Target R & D

Bob Zwaska

LBNE Collaboration Meeting

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Basis

- To reach its full potential, LBNE will require a target capable of withstanding 2 MW
  - ➢ The 2 MW capability can not come at undue cost to neutrino flux
  - ➢ This is the R&D challenge
- Initially LBNE will likely run with a 700 kW beam
  - ➢ This target will be optimized for 700 kW neutrino flux
  - ➢ Will be informed by 2 MW R&D
  - ➢ As of now, we are not planning on having an integrated target / horn 1
    - Will of course change if appropriate
- The R&D effort on targets is underway and quite active
  - ➢ Collaborations with other labs
  - ➢ Several areas of investigation underway
    - I am new to this my self – talk derived from work by others (Pat. H, Jim H., Nick S)

People

- Partial list of people working on target and target hall – related items

Fermilab
Kris Anderson (Target technical components)
Sam Childress (Target Hall infrastructure)
Lee Hammond (Target pile, Target Hall utilities)
David Hickson (Target Hall utilities)
Pat Hurh (Target technical components and infrastructure)
Jim Hylen (Target technical components and infrastructure)
Tom Lackowsi (Target Hall infrastructure)
Byron Lundberg (Target technical components)
Mike Martens (Target)
Joel Misek (Target: BLIP test, decay pipe)
Nikolai Mokhov (Target)
Vaia Papadimitriou (management)
Ryan Schultz (Target pile, remote handling)
Vladimir Sidorov (Target (NT02 autopsy), remote handling)
Zhijing Tang (Target: BLIP test)
Salman Tariq (Target pile, remote handling)
Karl Williams (Target Hall utilities)
Tim Wyman (Target Hall infrastructure)
Bob Zwaska (Target technical components)

IHEP
Valeriy Garkusha (Target)

RAL
Tristan Davenne (Target technical components)
Chris Densham (Target technical components)
Ottone Caretta (Target technical components)
Michael Fitton (Target technical components)
Peter Loveridge (Target technical components)
Matt Rooney (Target technical components)

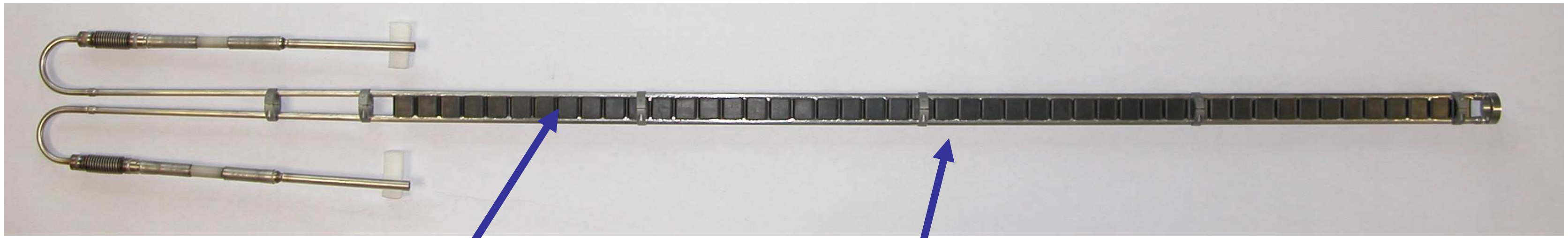
ANL
Jim Bailey (Target)
Henry Belch (Target)
Jim Grudzinski (Target)
Meimei Li (Target)

BNL
Harold Kirk (Target: BLIP test)
Nikolaos Simos (Target: BLIP test)
Nicholas Soulhas (Target: BLIP test)

ORNL/SNS
Tom Burgess (Remote handling)
Van Graves (Remote handling)
Mark Rennich (Remote handling)

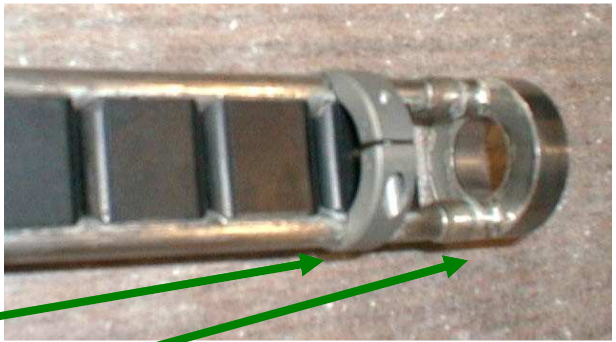
Start with the Devils we Know: Water-cooled Graphite

NuMI Target *long, thin, slides into horn without touching*



Graphite Fin Core, 2 int. len.

