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# Coil parts and tooling design and procurement status, infrastructure and practice coil winding

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High Field Magnet Review

April 28, 2016

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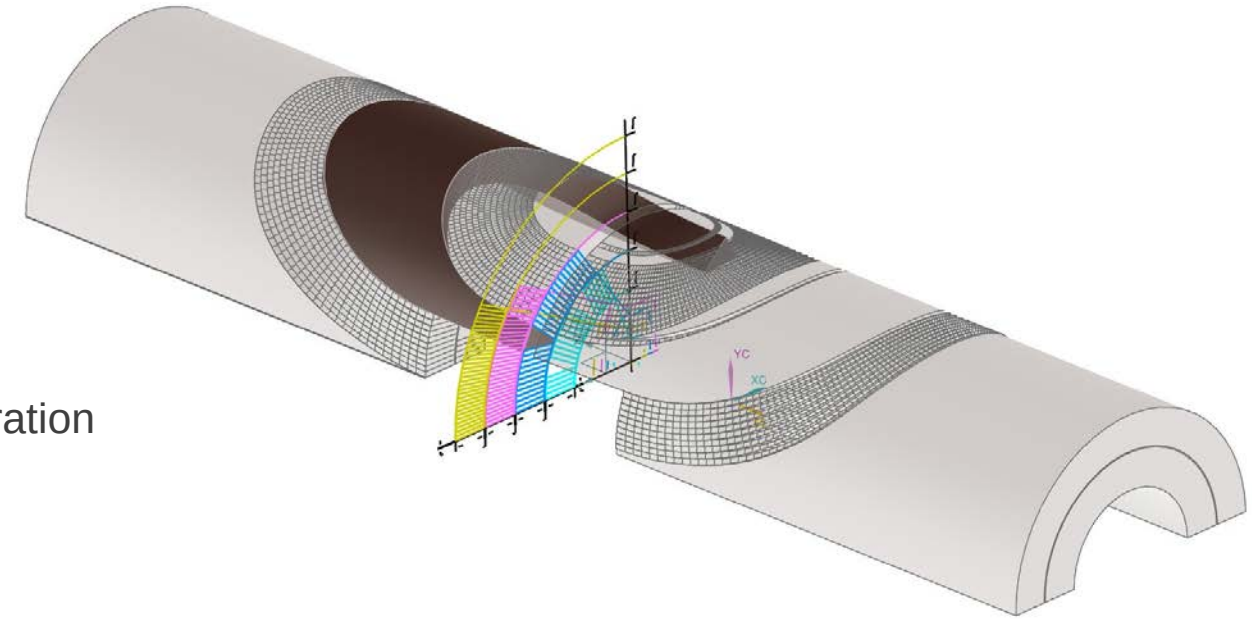
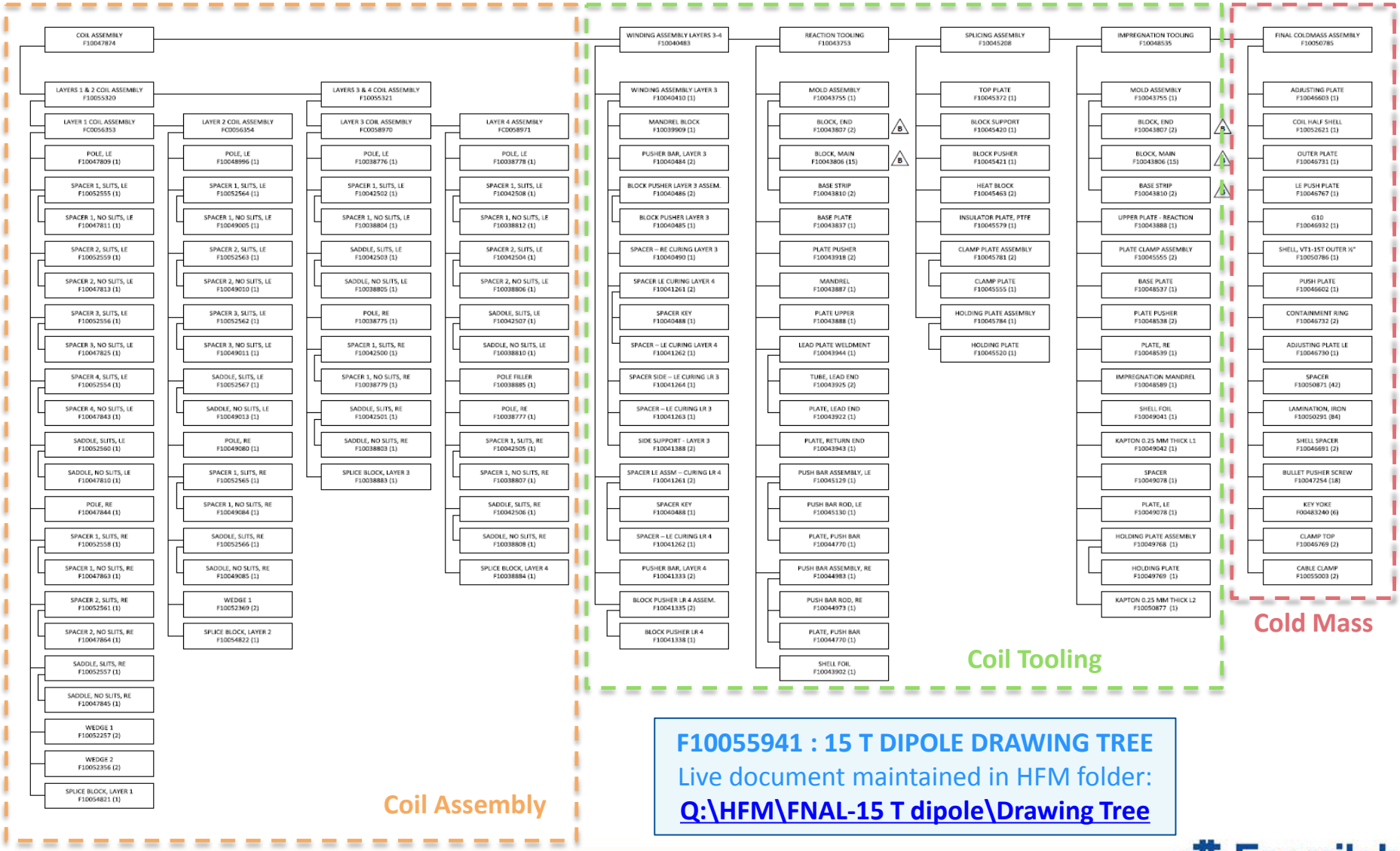


# Mechanical Layout and Components

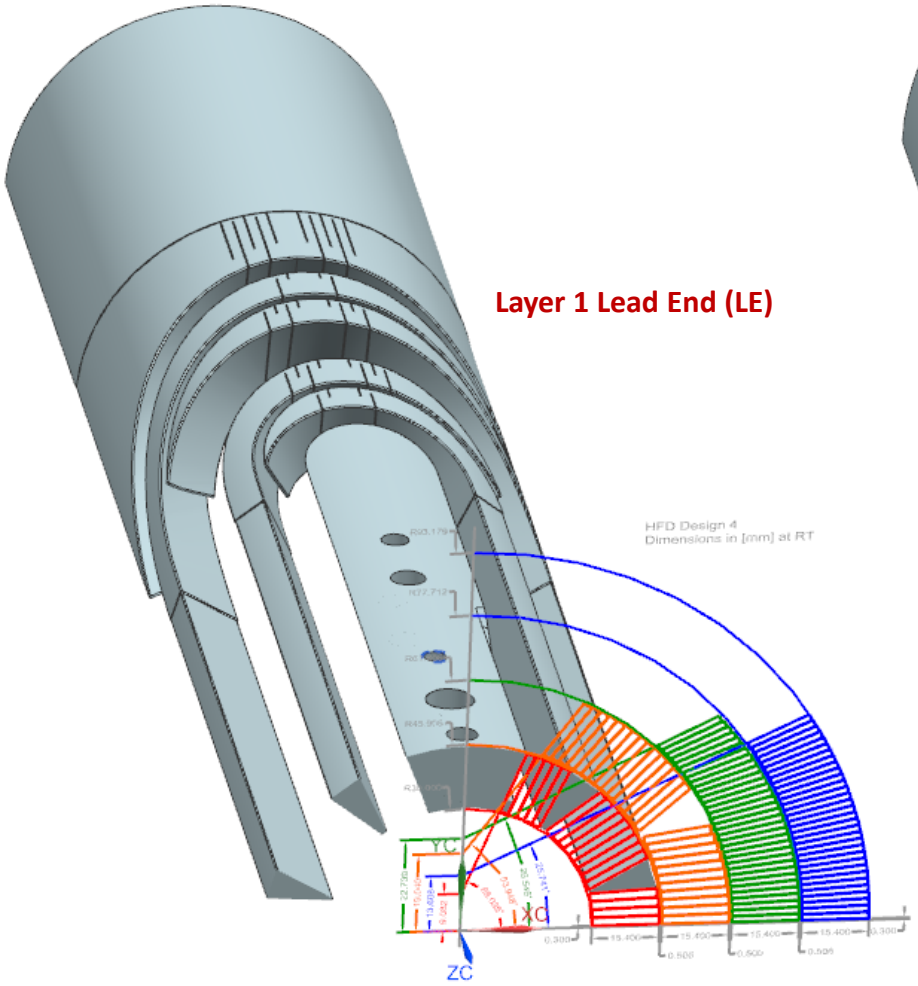


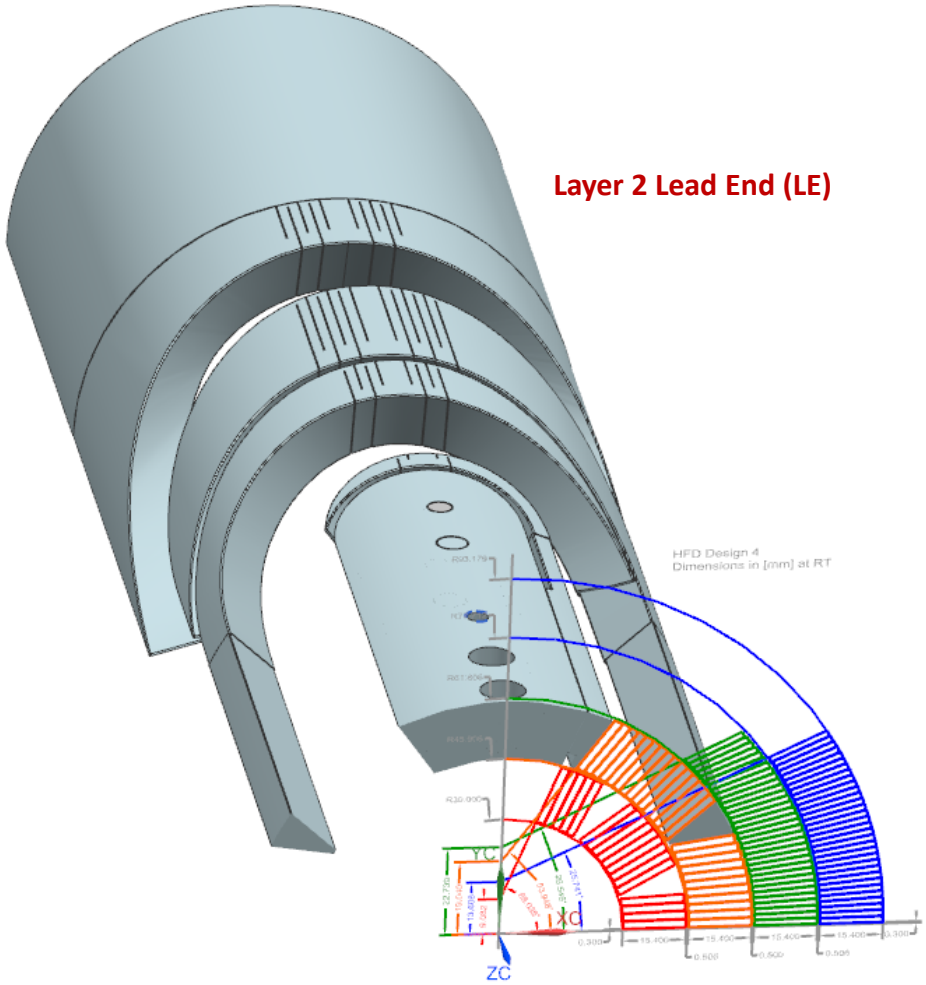

**F10055941 : 15 T DIPOLE DRAWING TREE**

Live document maintained in HFM folder:

**Q:\HFM\FNAL-15 T dipole\Drawing Tree**

# Mechanical Layout and Components



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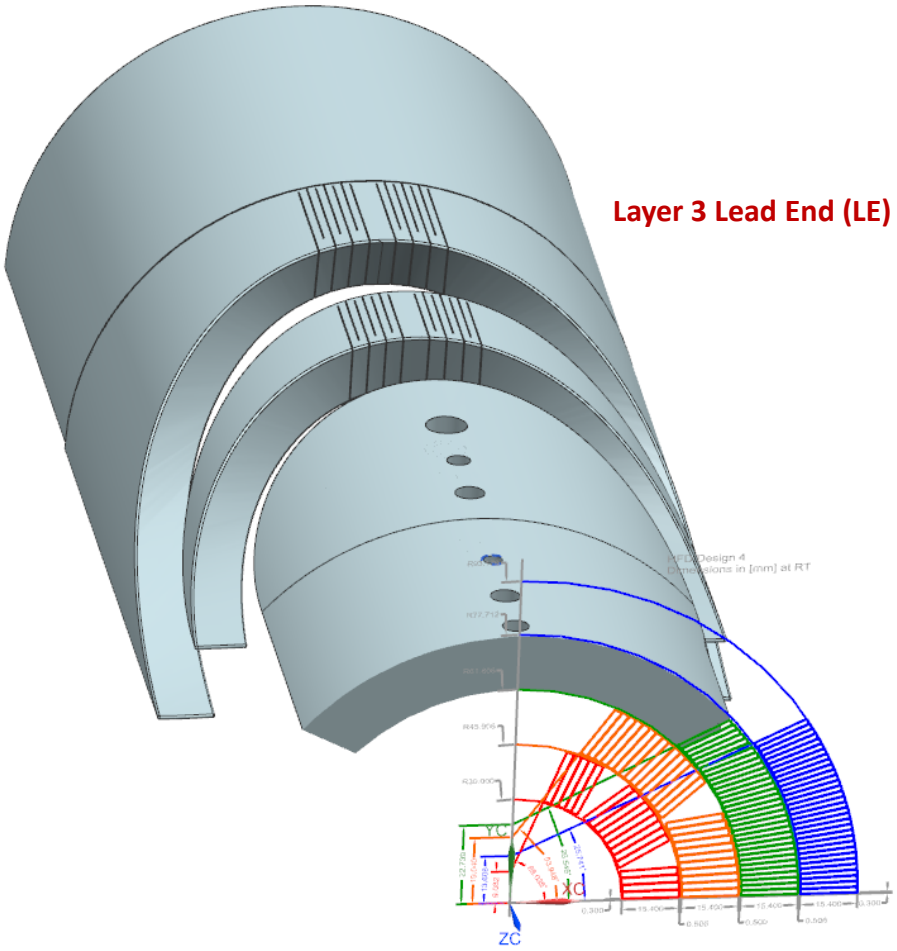
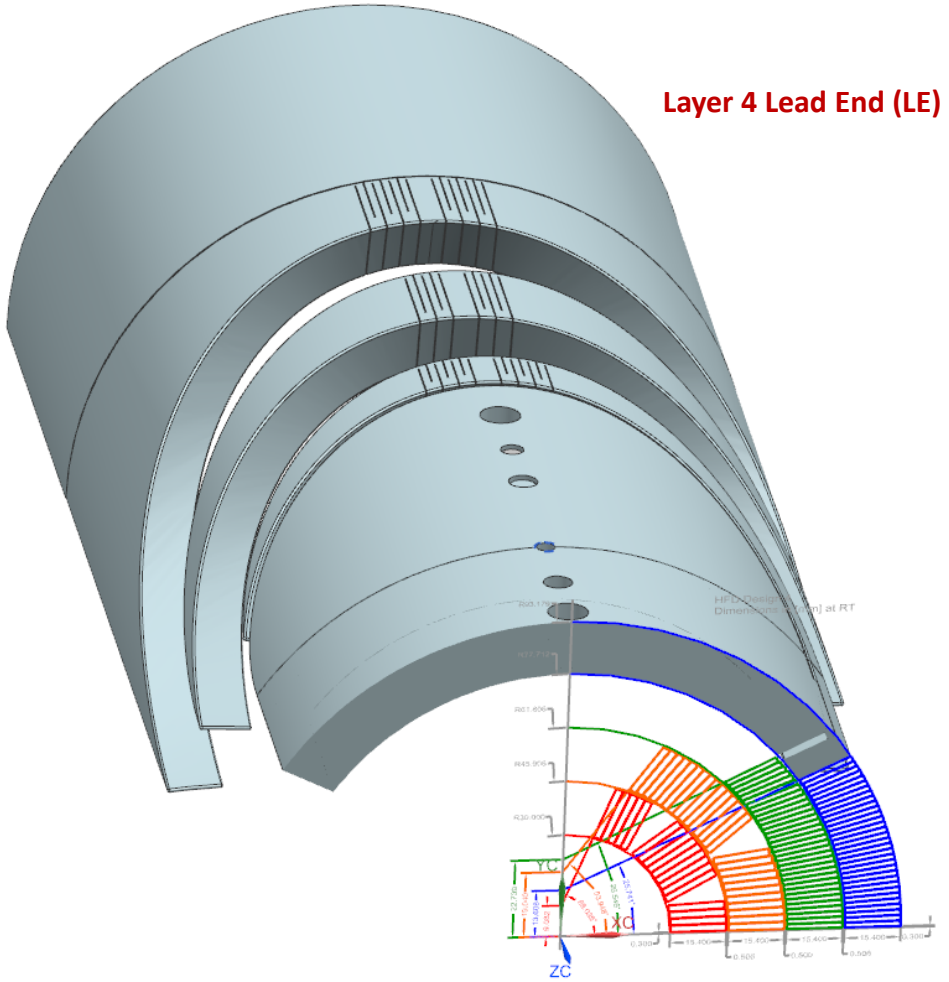
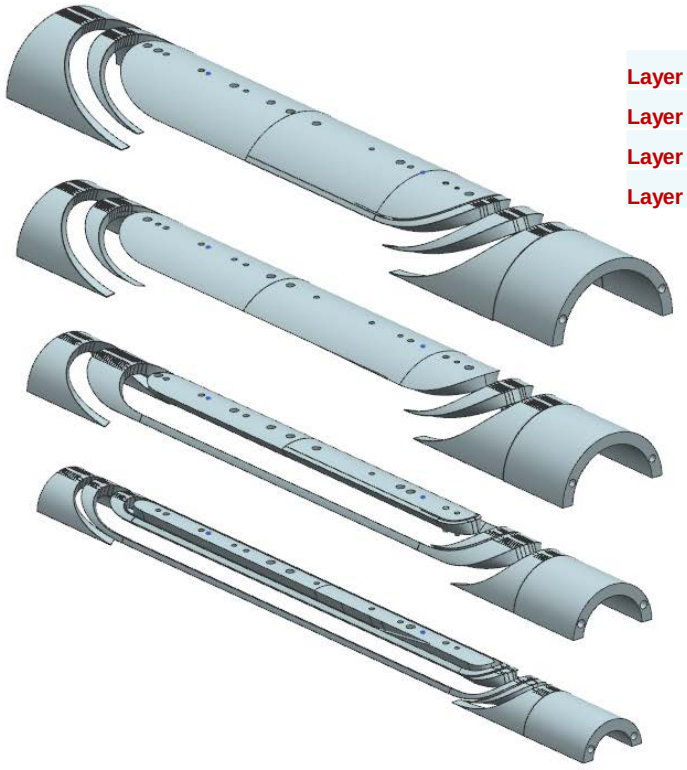
# Mechanical Layout and Components



