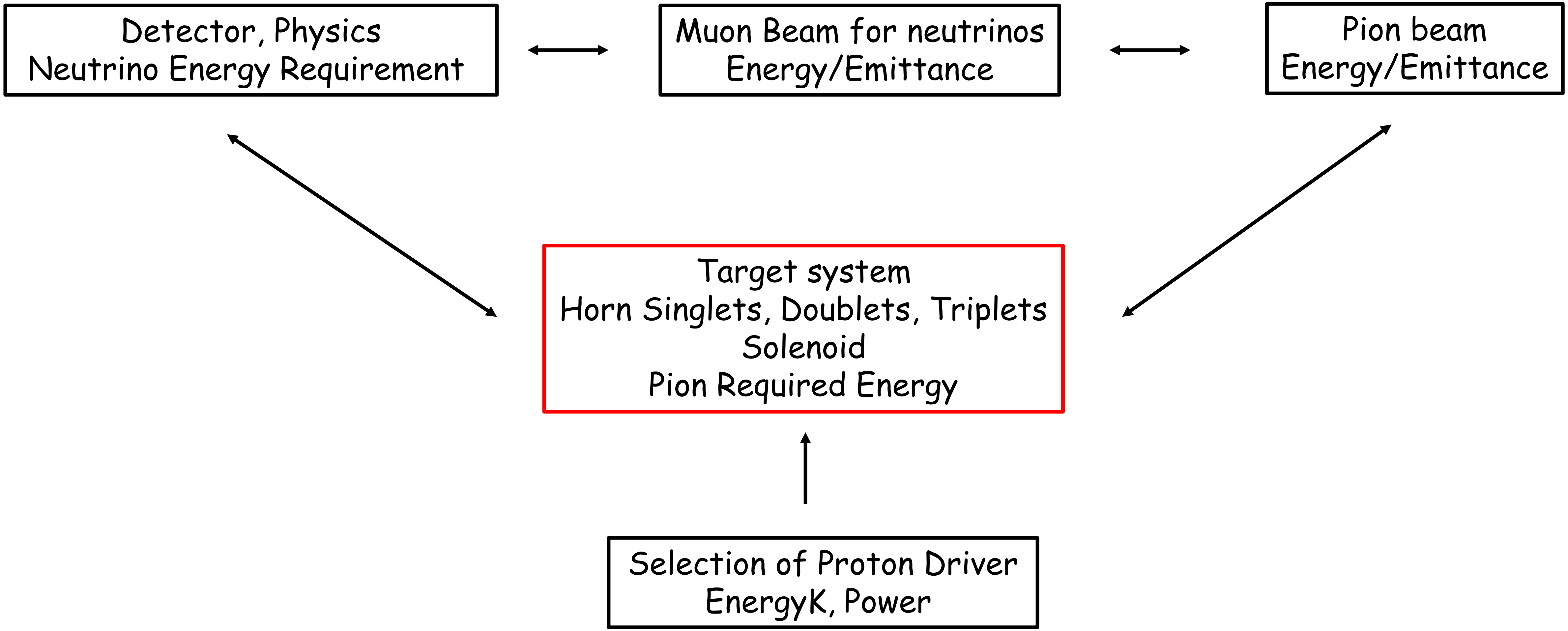
Pion-production target considerations

Nikos

Selection of the right parameters for nuSTORM's pion target

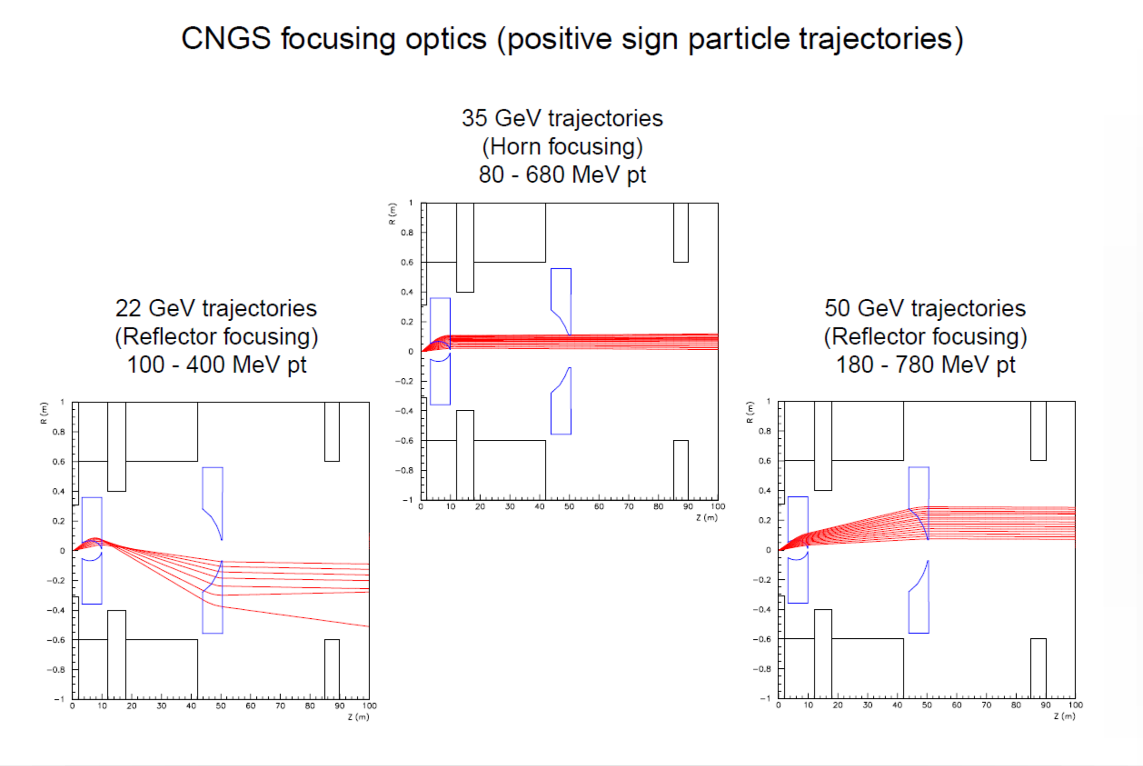


Target considerations for nuSTORM

- Horn(s) as focusing element of Aluminum-60xx variants
    - Current pulses like LBNF, T2(H)K, 300-400 kA
    - Reliable, proven longevity
    - π+ or π- can be selected
- Target of graphite
    - De facto material for LBNF, T2(H)K, used also at NuMI and CNGS
    - Adequate pion yields, less neutron radiation than higher Z materials
    - Be ready to operate with ~ 1 MW proton drivers
    - Use best grades of graphite, e.g. toyo tanso ig-43 for T2(H)K
    - Cooling design especially for MW proton drivers
    - Results from NuMI @ 1 MW and T2K @ 1.3 MW will prove their lifetimes and reliability

