18 member states:

Armenia, Azerbaijan, Belarus, Bulgaria, Cuba, Czech Republic, Georgia, Kazakhstan, Democratic People's Republic of Korea, Moldova, Mongolia, Poland, Romania, Russian Federation, Slovak Republic, Ukraine, Uzbekistan and Vietnam

6 associated members:

Egypt, Germany, Hungary, Italy, Serbia and Republic of South Africa

Laboratories:

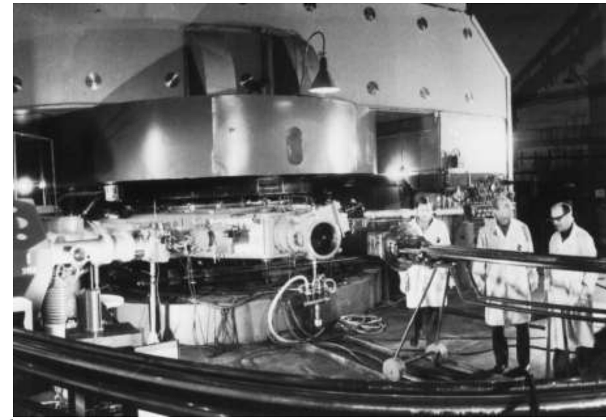
High Energy Physics
Nuclear Problems
Theoretical Physics
Neutron Physics
Nuclear Reactions
Information Technologies
Radiation Biology
University Centre

Flerov Laboratory of Nuclear Reactions

U400: 1-20A MeV

U400M: 6-100A MeV

U200: 3-15A MeV



fundamental physics

IC-100: 0.5-1.2A MeV

applied research

MT-25 (electron accelerator)

total staff ~ 400, scientists: > 100

Main activity:

- **synthesis of SHE**
- **fusion-fission dynamics & multi-nucleon transfer**
- **RIB:**
  - **structure (^{6,8,10}He, ^{5,7}H,…)**
  - **reaction mechanisms**
- **nuclear theory**
- **applied research**
  from polymeric membranes
  to micro-chips for space satellites
- ***education activity***

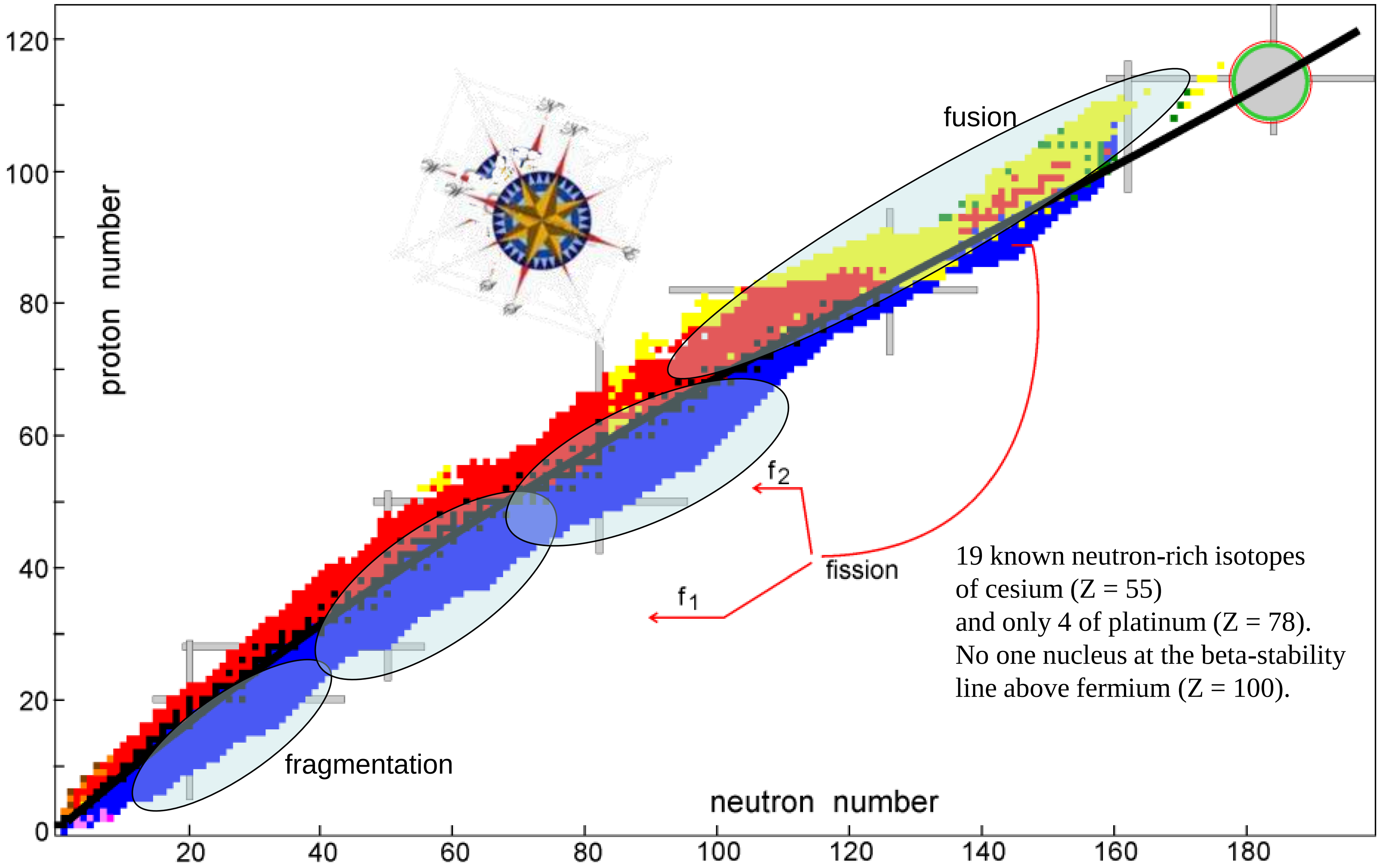
Synthesis and study of heavy and superheavy neutron rich nuclei

- **Unexplored "north-east" area of the Nuclear Map**
  - **- Nuclei below ^{208}Pb (astrophysical waiting point at N=126)**
  - **- Nuclei along the beta-stability line above Fermium**
  - **- Superheavy nuclei and the island of stability**
- **Fusion reactions**
  - **- What else can be done with fusion reactions ?**
  - **- Fusion reactions with RI beams ?**
- **Multi-nucleon transfer reactions**
  - **- Production of neutron-rich superheavy nuclei (U-like beam)**
  - **- Production of new neutron-rich heavy nuclei (Xe-like beam)**
  - **- Beams of accelerated fission fragments**
  - **- Experimental problems and separators of a new kind**
- **Summary** **(nearest and distant experiments)**

Valeriy Zagrebaev
Flerov Laboratory of Nuclear Reactions,
JINR, Dubna

for the 1-st International Symposium on the Science with KoRIA, 1-2 December, 2011

Unexplored "north-east" area of the nuclear map



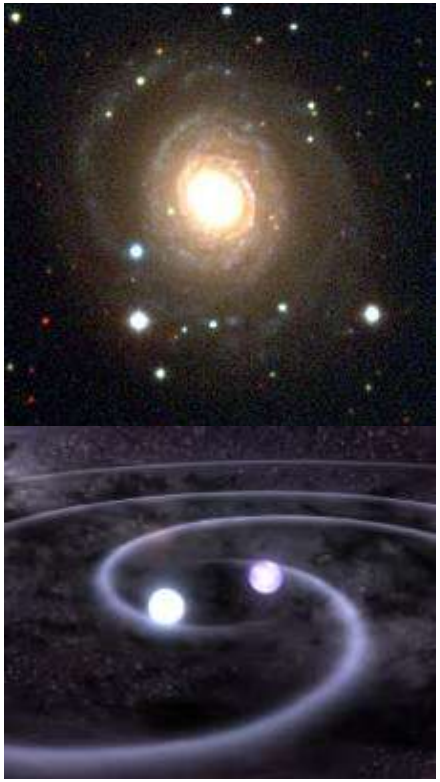
19 known neutron-rich isotopes of cesium (Z = 55) and only 4 of platinum (Z = 78).
No one nucleus at the beta-stability line above fermium (Z = 100).

Abundance of the elements in the Universe

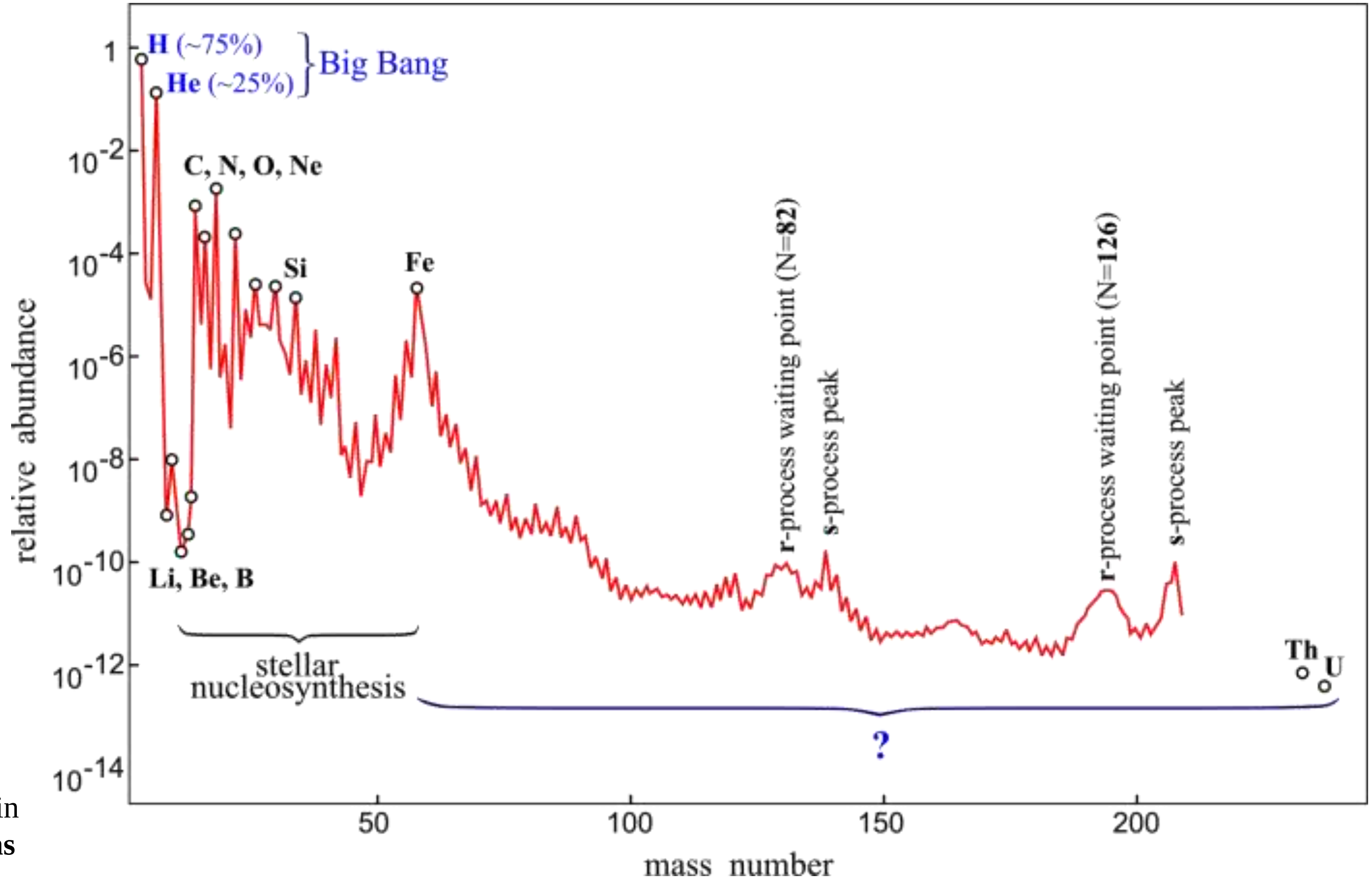
The 11 Greatest Unanswered Questions of Physics (National Research Council, NAS, USA, 2002):

1. **What is dark matter?**
2. **What is dark energy?**
3. **How were the heavy elements from iron to uranium made?**
4. **Do neutrinos have mass?**

