# Indian Efforts for Easier Manufacturing of Cryomodules

**Prashant Khare**

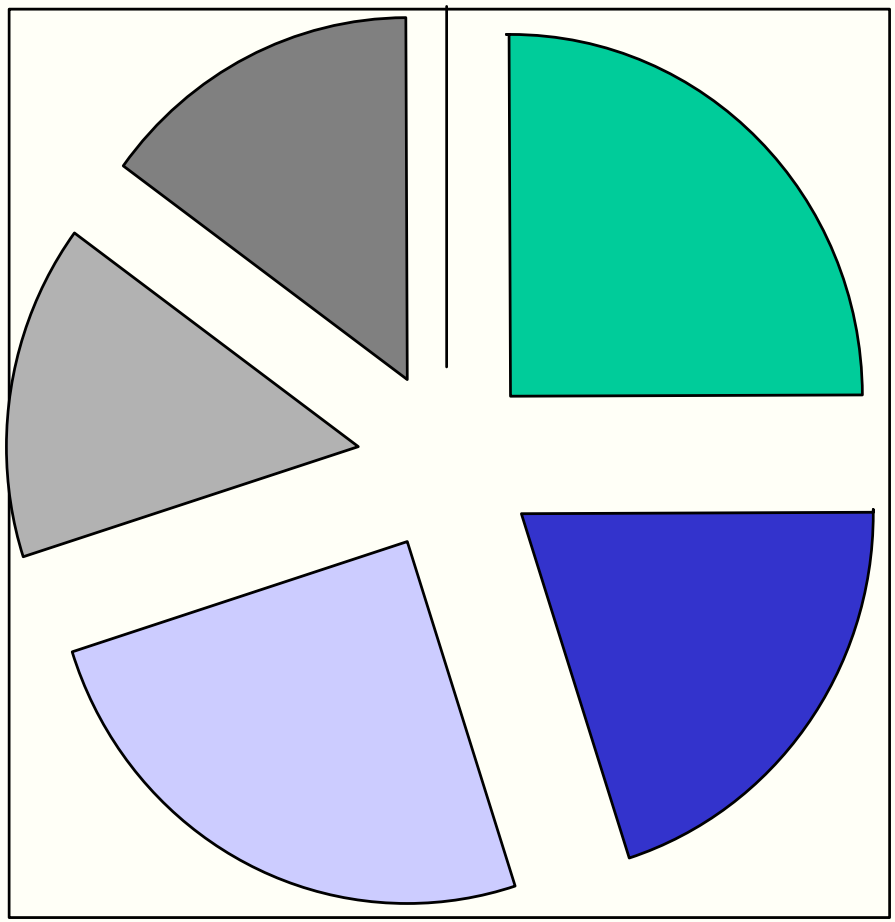
**RRCAT, India**

**Collaborators**:

**P.K.Kush,R.K.Khare, Vikas Jain,S.D.Sharma**

# SCRF Technology: Mission Critical Areas

*-the way we see it*



- SC Cavity Forming & EB Welding
- Cavity Processing
- Cryomodule Design & Proto.
- Cryogenic system
- RF Tech

# Rationale for Effort on Easier Manufacturing

- Like to understand design issues first,design,prototype and test and then move ahead, instead of just using existing designs.

- Our technical strength and capability to achieve economy of manufacturing lies in different sphere. Ex. CNC machining Vs EB Welding.

- Need to develop and demonstrate subsystems also, in reasonable time frame, as the infrastructure is also coming up.

- **WE UNDERSTAND**

*PRESENT DESIGN IS A RESULT OF YEARS OF INTENSE TECHNOLOGICAL EFFORT BY EXPERTS. & LITTLE SCOPE FOR IMPROVEMENT EXISTS.*

# New Value Engineering Concepts

**We would like to explore new designs only if**

**- Very significant cost advantage is apparent.**

**or**

**-Manufacturing time can be drastically reduced.**

**or**

**- Can think of alternate route which circumvents technologies, on which we don't have command.**

**-But will need timely expert advice.**

# Cryomodule Design Studies

## Cryogenic engineering intensive

- Cavity support & alignment system
- Thermal intercepts
- Helium Vessel for cavities & Magnetic Shielding.
- Cryogen Flow circuit
- Radiation Shields & MLI blankets

## Conventional Mech. Engg. dominated

- Vacuum Vessel
- Support Posts on Vacuum Vessel
- Tuners
- Transportation issues

## Multidisciplinary Areas

- Coupler
- Clean Room assembly
- Final assembly
- Alignment methodology

# STATUS

**Understanding design issues for different subsystems initiated.**

**A.Initially targeted cavity support system and helium vessel. Evolving a different concept for first activity.**

**B. In Parallel we are pursuing manufacturing of end group through alternate method.**

**C.A shorter cryomodule to house a couple of cavities is our goal.**

# Future Plans

A. Fabricate a scaled down cavity support system.

B. After two low RRR Nb end groups we will make end groups in high RRR Nb.

C. Start designing of helium vessel.

D. Gradually take up other subsystems which are mostly in our "core competence area".

Effort is to understand physics & engineering design issues completely before launching fabrication/ prototyping of the subsystem.

# Case Study 1 - End Group

## Design for Manufacturing

### Rationale for choosing this component :

- EBW based design will be time taking & waste lot of Nb.
- 60% cost of SC cavity due to expensive end groups.
- High manufacturing time.

### Goal

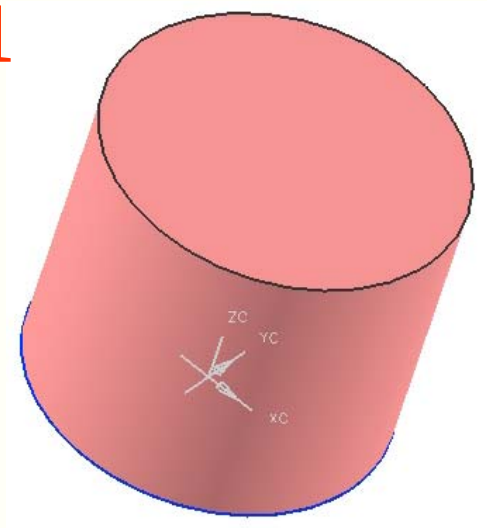
- Economy +Less development & manufacturing time.

### Approach

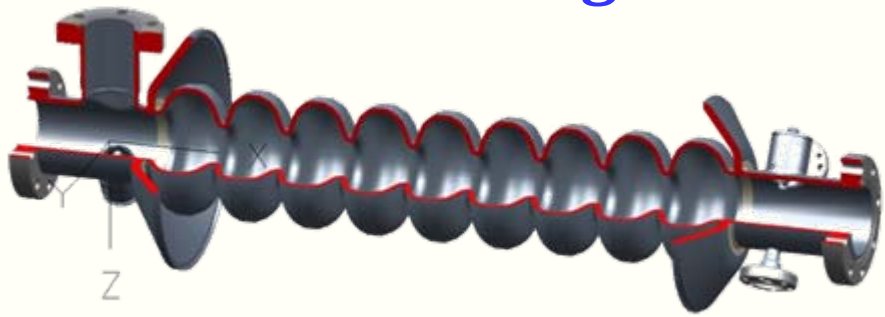
- Machining of end group from a single Nb block.
- Thus minimize costly EBW & pre weld processing.
- May bring down the cost of SC Cavity by 20-25%.
- End Group cost from $18000 to $13000 a piece.
- Extensive prototyping and testing required.

