

# Search for 283,284,285Fl decay chains

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M. V. Shumeyko, V. G. Subbotin, A. M. Sukhov,  
and G. K. Vostokin

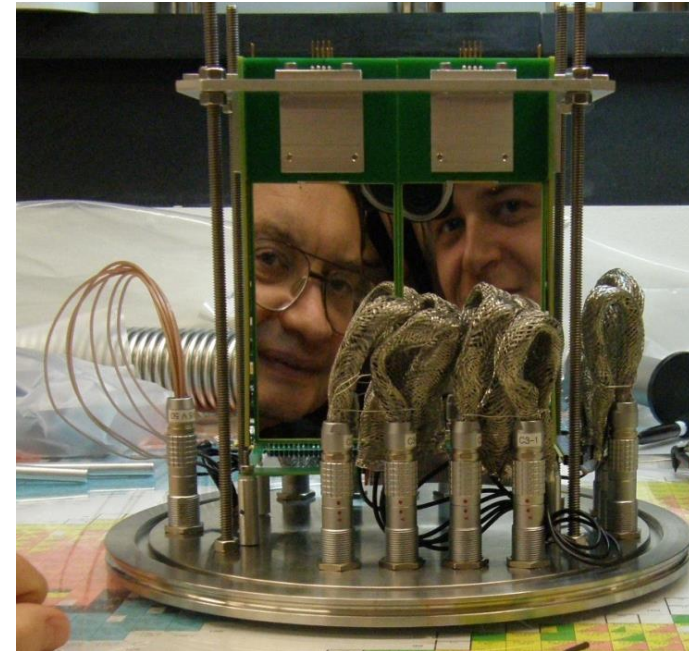
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*UTK/ORNL:* **R. K. Grzywacz**

*Vanderbilt:* J. H. Hamilton

*LLNL:* R. A. Henderson and M. A. Stoyer

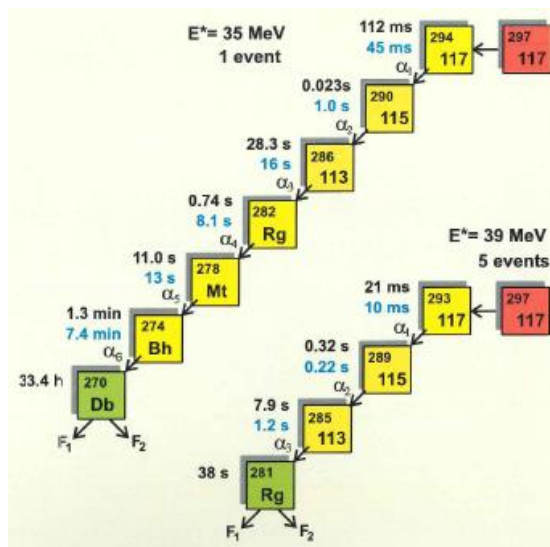


# Outline

- Super Heavy Nuclei – the Island and Mainland
- Reactions with  $^{239,240}\text{Pu}$  targets and  $^{48}\text{Ca}$  beam
- Digital detection system for Super Heavy Nuclei
- $^{239}\text{Pu}+^{48}\text{Ca}$  (6<sup>th</sup> Dec 2013-22<sup>nd</sup> Feb 2014,  $1.28 \times 10^{19}$  beam dose)  
at the DGFRS (Dubna)
- Summary

# Towards “Island of Stability”

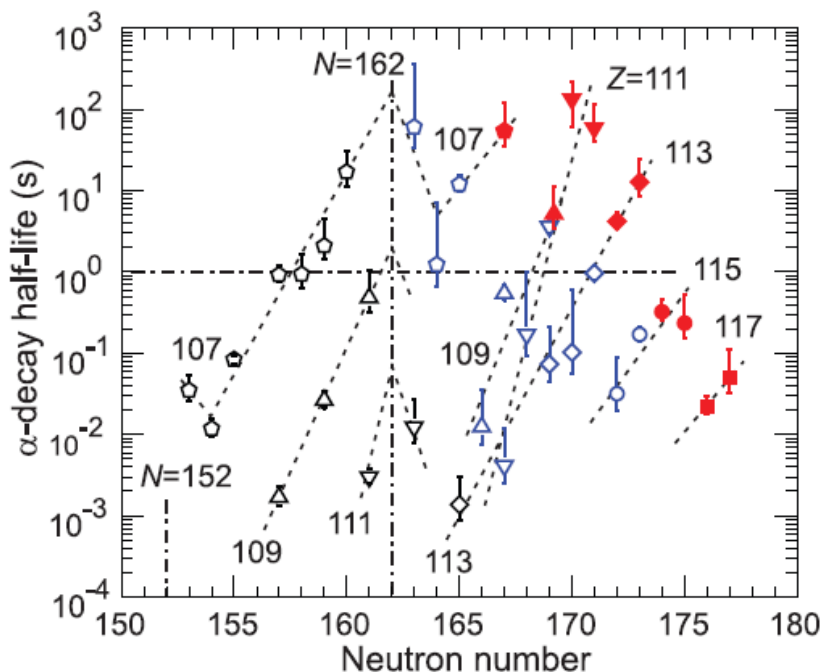
- New element  $Z = 117$  (Russia-US collaboration)



