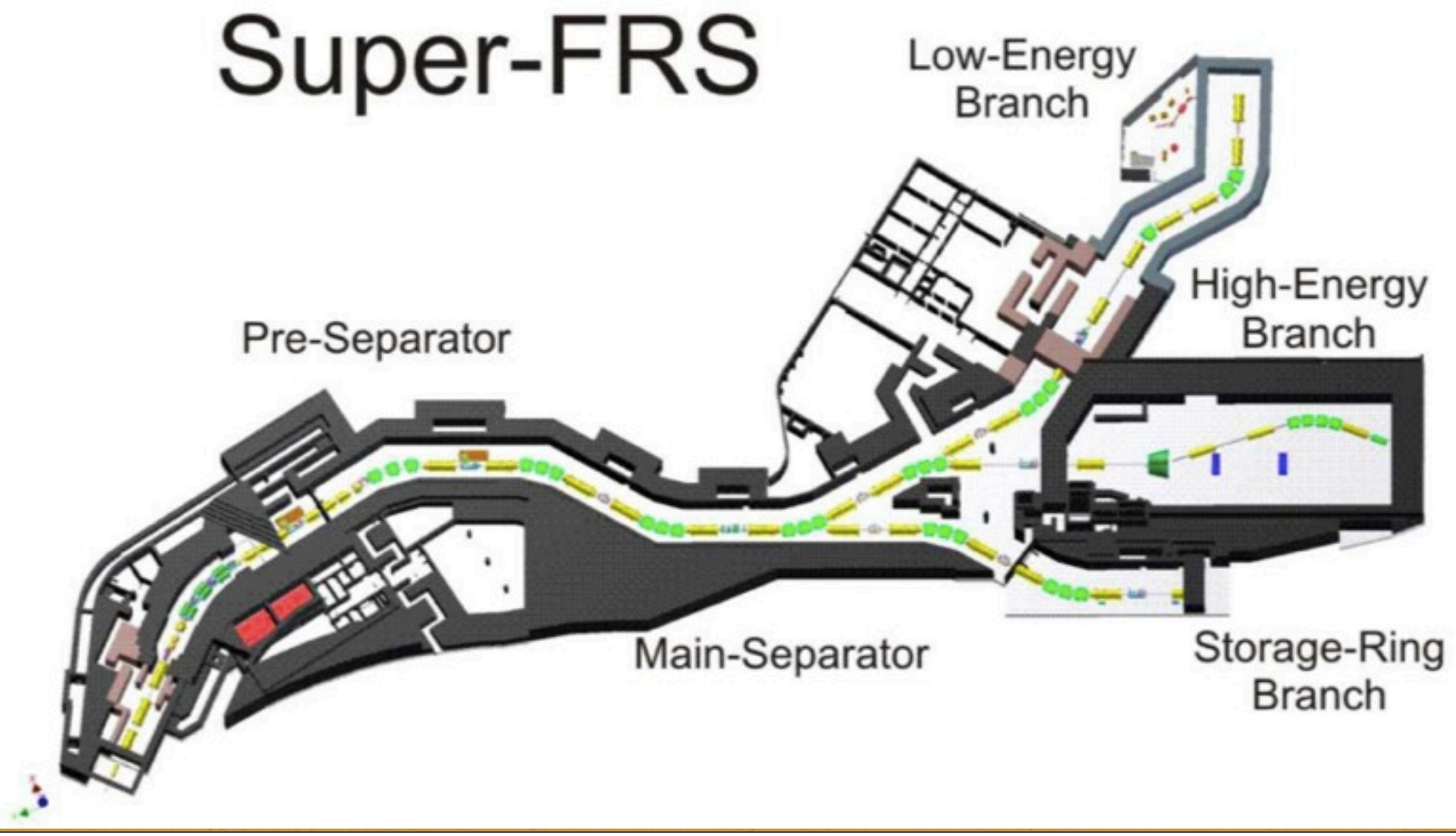
Super-FRS Science cases

Isao Tanihata as a spokes person of the Super-FRS collaboration

Report of the collaboration to the FAIR management

Draft, 2013-Nov-25

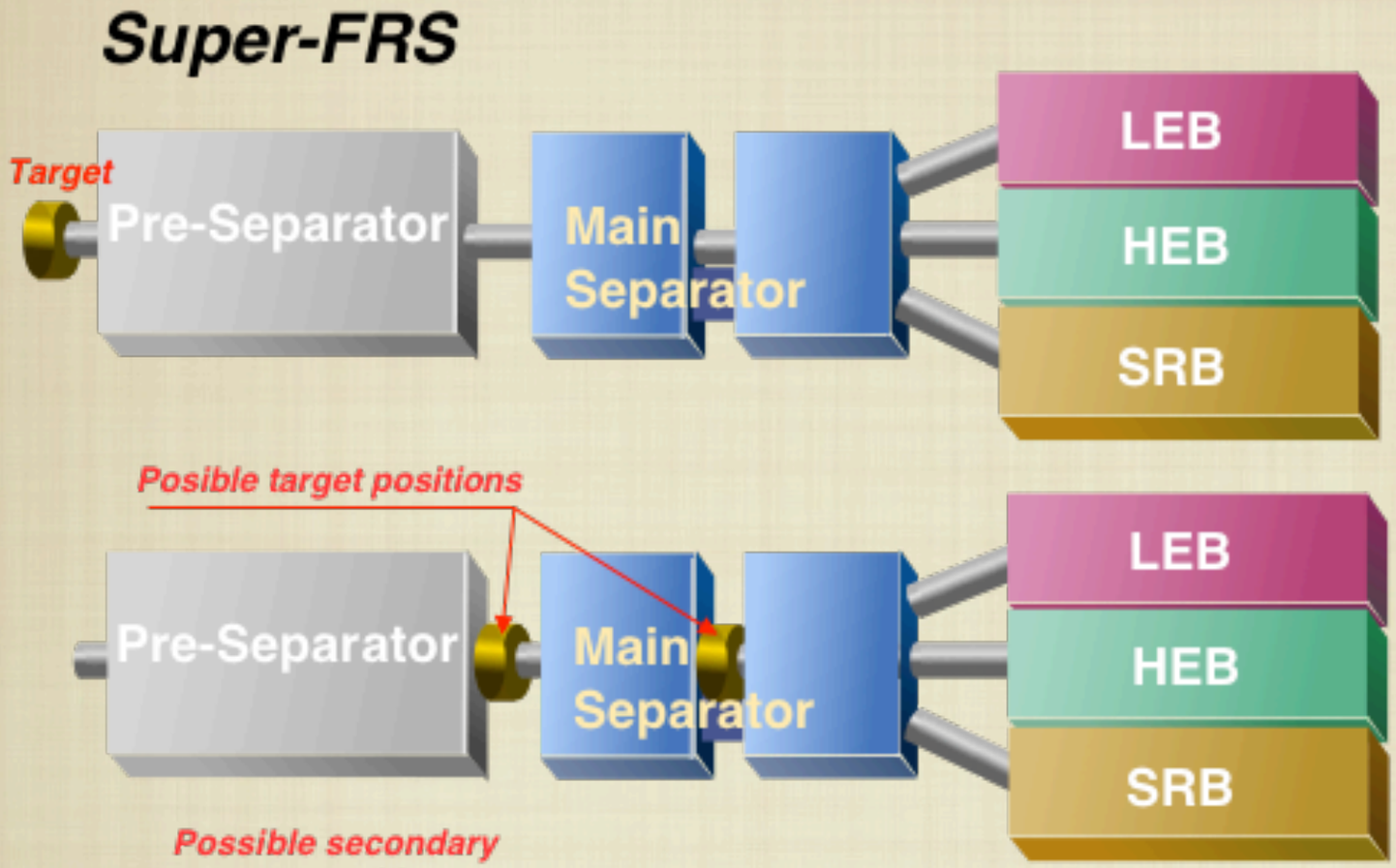
Talk mainly based on this document



Super-FRS features

- **High-energy primary and secondary nuclear beams**
  - ***>400A MeV, provides fully striped ions of heavy elements.***
- **High intensity**
  - ***The most exotic nuclei can be produced.***
- **High momentum resolution ($\Delta p/p$)**
  - ***10^{-4} or even better with dispersion matching modes.***
- **High separation power for exotic nuclei.**
- **Combination of a separator section and various spectrometer modes.**

