Experimental Nuclear Physics

2005 Activity Report

and

future prospects

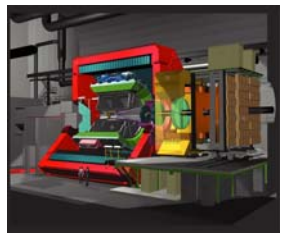
Alessandro Feliciello

I.N.F.N. - Sezione di Torino

CSN3 in figures

2005

484 FTE



29 experiments

38 Laurea degrees
17 Dottorato degrees (PhD)

282 papers

CSN3 activity

QUARK AND HADRON DYNAMICS

- nucleon spin physics
- nucleon resonances
- nuclear medium effect
- spectroscopy of hypernuclei
- kaonic atoms
- pionic atoms

PHASE TRANSITIONS OF NUCLEAR AND HADRONIC MATTER

- liquid-gas phase transition
- equation of state of nuclear matter (EOS)
- chiral symmetry restoration
- quark deconfinement
- Quark-Gluon Plasma (QGP)

NUCLEAR STRUCTURE AND REACTION DYNAMICS

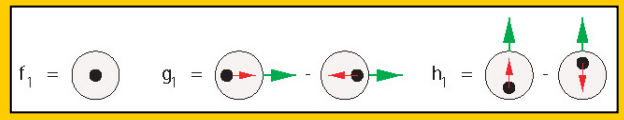
- fission and fusion reaction mechanism
- production and study of exotic nuclei
- structure of nuclei from γ spectroscopy
- radioactive ion beam

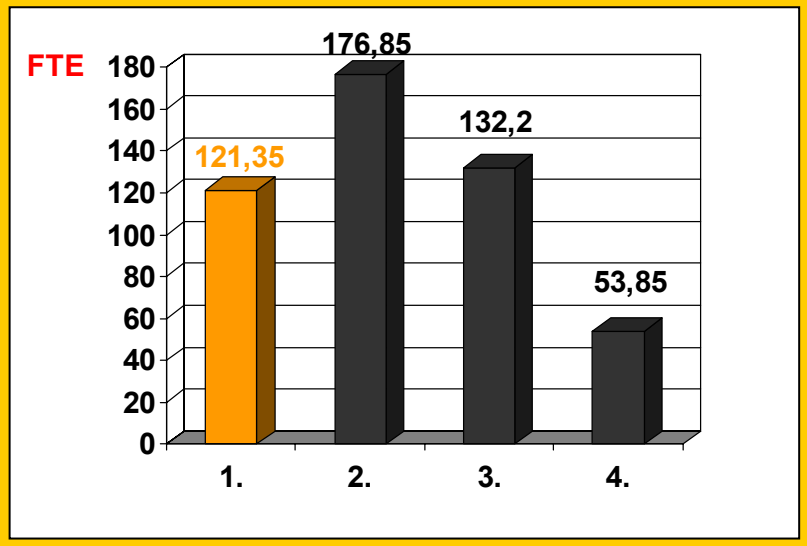
NUCLEAR ASTROPHYSICS AND INTERDISCIPLINARY RESEARCHES

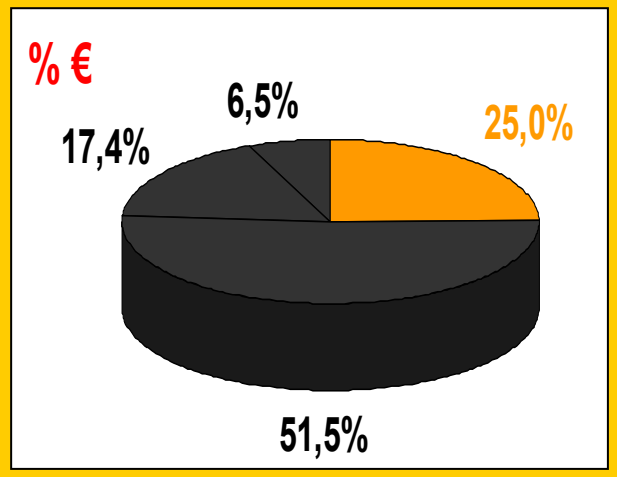
- measurement of cross sections at very low energies
- stellar evolution
- *pp* chain
- CNO cycle
- production and study of anti-hydrogen

1. Quark and hadron dynamics

experiments
- running: 7
- in preparation: 3







Nucleon spin

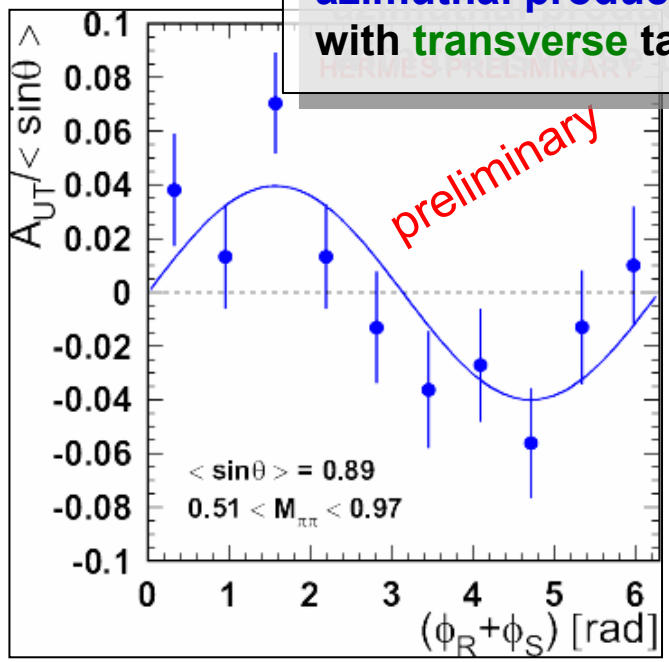
HERMES

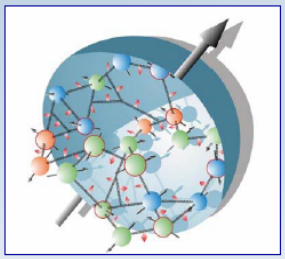
DESY

structure function
transversity

$$\Delta_T q(x) \otimes FF$$

di-hadron azimuthal production with transverse target



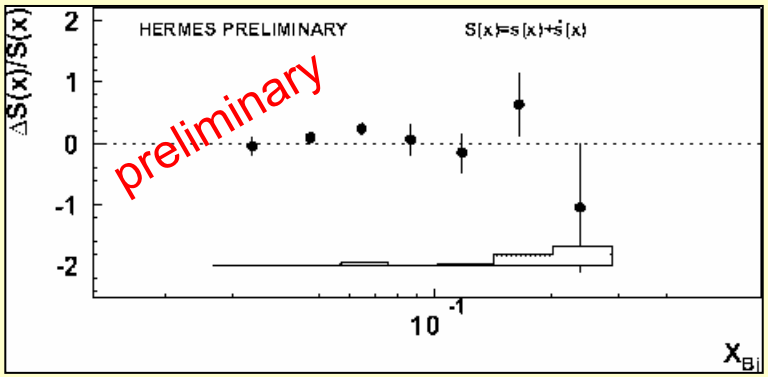


$|p\uparrow\rangle = \frac{1}{2} = \frac{1}{2}\,\Delta\Sigma + \Delta G + L_q + L_g$

$\Delta\Sigma = \Delta u + \Delta d + \Delta s$ → Spin dei Quark

ΔG → Spin dei Gluoni

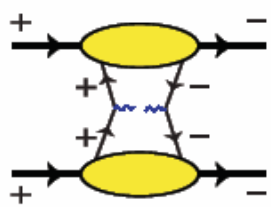
L_q, L_g → Momento Angolare Orbitale



no contribution from quark s

Direct measurement possible in 2015?

$p\uparrow p\uparrow \rightarrow l^+l^-X$



direct measurement
$\Sigma\Delta_T q(x) \cdot \Delta_T q(x)$

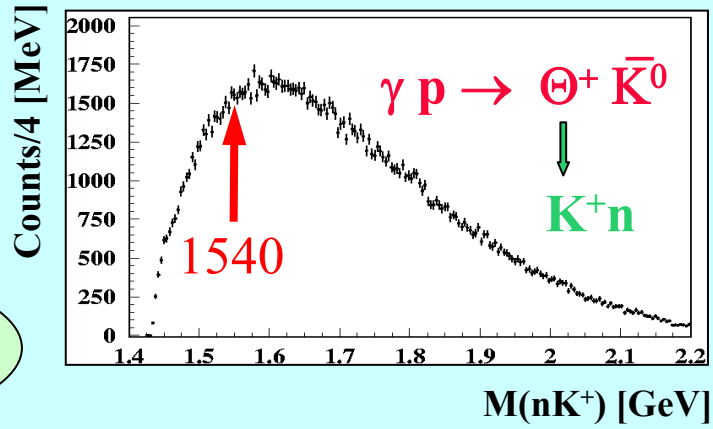
- PAX R&D
- Jülich & CERN
- antiproton polarization (?)

Search for exotic states, hadron spectroscopy…

AIACE — Jefferson Lab

- pentaquark hunting:
  measurements on protons and deuterons
  - $\gamma p \rightarrow \Theta^+ K^0$
  - $\gamma p \rightarrow \Theta^+ K^- \pi^+$
  - $\gamma p \rightarrow \Theta^{++} K^-$

12 GeV CEBAF upgrade



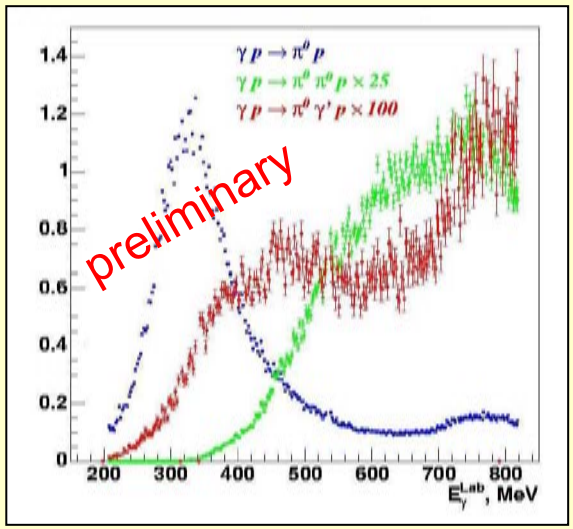
- NEW GDH measurement at low Q^2
  (< 0.05 GeV^2/c^2)

$\sigma_{U.L.}$ (95% CL) < 0.5-1.2 nb

CTT — universität mainz

Δ^+ resonance magnetic moment measurement

$$\gamma p \rightarrow \pi^0 p \gamma'$$



GRAAL — ESRF

asymmetry in the photoproduction of π^0 with quasi-free n

High precision measurements up to 2008

Strangeness nuclear physics

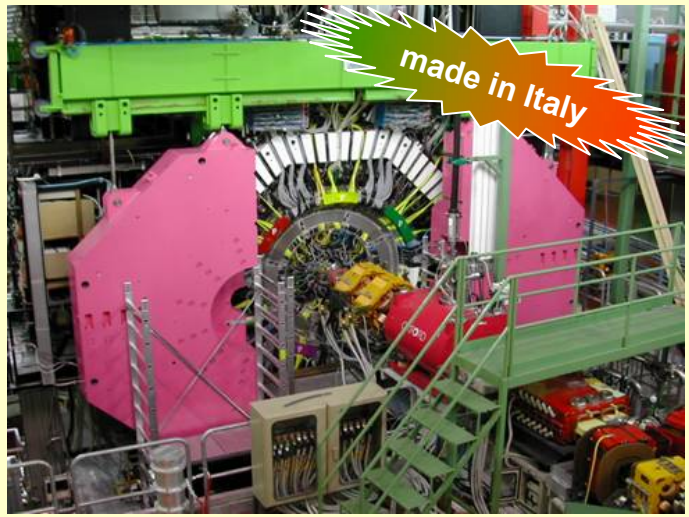
FINUDA

LNF

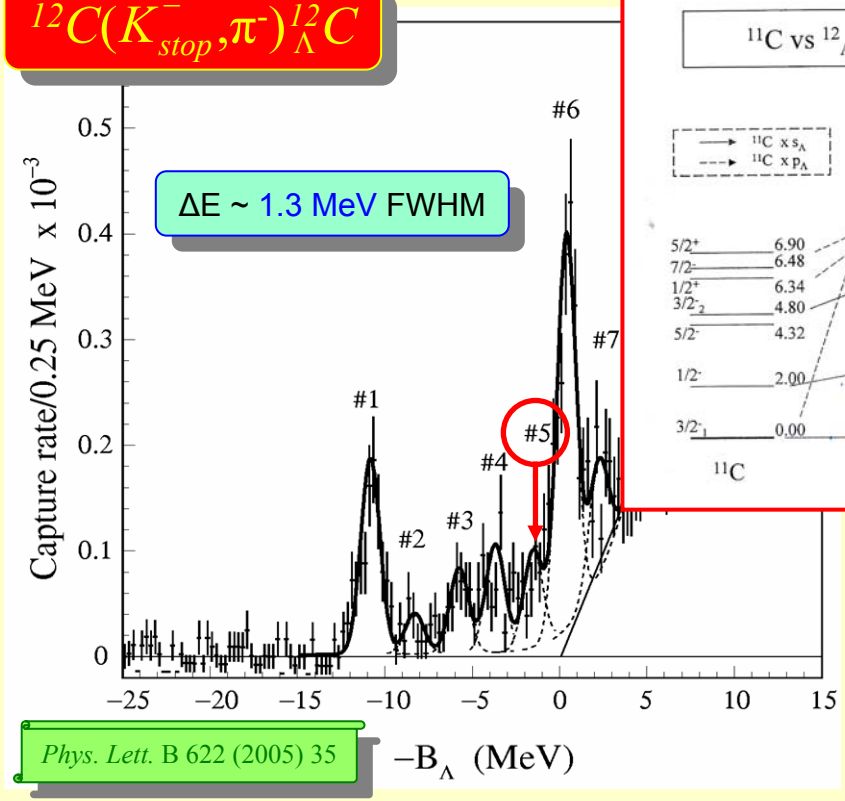
$$e^- + e^+ \rightarrow \phi \rightarrow K^- K^+$$

$$K^-_{stop} + {}^{A}Z \rightarrow {}^{A}_{\Lambda}Z + \pi^-$$

$${}^{A}_{\Lambda}Z \rightarrow \begin{cases} {}^{A}(Z+1) + \pi^- \\ {}^{(A-2)}(Z-1) + p + n \\ {}^{(A-2)}Z + n + n \end{cases}$$



