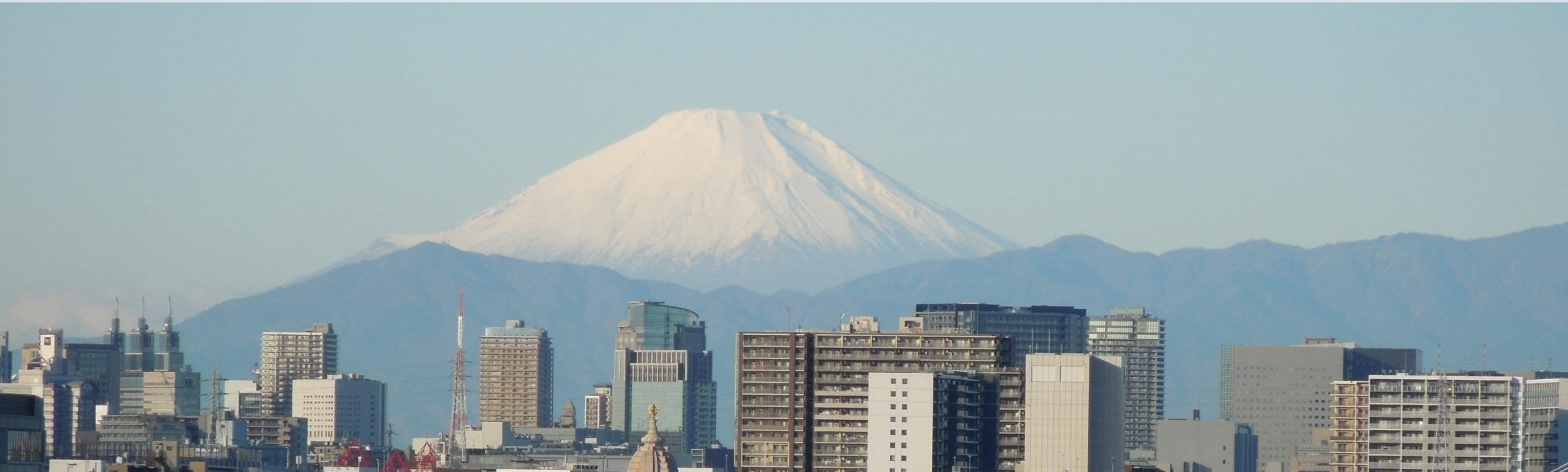
Nuclear Structure of Superheavy Nuclei Investigated at GSI-SHIP



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Helmholtz – Institut Mainz, D-55099 Mainz, Germany

22th ASRC International Workshop ‚Nuclear Fission and Exotic Nuclei'
Tokai (Japan), December 3 – 5, 2014

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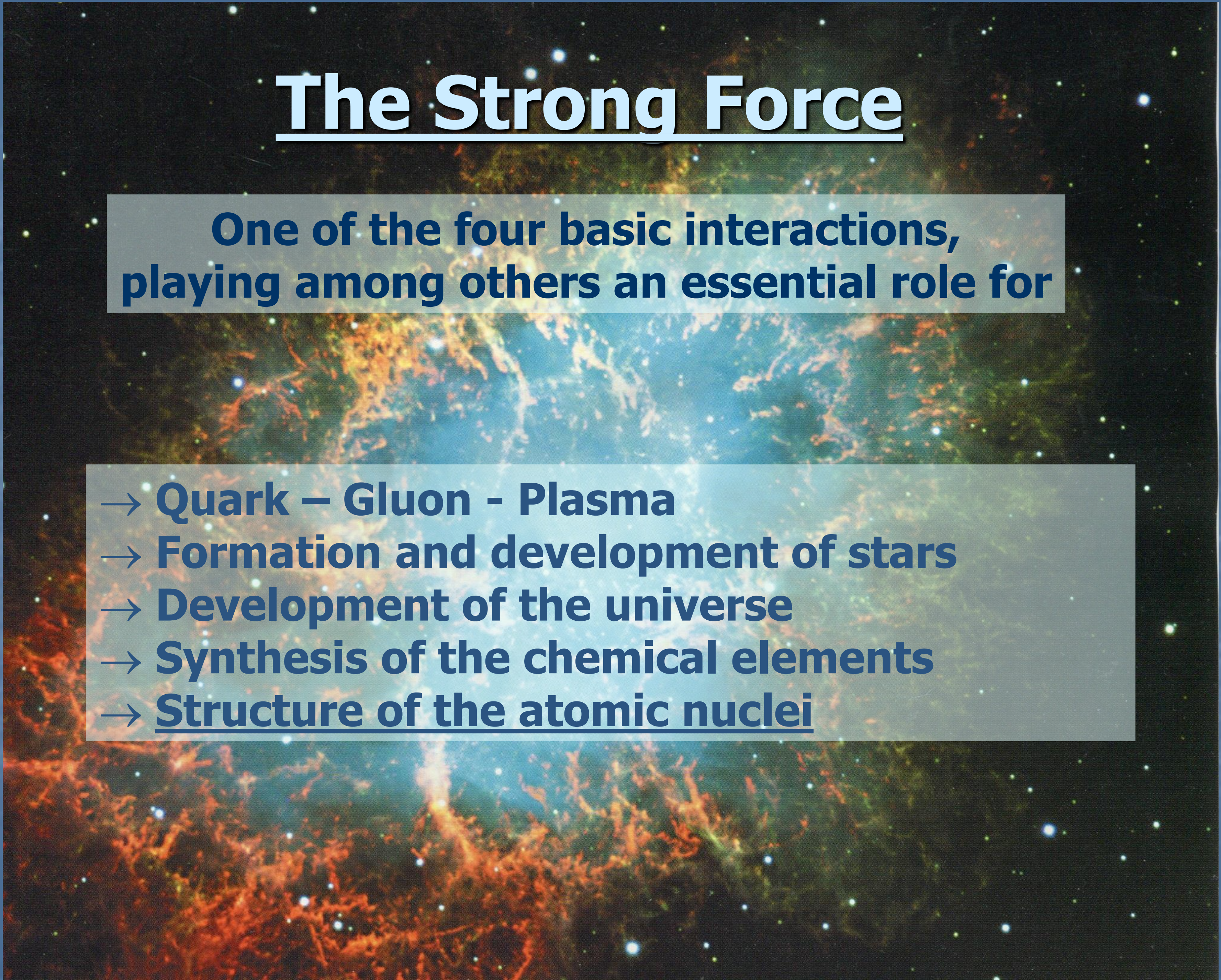
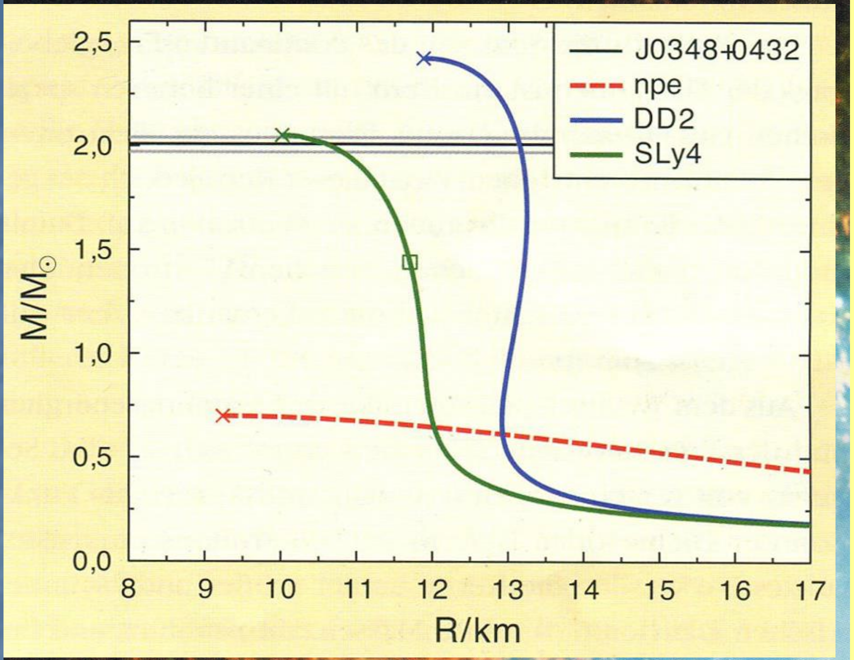


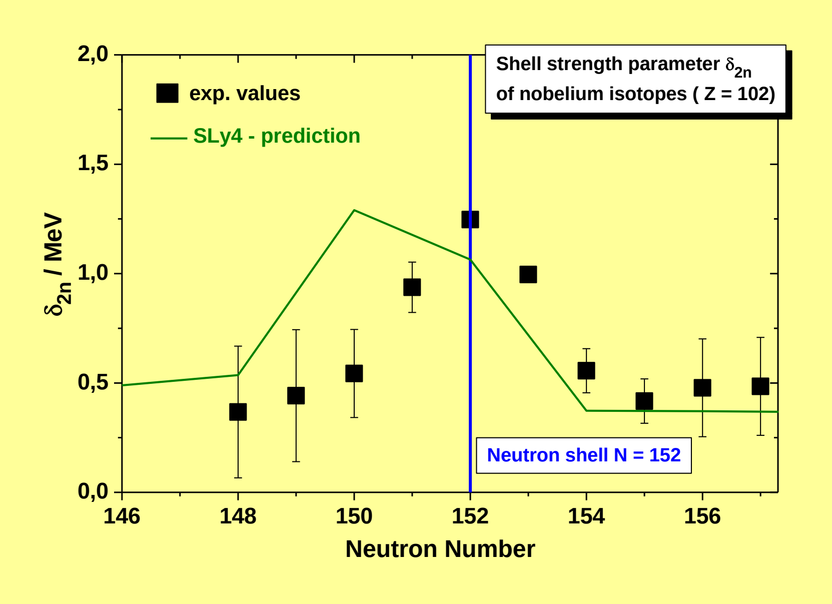
The Strong Force

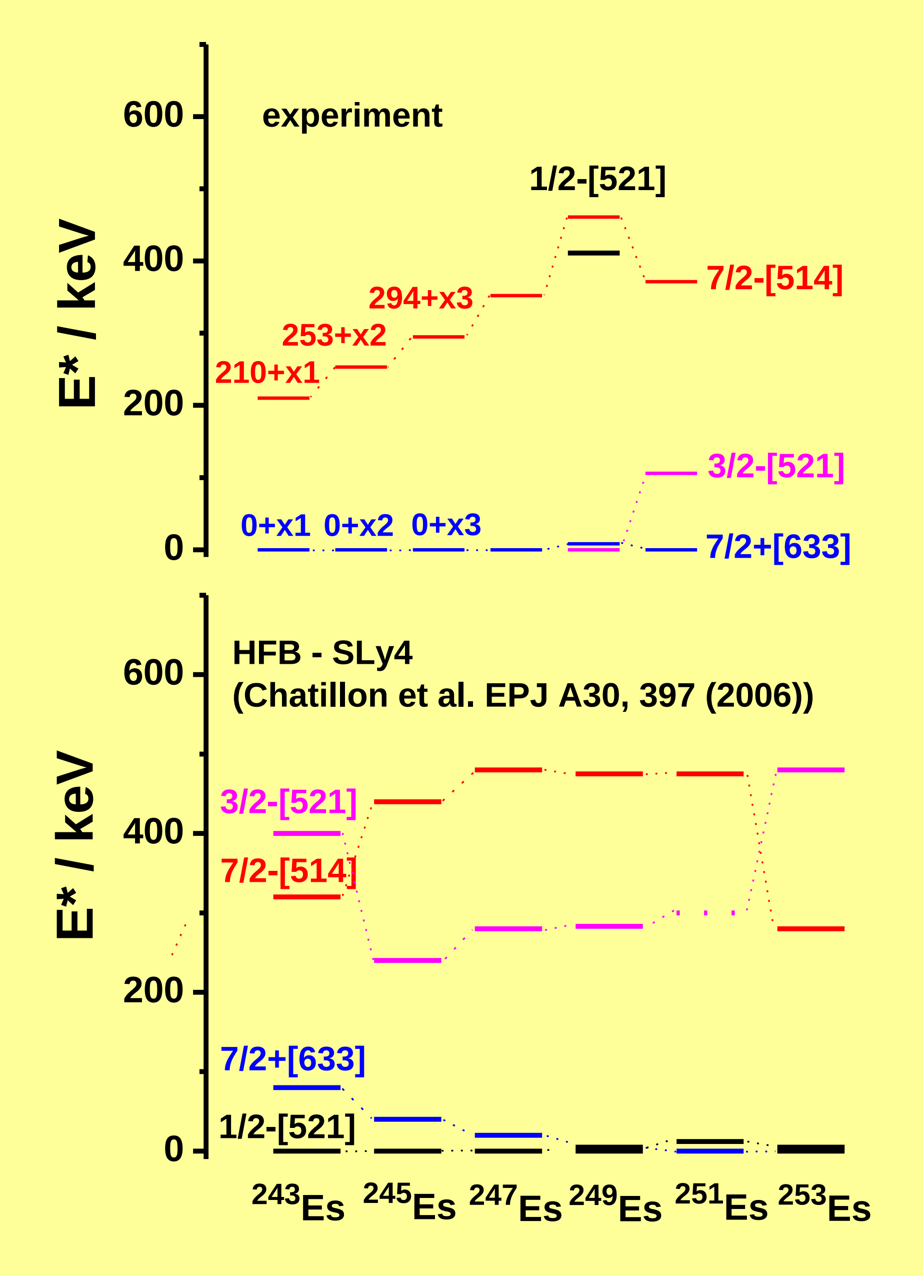
One of the four basic interactions, playing among others an essential role for

