Overview of India CERN Collaboration

Accelerators, Experiments and GRID Collaboration Activities

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Oh behalf of India CERN Collaboration

Raja Ramanna Centre for Advanced Technology, India

South Asian High Energy Physics Instrumentation Workshop on Detector Technology and Applications,
Kathmandu University, Kathmandu , Nepal

June 20, 2017

Outline of the talk

- Accelerator activities: India-CERN Collaboration
- Participation in Construction of Large Hadron Collider
  - Hardware contributions for construction of LHC
  - Participation in commissioning
  - Software development
- Beyond LHC : Novel Accelerator Technology
  - Compact Liner Collider (CLIC)- Starting with CTF3
  - Superconducting Proton LINAC(SPL) front end-LINAC 4
- GRID Collaboration
- Collaboration in High Energy Physics Experiments
  - Detectors: CMS, ALICE (Muon and PMD)
- Conclusion

The Large Hadron Collider (LHC)

- Highest ever energy per collision

  14 TeV in the p p-system

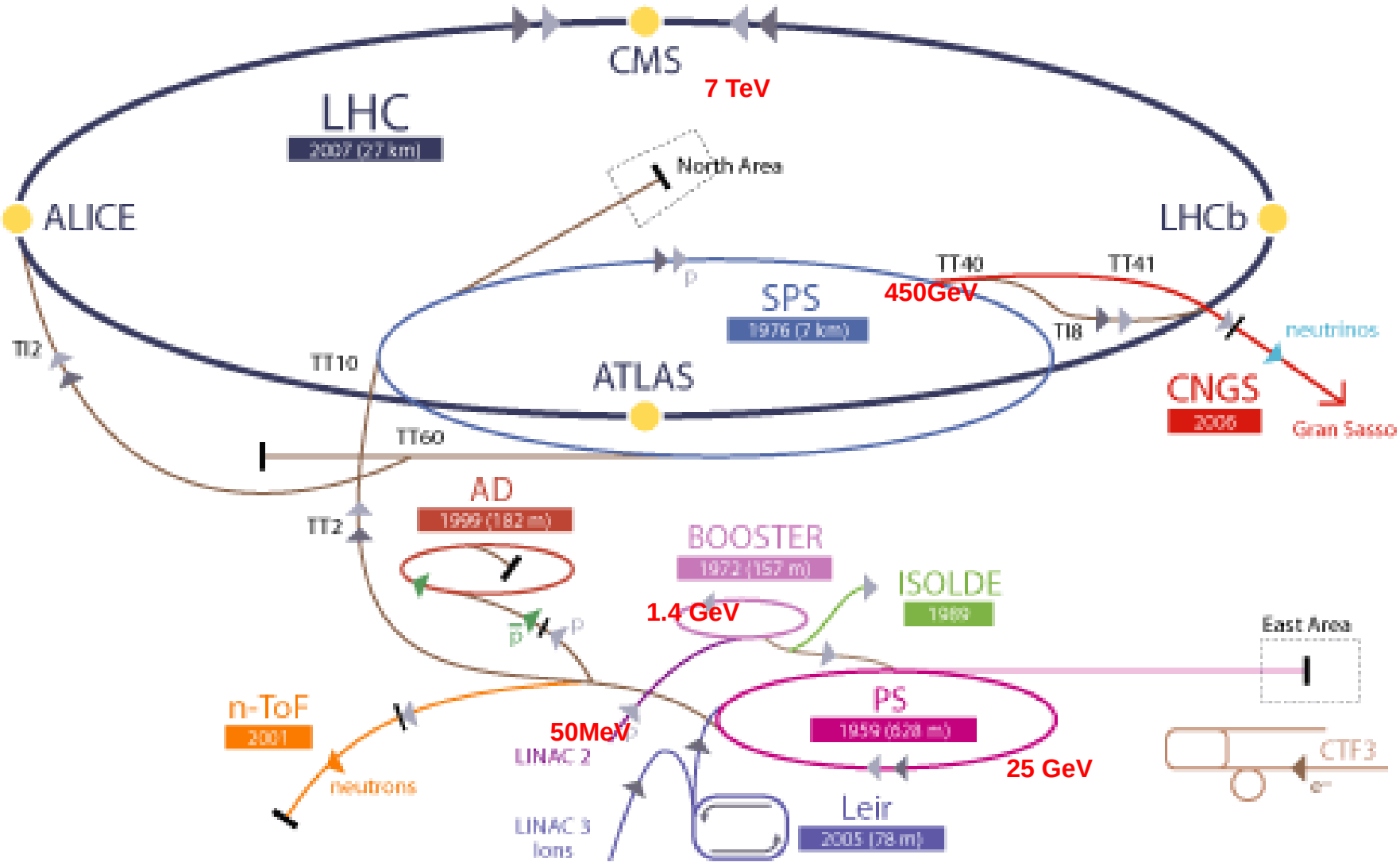
- Conditions as 10^{-10} – 10^{-12} s after the Big Bang (begining of universe)

- Installed in a tunnel of ~ 27 km circumference ~ 100 m below the ground passing through two countries Switzerland and France

- Constructed in worldwide collaborations

- India contributed in construciton and commissioning

CERN Accelerator Complex



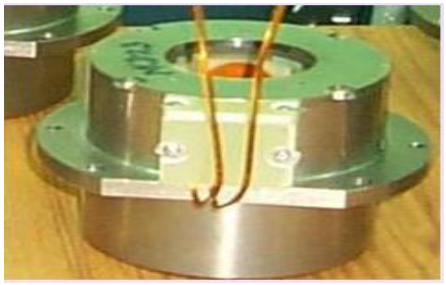
Indian Contributions for LHC accelerator

		Qty
1	50000 litres Liquid Nitrogen tanks.	2
2	Superconducting corrector magnets : Sextupole (MCS) Decapole and Octupole (MCDO)	 1146 616
3	Precision Magnet Positioning System (PMPS) Jacks	7080
4	Quench Heater Power Supplies QHPS	5500
5	Integration of QHPS units into racks	6200
6	Control electronics for circuit breakers of energy extraction system	70
7	Local protection units (LPU)	1435
8	SC Dipole magnet measurements, expert support.	100 Man yrs.
9	Expert support for Commissioning LHC Hardware, like, Cryogenics, Controls, Power converters, Protection systems	Upto 20 Man yrs.
10	Data management/analysis software upgrade and projects	41 Man yrs. equivalent
11	Development of JMT-II software	
12	Software dev -slow control of Industrial Systems of LHC	
13	Design calculations for Vacuum system for beam dump line	
14	Analysis of cryo-line jumper and magnet connections	

Superconducting Corrector Magnets for LHC

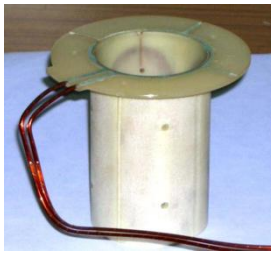
- The superconducting dipole electromagnets of the LHC are the most important technological challenge for the LHC design.
- LHC has 1232 Dipole magnets distributed in the 27 km circular tunnel in 8 sectors.
- Very high field of 8.3 T passing at a current of 11700A through its niobium-titanium (NbTi) cables to bend the 7 TeV beams around the 27-km ring of the LHC.

Superconducting corrector magnets correct the systematic field errors of main superconducting dipole magnets installed in the same cryostat. The prototypes were developed and tested by RRCAT and production was done by M/s KECL.



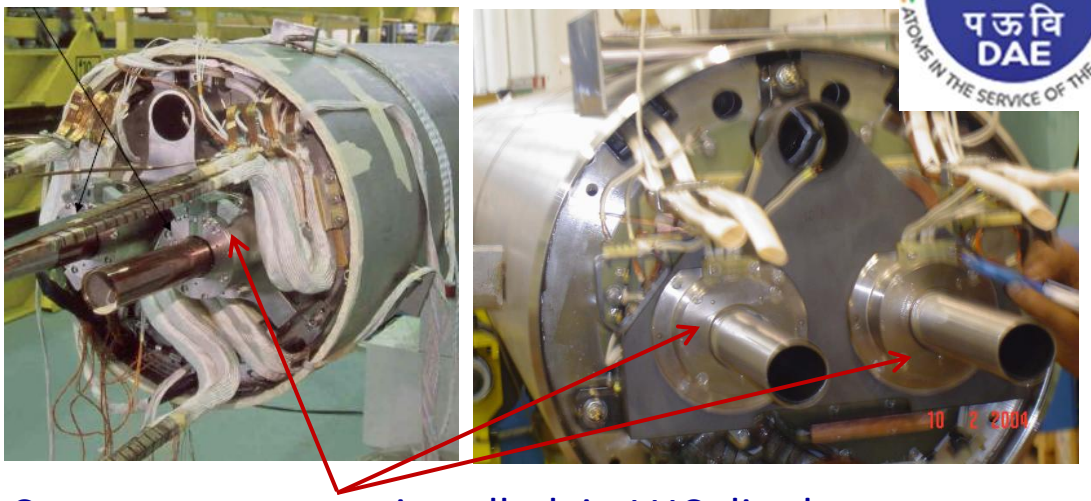
Decapole & Octopole corrector magent assembly

Sextupole Corrector Magnet (MCS)



Octupole Corrector Insert (MCO)

Cryogenic test facility to test corrector magnets at RRCAT



Corrector magnets installed in LHC dipole magnets

	MCS	MCD	MCO	Unit
Length with shield	160	110		mm
Temperature	1.9	1.9		K
Peak field	1.9	2.4	2.0	T

Superconducting corrector magnets supplied to CERN

Sextupole (MCS)	1146
Decapole & Octupole (MCDO)	616

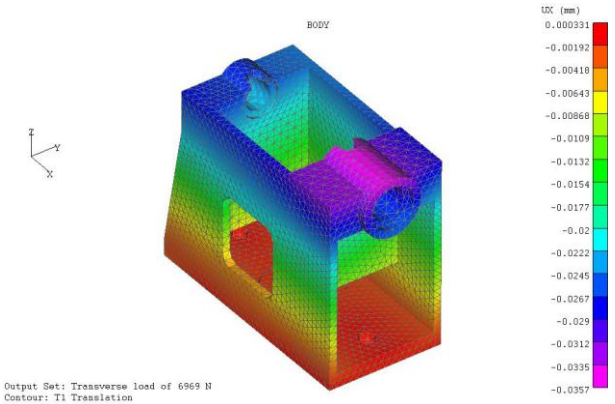
Precision Motion Positioning System Jacks

- Superconducting dipole magnets have to be aligned precisely.

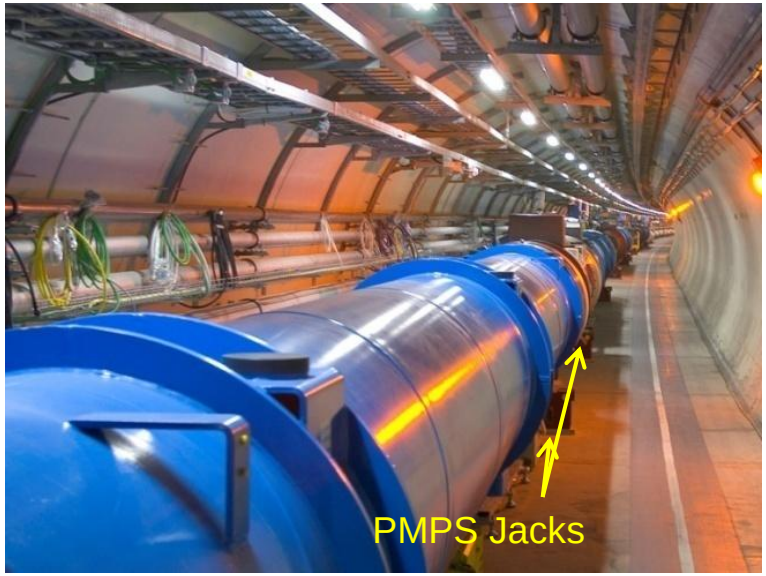
- The PMPS Jacks support the dipole magnets and have provisions for aligning them to a setting resolution of 50 microns. The prototypes were developed by RRCAT and production was done with the help of M/s Avasarala, Bangalore and M/s IGTR, Indore.

Table 1

Parameter	Value
Maximum loads on jacks: - Fz - Fx	170 kN 80 kN
Adjustable range in X-Y directions	≥ ±10 mm
Adjustable range in Z direction	±20 mm
Setting resolution (minimum incremental movement)	0.05 mm
Long term stability of position	≤ 0.1 mm/year
Nominal operating torque	<60 N.m
Gap between magnet and floor	340 mm
Overall transversal limitation	380 X 200 mm
Bearing pressure on tunnel floor	< 20 Mpa
Total integrated radiation dose	< 1 kGy



Deflection of jack body under transverse load.



LHC Superconducting dipole magnets supported on Indian PMPS jacks in tunnel

Series production delivered to CERN

- Precise alignment and support of 1232 numbers of 32 Ton, 15 meter long Superconducting dipole magnets of the LHC with a setting resolution of 50 micron.
- Total numbers supplied by RRCAT 7080
- Produced at M/s Avasarala, Bangalore and IGTR, Indore.

Quench Heater Power Supplies and Local Protection Units

For the protection of Superconducting Dipole magnets of LHC, Quench Heater Discharge Power Supply (QHPS) and Local Protection Units were developed and supplied with the help of ECIL, Hyderabad under RRCAT/BARC supervision.