# The Concept

**STEP 1**




**Procure Billet. By taking a billet cost of rolling is avoided.**




**SIZE** Diameter 130 mm
Length 120 mm

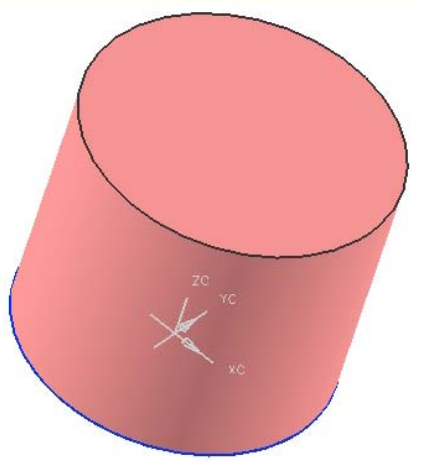
**Allowance** 4mm on diameter
6mm on length

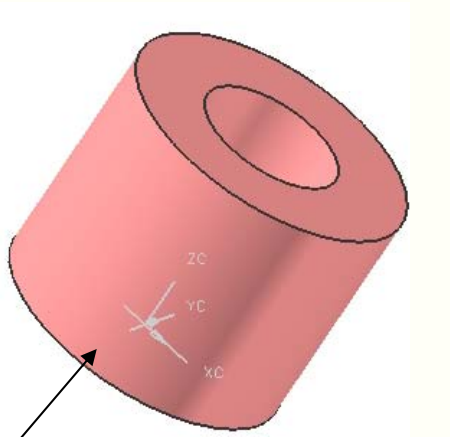
**COST** $ 6700 @ $500/kg)

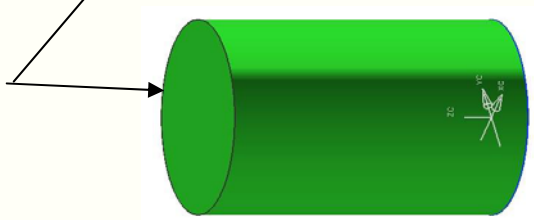
**To Be on safer side we are taking cost of Nb in form of a sheet**

