# Isolde Superconducting Recoil Separator

## Physics case

### Working team on Physics cases:

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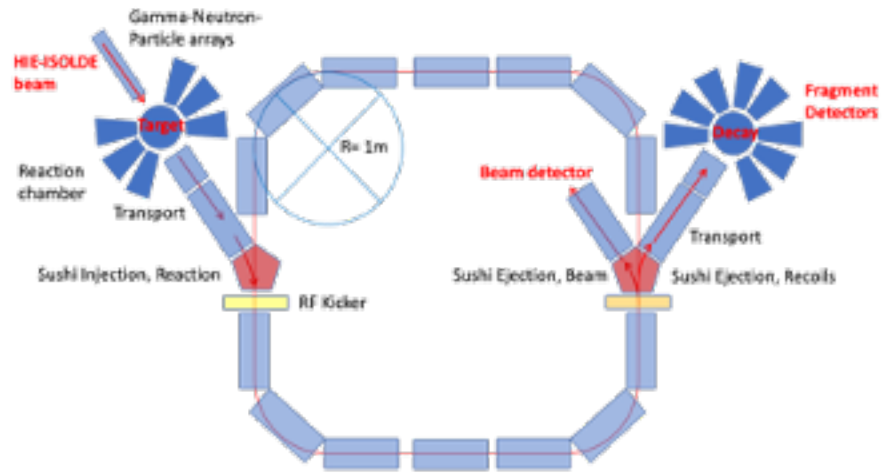
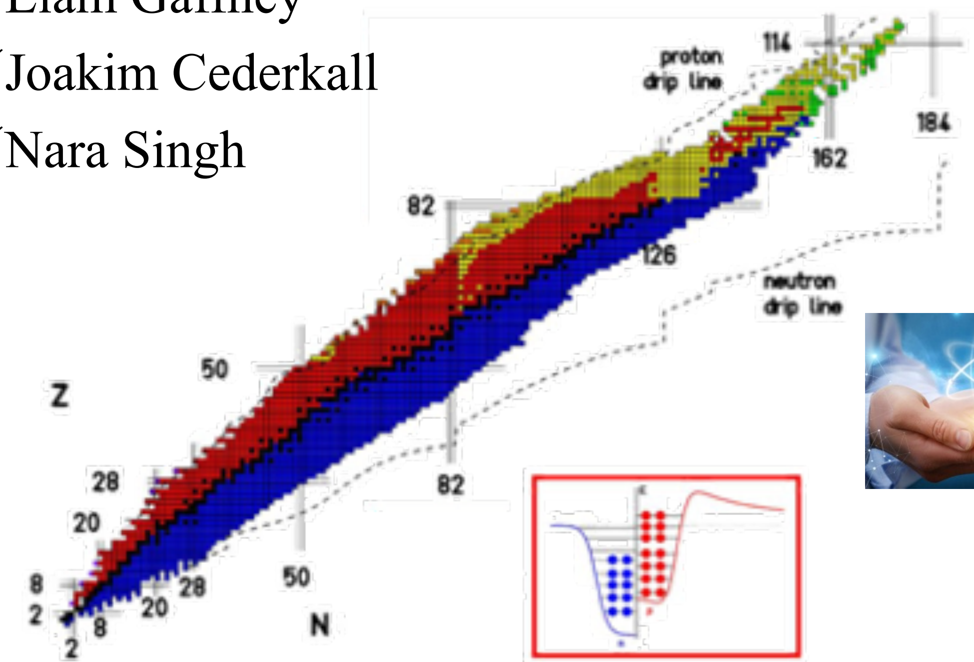
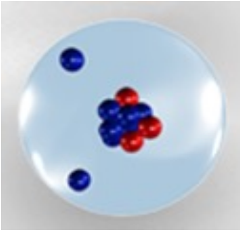
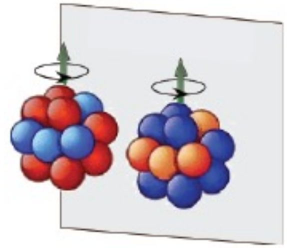
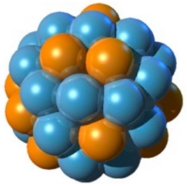
- ✓Joakim Cederkall
- ✓Nara Singh

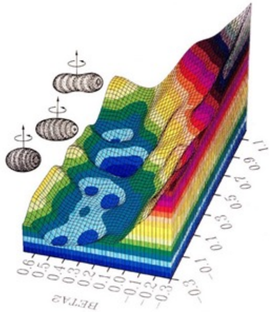




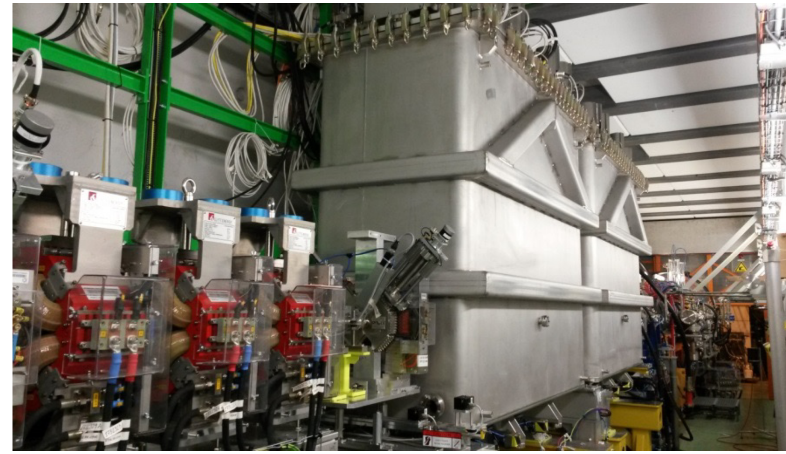




# HIE-ISOLDE Beams

Table 1.1: Requested beam characteristics at HIE-ISOLDE.

