Shock Tests on Tantalum and Tungsten

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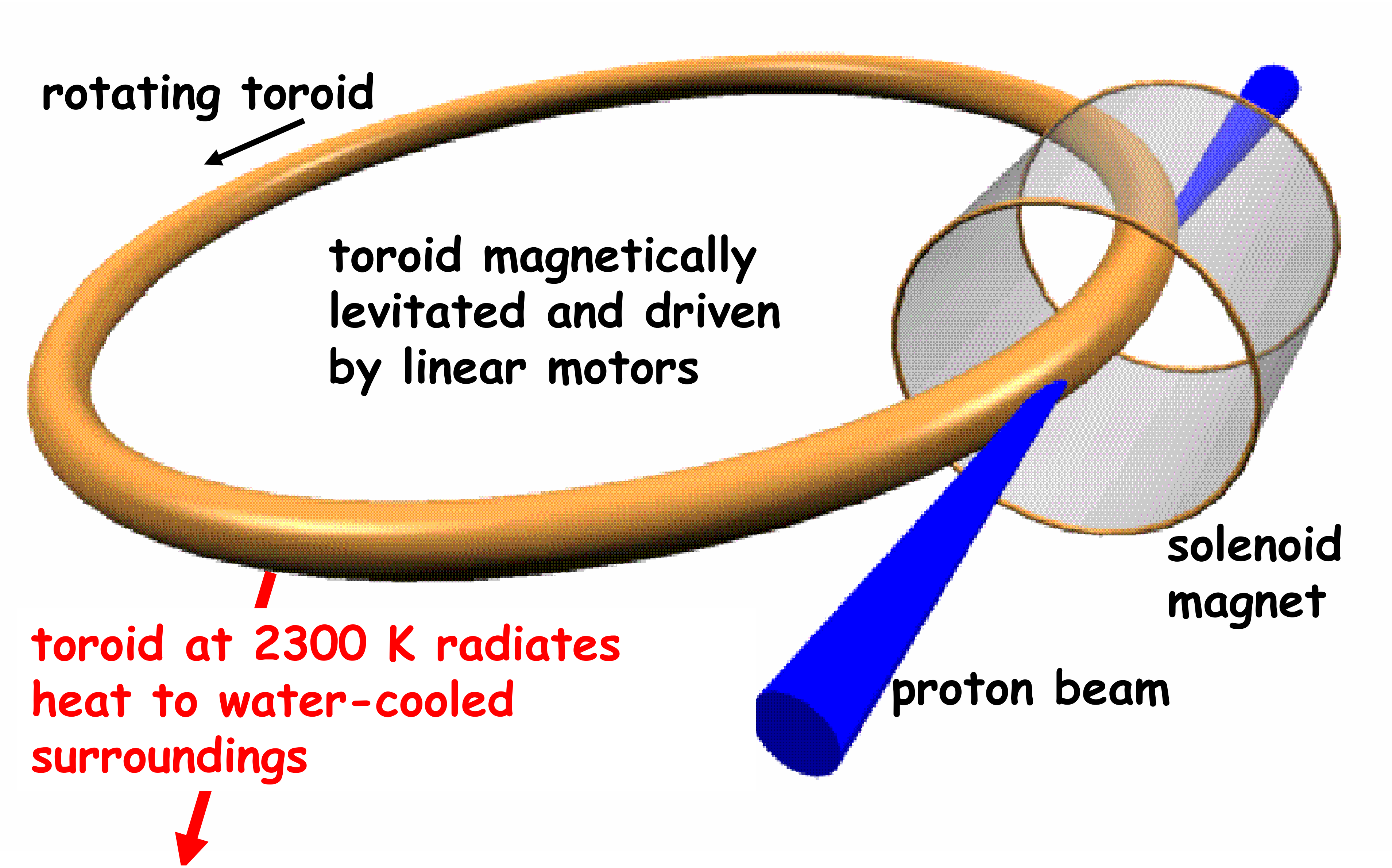
The original RAL Target concept -

(after Bruce King)

Schematic diagram of the radiation cooled rotating toroidal target



The alternative concept -

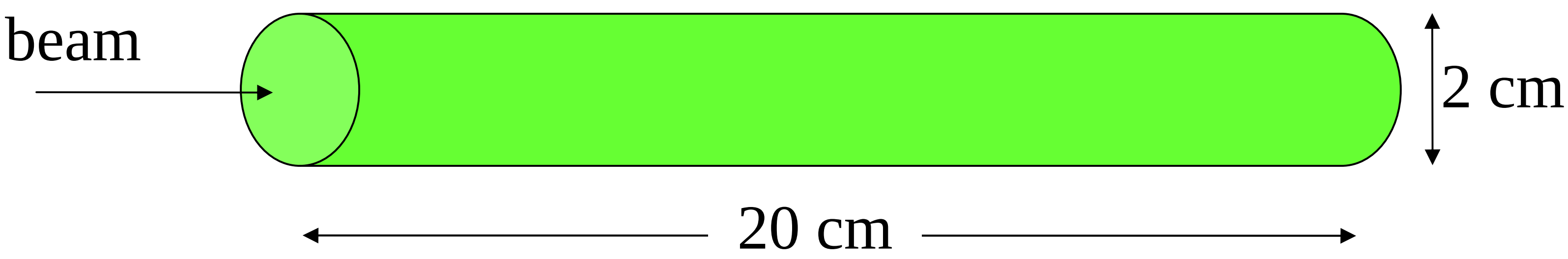
Individual Bar Targets

Target Parameters

Proton Beam

pulsed	50 Hz
pulse length	~40 μs
energy	~10 GeV
average power	~4 MW

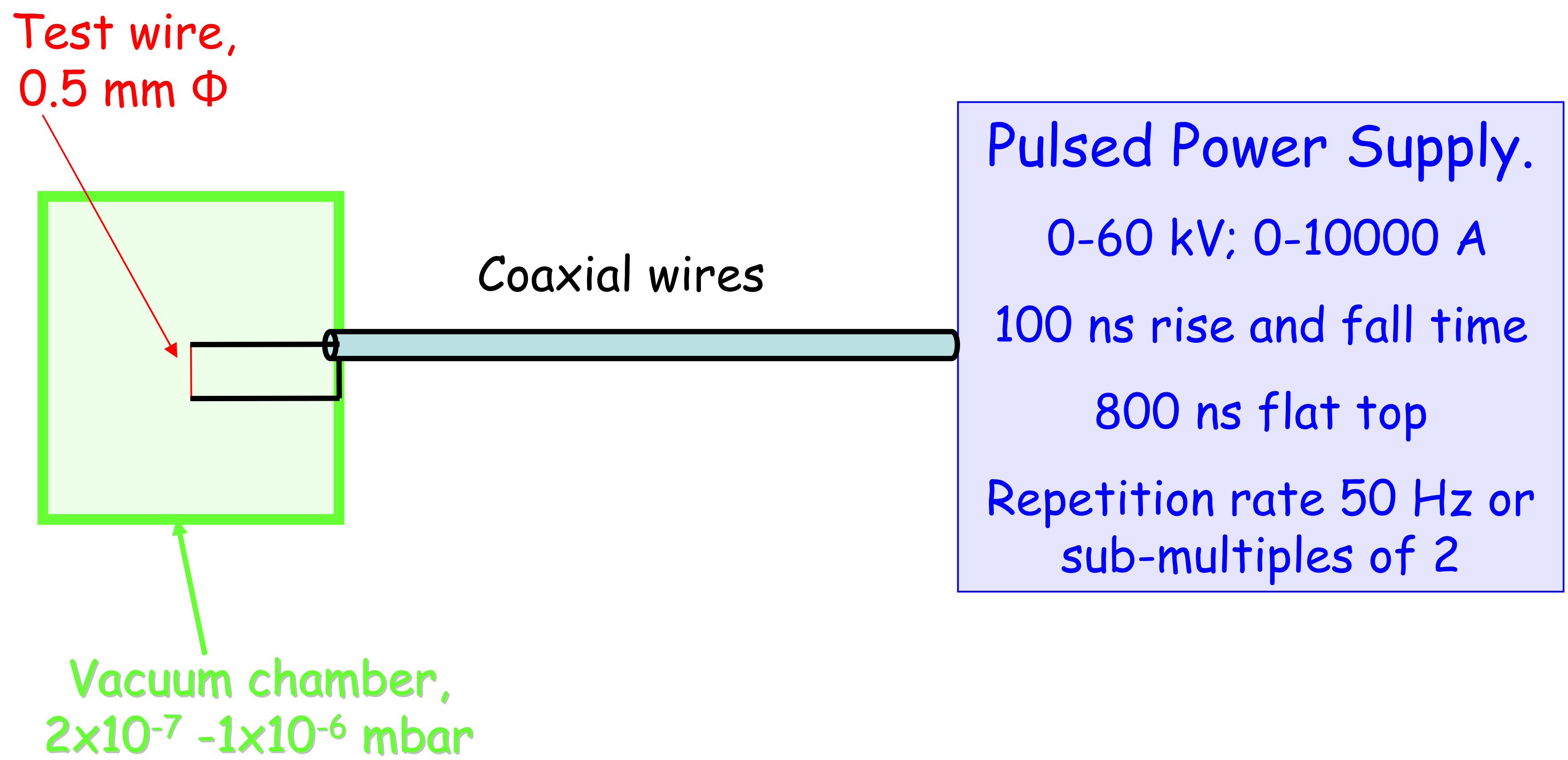
Target (not a stopping target)



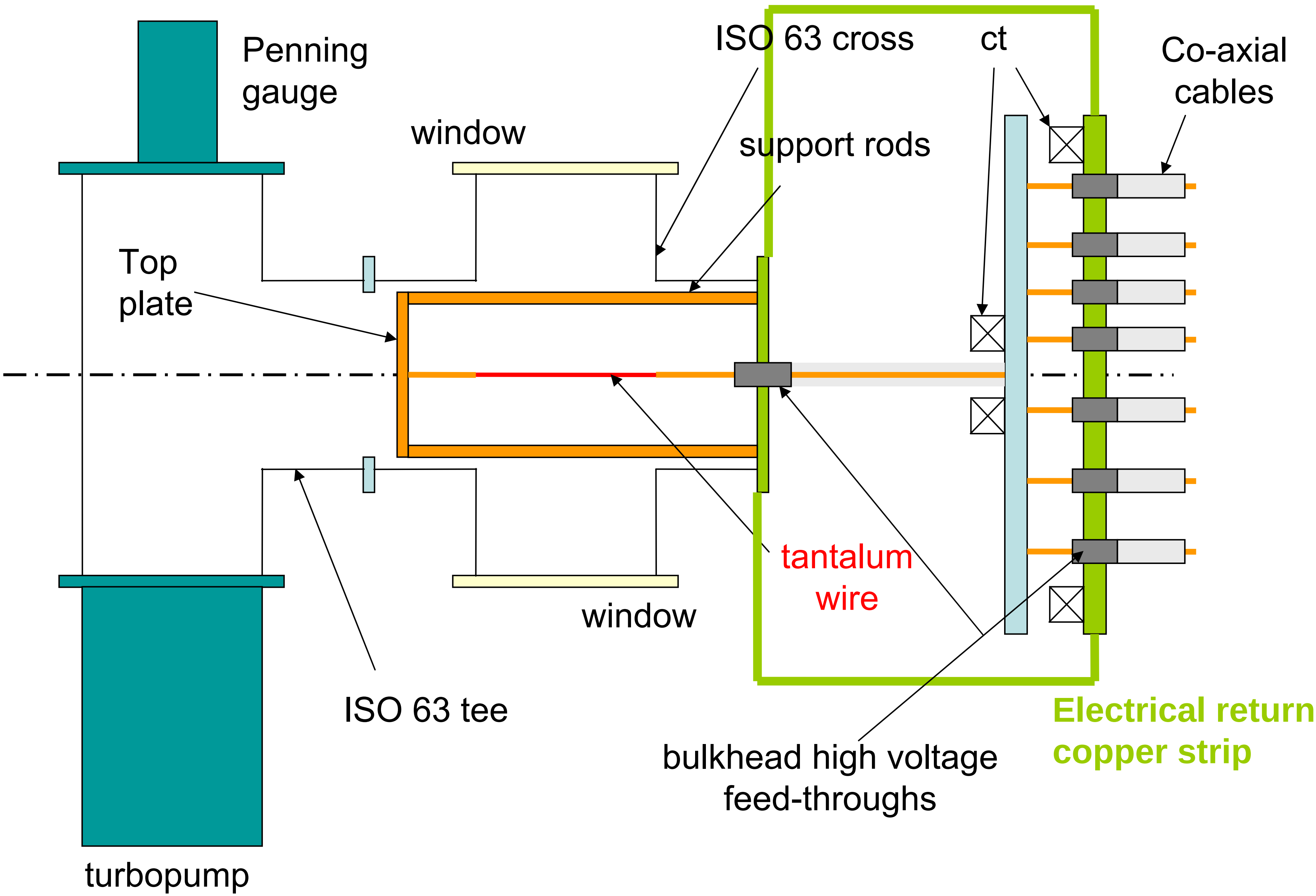
mean power dissipation	1 MW
energy dissipated/pulse	20 kJ (50 Hz)
energy density	300 J cm^{-3} (50 Hz)

