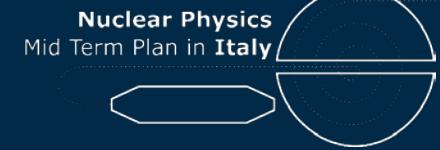


Nuclear Physics Mid Term Plan in Italy

LNS – Session

Catania, April 4th-5th 2022



WG 1 – NUCLEAR DYNAMICS

Sara Pirrone
INFN-Sezione di Catania, Italy

Heavy Ion Collision and Equation of State

Enrico De Filippo, INFN – Sezione di Catania, Italy

Clustering

Alessia Di Pietro, INFN – LNS, Italy

Fission Dynamics

Emanuele Vardaci, University Federico II, Napoli e INFN – Sezione di Napoli, Italy



ACTIVITIES TIMELINE

1

Nuclear Physics Mid Term Plan in Italy – LNS Session

	Phase A	Phase B	Phase C
HIC & EOS			
Clustering		.	
Fission Dynamics			

	Phase A	Phase B	Phase C
HIC & EOS			
Clustering	<p>Phase A: research activities/experiments almost ready to be performed</p> <p>Phase B: research requiring some test and feasibility study</p> <p>Phase C: research activities requiring R&D and/or development of devoted apparaata/facilities</p>		
Fission Dynamics		<p>TAG LNS-ND-EXP-nX (0-1-2...)(A-B-C)</p>	

Heavy Ion Collision and Equation of State

Enrico De Filippo, INFN – Sezione di Catania, Italy

WG: Enrico De Filippo, Giuseppe Cardella, Elena Geraci, Brunilde Gnozzo, Angelo Pagano, Massimo Papa, Sara Pirrone, Giuseppe Politi INFN-CT, Giovanni Casini, Silvia Piantelli INFN-FI, Fabio Risitano, Marina Trimarchi INFN-CT & UNIME, Nunzia Martorana, Emanuele Pagano, Francesca Rizzo, Paolo Russotto INFN-LNS

HIGHLIGHTS

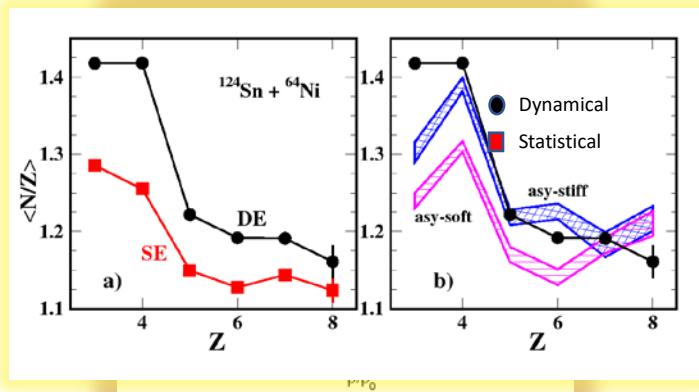
I. Symmetry Energy term in EOS precision measurements in sub-saturation density region $\rho < \rho_0$

a) IMFs production and their isotopic composition

Stable beams by CS

$^{96}\text{Zr} + ^{96}\text{Zr}$ 30 AMeV N/Z = 1.40 Neutron rich
 $^{96}\text{Ru} + ^{96}\text{Ru}$ 30 AMeV N/Z = 1.18 Neutron poor

LNS-ND-EXP-0B

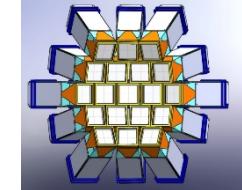
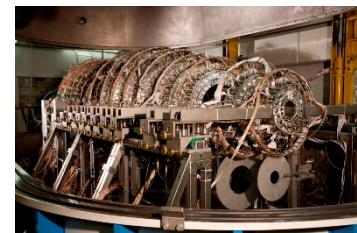


