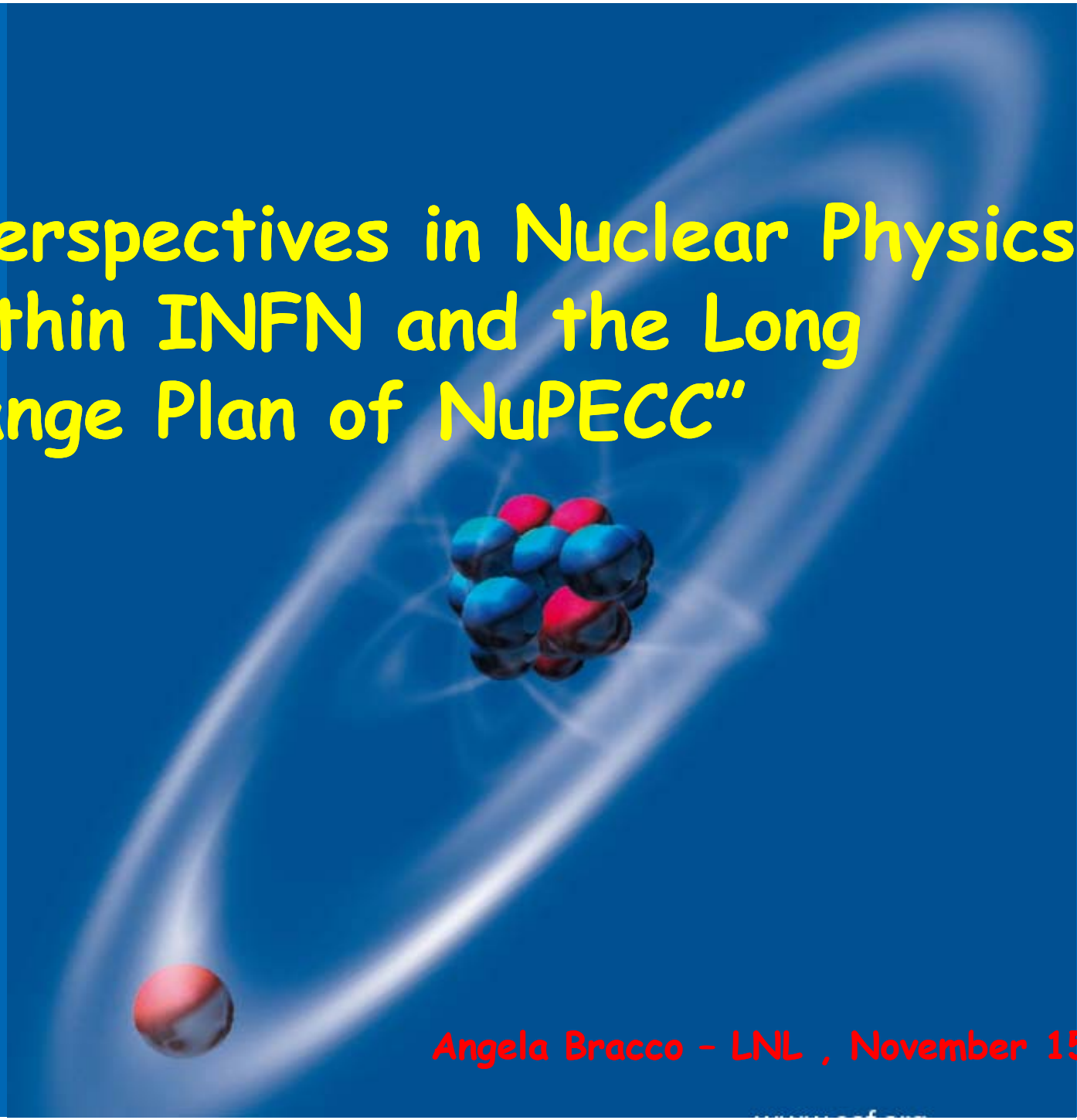
"Perspectives in Nuclear Physics within INFN and the Long Range Plan of NuPECC"



Angela Bracco – LNL , November 15, 2010

- The Nuclear Physics Scientific research lines : data from the 2009 report

- Selected relevant results and perspectives for the next years

- NuPECC Long Range Plan (and role of INFN)

- Final remarks

….. The 4 scientific lines

Line 1 -149 FTE:
Quarks and Hadron Dynamics (Jlab- LNF- GSI)

Line 2- 198 FTE:
Phase transitions in nuclear matter (160 in Alice)

CSN3
542 FTE

Line 4- 71 FTE:
Nuclear Astrophysics and interdisciplinary research (LNGS-LNS

Line 3- 121 FTE:
Nuclear Structure and reaction mechanisms (LNL-LNS)

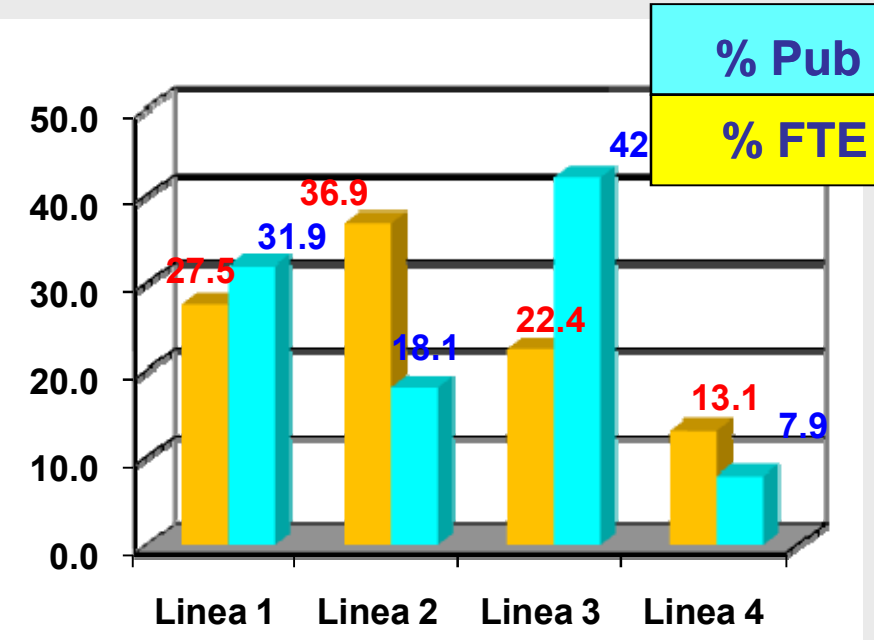
CSN3: Publications, presentations to conferences ….

In 2009:

240 Papers

486 Conference presentations

698 Reserachers+ 99 Tech.
542 FTE



Post doc 108

65 Doctoral students

(16 doctoral thesis completed)

27 Master thesis – 23 thesis
(3 years degree)

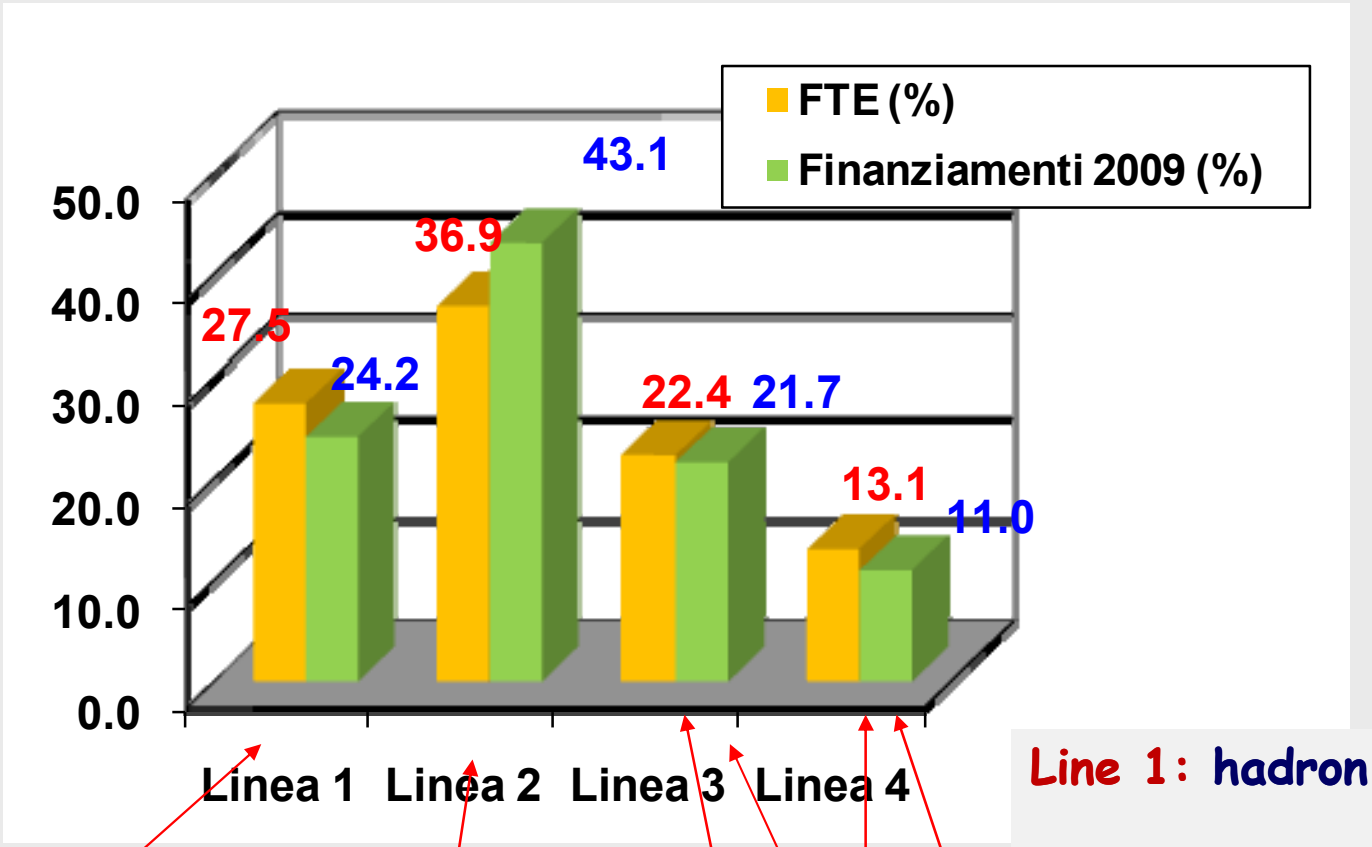
Line 1: hadron dynamics

Linea 2 : Phase Transition

Linea 3 : Nuclear Structure

Linea 4 : Nuclear Astrophysics

Distribution of fundings and of FTE in the reserach lines



LNF, JLAB, GSI

CERN

LNL-LNS-LNG

Post doct/doct

This ratio in 2010 is 0.75% of that of 2008

4 positions in nuclear physics among the 36

Line 1: hadron dynamics

Linea 2 : Phase Transition

Linea 3 : Nuclear Structure

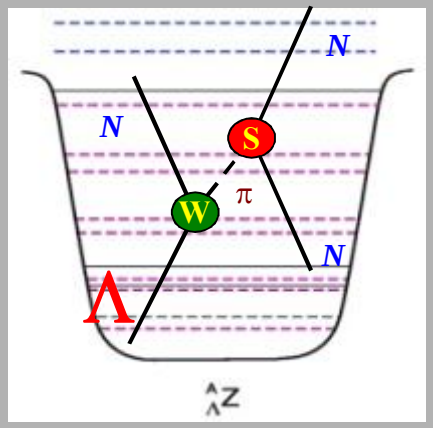
Linea 4 : Nuclear Astrophysics

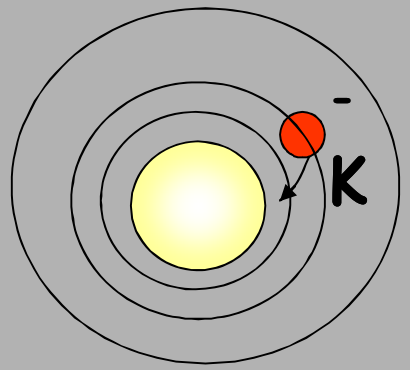
Quarks and Hadron Dynamics

- Problem of the spin
  Nucleon form factors (JLAB12)

- Barionic resonaces and
  Spectroscopy of mesons (JLAB12-MAMBO-PAINUC)

- Ipernuclei and Kaonic atoms (interaction Λ-N e K-N)
  (SIDDHARTHA- FINUDA)





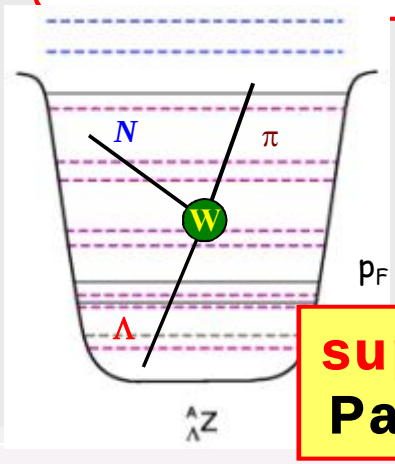
\+ R&D for PANDA e PAX (antiprotons at FAIR)

….. Λ decays in nuclei……. from FINUDA (LNF)

hypernucleus mesonic decay

$$\Gamma_T = \Gamma_M + \Gamma_{NM}$$
$$\Gamma_M = \Gamma_{\pi 0} + \Gamma_{\pi -}$$
$$\Gamma_{NM} = \Gamma_n + \Gamma_p + \Gamma_2$$

