Magnetic Force and Parameter Evaluation of High Current Striplines for Neutrino Beamlines

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HPRF

- Klystron
- RF Cavity
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- SLAC ACE3P EM Suite

&

- LBNL NERSC

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EM Simulations for Secondary BeamLine Components of NuMI

- High Current Striplines of Magnetic Horns

Outline

- Fermilab Accelerator Complex
- The Secondary Particle Production at Accelerator Based Sources (an example NuMI Target Hall)
- Secondary Particle Focusing Components
  - Magnetic Horn
  - High Current Striplines
  - Power Supply
- High Current Stripline Simulations
- Discussion & Conclusion

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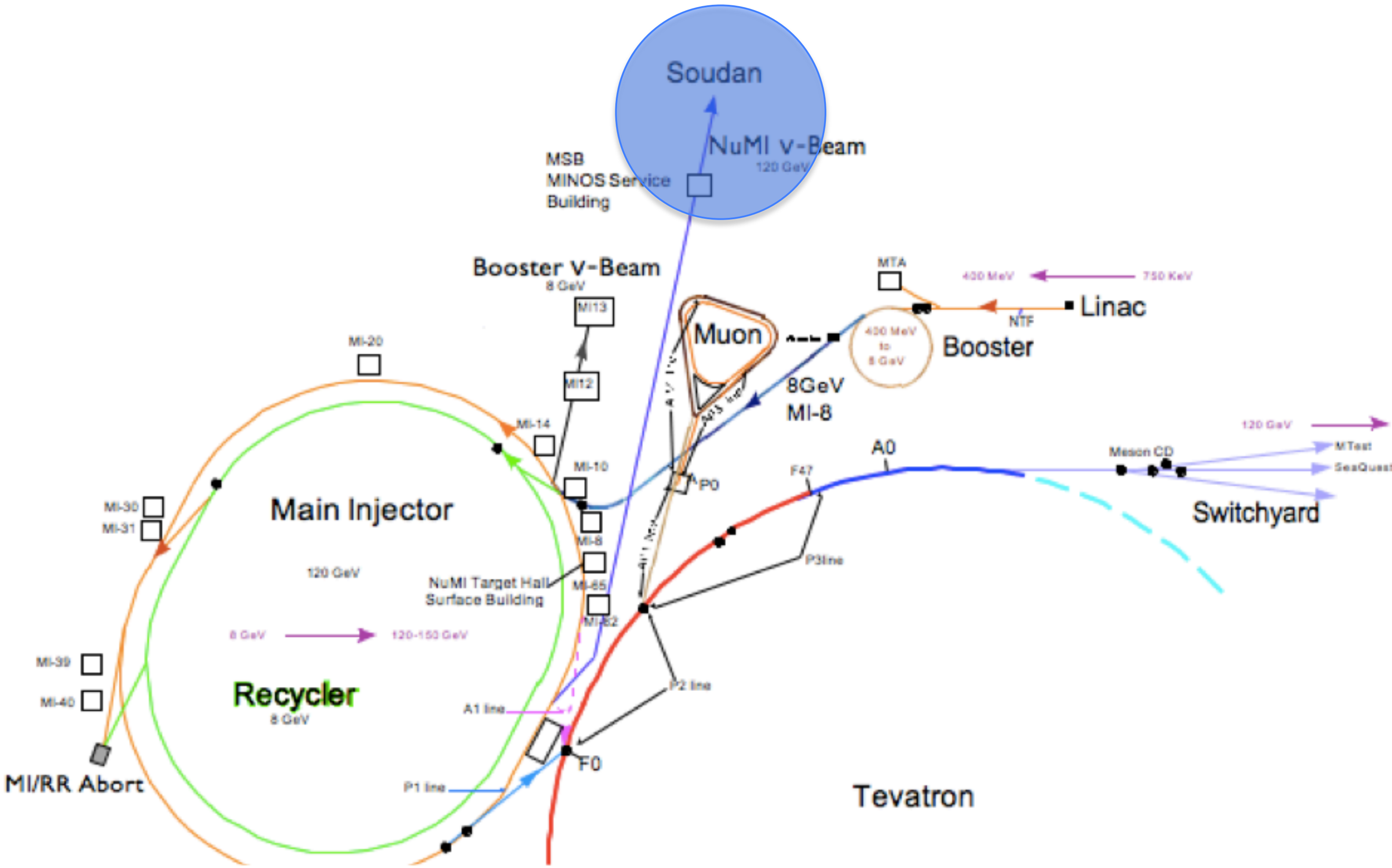
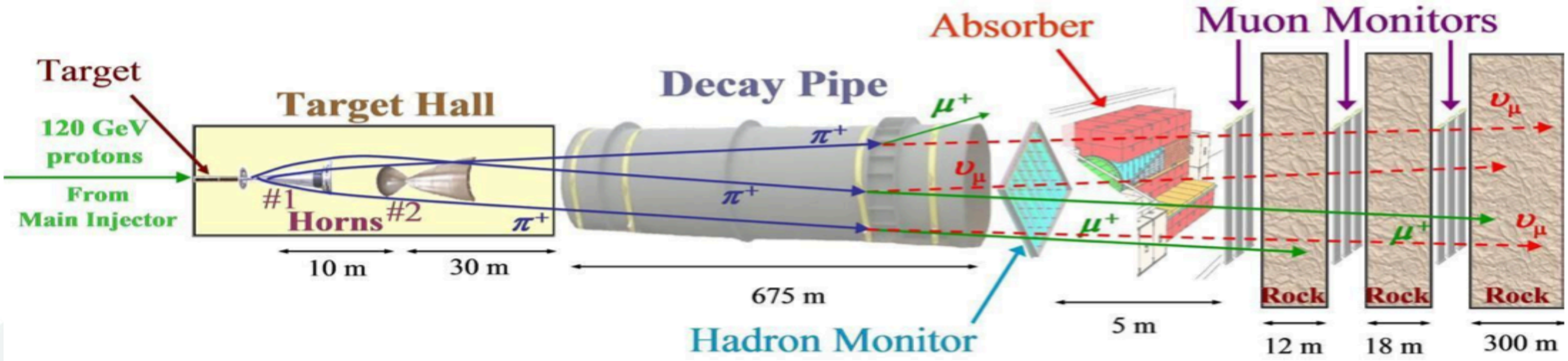
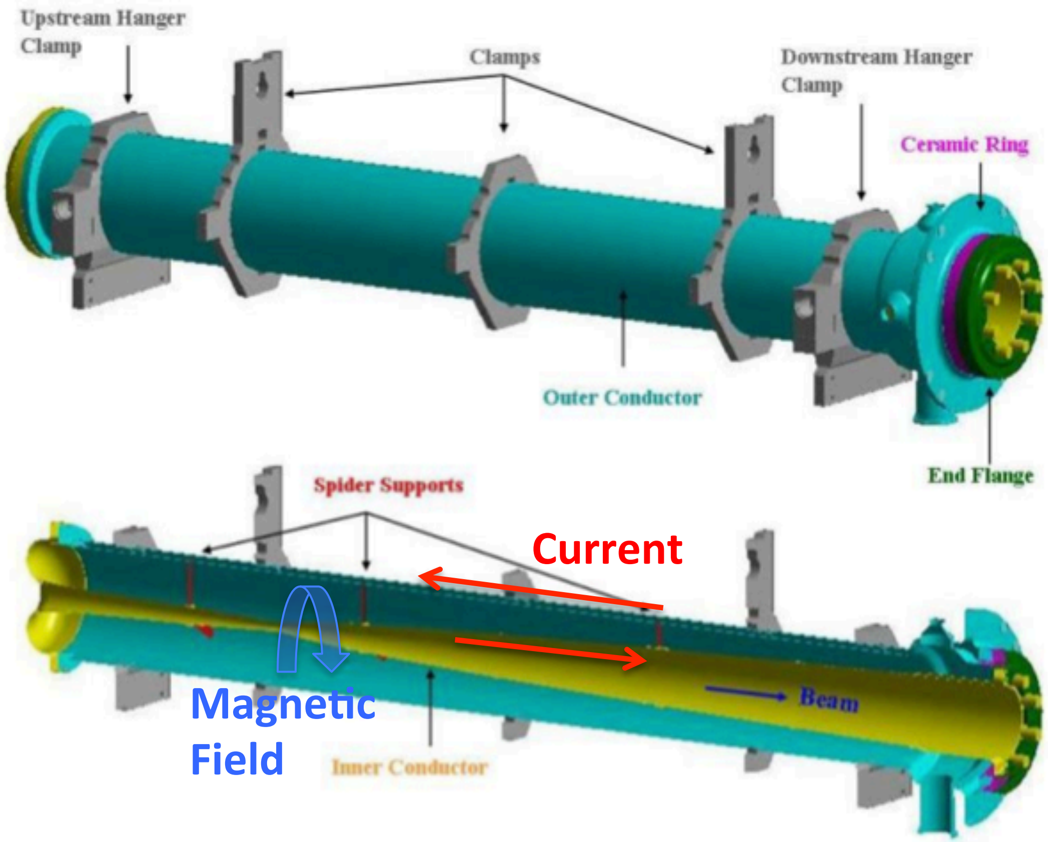


