

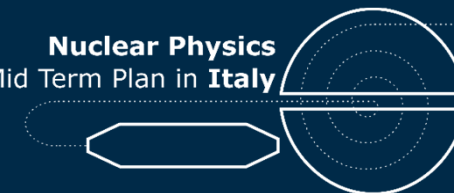
Nuclear Physics Mid Term Plan in Italy

LNL – Session

Legnaro, April 11th-12th 2022



Nuclear Physics
Mid Term Plan in Italy



CONCLUDING REMARKS



Fabiana Gramegna

INFN, Director of Legnaro National Laboratory , Legnaro, Italy

Laboratori Nazionali di Legnaro

Session LNL
 11-12 April 2022

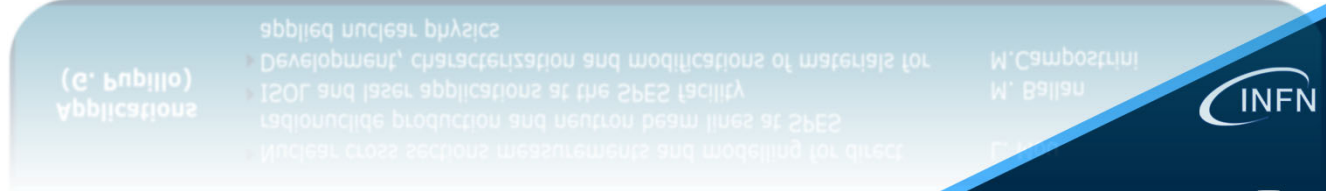





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The workshop is organized in specific working groups that will report their activities in the final event. These working groups will address the future research opportunities at LNL.

Working group (Chair)	Topic	Speaker
Nuclear Astrophysics (R. Depalo)	<ul style="list-style-type: none"> ▶ Nucleosynthesis up to the iron peak ▶ Nucleosynthesis of trans-iron elements ▶ Nuclear astrophysics theory 	A. Cacioli T. Kurtukian Nieto S. Cristallo
Nuclear Structure (D. Mengoni)	<ul style="list-style-type: none"> ▶ Shell evolution ▶ Light to medium-mass exotic nuclei ▶ $N \sim Z$ nuclei and isospin symmetry ▶ Deformation and collective states 	A. Gottardo S. Bottoni S. M. Lenzi F. C. Crespi
Nuclear Reactions and Dynamics (T. Marchi)	<ul style="list-style-type: none"> ▶ Physics overview: alpha clustering, dynamics and structure, thermodynamics, equation of state, collective motions ▶ Mechanisms/Tools: fusion-evaporation and pre-equilibrium emission ▶ Mechanisms/Tools: transfer, particle spectroscopy ▶ Mechanisms/Tools: fission and sub-barrier fusion 	F. Gulminelli & D. Dell'Aquila K. Mazurek & M. Cicerchia L. Gasques & F. Galtarossa M. Caamaño-Fresco & I. Zanon
Applications (G. Pupillo)	<ul style="list-style-type: none"> ▶ Nuclear cross sections measurements and modelling for direct radionuclide production and neutron beam lines at SPES ▶ ISOL and laser applications at the SPES facility ▶ Development, characterization and modifications of materials for applied nuclear physics 	L. Mou M. Ballan M. Campostrini



Jumping into the future:

Which are the driving questions?

Dark matter, Dark energy, black holes, gravitational waves ...

Where are we in this game?



Astronomical observations

Astrophysical simulations

Stellar nucleosynthesis

Stellar explosions

Nuclear structure and reactions observables

Theoretical calculations

Experiments

MANY-BODY METHODS

Large Scale Shell Model

Energy Density Functionals

No Core Shell Model

Coupled cluster method

Fermionic Molecular Dynamics

...

INTERACTIONS

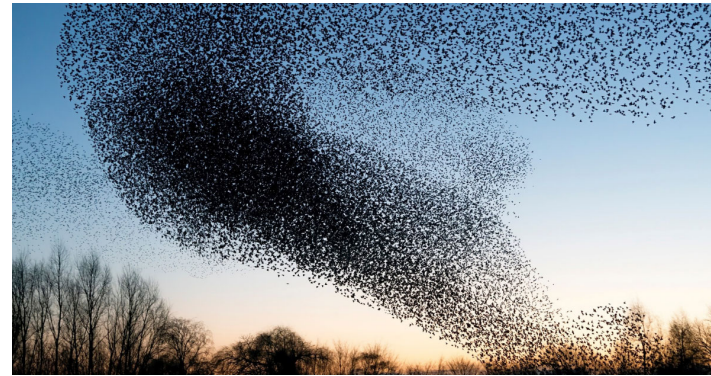
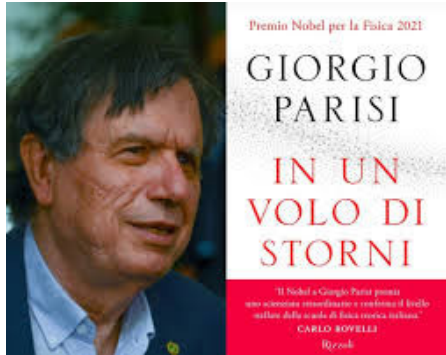
Phenomenological nuclear interactions

Unitary Transformations (SRG, UCOM, ...)

Chiral Effective Field Theory

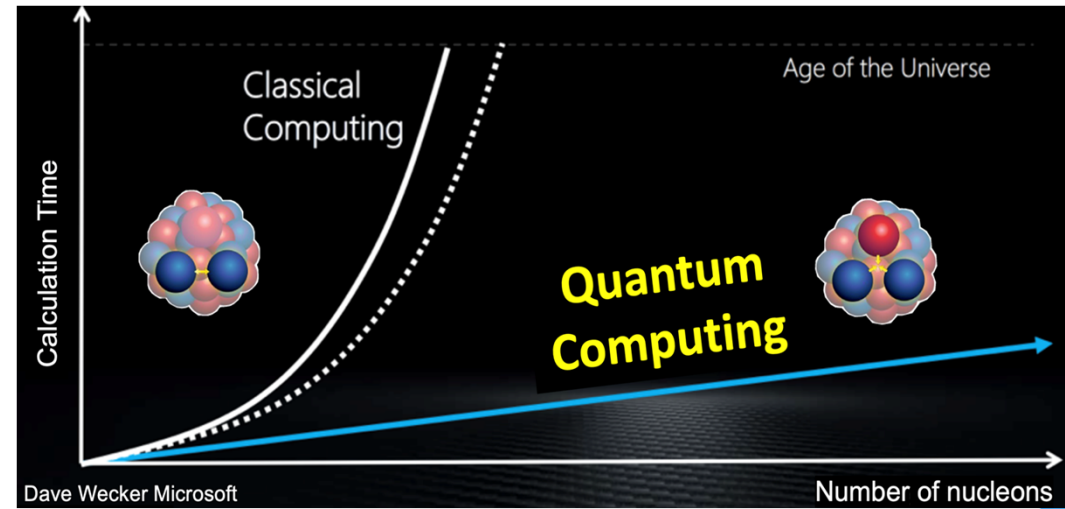
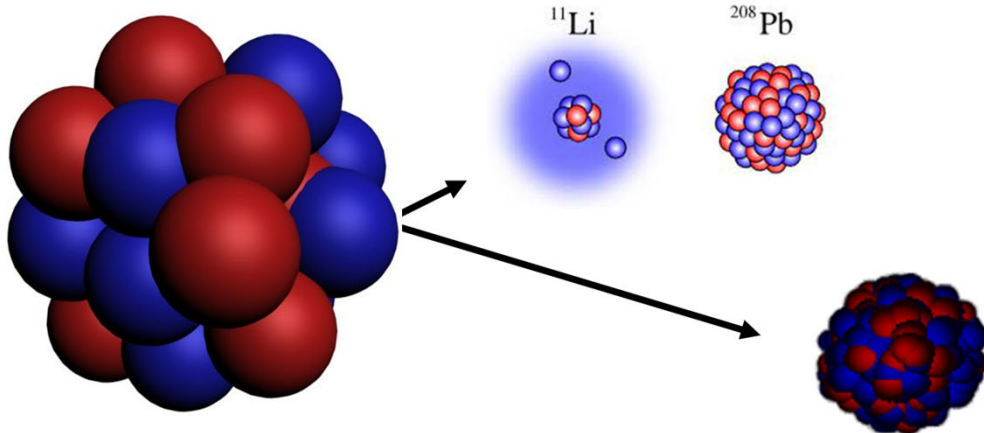
Low energy QCD