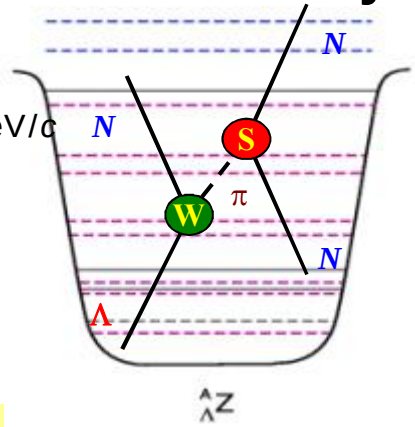
hypernucleus non-mesonic decay

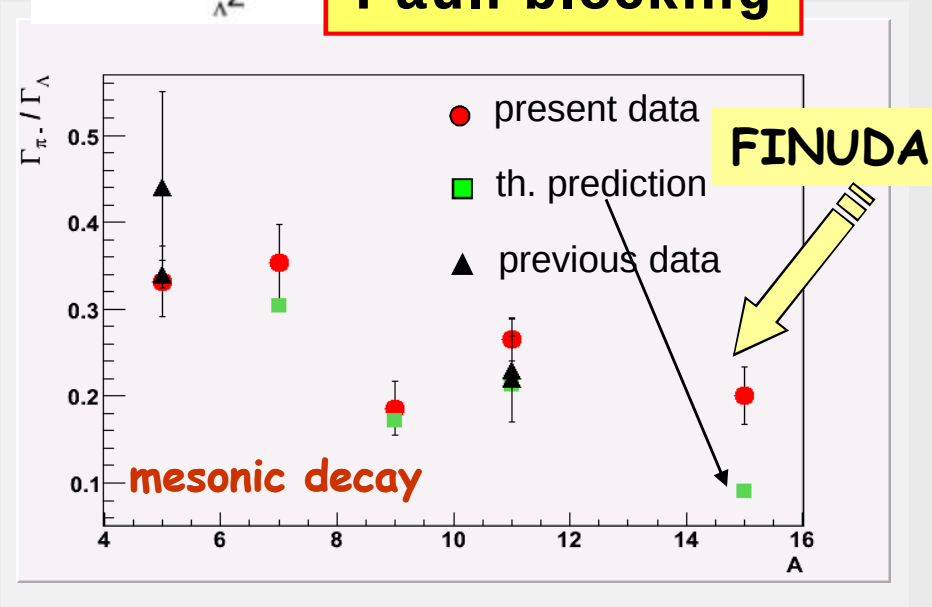


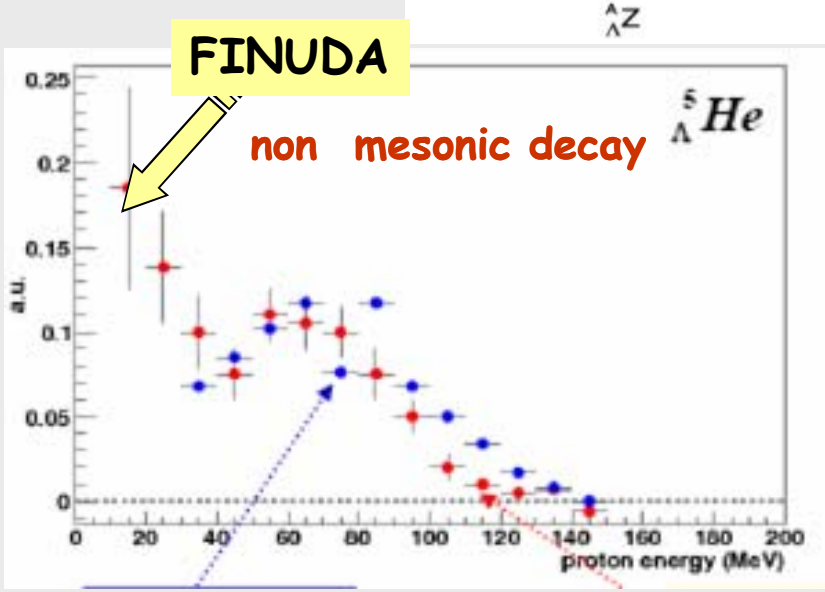
p_F ~ 270 MeV/c

suppressed by Pauli blocking

p_N ~ 400 MeV/c

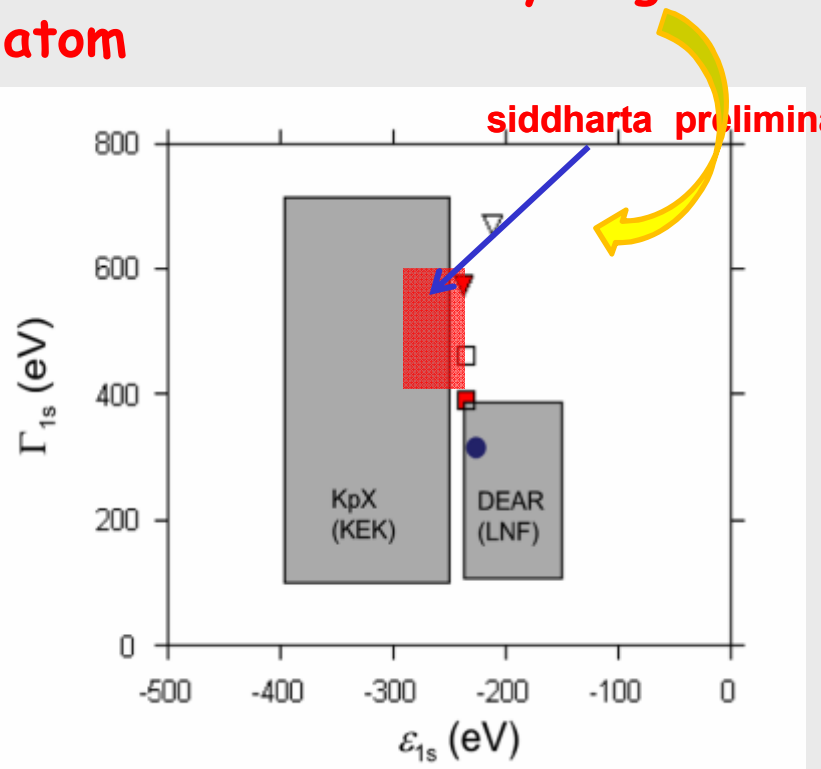






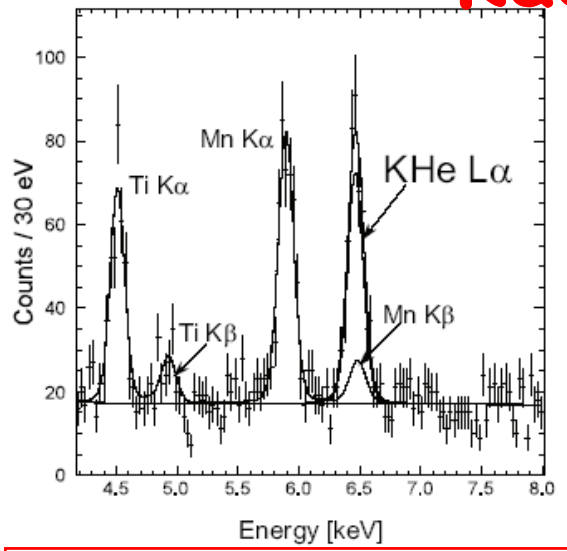
Kaonic atoms at LNF (SIDDHARTA)

Measurement of the energy for the level 1s for the hydrogen kaonic atom



PLB 681 (2009) 310

Kaonic ^{4}He

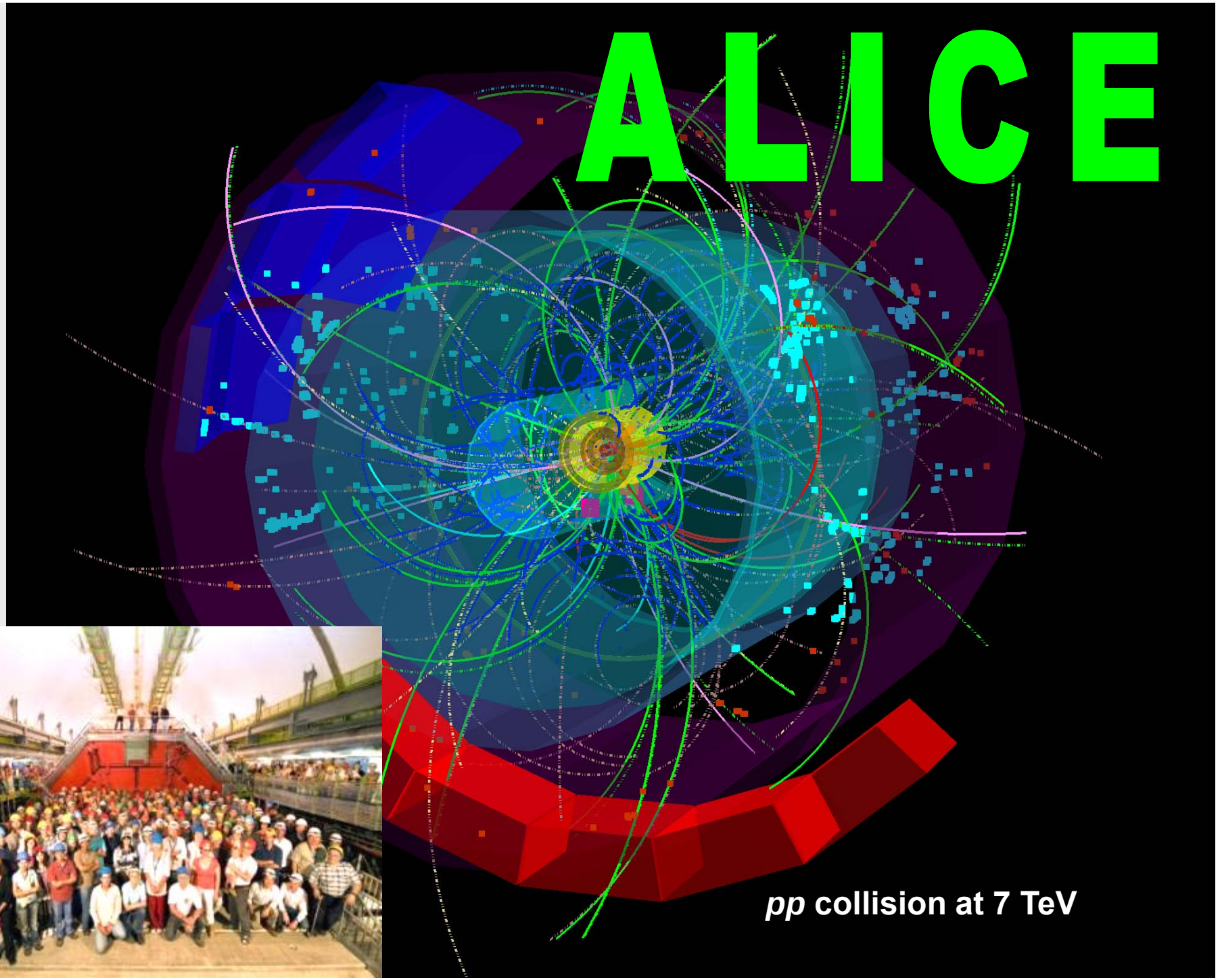


$$\Delta E = E_{\mathrm{exp}} - E_{\mathrm{e.m.}}$$
$$= 0 \pm 6\ (\mathrm{stat}) \pm 2\ (\mathrm{syst})\ \mathrm{eV}$$

In agreement with theory

For Kaonic deuteron more data with an improved set up and electronics are needed – proposed in the next years
Complementary experiments are made at JPARC