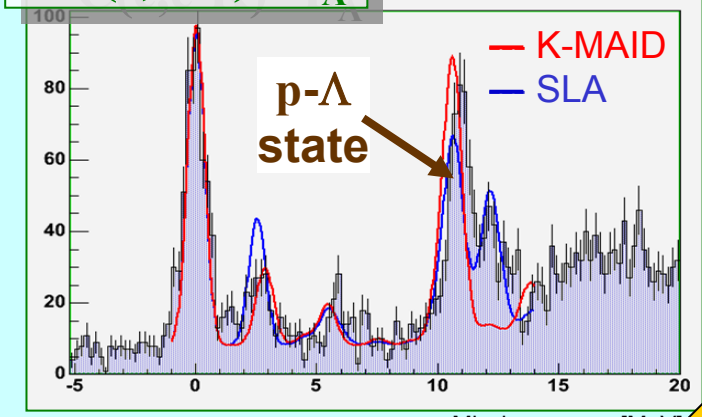
$^{12}C(K^-_{stop},\pi^-)^{12}_{\Lambda}C$



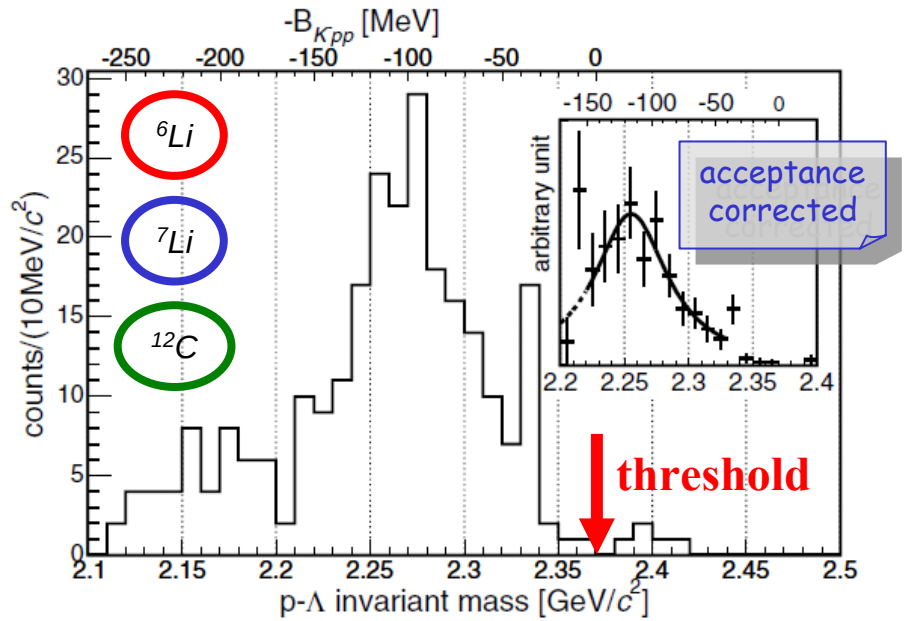
LEDA

Jefferson Lab

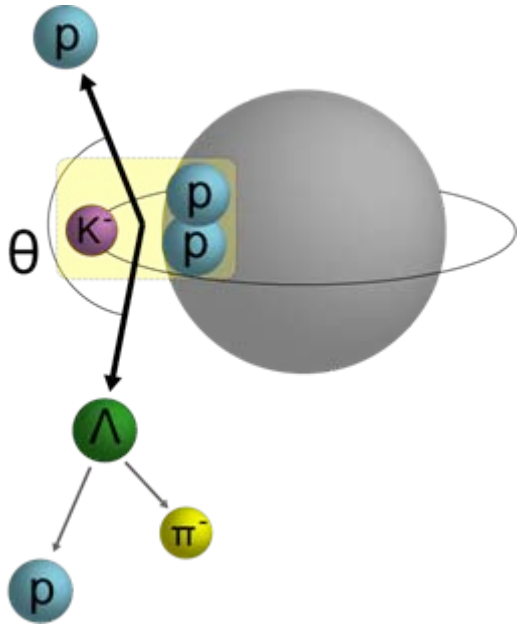
$^{12}C(e,e'K)^{12}B_{\Lambda}$



Strangeness nuclear physics



Phys. Rev. Lett. 94 (2005) 212303



$M = 2255 \pm 9$ MeV
yield ≈ 0.1 / stopped K^-

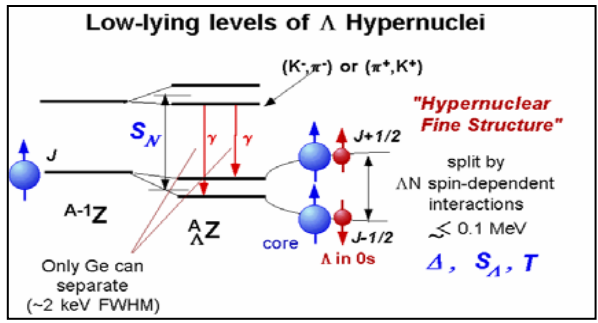
$$B = 115\ ^{+6}_{-5}\ ^{+3}_{-4}\ \text{MeV}$$
$$\Gamma = 67\ ^{+14}_{-11}\ ^{+2}_{-3}\ \text{MeV}$$

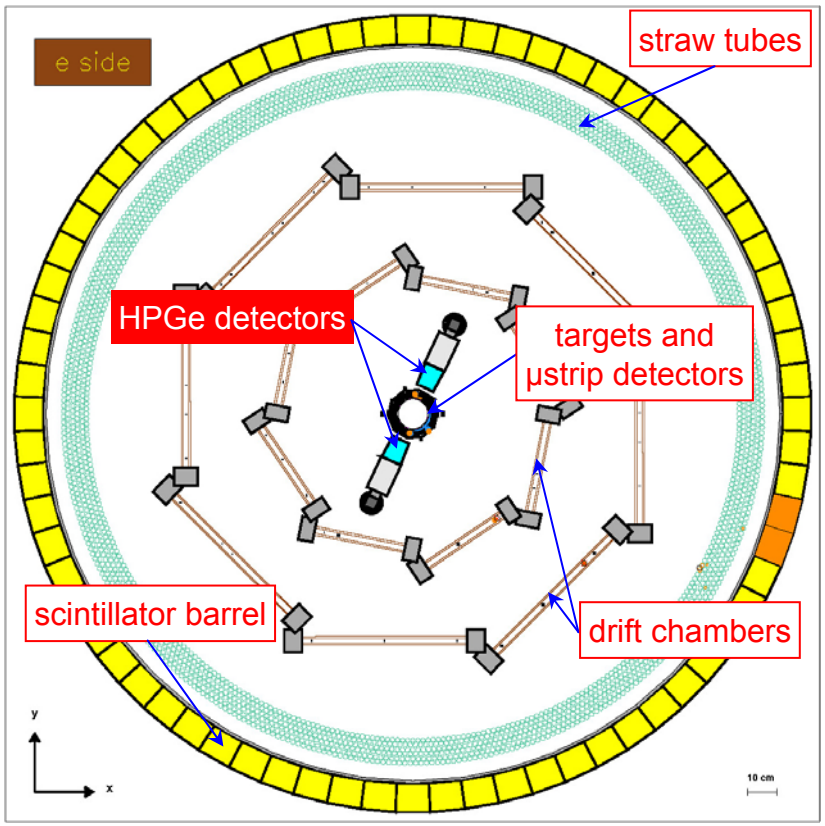
Short term plans

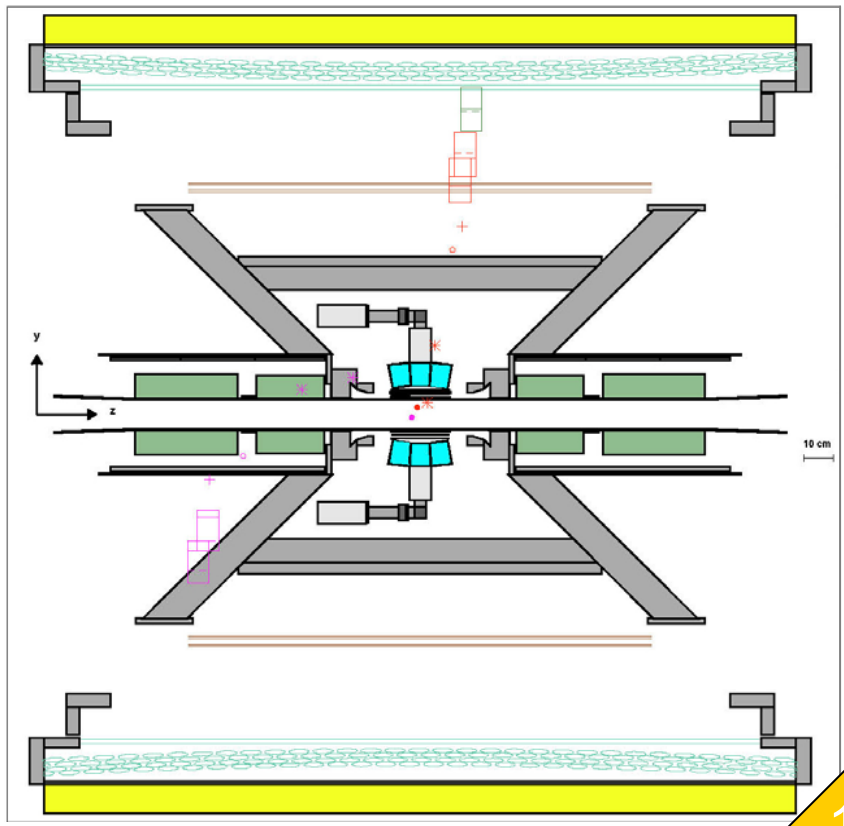
@ LNF

$$V_{\Lambda-N}(r) = V_0(r) + V_\sigma(r)\vec{s}_N\cdot\vec{s}_\Lambda + V_\Lambda(r)\vec{l}_{N\Lambda}\cdot\vec{s}_\Lambda + V_N(r)\vec{l}_{N\Lambda}\cdot\vec{s}_N + V_T(r)[3(\vec{\sigma}_N\cdot\vec{r})(\vec{\sigma}_\Lambda\cdot\vec{r}-\vec{\sigma}_N\cdot\vec{\sigma}_\Lambda)]$$

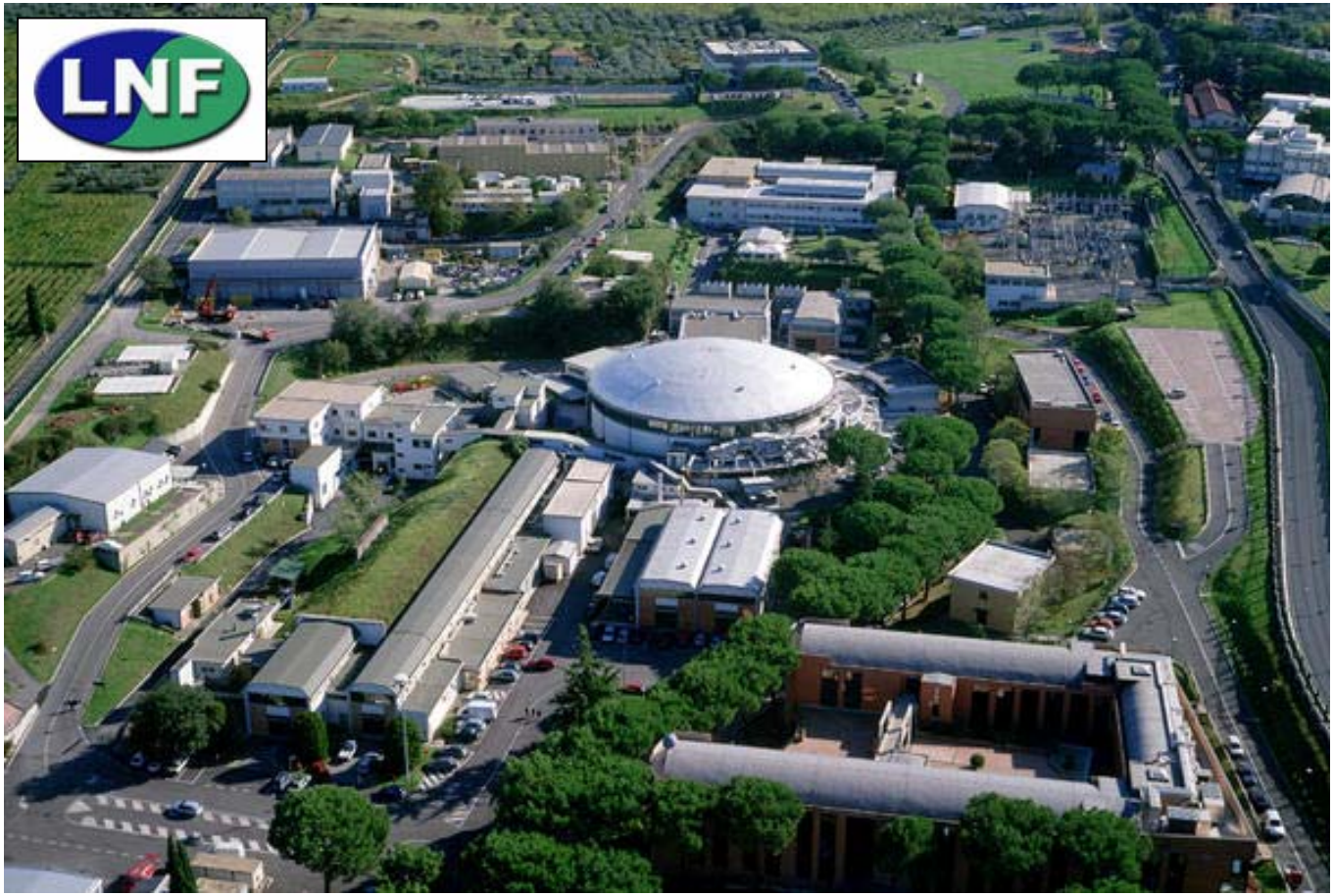
A, S_Λ, S_N, T



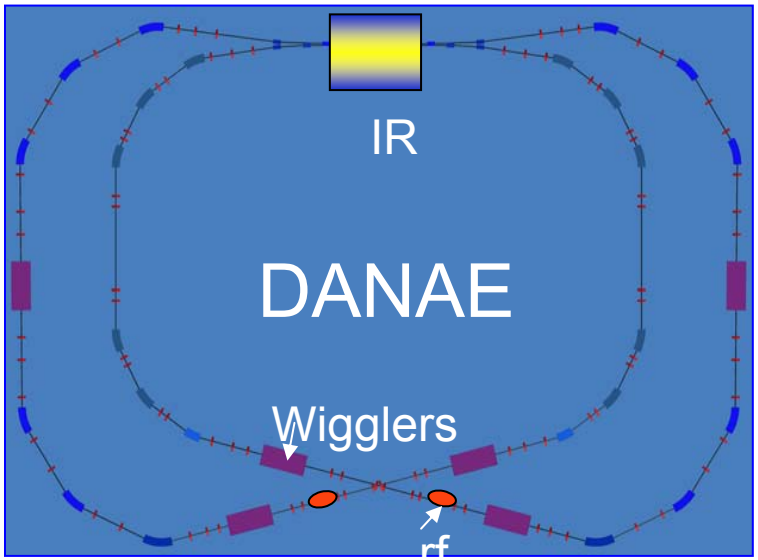




LNF future initiatives



Mid term plans



Physics cases:

- *Kaon* physics
- ☛ nucleon time-like form factors
- ☛ (deeply) bound kaonic states
- synchrotron light source
- $\gamma\gamma$ physics
- …

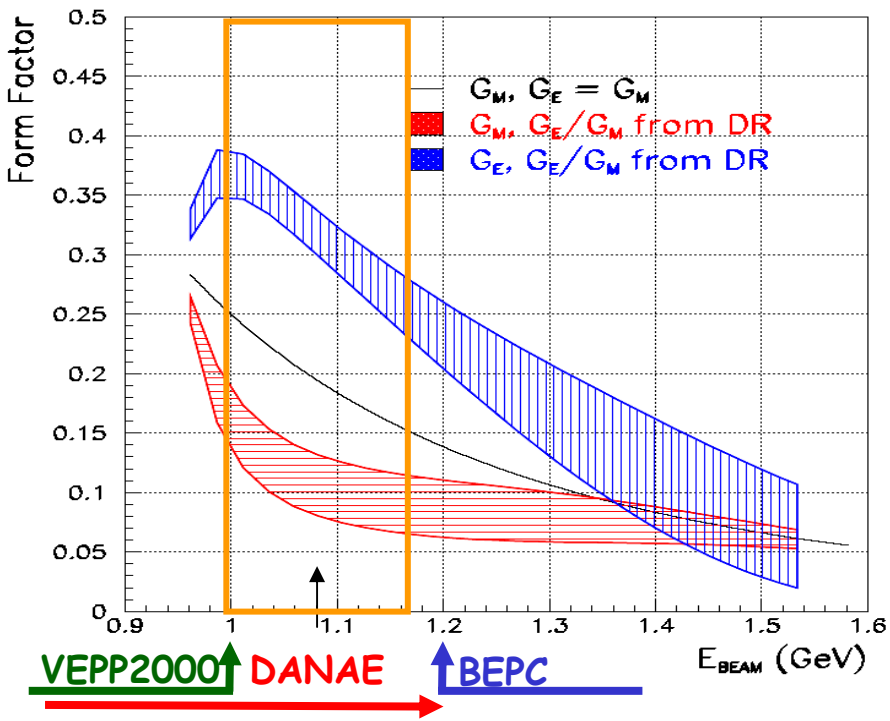
	Φ	
Energy (c.m.) (GeV)	1.02	2.4
Integrated $\mathscr{L}$ per year (fb^{-1})	10	
Total integrated $\mathscr{L}$ (5 years, fb^{-1})	>50	3
Peak $\mathscr{L}$ > ($cm^{-1}s^{-2}$)	$8 \cdot 10^{32}$	10^{32}

Mid term plans

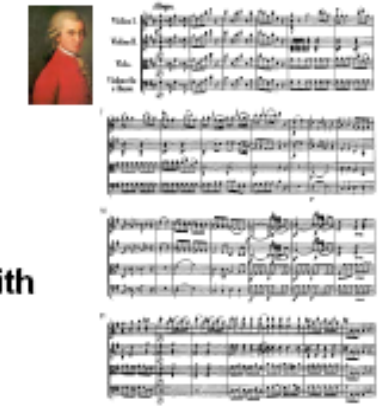
DANAE Nucleon Time-like form factor Experiment

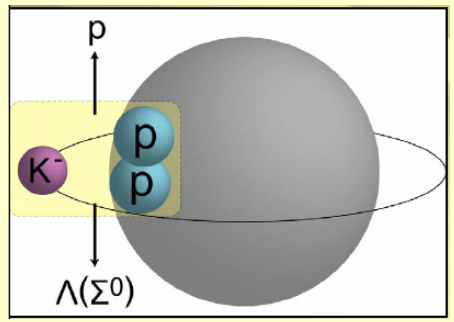
proton: well measured up to s ~ 15 GeV^2
- $e^+e^- \rightarrow ppbar$ (ADONE. DM1/2, FENICE. BaBar)
- $pbarp \rightarrow e+e^-$ (CERN PS135 & PS170, FNAL E760 & E835)

neutron: one single measurement from threshold up to s ~ 4.,4 GeV^2
- $e^+e^- \rightarrow nnbar$ (FENICE)



Antikaon
Matter
At
DAΦNE:
Experiments with
Unraveling
Spectroscopy

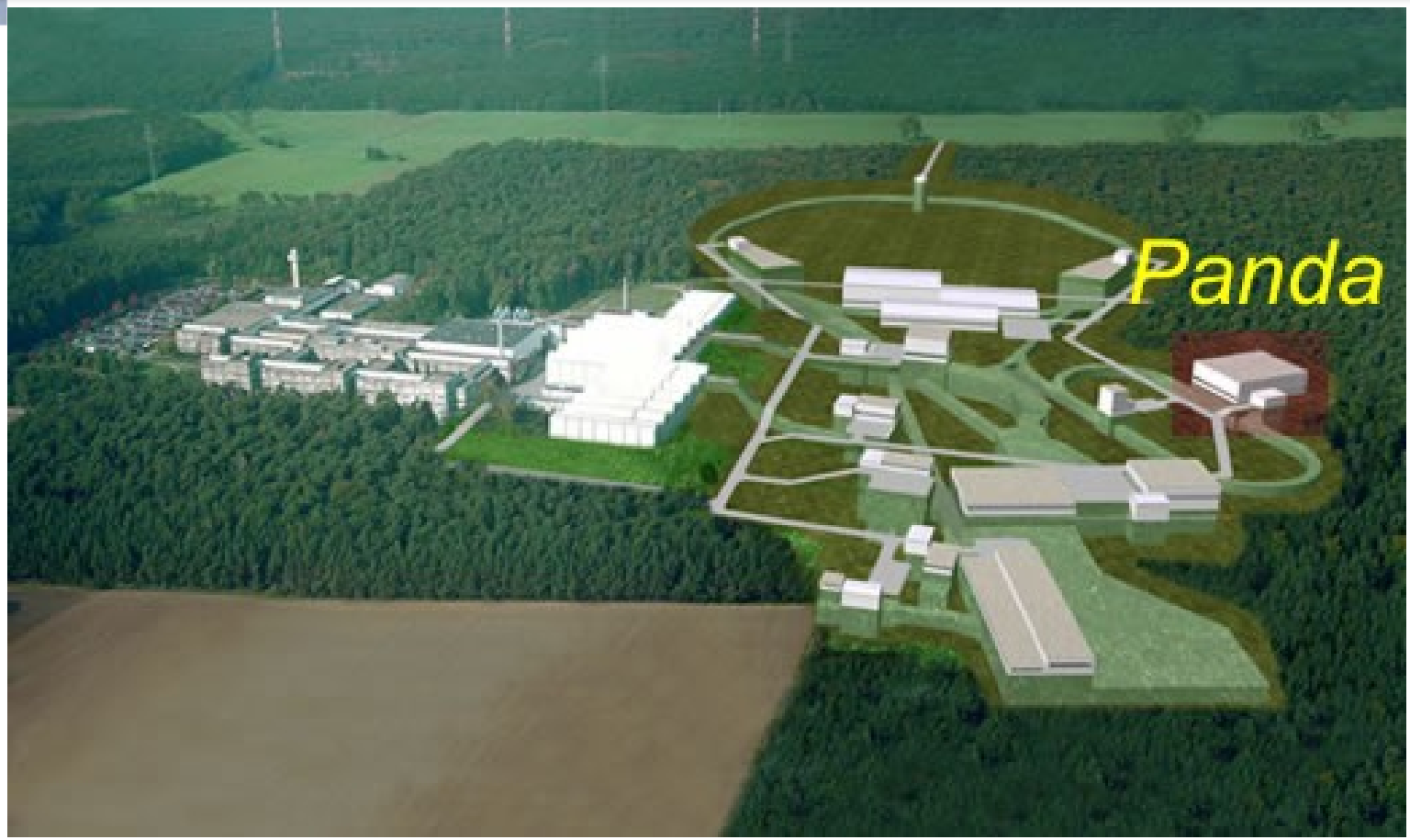




DANAE energy range well suitable

International facilities

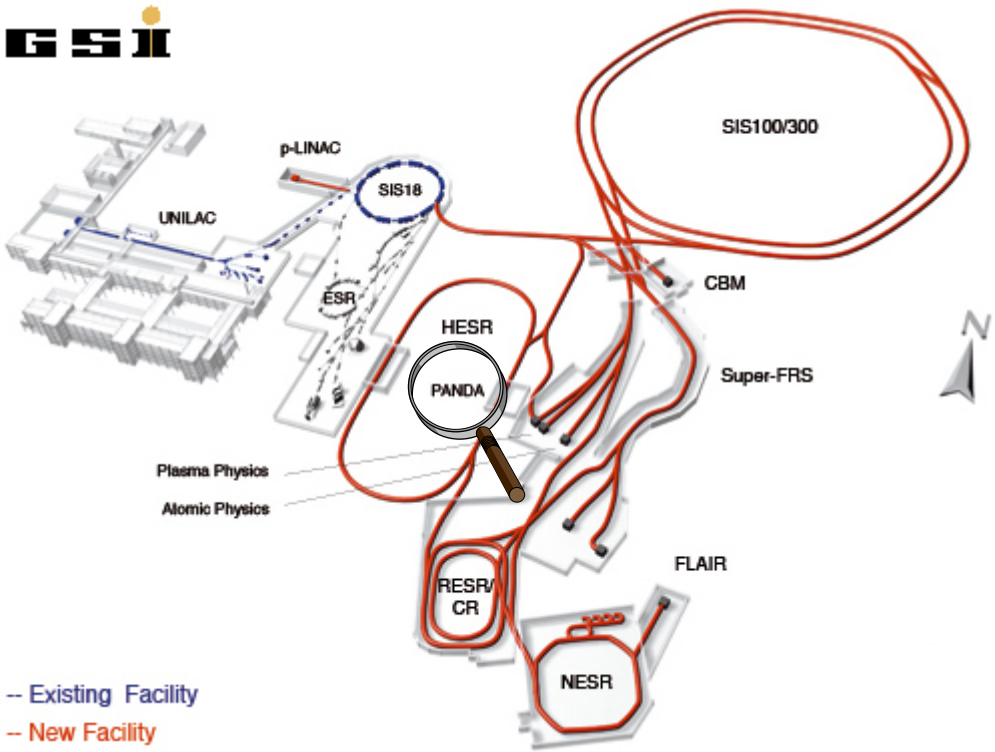
FAIR Facility for Antiproton and Ion Research



GSI

Long term plans

panda @ FAIR



Primary Beams

- 10^{12}/s; 1.5-2 AGeV; $^{238}U^{28+}$
- Factor 100-1000 over present intensity
- 2(4)x10^{13}/s 30 GeV protons
- 10^{10}/s $^{238}U^{92+}$ up to 35 AGeV
- up to 90 GeV protons

Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 AGeV; up to factor 10 000 in intensity over present
- Antiprotons 0 - 30 GeV

Storage and Cooler Rings

- Radioactive beams
- e^-– A (or Antiproton-A) collider
- 10^{11} stored and cooled 0.8 - 14.5 GeV antiprotons
- Polarized antiprotons (?)

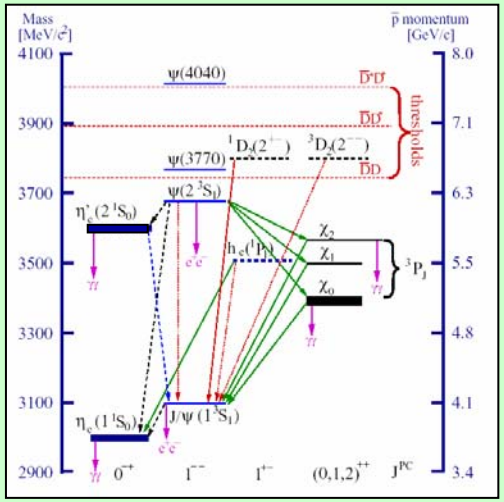
Key Technical Features

- Cooled beams
- Rapidly cycling superconducting magnets
- Parallel Operation

Long term plans

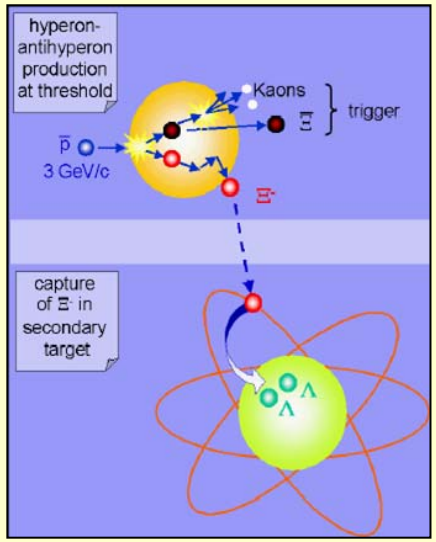
panda @ FAIR

High resolution charmonium spectroscopy



quark confinement

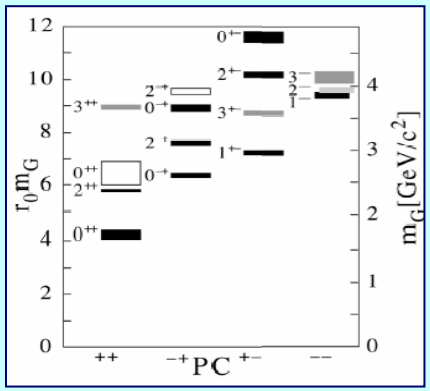
Strangeness nuclear physics



- double Λ ipernuclei γ spectroscopy

- nuclear structure
- low energy ΛN and ΛΛ interactions

Gluonic excitation

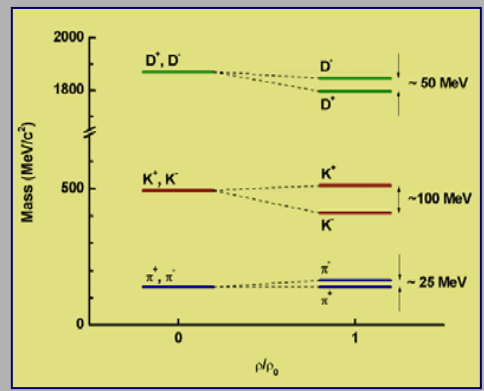


Search for:

- exotics
- hybrids
- glueballs

mass region 3 ÷ 5 GeV/c²

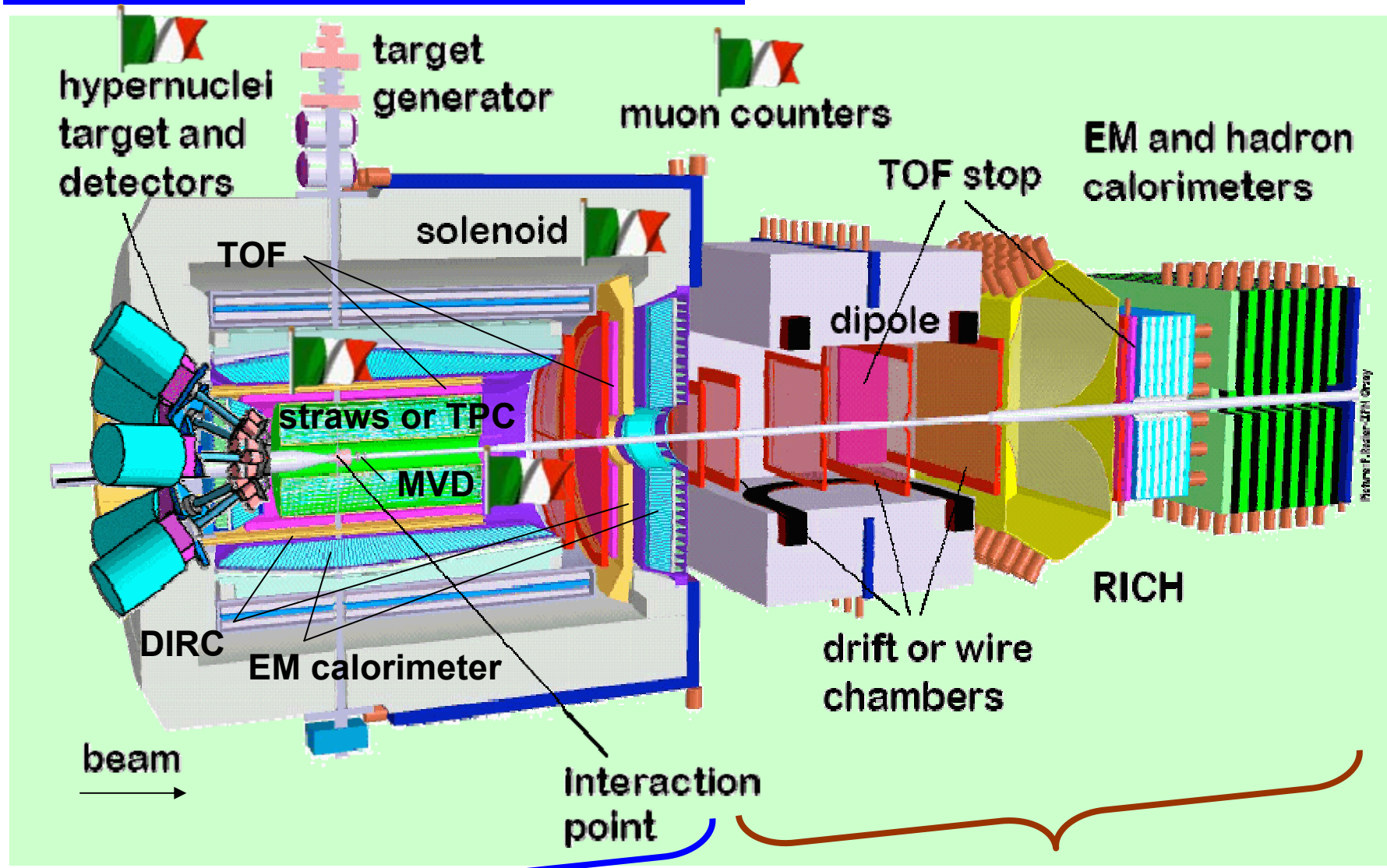
Medium effect



partial restoration of the chiral symmetry?

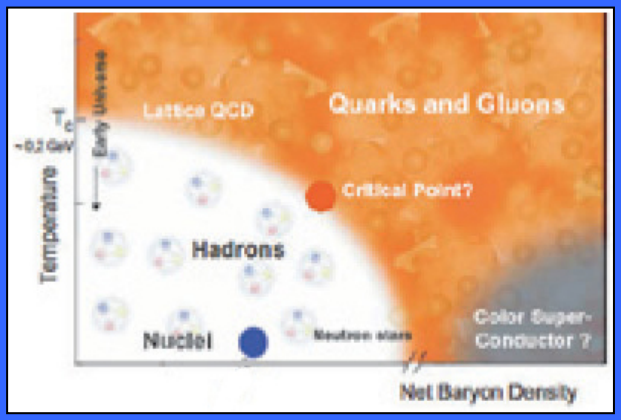
Long term plans

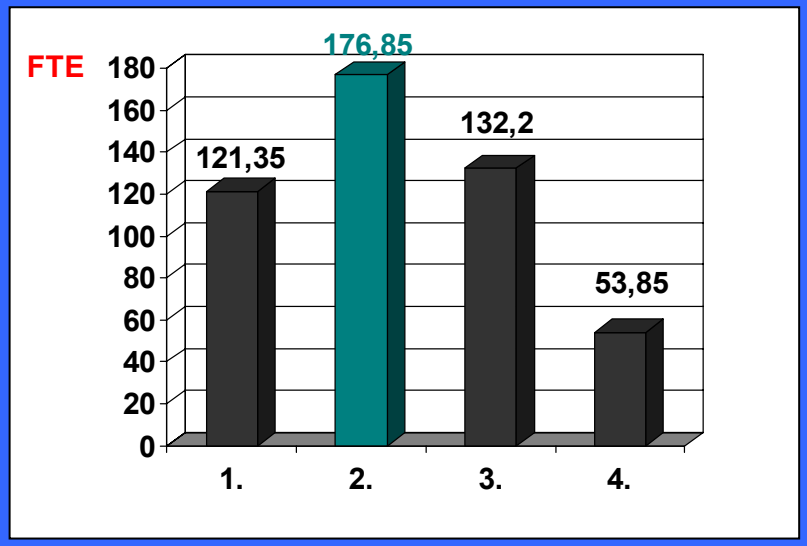
panda @ FAIR

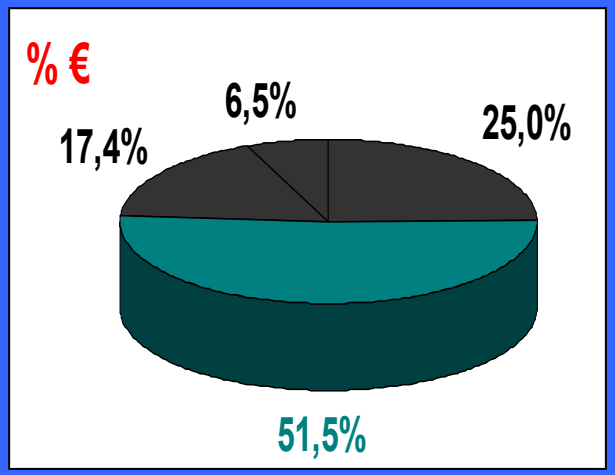


2. Phase transitions of nuclear and hadronic matter

experiments
- running: 3
- in preparation: 2

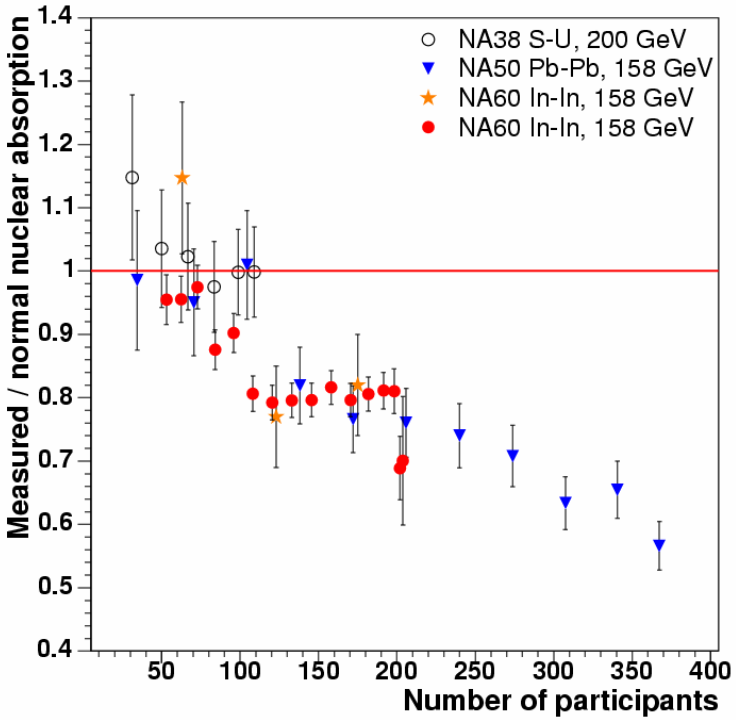


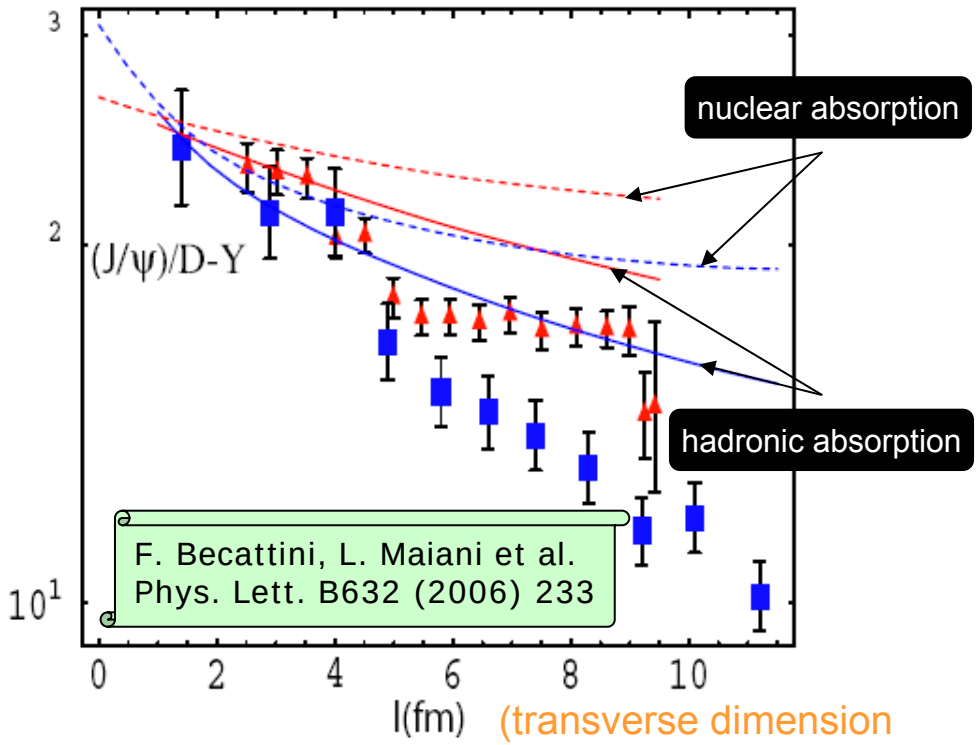




Anomalous J/Ψ suppression

J/Ψ suppression → quark and gluons decofinement

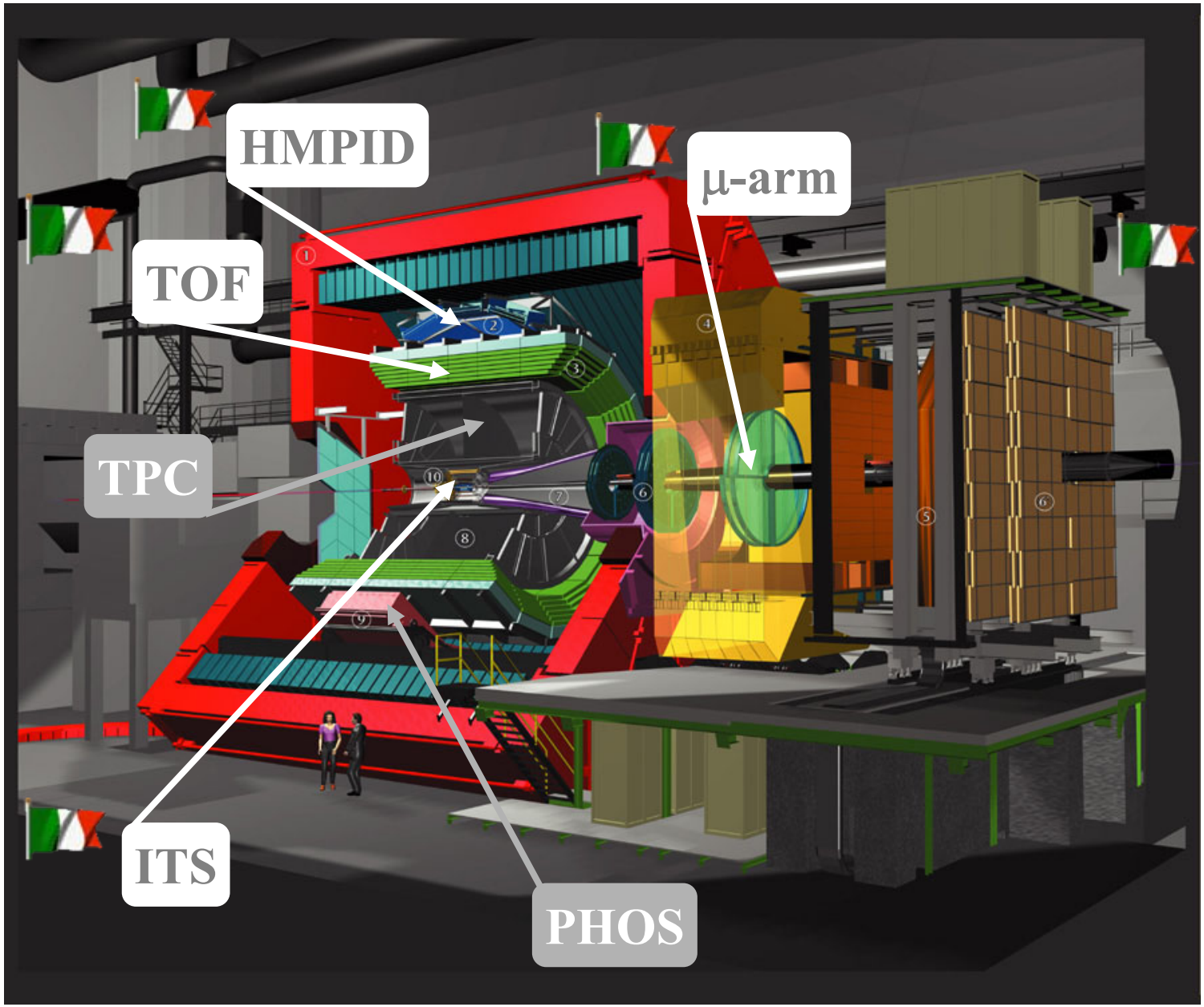




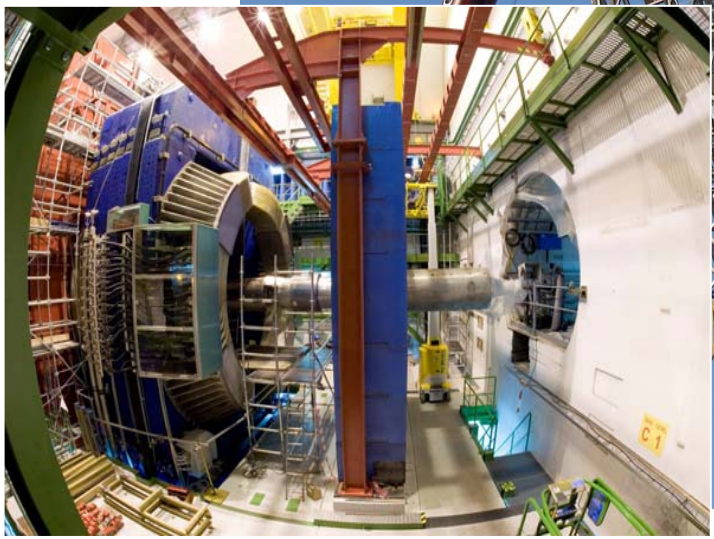
(transverse dimension of the interaction zone)

threshold for deconfinement is reached at SPS energy

Ready to go!



