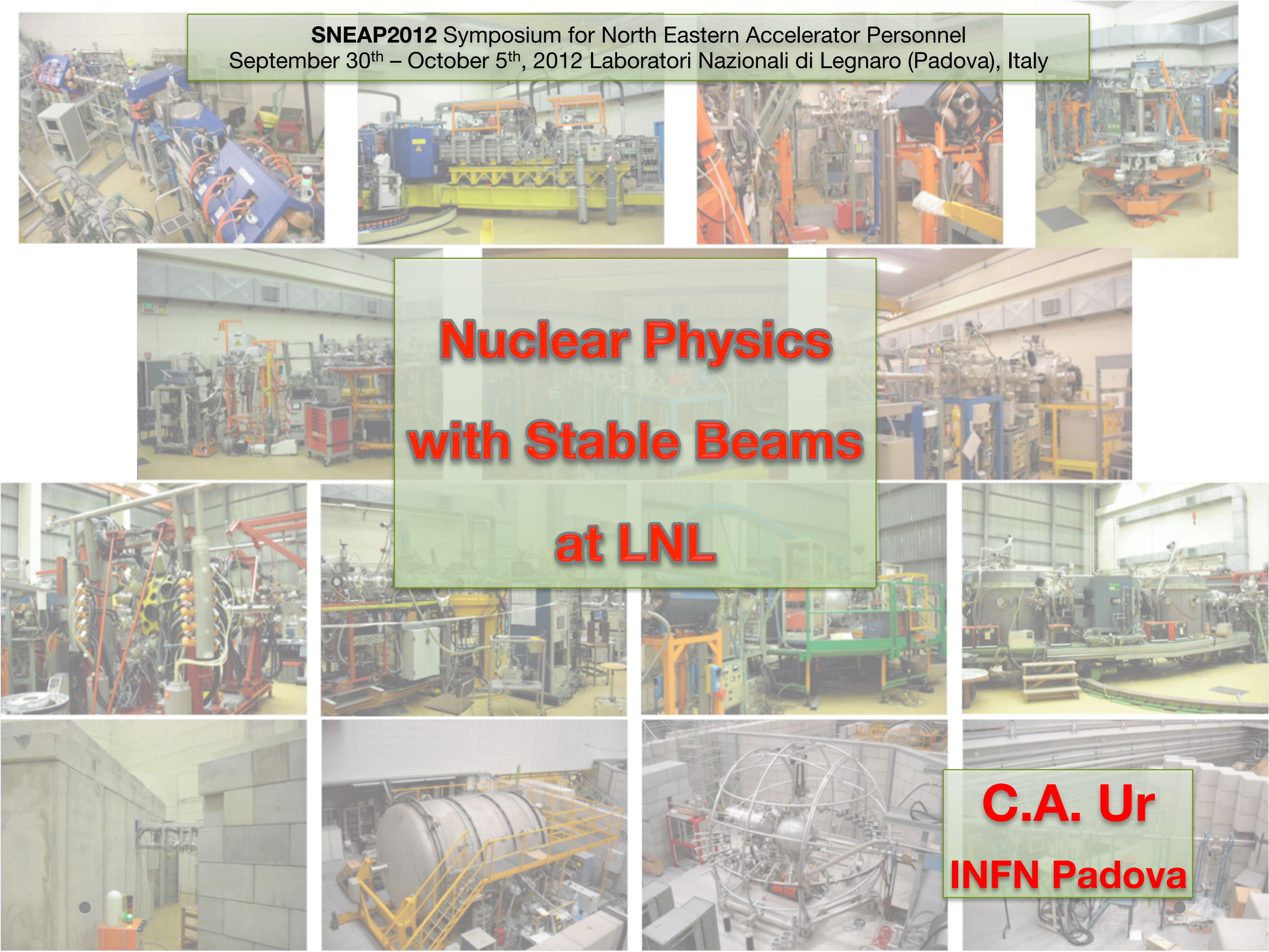
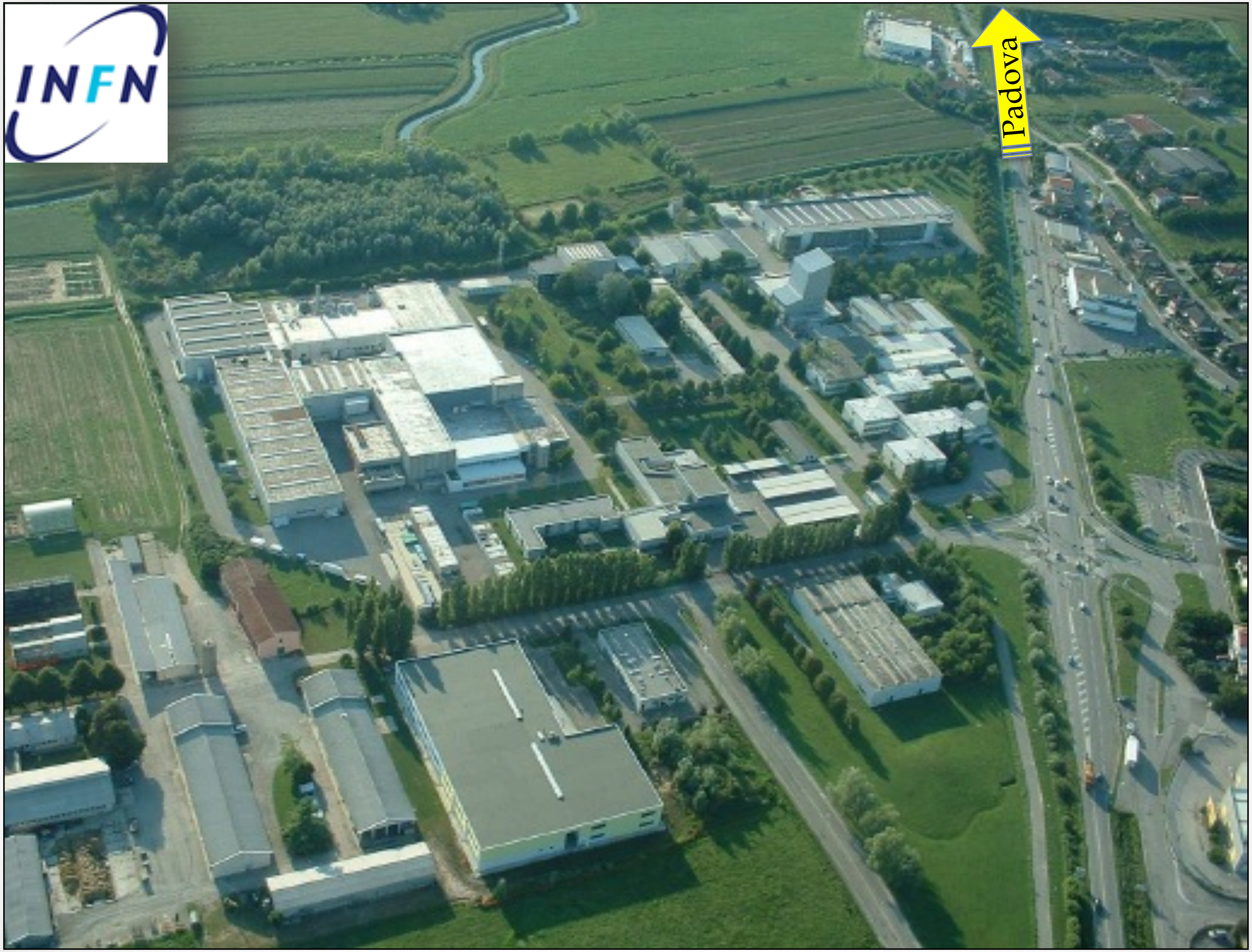
SNEAP2012 Symposium for North Eastern Accelerator Personnel
September 30th – October 5th, 2012 Laboratori Nazionali di Legnaro (Padova), Italy



Nuclear Physics with Stable Beams at LNL

C.A. Ur
INFN Padova

LABORATORI NAZIONALI DI LEGNARO



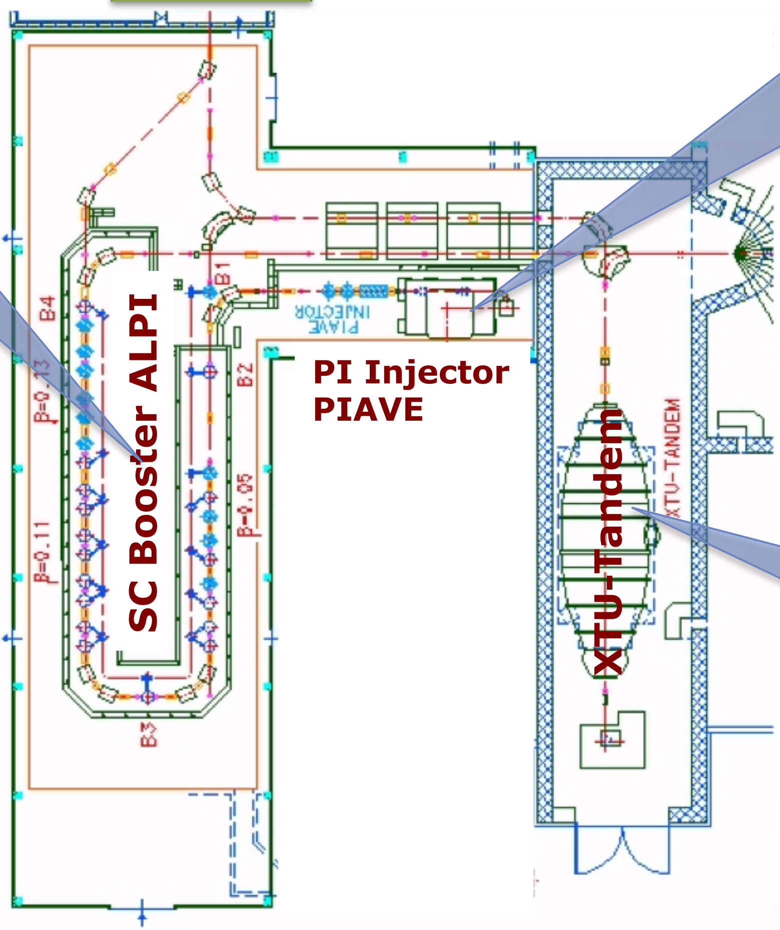
Laboratori Nazionali di Legnaro

THE TANDEM–ALPI–PIAVE COMPLEX

PIAVE HI Injector
LEGIS ECR source

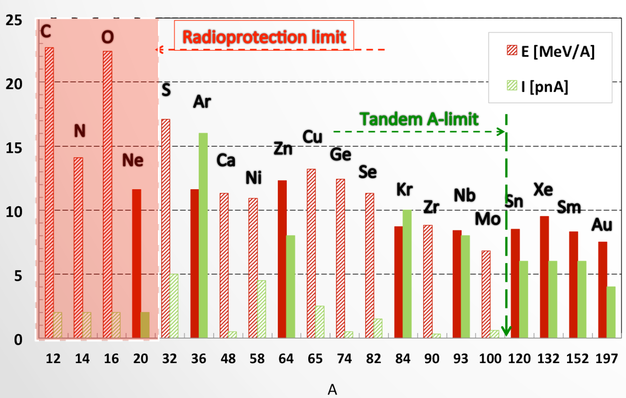
ALPI SC Booster
45÷52 MVeq
^{12}C – ^{208}Pb

