Target Options for a Neutrino Factory

Chris Densham, Otto Caretta, Tristan Davenne,

Mike Fitton, Peter Loveridge, Matt Rooney

Science & Technology Facilities Council
Rutherford Appleton Laboratory

Objectives for Target Station

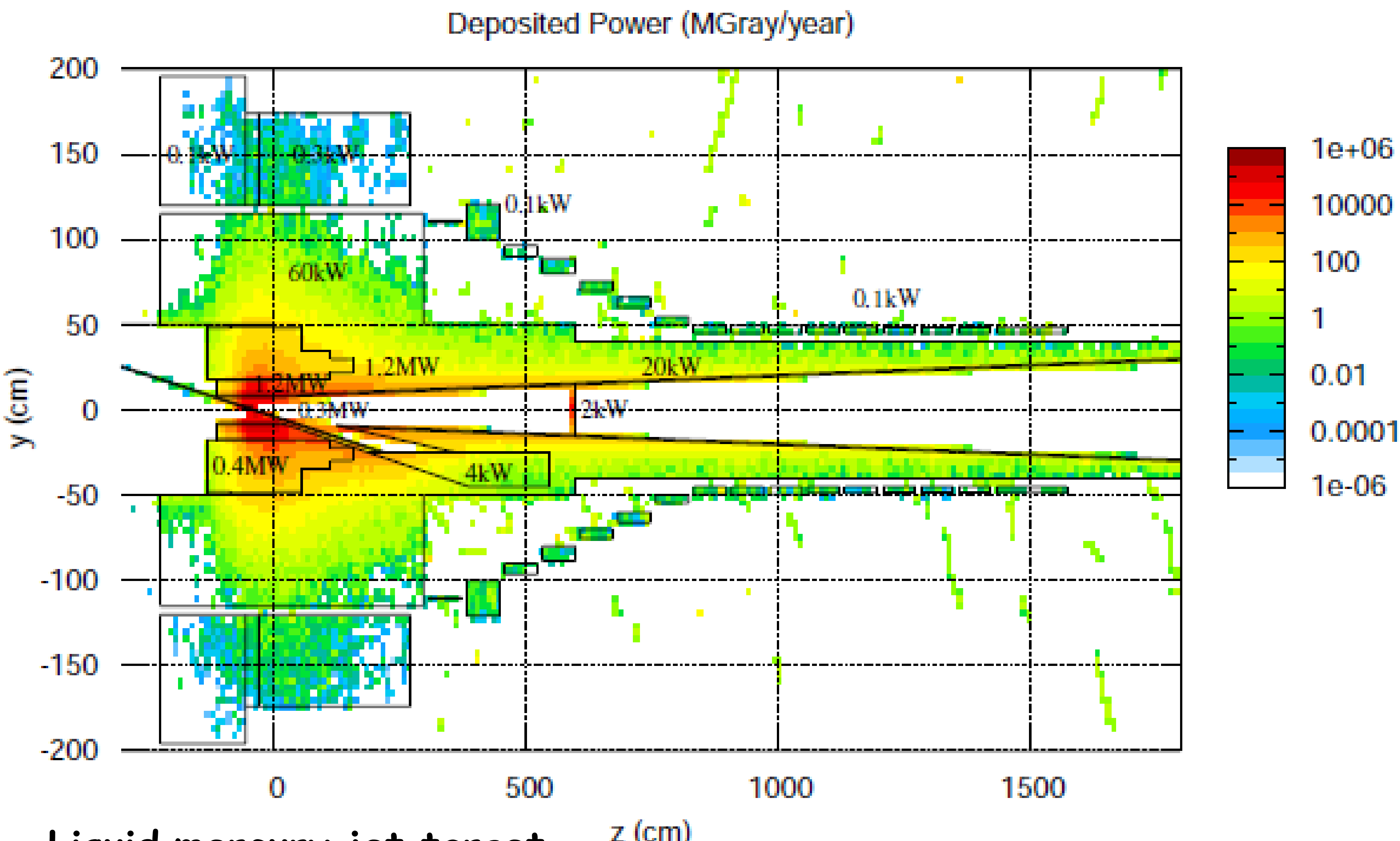
- Target Station is an engineering task
  - With scientific objectives
- Focus on NF (and MC?)
- Objective: maximise useful pion yield per 10^7 s year of operation, over 10 (20?) year lifetime
- Yield = instantaneous yield x reliability
  - Instantaneous yield is most fun to study
    - has received (almost) all attention so far
  - Reliability includes:
    - Mean time between failure
    - Speed of target, (shield, solenoid etc) changeover
    - Difficult (and less fun) to assess

Key target station issues	Candidate/required technologies
1. Target	1a. Liquid Hg jet 1b. Fluidised W powder 1c. Solid W bars 1d. Low Z targets
2. Beam window	Thin low Z windows (beryllium)
3. NC inner solenoid	Conventional copper
4. SC outer solenoid	4a. Nb3Sn 4b. HTS
5. Solenoid shield	WC
6. Target station engineering	Target integration Remote maintenance Shielding
7. Beam dump	7a Liquid Hg 7b For W bars? 7c W powder?
8. Horn back-up? (2 drivers for 2 signs!)	Conventional neutrino beam horn
9. Safety / environmental	!

NF vs MC?

- Muon Collider requires point-like source
- High Z target material strongly favoured
  - Liquid mercury jet is baseline
  - See Kirk MacDonald plenary talk tomorrow for latest news
- Convenient to regard Neutrino Factory target station as prototype for Muon Collider
- If one decouples NF from MC, does one end up with same answer?
- For a NF, are other options possible/preferable?
- Can the beam size be increased (from 1.2 mm (rms) baseline)?

Heat loads in baseline Target Station (J.Back)



