SOME THOUGHTS!!

on

A High Power, Radiation Cooled, Rotating Toroidal Target for Neutrino Production

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A Cu-Ni Rotating Band Target for Pion Production at Muon Colliders

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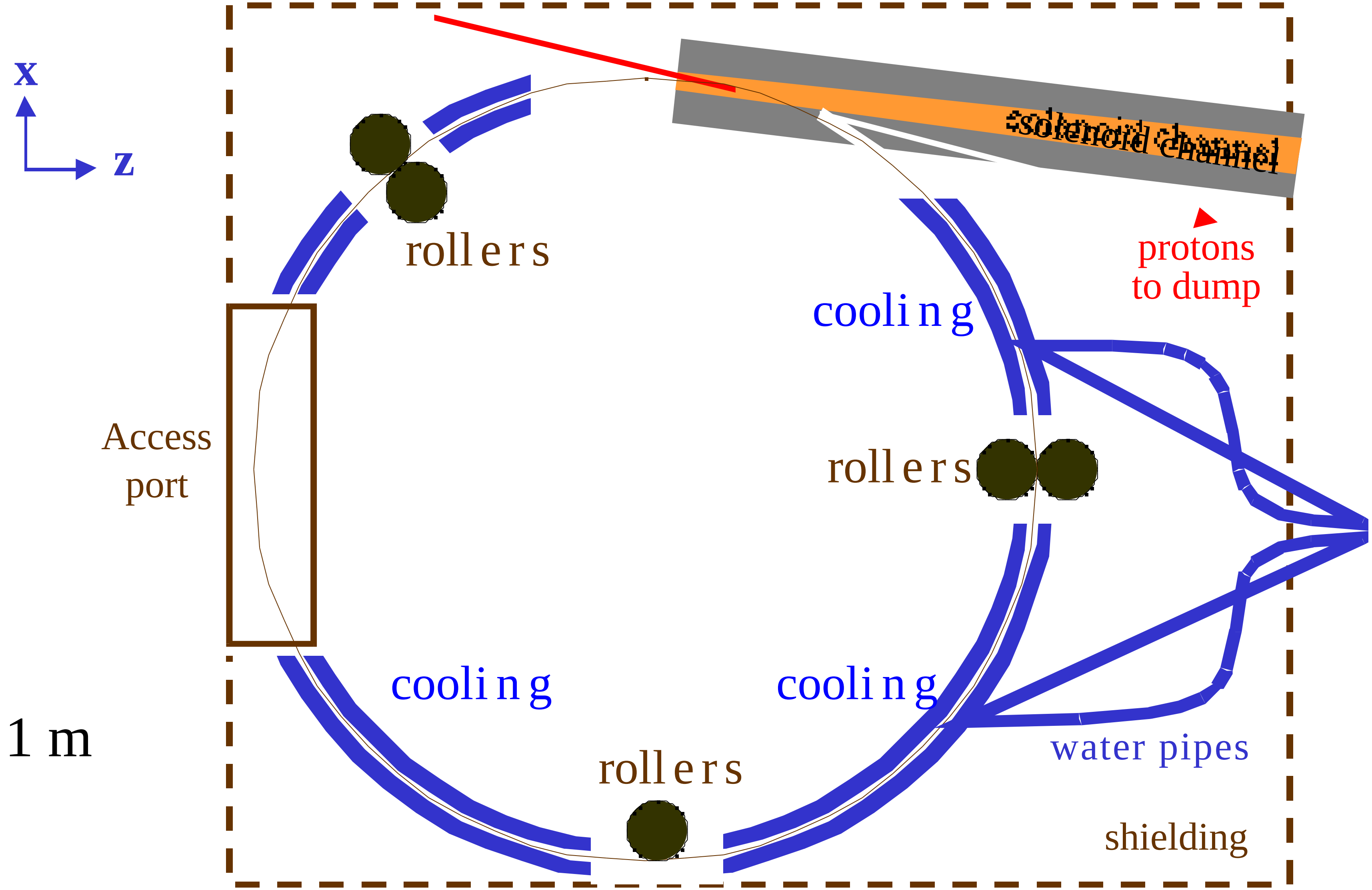
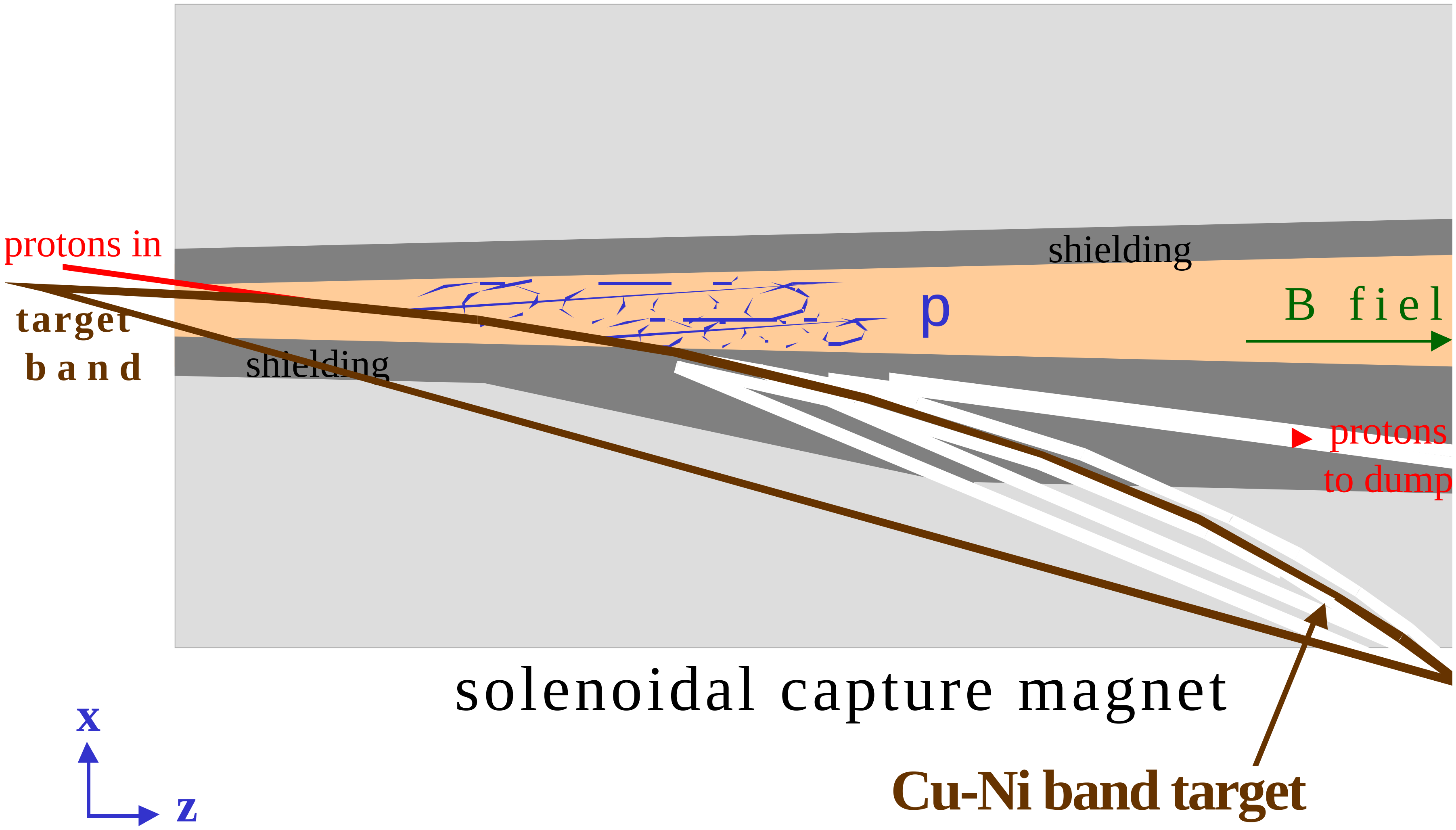
Scott Moser (St. Joseph's)