NuMI Target Hall



- Protons are accelerated at the particle accelerator with in several stages.
- The accelerated protons (120 GeV in our case) are extracted from the accelerator and directed on to a target where the protons interact with the target material, producing a large number of secondary pions among other particles.
- Shaped magnetic fields created by focusing horns are used to select out pions of the preferred charge, and focus them into a collimated beam.
- Then pions decay into neutrinos in decay pipe.

Secondary Particle Beamline Focusing Components



<u>A magnetic horn</u> is a device used in the production of neutrino beams.

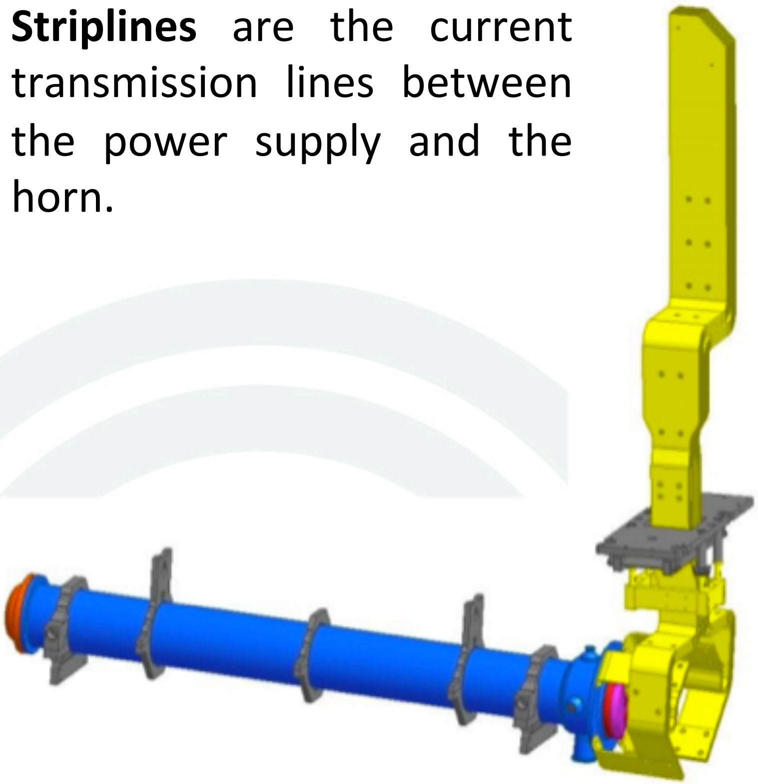
It focuses charged particles that will decay into neutrinos so that the resulting neutrino beam is as narrow as possible.

