An Overview of Indian Facilities and Research in Nuclear, Particle, Neutrino physics and Astrophysics

Satyaranjan Santra

Nuclear Astrophysics Section

Bhabha Atomic Research Centre

Outline

- Major research facilities in India
- Nuclear physics using facilities at Mumbai, VECC-Kolkata and IUAC-New Delhi
- Neutrino Physics Activities
- Astrophysics- facilities and research
- Collaborative studies in High Energy physics
- Future Mega Science Programmes
- Summary

Major Research Facilities

✓**Nuclear Physics:** Accelerators (Mumbai, Delhi & Kolkata) & reactors (Mumbai)

✓**Neutrino Physics:** Reactors (Mumbai, Kakrapar), International collaborations

✓**Astrophysics:** Radio Telescopes (Ooty and GMRT-Pune), Optical-IR astronomy (DOT-Nainital, HCT-Ladakh, VBT & KSO-Tamilnadu, MAIRO-Gurushikhar), UV & X-ray (ASTROSAT), Gamma ray (MACE & HAGAR-Hanley, TACTIC-Mt Abu, GRAPES-Ooty)

✓**Particle Physics:** Developing **Indigenous Detectors** for experiments using international facilities

Major particle accelerator labs for nuclear physics in India

15 UD Pelletron+Linac Facility, IUAC, New Delhi

14 MV BARC-TIFR Pelletron +Linac Facility, Mumbai

https://www.mapsofindia.com/states/

VECC, Kolkata

K130: E<10 MeV/A & K500: E~50 MeV/A

Accelerators & Reactors for Nuclear Physics Research, Mumbai

Beams: p, α and heavy ions up to A~50

14 MV BARC-TIFR Pelletron-Linac Facility, the Work horse of NPD

3 Beam Halls

Old beam Hall	New beam Hall-1	New beam Hall-2
(Beam energies of Pelletron only)	(Beam energies of Pelletron+Linac)	(Beam energies of Pelletron+Linac)
(**5 beam lines**)	(**3 beam lines**)	(**3 beam lines**)

Total 11 beam lines used for studies on

1. Nuclear reaction
2. Nuclear structure
3. Atomic & molecular physics
4. Material characterization & modification
5. Bio-sciences

6 MV FOTIA at BARC

Beams: p and Li

3 beam lines used for studies on

1. Low energy nuclear physics
2. Material characterization
3. Radiation biology

DHRUVA

DURGA
(Dhruva Utilization for Research using Gamma Array)

ISMRAN
(Indian Scintilator Matrix for Reactor Anti-Neutrino measurement)

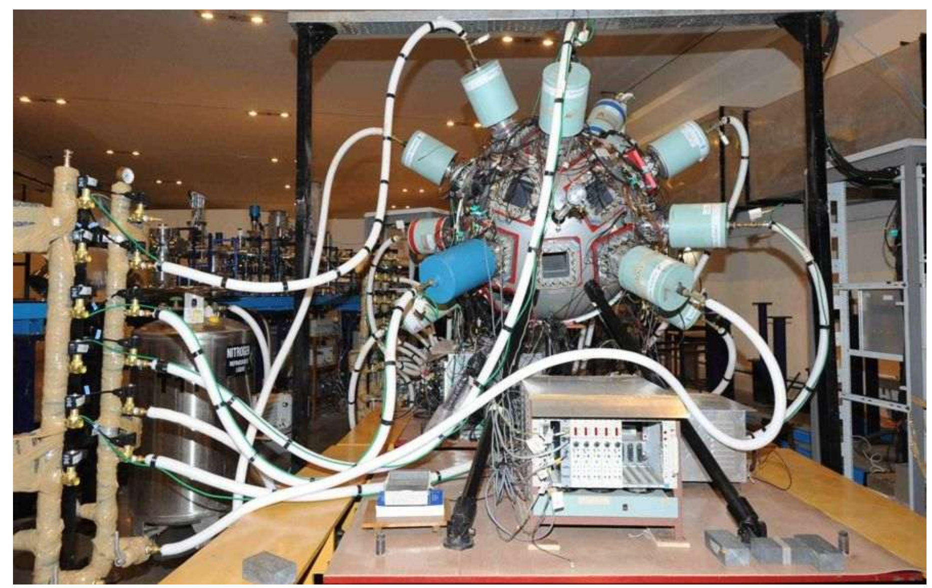
Beam Lines of BARC-TIFR Pelletron-Linac Facility, Mumbai

14 MV BARC-TIFR
Pelletron-Linac Facility

Old beam hall (5 beam lines)

New beam hall-1 (3 beam lines)

New beam hall-1 (3 beam lines)

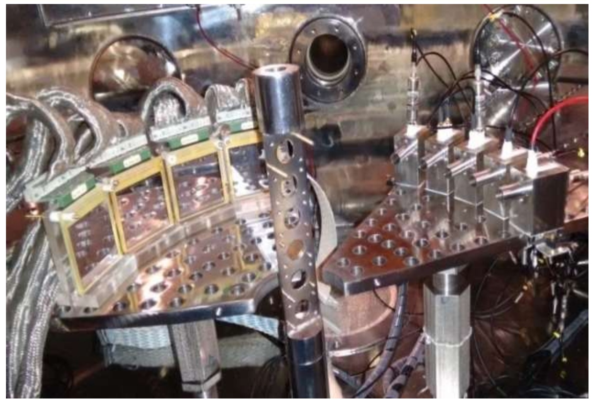


New beam hall-2 (3 beam lines)

Major Nuclear Physics Programmes of BARC

Nuclear level density measurement using liquid scintillators

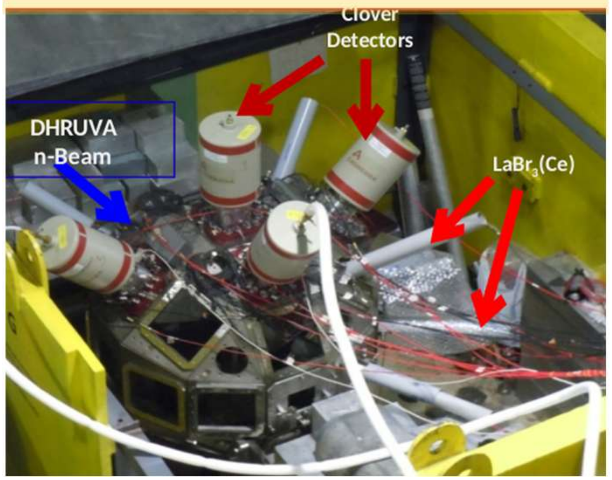
Reactions involving weakly bound projectiles using Si strip detectors



Gamma branching of Hoyle state of ^{12}C using 38 BGO Array

Fast neutron induced fission of Actinides using proton beam at FOTIA

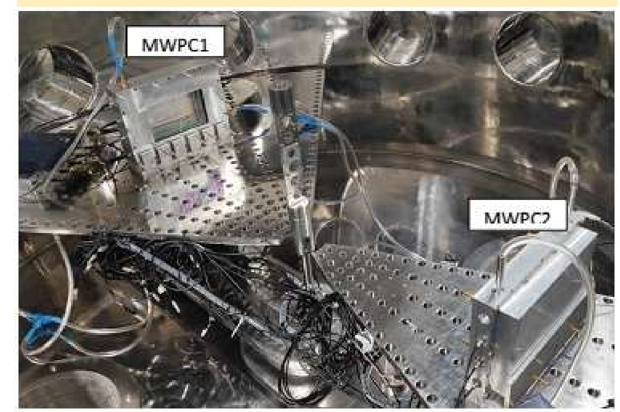
Fission fragment spectroscopy using DURGA at BARC



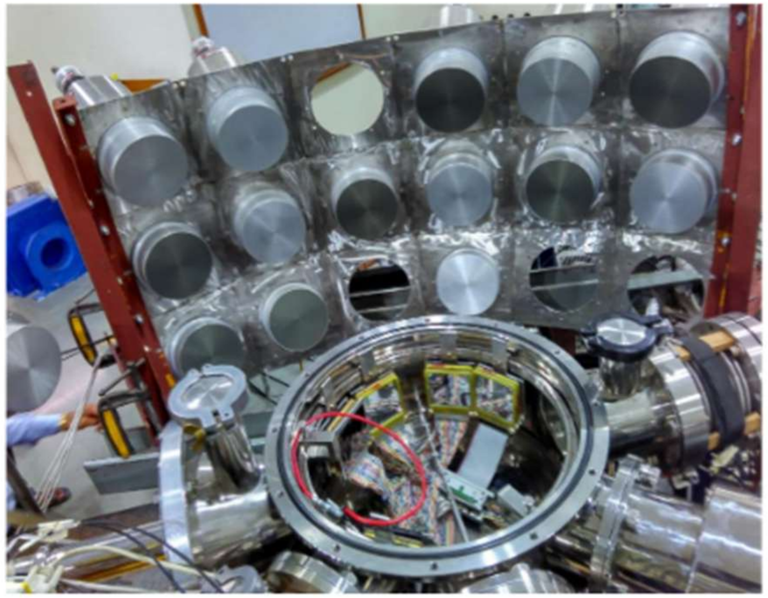
Indian Scintillators Matrix for Reactor Anti-Neutrinos (ISMRAN) at DHRUVA

Fusion measurement by offline Gamma activities using HPGe detectors

Fission mass distribution measurement using indigenous MWPC detectors



Evidence of large collective enhancement of NLD and its significance in neutron capture cross section



Experimental setup

7Li +159Tb, 169Tm @40~MeV
Ex ~ 25-28 MeV

T. Santhosh et al; Phys. Lett. B 841, 137934 (2023)
T. Santhosh et al; Phys. Rev. C *108, 044317* (2023)
G. Mohanta et al; Phys. Rev. C *100, 011602(R), 2019*
G. Mohanta et al; Phys. Rev. C 105, 034607 (2022).

Contents lists available at ScienceDirect
Physics Letters B
journal homepage: www.elsevier.com/locate/physletb
ELSEVIER
Physics Letters B 841 (2023) 137934

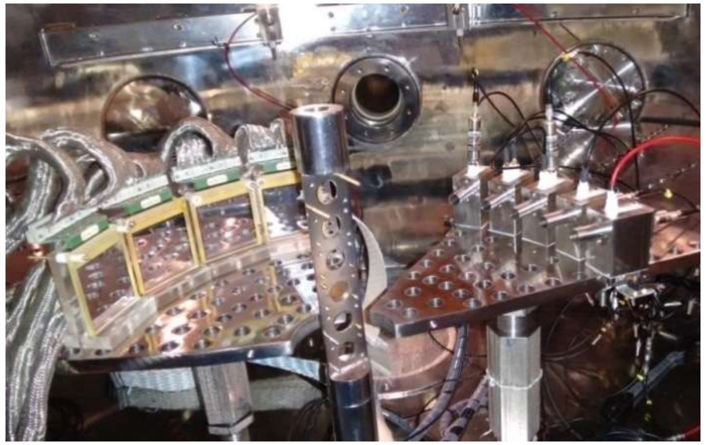
Experimental evidence of large collective enhancement of nuclear level density and its significance in radiative neutron capture

T. Santhosh [a,b], P.C. Rout [a,b,*], S. Santra [a,b], A. Shrivastava [a,b], G. Mohanto [a], S.K. Pandit [a,b], A. Pal [a], Ramandeep Gandhi [a,b], A. Baishya [a,b], Sangeeta Dhuri [a,b]

Measurements on:

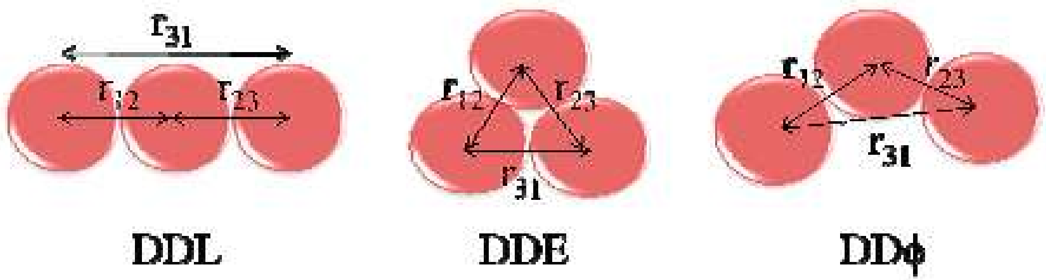
1) Nuclear level density,

2) Cluster structure involving neutrons and charged particles, e.g., $^{9}Be \rightarrow \alpha+\alpha+n$ and $^{5}He \rightarrow \alpha+n$



Study on Hoyle state in ^{12}C

1. Effect of initial 3α cluster configuration in ^{12}C on the direct decay of its Hoyle State



A. Baishya et al. Phys. Rev. C 104 024601 (2021)

Decay Modes	$\frac{\Gamma_{DD}}{\Gamma}(\approx \frac{P_{DD}}{P_{Seq.}})$	$\frac{\Gamma_{DD}}{\Gamma}(\approx \frac{P_{DD}}{P_{Seq.}})$
	$(V = V_C + V_l + V_N)$	$(V = V_C + V_l)$
DDϕ	$(6.2 \pm 0.6) \times 10^{-7}$	$(0.41 - 5.06) \times 10^{-7}$
DDL	$(1.6 \pm 0.2) \times 10^{-7}$	$(0.33 - 6.83) \times 10^{-8}$
DDE	$(1.4 \pm 0.1) \times 10^{-6}$	$(0.41 - 4.47) \times 10^{-6}$

2. Enhancement of ^{12}C production in extreme stellar environments by up-scattering:

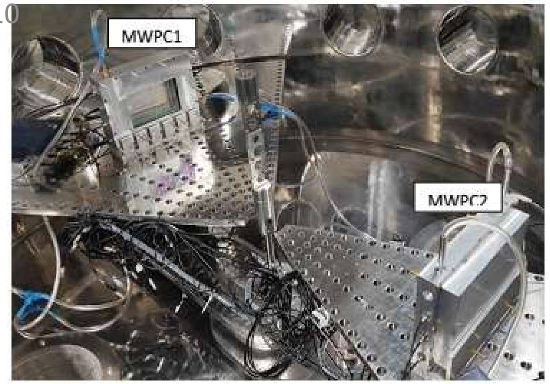
- A. Baishya et al PRC 108, 065807 (2023)

3. Search for Effimov state near Hoyle state of ^{12}C - A. Baishya et al., Submitted

4. Precision measurement of the upper limit on Direct Decay of the Hoyle state of ^{12}C

- A. Baishya et al. , to be submitted

-Detailed talk by **Abhijit Baishya**



MWPC Detectors: Exotic modes of fission

PHYSICAL REVIEW C **104**, L031602 (2021)

Letter

Observation of a fission mode with very short elongation for the neutron-rich ^{257}Md nucleus at high excitation energy

A. Pal,[1] S. Santra,[1,2,*] P. C. Rout,[1,2] Ramandeep Gandhi,[1] Abhijit Baishya,[1] T. Santhosh,[1,2] R. Tripathi,[2,3] and T. N. Nag[2,3]

PHYSICAL REVIEW C **107**, L061601 (2023)

Letter

Shell effect on fission fragment mass distribution at E^*_{cn} up to 70 MeV: Role of multichance fission

S. Santra,[1,2,*] A. Pal,[1] D. Chattopadhyay,[1,2,†] A. Kundu,[1,2] P. C. Rout,[1,2] Ramandeep Gandhi,[1,2] A. Baishya,[1,2] T. Santhosh,[1,2] K. Ramachandran,[1] R. Tripathi,[2,3] B. J. Roy,[1] T. N. Nag,[2,3] G. Mohanto,[1] S. De,[1,2] B. K. Nayak,[1,2] and S. Kailas[4]

PHYSICAL REVIEW C **110**, 034601 (2024)

Experimental evidence of shell effects in slow quasifission

A. Pal,[1,2,*] S. Santra,[1,2,†] P. C. Rout,[1,2] A. Kundu,[1,‡] D. Chattopadhyay,[1,§] Ramandeep Gandhi,[1,2] P. N. Patil,[3] R. Tripathi,[2,4] B. J. Roy,[1,2] Y. Sawant,[1] T. N. Nag,[2,4] Abhijit Baishya,[1,2] T. Santhosh,[1,2] P. K. Rath,[5] and N. Deshmukh[6]

- Super-short mode of fission
- Persistence of shell effect on fission at very high excitation energies
- Search for shell effect in slow quasi-fission

-Detailed talk by **Asim Pal**

Nuclear Structure Research Programme at Dhruva reactor, BARC

Dhruva **U**tilization in **R**esearch using **G**amma **A**rray (DURGA)

A Digital hybrid array of Compton-suppressed clovers (08) + $LaBr_3(Ce)$ fast scintillators (11)

✓Fission Fragment Spectroscopy (FFS)

Exploring neutron-rich fission fragment nuclei

✓Capture Gamma Spectroscopy (CGS)

Exploring low-spin structures and shapes of nuclei.

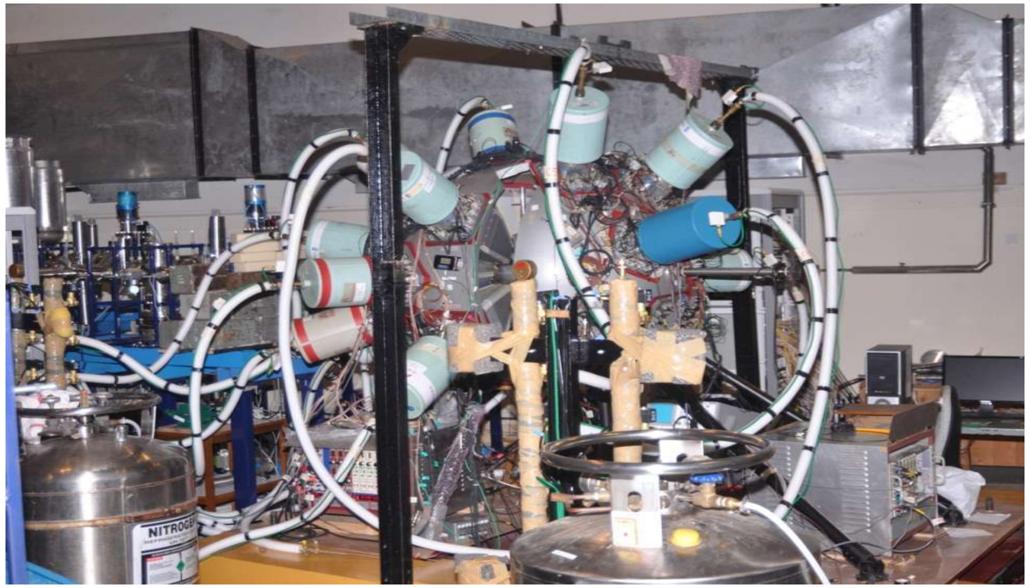
✓Decay Gamma Spectroscopy (DGS)

Measure half-lives, and structures of daughter nuclei.