From PAC99 and Lyon Workshop, July 1999

Plan View of Targetry Setup



Target Geometry



Target Specifications

Target dimensions: 0.6 cm thick x 6 cm high x 15.7 m circumference
=> heat removal of 40 -- 80 W/cm^2
=> water cooling OK

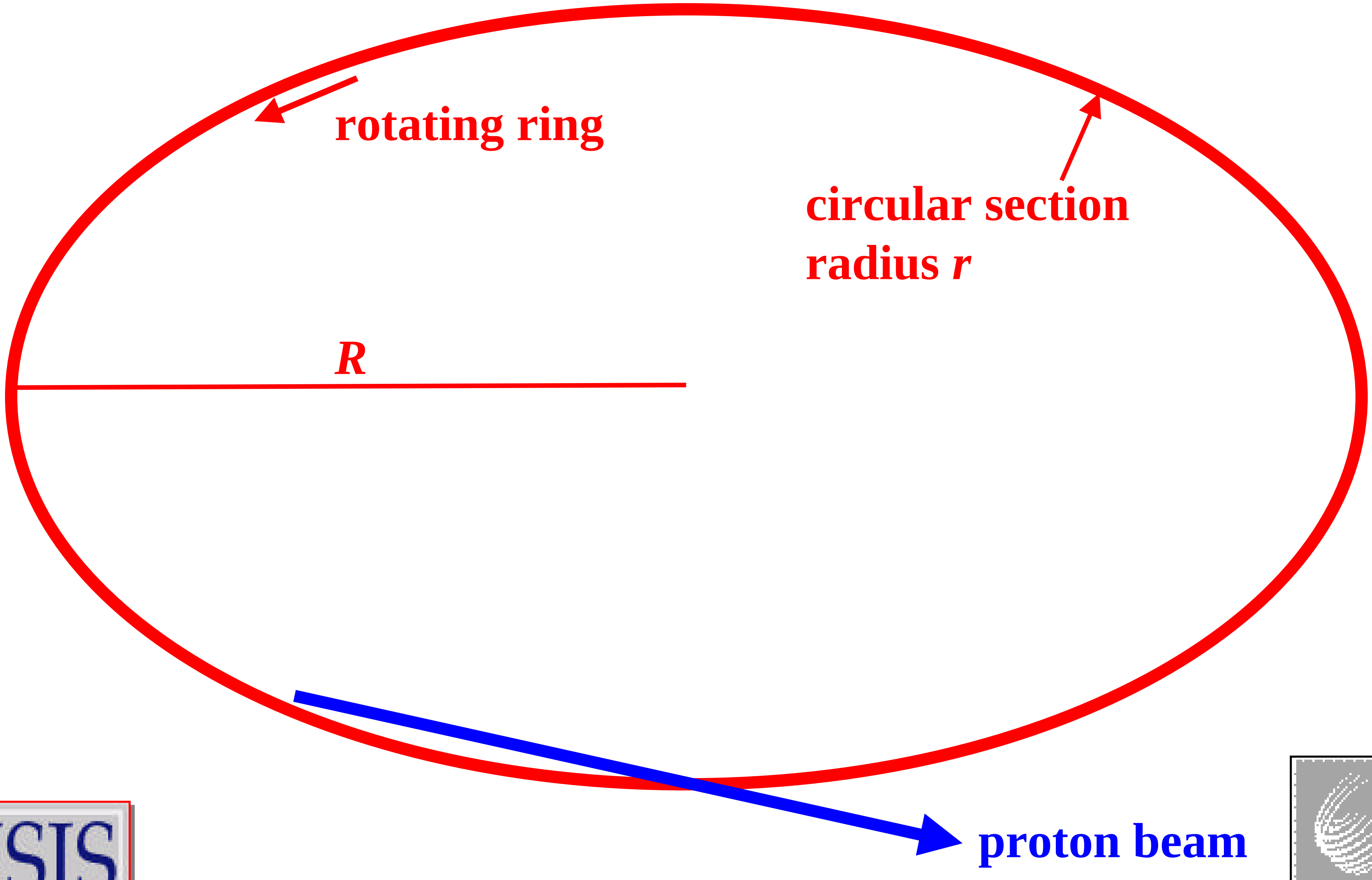
Material properties: Cu-Ni alloy (e.g. Olin 715)
elect. conductivity ~ 5% of Cu
interaction length = 15 cm

Target Rotation: velocity = 3 m/sec (=> heat from ~2 pulses overlap)

Solenoidal Magnet: (Bx,By,Bz) = (0,0,20) Tesla
bore diameter = 15 cm

Proton Beam: spot size: σ_x = 1.5 mm, σ_y = 10 mm
10^{14} 16 GeV protons/pulse @ 15 Hz (4 MW)