- → **Quark – Gluon - Plasma**
- → **Formation and development of stars**
- → **Development of the universe**
- → **Synthesis of the chemical elements**
- → **Structure of the atomic nuclei**

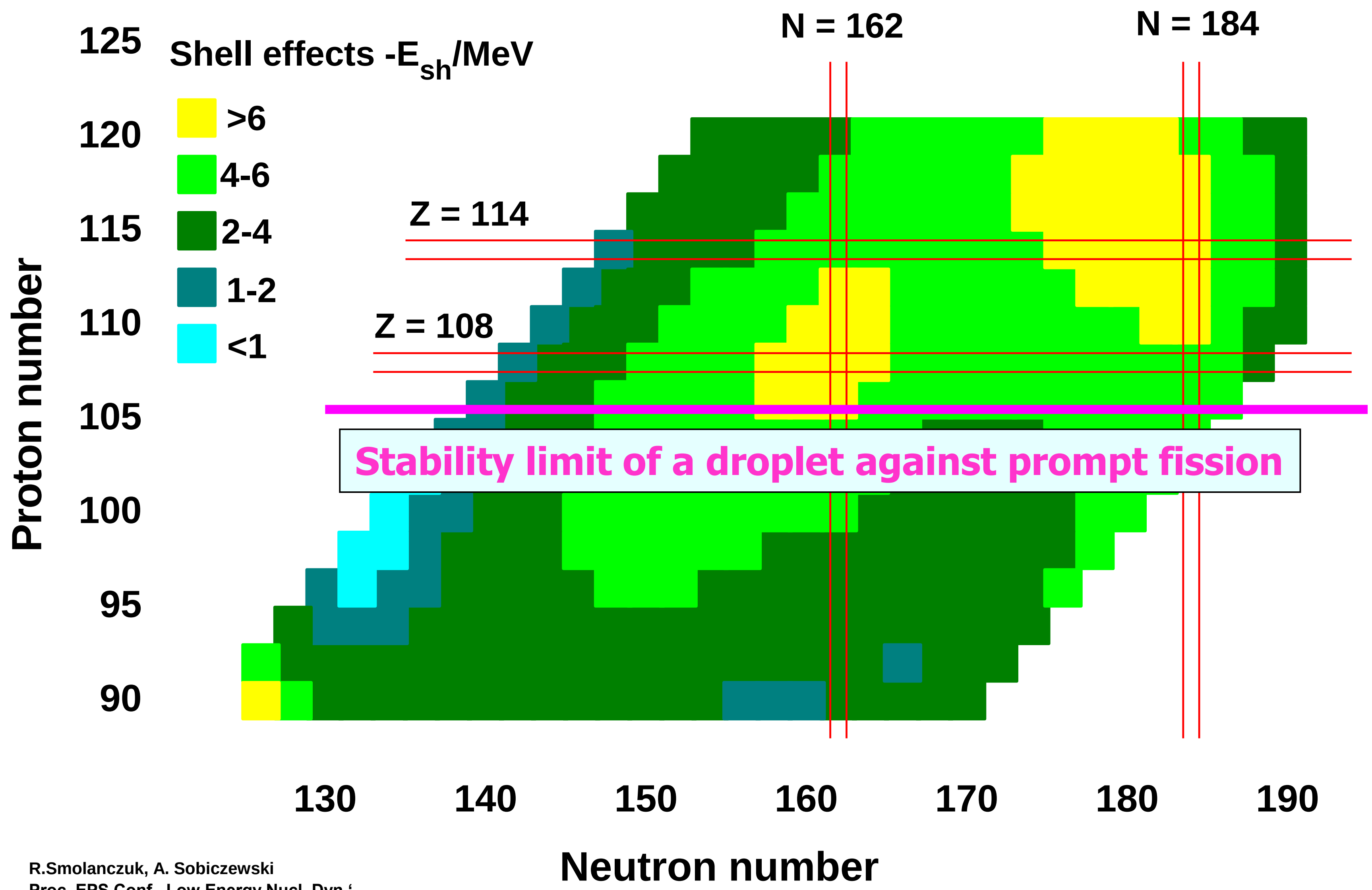
The Strong Force





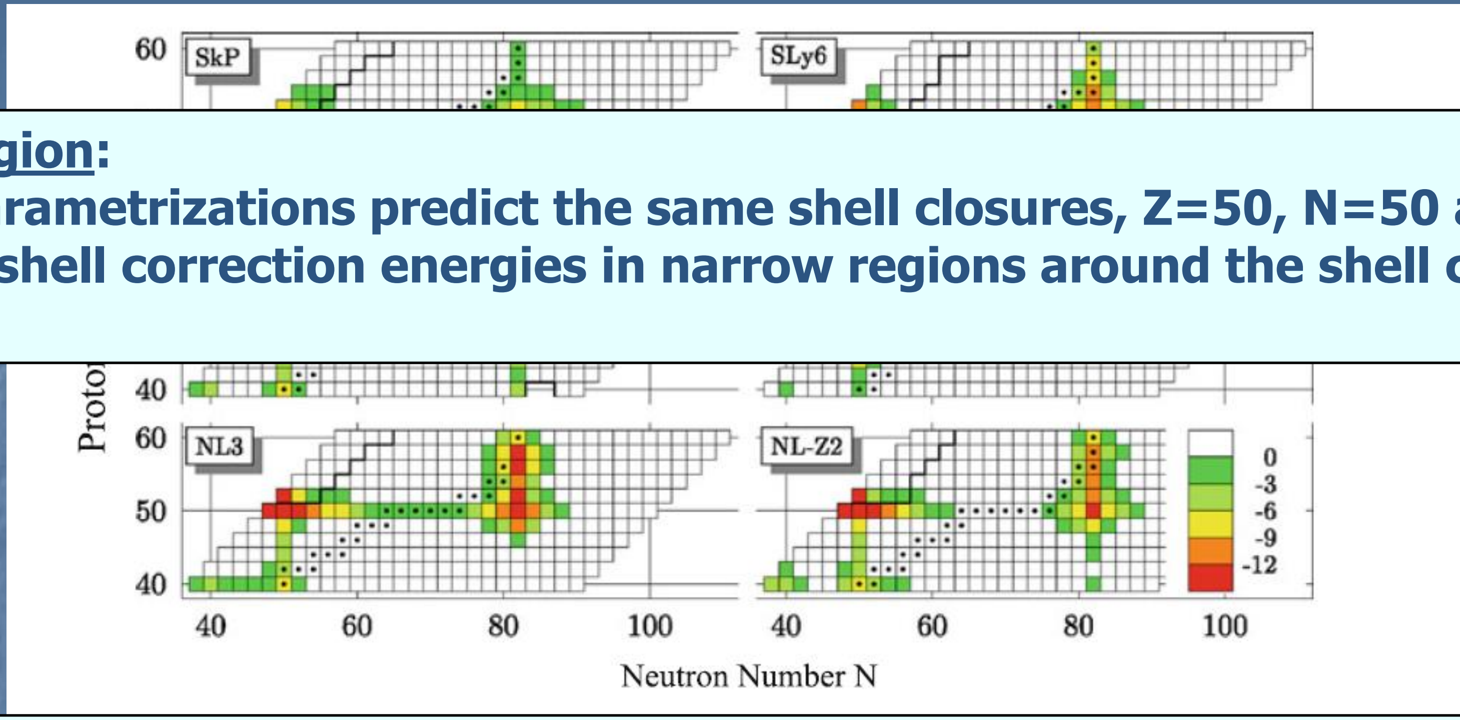


Macroscopic – Microscopic Predictions of Shell Effects



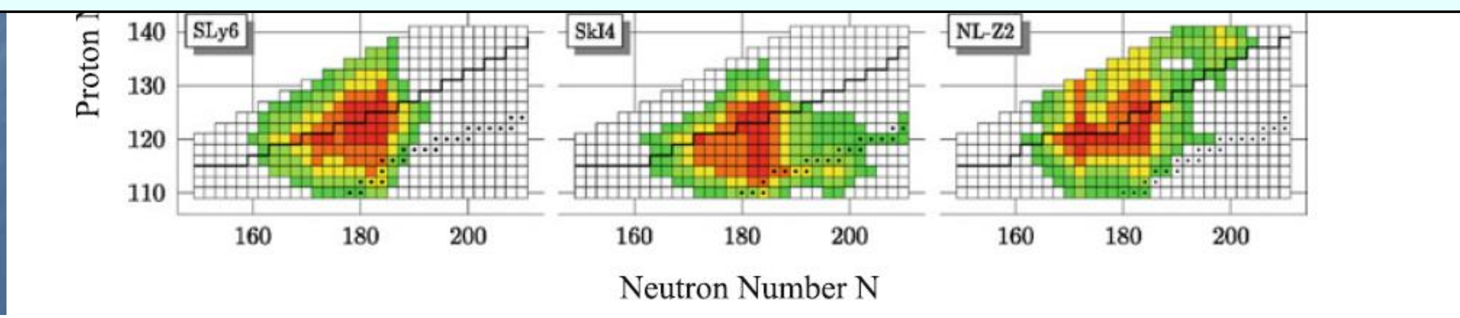
R.Smolanczuk, A. Sobiczewski
Proc. EPS Conf. ‚Low Energy Nucl. Dyn.‘,
St. Petersburg, Russia, 1995 & priv. comm.