Exp. Hall III

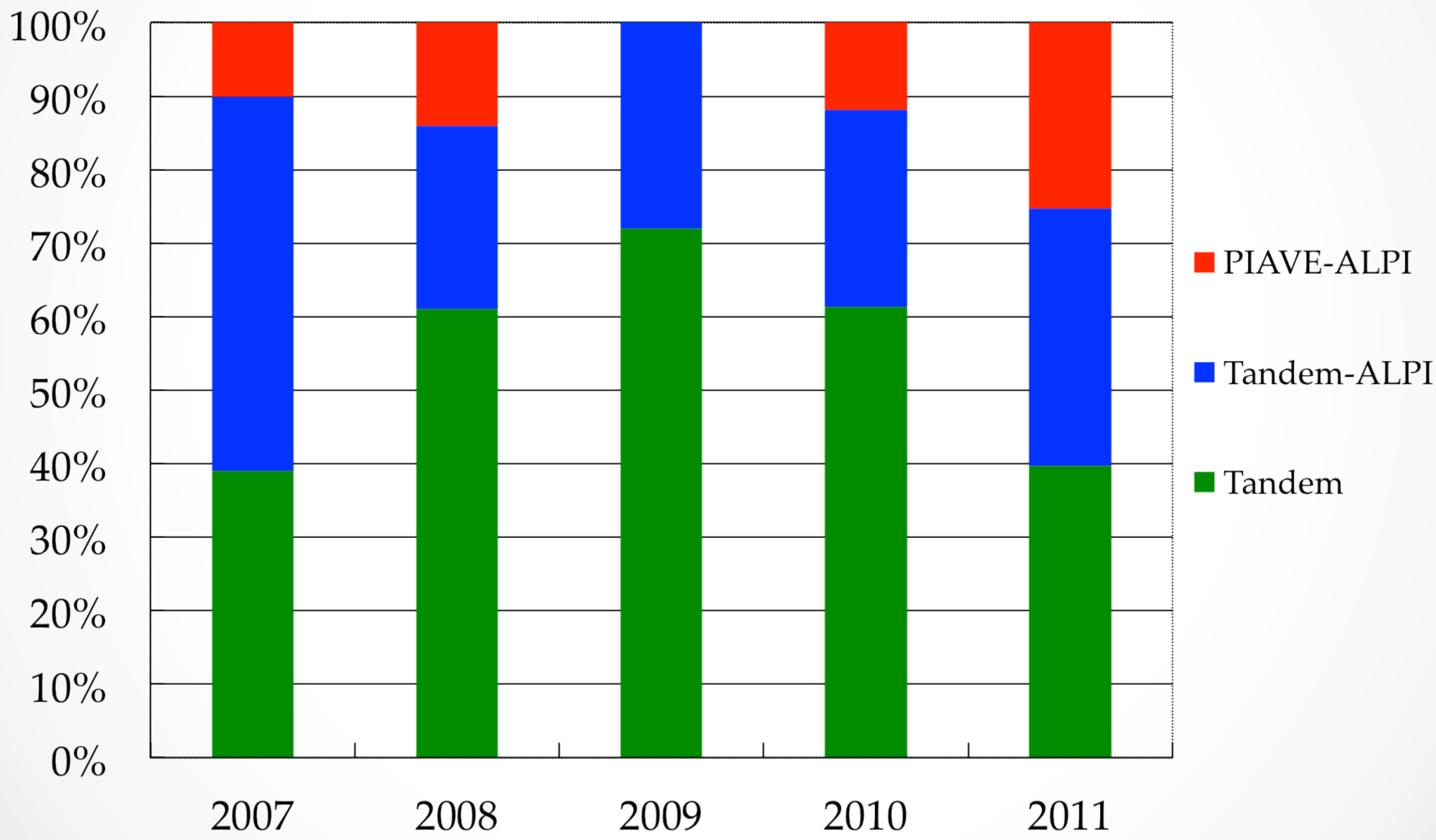


Exp. Halls I & II

Tandem XTU 15 MV
Van de Graaff
^{1}H – ^{197}Au



TAP Beam Time Share



Experimental Halls

Hall I – 7 beam lines with 8 experimental setups

Hall II – 4 beam lines with 5 experimental setups

Hall III – 1 beam line with 3 experimental setups

10 experimental setups – nuclear physics

5 experimental setups – interdisciplinary and applied physics

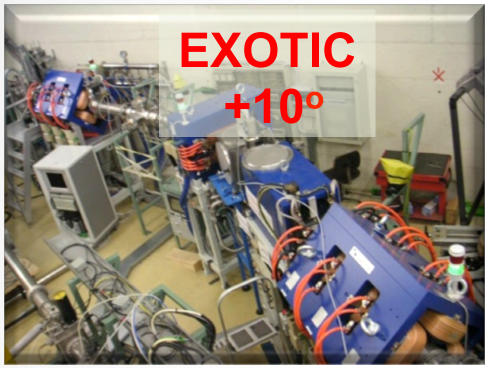
1 experimental setup – general purpose

EXPERIMENTAL HALL I

7 beam lines with 8 experimental setups

Experimental Hall I

3 experimental setups for nuclear physics research



Reaction Mechanism Studies

Reaction Mechanism Studies

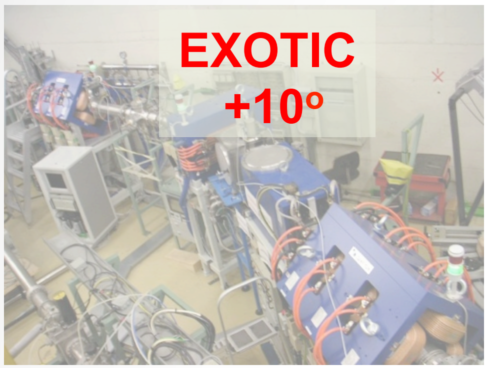
Nuclear Structure

Nuclear Structure

g–factors & Q moments

EXPERIMENTAL HALL I

4 experimental setups dedicated to interdisciplinary and applied physics research



Nanostructuring of superconductors, by means of swift heavy–ion beams

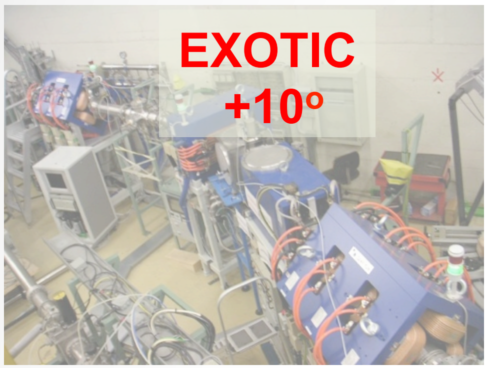
Track-Nanodosimetry of Light Ions

Heavy-Ion Broad-beam In-Air Irradiation Facility for Radiobiology Studies

Studies of radiation effects in detectors, electronic devices and systems for Space and High Energy Physics Applications

EXPERIMENTAL HALL I

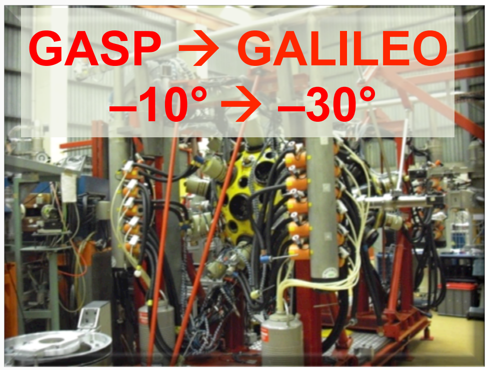
1 general purpose experimental setup



General Purpose

EXPERIMENTAL HALL II

4 experimental setups for nuclear physics research



Nuclear Structure

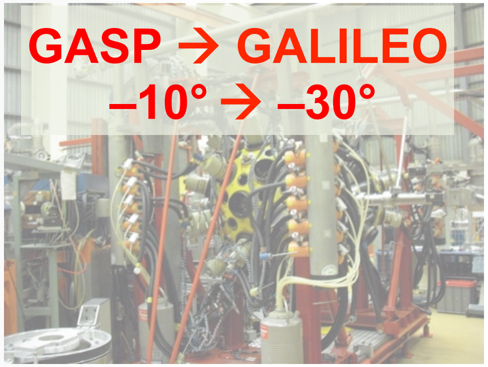
Reaction Mechanism Studies

Nuclear Structure

Reaction Mechanism Studies

EXPERIMENTAL HALL II

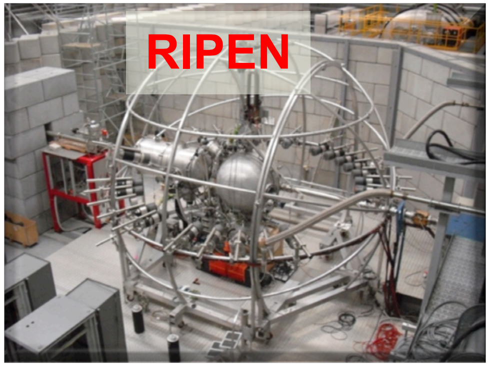
1 experimental setup for interdisciplinary physics research



Interdisciplinary Physics

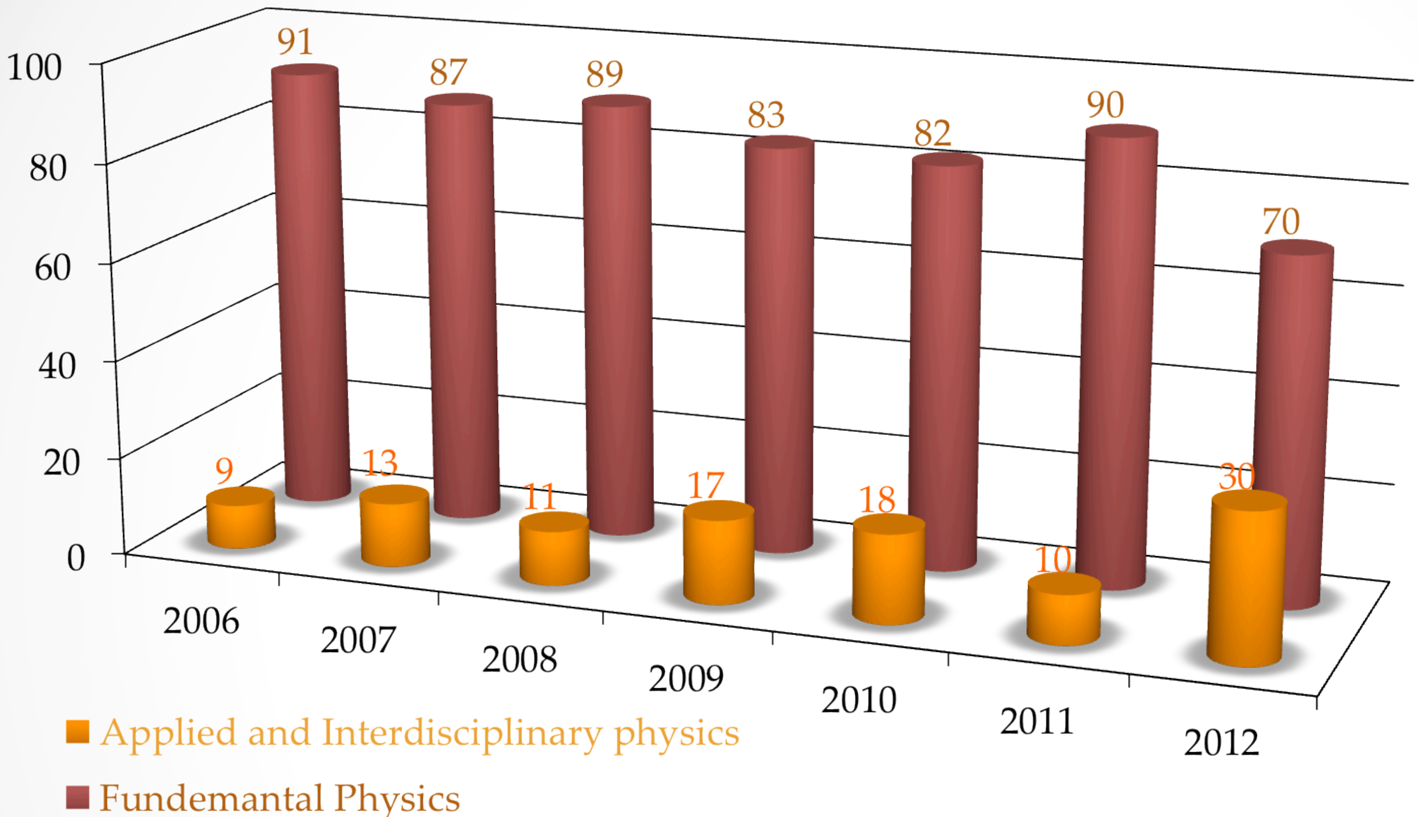
EXPERIMENTAL HALL III

3 experimental setups for nuclear physics research



Reaction Mechanism Studies

TAP Beam Time Assignment

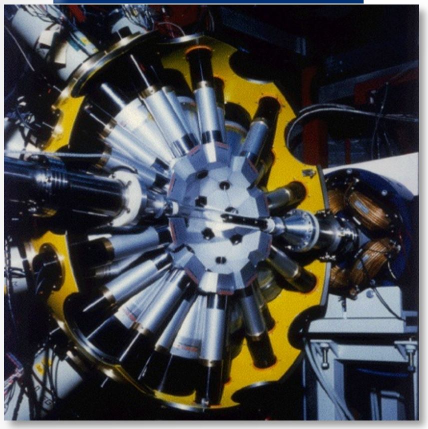


LNL
- open access laboratory
- Large Scale Facility of EC

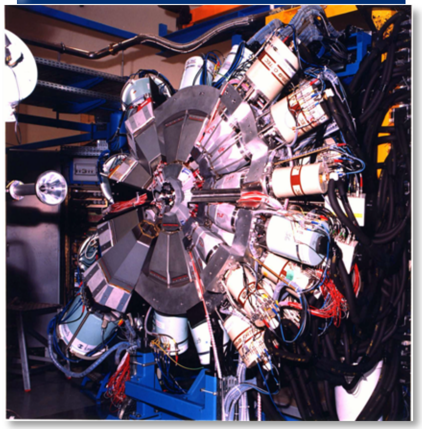
- PAC – Program Advisory Committee (7)
  evaluates nuclear physics experiment proposals
- USIP – User Selection for Applied and Interdisciplinary Physics (5)
  evaluates application & interdisciplinary experiment proposals

