Indian Contributions in LHC

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Tata Institute of Fundamental Research

On Behalf of India-LHC community

Workshop on What Next at LHC, Jan 8, 2014

Indian Participation at CERN

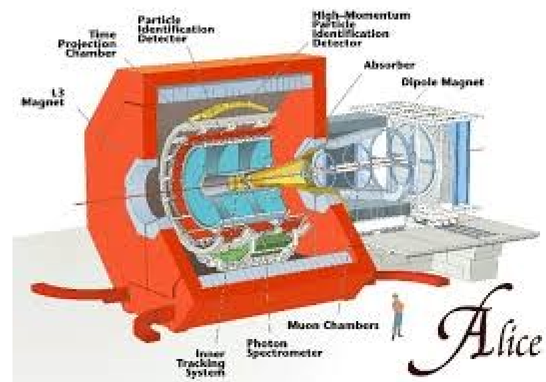
Pre-LHC: Fixed Target, L3, L3-Cosmic Experiments at CERN
D0 Experiment at Fermilab, USA

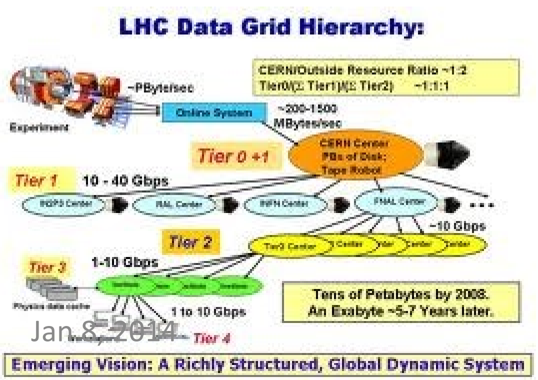
Contribution: Detector, Computing, Physics Analysis

LHC Participations: Since 1995

Accelerator

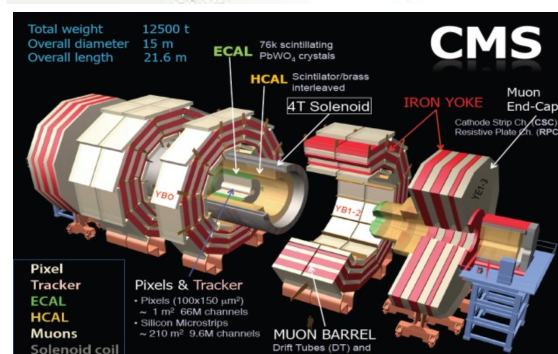
ALICE





GRID

CMS



CERN-DAE Cooperation Agreement signed in 1991

CO-OPERATION AGREEMENT

between

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

and

THE DEPARTMENT OF ATOMIC ENERGY (DAE)

OF THE GOVERNMENT OF INDIA

concerning

THE FURTHER DEVELOPMENT OF SCIENTIFIC AND TECHNICAL CO-OPERATION IN THE RESEARCH PROJECTS OF CERN

Article 10
Duration

This Agreement shall be in force for a period of five years from the date of its signature and will be automatically renewed for the same period unless six months' notice of termination is given by either party to the other.

Done at Geneva on 28 March 1991
in two copies in the English language.

For the Department of Atomic Energy of the Government of India (DAE)

P.K. Iyengar
Chairman, Atomic Energy Commission

For the European Organization for Nuclear Research (CERN)

C. Rubbia
Director-General

4/13/08 APS Meeting, St. Louis

India accorded *observer state* in 2002

Indian Participation at CERN

Accelerator

ALICE

CMS

WLCG

Inputs for this presentation

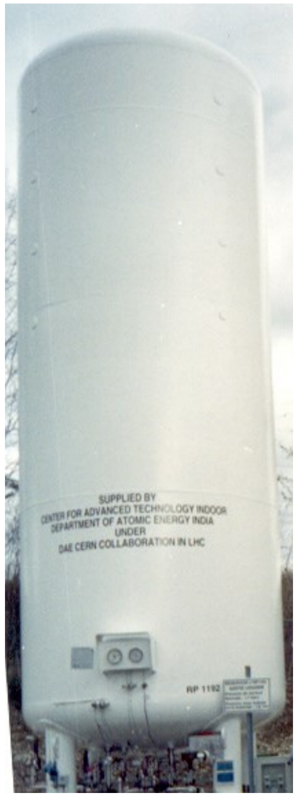
Contributions to LHC	P. Shrivastava
ALICE Experiment	T. Nayak S. Chattopadhyay
India-CMS Grid	K. Majumdar
CMS RPC	L. Pant
CMS Pre-shower	A. Topkar
CMS HF Backend	Debarati Roy

Contributions towards construction, installation and commissioning of LHC at CERN

Indian Contributions towards construction, of LHC accelerator

Towards Construction of LHC	Quantity
50000 litres Liquid Nitrogen tanks.	2
Superconducting corrector magnets :	
Sextupole (MCS)	1146
Decapole and Octupole (MCDO)	616
Precision Magnet Positioning System (PMPS) Jacks	7080
Quench Heater Power Supplies QHPS	5500
Integration of QHPS units into racks	6200
Control electronics for circuit breakers of energy extraction system	70
Local protection units (LPU)	1435

Liquid Nitrogen Tanks



2 Liquid Nitrogen Tanks of 50K litre

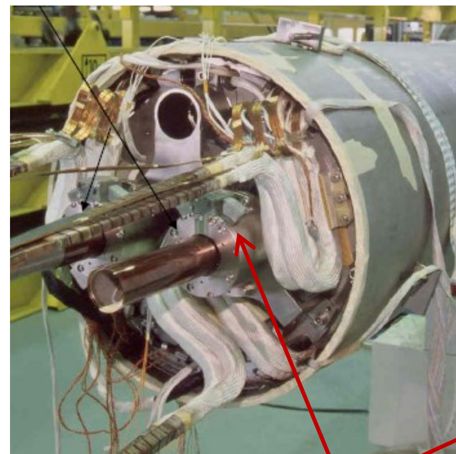
Designed and Fabricated in India in 1998

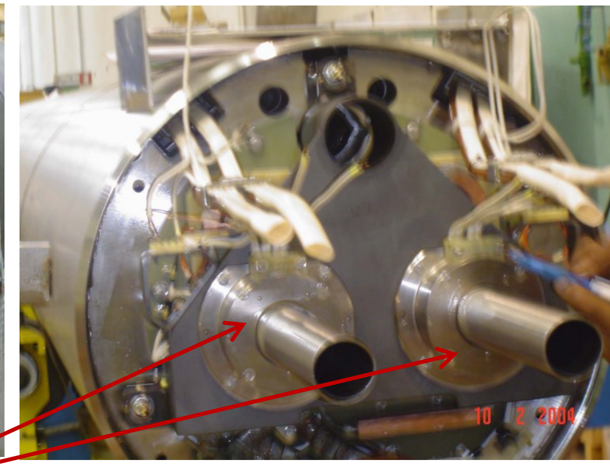
First Indian Contribution to LHC

Superconducting Corrector Magnets for LHC

Superconducting corrector magnets for the SC dipole magnets of LHC for correcting the systematic field errors main dipole, a crucial component installed in each dipole magnet of LHC.

Series production for LHC





Corrector magnets installed in LHC dipole magnet

	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

Quench Heater Power Supplies and Local Protection Units

For the protection of the 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

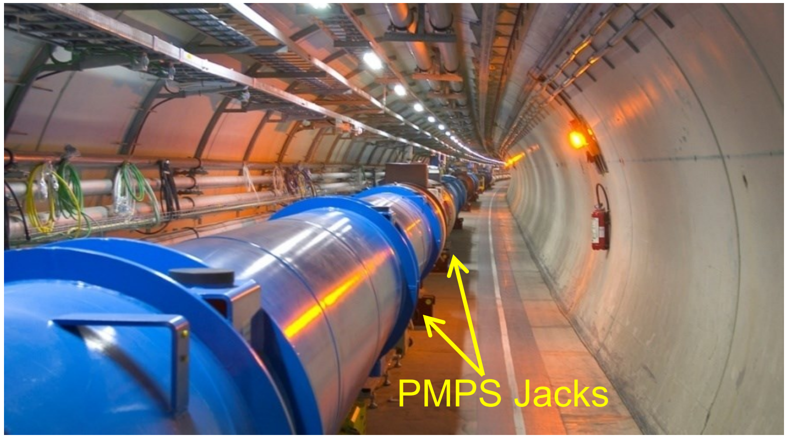
Breaker Control Electronics

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.

Precision Motion Positioning System Jacks

Superconducting dipole magnets of LHC are supported by the Indian Precision Motion Positioning System (PMPS) Jacks made by DAE with the help of Indian Industries.



LHC Superconducting dipole magnets resting 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

Quality control 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.

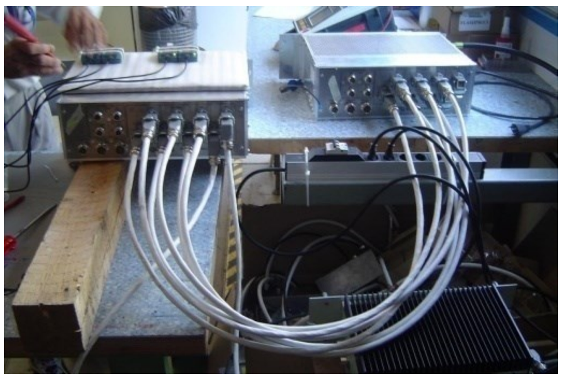
Test place for the SC dipole magnets

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

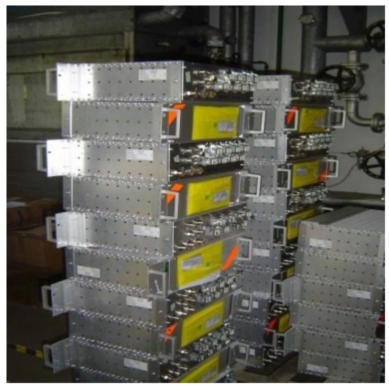
- The 15m long, 30 Ton heavy superconducting dipole magnet operates at a field of 8.3 Tesla
- Total ~1900 magnets were tested DAE engineers equivalent to 100 man years contribution.
- Testing & Qualification and training of each superconducting dipole magnets for 1) Cryo, mechanical & electrical insulation,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

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.

Indian Contributions towards installation and commissioning of LHC accelerator

I&C Activities	FTE Years
SC Dipole magnet measurements, expert support	100
Expert support for Commissioning LHC Hardware, like, Cryogenics, Controls, Power converters, Protection systems	20
Data management/analysis software upgrade and projects Development of JMT-II software Software dev -slow control of Industrial Systems of LHC Design calculations for Vacuum system for beam dump line Analysis of cryo-line jumper and magnet connections	41

Indian-CERN Accelerator Collaboration beyond LHC

- CERN's Novel Accelerator Projects :

  - Compact Linear Collider (CLIC)Test Facility

    CERN is setting 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. This novel concept will reduce the size and cost of a linear collider significantly.

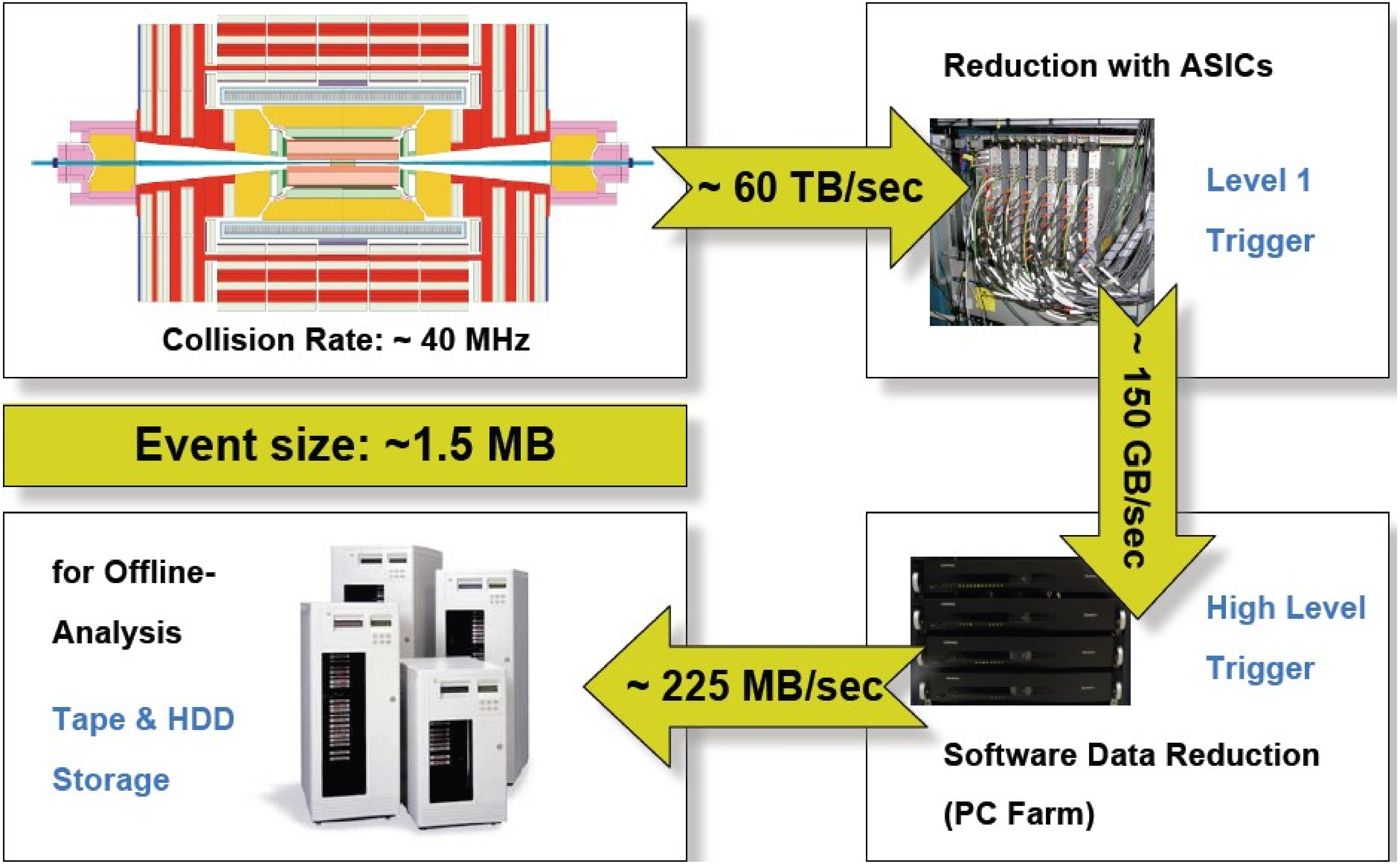
  - Linac-4, the front end of Superconducting Proton Linac

    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.

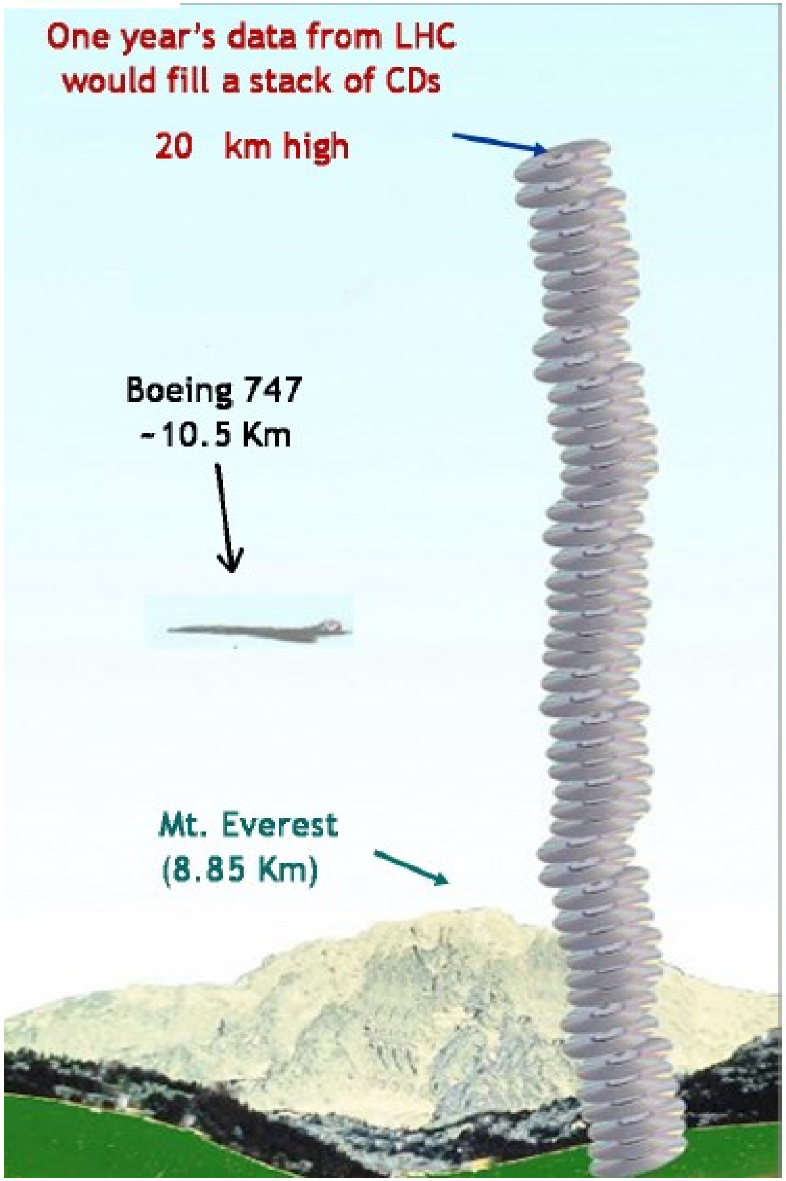
Participation in the above programs is highly beneficial to Indian accelerator projects.

Tier-2 Grid for ALICE and CMS

Data rates @ CMS as foreseen for design parameters



Today's data collection rate ~ 850 Hz



In hard numbers

LHC collides 6-8 hundred million proton-on-proton per second for several years.

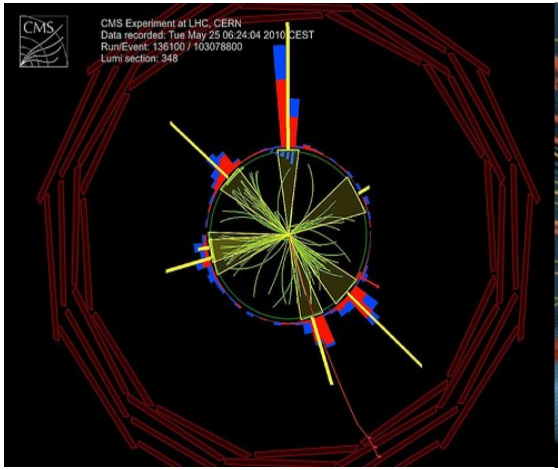
Only 1 in ~20 thousand collisions will have an important tale to tell, *but we do not know which one!*
→ so we have to search through all of them!
→ Huge task!

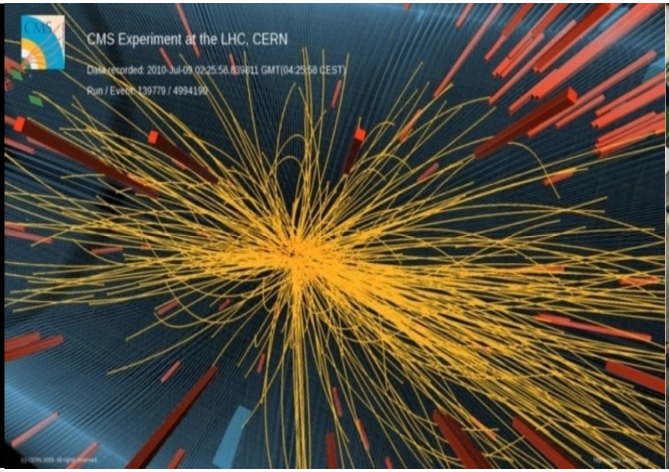
- 15 PBytes (10^{15} bytes) of data a year
- Analysis requires ~100,000 computers to get results in reasonable time.

GRID computing is essential

The GRID Computing Goal

• Science with broader global computing model
• Provide **Resources** and **Services** to store/serve O(10) PB data/year
• Provide convenient **access** to distributed computing resources for data analysis and visulaisation to all O(4000) collaborators





•Minimize constraints due to user localisation and resource variety
• Decentralize control and costs of computing infrastructure
➔ **Solution through LHC Computing GRID**
➔**Much faster delivery of physics**

To begin at the end:

Internal speed of computers have become comparable
to the speed of large distance network.

- The operations of the LHC machine and the experiments have been a great success.
- Fantastic output, often only days after the data is taken

➔ about 200 scientific publications per experiment in 3 years.