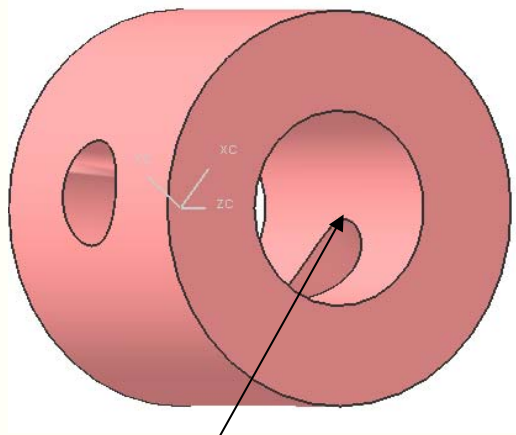
# The Concept

## STEP 2






## STEP 3

**Needs smooth radius to avoid sharp edge.**

**Use form tool**

## Wire cut operation

**Pipe size – I.D. 74 mm**

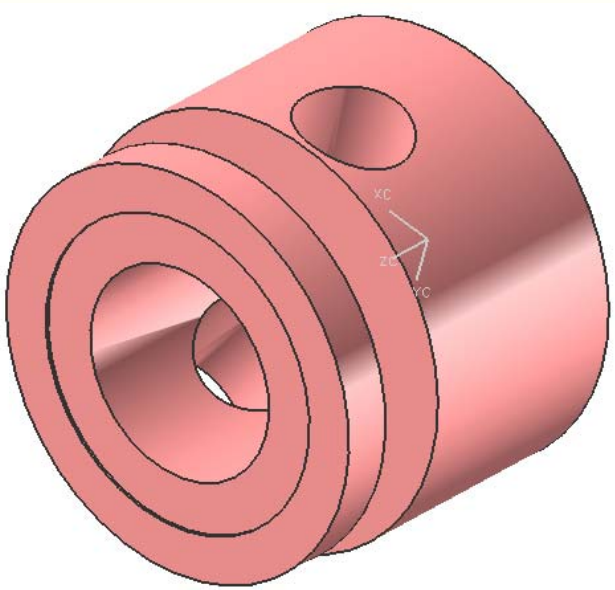
**O.D 130mm**

**Solid Cyl.– Dia. 64mm**

## Radial Drilling

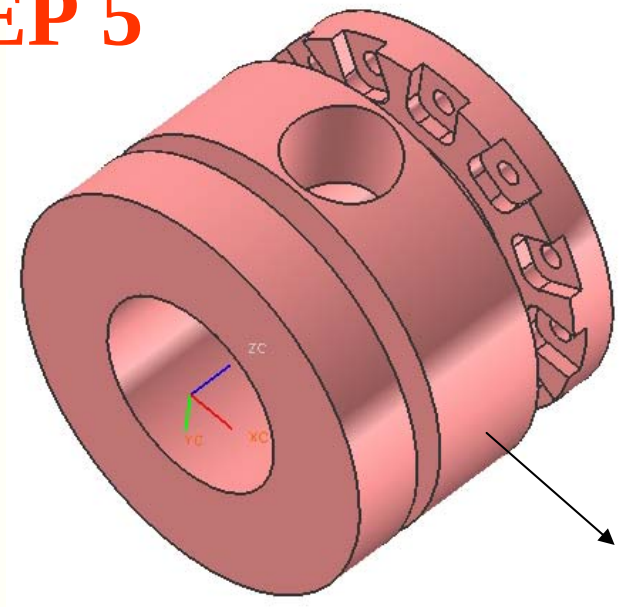
# The Concept

## STEP 4




TURNING INNER FLANGE

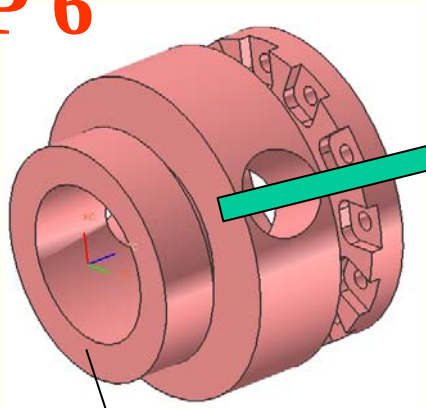
## STEP 5



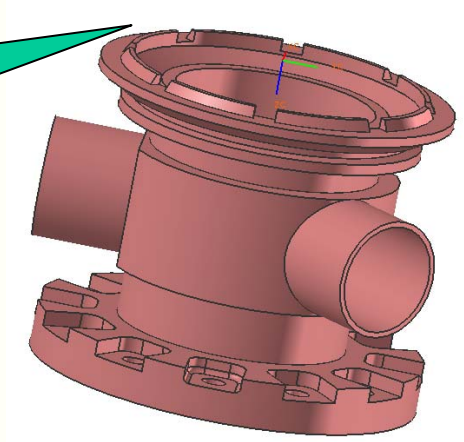

TURNING OUTER FLANGE & MILLING

# The Concept

**STEP 6**

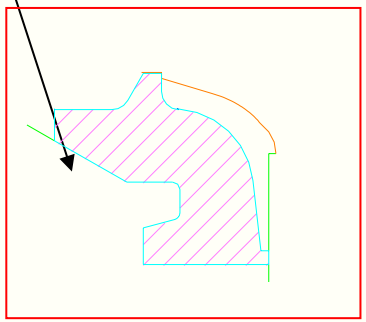


To give



**STEP 7**

**FINISHING INNER FLANGE TO PERFECT SHAPE (KEPT SIMPLE HERE)**



**a.** MILLING OFF EXTRA MATERIAL

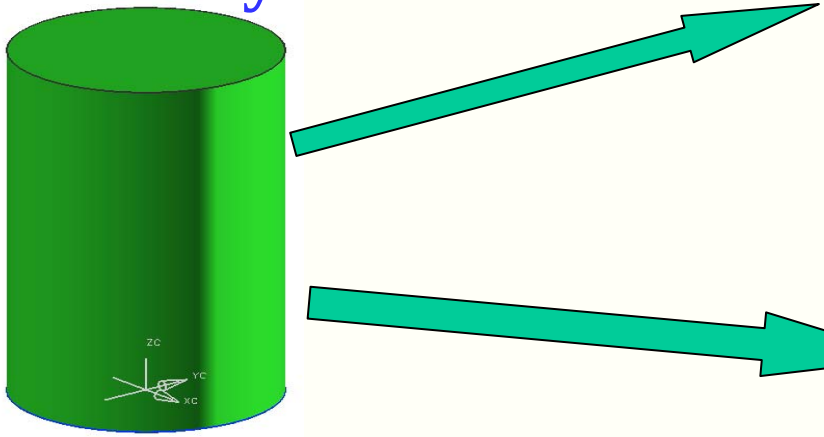
**b. Final turning for beam pipe and ports.**

**c.Leaving the reinforcement of tuner port (not shown).**

# The Concept

## STEP 8

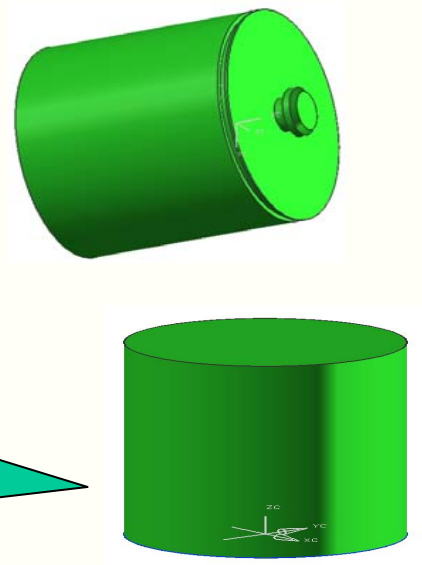
Parting of
Solid Cylinder



Size -- Dia 64 mm

Length 115mm

## STEP 9



Spare

Machining
Form teil
housing with
HOM spool
piece

DIA 64mm

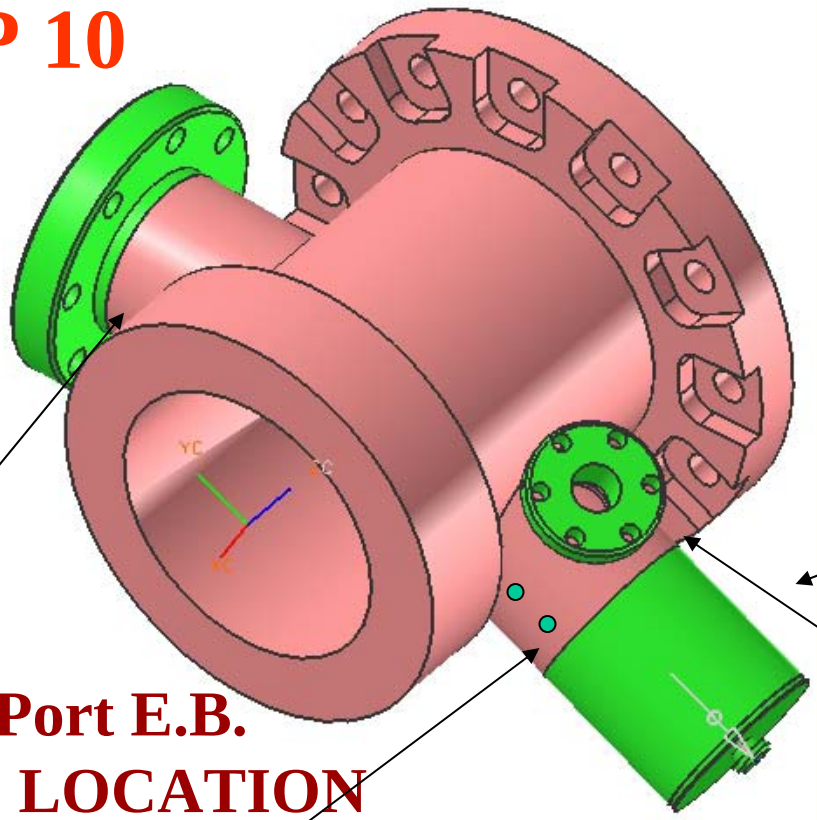
LENGTH 48 mm

Worth $ 750Avoided if industry can give a pipe

+ EDM wire cut cost $250 Total $1000

# Electron Beam Welding

**STEP 10**



**Tuner Port E.B. WELD LOCATION**

**STEP 11**

Form Teil Housing

Weld Location

**5 EB WELD JOINTS in all**

**STEP 12**

Welding of NbTi Flange

**STEP 13**

E.B. Weld Location for form tail.

# Advantages

- Just 5 EB weld Joints instead of 13.
- No pull outs.
- Machining operations.Better control on tolerances.
- Reduced time of manufacturing.
- Rejections go down as we are not experts at EBW.

- Further scopes for cost reduction
  - Billet in form of pipe.
  - Some use of scrap Nb.
  - Improvise process to take out stiffening rings.
  - Exploring use of just Dia 115mm billet.

# Interesting Economics

## *Indian Estimates*

**ECONOMICS**

| | |
|---|---|
| **1.Cost of Nb. Block @$500/kg** | **$6700** |
| **2.Cost of NbTi @$500/kg** | **$250** |
| **3.Machining cost** | **$ 2500** |
| **4.EB Welding @ $500/hr** | **$ 2500** |
| **5. Miscellaneous** | **$ 1000** |
| **TOTAL** | **$ 13000** |

**Buffers Available**

A.If billet is available in form of pipe $ 1000

Billet cost should be lower than sheets.

Any Value of Scrap?

