NuMI Beamline Upgrades to 700 kW and 1.2 MW

NBI2006 - 6th International workshop on Neutrino Beams and Instrumentation

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Mike Martens
Fermilab

Upgrading NuMI for Higher Power

Stage I : Reduce cycle time.
Use Recycler as a 8 GeV pre-injector.

Stage II: Increase Intensity.
Use Accumulator for momentum stacking

Started on Stage I conceptual design
Plan to have CDR in November

Just begun to think about
Stage II

	Best Operation	NuMI Design	Stage I (Recycler)	Stage II (Accumulator)
Beam power (kW)	280	400	700	1200
Cycle time (seconds)	2.0	1.9	1.33	1.33
MI intensity (10^{13} ppp)	3.0	4.0	4.9	8.2
Protons (10^{17} prot/hr) *	0.54	0.77	1.3	2.2
Protons * **(10^{20} prot/yr)**	3.1	4.3	7.4	12.4

* 44 weeks, 85% machine uptime, and 90% of peak intensity

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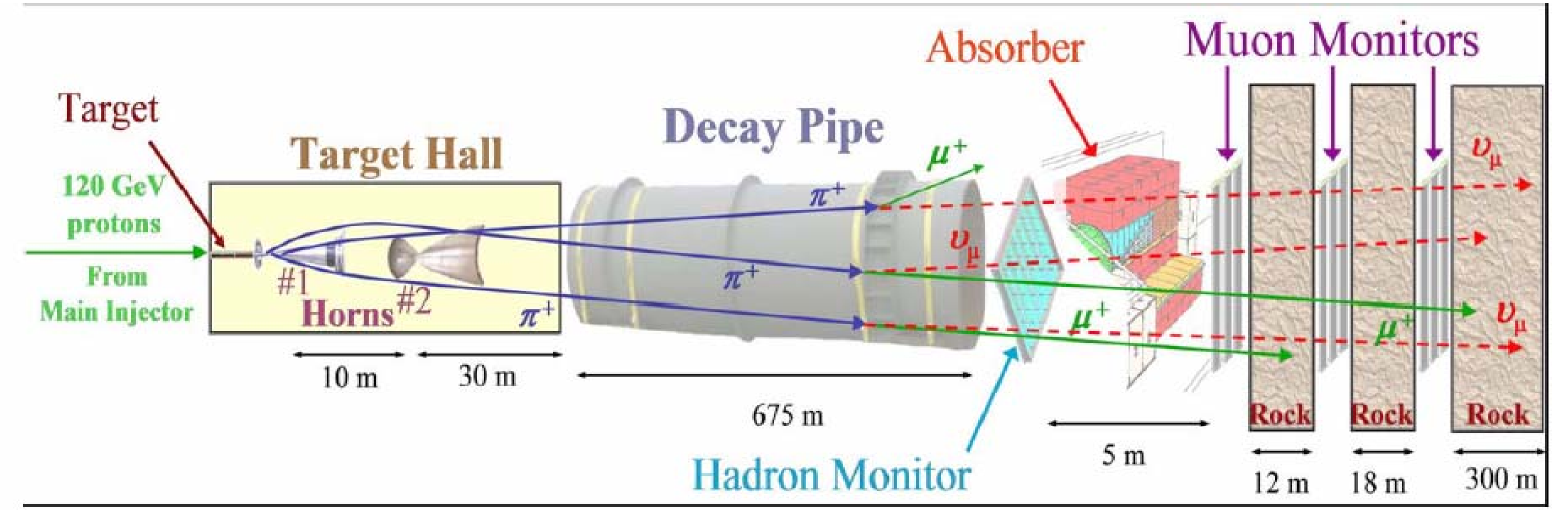
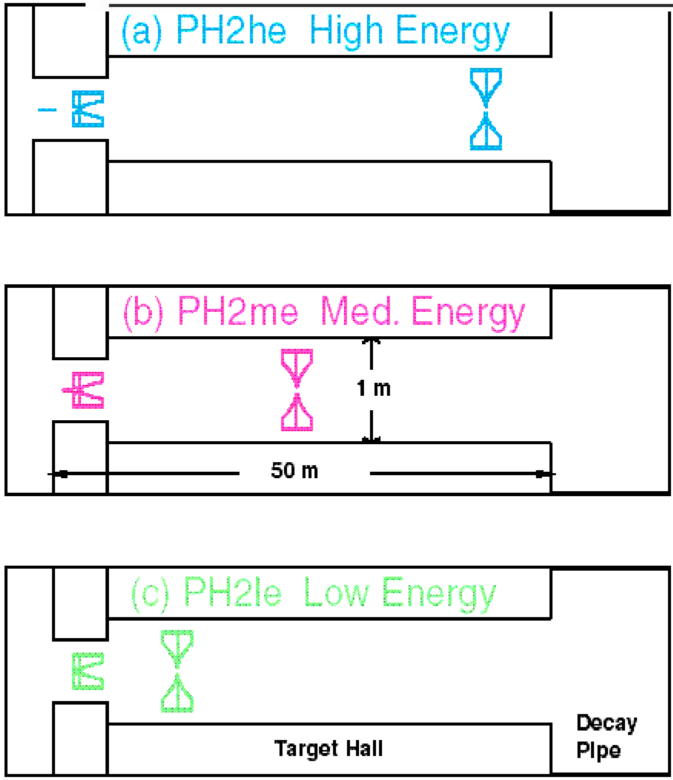
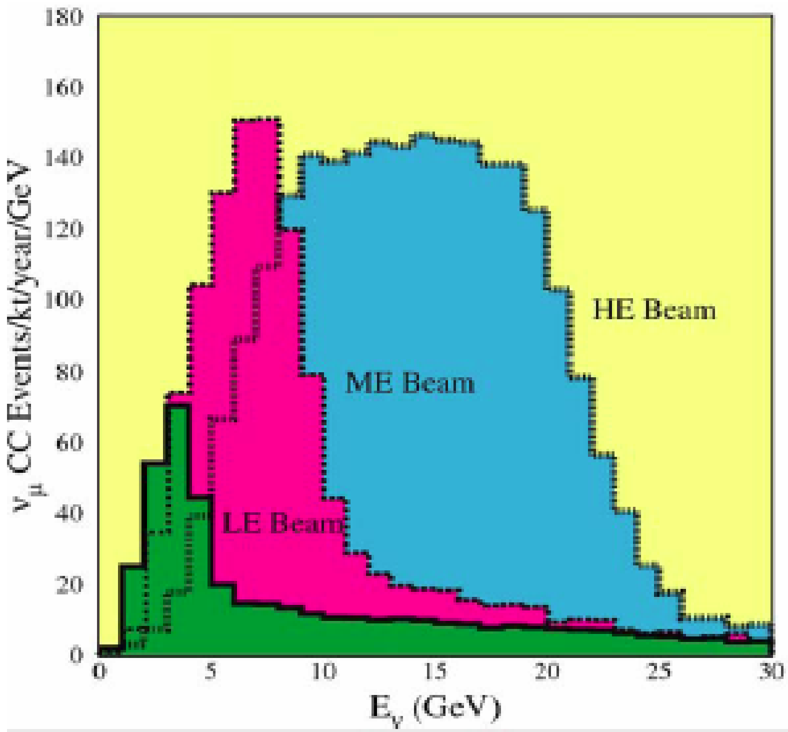
Producing a ν beam at NuMI







