Super-FRS Experiments

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At WASA at GSI/FAIR workshop

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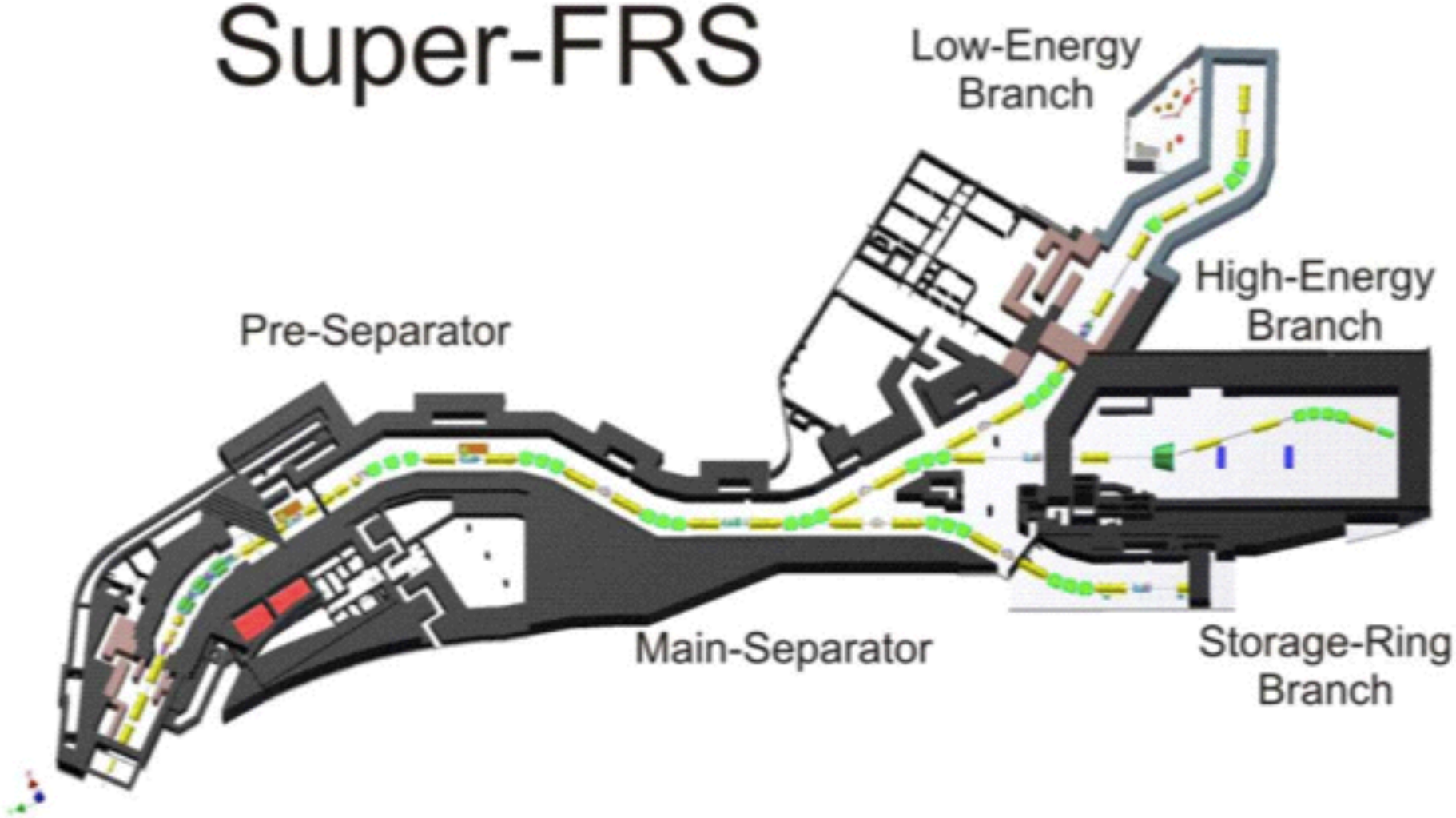
Super-FRS

