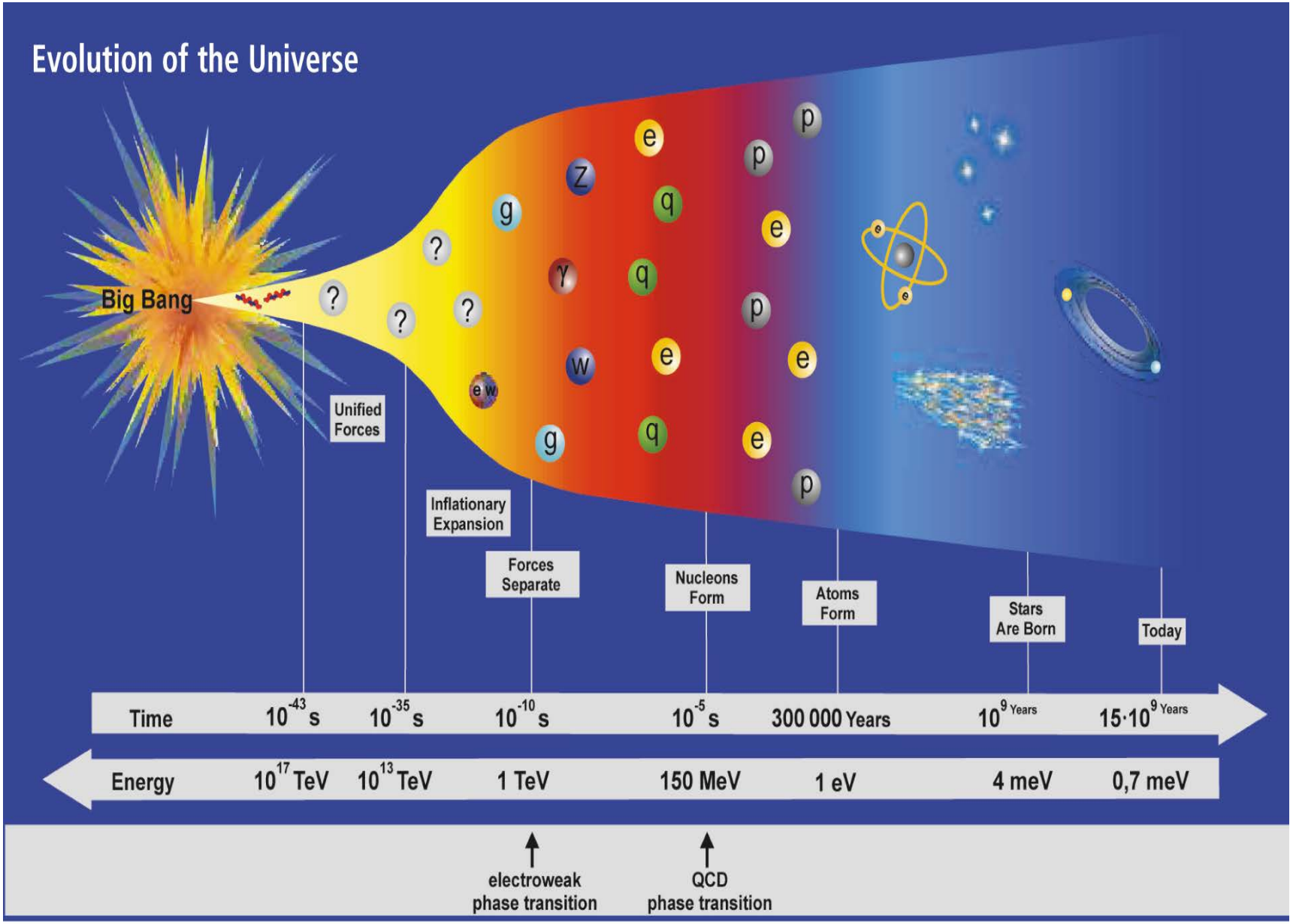
Indian participation in the Facility for Antiproton and Ion Research (FAIR)

(an upcoming accelerator centre at Darmstadt, Germany)

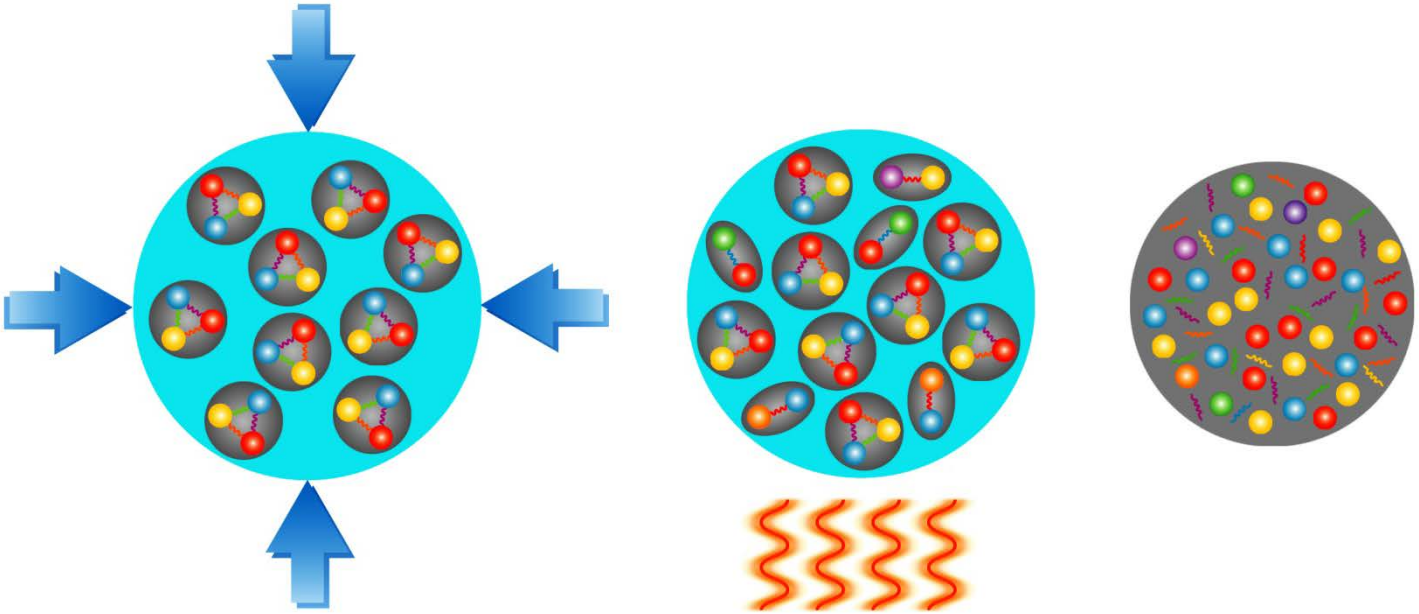
Subhasis Chattopadhyay
VECC-Kolkata

Quarks are confined



Transition from deconfined to confined: collide two heavy ions

States of strongly interacting matter

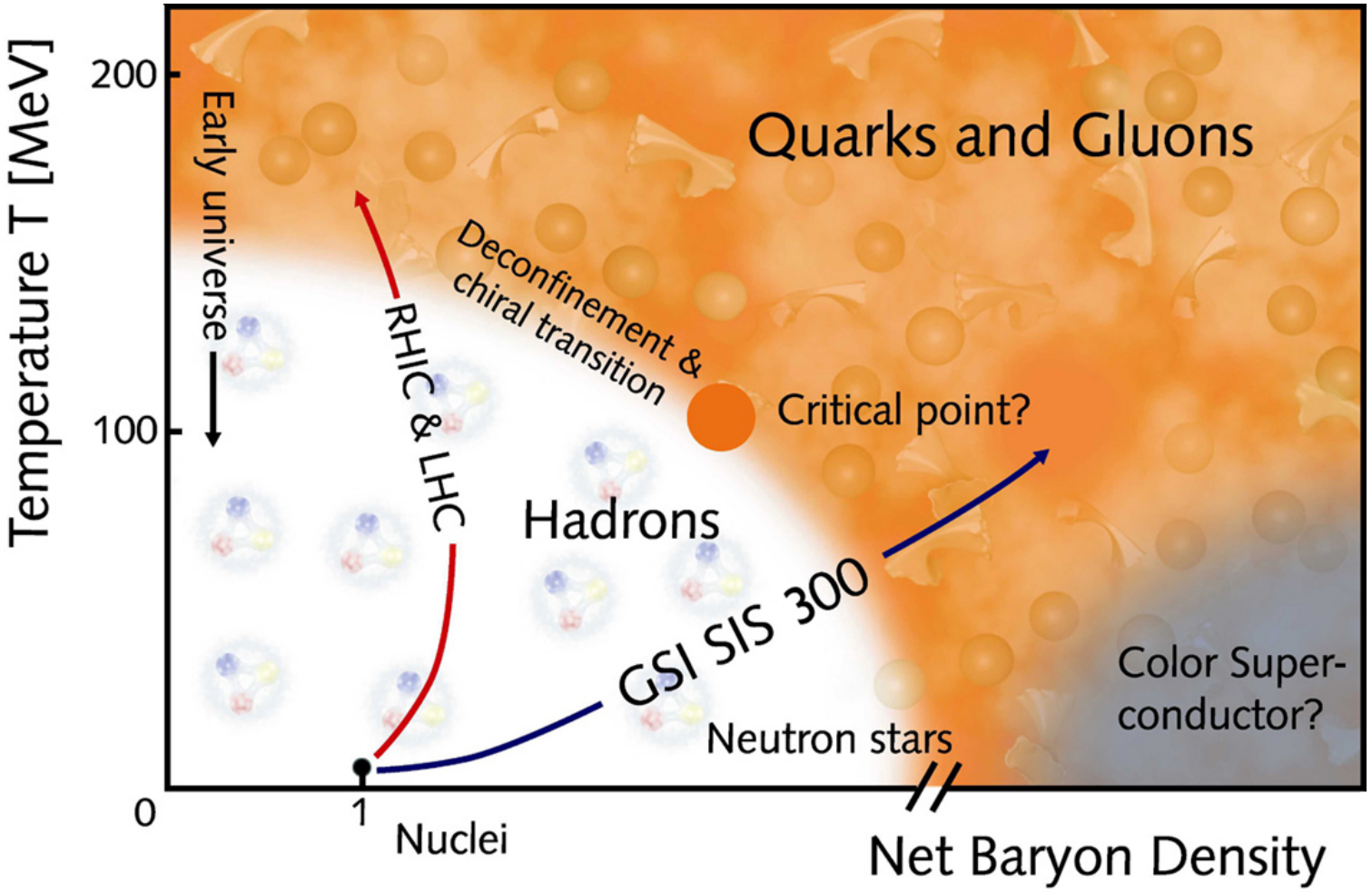


Compression + heating = quark-gluon matter

(pion production)