- **A unique facility in the country to carry out prompt-γ coincidence spectroscopy.**
- **The facility complements the existing experimental nuclear structure research programme in other heavy-ion accelerator centres (TIFR, VECC and IUAC).**

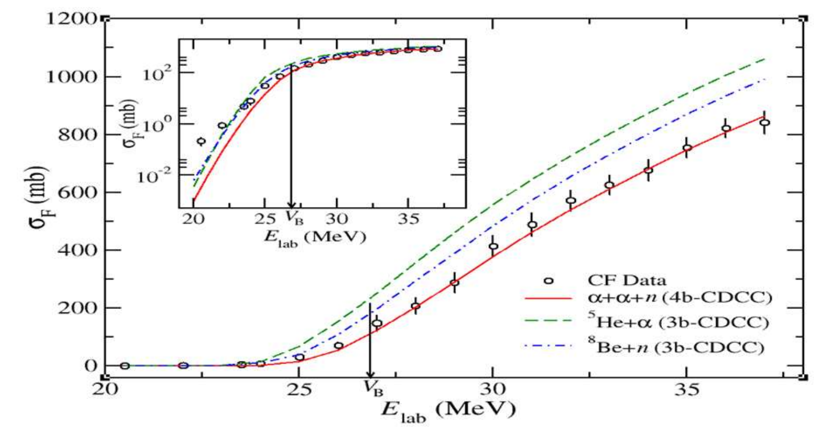
Detailed talk by: Dr. Somsundar Mukhopadhyay, NPD, BARC (somm@barc.gov.in)

Digital INGA with CPDA

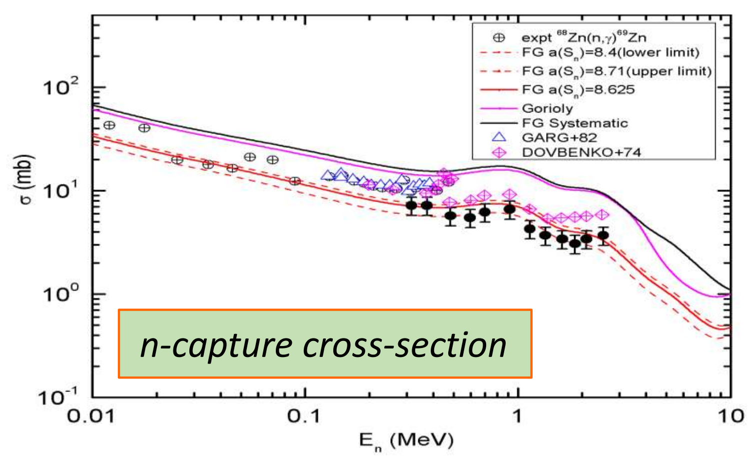


R Palit et al., EPJA 61(4) 1-36 (2025)

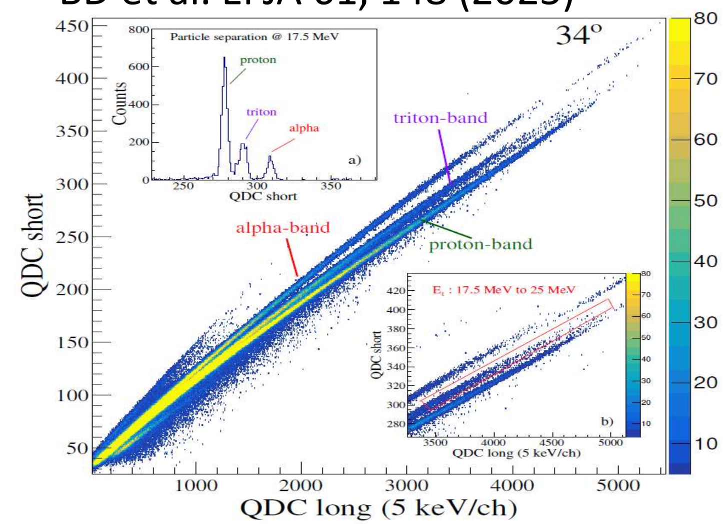
α-clustering in ^{9}BeBorromean Nucleus
AK et al., PLB 864, 139441 (2025)



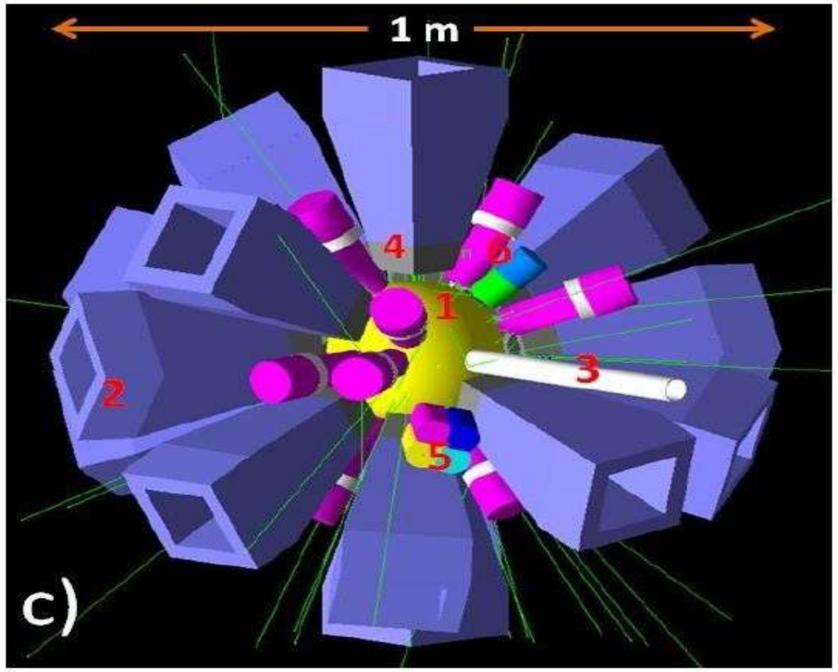
Gamma-gated particle spectrum
RS et al., PLB 806 (2020) 135487



Alpha-cluster structure in 54Cr
BD et al. EPJA 61, 148 (2025)



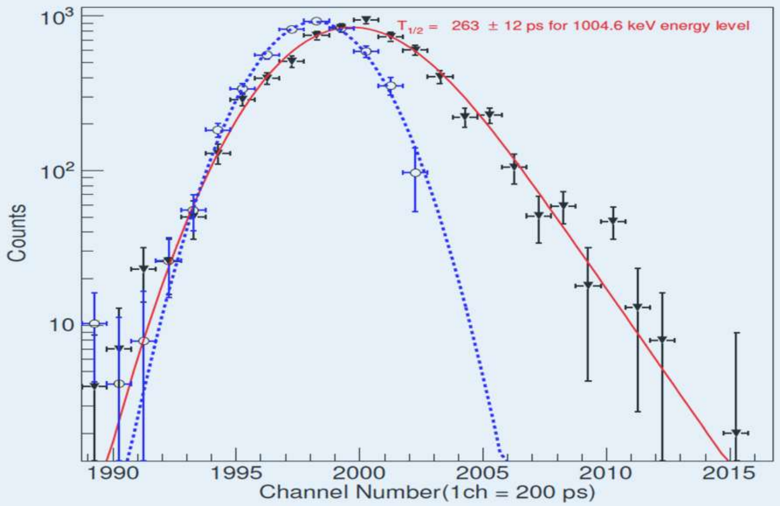
Exclusive spectroscopy measurements with Hybrid Array of HPGe Clover – LaBr3(Ce) detectors



RP et al., EPJST 233, 933 (2024).
BD et al., Jl. Of Instrum. Soc. Of India 51, 44 (2021)

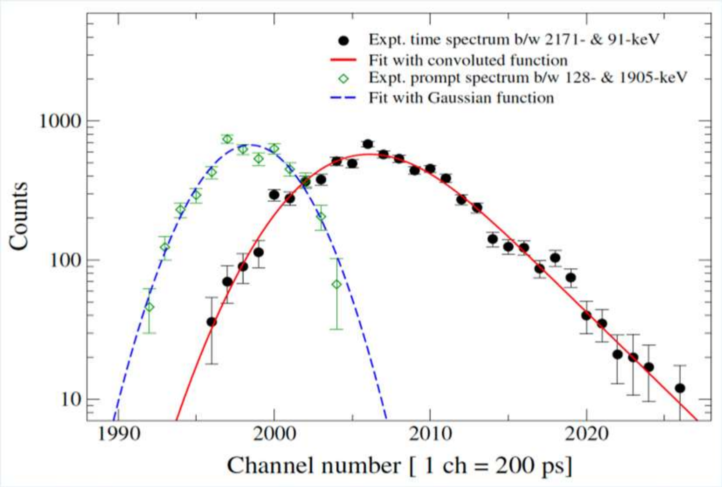
- Investigation of exotic nuclear shapes with Coulex, lifetime measurements and spectroscopy.
- Nuclear isomers
- Nuclear reaction dynamics
- Reactions for nuclear astrophysics

Evolution of octupole Correlations in La isotopes with fast timing



MdSRL et al., PRC104, Letter 011301 (2021)

Octupole-phonon and particle coupling in ^{91}Zr isotopes

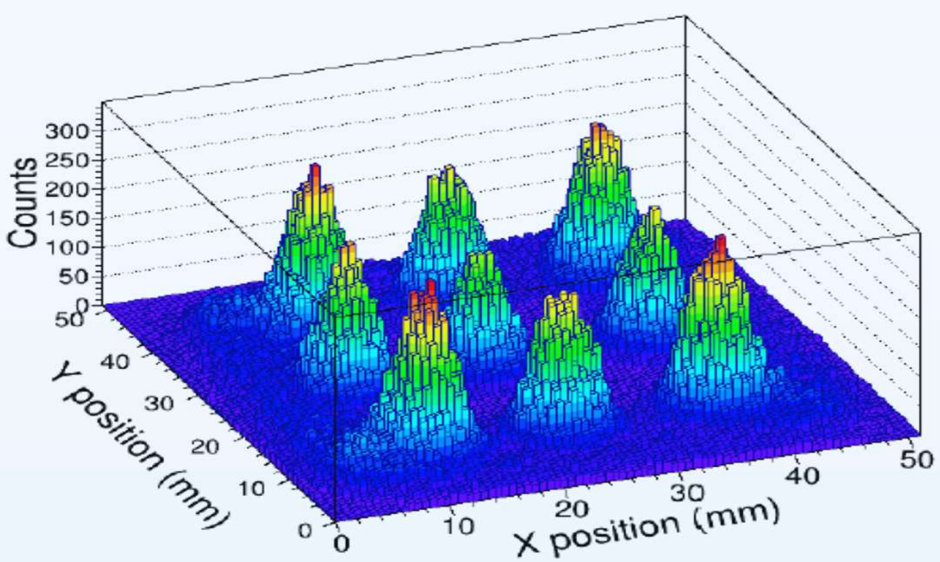


PD et al., et al. NPA 1057, 123035 (2025)

Position sensitive gamma ray detectors for basic research and applications

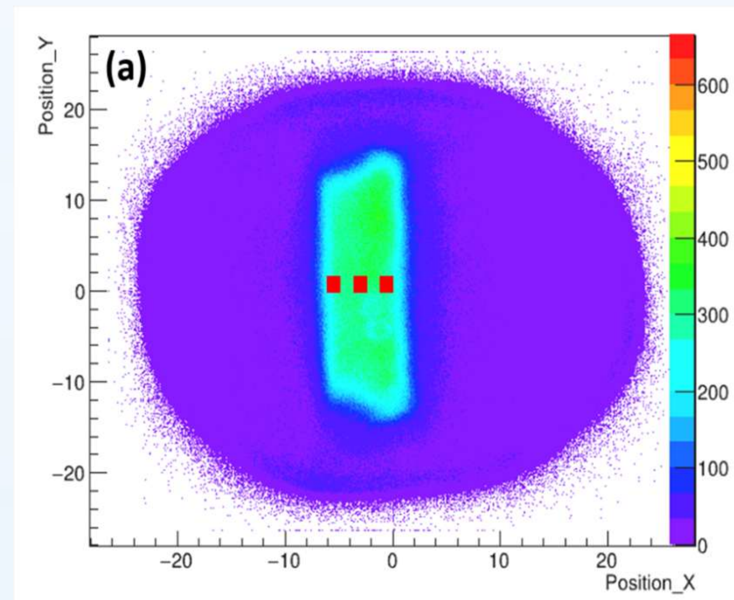
Development of position sensitive scintillator detector

B. Das et al., NIM A 1048 167928 (2023)



Pulse shape study in semiconductor detector and imaging

A. Sharma et al., NIM A 1051 168233 (2023)



Two Best student research paper awards in 7th International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA 2021), Prague, Czech Republic

Variable Energy Cyclotron Centre (VECC), Kolkata

K130 Cyclotron +
ECR Source
Energy ≤ 10 MeV/A

Mean field dominated
Binary decay

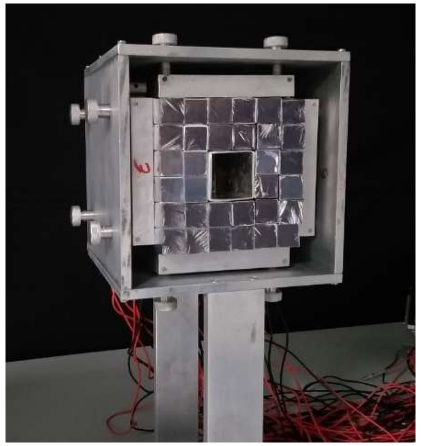
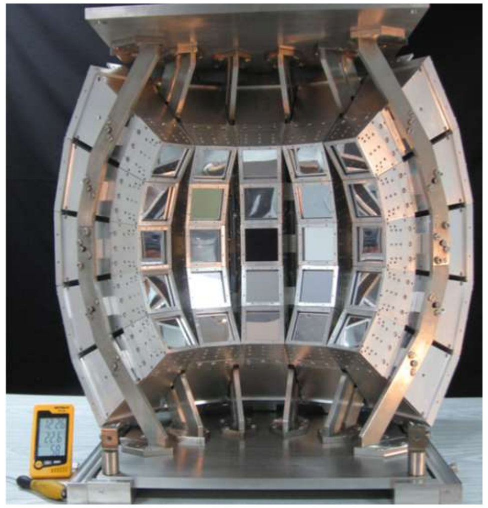
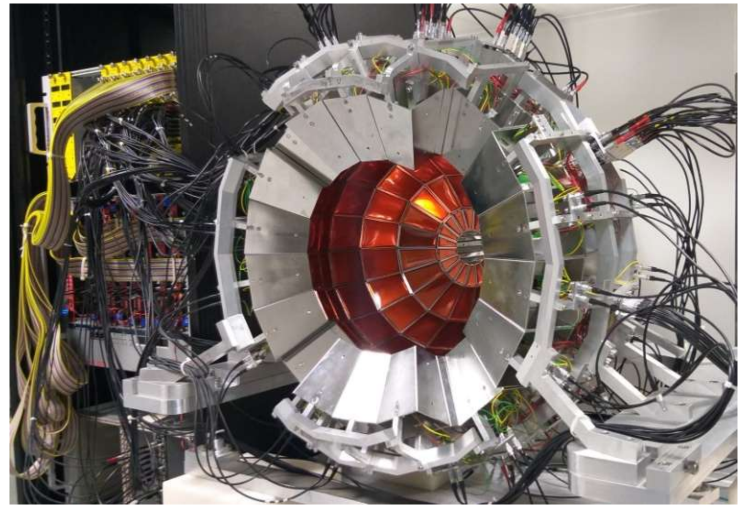
K500 Cyclotron +
ECR Source
Energy ~ 50 MeV/A

Presently running at 18 -30 MeV/A

Nucleon-nucleon collision
Multifragmentaion

Detectors for Nuclear Reaction Studies at VECC

4π **Ch**arged particle detector **A**rray for **K**inematic **R**econstruction and **A**nalysis (**ChAKRA**)

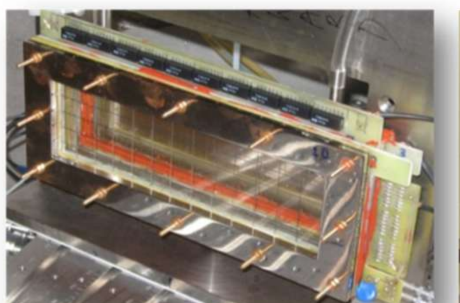
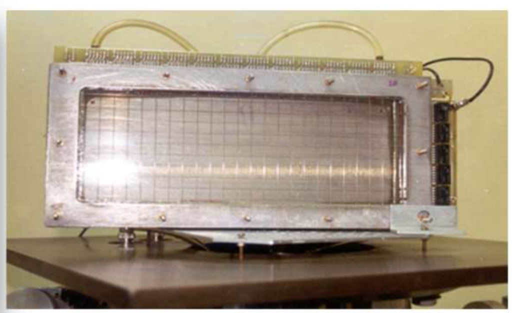
S. Kundu et. al., NIMA 943 (2019) 162411

Large segmented horizontal axis reaction chamber (SHARC)

Neutron Detectors array

K. Banerjee et. al., NIMA 608 (2009) 440

Multi wire proportional Counter

T. K. Ghosh et. al., NIMA 540 (2005) 285

Nuclear Reaction Studies at VECC

1. Fission dynamics in heavy and superheavy nuclei
2. Resonance states in light nuclei (Hoyle and Hoyle-analog states)
3. Investigation of nuclear level density
4. Multi-fragmentation and isoscaling studies
5. Cluster structures in light mass nuclei

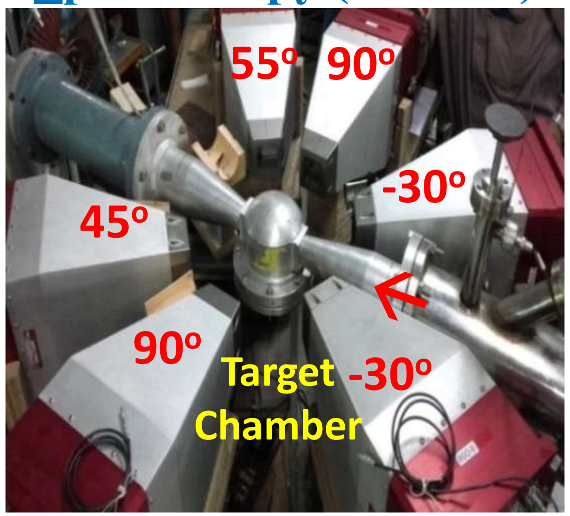
More details can be found on the plenary talk by
Tilak Kumar Ghosh, VECC

Nuclear structure studies at VECC

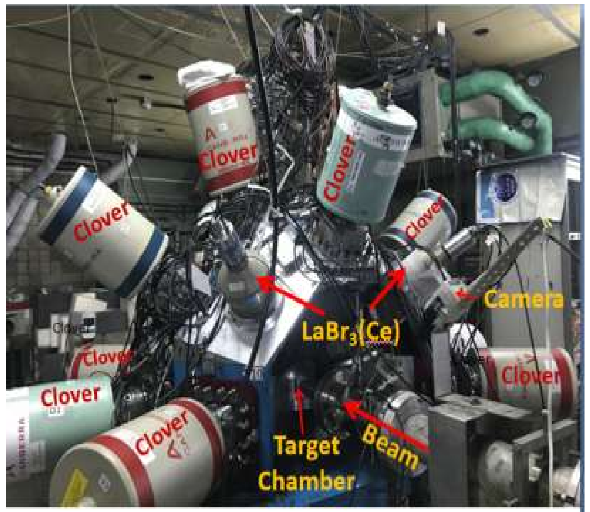
Probing shape of nuclei using high resolution spectroscopy:

Compton suppressed Clover HPGe Detectors Array

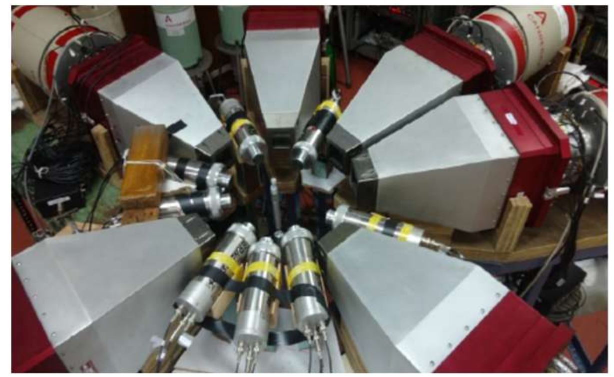
VECC array for NUclear Spectroscopy (VENUS)



Indian National Gamma Array INGA @ VECC



VENUS + VENTURE (Clover + Fast Scintillator)



VECC array for Nuclear fast Timing and angUlar corREIation studies

Beta-Gamma coincidence setup (HPGe and LEPS)

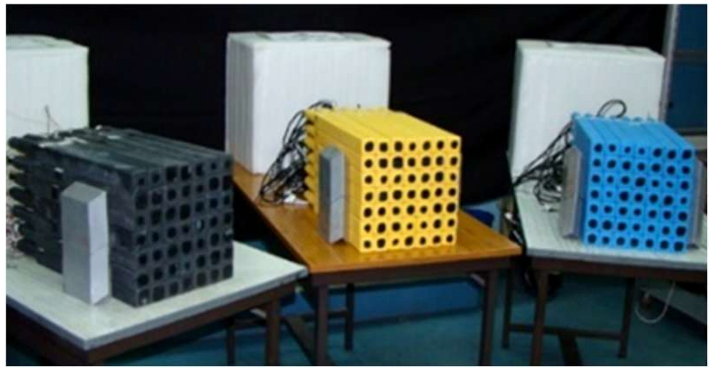
Experimental studies using light and heavy ion beams from K-130 cyclotron at VECC:

- Shape evolution and effect of high-j orbitals in near-spherical nuclei around the shell closures.
- Higher order shapes and symmetries in nuclei: Octupole and tetrahedral deformation
- Manifestation of triaxal shapes in transitional nuclei → Wobbling motion, Gamma vibration, chirality
- Lifetime measurements using fast timing techniques and Doppler Shift Attenuation Method

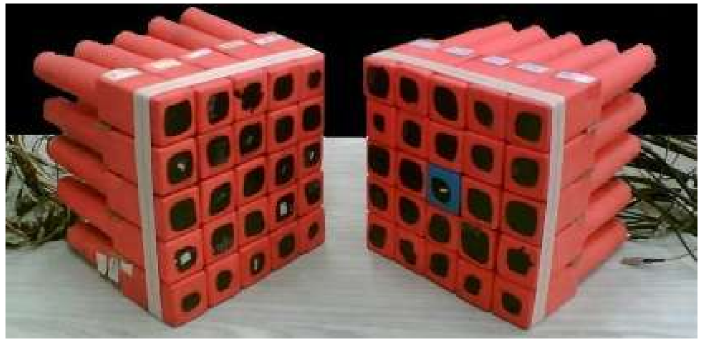
Nuclear structure studies at VECC

Probing Nuclear Structure at High excitations using Giant Dipole Resonance:

Large Area Modular BaF_2 Detector Array (LAMBDA)

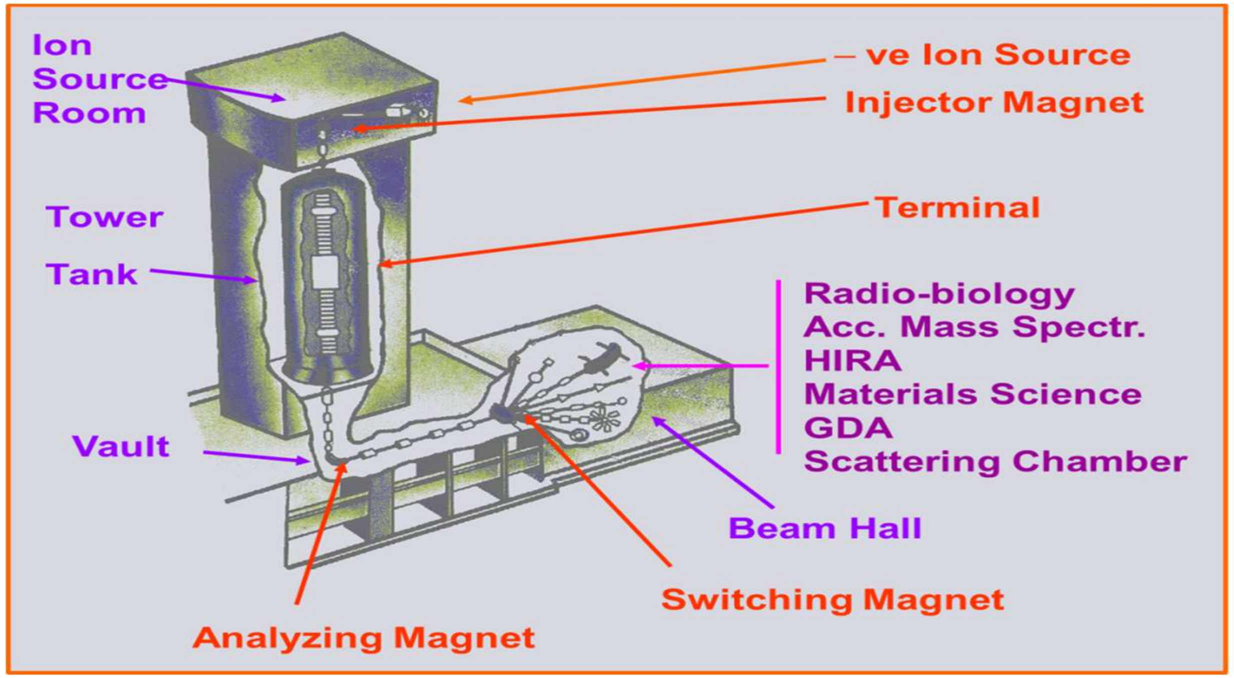


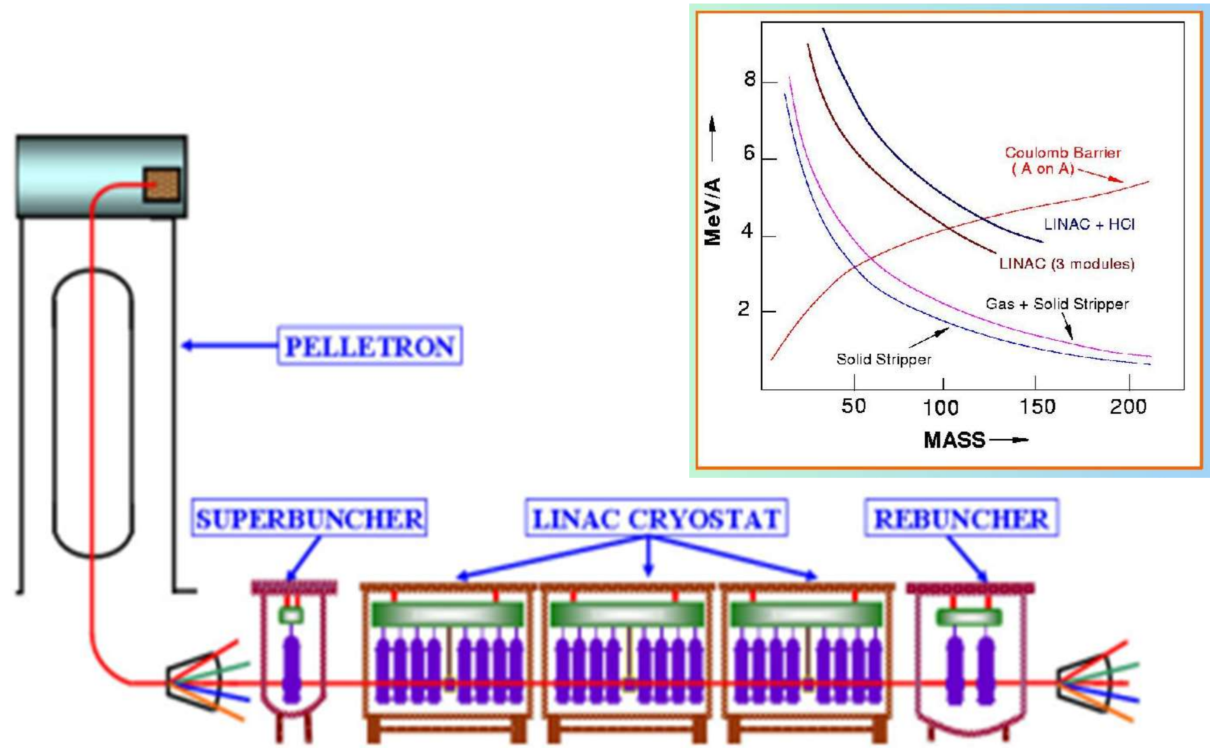
Gamma Multiplicity Filter



- Temperature and angular momentum dependence of the intrinsic GDR width
  - GDR at low temperature using Alpha beams from K-130 cyclotron
  - A new model has been proposed:
  - CTFM (critical temperature included thermal shape fluctuation model)
- Jacobi shape transition at high rotational frequencies and hyper-deformation in alpha cluster nuclei
- Isospin mixing studies via GDR
- Loss of collectivity at high temperatures
- Pre-equilibrium GDR
- Fission time scales & dissipative fission dynamics
- Fluidity of Finite Nuclear Matter
  - Experimental Determination of η/s for Finite Nuclear Matter

15UD Pelletron+LINAC at IUAC, New Delhi





Ions : H to Au, Current: 5-50 pnA, Energy: 30-250 MeV

Major Studies and Facilities

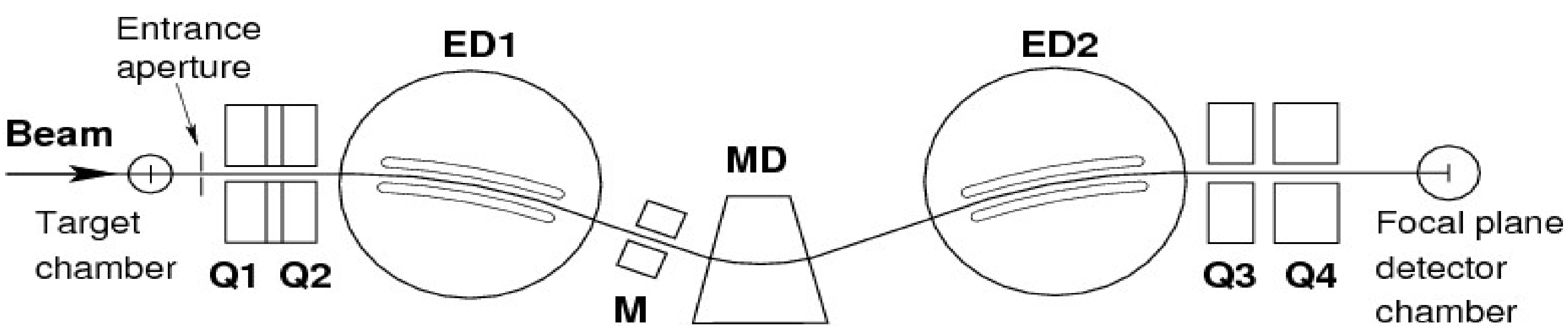
(a) Study of nuclear structure

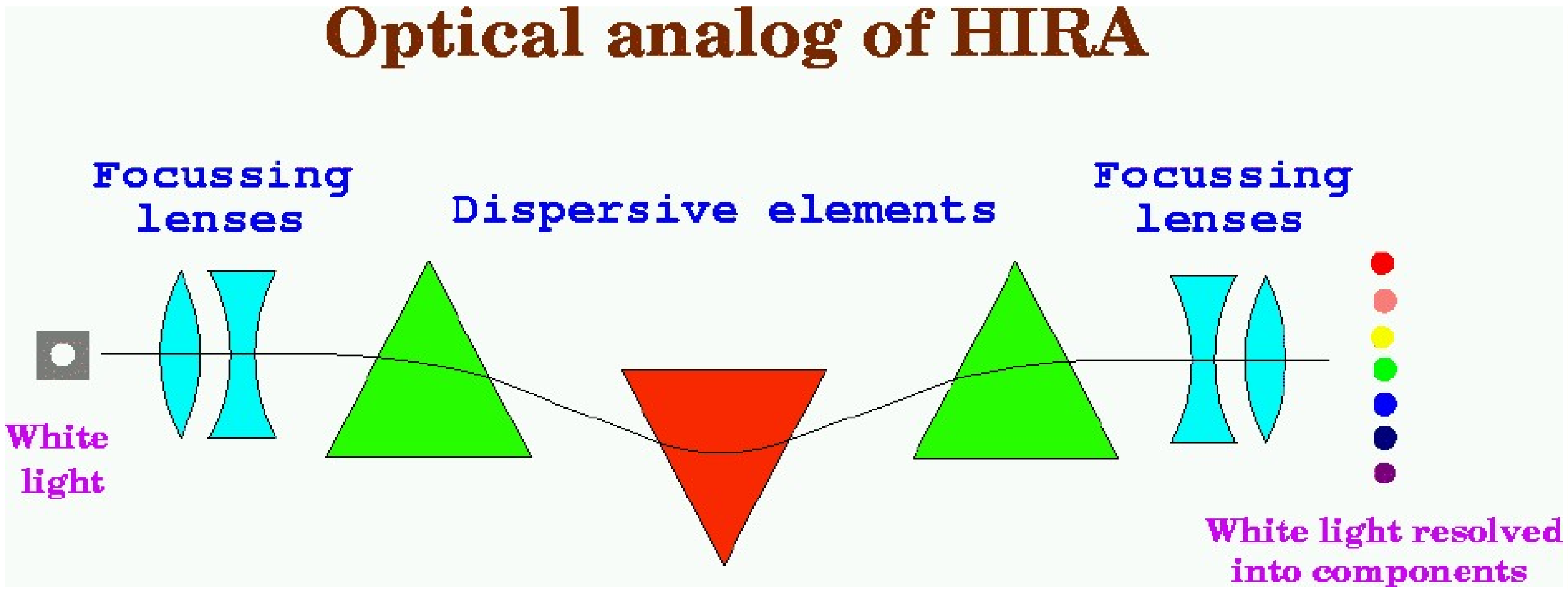
- ❑ Gamma Detector Array (**GDA** in BH-1)
- ❑ Indian National Gamma Array (**INGA** in BH-2)

(b) Study of reaction dynamics

- ❑ Heavy Ion Reaction Analyzer (**HIRA** in BH-1)
- ❑ HYbrid Recoil mass Analyzer (**HYRA** in BH-2)
- ❑ General Purpose Scattering Chamber (**GPSC** in BH-1)
- ❑ National Array of Neutron Detectors (**NAND** in BH-2)

Heavy Ion Reaction Analyzer (HIRA)

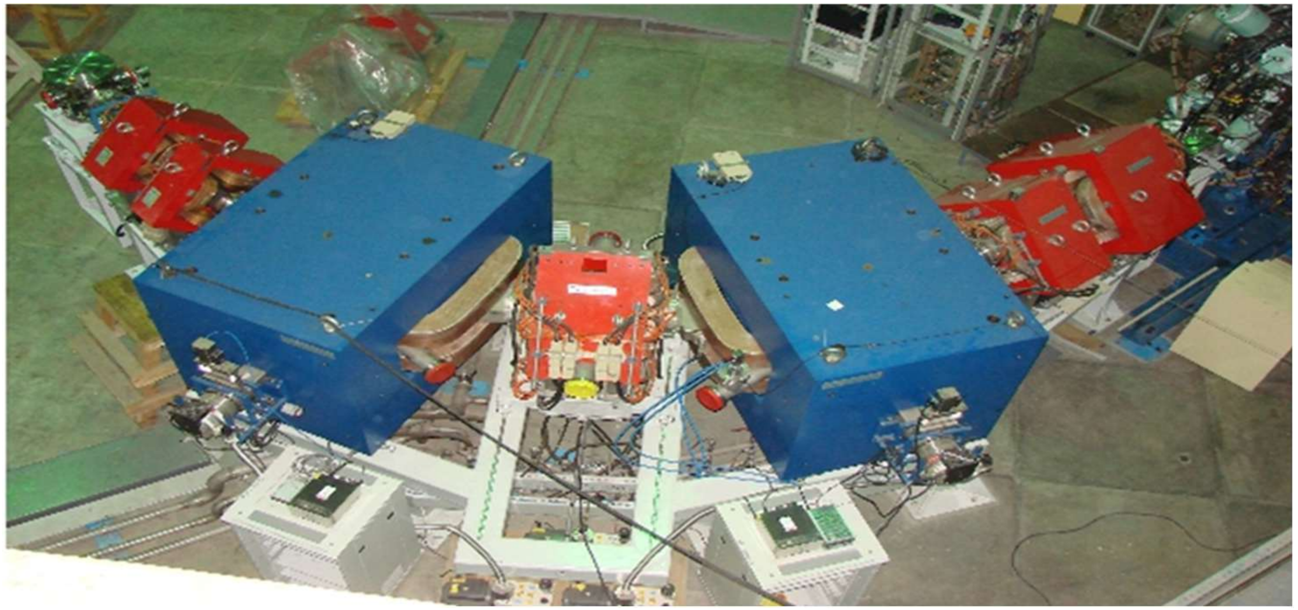




Characteristics:

- ❑An RMS, first of its kind in Asia
- ❑Efficient rejection of primary beam
- ❑Transport reaction products (ER, transfer products, or secondary beams) to the focal plane for detection and analysis.
- ❑^{7}Be beam: ^{7}Li(p,n)^{7}Be, 10^{4} pps

INGA-HYRA beam line



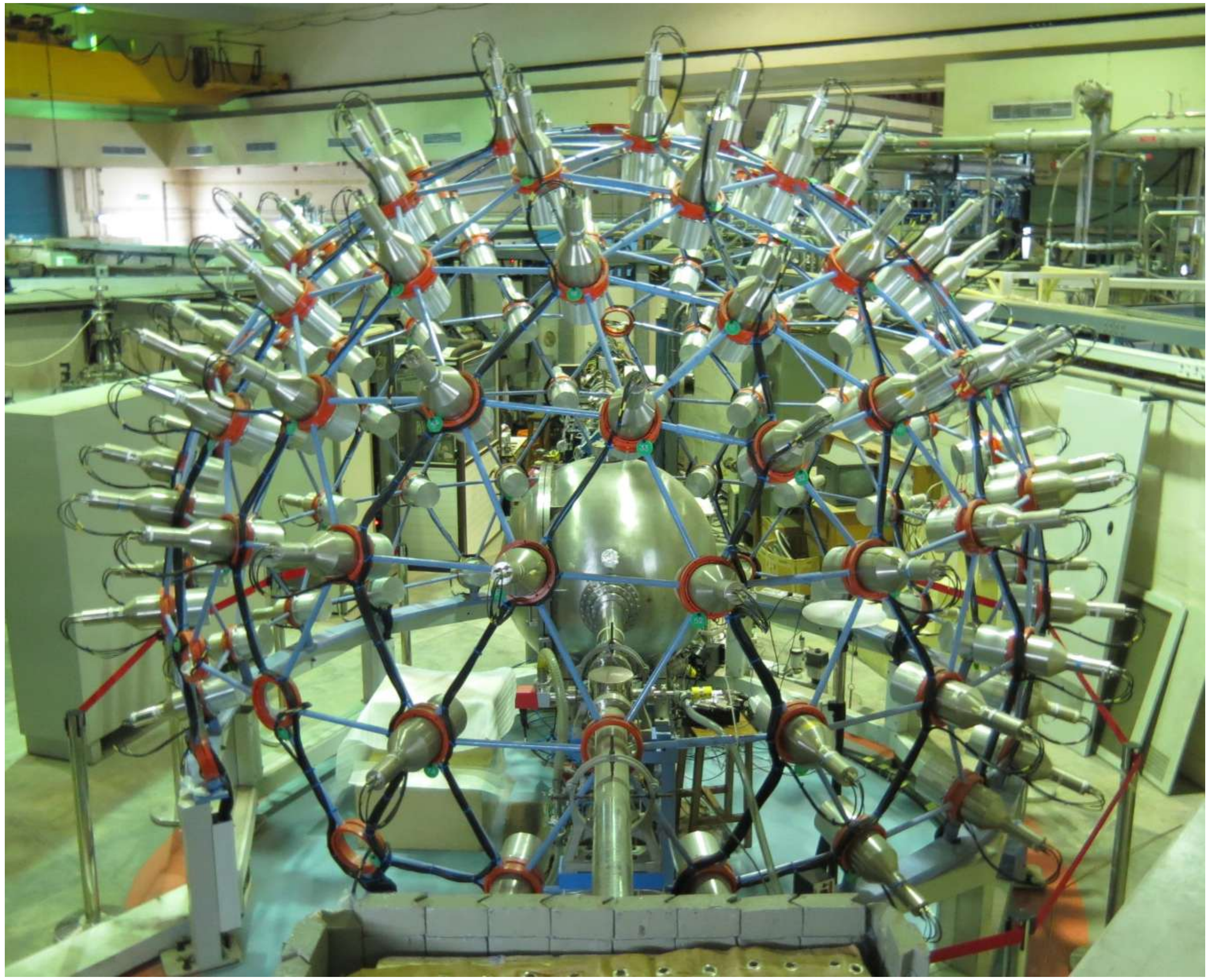
Characteristics:

❑Versatile, dual-mode (gas-filled/vacuum), dual-stage spectrometer/separator for heavy and light nuclei.