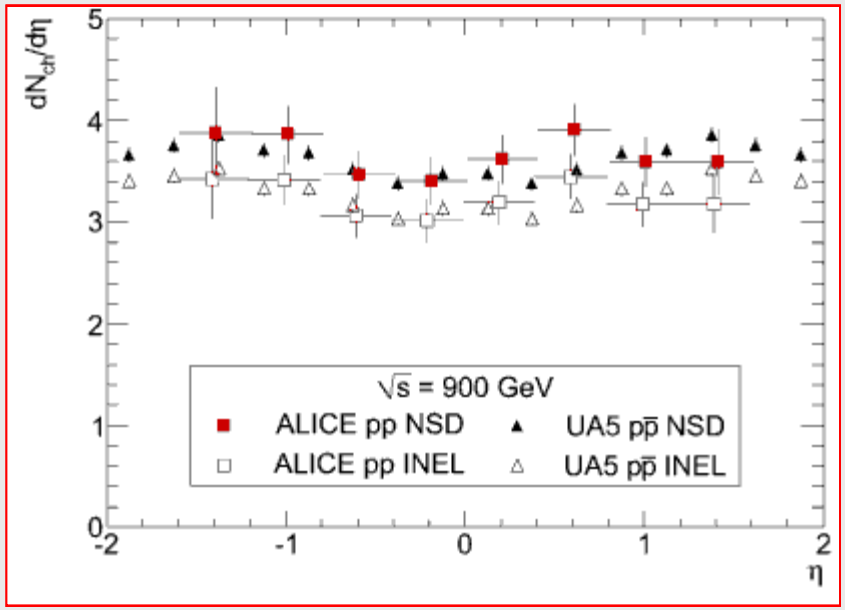
ALICE



pp collision at 7 TeV

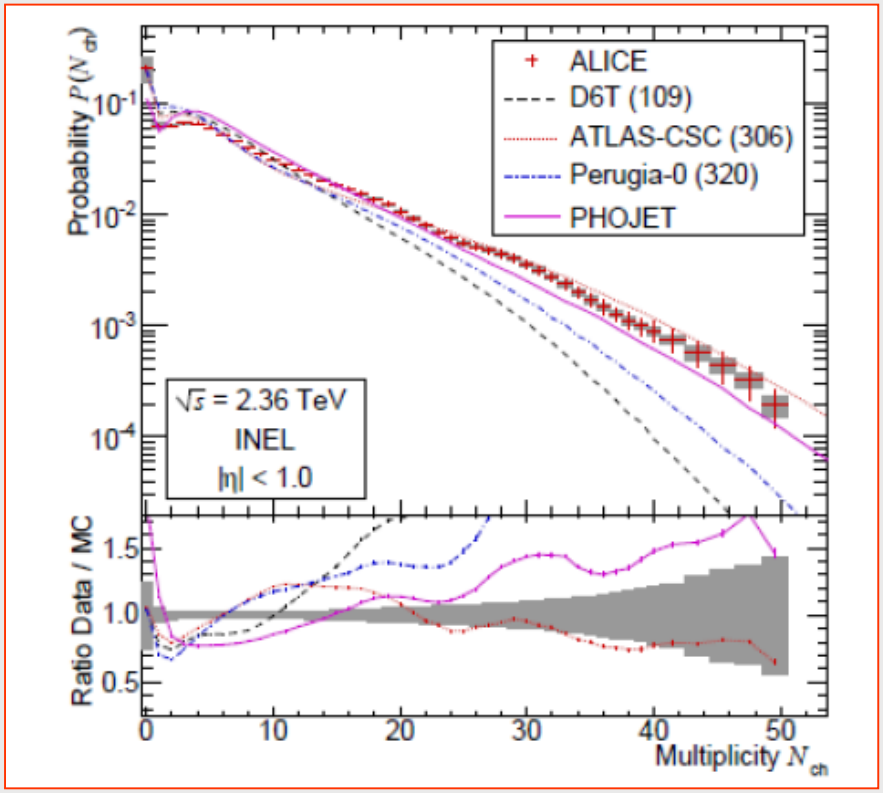
first LHC physics of ALICE

…sufficient to measure $dN_{ch}/d\eta$



Multiplicity at Unit of rapidity

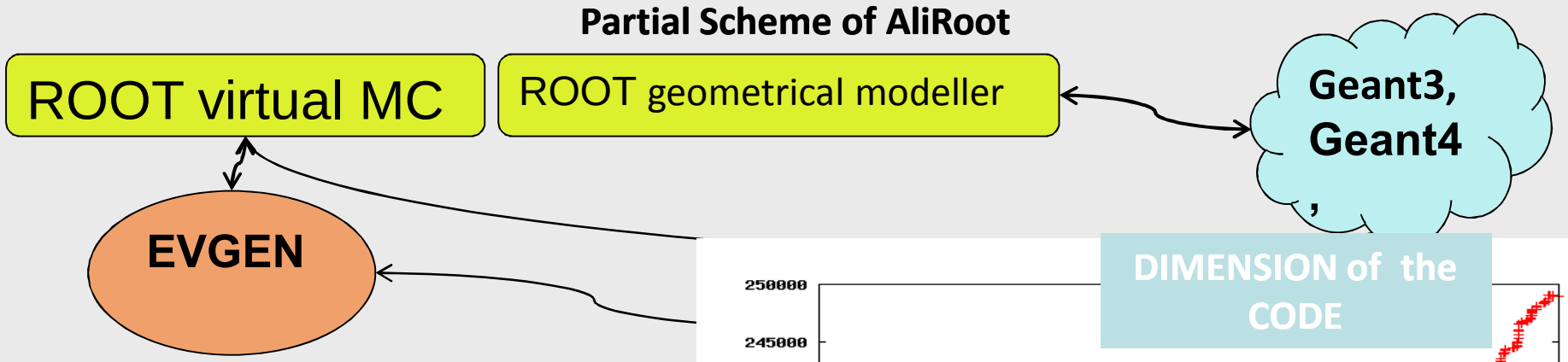
ALICE Collaboration Eur.Phys.J.C65:111 -125,2010



Multiplicity distribution of charged particles

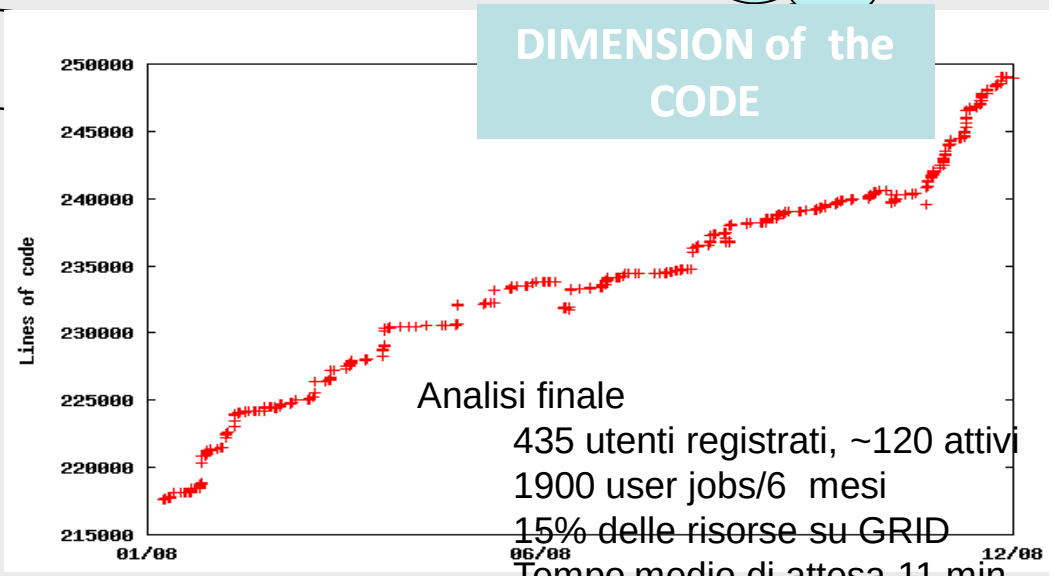
ALICE GRID in Italy

- **Tier-1: Fully operativ**
  - Storage on tape and fast Storage on disk
- **Tier-2:** Catania and Torino + Bari and Legnaro (in incubation)
- Italian sites offer approximately **20%** of the ALICE total computing



AliRoot: FRAMEWORK OFFLINE UNIQUE for SIMULATION – RECONSTRUCTION – ANALYSIS

well consolidated



Analisi finale

435 utenti registrati, ~120 attivi

1900 user jobs/6 mesi

15% delle risorse su GRID

Tempo medio di attesa 11 min (62% meno di 5 min)

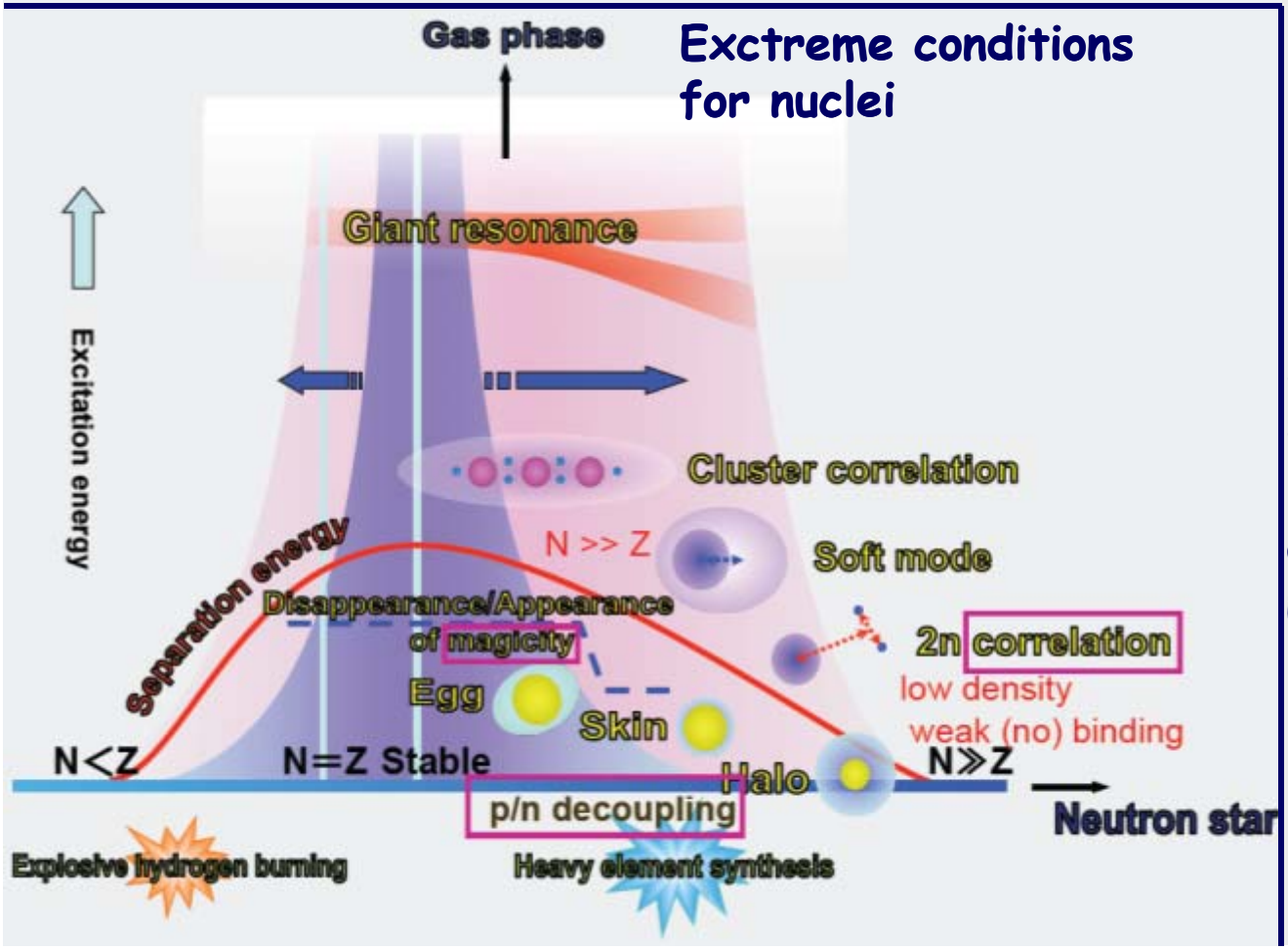
Tempo medio di run: 65 min

Nuclear Structure and reaction mechanisms

LNL 5-10 MeV/u — Heavy-ions — 50 MeV/u **LNS**

GAMMA- PRISMA
- EXOTIC- NUCLEX

MAGNEX- LNS_Stream
- Fribs - Exochim



Exctreme conditions for nuclei

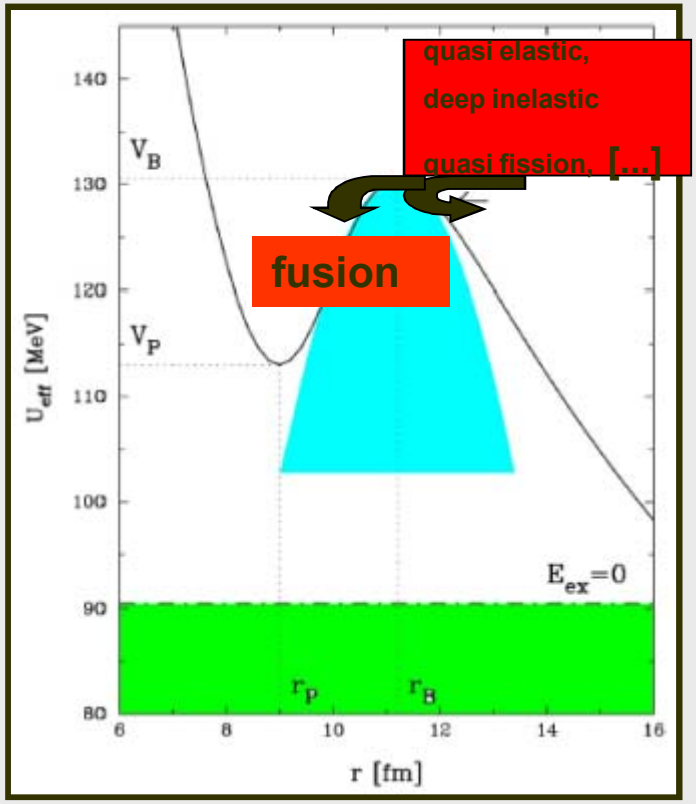
Reactions and decays

- Nuclear structure
- Equation of state

astrophysical implications nucleosynthesis

+ collaboration with GSI and GANIL

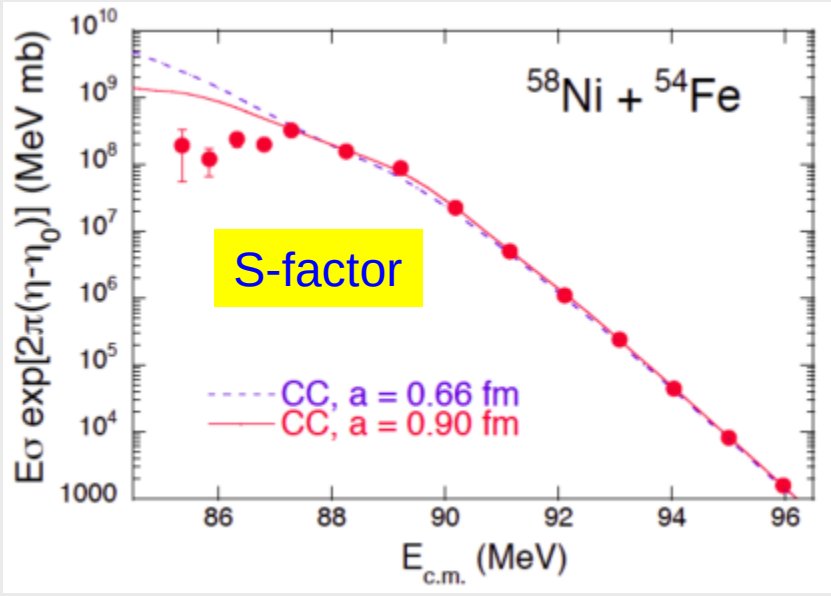
The PRISMA spectromer at LNL



Detailed measurements of reactions at the Coulomd barrier :