Schematic Diagram of the Toroid



COOLING

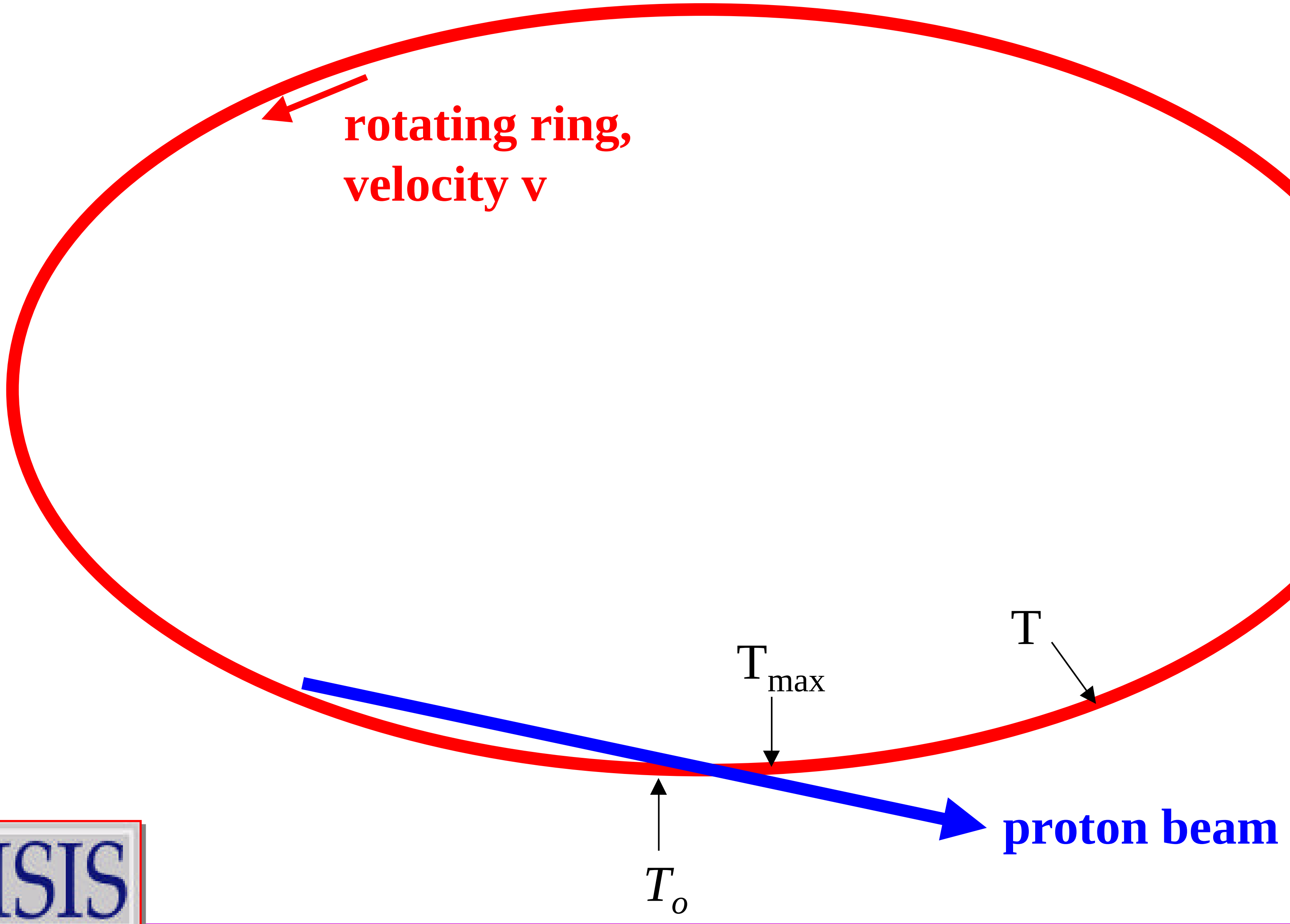
TOROID OPERATES AT 2500 K

RADIATION COOLED

ROTATES IN A VACUUM

VACUUM CHAMBER WALLS WATER COOLED

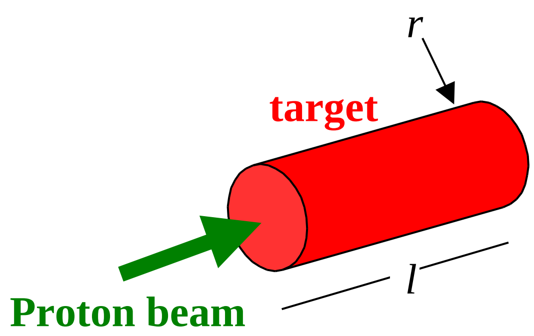
Schematic Diagram of the Toroid



Some Simple Heat Flow Equations

Stefan’s Radiation Law

$$\frac{dq}{dt} = 2\pi r l \varepsilon \sigma g \left(T^4 - T_e^4\right)$$



Thermal Capacity

$$Q = \pi r^2 l \rho S \left(T - T_o\right)$$

which gives the power as:

$$W = Q\frac{l}{V}$$

Assume dc proton beam

Where: *r* = the radius of the target section (1 cm)

***l* = the effective length of the target in the beam at any one time (20 cm)**

ε = the thermal emissivity (0.3)

σ = Stefan’s constant (5.67×10^{-12} W cm^{-2} K^{-4})

***g* = geometry factor (1)**

***S* = specific heat (Ta - 0.14 J g^{-1})**

ρ = density (Ta - 16.7 g cm^{-3})

