HIB@LNS: CONCLUDING REMARKS

F. Gramegna (LNL)

Laboratori Nazionali del Sud

14-15 December 2015

LNS → high intensity Superconducting Cyclotron for NUCLEAR PHYSICS

Upgrading of the Cyclotron → introduction by A. Pagano

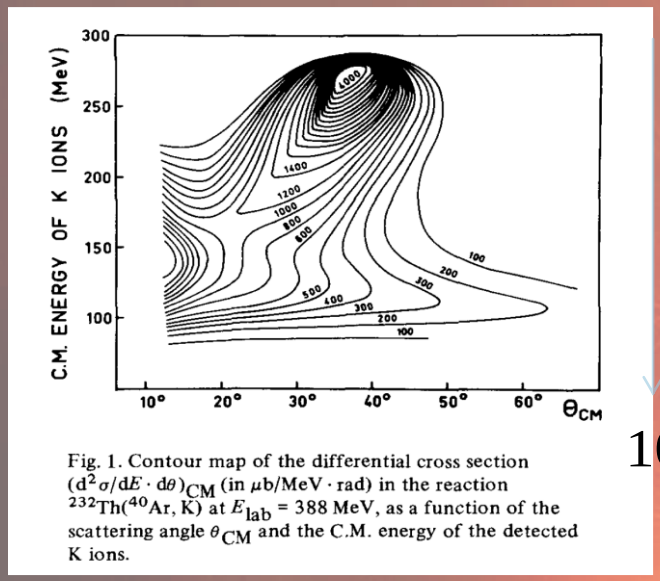
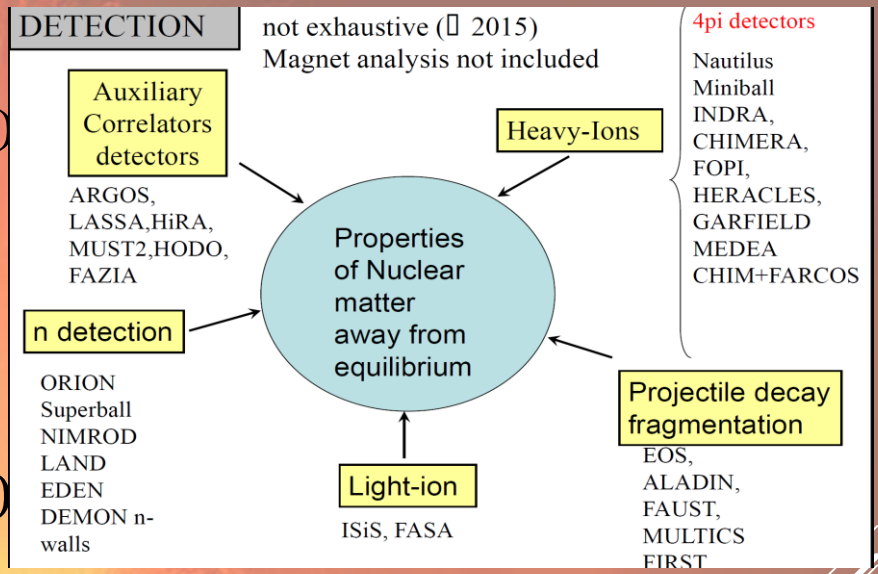


Fig. 1. Contour map of the differential cross section $(d^2\sigma/dE \cdot d\theta)_{CM}$ (in μb/MeV · rad) in the reaction $^{232}Th(^{40}Ar, K)$ at E_{lab} = 388 MeV, as a function of the scattering angle θ_{CM} and the C.M. energy of the detected K ions.

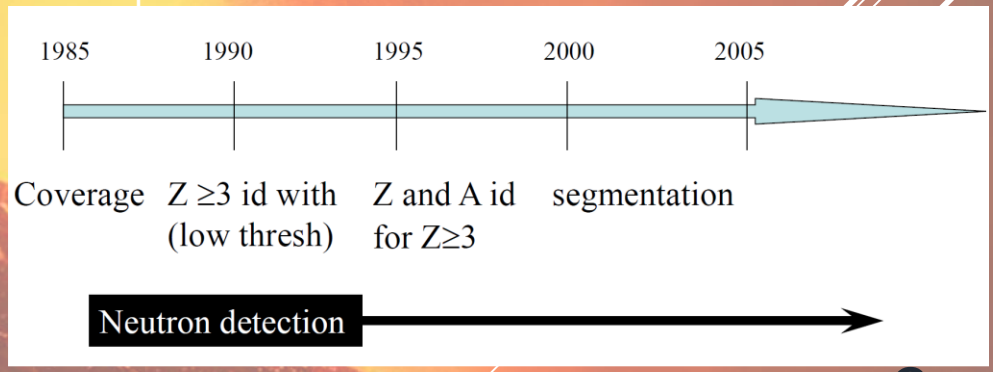
Time

$10^{-23} s (\approx fm/c)$

$10^{-20} s (\approx fm/c)$



Time scale of nuclear detection



The evolutionary character of the main reaction mechanism in HI above Coulomb energy (E/A > 10MeV/nucleon)

LNS & LNL: an italian working consortium for NUCLEAR PHYSICS

STABLE BEAMS:

- **LNS →**

✓ the Superconducting Cyclotron
(Intermediate energies → Reaction Dynamics)

✓ the TANDEM (Astrophysics)

- **LNL →**

✓ The SC LINAC ALPI & PIAVE
(low & medium energies → Reaction and Structure)

✓ The TANDEM (Nuclear Structure)

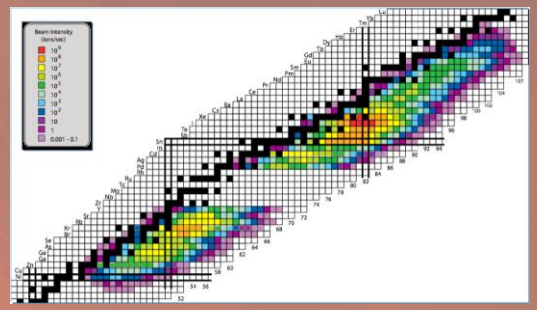
LNS & LNL: a working consortium for NUCLEAR PHYSICS

RADIOACTIVE BEAMS:
→ our BET on future

ISOL & FRAGMENTATION
LOW ENERGY & INTERMEDIATE ENERGY

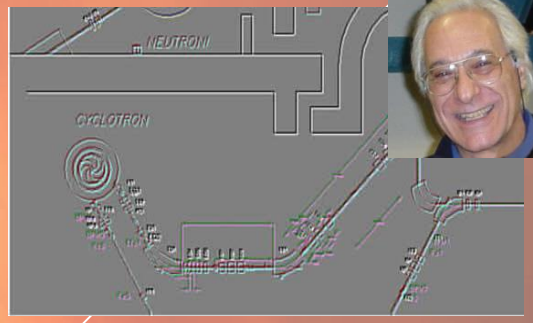
SPES: Selective Production of Exotic Species

- European framework
- Physics with SPES (mainly UCx fission but also SiC, B4C etc.)
- Instrumentation



