



NuMI/LBNF Horn and Stripline Welding

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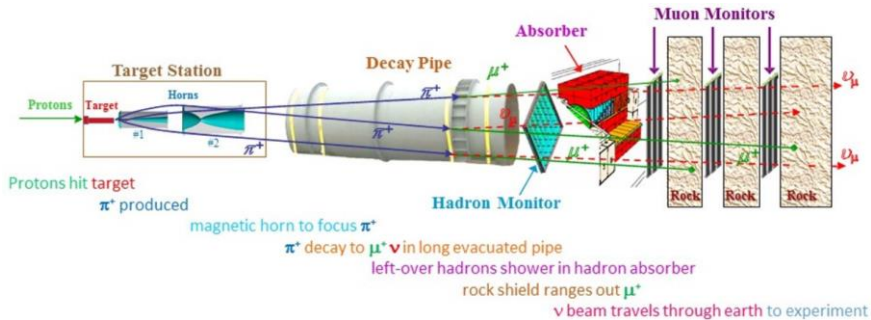
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Overview

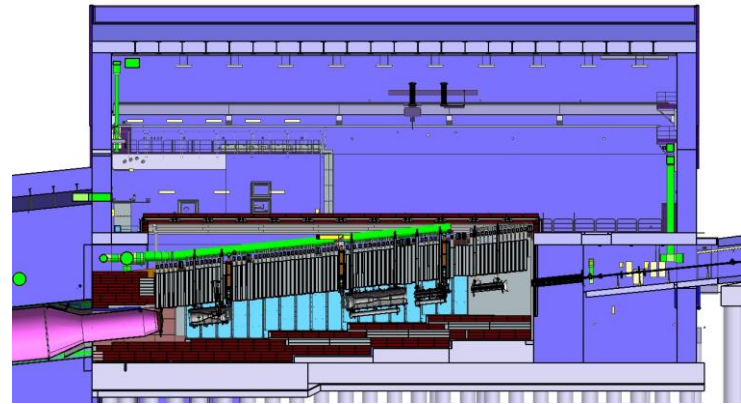
- Fermilab Project overview
 - NuMI Horns
 - LBNF Horns
- Inner Conductor (IC) Welding
- Stripline Friction Stir Welding (FSW)

NuMI/LBNF Project Overview

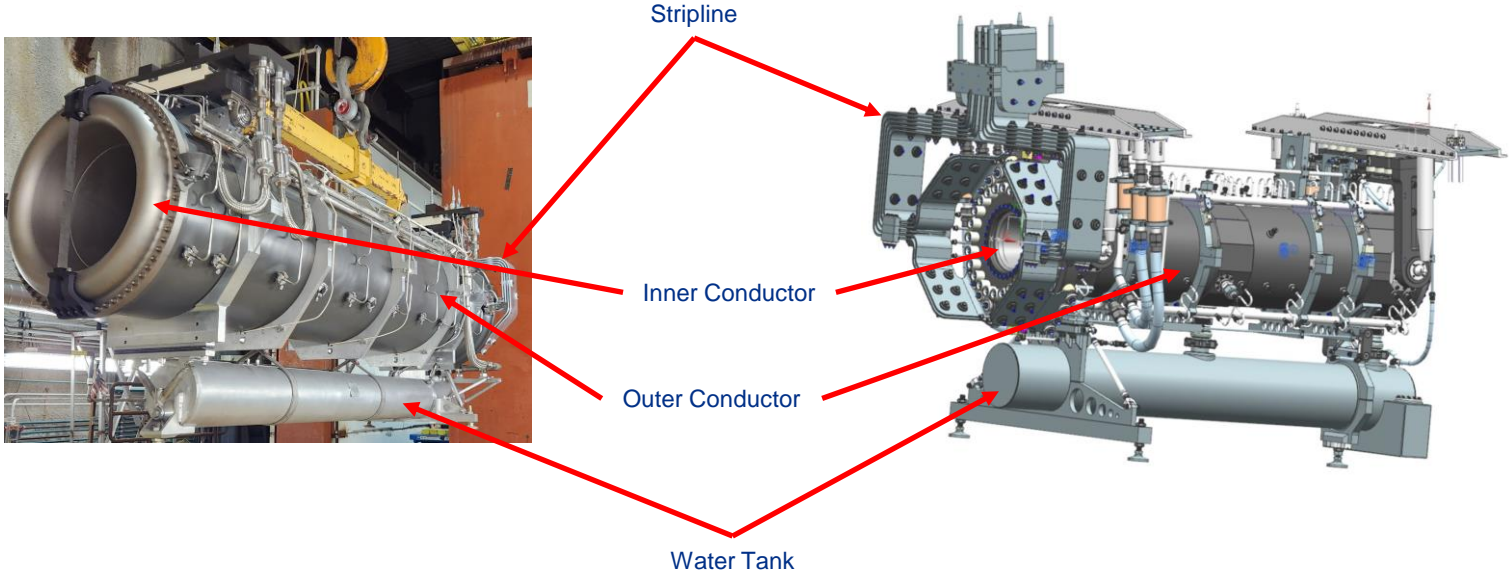
- Provides a neutrino beam for the NOvA experiment
 - ~500 Miles (800 km) from Batavia, IL to Ash River, MN
- 2 Horn System
 - Pulsed at 200kA with 2.3ms pulse width
 - Water cooled with sprayers for OC and IC
 - Nickel plated IC, anodized OC