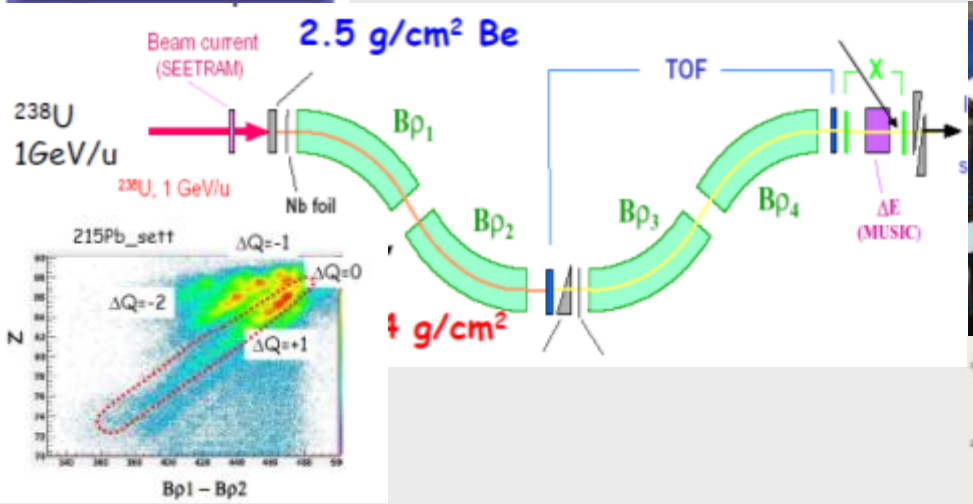
- **potential for nucleus-nucleus interaction**
- **the structure of nuclei far from stability (moderatly far)**

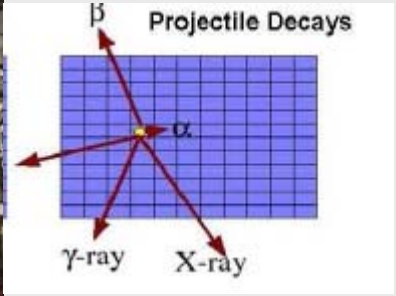
Fusion hindrance at low energies
(recent LNL results on ^{58}Ni + ^{54}Fe)
Astrophysical factor S

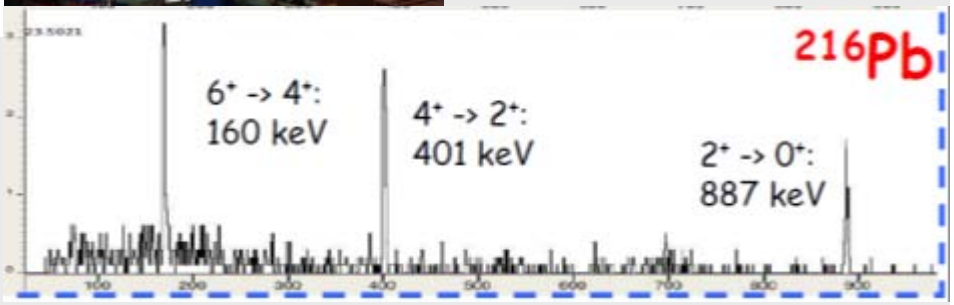


PR C81, 037601 (2010)

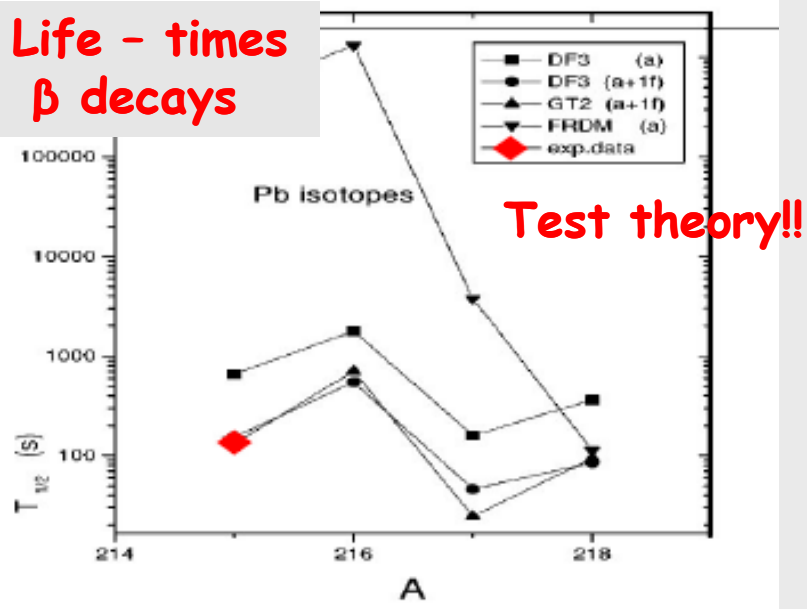
Esperiments at GSI at the Fragment separator with the array RISING







Life – times β decays



Test theory!!

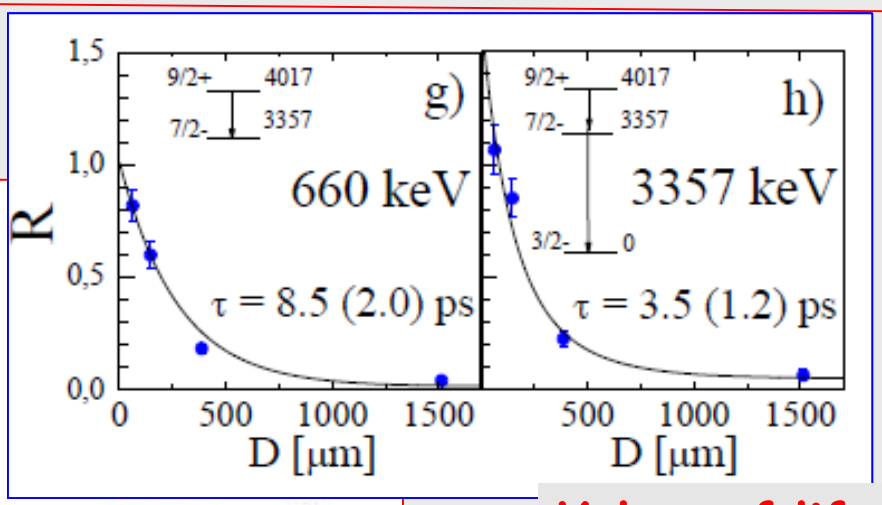
Gamma and beta decays for the study of the r-process of the nucleosynthesis.

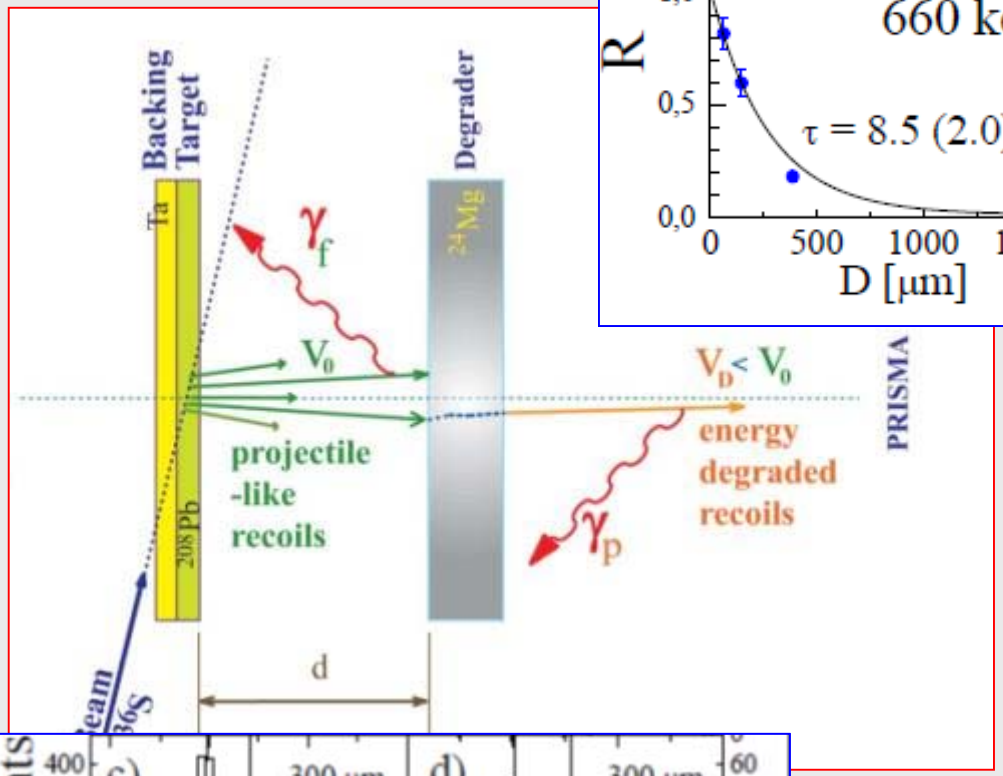
For neutron rich Pb nuclei Gamow-Teller strength – predictions largely varying.

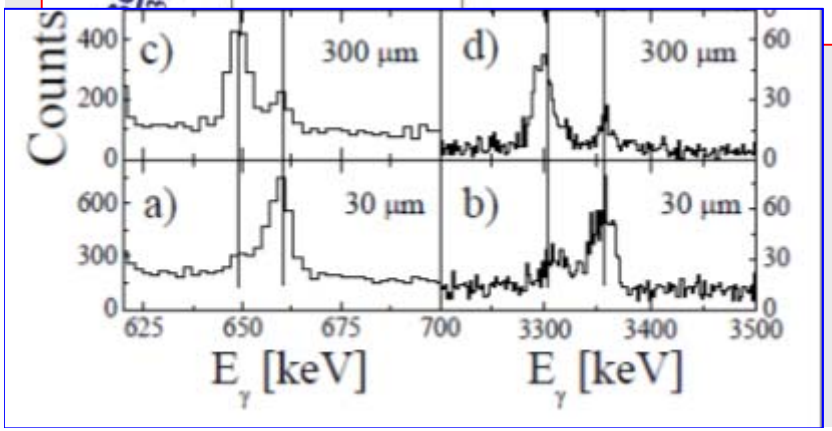
Life times of nuclear states and transitions probabilities

LNL

PRISMA-CLARA



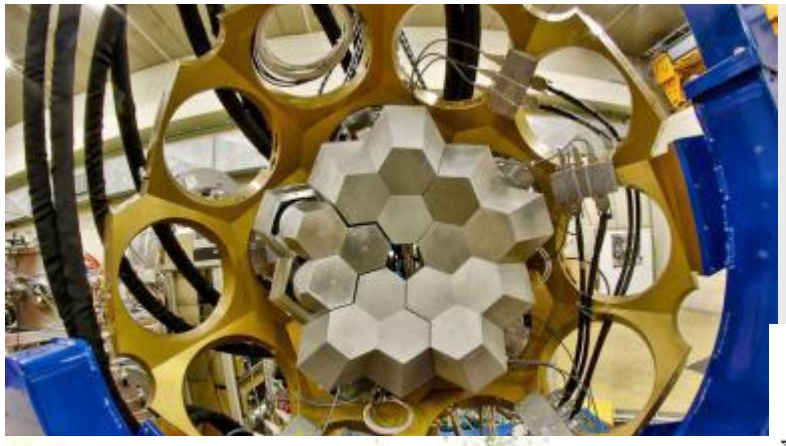




Values of lifetimes in ^{49}Ca:
Evidence of octupole vibration couplings with single particle states.

- **nature of the interaction**
- **couplings among different degrees of freedom**
- **Evolution with N/Z**

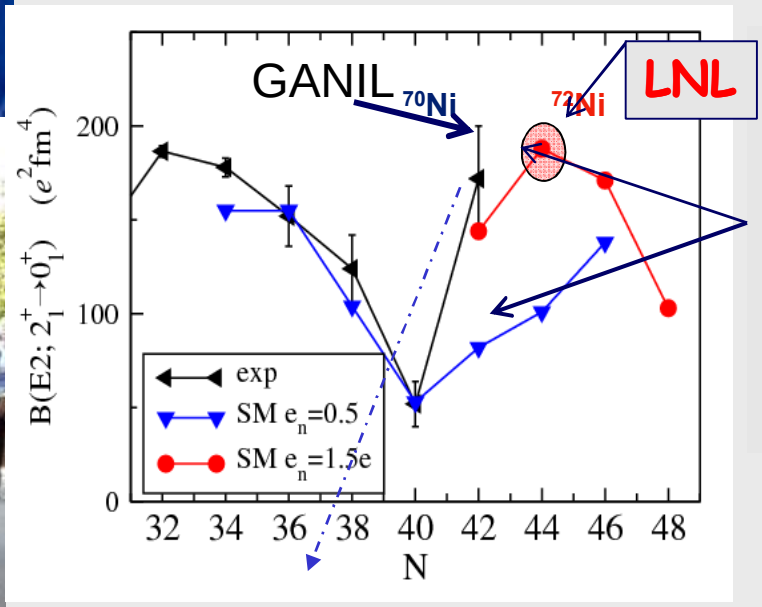
AGATA Demonstrator inauguration 9/5/2010



Measurement campaign (with ALPI)