# Mechanical Layout and Components

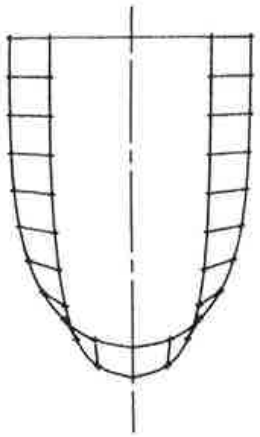


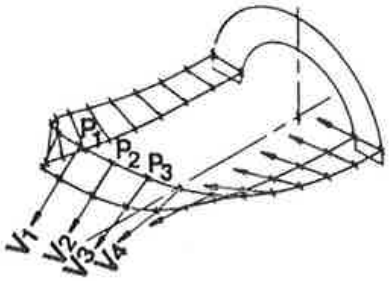
| | Poles | Spacers | Wedges | Saddles / Splice Blocks |
|---|---|---|---|---|
| Layer 1 | Ti-6Al-4V Grade 5 | C-642 Aluminum Silicon Bronze | C510 Phophor Bronze | 316L SS |
| Layer 2 | Ti-6Al-4V Grade 5 | C-642 Aluminum Silicon Bronze | C510 Phophor Bronze | 316L SS |
| Layer 3 | 316L SS | 316L SS | N/A | 316L SS |
| Layer 4 | 316L SS | 316L SS | N/A | 316L SS |

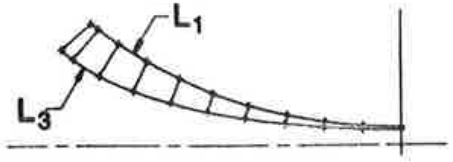

| | LE Spacers | RE Spacers | Wedges |
|---|---|---|---|
| Layer 1 | 4 | 2 | 2 |
| Layer 2 | 3 | 1 | 1 |
| Layer 3 | 1 | 1 | 0 |
| Layer 4 | 2 | 1 | 0 |

# Mechanical Layout and Components : End Parts

- BEND is an interactive end part design program developed by Joe Cook and Jeff Brandt at FNAL ~1990
- BEND creates a developable surface from user input. User input includes fixed cross-section geometry (e.g. from ROXIE), initial values of A-length and inclination angle, and optional adjustment parameters “SHIFT” and “BLUNT”

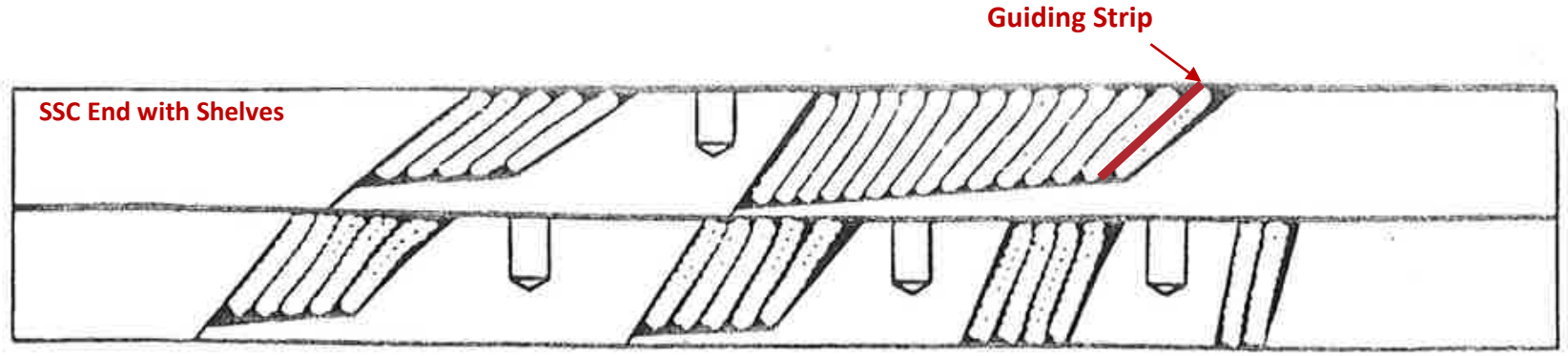




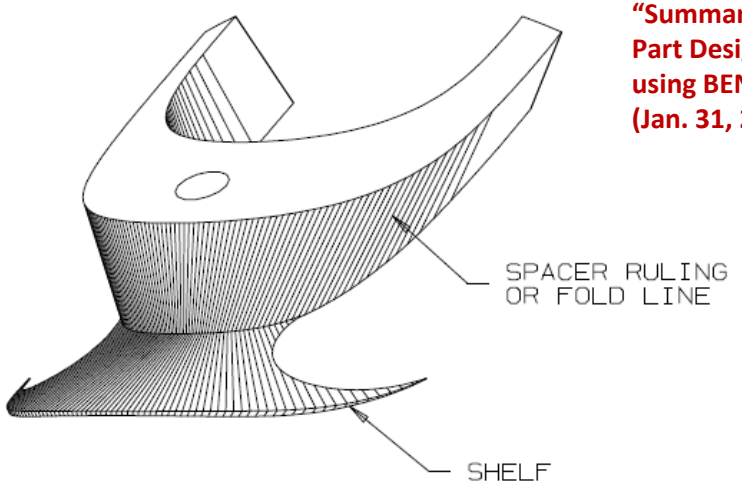



# Mechanical Layout and Components : End Parts

- BEND uses a “guiding strip” to define the cable group geometry; all optimization is done to this strip and other turns are simply stacked to this strip, meaning as turns become farther and farther removed from the rectifying developable they contain higher and higher strain. In practice the guiding strip is placed close to the inside surface of the current block. Large groups also must often be split to reduce built-up strain.



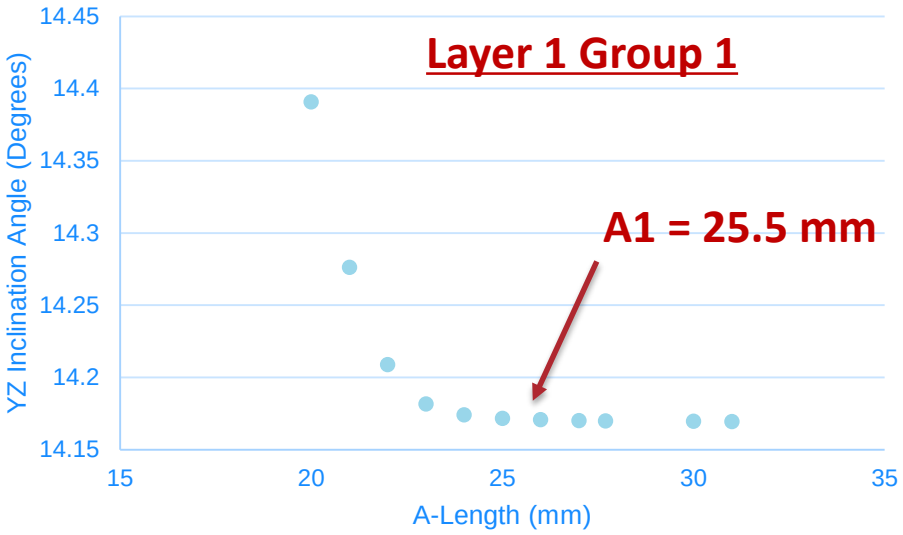

- BEND also prefers the use of shelf geometry to support cables with high inclination angles. With Ni3Sn magnets insulating shelves cannot survive the reaction process, meaning for winding stability the inclination angle must be artificially fixed between 15-25 degrees for BEND suggested angles > 25 degrees. As will be shown in later slides, this complicates the end part design due to the high strain contained in the cable.

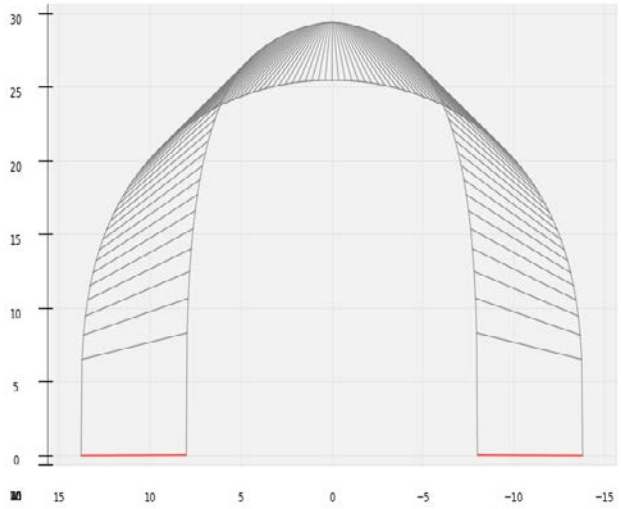



**“Summary of the End Part Design Process using BEND” R. Bossert (Jan. 31, 2013)**

# Mechanical Layout and Components : End Parts

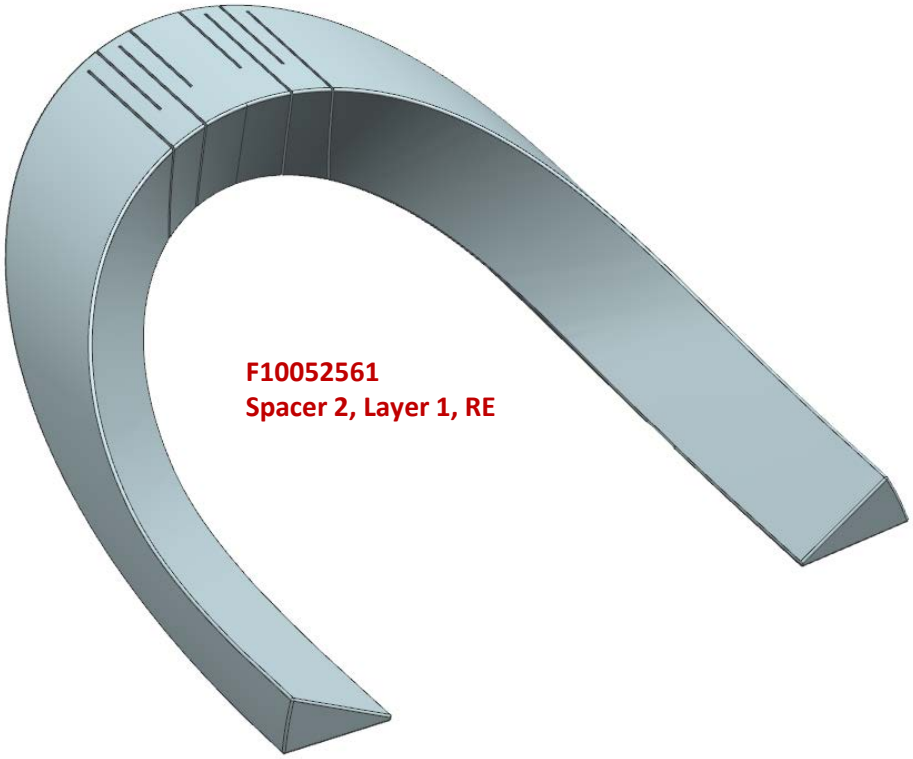
- Despite some groups requiring fixed inclination angles (see BEND parameters for Layers 1 & 2 in backup slides), BEND is still used to find best parameters. Initial a-length found using Suneel Yadav's documented method (TD-01-059) of looking for a-length convergence vs. YZ inclination angle
- End part then adjusted using "Coil End Part Design Procedure" (Brandt, TD-98-053)
- Based on previous experience (see Brandt TM-1735) limiting dL/L to 0.3, and radius of curvature to 2.5 mm, "SHIFT" and "BLUNT" can be manually used to tweak geometry to avoid problems with sharpness
- Python programs were written to allow for one-click visualization of BEND output and automatic generation of cable STEP files for quick iteration

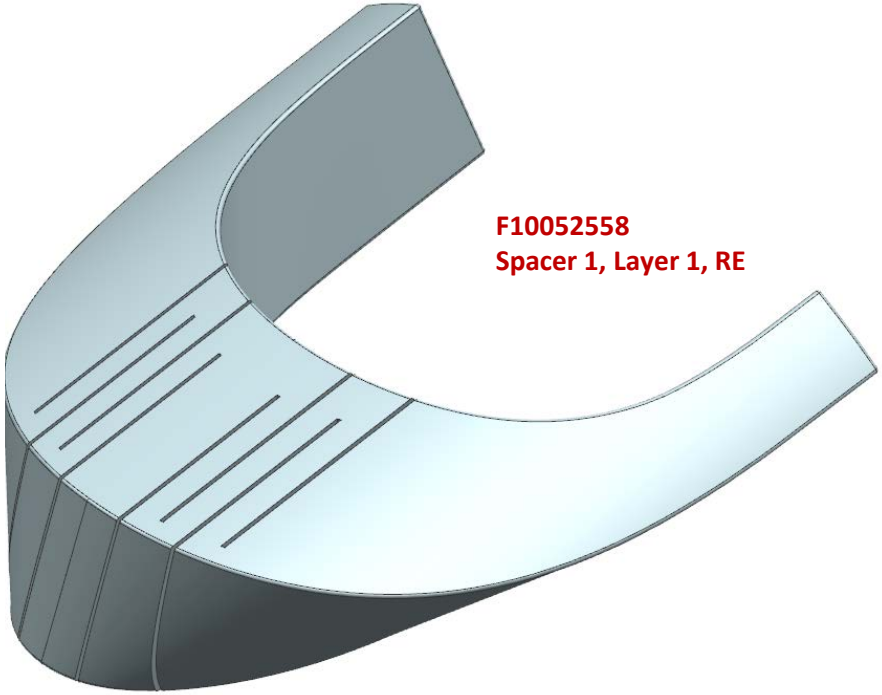


# Mechanical Layout and Components : End Parts

- Final mechanical parts slitted for flexibility



# Production : L1/L2 Winding and Curing

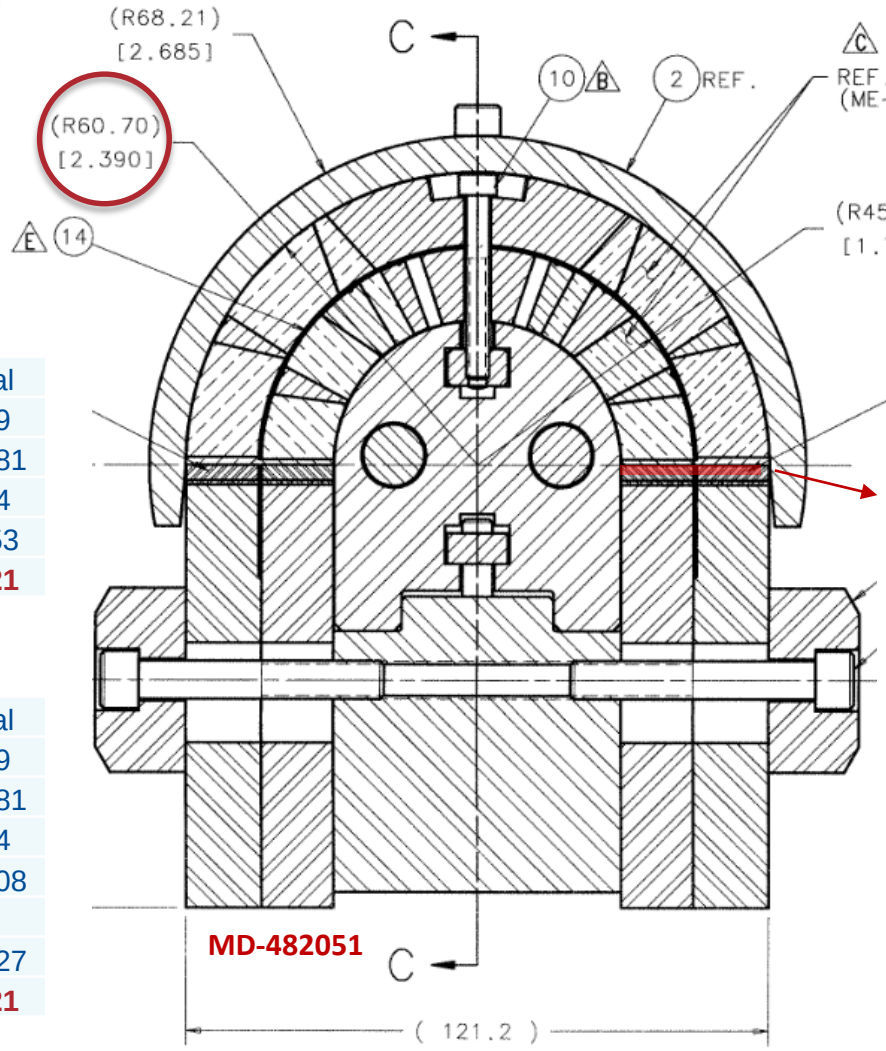
- We will use existing 11 T winding and curing tooling, with revision to spacers to accommodate jump cable and modify inner radii
- Cure cycle 150 ° C for 30 minutes at ~27 MPa

**Layer 1 (unreacted dims)**

| | Thick | IR | OR | Final |
|---|---|---|---|---|
| Mandrel | - | - | 29.9 | 29.9 |
| Kapton X 3 | 0.381 | - | - | 30.281 |
| L1 | - | 30.3 | 45.4 | 45.4 |
| S2 | 0.127 | - | - | 45.53 |
| Curing Spacer | - | **45.52** | **68.21** | **68.21** |

**Layer 2 (unreacted dims)**

| | Thick | IR | OR | Final |
|---|---|---|---|---|
| Mandrel | - | - | 29.9 | 29.9 |
| Kapton X 3 | 0.381 | - | - | 30.281 |
| L1 | - | 30.3 | 45.4 | 45.4 |
| S2 X 4 | 0.508 | - | - | 45.908 |
| L2 | - | 45.906 | 61 | 61 |
| S2 | 0.127 | - | - | 61.127 |
| Curing Spacer | - | **61.127** | **68.21** | **68.21** |