Predictions of Superheavy Nuclei



Tin – region:
→ All parametrizations predict the same shell closures, Z=50, N=50 and N=82
→ High shell correction energies in narrow regions around the shell closures

SHN region:
→ Shell closures are strongly dependent on the parametrization,
Z = 114, 120 or 126, N = 172 or 184
→ Wide regions of high shell correction energies are predicted



From: M.Bender et al. Phys. Lett. B 515, 42 (2001)

Physics Motivation for Synthesis and Nuclear Structure Investigations of SHN

Understanding nuclear structure of SHN is essential for understanding their properties and stability

i.e. the ‚strong force‛ and thus the ´limits of our world´

Topic Questions

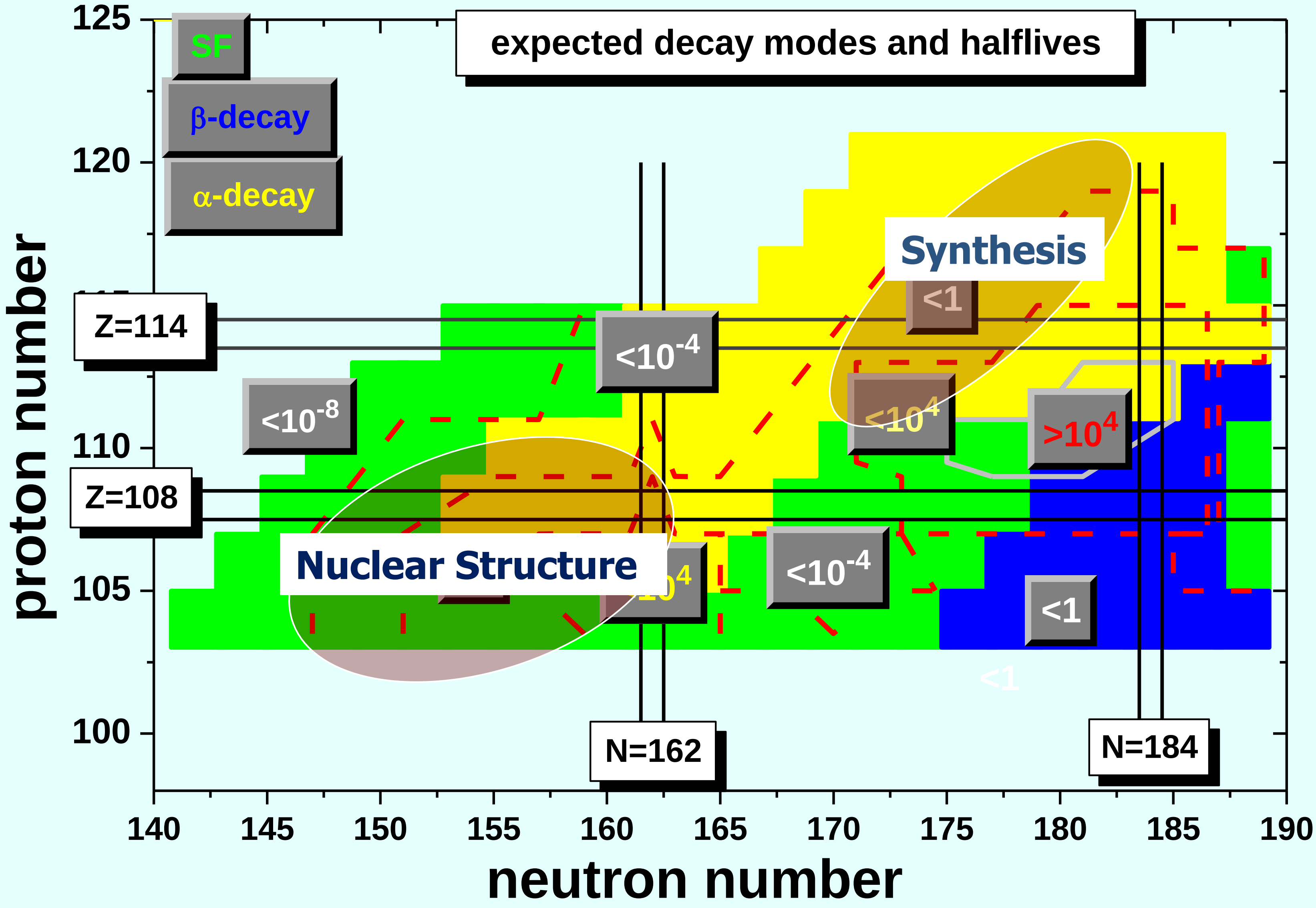
→ **Are there proton and neutron shells at all ?**

→ **How strong are they ?**

→ **Where are they located ?**

→ shell structure determines nuclear mass excess → determines Q-values for α- and β- decay

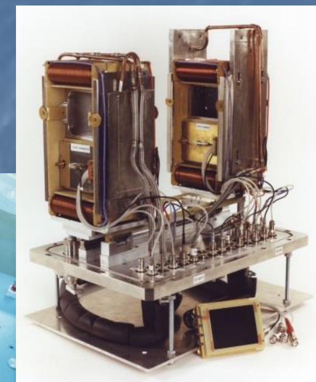
Expected Decay Modes and Halflives of SHN

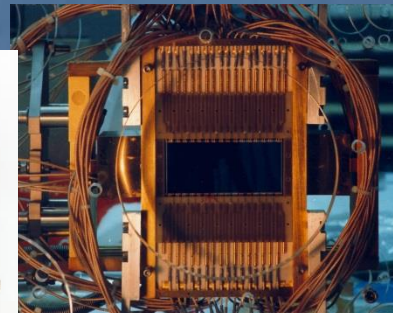


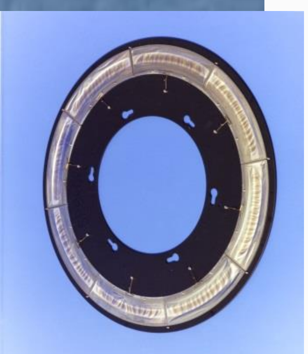
Velocity separator SHIP

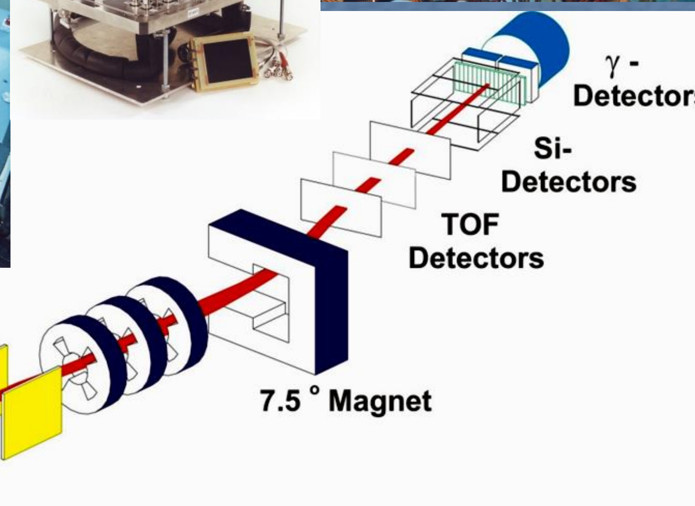
SHIP

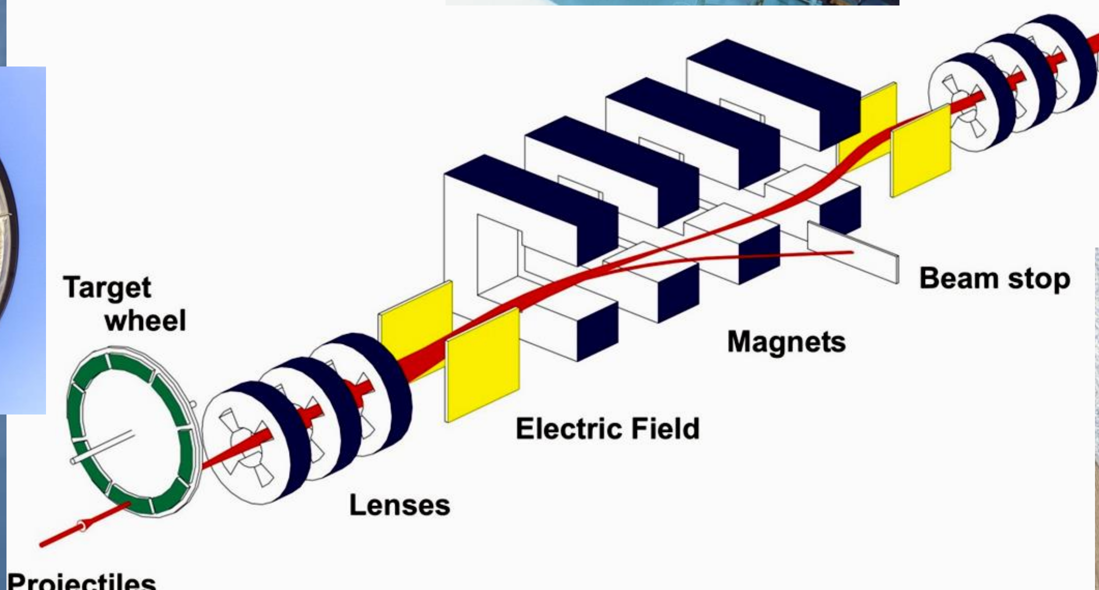
Separation time:	1 – 2 μs
Transmission:	20 – 50 %
Background:	10 – 50 Hz
Det. E. resolution:	18 – 25 keV
Det. Pos. resolution:	150 μm
Dead time:	25 μs

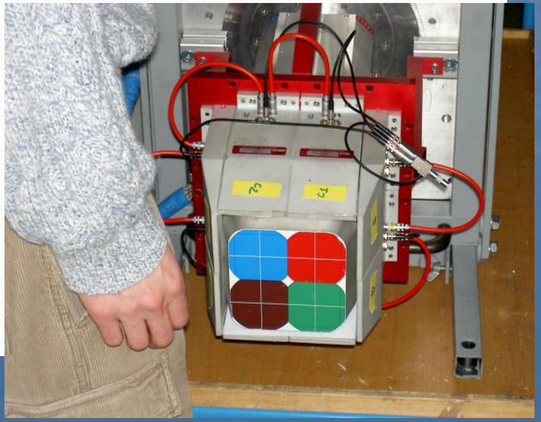












Decay Spectroscopy of SHN

Nuclear structure investigations require a large amount of events, but production rates of SHN are low (ca. 240 /d/nb)

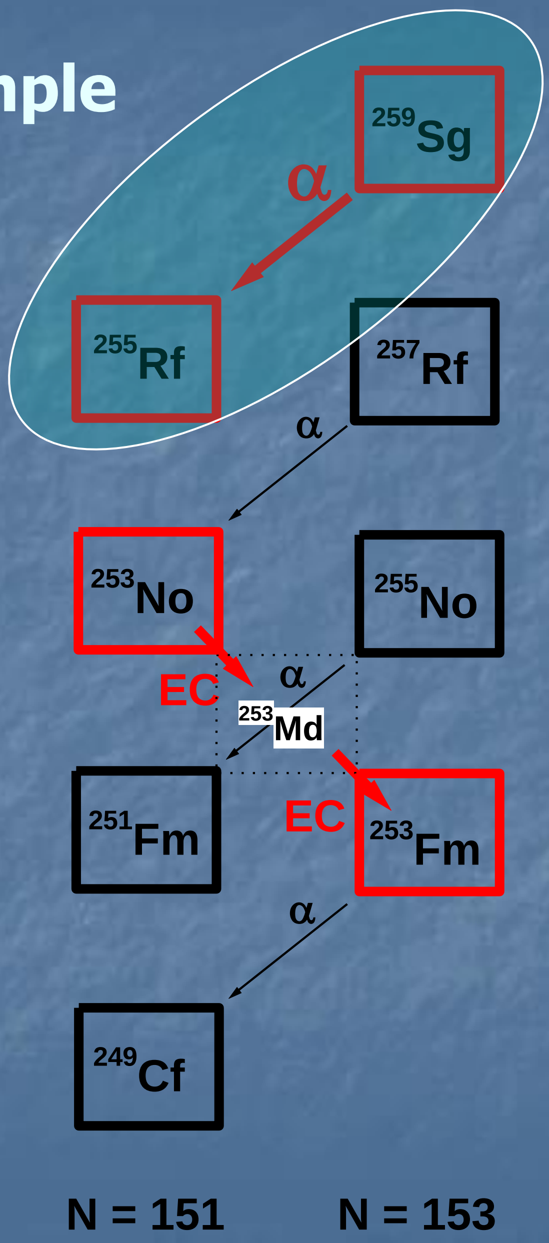
→ Nuclear structure of odd-A even Z nuclei is similar along isotone line