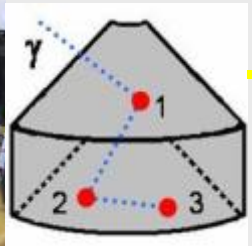
Nuclear collectivity in nuclei

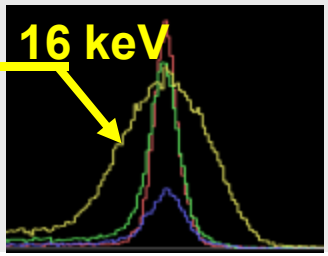
From low-lying vibrations and rotations to giant resonances



effect of neutron orbitals and role of tensor force

Several data analyses in progress





Excellent energy resolution and high count rates

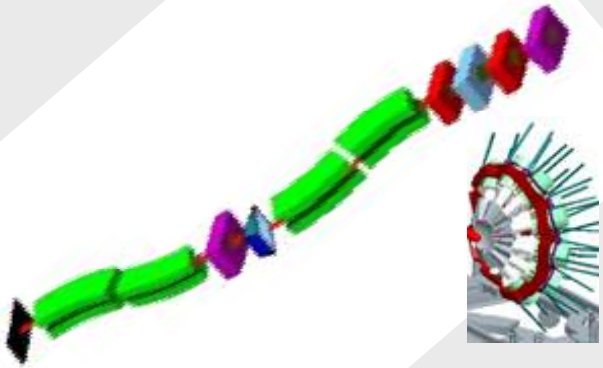
AGATA Demonstrator/1π Experimental program

June 2011 → LNL
6TC

AGATA D.+PRISMA

Total Eff. ~6%

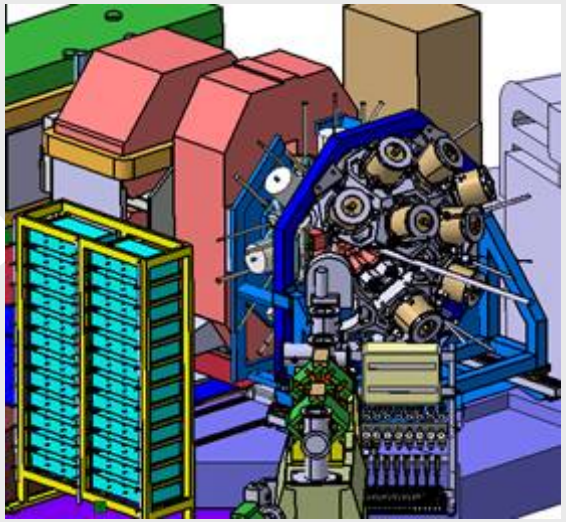
Dec 2011 → GSI/FRS
≥ 8TC



AGATA @ FRS

Total Eff. > 10%

July 2013 →GANIL/SPIRAL2
~15TC



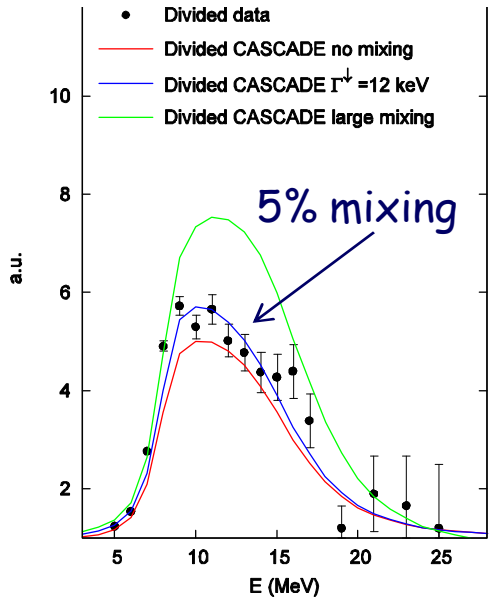
AGATA + VAMOS + EXOGAM

Total Eff. > 20%

NUCL_ex at LNL: Reactions and nuclear structure at finite T

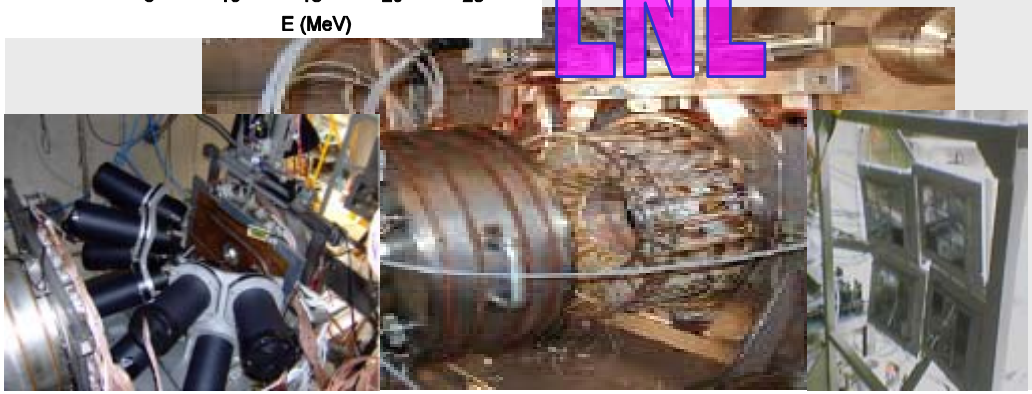
R&D for charged particle arrays to be used with radioactive beams (activity FAZIA - PP-SPIRAL2 in FP7)

GDR gamma-decay

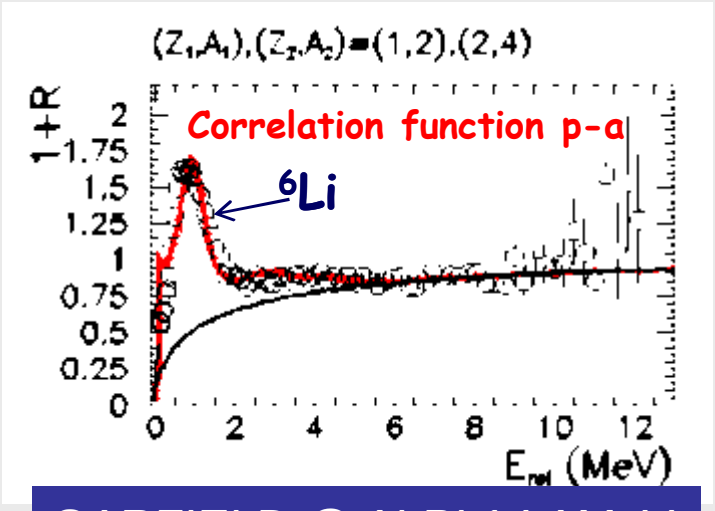


ISOSPIN MIXING (decay from GDR) at finite temperatura in ^{80}Zr (around the p drip line)

LNL



Onset of fragmentation fragmentation and nuclear thermodynamics



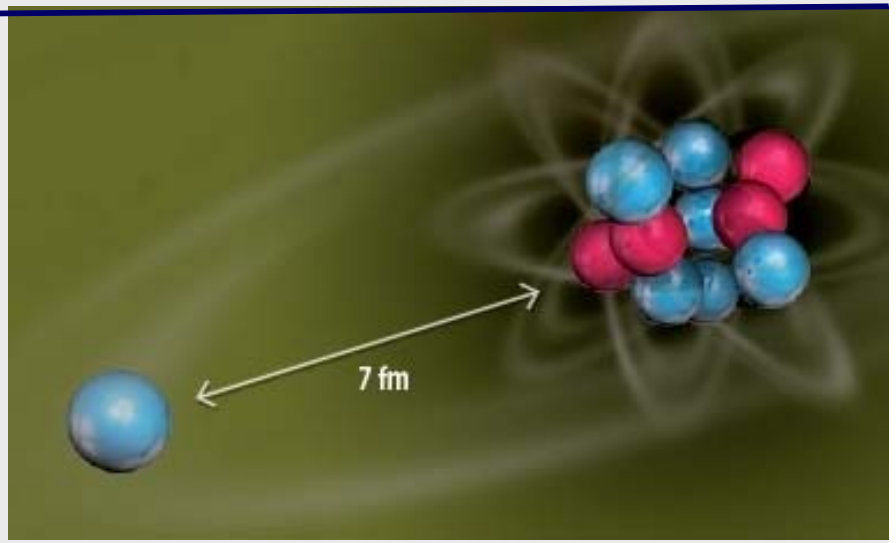
GARFIELD @ ALPI 14 AMeV

Correlation functions- evidence of population of unstable states before fragmentation

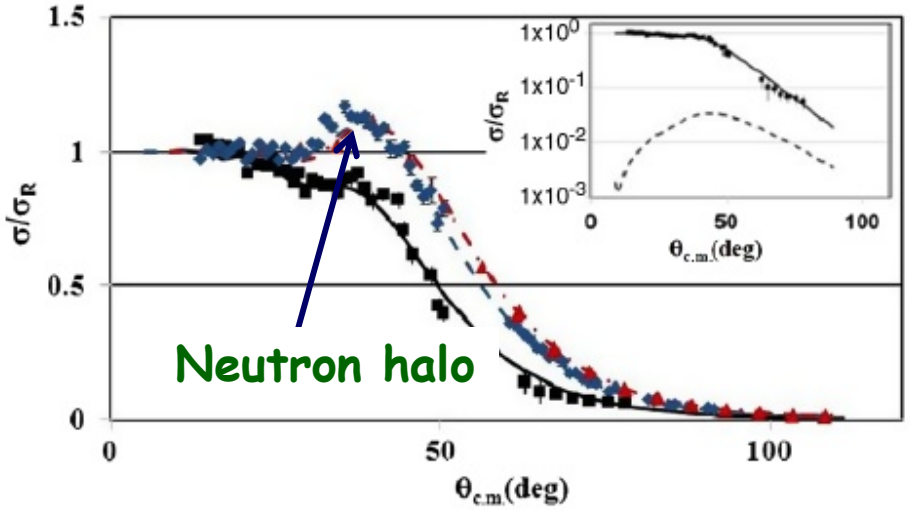
Halo structure of light nuclei (Be-Fl)

Value of elastic cross section depends on the features of the wave-function.

Comparisons of measurements with stable and unstable beams are necessary.



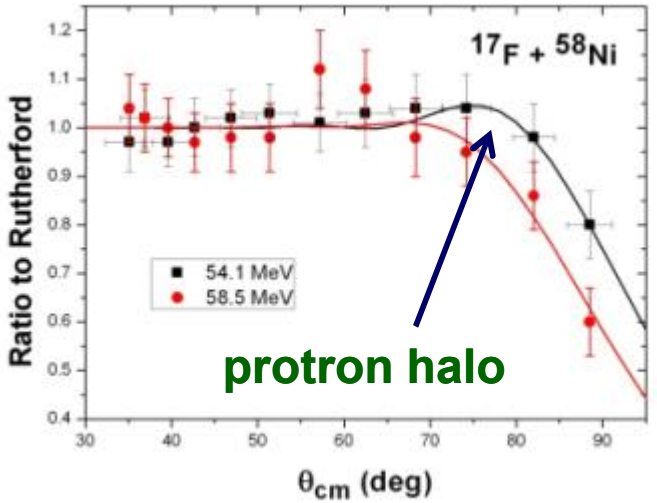
LNS_STREAM at LNS



Data taken at LNS and ISOLDE

PRL 105(2010)022701

EXOTIC at LNL

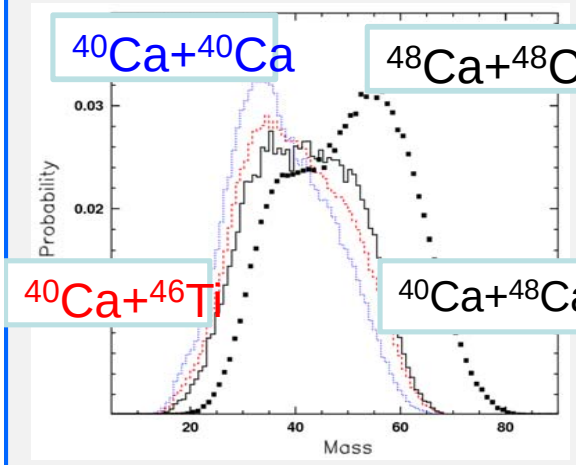


Isospin dependence of the equation of state

Experiment EXOCHIM (CHIMERA)

The radius of neutron stars depends on the value of the symmetry energy (related to the N-Z difference) in the nuclear equation of state

Mieasurements of charged particles

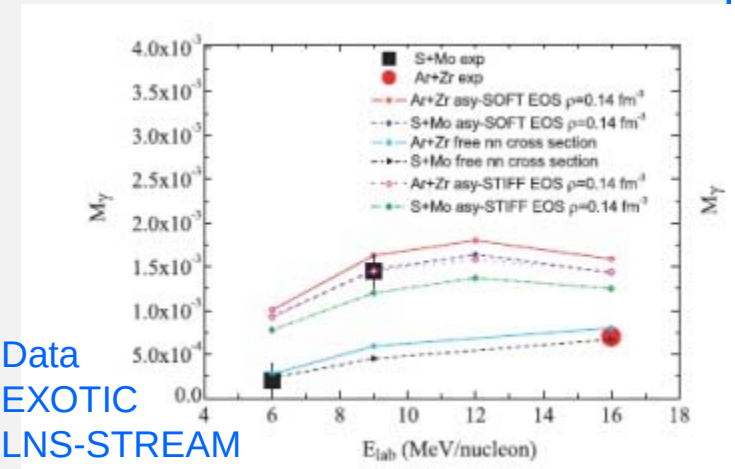


Mass of the largest fragment

Isospin effects in multifragmentation at Fermi energy

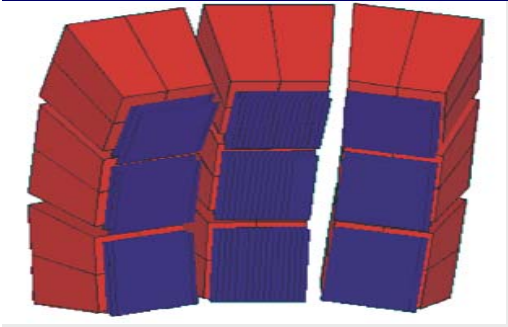
Experiments at the higher energy at GSI in 2011
Tests already made

