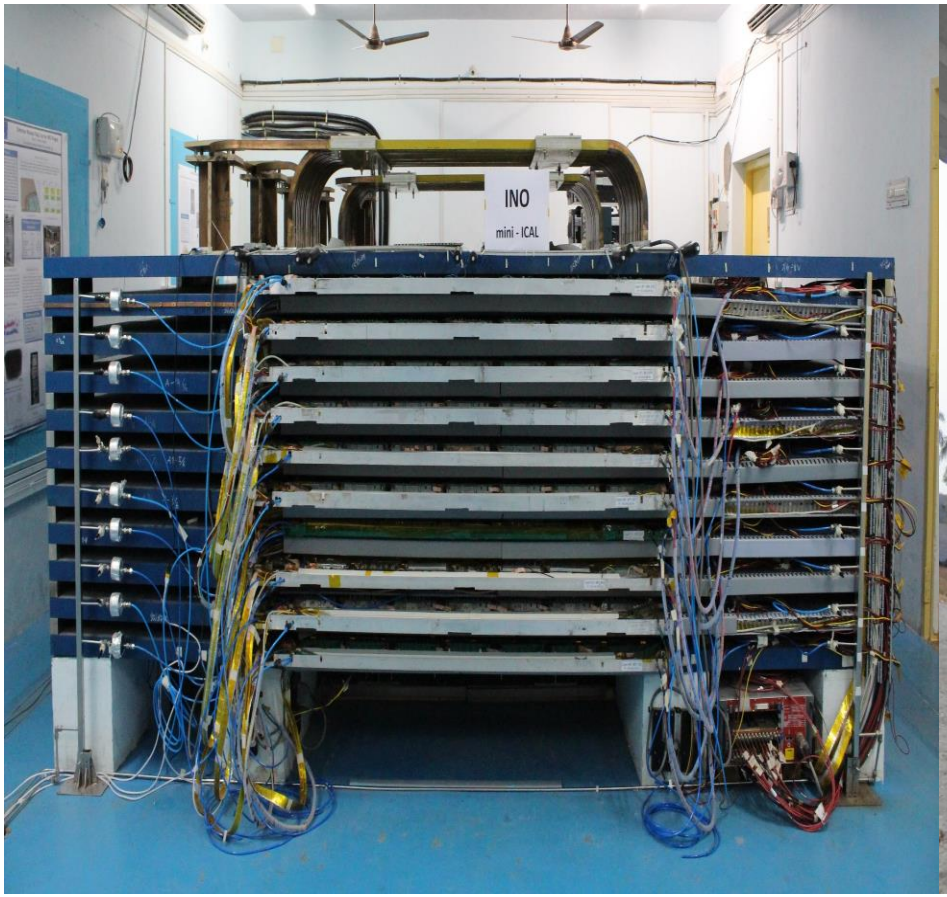
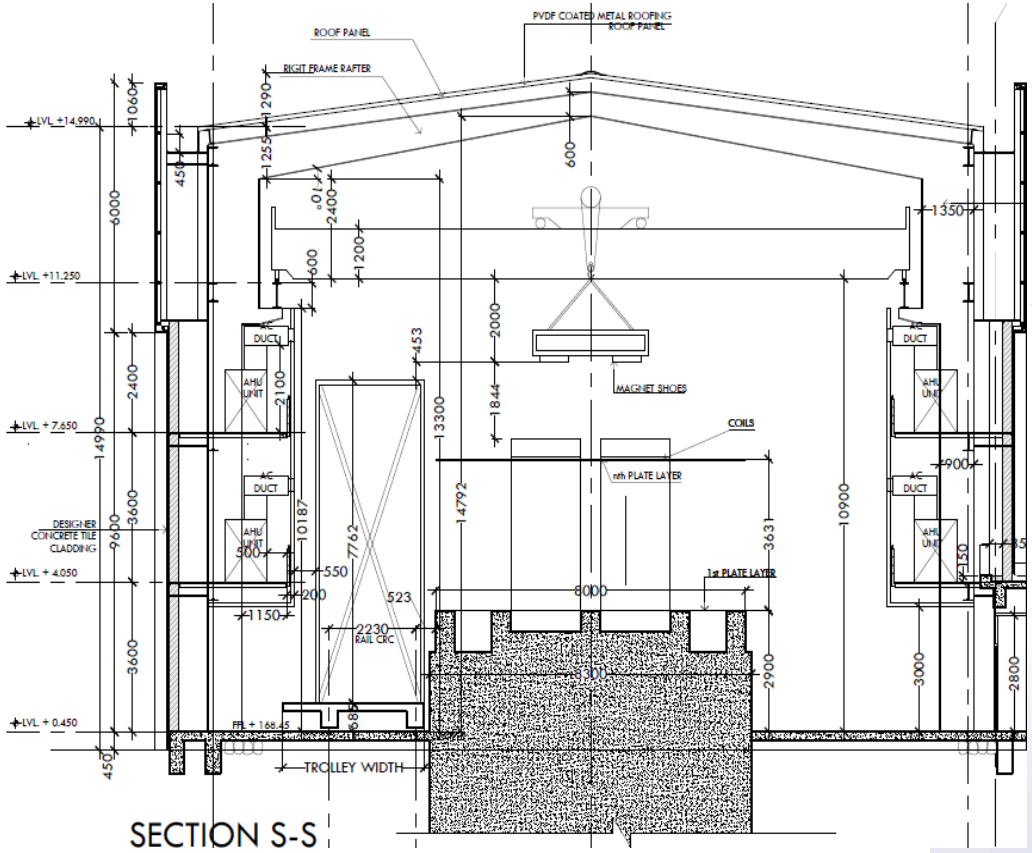
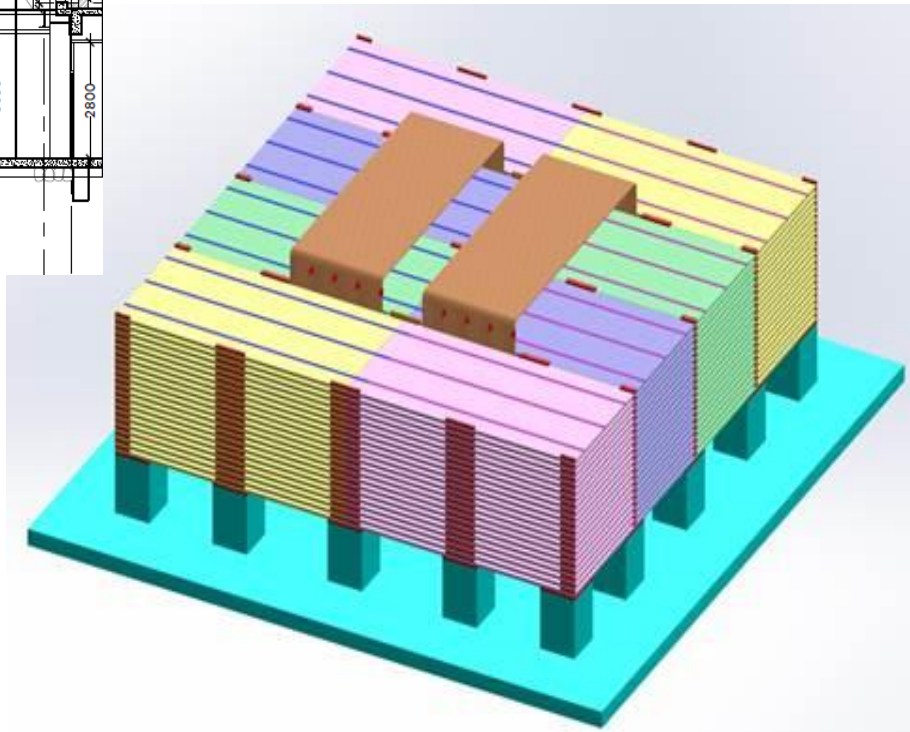
Engineering Journey for ICAL development



