Variable Energy Cyclotron Centre

Bikash Sinha
Homi Bhabha Professor

January 2010

Prof. Abdus Salam, during his 1986 visit to VECC

Major Accelerator Centres in India

- Saha Cyclotron: Now at Calcutta University
- Variable Energy Cyclotron Centre, Kolkata
  224 cm Variable Energy Cyclotron, room temperature
  K-500 Super Conducting Cyclotron Accelerator,
  Radio active ion beam facility for beams of rare isotopes
  Medical Cyclotron
- Raja Ramanna Centre for Advanced Technology, Indore
  (Indus-1 & Indus-2 SRS, 10 MeV Industrial Linac, DC Accelerator etc.)
- Bhabha Atomic Research Centre , Mumbai
  (7 MV FOTIA, 10 MeV e- Linac for Radiation Processing etc.)
- Inter University Accelerator Centre, New Delhi
  (15 MV Palletron & SC Linac Modules for energy augmentation etc.)
- Tata Institute of Fundamental Research, Mumbai
  (14 MV Palletron, SC 150 MHz QWR based Linac Booster for energy gain)
- Institute of Physics, Bhubaneshwar
  (3 MV Tandem Palletron Accelerator mostly for Materials Science)
- Cyclotron at Chandrigarh donated by USA
- Microtron at Mangalore University

Variable Energy Cyclotron Centre

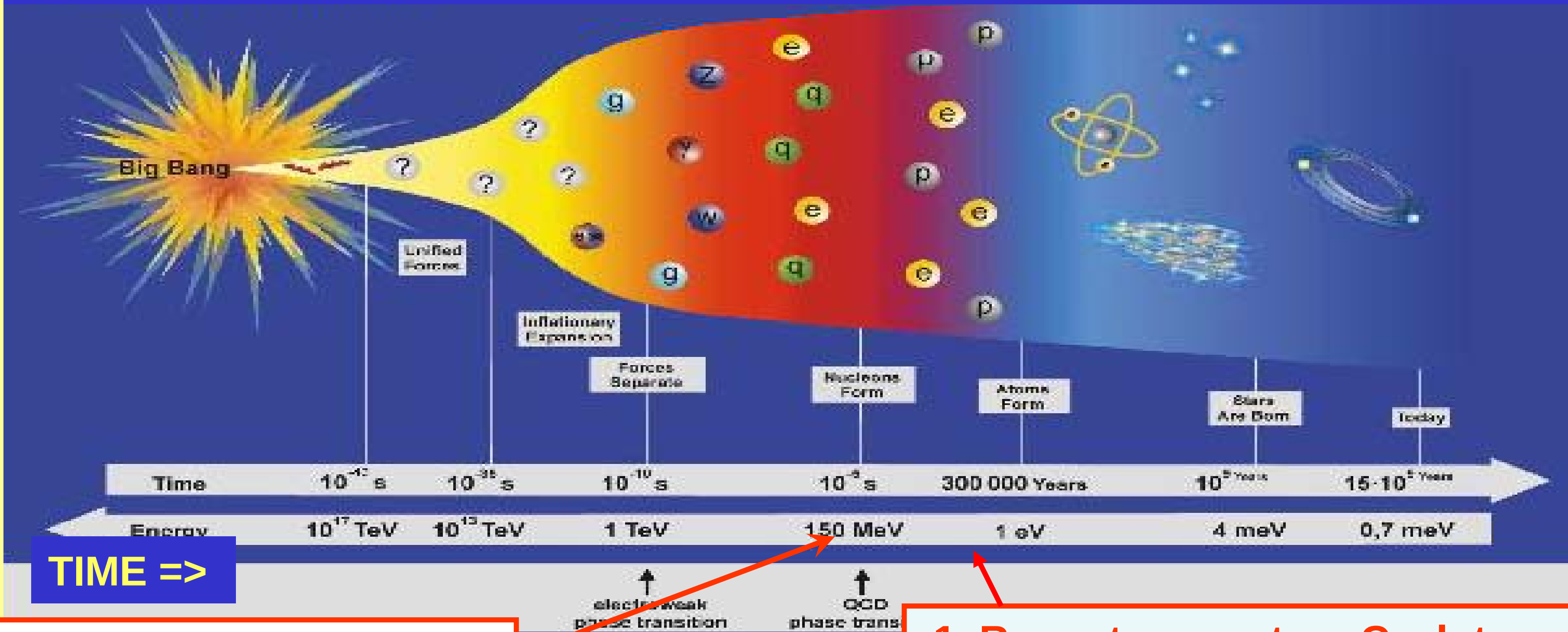
Department of Atomic Energy
Government of India
(r & D)

1. **224 cm Room Temperature Cyclotron, operational for almost thirty years**

   K=130 : ‘α’ ~ 100 MeV
   12_{C}, ^{20}Ne, ^{40}Ar

2. **K=500 : Superconducting Cyclotron : Commissioned on 25th August, 2009**
3. **Radioactive Ion Beam Facility (RIB)**
4. **CERN-INDIA Collaboration**
5. **FAIR – GSI & India Collaboration**
6. **Medical Cyclotron**
7. **Others**
   - **Helium Project**
   - **Nuclear Medicine**
   - **ADSS**
   - **Advanced Computing**

Exploring the Universe: R&D at VECC



7. Quark-Gluon Plasma
International Collaborations
Expts at CERN, BNL & GSI

1. Room temperature Cyclotron

2. Superconducting Cyclotron
Nuclear Structure
Liquid-gas phase transition

4. Medical Cyclotron
Medical Imaging

6. ADSS:
Future of
Nuclear Energy

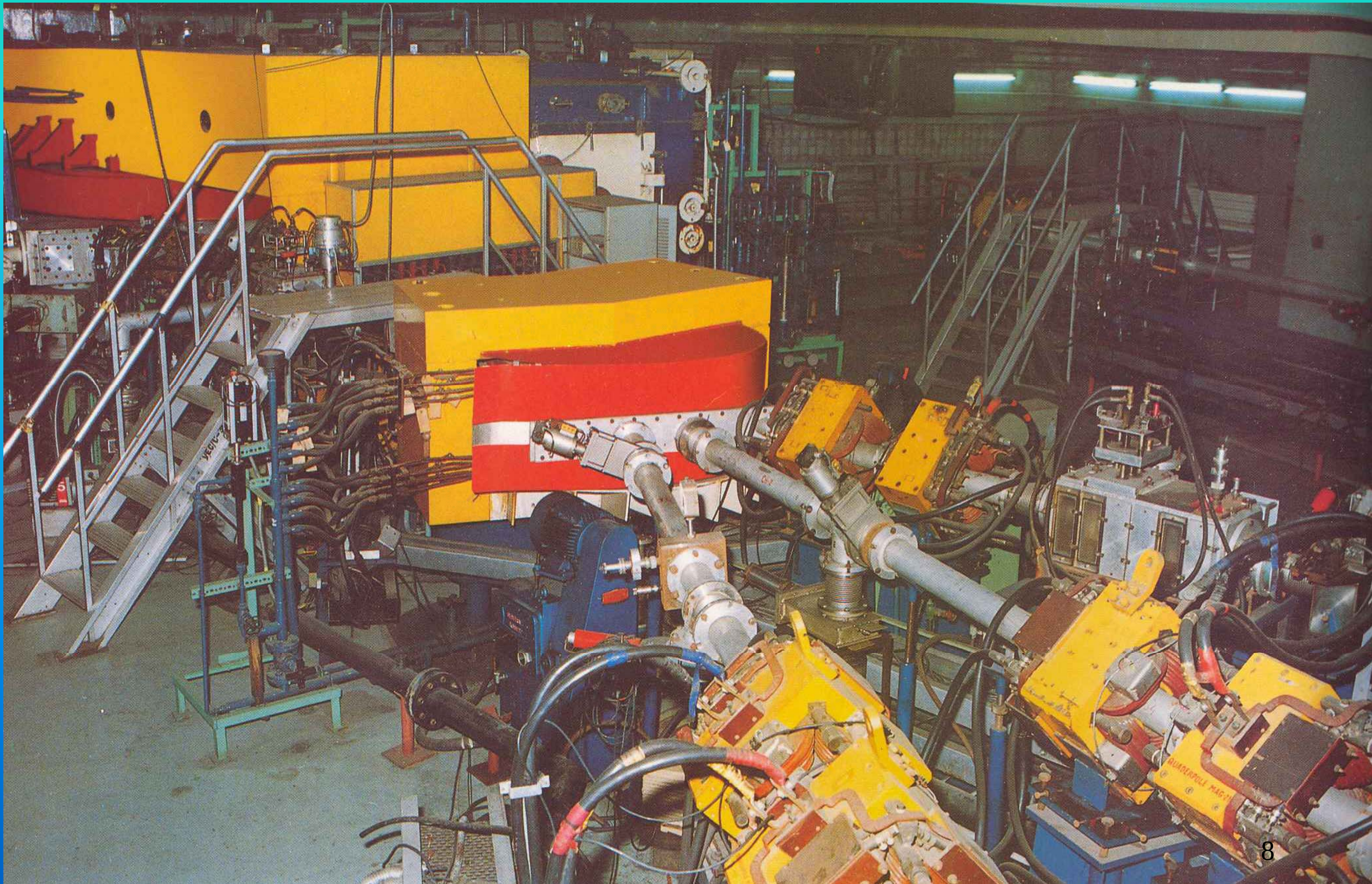
5. Helium project

3. Radioactive Ion Beam (RIB)
Nuclear Astrophysics
Heavy element synthesis in early universe

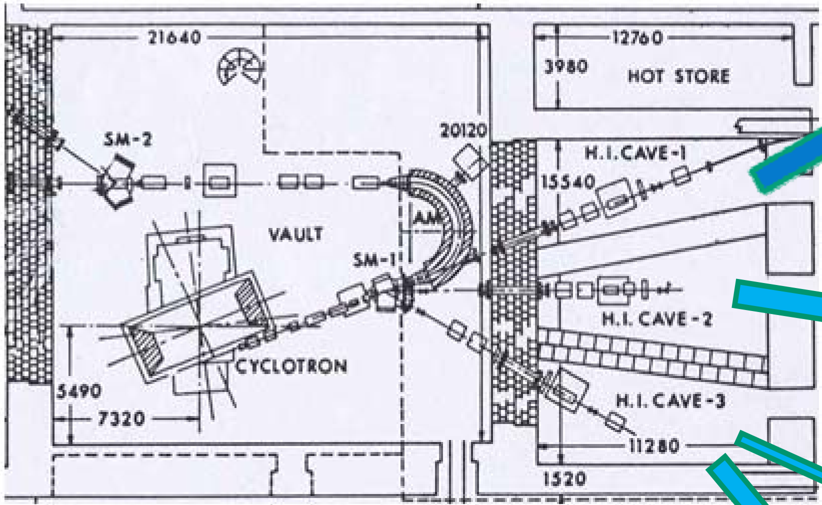
K=130

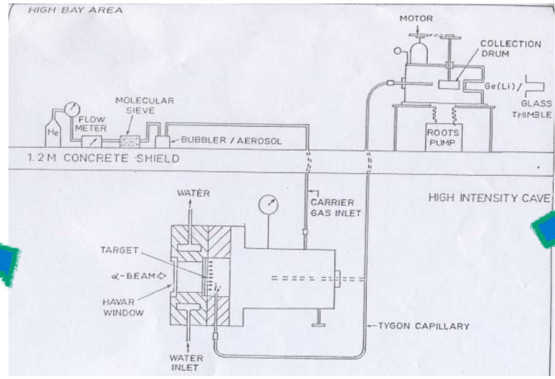
Room Temperature Cyclotron

VARIABLE ENERGY CYCLOTRON

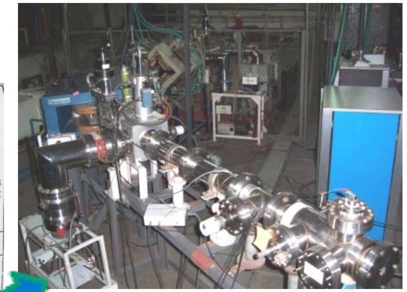


Experimental Facilities for K130 Cyclotron



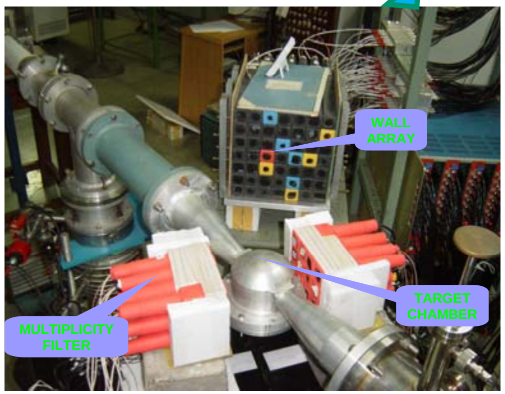


He-Jet Recoil Separation

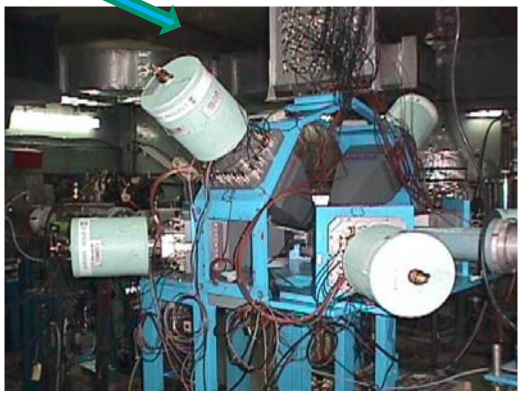


ISOL System

Scattering Chamber

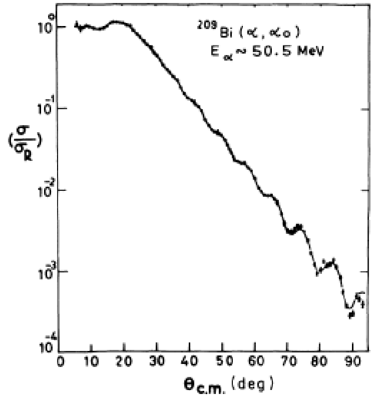


BaF2 Gamma Array

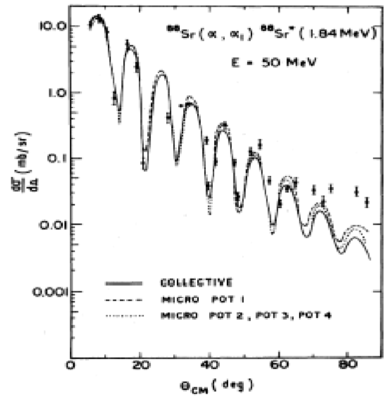


Indian National Gamma Array (INGA)

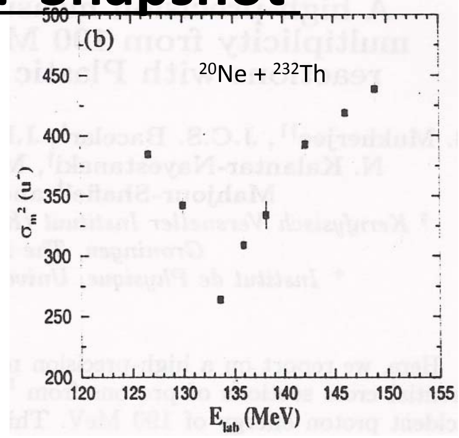
Experiments at K130 Cyclotron : Snapshot



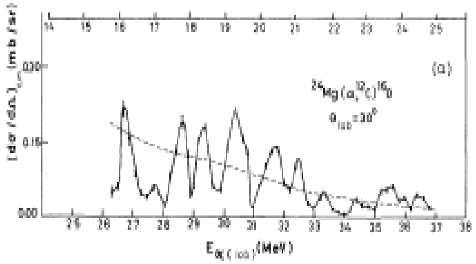
Elastic Scattering



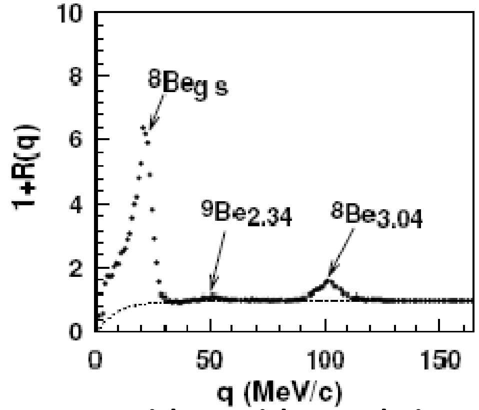
Inelastic Scattering / Transfer reaction