***V* = peripheral velocity of the toroid (cm/s)**

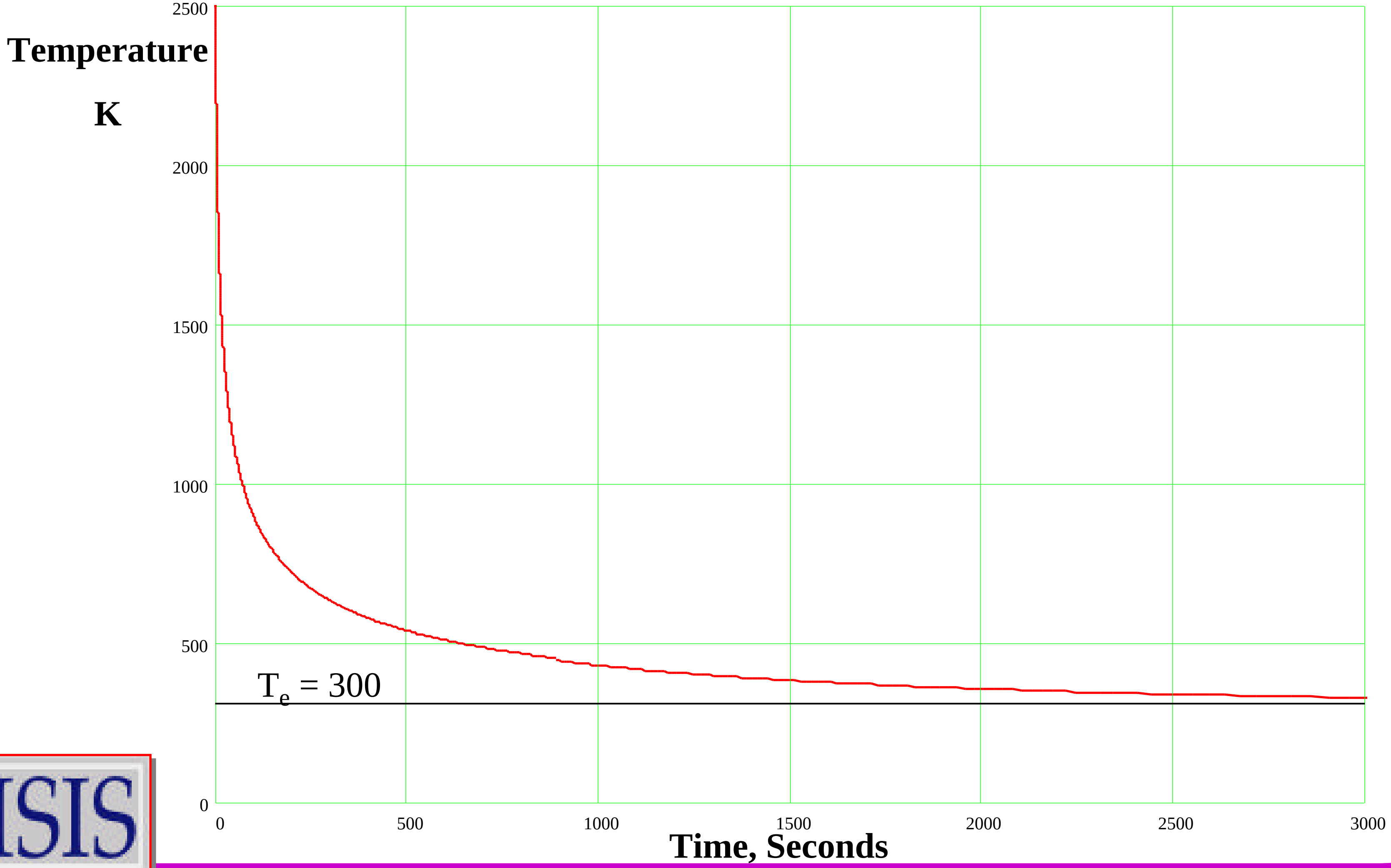
***T* = temperature (K)**

T_e = the temperature of the enclosure (300 K)

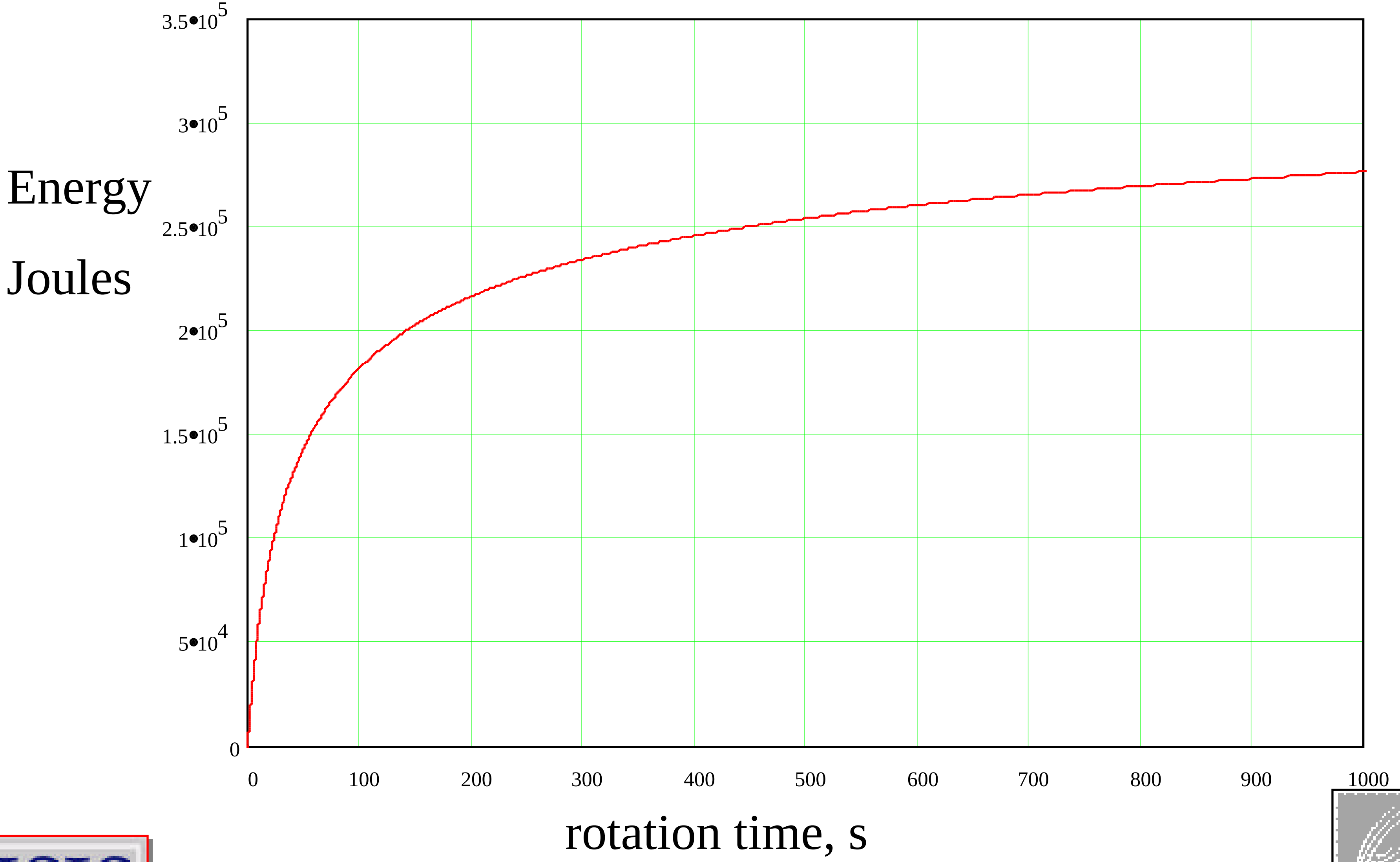
T_0 = the temperature of the target entering the beam (K)

