# CYREN

## Scientific Motivations

GANIL Scientific Council, February 1-2, 2024

# Outline

- Method
- Structure of the document
- Nuclear Physics:
  - Attractiveness
  - Some examples
- Interdisciplinary Reasearch => Clara Grygiel

# Method

- Document « CYREN Physics Motivations » written to support and justify the renovation program within the CYREN pre project
- Contribution to GANIL's vision of the future:
  - gathering various already written documents (IN2P3 prospectives, NUPECC LRP, pluriannual roadmap of GANIL, Spiro committee report,…)
  - numerous letters of intent from the interdisciplinary/multidisciplinary research and the need of GANIL facility (ARIBE to HE) to adress the prospects
  - Report on the needs and recommendations for interdisciplinary research at GANIL for the Michel SPIRO Commission, march 2021, led by N. Moncoffre and A. Cassimi
- Editorialization (documents under various forms depending on targets, context, etc; most of them rewritten; harmonization of details level; figures…)
- Send to GANIL direction; physicists for further completion
- Send to GANIL Scientific Council

# Starting point and goals

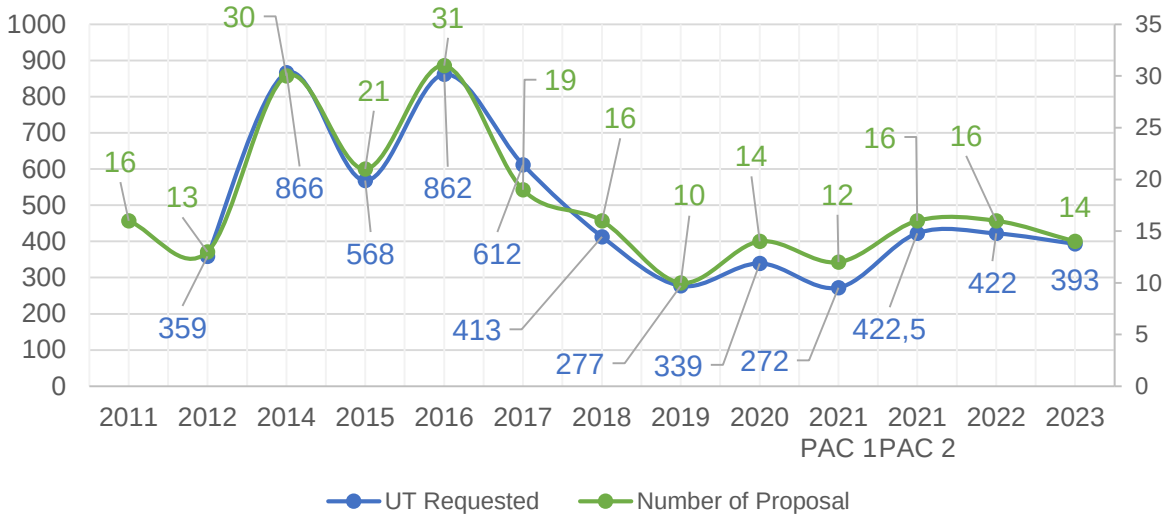
- Within the renovation program, the basic assumption is that it is a refurbishment ie w/o any upgrade (which might be not completely true)
- From this assumption, the physics program concentrates on:
  - An acceleration of the development of new SPIRAL1 beams
    - To deliver beams to the existing experimental areas of GANIL (nuclear structure, astrophysics)
    - For DESIR (mass measurements, precision measurements…)
  - To pursue and initiate new physics programs using the unique beams delivered by the cyclotrons (intensities, species, energy regime)
    - Nuclear physics
    - Interdisciplinary physics