**Layer 1 Shimming:**

**18 turns**
**4 % expansion**
**Bare cable mid thickness = 1.870**
**Shim = 1.870*.04*18 = ~1.3 mm**

**Layer 2:**

**1.870*.04*26 = ~1.9 mm**



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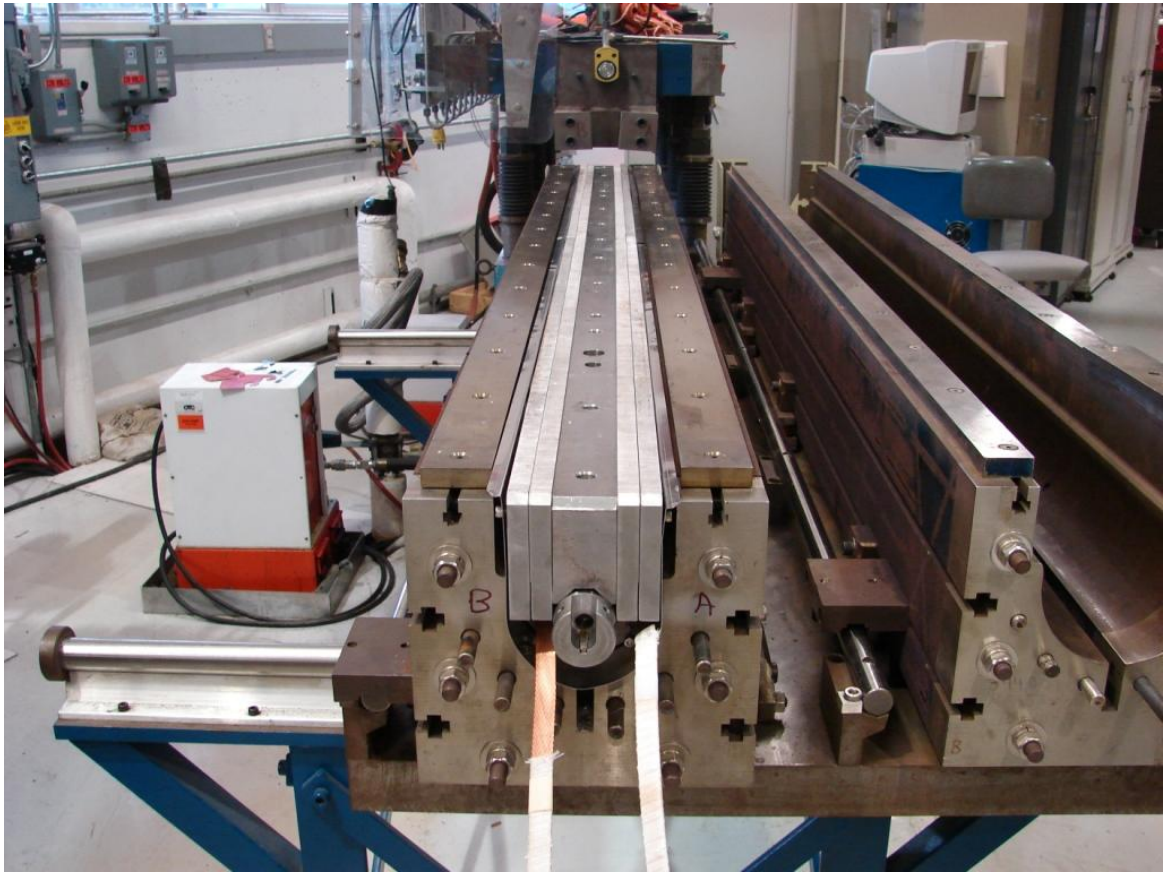
# Production : L1/L2 Winding and Curing



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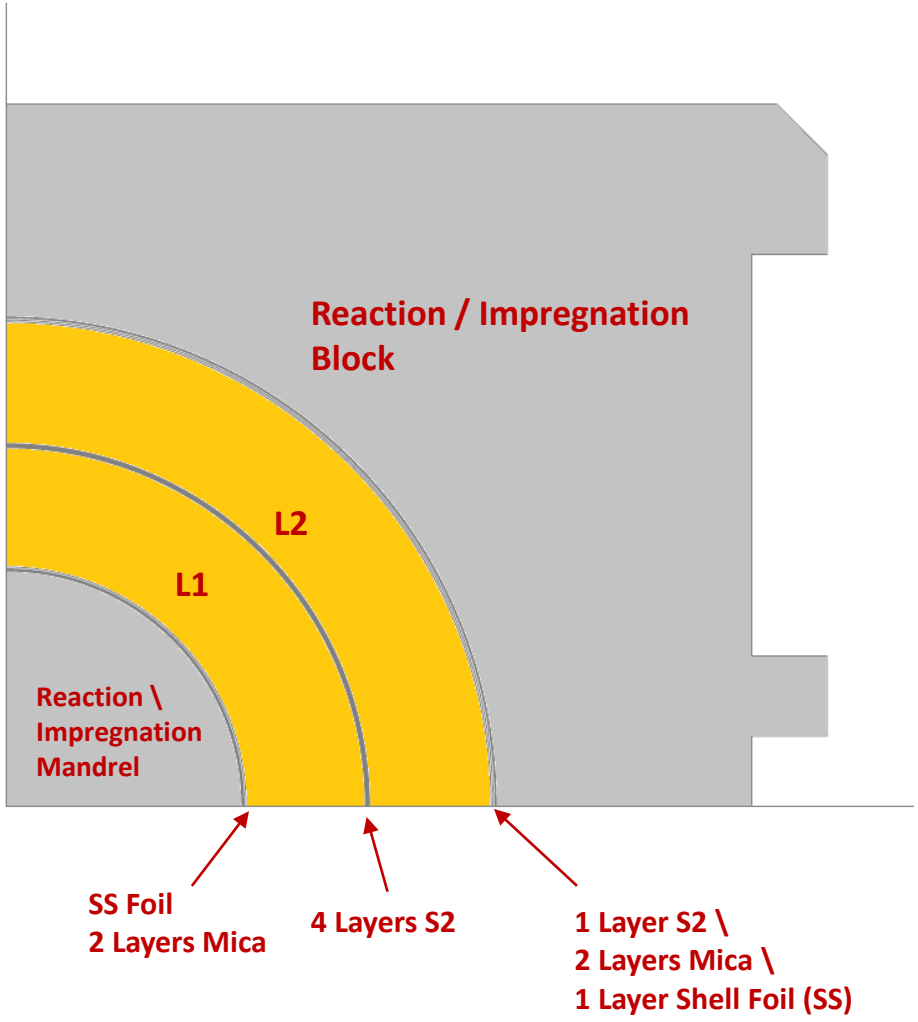
# Production : L1/L2 Reaction

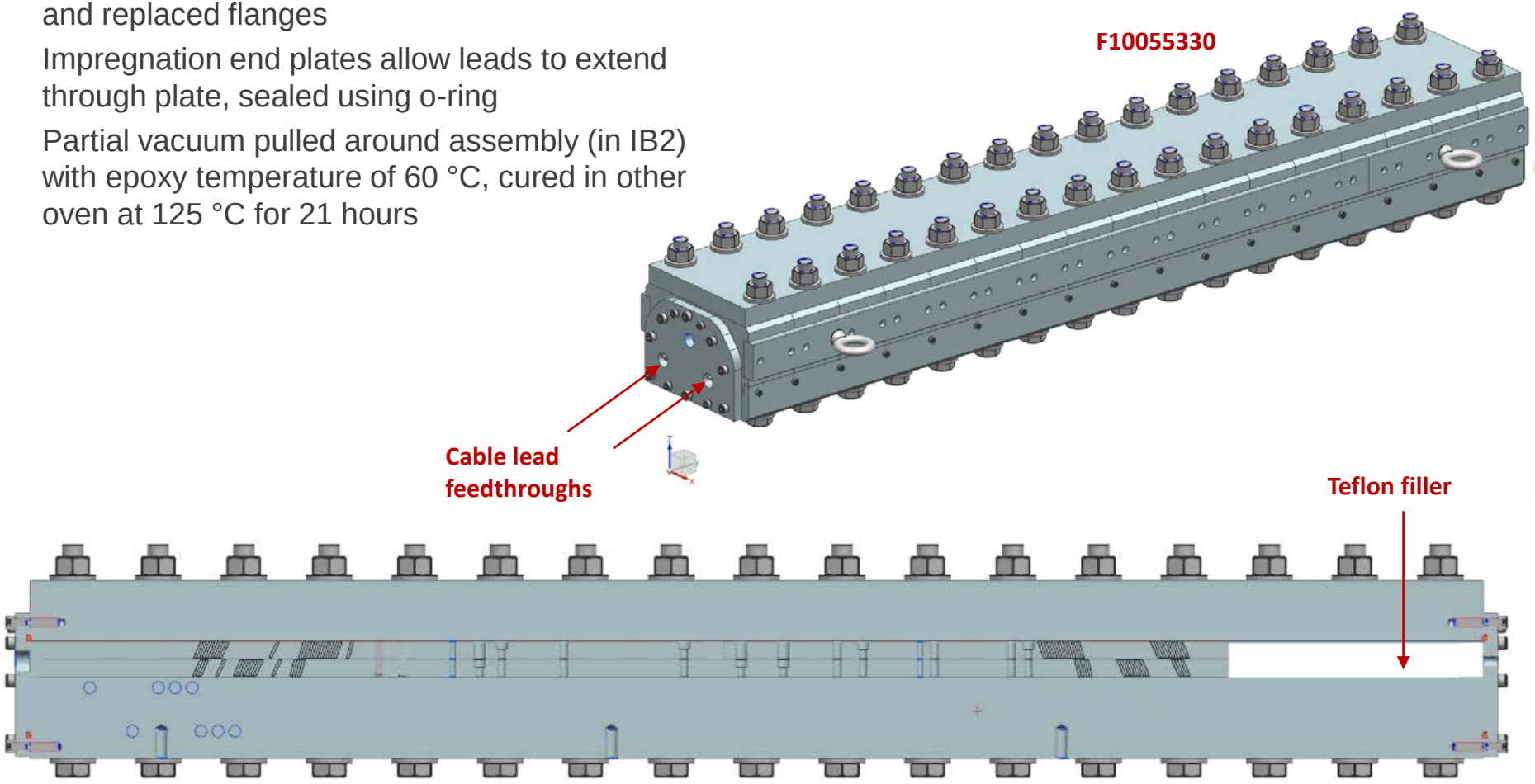
- 11 T Tooling will be modified by reducing length, new NX models and detailed drawings for these modifications have been completed – currently under review

| | Thick | IR | OR | Final |
|---|---|---|---|---|
| Mandrel | - | - | 29.8 | 29.8 |
| S2 | 0.127 | - | - | 29.93 |
| Mica X 3 | 0.375 | - | - | 30.3 |
| L1 | - | 30.3 | 45.4 | 45.4 |
| S2 X 4 | 0.508 | - | - | 45.908 |
| L2 | - | 45.906 | 61.306 | 61.306 |
| S2 | 0.127 | - | - | 61.433 |
| Mica X 2 | 0.25 | - | - | 61.683 |
| Shell Foil (SS) | 0.25 | - | - | 61.933 |
| Reaction Blocks | - | 61.94 | - | - |



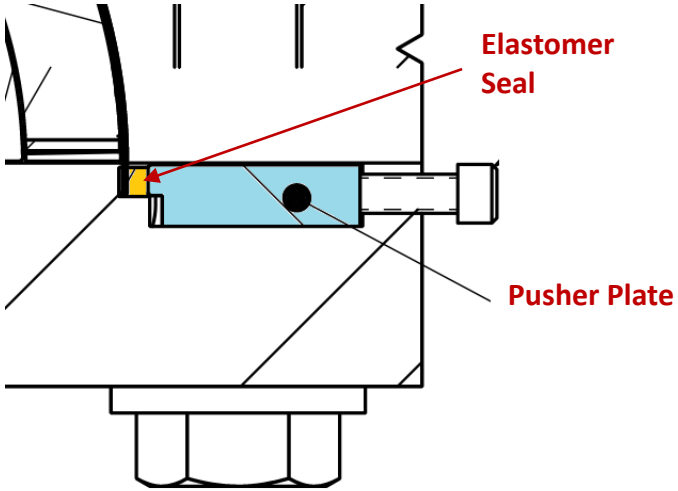
# Production : L1/L2 Impregnation

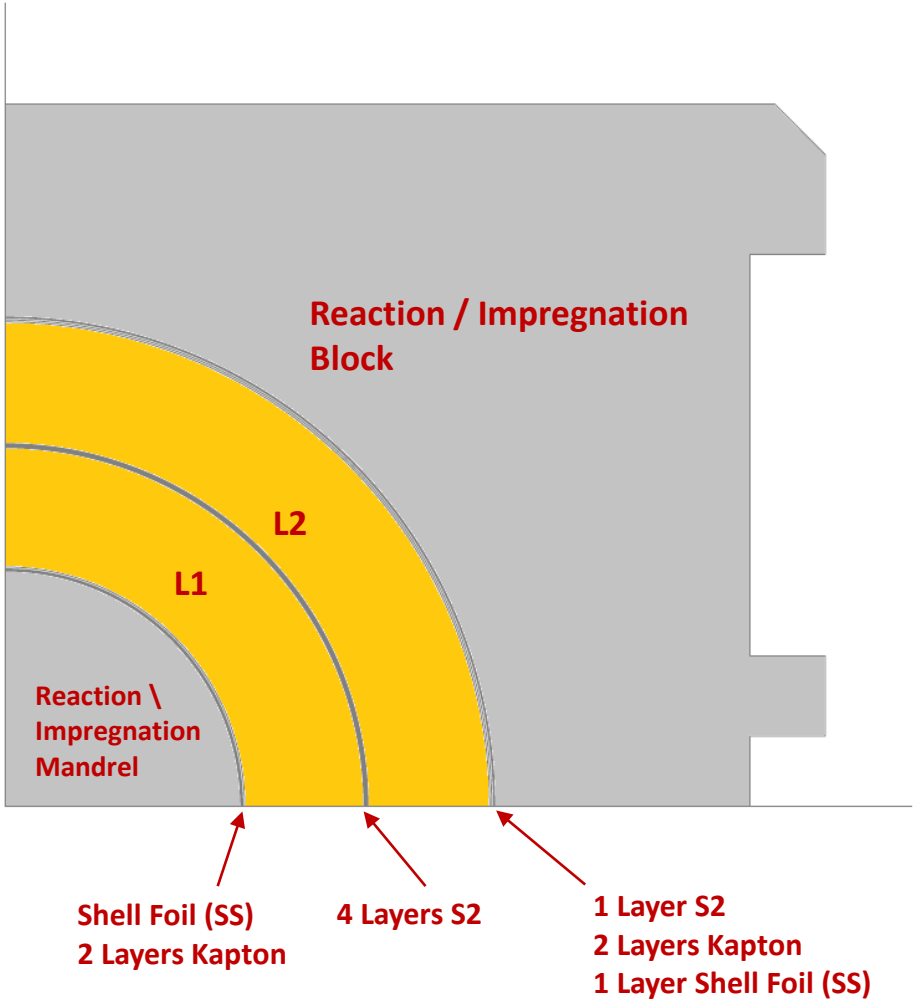
- Same 11 T tooling modified for reaction will be used for impregnation, but with elastomer seals and replaced flanges
- Impregnation end plates allow leads to extend through plate, sealed using o-ring
- Partial vacuum pulled around assembly (in IB2) with epoxy temperature of 60 °C, cured in other oven at 125 °C for 21 hours



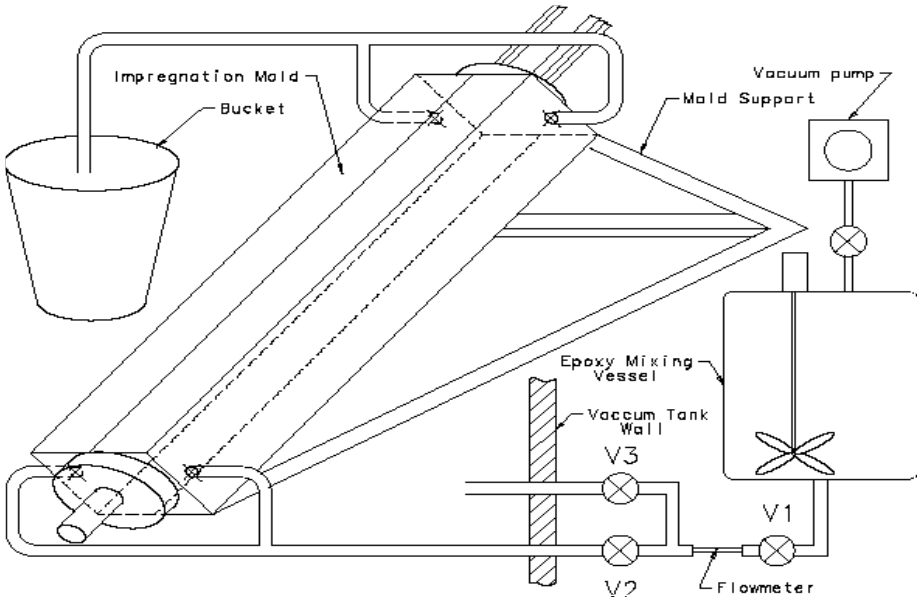
# Production : L1/L2 Impregnation

| | Thick | IR | OR | Final |
|---|---|---|---|---|
| Mandrel | - | - | 29.8 | 29.8 |
| Kapton X 4 | 0.5 | - | - | 30.3 |
| L1 | - | 30.3 | 45.4 | 45.4 |
| S2 X 4 | 0.508 | - | - | 45.908 |
| L2 | - | 45.906 | 61.306 | 61.306 |
| S2 | 0.127 | - | - | 61.433 |
| Kapton X 2 | 0.25 | - | - | 61.683 |
| Shell Foil (SS) | 0.25 | - | - | 61.933 |
| Reaction Blocks | - | 61.94 | - | - |



# Production : L1/L2 Impregnation




*Images taken from presentation "11 Tesla Demonstration Dipole", F. Nobrega 12/2011*