Radiactive Beams by FRAISE

$^{68}\text{Ni} + ^{124}\text{Sn}$ 25 AMeV (N/Z = 1.46 Neutron rich)
 $^{56}\text{Ni} + ^{112}\text{Sn}$ 25 AMeV (N/Z = 1.15 Neutron poor)

^{68}Ni from a primary of ^{70}Zn minimum intensity $\approx 10^6$ pps
 ^{56}Ni from a primary of ^{58}Ni minimum intensity $\approx 10^6$ pps

LNS-ND-EXP-0C



CHIMERA+FARCOMS



HIGHLIGHT

I. Symmetry Energy term in EOS precision measurements in sub-saturation density region $\rho < \rho_0$

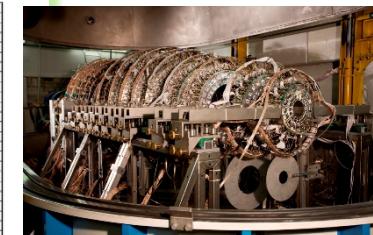
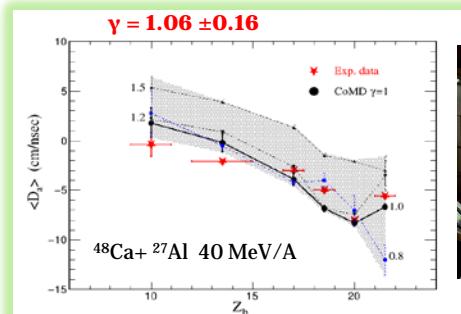
b) Dynamical Dipole and CoMD

HI - Stable beams by CS

High intensity stable beams (of the order of 10-20nA)

Ar, Ca isotopes + Ca, Ni targets 20-30 AMeV

LNS-ND-EXP-0B



c) Mid velocity fragments

Stable Beams by CS

$^{56}\text{Fe} + ^{40}\text{Ca}, ^{120}\text{Sn}, ^{208}\text{Pb} \sim 35 \text{ MeV/A}$

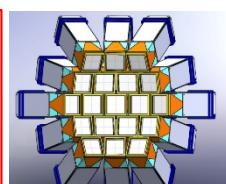
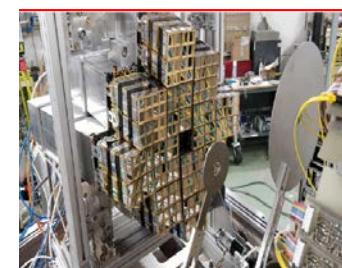
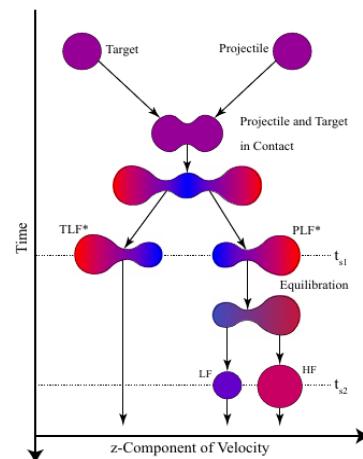
$^{78}\text{Kr} + ^{40}\text{Ca}, ^{120}\text{Sn}, ^{208}\text{Pb} \sim 35 \text{ MeV/A}$

