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Conventional Positron Target for a Tesla Formatted Beam

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Abstract: This note documents a set of expressions used to explore the issue of whether or not it is reasonable to consider a conventional positron source for a Tesla formatted beam. The critical issue is that of energy deposition in the conversion target and the comparison of the induced stress with the ultimate tensile strength of the target material. Since the length of the incident beam pulse is large in comparison to the ratio of beam size to the speed of sound, the concurrent pressure pulse dissipates in a time short compared to the overall pulse duration and one is left with only the semi-static thermal stress. The conclusion of this note is that for tangential target speeds of 100-125 m/s, two positron targets are necessary. For a target speed of 250 m/s, it is possible that a single target can handle to energy deposition. Additional issues that need to be addressed are given at the end. This note is informal in nature.

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Abstract

This note documents a set of expressions used to explore the issue of whether or not it is reasonable to consider a conventional positron source for a Tesla formatted beam. The critical issue is that of energy deposition in the conversion target and the comparison of the induced stress with the ultimate tensile strength of the target material. Since the length of the incident beam pulse is large in comparison to the ratio of beam size to the speed of sound, the concurrent pressure pulse dissipates in a time short compared to the overall pulse duration and one is left with only the semi-static thermal stress. The conclusion of this note is that for tangential target speeds of 100-125 m/s, two positron targets are necessary. For a target speed of 250 m/s, it is possible that a single target can handle to energy deposition. Additional issues that need to be addressed are given at the end. This note is informal in nature.

References:

[1] LCC-0089, "Structural Modeling of Tesla TDR Positron Target," Werner Stein, John C. Sheppard, July 2002.
[2] LCC-0088, "Thermal Stress Analyses for the NLC Positron Target," W. Stein, A. Sunwoo, J. C. Sheppard, V. Bharadwaj, D. C. Schultz, July 2002.
[3] http://www-project.slac.stanford.edu/lc/local/systems/Injector/Talks%20and%20Papers/BINP_Reports/append1.pdf
Appendix 1:HYDRODYNAMIC BEHAVIOR OF TARGET MATERIAL,Tatiana A. Vsevolozhskaya, *BINP*, January 12, 2000.
[4] MatLab M-File: Z:\positrons\egs4\conventional\wtarget.m and .\wtargetde.m, March, 2003
[5] Y. Batygin, Personal Communication.

Question: Can one consider a conventional positron target system for a Tesla beam format?

Answer: Why not. The primary issue to consider is that of the energy deposition in the target. If this turns out to be acceptable, then one gets to do significant work in developing the details.

Given below are tables listing positron beam, electron beam, and target parameters and Tungsten-26 Rhenium material data. The tables are followed by a series of expressions which are used to determine how many targets are required to handle to incident drive beam power. A comparison of these parametric results with LLNL simulations are made in order to check the validity of the parametric approach. A list of follow-on tasks is given. The actual results of this work is shown in a series of plots following the task list. And finally, an appendix is included which documents the scaling used to arrive at the various table entries for positron production that are used in the USLC Reference Design document, sections 3.4 and 3.5.

EGS4 was used to determine the energy deposition, raw positron yield, and positron distributions. Y. Batygin used Beampath to estimate the capture yield from the initial positron distributions. Matlab was used to combine the results of the simulations, evaluate the expressions, and make the plots.

Assume the following beam and target system:

Beam and Target

Parameter	Symbol	Units	Value
Number of e+ per Bunch	N_+		2×10^{10}
Bunch Separation	T_b	ns	337
Pulse Length	T_p	ms	1
Number of Bunches per Pulse	N_b		2820
Pulse Repetition Rate	Rep	Hz	5
Target Material	W		Tungsten
Target Thickness	X	r.l.	4.5
Tangential Target Velocity	V_t	m/s	100
Transverse Acceptance	$\gamma A_x=\gamma A_y$	m-rad	3×10^{-2}
Energy Acceptance	ΔE	MeV	40

Next assume a 6.2 GeV electron drive beam. For a 4.5 r.l. W target, 30 mm-rad, 40 MeV acceptance, the yield of captured positrons per incident electron is about unity. This assumption on unity acceptance depends on the incident beam size and on the acceptance of the the downstream channel, including damping ring. The also depends on the bunchlength of the positrons leaving the target. As shown in Figure 4, the yield as a function of incident beam size varies over a range from about 1.5 down to about 0.8 for $1.5\,mm < \sigma_{in} < 3\,mm$. In the case of the Tesla damping ring, the acceptance and hence yield may be less. Additional studies of the capture yield into the Tesla damping ring for the distributiotns of conventionally produced positrons are required.

Drive Beam and Additional Target Information

Parameter	Symbol	Units	Value
Energy of Drive Beam	E_0	GeV	6.2
Number of e- per Bunch	N_-		2×10^{10}
Bunch Separation	T_b	ns	337
Pulse Length	T_p	ms	1
Number of Bunches per Pulse	N_b		2820
Pulse Repetition Rate	Rep	Hz	5
Energy per Pulse	E_p	KJ	59
Target Thickness	X	r.l.	4.5
Target Thickness	X	cm.	1.577
Tangential Target Velocity	V_t	m/s	100
Raw Yield out of Target	Y_R	e^+/e^-	13
Est. Yield into Acceptance	Y_A	e^+/e^-	1
Target Absorption	$\Delta E_T/E_p$		0.19
Beam Lateral Speard	σ_s	mm	0.64
Normalized Peak Energy Deposition	Peak_dE/E/Vol-norm	mm^2/cm^3	21.4

Tungsten-26 Rhenium Material Data

Parameter	Symbol	Units	Value
Target Material	W-26Re		
Atomic Number	Z		74/75
Density	ρ	kg/m^3	19800
Specific Heat @500 ^{0}C	Cv	J/Kg-^{0}C	150
Young's Modulus @500 ^{0}C	E	Pa	4.02×10^{11}
Linear Coef. of Thermal Expansion	α	$1/^0C$	4.4×10^{-6}
Poisson's Ratio	ν		0.28
Speed of Sound	v_s	m/s	5124
Ultimate Tensile Strength @0 ^{0}C	UTE	Pa	1.6×10^{9}
Ultimate Tensile Strength @500 ^{0}C	UTE	Pa	1.25×10^{9}
Ultimate Tensile Strength @1000 ^{0}C	UTE	Pa	9.0×10^{8}
Gruneisen Coef.	Γ	Kg/J-^{0}C	2.639

