Review of High Power Proton Target Challenges

Heat Removal and Thermal 'Shock'

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Summary

The following target challenges will be addressed:

1)Heat removal (High Heat Flux Cooling)

2) Thermal "shock" (including cavitation in liquid cooling media)

5) Spatial Constraints (and magnetic field effects)

7) Physics optimization

Reference will be made to the following range of target examples each of which HPTG has some involvement:

- Mu2e → Muon Source
- T2K
- LBNE
- Numi-Nova
- Euronu
- Neutrino factory

Neutrino facilities

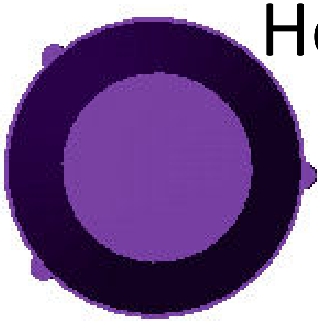
- ISIS
- ESS
- ADSR

Neutron Spallation

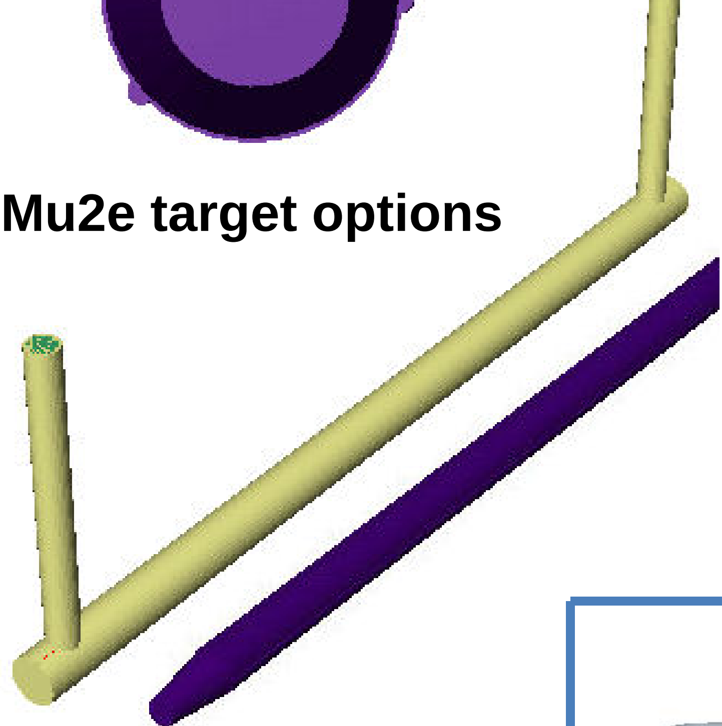
Heat Removal and Thermal 'Shock' Table

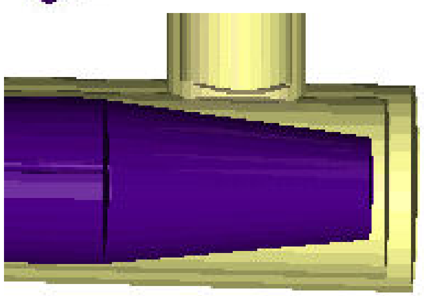
Target	Power Deposited [kW]	Peak Temperature Jump[K]	Existing or proposed solution
Mu2e	2	0.0014	Peripherally cooled cylinder
T2K	15	100	
Numi	4	364	Peripherally cooled segmented
Nova	8	253	
LBNE	23	75+	
ISIS	100	3.8	Segmented with cooling through core
EuroNu	200	62	
Neutrino Factory	500	1000?	Flowing or rotating target
ESS	3000	100	Rotating target with cooling through core of target
ADSR	7000?	5?	Liquid metal?