LNS-ND-EXP-0B

Radioactive Beams by FRAISE

Kr isotopes ~35 MeV/A

LNS-ND-EXP-0C



FAZIA Telescopes



HIGHLIGHT

II. Isospin influence on Nuclear Caloric Curve

To solve conflicting by theoretical models results & few data existing

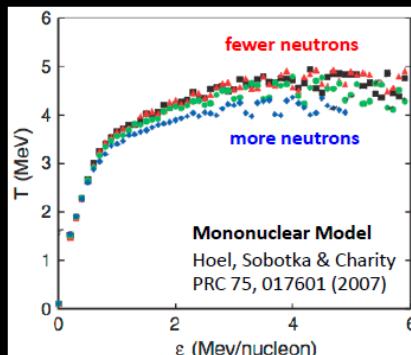
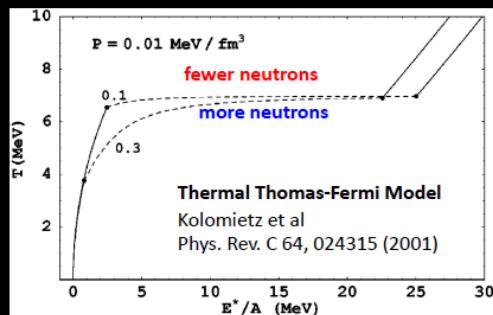
Radioactive beams by FRAISE

$^{34}\text{Ar} + ^{58}\text{Ni}$, $^{46}\text{Ar} + ^{64}\text{Ni}$ $E = 15\text{-}30 \text{ MeV/A}$
LNS-ND-EXP-0C

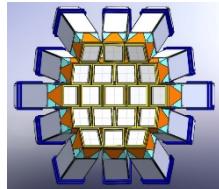
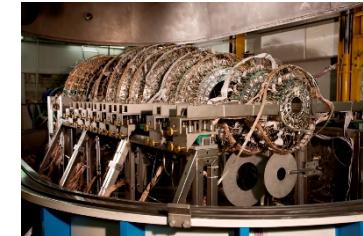
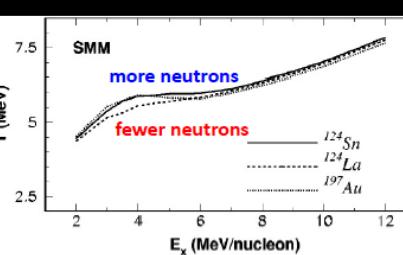
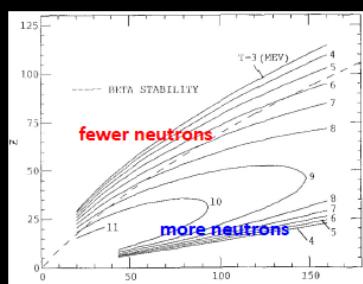
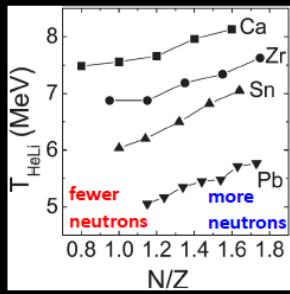
Theory

Different models make very different predictions about how the caloric curve may depend on n-p asymmetry.

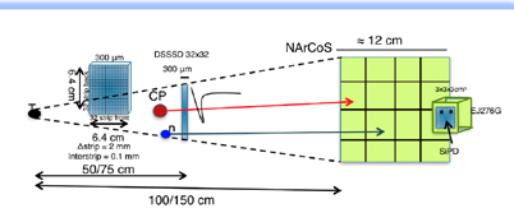
Neutron Rich
→ Lower T



Neutron Rich
→ Higher T



CHIMERA+FARCOS
+ Neutron detector



PRIN 2020
funded: project
ANCHISE



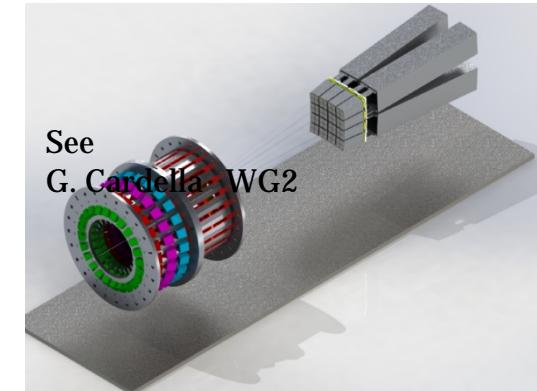
Nuclear Physics
Mid Term Plan in Italy



REQUEST FOR A NEW LARGE MULTIPURPOSE CHAMBER

Availability of a large multipurpose scattering chamber able to host a setup with the following features:

- Most fragments to be identified in Z and A to get highly exclusive data and to constrain transport models (in particular BU fragments and IMF from midvelocity)
- Sufficient coverage for large acceptance (QP, midvelocity)
- High granularity and good energy resolution for precision correlation studies
- Dedicated system to allow for absolute cross section determination
- Versatility for various geometry options and coupling with other detectors (e.g. gamma detectors or active gas target devices)



Drawing done by C.Cialdai INFN - Firenze

Radioactive Beams by FRAISE

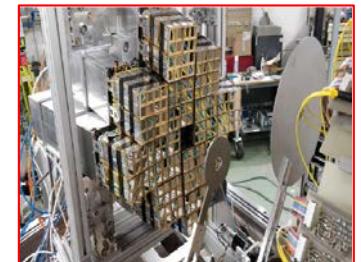
**Fragmentation cross section precision measurements
(lack of data on many systems)**

^{15}C , $^{14}\text{Be} + ^{12}\text{C}$, ^{197}Au 40 MeV/A

$^{16,20}\text{O} + ^{12}\text{C}$, ^{197}Au 40 MeV/A

(zero degree configuration)

LNS-ND-EXP-0A



FAZIA Telescopes



Nuclear Physics
Mid Term Plan in Italy



Clustering Alessia Di Pietro, INFN – LNS, Italy

WG: Alessia Di Pietro, PierPaolo Figuera, Domenico Torresi INFN-LNS, Juan Pablo Fernandez Garcia Univ. de Sevilla, Ivano Lombardo INFN-CT, Matko Milin Univ. Of Zagreb, Neven Soic Boskovic Inst, Zagreb

HIGHLIGHT

I. CLUSTER STATES IN ^{13}C AT VERY HIGH E^* AND OM RESONANCES

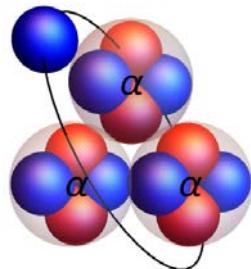


FIG. 6. Molecularlike picture of ^{13}C .

TANDEM Noble Gas Beams
 $^{4}\text{He} + ^{9}\text{Be}, \rightarrow ^{13}\text{C}^* E = 9\text{-}20 \text{ MeV}$
 $^{4}\text{He} + ^{10,11}\text{B}, ^{13}\text{C} \rightarrow ^{14,15}\text{N}^*, ^{17}\text{O}^*$
LNS-ND-EXP-0B

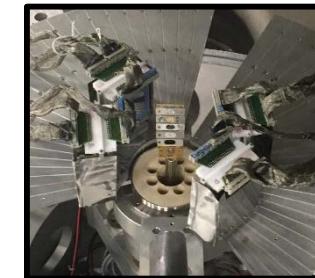


CT2000 High resolution detection

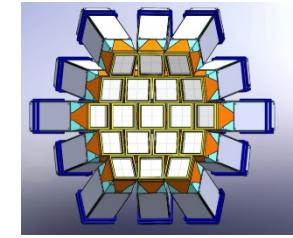
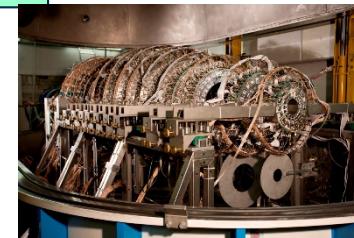
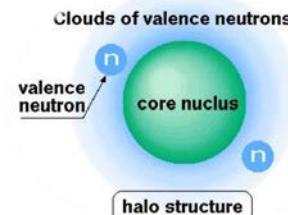
II. CLUSTERING IN p-RICH ENVIRONMENT & CONSTRAINT MODERN SHELL MODEL