NUCLEAR STRUCTURE RESEARCH

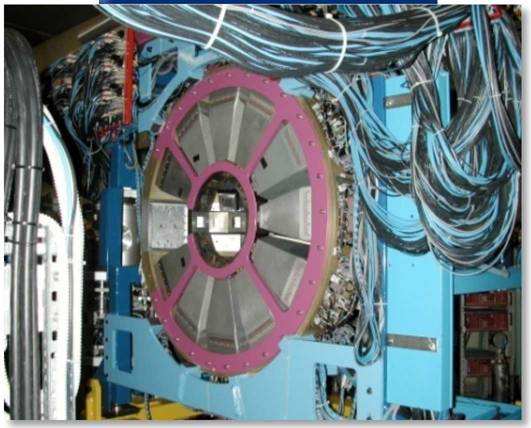
GASP 1992



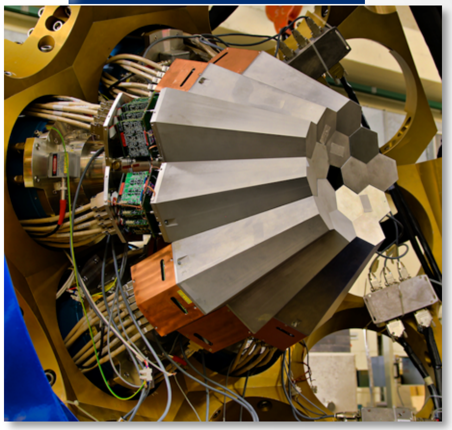
EUROBALL 1998



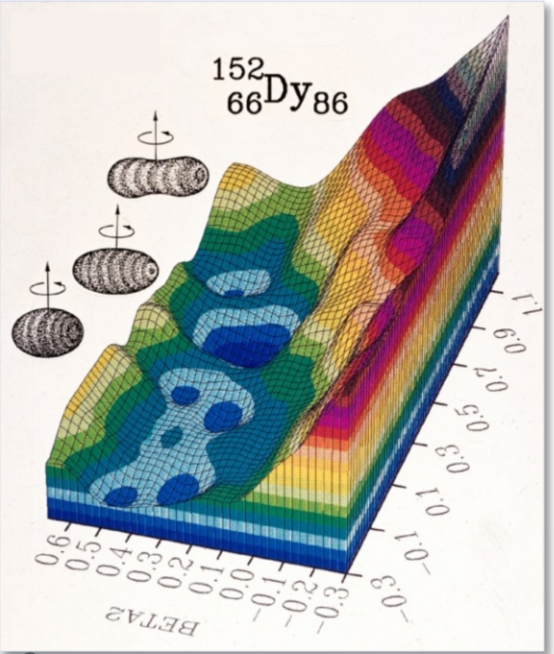
CLARA 2008



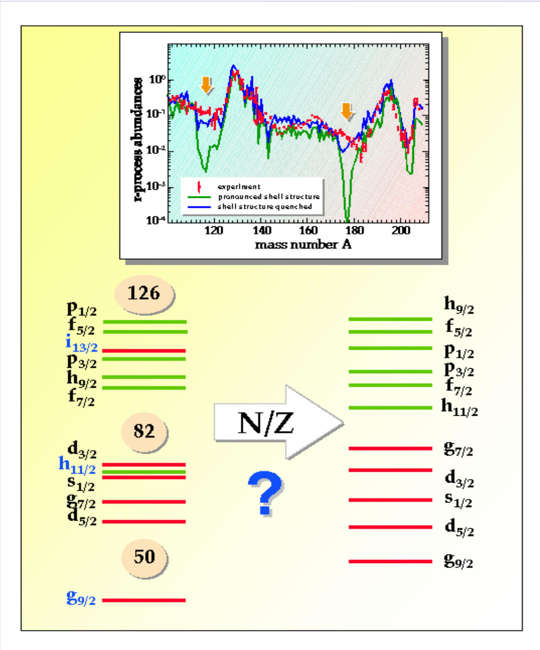
AGATA 2010



Gamma–ray (and particle) spectroscopy

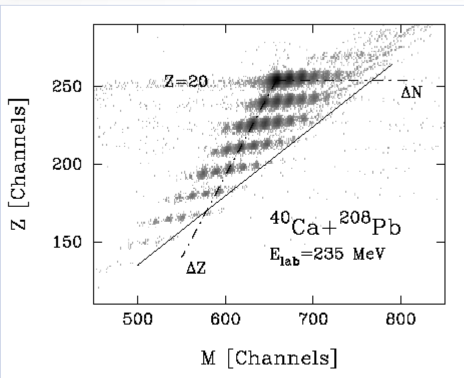


- High spin states
- Collectivity and shell model
- Isospin symmetries
- Isospin mixing in N=Z nuclei
- Spectroscopy at the dripline
- Shell stability and evolution in neutron rich nuclei
- Symmetries at the critical point
- Rotational damping



Reaction Dynamics Research

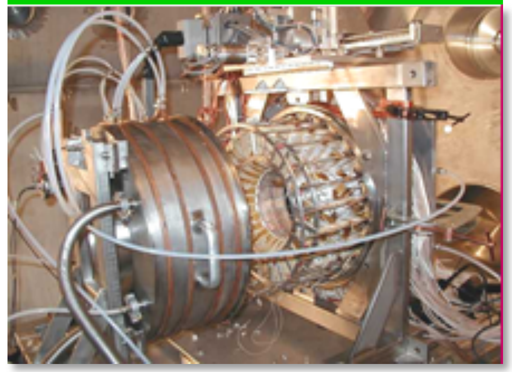
PRISMA and PISOLO

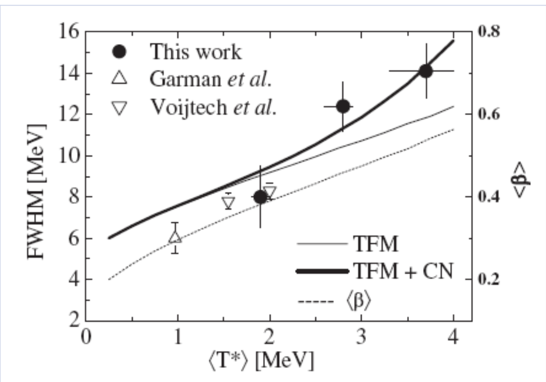


Mass spectrometers

- Multinucleon transfer
- Nuclear superfluidity (pair transfer)
- Near and sub-barrier fusion

GARFIELD and 8πLP

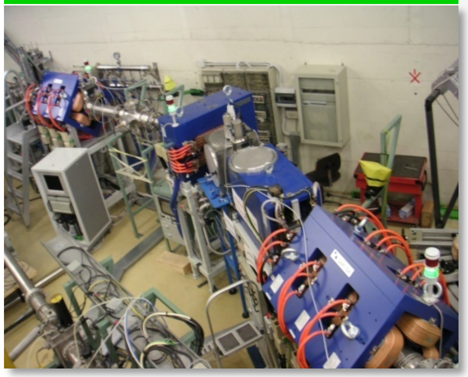


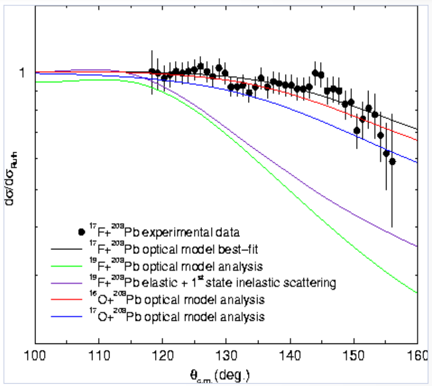


Large charged particle det.

- Multifragmentation at low excitation energies
- Nuclear level density
- Collective modes of excitations

EXOTIC





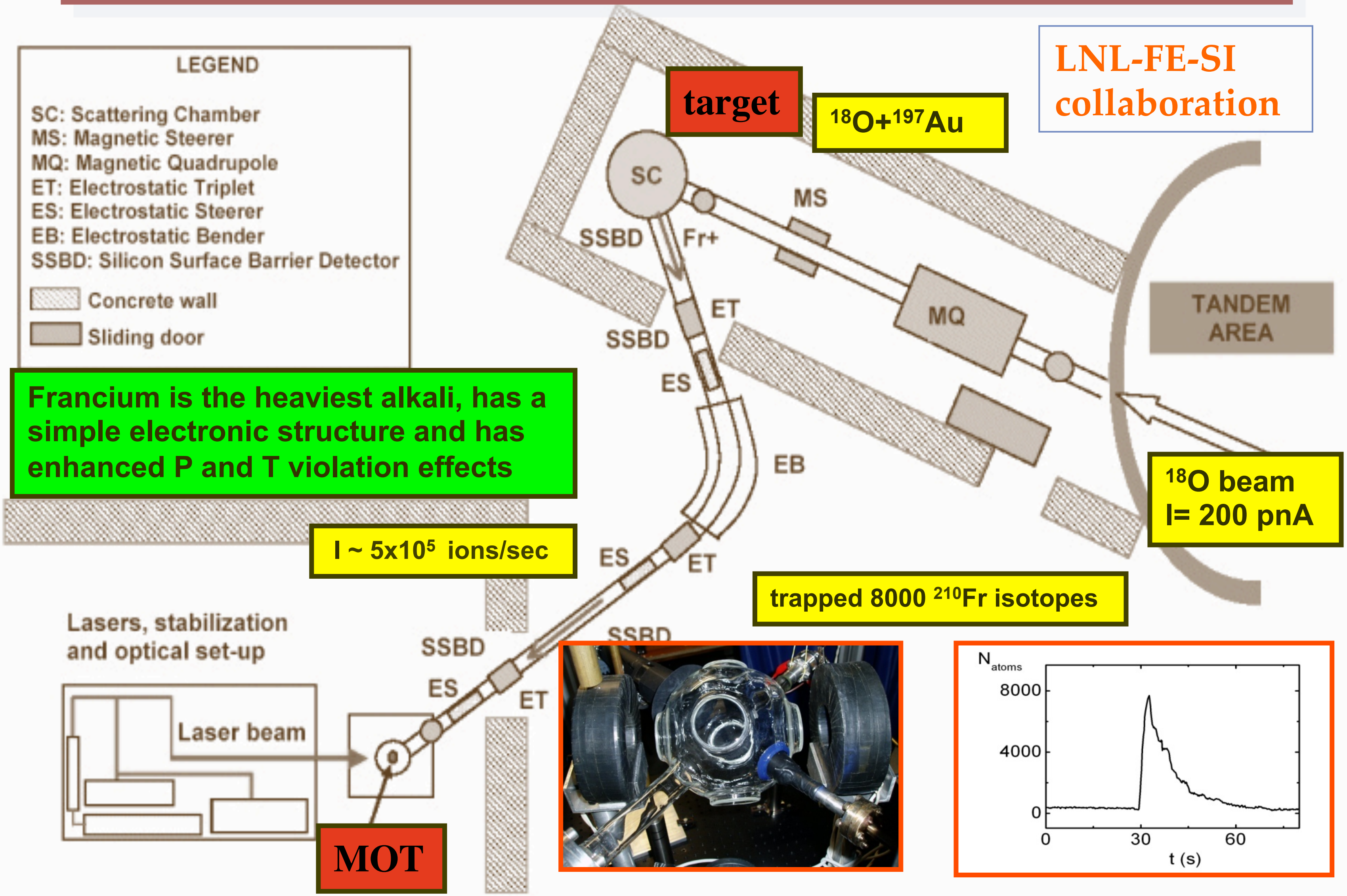
Secondary beam

- Break up processes
- Quasi elastic scattering with exotic light ions produced in secondary reactions

FUNDAMENTAL INTERACTION STUDIES

the TRAPRAD experiment : production and trapping of Fr isotopes

LNL-FE-SI collaboration



$^{18}O+^{197}Au$

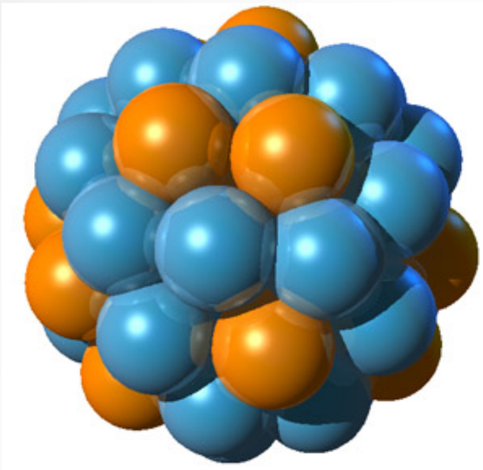
^{18}O beam
I= 200 pnA

Francium is the heaviest alkali, has a simple electronic structure and has enhanced P and T violation effects

I ~ $5x10^5$ ions/sec

trapped 8000 ^{210}Fr isotopes

STRUCTURE OF THE ATOMIC NUCLEUS

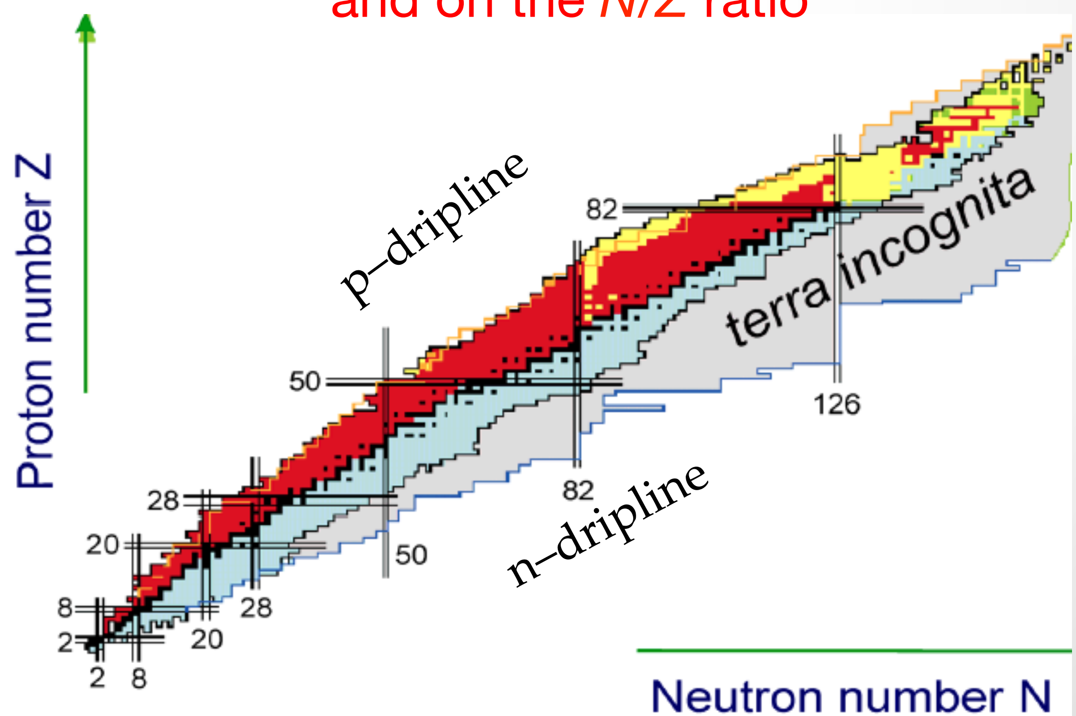


Nuclear Structure → understand how the *Z* protons and *N* neutrons arrange themselves in a bound system and how they react to external fields

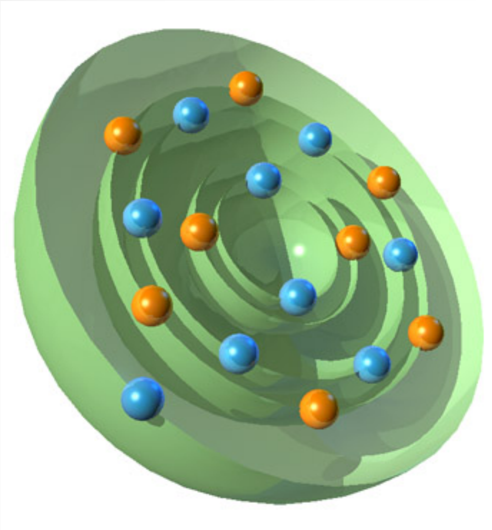
Z and *N* vary over a broad range → different features are expected depending on the mass number and on the *N/Z* ratio

What is the effective NN interaction?

