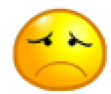
Superheavies:
short-term experiments and far-reaching designs

- **States of affairs** **(very short)**
- **Further prospects:**

Pessimistic view



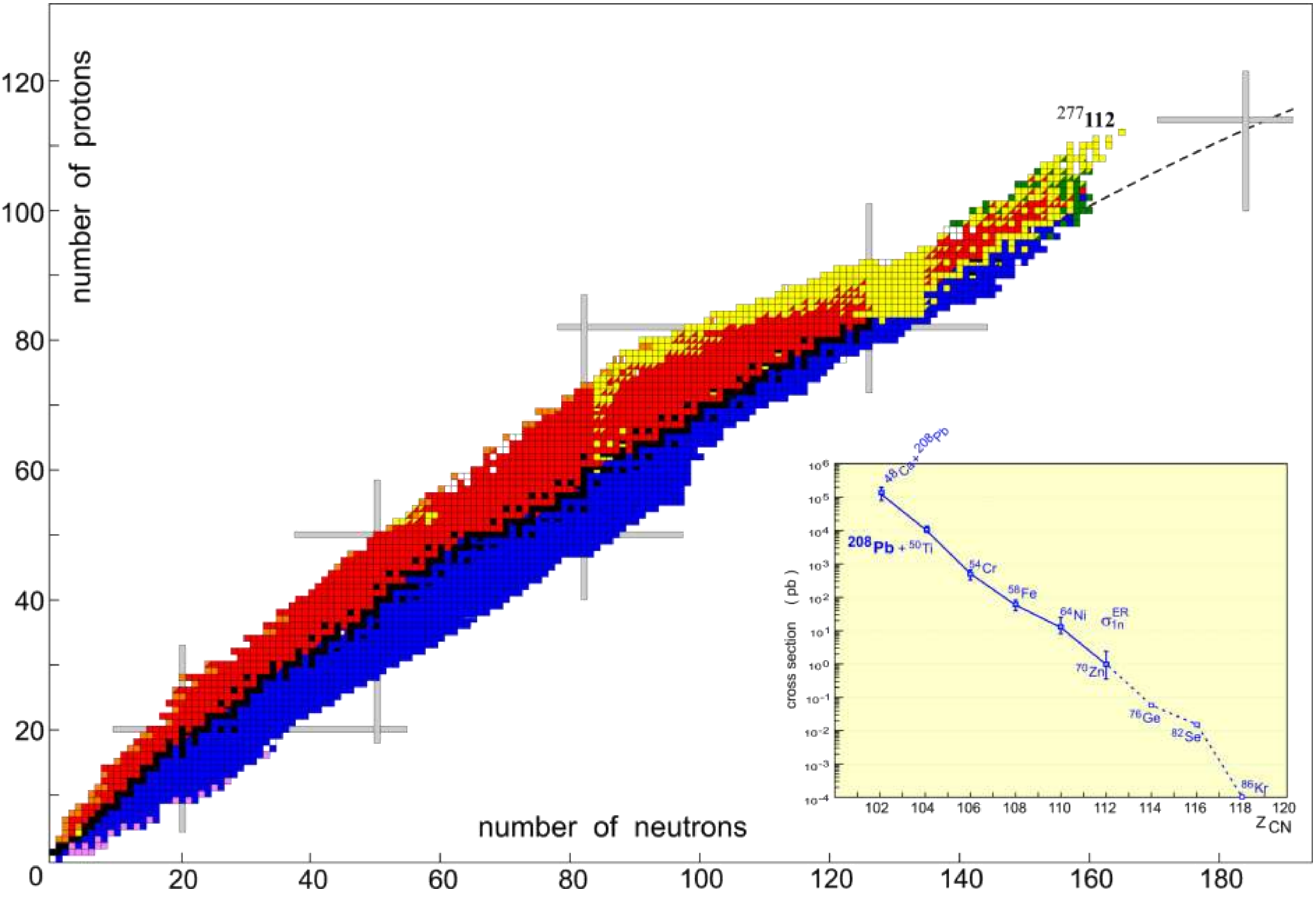
Optimistic view

Valeriy Zagrebaev

Flerov Laboratory of Nuclear Reactions, JINR, Dubna

for Symposium on Exciting Physics, *November 14, 2011*, Makutsi, SA

Nuclear Map in 2000

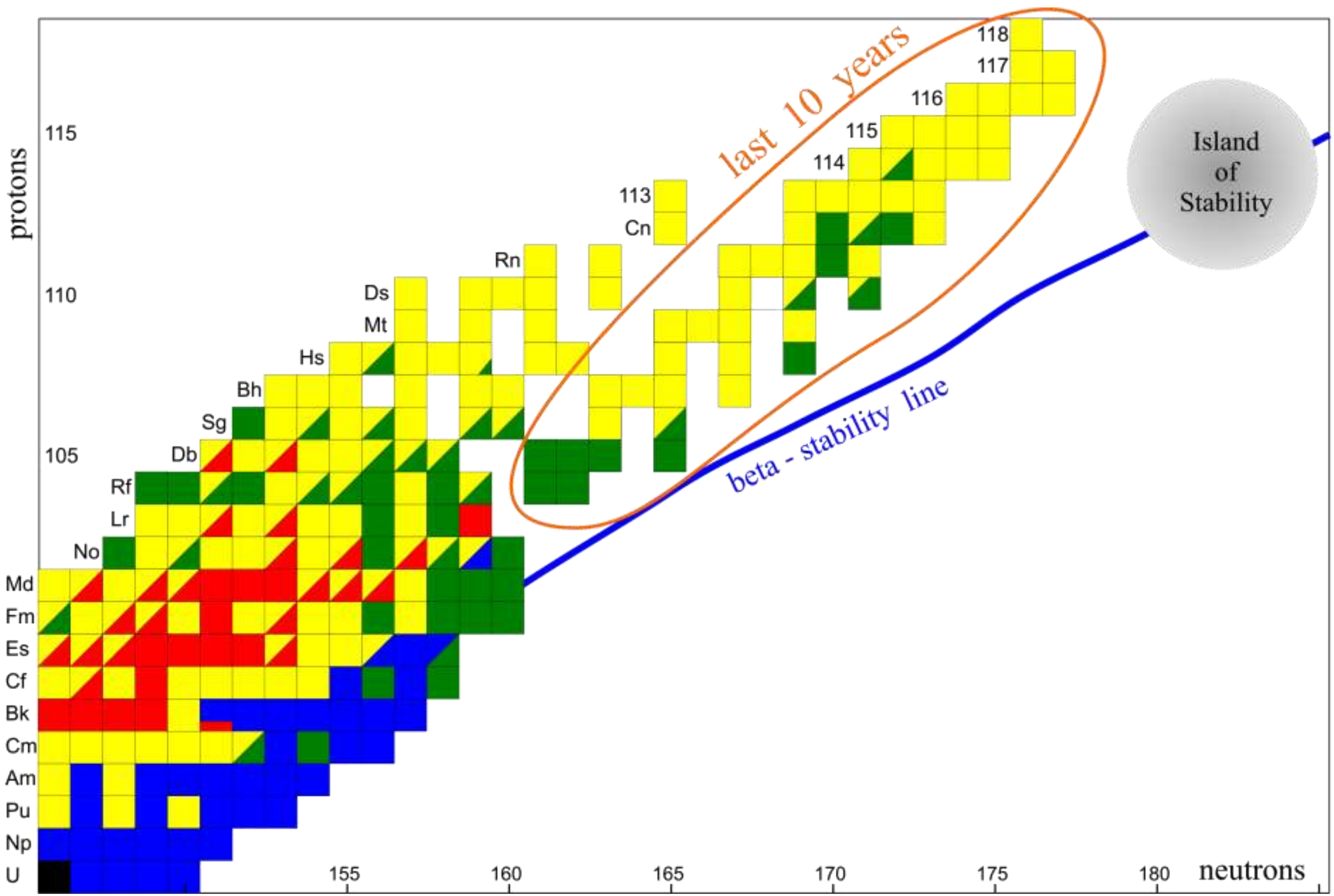


Synthesis of superheavy elements at FLNR

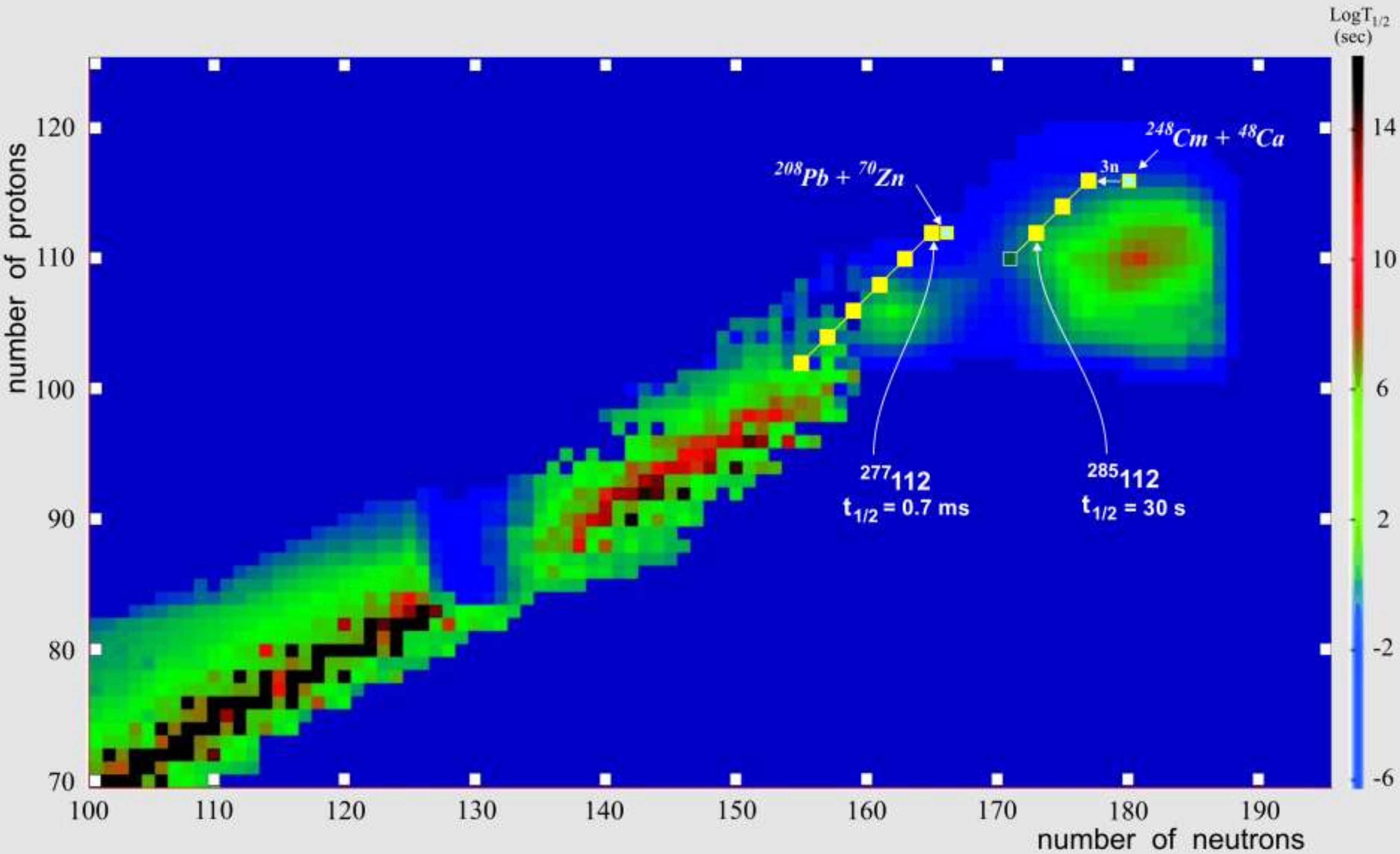
(^{48}Ca induced fusion reactions with actinide targets)