- It is not possible to test the full size targets in a proton beam and do a life test.

- Produce shock by passing high current pulses through thin wires.

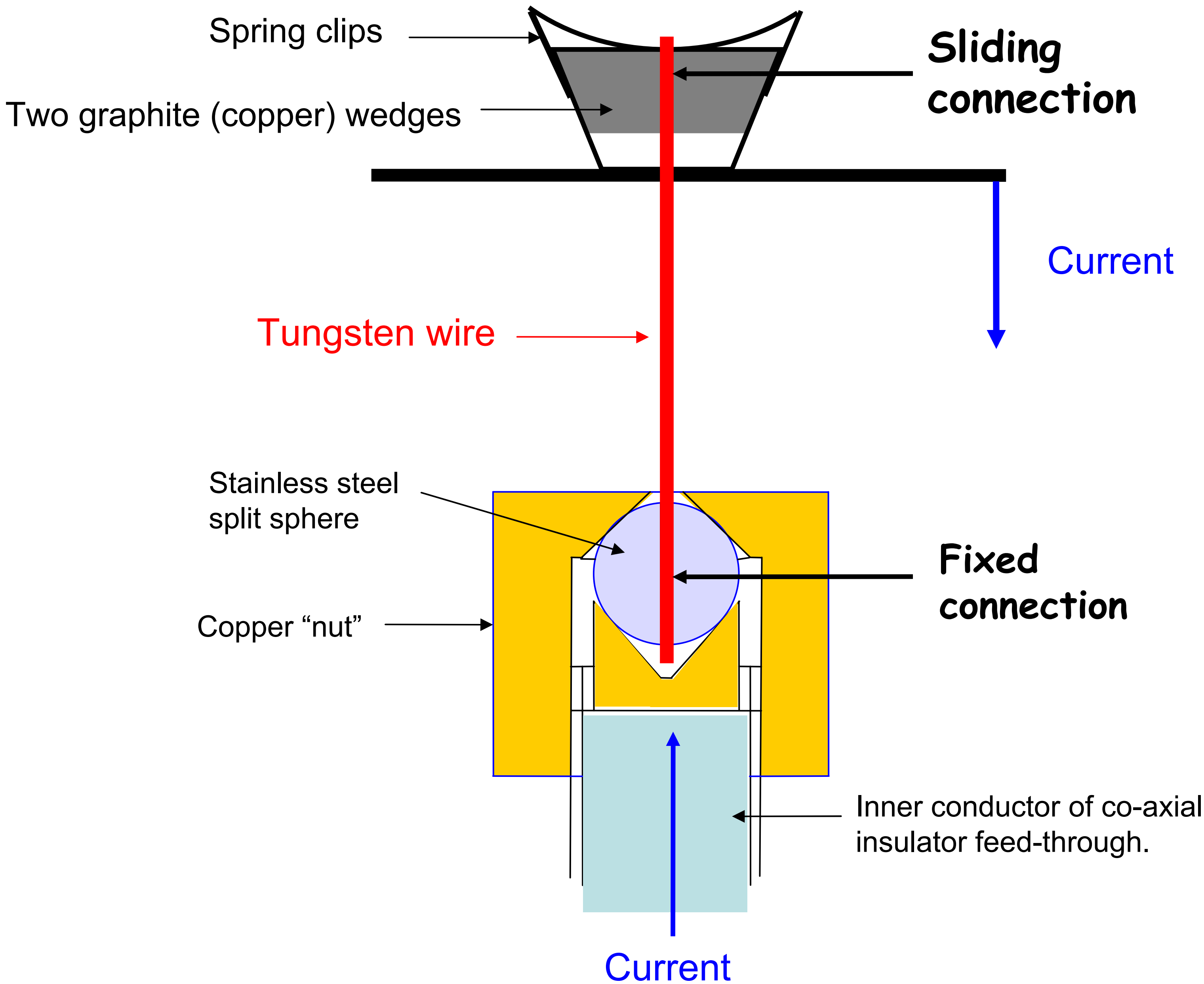


Schematic circuit diagram of the wire test equipment



Schematic section of the wire test assembly

Vertical Section through the Wire Test Apparatus

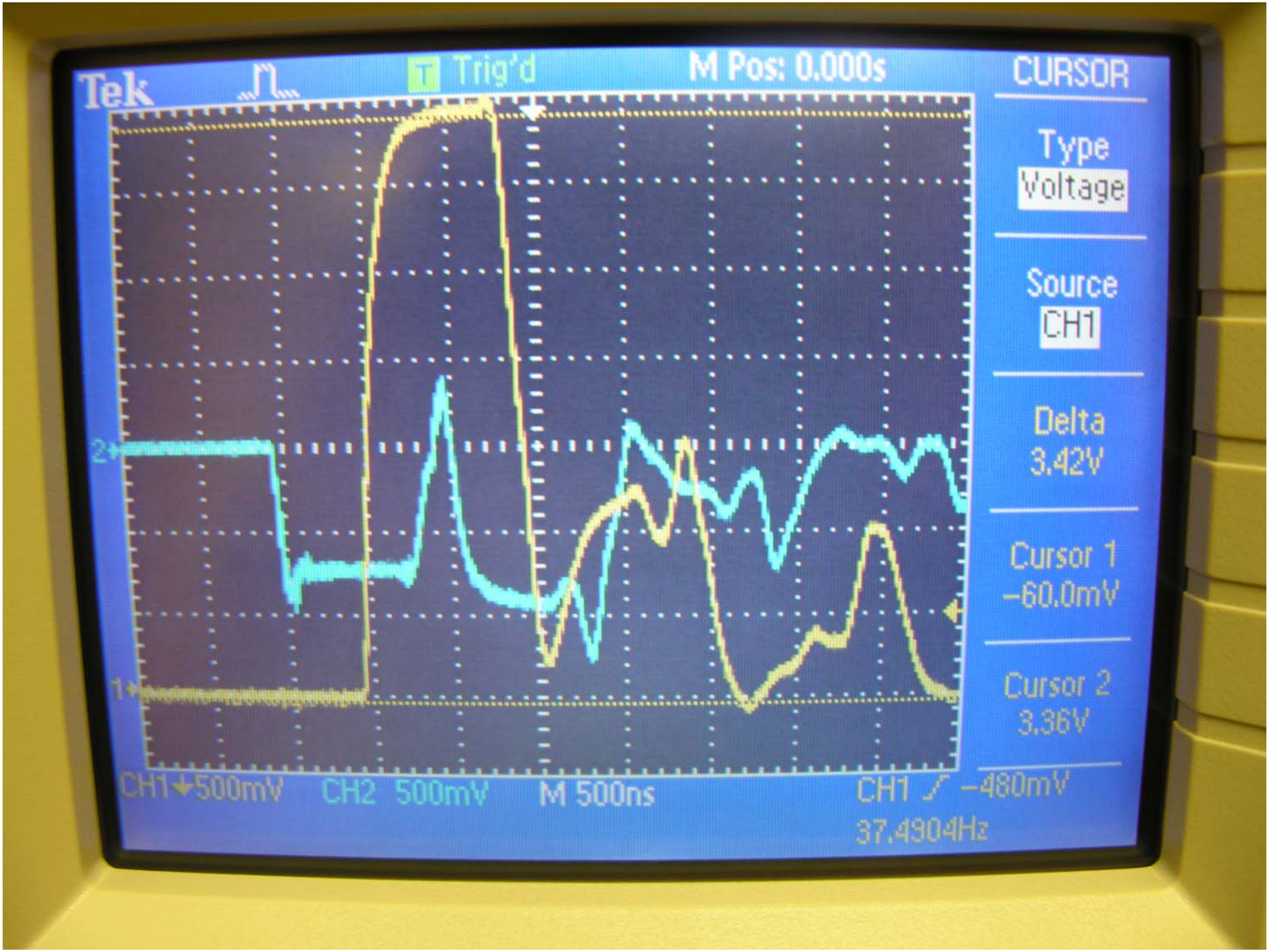


- **Need to independently vary the pulse current (energy density dissipated in the wire) and the peak temperature of the wire.** **(Not easy!)**

  1. Can vary the repetition rate (in factors of two).
  2. Can vary the wire length which changes the cooling by thermal conduction to the end connections.