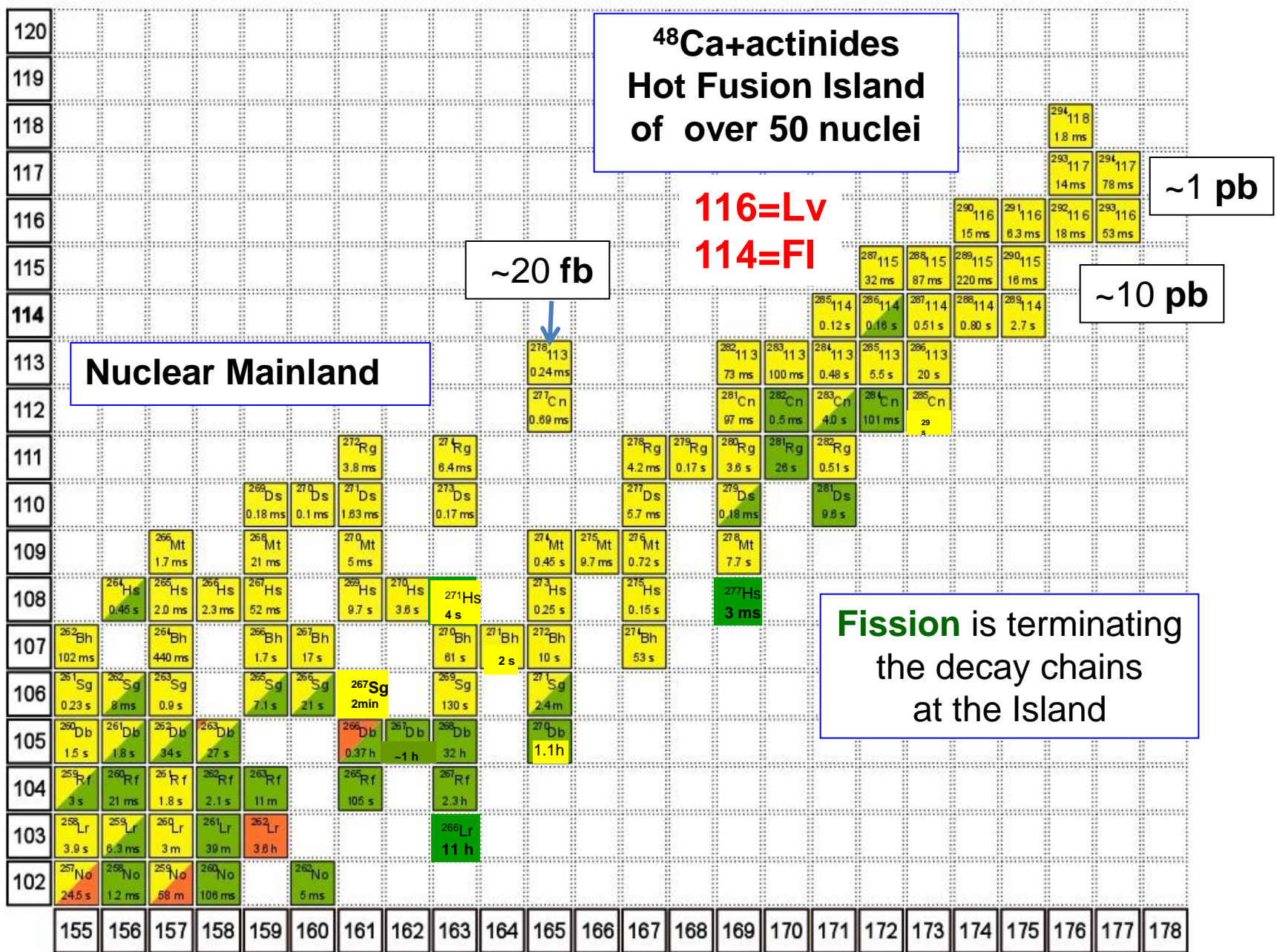
Yu. Oganessian et al.,  
PRL 104, 2010



Rose Boll and Shelley Van Cleve  
purifying  $^{249}\text{Bk}$  at ORNL





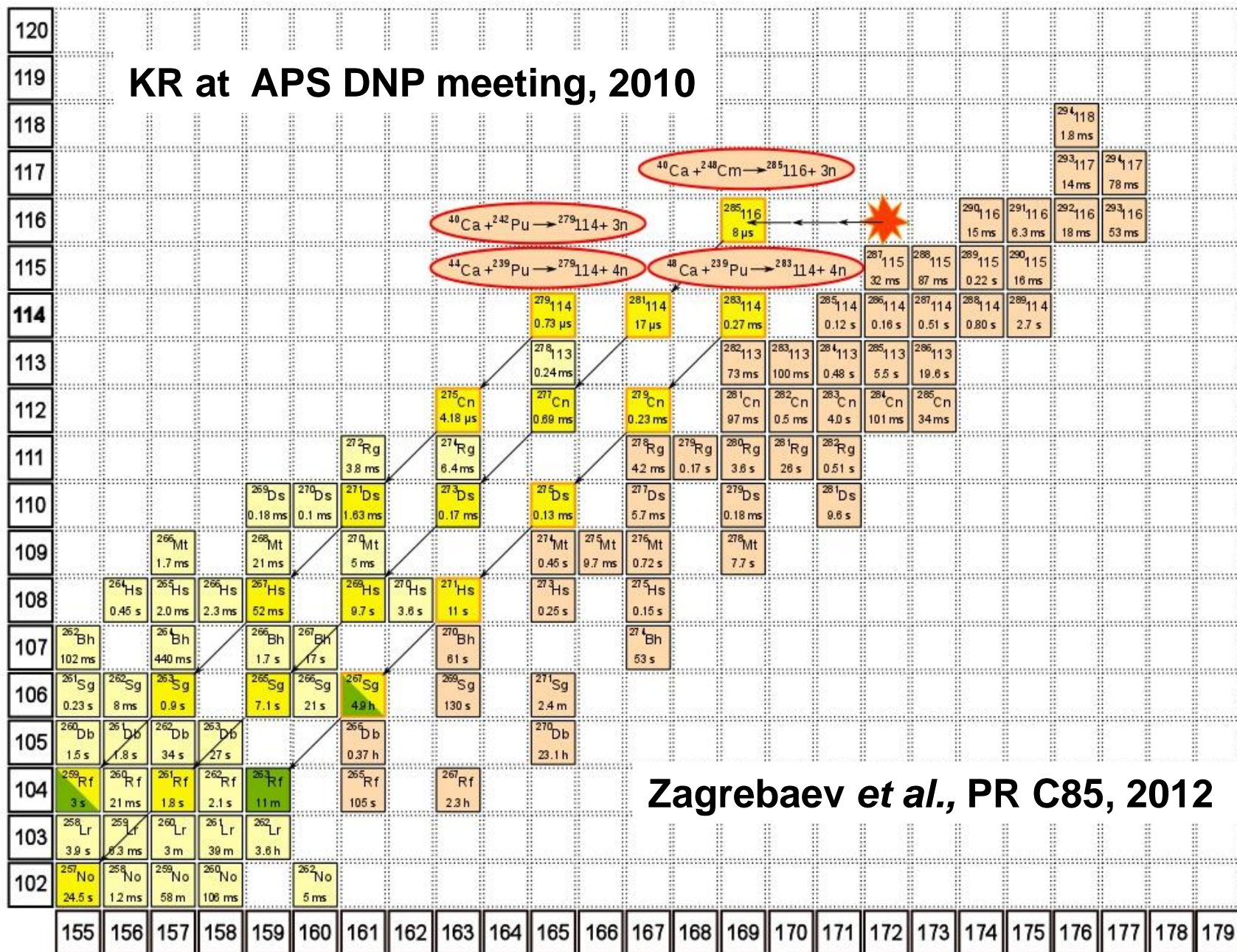


All nuclei from the Island were created using  $^{48}\text{Ca}$  beam, attempts to use  $^{64}\text{Ni}$ ,  $^{58}\text{Fe}$ ,  $^{54}\text{Cr}$ ,  $^{50}\text{Ti}$  + actinides were so far not successful



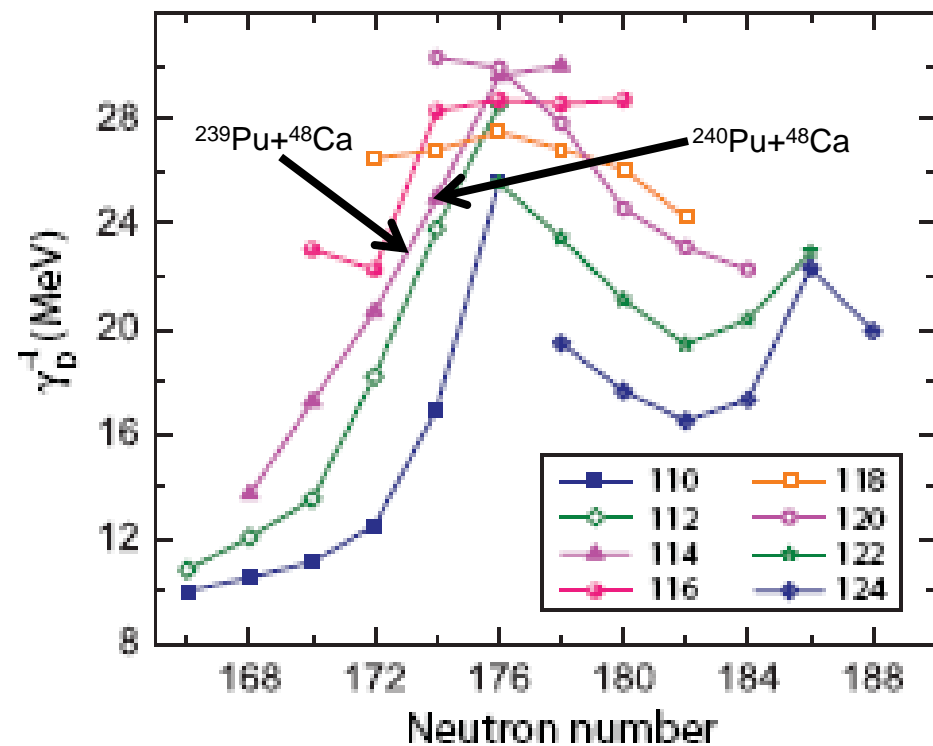
# Building bridges between the *mainland* and *super heavy island* understanding SHE production mechanism using $^{48}\text{Ca}$ , $^{44}\text{Ca}$ and $^{40}\text{Ca}$ beams