Yu. Oganessian, V. Utyonkov, et al. + Livermore + Oak Ridge

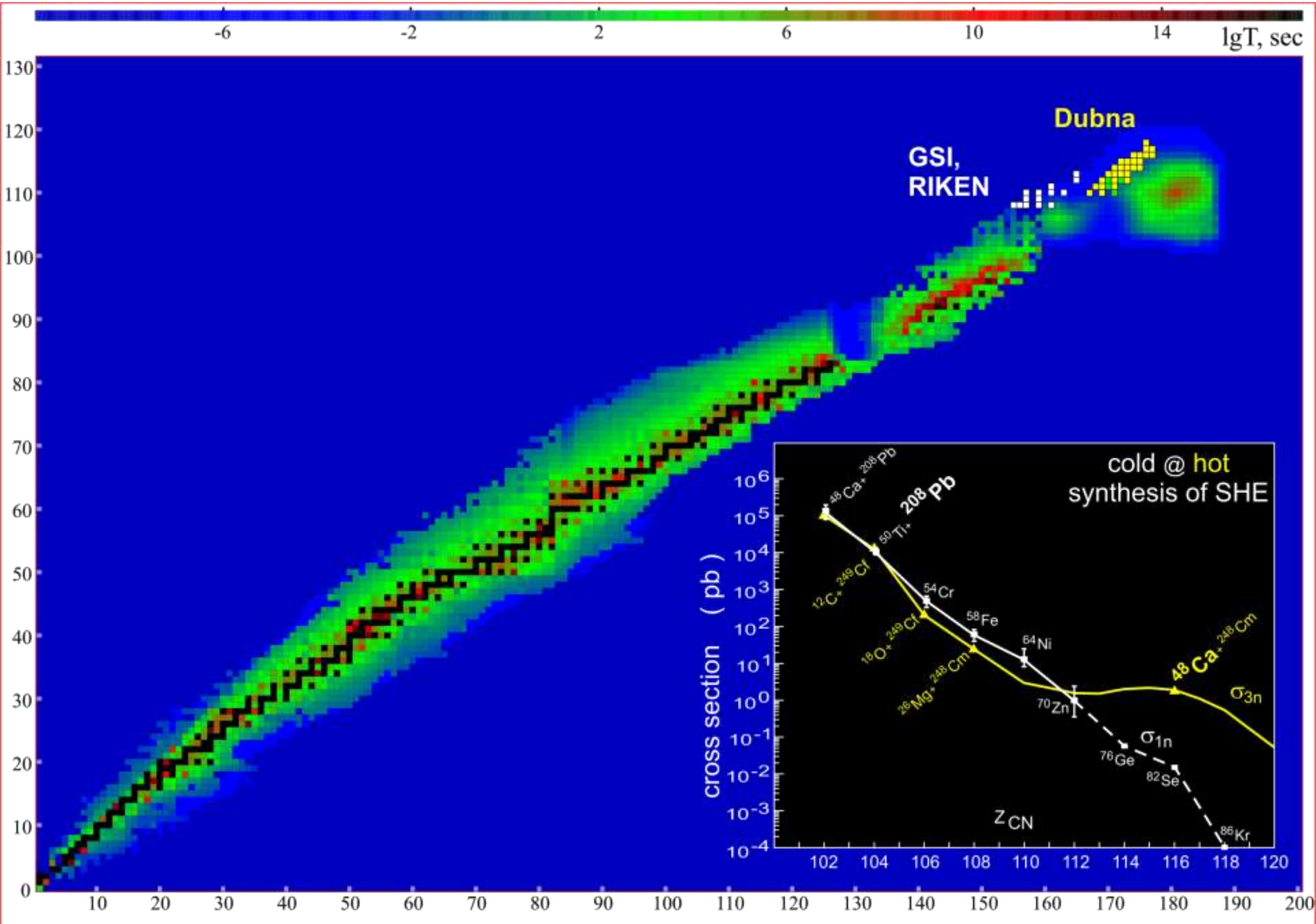
Great progress in synthesis of superheavy nuclei within last 10 years



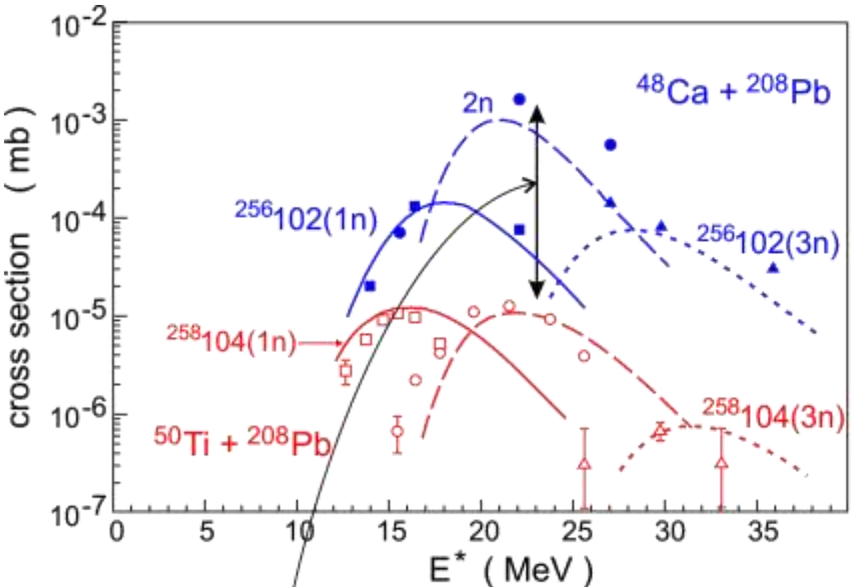
Approaching the Island of Stability



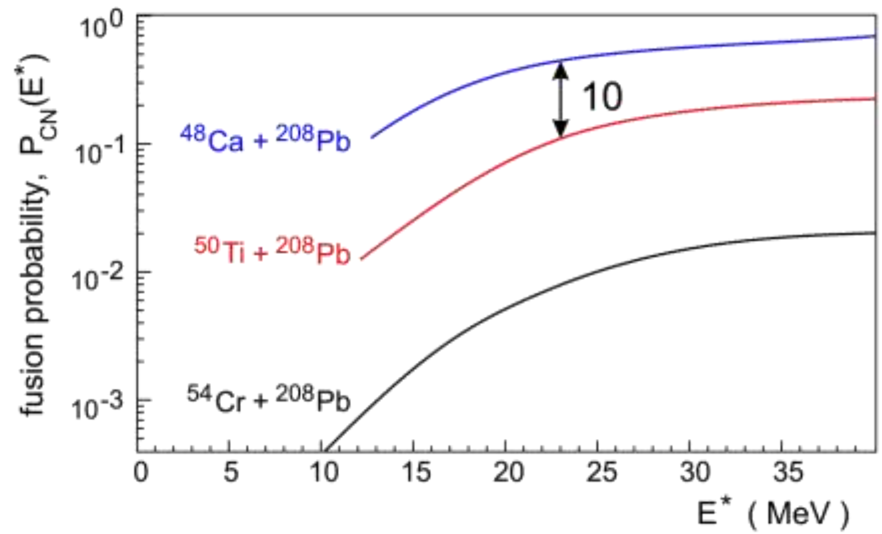
Drastic change in behavior of the cross sections (predictions of 2002)

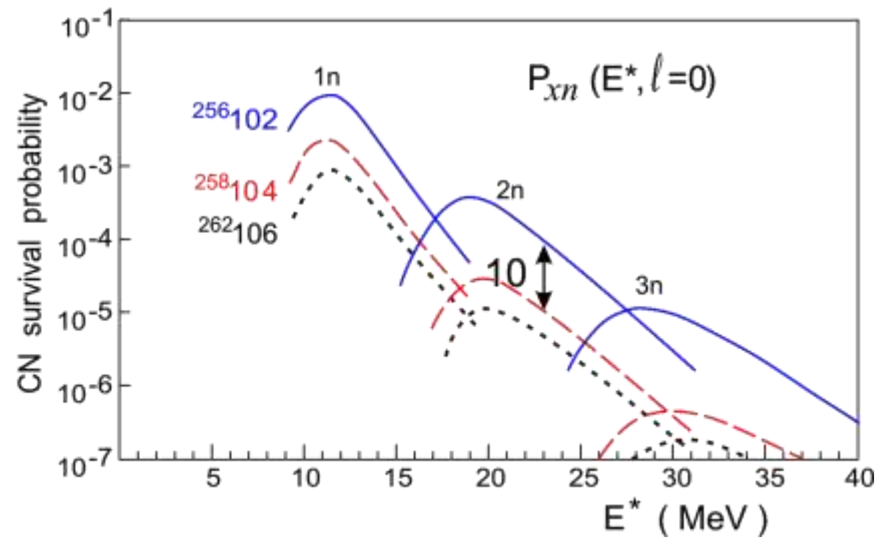


Epoch of ^{48}Ca is almost over. How much is ^{50}Ti worse?



$$\frac{\sigma(^{50}\mathrm{Ti})}{\sigma(^{48}\mathrm{Ca})} = \frac{1}{100}$$





	B_{LD}	δW	B_f	E_n
^{256}102	1.26	4.48	**5.7**	**7.1**
^{258}104	0.77	4.49	**5.3**	**7.6**

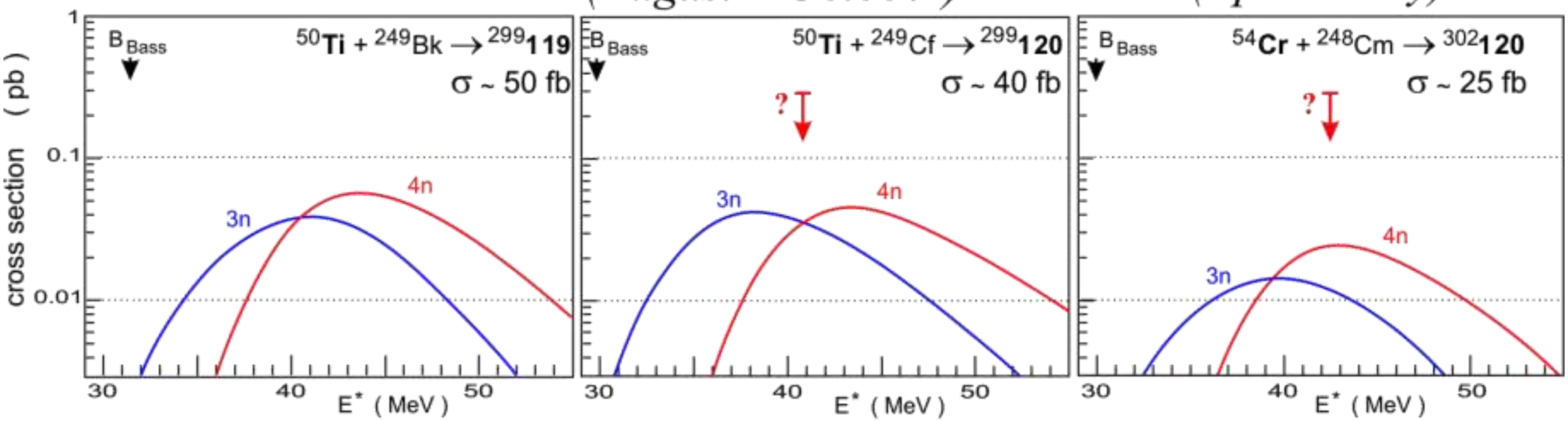
Beyond ^{48}Ca: ^{50}Ti and ^{54}Cr induced fusion reactions

Ti beam:

TASCA (August - October)

Cr beam:

SHIP (April - May)