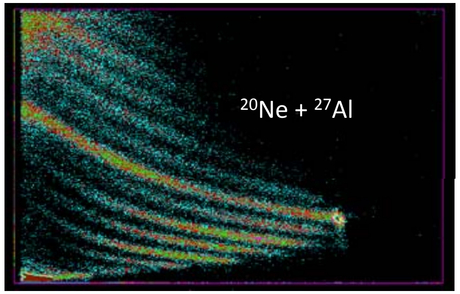
Fission / Quasi-Fission



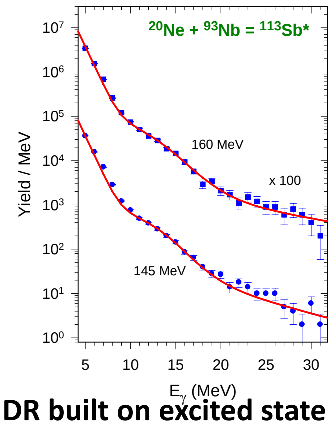
Quasimolecular resonance



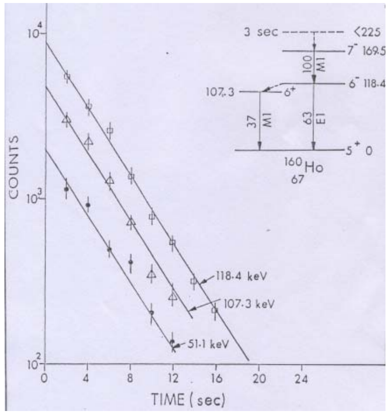
Particle-particle correlation



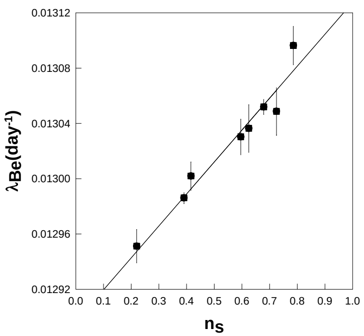
Complex Fragment Emission



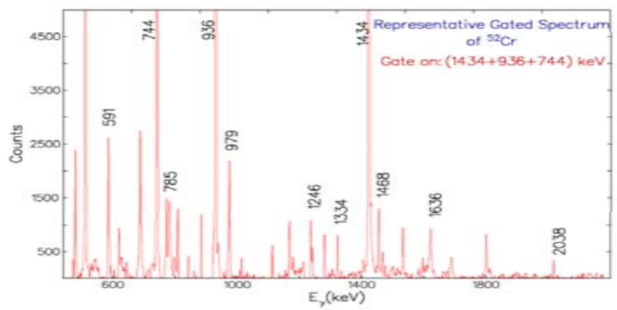
GDR built on excited state



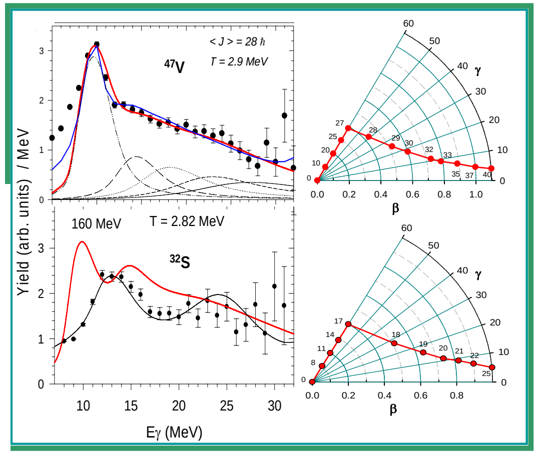
Decay of 3 s isomer of ^{160}Ho



Variation of ^{7}Be decay rate



Gated gamma ray specra from INGA



GDR splitting and deformation

Experiment with 4-Clover Array at VECC

INGA

VECC-IUCC-SINP COLLABORATION

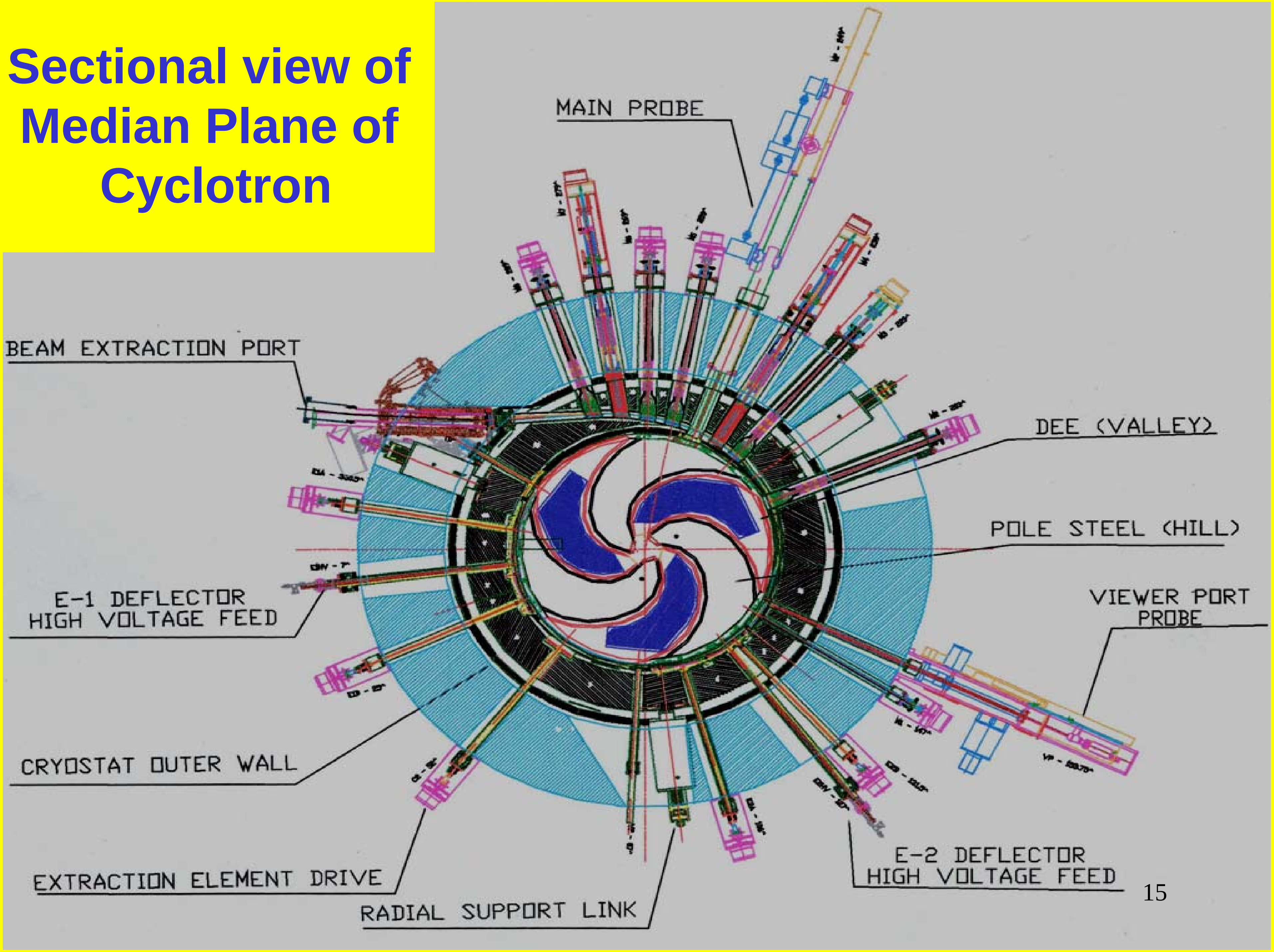
K=500

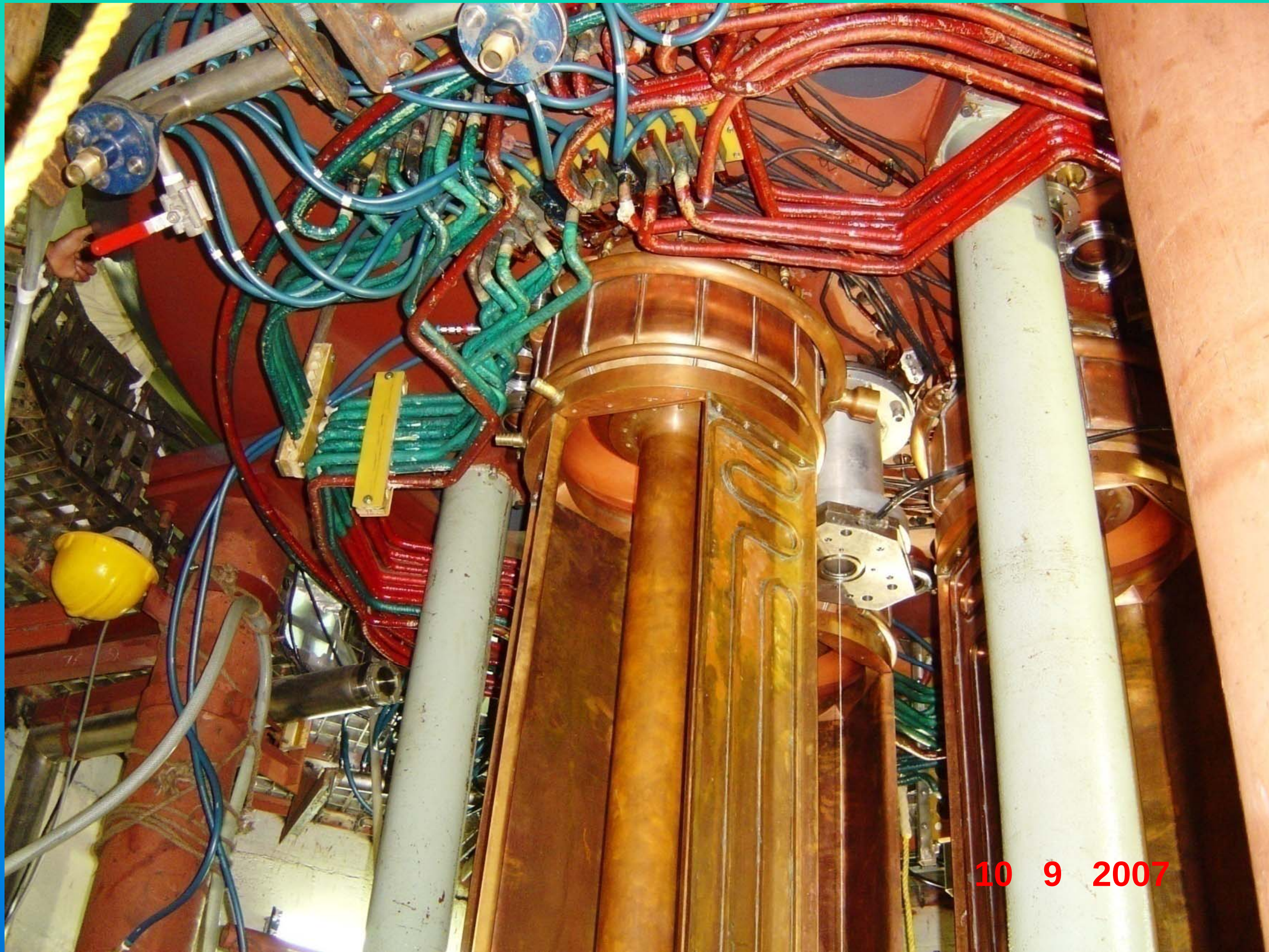
Superconducting Cyclotron

Dr. R. Chidambaram and Honourable Chief Minister Sri Jyoti Basu laying the foundation stone for the Superconducting Cyclotron building at VECC, on June 18, 1997

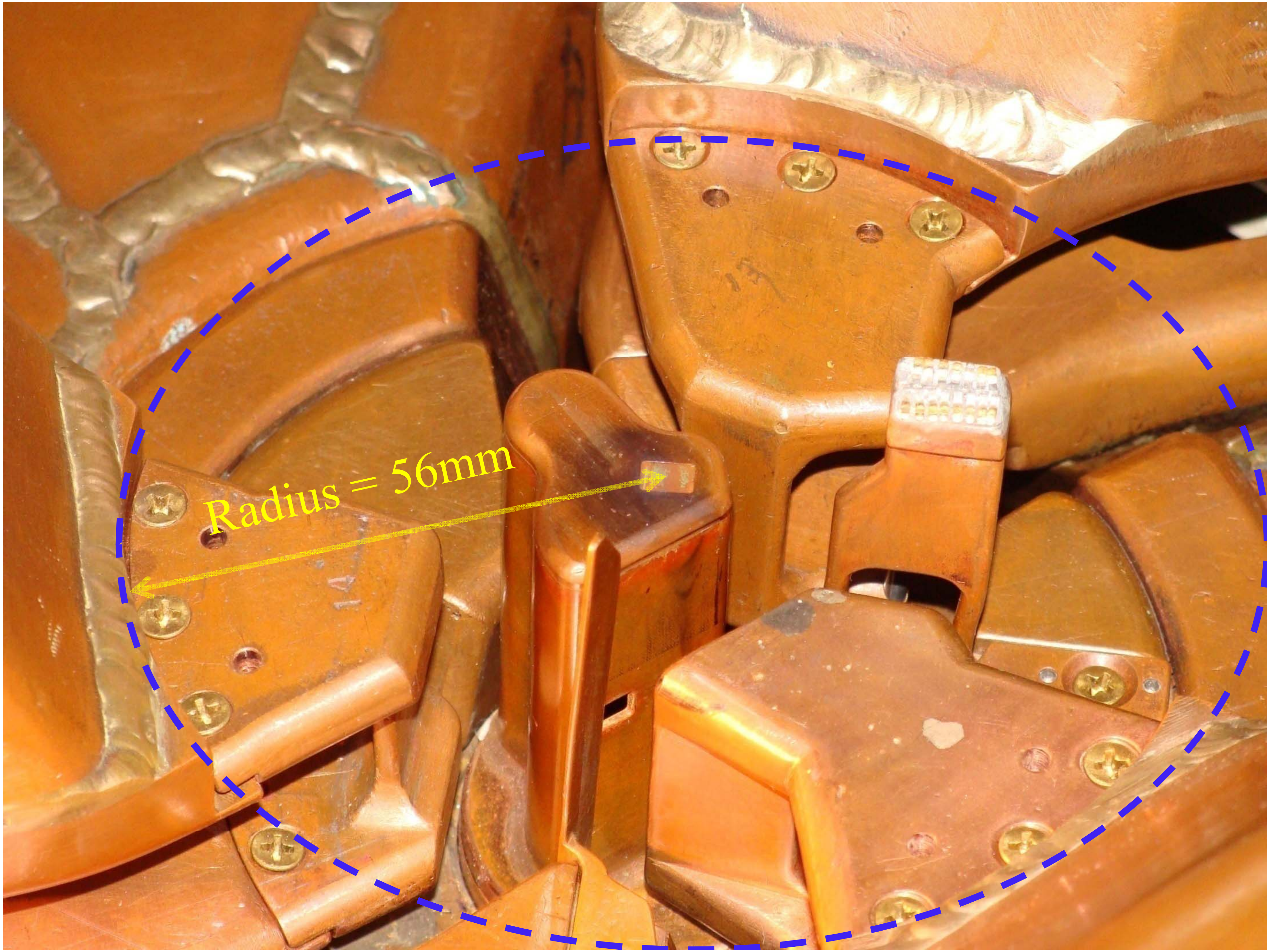
Honourable Chief Minister Sri Jyoti Basu singed on visitor book ,VECC, on June 18, 1997