Normalized Peak Energy Deposition, Peak_dE/E/Vol-norm:

A series of EGS4 runs were made to estimate the peak energy deposition in W-26Re for a 6.2 GeV electron beam incident on a 4.5 radiation length (r.l.) thick cylinder of target material. These runs were made as a function of the incident transverse, rms beam size,

σ_{in} over a range of $0.5\,mm \le \sigma_{in} \le 4.5\,mm$. The peak energy deposition as a function of incident beam size, $\left.\frac{dE/E}{Vol}(\sigma_{in})\right|_{Peak}$ was fit to the function:

$$\left.\frac{dE/E}{Vol}(\sigma_{in})\right|_{Peak} = \frac{dE/E/Vol-norm}{2\pi\left(\sigma_{in}^2+\sigma_s^2\right)} \quad \left(fraction/cm^3\right) \qquad (1)$$

wherein dE/E/Vol-norm is the peak energy deposition normalized to the cross sectional area of the shower which is taken to be $2\pi\left(\sigma_{in}^2+\sigma_s^2\right)$ in which σ_s is the lateral spread in the shower. dE/E/Vol-norm and σ_s are fit parameters. The EGS4 simulations and the fit to the data are shown in Figure 1 with dE/E/Vol-norm = 21.4 mm/cm^3 and σ_s = 0.63 mm (for σ_{in} in units of mm). dE/E/Vol-norm is a key parameter in the estimation of the energy deposition for a spinning target.

Incident Beam Pulse Energy, *BPE*:

$$BPE = qN\_E_0 = q\frac{N_+}{Y_A}N_b \times 6.2\times 10^9 \ (J) \qquad (2)$$

Note: The calculation of the *BPE* is for the "unity" gain situation, i.e. no overhead in positron production has been assumed. The engineering margin which must be assumed for the NLC is a multiplicative overhead factor between 1.5 and 2. This needs to be kept in mind when discussing the results.

Beam Stripe Area, *Area*:

$$Area = \sqrt{2\pi}\left(\sigma_{in}^2+\sigma_S^2\right)^{\frac{1}{2}}\left(V_tT_p\right) \qquad (3)$$

where σ_{in} is the incident rms beam size and σ_S is the lateral rms spreading of the shower.

Peak Temperature Rise, *ΔT*:

$$\Delta T = BPE \times \frac{(Peak\_dE/E/vol\_norm)}{\rho C_v \times Area} \qquad (4)$$

.

Semi-Static Thermal Stress, σ_{SS}:

$$\sigma_{SS} \cong \frac{\alpha \Delta T E}{2(1-\nu)} = BPE \times \frac{\alpha(Peak\_dE/E/vol\_norm)E}{2(1-\nu)\rho C_v \times Area} \qquad (5)$$

Gruneisen Coefficient, Γ:

$$\Gamma = \frac{3\alpha v_s^2}{C_v} \tag{6}$$

Vsevolozhskaya Expressions [3] for the minimum in the pressure wave, ${}_R P_{\min}$ and ${}_S P_{\min}$ for rapid and slow energy deposition (the minimum denotes to the peak in the negative pressure pulse):

For rapid energy deposition, $v_s T_p \le \left(\sigma_{in}^2 + \sigma_S^2\right)^{\frac{1}{2}}$:

$${}_R P_{\min}\left(0, -v_s t, t\right) \cong -1.28 \frac{\Gamma Q_0\left(0\right)}{\pi V} \tag{7}$$

occurs when $v_s t \cong 2.1\sigma$. For slow energy deposition, $v_s T_p \ge \left(\sigma_{in}^2 + \sigma_S^2\right)^{\frac{1}{2}}$:

$${}_S P_{\min}\left(0, -v_s t, t\right) \cong -0.54 \frac{\Gamma Q_0\left(0\right)}{\pi V} \frac{\sigma\sqrt{2}}{v_s T_p} \tag{8}$$

$$\frac{Q_0\left(0\right)}{V} = BPE \times \frac{(Peak\_dE/E/vol\_norm)}{Area} \tag{9}$$

The factor of π is a correction to the Vsevolozhskaya expression for the minimum in the pressure wave; this correction matches the results on the LLNL studies of Ti and W in the case of rapid energy deposition ($v_s T_p < \sigma$); this factor has been applied to the case of slow energy deposition and should be checked.

Rapid Energy Deposition

Maximum allowed energy deposition, $\left.\frac{\Delta E}{\Delta m}\right|_{J/g}^{\max}$:

$$\left.\frac{\Delta E}{\Delta m}\right|_{J/g}^{\max} = \frac{\pi}{2} \frac{UTE\left(Pa\right)}{1.28\rho\left(kg/m^3\right)\Gamma\left(kg/J-s^2\right)} = \frac{\pi}{2} \frac{UTE\left(ksi\right) \times 6894.7\left(\frac{Pa}{ksi}\right)}{1.28\rho\left(kg/m^3\right)\Gamma\left(kg/J-s^2\right)}. \tag{10}$$

The factor of π is a correction to the Vsevolozhskaya expression for the minimum in the pressure wave; this correction matches the results on the LLNL studies of Ti and W. The factor of ½ is for material aging. The factor of 1.28 is from Vsevolozhskaya.

Y.Batygin Capture [5]:

Full flux concentrator, 250 MeV initial acceleration, 1.9 GeV additional acceleration simulation. Y.B. capture number contains raw yield. Values obtained assume 0 ps initial bunchlength and have been scaled down by a factor of 10.5%/11.16%= 0.94. The YB data uses 4.5 r.l. W target, 6.2 GeV e- . By way of comparison, the emittance and capture yield of positrons from a 4.0 r.l. Hg target are shown along with the W simulations. The numerical yield values for the Hg have been scaled by the ratio of raw positron yield (W to Hg).