Heat removal from Peripherally cooled cylinder

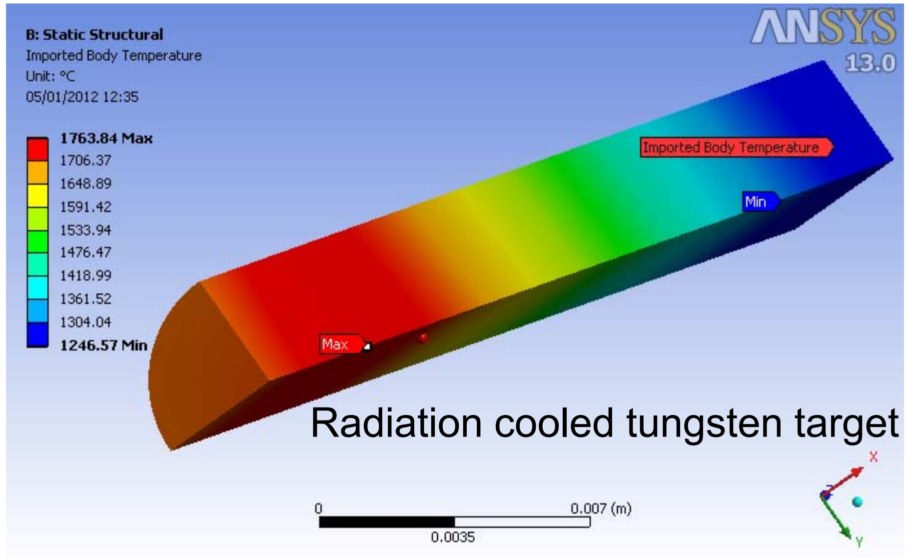


Mu2e target options

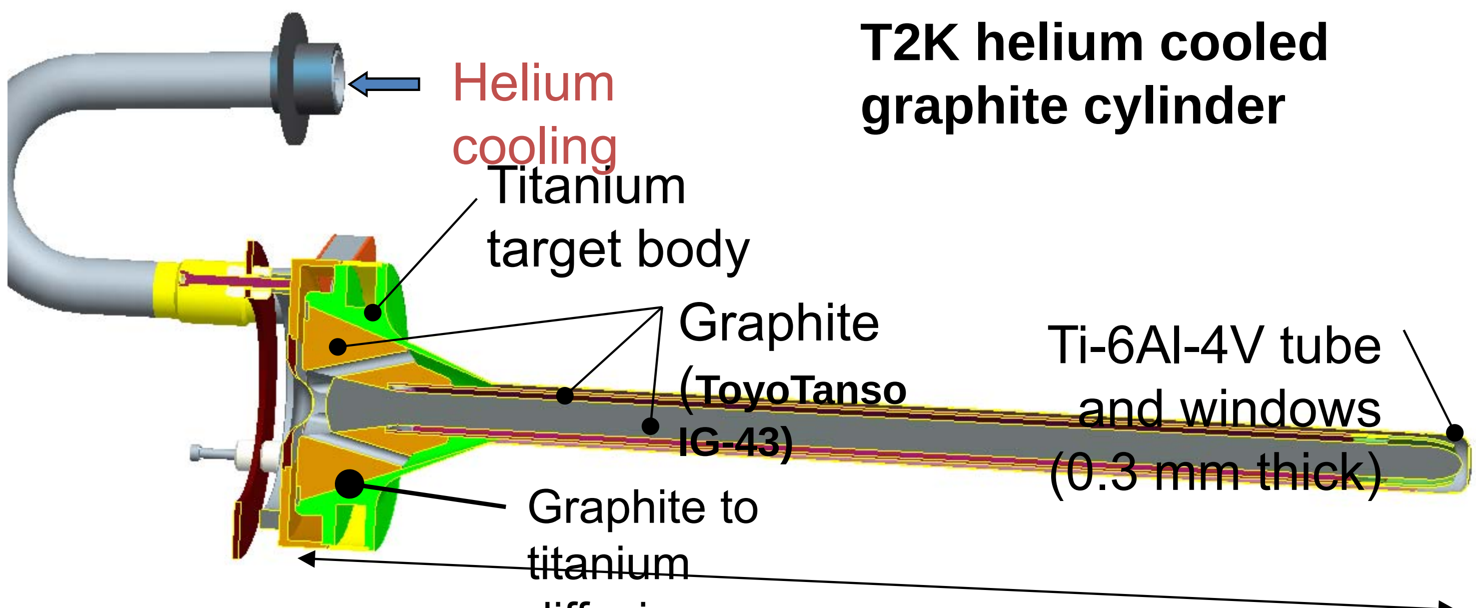




Water cooled gold target

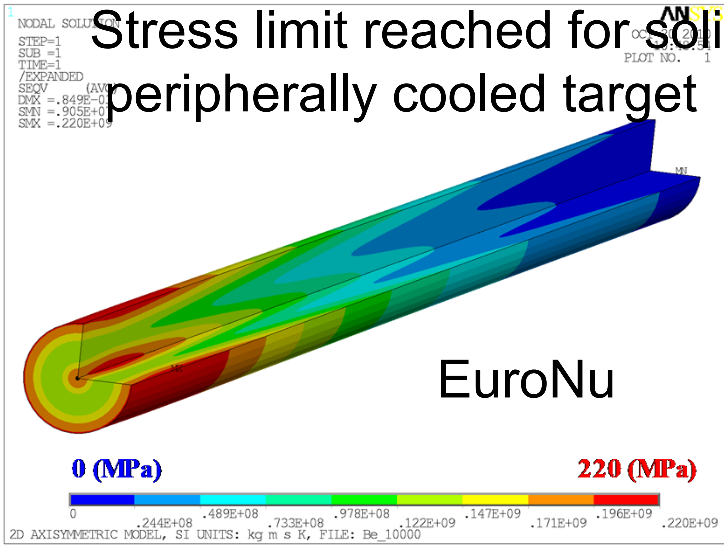


T2K helium cooled graphite cylinder



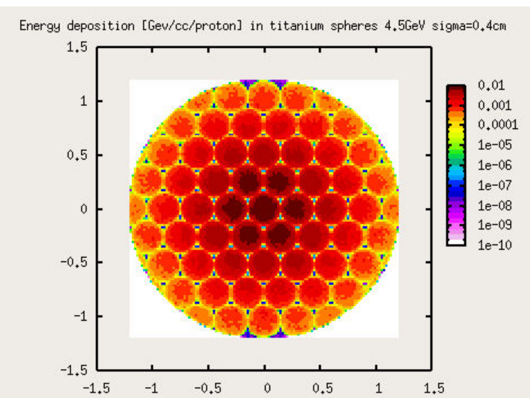
Heat Removal from segmented targets

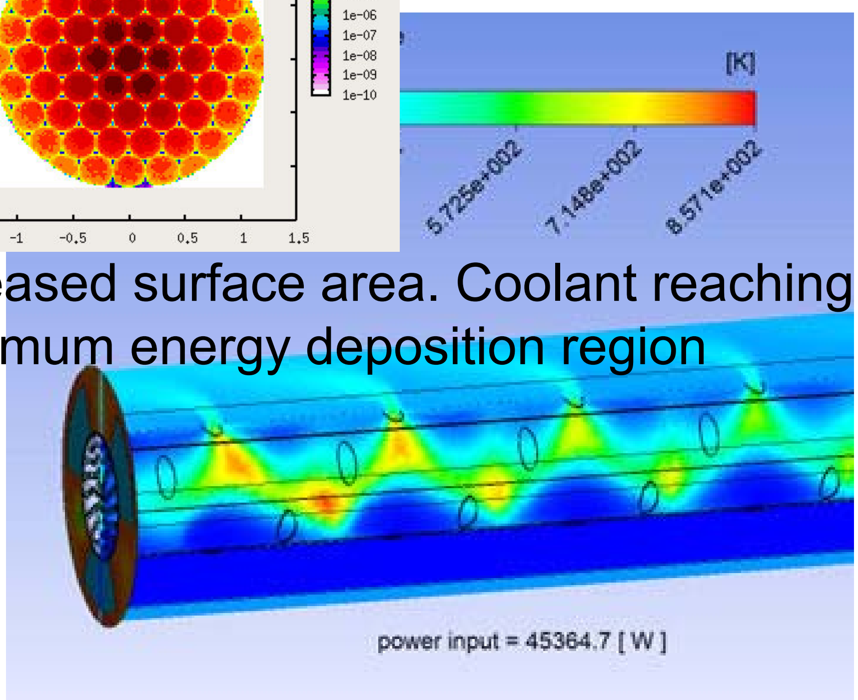
Stress limit reached for solid peripherally cooled target



EuroNu

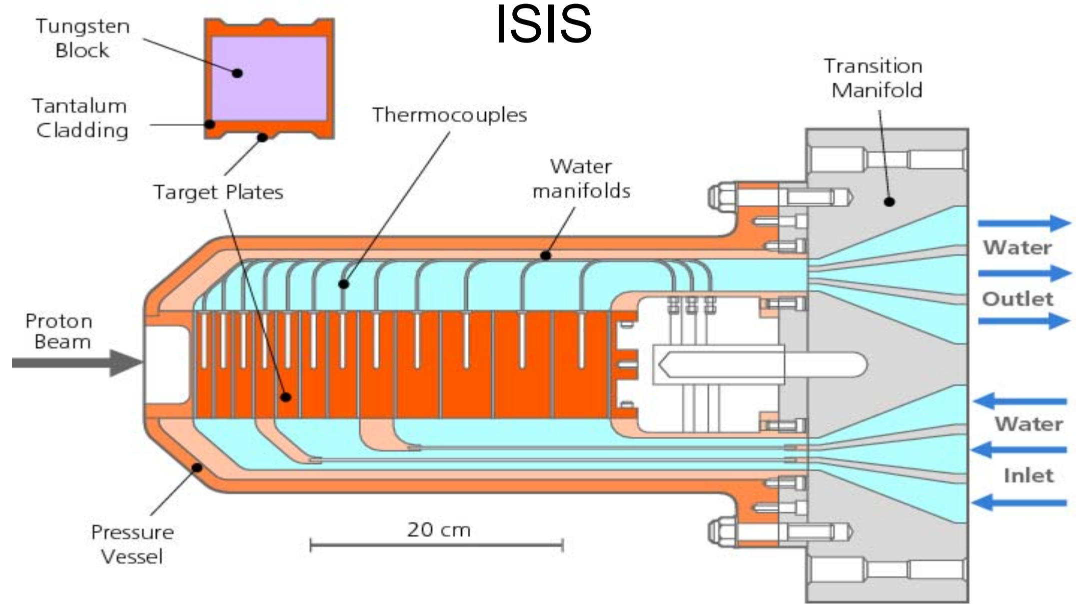
Packed bed segmented target

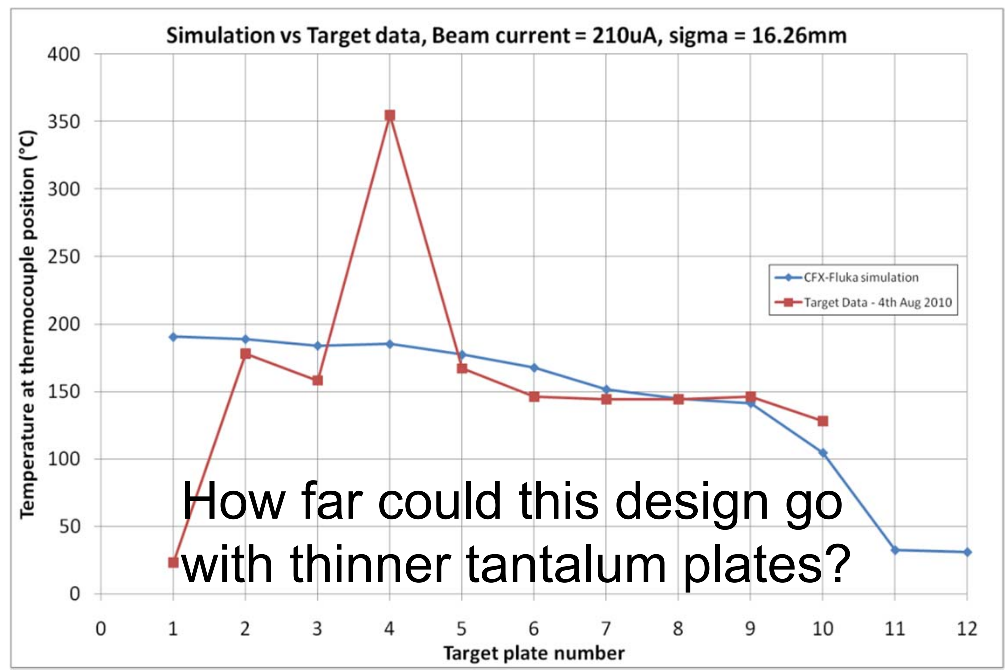




Increased surface area. Coolant reaching maximum energy deposition region

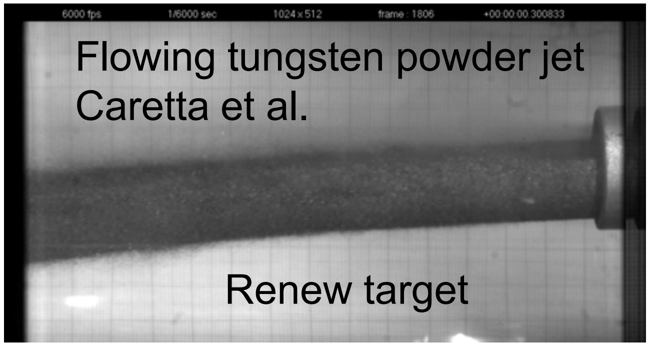
ISIS

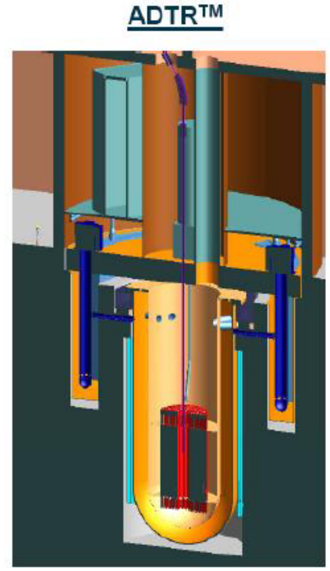




How far could this design go with thinner tantalum plates?

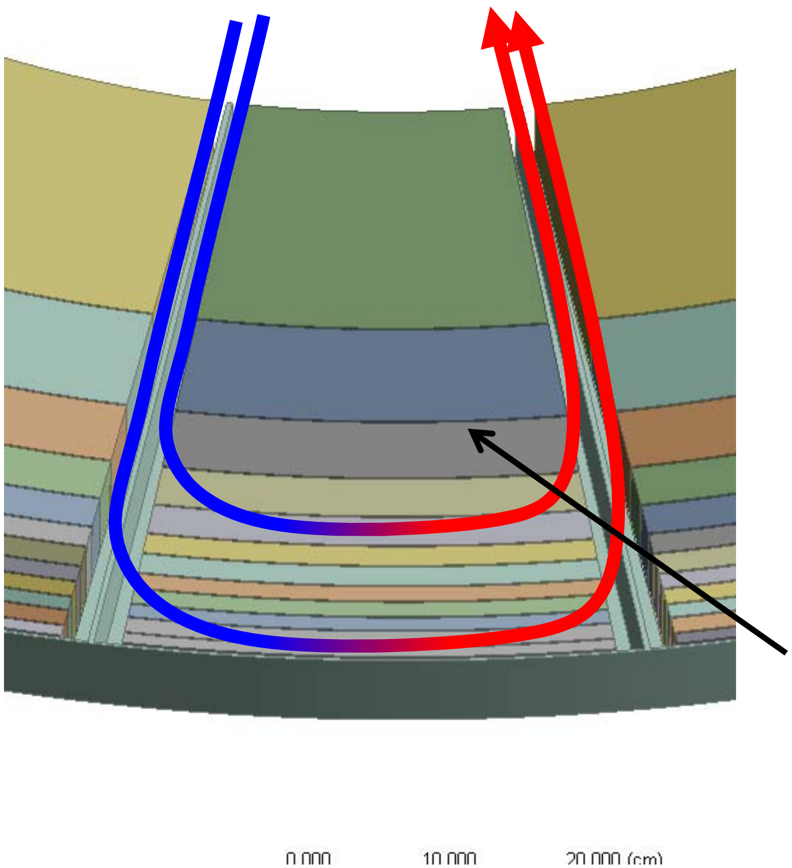
Heat removal from flowing /rotating target