→ Nuclear structure of odd-A even Z nuclei is similar along isotope line

→ Study of systematics of (low lying) Nilsson levels in odd A nuclei

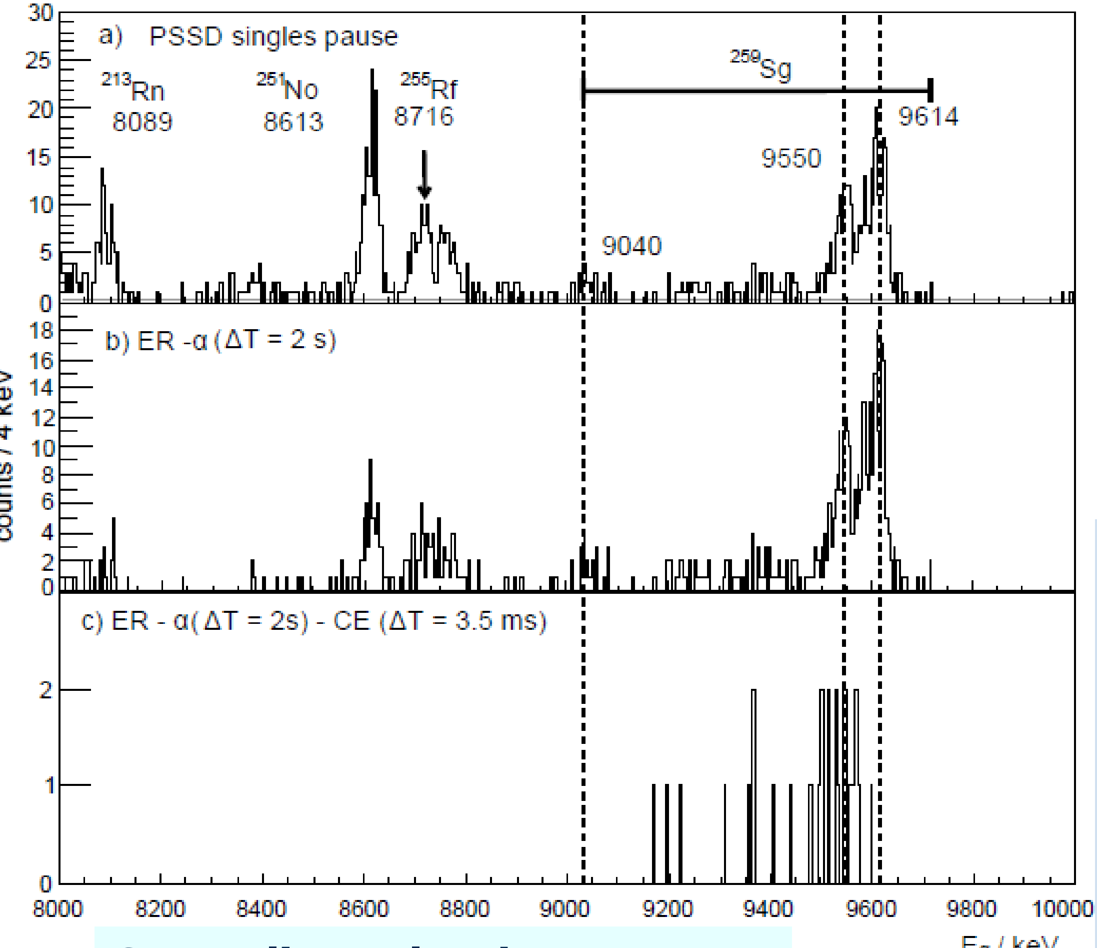
→ Study of K - isomers

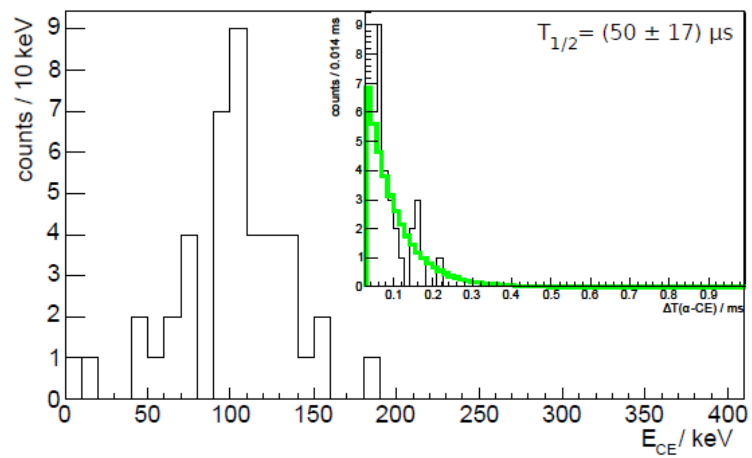
Example



Decay Study of ^{259}Sg

Production by $^{206}Pb(^{54}Cr,n)^{259}Sg$; σ ≈ 1 nb; α-decay from two states ^{259g}Sg ($T_{1/2}$ ≈ 410 ms) and ^{259m}Sg ($T_{1/2}$ ≈ 250 ms) observed

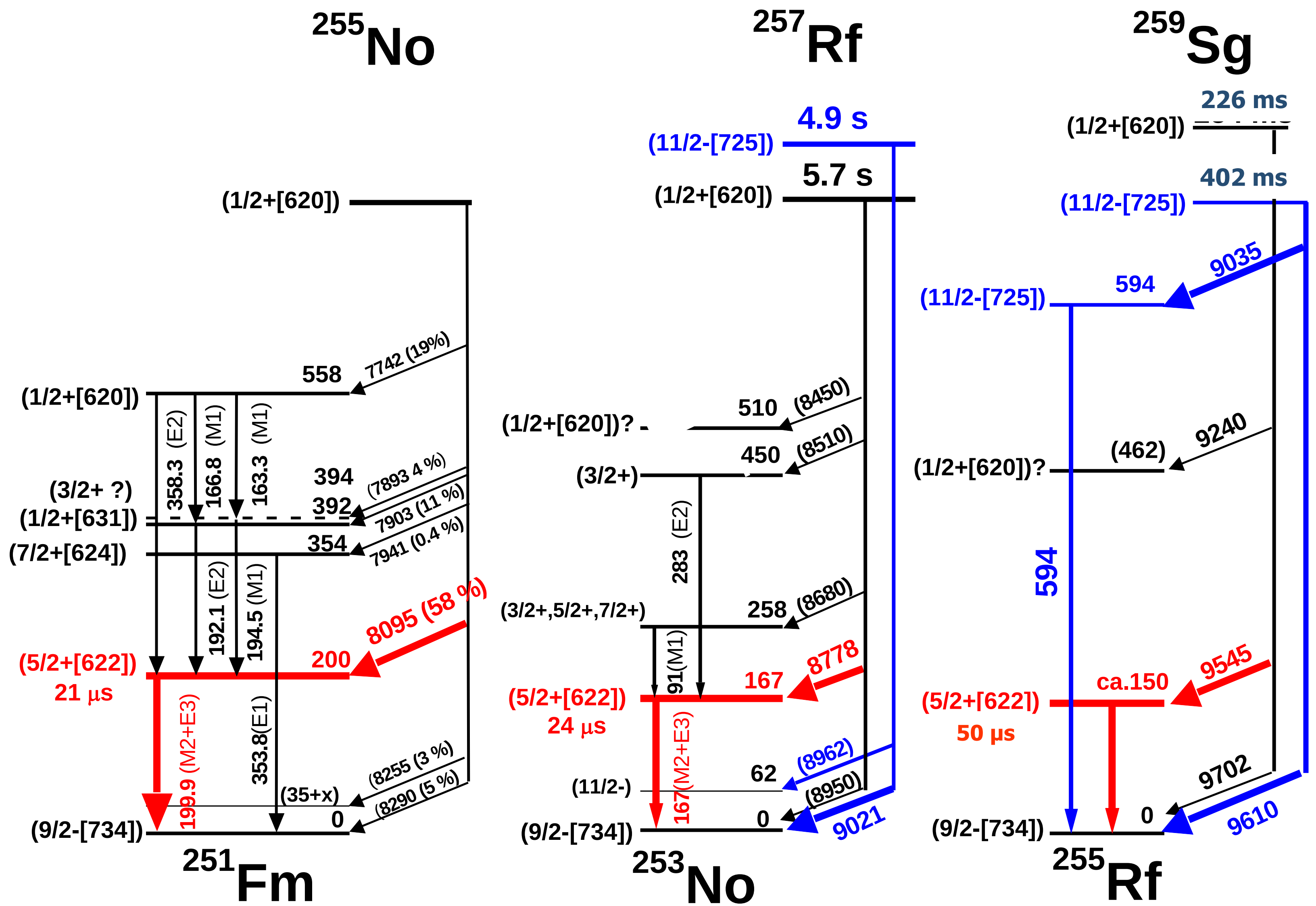




S. Antalic et al. subm. to EPJ A

CE not in coincidence with 9610 keV and 9035 keV lines !!
CE in coincidence with 9545 keV;
no gammas or K X-rays observed in del. coincidence with α – particles;
first decay scheme of ^{259}Sg based on α-, α-γ-, α-CE measurements and systematics for N=153 isotones

Decay schemes of the N=153 Isotones ^{255}No, ^{257}Rf, ^{259}Sg

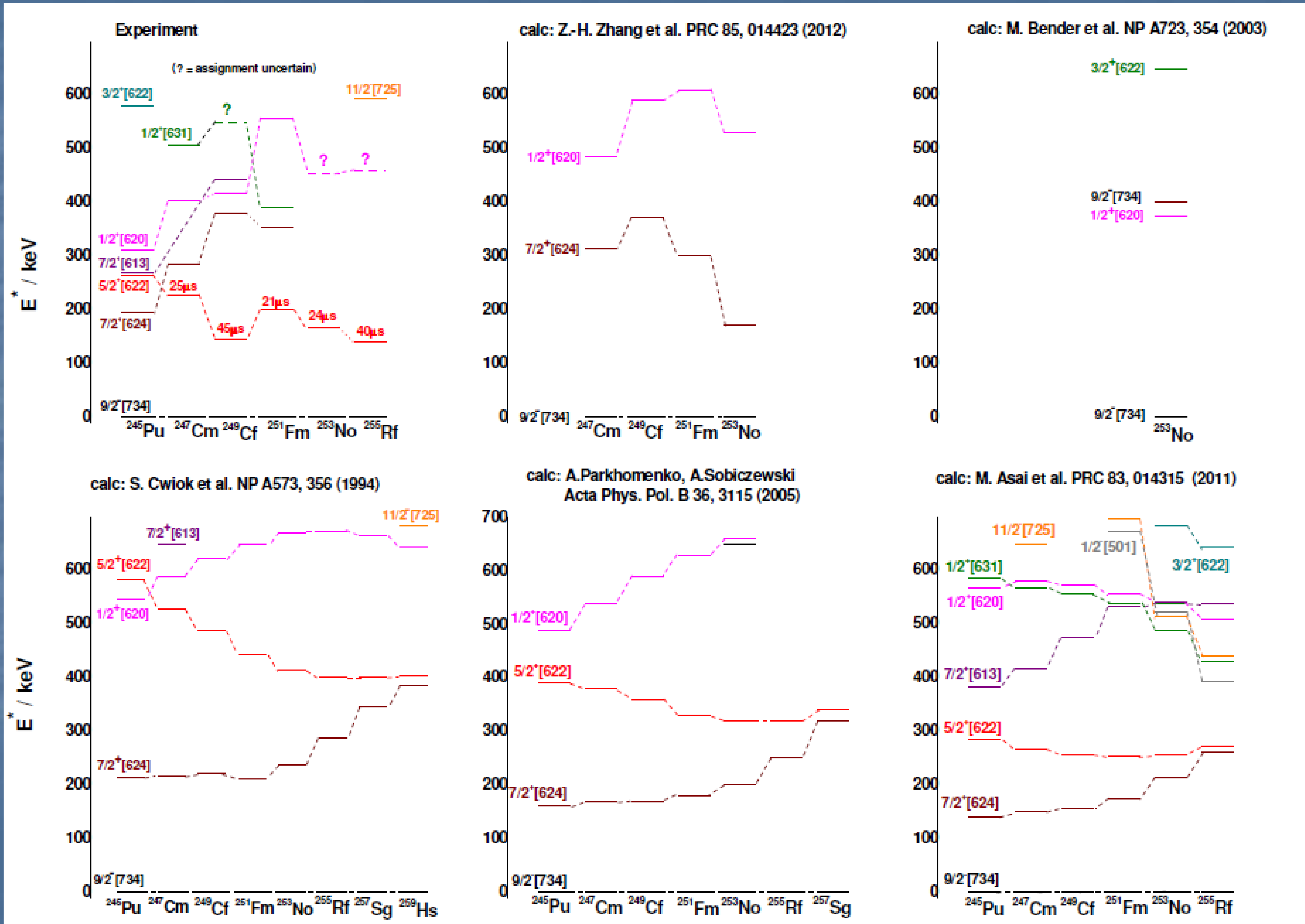


F.P. Heßberger et al. EPJ A29,165 (2006)