(6.4 mm x 15 mm x 20 mm) x 47 segments

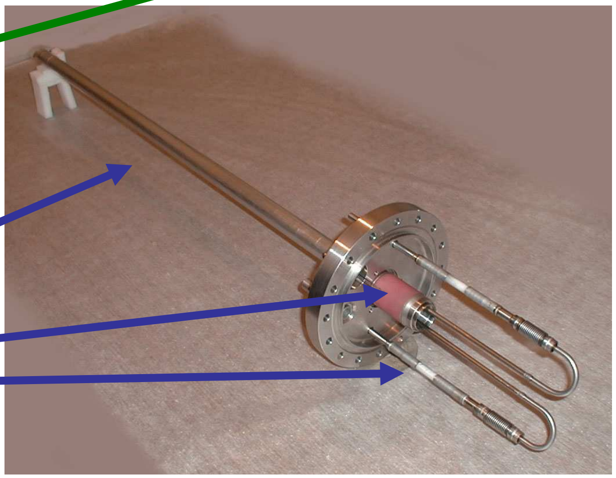


Water cooling tube also provides mech. support

(steel soldered to graphite)

Anodized Al spacer (electrical insulation)

Water turn-around at end of target



0.4 mm thick Aluminum tube *(He atmosphere, Be windows at U.S. and D.S. ends)*

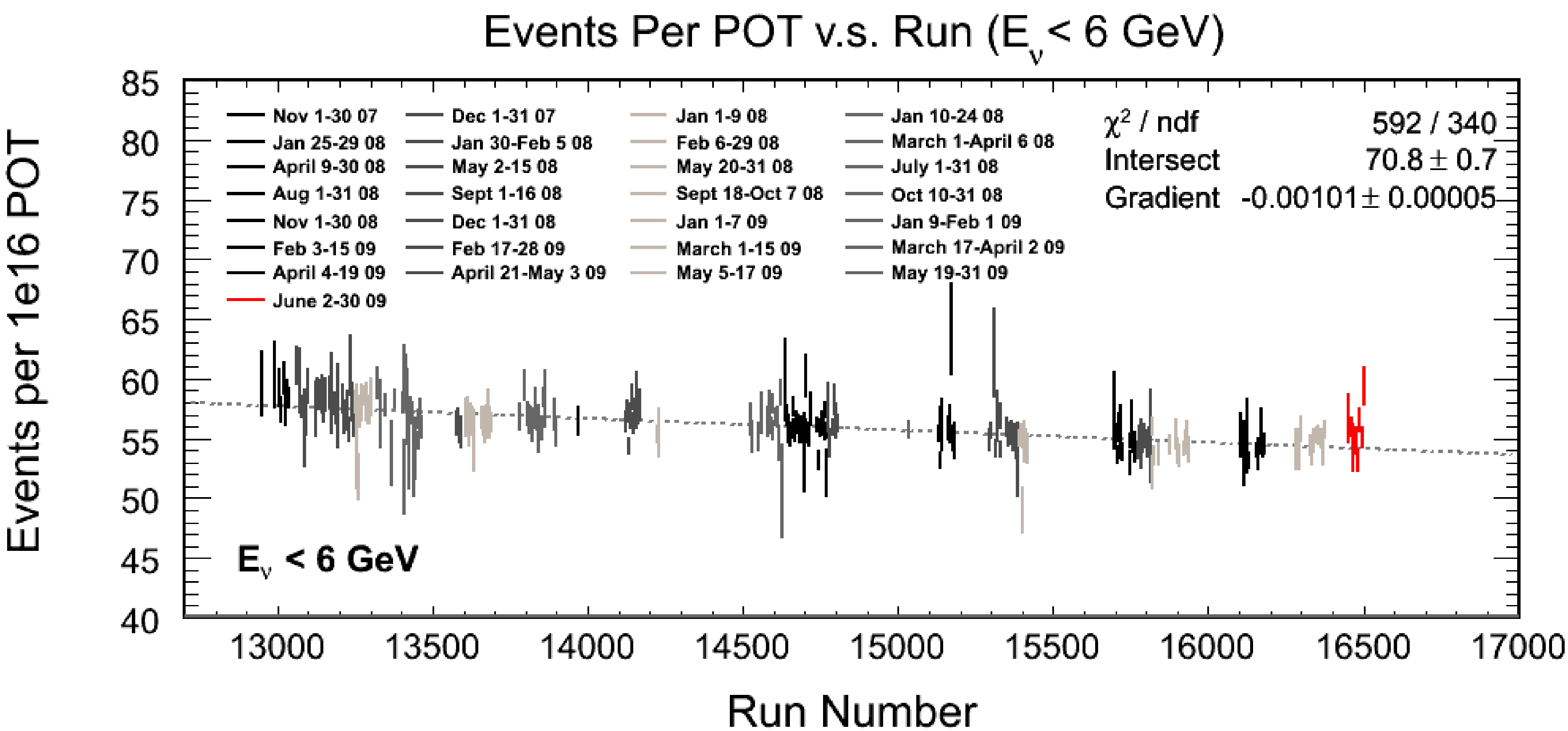
Ceramic electrical isolation

Evolving past NuMI

- The NuMI target is rated for ~ 450 kW
  - Originally 400 kW, more with larger beam spot
  - Necessarily complicated because it needs to fit in the horn
- NOvA target at 700 kW
  - Basically the same technology
  - Greater capability comes from being able to simplify the design by being away from the horn
- LBNE may be back in the horn
  - 700 kW initially, but need a target for 2 MW
  - Hope to improve the 700 kW design through the 2 MW process
  - Starting from a conceptual 2 MW design created by IHEP

NuMI Target Degradation

- Neutrino yield from the NuMI target degraded by ~5% over an exposure of ~ 6e20 protons



Extrapolate NuMI target lifetime to Project X

3 years running on this target, beam power 0.1 to 0.3 MW
NuMI accumulated 6 10^{20} POT @ 120 GeV → 4.44 MW-month

Assume Project X 2.3 MW @ 70% uptime → 4.4 targets / year

Similar to anti-proton production target,
but couple shifts/change compared to NuMI couple weeks/change

NuMI used 1.1 mm RMS beam spot
so integrated flux at center is 8 10^{21} POT / cm^2

If Project X target uses 3 mm spot size (9 mm radius target)
and radiation damage scales by (beam-radius)$^{-2}$ → 0.6 targets / year

Save many $M on rapid change-out capability ???