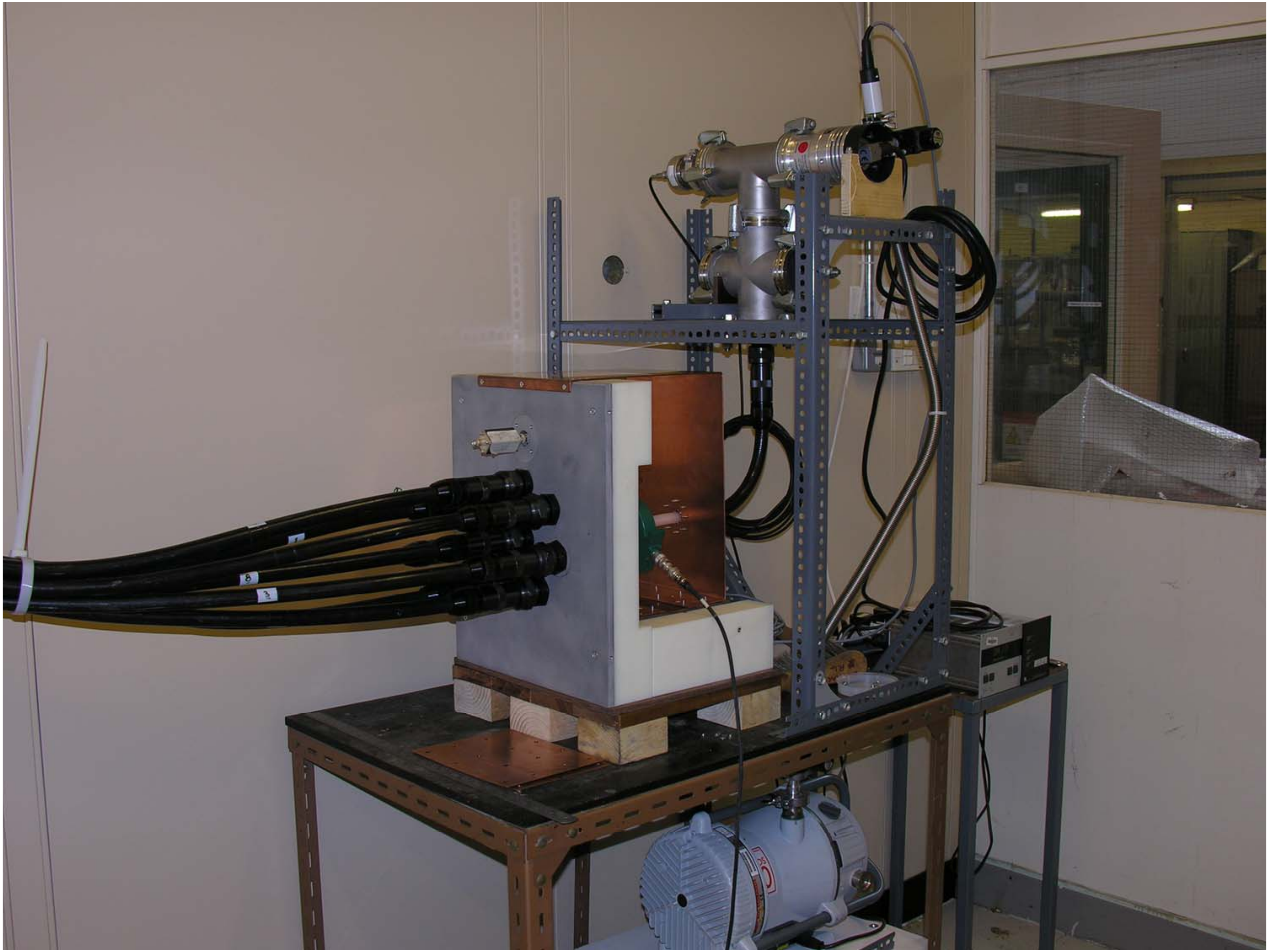
- **Must not fix both ends of the wire!**
- **Some problems encountered with getting reliable electrical end connections, particularly the top sliding connection.**

Picture of the pulse current

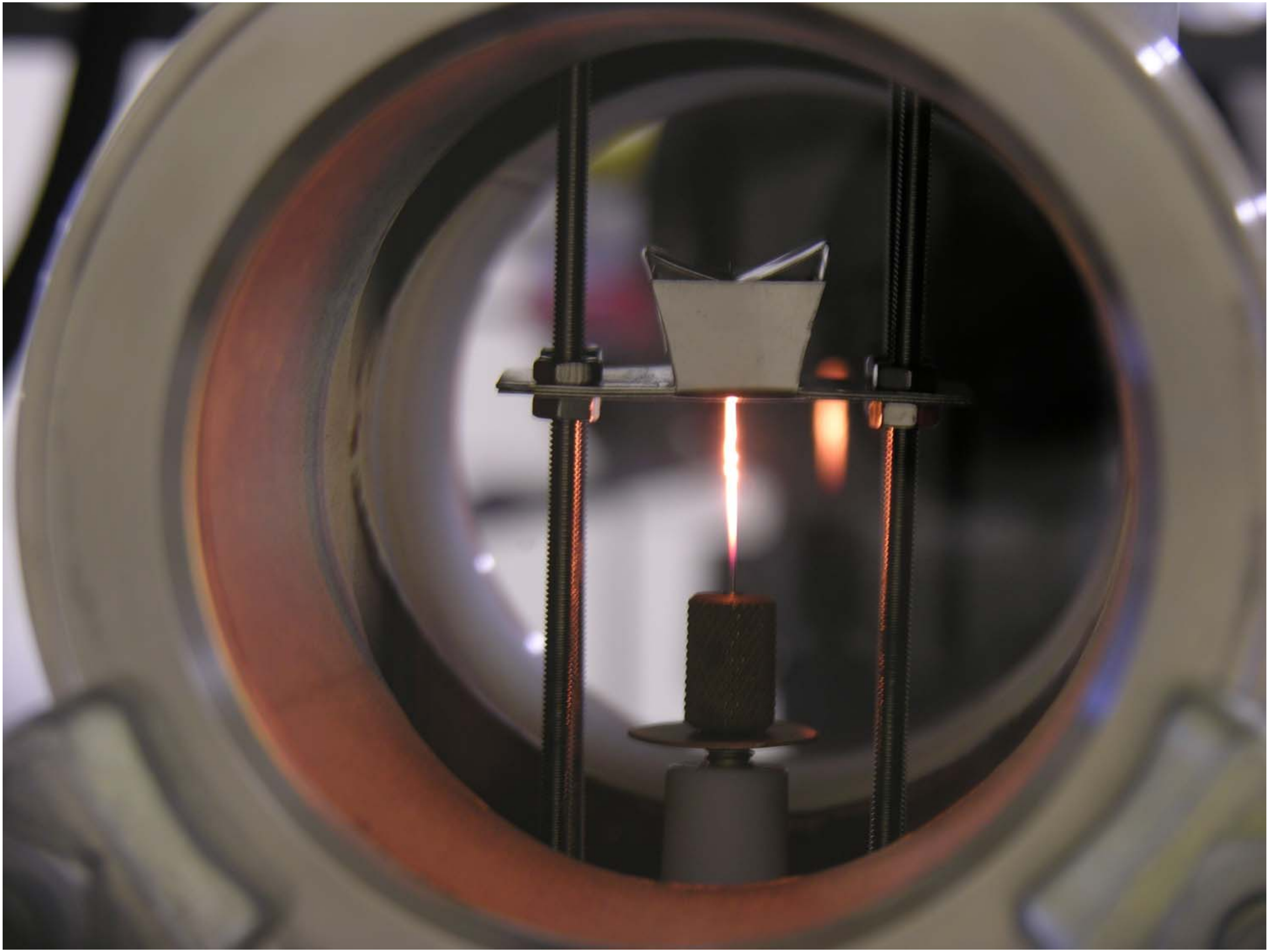


Tek
Trig'd
M Pos: 0.000s
CURSOR
Type
Voltage
Source
CH1
Delta
3.42V
Cursor 1
-60.0mV
Cursor 2
3.36V
CH1 500mV
CH2 500mV
M 500ns
CH1 ∕ -480mV
37.4904Hz

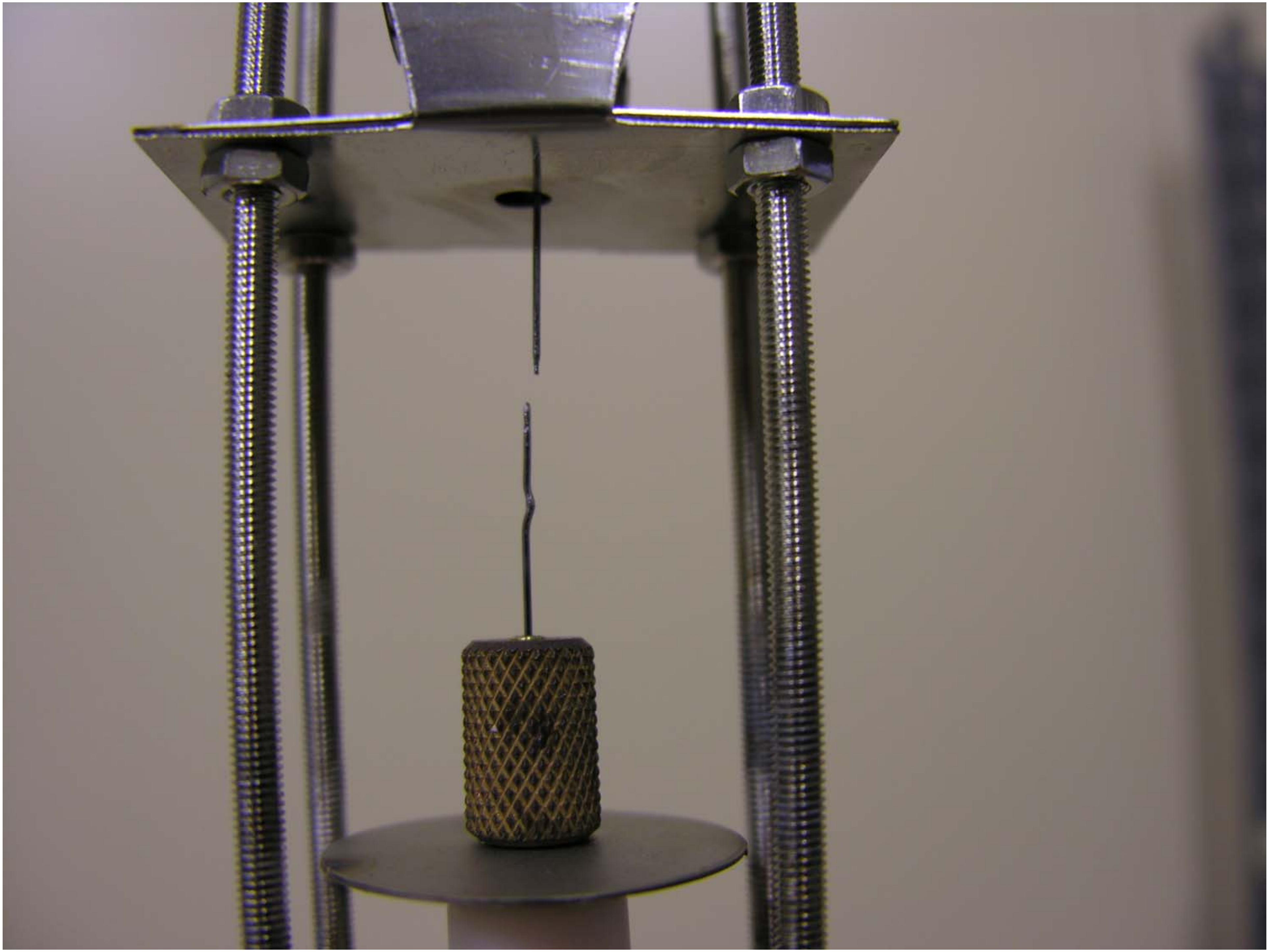
Picture of the wire test equipment



Photograph of the tantalum wire showing characteristic wiggles before failure.



A broken tantalum wire



Some Results of 0.5 mm diameter wires

Material	Lngth cm	Pulse Current A	Pulse Temp. K	Max. Temp K	Rep Rate Hz	No. of pulses to failure	Equivalent Target: Beam Power MW	Equivalent Target: Target dia cm
Tantalum	4	3000	60	1800	12.5	0.2×10^6		
Tantalum is not a very good material - too weak at high temperatures.								
Tungsten								
Broke when increased to 7200A (2200K)	3	4900	100	2000	12.5	$>3.4 \times 10^6$	2 4	2 3
Stuck to top Cu connector	3	6400	170	1900	6.25	$>1.6 \times 10^6$	4 8	2 3
Not broken;	2.5	5560	130	1900	12.5	4.2×10^6 +PLUS+	3 6	2 3
still pulsing		5840	140	2050	12.5	$>6.5 \times 10^6$	-	-

"Equivalent Target": This shows the equivalent beam power (MW) and target radius (cm) in a real target for the same stress in the test wire. Assumes a parabolic beam distribution and 4 micro-pulses per macro-pulse of 30 μs.

- Tungsten is a good candidate for a solid target and should last for several years.