Neutron stars Early universe

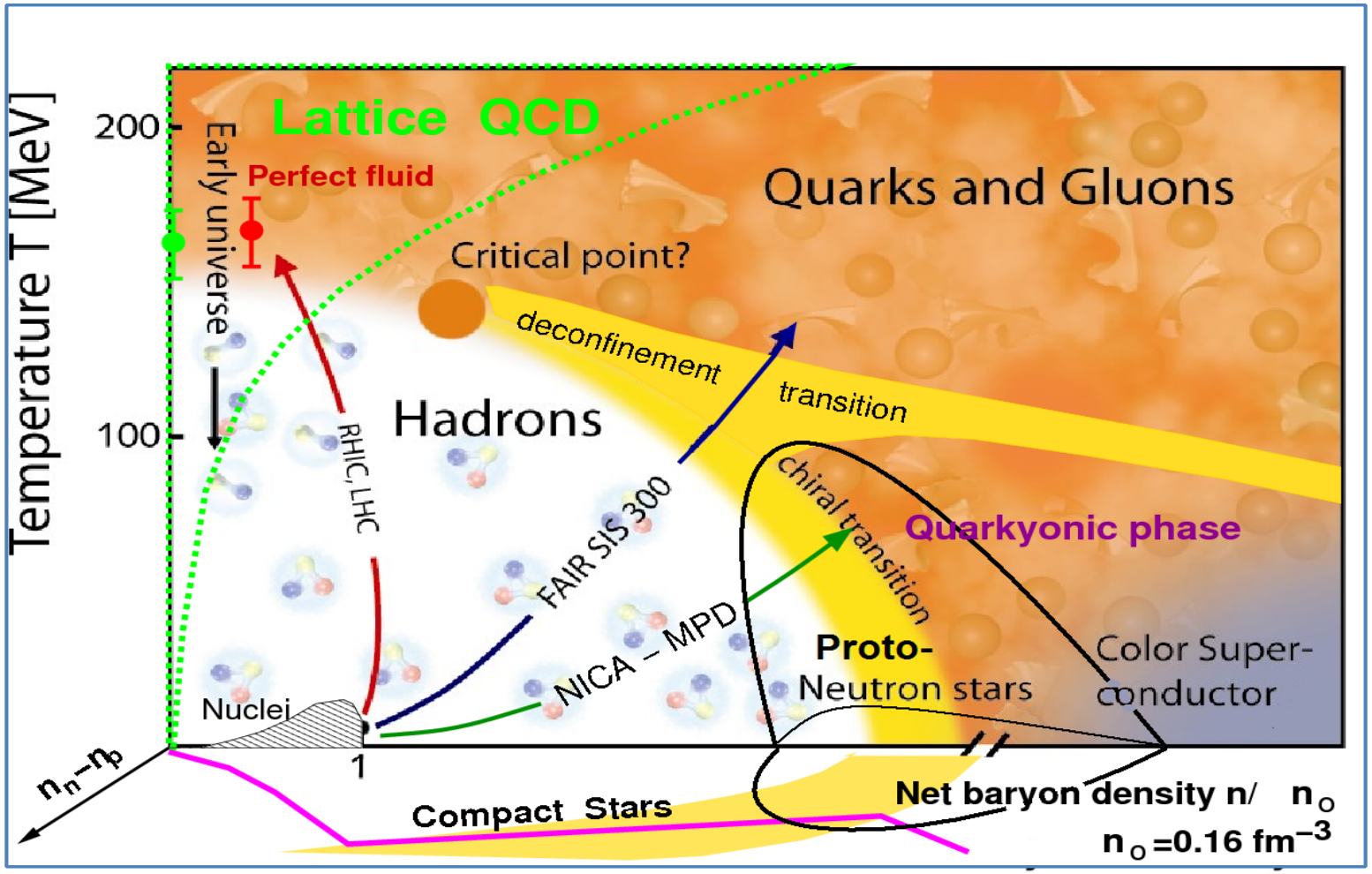
The phase diagram of strongly interacting matter



RHIC, LHC: high temperature, low baryon density

FAIR: moderate temperature, high baryon density

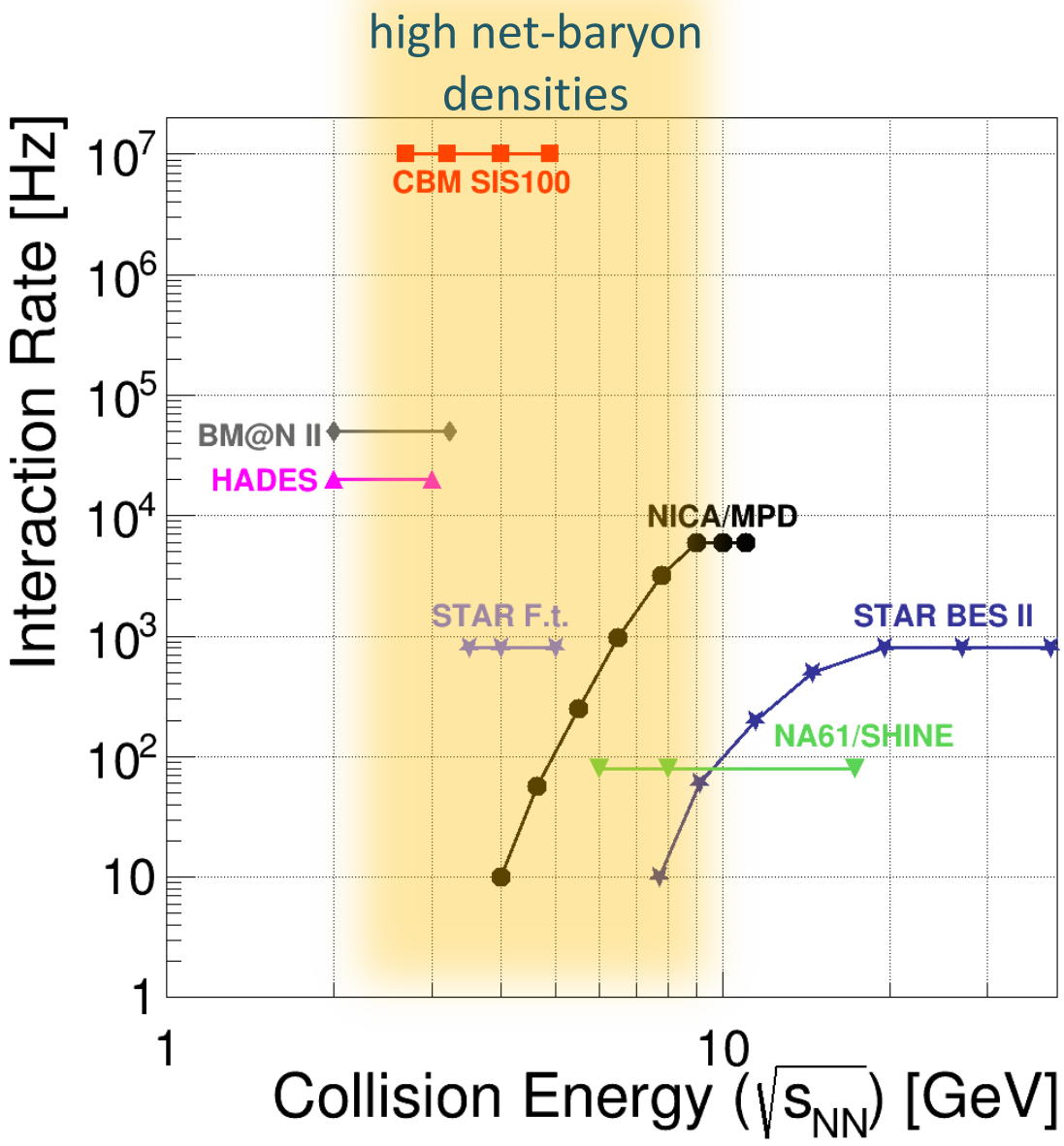
The phase diagram of strongly interacting matter



RHIC, LHC: high temperature, low baryon density

FAIR: moderate temperature, high baryon density

Experiments exploring dense QCD matter

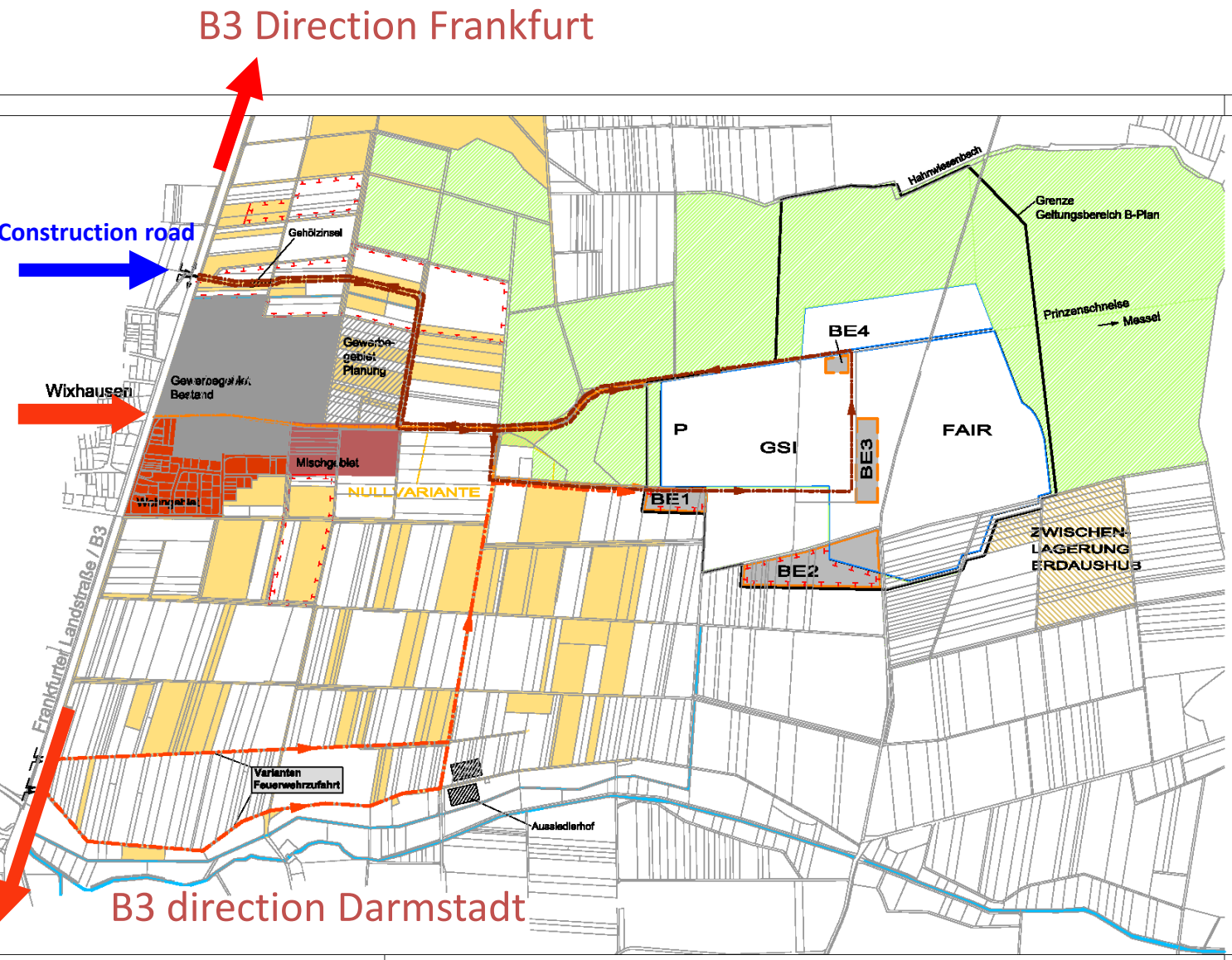


Renewed interest in high density nuclear matter

T. Ablyasimov et al., (CBM Collaboration) Eur. Phys. J. A 53 (2017) 60

7th February'07: signing of ministerial agreement on FAIR

Location of FAIR



Elements discovered at GSI-Darmstadt , Germany

107 Bohrium (Bh) Niels Bohr, (1981) December 1997

108 Hassium (Hs) German State of Hesse, March 14, 1984
December 1997

109 Meitnerium (Mt) Lise Meitner, Austrian physicist, theoretical description of nuclear fission
August 29, 1982 December 1997