QHPS and LPU installed in LHC


Quench Heater Power Supplies


Local Protection Units

Quench Heater Power Suppliers	5500
Local Protection Units	1432
Breaker control Electronics	70

LPU:

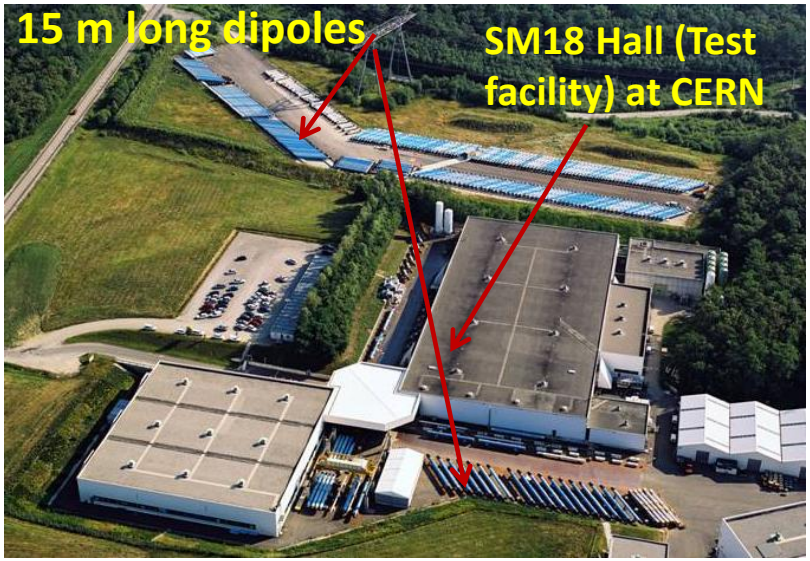
- Detects the Quench and triggers the Quench Heater Power supplies in any state of the powering cycle of the accelerator.
- Transfers the Quench data to the higher level LHC control system through data field bus link.
- Opens the interlocking current loop which initiates machine protection system.


Breaker Control Electronics

Tests and Qualification of the LHC Superconducting Dipoles

DAE engineers worked at SM18 Hall at CERN and completed crucial performance tests and qualification of all the LHC superconducting dipole magnets.

- The 15m long, 30 Ton heavy superconducting dipole magnet operates at a field of 8.3 Tesla
- Total ~1900 magnets were tested DAE engineers equivalent to 100 man years contribution.
- Testing & Qualification and training of each superconducting dipole magnets for 1) Cryo, mechanical & electrical insulation, 2) Quench performance and 3) Field Quality



H.E. Dr. A.P. J. Abdul Kalam The President of India at SM 18 Hall of CERN with DAE's engineers

SM 18 Hall The Test place for the SC dipole magnets

Commissioning of LHC Hardware Subsystems

Quench Protection System & Energy Extraction System:

- Individual System tests on 13 kA energy extraction system for main bending magnets, focusing and defocusing magnets installed at different sites along the LHC tunnel.
- Individual system tests on 600 A energy extraction system for corrector magnets at installation sites along the LHC tunnel.
- Testing of Dipole Quench Local Protection Units (DQLPU) before installation.

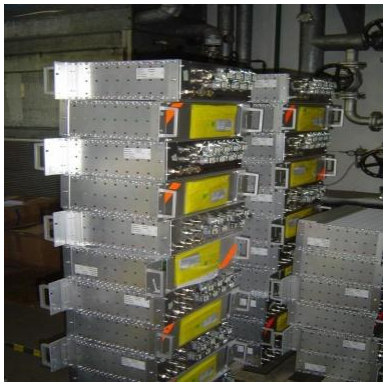
And commissioning of subsystems on sector 7-8:

- Initial commissioning from field control room.
- Testing of interlock systems before powering of different magnet circuits.
- Sector commissioning from CERN Control Centre.
  - Commissioning tests of main magnet circuits, matching section magnets, as well as for 600A corrector circuits.
  - Measurements in the tunnel.
  - Analysis of the post mortem data.

Commissioning of LHC Hardware Subsystems

Indian experts participated in the commissioning of the hardware subsystems of the LHC. These involved the Quench Heater Protection Systems, Cryogenic Systems, Power Converters Systems.

High voltage test set-up for nQHPS



nQPSRacks ready for installation

Determination of source of excessive frosting on the cryogenic subsystem & re-evaluation of safety valve size to withstand different accidental conditions etc.

Total support of ~18 man years was provided for LHC commissioning. Indian experts were also involved in the re-commissioning of some of the subsystems like nQHPS.

DAE-CERN Collaboration beyond LHC

- CERN's Novel Accelerator Projects :

  - Compact Linear Collider (CLIC)Test Facility

    CERN had set up CLIC Test facility CTF3 to test a concept in which a high intensity electron beam generates high microwave power at 12 GHz which in turn is used to accelerate another low intensity beam to high energy.

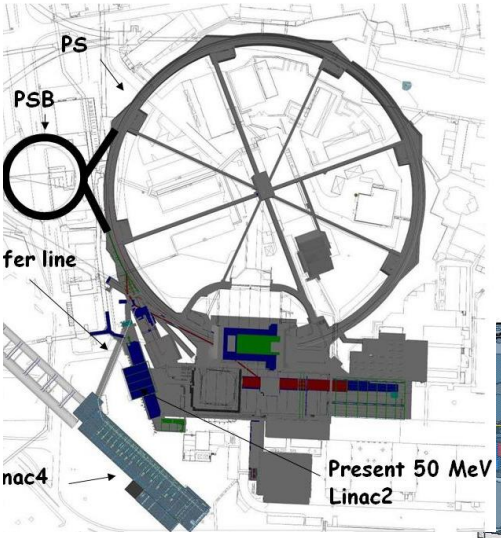
  - Linac-4, the front end of Superconducting Proton Linac

    Linac-4 project is to develop a linear accelerator as a front end for the superconducting proton linac which is planned to upgrade the luminosity of LHC machine in future.

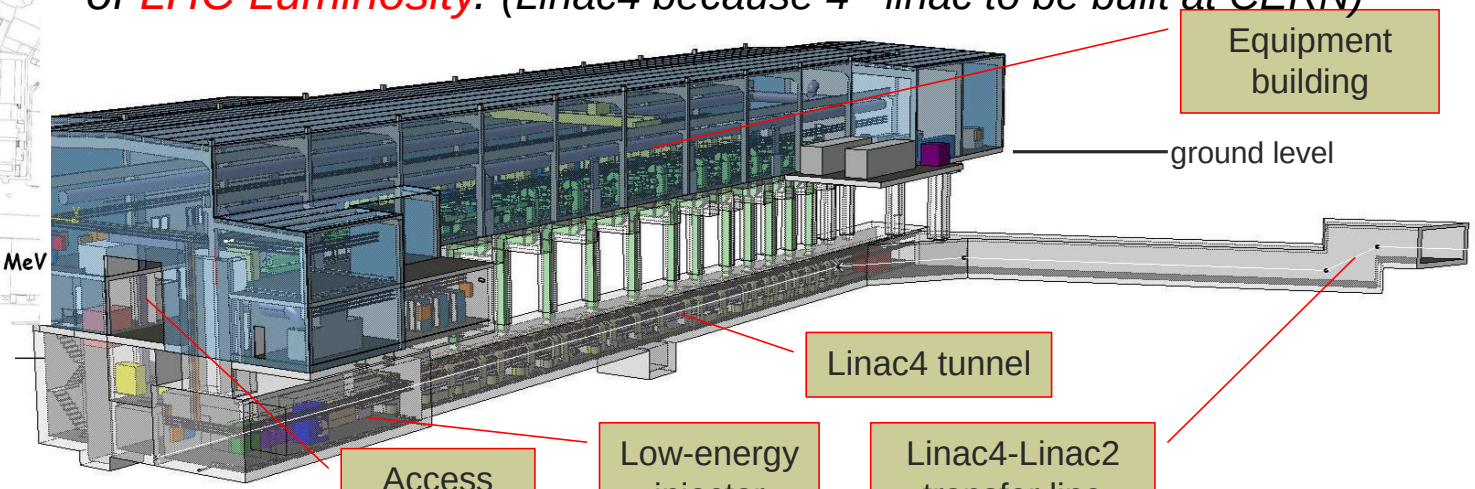
  Participation in the above programs is beneficial for accelerator community.

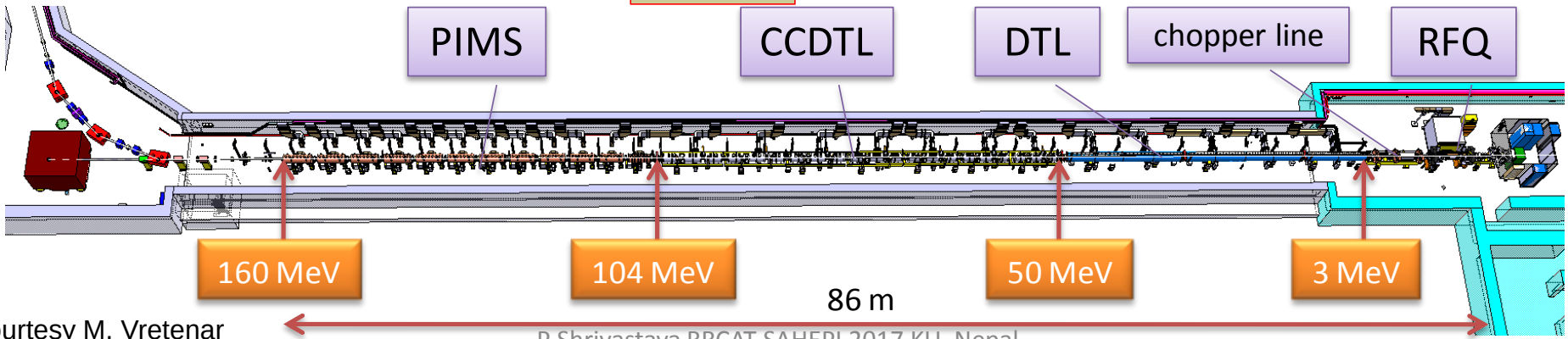
- Grid Computing and LCG Activities

Linac-4



Linac4 *is a 160 MeV H- linac being built at CERN to increase the injection energy into the PS Booster and to allow higher intensities from the LHC injector chain, in view of an upgrade of LHC Luminosity. (Linac4 because 4th linac to be built at CERN)*





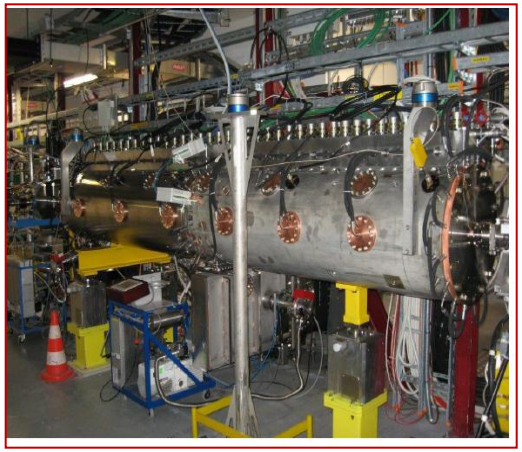
Courtesy M. Vretenar

Collaboration activities under NAT Protocol
LINAC 4 project

- 100kV state of the art prototype solid state bouncer modulator for LINAC4
- WR 2300 waveguide components, power couplers for LINAC4
- Participation in commissioning of the LINAC4 subsystems.
- India received four 352.21 MHz, 1MW CW klystrons and circulators along with RF waveguide components for our projects on SNS at RRCAT and ADS/LEHIPA at BARC.

100kV solid state modulator designed, developed and commissioned by RRCAT, Indore, for LINAC 4 cavity tests.

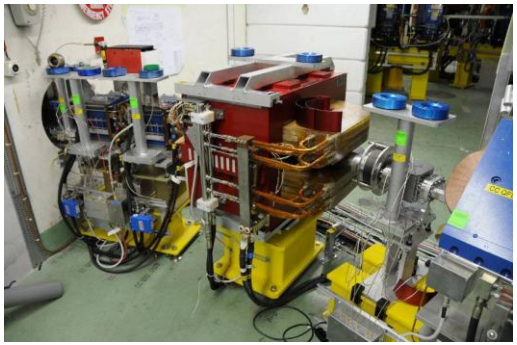
CERN klystron and circulator tested at 1MW peak power at RRCAT test stand.