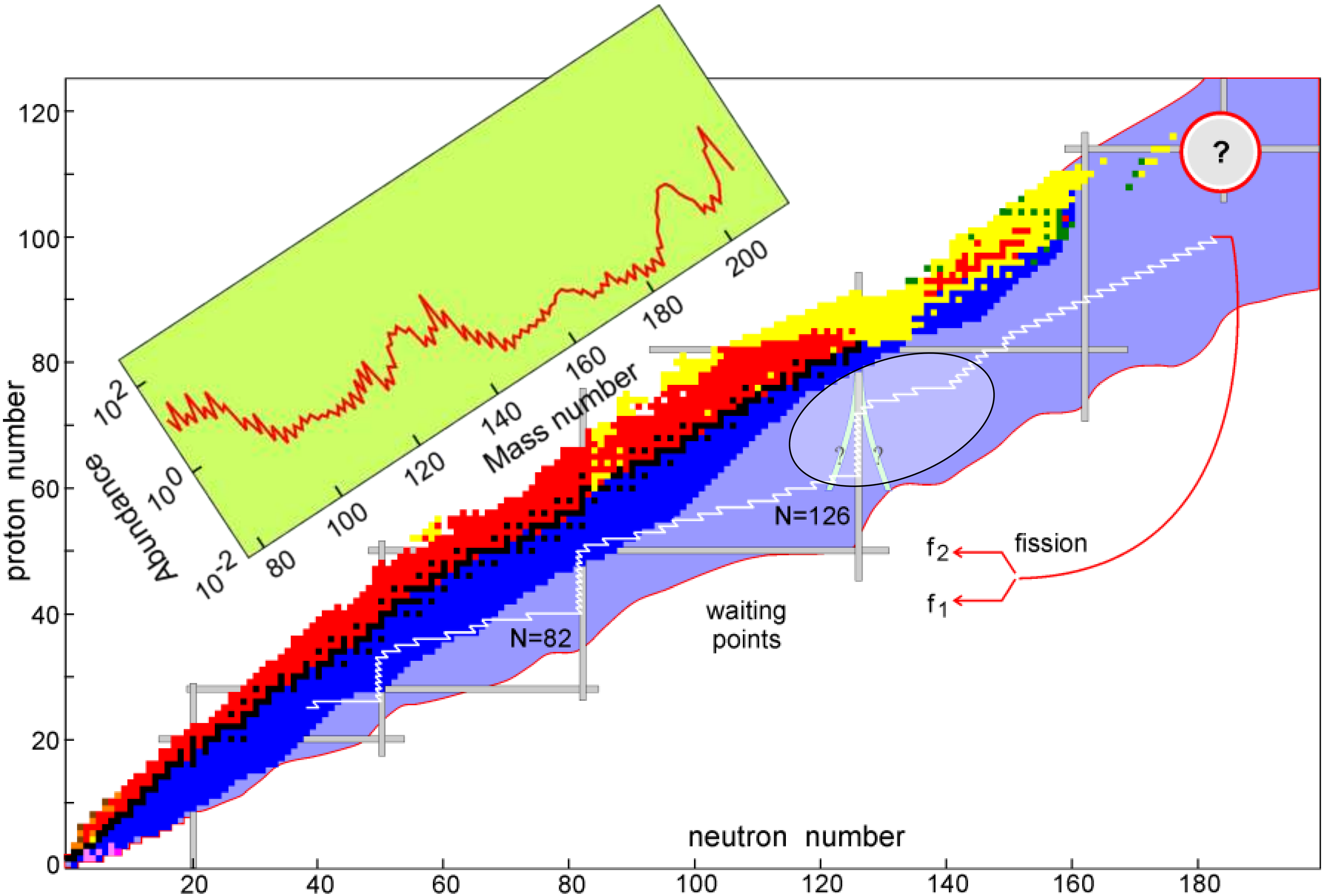
…



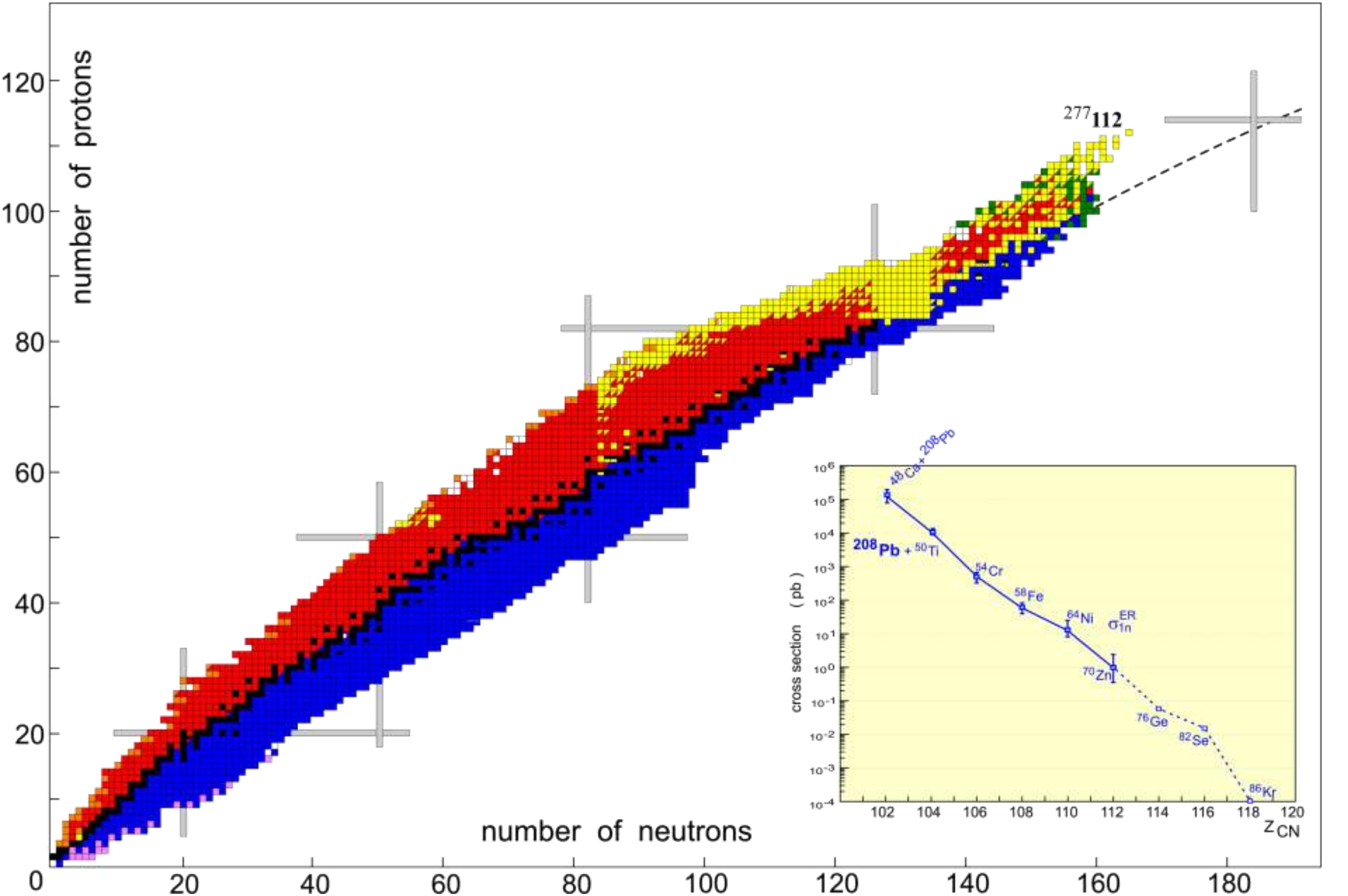
Strong neutron fluxes are expected in **core-collapse supernova explosions** or in the **mergers of neutron stars.**



r-process of nucleosynthesis
and the neutron closed shell in the region of N=126



Nuclear Map in 2000

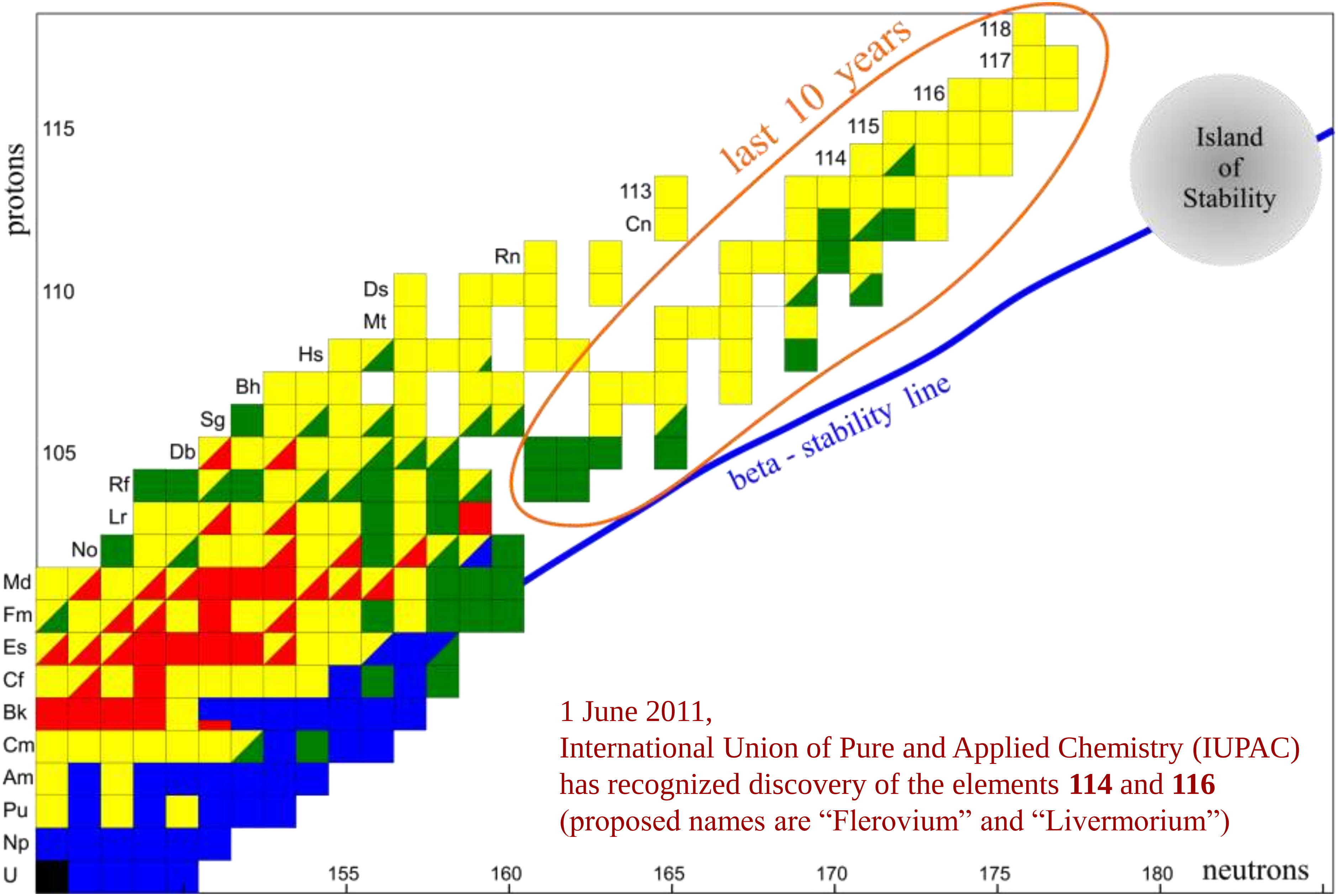


Synthesis of superheavy elements at FLNR (Dubna)

^{48}Ca induced fusion reactions with actinide targets

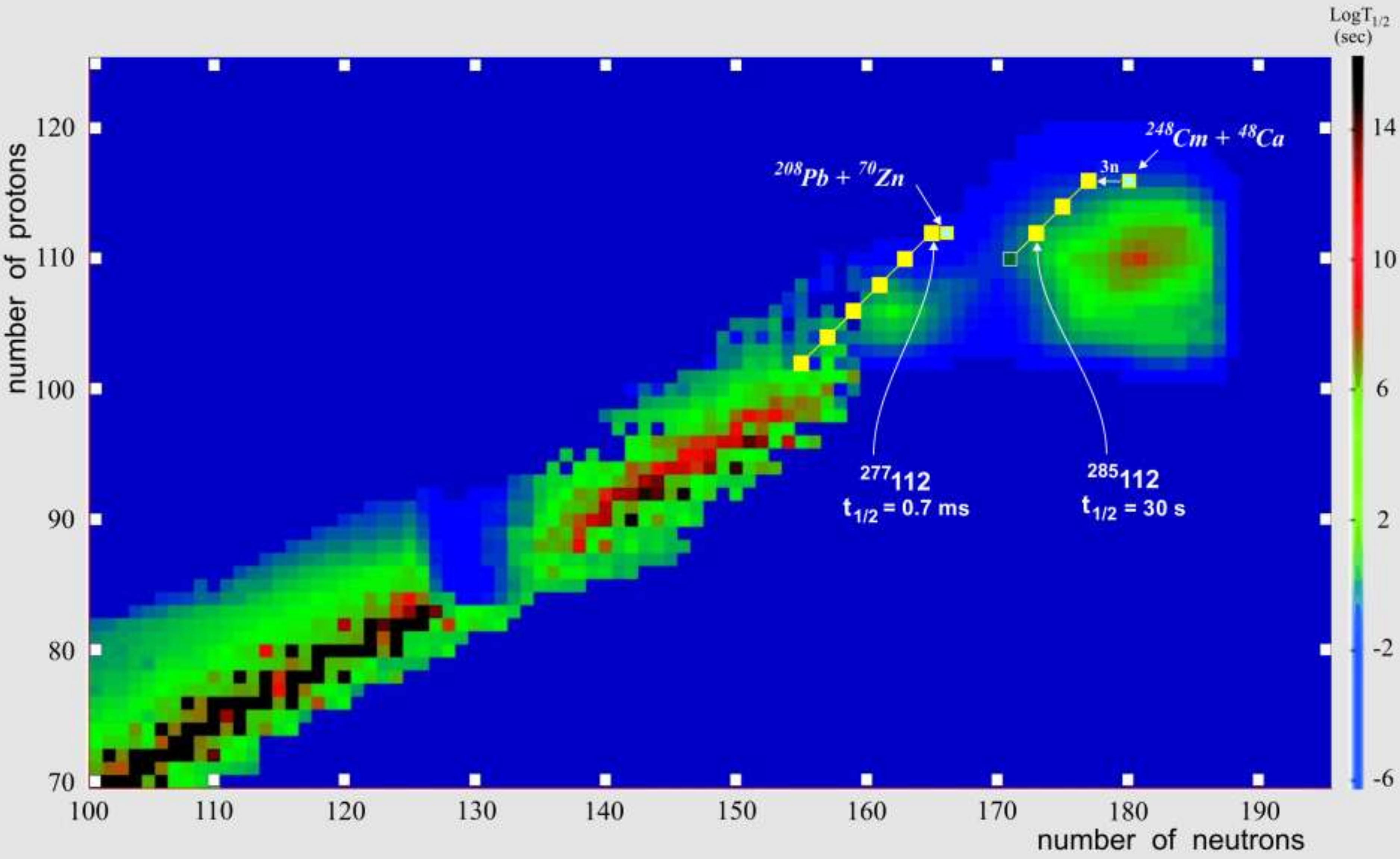
Yu. Oganessian, V. Utyonkov, et al. + Livermore + Oak Ridge