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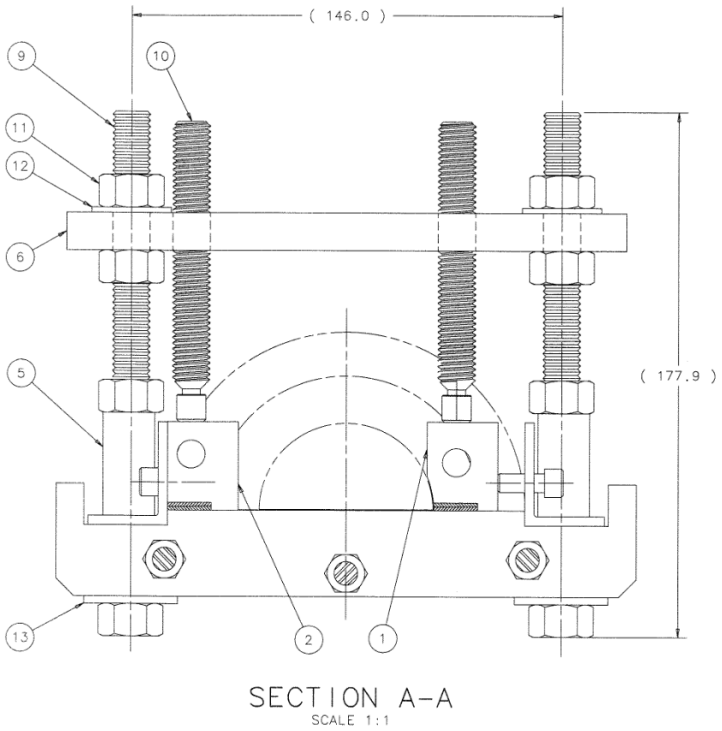
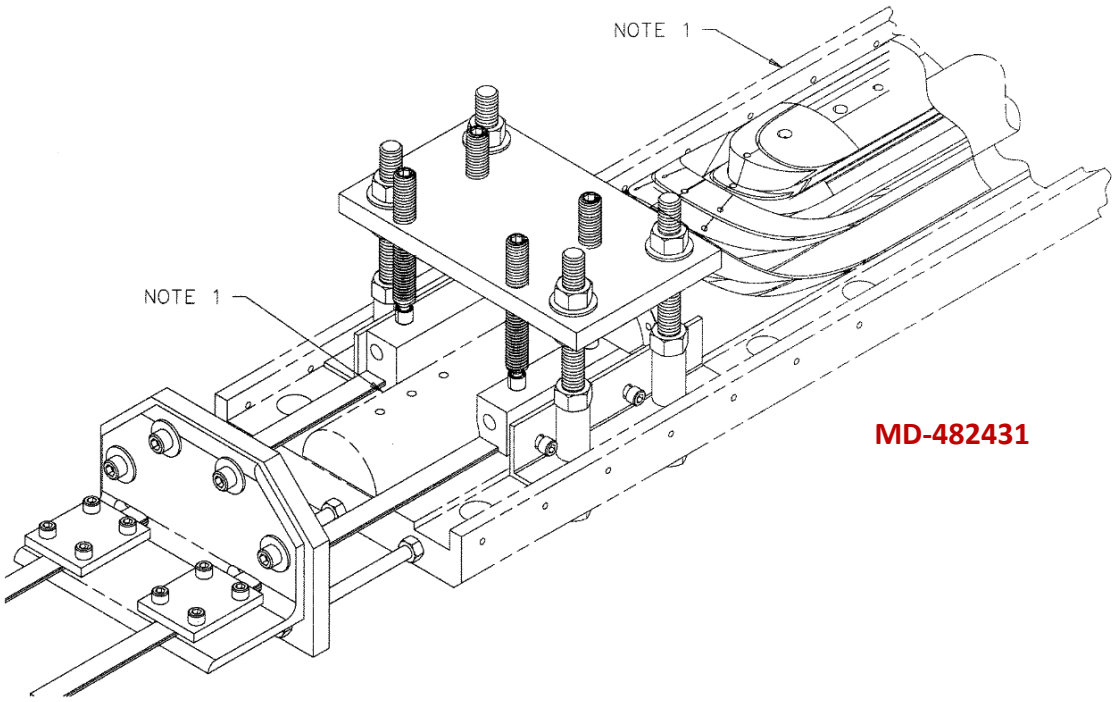
# Production : L1/L2 Splicing

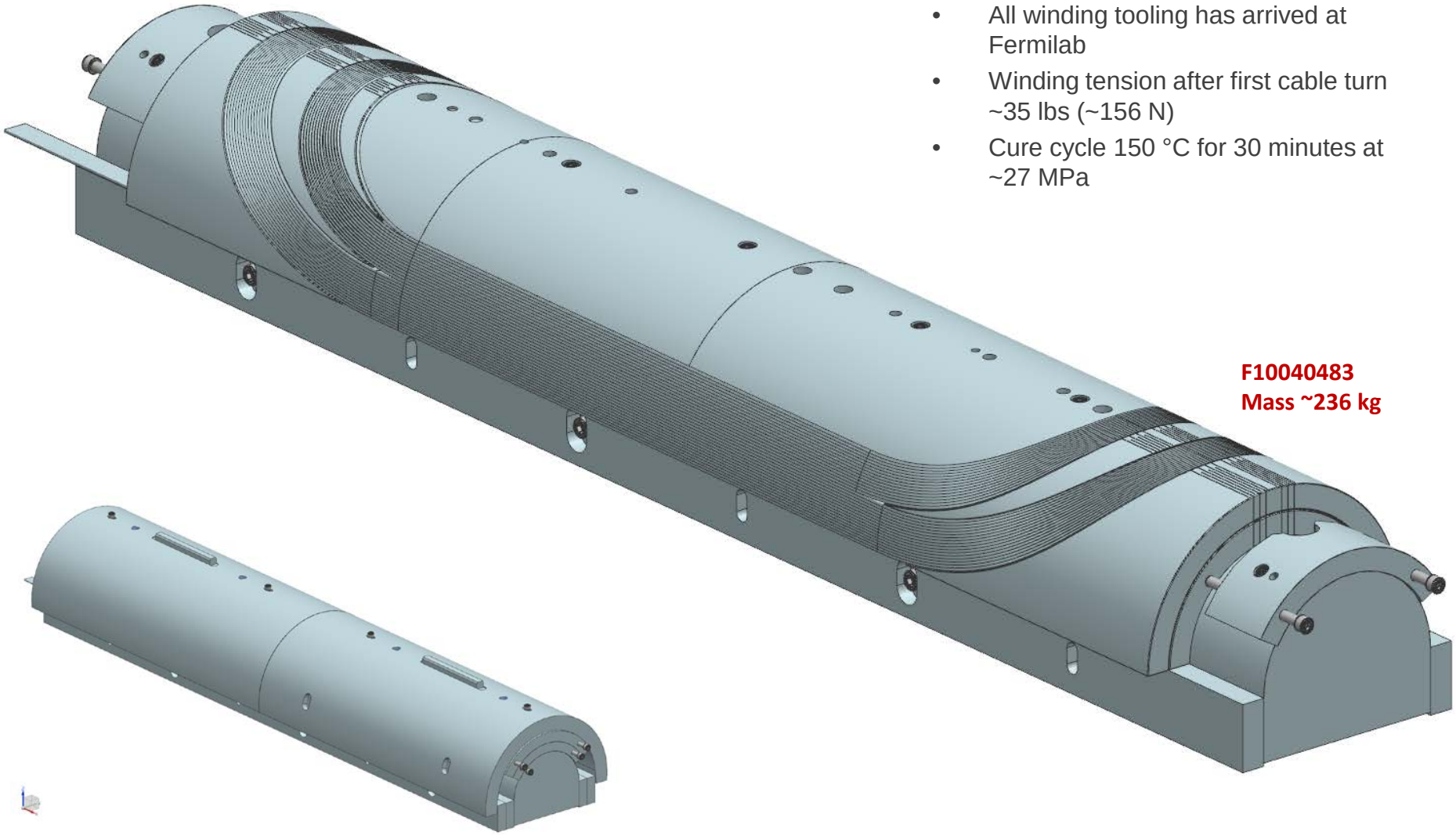
- Present plan is to use existing 11 T tooling and 11 T splicing procedure (detailed in backup slides)



# Production : L3/L4 Winding and Curing

- All winding tooling has arrived at Fermilab
- Winding tension after first cable turn ~35 lbs (~156 N)
- Cure cycle 150 °C for 30 minutes at ~27 MPa



**F10040483**
**Mass ~236 kg**



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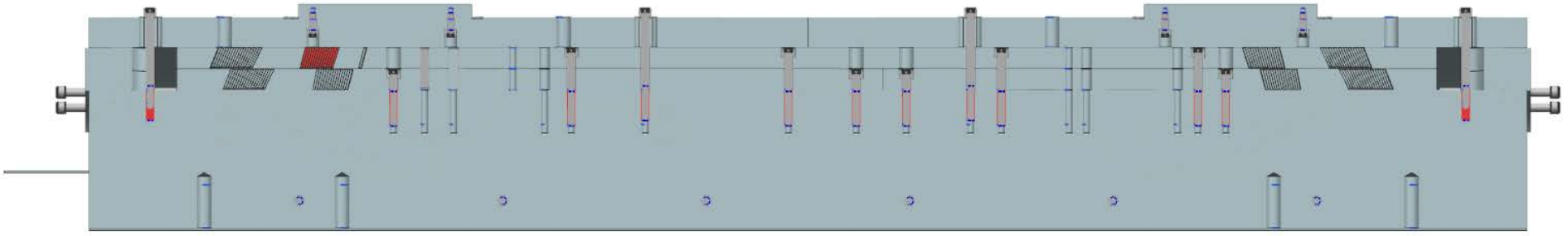
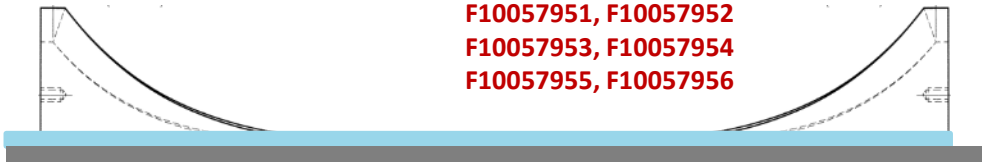
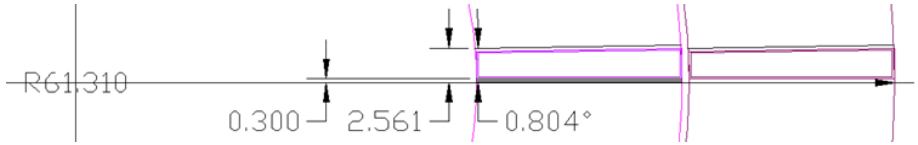
# Production : L3/L4 Winding and Curing

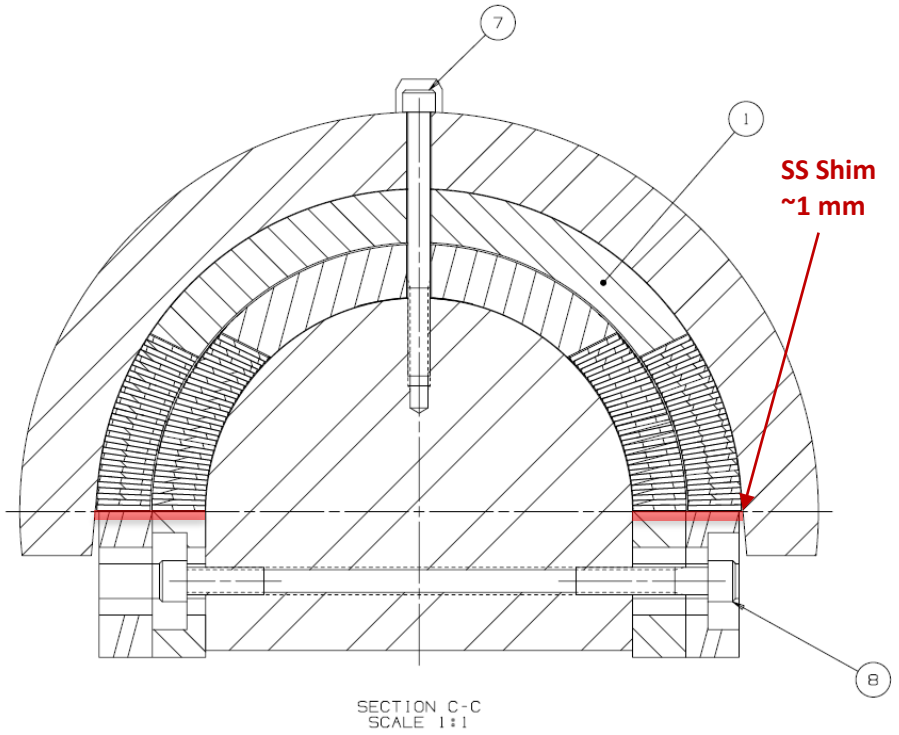


- "Technological saddles" or curing tooling saddles have been designed for the curing press – difference in coil expansion
- Layer 1, RE and LE saddle surface gaps increased by 1.295 mm
- Layer 2, RE and LE saddle surface gaps increased by 1.970 mm
- Layer 3, RE and LE saddle surface gaps increased by 1.674 mm
- Layer 4, RE and LE saddle surface gaps increased by 1.623 mm

**TECH. SADDLES : F10057949, F10057950**
**F10057951, F10057952**
**F10057953, F10057954**
**F10057955, F10057956**





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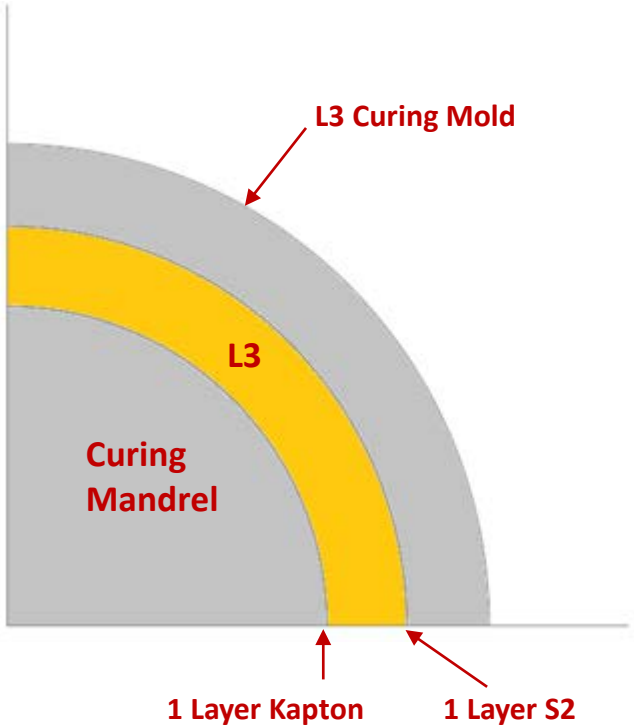
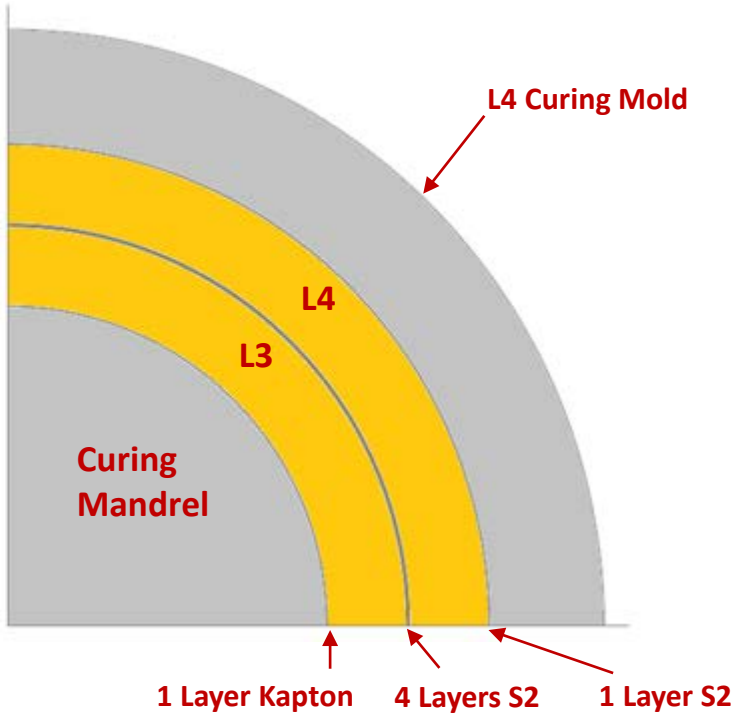
# Production : L3/L4 Winding and Curing



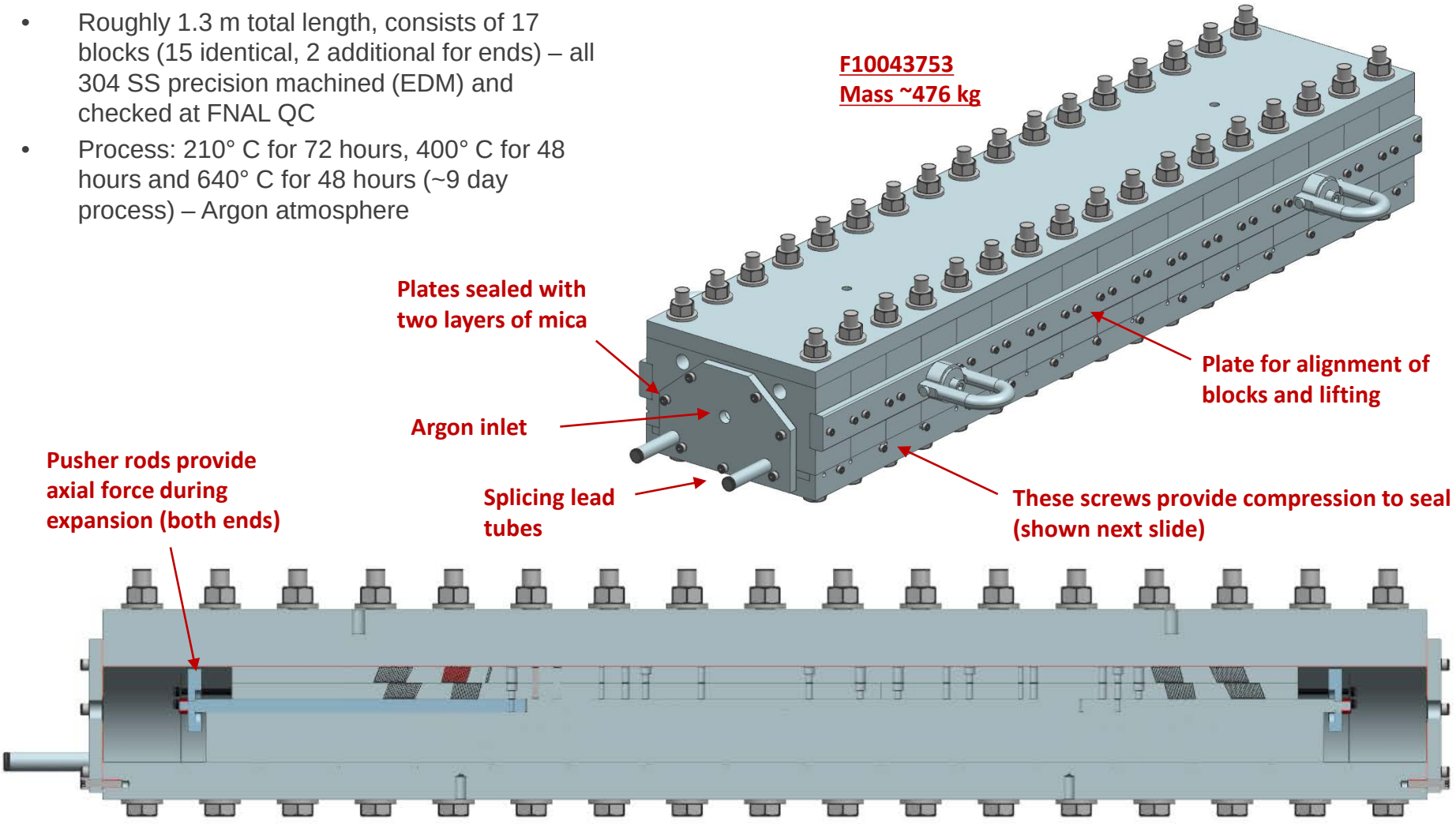




| | Thick | IR | OR | Final |
|---|---|---|---|---|
| **Mandrel** | - | - | 61.68 | 61.68 |
| **Kapton** | 0.127 | - | - | 61.807 |
| **L3** | - | 61.806 | 77.206 | 77.206 |
| **S2** | 0.127 | - | - | 77.333 |
| **L3 Curing Spacer** | - | 77.32 | 93.21 | 93.21 |

| | Thick | IR | OR | Final |
|---|---|---|---|---|
| **Mandrel** | - | - | 61.68 | 61.68 |
| **Kapton** | 0.127 | - | - | 61.807 |
| **L3** | - | 61.806 | 77.206 | 77.206 |
| **S2 X 4** | 0.508 | - | - | 77.714 |
| **L4** | - | 77.712 | 93.112 | 93.112 |
| **S2** | 0.127 | - | - | 93.239 |
| **L4 Curing Spacer** | - | 93.25 | 115.4 | 115.4 |