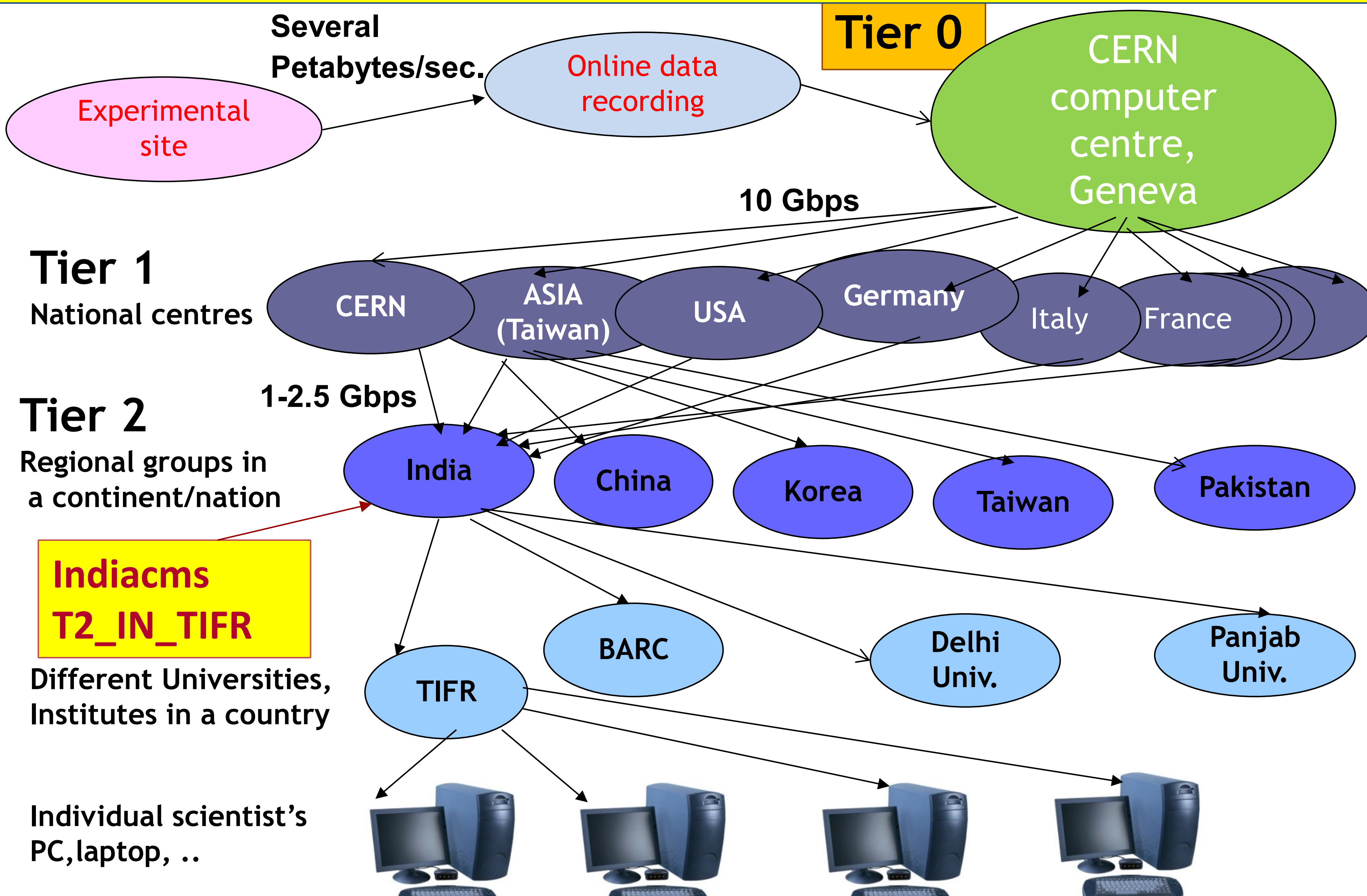
- Today >140 sites
- ~250k CPU cores
- ~100 PB disk

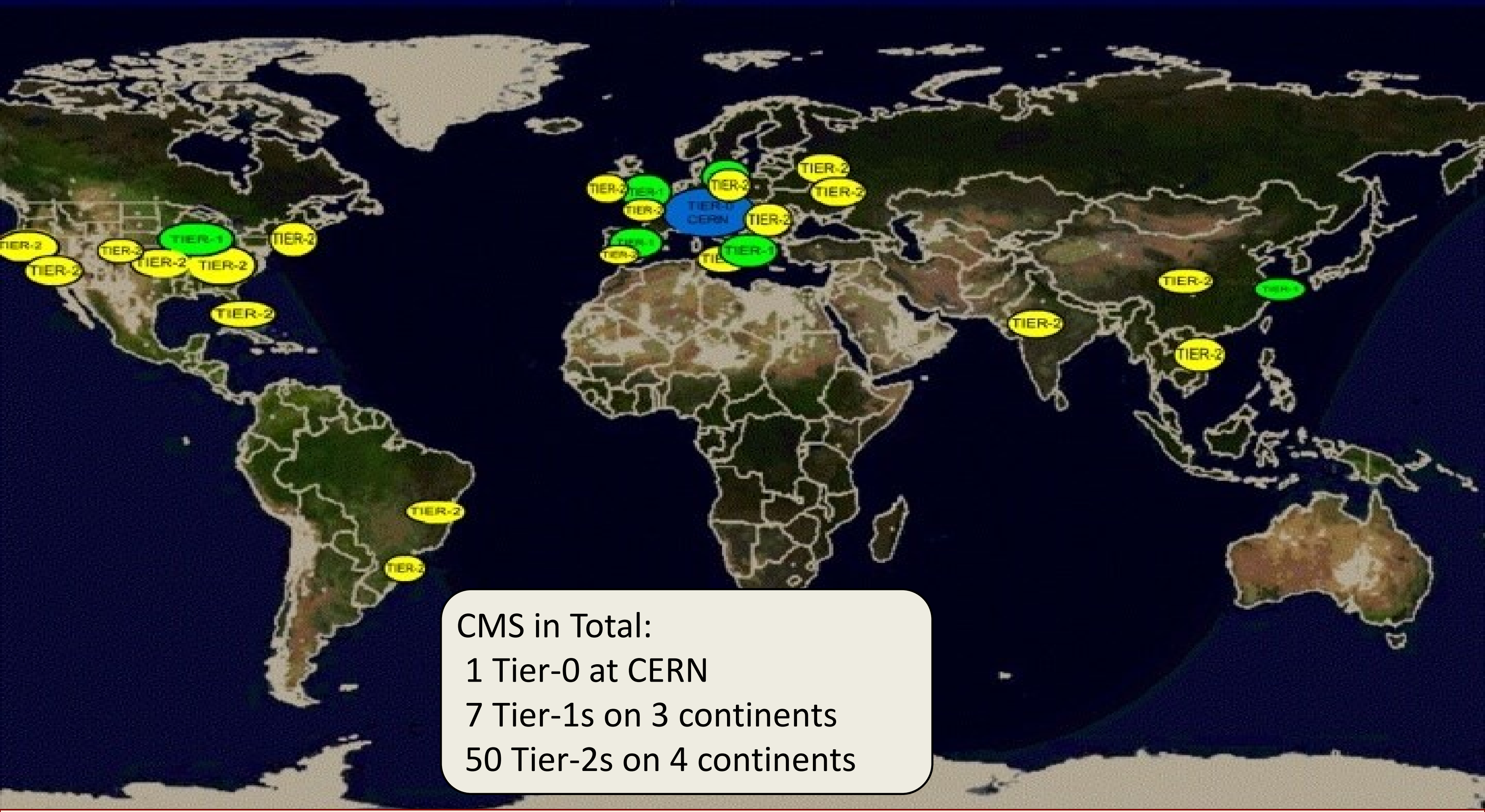
Amount of data written by LHC experiments during last 6 months: 19 Petabyte.
Expected volume of data by end of 1st phase of LHC operation: 30 PB.

Total transfer rate across globe: ~ 10 Gbps

LHC Computing Grid is the backbone of the success story

Layered Structure of CMS GRID → connecting computers across globe





CMS in Total:
1 Tier-0 at CERN
7 Tier-1s on 3 continents
50 Tier-2s on 4 continents

CMS T2 in India : one of the 5 in Asia-Pacific region

Today : 7 collaborating institutes in CMS: ~ 30 scientists + 40 students
2.1% of signing authors in publication,
Contributing to computing resource of CMS ~ 3%

Quick description of LHC grid tiers

Distributed Analysis is not a wish, it is a necessity

→ tools have to be reliable!

- First job of the offline system is to process and monitor data at T0.
- T0: 1 M jobs/day + test-jobs. traffic : 4Gbps input, > 13 Gbps served
- **CERN Tier 0 moves ~ 1 PB data per day, automated subscription**

- T1 processes data further several times a year, coordinates with T2s

- **T2s are the real workhorses of the system with growing roles**
  - → Hosts specific data streams for analysis
  - → Gets main data from T1s, recently more communications among T2s
  - → Typically 100k analysis jobs/day/experiment
  - → Site readiness is at high level
  - → 24X7 availability → lot of invisible effort!

Storage in T2 partitioned into central and local space.

T2-IN-TIFR, Mumbai

Resources
- CPU : 3000 (7000)
- Disk : 700 TB (950 TB)
- Nework (WAN) : 1.5 - 2 Gbit/s

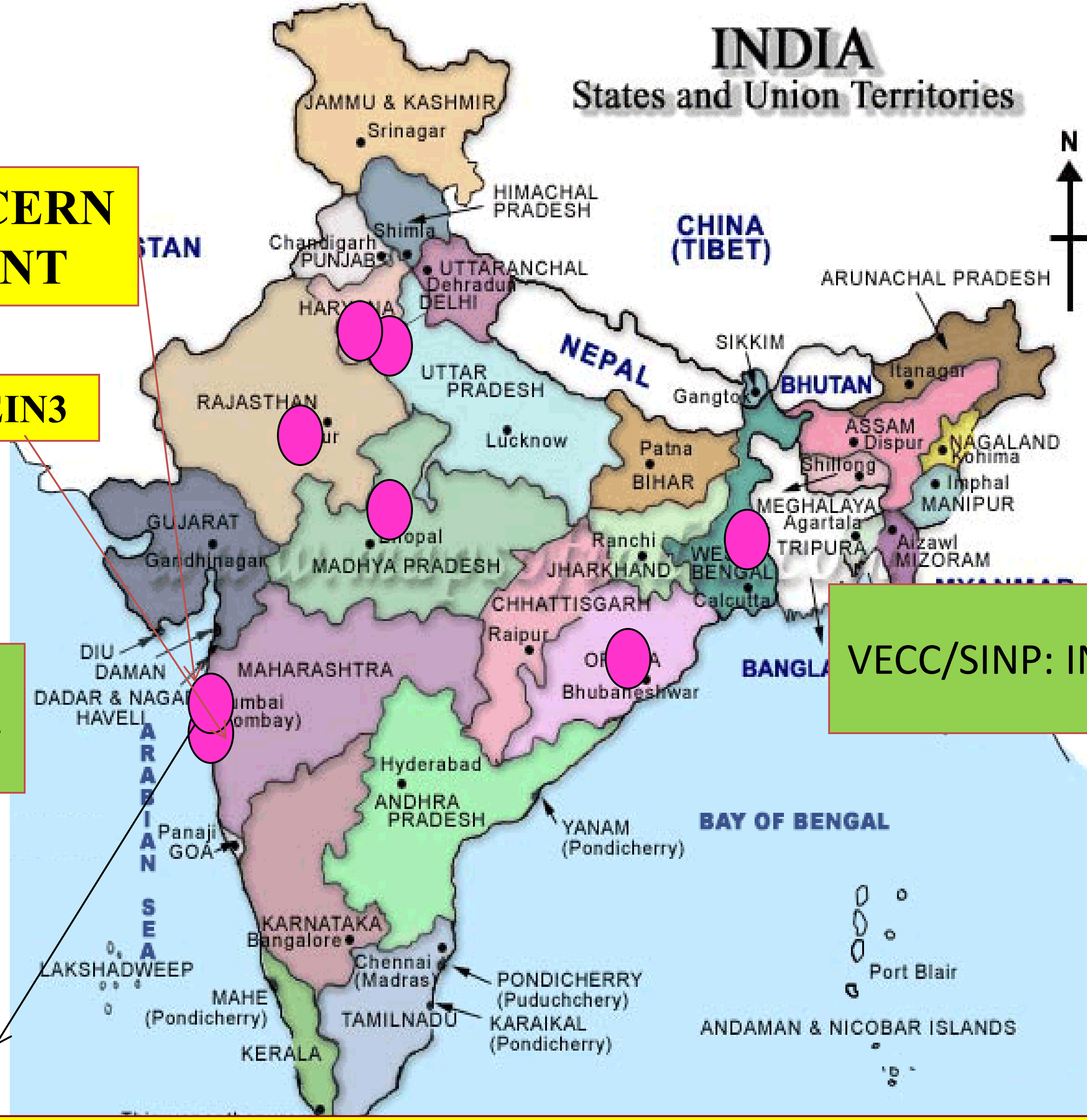
• Contributing to the computing efforts of CMS experiment → credits earned against mandatory service jobs.

End-user does not have to bother about the resources

Middleware:
- Storage Elements
- Computing Elements
- Workload Management
- Local File Catalogue
- Information System
- Virtual Organisation management
- Inter-operability among different GRIDs

A large amount of invisible human effort is essential

Network connections



1.5/2 Gbps to CERN peered to GEANT

2.5 Gbps NKN +TEIN3

TIFR-INDIACMS T2

VECC/SINP: INDIA

1 Gbps to VECC RRCAT, IPR

Sincere thanks to ERNET, EU-India grid and NKN for the support towards our effort in putng India in CMS-Grid map.

Site Description

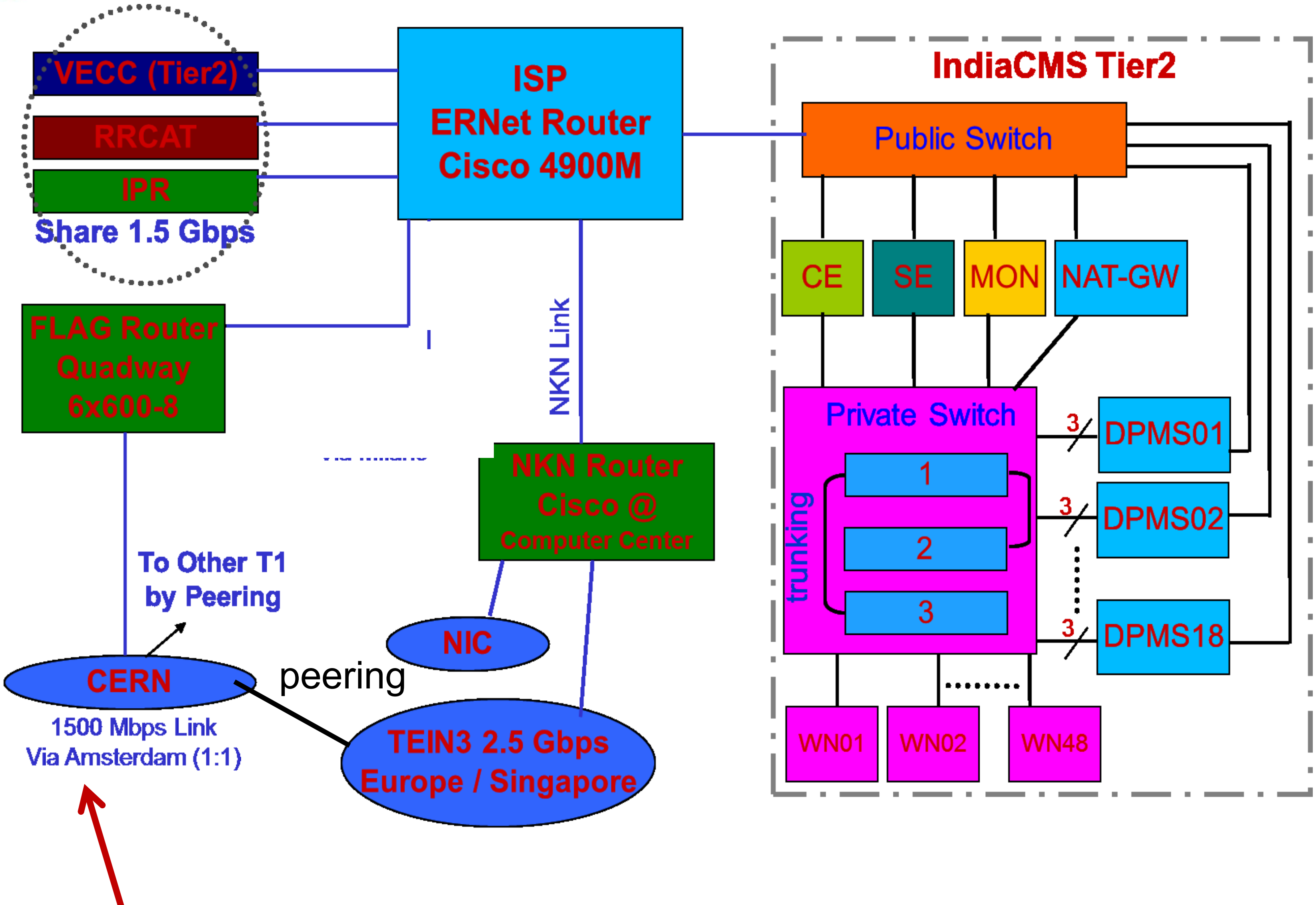
- 6 collaborating institutes at present, more in near future.
- BARC, Delhi Uni., Panjab Uni., TIFR (EHEP & HECR), VisvaBharati Uni.

➔About 50 physicists

3.5 FTE to manage the site till now, reducing gradually.

User Access to T2-IN-TIFR

- High end server as User Interface with the latest glite, root, CMS software versions (concurrent versions)
- GRID computing analysis facility using CMS-specific package CRAB
- Directly connected to T2 LAN
- Fast access to storage using RFIO
- 50 TB local disk space to users with individual directories
- AFS client, dedicated job slots (PBS) facilities
- Latest OS security patches
- ……………



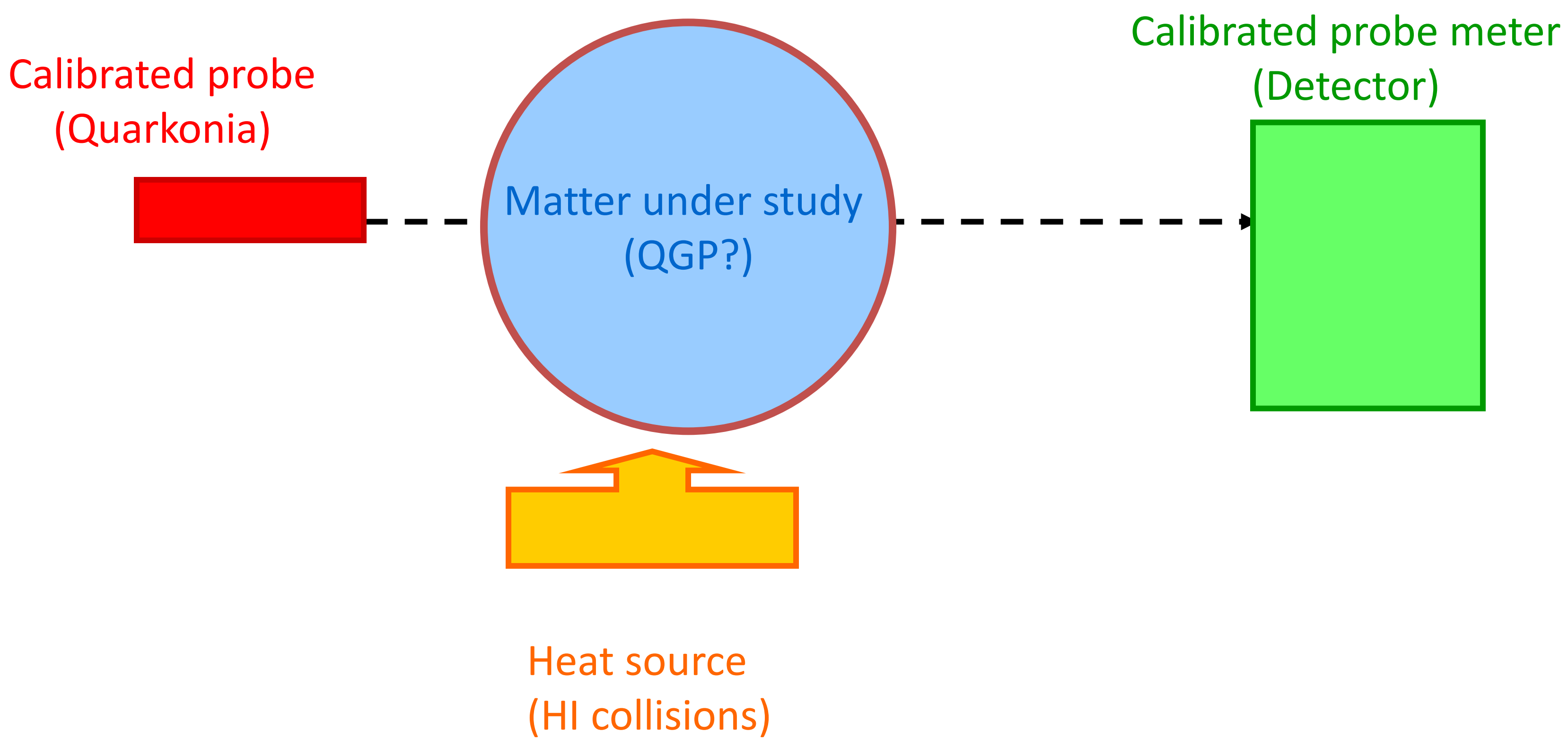
Upgraded to 2Gbps + 10 Gbps on "best effort"

India-ALICE Collaboration

Probing the Matter

How can we observe the properties of the created matter?