❑Study of quasi-fission via ERs

❑Fusion-fission reaction for SHE synthesis

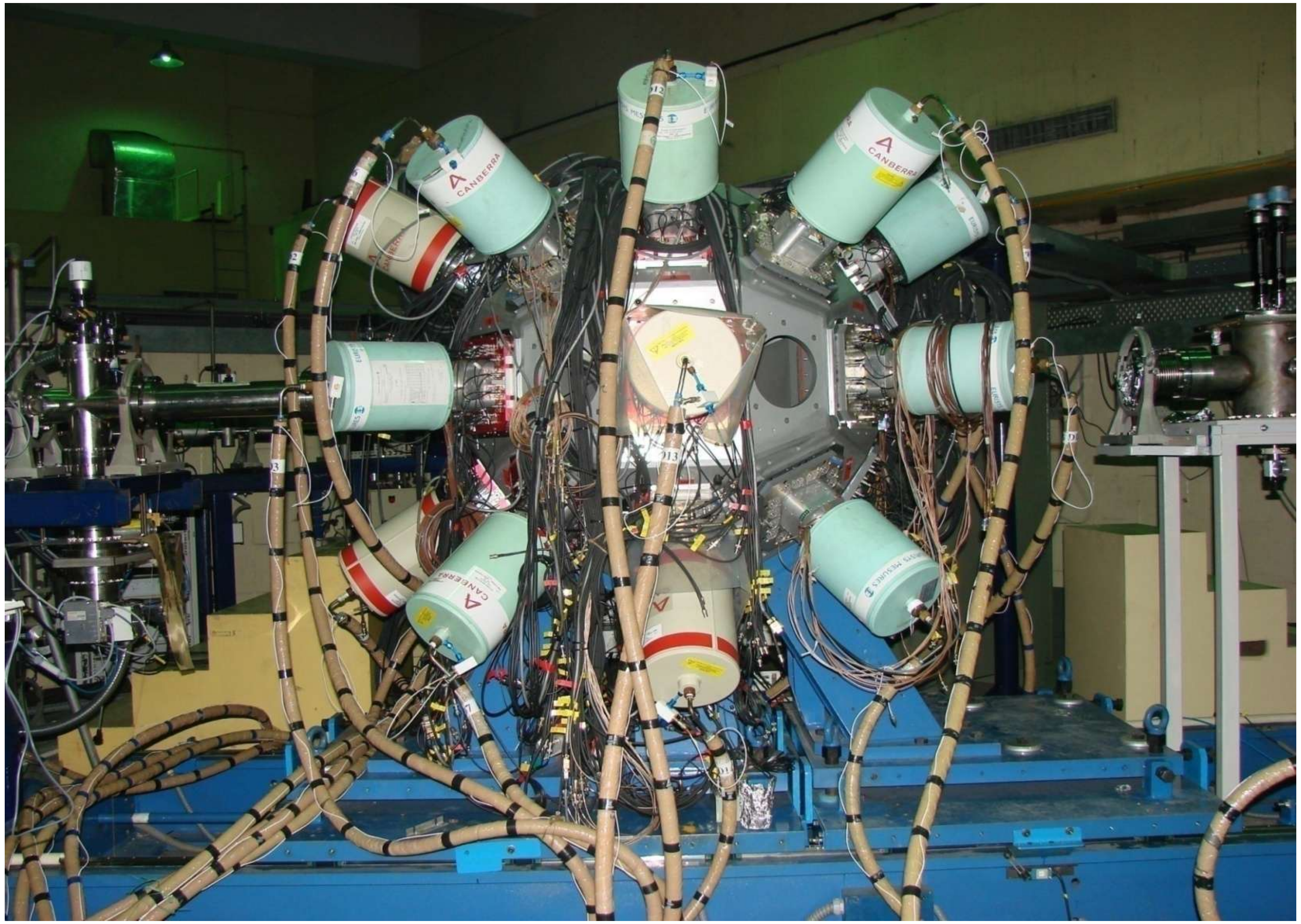
National Array of Neutron Detectors (NAND)



Physics with NAND

- Time scales associated with fusion-fission process
- Neutron multiplicity distribution measurements
- Formation and understanding of unstable heavy nuclei
- Study of nuclear viscosity
- Weakly bound neutron halo nuclei

Indian National Gamma Array (INGA) @ IUAC



Physics: Investigation of nuclear structure

Features

- Array of Compton-supressed Clover detectors with ~4π geometric coverage
- Individual shields subtend ~ 30° at the target
- Maximum 24 Clovers accommodated
- Total photopeak efficiency of INGA ~ 5%
- Array optimized for γ–γ–γ and higher fold data
- Can be used with auxiliary detectors like CsI-based charge particle detector array (CPDA)

2. Neutrino physics research in India

Neutrino physics research in India

Experiment

- **I**ndian **S**cintillator **M**atrix for **R**eactor **A**nti-**N**eutrino (ISMRAN) experiment at BARC
- **I**ndian **N**eutrino **O**bservtory (INO), TIFR, BARC, IICHEP
- **I**ndian **C**oherent **N**uclear **S**cattering **E**xperiment (ICNSE) at BARC

Theory

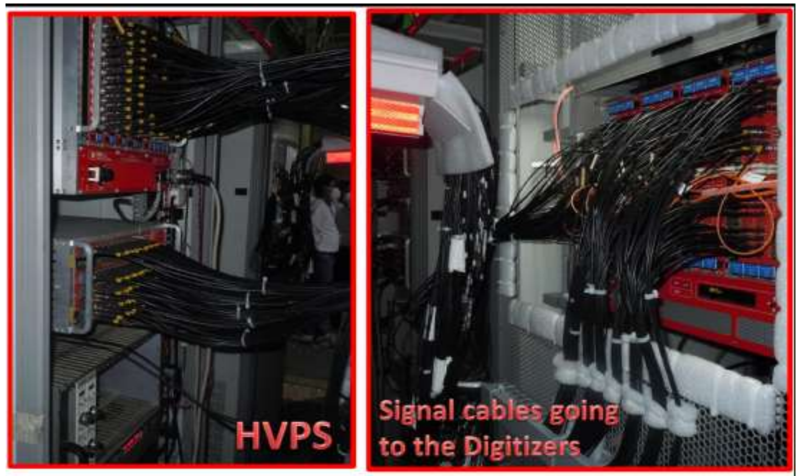
- India has strong theory groups in ν-physics since the 70s at AMU, Calcutta Univ., Calicut Univ., HRI, IIT (Bombay), IIT (Kharagpur), IMSc, Mysore Univ., PRL, SINP, TIFR.

Collaboration

- Neutrino Experiments: NOνA and MINERνA (Fermilab)

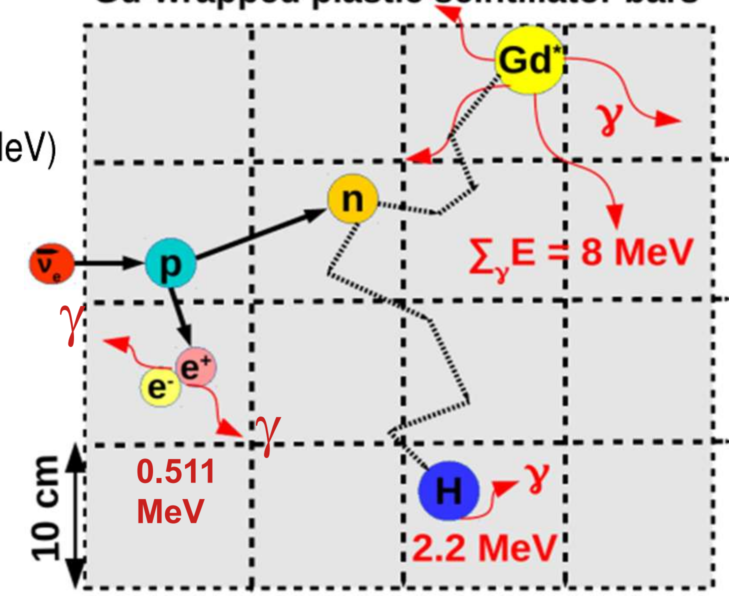
Indian Scintillator Matrix for Reactor Anti-Neutrino (ISMRAN) @BARC

- A 1m^3 plastic scintillator detector with Pb-shield+ muon veto detectors to measure reactor anti-ν_e at 13m, 19m @ 100MWth DHRUVA @BARC, Mumbai.

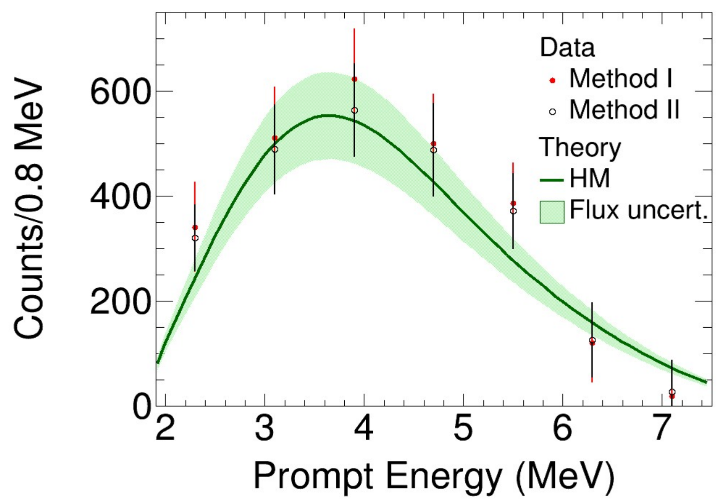


$\bar{\nu}_e + p \rightarrow e^+ + n$ (E_{th} = 1.806 MeV)

Gd-wrapped plastic scintillator bars



1m×10cm×10cm ×90 nos. bars+ 2 PMTs L&R



Anti-neutrino candidate events.

Reactor power : ~77 MW$_{th}$
D ~ 18 m, efficiency ~ 38 %
RON : 41 days, ROFF : 16 days
Candidate events : 2499 ± 224 (stat)
Expected rate : 2639 ± 52

The expected anti-neutrino rate in ISMRAN ~ 40 / day.

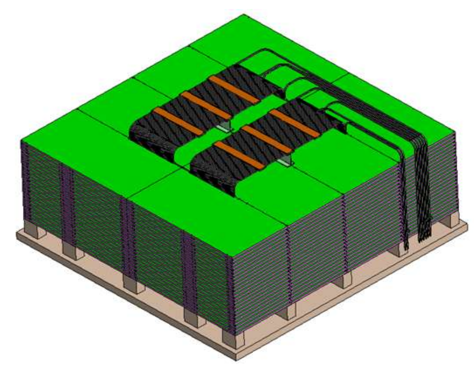
R&D activities related to INO

- 2m×2m glass RPCs, Front-end and back-end electronics, Data acquisition system, Simulation and data analysis software, A 85-ton 4m ×4m×1.2m mini-ICAL detector of cosmic muons with a max. B-field of ~1.4 Tesla, closed loop gas system (upto 4 components), chilled water system for Magnet PS and magnet coils etc.

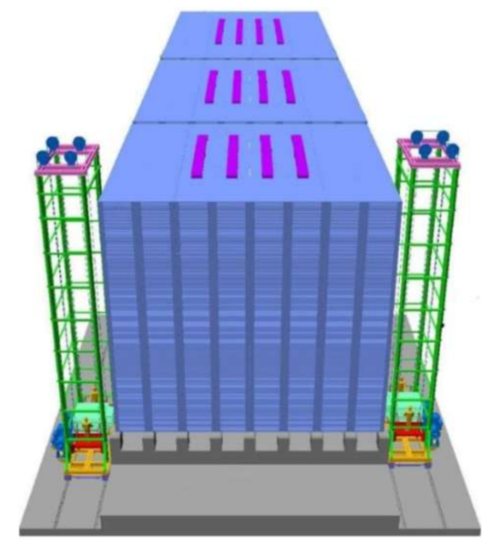
Building magnets – towards a magnetised ICAL for atmospheric ν_μ

35-ton Prototype magnet at VECC, Kolkata (2008-2010)

85-ton mini-ICAL detector at @ Madurai transit campus (2018)



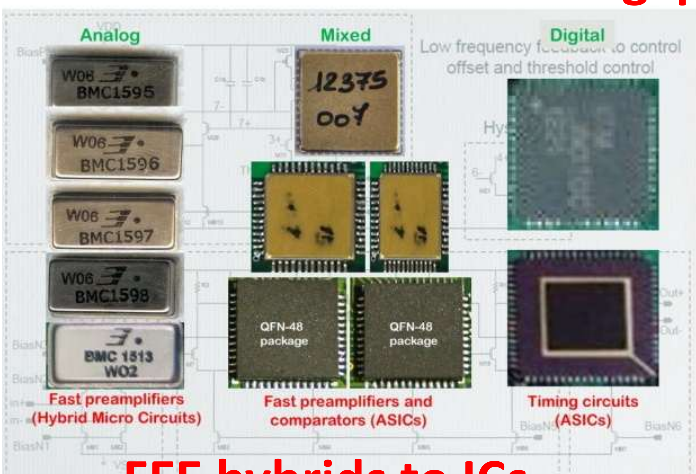
800-ton E-ICAL @ VECC, Kolkata (2023-24)?



