Status of Existing Positron Sources

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April 2005

- *Positron Sources*
- *SLC Positron Source*
  - *SLC target analysis*

THE INTERNATIONAL LINEAR COLLIDER (ILC)

- WORLD Collaboration
- Multi-billion dollar project
- Proposed e^+e^- linear collider
- 0.5-1.0 TeV center-of-mass energies
- Major elements
  - Electron injector
  - Electron damping ring
  - Main electron linac
  - Electron beam delivery to IR
  - **Positron Source**
  - Positron damping ring(s)
  - Main positron linac
  - Positron beam delivery to IR
  - IR
  - Detectors at IR

Parameter	Reference	Upgrade
Beam Energy *(GeV)*	250	500
RF gradient *(MV/m)*	28	35
Two-Linac length *(km)*	27.00	42.54
Bunches/pulse	2820	2820
Particles/bunch (10^{10})	2	2
Beam pulse length *(μs)*	950	950
Pulse/s *(Hz)*	5	5
σ_x(IP) *(nm)*	543	489
σ_y(IP) *(nm)*	5.7	4.0
σ_z(IP) *(mm)*	0.3	0.3
δ_E *(%)*	3.0	5.9
Luminosity $(10^{33} cm^{-2} s^{-1})$	25.6	38.1
Average beam power *(MW)*	22.6	45.2
Total number of klystrons	603	1211
Total number of cavities	18096	29064
AC to beam efficiency *(%)*	20.8	17.5

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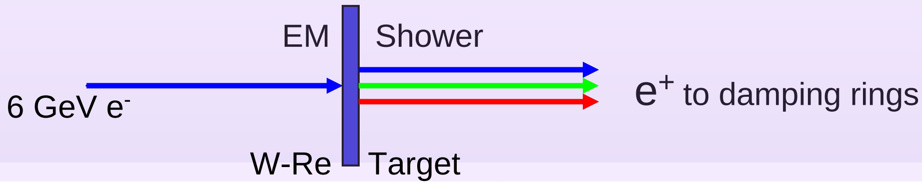
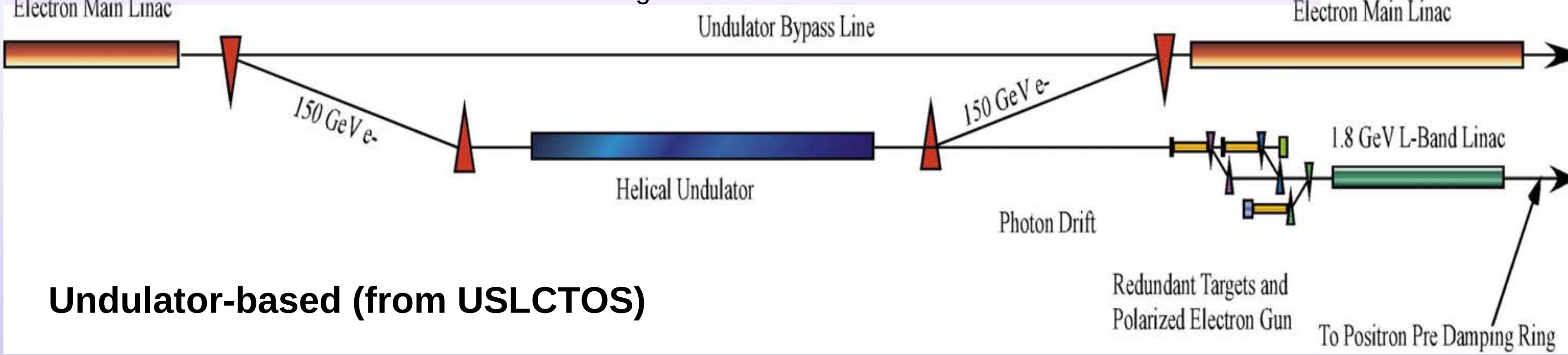
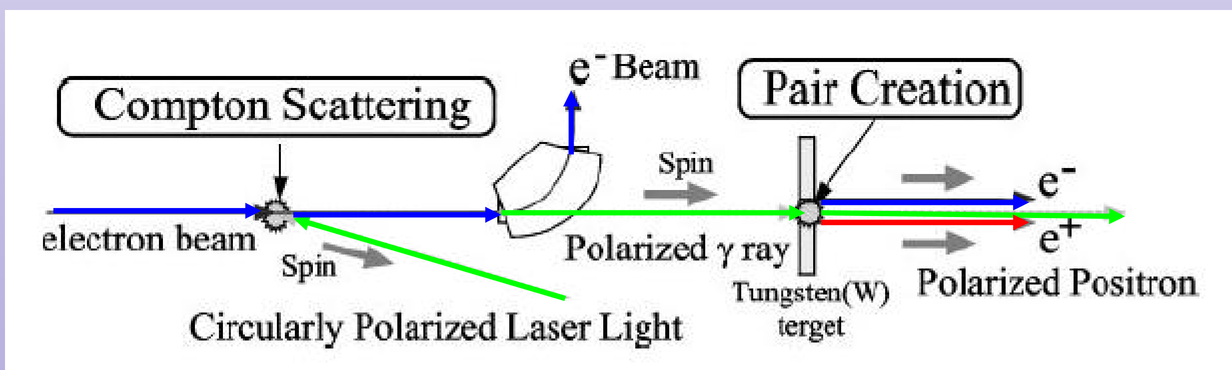
POSITRON PRODUCTION SCHEMES

Conventional





Undulator-based (from USLCTOS)

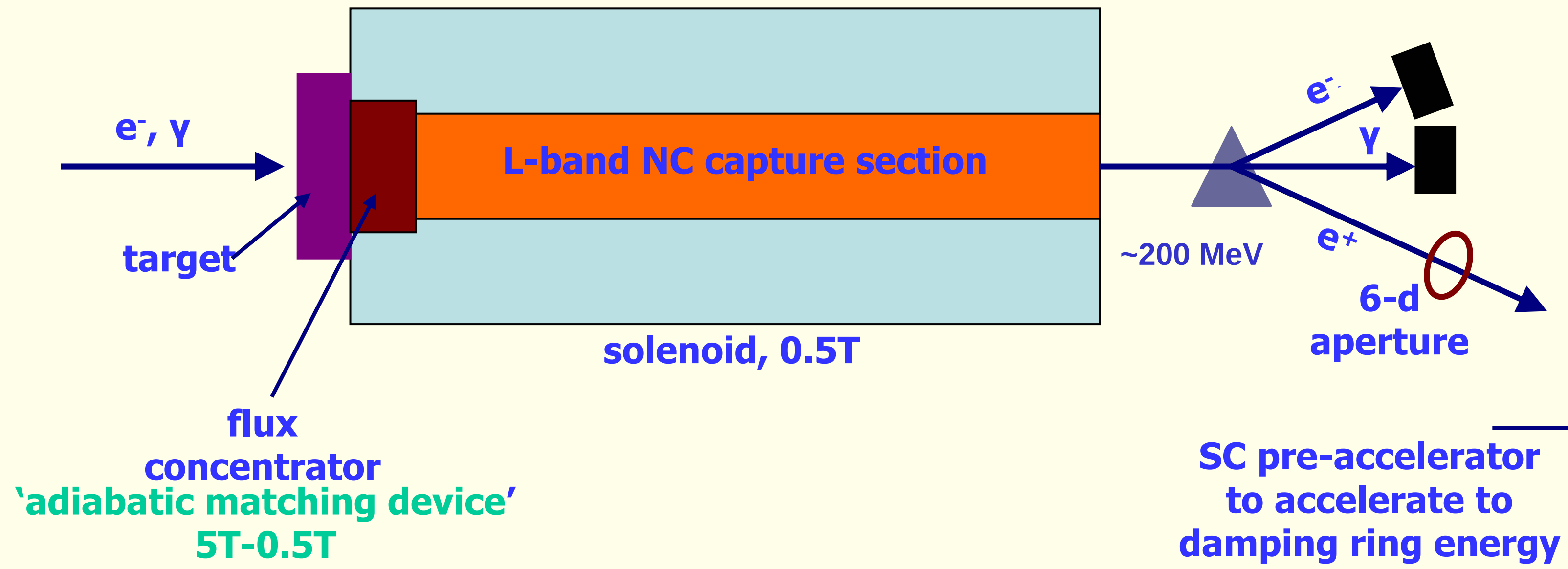


Radio-active sources – ^{22}Na

1 curie = 3.7 x 10^{10} disintegrations/second

(not really feasible)