A horn contains a toroidal magnetic field in the volume between two coaxial conductors.

Current flows along the inner conductor and back along the outer conductor.

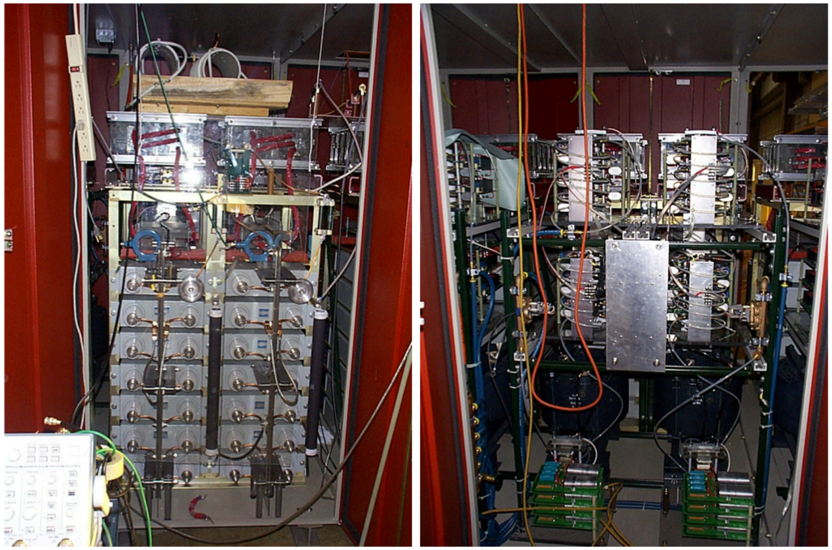
Secondary Particle Beamline Focusing Components

Striplines are the current transmission lines between the power supply and the horn.

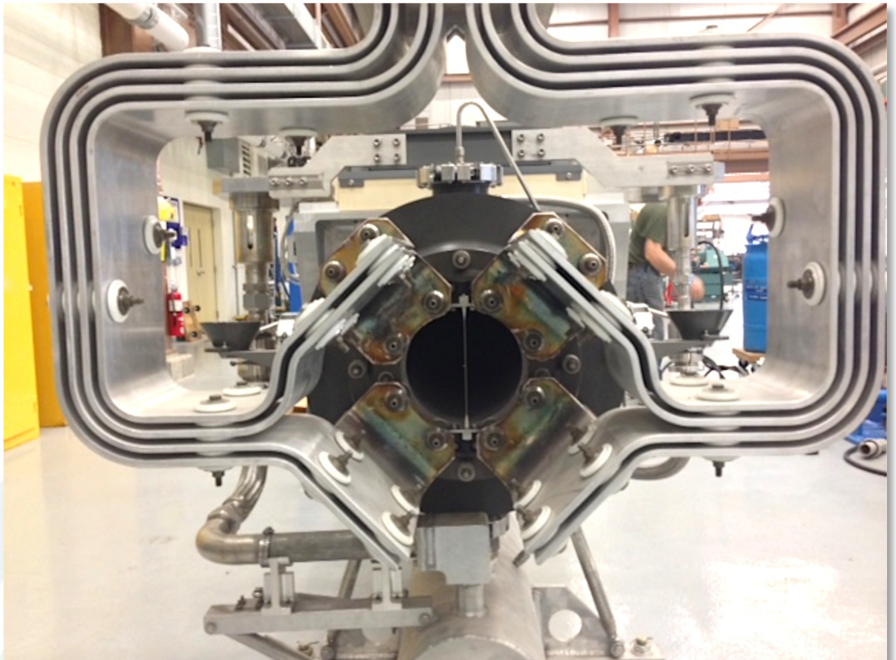


Magnetic horn power supply is a capacitor bank. Energy is stored in this capacitor bank and switched via silicon controlled rectifier (SCR) into the horn load.

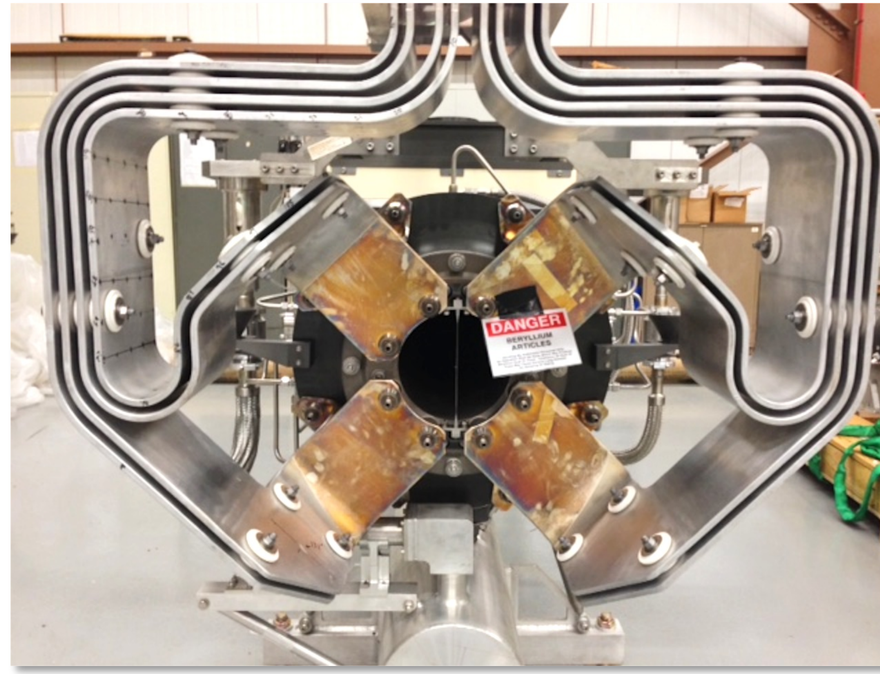
It produces a 200,000 A pulse at 722 V, over a 2.3 μs half sine wave every 1.33 s.