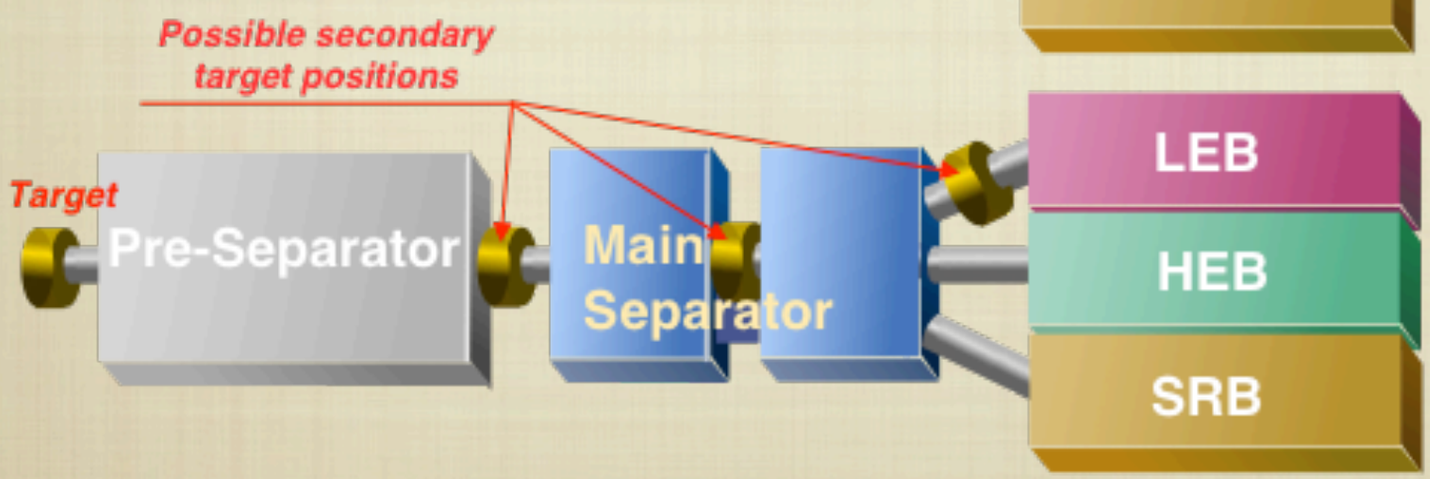
Various modes of Super-FRS



Super-FRS as high A and Q spectrometer
- Search for new isotopes
- Half life measurements

Super-FRS as HR 0 degree spectrometer
- η' bound nuclei and other mesonic atoms
- Tenor interactions

Super-FRS as HR 0 degree spectrometer
- Hyper nuclei
- Delta in nuclei



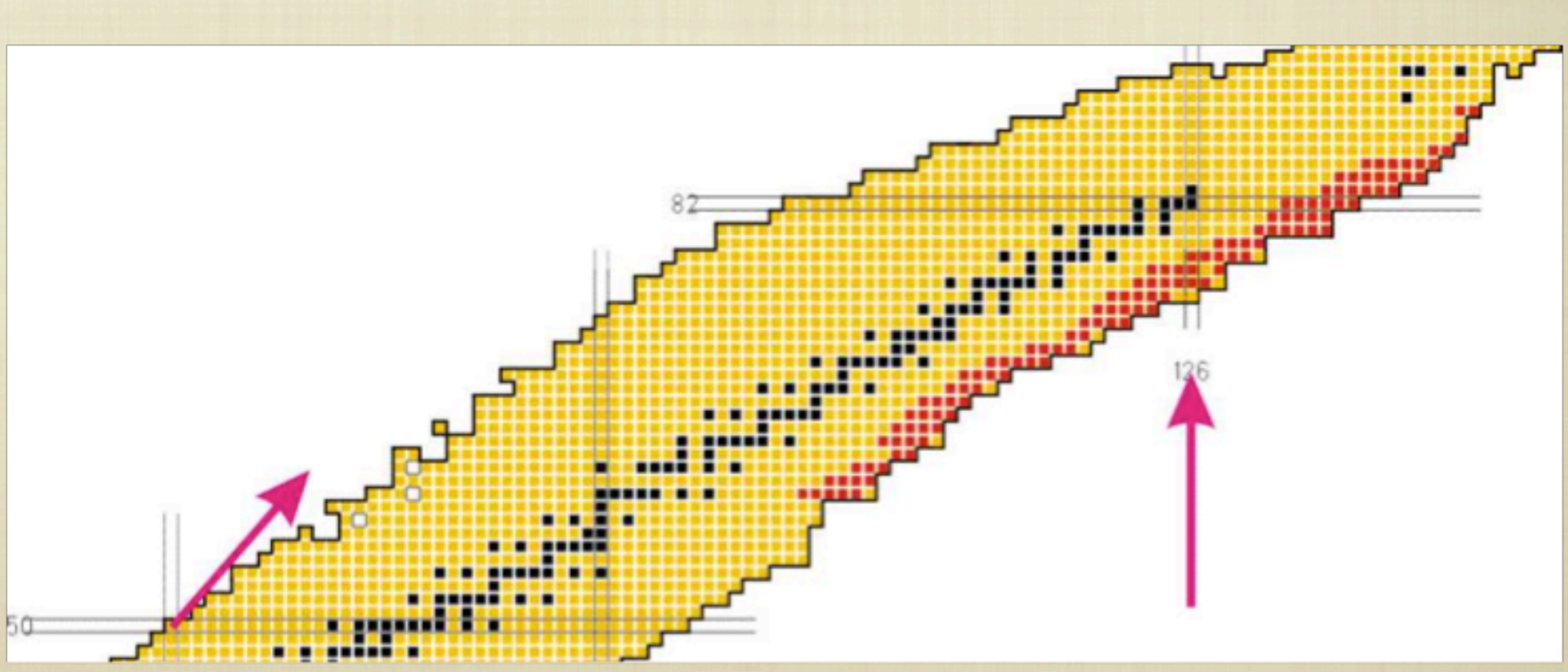
Super-FRS as RIbeam separator and spectrometer
- Low-q experiment with active target
- Interaction cross sections and charge changing cross sections
- Fragmentation of RIB
- LEB as despersion matching spectrometer..
- Atomic physics

Science Topics

- **Super-FRS for mass and charge separation**
  1. *Search for new isotopes and ground state properties*
  2. *Low-q experiments with an active target*
  3. *Atomic collisions*
- **Super-FRS as high-resolution spectrometer**
  4. *Exotic hypernuclei and their properties*
  5. *Spectroscopy of meson-nucleus bound system (mesonic atoms)*
  6. *Importance of tensor forces in nuclear structure*
  7. *Delta resonances probing nuclear structure*
- **Super-FRS as RIB separator+reaction spectrometer**
  8. *Nuclear radii and momentum distributions*
  9. *Synthesis of new isotopes and nuclear reaction studies with RIB*
  10. *Radioactive in-flight decays and continuum spectroscopy by particle emissions*

