Torus Coil

Construction and Geometry for Modeling

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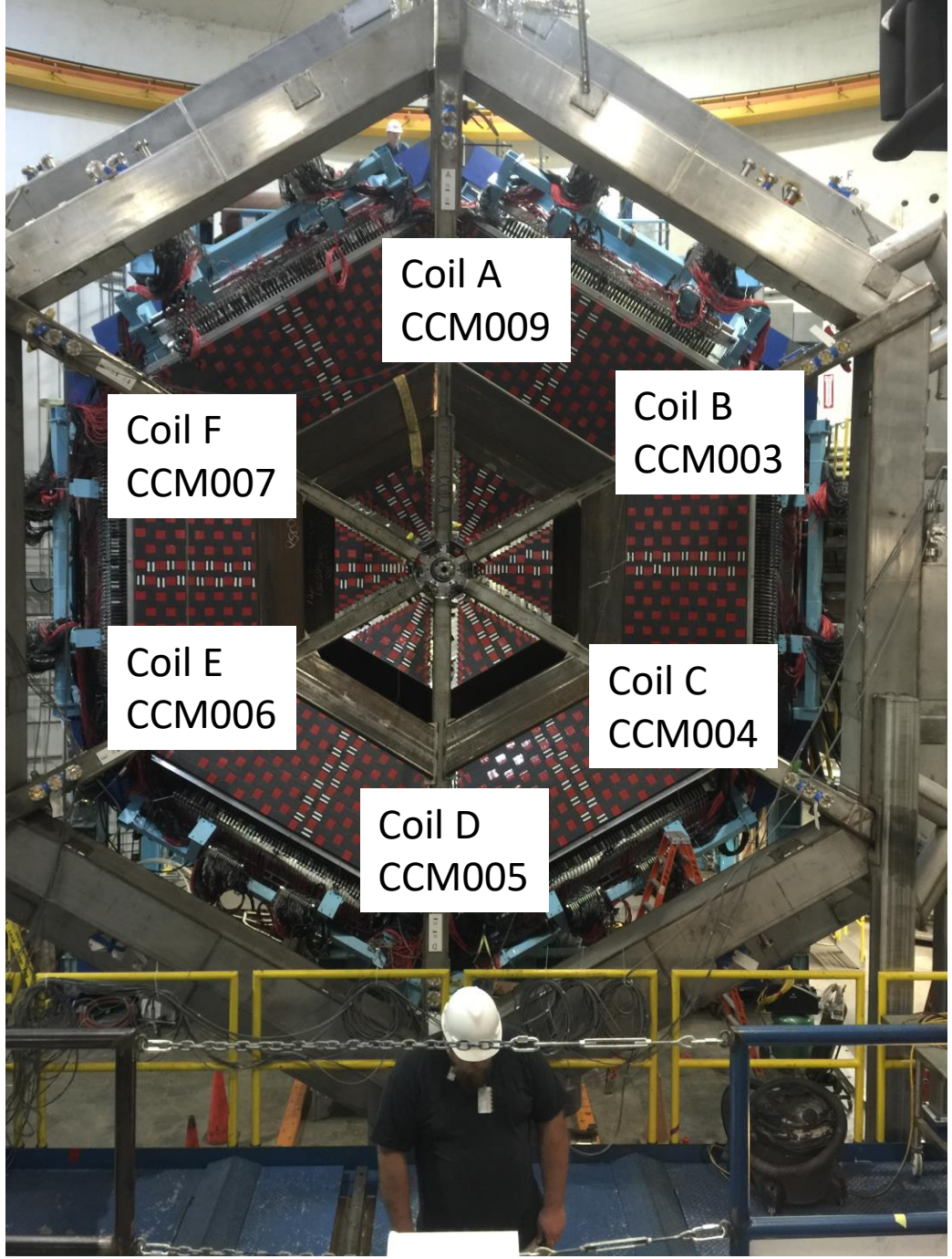
CLAS12 Collaboration Meeting

March 6, 2018

Introduction

- We all know in general what the CLAS12 Torus is
- In this talk I will attempt to explain challenges with winding 6 coils with the same geometry
- What we did to make them more consistent
- How we plan to model the coils in the next phase of magnetic field analysis
- In this talk there are lots of photographs to help to explain some of the issues and solutions



Outline

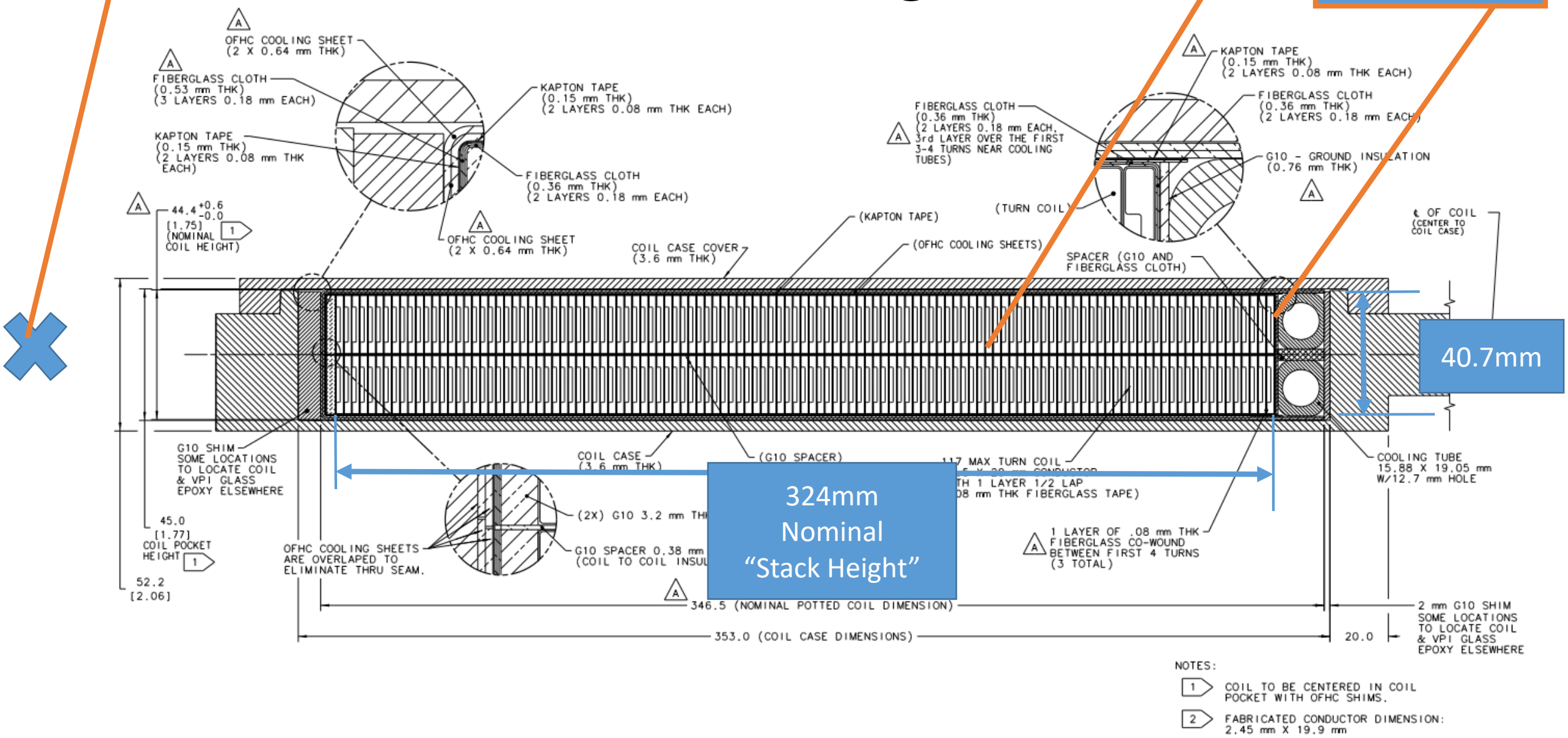
- Coil nominal geometry and construction process
- Winding/turn placement accuracy issues
- Resolution of issues
- Turn location measurement (Photogrammetry)
- Data Reduction
- Status

Coil Design

Beam location

Two layers also called pancakes

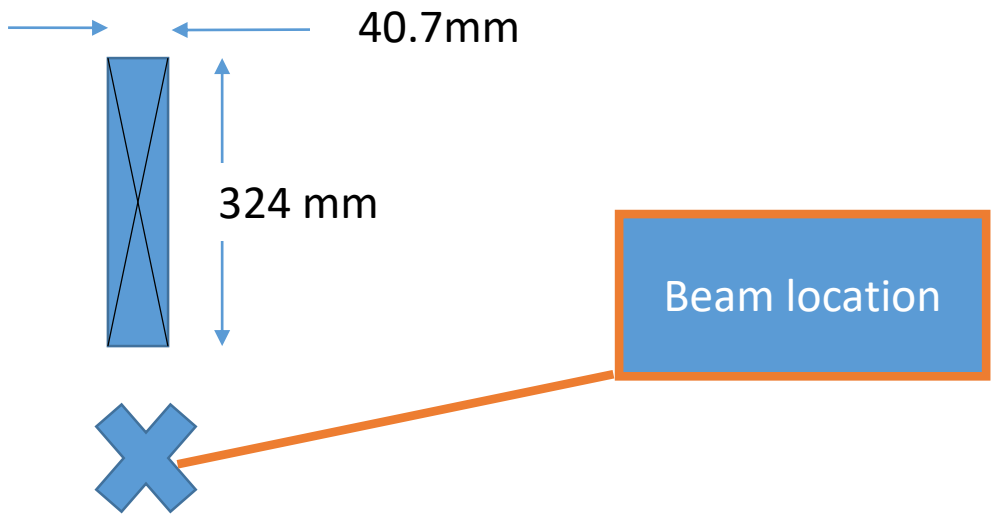
First Turn (Inner turn)

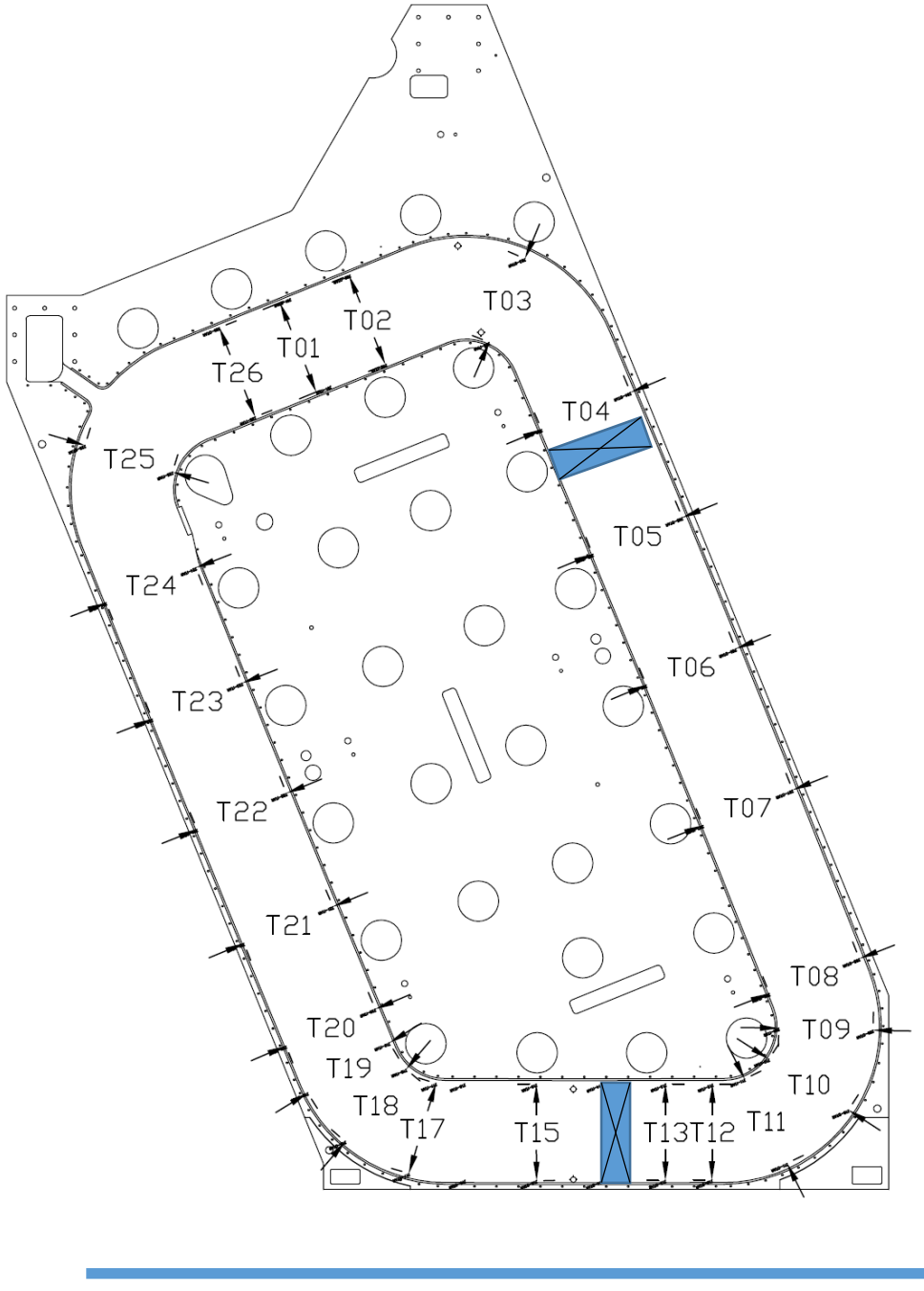


324mm Nominal "Stack Height"