# Production : L3/L4 Reaction Tooling

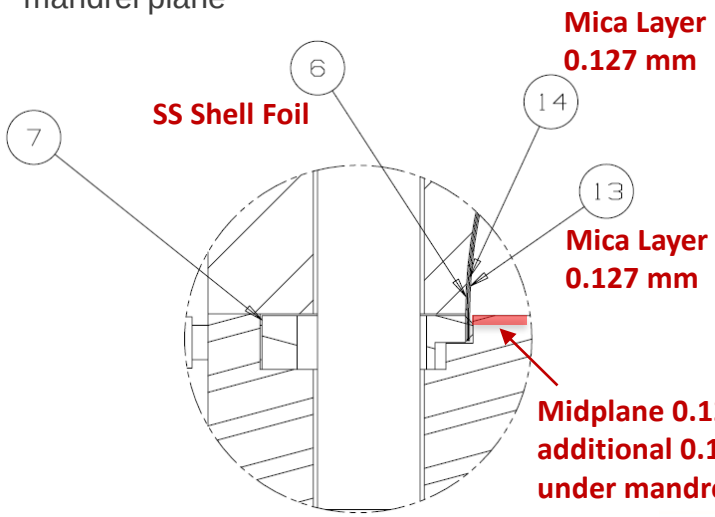
- Roughly 1.3 m total length, consists of 17 blocks (15 identical, 2 additional for ends) – all 304 SS precision machined (EDM) and checked at FNAL QC
- Process: 210° C for 72 hours, 400° C for 48 hours and 640° C for 48 hours (~9 day process) – Argon atmosphere

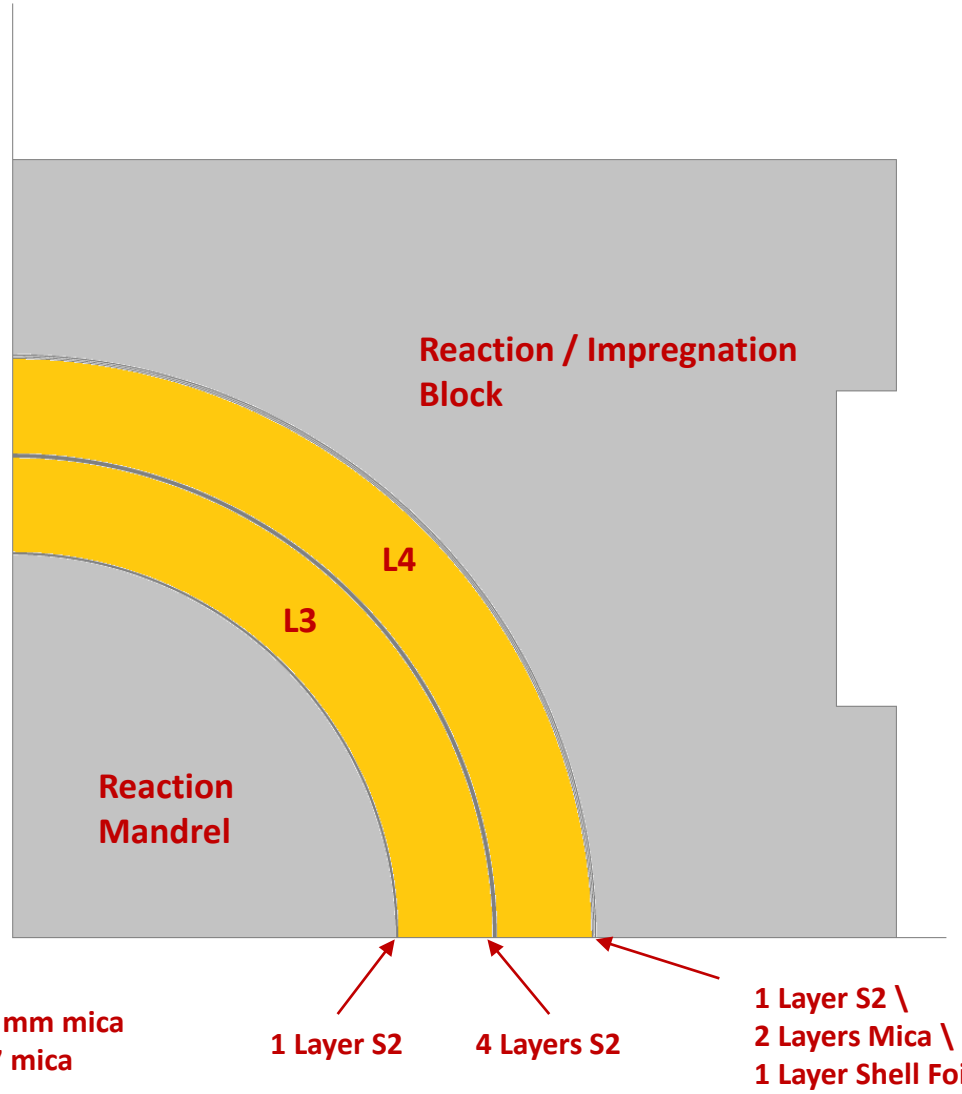


# Production : L3/L4 Reaction Tooling

| | Thick | IR | OR | Final |
|---|---|---|---|---|
| **Mandrel** | - | - | 61.61 | 61.61 |
| **Mica X 1** | 0.127 | - | - | 61.737 |
| **L3** | - | 61.806 | 77.206 | 77.206 |
| **S2 X 4** | 0.508 | - | - | 77.714 |
| **L4** | - | 77.712 | 93.112 | 93.112 |
| **S2 X 1** | 0.127 | - | - | 93.239 |
| **Mica X 2** | 0.254 | - | - | 93.493 |
| **Shell Foil (SS)** | 0.25 | - | - | 93.743 |
| **Reaction Blocks** | - | 93.68 | - | - |

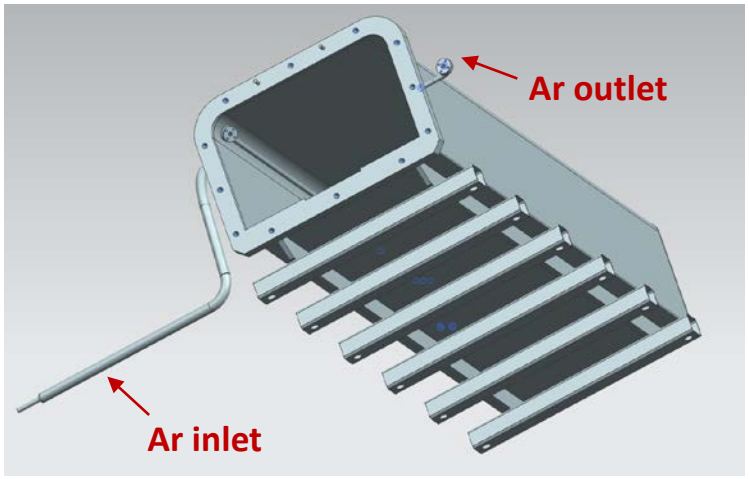
- "Plate pusher" pushes SS shell foil against two layers of mica to create seal below mandrel plane

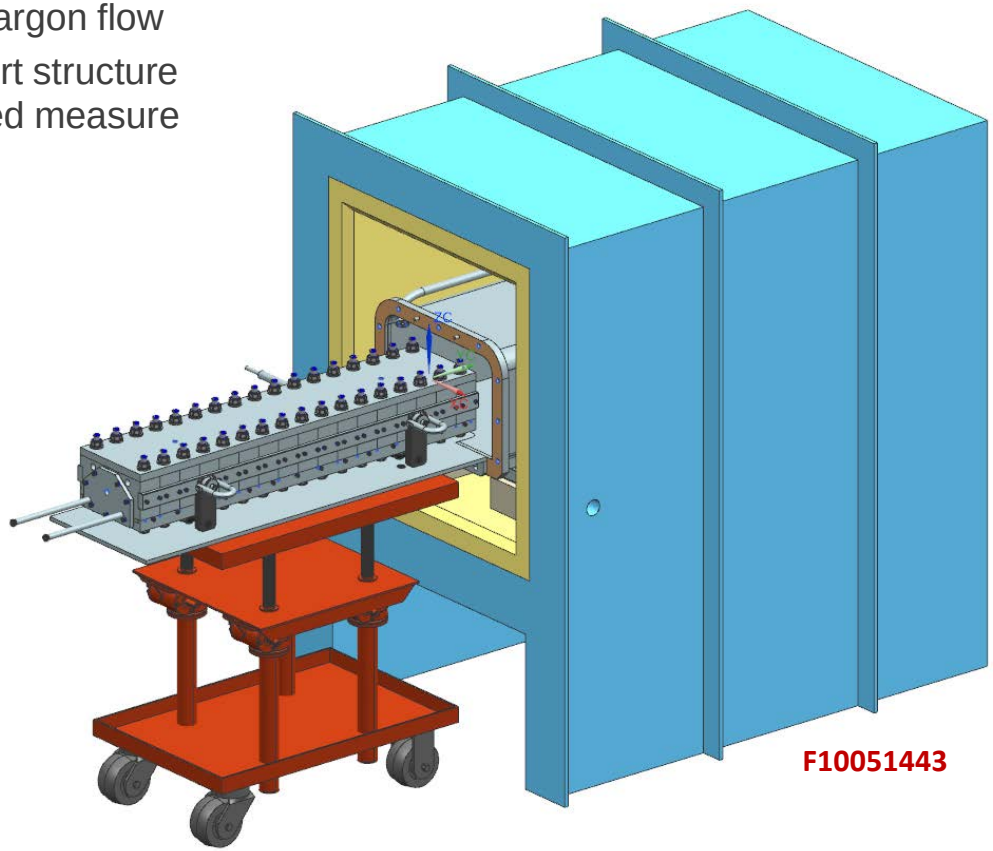


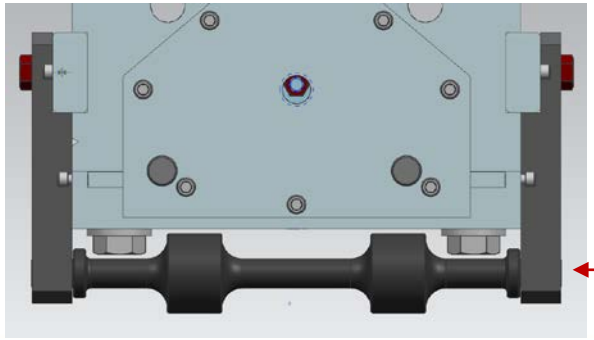



# Production : L3/L4 Reaction Tooling (Oven Retort)

- New stainless steel oven retort designed to allow for use of small oven in IB3 – fully welded design, argon flow
- Small oven upgraded with additional support structure underneath to allow for heavier loads, added measure of safety to manufactures' existing consent



**Steel roller assembly connects to reaction tooling, uses graphite-filled SAE 841 bearing bronze bushings**



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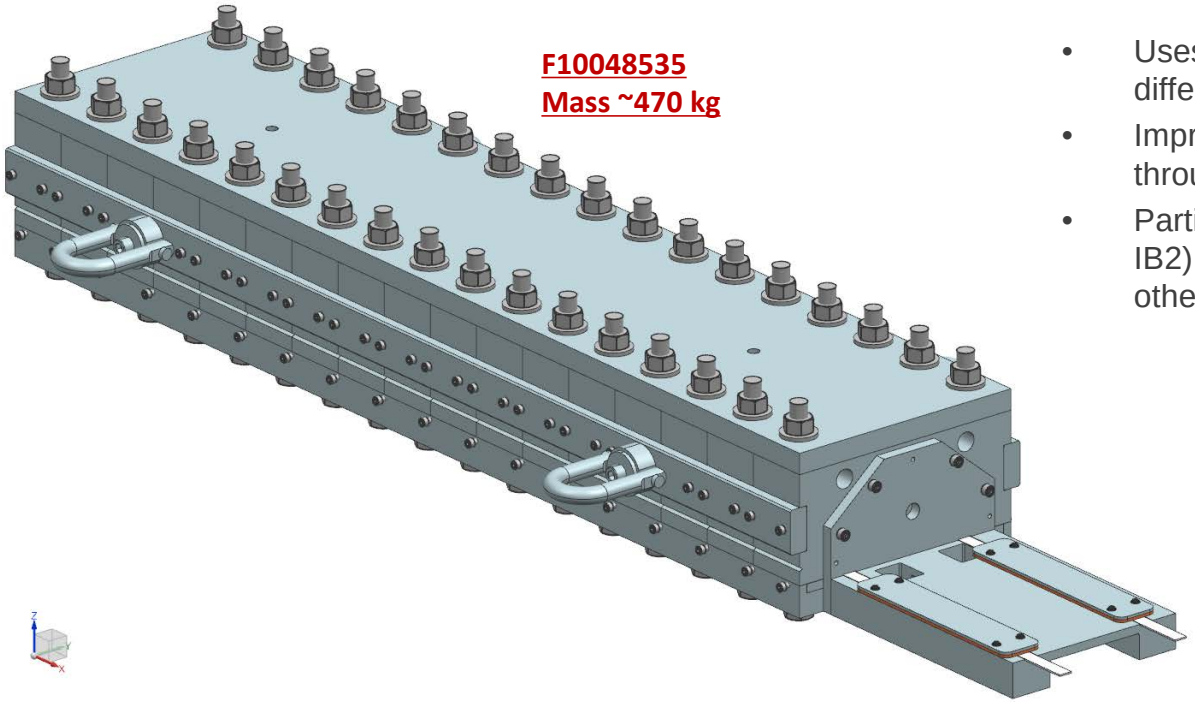
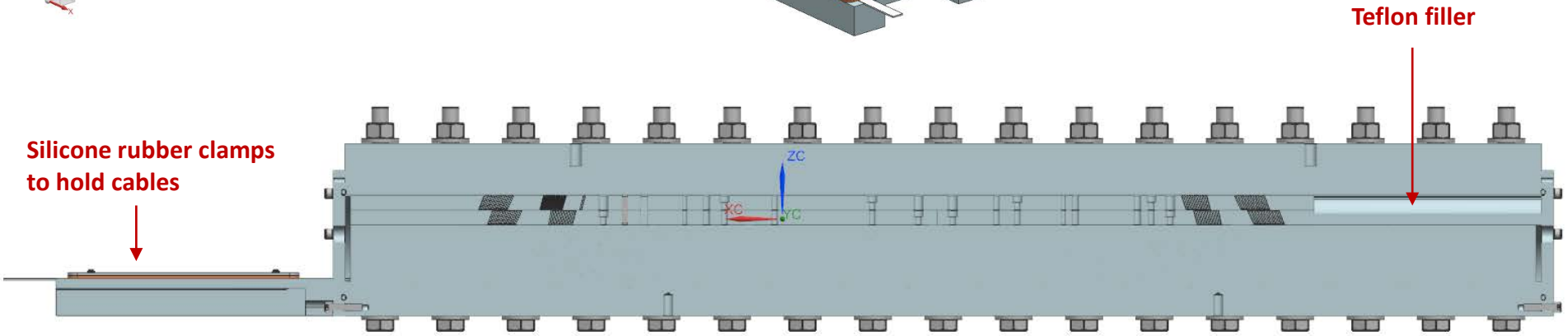
# Production : L3/L4 Impregnation Tooling