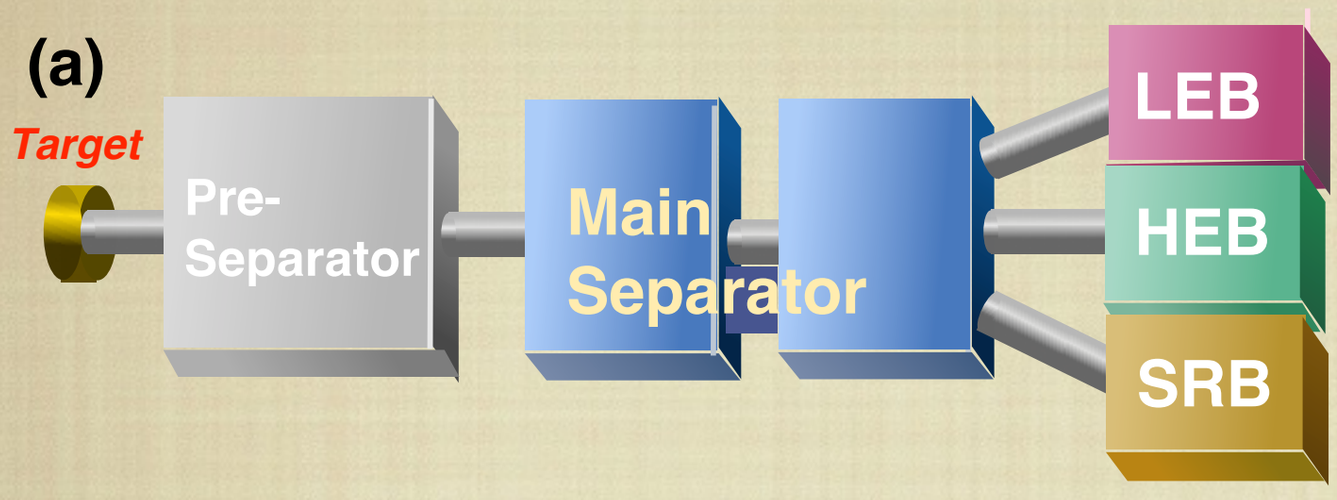

Low-Energy
Branch
High-Energy
Branch
Pre-Separator
Main-Separator
Storage-Ring
Branch

Uniqueness

- **FAIR Uniqueness:**
  - ***High-energy primary and secondary nuclear beams***
    - >400*A* MeV only at FAIR in the world.
    - Provides fully striped ions of the heaviest elements.
  - ***High intensity***
    - The most exotic nuclei can be produced.

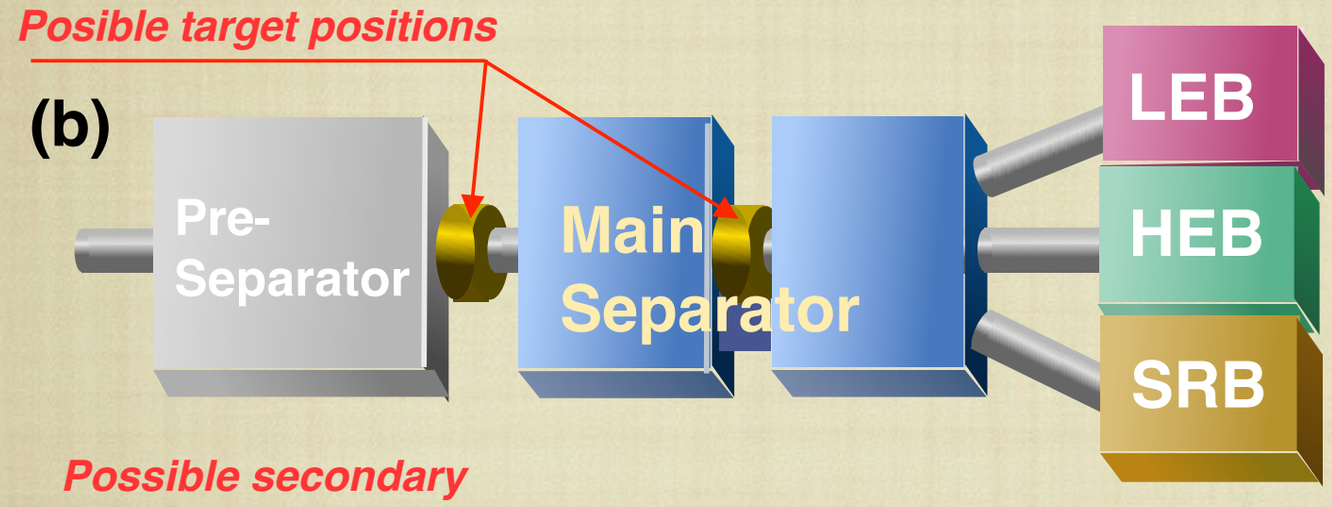
- **Super-FRS Uniqueness**
  - ***High separation power for exotic nuclei***
  - ***High momentum resolution (Δp/p)***
    - 10^{-4} or even better with dispersion matching modes.
  - ***Muti-staged spectrometer***
    - Combined use of a separator section and various spectrometer modes.