Engineering Module (E-ICAL)

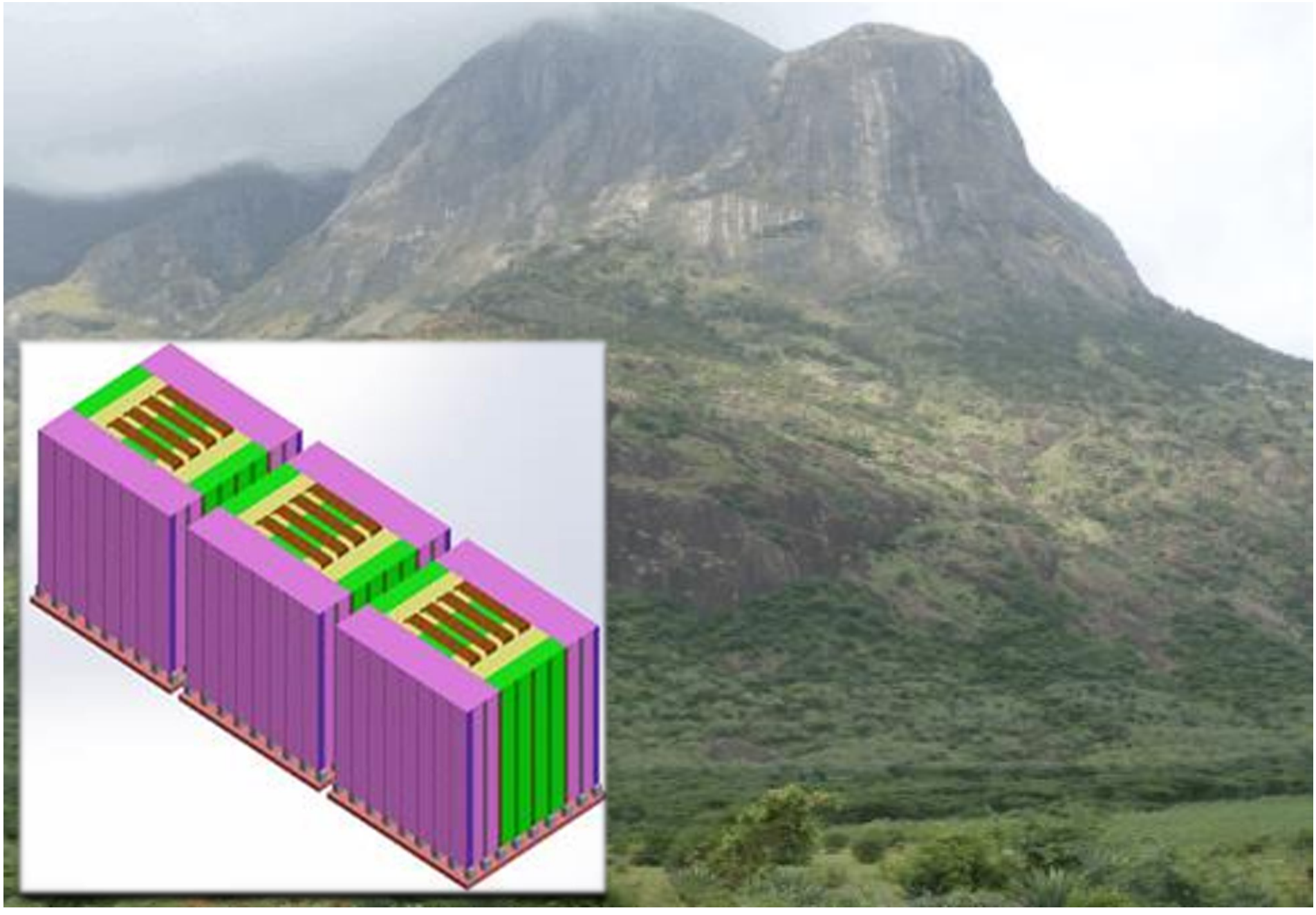


E-ICAL Layout Cross Section



E-ICAL Magnet Schematic

Full scale ICAL: underground



ICAL Magnets – A Comparison Contd.

