Production of new neutron rich heavy and superheavy nuclei

- **Fusion reactions**
  - **Elements 119 and 120 are on the way. What's the next?**
  - **Radioactive ion beams?**

- **Multinucleon transfer reactions**
  - **Shell effects in damped collisions of heavy ions?**
  - **Production of new neutron rich SH nuclei in transfer reactions**
  - **Production of new neutron rich Heavy nuclei in transfer reactions**
  - **Separation of the products of transfer reaction (GALS setup)**

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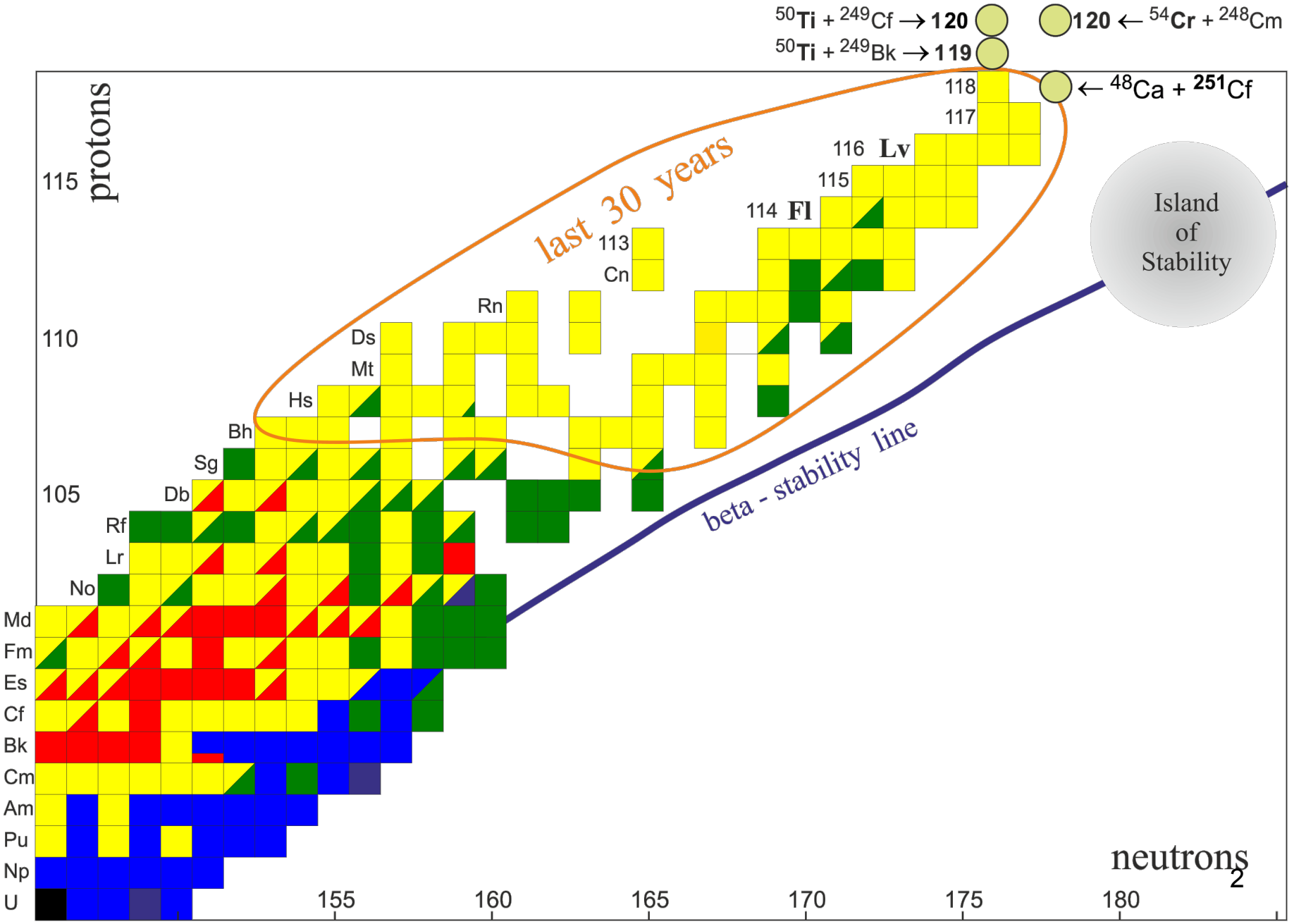
JINR *(Dubna)*

for "SHE-2015", *March 31, 2015*, A&M University, USA

We are still far from the Island of Stability



What is beyond 118 element?

Heaviest target: $^{249}Cf \rightarrow Z_{max} = 118$

↓

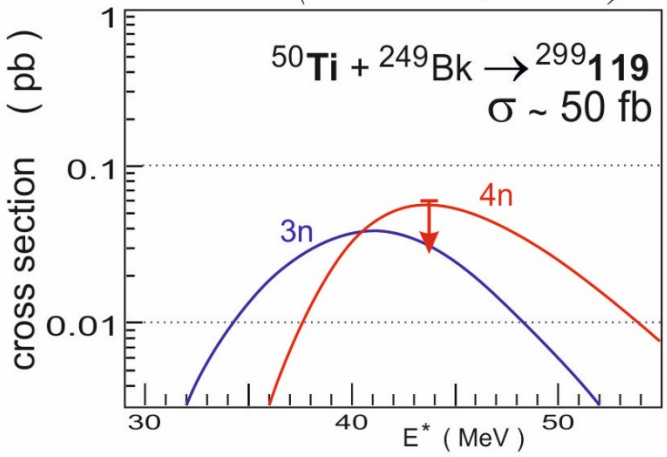
- **Heavier projectiles (^{50}Ti, ^{54}Cr, ^{58}Fe, ^{64}Ni)**
- **Heavier targets (^{251}Cf, ^{254}Es -???);**
- **Symmetric reactions: $^{136}Xe+^{136}Xe$, $^{136}Xe+^{150}Nd$, $^{150}Nd+^{150}Nd$;**
- **Multi–Nucleon–Exchange - Reactions with RIB (??, or colliders – technique – (K4-K10)):**
- **Nucleon transfer reactions ($^{136}Xe+^{208}Pb$, $^{238}U+^{248}Cm$).**

Sufficient increasing of overall experiment efficiency is needed!

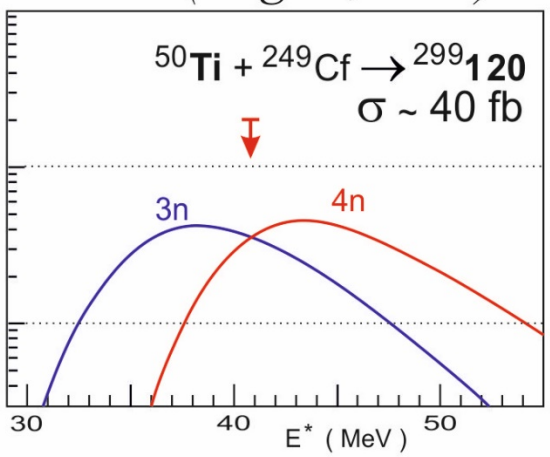
New elements 119 and 120 are coming !

Ti beam:

TASCA (October, 2012)

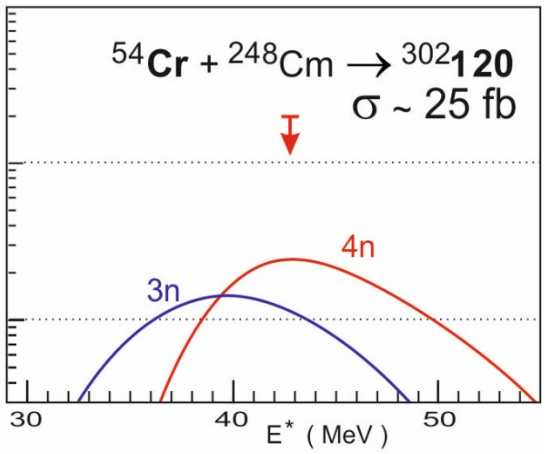


TASCA (August, 2011)



Cr beam:

SHIP (May, 2011)

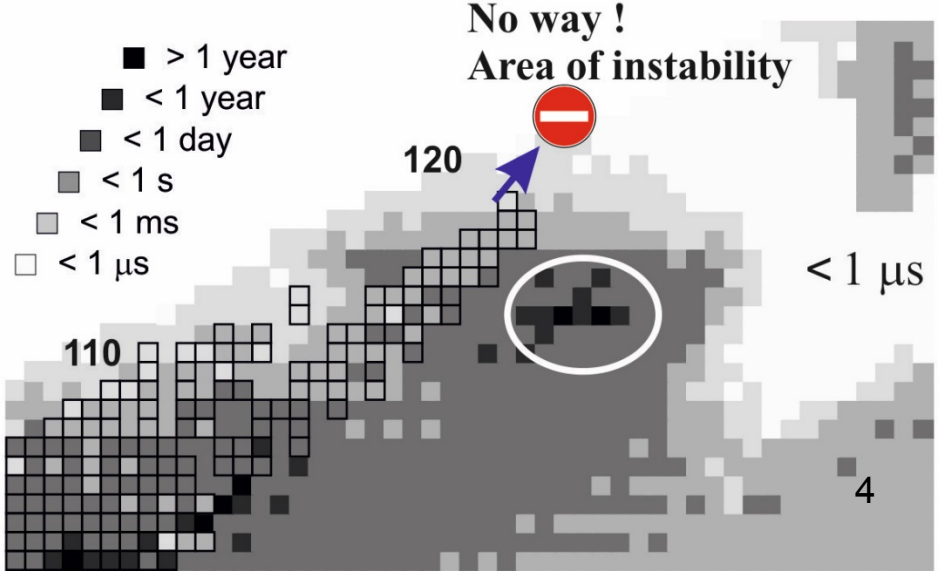


our predictions (PRC 2008):

