Pion Production from Water-Cooled Targets

Stephen Brooks / s.j.brooks@rl.ac.uk
UKNF meeting, Warwick, April 2008

Contents

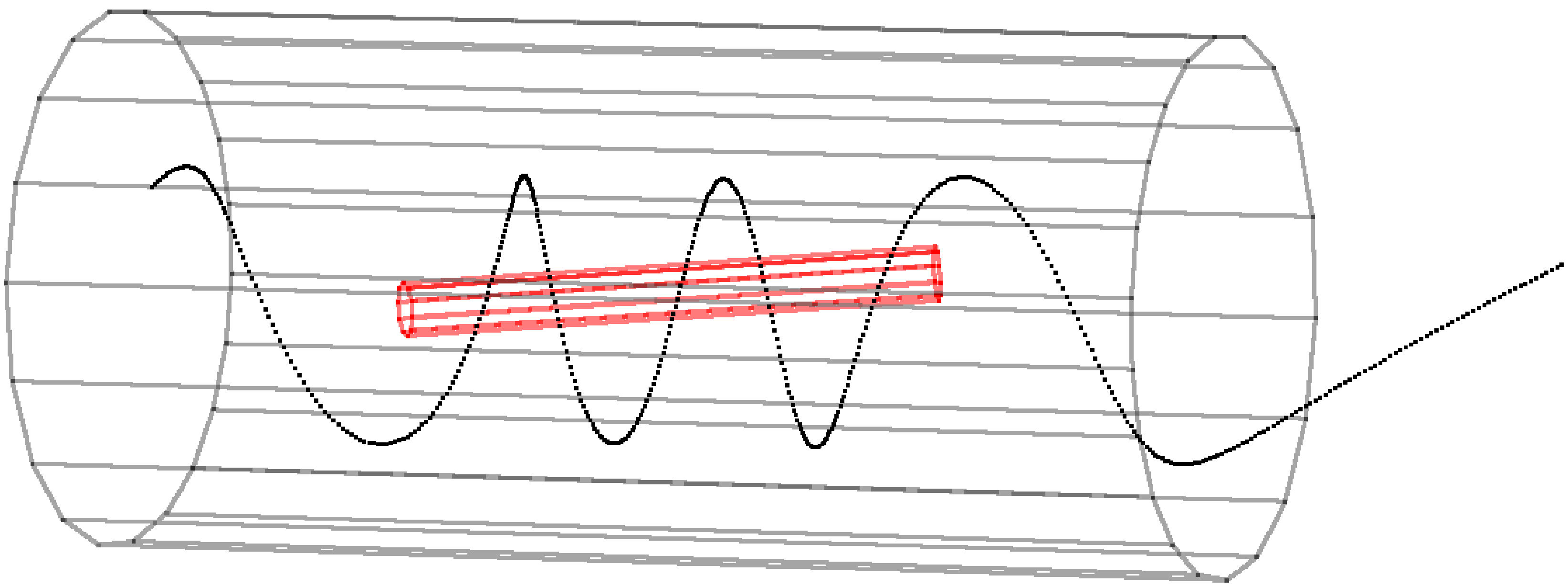
1. Recap of current UKNF solid target
2. Pros and cons related to water cooling
3. Results from MARS 15.07
   - Including water in & lengthening the target
   - Pion yield (reabsorption)
   - Additional heating
   - Pion temporal distribution
- Conclusions

1. Recap of current UKNF solid target

Traditional UKNF Solid Target

- $p^+ \rightarrow$ target $\rightarrow \pi^+, \pi^- \rightarrow \mu^+, \mu^- \rightarrow$ neutrinos
- Radiation-cooled solid rods of tungsten
  - Replaced every 50Hz beam pulse by chain or wheel (~200 in whole loop)
- 2-3cm diameter, 20-30cm length
- Inside initial 20T solenoidal capture field
  - Usable bore ~20cm diameter
  - Pions tend to spiral in magnetic field

Pion Motion

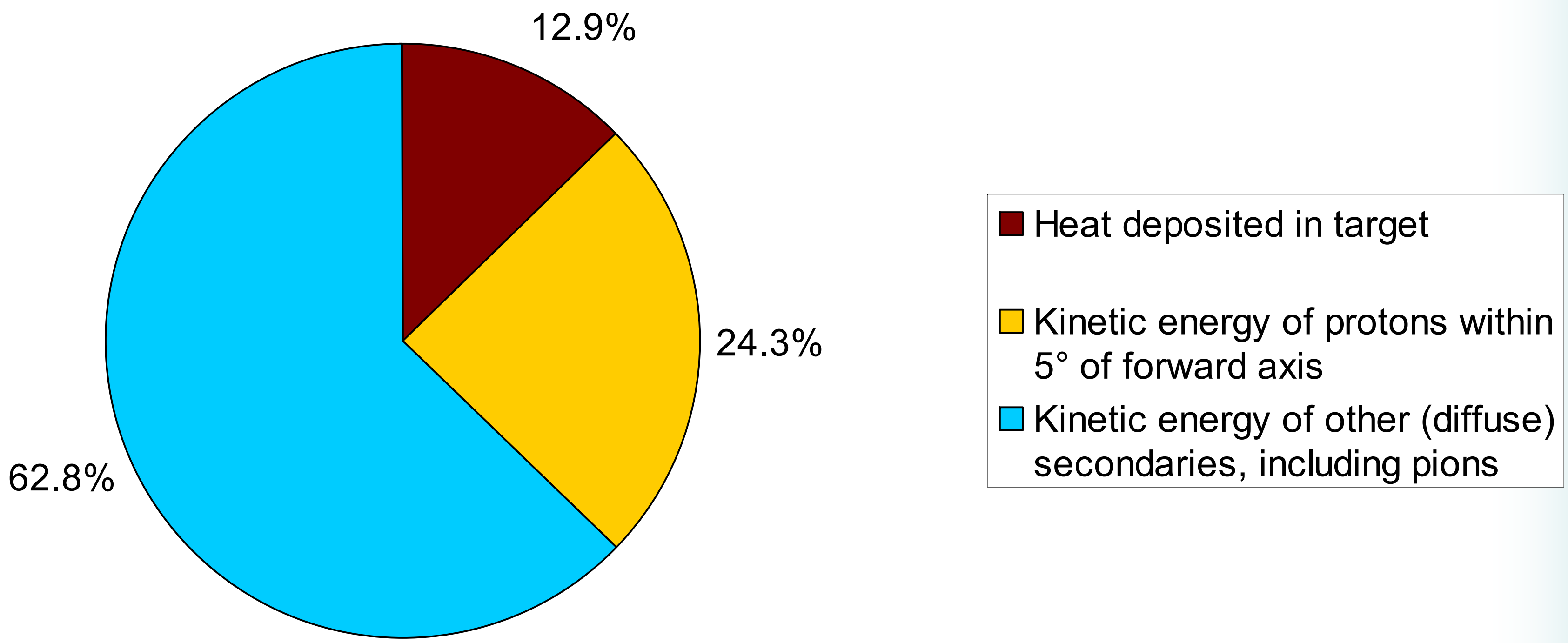


Stephen Brooks / s.j.brooks@rl.ac.uk
UKNF meeting, Warwick, April 2008

Main Design Problems

- Direct heating of the target from energy deposition
- Pions becoming reabsorbed
  - Target being too wide
  - Re-entering the target due to magnetic field
- Reabsorption produces more heating!
- A total of 20-30cm of high-Z target material thickness seems optimal