Sectional view of Median Plane of Cyclotron



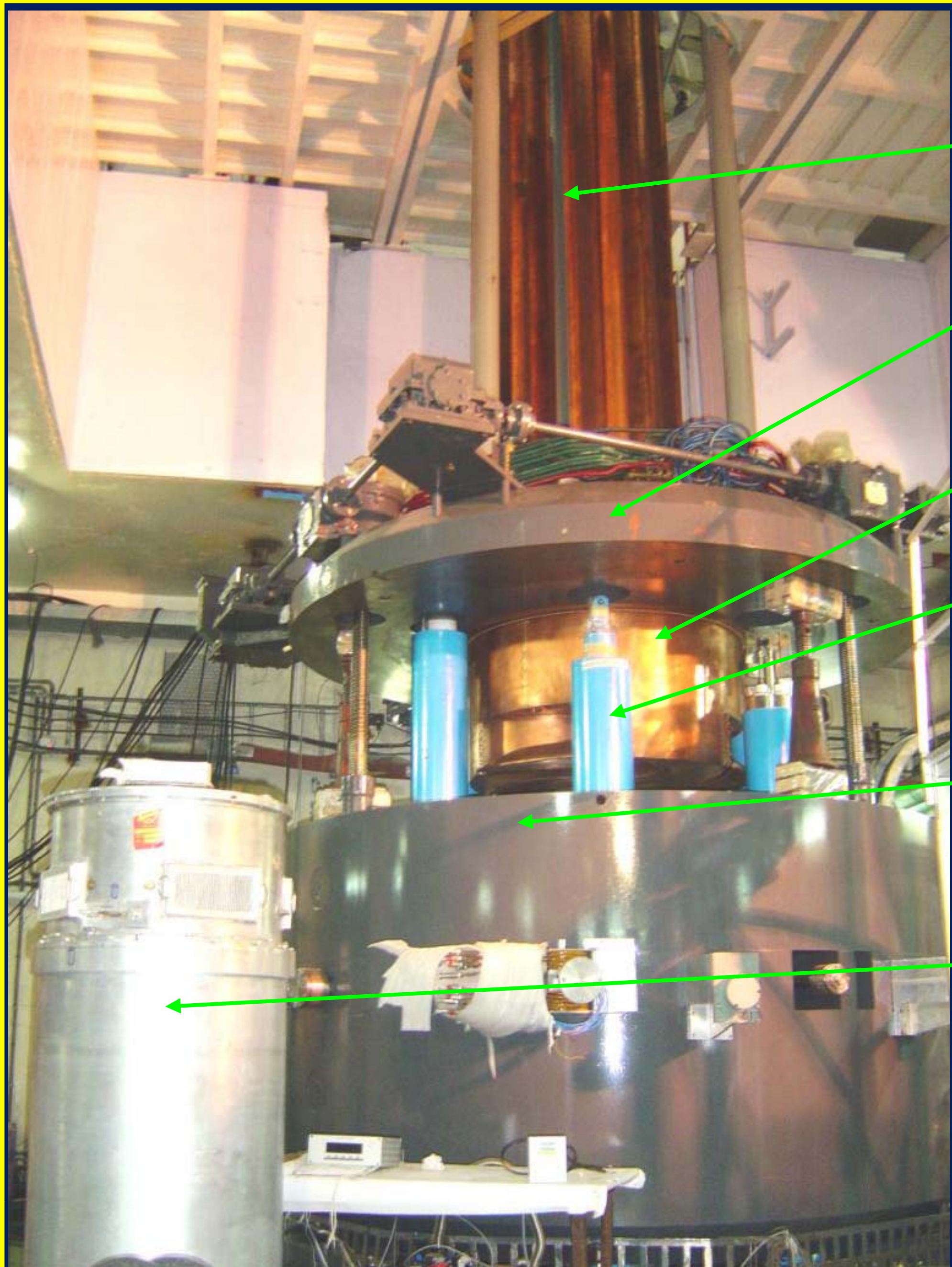


Lower outer conductor spinning assemblies

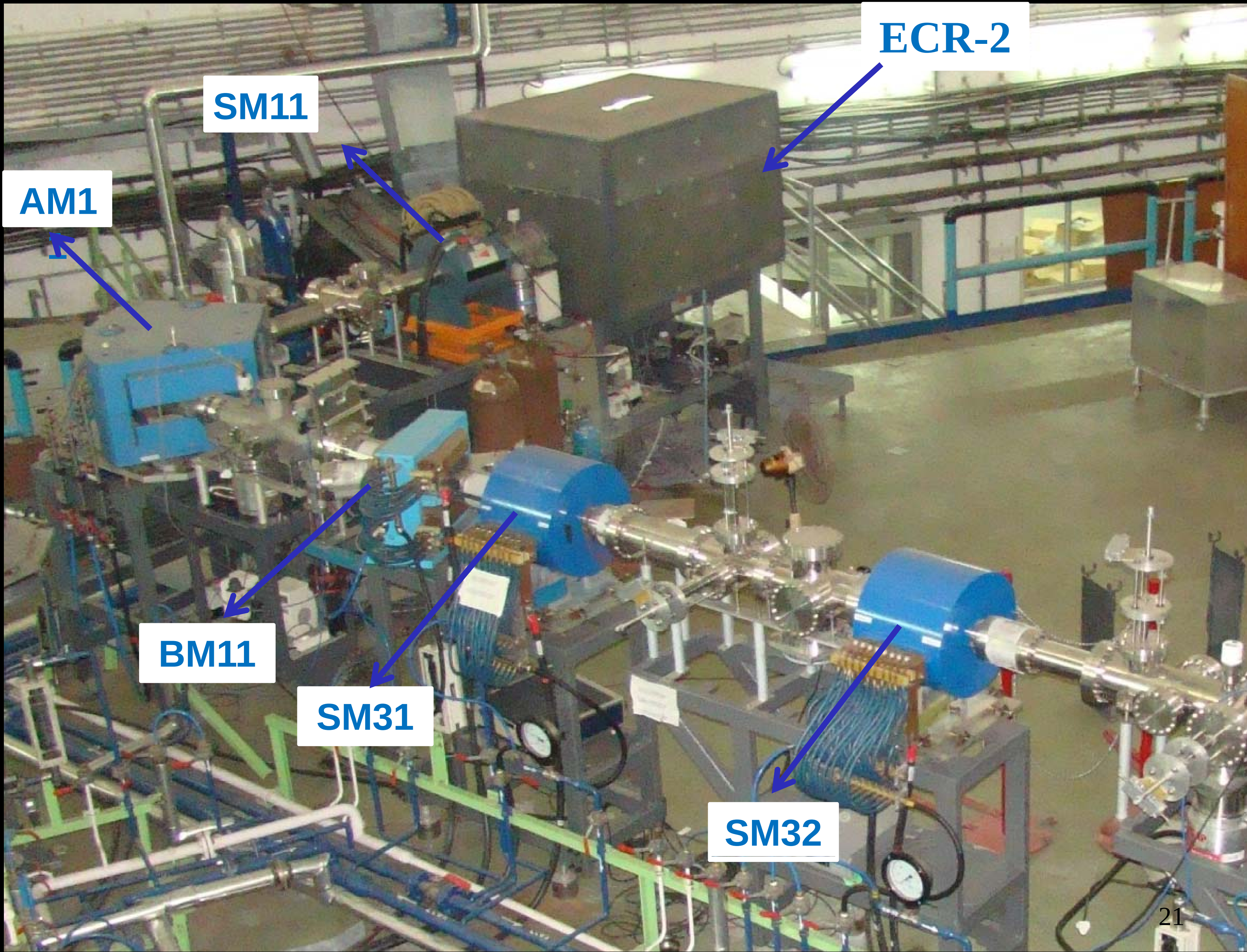

Radius = 56mm

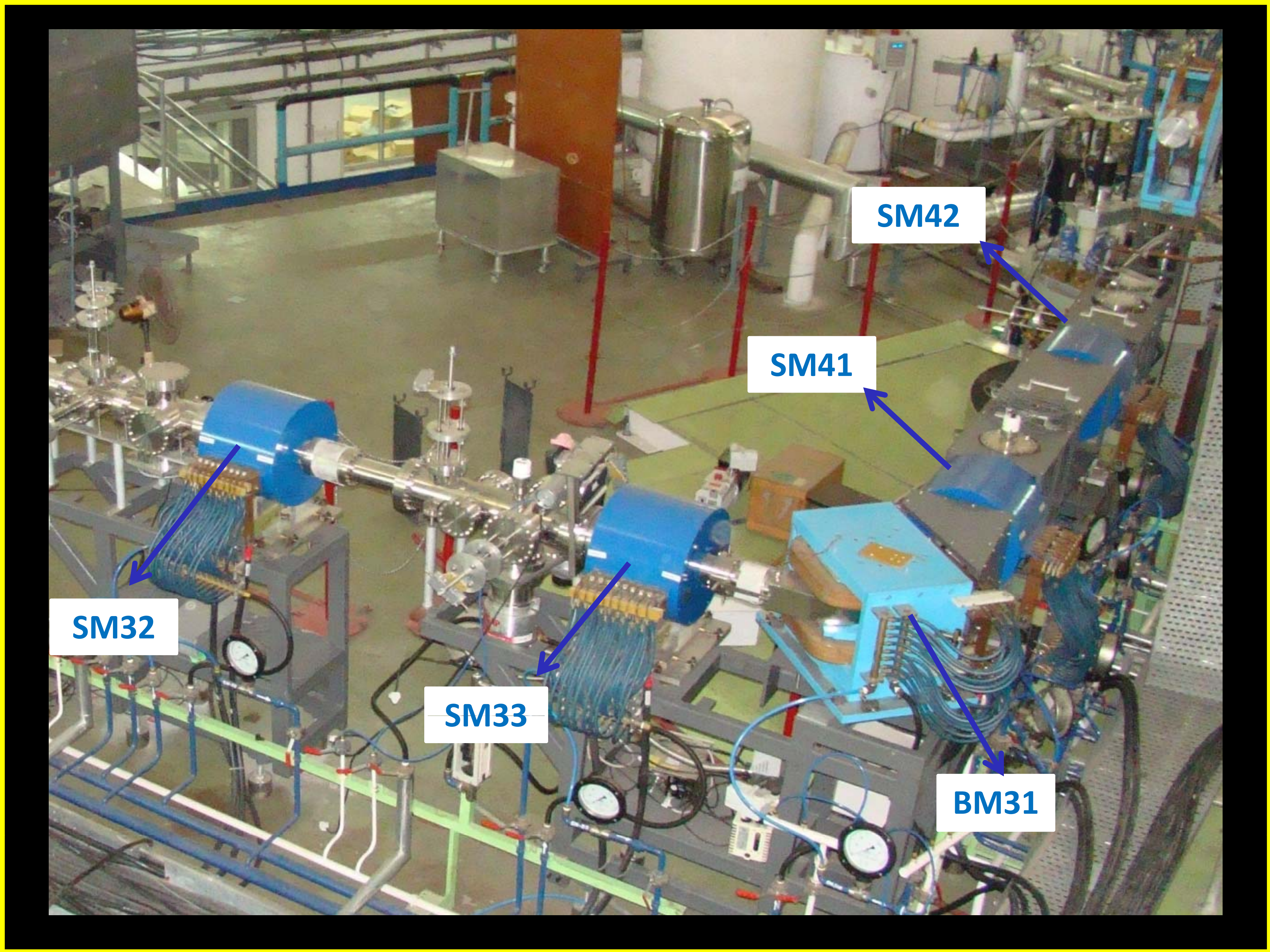
SUPERCONDUCTING CYCLOTRON WITH MAGNETIC CHANNEL AND MAIN BEAM PROBE DRIVES

Magnet Cool down to -269^{0} c (4.2 K) on 11th January 2005



K-500 cyclotron magnet and RF system


ECR-2
SM11
AM1
BM11
SM31
SM32



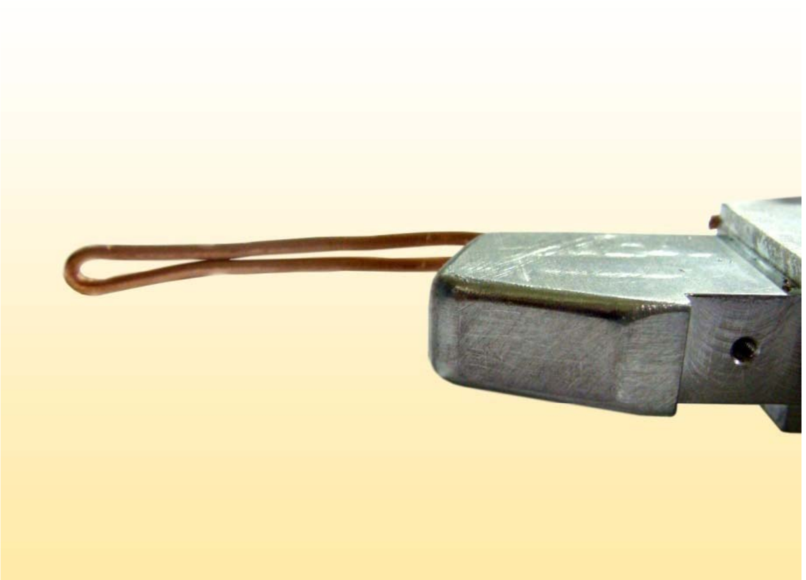
SM42
SM41
SM32
SM33
BM31

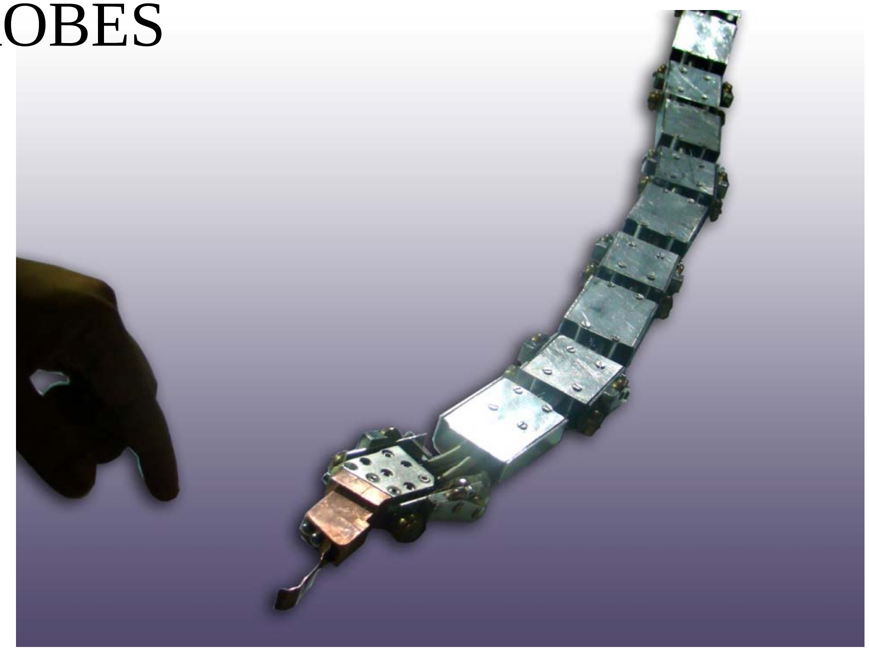
3 MeV ^{16}O beam

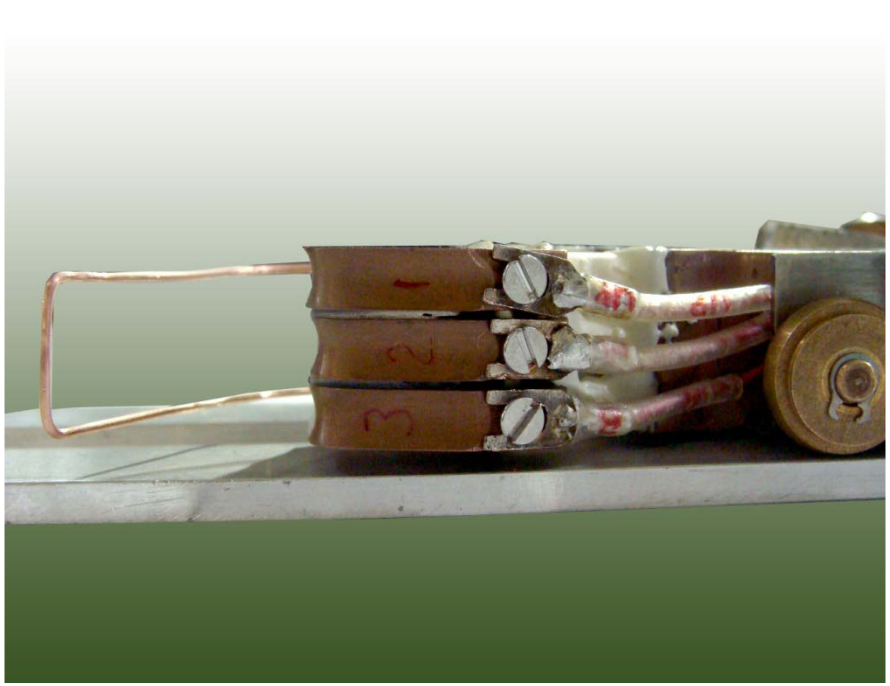
18 n Amp

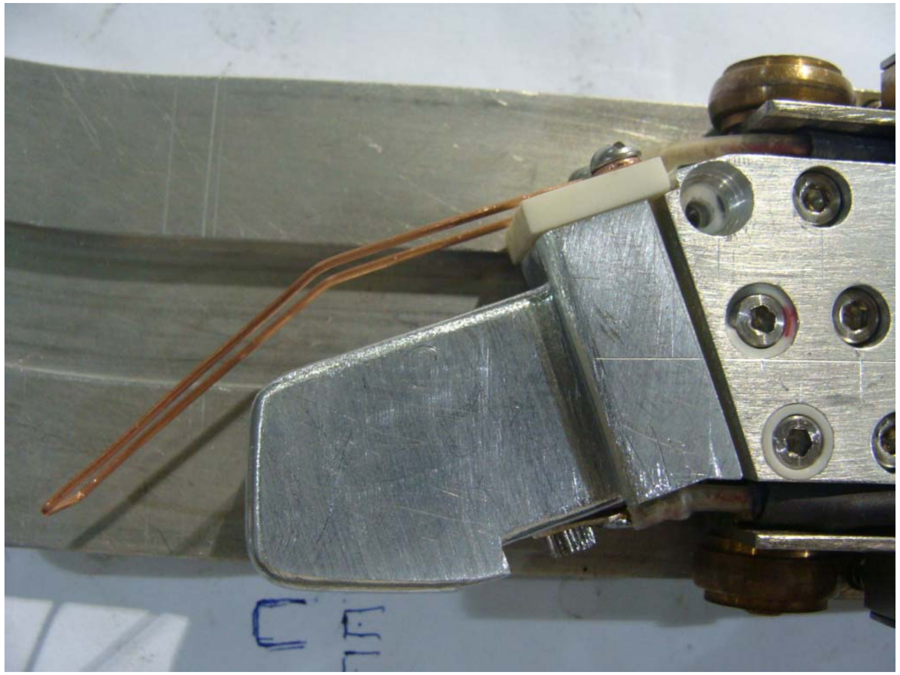
First Beam Injection : 11th May 2009

BEAM PROBES







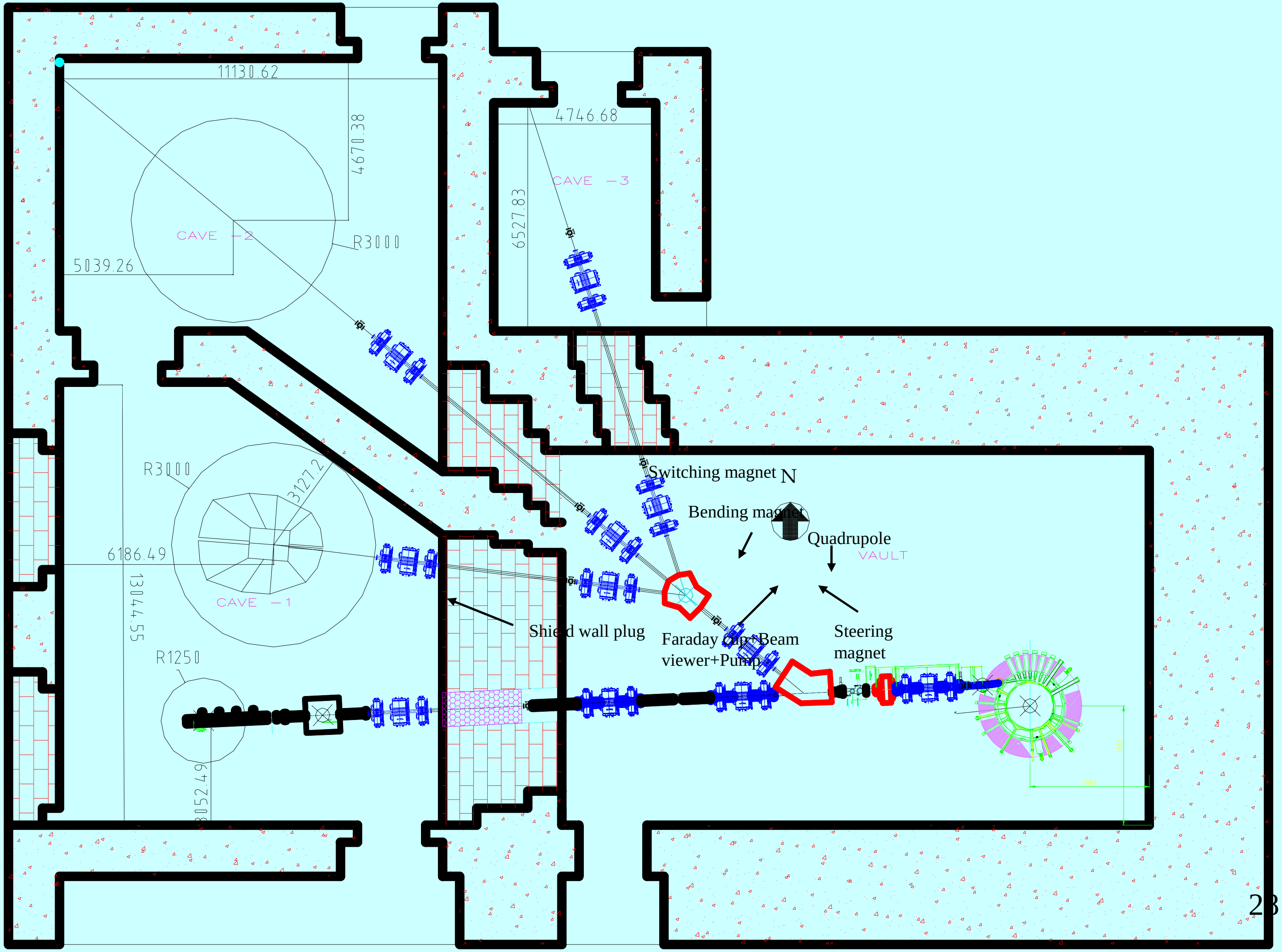



BEAM CH - 2 INTERLOCK
BEAM CH - 3 INTERLOCK
VACUUM PARAMETERS
BEAM CHAMBER - 2 (mbar)
2.601E-07
BEAM CHAMBER - 3 (mbar)
2.443E-07
MAGNET CURRENT
ALPHA (A)
380.66
UP LINER (mbar)
9.90E-02
LO LINER (mbar)
8.87E-02
OVC (mbar)
2.13E-06
BETA (A)
103.95
RF PARAMETERS
FORWARD POWER - A (kW)
4.619
FORWARD POWER - B (kW)
4.724
FORWARD POWER - C (kW)
4.783
REFLECTED POWER - A (kW)
0.034
REFLECTED POWER - B (kW)
0.037
REFLECTED POWER - C (kW)
0.03
PHILIPS
SCC MEDIAN PLANE CROSS SECTION
SCC OPERATION MANUAL


MAGNET ON RF ON BEAM ON


2.506E-07
2.351E-07
380.66
9.94E-02
8.93E-02
2.11E-06
103.95
4.4
4.624
4.76
0.032
0.035
0.029

K500 SUPERCONDUCTING CYCLOTRON EXTERNAL BEAMLINE LAYOUT



Major Facilities

Nuclear Physics

- **Scattering Chamber**
- **Charged Particle**

Detector Array

- **Neutron Detector Array**
- **High Energy Gamma Ray**

Array

- **Ion Trap**

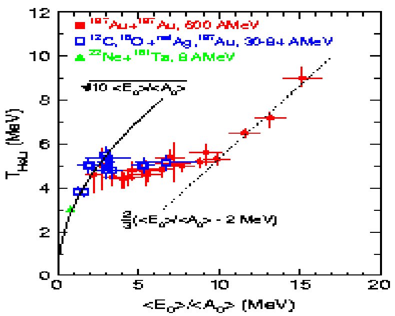
Condensed Matter
- X-ray Diffractometer
- Acoustic emission setup
- Vibrating sample magnetometer

Nuclear Chemistry
- Activation analysis
- Pneumatic carrier facility
- Multitracer studies

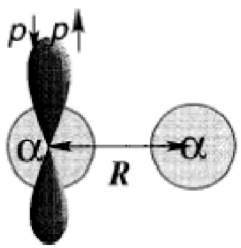
Nuclear Physics with superconducting cyclotron

Physics Goals :

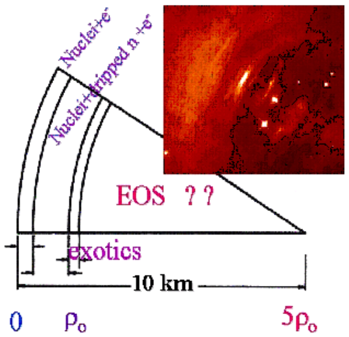
Liq. – gas Phase transition



Exotic Nuclear structures



Evolution of neutron star, supernovae



Temperature

Thermalisation

Dynamics

Deformation

EOS

Nuclear Compressibility

Asymmetric Nuclear matter And Stellar Evolution

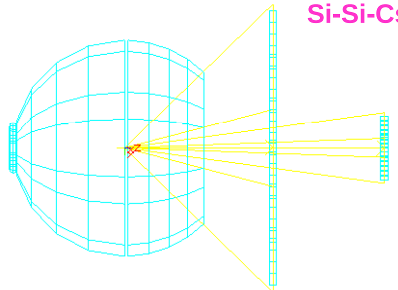
Super Heavy Nuclei

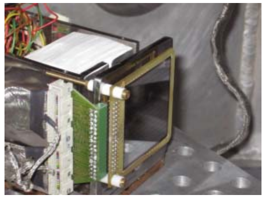
Facilities

Charged particle detector array

Back-ward Array
Si-CsI(Tl)

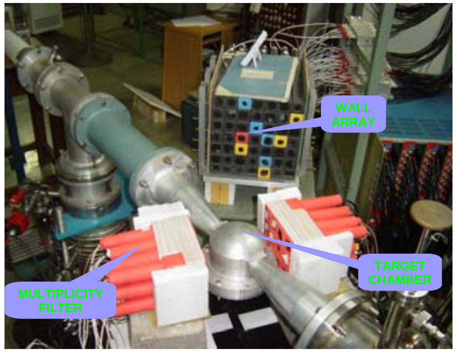
Forward Array
Si-Si-CsI(Tl)



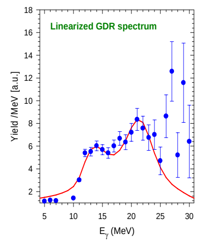


Prototype Si-Si-CsI(Tl) array

High energy gamma ray detector array



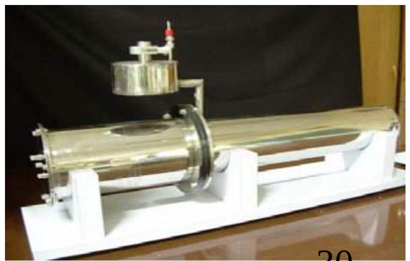
Gamma array at Exptl hall



Deformed configuration of 32S*
Studied by GDR splitting

Neutron Multiplicity detector

4π neutron multiplicity detector



Prototype neutron detector

General Purpose Scattering Chamber

Status : Installed and commissioned in SCC beam hall - 1

Cylindrical in Shape
(~1m dia., ~2.2 m long)

Three segments
placed on external rails

Nom. vacuum ~10^{-7} mb
2 turbo + 2 cryo
fully auto/manual/remote PLC driven operation

Target ladder : anywhere in the chamber
Movement by vac. Motors auto/remote PLC driven operation

