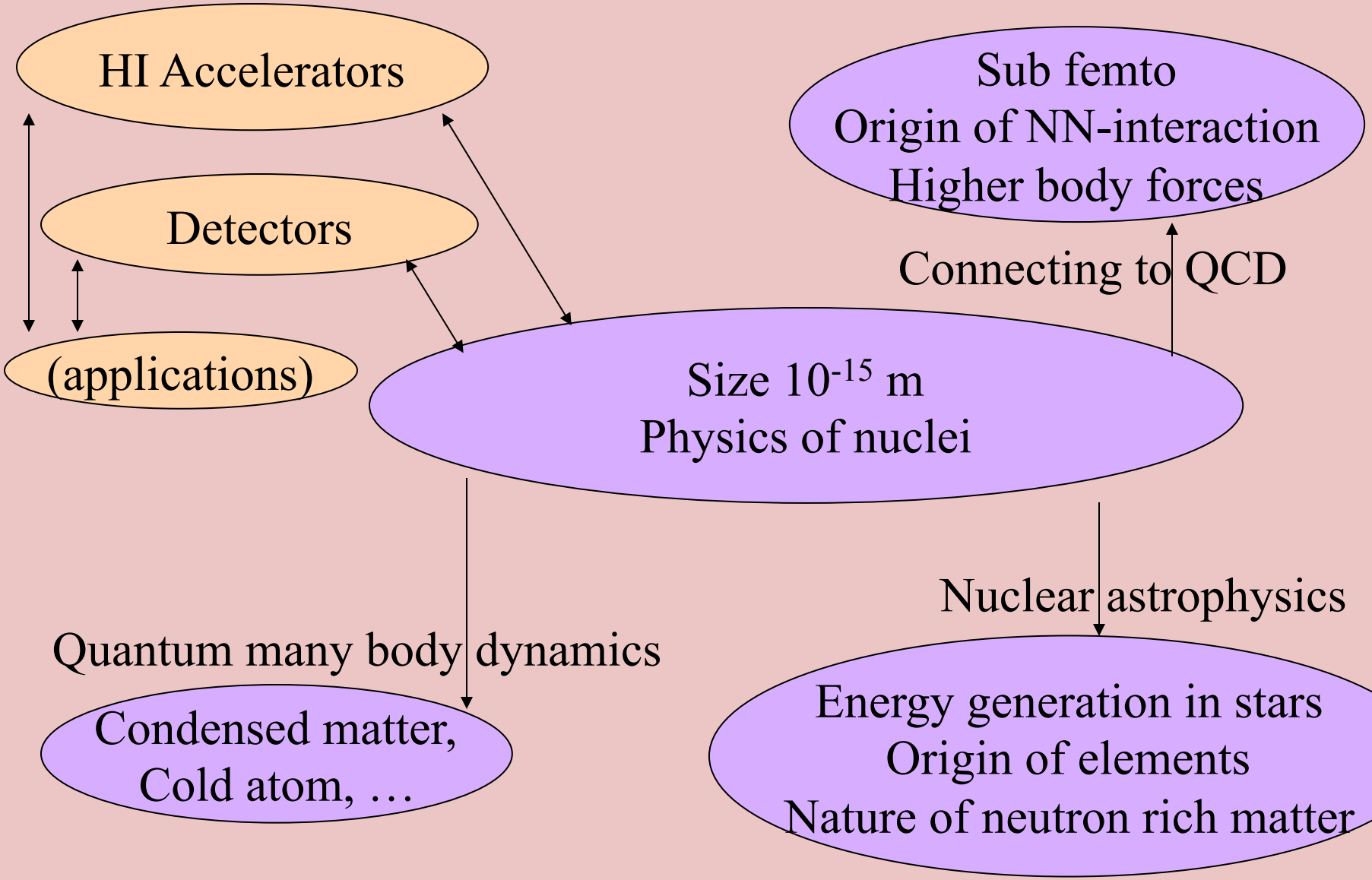
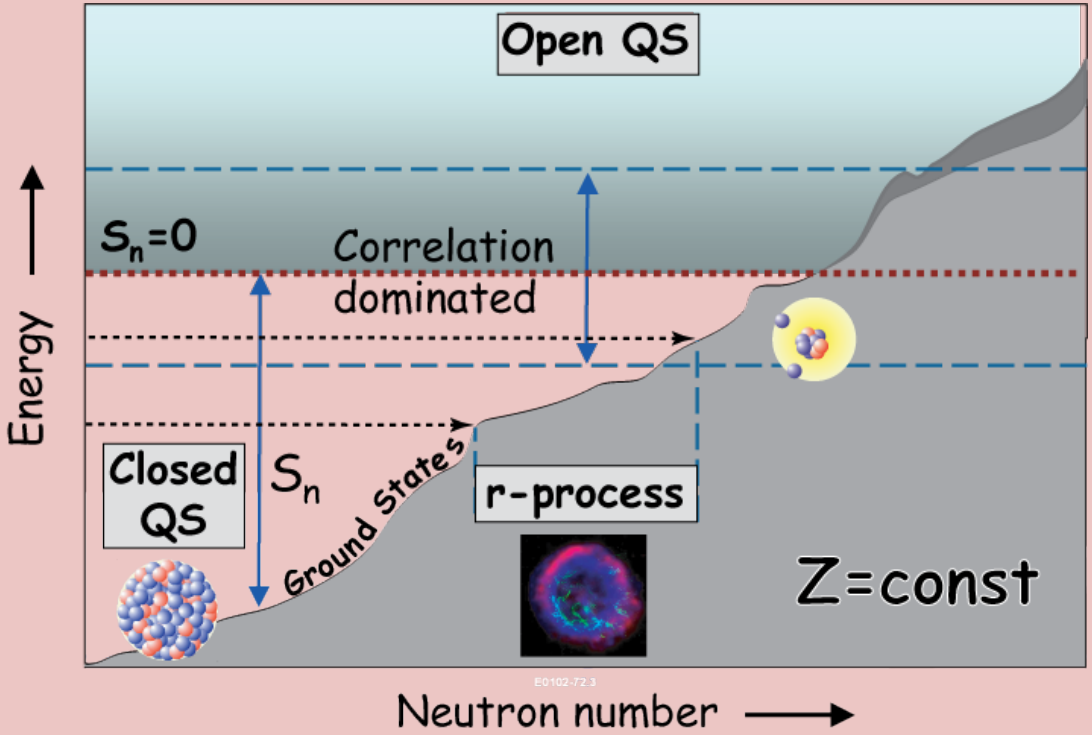
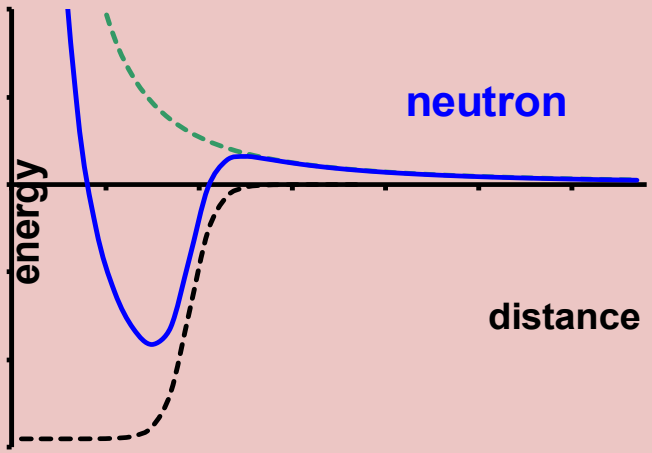
NuSTAR Program at FAIR
&
Indian Contribution

Rudrajyoti Palit
Tata Institute of Fundamental Research


HI Accelerators
Detectors
(applications)
Sub femto
Origin of NN-interaction
Higher body forces
Connecting to QCD
Size 10^{-15} m
Physics of nuclei
Quantum many body dynamics
Condensed matter,
Cold atom, …
Nuclear astrophysics
Energy generation in stars
Origin of elements
Nature of neutron rich matter

Physics of exotic nuclei





J. Dobaczewski et al. Prog. In Part. and Nucl. Phys. 59, 432 (2007)

Asymmetry in N & Z ratio, Fermi energy, density

Low density neutron matter

New Correlations

Tuning of certain terms in effective NN interaction

Novel decay modes

Nuclear Structure at extreme IsoSpin

What are the limits for existence of nuclei?