Horns for pion focusing

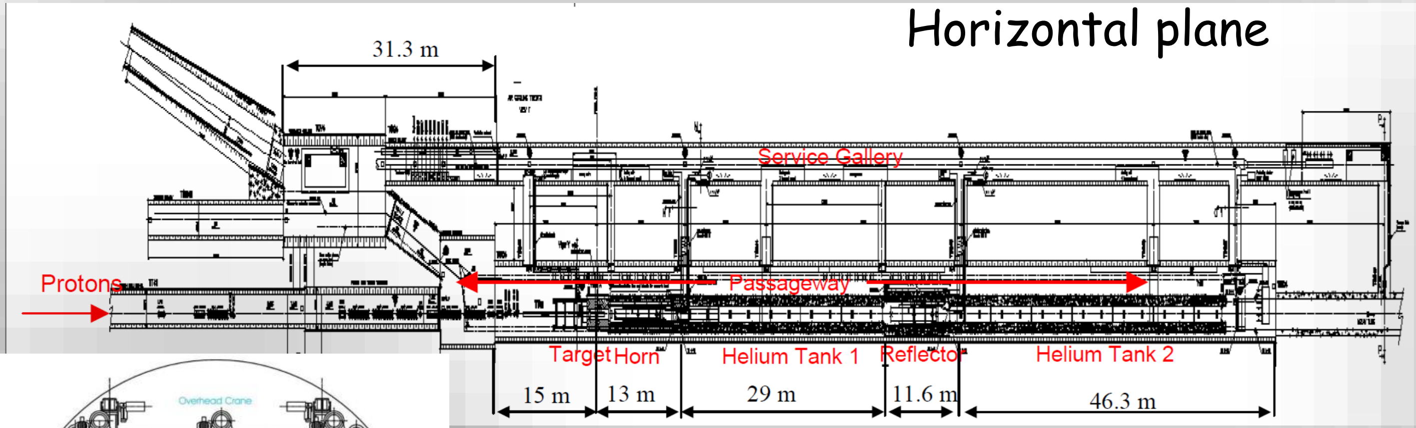
- Tailored to conventional neutrino beams from pions
- Focus a particular range of momentum, underfocus and overfocus, higher and lower momentum respectively
- Create wide or narrow energy bands for beams depending on the shape of inner conductor, number of horns, neutrino beam design
- Proven design at T2K, NuMI, T2K, NuMI, CNGS, SBN experiments
- Great experience on constructing and operating at CERN, JPARC, Fermilab

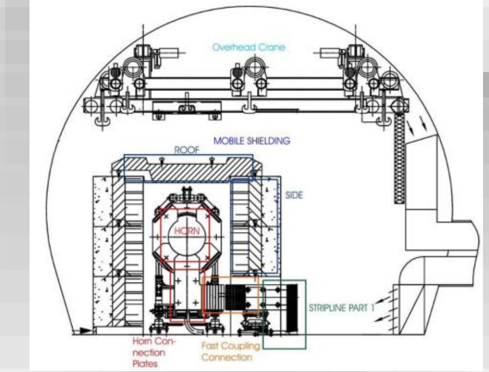


Examples of target stations with horns

CNGS/CERN (~510 kW)

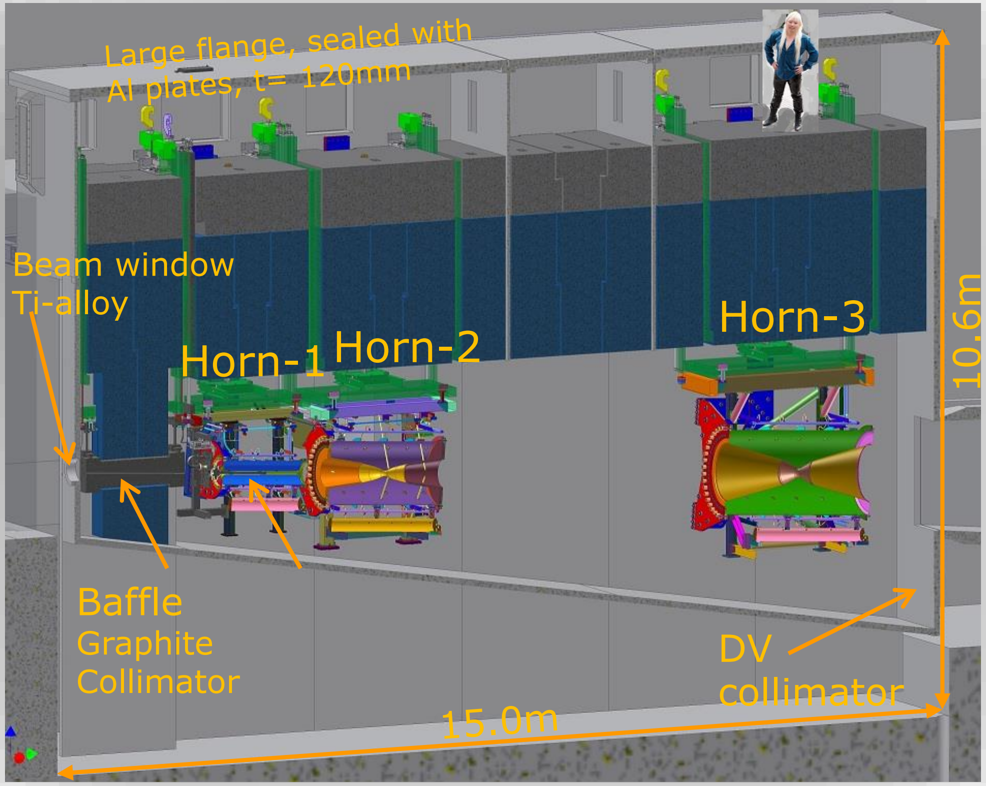
- Horn and Reflector on the floor, exchange though the tunnel with cranes and trolleys/rails





T2K/JPARC (1.3 kW)

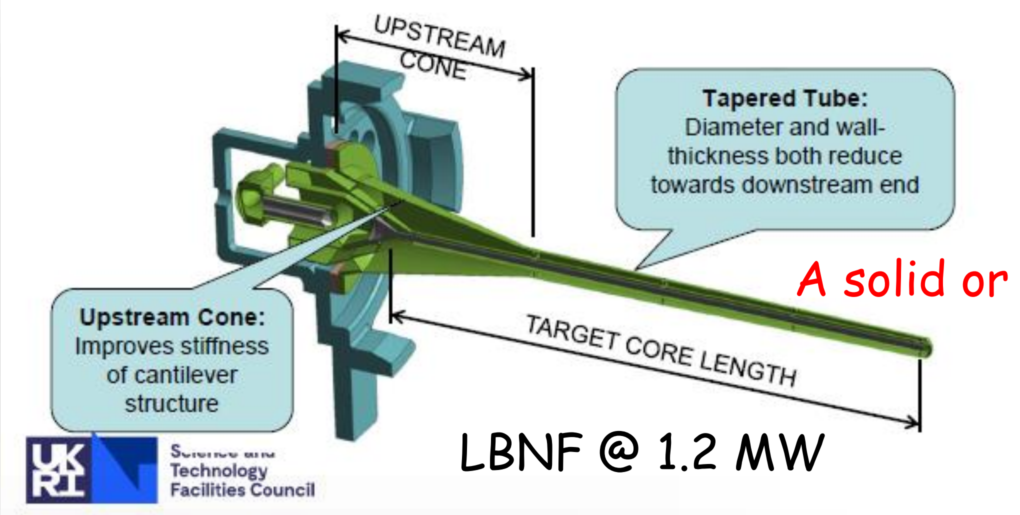
- 3 horns suspended in He environment, exchange with cranes through the roof