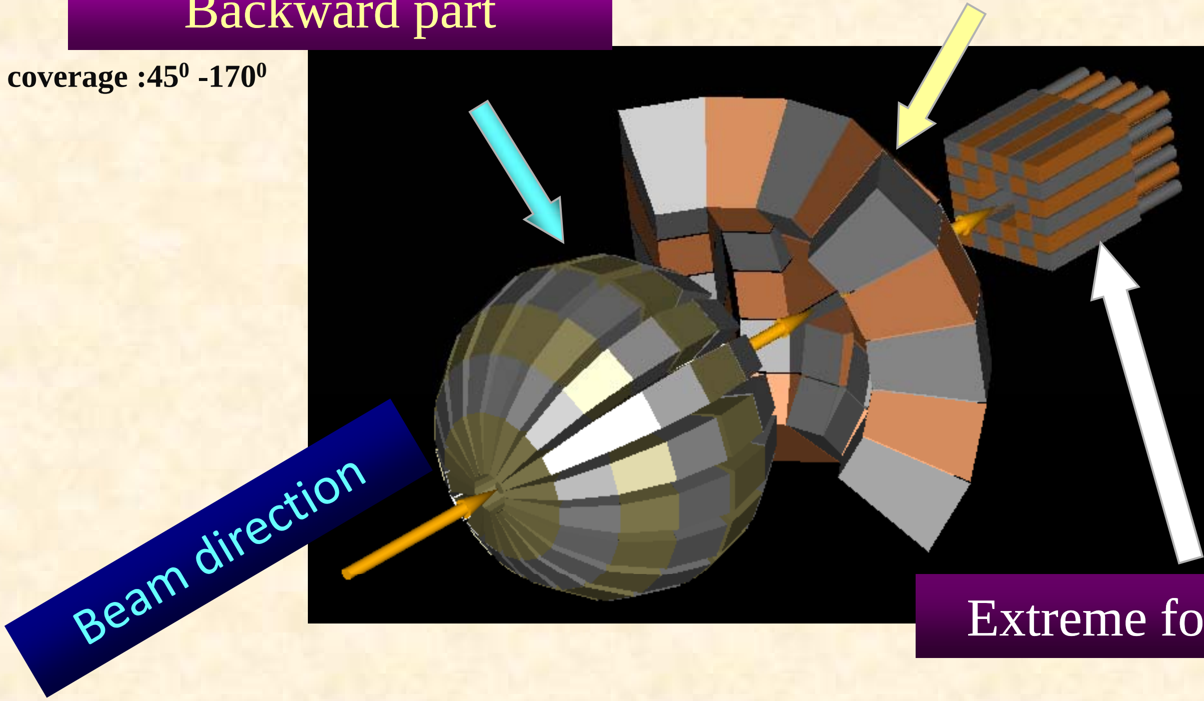
Charge particle detector array

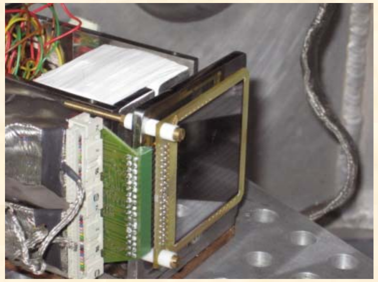
Forward part

Angular coverage : 7^0 - 45^0

Backward part

Angular coverage :45^0 -170^0





Prototype forward array telescope

Extreme forward part

Angular coverage :3^0 -7^0

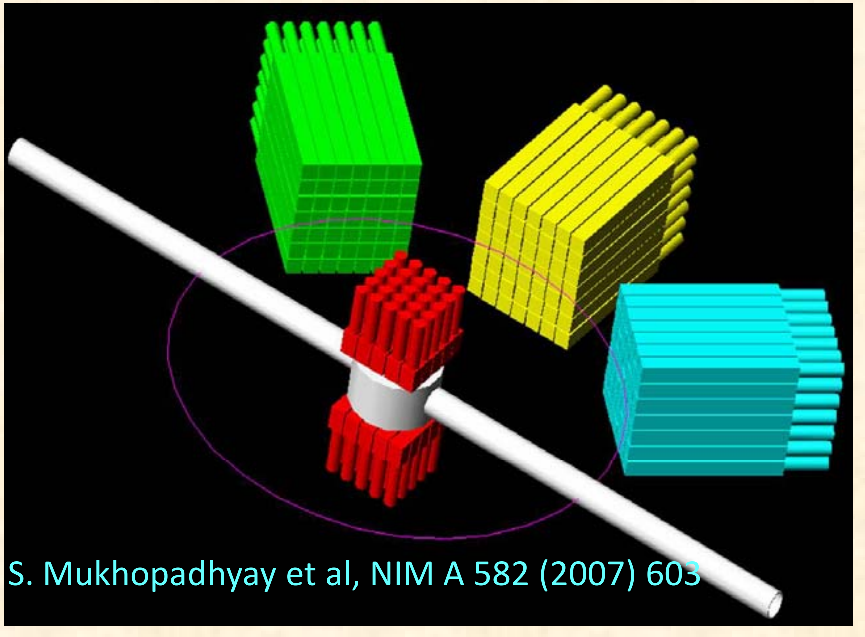
1. Forward Array - Si(SSSD – 50 μ)+Si(DSSD - 500 μ / 1 mm)+ CsI(Tl) (6 cm)telescopes : 24 No.
E_{res} (~1%), θ_{res} (~0.4^0) isotopic / Z resolution upto Z ~ 10 / 40

2. Backward Array- CsI(Tl) (2-4 cm) : ~300 nos. ; LCP upto Z ~ 3

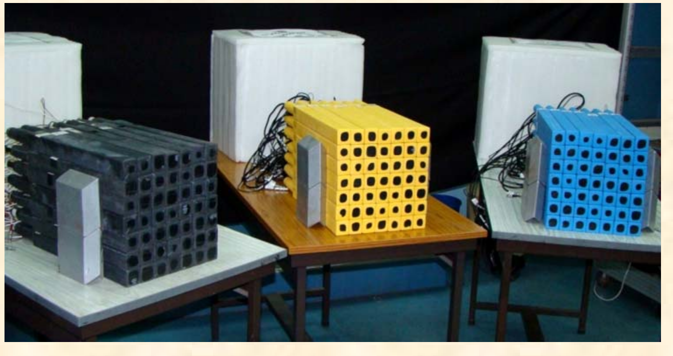
3. Extreme Forward Array – Plastic slow (10 cm) -fast (200 μ) phoswich : 32 nos.
LCP, energetic fragments, Low rad. damage, fast response

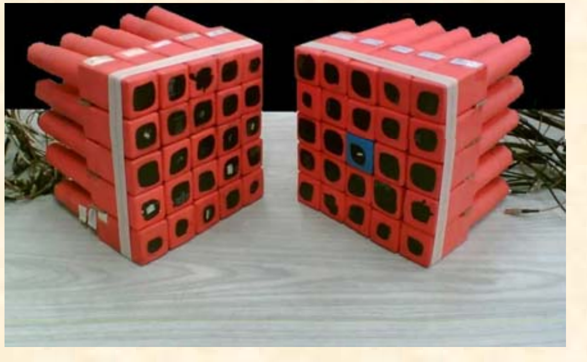
Large Area Modular BaF_2 Detector Array (LAMBDA)

Status : Completed



- 162 BaF2 Detector elements
  size - 3.5 x 3.5 x 35 cm^3
- 50 BaF2 multiplicity elements
  size - 3.5 x 3.5 x 5 cm^3
- Dedicated CAMAC electronics
- Dedicated Linux based VME DAQ
- Solid angle coverage ~ 6% of 4π



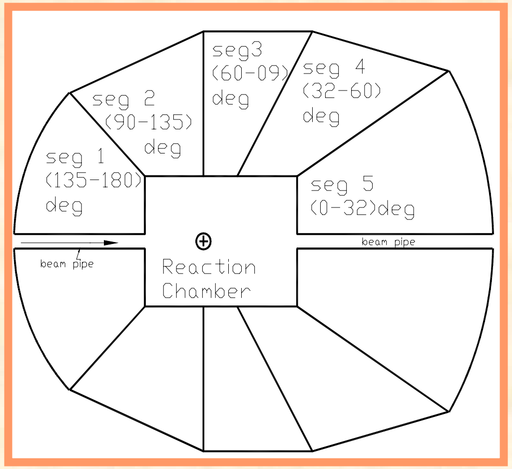


Detectors after fabrication

❑ Neutron 4π Multiplicity Detector

500 Litre , 1m dia, 2 sectors

BC521 Gd Loaded; completed



Future Plan :

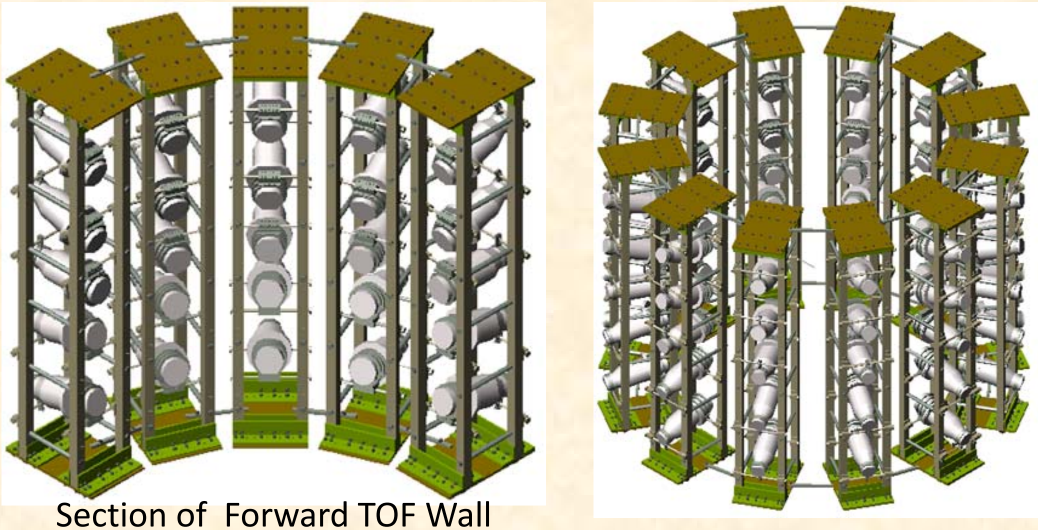
- 5 sector detector
- Eff. ~ 90% for 2 MeV neutron
- Eff. ~ 60% for 20 MeV neutron
- put CPDA inside

❑ Neutron Time Of Flight Array

Final Detectors (BC501)

Size : 5" / 7" long, 5" dia.
Time res. ~ 1.3 ns
Fig. of Merit > 1

Possible Configurations of TOF Array



Section of Forward TOF Wall

TOF Well

Experiemental Plans for K500 Superconducting Cyclotron : Broad Areas

CPDA / neutron TOF Array:

- Multiparticle correlation studies:
  - parametrization of hot sources
  - spectroscopy of exotic particle unstable nuclei and cluster structure
- EoS (asymmetry / density dependence of compressibility)
- Nuclear thermometry
- Reaction mechanism (multifragmentation, phase transition, relaxation time, ..)

LAMBDA gamma Array:

- GDR Studies : vanishing of collectivity and critical temp.
- Preequilibrium GDR studies
- Nuclear bremmstrhlung
- Time scale of fission , multifragmentation

Ion Trap :

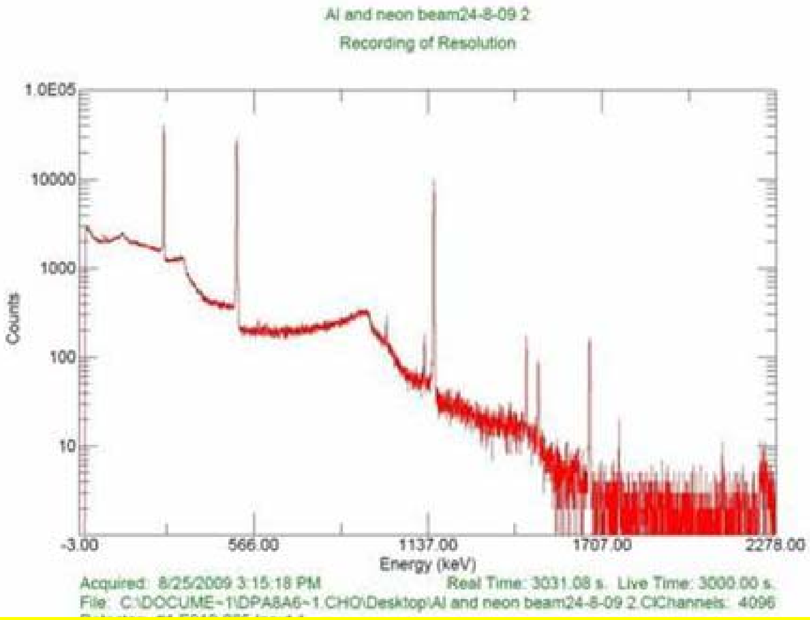
- High precision measurement (1 in 10^{-8}) of beta-decay end point energy
- precision mass measurement of exotic nuclei online (future plan)

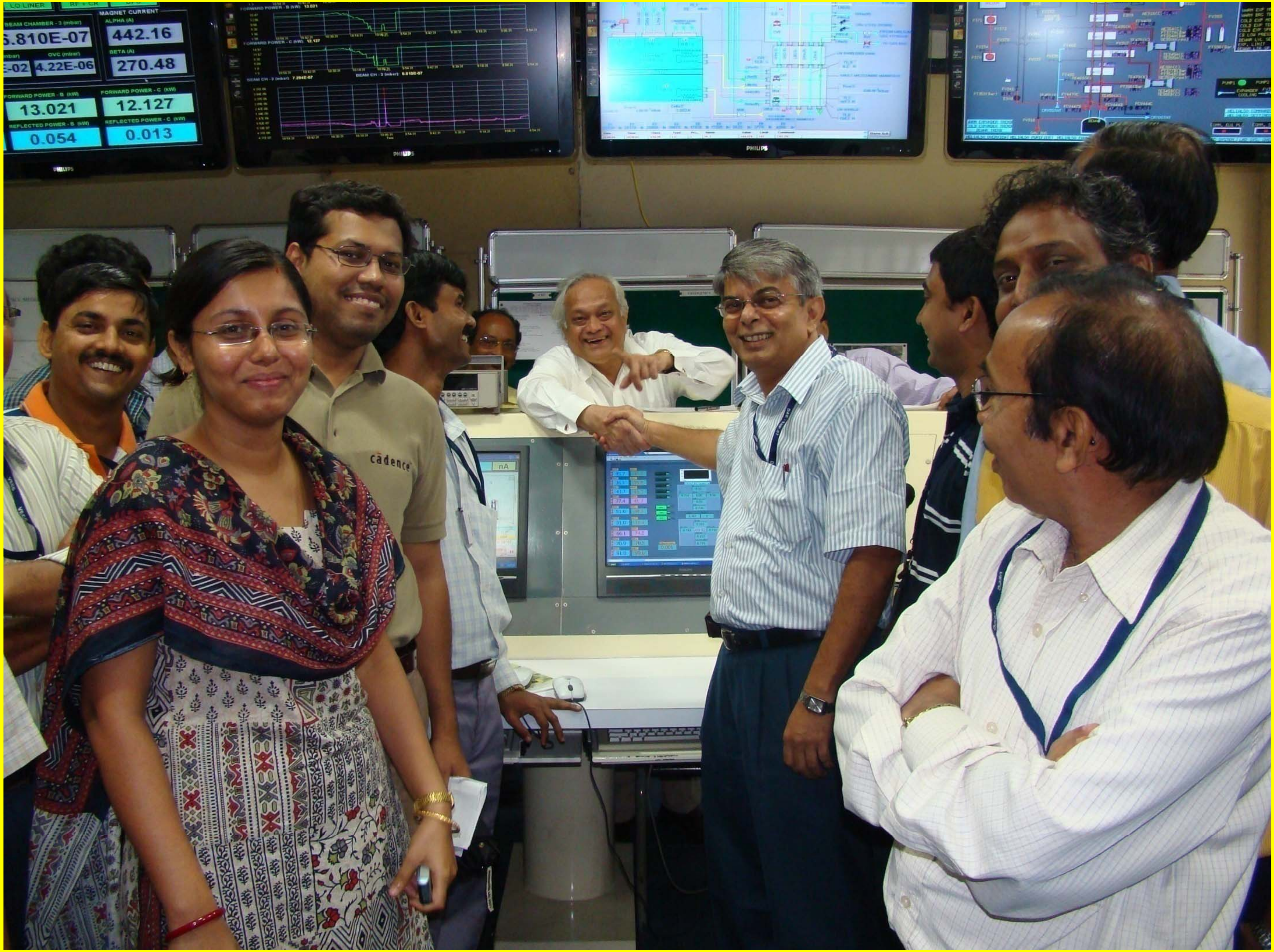
VECC's Superconducting Cyclotron Accelerates FIRST BEAM

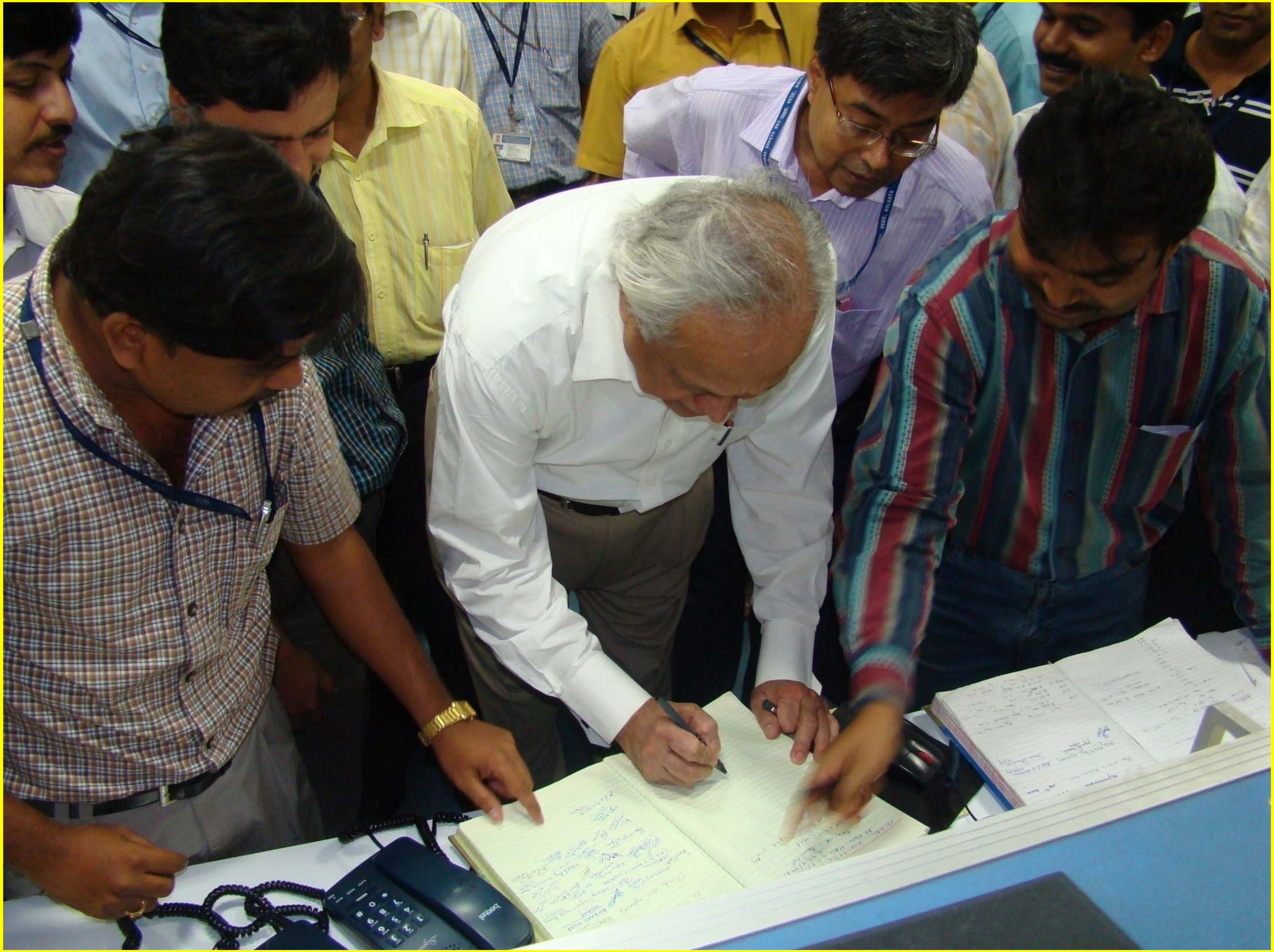
Date: 25^{th} August 2009, Time: 3:30 AM