Where are the proton and neutron drip lines situated?

Where does the nuclear chart end?

How does the nuclear force depend on varying proton-to-neutron ratios?

What is the isospin dependence of the spin-orbit force?

How does shell structure change far away from stability?

How to explain collective phenomena from individual motion?

What are the phases, relevant degrees of freedom, and symmetries of the nuclear many-body system?

How are complex nuclei built from their basic constituents?

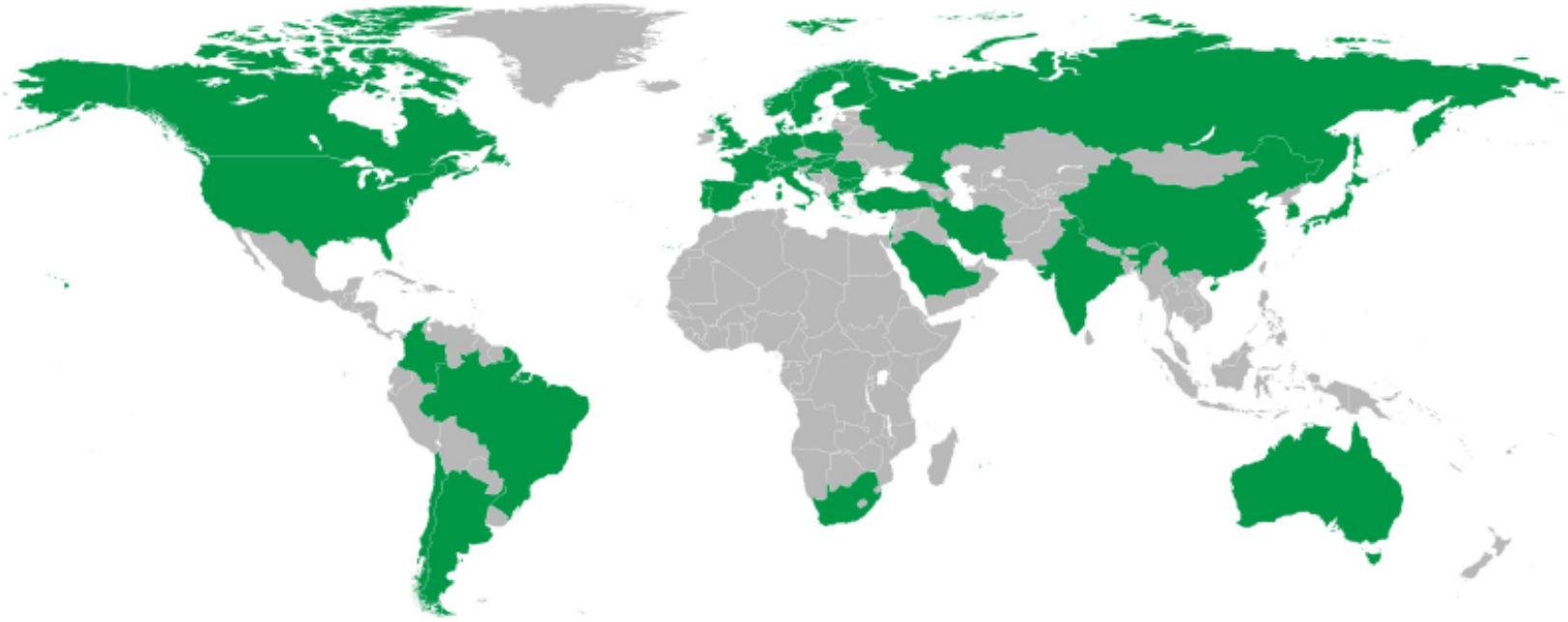
What is the effective nucleon-nucleon interaction?

How does QCD constrain its parameters?

Which are the nuclei relevant for astrophysical processes and what are their properties?

What is the origin of the heavy elements?