- In this time it will receive ~10-20 dpa. This is similar to the 12 dpa suffered by the ISIS tungsten target with no problems.

- Tantalum is too weak at high temperatures to withstand the stress.

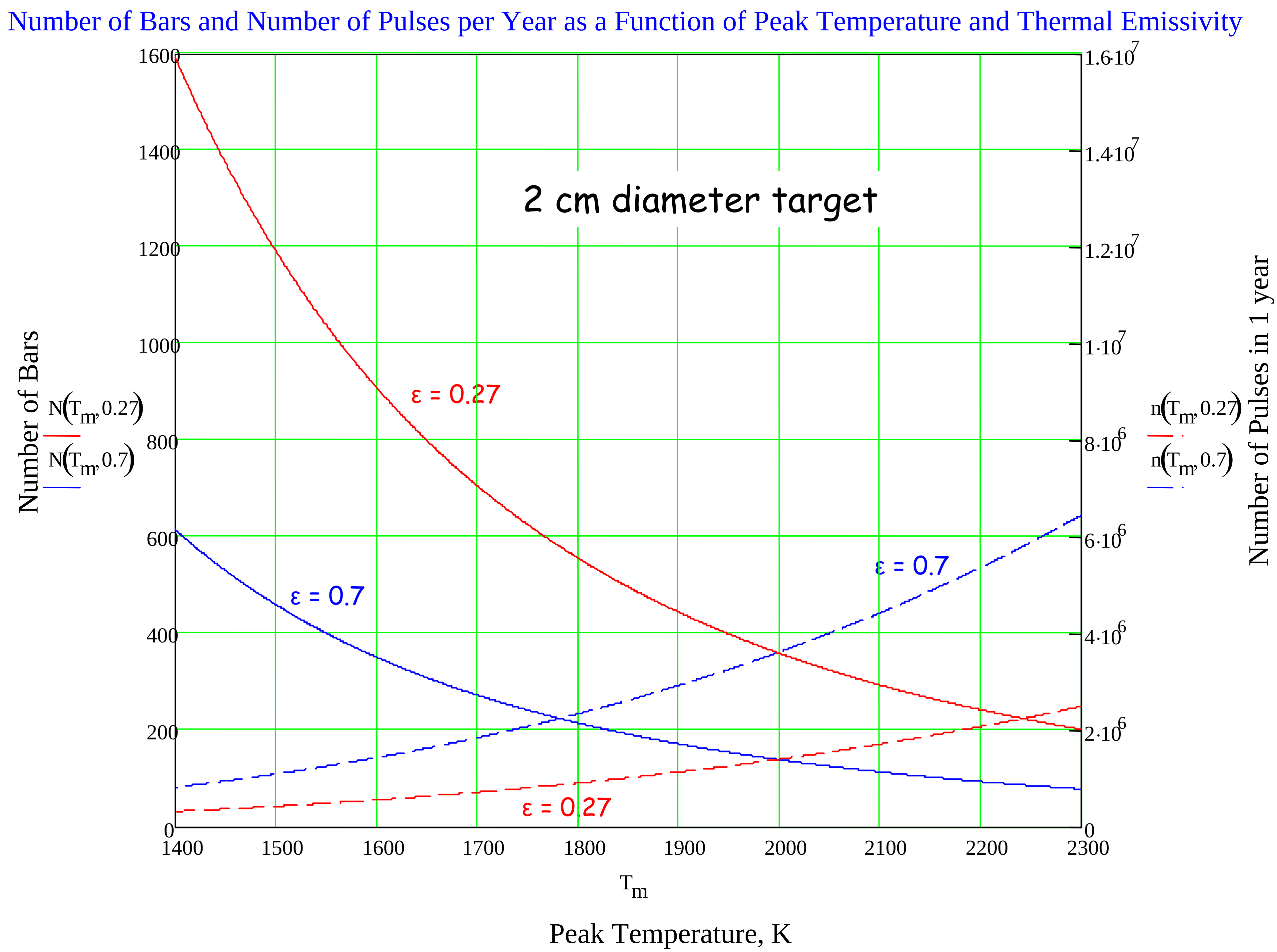
The Number of Bars

and

the Number of Pulses

(1 year is taken as 10^7 s)

- At equilibrium, a target bar heats up in the beam and then cools down by the same amount before entering the beam again.
- A new bar enters the beam at the rate of 50 Hz. i.e. every 20 ms.
- The more bars there are in the system then the fewer times any one bar goes through the beam in a year and the lower is the peak maximum temperature.
- This is illustrated in the next overhead (for two different thermal emissivities) where the number of bars and the number of pulses each bar will receive in 1 yr (10^7 s) is plotted against the pulse temperature.

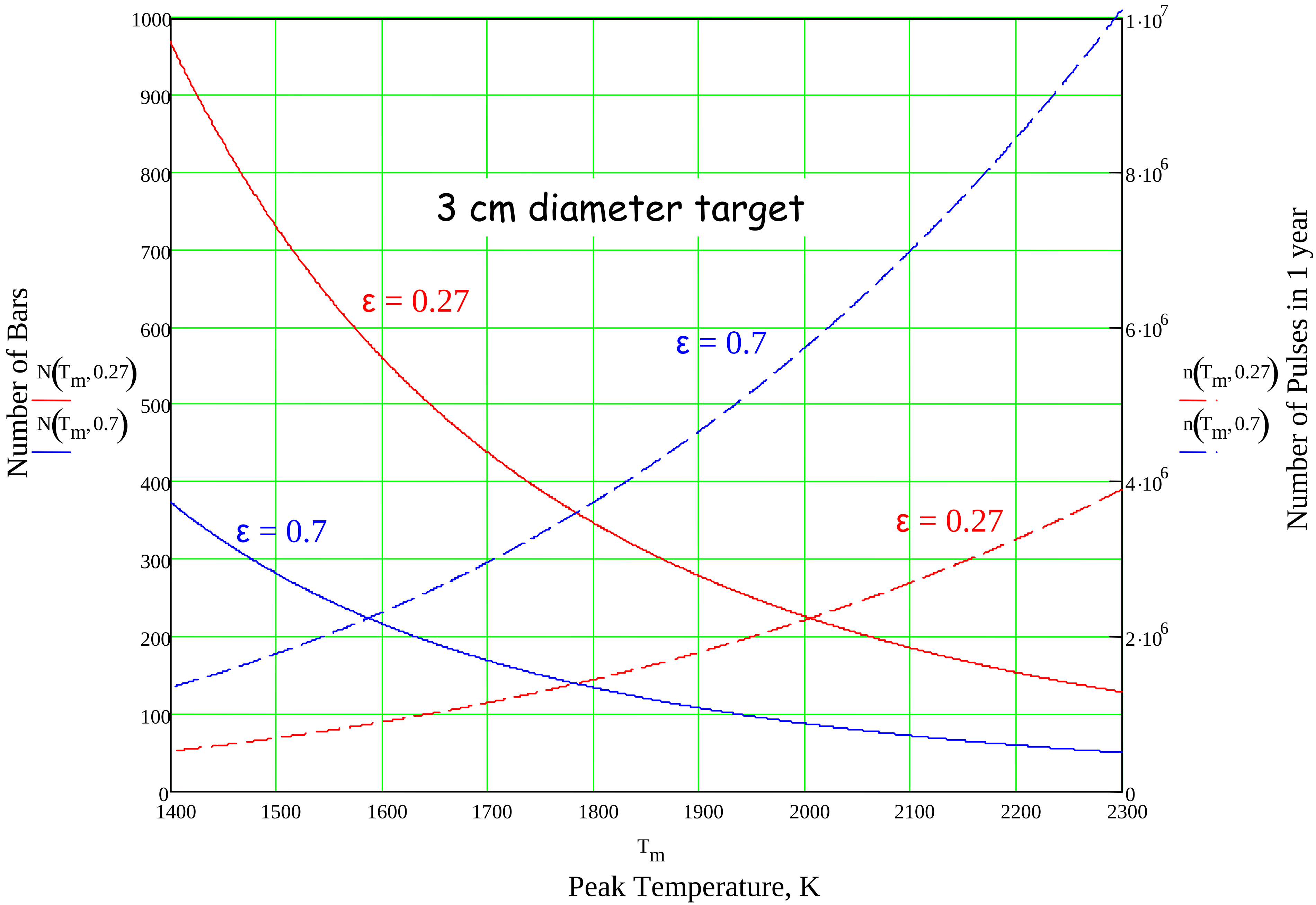


Number of Bars and Number of Pulses per Year as a Function of Peak Temperature and Thermal Emissivity
2 cm diameter target
ε = 0.27
ε = 0.7
ε = 0.7
ε = 0.27
Number of Bars
N(Tm, 0.27)
N(Tm, 0.7)
n(Tm, 0.27)
n(Tm, 0.7)
Number of Pulses in 1 year
Tm
Peak Temperature, K
0
200
400
600
800
1000
1200
1400
1600
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
0
2·10^6
4·10^6
6·10^6
8·10^6
1·10^7
1.2·10^7
1.4·10^7
1.6·10^7

A larger diameter target reduces the energy density dissipated by the beam (beam diameter = target diameter).

So going from 2 to 3 cm diameter reduces the energy density by a factor of 2 and the stress is also correspondingly reduced.

Number of Bars and Number of Pulses per year as a function of Peak Temperature and Thermal Emissivity



I believe that a solid tungsten target is viable from the point of view of

shock

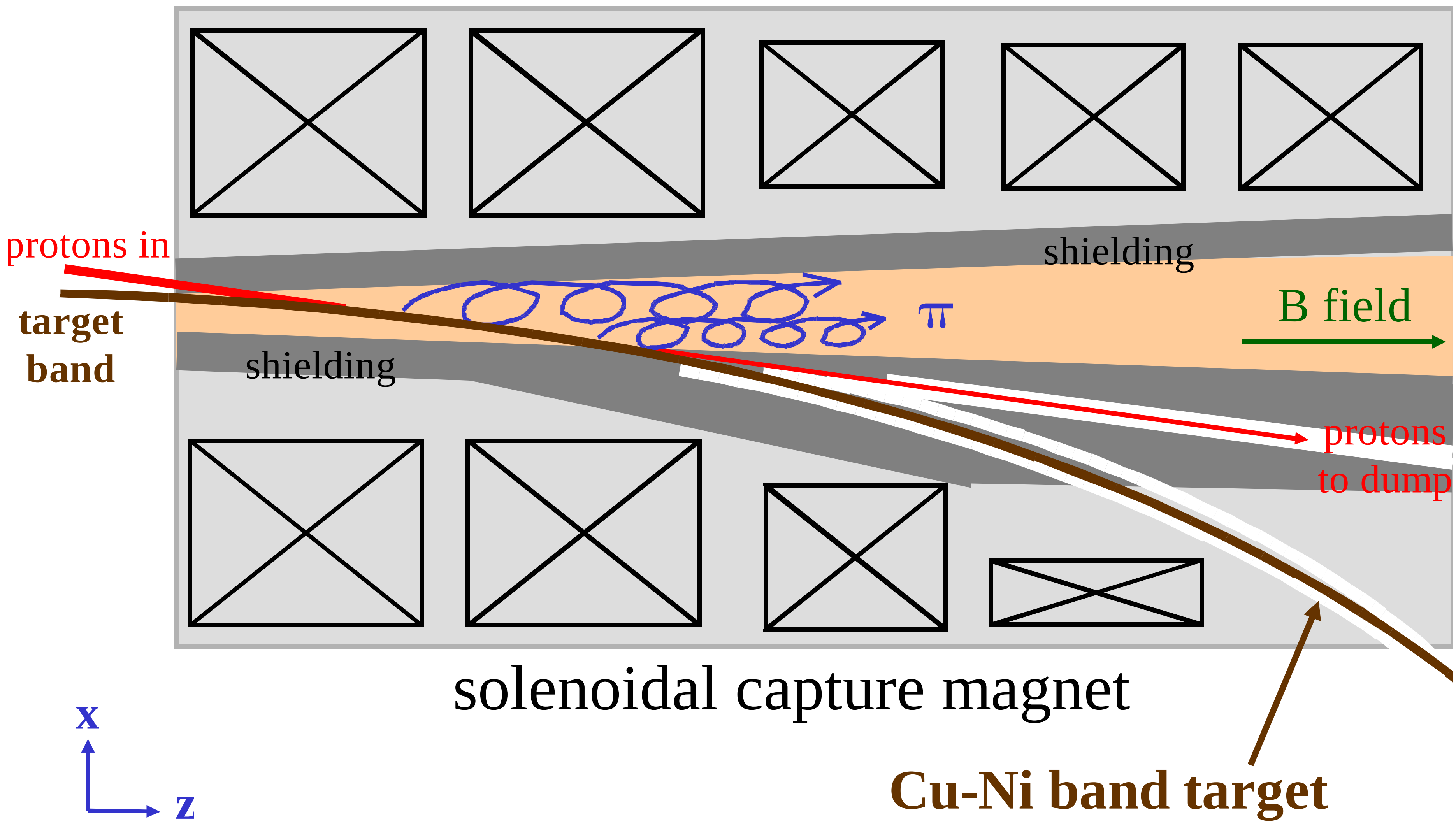
and

radiation damage.