Temperature Fall

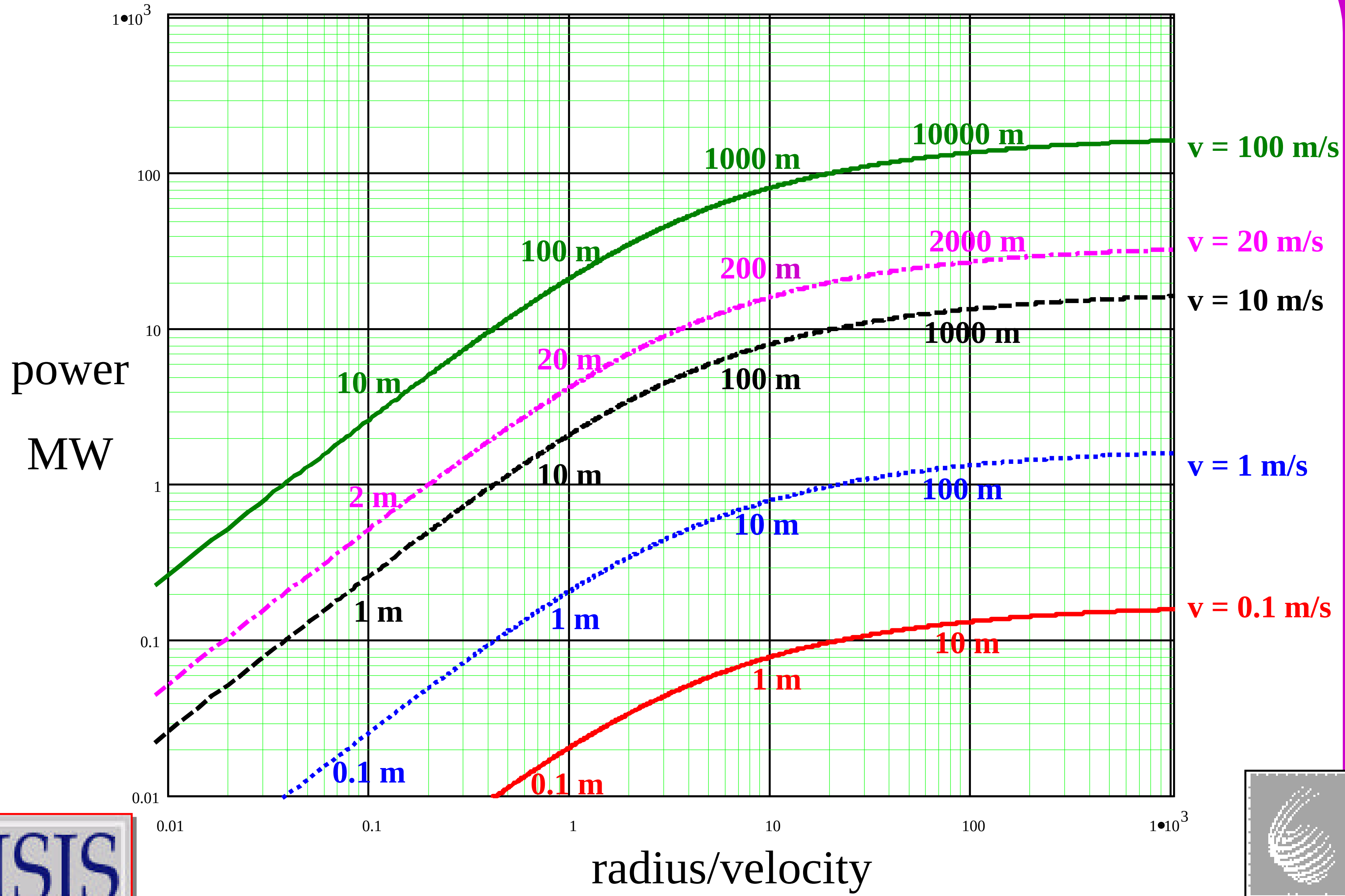
due to thermal radiation from a 2 cm diameter tantalum bar from 2500 K to an enclosure at 300 K



Energy Dissipated in the Target
20 cm long, 2 cm diameter



POWER DISSIPATION



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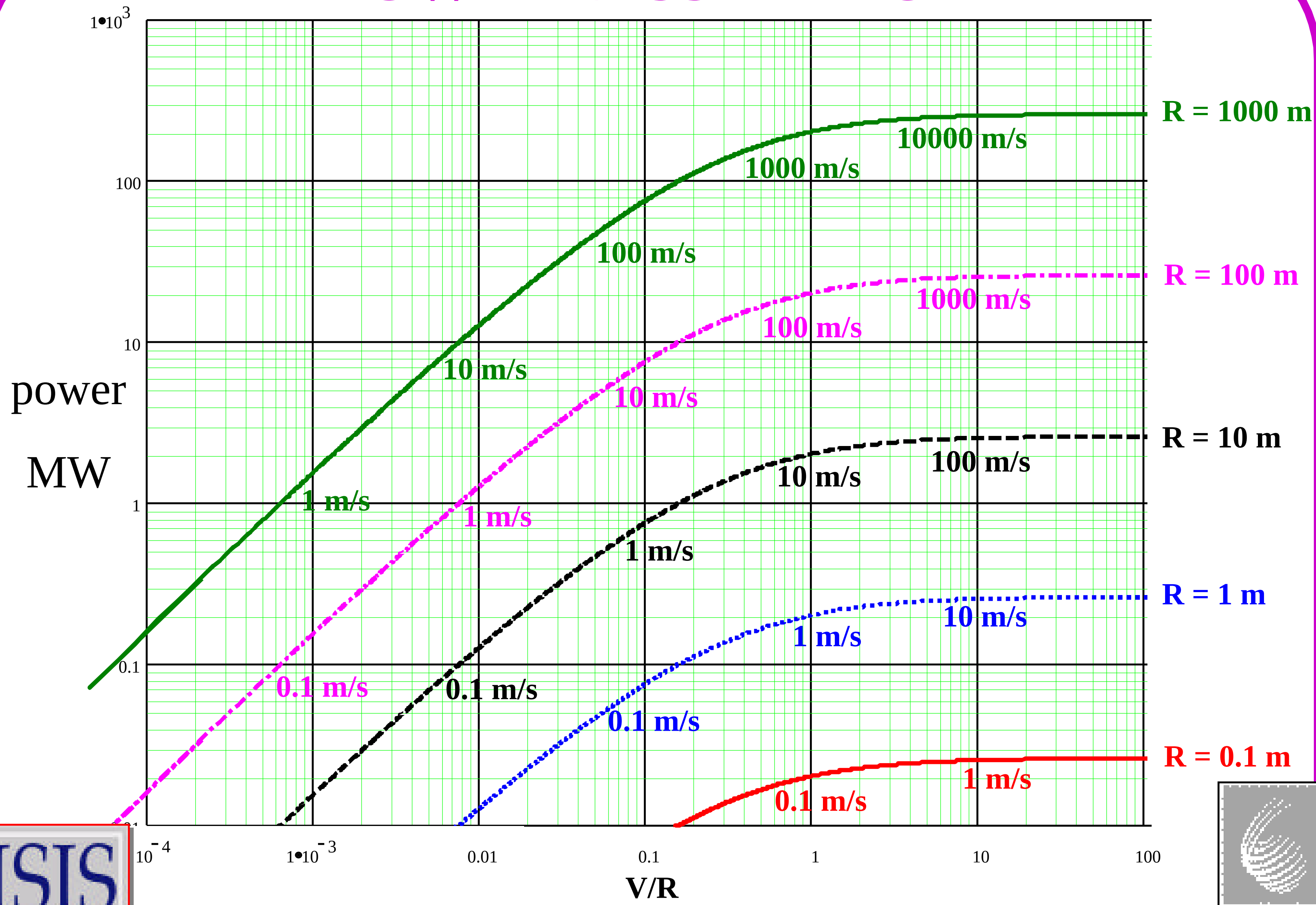
POWER DISSIPATION

