NuSPRASEN ENSAR2

Nuclear Structure Physics, Reactions, Astrophysics and Superheavy Elements Network

Discussion on nuclear reaction theory in Europe

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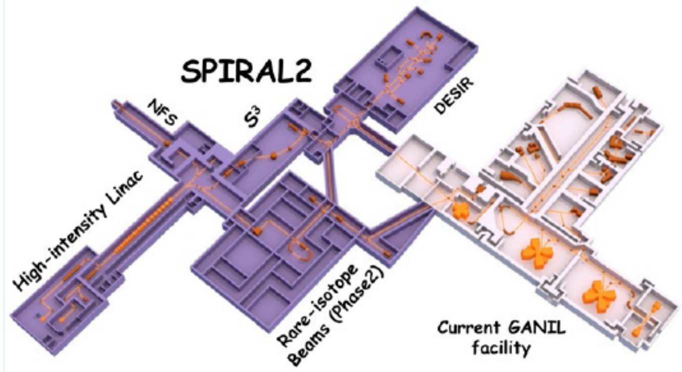
Outline:

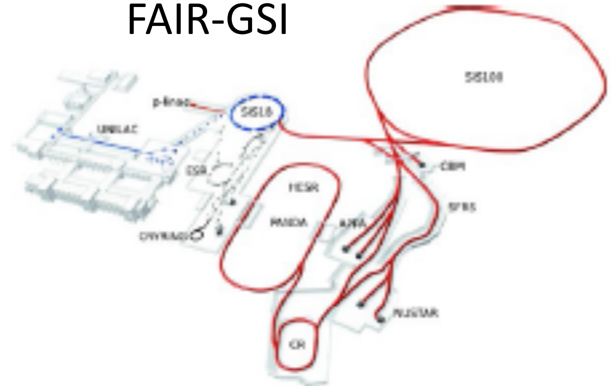
- Schematic view of nuclear (experimental) physics today
- Selected Challenges: from very low to very high energies
- The place of Nuclear (reaction) Theory in Europe

Schematic view of nuclear (experimental physics) today in Europe

From the theory point of view



FAIR-GSI



“Low energy” exotic beam facilities

< 20 A.MeV (SPIRAL2, SPES, ALTO, HIE-ISOLDE, …)

High energy facility

200 MeV-1 GeV

2018

RIBF-RIKEN, FRIB-MSU

ISOL

< 5 A.MeV (ISOLDE, …)

Low-to Medium Energy Facilities

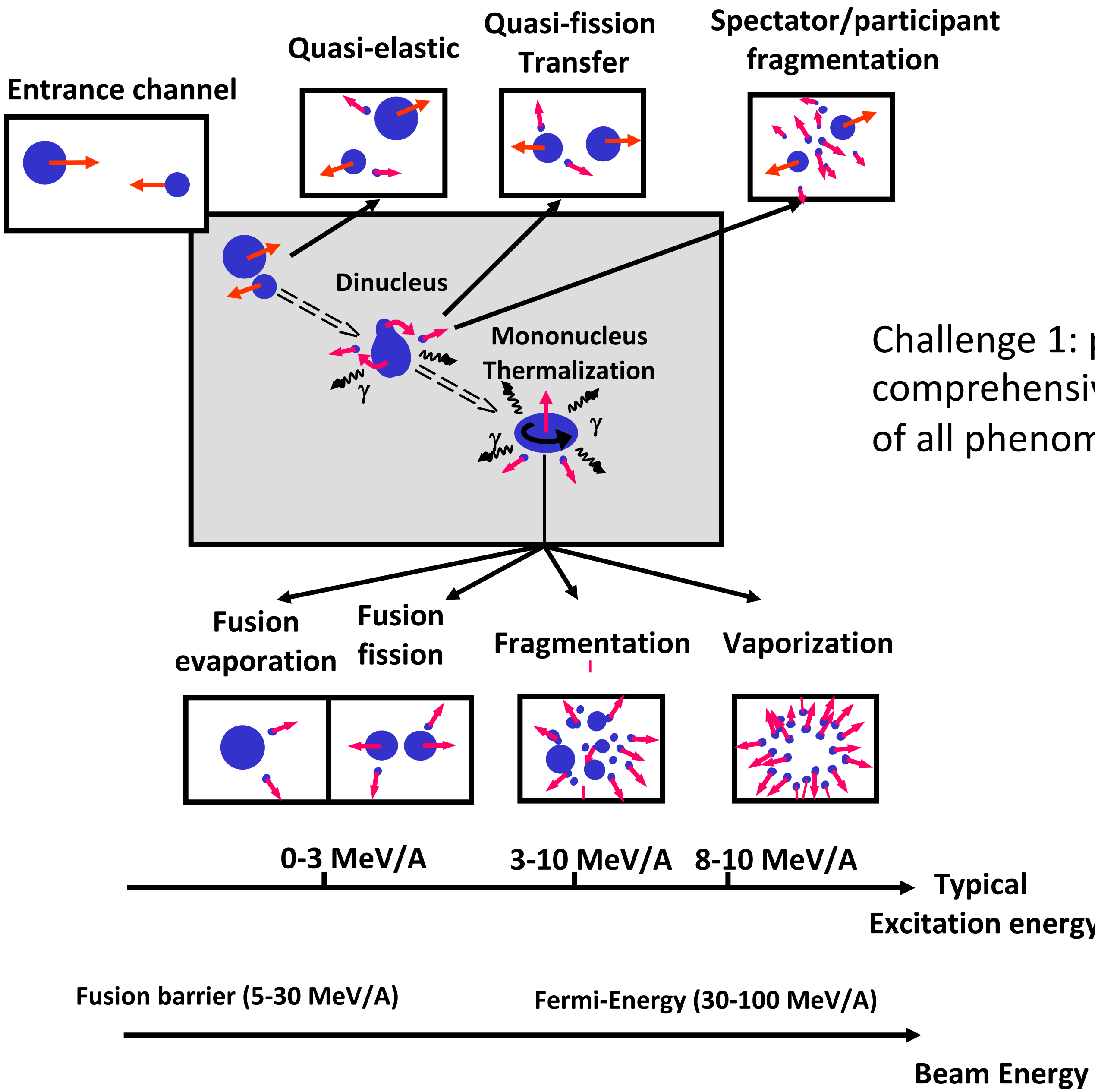
5 to 100 A.MeV (GANIL, LNS, …)

High Energy Facilities

>200 A.MeV (GSI, …)

Challenges for nuclear reactions

Richness and complexity of nuclear reaction



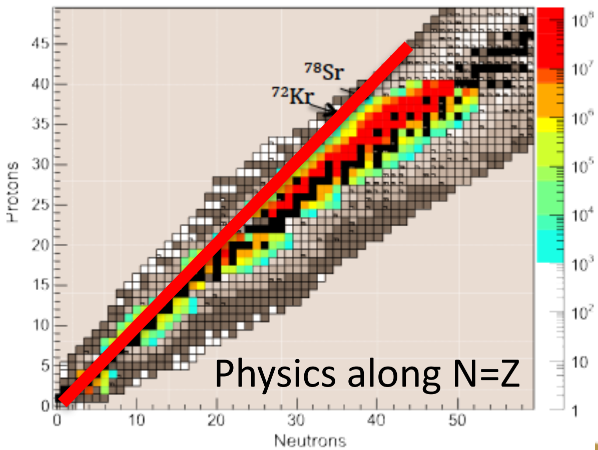
Challenge 1: provide a comprehensive description of all phenomena.

New particles
(pions, hyperons, …)

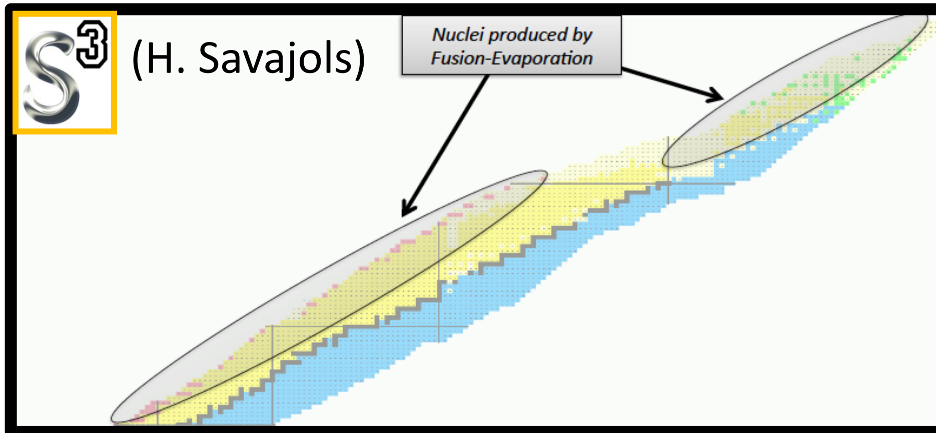
Illustration of the role of reactions on fragment production

