Design for a 2 MW graphite target for a neutrino beam

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Introduction

- Two years ago, a preliminary design study was done for a target for proton driver beam parameters. No further work has been done since then. All numbers, graphs shown are for proton driver parameters (about 10% different).

	Proton Driver (this talk)	Project X
Protons / spill	1.5e14	1.7e14
Repetition rate	1.33 seconds	1.40 seconds

- This design is by Valeri Garkusha et. al, IHEP Protvino (NuMI note 1100)

Important issues for target design

- Dynamic stress from short pulse
- Getting the DC heat out
- Radiation damage
- Efficiency of neutrino production

Issues for dynamic stress

To reduce dynamic stress, want:

- Fewer protons/pulse
  - Neutrino production scales approximately with beam power
    - so fewer protons at 120 GeV than eg 30 GeV helps
  - Having more pulses of fewer protons each would help

- Spread protons out in larger beam spot, use low density target
  - Horn has ~ 1m long depth of field, few mm wide collection area
    - so can use less dense target

- High heat capacity, so dE/dx produces less temperature rise

- Low coefficient of thermal expansion, so temperature rise produces less expansion

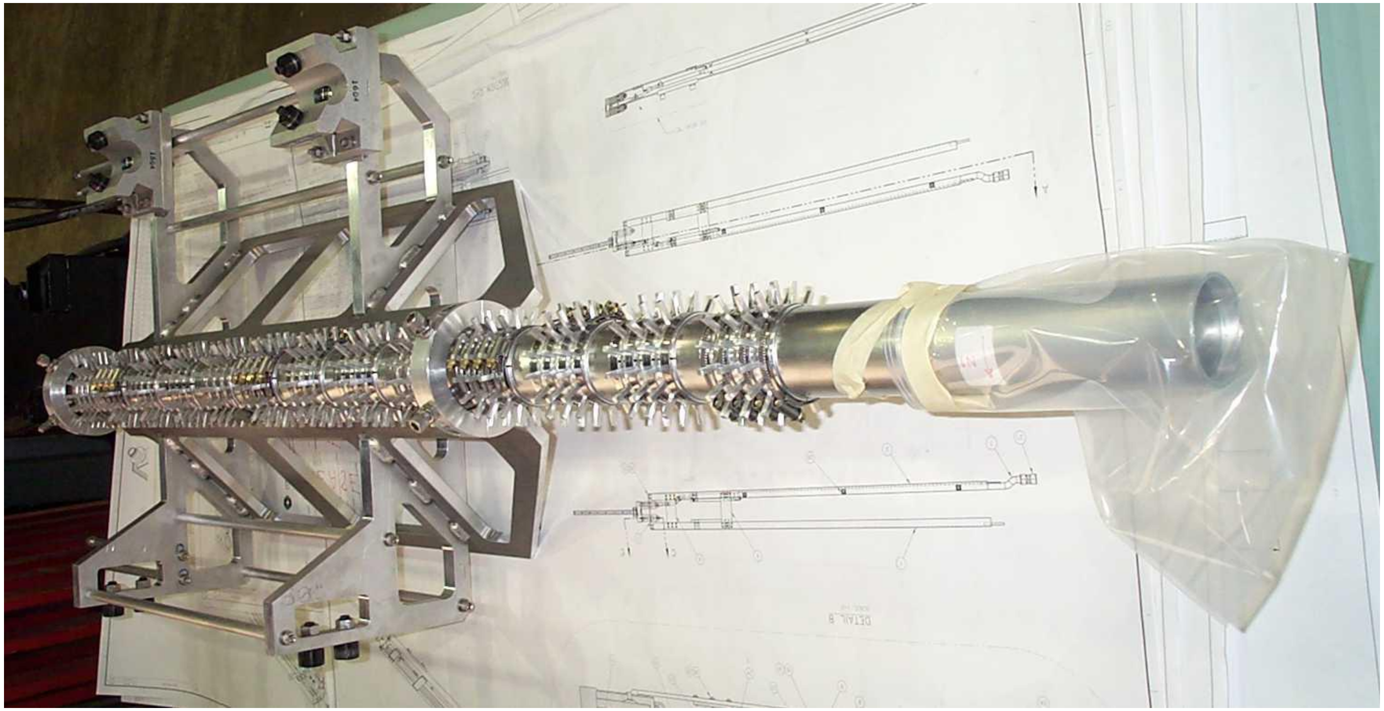
- Low Youngs Modulus, so thermal expansion produces less stress