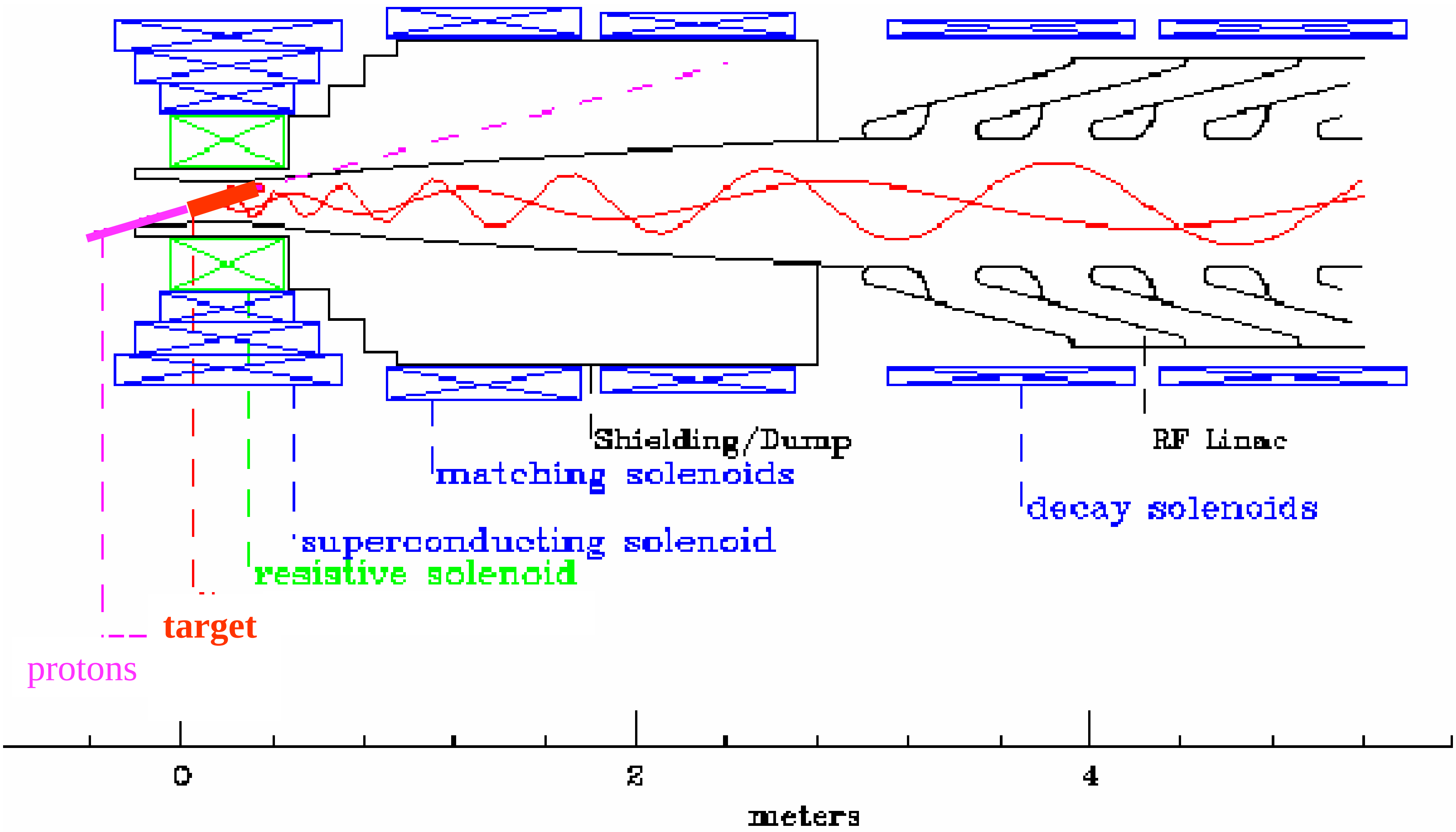
Target Mechanics

The original scheme

Target Geometry

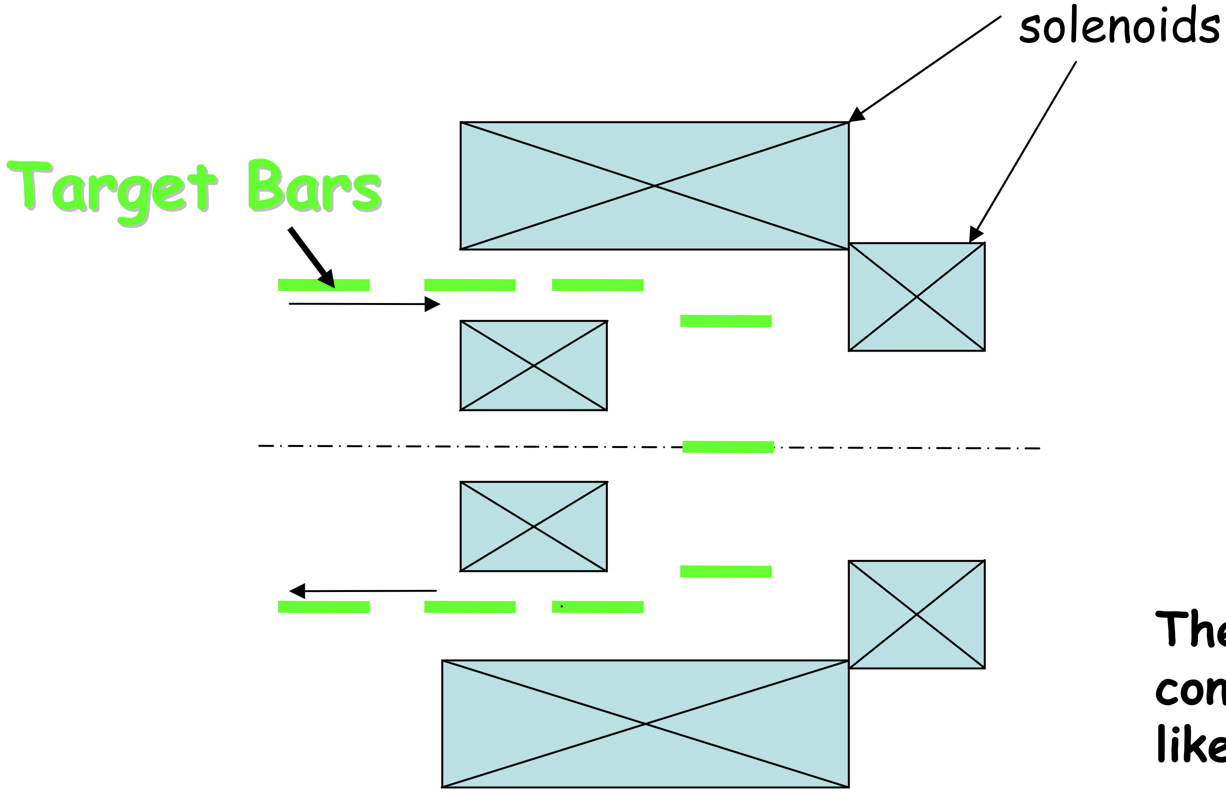


Bruce King



Typical Schematic Arrangement of a Muon Collider Target

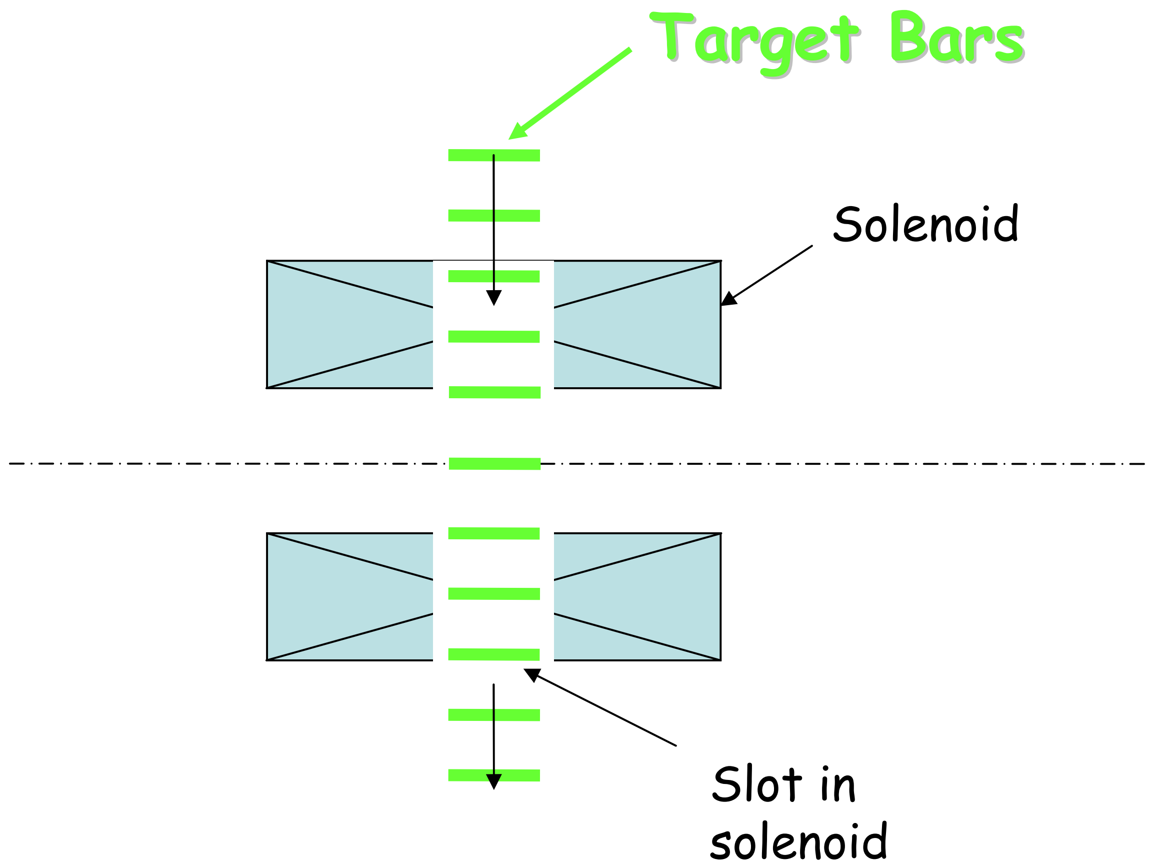
A possible alternative scheme



The target bars are connected by links - like a bicycle chain.