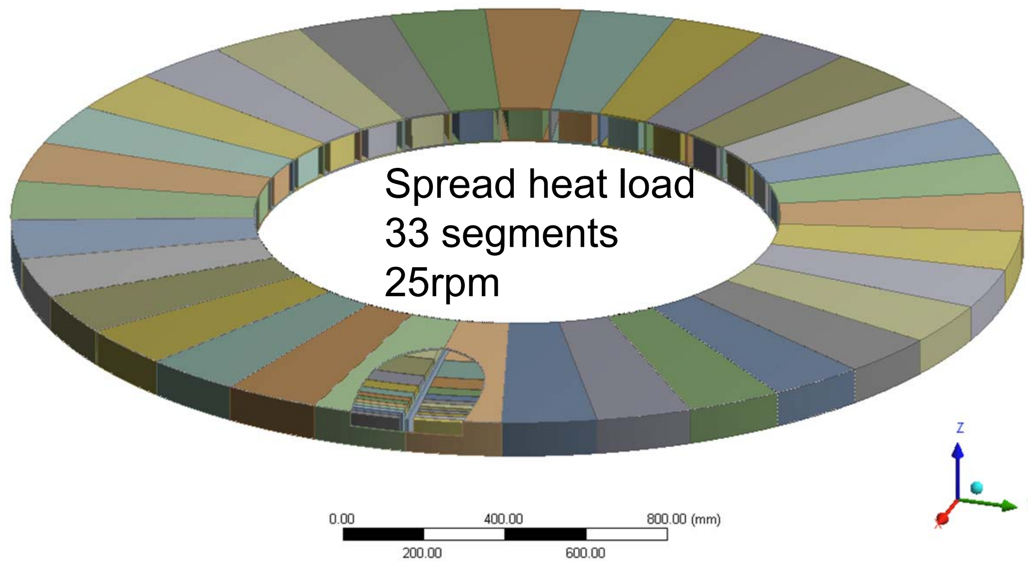




The minimum beam power for ADSR to be economically attractive is thought to be 10 MW. Bowman et al. 2011 PAC

Figure 2. The Jacobs" concept for beam delivery to a liquid lead spallation target in an ADSR. More detailed versions exist but cannot be made public.

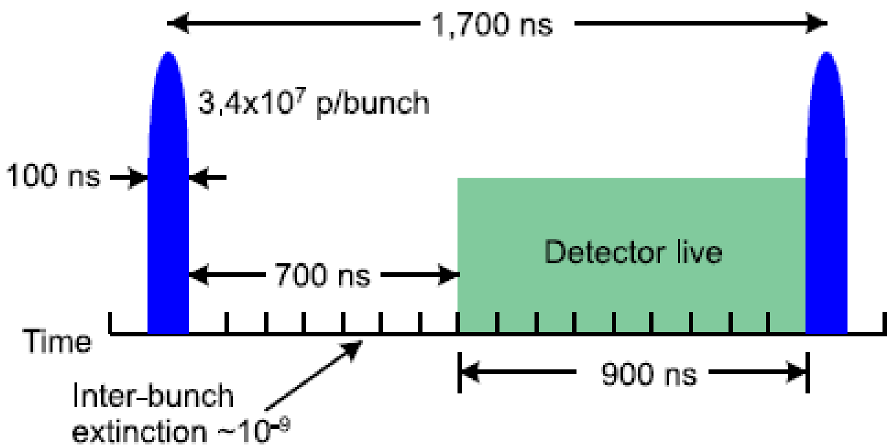




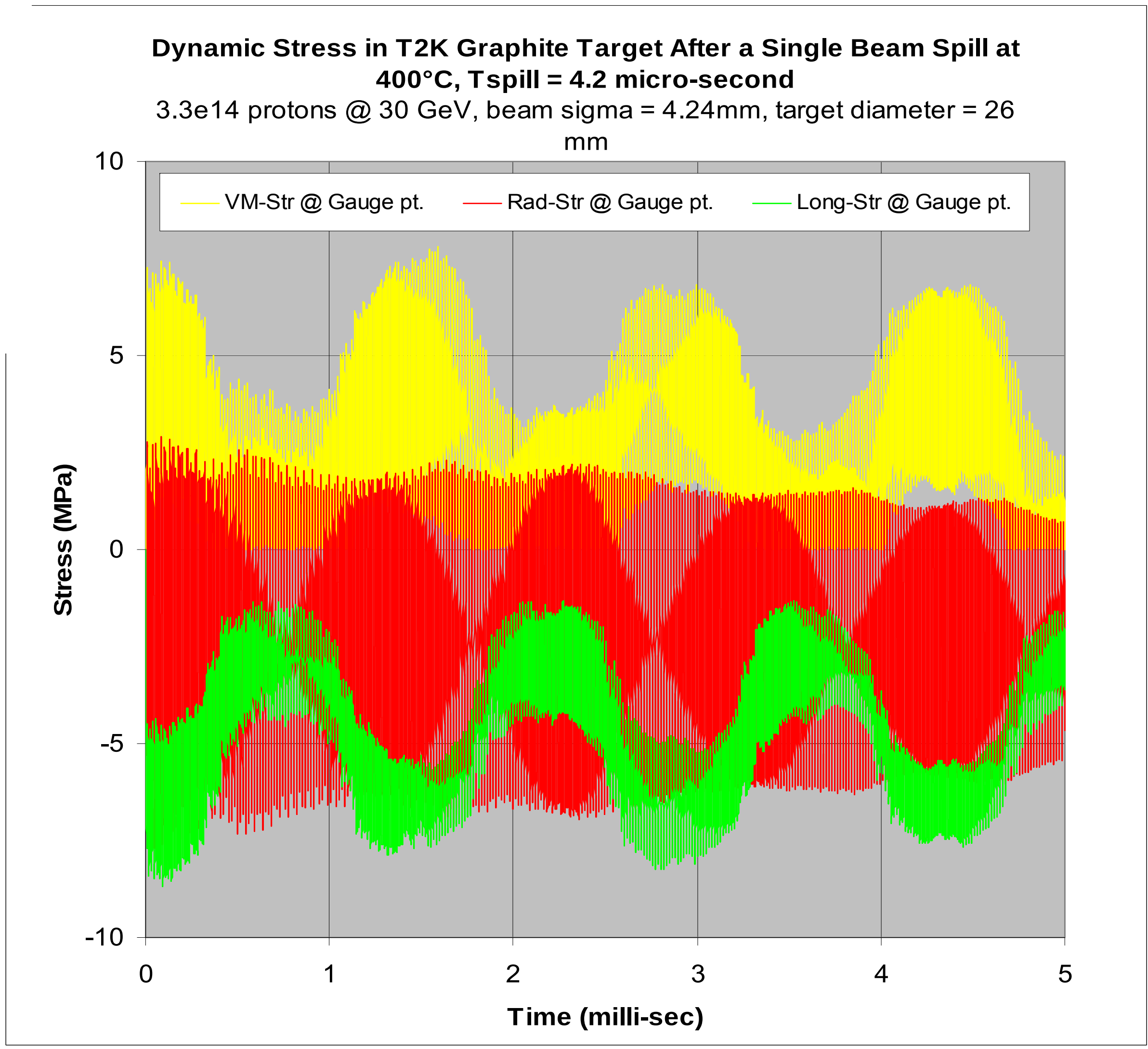
Helium cooled rotating target wheel
Latest ESS target design Kharoua et al.

Thermal shock in peripherally cooled solid target

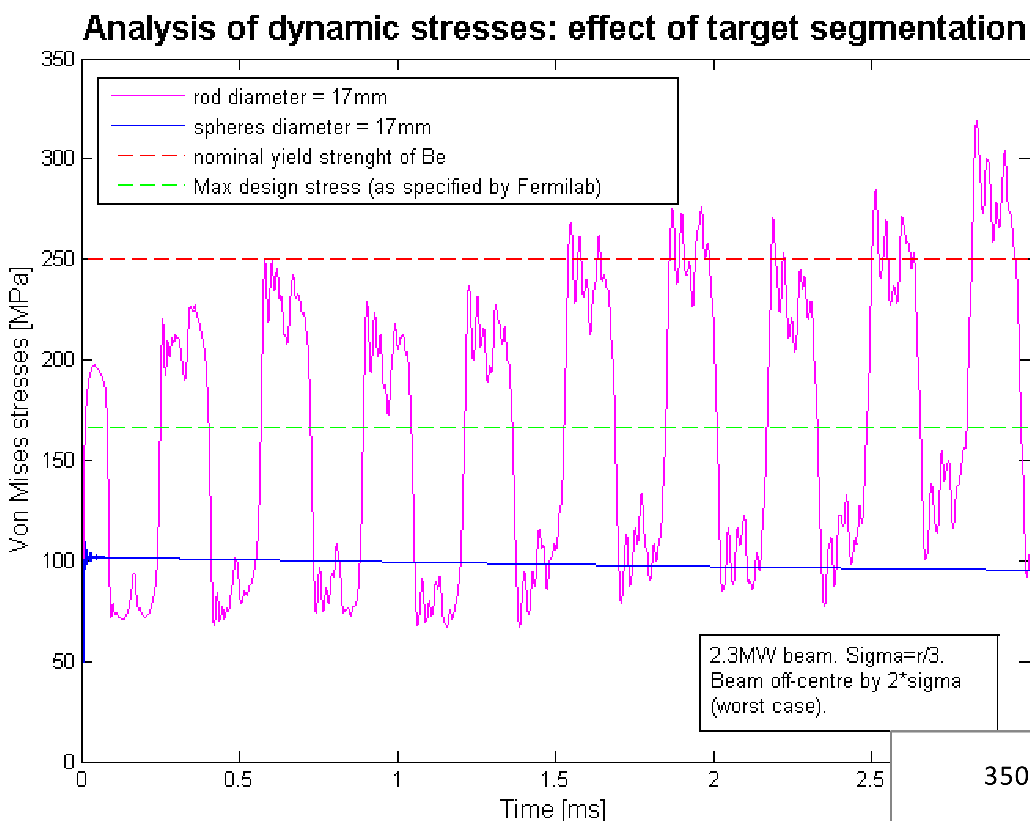
Mu2e beam structure results in negligible thermal 'shock'