Operational parameters

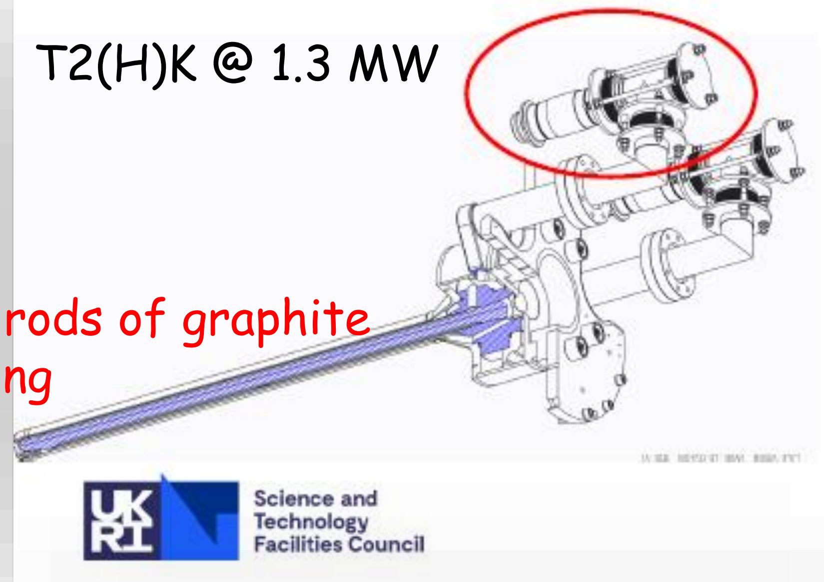
- Shielding/lifetime of parts
- Maintenance, remote handling, galleries
- Radioprotection/ALARA method
  - Radiation as low as reasonably achievable
- Safety following Laboratory/Country regulation

Target systems



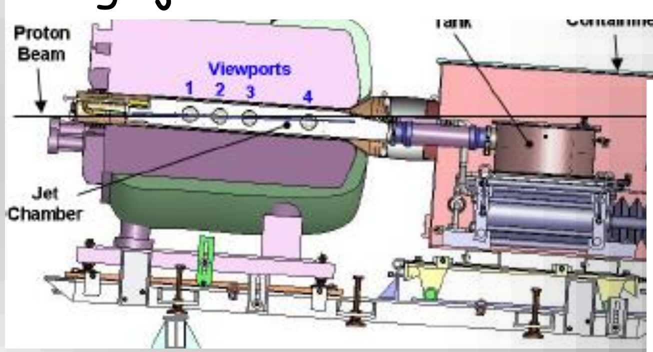
LBNF @ 1.2 MW

T2(H)K @ 1.3 MW



@ ~ 1 MW
A solid or several segmented rods of graphite with right cooling

Muon Collider / Neutrino Factory / MOMENT
Hg- jet @ multi-MW



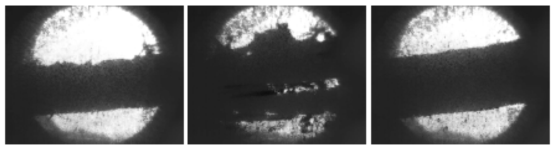
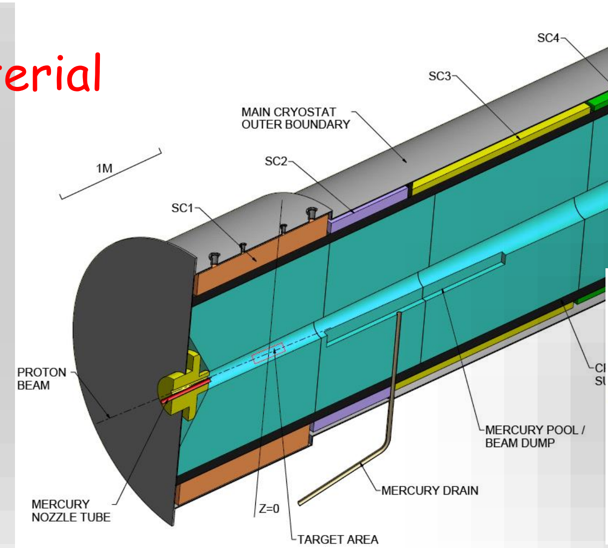


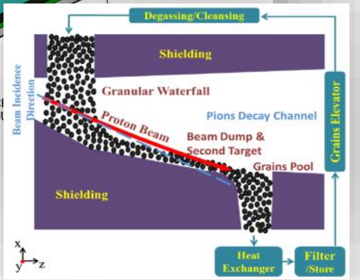
Figure 6 shows images at viewport 3 of an interaction of a 15-m/s jet and a 24-GeV, 10×10^{12} proton pulse in a 10-T solenoid field. A sequence of 200 images was collected at viewport 3 with a 2-ms frame interval .

Figure 6: A proton beam/jet interaction as viewed in viewport 3: Left: Image of the jet before interaction; Middle: Image of the interaction aftermath; Right: Image of the reformed jet stream.

@ multi-MW
Fluidized recirculated material
Liquids, granules
Jets. waterfalls

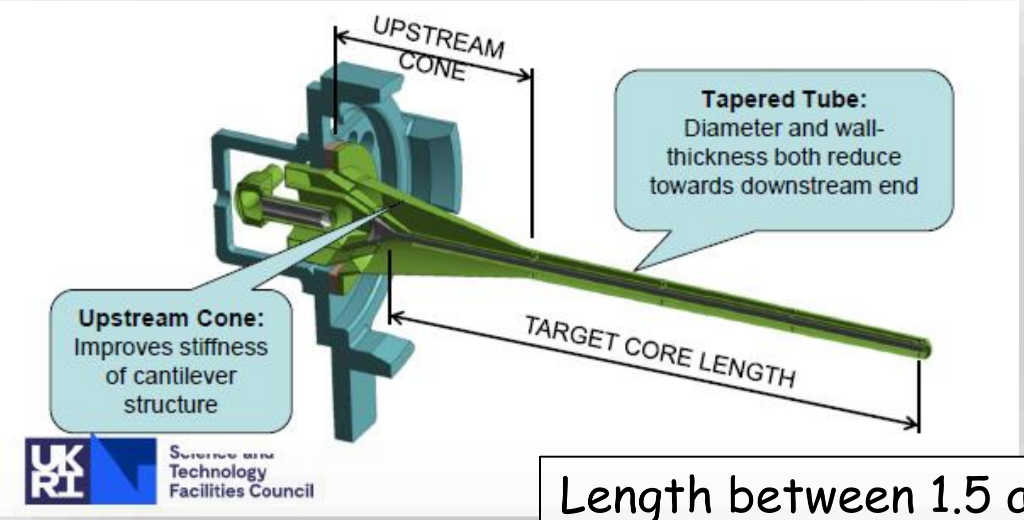
MOMENT's 14 T superconducting capture solenoid + waterfall target/tungsten carbide