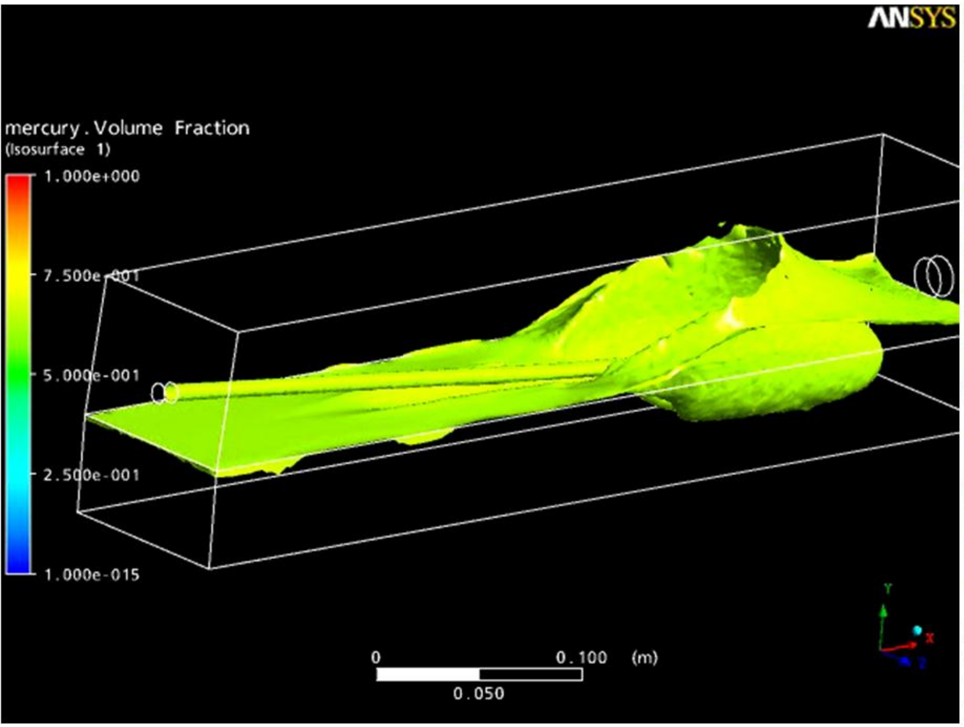
Liquid mercury jet target

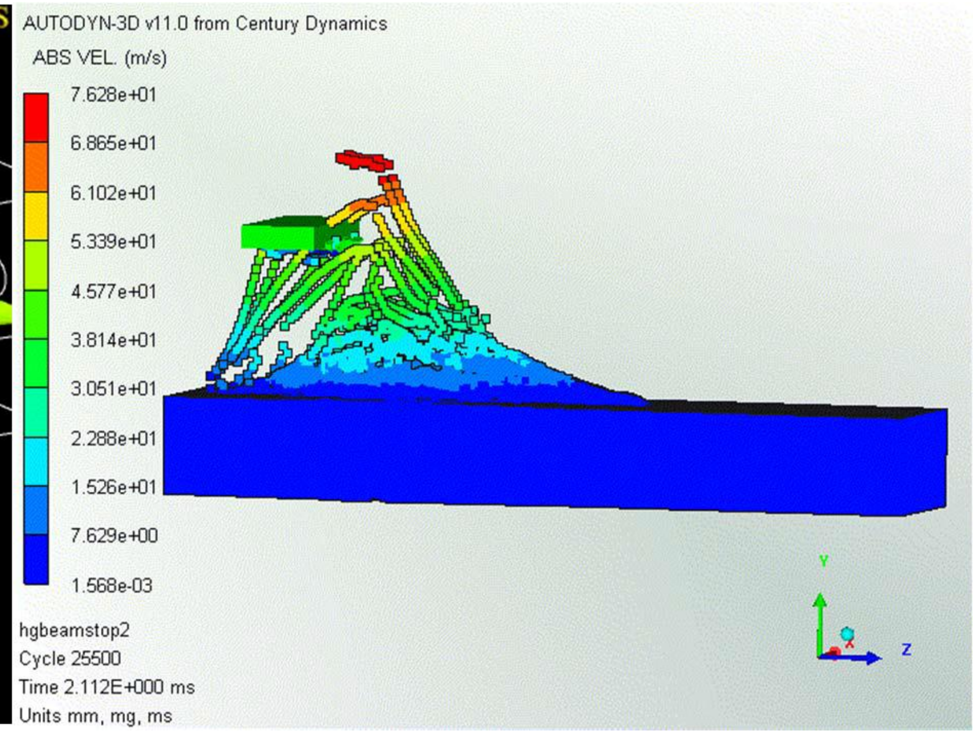
Baseline solenoid system:
Two factors lead to significant technical challenges

1. Demanding Magnet Parameters - *High field (14 Tesla) in a large bore (1.3 m)*
   - Huge magnetic forces (10,000 Ton)
   - Large stored energy (~600 MJ)
   - Low temperature margin of superconductor
   - Pushing at the limits of present superconductor technology

2. Harsh Radiation Environment – *Heating and material damage Issues*
   - Heat load from 4 MW pulsed proton beam
     - Total Heat load into the cold mass
     - Local Power Density
     - Instantaneous pulsed heating effects
   - Radiation damage to materials
     - Superconductor
     - Stabiliser
     - Turn-to-turn insulation
     - Load Bearing Elements

Plus one or 2 liquid mercury jet challenges





Disruption of beam dump by mercury jet

Disruption of beam dump by non-disrupted proton beam

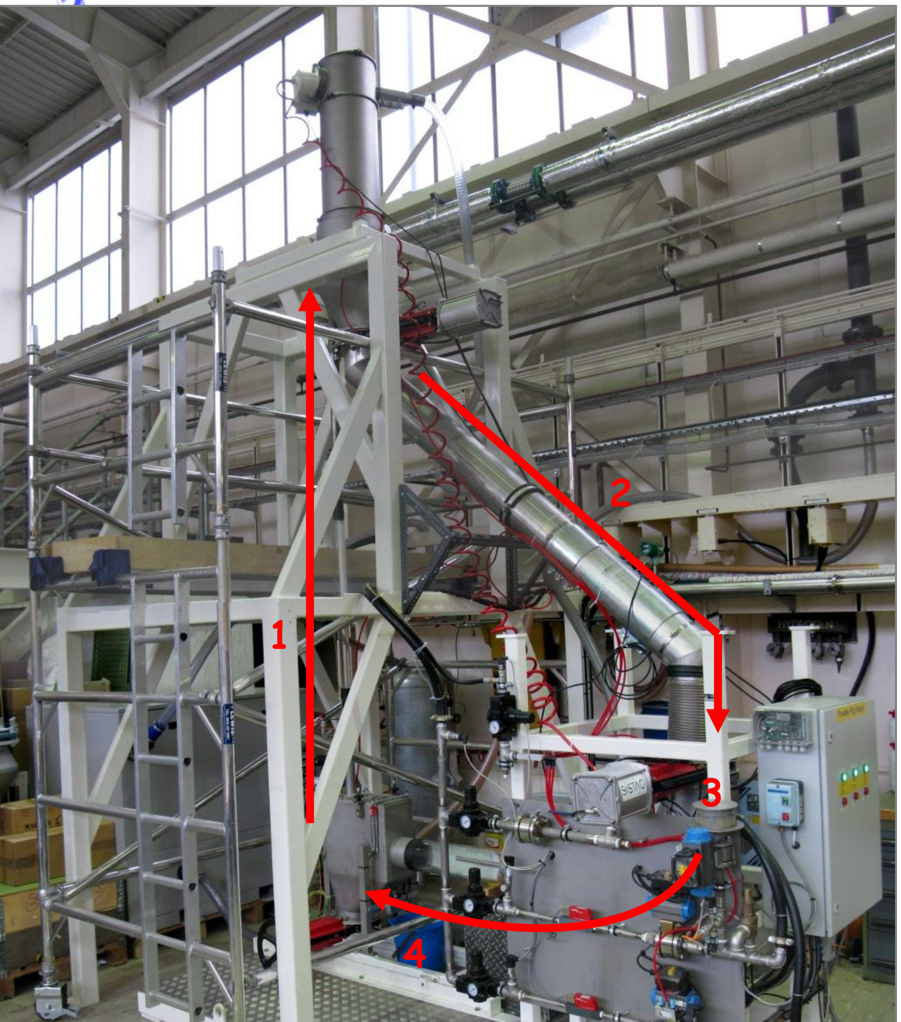
Tristan Davenne

Alternatives to liquid mercury jet?