High Current Striplines at NuMI



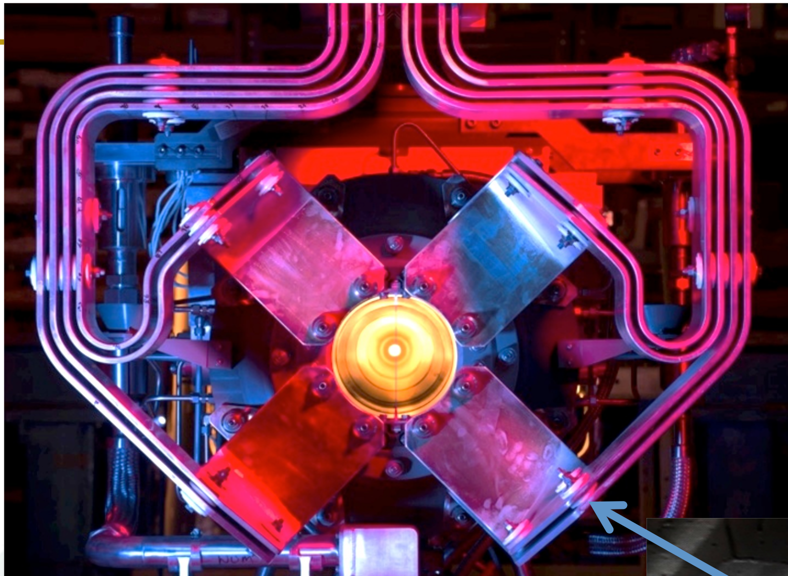
400 kW Design

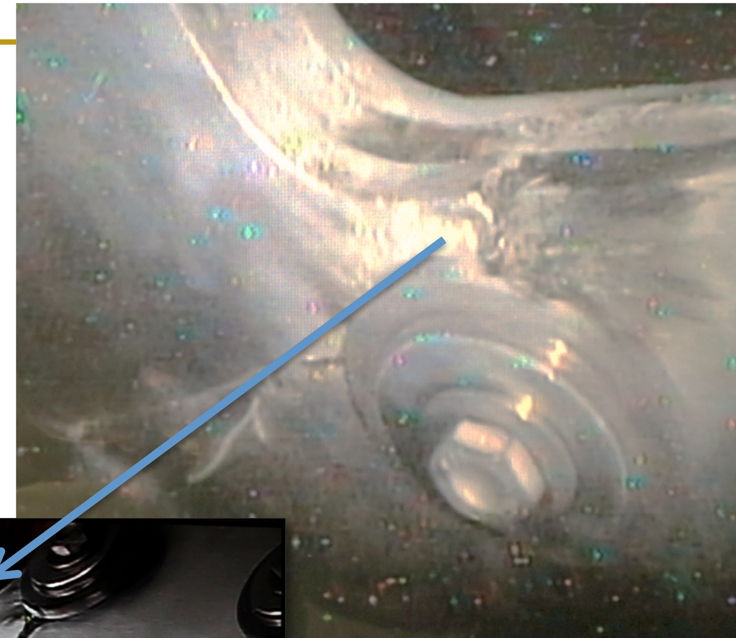


700 kW Design

- In 2013, Accelerator Complex and NuMI upgraded from 400 kW to 700 kW power.
- For 700 kW design flag parts of the stripline were moved outward to lessen beam heating and enhance convective air cooling by target chase air flow
- This results in longer unclamped distance on lower stripline
- This caused a failure.