- Future project to provide neutrinos for DUNE
 - ~800 Miles (~1300 km)
- Delivering to Lead, SD
 - Pulsed at 300kA
- Three horn system

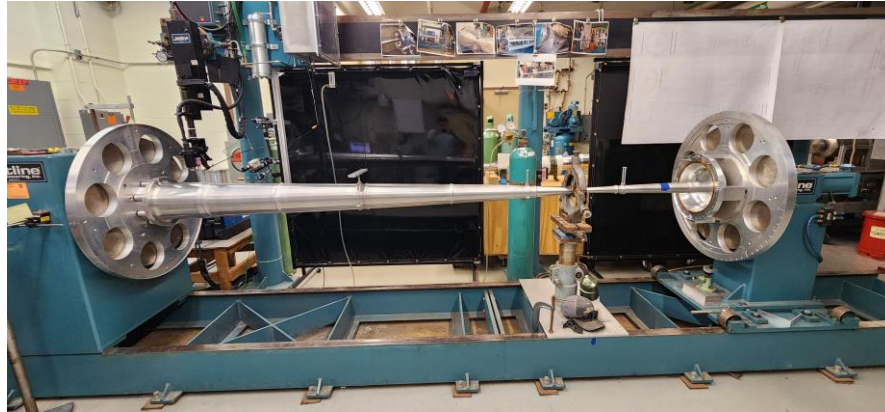


NuMI and LBNF Horns

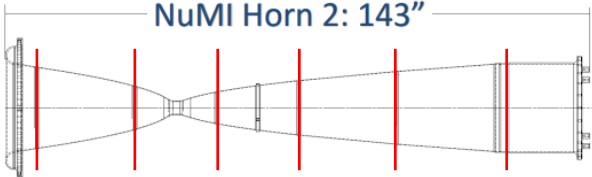
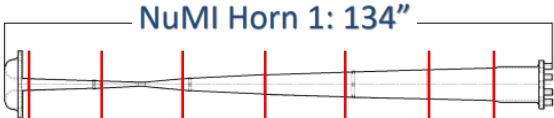


Inner Conductor Welding

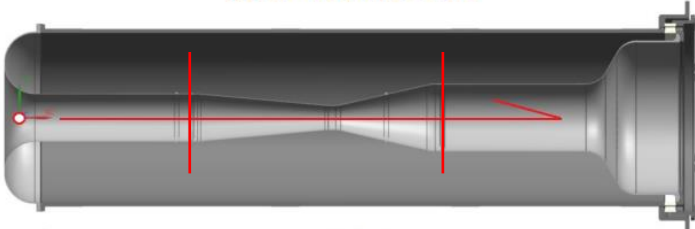
- NuMI Horn 1 and 2 have 7 and 6 welds respectively, LBNF Horns A, B, and C have 2 each
- Using a CNC TIG welder
 - Detailed process to strive for a ‘perfect’ weld
 - Welds need to survive high stresses in a hazardous environment (No IC has failed)
 - Multiple parameters to watch
 - Current, voltage, rotation speed, wire feed rate, gas purity, etc...