Caveats:

- Is 10% neutrino rate degradation considered acceptable?
- Will encapsulation of the graphite reduce the density decrease?
- Will higher temperature reduce the radiation damage?
- Would another grade of graphite do better?
- Will radiation damage really scale by (beam-radius)$^{-2}$?
- Radiation damage probably twice as fast for 60 GeV protons at same power

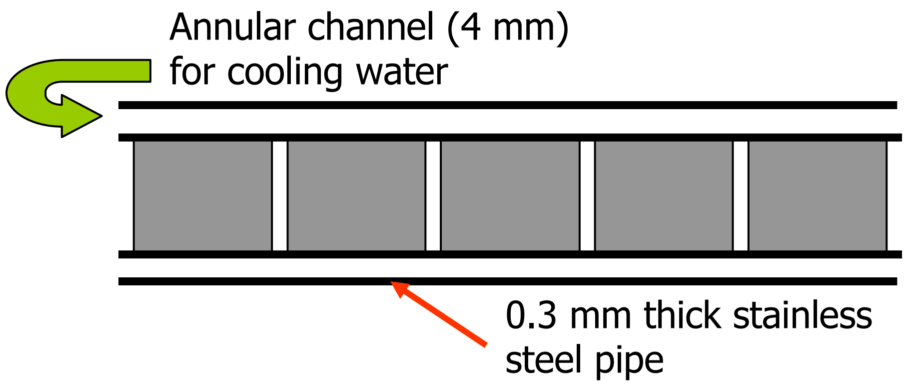
Scaling not so cheerful for CERN SPL with 30x more protons, so more later …

IHEP NOVA-Project X 2MW target

From 2005 study of graphite encapsulated in Al or steel sheath, with water cooling, graphite target stress and temperature were OK for 1.5e14 PPP 2 MW beam.

Remaining issues were:

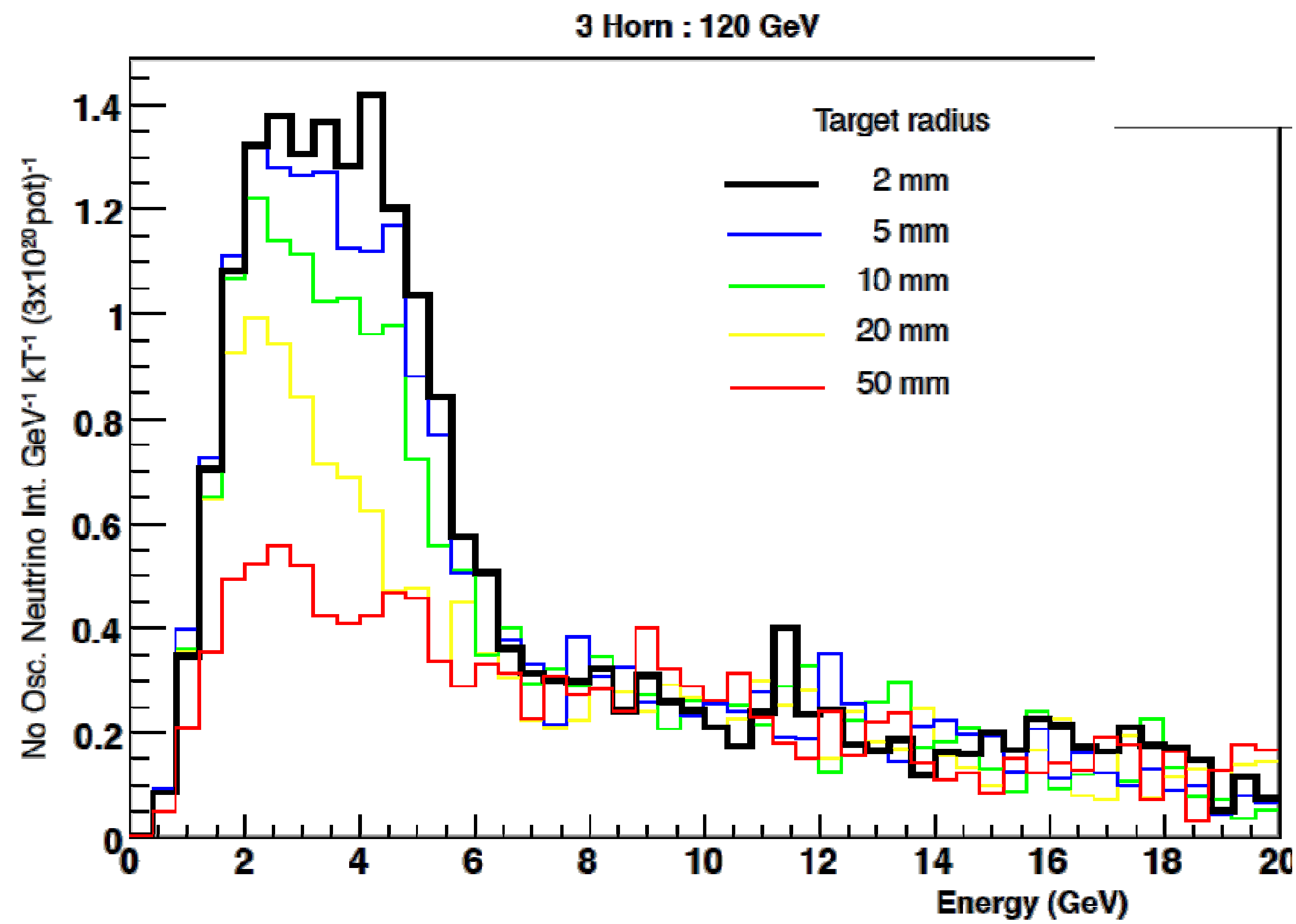
- Hydraulic shock in cooling water (150 atm.) *(suggested using heat pipe to solve)*
- Radiation damage lifetime *(est. at 1 year but not well known)*
- Windows + accident conditions