| Beam parameter | Description or value |
|---|---|
| Energy | continuous from < 0.7 to at least 10 MeV/u |
| Beam spot diameter | < 1 – 3 mm FWHM |
| Beam divergence | < 1 – 3 mrad FWHM |
| Micro-bunch structure[a] | no requirement of micro-bunching to bunch at < 1 ns FWHM with ~ 100 ns bunch spacing |
| Macro-bunch structure[a] | longer pulse lengths or cw operation |
| Energy spread | < 0.1% |



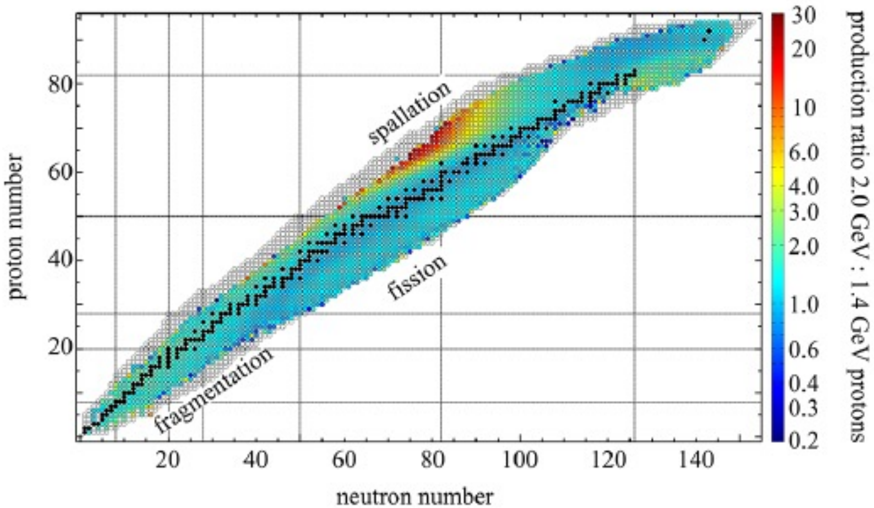



**Fig. 11.** The expected ratio across the nuclear chart for 2 GeV *versus* 1.4 GeV protons on a 62 g/cm$^2$ thick uranium target. The regions where the fragmentation, fission and spallation processes dominate are indicated. Courtesy of A. Gottberg.

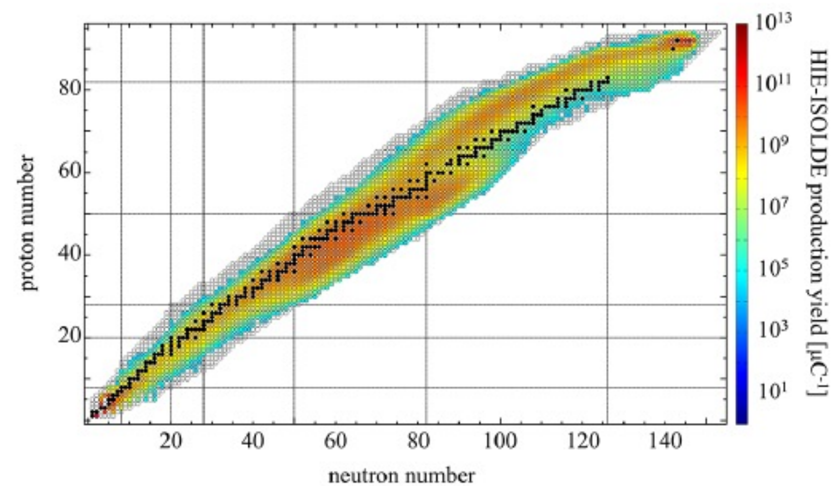


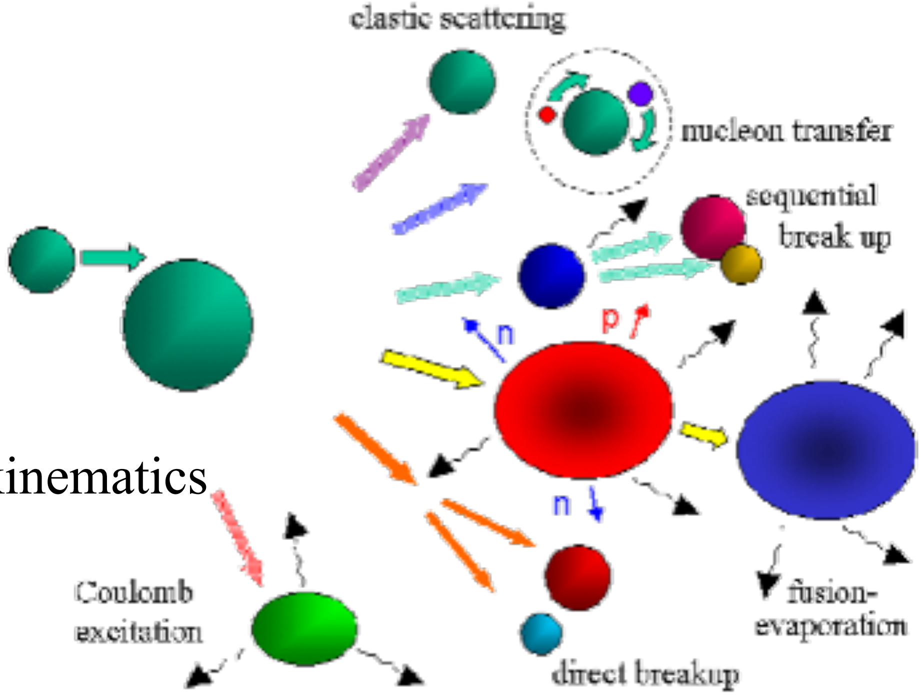

**Fig. 13.** The FLUKA [54] expected yields in $\mu C^{-1}$ across the nuclear chart assuming HIE-ISOLDE conditions, *i.e.* an energy of 2.0 GeV on a 62 g/cm$^2$ $UC_x$ target thickness in a cylinder of 1.8 cm diameter and 18 cm length surrounded by the conventional ISOLDE graphite sleeve and tantalum target container. Courtesy of A. Gottberg.