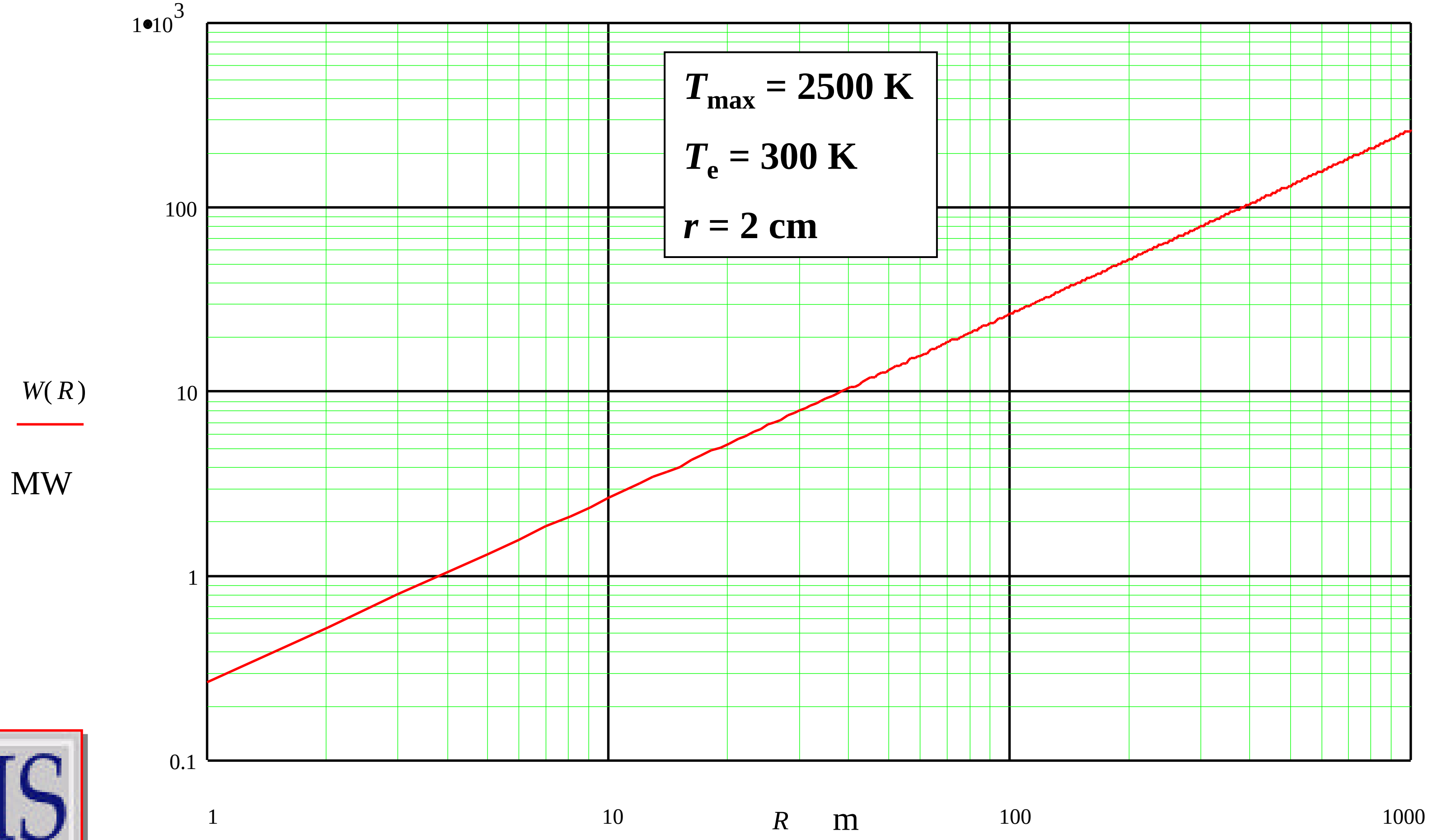


Maximum Power Dissipation

The maximum power that can be dissipated in a given size (surface area) target is found when the target rotates very fast and the whole target is at the maximum temperature. The power dissipation is given by:

$$W_{max} = 2\pi r 2\pi R \varepsilon \sigma g \left(T_{max}^{4} - T_{e}^{4}\right)$$