GENERIC POSITRON SOURCE



POSITRON SOURCES

	Energy (GeV)	Current (A)	Rate (Hz)	Target Material	Thickness (r.l.)	Power Dep (kW)	Matching	RF* (MV/m)	Yield (/e-/GeV)
ILC	**6.00**	**2.E+10**	**5*2820**	**W-26Re**	**4.0**	**30.00**		**	**0.150**
SLC	30.00	4.E+10	120	W-26Re	6.0	4.00	FC+TS+S	19	0.030
APS	0.20	1.0	30	W	2.0	0.48	S		0.006
CESR	0.15	1.7	60	W	2.0	0.30	$\lambda/4$ PS+S	10	0.013
BEPC	0.15	2.4	25	W	1.7		TS+S	10	0.025
SPRING-8	0.25	10.0	8	W-10Cu	2.0	1.00	PS+S	17	0.012
KEK	4.00	2x10nC	50	W	4.0	0.40	$\lambda/4$ PS+S	14	0.015
ORSAY	1.00	1.0	25	W-2Cu-2Ni	7.0	0.50	FC+S	10	0.021
SOLEIL	0.34	0.7	10	W	2.0	0.14	$\lambda/4$ PS+S	15	0.020
DESY	0.40	1.5	50	W	2.0	2.00	$\lambda/4$ PS+S	14	0.025
VEPP-5	0.30	1000.0	50	W	2.5	0.02	FC+S	18	0.050
LIL	0.20	1.4	100	W	2.0	0.60	$\lambda/4$ PS+S	9	0.030

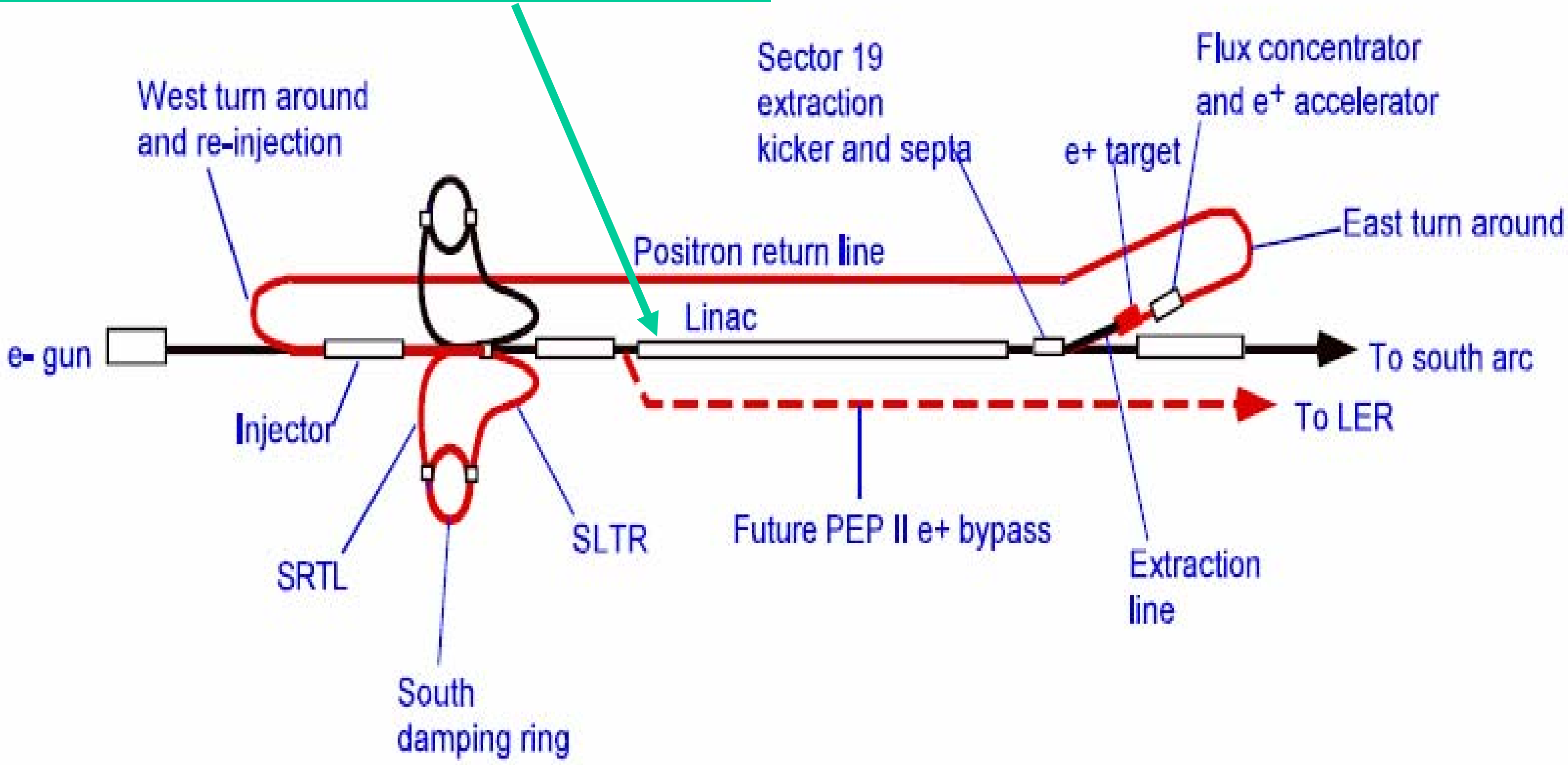
The SLC positron source comes closest to the ILC needs and it is not that close!

ILC source is ~ factor of 60 greater in flux and 8 in energy deposition into target.

**ILC Pulse length is 1 ms as opposed to ~ 1 μs that is typical for existing sources

SLC POSITRON SOURCE OVERVIEW

During SLC operation three bunches are accelerated down the SLAC linac
e^+, e^- and the e^- scavenger pulse



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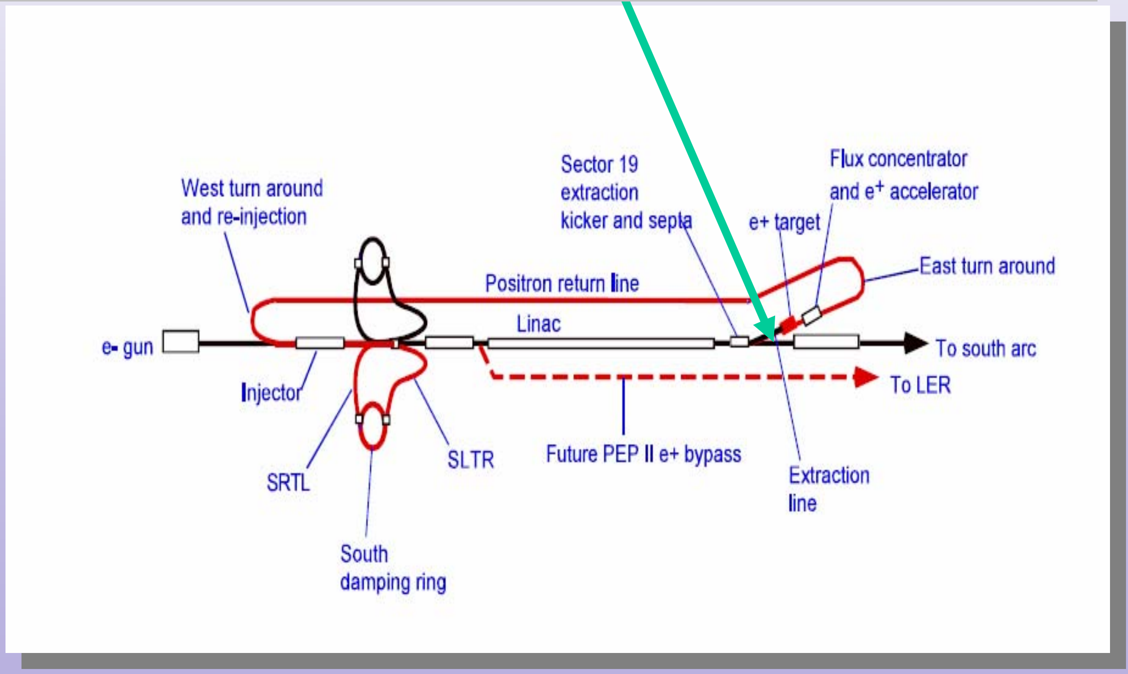
SLC POSITRON SOURCE – ELECTRON DRIVE BEAM

Energy	25-33 GeV
Intensity	1-5.0 10^{10} e-/pulse
Size	0.6 mm
Pulse energy	264 Joules/pulse
Pulse rate	1-120 Hz
Power	40W (1 Hz @ 1×10^{10})- 24kW(120Hz @ 5×10^{10})