What are the limits of existence for bound nuclei (driplines)?



THE SHELL MODEL



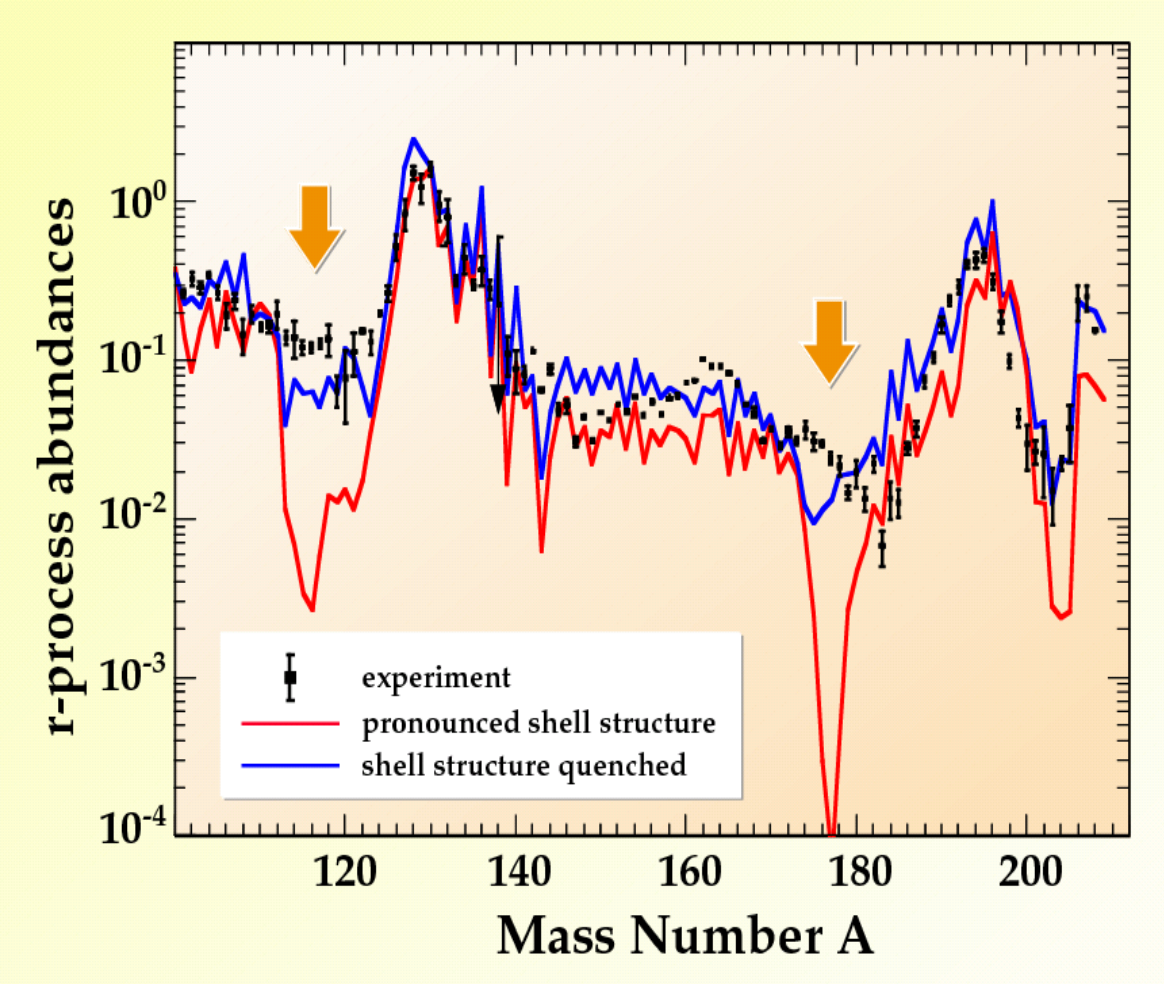
There is a "surprising" analogy between the description of bound electrons in atoms and bound nucleons in atomic nuclei.

Nuclear Shell Model
(M.Mayer et al, 1948-49)

This model is a highly successful one, but the prediction capabilities are somewhat limited when going to nuclei far from stability

Need to "tune" the model parameters collecting information on such nuclei!

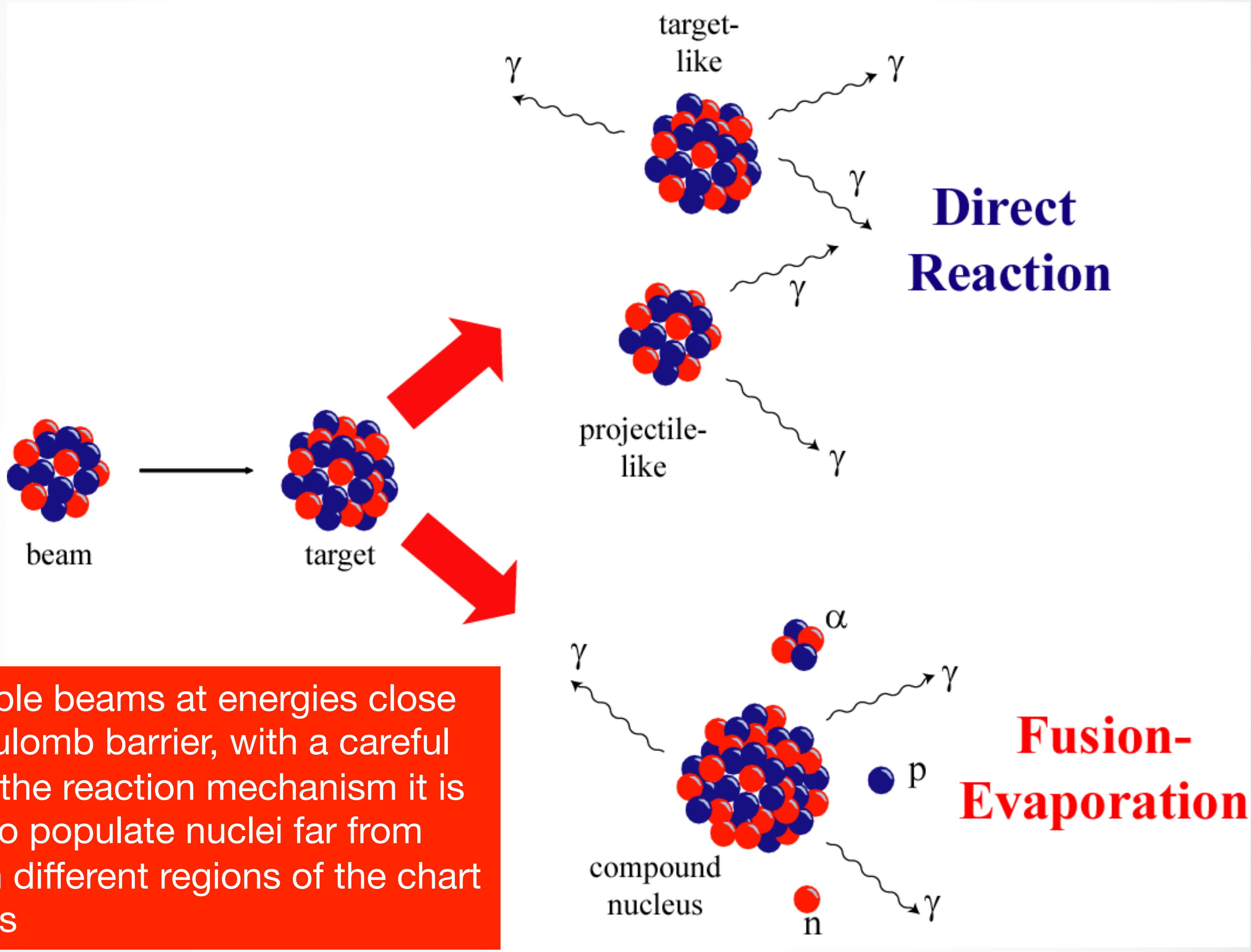
ASTROPHYSICAL CONSIDERATIONS



B.Pfeiffer et al., ZP A357 (1997) 235

The calculated abundances of heavy elements depend critically on the properties of rare n-rich isotopes involved in the r-process of nucleosynthesis

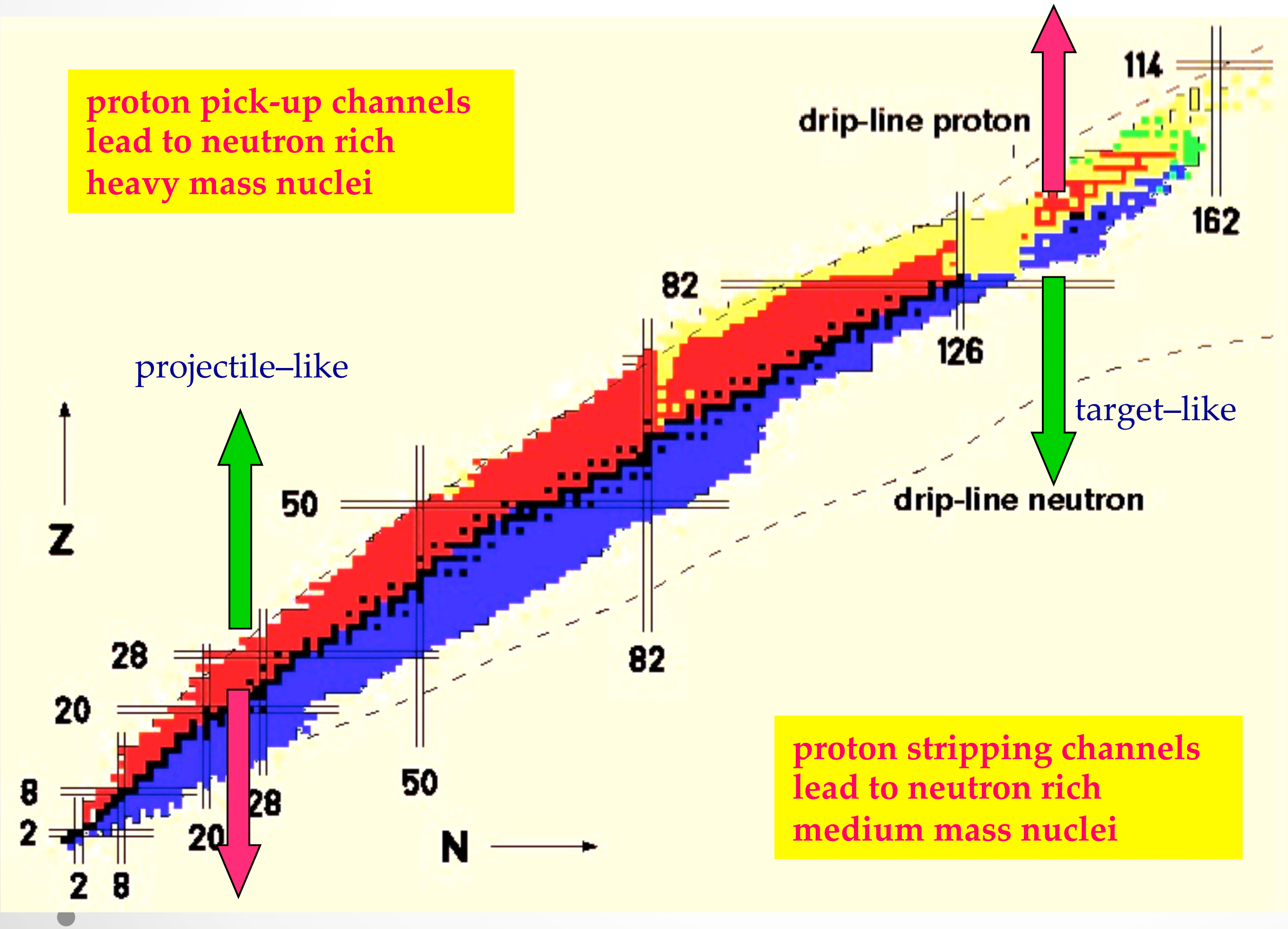
PRODUCING NUCLEI FAR FROM STABILITY

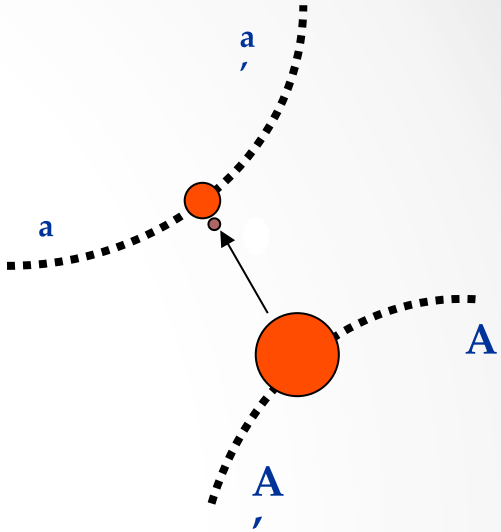


Using stable beams at energies close to the Coulomb barrier, with a careful choice of the reaction mechanism it is possible to populate nuclei far from stability in different regions of the chart of nuclides

GRAZING REACTIONS

Multi–nucleon transfer reactions and deep inelastic reactions are powerful tool for producing n–rich nuclei with stable beams