NUMI Target for 2 MW upgrades (IHEP, Protvino)

Effect of larger spot size

3 horn (T2K style) focusing but on-axis, horn radius changing with target radius



2 MW Target Challenges

- Single pulse failure
- Heat removal
- Radiation damage
- Thermal shock (stress waves)
- Spatial constraints
- Oxidation
- Residual radiation
- Physics optimization

Single Pulse Survivability

- Based mostly on basic mechanical properties:
  - Specific Heat
  - Coefficient of Thermal Expansion
  - Young's Modulus
  - Tensile Strength

Thermo-mechanical Efficiency

$$K \propto \frac{\sigma_t \, c_{p,avg}}{E \, \alpha}$$

- Fully understanding material requires FEA, including:
  - Thermal conductivity
  - Poisson's ratio
  - Compressive / Flexural strength

Materials (f/ Luca Bruno)

Graphites and hBN - Material Properties at 20 °C										
Property	**Unit**	**Carbone-Lorraine**			**SGL**				**POCO**	**h-BN**
		1940	2020	2333	R7500	CZ3	CZ5	CZ7	ZXF-5Q	AX05
Apparent Density	g cm^{-3}	1.76	1.77	1.86	1.77	1.73	1.84	1.88	1.78	1.91
Open Porosity	%	16	9	10	13	14	10	10	16	
Avg. Grain size	µm	12	16	5	10	20	10	3	1	
Young Modulus	Gpa	10	9.2	10	10.5	10	11.5	14	14.5	30
Thermal exp. Coeff.	µm/m °C	4.7	3.5	6	3.9	3.8	5.1	5.8	8.1	0.5
Thermal Conductivity	W/m°C	81	75	90	80	65	100	100		71/121
Electrical resistivity	µΩ m		16.5		14	18	13	13	19.5	$> 10^{14}$
Specific heat	J/kg °C	710	710	710	710	710	710	710	710	800
Flexural strength	MPa	45	41	76	50	40	60	85	115	22
Compressive Strength	MPa	91	100	167	120	90	125	240	195	23
Tensile strength	MPa	30	27	50	33	26	40	56	76	15
Ratio σ_c/σ_t	-	3.1	3.7	3.3	3.6	3.4	3.2	4.3	2.6	1.5
$K \sim (\sigma_t C_p)/(E\ \alpha)$	-	0.45	0.60	0.59	0.57	0.49	0.48	0.49	0.46	0.80

A wide range of graphites was investigated. Based on material data available in literature, the best candidates have been identified. The table shows a selection of grades considered.

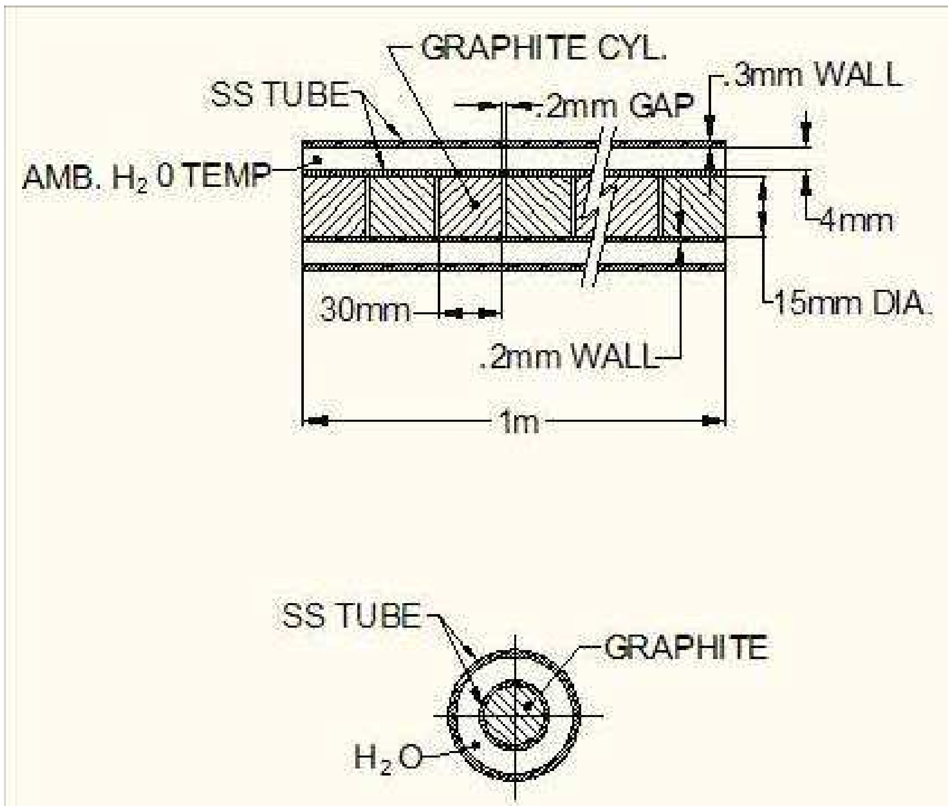
More Materials (f/ Jim H.)