Sl. No.	Parameter/ Description	Mini-ICAL	E-ICAL	Main ICAL
1.	Size (m)	4 x 4 x 1.8	8 x 8 x 3.1	16 x 16 x 15-each (3 modules)
2.	Weight	80 tons	660 tons	51000 tons (total)
3.	Plate size in m	1 x 2, 1.6 x 2, 1.2 x 2, 56mm tk	2 x 4, 56mm tk	2 x 4, 56mm tk
4.	Iron plates	77 (7/layer)	184 (8/layer)	15,000 (32/layer)
5.	No of layers	11	23	151
6.	No of RPCs	22 (2 x 2)	352 (2 x 2)	28,800 (total) 2 x 2
7.	No of coil & turns	2, 18/coil	2, 38/coil	4, 30/coil
8.	AT rating (for 1T field)	30.6kAT	52kAT	80kAT
9.	Conductor size in mm	30 x 30 with Ø17 hole	30 x 30 with Ø17 hole	30 x 30 with Ø17 hole

Deciding Magnetic Properties for ICAL magnet plates

Desirable magnetic properties of soft iron plate

1. Minimum residual magnetic field
2. Minimum cohesive force
3. High permeability, knee point

Acceptable Properties:

Sr. No	Parameters	Values (Allowable tol: 2%)
1.	The knee point of B-H curve	1.5 Tesla
2.	Saturation induction B_{sat}	2 Tesla
3.	Magnetic field intensity required for 1 T	< 350 A/m
4.	Magnetic field intensity required for 1.5 T	< 1500 A/m
5.	Maximum relative permeability	> 2300
6.	Coercive force	< 150 A/m
7.	Residual induction	1.2± 0.2 T

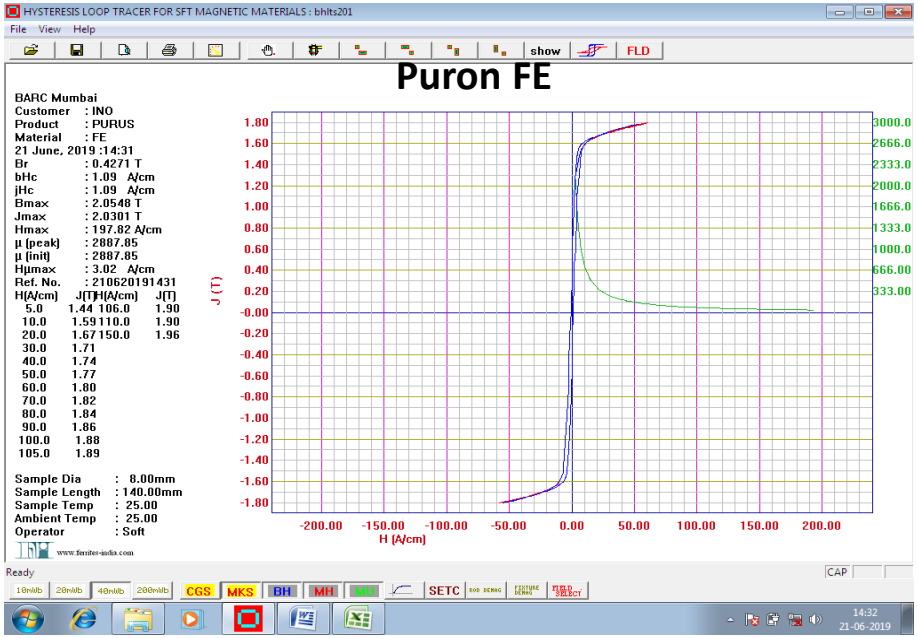
Impurities/additives present in iron result in changes in magnetic properties

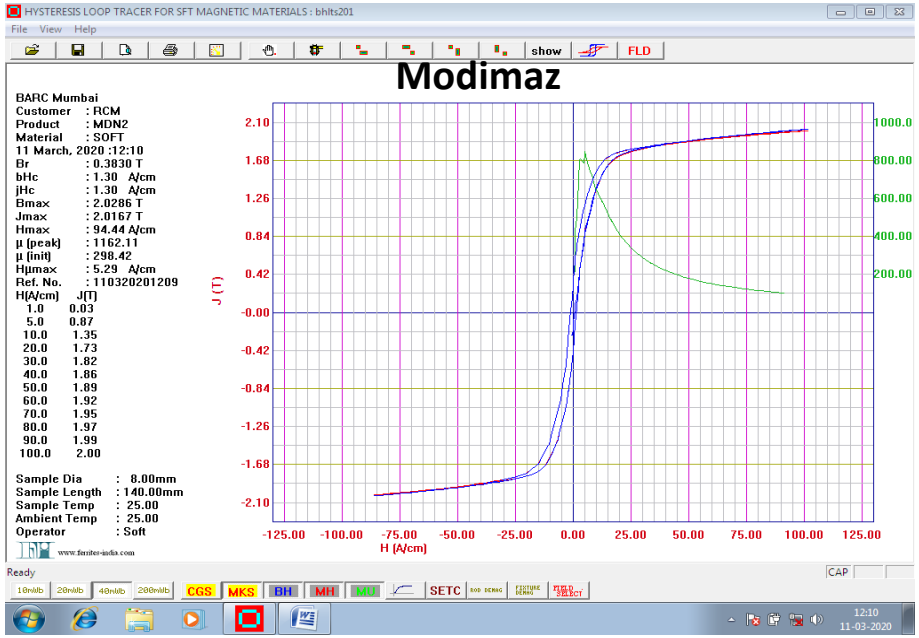
Plate rolling method, temperature control, metallurgical factors, plate machining methods etc also affect the magnetic properties.