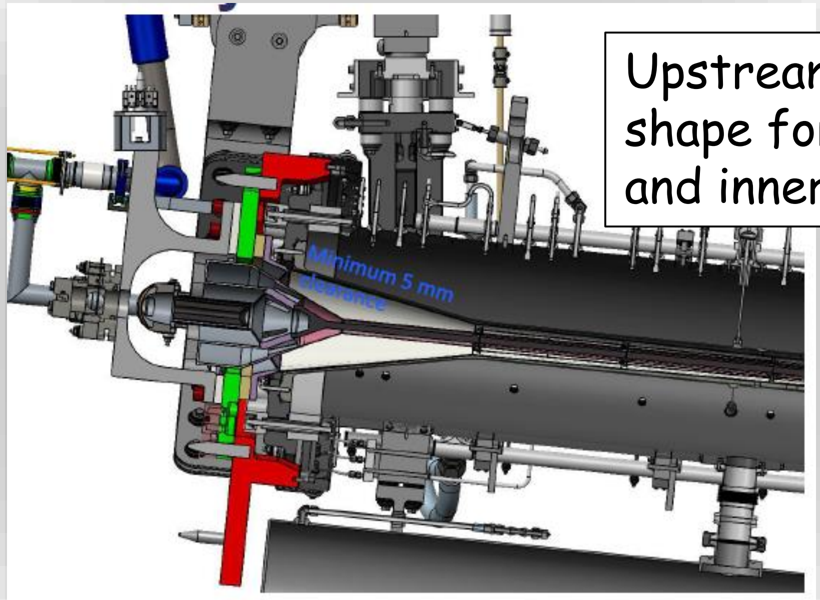


E.g., Proposed Graphite target for LBNF @ 1.2 MW, based on T2K experience

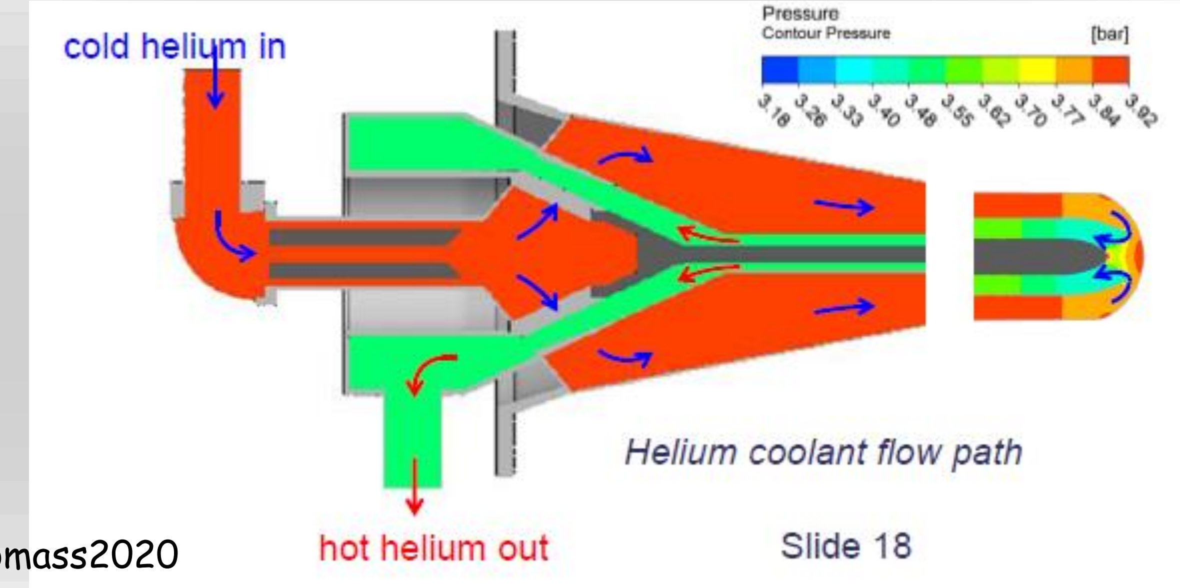
- Single cantilevered design
- Upstream conical support design
- Key to survival ability is cooling
- Graphite needs to be run hot to “anneal out” any damage” effect (~ 600 °C)
- Lifetime difficult to predict, data from T2K and NuMI + RaDIATE



Length between 1.5 and 1.8



Upstream conical shape for the target and inner conductor

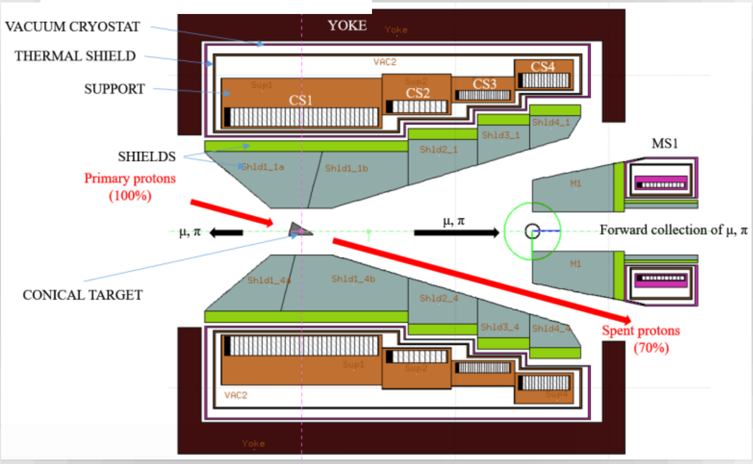


C. Densham @ Snomass2020

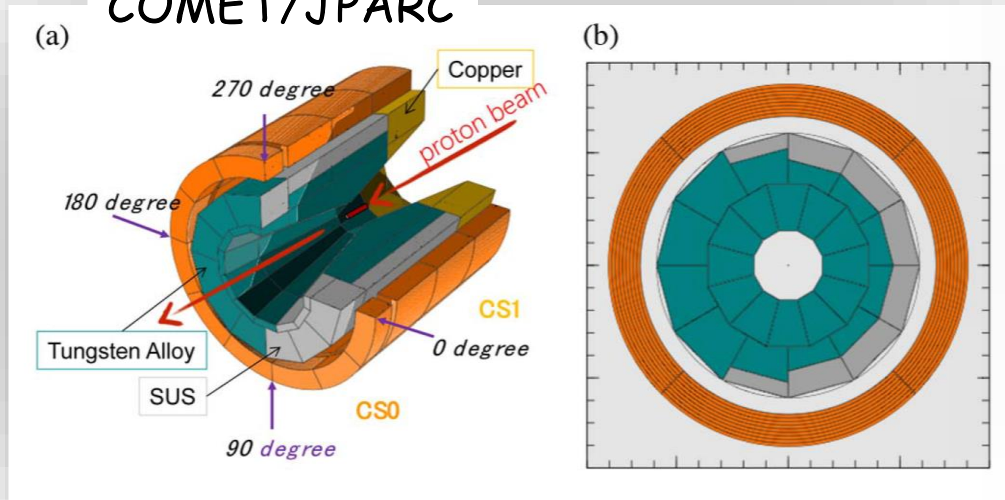
Superconducting solenoids at the target station