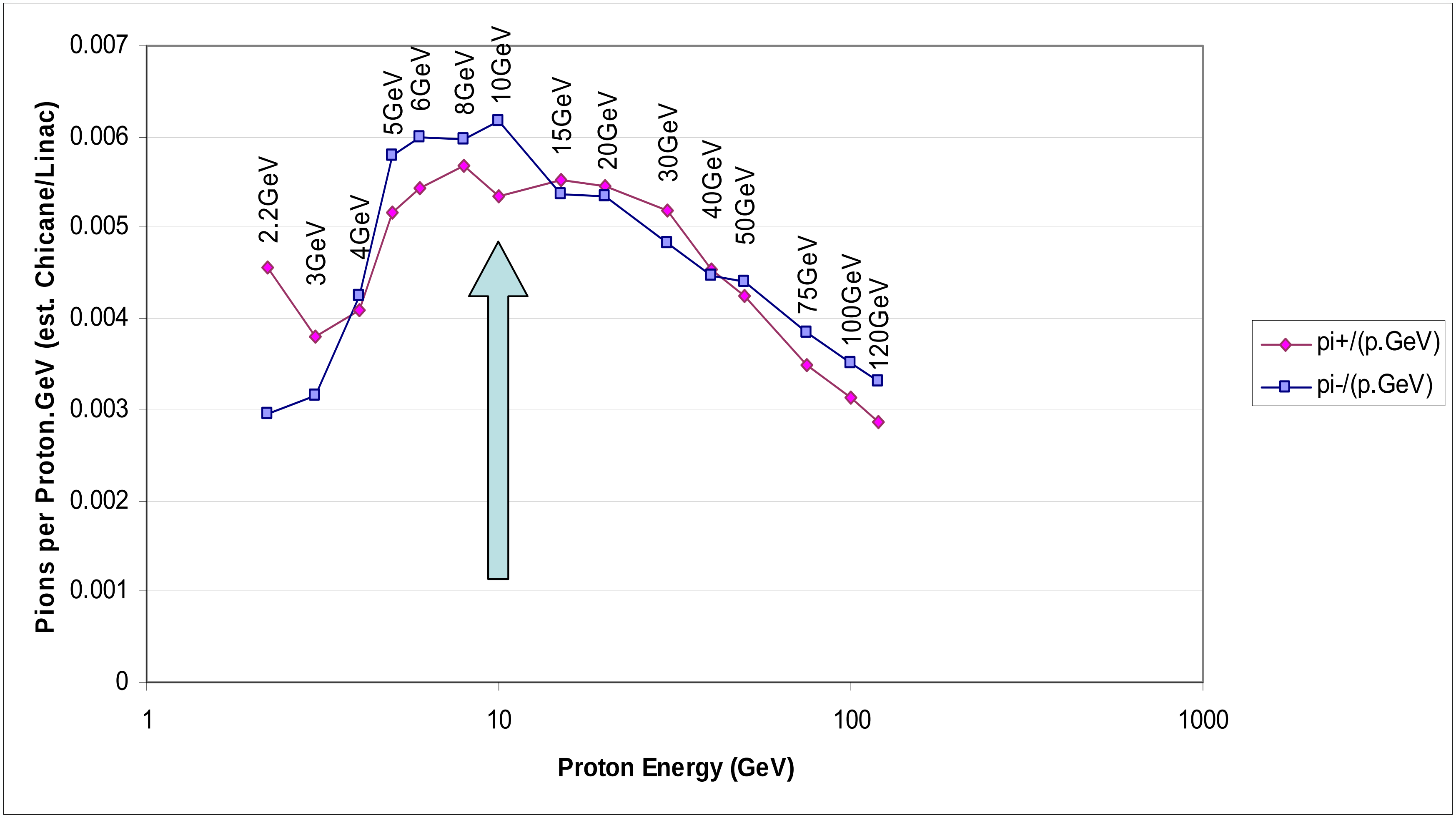
Where does the proton beam power go?



Figures from a **10GeV** proton beam (ISS baseline) hitting a 20cm long, 2cm diameter tantalum rod target