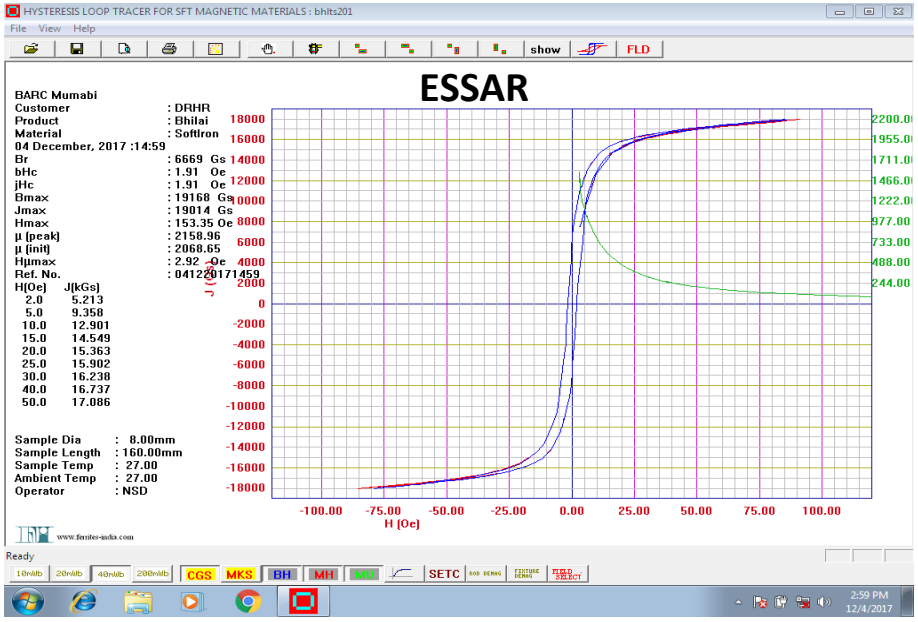
A detail study and trials have enabled us to finalize plate magnetic properties with respect to chemical composition, rolling and machining methods.

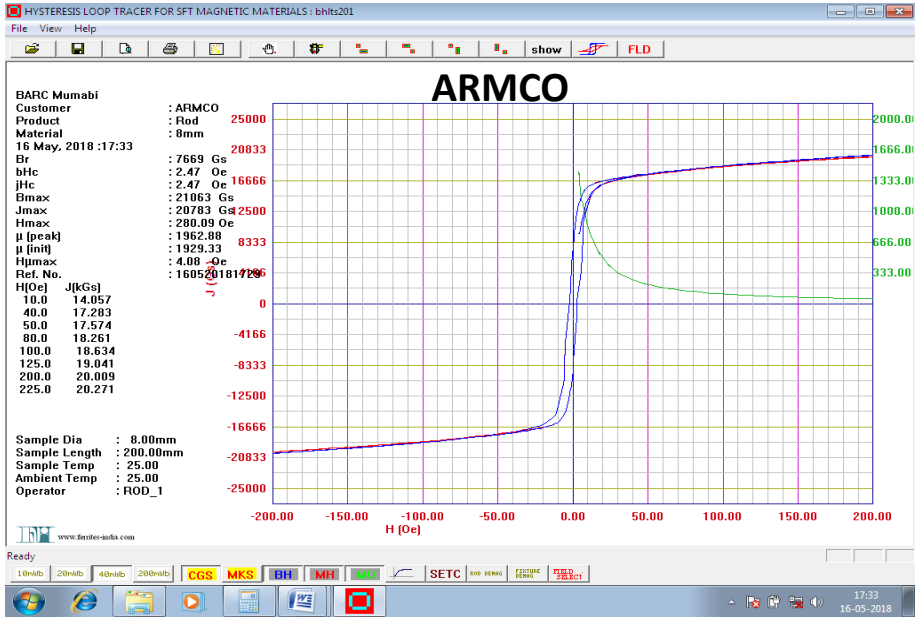
Plate samples of different configurations from industry were studied

Sample Studies contd.