Great progress in synthesis of superheavy nuclei within last 10 years

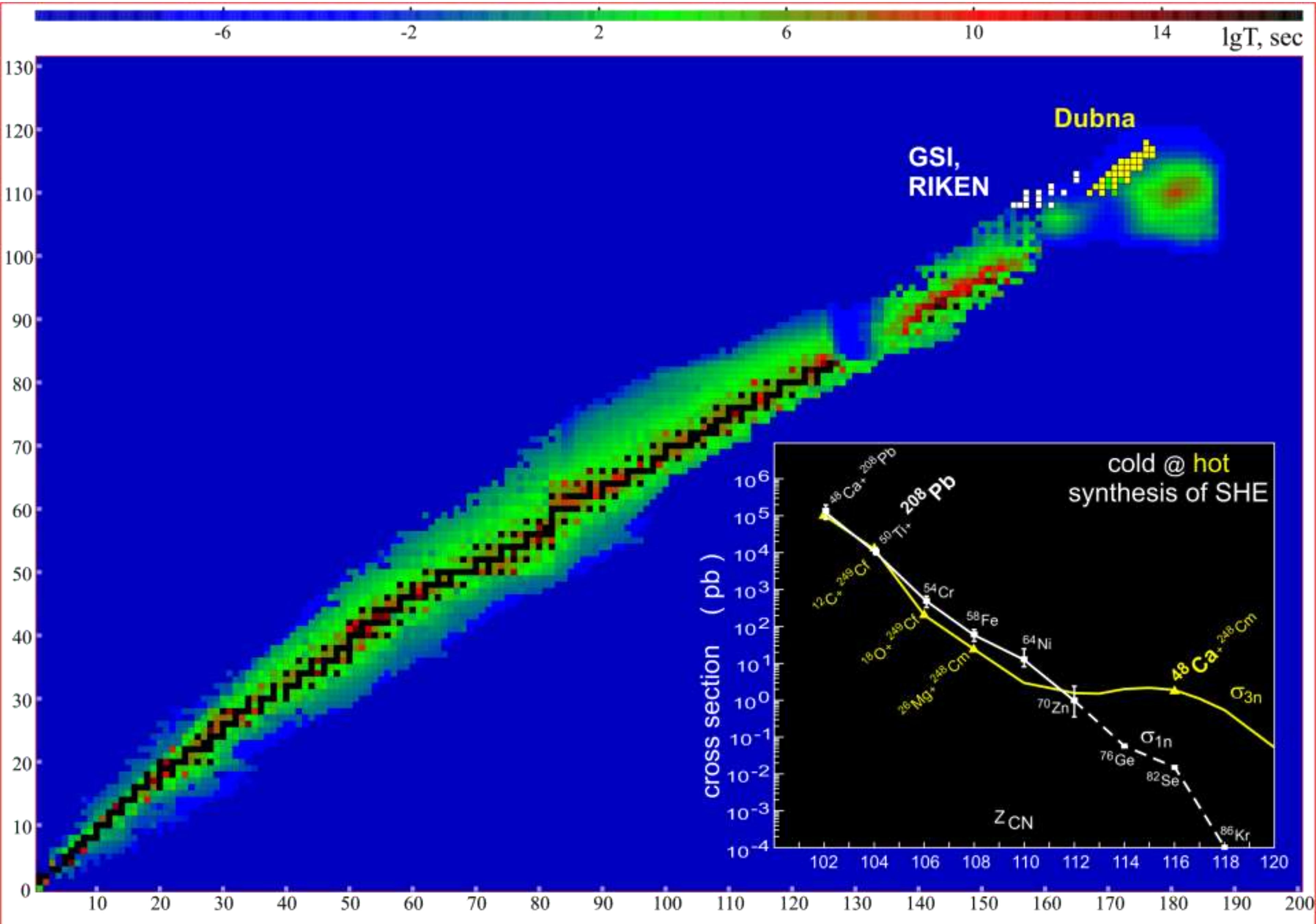


1 June 2011,
International Union of Pure and Applied Chemistry (IUPAC) has recognized discovery of the elements **114** and **116** (proposed names are “Flerovium” and “Livermorium”)

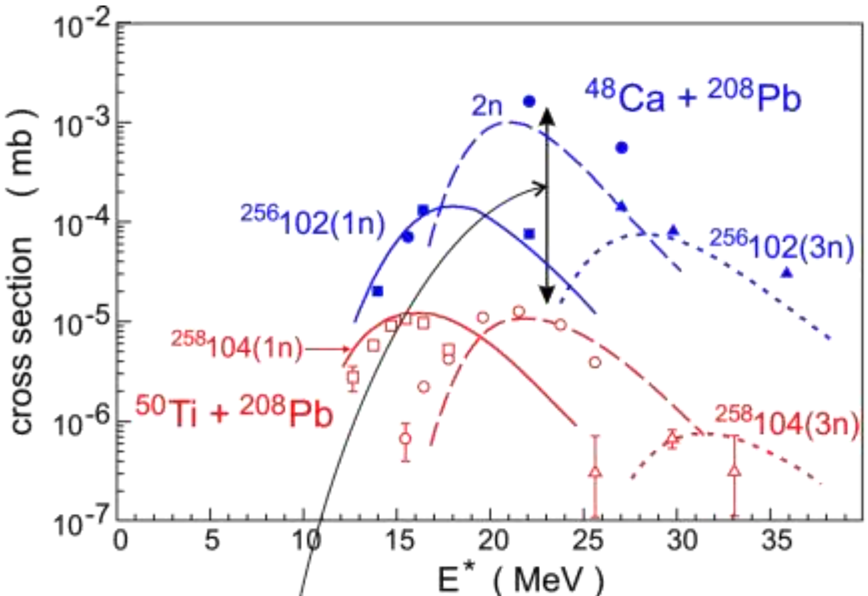
Approaching the Island of Stability

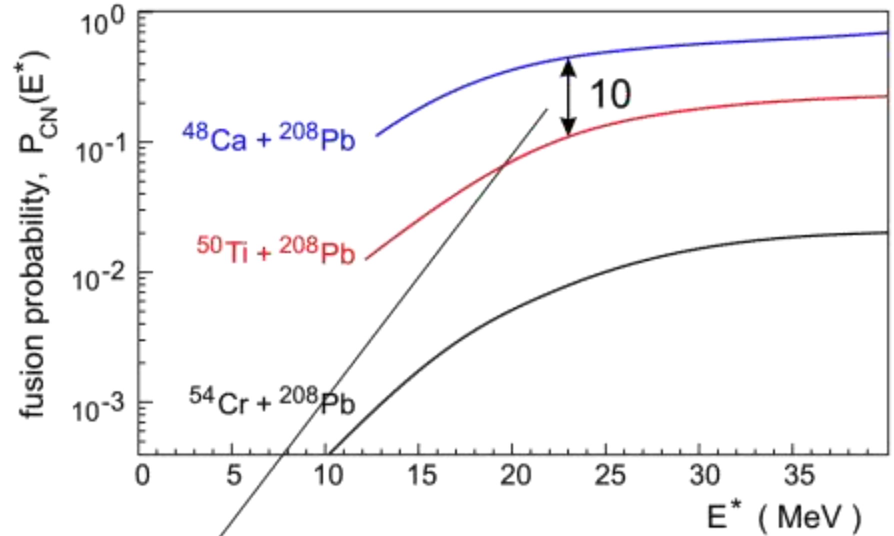


Drastic change in behavior of the cross sections (predictions of 2002)

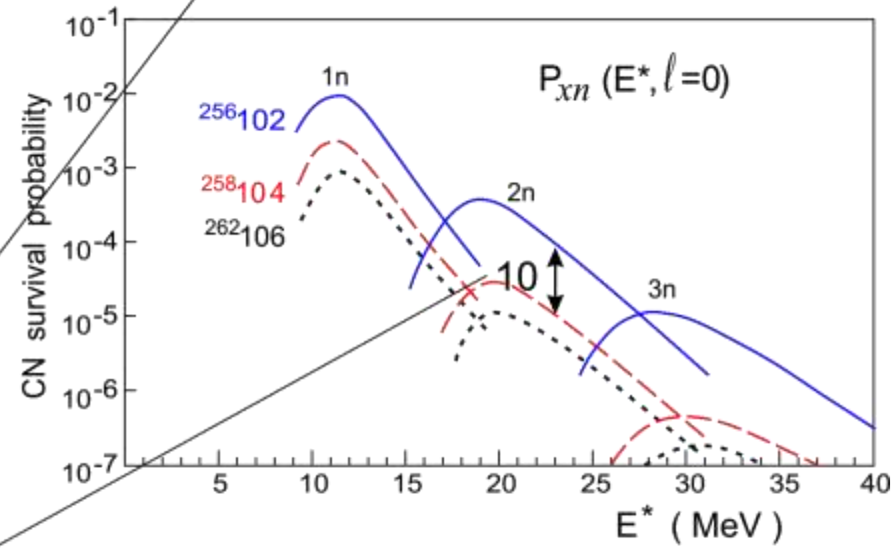


Epoch of ^{48}Ca is almost over. How much is ^{50}Ti worse?





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

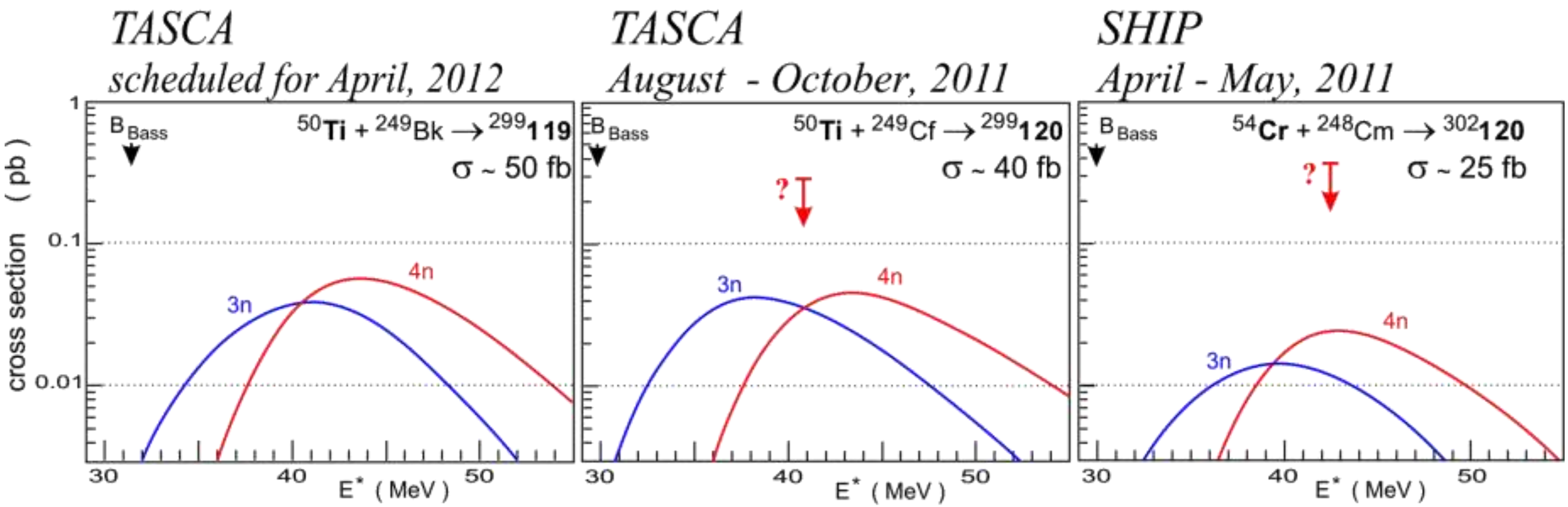


	B_{LD}	δW	B_f	E_n
^{256}102	1.26	4.48	5.7	7.1
^{258}104	0.77	4.49	5.3	7.6

$$\sigma^{xn}_{\mathrm{EvR}}(E) = \frac{\pi\hbar^2}{2\mu E} \sum_{\ell} (2\ell+1) P(\ell, E) \cdot P_{\mathrm{CN}}(\ell, E^*) \cdot P_{xn}(\ell, E^*)$$

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

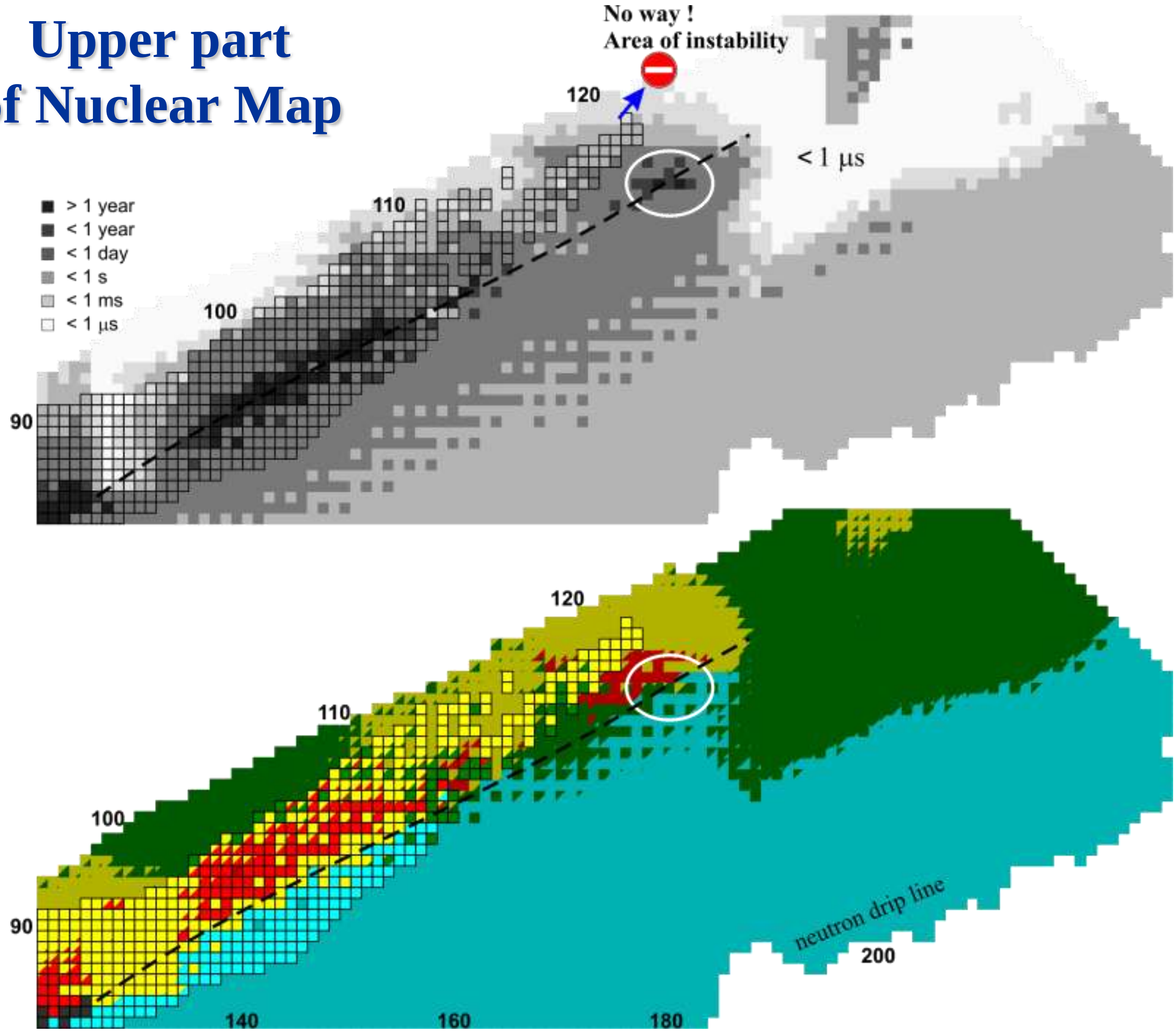
Ti beam: Cr beam:



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



How can we produce new heavy and superheavy neutron-rich nuclei ?

