Evolution of Pressure
In Positron Target Material for Future Linear Collider

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Outline:

Positron Production

The target material is one of the main challenges for positron source of any $e^+ - e^-$ linear collider

- The energy deposition in target materials leads to a rise of pressure in the region where such a deposition takes place [G.I. Silvestrov and T. A. Vsevolozhskaya].
- The induced stress by the beam could substantially reduce the lifetime of the target or other materials impinged by the incident intense photon or electron beam.
  - Although there are different opinions on the amount of stress (that is, in terms of percentage of material tensile strength) that can damage material (Experiment is needed, in other to confirm the actual value).

Comparison of Positrons Sources

Parameters	Units	SLC	CLIC (500GeV)*	ILC
Energy	GeV	1.19	2.86	5
No. of Positrons per bunch	-	5×10^{10}	0.74×10^{10}	3×10^{10}
No of Bunch(es) per Pulse	-	1	312	2625
Rate	Hz	120	50	5
Target Material	-	$W_{75} - Re_{25}$	$W_{75} - Re_{25}$	Ti-6%Al-4%V
Target Thickness	(X_0)	6	4.5	0.4
Source Beam	Particle	Electrons	Electrons	Photons
Source Beam Power	kW	17	67	131

*L. Rinolfi, POSIPOL Workshop, 2011

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Hydrodynamical Systems

In this ongoing study, we extend [T. A. Vsevolozhskaya, 1984 and Mikhailichenko, 2006] and analyze the features of destruction by considering the material behaviour from a hydrodynamical point of view and assumed:

- Gaussian distribution for energy deposited on the target;
- immobile target which implies no eddy currents; and
- a single bunch of the photon beam

Hydrodynamical Model For Target Material

The model comprises of:

- Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0, \qquad (1)$$

- Equation of Motion or Momentum Equation:

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u}\nabla)\mathbf{u} = -\nabla P, \qquad (2)$$

- Modified Equation of State (EOS) for the target Material

$$P = \frac{\Gamma(V)}{V} E, \qquad (3)$$

Linear Pressure Waves

To obtain the pressure acoustic wave equation, we linearized Eqn (1) - Eqn (3) and applying the equilibrium conditions. This leads to the linear pressure acoustic equation:

$$\ddot{P} - \nabla \cdot (c_s^2 \nabla P) = \frac{\Gamma}{V_0} \ddot{Q} \qquad (4)$$

where:

- P: Pressure
- c_s: speed of sound in the target material;
- Q: Energy deposited on the target material by the photon beam;
- V_0: Beam Volume; and
- Γ: Grüneisen co-efficient

Energy Deposition by Photons/Electrons

Energy deposited on the target can be described Gaussian distribution (see[Mikhailichenko, CBN06-1, 2006])

$$\dot{Q} = \frac{2cQ_{bunch}}{\sqrt{\pi}\sigma_z} \cdot \frac{z}{l_T} \exp\left(-\frac{(z-ct)^2}{{\sigma_z}^2}\right) \exp\left(-\frac{r^2}{{\sigma_r}^2}\right), \tag{5}$$

where:

- Q_{bunch}: energy deposited per bunch;
- σ_r, σ_z: bunch size, in radial and longitudinal direction respectively;
- L_T: target thickness

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Numerical Analysis of Pressure Wave Equation

In order to investigate the pressure wave in the target, Eq. 4 was numerically solved by using **FlexPDE**.

- The problem was described in 2-D cylinderical co-ordinates (z,r).
- The simulation was carried out using Tungsten (W) target material.
- In order to avoid a discontinuity in the simulation, the gaussian beam was shifted backward by 0.002m.