A few personal comments:

- A neutrino factory will not be built any time soon
- The target station is likely to be the limiting factor in the performance of the facility
- Worth spending time looking at as wide a range of alternatives as possible

Fluidised tungsten powder: broadly compatible with baseline



1. Suction / Lift
2. Load Hopper
3. Pressurise Hopper
4. Powder Ejection and Observation

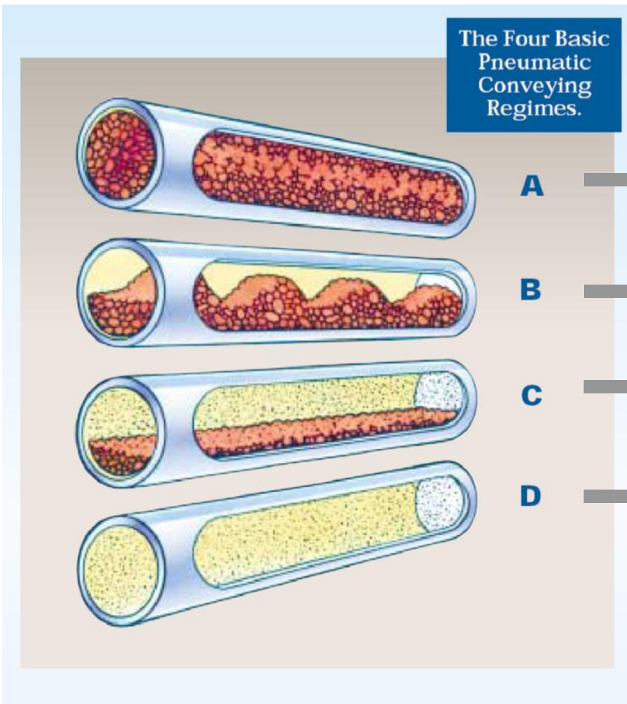
- Rig contains 100 kg Tungsten
- Particle size < 250 microns
- Discharge pipe length c.1 m
- Pipe diameter = 2 cm
- Typ. 2-4 bar (net) pneumatic driving pressure (max 10 bar)

Pneumatic Conveying Regimes Explored so Far

Low Velocity

Increasing Driver Pressure

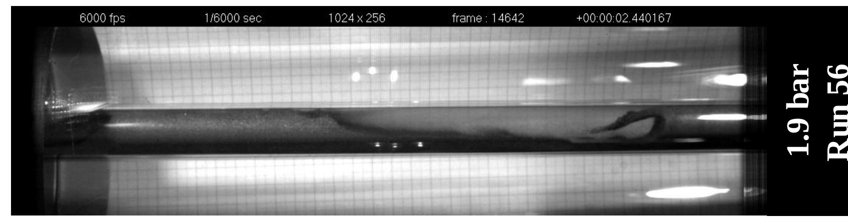
High Velocity



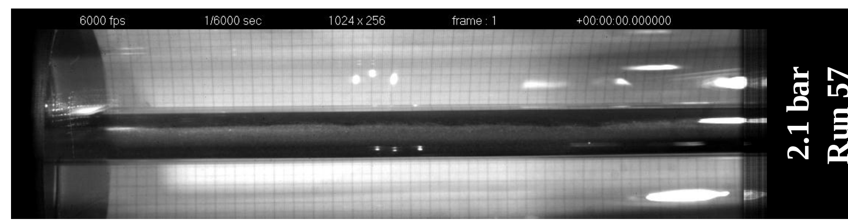
A. Solid Dense Phase

- Pipeline full of material, 50% v/v
- Low velocity
- Not yet achieved in our rig – further work