# STATUS

## Three Prototypes in Copper are Ready

First Prototype

Second Prototype

Third Prototype

Third Prototype

# Prototype in Low RRR Nb

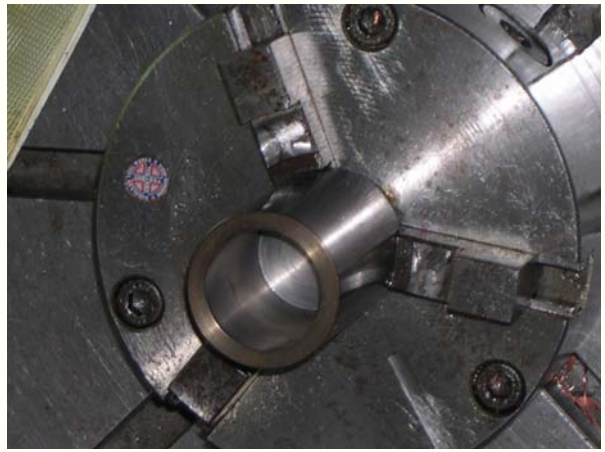
## Wire Cutting Operation

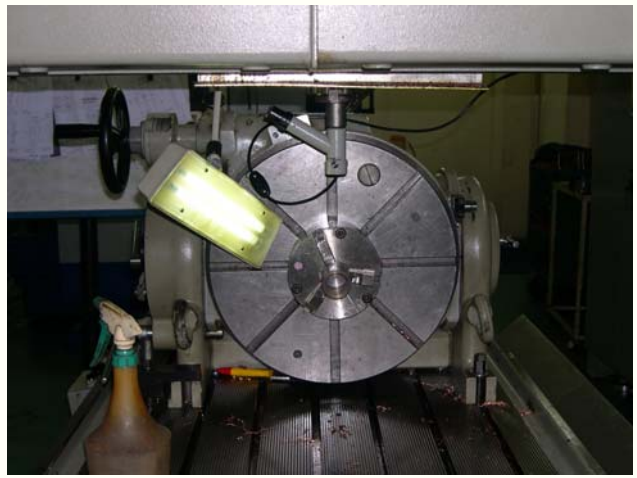
- Drill a hole of Diameter 4mm at radius 35 mm.
- EDM Wire Cut operation

# Machining of Form teil housing

**Solid Cylinder from wire cut operation**

## Machining





**A.Cutting Speed 230m/min**

**B. Feed 0.04mm/rev**

**C. Depth of cut 0.25mm**

# Summary

- We hope to complete the development of Low RRR Nb end group by the end of 2008.
- Then we can start on actual end group in high RRR Nb.

# Case Study -2 Cavity Support system

## Design for Manufacturing

### Rationale for choosing this component :

- Cumbersome and expensive method of making HGR pipe.
- Needs huge milling machine & transportation of structure.

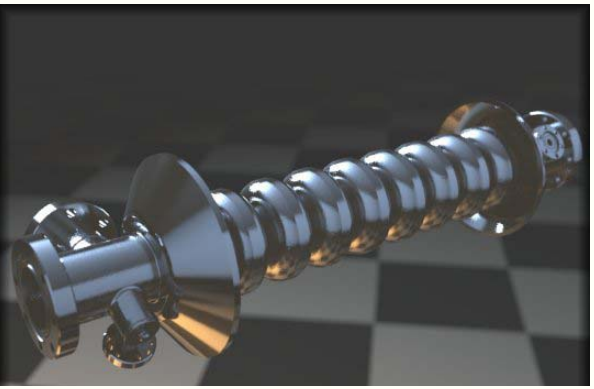
### Goal

- Use of commercially available pipe.
- Economy & ease in manufacturing. Reduced time also.
- Reduce the range for needle bearing block.

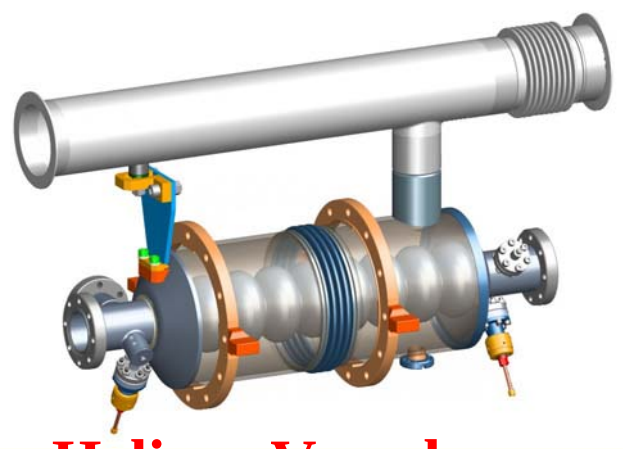
### Approach

Split the support and incorporate a joint to compensate pipe inaccuracy.Use pulse laser welding for low distortion.