We will study how the matter produced in heavy ion collisions affects well understood probes as a function of the temperature of the system



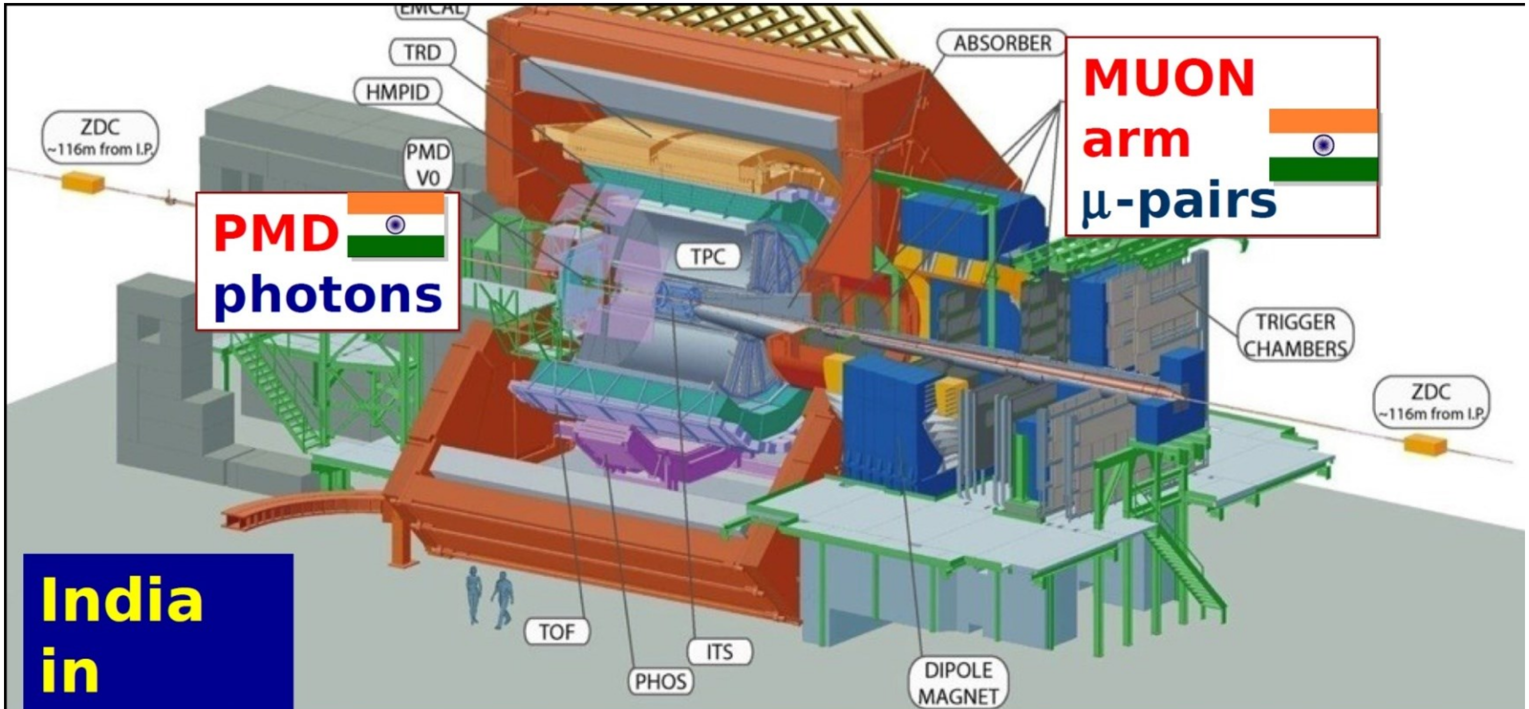
Indian members in ALICE

~100 Members

- Kolkata: VECC
- Kolkata: SINP
- Kolkata: Bose Institute
- Aligarh: Aligarh Muslim University
- Bhubaneswar: Institute of Physics
- Bhubaneswar: NISER
- Chandigarh: Panjab University
- Guwahati: University of Guwahati
- Indore: IIT
- Jaipur: Rajasthan University
- Jammu: University of Jammu
- Mumbai: Indian Institute of Technology, Bombay
- Mumbai: BARC

Involvement of Indian Scientists since the beginning of ALICE

tifr



India in ALICE

re of the technology:

⇨ Front-end electronics VLSI full-custom design and manufacturing: the **MANAS** chip (for PMD and MS)

⇨ high tech **PMD**:

- 100% Indian Project

⇨ **Muon Spectrometer**:

⇨ worldwide collaboration, with India as major player

-> Station 2 construction

● at the core of the Physics:

⇨ PMD:

- on the track of multiplicity & flow
- chase surprises (DCC)

⇨ Muon Spectrometer:

- Quarkonia puzzle

=> ALICE Upgrade Programs

4

Photon Multiplicity Detector (PMD)

An example of large-scale instrumentation

Goal: Measurement of photon multiplicity and its spatial distribution in the forward region on an event-by-event basis

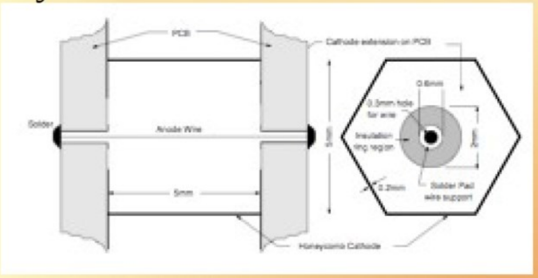
'MD in WA93, WA98, STAR and ALICE: Indigenous - from conception to commissionir

PMD Probes:

- Rapidity & Multiplicity distributions of photons
- Determination of reaction plane and probes of thermalization via study of azimuthal anisotropy
- Phase Transition: Multiplicity Fluctuations
- Signal of chiral symmetry restoration (DCC) through the measurement of charged particle and photon multiplicities in a common phase space

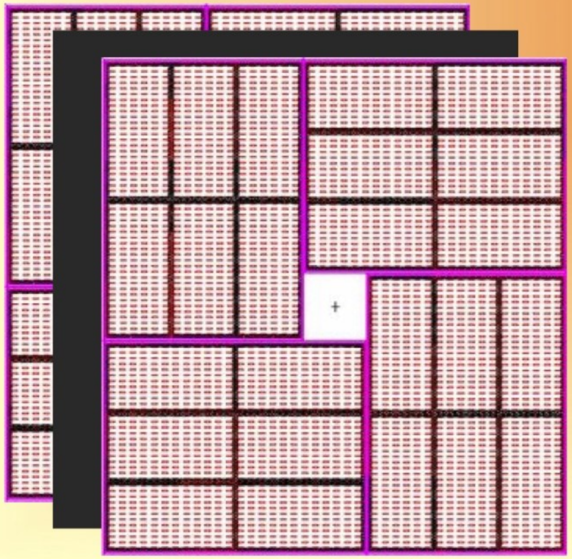
PMD in ALICE

Honeycomb cell:



PMD Modules:

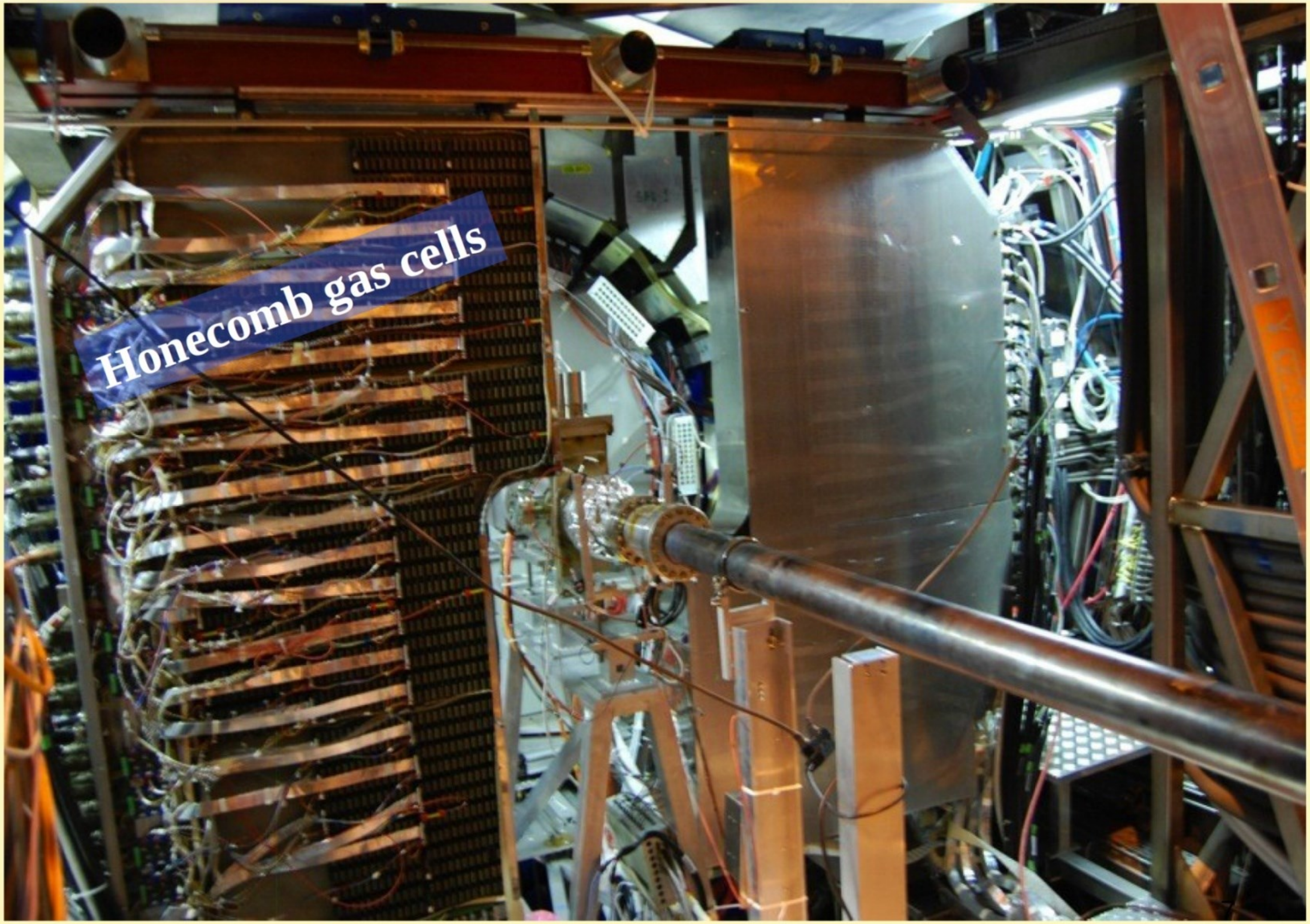
Module arrangement in ALICE:



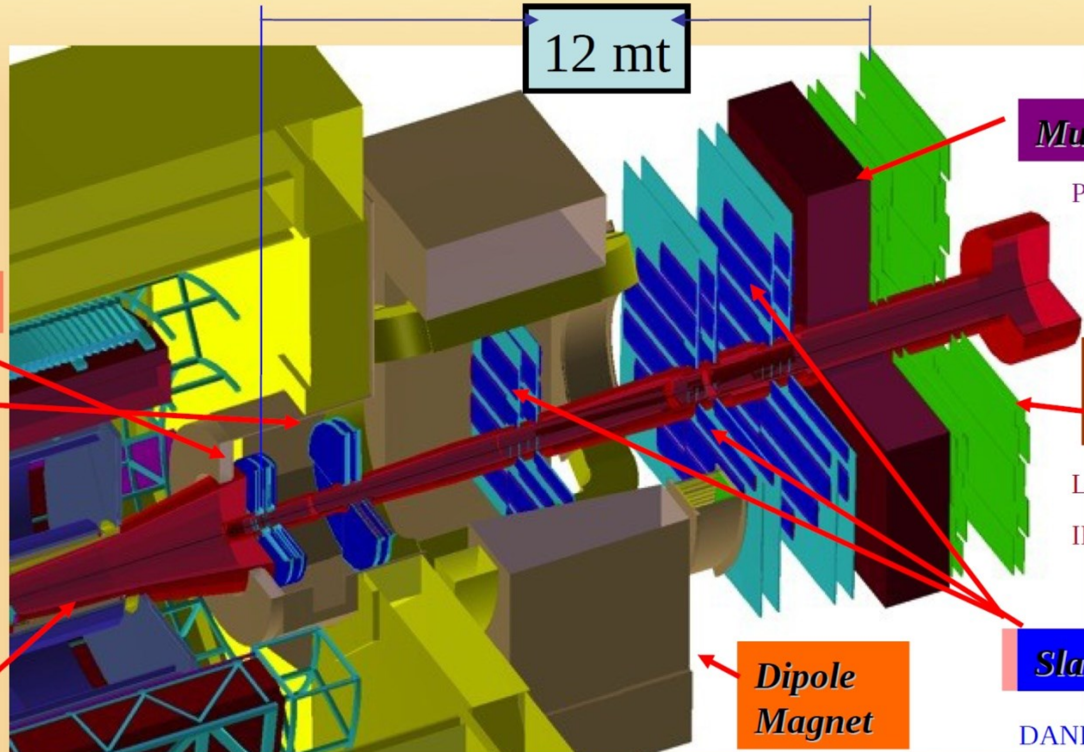
- Total no of honeycomb cells = 221184
- Cell depth = 0.5 cm
- Cell Cross section = 0.23 cm^2

- 1 module = 4608 cells read
- 1 module read by 72 FEE boards
- 1 FEE board = 64 cells (4 MANAS Chips).
- Each MANAS reads 16 channels
- Sensitive medium : Gas ($Ar+CO_2$ in the ratio 70:30)
- Total no of Modules = 48

PMD in the ALICE cavern



Muon Spectrometer in ALICE



Muon Absorber

PNPI Gatchina, Russia

Quadrants type

IPN Orsay, France

India

Trigger detectors

LPC Clermont, France

INFN Torino, Italy

Dipole Magnet

CERN

JINR, Russia

Slats type

DANIA Sacley, France

PNPI Gatchine, Russia

IPN Lyon, France

SUBATECH Nante, France

INFN Cagliari, Italy

Front Absorber

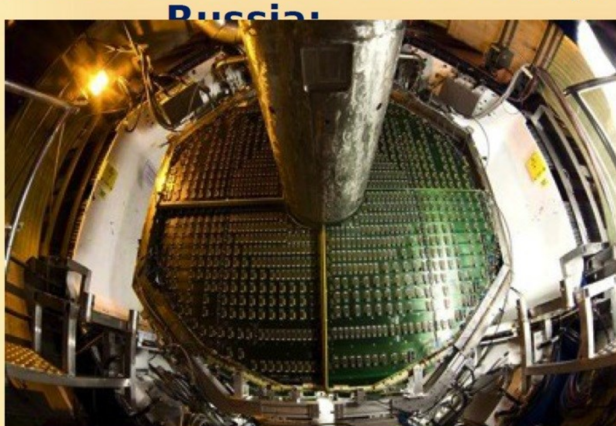
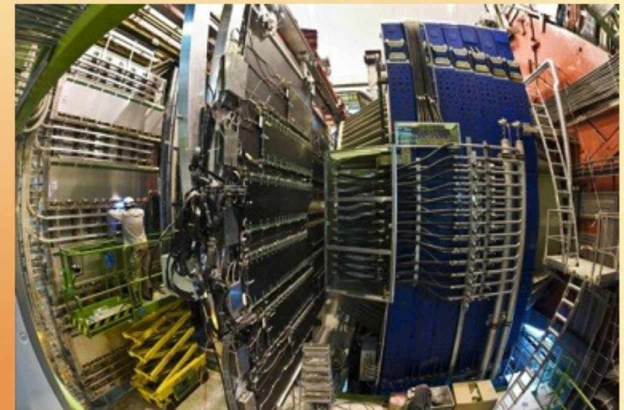
CERN + Collaborators

India

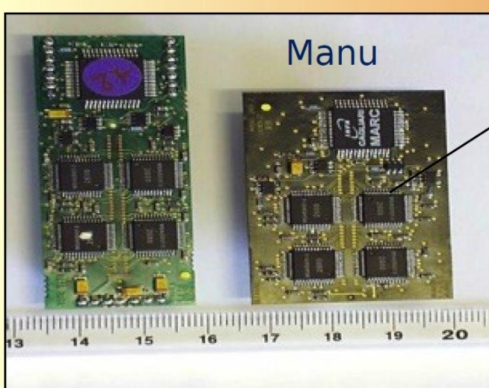
MUON tracking detectors:
- 5 stations
  - 2 quadrant type
  - 3 slat type
- 10 chambers (2 chambers / station)
- **1.1 Million Channel readout (SINP-AMU)**

Muon Spectrometer

Collaboration France, India, Italy, Russia:

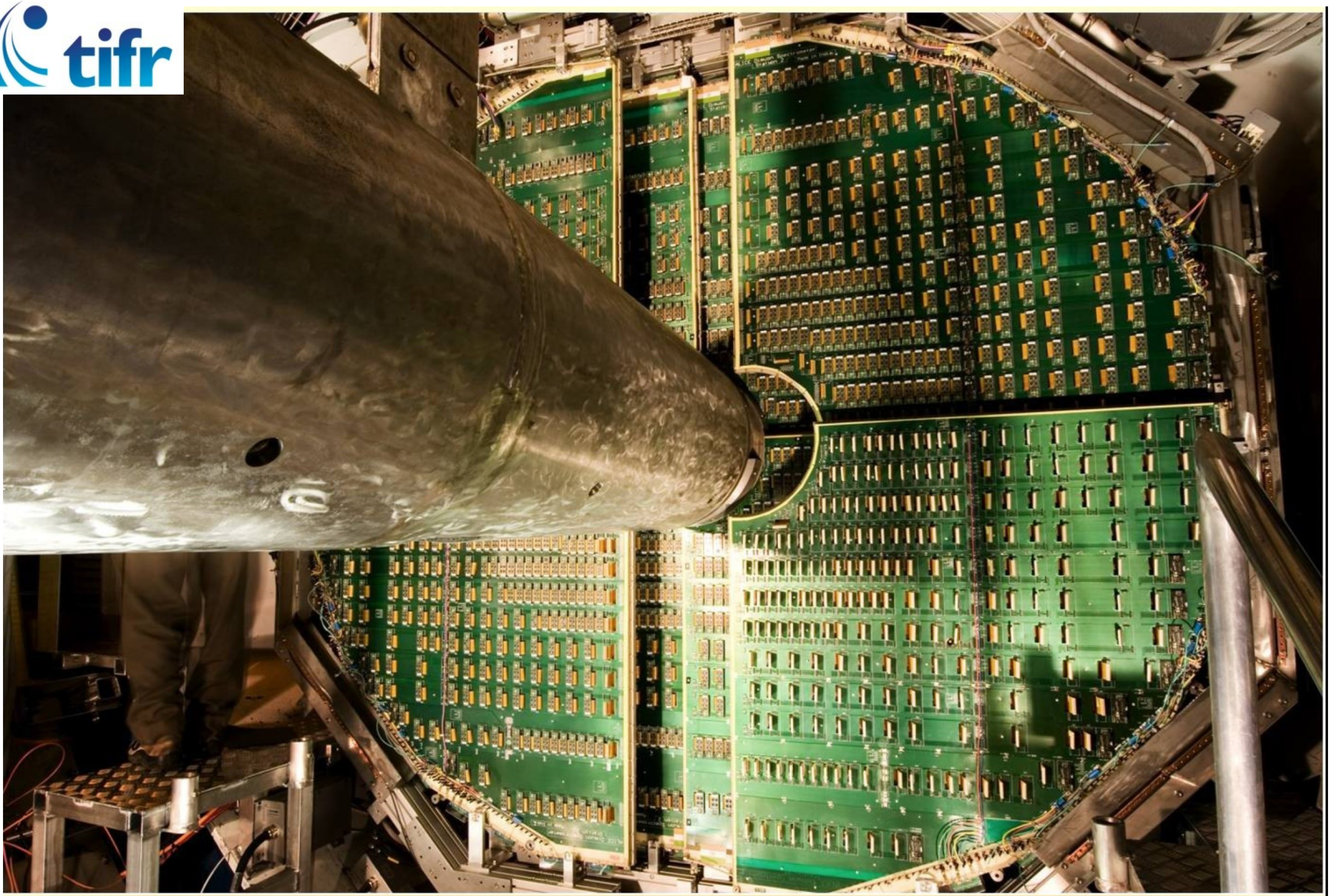



2nd Tracking station indigenously built in India



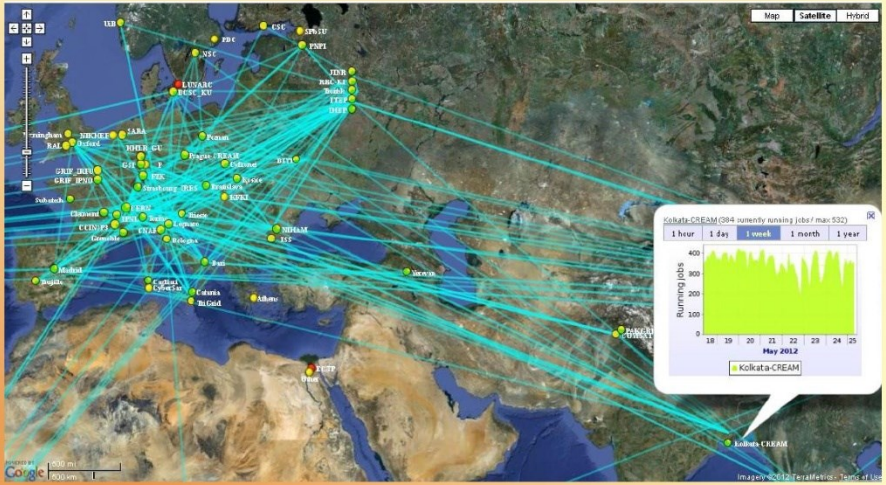
MANAS chip:
16-channel Amplifier, shaper, track-and-hold

Reads 1.1 million pads of tracking chambers



Muon Station2, Made in India (CERN Courier)

Kolkata ALICE Tier-2 GRID Computing Center



ALICE GRID Tier-2 centre:

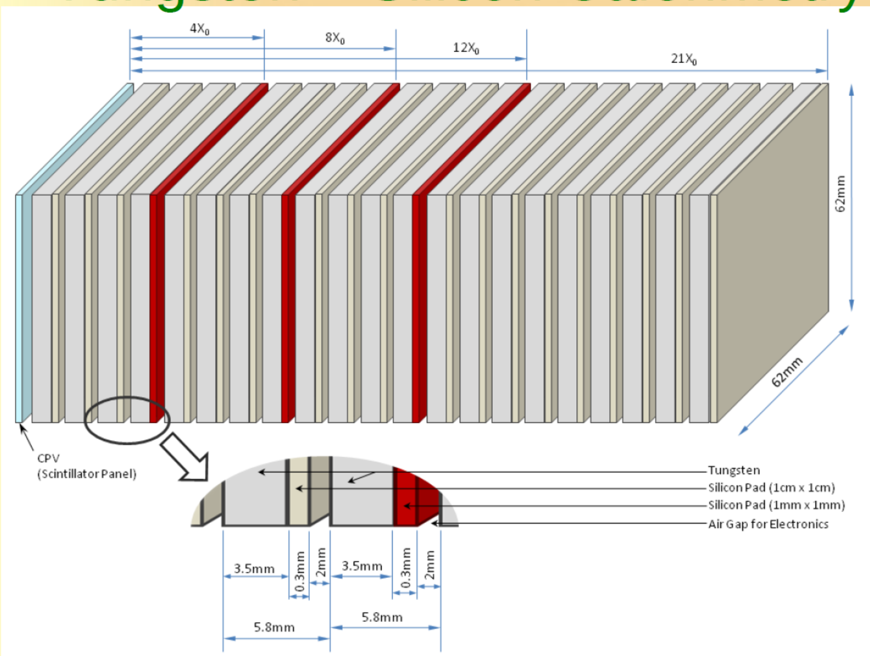
Implemented efficient cooling solution which reduced power consumption and increased overall performance of entire Kolkata Tier-2.