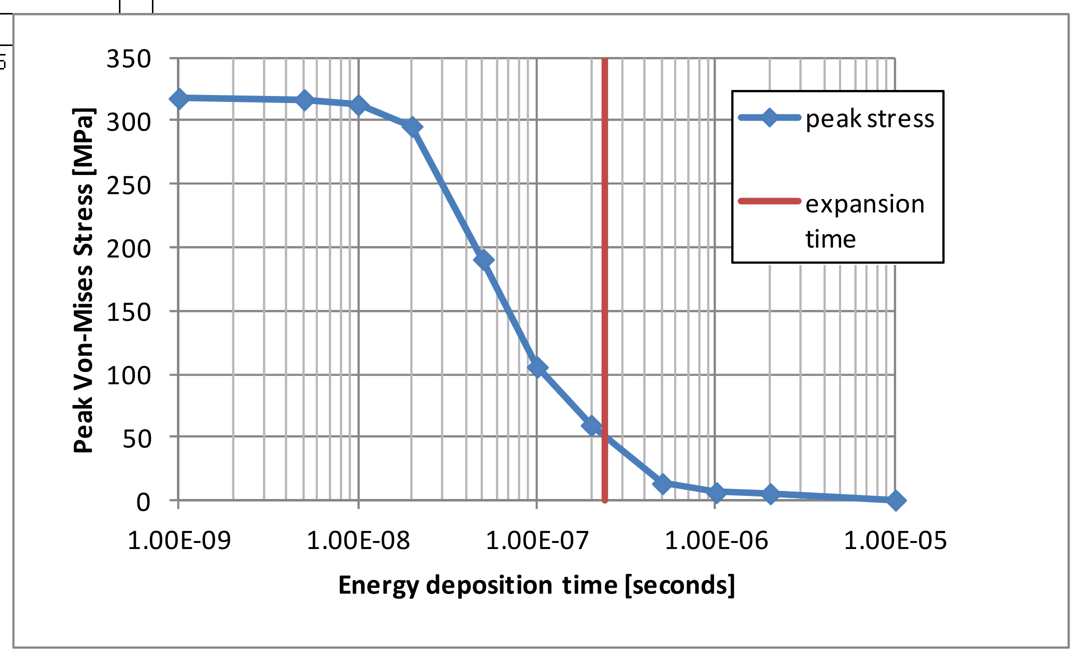
Significant temperature jump in T2K graphite cylinder results in a manageable peak dynamic stress of 6MPa
Temperature jump in helium negligible



Thermal Shock for a segmented target



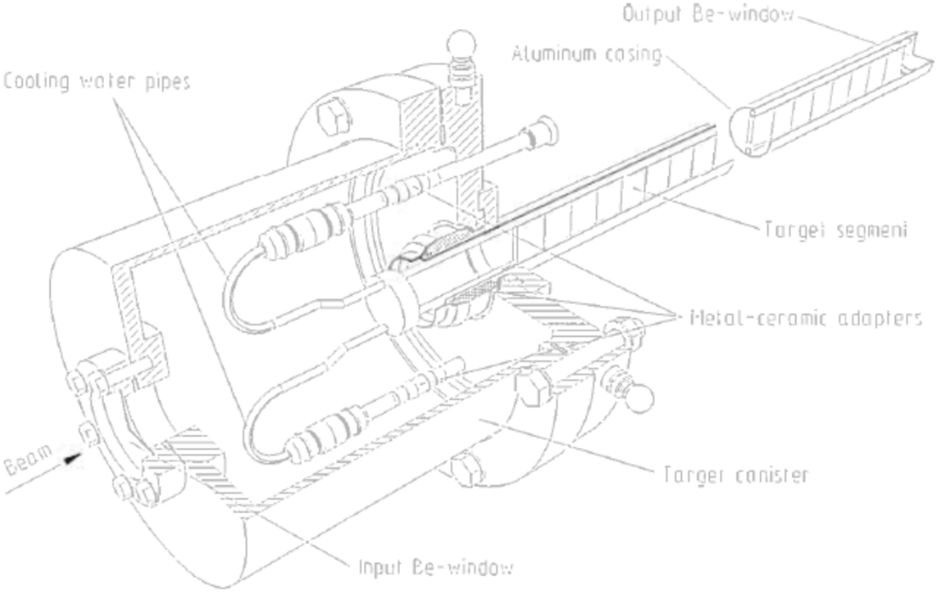
Dynamic stresses in beryllium cylinder compared to beryllium spheres as a result of LBNE 2.3MW beam

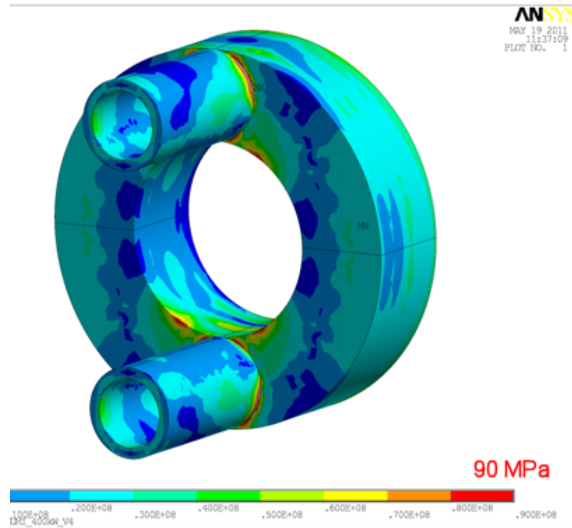


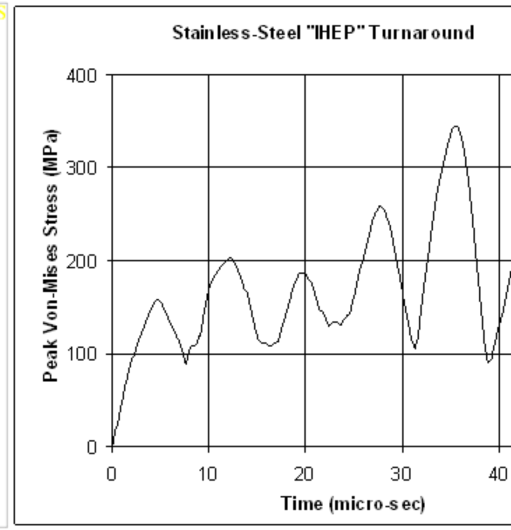
Relationship between peak dynamic stress and energy deposition time for a sphere

Expansion time α target size

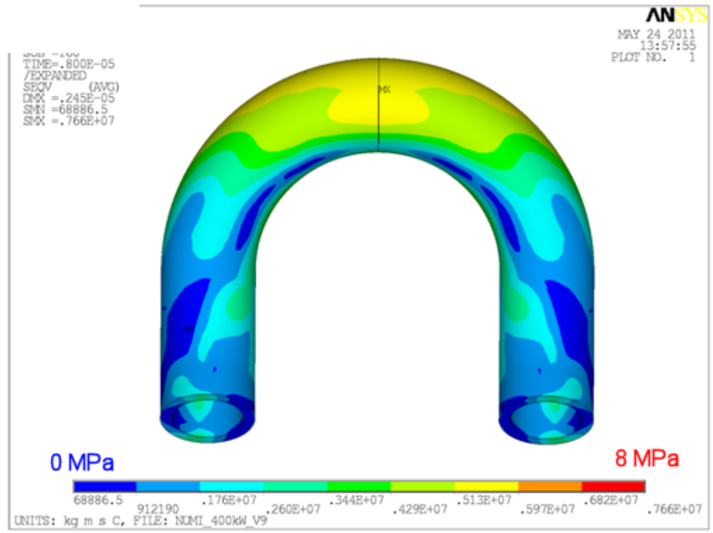
Segmented Target (Thermal Shock in coolant circuit)