- High yield strength

Beryllium has high yield strength, but high Youngs Modulus
Graphite has mediocre yield strength, but low Youngs Modulus

NuMI baffle as prototype of target

Graphite is good in compression, poor in tension,
so put pre-stress at outer radius by encapsulating in aluminum or steel



Existing NuMI baffle is 1.5 m long, 6 cm diameter graphite encapsulated in aluminum

Target would be 1 m long, 1.5 cm diameter – not too different from our baffle;
get rid of air cooling fins, add water cooling tubes

Other target details

- Graphite in 3 cm long segments with 0.2mm gaps for thermal expansion
- Helium atmosphere in target to prevent possibility of oxidation
- Encapsulation also maintains integrity of the target core in case of thermo-mechanical or radiation damage of some segments
- Encapsulation also prevents direct contact of the cooling water with the heated surface of graphite while providing a good thermal contact
- Study was done with Poco ZXF-5Q graphite (what we have in the NuMI target), although other graphites have up to 30% better Yield/Youngs-Modulus

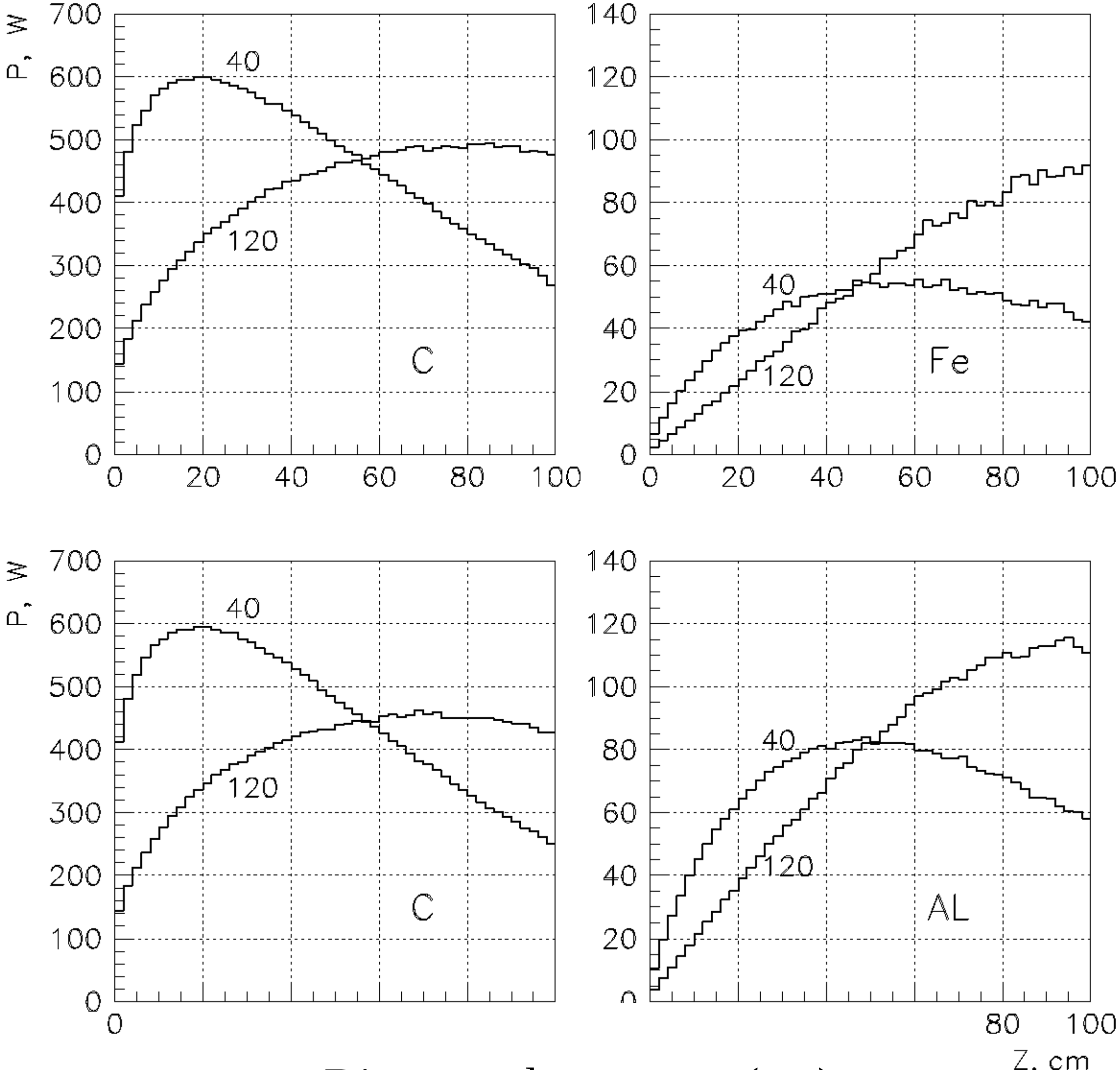
Pre-stress: ~ 10 MPa if 0.2 mm steel casing, ~13 MPa if 1mm aluminum casing