Number of Targets Required: Semi Static Thermal Stress

The number of targets required is set by dividing the semi static thermal stress, σ_{SS}, by the aged ultimate tensile strength of the target material at the anticipated peak temperature and rounding up to the nearest integer. Included in the expression is an explicit multiplicative *Overhead* factor. For this exercise, the *Overhead* is taken as 1.5 and the material degradation factor is 2. In Matlab syntax, N_{target} is given as

$$N_{target} = ceil\left[OverHead \times \frac{\sigma_{SS}\left(Y_A = 1\right)./Y_A\left(\sigma_{in}\right)}{\left(UTE(1000\,^0C/2\right)} \right] \tag{11}$$

CEIL Round towards plus infinity.
CEIL(X) rounds the elements of X to the nearest integers
towards infinity.

Number of Targets Required: Rapid Energy Deposition

In the case of an NLC formatted beam, the number of targets required is set by dividing the peak energy deposition by the maximum allowed energy deposition:

$$N_{target}^{Rapid} = ceil\left[Overhead \times \frac{1.28}{\pi} \times \Gamma \times \frac{BPE\left(Y_A = 1\right)/Y_A\left(\sigma_{in}\right)}{\left(UTE\left(T\right)/2\right)} \times \frac{Peak\_dE/E/vol\_norm}{2\pi\left(\sigma_{in}^2 + \sigma_s^2\right)} \right] \tag{12}$$

wherein the Overhead factor and the material strength degradation by a factor of 2 are shown explicitly.

Comparison with LLNL Simulations [1,2]:

Slow Energy Deposition:

For Tesla formatted photon beam, reference [1] found for a peak energy deposition of more than 200 J/g, the peak temperature rise was 440^0C and the associated material thermal stress was 2.68×10^8 Pa. For ΔT=440^0C, α_Ti= $9\times10^{-6}/{}^0C$, E_Ti = 1×10^{11}, ρ_Ti = 4.54 g/cm^3, and ν_Ti = 0.3, expression for semi static thermal stress gives a value of $\sigma_{SS} = 2.83\times10^8$ Pa which agrees with the Livermore calculation to within 5%.

Caveat, for a peak energy deposition of 216 J/g, C_v_Ti = 0.527 J/g-^{0}C, gives a peak $\Delta T=410^0$C, and now the expression for semi static thermal stress gives a value of σ_{SS} = 2.64×10^8 Pa which agrees with the Livermore calculation to about 2%. The problem of course is with the inconsistencies in the numbers even though there appears to be agreement.

In the case of tungsten, reference [2] states that after the peak shock due to the pressure wave has damped out, the semi static thermal stress in the NLC WRe target due to 33 J/g of energy deposition is 2.13×10^8 Pa associated with a peak $\Delta T=217^0$C. For C_v_W = 0.149 J/g-^{0}C, 33 J/g gives a peak $\Delta T=221^0$C, and the expression for semi static thermal stress in W gives a value of σ_{SS} = 2.72×10^8 Pa. This value is about 25% greater than the LLNL simulation.

The LLNL Ti simulation is a better match to the problem of "slow" energy deposition being considered here. It is essentially the same problem but with a different material. In the case of the LLNL WRe simulation, the predominant effect is the instantaneous pressure wave stress while the semi static thermal stress is an after affect. One expects in the WRe case, that the semi static thermal stress is less than that estimated for a peak peak $\Delta T=221^0$C due to some the decay of the temperature pulse from thermal conductivity but it is not obvious how much decrease there has been.

Rapid Energy Deposition:

In reference [2], it was found that a peak energy deposition of 33 J/g resulted in a peak $\Delta T=217^0$C and a peak Von Mises stress of 5.7×10^8 Pa. For C_v_W = 0.149 J/g-^{0}C, 33 J/g gives a peak $\Delta T=221^0$C, and the Vsevolozhskaya expression for rapid energy deposition of the minimum in the pressure in W gives a value of ${}_R P_{\min} = 6.15\times10^8$ Pa. This value is about 8% greater than the LLNL simulation. If say the energy deposition value is reduce to $33\frac{J}{g}\times\frac{217\,^0C}{221.5\,^0C}=32.3\frac{J}{g}$ which gives a values of ${}_R P_{\min} = 6.0\times10^8$ Pa which is now only about 5% greater than the LLNL simulation.

So, as in all cases, a proper thermal simulation is required to better pin down what will happen.

Additional Work Required:

Clean up Calculations, decide on acceptance

Full structural modeling à la LLNL

Radiation damage Estimates

Design studies for a 100-259 m/s, water-cooled target wheel.

Engineering discussions on how to remove $\sim 19\,\mathrm{kW}$ of absorbed power per target (3 target scenario)

Simulations of radiation environment due to 300 kW of drive beam

Engineering discussions on how to deal with radiation from 300 kW of drive beam

Discussions on what does the "flux concentrator" really look like and what is the capture yield with such a device.

EGS4/MatLab Results [4]