B. Discontinuous Dense Phase



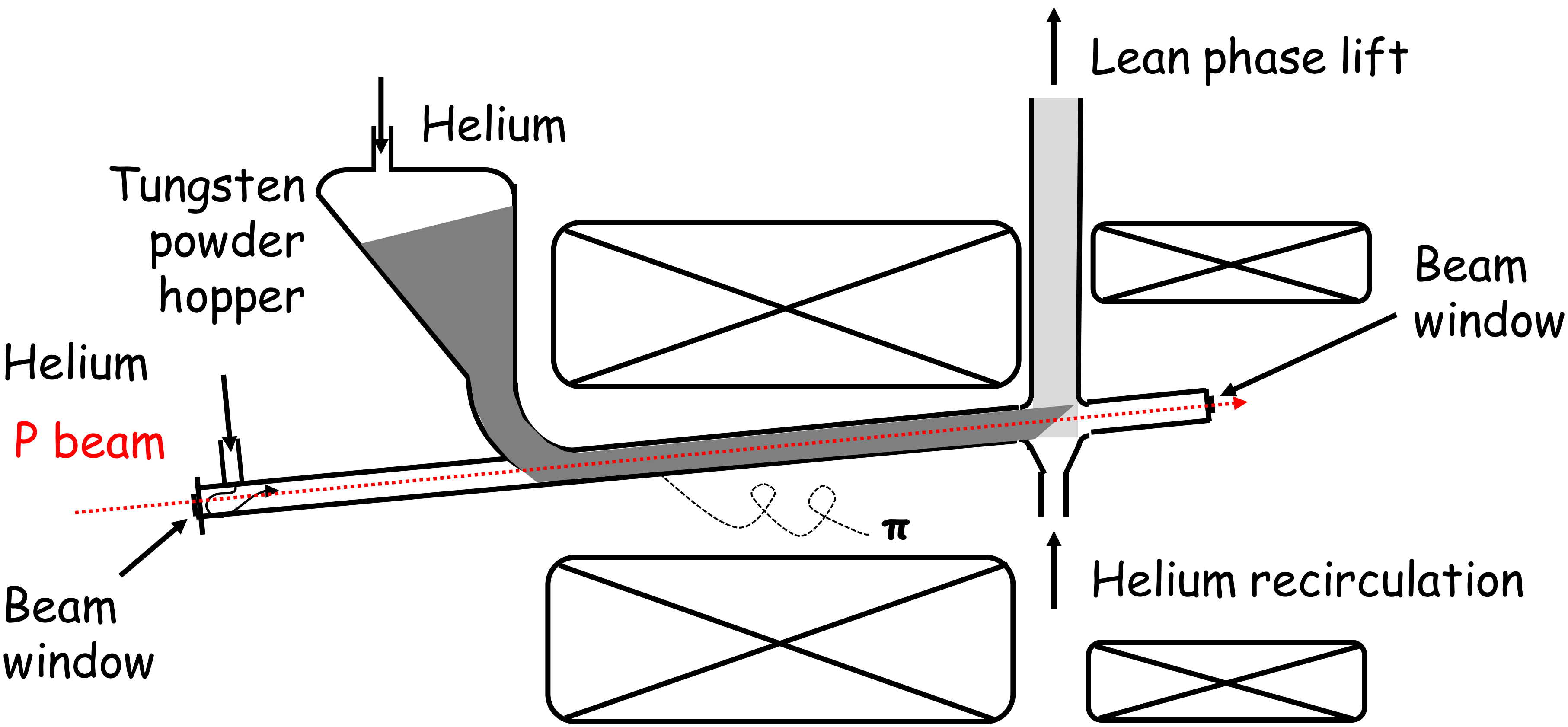
C. Continuous Dense Phase



D. Lean Phase

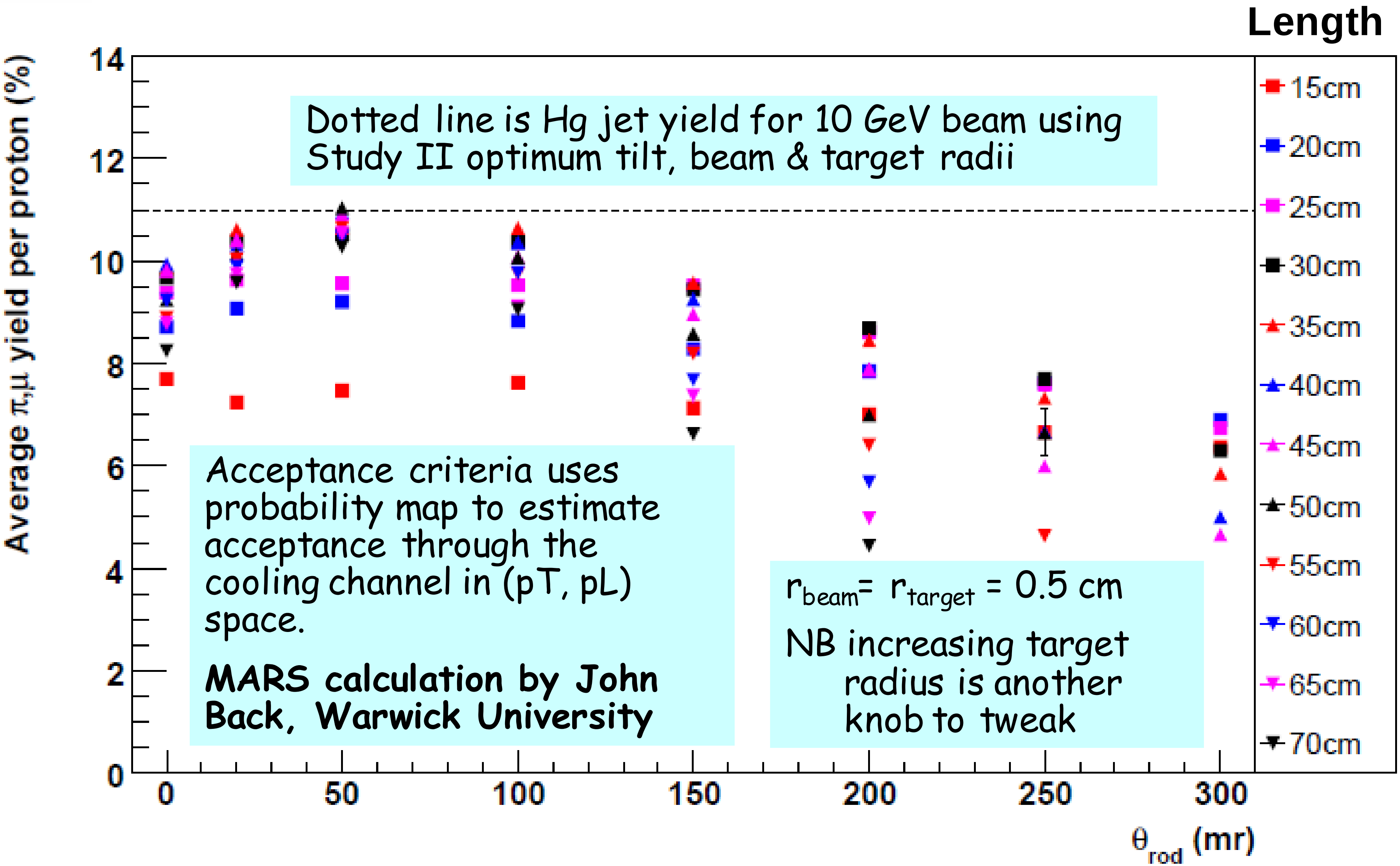
- Low fraction of solid material
- High velocity = erosion!
- Used in vacuum recirculation line

Schematic of implementation as a Neutrino Factory target



NB Alternative configurations possible

Pion+muon production for variable length 50% material fraction W vs 100% Hg



High Power Targets

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Meson Production at 8GeV (X.Ding)

Target	50% W (9.65 g/cm^3) with optimization*	Hg (13.54 g/cm^3) with optimization
Meson	29069 (pos: 14099 neg: 14970)	28819 (pos: 13613 neg: 15206)

***Target radius: 0.47 cm, target angle: 80mrad, target length: 45cm**

HIGH RADIATION TO MATERIALS – HIRADMAT@SPS

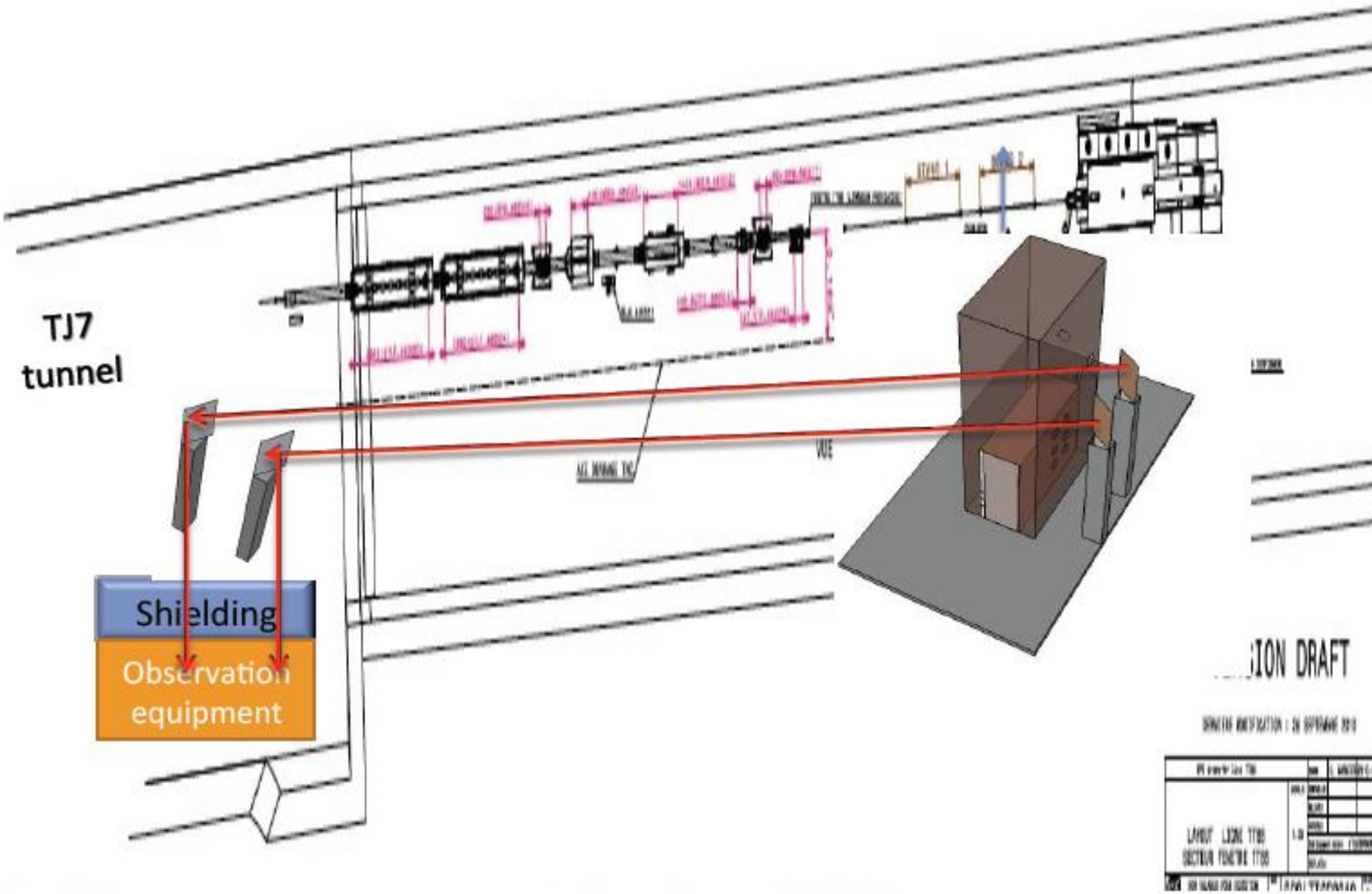
A NEW IRRADIATION FACILITY AT CERN FOR MATERIAL TESTING

Powder 'thimble' test is scheduled to be first ever experiment on HiRadMat this autumn