Various modes of Super-FRS

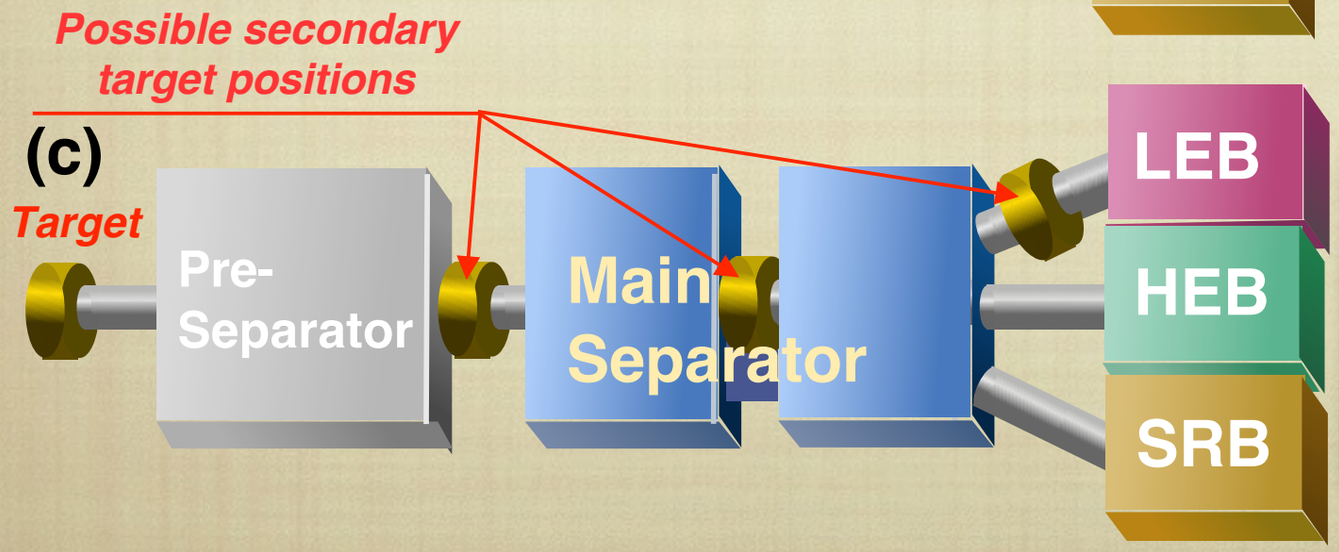


As high A and Q spectrometer
- Search for new isotopes
- Atomic physics

As high resolution 0º spectrometer
- η' bound nuclei and other mesonic atoms
- Tensor interactions



As high resolution 0º spectrometer
- Hyper nuclei
- Delta in nuclei



As RIbeam separator and spectrometer
- Low-q experiment with active target
- Interaction CC and charge changing CC
- Fragmentation of RIB
- LEB as despersion matching spectrometer.

Science Topics

- **Super-FRS for mass and charge separation**
  1. *Search for new*
  2. *Atomic collisio*
- **Super-FRS as high-resolution spectrometer**
  3. *Spectroscopy of meson-nucleus bound system (mesonic atoms)*
  4. *Exotic hypernu*
  5. *Importance of tensor forces in nuclear structure*
  6. *Delta resonances probing nuclear structure*
- **Super-FRS as multi-stage separator and high resolution reaction spectrometer**
  7. *Nuclear radii and momentum distributions*
  8. *Radioactive in-fl emissions*
  9. *Low-q experiments with an active target*
  10. *Synthesis of new isotopes and nuclear reaction studies with RIBs*
  11.* *Measurement of Beta-delayed neutron emission*

Early execution of those experiments are not only giving the outstanding physics but also essential for success of other NUSTAR experiments.

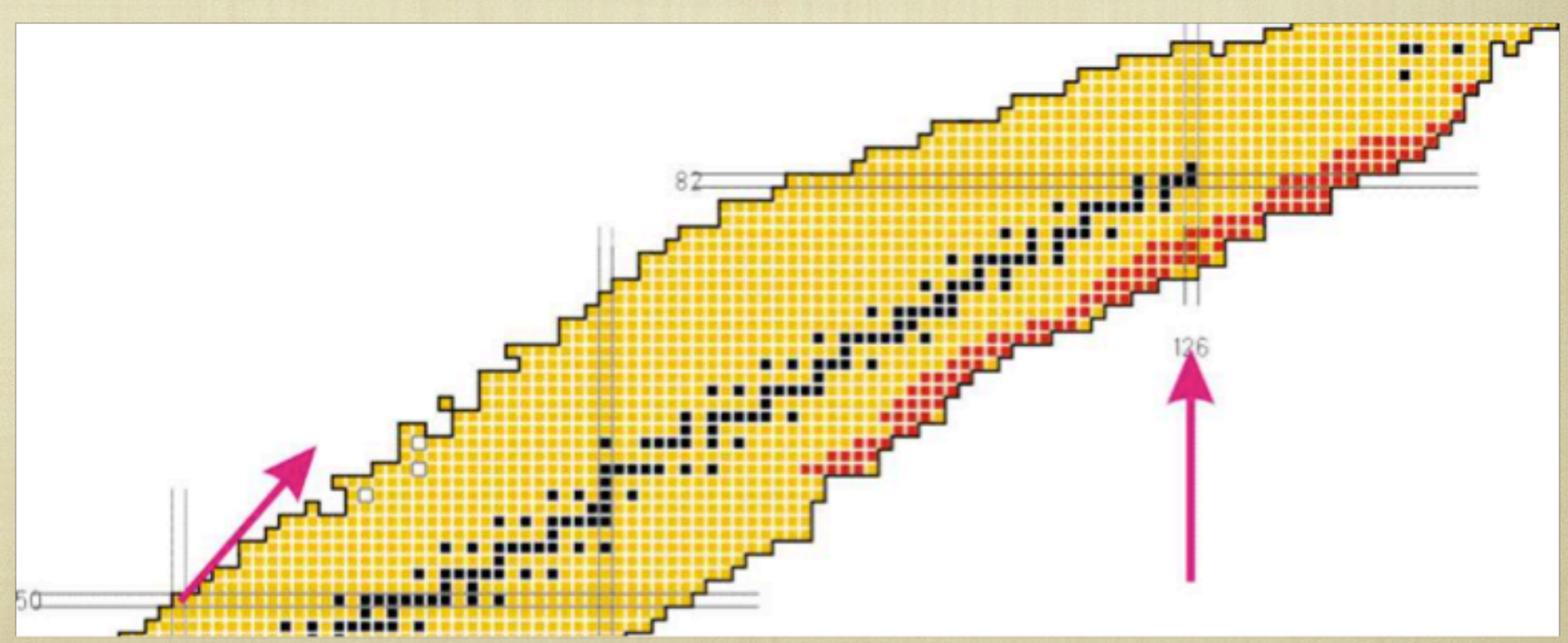
Experiments that can be done only at Super-FRS.