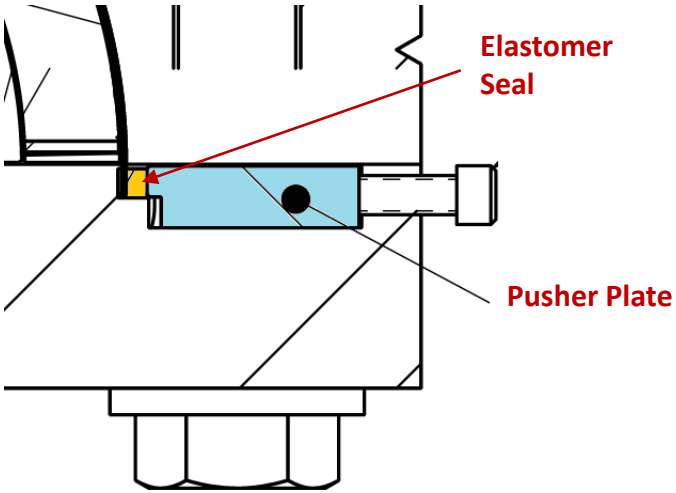


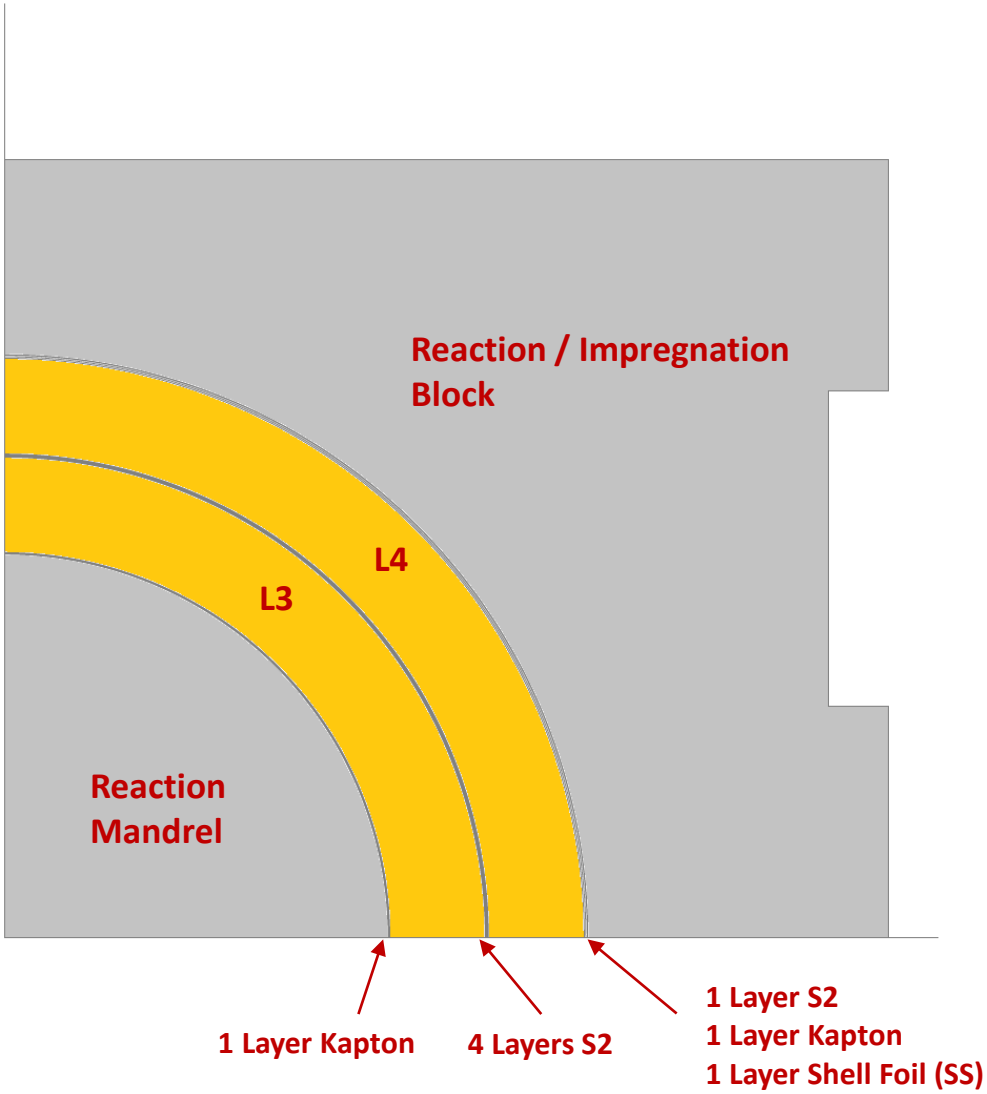

- Uses same tooling used for reaction, but with different insulation and sealing material
- Impregnation end plates allow leads to extend through plate, sealed using o-ring
- Partial vacuum pulled around assembly (in IB2) with epoxy temperature of 60 °C, cured in other oven at 125 °C for 21 hours



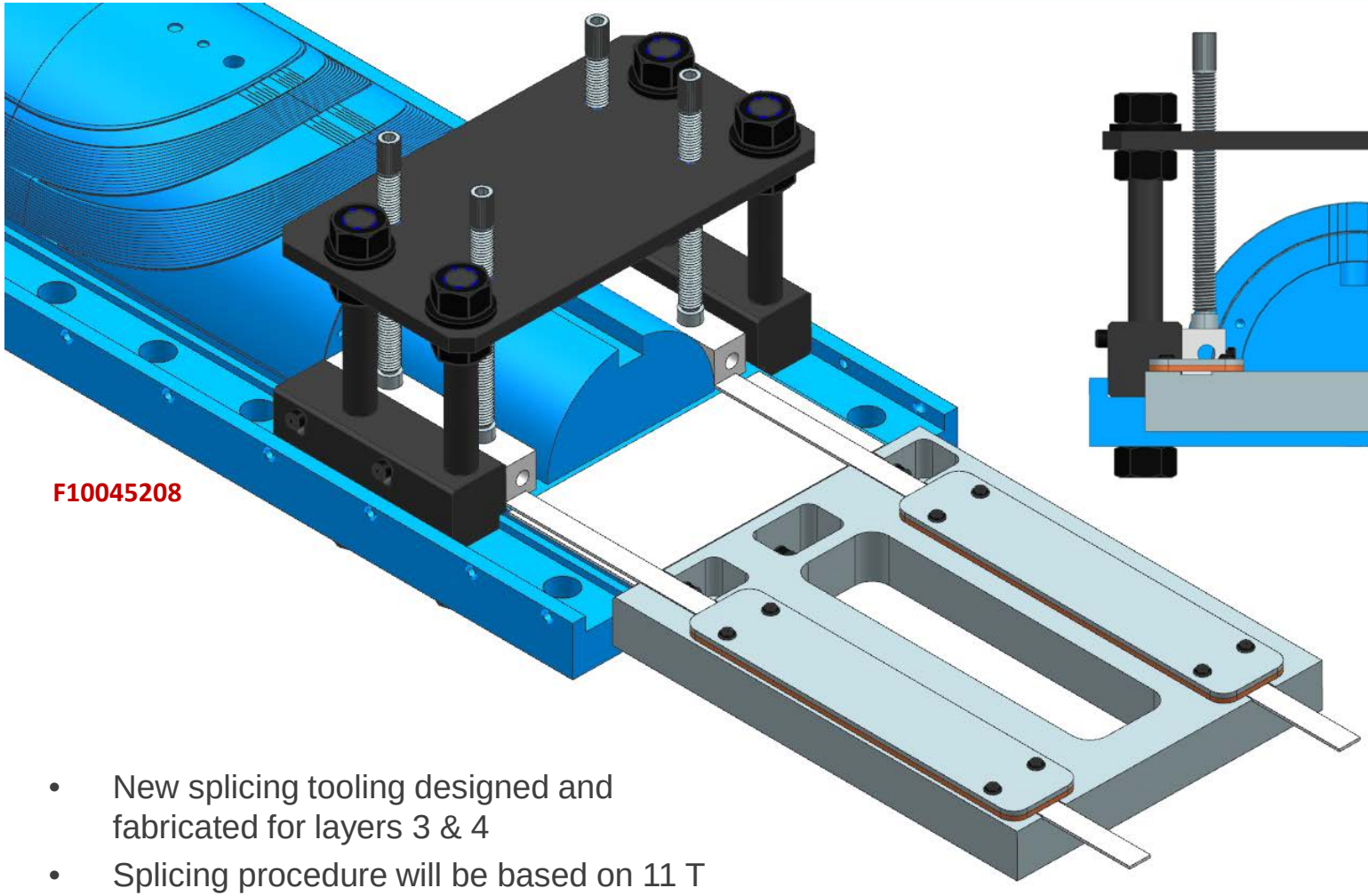
# Production : L3/L4 Impregnation Tooling

| | Thick | IR | OR | Final |
|---|---|---|---|---|
| Mandrel | - | - | 61.61 | 61.61 |
| Kapton | 0.125 | - | - | 61.735 |
| L3 | - | 61.806 | 77.206 | 77.206 |
| S2 X 4 | 0.5 | - | - | 77.706 |
| L4 | - | 77.712 | 93.112 | 93.112 |
| S2 | 0.127 | - | - | 93.239 |
| Kapton | 0.127 | - | - | 93.366 |
| Shell Foil (SS) | 0.25 | - | - | 93.616 |
| Reaction Blocks | - | 93.68 | - | - |



# Production : L3/L4 Splicing Tooling






- New splicing tooling designed and fabricated for layers 3 & 4
- Splicing procedure will be based on 11 T



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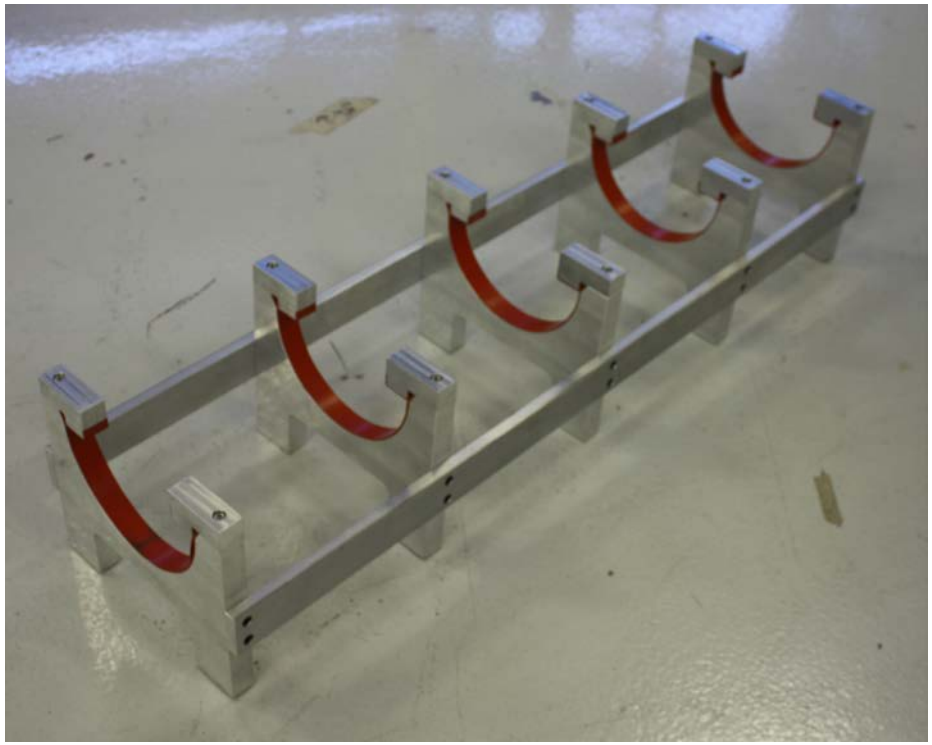
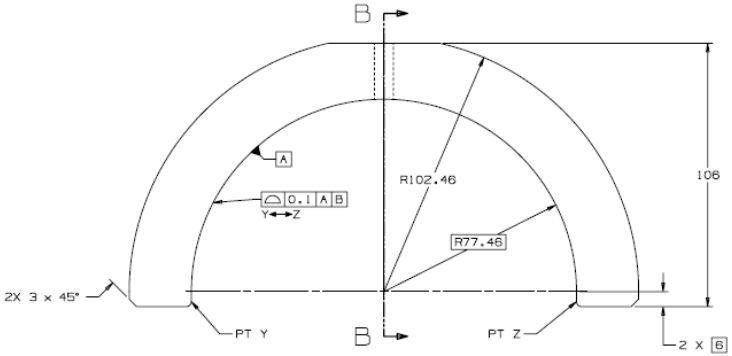
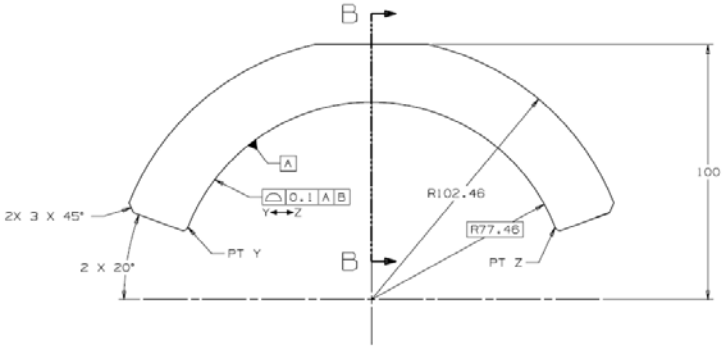
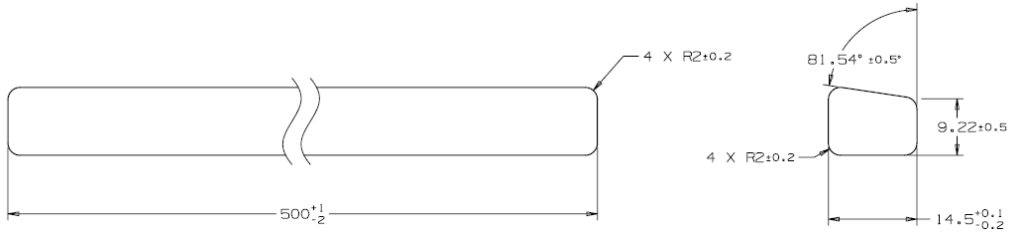
# Production : Storage Fixtures, Misc. Tooling

- New coil storage and holding fixture designed and fabricated for L3 & L4 (L1 & L2 will use existing 11 T equipment)
- Designed/fabricated misc. Teflon holding clamps for winding and tapered push bars





# Procurement Status

- All L3 & L4 End Parts are either in IB3 or in QC (unslitted parts, poles, saddles, etc.)
- L3 & L4 Tooling (Reaction, impregnation, splicing) have arrived at Fermilab, some parts remain in QC
- L1 & L2 End Parts have been sent out for quote, surfaces will be updated during test winding
- L1&L2 impregnation and oven retort drawing packages currently being checked and will send out in coming weeks

Live document maintained in HFM folder:

**Q:\HFM\FNAL-15 T dipole\Procurement**

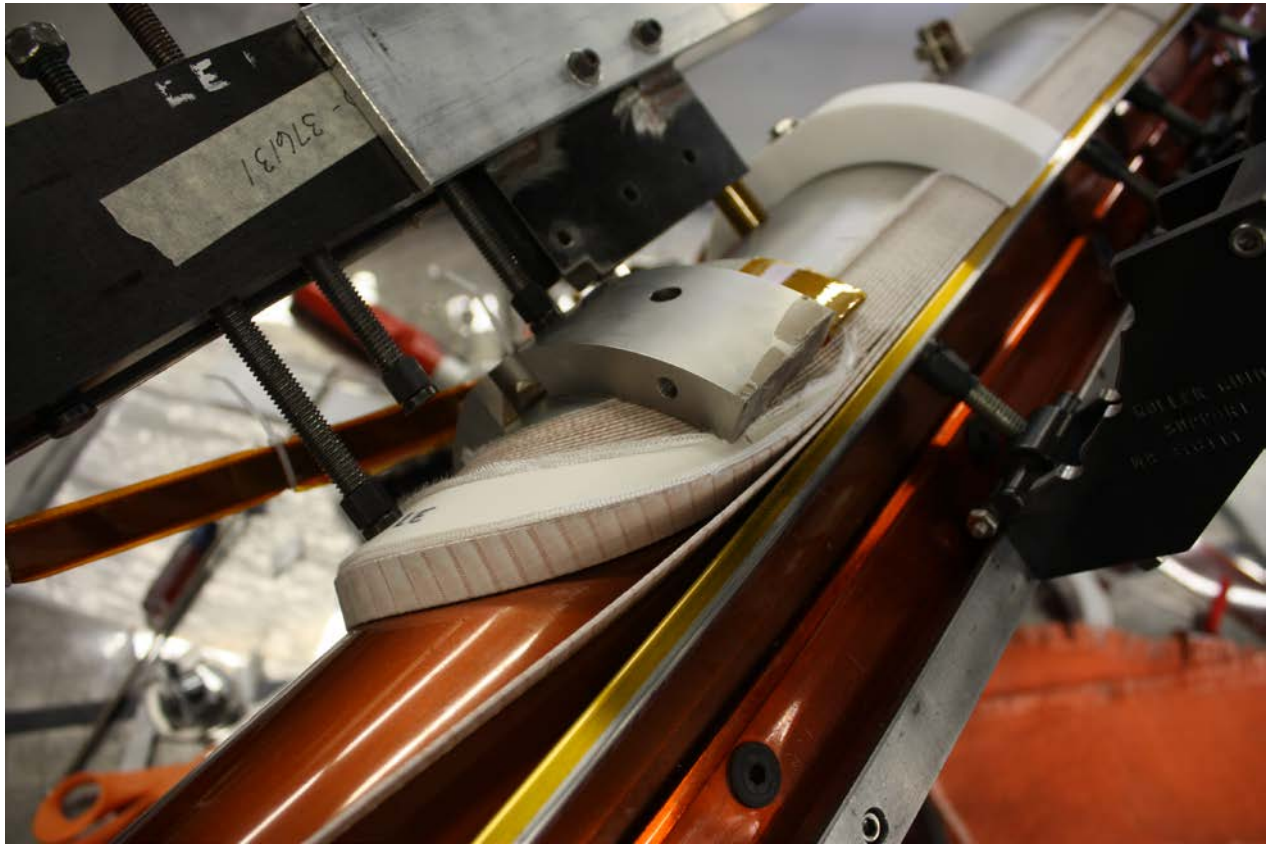
| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 T End Parts | F10038812 | SPACER, TRANSITION - LEAD END 15T DIPOLE L4 | 3 | $865.00 | $2,595.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003251 | In QC |
| | F10038885 | POLE FILLER | 3 | | | | | | | | | In QC |
| | F10038805 | SADDLE, LEAD END 15T DIPOLE L3 | 3 | $1,210.00 | $3,630.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003251 | In QC |
| | F10038779 | SPACER, RETURN END 15T DIPOLE L3 | 3 | $1,020.00 | $3,060.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003251 | In QC |
| | F10038804 | SPACER, LEAD END 15T DIPOLE L3 | 3 | $1,160.00 | $3,480.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003251 | In QC |
| | F10038884 | SPLICE BLOCK, 15T DIPOLE L4 | 3 | $957.50 | $2,872.50 | | 10-Aug-15 | 25-Sep-15 | 623582 | 257088 | ED0003251 | Here in IB3 Magnet Lab |
| | F10038810 | SADDLE, LEAD END 15T DIPOLE L4 | 3 | $1,430.00 | $4,290.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003251 | In QC |
| | F10038807 | SPACER, RETURN END 15T DIPOLE L4 | 3 | $1,160.00 | $3,480.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003251 | In QC |
| | F10038806 | SPACER, LEAD END 15T DIPOLE L4 | 3 | $1,130.00 | $3,390.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003251 | In QC |
| | F10038777 | POLE, RETURN END 15T DIPOLE L4 | 3 | $1,970.00 | $5,910.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003251 | In QC |
| | F10038883 | SPLICE BLOCK, 15T DIPOLE L3 | 3 | $910.00 | $2,730.00 | | 10-Aug-15 | 25-Sep-15 | 623582 | 257088 | ED0003251 | In QC |
| | F10038808 | SADDLE, RETURN END 15T DIPOLE L4 | 3 | $1,410.00 | $4,230.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003251 | In QC |
| | F10038803 | SADDLE, RETURN END 15T DIPOLE L3 | 3 | $1,160.00 | $3,480.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003251 | In QC |
| 15 T Poles | F10038778 | POLE, LEAD END 15T DIPOLE L4 | 3 | $2,225.00 | $6,675.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003255 | In QC as of March 21 |
| | F10038777 | POLE, RETURN END 15T DIPOLE L4 | 3 | $1,970.00 | $5,910.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003255 | In QC |
| | F10038776 | POLE, LEAD END 15T DIPOLE L3 | 3 | $2,090.00 | $6,270.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003255 | Here in IB3 Magnet Lab |
| | F10038775 | POLE, RETURN END 15T DIPOLE L3 | 3 | $1,905.00 | $5,715.00 | | 10-Aug-15 | 6-Nov-15 | 624108 | 257319 | ED0003255 | Here in IB3 Magnet Lab |
| 15 T Cabling Mandrel | F10040026 | MANDREL WITH SLOT, 15T | 1 | | | | 30-Jun-15 | | | | ED0003221 | Arrived |
| 15 T Tooling | F10040486 | BLOCK PUSHER LAYER 3 ASSEMBLY | 2 | $1,087.50 | $2,175.00 | | 10-Aug-15 | 25-Sep-15 | 623582 | 257088 | ED0003268 | In QC |
| | *F10040485* | *BLOCK PUSHER LAYER 3* | *0* | | | | *10-Aug-15* | | | | *ED0003268* | |
| | F10040490 | SPACER - RETURN END CURING LAYER 3 | 2 | $3,985.00 | $7,970.00 | | 10-Aug-15 | 25-Sep-15 | 623582 | 257088 | ED0003268 | In QC |
| | F10039909 | MANDREL BLOCK | 1 | $10,750.00 | $10,750.00 | | 10-Aug-15 | 18-Sep-15 | | | ED0003268 | In QC |

