Simulation on ILC undulator based source with liquid lead target

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Parameters

- Undulator: K=0.92, lu=1.15cm
- AMD: 6T-0.5T in 14cm, immersed target
- Target: 0.5X0 liquid lead
- Yield estimated at 125MeV using damping ring acceptance window.
- No photon collimator applied
- Distance from target to undulator is 500m

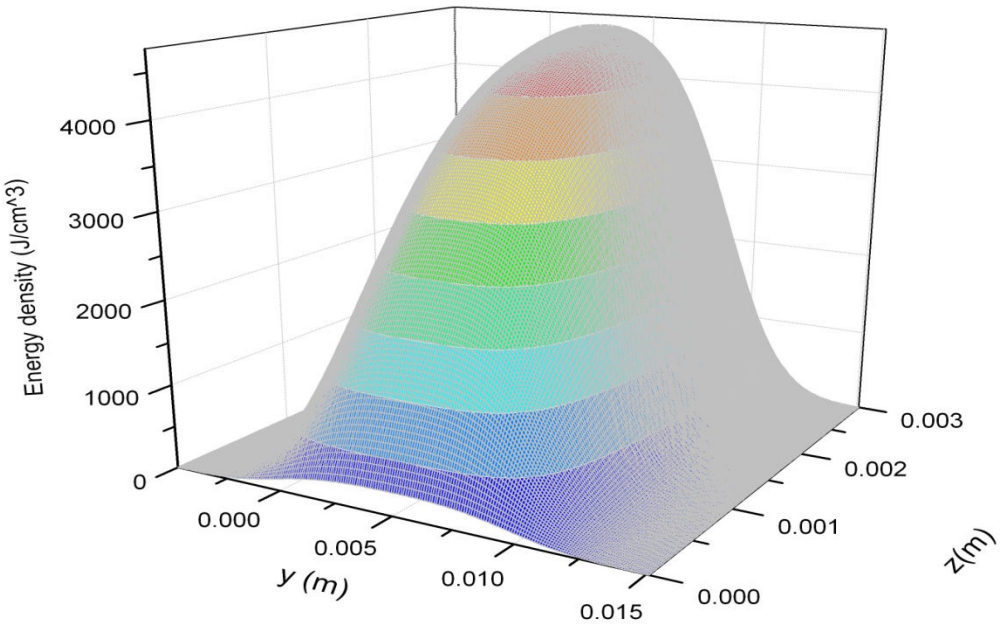
EGS4 and PARMELA results

- Yield is about 2.09 per 100m
- Energy deposition per captured e+ 54.8MeV
- Assuming 2e10 e+ captured per bunch then energy deposition per bunch is 0.1758 J in target without windows
- Assuming 2e10 e+ captured per bunch then energy deposition per bunch is 0.18376 J in target, 0.00818J in upstream window (BN) and 0.0436J in downstream window (BN ~4mm).