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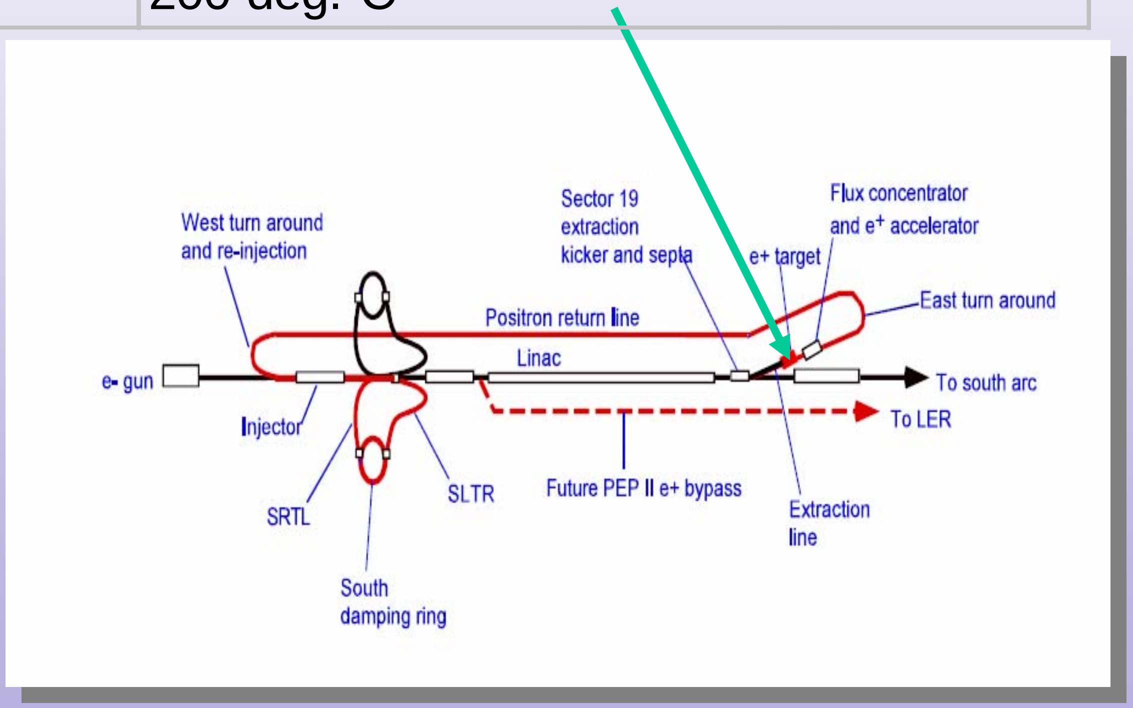
SLC POSITRON SOURCE – TARGET

Material	74% W - 26% Re
Length	6 radiation lengths
Target Energy Dep.	53 Joules/pulse
Target Power Dep.	4 kW
Pulse ΔT	380 deg. C
Temperature	200 deg. C



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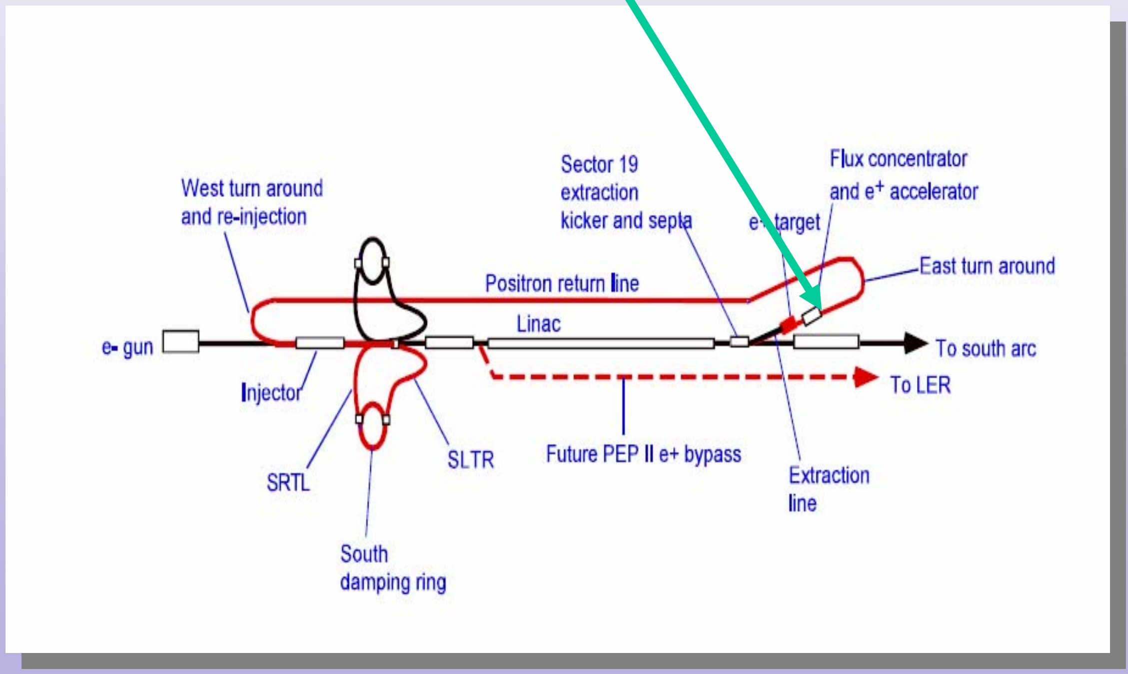
SLC POSITRON SOURCE – CAPTURE SECTION

FLUX Conc.	6 Tesla, 20 cms
Tapered Solenoid	1 Tesla - 0.5 Tesla
DC Solenoid	0.5 Tesla
Capture RF	s-band , 19 MV/m
Final energy	200 MeV



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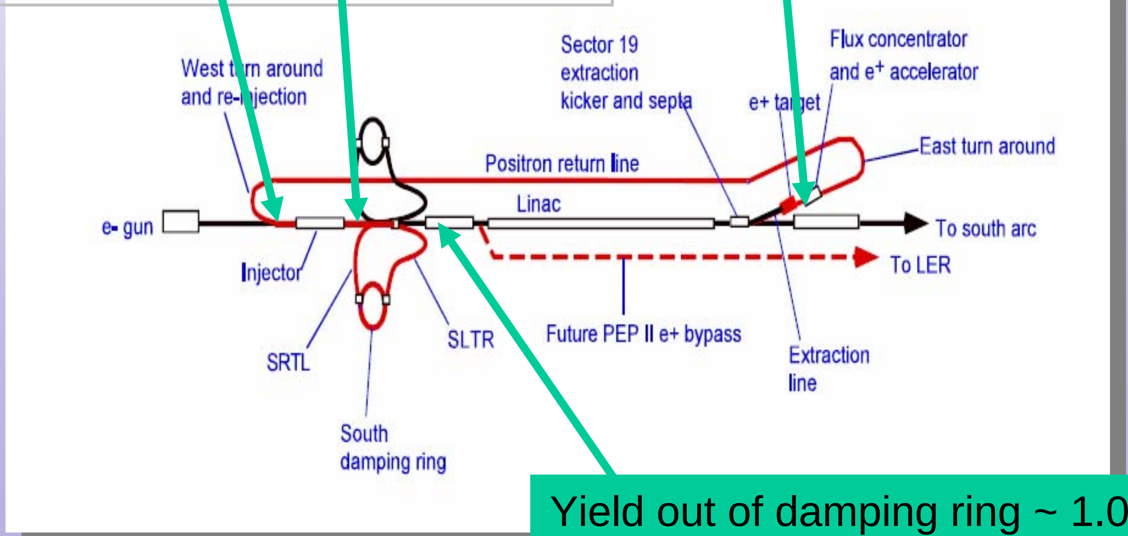
SLC POSITRON SOURCE – BEAM