Kolkata Tier-2 Resources:

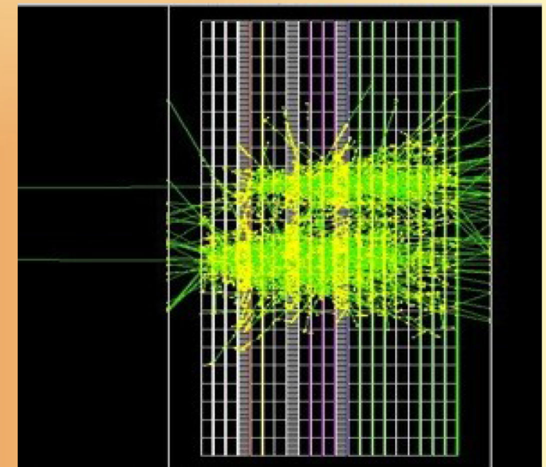
- ***476 Cores Computing,***
- ***230TB Storage,***
- ***1Gbps Network speed,***
- ***A Tier-3 cluster comprises150 core and 37TB storage***

Looking ahead for next 10 years: ALICE Upgrade: A New Forward Calorimeter

Tungsten – Silicon Calorimetry



A new initiative using silicon detectors made in India



25 Layers (each $1m^2$ area)

- **22 layers of 1cm x 1cm silicon pads (500 K channels)**
- **3 layers of 1mmx1mm silicon pads (3 Million channels)**

Physics:

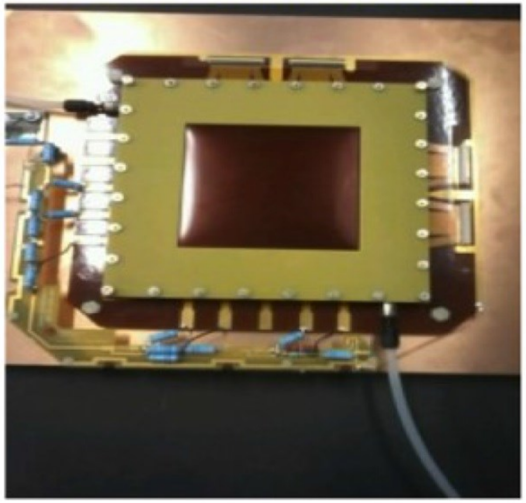
- **Initial State: Low-x Gluon Saturation**
- **Initial State: Nuclear PDFs**
- **Probing the strongly interacting matter thru the study of jet**

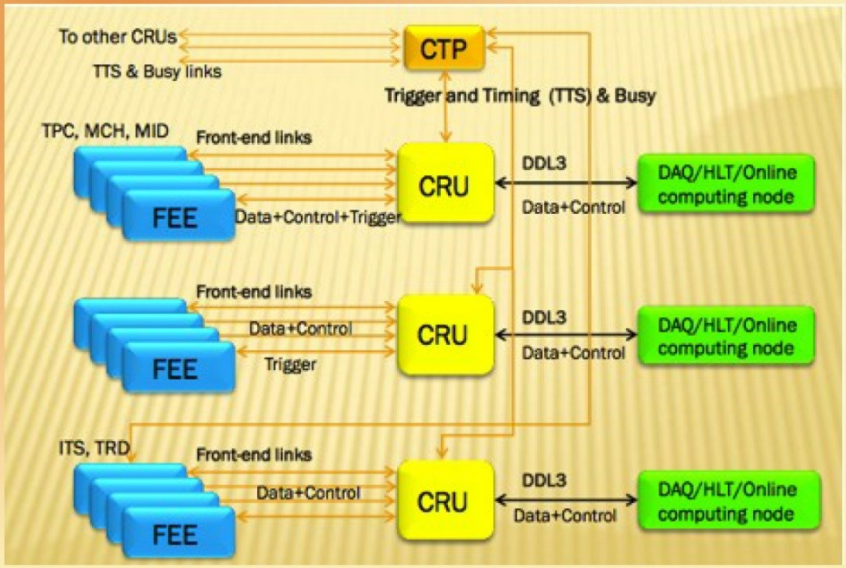
ALICE Upgrade

UPGRADE:

- CRU: FPGA based Common Readout Unit design and fabrication
- TPC: GEM detectors for TPC upgrade
- MFT: Muon Forward Tracker
- O2: Upgrade of online/offline systems

• 3 standard GEM foils (10X10cm)

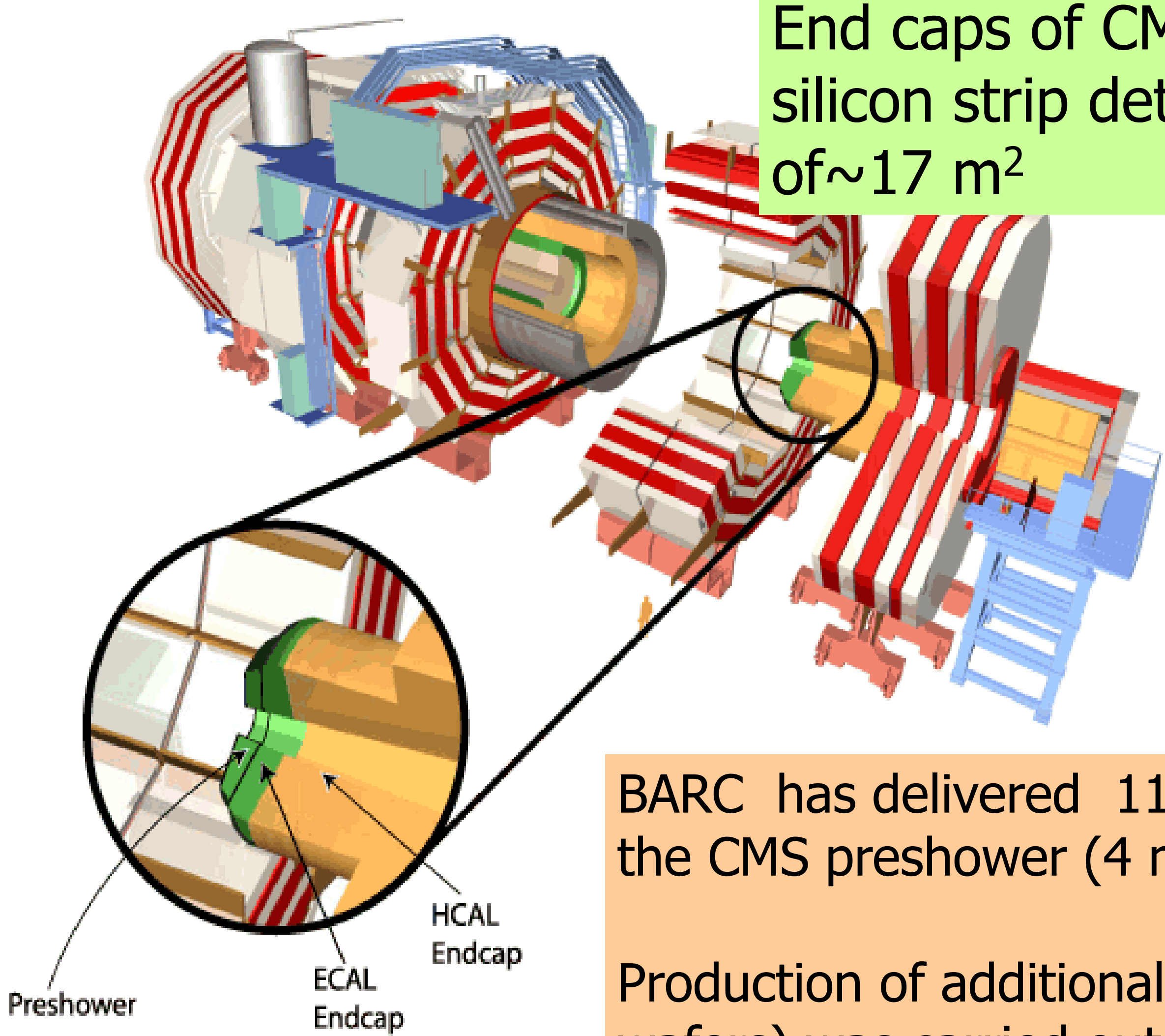




Contributions to CMS: Pre-shower Detector

CMS Preshower Detector

End caps of CMS detector has ~4300 silicon strip detectors covering area of~17 m^2



BARC has delivered 1100 detector modules for the CMS preshower (4 m^2)

Production of additional detectors (~400 wafers) was carried out to meet the shortfall

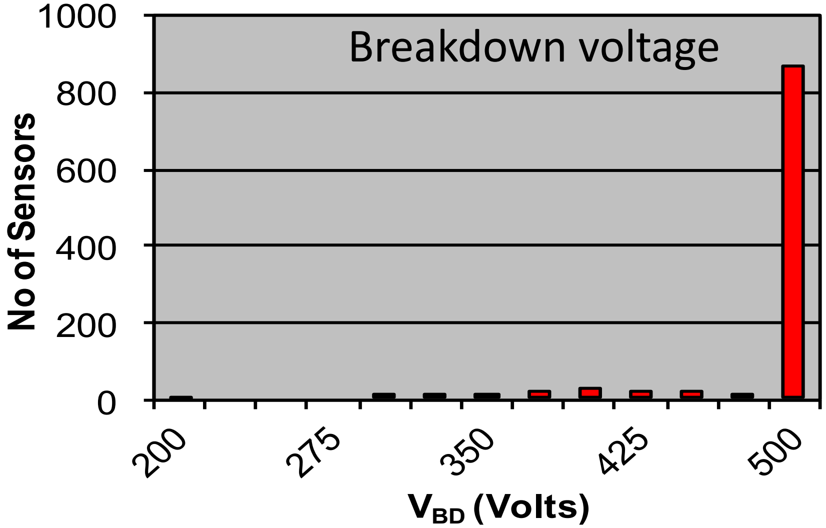
The Preshower Silicon Detector

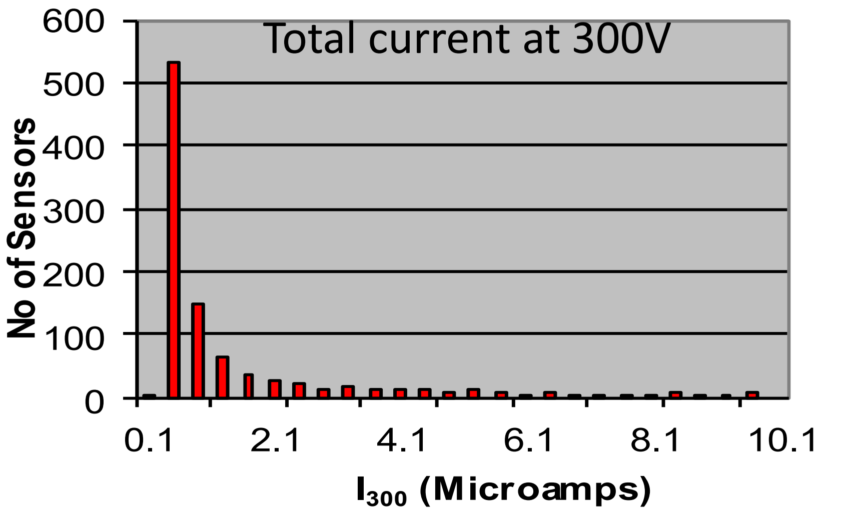
Preshower silicon strip detector is being used for π^0/γ rejection in the ECAL, CMS

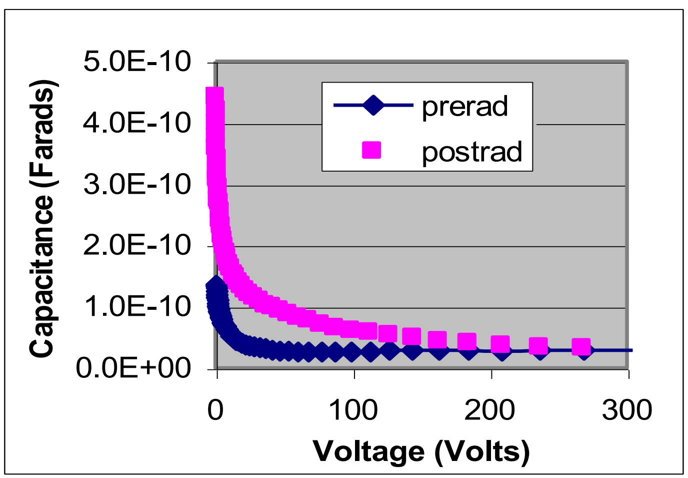
- Strips of 1.80 mm width with a pitch of 1.9 mm
- Area - 63mm x 63mm

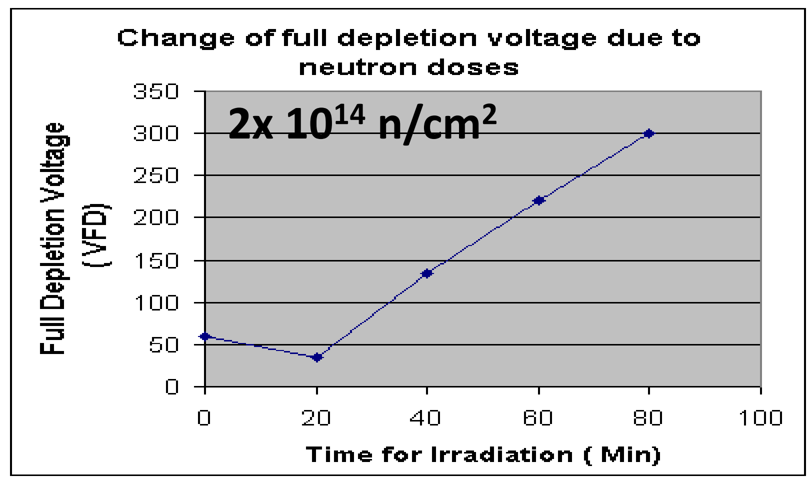
Detector specifications are very stringent as they are to be operated in a high radiation background of neutrons ($2\times10^{14}/cm^2$) & gamma (10Mrad) for a long period of ten years

Performance of detectors supplied to CERN









Detector Specifications

Electrical

High breakdown voltage

Breakdown voltage >= 300V/500V

Low leakage:<= 10 μA at 300V

Uniformity of all strips:

Max. 1 strip with > 5 μA at 300V

Geometrical

Tight control over dimensions

Length 63.0 +- 0.1 mm

Width 63.0 +0.0, -0.1 mm

Fabrication Process

High resistivity <111>,
FZ wafers

Ion implanted junctions with oxide passivation

P+ guard rings

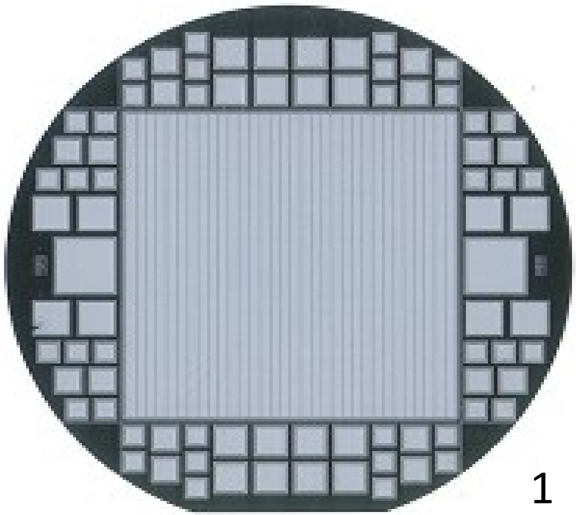
Gettering to reduce leakage currents

Aluminum metallization

PSG passivation on the top

- Fabrication process optimized in eight batches to achieve desired specifications

Wafers designed and fabricated during various stages of development



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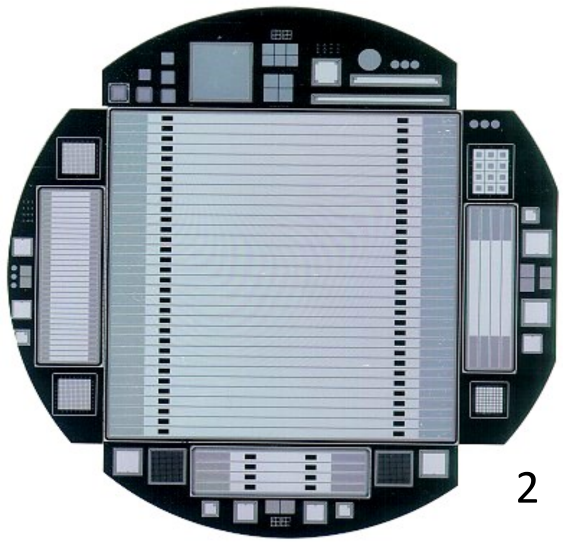

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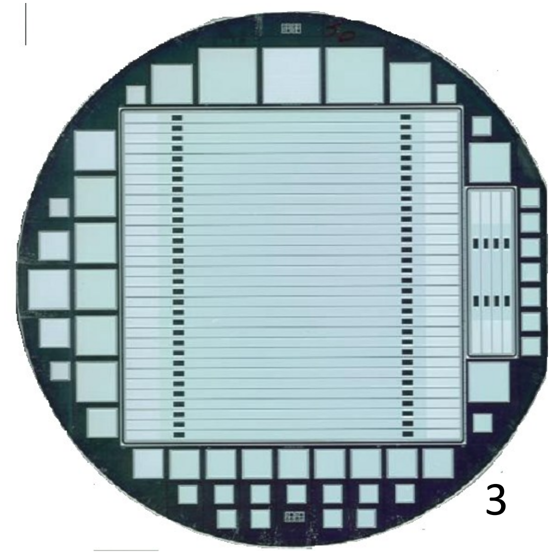

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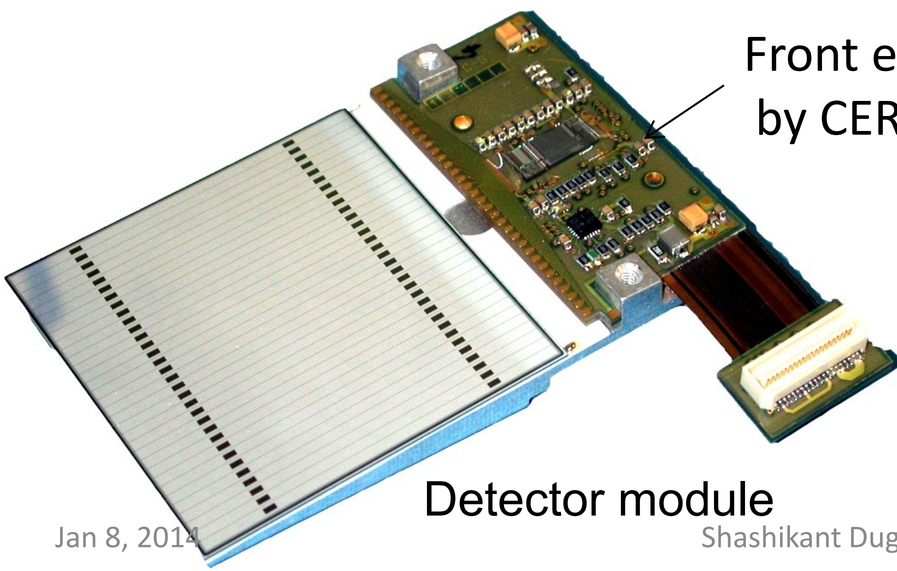
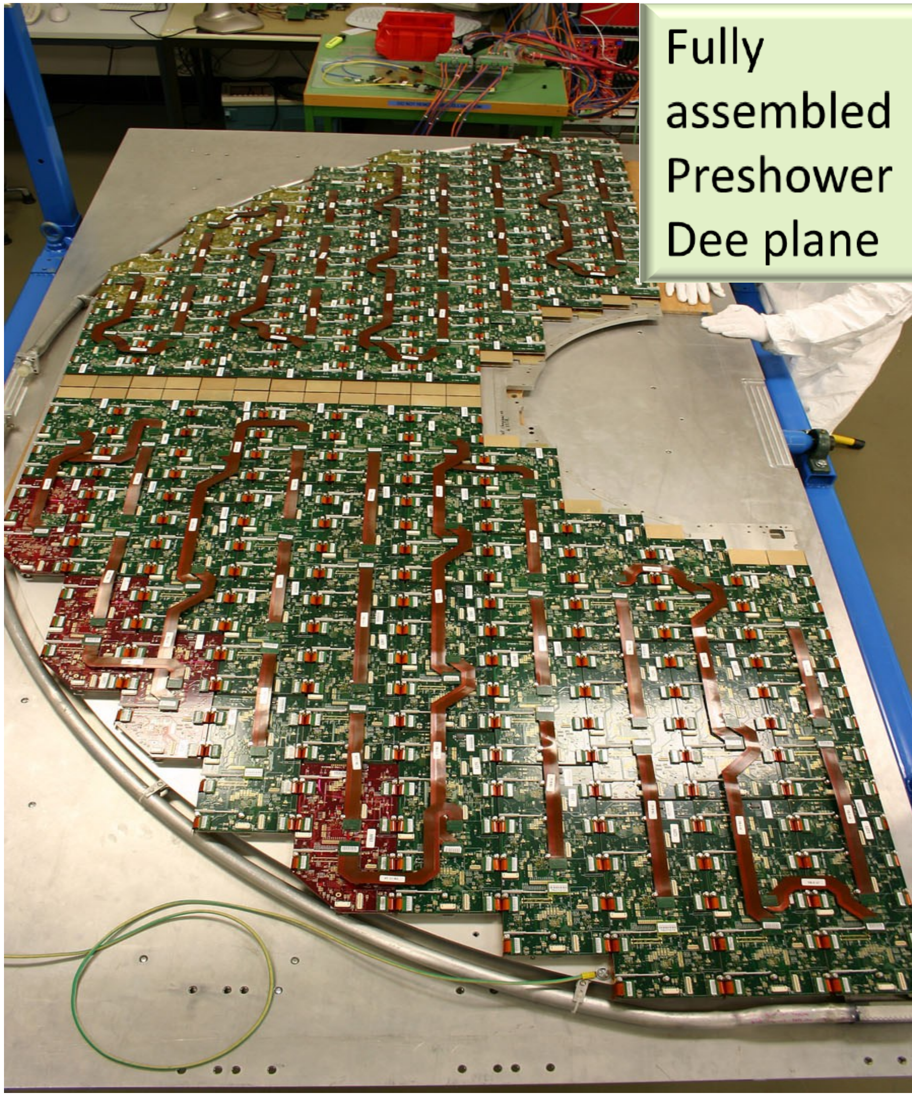