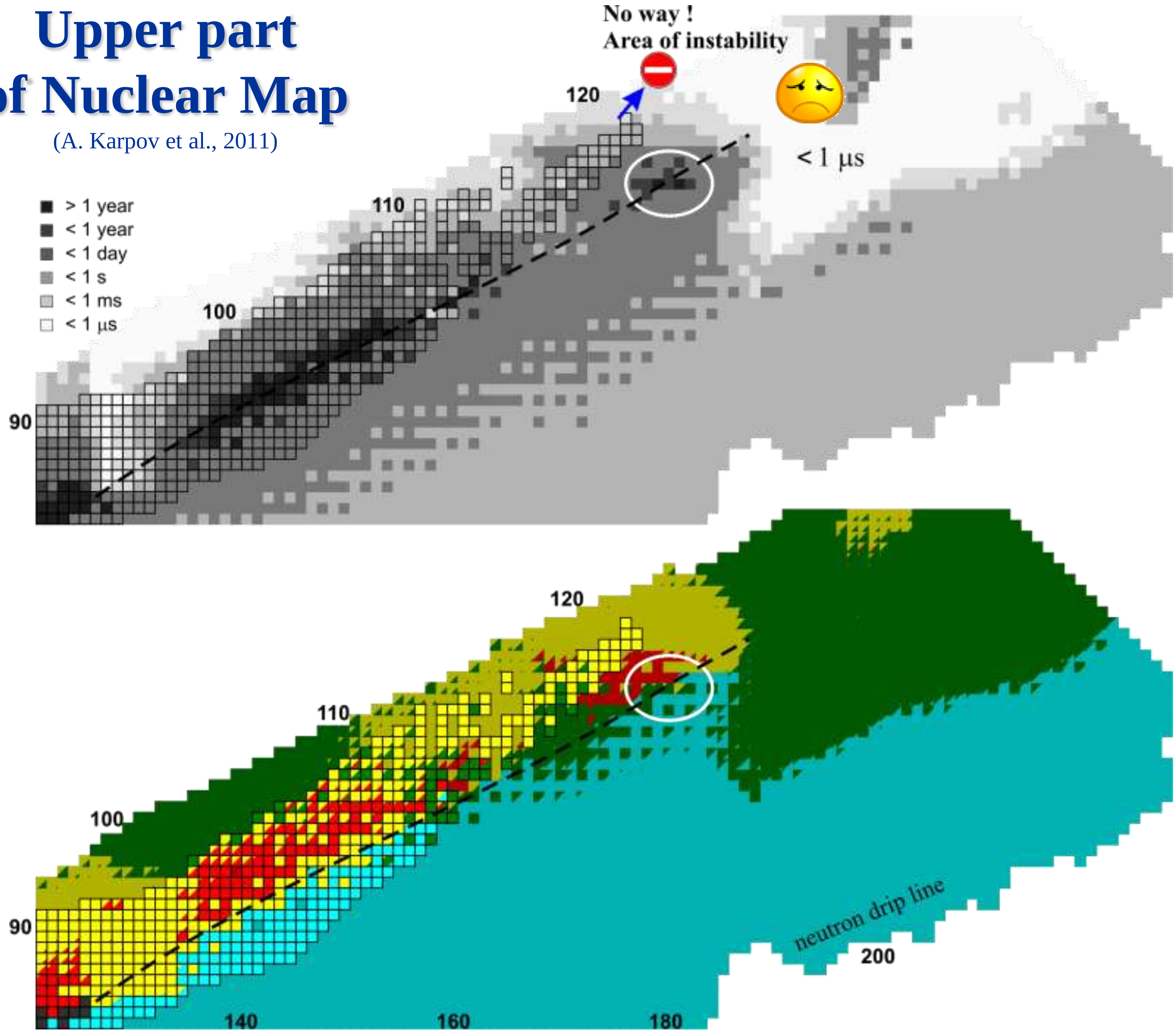


factor $\frac{1}{20}$ as compared to ^{48}Ca

Maybe these elements are the last ones
which will be synthesized in nearest future !?

Upper part of Nuclear Map

(A. Karpov et al., 2011)



How can we synthesize superheavy nuclei ?

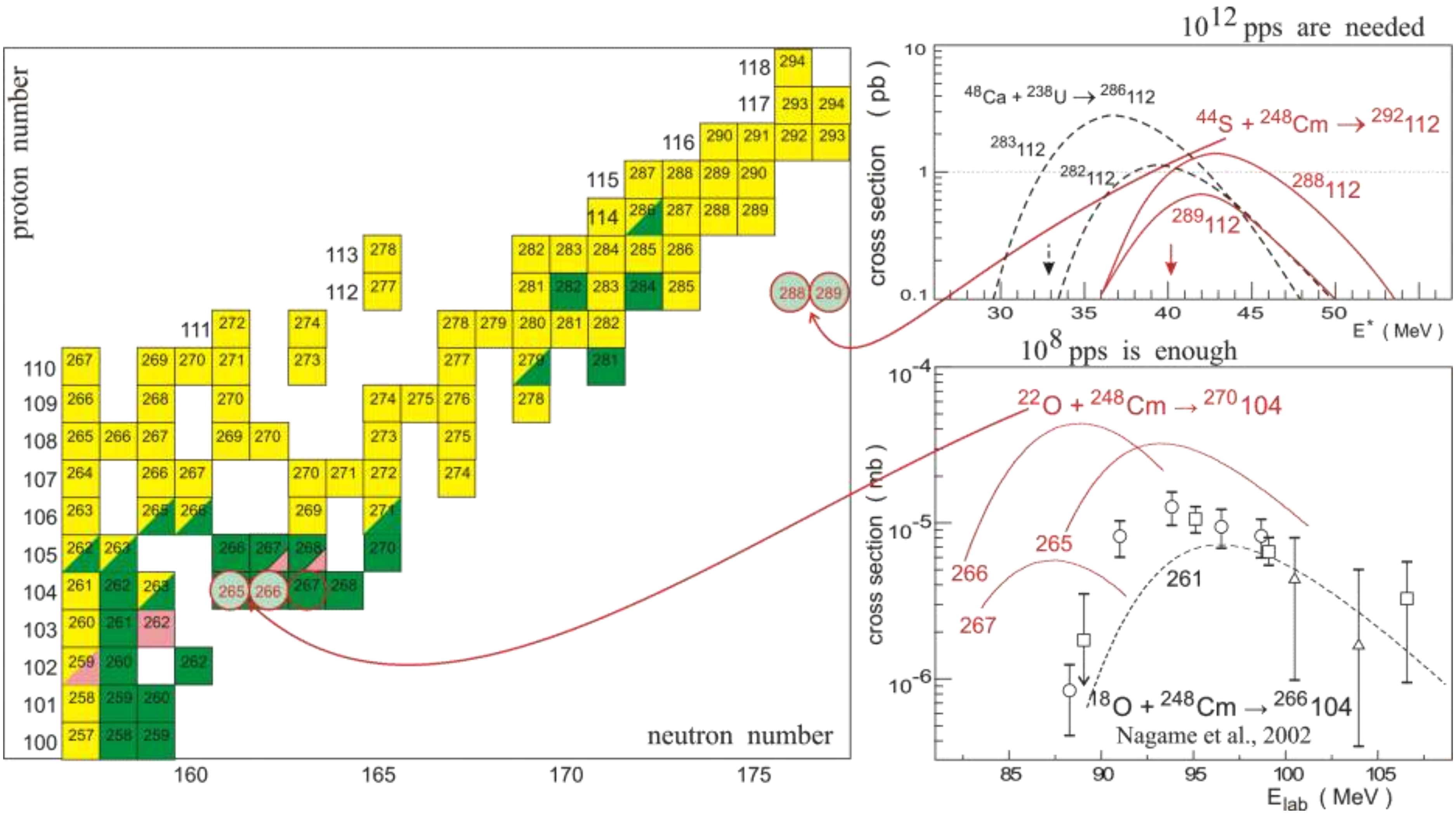
1. Fusion reactions: beams of stable nuclei

2. Fusion reactions with radioactive beams
   (e.g., $^{22}O+^{248}Cm$, …)

3. Multi-nucleon transfer reactions

4. Neutron capture processes

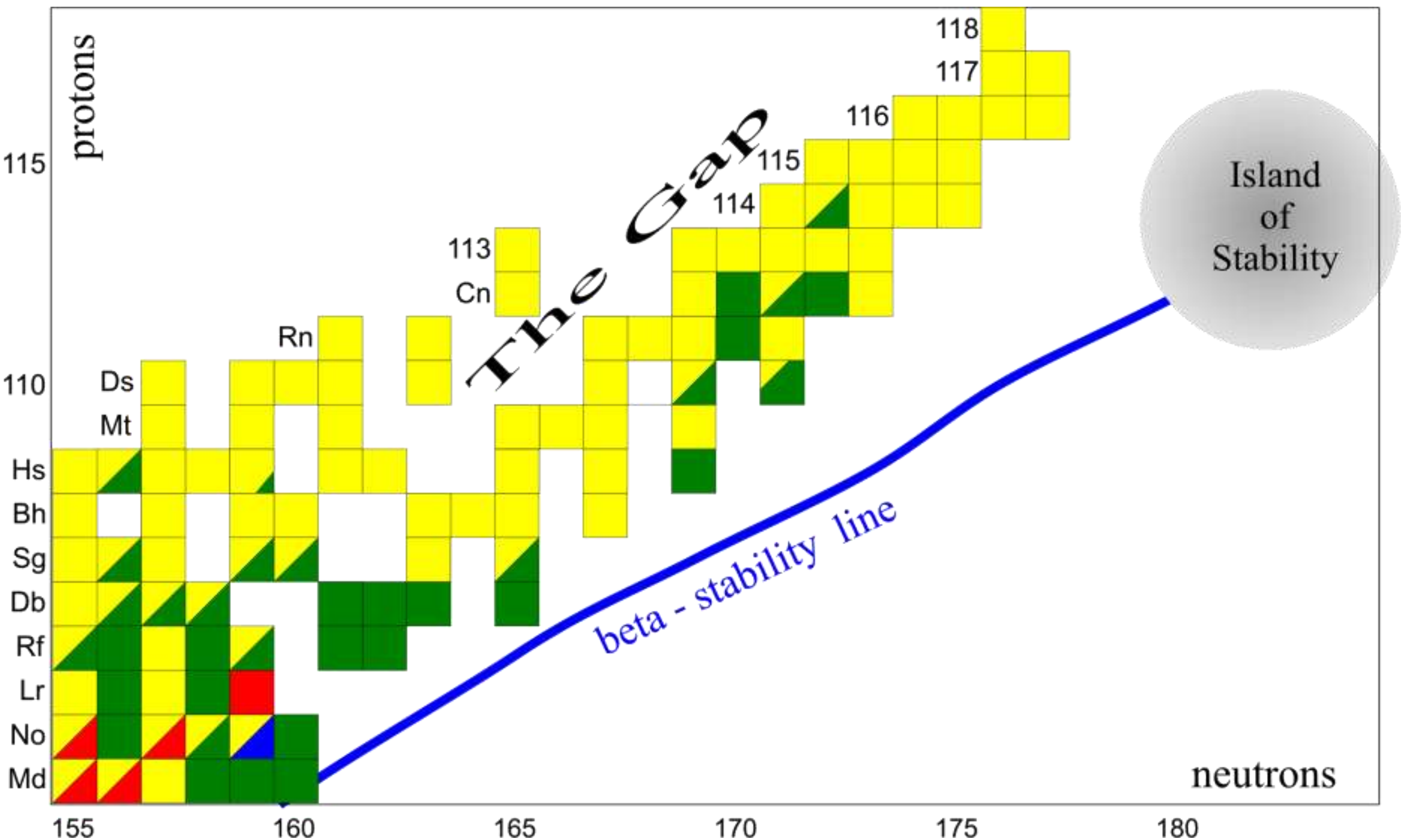
Use of low-energy Radioactive Ion Beams for production of neutron rich superheavy nuclei ?