Schematic diagram of the target and collector solenoid arrangement

or

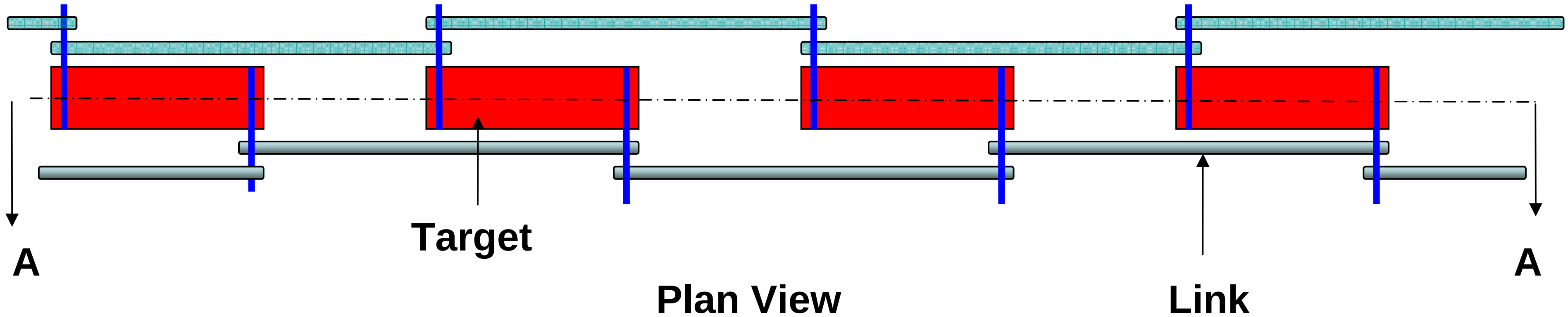


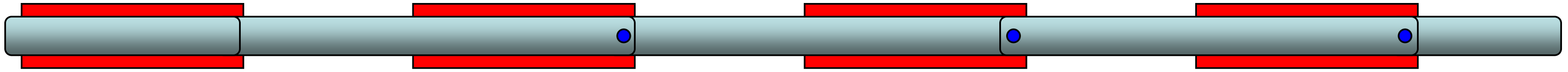
Schematic diagram of the collector solenoid with a slot for the target bars.

