^{270}Ds and Its Decay Products
– Decay Properties and Experimental Masses

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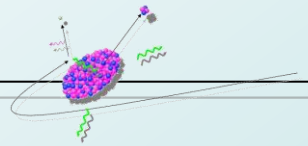
Sochi, September 8th 2011

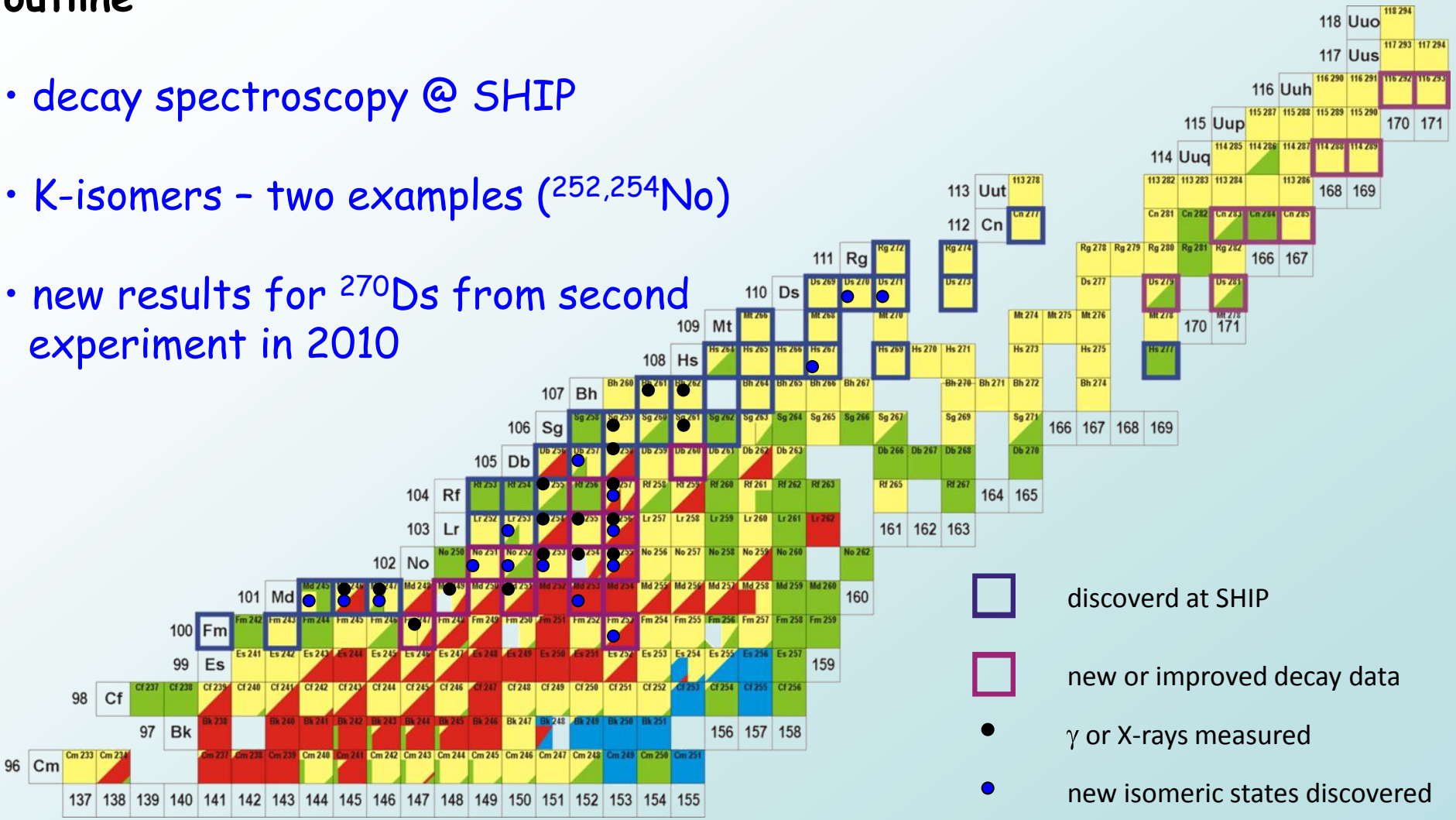
Nuclear Structure Studies at SHIP

- Status Overview



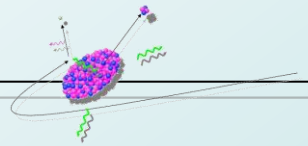
outline

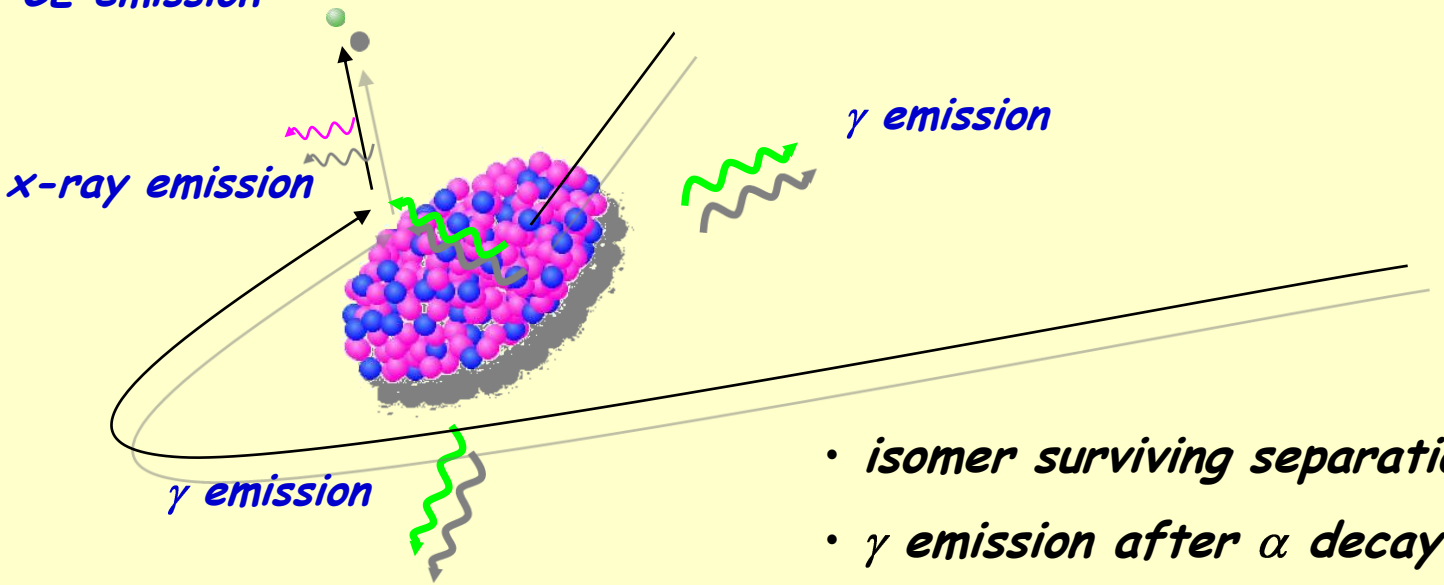
- decay spectroscopy @ SHIP
- K-isomers – two examples (^{252,254}No)
- new results for ^{270}Ds from second experiment in 2010



Nuclear Structure of SHE

- Decay Spectroscopy at SHIP/TASCA



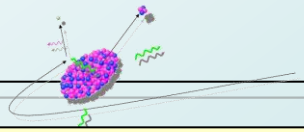


- isomer surviving separation
- γ emission after α decay
- CE for highly converted transitions + X-ray emission

evaporation residue after separation

Nuclear Structure of SHE

- Decay Spectroscopy at SHIP/TASCA

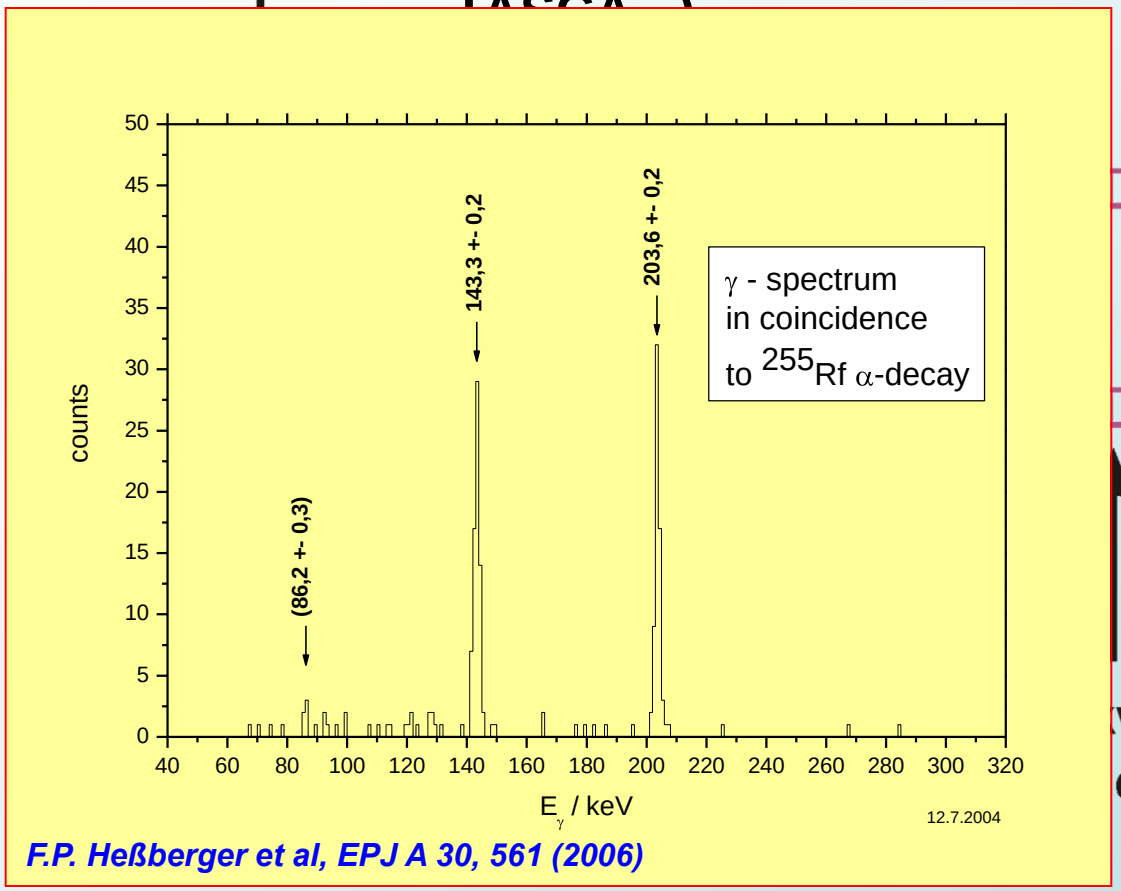


- **inclusive measurement**
  - ER, α's, γ's and e⁻
- **clean**
  - particle discrimination
  - ER-α-γ correlations
- **highly efficient**
  - close geometry
  - stopped source

Target (rot. wheel)

Separator (e.g. SHIP, TASCA, ...)