Beam Specification

Ion	: Ne(+3)
Magnetic Field	: 3.08 T
Frequency	: 14 MHz
Harmonic No.	: 2^{nd}
Injection Voltage	: 4.4 kV
Dee Voltage	: 46 kV
Extraction Radius	: 660 mm
ENERGY	**: 88 MeV**
CURRENT	**: 73 enA**

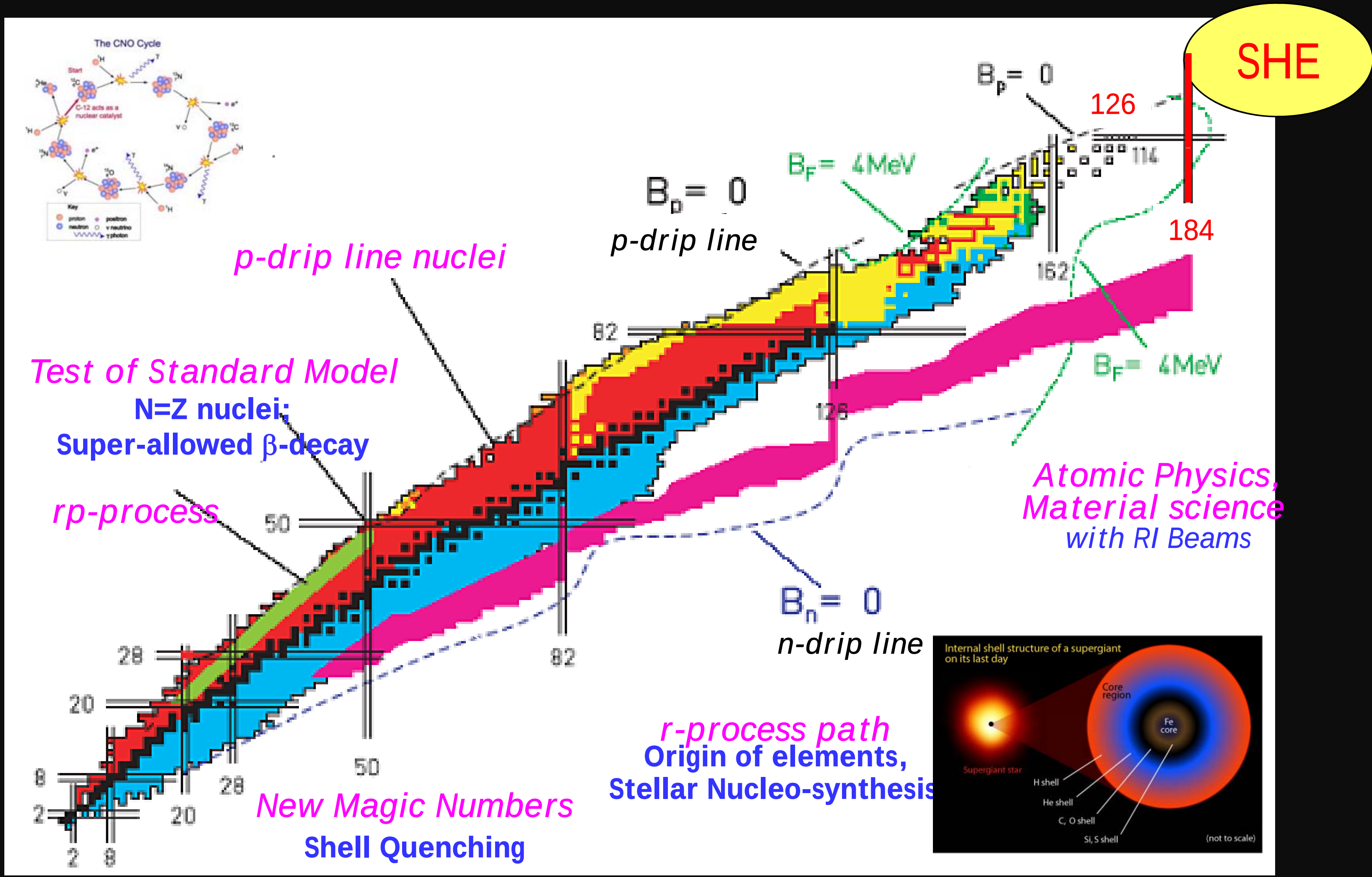



LO LINER
MAGNET CURRENT
BEAM CHAMBER - 3 (mbar)
ALPHA (A)
.810E-07
442.16
OVC (mbar)
4.22E-06
BETA (A)
270.48
FORWARD POWER - S (kW)
13.021
FORWARD POWER - C (kW)
12.127
REFLECTED POWER - S (kW)
0.054
REFLECTED POWER - C (kW)
0.013
PHILIPS
cadence

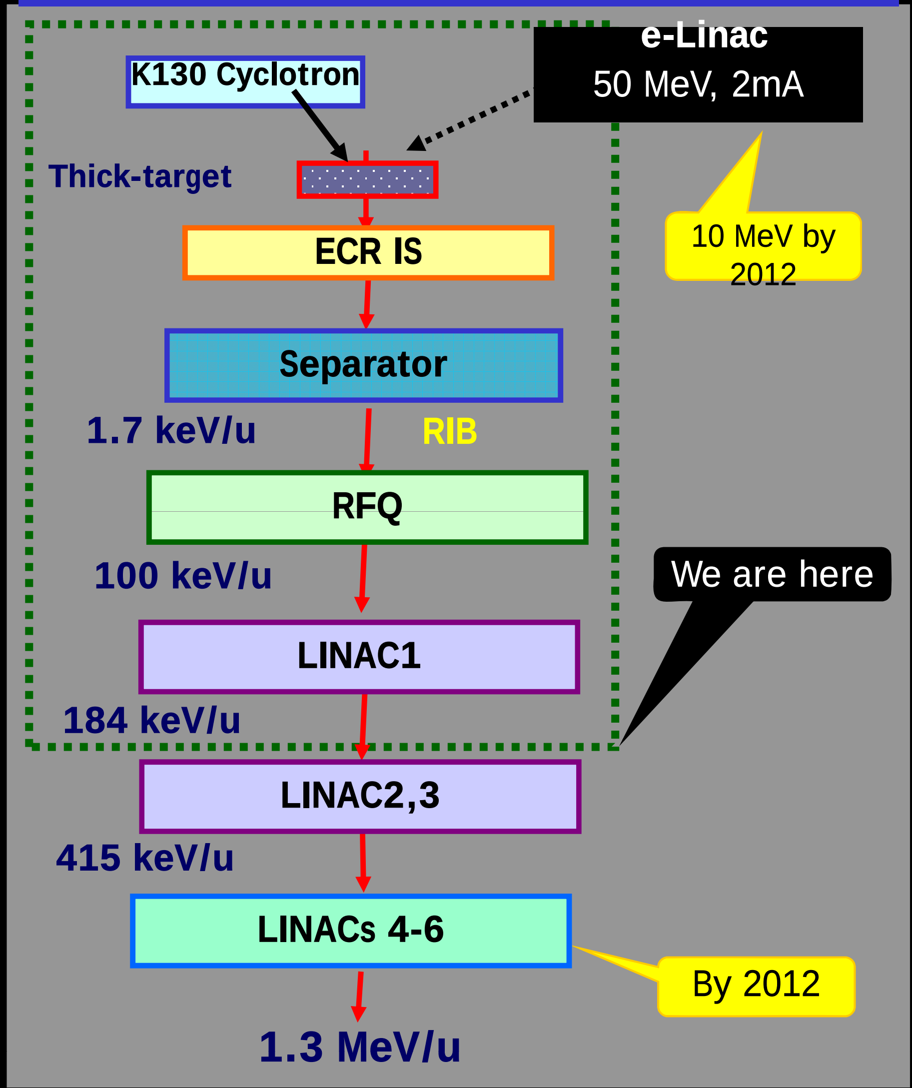


Radioactive Ion Beam Facility

Radioactive Ion Beams : Future in Nuclear Physics & Astrophysics

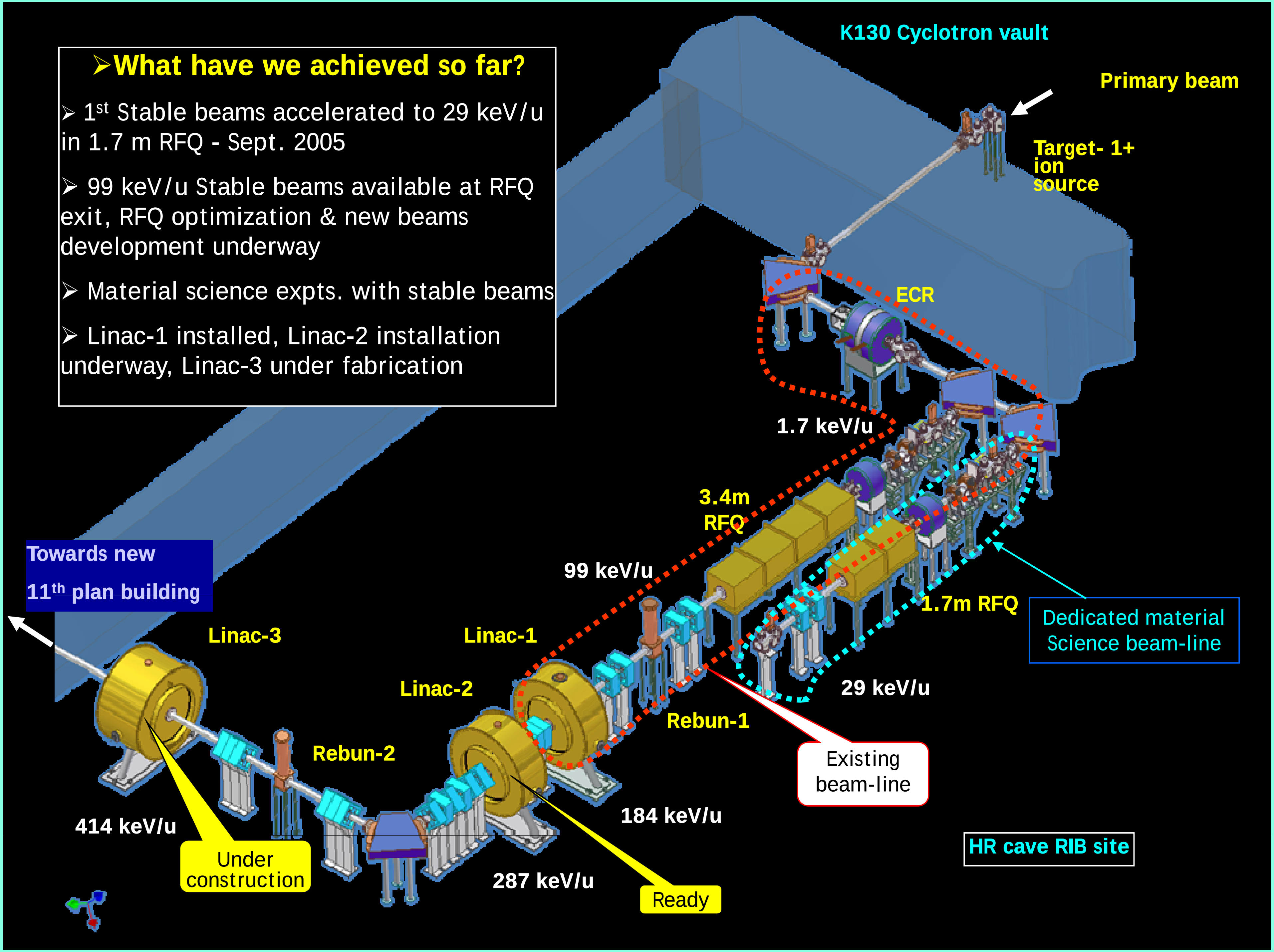


VECC Radioactive Ion Beam project
Schematic Layout



➢What have we achieved so far?

- ➢ 1st Stable beams accelerated to 29 keV/u in 1.7 m RFQ - Sept. 2005
- ➢ 99 keV/u Stable beams available at RFQ exit, RFQ optimization & new beams development underway
- ➢ Material science expts. with stable beams
- ➢ Linac-1 installed, Linac-2 installation underway, Linac-3 under fabrication

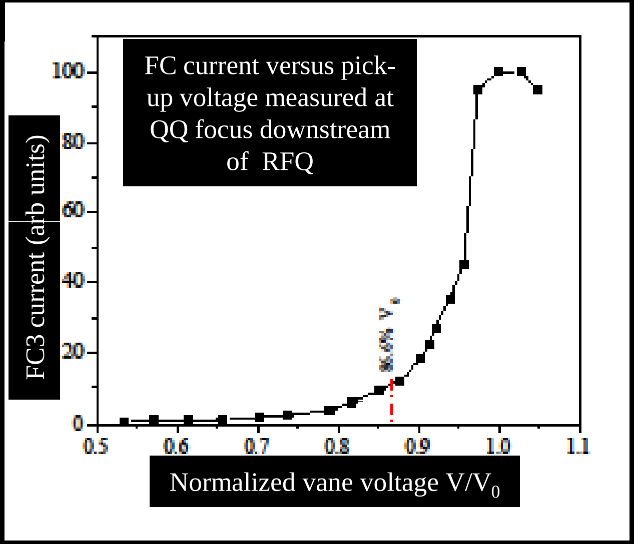


3.4m RFQ: commissioned in July 2008

- $q/A=1/14$; input = 1.75 keV/u; output = 100 keV/u, 3.4m long, vane length ~ 3.12m, resonating at 37.83 MHz

- RFQ made at CMERI Durgapur, Cavity, Cu plating at GSI, Darmsadt via Danfysik

- Measured transmission efficiency at RFQ exit for O^{5+} ~ 90 %

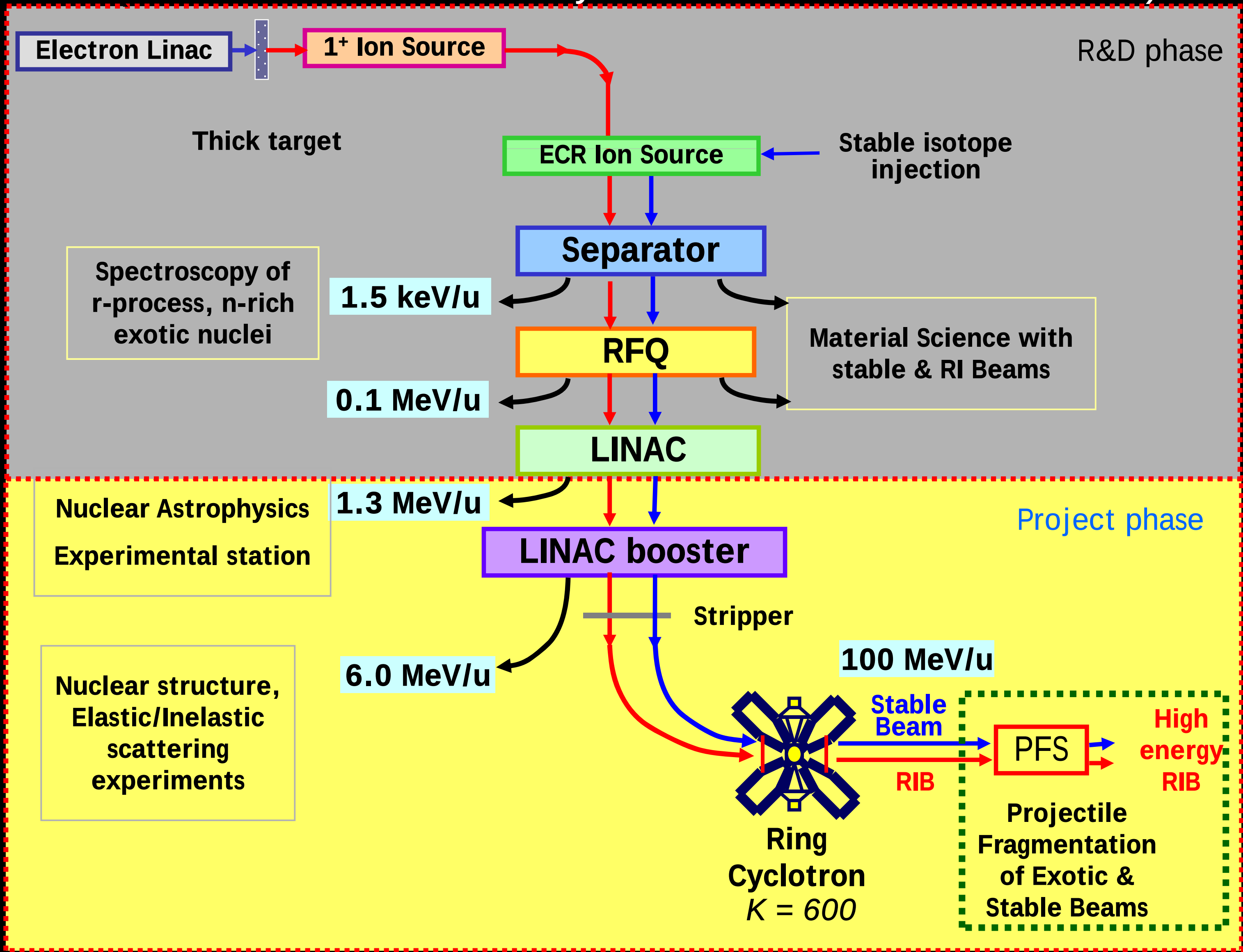


3.4m RFQ during installation

RIB project site

The Future ? Proposed Mega Science facility ANURIB

Advanced National facility for Unstable & Rare Ion Beams)