Ready to go!

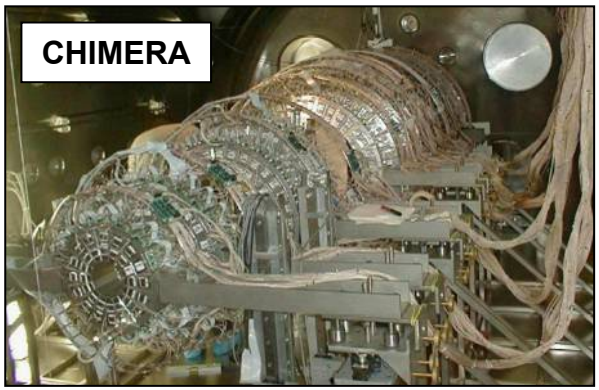


EOS for nuclear matter

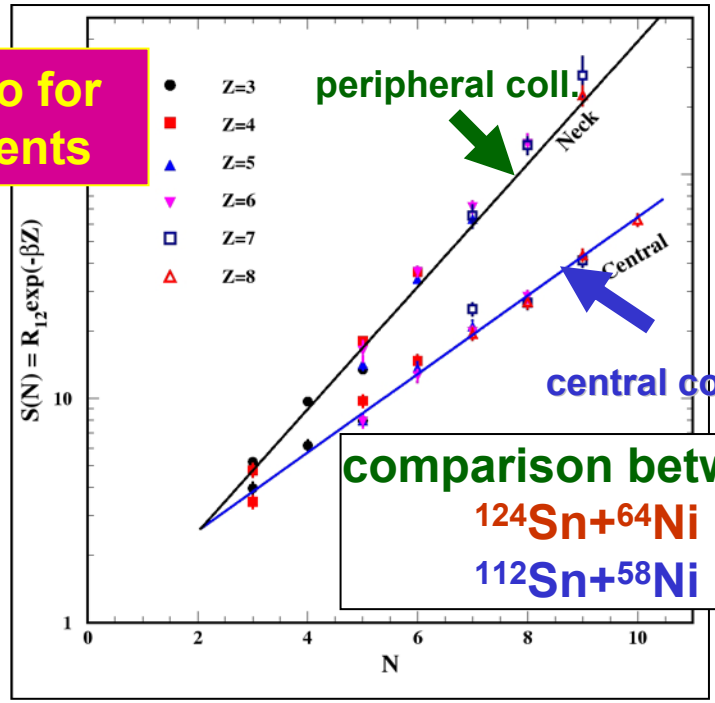
Isospin dependence of EOS:

$$E(\rho,\delta) \approx E(\rho,\delta=0) + E_{sym}(\rho)\delta^2, \quad \delta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$$

symmetry energy
(information for neutron stars)

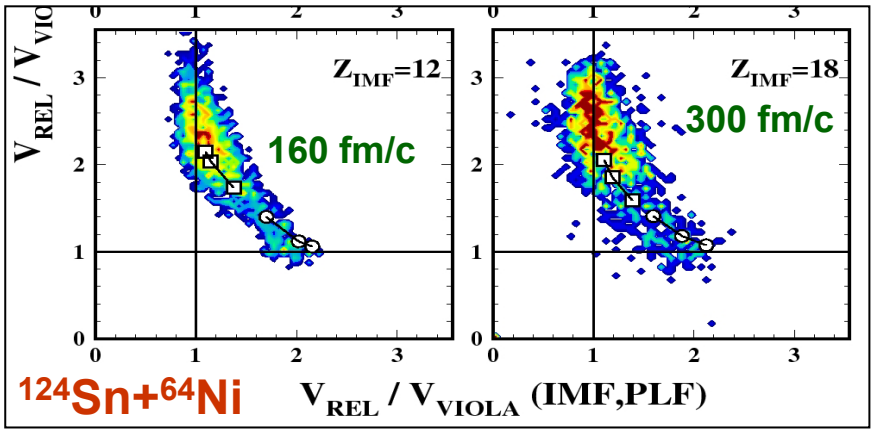


Isotopic ratio for light fragments



comparison between
^{124}Sn+^{64}Ni
^{112}Sn+^{58}Ni

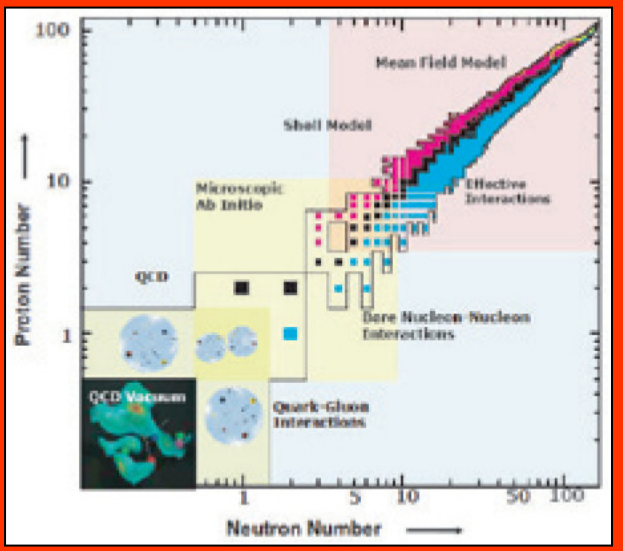
Correlation of velocity of the fragments: tool to identify the transition between prompt and sequential emission

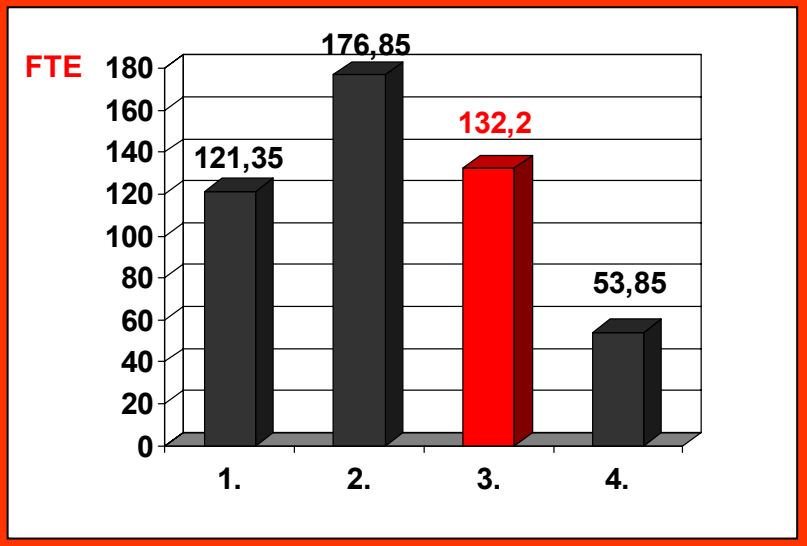


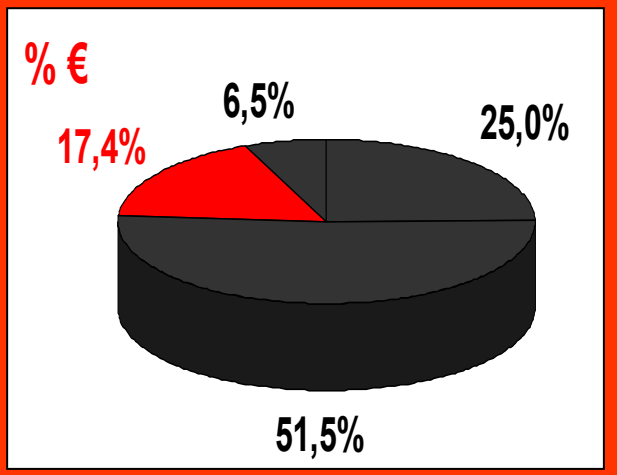
other physics topics:
- isospin symmetry
- production clusters
- termodynamics and formation time

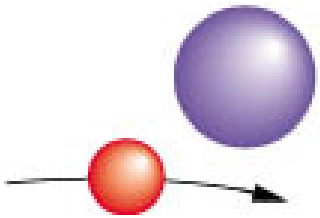
3. Nuclear structure and reaction dynamics

experiments
- running: 7
- in preparation: 1









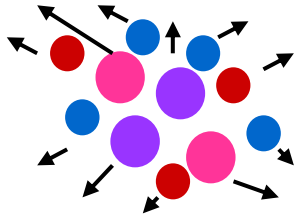
Collisions between ions

(limited energy range and large variety of ions)

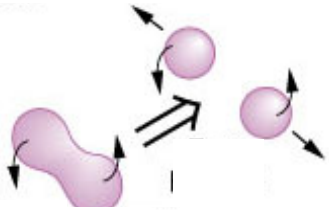
50 MeV/A

ENERGY

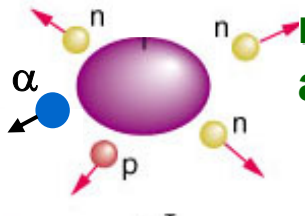
5 MeV/A

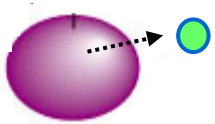


Multifragmentation
Equation of state; liquid-gas phase transition

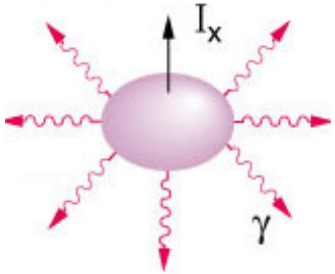


Fusion, fission; nuclear viscosity; thermodynamics; nuclear structure at finite temperature





Nuclear structure under barrier fusion; weakly bound states and resonances



Nuclear structure at extreme conditions of isospin, T and angular momentum

INFN LNS

- ISOSPIN

LNL

- NUCLEX
- FIESTA
- N2P

INFN LNS LNL

- PRISMA
- MAGNEX
- EXOTIC

LNL GANIL BBII

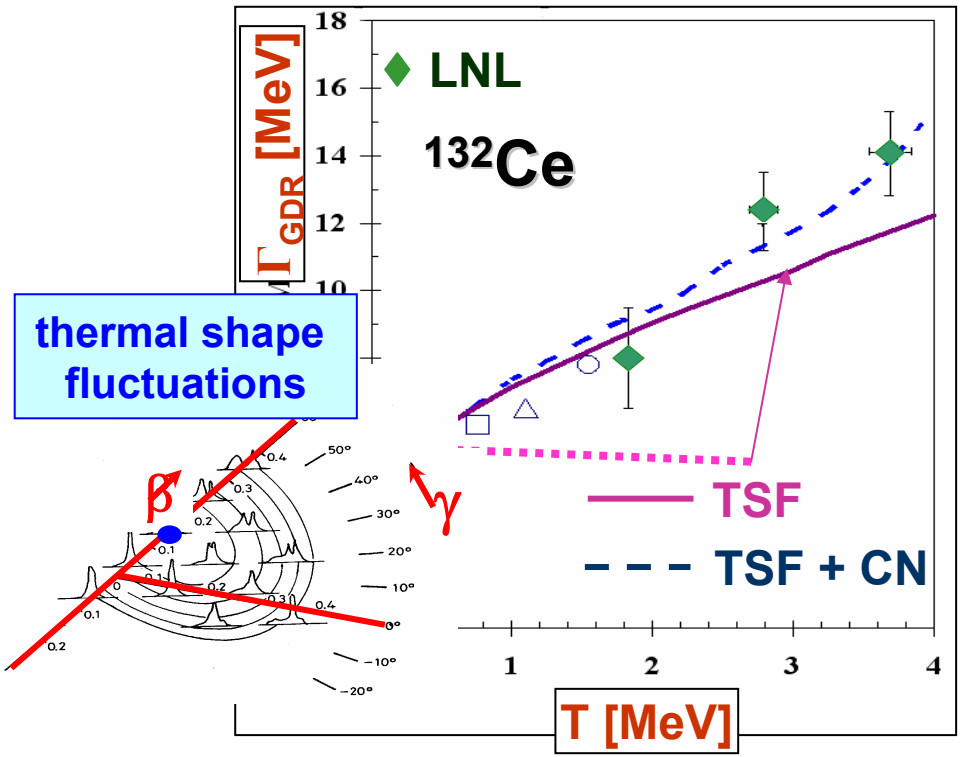
- GAMMA

Nuclear Structure

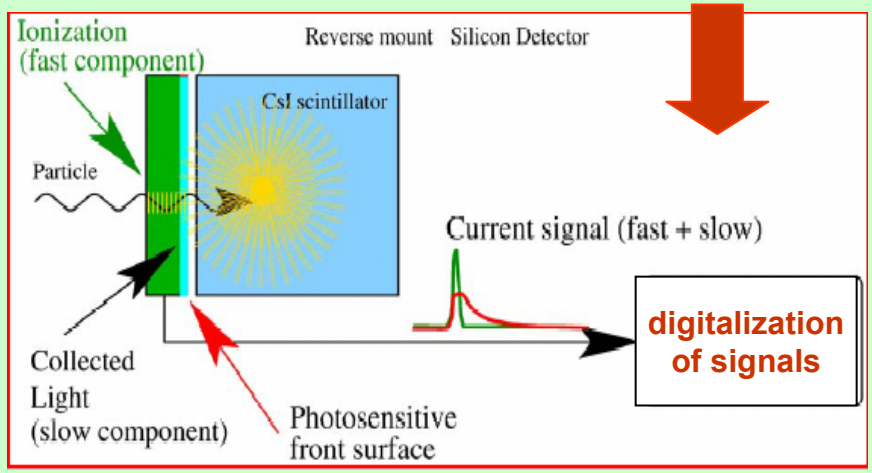
NUCL-EX LNL

- dipole vibration (GDR) to investigate the nucleus shape at finite T and the damping mechanisms

- onset of multifragmentation thermodynamics



R&D of instrumentation for radioactive beams (FAZIA)