KR at APS DNP meeting, 2010

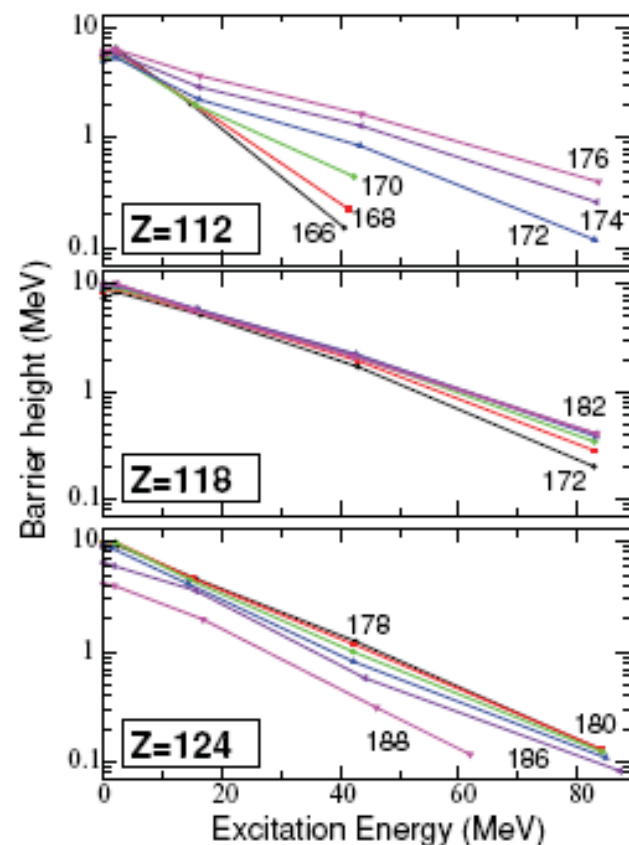


Zagrebaev et al., PR C85, 2012

# Systematic study of fission barriers in **excited states** of superheavy nuclei



Inverse damping parameter  $\gamma_D^{-1}$   
for even-even **compound** nuclei



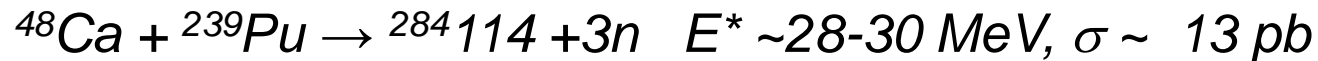
$$E_B \sim \exp(-\gamma_D \times E^*)$$

Denisov, Hofmann, PR C61, 2000

Itkis, Oganessian, Zagrebaev, PR C65, 2002

# Examples of production cross section predictions

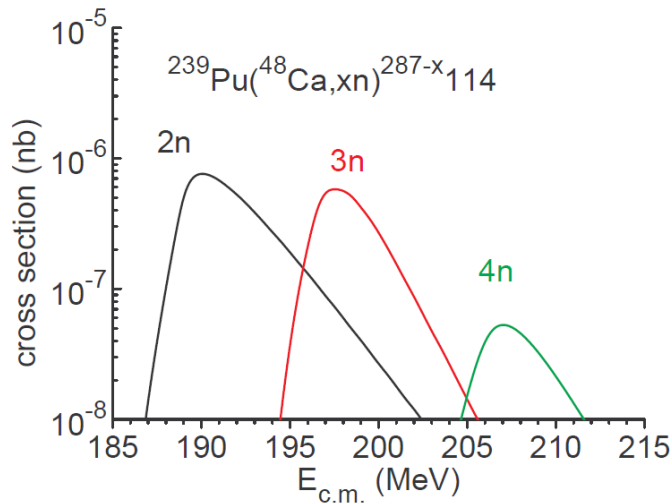
*Walter Loveland, private communication, 2010*



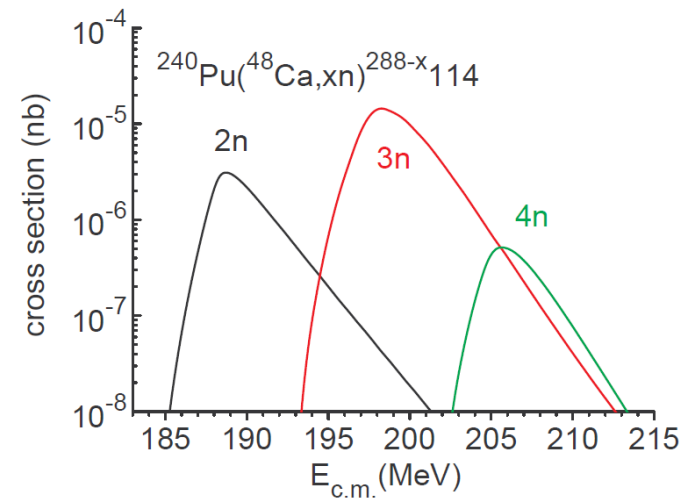
***let's run and hit  $^{239}\text{Pu}$  with  $^{48}\text{Ca}$  !***

Well, let's check with others before running ....

from **Krystyna Wilczyńska**, see **Siwek-Wilczyńska, Cap, Kowal et al., PR C86, 2012**

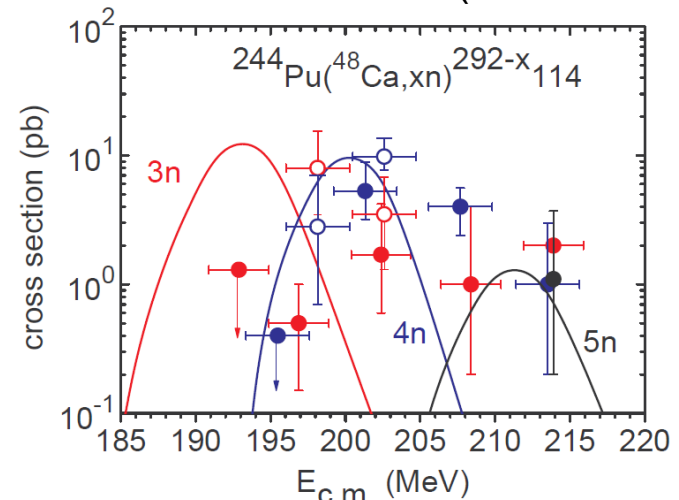
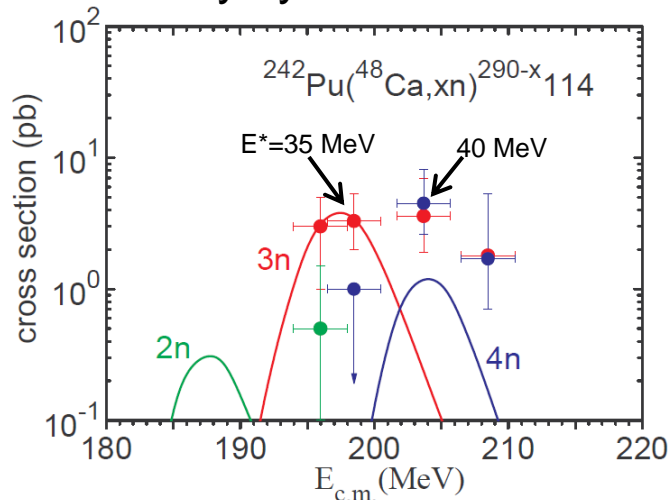