# Physics opportunities

The ISRS allows an application of several reaction mechanisms to produce exotic nuclei in the energy levels of interest, decays of which can be observed by detecting particles or photons with the existing and planned detection systems

## Reaction mechanisms

- ✓ Deep inelastic reactions
- ✓ Coulomb dissociation
- ✓ Transfer reactions in inverse kinematics
- ✓ Multinucleon transfer reactions
- ✓ Fusion evaporation reactions in inverse kinematics
- ✓ Transfer, breakup and fusion reactions
- ✓ Resonant elastic scattering

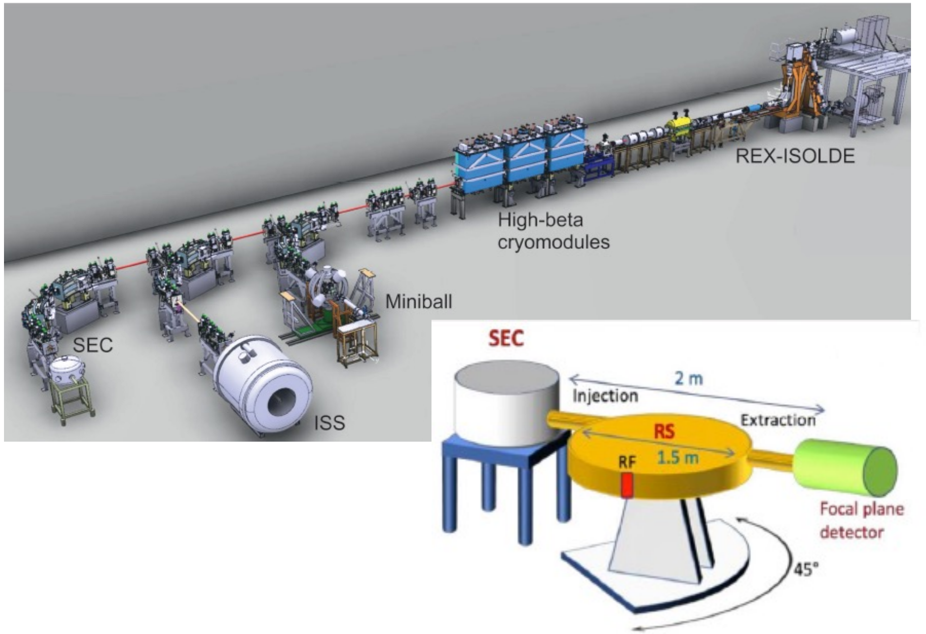


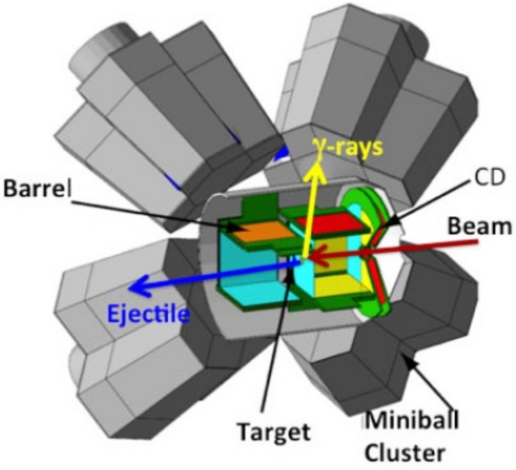
# Technical specifications

***Physics cases that can benefit from ISRS:***

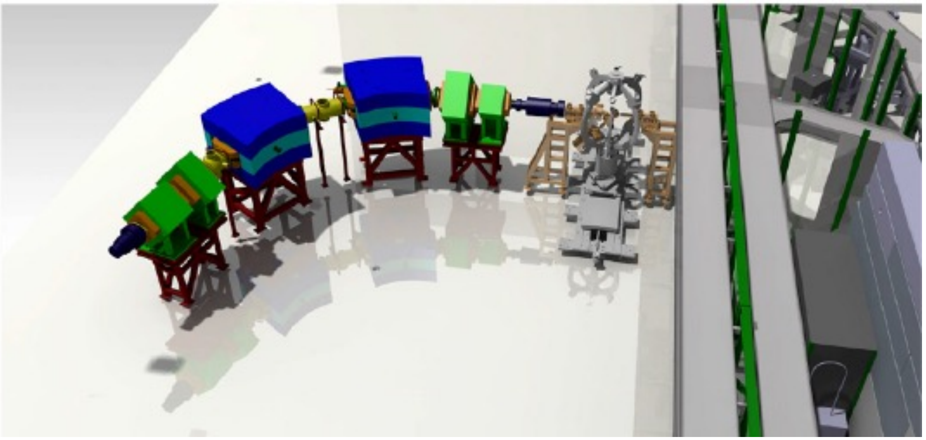
Detection of recoils alone, close to zero degree.
Recoil in coincidence with other detectors for particles, neutrons or gammas at reaction target or at focal plane (decay spectroscopy).
Existing detectors:

Line XT03:GLORIA, SED, SAND
Line XT02: ISS
Line XT01: MINIBALL, HI-TREX




Coincident measurements, like T-Rex-Minibal + 0 degree detection. Couple with a new MR-TOF.