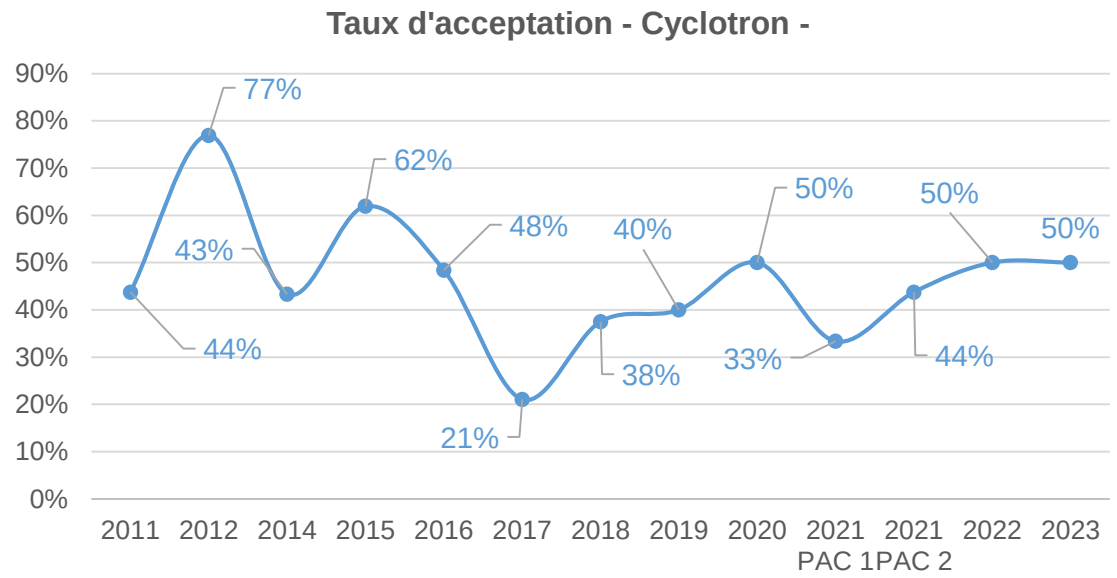
# Structure of the document

Introduction

1. Nuclear Physics
    1. Fundamental interactions
    2. Mass measurement of neutron rich light nuclei
    3. Nuclear structure and astrophysics
    4. Fission
    5. Nuclear dynamics and thermodynamics : the equation of state for nuclear matter
2. Interdisciplinary Research
    1. Materials science at GANIL : inorganic materials
    2. Materials science at GANIL : organic and hybrid materials under irradiation using GANIL ions
    3. Interdisciplinary research in laboratory astrophysics : studies of irradiation effects on molecular ices in various spacials environments
    4. Astrophysics
    5. Atomic and molecular physics at GANIL
    6. Conclusions and outlook

# Cyclotrons attractivity (nuclear physics)




- A strong and constant beam time request on the cyclotrons(~50% average acceptance ratio)
- Significant influence of detectors/campaigns of large setups (detectors, collaborations):
  - AGATA/VAMOS/NEDA/MUGAST
  - EXOGAM/LISE/MUGAST/ZDD
  - EXOGAM/VAMOS/PISTA