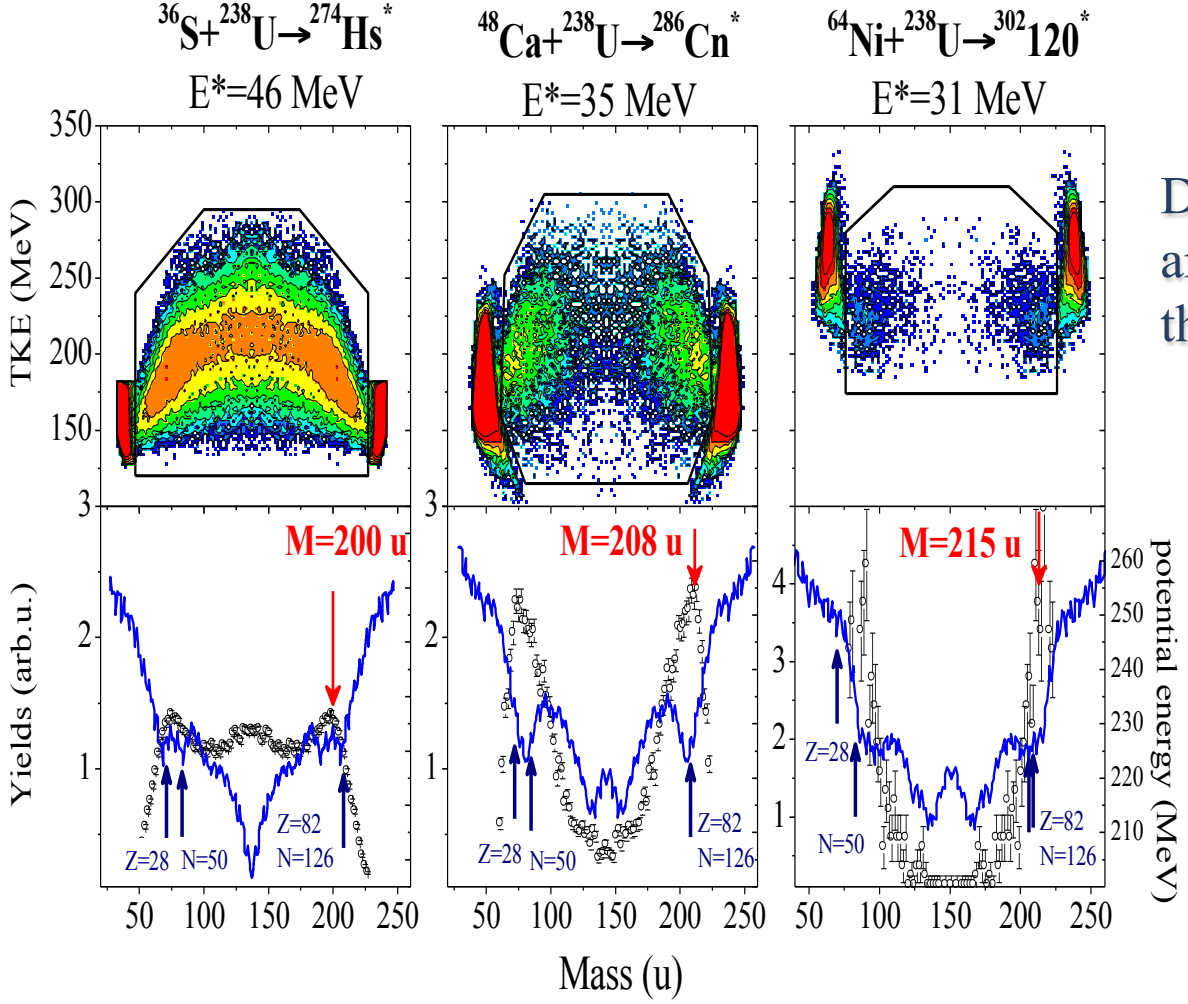
factor $\frac{1}{20}$ as compared to ^{48}Ca

Approaching the area of instability:

Probably, these elements are the last ones which will be synthesized in the nearest future

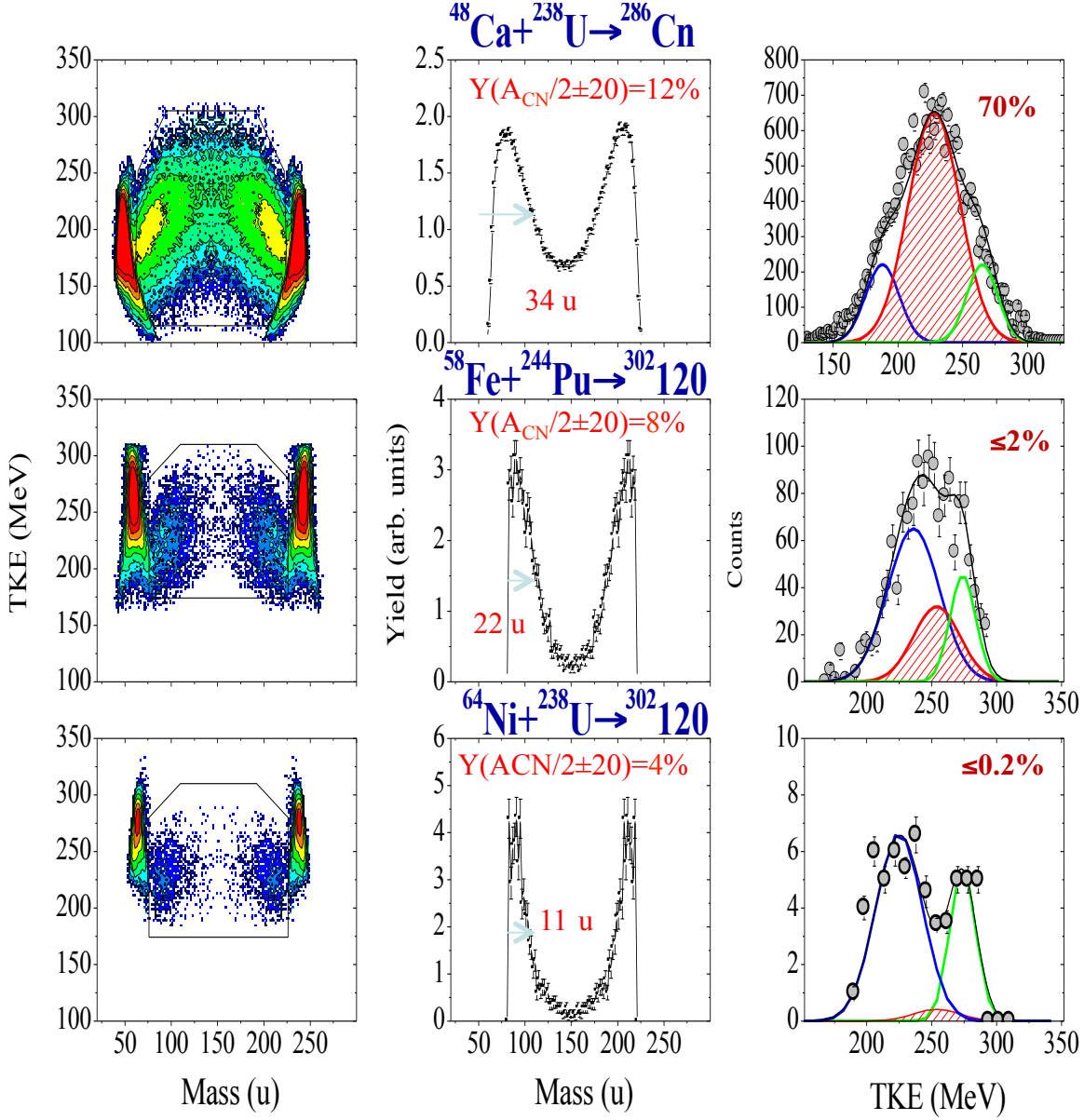


Mass-energy distributions of binary reaction fragments



Driving potentials are calculated with the NRV code (nrv.jinr.ru)

•G.N. Knyazheva, I. Itkis, E.M. Kozulin. *The time scale of quasifission process in the reactions with heavy ions. International Symposium Entrance Channel Effect on the Reaction Mechanism in Heavy Ion Collisions, Messina (Italy) - November 6-8, 2013,*
Journal of Physics: Conference Series 515 (2014) 012009.

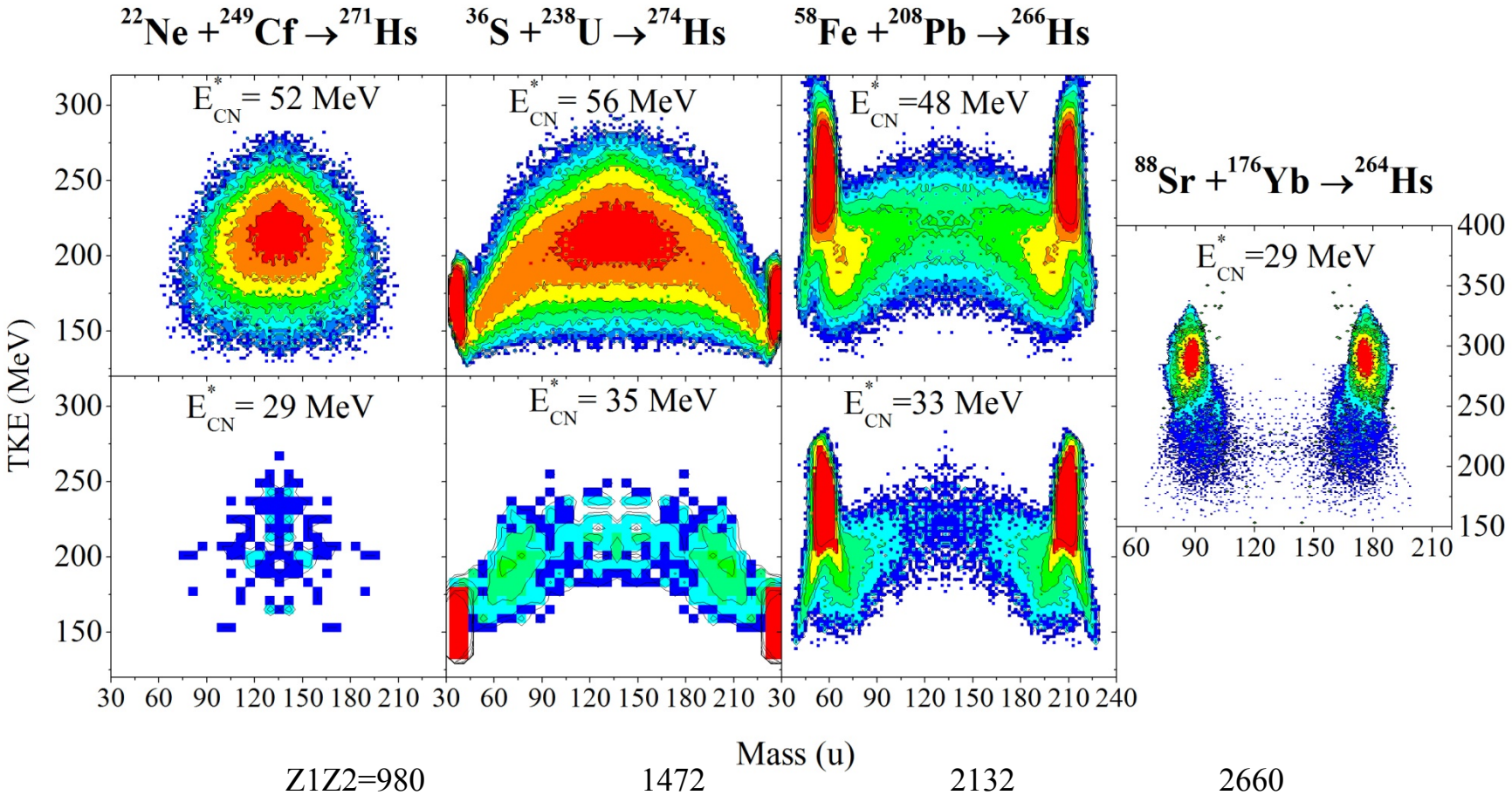


$E^*_{CN}\approx 45$MeV

for $A_{CN}/2\pm 20$

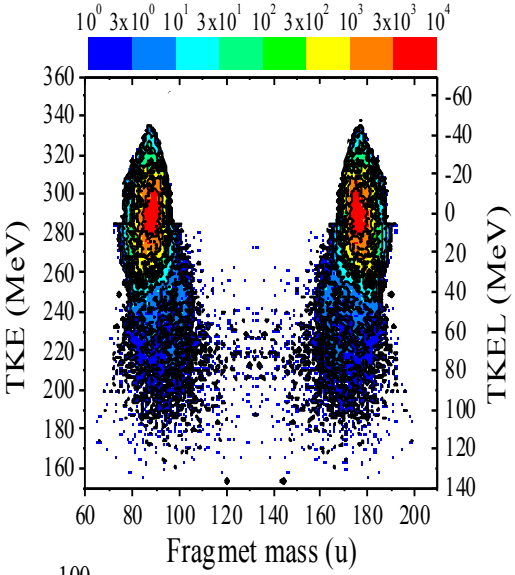
E.M. Kozulin et al., *Dynamics of the $^{64}Ni+^{238}U$ reaction as a possible tool for synthesis of element with Z=120.* **Phys. Lett. B686, (2010), 227-232.**