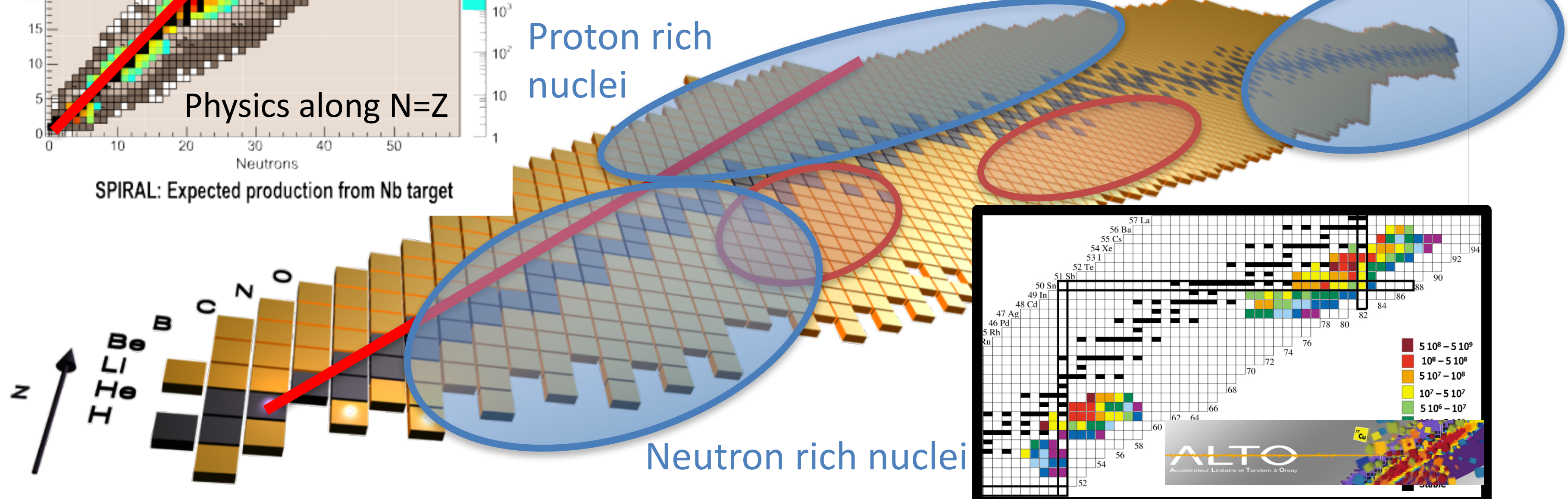
Nuclei at the frontiers

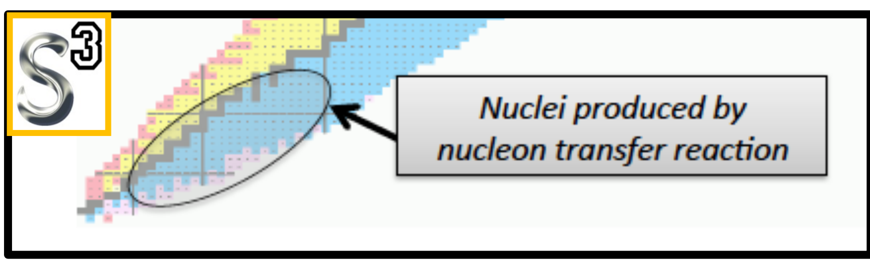
Spiral 1 upgrade (P. Delahaye)



SPIRAL: Expected production from Nb target





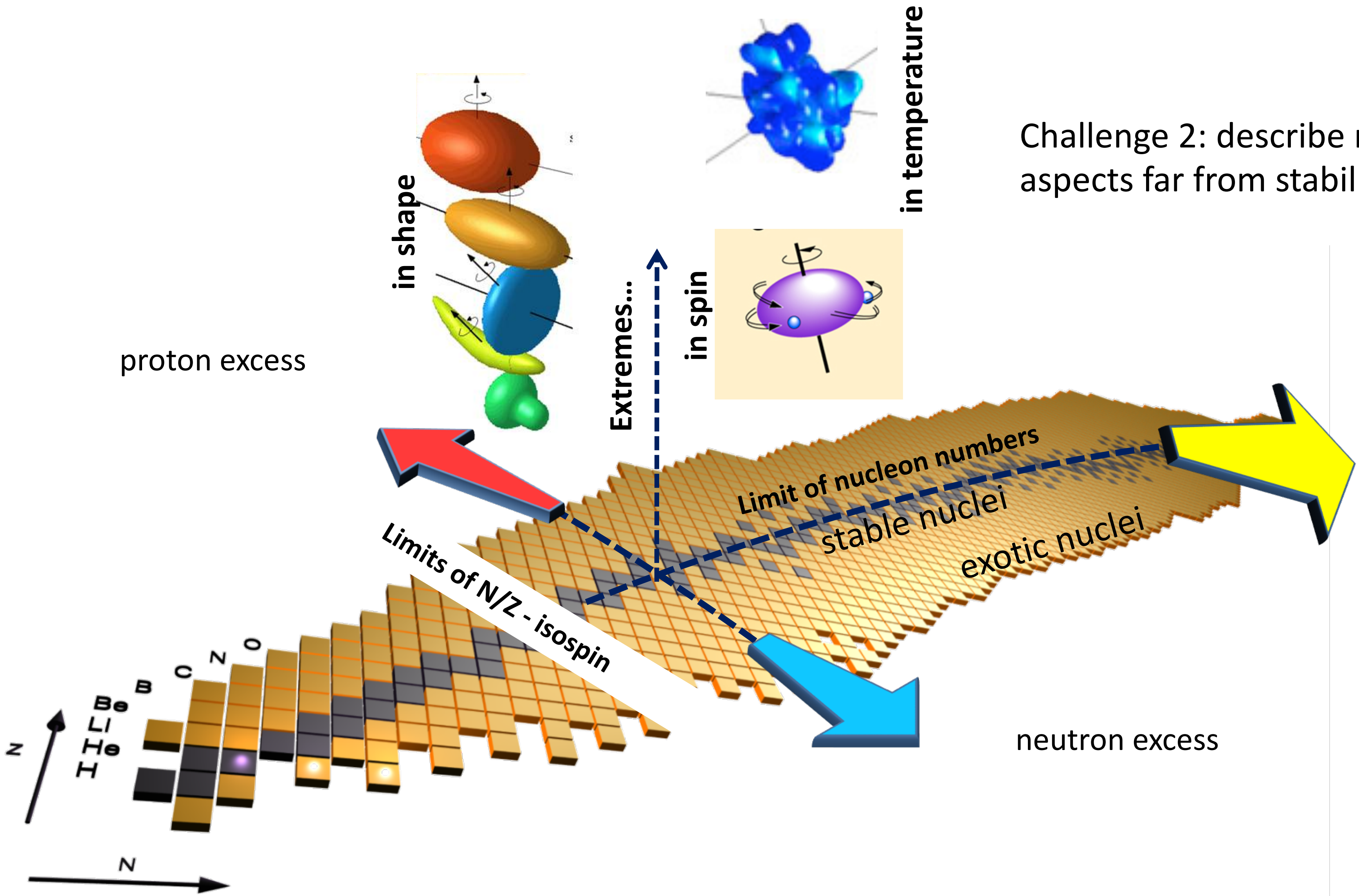


Spiral2 DESIR EURISOL ALTO Accélérateur Linéaire et Tandem à Orsay S^3

Nuclear Physics today

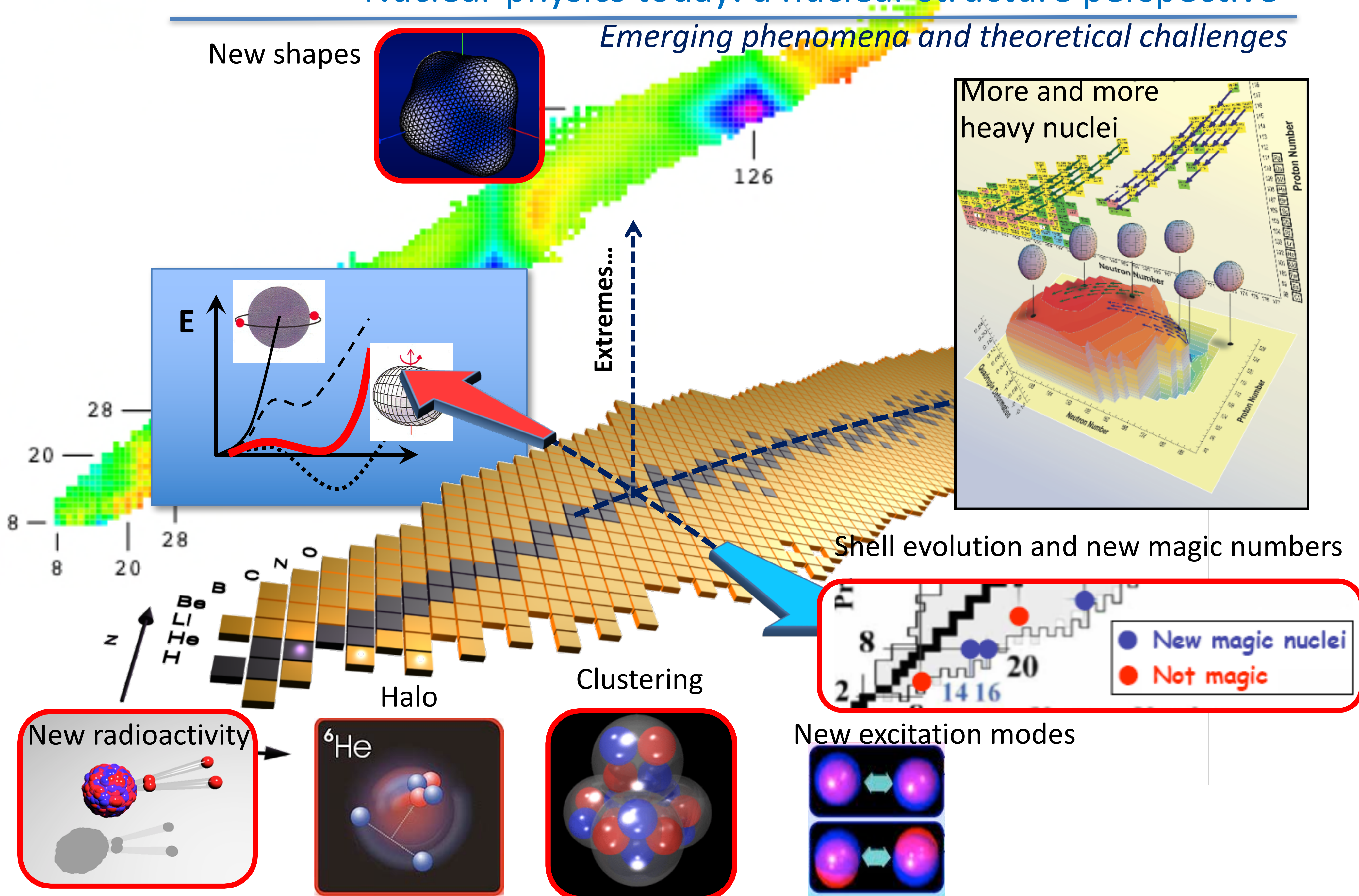
Nuclei at the frontiers

Challenge 2: describe new aspects far from stability.