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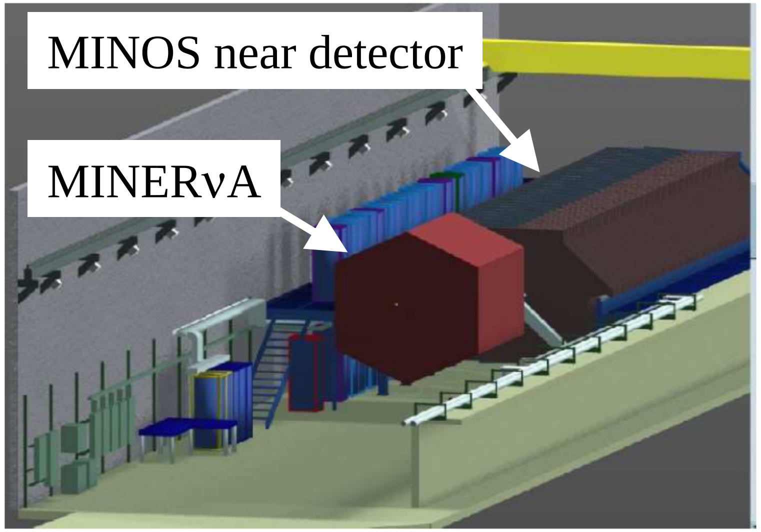
Future Experiments

MINERνA

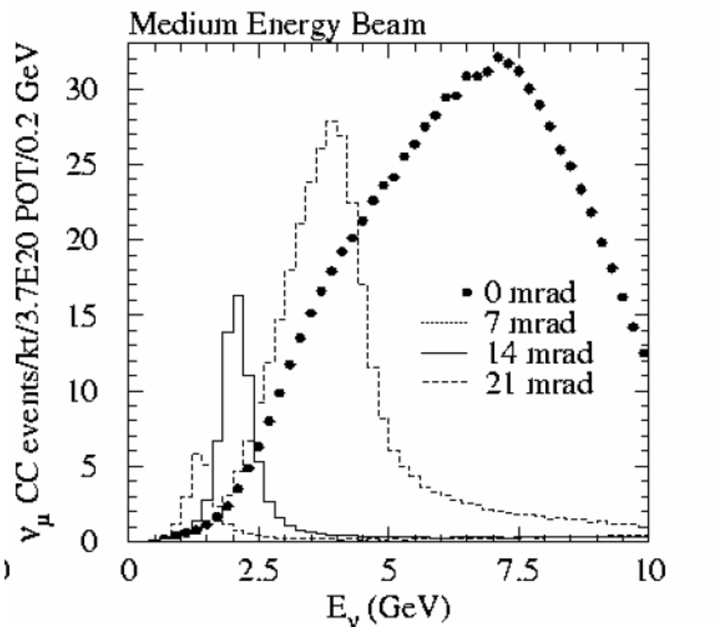
Quantitative Study of Low-energy ν - Nucleus Interactions



Detector Ready ~ Summer of 2009.
Desire ~7×10^{20} POT in LE mode

NOνA

Off Axis ν_e Appearance Experiment
14 mrad off-axis @ 810 km



5 kT of detector ready ~2011.
30 kT ready in ~2013
Desire ~7×10^{20} POT/yr in ME mode

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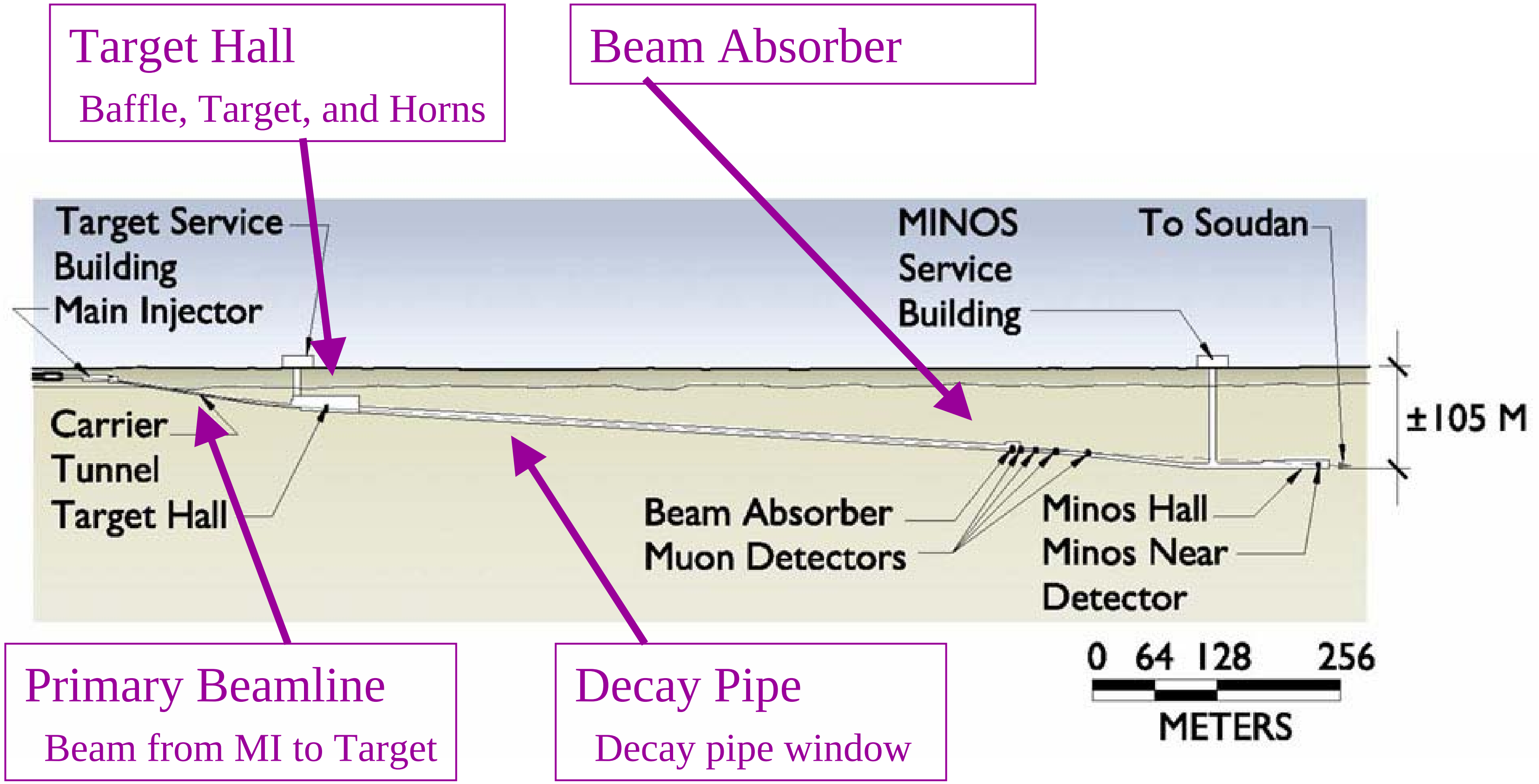
Major Components of NuMI Beamline & the usual issues (radiation, heating, etc.)



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Shorter Cycle for Primary Beamline

- From 1.9 ⇒1.33 second rep-rate
- Extraction Lambertsons are OK, upgrade PS for kicker
- Present power supplies are adequate (tap adjustments needed)
- Adjust ramps to maintain viable RMS currents for magnet cooling
- Replace some magnets (QQM 3Q120 Quads)
  - **25-30 year old magnets**
  - **Coils do not have direct cooling.**
  - **Limited number of spares**
- Build 6 new quadrupole
  - QQB design
  - Internal Coil Cooling
  - Fewer turns, higher field/amp
  - More robust

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Increased Primary Beam Intensity

- Essential to keep integrated losses low for groundwater and component protection.
- There is plenty of aperture in the primary beamline
- Currently we run with losses an order of magnitude below the safety factor

- Beam Permit System precludes a 2nd bad pulse.
- Losses at ~ few x10^{-5} fractional loss will pull the abort
- Magnet currents out of limits will pull the abort.