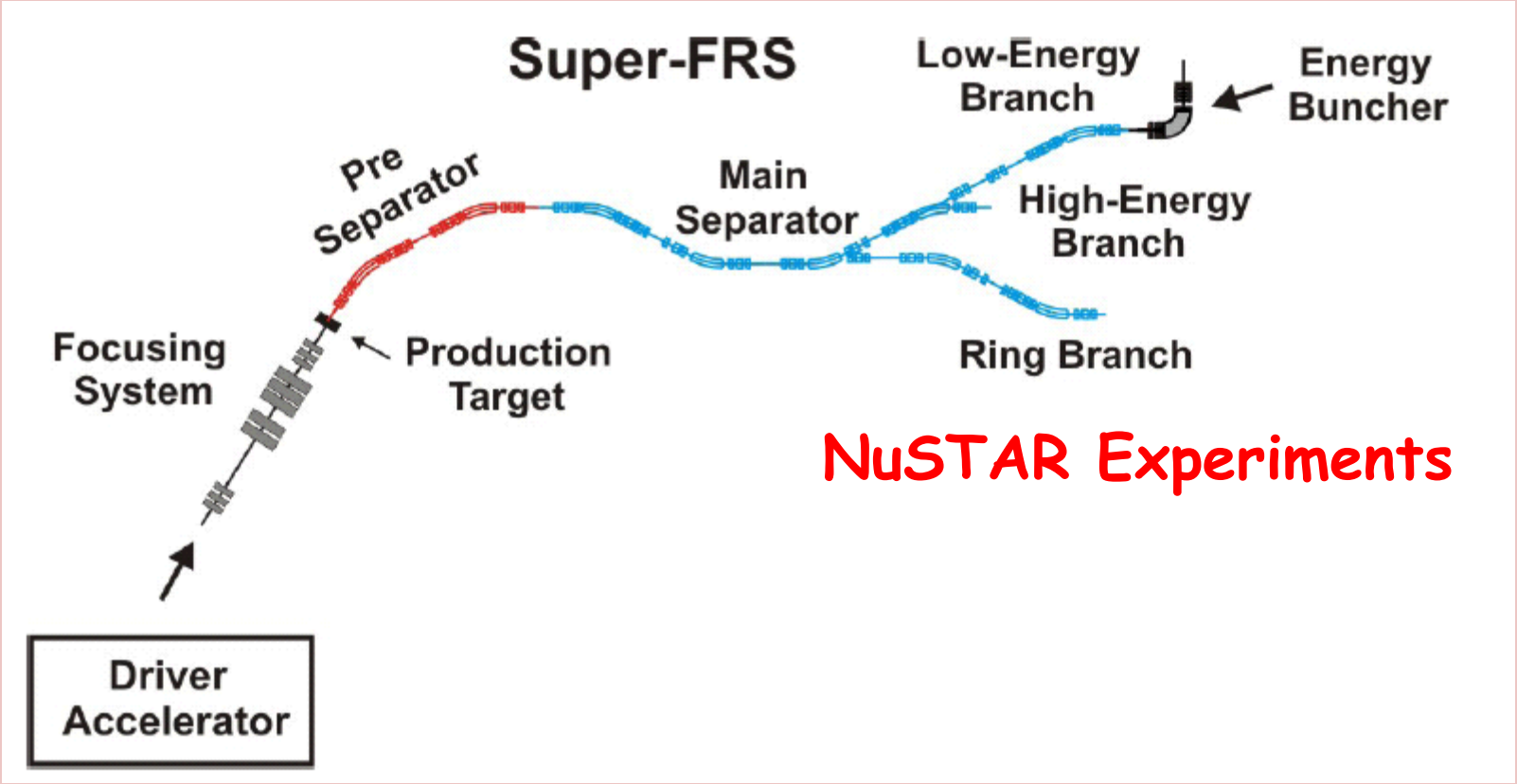
NUSTAR Collaboration



>800 registered NUSTAR members
38 countries
>180 institutes

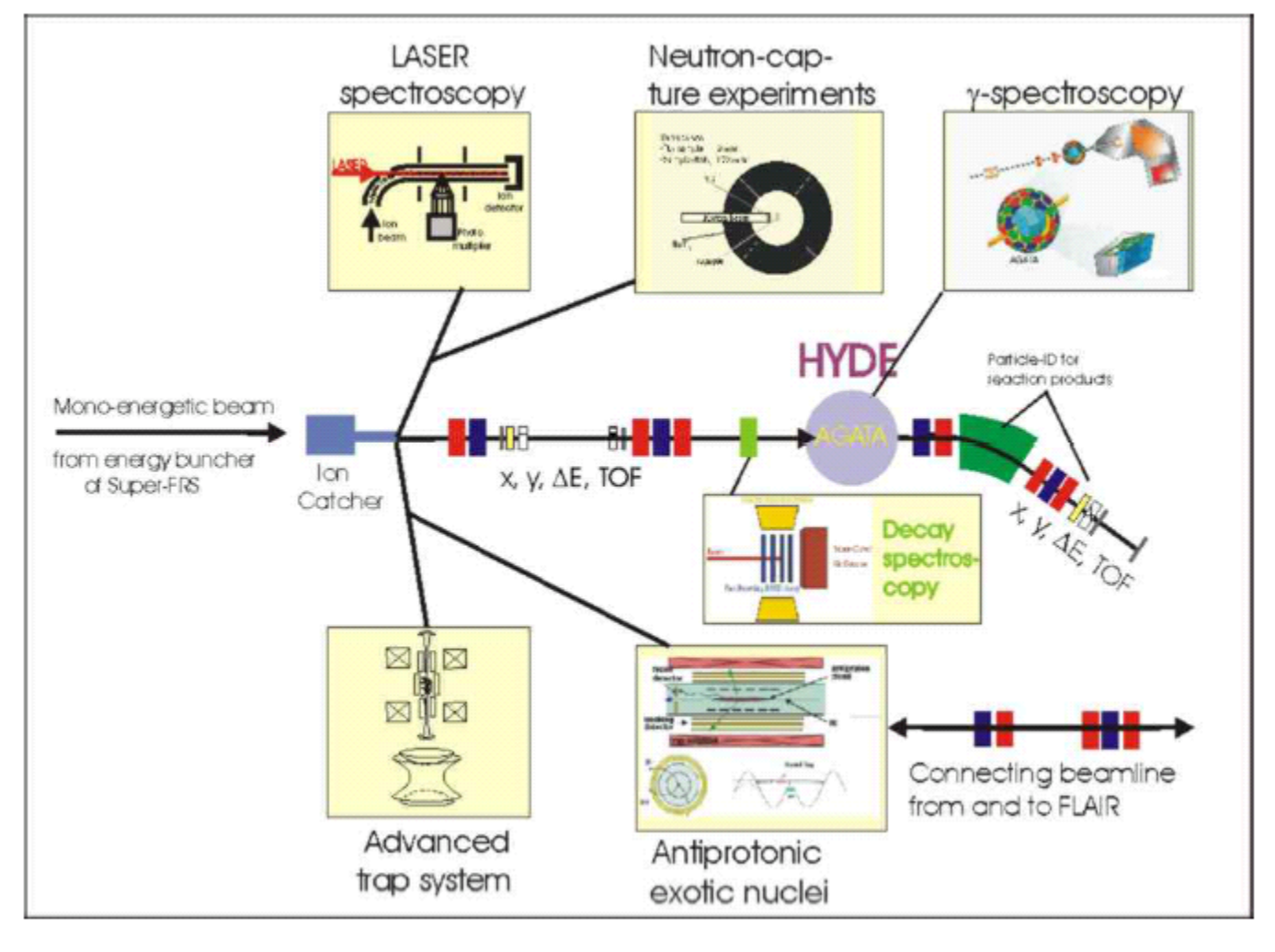
Major Objective of FAIR

Radioactive Ion Beams

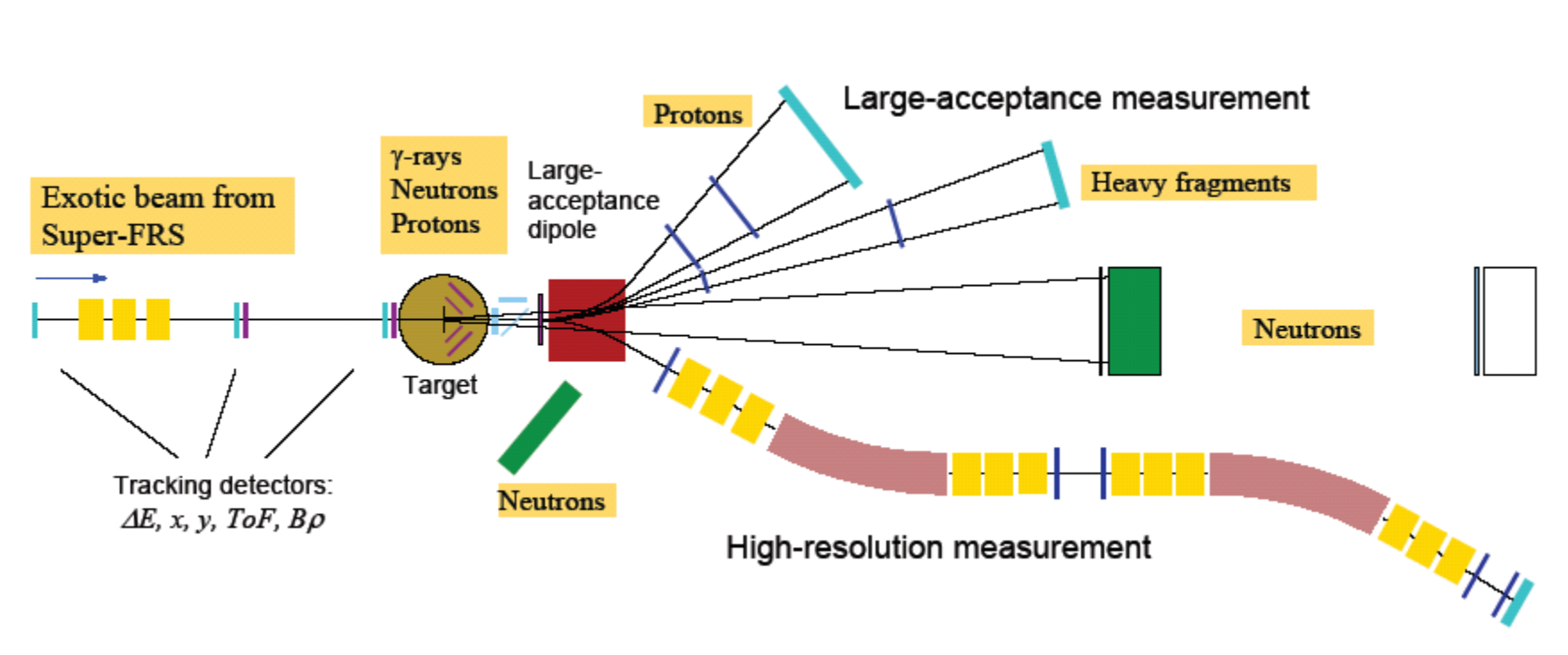


Superconducting Fragment Separator

Low Energy Branch



High Energy Branch



Kinematically Complete Detection

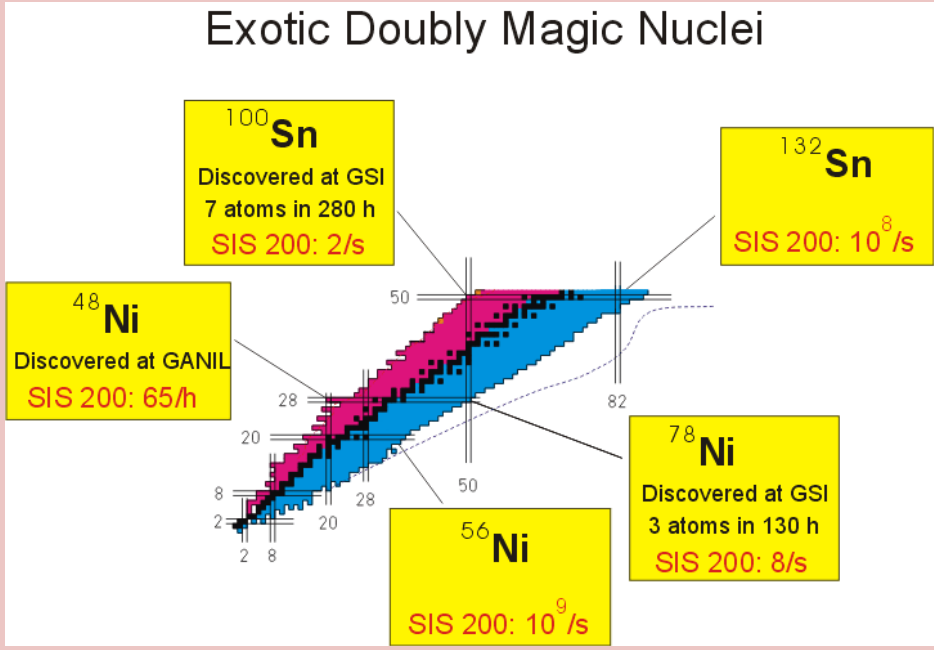
Different set-ups within NUSTAR asking similar questions