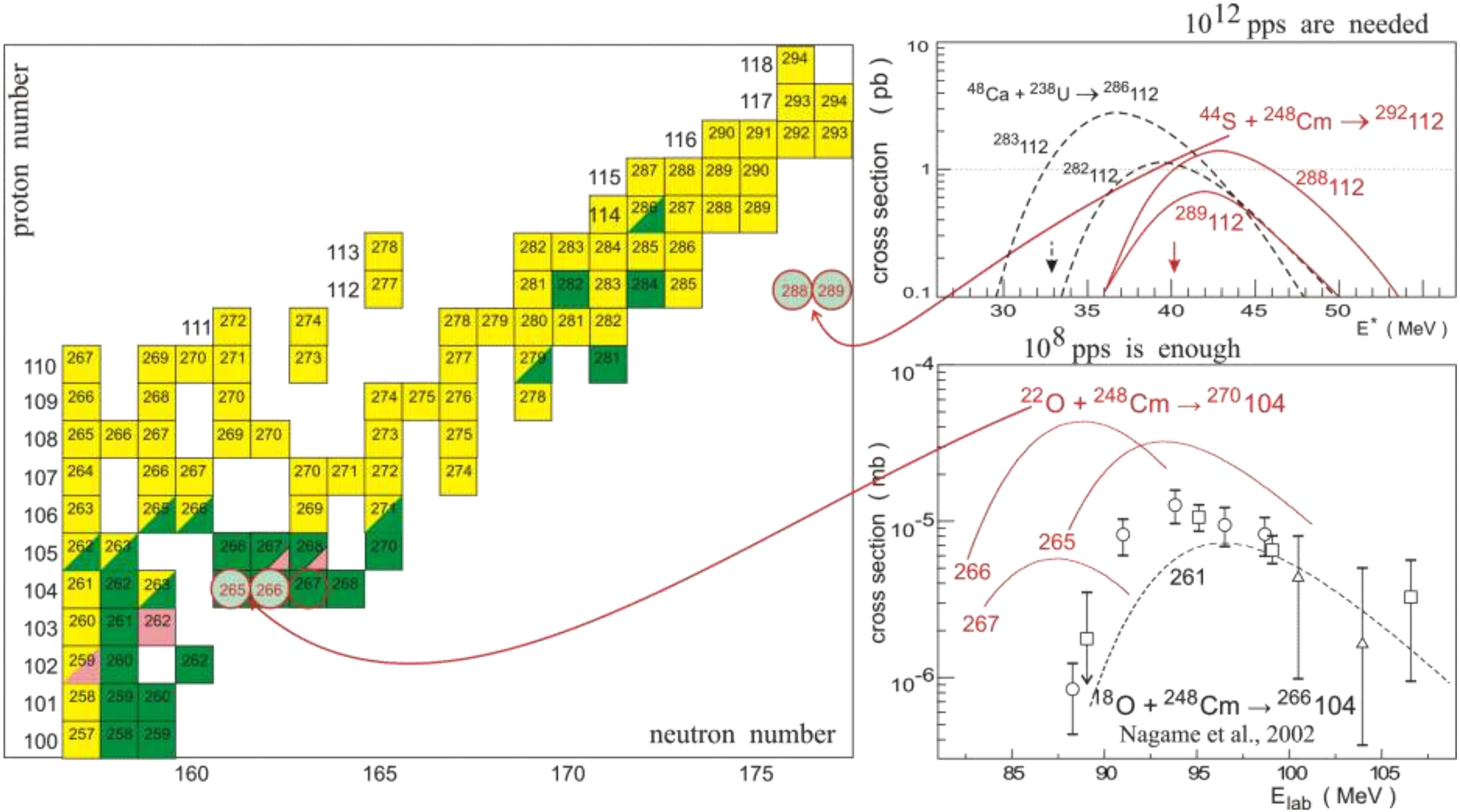
1. **Fusion reactions of stable nuclei**

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

3. **Multi-nucleon transfer reactions**

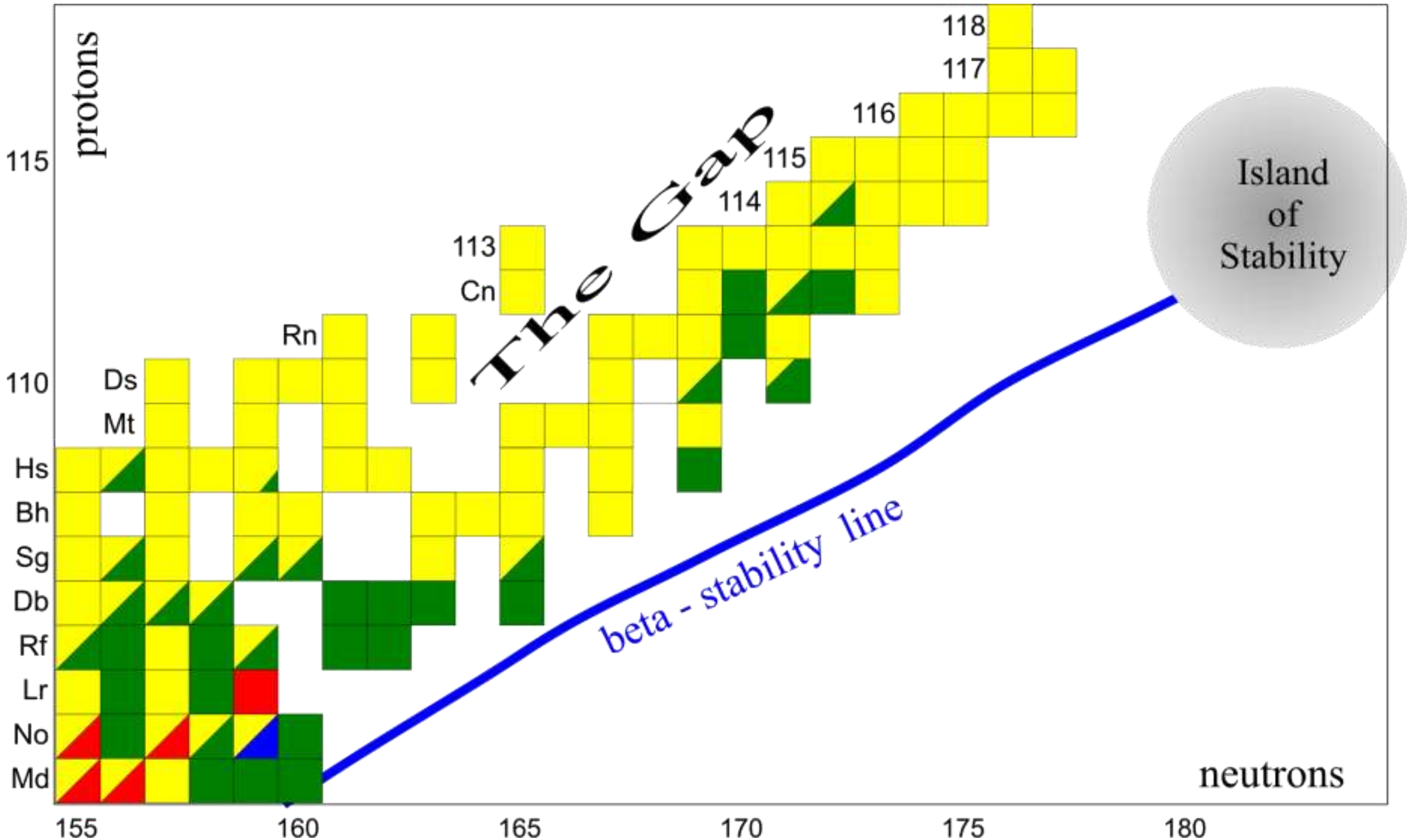
4. **Neutron capture processes** (pulsed reactors of new generation)

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

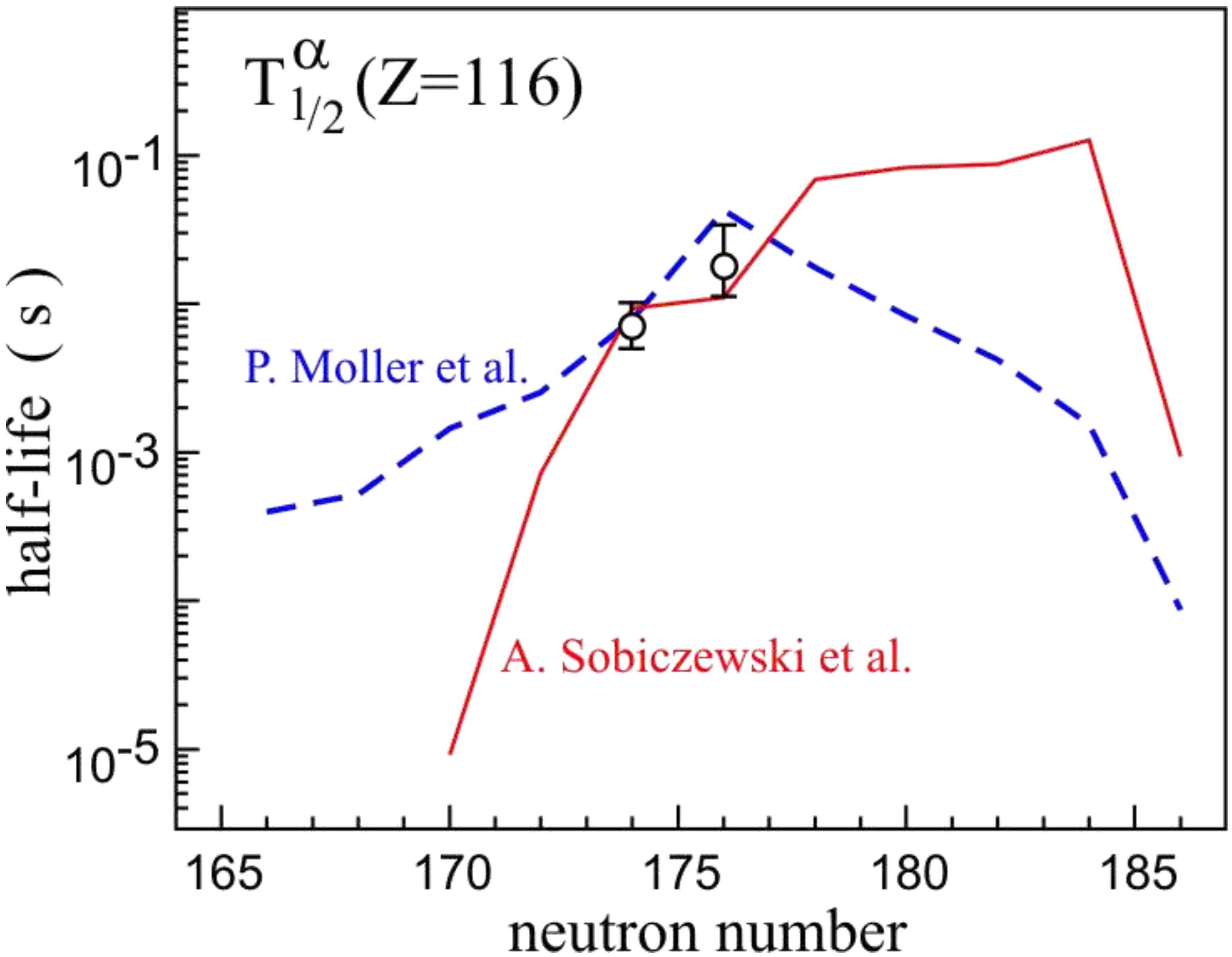


No chances today. But in future ?