Original Field Calculation

- Actual Torus has 234 Turns in each coil.
- Torus operates at 3770A => 882,180 Ampere-Turns
- Original model based on Based on 6 single turn coils
- Single turn carries 882,180A





Coils Wound and Epoxied at FNAL

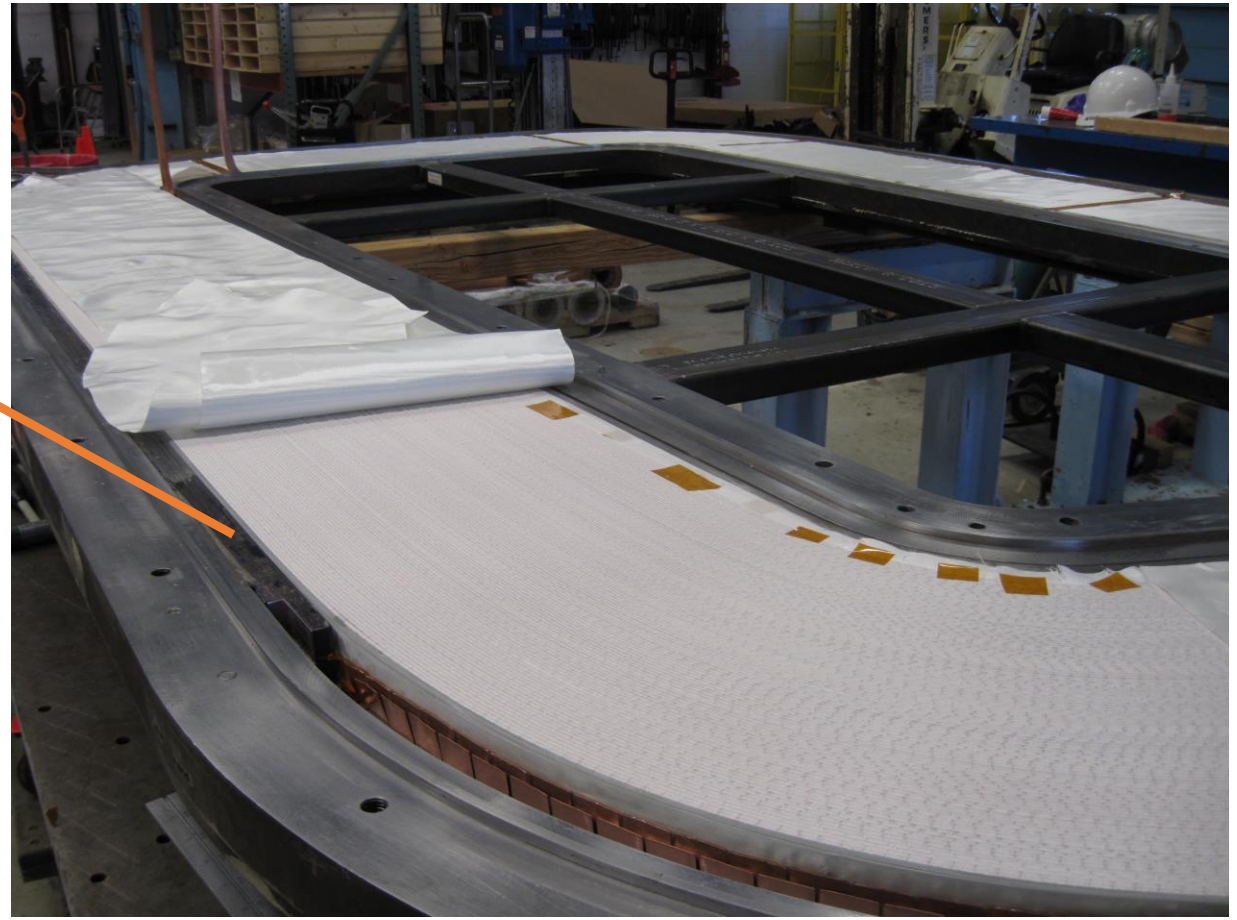
- All coils use the same mold
- What could go wrong??

Coil Potting Mold

- CNC Machined
- Multi piece to allow coil removal
  - Bottom
  - Top
  - Inner ring
  - Outer ring

CCM001 wound and in potting mold

Shim bar used to clamp the coil and sets outside turn position in the straight sections



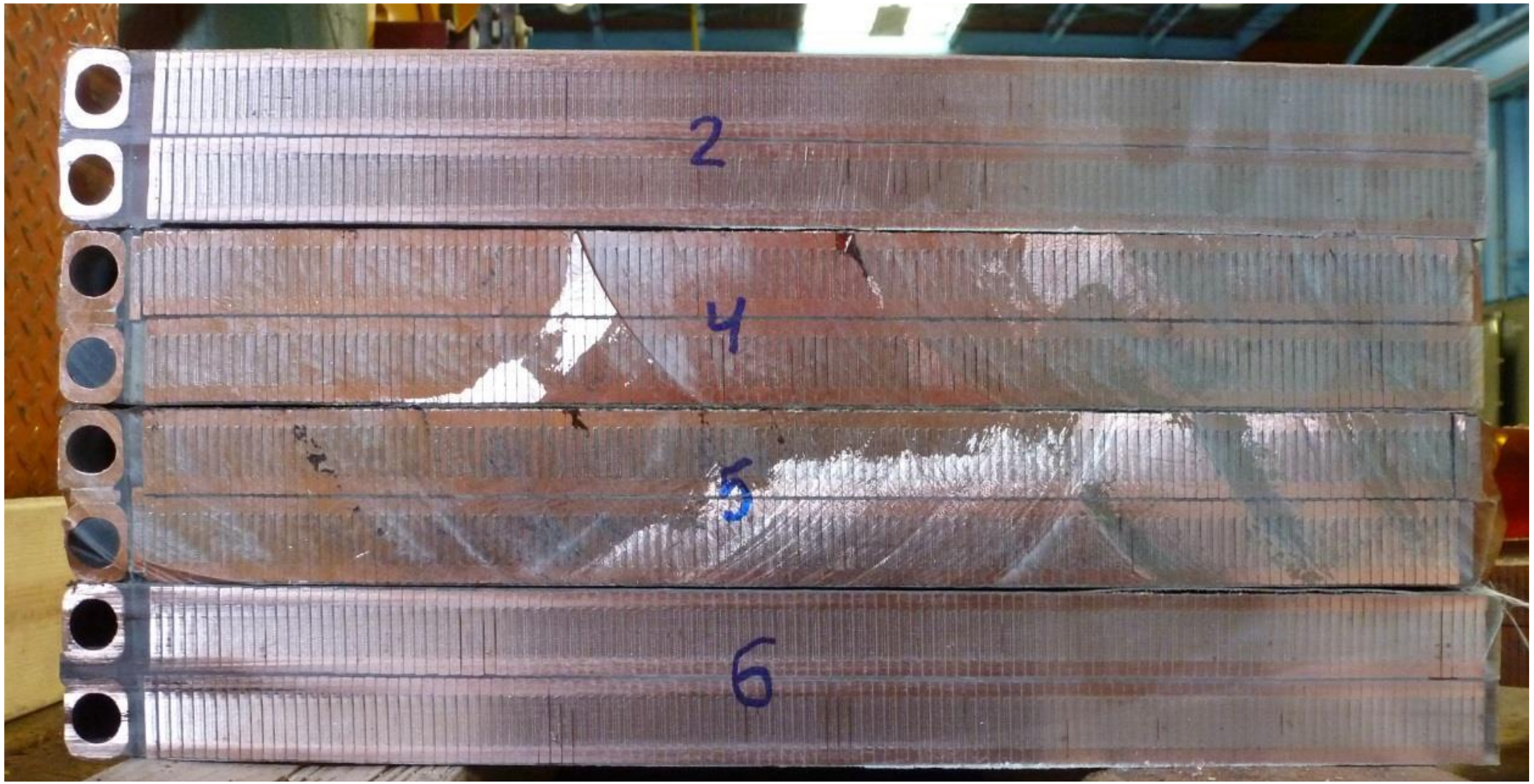
Coil prior to clamping

Notice gaps between turns

Sectioning the practice coil (PR02 – was to be CCM002) at FNAL to look for voids

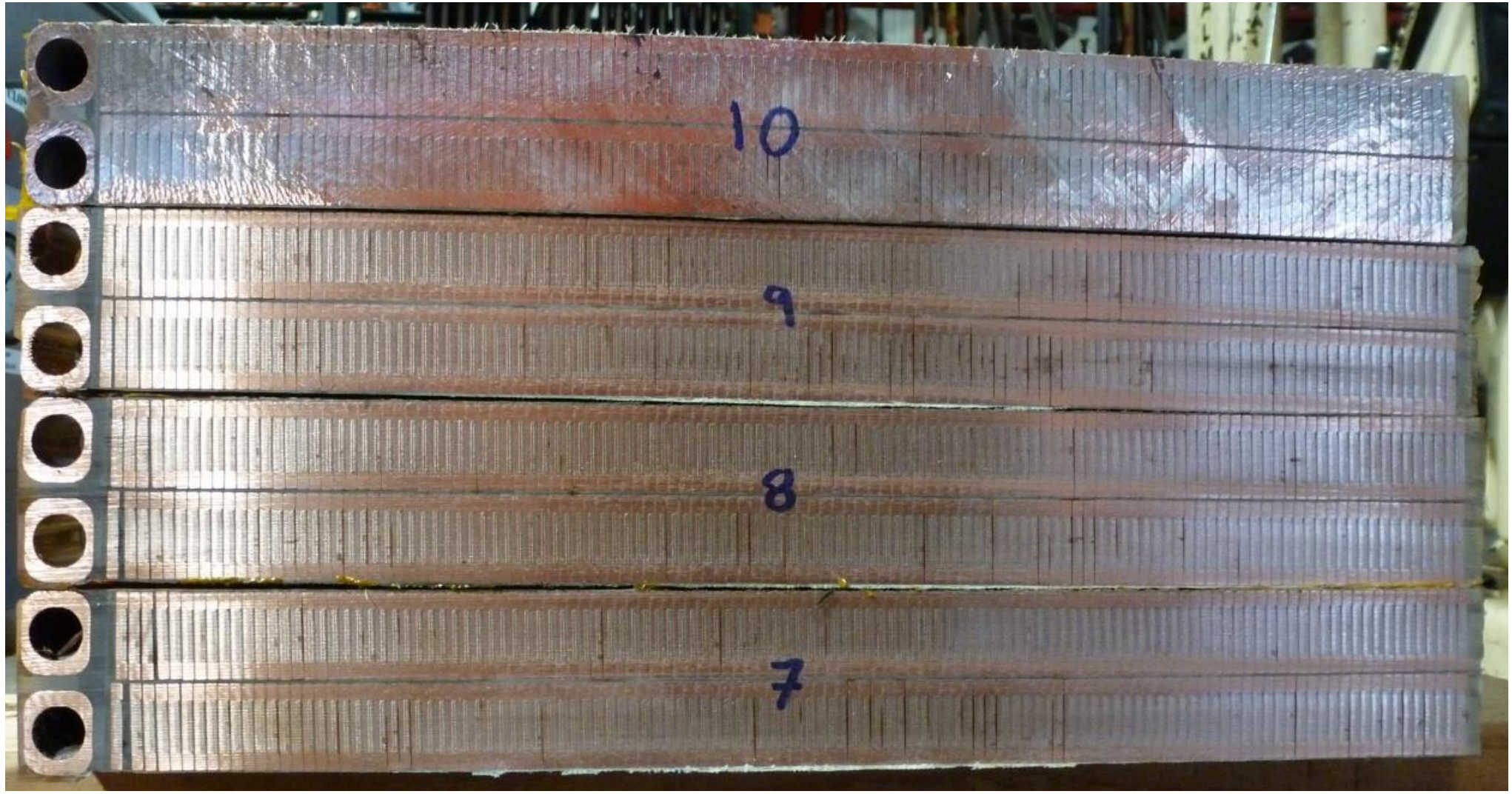
Sectioned practice Coil at FNAL

- No Voids
- Conductor Placement not great
- How to solve?