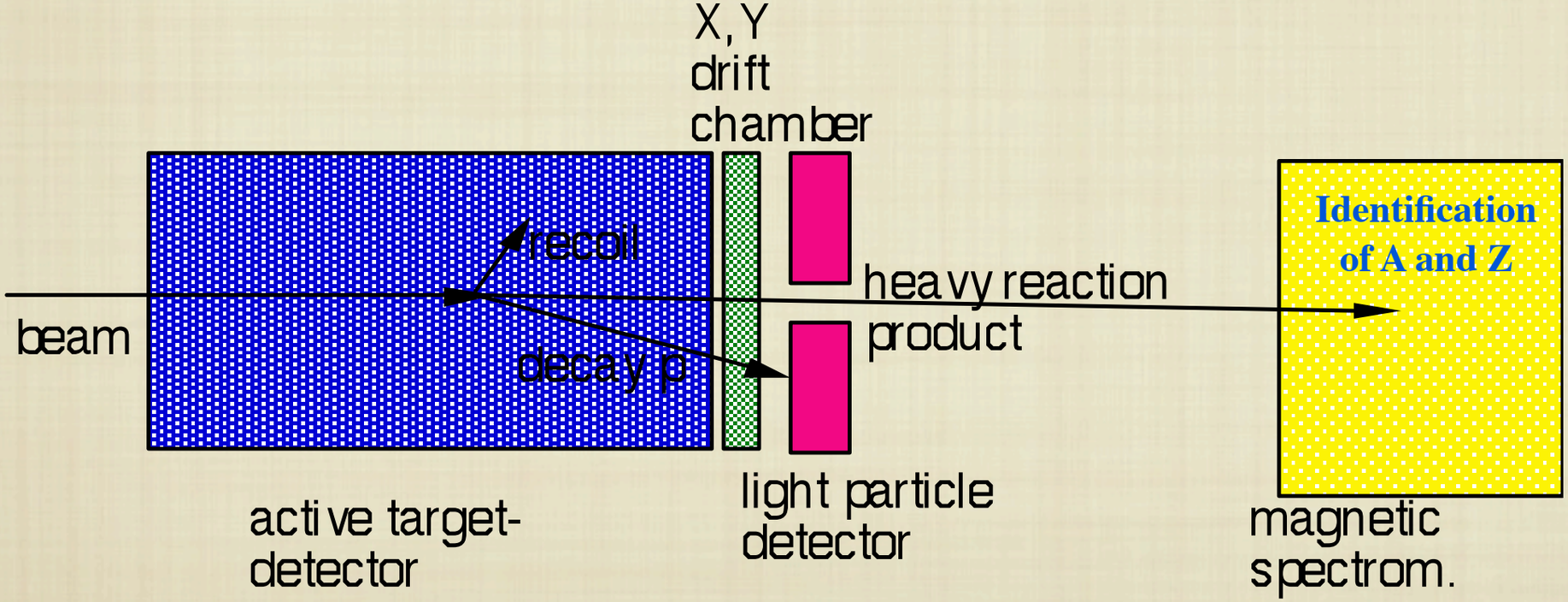
1. Search for new isotopes and ground state properties

- **Take advantage of *E*>500*A* MeV U or other beams, many new isotopes would be produced.**
- **The determinations of production cross sections of unstable nuclei are imperative for Super-FRS operation.**



2. Low-q experiment with an active target

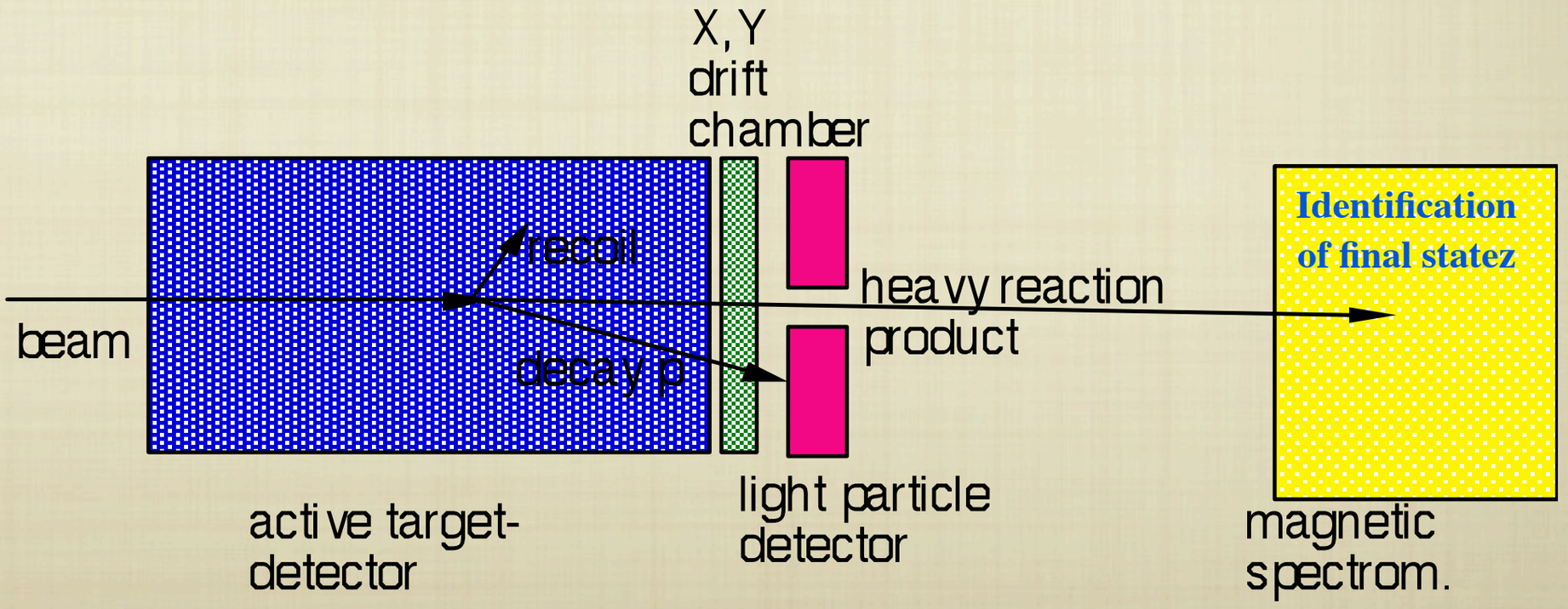
- **Elastic scattering of heavy neutron rich nuclei for study of nuclear distribution and neutron skin.**
- **Such systematic studies provide the information on EOS of symmetric nuclear matter.**



- ***Some overlap with usage of other facility (R3B) has to be discussed continuously for mutual improvement.***

2. Low-q experiment with and active target (II)

- **When heavy nuclei such as Sn isotopes are concerned.**
  - ***Recoil proton energies for the first bump exceed the range of active target. Therefore the inelastic scattering would not be separated by the active target itself.***
  - ***A forward high-resolution spectrometer can resolve excited states but need better than $8x10^{-5}$ momentum resolution.***