110 Darmstadtium (Ds) Darmstadt, location of GSI
November 9, 1994 ,August 2003

111 Roentgenium (Rg) Wilhelm Conrad Röntgen,
December 8, 1994 November 2004

112 Copernicium (Cn) Nikolaus Kopernikus,
February 9, 1996 February 2010

FAIR accelerator and Indian participation

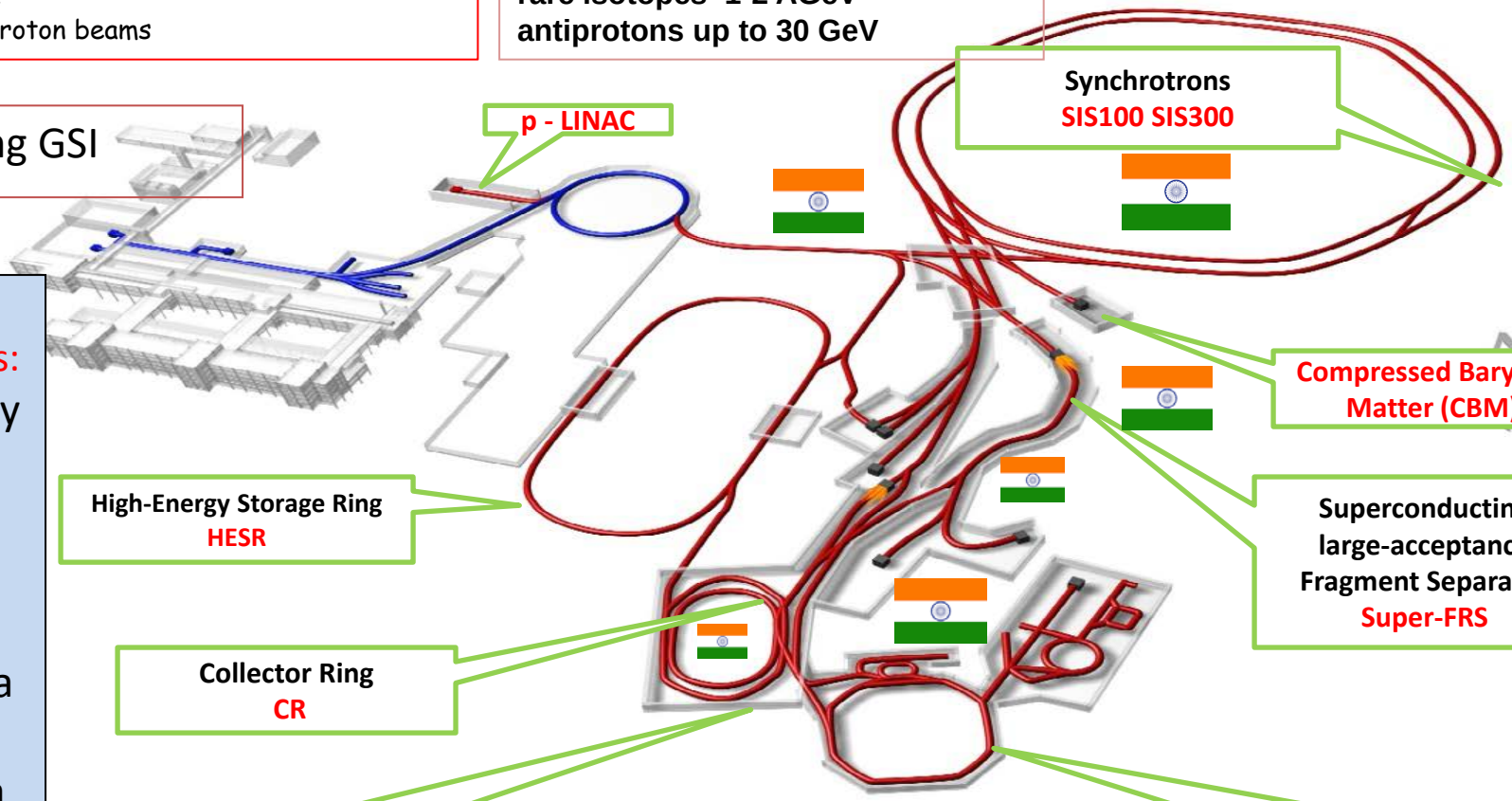
High Intensity beams:
1000 x
For primary HI beam
10 000 x
For radioactive ion beams
10 0 x
For antiproton beams

Primary beams:
10^{12} /s $^{238}U^{28+}$ 1-2 AGeV
$4 \cdot 10^{13}$/s Protons 90 GeV
10^{10}/s U 35 AGeV (Ni 45 AGeV)

Secondary beams:
rare isotopes 1-2 AGeV
antiprotons up to 30 GeV

- Highest Beam Intensities
- Brilliant Beam Quality
- Higher Beam Energies
- Highest Beam Power
- 4 parallel operations

Existing GSI



Member Countries:
Germany
Russia
India
France
Poland
Romania
Finland
Slovenia
Spain
Sweden
UK