*it is **NOT** a printing mistake !*  
**predicted  $\sigma \sim 1$  femtobarn**



about 10 times higher  $\sigma$   
 but still only  $\sim 10 - 20$  femtobarns

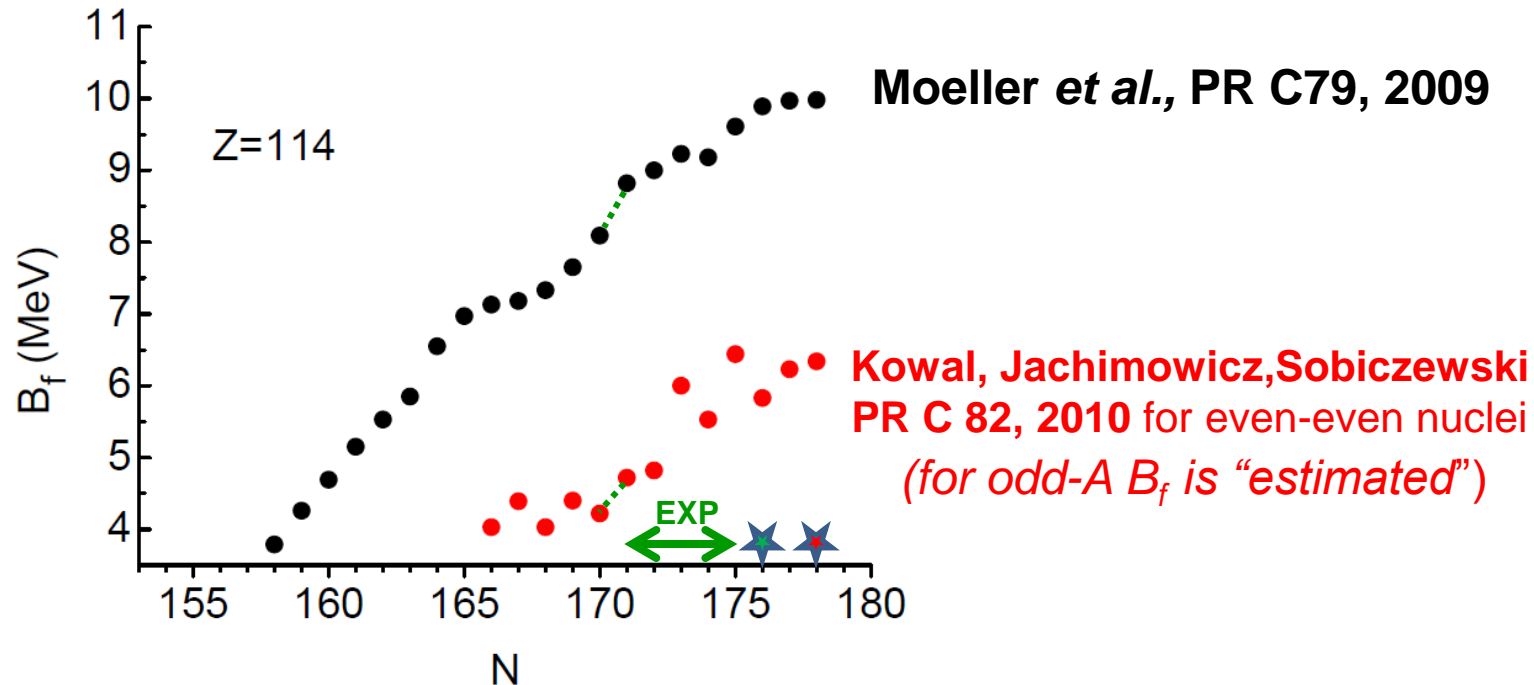
.. and Krystyna et al. seem to reproduce measured X-sections (*more or less* ..)



**let's forget about hitting  $^{239}\text{Pu}$  with  $^{48}\text{Ca}$  !**



Krystyna Wilczyńska *et al* used fission barriers values  $B_f$  from M. Kowal *et al* calculations in her X-section calculations



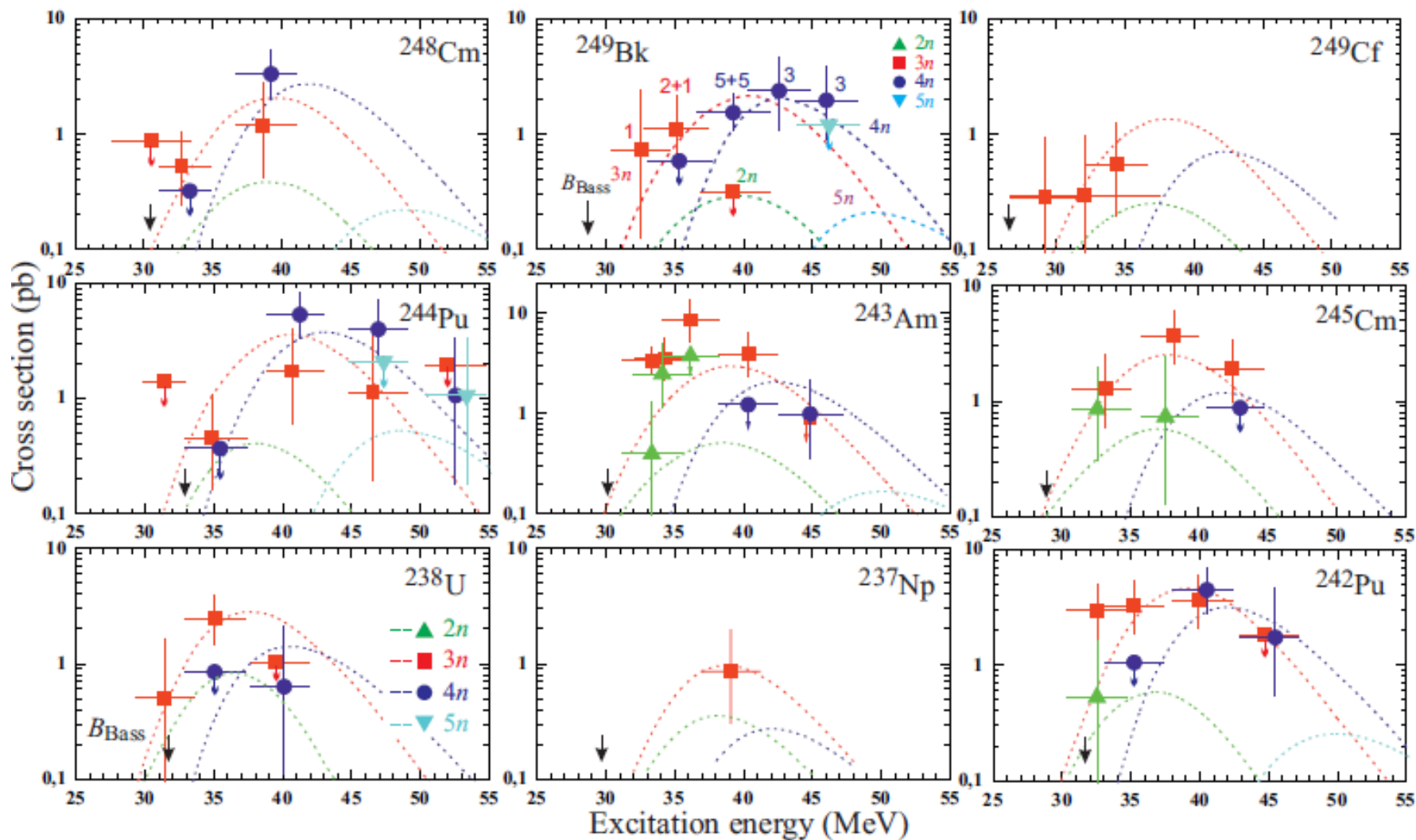
~ 300 keV difference in  $B_f$  value corresponds to about an order of magnitude change in X-section value

note the ~ 0.7 MeV drop in  $B_f$  value between  $^{285}\text{Fl}$  and  $^{284}\text{Fl}$