Development of a modular detector in an international collaboration (ITALY-FRANCE)

measurements performed with ALPI:

^{64}Ni + ^{68}Zn

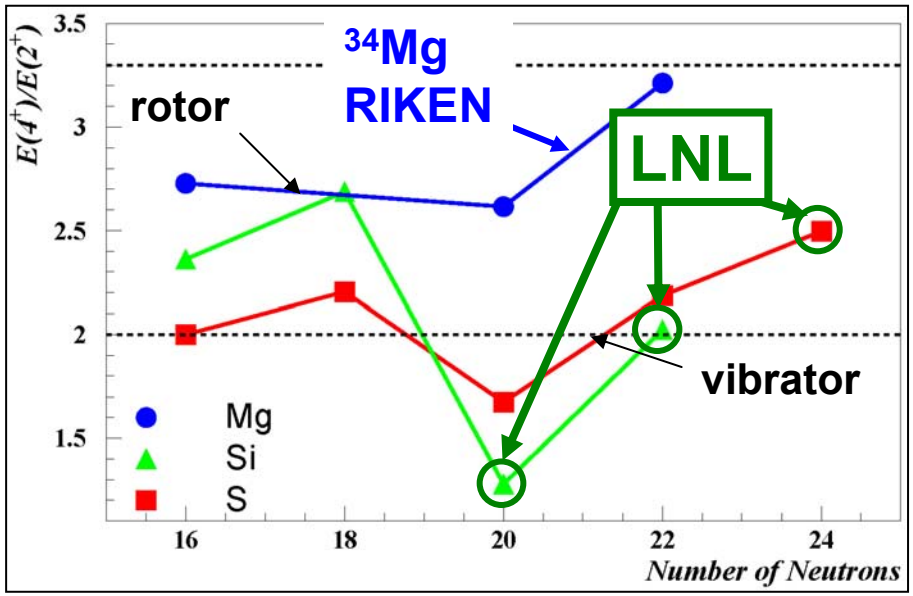
E_{lab} = 300 ÷ 500 MeV

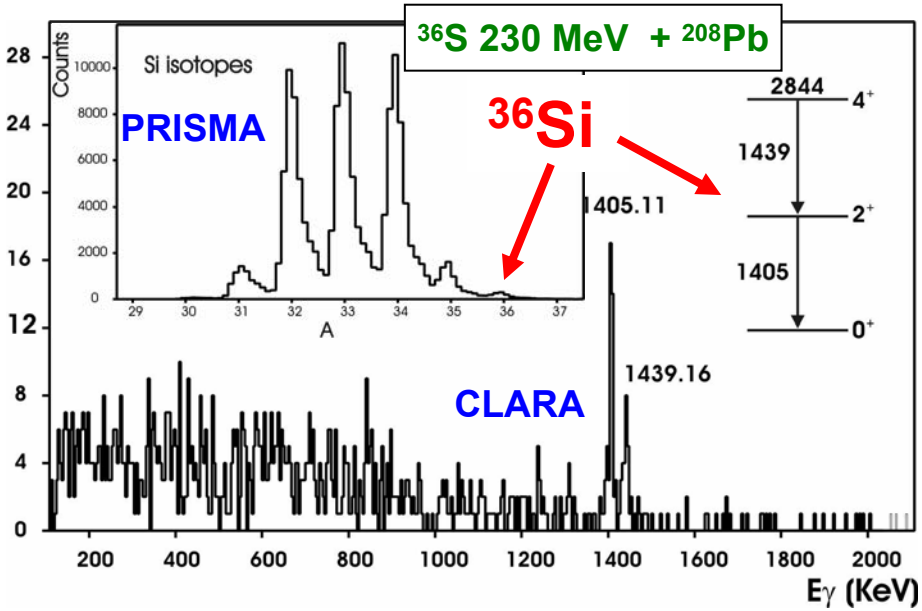
Nucleus shape

GAMMA LNL

Study of unstable neutron rich nuclei with $N \approx 20$

Spacing between 2^+ and 4^+ provides information on the nuclear shape

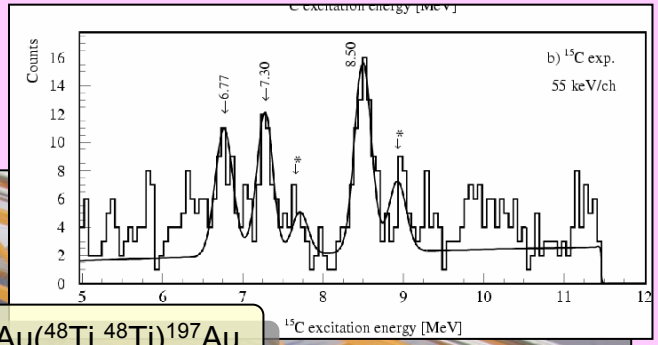




Transition between rotational and vibrational regimes observed for Si and Mg at $N = 22$

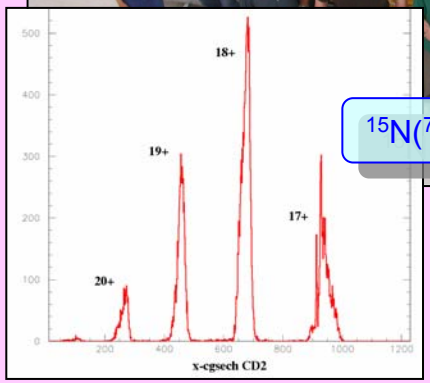
Light exotic nuclei

measurements with the radioactive ^{8}Li beam produced with EXCYT



^{197}Au(^{48}Ti,^{48}Ti)^{197}Au

^{15}N(^{7}Li,^{7}Be)^{15}C



MAGNEX

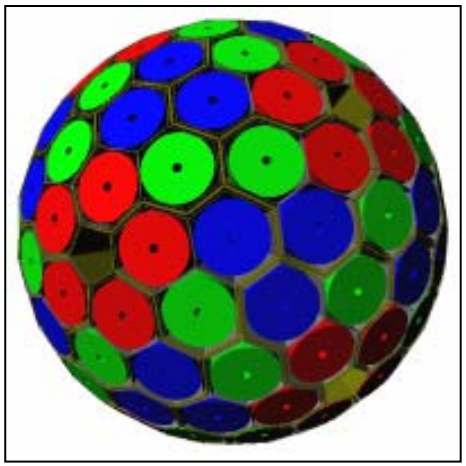
EXOTIC

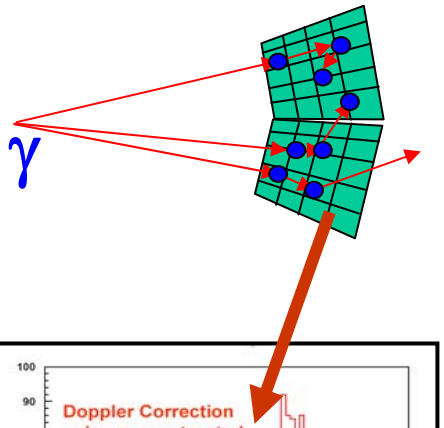
LNL

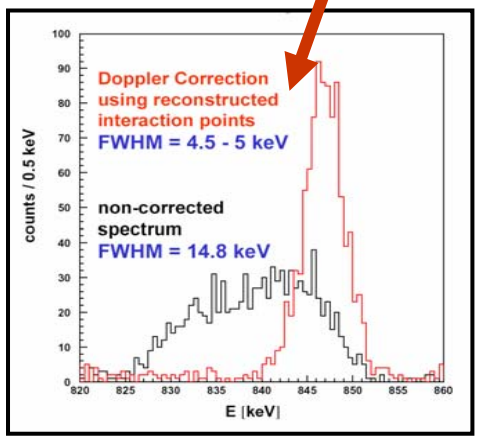
- ^{17}F + ^{208}Pb break-up and elastic scattering
- study of the proton halo structure

Gamma spectroscopy (AGATA)

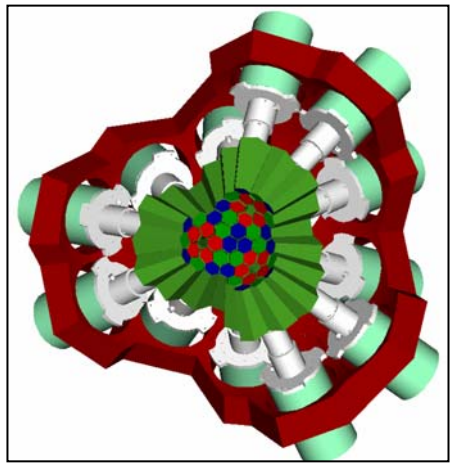
European Collaboration





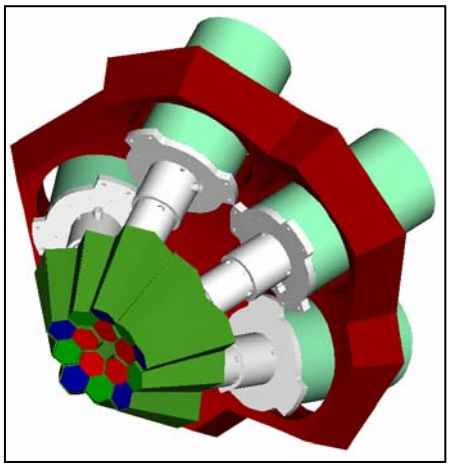


1π array
(15 triple clusters)



- nuclear structure in exotic nuclei
- single particle properties
- collective, shape and symmetry properties

Demonstrator
(5 triple clusters)



demonstrator
installed at LNL
in 2007 and 2008

coupled to PRISMA

First "tracking array"

Accelerators: SPES, SPIRAL2,.
HI-stable, FAIR

- 1π in operation in 2010 coupled to ancillary detectors
- 4π AGATA ready in 2018

LNL activity report and and future initiatives

From 01.01.2006 to 30.06.2006

- ✓ 2420 h beam delivered to users
  XTU, XTU-ALPI, PIAVE-ALPI, PIAVE+ALPI
- ✓ 360 h machine development
- ✓ 480 h maintenance
- ✓ 190 h failures
- ✓ 24 h safety radiation tests

PIAVE commissioning

Date	Beam	Set-up	Result
Jan 23-27	**5 MeV/A** ^{22}Ne & ^{132}Xe **PIAVE+ALPI** tests	Prisma+Clara	**OK**
Feb 13-16	^{40}Ar, **PIAVE+ALPI** tests	Prisma+Clara	**OK**
Mar 25-26	^{40}Ar **330 MeV PIAVE+ALPI** tests	Garfield	**OK**
Apr 3-9	^{40}Ar **330 MeV PIAVE+ALPI** tests	Prisma+Clara	**OK**

Beam	E [MeV] - (1 foil) with the most probable charge state	Average current on target [pnA] (1 foil)	E [MeV] (2 foils)
^{12}C	251	10	288
^{16}O	303	30	342
^{32}S	461	18	586
^{48}Ca	457	1	648
^{58}Ni	555	5	794
^{65}Cu	543	2	794
^{74}Ge	519	2	838
^{82}Se	559	1	880
^{90}Zr	526	1.5	976
^{104}Ru	612	1	1008

List of other ion species: http://www.lnl.infn.it/%7Essi/Ion_Beams.htm

Available PIAVE-ALPI beams

Dec 05 – Apr 06
Full Beam Tests

Beam	Maximum energy [MeV] (MeV/A)	Beam Current on target [pnA]
$^{22}Ne^{4+}$	147 (6.7)	10
$^{40}Ar^{9+}$	330 (8.25)	4÷10
$^{84}Kr^{15+}$	555 (6.6)	5÷10
$^{132}Xe^{18+}$	675 (5.1)	2

From October 2006 Regular Operation (and more ECR-beam tests)

Improvements needed on PIAVE:
1. Present ECRIS Alice is limited (current and charge state)
2. 5 MHz Buncher/Chopper required

Future plans

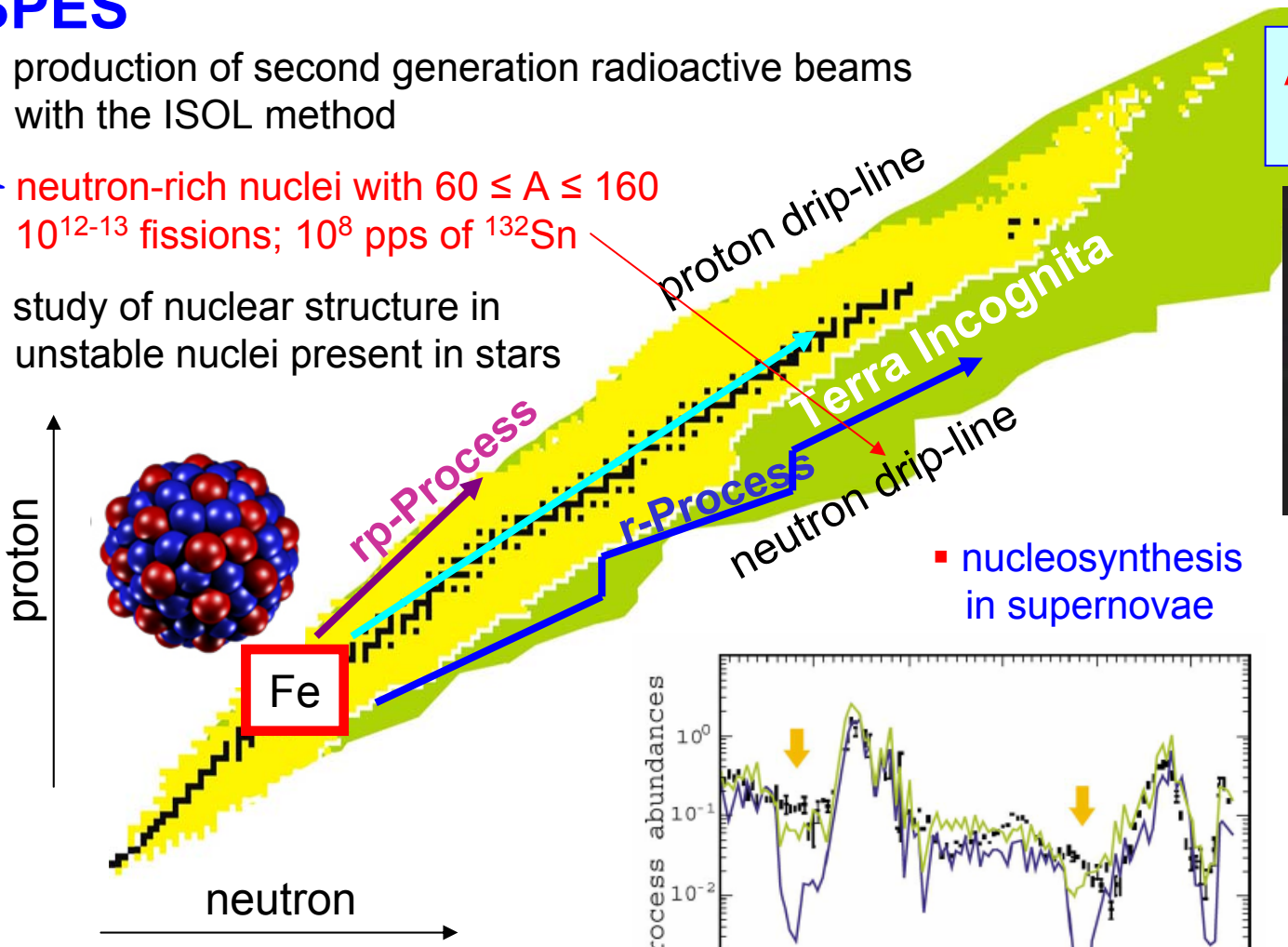
LNL

SPES

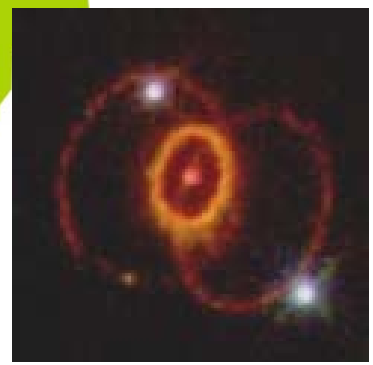
- production of second generation radioactive beams with the ISOL method