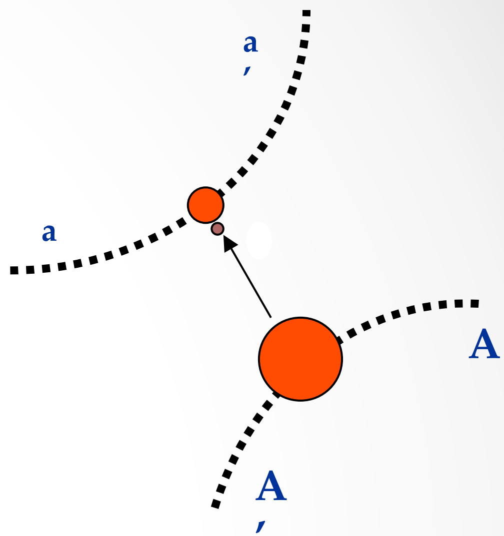


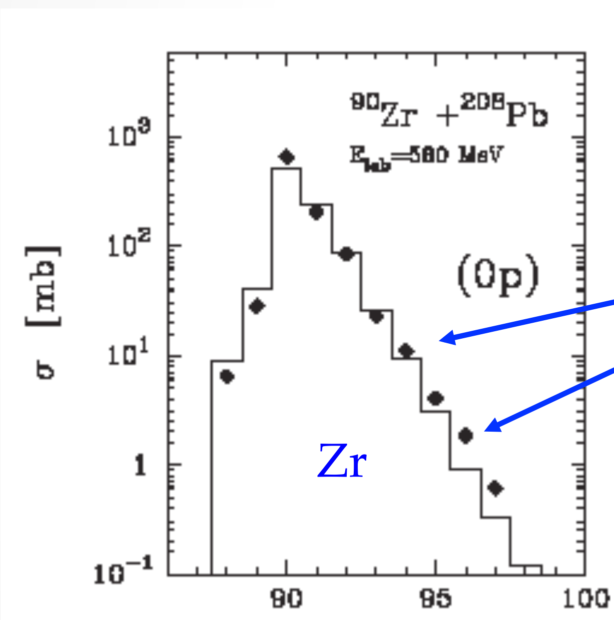
Sensitive to degrees of freedom

- single particle states
- surface vibrations
- pair transfer

GRAZING REACTIONS

Multi–nucleon transfer reactions and deep inelastic reactions are powerful means for producing n–rich nuclei with stable beams





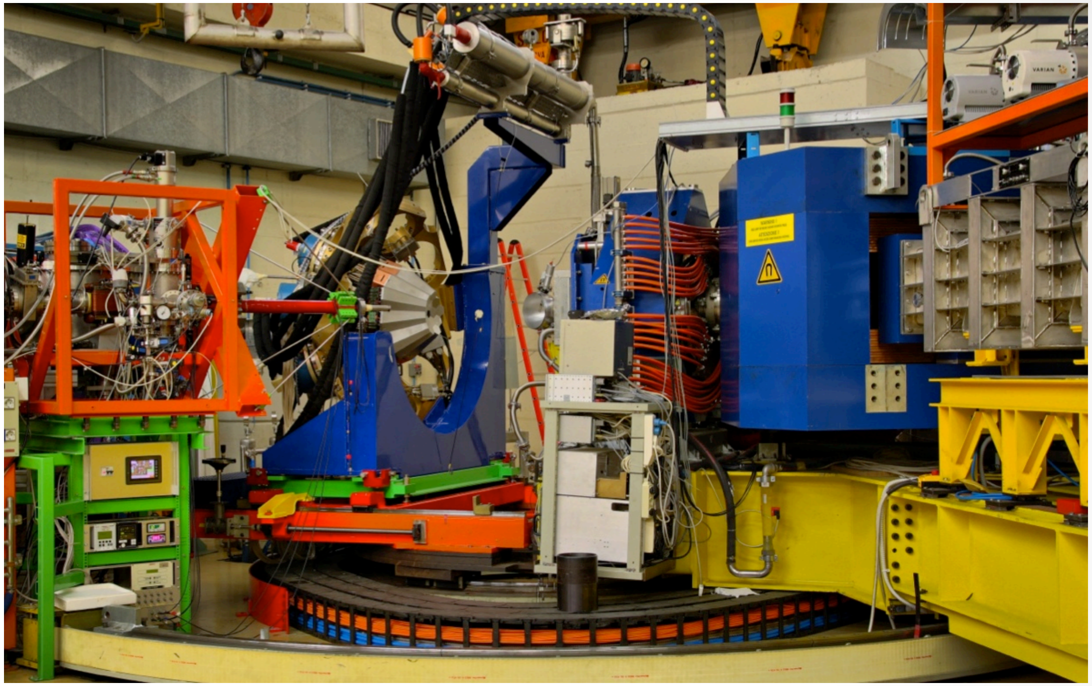
Cross section drops by roughly two orders of magnitude increasing by two the number of transferred neutrons

more neutron rich nuclei

→ need of highly efficient detection devices

LNL – powerful combination of a large acceptance mass spectrometer PRISMA and state–of–the–art gamma–ray spectrometer AGATA

Grazing Reactions



5 asymmetric triple-clusters
36-fold segmented crystals
555 digital-channels
Eff. 3 – 8 % @ M_γ = 1
Eff. 2 – 4 % @ M_γ = 30
Full EDAQ with on line PSA and γ-ray tracking
First installation site: **LNL**

AGATA: array of position sensitive segmented Ge detectors

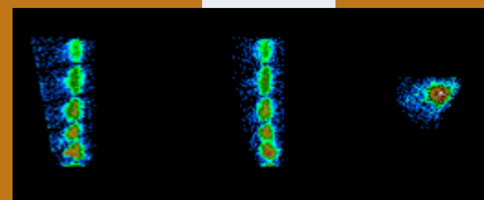
Main issue is Doppler correction capability
→ coupling to beam and recoil tracking devices

PRISMA: large acceptance magnetic spectrometer providing event–by–event Z, A identification as well as velocity for the ions entering the device

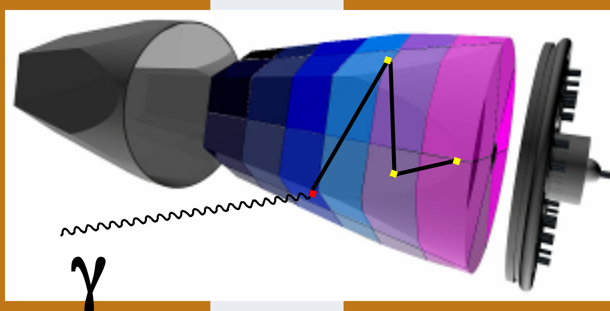
THE AGATA ARRAY

Identified interaction points

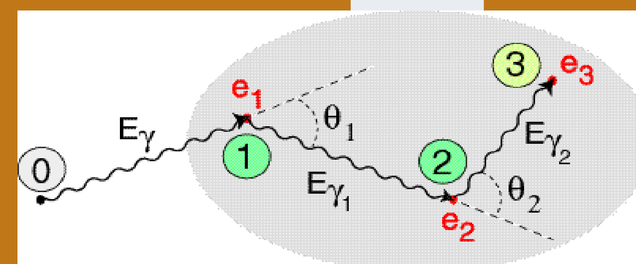
$(x,y,z,E)_i$



Highly segmented HPGe detectors

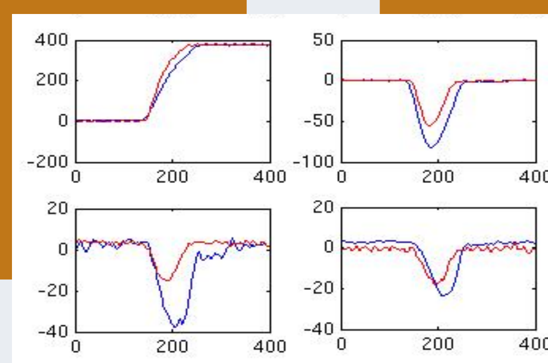


Reconstruction of scattering sequence from Compton vertices



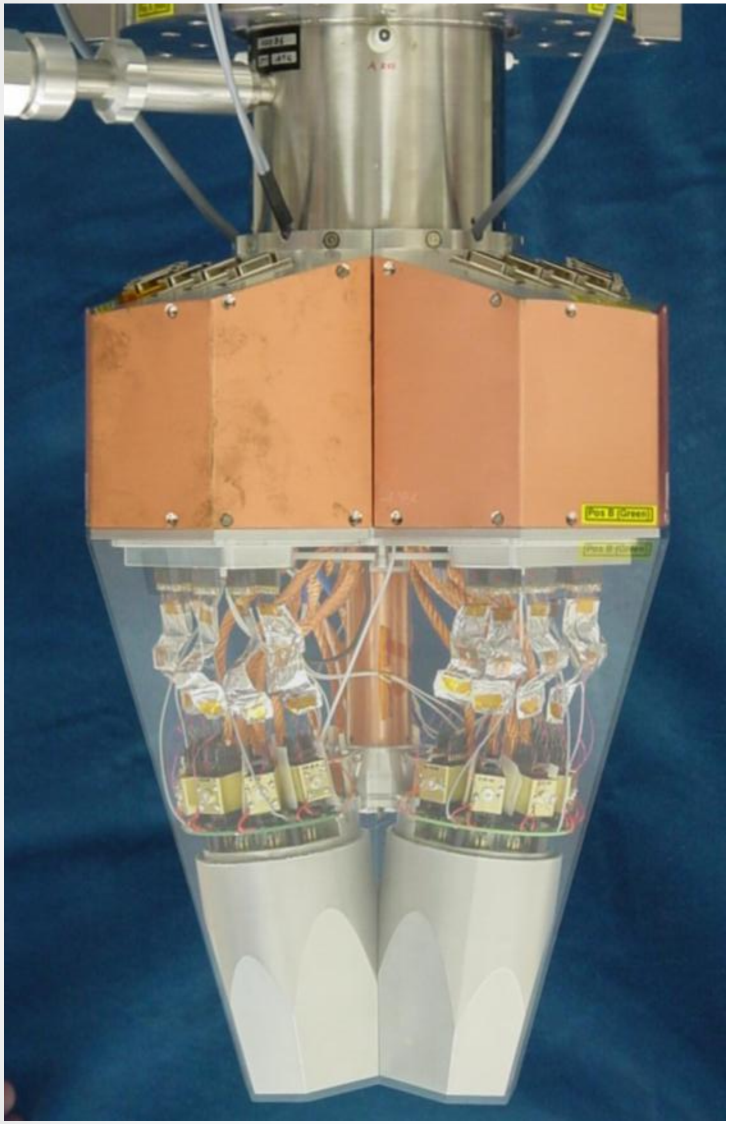
Pulse Shape Analysis to decompose recorded waves

Digital electronics to record and process segment signals



Reconstructed gamma-rays

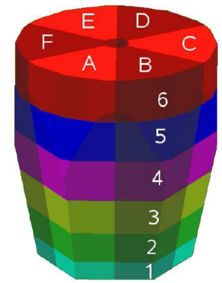
The AGATA Array



AGATA Asymmetric Triple Cryostat
Manufactured by CTT

Volume ~370 cc   Weight ~2 kg
(shapes are volume-equalized to 1%)