Experiments taking advantages of multi-stage spectrometer design of the Super-FRS.

1. Search for new isotopes and ground state properties

(Pietri, Jokinen, Plaβ et al.)

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



Experience continues from FRS.

2. Atomic collisions

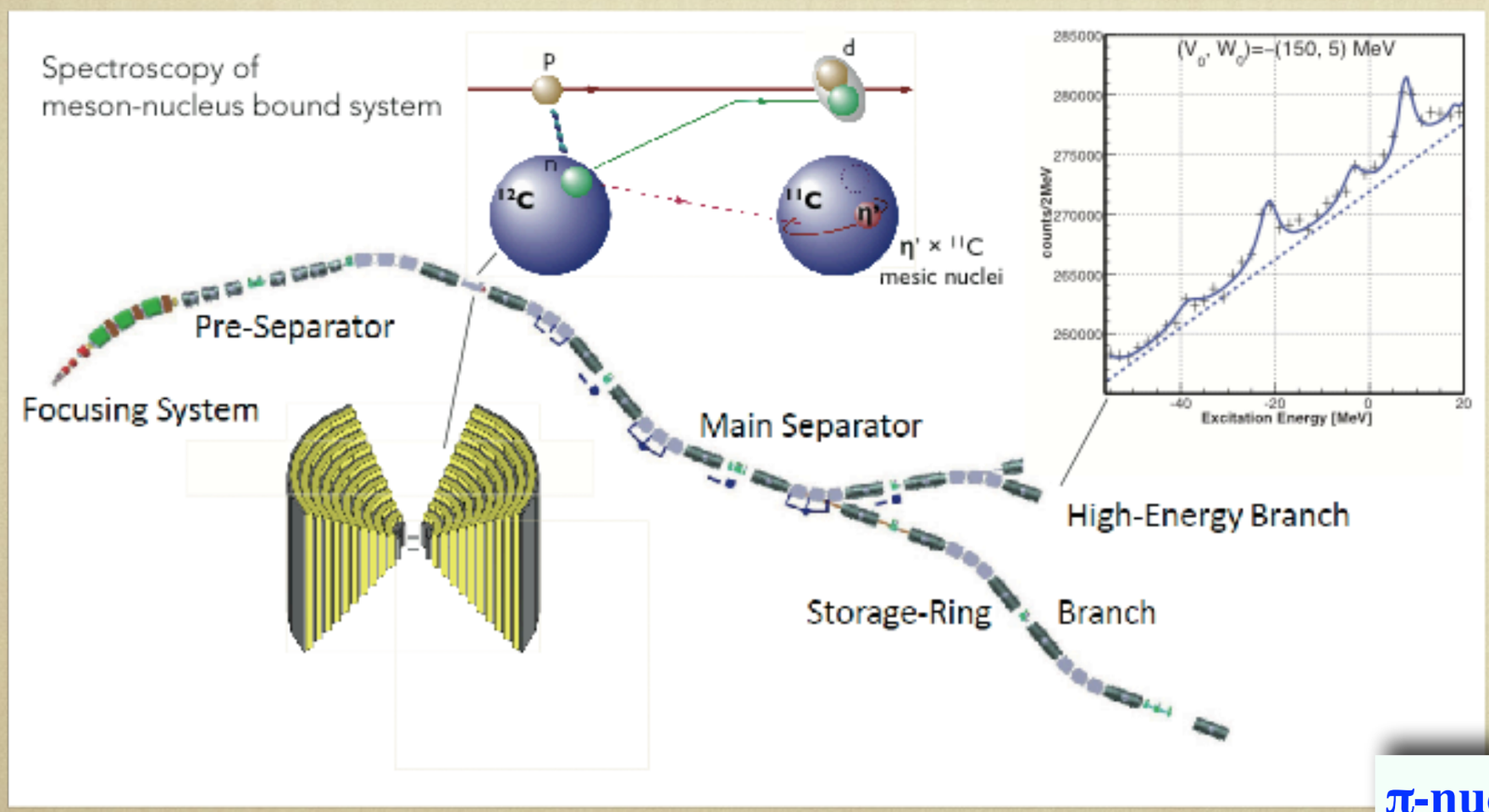
(Purushothaman, Geissel et al.)

- **Accurate knowledge of the atomic interaction of ions penetrating through 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 also for gas stopping cells optimization.***
- **Resonant coherent excitation in crystals (nuclear Okorokov effect) will be measured for the first time.**

Experience continues from FRS.