Complex many body systems



Nuclei are complex **many-body quantal systems** consisting of many nucleons, up to ~ 300 , resulting in a rich variety of quantum phenomena, with an energy domain that goes from **few eV to GeV**. The nuclear interaction is still very little known.

Required a **comprehensive theory** that *describes quantitatively and predicts* the properties of the entire nuclear landscape.



The progress in the understanding of nuclei is driven by major advances of **experimental and theoretical tools**.



Jumping into the future:

Where are we in this game?

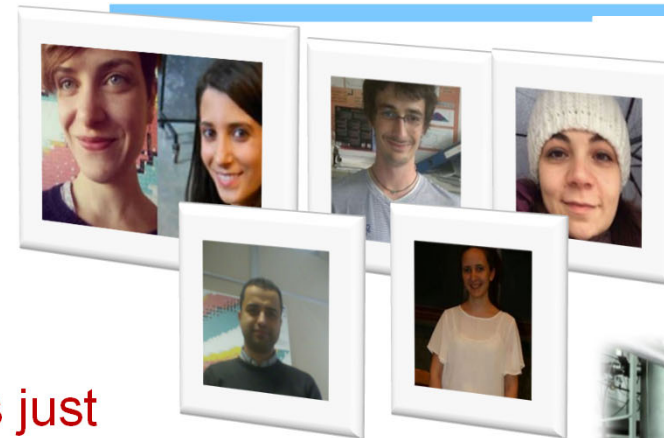
Having **young people** into the game!

Searching for **New&Good Ideas** → **don't do things just because every one does it** → **find your road, find your questions,**
give rise to your emotions

Having the right **Instruments!**

Facilities → Good Beams & Good Targets

State of the art Instruments → resolution in energy, mass, charge, low identification threshold, high efficiency, correlations methods



- The workshop has highlighted how the **collaboration with theoreticians** is crucial in order to be always updated on the most interesting and relevant physics.

WG1 (S. Cristallo): Nuclear Astrophysics theory

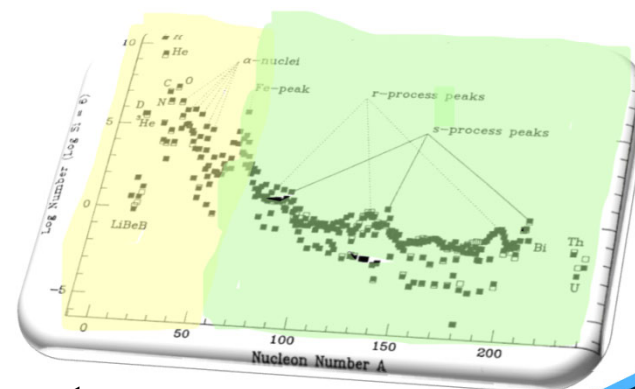
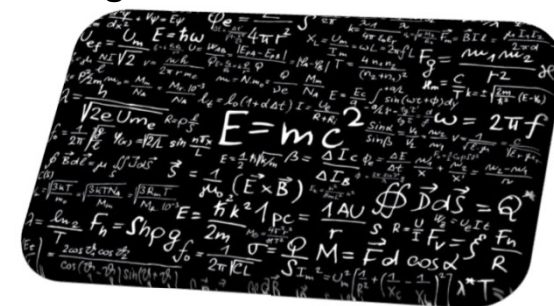
Bridge between nuclear physics and the Universe...

- Sensitivity study on neutron capture rates for r-process
 - Sensitivity study on beta decay rates for r-process
 - Overview on s- and i- processes
 - Guidance on most interesting cases for the synthesis of light-elements
- Already today, LNL can provide beams to tackle a variety of nuclear astrophysics cases (both at big and small machines) and even more possibilities will open in the future. However, **some scientific cases require additional work** on beam diagnostic, beam development and beam intensities.



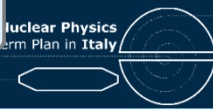
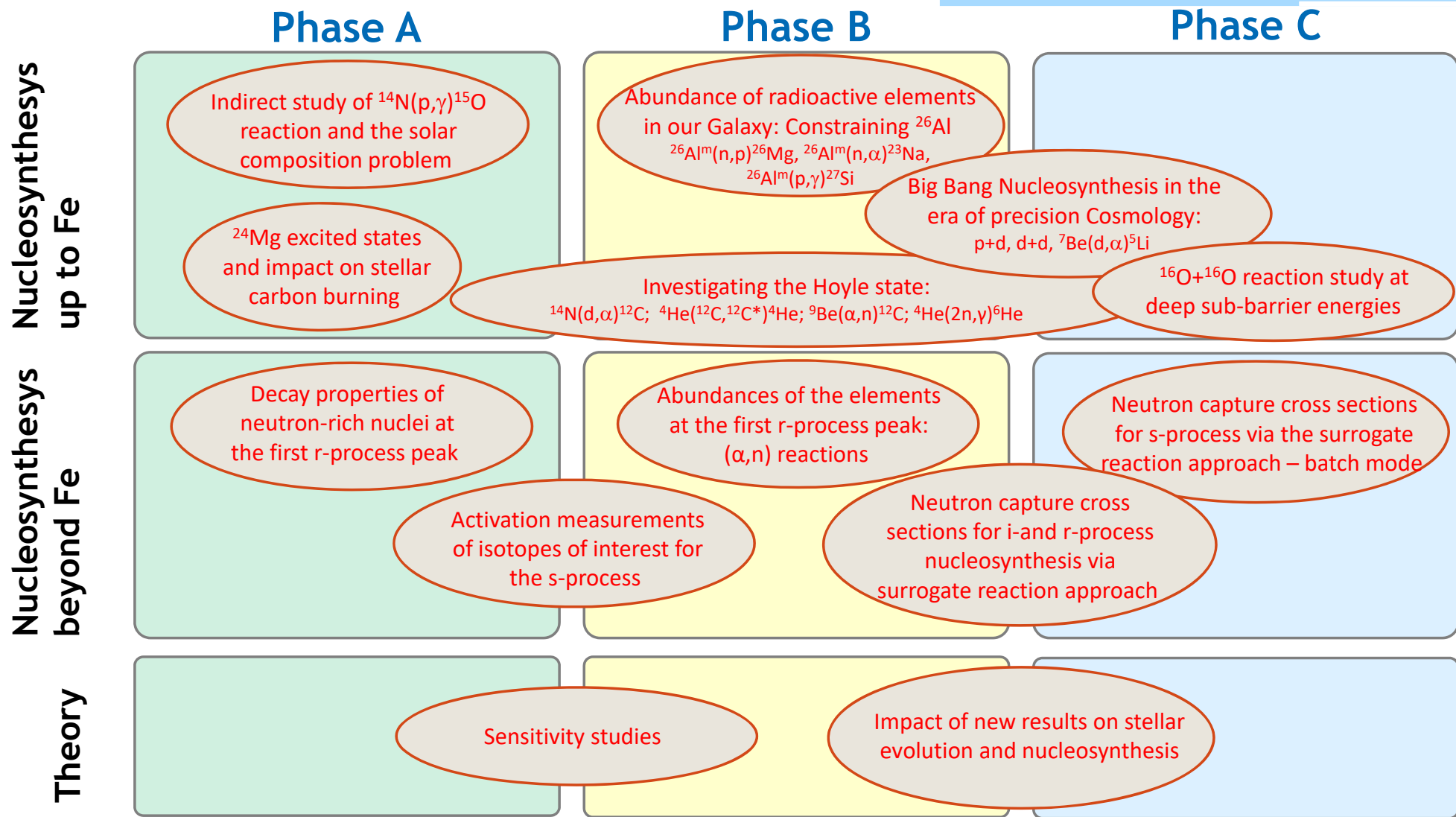
Stellar modelling and astronomical observations are ever-evolving, and so is the available literature on nuclear physics experiments.