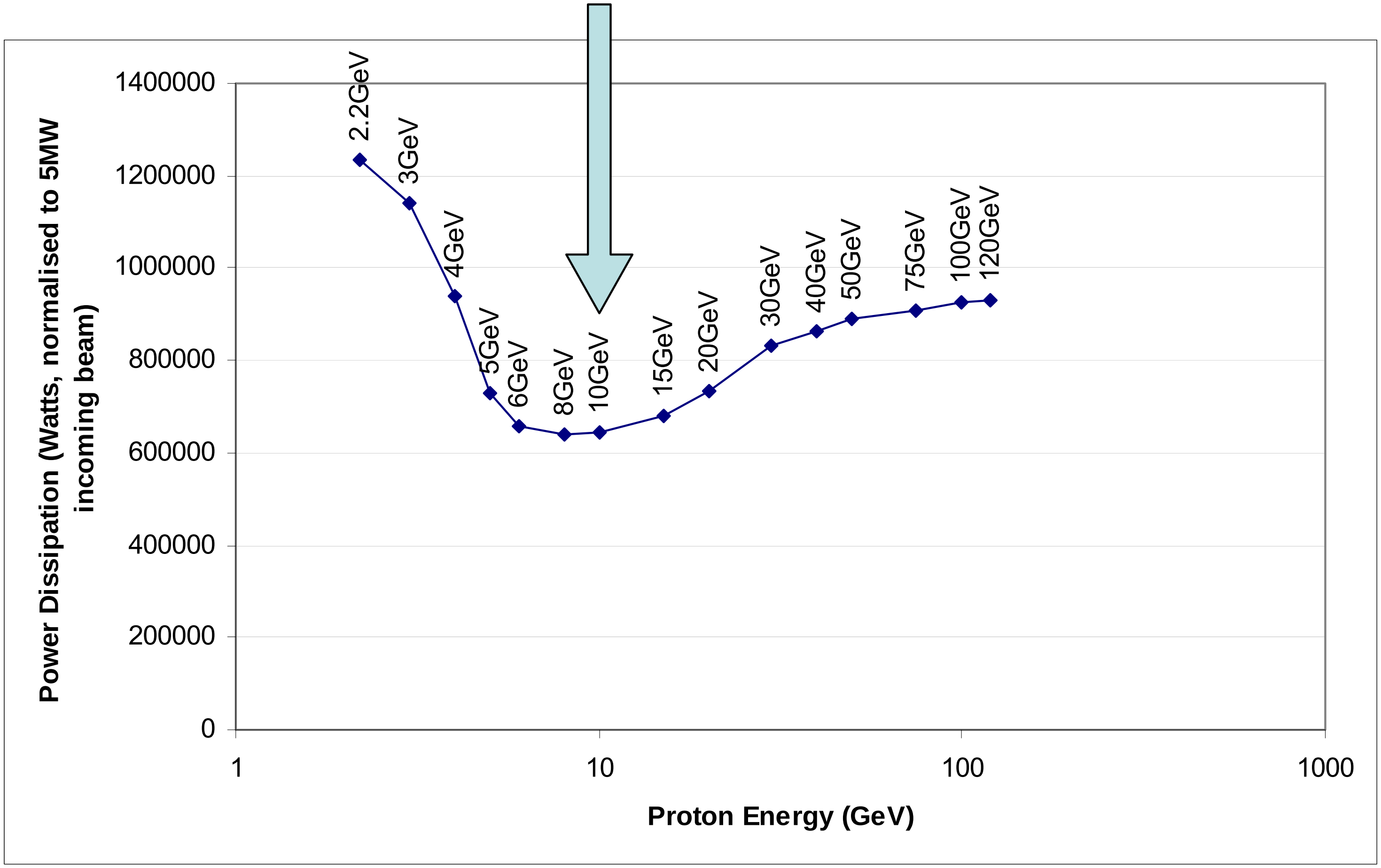
Stephen Brooks / s.j.brooks@rl.ac.uk

Muon Transmission from MARS15-Generated Pions



Stephen Brooks / s.j.brooks@rl.ac.uk
UKNF meeting, Warwick, April 2008

Energy Deposition in Rod (heat)



- Scaled for 5MW total beam power

Stephen Brooks / s.j.brooks@rl.ac.uk
UKNF meeting, Warwick, April 2008

Not Multi-Megawatt Heating

Machine	Beam power	Proton energy	Heating power
ISS beam	4MW	10GeV	514kW ×3
UK neutrino factory scenarios	4MW	8GeV	512kW
	5MW	10GeV	643kW ×4
	5MW	8GeV	640kW
ISIS neutron source	169kW	800MeV 211μA	169kW ×1

Stephen Brooks / s.j.brooks@rl.ac.uk
UKNF meeting, Warwick, April 2008

2. Pros and cons related to water cooling

Why it "wouldn't work"

- Additional water would reabsorb too many pions
  - It would also increase heating in itself
- Increasing the target length would increase longitudinal time-spread of pions
  - 1m length = 3ns > 1ns RMS of proton beam
- Water-cooling has a maximum of 1MW
  - Would require 50% water in the small target

False Assumptions Corrected

- Additional water would reabsorb too many pions
  - ρ_{Water} = 1.0 g/cc, $\rho_{tungsten}$ = 19.2 g/cc
- Increasing the target length would increase longitudinal time-spread of pions
  - Pions of interest >250 MeV/c momentum
  - $\beta > 0.87$, $\beta_{protons} = 0.996$, only lag matters
- 1MW is enough capacity

Advantages of Water Cooling

- Conventional technology
  - Many examples in operation
    - Including elsewhere in the target assembly! E.g. cooling for the normal-conducting solenoids
  - No solid moving parts (apart from pumps)
  - Radioactive flow loop isn't liquid mercury
    - Although there is still some tritium to deal with
- All parts of target stay below about 200°C

Disadvantages of Water Cooling

- Water will cavitate if the instantaneous temperature rise is too high, erode walls
  - Also if the flow rate is too high for pressure
- Flow manifold has to be somewhere and enter/exit the target
- Pressures may have to be large to induce sufficient flow rate
- Relies on fluid dynamics, requires much more careful design than in this talk