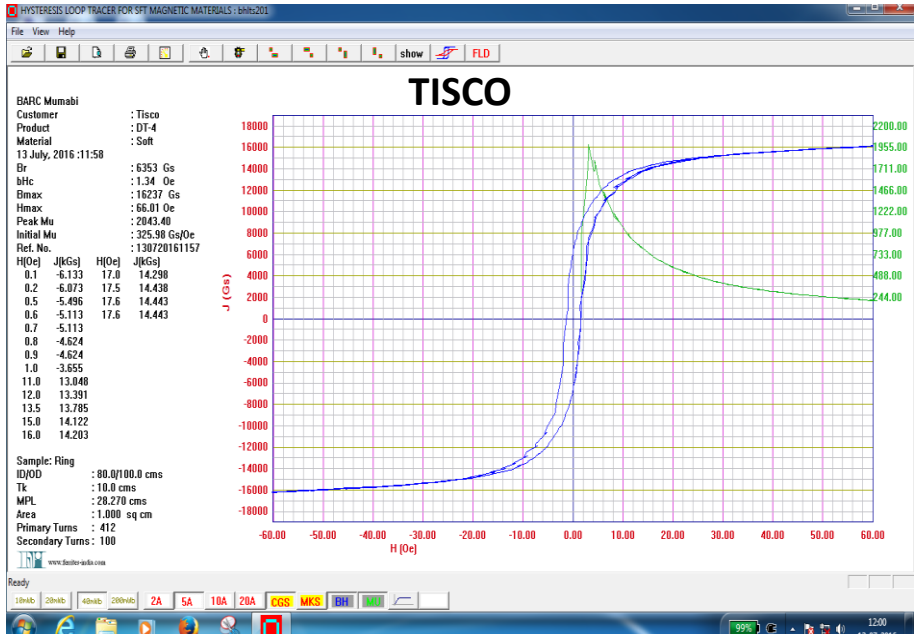




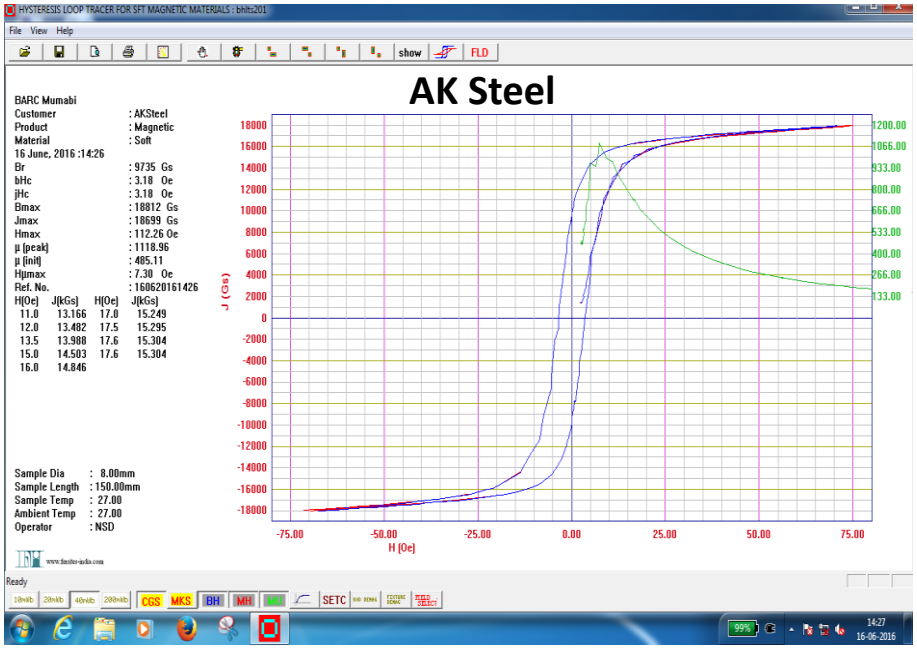


Sample Studies contd.

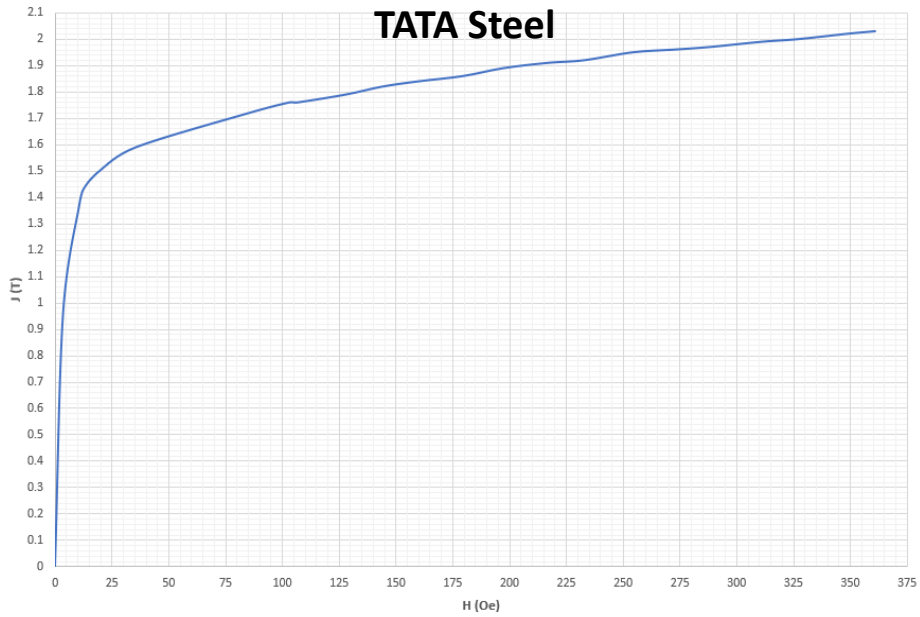
TISCO



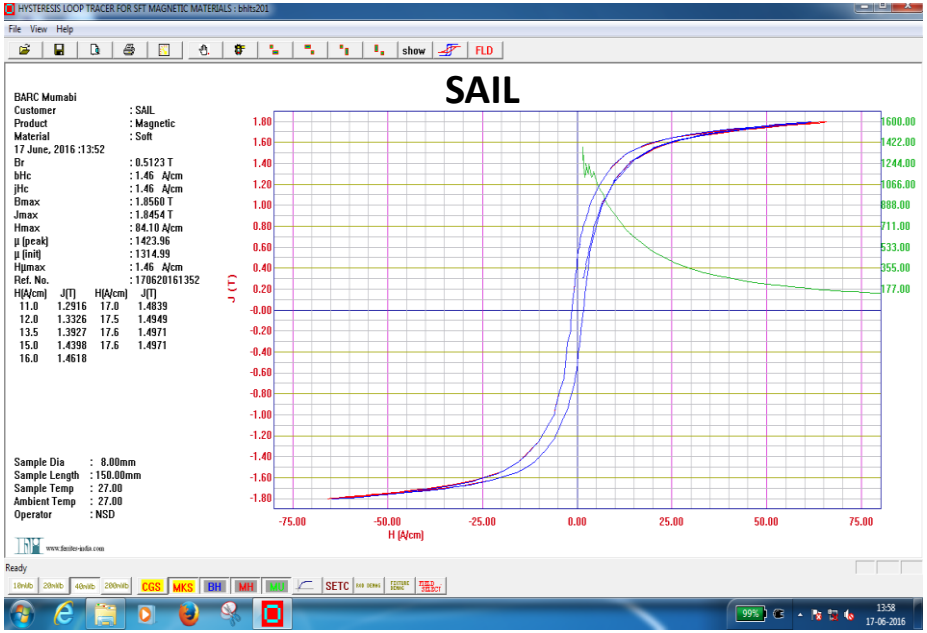
AK Steel



TATA Steel



SAIL



Deciding Chemical Composition

- Reducing carbon content increases soft iron nature
- This inturn decreases structural strength.
- Using simulations of mechanical and magnetic simulations, optimal value of carbon was decided for necessary strength and magnetic field.
- The simulation results were reflected in actual assembly with 5% deviation
- Finalized chemical composition in percentage (ESSAR):

Elements	C	Mn	P	S	Si	Al	N (CPPM)	Fe
Percentage (%)	0.07	0.35	0.019	0.009	0.1	0.01	65	Balance
	± 0.02	±0.05	±0.004	±0.001	±0.1	±0.01	± 5	to be reported

Plate Machining

- To meet functional requirements only edges of iron plates machined. Rolled surfaces are not machined.
- Heat Affected zone created by Plasma cutting was removed by further machining / waterjet cutting.
- Time and cost comparisons for waterjet machining and conventional machining provides deciding inputs for subsequent plate machining.
- Standard setting for plate machining has been established to achieve drawing specifications.