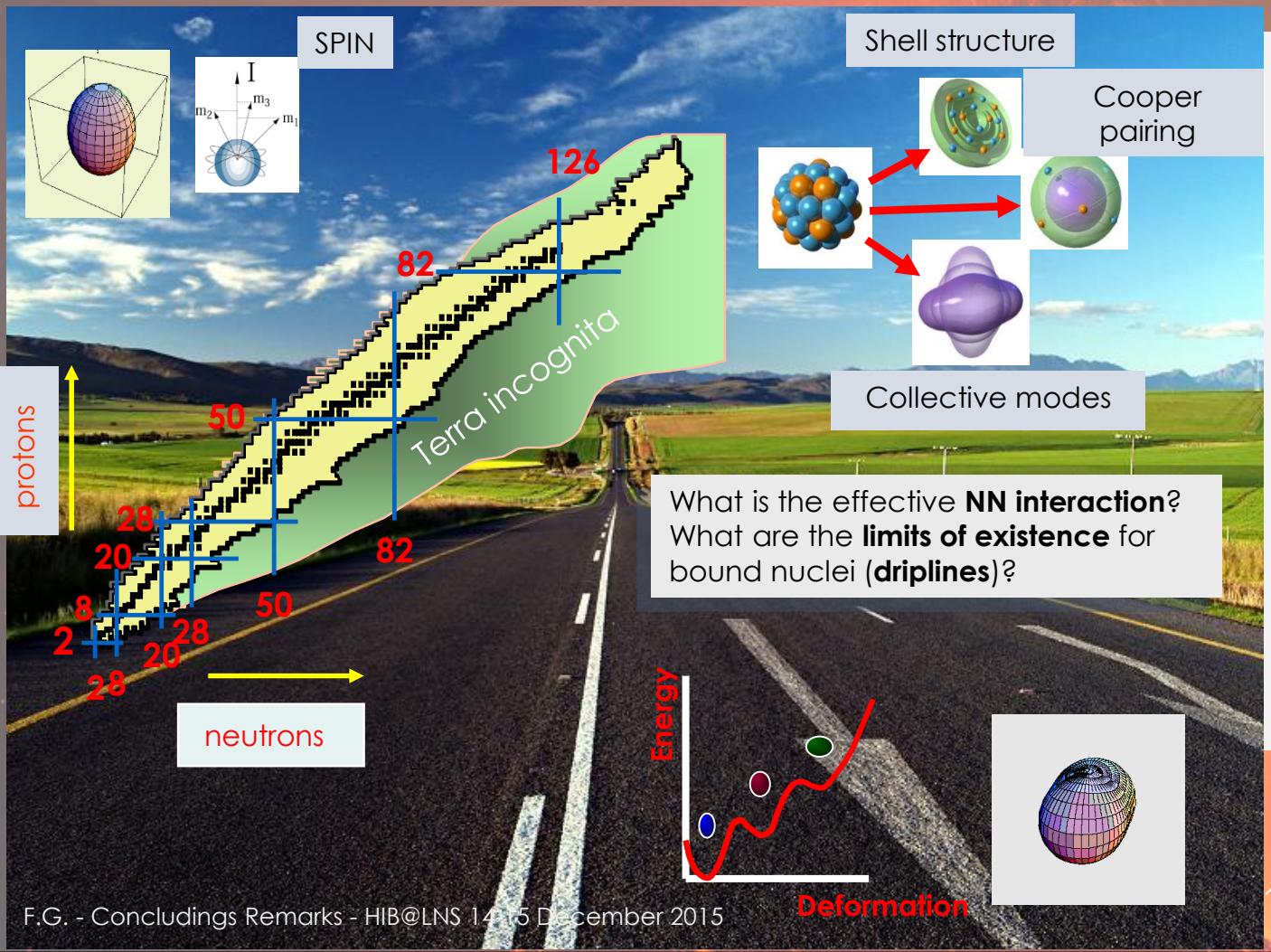
FRIBS: Radioactive Ion Beams at Intermediate Energy produced by the In-Flight method at LNS

- European framework
- Physics with FRIBS (intermediate energy, light ions)
- Instrumentation



The Why and How of Radioactive Beam Research

Atomic nuclei are one of the richest and most challenging **quantum systems** with a finite number of strongly interacting fermions of two kinds: **protons and neutrons**



Still **crucial** and **long-standing questions** remain:

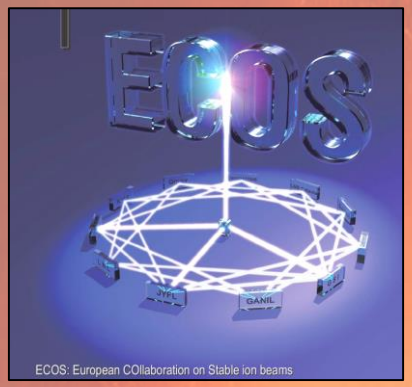
- What are the **limits for the existence** of nuclei?
- Which is the shell evolution (**magic numbers, proton - neutron interaction, shell gap creation and disappearance**)?
- How does the nuclear force depend on the **proton-to-neutron ratio**?
- How can **collective phenomena** be explained from individual motion?
- Is it possible to explain **complex nuclei** on the basis of simple building blocks?

LNS & LNL: a working consortium for NUCLEAR PHYSICS

The **mainframe** in which the two Laboratories are working is at **European level**:

ECOS (talk by F. Azaiez)

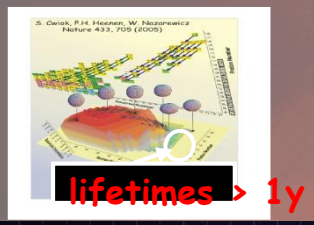
not only **RIBs** but **intense stable beams** needed



The Science with **high intensity stable ion beams**, Beam intensity limitations and technical developments for various types of research lines!

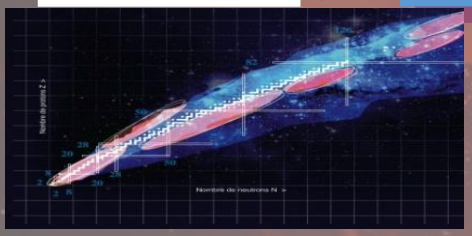
- N=Z nuclei (in–beam spectroscopy and decay studies)
- SHE search (Super heavy nuclei (in-beam spectroscopy and decay studies)
- Neutron-deficient nuclei (in-beam spectroscopy and decay studies)
- Nuclear astrophysics

Science Key Questions

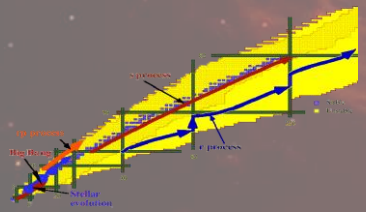


What are the limits of the heaviest elements?

SCIENCE Magazine- Top 125 Questions:
Are there stable high-atomic-number elements?



What are the limits of stability?



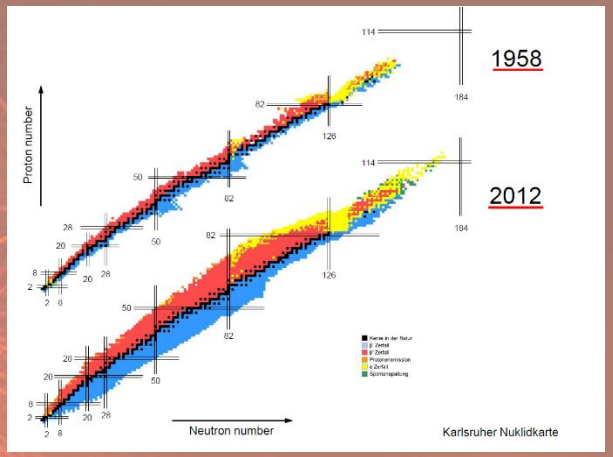
How the elements are made in the Universe?

LNS & LNL: a working consortium for NUCLEAR PHYSICS

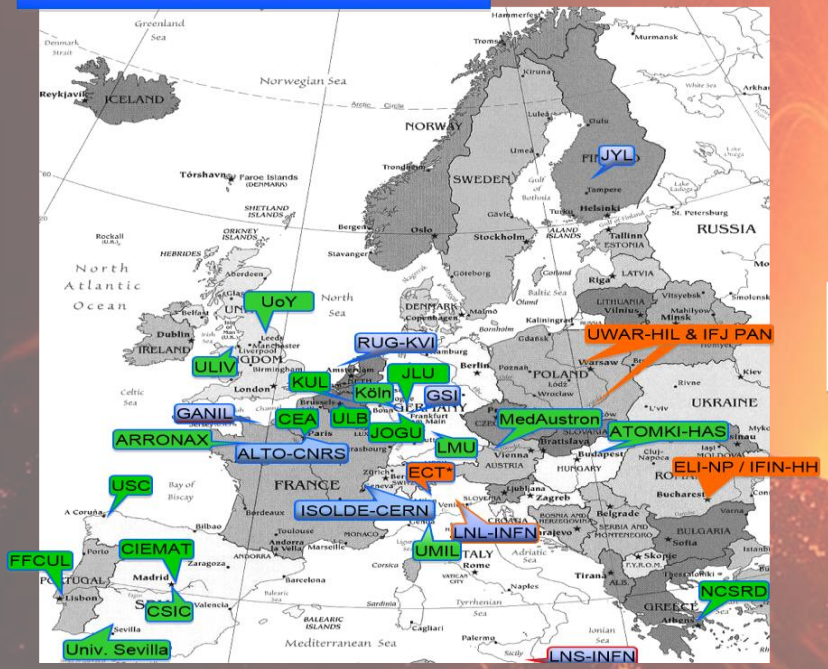
The mainframe in which the two Laboratories are working is at **European level**:

ECOS (talk by F. Azaiez) →

Did we progress?