Energy	0.2 GeV
Energy Spread	2%
Emittance (inv)	0.0042 m-radian

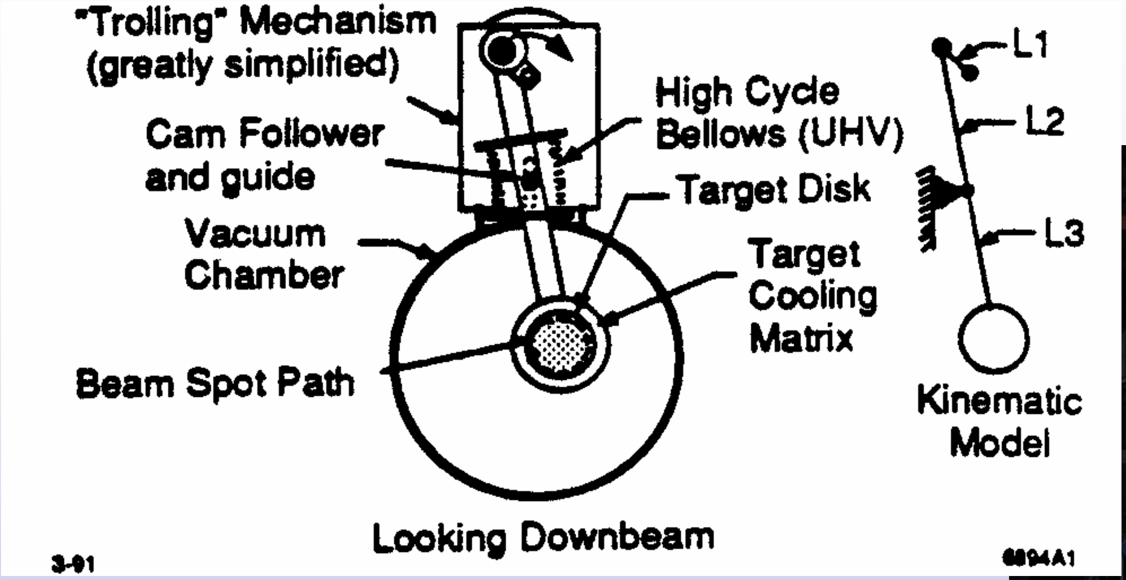
Energy Range	2-20 MeV
Emittance (inv.)	2 mm x 2.5 MeV/c = 0.01 m-radians
Yield (e+/e-)	2.5 into the s-band capture

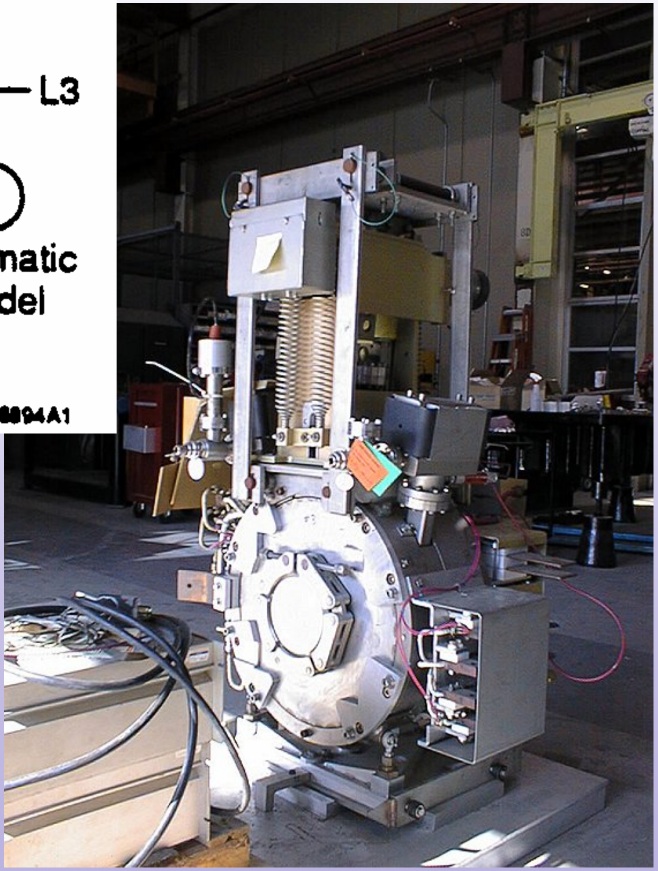
Energy	1.19 GeV
Energy Spread	0.50%
Emittance (inv)	0.002 m-radians



Yield out of damping ring ~ 1.0

SLC POSITRON TARGET





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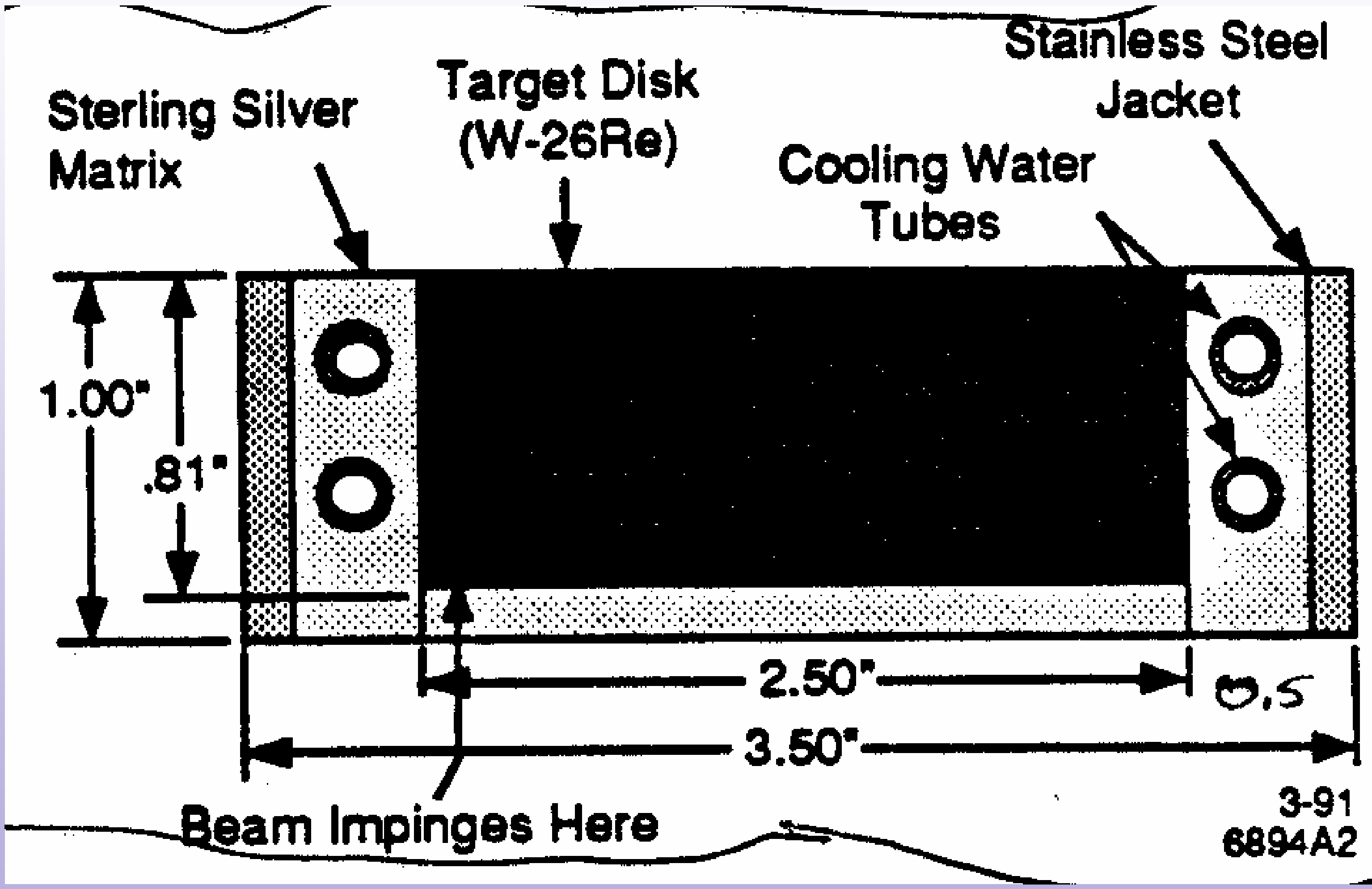
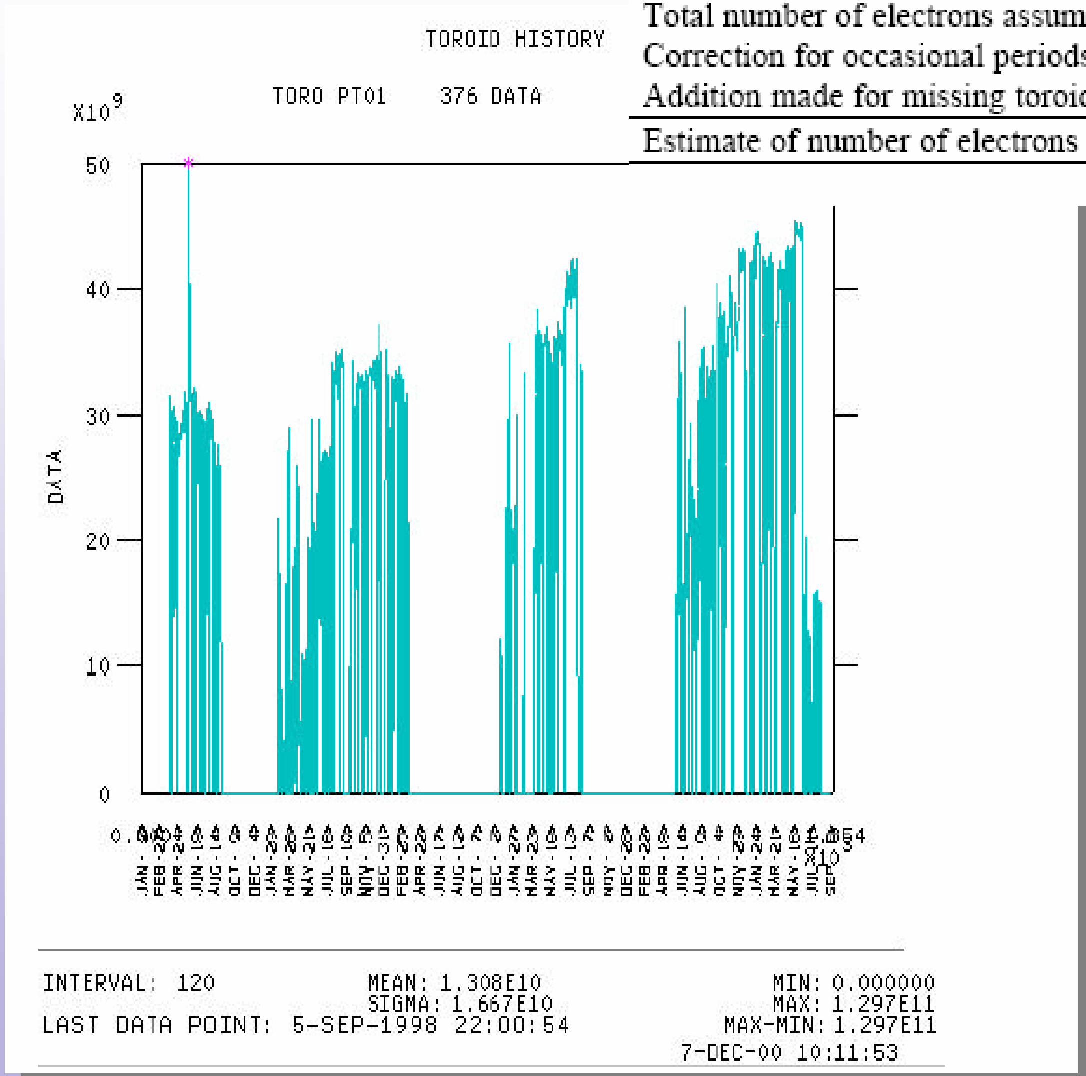
SLC POSITRON TARGET SCHEMATIC