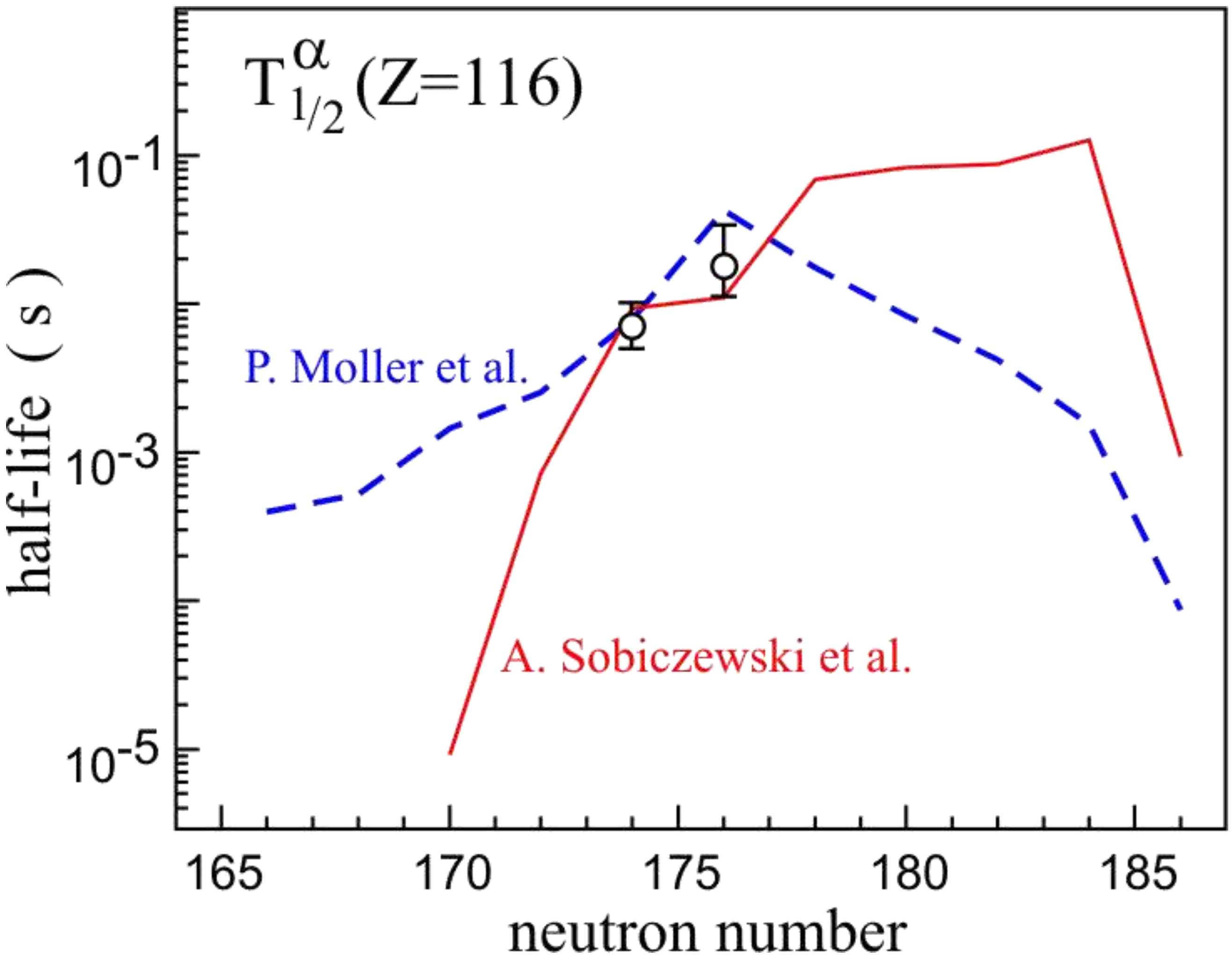
No chances today and in nearest future

Optimistic view of SHE future

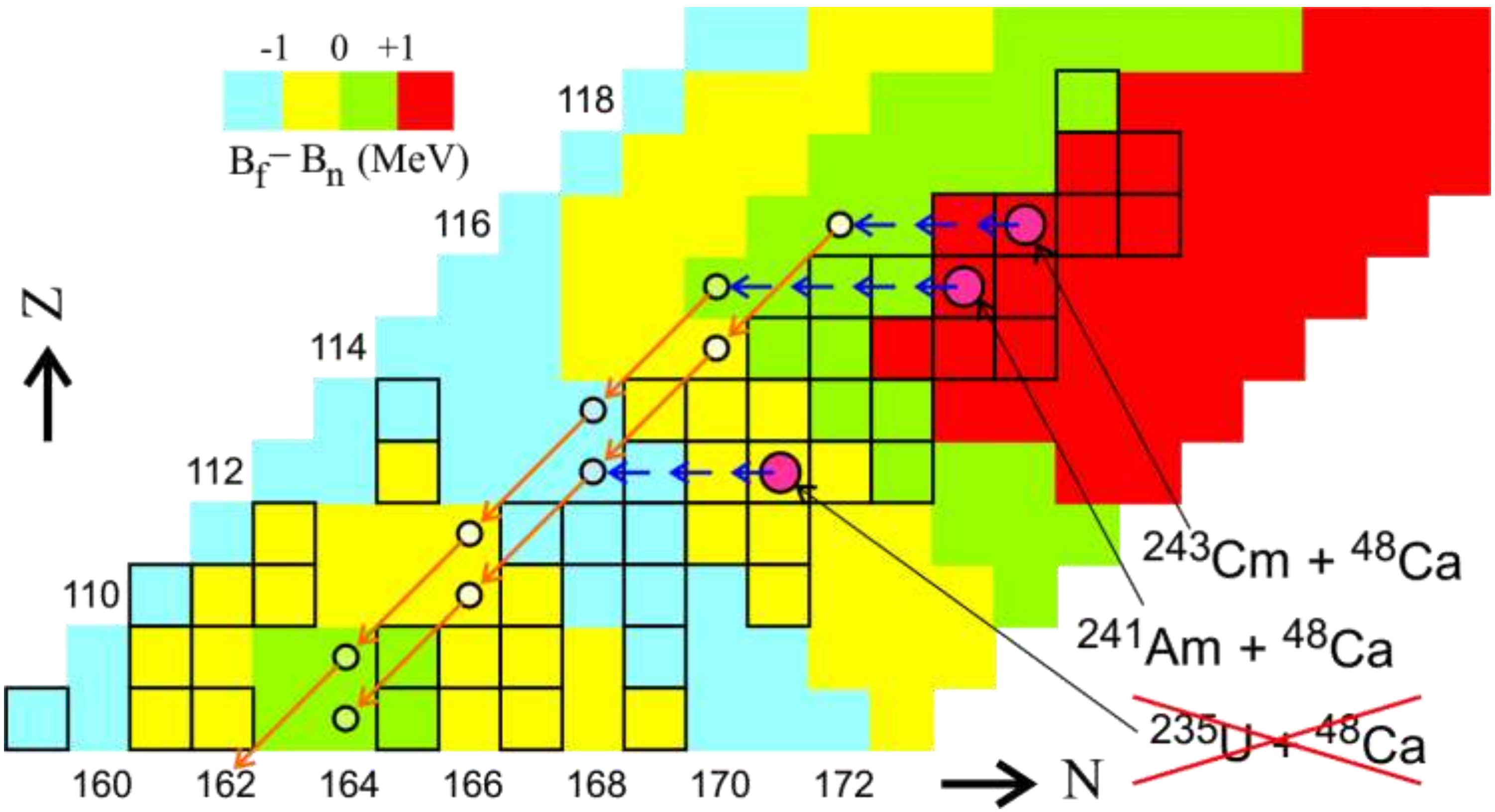
First, we should darn the gap in superheavy mass area?



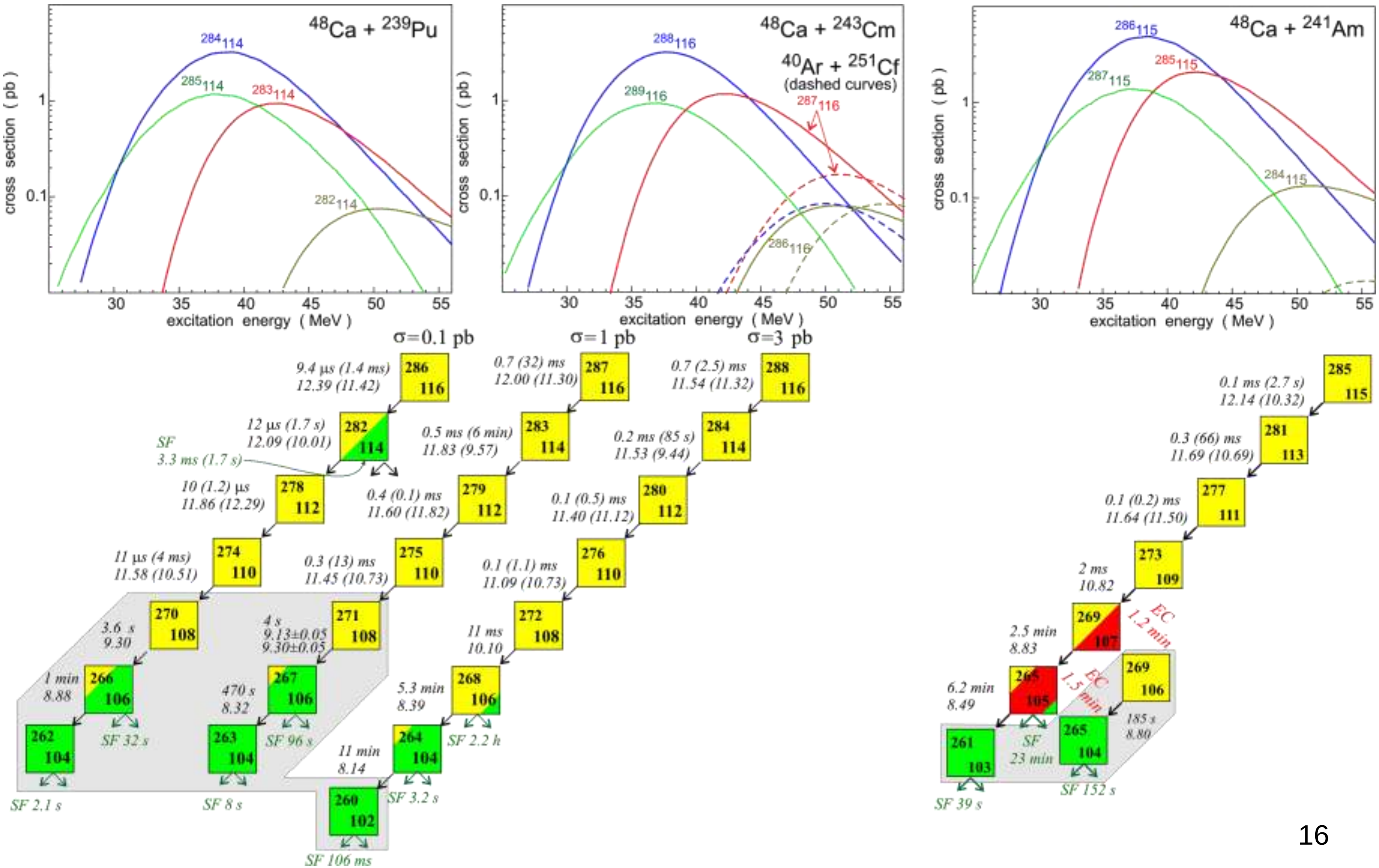
Our ability of predictions in superheavy mass area