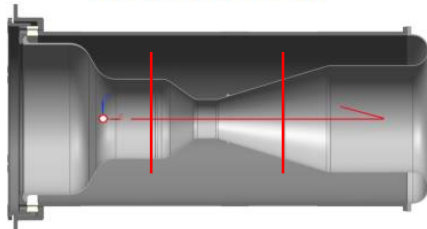
NuMI/LBNF IC Comparison



LBNF Horn B: 163"

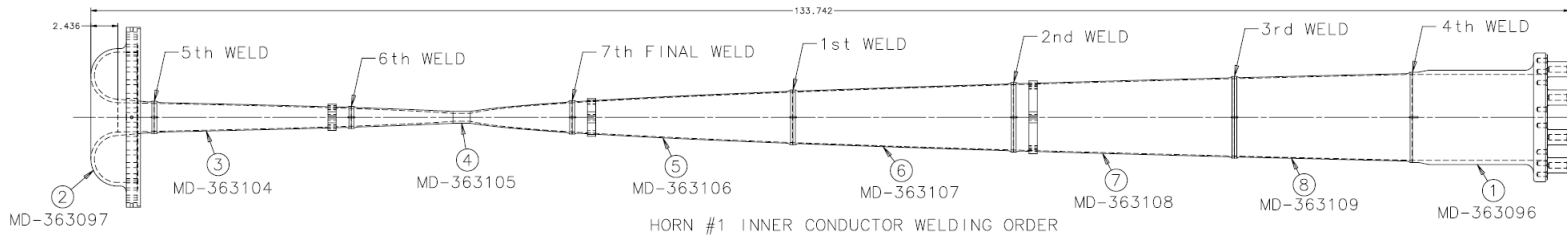
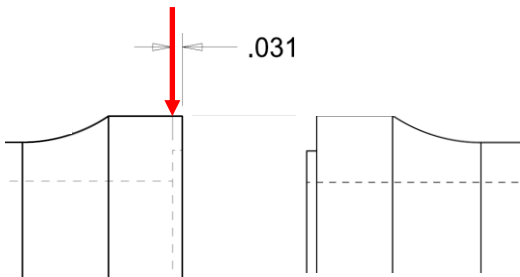


LBNF Horn C: 90"



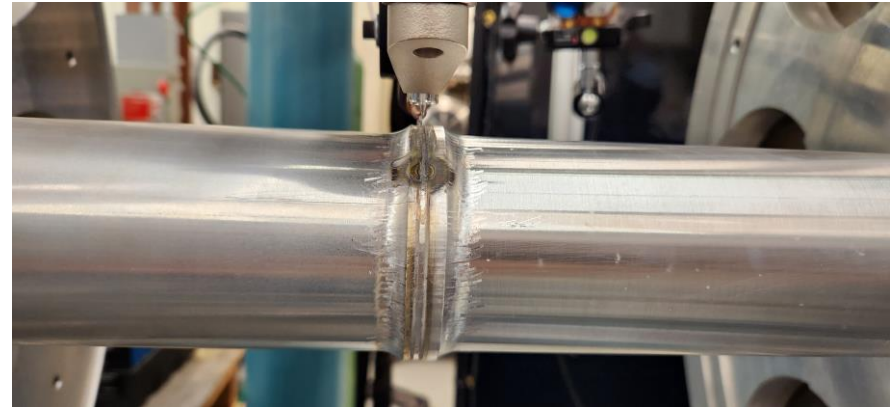
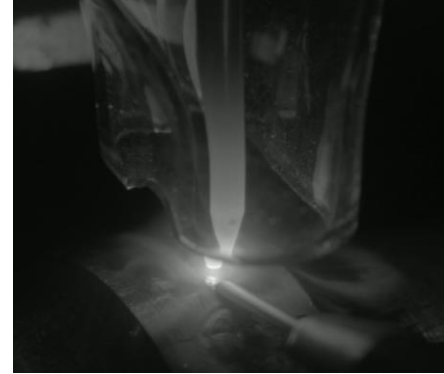
Inner Conductor Welding

- Weld is made over the 'step in' to have the under bead over the inner seam
- Weld prep is made to lock in the two pieces
- LBNF reuses this design