BEAM STATISTICS FOR SLC TARGET

Total number of electrons assuming constant 120 hz operation:		2.57×10^{20}
Correction for occasional periods of lower rep. rate	9%	-2.27×10^{19}
Addition made for missing toroid data 2/10/93 - 3/29/93		$+1.14 \times 10^{19}$
Estimate of number of electrons on target		2.46×10^{20}



Data from Jan 93 – Oct 98

Target ran for almost five years
And then failed because of a
Water to vacuum leak

Analysis of failed target at LANL

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SLC TARGET PICTURES (LANL)

- *Beam incident face*

- *Beam exit face*

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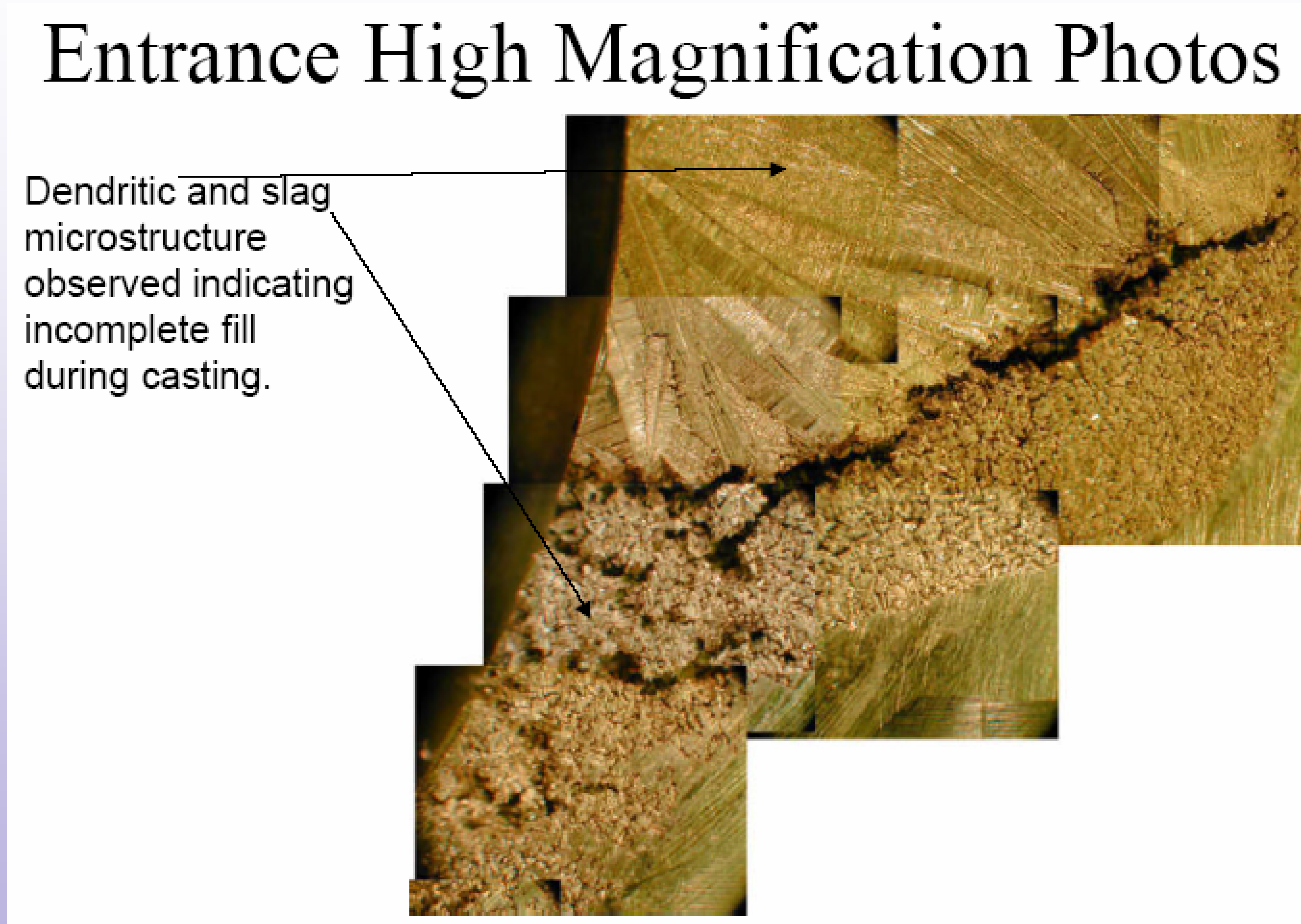
TARGET DETAIL – BEAM INCIDENT FACE