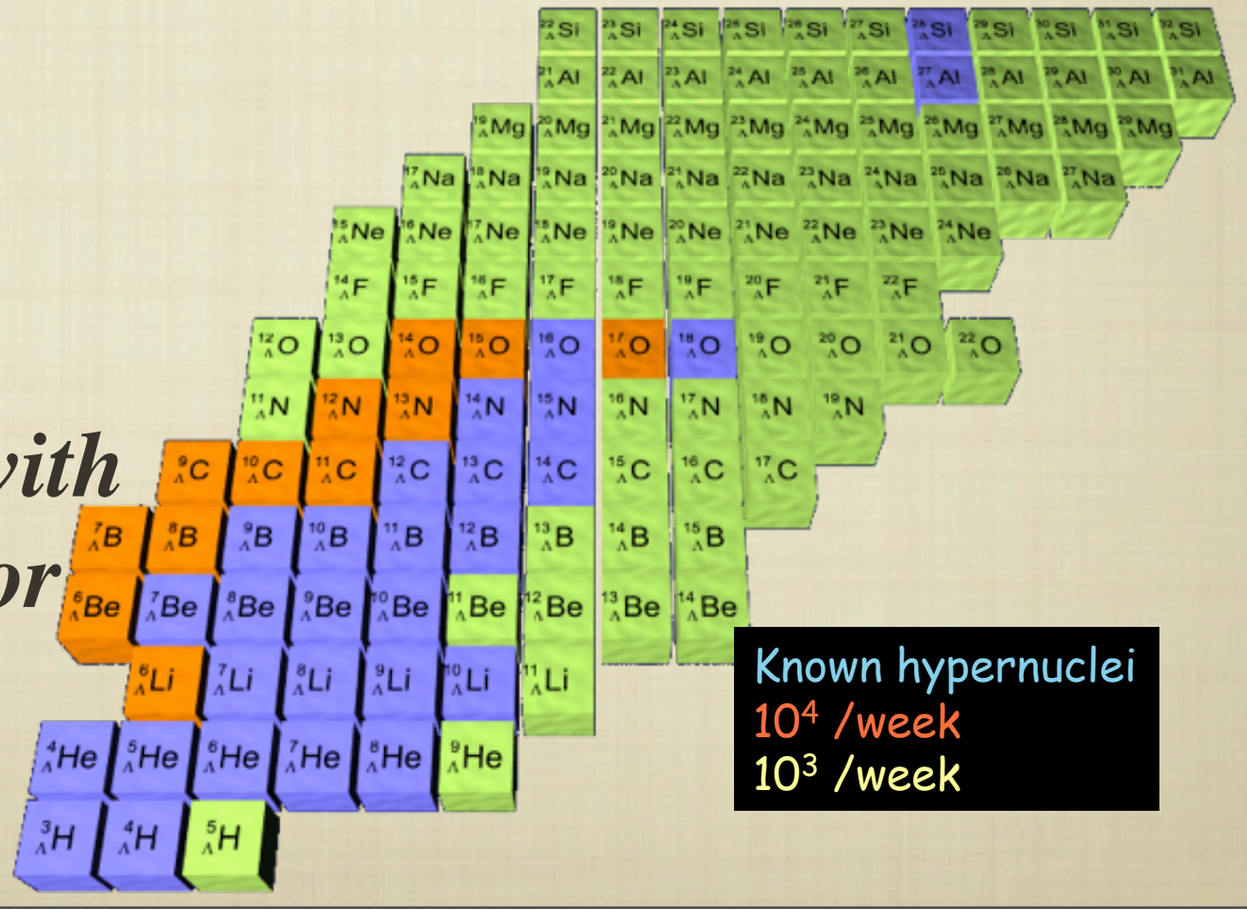
3. Atomic collisions

- **Accurate knowledge of the atomic interaction of ions penetrating though a matter, such as charge state distributions of ions of heavy elements, is essential**
  - ***It is important also for delivering RIB from Super-FRS.***
- **New data for stopping power, energy and angular straggling will be obtained at high energies.**
  - ***Important for gas stopping cells optimization.***
- **Coherent crystal effects for ions such as nuclear Okorokov effect will be studied for the first time.**

4. Exotic hypernuclei and their properties

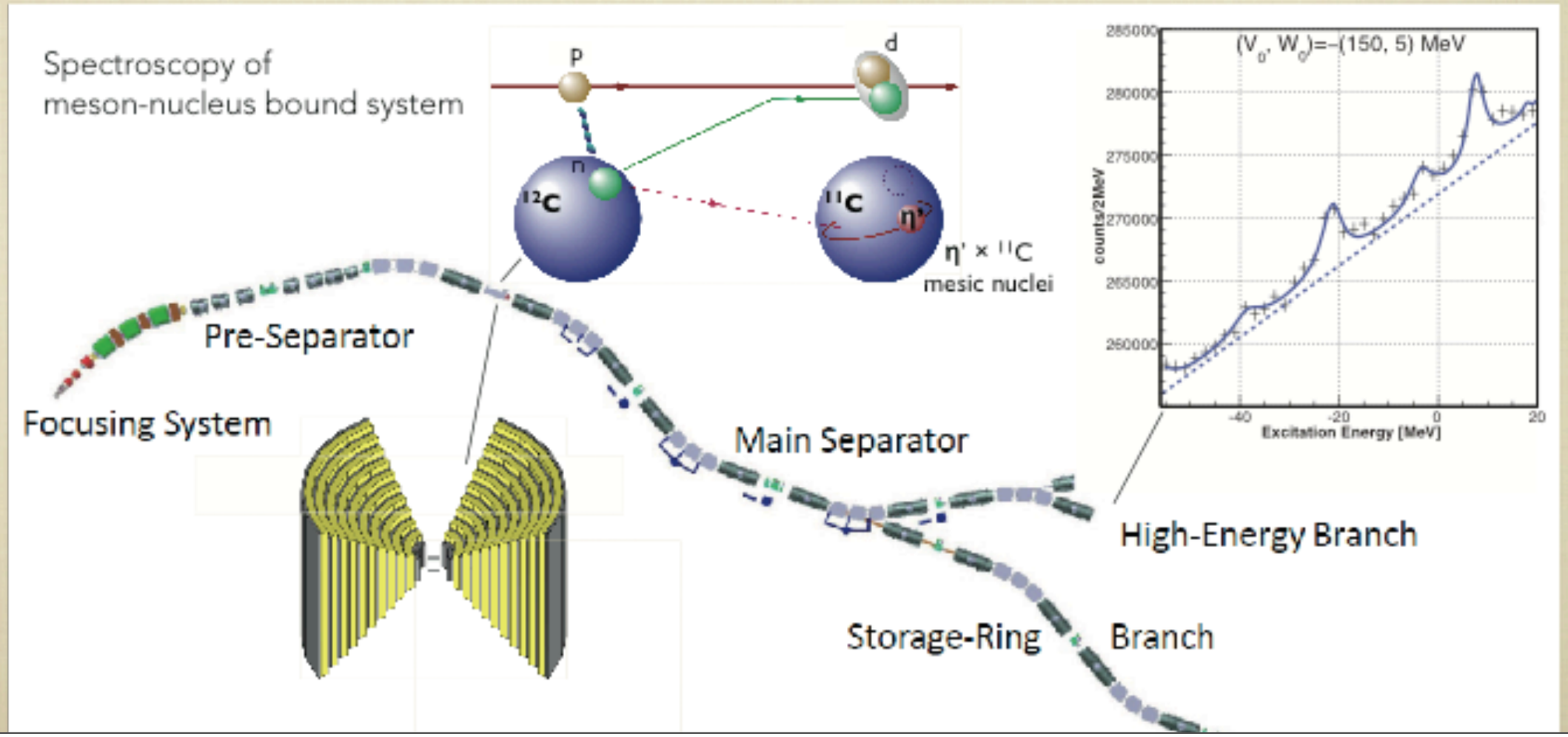
- **Production of hypernuclei by high-energy (>1.2*A* GeV) heavy-ions peripheral collision is expected to have large cross sections.**
- **Also this method is suitable for determination of lifetime.**
- **Pilot experiment shows several new evidences of $^{3}_{\Lambda}$H, $^{4}_{\Lambda}$H**
  - ***The lifetime have also been determined.***
- ***$^{3}_{\Lambda}$n has been suggested.***
- ***Higher resolution of mass with FRS/Super-FRS will help for identifications.***

Land scape with FRS/Super-FRS



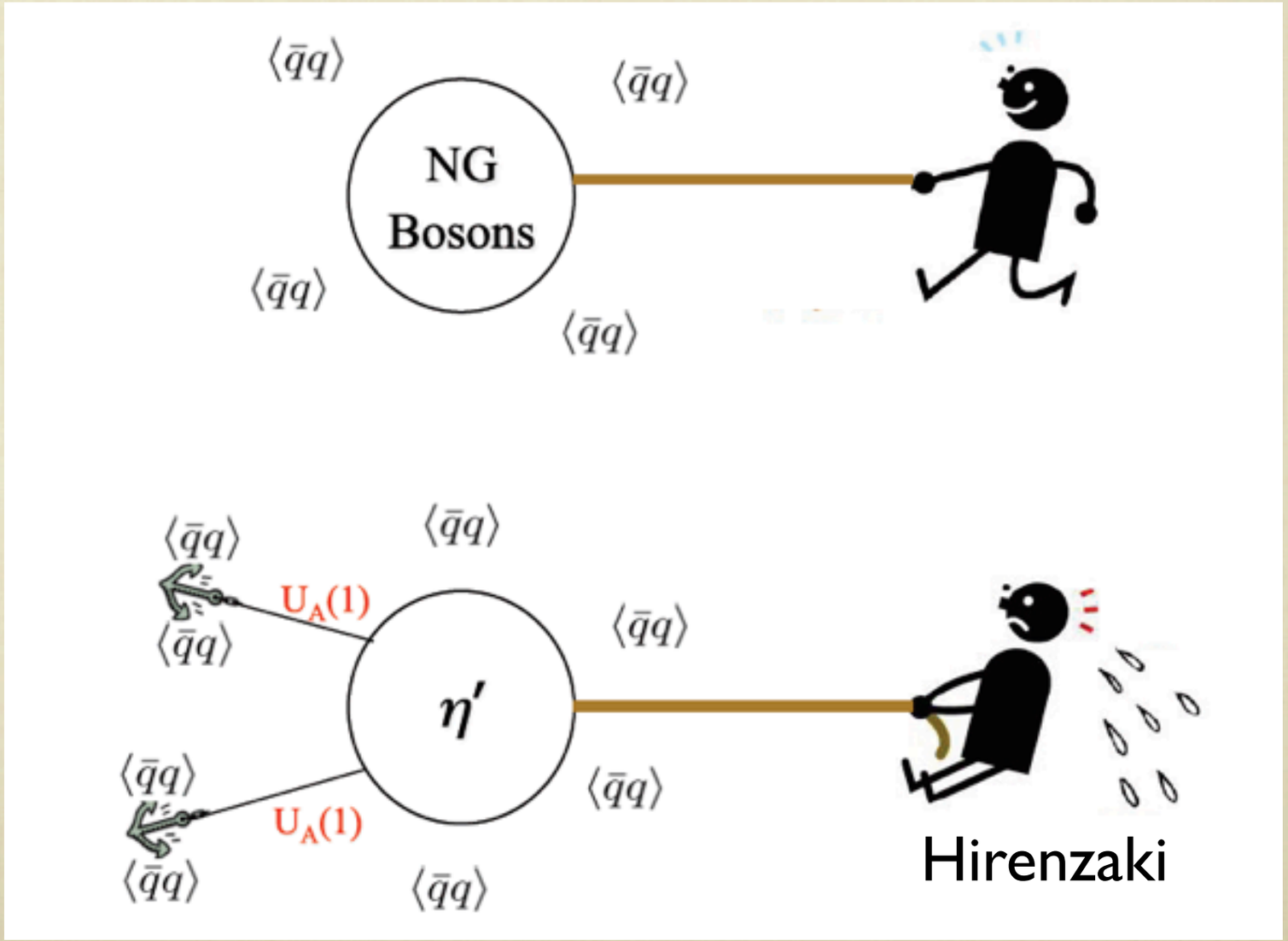
5. Spectroscopy of meson-nuclus bound system (mesonic atoms)