Measurements of gamma-rays

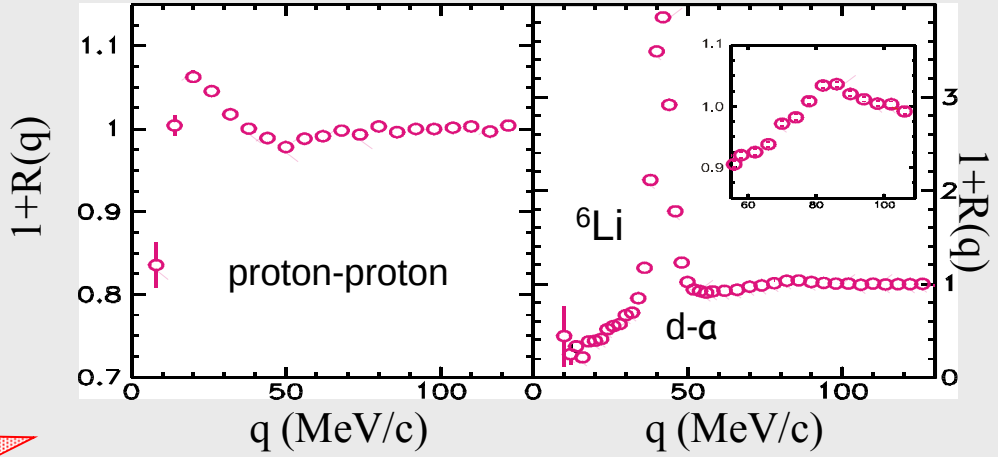


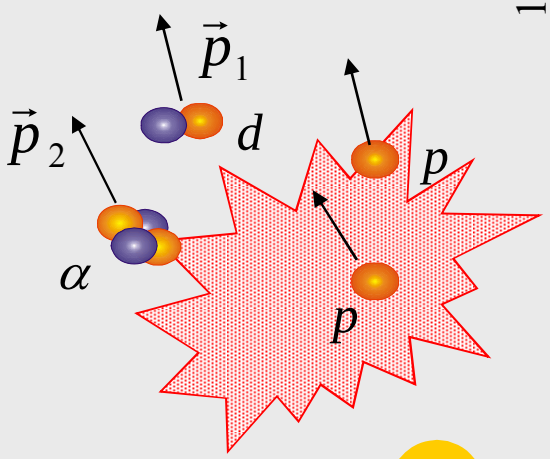
Data
EXOTIC
LNS-STREAM

EXOCHIM future: Symmetry energy and imaging

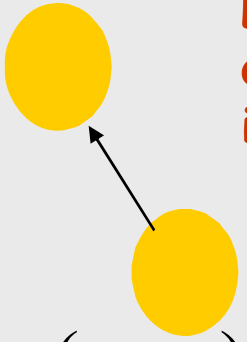


Sensitive to space-time properties



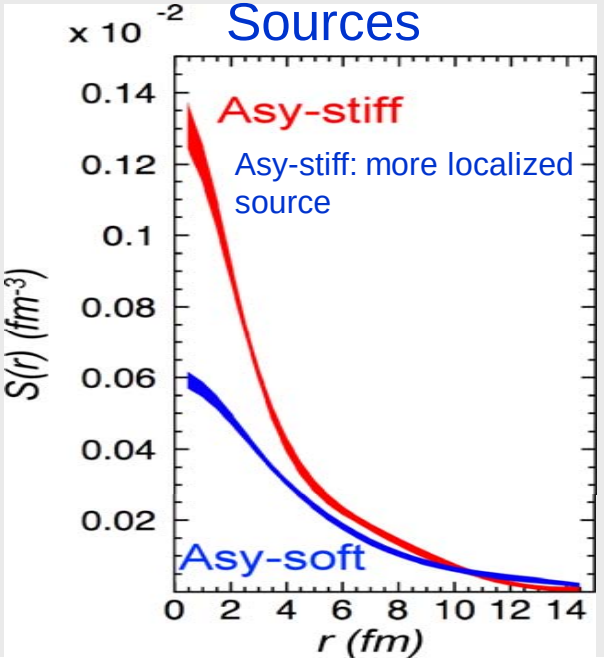


Localization of emitting sources in collisions



$$1 + R(q) = k \cdot \frac{Y_{coin}\left(\vec{p}_1, \vec{p}_2\right)}{Y_{evt.mixing}\left(\vec{p}_1, \vec{p}_2\right)}$$

Sources

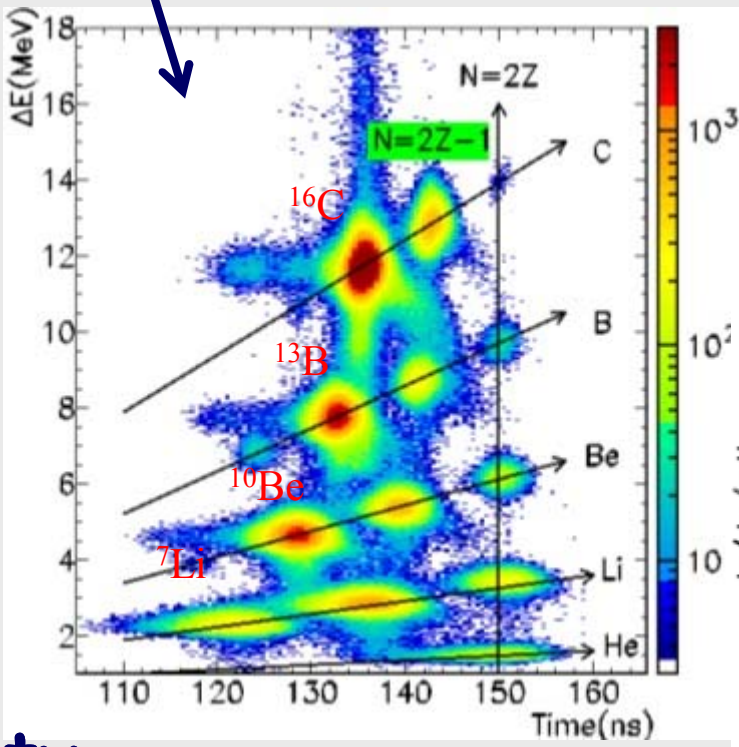


Fragmentation of beams at LNS : reaction with ^{16}C and ^{13}Be at 50 MeV/u

^{18}O primary beam

-magnet setting on ^{11}Be

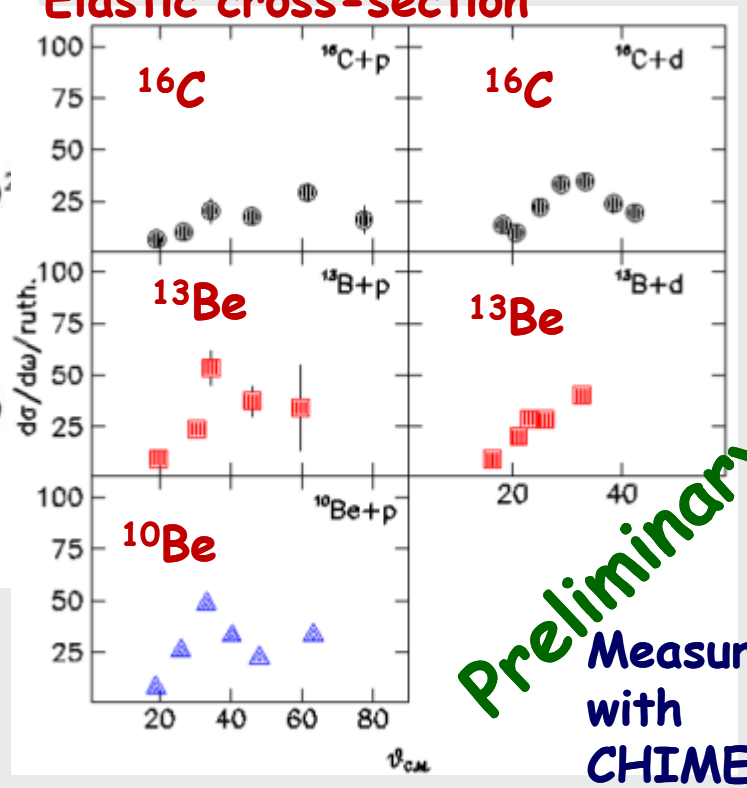
strip 140 mm thick



Unique energy interval !

Trasmission will be improved
Production studies in progress

Elastic cross-section



Preliminary

Measurements with CHIMERA 10^{4-5} pps

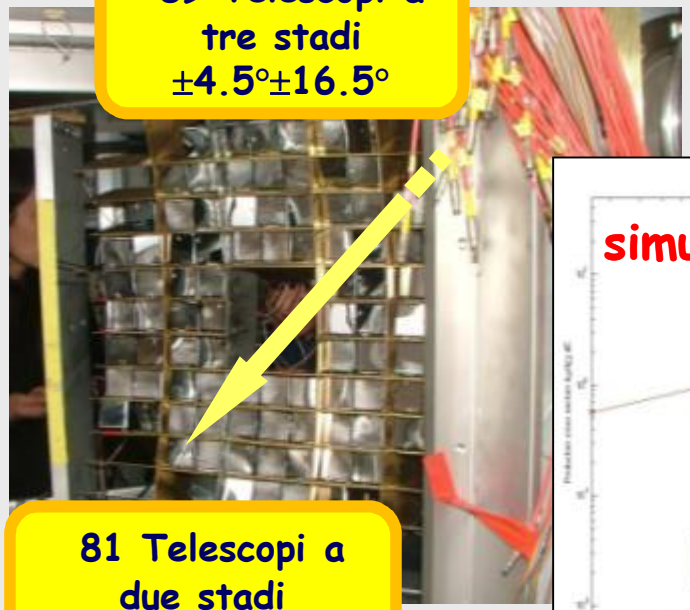
Activity
Exp. FRAG and EXOCHIM

Measurements at LNS and GSI for ^{12}C beams

- fragmentation of medium-light ions, such as *carbon ions* , in the energu interval 40 MeV/A to 400 MeV/A (LNS e GSI)

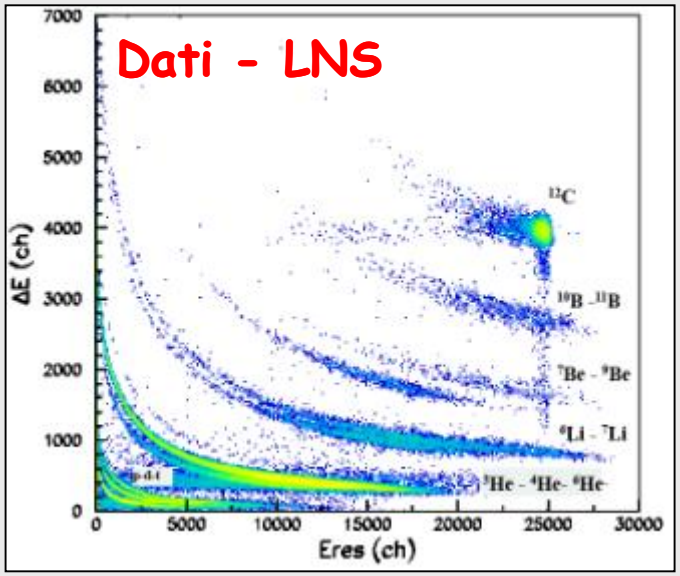
- **exclusive data of particular interest in adroterapia**

A new calorimeter and tracker under constructions



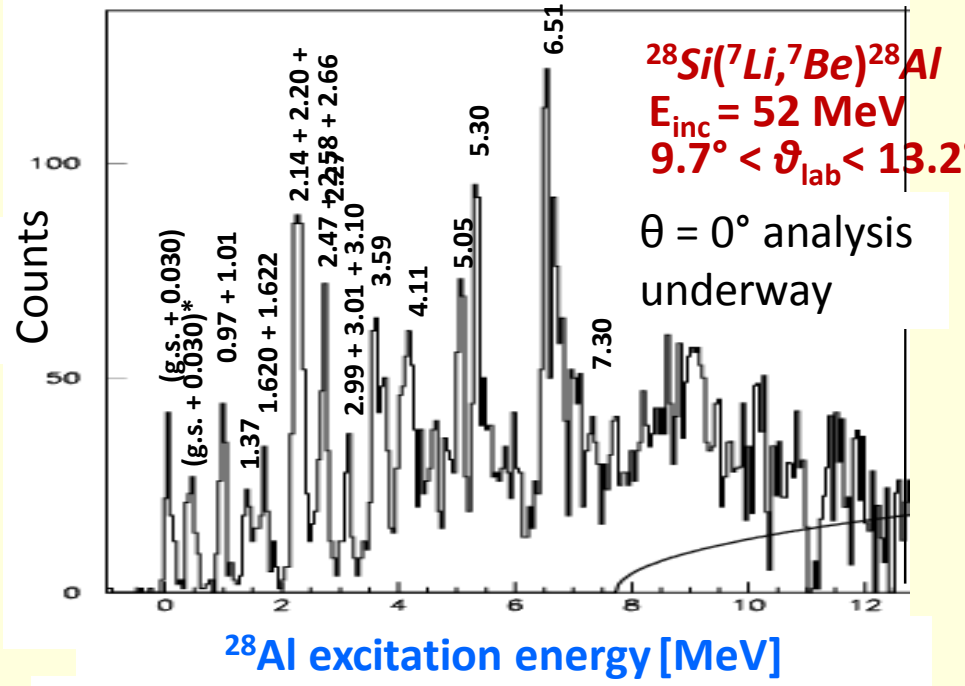
$^{12}C+^{197}Au$ (62AMeV)