Nuclear physics today: a nuclear structure perspective

Emerging phenomena and theoretical challenges



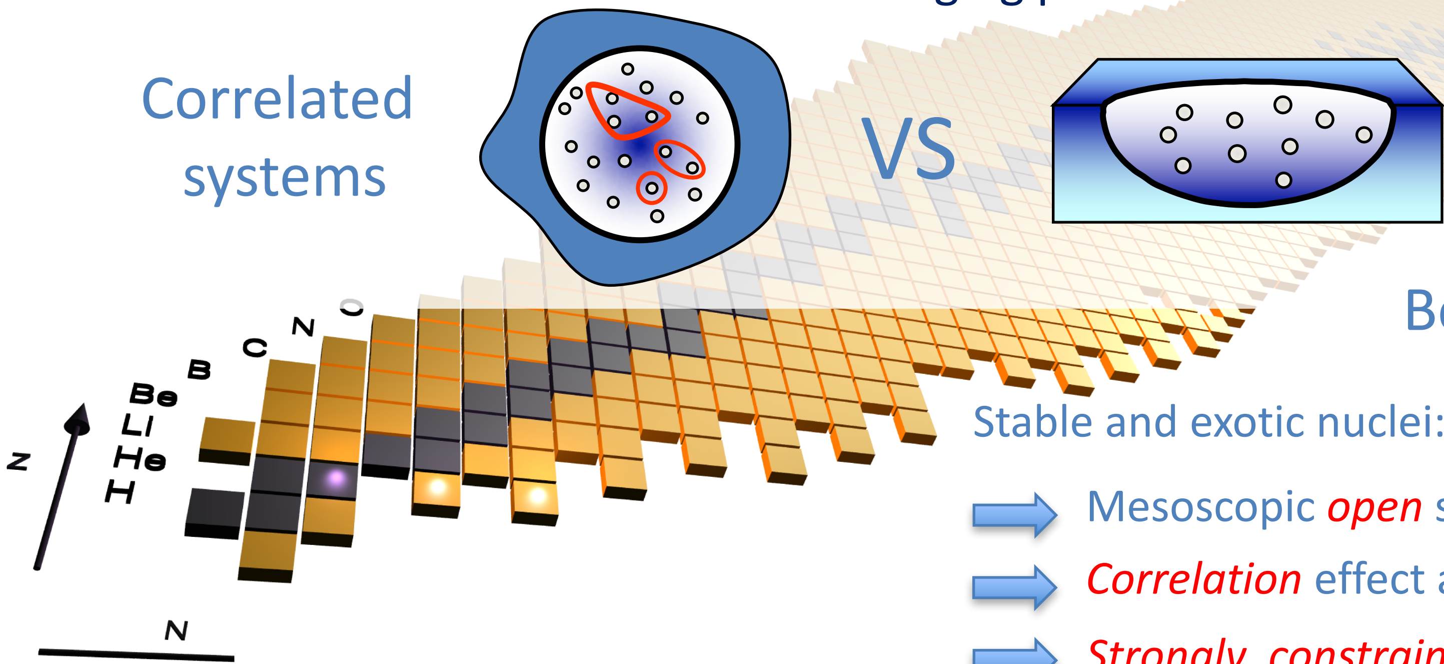
Motivation for Exotic nuclei: understanding the sructure of nuclei

Emerging phenomena and theoretical challenges

Correlated systems

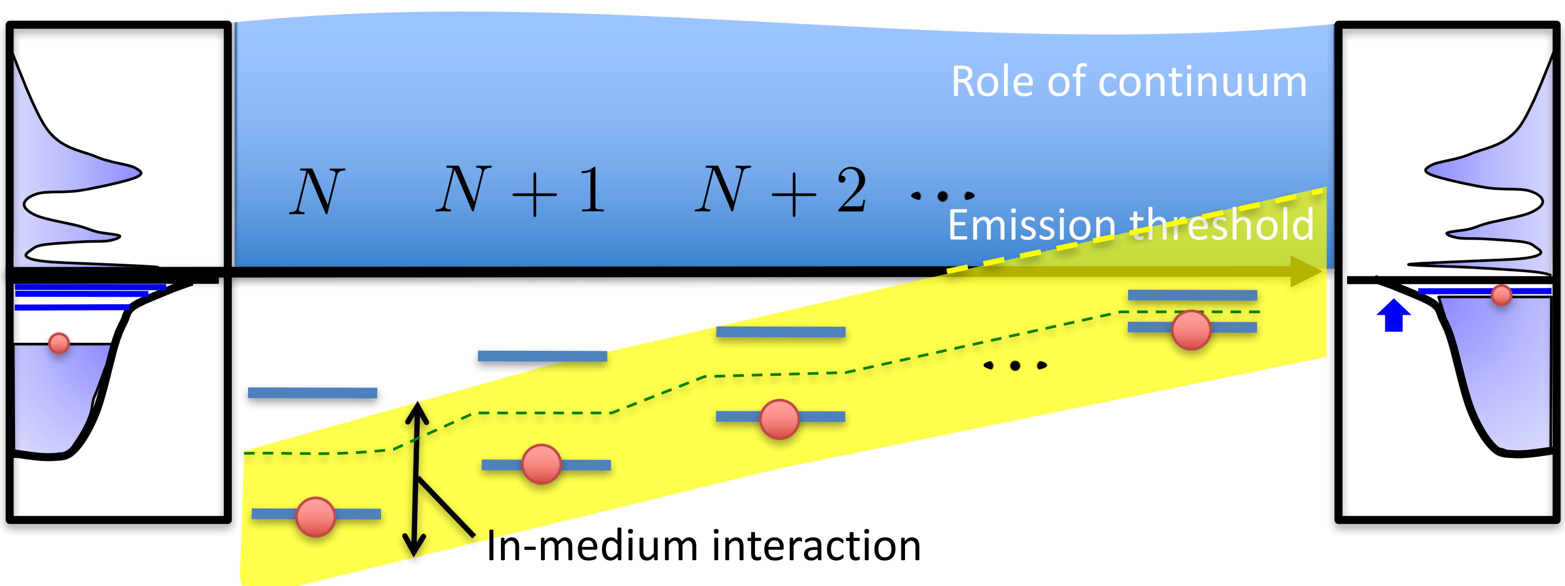
VS

Density Functional approach in and Beyond mean-field



Stable and exotic nuclei:

- Mesoscopic *open* systems.
- *Correlation* effect are enhanced
- *Strongly constrains the Interaction*



Beam Energy

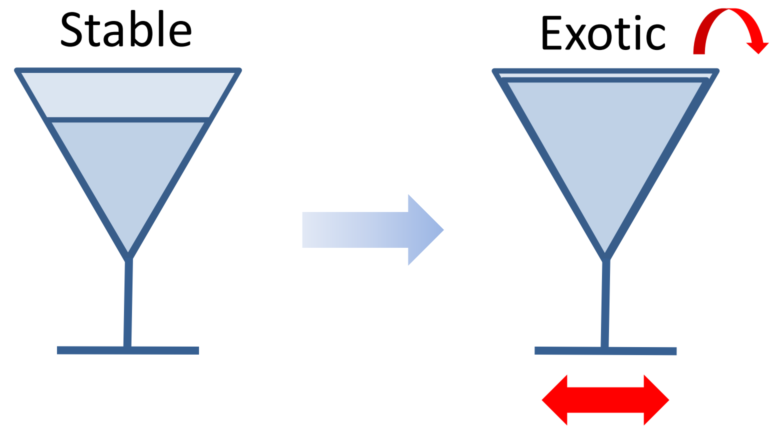
5 MeV/A

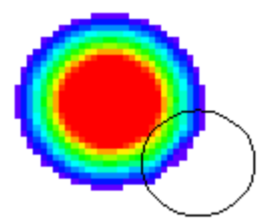
10 MeV/A

50 MeV/A

100 MeV/A

- Fusion
- Transfer★
- Break-up★
  (Nuclear, Coulomb)
- Knock-out★



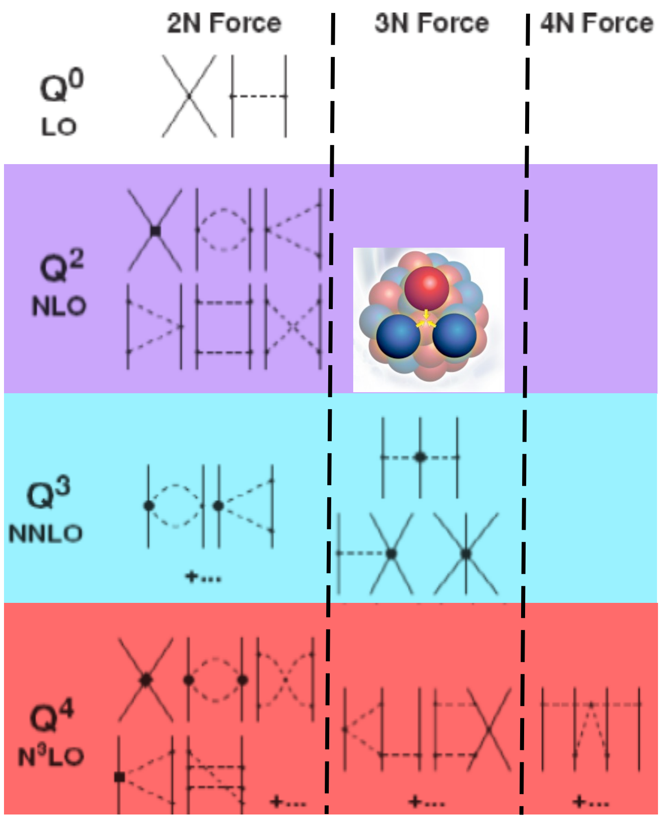


★ Spectroscopic tools

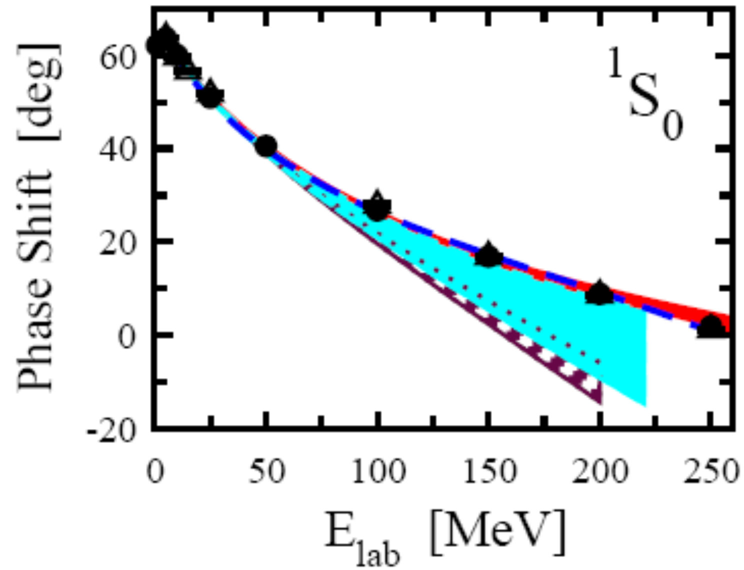
Starting point : Chiral Lagrangian

$$\mathcal{L}_{QCD} \longrightarrow \mathcal{L}_{EFT} = \mathcal{L}_{\pi\pi} + \mathcal{L}_{\pi N} + \mathcal{L}_{NN} + \cdots$$