**Prototyping not started.Looking for issues that are not addressed.**

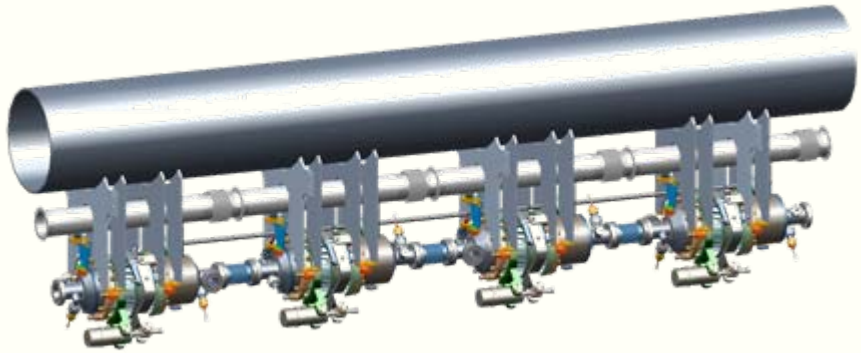


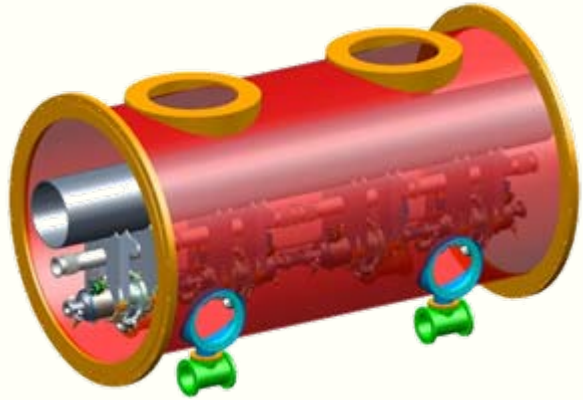
A Typical SC Cavity



Helium Vessel

Beginning Cold mass Structure

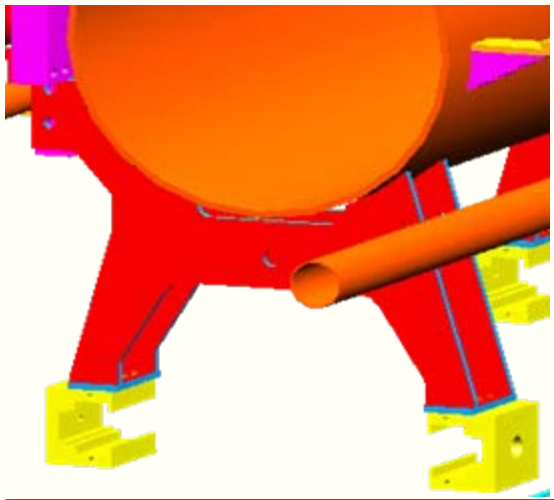


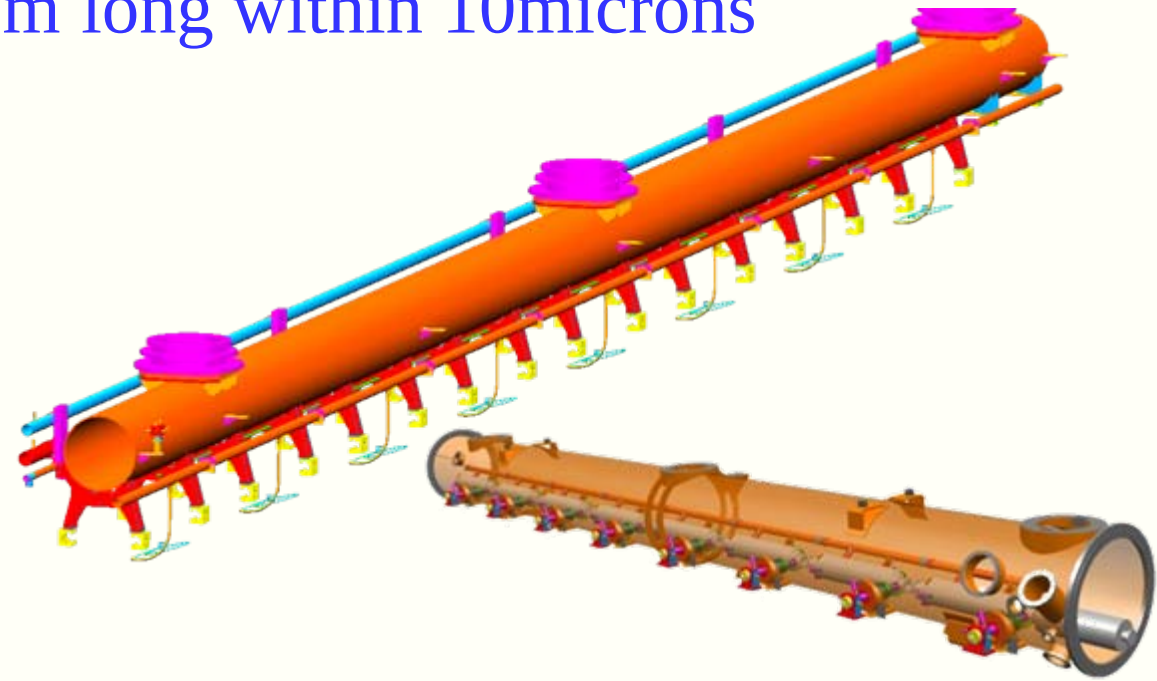


3.9 GHz Cryomodule

# Present manufacturing Scheme

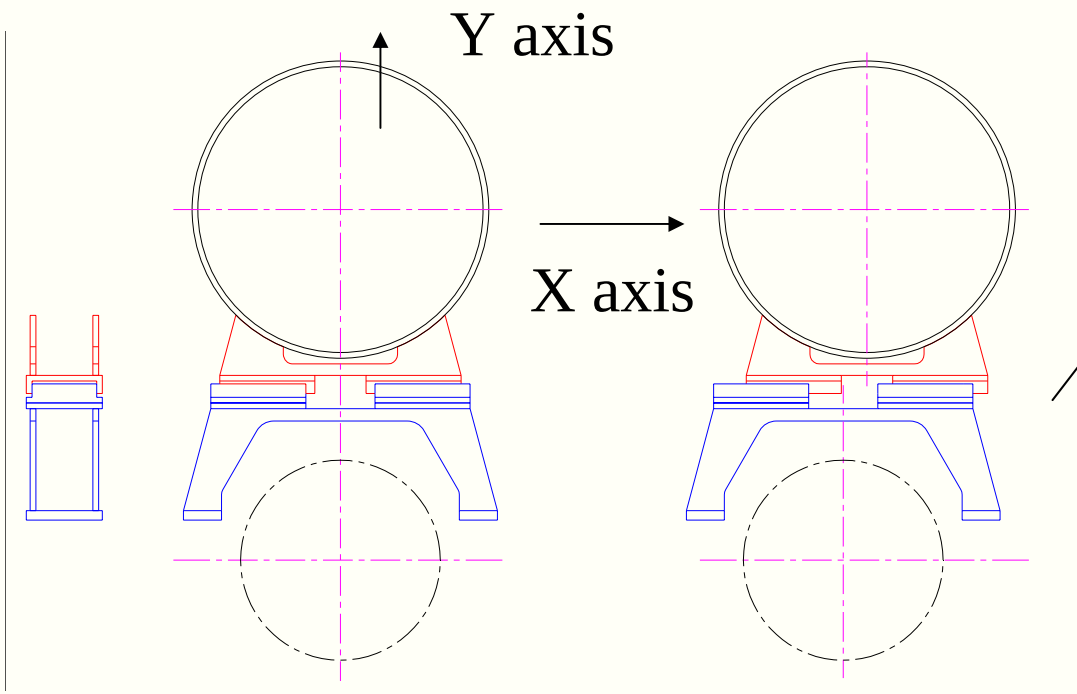
- 12m long pipe dia 300mm is being fabricated. Strict tolerances on straightness & circularity.
- Made in three segments, welded together and straightened.
- Hangers are welded to this 12m long structure.It is machined on a milling machine 14 m long within 10microns

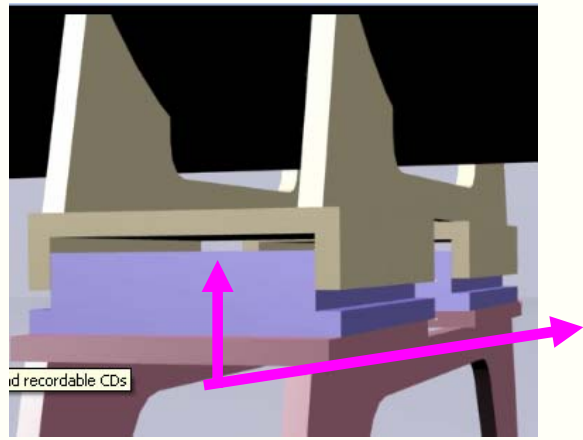




# Principle

**Split hanger in 2 parts.Weld them with pulse Laser to compensate irregular pipe shape. C-T Joint allows positioning in xx and yy directions**



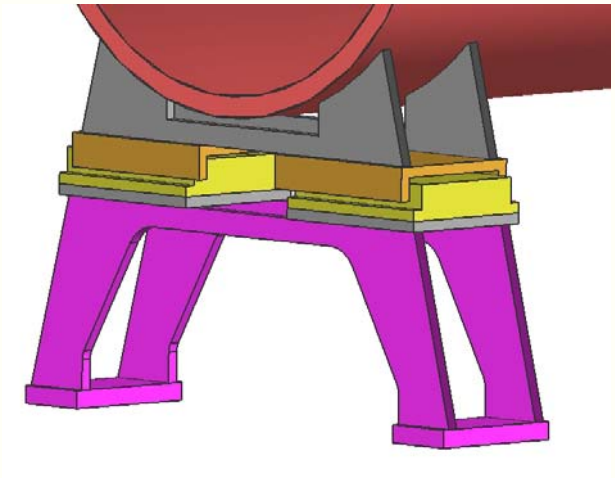



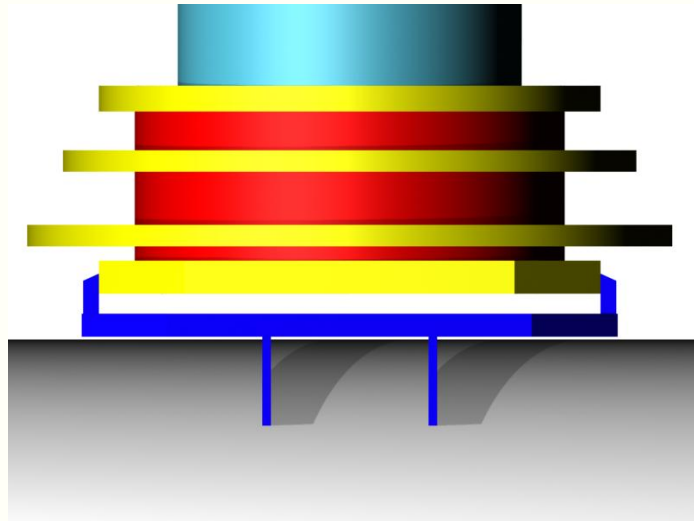
**C-T compensates for any irregular shape of pipe in XY Plane.**