FP8 ENSAR2 **Partners of**



7 ⇒ 10 TNA Facilities

30 ⇒ 30 beneficiaries
15 countries

Community: 2700-3000 scientists and highly qualified engineers

Close collaboration with infrastructures outside Europe:
Canada: TRIUMF
China: IMP Lanzhou
Japan: RIKEN & RCNP
Russia: Dubna/JINR
South Africa: iThemba
United States: NSCL & ANL

ENSAR2

LIA CollAGAIN
LIA POLITA
LIA COPIGAL

LNS → high intensity Superconducting Cyclotron for NUCLEAR PHYSICS

NUMEN: → HI -DCE a method to have access to the neutrino mass → talk by F. Cappuzzello

New physics for the next decades

but
requires

Nuclear Matrix Element (NME)!

$$\left|M_{\varepsilon}^{\beta\beta 0\nu}\right|^2 = \left|\left\langle \Psi_f \middle| \hat{O}_{\varepsilon}^{\beta\beta 0\nu} \middle| \Psi_i \right\rangle\right|^2$$

2003 – LoI DCE reaction focused on TANDEM
2012 proposal DCE with HI → useful for 0νββ
2014 --> WHAT's NEXT → NUMEN → upgrading the CS (larger intensity) → Upgrading the Focal Plane Detectors and electronics.

Data from Magnex give first evidence of getting quantitative results abiut nuclear matter elements from experiments:
The 40Ca(18O,18Ne)40Ar reaction.

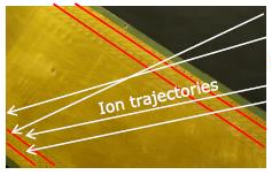
Challenging some hot cases in Phase 2

Reaction	Energy (MeV/u)	2016 I	2016 II	2016 III	2016 IV	2017 I	2017 II	2017 III	2017 IV	2018 I	2018 II	2018 III	2018 IV
^{116}Sn (^{18}O,^{18}Ne) ^{116}Cd	15-30	Approved experiment											
^{116}Cd (^{20}Ne,^{20}O) ^{116}Sn	15-25	Approved test											
^{130}Te (^{20}Ne,^{20}O) ^{130}Xe	15-25												
^{76}Ge (^{20}Ne,^{20}O) ^{76}Se	15-25												
^{76}Se (^{18}O,^{18}Ne) ^{76}Ge	15-30												
^{106}Cd(^{18}O,^{18}Ne) ^{106}Pd	15-30												

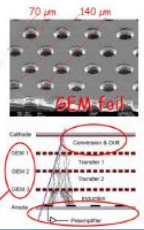
Major upgrade of LNS facilities: the MAGNEX spectrometer

- The MAGNEX focal plane detector rate (from 2 kHz to several MHz)

From multi-wire tracker



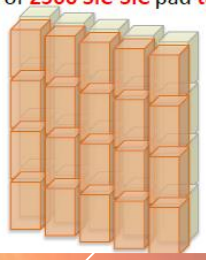
To micro-pattern tracker



- R&D key issue : GEM-based tracker at low pressure and wide dynamic range
- INFN-LNS (M. Cavallaro), collaboration with INFN-LNF, CERN, INFN-BA

From wall of 60 Si pad

To wall of 2500 SiC-SiC pad telescopes



A big challenge!

0.9 M€ call approved by INFN CSN5 (SICILIA)
P.I. S.Tudisco, collaboration with CNR, STM, FBK

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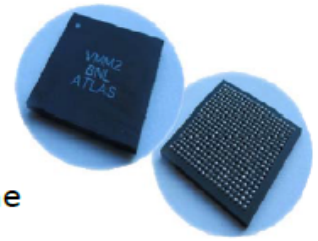
LNS → high intensity Superconducting Cyclotron for NUCLEAR PHYSICS

NUMEN: Upgrading of electronics needed → talk by D. Bonanno

Upgrade of the MAGNEX detector→ upgrade of Front End & Read Out electronics for the FOCAL PLANE

Front-end and read-out electronics (See talk D.Bonanno)

ELECTRONICS PROTOTYPES (D. LoPresti)



1) ASIC front–end chip:

for FPD chip VMM2(3) in collaboration with Brookhaven National Laboratory ($8x10^4$ transistor/channe for 64 channels)

for PM and PM-like signal chip DRS4 commercial chip delivered by PSI

2) Read – out: new generation of FPGA and System On Module (SOM)

Number of channels

- Gas tracker ~ 30000 ch
- SiC-SiC ~ 7500 ch
- Gamma array ~ 2500 ch

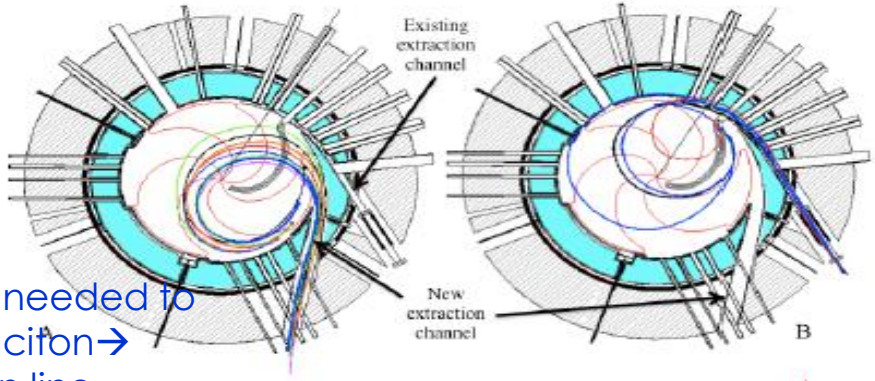
Tot ~ 40000 ch

LNS → high intensity Superconducting Cyclotron for NUCLEAR PHYSICS

Upgrading of the Cyclotron needed → talk by A. Galan, D. Rifuggiato

Major upgrade of LNS facilities: The CS accelerator

The CS accelerator current (from 100 W to 5-10 kW);

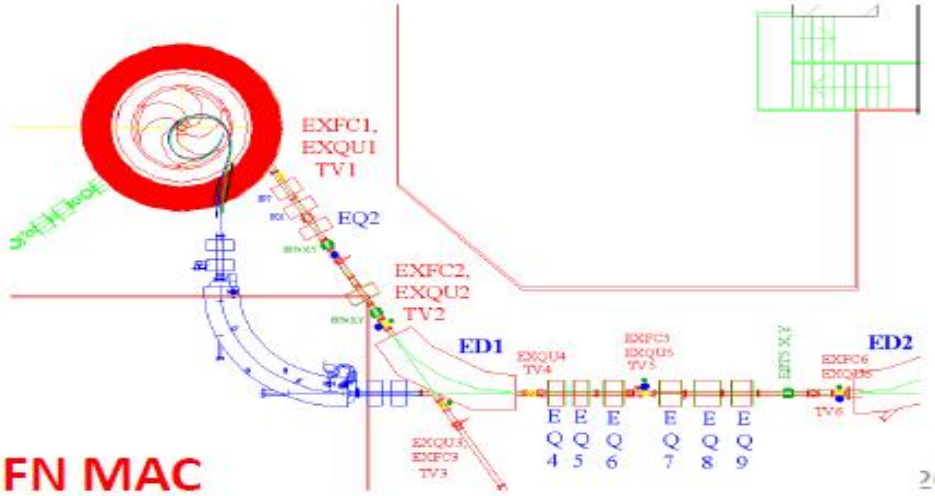


To enhance the extraction efficiency

Extraction by stripping

New channel needed to optimize extraciton→ new extraction line
New Switching magnet