	Aluminum 6061-T6	AlBeMet	Beryllium I-220H
Density (g/cm3)	2.7	2.1	1.85
Young Modulus (GPa)	69	196	303
Thermal exp. Coeff. (ppm/C)	23.4	13.9	11.4
Thermal conductivity (W/mC)	180	212	216
Electrical resistivity (micro-ohm m)	0.038	0.033	0.043
Specific heat (J/kgC)	963	1506	1925
Tensile strength (MPa)	310	305	448
K (but also need to scale by density and dE/dx, so Al another x 1.5 worse)	0.185	0.17	0.25

- Bottom line: graphite is good, h-BN may be better, Al is no-go, Be and Be/Al are possibilities

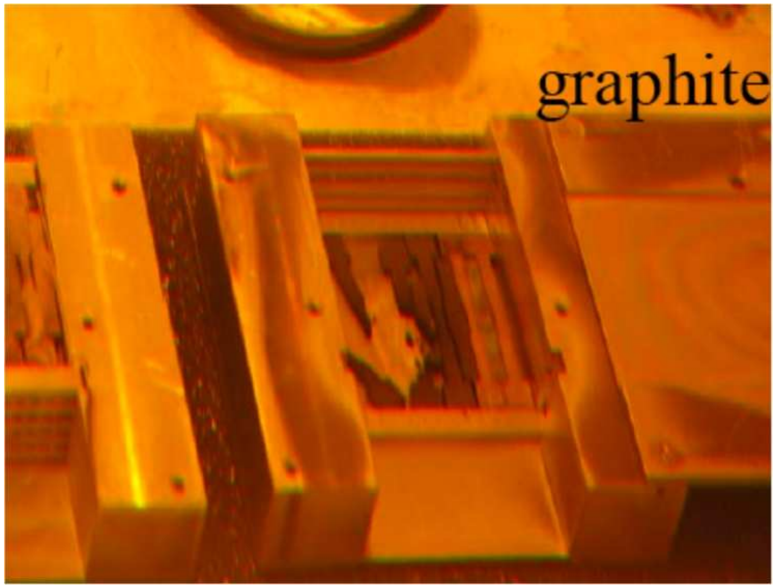
Heat Removal

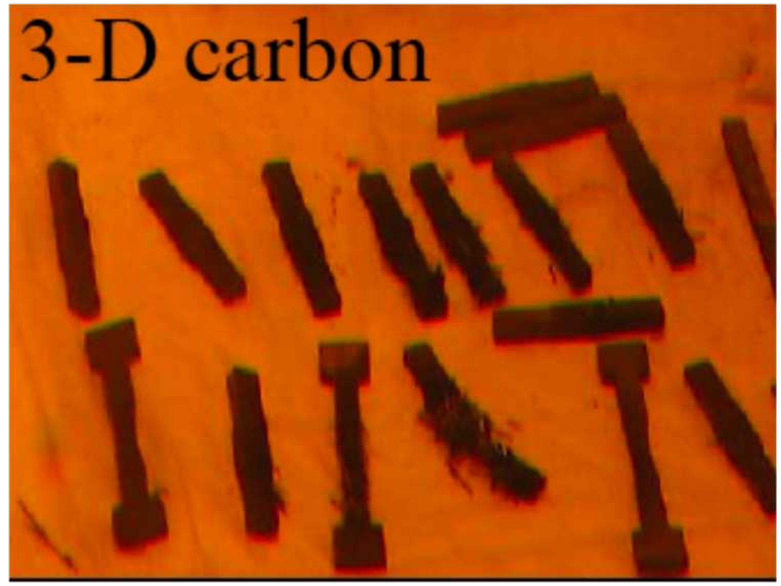
- 25-30 kW total energy deposited (IHEP)
- Easy to remove with water



- Tritium production
- Hydrogen gas production
- Thermal shock in water (Water Hammer)
- 150 atm IHEP report – now thought to be much less