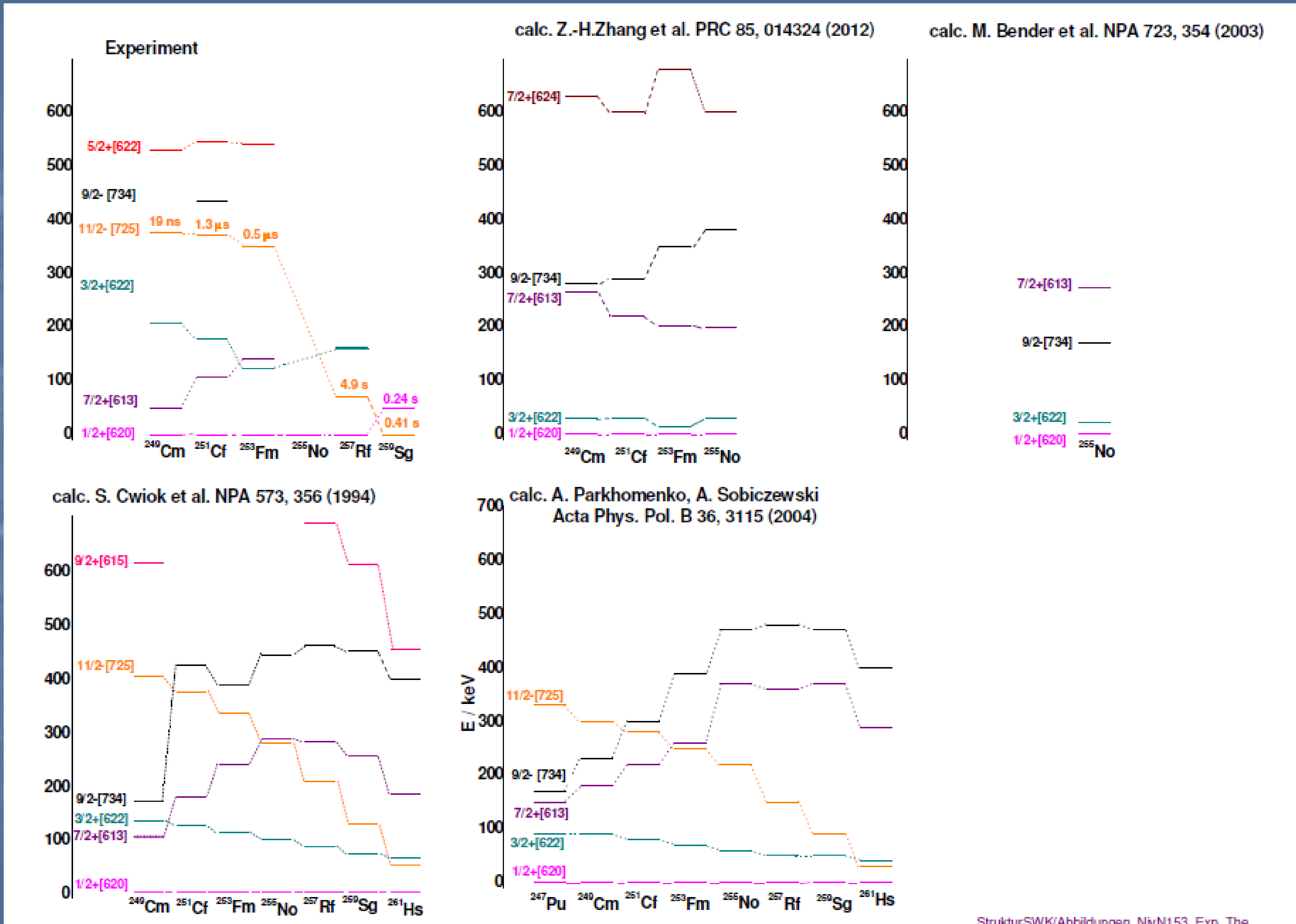
F.P. Heßberger et al. Z.Phys. A 359,415 (1997)
B. Streicher et al. EPJ A 45, 275 (2010)

S. Antalic et al. subm. to EPJ (2014)

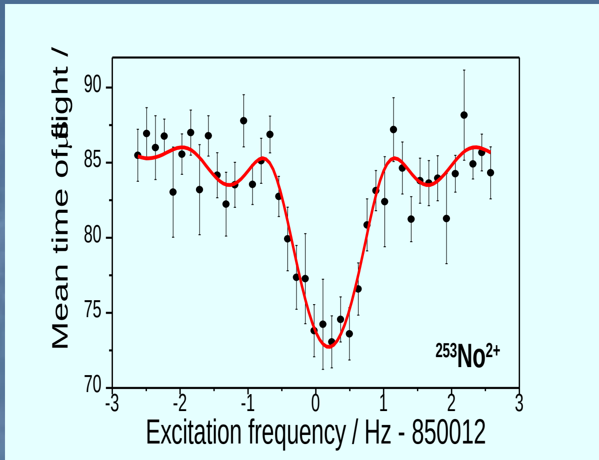
Nilsson-Levels in N=151 Isotones

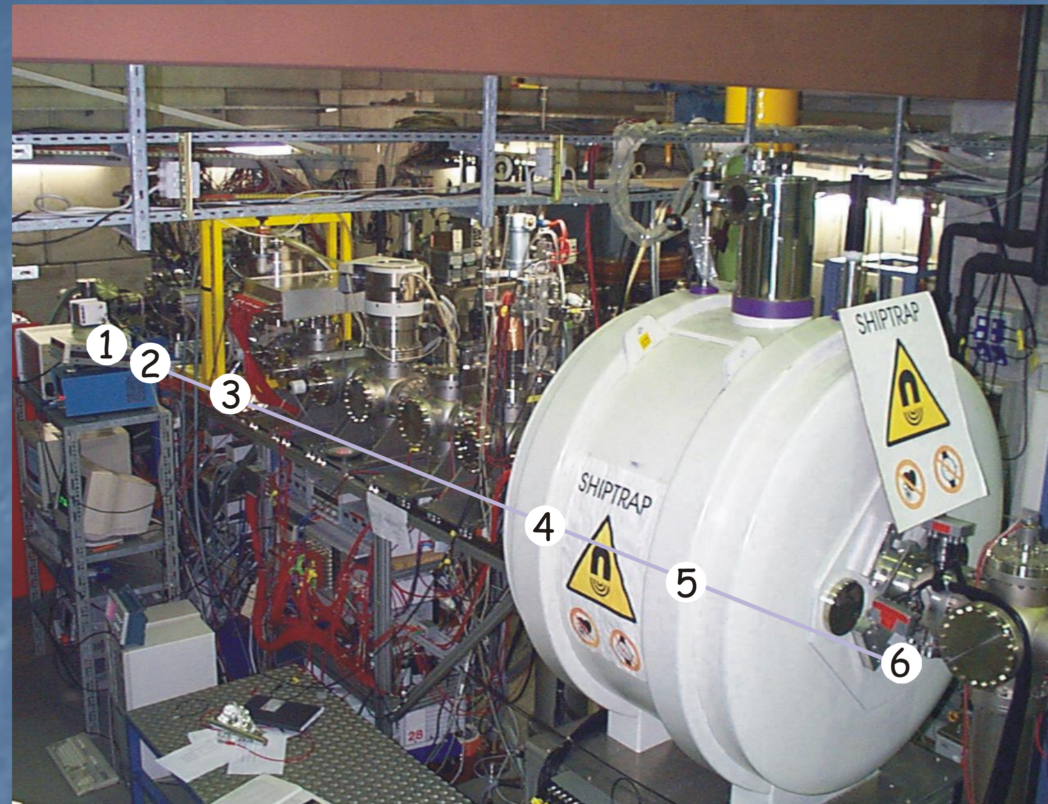


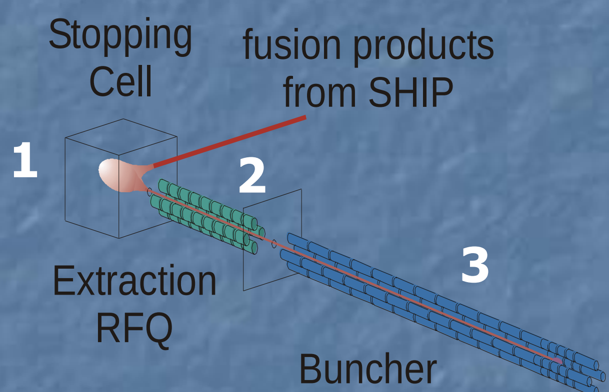
Nilsson-Levels in N=153 Isotones



SHIPTRAP







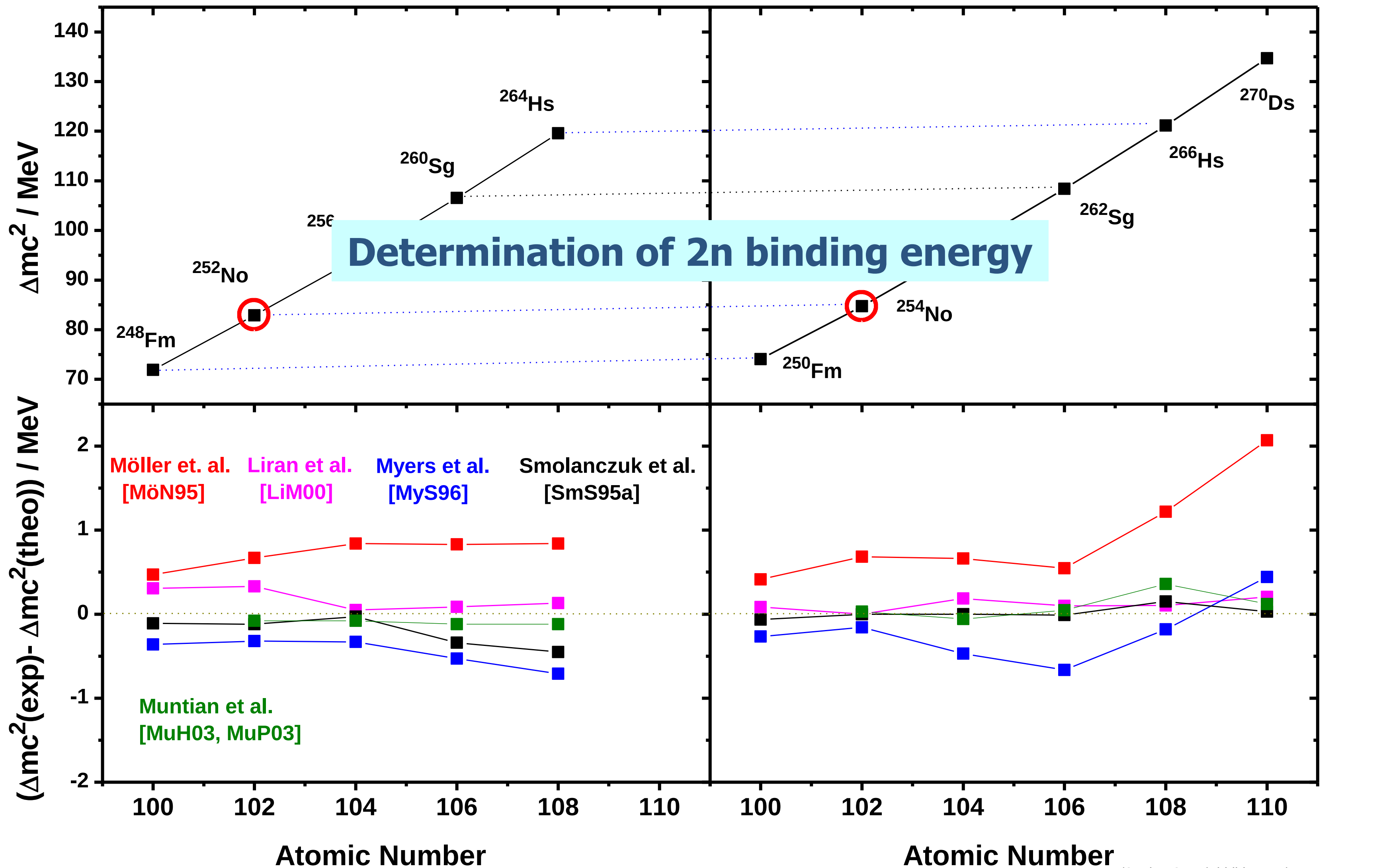
1. deceleration
2. cooling
3. accumulation
4. purifcation
5. storage
6. detection