- The beam transport line transmission efficiency to nearly 100%



Project submitted to INFN MAC

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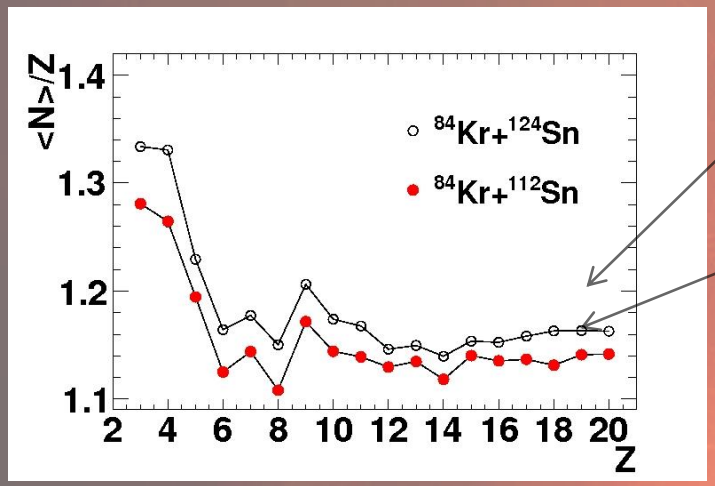
LNS → high intensity Superconducting Cyclotron for NUCLEAR PHYSICS

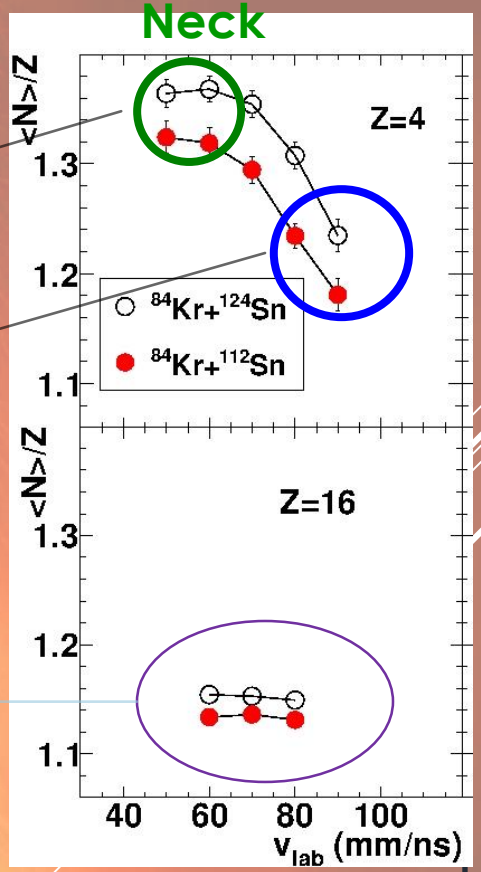
Physics cases:

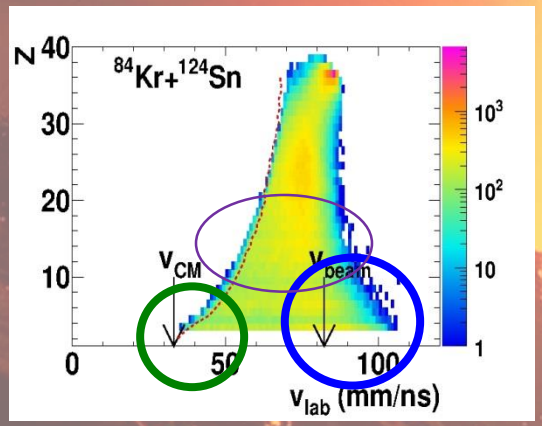
Isospin Physics with FAZIA: physics at intermediate energy→ talk by S. Piantelli



<N>/Z of QP phase space products systematically higher when the target is nrich

<N>/Z of neck emitted fragments higher than <N>/Z of QP evaporated fragments





No dependence on lab velocity for QP fission fragments

S.Barlini et al., PRC87(2013)054607

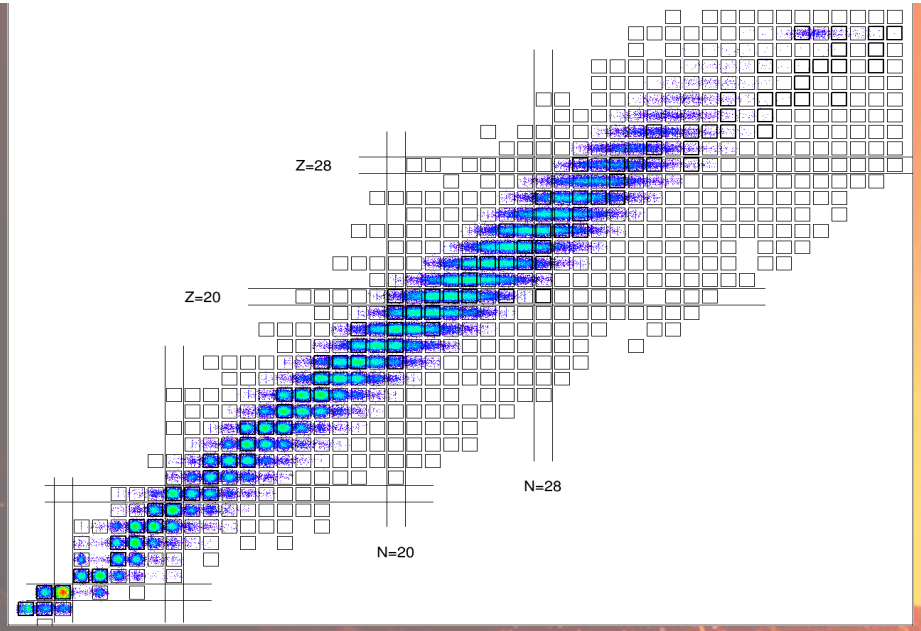
LNS → high intensity Superconducting Cyclotron for NUCLEAR PHYSICS

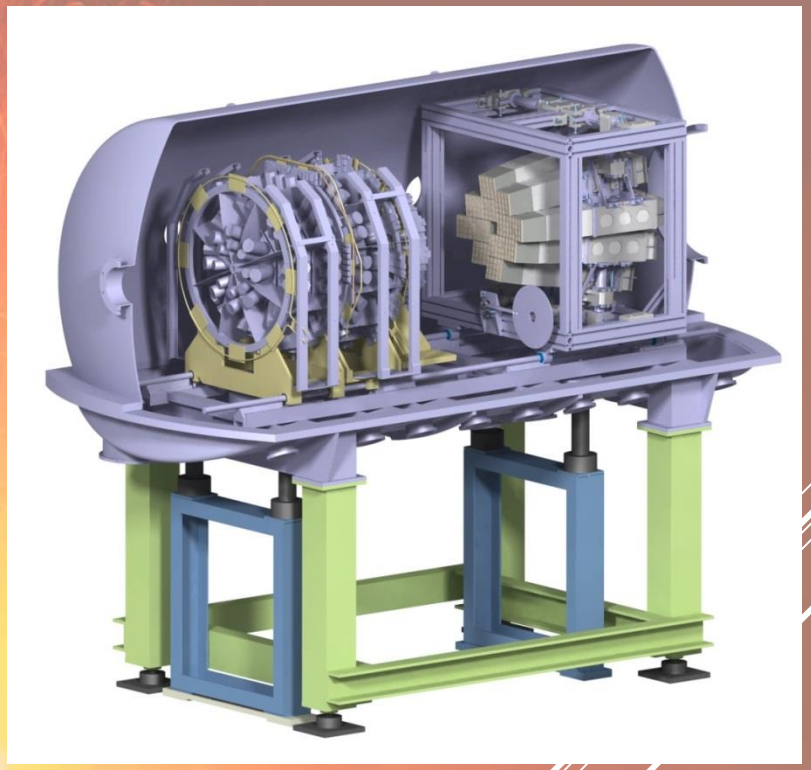
Physics cases

FAZIA present and future → talk by N. Le Neindre

Excellent resolutions in terms of A,Z, Energy

^{80}Kr+$^{40-48}$Ca @ 35 A MeV IsoFazia experiment, June 2015, LNS Catania





Good resolution, excellent results but low intensity for detectors and electronics → only the upgraded FRIBS program can be considered

Severl campaign:
FAZIA@LNS
FAZIA+INDRA @GANIL
FAZIA @SPES
FAZIA @HIB-CS?→ with FRIBS?