Feynman diagrams

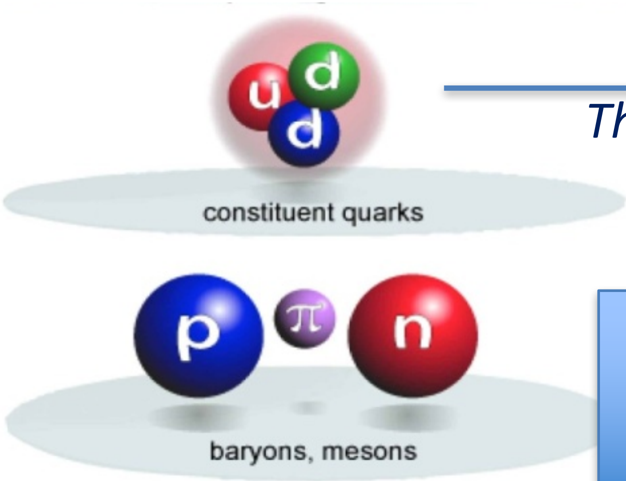


Epelbaum et al, arXiv:0811.1338



- “Direct” link to QCD (chiral)
- Systematic Constructive method
- Consistent NN, 3N, 4N …

The ab-initio breakthrough: another challenge for reaction theory



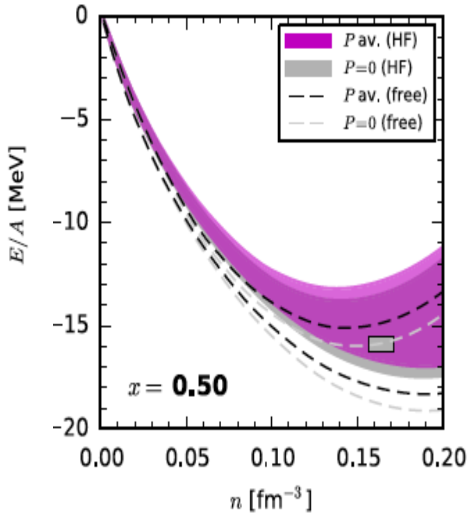
"Empirical" Input (EDF, …) → Reaction models ← Ab-initio "less empirical" input

Another Challenge for the next decade:
Provide a consistent "ab-initio"
Description of static and *dynamical* properties of nuclei.

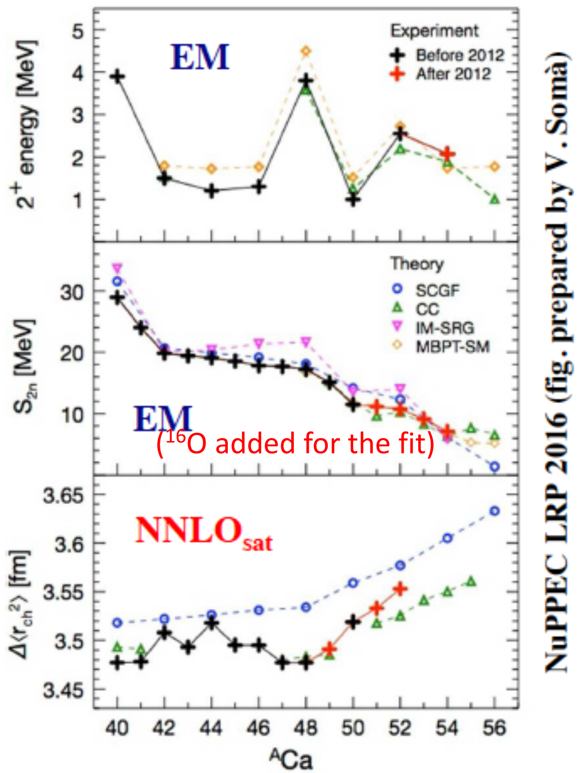
Difficulty: convergence and power counting

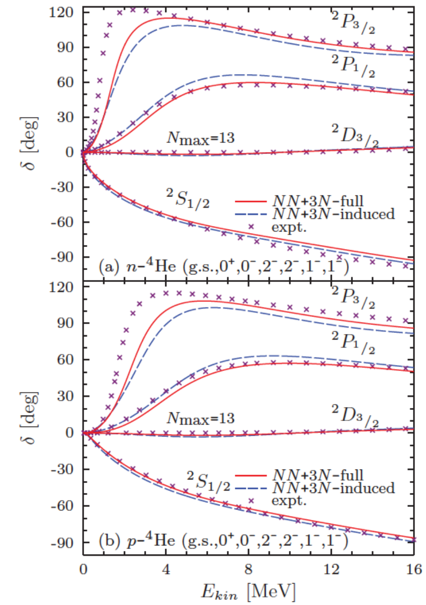
What about the unification of theory for nuclei?

Symmetric matter EOS

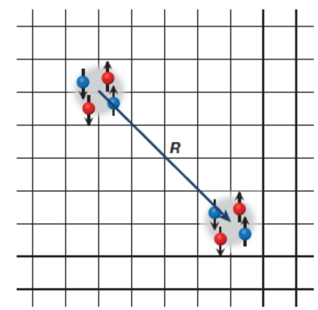


Drischler, et al, Phys. Rev. C 93 (2016)





Hupin et al, PRC 88 (2013)

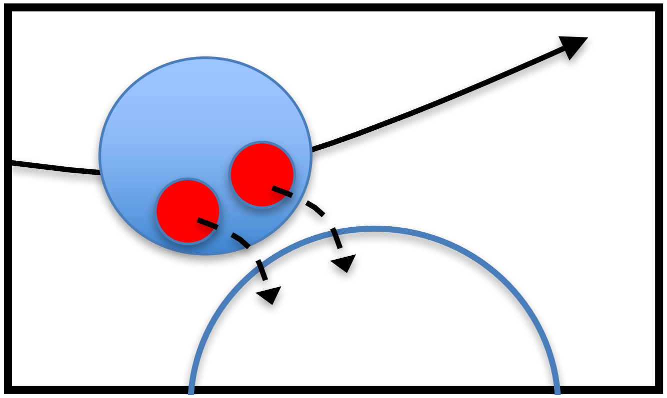


Elhatisari et al, Nature 528 (2015)

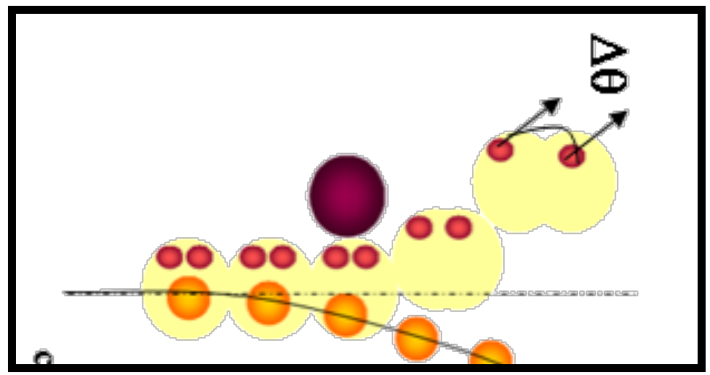
Study of specific dynamical phenomena per se