More sections through the practice coil

- Similar results in other locations



Excerpt from Coil Winding Report

- The **two potted coils CCM001 and PR02** were very precisely **measured by** the FNAL Survey team. The surveys included use of a **laser tracker and photogrammetry**. After data reduction **it was found that** the **average location of turns along the hub straight section varied by 0.8mm and the turn to turn** (T2T) spacing **distance ranged** from **2.700mm to 4+mm**. It must be noted that the **largest variances were always at the hub** and this is due to the effect commonly called **dog boning** in the magnet coil winding business. This dog boning effect creates turns that are not close to the cooling tube at the ends of the coil straights due to the bending stiffness of the conductor. **Depending on how the coil is clamped and variables such as winding tension** and others which are not under precise control (such as exact yield stress of the cable) **the amount of dog boning per coil varies**

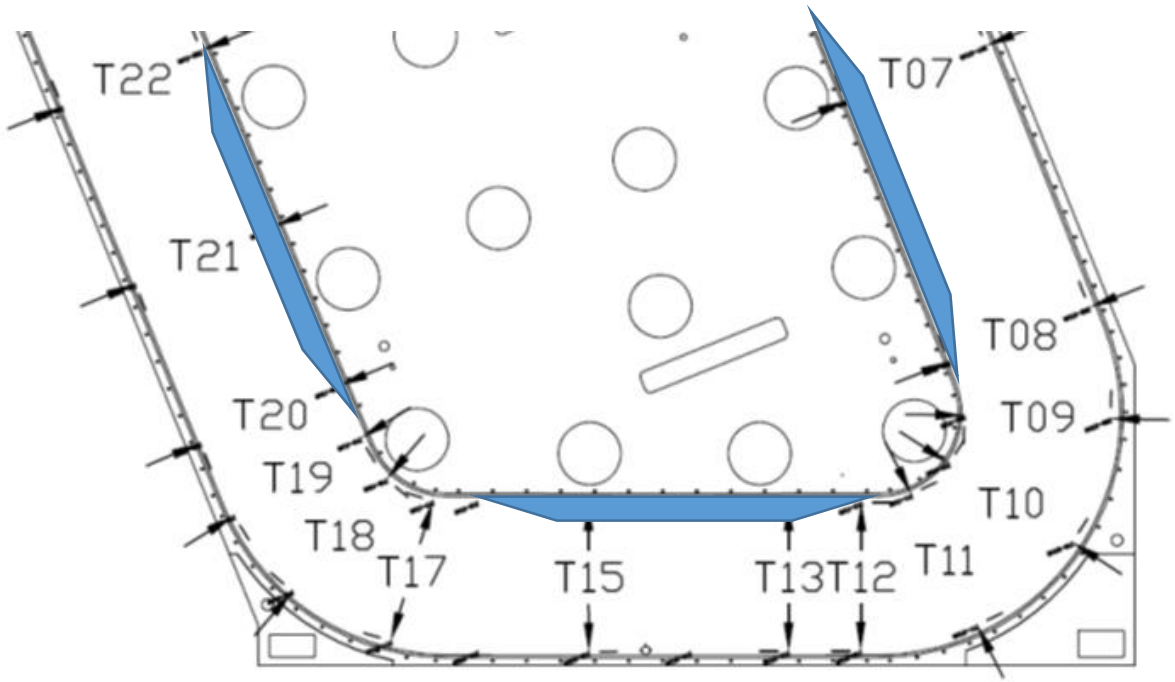
CLAS12 Torus Coil Winding – Clamping Report and Procedure

D. Kashy

9/12/2014

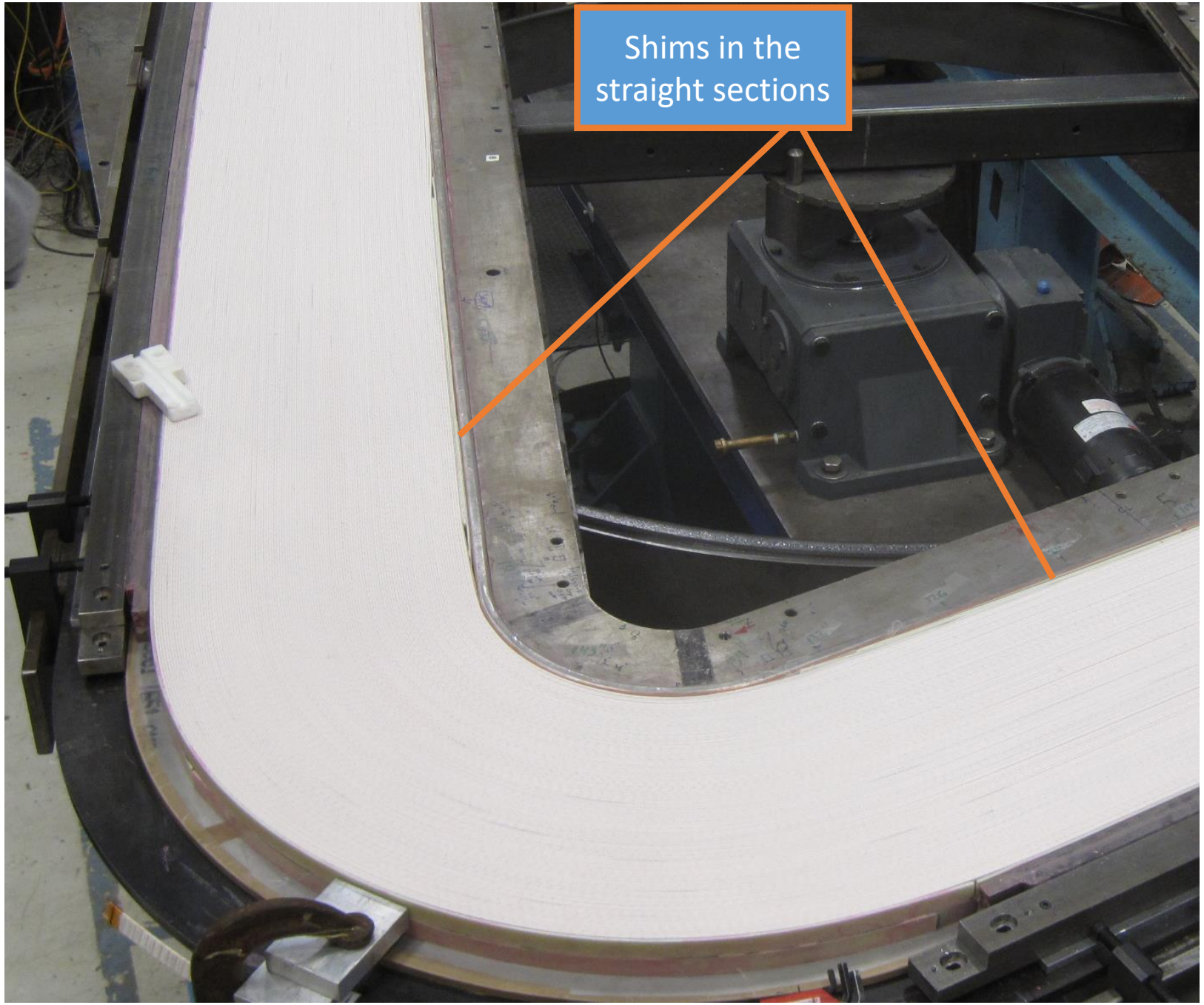
Solution for accuracy at and near the Hub

- Force the conductor to be compacted to specific dimensions moving extra conductor to locations far from the Torus Cold Hub/beamline.
- To do this we added shims along straight sections at hub and on upstream and downstream straights, between the cooling tube and the inner turn



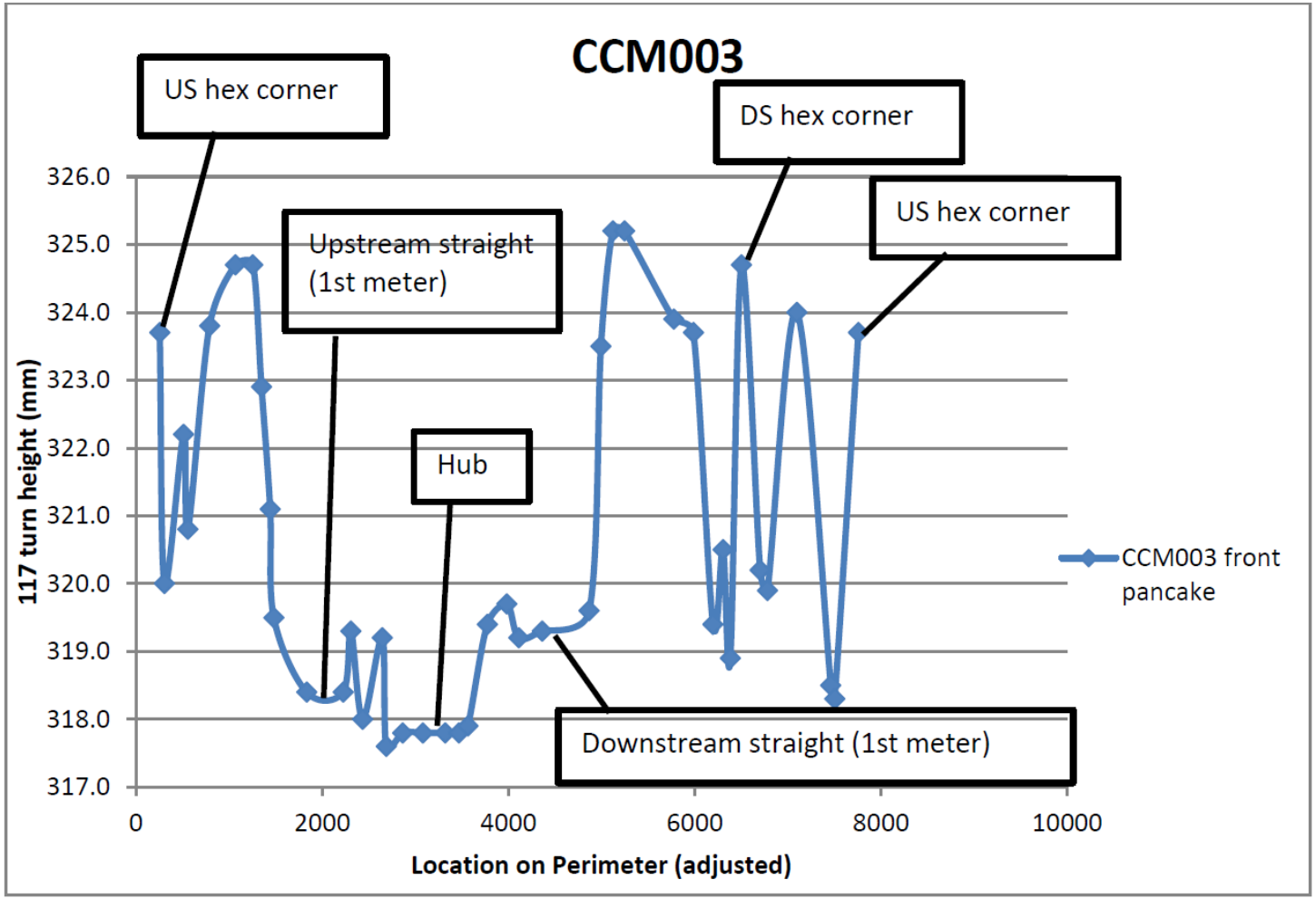
Wound and Clamped Coil on Winding Table

- Extra conductor pushed away from hub
- This is done to achieve accurate winding near the beamline