- Crossing a threshold? Single bad pulse can cause component damage.
- Monitor power supply currents to ~ 0.01% for Beam Permit System. (Presently we monitor to 0.5%)

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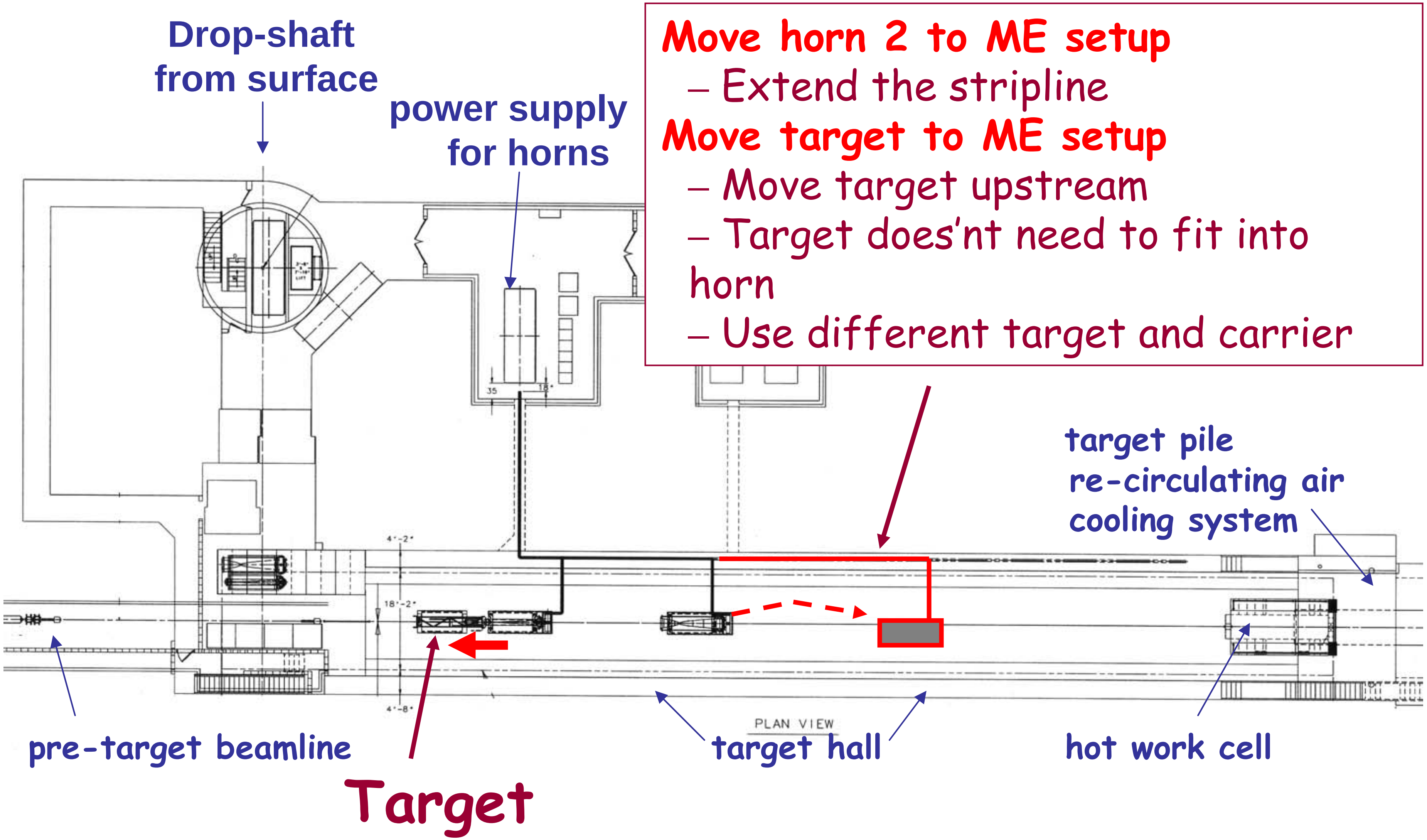
NuMI Target Hall Layout for NOνA

Medium Energy Beam

Move horn 2 to ME setup
- Extend the stripline

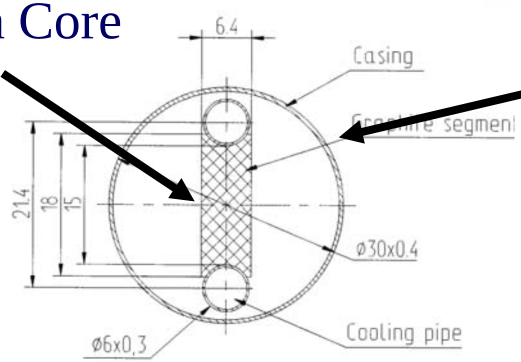
Move target to ME setup
- Move target upstream
- Target does'nt need to fit into horn
- Use different target and carrier