Detector module

Silicon detectors produced by BARC cover an area of 40,000 cm^2 in the CMS detector of LHC

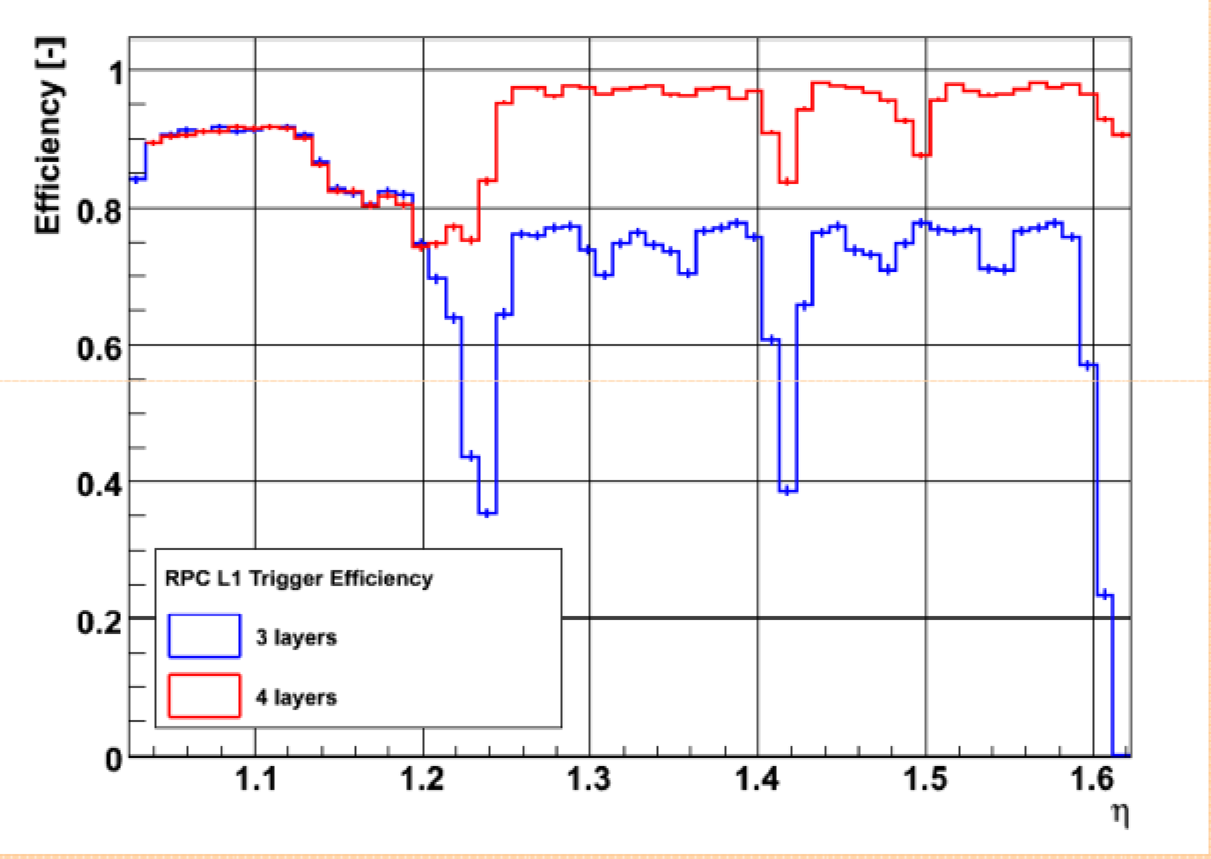
The assembled end cap with micromodules – Assembly, Installation and Commissioning by CERN

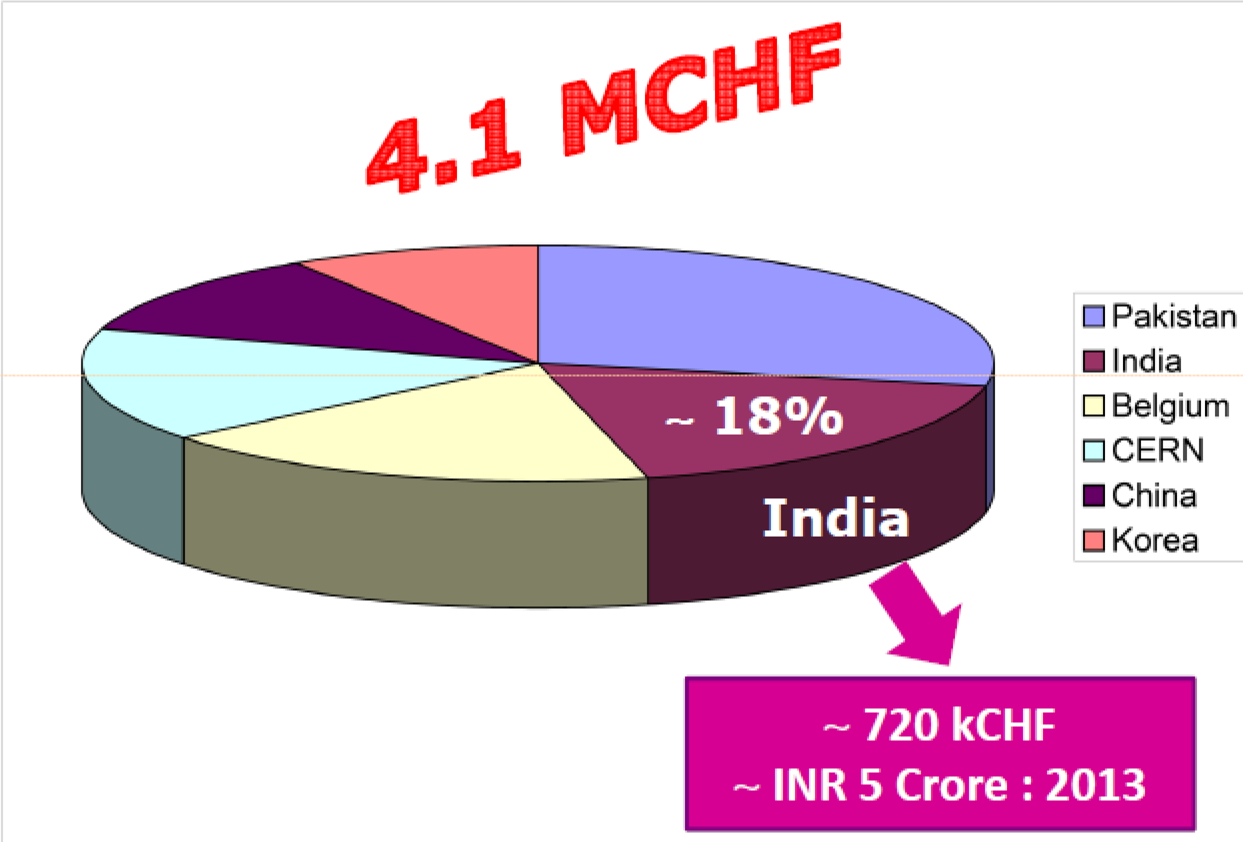


Fully assembled Preshower Dee plane

Contributions to CMS:
RPC for the 4^{th} end cap upgrade
$1.2 < \eta < 1.6$

Simulated trigger efficiency plot : Piet Verwilligen



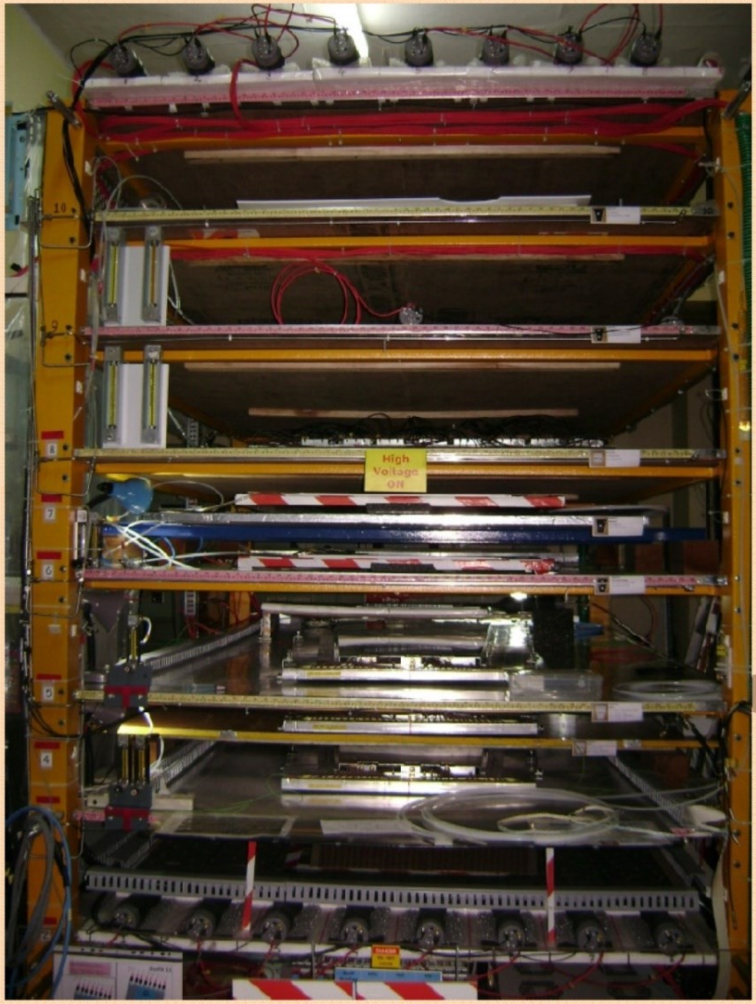


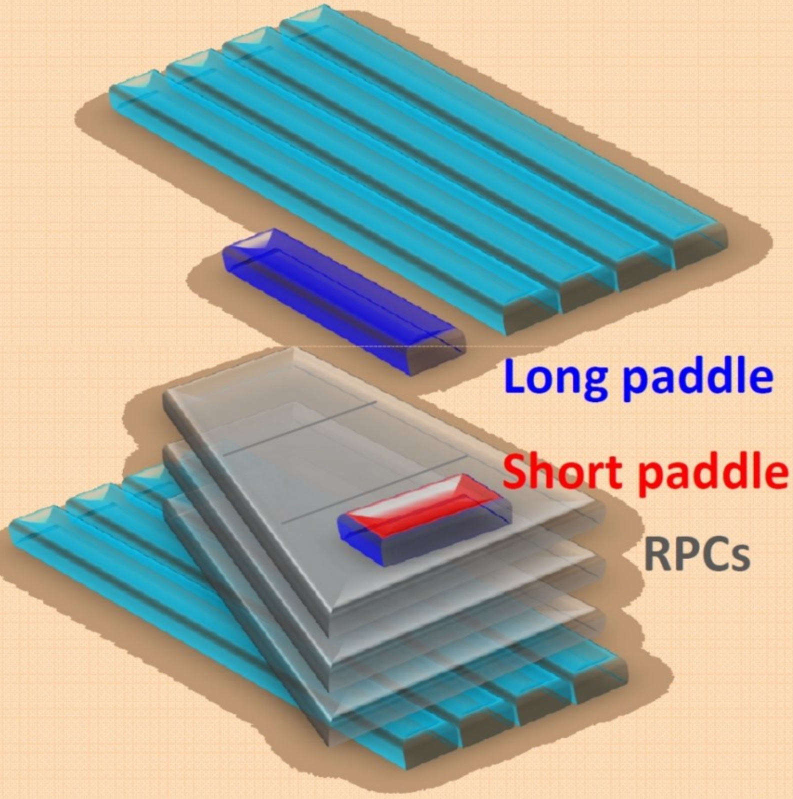
Indian contribution for services : 320 kCHF

HV & LV Hardware from CAEN, Embedded Assembly Systems : EASY

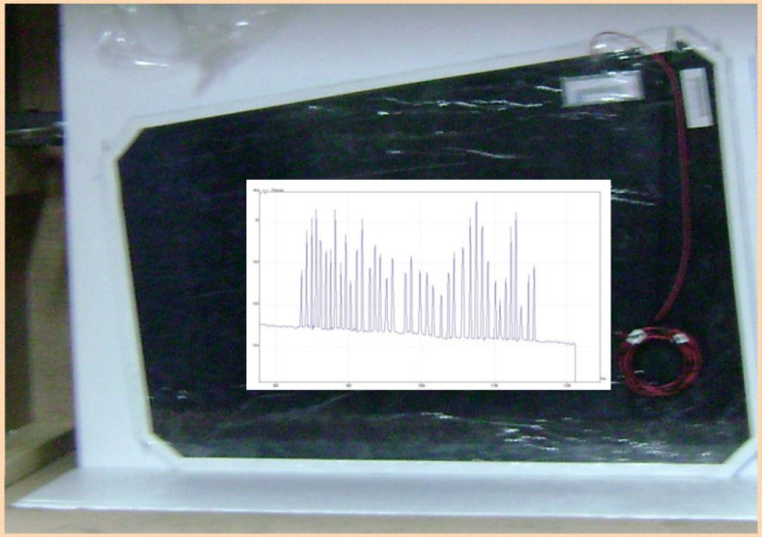
RPC being assembled at NPD-BARC : RE4/2 RPCs : 50 units

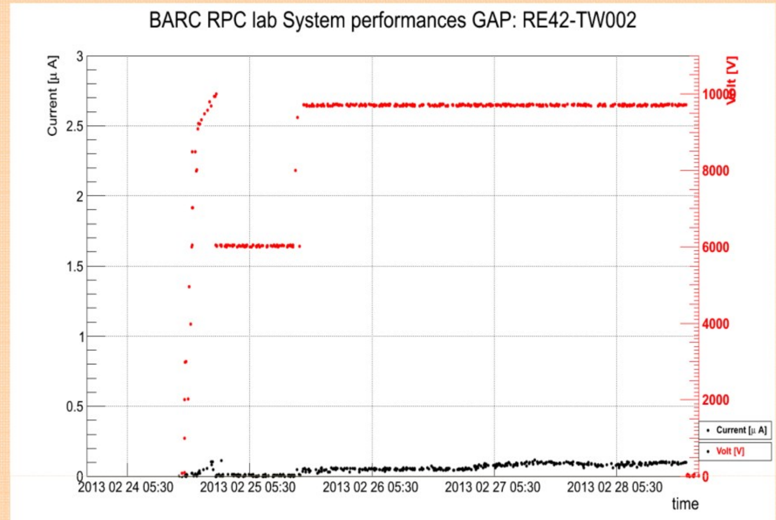
RPC characterization in the hodoscope with cosmic muons

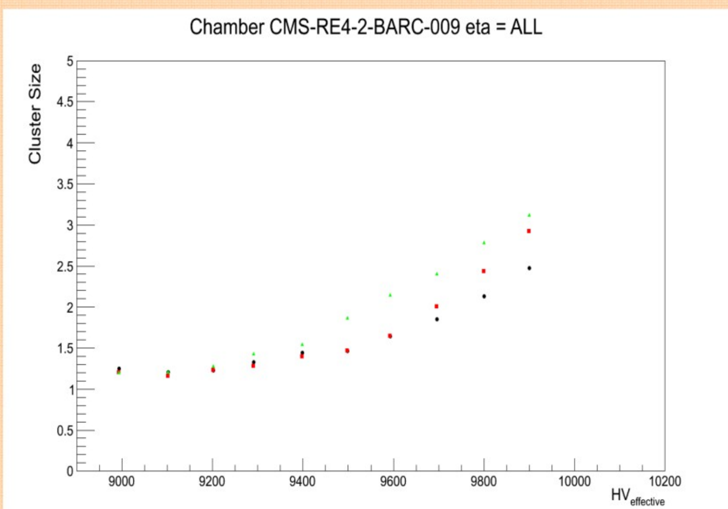


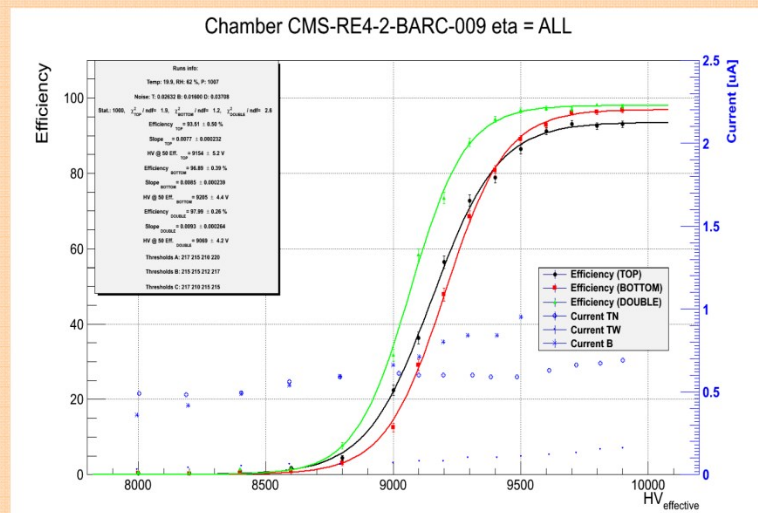


Quality Control before & after building RPCs at NPD-BARC : Leak & Spacer test, HV Scan, Efficiency and Cluster size