It is crucial to keep an active dialogue with astrophysicists to be updated on the most interesting scientific cases.



WG2 (A. Cacioli): Nucleosynthesis up to the Fe peak

WG3 (T. Kurtukian - Nieto): Nucleosynthesis of trans-iron elements

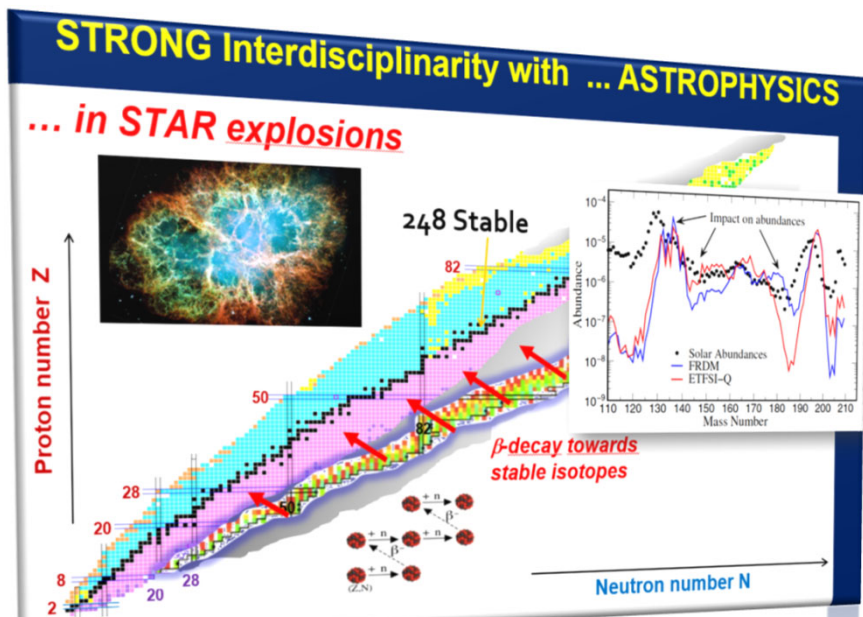


▪ **Why in LNL?**

1. Availability of beams @ different facilities: AN2000, CN, TANDEM, EXOTIC, SPES....
2. The installation of innovative targets (CTADIR, SUGAR, ATS, ...) and detectors (AGATA, NEDA, GRIT, ...) is crucial to tackle many interesting nuclear astrophysics cases.

▪ **Networks & Connections?**

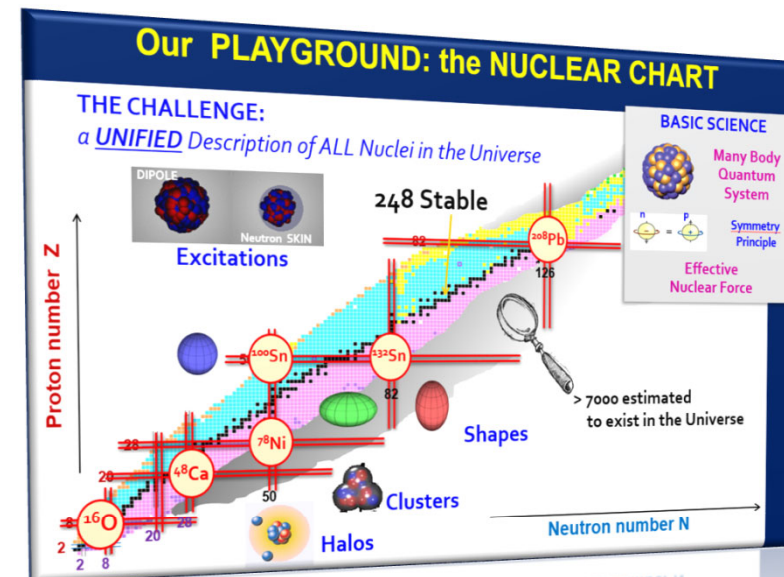
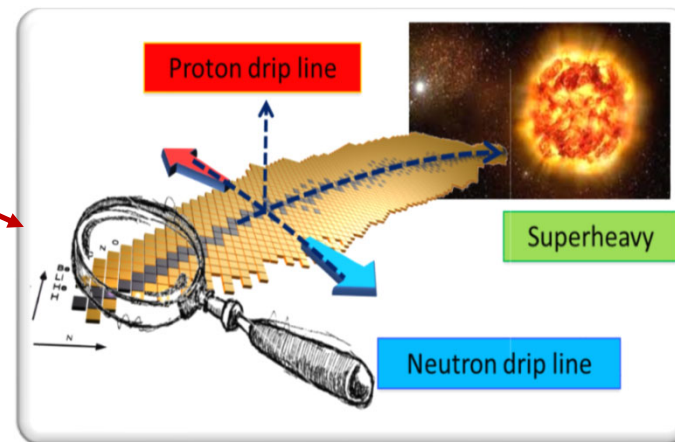
1. Many members of the WG are already part of the GIANTS (Gruppi Italiani di Astrofisica Nucleare Teorica e Sperimentale).
2. LNL is involved in the ChETEC-INFRA European network, with tasks on:
 - neutron detection
 - target production/characterization for Nuclear Astrophysics
3. the EU nuclear astro community has a close collaboration with IReNA, in the USA.



At the moment, the nuclear astrophysics community at LNL is made from a **few small groups**. In order to perform successful nuclear astrophysics campaigns, especially at SPES, it is important to **push and make it grow** an increasingly strong and large community within LNL, as well as foster the collaboration between existing groups and with the international community.