**Initial information says that pipe may have a camber of 15-20mm .**

# Proposed Scheme

## Proposed Change In Cavity Supports

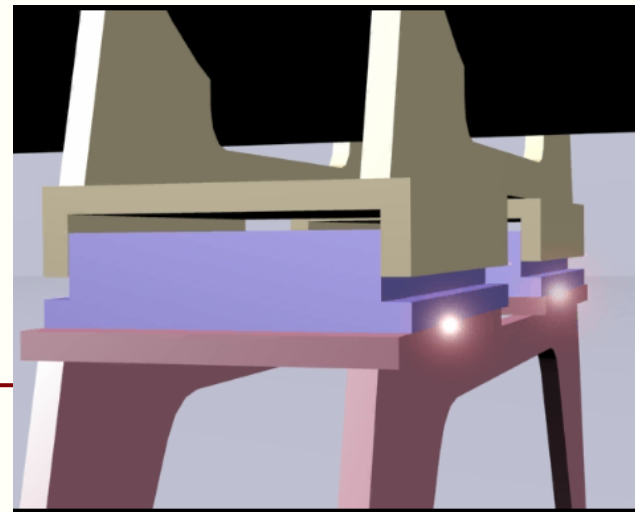


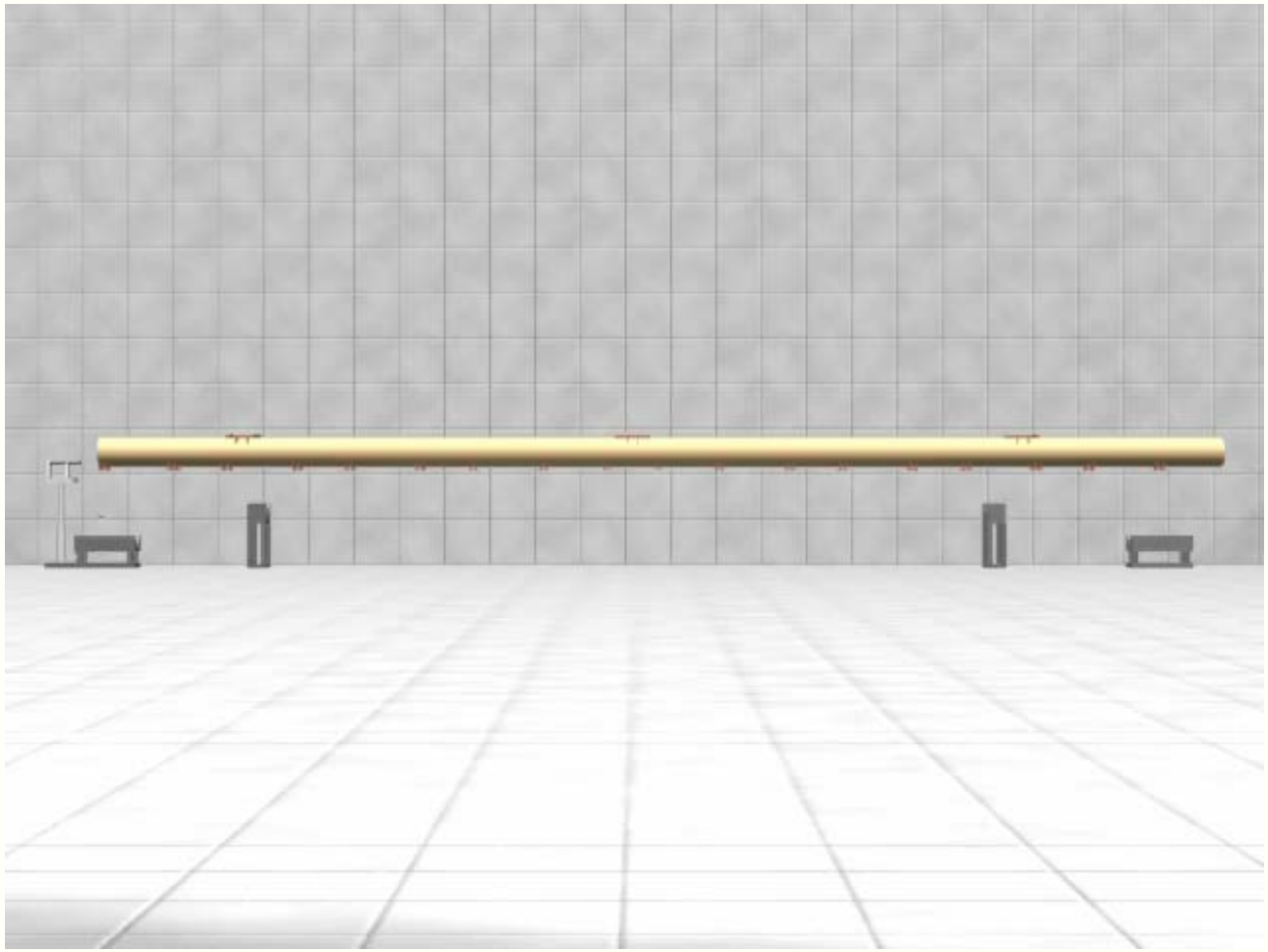


A C-T joint interposed at the top too.

## Laser welding

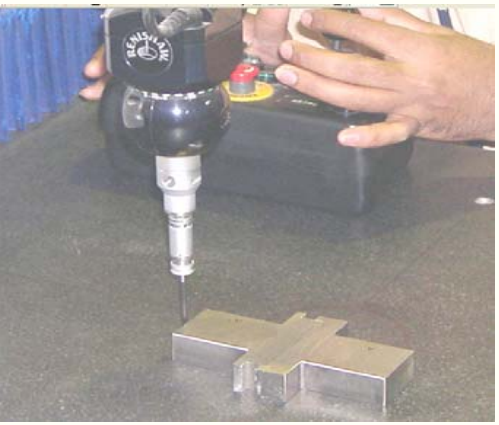
**Nd-YAG in pulse mode, ensures low welding distortion at bottom part of hanger.**