Dimensions of Coil CCM3 with improved technique

- Measured with a digital caliper
- CCM 003 (first used coil)
- With shims installed
- Dimensions after winding and clamping



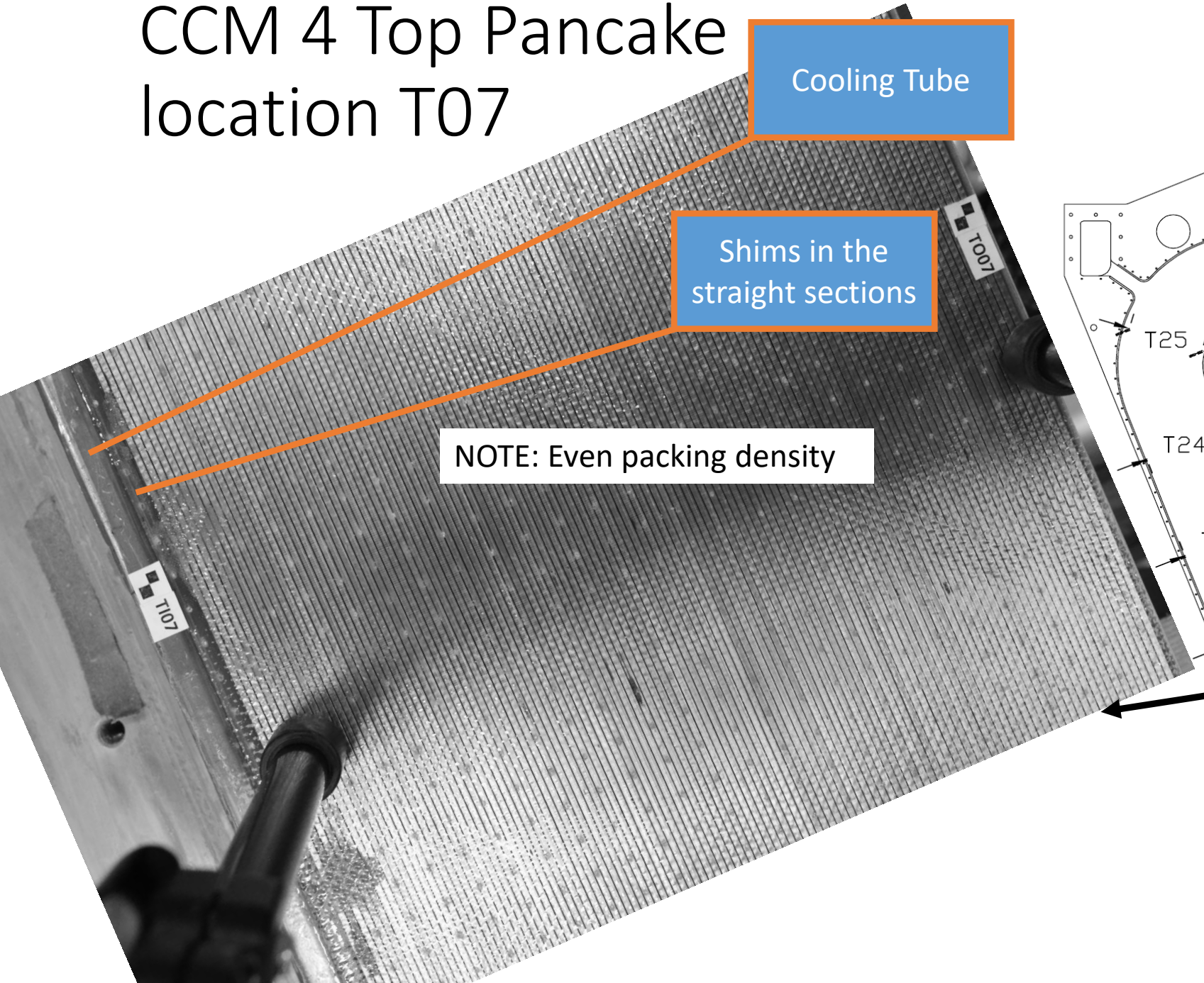
Results of CCM003 front side pancake shimming (measurement tolerance ~+/-0.1mm)

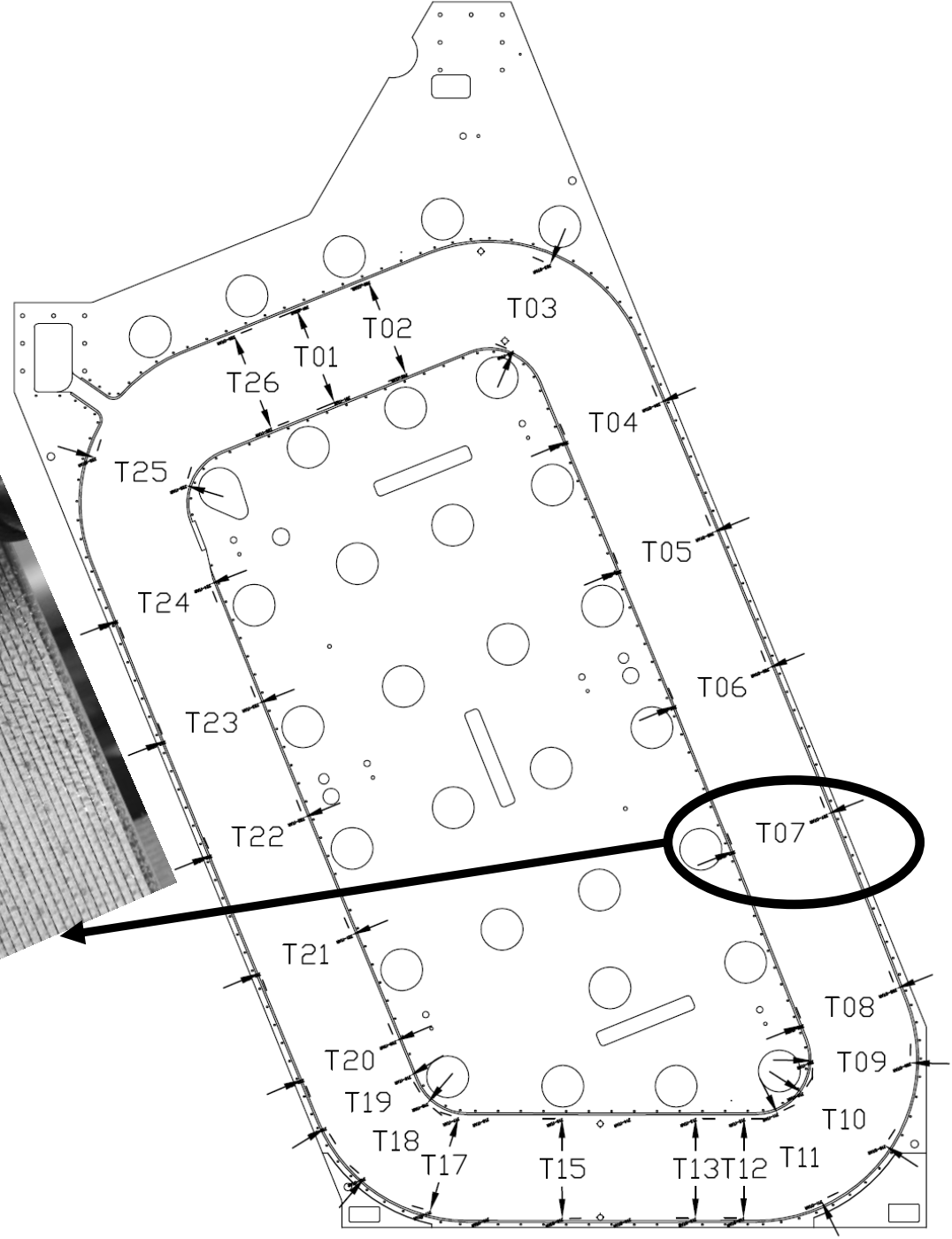
Next few slides show coils after potting

- These photos were taken by the FNAL survey team with Photogrammetry equipment

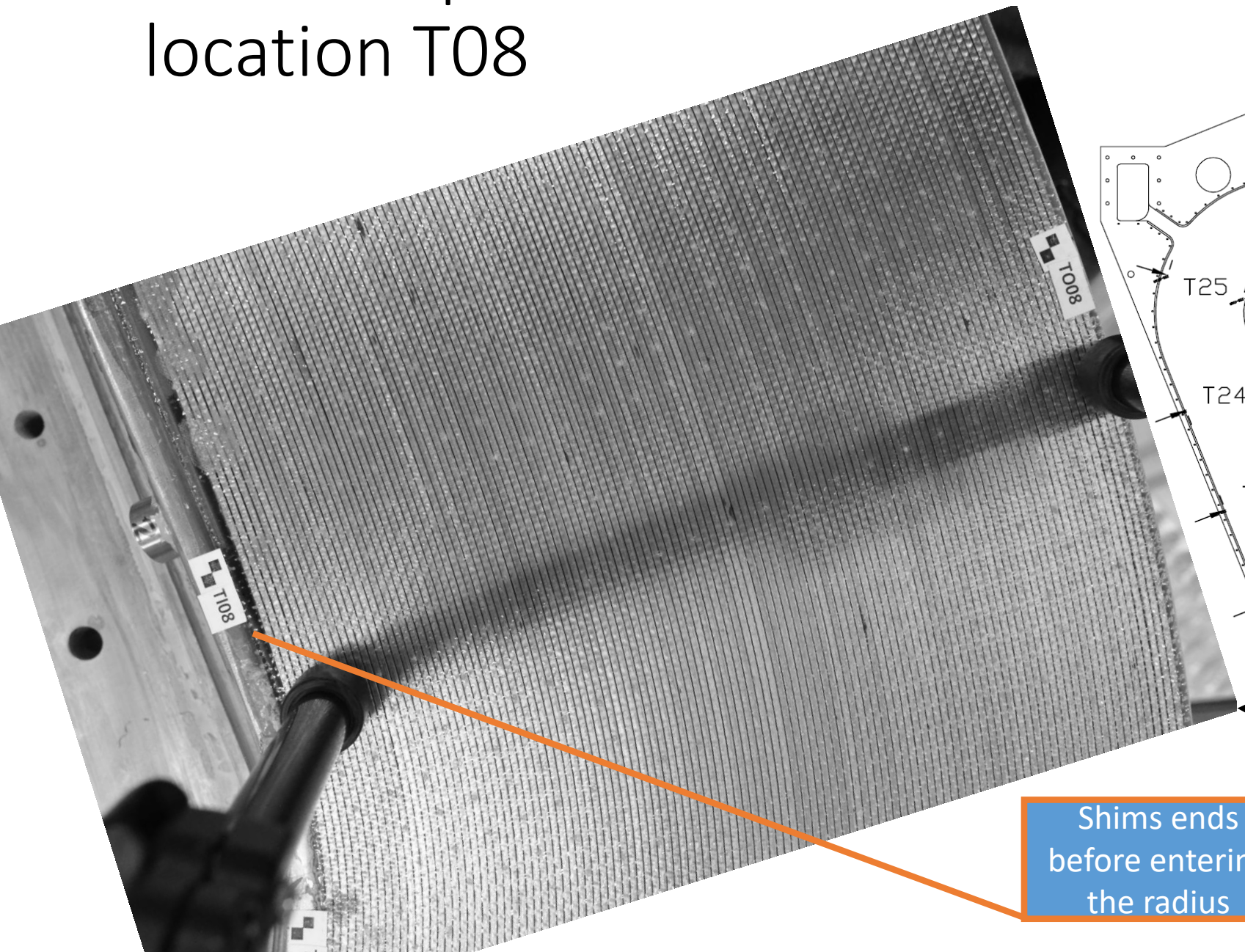
- *Photogrammetry* is the science of making measurements from photographs, especially for recovering the exact positions of surface points. (Source Wikipedia)