	Super-FRS	R3B	ILIMA	EXL	ELISE	AIC	HISPEC DESPEC	exo+pbar	MATS	LASPEC
Masses			bare ions, mapping study				Q-values, isomers		dressed ions, highest precision	
Half-lives	ps...ns-range		bare ions, s...h				dressed ions, µs...s			
Matter radii	interaction x-sect	matter radii		matter densitiy distributions		matter radii from absorption		nuclear periphery		
Charge radii					charge density distribution					mean square radii
Single-particle structure	high resolution, angular momentum	complete kinematics, neutron detection		low momentum transfers			high-resolution spectroscopy			

Taken from a talk by Nasser Kalantar-Nayestanaki

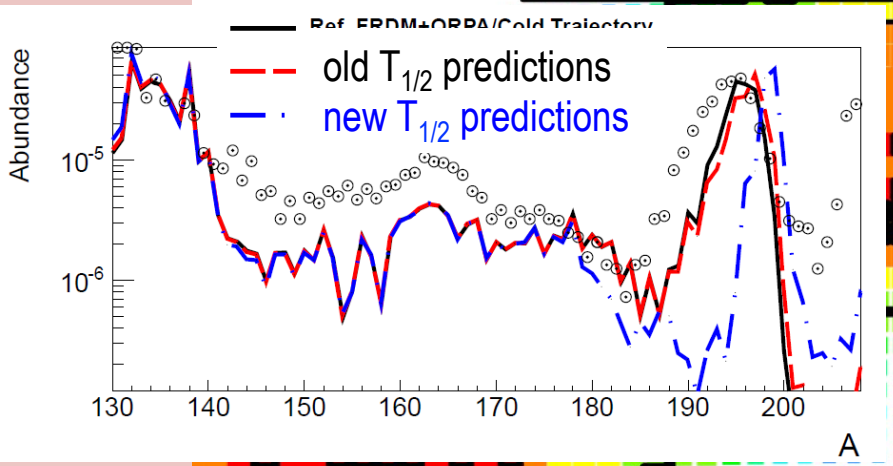
Experimental Opportunities

- ***Better Intensity***
- **Primary beam intensity (*H to U*) gain factor : > 100**
- **Improved fragment transmission (fission products !) in SuperFRS and to the storage rings**
- **Total gain factor: up to 10000**
- **Fragment beam energy ~ 1 GeV/u**
  - ⇨ **Gain in luminosity**
  - ⇨ **Fully stripped ions**
  - ⇨ **Impurity-free beams**



The N=126 Physics case

Previous GSI measurements contradict earlier lifetime predictions!
→ Mass abundances not understood!



Mass abundances depend on the detailed structure of N=126 nuclei around the 3rd r-process waiting point

NUSTAR aims to measure:
-masses
-β-lifetimes
-neutron-branchings
-strength distributions
-level structure

Important unique NUSTAR-LEB experiment

Nuclear Structure & Reactions with stable beams

High Spin, High Temperature in medium & high A
Reactions with weakly bound Low A
Fission Dynamics in high A

Accelerator Centres

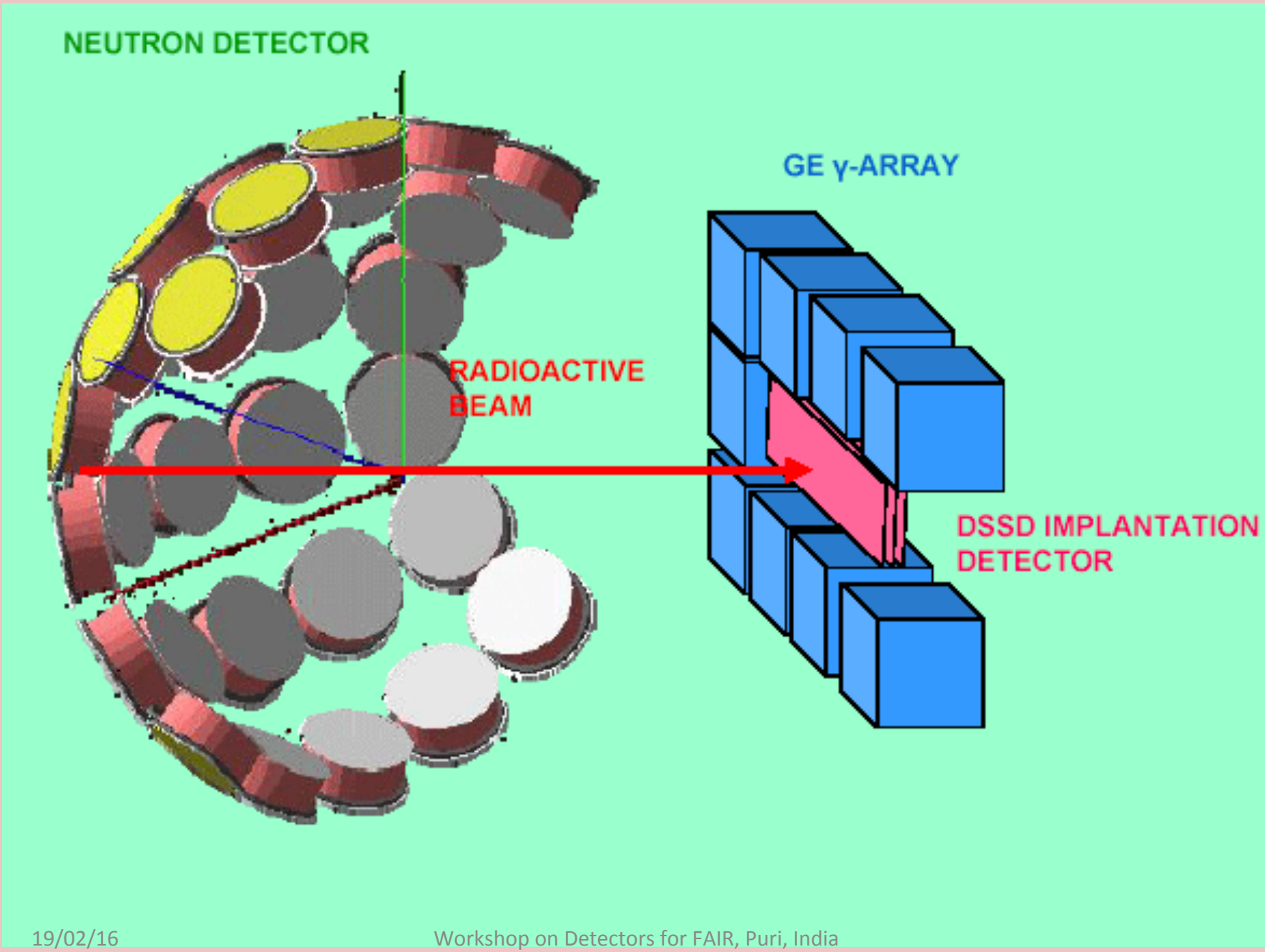
- TIFR-BARC Pelletron Linac Facility
- IUAC Pelletron Linac
- VECC Cyclotron K~130, K~500
- Upcoming facilities
  - SINP Nuclear Astrophysics
  - PU Low Energy Tandem