- **The discovery of deeply-bound pionic state in heavy atoms with FRS opened a new field of fundamental studies of the meson-nucleus interactions, which contribute to the understanding of the non-trivial structure of the vacuum of QCD.**
- **Observation of η'-bound nuclei with (p, d) reaction is the first aim of the experiment.**



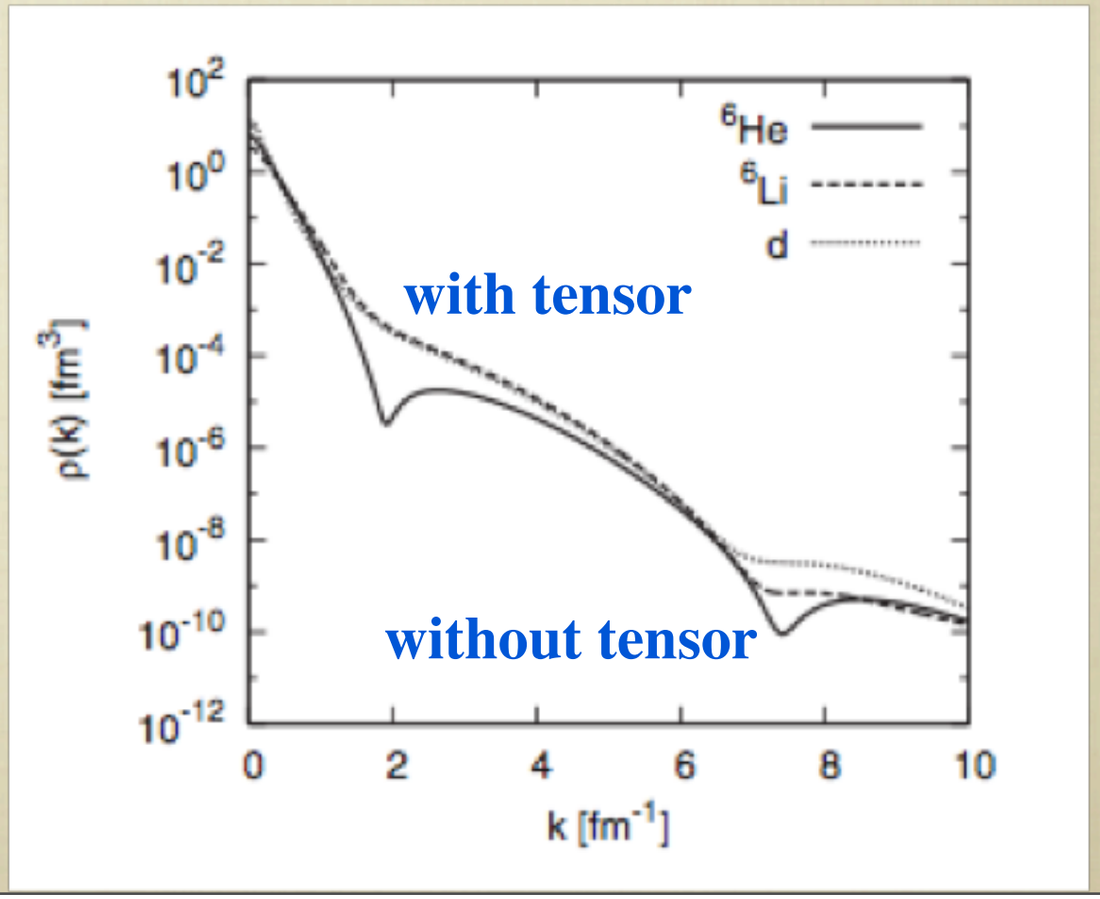
Why η' Meson

- **η' meson is a singlet among SU3 pseudo-scalar mesons but has unexpectedly heavy mass.**
  - ***It is considered to be due to the coupling to QCD vacuum.***
  - ***Therefore a change of mass is expected in nuclei.***



6. Importance of tensor forces in nuclear structure

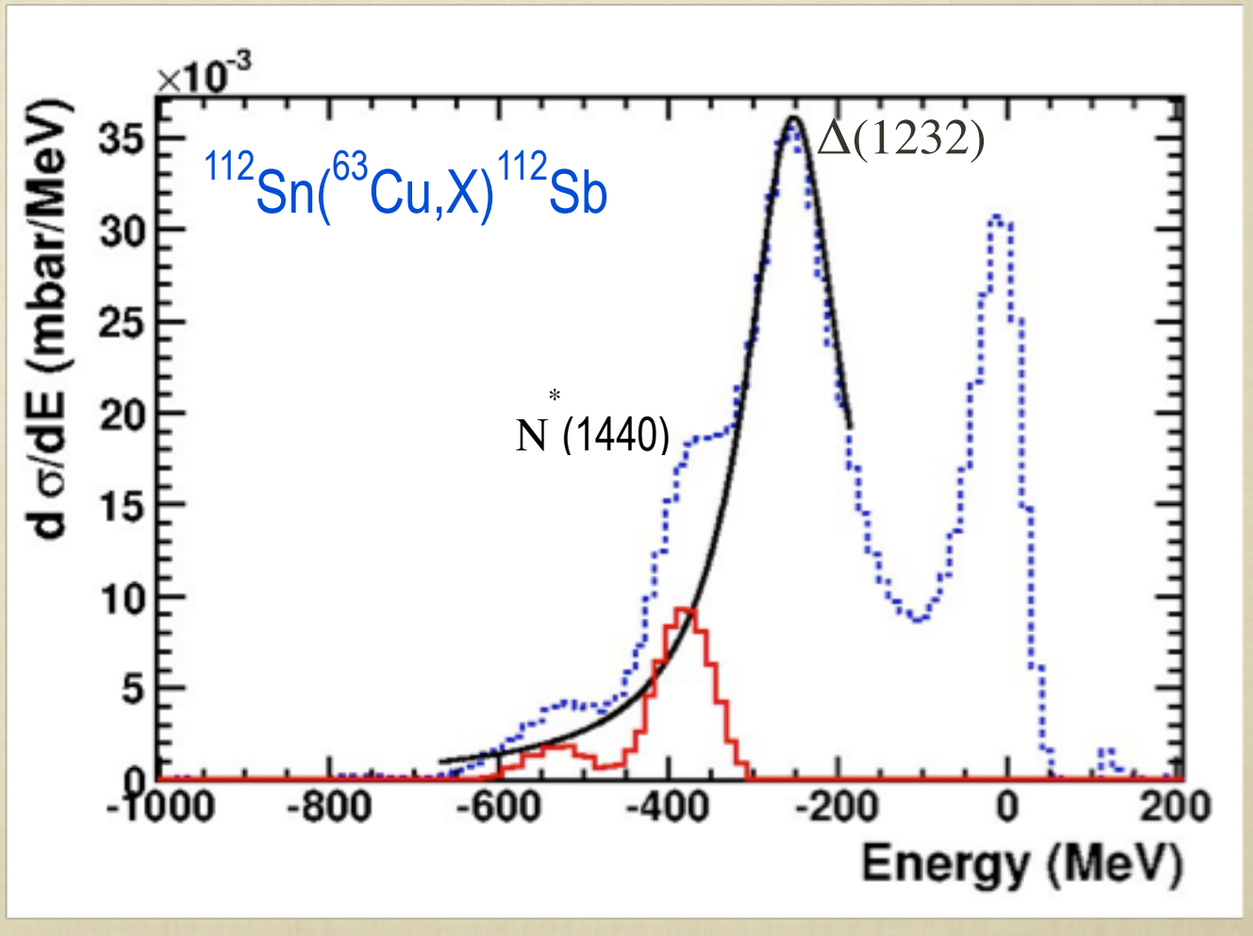
- **Although it is important for binding nuclei, tensor forces have not been treated explicitly in most of successful nuclear structure models such as mean field models and shell models.**
- **Those important contributions are though nucleons with high momentum.**
- **Studies of such high momentum nucleon (P~2 fm^{-1}) will be done by high-energy pick-up reactions.**
  - ***(p,d), (d,^{3}He), (d,t), (p,pd), (p,nd) reactions***
  - ***In some cases***
  - ***(p,pd), (p,nd) reaction may be better at R3B***
  - ***It has to be carefully evaluated.***