Focal Plane



F.P. Heßberger et al, EPJ A 30, 561 (2006)

high eff.
ε ≈ 15%

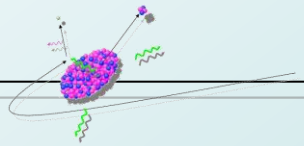
'STOP'
α

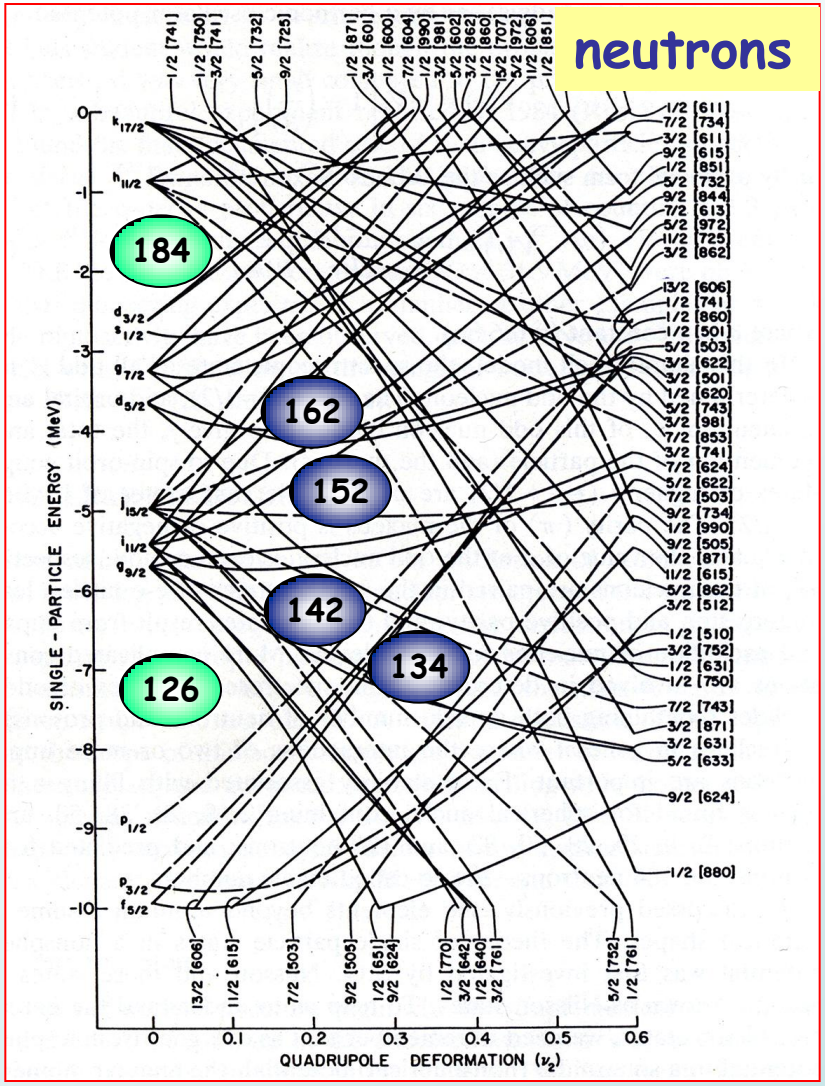
'ward'
CE

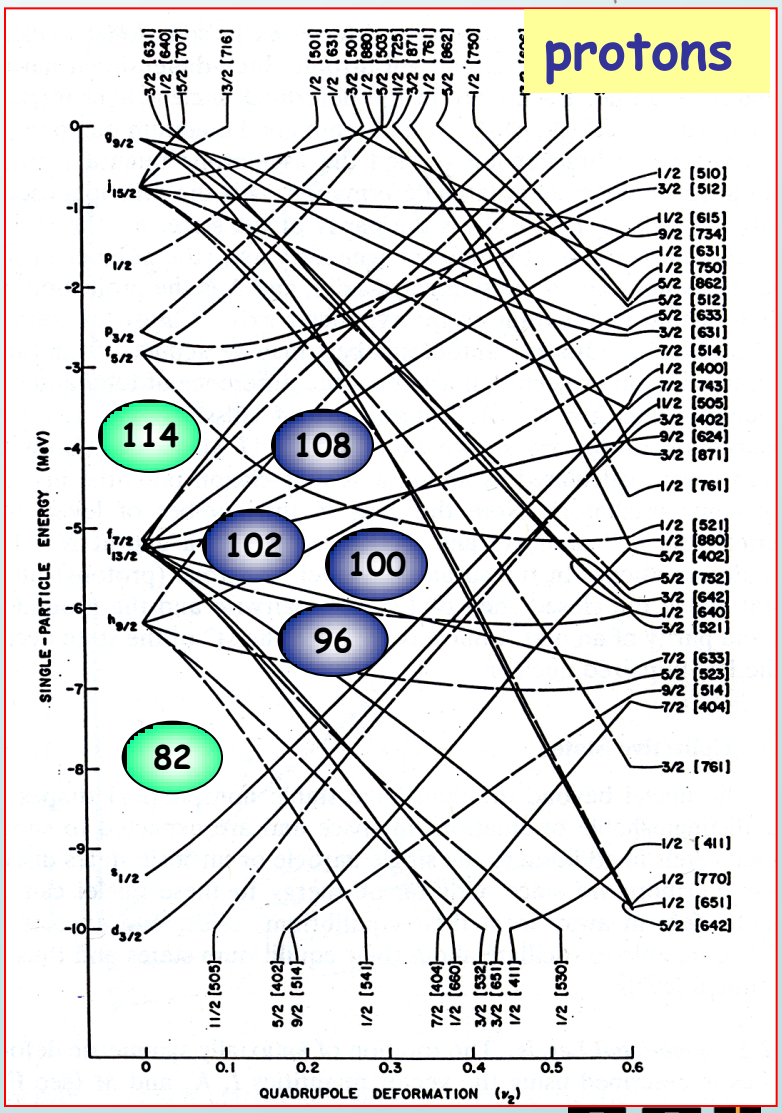
γ - ray
(segmented)