Two Cu coated SS WR 2300 waveguide power couplers installed in the DTL/CCDL in LINAC 4 tunnel at CERN

Collaboration activities under NAT Protocol
Contribution to CLIC/CTF3 at CERN

- Optics design of TL2
- 5 dipole magnets
- 62 Vacuum chambers
- Software development for controls for CTF3
- Components of Power extraction and Transfer Structure, PETS bars
- 20 kW Wide Band Solid State RF Amplifier for harmonic buncher for CLIC



Dipole magnets

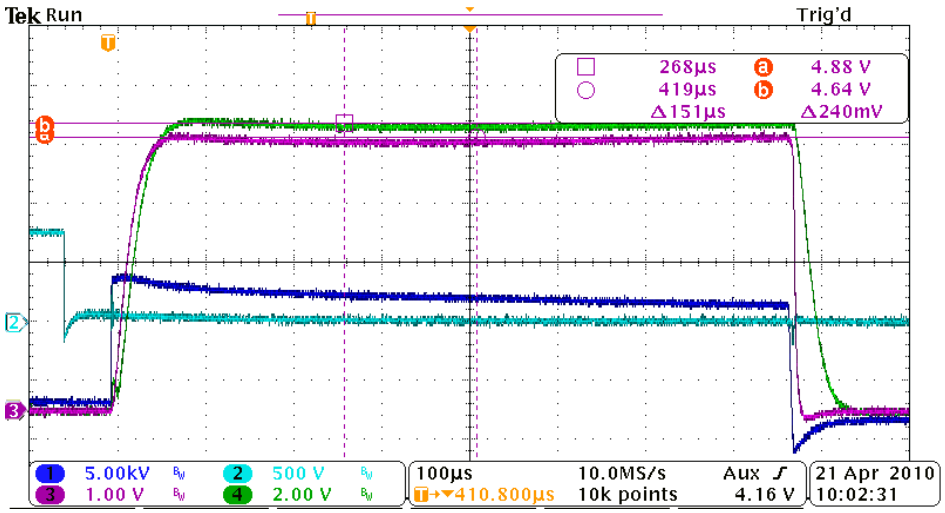
Vacuum chambers of various profiles in TL2 of CTF3

20kW wide band SSPA delivered to CERN

Solid State Modulator for LINAC 4 Project

The all solid state bouncer modulator for LEP 1 MW klystron for LINAC 4 project at CERN was successfully designed, developed and commissioned by RRCAT. Modulator passed all tests and accepted by CERN. Presently it is in use at SM18 Hall at CERN for testing accelerator cavities.

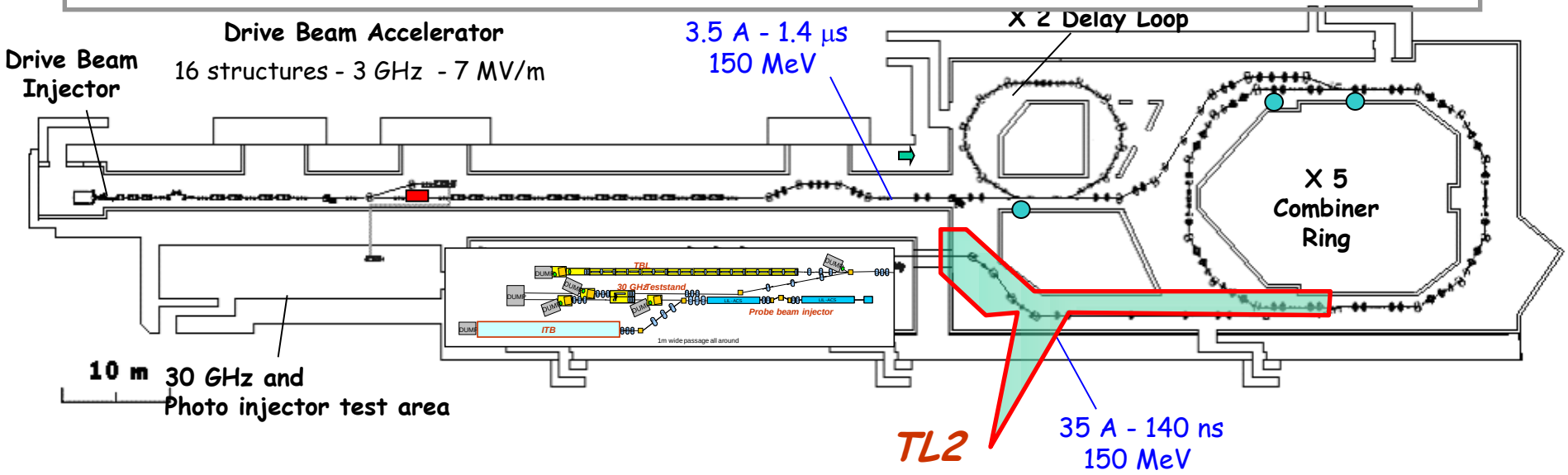
Results of acceptance tests at CERN. 100kV, 20A, 800 µsec, 2 Hz



CONTRIBUTIONS TO CLIC TEST FACILITY3 @ CERN

(1) A "drive beam" to create 12 GHz RF source",(2) Extract RF power via PETS &

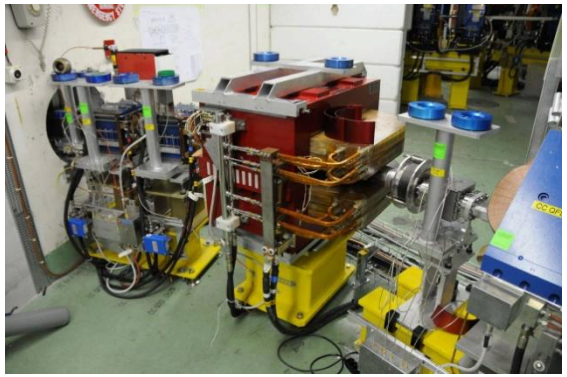
(3) Use RF power to accelerate e+-e- beams that will collide.



India contributed to construction & commissioning of TL2 of CTF3 :

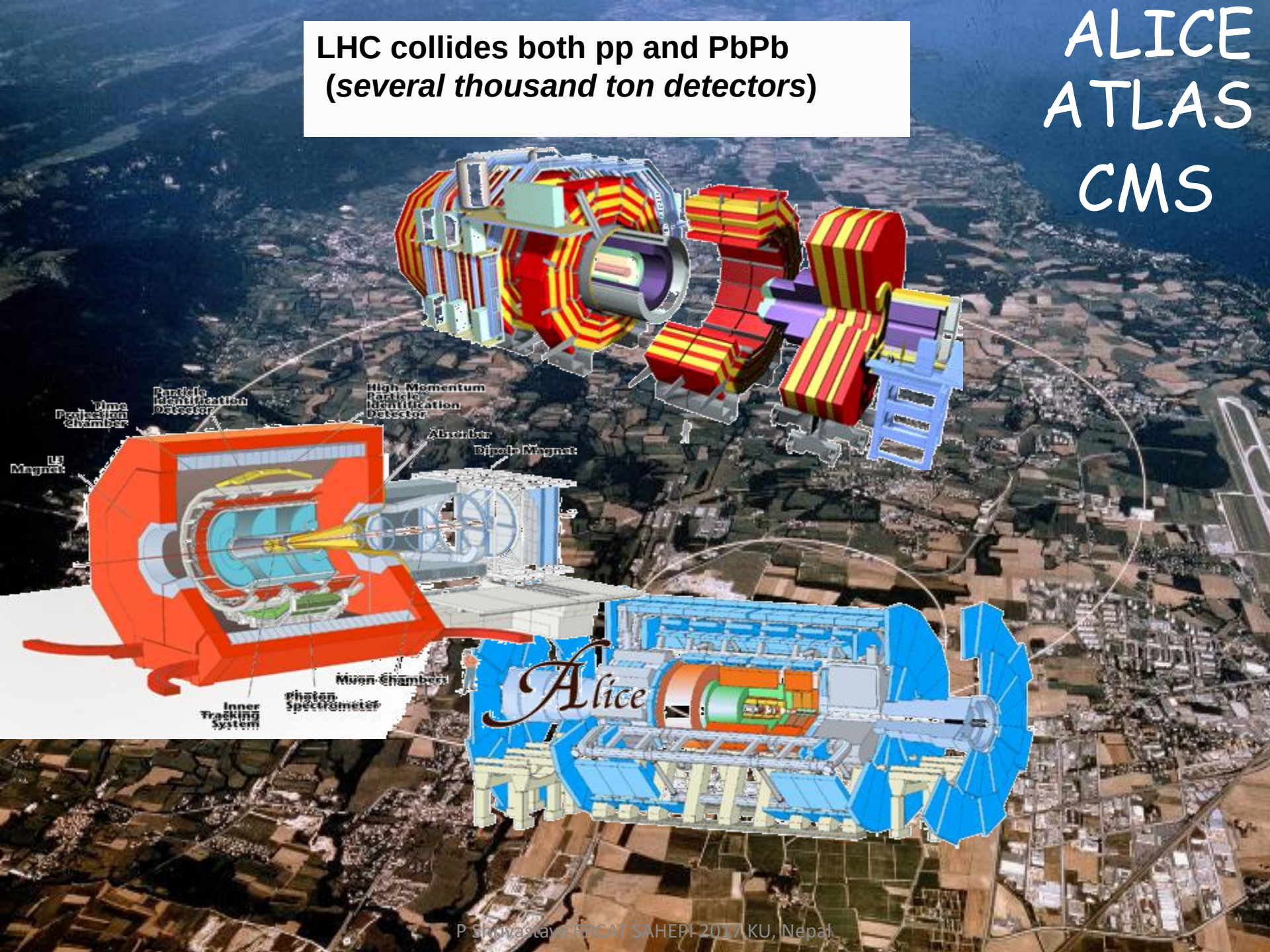
RRCAT Vacuum chambers and dipole magnets in CTF3

1)Optics design of TL2 & participation in commissioning,
2) 5 dipole bending magnets,
3) 62 Vacuum Chambers &
4) software for CTF3 controls



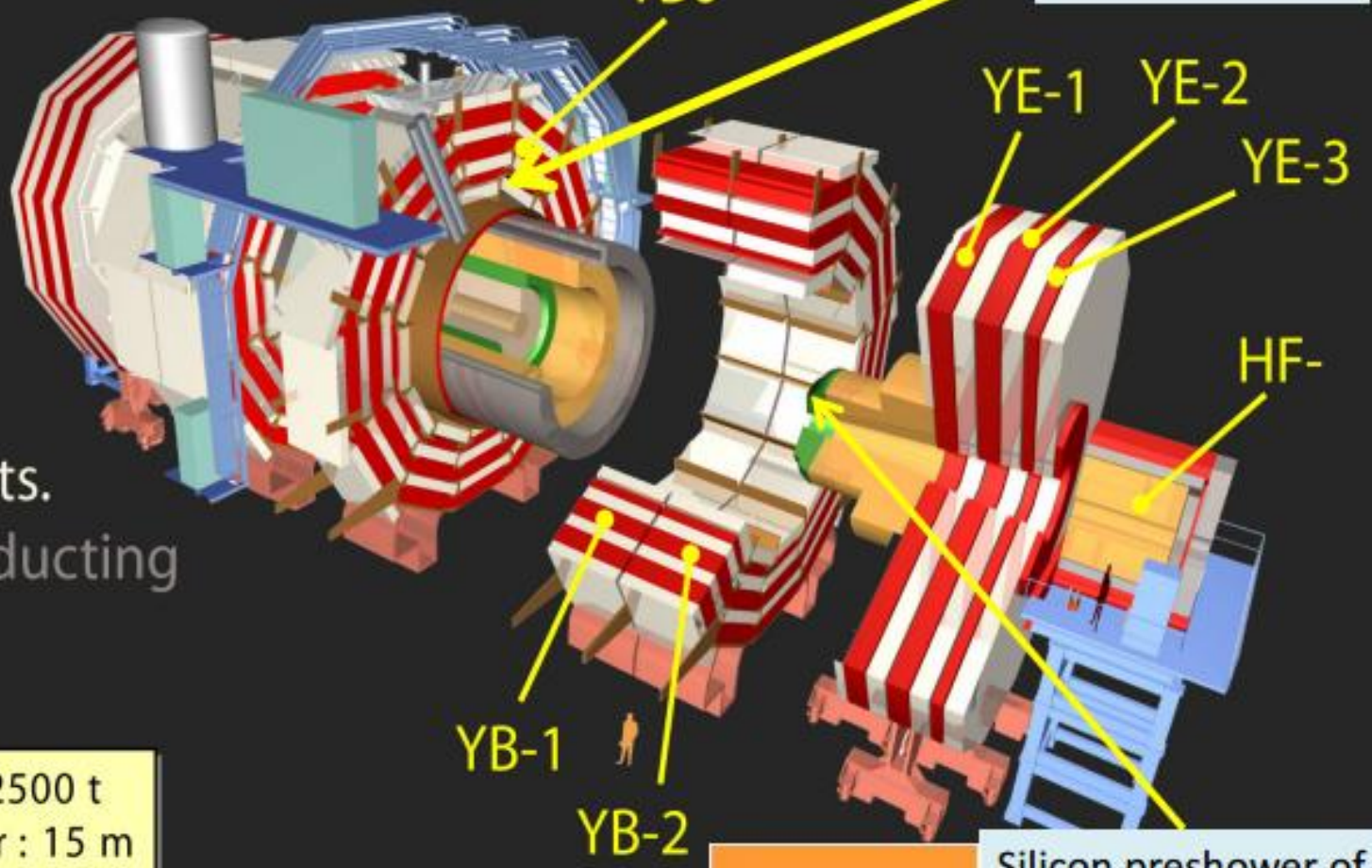
LHC collides both pp and PbPb
(*several thousand ton detectors*)