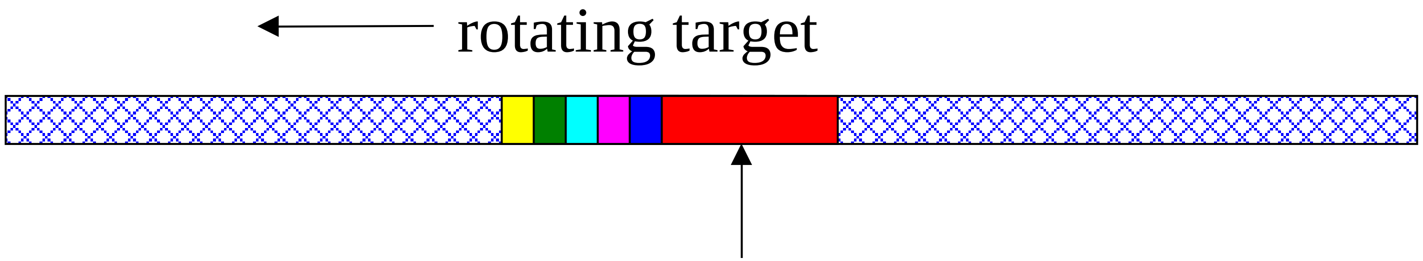
$$W_{max} = 2.622 ? 10^{3} ? R$$



PULSED EFFECTS

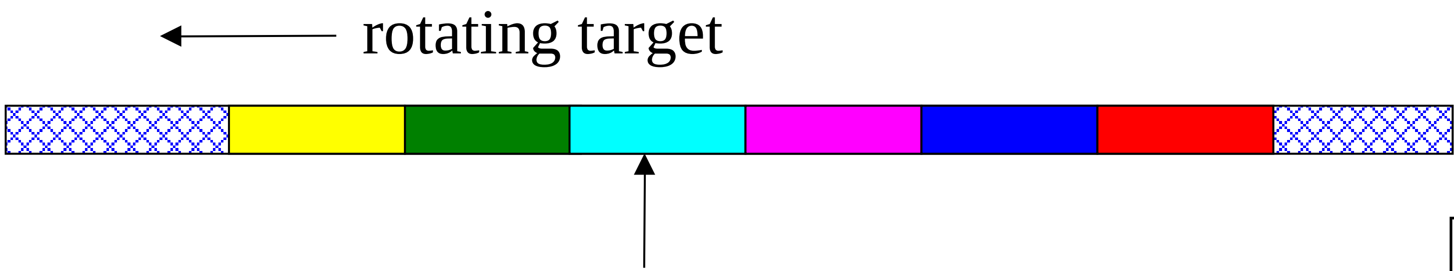
The proton beam has a very short pulse length (~1 μs) at 100 Hz rate.

If the target rotation is slow - the areas illuminated by the pulses overlap



individual overlapping beam pulses on the target, 20 cm long

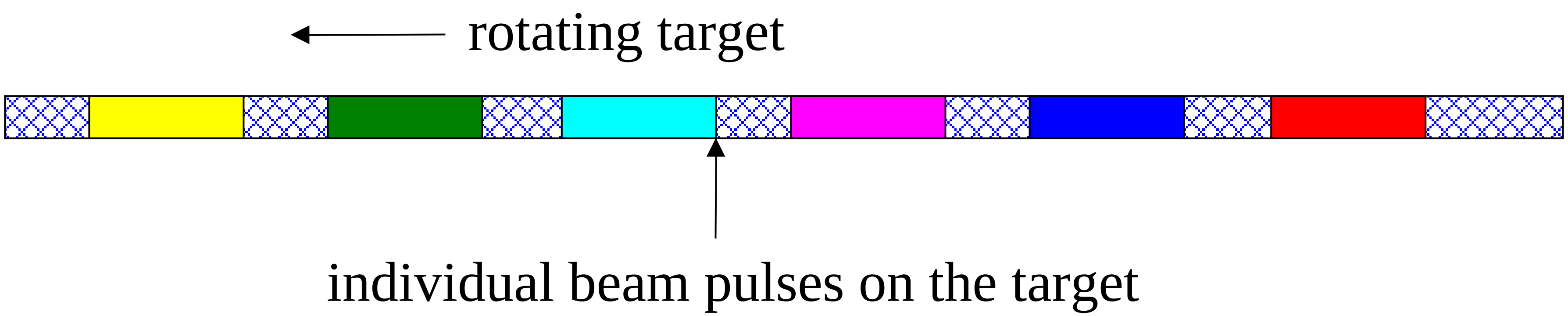
As the rotation gets faster the areas illuminated by each pulse separate until at v = 20 m/s they just touch.



individual beam pulses on the target

PULSED EFFECTS

At speeds greater than 20 m/s the areas of each pulse separate



There is no point in getting into this regime since the target radius and velocity are larger than is necessary for optimum power dissipation.

The maximum power at a pulse repetition rate *f* is:

$$W = 0.322 \cdot f$$

$$W = 32 \text{ MW at } 100 \text{ Hz}$$

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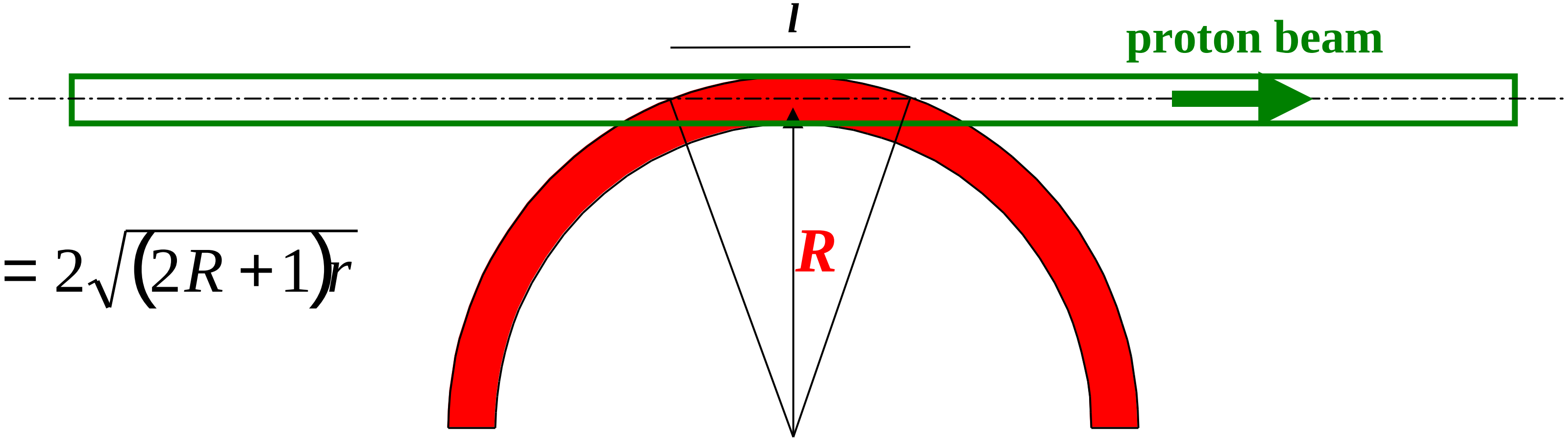
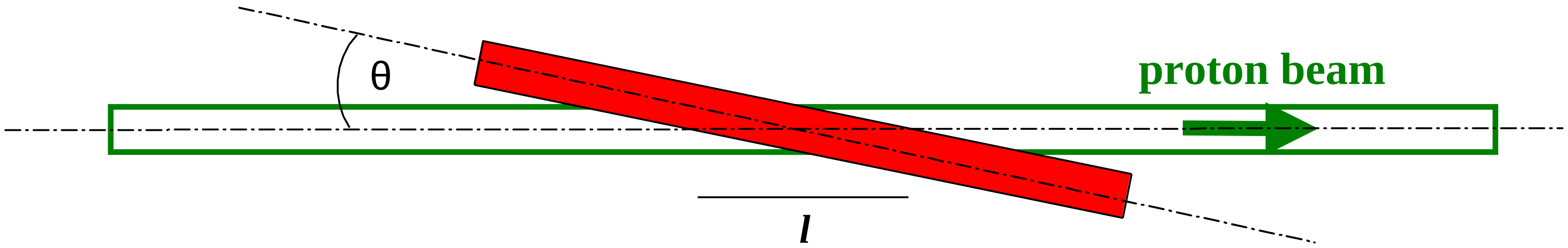
Target Length



$$l = 2\sqrt{(2R+1)r}$$

With l =20 cm, r =1 cm, R must be 45 cm - rather restrictive.