Indian contribution: 3% in construction of FAIR

Indian in-kind accelerator items to the FAIR project

In-kind Accelerator items identified from India

I. Ultra-stable Power Converters for FAIR magnets: ECIL – provider: 678 units , Design: DAE labs

339 shipped and accepted

II. Ultra-high Vacuum Chambers for beam diagnostics –VT-Blore, provider: 71 Units

58 shipped and accepted

III. Beam Stopper to stop high intensity beams with proper cooling: 3 Units

Design- CMERI-CSIR, Durgapur

PO issued to an Indian company

IV. Co-axial power cables (194 Km, 4 types):

PO issued to an Indian company

V. IT-cables (16 types) : PO to be issued in November 2022

VI. *Steel roof-shielding (~700 tonne): Final vendor search by December 2022*

VIII: Design of superconducting magnets for FAIR, completed: VECC team

Ultra-stable Power converters

At ECIL-Hyd

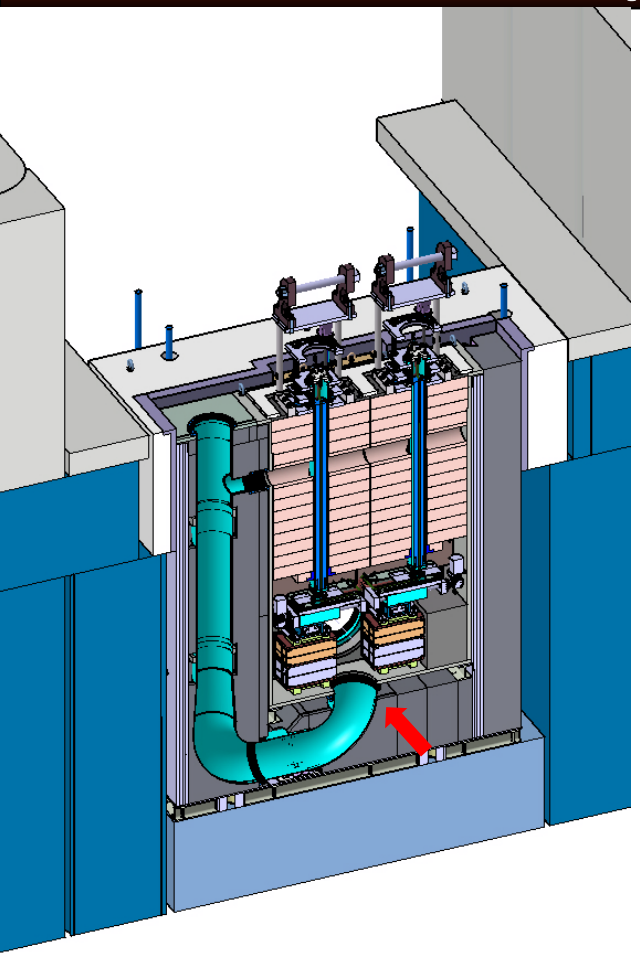
At FAIR, Germany

Ultra-high vacuum chambers

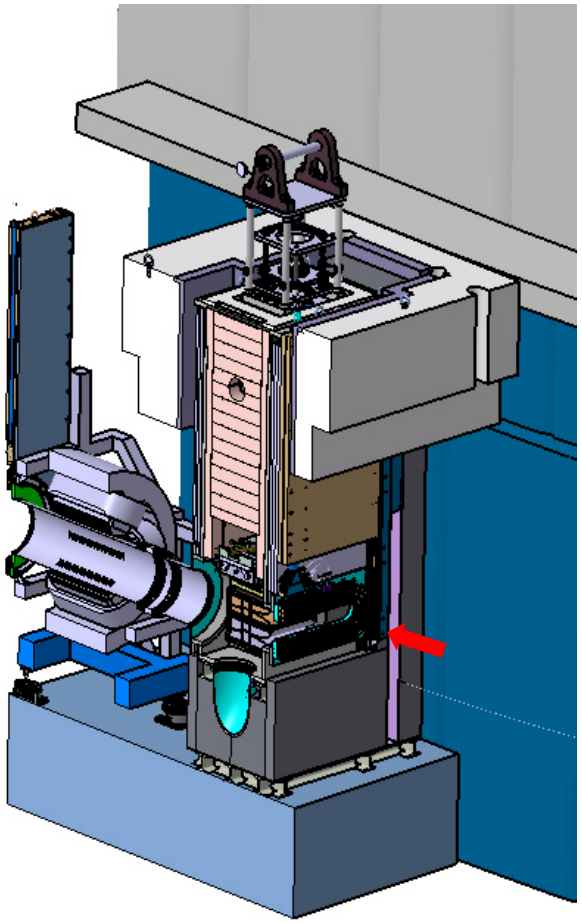
Vacuum Technique , Blore

At FAIR, Germany

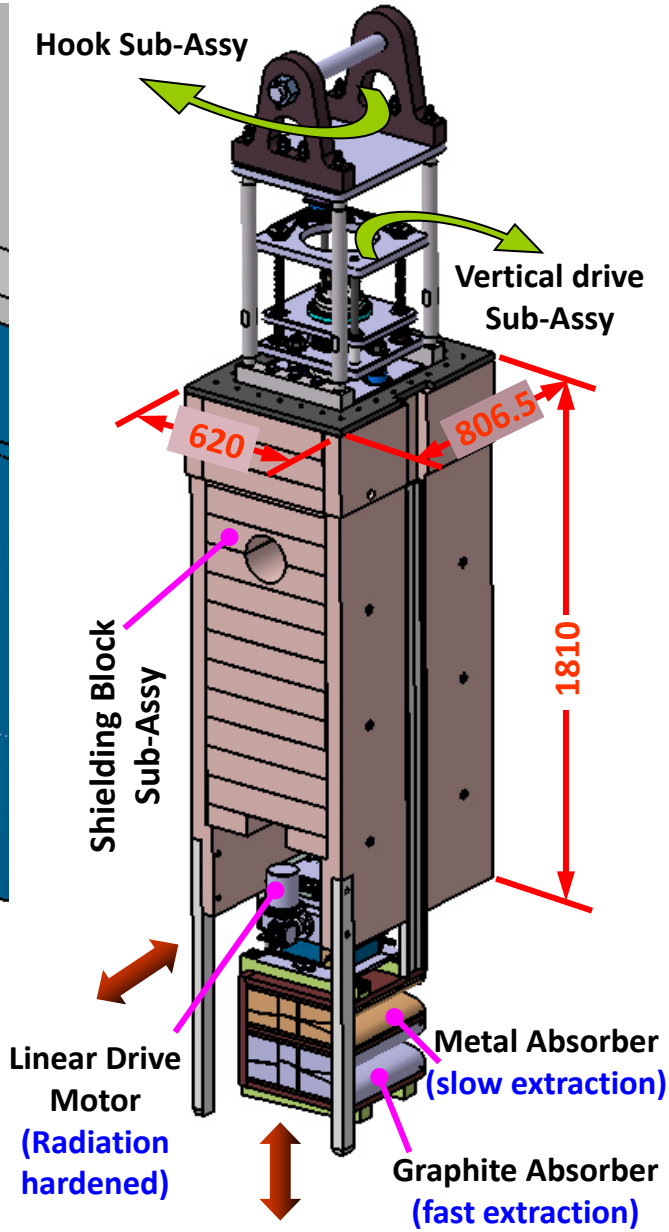
Beam stopper (design: CMERI-Durgapur)



Transverse section view



Longitudinal section view



BC1, BC2, BC3 Cavity Dimensions

Structural Frame

- Dimensions (LxBxH): 2838mm x 860mm x 3350mm
- **BC1, BC2 and BC3 frames are identical**

Vacuum Cavity

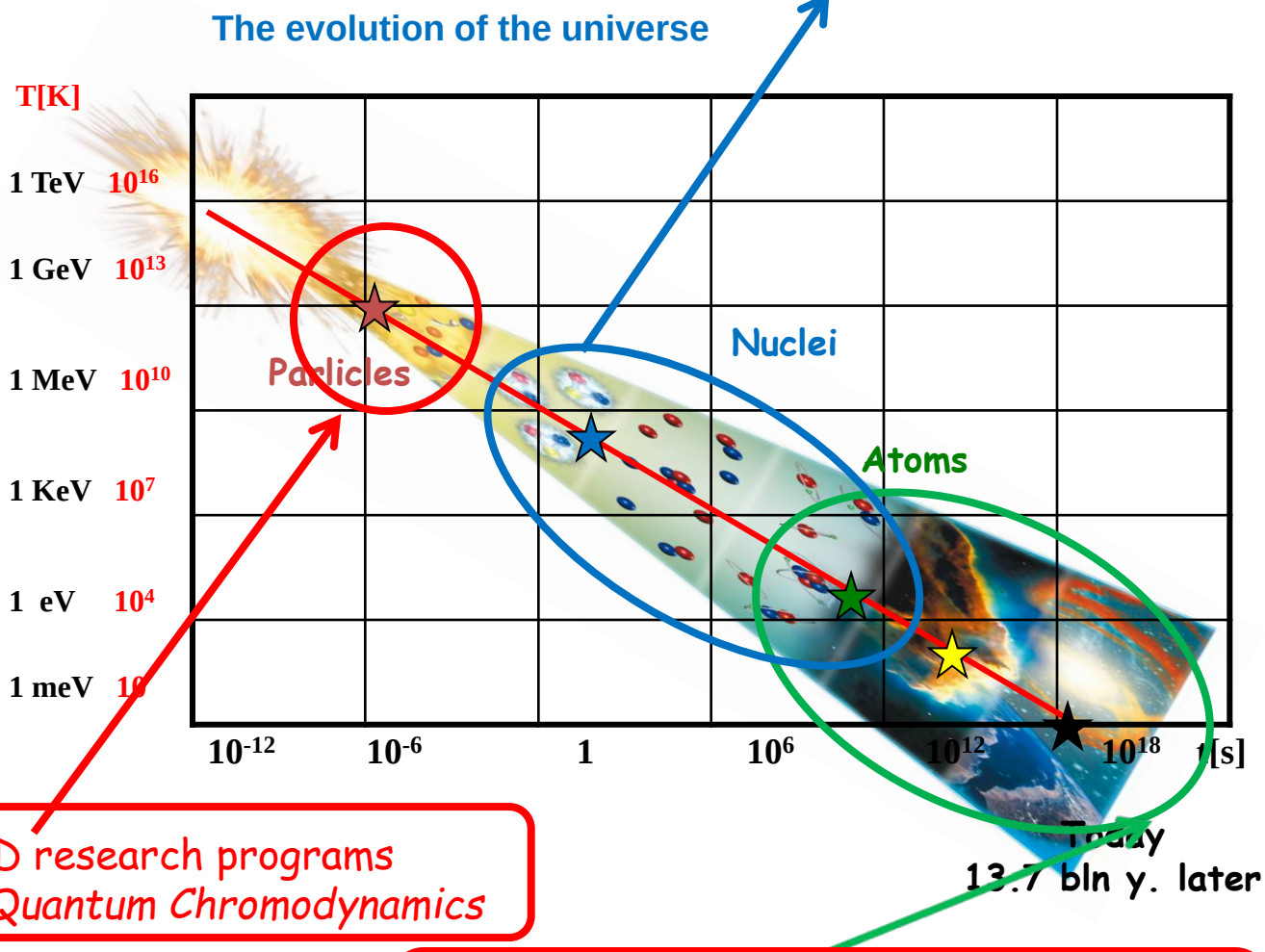
- Dimensions (LxBxH): 1600mm x 600mm x 2520mm

BC3 Top Plug Assy (≈7.0t)

FAIR physics

FAIR Research

FAIR – NUSTAR research programs
(Nuclear Structure, Astrophysics and Reactions



FAIR – QCD research programs
(Quantum Chromodynamics

FAIR – APPA research programs
(Atomic ,Plasma Physics and Applications)

NuSTAR: Nuclear Structure, Astrophysics, Reactions

Quest for the limits of existence

- **Halos, Few Body Correlations**
- **Changing shell structure far away from stability**
- **Skins, new collective modes, nuclear matter, neutron stars**
- **Origin of the elements**

10^{10}/s
10^{8}/s
10^{6}/s
10^{3}/s
10^{0}/s
10^{-3}/s
10^{-6}/s

➔ Combine accurate **nuclear physics** with precision **astronomy** to **constrain astrophysical scenarios**

r-process path

Halos

Neutron Skins

Pygmy Resonance

Neutron stars

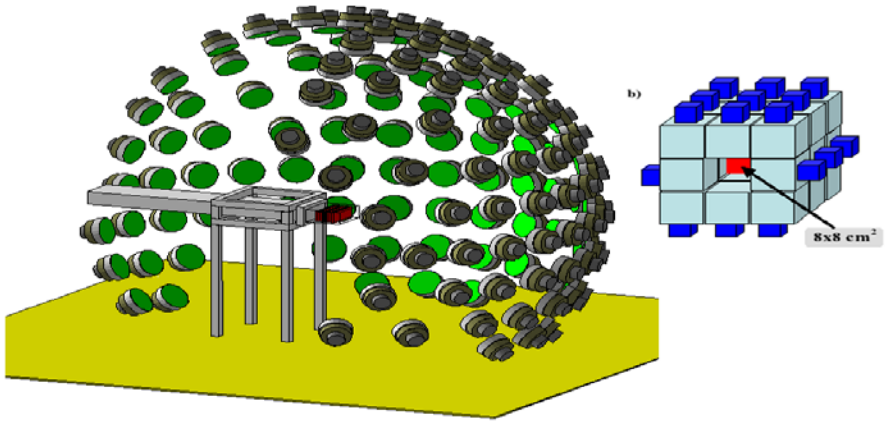
?