ALICE
ATLAS
CMS



Cartoon of presently working CMS Detector

- Designed meticulously for hard collisions
- Serving well even for softer ones



Hadron Outer calorimeter
TIFR, U.Panjab

Pixels
Tracker
ECAL
HCAL
MUON Dets.
Superconducting Solenoid

Total weight : 12500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

Silicon preshower of Electromagnetic Cal
BARC, U.Delhi

Salient contributions from India in CMS experiment

1. Detector R&D in 1990s
2. Study of scintillator material for the electromagnetic detector and design of its granularity
3. Optimization study of tracker detector material/geometry
4. Fabrication of subdetector systems, installation, testing
5. Physics studies for optimization of detector in preparatory stage
6. Software development for detector simulation
7. Studies with test beam, cosmic ray muons
8. Data collection, data quality monitor
9. Understanding of detector performance, possible improvements
10. Calibration of detector
11. Physics analyses, review of collision data leading to publications
12. Several collaboration-wide responsibilities within CMS
13. Representing collaboration in international conferences
14. In CMS grid computing via Tier2 centre
15. Detector upgrade for future operational phases of LHC including R&D

India CMS Collaboration

BARC, Mumbai	Delhi Univesity	GHG Khalsa College, Ludhiana
IISER Pune	IIT Bhubaneswar	IIT Bombay
IIT Madras	IISc Bangalore	IOP, Bhubaneswar
NISER, Bhubaneswar	Panjab University, Chandigarh	SINP, Kolkata
Shoolini University, Himachal Pradesh	TIFR, Mumbai	Visva Bharati, Santiniketan

Detector hardware from India

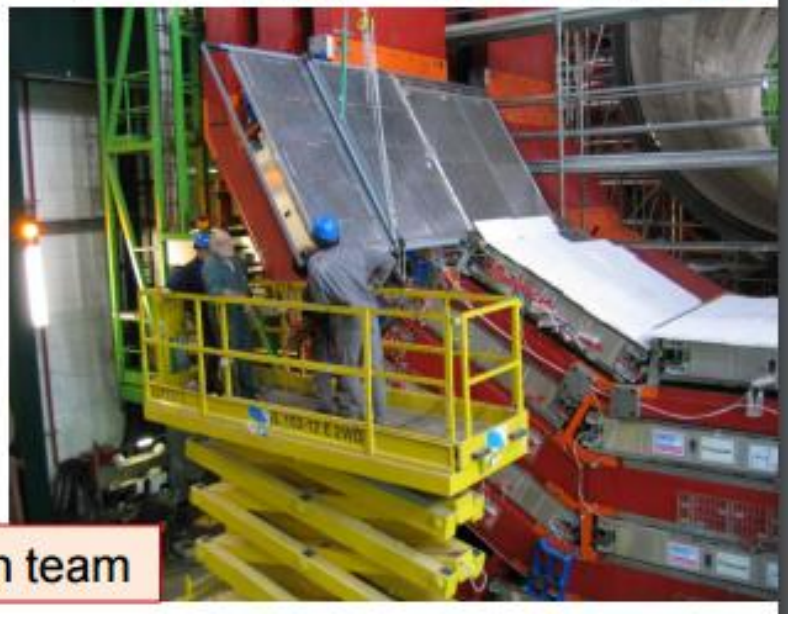
Outer hadron calorimeter (HO): crucial for containment of energetic hadronic jets ➔ improves performance of physics with jets and missing energy
➔ crucial for discovery

Preparation➔ Simulation and test beam studies

Fabrication at **TIFR and Panjab University**.

- 432 plastic scintillator trays ~ 2.5 m* 40 cm
- 72 honeycomb housing

- Quality control at every stage➔ tools developed
  → test of light transmission across spliced fibres
  → study of signals due cosmic ray muons, radioactive sources



- Accessories for 2154 photo-detector readouts
- Control boards for next version of photo-sensors (Silicon Photo Multiplier) being fabricated and tested.

CMS achievement award to HO installation team

Courtsey: Kajari Majumdar, TIRF, Mumbai

1. CMS at LHC

1. Si-Pre Shower Detectors (Si-PSDs) :
   pre-2010 (NPD-BARC, ED-BARC & Delhi U)

2. Resistive Plate Chambers (RPCs) :
   Long Shutdown-1 (2013-2014) (NPD-BARC & Panjab U)

3. Gas Electron Multipliers (GEMs) for GE1/1 upgrade :
   (2018-2019) (NPD-BARC, Delhi U, Panjab U, SINP)

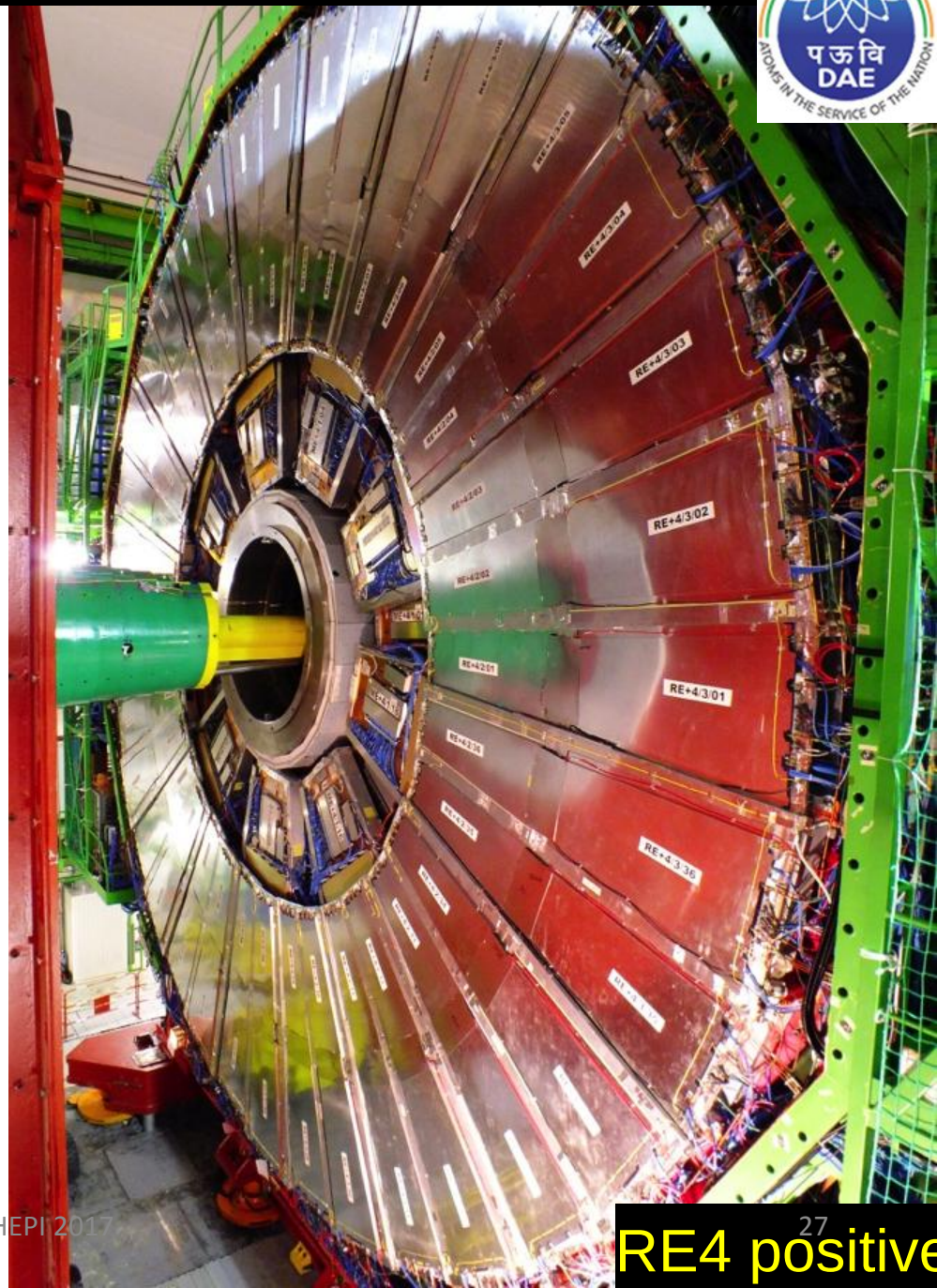
4. Heavy Ion Physics Analyses (Pb-Pb, p-Pb)

5. High Granularity Calorimeter (HGCAL) for CMS :
   (2017-2022...)
   (NPD-BARC, TIFR, SINP, IISER, IISc, DU, PU.....)

Courtesy: L.M. Pant, BARC, Mumbai

The two end-caps (RE4 ±) commissioned in May 2014

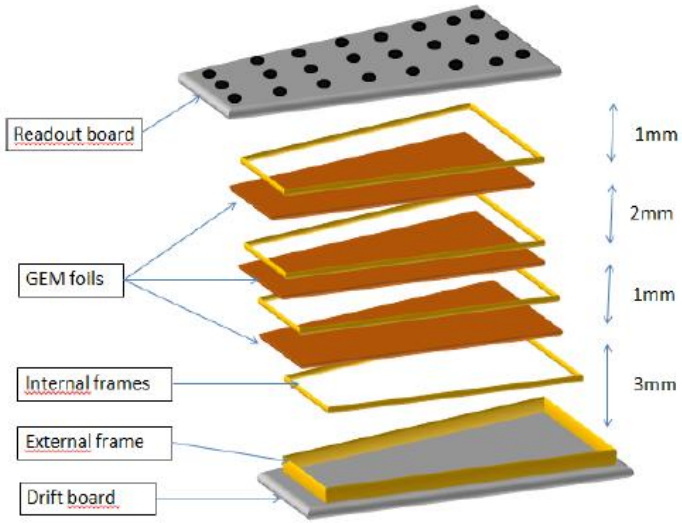
RE4 negative



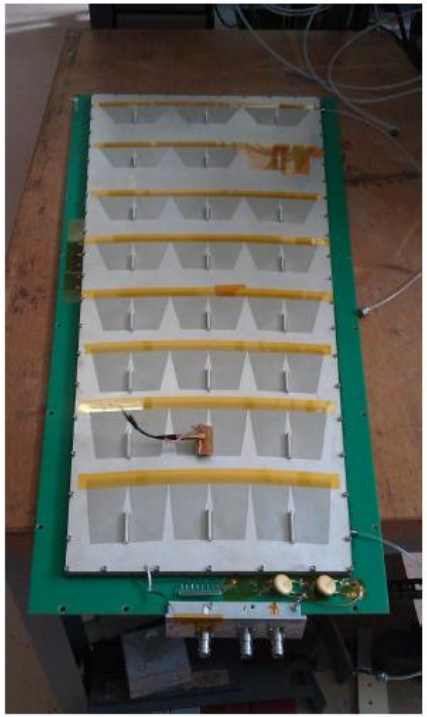
RE4 positive

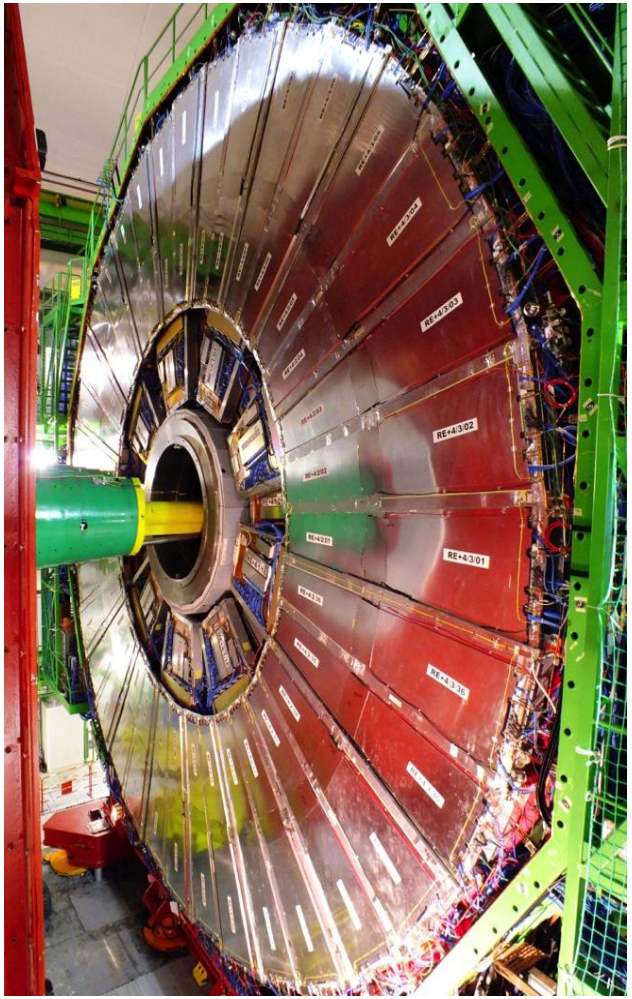
GE11 upgrade of CMS detector (2018-2019)