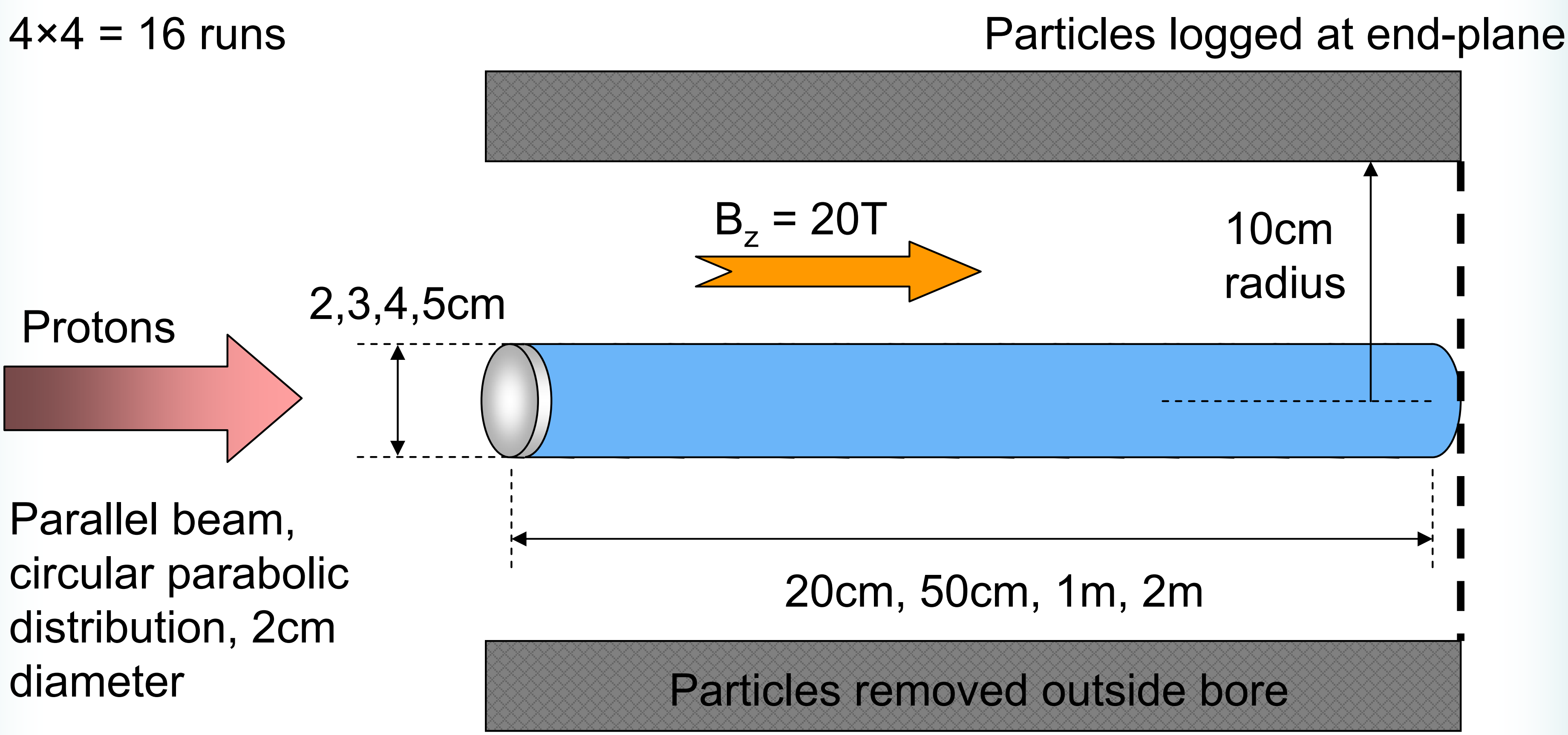
Naïve Flow Rate Calculation

- Assumes perfect:
  - Conductivity of metal target pieces
  - Thermal conduction from target to water
  - Mixing of water
- P_{in} = 700kW; ΔT = 50K
- Flow rate 3.34 kg/s
- Speed 10.6 m/s for 2cm diameter pipe
  - Will be more than this realistically