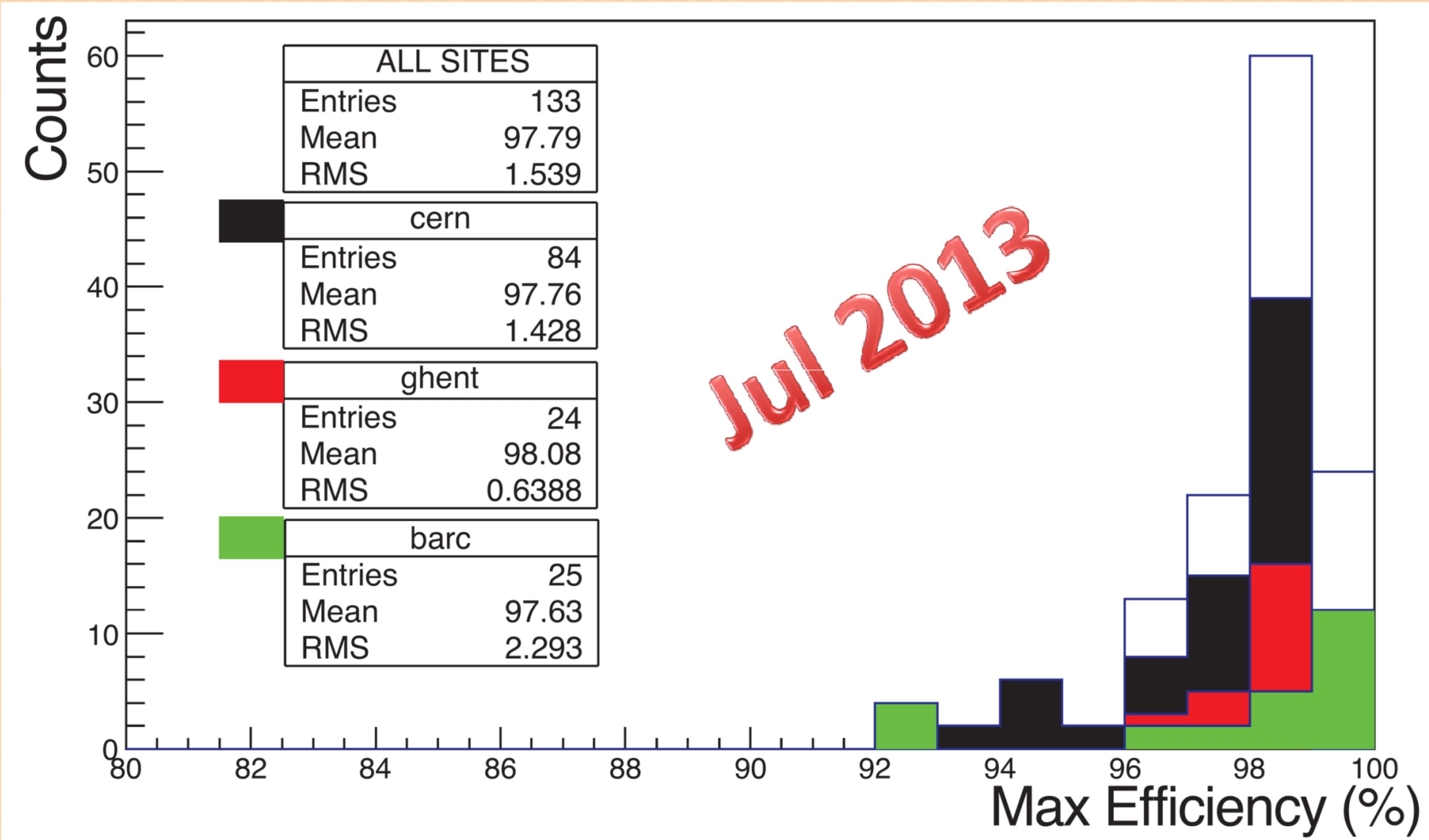




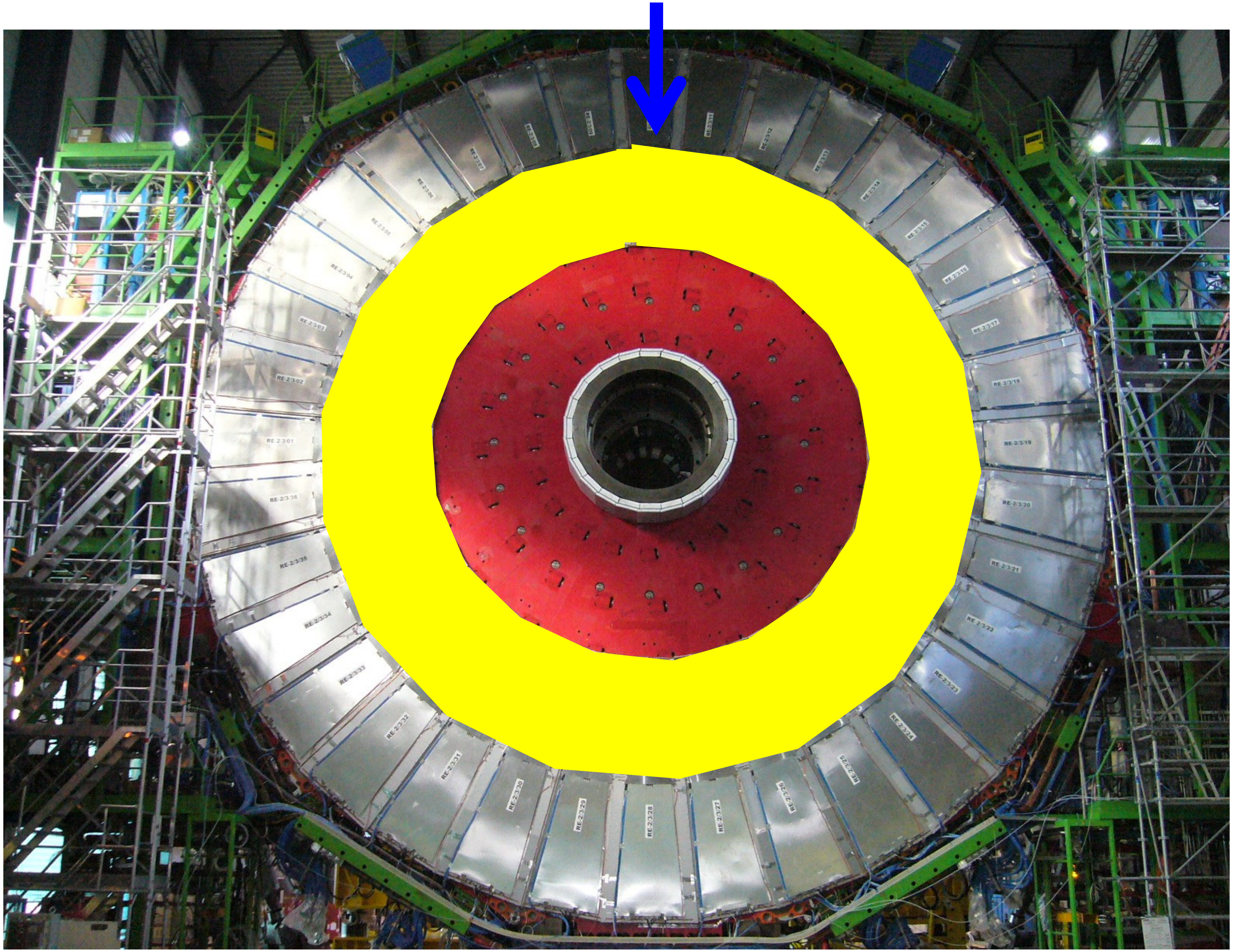




RPC Performance from three sites : Material Progress Review : 24th July 2013



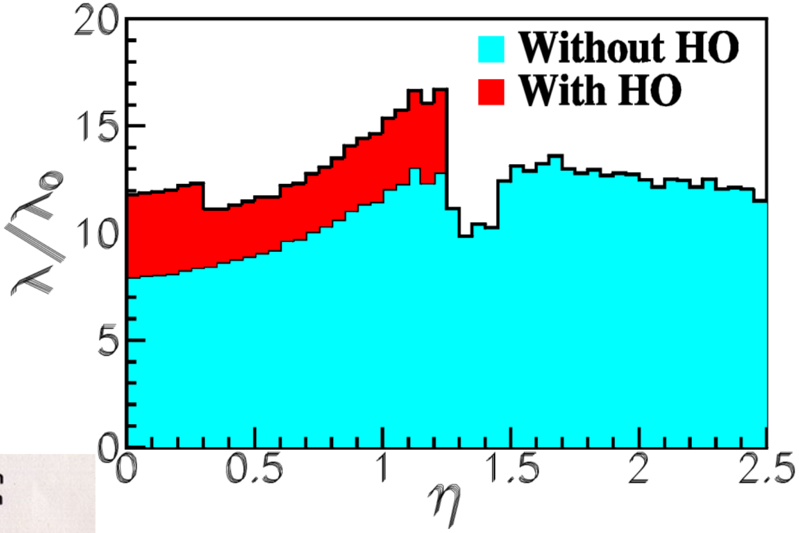
RE4/2 sector : 2 end caps x 36 chambers + spares = 100 chambers

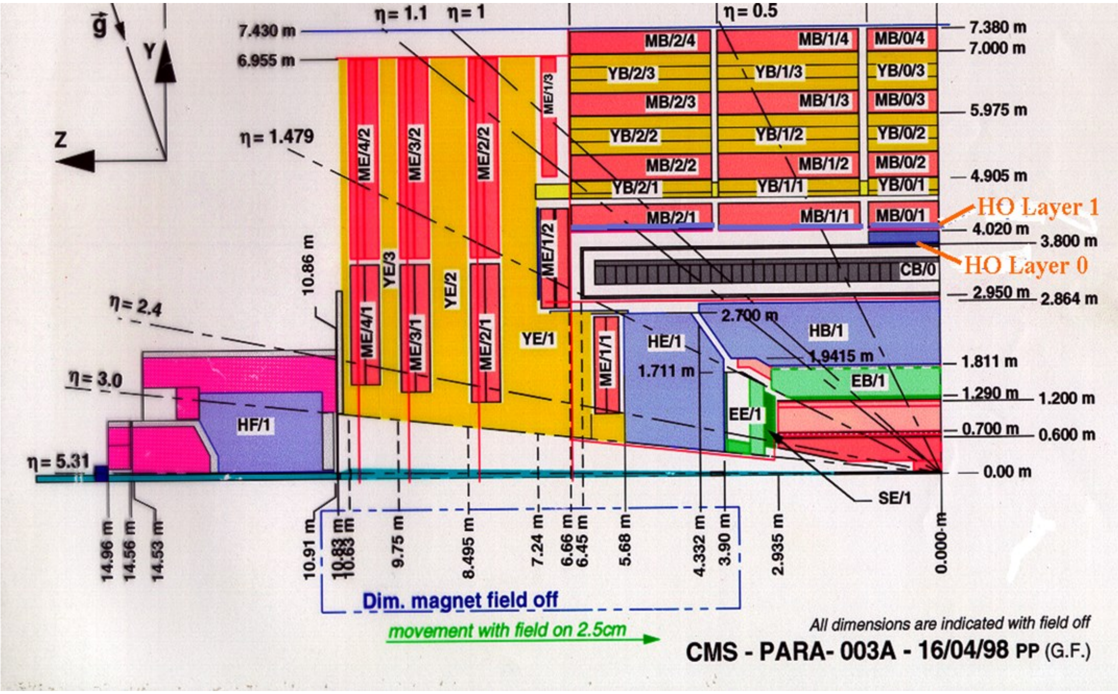


Contributions to CMS: Outer Hadron Calorimeter

Outer Hadron Calorimeter (HO)

In the central region, HB is not thick enough to contain hadronic shower fully, particularly those fluctuated showers which develop deep inside the HCAL.

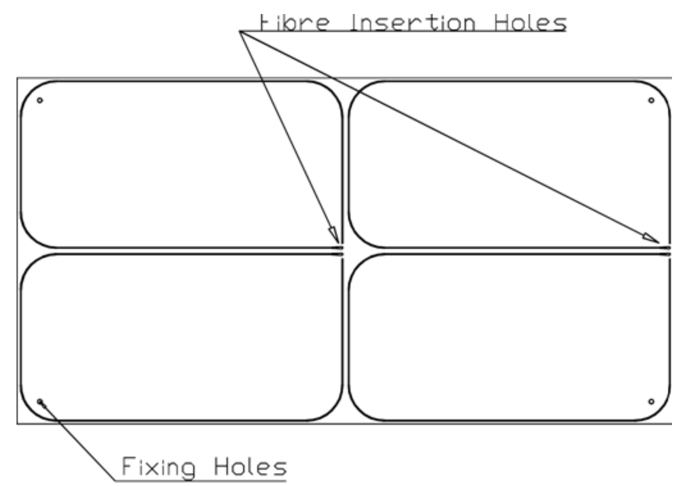




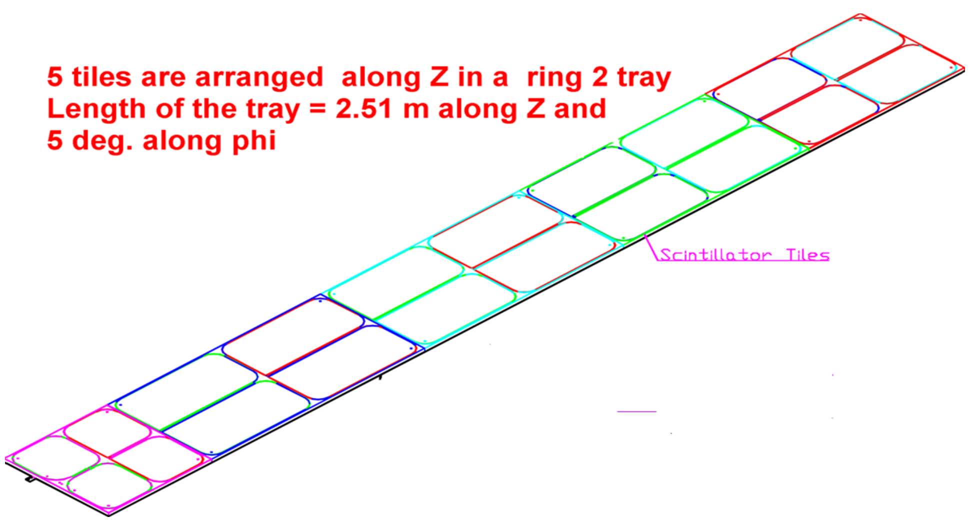
HO configuration

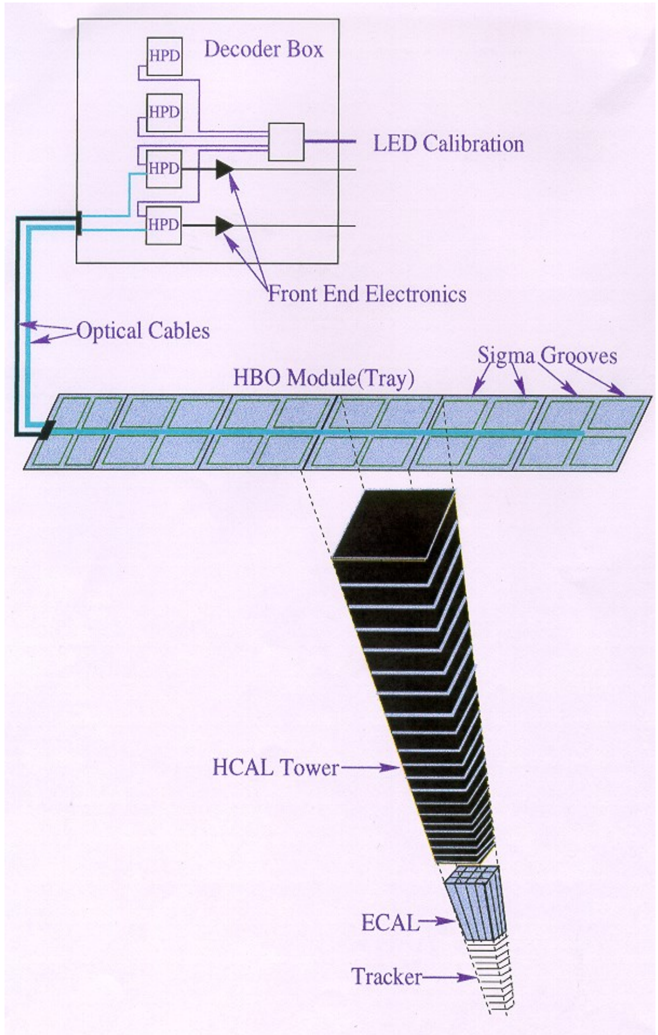
- Rapidity coverage ($|\eta| < 1.26$) occupied by the five Muon Rings. (YB= -2,-1,0,1,2)
- Two layers in YB0 on either side of the 18 cm thick tail catcher iron at R=3.82m and 4.07m (Ly0, Ly1)
- One Layer in outer rings YB = ±1, ±2 at R= 4.07m
- Active element: 10 mm thick scintillator with 0.94 mm WLS fiber embedded in sigma grooves
- Granularity: $\Delta\eta \times \Delta\phi = 0.087 \times 0.087$
- No. of of scintillator s = 2736
- Photo-Readout Element:
  - Hybrid Photo Diode (HPD) →Silicon photo multiplier (SiPM)

Design Schematics

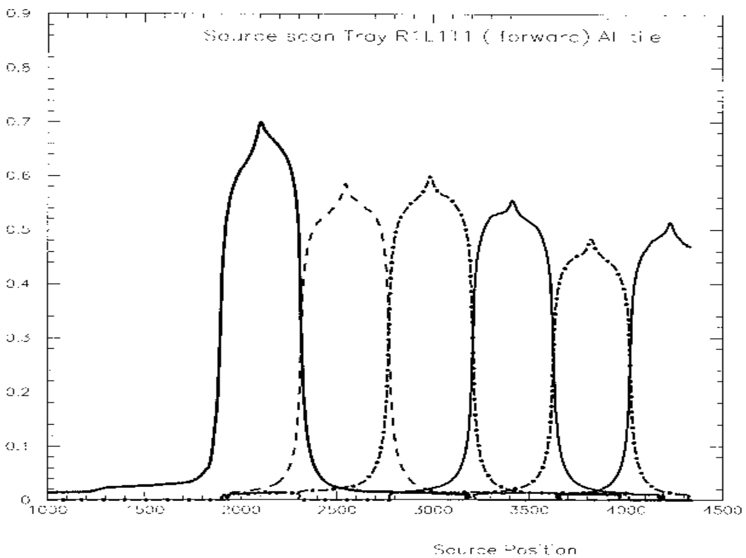


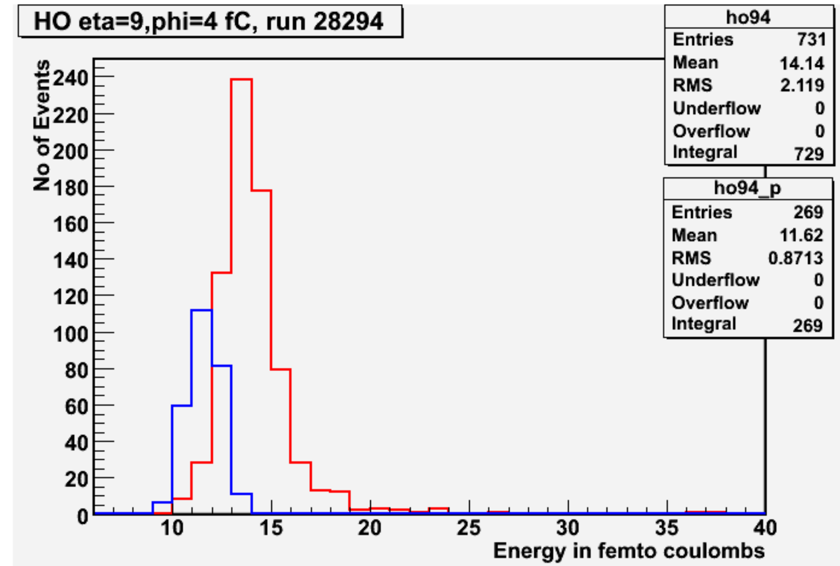
5 tiles are arranged along Z in a ring 2 tray
Length of the tray = 2.51 m along Z and
5 deg. along phi

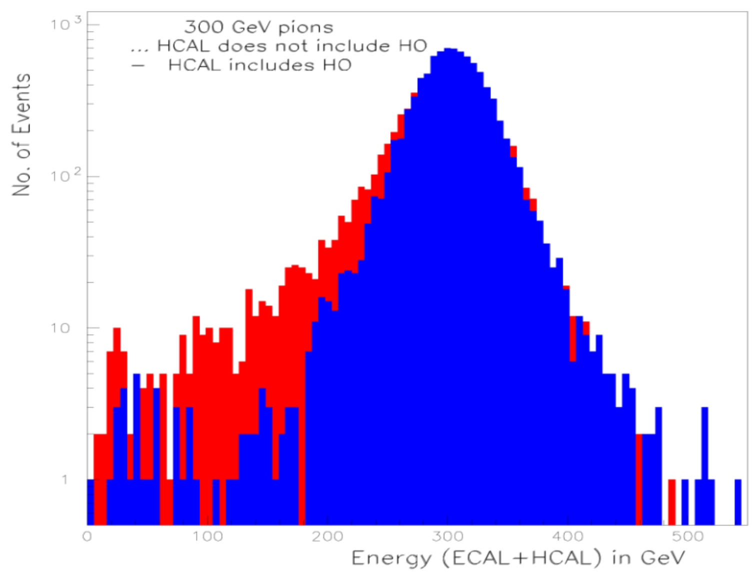


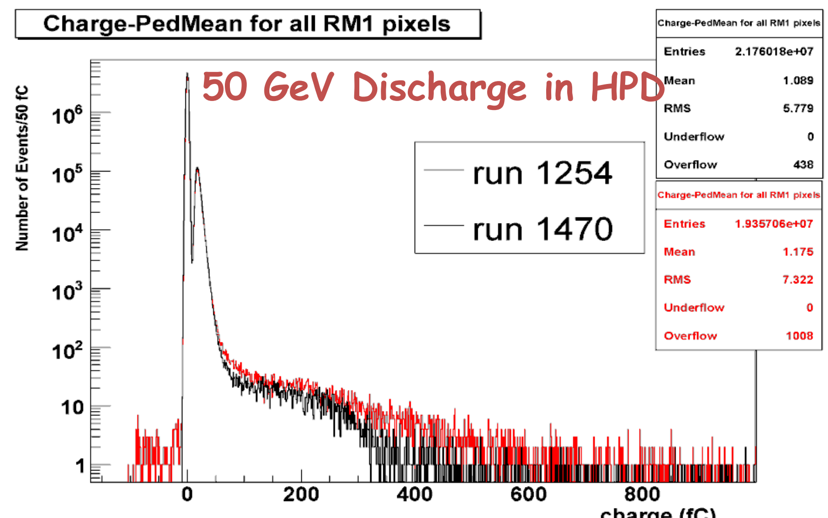


HO Calibration and Validation





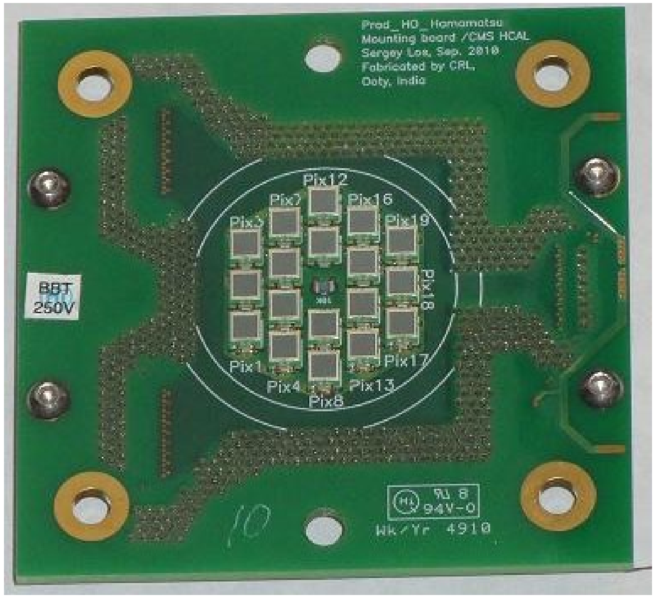




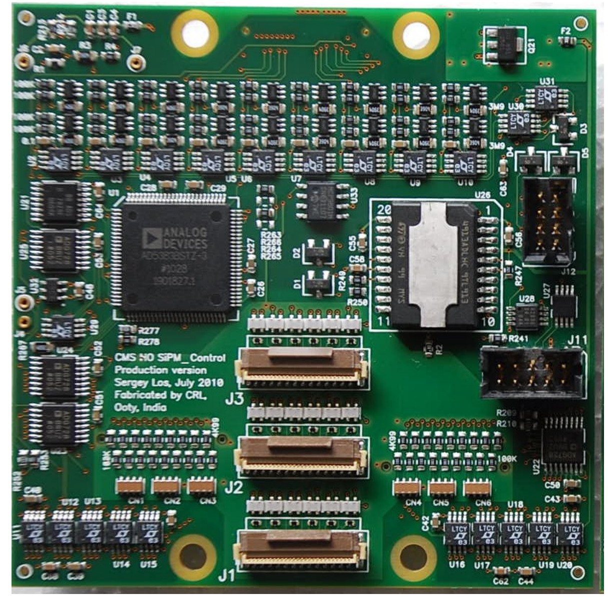
Scope of Activity

- **Validation of SiPM for CMS environment**
  - **Testbeam studies, stability, radiation hardness, magnetic field immunity, saturation effects**
- **Fabrication of 160 SiPM Control Boards in India**
  - **Each board has 18 Channels**
  - **Control boards provides generates bias voltage for each channel, monitors current, temperature etc.**
  - **Entire production and quality control of 160 boards to be carried by Indian group in India**
- **Quality Control of Control Boards and SiPM Boards (160+160) at India:**
  - **Setting up stand-alone DAQ system for Control and SiPM boards**
  - **Development of software for QC Data Analysis**
  - **Generating QC report for each board**
- **Installation and Commissioning:**
  - **Removal of 132 Readout Modules, Assembly of Readout Modules, QC and burn-in test at CERN, Installation of 132 Readout Modules**