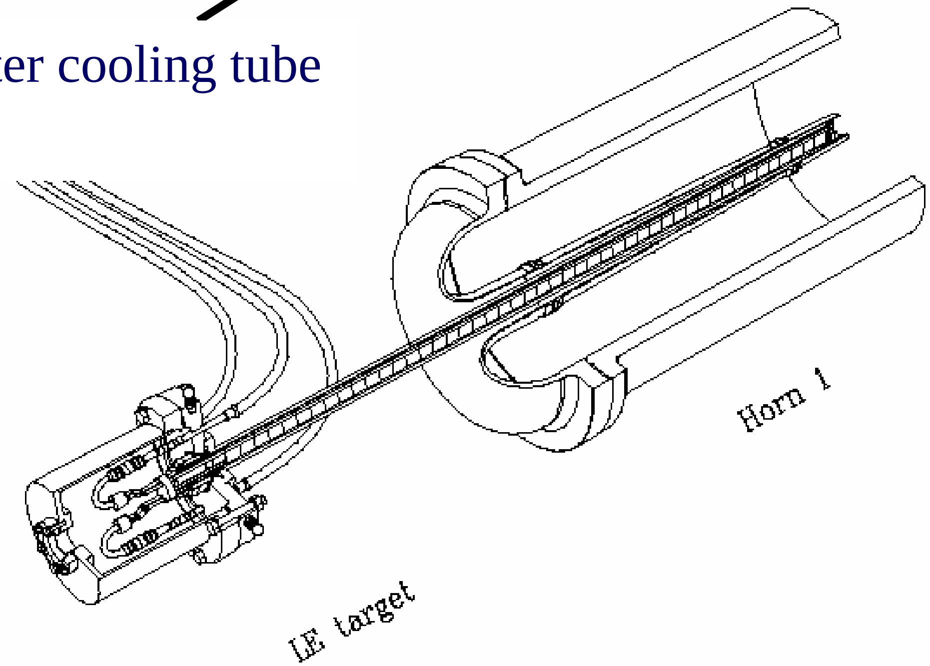


Low Energy Target

Graphite Fin Core

Water cooling tube





Low Energy Target
fits inside the horn

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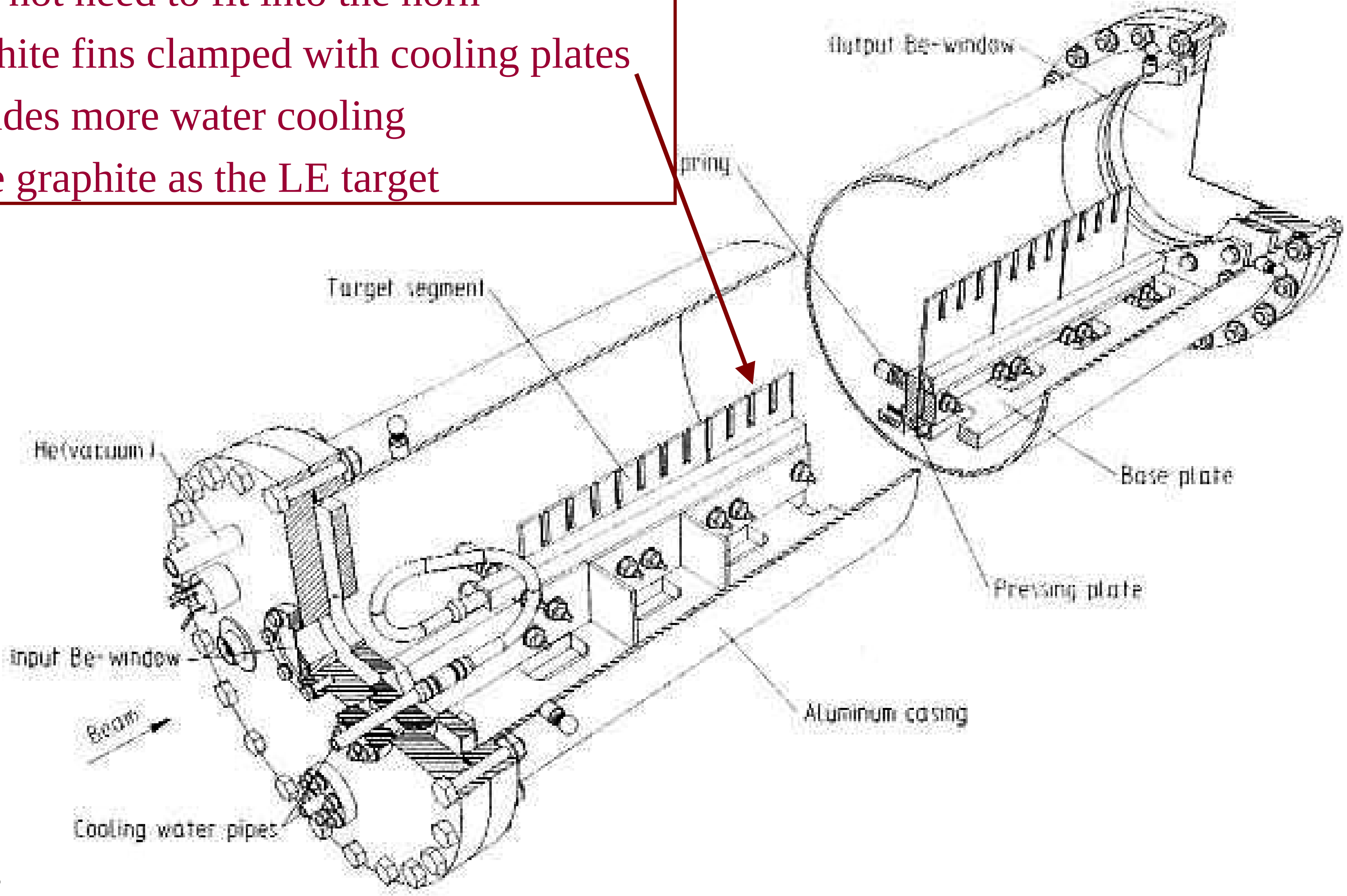
Medium Energy Target

Medium Energy Fin design:

- Does not need to fit into the horn
- Graphite fins clamped with cooling plates
- Provides more water cooling
- Same graphite as the LE target



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Target and Horn Alignment

- Most likely will run for ~1 year in LE for MINERvA.
- MINERvA indicates that we need to keep present tolerance of +/- 0.5 mm for survey and +/- 0.5 mm for thermal effects.

- Switch to ME configuration for NOvA (~several month shutdown)
- IHEP Medium Energy (ME) target design.
- Target 1.35 meters upstream, 1.2 meter long, 6.4 mm wide.
- IHEP calculation of temp and stresses on ME target (October 30.)
- No remote longitudinal motion of target.
- Horn 2 located 23 meters downstream of horn 1.
- NOvA has started looking at alignment issues.

http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=2392

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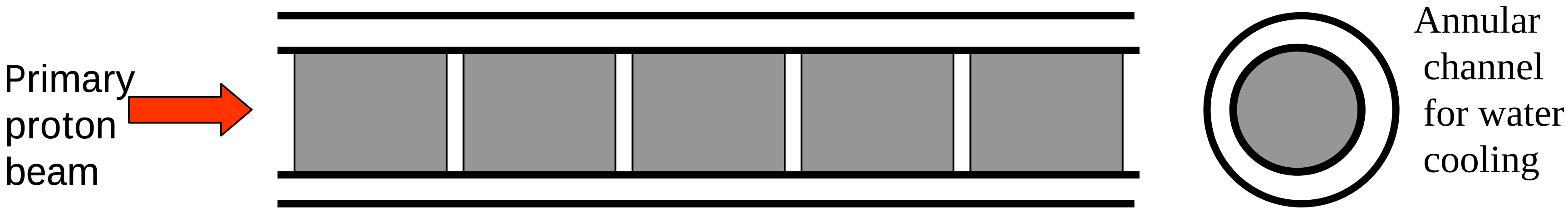
Target Design for yet higher power

Encapsulation of graphite cylinders (segments) with a prestress of about 10 MPa into stainless steel or aluminum thin-walled pipe:



- Provides an integrity of the target core and keeps it even in the case of thermo-mechanical or radiation damages of some segments
- Prevents a direct contact of the cooling water with the heated surface of graphite
- Provides a good thermal contact between graphite and metal pipe

Suitable for higher beam power (maybe even 2 MW)

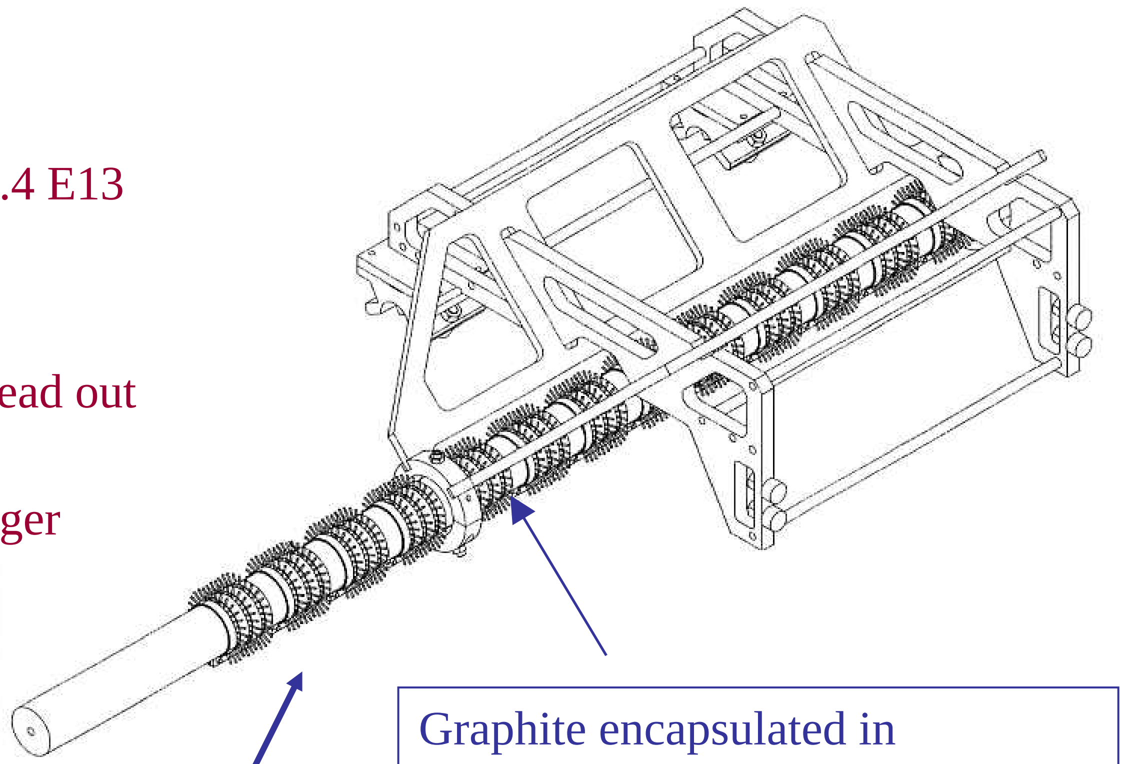
but ~10% fewer neutrinos / POT

Baffle Modifications

Baffle protects beamline elements from single pulse mis-steered beam.