NUCLEAR PHYSICS: Building up our precious mosaic



- Complementary **experimental techniques** and cross approaches to the workings groups, assisted by **theoretical guidance**, led to define **challenging physics goals** to **boost our understanding of nuclei especially far from the stability**

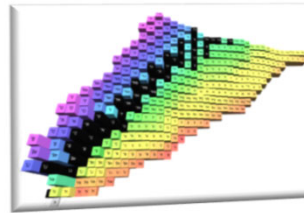


Concluding remarks from Nuclear Structure working group

Fabiana Gramegna

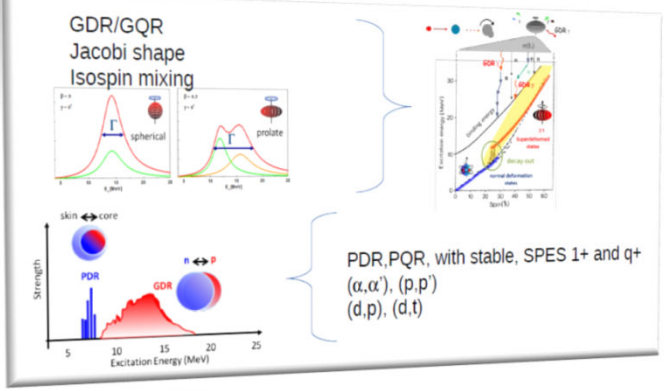
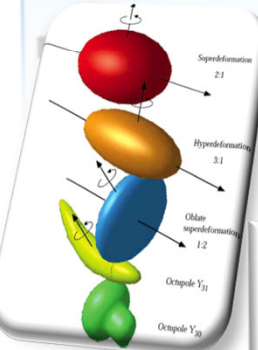
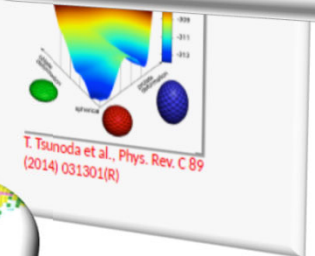
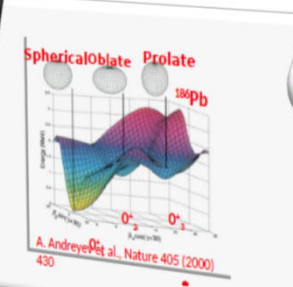
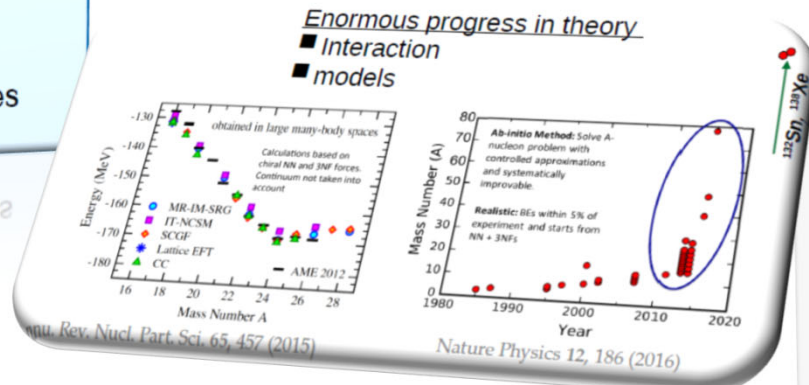
Nuclear Physics Mid Term Plan in Italy – LNL Session

- Light and medium-mass exotic nuclei
- $N \sim Z$ nuclei and isospin symmetry
- Shell evolution
- Deformation and collective modes



- The **International community** extensively participated to the mid-term plan for the nuclear structure at LNL, addressing a **rich panorama of physics opportunities**, encompassing **shell evolution** and **collective phenomena**, properties of **light and medium-mass exotic nuclei** and **$N \sim Z$ nuclei**.

Stable beams (fission): core-coupled states and intruders
1+ SPES beams: Beta decay
q+ SPES beams: lifetime (plunger or DSAM) after transfer (d,p), (d,t), coulex on intruder states



$N \sim Z$ nuclei and isospin symmetry

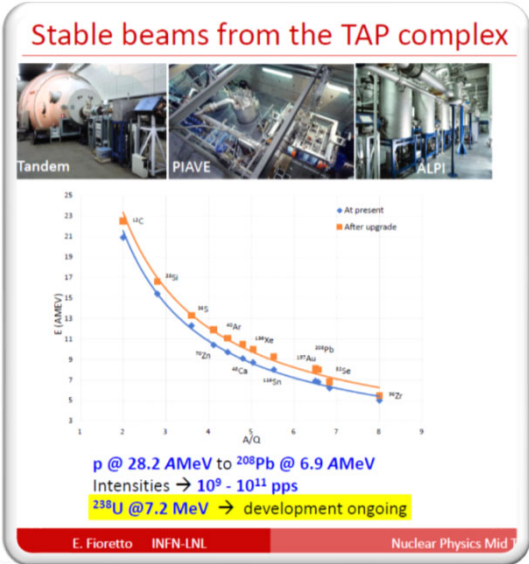
- p-n pairing
- fundamental interactions
- alpha clusterization
- Isospin symmetry breaking
- Nuclear shapes and coexistence
- Coupling to the continuum
- Nuclear Astrophysics

Concluding remarks from Nuclear Structure working group

Fabiana Gramegna

Nuclear Physics Mid Term Plan in Italy – LNL Session

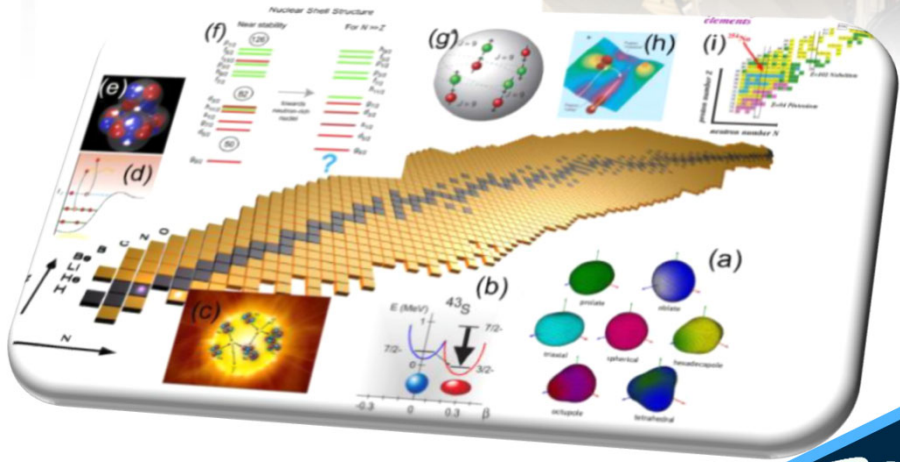
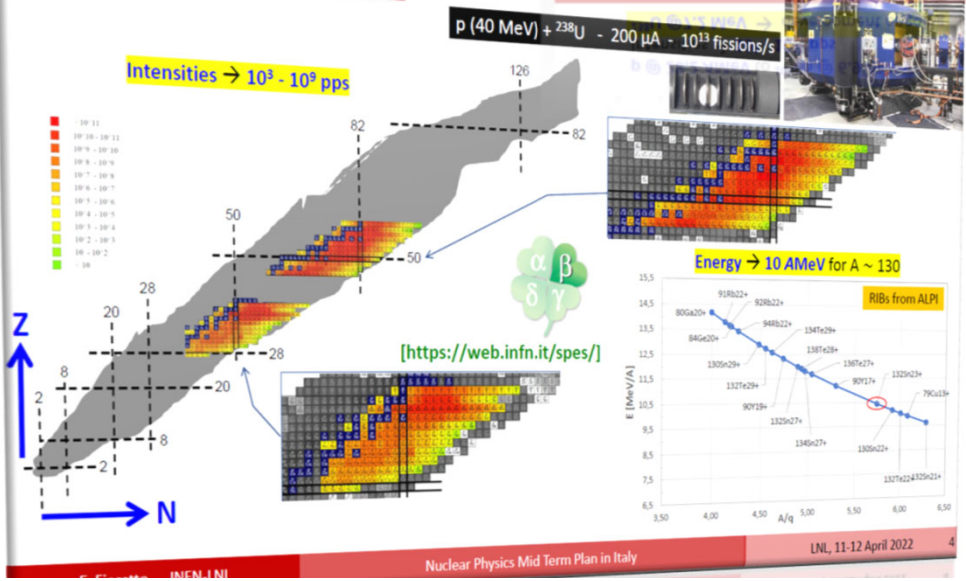
- The development of **new beams**, the availability of **exotic targets** as well as the operation of new accelerator complex **SPES** would guarantee a leading position to the laboratory within the panorama of nuclear structure community