3. Spectroscopy of meson-nuclus bound system (mesonic atoms) (Itahashi, Weick et al.)

- **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 contributes 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.**



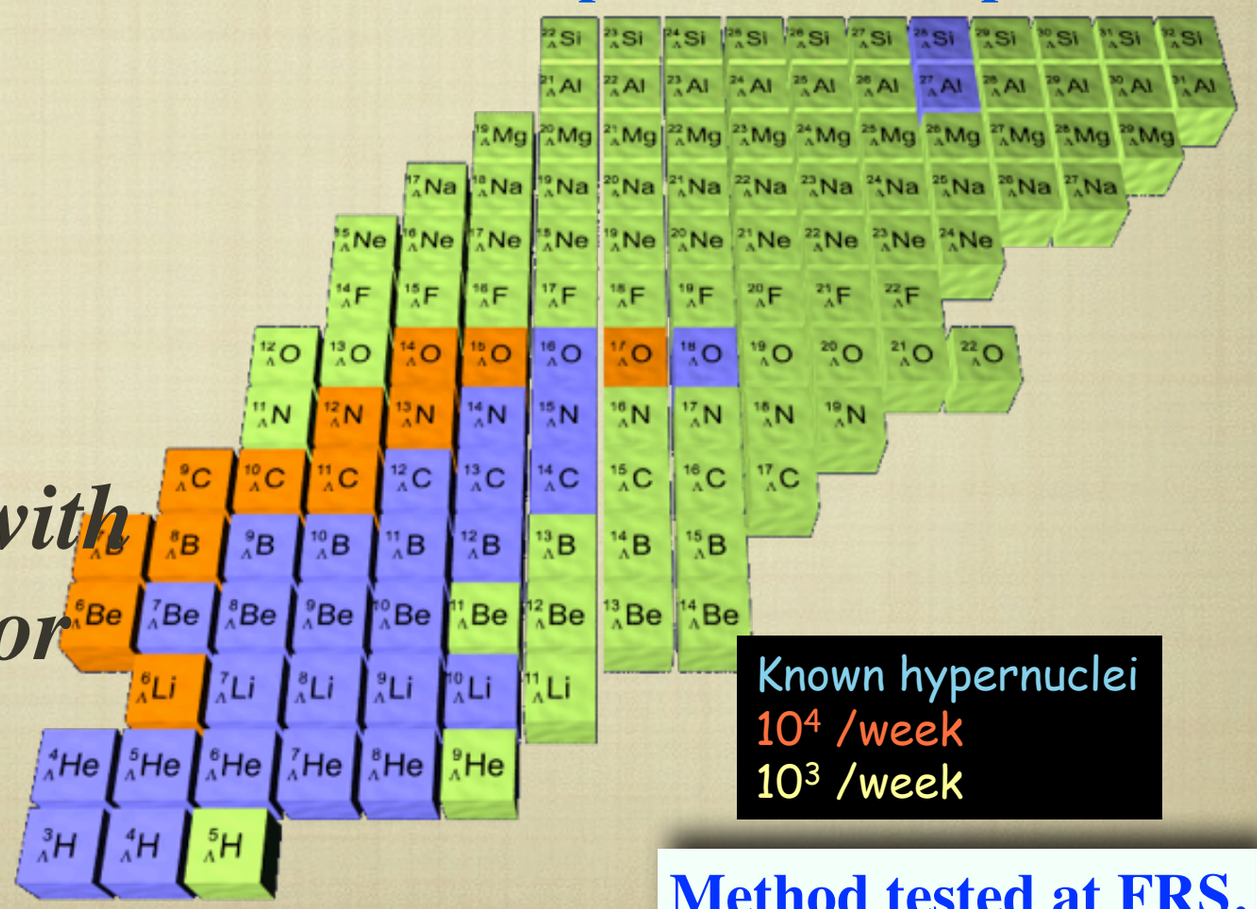
π-nucleus discovered at FRS.

4. Exotic hypernuclei and their properties

(Saito, Nociforo et al.)

- 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
- 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