# Technical specifications

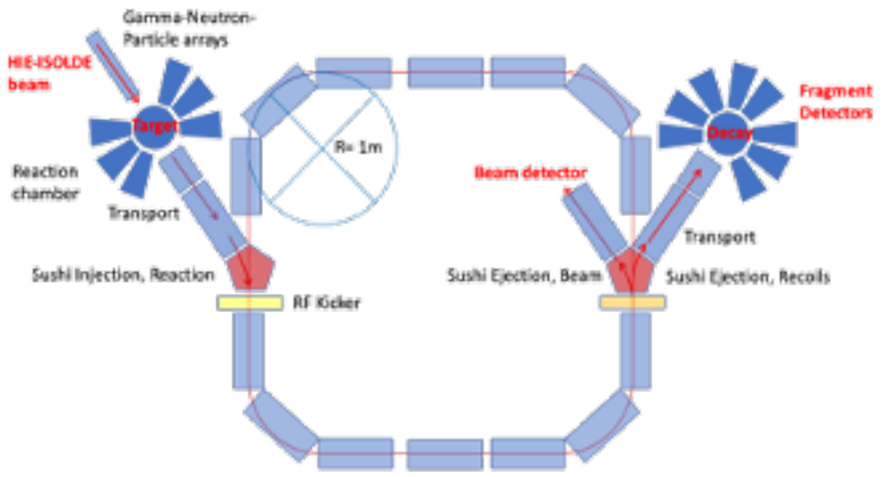
***Performance requested of the instrument***

Energy: $4 \leqslant E_{lab}/A \leqslant 10$ MeV
Large acceptance (~ 15 degrees)
Energy resolution < 100 keV
Time resolution ~ 100 ns (for coincidences)
Excellent angular resolution (to allow kinematic reconstruction and Doppler correction) ~ 0.1 degrees(to be confirmed).
Event-by-event PId for :

- physical separation of reaction products of interest from the beam, isobaric beam contaminants, fusion-evaporation reactions with target
- At least VAMOS-like $\Delta Q/Q \sim 1/70$ (FWHM), $\Delta M/M \sim 1/200$ (FWHM) $\Delta Z/Z \sim 1/60$ (FWHM).

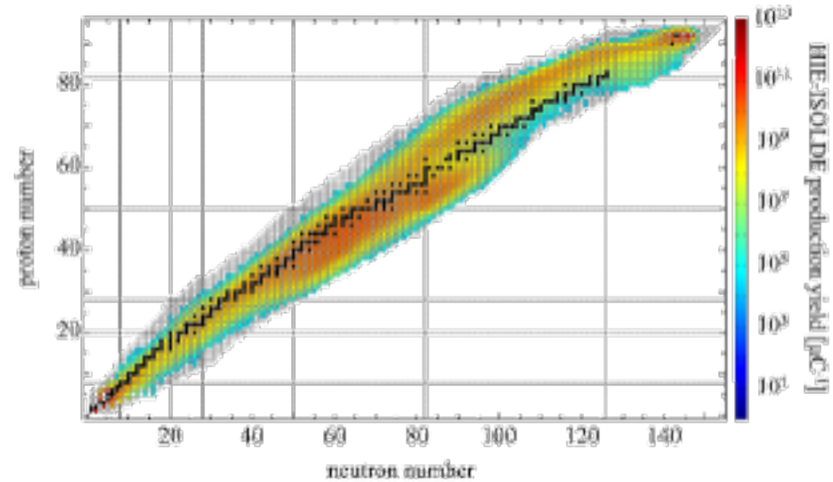
**Targets :**

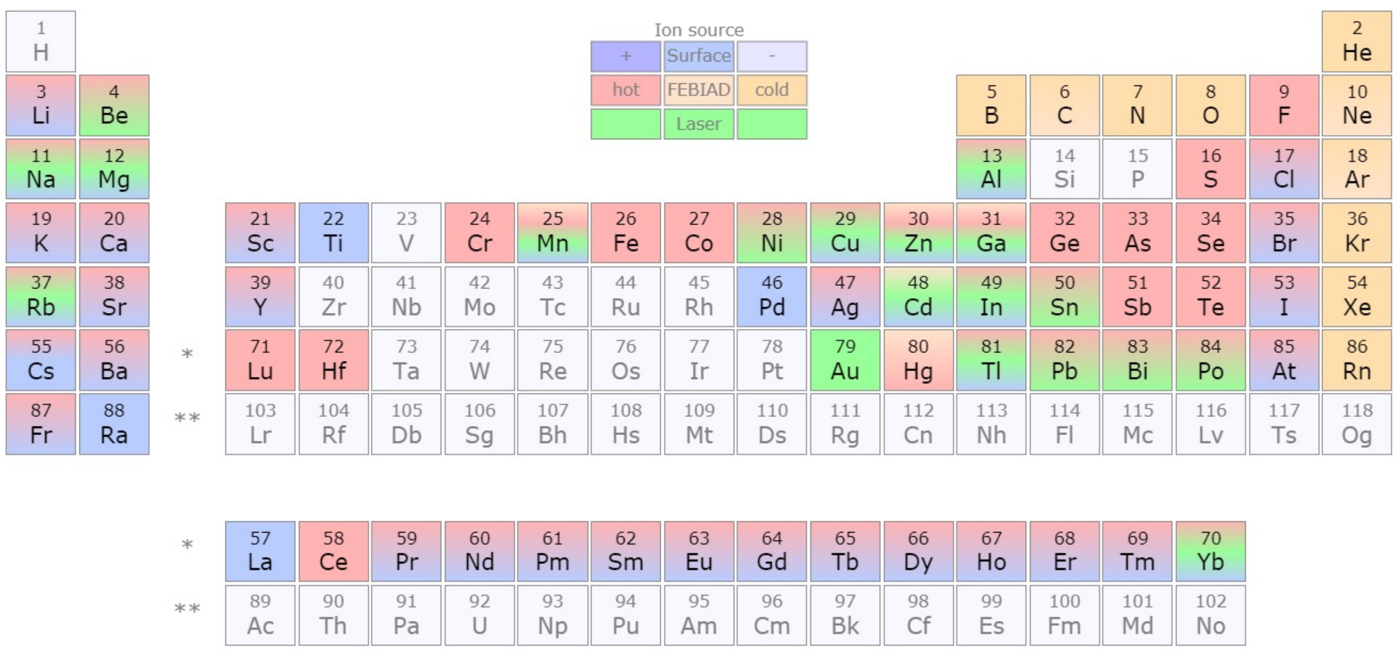
- ✓ Solid (also implanted) and cryogenic targets (H,3He,LHe), 12C.
- ✓ Solid 208Pb targets.
- ✓ Maybe also 198Pt and 193Ir targets.