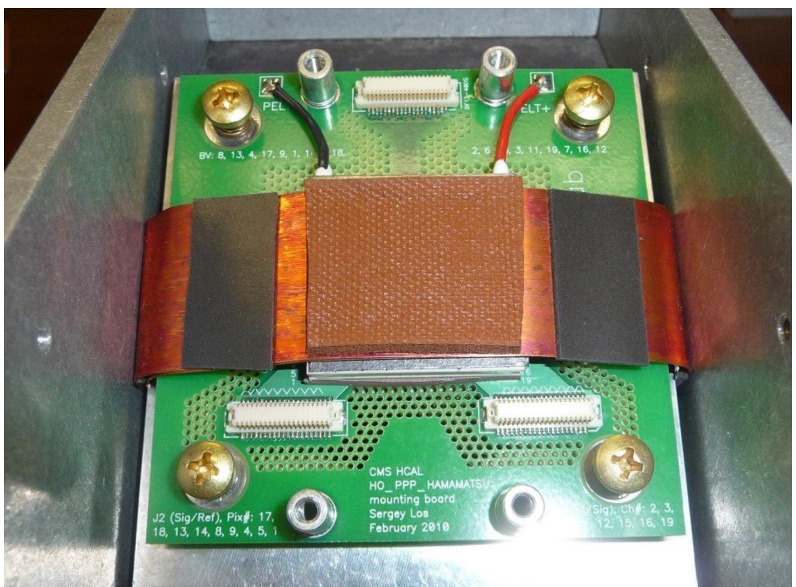
HO Readout Module Assembly

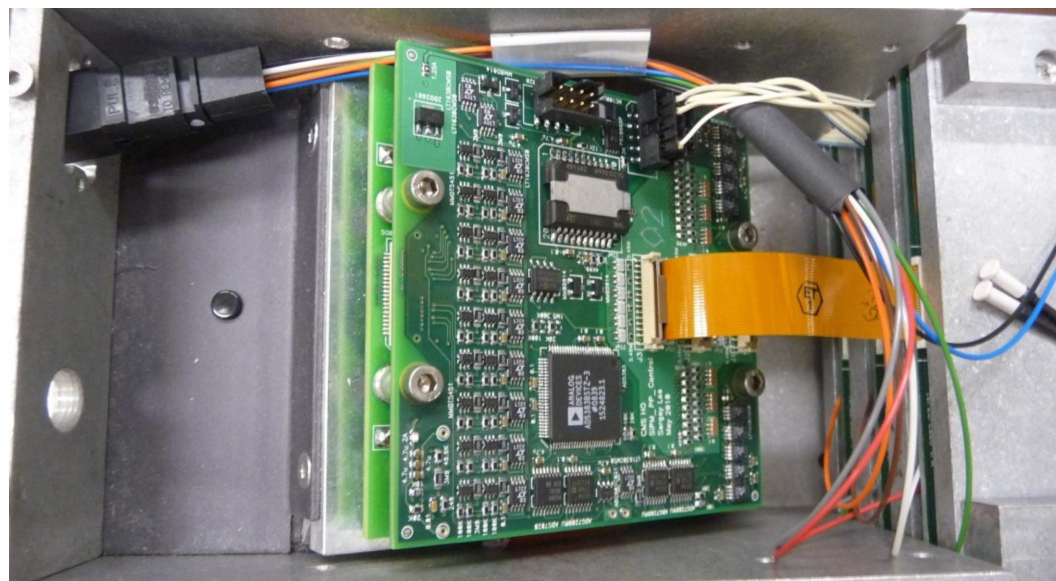


SiPM Mounting Board

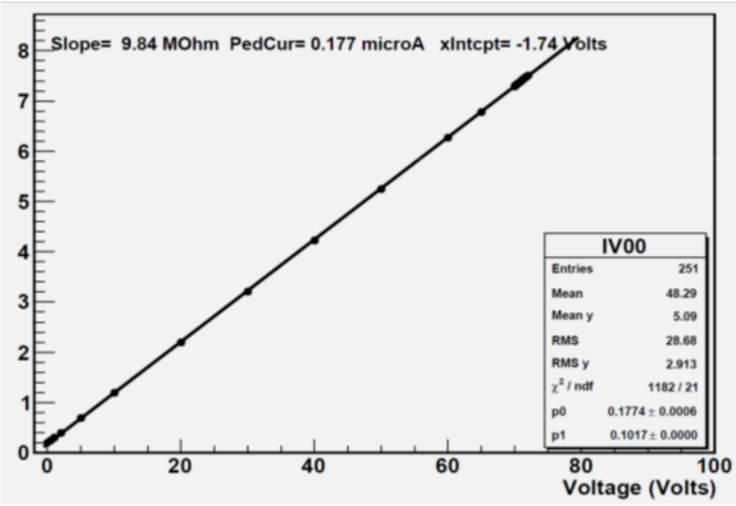


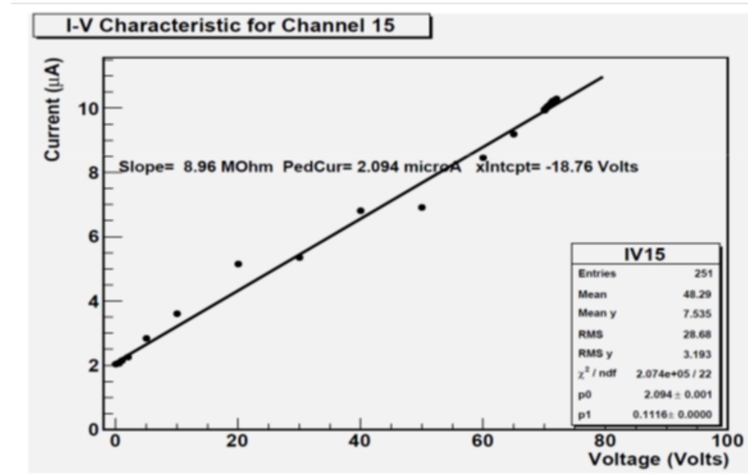
SiPM Control Board

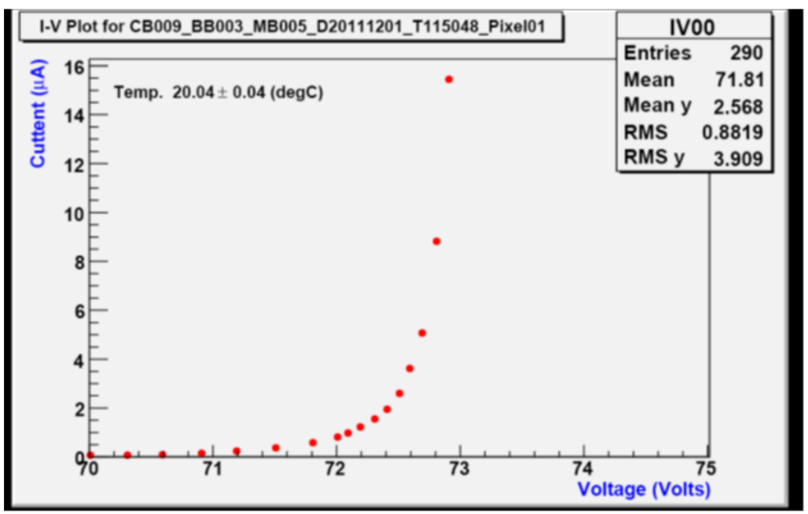


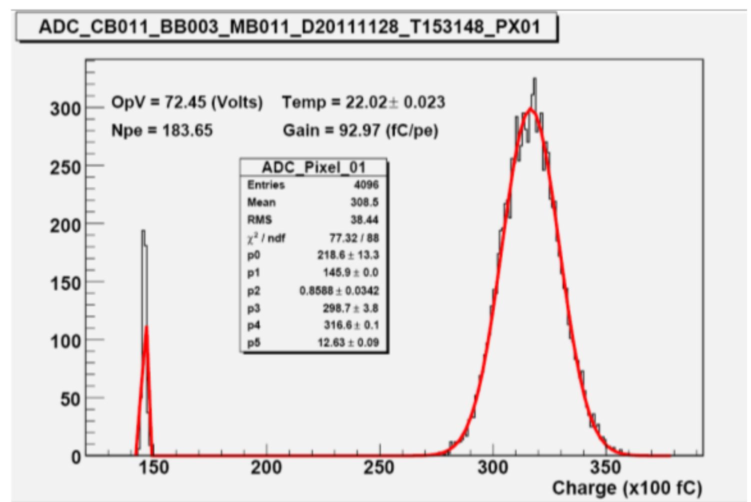


QC Results of HO Hardware
(Carried out at GRAPES-3, Ooty)

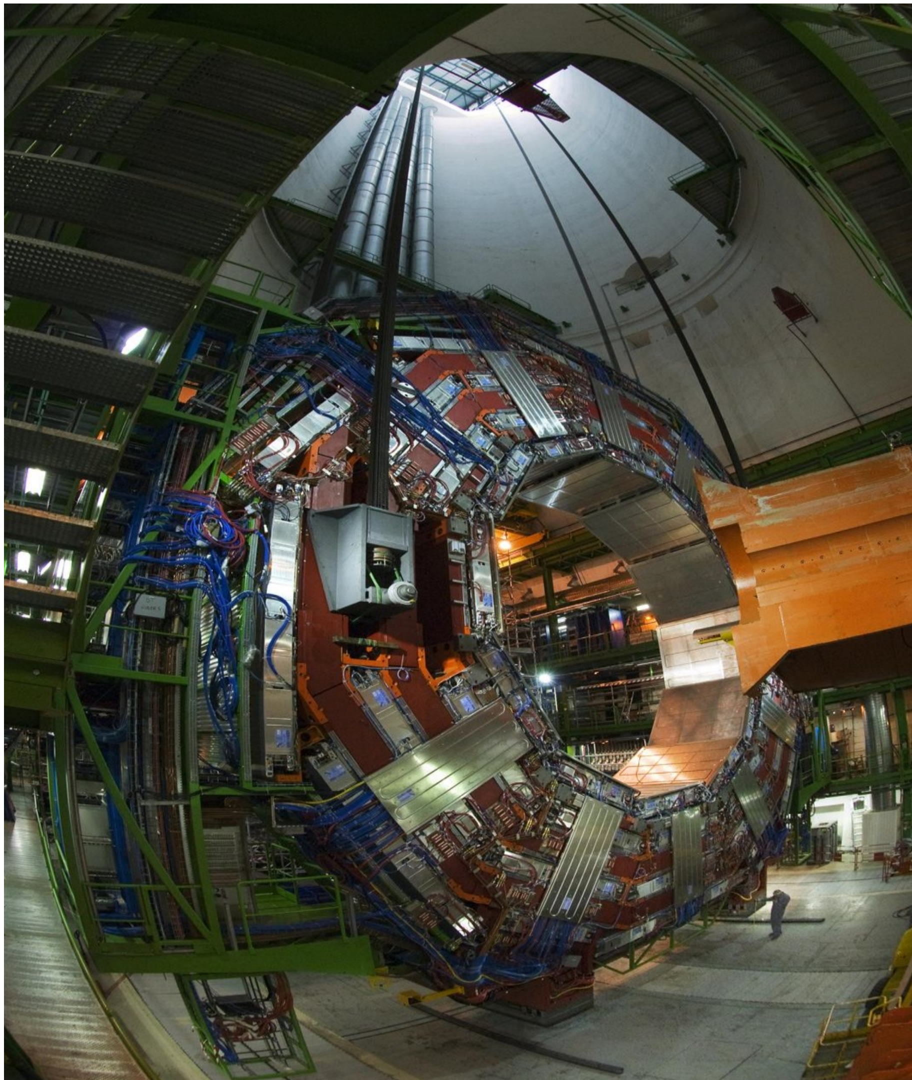


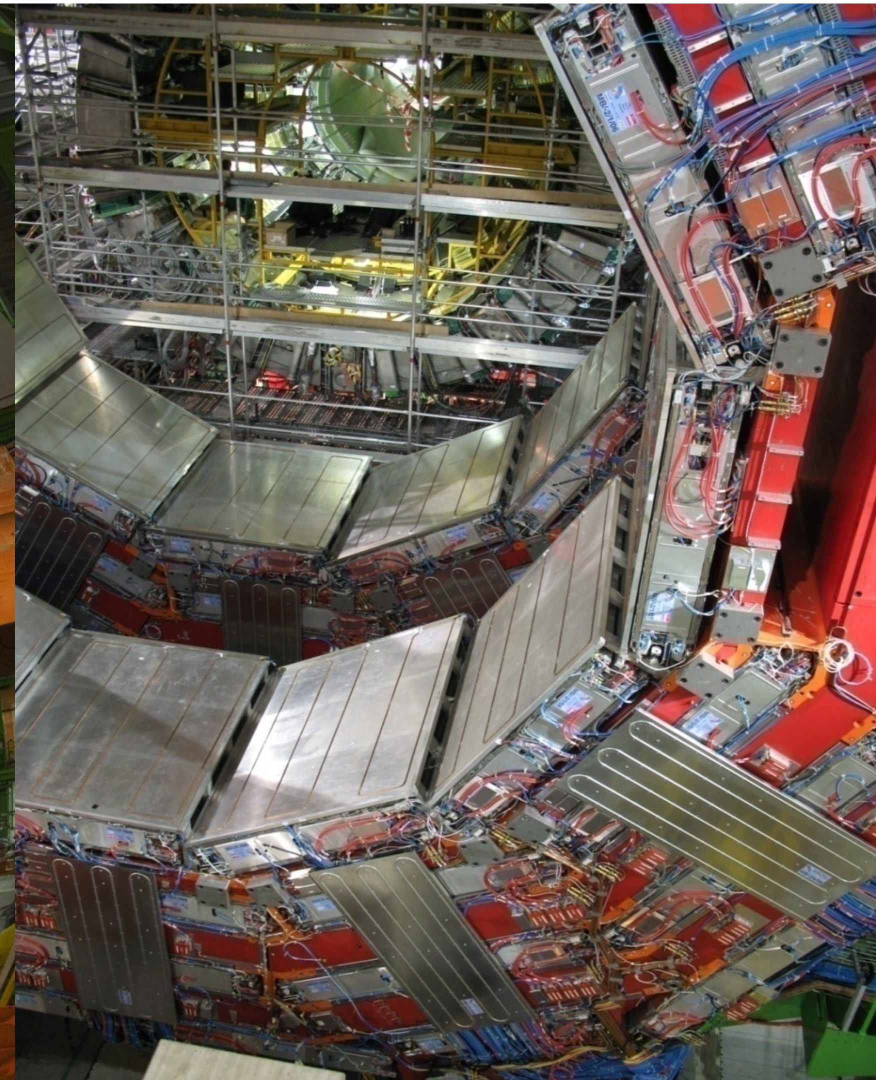




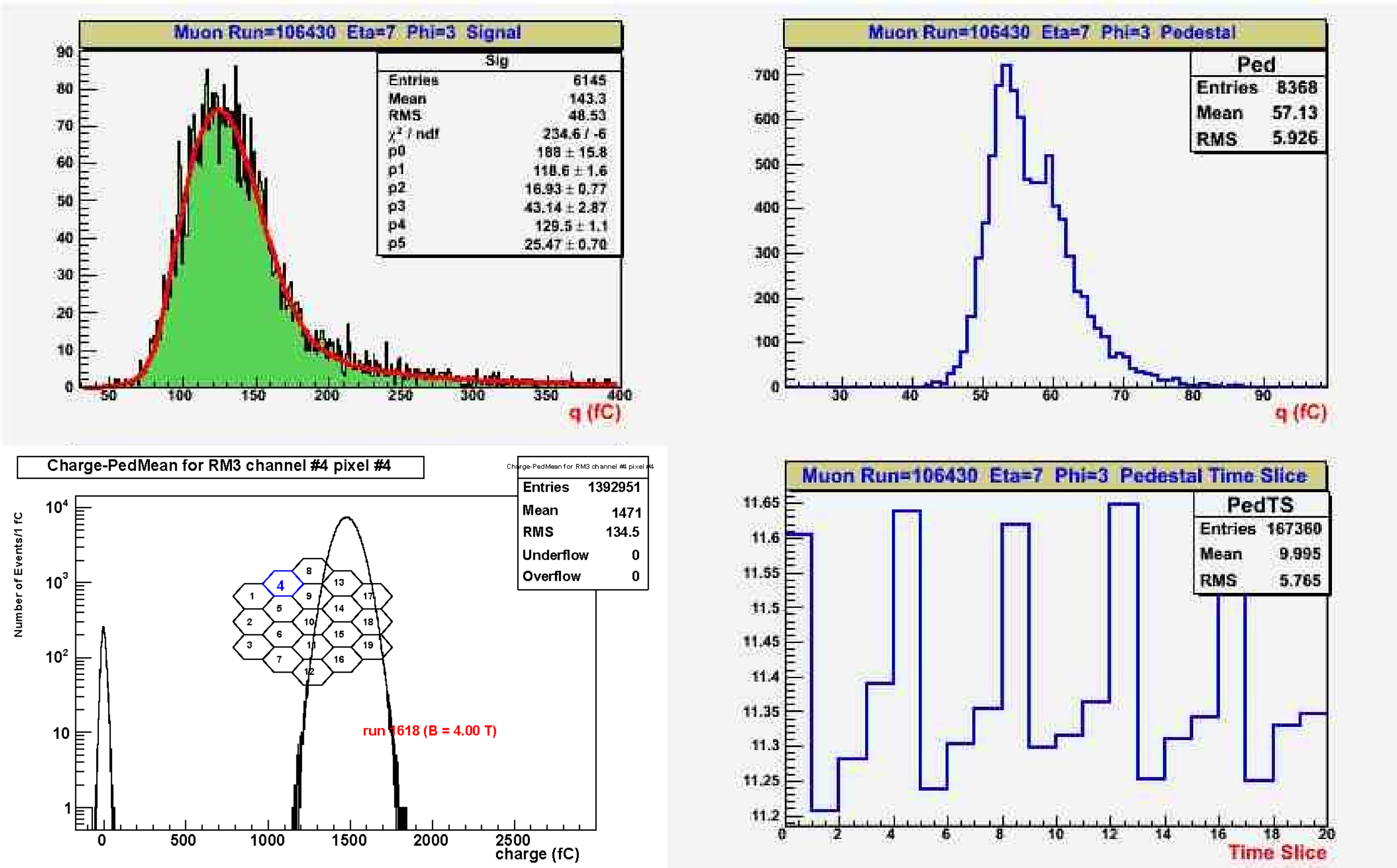


Outer Rings with instrumented HO

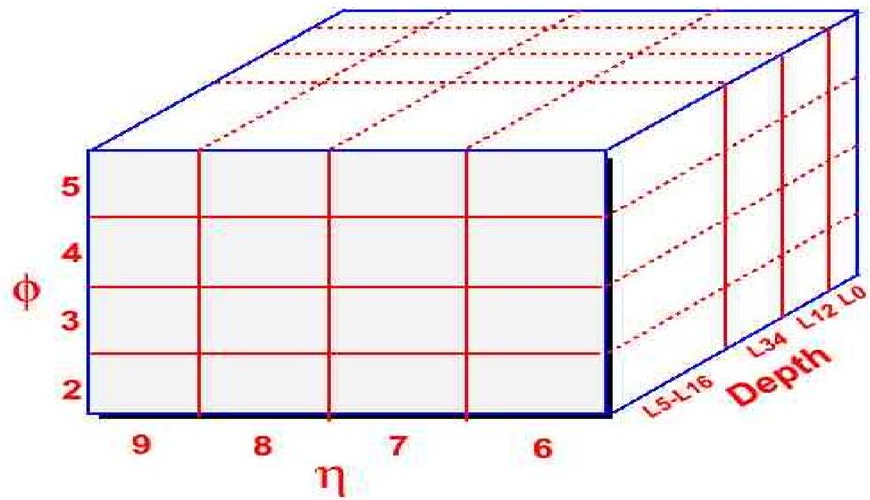


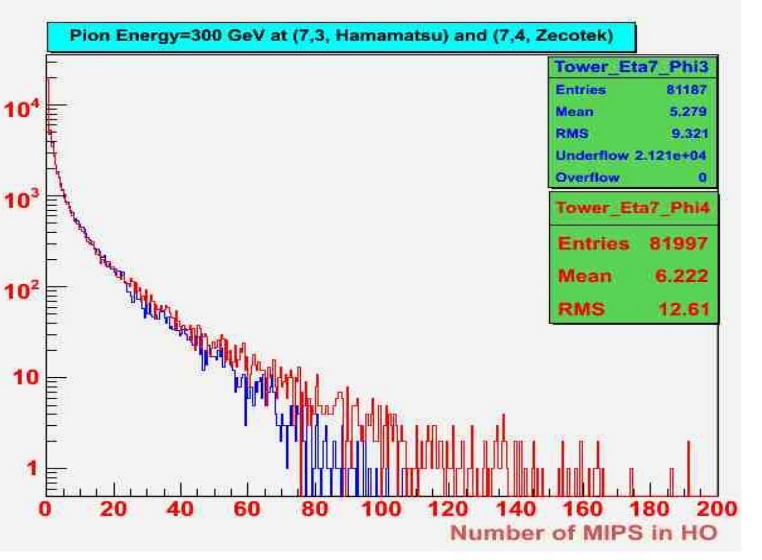


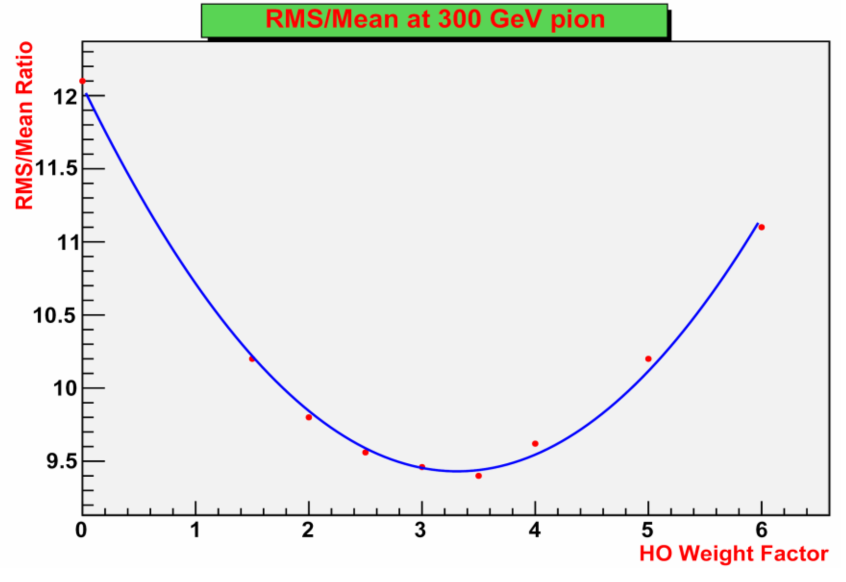
HO Calibration with 150 GeV Muons and LED