Potential use of GEMs in Medical Imaging

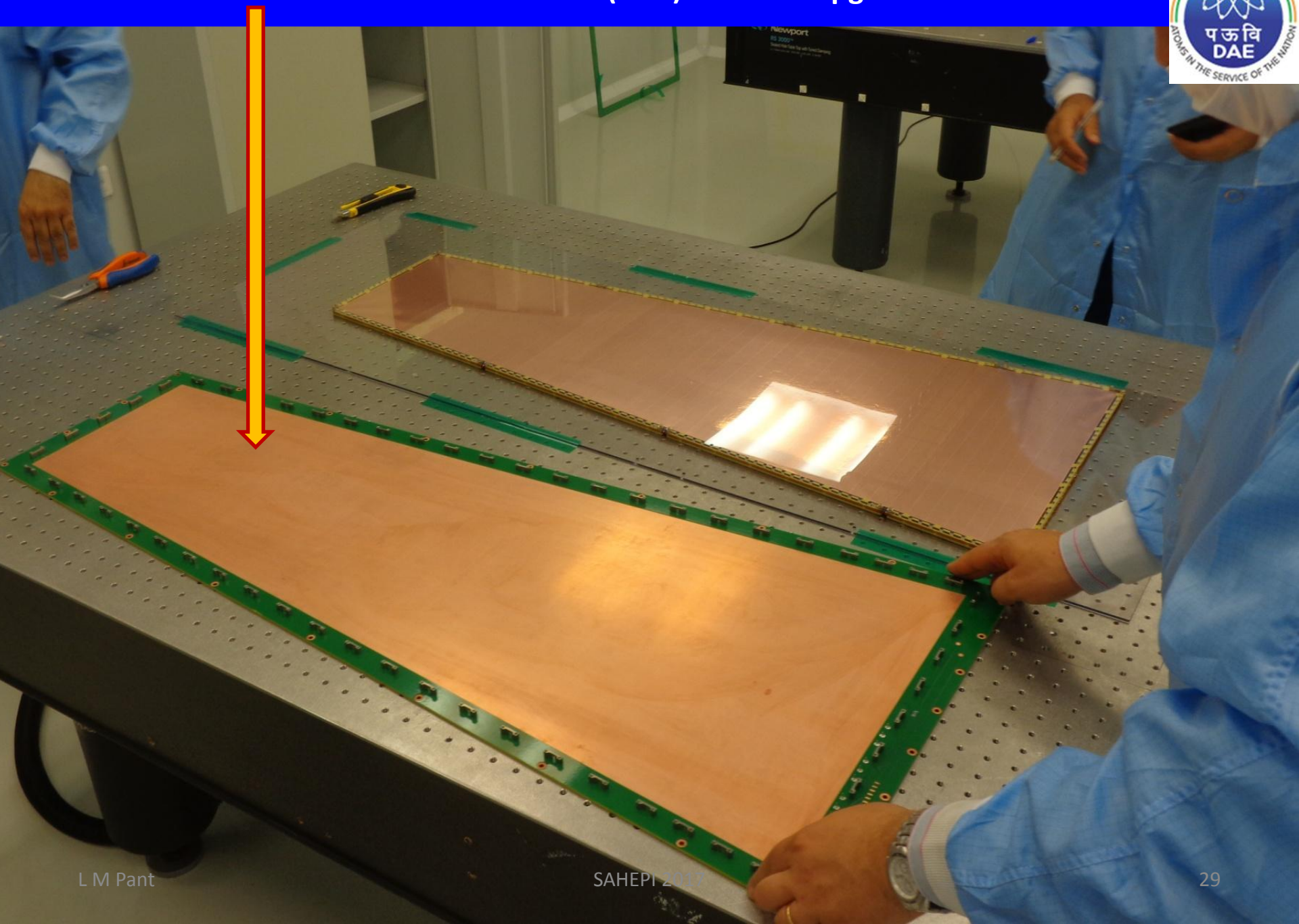


- Single-mask & self-stretching techniques
- Gap sizes: 3/1/2/1 mm
- Sectors : 3 columns x (8-10) η partitions
- Strip pitch: 0.6-1.2mm
- 1D readout of up to 3840 channels
- 35 HV sectors





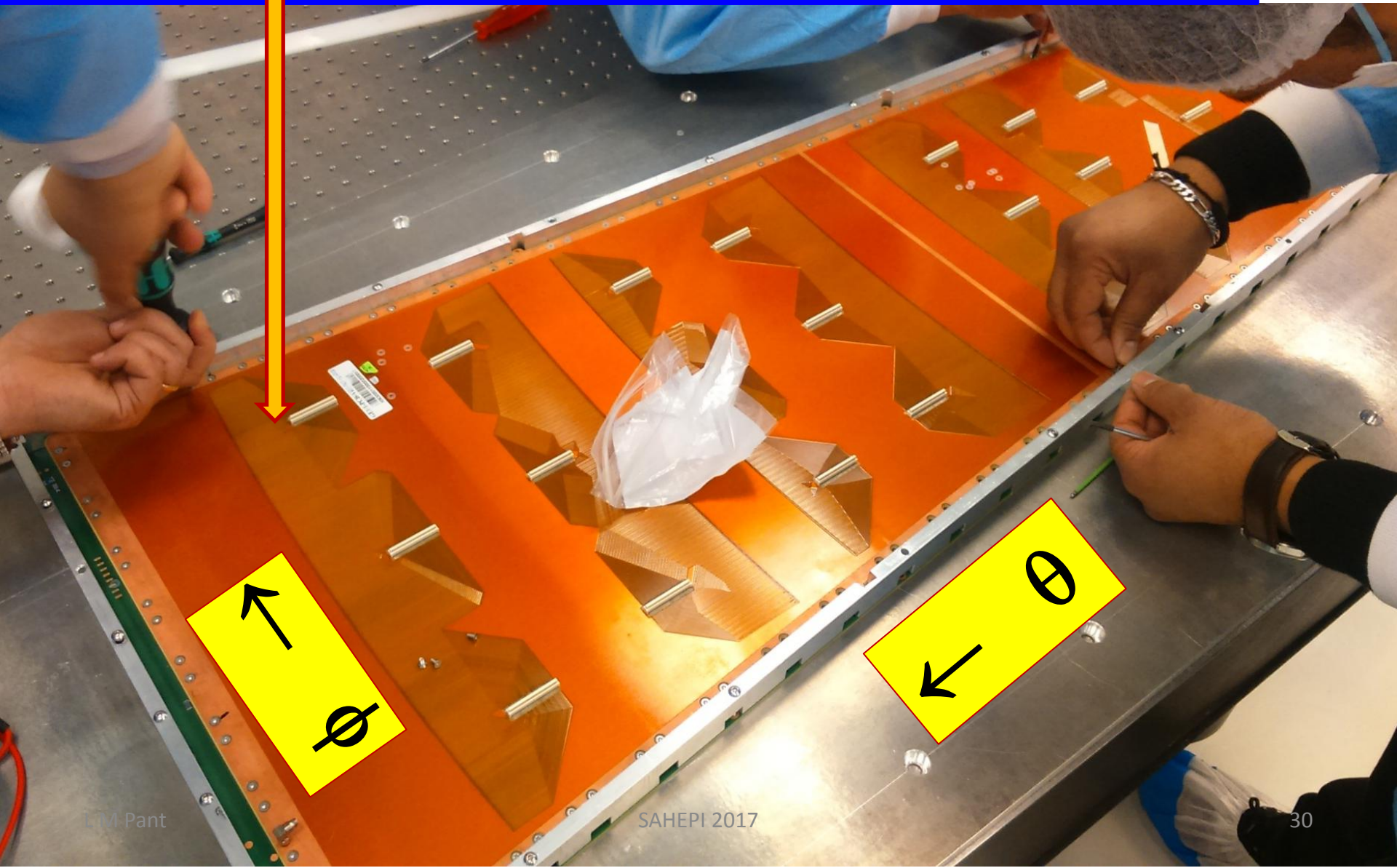
Drift Cathode Board (DCB) for GE11 upgrade



Read Out Boards (ROB) for GE11 upgrade

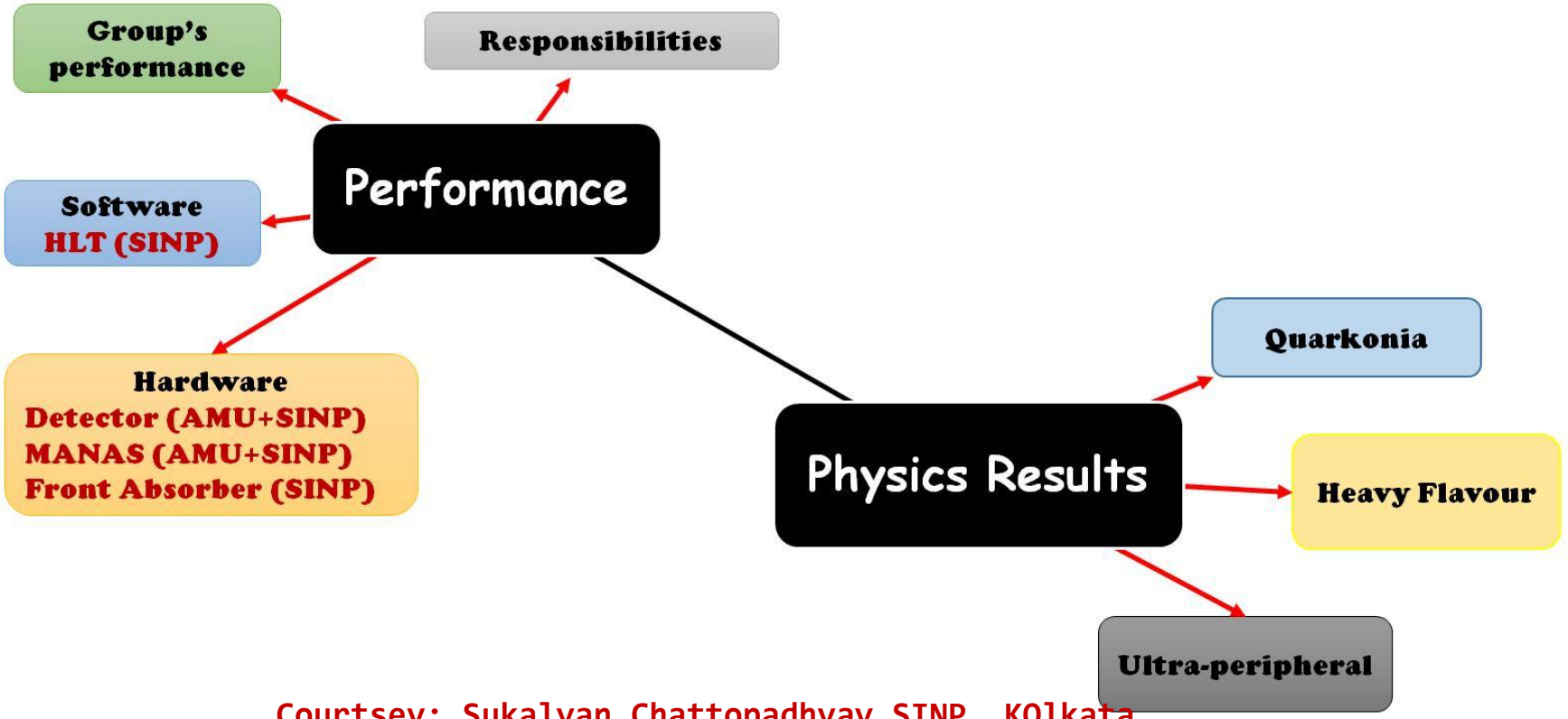
θ : Eight Segmentations

ϕ : 384 Segmentations



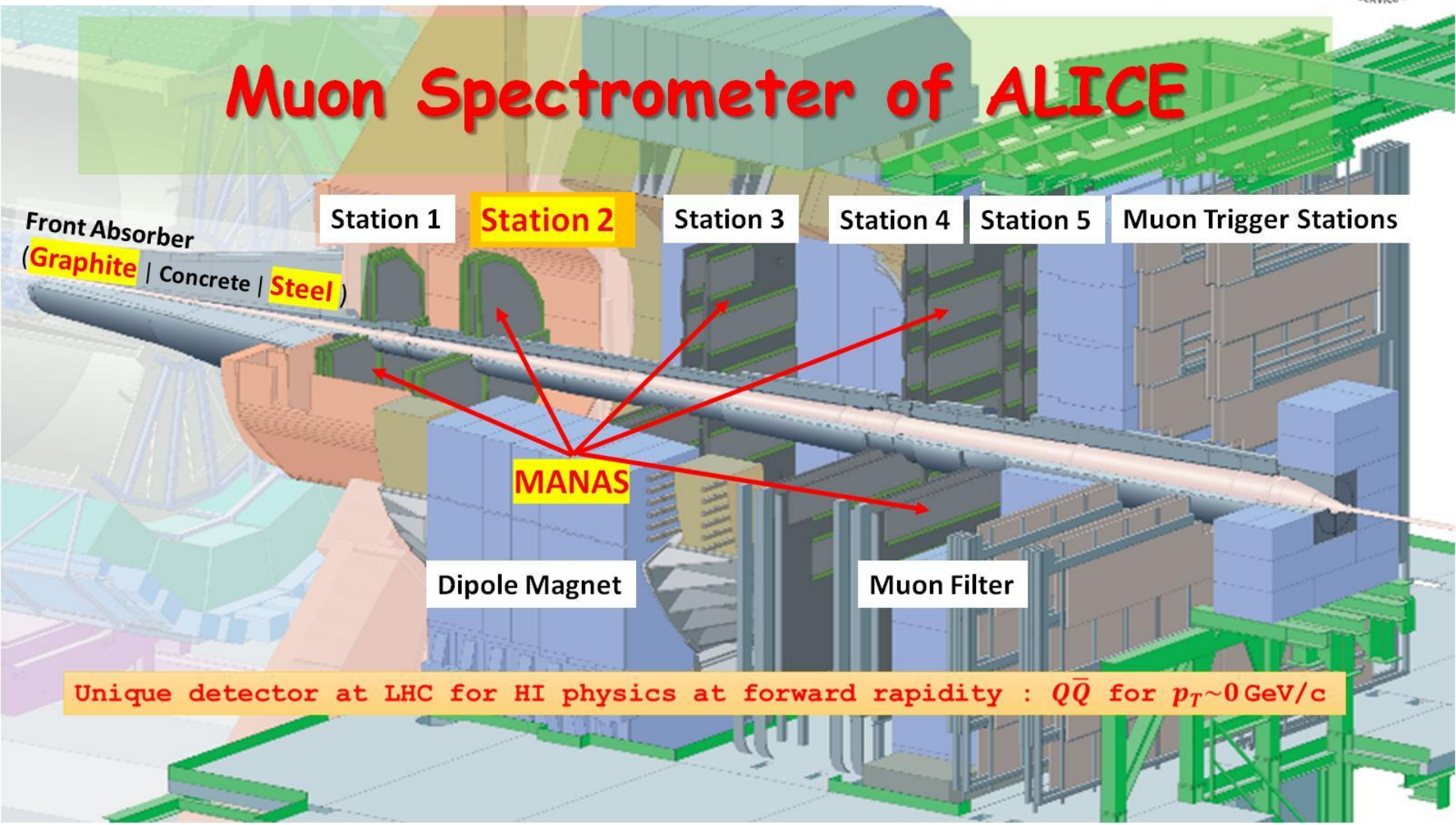
Indian Collaboration to the ALICE Muon Spectrometer