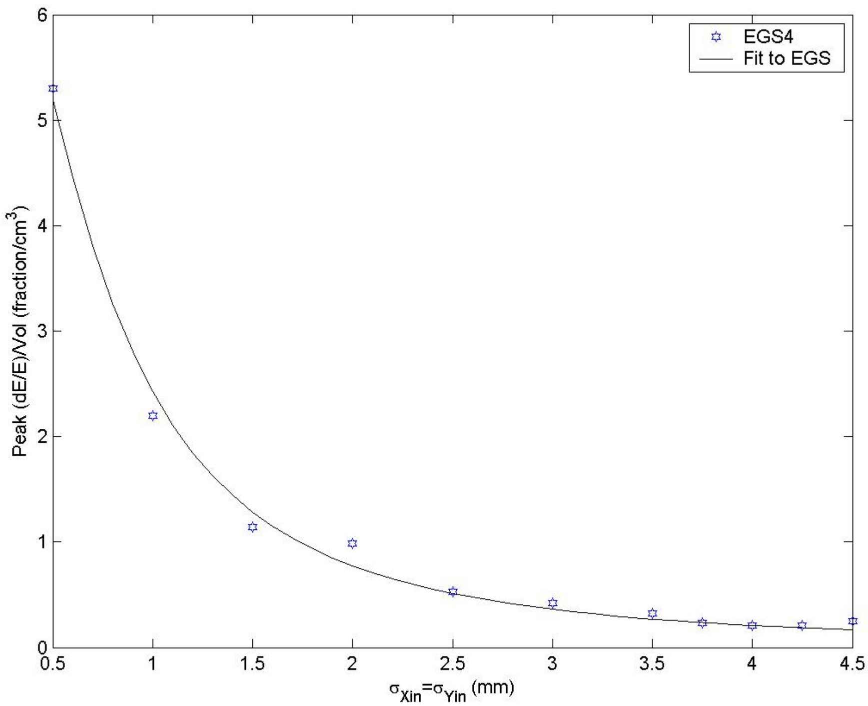

Figure 1: Peak energy deposition in 4.5 r.l. of W as a function of input beam size. The incident beam is a 6.2 GeV electron beam. 1000 incident particles were used in the simulations. The plot symbols are the results of the EGS4 runs. The solid line is a fit to the EGS4 runs in which the effective beam size is given as $\sigma_{eff} = \sqrt{\sigma_{in}^2 + \sigma_S^2}$, wherein σ_{in} is the incident beam size and σ_s is an additive lateral spread which accounts for the transverse growth of the shower due to multiple scattering. In figure 1, $\sigma_s = 0.63$ mm.

For small values of σ_{in}, the fractional peak energy deposition per cm^3 exceeds unity because the actually volume of the shower is small compared to 1 cm^3. The total absorbed beam energy for 6.2 GeV electrons incident to 4.5 r.l. of W is about 19%. It turns out that the peak absorbed energy per unit volume at a depth of 4 r.l. in W is the same as the peaks at 4.5 r.l. and the overall absorption is about 14% (for 4 r.l.).

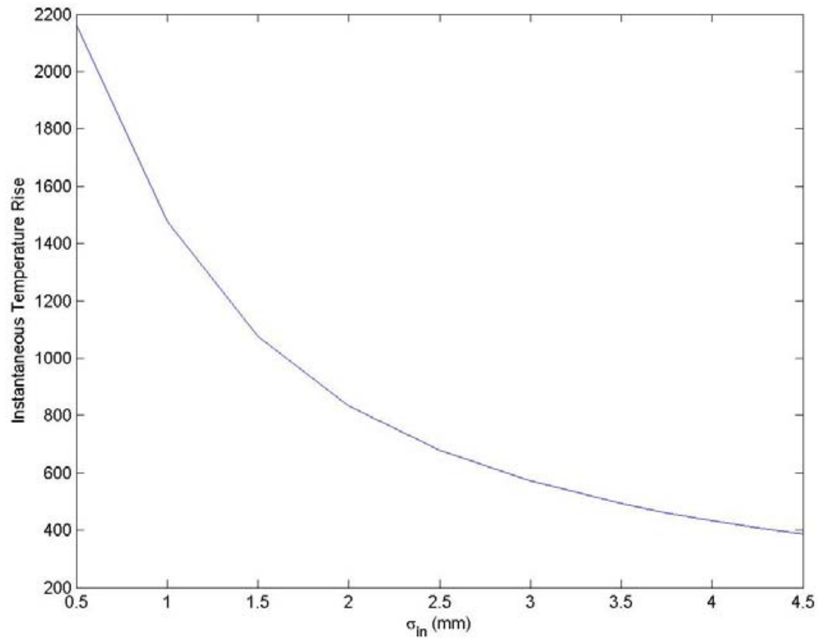

Figure 2a.: Instantaneous temperature rise in W-26Re-target for 59 kJ incident, 6.2 GeV electron beam as a function of the incident beam size. Unity yield is assumed to set incident total energy. The target is spinning with a tangential velocity of 100 m/s. This is an evaluation of equation (4).

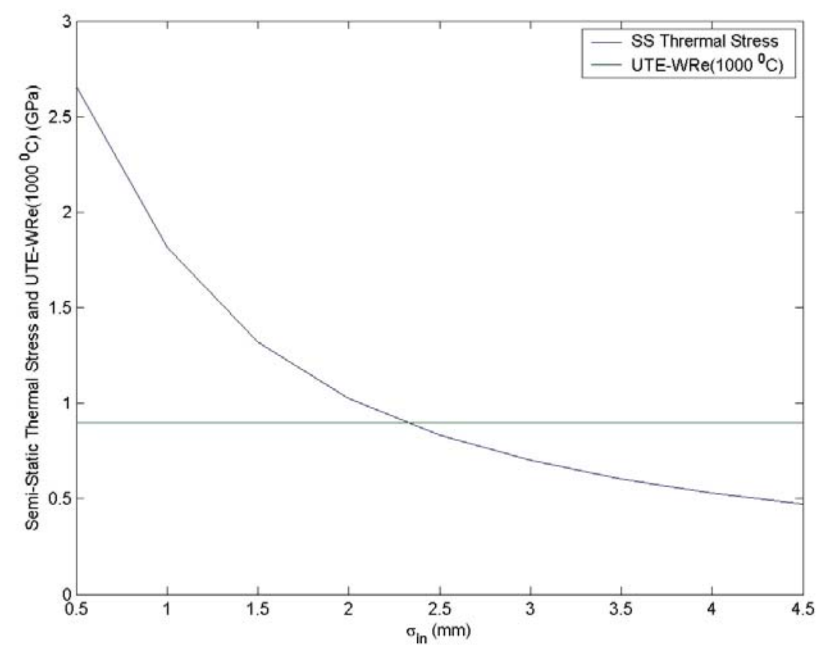

Figure 2: Semi-static thermal stress in W-target for 59 kJ incident, 6.2 GeV electron beam as a function of the incident beam size. Unity yield is assumed to set incident total energy. The target is spinning with a tangential velocity of 100 m/s. This is an evaluation of equation (5).