Parameter Table

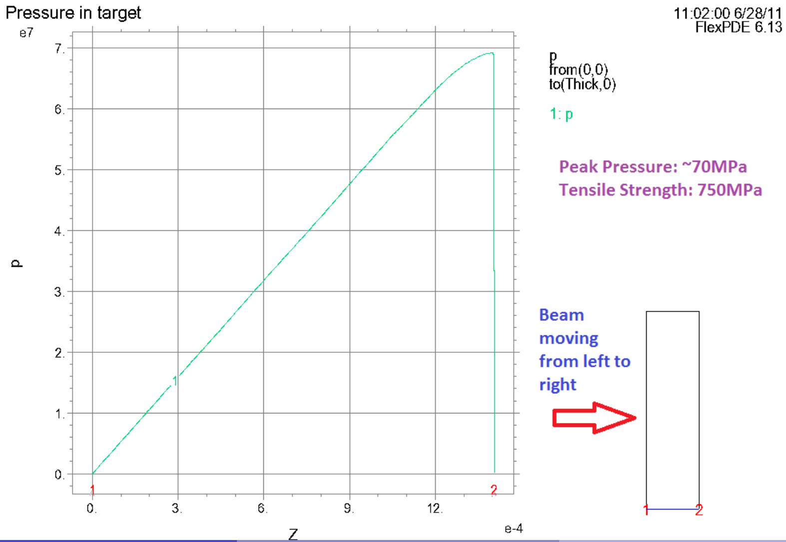
Table 2: Target Material Parameters

Parameters	Coordinate	Units	Tungsten (W)
Target Thickness	z	mm	1.408
Radius	r	m	0.005
Grüneisen constant	-	-	1.647
Sound Speed	-	ms^{-1}	5174
Density	-	Kgm^{-3}	19250

Photon/Electron Beam Parameters

Parameters	Symbol	Units	Value
Beam Length	σ_z	m	0.0003
Radius	σ_r	m	0.0002
Energy Deposity per bunch/pulse	Q_{bunch}	J	0.4

Result: Target Response immediately after the photon beam has left



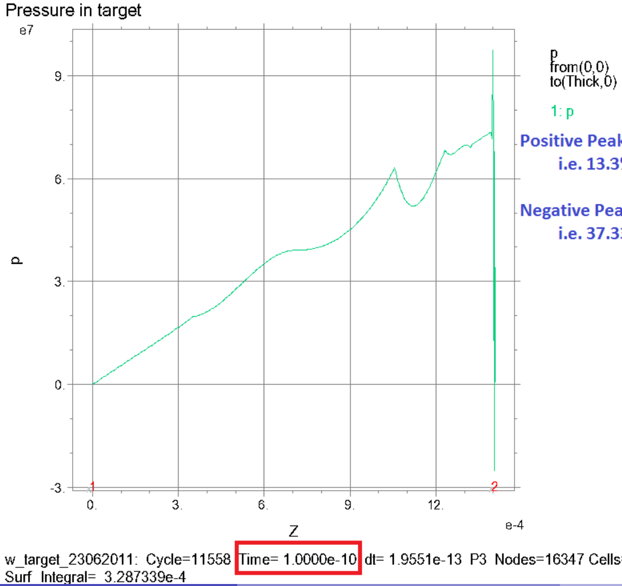
Result and Discussion on ILC Parameters for Tungsten Target

Previous slide show pressure evolution in the target just immediately after photon beam has left the target (the beam shift of $\sim 6.67ps$ was taken into account).

- Only positive pressure which represents the compression of the target by the photon beam can be observed.

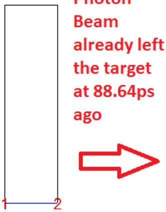
- The peak pressure is approximately $70MPa$, which is just 9.3% of the material tensile strength.

Result: Target Response at 0.1ns



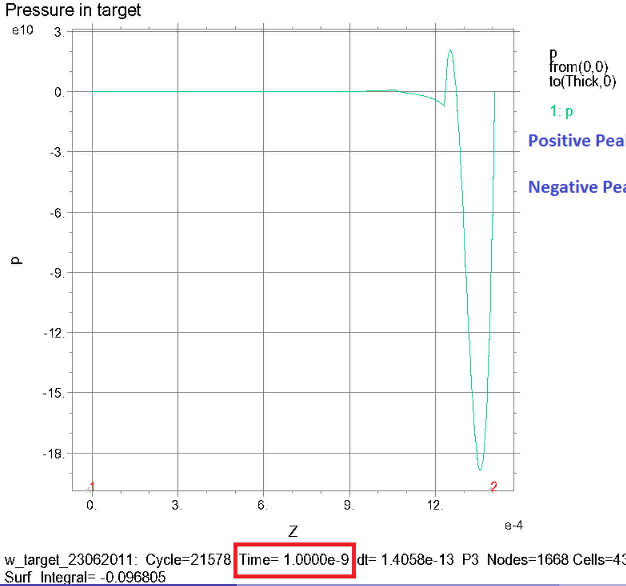
Positive Peak Pressure: ~100MPa
i.e. 13.3% of Tensile Strength

Negative Peak Pressure: ~280MPa
i.e. 37.33% of Tensile Strength



Photon Beam already left the target at 88.64ps ago

Result: Target Response at 1ns



Positive Peak Pressure: ~20GPa

Negative Peak Pressure: ~190GPa

Photon Beam already left 0.99ns ago

Discussion of Result on ILC Parameters for Tungsten Target

➪ The pressure evolution in the target when the photon beam has left the target already at $\sim 0.99ns$ ago, was shown in previous slide, .