- Tailored for
  - μSR, LFV violation physics with kW targets (EMuS, Mu2e, COMET…)
  - Maximum power 100 kW -> Mu2e-II for 3 years
  - Neutrino Factories and Muon Colliders with multi-MW targets
- Best choice for high-Z fluidized and recirculated targets as liquid/granular jets or waterfalls
- Double sign collection for pions, needed for muon colliders
- Extensive shielding for coils, complicated design, expensive
- Maximum lifetimes based on Monte-Carlos and specific dose limits for their superconducting wires
  - Their longevity is not proven in practice like horns

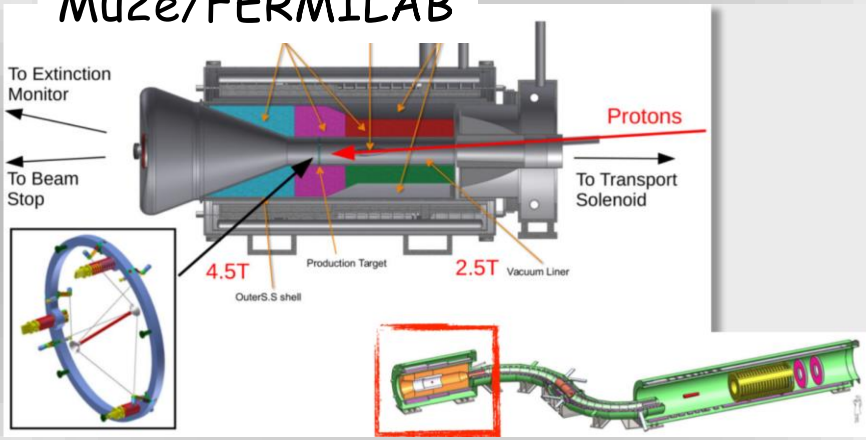
EMuS/CSNS



COMET/JPARC



Mu2e/FERMILAB



RaDIATE international collaboration
Radiation Damage In Accelerator Target Environments

Predicting and improving lifetimes and reliability of targets, beam windows, focusing devices and other equipment

nuSTORM can benefit and apply the results of this research

Activities so far

a) High-Energy Proton Irradiation Campaign (BLIP, BNL)

- Multiple material irradiation, Graphite, Titanium, Beryllium – Post-Irradiation Examination (PIE)

b) In-Beam Thermal Shock Testing (HiRadMat, CERN)

- Beryllium beam impact experiment
- multiple material (including BLIP irradiated specimens)

c) Autopsy and PIE

- NuMI Beryllium Primary Beam Window / micro-mechanical and helium bubble studies
- NuMI-MINOS target graphite fins

d) Low-Energy Ion Irradiation

- Beryllium at Surrey/Oxford/KIT

Recent results

- RaDIATE BLIP irradiation PIE status and preliminary results on Beryllium and Titanium
- Beryllium micro-mechanical and helium bubble studies
- Graphite characterization at Bristol
- In-beam thermal shock testing (HiRadMat @CERN)
- NT-02 graphite fin swelling analysis

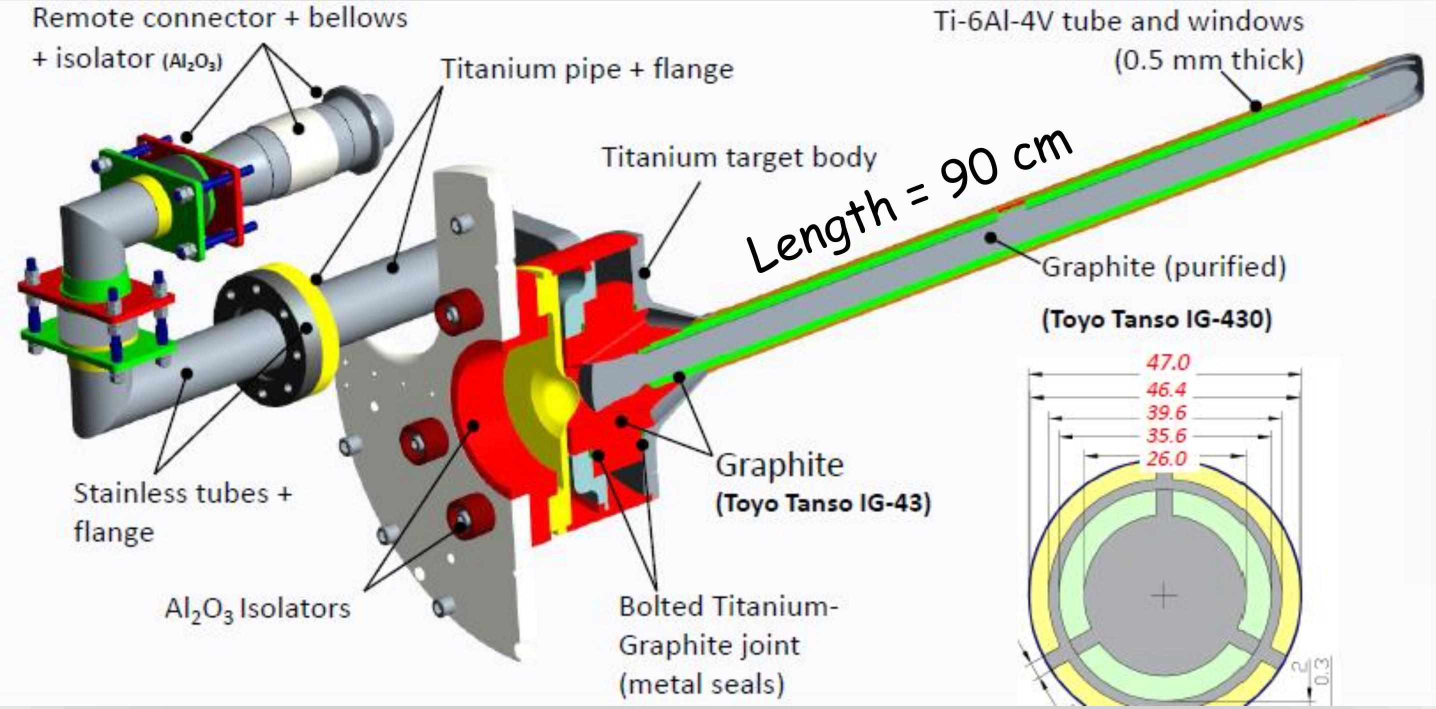
Patrick Hurh @ NBI2019
C. Densham @ Snomass2020