3. Results from MARS 15.07

Simulation Geometry

4×4 = 16 runs



Parallel beam, circular parabolic distribution, 2cm diameter

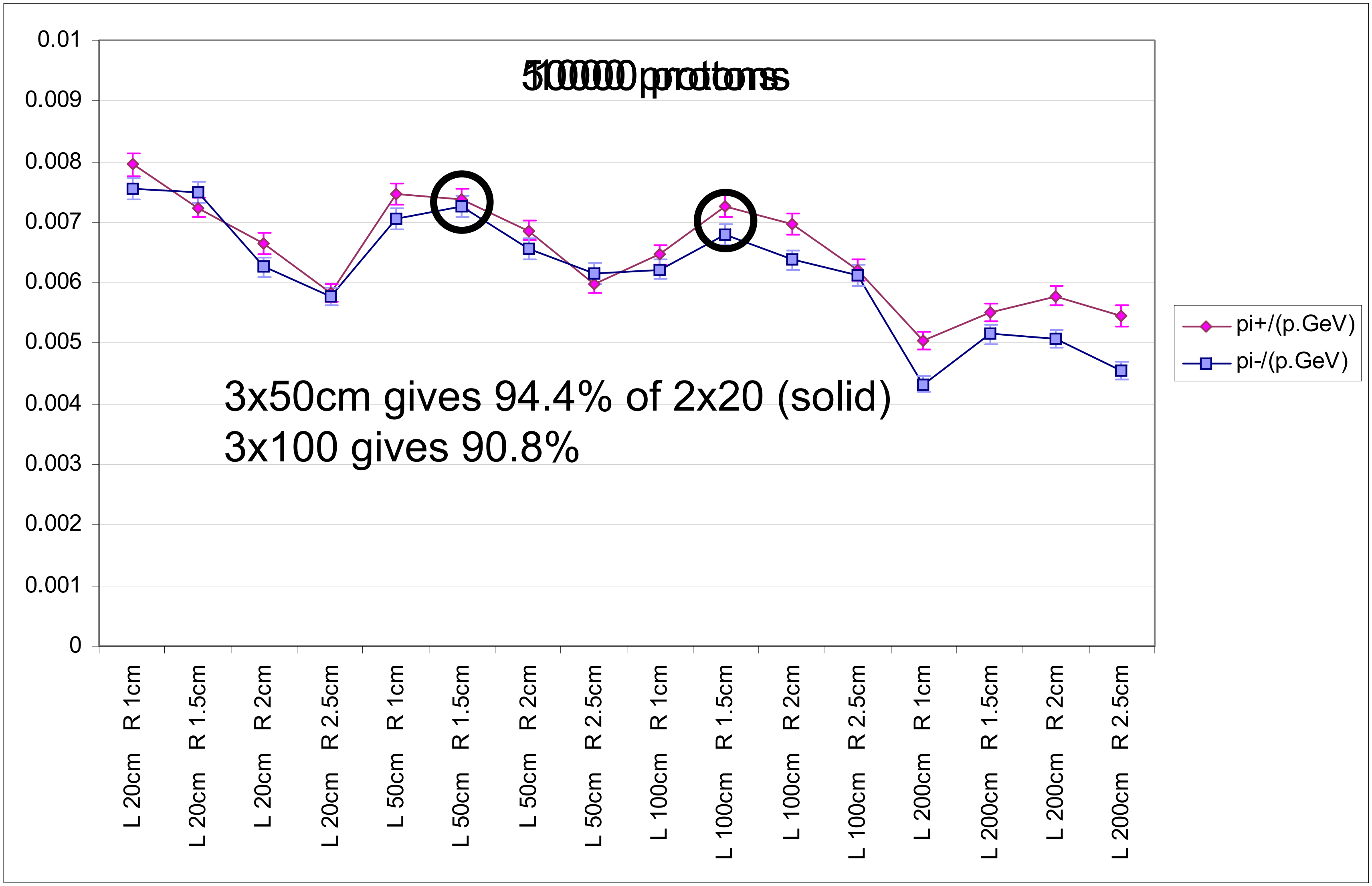
Tantalum “coin”, 2mm thick →

100 coins in target for 20cm total Ta thickness

Three Figures of Merit

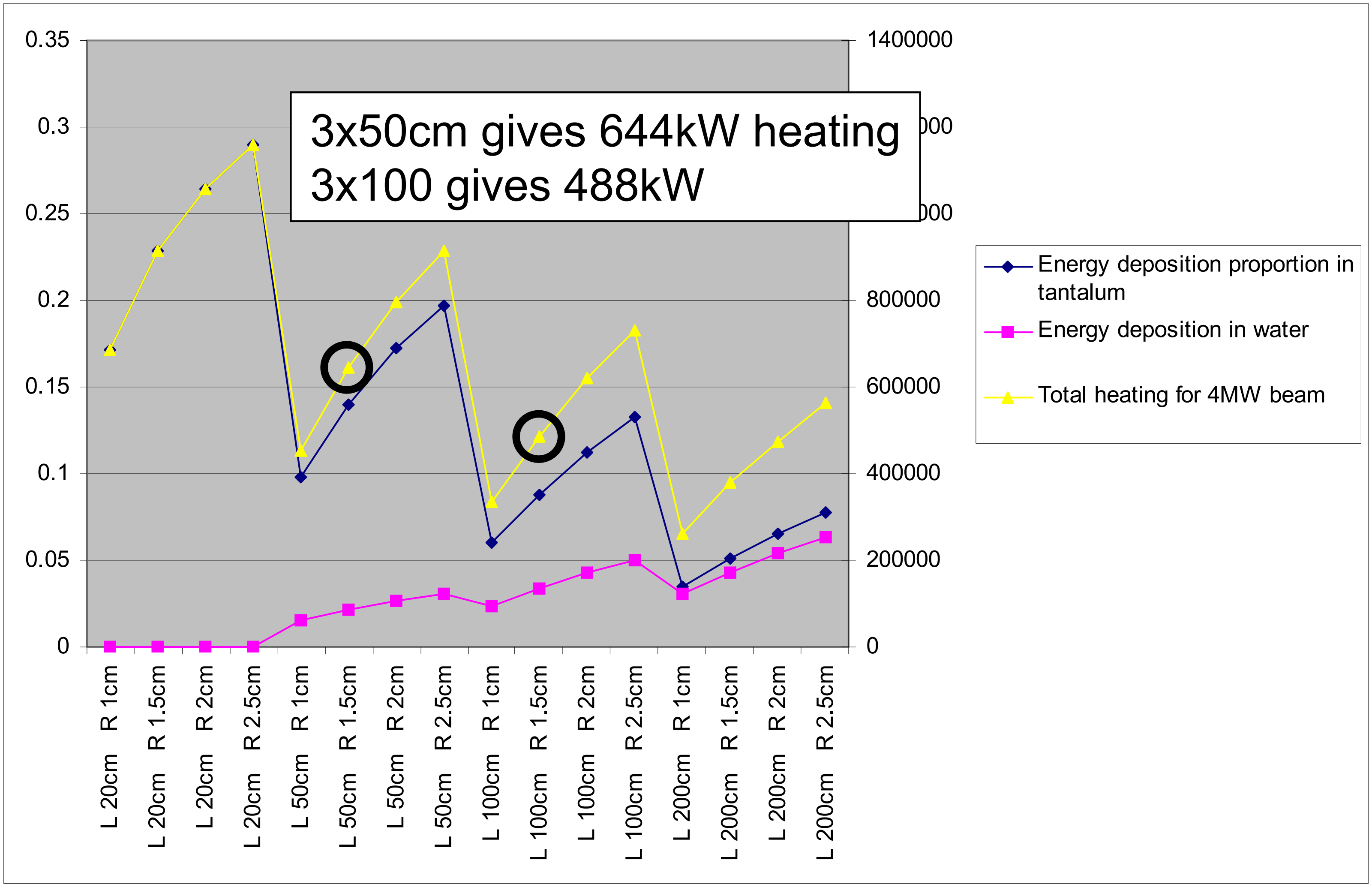
- Useful pion yield
  - Weighted depending on (p_L,p_T) momenta
- Amount of heating in the system
  - How much does the water contribute?
- Time-spread acquired from long target
  - Only interested in “useful” pions here too