Beam spot size: 1.5 mm RMS

Energy deposition (kW):

Proton beam energy	40 GeV		120 GeV	
Graphite core	23.3	22.7	20.8	19.7
Steel pipe	2.2	—	2.7	—
Aluminum pipe	—	3.4	—	3.7
The whole target	25.5	26.1	23.5	23.4

Energy deposition (MARS Monte Carlo)

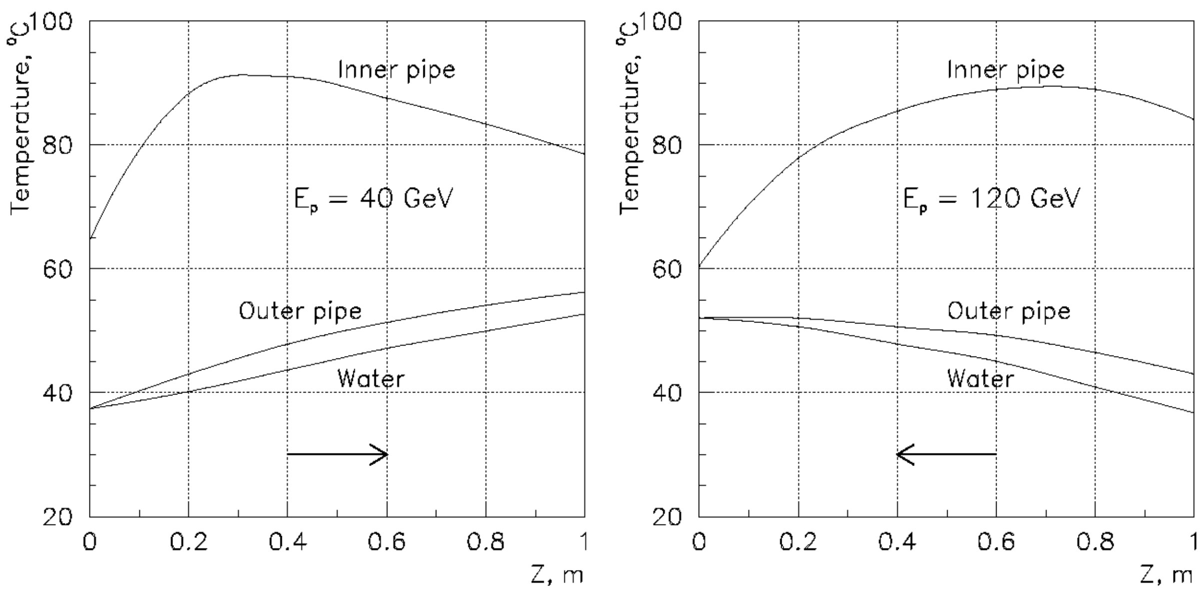


Distance along target (cm)

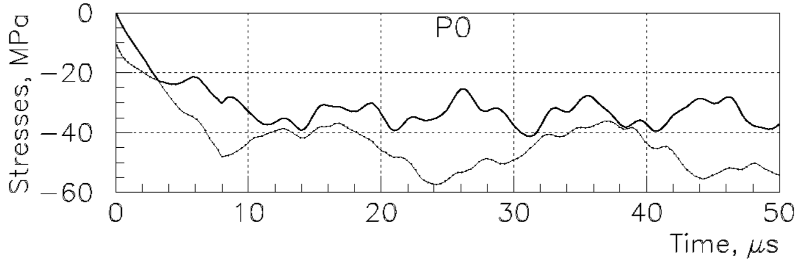
Target temperature and cooling water

Table 3: Temperatures in target segments with the highest EDD.