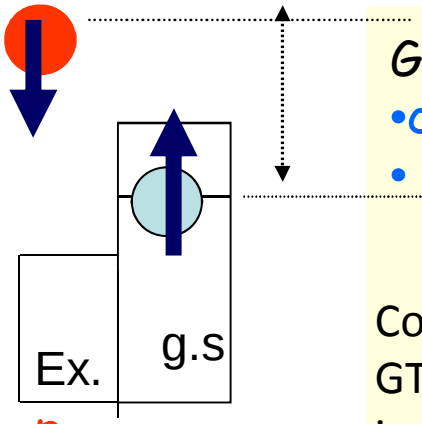
$^{12}C+^{197}Au$ (62AMeV)



MAGNEX at LNS

$\sigma_{CEX}(GT, q \to 0) \propto B(GT)$ charge exchange reactions





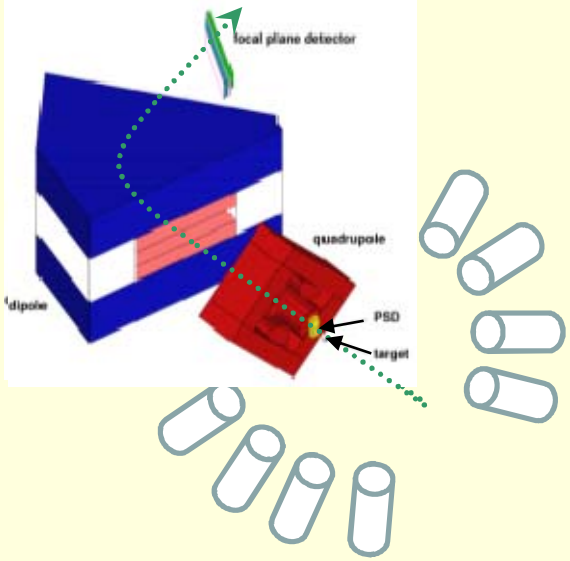
Gamow-Teller strength
- charge exchange reactions
- β decay

Comparison with known GT transitions in (p,n), (^{3}He,t)

From 2011 upgrade of the experimental apparatus

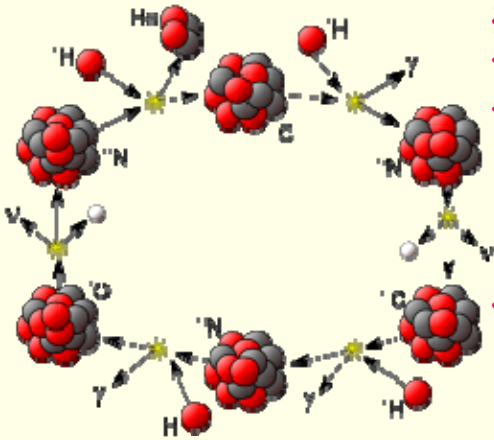
n detectors
decay from resonance states

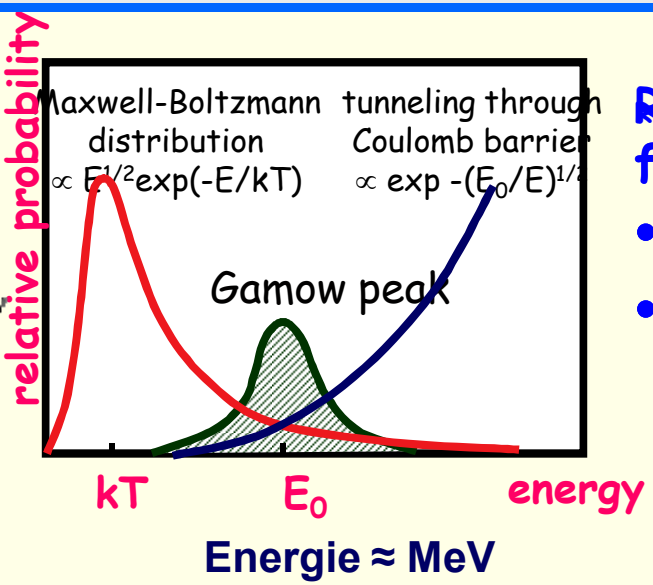
detectors provided by Orsay (LEA agreemente collaboration)



Several results on :
- **pair transfer**
- **search for pair vibrations**

Nuclear astrophysics and interdisciplinary reserach



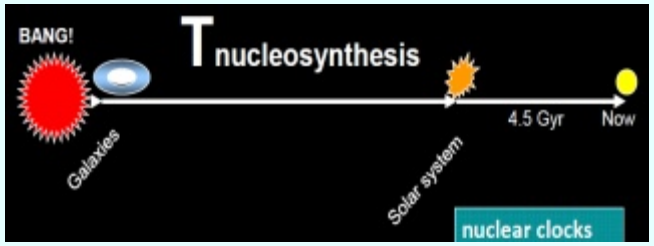


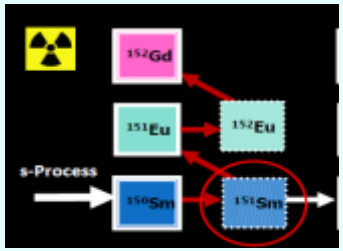
Energie ≈ MeV

Reactions at stellar energies for :

- **Energy generation**
- **Nucleosynthesis**

(exp LUNA, ASFIN e ERNA)





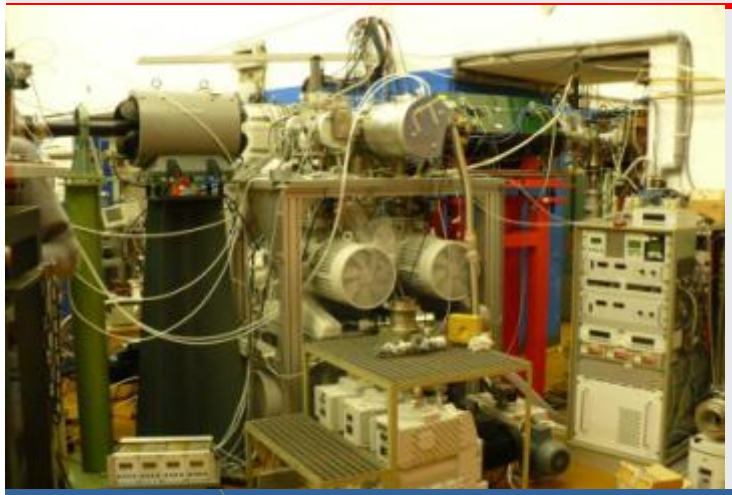
- Neutron capture for astrophysics and application in reactors of new generation.

n_TOF al CERN

- Annichilation of anti protons in nuclei 5keV – 5 MeV region of cosmological interest ASACUSA + R&D AEGIS

- Pauli principle violation in atomic transitions (LNGS) (exp VIP)

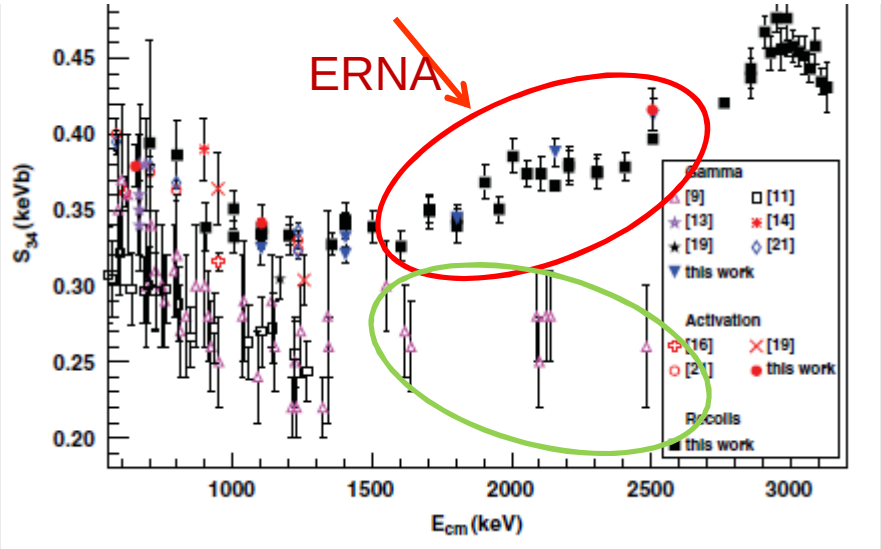
ERNA – Separator at Caserta : reaction for astrophysics



Gamma and electron detectors under development

Measurements of reactions in inverse kinematics

Astrophysical factor for $^{3}He(\alpha,\gamma)^{7}Be$



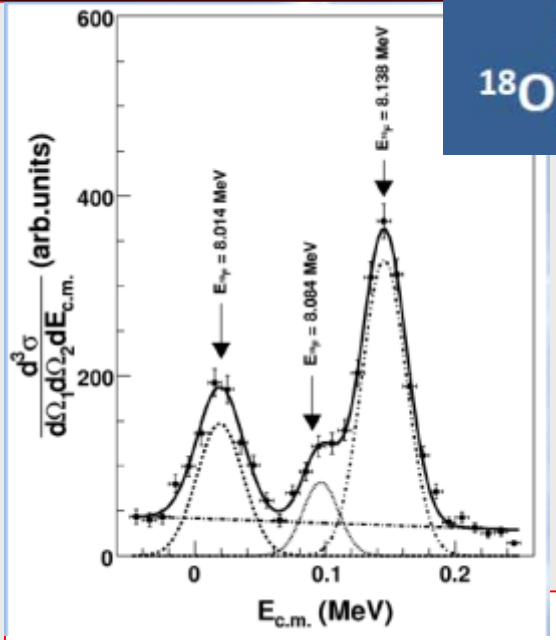
PRL102(2009)232502

- $^{7}Be(p,\gamma)^{8}B$ **In program**
- ^{7}Li BBN p-p solar neutrino-Borexino
- $^{12}C(\alpha,\gamma)^{16}O$
- He burning $^{14,15}N(\alpha,\gamma)^{18,19}F$
- $^{12}C+^{12}C$ $^{12}C+^{16}O$ C burning

- Useful to determine the flux of solar neutrinos
- Implications for the BBN

Astrophysical Application (exp ASFIN)

First Experimental Measurement of the $^{18}O(p,\alpha)^{15}N$ Reaction at Astrophysical Energies



The Fluorine problem in the Asymptotic Giant Branch :

These cross sections are important for the models of mechanisms at the stellar interior.

INDIRECT REACTIONS

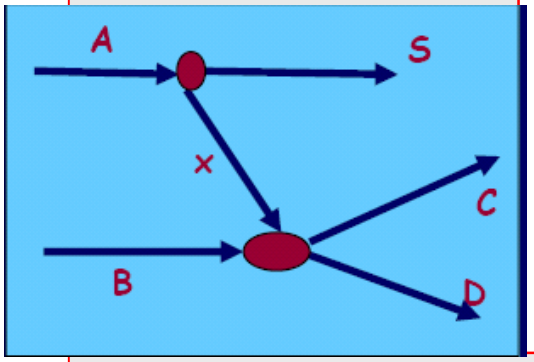
$^{15}N + p \rightarrow \alpha_o + {}^{12}C$

$^{17}O + p \rightarrow \alpha + {}^{14}N$

$^{18}O + p \rightarrow \alpha + {}^{15}N$

$^{19}F + \alpha \rightarrow {}^{22}Ne + p$

Measurements at LNS and RIKEN



$^{15}N + d \rightarrow \alpha_o + {}^{12}C + n_{spect}$

$^{17}O + d \rightarrow a + 14N + n_{spect}$

$^{18}O + d \rightarrow \alpha + {}^{15}N + n_{spect}$

$^{19}F + {}^{6}Li \rightarrow {}^{22}Ne + p + a_{spect}$

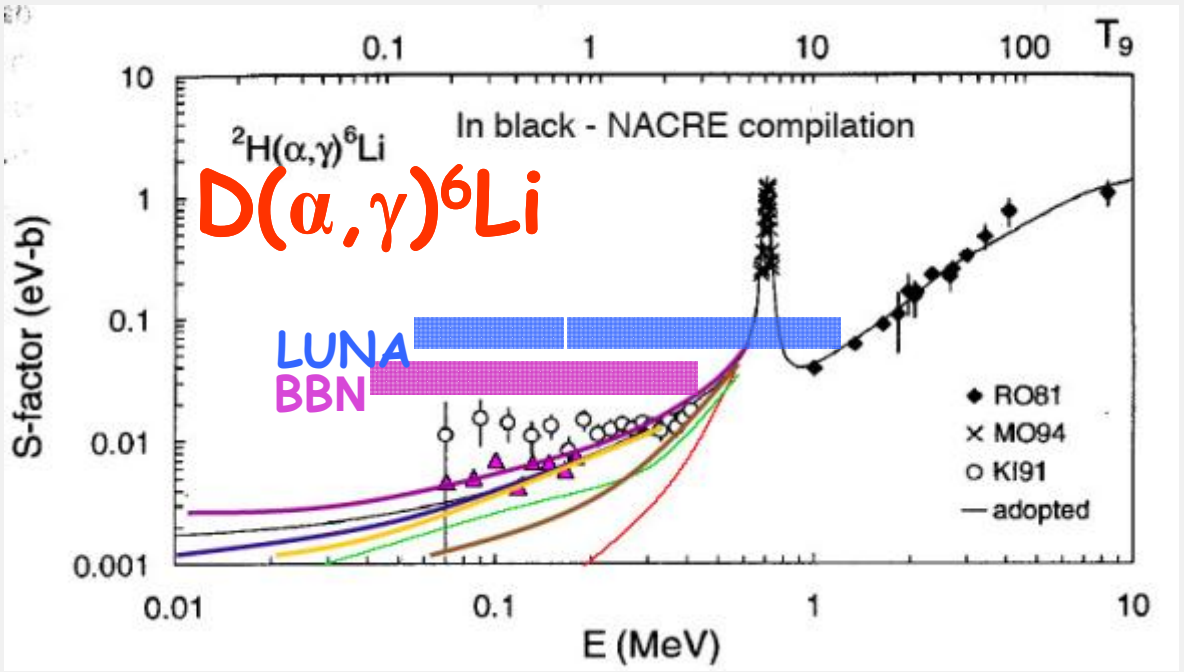
Esperiment LUNA at LNGS

Key reaction for the production of ^{6}Li from the BBN

Direct measurements in the region of BBN di not exist

Large discrepancies among the data.