Useful Pion Yield

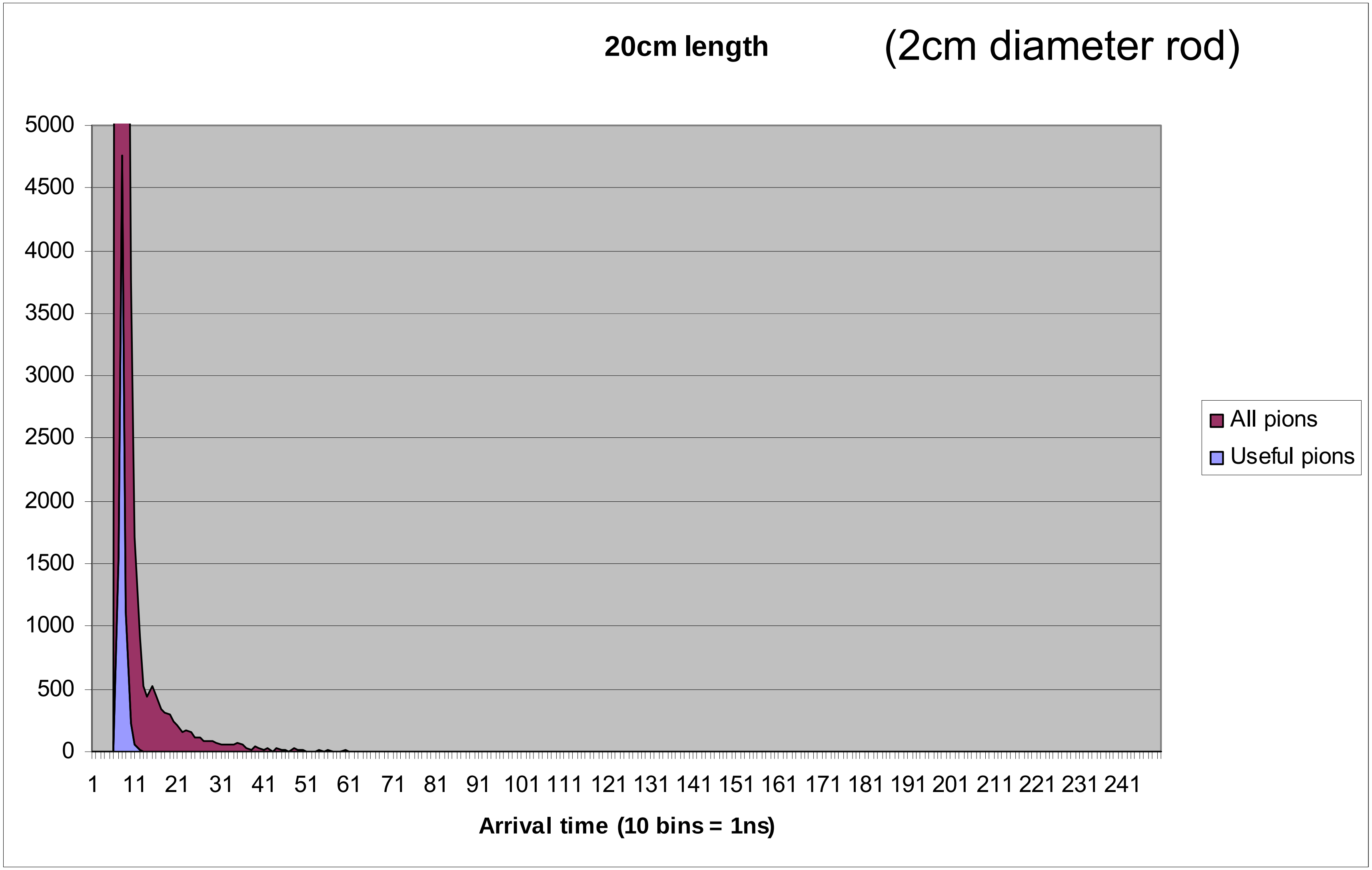


Stephen Brooks / s.j.brooks@rl.ac.uk

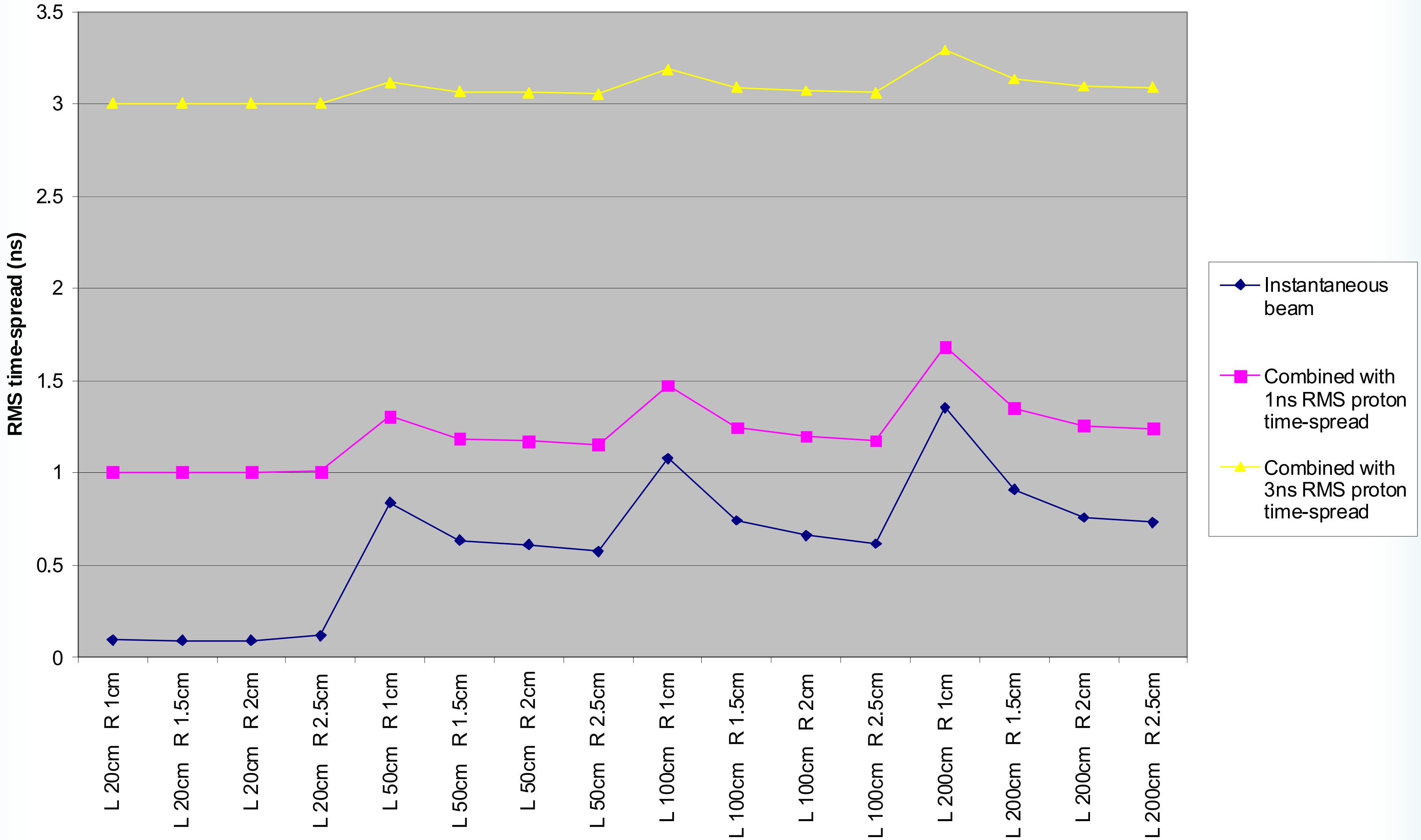
Amount of Heating



Arrival Time Distribution

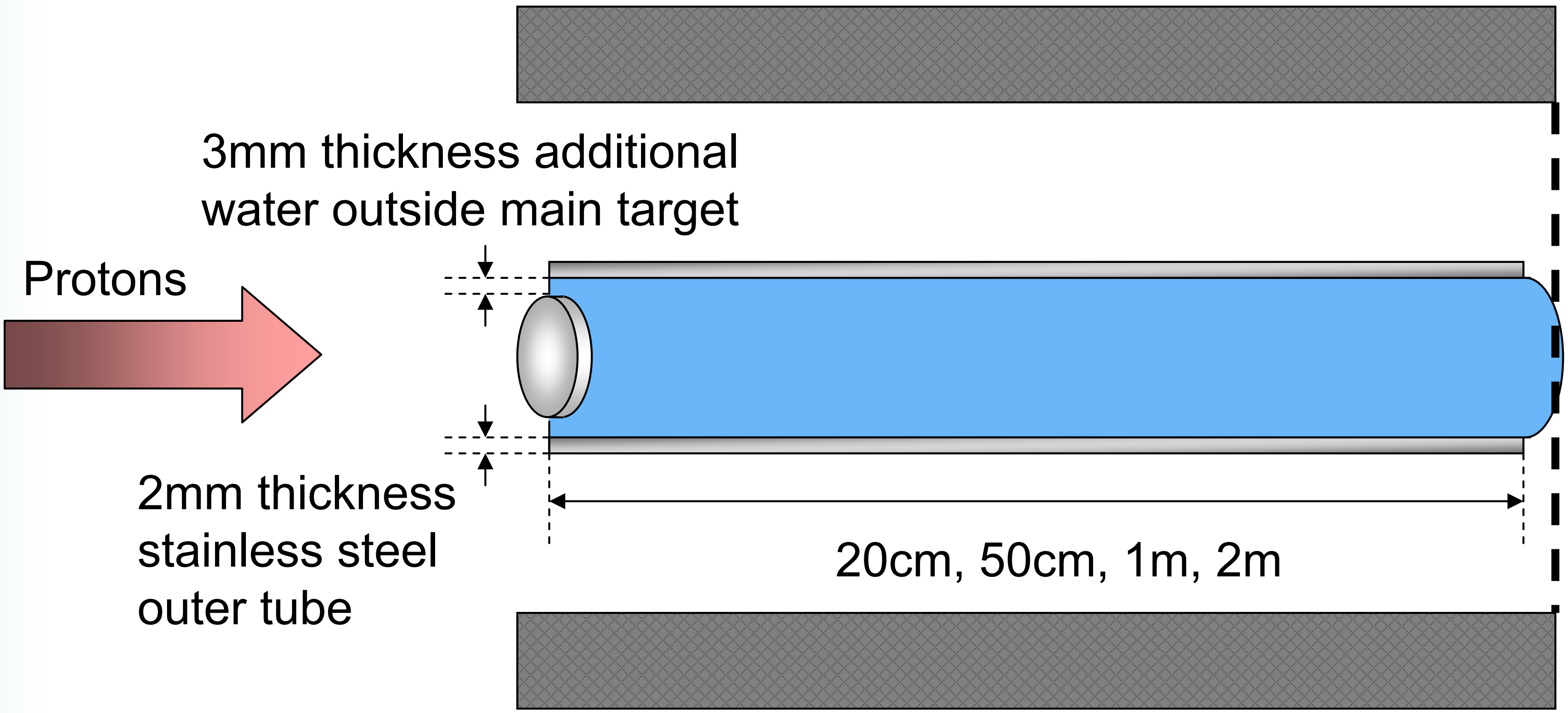


RMS of Useful Arrival Times



Modified Geometry

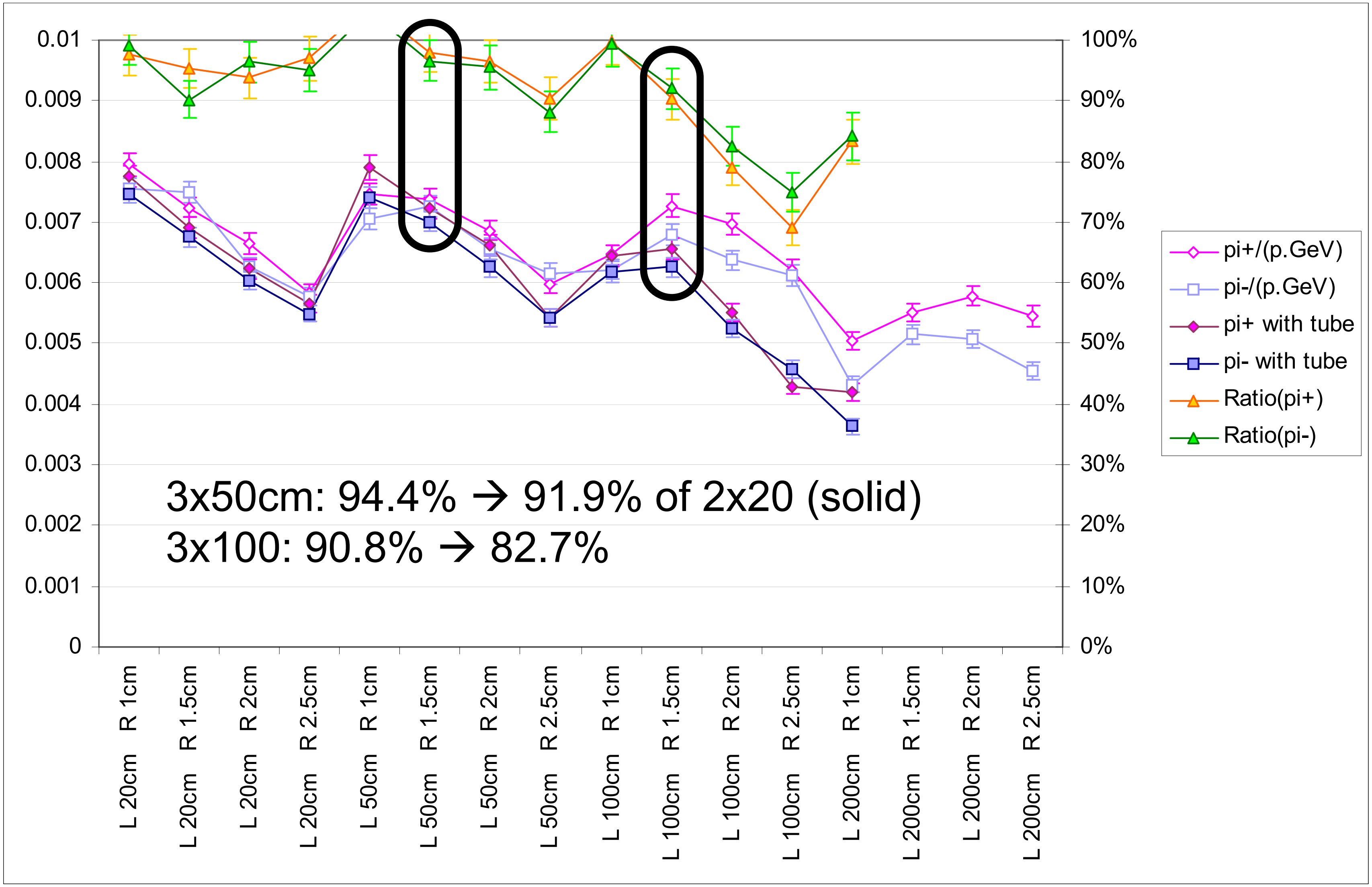