# Physics cases

- ✓ Weakly bound nuclear systems and clusters
- ✓ Shape coexistence and nuclear isomerism
- ✓ Evolution of Nuclear Shells
- ✓ Isospin symmetry
- ✓ Pairing
- ✓ Nuclear astrophysics
- ✓ Physics beyond standard model



# White Book Timeline

<u>Milestones :</u>

MS1. First Workshop and report on physics cases (M24)

MS2. Second Workshop and report on physics cases (M48)

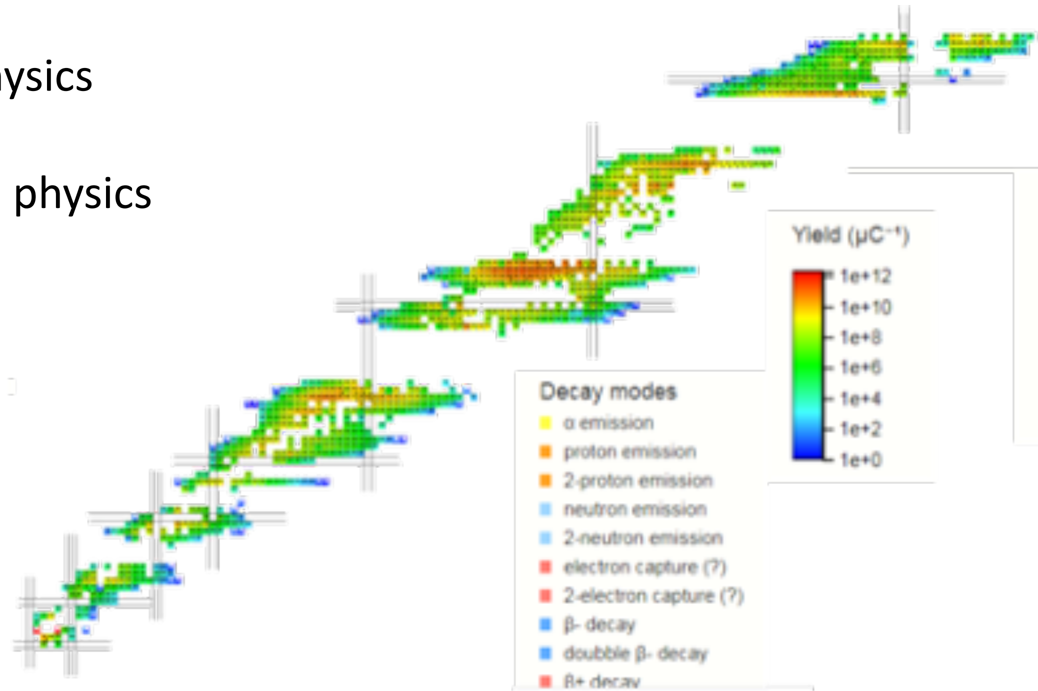
MS3. Final White Book (M60)

<u>Deliverables :</u>

D1. First Physics case Report (M24)

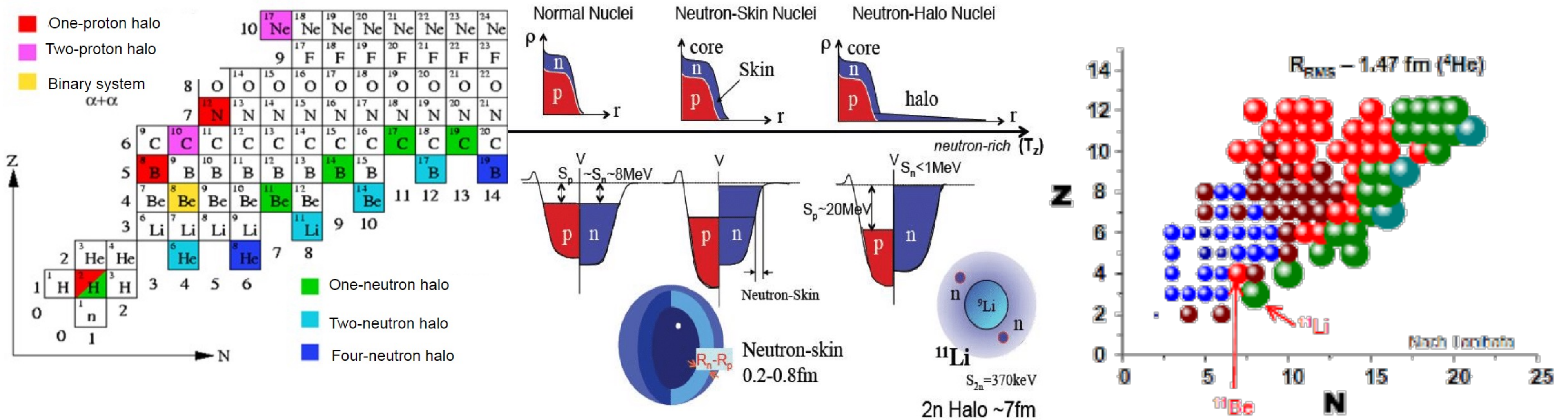
D2. Second Physics case Report (M48)