- OK for thermal shock up to 5.4 E13
- 75% more fins for cooling.

- Move further upstream to spread out shower more?
- Increase hole diameter for larger beam size?

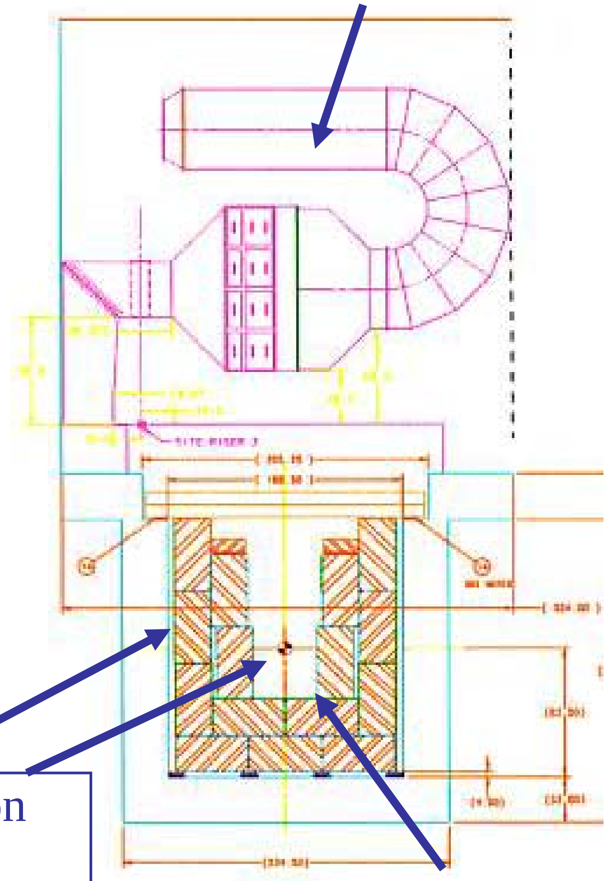


Graphite encapsulated in aluminum 150 cm long , 11 mm diameter hole for beam. Air-cooled

Space to increase air-cooling fins

Target Hall Air Conditioning

- Target Hall Cooling
  - Closed loop air re-circulating system
  - Designed to maintain positional stability of target/horns
  - 25,000 cfm air flow
  - 240 kW of cooling
  - 18 mph wind in beam channel
- Upgrade Chiller for 700 kW
  - Add more chiller coils
  - Operate at higher chase temperature
- For 1 MW looking at water cooling



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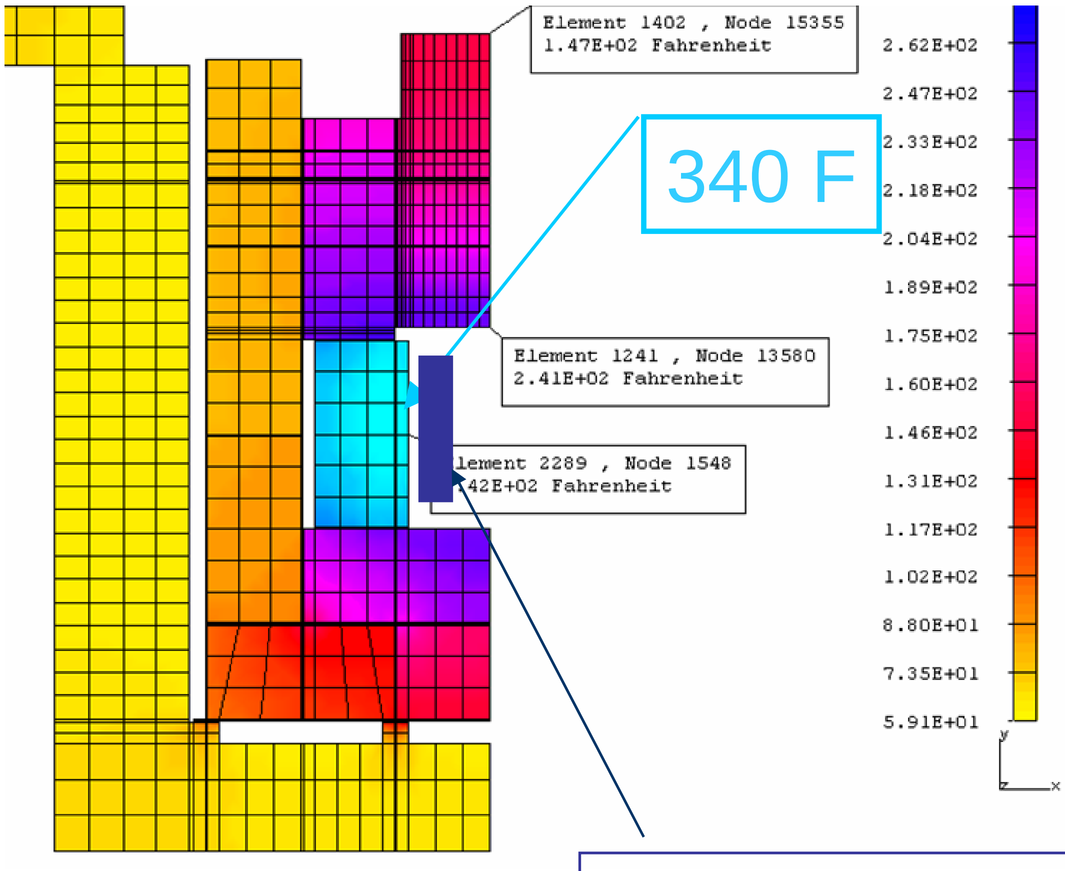
Target Pile Temperature



Preliminary Calculation
(from A. Stefanik)

Uses 2D approximation

Overestimates temperature rise for present 200 kW ops.

For 800 kW find 340 F in the steel shielding

Most of energy deposition is in the first ~1 inch of the shielding

Add ~1 inch thick water cooled plates for 1.2 MW operations?