7. Delta resonances probing nuclear structure

- **Charge changing reactions with high-energy heavy ions provide unique possibilities to study baryon resonances, including Δ-resonances, in exotic nuclei**
  - ***So far Δ-resonances in nuclei has been studies exclusively in stable or near stable nuclei***

- **Studying**
  - ***In-medium properties of baryon resonance in isospin asymmetric nuclear matter***
  - ***Gamow-Teller transition strength***
  - ***Radial distribution of neutrons and protons***
  - ***Nuclear matrix elements for inelastic neutrino interactions***



8.Nuclear Radii and momentum distribution

- **Determinations of nuclear matter radii by the interaction cross sections and proton radii by the charge changing cross sections.**
- **Spectroscopy of exotic nuclei by momentum distribution measurement of the projectile fragments**
- **With Super-FRS measurement can be extended to much heavier nuclei such as Ni and Sn isotopes.**

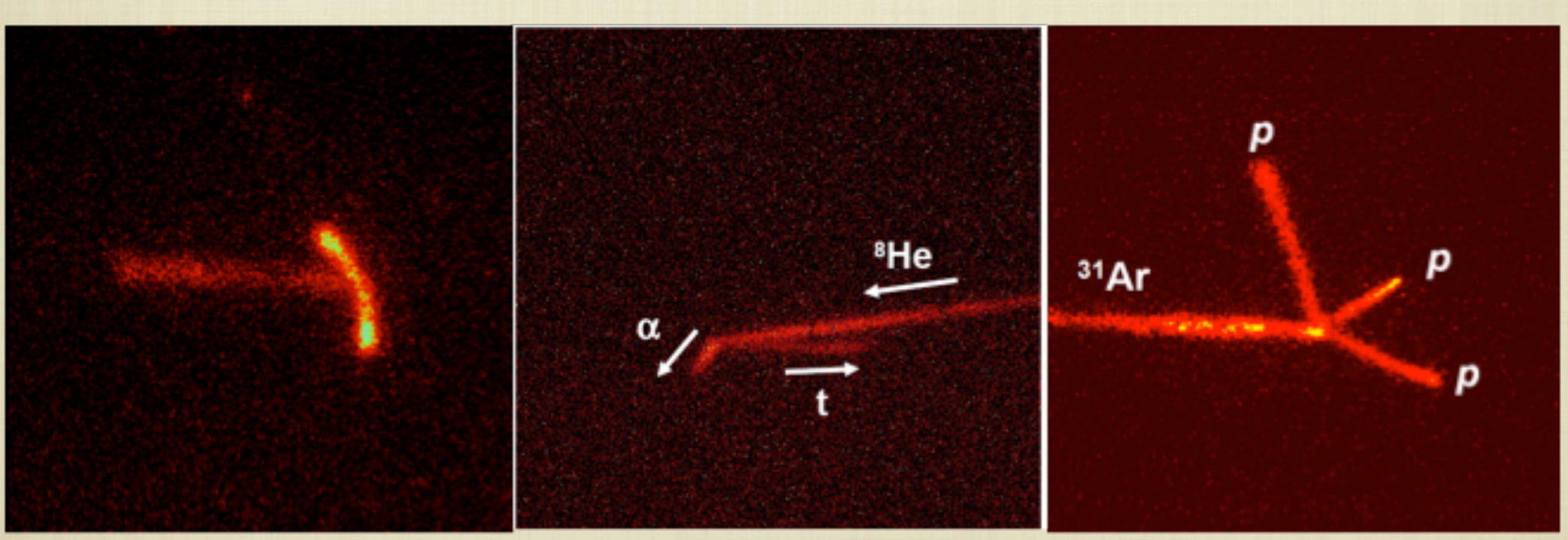
- ***More exclusive measurements of fragmentation could be better done in R3B.***
- ***Need continuous discussion for optimization for such cases.***

9. Synthesis of new isotopes and nuclear reaction studies with RiB

- **At Low Energy beam line.**
- Experiments with RIB at Coulomb-barrier energies challenge a new field for reaction studies.
  - *Which will contribute to a better understanding of deep inelastic, fusion-fission and complete fusion reactions.*
- This knowledge is essential for the extension of the nuclear chart towards superheavy elements beyond the existing limit. They will possibly give access to new neutron-rich isotopes beyond uranium, and also below uranium, both regions are not accessible in fusion reactions with stable beams nor in fragmentation reactions.

10. Radioactive in-flight decays and continuum spectroscopy by particle emission

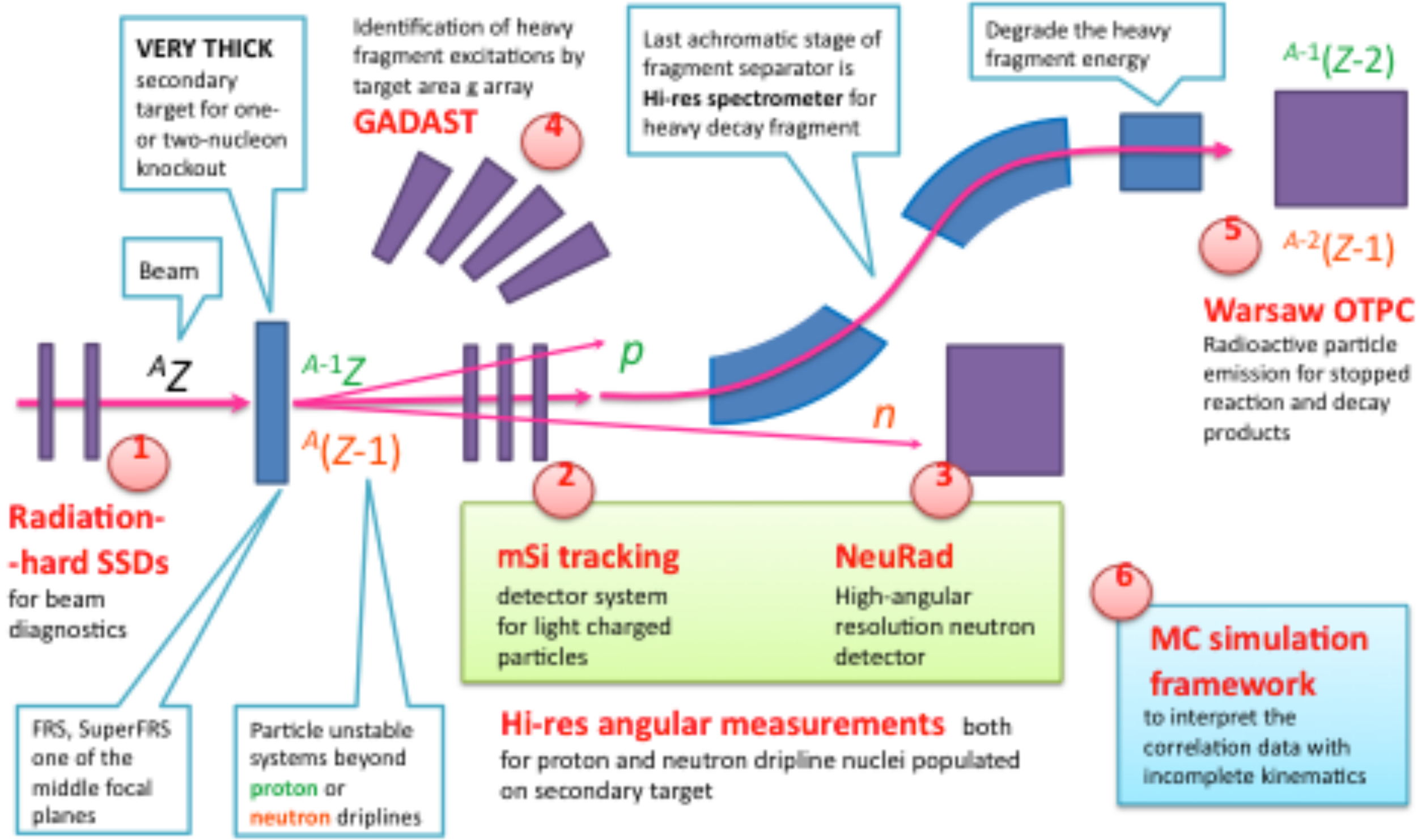
- **Study decays (particle emission) of nuclear beyond the drip line and other resonances.**
  - ***One-, two- four- proton decays, two-proton decay***
  - ***Neutron radioactivity***