Parameters of liquid lead and BN window

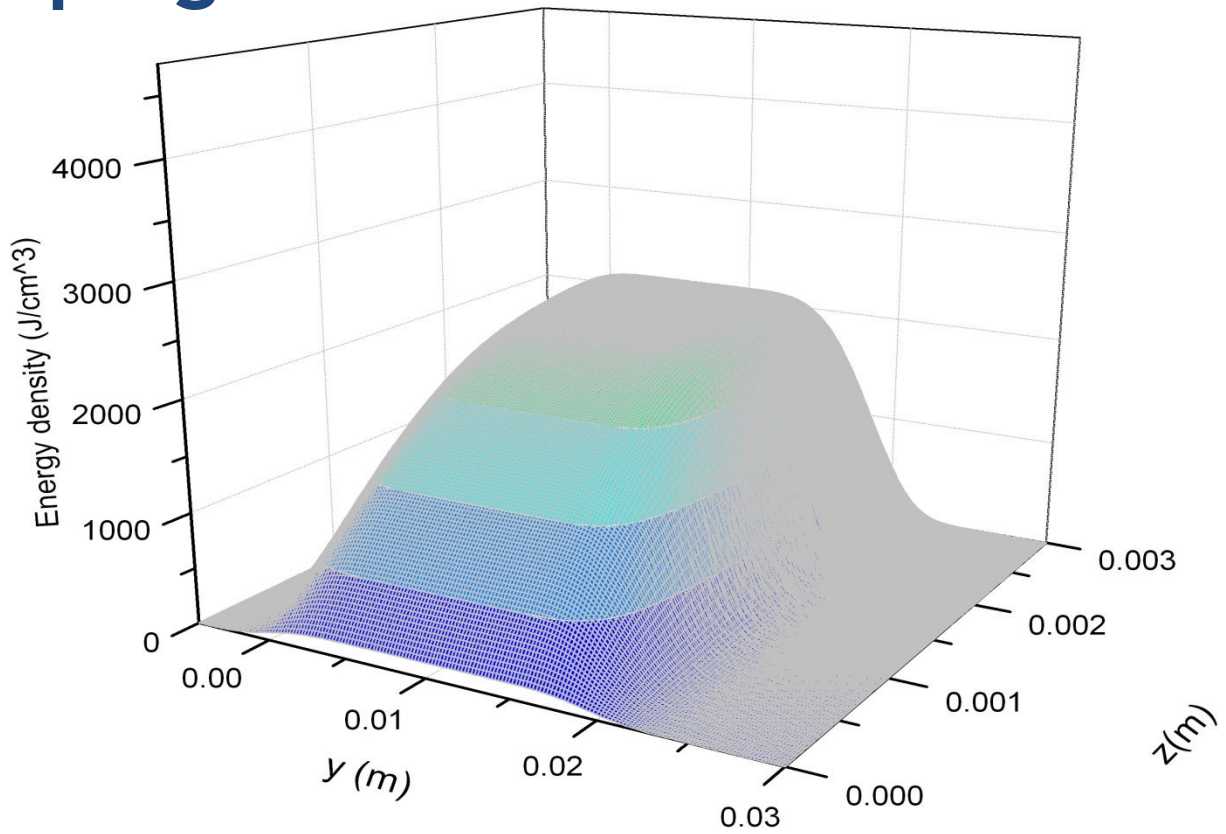
- Energy required to heat the liquid lead from 600K up to boiling point(2022K): Q_b=~197.7J/g <~=> 2241.9 J/cm^3
- Latent heat for vaporization of lead: Q_L =~871J/g <~=> 9877 J/cm^3
- To heat the liquid lead from 600K into vapor needs $Q_v=Q_b+Q_L$ =~ 12119 J/cm^3
- Maximum use temperature of BN is ~3000^{o}C
- The current window brazing material (?, from Omori,) will be melted at ~900^{o}C

Distribution of deposited energy density pumping at 10m/s



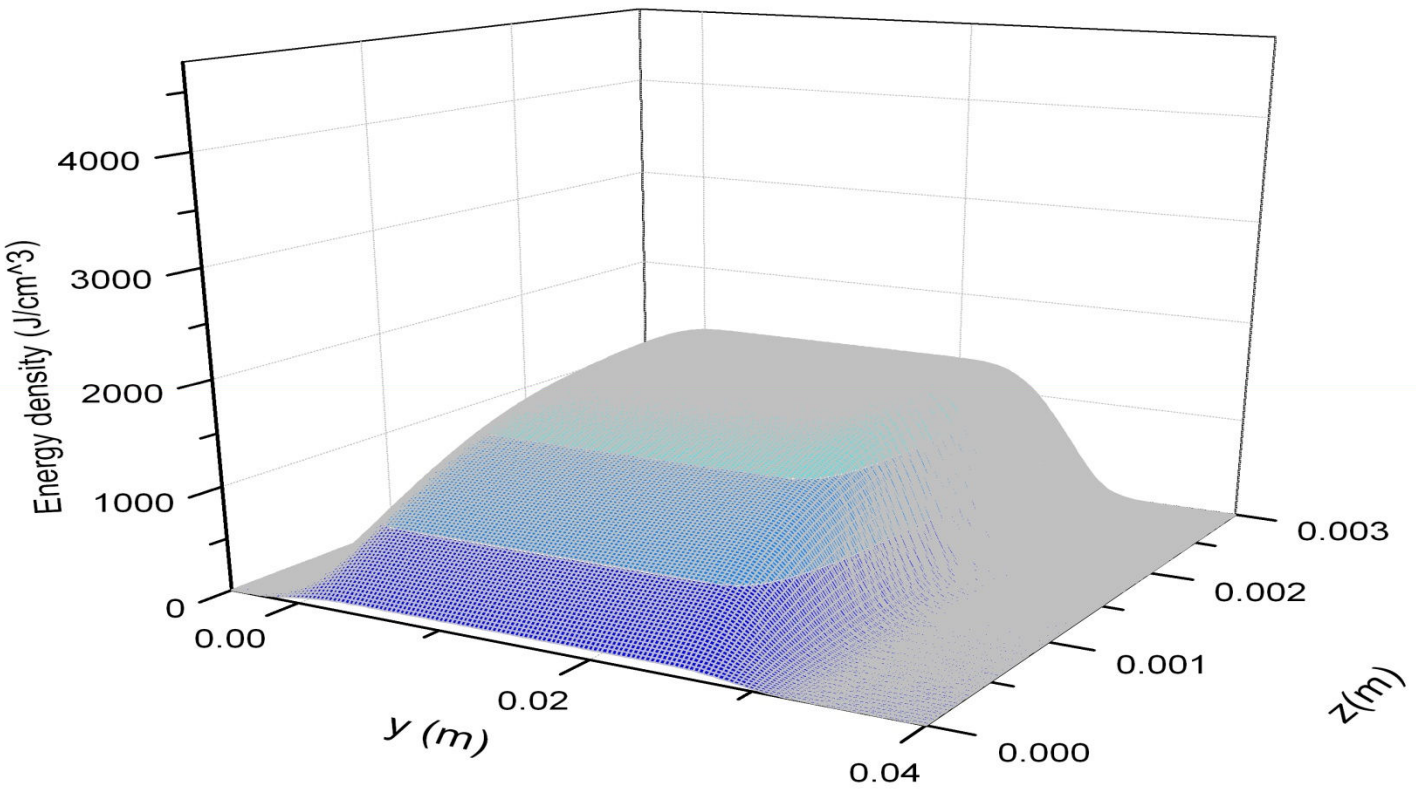
- Energy density goes over 2241J/cm^3 easily but stays bellow the point of vaporization. The lead will stays in liquid form.
- The energy density on window surface is high enough to bring the temperature over the melting point of brazing material for current configuration.