80 mm



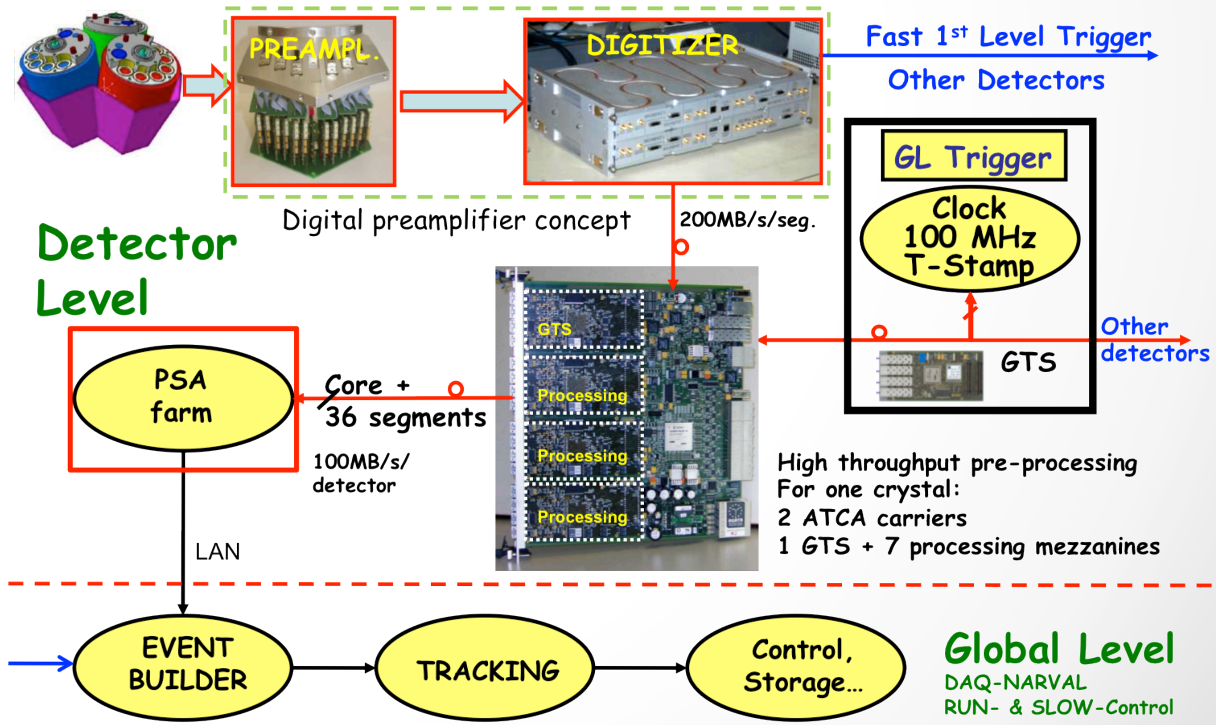
90 mm

6x6 segmented

Cold FET for all signals

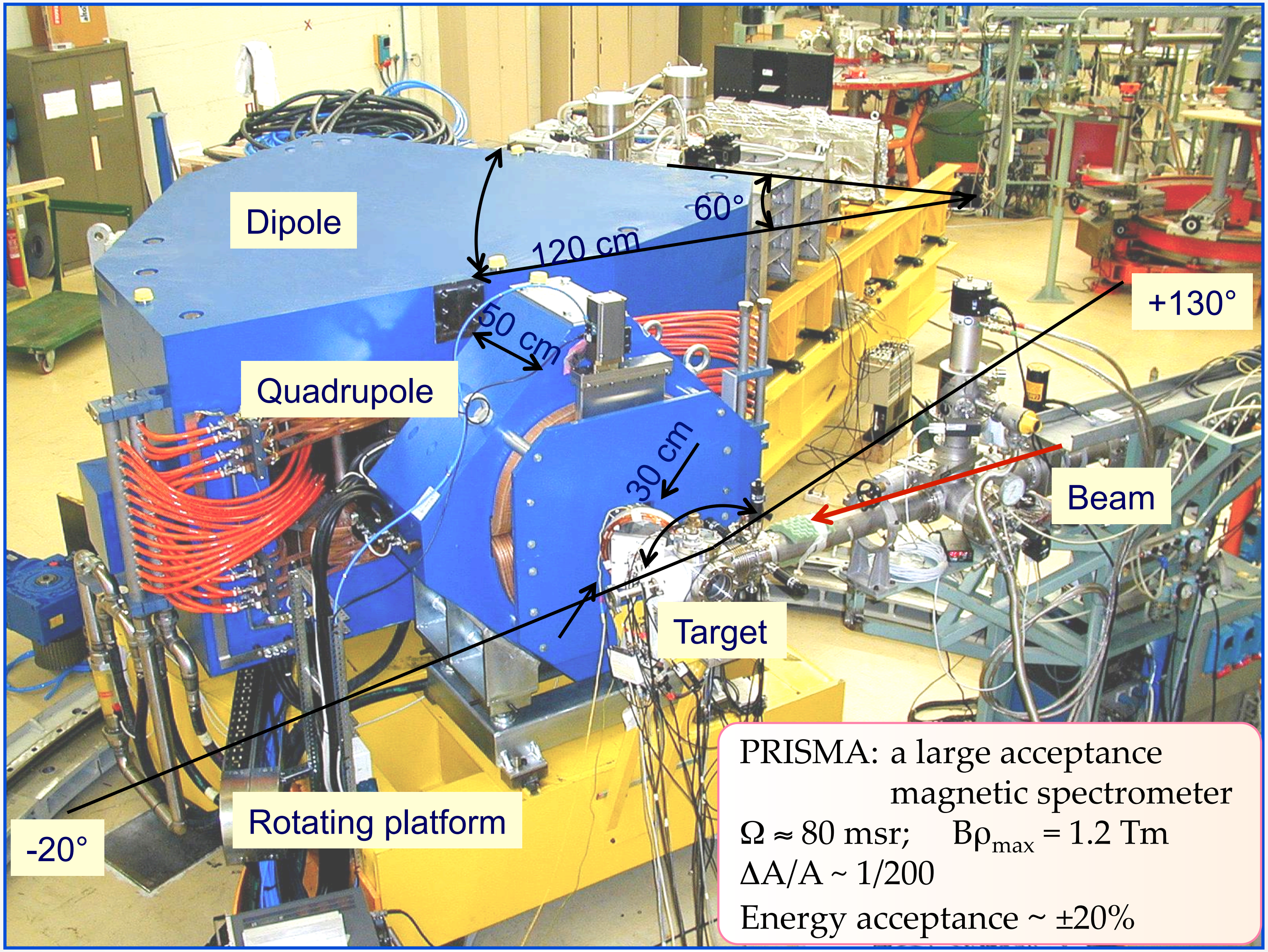
Energy resolution
Core: 2.35 keV
Segments: 2.10 keV
(FWHM @ 1332 keV)

A. Wiens et al. NIM A 618 (2010) 223
D. Lersch et al. NIM A 640(2011) 133

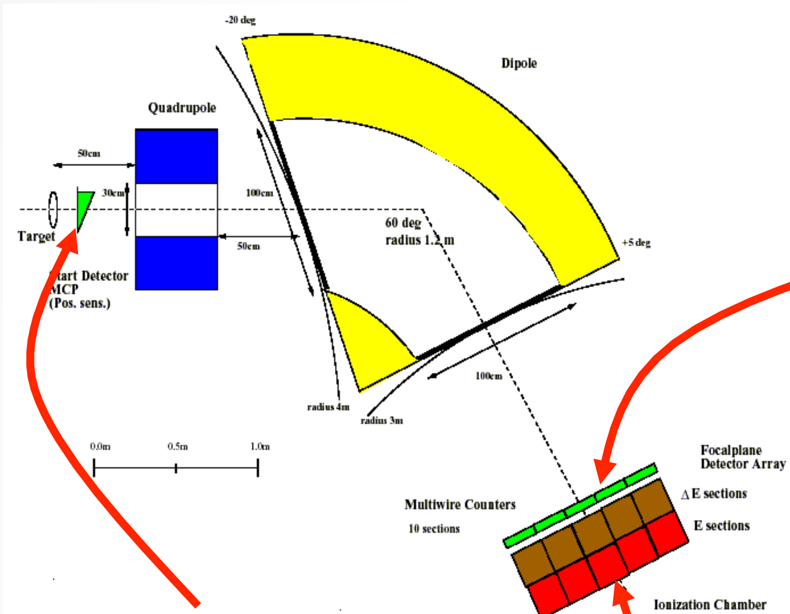


Other detectors:
interface to GTS, merge time-stamped data into event builder, prompt local trigger from digitisers

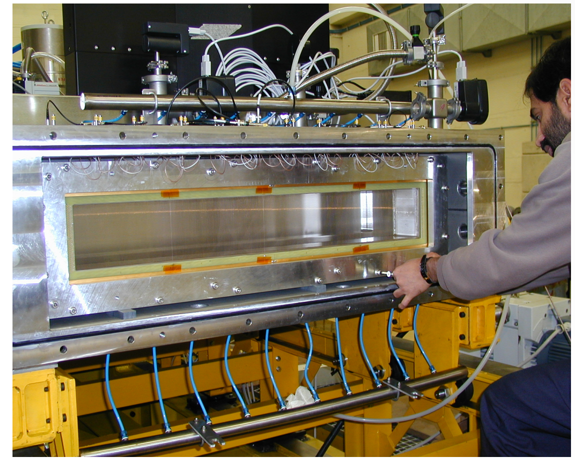
THE PRISMA SPECTROMETER



THE COMPONENTS OF PRISMA

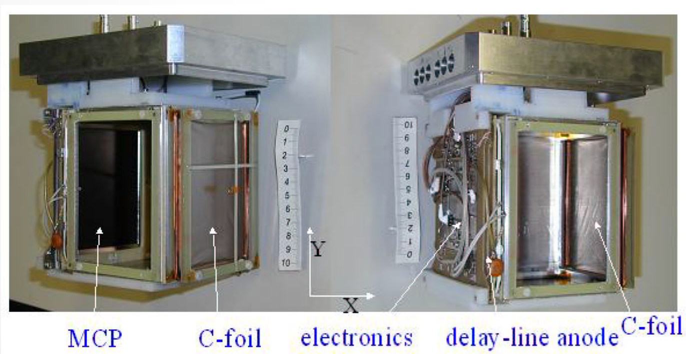


10 sections Multiwire PPAC



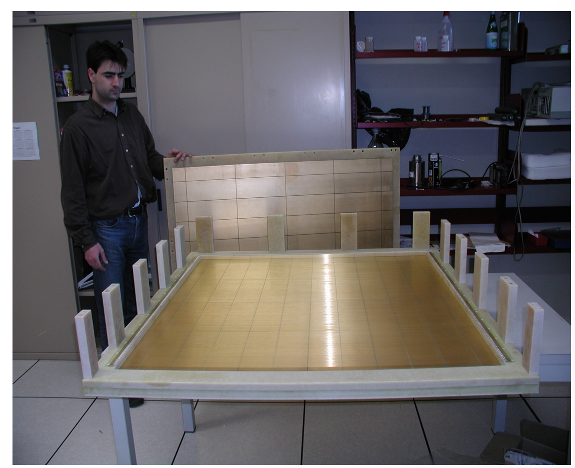
S.Beghini et al. LNL annual Report 2000 pg.163

Position sensitive MCP



G.Montagnoli et al. LNL annual Report 2000 pg.165

10 x 4 sections Ionization Chamber

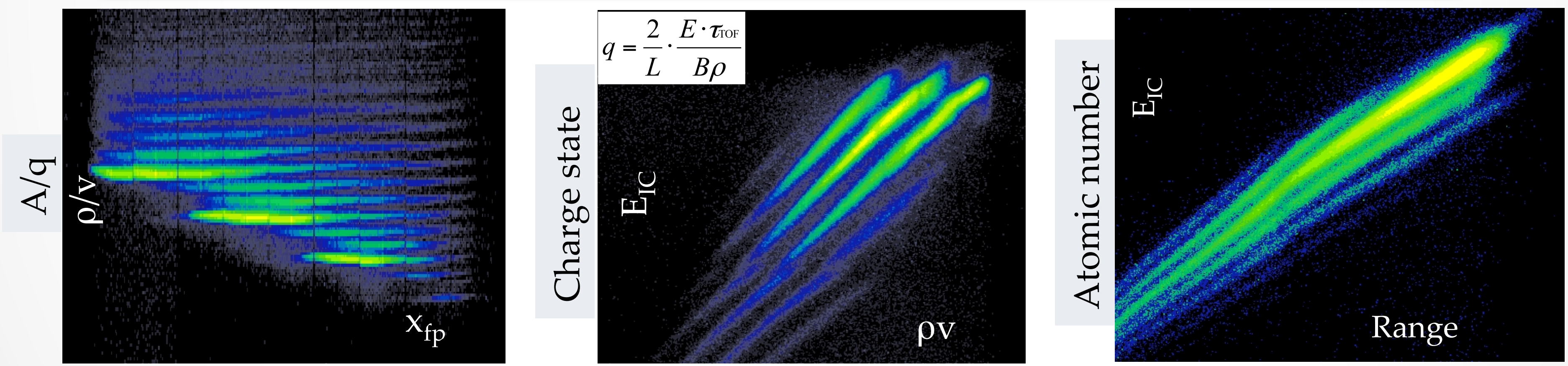


Measured Observables

- **Time of flight** → directly involved in calculation of speed, therefore of
  - **mass**
  - **Q-value**
  - **γ-ray energies (Doppler correction)**

$$B\rho = A \cdot \frac{v}{q} \propto X$$

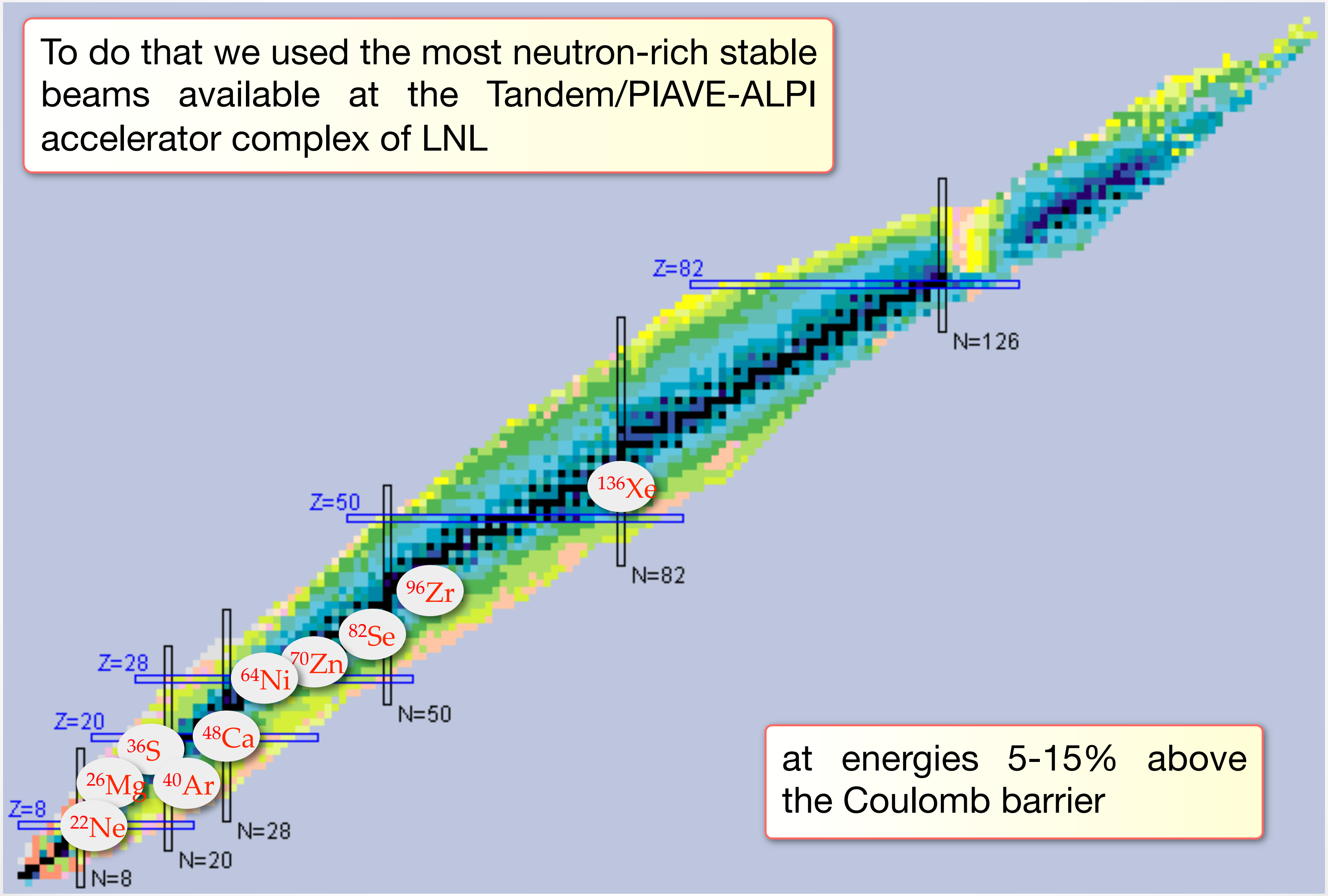
- **Entrance and focal-plane space coordinates** → used to reconstruct
  - **total distance L covered inside PRISMA** ($v = L/\tau_{TOF}$)
  - **trajectory curvature radius r** in dipole magnet
- **Energy released in the IC** (each section) → used to select events (Z and q)