- The presence and support of **cutting-edge instruments** (AGATA, GRIT, NEDA, PARIS, CTADIR, PRISMA, ACTAR, ..) are key to achieve the physics objectives that have emerged




Re-accelerated SPES RIBs



Highlights over time

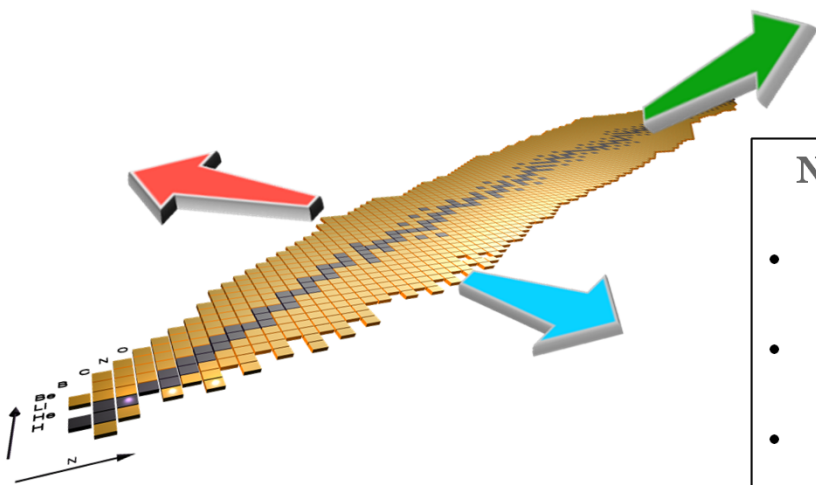
Daniele Mengoni

Nuclear Physics Mid Term Plan in Italy – LNL Session

time ... 

	A	B	C
Light and medium mass exotic nuclei	γ decay from near-threshold states	Particle decays from cluster states	γ decay from near-threshold states Nucleon correlations and molecular orbitals Isoscalar Giant Monopole Resonance in light deformed nuclei Proton excitations and 0+ states in Ar isotopes
N~Z nuclei	Isospin symmetry breaking, shape coexistence – lifetime measurements	Fundamental interactions (precision measurement of mirror beta decay branching ratios)	T=0 vs T=1 p-n pairing
Shell Evolution	New theory developments for shell structure Shell-evolution around N=50: shape coexistence and gap reduction towards 78Ni		
		Shape coexistence and type II shell evolution around N=60 in Zr, Sr	Lifetimes after transfer reactions for interplay of deformation and single particle Shell-evolution at N=82 around 132Sn
Deformation and Collective modes	GDR/GQR gamma+particle decay, Jacobi shape	PDR (alpha scattering inv. kin. with different stable nuclei and SPES beams) and PDR Beta Decay	

THE WHY AND HOW IS STILL IMPORTANT TO INVESTIGATE NUCLEAR REACTIONS

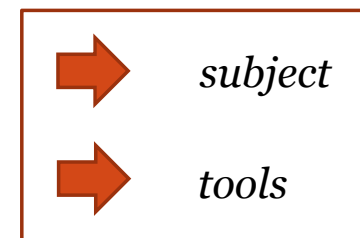
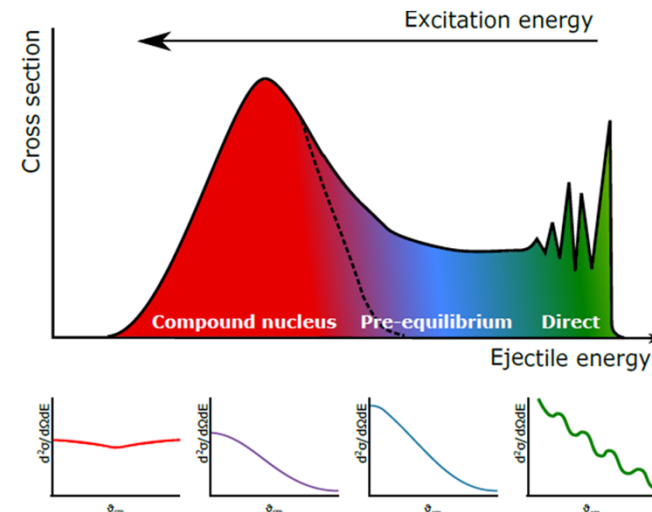


Nuclear Physics will exploit stable and Radioactive ion beams to:

- **Explore** and locate the extremes of nuclear existence
- **Discover** exotic properties of nuclei (shapes, structure evolution)
- **Explain** the role of isospin in complex systems (nEOS, E_{sym})