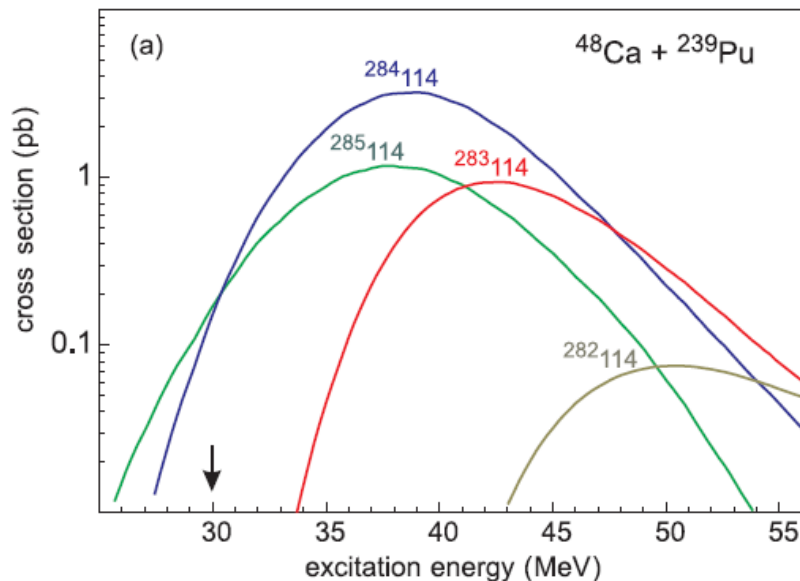
↔ identified  $^{285-289}\text{Fl}$  isotopes

Valery Zagrebaev's *et al.*, predictions

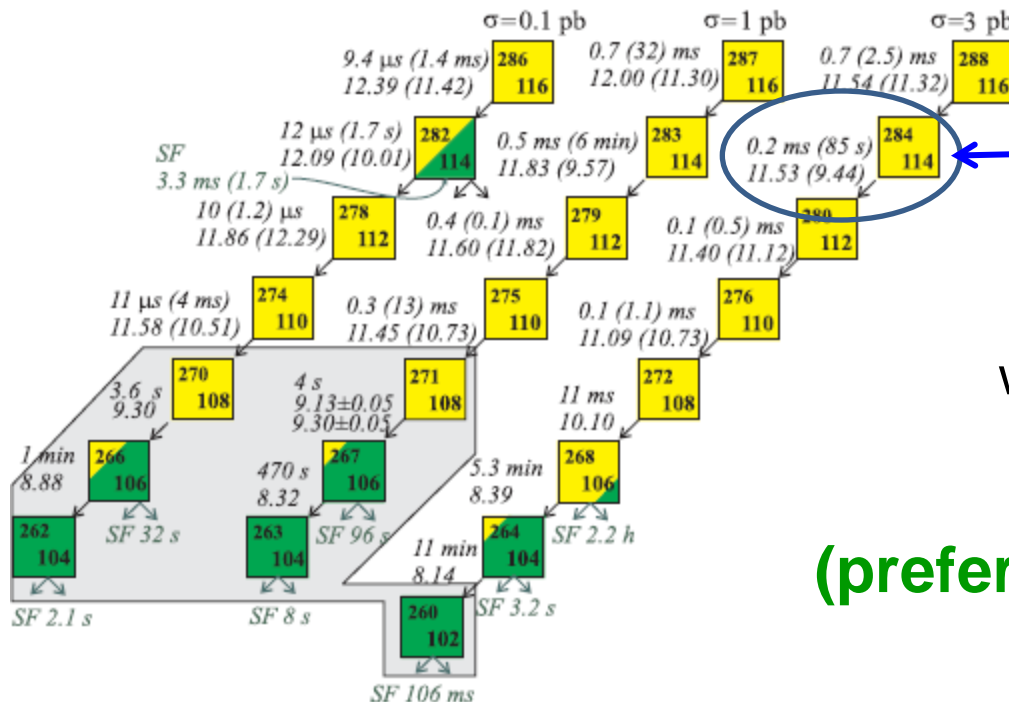
see, e.g., Zagrebaev, Karpov, Greiner; PR C85, 014608, 2012



It looks good for the cases, where experimental data are known  
(but Krystyna *et al.* had a reasonable agreement, too)



More optimistic values  
 $\sigma \sim 1 - 3$  picobarn  
 $E^* \sim 38$  MeV maximizes  $\sigma(^{284}\text{Fl})$



Kowal 2014:  $E_\alpha \sim 11.5$  MeV  
 Muntian 2003:  $E_\alpha \sim 11.5$  MeV, 0.2 ms  
 Moeller 1997:  $E_\alpha \sim 9.4$  MeV, 85 s

very rich decay properties  
 were predicted by Zagrebaev *et al*

**Let's run !!**  
 (preferably with  $^{240}\text{Pu}$  first)



# Connecting Hot Fusion Island with Nuclear Mainland

## search for new Z=114 Flerovium isotopes and their decay products

<b>4n</b>		<b>3n</b>	<b>2n</b>	<b><sup>240</sup>Pu+<sup>48</sup>Ca</b>		
<b>4n</b>		<b>3n</b>	<b>2n</b>	<b><sup>239</sup>Pu+<sup>48</sup>Ca</b>		
Fl/283 4 ms 10.8	Fl/284 2 ms 10.6	Fl/285 0.1 s 10.3	Fl/286 0.12 s 10.19	Fl/287 0.48 s 10.02	Fl/288 0.80 s 9.94	Fl/289 2.6 s 9.82
Cn/279 1 ms 10.9	Cn/280 0.4 ms 10.6	Cn/281 0.1 s 10.31	Cn/282 0.82 ms	Cn/283 3.8 s 9.54	Cn/284 97 ms	Cn/285 29 s 9.15
Ds 275 50 μs 11.2	Ds 276 0.2 ms 10.8	Ds 277 6 ms 10.57	Ds 278 10 ms 10.1	Ds 279 0.20 s 9.70	Ds 281 11 s	
Hs 271 1 s 9.3	Hs 272 0.2 s 9.5	Hs 273 0.2 s 9.59	Hs 274 10 ms 9.4	Hs 275 0.19 s 9.30	Hs 277 3 ms	
Sg 267 80 s 8.2	Sg 268 10 s 8.3	Sg 269 2 min 8.57	Sg 270 1 s 8.6	Sg 271 1.9 m 8.54		
Rf 263 8 s 8.0	Rf 264 5 s 7.8	Rf 265 2 m	Rf 266 10 s 7.4	Rf 267 1.3 h		

Vladimir Utyonkov's estimations

$^{240}\text{Pu}$  material from Oak Ridge delivered to Dubna on 27<sup>th</sup> Dec. 2013  
(after 51 weeks of paperwork)