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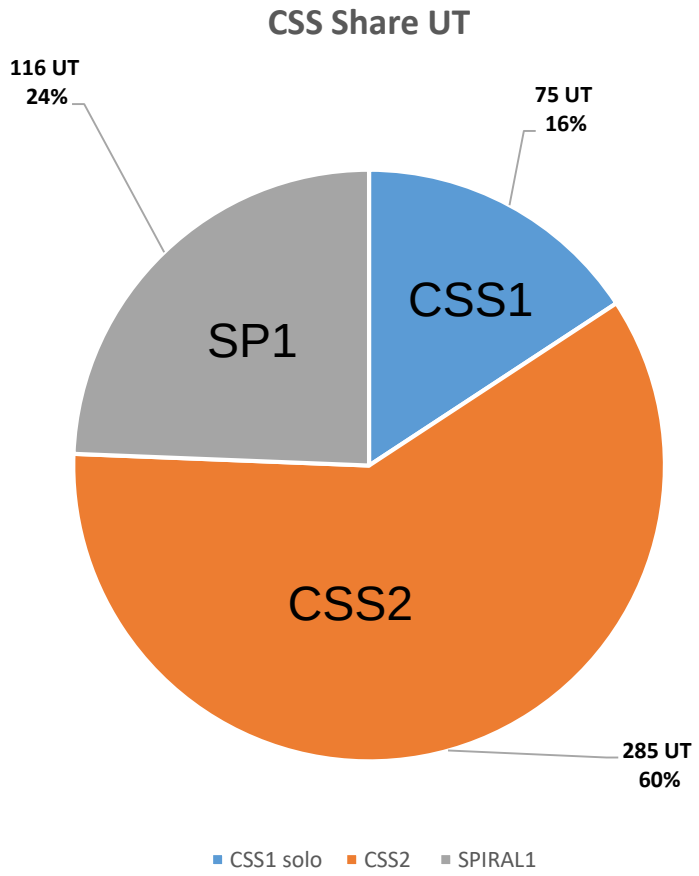


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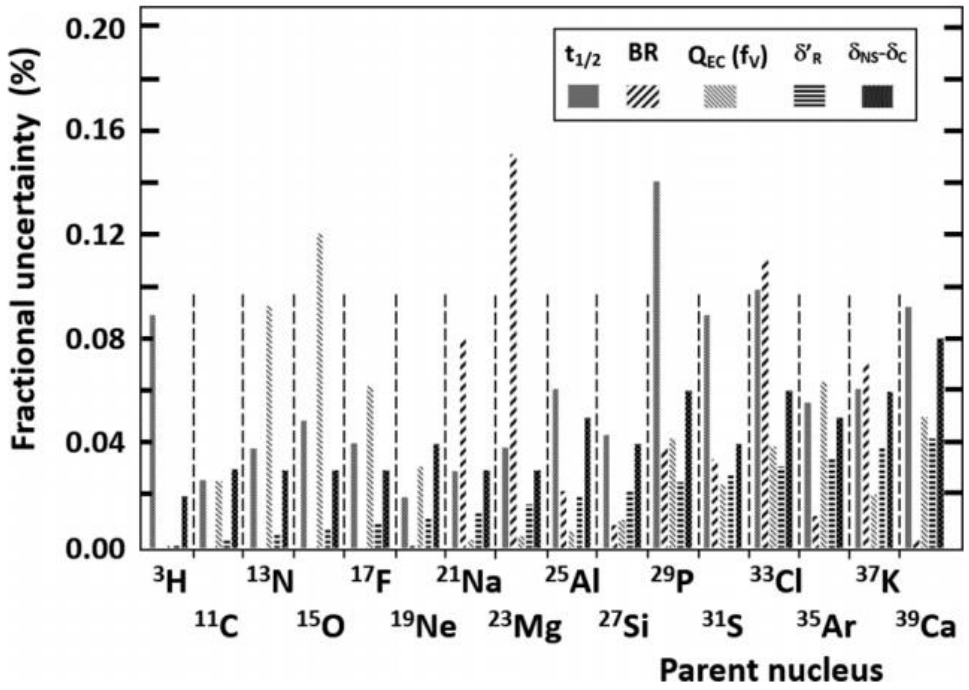
- 2023: a large majority requests CSS1+CSS2 (high energy, SP1)

# Main motivations

- The main pillars of the motivations:
  - (new) RIBs from SPIRAL1 for
    - DESIR physics program (fundamental interactions, mass measurements)
    - (+CIME) Nuclear structure/astrophysics
    - (+CIME) Studies as a function of N/Z: structure at high E*, level density
  - RIBS from fragmentation
    - Nuclear structure (shells, pairing, clustering, astrophysics)
  - Heavy stable beam, inverse kinematics for nuclear dynamics
    - At « low » energy: fission program at VAMOS+PISTA
  - Stable beams at high energy
    - At « high » energy: EOS (as a function of density), vaporization/clusterization,…