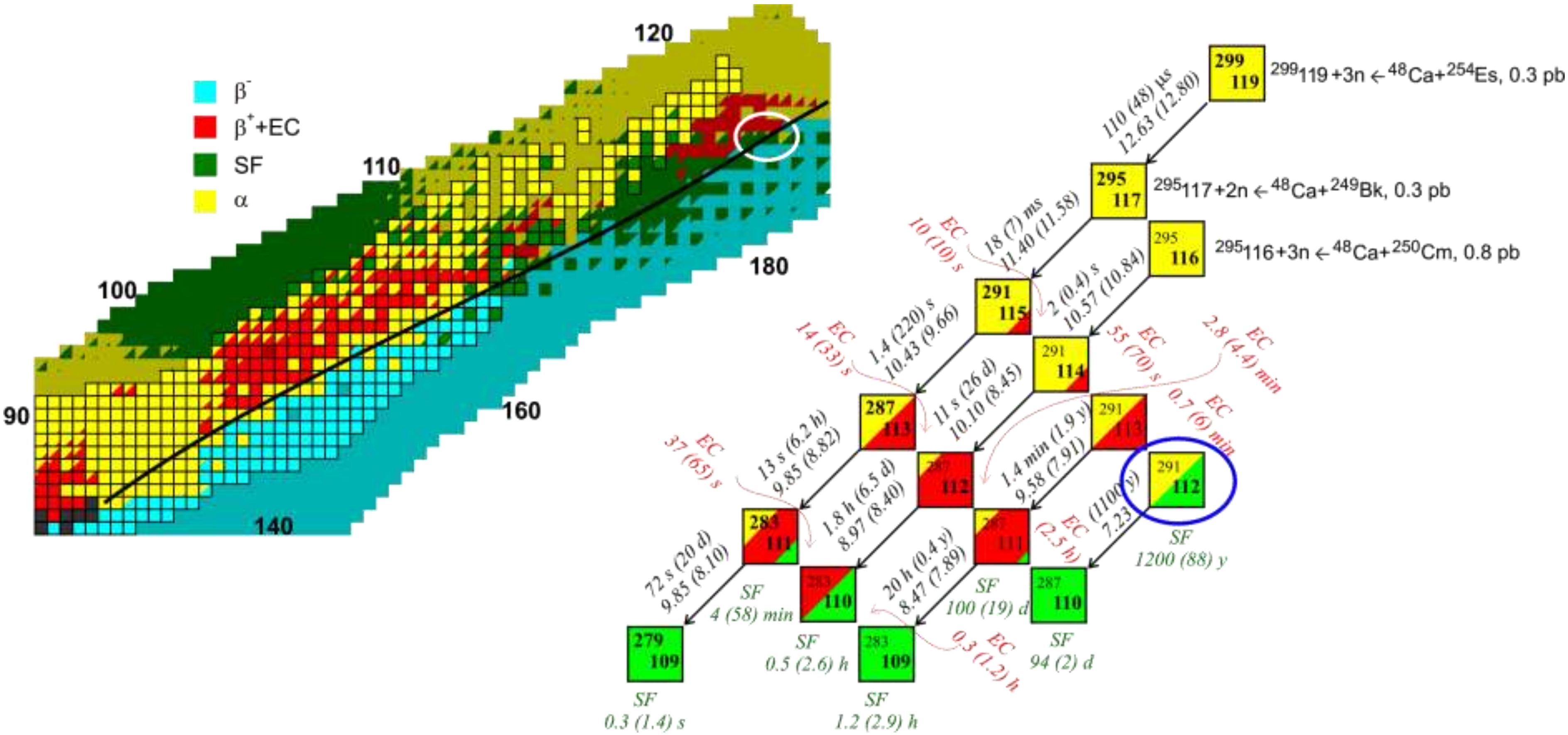
It is easier to darn the gap from above



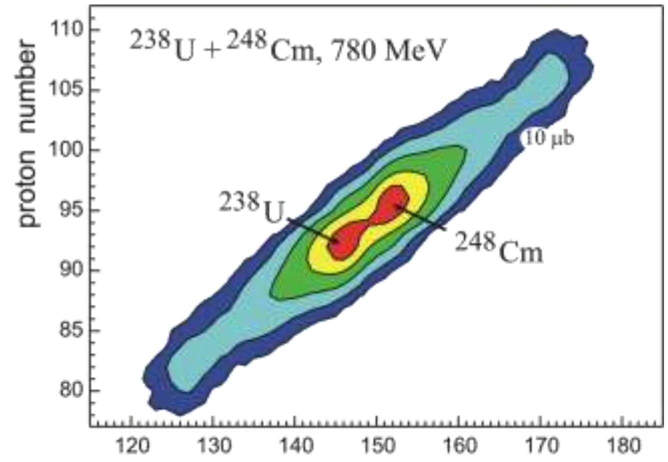
Cross sections are high enough to perform experiments at available facilities

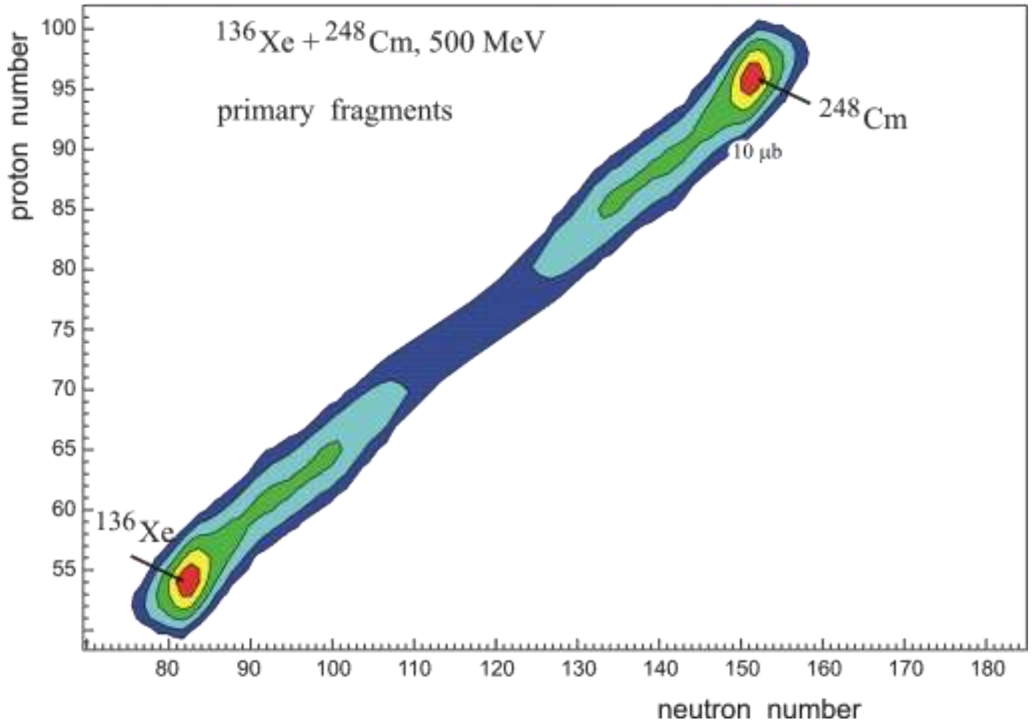


Narrow pathway to the island of stability from the north-west side !

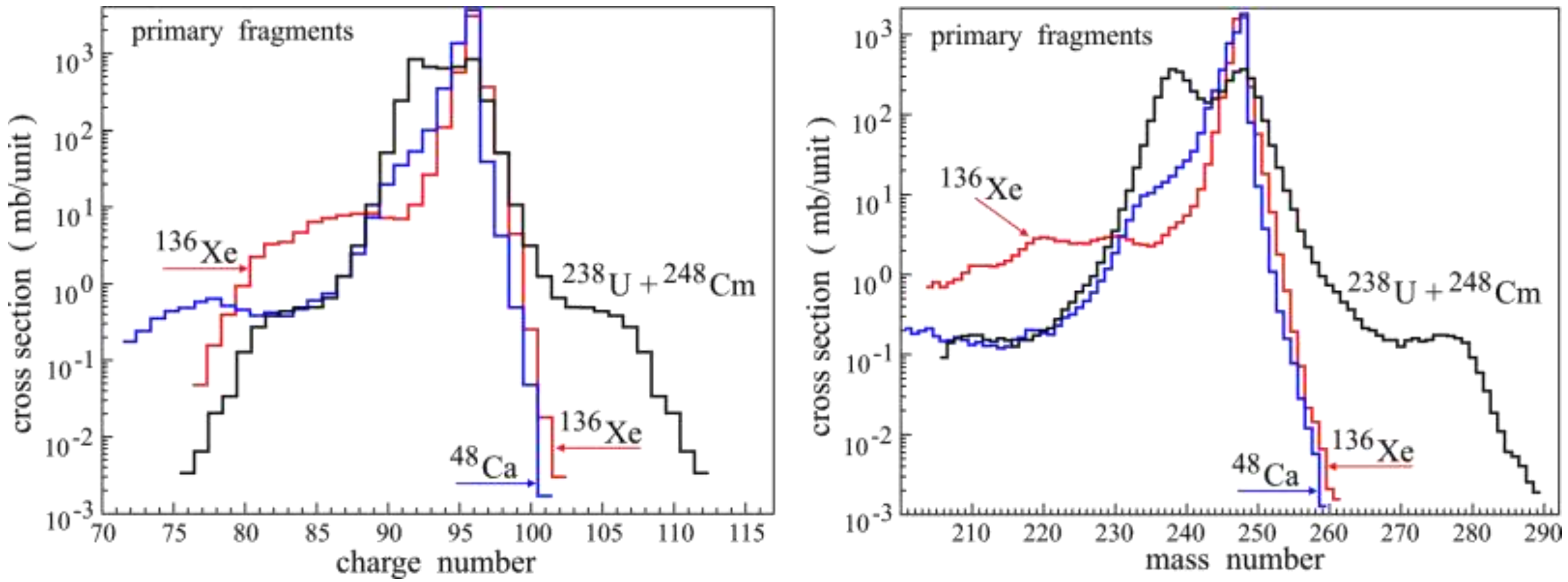


Multi-nucleon transfer for production of superheavies
(choice of reaction is very important)