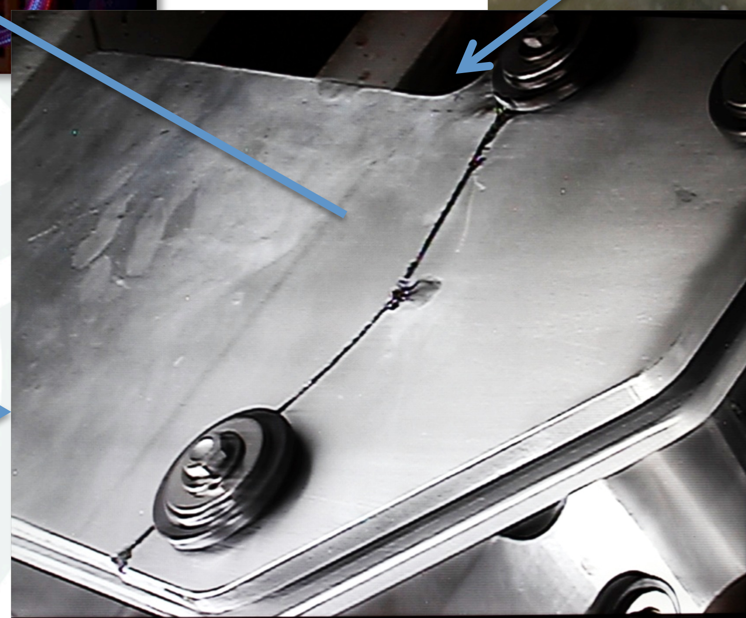
The Failure in June 2015





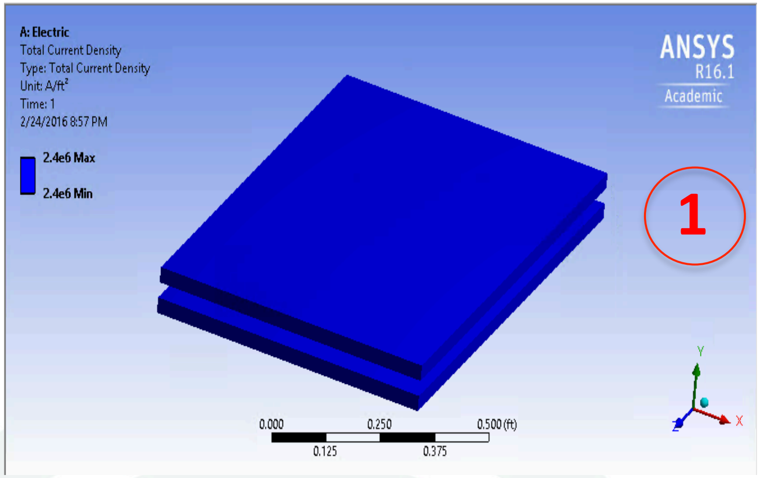
PH1-04 accumulated ~27 million pulses out of a desired 50 million

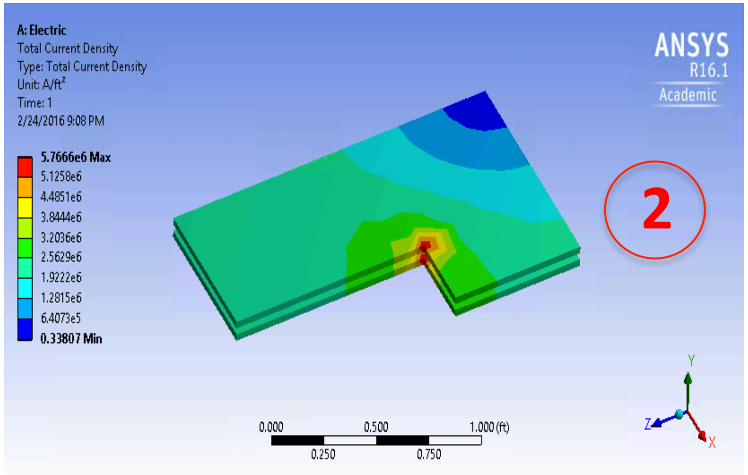
Crack in outer stripline layer on the underside (looking from bottom up)

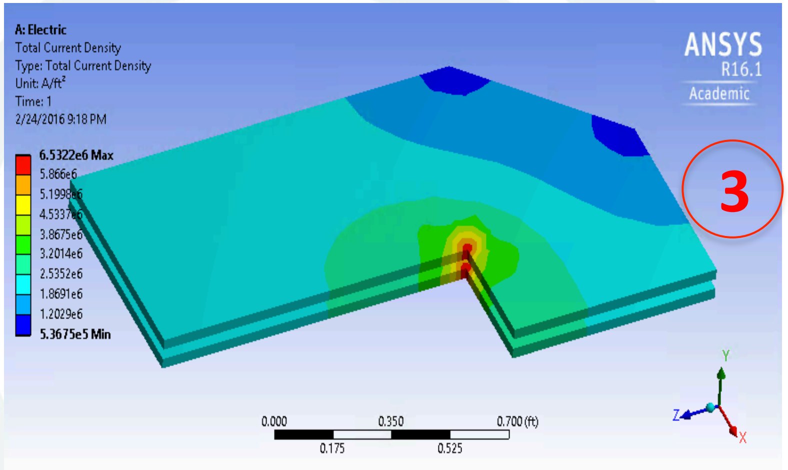


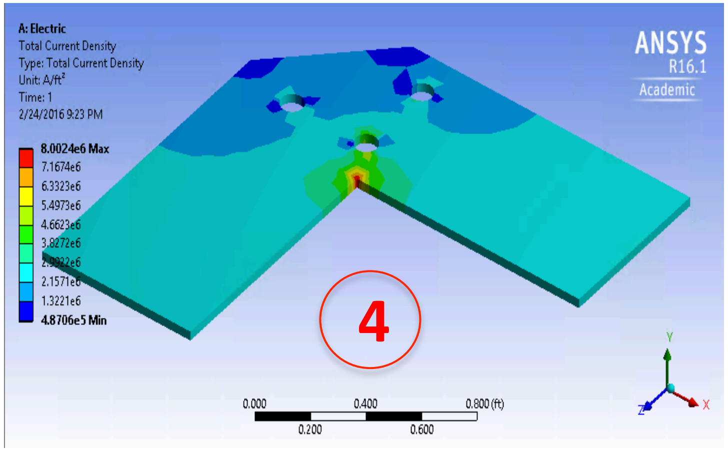
Appears to have been initiated on inside radius or clamp bolt hole