Thank You

The End

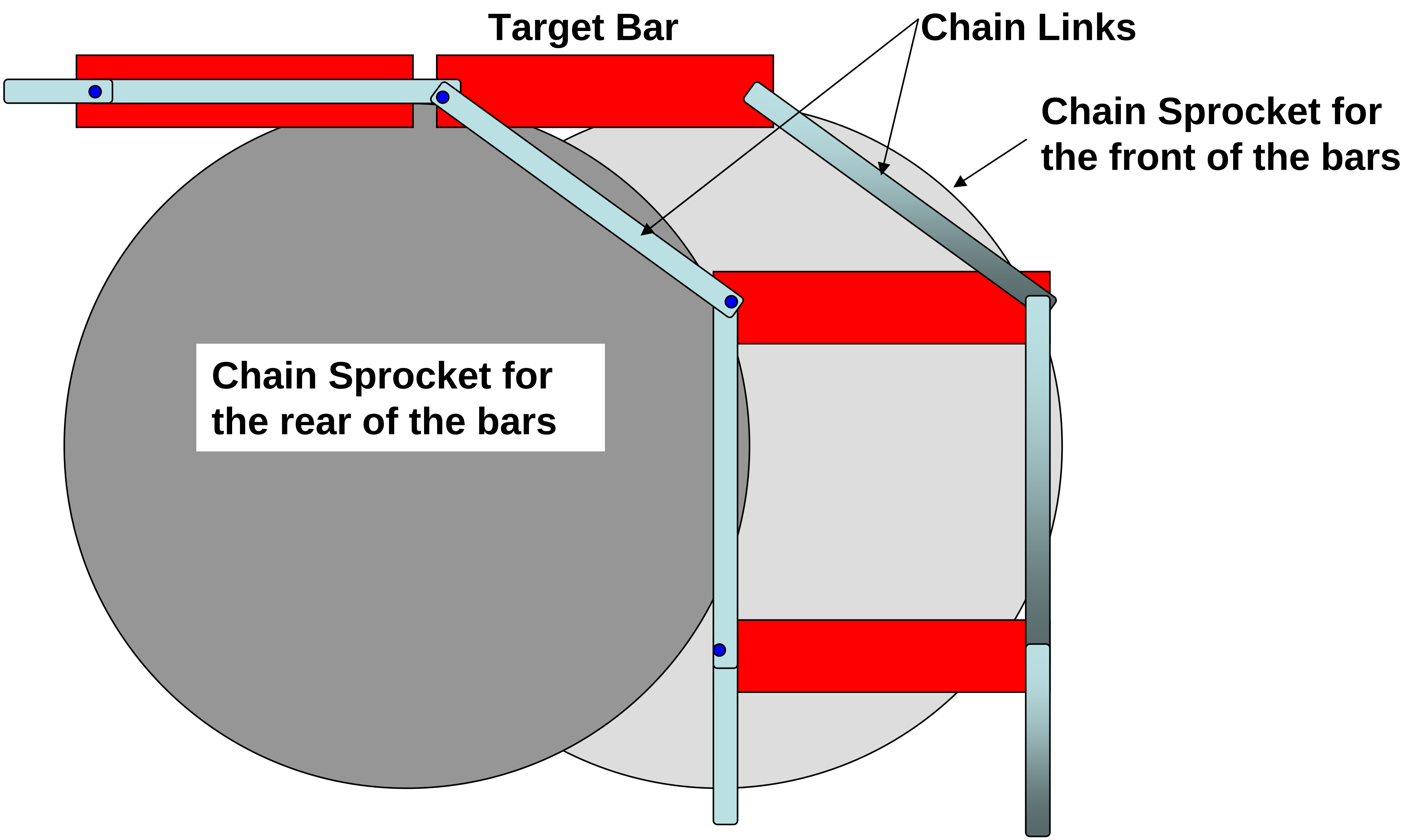
A possible way of linking the targets

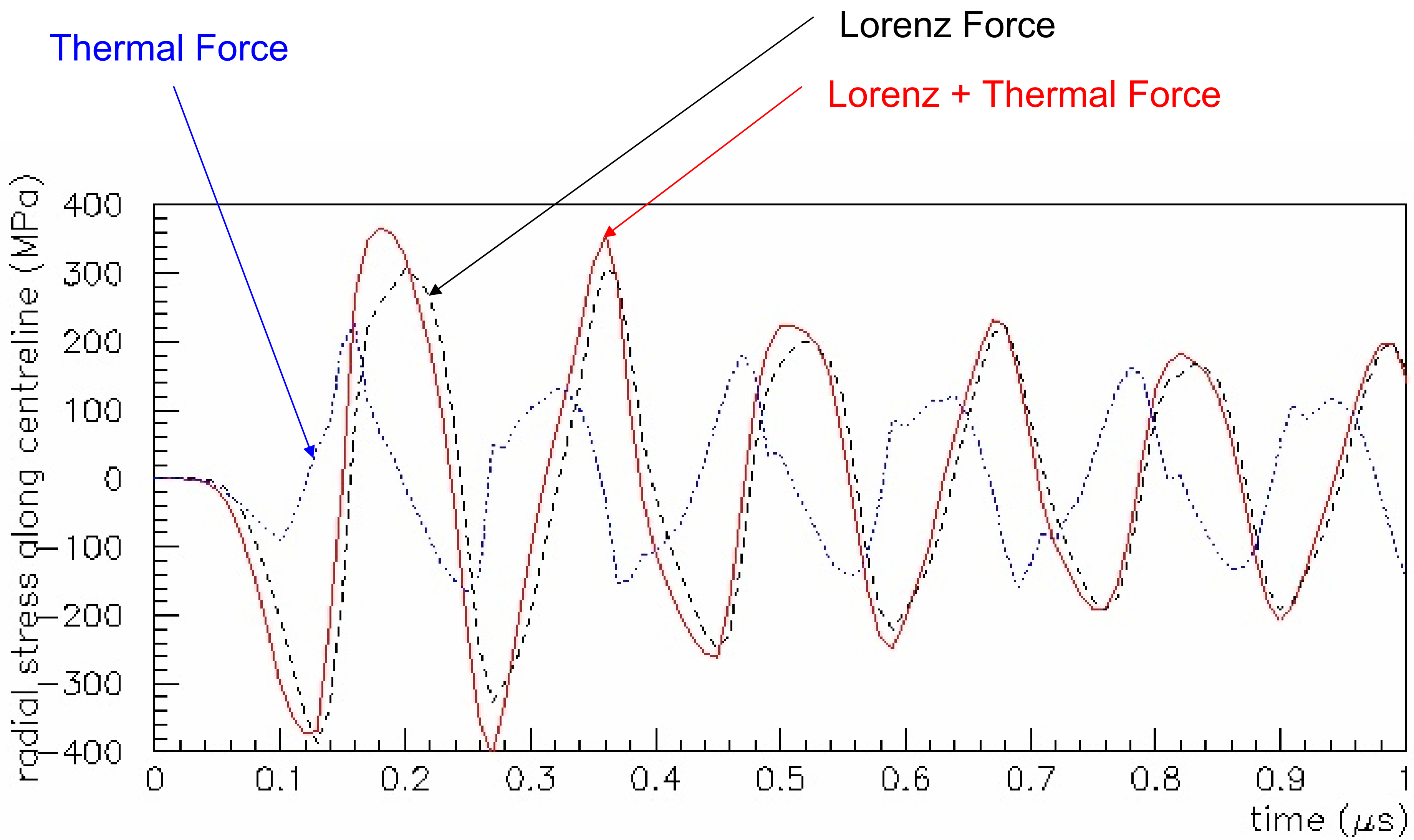




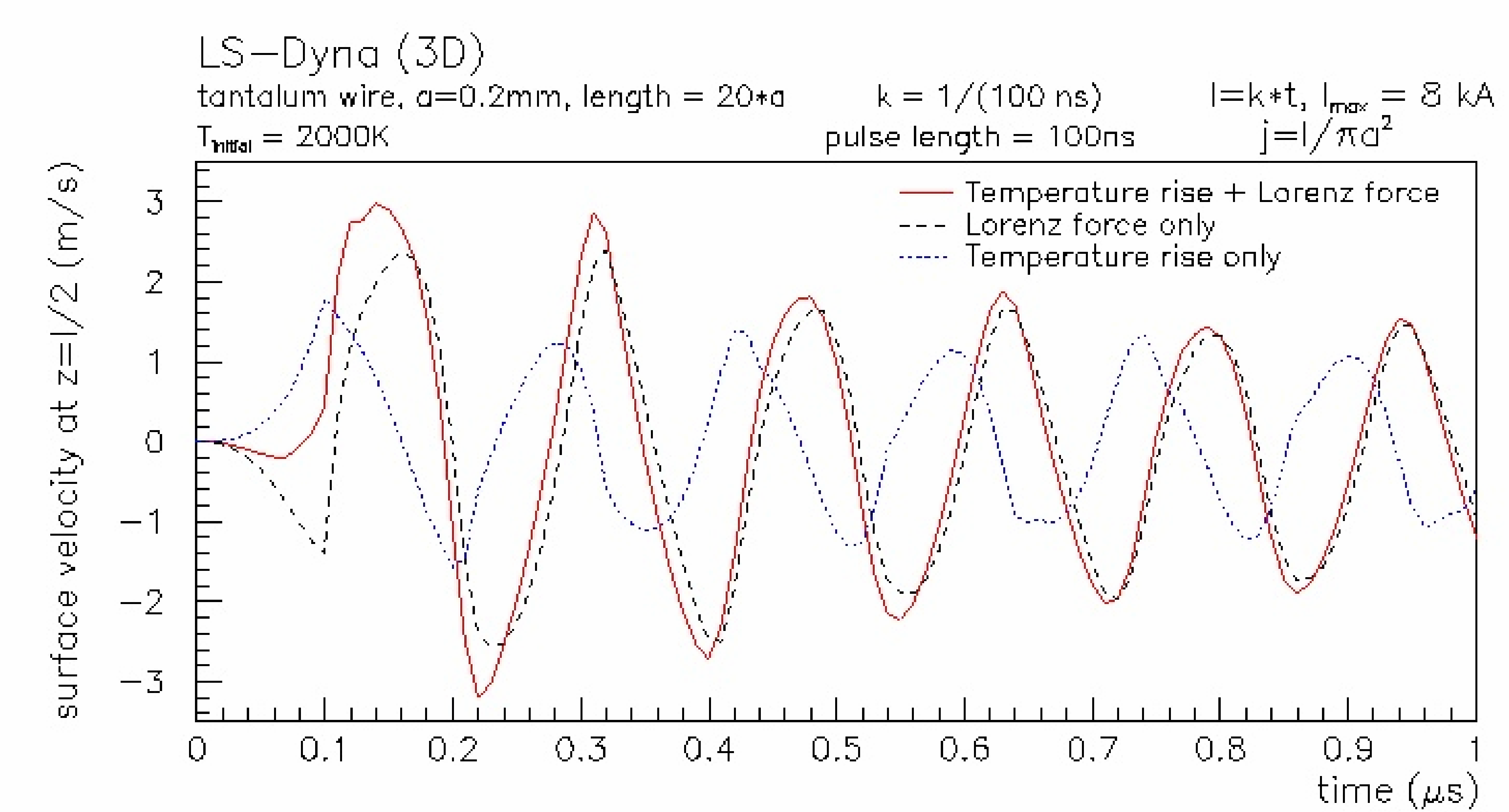
Section AA

Schematic arrangement of the chain mechanism for the target bars

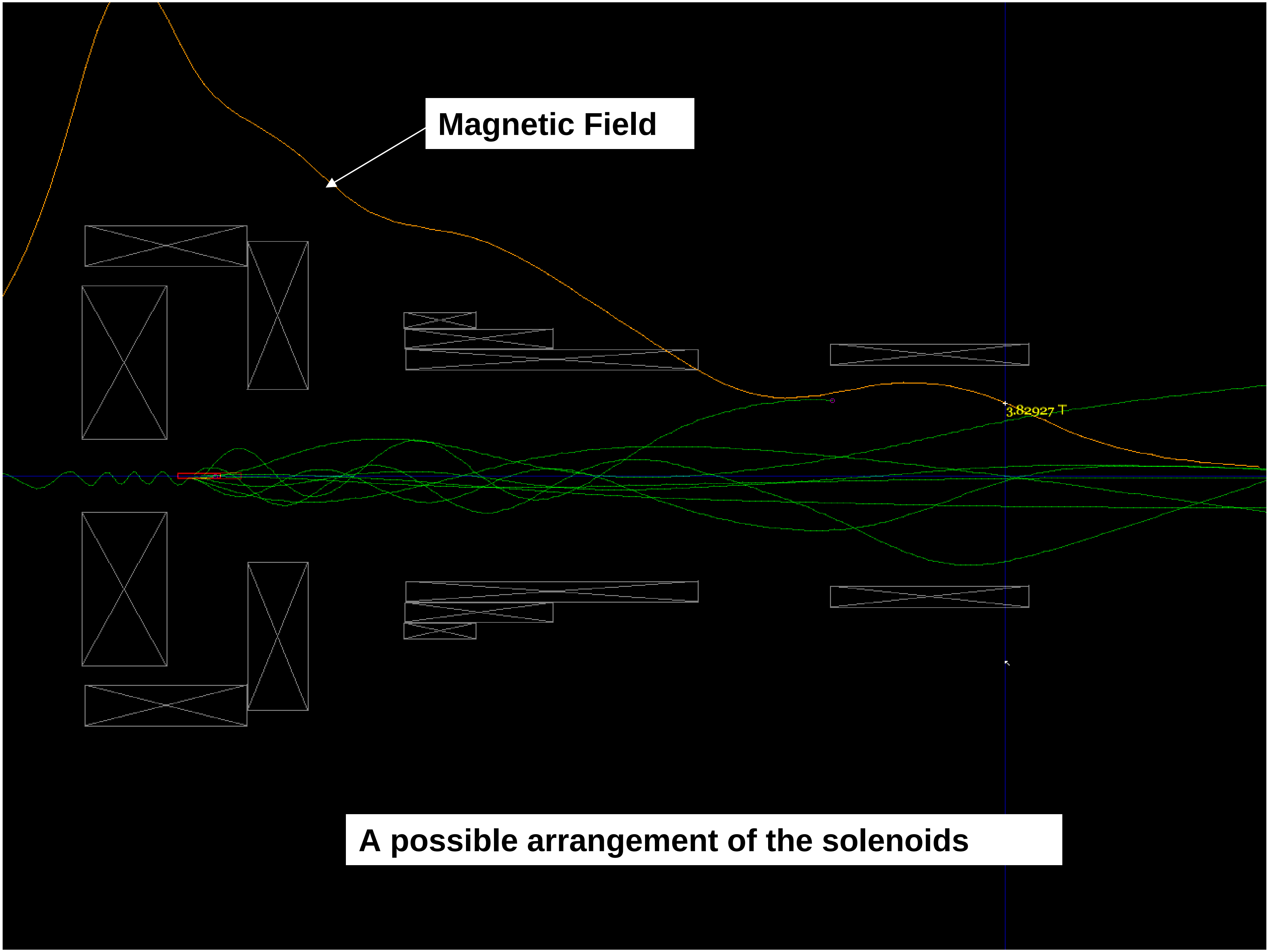



Thermal Force
Lorenz Force
Lorenz + Thermal Force
radial stress along centreline (MPa)
400
300
200
100
0
−100
−200
−300
−400
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
time (μs)

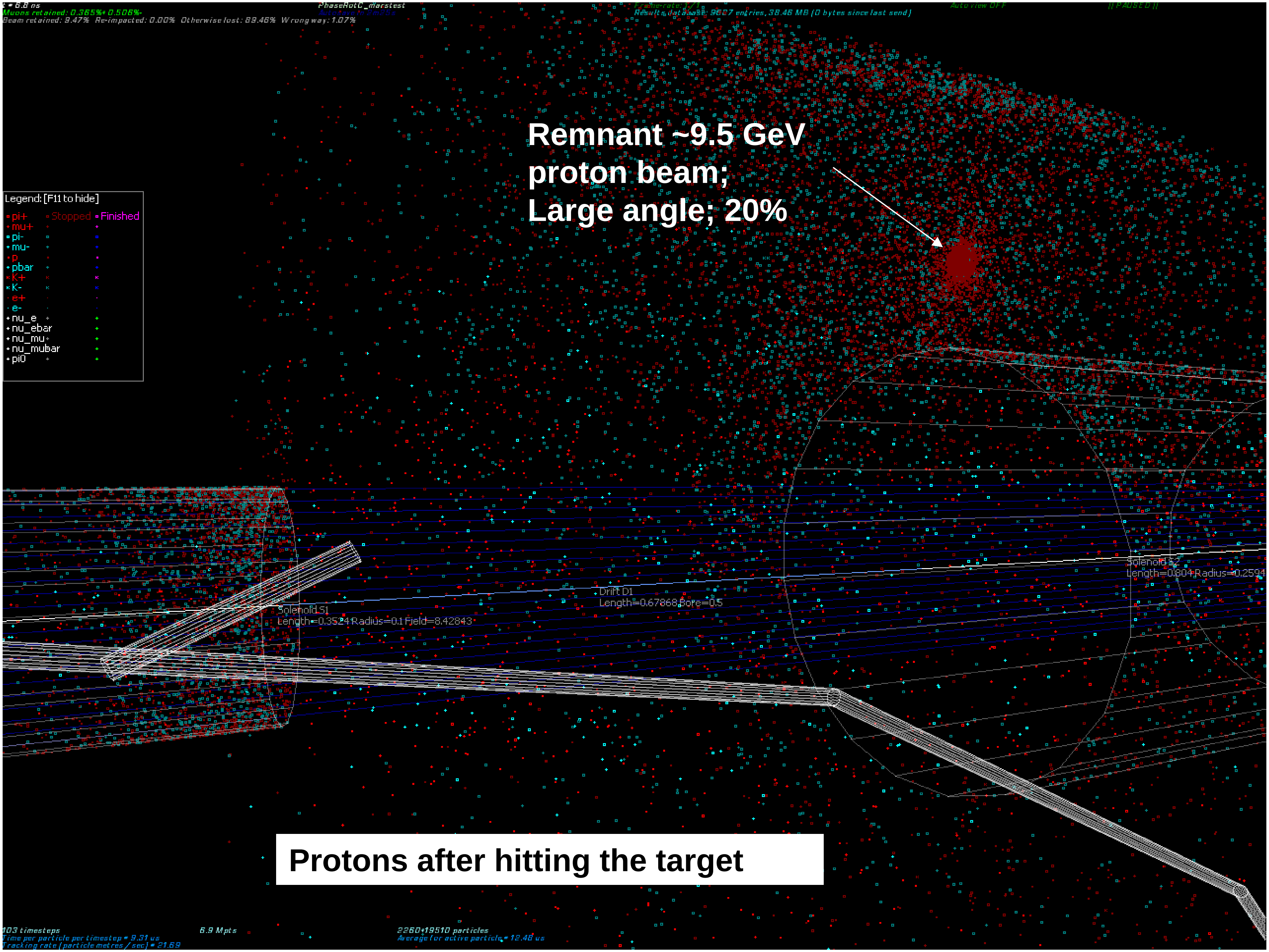
100 ns pulse



LS−Dyna (3D)
tantalum wire, a=0.2mm, length = 20*a
k = 1/(100 ns)
I=k*t, I_max = 8 kA
T_initial = 2000K
pulse length = 100ns
j=I/πa²
Temperature rise + Lorenz force
Lorenz force only
Temperature rise only
surface velocity at z=l/2 (m/s)
time (μs)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
3
2
1
0
−1
−2
−3