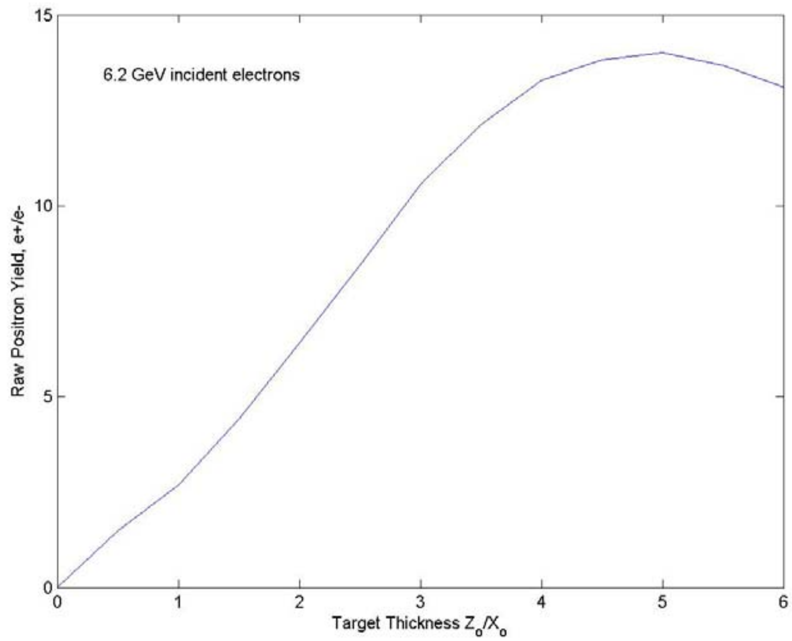

Figure 3: Raw yield of positrons as a function of W target thickness for 6.2 GeV incident electrons. 1000 incident particles were used in each run. EGS4 simulations.

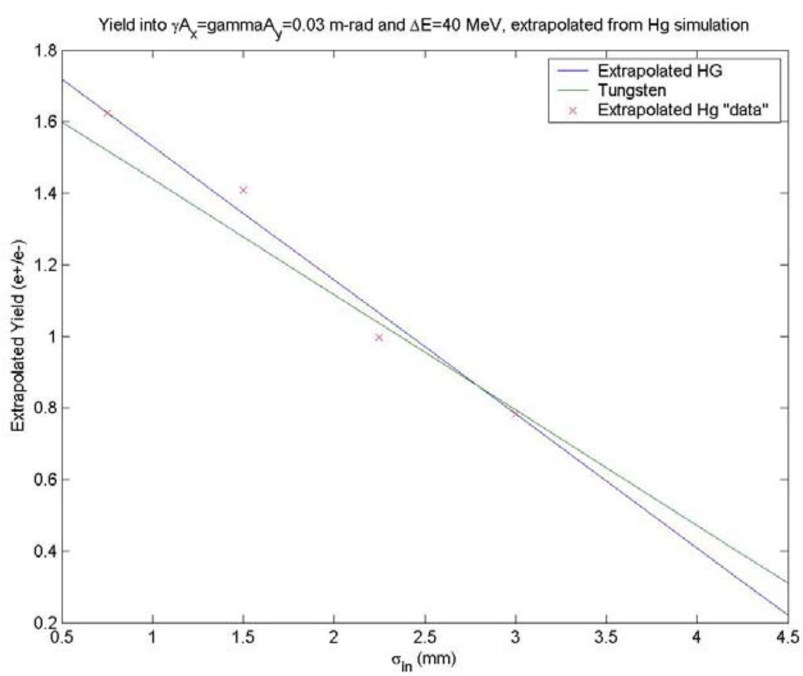

Figure 4: Capture yield of positrons per incident electron into an acceptance of $\gamma A_x = \gamma A_y = 0.03$ m-rad and $\Delta E = 40$ MeV at 1.9 GeV (the NLC acceptance specification). The yield shown is taken from the positron capture simulations done by Y. Batygin using e^+ generated in 4 r.l. of Hg but scaled from full width bunchlength of $\tau = 0$ to $\tau = 4.83$ ps

(10.5%/11.16%) and for a total number of emitted positrons from the W (raw yield = 13.94 e^+/e^- for 4.5 r.l. W and 6.2 GeV e^-).

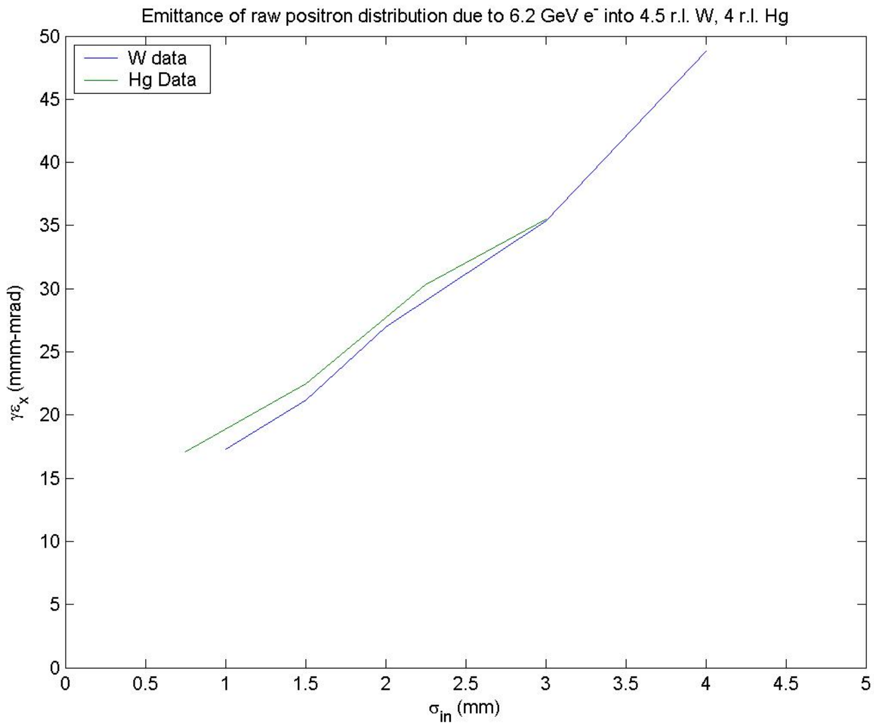

Figure 5.: The normalized emittance of the total positron distribution generated by 6.2 GeV electrons incident to 4.5 r.l. (1.58 cm) of W and 4.0 r.l. (1.82 cm) of Hg. Note the similarity for the different materials. This similarity is the justification of using the Hg yield "data" until the W "data" is processed.