Nuclear Structure of Heavy Nuclei

- Single Particle Levels and Deformation

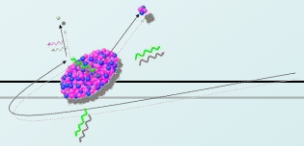


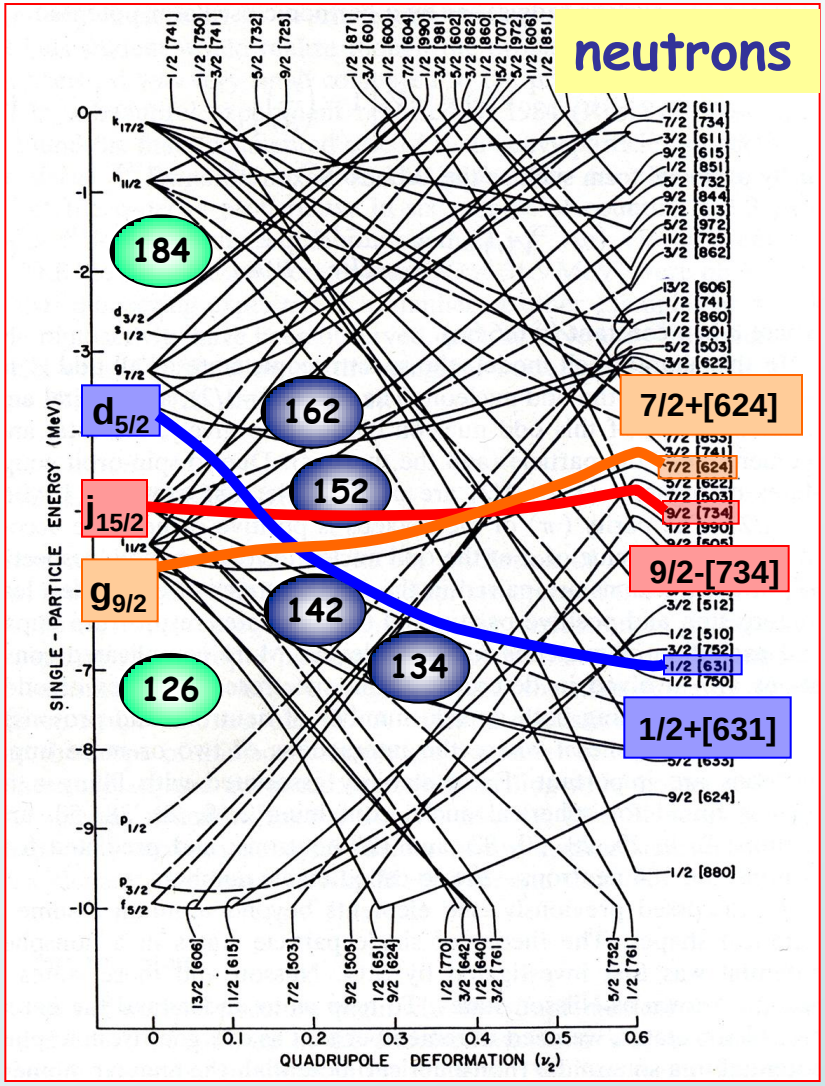


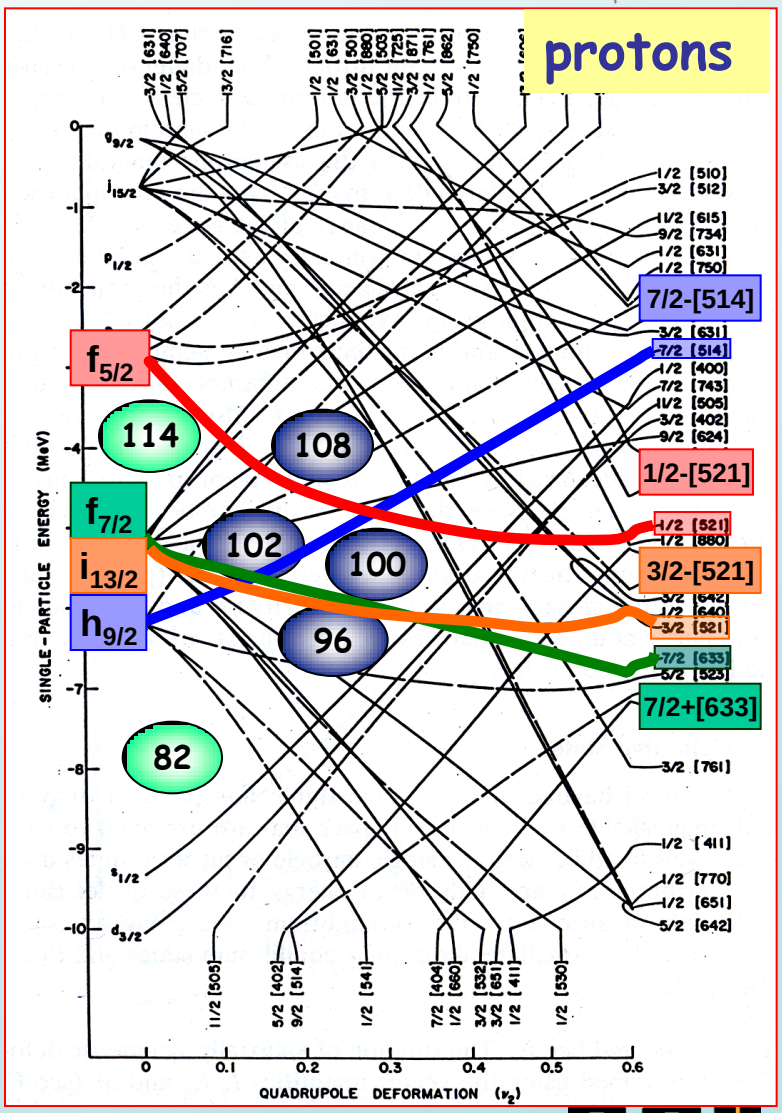


Nuclear Structure of Heavy Nuclei

- Single Particle Levels and Deformation



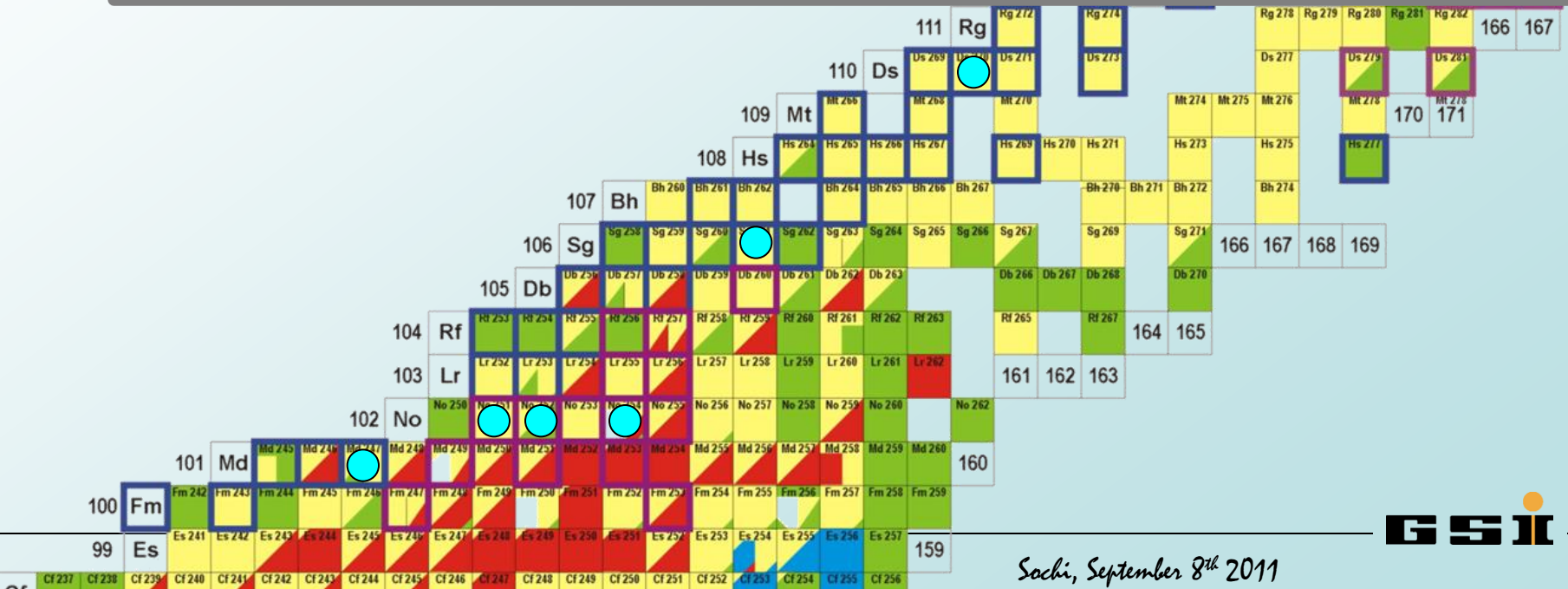




Nuclear Structure of the Heaviest Nuclei:

- Production Rates

reaction	σ/nbarn	I_{beam}/pμA	countrate
$^{208}Pb(^{48}Ca,2n)^{254}No$	2000	1	15000 /h
		(at RITU/Jyväskylä	200 /h)
$^{206}Pb(^{48}Ca,2n)^{252}No$	430	1	3300 /h
$^{206}Pb(^{48}Ca,3n)^{251}No$	25	1	200 /h
$^{209}Bi(^{40}Ar,2n)^{247}Md$	7	3	80 /h
$^{208}Pb(^{54}Cr,1n)^{261}Sg$	2	1	15 /h
$^{207}Pb(^{64}Ni,1n)^{270}Ds$	0.013	0.5	1 /d



K-isomers for Z = 96 - 110

- Experimental Information

13 cases:

even-even:	10
even-odd:	2
odd-even:	1

Sg and Hs isotopes?

$T_{1/2}$: 70 ns (^{256}Fm) – 1.92 s (^{250}Fm)

E*: 1-1.5 MeV (2.5 MeV for ^{254m2}No)

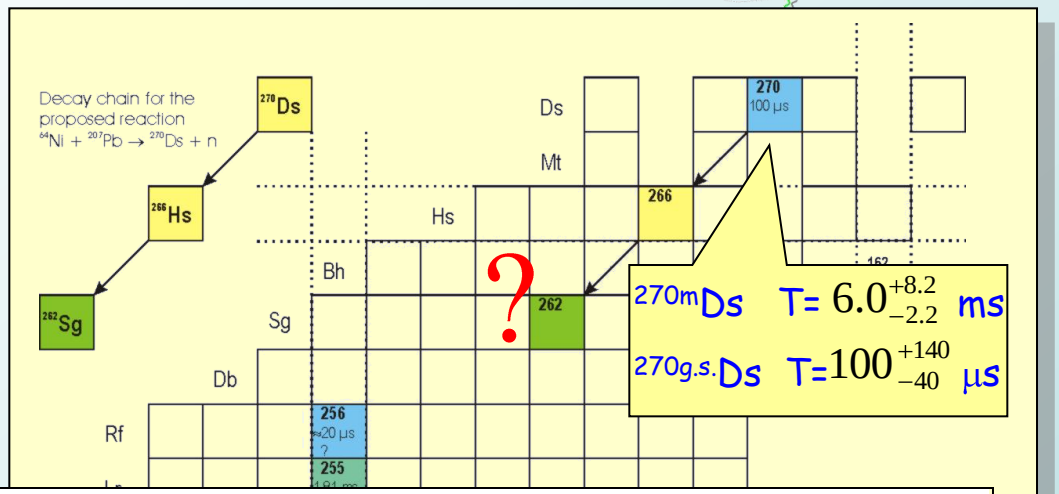


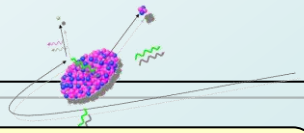
Table 1
Table of known K-isomers in even–even nuclei in the heavy and superheavy elements

Nucleus	K^π	$T_{1/2}$	E_x	Decay Mode	Configuration	Reference
^{244}Cm	6^+	34 ms	1.040 MeV	γ	$5/2^+[622]_\nu \otimes 7/2^+[624]_\nu$	[135,171]
^{246}Cm	8^-	–	1.179 MeV	γ	$7/2^+[624]_\nu \otimes 9/2^-[734]_\nu$	[138]
^{248}Fm	–	≃8 ms	–	γ	-	[148]
^{250}Fm	8^-	1.92 s	1.195 MeV	γ	$7/2^+[624]_\nu \otimes 9/2^-[734]_\nu$	[82]
^{256}Fm	7^-	70 ns	1.425 MeV	γ,SF	$7/2^+[633]_\pi \otimes 7/2^-[514]_\pi$	[69]
^{250}No	(6^+)	42 µs	–	SF,γ?	$(5/2^+[622]_\nu \otimes 7/2^+[624]_\nu)$	[118]
^{252}No	8^-	110 ms	1.254 MeV	γ	$7/2^+[624]_\nu \otimes 9/2^-[734]_\nu$	[169]
^{254}No	8^-	266 ms	1.293 MeV	γ	$7/2^-[514]_\pi \otimes 9/2^+[624]_\pi$	[77,78]
^{254}No	–	184 µs	≃2.5 MeV	γ	–	[77,78]
^{270}Ds	9^-,10^-	6 ms	≃1.13 MeV	α	$11/2^-[725]_\nu \otimes 7/2^+[613]_\nu$ $11/2^-[725]_\nu \otimes 9/2^+[615]_\nu$	[22]

In some cases the K^π or configuration assignments are tentative and have not been made on the basis of unambiguous experimental data. See relevant references for details.

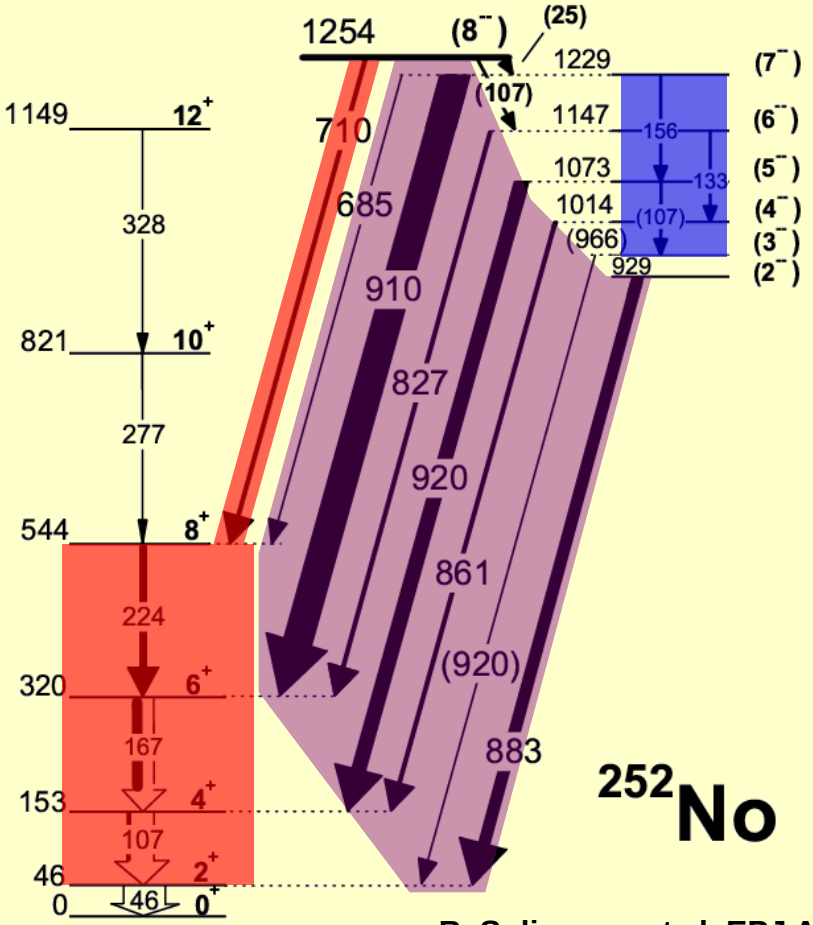
Nuclear Structure of the Heaviest Nuclei:

- Isomeric states: ^{252}No

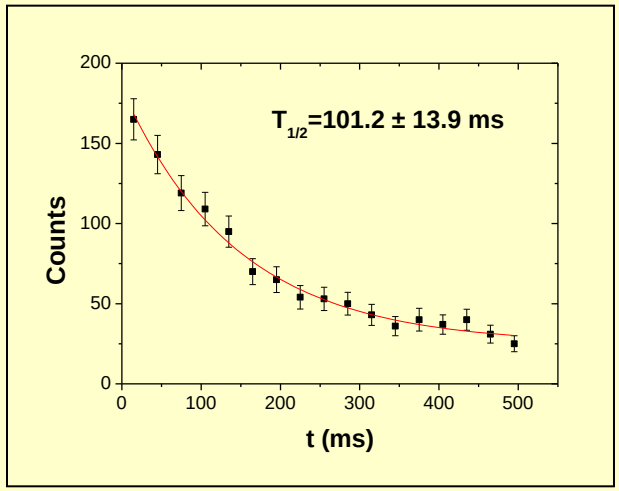


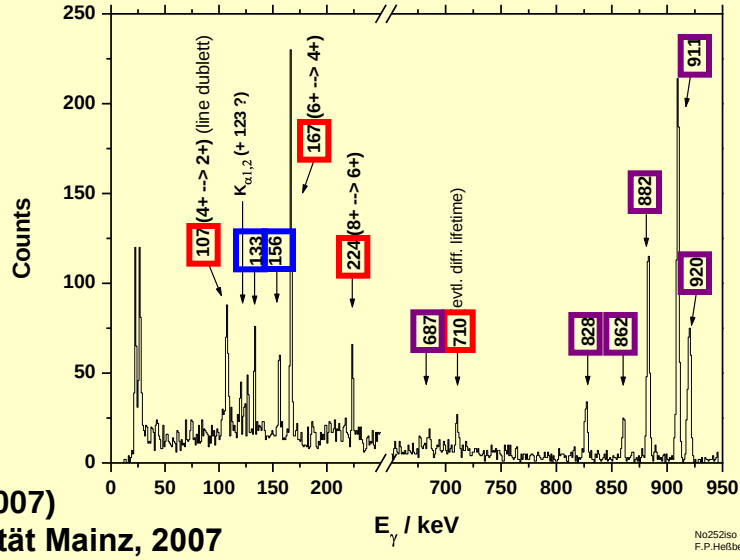
$T_{1/2}$ = 110 ± 10 ms

^{206}Pb(^{48}Ca, 2n)^{252}No



^{252}No



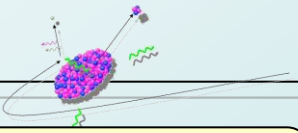


B. Sulignano et al. EPJ A33, 327 (2007)
B. Sulignano, PHD thesis, Universität Mainz, 2007

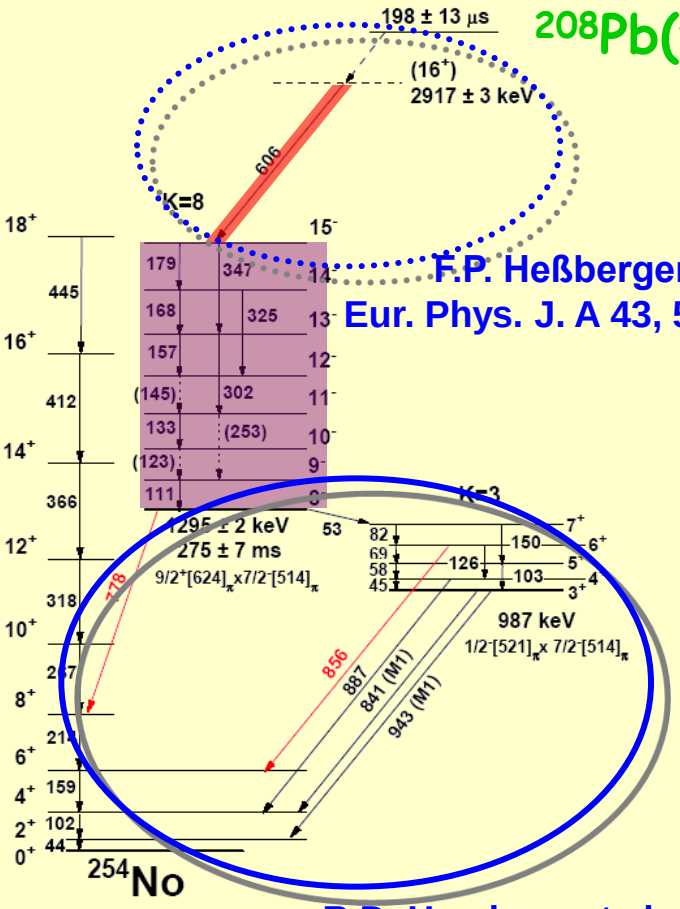
No252iso
F.P.Heßberger 8.8.2006

Nuclear Structure of the Heaviest Nuclei:

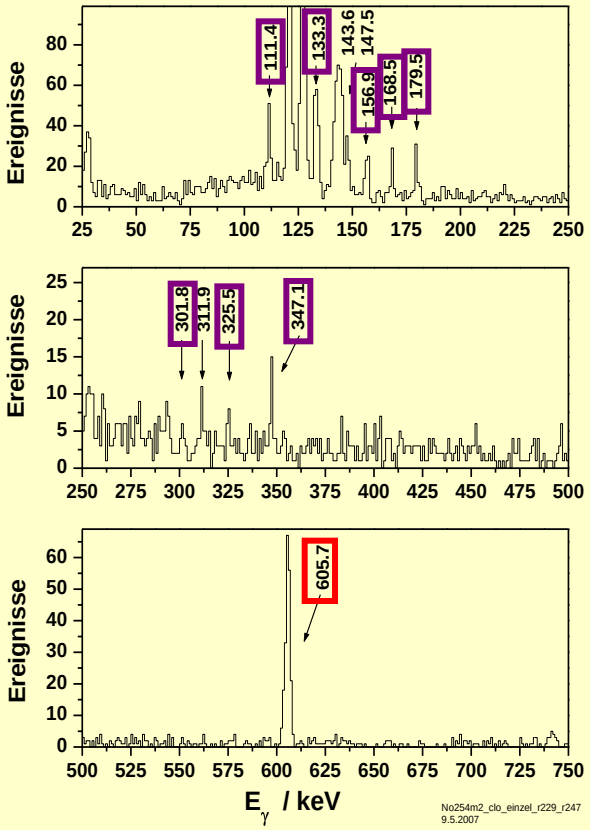
- Isomeric states: ^{254}No



^{208}Pb(^{48}Ca, 2n)^{254}No



F.P. Heßberger et al.,
Eur. Phys. J. A 43, 55-66 (2010)



R.D. Herzberg et al.,
Nature 442, 896 (2006);
S.K. Tandel et al.,
Phys. Rev. Lett. 97, 082502 (2006)

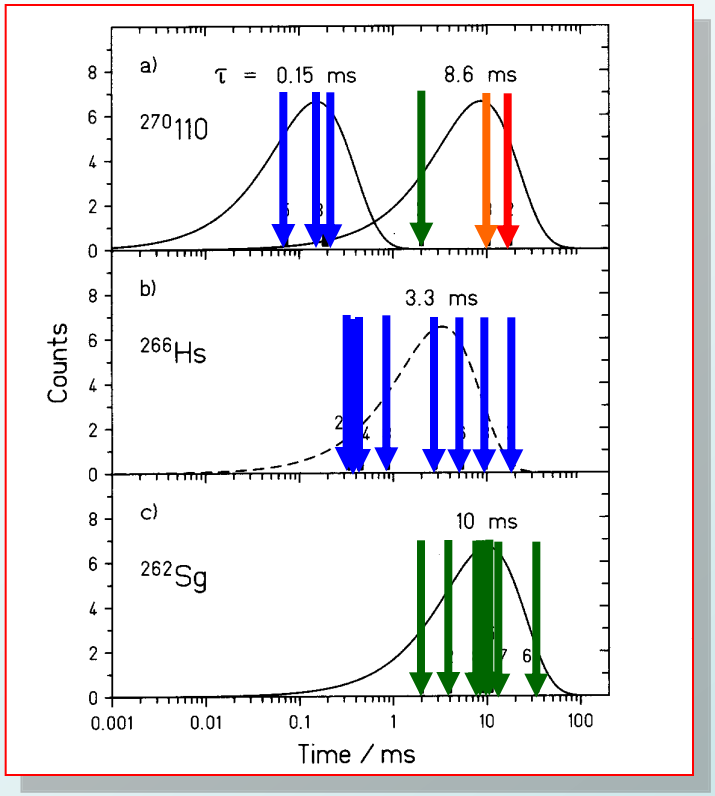
^{270}Ds and its Decay Products

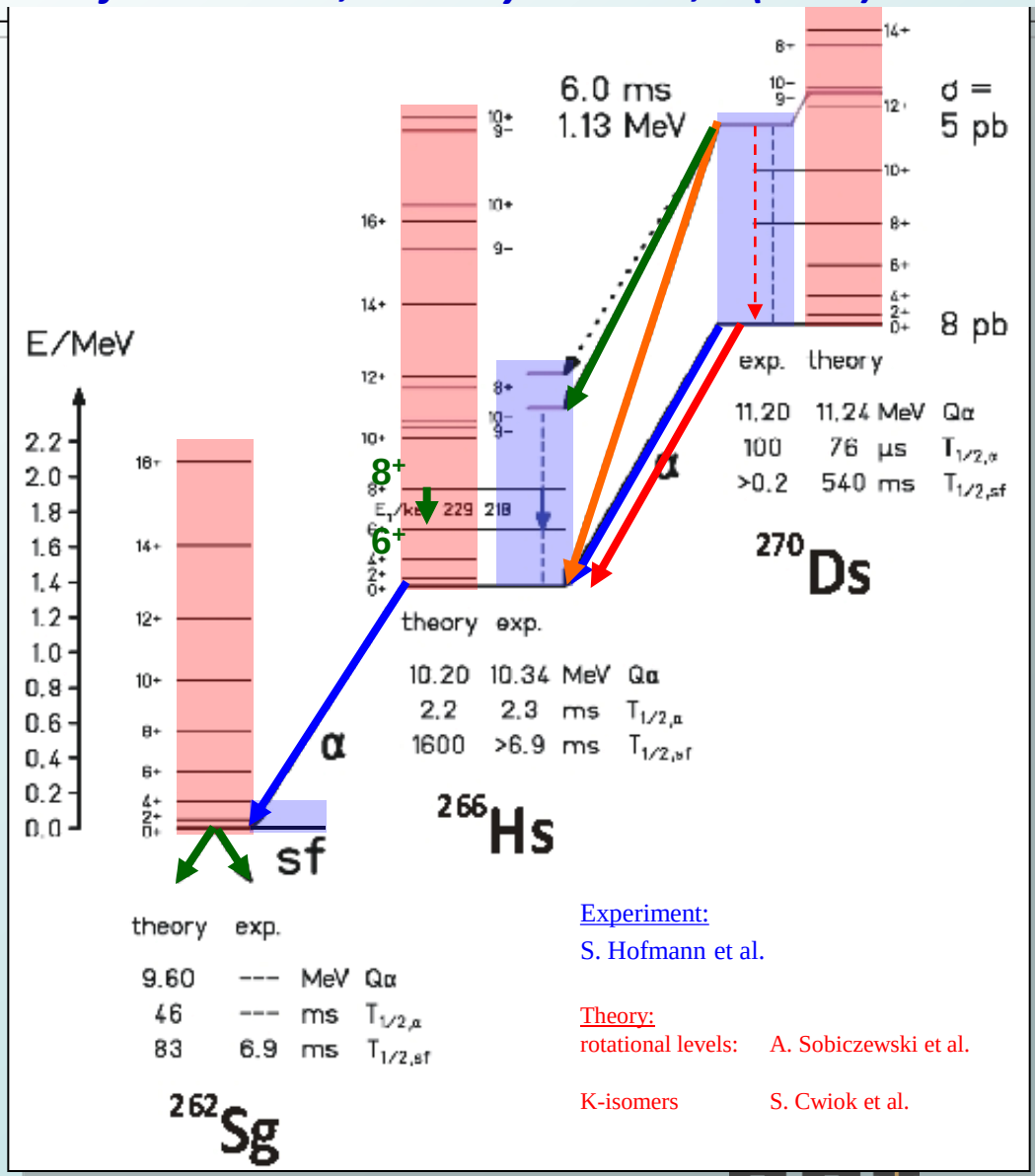
- 1st experiment in 2000 (S. Hofmann et al., Eur. Phys. J. A 10, 5 (2001)

^{270}Ds→^{266}Hs (6 chains)
chain# 1, 3 and 5
chain# 2
chain# 8
chain# 7

^{266}Hs→^{262}Sg (8 chains)
chain# 1-8

^{262}Sg decay (8 chains)
chain# 1-8





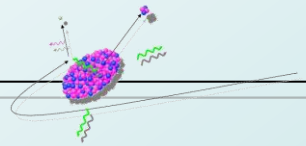
Experiment:
S. Hofmann et al.

Theory:
rotational levels: A. Sobiczewski et al.