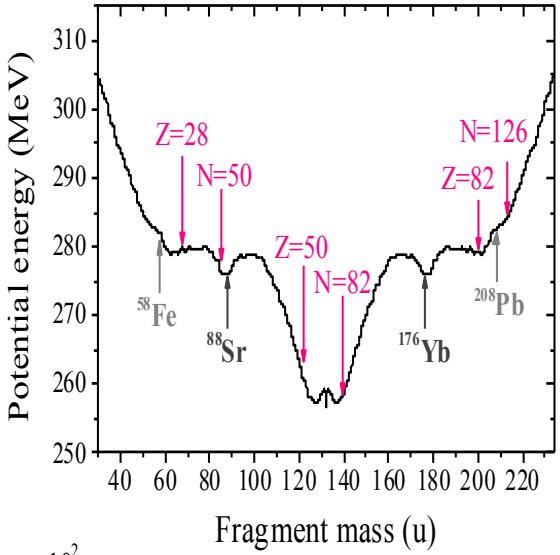
Influence of entrance channel

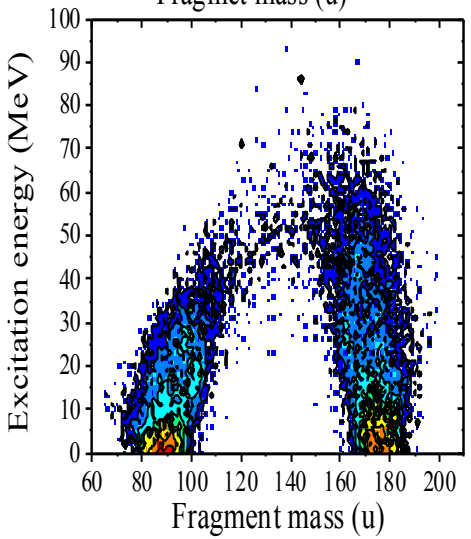


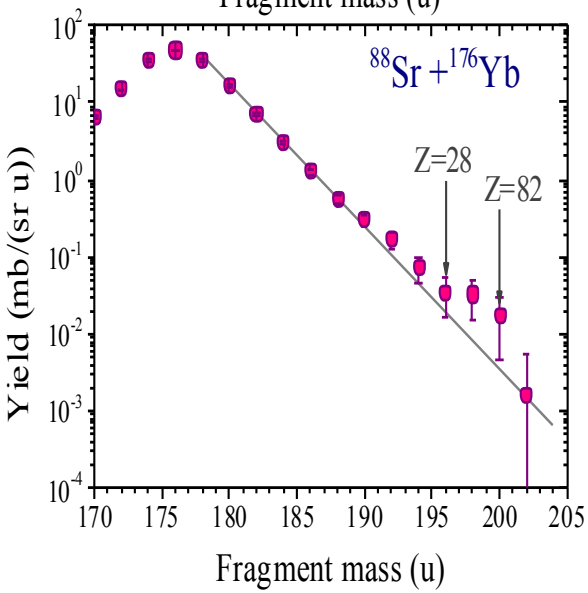
•E.M.Kozulin, G.N.Knyazheva, I.M.Itkis, E.M.Gazeeva, N.I.Kozulina, T.A.Loktev, K.V.Novikov, I.Harca. *Shell effects in fission, quasi-fission and in multi-nucleon transfer reactions. International Symposium Entrance Channel Effect on the Reaction Mechanism in Heavy Ion Collisions*, Messina (Italy) - November 6-8, 2013, **Journal of Physics: Conference Series 515 (2014) 012010.**

^{88}Sr+^{176}Yb: shell effects in damped collisions



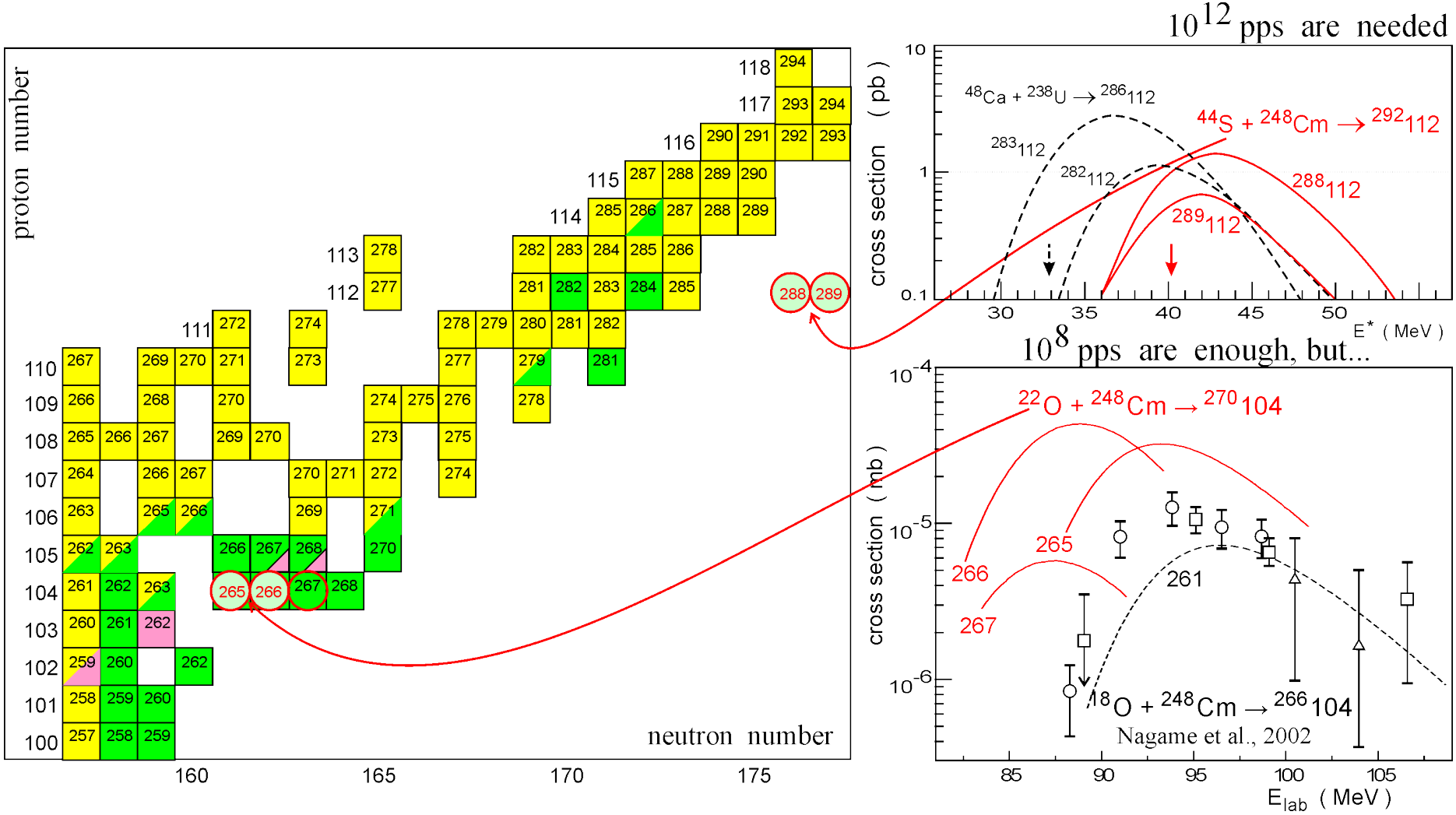






•E.M. Kozulin, G.N. Knyazheva, S.N. Dmitriev, I.M. Itkis, M.G. Itkis, T.A. Loktev, K.V. Novikov, A. Baranov, W.H. Trzaska, E. Vardaci, S. Heinz, O. Beliuskina, S.V.Khlebnikov. *Shell effects in damped collisions of ^{88}Sr with ^{176}Yb at the Coulomb barrier energy*. **Phys. Rev. C89, 014614 (2014).**

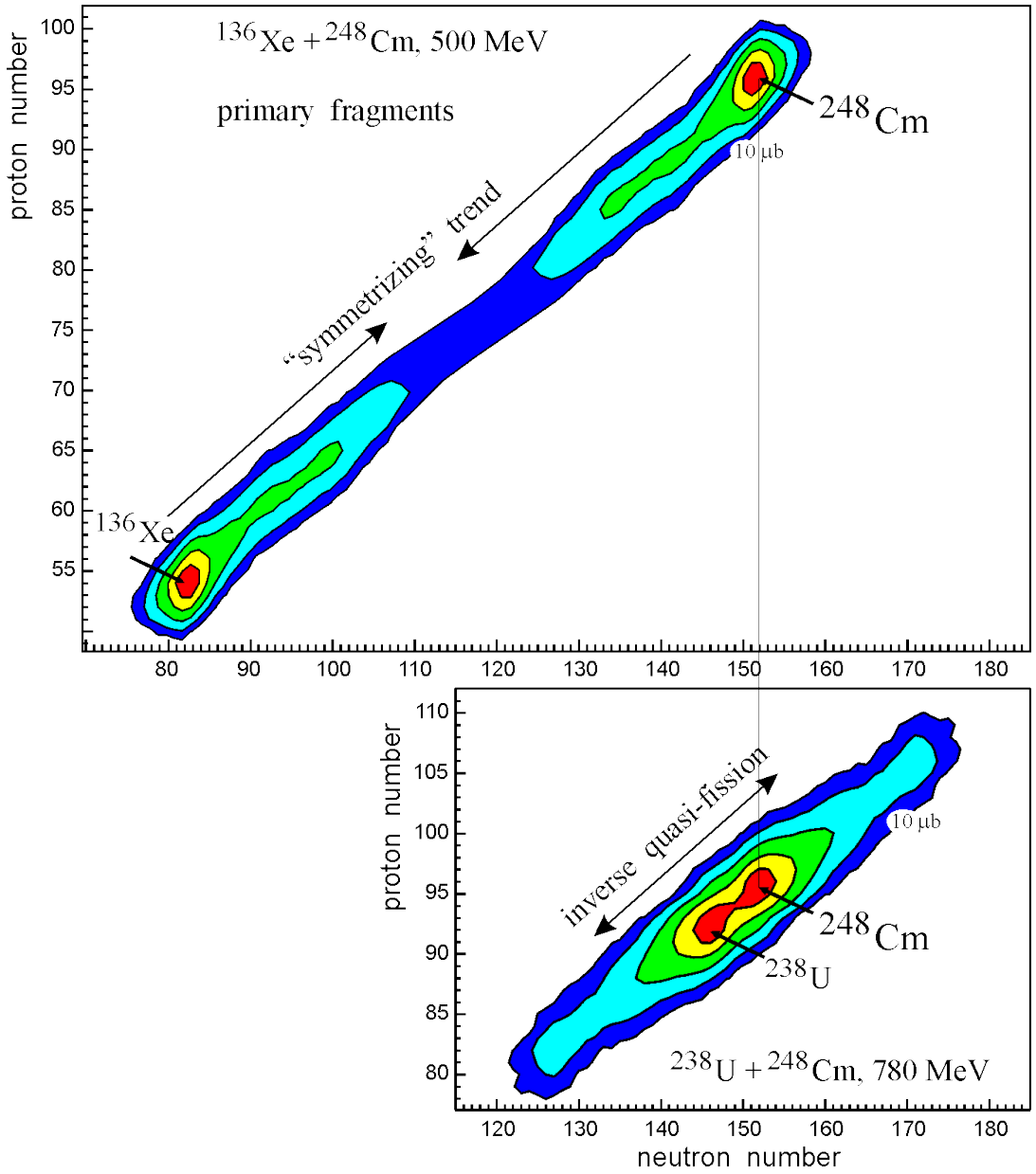
Fusion reactions with Radioactive Ion Beams for the production of neutron rich superheavy nuclei ?