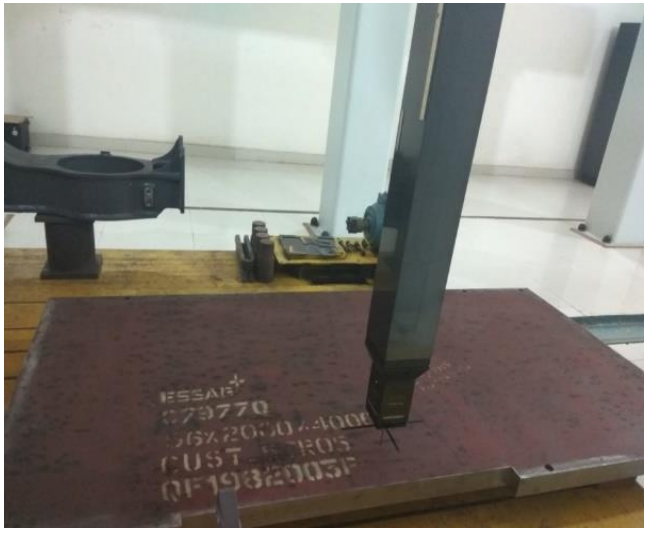
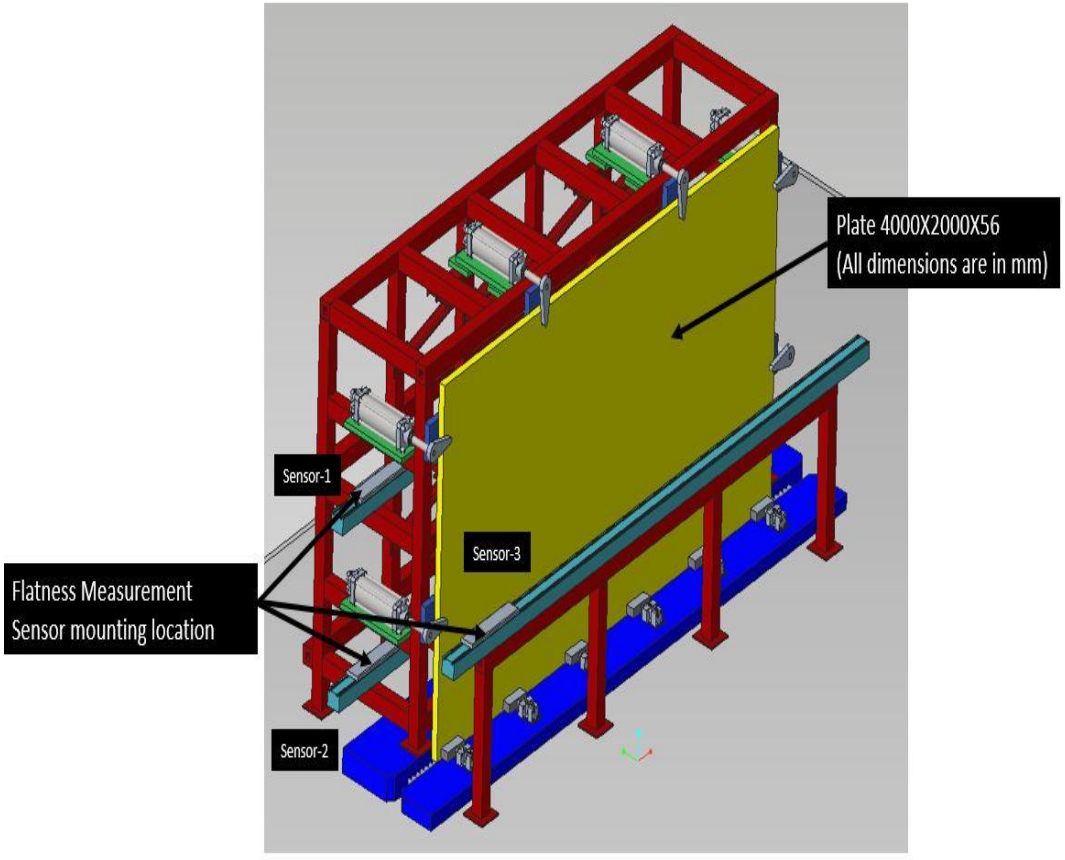


Plate Flatness

- Based on height of RPC tray, plate flatness, plate deflection, and assembly tolerances ,gap between two Iron plate layers has been finalized to be 45mm.
- This minimum gap has been taken to decide full scale ICAL height in a cavern.
- An stringent value of 4mm flatness in a length of 4meter has been decided against ASTM standard of 8mm.
- A laser based plate flatness measurement system is under development.



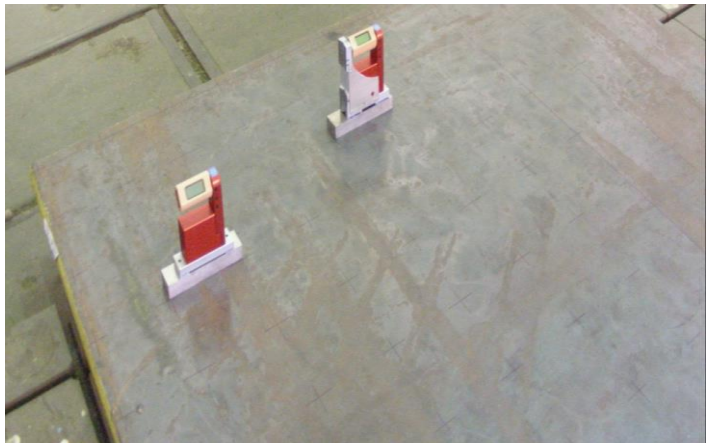
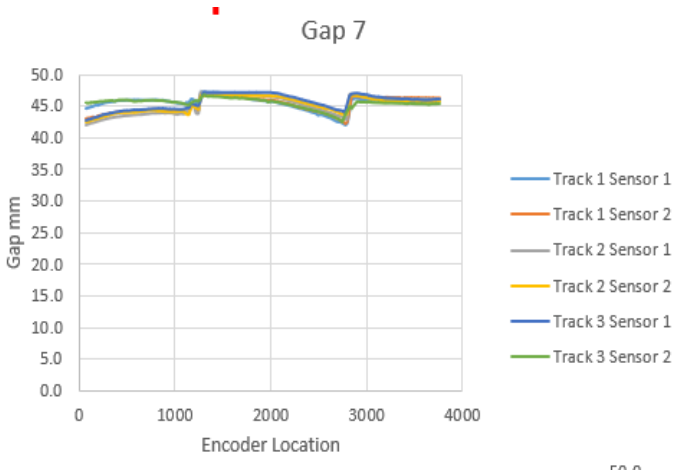