TANDEM Noble Gas Beams
 $^{3}\text{He} + ^{6}\text{Li}, ^{10}\text{B}, ^{12}\text{C}, ^{14}\text{N}, ^{16}\text{O} \rightarrow \dots E=10\text{-}30 \text{ MeV}$
 One proton transfer (spectroscopic factor)
 2p transfer
 N- α cluster configuration
LNS-ND-EXP-0B



HIGHLIGHT**III. CLUSTERING STRUCTURE OF ^{10}Be , ^{13}B , ^{14}C , $^{18,20}\text{O}$** **Batch Mode TANDEM Beams** $^{10}\text{Be} \rightarrow ^6\text{He} + ^4\text{He}$ E = 40MeV $^{10}\text{Be} + ^4\text{He} \rightarrow ^{14}\text{C}^* \rightarrow ^{10}\text{Be} + ^4\text{He}$ **LNS-ND-EXP-0A** **^{14}C production in batch-mode**

development in collaboration with PSI useful to study new cluster states, and theoretical comparison, possible $^{14}\text{C} + ^7\text{Li}$ to study $^{14}\text{C} + \alpha$ structure in ^{18}O and ^{20}O

building block of heavier cluster structure**CT2000-CLAD****FRAISE Beams (CLUB 2020- COVID cancelled)** $^{13}\text{B} \rightarrow ^{12}\text{Be} + p, ^9\text{Li} + \alpha, ^{10}\text{Be} + t, ^7\text{Li} + ^6\text{He}$ E < 50 MeV**LNS-ND-EXP-0A****CHIMERA+FARCOS****IV. Investigation of halo effect on dynamics with ^{14}Be , ^{15}C , ^{17}Ne on ^{208}Pb** **HI Radioactive beams by FRAISE**p-halo n-halo E= 10-15 MeV/A I= $10^2 - 10^5$ pps ^6He , ^{11}Li , ^{11}Be , ^{14}Be , ^{15}C , ^8B , ^{17}N ^{14}B , ^{15}C , ^{17}Ne + ^{208}Pb **LNS-ND-EXP-0B**Nuclear Physics
Mid Term Plan in Italy

INFN



Fission Dynamics Emanuele Vardaci, University Federico II & INFN – Sezione di Napoli, Italy

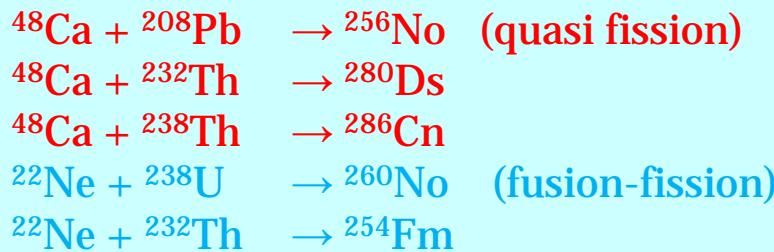
WG: Di Nitto, G. La Rana, D. Pierroutsakou, T. Banerjee -UNINA& INFN-NA, F. Cappuzzello , M. Cavallaro, D. Carbone - UNICT&LNS, E. Kozulin, A. Karpov. A. Bogachev, G. Knyazheva, K. Novikov, V. Saiko- *JINR, Dubna, Russia*, C. Borcea, S. Calinescu, C. Petrone, F. Rotaru, M. Stanoiu -*IFIN-HH, Bucharest, Romania*, P. Nadtochy *Omsk State Technical University Omsk, Russia*, T. Dickel, D. Kumar -*GSI and University of Giessen, Germany*

HIGHLIGHT

I. Exploring Magic Numbers in Fusion-Fission and QuasiFission

HI Beams by CS

E=5-10 AMeV



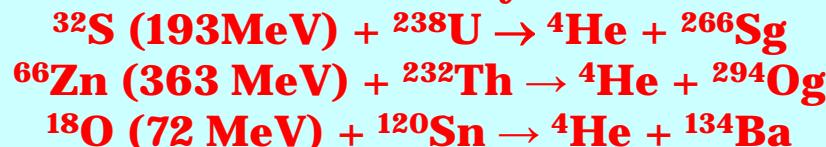
LNS-ND-EXP-0B

Exp. Setup:

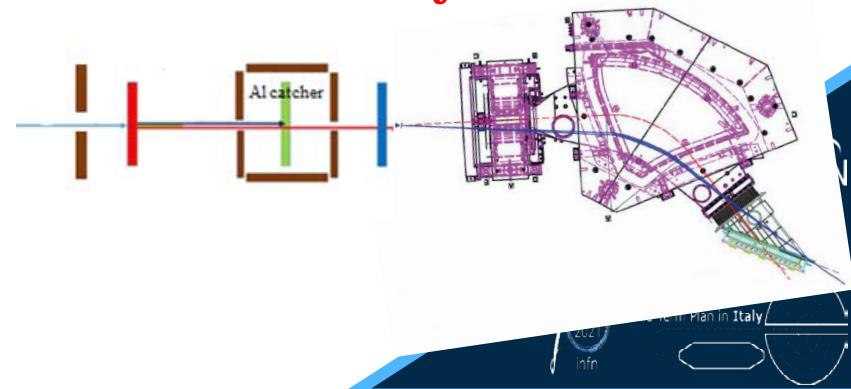
MAGNEX+ TOF arm + γ multiplicity filter

II. PRODUCTION OF SUPERHEAVY ELEMENTS (two body reactions)

HI Beams by CS



LNS-ND-EXP-0B



III. SHE PRODUCTION & NEW n-RICH (multinucleon transfer)

HI Beams by CS E=5-10 AMeV

$^{122}\text{Sn} + ^{208}\text{Pb}$
 $^{136}\text{Xe} + ^{202}\text{Os}$
 $^{48}\text{Ca} + ^{238}\text{Th}$
 $^{70}\text{Zn} + ^{238}\text{U}$
 $^{70}\text{Zn} + ^{232}\text{Th}$

LNS-ND-EXP-OB

Measured parameters:

- ToF, X, Y, Energy of each fragment

Extracted parameters:

- Velocity, Energy, Angles

Computed parameters :

- Masses and TKE

E silicon detector

Position sensitive
Stop detector
X, Y, ToF

ToF
Start detector

fragment 1

Target

Beam

fragment 2

MCP-based start and stop detectors with
electrostatic mirror

Double Arm TOF-E CORSET

+MAGNEX

Beam Degrader System?



Nuclear Physics
Mid Term Plan in Italy



1951-2021
infn

Phase A: research activities/experiments almost ready to be performed

Phase B: research requiring some test and feasibility study

Phase C: research activities requiring R&D and/or development of devoted appara/ facilities