Nuclear Reactions

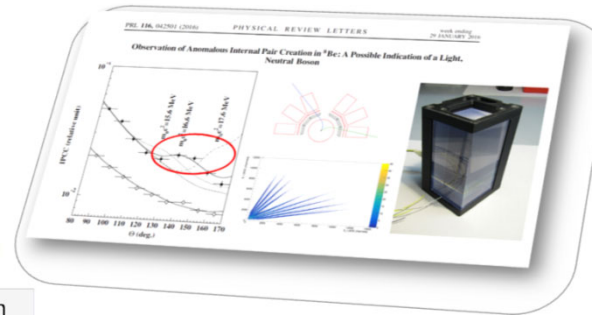
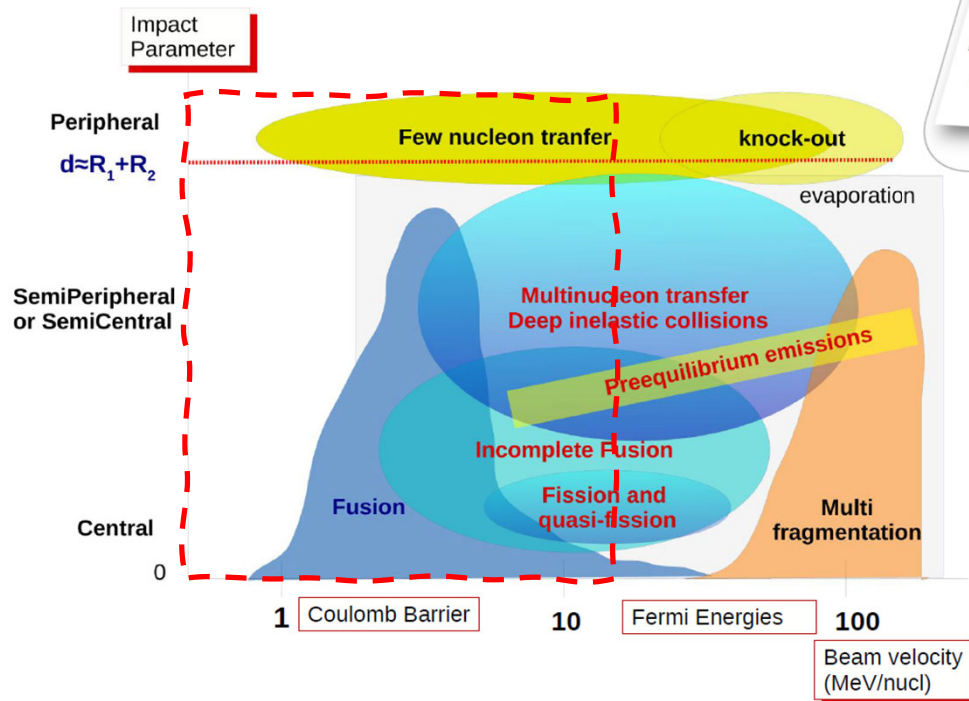
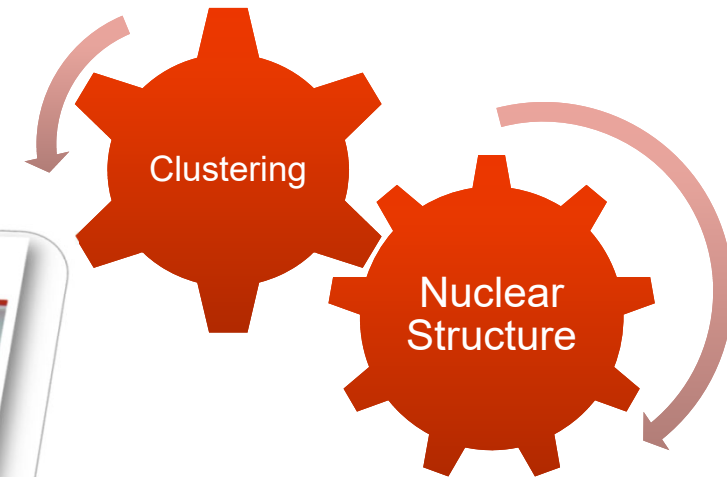
- Characterize the **mechanisms** that drive nuclear reactions and describe **reaction dynamics**
- Study the **interplay** between structure and reactions
- **Provide nuclear data**



Understand the physics of the **nuclear force** within the many-body nuclear system, **probing fundamental symmetries and interactions**

Reaction dynamics as *the subject*:

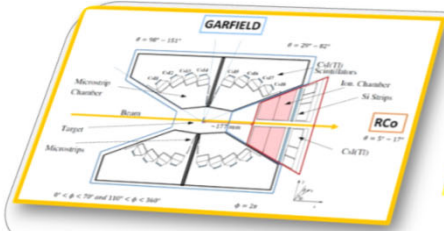
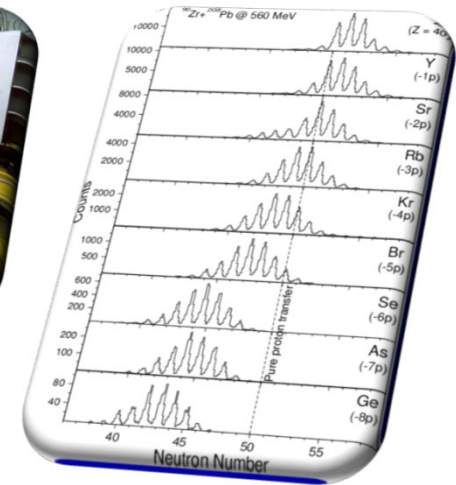
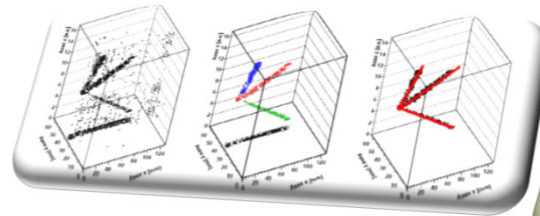
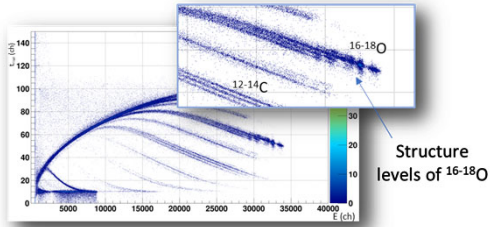
- Probing quantum effects in sub-barrier fusion
- **Dynamical production of e+e-** in sub-barrier reactions of light ions
- Consistent description of **fusion and fission** processes
- Consistent description of **out-of-equilibrium** processes



Reaction dynamics as a *laboratory*:

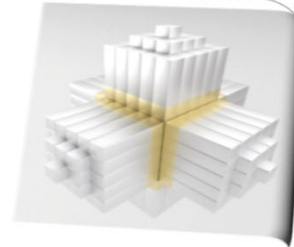
- Population of **super-heavy elements** through transfer reactions
- Study of **nucleon-nucleon correlations**
- Study of **structure properties: ANCs, halos, collective excitations**
- Accurate measurement of **reaction cross-sections** and related techniques

Exp KEYWORDS: energy, mass and charge resolution; completeness of the event reconstruction, low identification thresholds



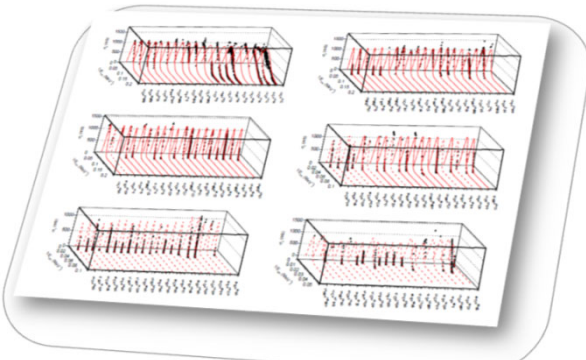
High angular coverage particle detectors with good PID performances and low thresholds. Many ancillaries: Rco, FARCOS, FAZIA, ...

The challenge: provide absolute cross-sections!