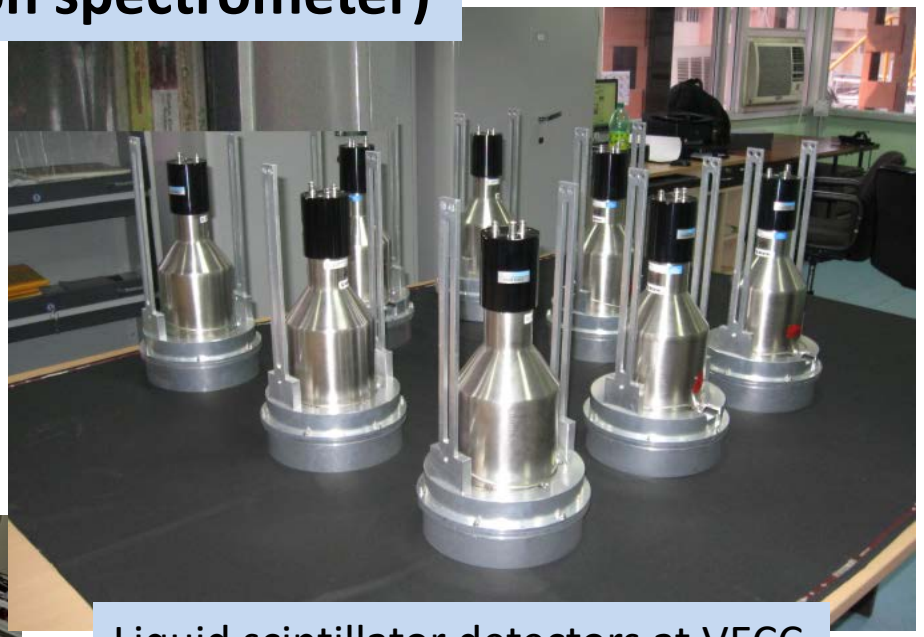
N

EOS

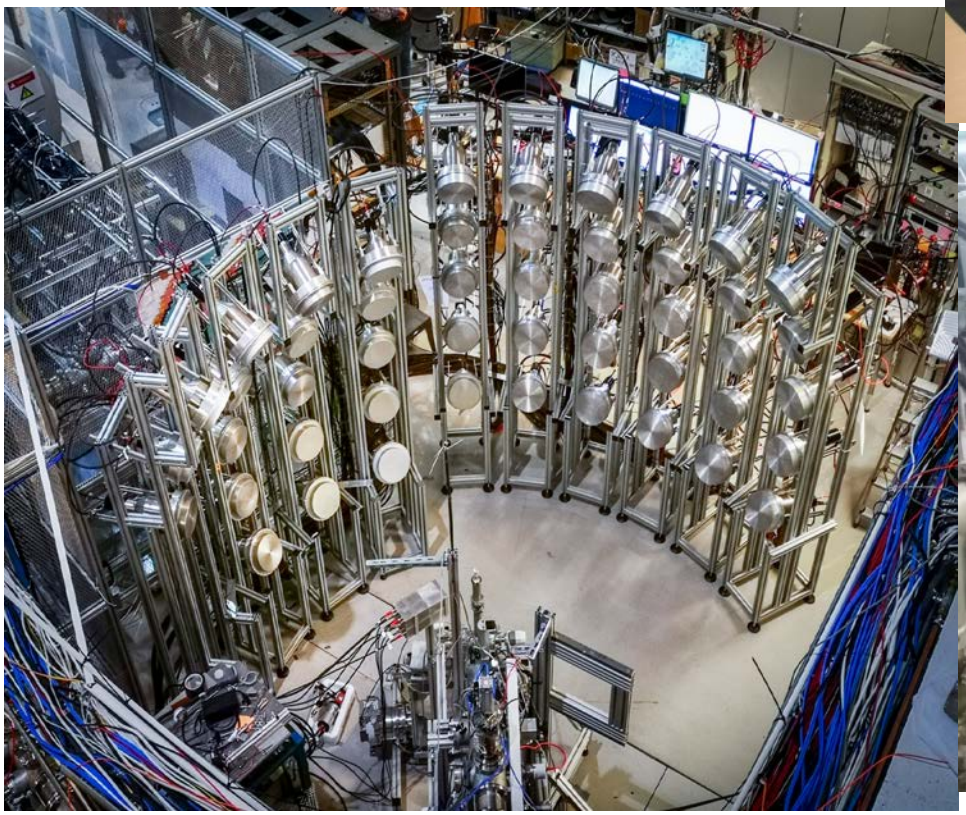
17

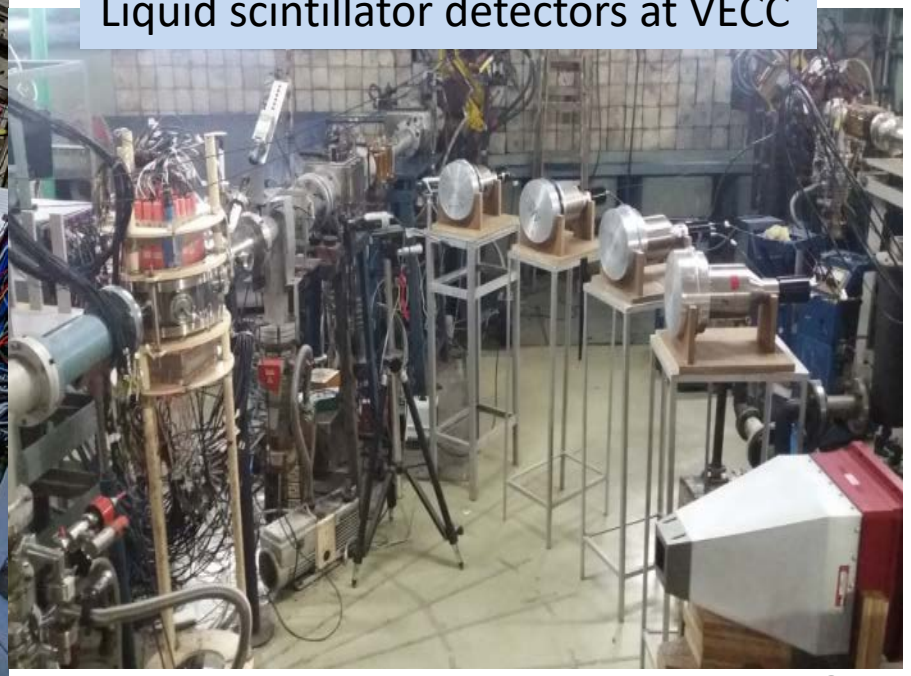
MONSTER Array (neutron spectrometer)



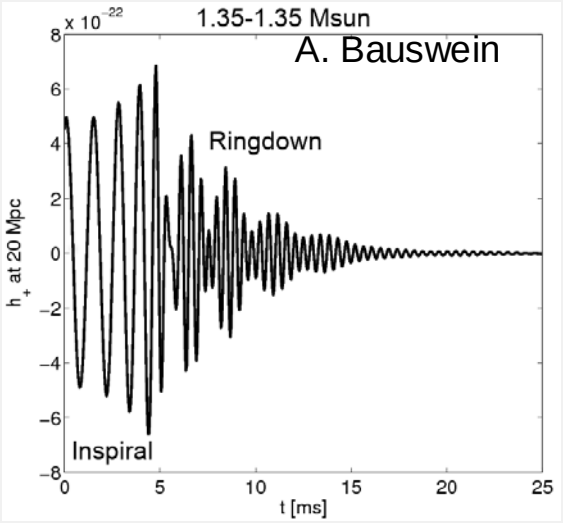


Liquid scintillator detectors at VECC



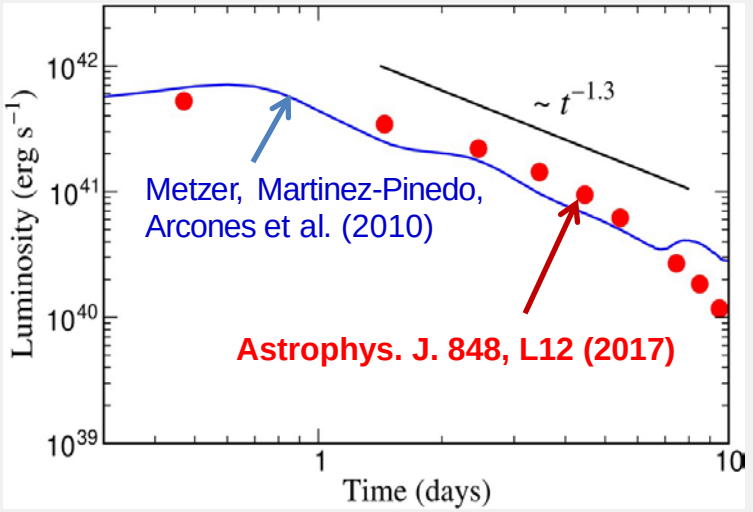


Astrophysical site of heavy element production (r process) in the universe: Neutron star merger !



Gravitational Wave Signal

Copyright: Dana Berry, SkyWorks Digital, Inc



Electromagnetic "Kilonova" Signal

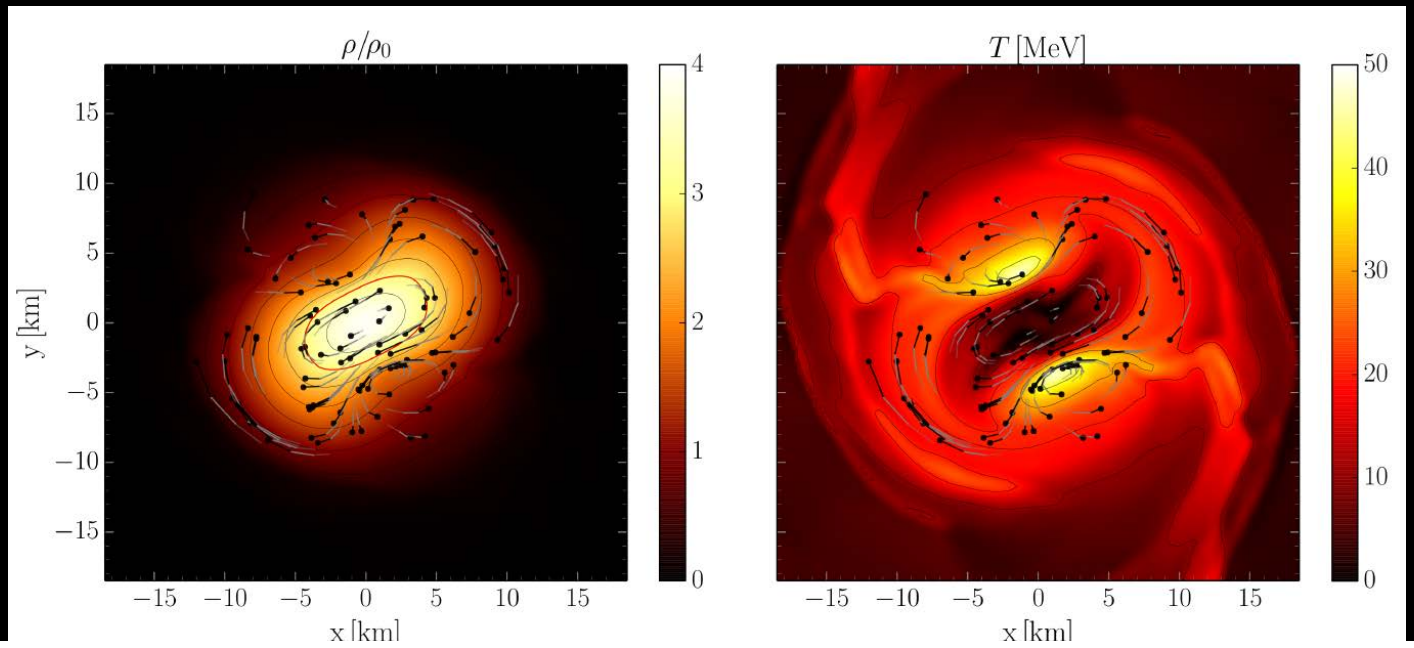
- Electromagnetic "Kilonova" signal due to "r process" in neutron star merger theoretically predicted by GSI scientists in 2010.
- Confirmation by recent astronomical observations after gravitational wave detection from GW170817 (August 2017).
- Source of heavy elements including gold, platinum and uranium.

Renewed interest

Neutron star mergers and heavy-ion collisions

density

temperature

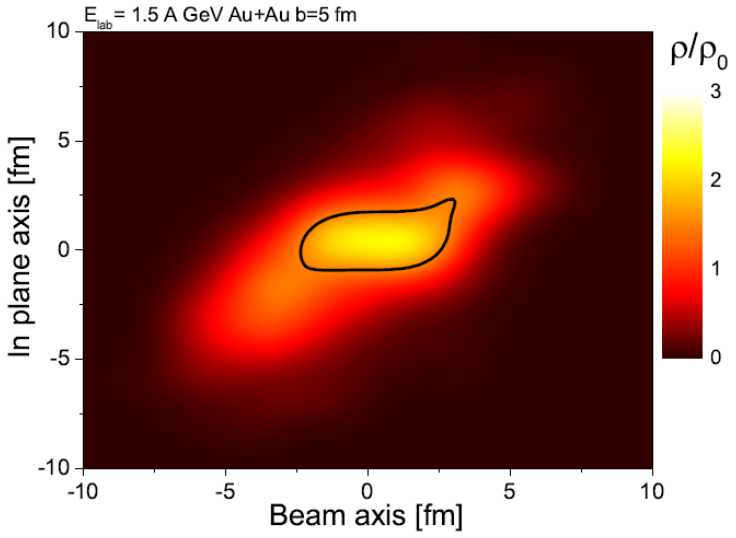


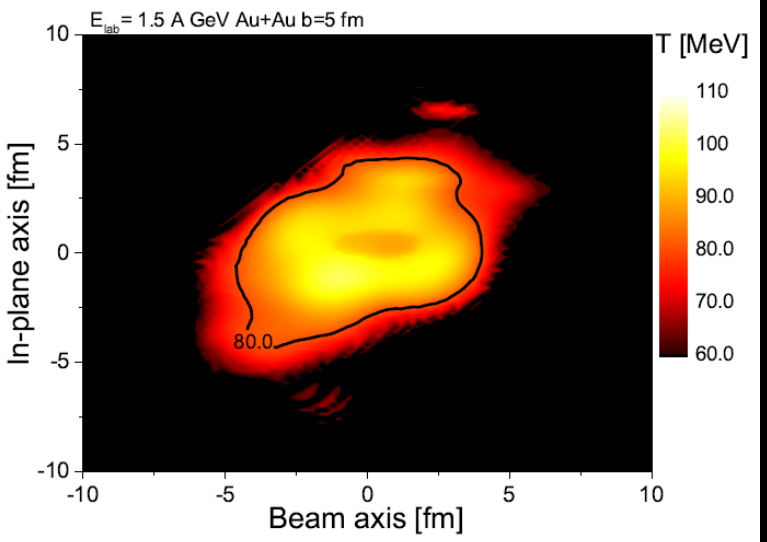
M. Hanauske et al., J. Phys.: Conf. Ser. 878 012031