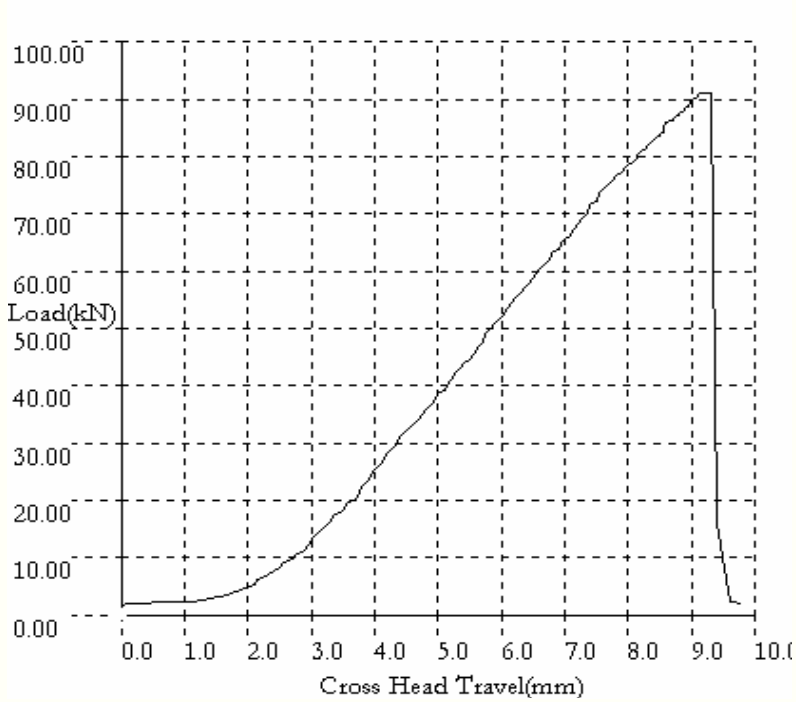


# Welding Trials

Laser welding of prototype C-T joint



Distortion measurement(on CMM)

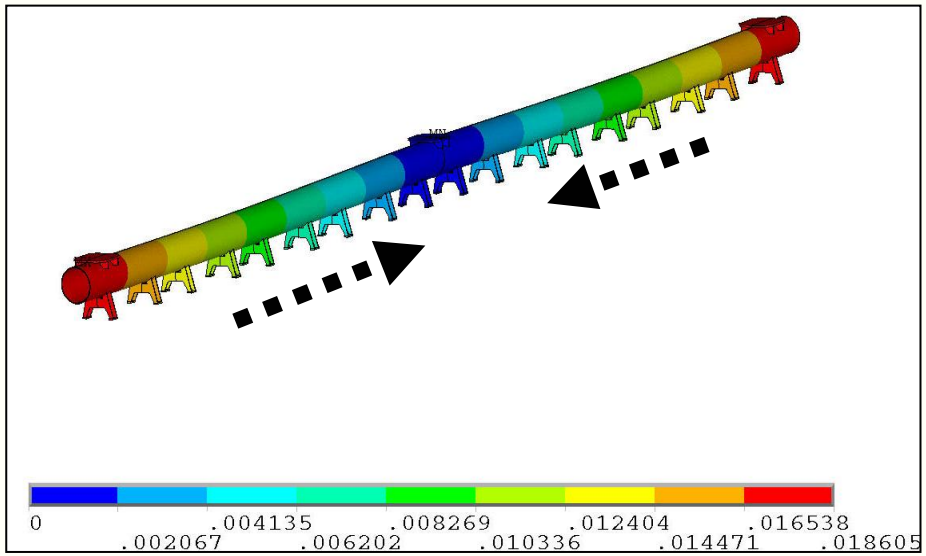



Tensile testing result

A. Distortion after laser welding (measured by CMM, 6 microns
B. Distortion after thermal cycling after laser welding 4 microns
C. Joint's strength 9 Tonnes
D. Weld Length & depth of penetration L=43mm depth 1.5mm