Better to tilt the plane of the toroid with respect to the proton beam centre line:



$$\theta \quad \frac{2r}{l}$$

θ = 1/10 radians = 5.7 degrees

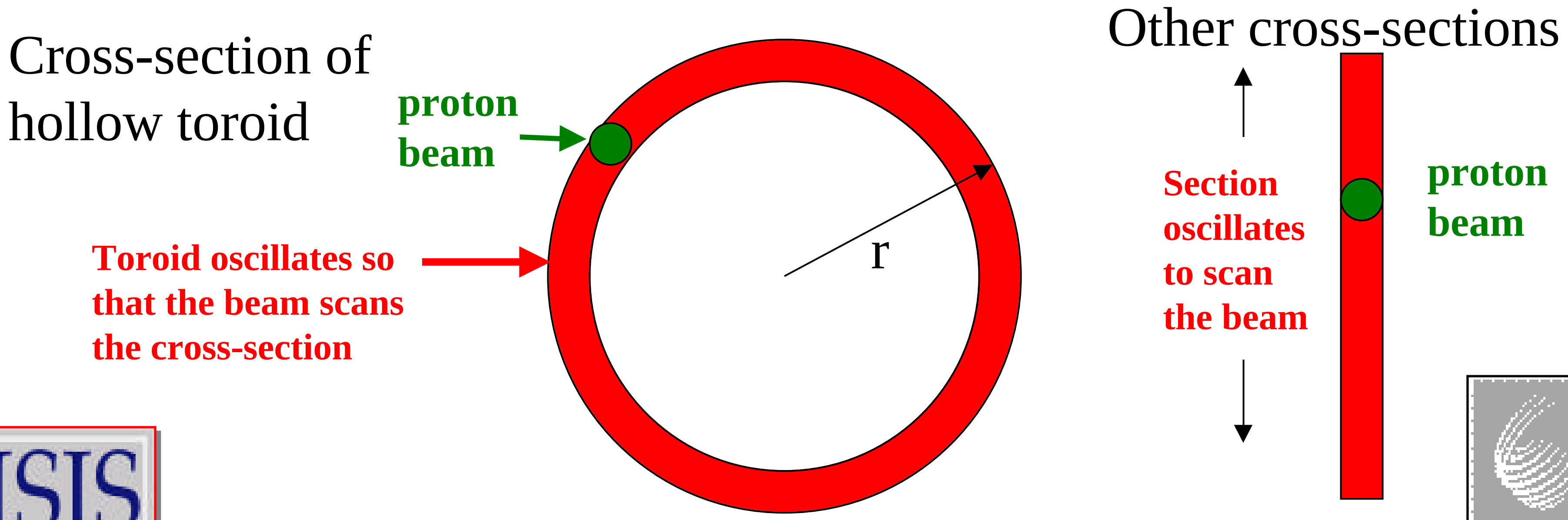
Increasing the Power Dissipation

INCREASE:

- the thermal emissivity to 0.8 (increase by factor 2.5)
- the radius *r* - to 2 cm (increase by factor 2)
- the maximum temperature use tungsten - T_{max} = 3000 K (increase by factor 2)

These measures would give a factor of 10 increase in power dissipation.

Small proton beam with thin walled toroid of large radius, *r*.

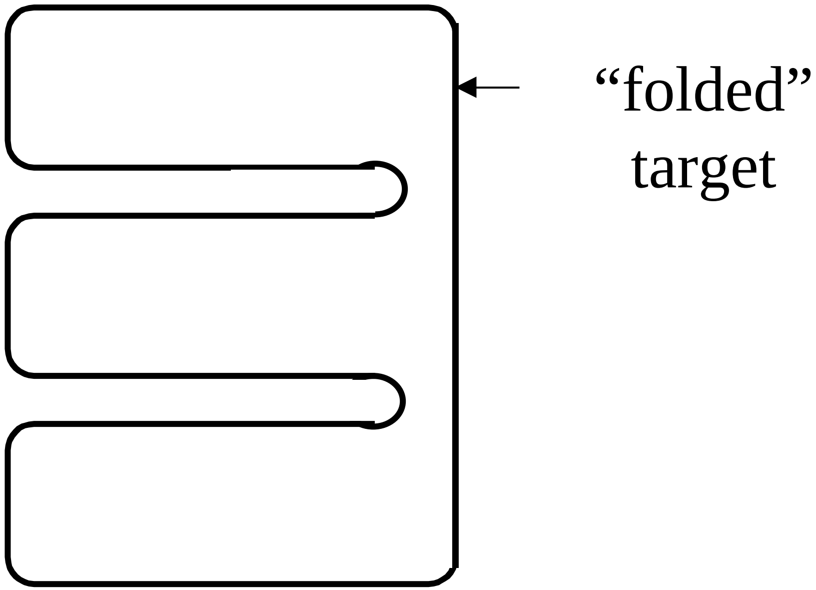


Mechanics

The whole toroid could be supported and driven on rollers or by electromagnetic levitation.

The toroid could be one solid piece or jointed sections.

The target could be “rolled up” to take up less space:



!!Much more work needed!!

Temperature Rise at the Centre of the Target

The centre of the target will be hotter than the surface. The temperature is given by,

$$T_c - T = \frac{W}{2\pi R\,?4\pi K}$$

where *K* is the thermal conductivity. This is for a uniform power distribution over the cross section of the target. The value increases by 3/2 for a parabolic profile. Note that the temperature rise is independent of *r*. With *K* = 0.83 W/cm/K at high temperatures for tantalum, this gives a temperature rise at the centre of the target of ~20 K. The temperature rise is less for tungsten due to its higher conductivity.