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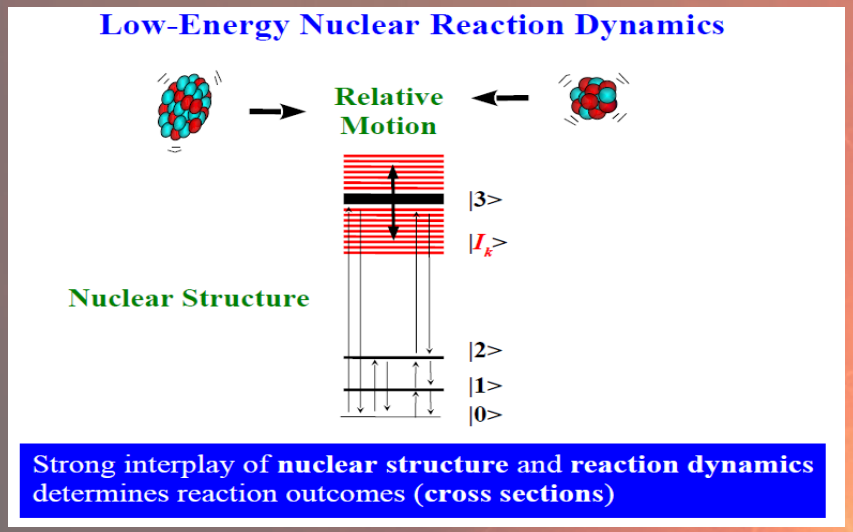
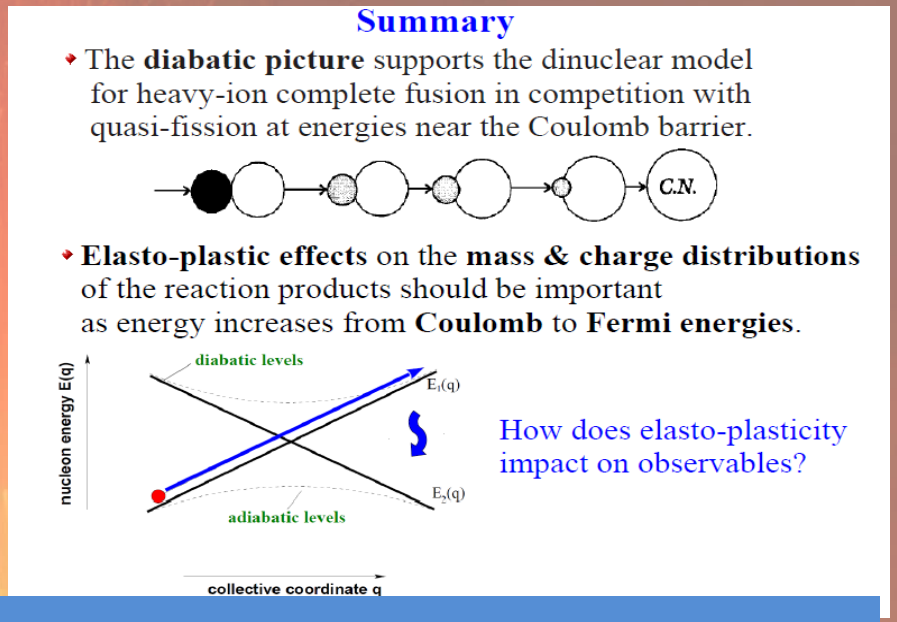
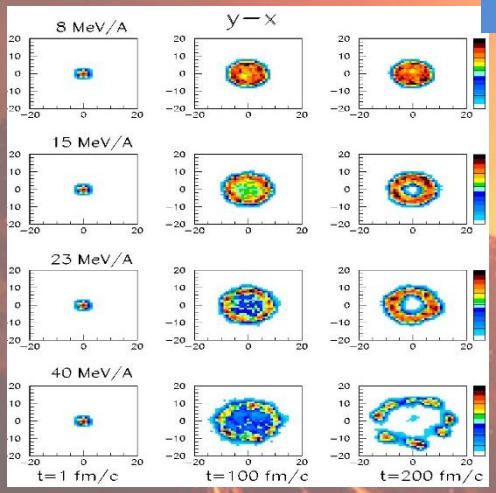
Transfer-like reactions from Coulomb to Fermi energy → talk by Diaz-Torres



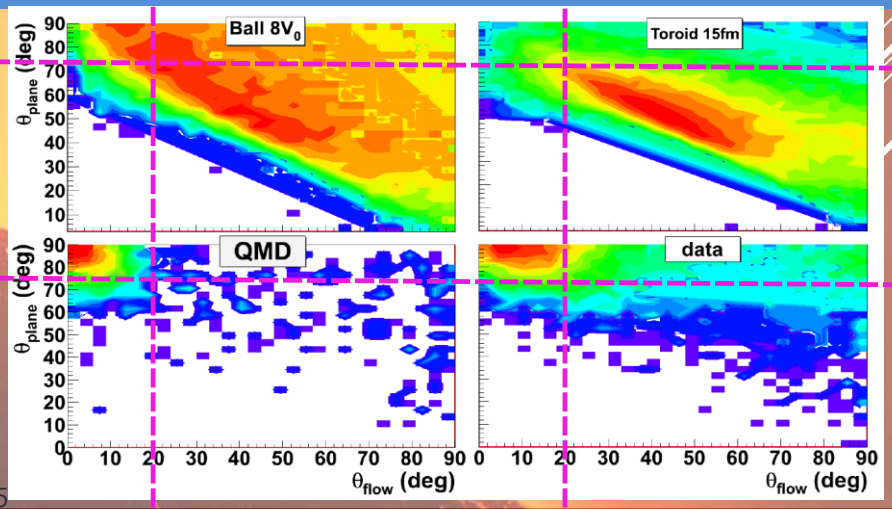


hyperheavy toroidal nuclear systems

Talk by R. Planeta



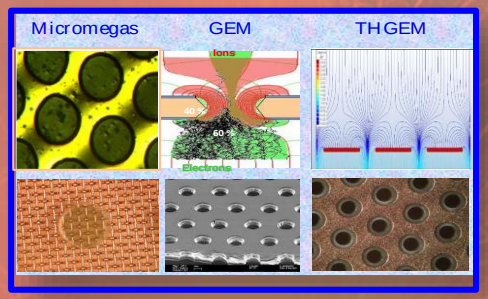
Location of toroidal events on the Θ_{plane} vs Θ_{flow} plane

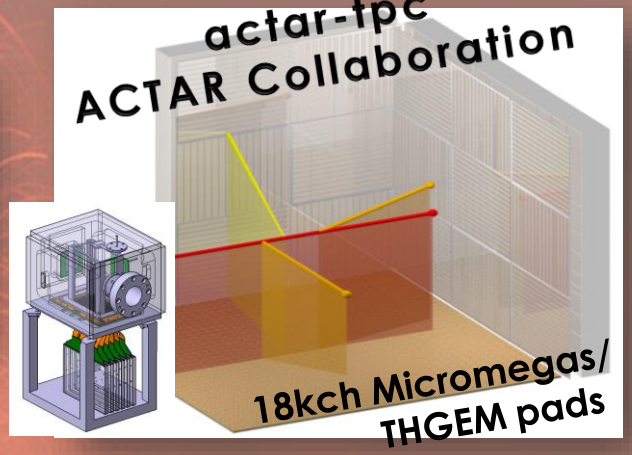


LNS → high intensity Superconducting Cyclotron for NUCLEAR PHYSICS

Development of new instrumentation/electronics:

Instrumenting a Nuclear Physics Program → talk by E. Pollacco



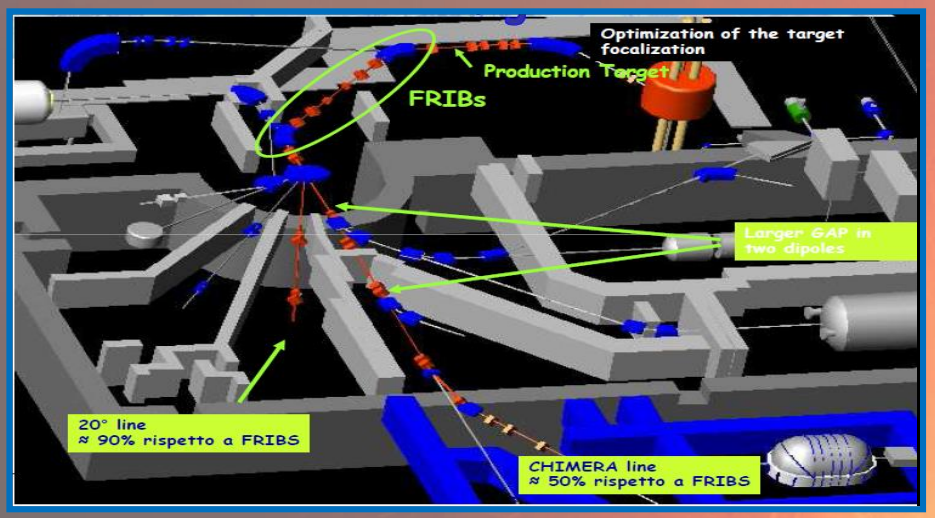


- **Instrumentation for intense beams at LNS is a significant challenge.**
- **Path towards success is <u>time</u> for development.**
  - **Apply new detection media (*experimentalist*).**
  - **New electronics (*engineering support*).**
  - **New structure in the labs to analyse & extract the physics from data (*physicists*).**

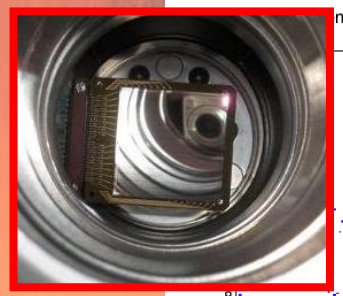
Develop SPECIFIC/NOUVELLE physics program → SPECIFIC instrument.

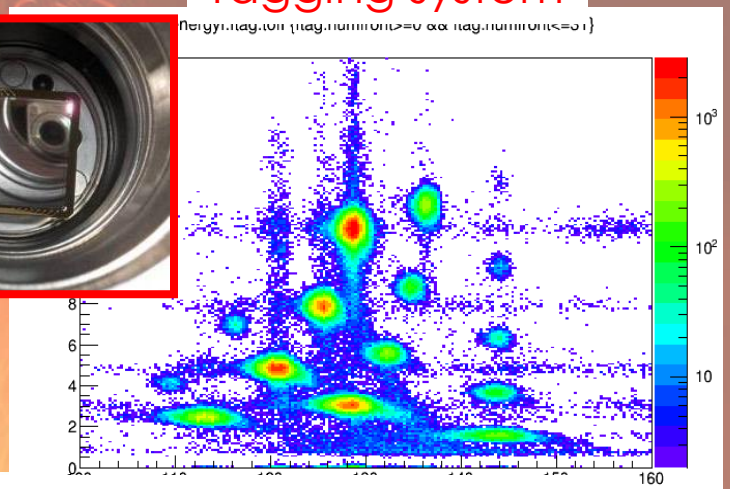
LNS → high intensity Superconducting Cyclotron for NUCLEAR PHYSICS

FRIBS: The exotic beams by fragmentation → talk by G. Cardella

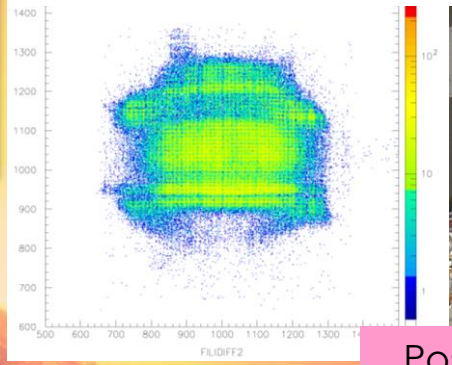


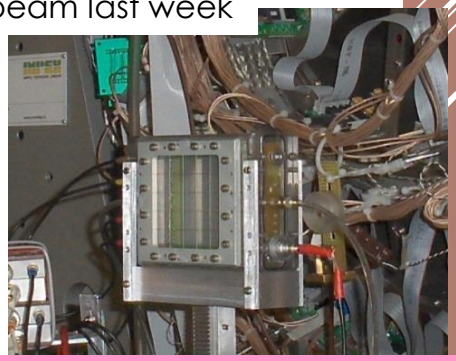
Tagging system





With 68Ni fragmentation beam last week





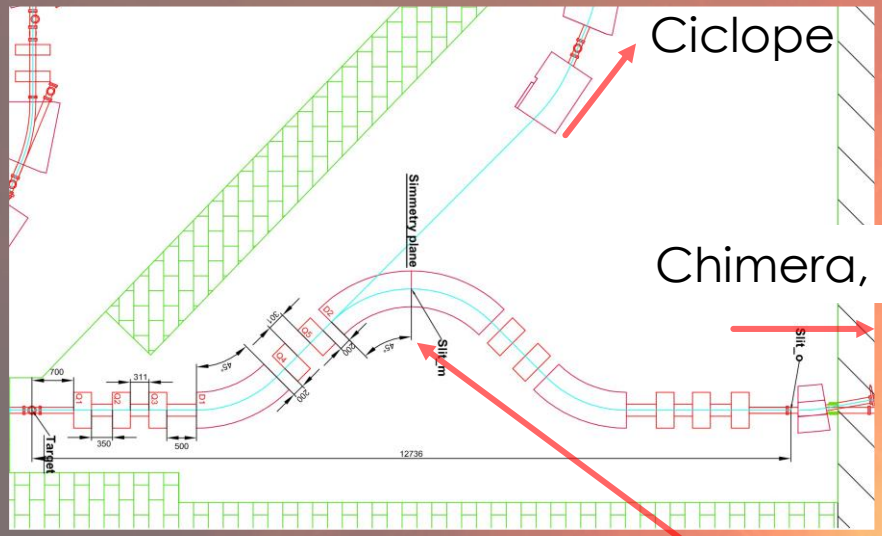
Position sensitive PPAC to measure trajectory

The cyclotron intensity upgrade and the installation of a new fragment separator open very interesting perspectives for the use of fragmentation beams at LNS

Intensity upgrade → good for lighter masses
New spectrometer→ larger efficiency for higher masses
→ Improvement in the tagging
→ Improvement in the detector system

LNS → high intensity Superconducting Cyclotron for NUCLEAR PHYSICS

Study of **new FRIBs facility line** → talk by A. Russo



the system performance must be studied for this line

- **The new system guarantees very good optic performances.**
  The beam can be easily delivered to different experimental rooms.

The new FRIBs solution consists in: 2 - triplets
2 - doublets
2 - 45° dipoles
1 - 90° dipole