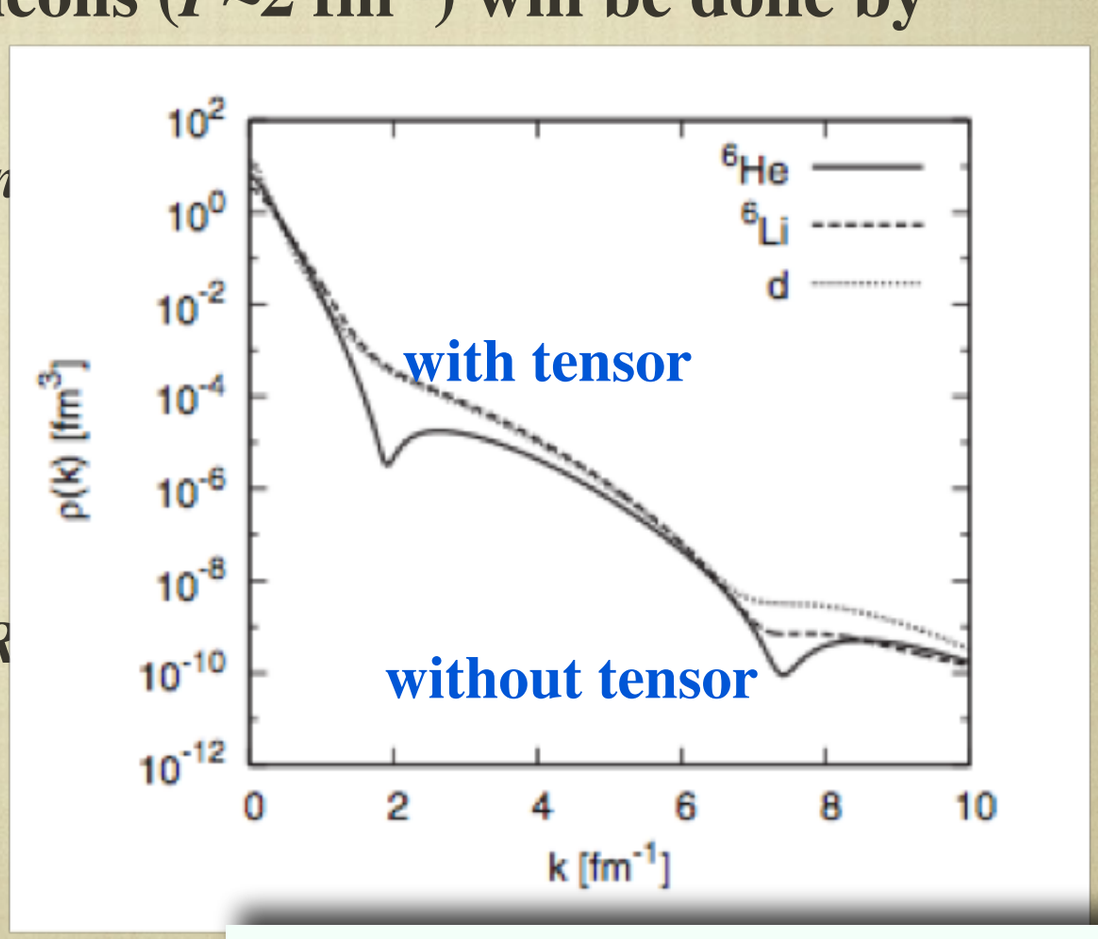


Method tested at FRS.

5. Importance of tensor forces in nuclear structure

(Ong, Terashima, Toki et al.)

- **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 through nucleons with high momentum.**
- **Studies of such high-momentum nucleons (P~2 fm^{-1}) will be done by high-energy pick-up reactions.**
  - ***(p,d), (d,^{3}He), (d,t), (p,pd), (p,nd) reaction***
  - ***In some complementary cases***
  - ***(p,pd), (p,nd) reactions may be better at R***
  - ***It has to be carefully evaluated.***



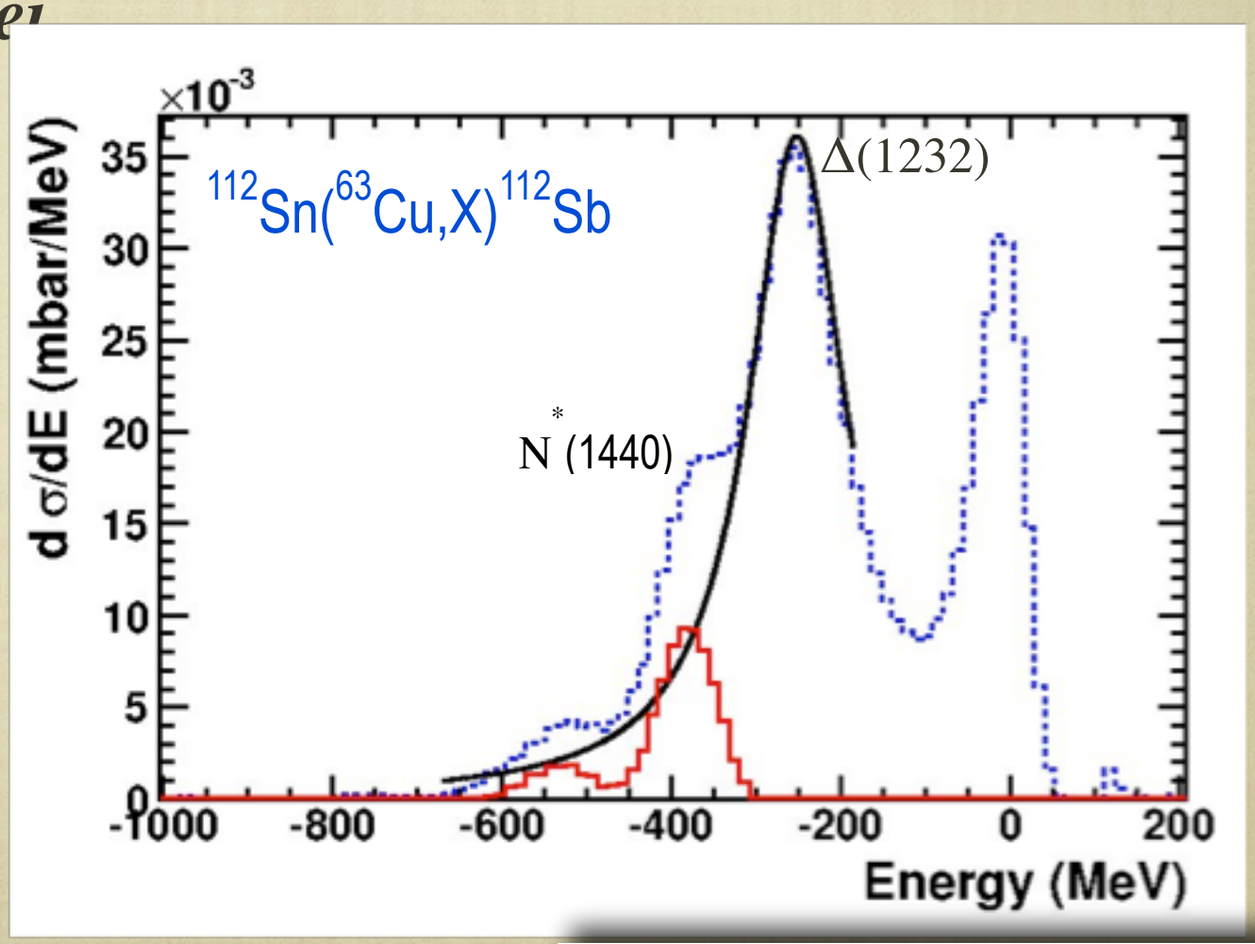
Pilot experiment planned at FRS.