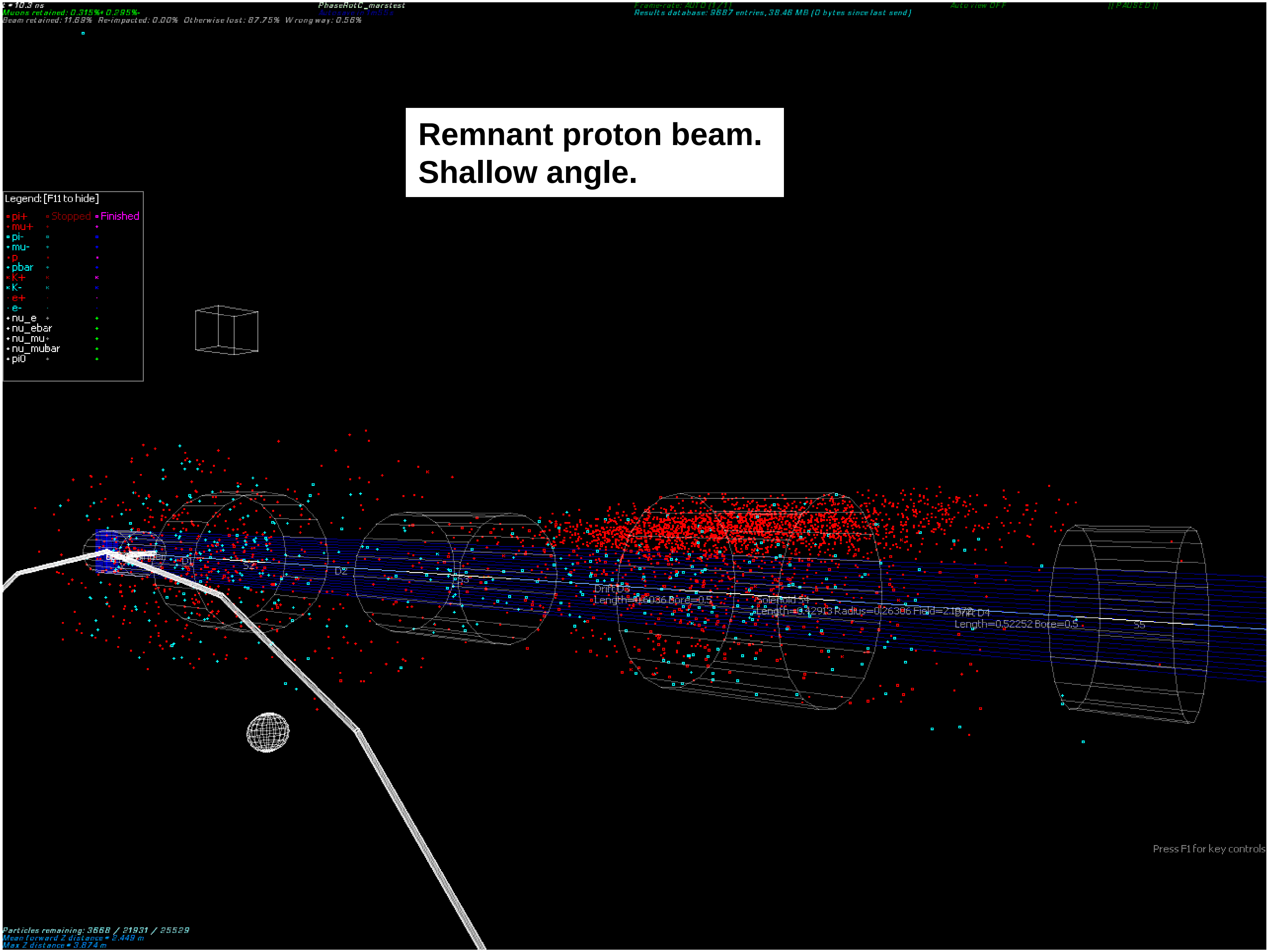

Magnetic Field
3.82927 T
A possible arrangement of the solenoids

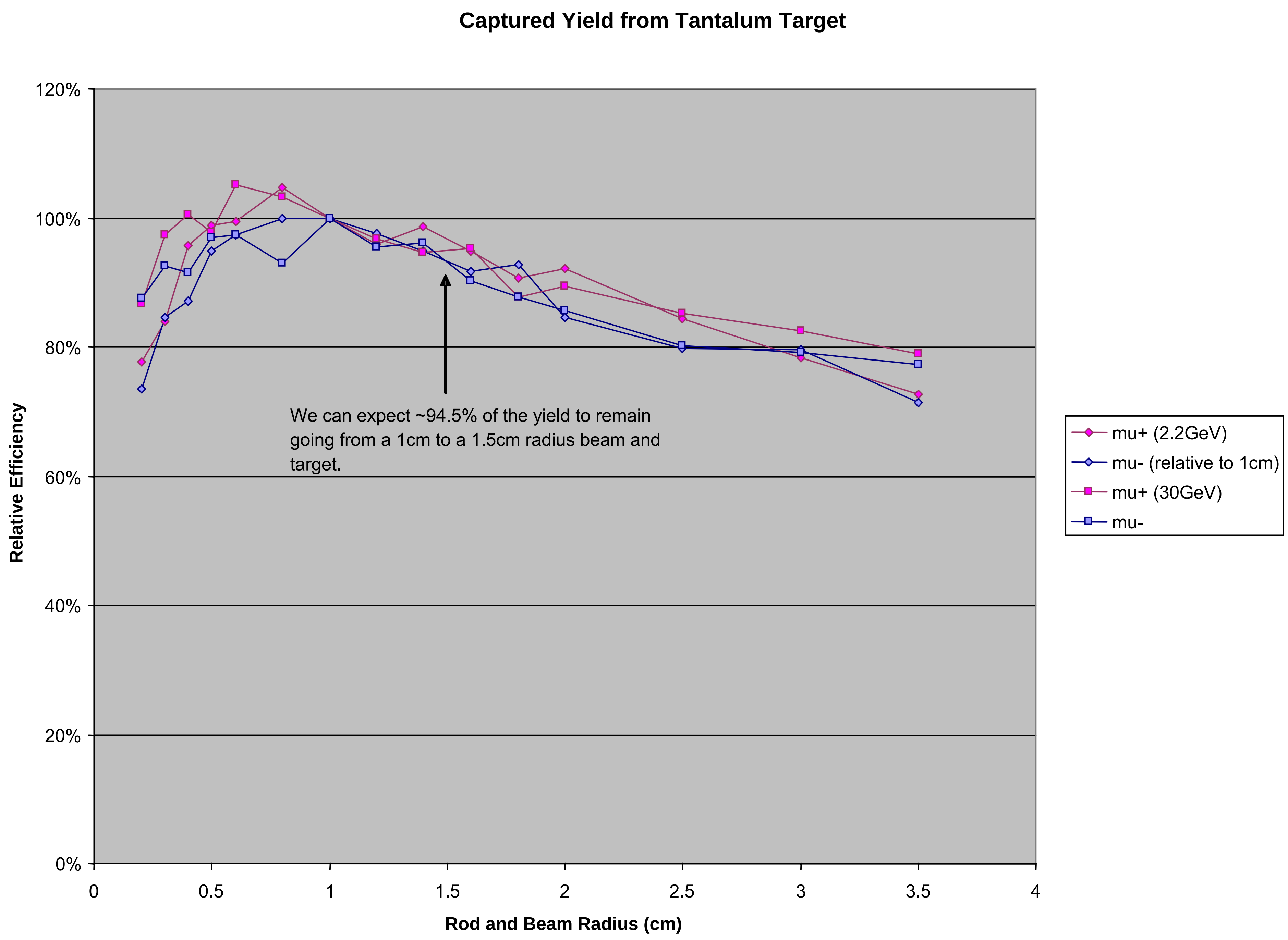
Remnant ~9.5 GeV proton beam;
Large angle; 20%



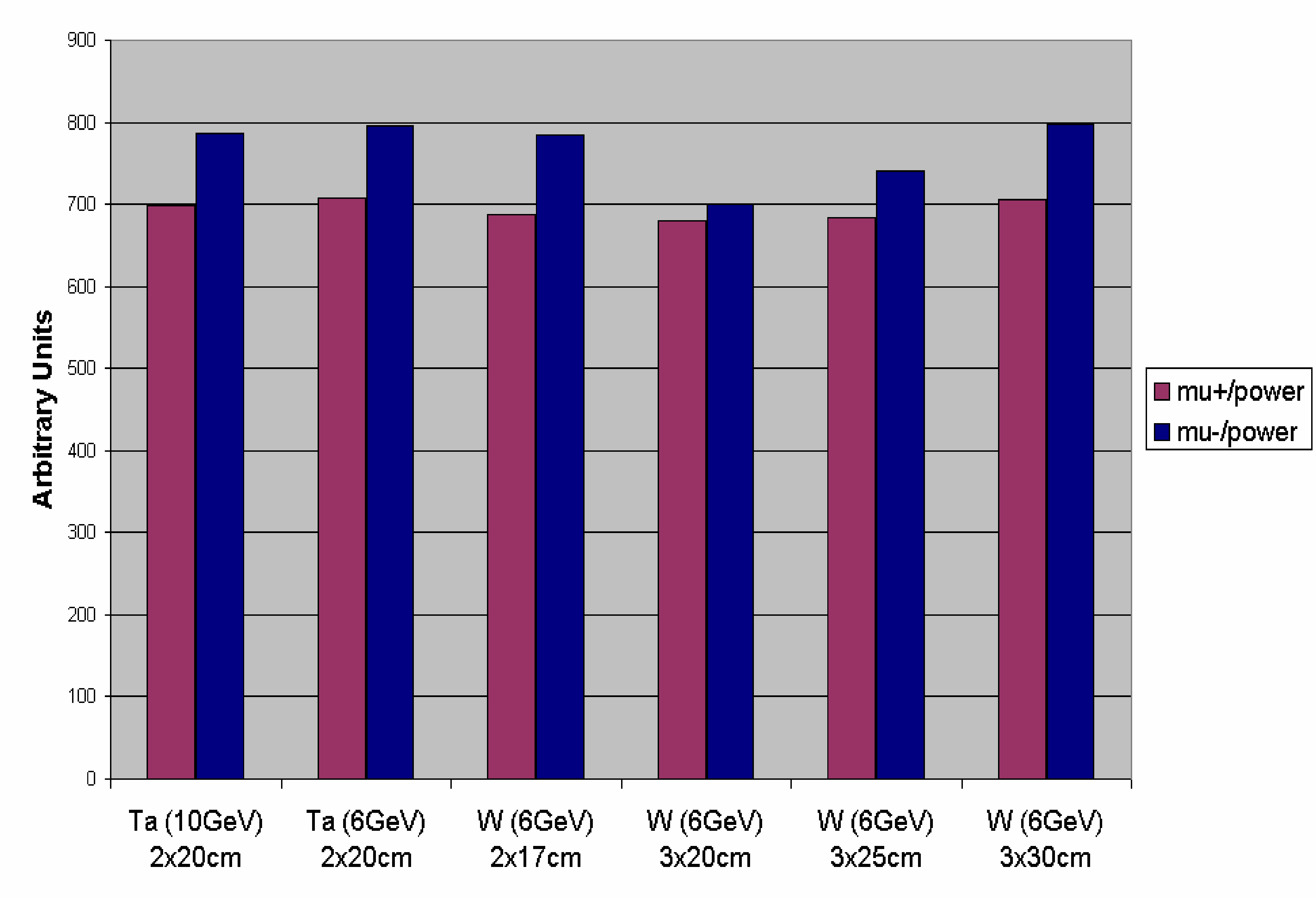
Protons after hitting the target

Remnant proton beam.
Shallow angle.





Captured Yield from Tantalum Target
120%
100%
80%
60%
40%
20%
0%
Relative Efficiency
0
0.5
1
1.5
2
2.5
3
3.5
4
Rod and Beam Radius (cm)
We can expect ~94.5% of the yield to remain going from a 1cm to a 1.5cm radius beam and target.
mu+ (2.2GeV)
mu- (relative to 1cm)
mu+ (30GeV)
mu-



Pion Yield for different target lengths