Theory differs more than an order of magnitude.

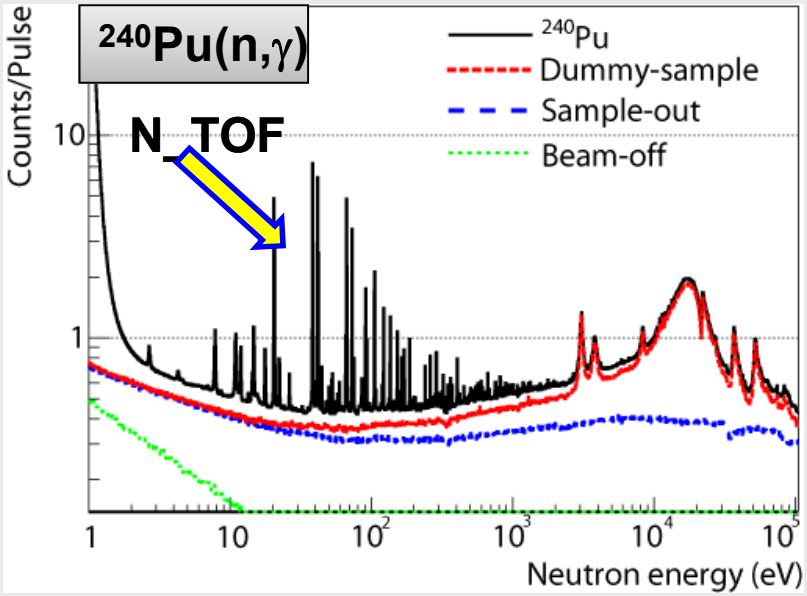


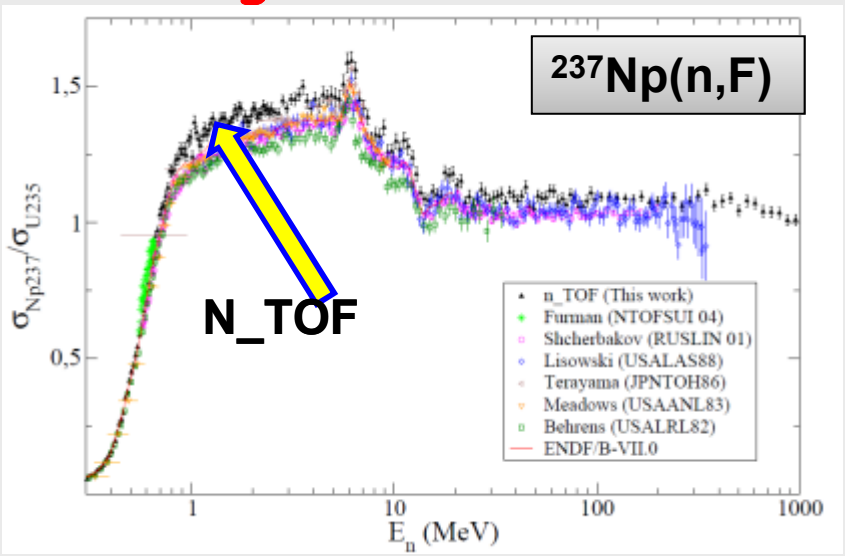
Models of BBN predict quantities of ^{6}Li 2-3 order of magnitudes lower than the measurements in stars metal poor. ->
Cross section under estimated or sources of ^{6}Li?

Design for measurements with 4 MeV accelerators

n_TOF

Cross section measurements of neutron capture of astrophysical interest and for emerging nuclear technologies.



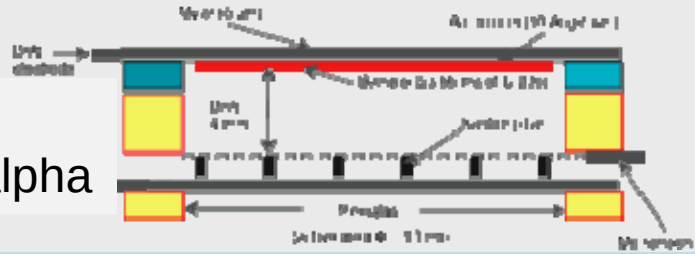


First capture measurement in the region of reslved resonances (up to 1 keV).

6% accuracy (up to 1 keV).

Information on nuclear properties (level spacing, average gamma widths, etc…) were deduced.

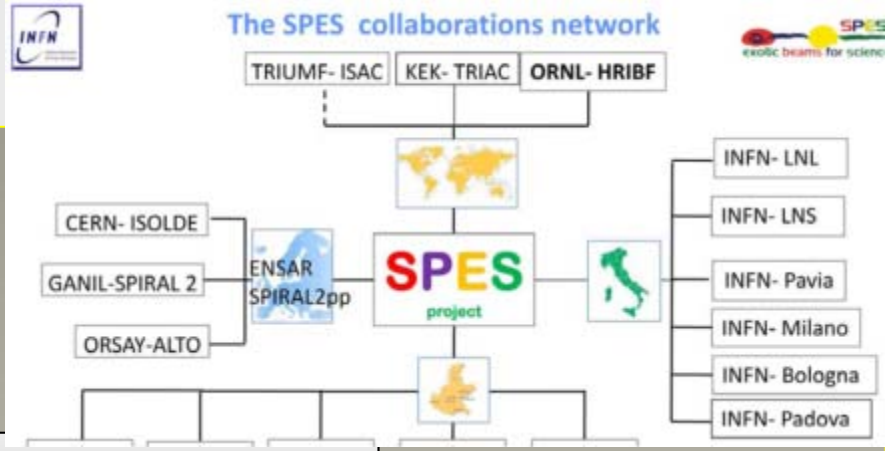
New detector for fission and alpha



Total number of e protons for the approved experiments (up to now): **40x10^{18} (> 3years)**

SPES ISOL facility

Cyclotron 750 μA, 70 MeV (max) for protons in two exit ports:
- RIB - up to 300 μA p on UCx
- Application - up to 500 μA



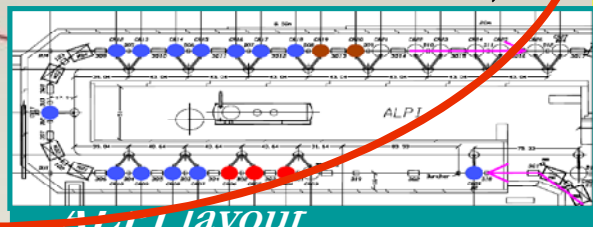
Additional target station
(special plants second priority)
RIB or neutron production

transport/beam cooler/separator

Charge Breeder
1+ → n+

High Resolution
Mass Spectrometer
1/20000

(Post Accelerator)



UCx target station
10^{13} fission/s

G.Prete

NuPNET Call

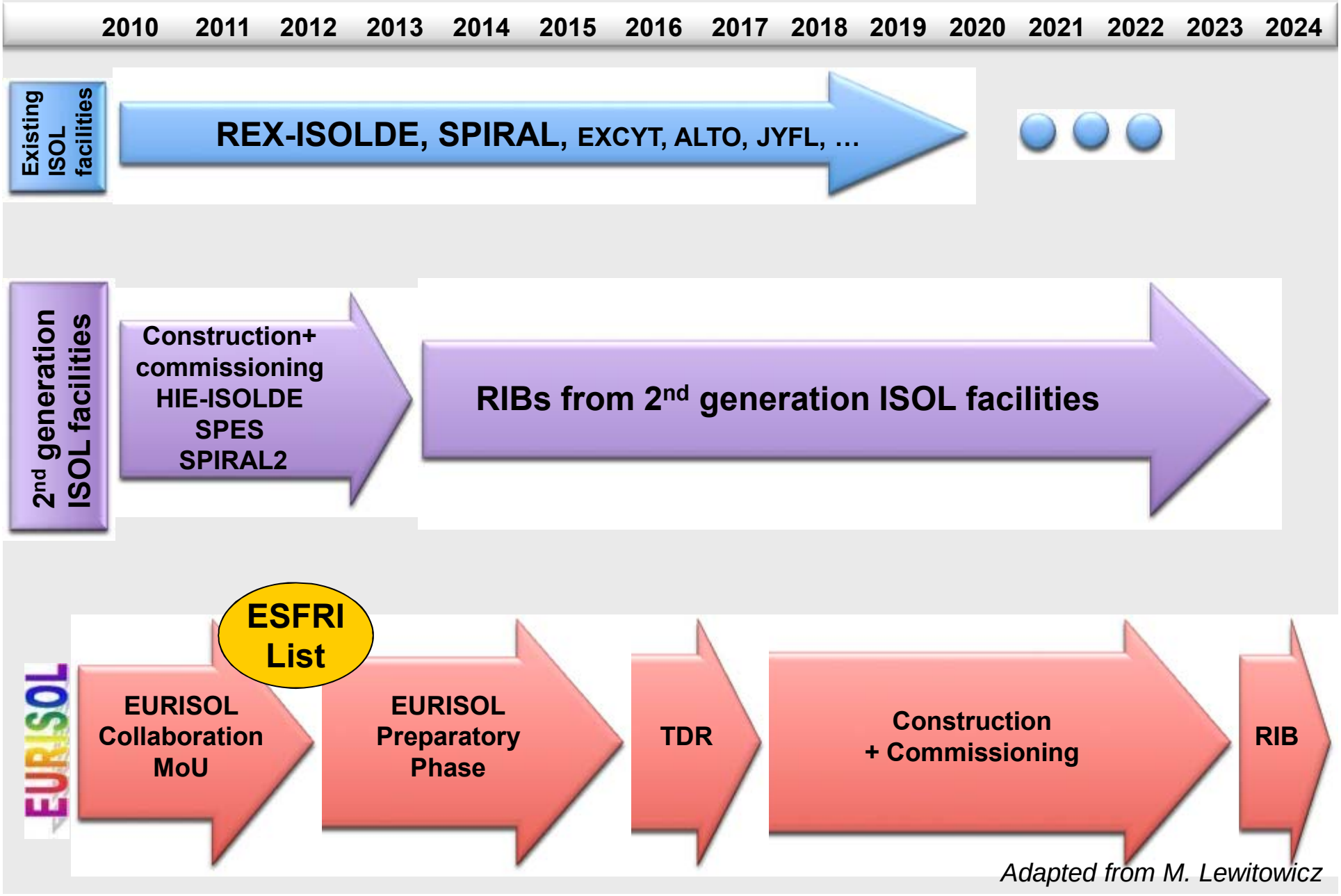
1st topic: R&D on new detector technologies in nuclear physics.

- Gamma and neutron detection technologies based on new scintillation materials and new photo-sensors (APDs, SiPMs…).
- Silicon and micropatterned gas tracking detectors (GEM, Micromegas): low and high energy applications.
- Large-area diamond detectors for beam monitoring or timing.
  These technologies are important for the nuclear research infrastructures selected in the ESFRI list: FAIR and SPIRAL2.

2nd topic: R&D on Eurisol technologies: accelerator components, target and ion sources.

3rd topic: Targeted action on nuclear structure and reactions theory.

Timeline for European ISOL RIB facilities



Adapted from M. Lewitowicz

LRP2010 NuPECC Recommendations

- **Complete ESFRI Facilities**
  - **FAIR** with **PANDA, CBM, NuSTAR** and **APPA**
  - **SPIRAL2** at GANIL including **S3** and **DESIR**
- **Perform Major Upgrades**
  - **HIE-ISOLDE** at CERN
  - **SPES** at INFN-LNL
  - **AGATA**
  - **SC Linac** at GSI
- **Support ALICE at CERN**
  - Upgrades for nuclear beams programme at LHC to expand physics reach
- **Support Theory**
  - RI **ECT*** in Trento
  - Projects for advanced studies related to the experimental roadmap
  - Dedicated high-performance computing facilities
- **Fully exploit Existing Facilities**
  - Lepton beam facilities **ELSA** in Bonn, **MAMI** in Mainz, **COMPASS** at CERN, **DAΦNE** at INFN-LNF, and hadron beam facilities **COSY** at FZ Juelich and **GSI** in Darmstadt
  - Heavy ion beam facilities at **JYFL, KVI, GSI, GANIL, IPNO, ISOLDE, INFN-LNL** and **INFN-LNS**
  - **AD** at CERN & upgrade **ELENA**
  - **Smaller scale national and university labs** across Europe
- **Support Nuclear Physics applications & education**
- **Promote Planning for Future Large-Scale Facilities**
  - **EURISOL** as RI in future updates of **ESFRI** list
  - Technical Design Study for intense radioactive beams at ISOL@MYRRHA
  - Technical Design Studies for PAX and ENC at FAIR
  - Technical Design study for nuclear physics experiments & applications at ELI
  - Technical Design Study for LHeC at CERN

CONCLUSION

• The community working in nuclear structure and reaction dynamics is very active and preparing well the way towards SPES.

• At LNS EXCYT is asked to provide other unstable beams in addition to ^{8}Li . Some beams from fragmentation reactions are being produced.

• Instrumentation

upgrades of CHIMERA and R&D (FAZIA)
AGATA demonstration + construction of 1π

• With SPES radioactive beams we plan to contribute (together with the work at GANIL, ISOLDE, GSI, RIKEN, MSU) to the study of nuclear structure properties needed to understand the nature of stars, where the elements come from, and how complex patterns arise from relatively simple building blocks.

•Long range plan del NUPECC is print

For SPES it is important to keep the timelines !