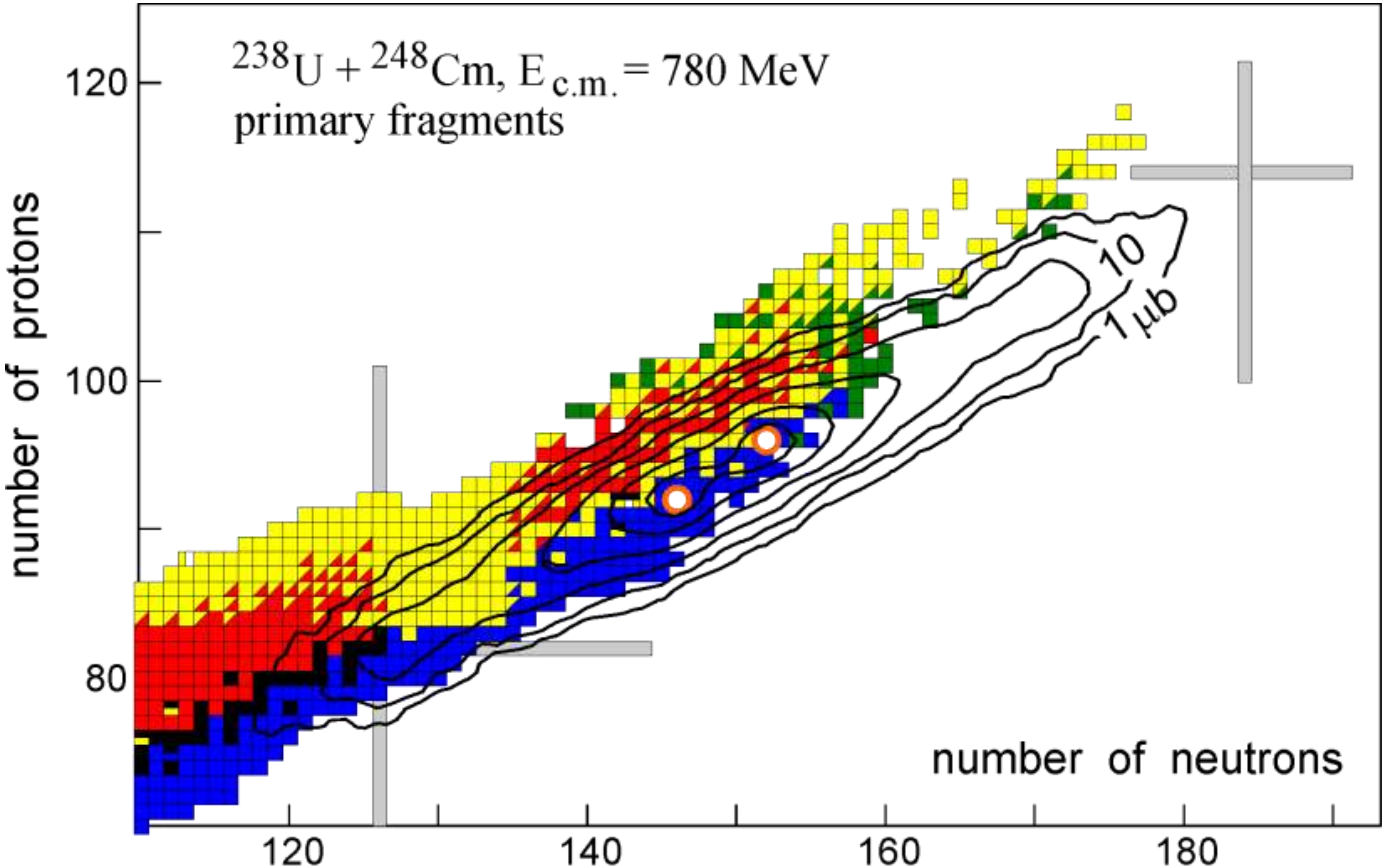




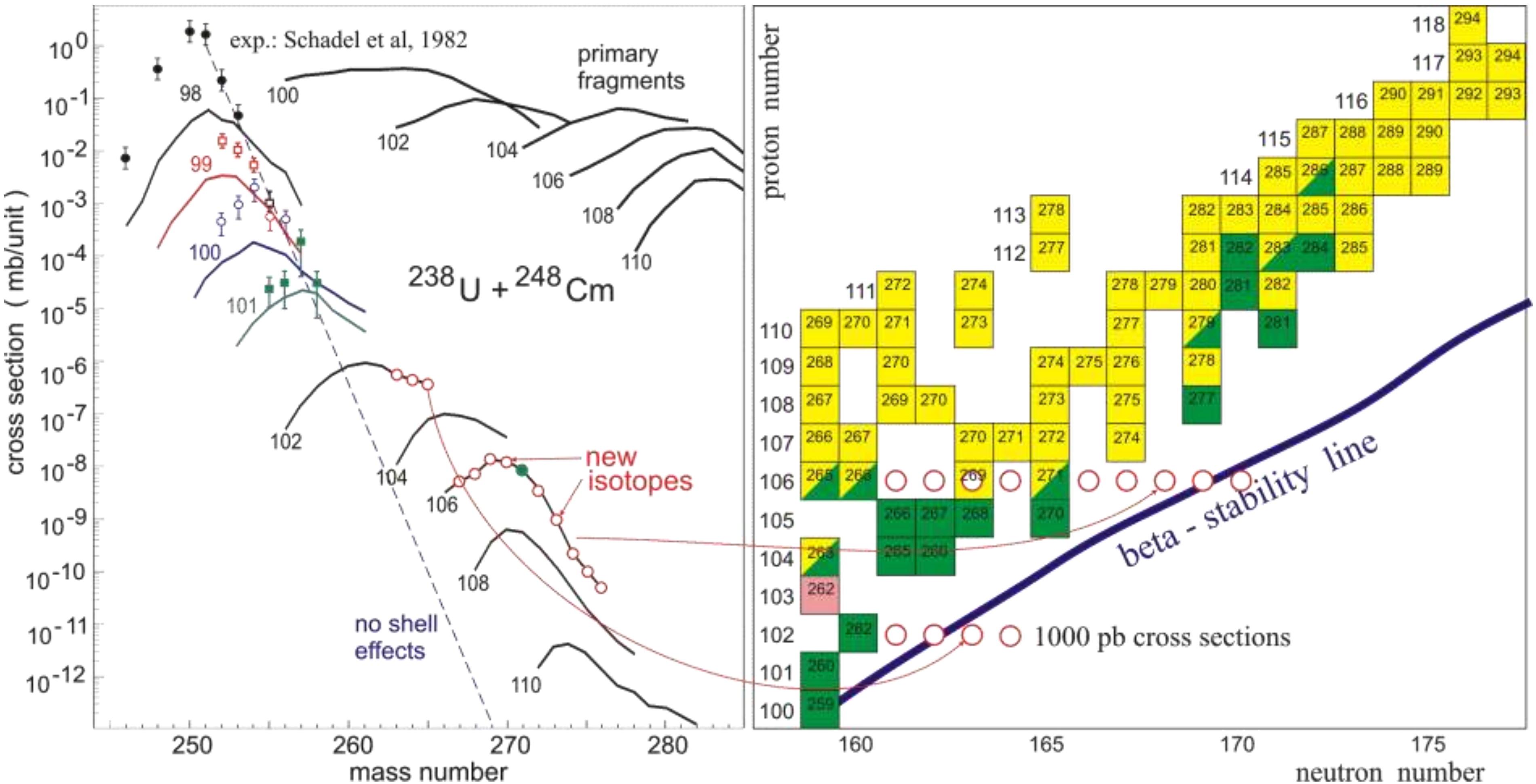
Only U-like beams give us a chance to produce neutron rich SH nuclei in transfer reactions



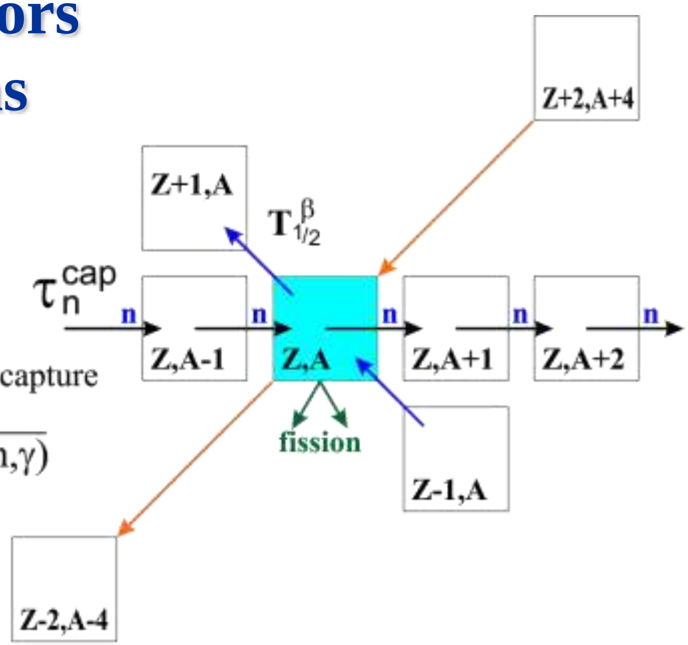
238U + 248Cm. Primary fragments



Study of transfermium nuclei along the line of stability becomes possible at last



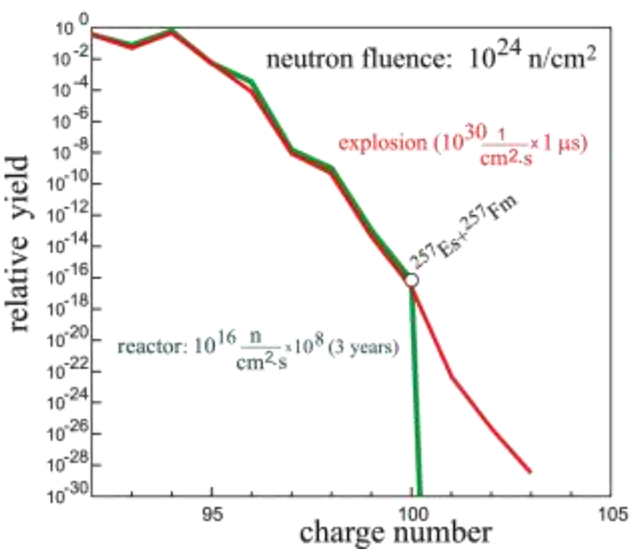
Nucleosynthesis in reactors and in nuclear explosions

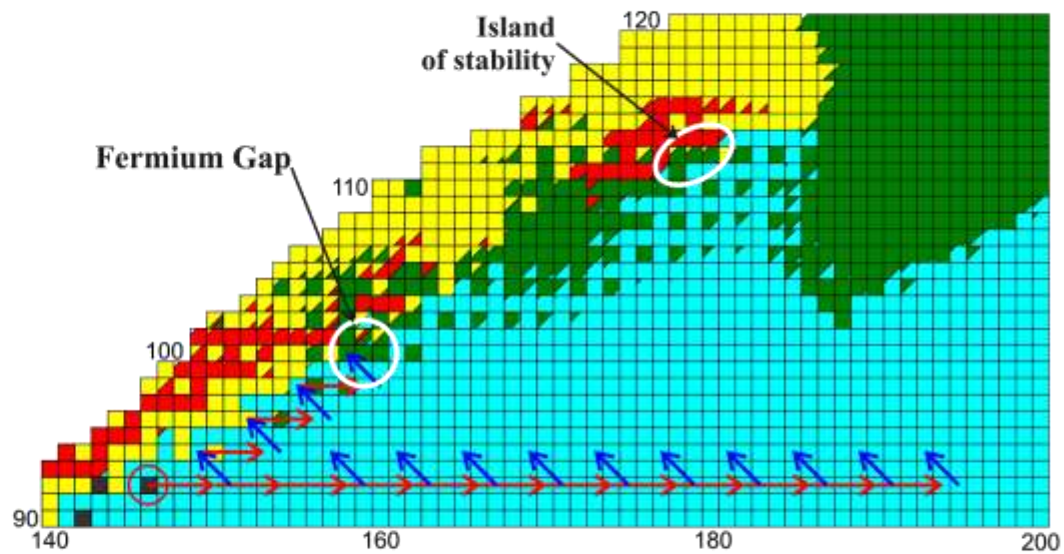


time of neutron capture

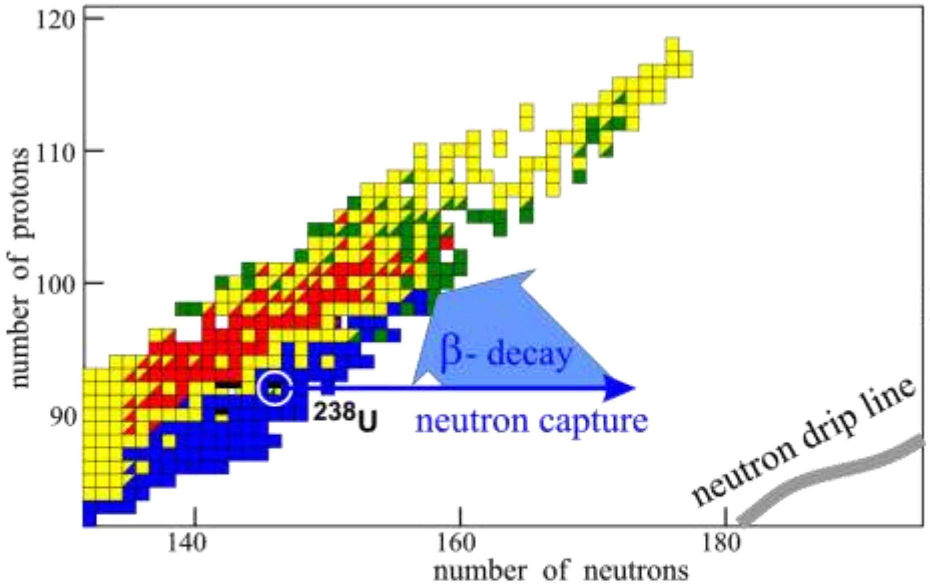
$$\tau_n^{cap} = \frac{1}{n_0 \times \sigma(n,\gamma)}$$