Ilias Efthymiopoulos, CERN

4th HPTWorkshop - Malmoe , May 6, 2011

Experimental setup



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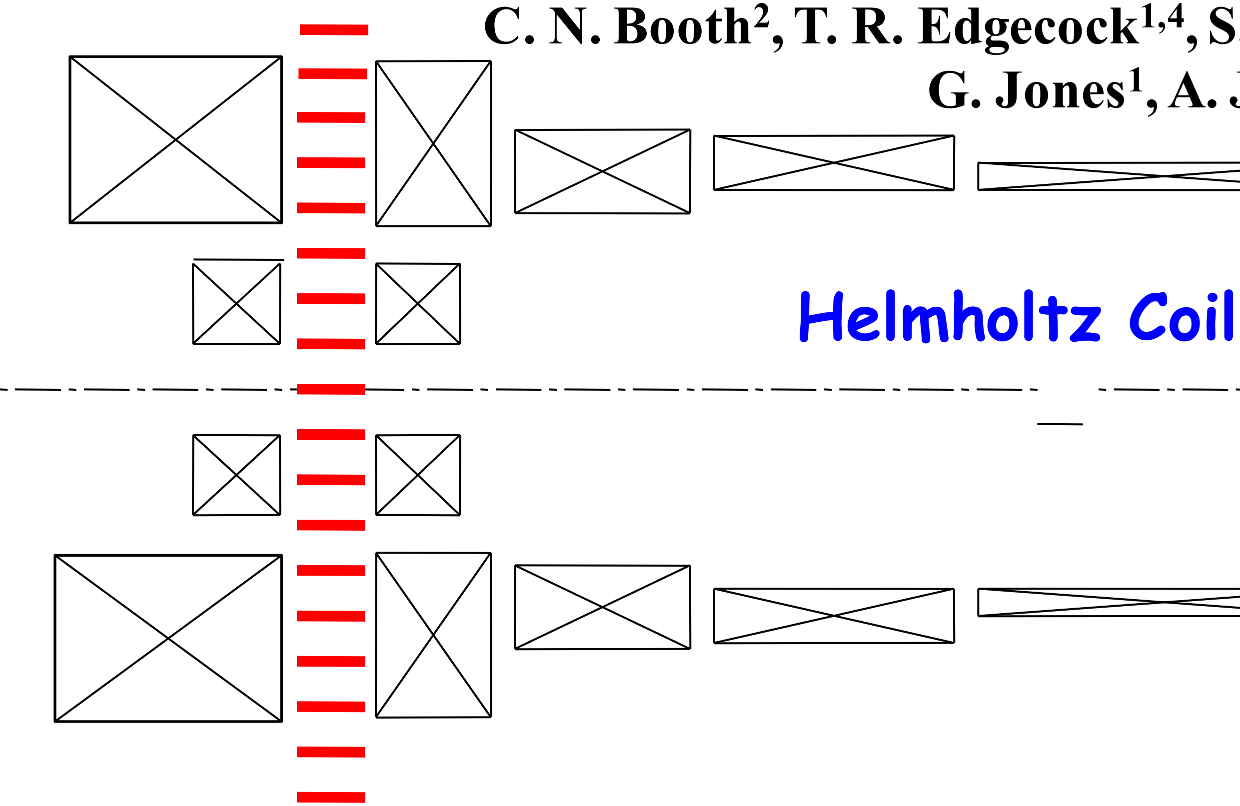
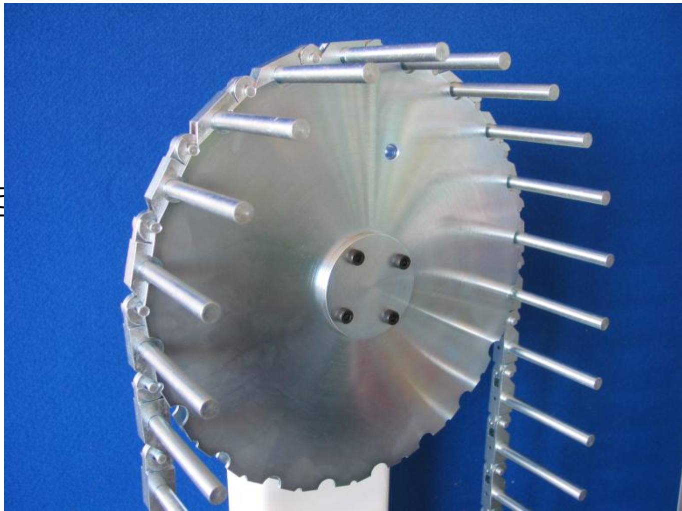
ISIS

Re-circulating solid tungsten bar ideas

J. R. J. Bennett[1], G. P. Škoro[2], J. J. Back[3], D. W. J. Bellenger[1], C. N. Booth[2], T. R. Edgecock[1,4], S. A. Gray[1], D. M. Jenkins[1], L. G. Jones[1], A. J. McFarland[1], K. J. Rogers[1].

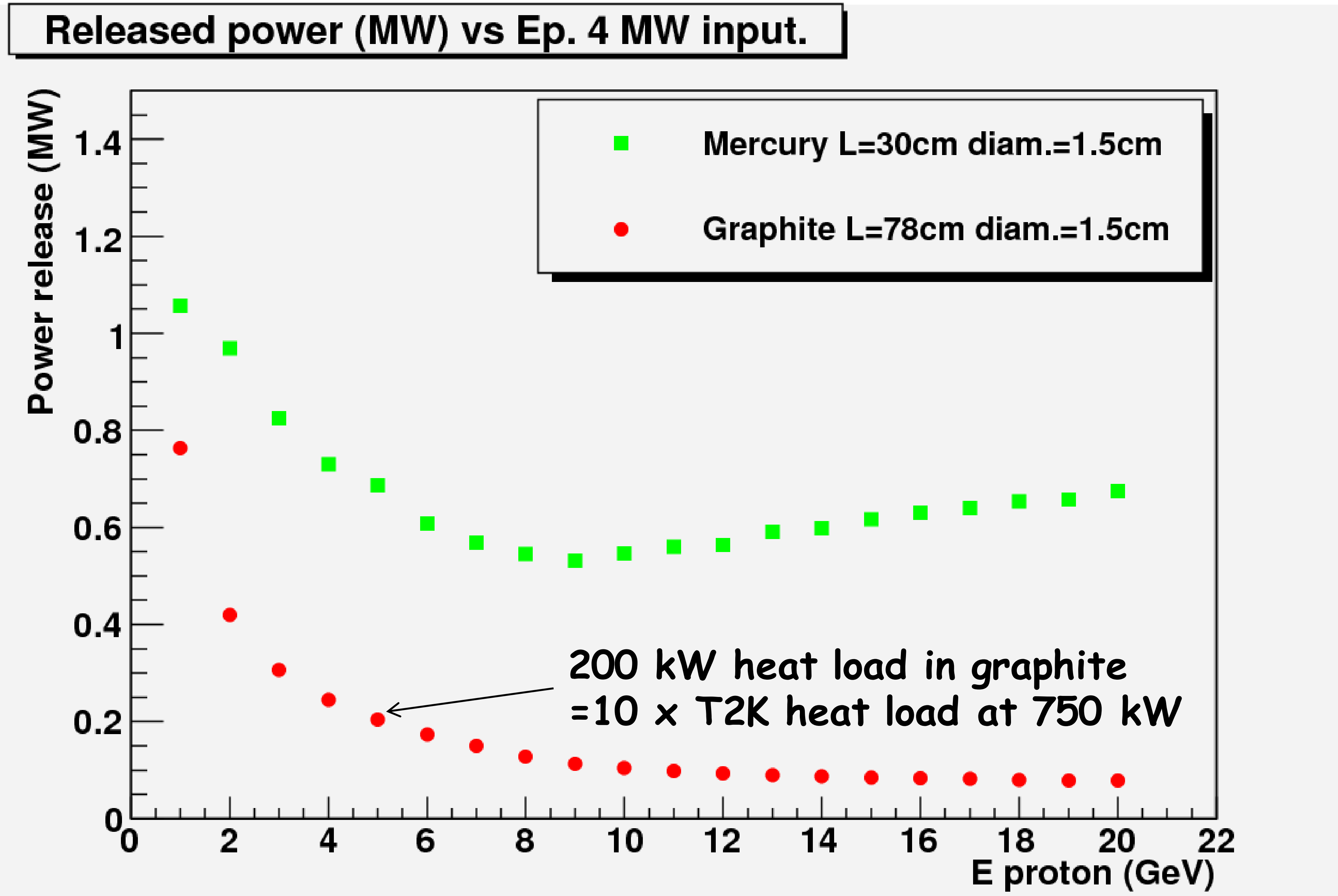




That's enough about heavy metals

- Is a low Z target an attractive option for a Neutrino Factory?