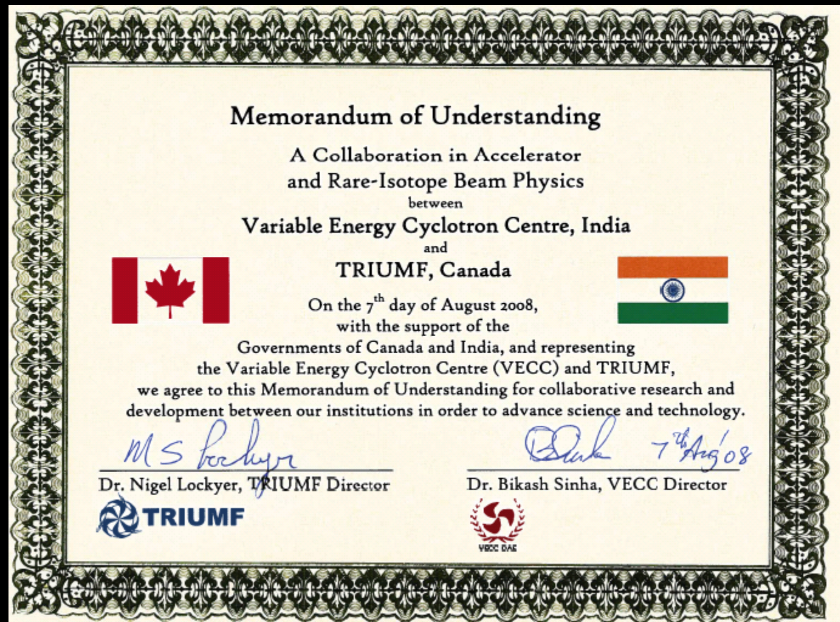
VECC-RIKEN collaboration

VECC-RIKEN collaboration
signing on April 16, 1996

Publications from VECC - RIKEN collaboration

1. β-decay of the proton-rich nucleus 24Si and its mirror asymmetry: Y. Ichikawa, T. K. Onishi, D. Suzuki, H. Iwasaki, T. Kubo, V. Naik, A. Chakrabarti, N. Aoi, B. A. Brown, N. Fukuda, S. Kubono, T. Motobayashi, T. Nakabayashi, T. Nakamura, T. Nakao, T. Okumura, H. J. Ong, H. Suzuki, M. K. Suzuki, T. Teranishi, K. N. Yamada, H. Yamaguchi, and H. Sakurai; Phys. Rev. C 80, 044302 (2009)
2. Beta decay study of Tz = -2 proton-rich nucleus 24Si: Y. Ichikawa, T. Kubo, N. Aoi, V. Banerjee, A. Chakrabarti, et. al. and H. Sakurai; European Physics Journal A 2009
3. Design of a “two-ion source” Charge Breeder using ECR ion source in two frequency mode, Damayanti Naik, Vaishali Naik, Alok Chakrabarti, S. Dechoudhury, Sumanta Kumar Nayak, H.K. Pandey & Takahide Nakagawa, *Nucl. Instrum. & Meth* A547 (2005) 270.
4. The design of a four-rod RFQ LINAC for VEC-RIB facility, Alok Chakrabarti, Vaishali Naik, S. Dechoudhury, D. Bhowmick, D. Sanyal, A. Bandyopadhyay, T.K. Chakraborty, M. Mondal, S. Nayak, H. Pande, T.K. Bhaumik, A Giri, D. Bhattacharya, T.J. Sen, S. Bhattacharya, O. Kamigaito, A. Goto, Y. Yano – Nucl. Instrum. & Meth. A535 (2004) 599.
5. Beta-delayed proton decay of 24Si. V. Banerjee, T. Kubo, A. Chakrabarti, H. Sakurai, Arup Bandyopadhyay, K. Morita, S.M. Lukyanov, K. Yoneda, H. Ogawa and D. Beaumel. Phys. Rev. C63 (2001) 024307.
6. Design of a two-ion-source (2-IS) beam transport line for the production of multi charged radioactive ion beams. V. Banerjee, A. Chakrabarti, A. Bandyopadhyay, S. Chattopadhyay, A. Polley, T. Nakagawa, O. Kamigaito, A. Goto, Y. Yano. Nucl. Instrum. & Meth. A447(2000) 345
7. Design of the RFQ & Linac postaccelerator for VEC-RIB facility, A. Bandyopadhaya, O Kamigaito, A. Chakrabarti, V. Banerjee, P. Ghosh, A Goto & Y. Yano ; Journ. of Phys. G : Nucl. Part. Phys., 24 (1998) 1367.
8. Beta delayed proton spectroscopy of 24Si, V. Banerjee, T. Kubo, A. Chakrabarti, H. Sakurai, A. Bandyopadhyay, K. Morita, S.M. Lukyanov, K. Yoneda, H. Ogawa and D. Beaumel. Journ. of Phys. G : Nucl. Part. Phys., 24 (1998) 1403.
9. Beta-delayed proton and gamma spectroscopy of 24 Si: Y. Ichikawa, T. kubo, V. Banerjee, A. Chakrabarti, et.al: RIKEN Acc. Prog. Rep. 39 (2006) 65
10. Design of an ECRIS for Online production of RI Beams from VEC-RIB Facility : V. Banerje, A. Bandyopadhyay, A. Chakrabarti, P. Ghosh, S. Bhattacharya, S. Chattopadhyay, A. Polley, T. Nakagawa, A. Goto, Y. Yano. Proc. of DAE Symposium on Nual. Phys. 39B (1996) 380.
11. The Design of a *low*-β RFQ LINAC for *low q/A* Heavy-ion Acceleration : A. Chakrabarti, V. Banerjee, A. Bandyopadhyay, S. Bhattacharya, P. Ghosh, S. Chattopadhyay, A. Polley, J. Chowdury, K.P. Basu, D. Guha, O. Kamigaito, A. Goto and Y. Yano. Proc. of DAE Symposium on Nucl. Phys. 39B (1996) 386.
12. Production of heaviest proton-rich mirror species 61Ga, 63Ge, 65As : I. Taninata, A. Chakrabarti, M. Yanokura, H. Xu, X. Bai, M. Fujinaki, N. Inabe, K. Kimura, T. Kubo, H. Kumagai, T. Nakagawa, T. Suzuki, T. Mukherjee. 4th Int. Conf. on Nucleus-Nucleus Collision, June 10-14. (1991), Kanazawa, Japan.
13. Identification of Z near 30 nuclei : M. Yanokura, H. Xu, A. Chakrabarti, X. Bai, M. Fujinaki, N. Inabe, K. Kimura, T. Kubo, H. Kumagai, T. Nakagawa, T. Suzuki, T. Mukherjee, I. Tanihata. RIKEN Acc. Progress Report 24 (1990) 17.

MOU between VECC & TRIUMF signed



Memorandum of Understanding

A Collaboration in Accelerator and Rare-Isotope Beam Physics

between

Variable Energy Cyclotron Centre, India

and

TRIUMF, Canada

On the 7th day of August 2008, with the support of the Governments of Canada and India, and representing the Variable Energy Cyclotron Centre (VECC) and TRIUMF, we agree to this Memorandum of Understanding for collaborative research and development between our institutions in order to advance science and technology.

Dr. Nigel Lockyer, TRIUMF Director

Dr. Bikash Sinha, VECC Director

TRIUMF

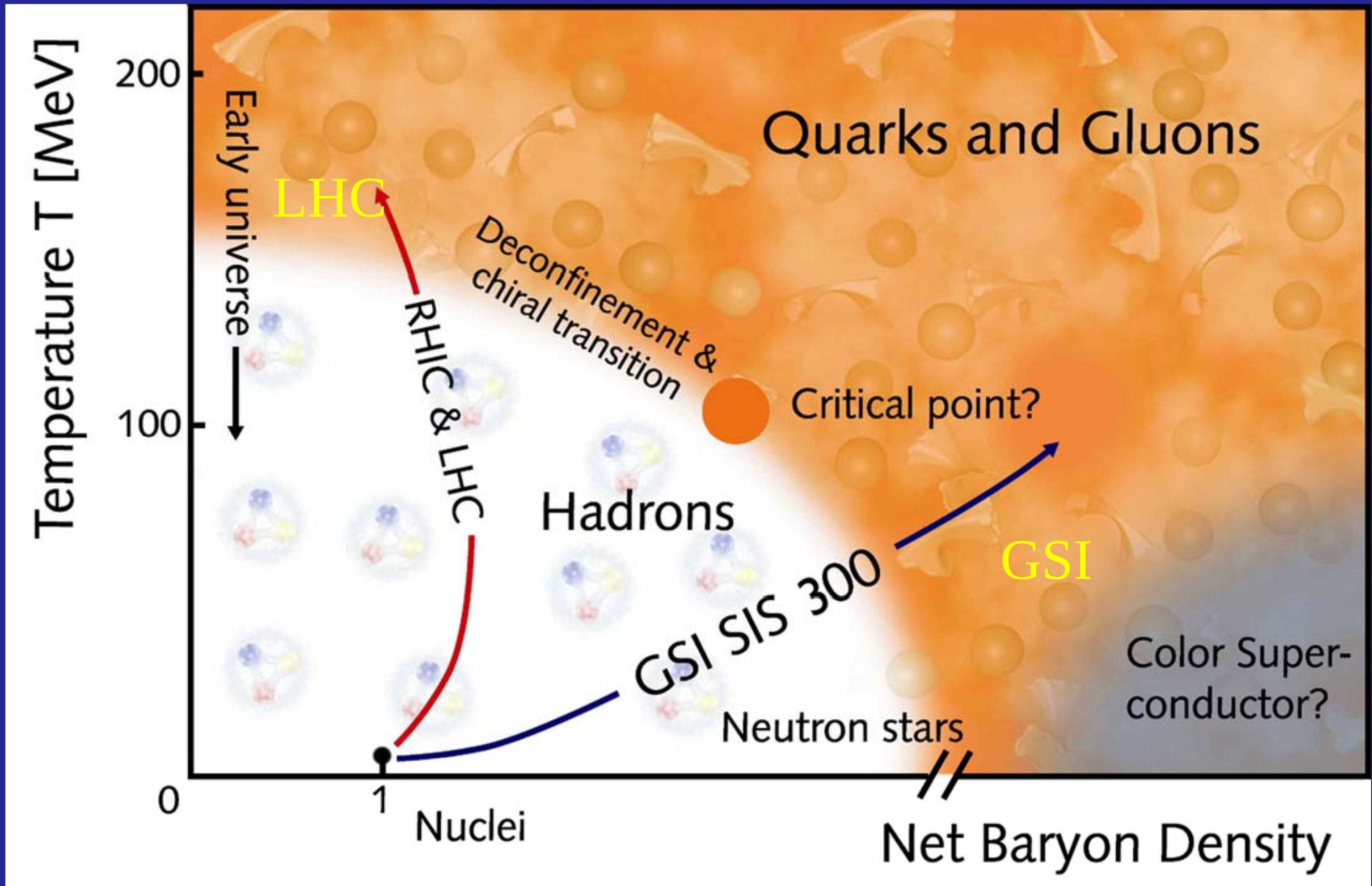
VECC DAE

VECC - TRIUMF collaboration in areas that broadly come under the field of Accelerator and Rare Isotope Beam Physics

The collaboration starts with the Design & Development of an Injector Cryo Module (ICM), which is the front end of a state of art SC Electron Linac , and will deliver 5-10 MeV electron beams

International Collaboration

The phase diagram of strongly interacting matter



RHIC, LHC: high temperature, low baryon density

FAIR: moderate temperature, high baryon density

Radiation from Quark Gluon Plasma – India at CERN-SPS

WA93 & WA98 at CERN

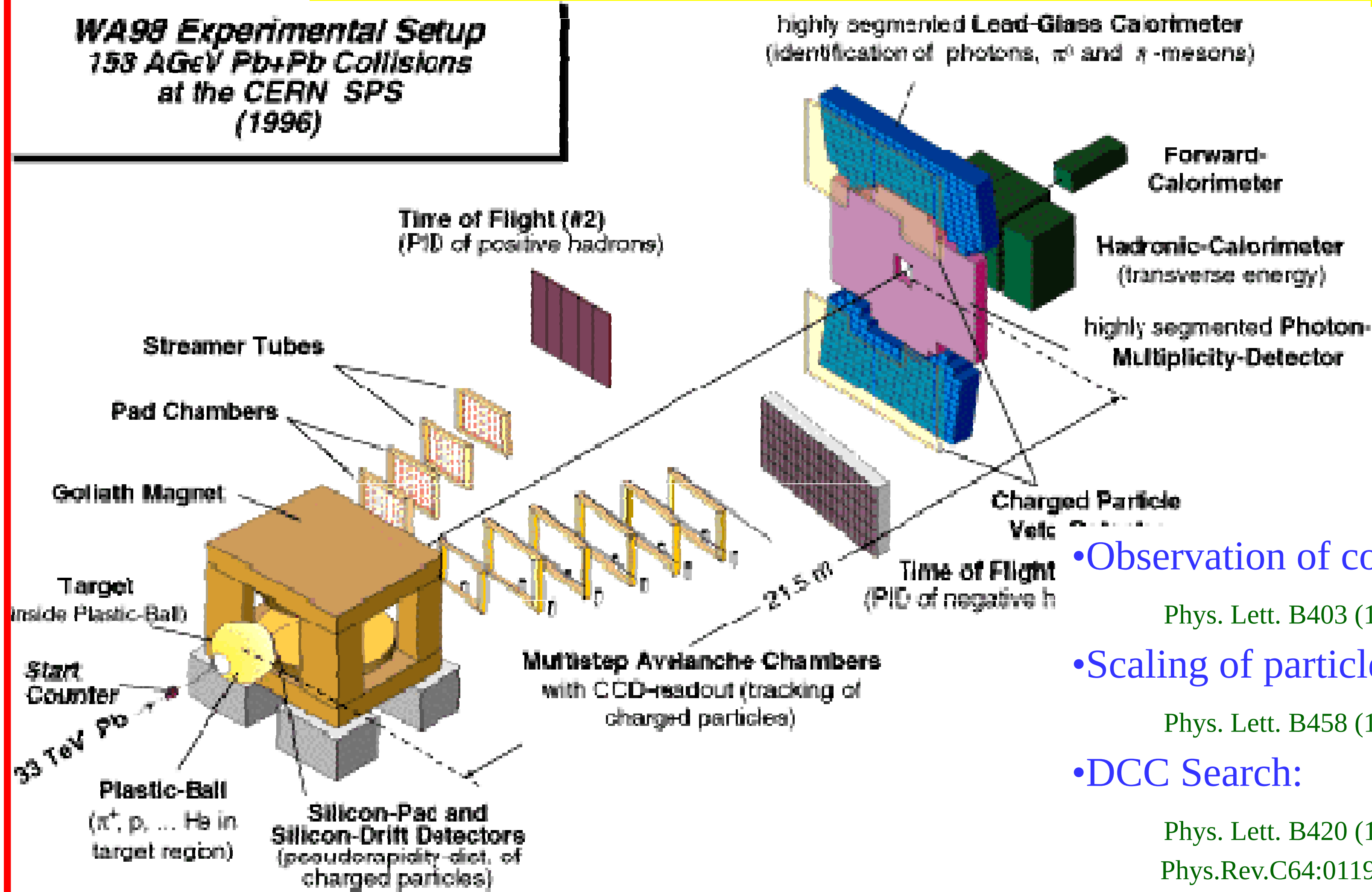
Conception in 1989

WA93 is the first Experiment at SPS to observe collective flow

Building blocks of PMD

WA98 is the first Heavy-ion experiment to study signals of Disoriented Chiral Condensate (DCC)

WA98 Experiment at CERN-SPS



- Observation of collective flow

  Phys. Lett. B403 (1997) 390.

- Scaling of particle production:

  Phys. Lett. B458 (1999) 422.

- DCC Search:

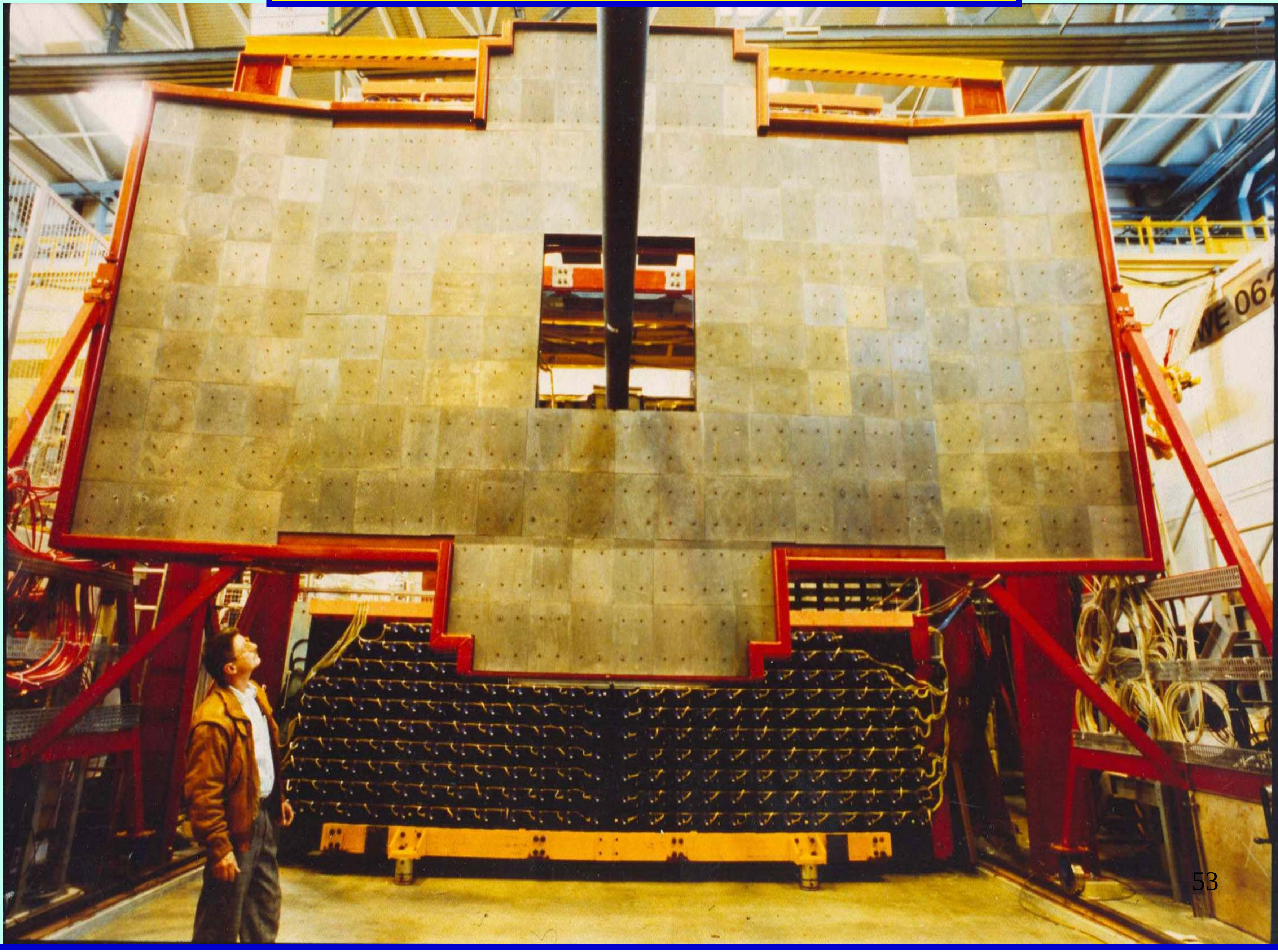
  Phys. Lett. B420 (1998) 169
  Phys.Rev.C64:011901,2001,
  Phys. Rev. C 2003

- Fluctuations:

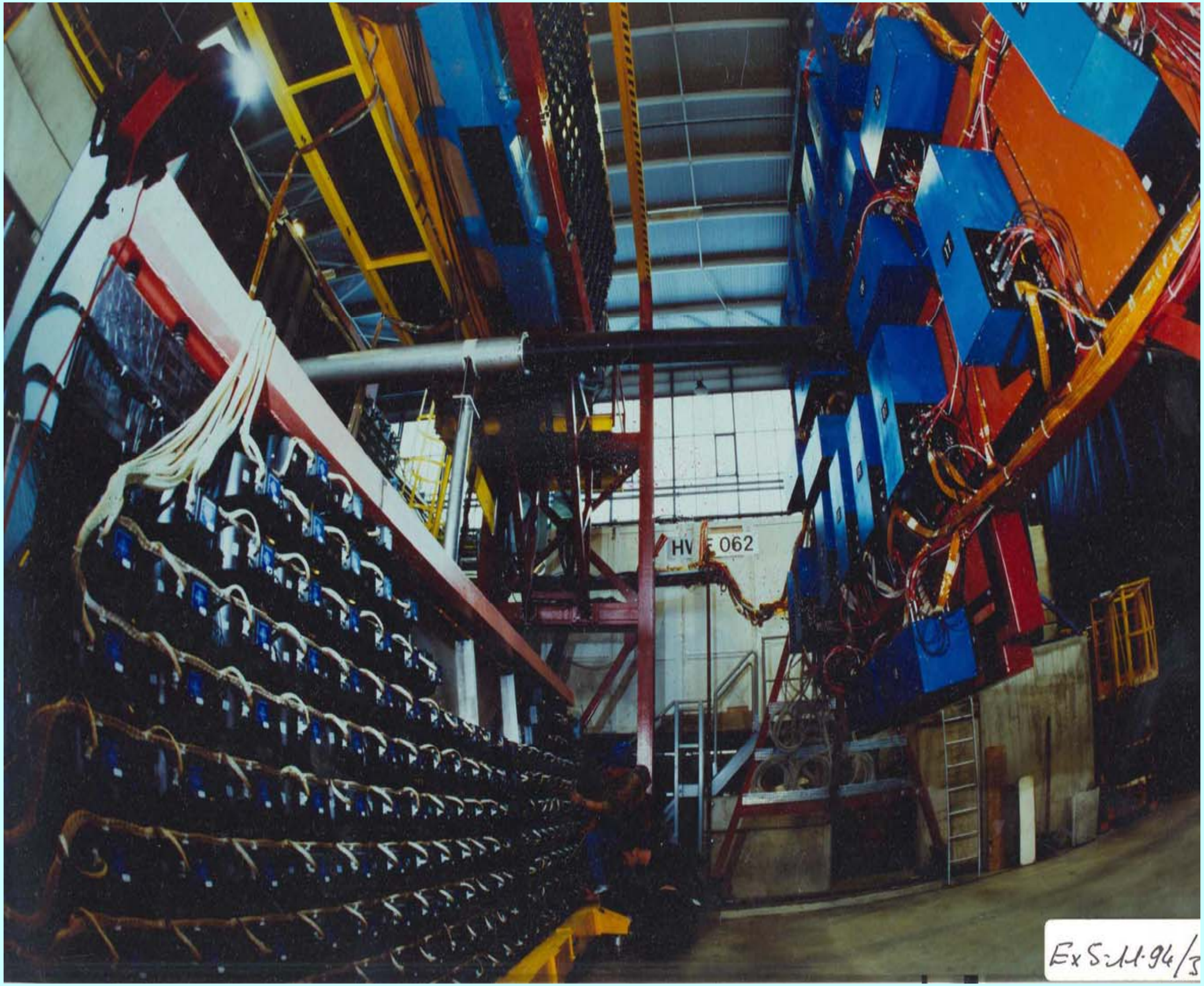
  Phys. Rev. C, May 2002

– **DIRECT PHOTONS**

PMD in WA98 Experiment



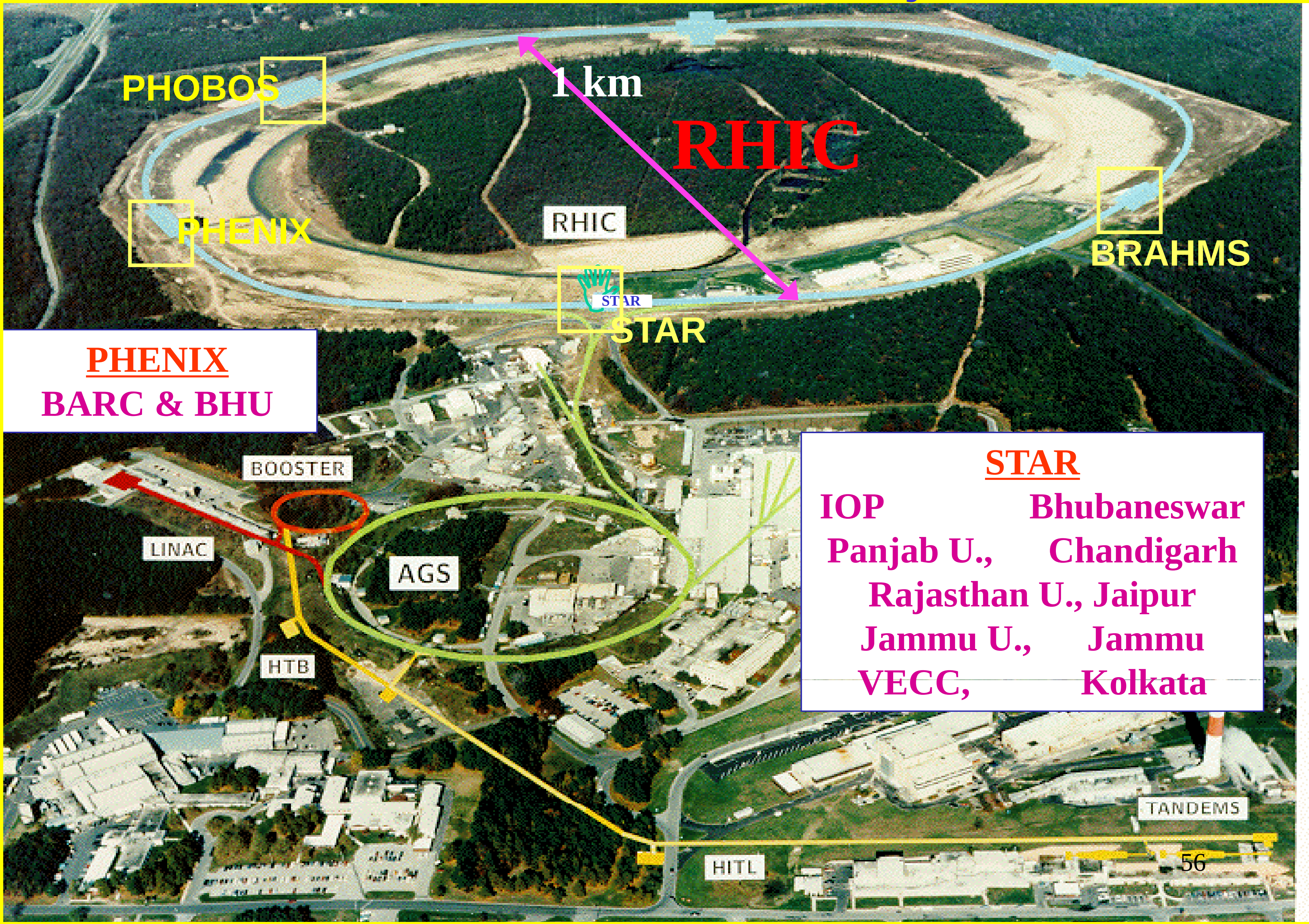
Photon Calorimeter in WA98 Experiment



Search for Quark Gluon Plasma at Relativistic Heavy-ion Collider at BNL

Seeking the BIG BANG through MINI BANG

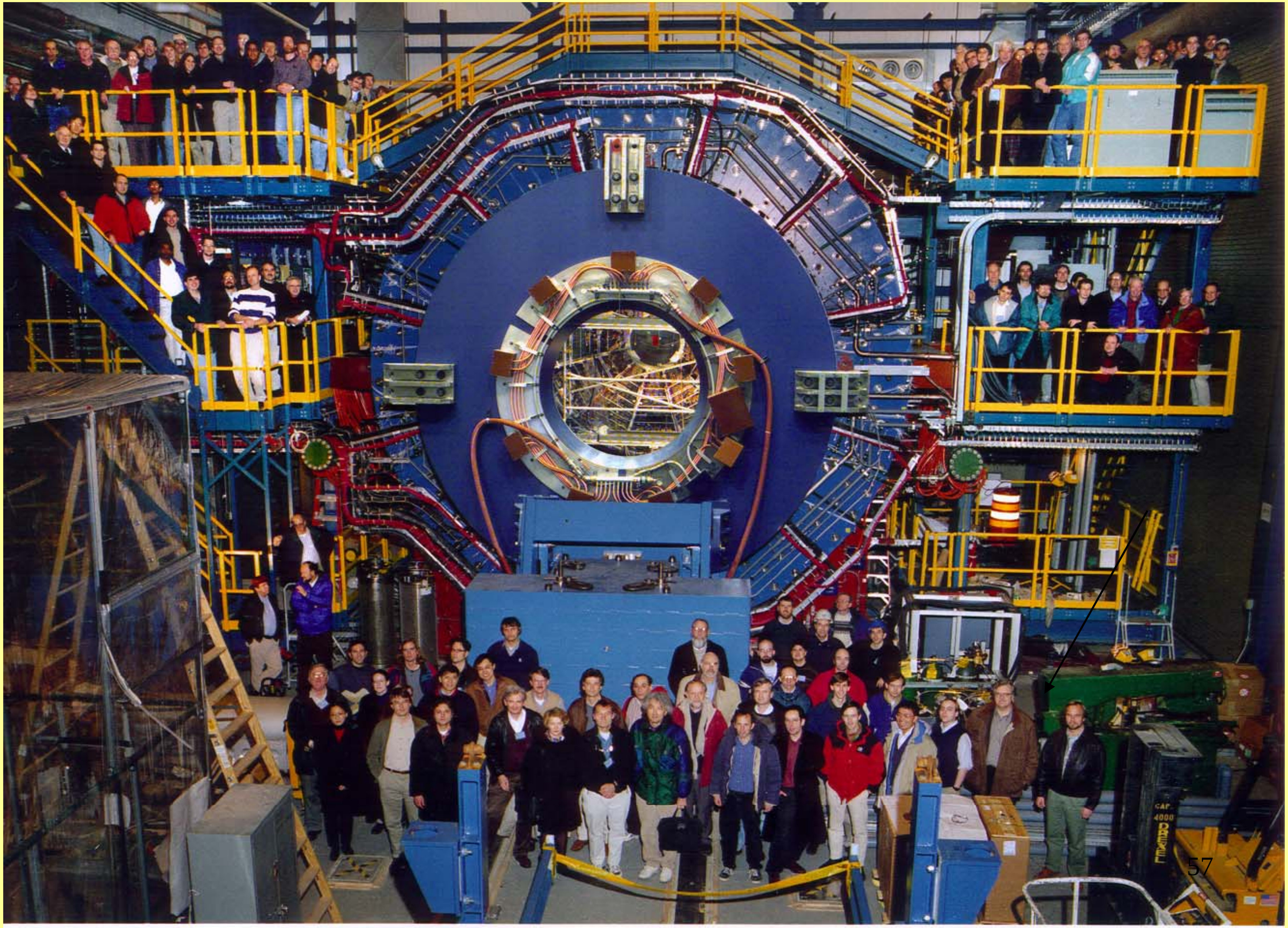
Brookhaven National Laboratory, New York



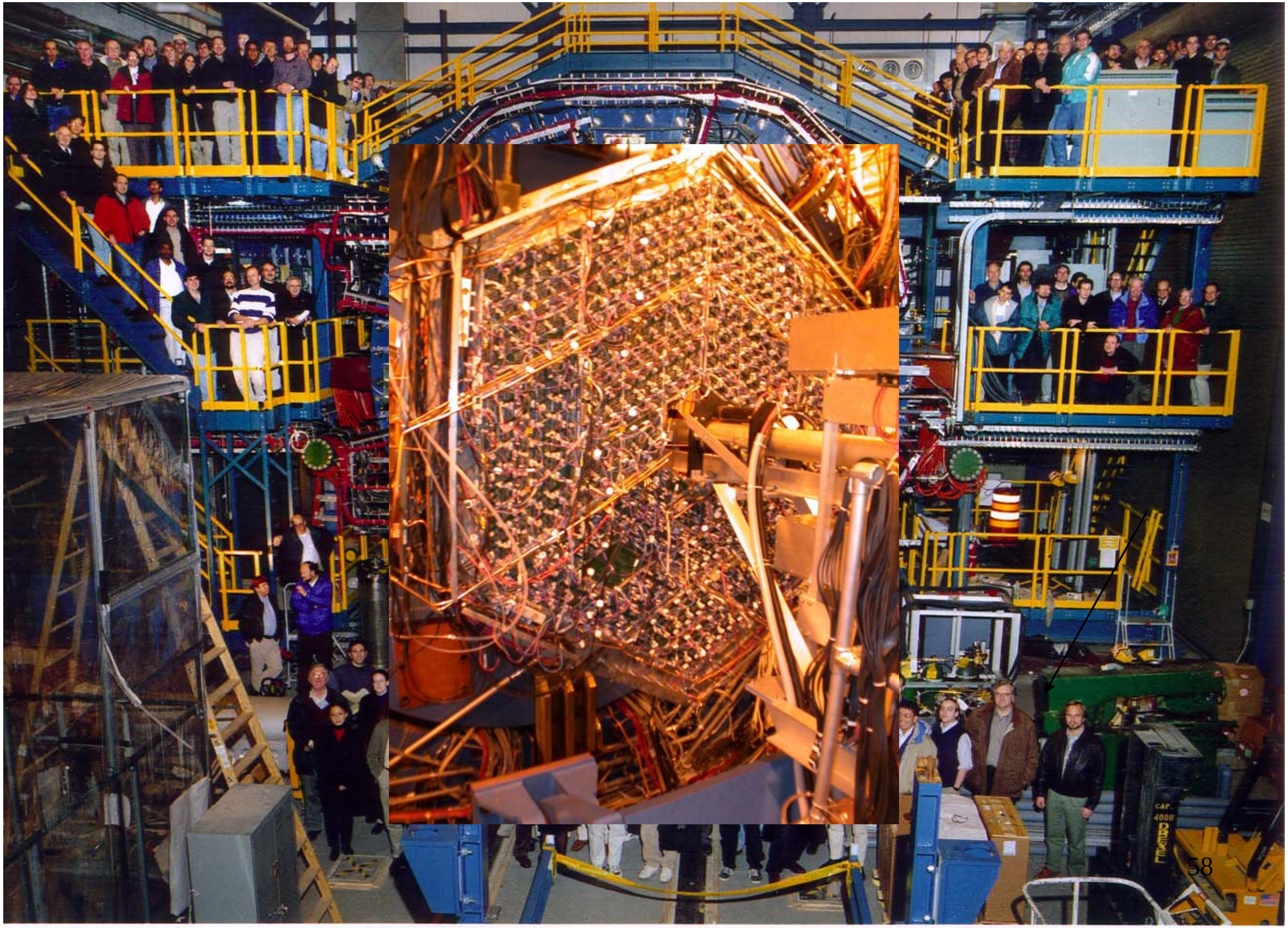
PHENIX
BARC & BHU

STAR
IOP Bhubaneswar
Panjab U., Chandigarh
Rajasthan U., Jaipur
Jammu U., Jammu
VECC, Kolkata