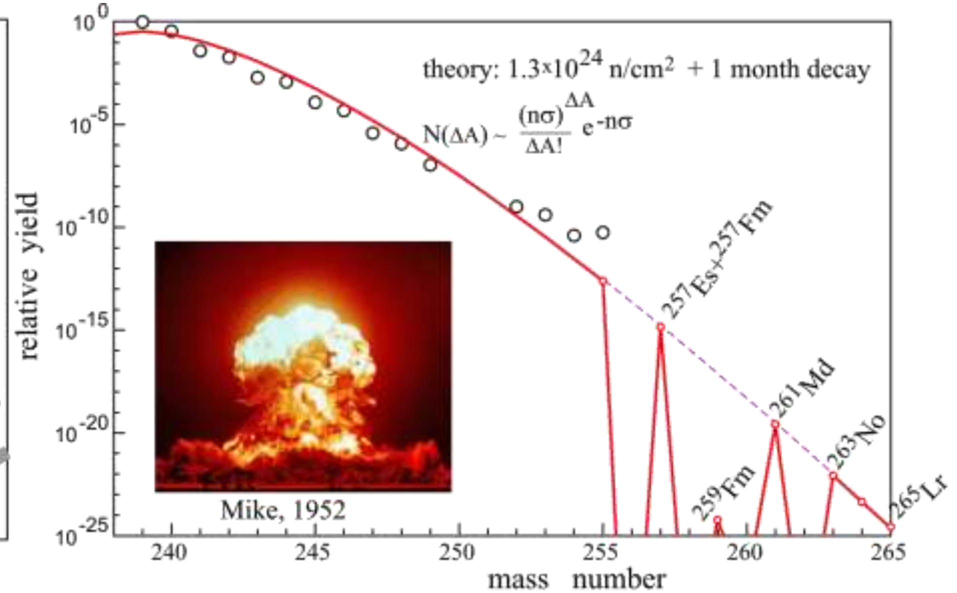
$$\frac{dN_{ZA}}{dt} = N_{ZA-1}\, n_0\, \sigma^{n\gamma}_{ZA-1} - N_{ZA}\, n_0\, \sigma^{n\gamma}_{ZA} - N_{ZA}\frac{\ln 2}{T^{\beta}_{ZA}} - N_{ZA}\frac{\ln 2}{T^{\alpha}_{ZA}} - N_{ZA}\frac{\ln 2}{T^{fis}_{ZA}} + N_{Z-1A}\frac{\ln 2}{T^{\beta}_{Z-1A}} + N_{Z+2A+4}\frac{\ln 2}{T^{\alpha}_{Z+2A+4}}$$





Rapid neutron capture in nuclear explosions



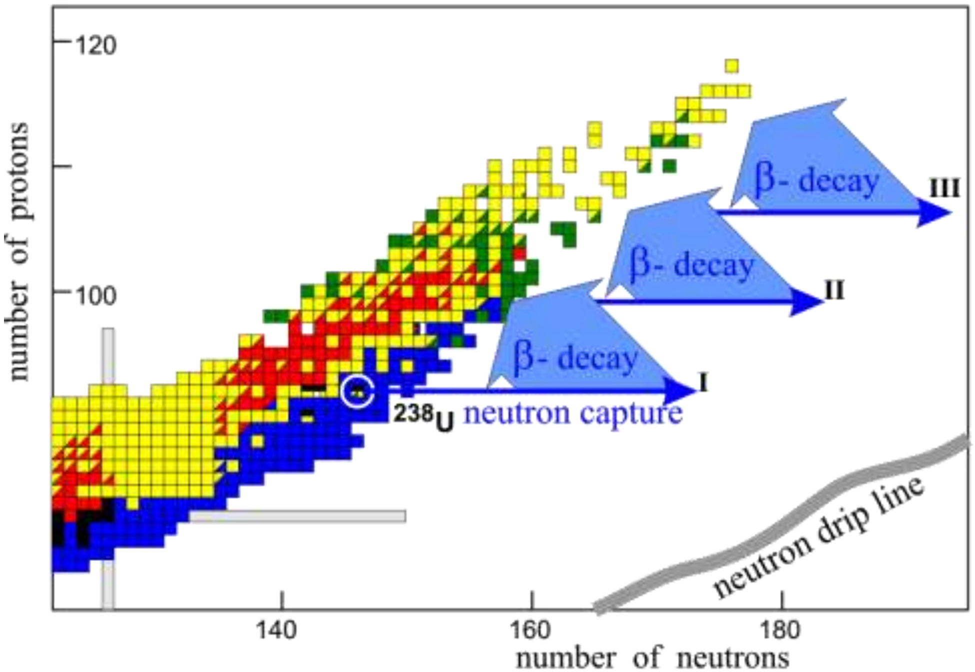


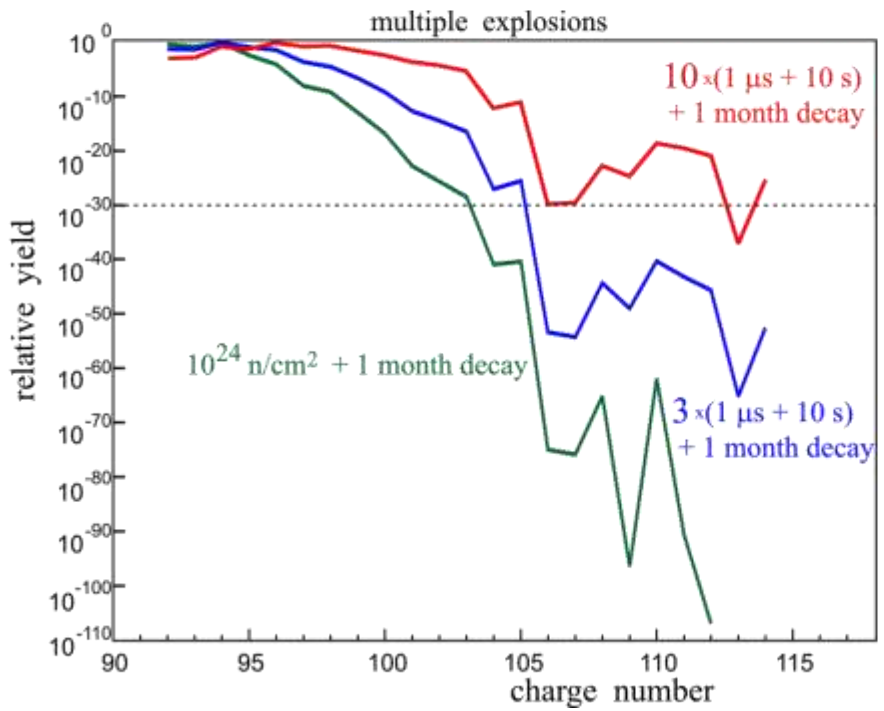
How much could be enhancement in the yield of superheavies in multiple (one by one) nuclear explosions **?**

(the idea was already discussed by Edward Teller and his colleagues 40 years ago)

Multiple nuclear explosions

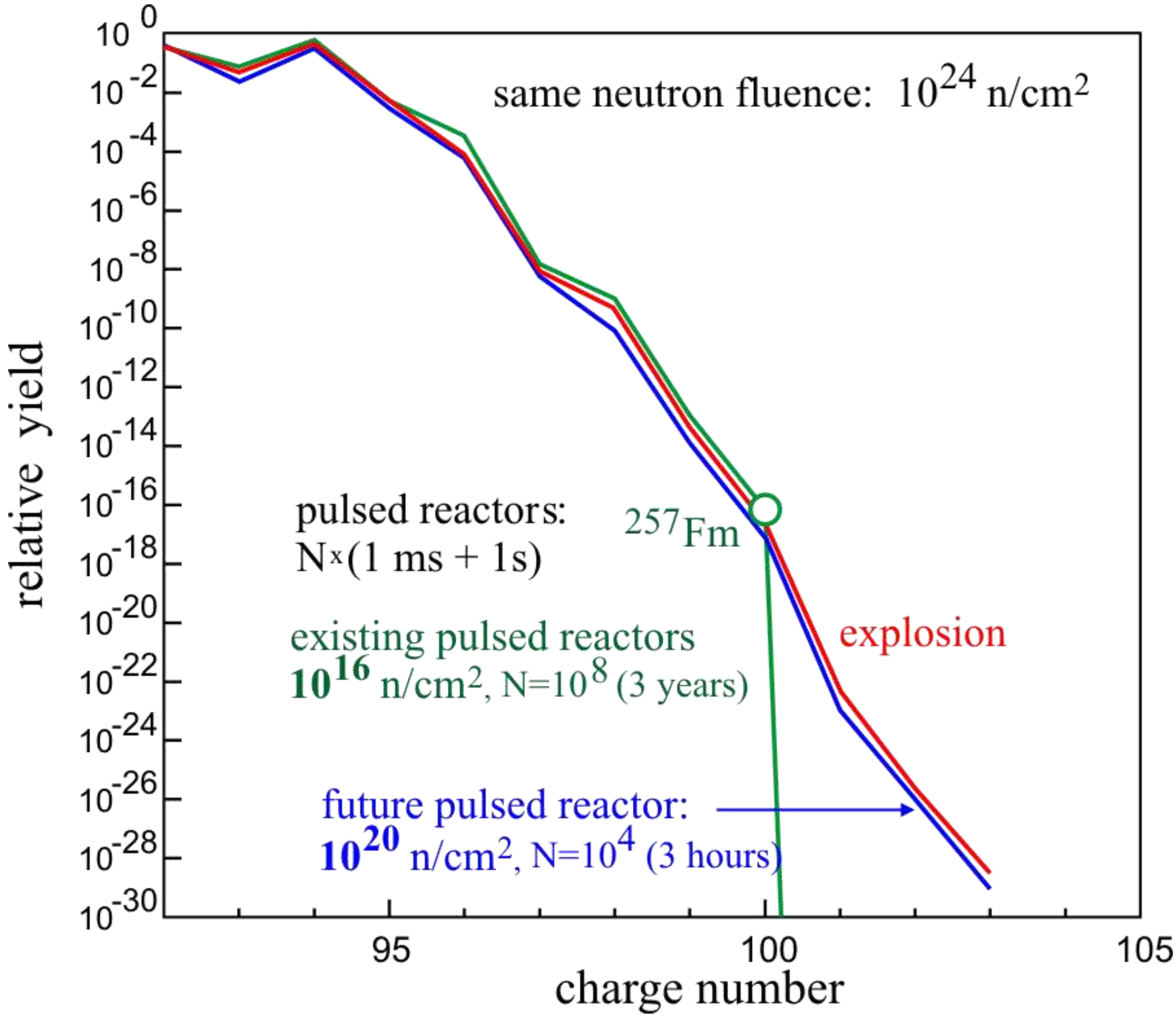
(Edward Teller: Technically it is quite possible)





Probability for formation of element 112 increases by **90 orders** of magnitude **!**

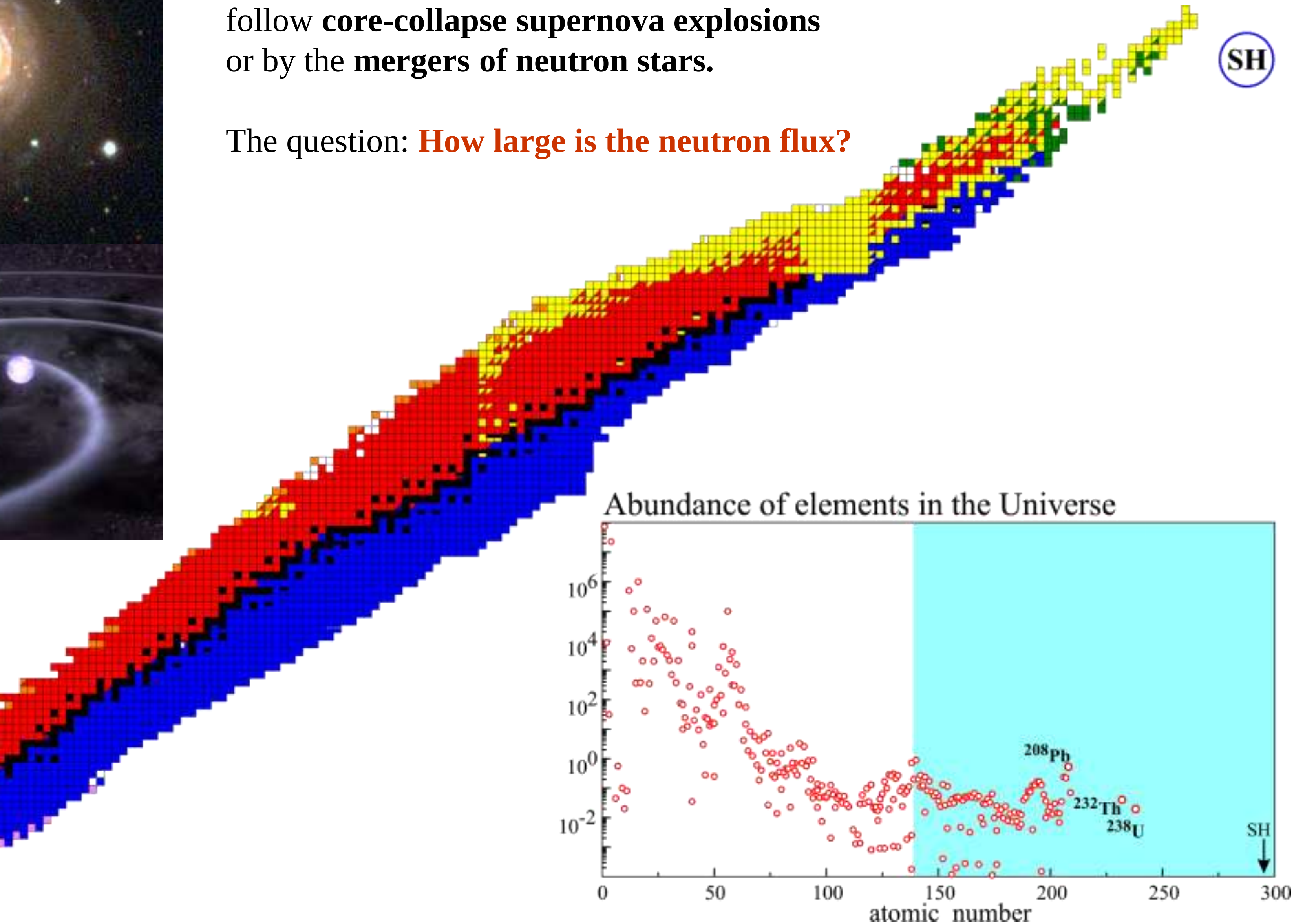
Next generation of Pulsed Reactors: We need factor 1000 only !