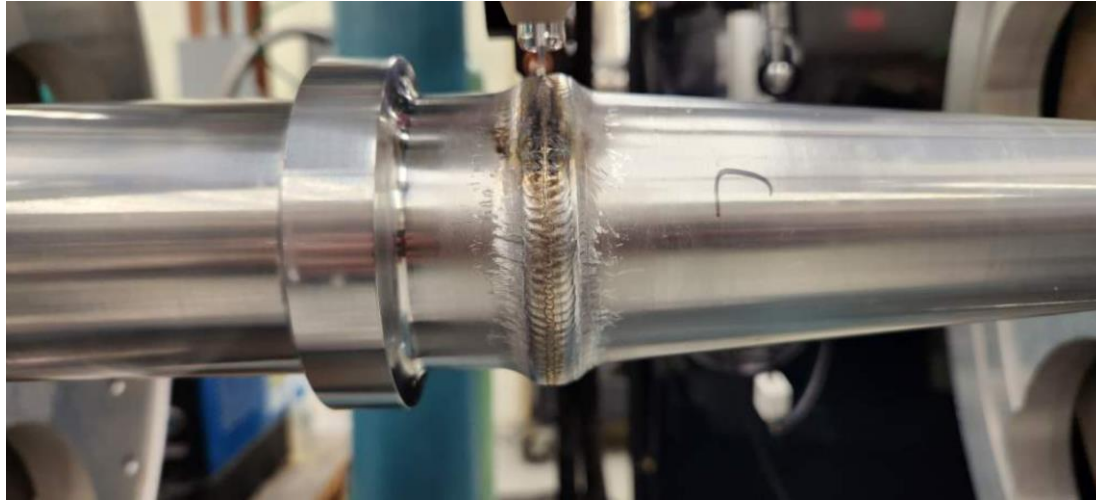
Inner Conductor Welding

- Preparation includes
 - Dimensional inspections (thickness is very important)
 - Ultrasonic cleaning
 - Enclosing in an argon filled bag
 - Scraping off top oxide layer, intending to weld within a few hours
- Post Weld Work
 - X-Ray inspections
 - Weld camera videos, parameter plots, inspection pictures



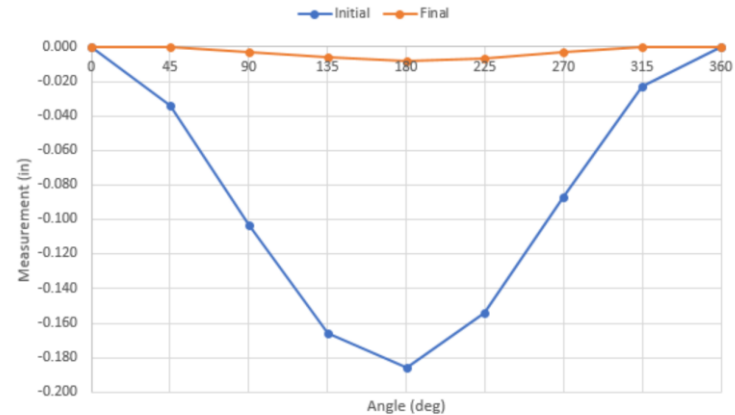
Inner Conductor Welding

- Cover passes are done on welds that are too hot
- Prefer to be hotter so that we ensure a complete under bead
- Uses the magnetic oscillation on the CNC TIG welder



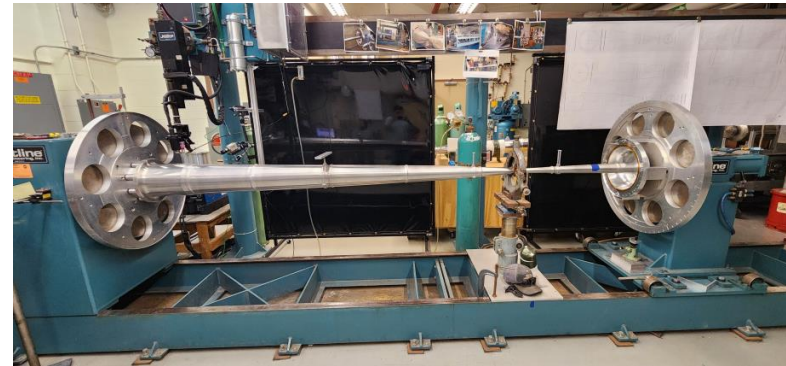
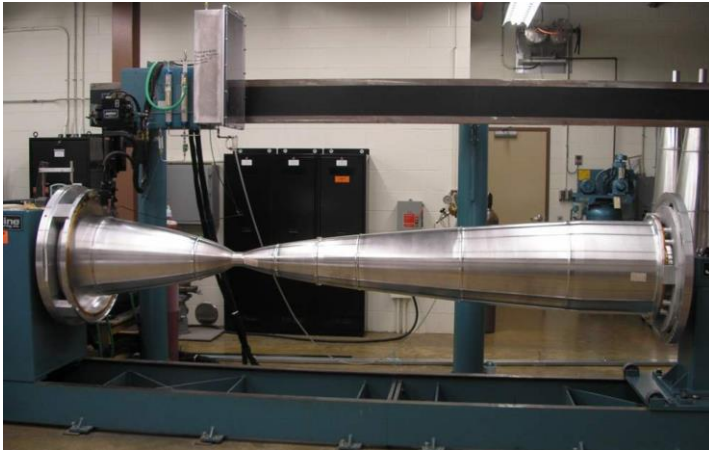
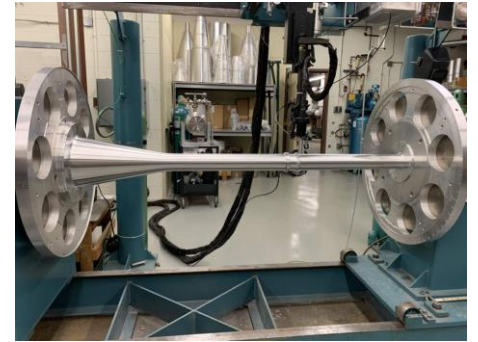
Inner Conductor Welding

