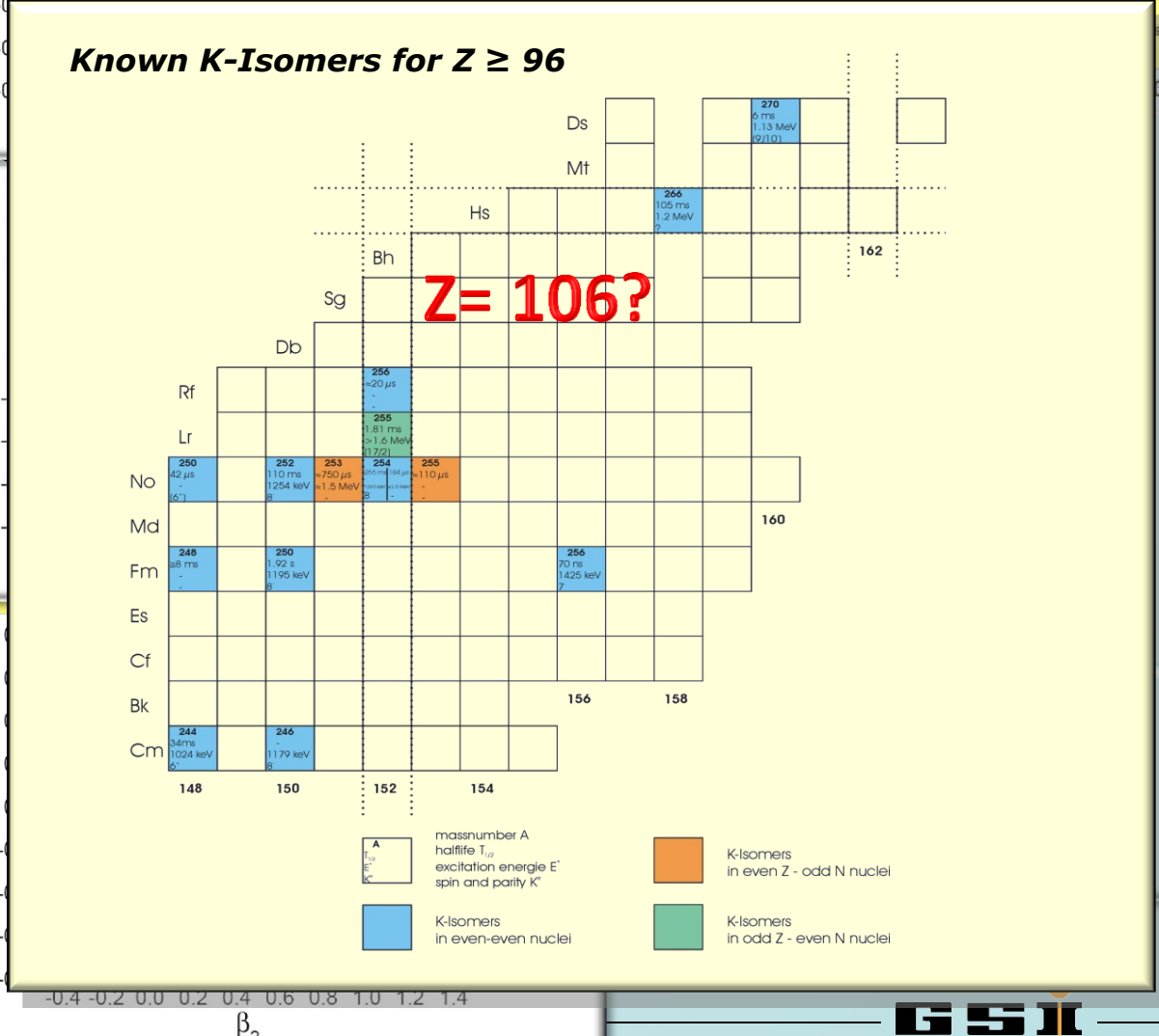
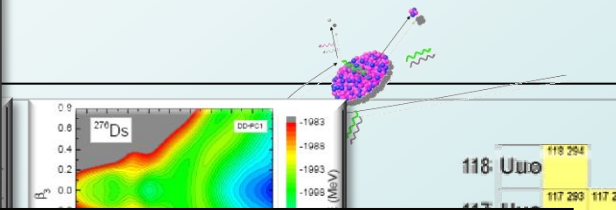
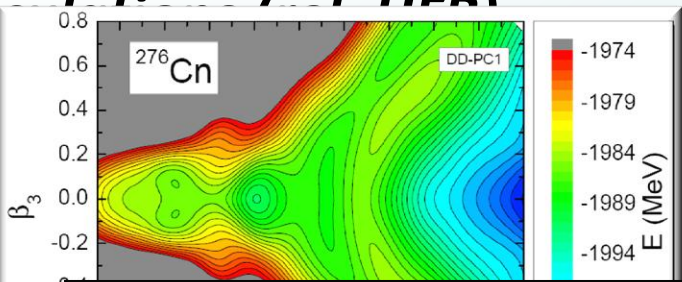
Rel. Hartree Bogoliubov PES  
 $E(\beta_{20};\beta_{30})$

- axial symmetry
- $\Delta E = 1 \text{ MeV}$ .