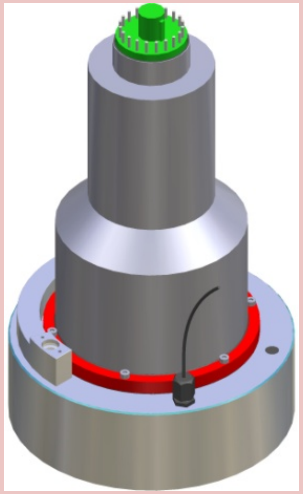
NuSTAR-India

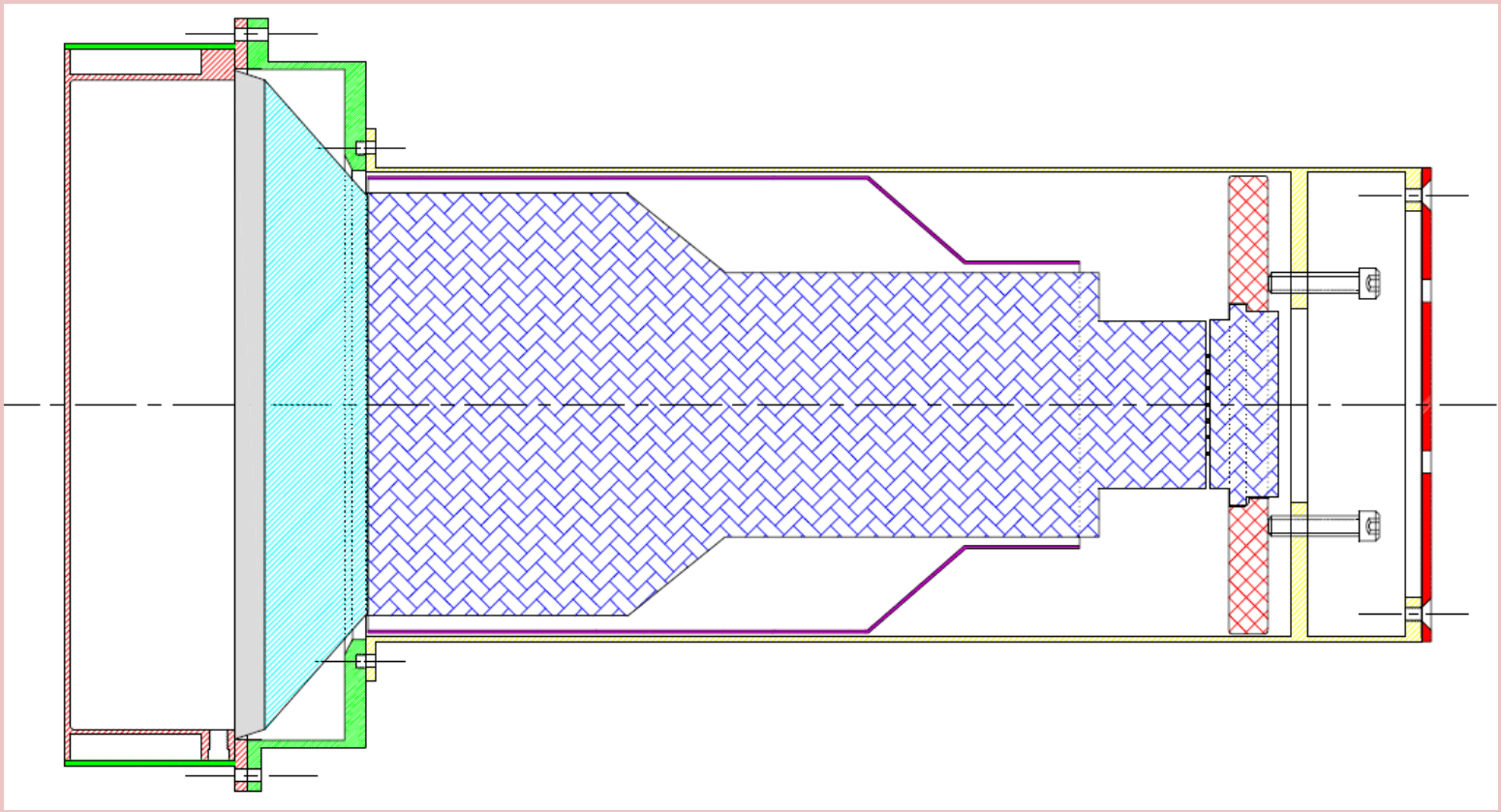
Proposals for Experiments

Active Participation R&D and Deliverables

- DESPEC Gemarnium Array Spectrometer (DEGAS) (TDR accepted)
- MOdular Neutron SpectromeTER (MONSTER) (TDR accepted)
- Precision **M**easurements using **A**dvanced **T**rapping **S**ystem (MATS) (TDR accepted)
- Active targets
- Beam tracking detectors for NUSTAR


NEUTRON DETECTOR
GE γ-ARRAY
RADIOACTIVE
BEAM
DSSD IMPLANTATION
DETECTOR





MONSTER cell

Detector design requirements for DEGAS

Maximum sensitivity to measure discrete gamma rays in presence of strong backgrounds

1. Solid angle coverage & detector granularity
2. Full-energy efficiency
3. Energy resolution and P/B ratio
4. High background suppression capability
5. Good time resolution and rate capability
6. Angular correlation and polarization sensitivity
7. Versatility

Phase-wise Implementation of DEGAS

1. Phase I:

RISING Detectors in triple cluster with e-cooling.

BG suppression with active BGO shield.

New pre-amplifier, slow control and DDAQ

2. Phase II:

AGATA Triple cluster along with EB triple cluster

Imaging capability of AGATA (backside of implanter)

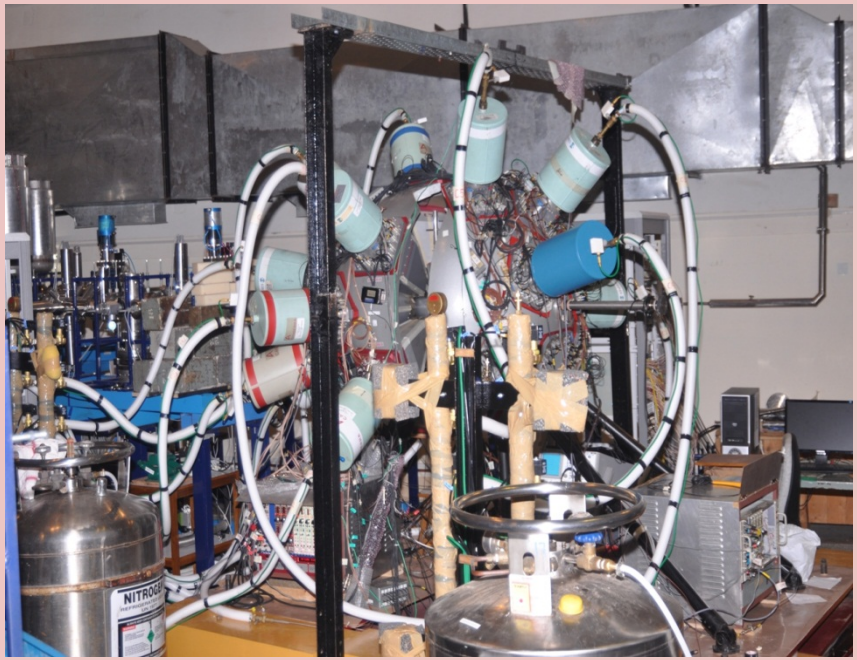
DSGeSD as an implanter and decay detector

3. Phase III:

R&D for gamma-imaging detector (planar stack/point contact/Scintillator-Ge hybrid)