# Test Winding and End Part Development

# Test Winding and End Part Development

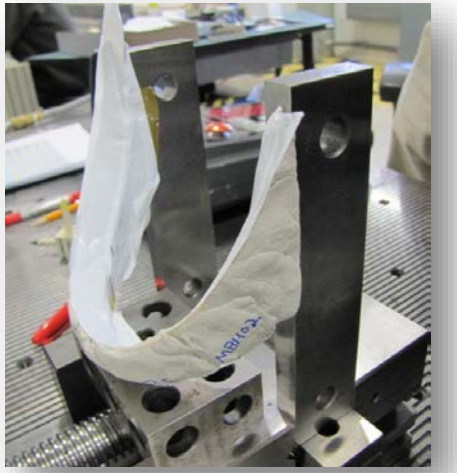
- Presently performing test winding of Layer 3
- Insulated copper cable, tension ~35 lbs (~156 N)
- Using binder on each turn to prevent strand popping
- Each turn on LE and RE, recording angle and distance on mandrel

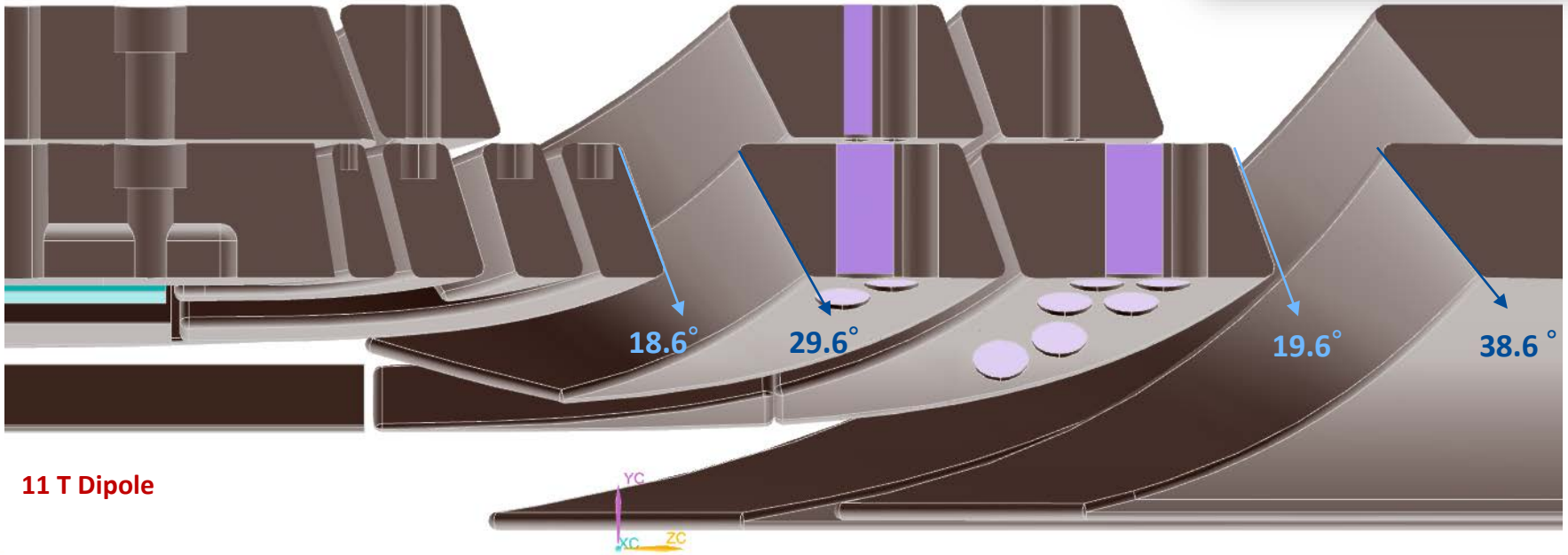
| | coil 3 | | 04.07.16 | practice | A101 copper |
|---|---|---|---|---|---|
| | LE | | | RE | |
| Turn | top | Bottom | | Top | Bottom |
| 1 | 7.562 | 7.491 | | 7.621 | 7.500 |
| 2 | 7.487 | 7.297 | | 7.564 | 7.380 |
| 66° 3 | 7.486 26 | 7.207 | | 7.490 | 7.304 |
| 4 | 65° | 1.1140 | | 65.5° | 1.131 |
| 5 | 65.5 | 1.0655 | | 645 | 1.112 |
| 6 | 64.5 | 0.9825 | | 64 | 1.036 |
| 7 | 61.5 | 0.8755 | | 62.5 | 0.9555 |
| 8 | 60.0 | 0.7970 | | 61.5 | 0.867 |
| 9 | 59.5 | 0.7240 | | 60.5 | 0.7895 |
| 10 | 59.0 | 0.6370 | | 60.0 | 0.7165 |
| 11 | 58.0 | 0.5435 | | 59.0 | 0.6245 |
| 12 | 57.5 | 0.4830 | | 57.5 | 0.5405 |
| 13 | 57.0 | 0.4525 | | 57.0 | 0.4550 |
| 14 | 57.0 | 0.3030 | | 56.5 | 0.3690 |
| 15 | 56.0 | 0.2210 | | 56.0 | 0.2885 |



# Test Winding and End Part Development

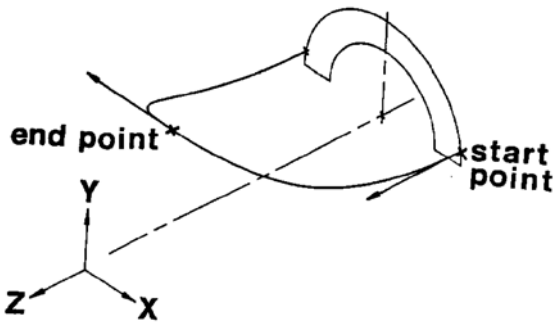
- Due to fixed artificial inclination angle ~15˚ (vs BEND suggested 38.8˚ ) the strain in the cable is very large leading to expansion of cable edge and large angles – large deviation from initially designed spacers
- Similar to experience with 11 T dipole:
- End parts for 11 T iteratively performed in ROXIE, with saddles using clay and coordinate measuring



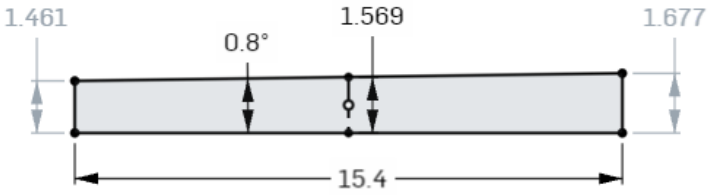


# Test Winding and End Part Development

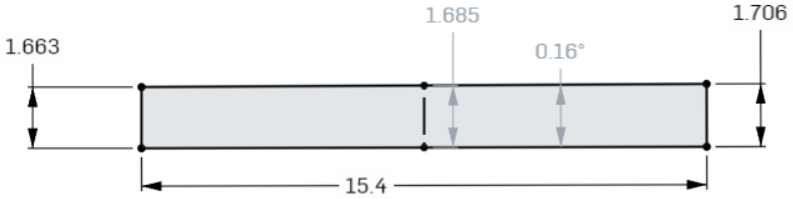
```
GO      = .TRUE.
  ASYM    = .FALSE.
  DIRECT  = .FALSE.
  OD      = .TRUE.
  SHAP    = .FALSE.
  SHAPE(0) = 0
  SHAPE(1) = 0
  SHAPE(2) = 0
*   Evaluate the THICKM and KANGLE correction factors.
  FAT1    = ( 11. + .70) / 11.
  FAT2    = ( 11. + .81) / 11.
*   Set the keystone-widening ratios.
  KEY1    = .5
  KEY2    = .2

*   Read possible alternatives to the default options.
 110 DO 112  J=1,NOPTNS
     IARRAY(J) ....
```



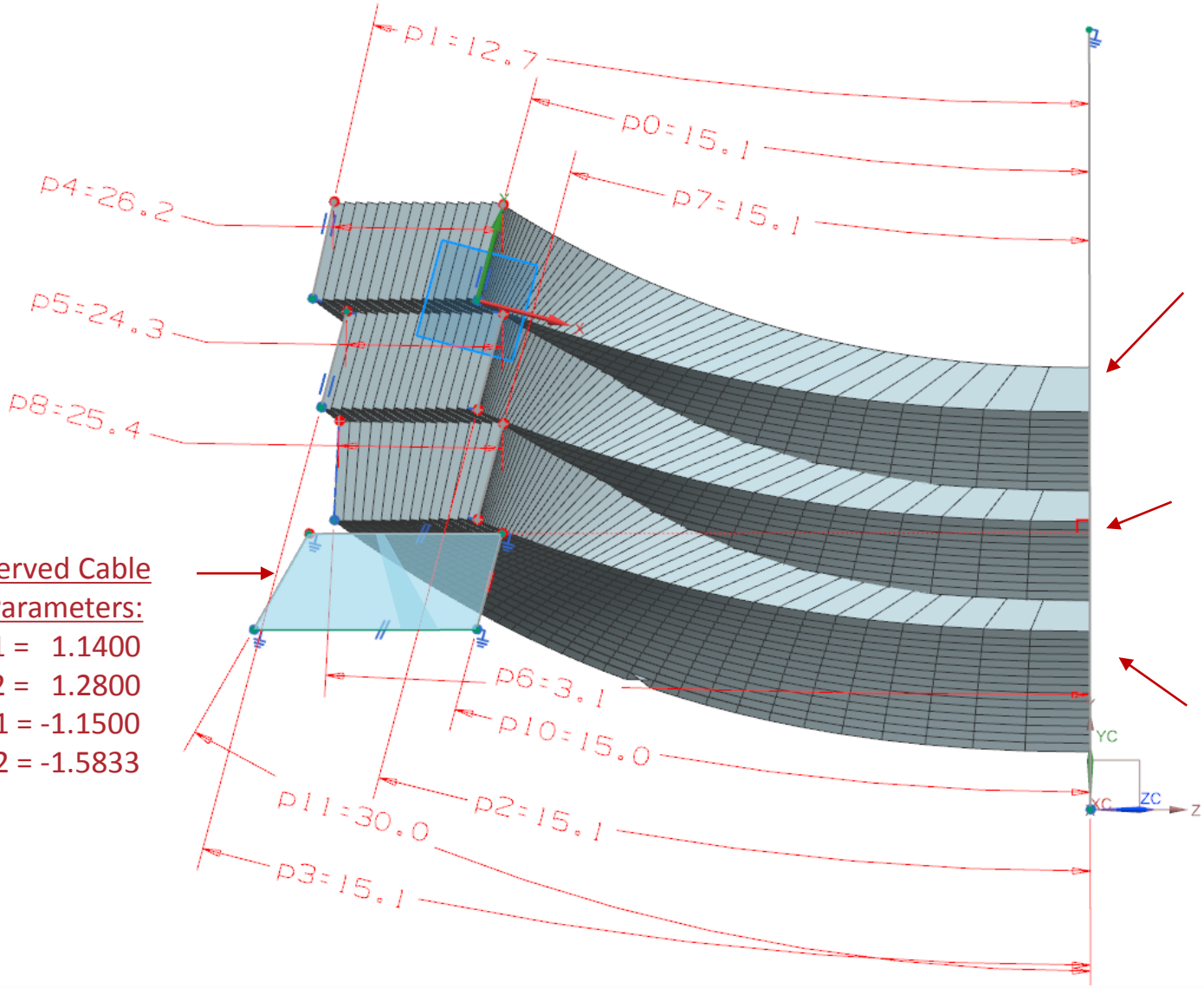

- BEND code has parameters “FAT” and “KEY” in fortran code for adjusting behavior of end cable based on experience, values presently coded:
  - FAT1 = 1.0636 // KEY1 = 0.500
  - FAT2 = 1.0736 // KEY2 = 0.200
- Recall BEND uses 50 points for spline on developable surface : FAT1 and KEY1 control point 25, while FAT2 and KEY2 control point 50 (end point) – cubic interpolation between
- KEY decreases angle, i.e. KEY=0.2 means at midplane angle reduced to 20% of present value (0.800 ˚ X 0.2 = .16 ˚ )
- Likewise, FAT controls thickening of cable
- Adjustments made to these parameters are usually small (less than 10%), but large deviations allow use of BEND to generate CAD files with distorted geometry




**FAT2 = 1.0736**
**KEY2 = 0.200**



# Test Winding and End Part Development



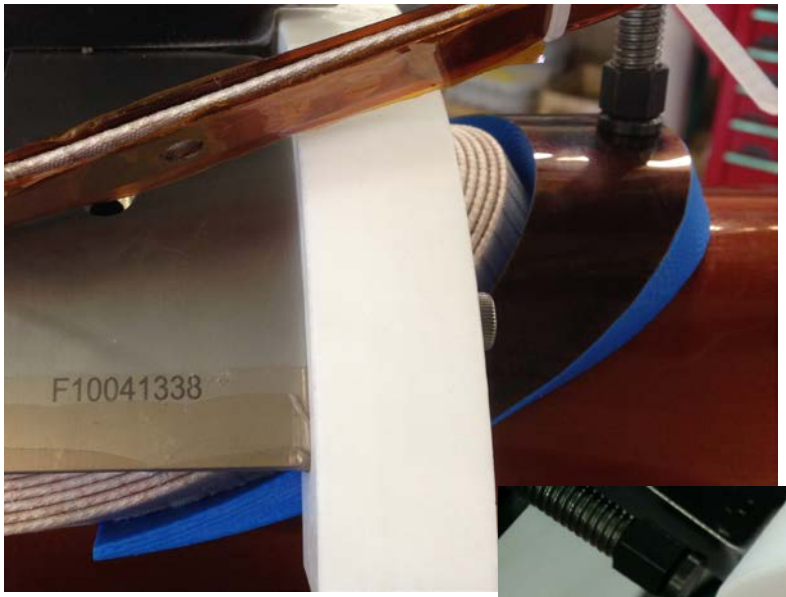

Observed Cable Fit Parameters:
FAT1 = 1.1400
FAT2 = 1.2800
KEY1 = -1.1500
KEY2 = -1.5833

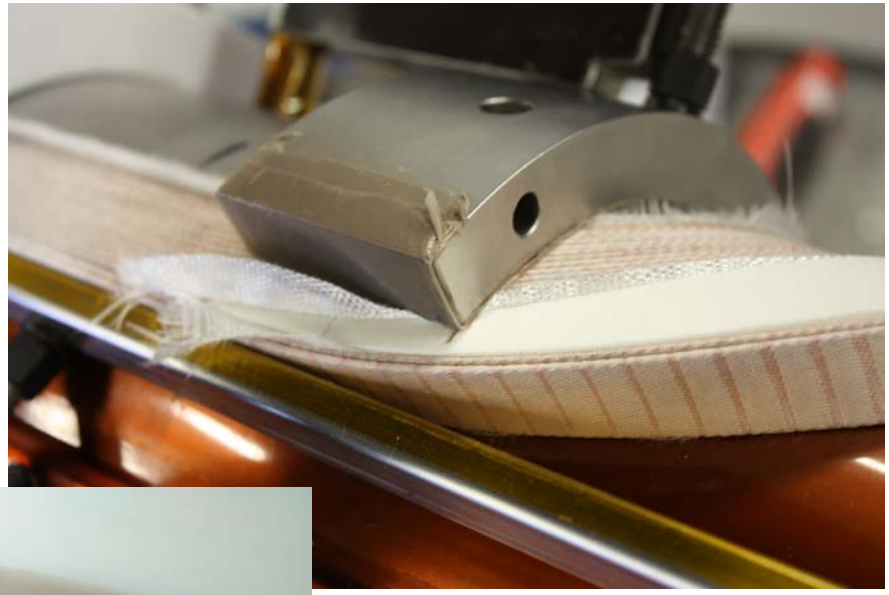
Default Parameters (Initial Design):
FAT1 = 1.0636
FAT2 = 1.0736
KEY1 = 0.500
KEY2 = 0.200