# DESIR physics program with SP1 beams: Fundamental interactions



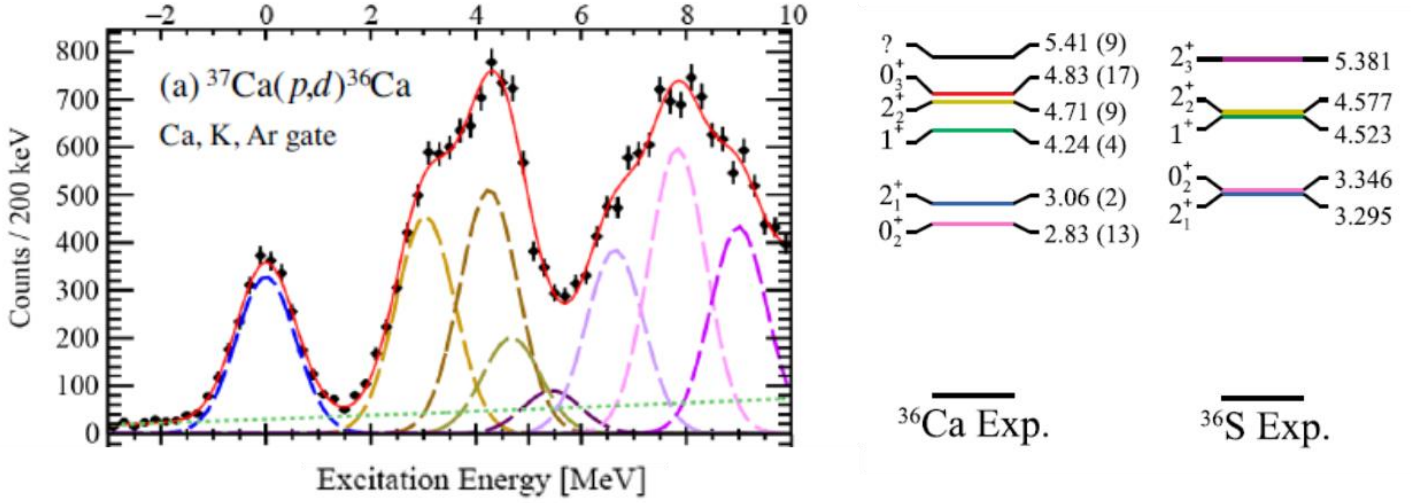

*N. Severijns et al., Phys. Rev. C 107, 015502(2023)*

- Complementary to high energy experiments, high-precision measurements of nuclear beta decay to:
  - search for signs of physics beyond the SM
  - better constrain some of its hypotheses
- Three ways:
  - search for exotic weak interaction currents of scalar (*S*) and tensor (*T)* types
  - search for time-reversal symmetry-violating processes.
  - tests of the unitarity of the CKM matrix and of the CVC (conserved vector current) hypothesis:
    - reducing uncertainty in Ft values associated with mirror transitions
    - Measurements of BR and half-life
    - Need ultra pure beams: PIPERADE

⇒ **Need (new) RIBs beams from SP1 => CSS1+CSS2** ($^{21}$Na, $^{23}$Mg, $^{29}$P, $^{33}$Cl, $^{37}$K, $^{39}$Ca, $^{41}$Sc…)

# Shell structure at « high » energy: single nucleon transfer reactions

- Well characterized probe: access to E*, J, π, spectroscopic factors => evolution of shell structure