51-kton ICAL

Glass RPC gap at St. Gobain

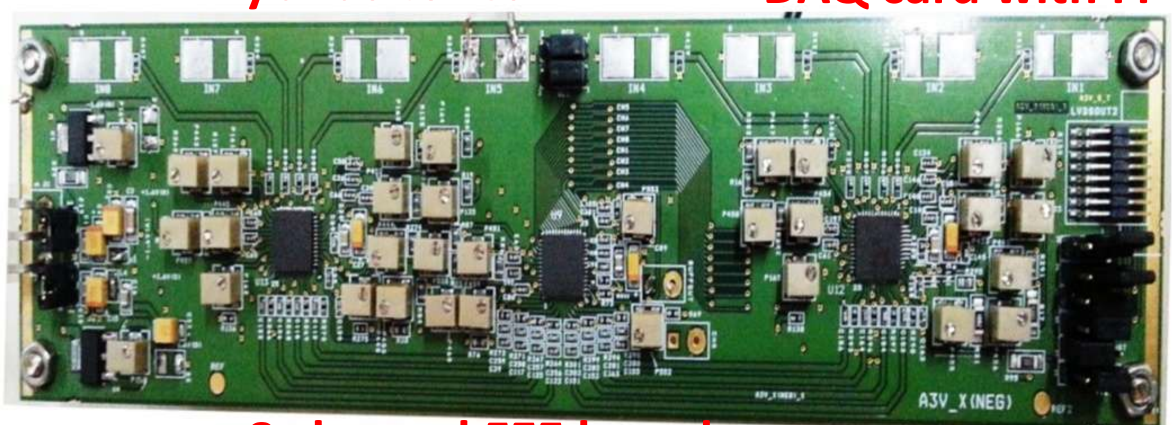
Closed loop gas system



FEE hybrids to ICs

DAQ card with FPGA, HPTDC

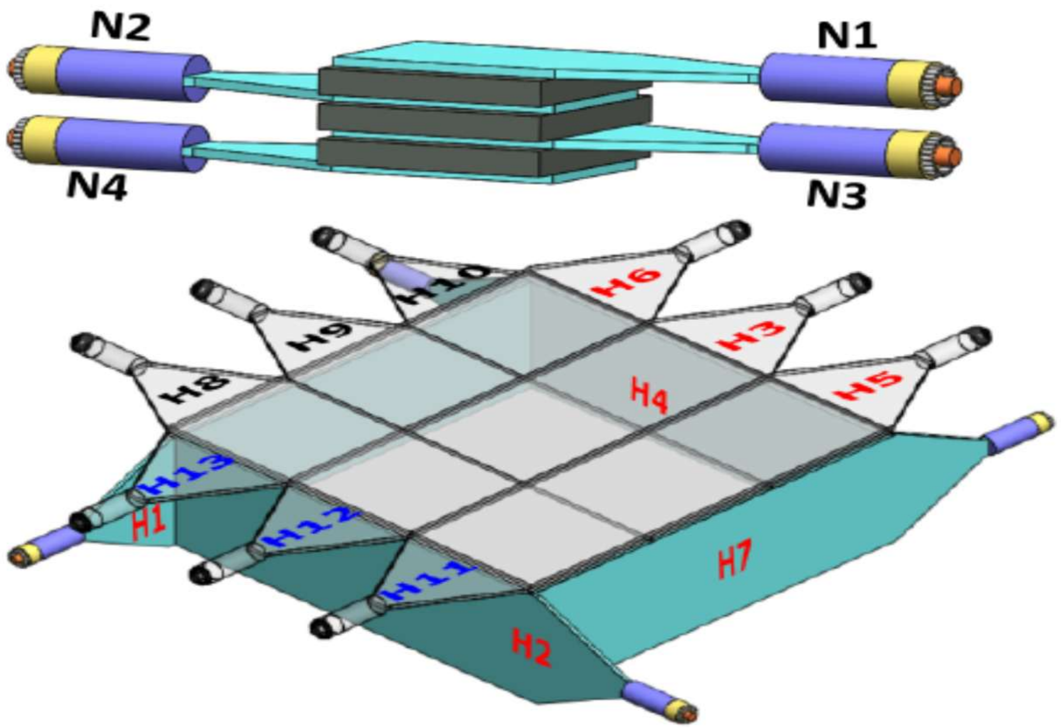
±5 kV DC-DC HV card



8 channel FEE board

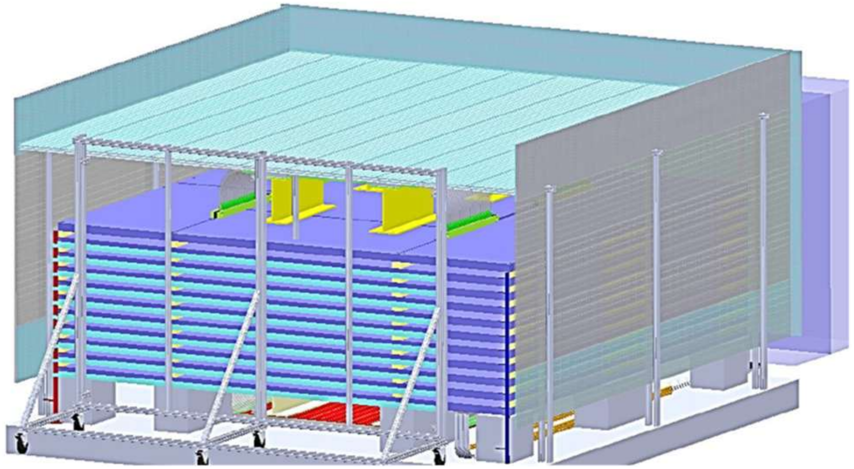
Trigger and Calibration system

A cosmic muon veto detector (CMVD) built by INO GTP students



Veto efficiency = 99.978 ± 0.003 %

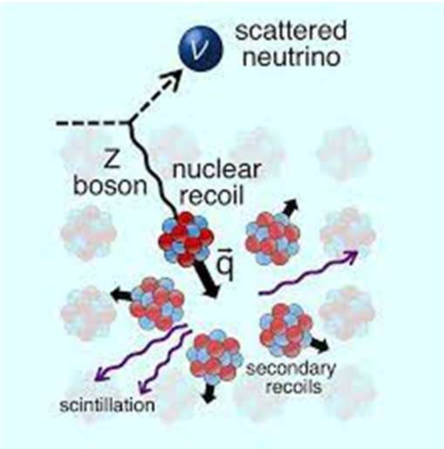
N. Panchal et al JINST ***12****, T11002 (2017)*

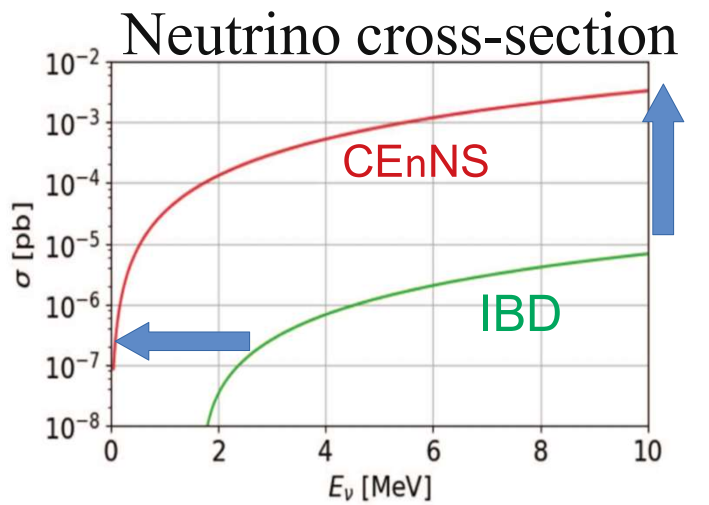


CMVD for mini-ICAL

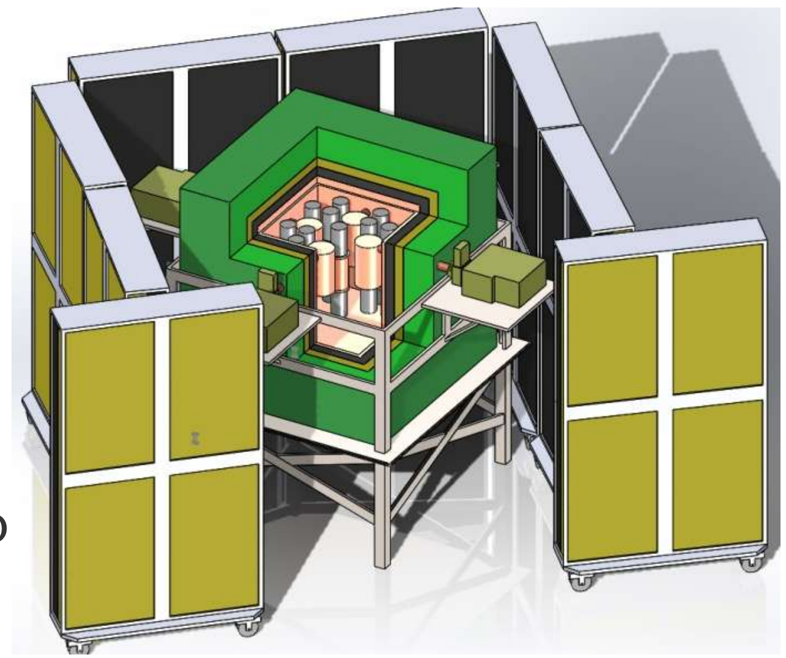
Mamta Jangra *et al.*, J. Inst. **16,** P11029 (2021)
Mamta Jangra *et al.*, J. Inst. **17**, P07019 (2022)

Coherent elastic neutrino-nucleus scattering (CEnNS)





200 x more cross section than IBD
No reaction threshold as IBD.



Proposed detector : HPGe

Challenge is to measure very small Signals (< 40 keV).

Point Contact HPGe detectors
Mass: 2.4 kg/HPGe crystal, Threshold: 150 - 180 eV_{ee},
Electrically cooled to below 77K
Surrounded by NaI(Tl) detectors for anti-compton shield

- Large cross sections – small detectors
- Possibility to measure $\sin^2\theta_W$ at low energies
- Measurements of neutron form factors
- Nuclear reactor monitoring
- Precision flavor-independent neutrino flux measurements for oscillation experiments
- Sterile neutrino searches
- Input for DM direct detection (neutrino floor)

Proposed experimental setup at :
1) Upgraded APSARA (BARC) : 2 MWth : 6 m from core
2) Kakrapar Atomic Power Station : 2.1 GWth : 30 m from core

Time line : 2028 installation and data taking

3. Astrophysics

Radio Astronomy (NCRA, Pune / TIFR, Mumbai)

Ooty Radio Telescope (ORT), Ooty

Giant Meterwave Radio Telescope (GMRT), Pune
(largest & most sensitive at meter wavelentghs)

Goals :

❖Galaxy evolution and neutral hydrogen (HI) mapping at high redshifts.
❖Pulsar discoveries and studies of pulsar emission mechanisms.
❖Transient radio sources and Fast Radio Bursts (FRBs).

Optical -IR Astronomy

(IIA Bangalore, ARIES Nainital, PRL Ahmedabad)

3.6 m Devasthal Optical Telescope, **Nainital**

2 m Himalayan Chandra Telescope (HCT) & 0.7 m GROWTH-India Telescope At Hanle, **Ladakh**

2.3 m Vainu Bappu Telescope (VBT) Kavalur, **Tamil Nadu**

Kodaikanal Solar Observatory (KSO), **Tamil Nadu**

1.2 m Mt Abu IR observatory, Gurushikhar **Rajasthan**

Goals :

- ❑Spectroscopic studies of high-redshift galaxies, quasars,
- ❑Time-domain observations of transient sources such as supernovae, GRB afterglows.
- ❑Stellar population studies and metallicity evolution in nearby galaxies.

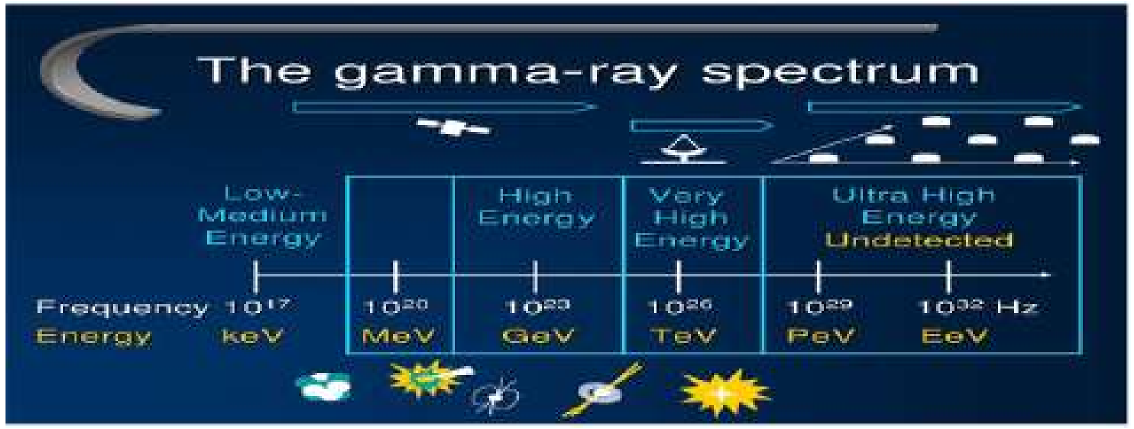
UV & X-ray Astronomy
(IUCAA Pune, TIFR Mumbai, IIT Bombay and others)

Launched in 2015, India's first space observatory

Goals :

- ❑Understanding High-Energy Phenomena and Compact Objects
- ❑Multi-Wavelength Studies of Active Galactic Nuclei (AGN) and Galaxies
- ❑Stellar, Solar, and Interstellar Medium Studies
- ❑Time-Domain and Transient Astronomy

Gamma Ray Astronomy (BARC Mumbai)



Highest energy window of the electromagnetic spectrum.
☐ Remains to be fully explored.

TACTIC Telescope @ Mount Abu, Rajasthan
Energy Threshold ~ 1 TeV

Present

MACE Telescope @ Hanle, Ladakh
Energy Threshold ~ 30 GeV

Goals :

- ❑Origin of Cosmic rays
- ❑Probing the Extreme Universe — Particle Acceleration and gamma-ray Emission Mechanisms in AGNs
- ❑Understanding Cosmic Evolution and Extragalactic Background Light (EBL)
- ❑VHE emission from Pulsars
- ❑Time-Domain Astrophysics and Multi-Messenger Connections

Cosmic Ray Physics (TIFR, Mumbai)

Gamma Ray Astronomy PeV EnergieS (GRAPES) , Ooty : Particle Detector Array

Study of cosmic rays with an array of air shower detectors and a large area muon detector.

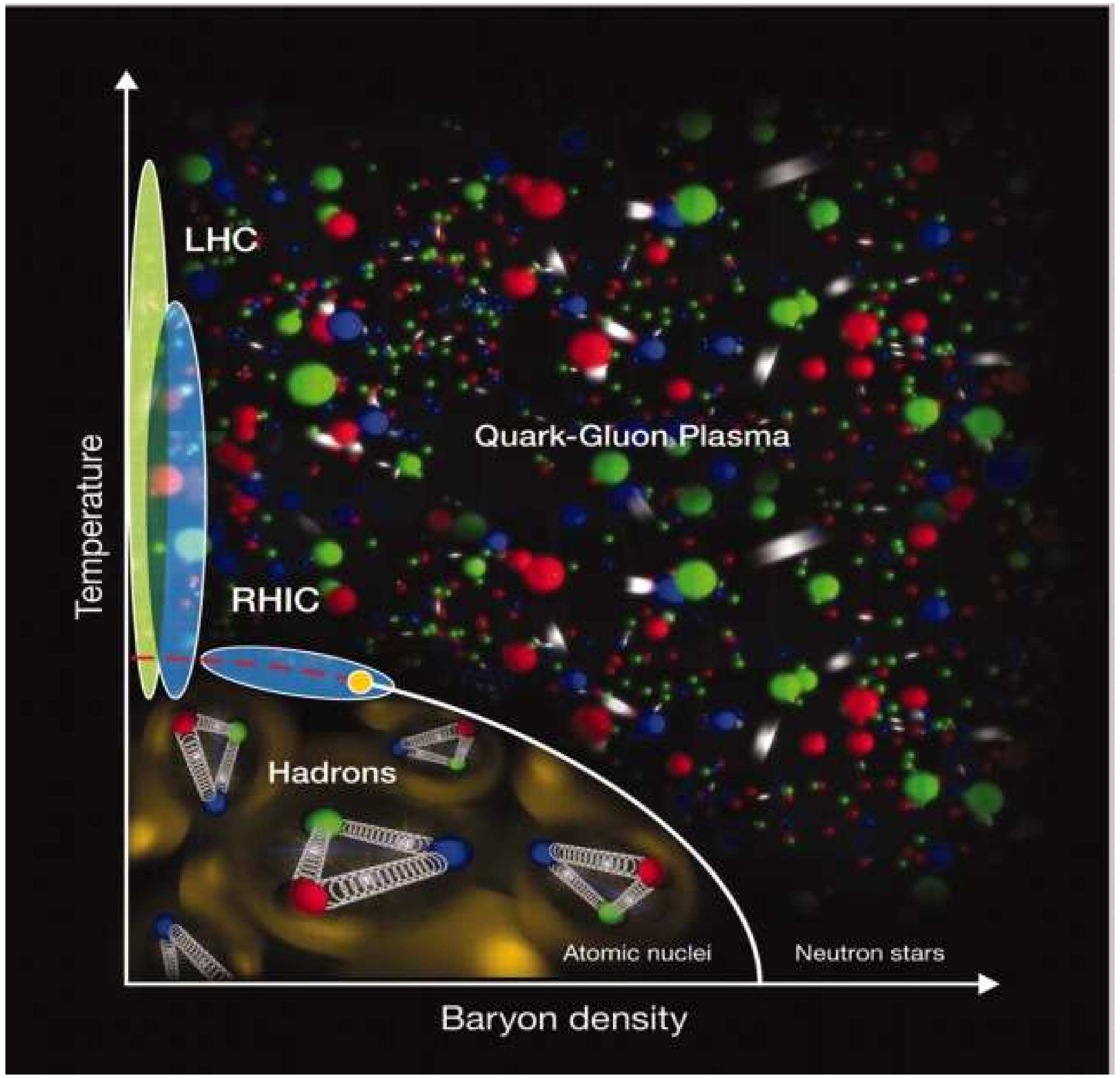
Goals :

- Study of High-Energy Cosmic Rays and their Origin
- Investigate the energy spectrum, composition, and arrival directions of primary cosmic rays in the 10^{13}–10^{16} eV (TeV–PeV) range.
- Understanding Space Weather and Geomagnetic Phenomena

4. High Energy Physics

High energy heavy-ion programs in India

(involving International Collaborations)



1. LHC @ CERN
- CMS (Higgs, quarkonium, Jet)
- ALICE

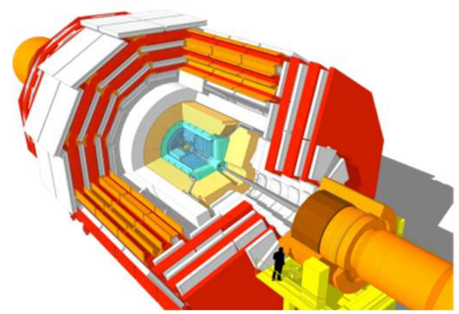
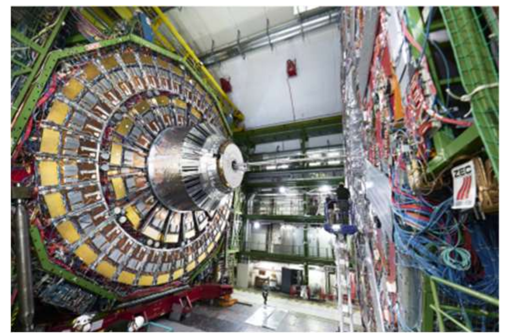
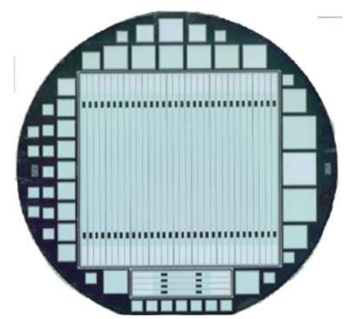
2. RHIC @ BNL
- STAR (Critical end point, de-confinement of quarks and gluons)
- PHENIX

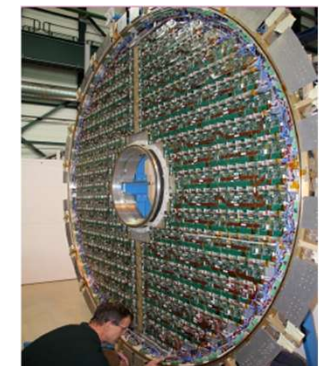
3. FAIR @GSI
- CBM (QCD phase diagram, particle physics)

LHC (CMS) experiments

Physics Goals

- Higgs boson and it's associated physics
- Coupling to top, bottom and charm quark contributions to the physics of associated Higgs
- Study of quarkonium production
- Jet-physics

Assembly of RPCs @ BARC

32-strip Preshower silicon sensor wafer on 4" inch wafers developed by BARC

CMS:

BARC & BEL: 1100 detector modules and electronics for silicon-based pre-shower detectors used for γ and π rejection resistive plate chambers, and gas electron multiplier (GEM) detector modules for muon detection.