n-star merger

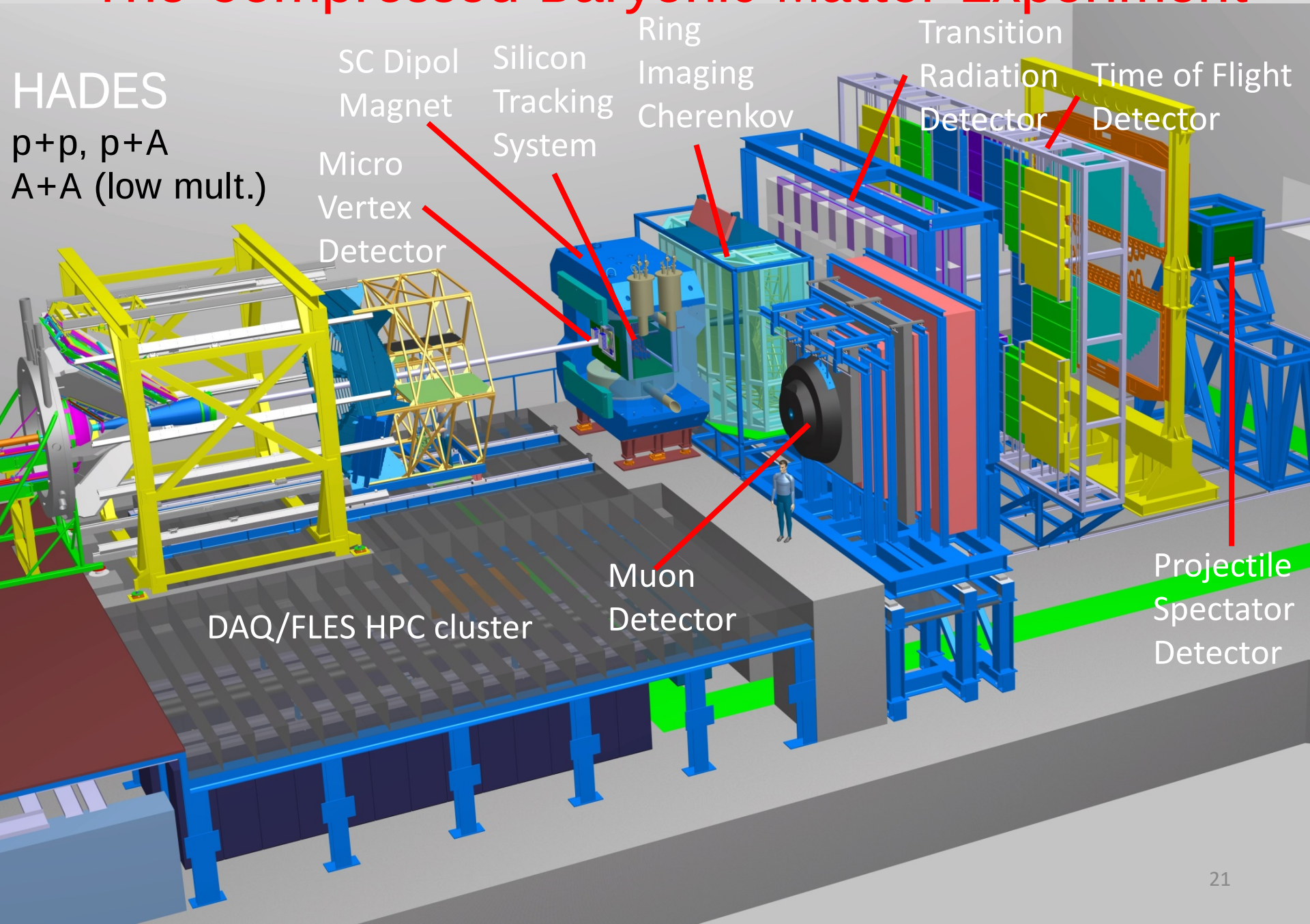
EOS

Au +Au 1.5A GeV





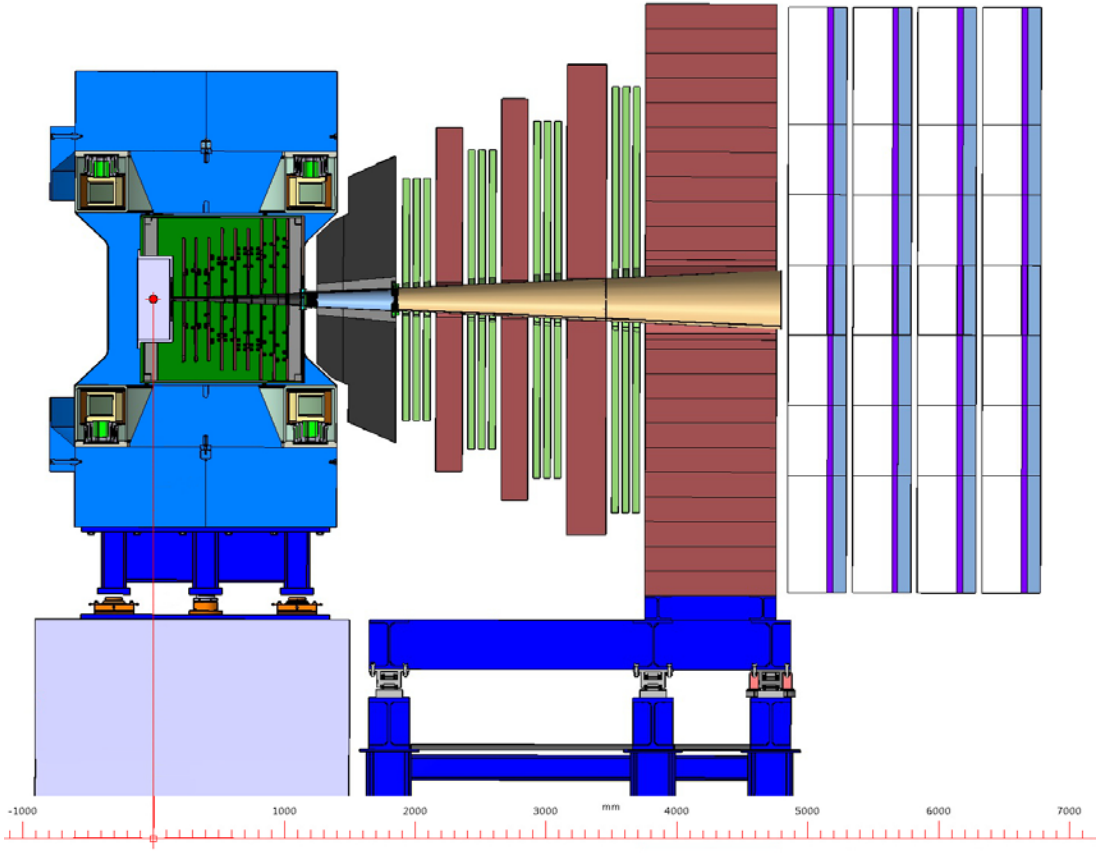
The Compressed Baryonic Matter Experiment



CBM experimental challenges

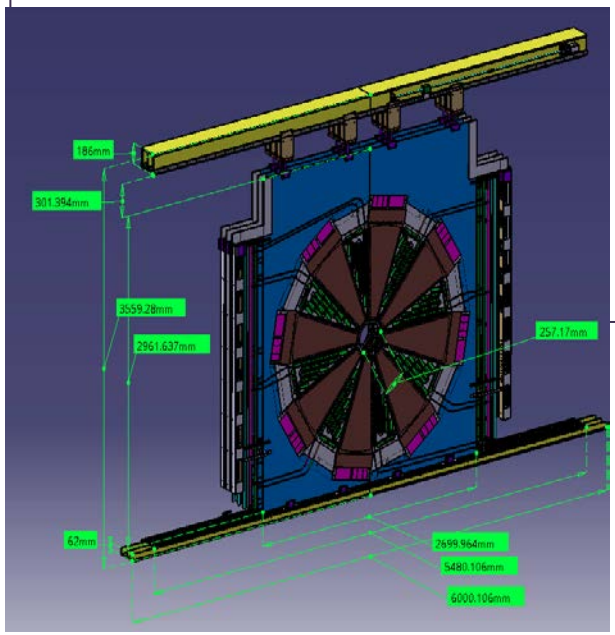
- 10^5 - 10^7 Au+Au reactions/sec
- determination of (displaced) vertices ($\sigma \approx 50$ μm)
- identification of leptons and hadrons
- fast and radiation hard detectors
- free-streaming readout electronics
- high speed data acquisition and high performance computer farm for online event selection
- 4-D event reconstruction

The **Mu**on **Ch**ambers (MUCH) at the compressed baryonic matter (CBM) experiment (Indian contribution)

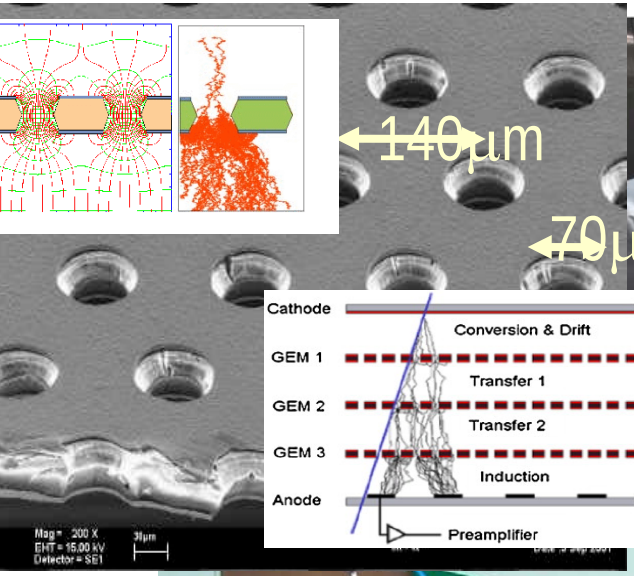


Detection of
Low mass vector mesons
and charmonia via
Di-muon channel

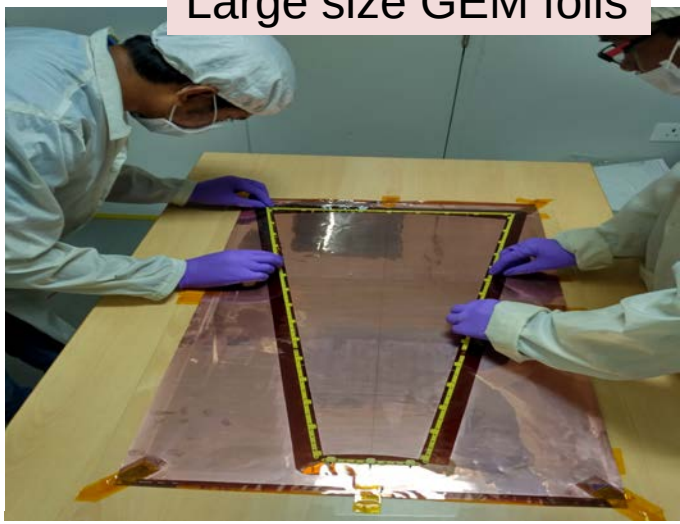
First two stations: GEM
3rd and 4th stations:RPC