- Straightening
 - Using the same CNC TIG welder without adding wire
 - Typically, +/- 30 Degree passes around 80 Amps
 - Specification calls for +/-0.010” (0.254 mm)
 - Usually less that 0.005”
 - Can take several days to straighten
 - Determines magnetic field quality
 - Axial and radial (at the neck)



Inner Conductor Welding

- Using the same system for LBNF
- Horn B is too long for our tracks
 - Need to add ~1 m
- Horn 2 weld diameters will give us a starting point for LBNF large diameters



~1 m

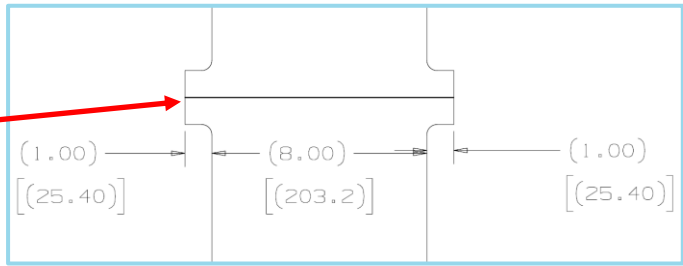
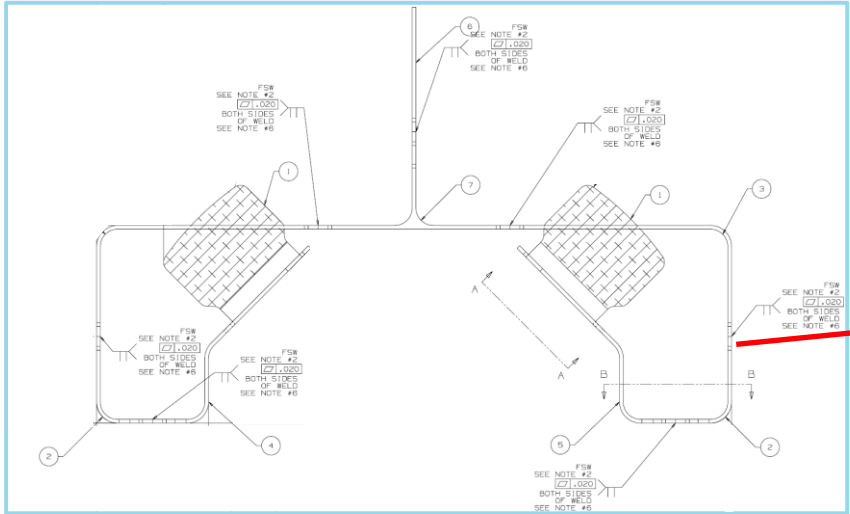
Striplines

- Provides the power to the horns
- Made of 3/8" (~9.5mm) layers for 6013, 6101, 6061 Aluminum
- Subjected to high stresses due to 200/300 kA
- Joined using FSW to retain a higher average weld efficiency
 - TIG welding is ~50%, FSW is ~70%