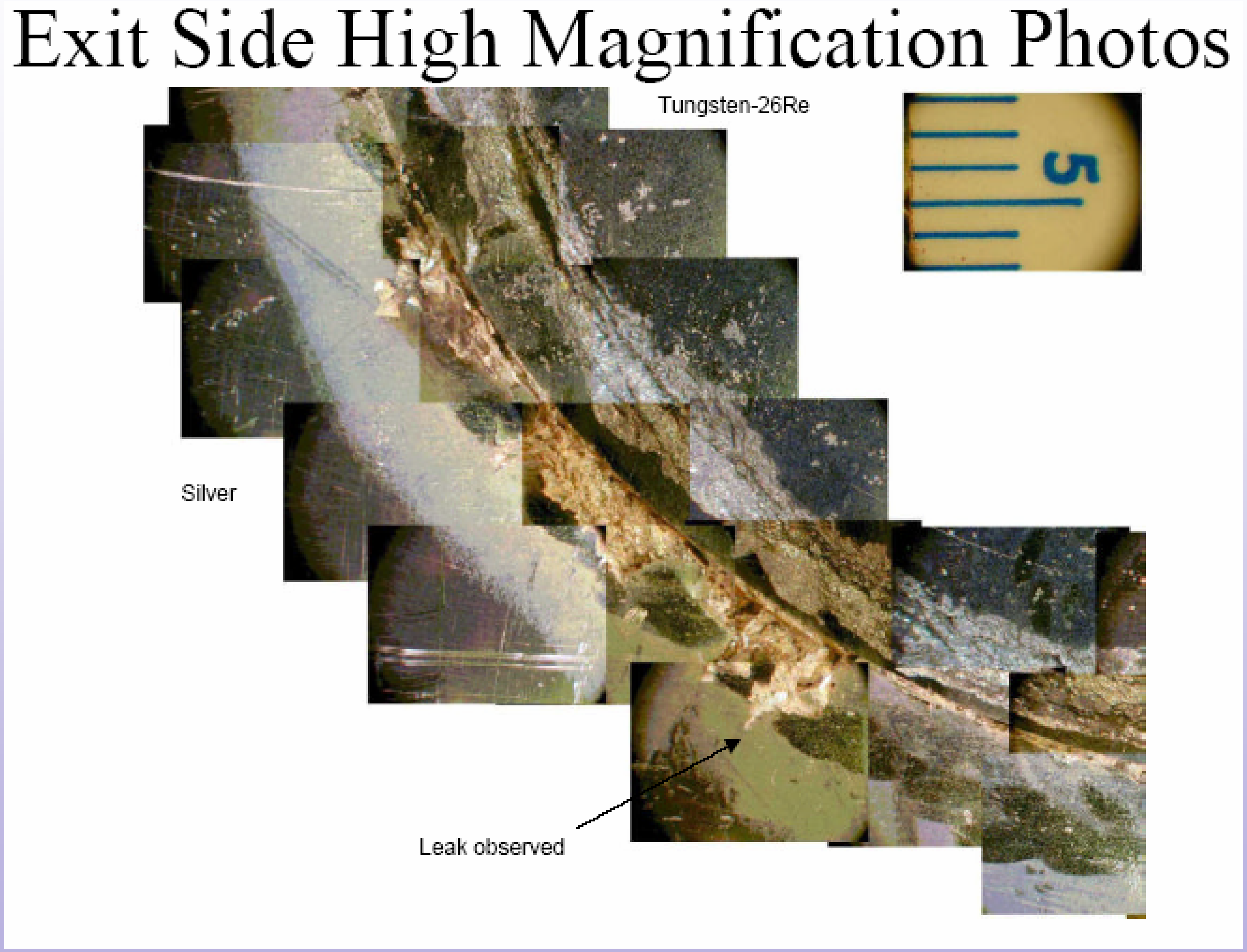
TARGET DETAIL – BEAM EXIT FACE

DETAIL OF SILVER CASING



DETAIL OF BEAM EXIT SIDE TUNGSTEN

DETAIL OF BEAM EXIT SIDE TUNGSTEN



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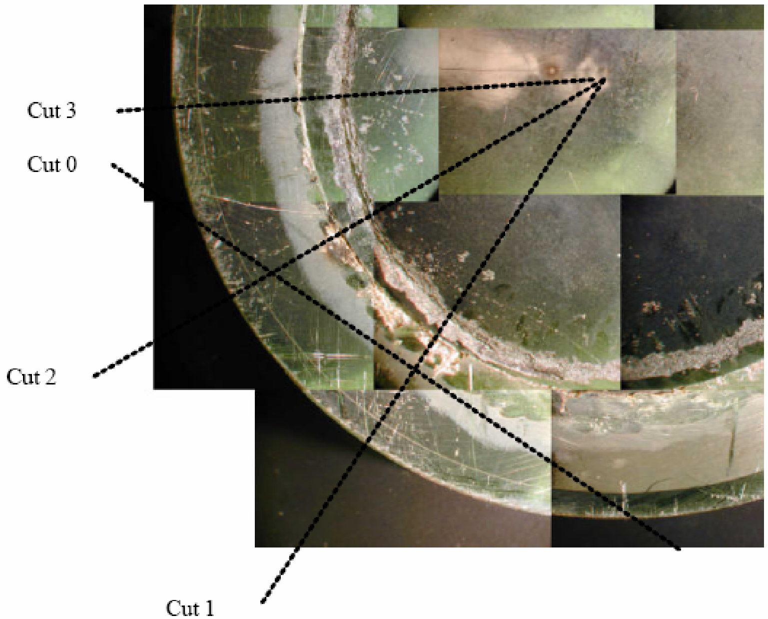
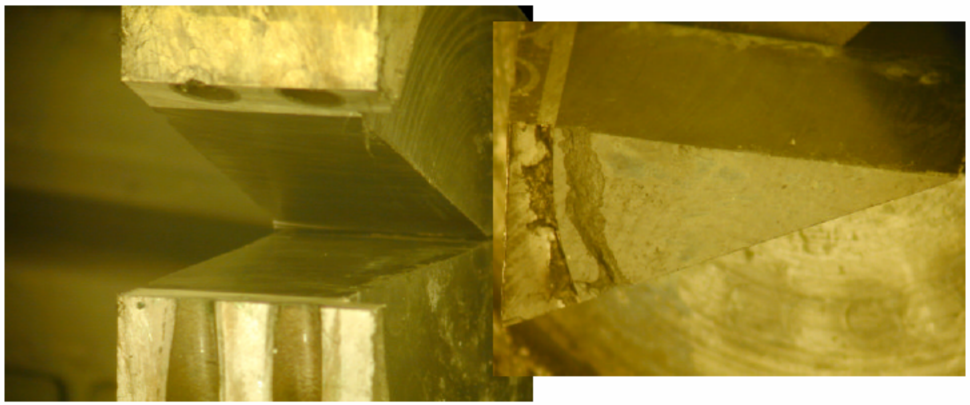
TARGET CUTS