Dubna, Dec.2013

# New ORNL-UTK detectors and digital data acquisition system

similar DAQ was serving many ORNL RMS expts, PSSD+Si-box+MCPs at Z=120 exp at SHIP and now is used at **JAEA RMS** /R. Grzywacz/

## MICRON detectors

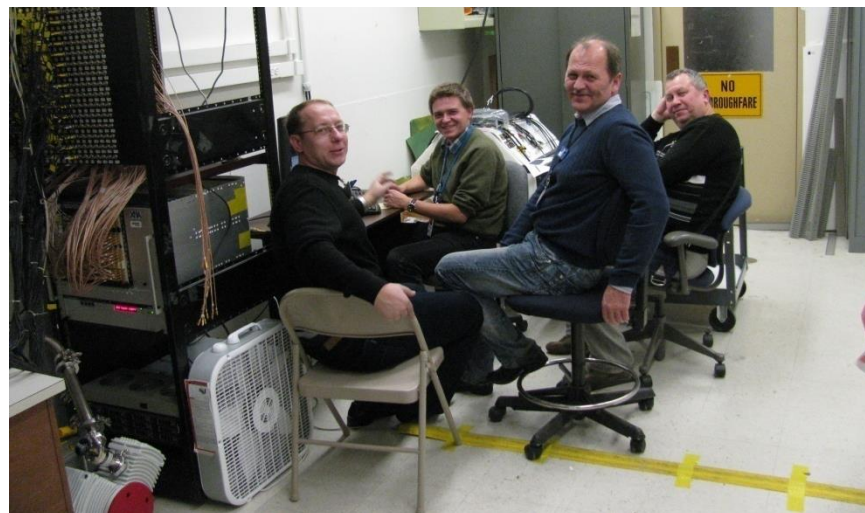
128 x 48 mm  
1 mm wide strips, 300  $\mu\text{m}$  **DSSD**  
and  
matching single **Si-veto** detector

six 120 x 65 mm single Si  
forming **Si-box**



## MESYTEC

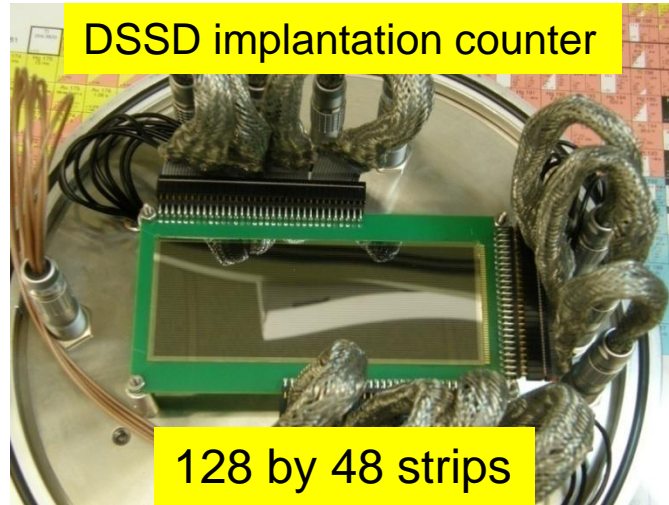
lin-log preamps  
XIA Pixie16 rev D  
(208 channels)  
Dell Power Edge



# ORNL-UTK 8-detector and digital data acquisition system operating at the Dubna Gas Filled Recoil Separator (DGFRS)

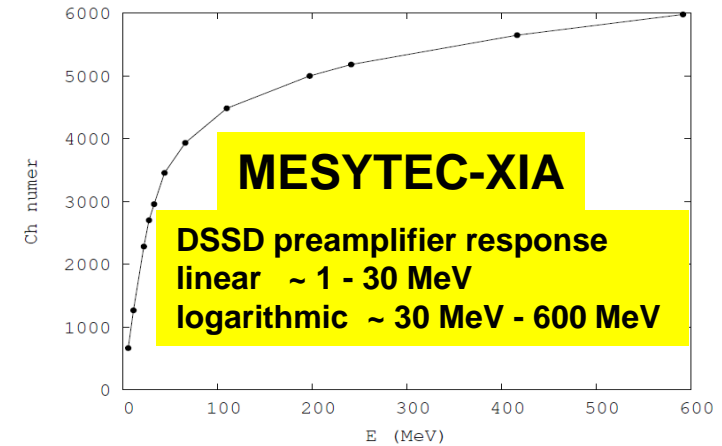


Si-detector stack



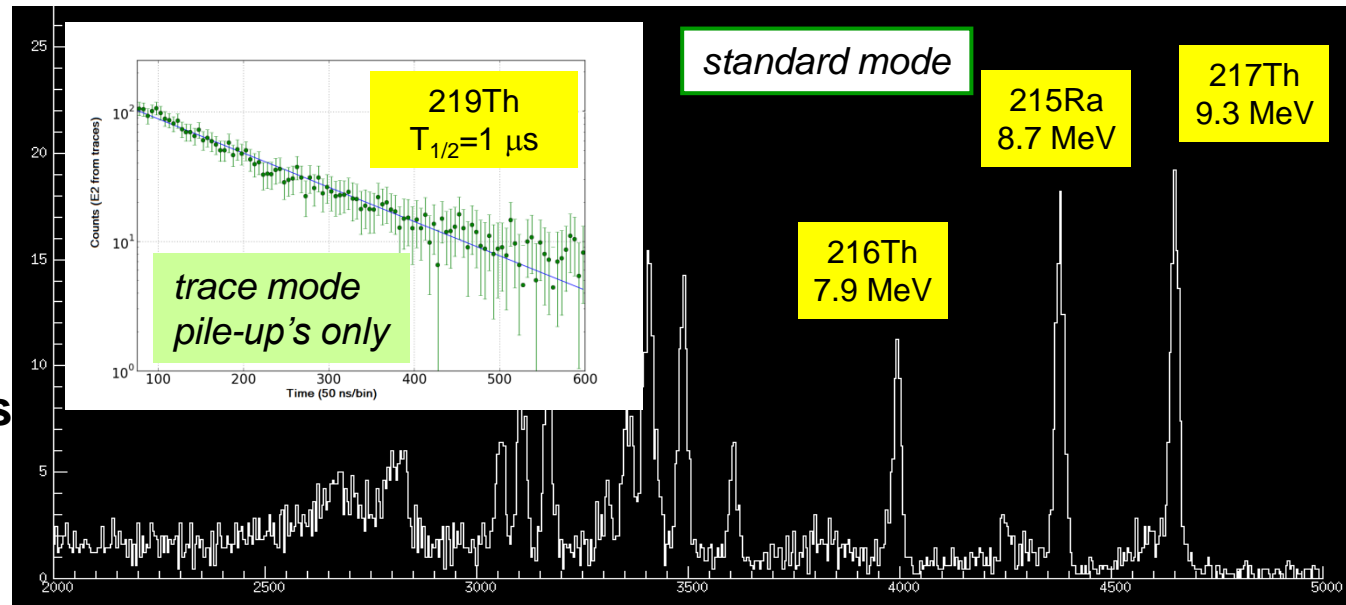
DSSD implantation counter

128 by 48 strips



$\alpha$ -emitters including  
1  $\mu$ s activity of  $^{219}\text{Th}$   
studied at the DGFRS  
during  $^{48}\text{Ca} + ^{\text{nat}}\text{Yb}$  run  
Nov.-Dec. 2013.