Concluding

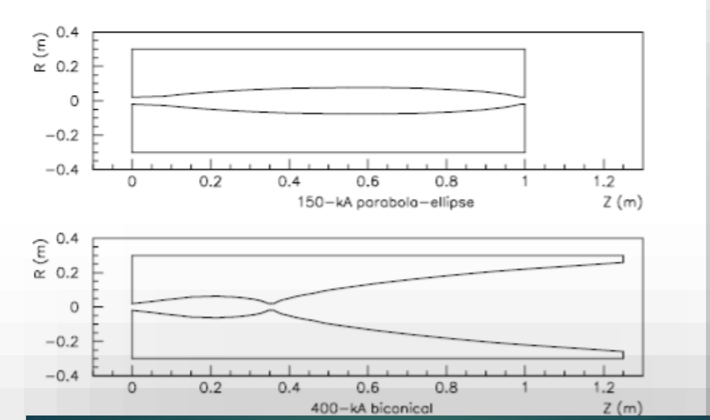
For nuSTORM probably the right system for pion capture system might be:

- A horn with a proper shape of inner conductor to fulfill the pion capture requirements
- Best grades of graphite and special cooling for the target to be ready for a MW primary proton beam power

E.g., like T2(H)K state of the art target design



Inner conductors may vary e.g.,



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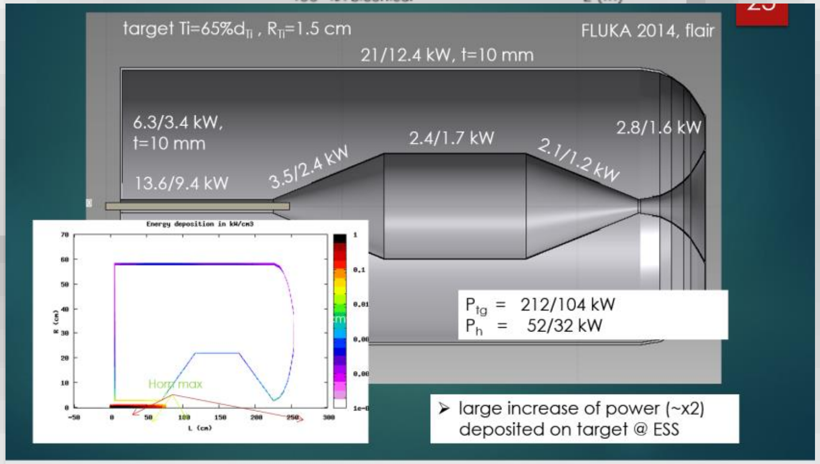
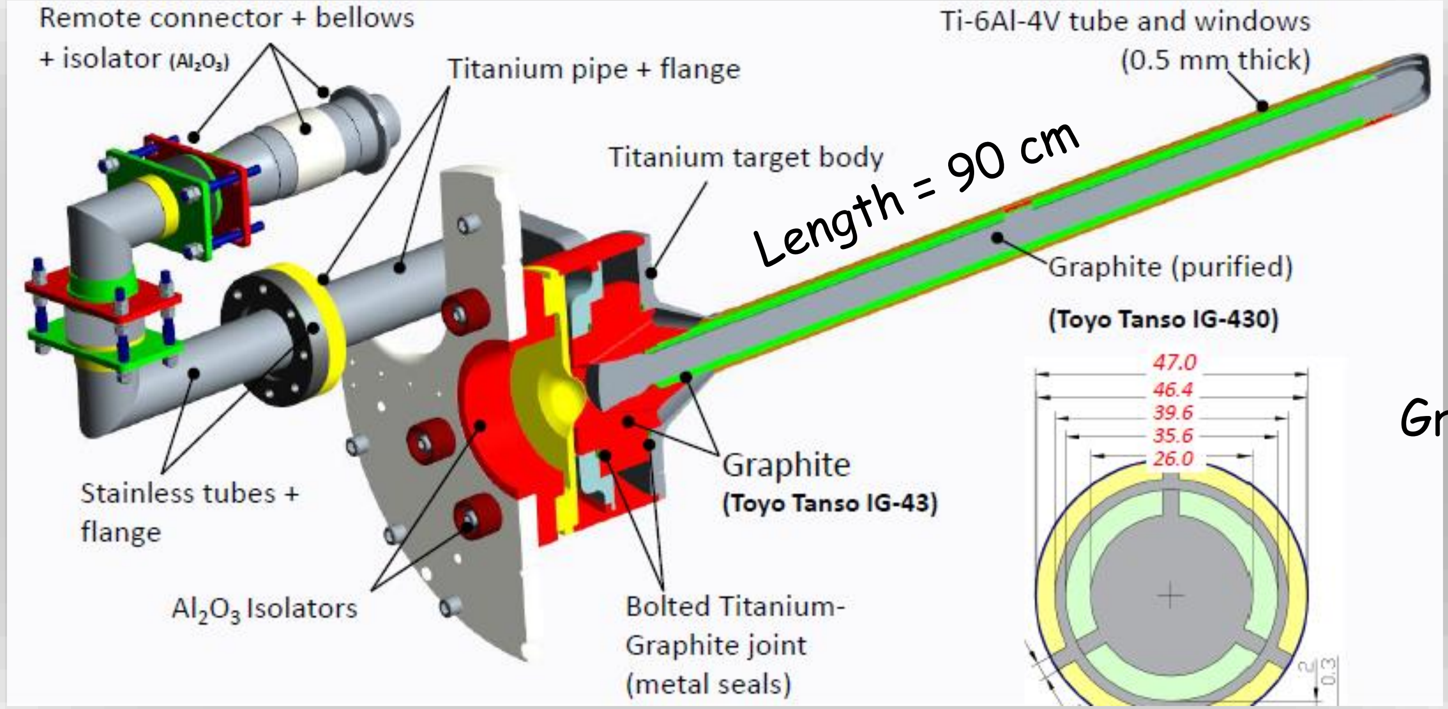


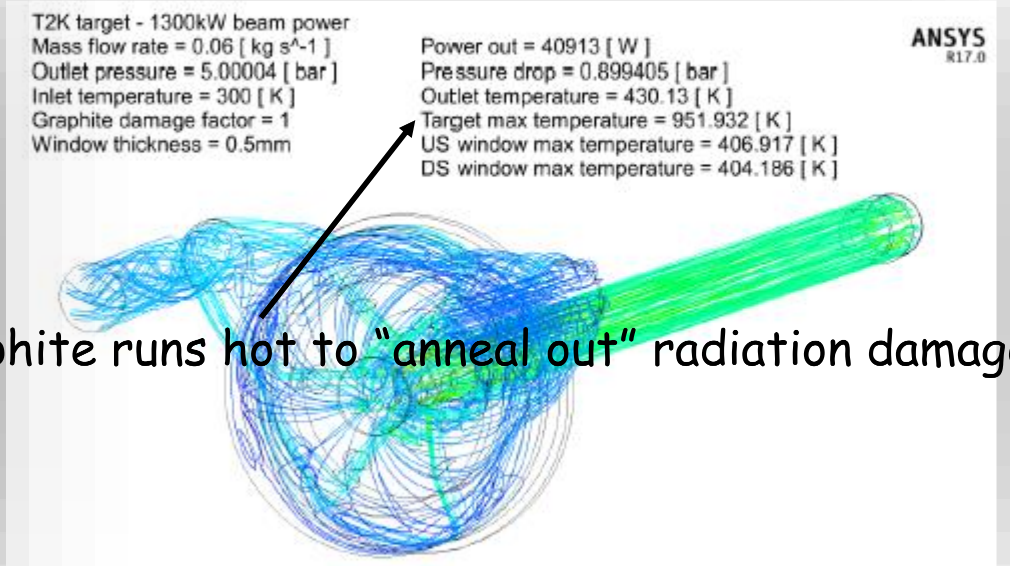
Thank you

T2(H)K @ 1.3 MW

upgrade the design of 750 KW -> 1.3 MW (2023)