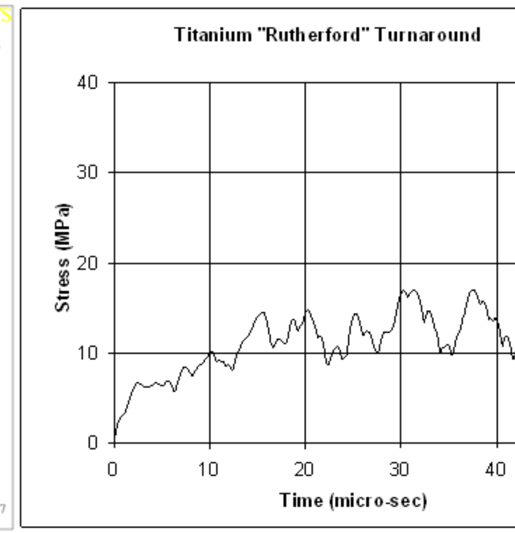






5K temperature jump in water
40K temperature jump in Steel cooling tubes





Thermal Shock in flowing targets

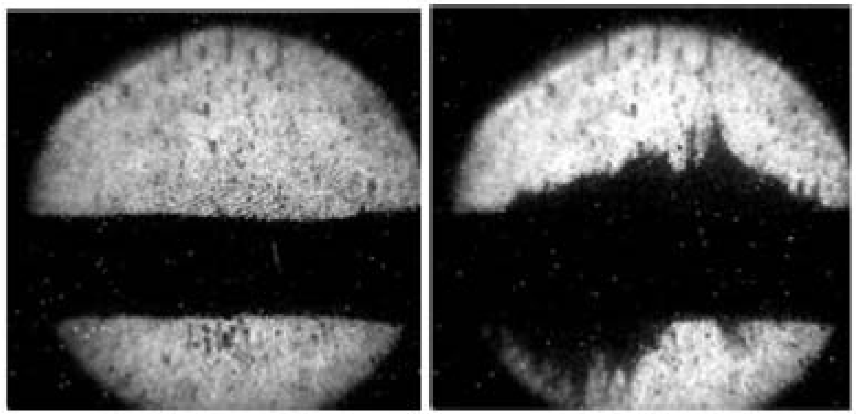
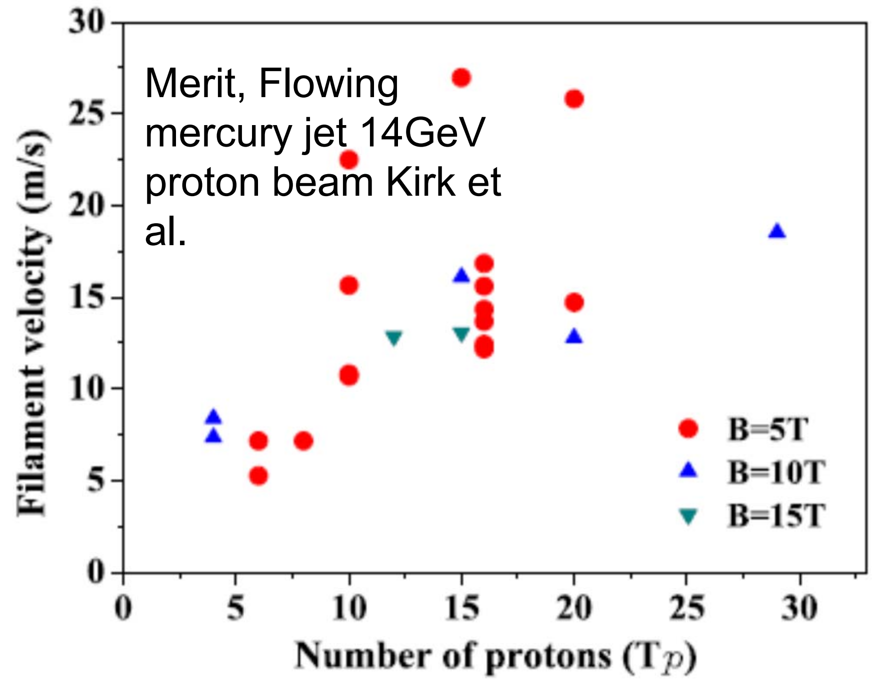
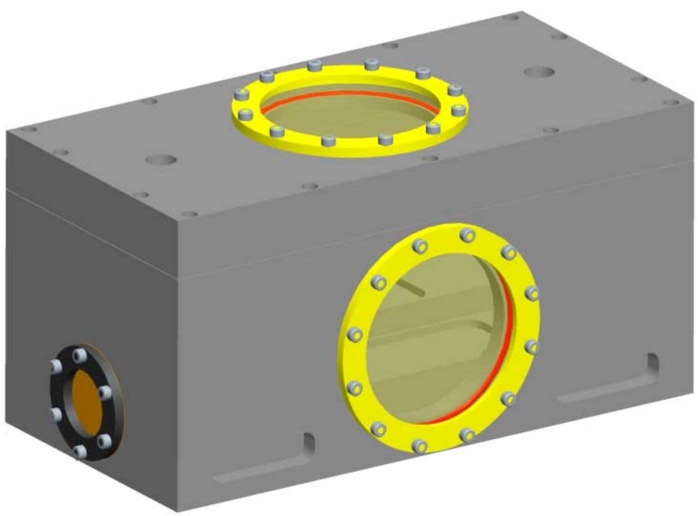


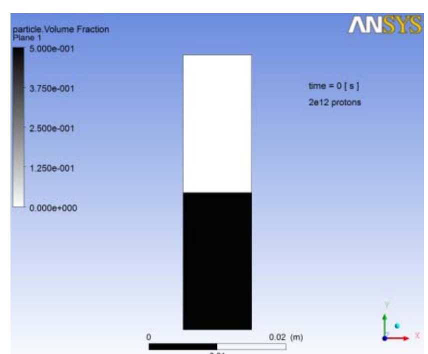
Figure 5: A proton beam/jet interaction as viewed in view port 2: Left image: before interaction; Right image: 350 μs after proton beam arrival.

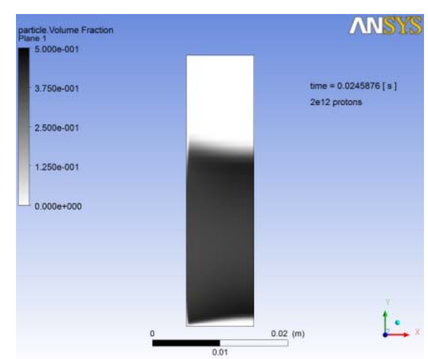




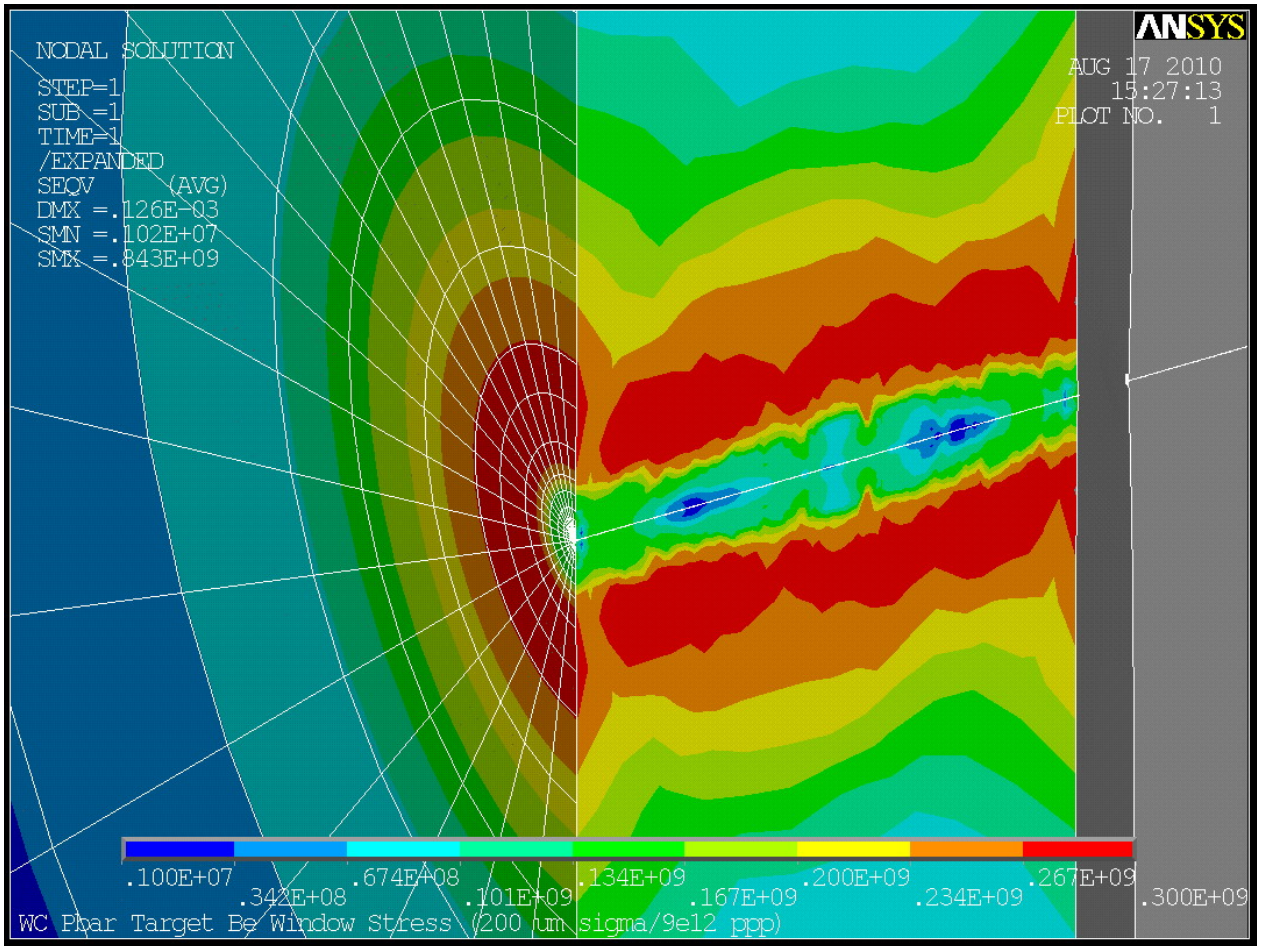
How will tungsten powder react to proton beam interaction?

Hi Rad Mat experiment planned for April 2012





(Thermal Shock what is the limit?)



P.Hurh et al.