D3. Final White Book (M60)




| | TIMETABLE | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $1^{st}$ y | | | $2^{nd}$ y | | | $3^{rd}$ y | | | $4^{th}$ y | | | $5^{th}$ y | | |
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| **1. System specifications and selection of technologies** | | | | | | | | | | | | | | | |
| 1.1 Requirements review | ■ | ■ | | | | | | | | | | | | | |
| 1.2 Physics case/Whitebook | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| 1.3 ISRS cost and timeline evaluation | | | | | | | | | | | | ■ | ■ | ■ | ■ |

# Weakly bound nuclear systems and clusters

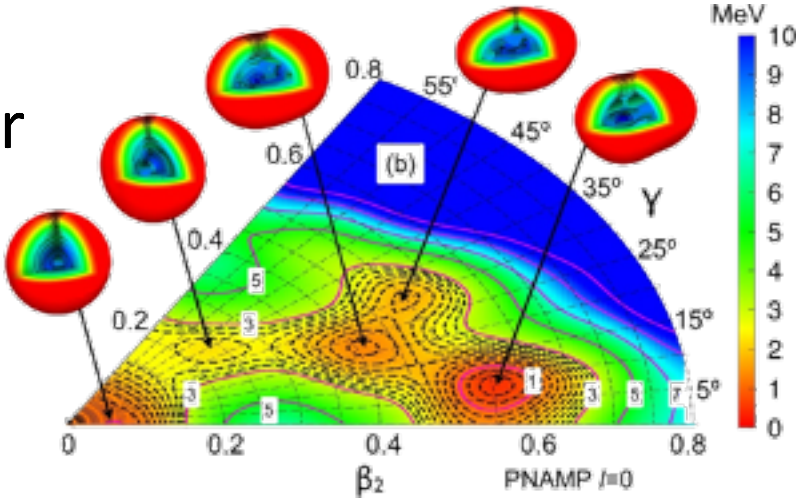


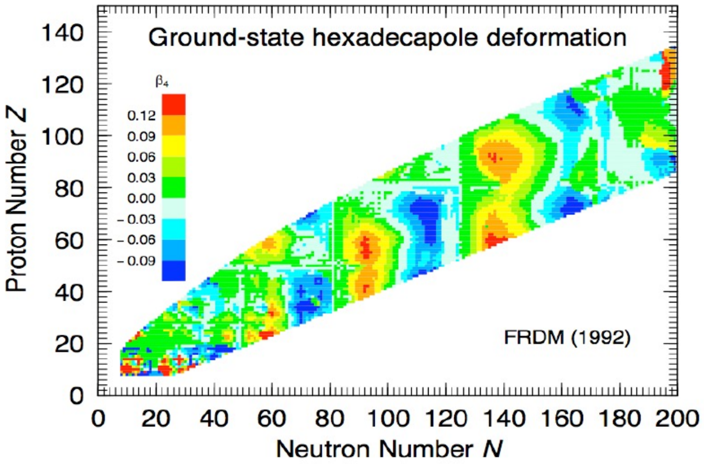

- ✓ Known examples of ground states halos are the neutron-rich isotopes $^{6,8}$He, $^{11}$Li, $^{11,14}$Be, $^{14}$B, $^{15}$C and $^{19}$C, and theoretical predictions exists for $^{12}$Be, $^{17, 19}$B, $^{17, 22}$C, $^{22}$N, $^{23}$O, $^{24, 26, 27, 29}$F, $^{29}$Ne.
- ✓ On the proton rich side the Coulomb potential prevents the formation of the halo and clear evidence of proton haloes occurs for $^8$B and $^{17}$Ne.
- ✓ Proton skins are expected to be generally larger than neutron skins for comparable values of proton-neutron asymmetry. The only neutron skin confirmed so far is the case of $^8$He and $^{20}$Mg
- ✓ Common cluster structures are formed with α-particles. Exotic cluster in $^{15\text{-}18}$C, $^{17\text{-}22}$O and $^{26\text{-}30}$Mg and the transition to molecular and bubble- structures in the region of N ~ Z around $^{36}$Ar or $^{48}$Cr can be studies by nucleon pick-up reactions .

# Shape coexistence and nuclear isomerism

- ✓ In the mass 80 region shape-coexistence is expected to appear around N=Z=34, 36 and in the neutron rich mid-shell nuclei near Z = 82 proton shell closure

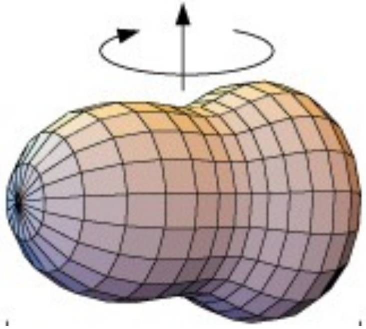
$^{80}Zr$



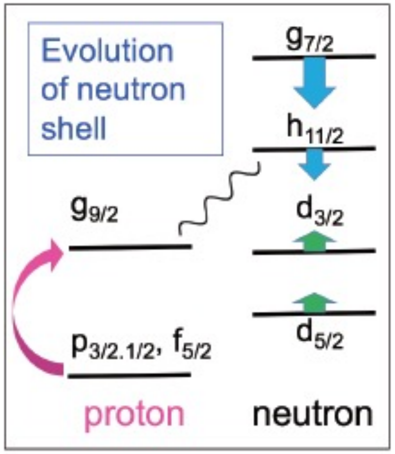




The N~Z A~80 nuclei in the Kr region and their neutron rich isotopes where shape coexistence is expected and will be the initial cases in line with the endorsed I-152 and I-207 that also aim to study higher order deformations including hexadecapole deformations.