STAR experiment at RHIC, BNL

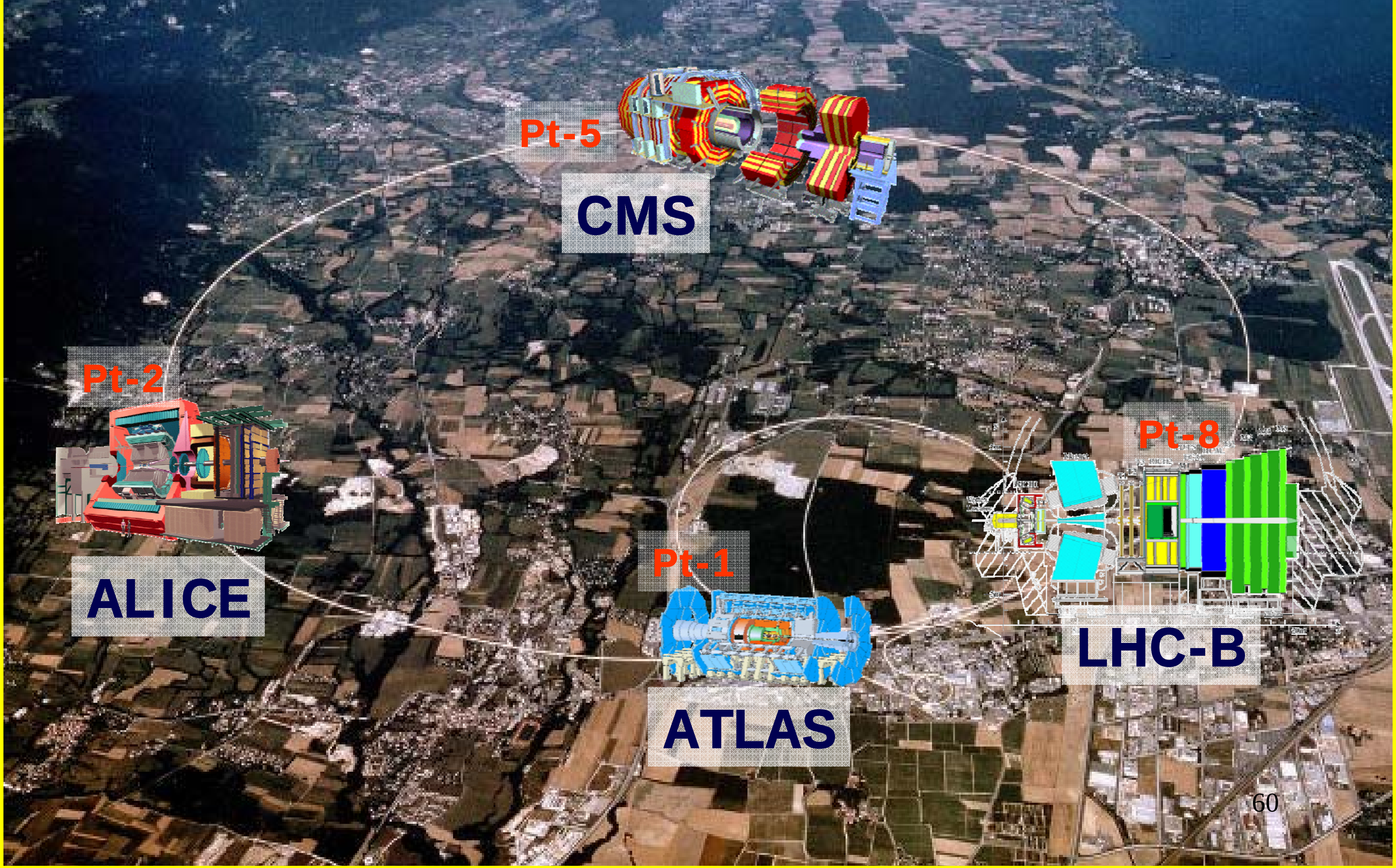


STAR experiment at RHIC, BNL



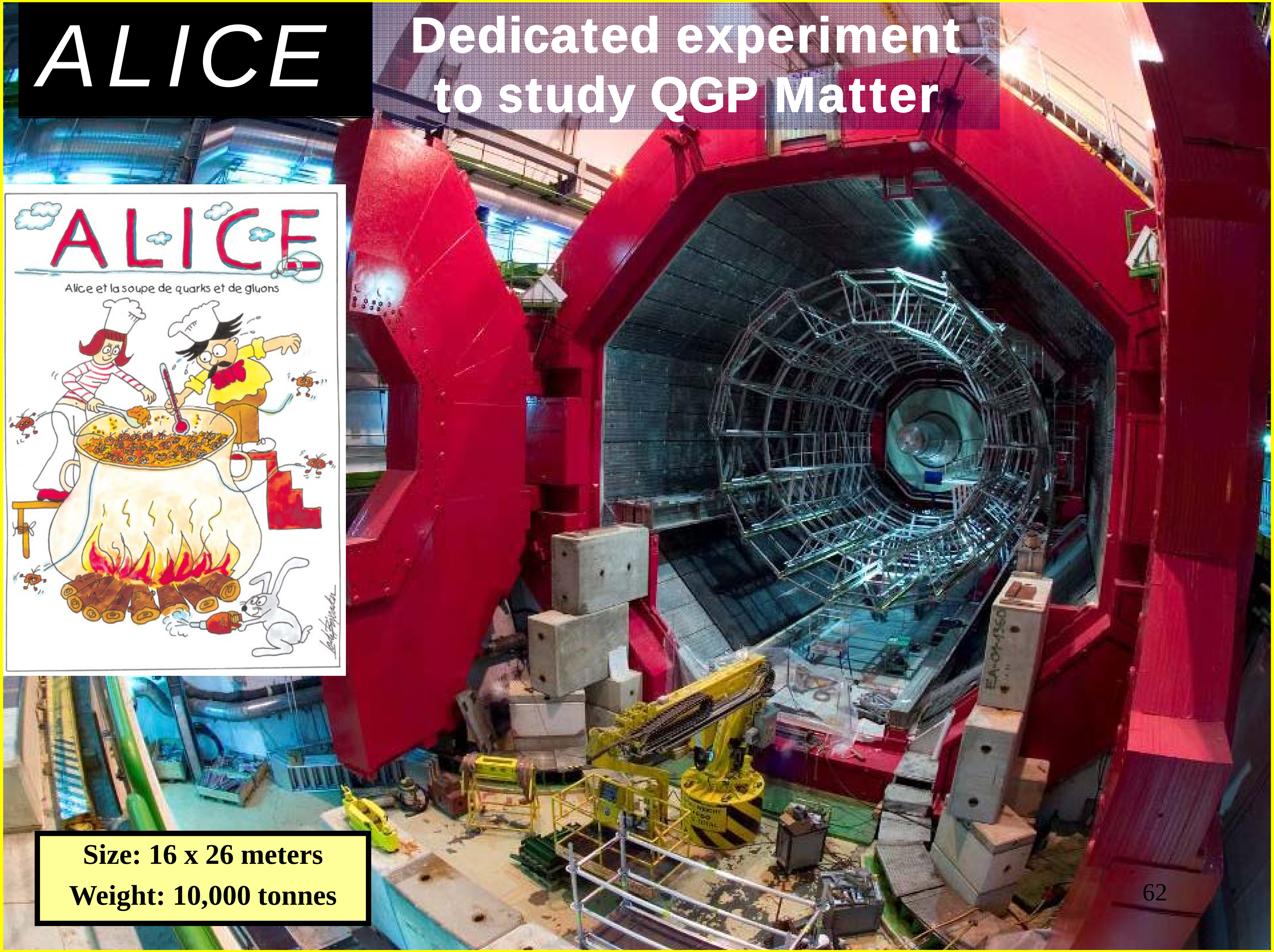
STAR

The LHC and its experiments …



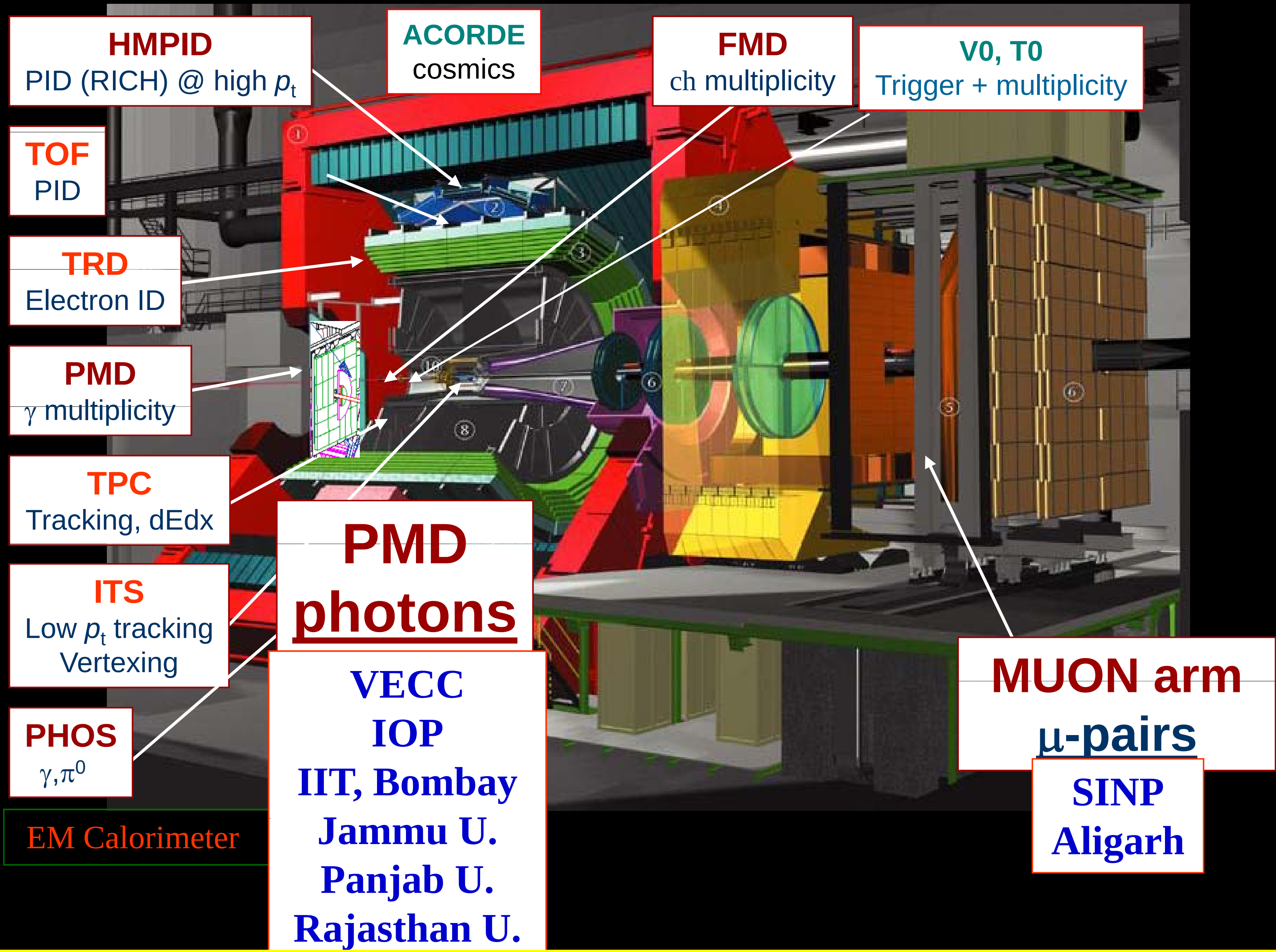
ALICE

Dedicated experiment to study QGP Matter



Size: 16 x 26 meters
Weight: 10,000 tonnes

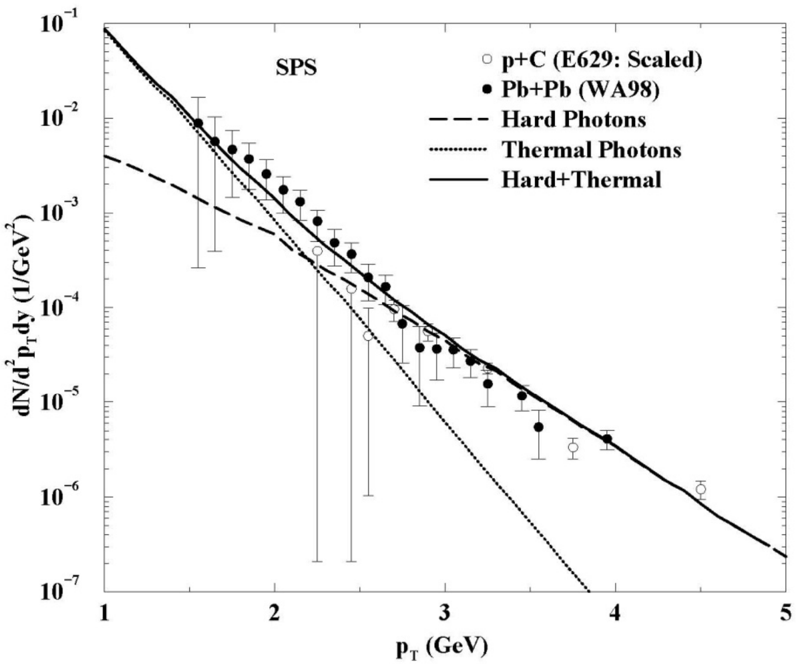
ALICE layout



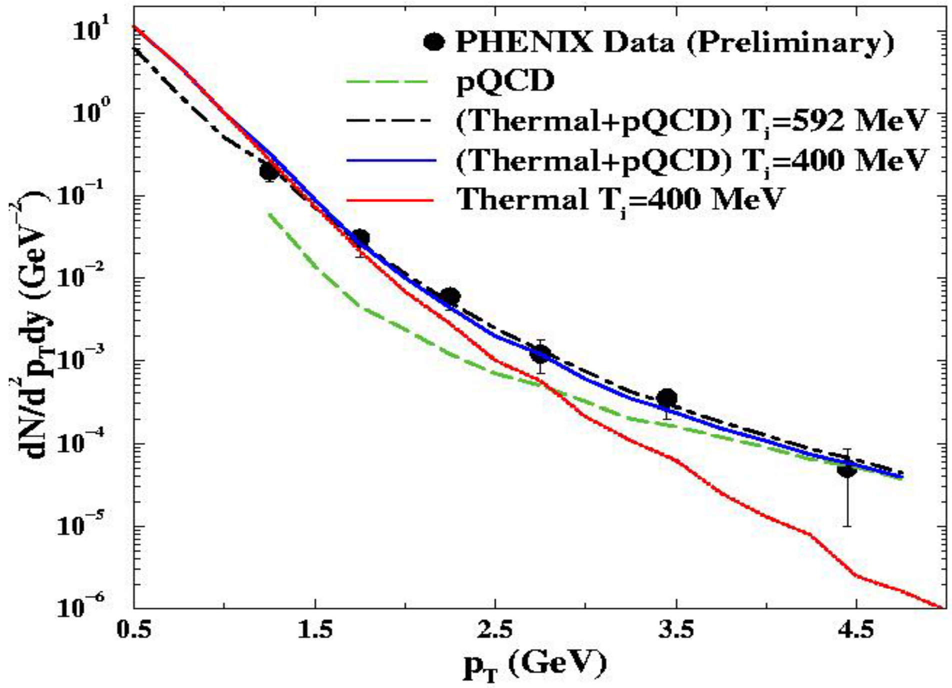
Thermal Photon productions

P_T spectra of photons

Photon : SPS (Pb+Pb)



Photon : RHIC (Au+Au)



Phys. ReV. C,63,021901,2001.

(J. Phys. G,34,871, 2007)

With T_i=200 ,T_f=120 MeV

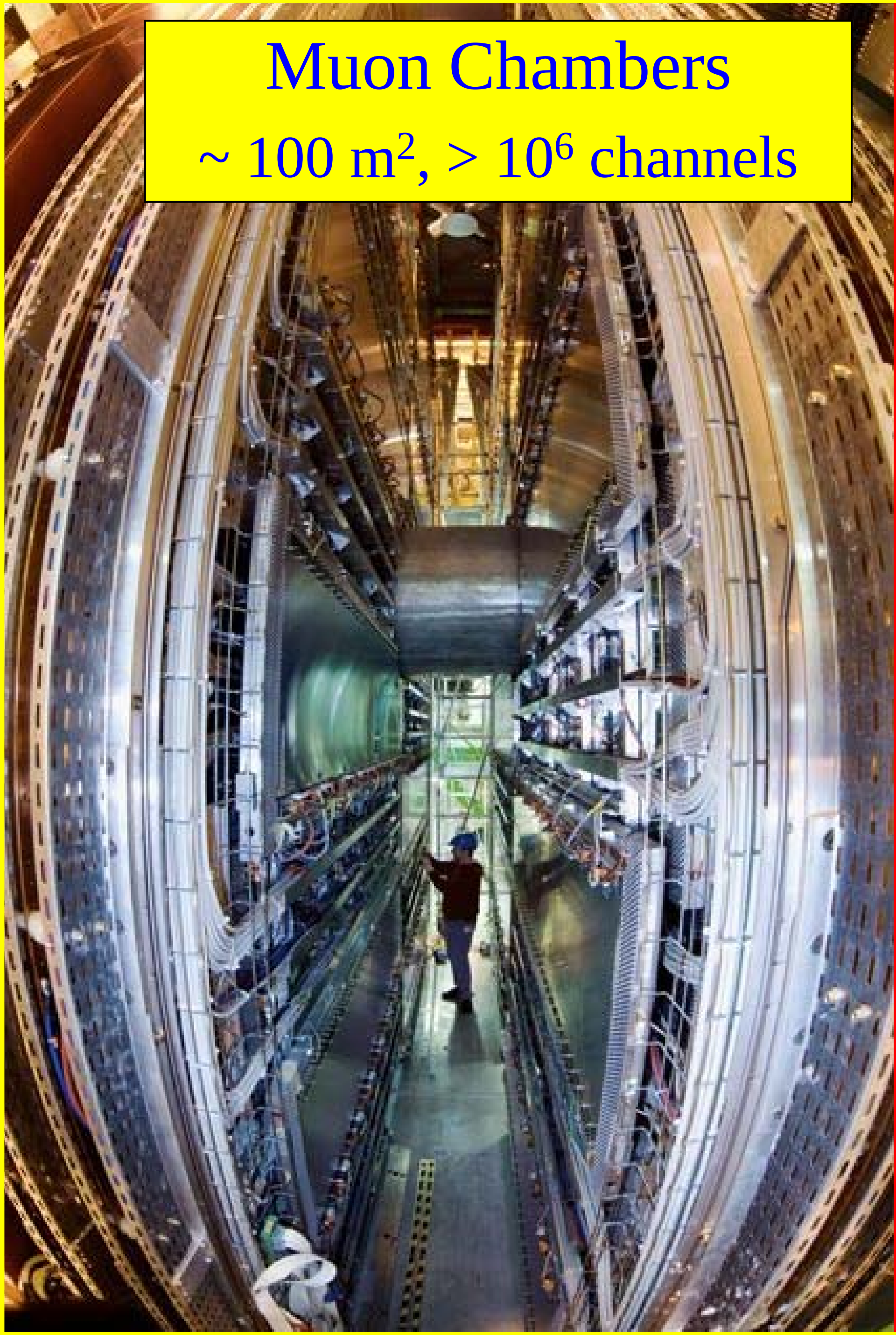
With T_i=400 and T_f=120 MeV

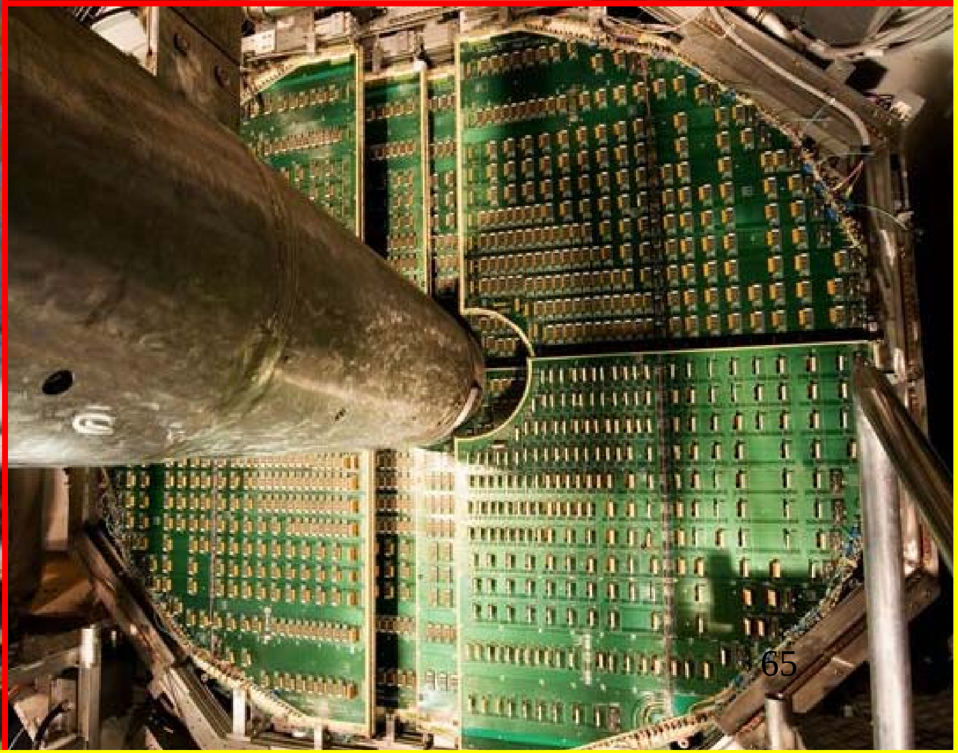
Pb+Pb Collision at 158A GeV

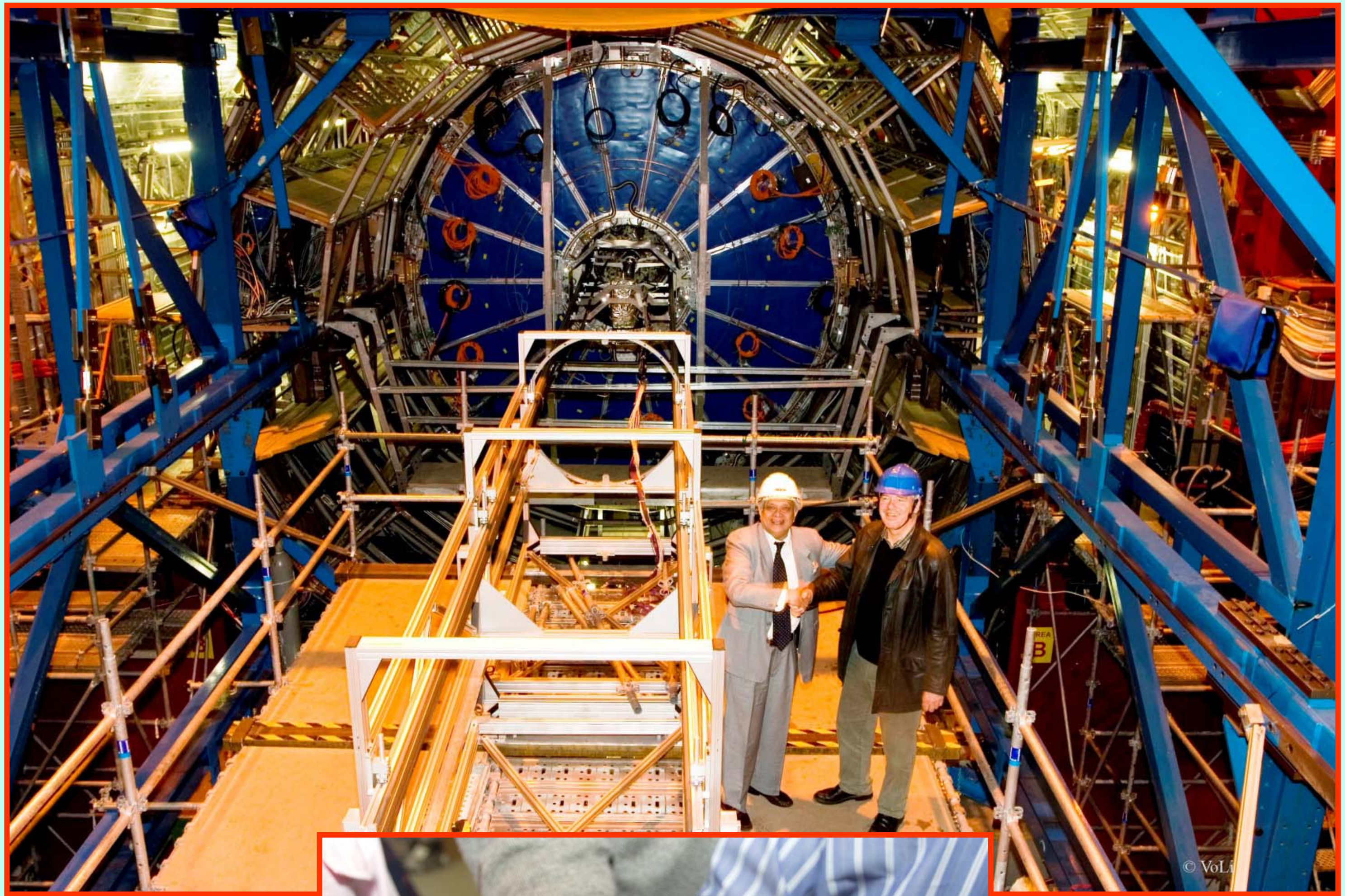
Au+Au collision at c.m energy=200 GeV/A

Muon Chambers

~ 100 m^2, > 10^6 channels







MANAS Chip


© VoLi

Indian Delegates in the ALICE experiment for the LHC Inauguration

JOINT DECLARATION

CONCERNING THE PARTICIPATION IN CONSTRUCTION AND OPERATION OF THE INTERNATIONAL FACILITY FOR ANTIPROTON AND ION RESEARCH (FAIR)

The Minister for Science & Technology and Earth Sciences

Government of India

Kapil Sibal

The Federal Minister of Education and Research

Federal Republic of Germany

Dr. Annette Schavan

LHC GRID TIER-2 CENTRE at VECC

VECC Tier-2

600 node cluster
240TB disk space
24X7 operation
Active in ALICE computing

Atomic Energy Commission meeting, 24th August 1964 at Trombay, Bombay, chaired by Dr. H. J. Bhabha along with Member Finance and J.R.D. Tata – Dr. Raja Ramanna, Director, Physics Group at AEET in **Item 6** made a strong case for Purchase of Accelerators. He argued for "Tandem Van de Graaff" and/or A.V.F. Cyclotron; he went on to point out the damage (if the accelerators were not obtained) it would cause to nuclear research work in India, citing the high quality work done at Saha Institute of Nuclear Physics, Calcutta and at Trombay as well as TIFR. There was no doubt that such facilities are essential but finance in those days were a serious impediment.

“6. The approval in principle of the Atomic Energy Commission is requested to acquire/build the two accelerators, namely “Tandem Van-de-Graff” and “A.V.F. Cyclotron” at a cost of Rs. 3.2 crores Significant developments of this proposal will be reported to the Commission from time to time”.

The minutes of the meeting was signed by Mr. R. Bhaktavatsalu, Joint Secretary of DAE, dated 20th August 1964.

That is the story of the Calcutta’s Cyclotron Centre, and the genesis of Variable Energy Cyclotron at Salt Lake, to be “Conveniently available at the Saha Institute of Nuclear Physics and the Universities in Calcutta.

Thousands of stars blink away forever.

In the backdrop,

Nataraj is alone and silent.

नित्याय त्रिगुणात्मने पुरजिते कात्यायनी-श्रेयसे
सत्यायादिकुटुंबिने मुनिमन: प्रत्यक्ष-चिन्मूर्तये ।
मायासृष्ट-जगत्त्रयाय सकलाम्नायान्त-संचारिणे
सायं ताण्डव-संभ्रमाय जटिने सेयं नतिश्शंभवे ॥ ५६ ॥

"O Omnipresent, the embodiment of all virtues, the creator of this cosmic universe, the king of dancers, who dances the *Ananda Tandava* in the twilight, I salute thee."

(Source: Verse No. 56, Sivanandalahari by Sri Adi Sankara)

Presented by: The Department of Atomic Energy, Government of India.