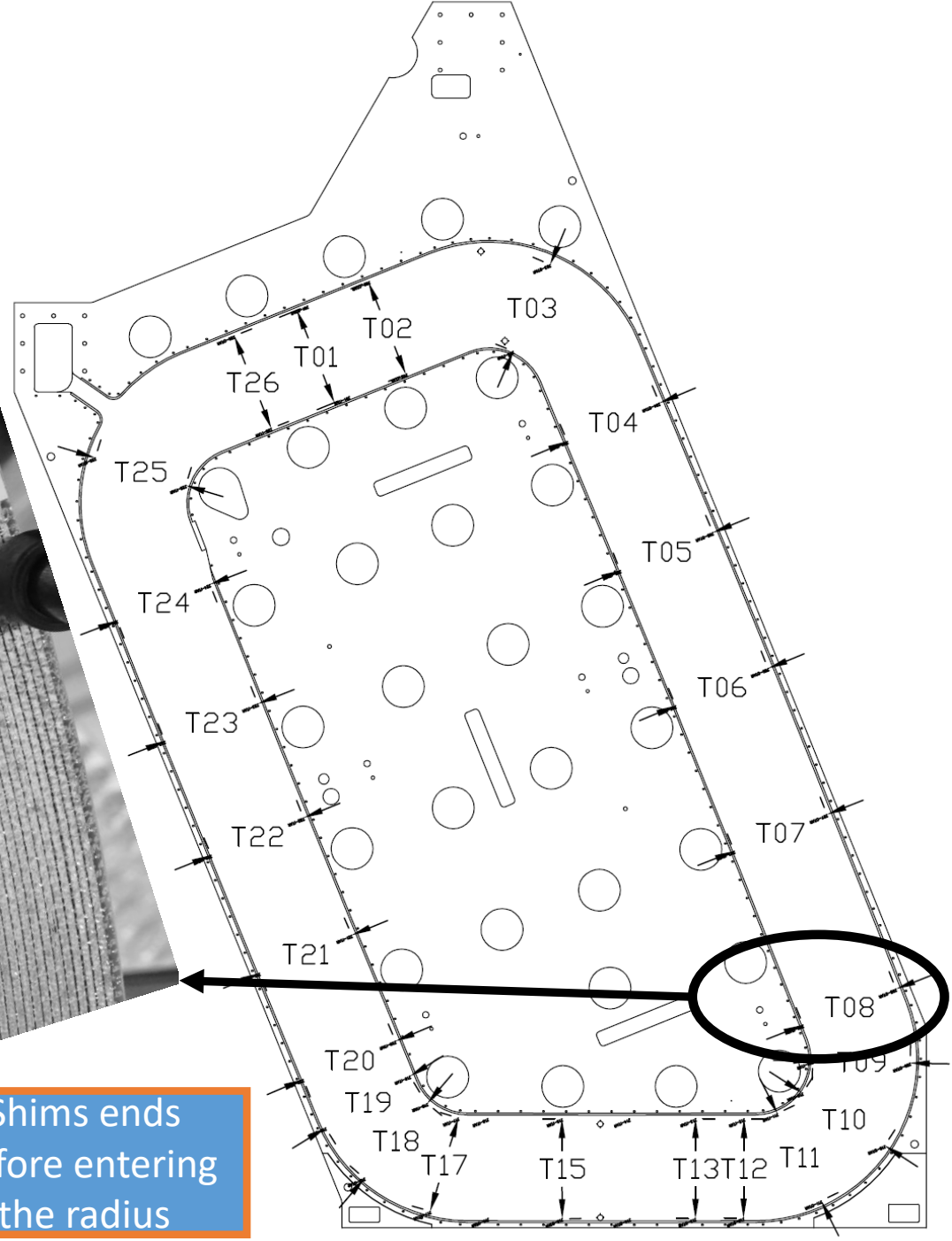
CCM 4 Top Pancake location T07





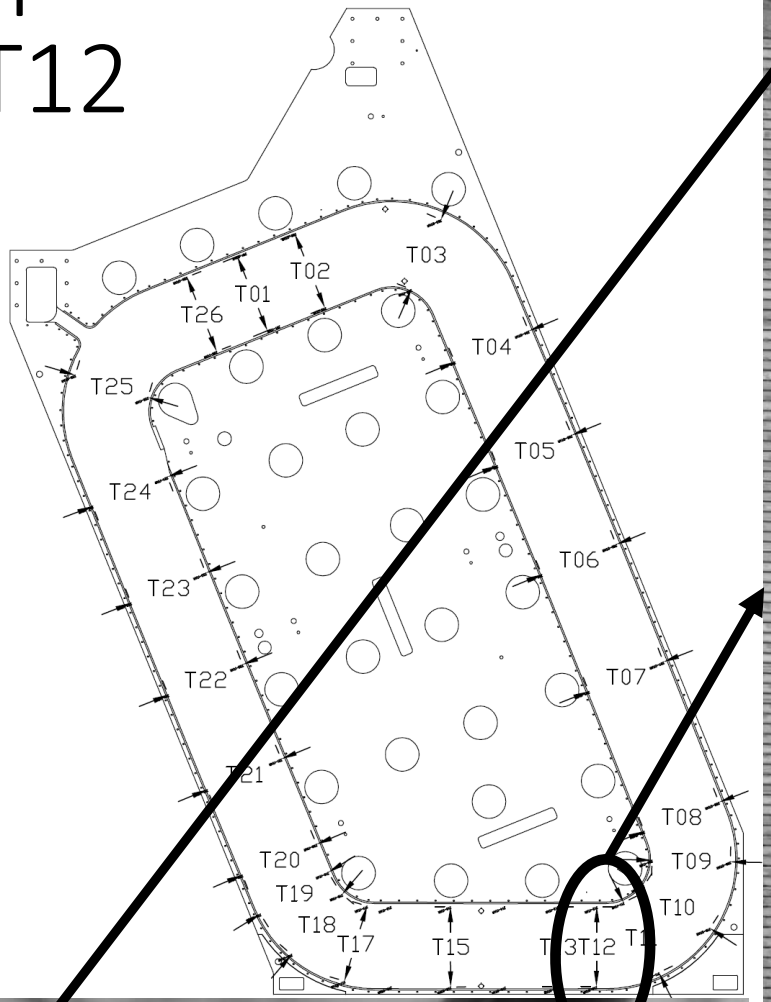
CCM 4 Top Pancake location T08

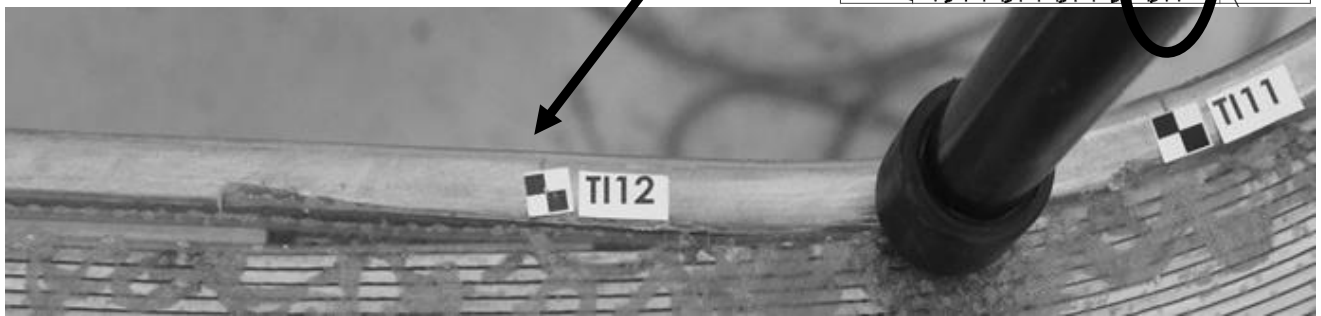


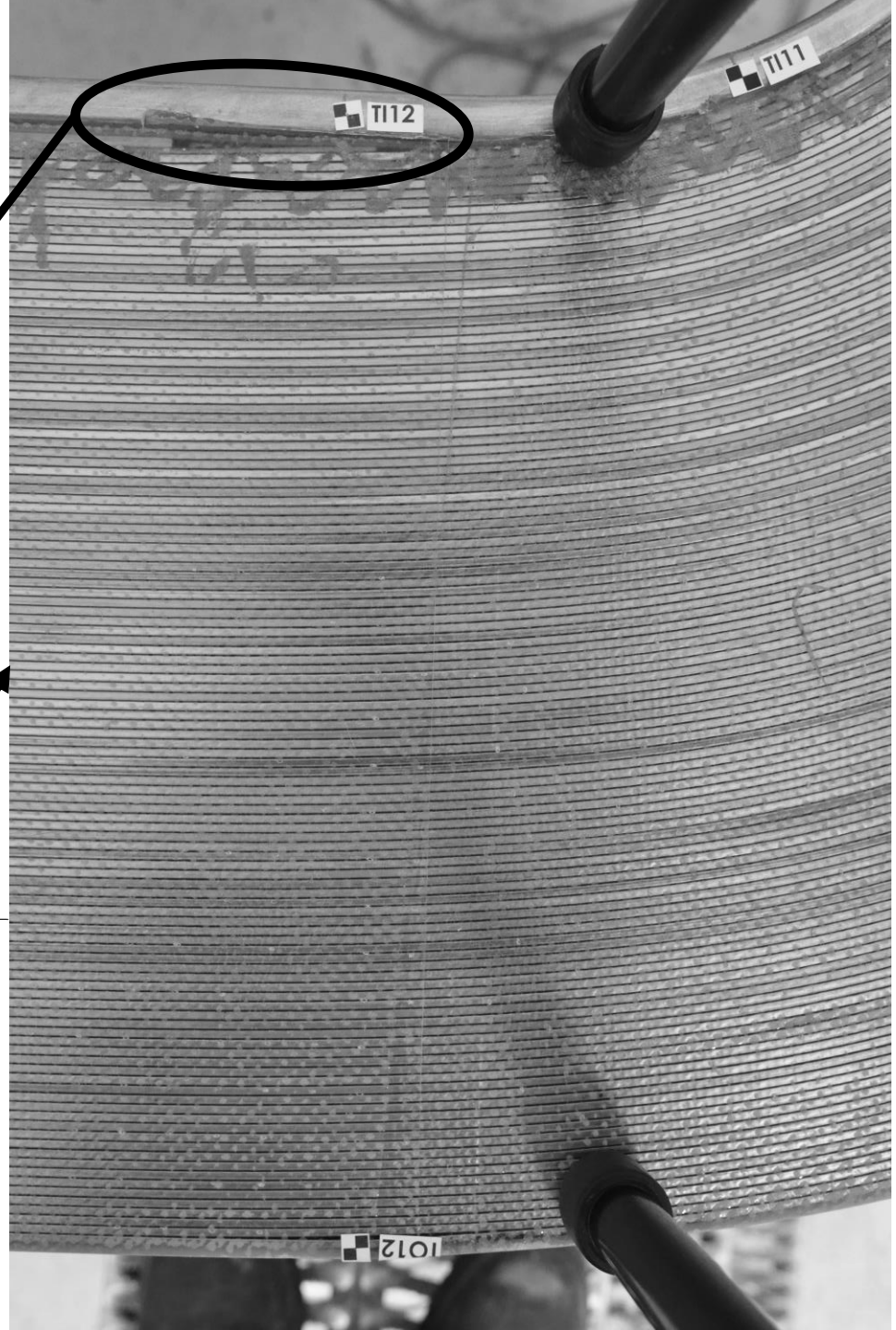


Shims ends before entering the radius