Current Density Simulation Results of Stripline Plates using ANSYS Electric

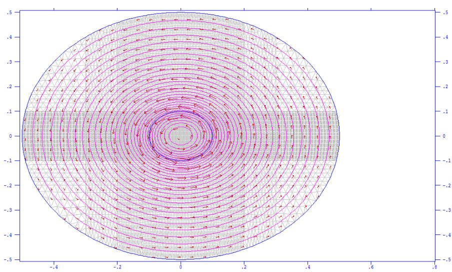


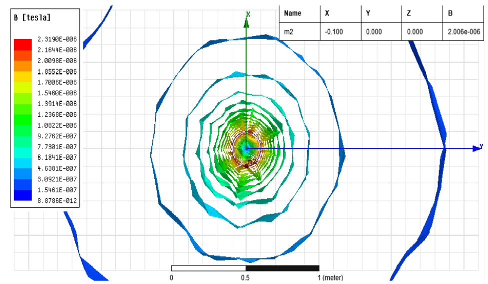




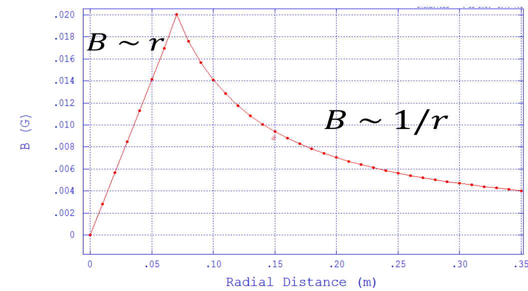


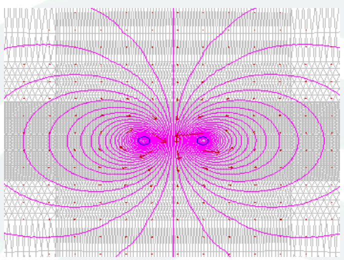
Accuracy Check of POISSON and ANSYS with Theory for Magnetostatic Effects of Stripline Plates