No chances today and in the nearest future

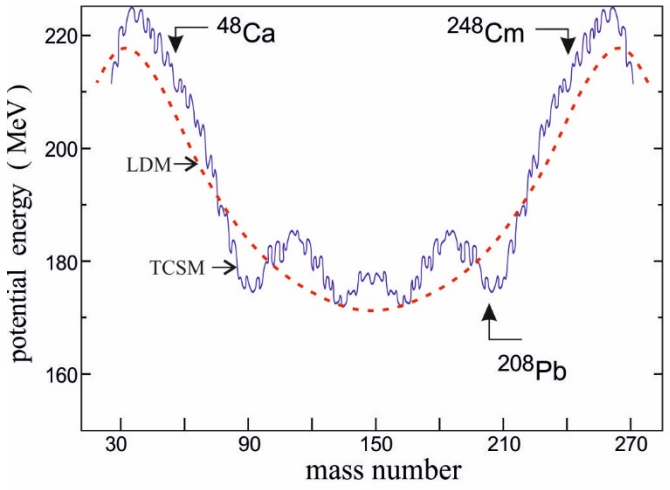
Multinucleon transfer reactions for synthesis of heavy and superheavy nuclei

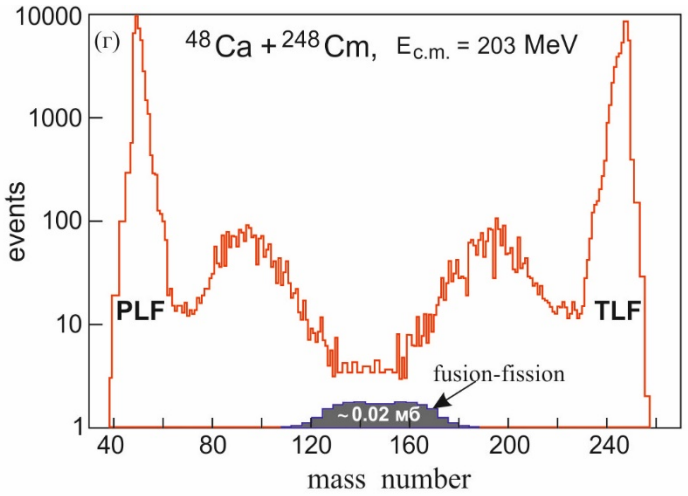
Production of superheavies in multi-nucleon transfers (choice of reaction is very important)



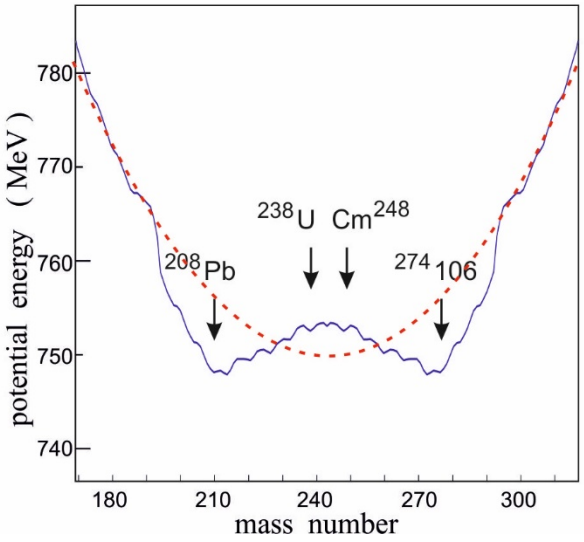
Shell effects: Pb valley

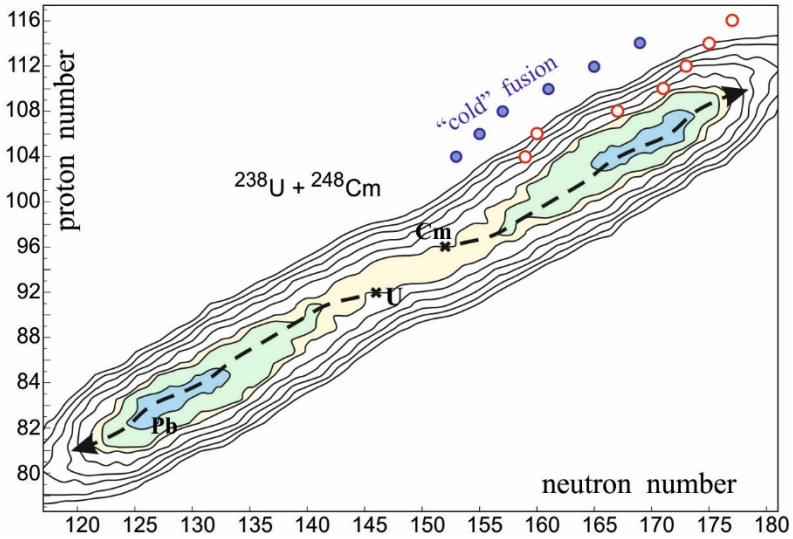
normal (symmetrizing) quasi-fission



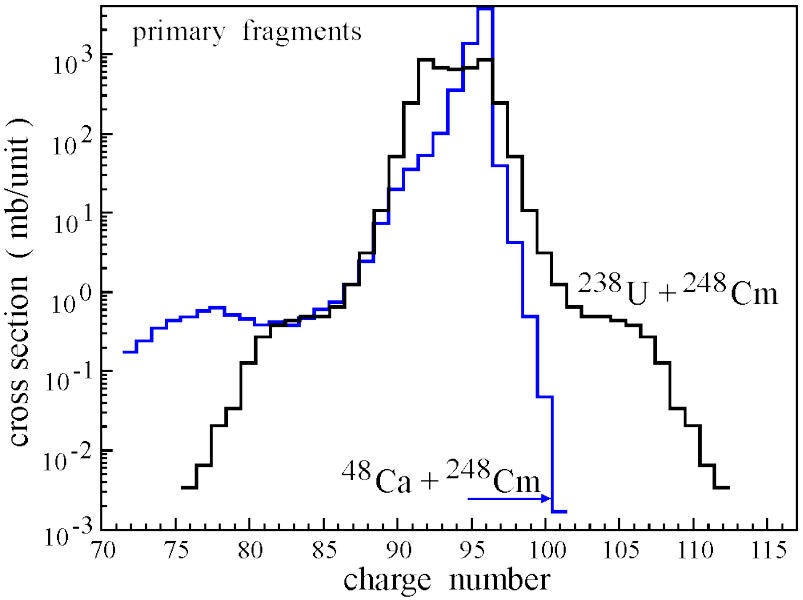


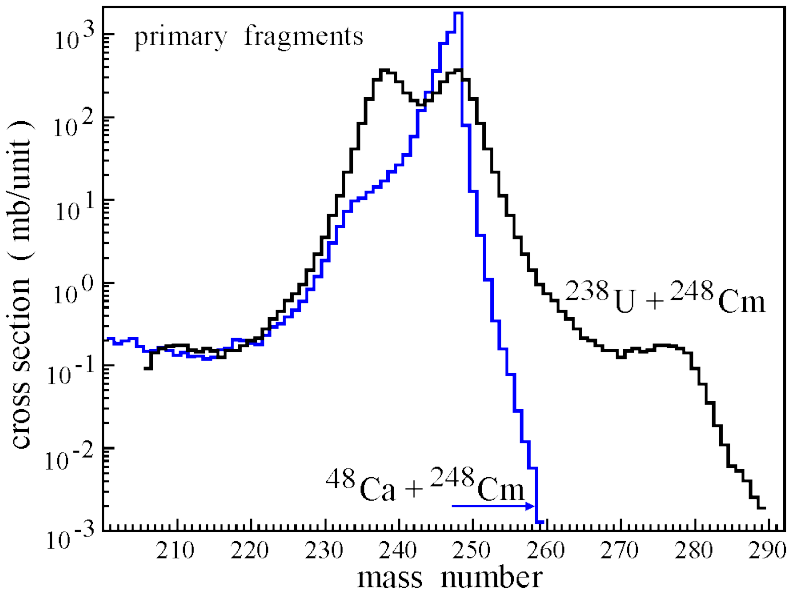
inverse (anti-symmetrizing) quasi-fission

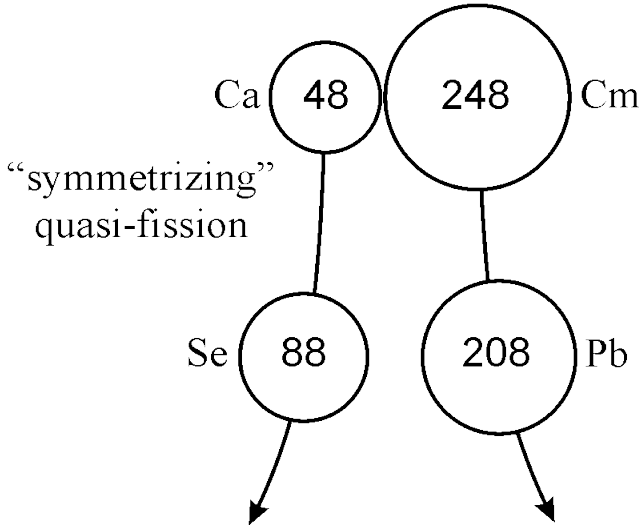


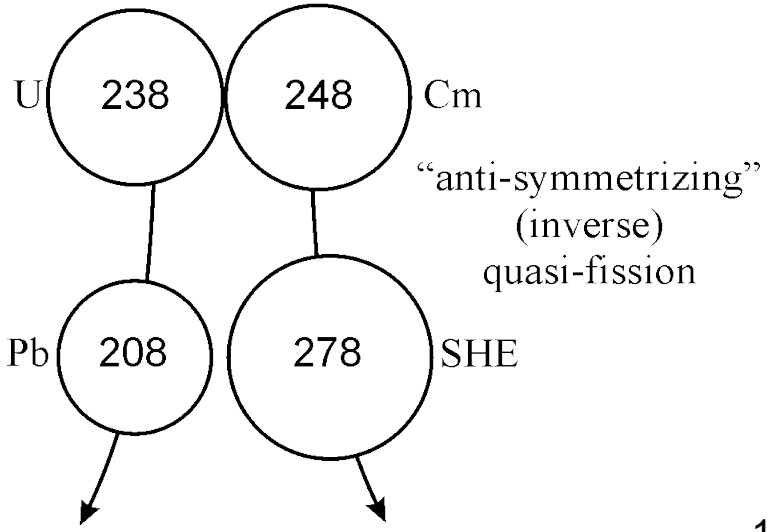


U-like beams give us more chances to produce neutron rich SH nuclei in “inverse quasi-fission” reactions