CCM 7 Top Pancake location T12

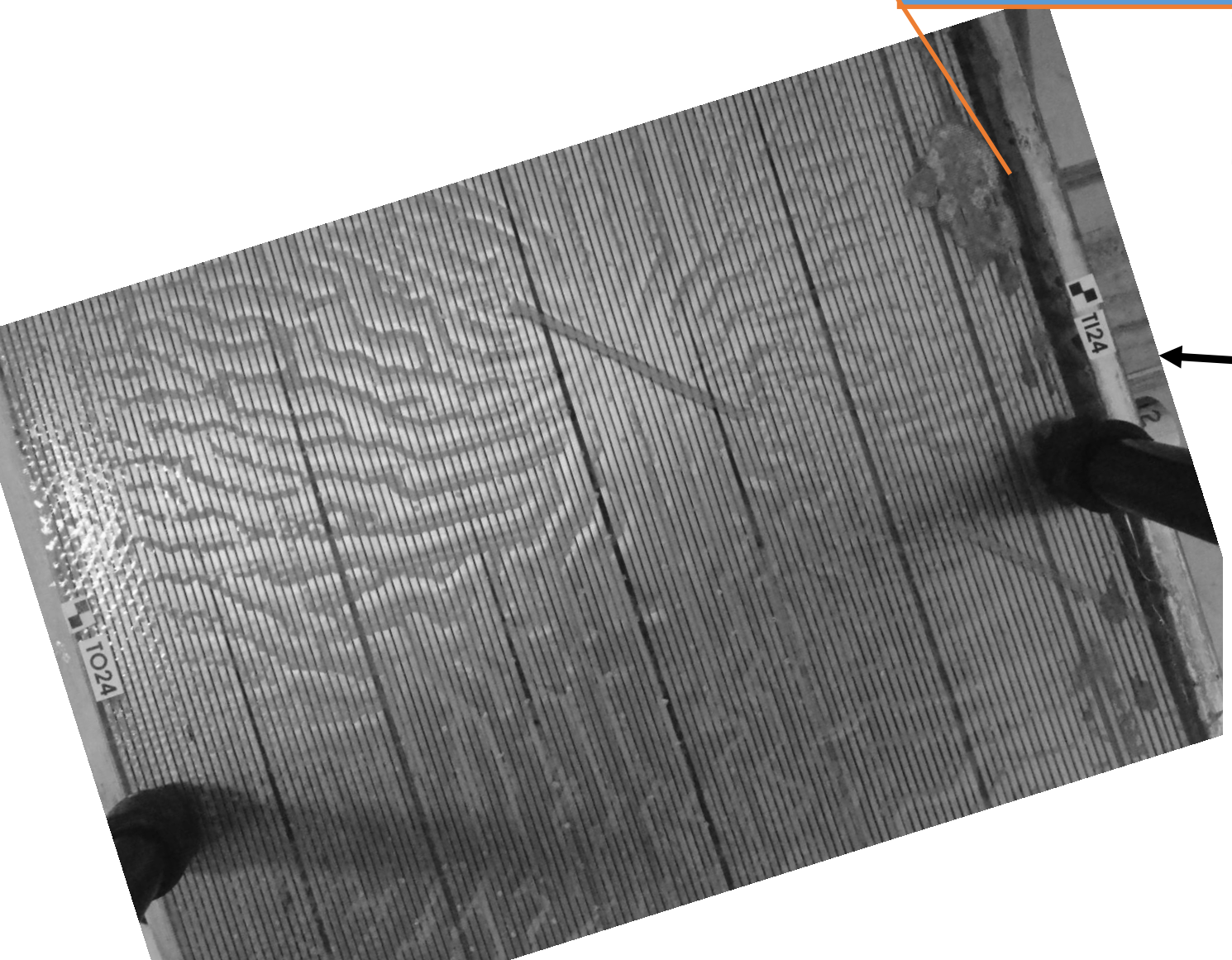


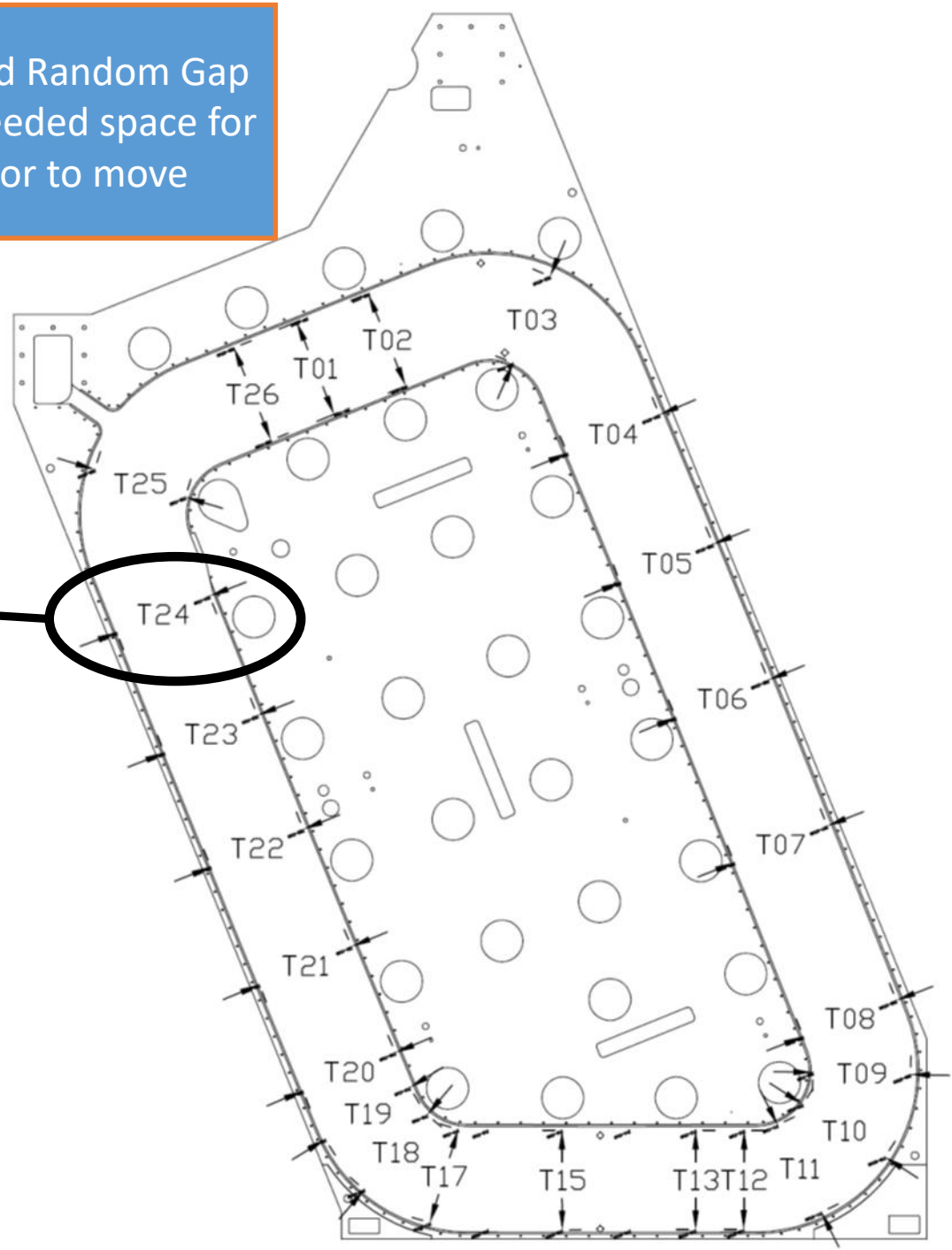




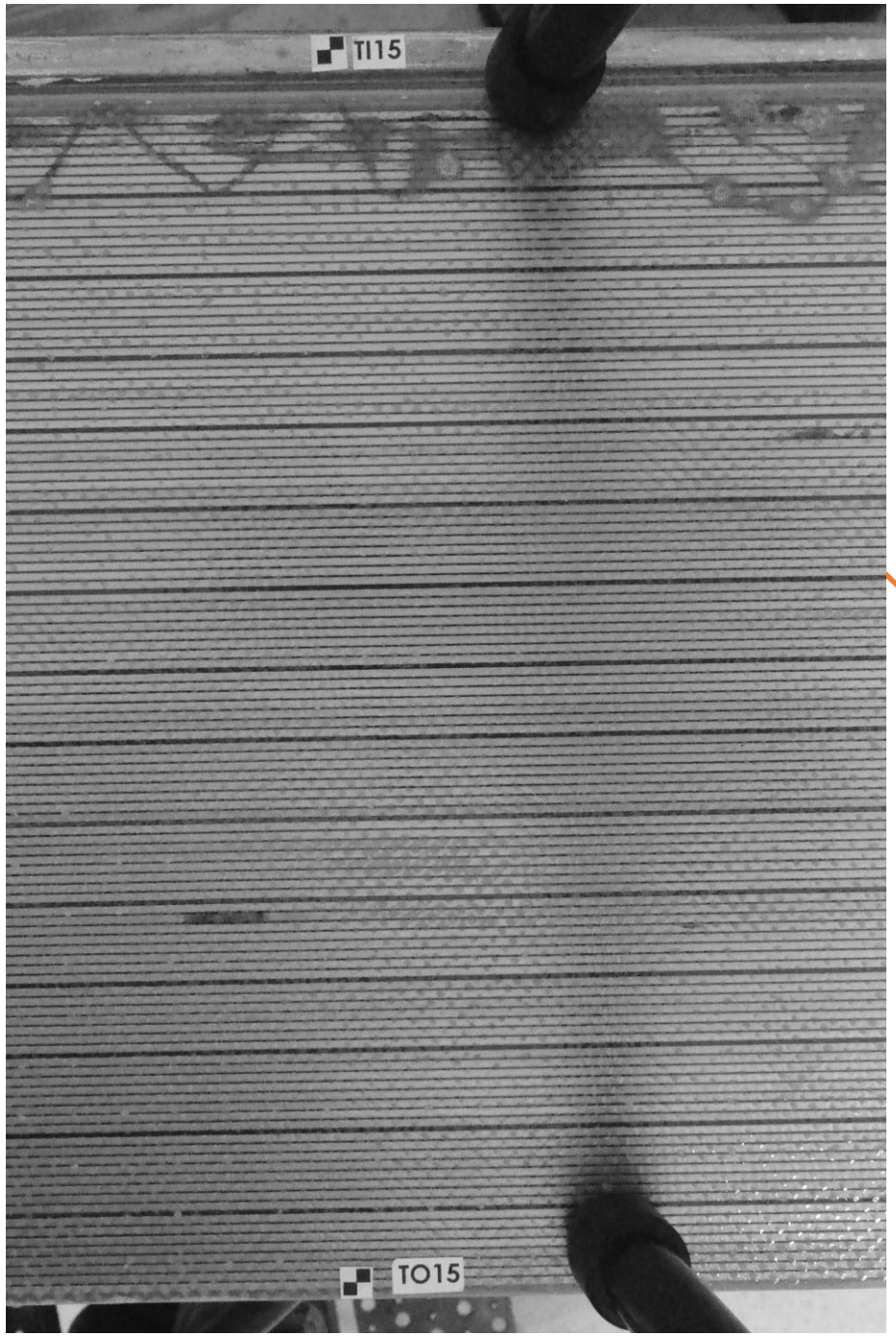
CCM 9 Top Pancake location T24

NOTE: Uncontrolled Random Gap
NO SHIMS here, Needed space for Excess Conductor to move