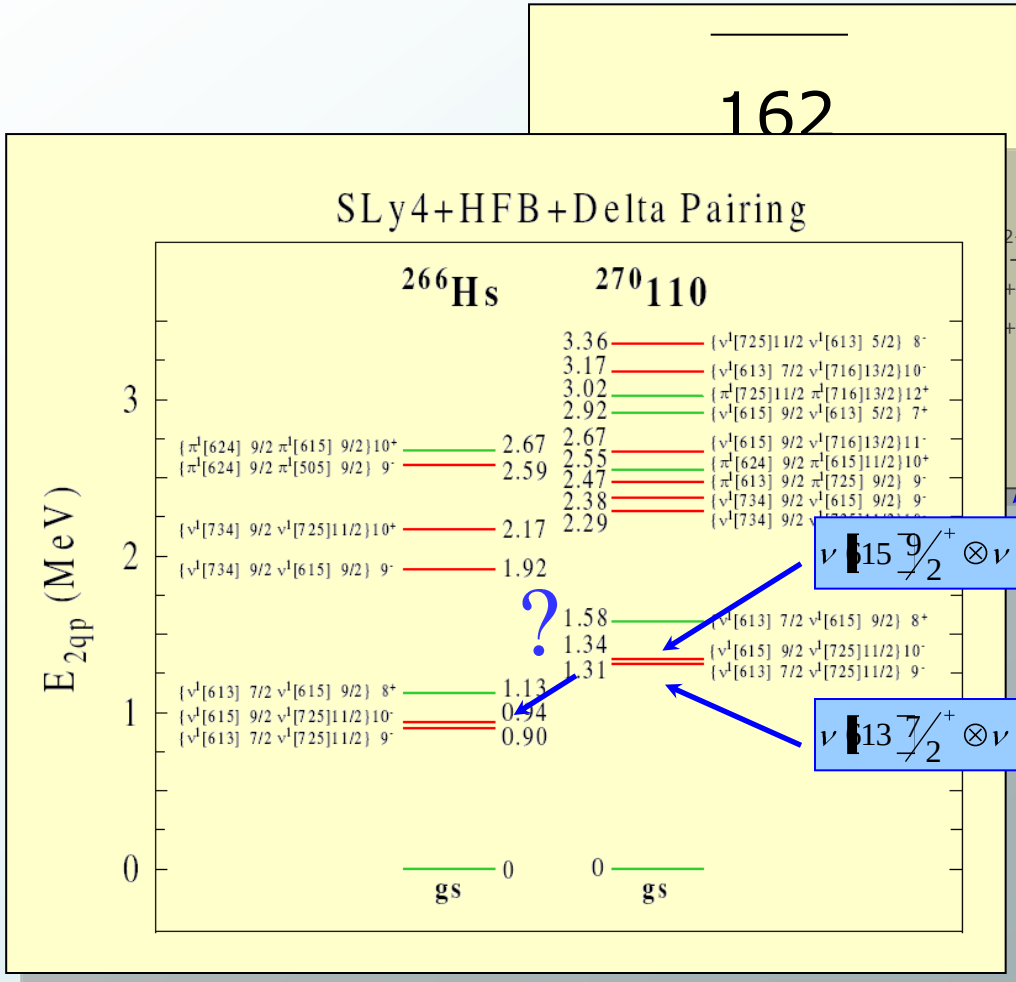
K-isomers S. Cwiok et al.

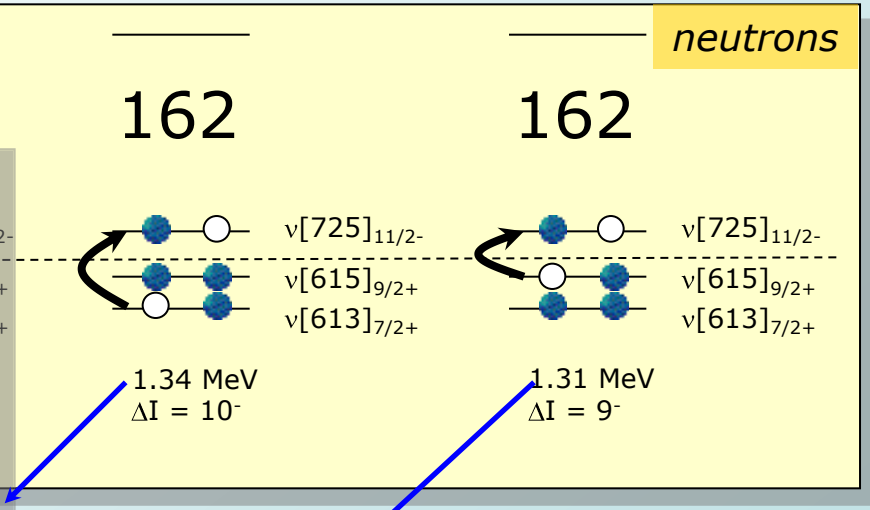
K-isomer in ^{270}Ds

- Theory Predictions: quasi particle excitation



^{270}Ds: Z=110 N= 160





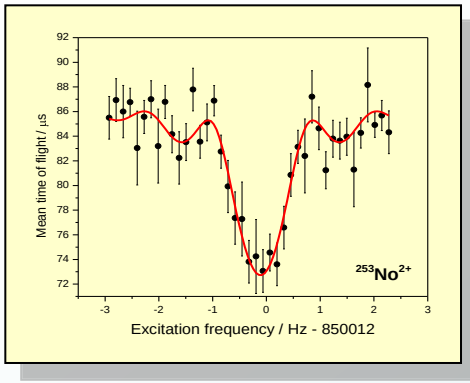
$\nu\left[615\frac{9}{2}^{+}\right] \otimes \nu\left[725\frac{11}{2}^{-}\right]$

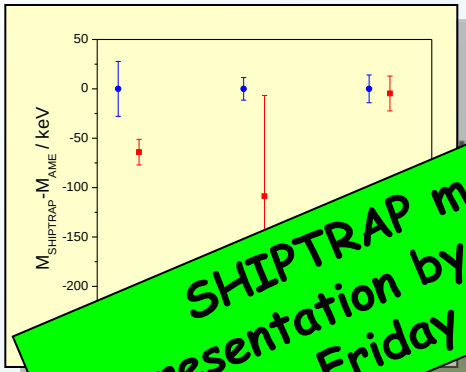
$\nu\left[613\frac{7}{2}^{+}\right] \otimes \nu\left[725\frac{11}{2}^{-}\right]$

S. Cwiok, et al.
HFB

Decay Chain of ^{270}Ds from ^{64}Ni+^{207}Pb

- Results from October 2000 and Possible Extension





$^{252}_{102}$No$_{150}$	$^{253}_{102}$No$_{151}$	$^{254}_{102}$No$_{152}$
2.44 s 0$^+$ M 82881 (13) α=67% SF=32.2 (5)%...	31 us 5/2$^+$# Eex 129 (19) α=?	1.62 m 9/2$^-$# M 84470# (100#) α=? β$^+$=20#%...	280 ms Eex 500# (100#) IT>80% α?	51 s 0$^+$ M 84724 (18) α=90 (4)% β$^+$=10 (4)%...

SHIPTRAP
August 2008

SHIPTRAP mass measurements
→ presentation by Enrique Minaya Ramirez,
Friday session 9:40 h

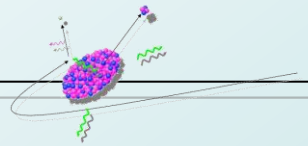
α?

110 Ds: Ds 269, Ds 270, Ds 271, Ds 273
109 Mt: Mt 266, Mt 268, Mt 270
Hs 264, Hs 265, Hs 266, Hs 267, Hs 269, Hs 270, Hs 271
Bh 264, Bh 265, Bh 266, Bh 267, Bh 270
Sg 263, Sg 264, Sg 265, Sg 266, Sg 267
Db 258, Db 259, Db 260, Db 261, Db 262, Db 263, Db 266, Db 267, Db 268
Rf 255, Rf 256, Rf 257, Rf 258, Rf 259, Rf 260, Rf 261, Rf 262, Rf 263, Rf 267
Lr: Lr 252, Lr 253, Lr 254, Lr 255, Lr 256, Lr 257, Lr 258, Lr 259, Lr 260, Lr 261, Lr 262
161, 162, 163
102 No: No 250, No 251, No 252, No 253, No 254, No 255, No 256, No 257, No 258, No 259, No 260, No 262
Md 247, Md 248, Md 249, Md 250, Md 251, Md 252, Md 253, Md 254, Md 255, Md 256, Md 257, Md 258, Md 259, Md 260
160
Fm 246, Fm 247, Fm 248, Fm 249, Fm 250, Fm 251, Fm 252, Fm 253, Fm 254, Fm 255, Fm 256, Fm 257, Fm 258, Fm 259

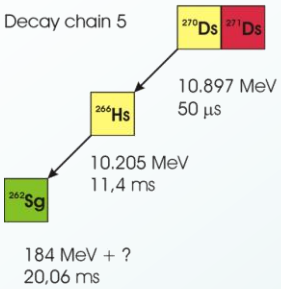
GSI

Observed types of decay chains I

- ER-α-α-sf



a) ER-a-a-sf



15 chains

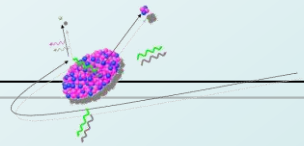
ER:
Time: 761391.182
MP: 1531
Strip#: 11
E: 38.72 MeV
Posyt: 14.75 mm
Posyb: 18.41 mm
ToF:1409

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

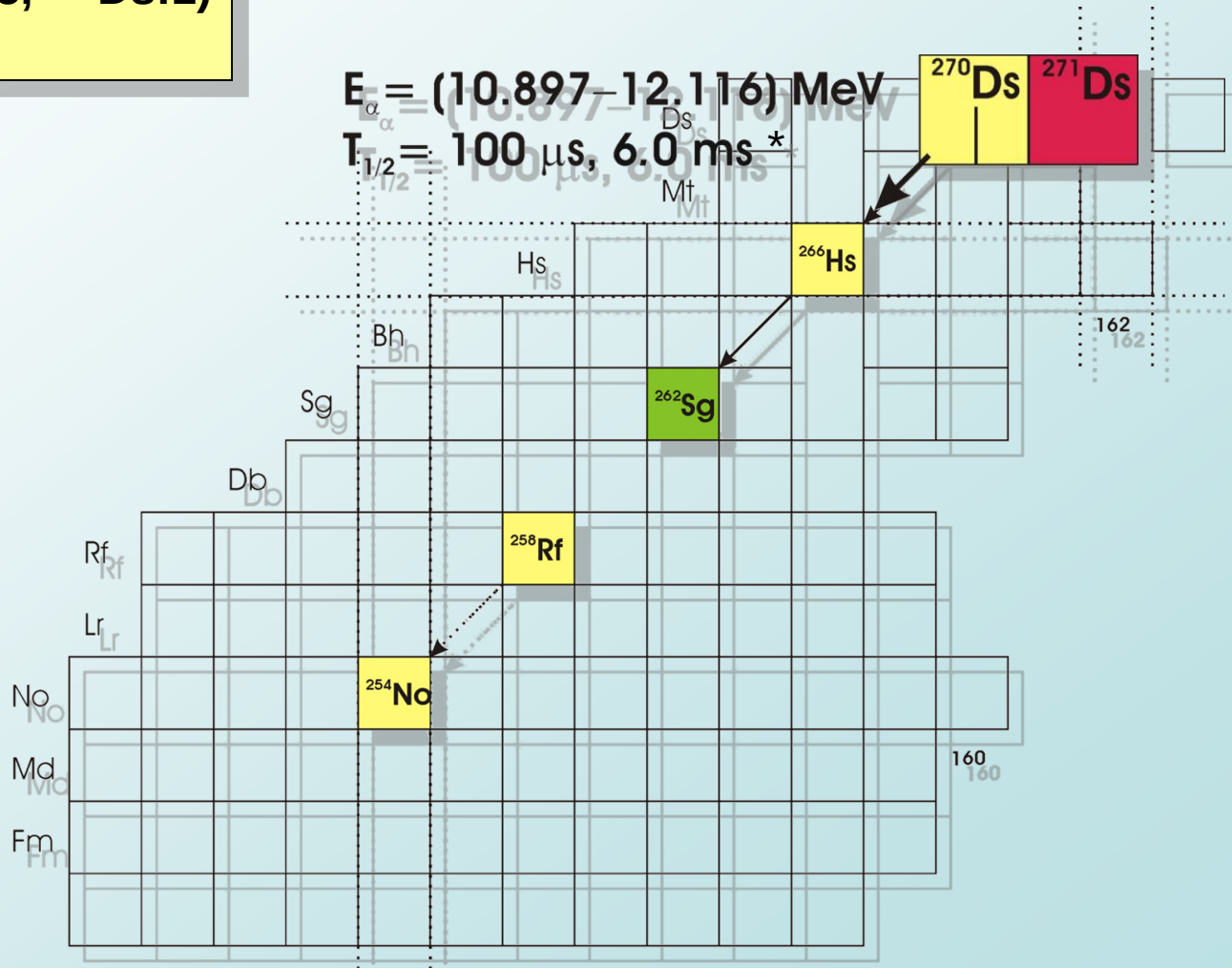
266Hs:
Time: 761391.193
MP: 12976
Strip#: 11
Estop: 10205.4 keV
Posyt: 15.29 mm
Posyb: 20.57 mm
Posyt(HE): 10.25 mm