- Only increase the pressure from 1 -> 5 bar, for higher He mass flow,
- Re-optimization of the Ti windows, upstream and downstream
- The LBNF target will be based on the experience of T2K @ 1.3 MW





Graphite runs hot to "anneal out" radiation damage

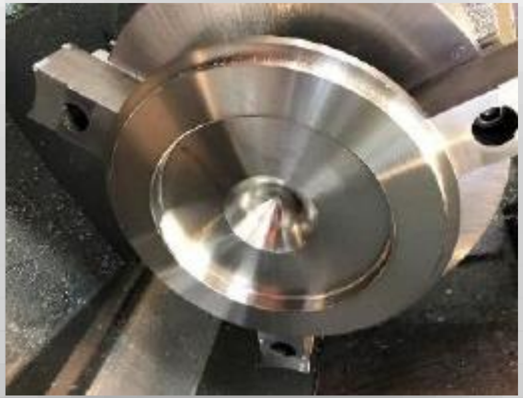
Eric Harvey-Fishenden @ NBI2019
C. Densham @ Snomass2021

T2(H)K @ 1.3 MW target windows upgrade

Reshaping of the windows in order to decrease pressure stresses by a factor of 3 and maintain good cooling, windows' thickness = 0.5 mm, Ti-6Al-4V

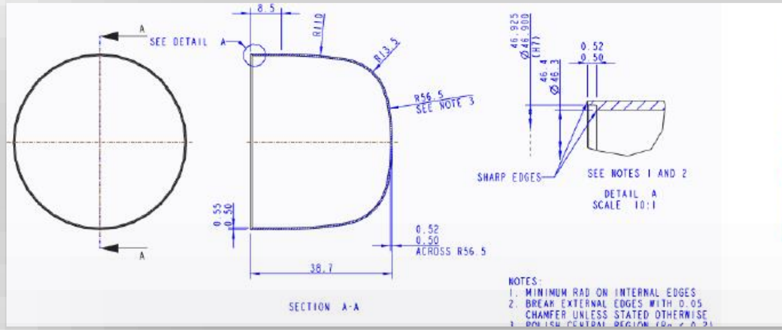
Upstream window:

- plate thickness increased

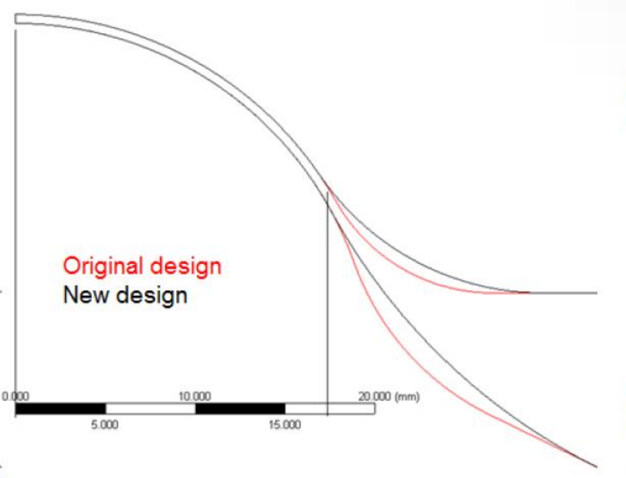


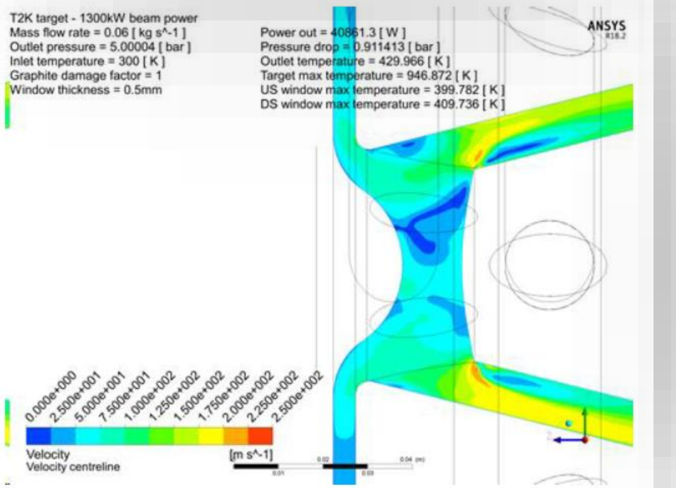
Downstream window:

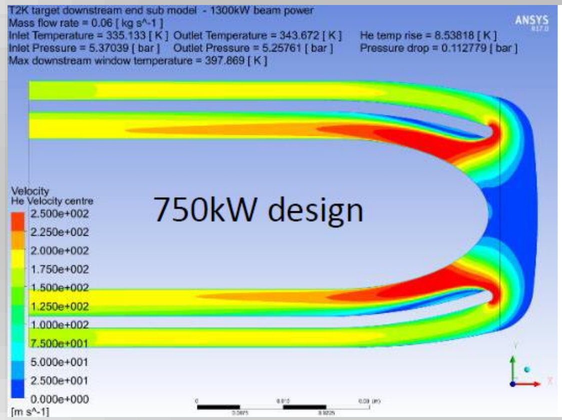
- curvature increased

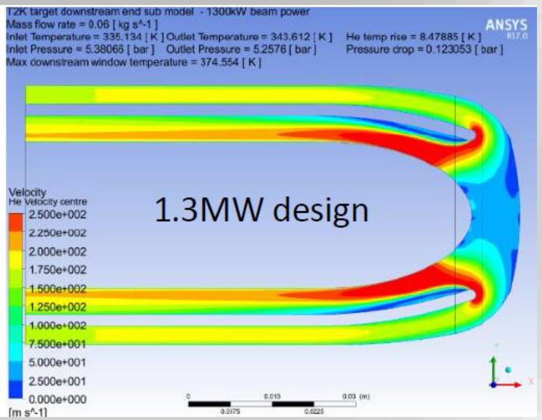


Prototype currently in manufacture





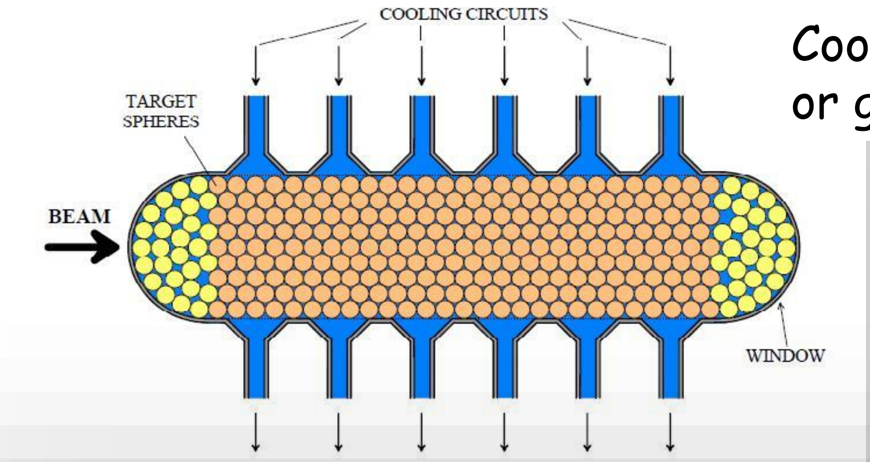




Dave Pushka @ NBI2019

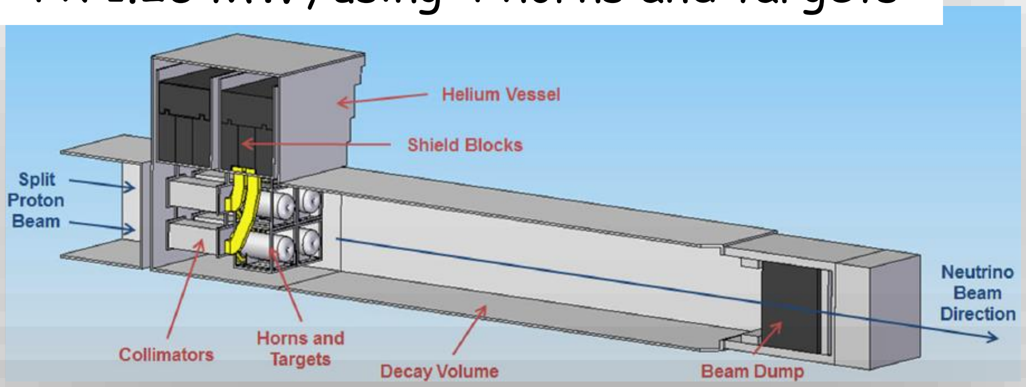
Packed-Bed Target for ESSnuSB, @ 5 MW

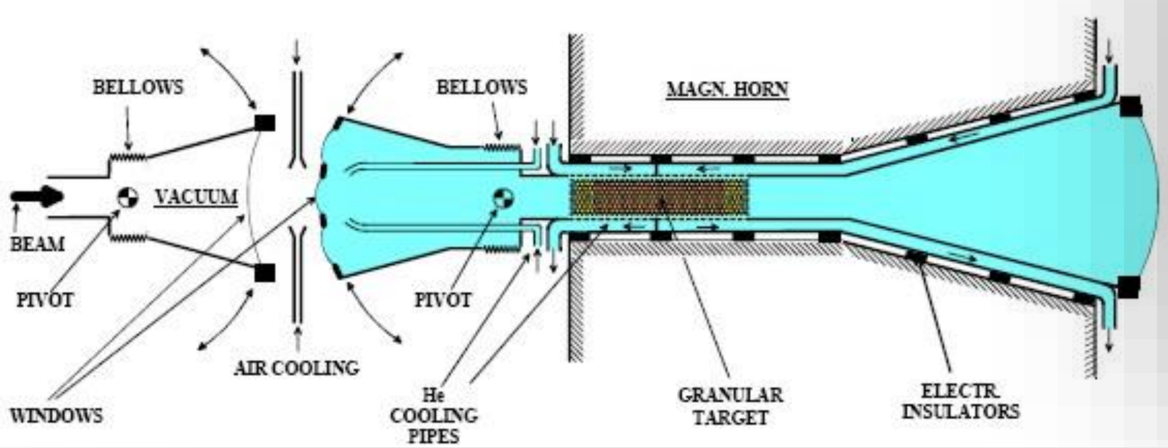
Packed bed concept targetry explores transverse cooling, and uniform heating of the spheres to reduce stresses
firstly proposed at CERN (2001) by P. Sievers



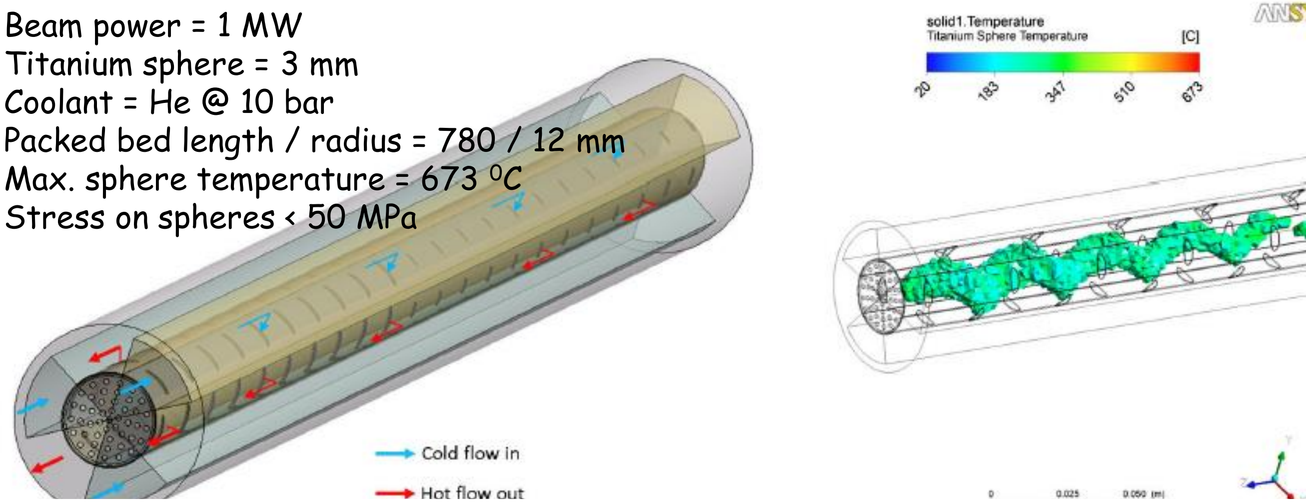
Coolant water or gas He

ESSnuSB target station splits the 5 MW to 4 x 1.25 MW, using 4 horns and targets





Beam power = 1 MW
Titanium sphere = 3 mm
Coolant = He @ 10 bar
Packed bed length / radius = 780 / 12 mm
Max. sphere temperature = 673 ^{0}C
Stress on spheres < 50 MPa



Older study 2010-12,
perhaps obsolete in the rising of T2(H)K and LBNF targets