Connections with Indian Research Program in gamma spectroscopy

INGA campaign



Physics Highlights

Search and characterization of novel excitation

Magnetic and Anti-Magnetic Rotation

Degenerate dipole bands and chirality

Wobbling Excitation

Shell model excitation and emergence of collectivity

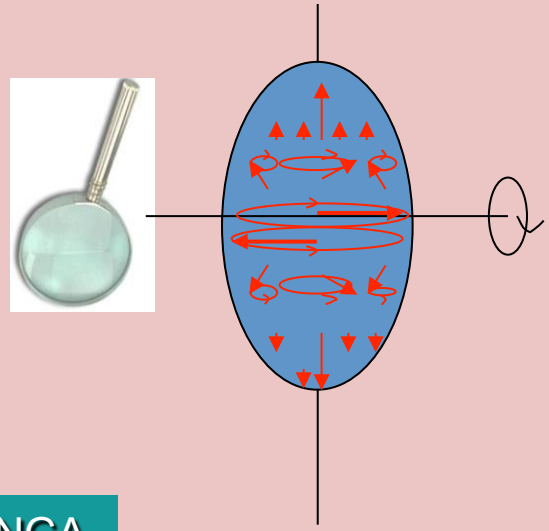
Isomers and its application

Fission fragment spectroscopy

Reaction dynamics study

BARC, IUAC, IUC-KC, SINP, TIFR, VECC, IITs, Univ

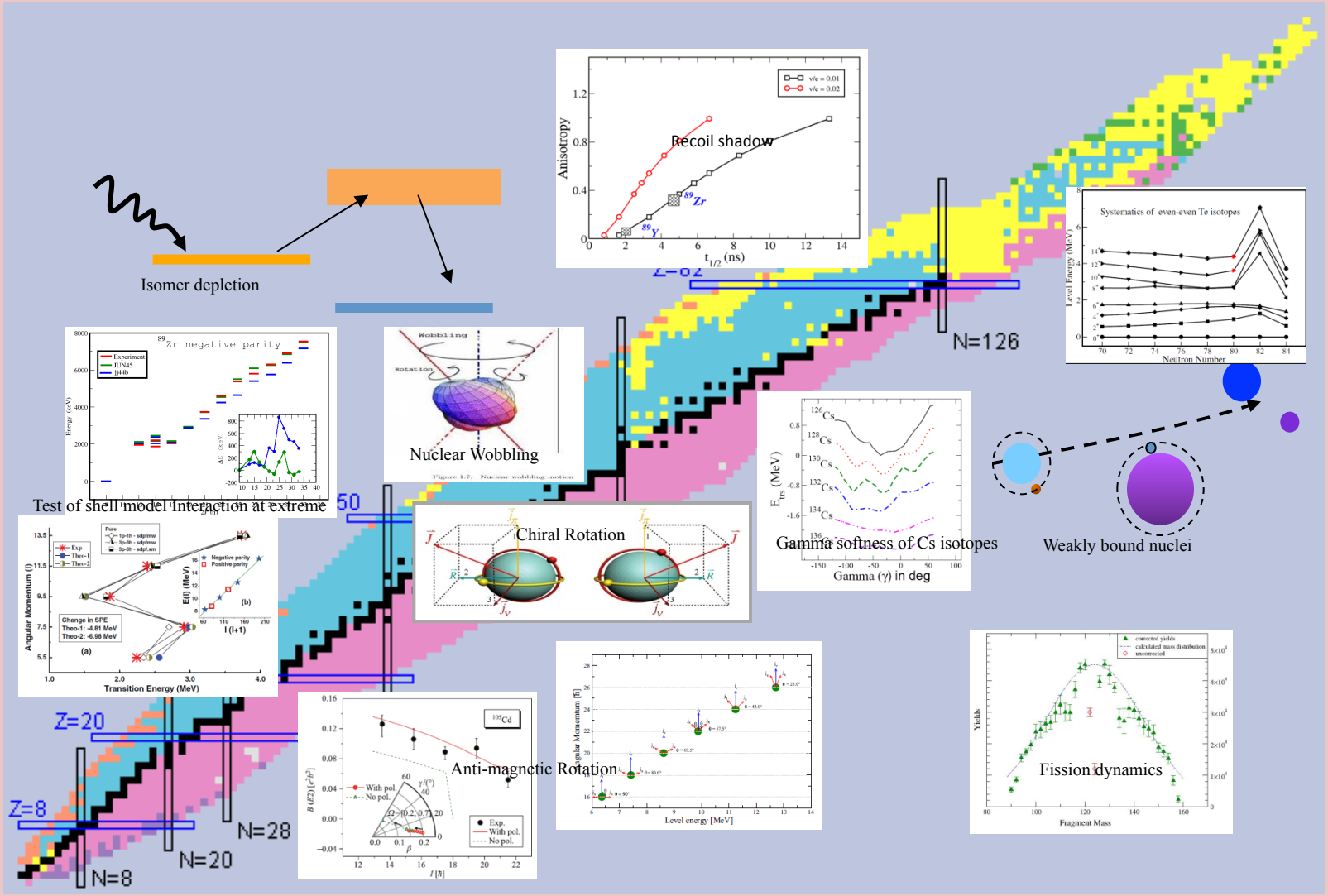
Investing in the polarization measurements of gamma rays and "wide-range timing spectroscopy" proved to be a successful approach for creating our specific "niche" and complement research at large scale facilities.
Experiments: ~3600 hrs (50 Experiments in 3 years)
60 researchers including 25 PhD students



DSP based DAQ has Increased the data throughput by 10 times for INGA

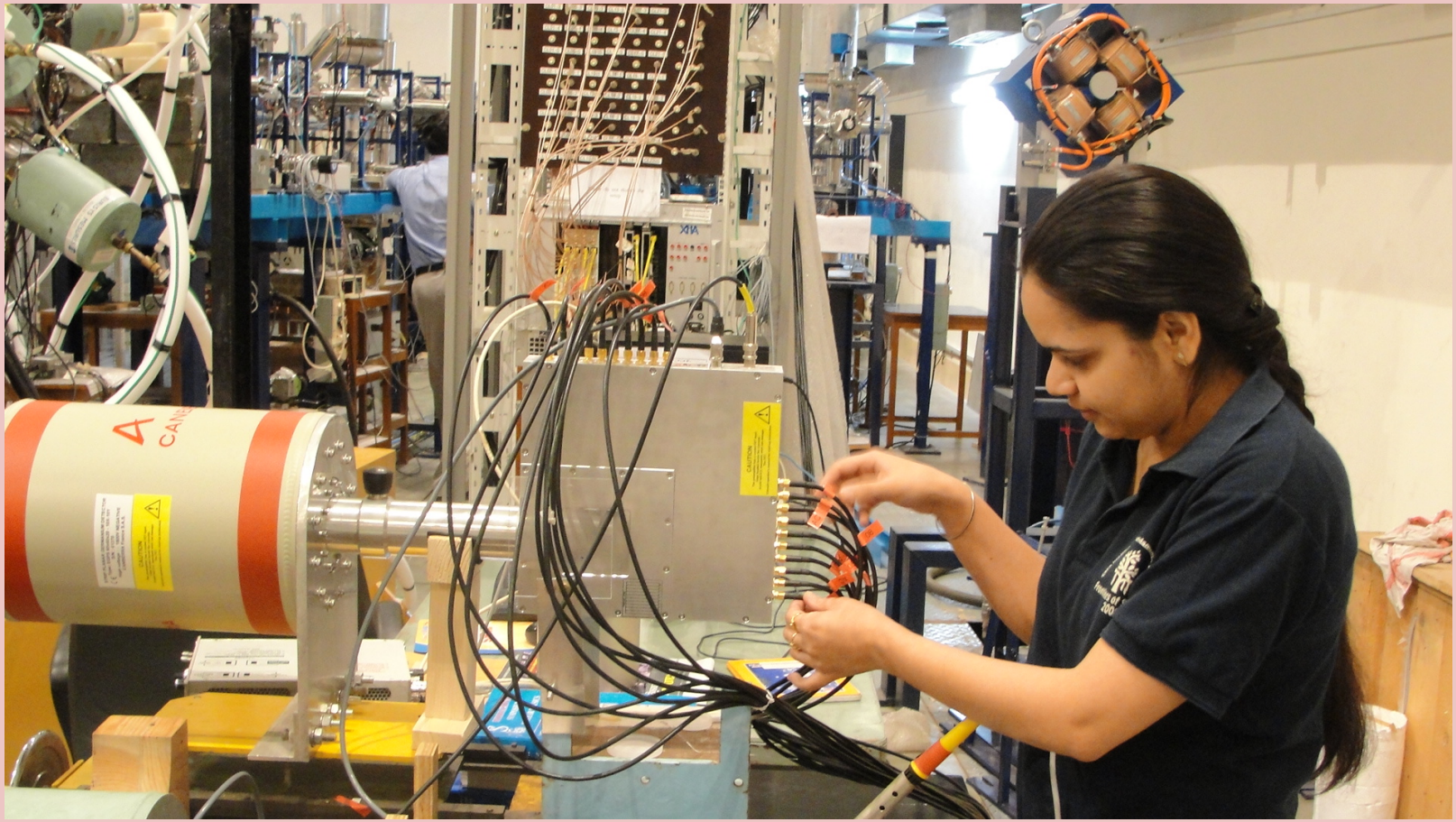
R. Palit et al., NIMA680, 90 (2012)