Formation of SH elements in astrophysical r-process

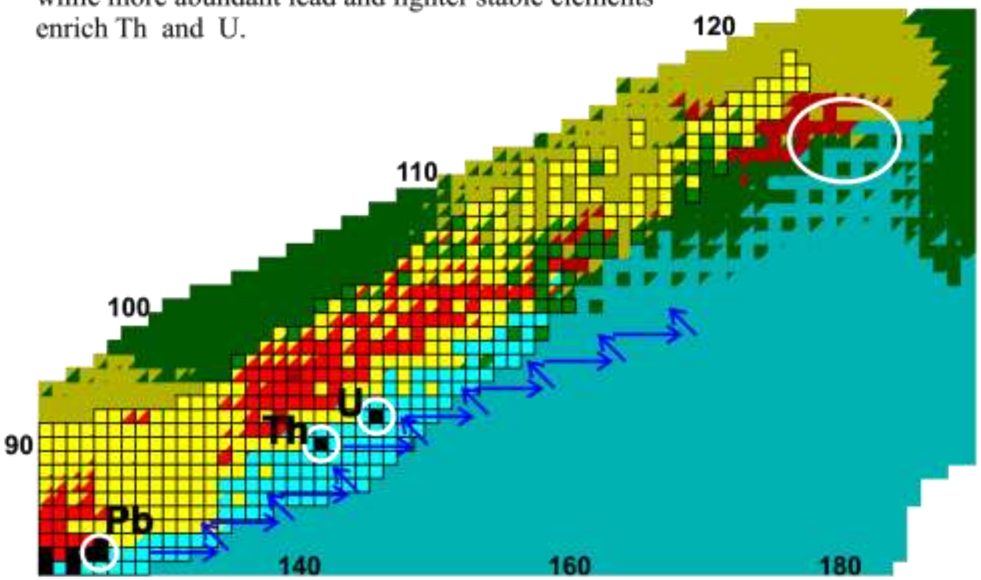
Strong neutron fluxes are expected to be generated by neutrino-driven proto-neutron star winds which follow **core-collapse supernova explosions** or by the **mergers of neutron stars.**

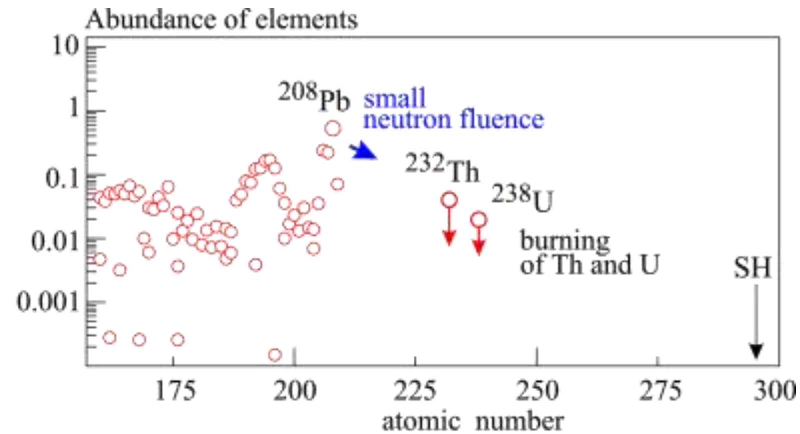
The question: **How large is the neutron flux?**

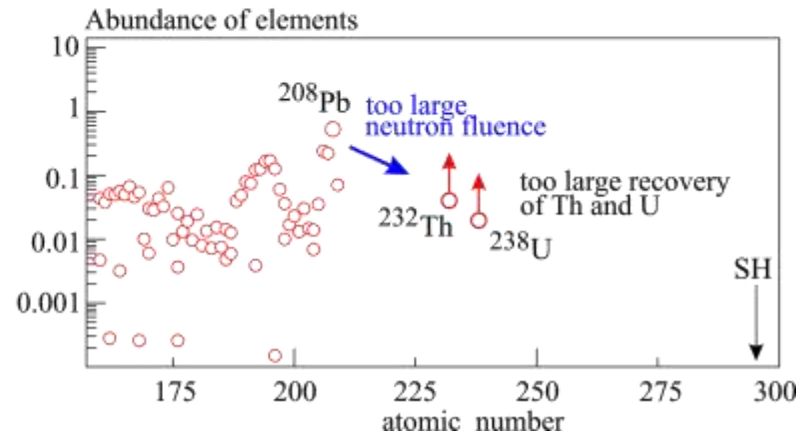


Formation of SH elements in astrophysical r-process: fit of unknown neutron fluence

During neutron irradiation initial Th and U material are depleted transforming to heavier elements and going to fission, while more abundant lead and lighter stable elements enrich Th and U.



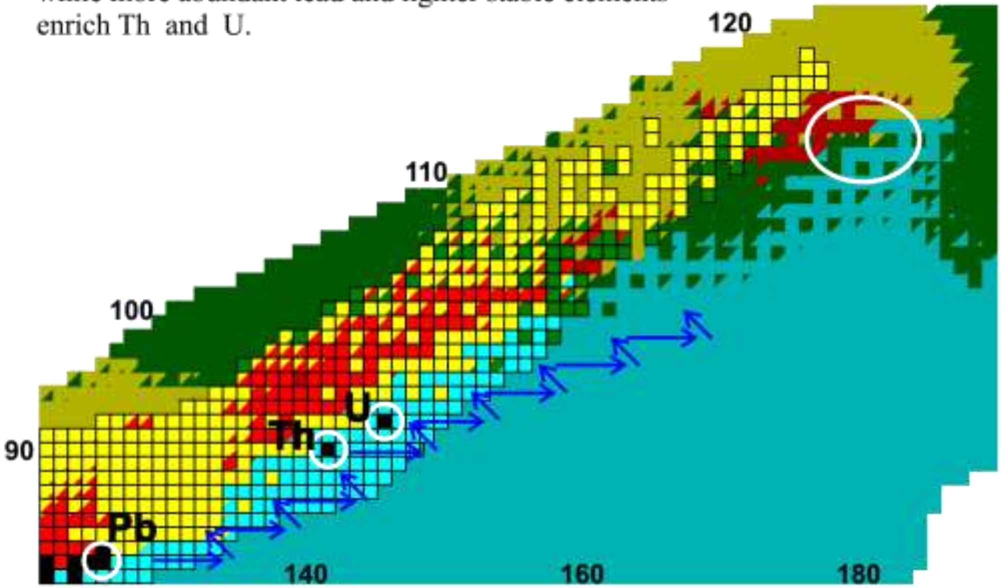


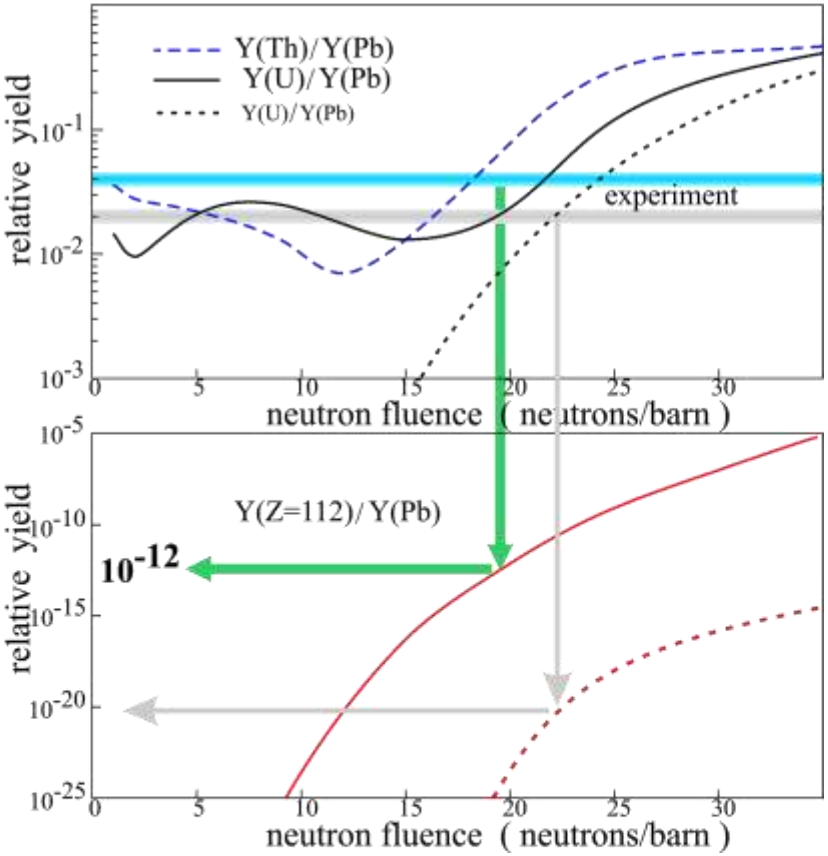


Unknown total neutron fluence is adjusted in such a way that the ratios Th/Pb and U/Pb keep its experimental values.

Formation of SH elements in astrophysical r-process

During intensive neutron irradiation initial Th and U material are depleted transforming to heavier elements and going to fission, while more abundant lead and lighter stable elements enrich Th and U.





Unknown total neutron fluence is adjusted in such a way that the ratios Th/Pb and U/Pb keep its experimental values.

For a given neutron fluence one gets the relative yield of SH elements, SH/Pb.

Summary

- **Elements 119 and 120 may be really synthesized in the Ti and/or Cr fusion reactions with cross sections of about 0.02 - 0.04 pb. Perhaps they are the last SH elements with $T_{1/2} > 1$ μs ?**

- **The gap in SH mass area can be easily filled in fusion reactions of 48Ca with lighter isotopes of actinides.**

- **The narrow pathway to the island of stability is found at last !**

- **Multi-nucleon transfer reactions are to be used for synthesis of neutron enriched long-living SH nuclei close to beta-stability line. 48Ca and 136Xe beams are insufficient. Uranium-like beams are needed !**

- **A macroscopic amount of the long-living SH nuclei located at the island of stability may be produced with the use of pulsed nuclear reactors of the next generation (factor 1000 is needed).**

- **Production of long-living SH nuclei in the astrophysical r-process looks not so much pessimistic: relative yield of SH / Pb is about 10^{-12}.**

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Walter Greiner (FIAS, Frankfurt)

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