Probe of long-range correlations with nuclear evolution

2n-transfer reactions



2n-break-up reactions



2 particle radoactivity

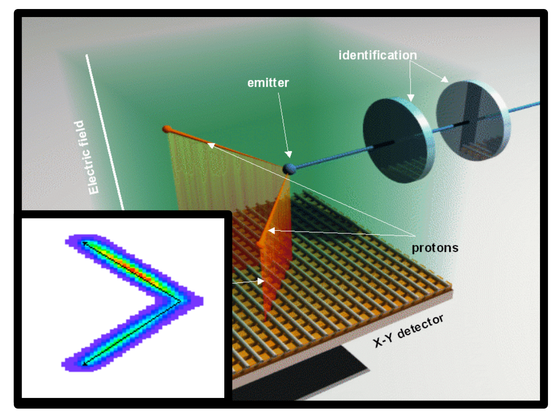


Illustration: Description of particle transfer below the Coulomb barrier

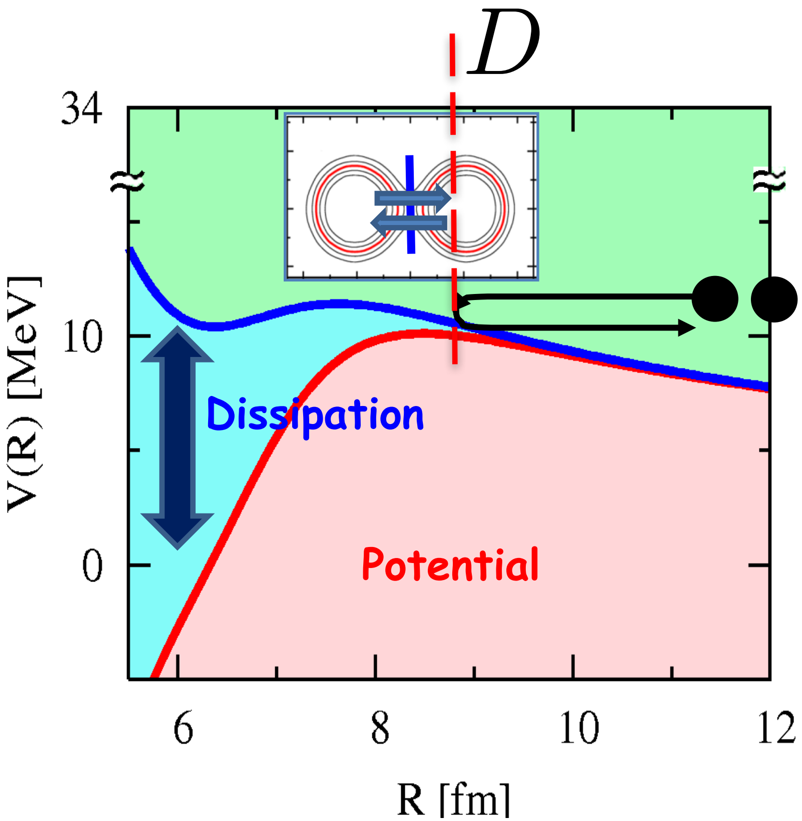
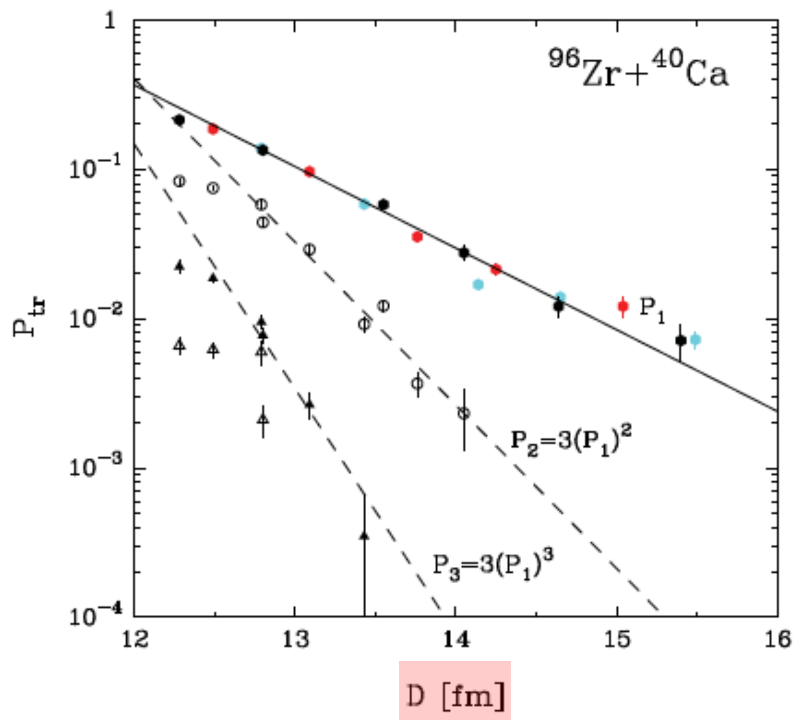


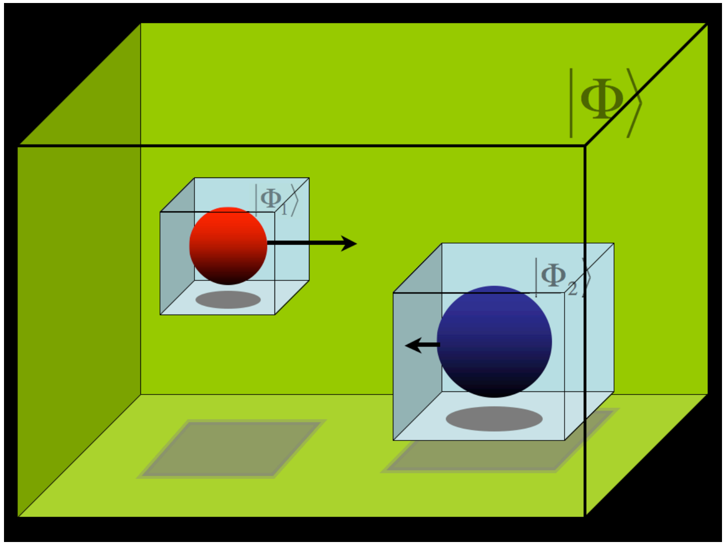
Illustration of precise data

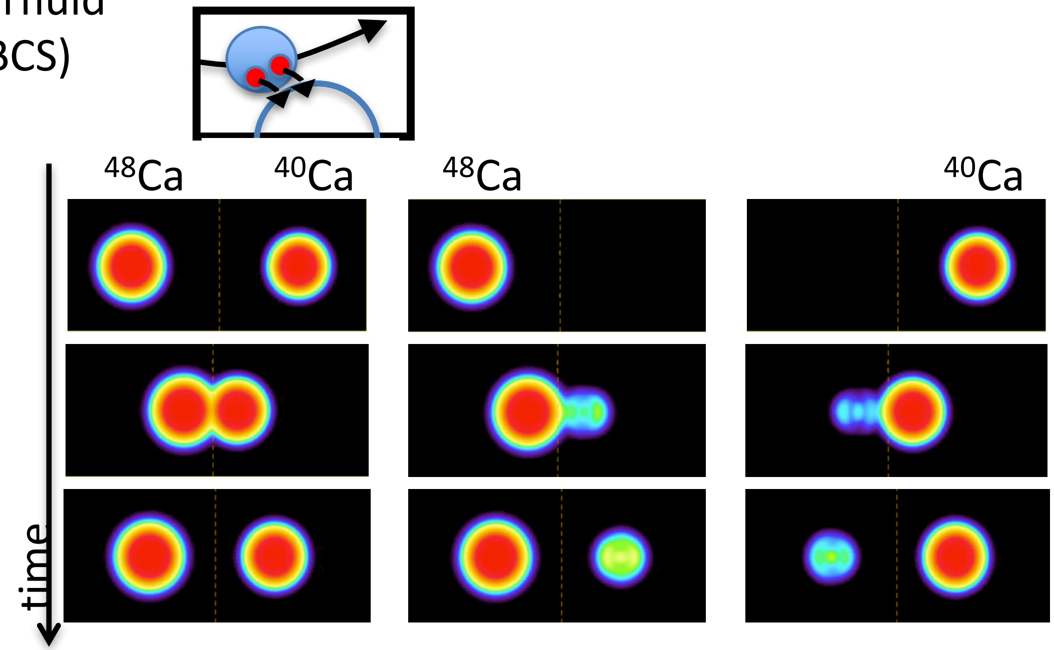


Corradi et al, Phys. Rev. C 84 (2011)

Theory versus experiments

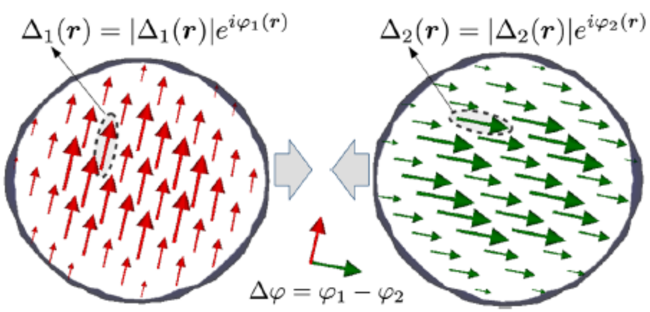
Unrestricted simulation of collisions with superfluid nuclei can now be performed (TDHFB, TDHF+BCS)





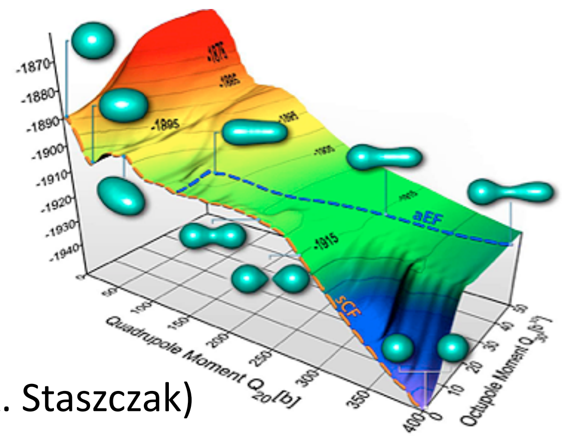
Scamps et al, PRC 87 (2013).

Collision between two superfluid nuclei: new aspects due to gauge-angle orientation?

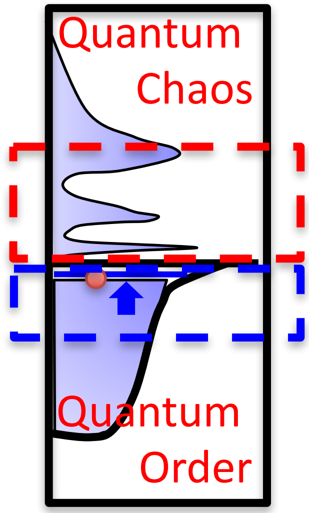


Magierski et al, PRL 119 (2017)

Large amplitude collective motion:
Bridging to the low excitation (order) to high excitation regime (disorder)



(from A. Staszczak)



Exotic

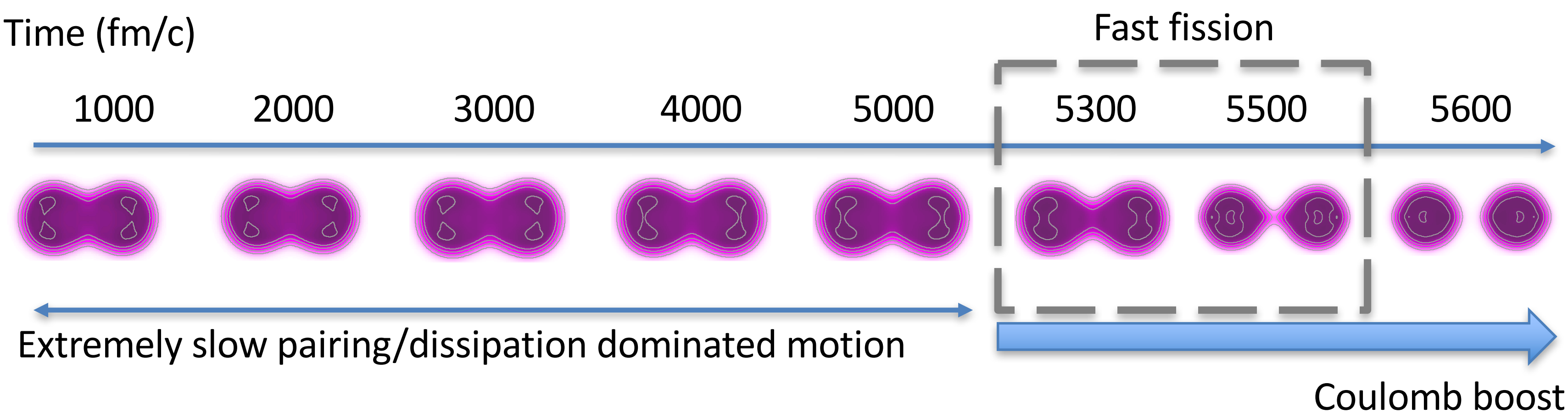
Many-body treatment of internal disorder