- ***Complimentary with missing mass, invariant mass measurements.***

EXPERT:

EXotic Particle Emission and Radioactivity by Tracking



"External" synergy for EXPERT components

EXPERT works best as a setup

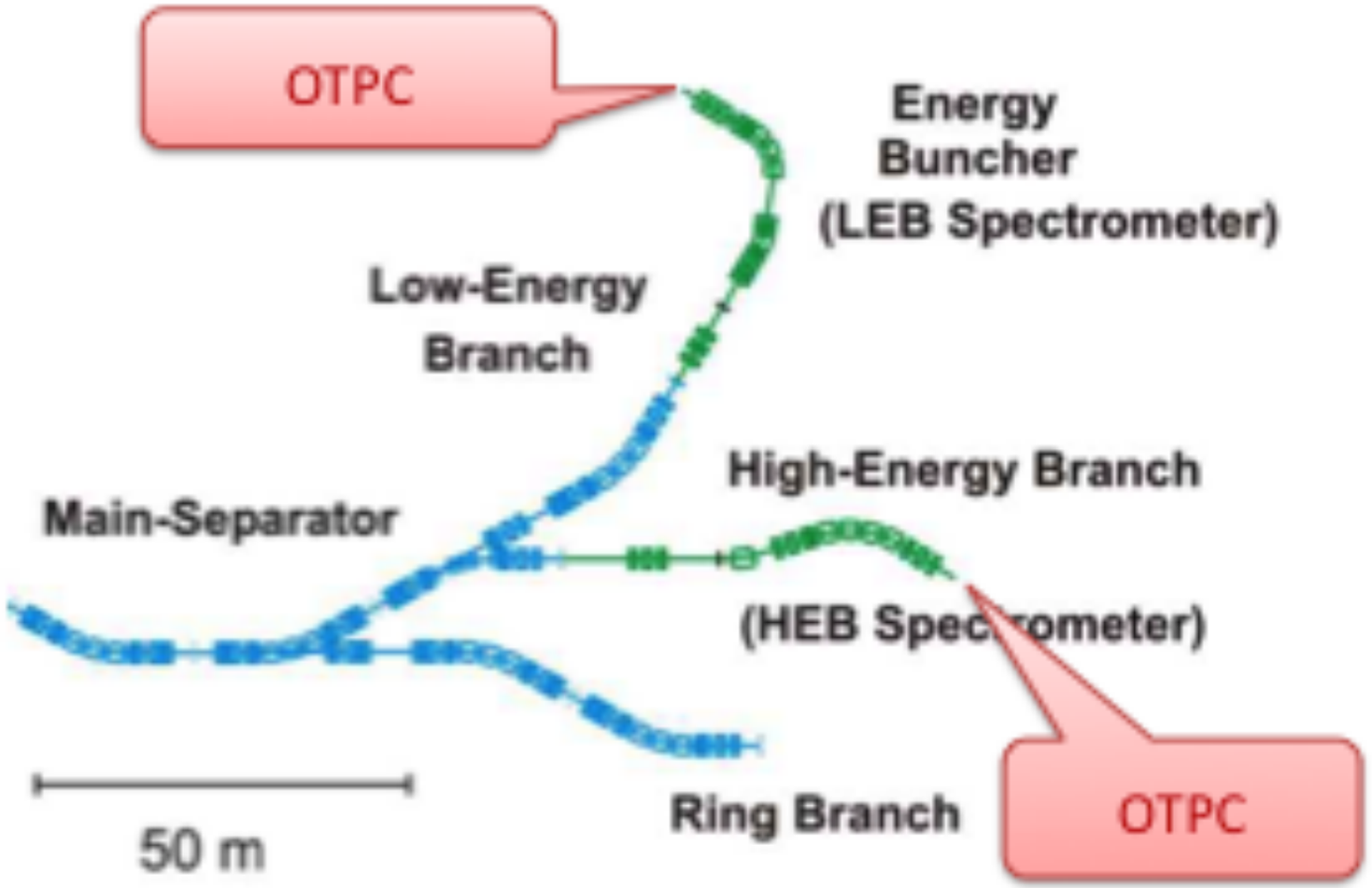
However: "modular" and "mobile" initiative

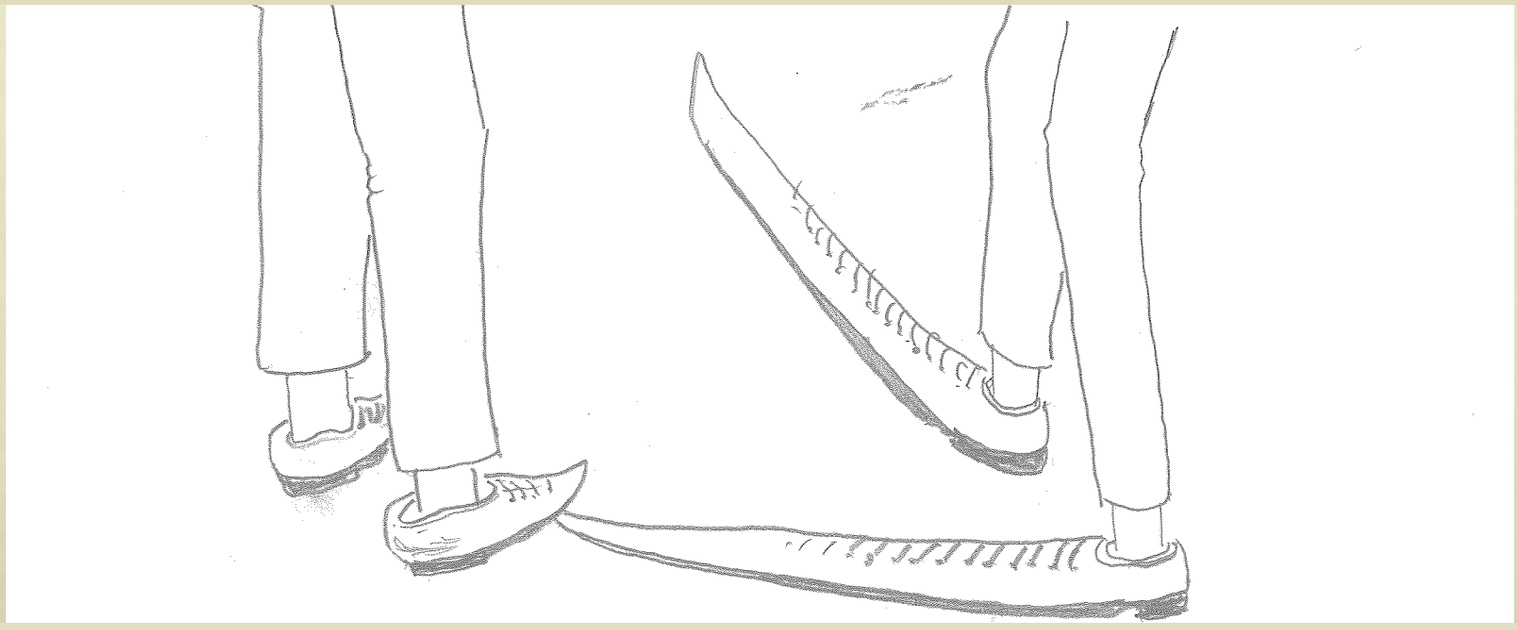
Expert components can be used at different NUSTAR experiments