Trajectories are reconstructed through an iterative procedure depending only on the ratio of fields in the dipole and the quadrupole and providing **trajectory length** and **curvature radius**

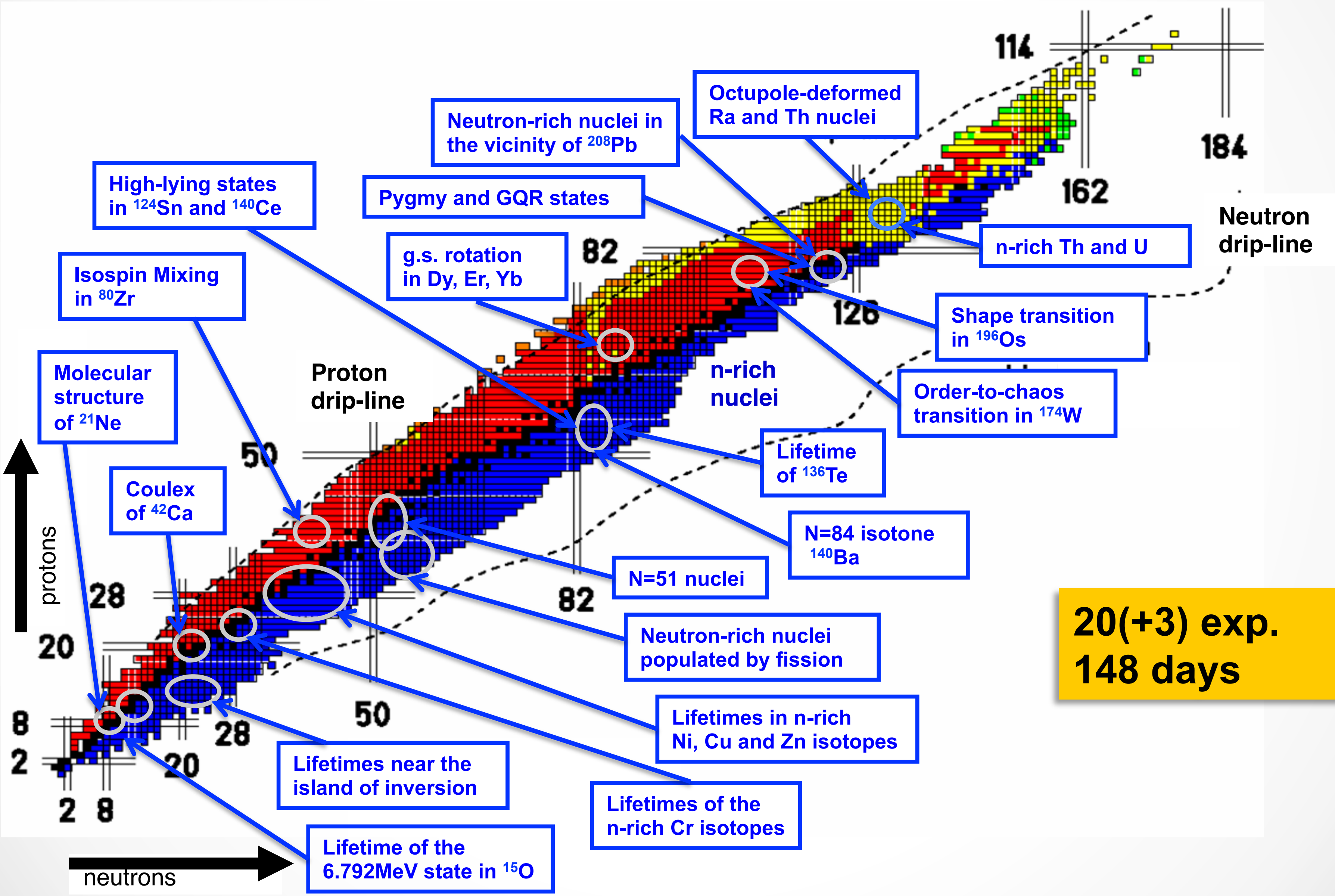
Grazing Reactions

To do that we used the most neutron-rich stable beams available at the Tandem/PIAVE-ALPI accelerator complex of LNL



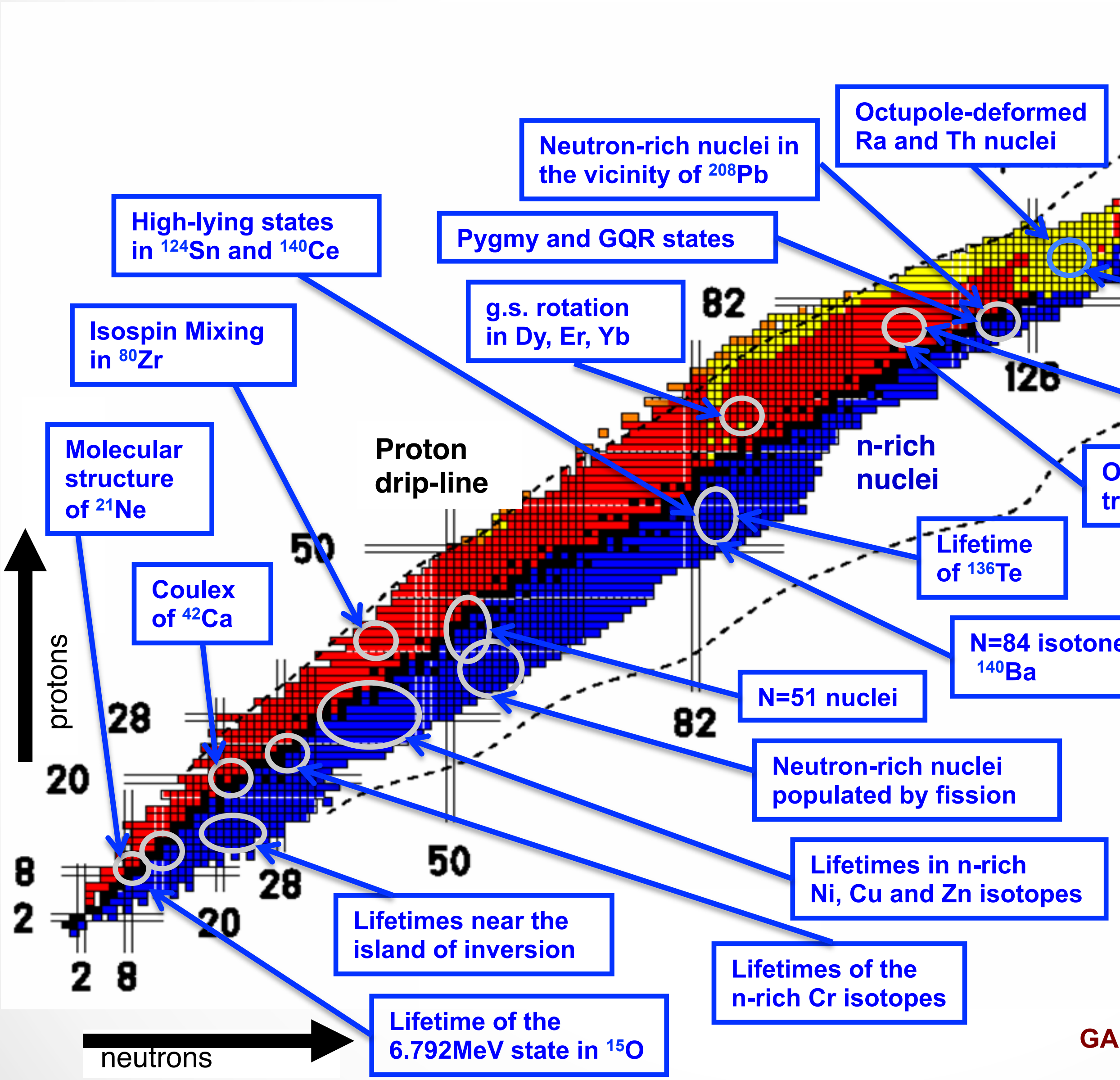
at energies 5-15% above the Coulomb barrier