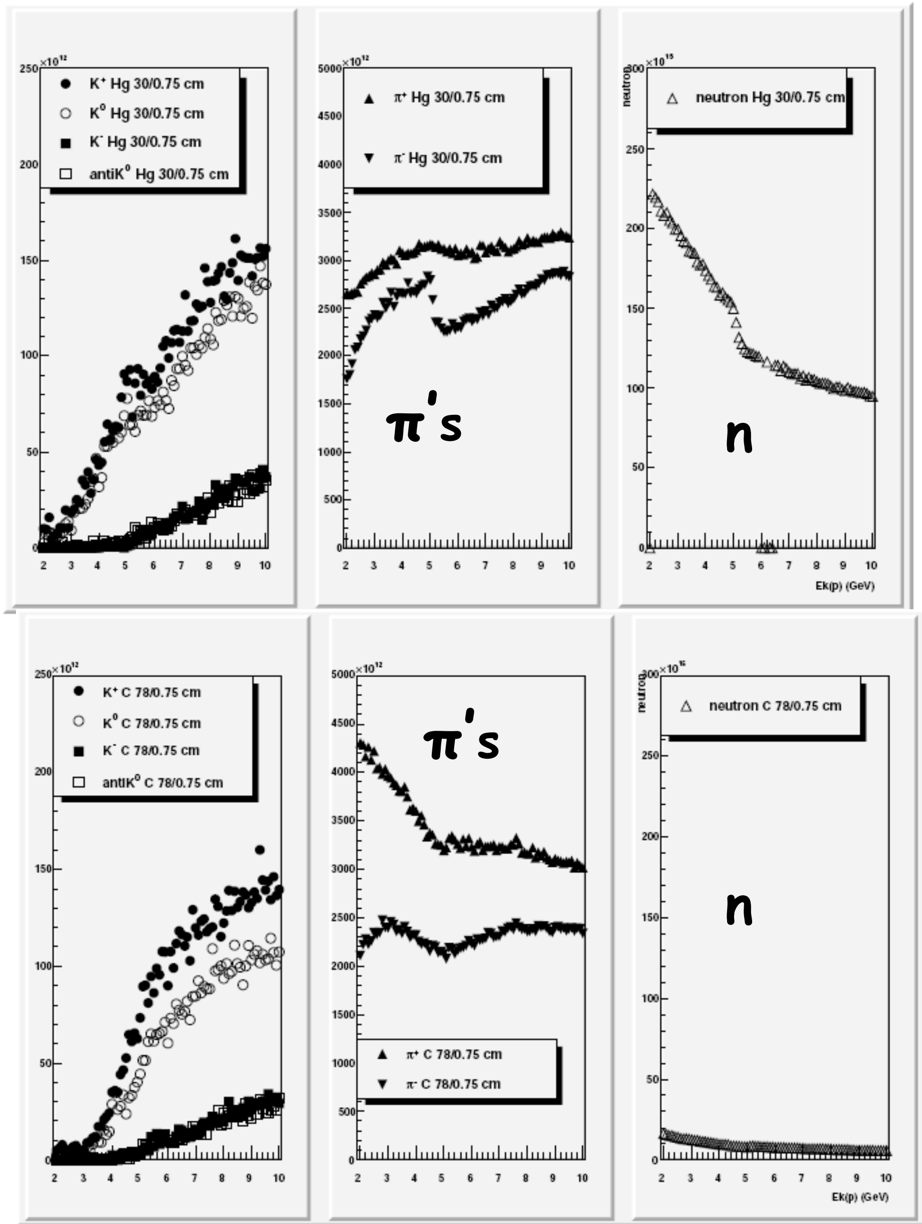
Target material & heat loads (A. Longhin)



Particle production vs target material

Hg

C

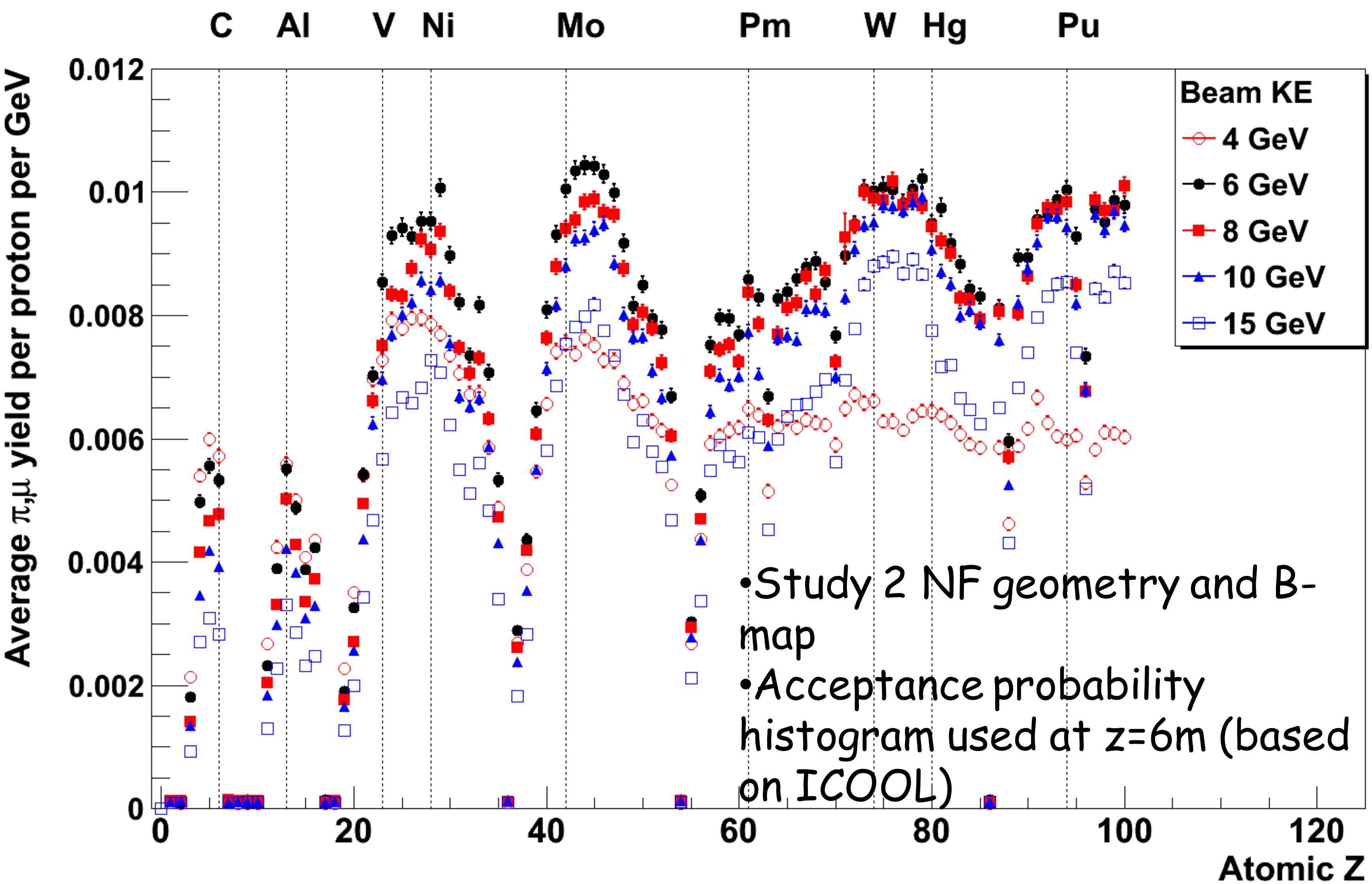


- Proton kinetic energy = 2-10 GeV
- Integrated pion yields comparable for carbon and mercury targets
- Neutron flux for Hg reduced by ~ x15 with C !!