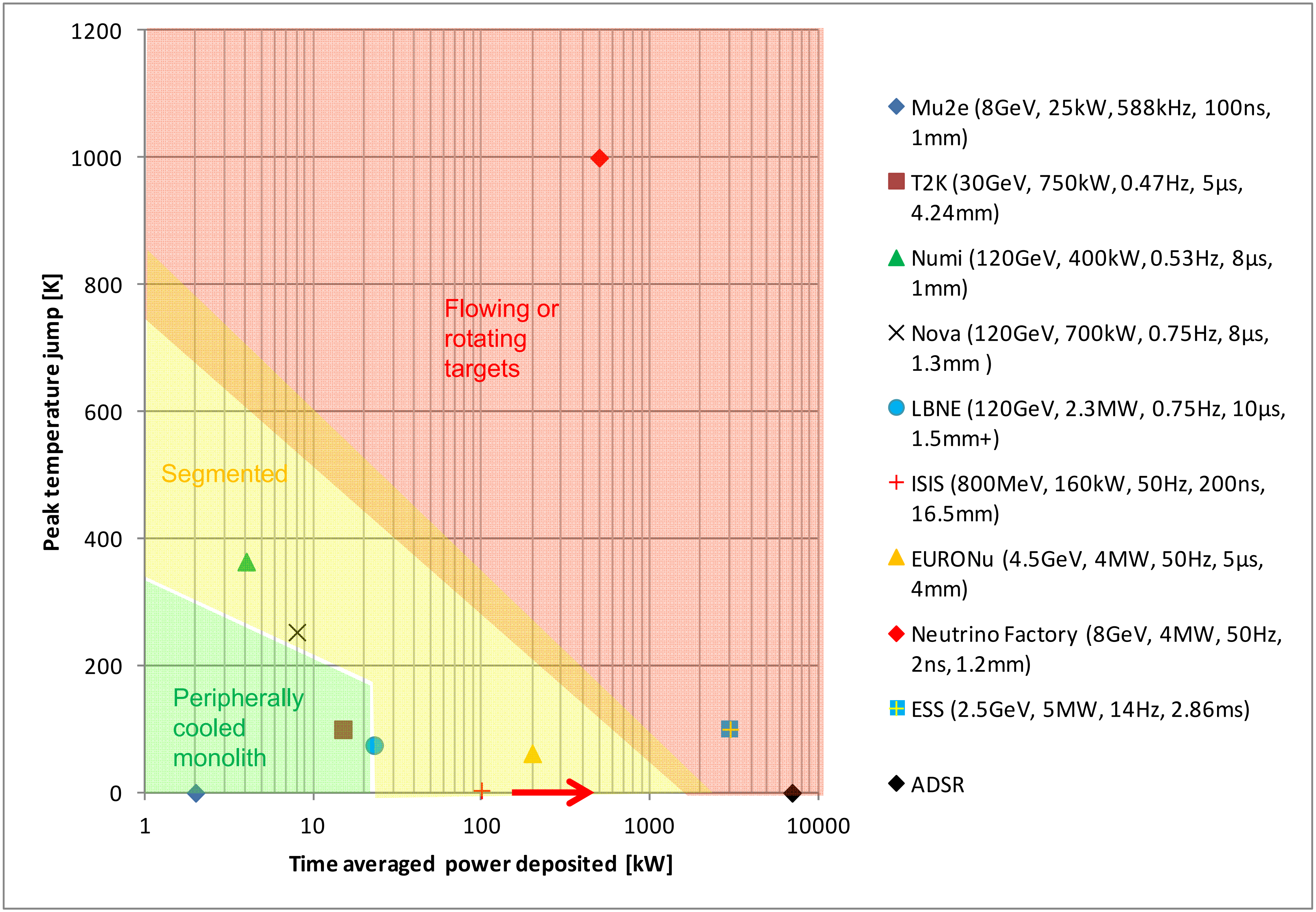
Predicted Peak Energy Deposition for LBNE 2.3 MW with 1.5 mm beam sigma radius was 846 J/cc and thought to cause stresses too high for Be to survive

But P-bar Target (FNAL) has a Beryllium cover that regularly sees 1000 J/cc and shows no evidence of damage

ANSYS analysis for similar conditions suggests peak equivalent stresses of 300 Mpa (elastic-plastic, temp-dependent mat'l properties, but not dynamic)

Dynamic stresses could be 30-50% higher

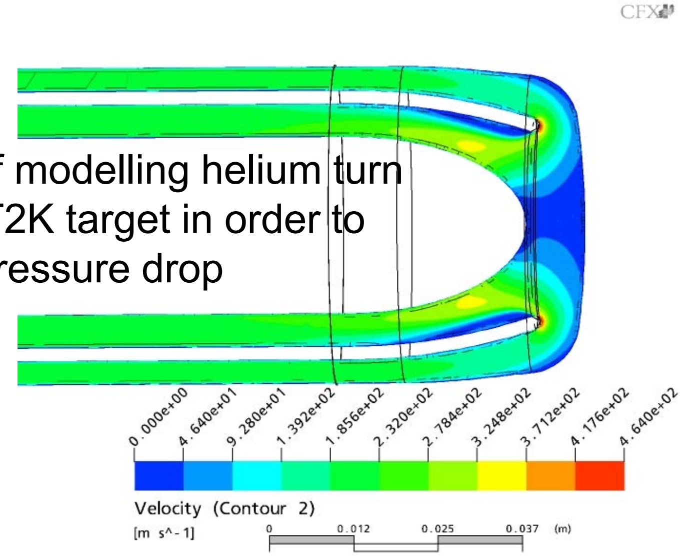
Heat Removal and Thermal Shock Summary

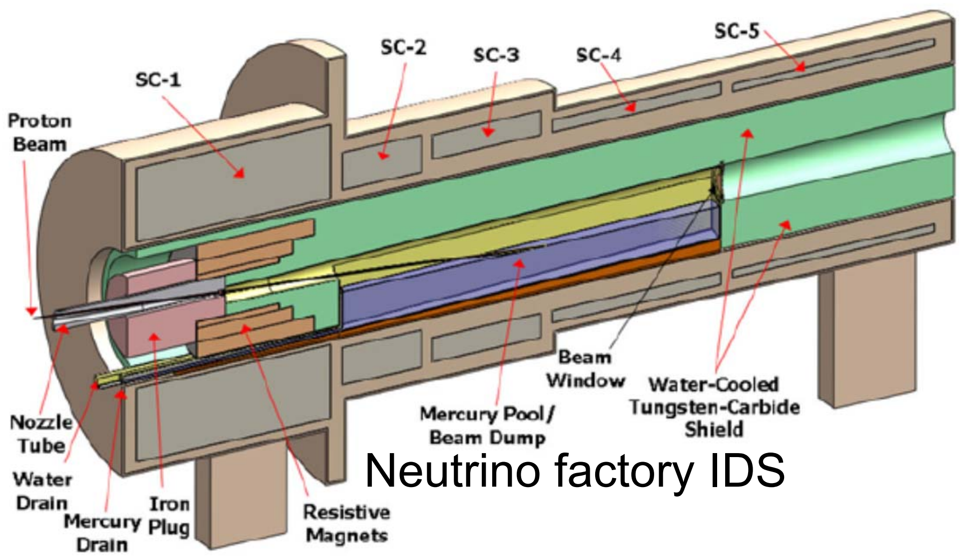


Spatial Constraints

T2K, Numi, LBNE, Euronu all need to fit within a horn, considerable challenge to fit target, support structure and cooling channels

Example of modelling helium turn around in T2K target in order to minimise pressure drop





Neutrino factory IDS

Mu2e and Neutrino Factory target must fit within superconducting solenoids. Space for an individual target not so hard but for a flowing target or rotating target is more challenging especially considering required solenoid shielding

For Neutron spallation sources such as ISIS and ESS the primary spatial constraint is that the target fits within the moderators

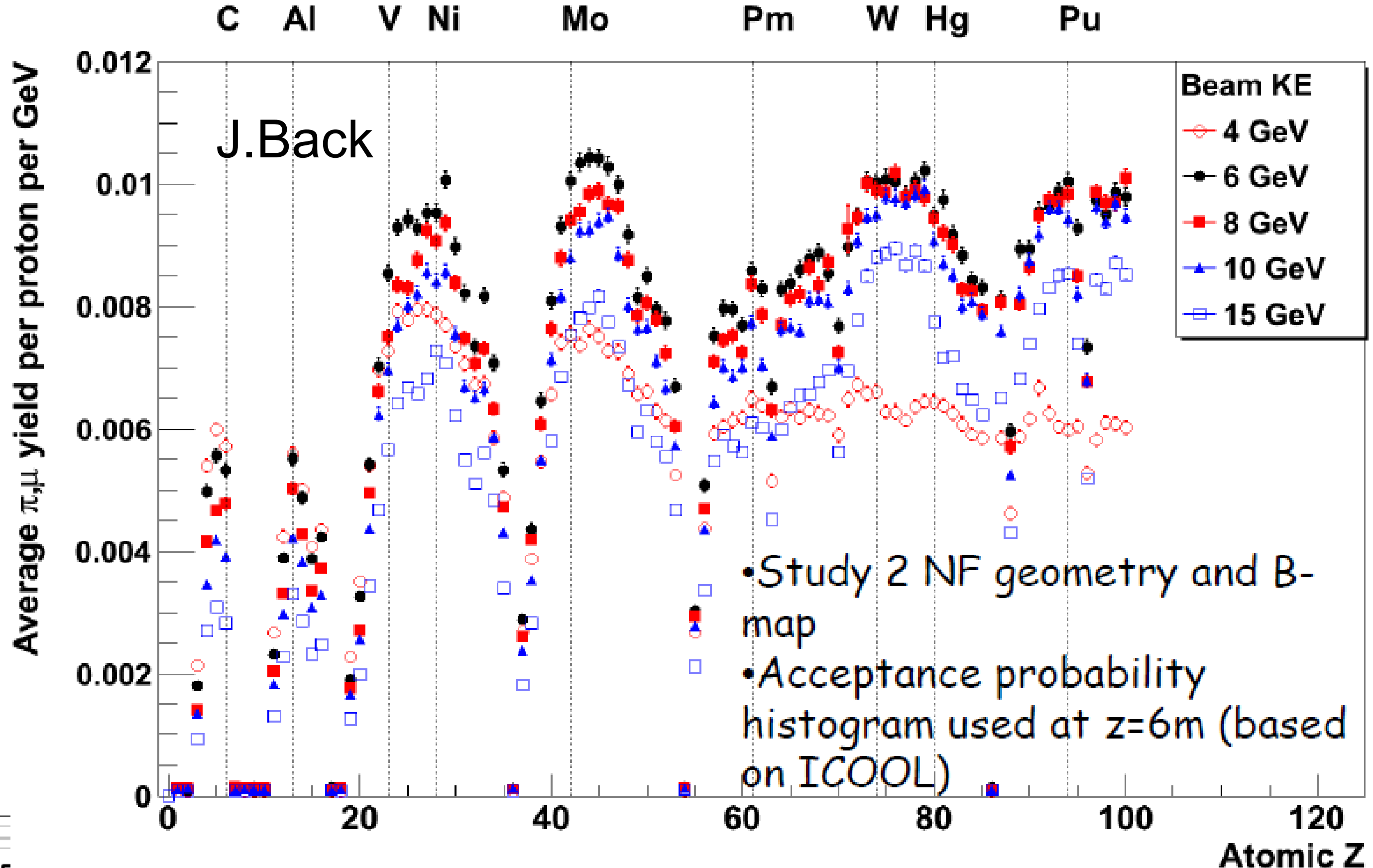
For ADSR the target must fit within a nuclear reactor core