EXPERIMENTAL CAMPAIGN AT LNL

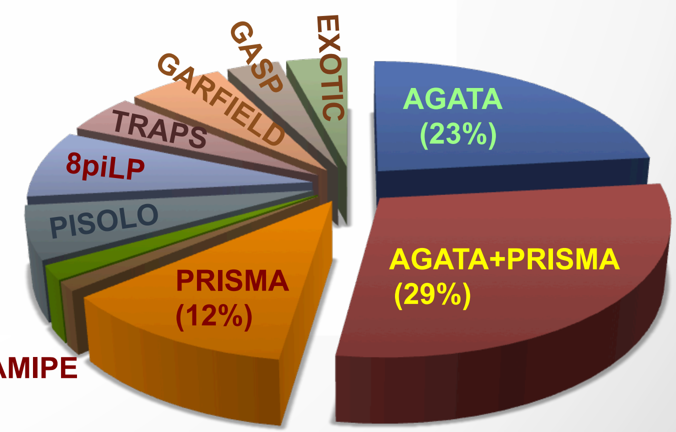


20(+3) exp.
148 days

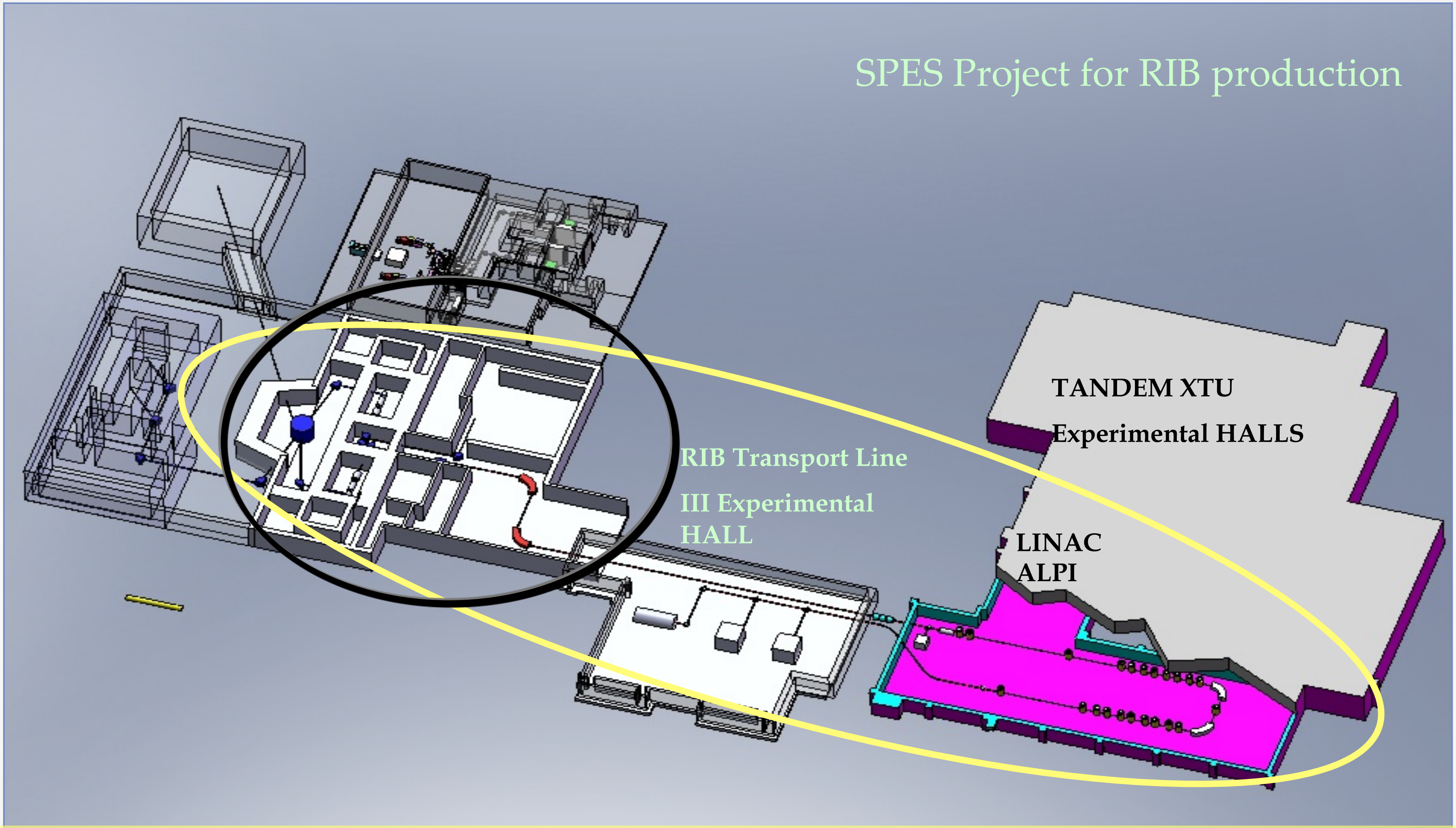
EXPERIMENTAL CAMPAIGN AT LNL



25.02.2011 – 25.03.2012



FUTURE PERSPECTIVES

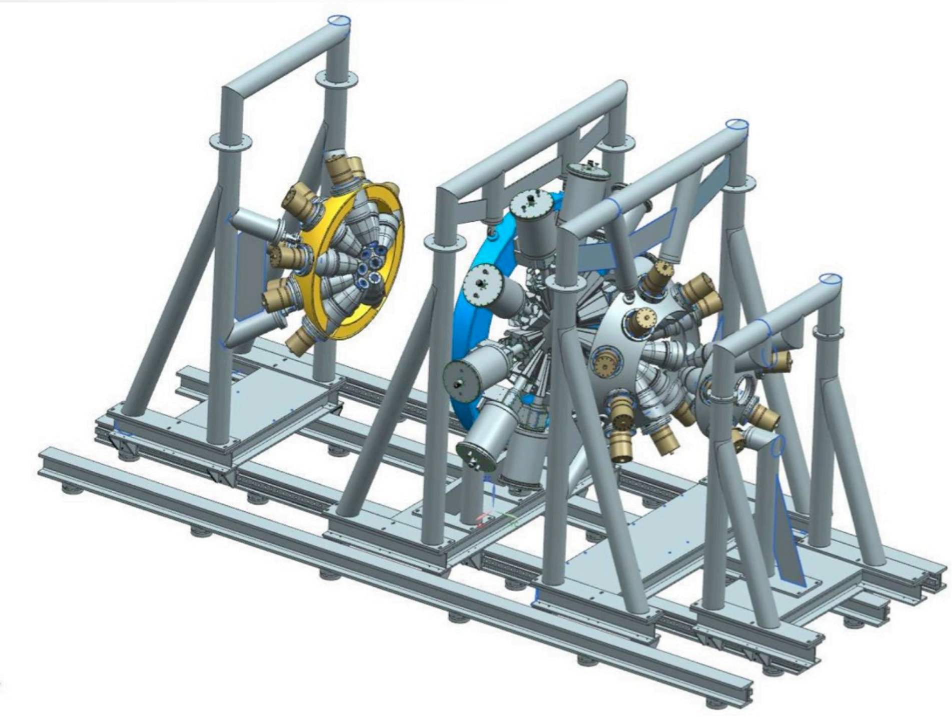


Primary Beam: Cyclotron 300 μA, 70 MeV (max) for protons in two exit ports for RIB

Production Target: UCx multi-foil , up to 10^{13} fission s^{-1}

Post-accelerator: PIAVE-ALPI Superconductive Linac up to 11 AMeV for A=130

THE GALILEO GAMMA–RAY ARRAY



Gamma–ray detectors

30 GASP detectors @ 22.5cm

5	5	5	5	5	5
29°	51°	59°	121°	129°	151°

10 triple cluster @ 24cm

90°

take advantage of the recent technical developments for AGATA

preamplifiers, digital sampling, preprocessing, DAQ

→ **high counting rates (30–50 kHz/det)**

use of existing detectors

EB cluster detectors capsules

GASP detectors

→ **high photopeak efficiency**

use beam facilities at LNL

Tandem, ALPI, PIAVE – stable

SPES – RIB

→ **production of new nuclei**

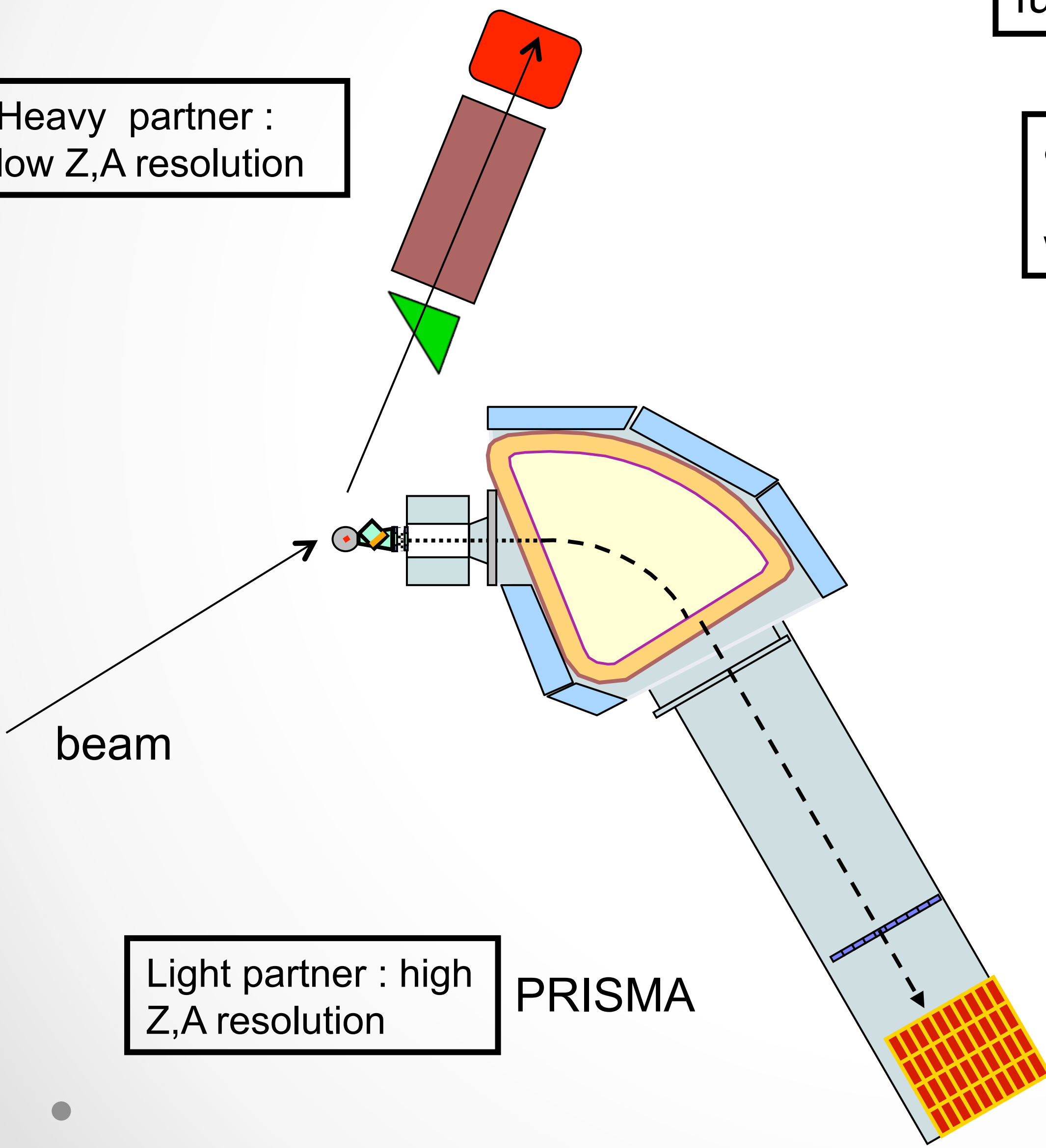
ε_{ph} ~ 8%   P/T ~ 50%

The PRISMA2 Project

Detection of kinematically coincident fragments (MCP,TOF,DE-E,Q1,Q2)

Installation of a $LaBr_3(Ce)$ array for multiplicity measurements for binary or fusion reactions products

Heavy partner : low Z,A resolution

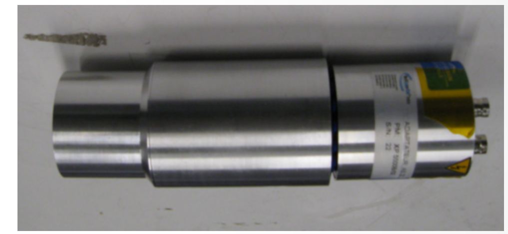


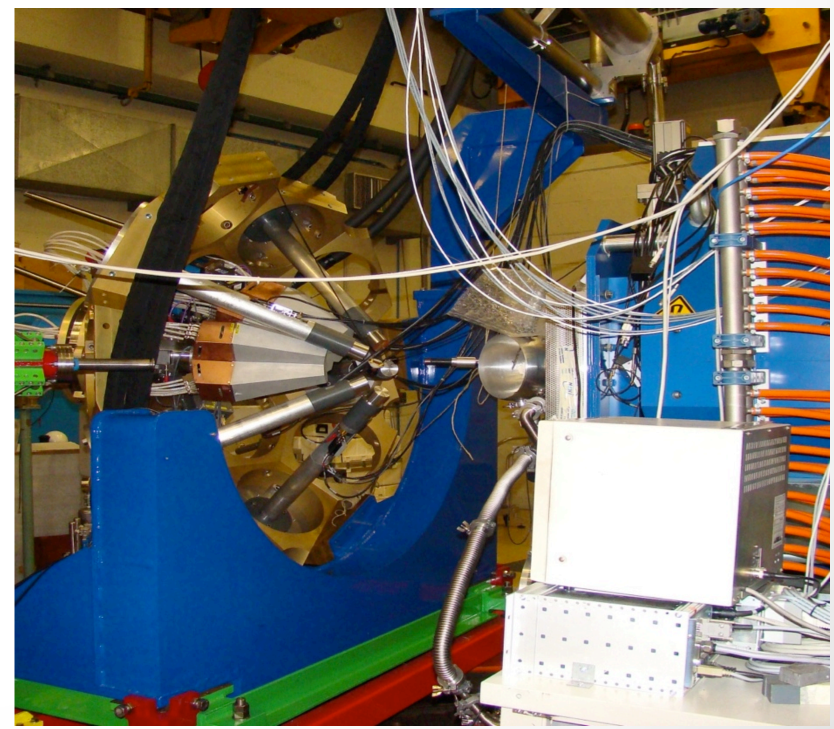
beam

Light partner : high Z,A resolution

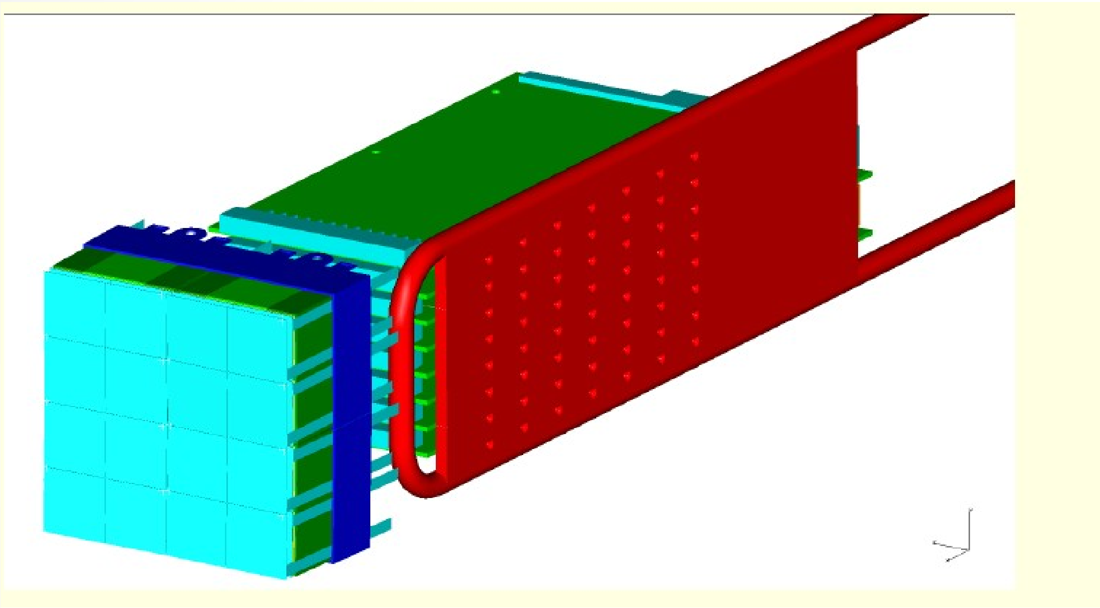
PRISMA

8 2”x2” detectors in collaboration with IRB Zagreb





THE FAZIA DEMONSTRATOR



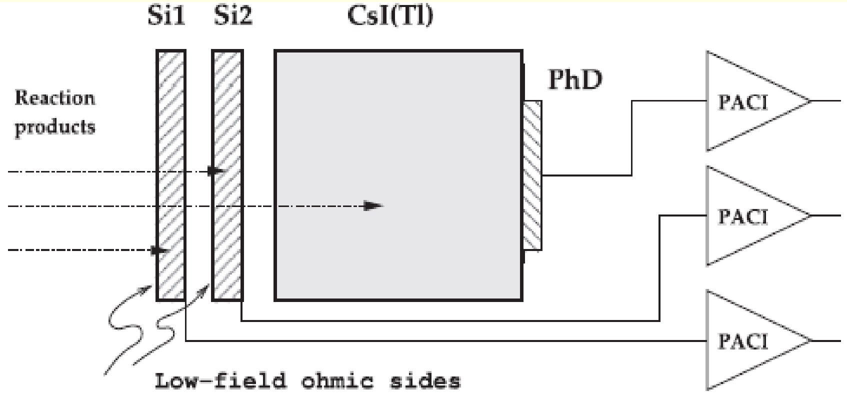


Fig. 1. Schematic drawing of a three-element telescope, with the charge and current preamplifiers (PACI) built by the FAZIA collaboration and the photodiode (PhD).

at LNL the Demonstrator

can be used in a coupled configuration with:

- GARFIELD in the large HuygensVat Sc. Chamber by replacing the Ring Counter
- RIPEN and other parts (for gamma rays detection and/ or charged particles) in a new chamber

CONCLUSIONS

LNL promotes a high level basic nuclear physics, applied and interdisciplinary physics research, based on the use of heavy ion beams delivered by the Tandem–ALPI–PIAVE complex, in collaboration with universities and other research centers at an international level

Nuclear structure and reaction mechanisms at energies close to Coulomb barrier are studied with forefront instrumentation (gamma–ray arrays, tracking spectrometers, charge particle arrays)

The SPES project will allow to extend the nuclear physics research towards challenging and significant studies in heavy ion physics with RIB’s