R&D for Silicon detector for FoCal @ ALICE

Started with N-type detector array

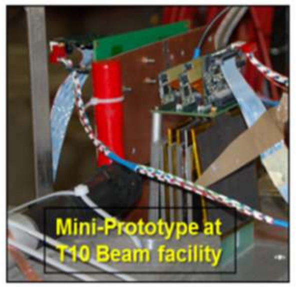
N-type detectors

TB 2011

Lab set up

1 cm^2

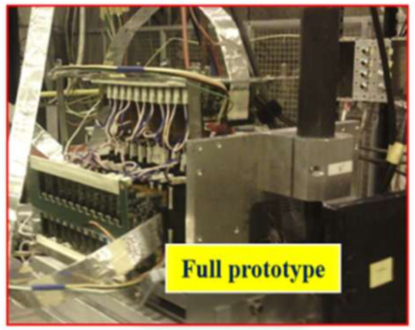
TB 2012



Prototype @ PS

5 x 5 array with 1 cm^2

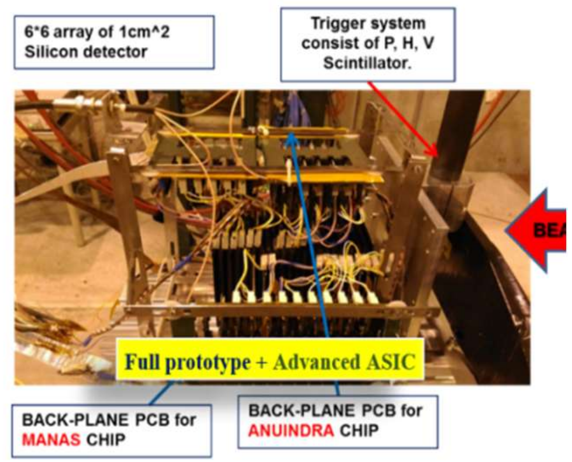
TB 2015



Prototype @ SPS

6 x 6 array with 1 cm^2

TB 2017



Prototype @ SPS

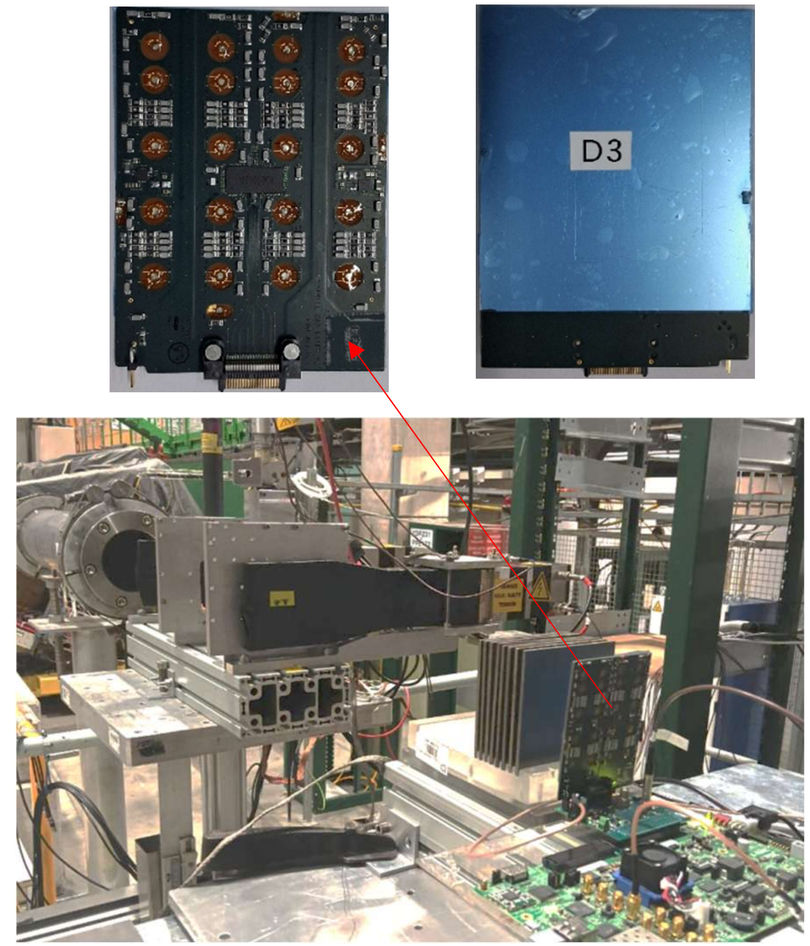
6 x 6 array with 1 cm^2

Final requirement

P-type 8 x 9 array on 6” wafer

P-type Detectors

TB 2024 & 2025

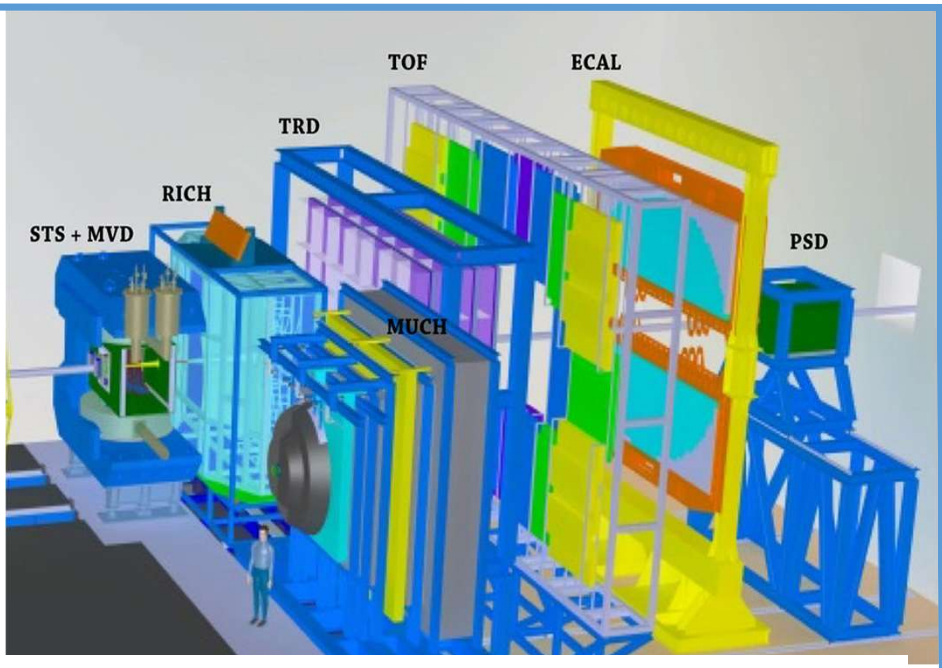


Wafer thickness: 300 mm (for bot n & p type)

Resistivity ~ 4 → 8 k ohm

Detectors are designed, process optimized & fabricated in India

Indian participation in CBM @ FAIR

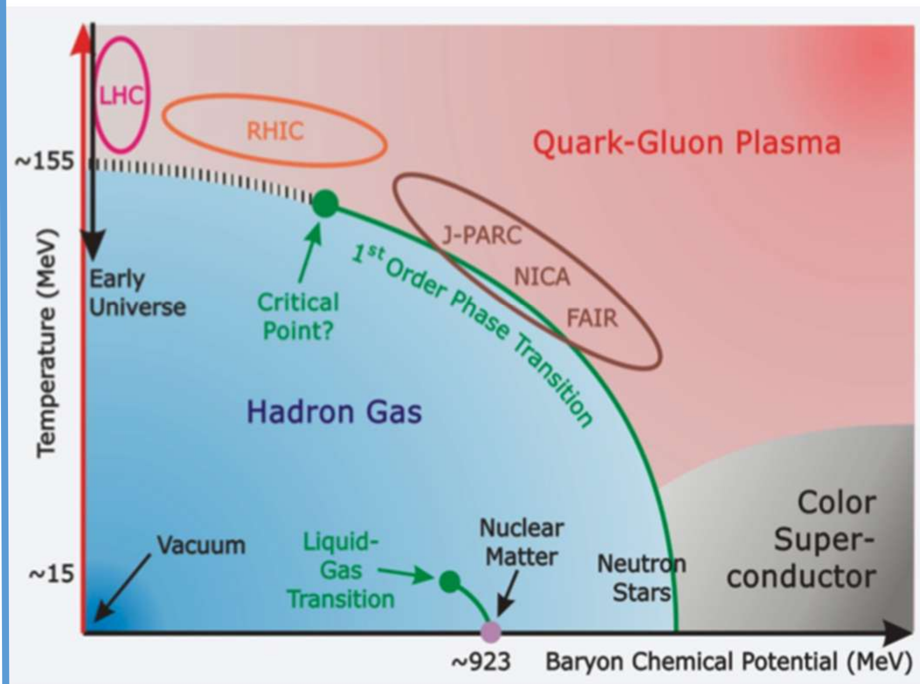


Fixed target experiment
@SIS100
Ebeam: 2-14A GeV for heavy ions and 2-29A GeV for proton beams
@SIS300
Ebeam: 2-35A GeV for heavy ions and 2-89A GeV for proton beams
Interaction rates up to 10 MHz

Physics goals :

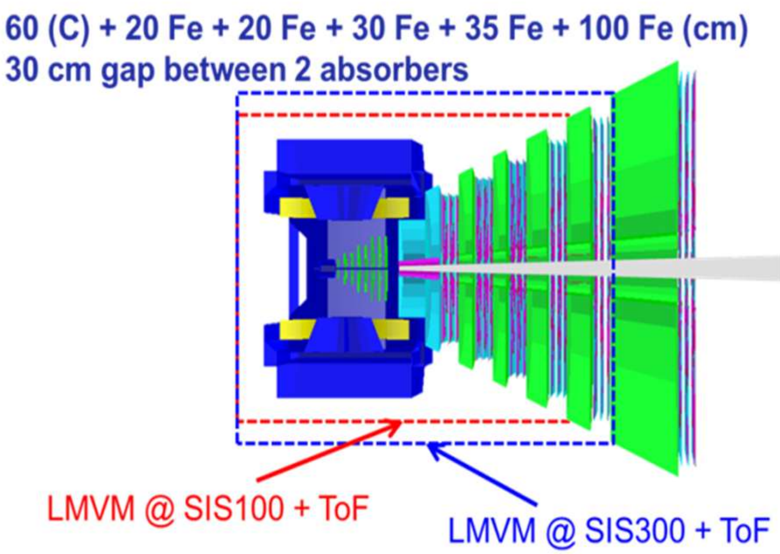
❖QCD phase diagram at mod. temp. & high net-baryon density

❖Measure rare diagnostic probes : multi-strange hyperons, charmed particles and vector mesons decaying into lepton pairs with unprecedented precision and statistics



Ref: Eur. Phys. J. A, 53 (3): 60, 2017

MuCh System @ CBM

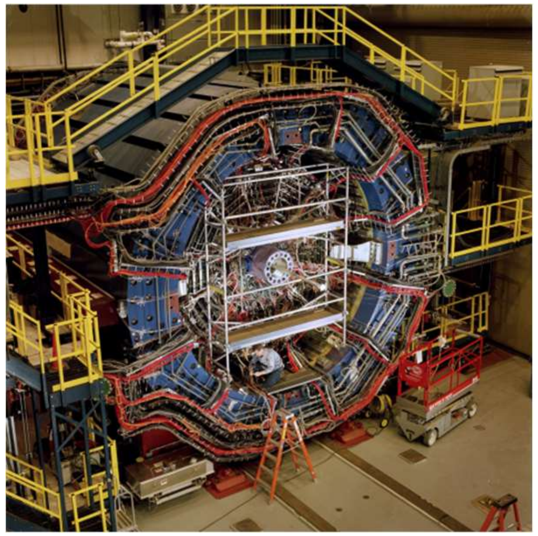


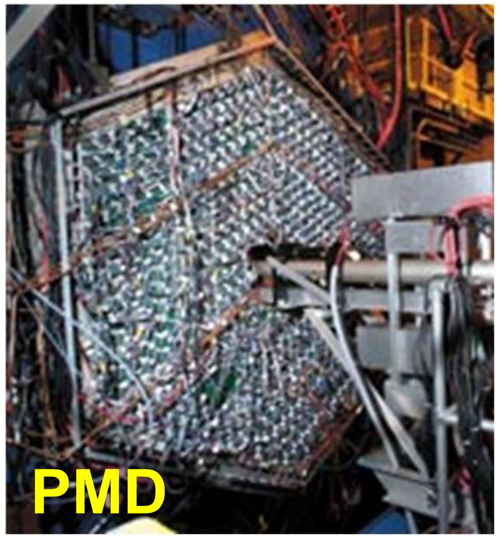
GEM Detectors for the 1st and 2nd stations

Courtesy: Zubair, VECC

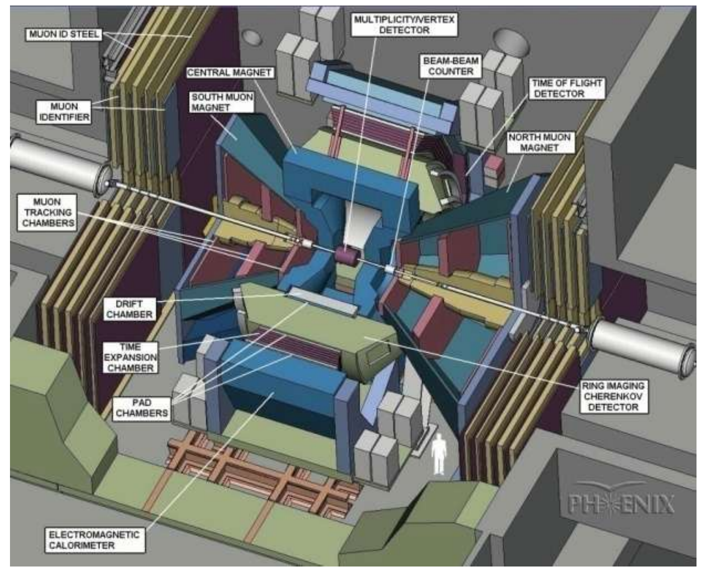
Indian participation in RHIC @ BNL

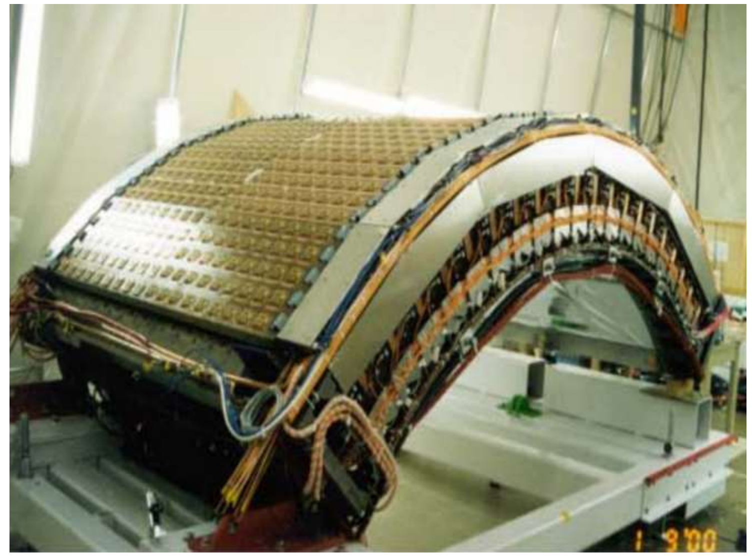
STAR





PHENIX





BARC involved in making Drift Chamber for charged particle tracking @ PHENIX

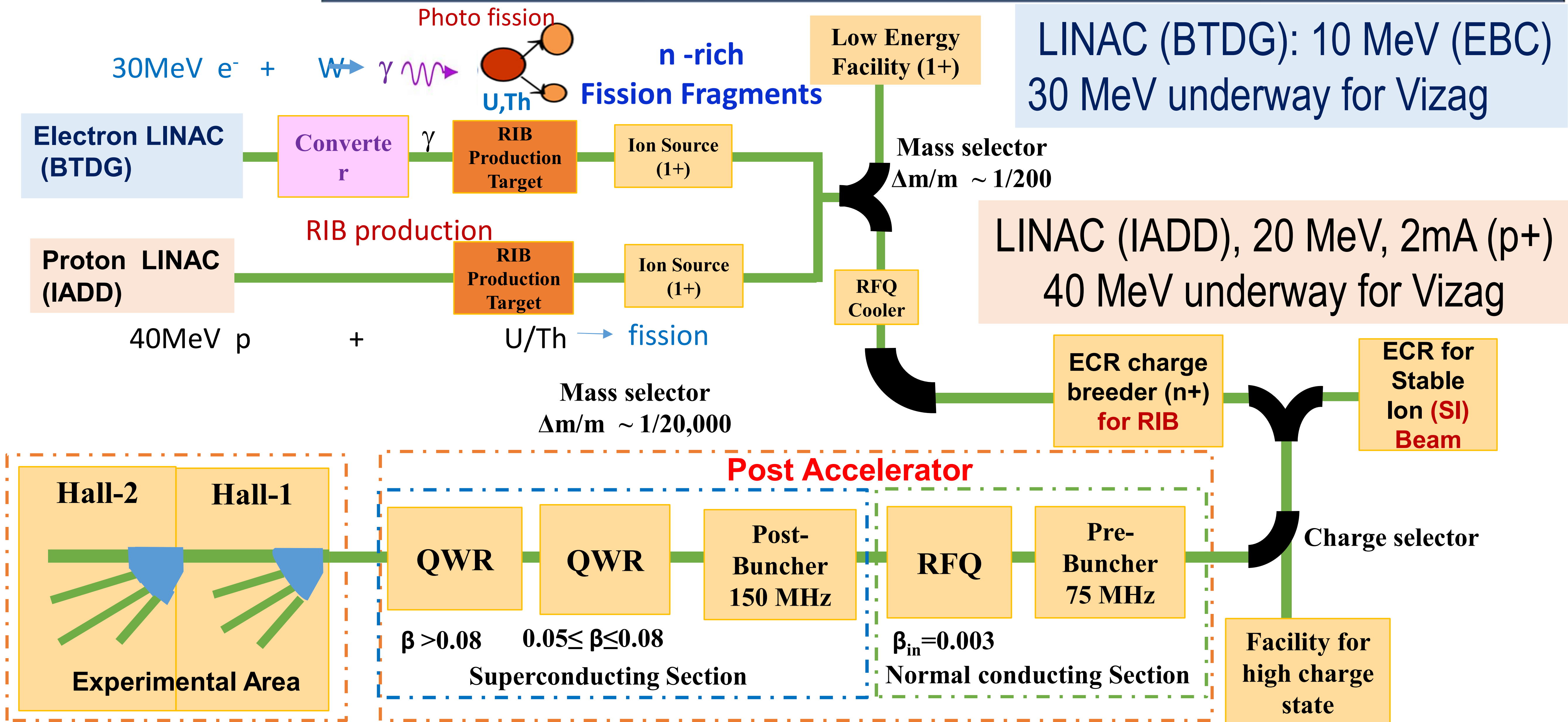
Physics Goals:

- Study the phase diagram of strong Interactions, Critical End Point
- Properties of de-confined state of quarks and gluons (QGP)

Future Mega Science Facilities

NUCLEAR MATTER …

STABLE AND UNSTABLE BEAM FOR HEAVY ION RESEARCH (SUBHIR)



RIB facilities worldwide : CERN–ISOLDE, FRIB, GANIL, GSI, RIKEN
Upcoming: TRIUMF, SPIRAL2, FAIR, SPES, ITHEMBA

Area: 50 x 200 m^2

UV & X-ray Astronomy

(IUCAA Pune, TIFR Mumbai, IIT Bombay and others)

Present : ASTROSAT

Launched in 2015,
India's first space observatory

Future : Daksha

Order of magnitude more sensitive than
any existing mission

Goals :

- ❑Understanding High-Energy Phenomena and Compact Objects
- ❑Multi-Wavelength Studies of Active Galactic Nuclei (AGN) and Galaxies
- ❑Stellar, Solar, and Interstellar Medium Studies
- ❑Time-Domain and Transient Astronomy

Gamma Ray Astronomy (BARC Mumbai)

Future :
Stereo MACE Telescope
@ Hanle, UT of Ladakh

Goals :
Improved Angular
Resolution and Sensitivity

Gravitational Wave Observatory

Laser Interferometer Gravitational-wave Observatory (LIGO) - India @ Hingoli

LIGO-India is a planned advanced gravitational-wave observatory to be located in India as part of the worldwide network.