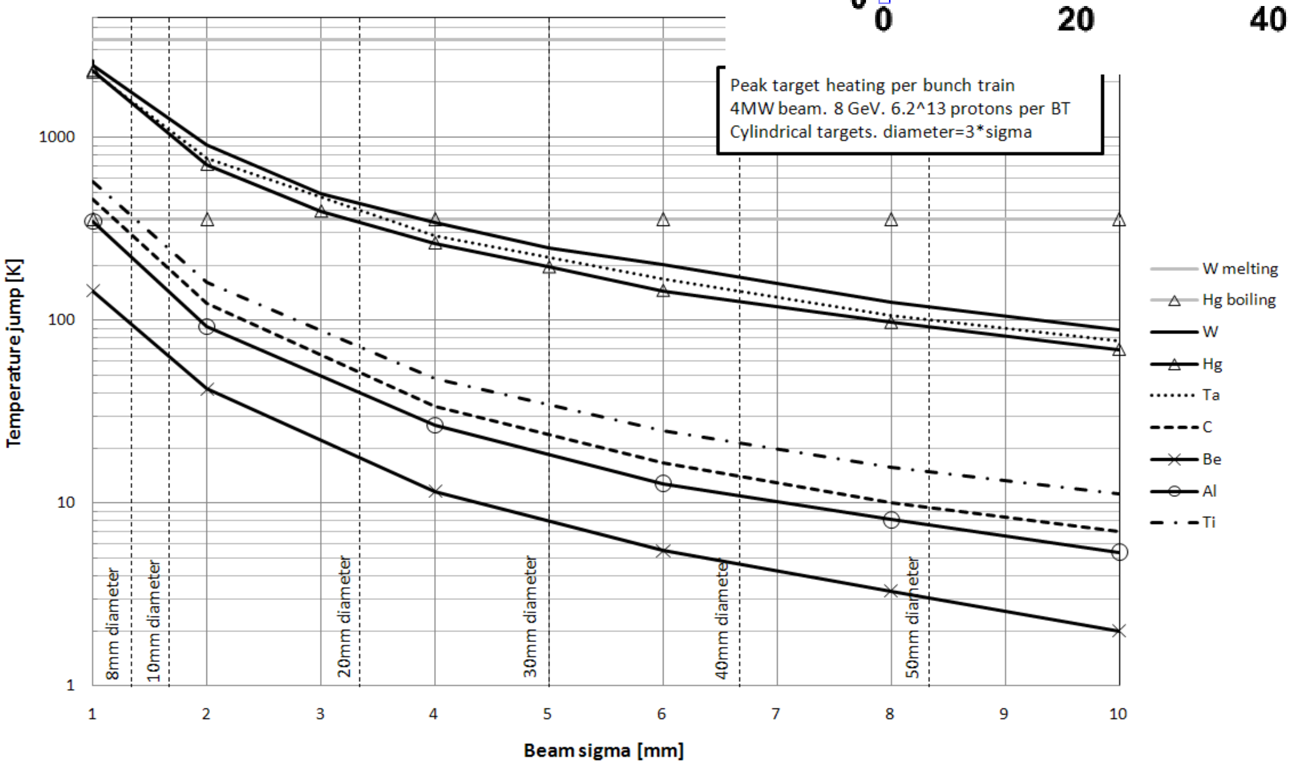
Physics optimization

Yield per proton vs. Design conservatism

Example: Choice of density

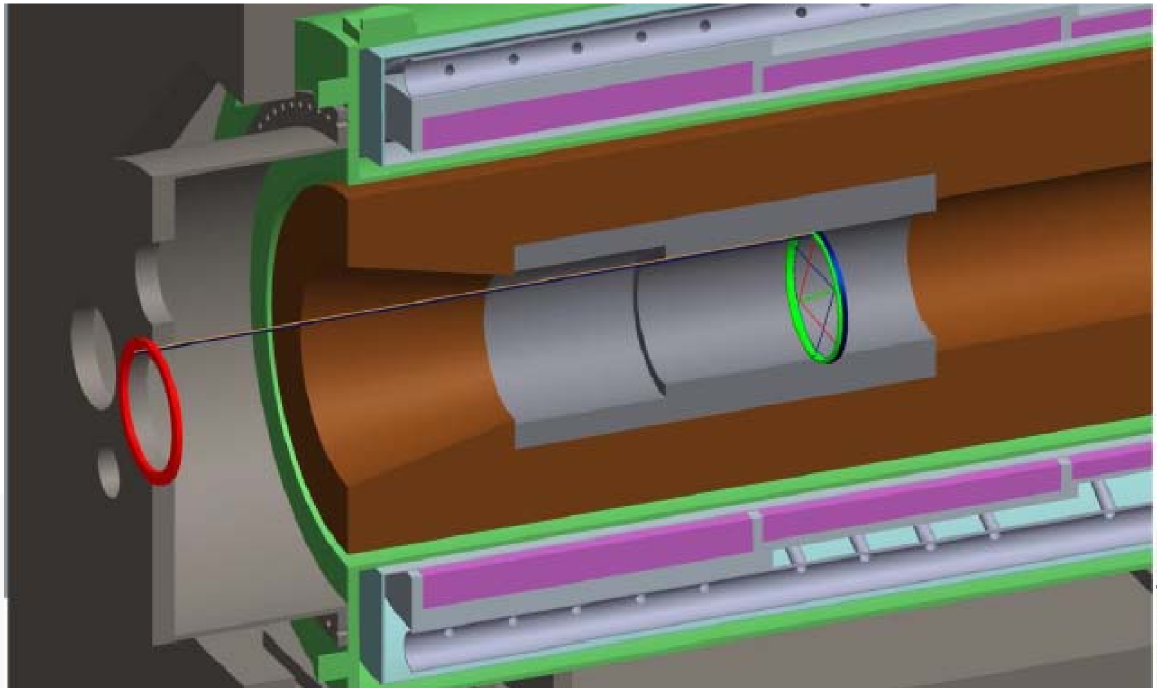
Temperature jump significantly lower in low Z materials with neutrino factory beam parameters