Plate corrosion resistance treatment for 40 years life

Iron Plate coating		
Product Detail / Specification	Product Name	DFT-µm
Inorganic Zinc silicate primer F-9 > 80% Zinc	Zinc -0- Sil 75 - Grey	75
High build epoxy intermediate coat	Pentadure HB 5540	125
High build epoxy MIO	Pentadure HB MIO 5567	125
Aliphatic Acrylic PU top coat	Pentathane HS 4510	50
Thinner	Thinner for Above	
	Total Film Thickness µm	375

Plate gap measurement

- Gap between two layers is created by SS spacers. Plates are locked by pins in spacers.
- Variation in gap due to plate flatness (~4mm), thickness tolerance(~0.5 mm) & assembly tolerance(~0.1mm) and plate deflection.
- Gap margin 10mm can come down to 1mm.
- Gap measurement during assembly by analogue inductive proximity sensor set up.
- Vehicle with 2 sensors driven by timer pulley.
- Sensor location measured by encoder
- PLC controlled DAQ panel for data acquisition.
- The system is operated through custom built software.



Copper Coil

- Copper coil procured in spools of 200 mtr.
- Special tools, dies, Jigs,fixtures developed for de-twisting/straitening and forming.
- Gap between two consecutive conductor : 12mm available for in-situ brazing.
- Total joints to be brazed: 80 Nos.

Brazing machine design criteria:

i. Localized heating for brazing efficiency.
ii. Low time of brazing
iii. Heating element suitable to 12mm gap.
iv. Low joint electrical resistance

Brazing machine was developed with

i. Induction heating method & water cooled inductor of 10mm thickness.
ii. Joint brazing time: 30s (Excluding setup)
iii. silver based filler for low joint resistence








Assembly: Mini ICAL

ICAL Assembly

- Special consideration and preparation is required for assembly of an ICAL magnet

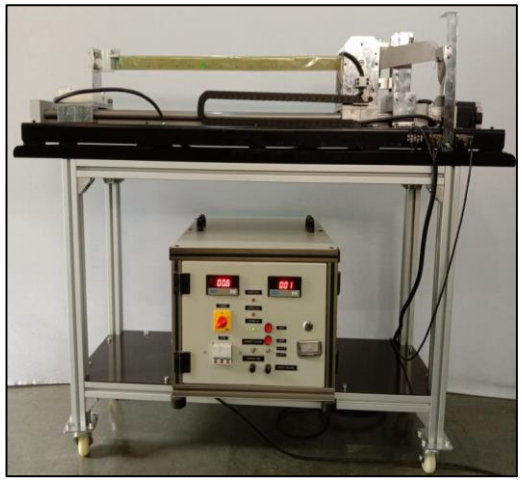
1. Space available
2. Plate handling method and safety during plate handling
3. No damage to plates and to corrosion resistant coating of the plate during handling
4. Matching of the plate with respect to adjacent plates
5. Assembly gap among adjacent plates
6. Achieving intended gap between two plates for placement of hall probe sensors.
7. Matching plate holes with spacer pins
8. Flatness of one layer of plate assembly
9. Fixing of aluminium guides on the plate for tray movement
10. Assembly of next layer of plates
11. Measurement of gap between two layers and correction in the assembly if required with respect to required gap of 45 mm
12. Placement of search coil on designated plate layers
13. Provision for supporting data cables etc

Magnetic Field Measurement

Technique Name	Type	Range(mT)	Accuracy	Frequency Response	Applicability	Remarks
Fluxmeter	Vector	1to 10^4	High	AC	Applicable	Wide range, Good accuracy
Hall sensor	Vector	10^2 to 10^4	Medium	DC and AC	Applicable	Wide range, Good accuracy
Fluxgate	Vector	$10^{-9}$to 5	Medium	DC and AC	Not Applicable	Low range upto 5mT
Magneto-resistance	Scalar	5×10^{-1} to 5	Low	DC and AC	Not Applicable	Low range, Low accuracy
NMR	Scalar	5×10^2 to 10^4	Very High	DC	Not Applicable	Range starts from 500mT stability problem , difficult to implement
Squid	Vector	2×10^{-9} to 1	Low	DC	Not Applicable	Low range, Low accuracy, Need very low temperature
Magneto-optical	Scalar	50 to 10^4	Very low	DC	Not Applicable	Low accuracy

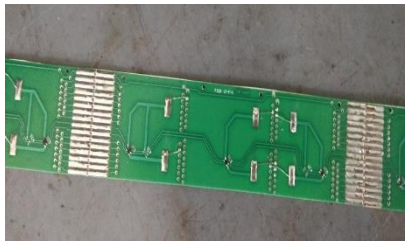
- The magnetic measurement system at Mini ICAL magnet is a search coil and hall probe-based system.
- Search coil measures the average field inside the cross-sectional area of iron plate during dynamic conditions ie ramping up and ramping down. Hall probe measures the field during both steady state & dynamic condition of the magnet.
- A series of equidistant hall probes inserted in the gap between adjacent plates in specific layers. To account for non-linearity of hall probes electromagnet based multi point calibrator at multiple reference field points.
- The magnetic field values obtained from hall probes and search coil are being continuously monitored and stored

Magnetic Field Measurement



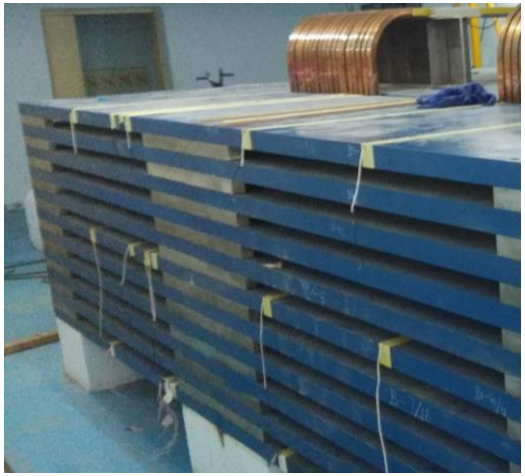
Multipoint calibration unit for hall sensors