Goals :

- Detection and Characterization of Gravitational Waves: Measure waveforms, masses, and spins of compact objects
- Enhancing the Global Gravitational-Wave Network : Strengthen the international network of GW detectors (LIGO–Hanford, LIGO–Livingston, Virgo, KAGRA) for better sky localization
- Multi-Messenger and Fundamental Physics : Joint GW–EM detections to study nucleosynthesis and GRB origins.

Summary

❖Major accelerator facilities & experimental setups for nuclear physics

❖Reactors & experimental setups for neutrino physics and nuclear spectroscopy

❖Telescopes & observatories for astrophysics

❖Detector developments for High energy physics

❖Future mega-science projects

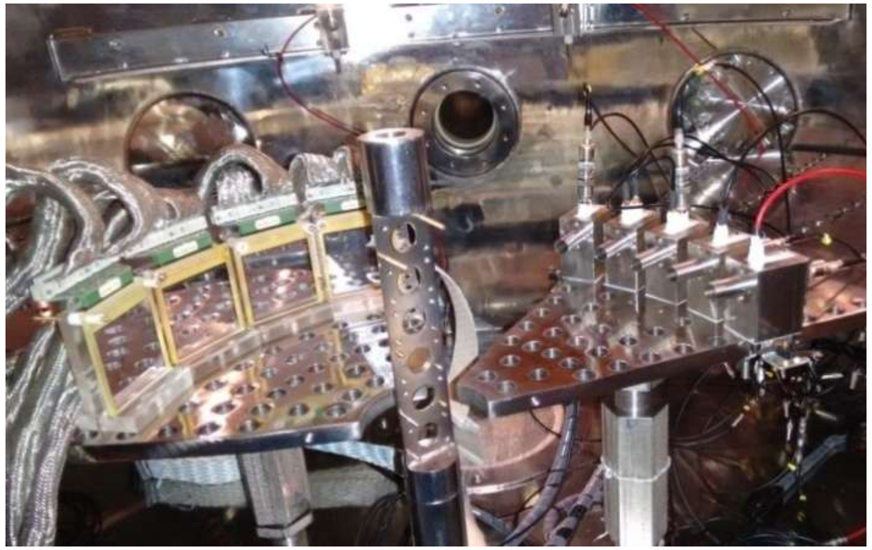
Acknowledgements

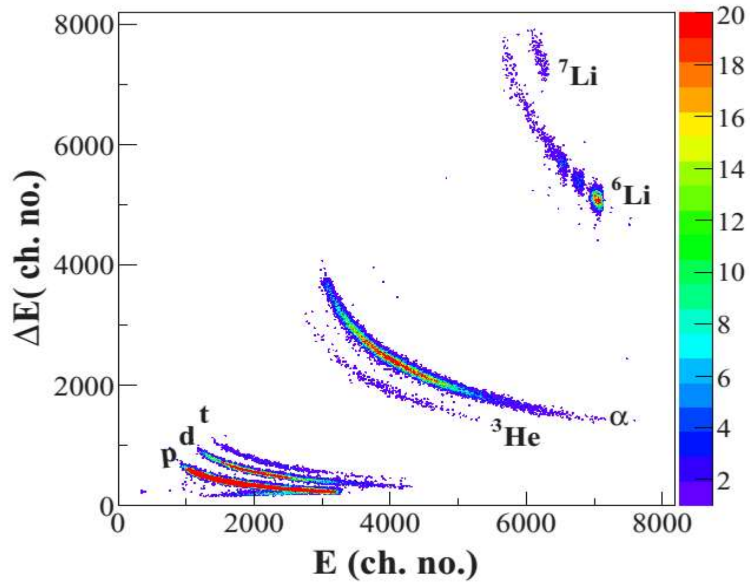
Dr. V. M. Datar, (Neutrino Physics)
Dr. Subir Nath, IUAC
Dr. Kaushik Banerjee & Dr. Zubair, VECC
Dr. R. Palit, TIFR (Nuclear structure)
Dr. Dipak Mishra, BARC (HE physics)
Dr. K. K. Singh, BARC (Astrophysics)

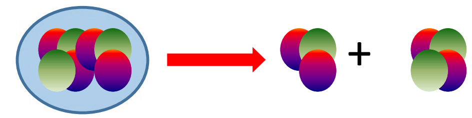
Thank you for your kind attention

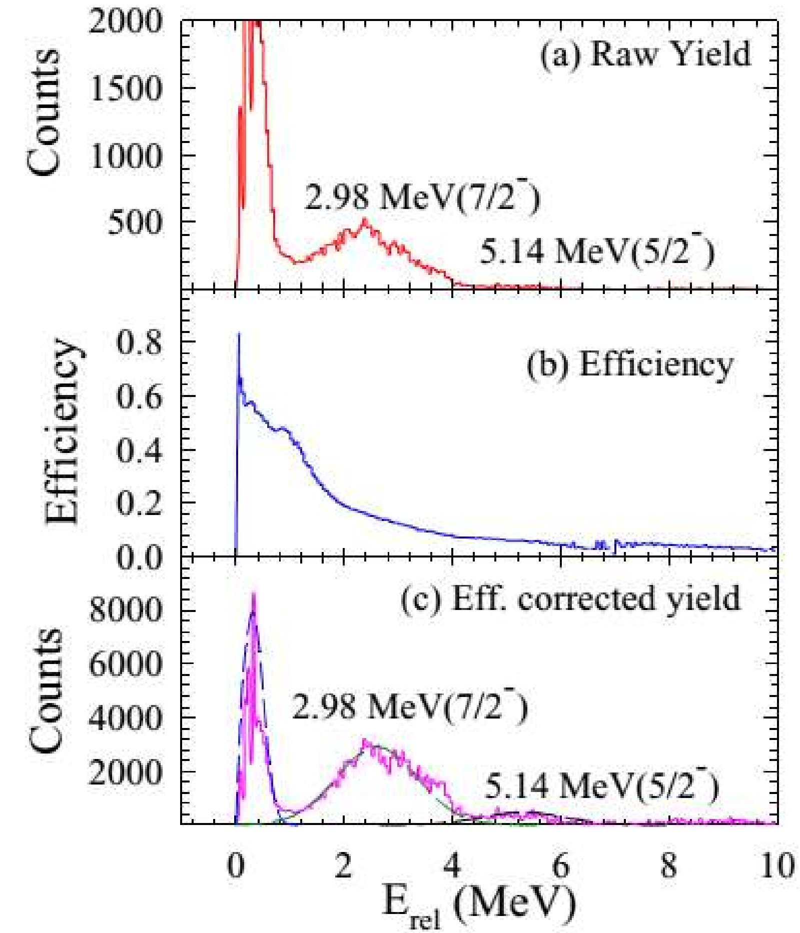
Backup slides

Breakup of radioactive ^{7}Be in ^{112}Sn(^{6}Li,^{7}Be→ 3He+α) reaction









Observation of resonant states via 7/2- and 5/2- for the first time

State	E_{rel} (MeV)	Γ (MeV)	E_{rel}^{lit} (MeV)	Γ^{lit} (MeV)
^{7}Be(7/2-)	2.60	1.76	2.98	0.175
^{7}Be(5/2-)	5.30	1.76	5.14	1.2

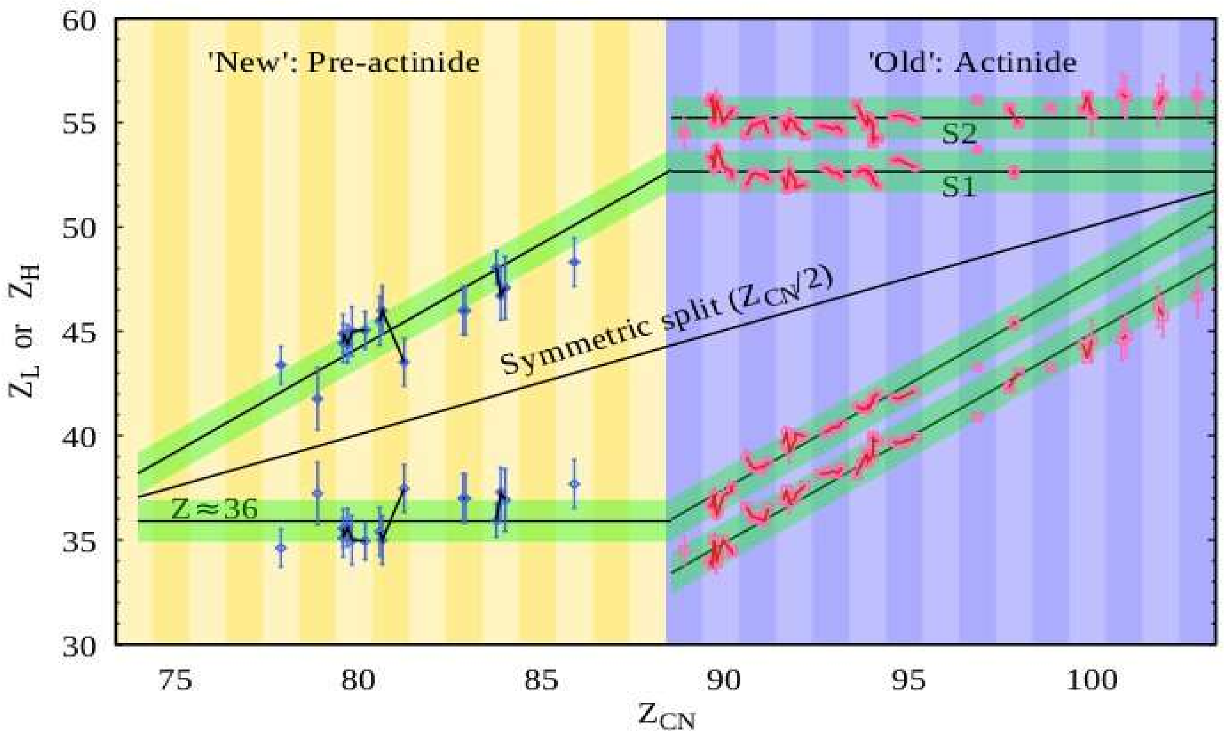
Breakup of ^{7}Be → ^{3}He+α: *D. Chattopadhyay et al., Phys. Rev. C 102, 021601 (R) (2020)*

Breakup of ^{8}Be(0+,2+,4+)→ 2α: *D. Chattopadhyay et al., Phys. Rev. C 98, 014609, 2018.*

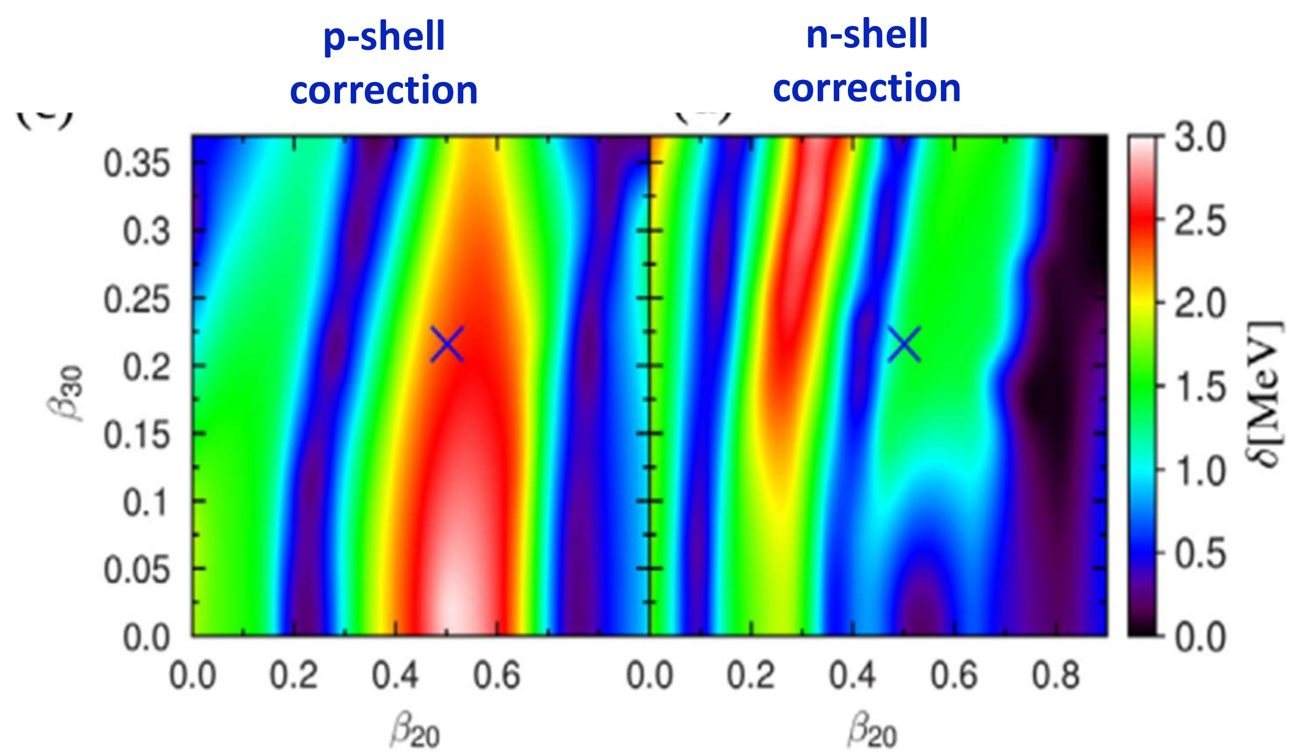
Cluster structure of ^{7}Li as ^{6}He+p: *D. Chattopadhyay et al., Phys. Rev. C **97**, 051601(R), 2018.*

ICF in ^{6}Li+^{238}U: *A. Pal et al. Phys. Rev. C **99**, 024620(2019).*

Dominance of proton shell closure in fission



Results of microscopic energy density functional (EDF) framework

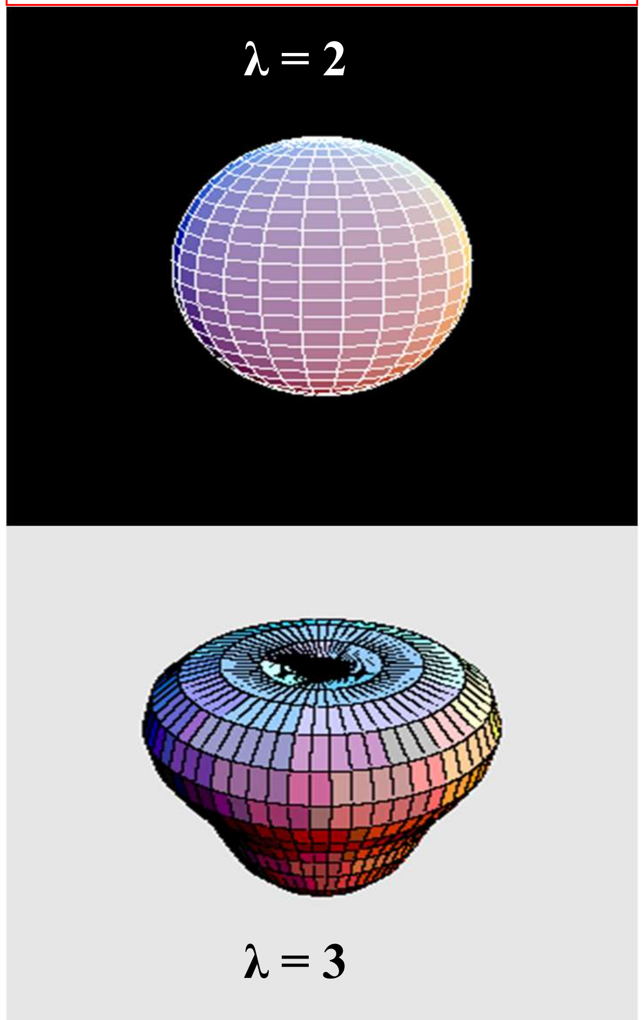


- ❑Proton shell closure guides the fragments
- ❑Pre-actinide: Z_L is fixed
- ❑Actinide: Z_H is fixed

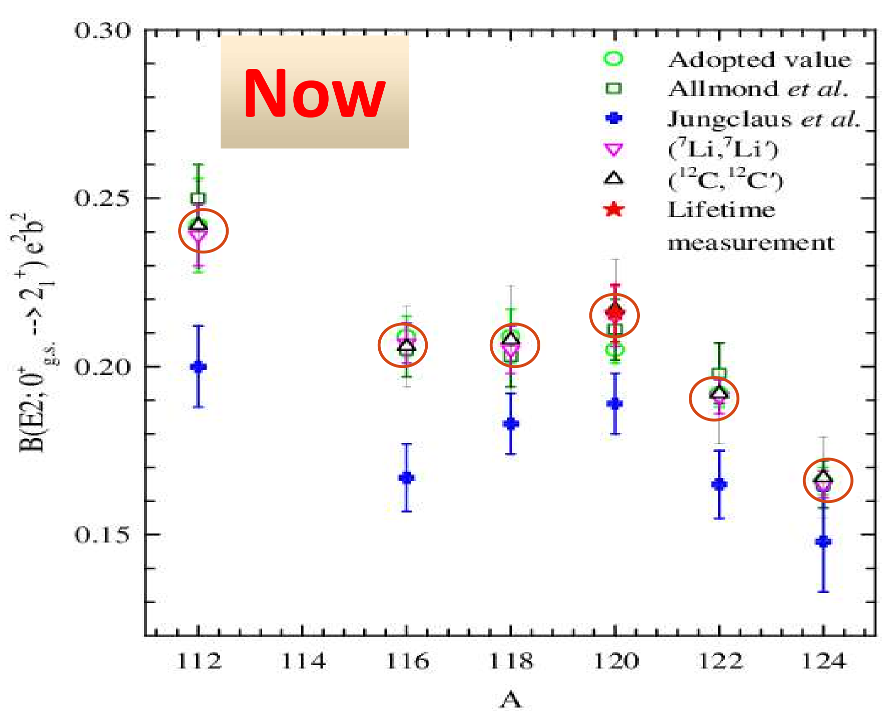
K. Mahata et al. Physics Letters B 825, 136859 (2022)

Electric quadrupole and octupole transition strengths in Sn isotopes

The Sn isotopes



→Signatures of collectivity in the low-lying **quadrupole (λ =2)** and **octupole (λ=3)** transitions→ observed for isotopes of ^{100}Sn (N=50) and ^{132}Sn (N=82)



→However, a large variation in both B(E2) and B(E3)

Two methods: Inelastic scattering **[$B(E\lambda) = (3Z^*\delta_\lambda^{ch}/4\pi)^2$** $(e^2fm^{2\lambda})$] and Life time measurement by Doppler Shift Attenuation analysis

$B(E2;2+\rightarrow 0_{g.s.}+)^{-1} = 0.245 \times 10^9 (E_\gamma^0)^5 \tau_{2+}$

employed to obtain a consistent picture.