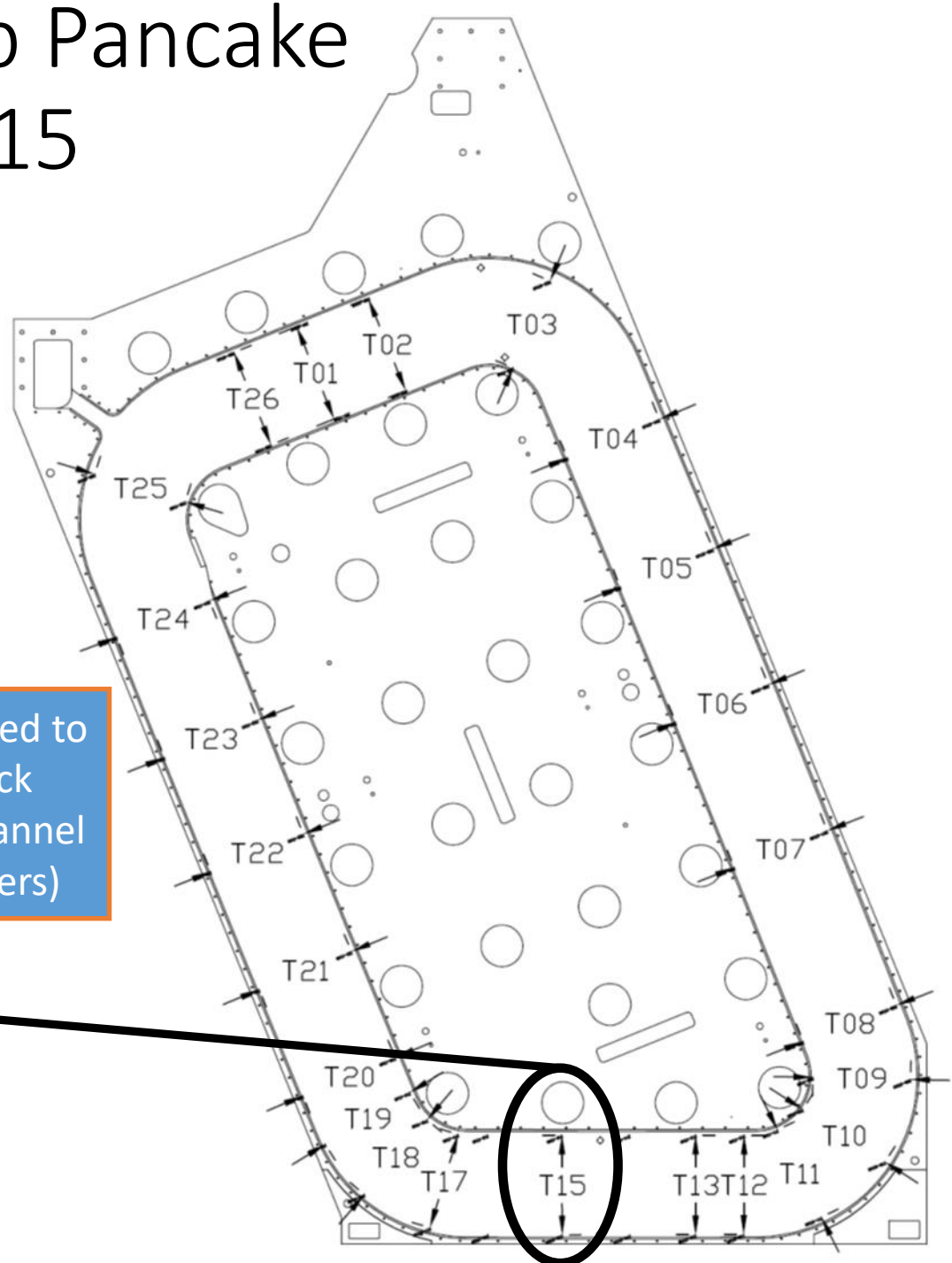




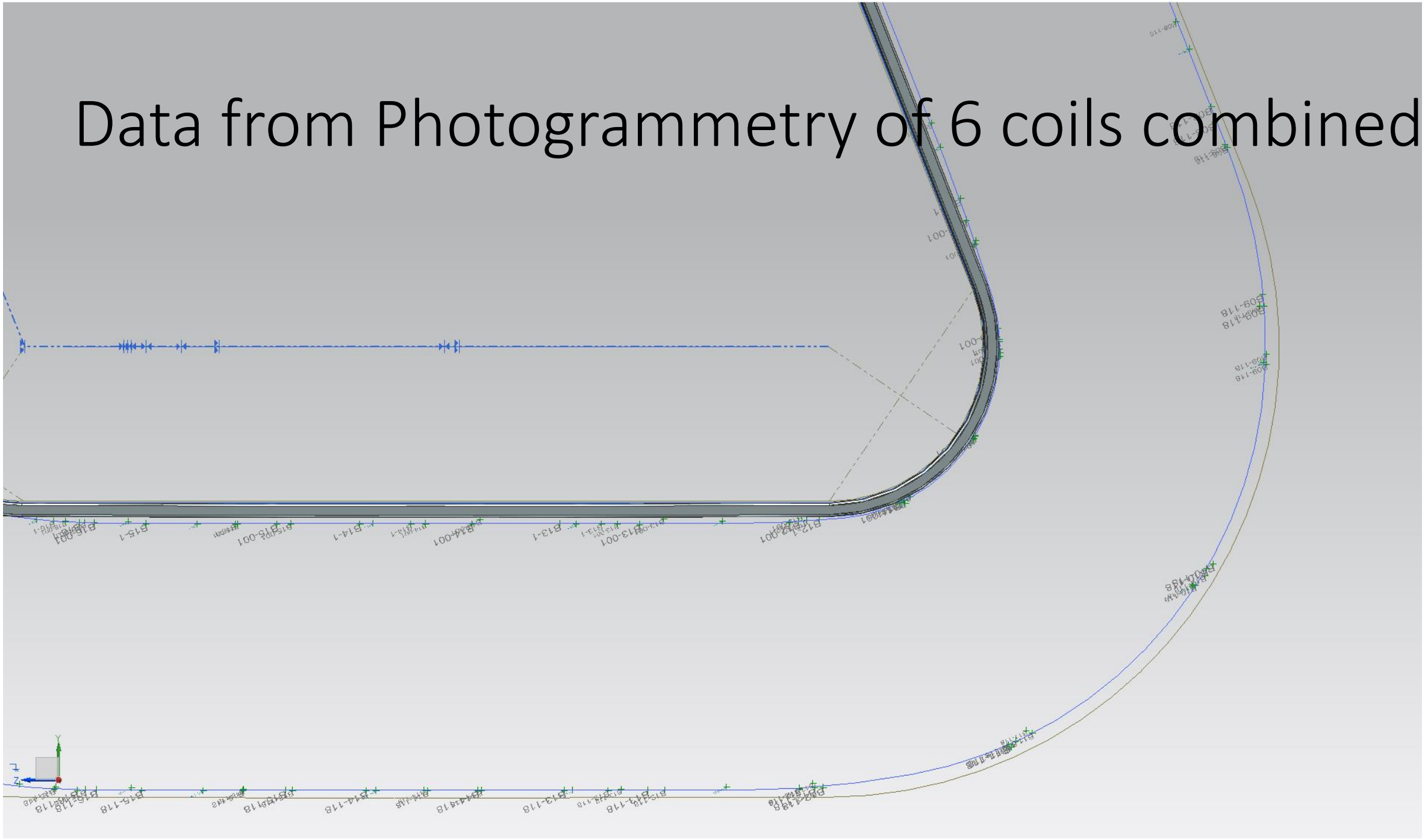
CCM 9 Top Pancake location T15

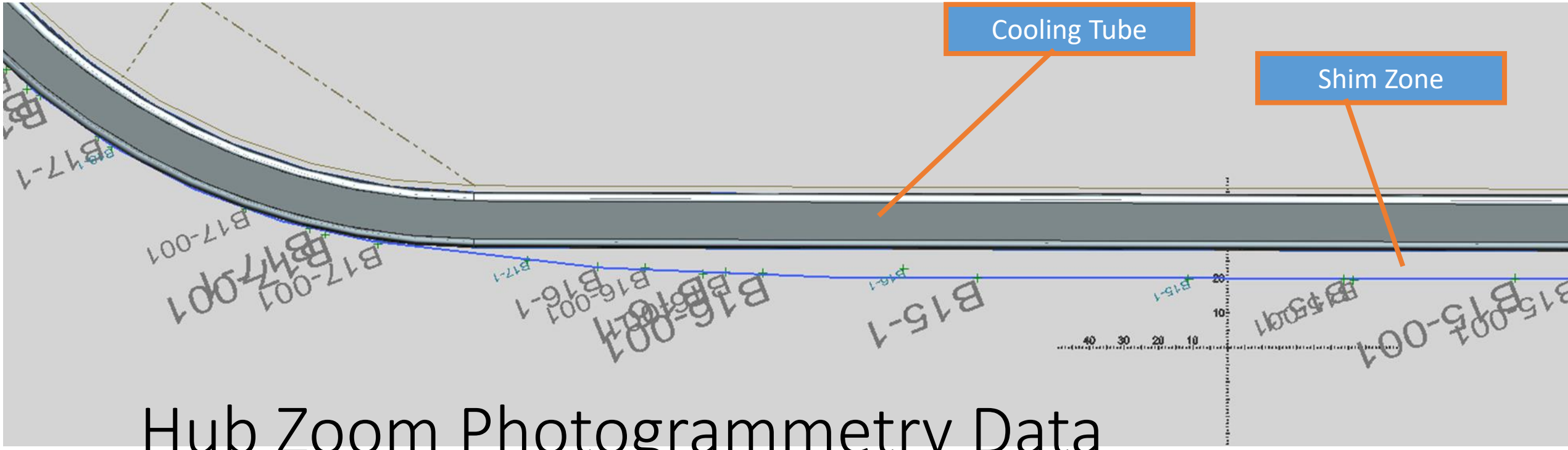


NOTE: Fillers needed to achieve full stack height (copper channel thinner than others)