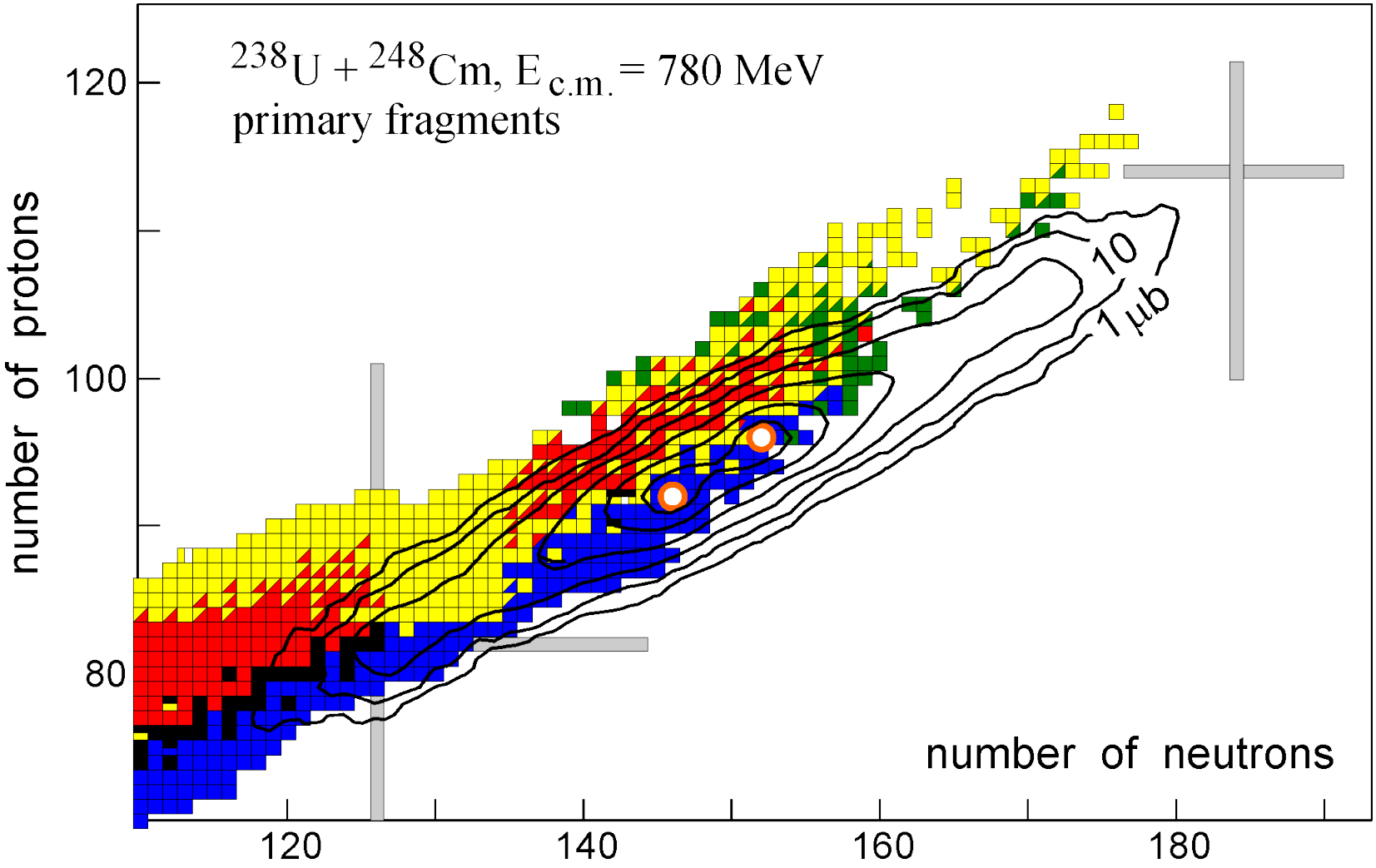




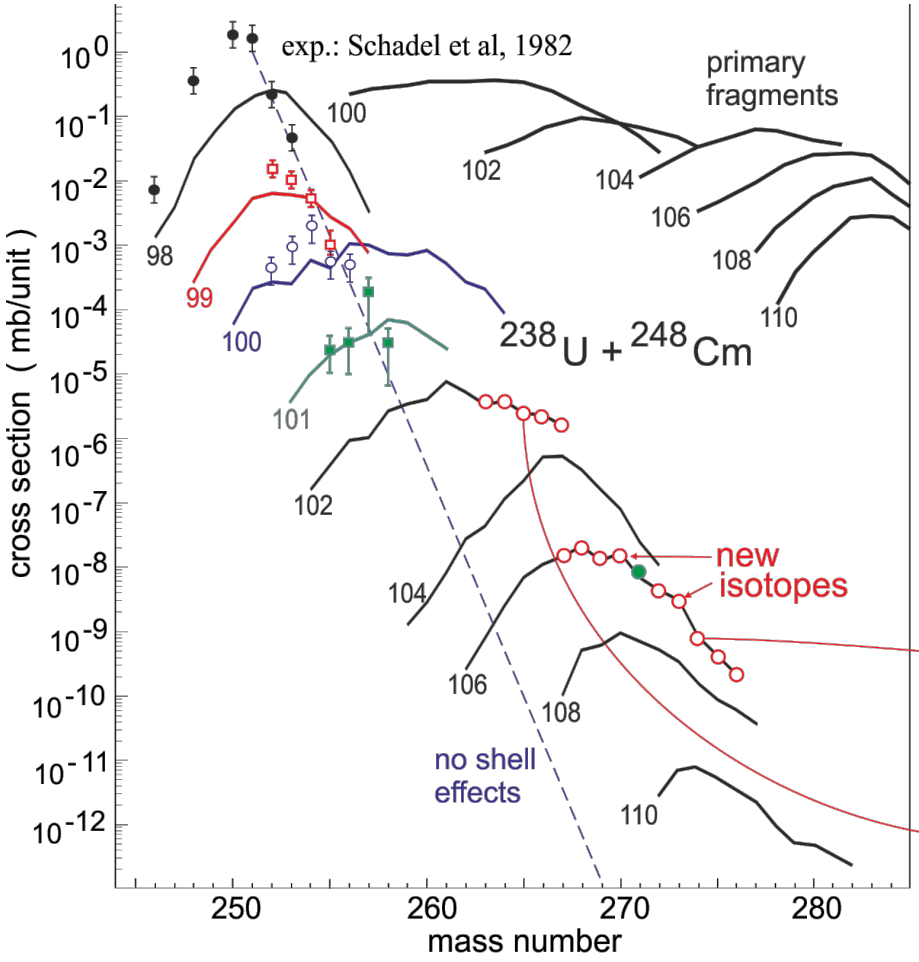


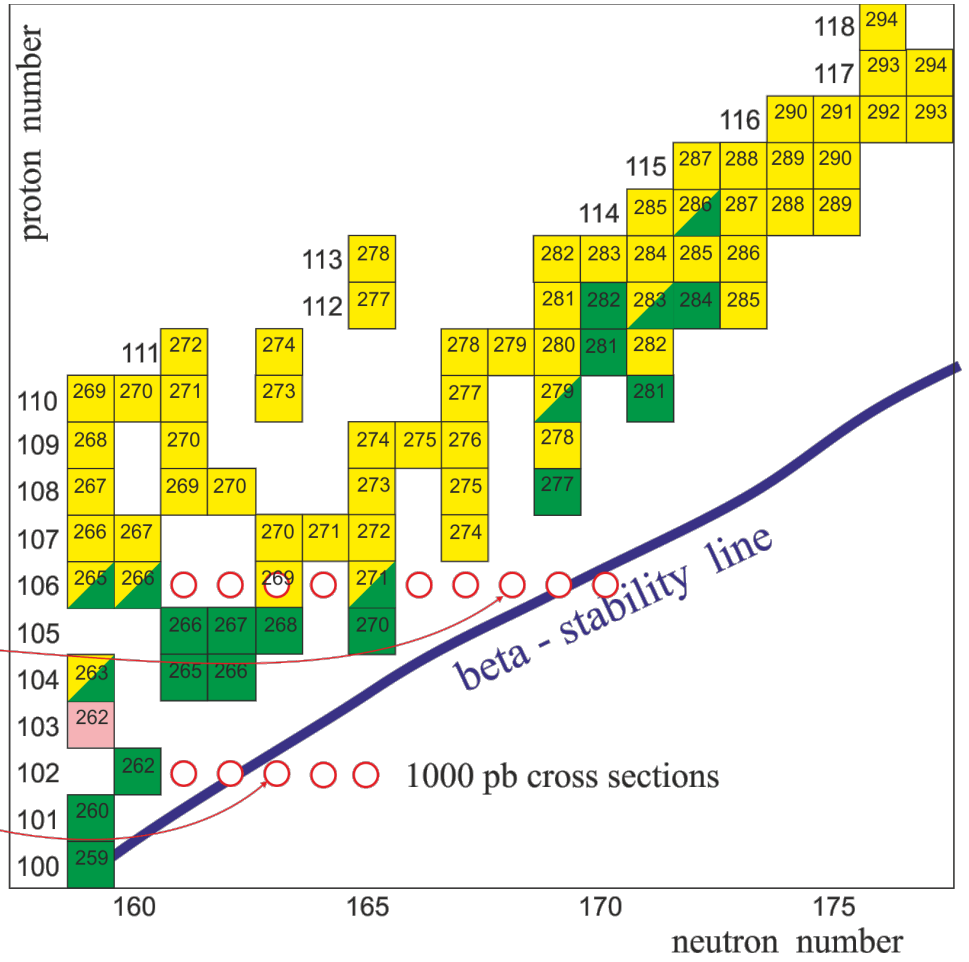
experiment is scheduled for March at GSI (we want to see Pb+x, then Pb+Ca+Pb)

$^{238}U + ^{248}Cm$. Primary fragments



Production of transfermium nuclei along the line of stability looks quite possible (only if there are shell effects!?)