Physics Highlights of INGA Collaboration

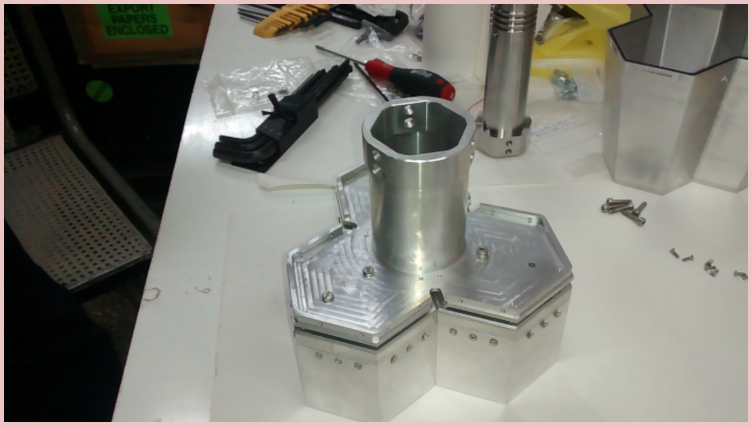


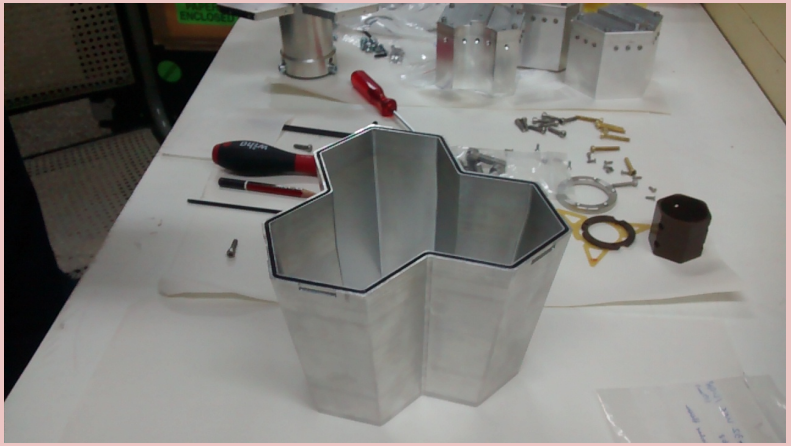
Results (2011-2015): 35 publications (2 PRL, 3 PLB, 1 NIMA)

Testing of Planar Ge detector at TIFR



Mechanics of DEGAS detectors fabricated at TIFR

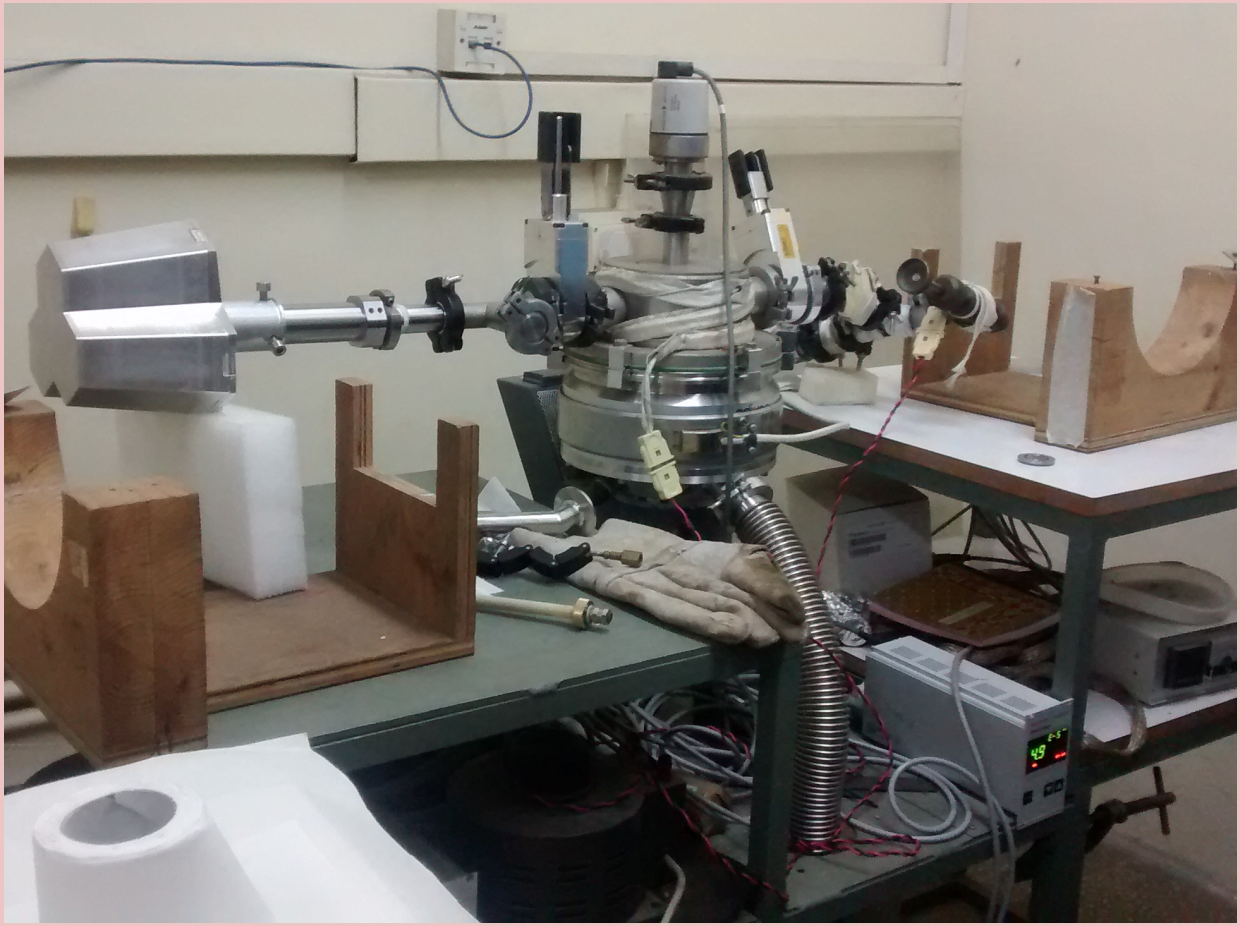




Mechanics of DEGAS detectors fabricated at TIFR

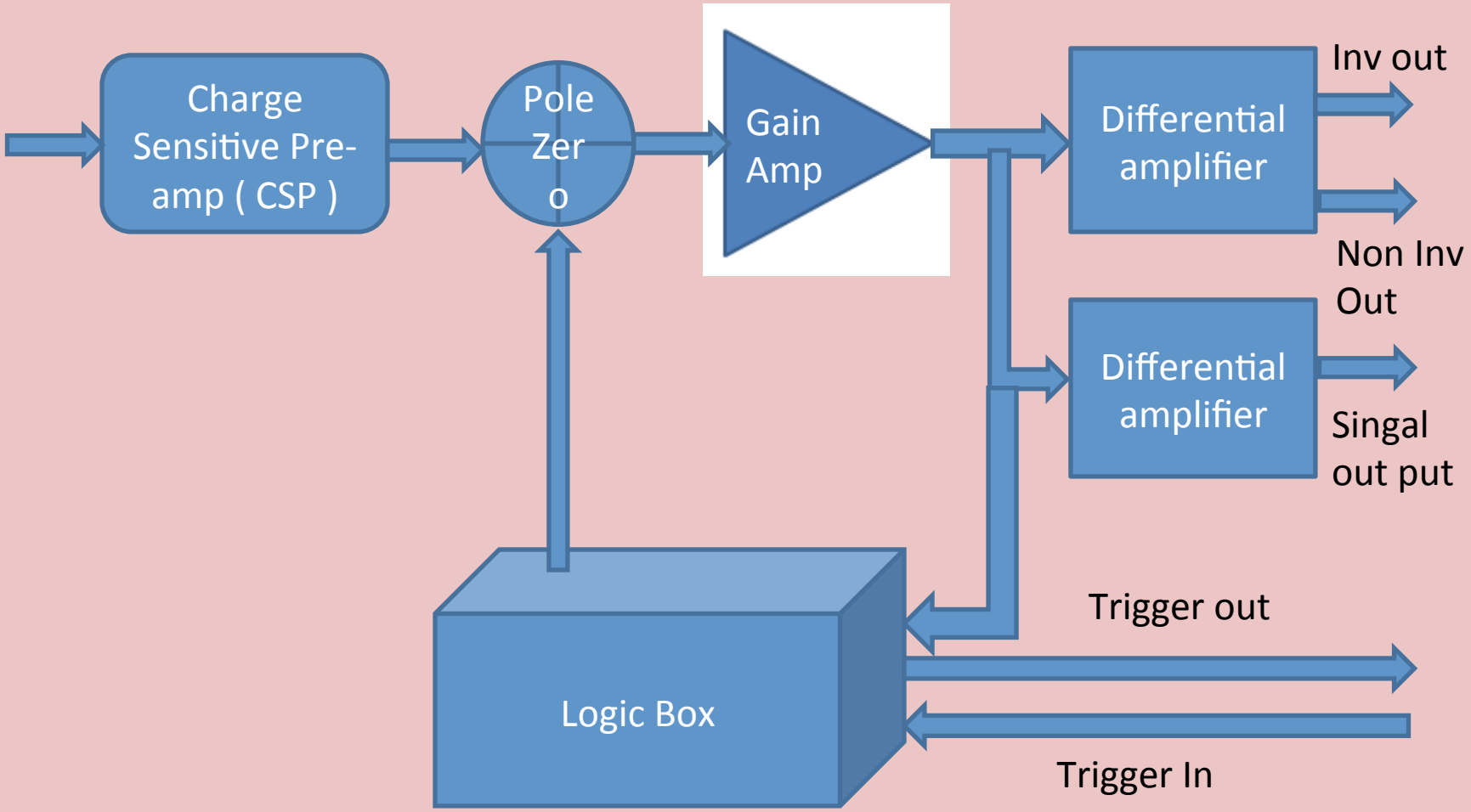
Fabrication and Testing of Cryostat in India