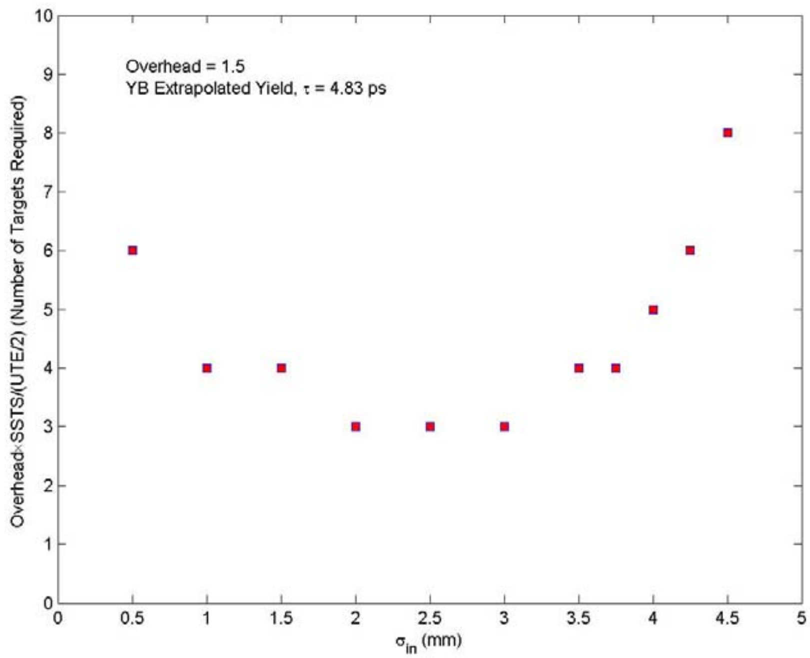

Figure 6.: The number of targets as a function of incoming beam spot size required to keep the semi static thermal stress to below UTE(1000^{0}C)/2. The extrapolated capture yield data has been used to estimate the incident BPE.

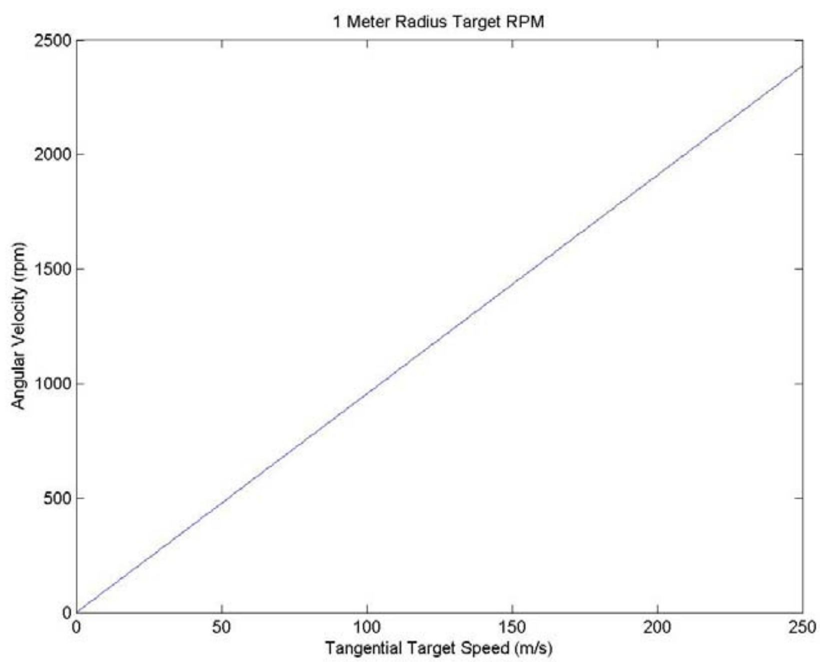

Figure 7.: Required rotational speed for a 1 meter radius target. For a 0.5 m radius target and tangential velocity of 100 m/s, an angular velocity of 1909 rpm is required. Note that the SLAC accelerator water pumps rotate at 1800 rpm; 3600 rpm is a standard pump speed.

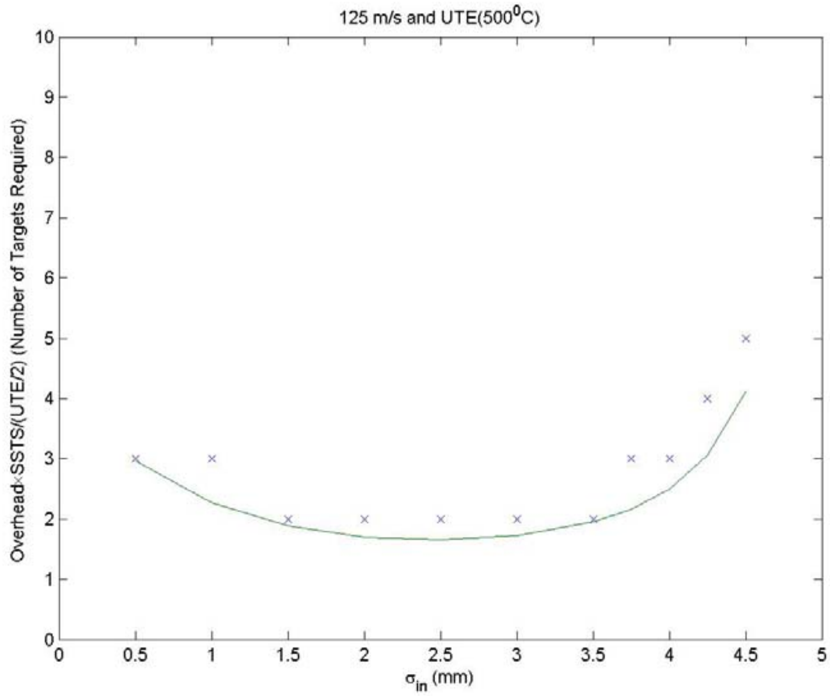

Figure 8.: Number of targets for V_t=125 m/s and UTE(500^0C). This indicates that one can conceivable drive the number of targets required down to 1 for target speed of about 250 m/s. Note that the speed of sound in air is about 330 m/s.