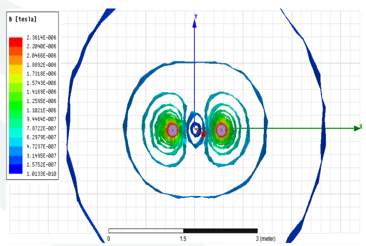


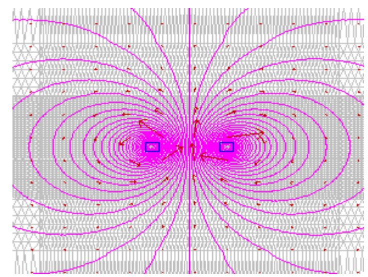


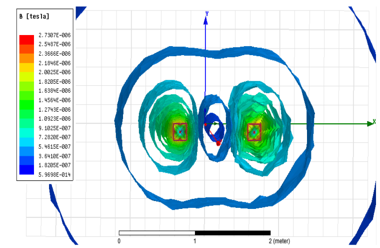
$$B = \frac{\mu_0 I}{2\pi d}$$

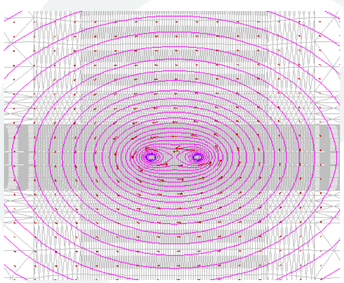


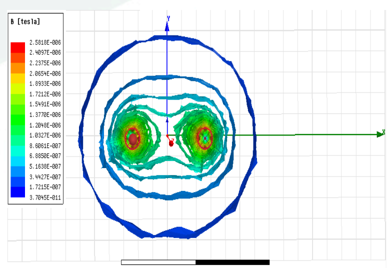


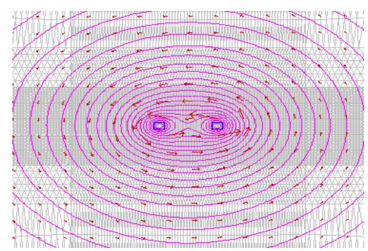


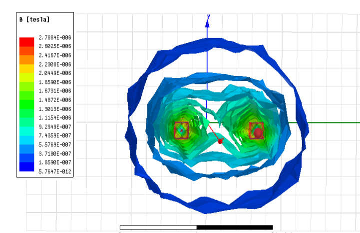






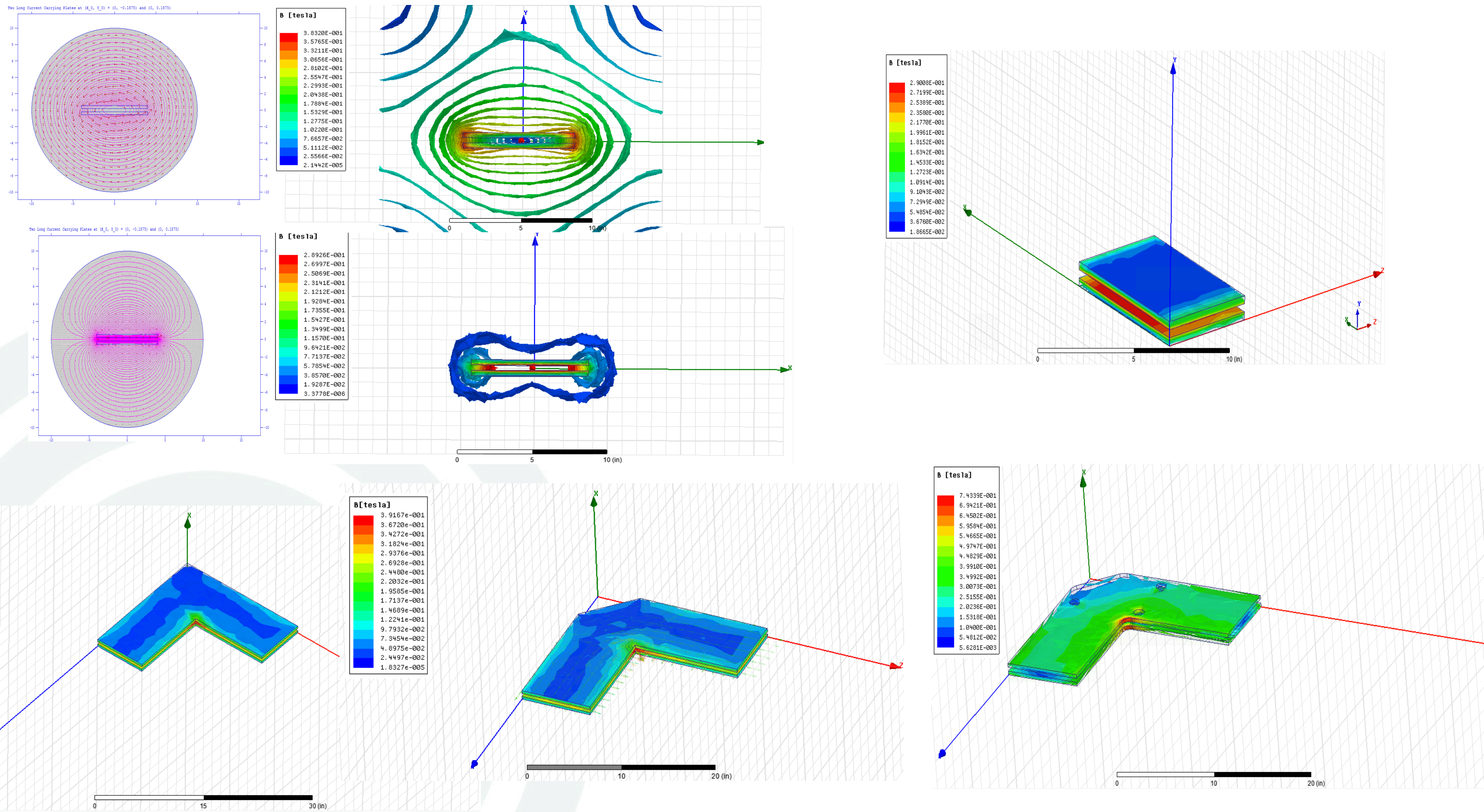






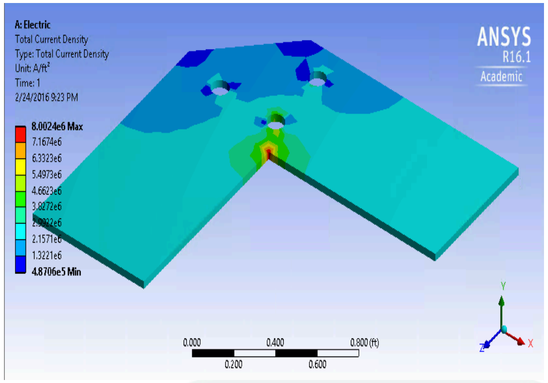
$$\frac{F_{Magnetic}}{Length} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

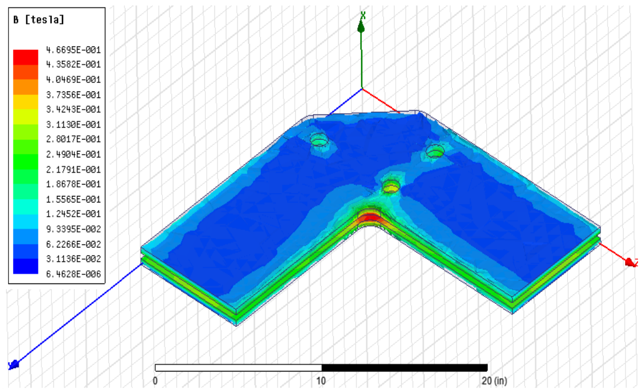
Magnetostatics Simulations of High Current Stripline Plates Yielding Magnetic Pressure

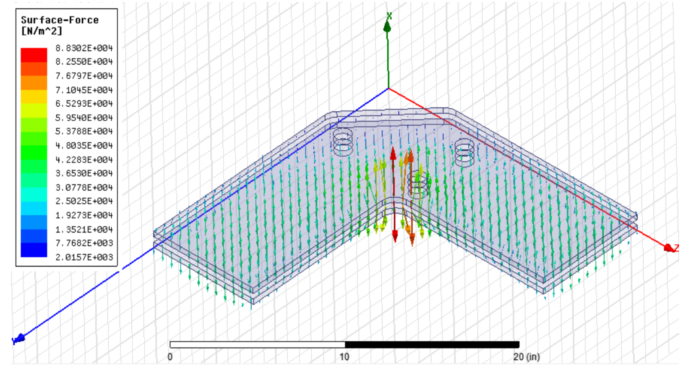


- Inclusion of the chamfering and bolt holes effected the current density and forces, but not critically.

EM Simulation Results of Flag Plates





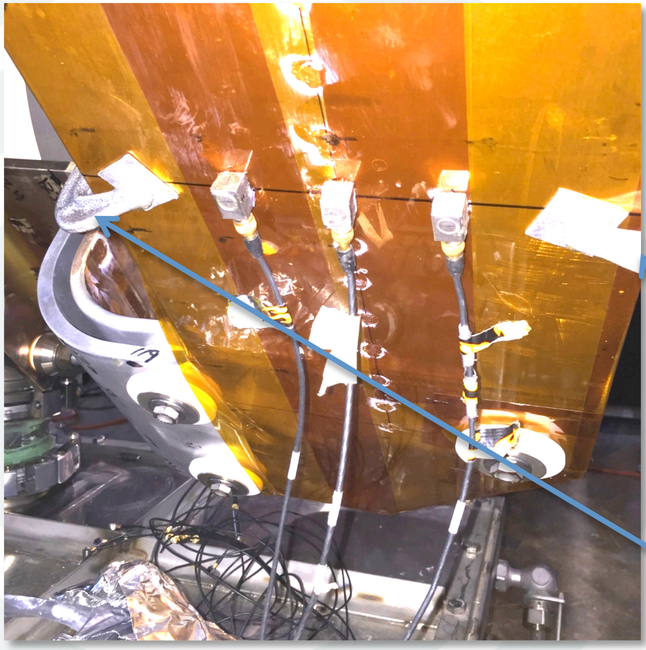


- The current density is found to be ~3 times larger in the corners.
- The magnetic field was found to be ~2 times larger at the inner corner of the plates as compare to the straight plates case.
- The pressure was found to be ~ 8.8 x10^4 N/m^2 at the highest point which was ~2.5 times higher than seen on average.
- It is better if the inner corner radius of the plate will be enlarged for the higher current required in the next designs.
- According to these results the main reason for the failure is not the magnetic interaction between stripline plates.