Rectangular Cable:
FAT1 = 1.0000
FAT2 = 1.0000
KEY1 = 0
KEY2 = 0

No cross-section change:
FAT1 = 1.0000
FAT2 = 1.0000
KEY1 = 1.0000
KEY2 = 1.0000

# Test Winding and End Part Development



**1) Large gaps, splines don't align**

**2) Nose angle and spacing ok, legs need adjustment using FAT1 and KEY1**

**3) Parameters adjusted to good match**

- Rapid prototyping allows us to quickly iterate different end spacer designs



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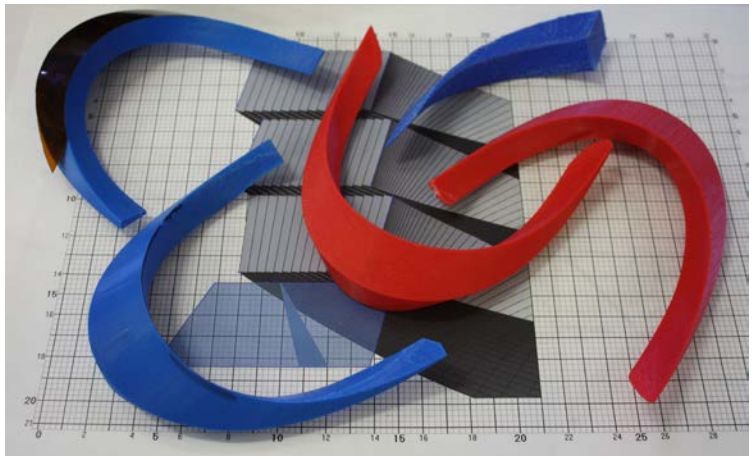
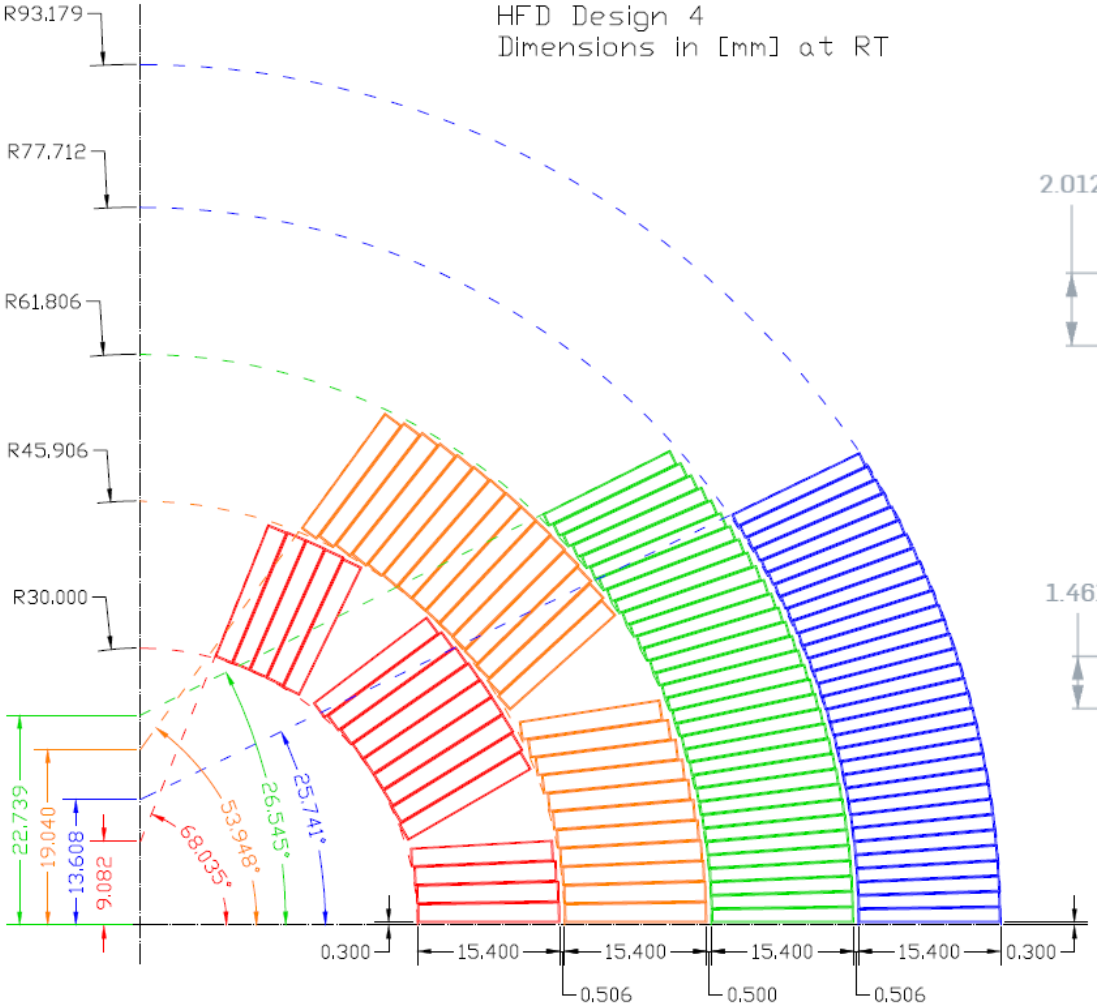
# Summary

- Mechanical design for all layers of the magnet including preliminary end parts has been completed, and drawings released
  - Layers 3&4 at FNAL
  - Layers 1&2 out for quotes
- All tooling has been designed and fabricated for layers 3&4, layers 1&2 will use 11 T tooling with minimal modification
- We have a well developed process for using BEND both for preliminary design, and later in test winding as a CAD generation tool – we are capable of creating end parts that match cable geometry using rapid prototyping
- The plans for winding, curing, reaction, and impregnation are well understood and built upon the experience of 11 T
- Documentation of the design process and procurement status is being maintained in the HFM folder

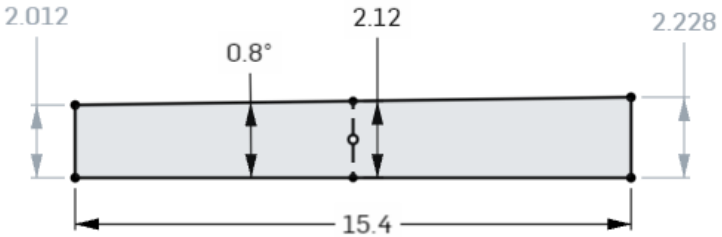


# Backup Slides

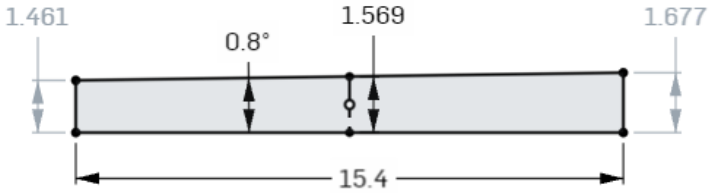
# Mechanical Layout and Components




## Layers 1&2 Cable Cross Section




## Layers 3&4 Cable Cross Section




**15 T Design and Parameter Specification Document : TD-16-004**



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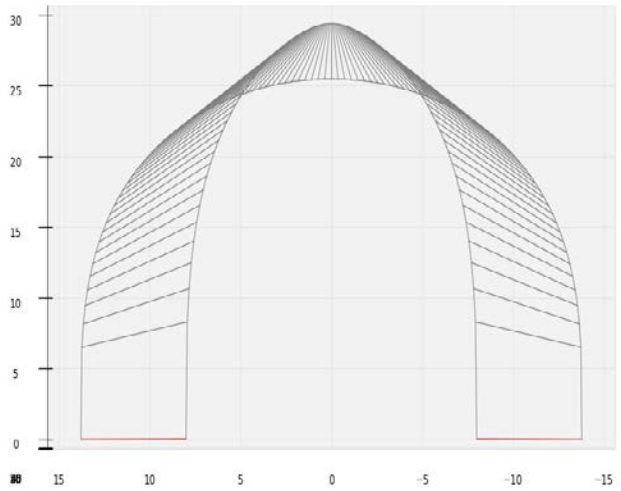
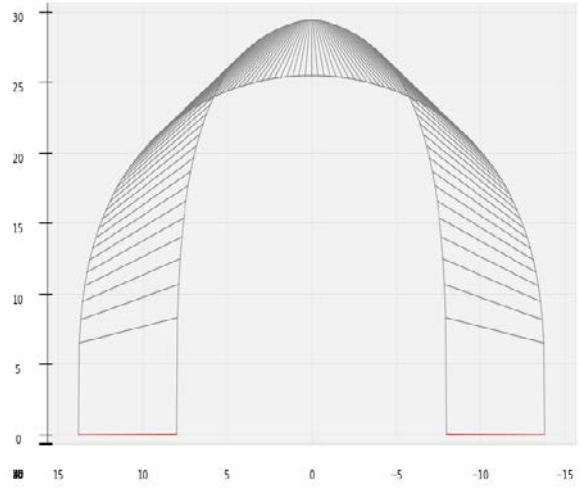
# Mechanical Layout and Components

# Mechanical Layout and Components : End Parts

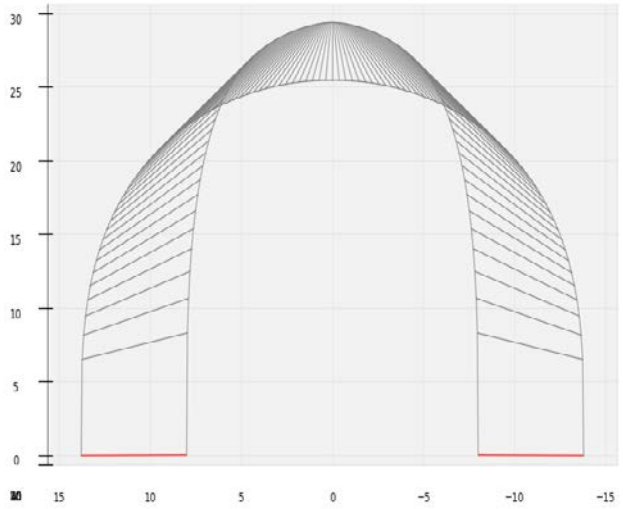



A = 25.5 mm, shift = 0.00, blunt = 0.00

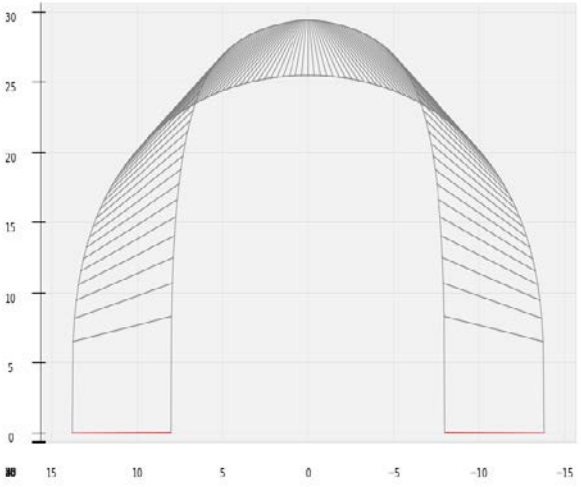



A = 25.5 mm, shift = 0.00, blunt = 0.25

**Effect of "blunt" on Layer 1 Pole RE**




A = 25.5 mm, shift = 0.00, blunt = 0.35




A = 25.5 mm, shift = 0.00, blunt = 0.50



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# Mechanical Layout and Components : End Parts

| Outer Radius | Inner Radius | Mid-Thickness | Keystone Angle of the Cable |
|---|---|---|---|
| 45.400 | 30.000 | 2.120 | 0.804 |

**Layer 1 BEND Input Parameters and Design Variables**

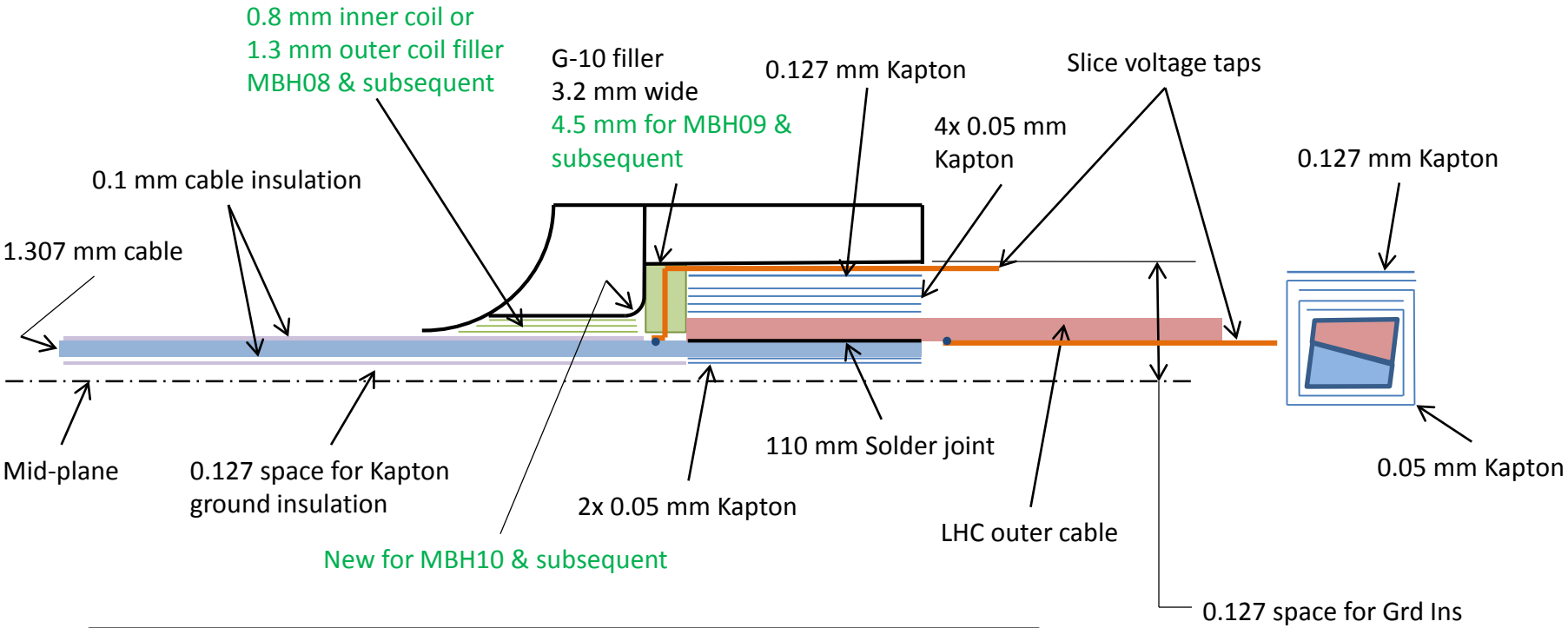
| FILE # | | | Outer Starting Angle of the Guiding Strip | Initial Edge Angle of the Guiding Strip | Group Array | Fixed A-Length (mm) | Offset | BEND Suggested Edge Angle (YZ Inclination) | Chosen Edge Angle (YZ Inclination) | Shift | Blunt |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | L1_01R | | 17.6741947463600 | 21.9652782322400 | 0, 5 | 25.5 | 0.0 | 14.1710985886339 | **14.17** | 0.000 | **0.400** |
| 2 | L1_01L | T | 20.4902189514451 | 22.7696825857824 | 0, 4 | 25.5 | 0.0 | 16.2337890056048 | **16.28** | 0.000 | **0.400** |
| 3 | | NT | 17.6741947463600 | 21.9652782322400 | 0, 4 | 25.5 | 0.0 | 14.1696123015649 | **16.28** | 0.000 | **0.400** |
| 4 | L1_0102 | NT | 28.9294794072700 | 25.1828956464299 | 0, 1 | 46.0 | 0.0 | 21.9258195194720 | **25.00** | 0.000 | 0.000 |
| 5 | | T | 42.8444619977200 | 52.7704608179693 | 0, 1 | 46.0 | 0.0 | 32.1522174696665 | **25.00** | 0.000 | 0.000 |
| 6 | L1_02R | | 42.8444619977200 | 52.7704608179693 | 0, 9 | 62.0 | 0.0 | 29.5934101367517 | **25.00** | 0.000 | 0.000 |
| 7 | L1_02L | T | 45.6918681428100 | 53.5748651715466 | 0, 8 | 62.0 | 0.0 | 31.8860299582876 | **25.00** | 0.000 | 0.000 |
| 8 | | NT | 42.8444619977200 | 52.7704608179693 | 0, 8 | 62.0 | 0.0 | 30.0876815359795 | **25.00** | 0.000 | 0.000 |
| 9 | L1_0203 | NT | 65.4241459542100 | 59.2056956464504 | 0, 1 | 95.0 | 0.0 | 37.3645492479601 | **25.00** | **-1.200** | **0.100** |
| 10 | | T | 78.3323351698300 | 86.7823825857886 | 0, 1 | 95.0 | 0.0 | 43.4553852417222 | **25.00** | **-1.000** | **0.180** |
| 11 | L1_03R | | 78.3323351698300 | 86.7823825857886 | 0,4 | 110.0 | 0.0 | 40.8673861596706 | **25.00** | **-1.000** | **0.100** |
| 12 | L1_03L | T | 81.1684247424100 | 87.5867869393240 | 0, 3 | 110.0 | 0.0 | 42.1889361313519 | **25.00** | 0.000 | 0.000 |
| 13 | | NT | 78.3323351698300 | 86.7823825857886 | 0, 3 | 110.0 | 0.0 | 41.3663680679966 | **25.00** | 0.000 | **0.100** |

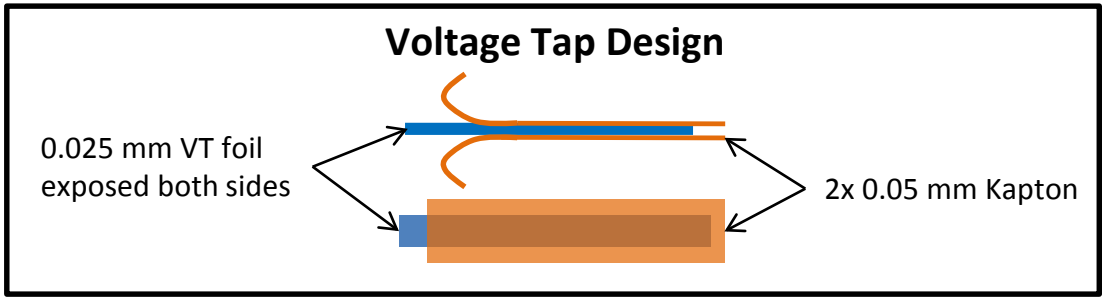
| Outer Radius | Inner Radius | Mid-Thickness | Keystone Angle of the Cable |
|---|---|---|---|
| 61.306 | 45.906 | 2.120 | 0.804 |

**Layer 2 BEND Input Parameters and Design Variables**

| FILE # | | | Outer Starting Angle of the Guiding Strip | Initial Edge Angle of the Guiding Strip | Group Array | A-Length (mm) | Offset | BEND Edge Angle (YZ Inclination) | Chosen Edge Angle (YZ Inclination) | Shift | Blunt |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | L2L1 | T | 18.7888707311381 | 21.9652782322400 | 0, 1 | 30.0 | 0.0 | 15.1149905463471 | 15.12 | 0.000 | 0.000 |
| 15 | L2L1 | NT | 25.5198049015100 | 36.0515346966200 | 0,1 | 30.0 | 0.0 | 22.0759225983769 | 15.12 | 0.000 | 0.000 |
| 16 | L2_01R | | 25.5198049015100 | 36.0515346966200 | 0, 15 | 40.0 | 0.0 | 19.9602504584718 | 19.96 | 0.000 | 0.000 |
| 17 | L2_01L | T | 25.5198049015100 | 36.0515346966200 | 0, 14 | 40.0 | 0.0 | 19.9602504584718 | 19.96 | 0.000 | 0.000 |
| 18 | L2_01L | NT | 27.6346377137399 | 36.8559390502100 | 0, 14 | 40.0 | 0.0 | 21.7472957724923 | 19.96 | 0.000 | 0.000 |
| 19 | L2_0102 | NT | 66.5517125280000 | 81.1515521108709 | 0, 1 | 85.0 | 0.0 | 41.6591732800196 | 25.00 | **-0.800** | **0.150** |
| 20 | | T | 54.8013603403924 | 47.3131956464600 | 0, 1 | 85.0 | 0.0 | 35.3844020184996 | 25.00 | **-1.200** | **0.150** |
| 21 | L2_02R | | 66.5517125280000 | 81.1515521108709 | 0, 11 | 92.0 | 0.0 | 40.5170435655769 | 25.00 | 0.000 | **0.200** |
| 22 | L2_02L | T | 66.5517125280000 | 81.1515521108709 | 0, 10 | 92.0 | 0.0 | 40.5170435655769 | 25.00 | 0.000 | **0.200** |
| 23 | | NT | 68.7012568555700 | 81.9559564644308 | 0, 10 | 92.0 | 0.0 | 41.5803042862661 | 25.00 | 0.000 | **0.200** |

# 11 T Power Lead Splice Insulation Design




***NOTE: This slide taken from presentation "11 T Coil Design, Tooling, & Fabrication Rvw", F. Nobrega 12/6/2013***