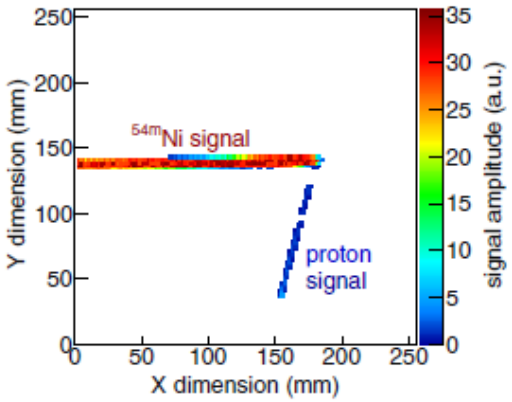

- Example of (p,d) transfer at LISE
- Liquid hydrogen target
- Comparison of mirror nuclei
- Observation of extremely large MED
- Benchmark case for ab initio calculations breaking isospin symmetry

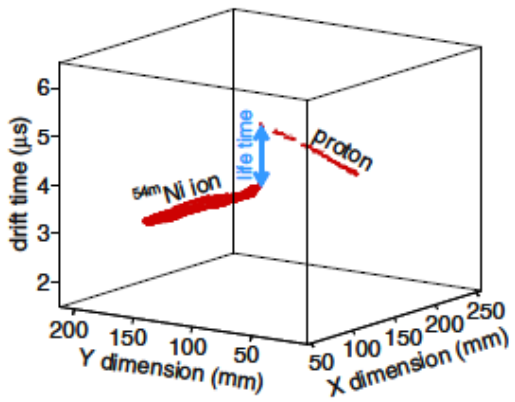
*L. Lalanne et al, Phys. Rev. Lett 129, 122501 (2022)*

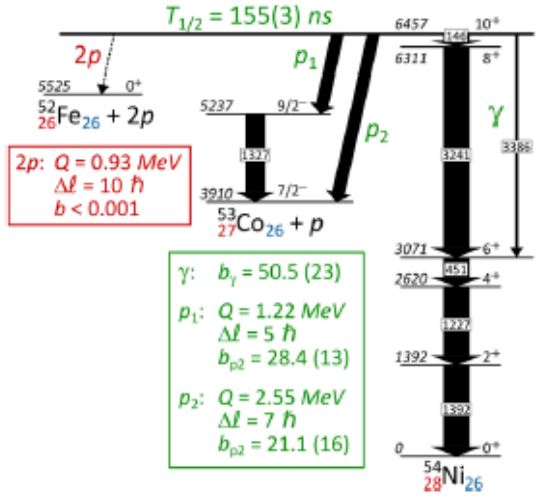
**=> Need « high » energy and intense stable beam (CSS1+CSS2)**