4×4 = 16 runs



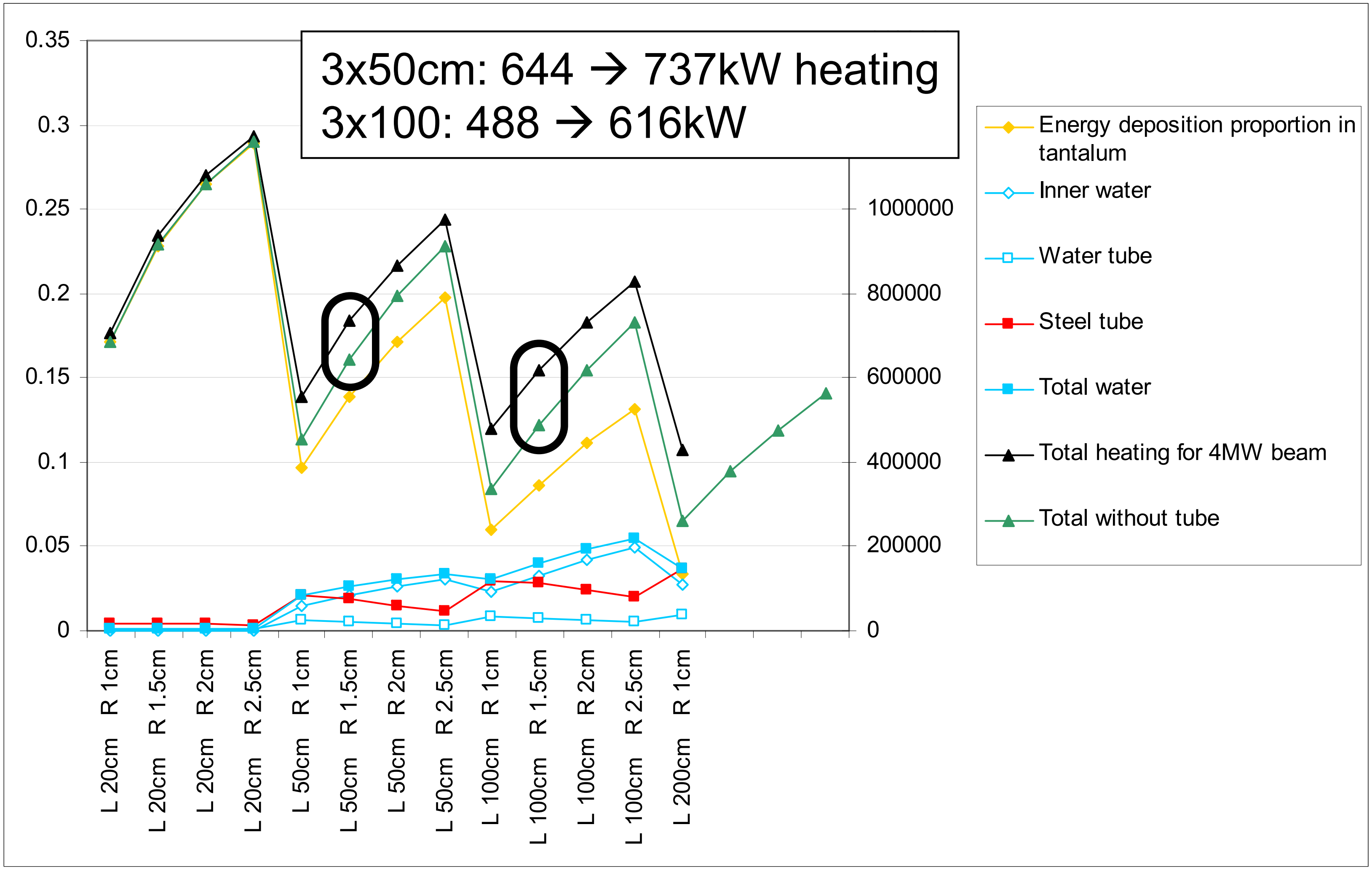
Tantalum “coin”, 2mm thick →

100 coins in target for
20cm total Ta thickness

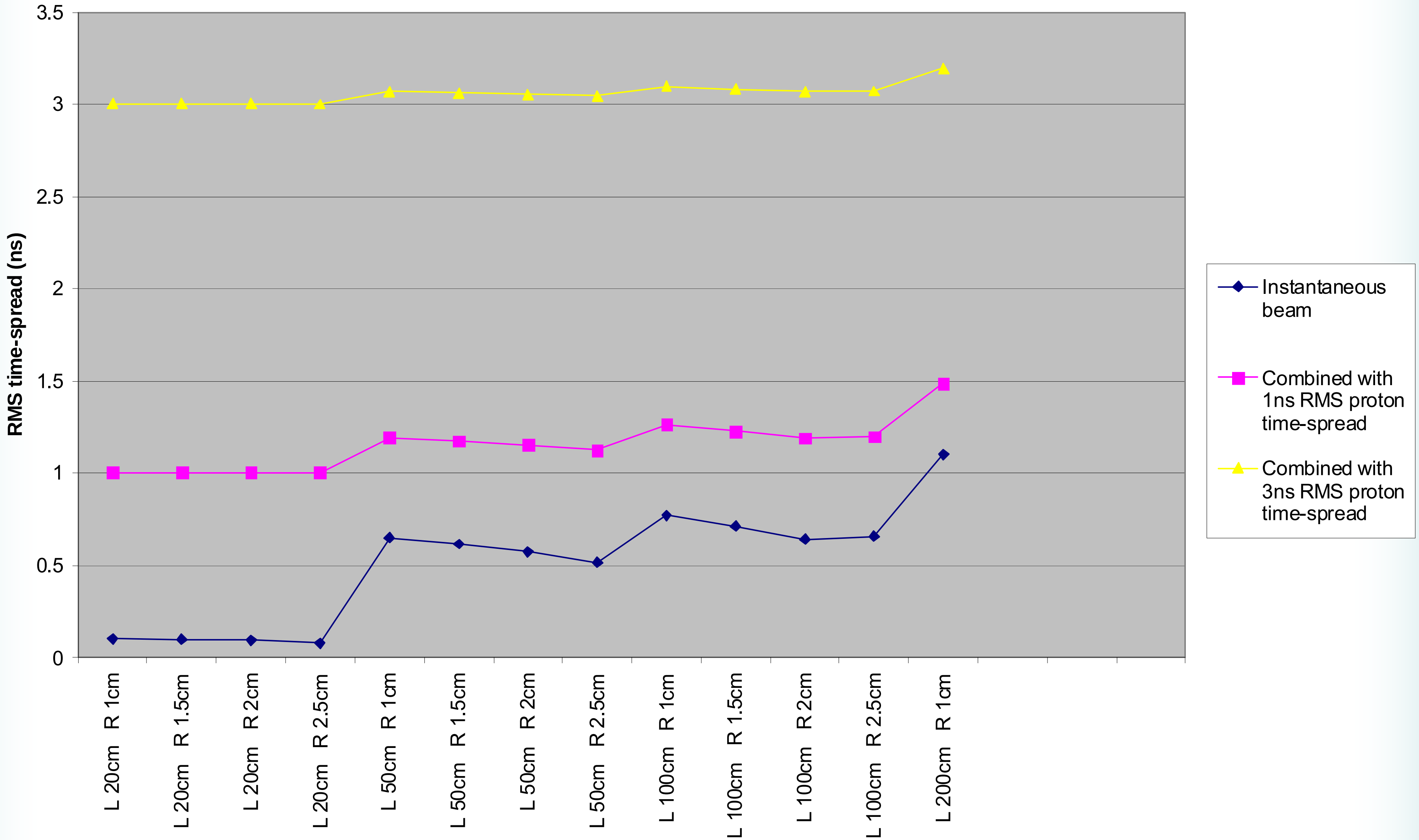
Modified Pion Yield



Amount of Heating



RMS of Useful Arrival Times



Stephen Brooks / s.j.brooks@rl.ac.uk
UKNF meeting, Warwick, April 2008

Conclusions

- The neutrino factory requirements do not seem to preclude a water-cooled target
  - Fast particle production targets can have a much lower % heat load than slow targets
- Does this also mean an SNS-style enclosed mercury target might work?
- Need to investigate in more depth to either verify or exclude these options