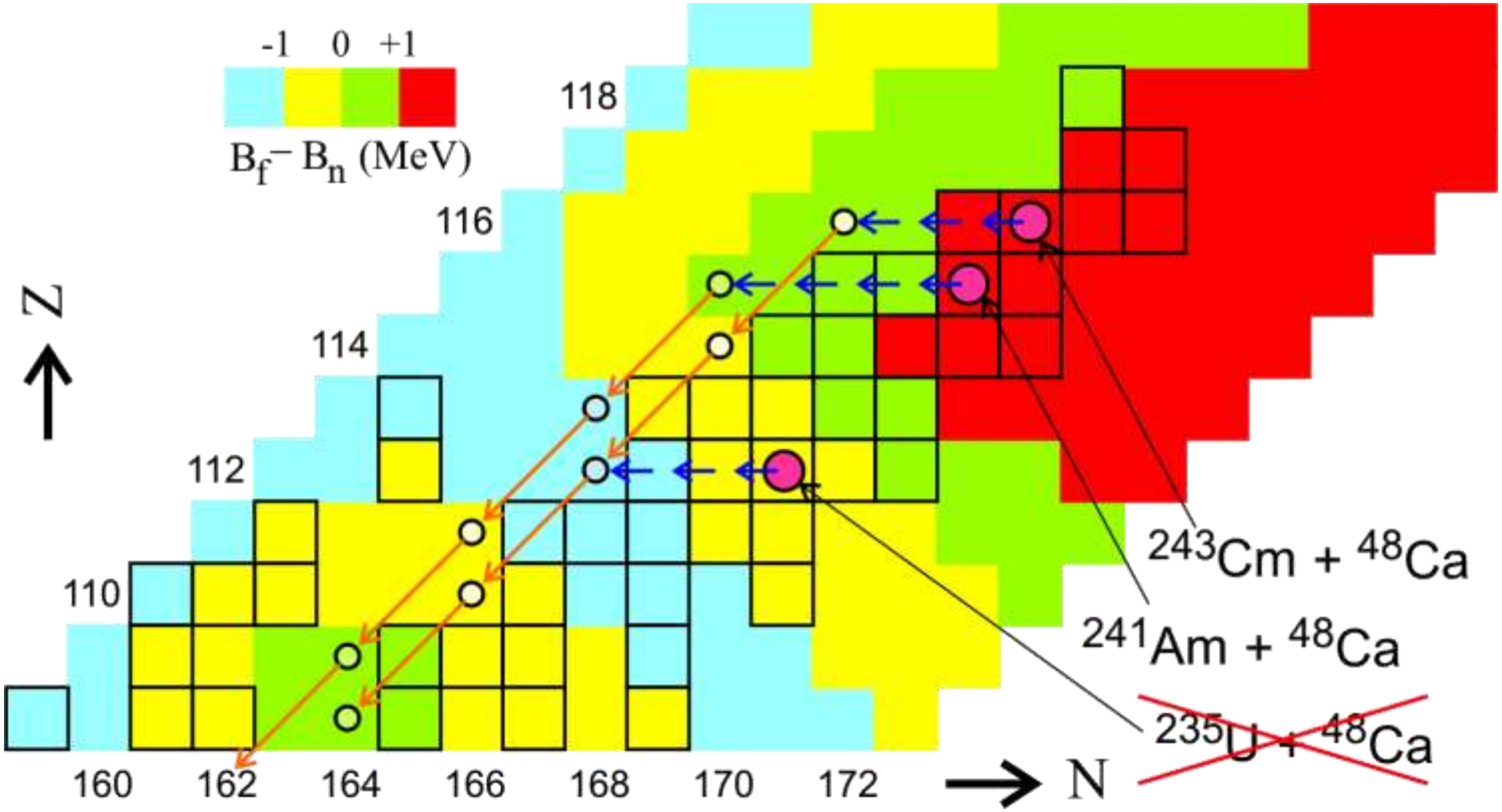
First, we should darn the gap in superheavy mass area?



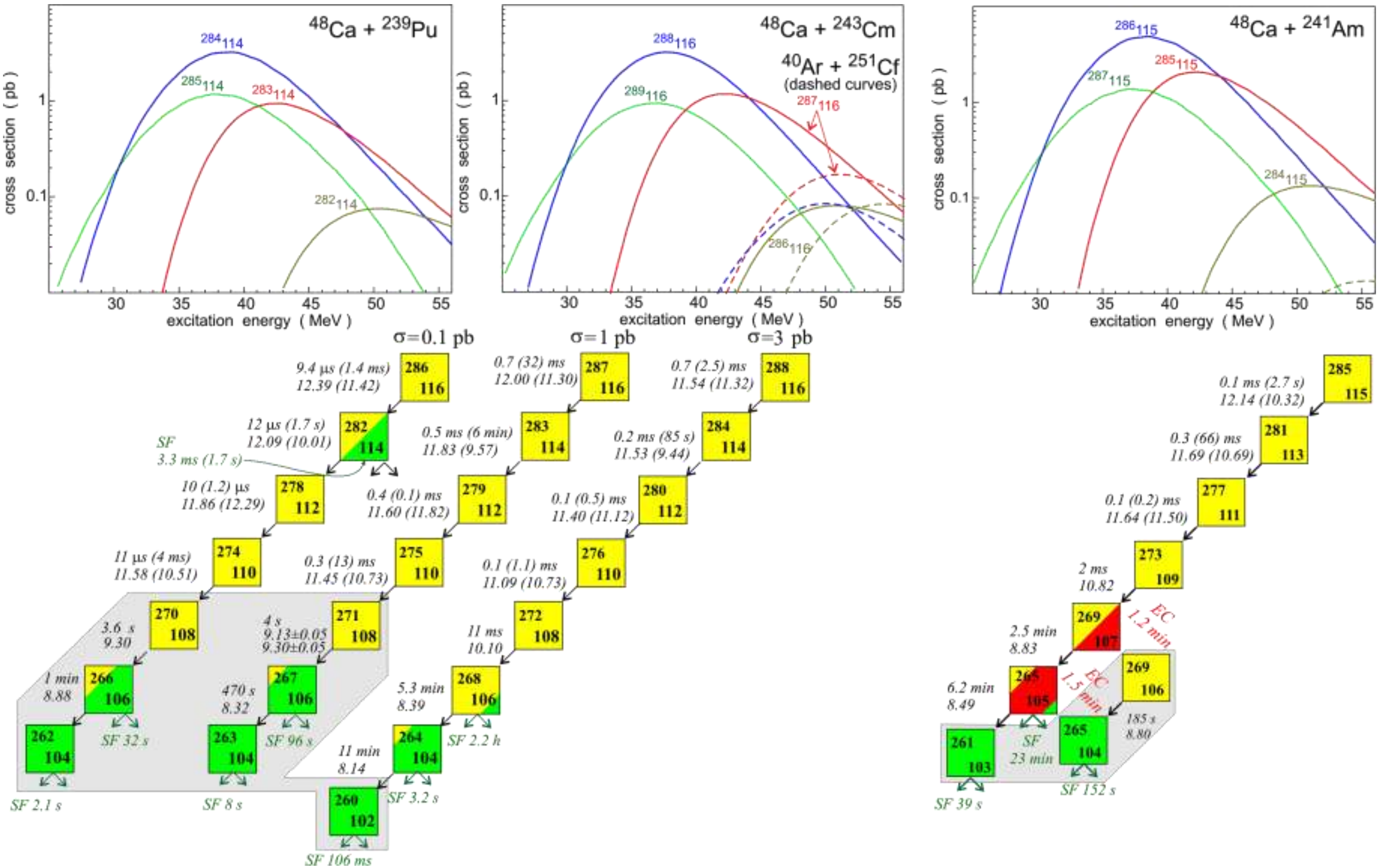
Our today ability of predictions in superheavy mass area



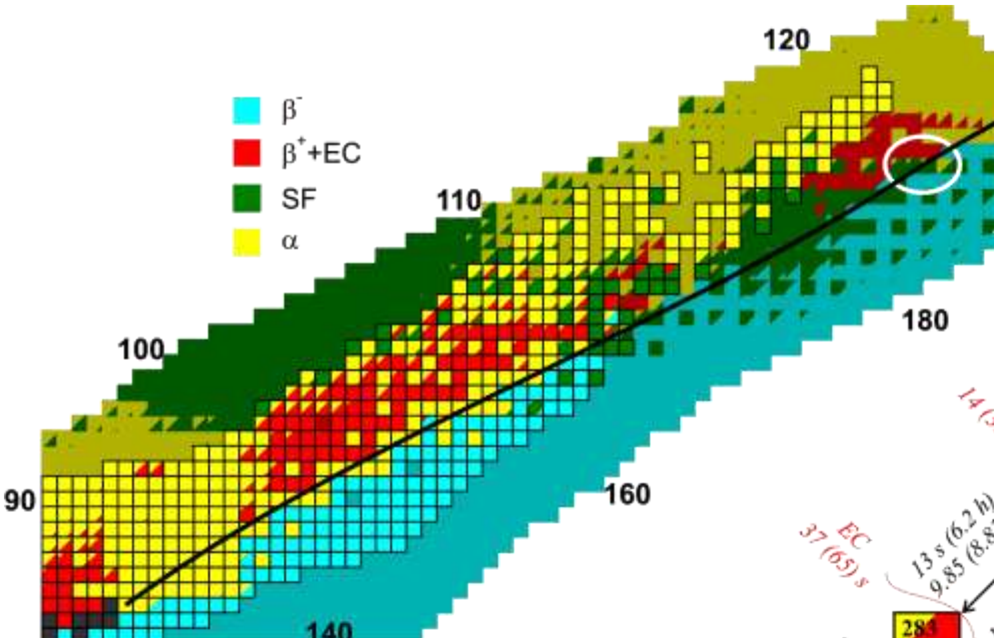
It is easier to darn the gap from above !

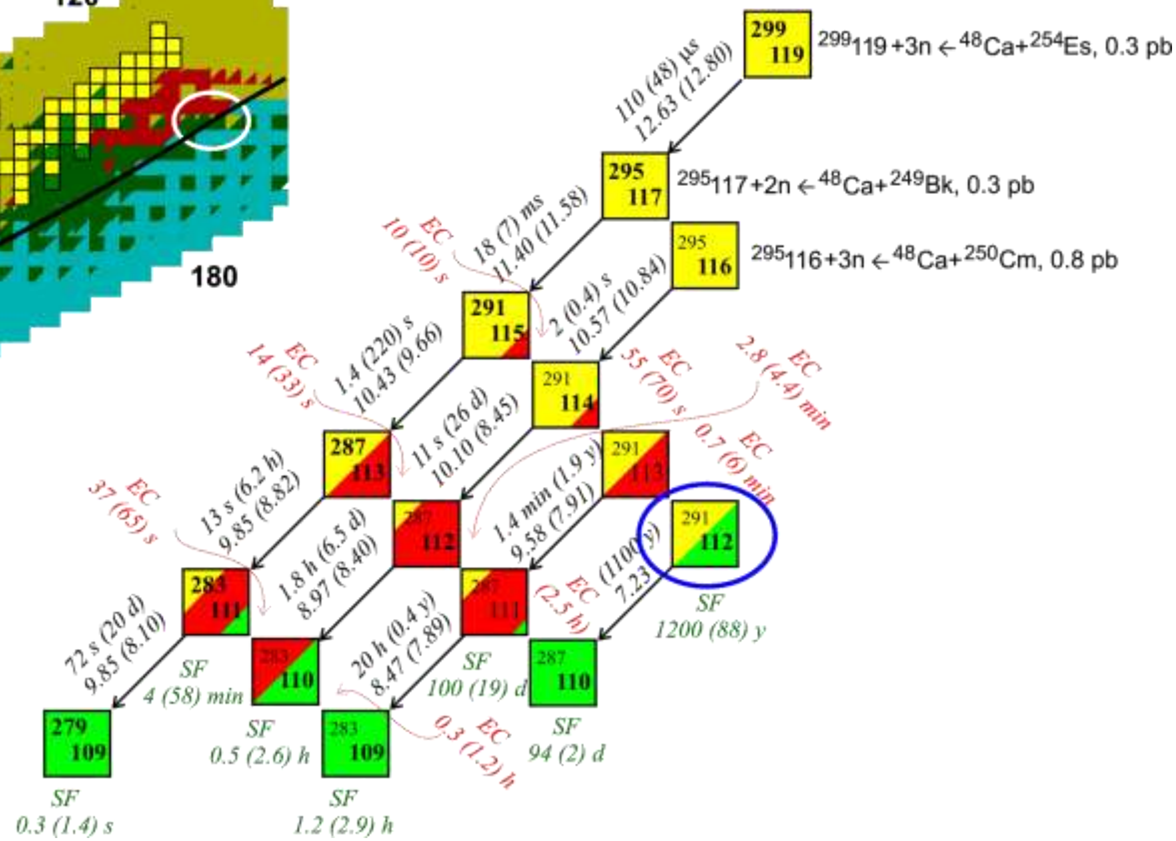


Cross sections are high enough to perform experiments at available facilities



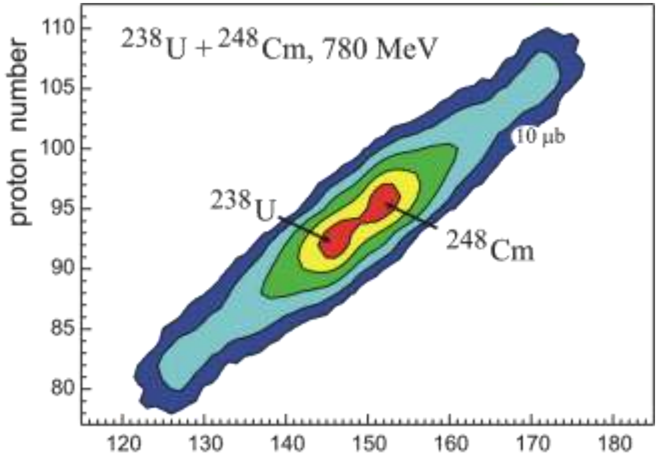
Narrow pathway to the island of stability !