Radiation Damage

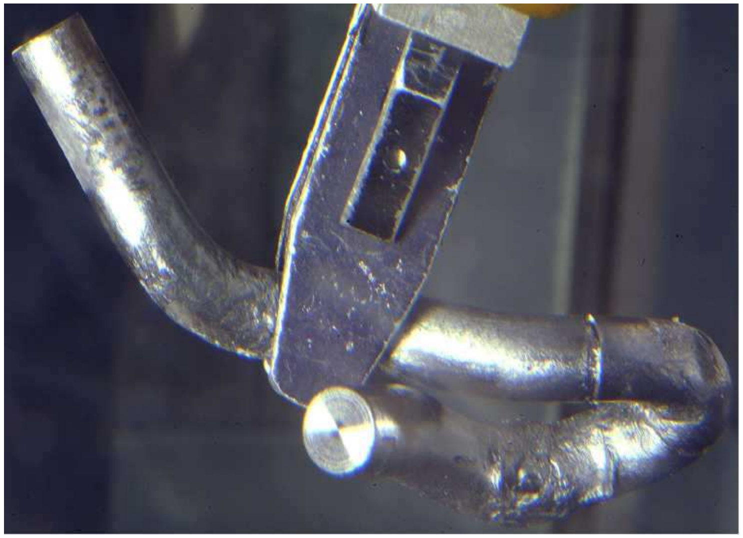


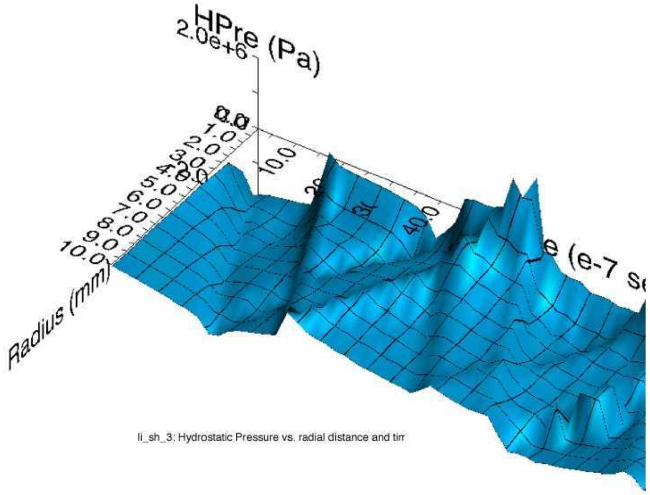


- Atom displacement causes changes in material properties
  - Also Helium production produces internal presure
- Not much literature on high energy proton irradiation of materials
- Lots of information on low energy neutron irradiation (nuclear reactors)

Pictures from N. Simos talk

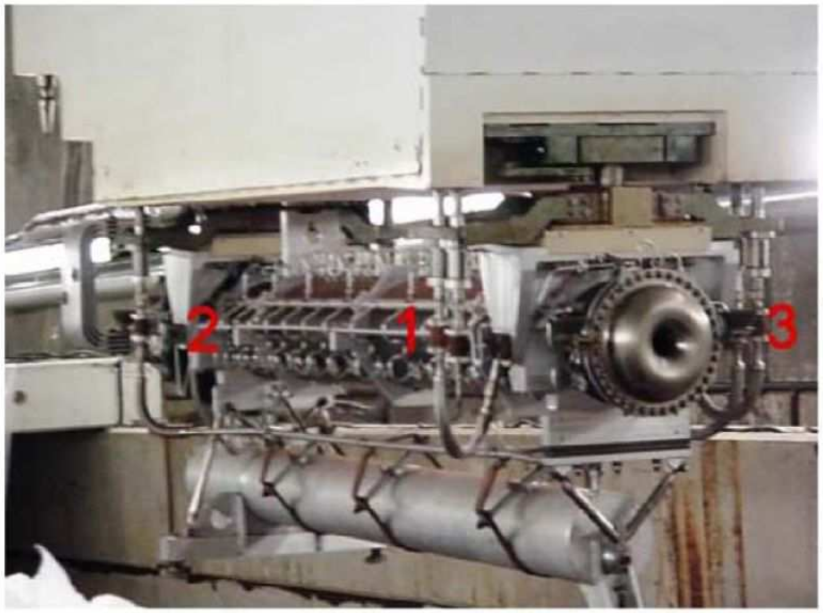
Thermal Shock





- Sudden expansion of material surrounded by cooler material creates a sudden local area of compressive stress
- Stress waves (not shock waves) move through the target material
- Plastic deformation or cracking can occur