Distribution of deposit energy density pumping at 20m/s



- Energy density goes over 2241J/cm^3 by about 200 J/cm^3 which is far bellow the point of vaporization. Lead will stay in liquid form.
- Energy density on window surface stays bellow the point where temperature will exceed the melting point of brazing material without considering the heat conduction.

Distribution of deposit energy density pumping at 30m/s

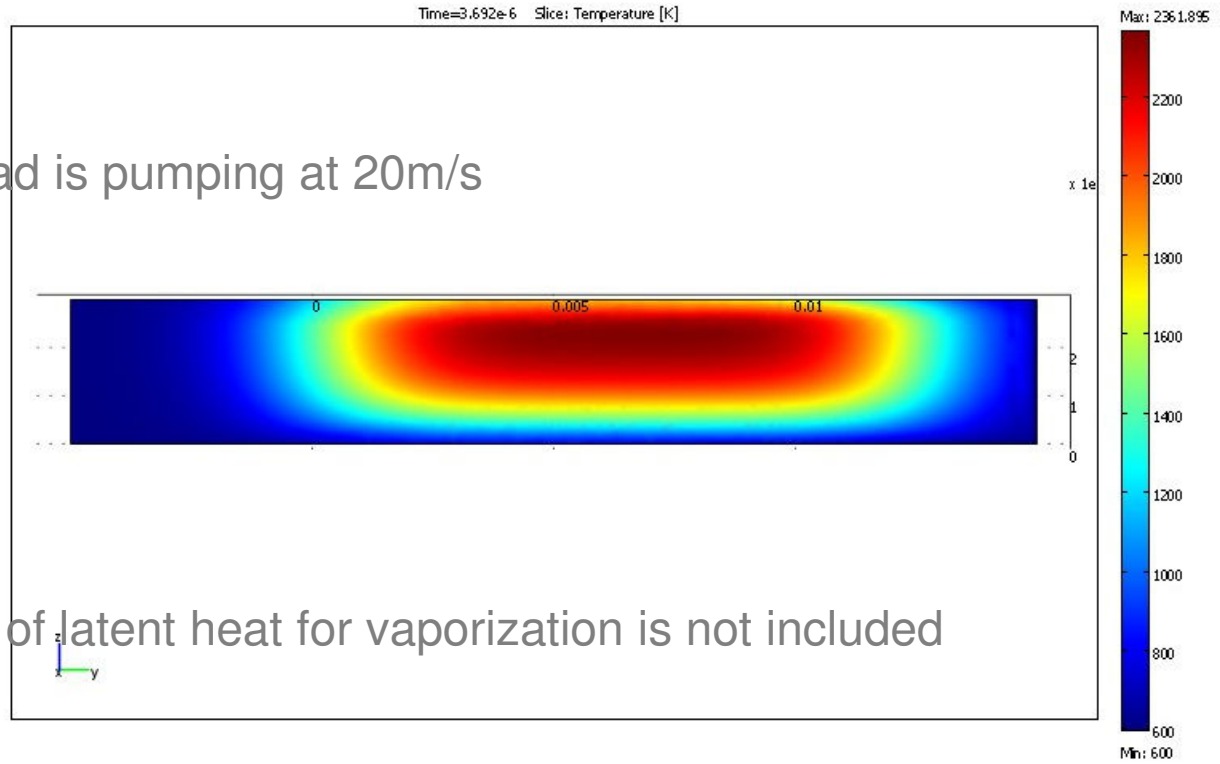


- Energy density stays bellow 1600J/cm^3 in the target and the lead will stay in liquid form.