Areas of current participation – ALICE-MS



Courtsey: Sukalyan Chattopadhyay,SINP, KOlkata

Muon Spectrometer of ALICE

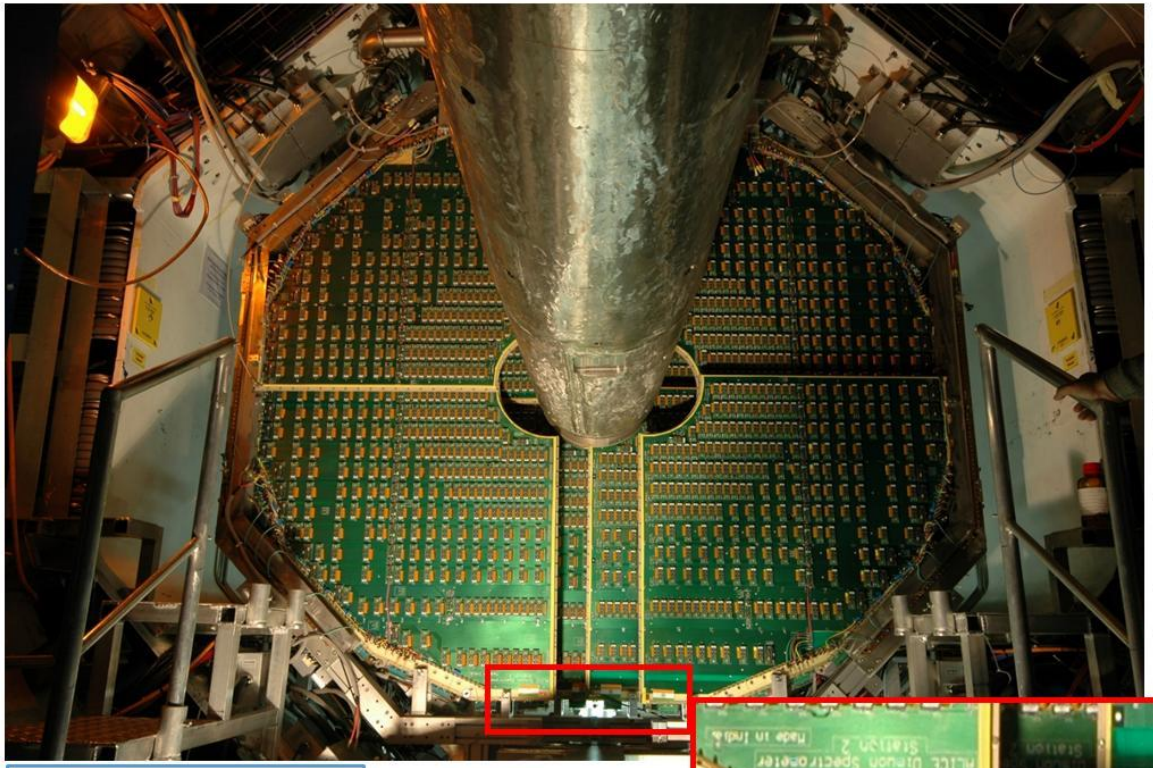


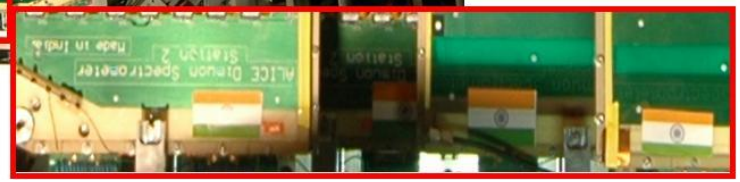
Unique detector at LHC for HI physics at forward rapidity : $Q\bar{Q}$ for $p_T \sim 0$ GeV/c

Courtsey: Sukalyan Chattopadhyay, SINP, KOlkata

Indian Collaboration to the ALICE Muon Spectrometer

Hardware : Detector





1 Crore ₹ (1 Chf = 35 ₹)

Part of Sanjoy Pal's thesis

Kolkata :-

- ✓ R&D of prototype & Design
- ✓ Fabrication of CPC
- ✓ QA validation of 2,25,280 channels
- ✓ Readout PCB testing & integration

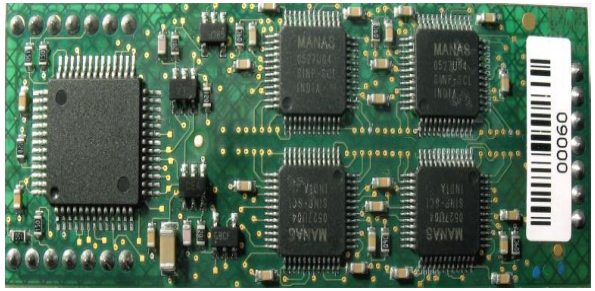
CERN :-

- ✓ HV validation
- ✓ LV setup & readout validation CERN→P2→Cavern
- ✓ LDC configuration of ALICE-DAQ
- ✓ Installation complete 2007

Courtsey: Sukalyan Chattopadhyay, SINP

Hardware : MANAS

1.1 Million readout channels of Muon Tracker]

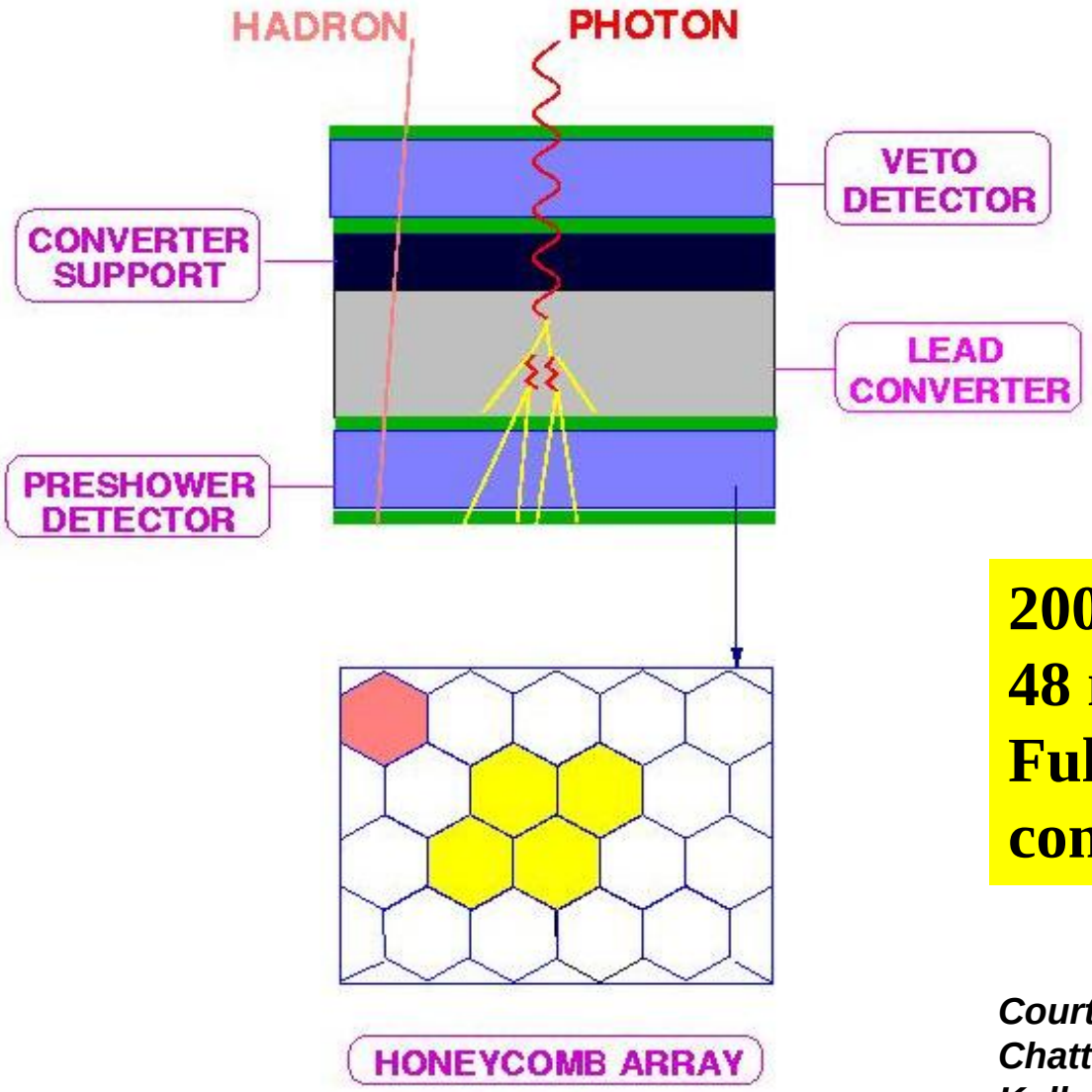


Packaged dimension – 7 mm X 7 mm
Analog-Digital Chip - ~ 6, 000 Transistors
16 channel readout

- ✓ **Designed in SINP→fabricated in SCL**
- ✓ **Validated in SINP test-bench at room and at 50^{o}C (more than 1,350,000 channels)**
- ✓ **88,000 devices delivered to the DiMuon Collaboration by October, 2006.**
- ✓ **20,000 devices delivered to PMD collaboration by December, 2006.**
- ✓ **All devices (1,50,000) have been tested - determination of the operating point (V_{bias} & i_{bias})**
- ✓ **First large scale production of ASIC in India – meets the stringent requirements of a International Collaboration**

Courtsey: Sukalyan Chattopadhyay

Photon Multiplicity Detector (PMD)



200000 cells
48 modules
Fully Indian contribution

Courtsey: Subhasis Chattopadhyay,VECC, Kolkata

ALICE-India collaboration

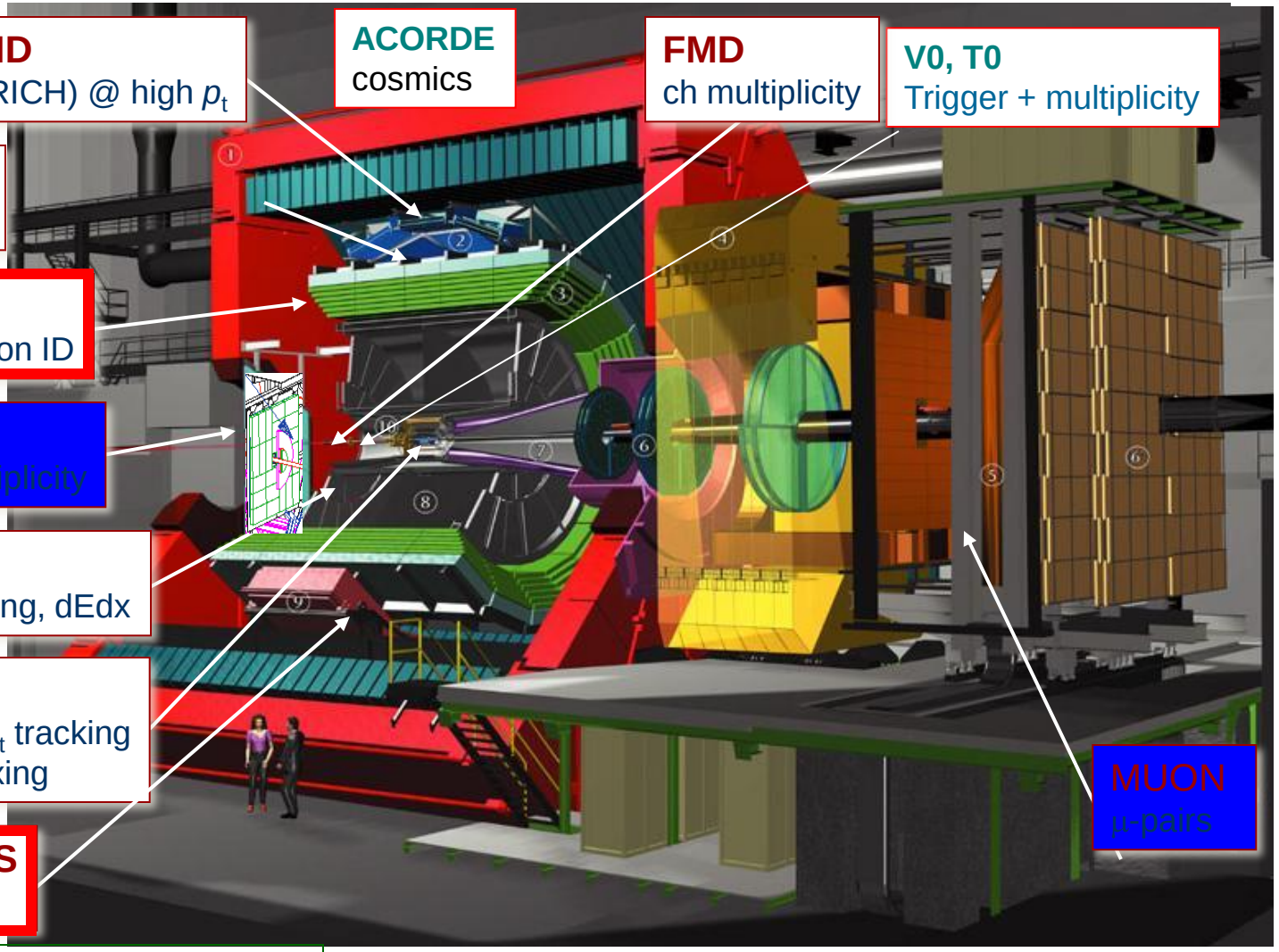
Design, simulation, building and operation of PMD (Entire Indian contribution)