	Phase A	Phase B	Phase C
HIC & EOS		<p>Esym precision measurements $\rho < \rho_0$</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> Stable beams by CS $^{96}\text{Zr} + ^{96}\text{Zr}$ 30 AMeV $^{96}\text{Ru} + ^{96}\text{Ru}$ 30 AMeV </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> HI (10-20nA) - Stable beams by CS Ar, Ca isotopes + Ca, Ni targets 20-30 AMeV </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> Stable Beams by CS $^{56}\text{Fe} + ^{40}\text{Ca}, ^{120}\text{Sn}, ^{208}\text{Pb}$ ~35 MeV/A $^{78}\text{Kr} + ^{40}\text{Ca}, ^{120}\text{Sn}, ^{208}\text{Pb}$ ~35 MeV/A </div>	<p>Esym precision measurements $\rho < \rho_0$</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> Radiactive Beams by FRAISE $^{68}\text{Ni} + ^{124}\text{Sn}$ 25 AMeV ^{68}Ni primary ^{70}Zn $^{56}\text{Ni} + ^{112}\text{Sn}$ 25 AMeV ^{56}Ni primary ^{58}Ni </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> $^{15}\text{C}, ^{14}\text{Be} + ^{12}\text{C}$ 40 MeV/A $^{32,38}\text{S} + ^{28}\text{Si}$ 40 MeV/A </div> <p>Isospin on Nuclear Caloric Curve</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> $^{34}\text{Ar} + ^{58}\text{Ni}$, $^{46}\text{Ar} + ^{64}\text{Ni}$ 15-30 MeV/A </div> <p>Fragmentation σ precision measurements</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> $^{15}\text{C}, ^{14}\text{Be} + ^{12}\text{C}, ^{197}\text{Au}$ 40 MeV/A $^{16,20}\text{O} + ^{12}\text{C}, ^{197}\text{Au}$ 40 MeV/A </div>
Clustering	<p>Clustering structure</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> Batch Mode TANDEM Beams $^{10}\text{Be} \rightarrow ^6\text{He} + ^4\text{He}$ E = 40MeV </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> FRAISE Beams $^{13}\text{B} \rightarrow ^{12}\text{Be} + p, ^9\text{Li} + a, ^{10}\text{Be} + t, ^7\text{Li} + ^6\text{He}$ E <50 MeV </div>	<p>Cluster in ^{13}C – Cluster in p-rich envirom.</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> TANDEM Noble Gas Beams $4\text{He} + 9\text{Be}, \rightarrow ^{13}\text{C}^*$ E = 9-20 MeV $4\text{He} + ^{10,11}\text{B}, ^{13}\text{C} \rightarrow ^{14,15}\text{N}^*, ^{17}\text{O}^*$ </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> $^3\text{He} + ^6\text{Li}, ^{10}\text{B}, ^{12}\text{C}, ^{14}\text{N}, ^{16}\text{O} \rightarrow \dots$ E=10-30 MeV </div> <p>Halo effect on dynamics</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> HI FRAISE Beams $^{14}\text{B}, ^{15}\text{C}, ^{17}\text{Ne} + ^{208}\text{Pb}$ </div>	
Fission Dynamics		<p>Exploring Magic Numbers</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> HI Beams by CS E=5-10 AMeV $^{48}\text{Ca} + ^{208}\text{Pb} \rightarrow ^{256}\text{No}$ $^{48}\text{Ca} + ^{232}\text{Th} \rightarrow ^{280}\text{Ds}$ $^{48}\text{Ca} + ^{238}\text{Th} \rightarrow ^{286}\text{Cn}$ $^{22}\text{Ne} + ^{238}\text{U} \rightarrow ^{260}\text{No}$ $^{22}\text{Ne} + ^{232}\text{Th} \rightarrow ^{254}\text{Fm}$ </div> <p>SHE PRODUCTION</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> ^{32}S (193MeV) + $^{238}\text{U} \rightarrow ^4\text{He} + ^{266}\text{Sg}$ ^{66}Zn (363 MeV) + $^{232}\text{Th} \rightarrow ^4\text{He} + ^{294}\text{Og}$ ^{18}O (72 MeV) + $^{120}\text{Sn} \rightarrow ^4\text{He} + ^{134}\text{Ba}$ </div> <p>Multinucleon Transfer</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;"> E=5-10 AMeV $^{122}\text{Sn} + ^{208}\text{Pb}$ $^{70}\text{Zn} + ^{238}\text{U}$ $^{136}\text{Xe} + ^{202}\text{Os}$ $^{48}\text{Ca} + ^{238}\text{Th}$ $^{70}\text{Zn} + ^{232}\text{Th}$ </div>	

Upgrading LNS to the future of Nuclear Dynamics:

- Noble gas source for the Tandem ($^{3,4}\text{He}$, $^{20,21,22}\text{Ne}$ beams)
- Fe, Zr, Ru beam production (new oven?)
- Development of ^{36}Ar isotopes for FRAISE (^{34}Ar requestes)
- Development $A=20-70$ isotopes for FRAISE
- Beam Degrader System
- New large multipurpose chamber, able to host large devices and to receive FRAISE beams