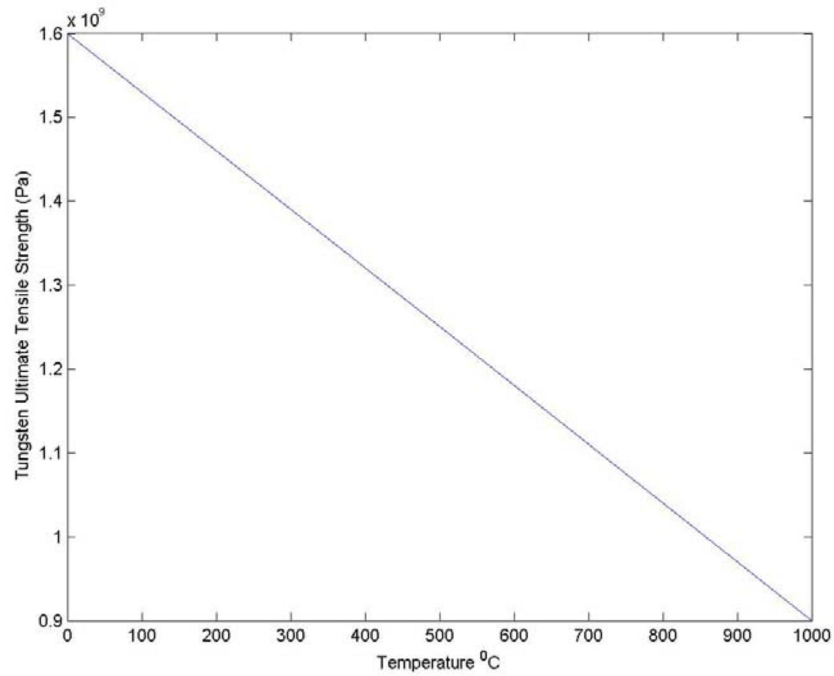

Figure 9.: Ultimate Tensile Strength of Tungsten-26 Rhenium as a function of temperature.

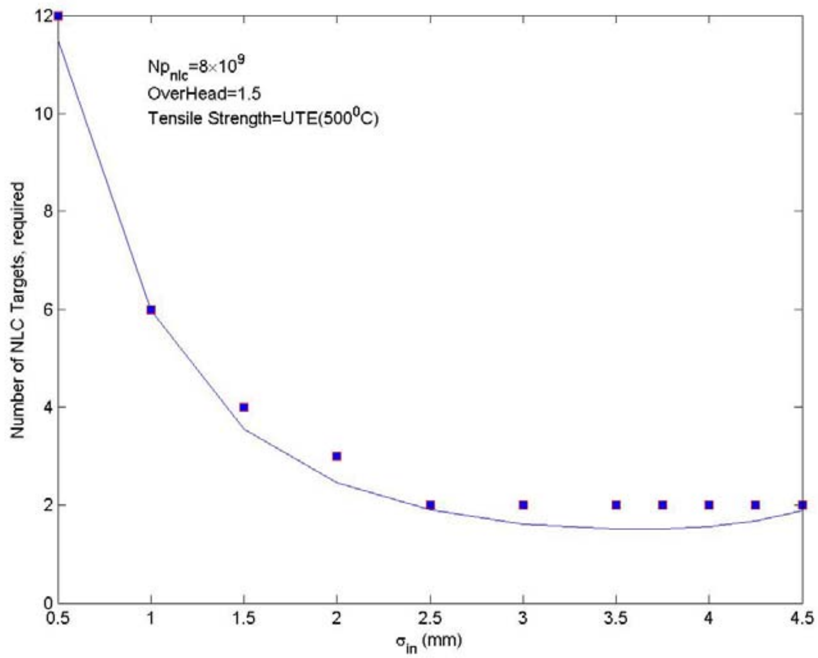

Figure 10.: Number of targets for the NLC formatted beam. In this case, the beam consists of 192 bunches of 8×10^9 electrons per bunch at 50 GeV. The expression for rapid energy deposition is used. The reference design for the NLC calls for a 1.6 mm incident spot and 3 targets are required.

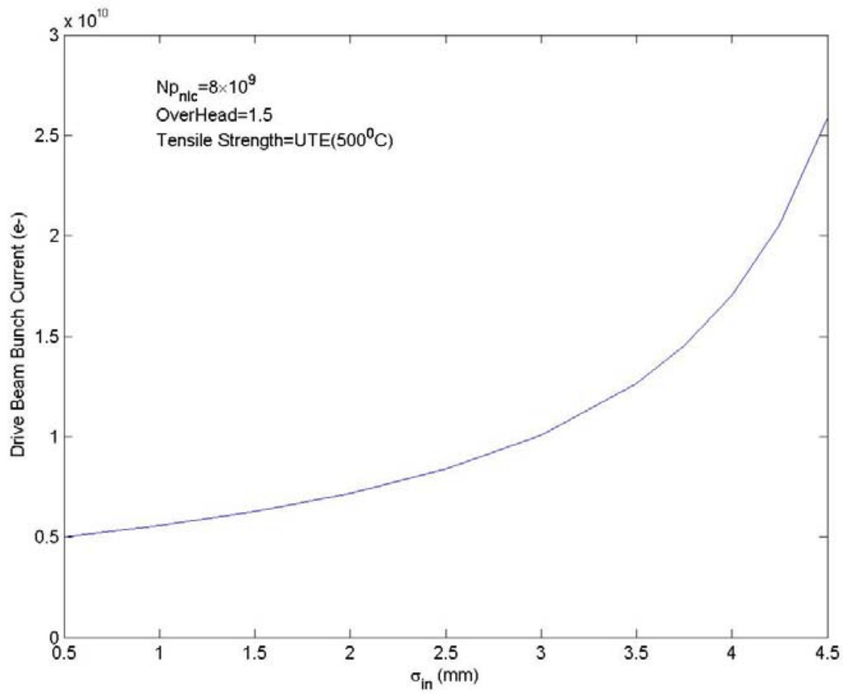

Figure 11.: Required drive beam per bunch current as a function of incident beam size for the NLC formatted beam.