1. VECC-Kolkata
2. IOP-Bhubaneswar
3. NISER-Bhubaneswar (joined later)
4. UR-Jaipur
5. JU-Jammu
6. PU-Chandigarh
7. IIT-Mumbai
8. IIT-Indore (Joined later)
9. GU-Guahati (joined later)

Muon system at ALICE

1. SINP-Kolkata
2. AMU-Aligarh

ALICE at LHC layout (5.7 TeV)



HMPID
PID (RICH) @ high p_t

ACORDE
cosmics

FMD
ch multiplicity

V0, T0
Trigger + multiplicity

TOF
PID

TRD
Electron ID

PMD
γ multiplicity

TPC
Tracking, dEdx

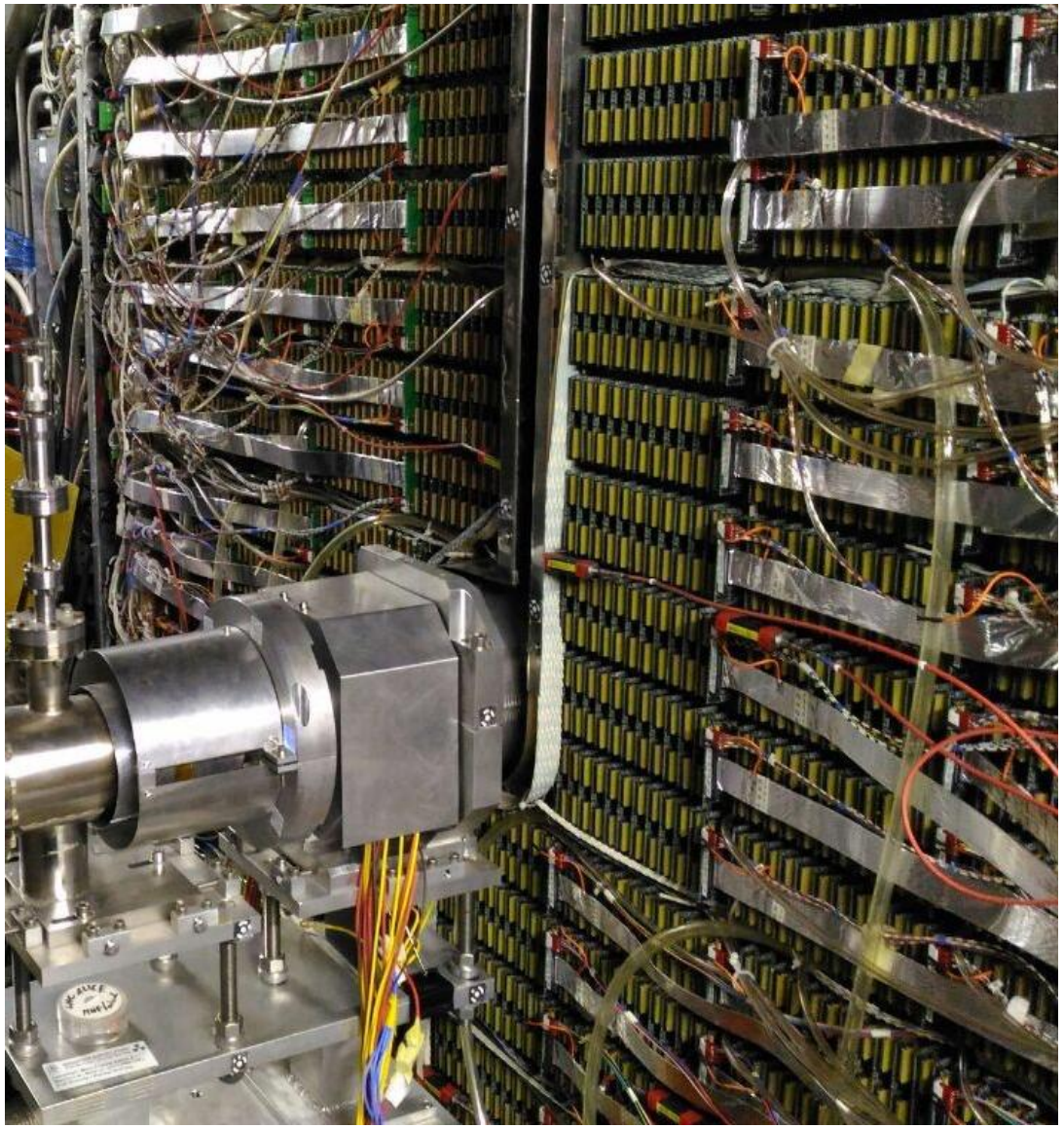
ITS
Low p_t tracking
Vertexing

PHOS
γ, π^0

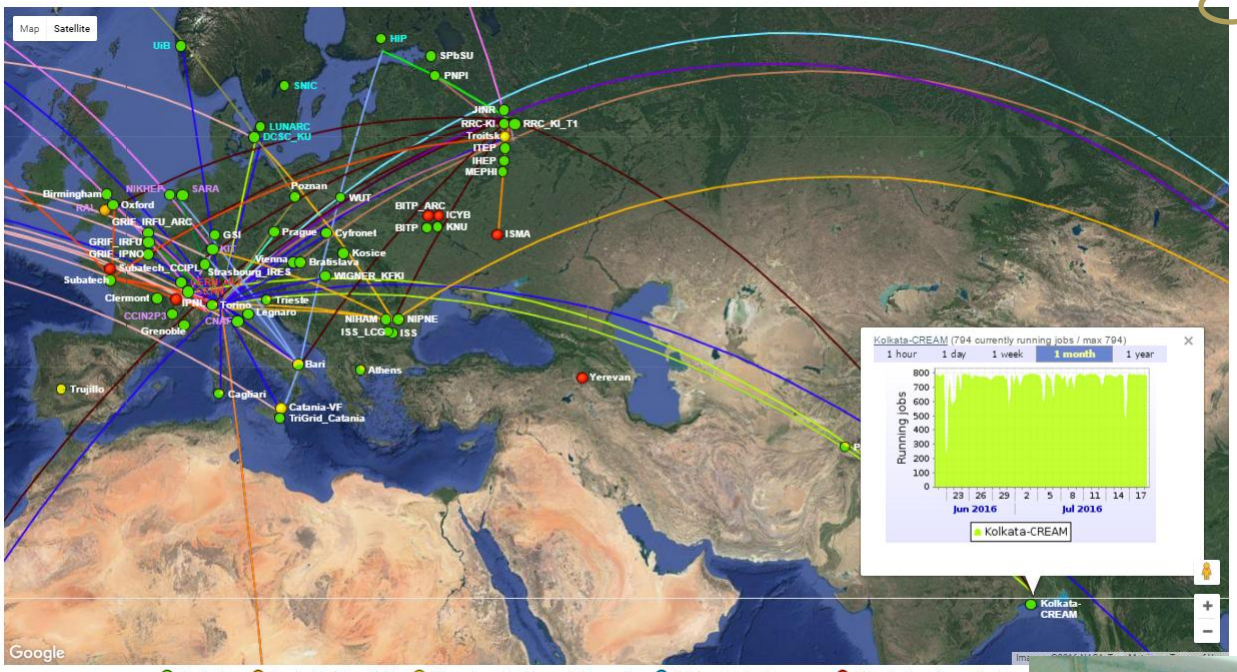
MUON
μ-pairs

EM Calorimeter (future)

PMD in March-April 2017 at shutdown period



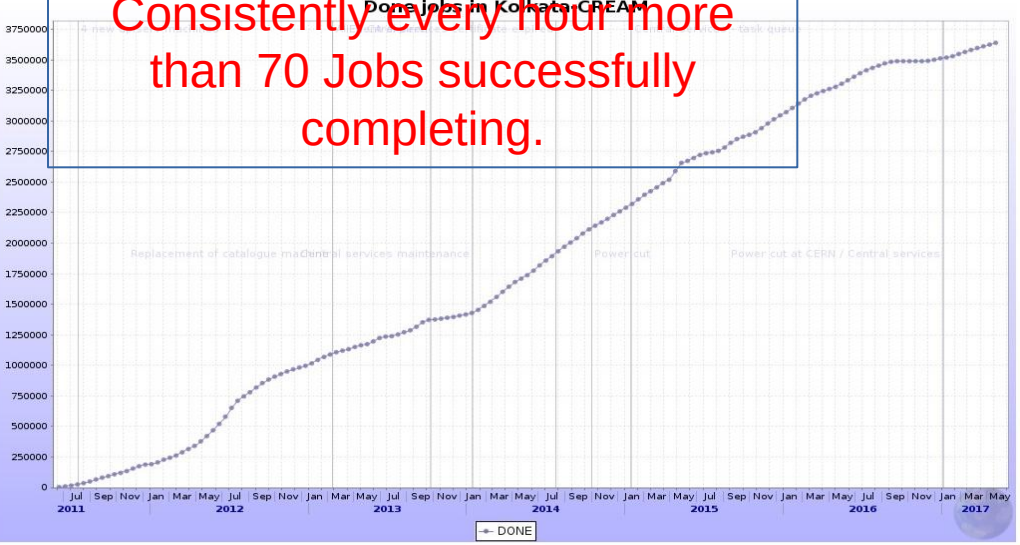
ALICE GRID Computing Facility at VECC, Kolkata



More than 3750000 jobs completed during last Six Years.

Running jobs | Running jobs but no ML info | Site service problem(s) prevents job execution | No jobs match the site resources | ML service down & no running jobs

Consistently every hour more than 70 Jobs successfully completing.



Done jobs in Kolkata-CREAM

LHC Computing

- LHC (Large Hadron Collider) has become operational.
- Data rates per experiment of >100 Mbytes/sec.
- >1 Pbytes/year of storage for raw data per experiment.
- Computationally problem is so large that can not be solved by a single computer centre
- World-wide collaborations and analysis.
  - Desirable to share computing and analysis throughout the world.