Masses Measured

^{252,253,254,255}**No**

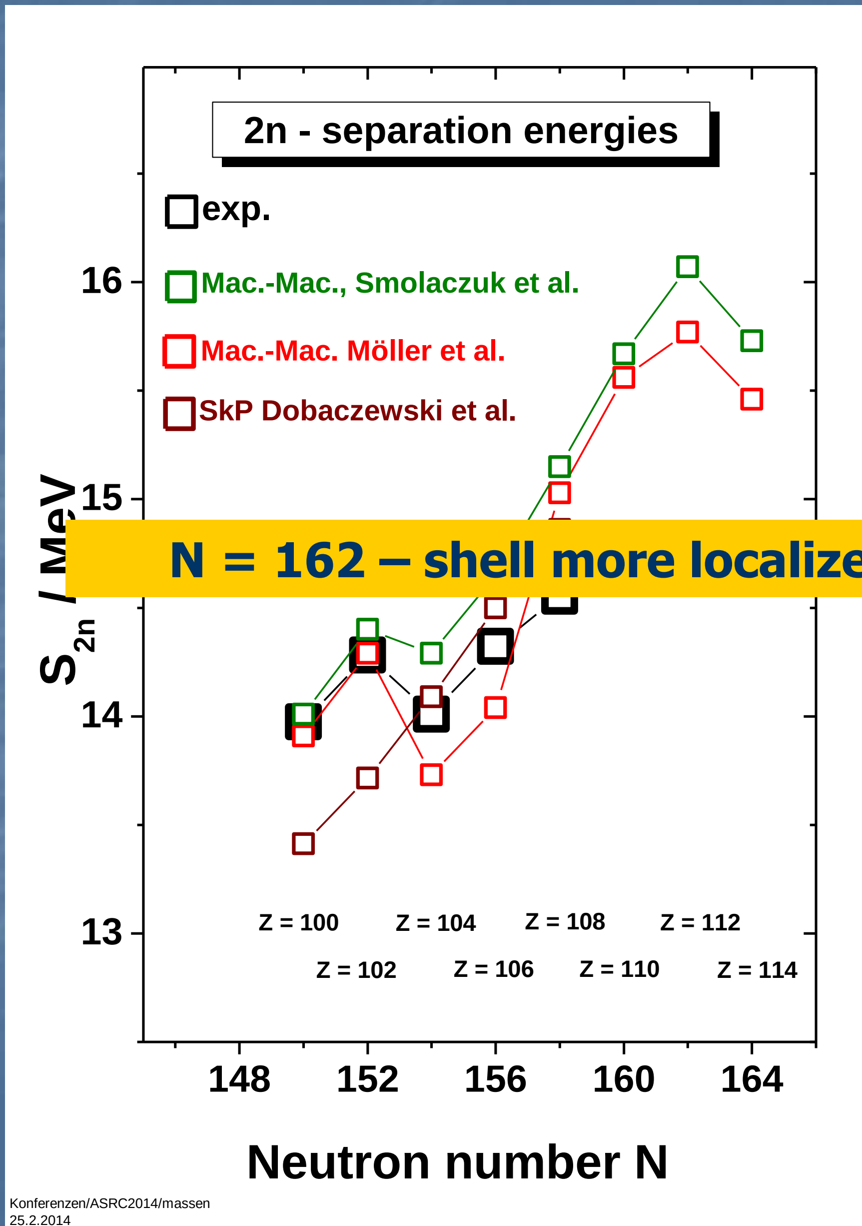
^{255,256}**Lr**

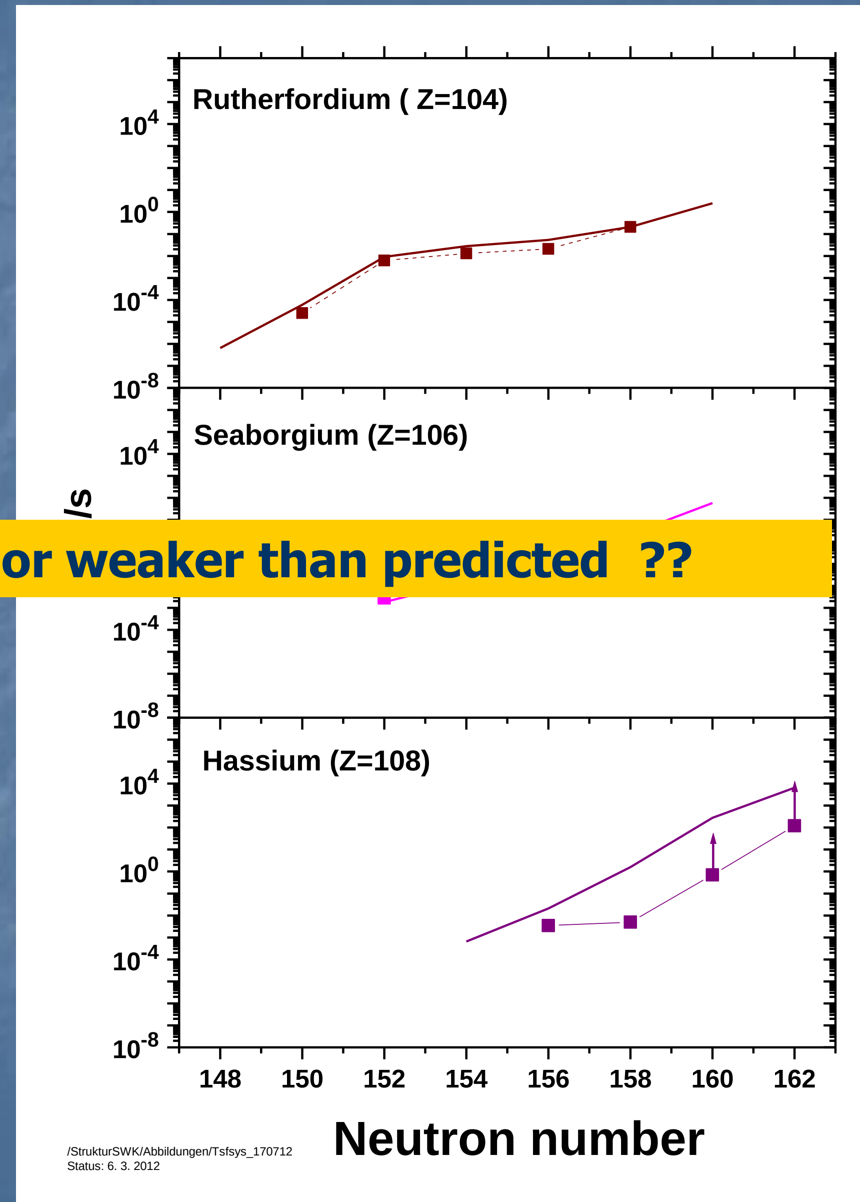
Masses of N-Z = 48, 50 even-even nuclei



/StrukturSWK/Abbildungen/Massen,
F.P. Heßberger, 16.4.2013

Shell strength towards N = 162



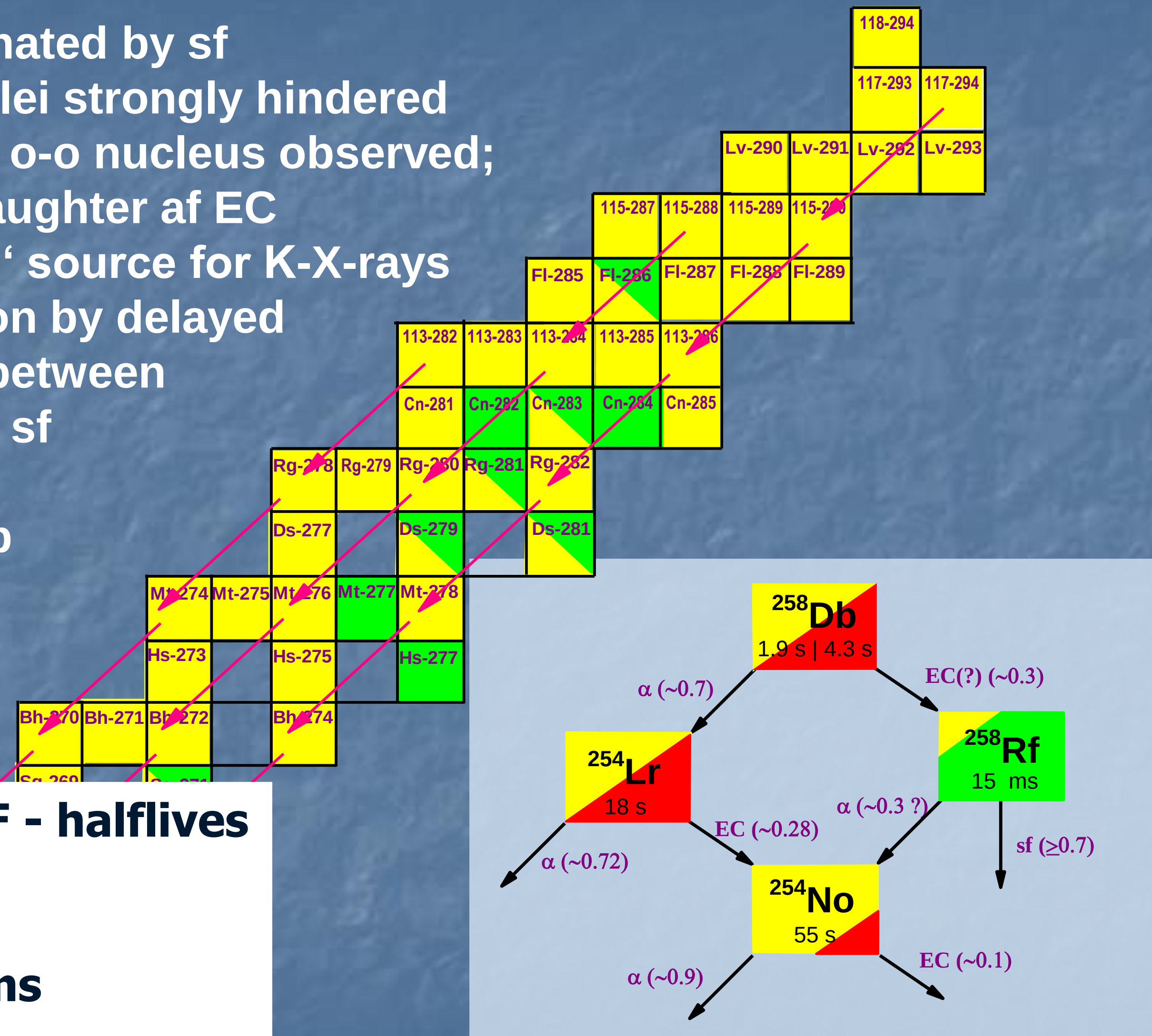


N = 162 – shell more localized or weaker than predicted ??