Appendix A
USLC Reference Design Positron System Numbers

The following was used to generate some of the numbers for the USLC Reference Design description of the warm and cold option positron systems.

References:

[1A] Z:\Positrons\Polarized Positrons\helicalspect_more.m
[2A] Z:\Positrons\egs4 runs\Conventional\wtarget.m
[3A]J.C. Sheppard Notebook: 2/22/02-10/8/03
[4A] LCC-0089: TESLA TDR Positron Target
[5A] LCC-0087: NLC Polarized Positron Photon Beam Target Thermal Structural Modeling
[5A] LCC-0133, Conventional Target for a Tesla Formatted Beam

From [1A], for 10 harmonics on undulator radiation, K=1, the ratio of energy in a $\gamma\theta$ cut of 1.4142 is sum(Hsumc)/sum(Hsum) = 0.7038.
The first harmonic cutoff is 10.68 MeV for l=1 cm, K=1, E_{e-}=150 GeV.
The average photon energy for the uncut spectrum is $\langle E_\gamma \rangle$ = 12.1 MeV
The average photon energy for the $\gamma\theta$ = 1.4142 cut spectrum is $\langle E_{\gamma c} \rangle$=16.9 MeV
The average photon energy for the modeling in [4] is $\langle E_\gamma \rangle$ = 22.1 MeV

From [3A] page 142, 8/6/03:

$\langle E_\gamma \rangle$	$\Delta E/E$ absorbed in 0.4 rl Ti
12.1 MeV	8.6%
16.9 MeV	8.1%
22.1 MeV	6.8%

The loss thru the undulator for 153 GeV incident beam: 4.9 GeV/e- for 150 m undulator
6.5 GeV/e- for 200 m undulator

For SC unpol: $qNe\Delta E/e- = q(2\times10^{10})(2820)(4.9\text{ GeV}) = 44.3$ kJ
For SC pol: $qNe\Delta e/e\text{-}x\text{Trans} = q(2\times10^{10})(2820)(6.5\text{GeV})(0.7038) = 41.3$ kJ

For NC unpol: $qNe\Delta E/e- = q(0.75\times10^{10})(192)(4.9\text{ GeV}) = 1.13$ kJ
For NC pol: $qNe\Delta E/e\text{-}x\text{Trans} = q(0.75\times10^{10})(192)(6.5\text{GeV})(0.7038) = 1.055$ kJ

Scaling from [4A]: $\langle E_\gamma \rangle$=22.1 MeV, 9.6 J/bunch, 2820 bunches on 0.4 rl Ti at 50 m/s gives 210 J/g dE/E_peak corresponding to 396^0C temperature rise. For 100m/s target and different absorptions:

$$\Delta T\_sc\_unpol = 396^0 C \times \frac{44.3kJ \times 8.6\%}{9.6 \times 2820 \times 6.8\%} \times \frac{50\ m/s}{100\ m/s} = 410^0 C$$

$$\Delta T\_sc\_pol = 396^0 C \times \frac{41.3kJ \times 8.1\%}{9.6 \times 2820 \times 6.8\%} \times \frac{50\ m/s}{100\ m/s} = 361^0 C$$

Scaling from [4A]: <E_γ>=22.1 MeV, 722 J on 0.4 rl Ti gives 113 J/g dE/E_peak corresponding to 213^0C temperature rise. For different absorptions:

ΔT_nc_unpol= $213^0 C \times \frac{1.13 kJ \times 8.6\%}{0.722 kJ \times 6.8\%} = 422^0 C$

ΔT_nc_pol = $213^0 C \times \frac{1.055 kJ \times 8.1\%}{0.722 kJ \times 6.8\%} = 371^0 C$

Conventional Targets: Assume that yield is 1.5 and hence the drive beam has the same intensity as the colliding beam; 6.2 GeV. References [2A], [3A] page 97, [5A]

SC option: Nt=2=number of targets, spinning at 125 m/s, 4 rl W, 14% absorption

E_on_target=qNbnbE/Nt=q(2820)(2x10^{10})(6.2 GeV)/2=28.009 kJ

2.5 mm spot on spinning target, the reference spot area is
$2\pi\left(2.5^2 + 0.4\right) mm^2 = 41.8\, mm^2$

The stripe area is $\left(2\pi\right)^{\frac{1}{2}}\left(2.5^2 + 0.4\right)^{\frac{1}{2}} \times (v_t T_p) mm^2 = 808\, mm^2$
For 2.5 mm incident beam the fractional peak energy deposition is 0.5125/cm^3

The temperature rise in W is
$$\Delta T = \frac{dE/E}{vol} \times \frac{\mathrm{Re}f\_area}{Stripe\_area} \times \frac{\Delta E_{inc}}{\rho C_v} = 0.5125 \times \frac{41.8}{808} \times \frac{28009}{19.3 \times 0.150} = 256^0 C$$

NC option: Nt=3=number of targets, spinning at 4 rl W, 14% absorption

E_on_target=qNbnbE/Nt=q(192)(0.75x10^{10})(6.2 GeV)/3=477 J

1.6 mm spot on spinning target

For 1.6 mm incident beam the fractional peak energy deposition is 1.15/cm^3

The temperature rise in W is
$$\Delta T = \frac{dE/E}{vol} \times \frac{\Delta E_{inc}}{\rho C_v} = 1.15 \times \frac{477}{19.3 \times 0.150} = 189^0 C$$