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

- ^{270}Ds α-decay



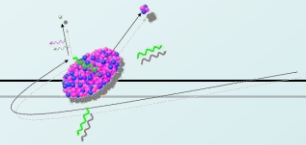
- 26 decay chains (^{270}Ds: 25, ^{271}Ds:1)
- new spectroscopic data



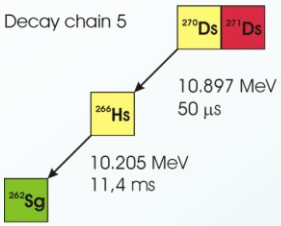
* $T_{1/2}$ from *S. Hofmann et al., Eur. Phys. J. A 10, 5 (2001)*

Observed types of decay chains II

- ER-α-sf



a) ER-α-α-sf



15 chains

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Posyb: 18.41 mm
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270Ds:
Time: 761391.182
MP: 1581
Strip#: 11
Estop: 10897 keV
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266Hs:
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MP: 12976
Strip#: 11
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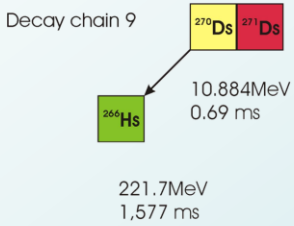
262Sg:
Time: 761391.213
MP: 13036
Strip#: 11
Estop: 184.58 MeV
Posyt: 14.70 mm
Posyb: 18.85 mm
Box#: 20
Ebox: --- MeV
Egamma3: 678.8 keV

b) ER-α-sf



8 chains

⇒ sf(^{266}Hs) = 32%

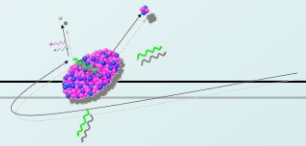
ER:
Time: 1281611.582
MP: 1547
Strip#: 9
E: 47.65 MeV
Posyt: 17.63 mm
Posyb: 15.95 mm
ToF:1417

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

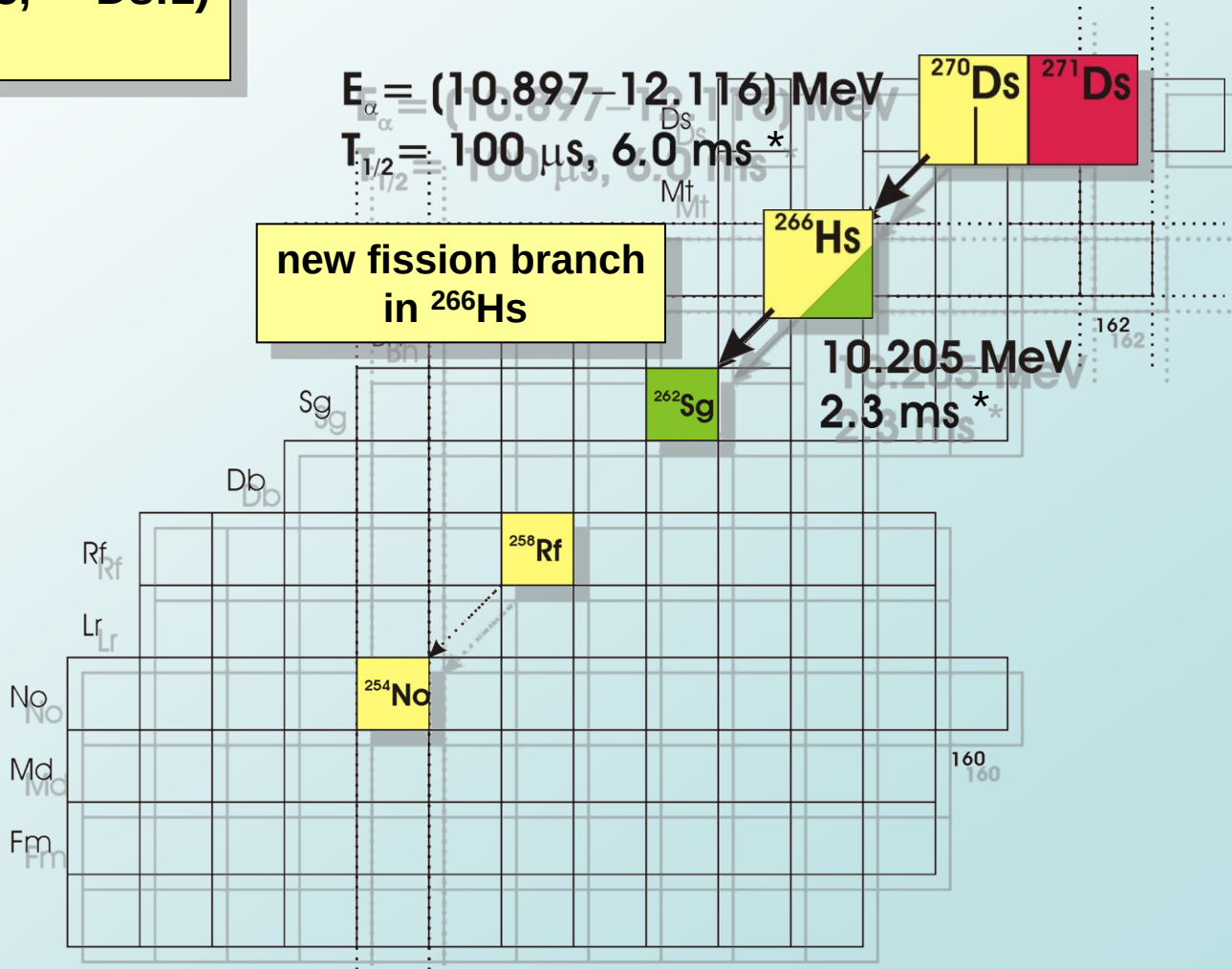
266Hs:
Time: 1281611.584
MP: 3812
Strip#: 13
Estop: 221.71 MeV
Posyt: 17.74 mm
Posyb: 16.03 mm
Box#: ---
Ebox: --- MeV
Egamma: --- keV

^{270}Ds

- ^{266}Hs sf-branch



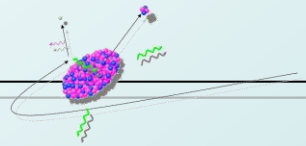
- 26 decay chains (^{270}Ds: 25, ^{271}Ds:1)
- new spectroscopic data



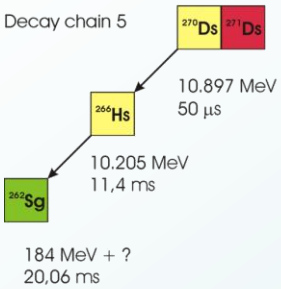
* $T_{1/2}$ from *S. Hofmann et al., Eur. Phys. J. A 10, 5 (2001)*

Observed types of decay chains III

- ER-α-α-α-sf



a) ER-α-α-sf



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

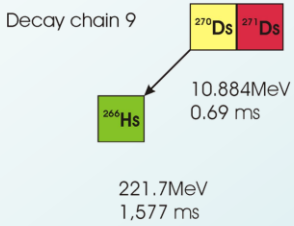
270Ds:
Time: 761391.182
MP: 1581
Strip#: 11
Estop: 10897 keV
Posyt: 15.36 mm
Posyb: 20.45 mm
Posyb(HE): 18.32 mm
Egamma1: 1126.9 keV

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-α-sf



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

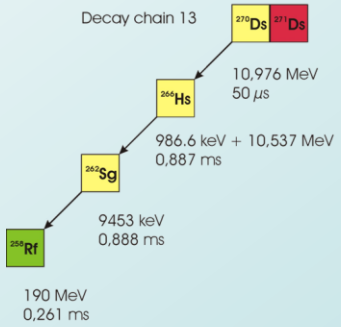
270Ds:
Time: 1281611.582
MP: 2235
Strip#: 9
Estop: 10883.9keV
Posyt: 18.10 mm
Posyb: 16.50 mm
Posyt(HE): 18.18 mm
Posyb(HE): 16.09 mm
Box#: 21
Ebox: 12047.2 keV

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

⇒ **sf(^{266}Hs) = 32%**

c) ER-α-α-α-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

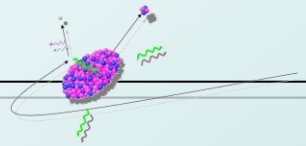
262Sg:
Time: 1960630.184
MP: 3755
Strip#: 10
Estop: 9453.1 keV
Posyt: 15.17 mm
Posyb: 18.60 mm
Posyt(HE): 20.43 mm
Posyb(HE): 15.62 mm