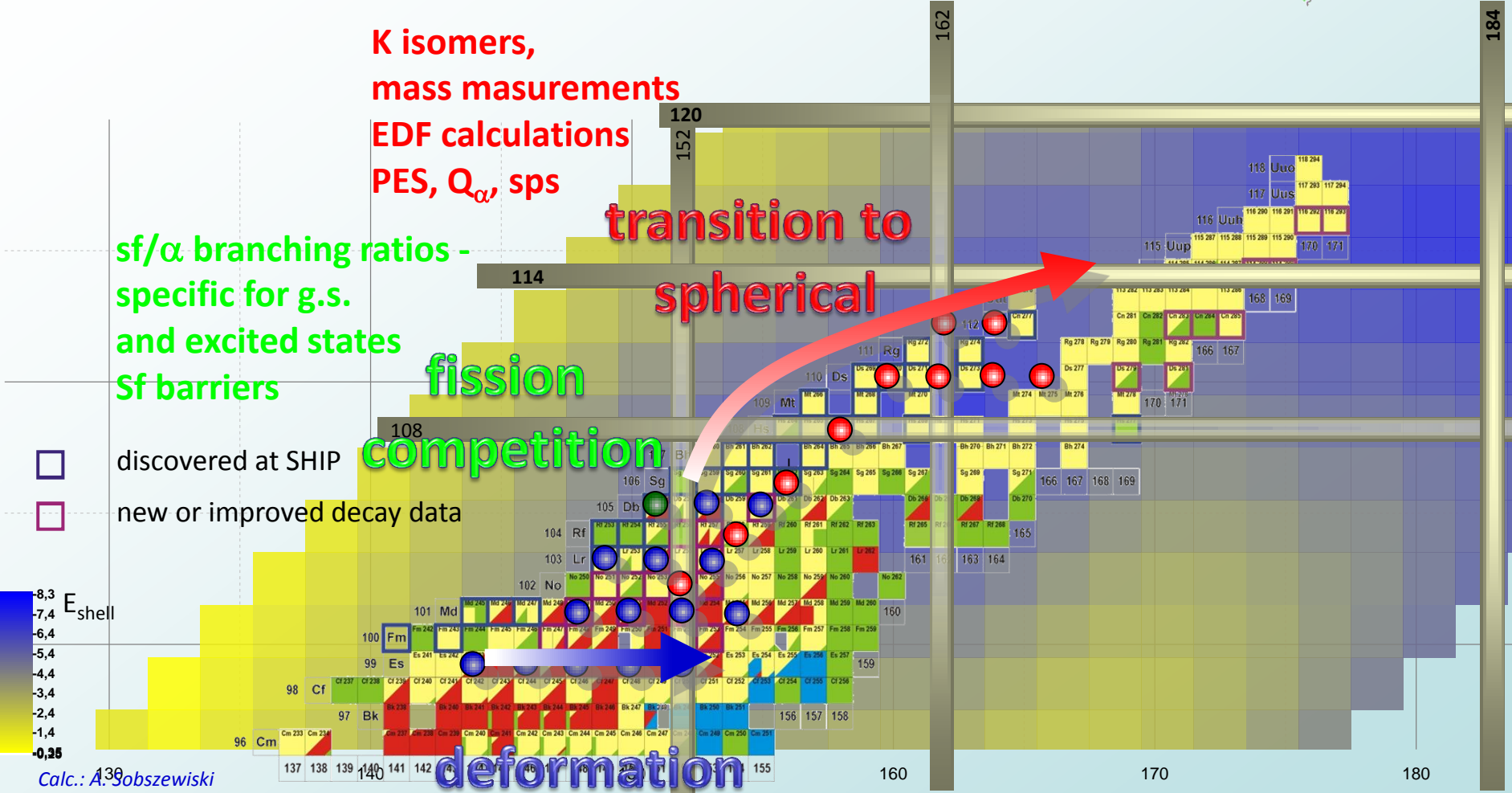
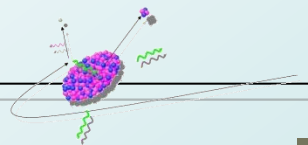
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# Summary and outlook

- approaching and understanding SHE



K isomers,  
mass measurements  
EDF calculations  
PES,  $Q_{\alpha}$ , sps

sf/ $\alpha$  branching ratios -  
specific for g.s.  
and excited states  
Sf barriers

transition to  
spherical

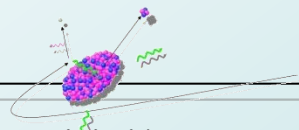
fission  
competition

- discovered at SHIP
- new or improved decay data

deformation  
single particle states (sps)  
transition energies



# The SHIP Collaboration



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