6. Delta resonances probing nuclear structure

(Benlliure, Lenske et al.)

- **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 studied 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***



Some data obtained at FRS.

7. Nuclear Radii and momentum distribution

(Kanungo, Prochazka et al.)

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

Experiments developed at FRS lead the world study of exotic nuclei.

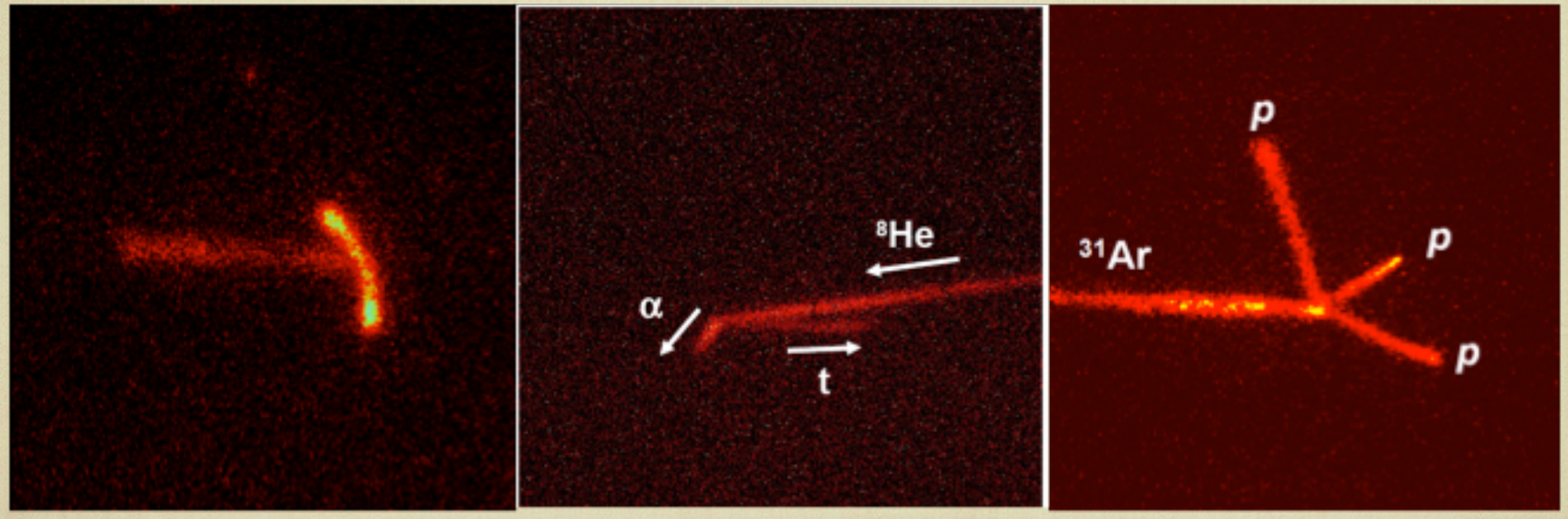
Halos, neutron skins, new magic numbers, and spectroscopy of drip line nuclei.

- ***More exclusive m… done in R3B.***
- ***Need continuous discussion for optimization for such cases.***

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

(Fomichev, Pfützner, Mukha et al.)

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



- ***Complementary with missing mass, invariant mass***

EXPERT:

EXotic Particle Emission and Radioactivity by Tracking

VERY THICK secondary target for one- or two-nucleon knockout

Identification of heavy fragment excitations by target area g array

GADAST

4

Last achromatic stage of fragment separator is **Hi-res spectrometer** for heavy decay fragment

Degrade the heavy fragment energy

$^{A-1}(Z-2)$

5

$^{A-2}(Z-1)$

Warsaw OTPC

Radioactive particle emission for stopped reaction and decay products

Beam

^{A}Z

^{A-1}Z

$^{A}(Z-1)$

p

n

1

2

3

Radiation--hard SSDs

for beam diagnostics

mSi tracking

detector system for light charged particles

NeuRad

High-angular resolution neutron detector

FRS, SuperFRS one of the middle focal planes

Particle unstable systems beyond proton or neutron driplines

Hi-res angular measurements both for proton and neutron dripline nuclei populated on secondary target