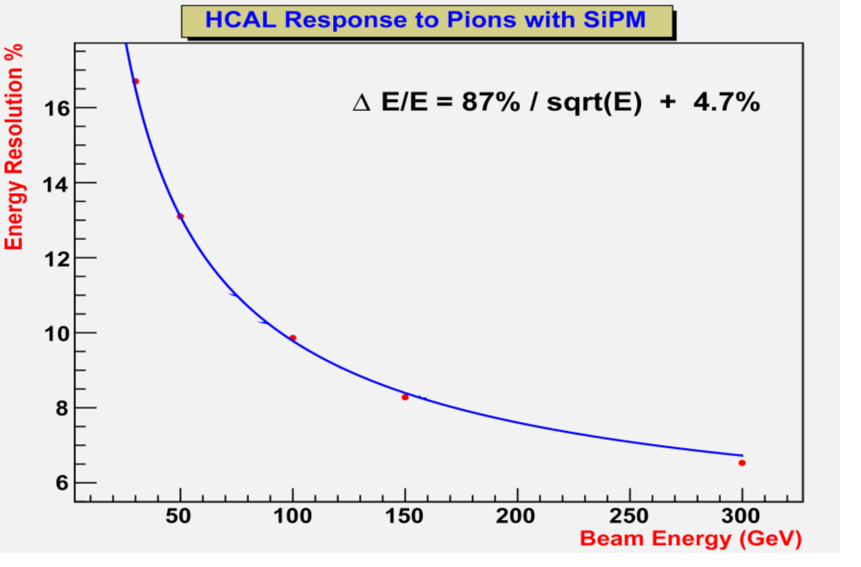


Pions for HB+HO with SiPM Readout at TB2009

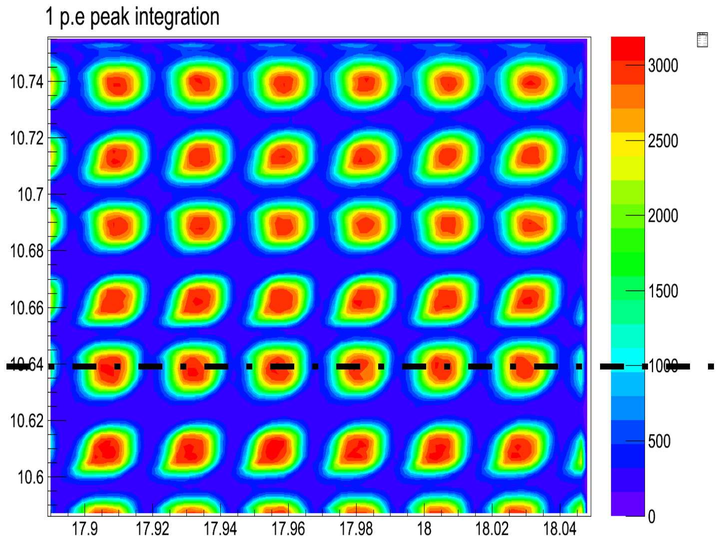


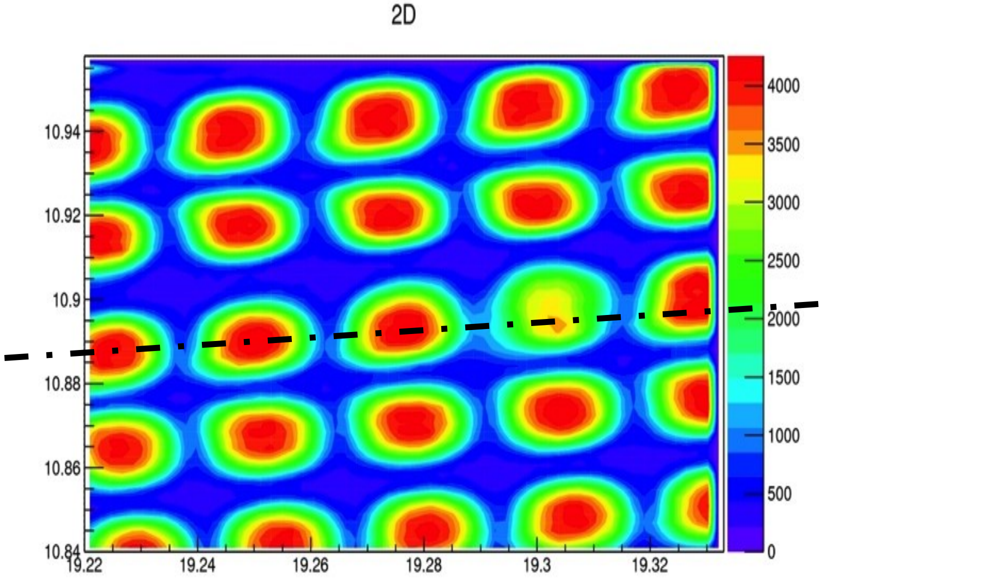


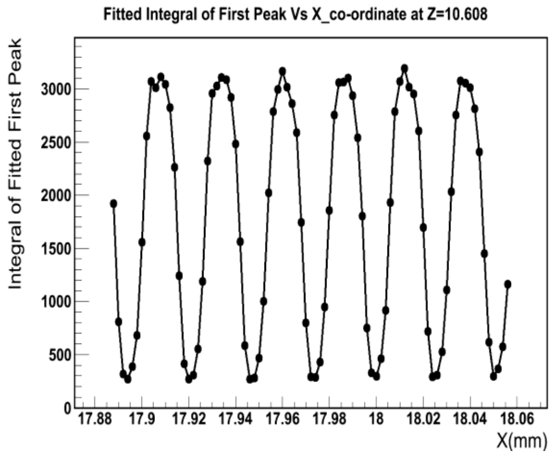


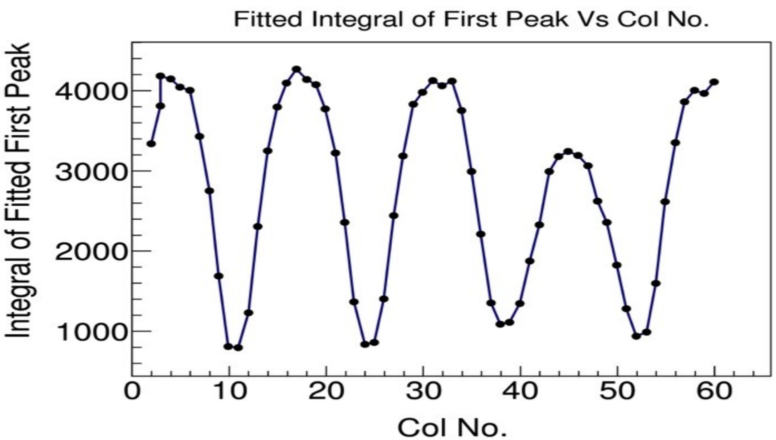


Micron Resolution Optical Scanner Fabricated at TIFR





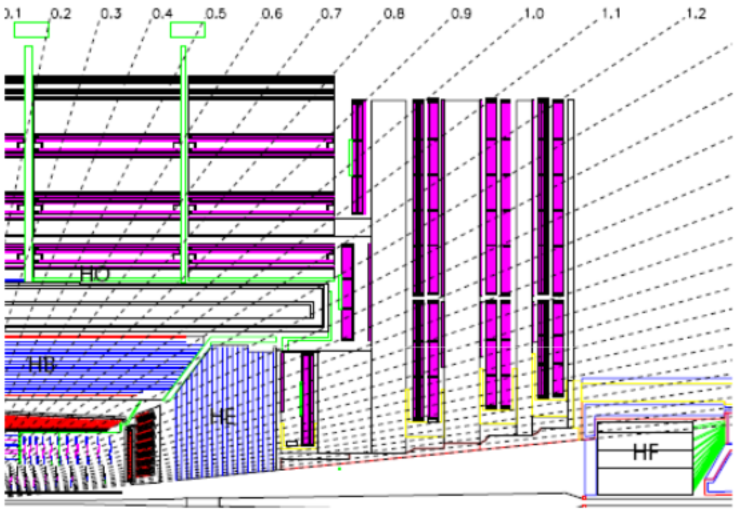




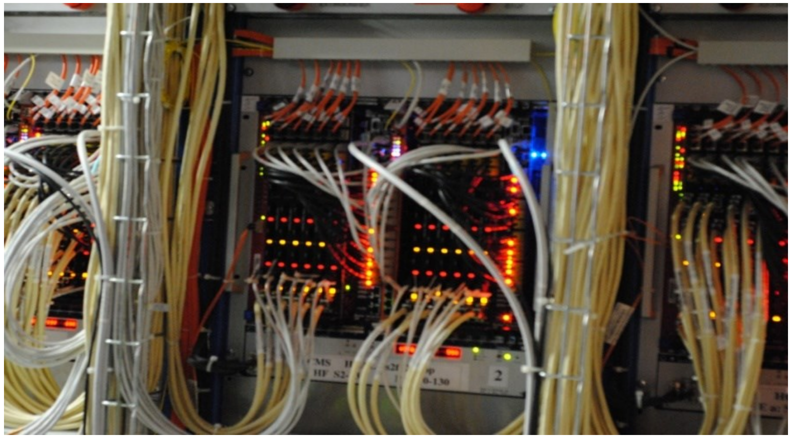
Uniformity of pixel gain , photon detection efficiency, x-talk etc.

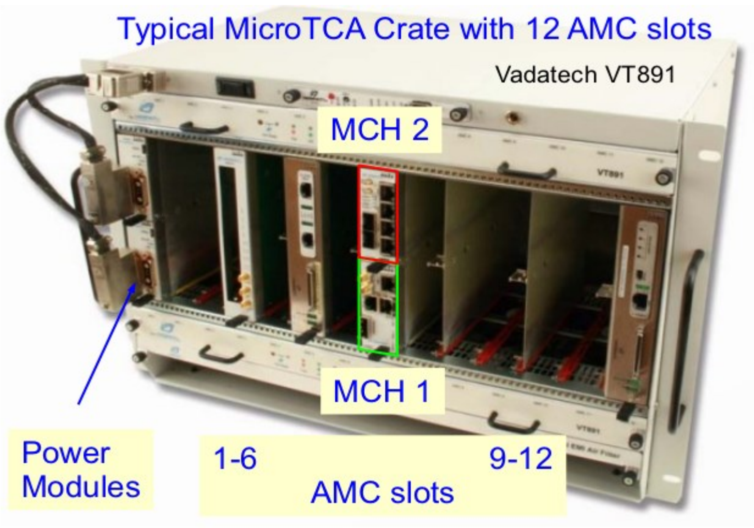
Contributions to CMS: HF Backend Electronics

HF Backend upgrade VME → μTCA



CMS Hcal longitudinal view





<u>Why this upgrade?</u>

Increase of energy as well as luminosity in the LHC requires an increase in channel count of the readout part of the HCAL.

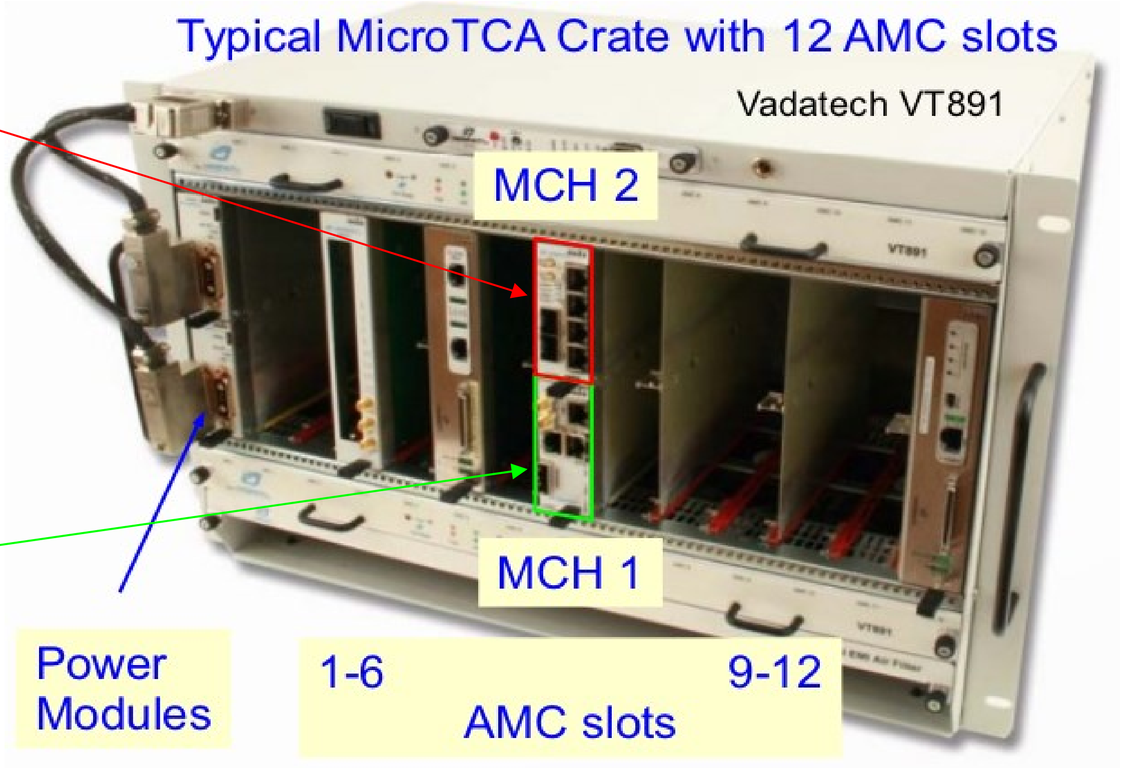
=> Will result an increase in data volume

=>Thus will require an upgrade of the back-end electronics.

μTCA

The Custom one: Distributes the LHC clock and collects data from μHTRs and sends them to CDAQ.

The Commercial one: Controls the power to all AMC modules



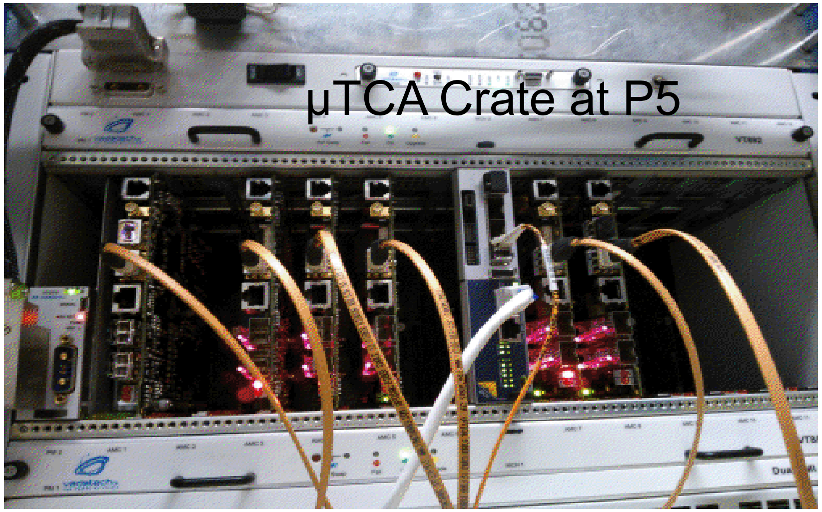
AMC/μHTR Card receives front end data and generates Trigger Primitives.
Hold the data pipeline while waiting for L1 Accept.
Also capable of luminosity calculation.

Developed firstly by telecommunication Industry.

Consists of 12 μHTR cards => (Minnesota + India). MCH2/AMC13 =>Boston

Fabrication, Testing and Installation

- 10 AMC cards (each has 12 layers) are made in an Indian Industry at Bangalore as a joint project of SINP and UMN.
- Initial tests such as blinking test, loading Firmware, assigning IP and MAC Address, data link test done at SINP
- A μTCA crate (Vadatech) has been installed at P5 in parallel to the existing VME.
- μHTR card (from the oldest design to the latest one) is fabricated, tested and validated successfully in India.
- For HF there will be 36 cards(in use) +18 cards(as spare).

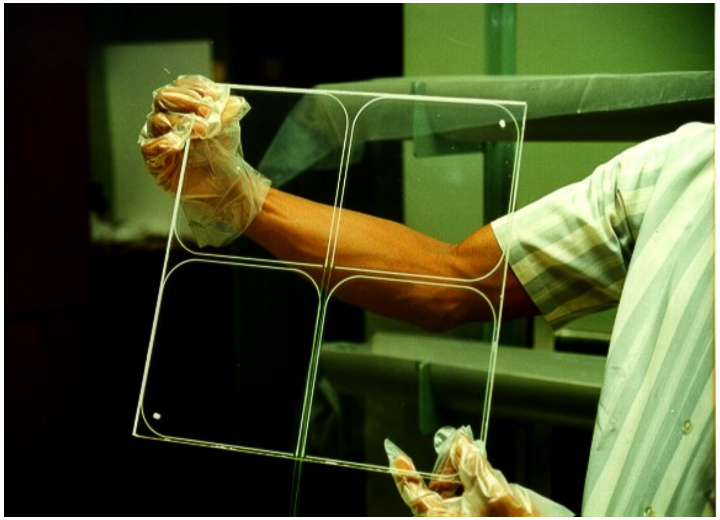


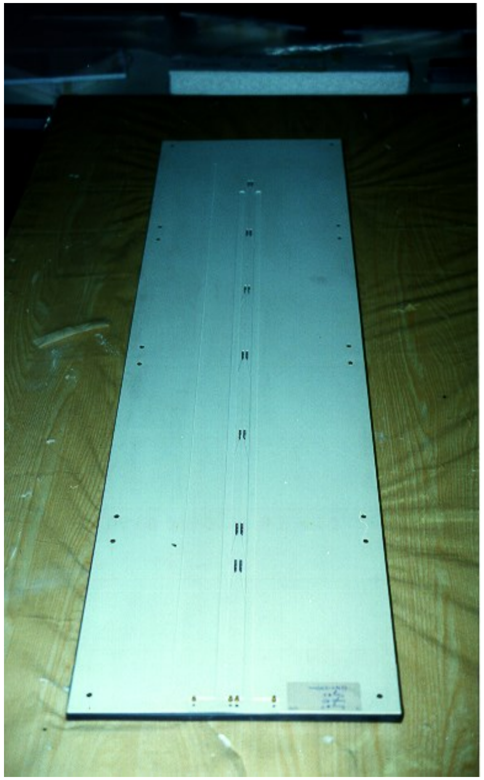
Summary

- **India-CERN Collaboration model has been very successful and productive**
  - India-CERN Coop. Agreement → Observer State → ….
  - Accelerator, Grid, ALICE, CMS
    - Hardware, Computing, Physics Analysis
- **Plans to participate upgrade activities**
  - LHC: Compact Linear Collider, LINAC-4 upgrade
  - Grid: Upgrade of computing resources, data links
  - ALICE: GEM, Muon Forward Tracker, Front end electronics
  - CMS: RE4, HCAL and Tracker upgrade
- **Need for developing human resources with engineering physics expertise**

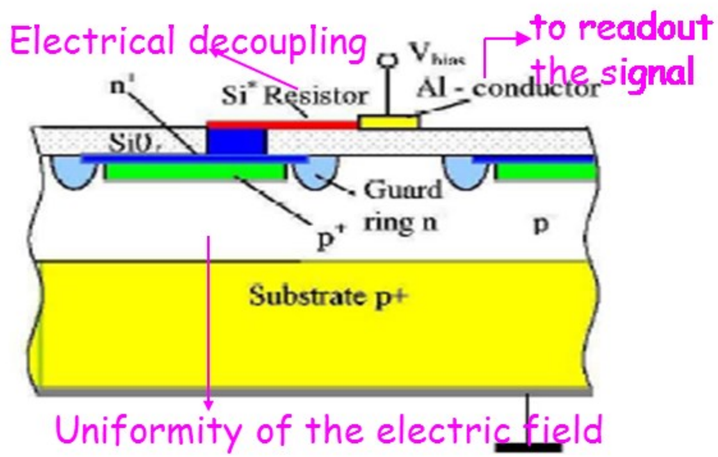
tifr

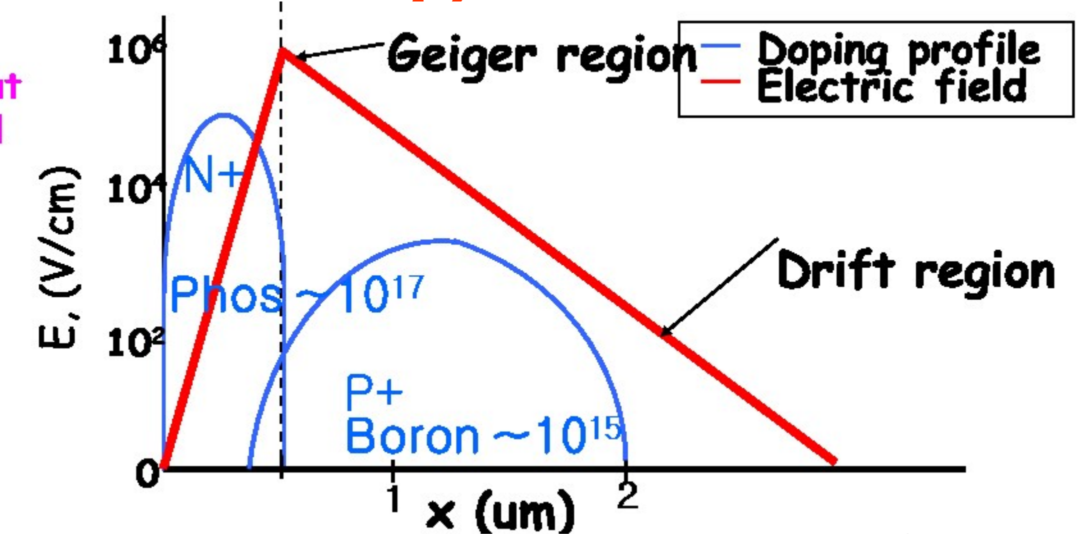
HO Detector Assembly





Typical design





Topology of SiPM