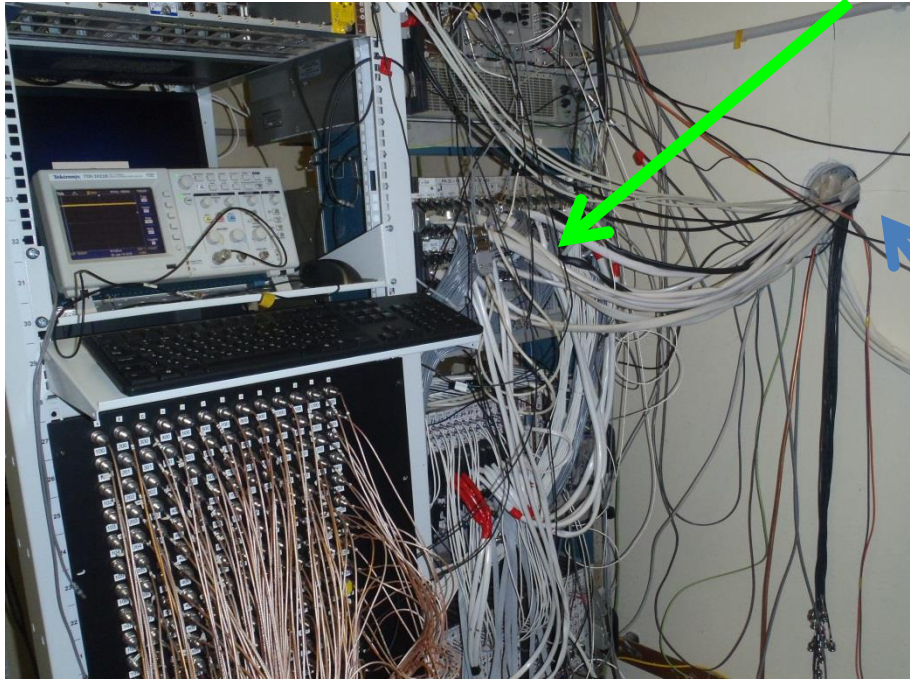
Search for new isotopes  
of element Z=114 (Fl)  
with  $^{239}, ^{240}\text{Pu}$  targets  
started on 6<sup>th</sup> Dec. 2013



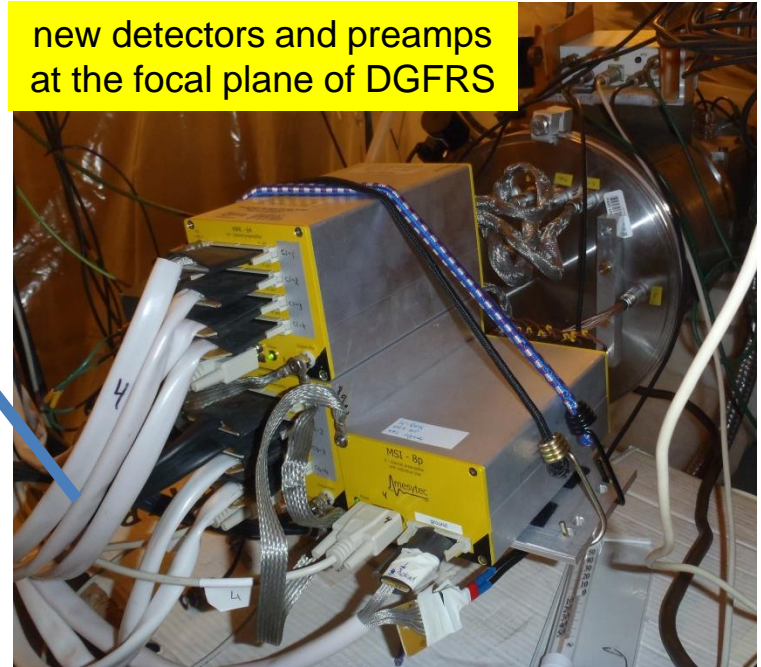
energy of  $\alpha$ -particles



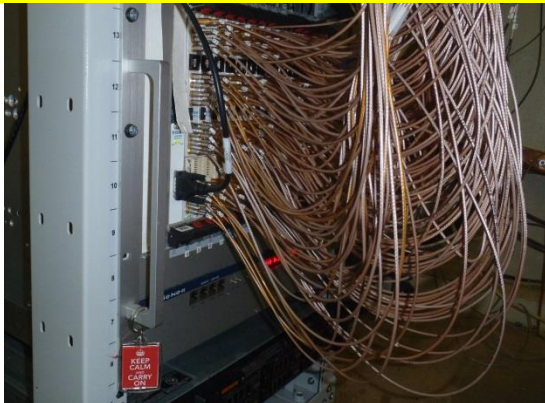
# Digital and analog electronics serve new detector system after preamp signals splitters modules



new detectors and preamps  
at the focal plane of DGFRS



208 channels of 100 MHz Pixie16



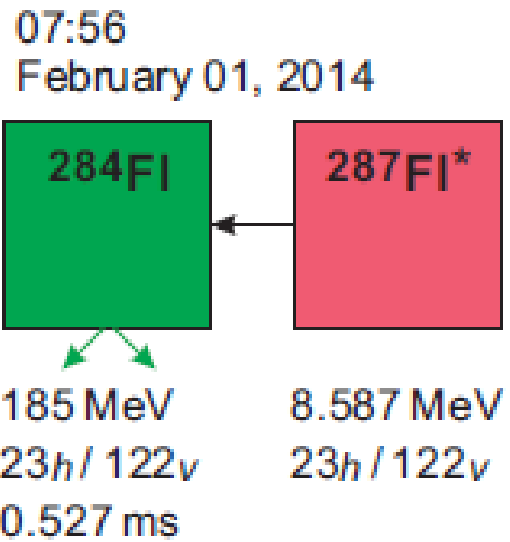
2 MWPCs +  $(128+48)=176$  strips DSSD + 1 Si-veto + 6 Si-box

multiplexing used in analog electronics (so far)

low gain for front 48 strips and higher gain for back 128 strips  
in digital branch

Test reaction:  $^{48}\text{Ca}$  (216 MeV mid-target) +  $^{\text{nat}}\text{Yb}$  (0.5 mg/cm<sup>2</sup>)  $\rightarrow$   $^{216-219}\text{Th}$   
Main experiment:  $^{48}\text{Ca}$  (245 MeV) +  $^{239}\text{Pu}$ (0.5 mg/cm<sup>2</sup>) $\rightarrow$  $^{287}\text{Fl}^*$ (**E\* ~ 38 MeV**)  $\rightarrow$   $^{284,283}\text{Fl}$

Finally one candidate event shows up, observed consistently in analog and digital ACQs.