16/02/2016

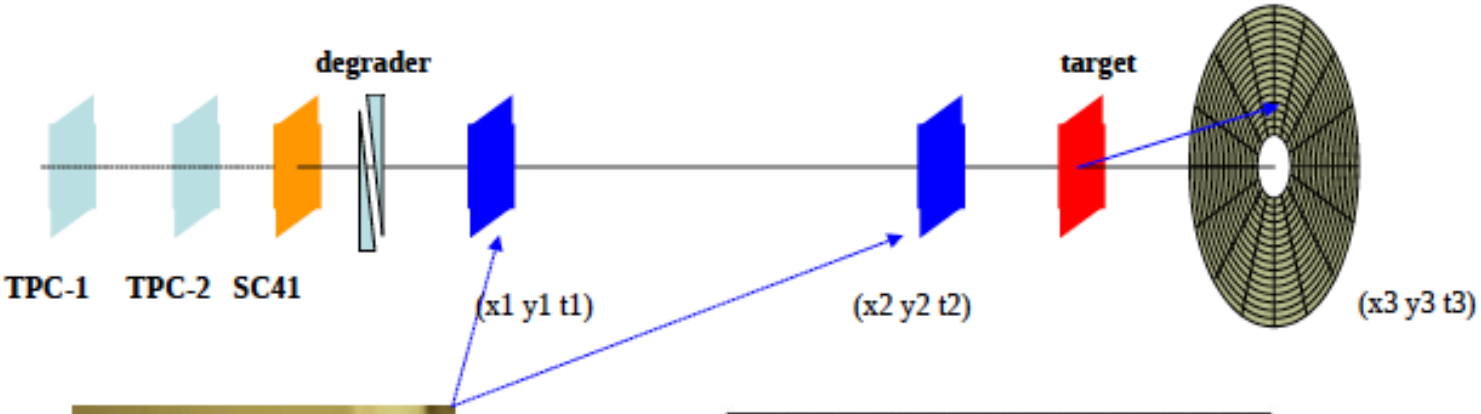


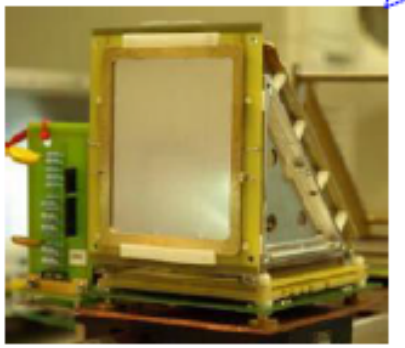
Talk by Ivan Kojouharov

Pre-amp Block diagram for DEGAS



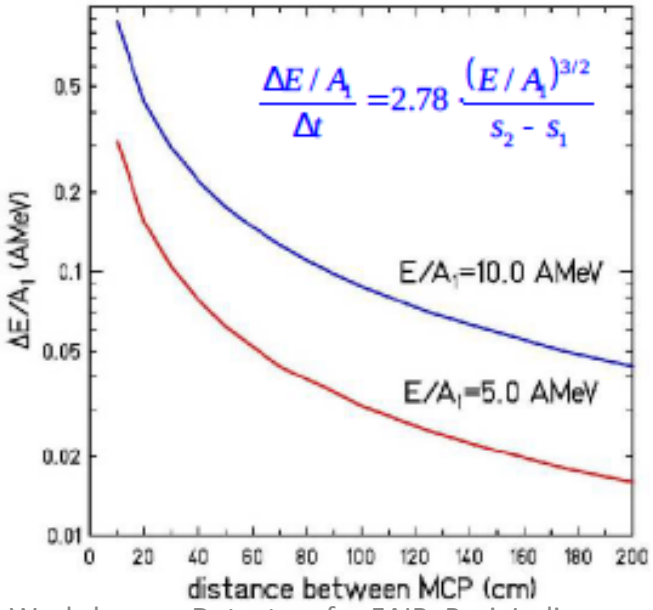
Slowed down beams - beam energy measurement





electrostatic mirror + MCP detector

position resolution ~ 1 mm
time resolution ~ 100 ps



experimental results:

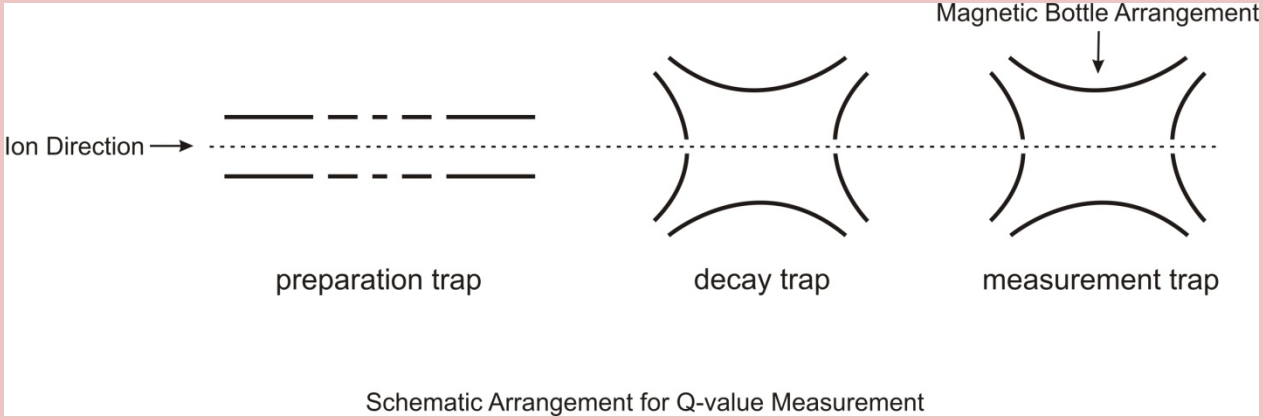
velocity β
beam energy E/A1
scattering angle θcm

Talk by A. Jhingan

Decay Studies

Q-value Measurements using a Penning trap system.

Short-lived parent nucleus (half-life 50 ms or less) not a limitation
Daughter has to be relatively long-lived (half-life ~ 10 s)
Q-value should be relatively high >5 MeV for a high accuracy measurement.



Schematic Arrangement for Q-value Measurement

Recoiled daughter nucleus should enter measurement trap axially through a small axial hole (< 100 micron).

Single ion measurement

VECC Penning trap Project

A Penning trap Project going on at VECC.

Magnet-cryostat cooled to 4K.

Cryogenic insert tested.

A prototype Penning trap already fabricated at VECC Workshop.

Final drawing and design going on.

Our MATS program would be complementary to our VECC program.

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NuSTAR-INDIA goal
Structure of Exotic nuclei

- **Unique Physics Opportunity with Exotic Neutron Rich Nuclei ar NUSTAR, FAIR**
- **Established expertise (National Labs)**
- **Nustar will be a value addition to on-going in-house experimental projects**
- **Initiate and nurture high-tech R&D (Universities) & HRD**
- **Linkage between NUSTAR-India and FAIR, to be strengthened**
- **Deliverables for NUSTAR towards funding**

Thanks!