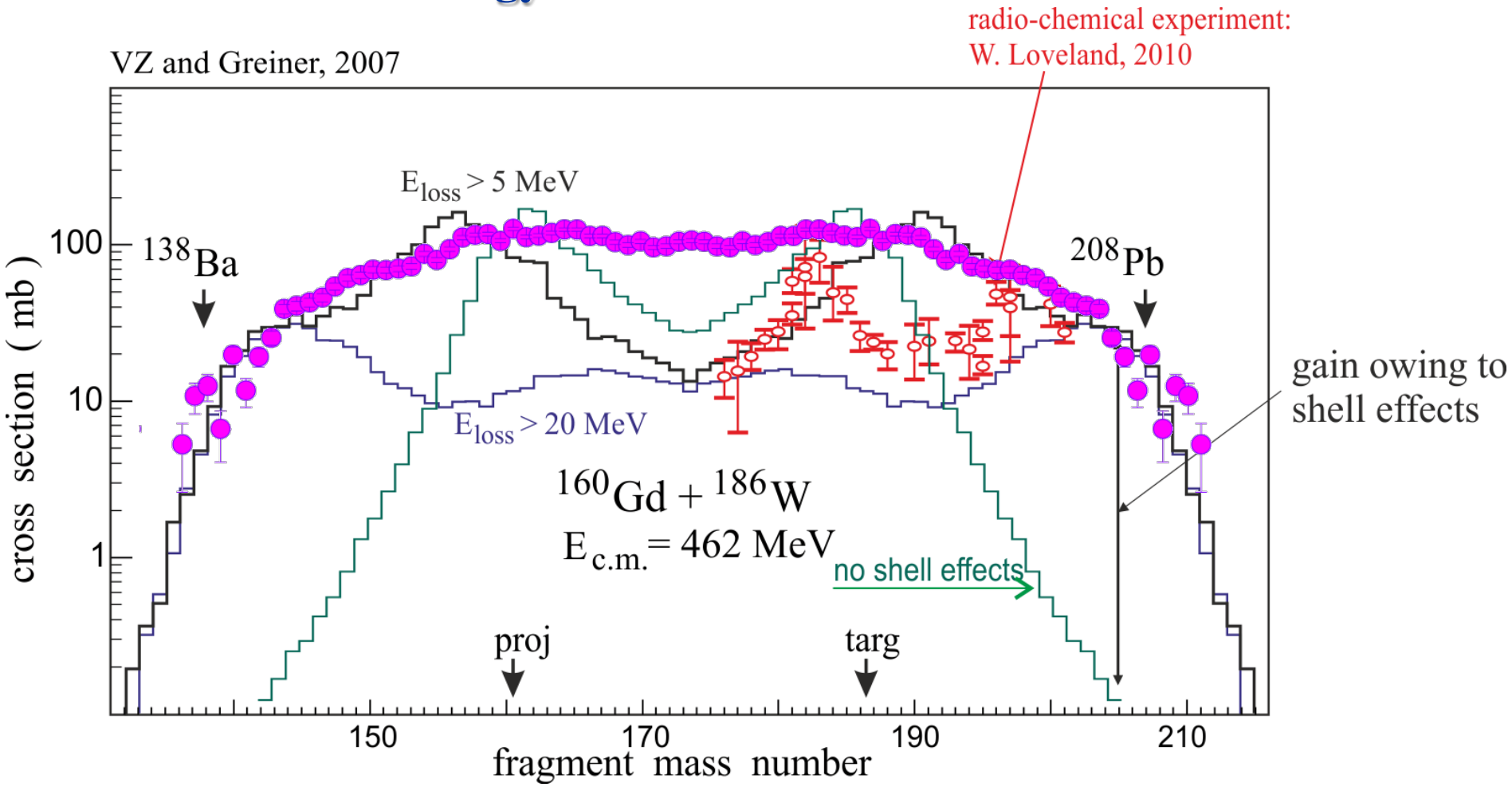




Rather wide angular distribution of reaction fragments:
a new kind of separators is needed

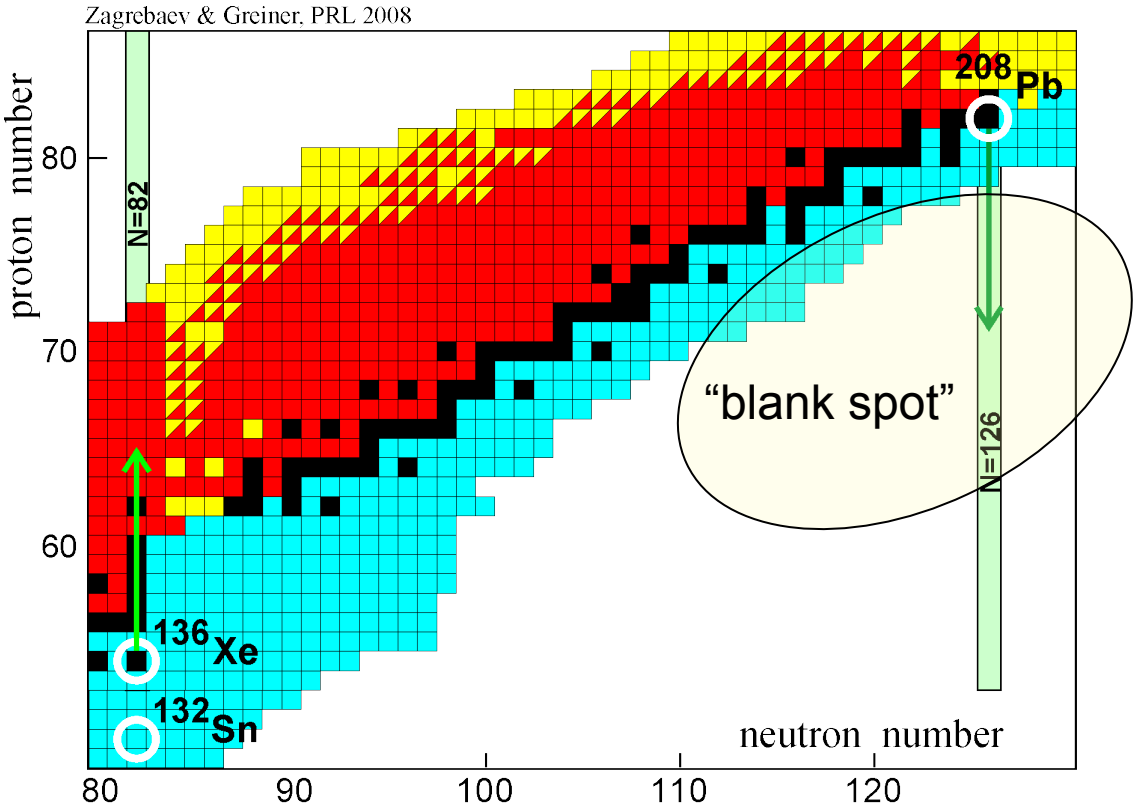
experiments on Au+Th and U+Th are currently going on in Texas *(without separators)*

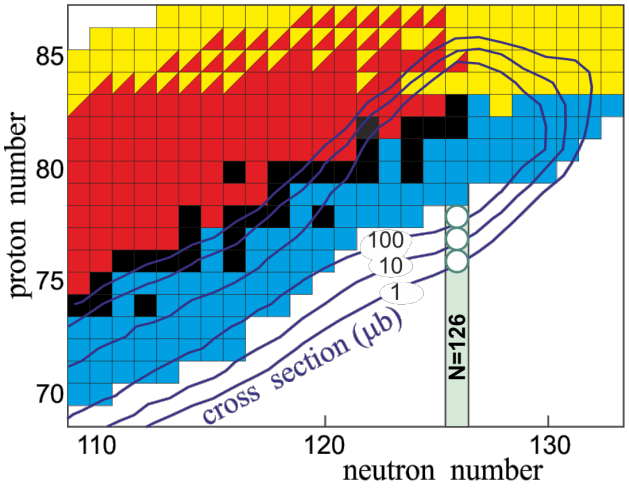
Test (surrogate) reaction aimed on a search for the shell effects in low-energy multi-nucleon transfer reactions

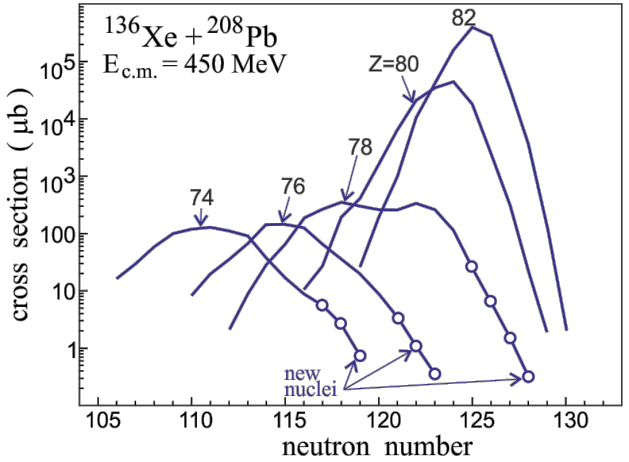


The experiment was performed (September 2014) at the Flerov Laboratory (Dubna)

New heavy nuclei in the region of N=126







proton transfer along the neutron closed shells:

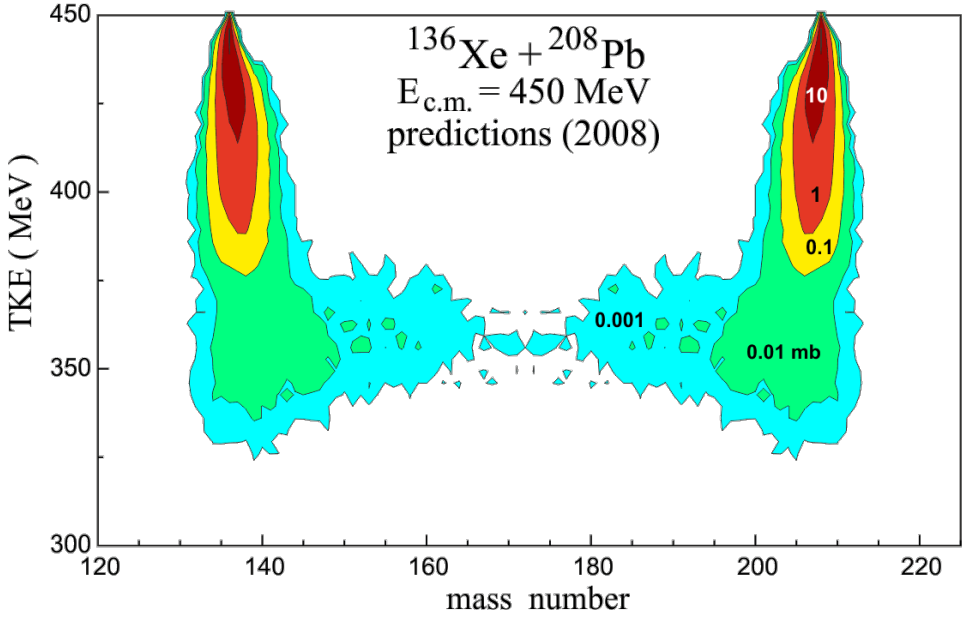
$$^{136}Xe_{N=82} + {}^{208}Pb_{N=126} \rightarrow {}^{136+\Delta Z}X_{N=82} + {}^{208-\Delta Z}Y_{N=126} + Q \approx 0$$