Z – Identification of SHE

→ α-chains terminated by sf
→ sf of o-o – nuclei strongly hindered
→ maybe no sf of o-o nucleus observed; but sf of e-e daughter af EC
→ EC is a ‚certain‘ source for K-X-rays
→ Z – identification by delayed coincidences between K – X-rays and sf

→ test-case: ^{258}Db



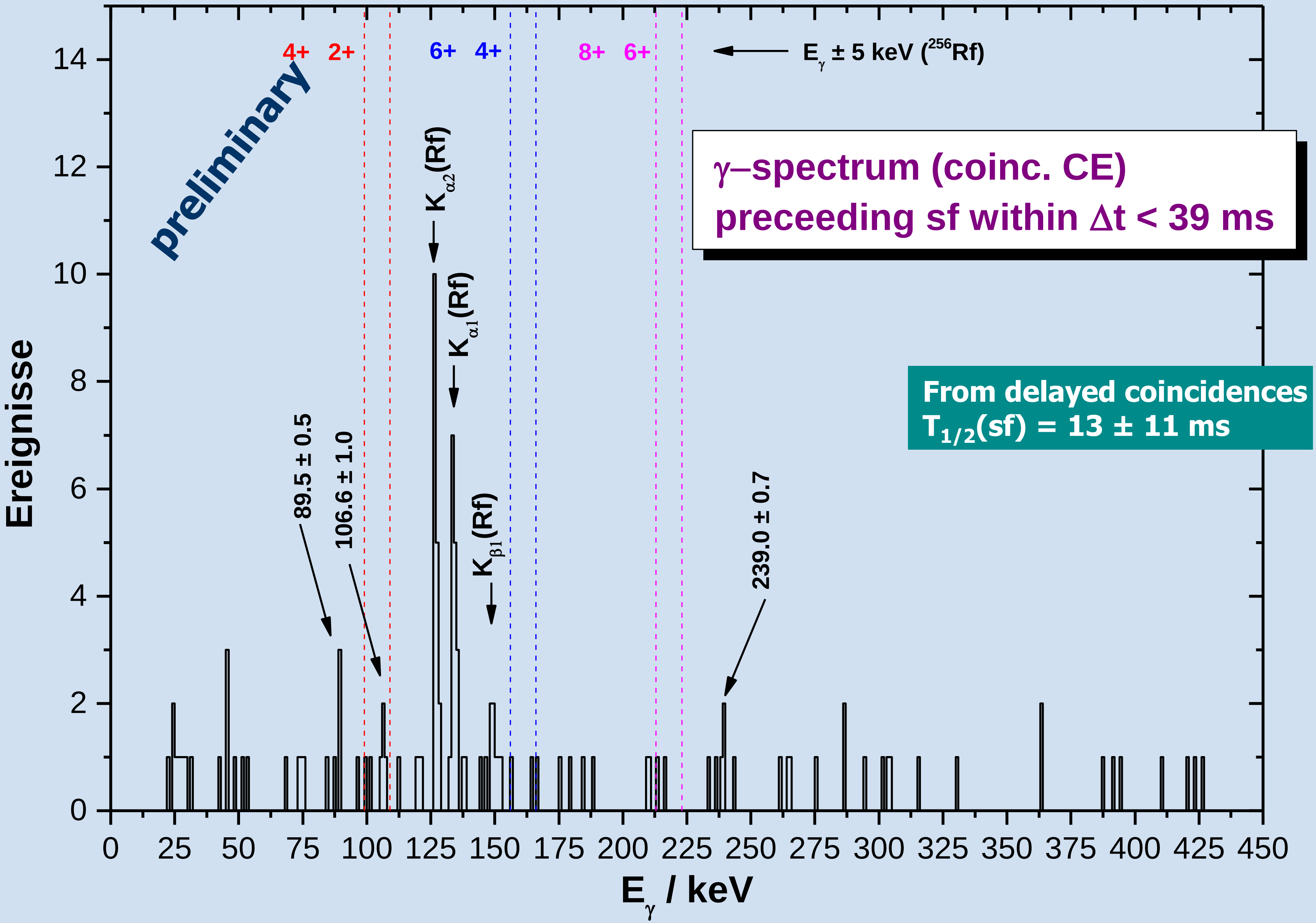
Proton Number: 102, 104, 106, 108, 110, 112, 114, 116, 118

Neutron Number: 156, 158, 160, 162, 164, 166, 168, 170, 172, 174, 176, 178, 180

Predict. SF - halflives
^{266}Rf: 23s
^{268}Rf: 1.4s
^{270}Rf: 20 ms

StrukturSWK/Abbildungen/NukaSHE

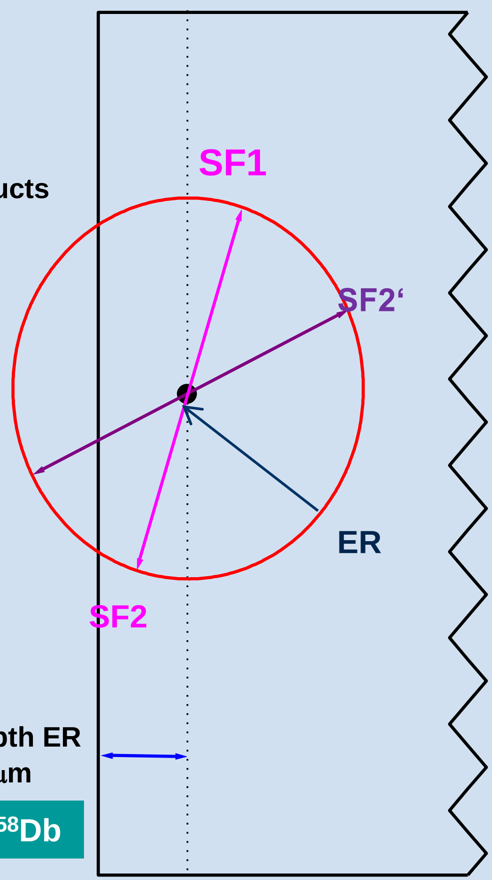
Direct Prove of EC of ^{258}Db



<TKE> Measurement of $^{255,256,258}Rf$

Implantation depth of ER < range of SF products
p(sf1+sf2) ≈ 40%
large PHD due to high ionisation density

range of sf products
ca. 22 µm

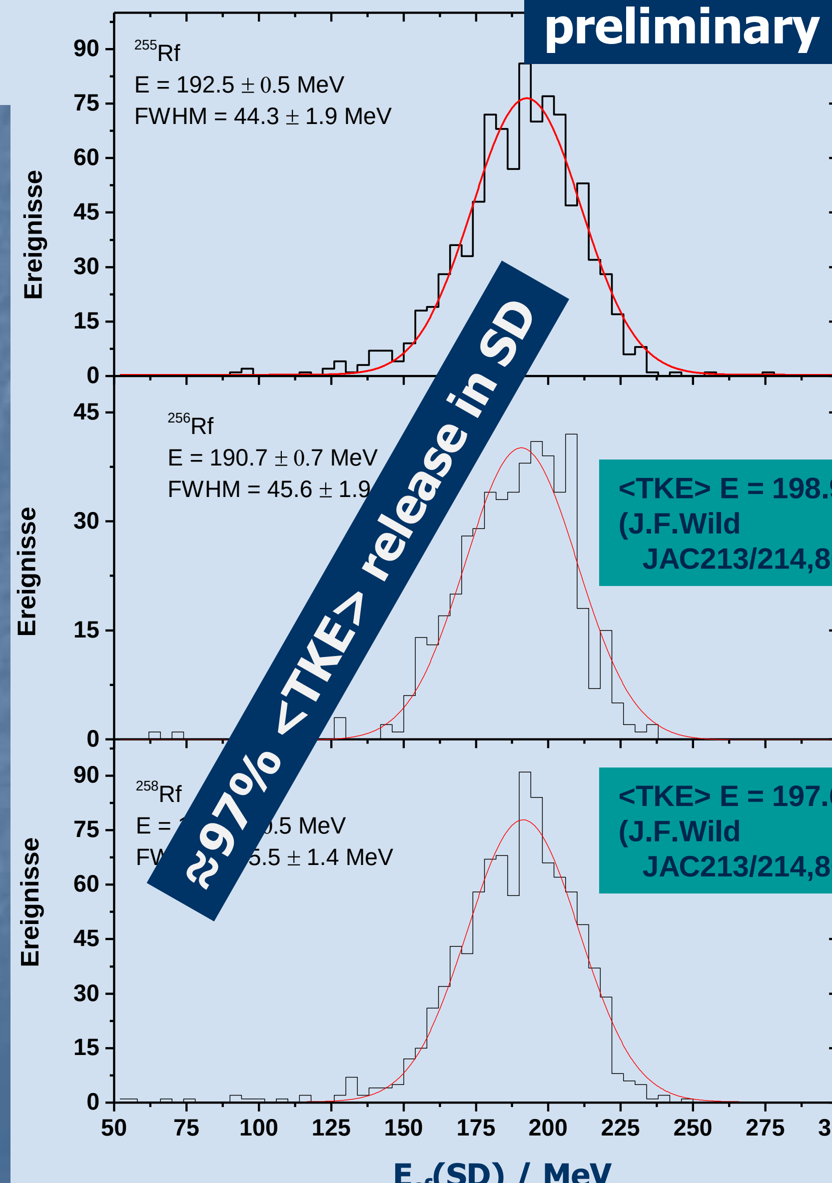


Impl. Depth ER
ca. 6-10 µm

≈ 7µm for ^{258}Db

Stopdetektor (SD)

preliminary

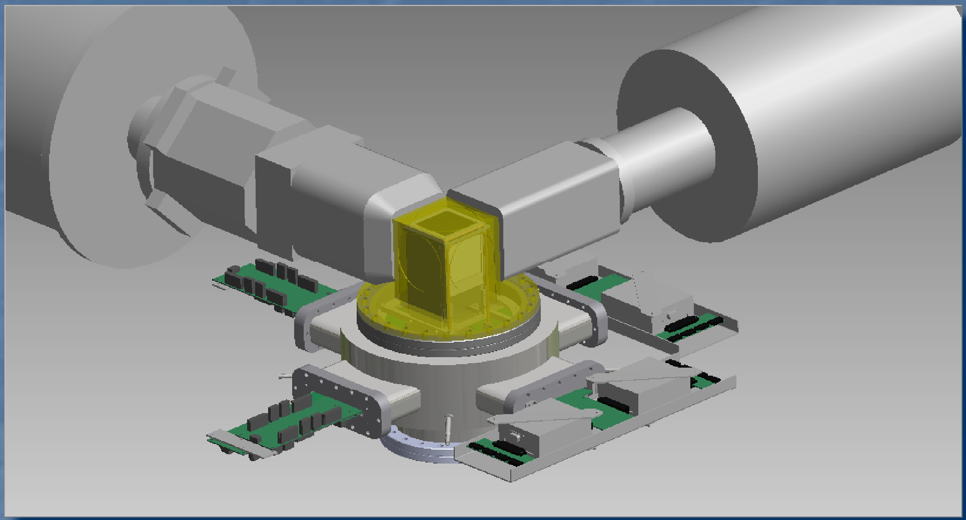


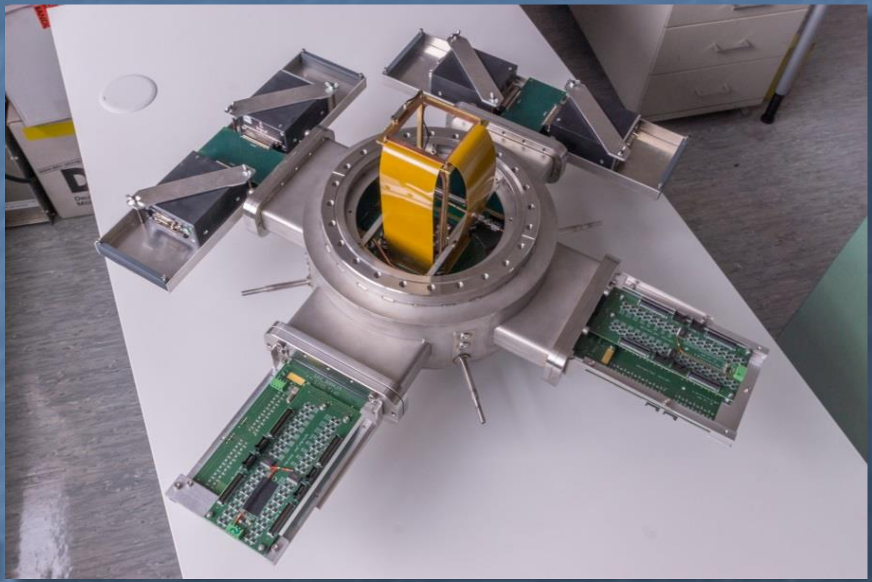
≈97% <TKE> release in SD

<TKE> E = 198.9±4.4 MeV
(J.F.Wild
JAC213/214,86 1994)

<TKE> E = 197.6±1.1 MeV
(J.F.Wild
JAC213/214,86 1994)