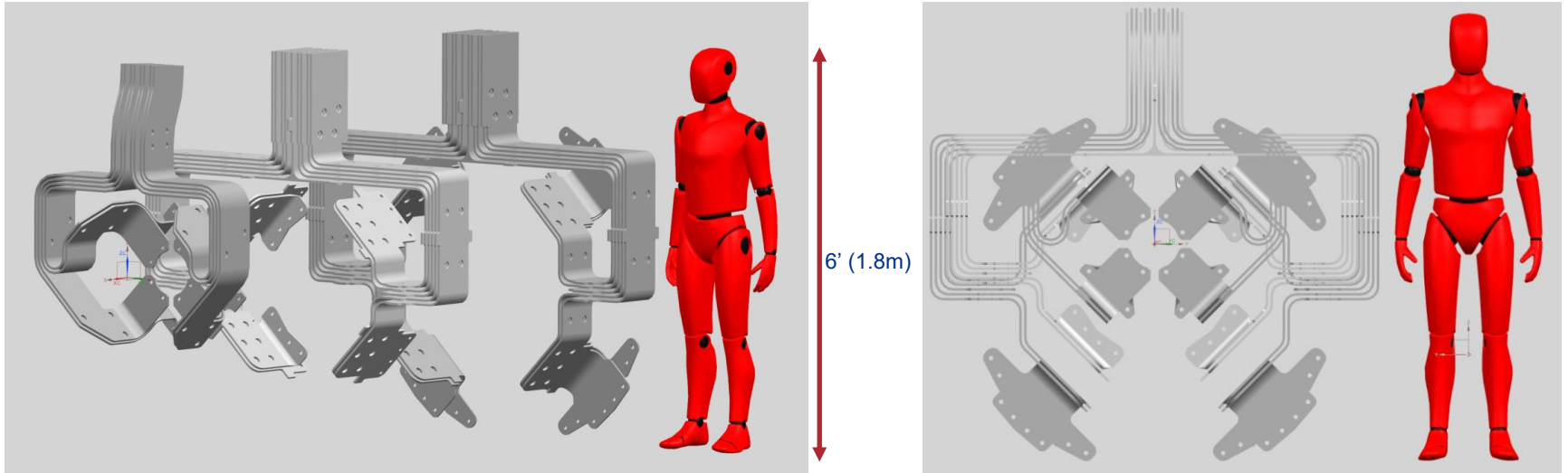
Striplines

- Horn A and Horn B/C have 29 welds over 9 layers (1-3 welds per layer, 9 welds on layer 5)
- Welds have run-off tabs for the pin tool to enter/exit
- Mating surfaces need sharp edges



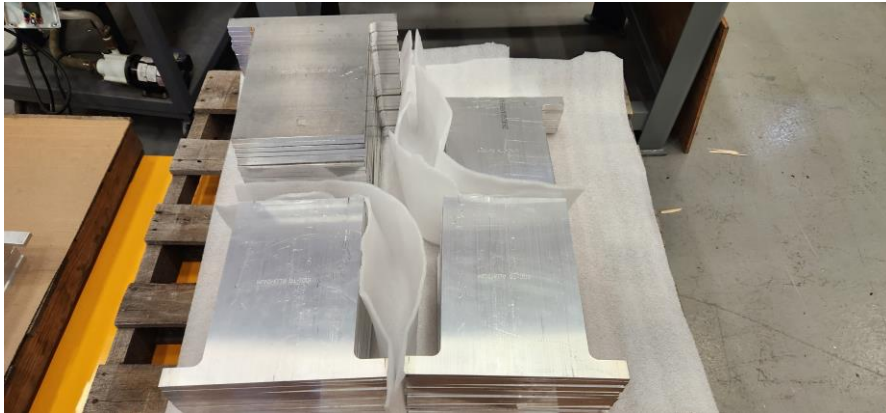
Striplines

- Significantly larger compared to NuMI
- Vibration analysis required to test lifetime
- Welding is done externally, but vendors are rare



Striplines

- Samples used for qualification
 - Mimic stripline piece geometry
 - Include run-off tabs
- Three alloys are used for four combinations