Degrader inside the 90° dipole

Magnex could use it as energy spread selector

LNS → high intensity Superconducting Cyclotron for NUCLEAR PHYSICS

FRIBS: the common problem of beam diagnostics→ talk by E. Pagano

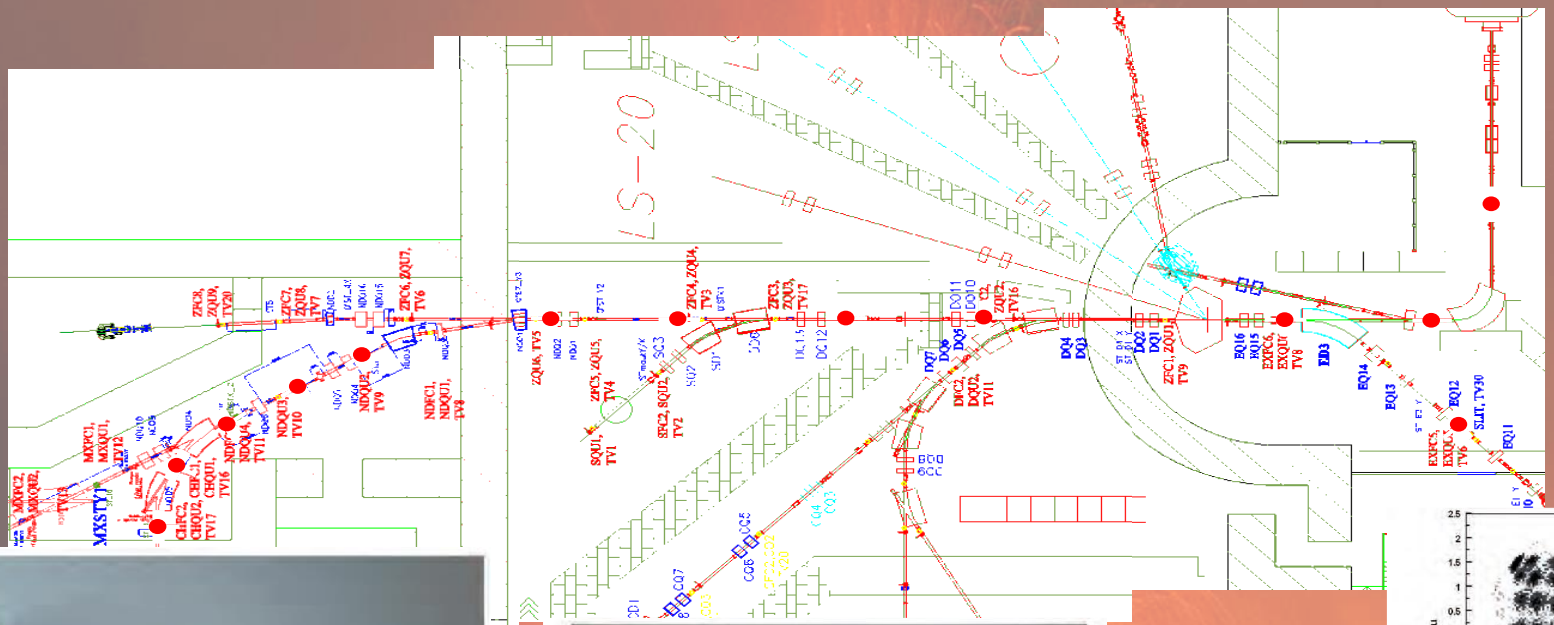


Fig. 2. Beam particle counter, based on a plastic scintillator coupled to a photomultiplier.

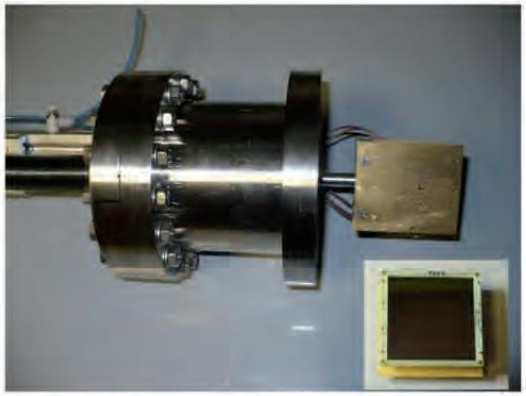


Fig. 3. PSSD mounted in a pneumatic actuator. The mask made by brass is 2mm thick.

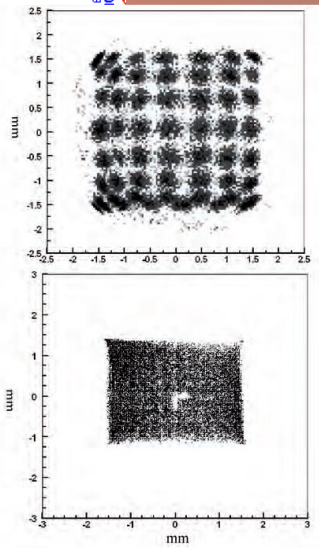
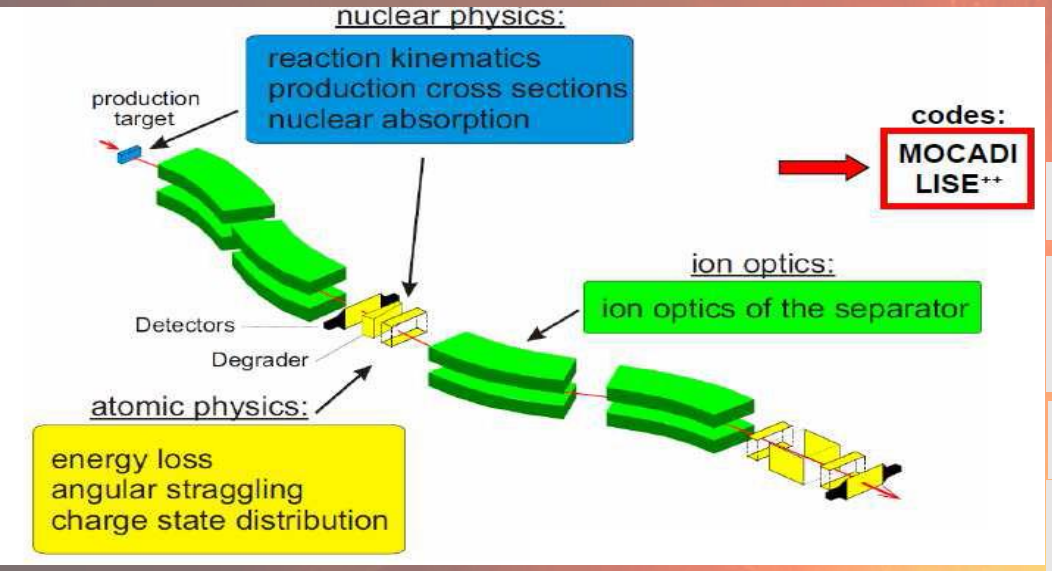


Fig. 4. Corrected beam profiles of a EXCYT (a) and a FRIB (b) beam, acquired by means of the PSSD and using two different masks.

LNS → high intensity Superconducting Cyclotron for NUCLEAR PHYSICS

Development of new instrumentation:

PID for in-flight radioactive separator → talk by C. Nociforo



Bρ – ToF – ΔE method

Time Projection Chamber (TPC)

´Twin´ Gas Electron Multiplication (GEM)-TPC

Plastic scintillator readout by PMTs

pcCVD-DD (0.3mm) and scCVD-DD (0.09mm)

The Super-FRS itself takes well established detection system, like the FRS one, to its operation limit → preserve high resolution at the highest rate.

To obtain a clean PID:

Bρ reconstruction needs high-precision tracking detectors, higher efficiency : FRS TPCs → Super-FRS Twin GEM-TPC

ToF detector with timing resolution **$\sigma t < 50$ ps**

ΔE detector with pile-up correction, stripper between MUSIC sections helps to disentangle charge states.

MAGNEX : exotic nuclei & isospin with RIB and stable beams → talk by C. Agodi

Outlook

- **MAGNEX: a magnetic spectrometer with a large acceptance and high energy, mass and angular resolution, allowing 0^0 measurements**
  - **NUMEN** **HIB @ LNS** **MAGNEX + CS Upgrade**
- **FRIBS @ LNS for ISGMR in exotic nuclei**
- **Drip line: spectroscopy studies with tiny cross sections**

High Intensities CS Beams @ LNS:
New challanging series of experimental studies !