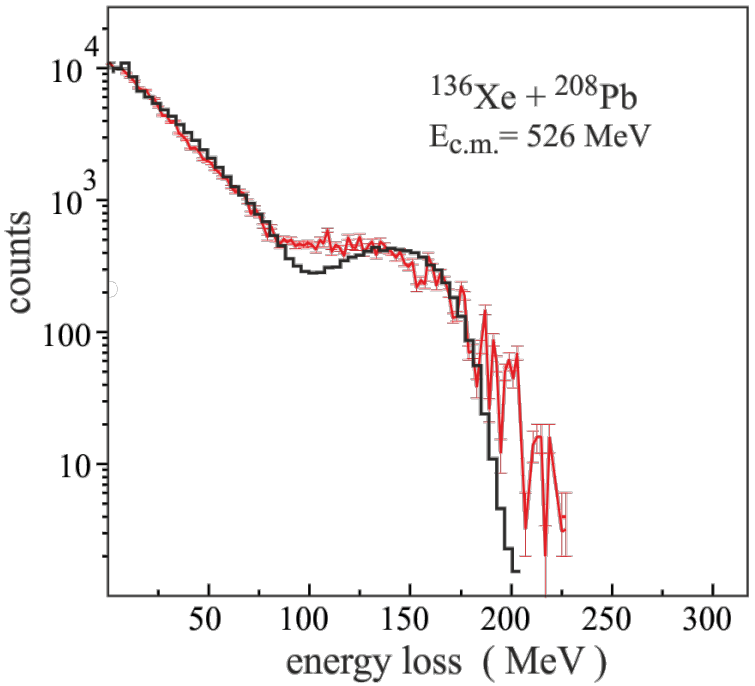
Reactions with $Q \approx 0$ are very favorable for proton transfer

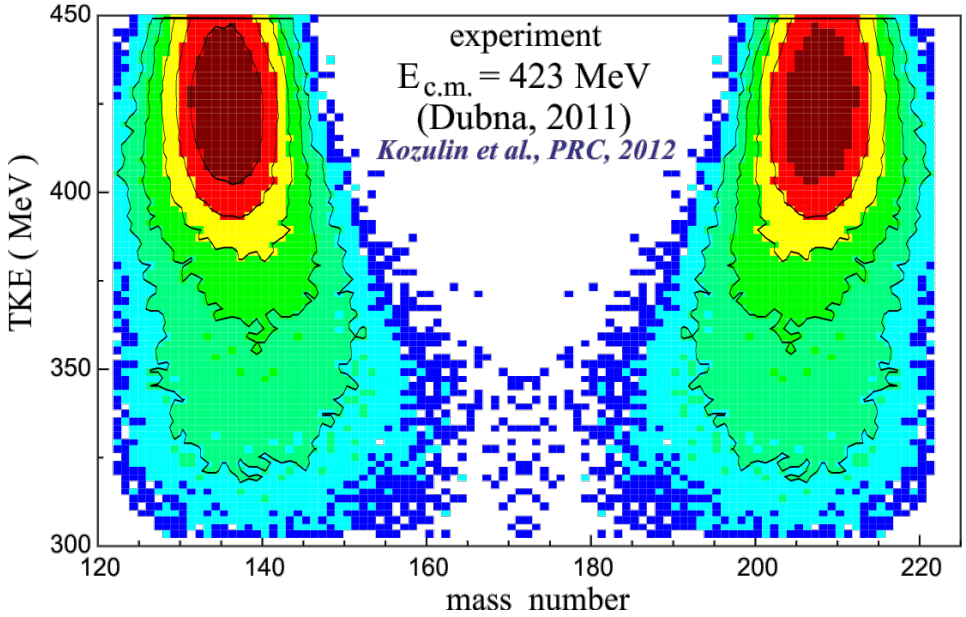
The use of ^{132}Sn is even better !

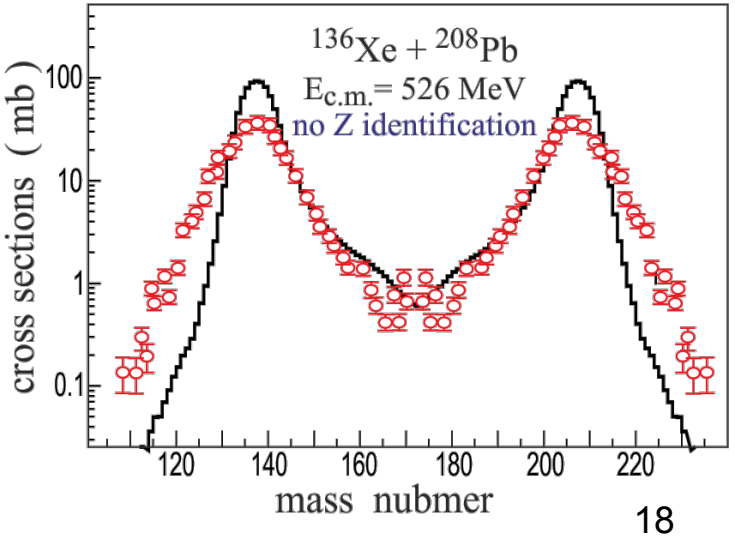
Several tens of new neutron-rich nuclides can be produced with cross section higher than one microbarn in the near-barrier collision of 136Xe with 208Pb

Test experiment on ^{136}Xe + ^{208}Pb collisions (Dubna, 2011)



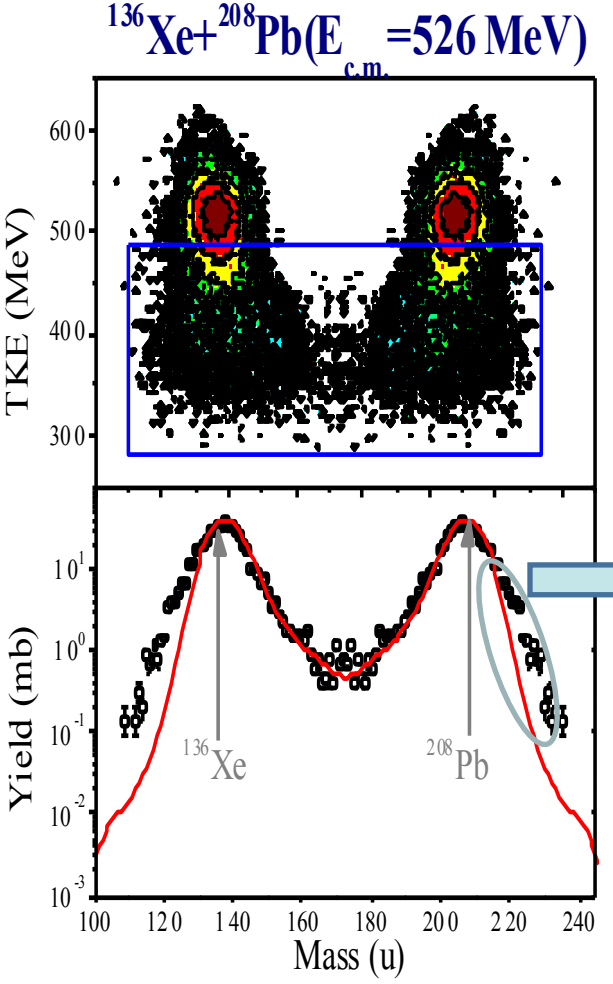




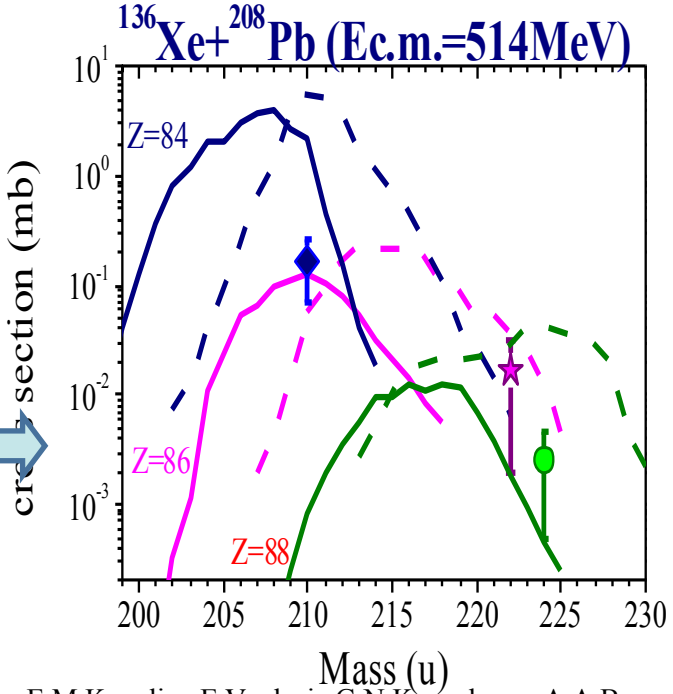


Experiment with Z identification of PLF was performed in Legnaro last summer

$^{136}Xe+^{208}Pb$: productions of heavy neutron-rich nuclei in multinucleon transfer reaction



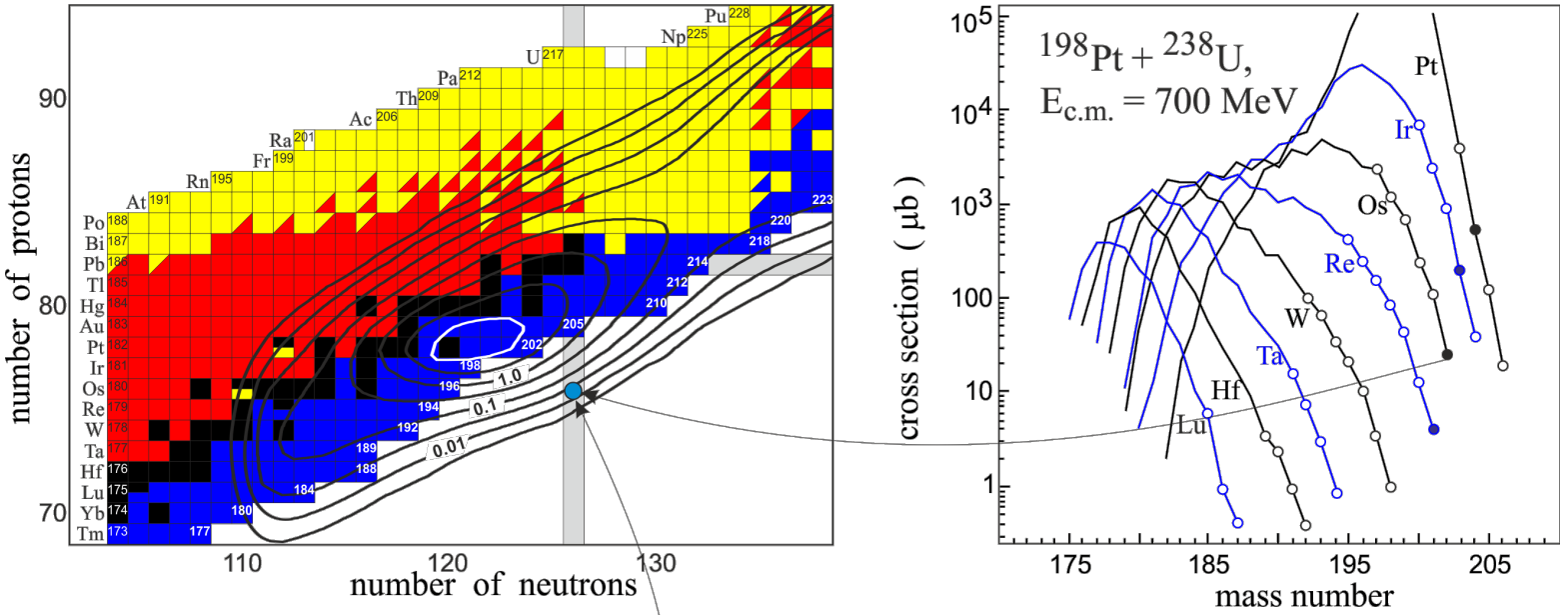
Cross section for ^{210}Po, ^{222}Rn, ^{224}Ra (Activation analysis)



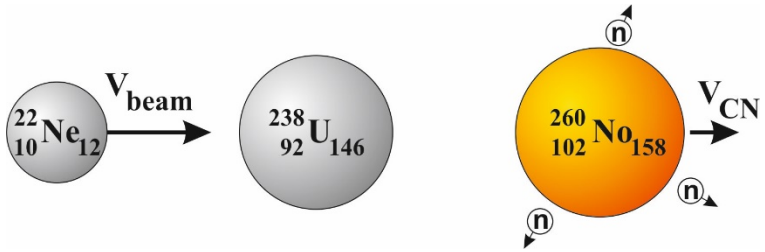
•E.M.Kozulin, E.Vardaci, G.N.Knyazheva, A.A.Bogachev, S.N.Dmitriev, I.M.Itkis, M.G.Itkis, A.G.Knyazev, T.A.Loktev, K.V.Novikov, E.A.Razinkov, O.V.Rudakov, S.V.Smirnov, W.Trzaska, V.I.Zagrebaev. Mass distributions of the ^{136}Xe + ^{208}Pb at laboratory energies around the Coulomb barrier: a candidate reactions for production neutron-rich nuclei at N=126.