Residual Radiation

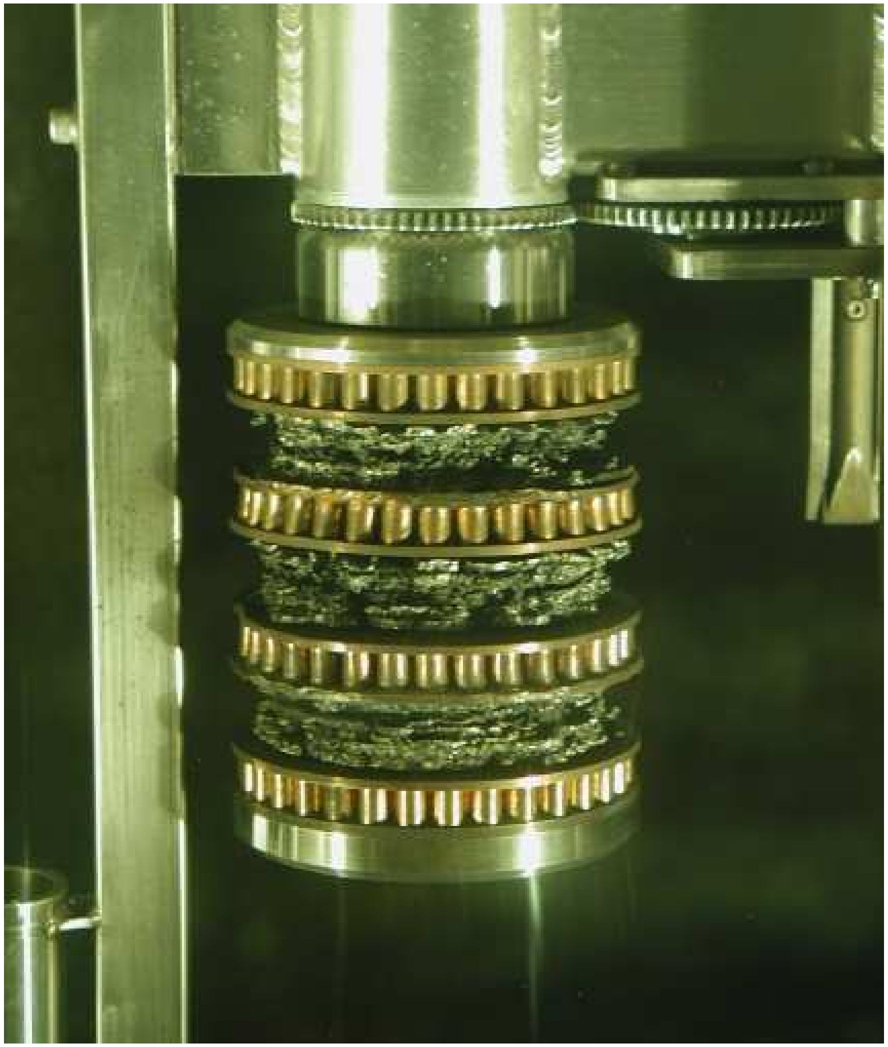


Measured dose rates for Horn 1 water line repair

Point	Doserate @ 1 foot (mr/hour)	Doserate On Contact (mr/hour)
1	35000	75000
2	40000	75000
3	35000	80000

- Dose rates for 2 MW beam components estimated at 300-400 Rad/hr
- Systems for component change-out and repair must be developed
- Operations activities must be integrated into the conceptual design of target components

Survivability is relative



- P-bar consumable target
  - Ran in consumable mode for 2 plus years
  - Change-out time 12 hours maximum
  - Over-heating, oxidation, thermal shock led to damage

Target R&D Work Packages

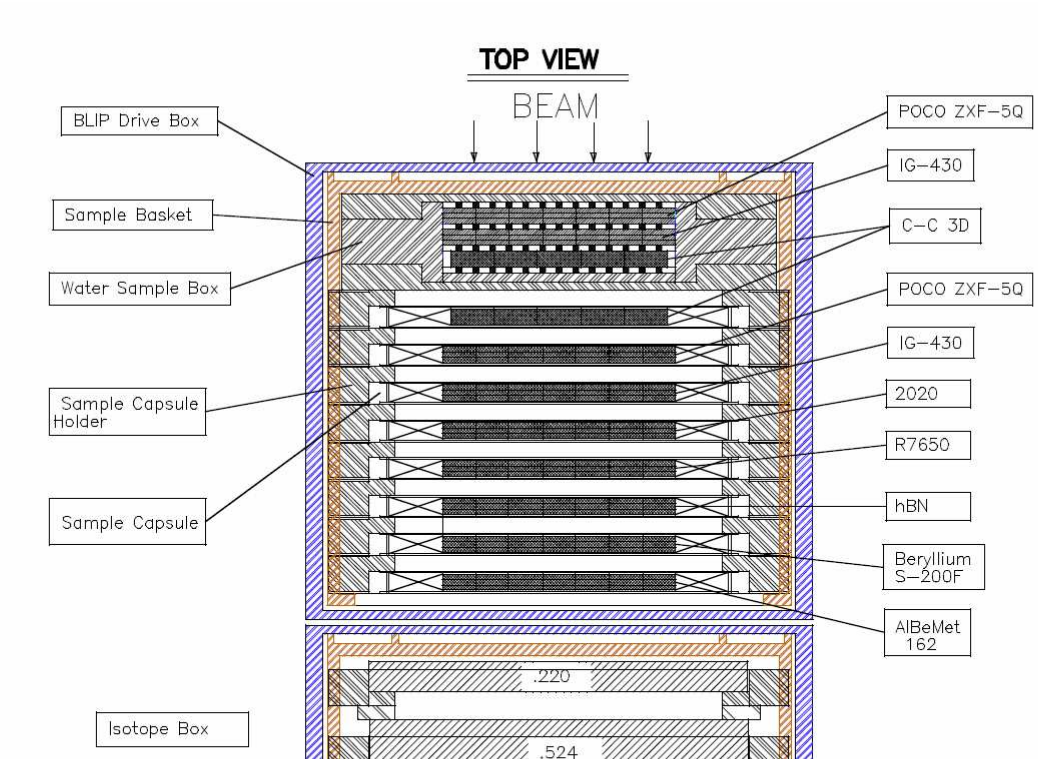
- Water hammer investigation/experiment
- Radiation damage investigation/experiment
- Beryllium thermal shock investigation
- Integrated target/horn conceptual design
- 700 kW target design (using IHEP 2 MW core concept)