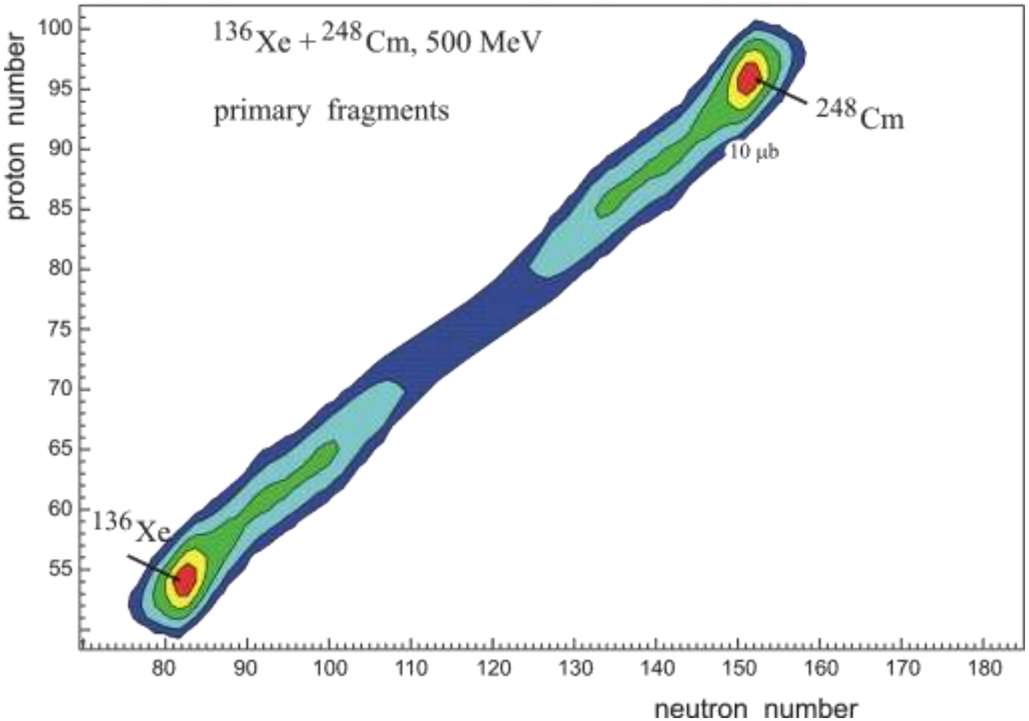




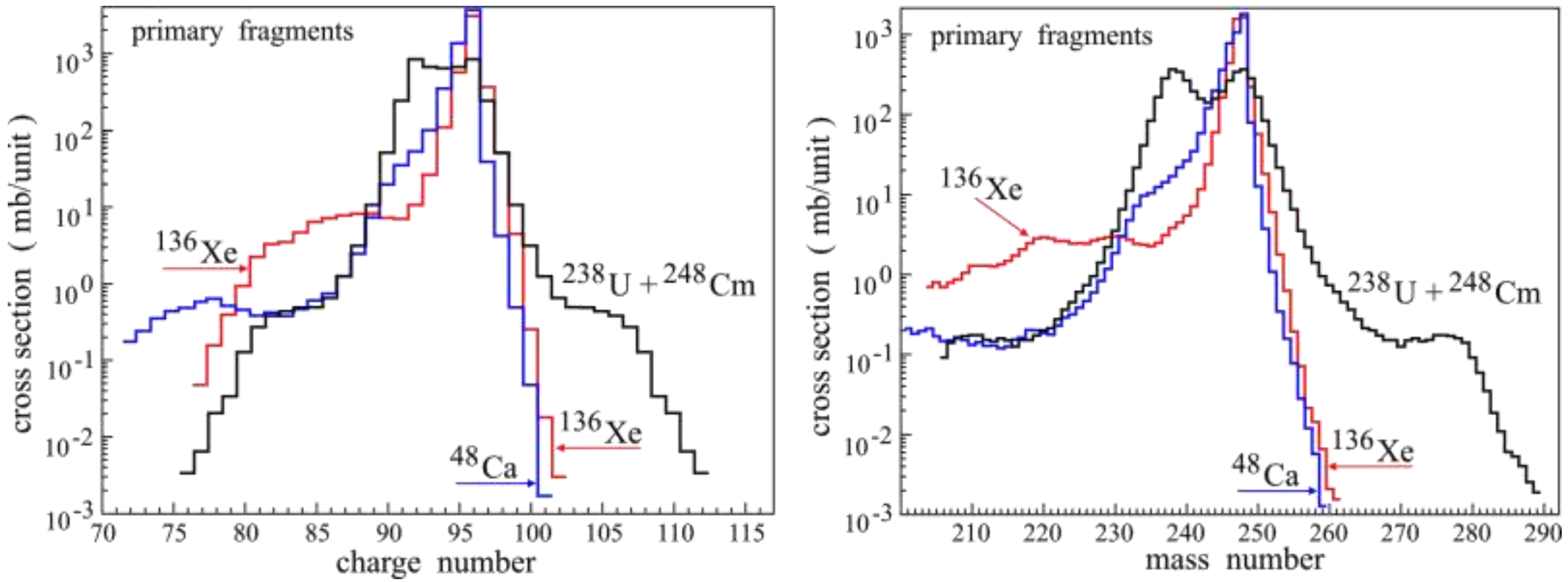
Production of SH nuclei in multi-nucleon transfer reactions

(choice of reaction is very important)

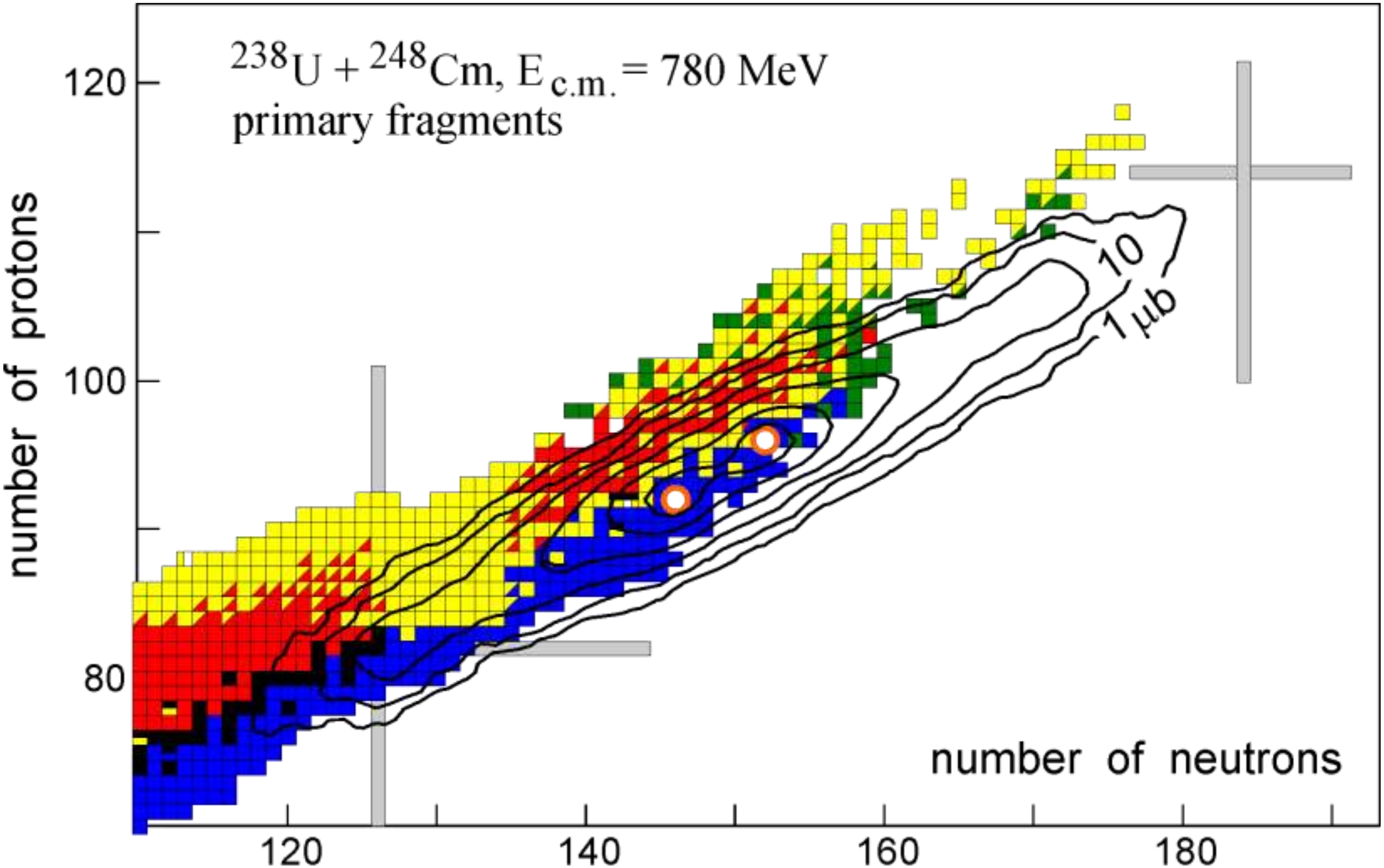




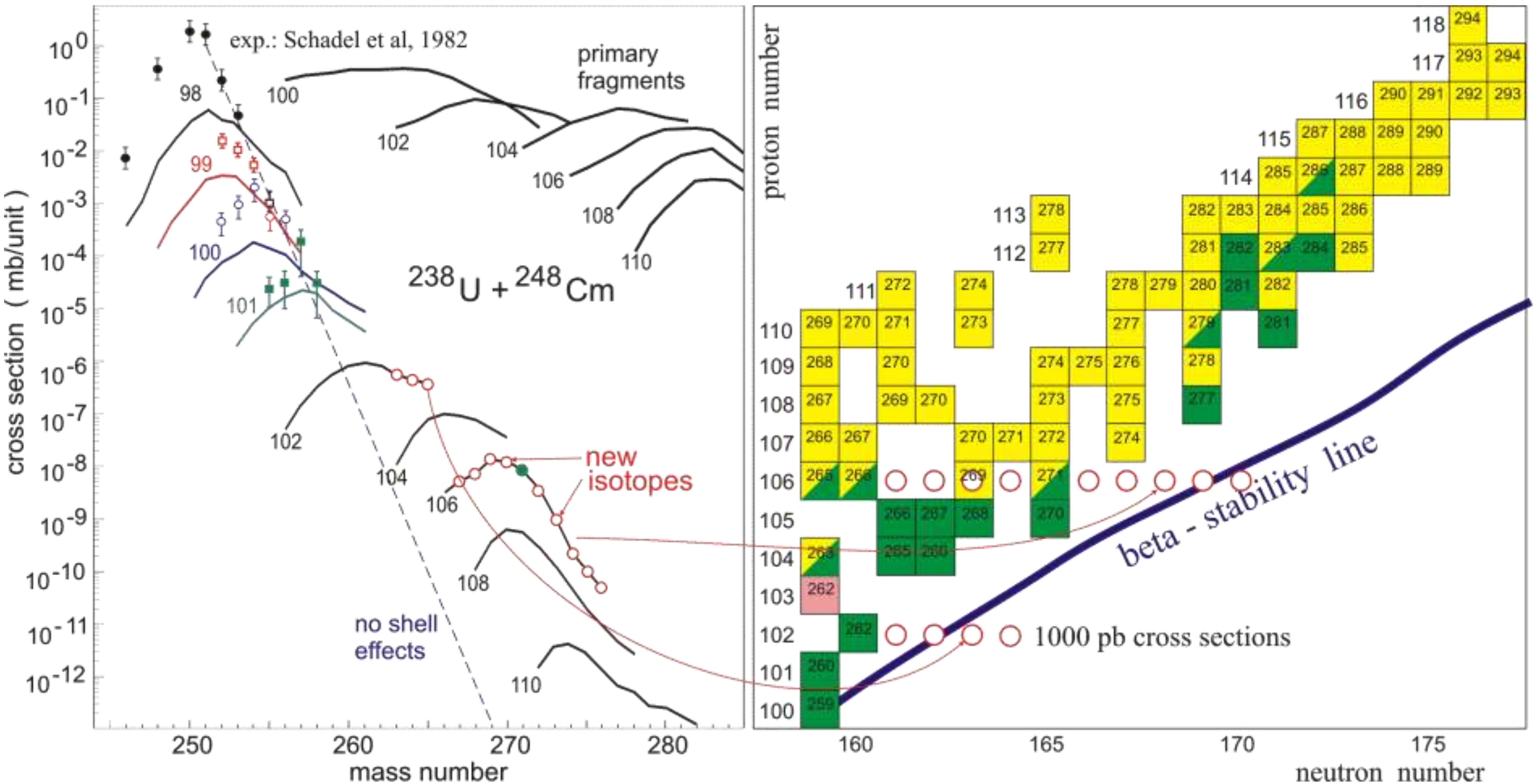
Only U-like beams give us a chance to produce neutron rich SH nuclei in transfer reactions



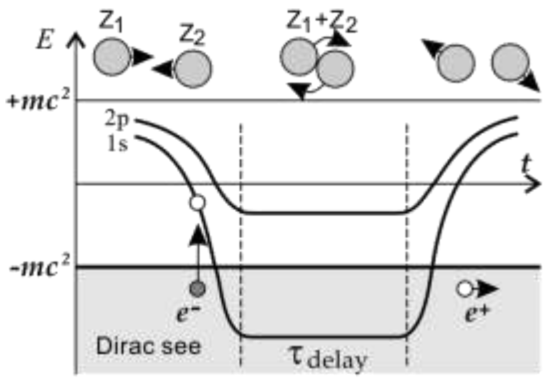
238U + 248Cm. Primary fragments

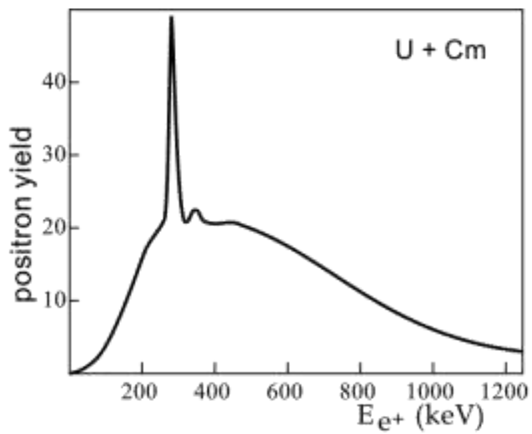


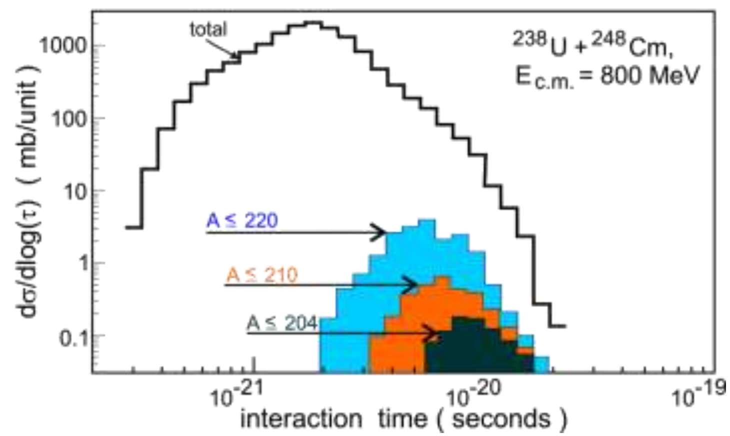
Study of transfermium nuclei along the line of stability becomes possible at last