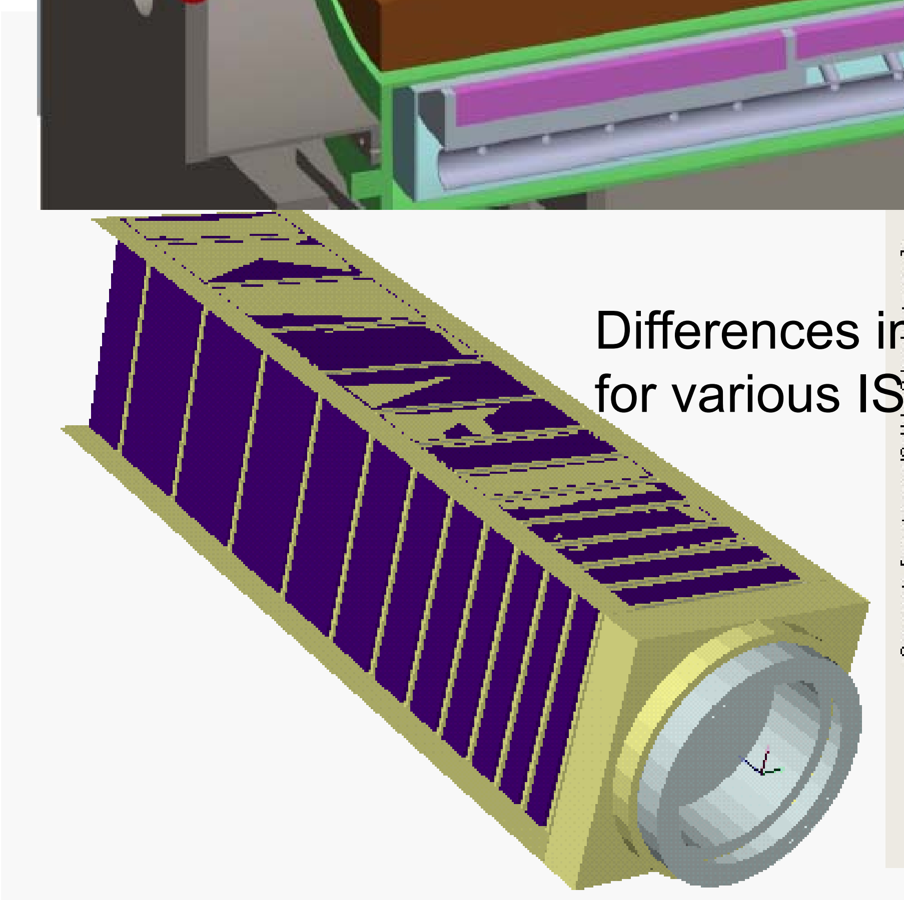


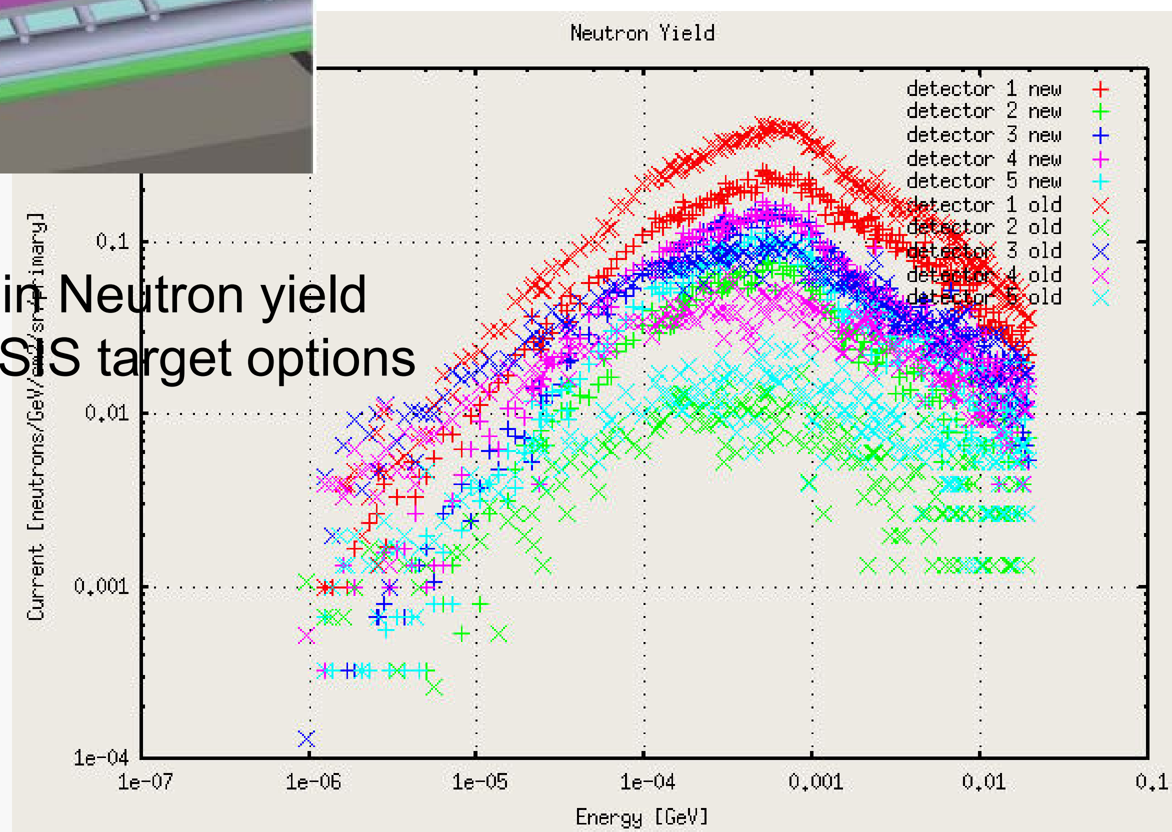
Does a neutrino factory really need to be made from mercury or tungsten

Physics optimization



Mu2e target support design
Minimizing material around target to minimize particle reabsorption





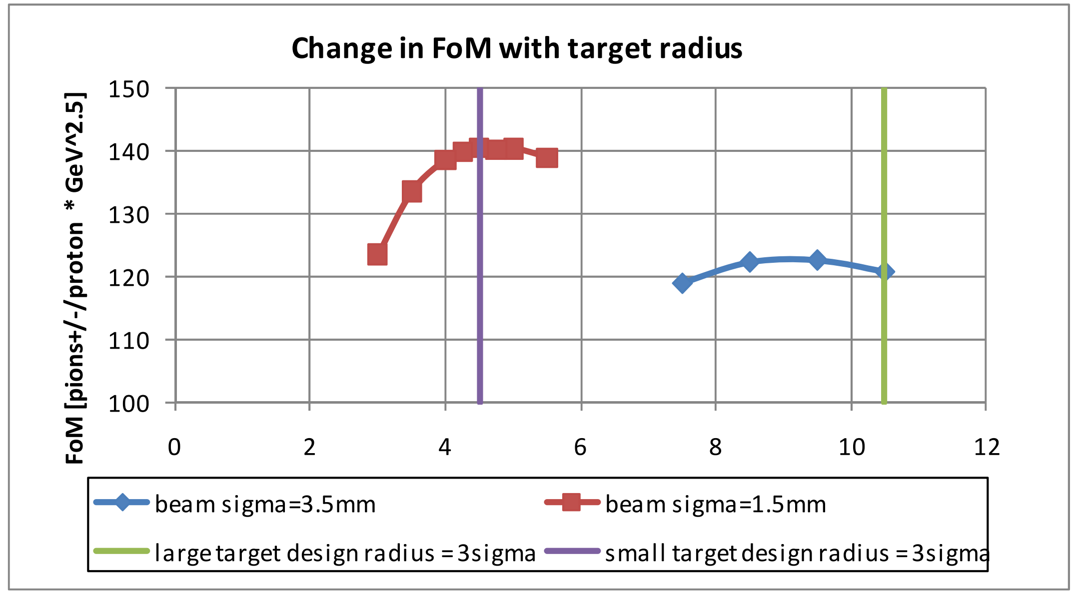
Differences in Neutron yield for various ISIS target options

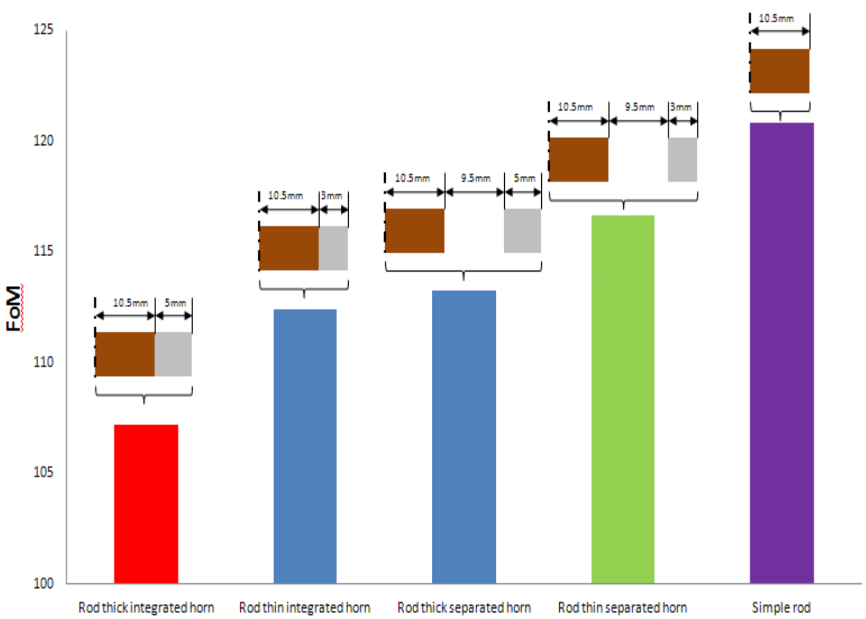
Physics optimization

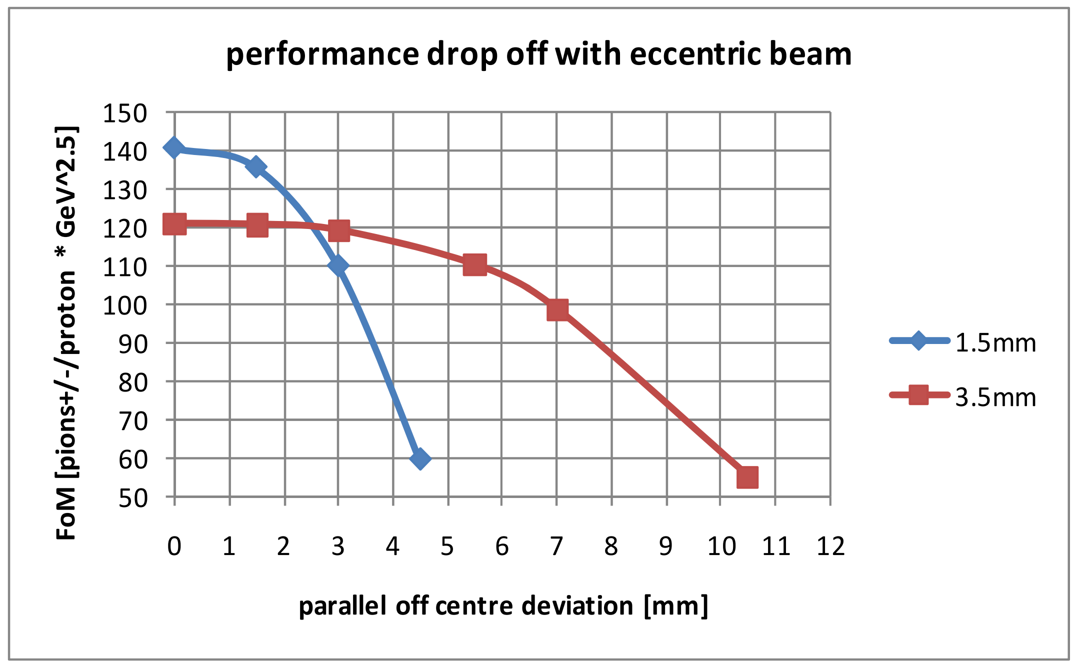
$$FoM = \sum_{n=1}^{21} (Ecen_n)^{2.5} \int_{Emin_n}^{Emax_n} \int_0^{\Delta p} \frac{\partial^2 N}{\partial E \partial p} \partial p \partial E$$

B.Zwaska

For LBNE study
Figure of merit used
at concept stage to
compare designs







Physics performance considered in parallel with engineering design

Conclusions

Peripherally cooled cylindrical monolith targets have limited heat dissipation capability as a result of both steady state and dynamic stresses.

Segmented internally cooled stationary targets can accommodate much higher heat loads and higher power densities.

A pebble bed target is being considered for Euronu and may be relevant for other facilities where a solid cylindrical target would not be viable. R & D in pebble bed or other segmented targets is required for future neutrino facilities and also for ISIS upgrades and optimizing designs such as ESS.

Target designs are often based on a static yield stress limit. However there is some evidence to suggest the static yield stress can be safely exceeded. The Hi-rad mat facility offers a good opportunity to test this with some single pulse failure tests.

Single pulse failure testing and beam sweeping are both interesting from the point of view of determining how far stationary targets can be pushed before a flowing or rotating target is genuinely required.

Physics performance is a function of reliability as well as optimum particle yield so try to choose the simplest target design possible.