# Shell structure at « high » energy: single nucleon transfer reactions

- Search or rare decays using ACTAR TPC



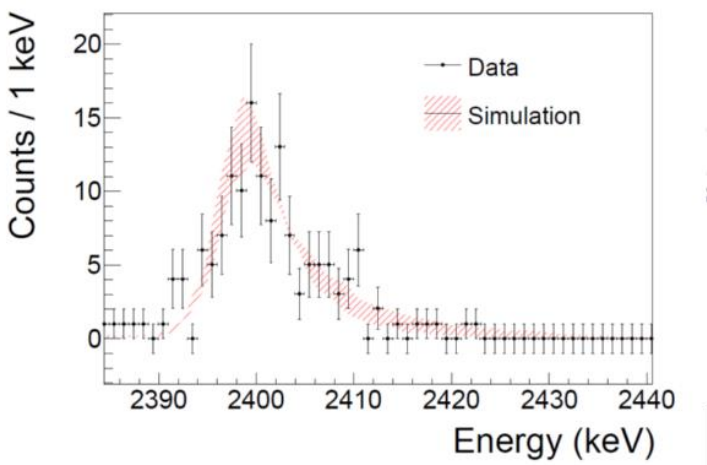

*J. Giovinazzo et al, Nat Commun 12, 4805 (2021)*

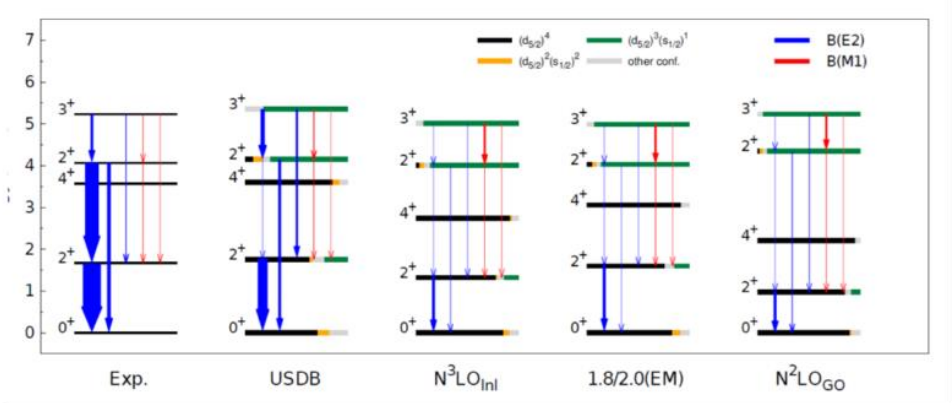
- Rare decays at the dripline: bxp, bαp, bpα,…
- Very thick gas target to compensate low beam intensities
- Vertex reconstruction+lifetime
- ~Insensitive to beta and low charged particle thresholds
- Direct observation of p decay from $10^+$ isomer in $^{54}$Ni to g.s. and 1$^{st}$ exc state in $^{53}$Ni
- Reconciles the picture of similar decay pattern in mirror nuclei ($^{54}$Fe)

**=> Need « high » energy and intense stable beam (CSS1+CSS2)**

# Shell structure with SP1 beams: exclusive measurements to probe theories

- AGATA-VAMOS-MUGAST coupling



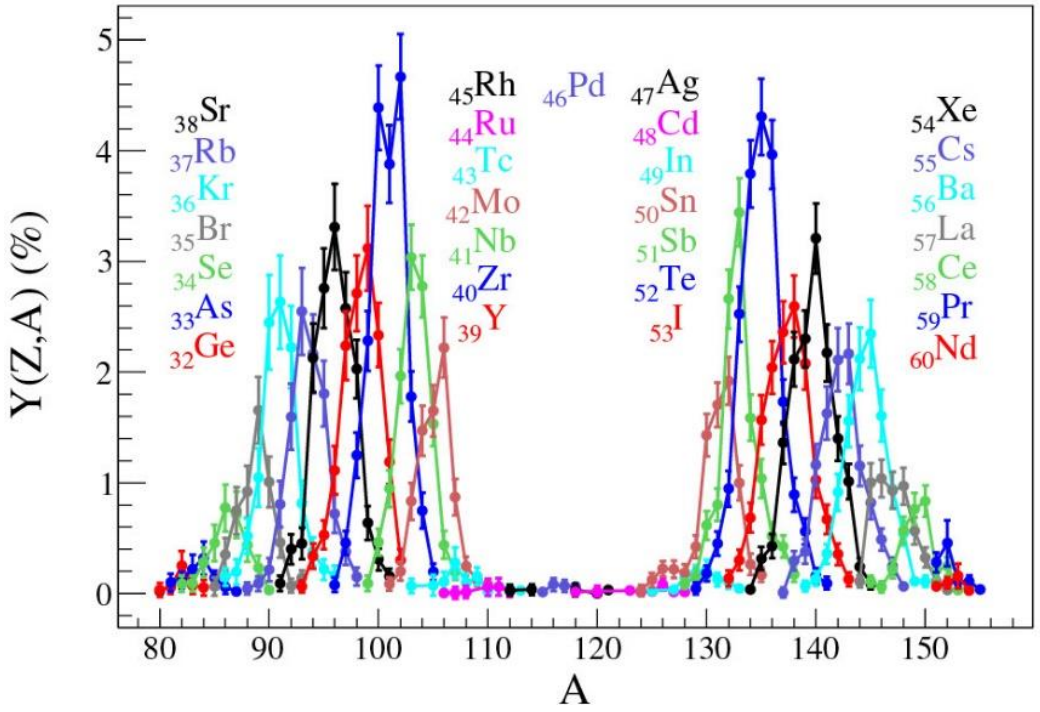

- Example of (p,d) transfer with $^{19}$O beam from SP1
- Precise (p,d) probe+exclusive measurement
- Lifetime measurement
- Elaborate test of theories