Enhanced Focal Plane Detector Set-up for SHE Spectroscopy

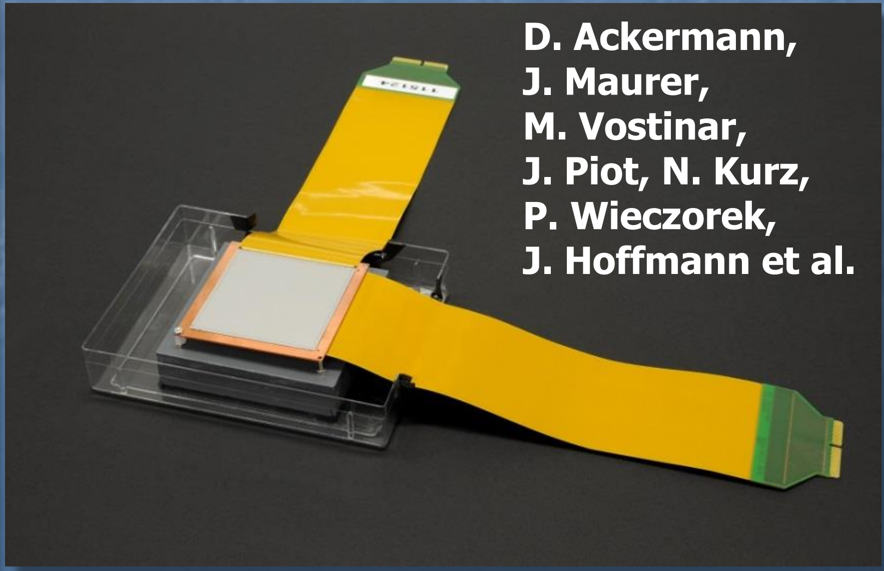




configuration
- *stop detector: 1 × DSSD (60×60 strips)*
- *box detectors: 4 × SSSD (32 strips)*
- *overall particle - γ-efficiency ≈ 40%*

chamber
- *compact (overall length 35 cm)*
- *Al-cap with thin γ window (1,5 mm)*
- *compatible due to 150 mm standard flange*
- *electronics partly integrated (vacuum)*

DSSD
- *integrated cooling (Cu-frame) and connection (flex-PCB)*
- *60×60 strips/mm (pitch 1 mm)*
- *300 μm*



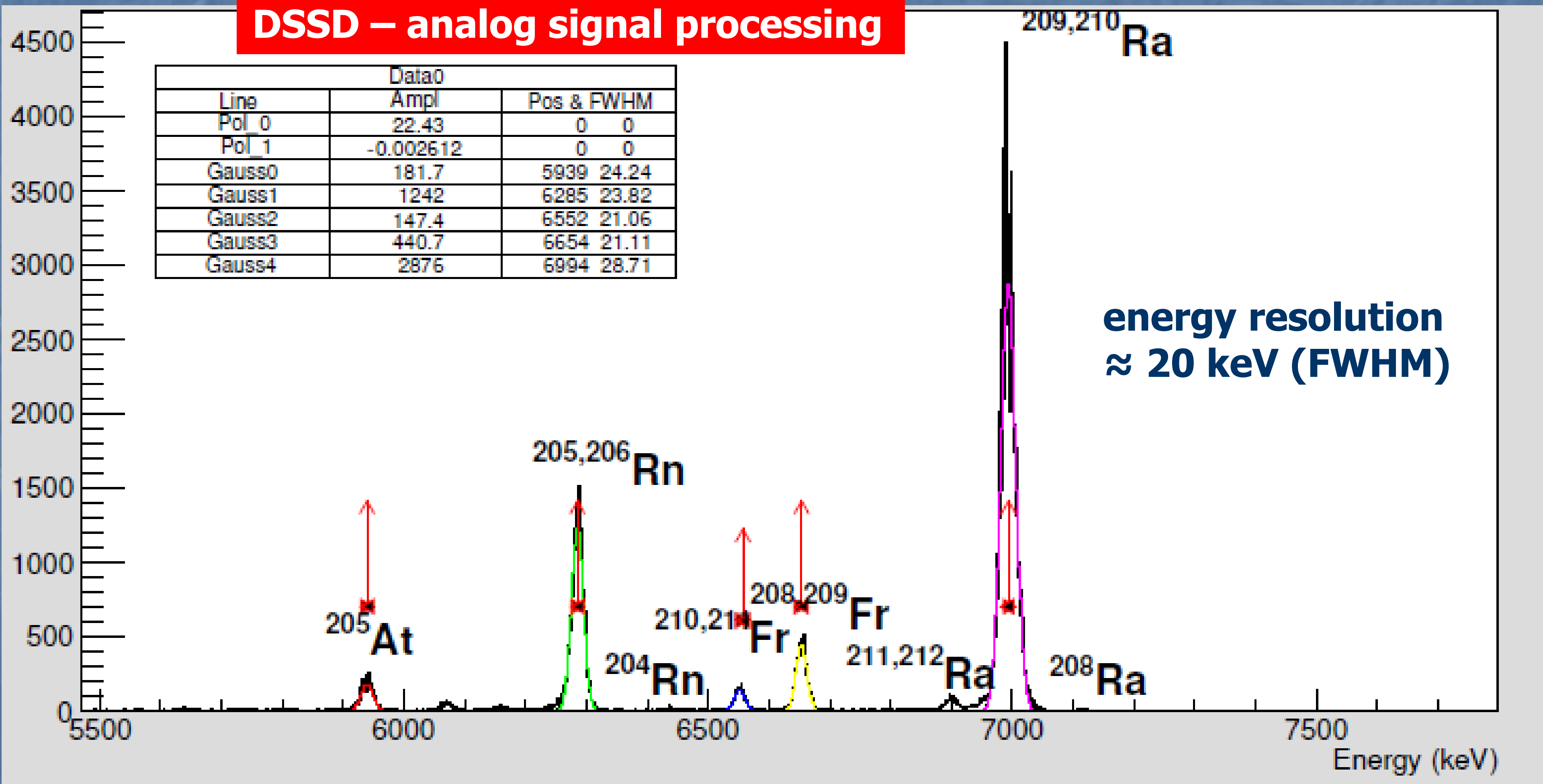
D. Ackermann, J. Maurer, M. Vostinar, J. Piot, N. Kurz, P. Wieczorek, J. Hoffmann et al.

Enhanced Focal Plane Detector Set-up for SHE Spectroscopy

First on-line test at LISE – Wienfilter GANIL, november 2014

^{40}Ar (4.66 AMeV) + ^{174}Yb → ^{209,210}Ra

DSSD – analog signal processing

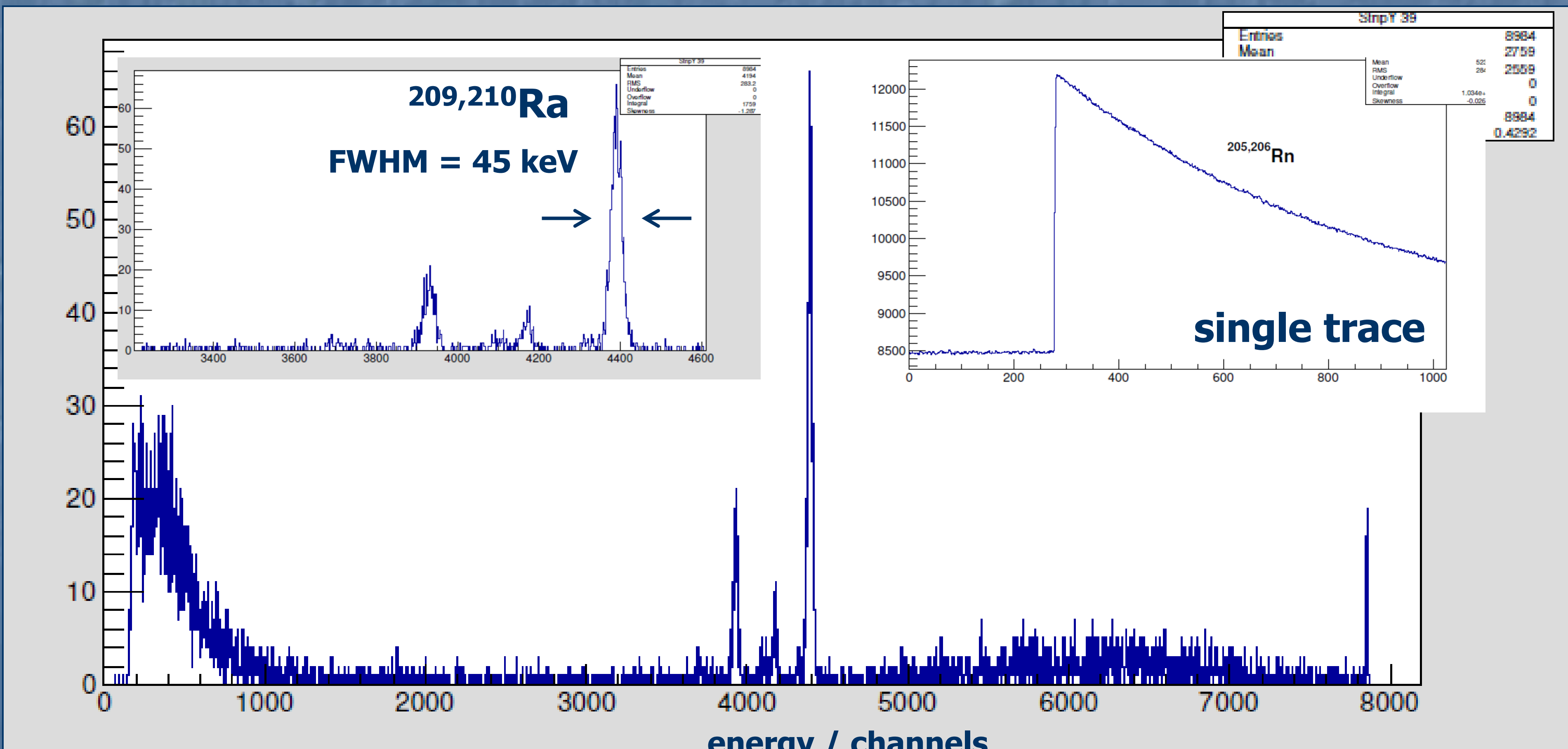


Data0		
Line	Ampl	Pos & FWHM
Pol_0	22.43	0 0
Pol_1	-0.002612	0 0
Gauss0	181.7	5939 24.24
Gauss1	1242	6285 23.82
Gauss2	147.4	6552 21.06
Gauss3	440.7	6654 21.11
Gauss4	2876	6994 28.71

energy resolution ≈ 20 keV (FWHM)

Enhanced Focal Plane Detector Set-up for SHE Spectroscopy

Digital signal processing → FEBEX + conventional PA
DSSD, Ge-detectors, ...
• fast timing • deadtime free • pulse shape analysis options



Summary and Conclusions

→ Macroscopic – microscopic models did a great job in predicting a region of ‚relative' high nuclear stability above the actinides (‚superheavy elements') at Z = 114 and N = 184

→ Selfconsistent models using effective NN – interaction put the ‚old' shell predictions in question, Z = 120, 126 and also N = 172 appear as possible candidates for proton and neutron shells

→ Nuclear spectroscopy is a suited method to obtain detailed information about the nuclear structure and the underlying nuclear force and to test the predictive power of models with respect to location and strengths of nuclear shells (even without reaching the ‚center')

→ Precise mass and Q_α – value measurements allow to determine the strength of nuclear shells in the region of SHE

→ Nuclear spectroscopy is also an unambiguous method to determine the atomic number by measuring K – X-rays either from deexcitation of nuclear levels populated by α – decay or from EC.

→ On long-term view a general (or common) parametrization of the ‚strong force' to decribe commonly evaluation of the universe and the stars as well as the atomic nuclei is desired; investigation of superheavy nuclei are hopefully a valuable tool to reach that aim.

Collaboration

GSI, Darmstadt
D. Ackermann, M. Block, S. Heinz, F.P.H., J. Hoffmann, S. Hofmann, B. Kindler, I. Kojouharov, J. Khuyagbaatar, N. Kurz, B. Lommel, P. Wieczorek

Helmholtz Institut Mainz
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C. Droese *(also EMA Univ. Greifswald, Germany*)

Comenius University Bratislava, Slovakia
S. Antalic, Z. Kalininova, B. Andel

GANIL, Caen, France
J. Piot, M. Vostinar, H. Savajols, Ch. Stodel