Courtsey; B.S. Jagdeesh, BARC, Mumbai

The Journey so far, in-short

- The the Grid Computing activities were convered under a Protocol under which:
  - 50 FTE effort committed and this commitment was successfully honoured in the period from 2003-2007. This effort was accounted for as equivalent of 7.5 Million ChF and contributed in a major way in India getting the 'Observer' status. This was extended on mutual interest basis after 2007.
  - BARC, RRCAT, TIFR, VECC among agencies that participated
  - ELFMS (Lemon /Quattor) and Grid Monitoring (Gridview) projects have been the success stories of BARC
- various contributions in the areas of Grid and Cloud Computing have been done through various Addenda

FTE --- Full Time Equivalent = person year

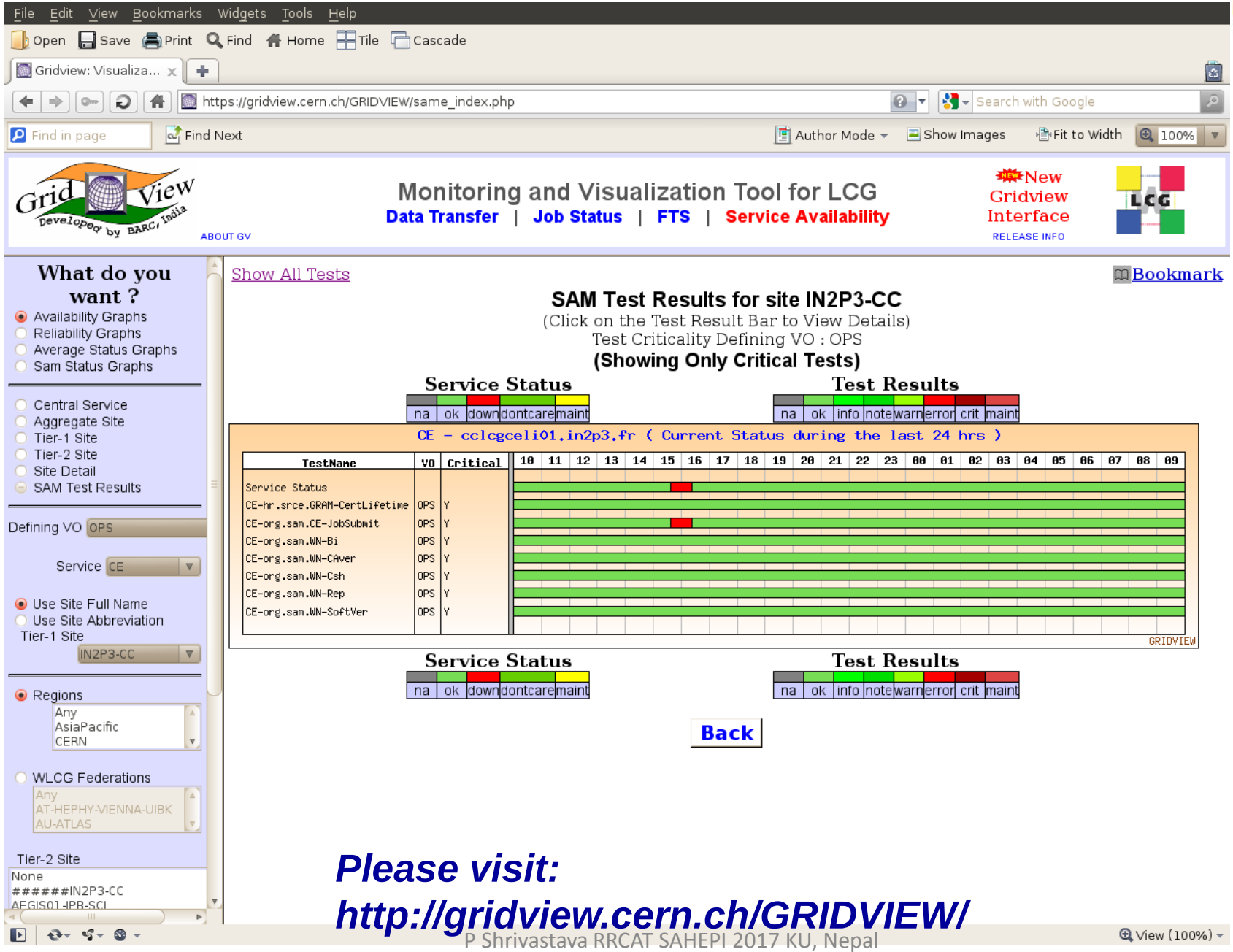
Courtsey; B.S. Jagdeesh, BARC, Mumbai

- MyWLCG, a personalized Grid Monitoring software was developed.

- Cloudman, “a high level resource management tool to provide a central place to configure resource in a computer centre at an abstract level” was completed.

- Cloud Accounting Project
- Distributed Quota Management
- Openstack Quota Management (Contribution to penstack)
- Currently, the work in on in the area of ‘Data Analytics’

Courtsey; B.S. Jagdeesh, BARC, Mumbai



Please visit:

http://gridview.cern.ch/GRIDVIEW/

Courtsey; B.S. Jagdeesh, BARC, Mumbai

India Becomes Associate Member of CERN

- Indian Participation since 1960s.
- RRCAT participation since 1990s.
- Cooperation Agreement in 1991
- LHC, GRID Protocols 1996.
- NAT Protocol 2006
- Construction of the LHC
- CMS, ALICE experiments.
- LHC Computing Grid .
- NAT accelerators SPL, CLIC

His Excellency Mr Amandeep Singh Gill Ambassador & CERN Director General Fabiola Gianotti, exchanging papers for India's Associate Membership with CERN on January 16, 2017

In recognition of substantial contributions, India was granted Observer status to the CERN Council in 2002.

The success of the DAE-CERN partnership regarding the LHC has also led to cooperation on Novel Accelerator Technologies through DAE's participation in CERN's Linac4, SPL and CTF3 projects, and CERN's contribution to DAE's programmes.

http://home.cern/about/updates/2017/01/india-becomes-associate-member-state-cern

Science and Technology Activities at Raja Ramanna Centre for Advanced Technology, Indore

http://www.rrcat.gov.in

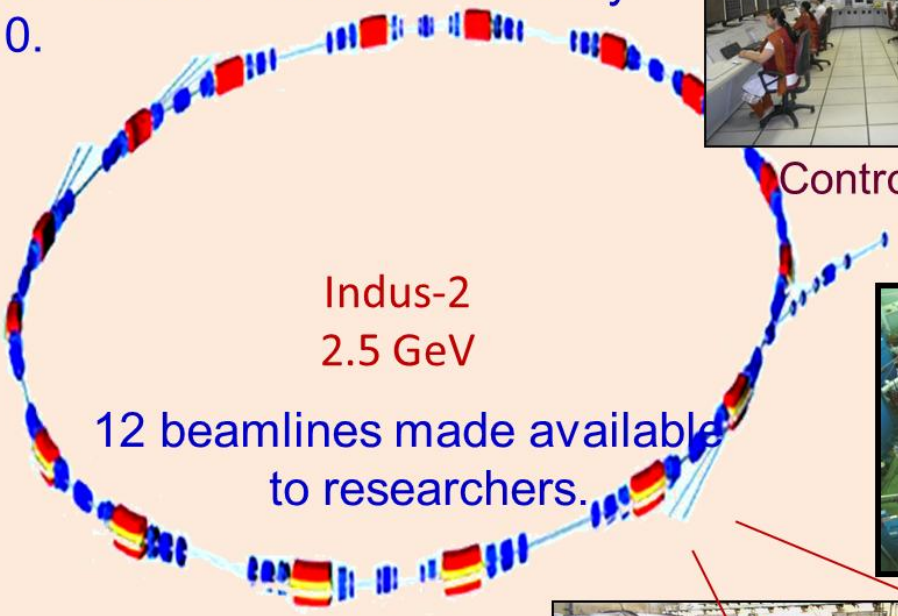
Core Programs of RRCAT

- Synchrotron Radiation Sources (Indus-1 & 2) electron accelerators
- High energy proton accelerator development
- Smaller electron accelerators for societal applications
- Lasers and their applications
- R&D in materials, cryogenics, superconductivity etc.
- Collaborations in international projects
- Applications of Lasers & Accelerators in Medicine, Industry, Agriculture and National programs
- Applications of Synchrotron Radiation Sources
- Outreach Programme

Indus Accelerator Complex

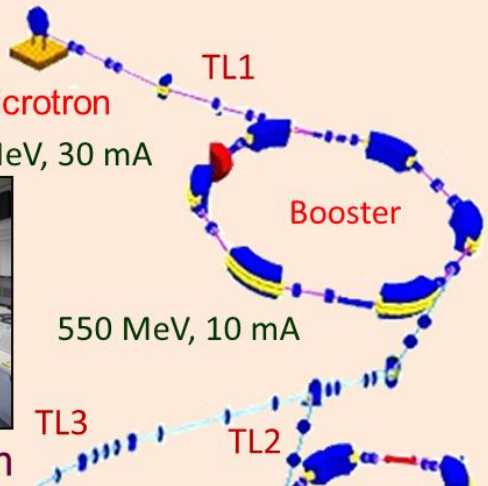
Indus–1 and Indus-2 synchrotron radiation sources are national facilities operating in round-the-clock mode since February 2010.

Control Room



Indus-2
2.5 GeV

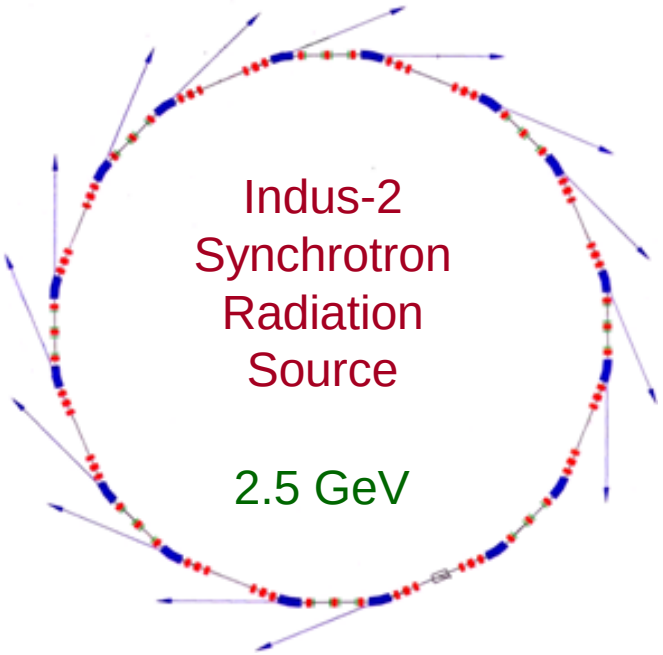
12 beamlines made available to researchers.



A section of Indus-2 tunnel (172.5 m)

Development and Operation of Indus-2 Accelerator

Indus-2 is a conglomeration of several advanced technologies



- Dipole, Quadrupole, Sextupole magnets
- Magnet power supplies
- Injection magnets
- Control System
- RF System
- UHV System
- Beam Diagnostics
- Survey & Alignment
- Radiation Safety
- LCW / Precision temperature control

- About 400 scientists, engineers and technical staff have worked on its development for more than 10 years.
- The machine is operated by staff members (65 Nos.) who have been trained and licensed to operate Indus-2 as per AERB stipulations.

A+ | A | A- Search DAE...

Government of India | Department of Atomic Energy

Raja Ramanna Centre for Advanced Technology

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Indus-2 Beamlines

Apply for a Beamtime New

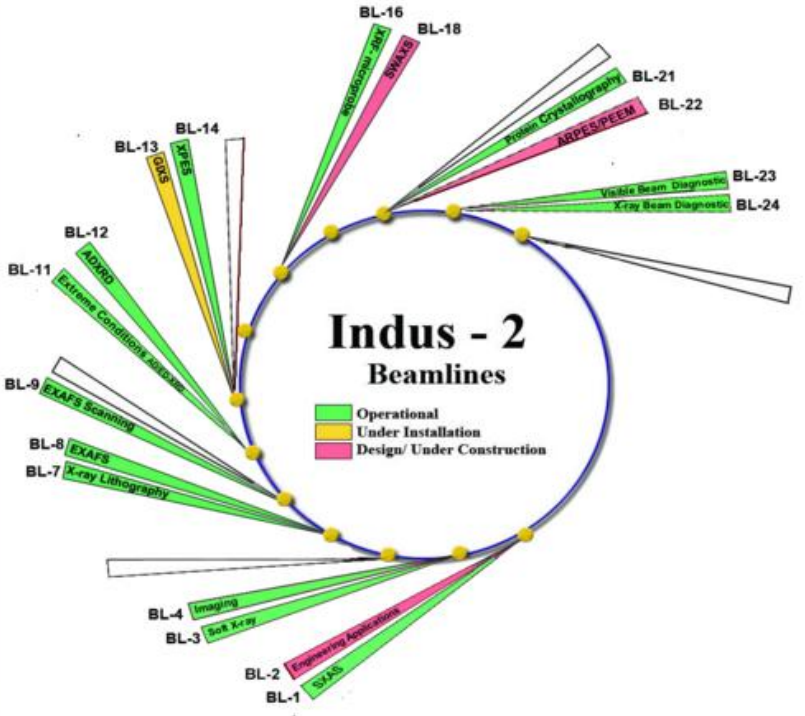
Indus-1 Beamlines

- SXAS (BL-01) (Commissioned)
- Engineering Applications (BL-2) (Design & Construction Phase)
- Soft X-ray reflectivity (BL-3) (Commissioned)
- Imaging (BL-4) (Commissioned)
- X-ray Lithography (BL-7) (Commissioned)
- EXAFS (BL-8) (Commissioned)
- EXAFS Scanning (BL-9) (Commissioned)
- Extreme conditions AD/ED-XRD (BL-11) (Commissioned)
- ADXRD(BL-12) (Commissioned)
- GIXS(BL-13) (Under Installation) (To be commissioned soon)
- XPES (BL-14) (Commissioned)
- XRF- microprobe (BL-16) (Commissioned)
- SWAXS(BL-18) (Design & Construction Phase)
- Protein Crystallography (BL-21) (Commissioned)
- ARPES/PEEM (BL-22) (Design & Construction Phase)

Beamlines for beam diagnostic experiments

- Visible Beam Diagnostic (BL-23) (Commissioned)
- X-ray Beam Diagnostic (BL-24) (Commissioned)

Commissioned | Under Installation | Design & Construction Phase



Last updated: **January 2017**

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For details pl visit http://www.rrcat.gov.in/technology/accel/srul/beamlines/index.html

Conclusion:

- India Contributed towards construction of LHC, commissioning of hardware, test and measurements of SC dipoles magnets, software development. The components were produced in Indian industries.
- The DAE CERN Collaboration has grown for Joint Participation in Novel Accelerator Technology projects like CLIC and SPL through NAT Protocol.
- India has significantly contributed in the construction of detectors. (ALICE, CMS) as well as in LHC GRID development and deplyoment.

Thank You!

http://www.rrcat.gov.in/