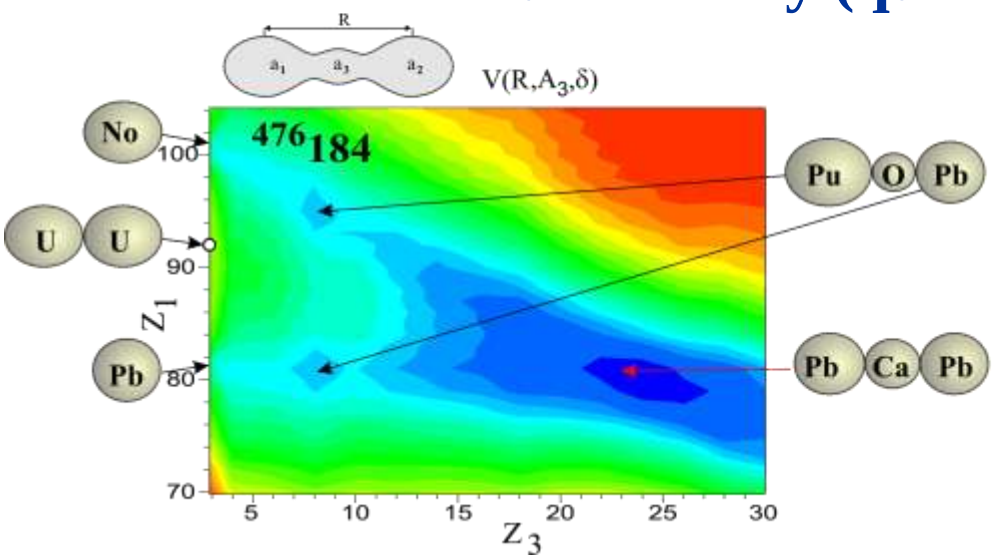
Spontaneous positron formation in supercritical electric field
(Z > 173)







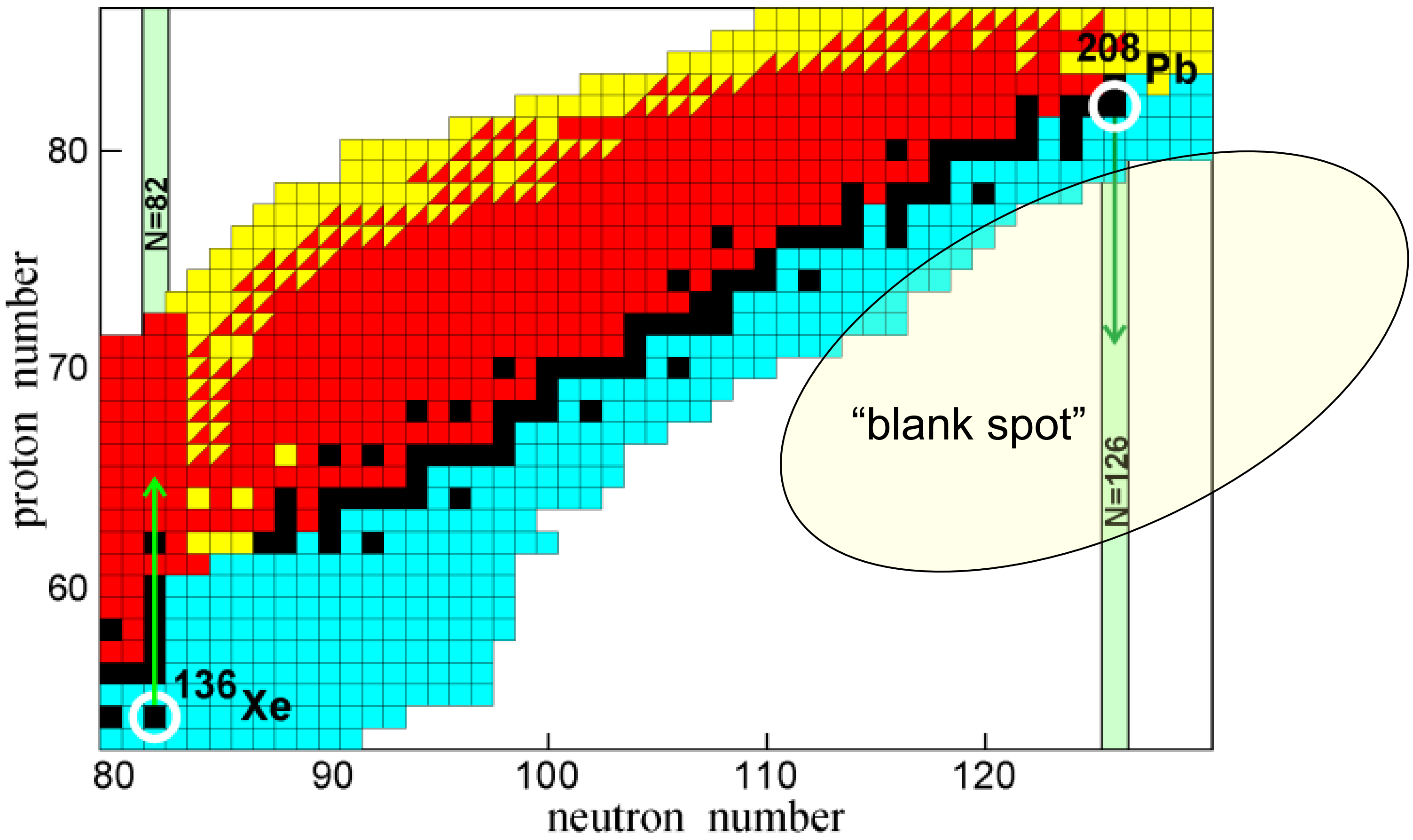
True Ternary (quasi)-Fission



$$U + U \rightarrow Pb + Ca + Pb$$

Production on NEW heavy nuclei in the region of N=126

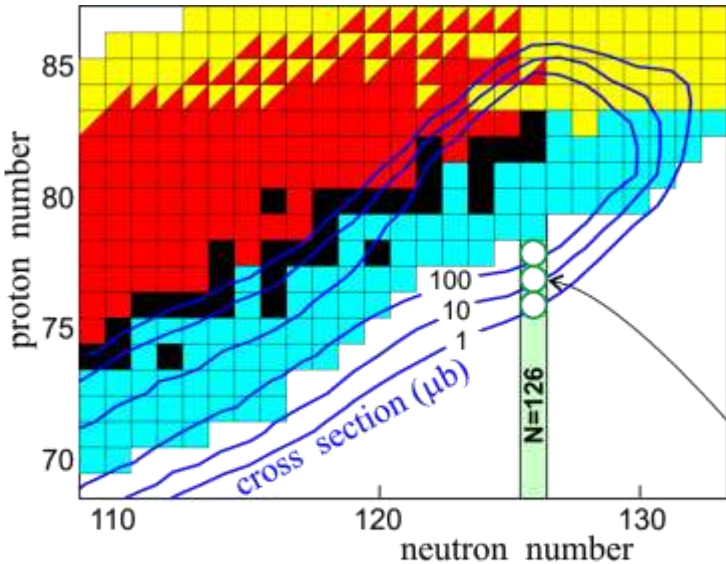
(Zagrebaev and Greiner, Phys. Rev. Lett., 2008)

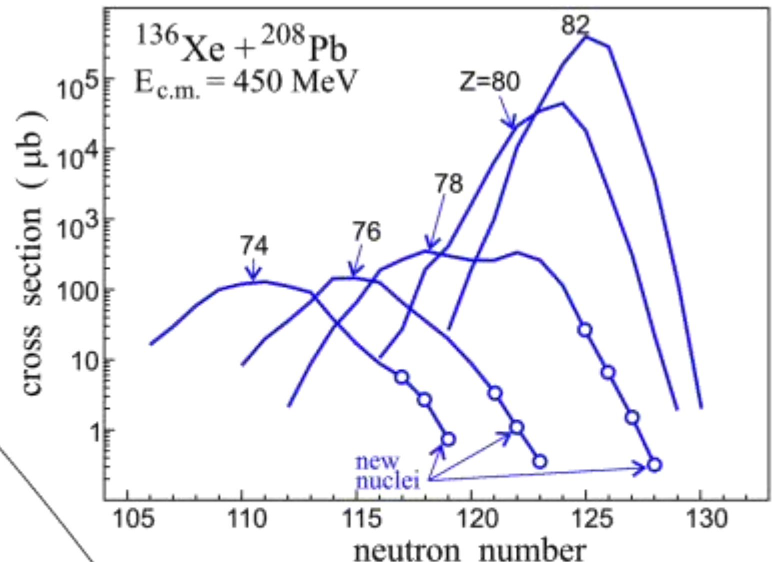


proton transfer along the neutron closed shells:

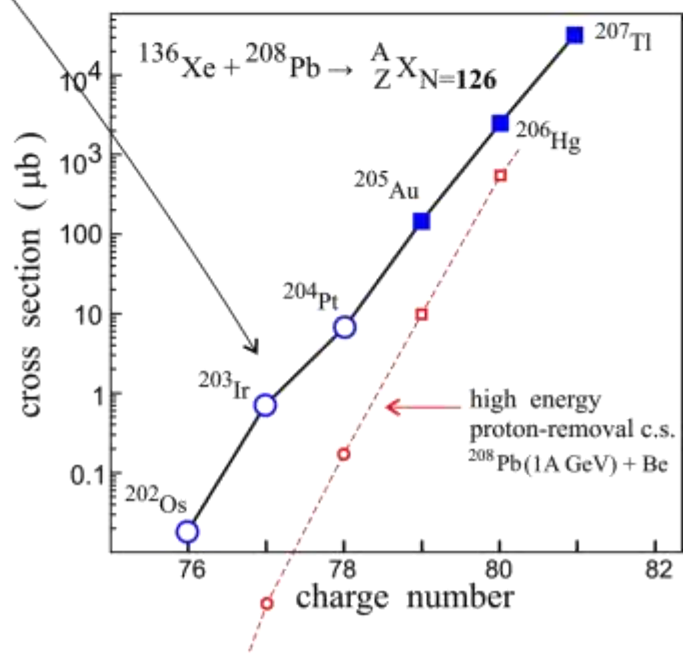
$$^{136}Xe_{N=50} + {}^{208}Pb_{N=126} \rightarrow {}^{136+\Delta Z}X_{N=50} + {}^{208-\Delta Z}Y_{N=126} + Q \approx 0$$