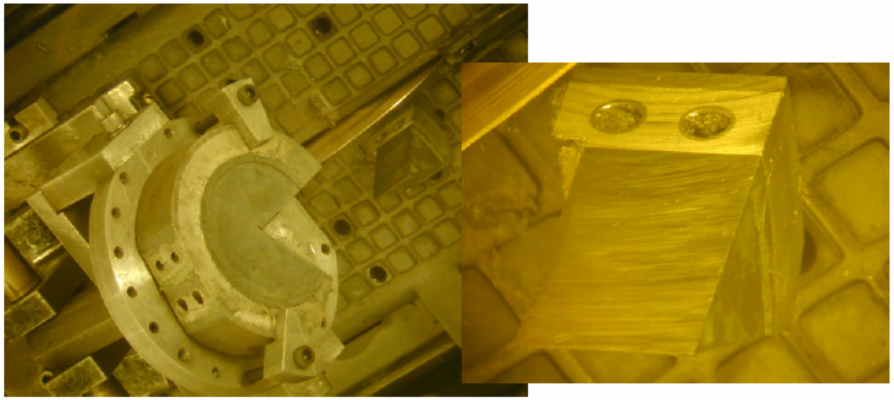
Locations Where Cuts were Taken



Cut 1 and 2



Cut 2 and 3



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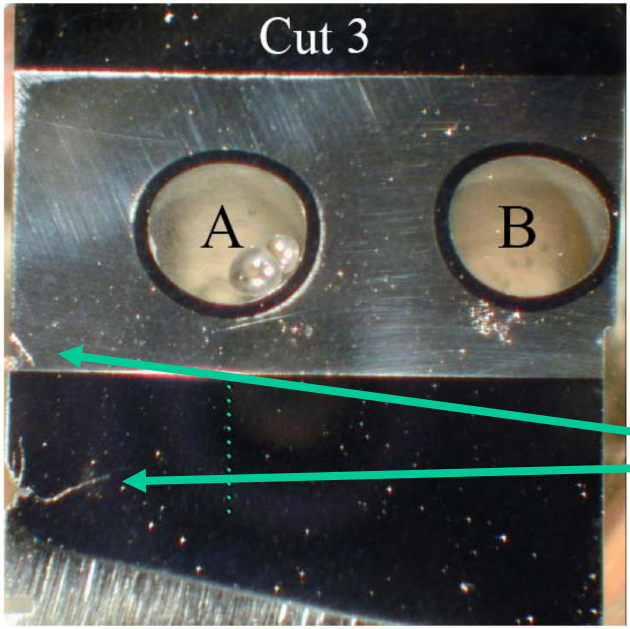
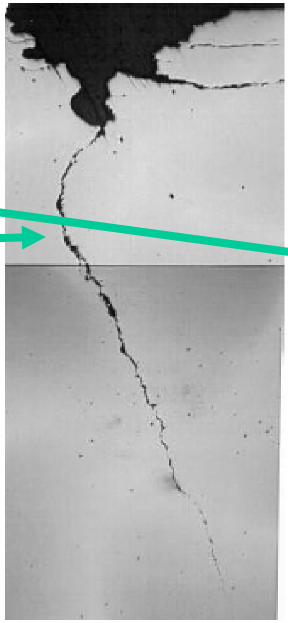
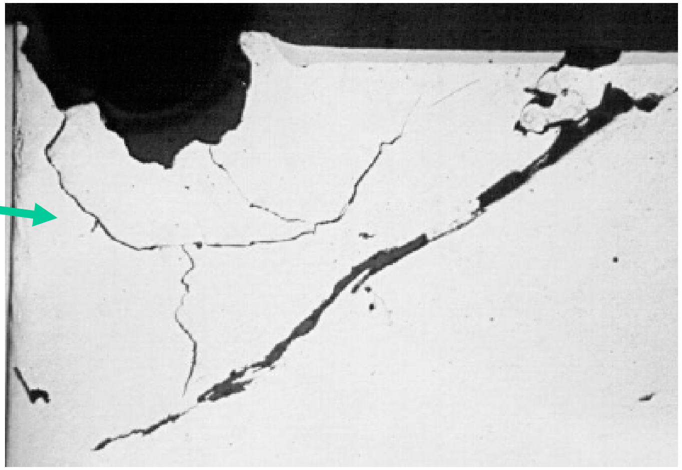
DETAIL OF CRACKING IN SILVER & TUNGSTEN

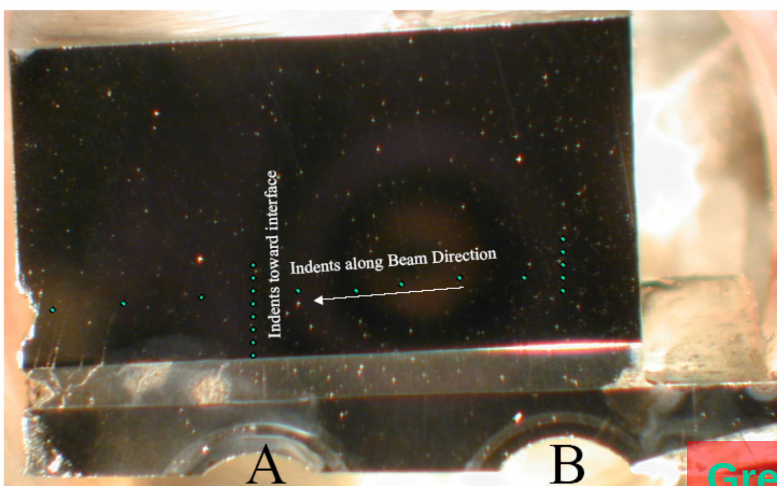


Cracking in Tungsten and Silver on Cut 3





Cut 1



Material	Hardness (kg/mm^2)	Hardness after 3.7 10^{20} p/cm^2	Irradiation Temperature (C)
Tungsten	489	583	300
W-25Re	482	784	720

Green dots are positions for hardness tests

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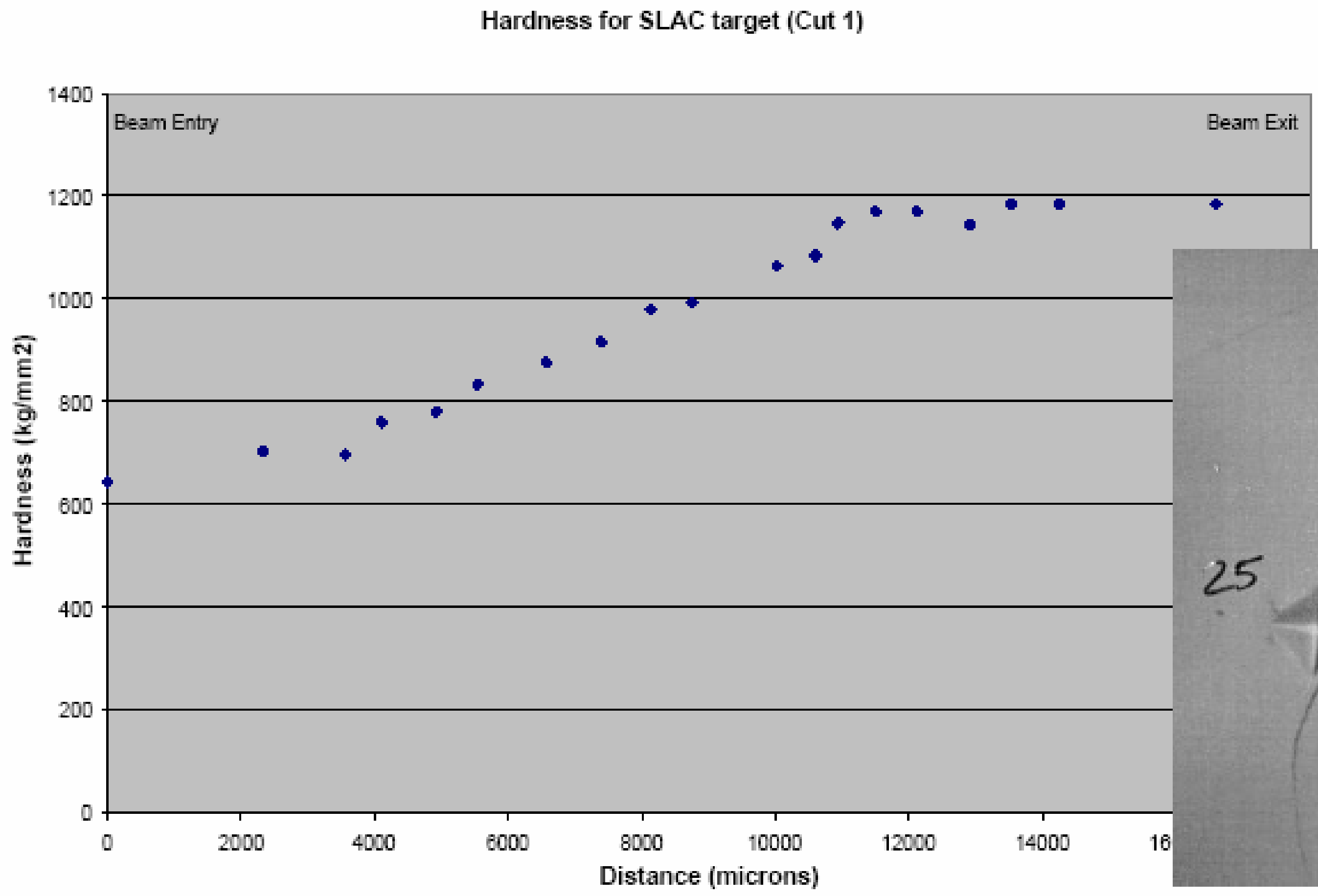
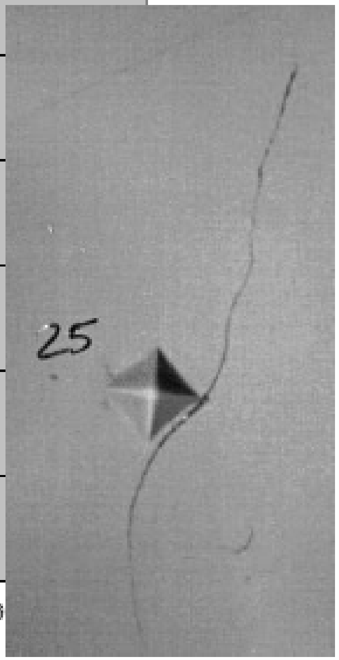
TARGET HARDNESS vs POSITION ALONG BEAM