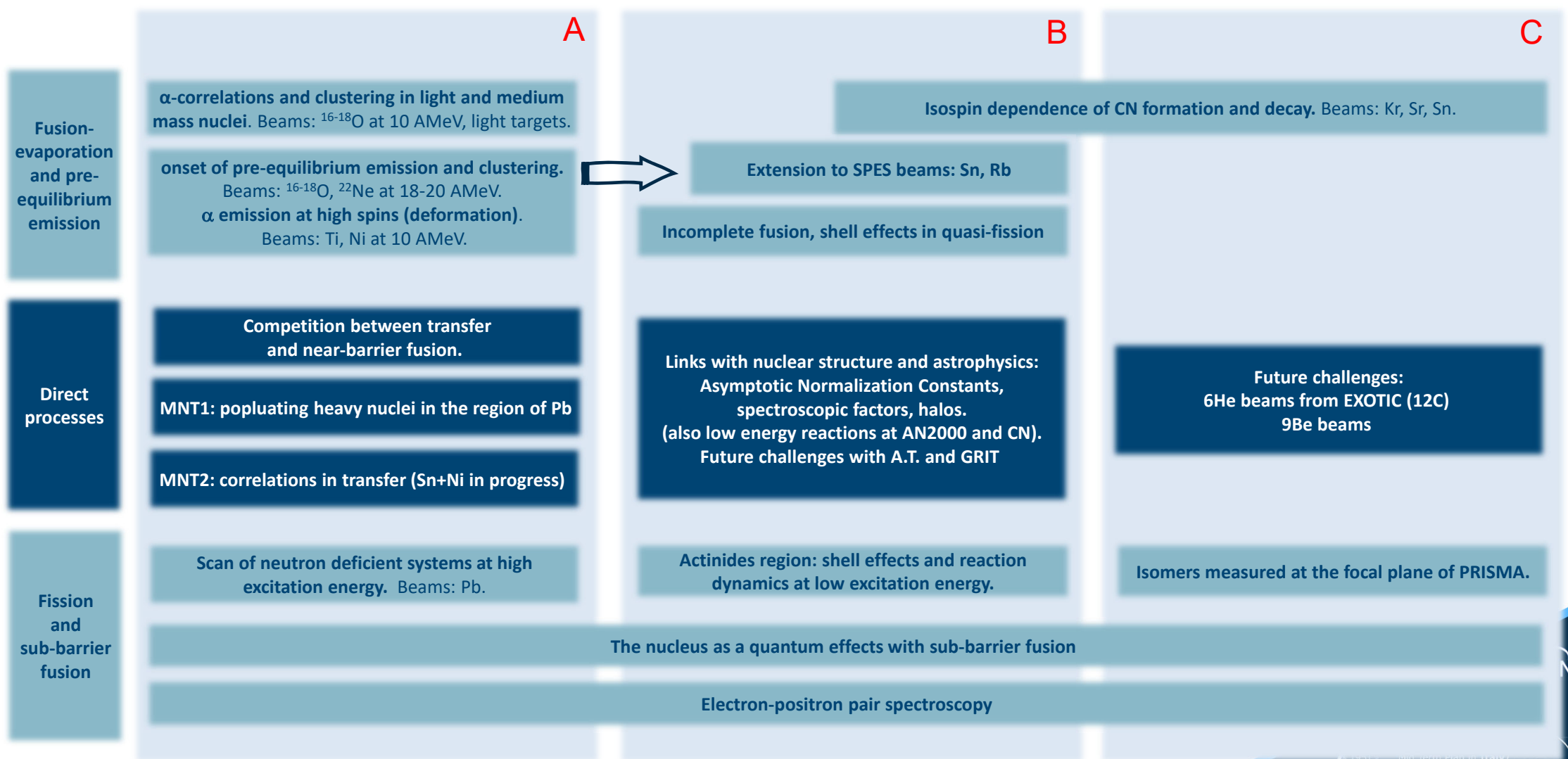


Artificial Intelligence: can it help in the complexity of reaction mechanisms?

Theo KEYWORDS: signatures & exp. observables, MC methods to filter theo data to take into account distorted experimental distribution comparisons.

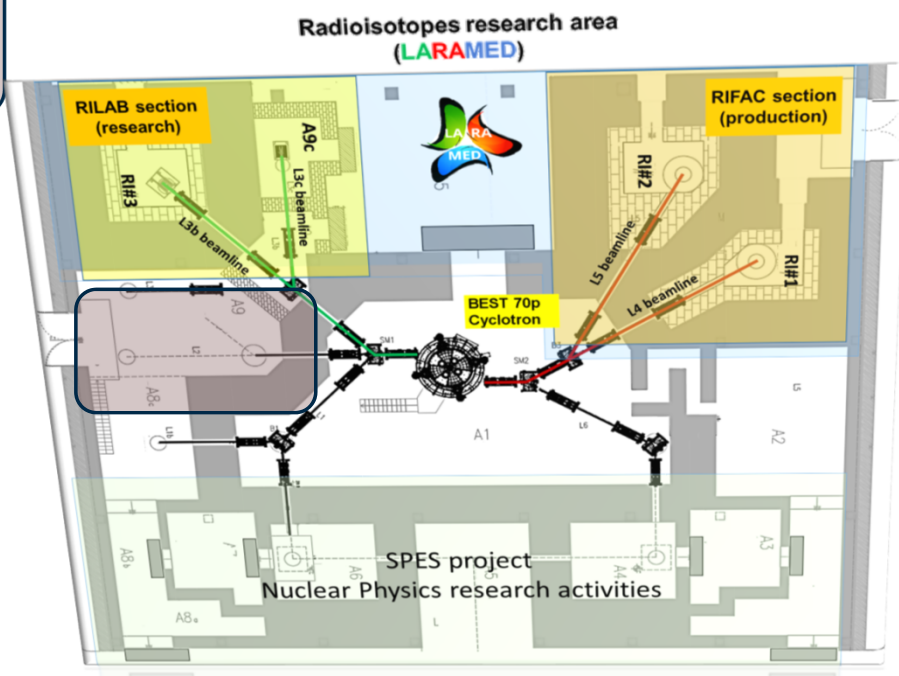


Readiness . . .

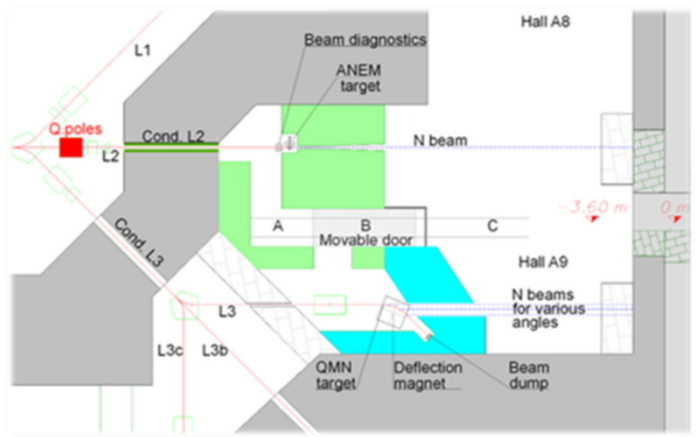


Nuclear cross sections measurements and modelling for direct radionuclide production and neutron beam lines at SPES (L. Mou)

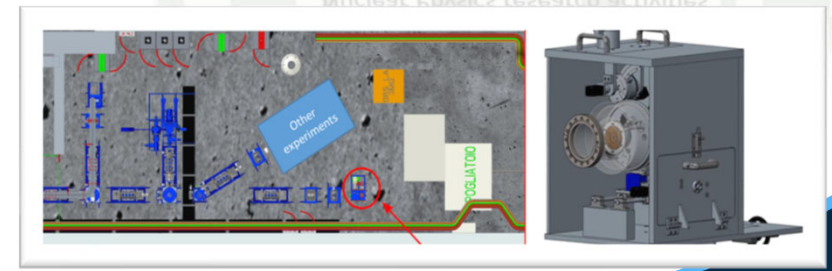
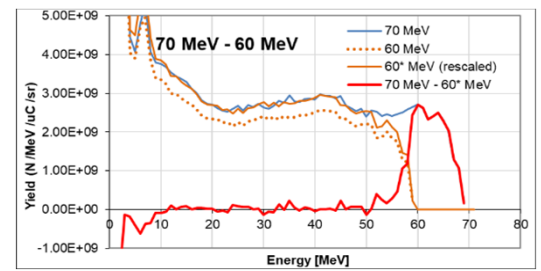
- **Proton-induced nuclear cross sections** measurements for medical RNs:



- **Neutron facility at SPES**



NEPIR-0: Pseudo monochromatic *n*-beam

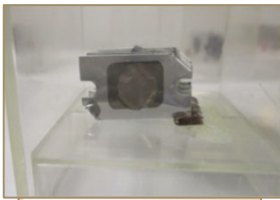


IRIS system

- Target development and characterization (e.g.. IBA techniques) for nuclear physics experiments → LUNA, EUROLABS, SPES etc.