# VERIFICATION OF FEA MODEL

## Cool-down of HGR pipe from Room temperature to 2 K




B. C's.

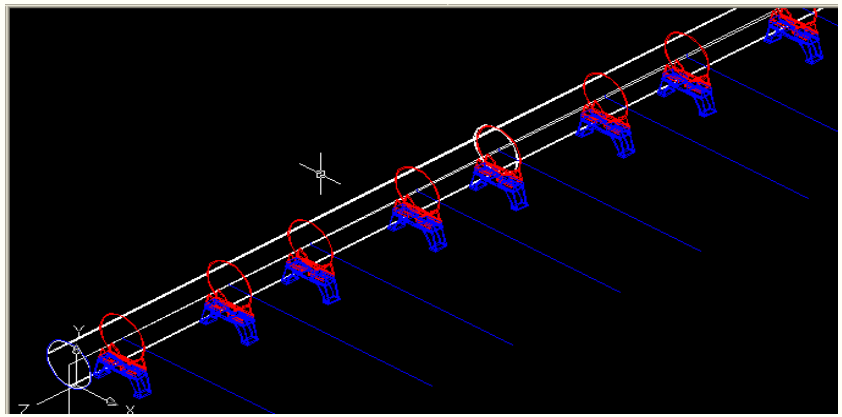
Fixed at the top at center

Ux & Uy restrained at both ends

Loads:-

Self weight + Cavity assembly

**Axial Contraction :-**
**18.608 mm from each side**



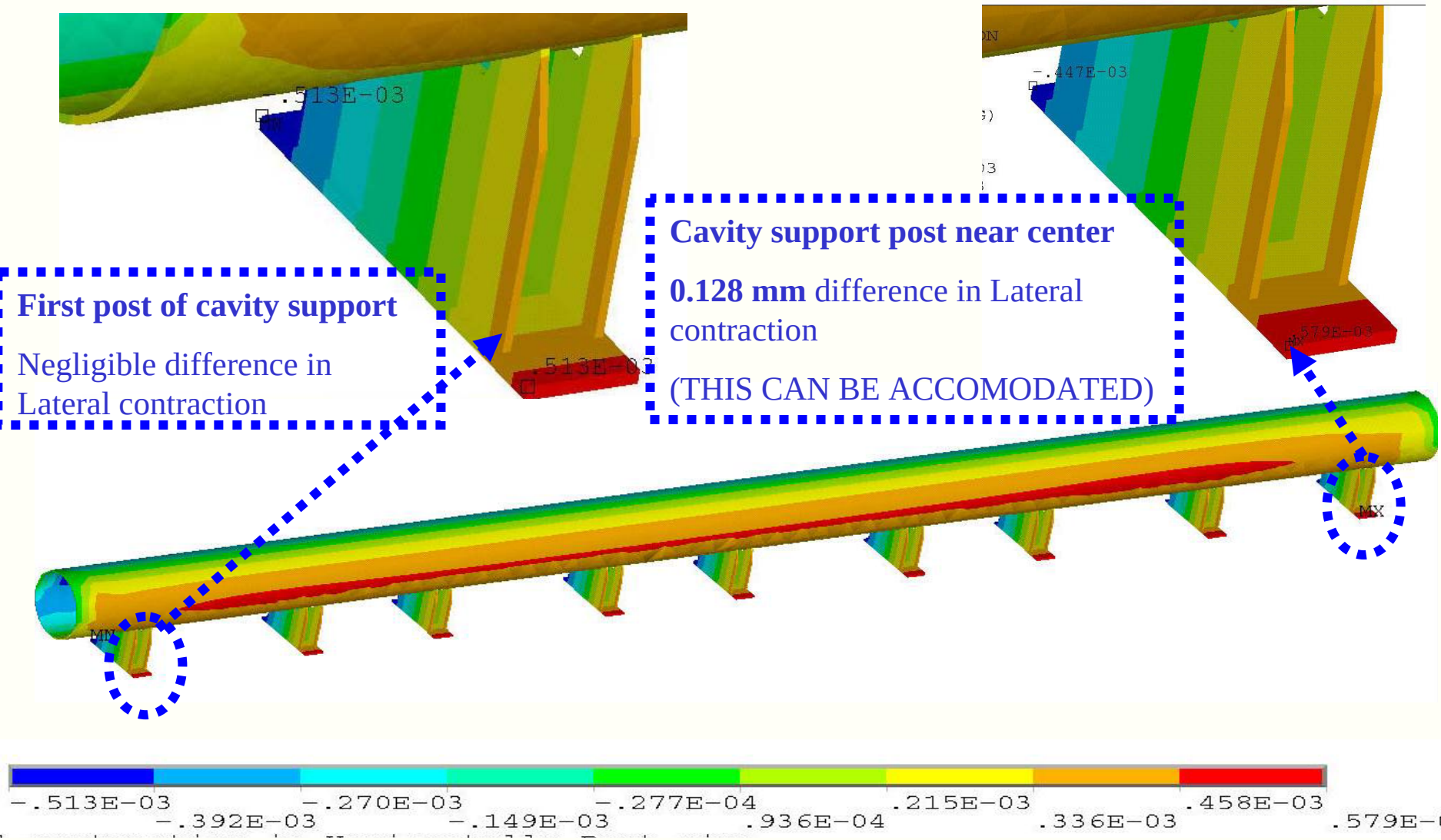
1st Model

Camber of 20mm in Horizontal Plane

2nd Model

Camber of 20mm in Vertical Plane

# Effect of camber on Lateral Contraction




**First post of cavity support**

Negligible difference in Lateral contraction

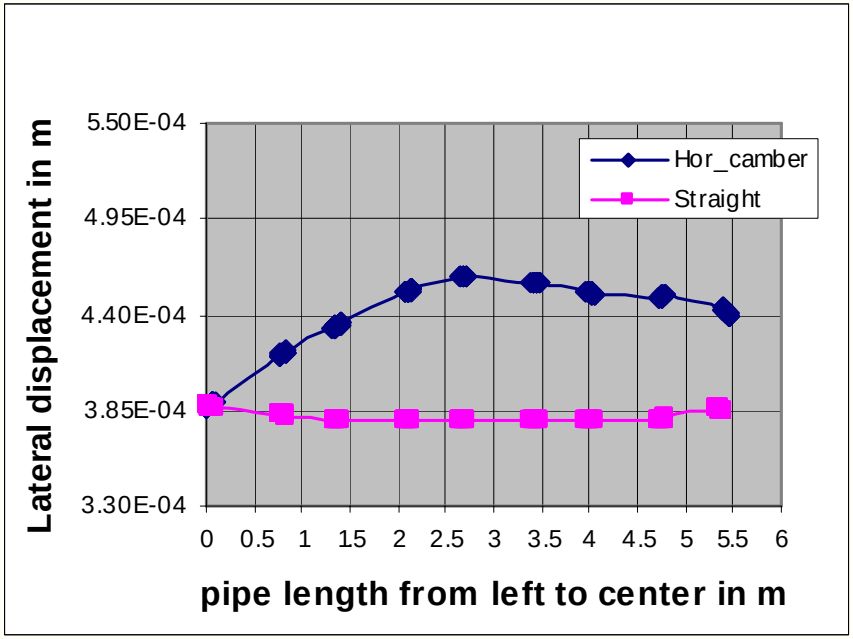
**Cavity support post near center**

**0.128 mm** difference in Lateral contraction

(THIS CAN BE ACCOMODATED)

# Load Cases: Two load cases

| Pipe Type | Load Case | Vertical displacement Of support pad | Lateral Displ. Of support pad |
|---|---|---|---|
| Straight Pipe | LC1 | 1.67mm | 0.385mm |
| Pipe with 20mm camber in Horizontal plane | LC1 | 1.6mm (not different from 1.67mm in LC1) | 0.464mm increased by 79 micns (0.464-.385) |
| Pipe with 20mm camber in Vrt. plane | LC1 | 1.545mm Decreased by 125 microns (1.67-1.545) | 0.385mm (same as in straight pipe LC1) |
| Straight Pipe | LC2 | 1.663mm | 0.408mm |
| Pipe with 20mm camber Horizl Plane<br>Pipe with 20mm camber in Vert plane | LC2<br><br><br><br>LC2 | 1.635mm (not different from 1.663 mm in LC1)<br><br>1.535mm decreased by 128 microns(1.663-1.535) | 0.509mm increased by 101microns (0.509-0.408)<br>0.387mm(lesser than 0.408mm) |



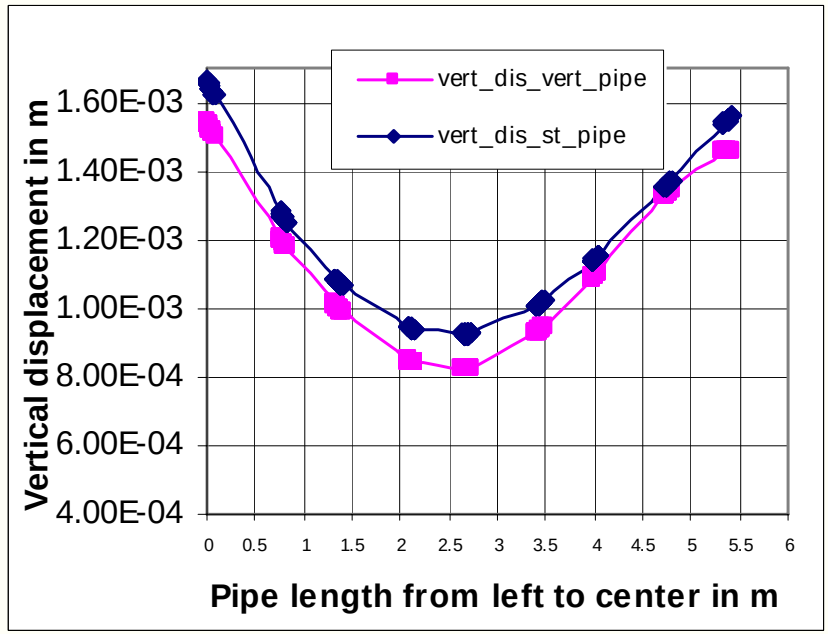




**Fig 16 Comparison of displacement in horizontal & vertical cambered pipe with straight pipe.**

**LC1 (self weight + cavity load + cool down)**

**LC2 (self weight + cavity load + cool down + 4bar pressure)** have been considered

# Interesting Economics

**ECONOMICS** *Indian Estimates*

**1.Cost of Commercially available pipe $ 10000**

**2.Cost of 16 C-T Joints $1500**

**3. Cost of top 3C-T Joints $ 2500**

**4.Laser Welding $ 3000**

**-----Not sure what all parts were included in the list**

**US industrial study (By Fermi lab and Jlab) says,**

**HGR pipe assembly along with needle roller assembly, but without support posts will cost $82,000**

**Looks Like this scheme will be significantly cheaper.Around $40000.**

# Summary

- FEA shows enhancement in displacement
  128 microns (in worst load condition) i.e.LC2
  79microns in LC1. Within tolerable range.

- Using commercially available pipe for economy & ease of manufacturing.
- C-T joints costing $80 per piece (16 no's).

- Concerns
  Joining of pipe to support structure.
  Validation of laser welded joints as per code.

# THANKS