- ✓ An interesting exotic shape is the octupole deformation observed in neutron-rich isotopes around A = 144 or 225, which builds up from Fermi-surface single-particle orbitals differing by three units of angular momentum.



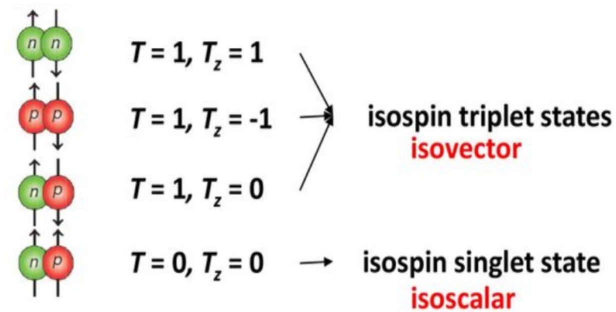
# Evolution of Nuclear Shells, Isospin symmetry, Pairing




The selectivity of single neutron and proton transfer reactions has been widely used to unravel the evolution of the shell structure. Typical reactions like (d,p), (p,d), (t,p) and (3He,d) at energies around 10 MeV/A can be used to induce transitions to specific states in the recoiling nucleus.

**Single particle transfer of n and p to single particle dominated states (etc) close to double shell closures, specifically the Sn-100 region.**

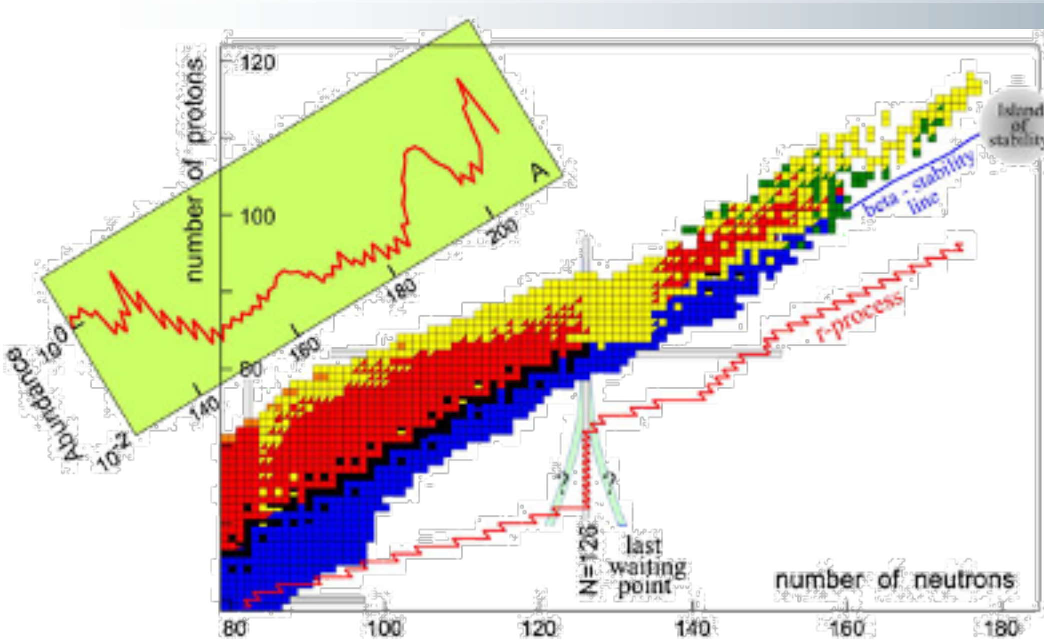
Charge dependence of the nuclear interaction and the quantification of isospin impurities. Such studies can be carried out through Coulomb excitation and single-particle transfer reactions through simultaneous (d,n) and (d,p) measurements with beams of self-conjugate nuclei.

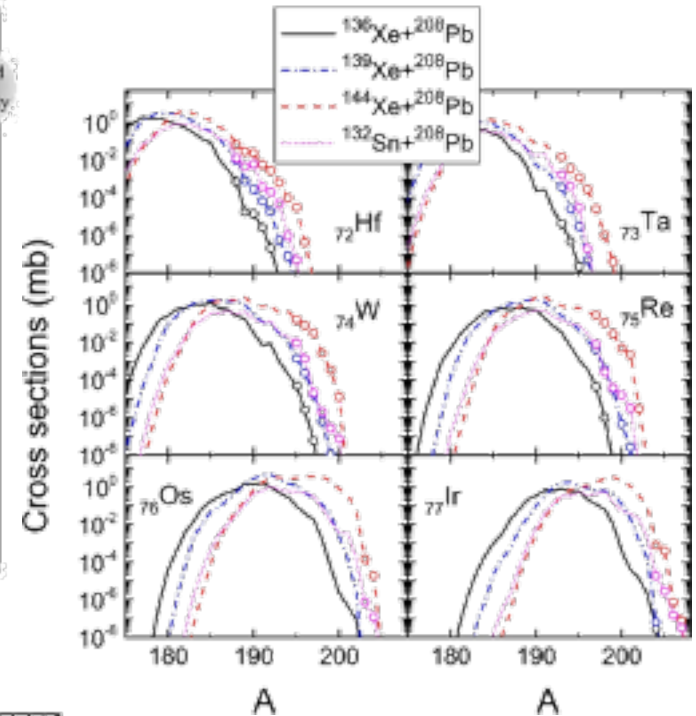



Two-nucleon transfer reactions are particularly suitable for this investigations as the transfer probability depends directly on the strength of the pairing interaction.