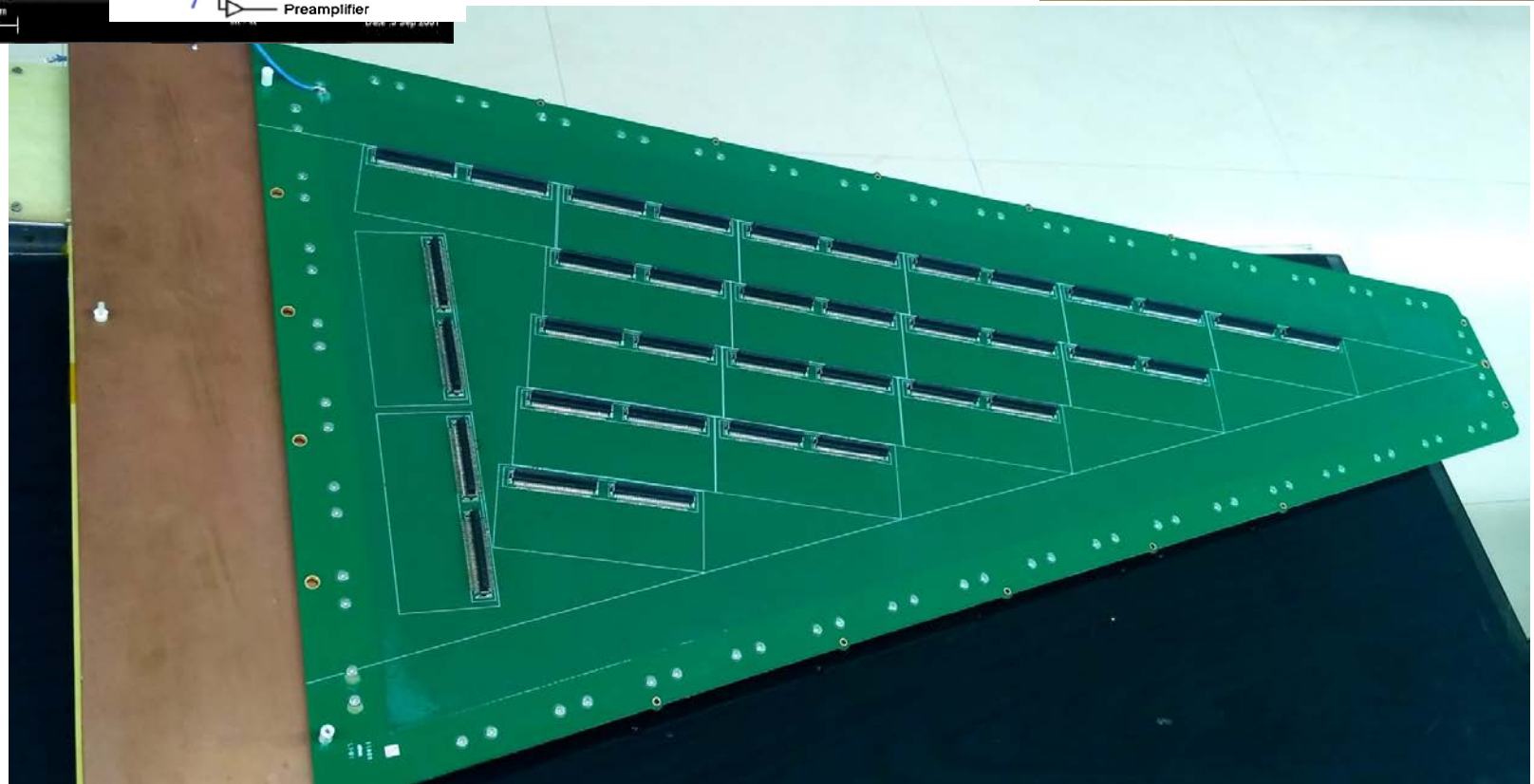


GEM Module Fabrication

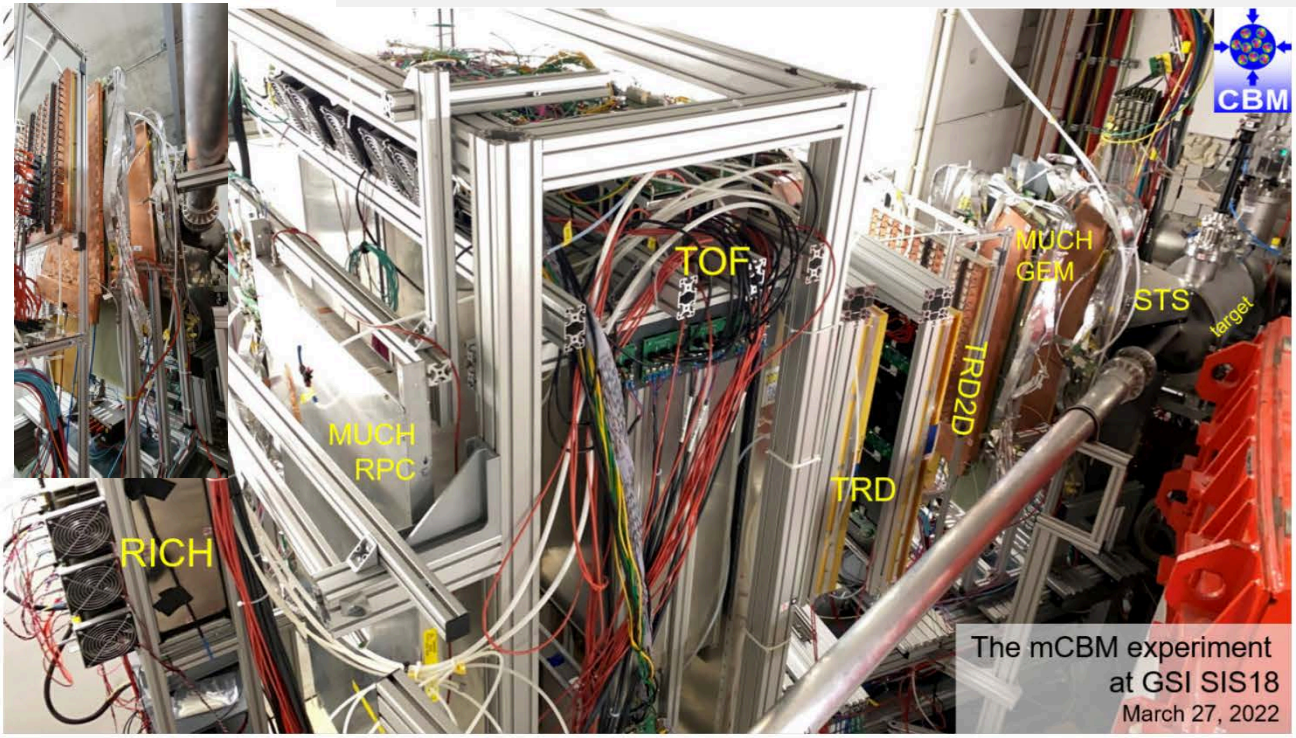


Large size GEM foils





FAIR phase-0: mini-CBM experiment at SIS18@GSI

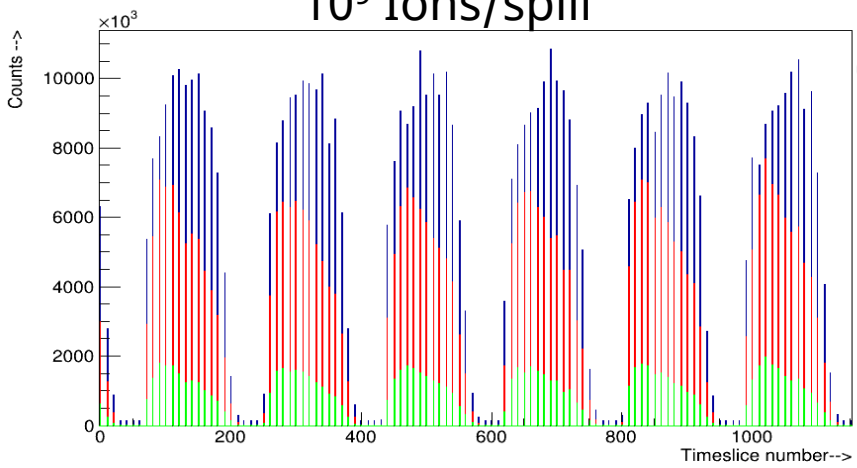


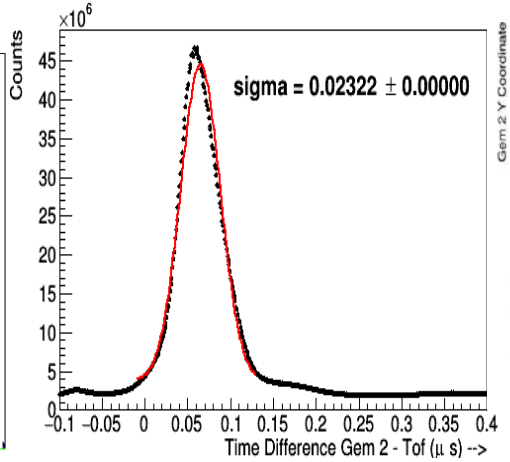
Ni + Ni, T = 1.93 AGeV
May 26, 2022
av. collision rate: 400kHz
av. data rate 1.5 GB/s to disc,
- in total 32 TB tsa files
- total duration of runs 05h 55m
- approx. $6 \cdot 10^9$ collisions

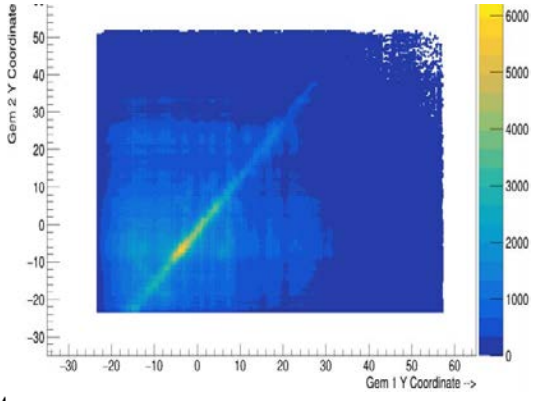
run 2391: **first, preliminary results**

Au + Au, T = 1.23 AGeV
June 17 - 18, 2022
a) av. collision rate: 300 - 400kHz
av. data rate 2.4 GB/s to disc
b) av. collision rate: 200 - 300kHz
av. data rate 1.5 GB/s to disc,
- in total 180 TB tsa files
- total duration of runs 34h 33m
- approx. $2 \cdot 10^{10}$ collisions