(7Li,7Li') – A. Kundu et al., Phys. Rev. C **99**, 034609 (2019).
(12C,12C') – A. Kundu et al., Phys. Rev. C **100**, 024614 (2019).
^{120}Sn(^{32}S,^{32}Sγ) - A. Kundu et al., Phys.Rev. C 100, 034327 (2019)
^{112}Sn(^{32}S,^{32}Sγ) - A. Kundu et al., Phys. Rev. C **103**, 034315 (2021)

Nuclear Structure Research Programme using INGA facility at TIFR & VECC

✓ Exotic nuclear phenomena in transitional and deformed nuclei

- Exploring the extent of rigid or limited triaxiality in transitional nuclei.
- Exploring octupole correlation and stable octupole deformation in rare-earth nuclei.
- Exploring multi-phonon vibration in deformed nuclei.

✓ Exotic nuclear excitations in the $f_{7/2}$-shell nuclei (A~50 mass region)

✓ Fission Fragment Spectroscopy

Physics Letters B 825 (2022) 136848

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Evidence for competing bi-faceted compound nucleus fission modes in ^{232}Th(α,f) reaction

Aniruddha Dey[a,b], D.C. Biswas[a,c], A. Chakraborty[b,*], S. Mukhopadhyay[a], A.K. Mondal[b,1], K. Mandal[b,2], B. Mukherjee[b], R. Chakrabarti[d], B.N. Joshi[a], L.A. Kinage[a], S. Chatterjee[e], S. Samanta[e], S. Das[e], Soumik Bhattacharya[c,f], R. Banik[g], S. Nandi[c,f], Shabir Dar[c,f], R. Raut[e], G. Mukherjee[c,f], S. Bhattacharyya[c,f], S.S. Ghugre[e], A. Goswami[h,3]

PHYSICAL REVIEW C 109, 064311 (2024)

Extended level structure of ^{51}Cr with measured mean lifetimes of yrast states in agreement with shell-model calculations

R. Chakrabarti[1,*] S. Mukhopadhyay[2,3,†] B. V. John[2,3] D. C. Biswas[2,3] S. K. Tandel[4] L. S. Danu[2] Y. K. Gupta[2,3] B. N. Joshi[2] G. K. Prajapati[2] S. Saha[5] J. Sethi[5] and R. Palit[5]

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Lifetime measurement and shell model description of negative parity states up to band-termination in ^{49}V

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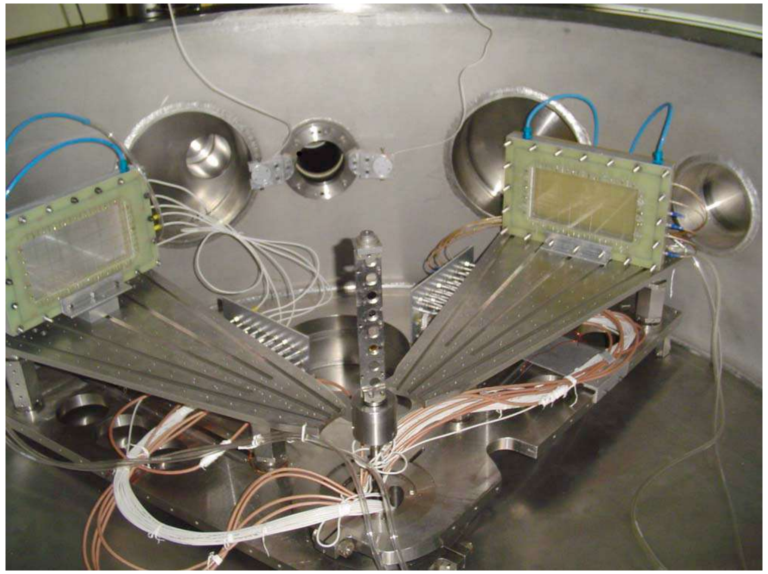
1.5 m General Purpose Scattering Chamber



Major studies

- Light particle (n, p, α) emission in fusion reactions
- Study of orbiting behavior in ^{16}O induced reactions
- Study of in-elastic scattering in microscopic formalism
- Dynamical and entrance channel effect in fusion reaction via neutron multiplicity measurement
- Heavy ion induced fission fragment angular and mass distribution at near/sub-coulomb barrier
- Study of complete and incomplete fusion and pre-equilibrium emission in nuclear reactions induced by heavy ions

Evolution of experimental Neutrino Science in India

- 1965: Atmospheric neutrinos discovered at Kolar Gold Fields mine by a TIFR-Osaka-Durham collaboration.
- 1982: A 140-ton iron calorimeter (later 350-ton) set up to search for proton decay and set the best lower bound on its lifetime.
- 2002: Six DAE institutes signed an MoU to set up an underground lab the India-based Neutrino Observatory (INO) with a flagship 50-kton iron calorimeter to measure atmospheric neutrinos. Pottipuram, in Theni, Tamil Nadu, was the site for INO.
- 2014: The Govt. of India gave financial approval for INO → R&D activities carried out.

Possible searches for exotic particles at ICAL

1. Dark matter (DM) decay to $\mu^+\mu^-$

Anomalous events at KGF (8 ~1964-1990) could be from decay of light DM (Murthy, Rajasekaran 2014). ICAL/ICAL+ could look at $\Phi_{DM} \rightarrow \mu^+\mu^-$ ($M_{DM} \sim 1 - 50$ GeV/c^2). Simulation study showed issue could be resolved in 3-4 years. However, if $\Phi_{DM} \rightarrow \nu_\mu + \bar{\nu}_\mu$ much more stringent bounds on DM lifetime from existing neutrino detectors exist.

__N. Dash__, V.M. Datar, G. Majumder, Pramana __86__, 927 (2016)

2. Cosmic Magnetic Monopole search

More stringent bounds (by ~5 compared to MACRO expt.) on cosmic magnetic monopole flux using ICAL/ICAL+

__N. Dash__, V.M. Datar, G. Majumder, Astropart. Phys. __70__, 33 (2015)

Building GEM for Muon detection @CBM

Main issues:

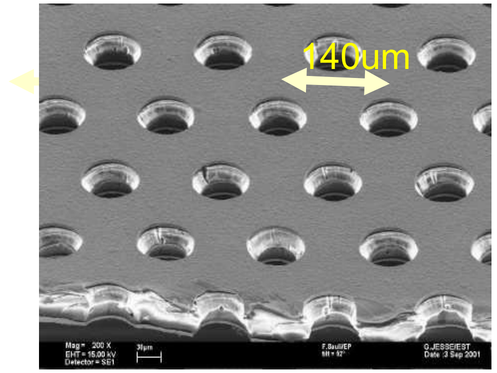
- ➤High collision rates ~ 10 MHz
- ➤High granularity ~ average hit rate is about 0.4 hit/cm^2
- ➤Radiation resistant –high neutron dose ~10^{13} n.eq./sq.cm/year
- ➤Large area detector –modular arrangement
- ➤Data readout in a self triggered mode

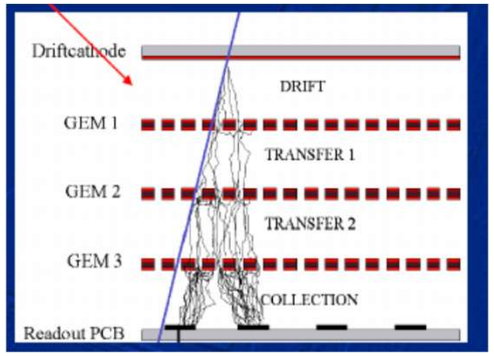
and event reconstructed offline by grouping the timestamps of the detector hits.

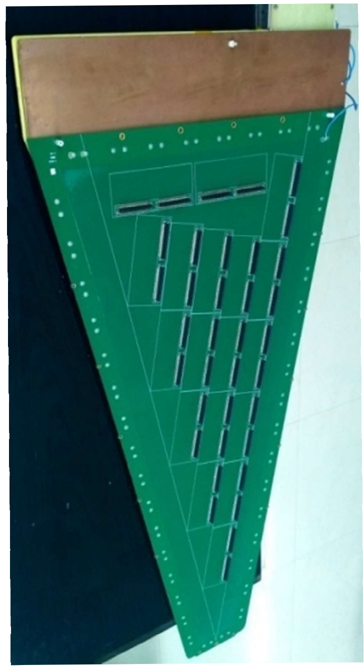
First two stations based on Gas Electron Multiplier technology (GEM)

To build : GEM for Station1 (2) : 60 (72)
Status: In production phase for station1

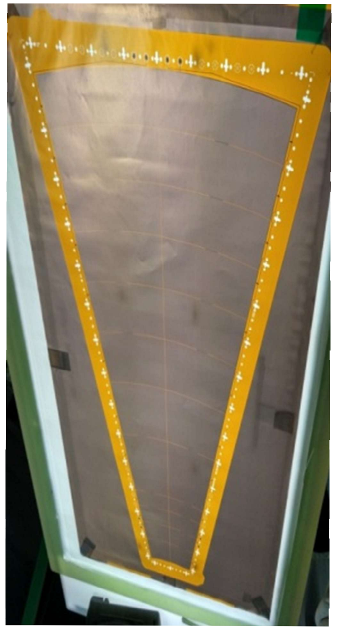
Gas Electron Multiplier (GEM) and its working principle







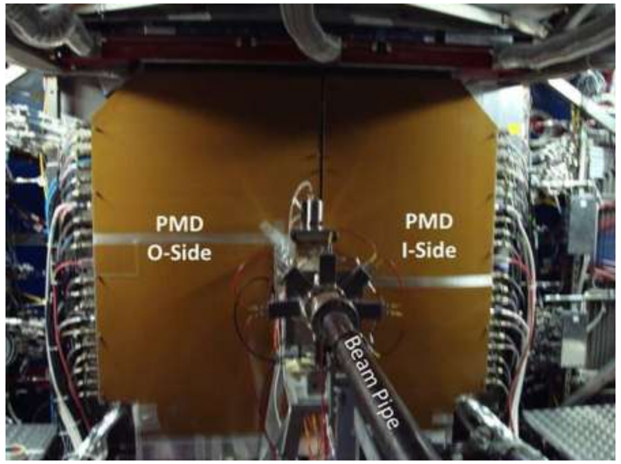
Large size GEM prototype For station1

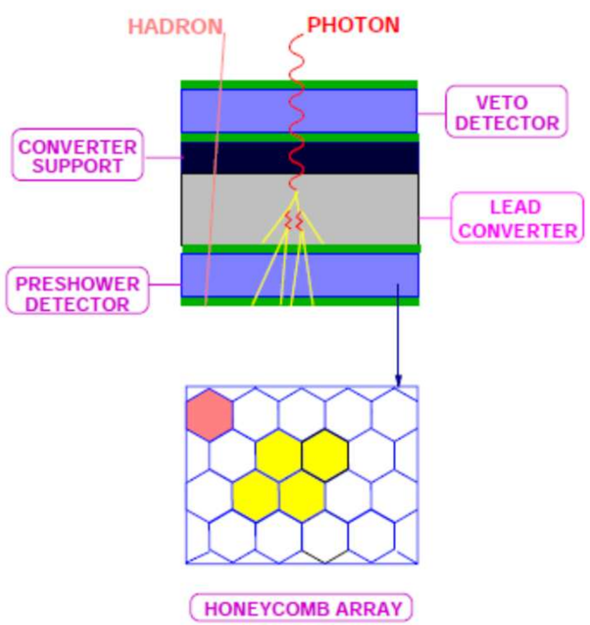


(Anand Dubey, VECC, Kolkata)

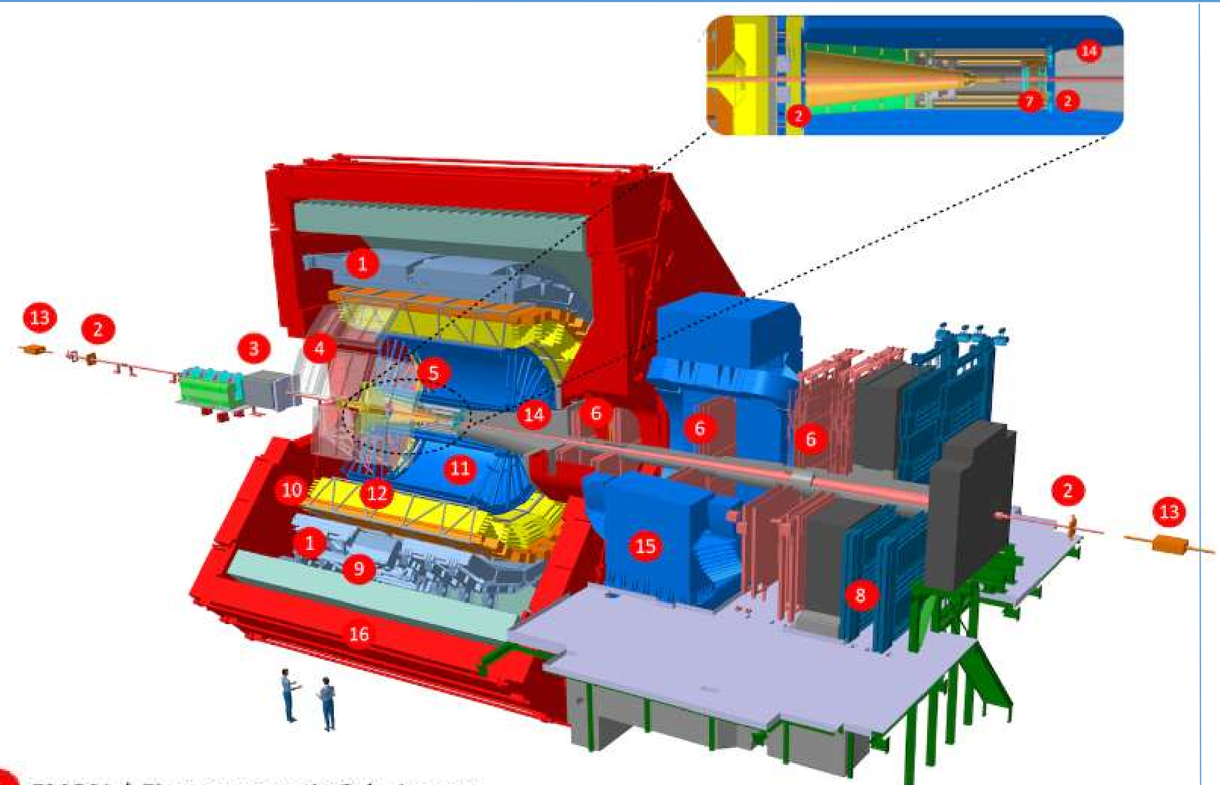
Indian (VECC) participation in ALICE experiment at CERN

Past



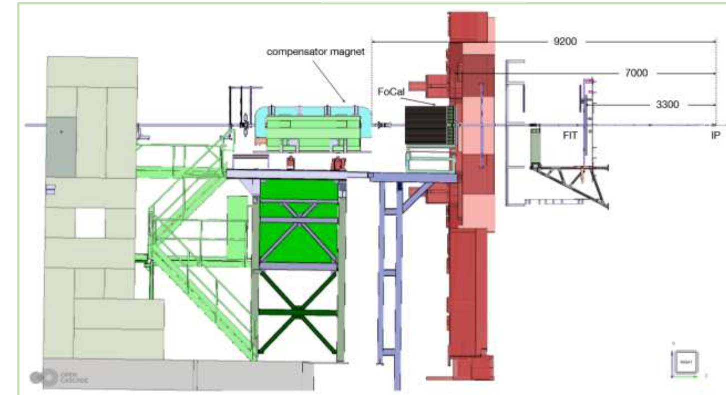


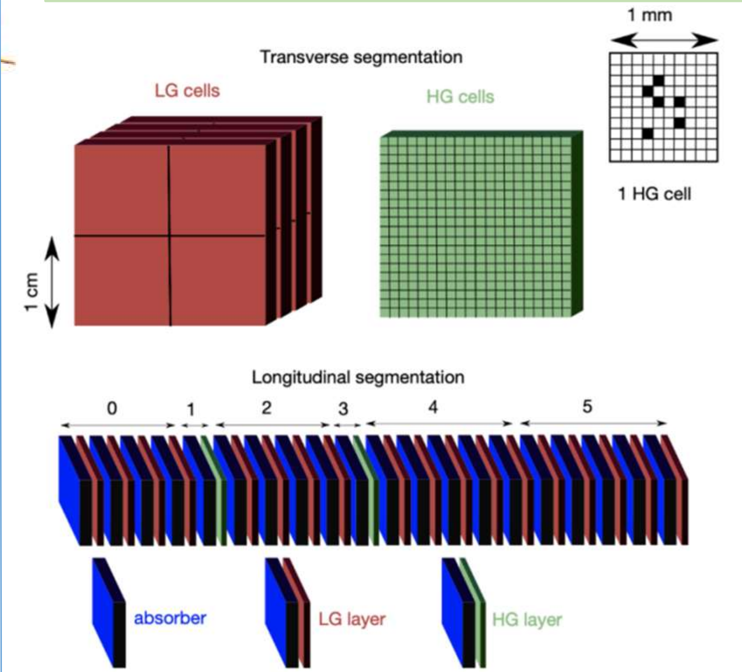
Gas based detectors to count photons (energy measurement Limited)



1. EMCAL | Electromagnetic Calorimeter
2. FIT | Fast Interaction Trigger
3. FoCal | Forward Calorimeter (in front of compensator magnet)
4. HMPID| High Momentum Particle Identification Detector
5. ITS| Inner Tracking System
6. MCH| Muon Tracking Chambers
7. MFT| Muon Forward Tracker
8. MID| Muon Identifier
9. PHOS/CPV| Photon Spectromete
10. TOF| Time Of Flight
11. TPC| Time Projection Chamber
12. TRD| Transition Radiation Detector
13. ZDC| Zero Degree Calorimeter
14. Absorber
15. Dipole Magnet
16. L3 Magnet

Future





Calorimeter with Silicon detectors to counts, track and measure energy of photons, electrons, hadron

Measurement of (n,xp) cross section using surrogate reactions

- In an efficient fusion reactor:

$$D + T \rightarrow \alpha\ (3.5\ \text{MeV}) + n\ (14.1\ \text{MeV})$$

Structural Material (SS)

(n,xp)   (n,xα)

(n,xp) & (n,xα) cross-section data have a critical importance for safety and design analysis of a fusion reactor

Swelling and embrittlement of structural material of a fusion reactor

Element	Percentage
Cr	16-18%
Fe	65-72%
Ni	10-14%
Mn	2-3%

Radio Nuclide	Half life (Year)
^{53}Mn	3.74E+6
^{55}Fe	2.73
^{60}Fe	1.5E+6
^{60}Co	5.27
^{59}Ni	7.6E+4
^{63}Ni	100.1

→ ^{53}Mn(n,xp) : R. Gandhi et al, Phys. Rev. C **100**, 054613 (2019).
→ ^{59}Ni(n,xp) : J. Pande et al., Phys. Rev. C **99**, 014611(2019).
→ ^{57}Co(n,xp) : R. Gandhi et al, Phys. Rev. C 106, 034609 (2022)
→ ^{58}Co(n,xp) : R. Gandhi et al, EPJ A **59**, 187 (2023)