- neutron-rich nuclei with $60 \le A \le 160$
  $10^{12\text{-}13}$ fissions; 10^{8} pps of ^{132}Sn

- study of nuclear structure in unstable nuclei present in stars



Astrophysical implications

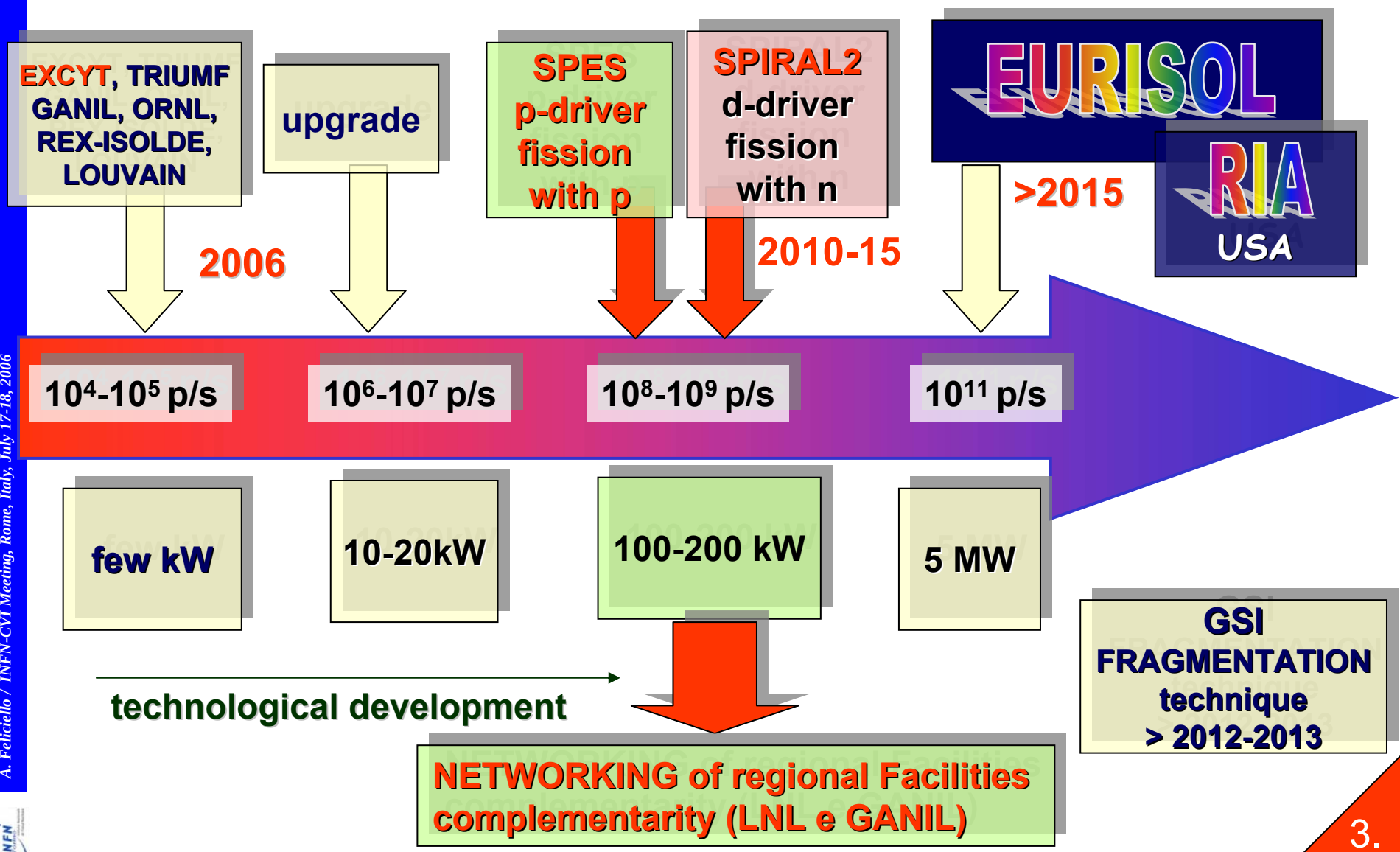


- nucleosynthesis in supernovae

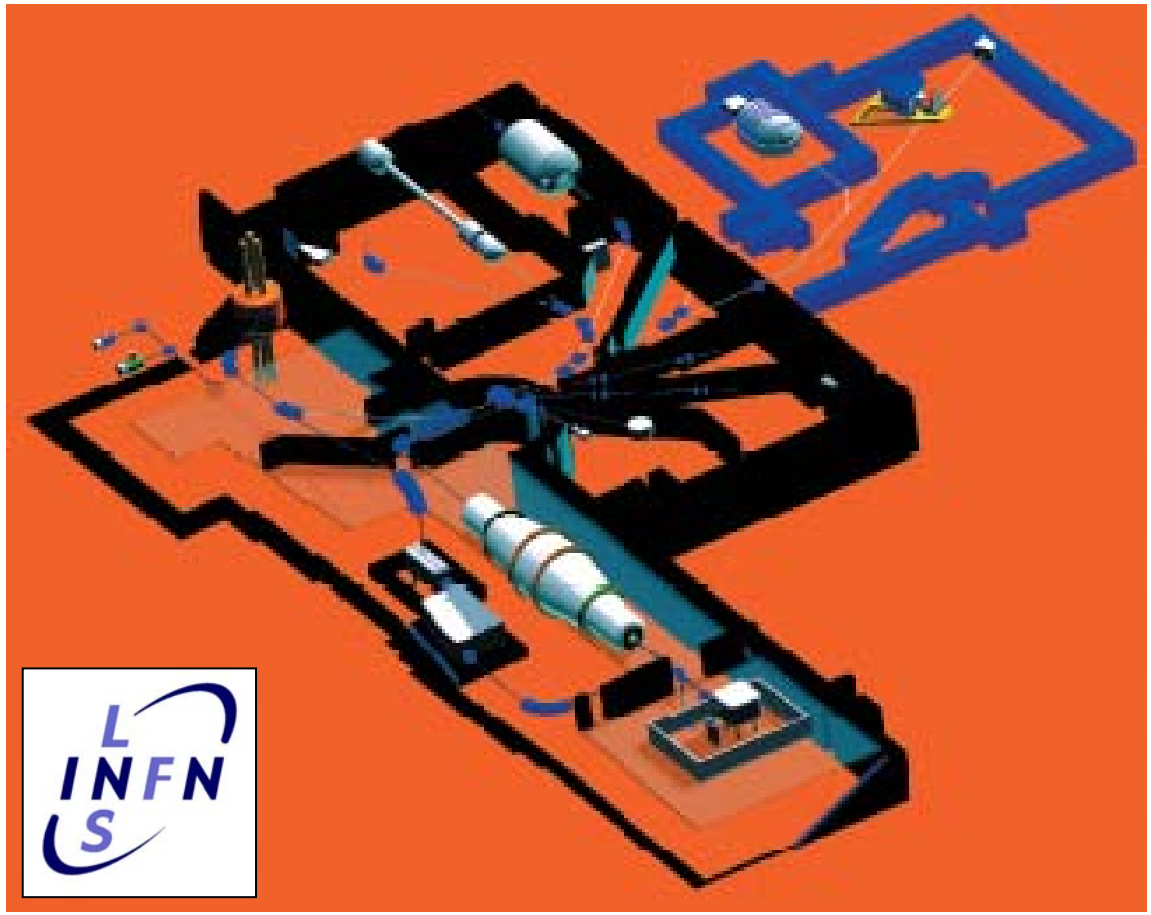
- abundances in r-process
- waiting points nuclei

Facilities for RIB production

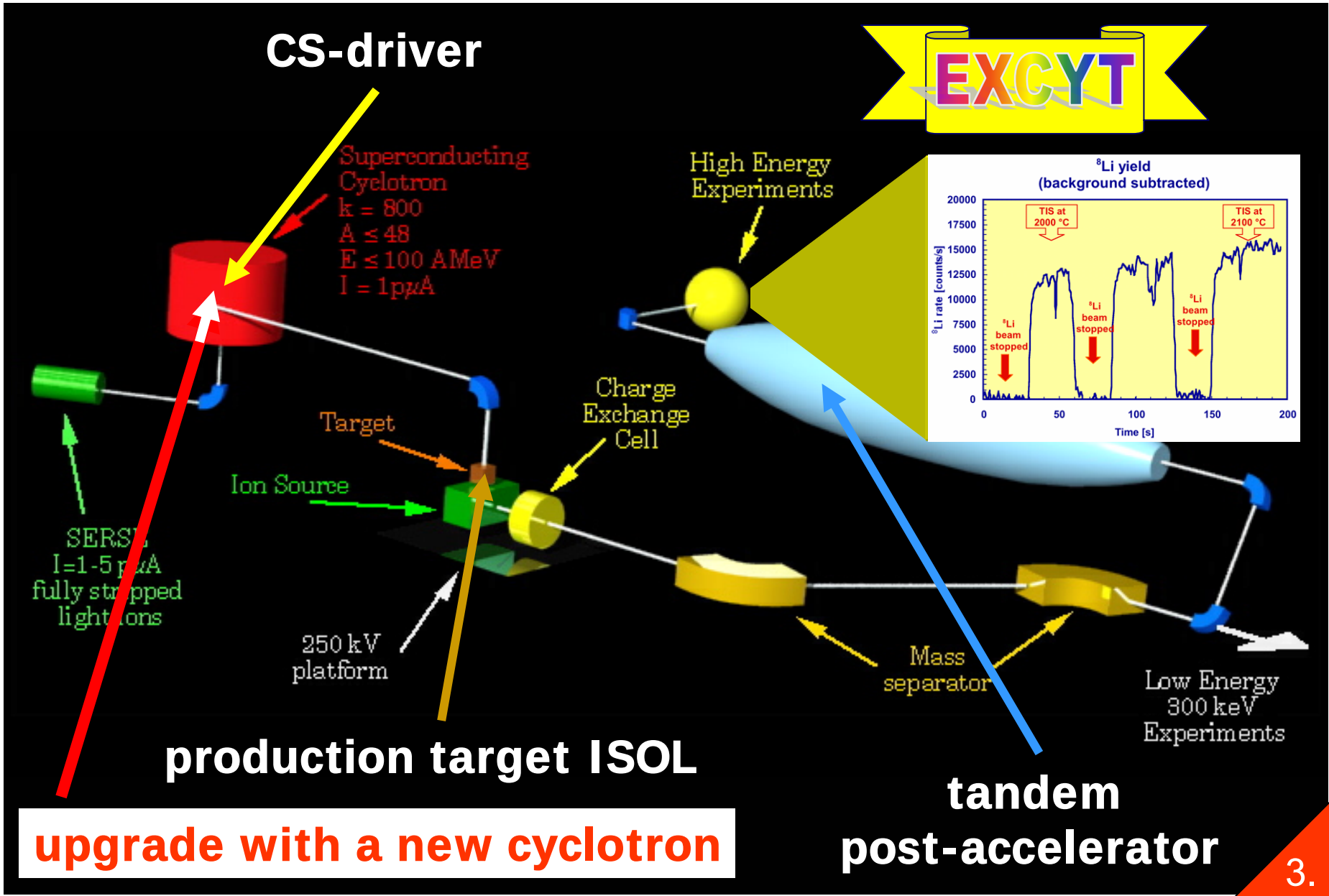
(ISOL method)



LNS activity report and and future initiatives



Future plans



EXCYT status

The commissioning of the facility is in an advanced phase

- ✓ Production of a ^{8}Li+ beam on the ^{12}C target by fragmentation of a 20 watt 45 AMeV ^{13}C beam from the Superconducting Cyclotron
- ✓ Evaluation of the charge exchange efficiency for a ^{7}Li+ beam vs. the source voltage. Transport of the obtained ^{7}Li- beam up to the exit of the Tandem accelerator
- ✓ Production of a ^{8}Li+ beam on the ^{12}C target by fragmentation of a 70 watt 45 AMeV ^{13}C beam. Transport of the obtained beam up to the exit of the Tandem accelerator (5.0 10^{5} pps)
- ✓ R&D to improve beam transmission and beam production: work in progress
- ✓ Beam tests to increase the extracted beam (^{13}C) intensity from the Cyclotron (100 → 200 watt): work in progress

a CEC efficiency between 2.2% and 2.5% has been obtained

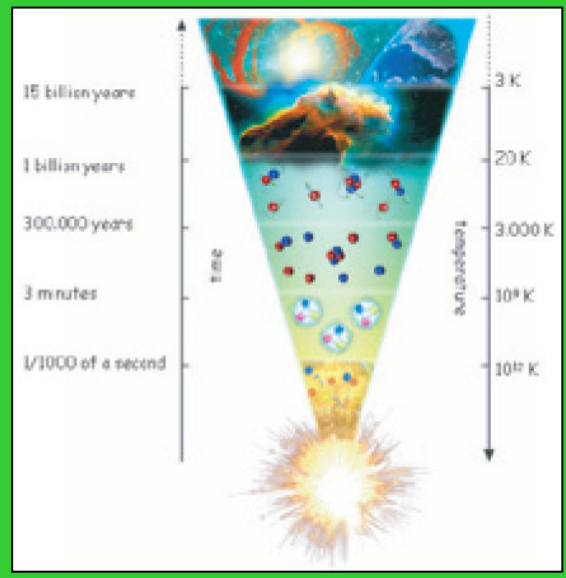
Next step:

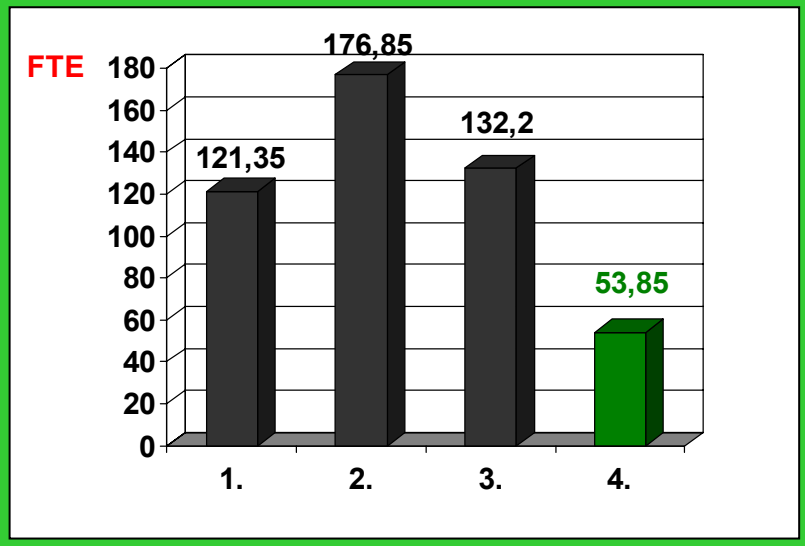
to perform in 2006 all the experiments already approved by the PAC with ^{8}Li and ^{9}Li beams

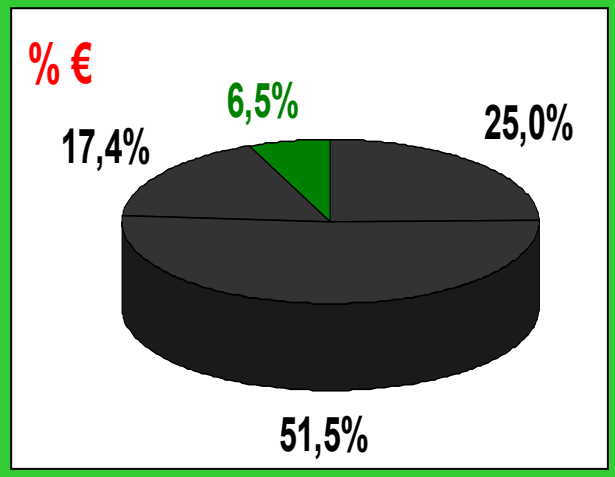
(960 hours for 4 experiments: BIGBANG, RCS, RSM, MAGNEX-RIB)

4. Nuclear astrophysics and interdisciplinary researches

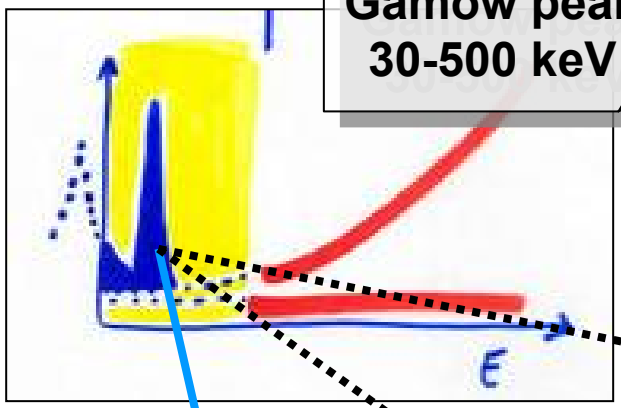
experiments
- running: 5
- in preparation: 1







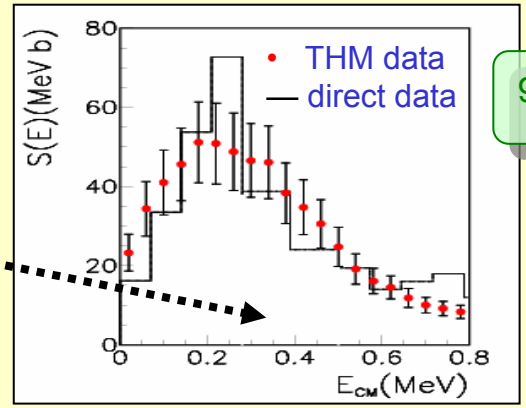
Nuclei in the Universe



indirect

ASFIN2

INFN LNS

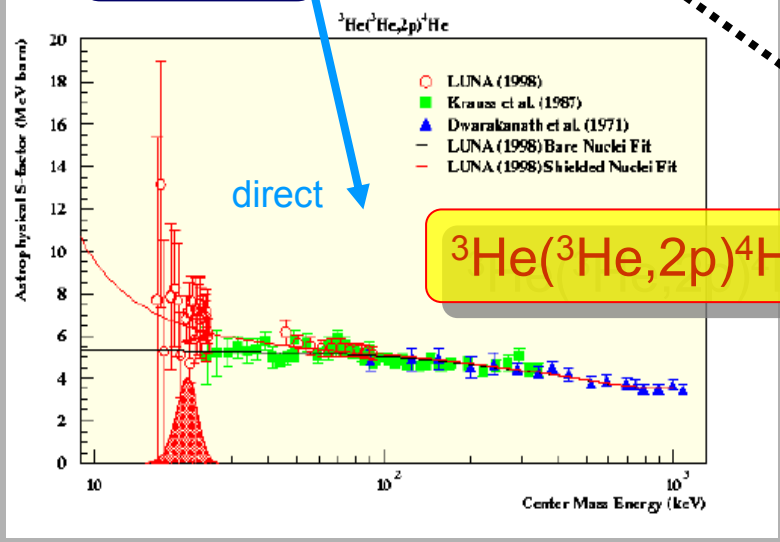


$^{9}Be(p,\alpha)^{6}Li$

TH indirect method
(3-body reaction)

LUNA

LNGS



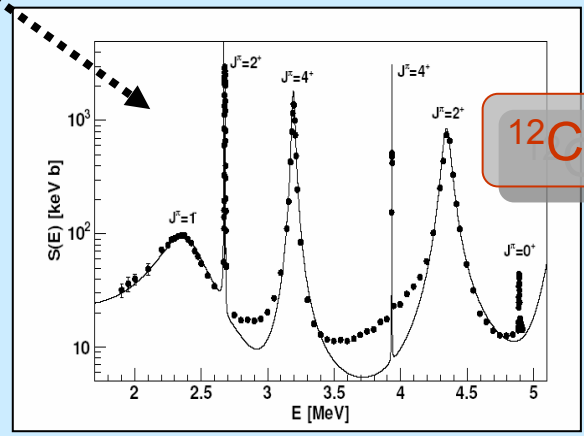
direct

$^{3}He(^{3}He,2p)^{4}He$

σ_{min} = 20 fb, with 2 events/months

indirect

ERNA



$^{12}C(\alpha,\gamma)^{16}O$

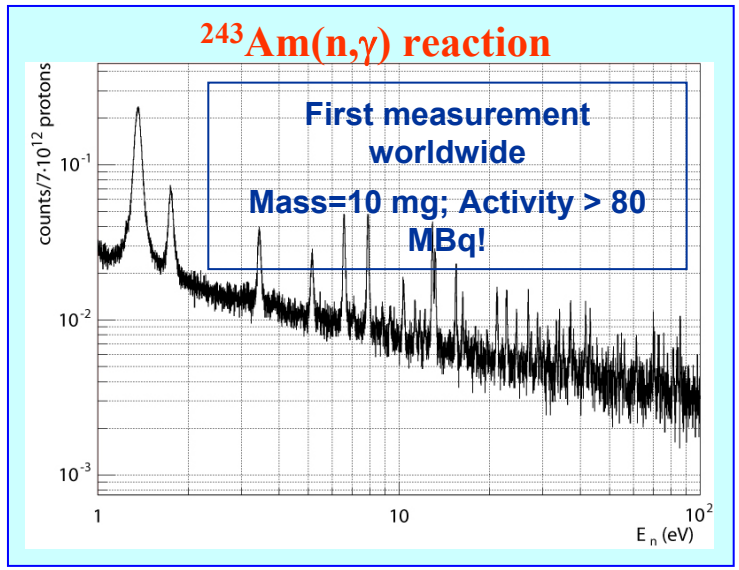
inverse kinematics

Applied nuclear physics

measure in actinides with long lifetimes

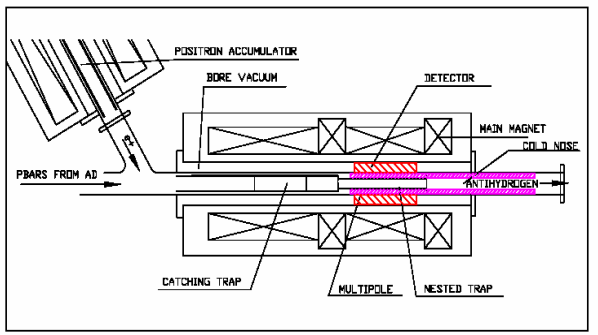
Experimental Program 2006-2010:

- measurements on Mo, Ru,. Pd, Fe, Ni, Zn, Se (Stellar Nucleosynthesis and ADS);
- neutron capture cross section on radioactive isotopes of U, Pa, Am and Cm (useful for energy energy production and radioactive waste incineration).

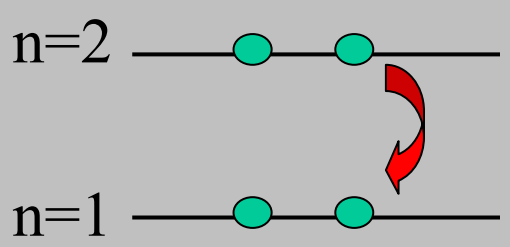


Fundamental physics

R&D for cooling of anti-hydrogen and spectroscopy at AD



Test of the Pauli principle validity



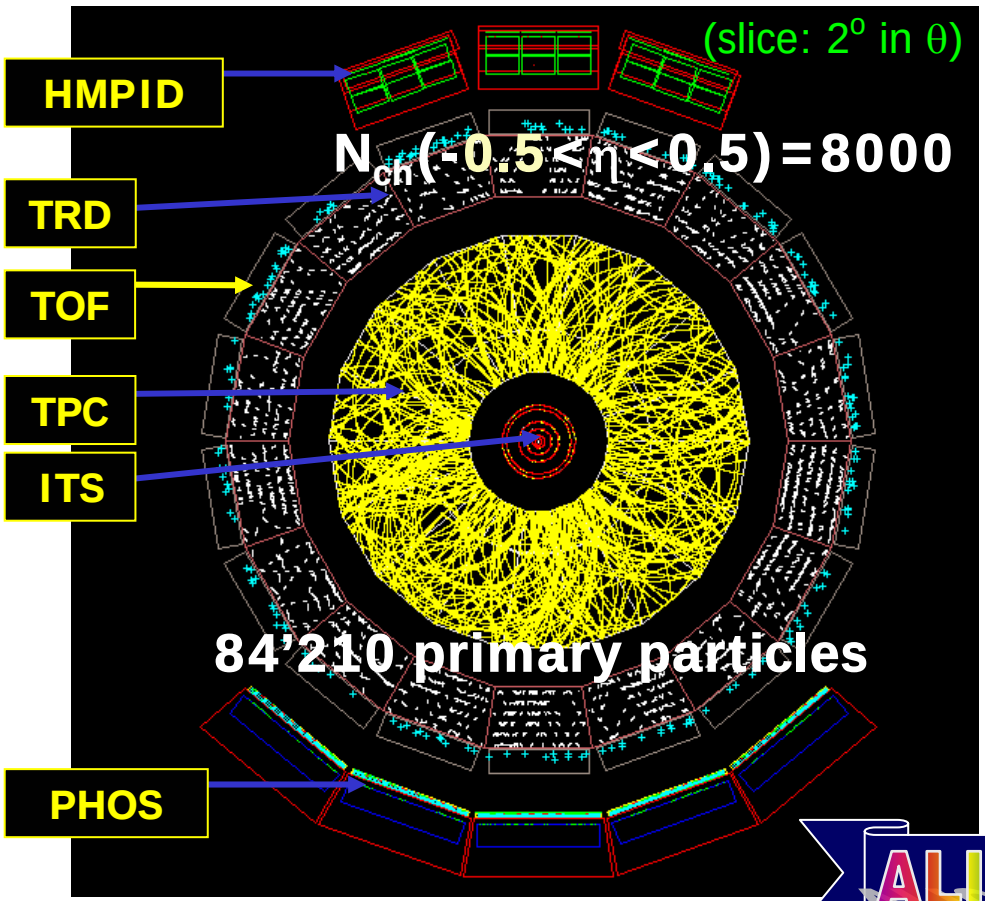
atomic transition in Cu

$\beta^2/2 \leq 6 \times 10^{-31}$

(the transition energy is different than the nominal energy)

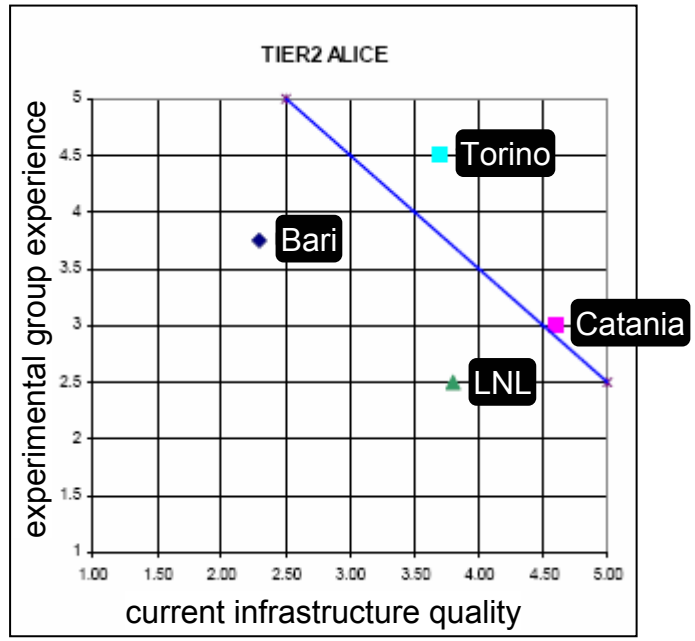
GRID

modern experiments need
modern infrastructures: GRID



recent achievements:

- ✓ significative progress in distributed computing model developing and testing
- ✓ satisfactory results of the LCG service challenge 3
- ✓ continuous activity on simulation and analysis
- ✓ first 2 TIER2 approved at CT and TO



Summary

- Short term plans:
  - (successful) completion of: approved experiments
    R&D projects → upgrades

- Mid/Long term plans:
  - AGATA: detector R&D → nuclear structure
  - PANDA: detector R&D → antiproton physics + strangeness physics
  - PAX: machine dev. → direct transversity

- National Laboratories activities:
  - LNF ↔ DANAE: high $\mathscr{L}$ + adj. c.m. energy → nucleon f.f. + DBKS
  - LNL ↔ SPES: RIB (A > 60) → nuclear structure
  - LNS ↔ EXCYT: RIB (A < 60) → nuclear astrophysics + EOS
  - LNGS ↔ LUNA: new accelerator → nuclear astrophysics