(lower neutron flux => lower heating and radiation damage to solenoid system)

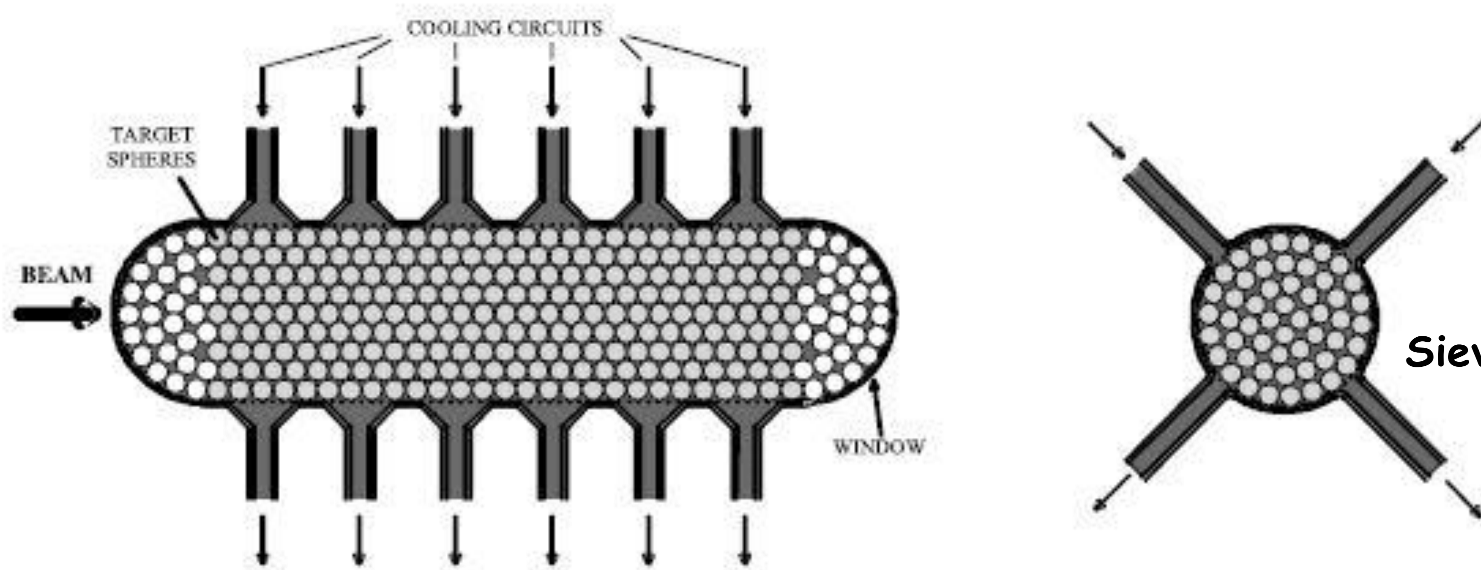
(A. Longhin)

Useful pion/muon yields for different Z's and beam energies (J.Back)



- Study 2 NF geometry and B-map
- Acceptance probability histogram used at z=6m (based on ICOOL)

Packed bed ideas: more attractive for lower Z



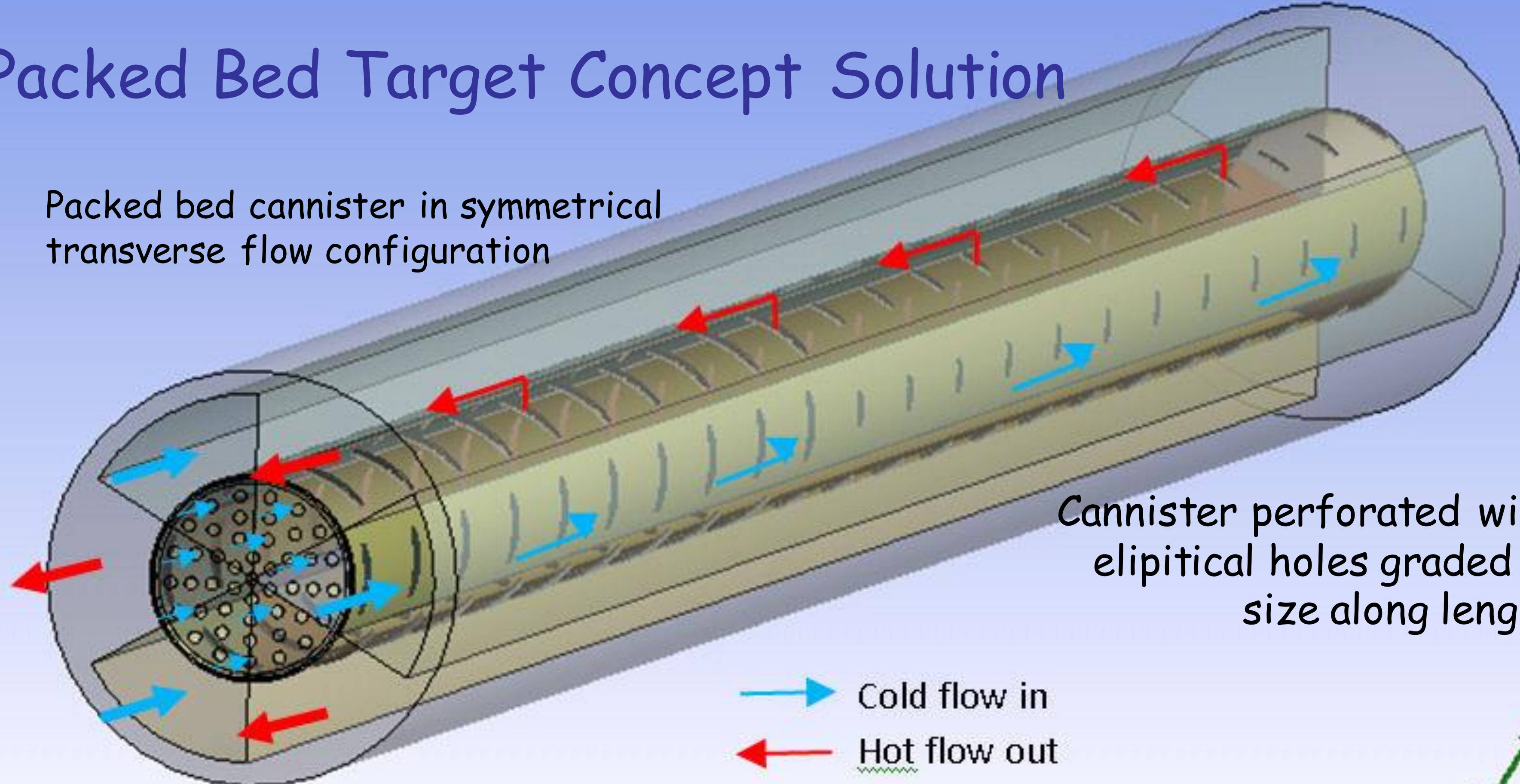
Sievers 2001

Relevant papers:

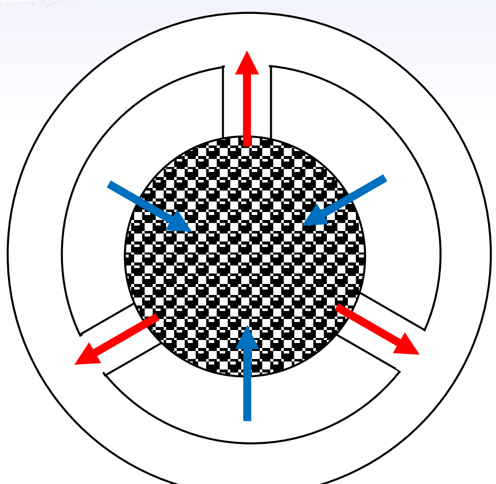
- *A helium gas cooled stationary granular target (Pugnat & Sievers) 2002 [considered for a neutrino factory target with 4MW beam]*
- Conceptual Designs for a Spallation Neutron Target Constructed of a Helium-Cooled, Packed Bed of Tungsten Particles (*Ammerman et al.*) [ATW, 15MW power deposited, 36cm diameter]

Packed Bed Target Concept Solution

Packed bed cannister in symmetrical transverse flow configuration



Cannister perforated with elipitical holes graded in size along length



Model Parameters

Proton Beam Energy = 4.5GeV

Beam sigma = 4mm

Packed Bed radius = 12mm

Packed Bed Length = 780mm

Packed Bed sphere diameter = 3mm

Packed Bed sphere material : Titanium Alloy

Coolant = Helium at 10 bar pressure

And let's not forget about beam windows

-T2K beam window (M Rooney)

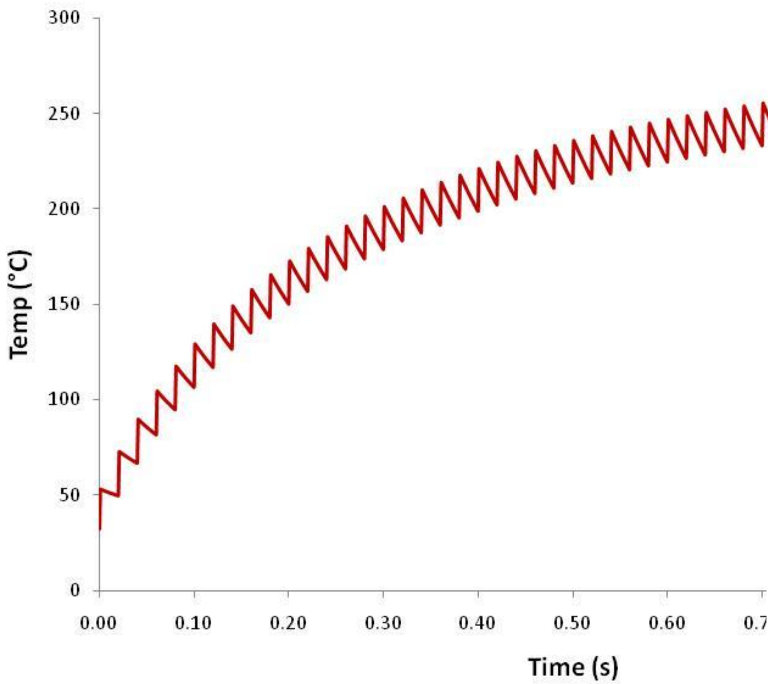
-Double-skinned titanium alloy window, cooled by helium gas

- Installed October 2009

- Designed for 30 GeV, 0.75 MW beam power

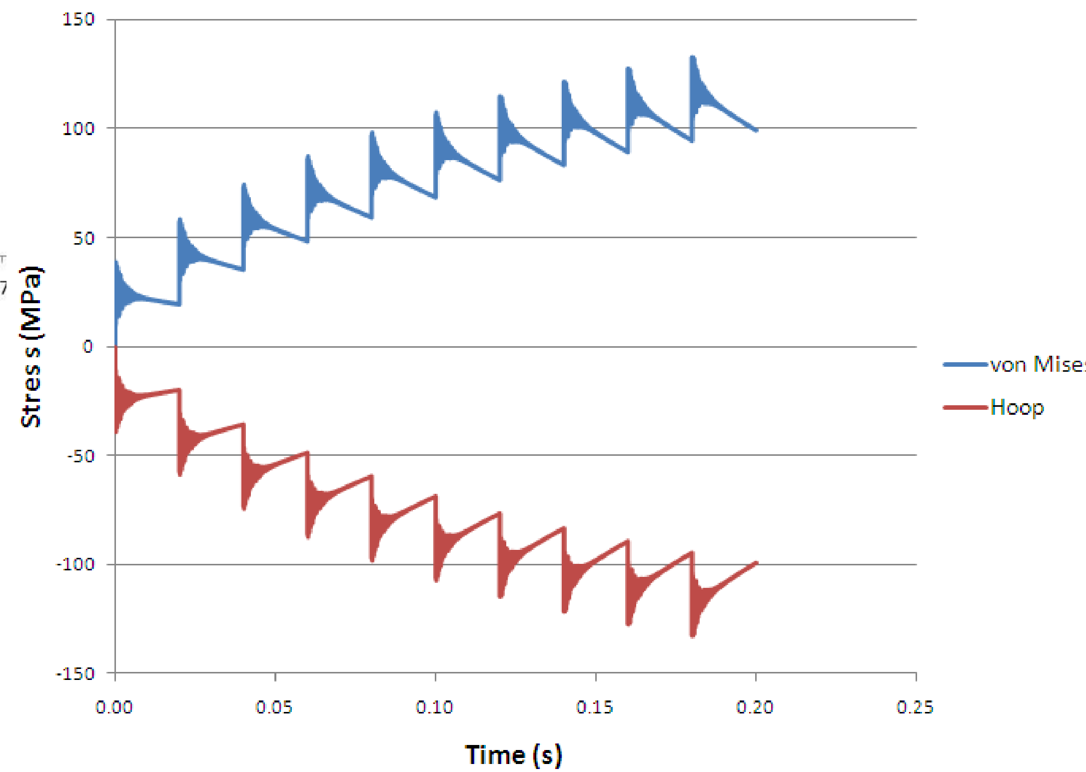
High Power Targets

4 MW beam window



HP SPL beam parameters

Beam energy: 5 GeV
Protons per pulse: 1.5×10^{14}
Frequency: 50 Hz
Pulse length: 5 microseconds
Beam size: 4 mm (rms)



Yield strength of beryllium @ 260°C is around 200 MPa. This leaves a small safety factor for a beryllium window with these beam parameters.

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A few comments on future programme

- Target technology
  - main focus of NF/MC target station work since Study II (ie last 10 years)
  - at least 1 'champion' of each of 3/4 target technologies
  - Good to have alternatives (provided does not distract from other work that needs to be done – see below)
- Solenoid System
  - Most critical technological issue for NF/MC Target Station?
  - Current baseline appears far from feasible
  - NB 'Brute force' solution with extra shielding:
    - Stored energy α r^2
    - Only very recently receiving any attention
- Activation/handling/safety/environmental issues
  - The other most serious feasibility issue?
  - Nobody working on it?

Cost / Design Issues

- Cost ⇔ technical risk
- Build costs ⇔ running costs?
- Integrated yield ⇔ integrated costs?
- Target Station Design choices depend on grasp of these issues
- May be worth revisiting:
  - Beam energy
  - Target Z
  - Beam size
  - Solenoids vs horns (and 2 proton drivers...)?