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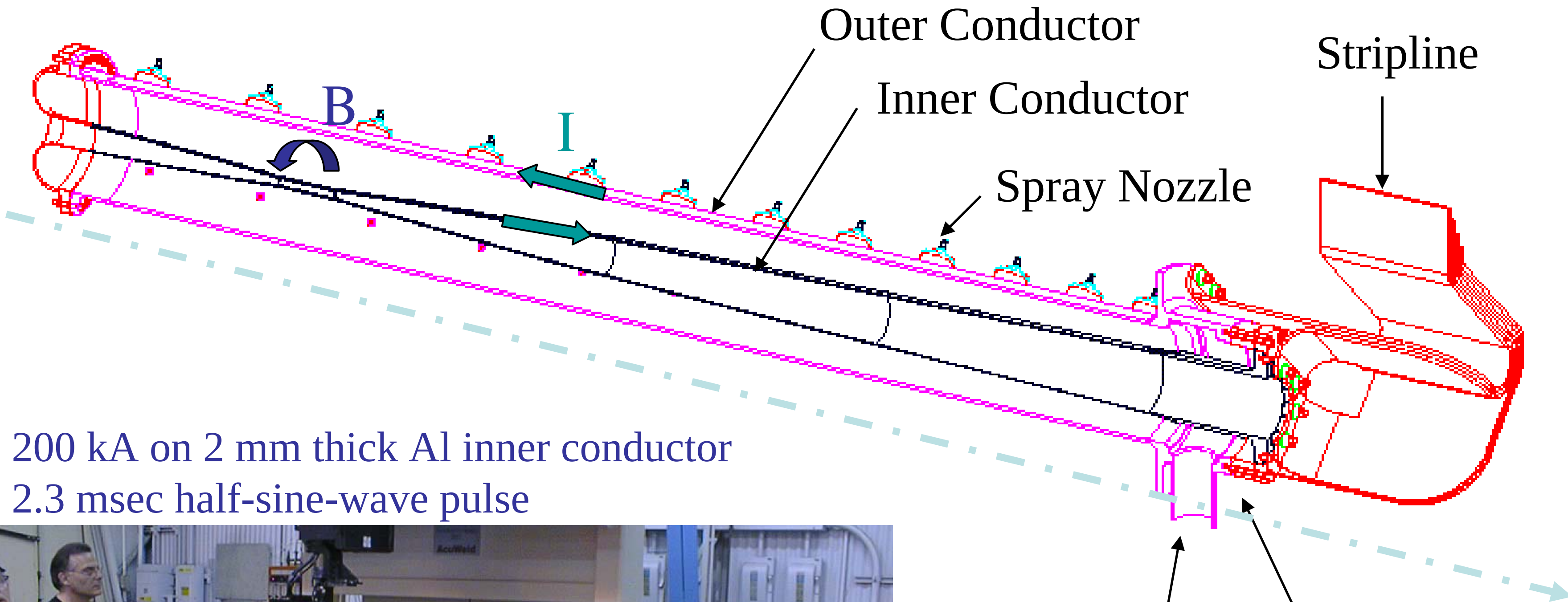
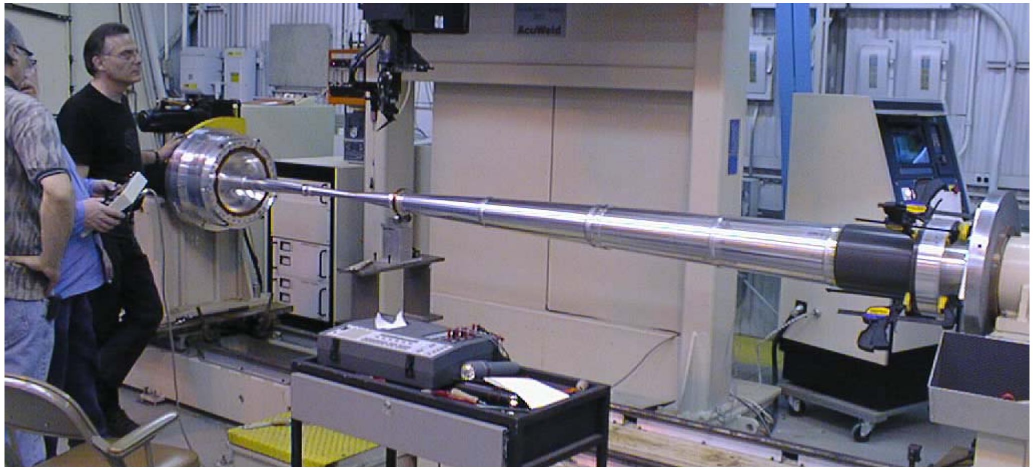
NuMI Magnetic Horns



200 kA on 2 mm thick Al inner conductor
2.3 msec half-sine-wave pulse



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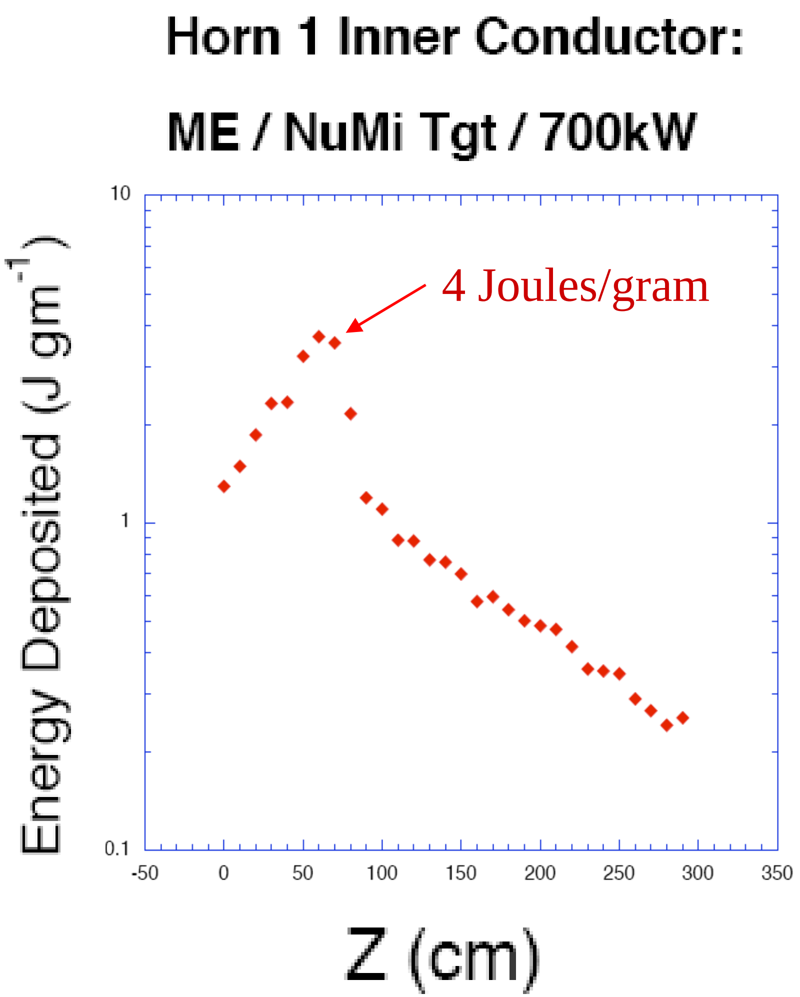
Horn 1 Modifications



Beam heating in horn 1 outer conductor is an issue (is 12 kW M.E. beam base design)

Uneven water cooling can cause outer conductor to “potato-chip”, causing misalignment of focusing

Reduce thickness of outer conductor from 1 inch to 5/8 inch and add more cooling to maintain uniformity to ~ 6 deg C

Heating of horn 1 inner conductor?
(I^2R + beam energy deposition)

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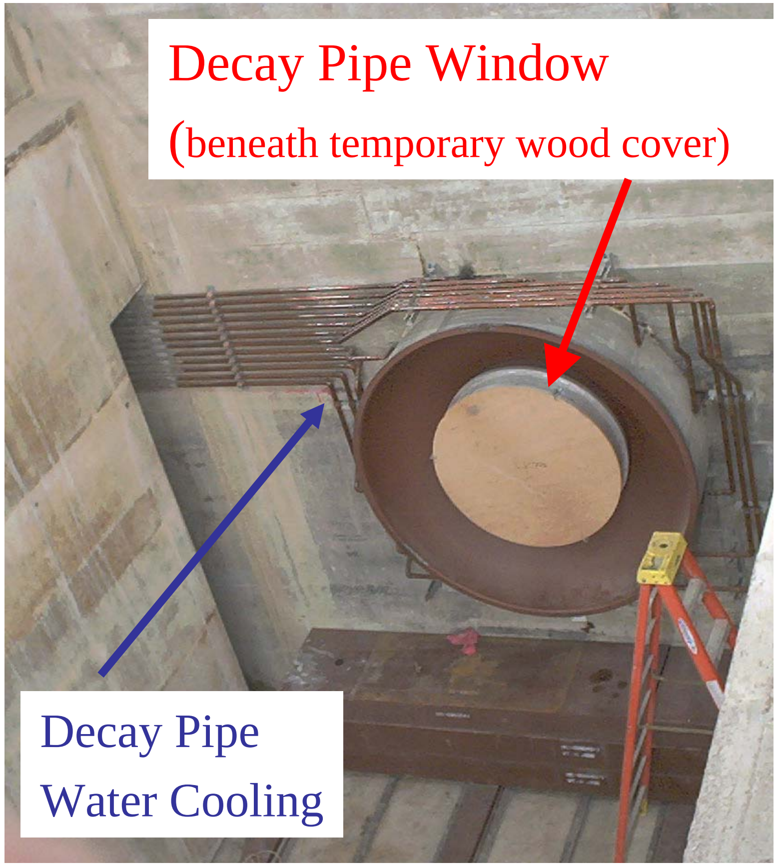
Decay Pipe and Hadron Absorber