*I. Zanon et al, Physical Review Letters 131, 262501 (2023).*

**⇒ Need (new) SP1 beams => CSS1+CSS2**

# Transfer/fusion induced fission: measurements of observables at scission

- Fission with VAMOS+PISTA




*D. Ramos: VAMOS +SPIDER in the $^{238}U+^{9}Be$ reaction*

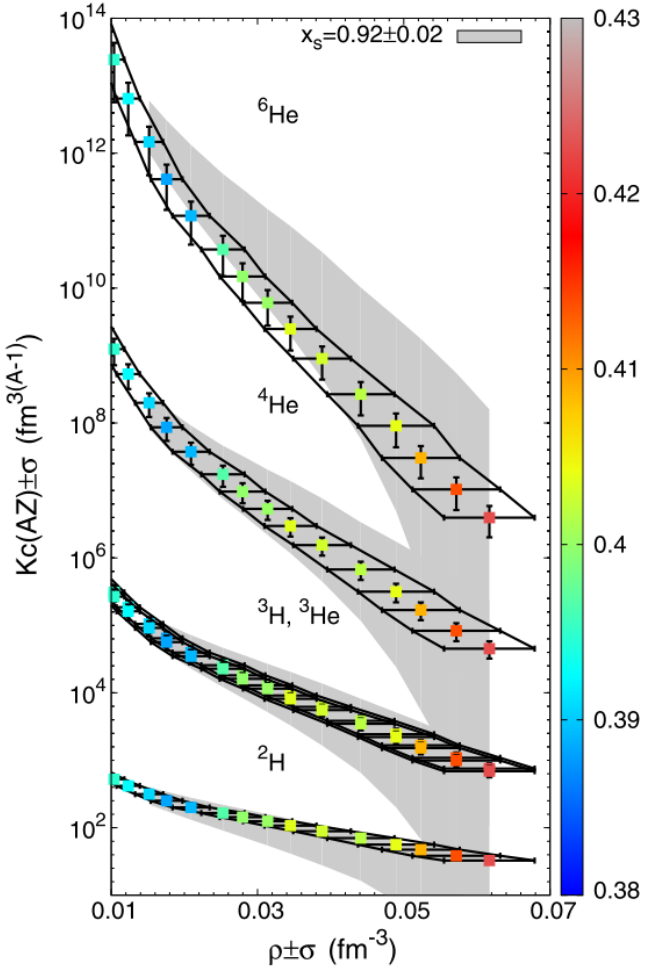
- VAMOS-2 arms+PISTA:
- Simultaneous measurement of E* and v of the two fragments
- Determination of fission observables at scission (for the first time):
  - Isotopic mass distribution
  - Kinetic energies
  - Neutron evaporation multiplicity
- Studies as a function of N/Z
- Comparison with theories

**⇒ Need heavy beams, « low » energy => CSS1**

# Multifragmentation/vaporization of n-rich systems: clusters and chemical equilibrium constants in gas

- Clusters measured with FAZIA-INDRA

*H Pais, Phys. Rev. Lett. 125, 012701 (2020)*




- Xe+Sn data measured with INDRA
- Determination of the chemical equilibrium constants $K_c(A,Z)$ == cluster production rates in proton or neutron gas at equilibrium and finite T
- $K_c(A,Z)$ depends on T and (p, n, cluster) densities
- If extracted from nuclear data, can be applied to core collapse SN simulation

⇒ **Need « high » energy (up to 60 MeV/A) beams => CSS1+CSS2**

➔ Interdisciplinary Research