6

MC simulation framework

to interpret the correlation data with incomplete kinematics

“External” synergy for EXPERT components

EXPERT works best as a setup

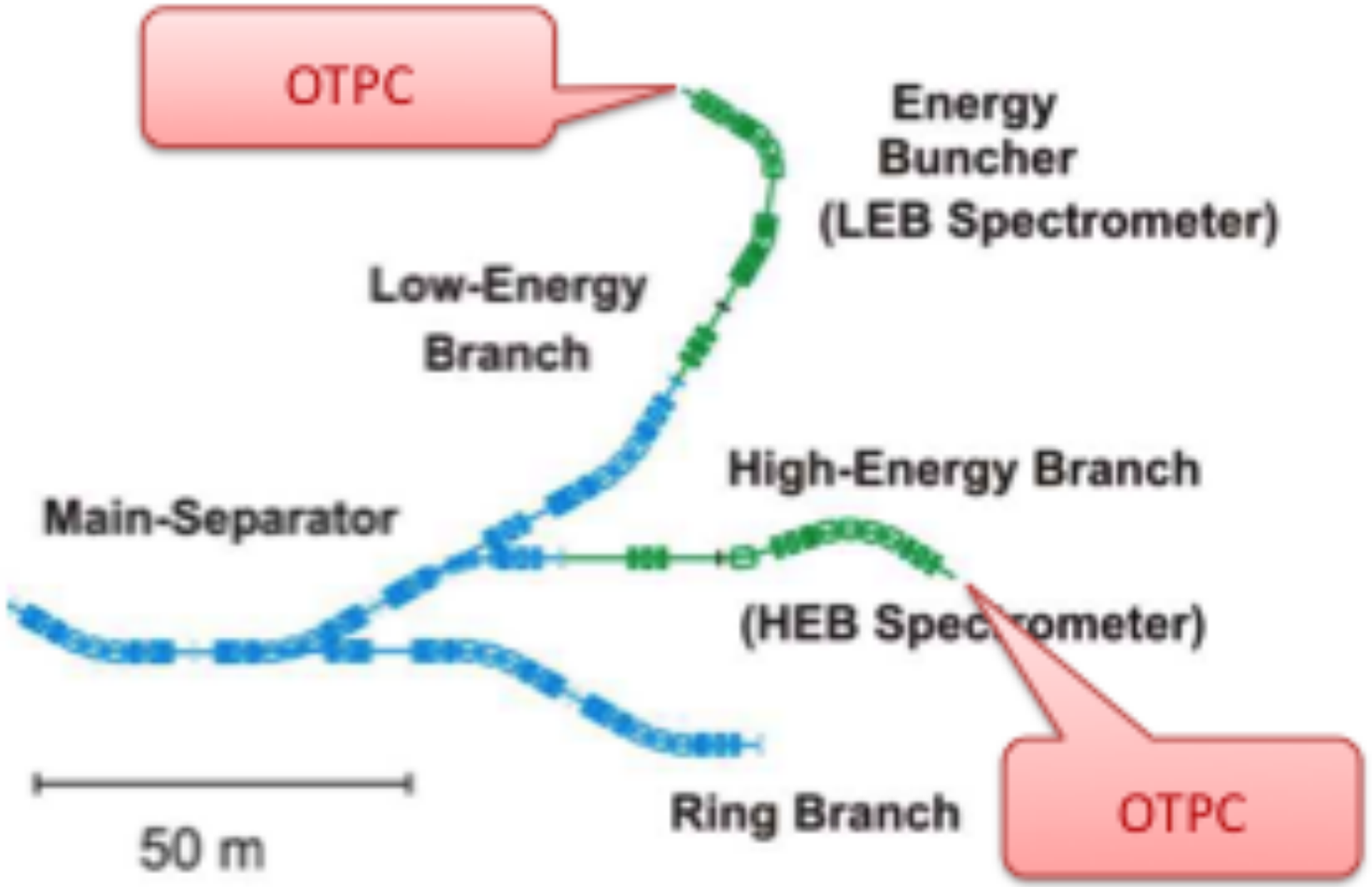
However: “modular” and “mobile” initiative

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**



10. Nuclear reaction studies and synthesis of isotopes with low-energy RIBs

(Heinz, Winfield et al.)

- **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

11* A Novel Method for Measuring β-Delayed Neutron Emission

Use a novel method to measure β-delayed neutron emission probabilities (Pxn):

1. Obtain pure isotopes with the FRS.
2. Contain them in the Cryogenic Stopper Cell for decay.
3. Then identify and count the precursor and recoil isotopes in the MR-TOF-MS.

The method is unique in its straight-forward and background-free measurement of multi-neutron emission probabilities – 4 new P_{2n} values will be measured for $^{136\text{-}138}$Sb and ^{142}I, the heaviest β_{2n} precursor measured yet.

1. The Super-FRS collaboration aims for unique science at FAIR facility. A new partner on the FAIR boat. It is important to note that the Super-FRS collaboration will pursue a scientific program within NUSTAR, which is complementary to the capabilities of other detection setups. The identity of the collaboration is guided by its physics goals and related instrumentation. Super-FRS collaboration aims at experiments, which address excellent science and applications and which are unique on the worldwide scale and within the NUSTAR collaboration.
2. It has experience and expertise with the presented topics: physics ideas and experimental ideas to take advantages of the high-resolution/high-precision spectrometer setups.
3. Program is timely. Many programs are unique even after several years of developments in the world.
4. It gives highly cost effective science outputs for modest extra costs
5. New partners would bring additional funds!

Please provide us your continuous support, suggestions and guidance.