Phys. Rev. C86, 044611 (2012).

Production of new neutron rich heavy nuclei located along the last "waiting point" of astrophysical nucleosynthesis: Choice of reaction ?

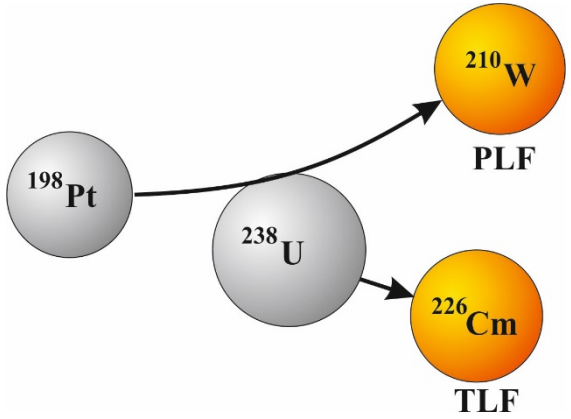


Fusion reactions



How to separate a given nucleus from all the other transfer reaction products ?

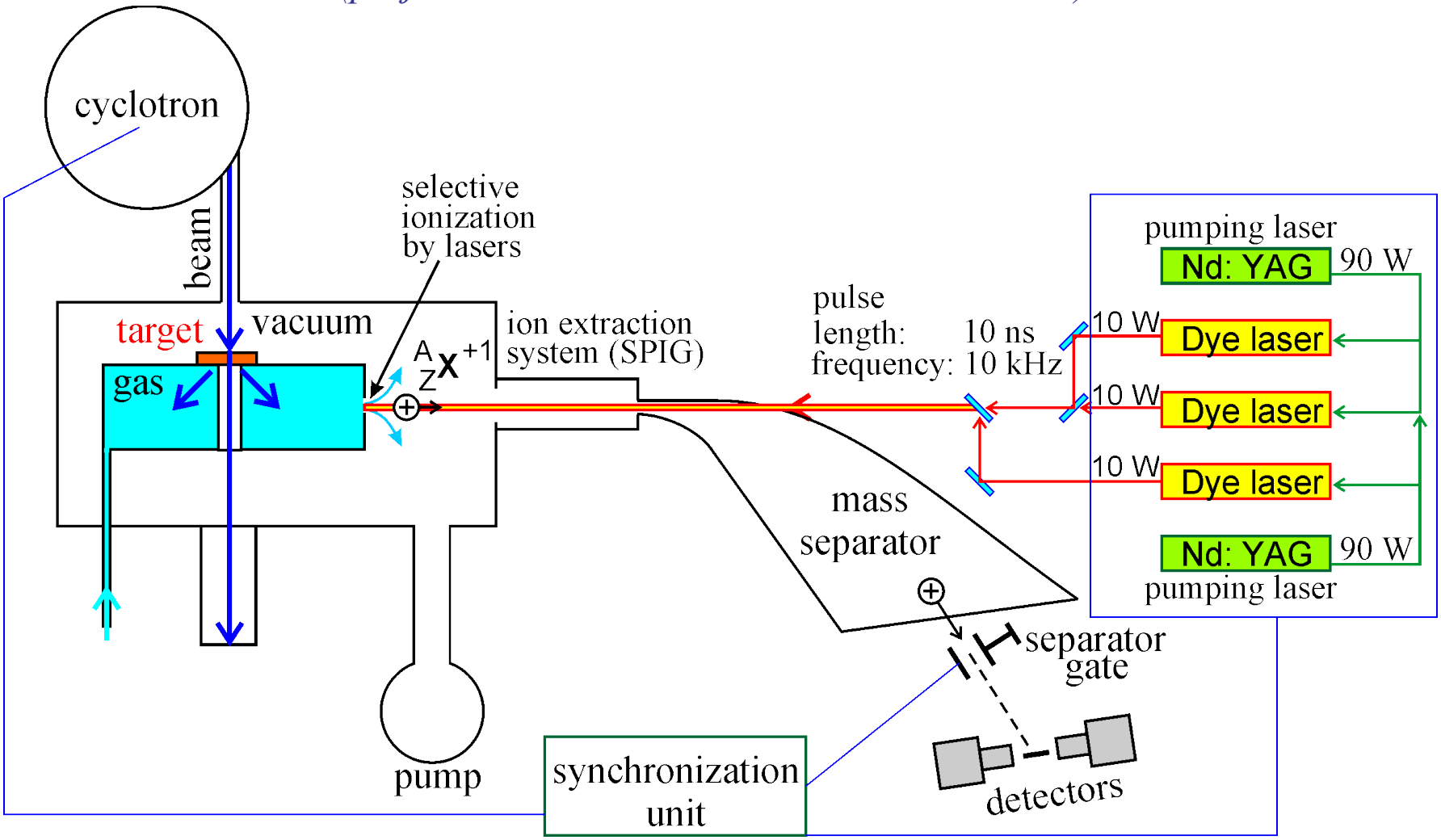
Transfer reactions



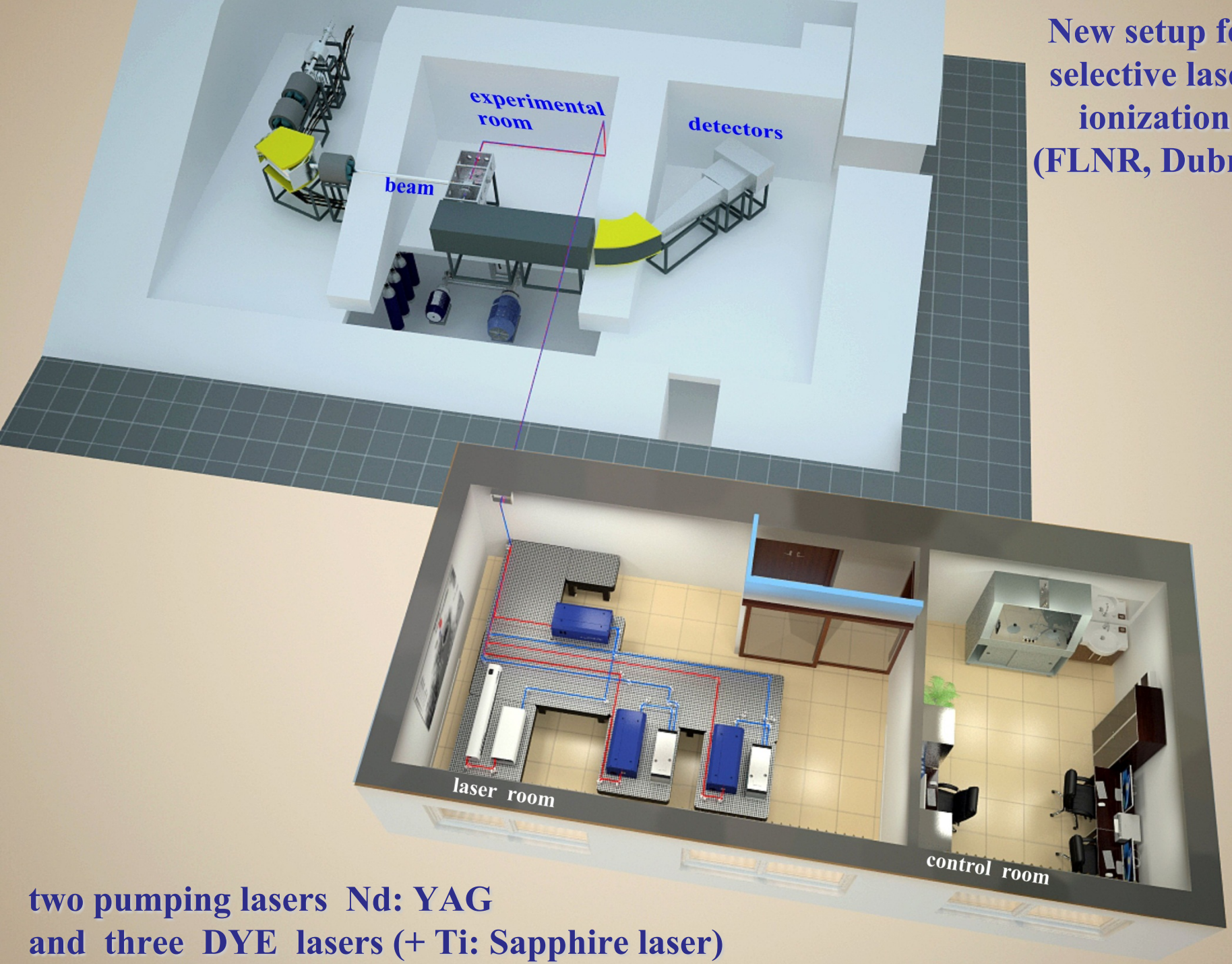
Available separators are not applicable !

New setup for selective laser ionization and separation of multi-nucleon transfer reaction products stopped in gas

*(project **GaLS**, to be realized in Dubna in 2015)*



New setup for selective laser ionization (FLNR, Dubna)



two pumping lasers Nd: YAG
and three DYE lasers (+ Ti: Sapphire laser)

Summary

- **Elements 119 and 120 can be really synthesized in the Ti and/or Cr fusion reactions with cross sections of about 0.05 - 0.02 pb.**

- **Multi-nucleon transfer reactions can be really used for synthesis of neutron enriched long-living SH nuclei located along the beta-stability line. U-like beams are needed as well as new kind of separators.**

- **Shell effects in production of trans-target nuclei (inverse quasi-fission) should be proved experimentally at last.**

- **Transfer reactions give a unique possibility for synthesis of heavy neutron-rich nuclei with N=126 – the last "waiting point" of astrophysical nucleosynthesis.**

- **Selective laser-ionization technique (GALS setup being developed at FLNR) is a powerful method of separation of the products of transfer reactions.**