10^9 Ions/spill

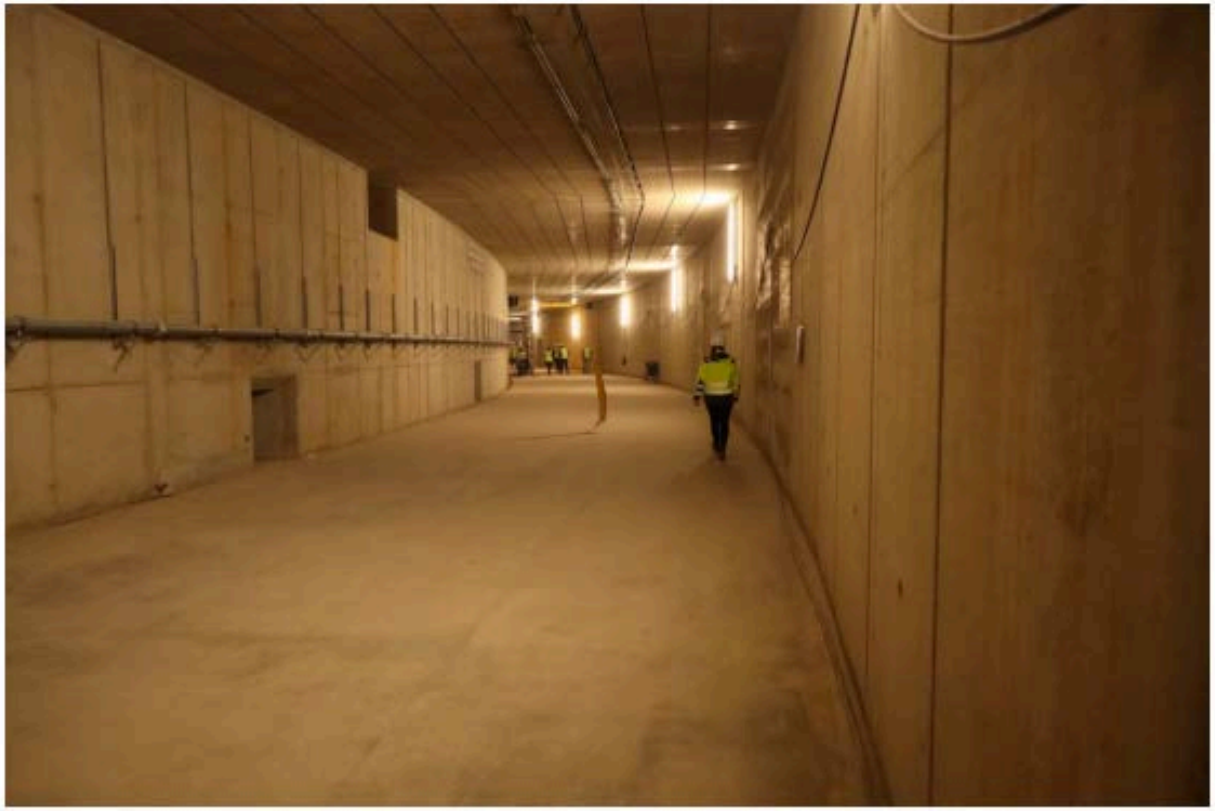






FAIR: Construction Field

Towards SIS100



1100 m trip under the roof


CBM CAVE
Installation: 2026

FAIR in final form

Delayed due to regulatory and
recent International events involving Russia
Beam expected ~2027

1. FAIR will explore a range of physics goals including
   - *Strongly interacting matter under extreme density*
   - *Nuclei under extreme conditions of n/p number*

1. Indian participation includes key accelerator equipment
2. and advanced detectors

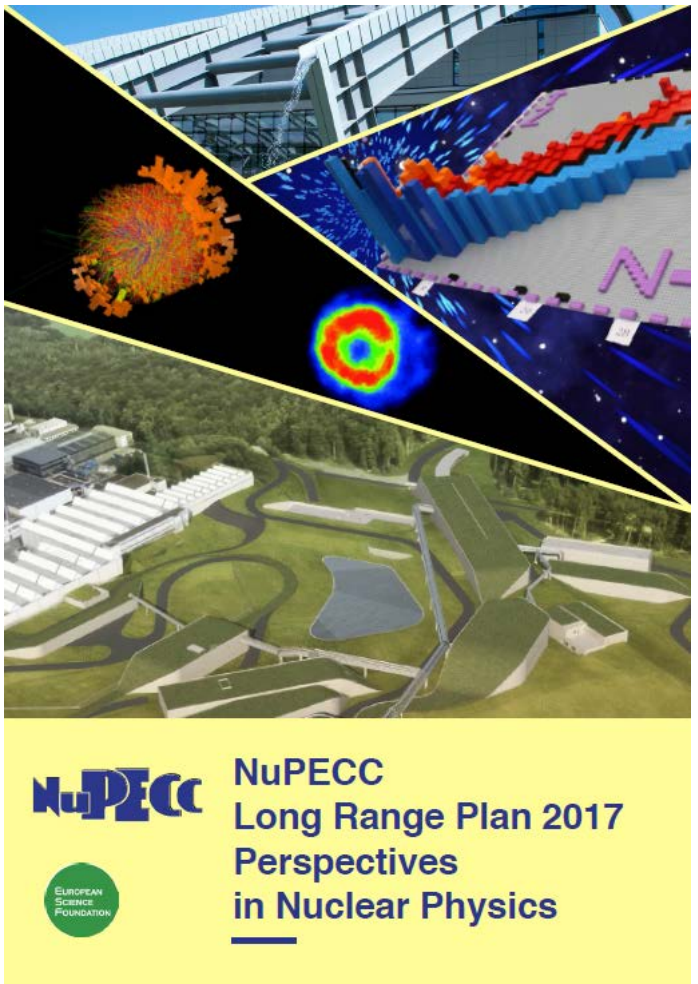
3. Hoping to overcome various issues soon and start taking data

Instead of a summary: NuPECC recommendation

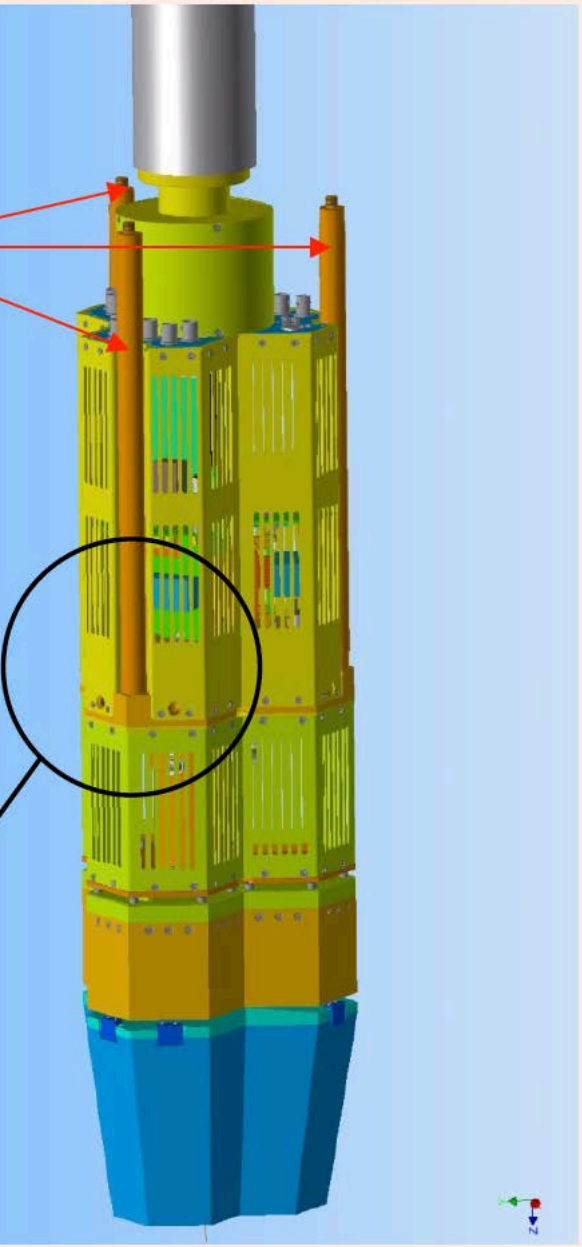
Key Summary Recommendation of the NuPECC Long Range Plan 2017 presented in Brussels on Nov 27th :

Complete urgently the construction of the ESFRI* flagship FAIR and develop and bring into operation the experimental program of its four scientific pillars APPA, CBM, NUSTAR and PANDA.

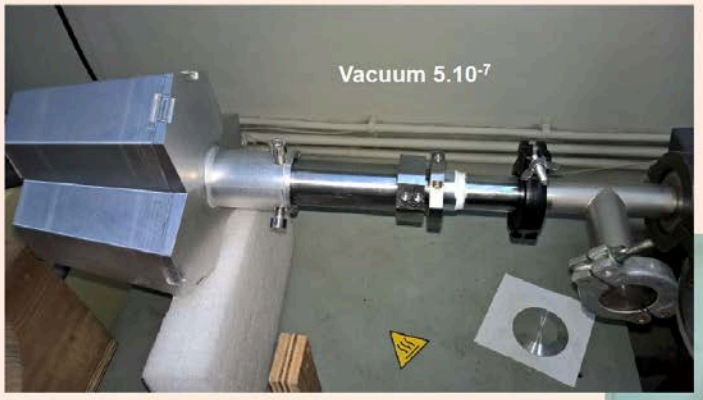
FAIR is a European flagship facility for the coming decades. Worldwide unique it will allow for a large variety of unprecedented fore-front research in physics and applied science. It focuses on the structure and evolution of matter. Its multi- faceted research opens a new era in our understanding of the fundamental building blocks of matter and the forces as well as of the evolution of our Universe: the new possibilities for research in Darmstadt are unique and are expected to produce ground breaking new insights for nuclear research.



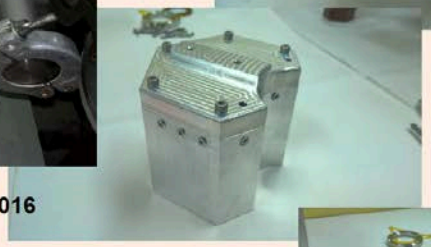
*European Strategy Forum on Research Infrastructures

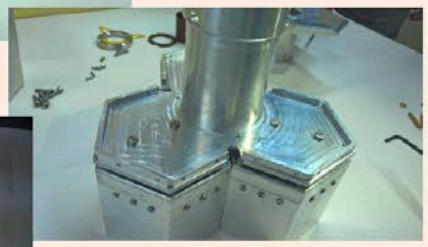


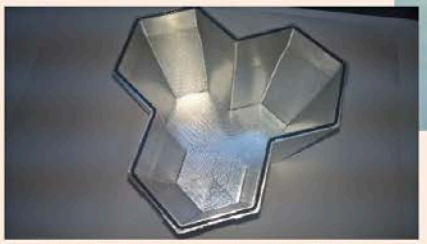
DeGas Spectrometer: R&D, production and installation of crystal detectors



First mechanics test, TIFR, Mumbai, India, February 2016







First test and characterization – 2016
In operation – Spring 2018