Carbon stripper foils



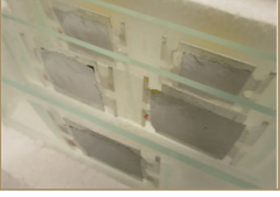
¹⁸⁴W on carbon



natAu on ⁵⁸Ni



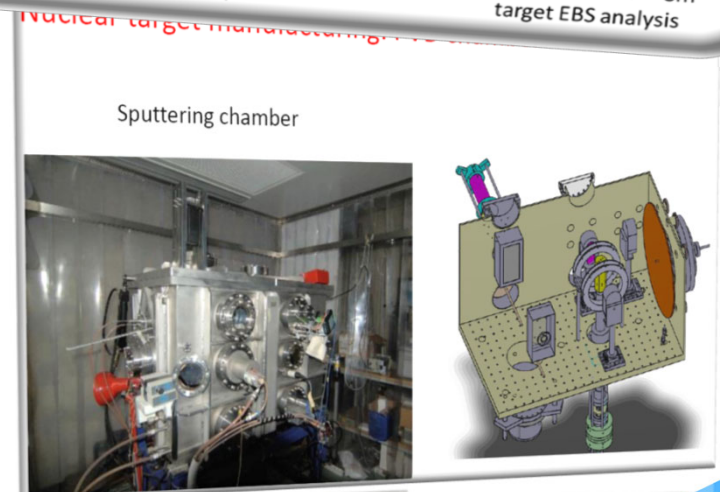
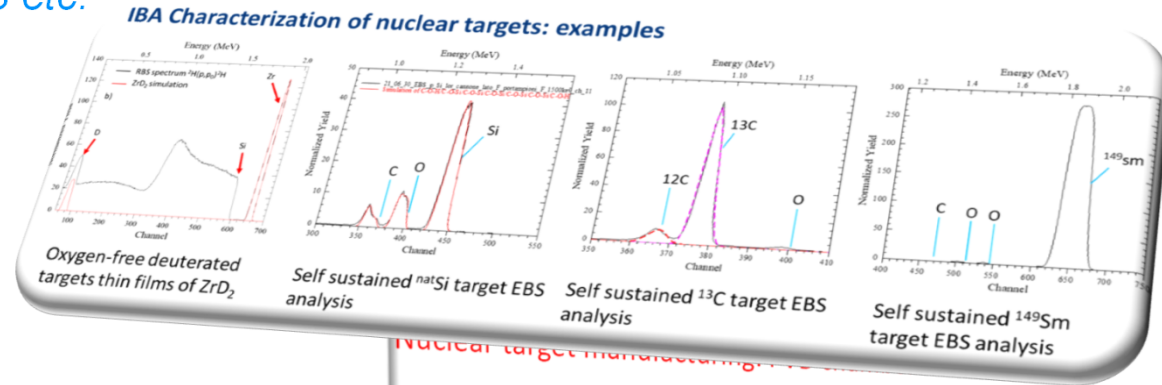
¹⁴⁸Sm on Ta



⁵⁴Fe on Au



¹⁰⁶Cd



Nuclear cross section measurements for applications at LNL

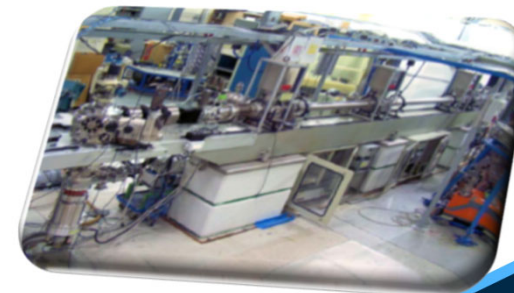
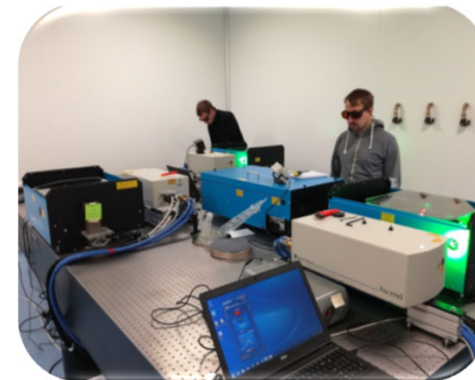
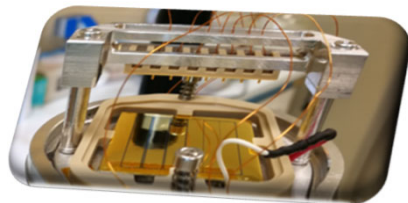
- Medical radionuclides production with p beams with the dedicated facility
- Neutron-induced reactions
- Charged-particle induced reactions for target characterization

Nuclide production and laser spectroscopy with ISOL

- Development of ISOL beams for medicine and nuclear physics
- Decay spectroscopy of nuclide of medical interest

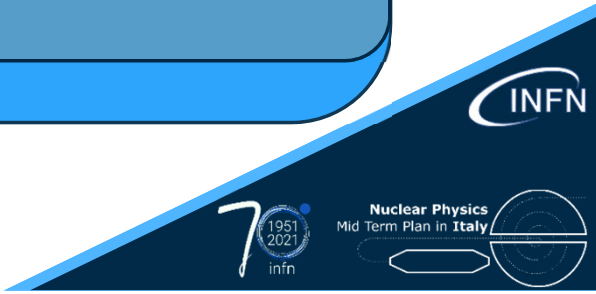
Ion-solid interaction

- Study of radiation damage of materials, devices and novel detectors
- Ion beam microanalysis for nuclear targets development



	Phase A	Phase B	Phase C
SPES_ direct-activation& modeling <i>L.Mou</i>	Benchmark-exp_p_30-70MeV Medical RNs xs_p_30-70MeV Modeling xs_medical RNs		Deuterons_Alpha_beams Neutrons_beams
SPES_ ISOL&laser <i>M. Ballan</i>	Off-line_exp ISOL targets development	On-line_exp Decay spectroscopy on ISOL-produced RNs	
IBA&ion-solid-interaction <i>M. Campostrini</i>	Target characterization for nuclear & astro physics XS_meas_for IBA up-to-5MeV	Ion-solid int & neutrons SEE & bulk damage _ Single Ion & Large area Irr.	Detector development & test

Phase A: Activities ready to be performed
Phase B: Activities still requiring test and feasibility study
Phase C: Activities requiring R&D and/or infrastructures construction



Planning the Future:

All groups have underlined the importance of connections/collaborations between **experimentalists and theoreticians!**

Challenging Opportunities are coming available at LNL for new experiments with new beams, targets & experimental instruments at the status of art → this will mean that **our sensitivity** will gain **several order of magnitude** so to permit in specific cases to join **regions of knowledge** not previously accessible → essential parts of the mosaic!

The LNL needs to have a **solid perspective for the young scientists** working in these fields → critical mass has to be guaranteed.

The **new infrastructures with new beams** must become operative as soon as possible → great efforts must be devoted from everyone inside the Laboratory and outside (users & management) to make this happen.

All these possibilities will be **complemented** with those already described in the previous workshop **coming from LNS**