Possible Solutions

- EM simulation results of the flag plates showed the magnetic force is not high enough to cause the stress fracture by itself,
- These fractures are more likely related to fatigue failure due to insufficient damping of vibrational modes.

There are possible solutions to avoid vibrational effects:

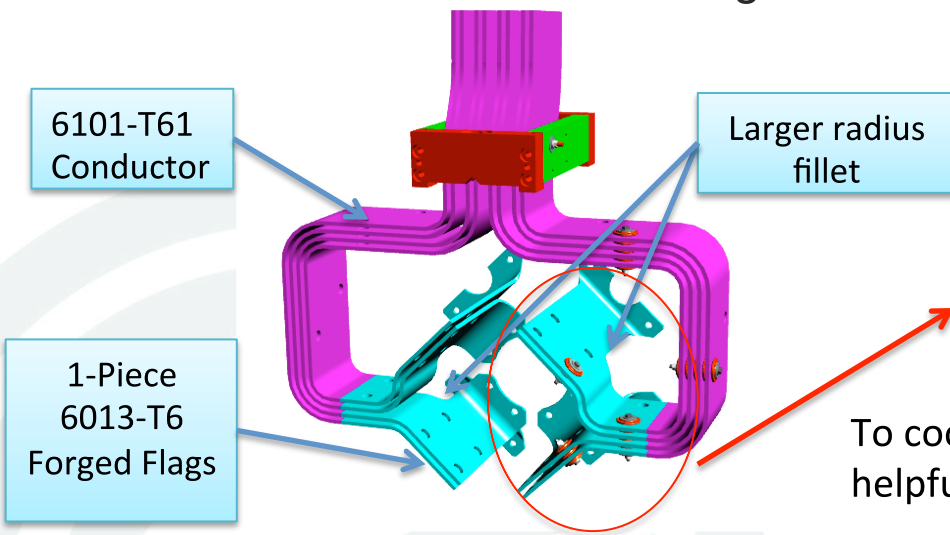


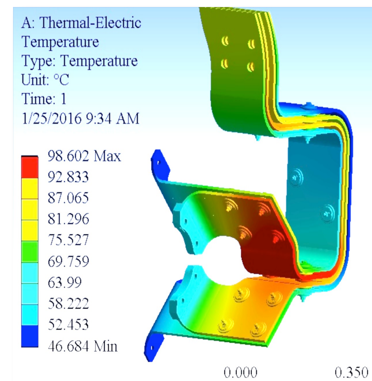
Bolt the 700 kW stripline in a more rigid way for damping it rapidly after each pulse passed on it.

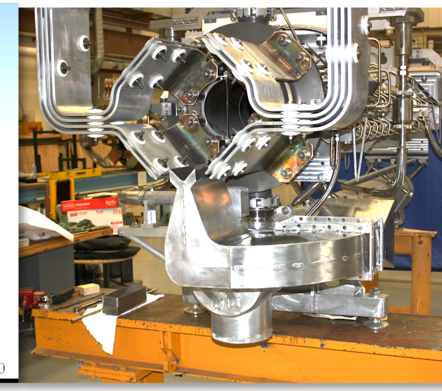
Clamp large unsupported section of stripline to reduce or eliminate 424 Hz mode, 6” up from restraint centerline (point 7)

The Long Term Solution

- New stripline package for 700 kW horn based upon 400 kW stripline package design with some geometry, material and cooling improvements seems more reliable as a long-term solution.







To cool the 400 kW stripline with an air diverter will be helpful to keep the temperature < 100 °C.

- Larger radius bend to increase material at stress concentration
  - Aluminum alloy 6013 for flag regions
    - higher fatigue and fracture toughness than 6101
  - Extruding flags through radius
    - Achieves better grain alignment transverse to crack propagation direction

Conclusion

- Detailed EM simulations of high current stripline showed increased stress on bolt holes and inner corner radius.
- Inner corner radius of the plate will be enlarged for the next design.
- New one piece flag part will provide more stability.

Revised design takes these into account.

References

- J. Warren, et al., “POISSON/SUPERFISH Reference Manual,” Los Alamos National Laboratory report LA-UR-87-126 (1987).
- ANSYS Academic Research, Release 16.1
- Adamson P. et al. “The NuMI neutrino beam.” Nuclear Instruments and Methods in Physics Research Section A: accelerators, Spectrometers, Detectors and Associated Equipment, 806, 279-306.
- Yun He “Magnetic Focusing Horns for Neutrino Experiments”, Fermi National Accelerator Laboratory, 12/17/2010.
- Michel Sorel, Columbia University (for the the Mini BooNE Collobartion) “Miniboone One Cool Horn” NFWG Seminar, CERN, August 2002.
- Sipahi, Taylan, et al. “Simulations of High Current NuMI Magnetic Hon Striplines at FNAL” 7th International Particle Accelerator Conference (IPAC’16), Busan, Korea, May 8-13, 2016 JACOW, Geneva, Switzerland.
- P. Hurh (on behalf of the Target System Department Engineering and Operations Team), “NuMI Horn Stripline Failure, Analysis, and Recovery or The Case of the Cracked Stripline”, Fermilab, April 14, 2016.

Thank you…

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