Production on new heavy nuclei in the Xe + Pb collisions

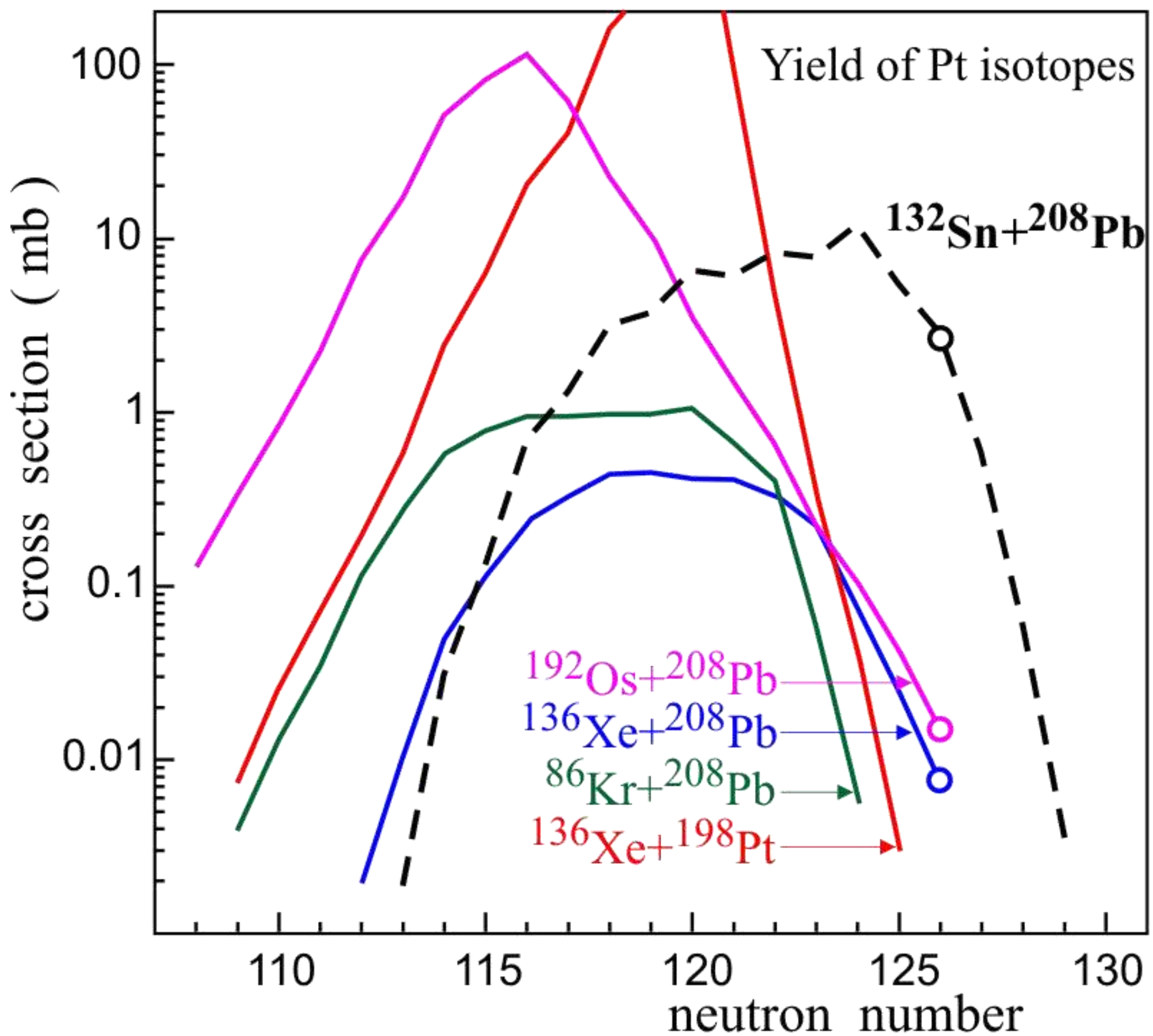




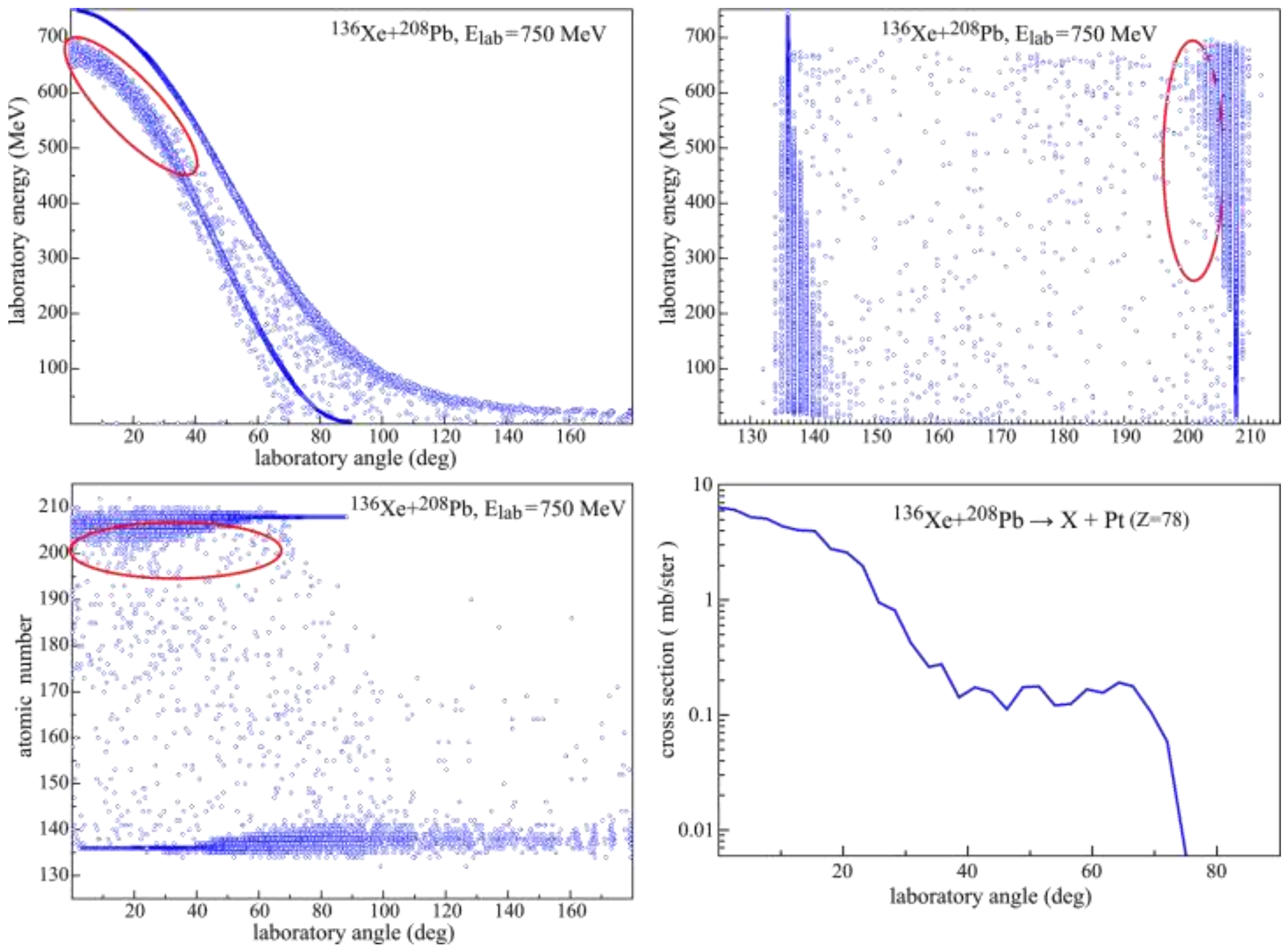
Several tens of new neutron-rich nuclides can be produced with cross section higher than one microbarn in the near-barrier collision of 136Xe with 208Pb



Production of heavy neutron-rich nuclei in transfer reactions with different stable and RI beams

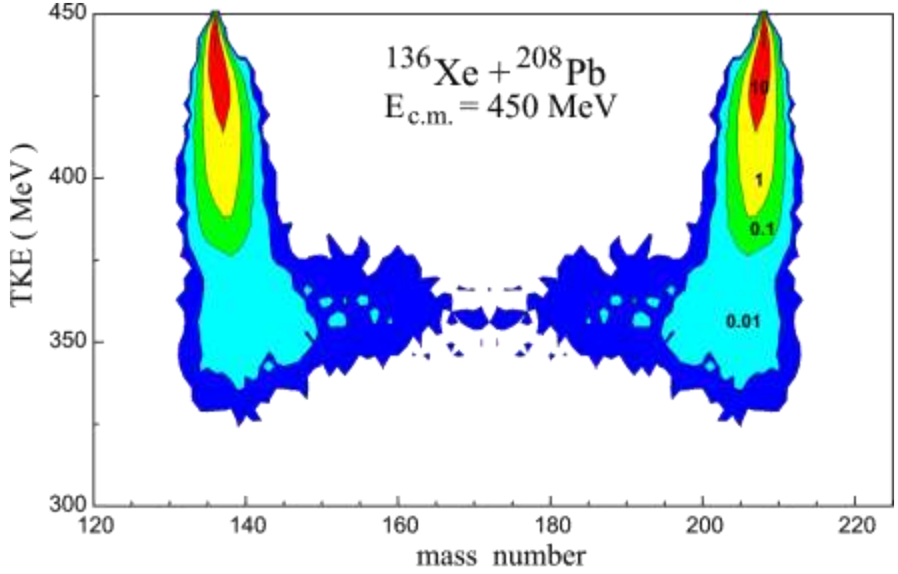


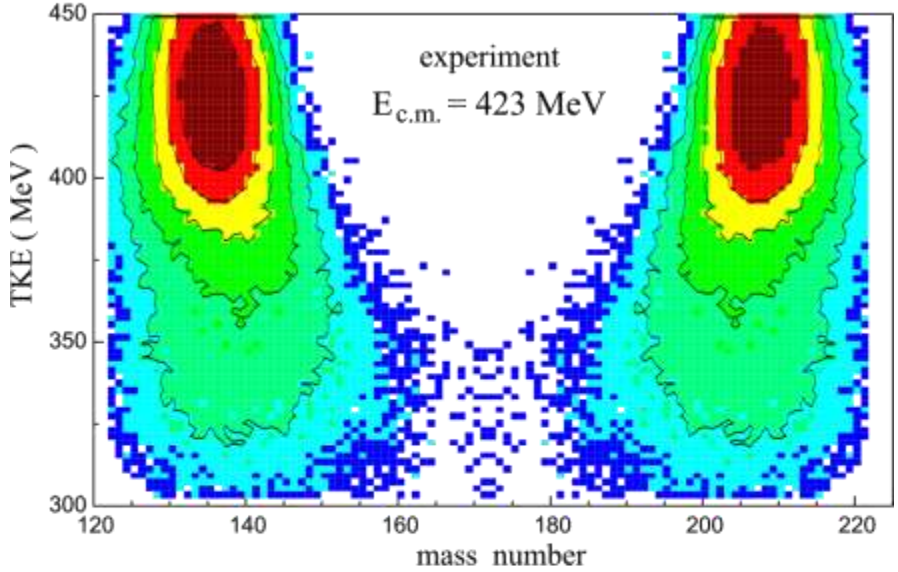
Simulation of typical experiment in the laboratory frame



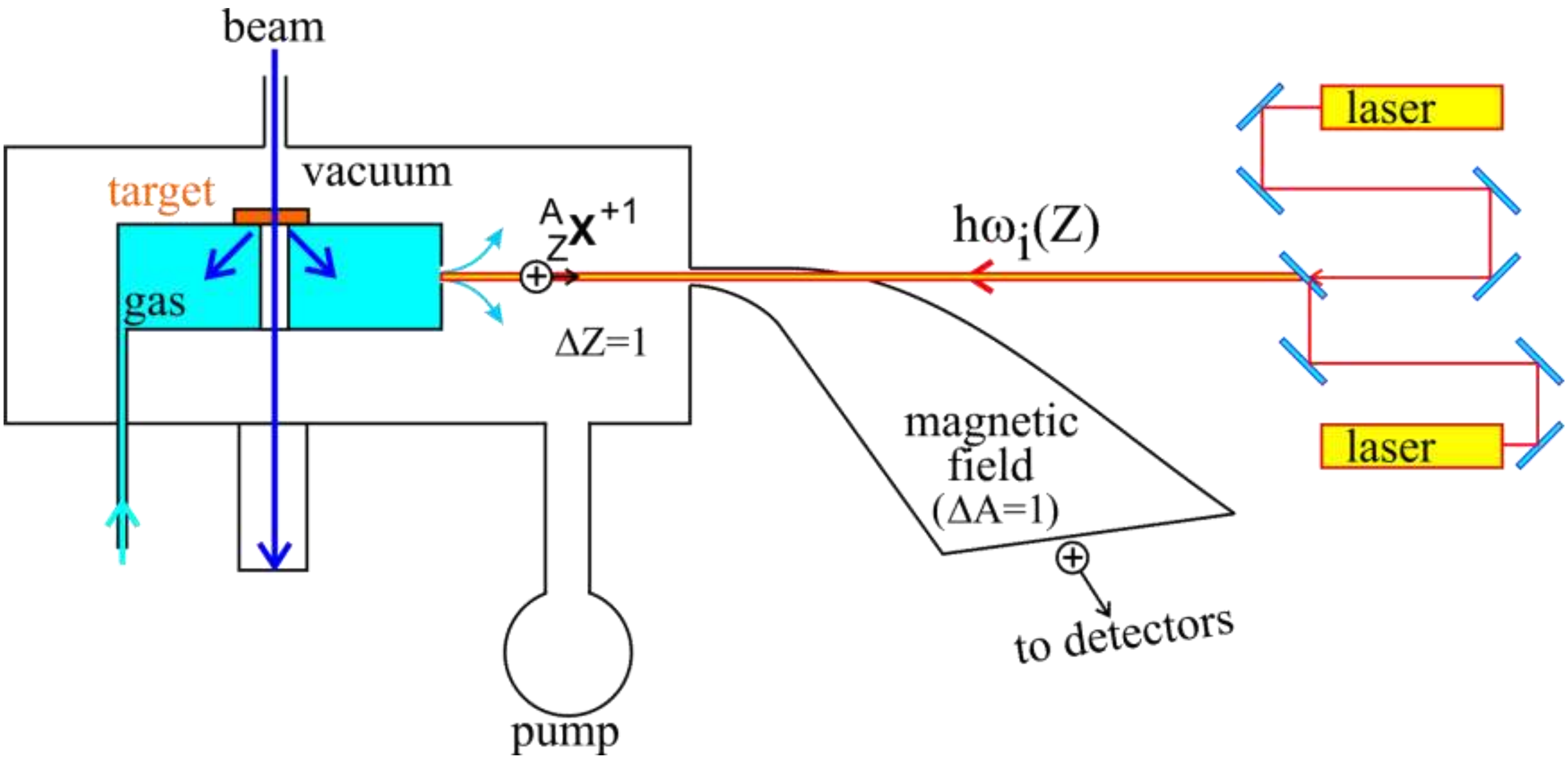
(1) The yield of new neutron-rich isotopes is maximal at beam energy slightly above the Coulomb barrier
(2) Desired reaction products are forward directed (no any grazing features)

Test experiment has demonstrated good agreement with our expectations





Schematic view of a new FLNR setup for resonance laser ionization of nuclear reaction products stopped in gas (IGISOL project)



Physics:
study of new neutron-rich heavy nuclei produced in
- multi-nucleon transfer reactions
- quasi-fission process

Experiments started at:
- FLNR (Dubna)
- Jyvaskyla (Finland)

Proposals submitted to:
- GSI (Darmstadt)
- Legnaro (Italy)

Summary
(nearest and distant experiments)

- **Elements 119 and 120 may be synthesized next year 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 $T_{1/2} > 1\ \mu s$?

- **The gap in SH mass area (Z = 105 – 116) can be filled in fusion reactions of 48Ca with lighter isotopes of actinides (^{239}Pu, ^{241}Am and ^{243}Cm). Cross sections are about 1 picobarn.**

- **Possible narrow pathway to the island of stability is found at last:**
  $^{48}Ca + ^{250}Cm \rightarrow {}^{295}116(\alpha) \rightarrow {}^{291}114(\beta+) \rightarrow {}^{291}113(\beta+) \rightarrow {}^{291}112(T_{1/2} \sim 100\ yrs)$, $\sigma \sim 0.8\ pb*0.1*0.5$

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

- **Several tens of new neutron-rich isotopes of elements with $Z = 70$ - 80 (also those located along the closed neutron shell $N = 126$, astrophysical waiting point) can be produced in low-energy collisions of $^{136}Xe + ^{208}Pb$ with cross sections higher than one microbarn.**

- **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).**

- **Separators of a new kind are needed for transfer reaction products with Z > 70 (IGISOL ?).**
  New detector equipment is also needed for studying new neutron rich beta-decaying nuclei.