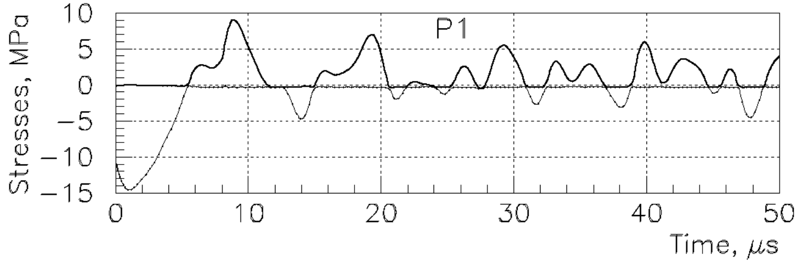
Primary proton beam energy, GeV	40	120
Segment number	2	6
EDD at the beam axis, GeV/cm^3/proton	0.025	0.033
Temperature of a water (see Figure 2), °C	37	50
Temperature at the beam axis, °C		
before the beam spill	120	80
after the beam spill	380	430
Temperature rise at the beam axis, °C	260	350



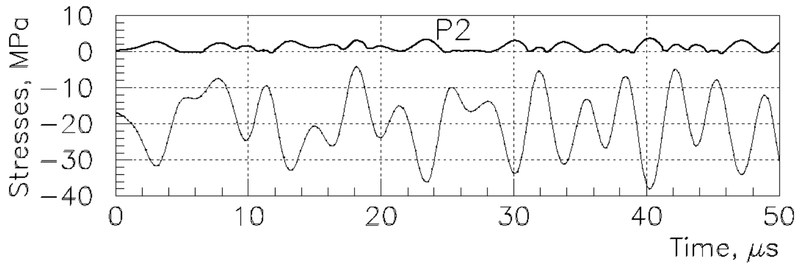
Time evolution of stresses (sigma1 and sigma3 shown)



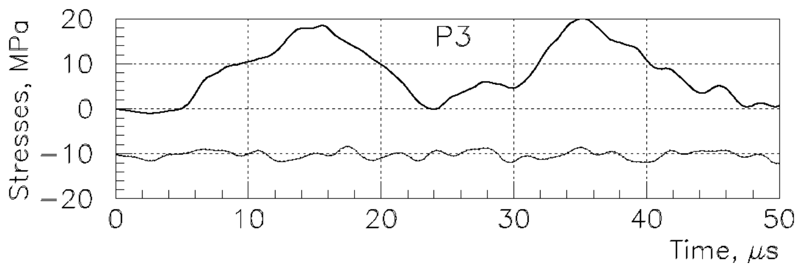
Midpoint of segment



Center of end of segment



Outer radius end of segment



Outer radius center of segment

Compare stress to failure

Taking into account decrease of yield strength of 0.5 due to fatigue and applying Mohr-Coulomb criteria, the safety factors (failure stress divided by calculated stress) are:

Table 4: Safety factors for different points of target segments with the highest EDD.

Beam energy, GeV	40	120
$P0(0,0)$	2.3	1.9
$P1(0,l/2)$	7.5	5.5
$P2(r_0,l/2)$	2.7	2.3
$P3(r_0,0)$	2.8	2.0

Hence calculation says graphite should not fail.

(However, even if a segment fails, there is really no place for it to fall apart into?)

Target cooling design

Water in the cooling tube would experience 2 ksi hydraulic shock from heating by the beam spill. Two ways have been suggested to reduce this:

- Two phase flow – e.g. bubble helium through the water similar to what we did when the 1st NuMI target developed a leak

- Use "heat pipe" evaporative cooling

Work is needed to prototype and evaluate these and possibly other schemes

Further work is also needed on window design, although calculations for use of graphite windows is encouraging.