Hall probe PCB inserted for magnetic measurement

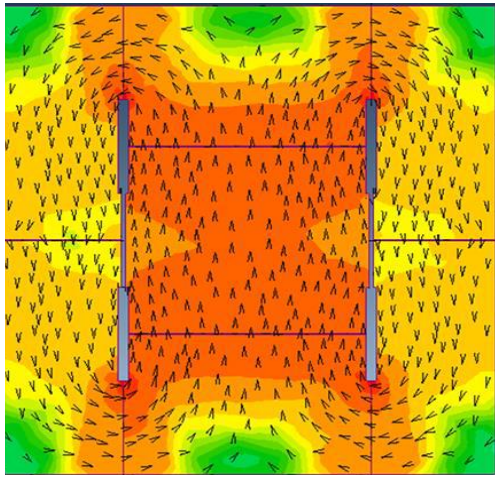


Hall sensor PCB strip

Polarity reversal switch for demagnetization



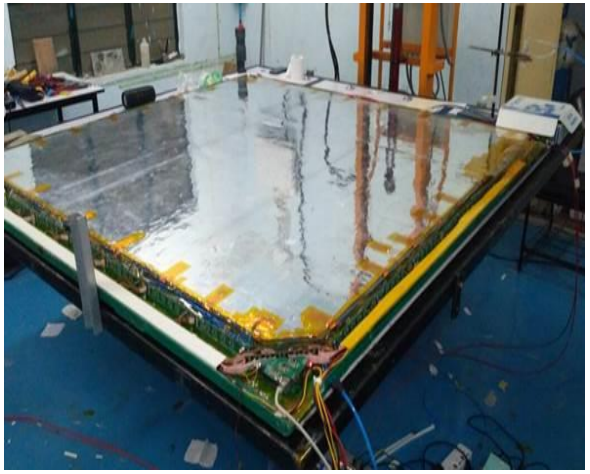
Search coils for magnetic measurement



Magnetic field pattern in a layer

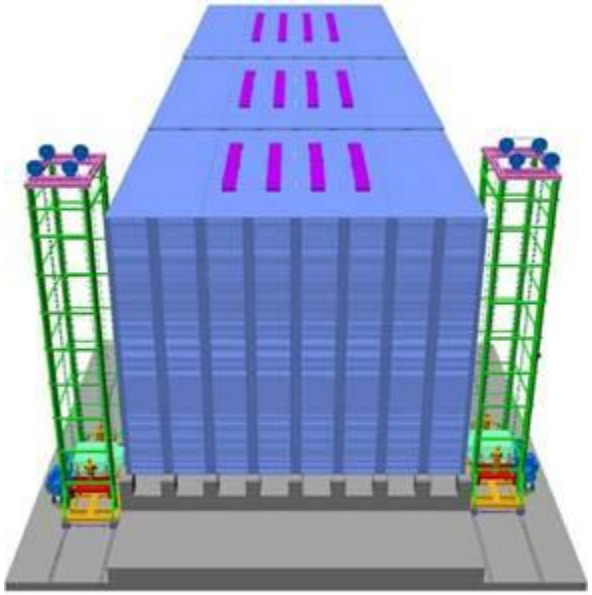
RPC Trolley & Shelf Automation

RPC Trolley

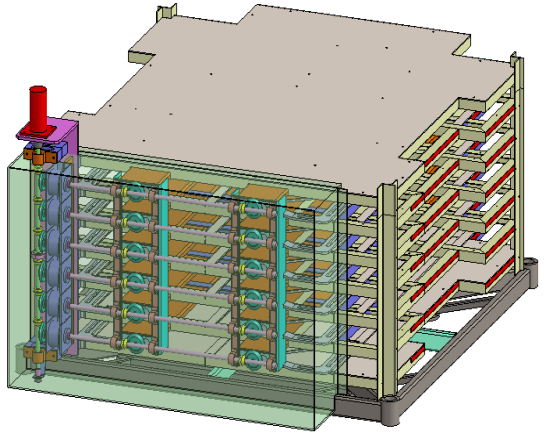


Assembled RPC ready for insertion in Min ICAL

Manual insertion of RPC in Mini ICAL

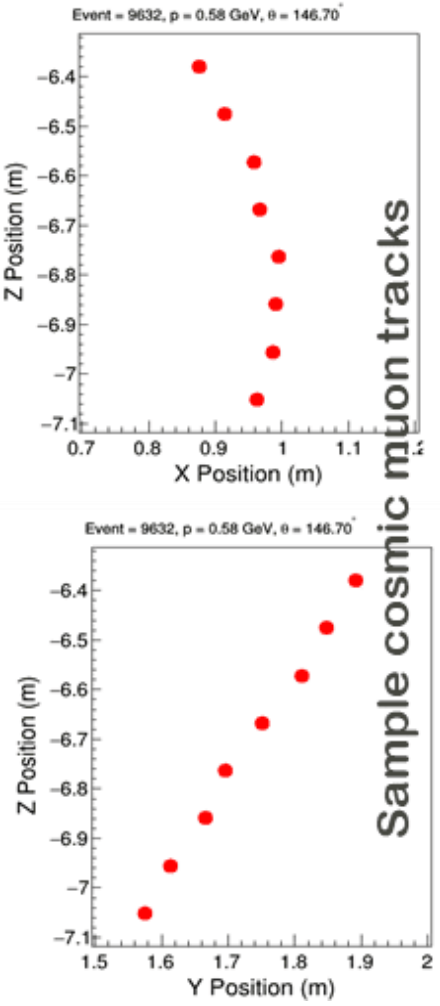


RPC Trolley @ Main ICAL Schematic



RPC Shelf Automation

Cosmic muon tracks @ Mini ICAL



Thank you