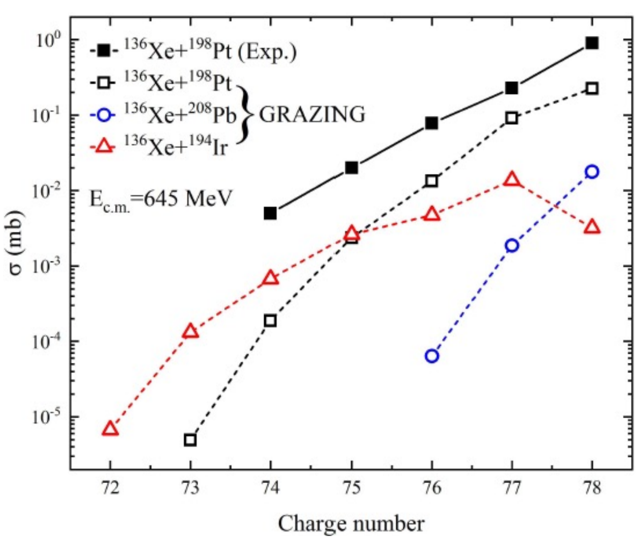
The development of high density 3,4He and tritium loaded foils and cryogenic targets opens the possibility to study (4He,d), (3He,n), (3He,p) or (t,p) reactions using moderate intensity radioactive beams in inverse kinematics.

# Nuclear Astrophysics Towards Terra Incognita

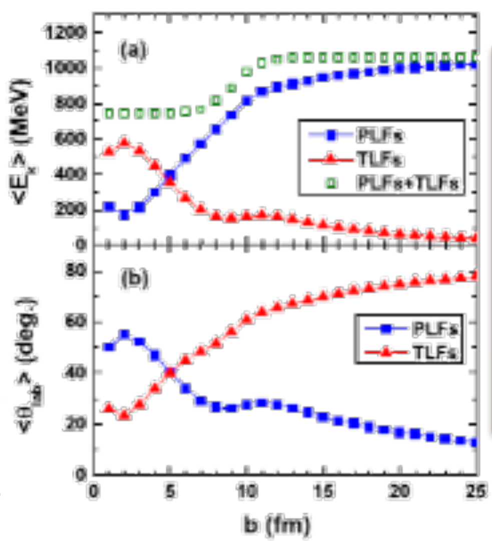



Long Zhu, Jun Su, Wen-Jie Xie Feng-ShouZhang.
Physics Letters B 767 (2017) 437–442

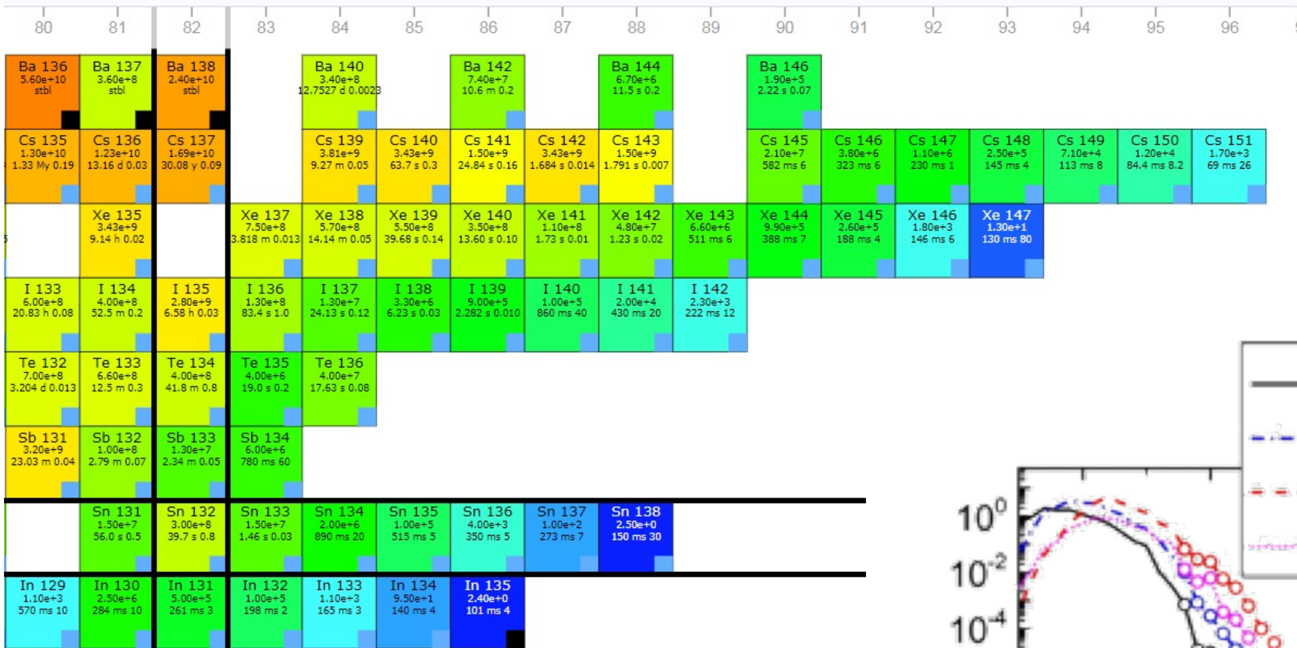



*Jiang X and Wang N Front. Phys. 8:38 (2020)*




**Should one focus at the grazing angle or should one look at near central collisions where the products are emitted near 0°?**

**The relevant collisions for producing heavy n-rich transfer products are the near central (deep inelastic) collisions (DIC) according to Feng-Shou Zhang et al, and V. Zagrebaev et al.**




:aken from *The NUBASE2016 evaluation of nuclear properties*, Audi, G., et al., Chinese Physics C, v