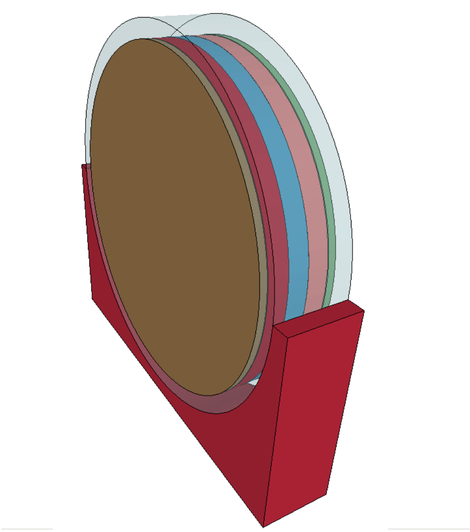
Water Hammer - ANL

- Analysis and simulation to investigate water hammer effect
  - Instantaneous temperature rise producing large pressure wave
- Benefit - Single phase water cooling
  - Otherwise may have to have a more complicated water system
- Initial investigations
  - IHEP estimated 150 atm (probably too much)
- ANL concludes IHEP ignored flexibility of walls
  - Recalculated water hammer of < 50 atm (probably acceptable)

Radiation Damage

- Irradiation test at BLIP with new promising materials in vacuum (instead of water bath)
  - ➢ 140 MeV protons – better than neutrons
- Investigate radiation damage in candidate materials
  - ➢ Graphite, Be, Albemet, h-BN
- New MARS capabilities with be put to test
  - ➢ DPA model / Helium production





Beryllium Thermal Shock

- Analysis to explore the use of Be as a target material
- Benefits
  - Longer target lifetime
  - Elimination of windows and pump/purge system
  - Possible integrated target/horn design
- Difficulties:
  - Worse K-factor
  - Greater susceptibility to helium build-up
- RAL working on this – T2K window experience

700 kW Target Design - IHEP

- Using 2 MW target "core" design, complete conceptual design of an LBNE baseline target assembly capable of 700 kW beam power
  - Facilitates baseline cost/schedule estimate
  - Provides experience with the IHEP 2 MW design concept
- IHEP has built the NuMI (MINOS and NOvA) targets

Other Target Hall Issues

- Remote stripline connection (ORNL, RAL, ANL)
- Radioactive component handling (ORNL)
- Radiation accelerated corrosion (ANL, BNL)
- Air versus water cooled decay pipe (ANL, ORNL)
- High current horn conceptual design (??)
- Water cooled chase steel shielding (ANL, ORNL)
- Heat pipe target cooling (IHEP)

Target Hall Instrumentation

- Additional instrumentation in and near target hall to support beam operation
  - Commissioning
  - Beam-based Alignment
  - Beam Permit
  - Long-term Monitoring
- Interfaces with other instrumentation systems
  - Primary beam
  - Systems (RAW, air, temps)
  - Neutrino beam monitors
- Varying needs of reliability
  - Every pulse for beam permit
  - Monthly or yearly for alignment/commissioning
- Software is needed to bring everything together

Quick list of NuMI Tools/Instrumentation

Basis for LBNE

- **Shape of target and baffle**
- **Cross-hairs on horns, and horn neck**

Features used

- **Baffle thermocouples**
- **Budal Monitor**
- **Horn BLMs**
- **Hadron Monitor**
- **Muon Monitors**

"Target Hall" Instrumentation

- **BPMs**
- **Profile Monitors**
- **Toroids**
- **MINOS Near Detector**

External Instrumentation

Needs for Target Hall Instrumentation

- Specialized devices need design and construction
  - Budal Monitor, Horn cross-hair monitors, thermocouple system, hadron monitor, target decay monitor
  - Difficult environments, varying needs for reliability
- These devices also need substantial beam simulation
  - Determine alignment tolerances
    - First step to defining specifications
  - Determine particle fluxes, radiation environment
  - Demonstrate the functionality of instrumentation
- Likelihood that some devices will need beam tests
  - At NuMI and elsewhere
- A strong software framework and emphasis on integration is also needed
  - Better and quicker studies
  - Reduces barriers to studies
- Collaborator input is more than welcome

Summary

- A 2 MW target is a big R&D target for LBNE
  - Unfortunately, we will start with 700 kW
    - This target is not the NOvA target
- Fortunately, we have a lot of approaches for new targets
  - New materials, new assemblies, new simulations
  - Several external collaborations
  - Work will converge on a target design
    - Also, impacts other target hall systems
- Target Hall Instrumentation is also under study
  - Needed to confirm that the beam is of adequate quality
- Active work in some areas, but more collaborator work would be helpful
  - Simulations at the top of the list
  - Others: prototyping, engineering, beam tests