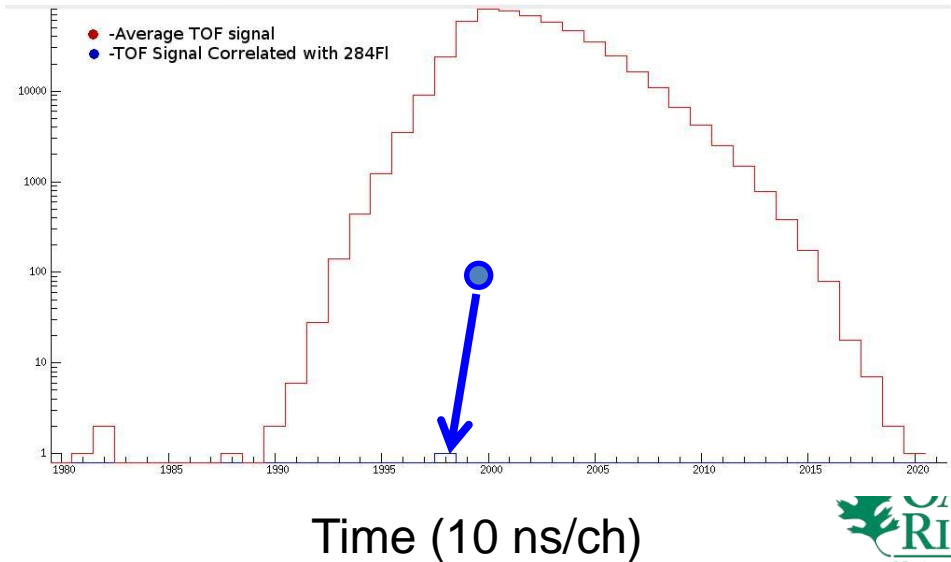


Analog data analysis:  
**V.K. Utyonkov, Feb.-March 2014**

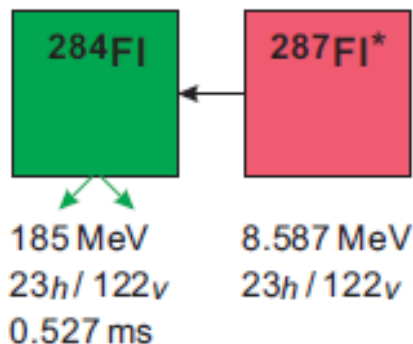
Evaluation of digital data stream by  
**Nathan Brewer, Feb.-March 2014**

valid two MWPCs and TOF signals

front/back recoil energies and high  
SF energy values matching within  
current energy calibration



07:56  
February 01, 2014



**VALID implantation – fast SF decay event (random origin  $< 10^{-7}$ , V. K. Utyonkov)**

previous good “recoil” ( $E > 5$  MeV, valid TOF) implanted in the same pixel 7.6 hours earlier

## Assignment of the event:

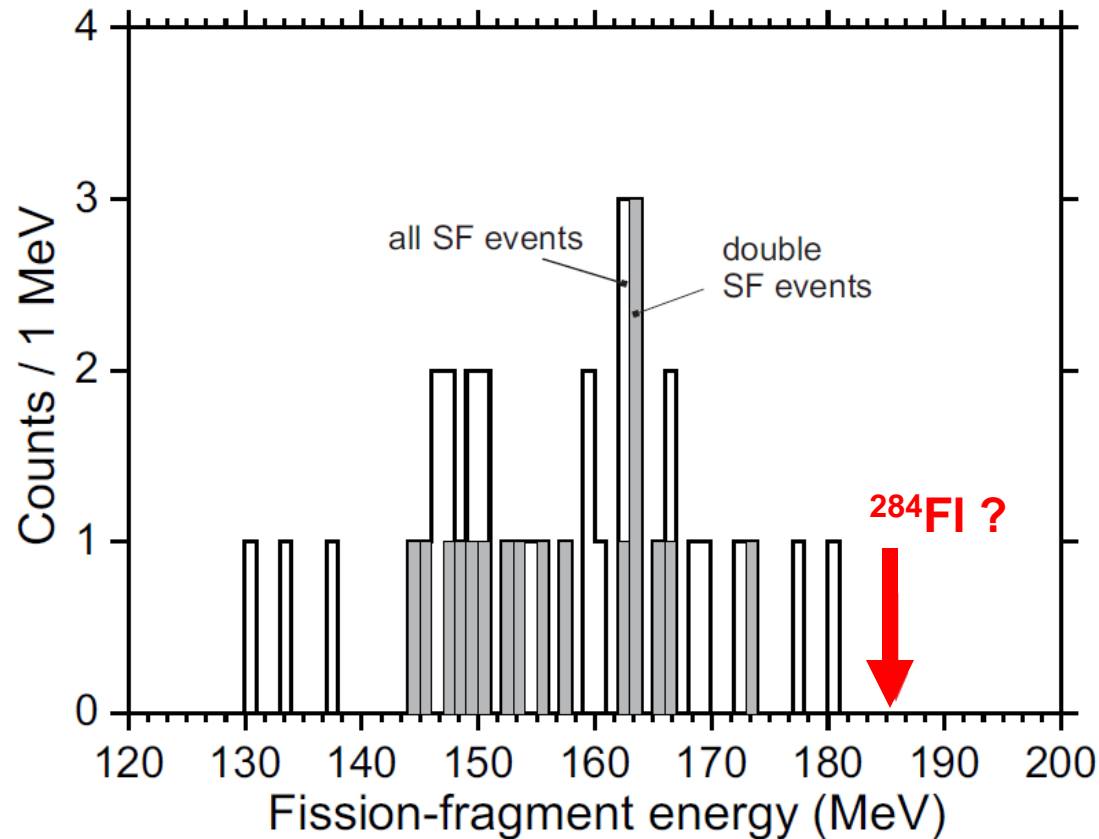
**$^{284}\text{Fl}$**  or, e.g.,  $^{240\text{m}}\text{Am}$  SF 0.9 ms isomer from +1p transfer on  $^{239}\text{Pu}$ ?

If it is  **$^{284}\text{Fl}$** :  $\sigma \sim 0.3$  pb (10 times below Zagrebayev’s, 100 times above Krystyna’s  $\sigma_{\text{cal}}$ )

Relatively large SF energy points to higher-Z nucleus ( $Z=114$  Fl vs  $Z=95$  Am)



Collection of SF decay energies from SF-isomers created in transfer reactions between  $^{238}\text{U}(1)$ ,  $^{242}\text{Pu}(8)$  and  $^{243}\text{Am}(23)$  targets and  $^{48}\text{Ca}$  beams observed at the DGFRS experiments, **V.K. Utyonkov 2014**



Relatively large SF energy points to higher-Z nucleus (Z=114 Fl vs Z=95 Am)

**No other events indicating the presence of SF isomers in Am and Pu isotopes around mass 239 were identified.**

Evaluation continue ...

- We need more events to determine better the half-life to show that new SF-activity does not match known SF-isomer next to  $^{239}\text{Pu}$ .**
- Other (lower) beam energy ? SHE Factory experiment**
- Experiment with  $^{240}\text{Pu}$  target and  $^{48}\text{Ca}$ , 4n channel  $\rightarrow$   $^{284}\text{Fl}$**

# Summary

- Program of “connecting Island to Mainland” started at the DGFRS
- New detection system implemented and tested at the DGFRS, parallel digital and analog data acquisition, high DSSD segmentation, sensitivity to sub- $\mu$ s half-lives (R. Grzywacz).
- The reaction between  $^{239}\text{Pu}$  and  $^{48}\text{Ca}$  was studied at the DGFRS. At  $\sim 10^{19}$  beam dose one candidate event for SF activity of  $^{284}\text{Fl}$  detected. If it is  $^{284}\text{Fl}$ , then  $\sigma \sim 0.3$  pb, off-line analysis is in progress
- Experiment with  $^{240}\text{Pu}+^{48}\text{Ca}$  is scheduled for May/June 2014
- Long experiment with mixed-Cf target ( $^{249,250,251}\text{Cf}$ ) +  $^{48}\text{Ca}$  is planned to be started, when Cf target sectors from Oak Ridge reach Dubna  
3 out of 12 target sectors ready on 3/14/2014,  $0.33 \text{ mg/cm}^2$
- Dubna’s “SHE Factory” is getting built ( $\sim 2017$ )



## Photo-impressions from Dubna, Dec 2013 and Jan 2014



Volga River and Orthodox Baptizing



Thank you for listening  
*and Reimei for supporting this workshop*