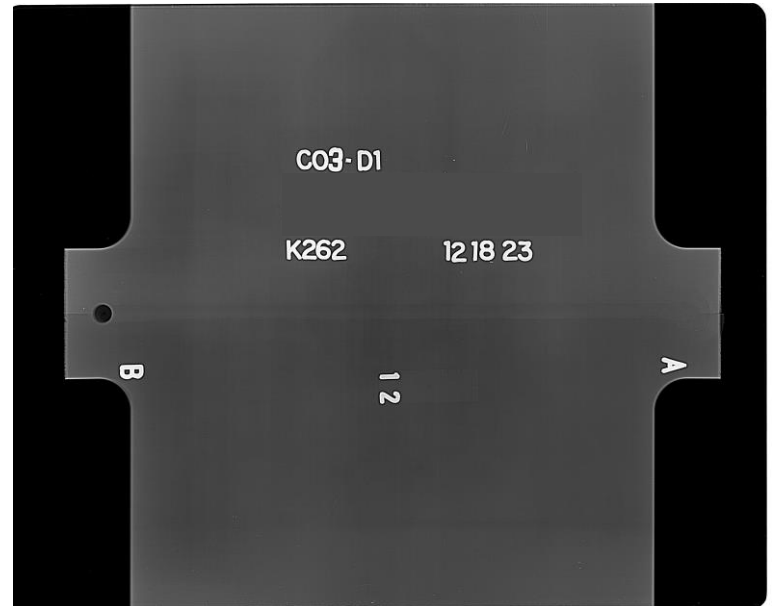
Striplines

- Quality assurance
 - Also need to classify according to NAS 1514
 - Perform material property testing
 - Tensile strength
 - Bending testing



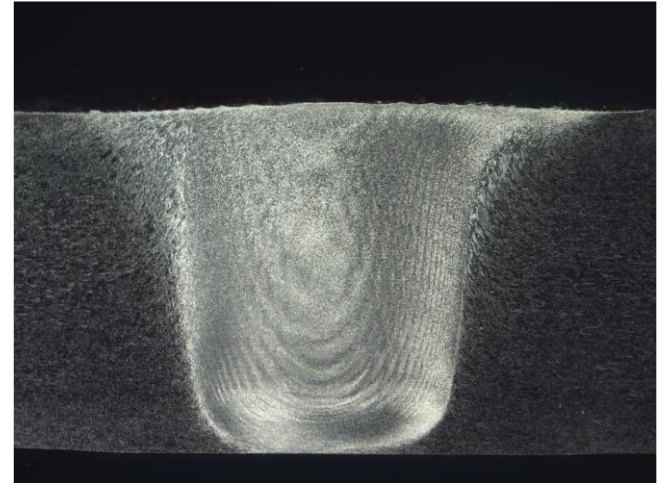
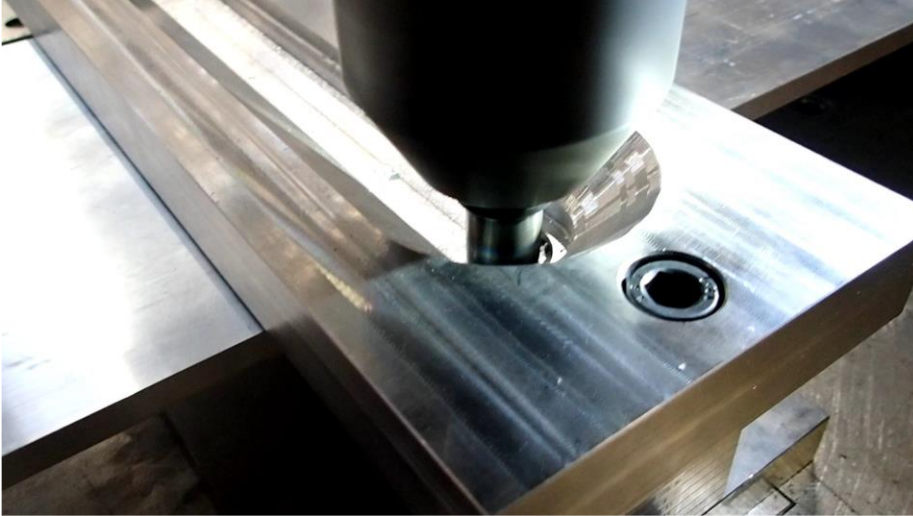
Striplines

- X-Rays showed complete penetration
 - No voids
 - Great confidence to continue FSW with this vendor



Striplines

- FSW is quick and with minimal heat
- Vendor qualification produced great results
- Welding Horn A stripline



Summary

- Horns are a crucial component for the experiment
- Having perfect welds is required to avoid horn failures
 - A well documented quality assurance procedure is priceless
 - Lessons learned from NuMI are directly transferable to LBNF
- FSW has proven to be reliable for the striplines
 - Vendor qualification is time consuming, but well worth the effort
- Welding solutions need to be viable for a 30-year project