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

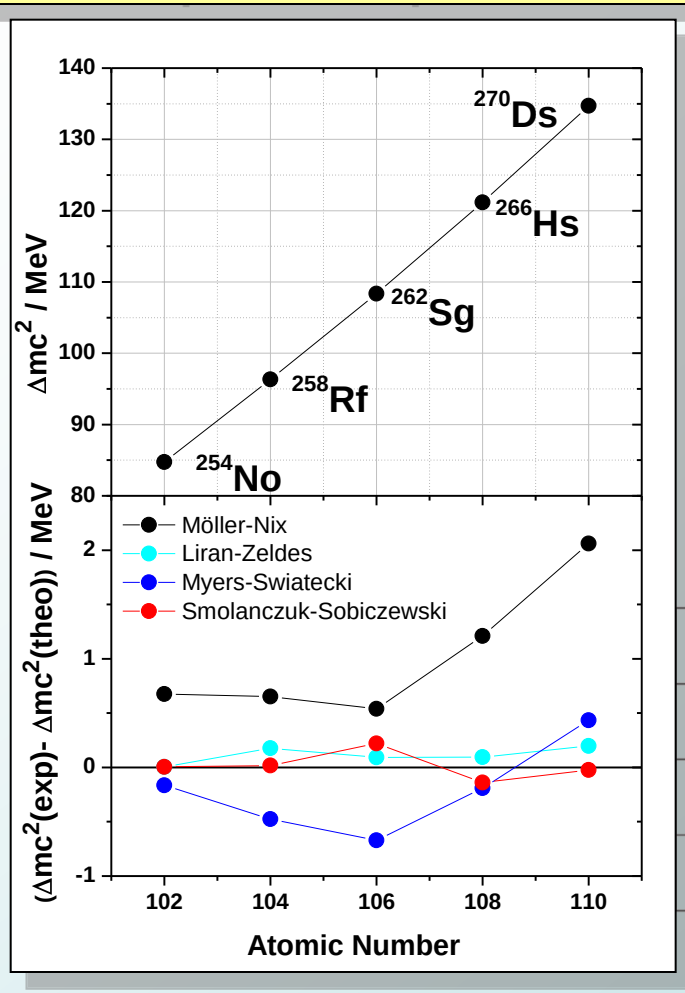
2 chains

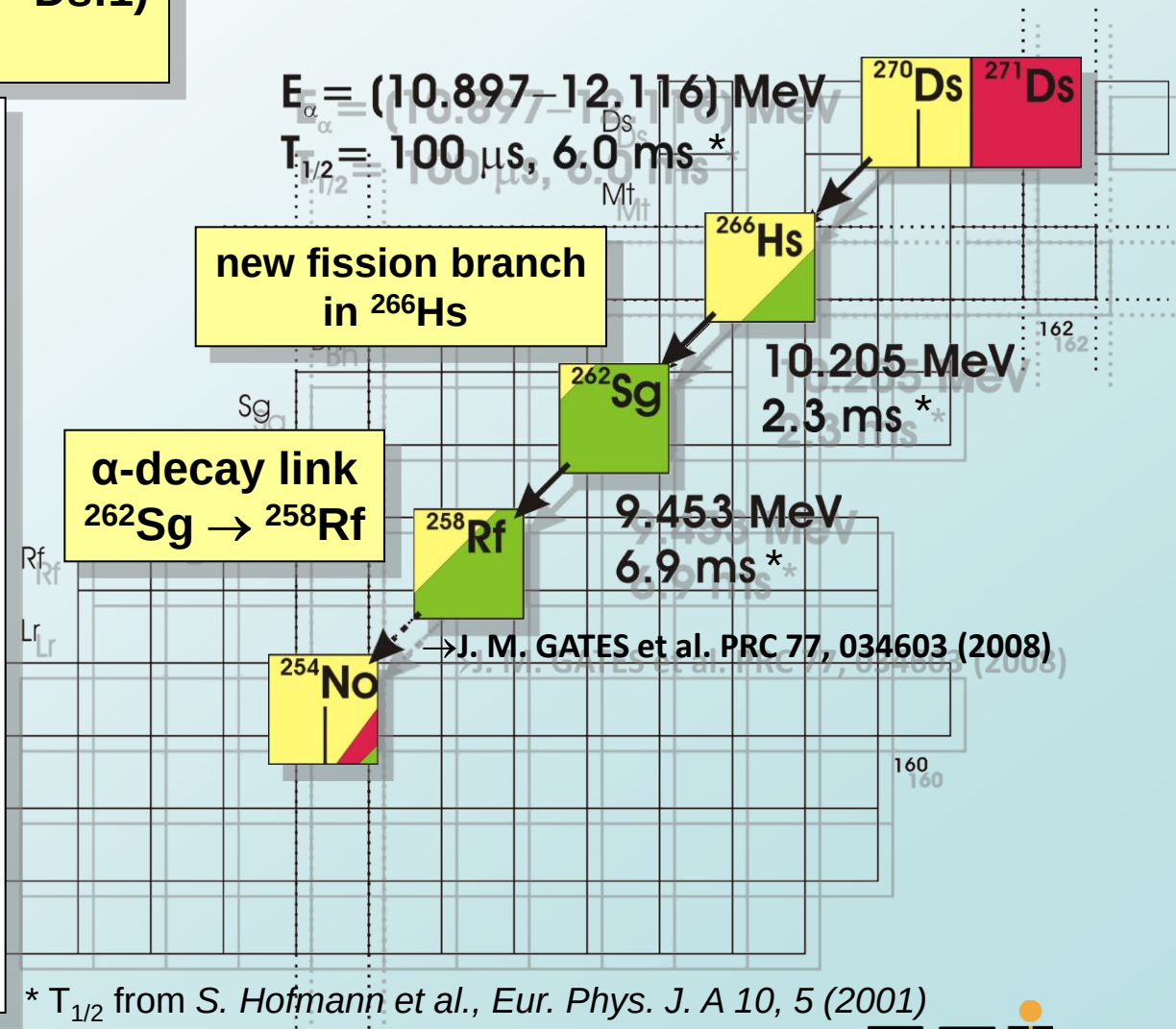
⇒ **α(^{262}Sg) = 8%**

- News III – ^{262}Sg α-branch → link to ^{254}No



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

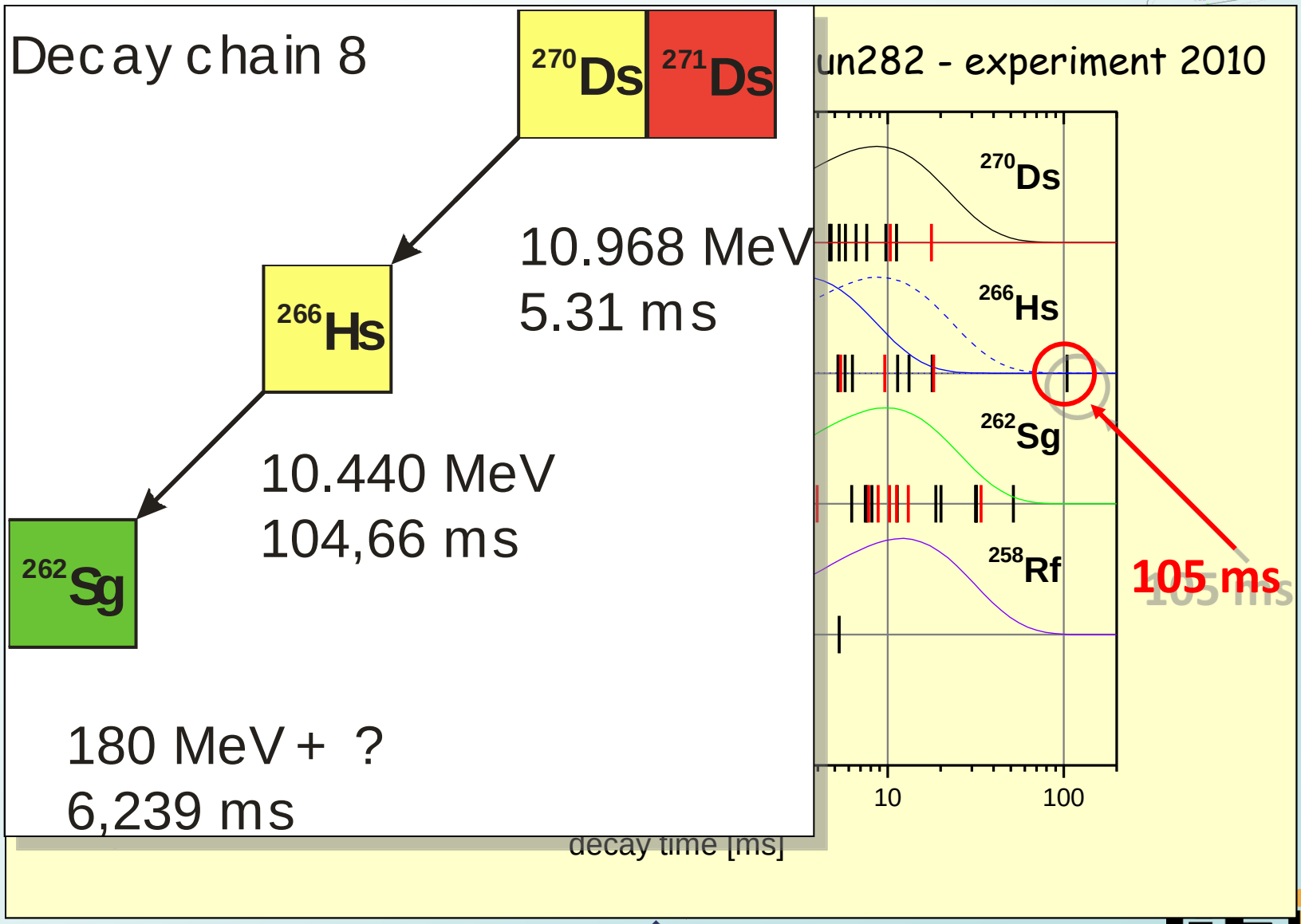




* $T_{1/2}$ from *S. Hofmann et al., Eur. Phys. J. A 10, 5 (2001)*

Decay details

- time distributions



^{270}Ds Decay Scheme

^{270}Ds:

13 g.s. decays - 2 γ's: 175/741 keV
12 isomer decays - 1 γ: 1094 keV
(in 2000: 3:3 + 1 γ)

chain 8:
E_α 200-300 keV lower

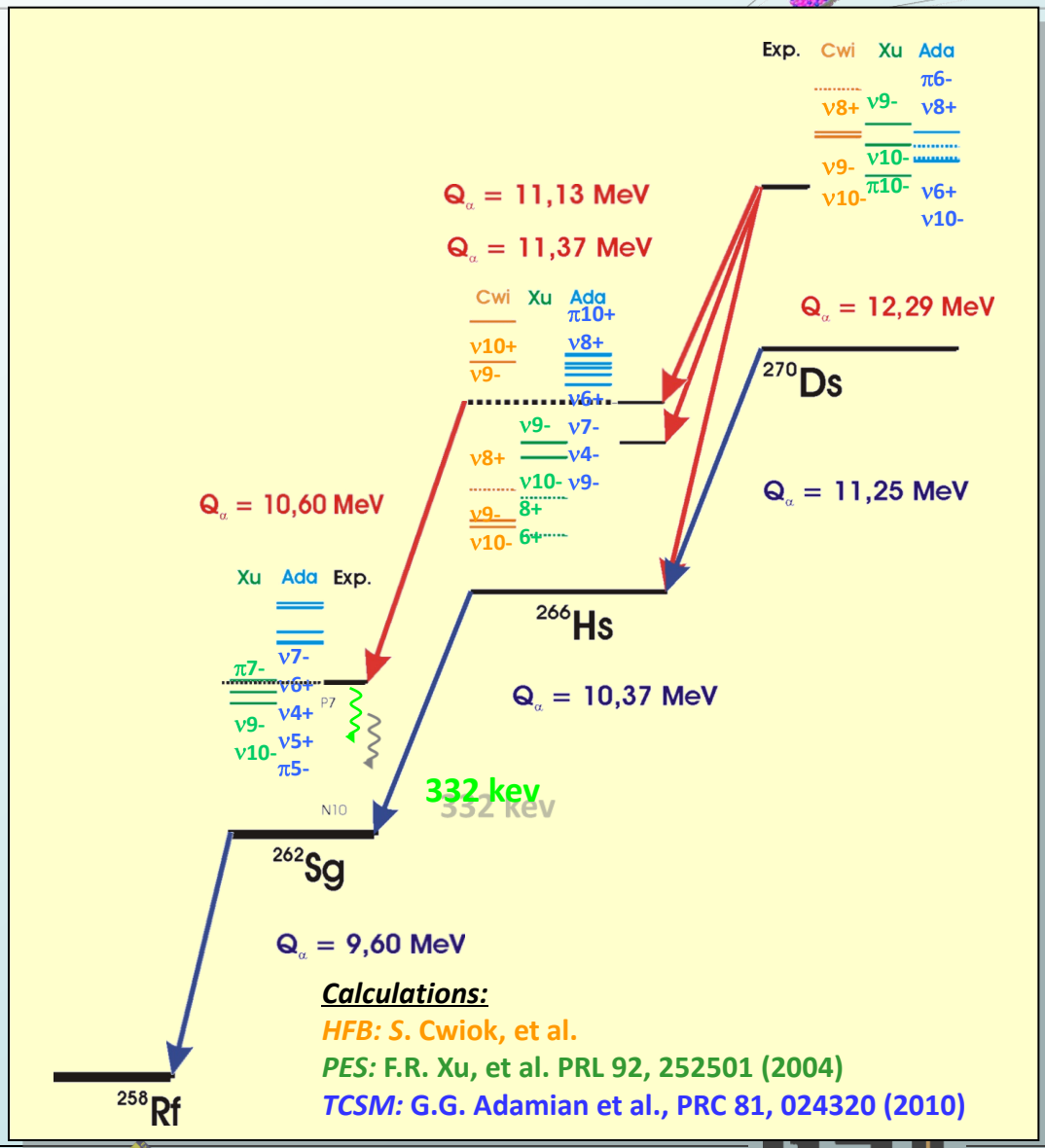
^{266}Hs:

16 g.s. decays
1 isomer decay
with a 332 keV γ-ray

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

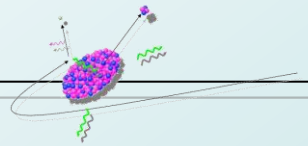
^{262}Sg:

α decay observed for the first time
(1 full E, 1 escape)



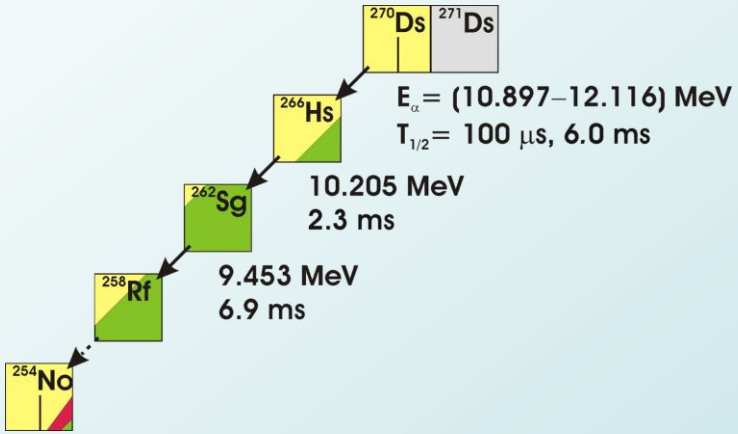
Summary

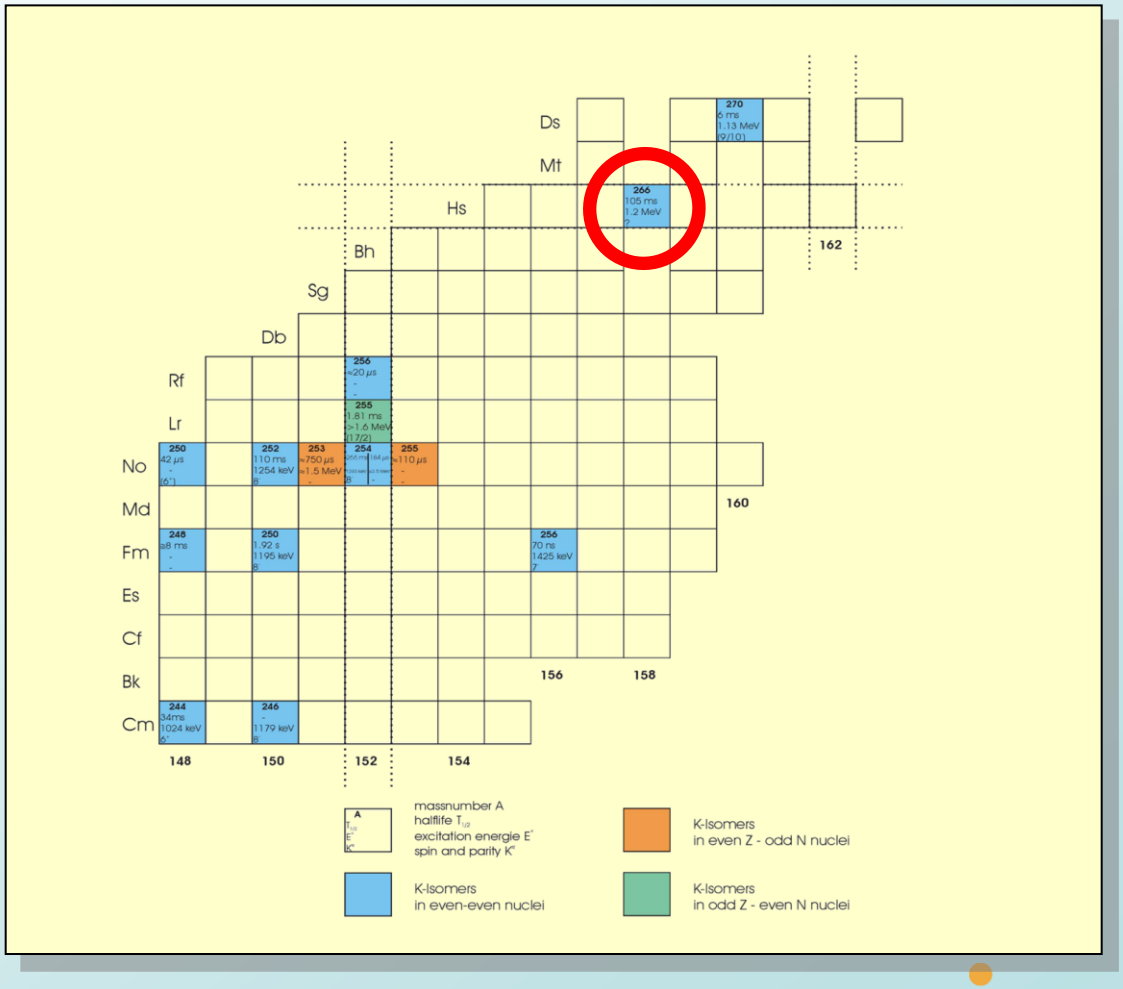
- Achievements



ground state, decay and structure properties up to Z=110

- α-γ coincidences (total: 4)
- fission branch in ^{266}Hs
- experimental mass for ^{270}Ds
- new K-isomer ^{266} Hs

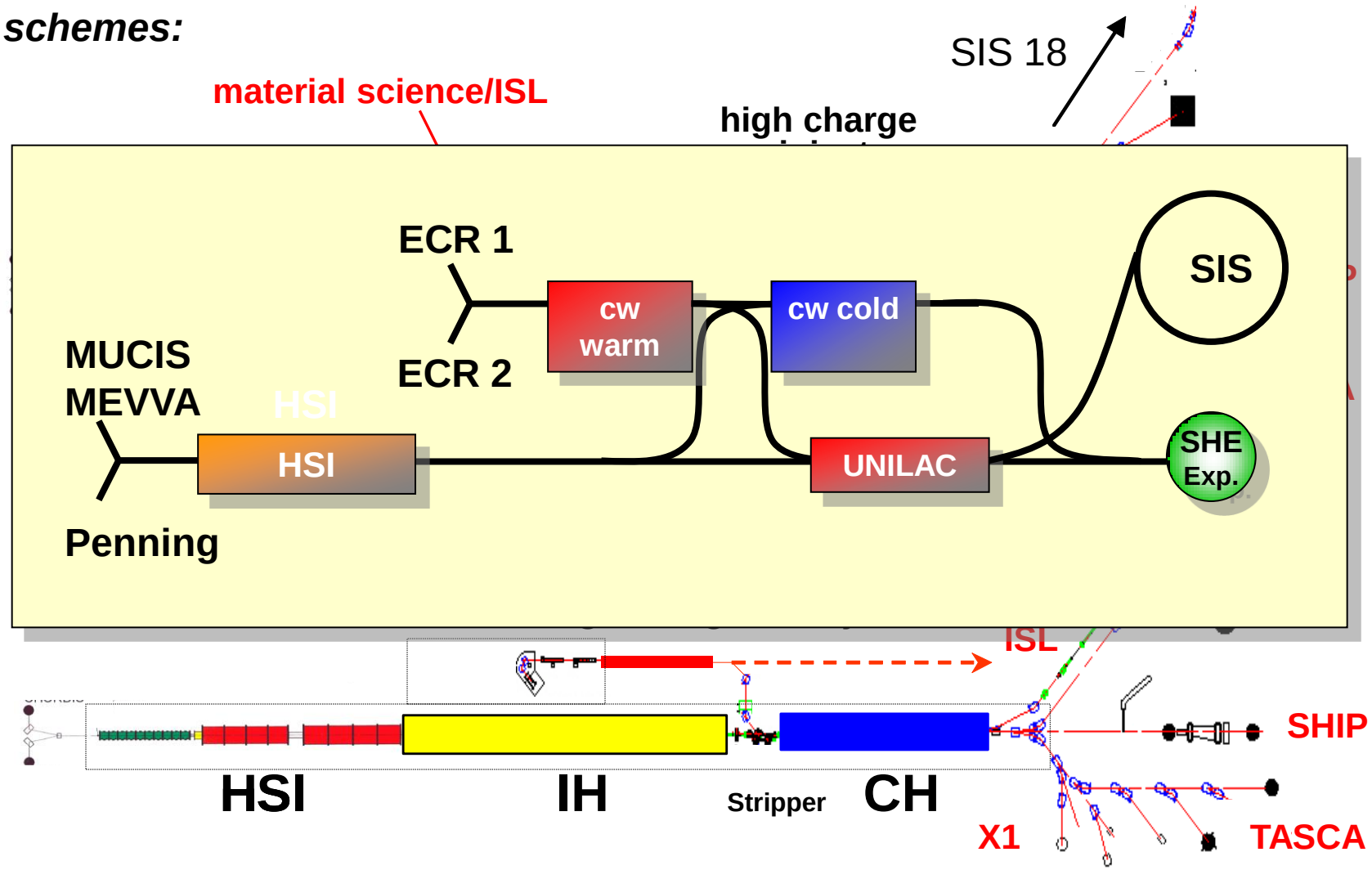




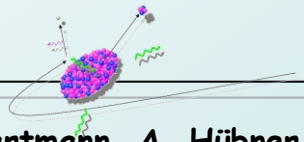
SHE Synthesis and Nuclear Structure of SHE

- Roadmap/Long Term

Possible GSI acc. schemes:



The SHIP Collaboration



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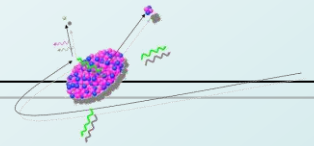

The **ECOS** Network Activity in the **ENSAR** framework of the EU FP7 program has among others with its Task 2 the objective to promote **synergies in the field of Super-Heavy Element (SHE) research**, described as follows:

*"For this task ECOS is aiming for **bringing together the groups with research activities on SHE using high-intensity ion beams** for an exchange of new ideas and techniques related to the use of very high intensity stable beams. In particular, Task 2 will propose an **optimisation of resources** (beam time, target technology, detectors) in the field of SHE research **among TNA facilities**."*

The **ENSAR-ECOS** Workshop on **FU**ture **S**uper-**H**eavy **E**lement **S**trategy – **FUSHE 2012** is one very important milestone in this process. It will provide a **forum for the SHE community to discuss and define the future strategy to reach** the common goal – the establishment and investigation of the region of spherical shell-stabilised super-heavy nuclei – the so called **"Island of Stability"**.

FUSHE 2012 - Venue




The *Conference&Sports Hotel Erbismühle* is located in a nice valley, the *Weiltal*, in the *Taunus hills* about 50 km north of Frankfurt (50 km to Frankfurt main station and 55 km to Frankfurt airport) close to the *village Weilrod* in the centre of Germany.

72 rooms €90 (€60 double occupation) + interesting food option

The *Taunus hills* have formed the northern border of the Roman Empire and traces of it can still be visited today like the rebuilt Roman Castle *Saalburg* together with a few meters of the *limes*, the Roman border installations and defence line against the barbarians north of it…

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