From empirical to less-empirical
Microscopic theories

From dynamical to statistical approach

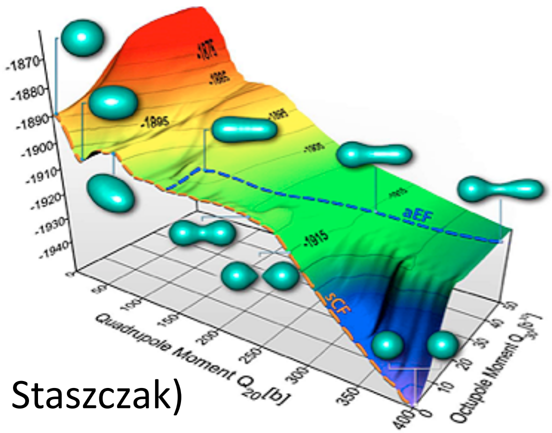
Time-dependent description of fission

Time (fm/c)



Large amplitude collective motion:
Bridging to the low excitation (order) to high excitation regime (disorder)

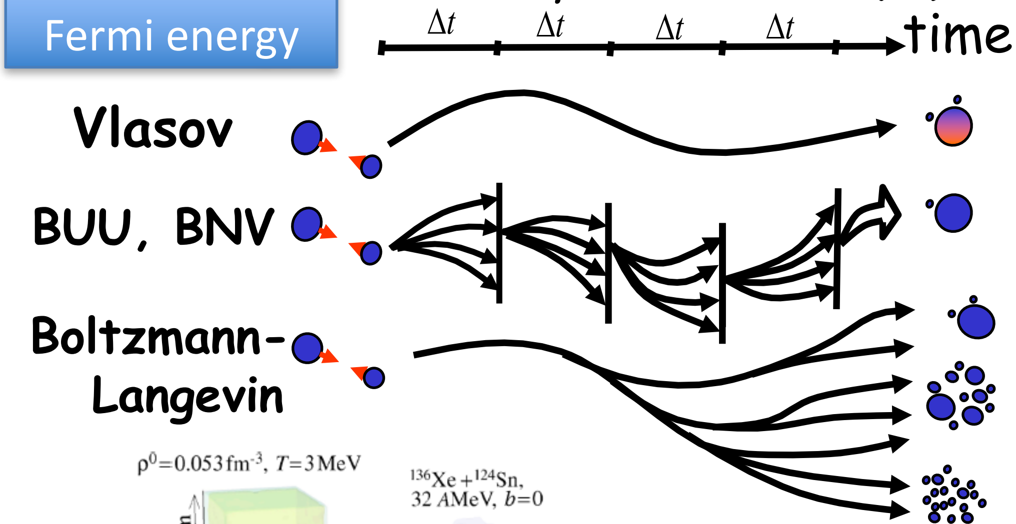
Very-low energy

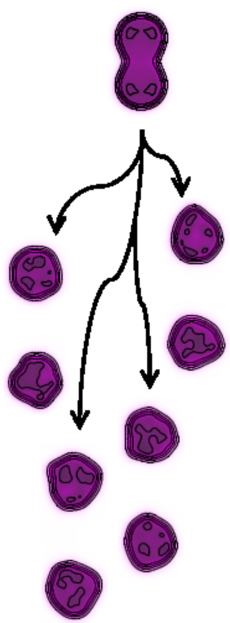


(from A. Staszczak)

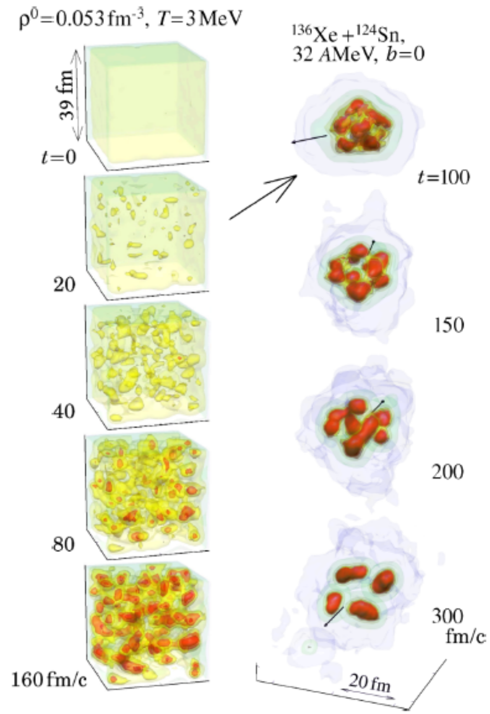
Collisions at Fermi energy

Adapted from J. Randrup et al, NPA538 (92).





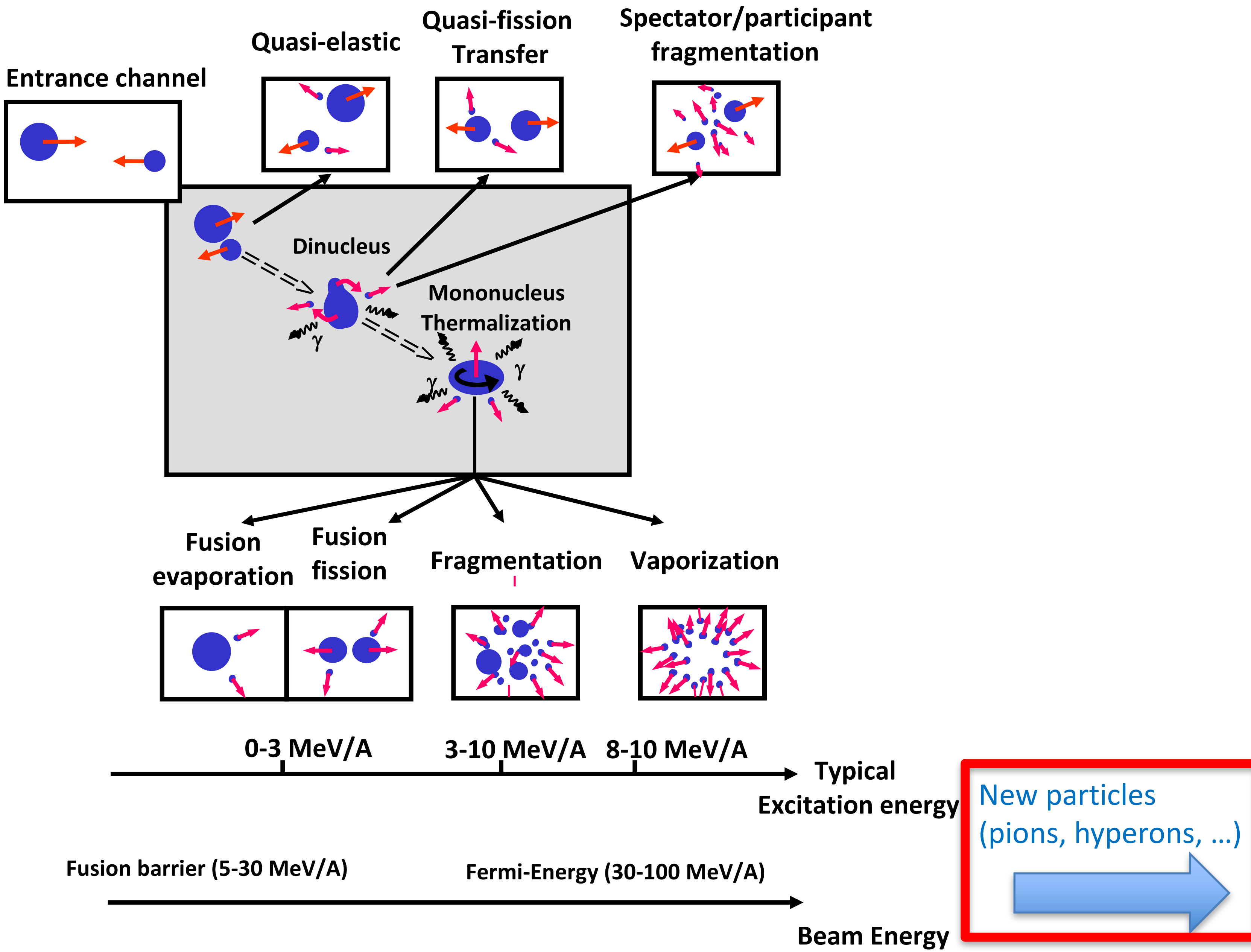
Unification?



Tanimura et al, PRL118, (2017)

Napolitani, Colonna, PRC 96, (2017)