➪ It was observed that the pressure continues to grow in time and the big negative pressure appears in the simulation when the photon beam has already left the target.

➪ The positive peak pressure is approximately $20GPa$ and negative peak pressure is approximately $190GPa$ which are 2667% and 25333% of the material tensile strength respectively.

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Summary

In this report we analyzed the pressure generated by energy deposition in positron targets at future linear collider.
In the case of ILC

- The huge negative pressure shown in [A. Mikhailichenko] was confirmed, its magnitude continuously growing with time. The reason for this behavior is not yet fully understood.
- Since the pressure propagation continues when the photon beam left the target, the results depend strongly on the time chosen to run the simulation.
- If this high negative pressure is real, pressure induced by one single photon bunch (1ps) $>>$ yields tensile stress of the Tungsten target, which the material can not cope with.

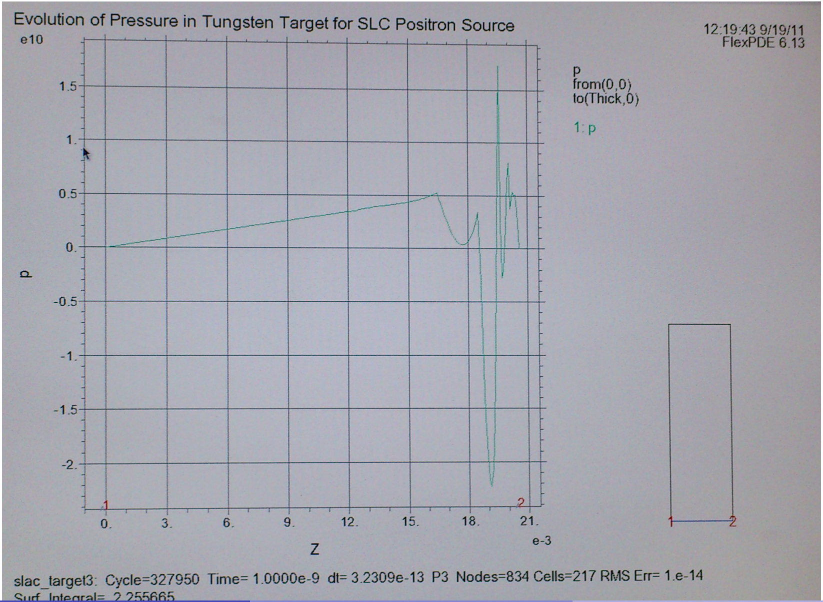
Outlook

- The cumulative effect of multiple bunches over a long run time will have great impact on the fatigue failure of the material
- So far, a Gaussian distribution was assumed for the energy deposition on the target, only one bunch and only linear wave effects have been included; a more detailed analysis is in progress.
- Plans: The improved model will include a realistic photon beam profile, possible non-Linear wave effects, multi-bunch effects and rotation of the target.

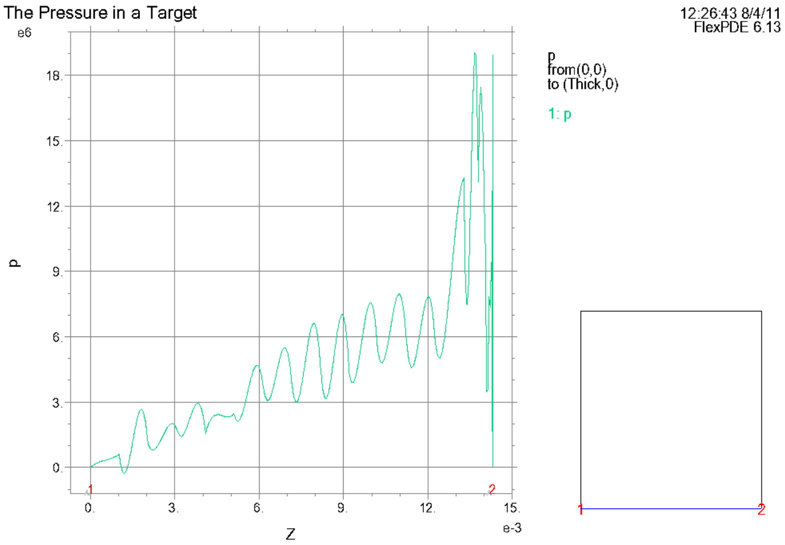
Thank You!

BACK UP SLIDES

Result on SLC Target



Result on ILC Parameters for Titanium Target



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Surf_Integral= 4.107896e-3