- Decay pipe
  - is under vacuum
  - cooling can be increased with faster water flow.
- Decay Pipe Window
  - Thin aluminum window
  - OK for up to 10 consecutive accident pulses at the higher intensity
- Hadron Absorber
  - OK for 10 consecutive accident pulses at the higher intensity
  - Needs investigation of water cooling for DC operations

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Conclusions

- Working towards CDR by November for 700 kW NuMI upgrade.
- Still lots of engineering work left.
- Major concerns are
  - Target Chase Cooling
  - Horn Modifications
  - Tritium Production (See Saturdays talk)
- Started thinking (although only a little) about 1.2 MW upgrades.

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The Usual Issues Related to More Power

- Thermal shock
  - Increased per pulse intensity
- Removing larger heat load
  - 1.2 MW beam in ⇒ 1.2 MW of heat out
- DC thermal stress limit and heat damage to material
- Radiation damage lifetime of materials
- Mis-alignment from thermal expansion
  - Alignment important for experiment systematic error
- Safety
    - Radiation safety
    - Groundwater Protection
    - Airborne Activation
    - Prompt Radiation
    - Residual Activation

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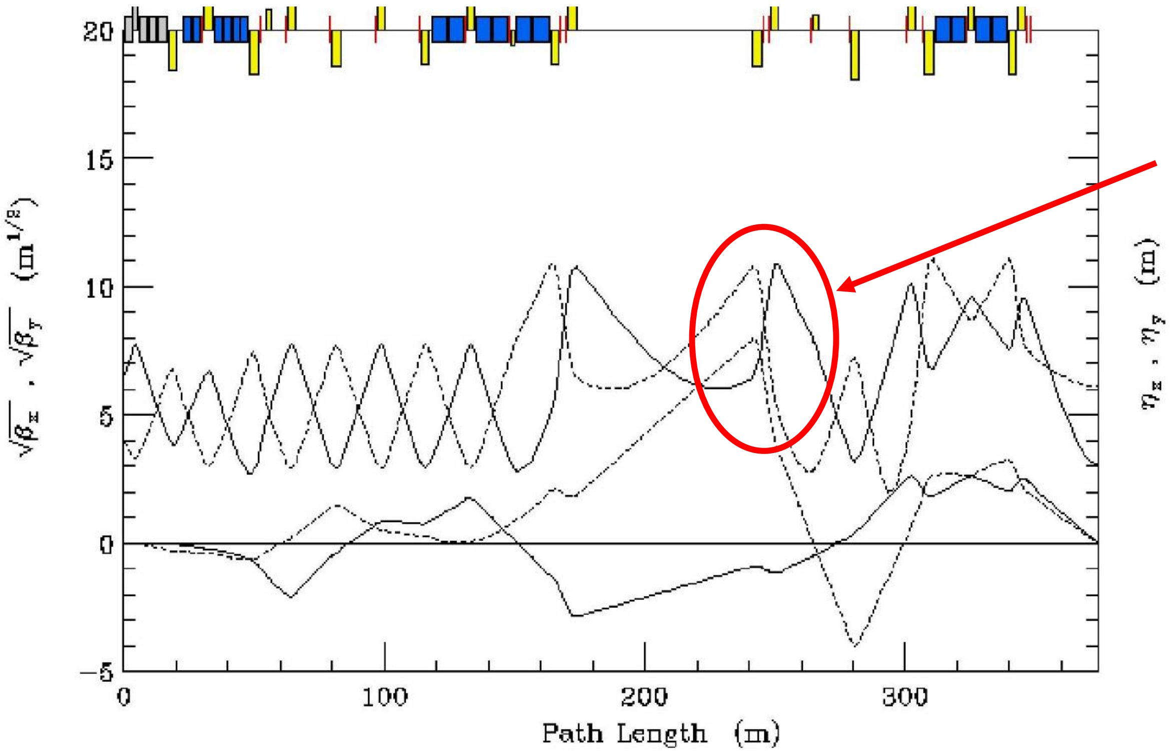
Primary Beamline Optics

Plenty of aperture.



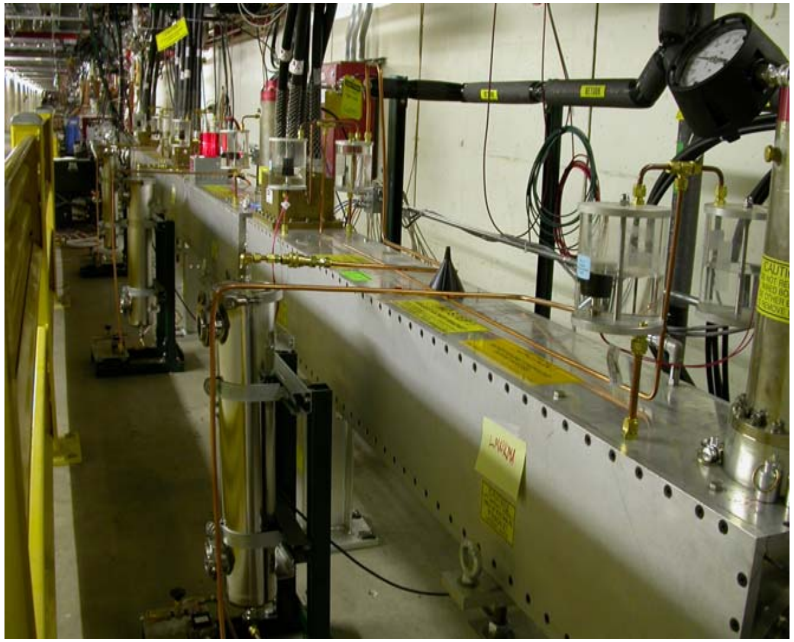
@ max dispersion point

Beam size is ±7 mm (95%)
Aperture is ±35 mm

Keep fractional beam losses below 10^{-5}
(Groundwater protection, residual activation)

NuMI Extraction Kickers

- Kicker and Lambertsons are fine
  - Aperture is sufficient
  - Extraction is clean
  - No issues with radiation
- Available charging time drops
  - From 1.3 secs ⇒ 0.7 secs
  - Upgrade charging supply
  - Upgrade fluorinert to water heat exchanger