Hardness vs. Position on Cut 1





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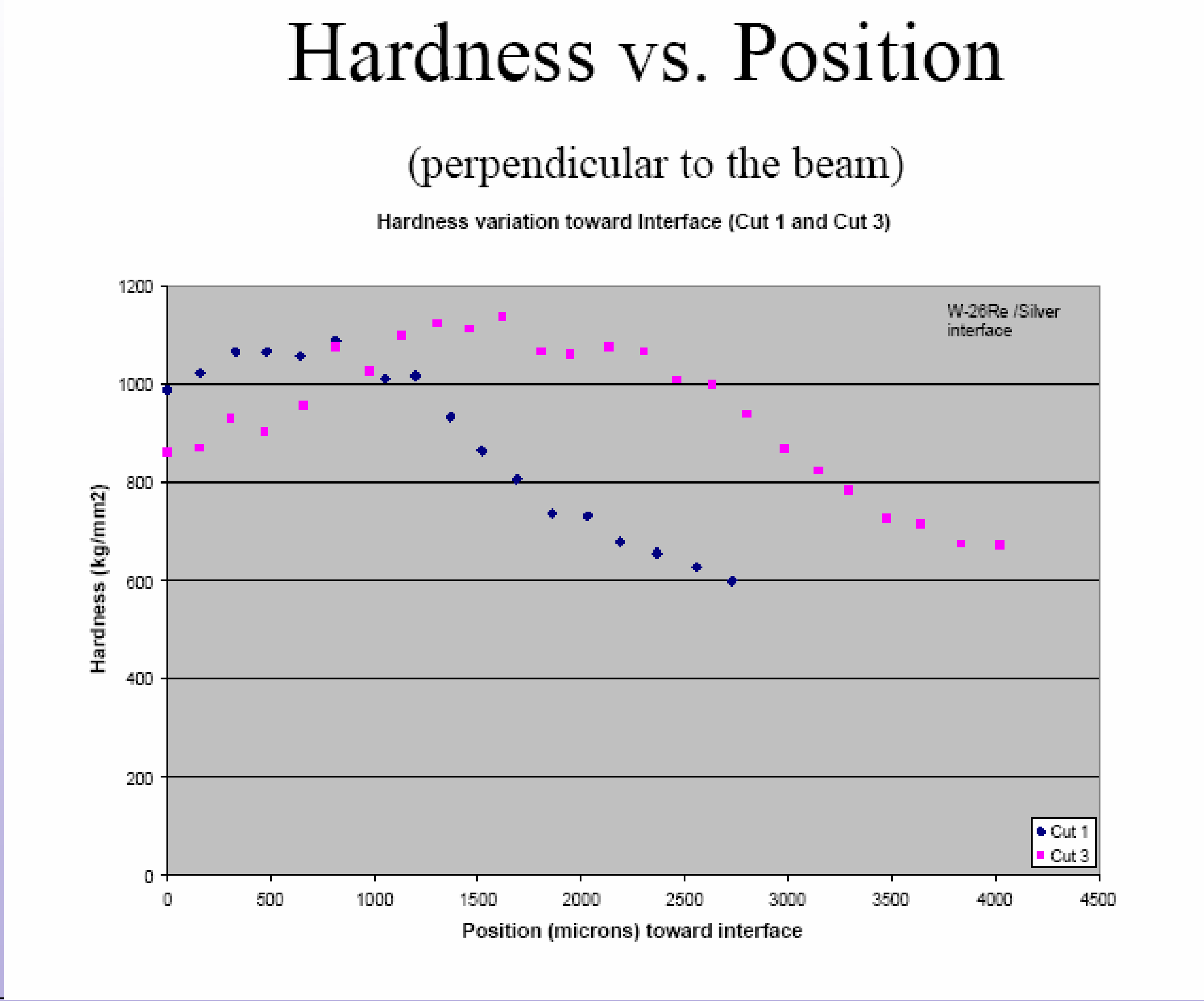
TARGET HARDNESS vs. TRANSVERSE POSITION



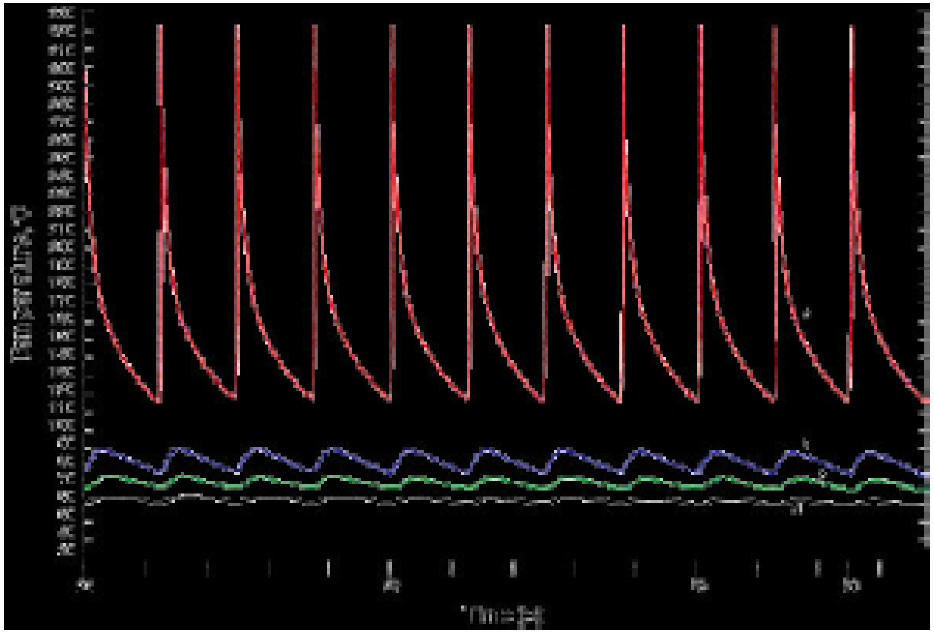
TEMPERATURE & SHOCK/STRESS ANALYSIS

- *ANALYSIS DONE AT LLNL*
  - *Thermal heat transfer analysis to determine temperature fluctuations in the target assembly*
  - *Thermal shock stress analysis due to the rapid beam energy deposition in the W-Re and stress analysis after initial pressure waves dissipate*
- *Reminder*
  - *Cooling tubes developed a leak*
  - *Target developed cracks and loss of material on the beam exit face*
  - *Thermal energy deposited increased from 4.4 kW to 5 kW towards the end of its life*
- *Beam parameters*
  - *Beam spot is 0.8 mm with Gaussian profile*
  - *Deposited beam energy various from a low near the front of the target to a maximum of 34 J/g at the back of the target*
  - *Pulse rate 120 Hz, target moves 3 mm after each pulse. Same spot is hit every 0.5 seconds*

THERMAL HEAT TRANSFER

Temperature history in SLC target (4.4 kW power)

- Peak temperatures reach 330 °C. Temperatures relax down to 120 °C over 0.5 seconds.
- Maximum coolant tube temperature is approximately 80 °C. This temperature is well below values leading to boiling crisis problems.



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SHOCK STRESS ANALYSIS HIGHLIGHTS

- *Thermal shock stress analysis for SLC target*
  - *The rapid beam energy deposition results in a rapid rise in material temperature and a rapid material expansion. The resulting pressure waves travel out from beam spot region at sonic speeds*
  - *Material near the beam exit side of the target experiences the highest pressures, the material initially reaches a high state of compression and then rebounds to a high tensile state*
  - *Effective stress (von Mises) values reach a maximum value of ~5 x 10^8 Pa (72 ksi)*
- *Effective stress after pressure wave dissipates*
  - *After a short tome (100 μs), a steady state temperature condition imposes a steady stress state in the target, with a peak effective stress of 2.7 x 10^8 Pa (39 ksi)*
  - *This stress state would also occur if the beam energy was deposited over a time period of many microseconds*

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SHOCK STRESS ANALYSIS HIGHLIGHTS (2)

SHOCK STRESS ANALYSIS HIGHLIGHTS (2)

- *Conclusions – effective stress is close to fatigue limit*
  - *Due to cyclical loading, fatigue failure may occur*
  - *One general criteria is that failure occurs if effective stress are greater than 50% of the material ultimate strength*
    - *For SLC target temperatures, ultimate strength is between 130 and 190 ksi*
    - *50% of this is 65 – 95 ksi*
    - *The calculated effective stress of 72 ksi is close to the above fatigue limit*
  - *No plastic deformation is expected*

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SUMMARY

- *~ 10 accelerator positron sources worldwide*
  - *Only the "conventional" production scheme is used*
- *SLC is the closest in performance to what is needed by the ILC*
  - *Still a factor of 60 fewer positrons/sec*
  - *Factor of six less power deposited on target*
- *Target is the hardest part of the positron source*
  - *Beam energy deposition*
  - *Associated cooling systems*
  - *Shock & stress effects have to be taken care of – moving target*
  - *Target damage (DPAs) need to taken into account*
  - *Target will be run close to the edge*
- *Capture system (magnet & RF) need care*

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