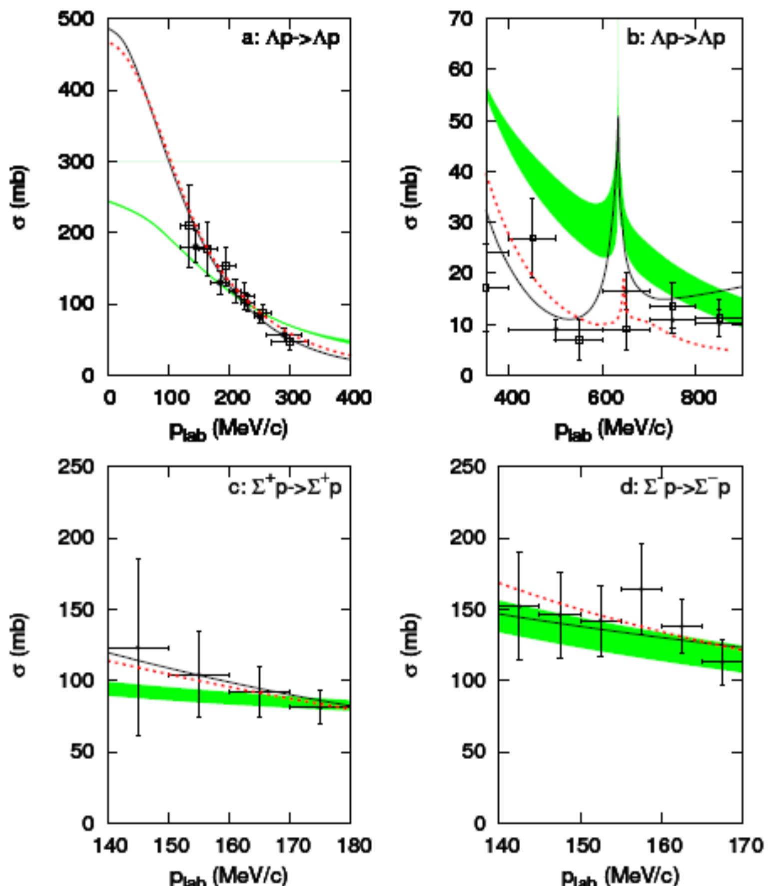
New species production



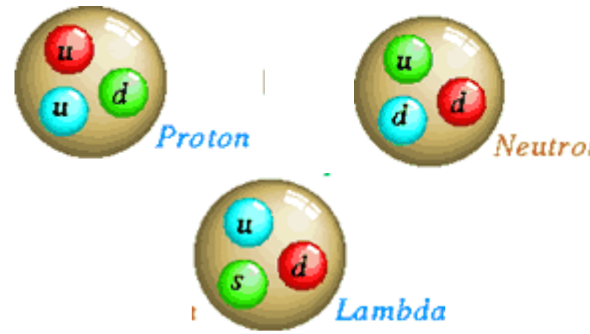
Ab-initio vs experiments

From nuclei to hypernuclei

YN Interaction



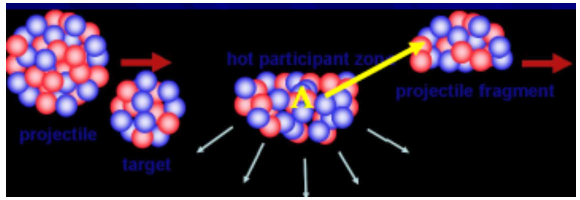
Polinder et al, NPA (2006)



■ LO EFT
— Jülich 04
— Nijm 97f

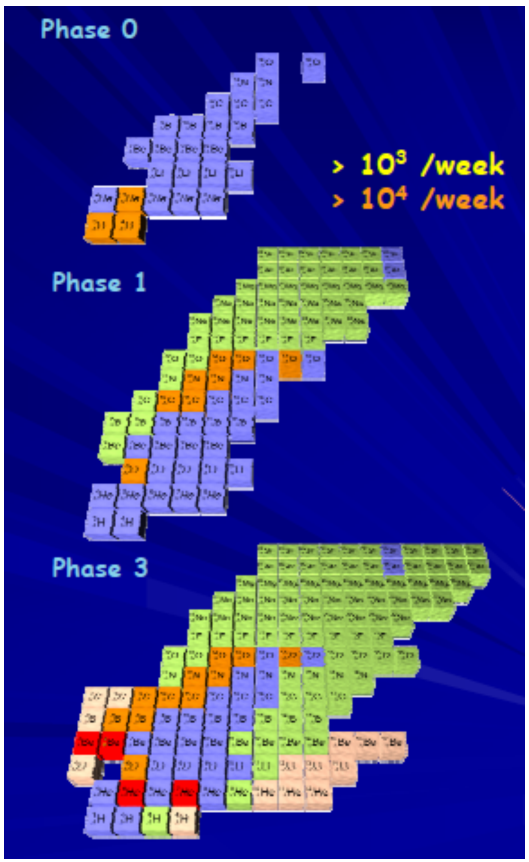
35 data only
(for comparison nn, np… between 2000/3000 data)

New opportunites at FAIR

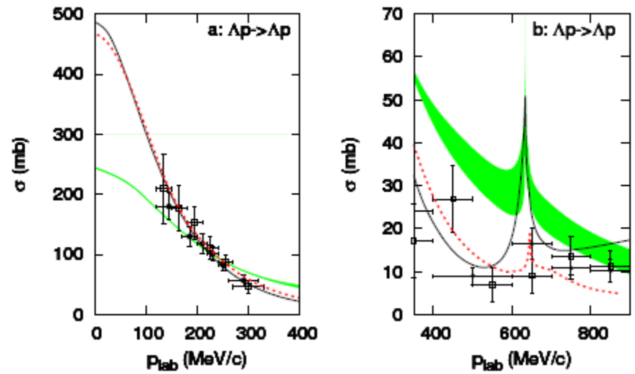


Example : $^{12}C + ^{12}C \rightarrow {}^{A}_{\Lambda}Z + K^{+,0} + X$

HypHI program at GSI (from Saito et al)

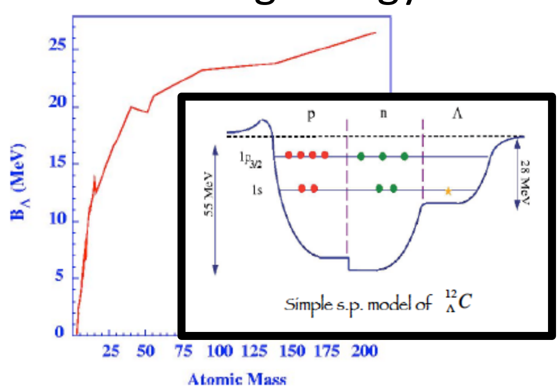


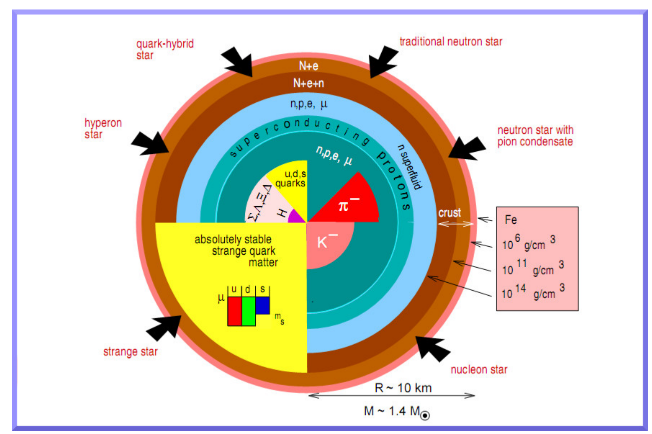
Constraint on the Hyperon-Nucleon interaction