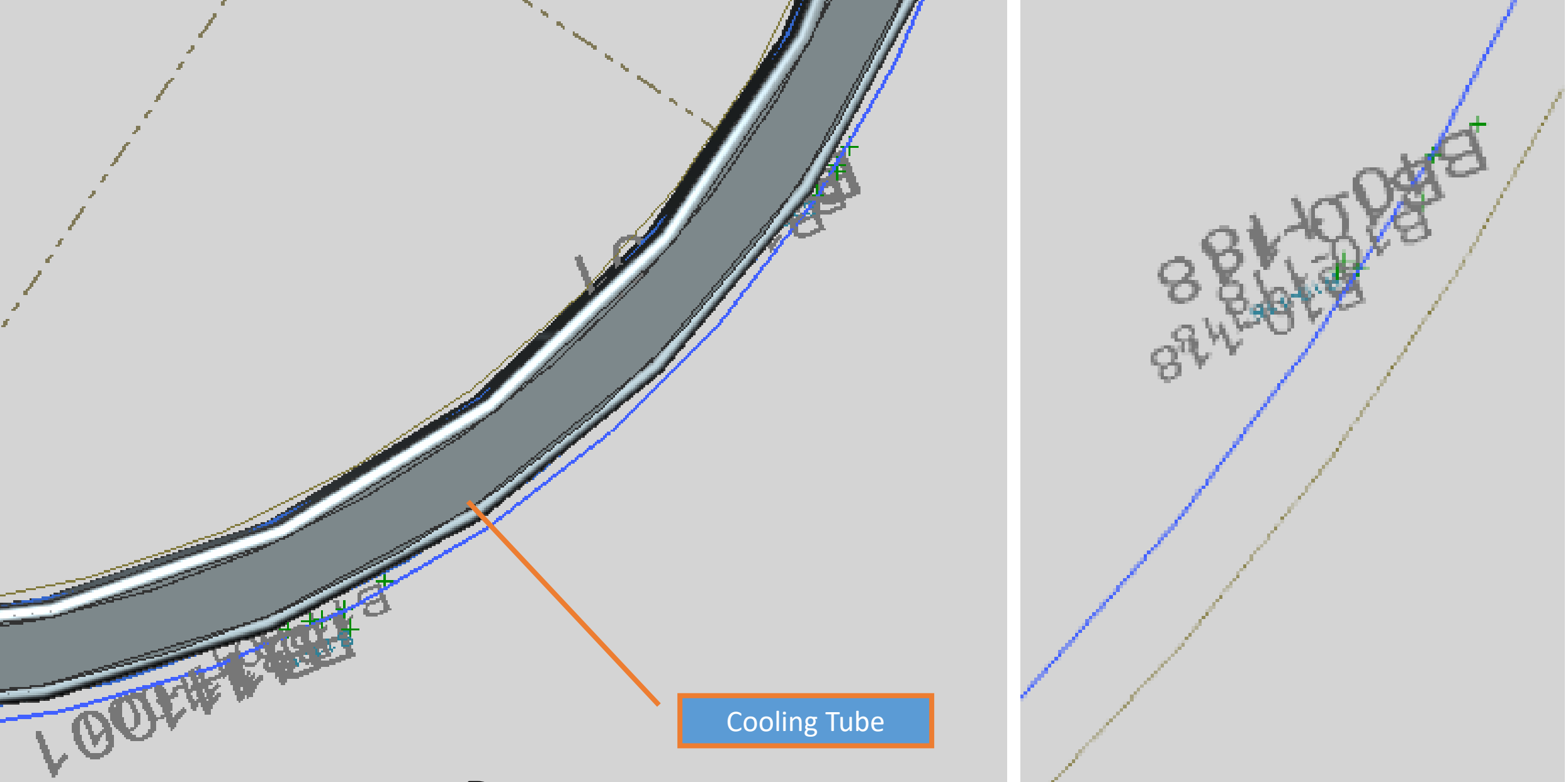


Data from Photogrammetry of 6 coils combined





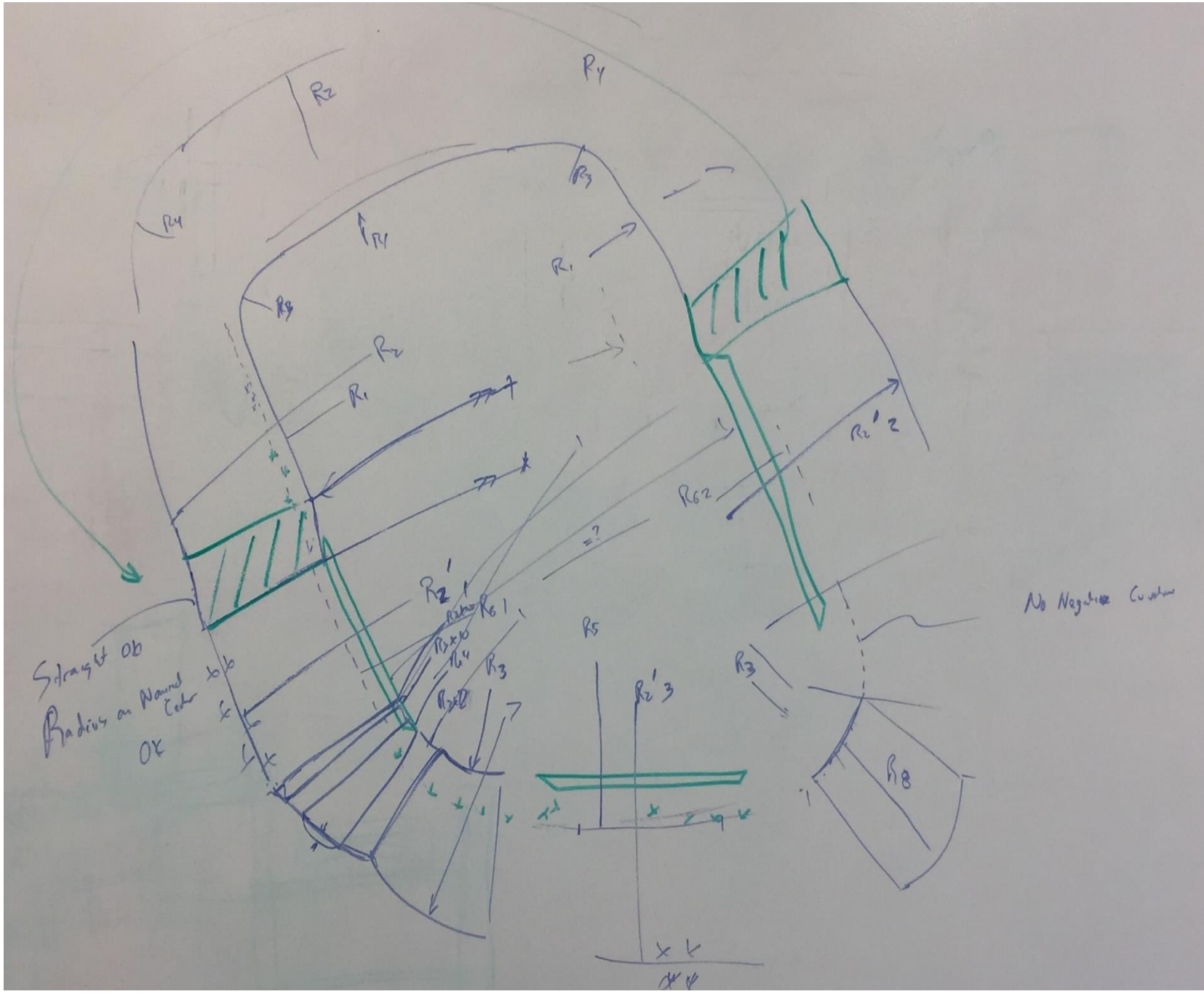
Hub Zoom Photogrammetry Data of 6 coils combined



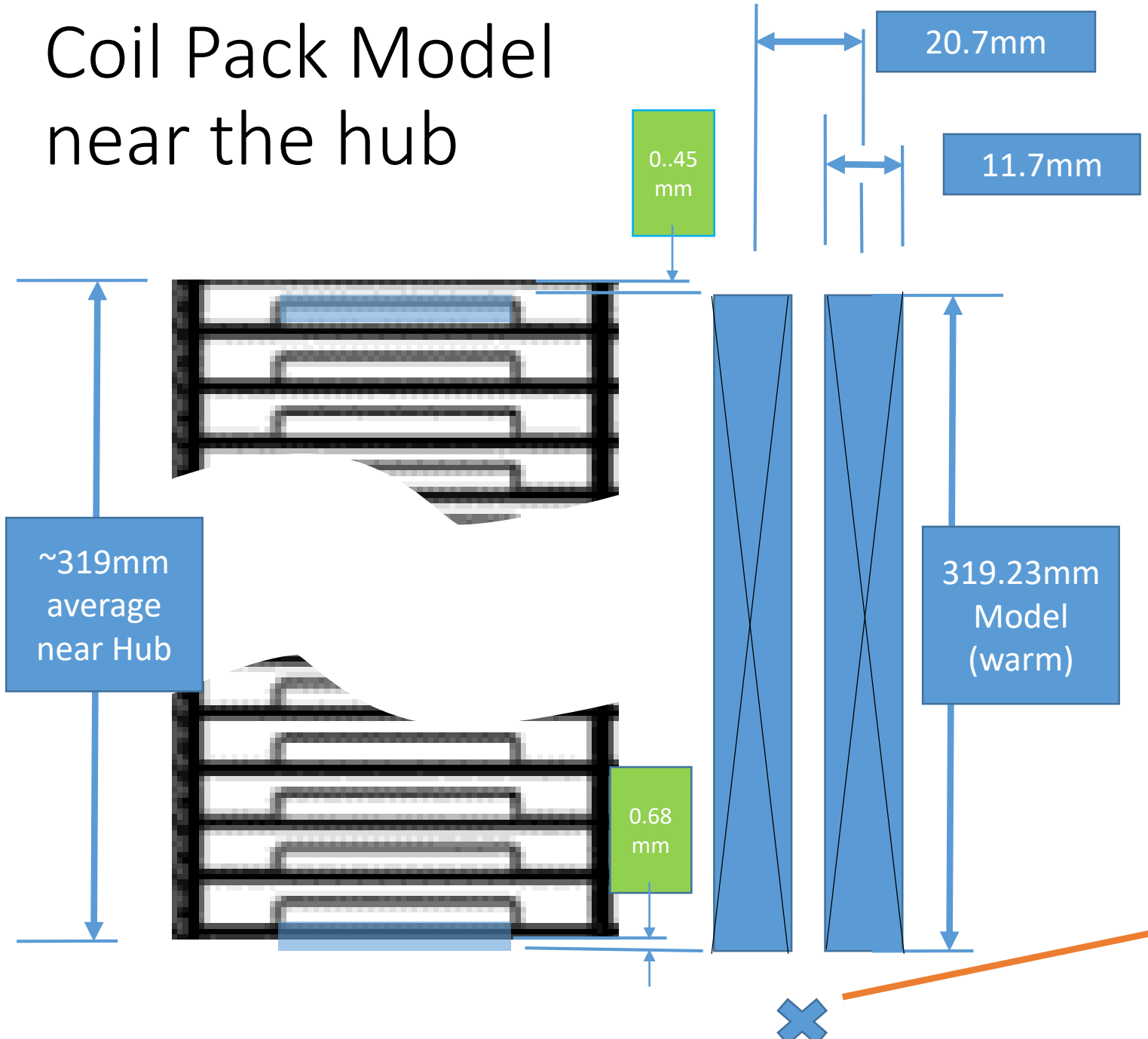
Downstream corner zoom – Photogrammetry data of 6 coils combined

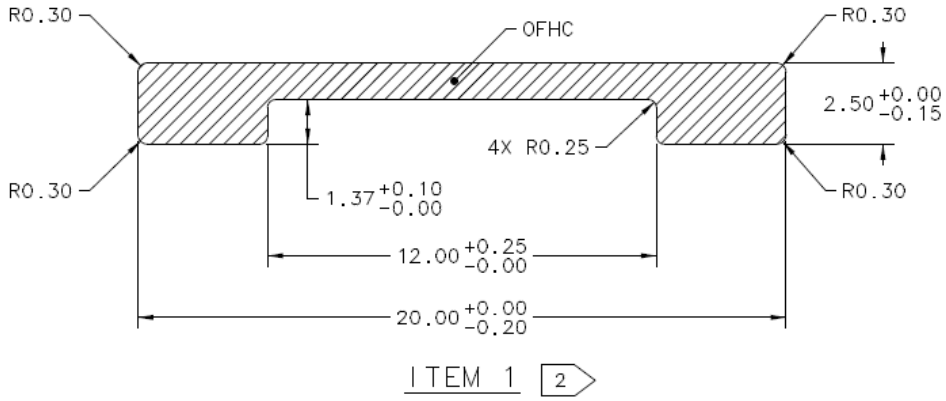
Goal

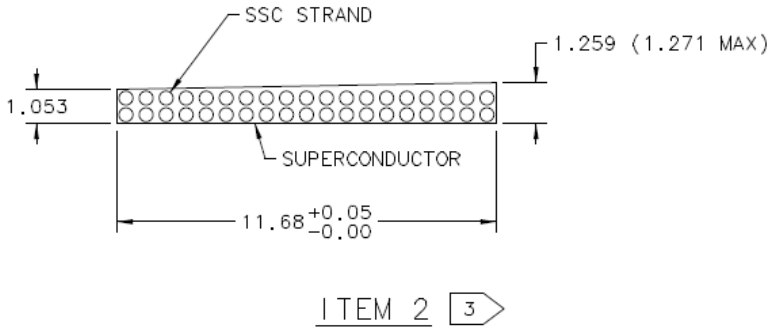
- Develop a 6 fold symmetric model that represents our best average of the coils we have
  - Use measured geometry to create a nominal coil
  - Model as 12 pancakes vs 6
- Run Tosca
- Move a coil and re-run
- Let Mac and Team learn effects
- Study statistics of discrepancies between coils
- If needed develop and analyze a non-symmetric 6-coil geometry



Coil Pack Model near the hub







Status and Next Analysis model

- Status
  - Data from inner and outer turns combined in one file – completed 2/29/18
  - Data being fit to curves and trapezoids at present – complete today
  - Start Tosca model generation this week
- Next Analysis
  - Based on six 2-turn coils with more representative geometry
  - Each turn carries 441,090A
  - Should have results in a few weeks