RH SSDs – generic SFRS usage

GADAST – different scenarios, e.g. "Topic 8" by Kanungo

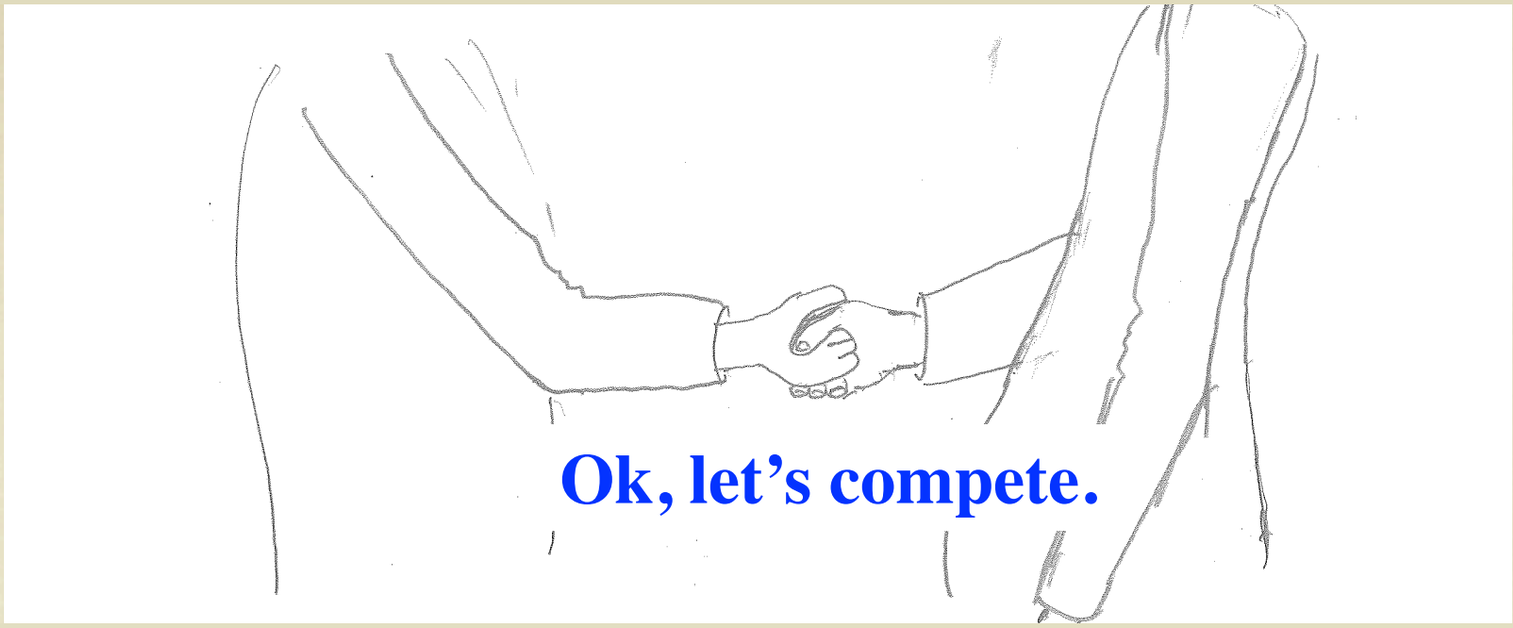
OTPC – two additional locations
- **at LEB**
- **at R3B**

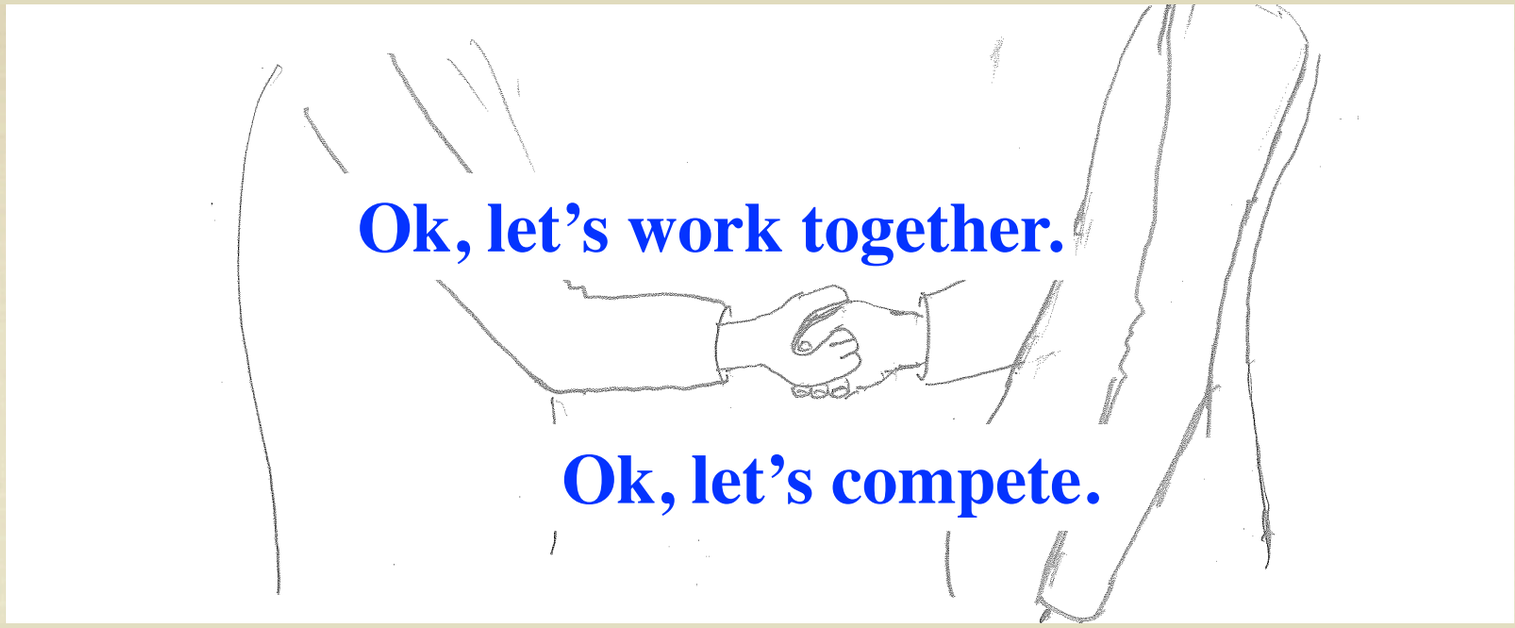





Oh No! Don’t step on my foot!


Ok, let’s work together.


Ok, let’s compete.


Ok, let’s work together.
Ok, let’s compete.

Hoping great outcome of NuSTAR and Super-FRS collaborations

Thank you very much for your attention.

List of conveners

2.1 New isotope search experiments (Pietri, Jokinen, Plaß et al.)
2.2 Nuclear radii and momentum distributions (Kanungo, Prochazka et al.)
2.3. low-q with Active Target (Egelhof, Kalantar et al.)
2.4 Exploration of exotic radioactivity modes (Fomichev, Pfützner, Mukha et al.)
2.5 Exploration of tensor force (Ong,Terashima, Toki, et al.)
2.6 Delta resonances probing nuclear structure (Benlliure, Lenske et al.)
2.7 Mesonic atoms and in-medium effects (Itahashi, Weick et al.)
2.8 Exotic hypernuclei and their properties (Saito, Nociforo et al.)
2.9 Low energy reactions (Heinz, Winfield et al.)
2.10 Atomic collision experiments (Purushothaman, Geissel et al.)