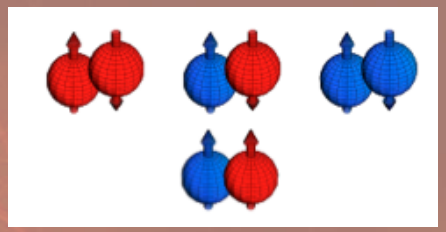
LNS → high intensity Superconducting Cyclotron for NUCLEAR PHYSICS

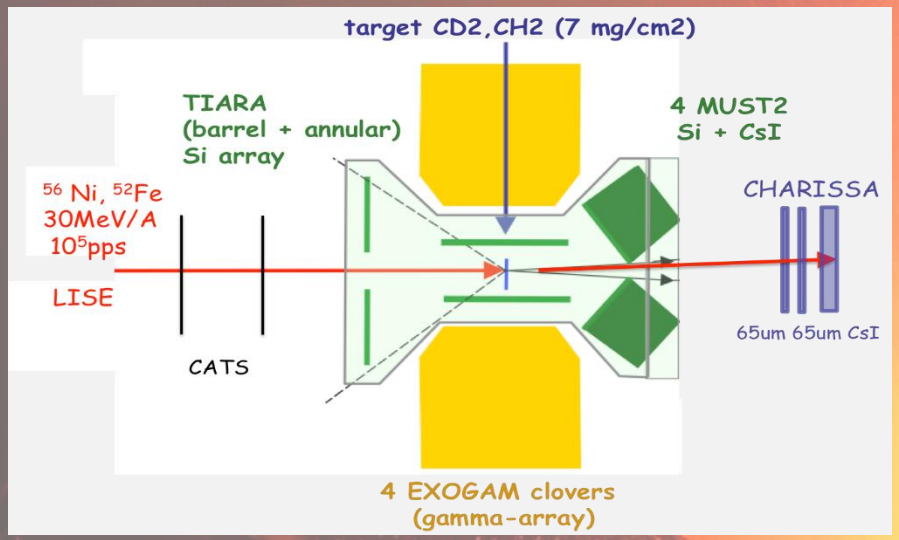
Study of **Neutron proton pairing through transfer reactions** → talk by M. Assie

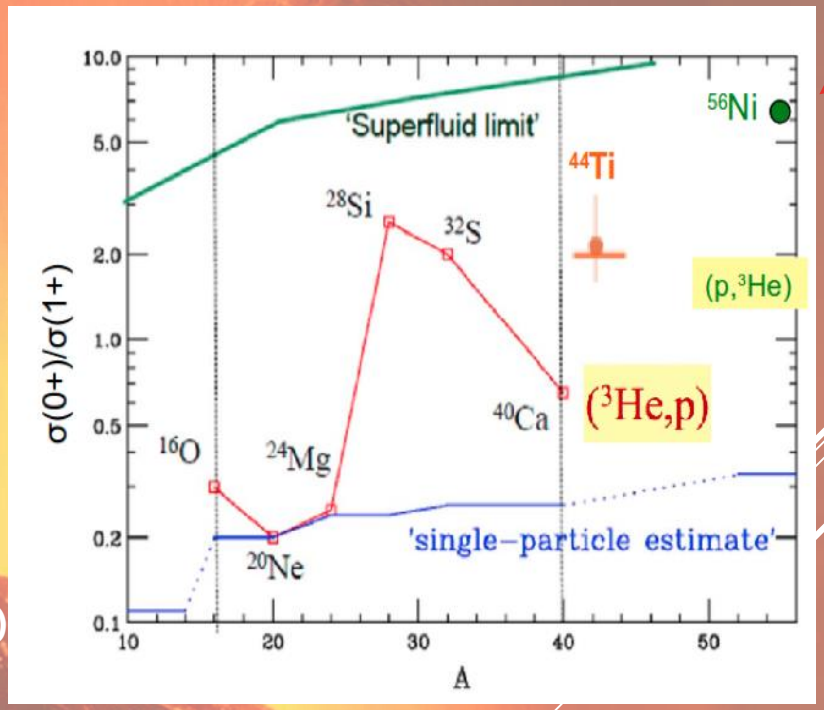
Pairing in the T=0 or 1 np channel :
GANIL experiment

T=1

T=0







Strong coupling

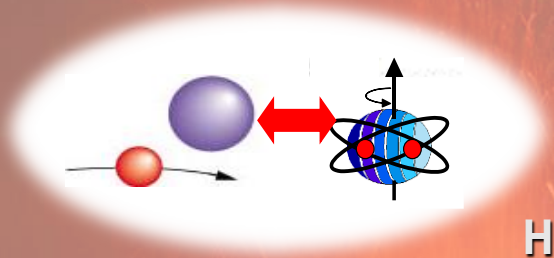
Theory: Form Factors- Beyond the MF

Experiment: analysis of ^{56}Ni(p,3He), ^{56}Ni(d,alpha)
analysis of ^{56}Ni(p,3He), ^{52}Fe(d,alpha)
No T selection in p,3He only T=0 in d, alpha

Transfers proportional to the number of pairs
σ(0+)/σ(1+) --< strenght of the np coupling

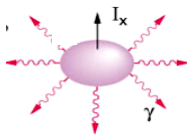
NUCLEAR PHYSICS in Italy: common strategies

L3 - Nuclear Structure and Reaction Mechanisms



5-10 MeV/u → Heavy-ions 50 MeV/u

Decays
(in beam)



Shell structure
Collettive modes-shape vs N/Z

Symmetries

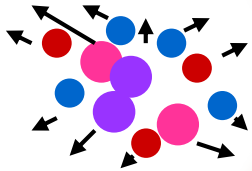
Reactions

peripheral

Nuclear structure

Termodynamics
Viscosity-high spin

Multi-framm



Equation of state

LNL

GAMMA- PRISMA- EXOTIC- NUCLEX

MAGNEX- LNS_STREAM - FRIBS - EXOCHIM

LNS

NUCLEAR PHYSICS in Italy: common strategies ?

Personnel & Structures in the Laboratories

National & International Laboratories needs a structure:

Divisions – Services- Technologies -Experimental groups

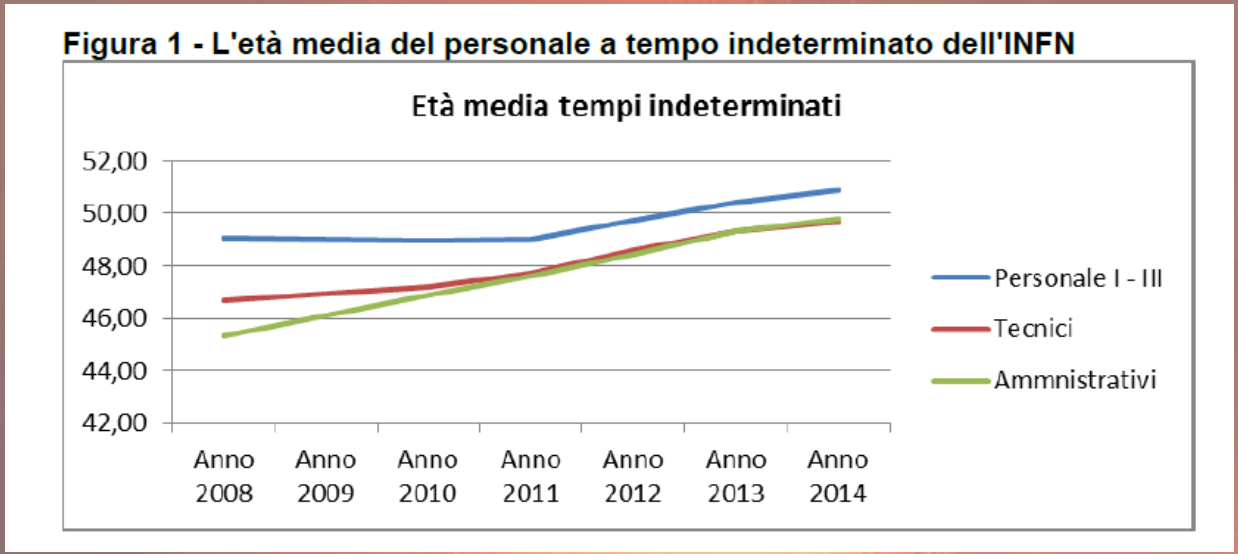
Support to National & International Users

LNS & LNL can have common problems and should find common solutions

No anthagonism but cooperation and collaboration to be a unique stronger Community

NUCLEAR PHYSICS in Italy: common strategies

Young people & the future



In the next future for EPR (Public research Institutions):
60% of Turn over fr researcher & engineers
20& or 60% for technicians ? → this is a big issue for Laborarories !!!
20% for administration people

We may have a certain number of new positions for researchers → how many for INFN? How many for Nuclear Structure & Dynamics? Will it be discussed a scientific plane as an united national community in order to reinforce all the NP future Community ?

Thank you