Understand their properties

Binding energy

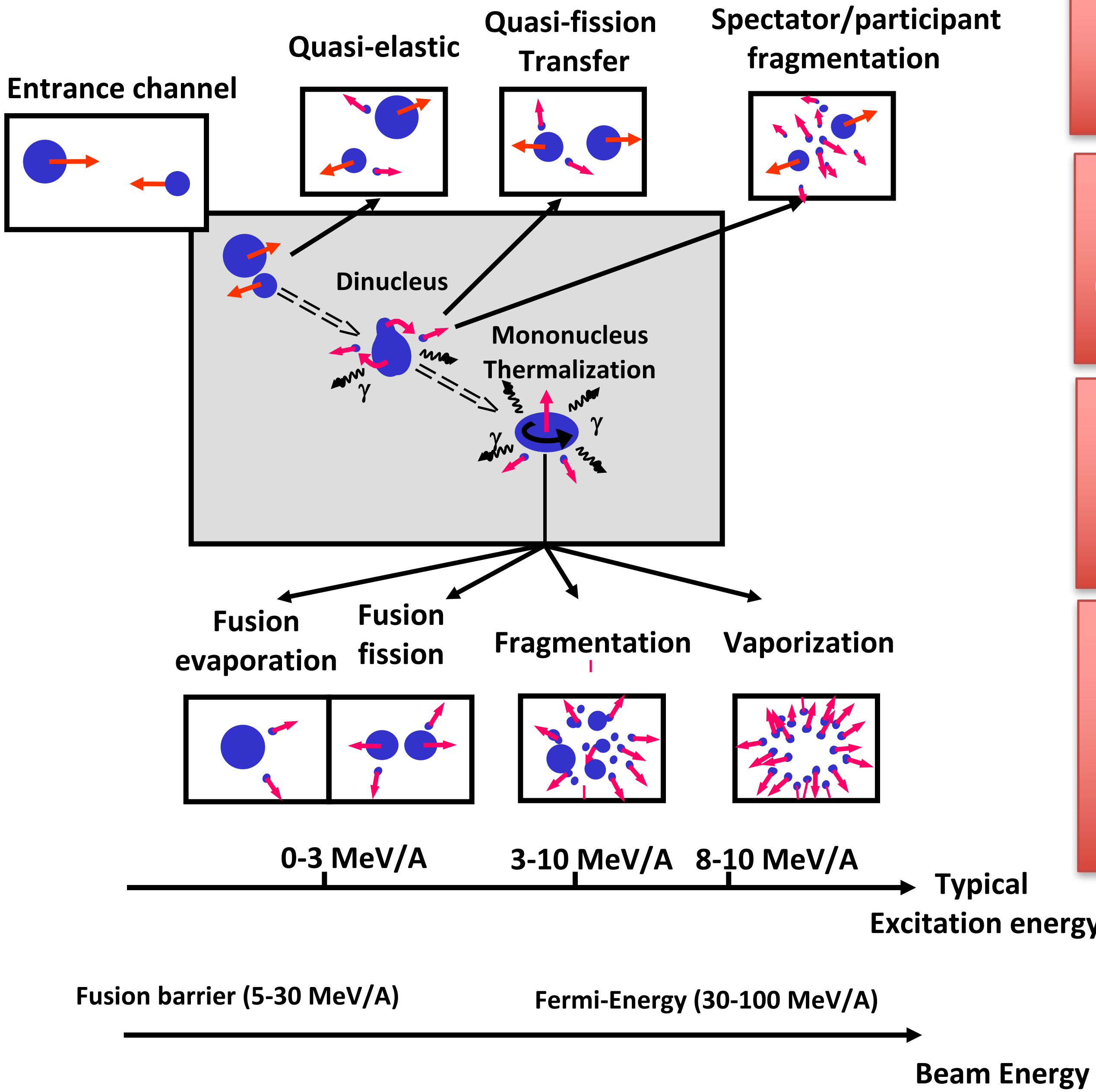




Challenges for nuclear reactions

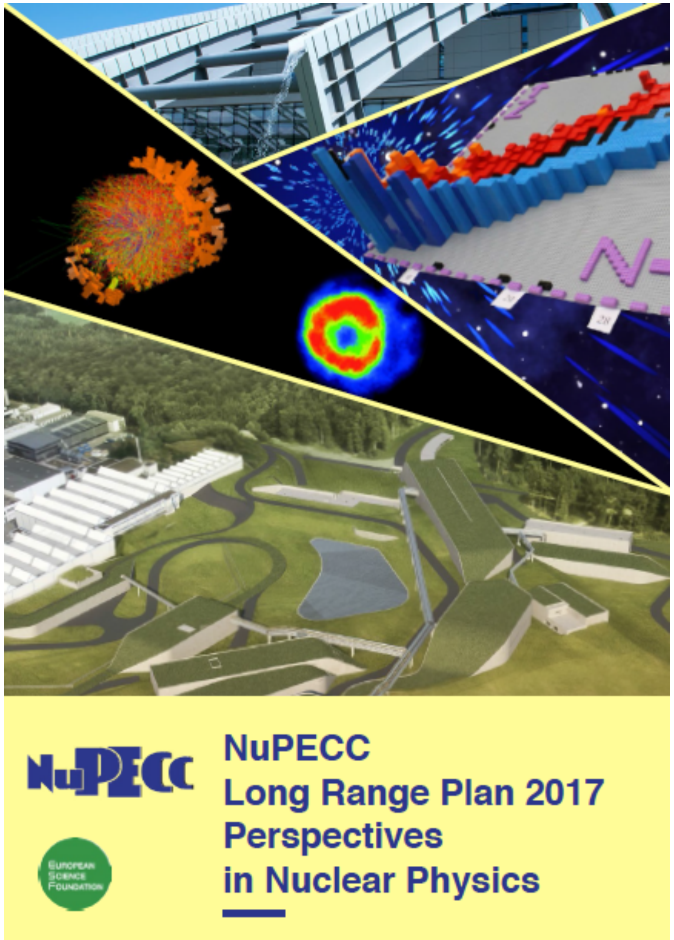
Richness and complexity of nuclear reaction

- Physic close to the Coulomb barrier
- Deep Inelastic collisions
- From DIC to multi-fragmentation
- Relativistic Heavy-Ion collisions

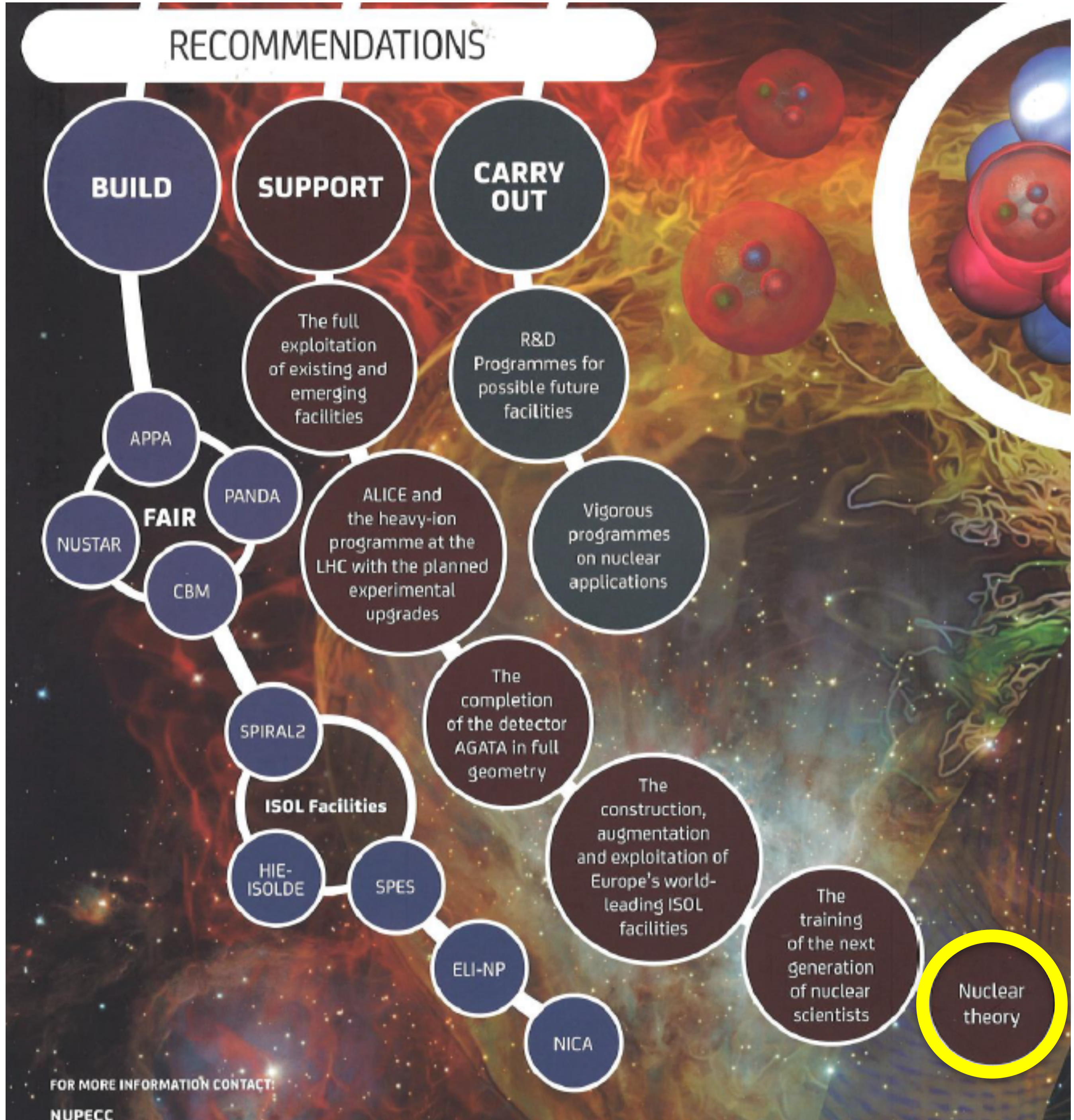


- Spectroscopic reactions
- Exotic nuclei Production (including super-heavy elements)
- New particle production (hyperons)
- Applications of reactions (hadro-therapy, space-irradiation, ...)

New particles (pions, hyperons, ...)



www.esf.org/fileadmin/user_upload/esf/Nupecc-LRP2017.pdf



1. HADRON PHYSICS

Third recommendation: Support for theory and computing

Many of the major insights of recent years have been gained by confronting increasingly sophisticated theoretical tools with experimental data. The interplay between complementary theoretical approaches such as lattice QCD, effective field theories and functional methods has been a great asset for obtaining a deep understanding of hadronic properties in terms of fundamental interactions. Further progress depends crucially on the availability of large-scale computing facilities. We recommend that European computing laboratories receive the support that is necessary to provide an environment for internationally competitive calculations in lattice QCD.

2. PROPERTIES OF STRONGLY INTERACTING MATTER AT EXTREME CONDITIONS OF TEMPERATURE AND BARYON NUMBER DENSITY

Theory developments

- Theoretical work in the field of heavy-ion collisions should be guaranteed continuous support, both in its phenomenological aspects (theoretical support needed to interpret the results and to provide feedback to the experimental programme) and in its more ab initio works (quantum chromodynamics).
- A close collaboration between theorists and experimentalists should be encouraged and nurtured, since most progress in heavy-ion physics stems from a continuous exchange between them.

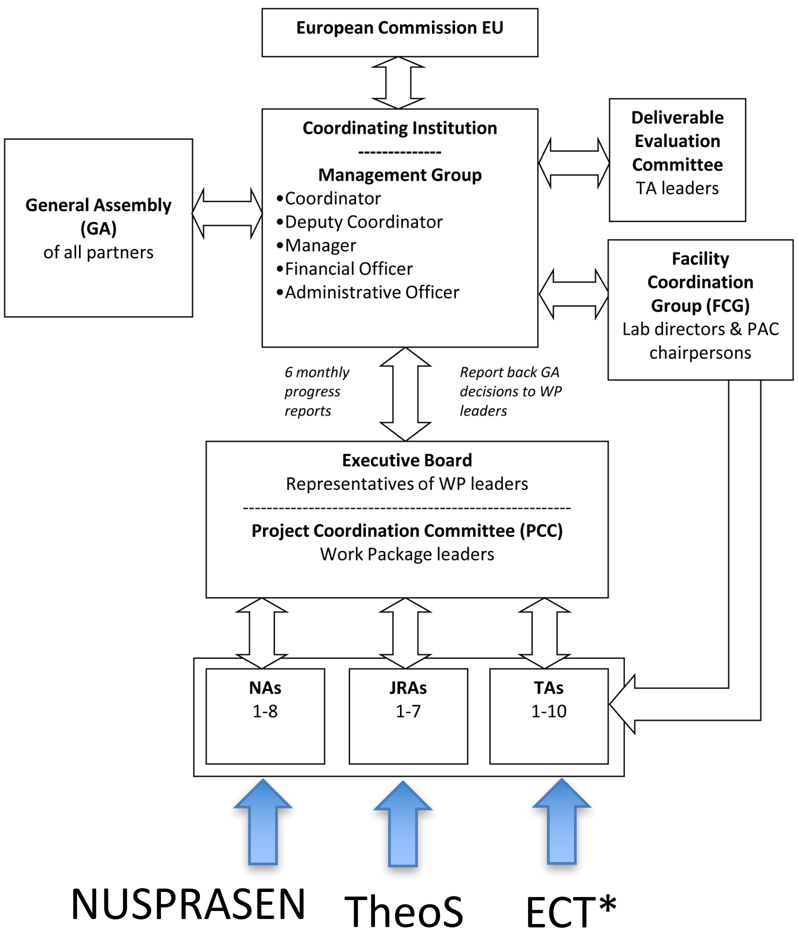
3. NUCLEAR STRUCTURE AND REACTION DYNAMICS

Support is needed for theory focusing on a universal description of nuclear structure to provide bridges between the ab-initio, shell model and EDF methods. Effort should be made to integrate reaction dynamics and nuclear structure so that the input required for reaction calculations is based on state-of-the-art structure calculations. The challenge of interpreting the extraordinary variety of nuclear data requires expansion of the theory community in terms of available manpower and also in available computational resources.

4. NUCLEAR ASTROPHYSICS

We recommend support for ECT* at Trento to continue its leading role training young researchers in theoretical nuclear astrophysics.

Theory network within the ENSAR2 consortium



TheoS main node and associates