NuMI extraction kickers in MI Tunnel

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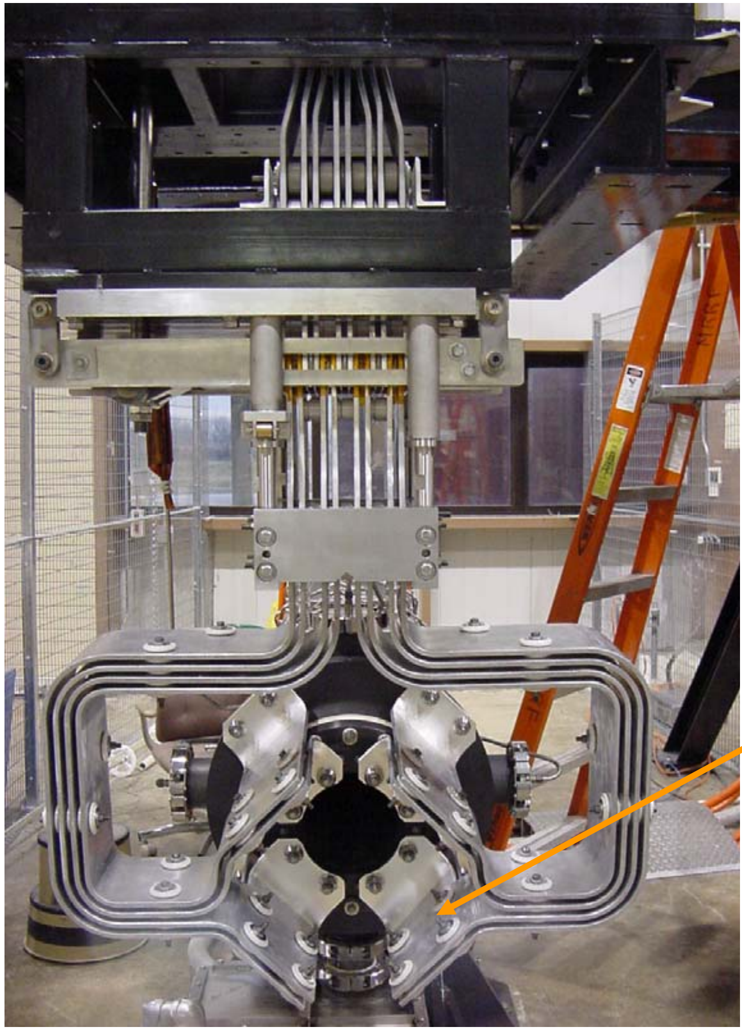
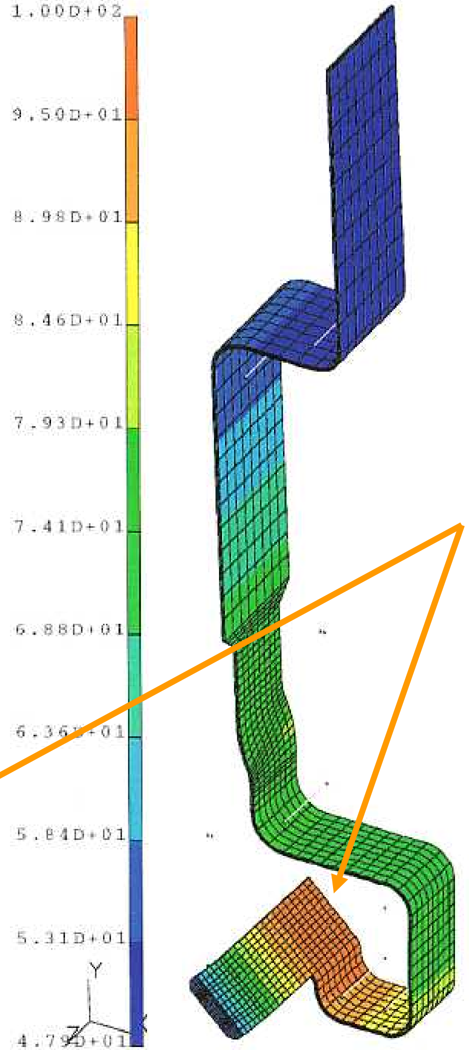
Horns

- Horn 1 Design
  - Beam heating in outer conductor is an issue (is 12 kW M.E. beam base design)
  - Have calculation of horn 1 inner conductor energy deposition from Byron
  - Can begin stress calculations of inner conductor.
  - Heating is still an issue (I^2R + beam energy + radiation heating from ~300 F shielding blocks.)
  - Byron looking at energy deposition in horn 1 hangers
  - Need to re-design the carriage??
- Horn 2
  - Design OK for 700 kW.
- Horn Power Supply
  - Can charge fast enough at 1.3 second rep-rates and not exceed power dissipation limits in either the PEI , the capacitor bank, or the striplines.

Horn Power Strip-line Heating





Aluminum stripline
reaches 100 deg C
with air at 13 deg C
in base design

Will need to be checked

Medium Energy Neutrino Beam

Medium Energy Beam is better for NOvA (14 mrad off-axis)

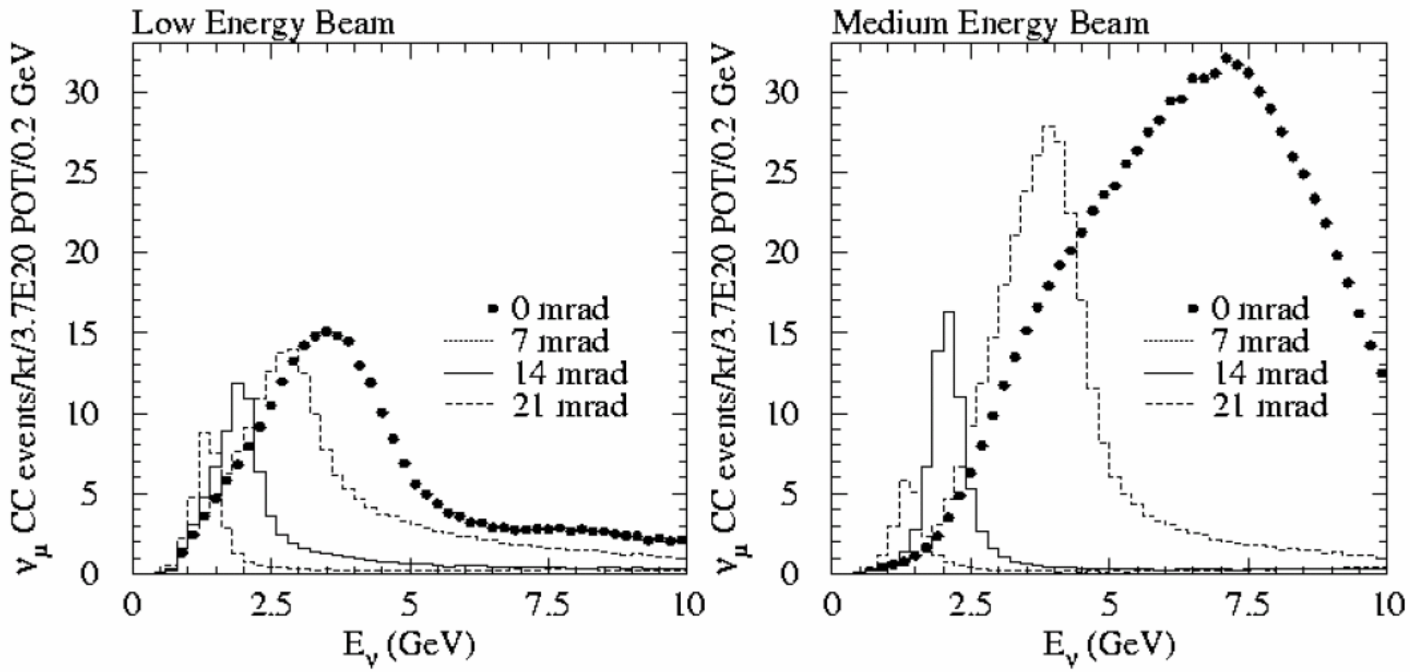


Fig. 2.7: CC ν_μ event rates expected under a no-oscillation hypothesis at a distance of 800 km from Fermilab and at various transverse locations for the NuMI low-energy beam configuration (left) and medium-energy beam configuration (right).

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Target, Baffle, Target Carrier installed in target pile