Radiation damage

Although radiation damage data is not available for ZXF-5Q,
neutron damage data for AXFQ and AXZQ indicate that for one year operation

- dimensional changes are not very large
- two times decrease of the thermal expansion coefficient will compensate approximately the same increase of the modulus of elasticity keeping by this means stresses constant
- the strength of graphite increases with irradiation over this period

(for a 40 GeV proton beam, radiation damage is about 3 times as fast)

So currently estimate radiation damage lifetime as 1 year.

Efficiency of neutrino generation

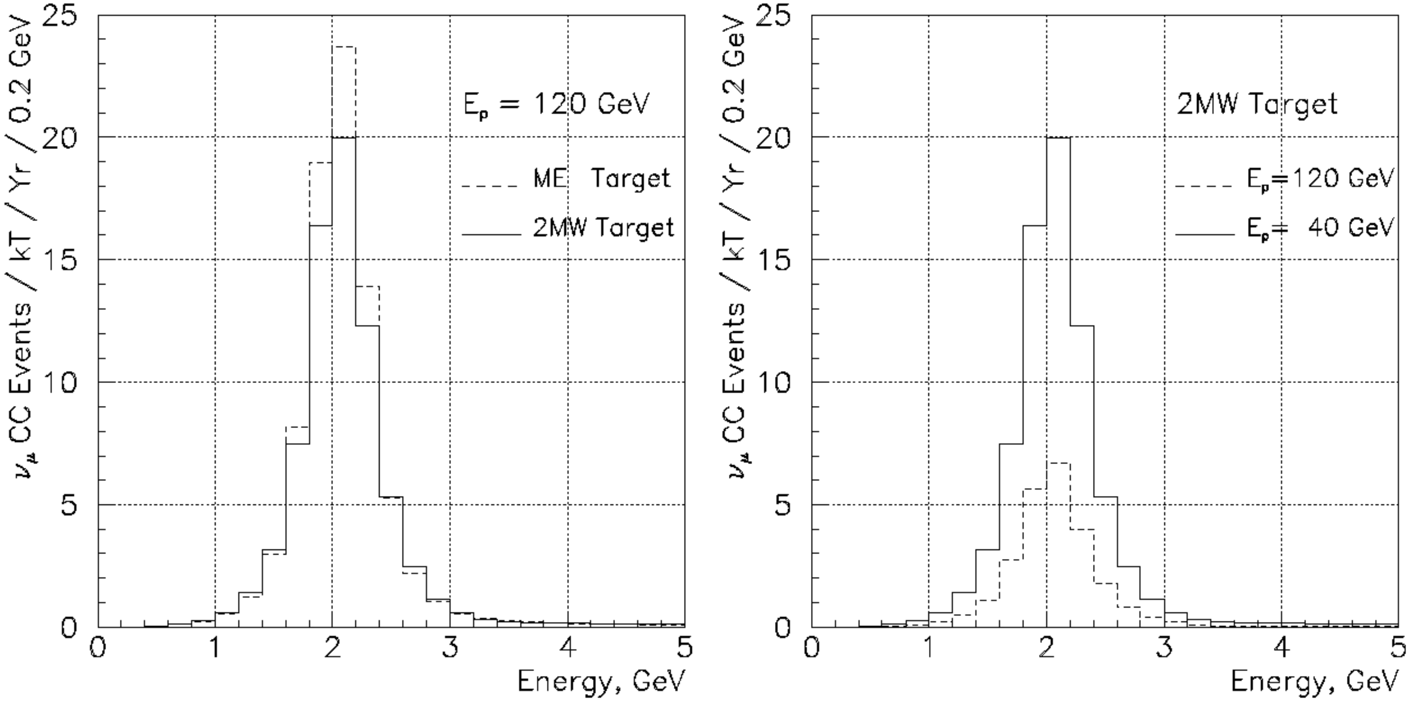


Figure 9: Neutrino event rates at the far detector for the 14 mrad off-axis NuMI beam (1 year = 3.8×10^{20} protons on the target).

The "2MW" target is about 10% less efficient at neutrino generation than a 0.4 MW "Medium Energy" target

(ME target is more optimized to NoVA than the existing LE target)

Neutrinos vs. length and radius of target