Heat transfer simulation result without considering the latent heat

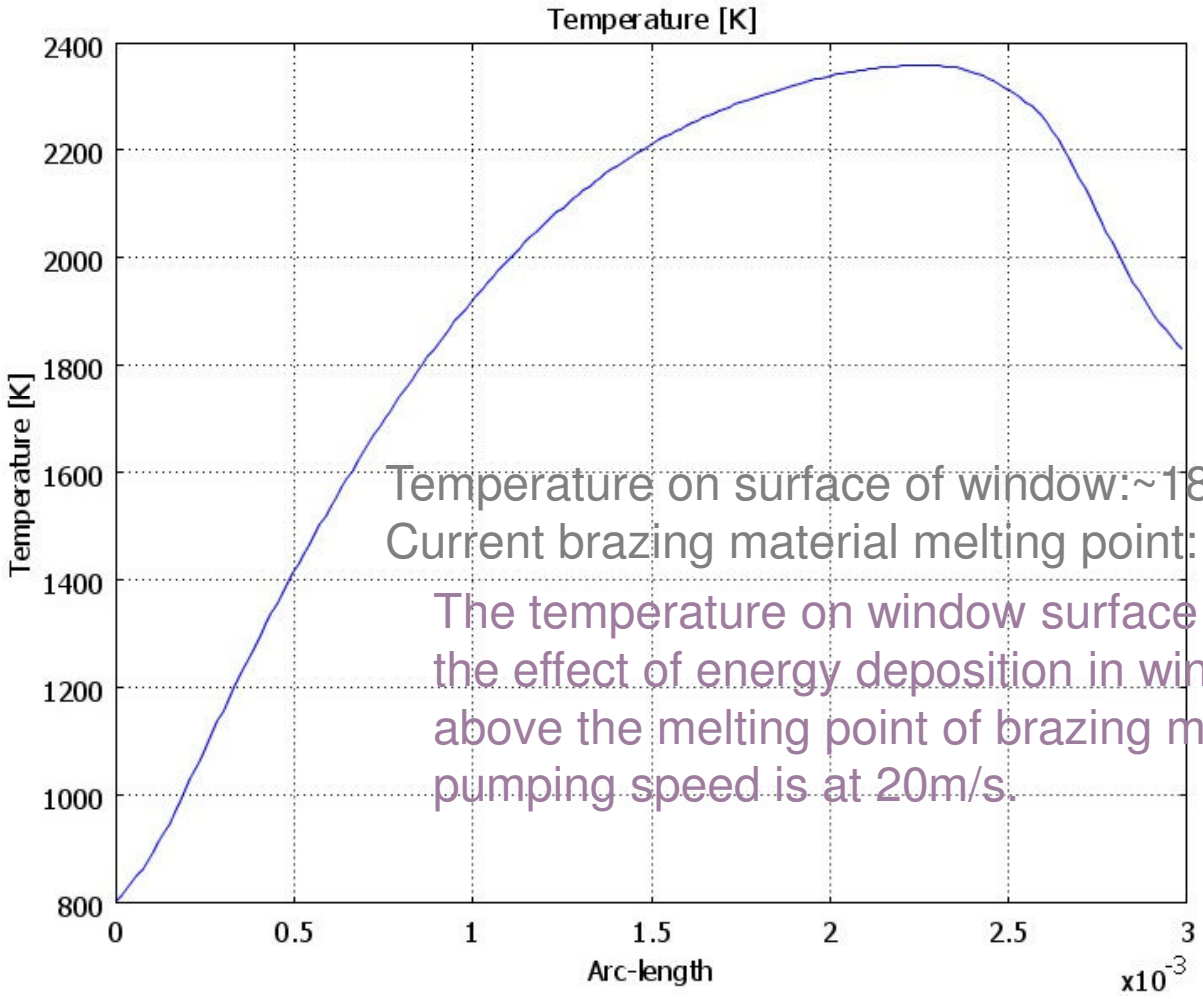
The liquid lead is pumping at 20m/s

The effect of latent heat for vaporization is not included



With heat conduction considered, the temperature on surface of the window is about 1800K and is higher than the melting point of current window brazing material.

Temperature distribution along the depth of target at the middle of bunch train when pumping speed is 20m/s



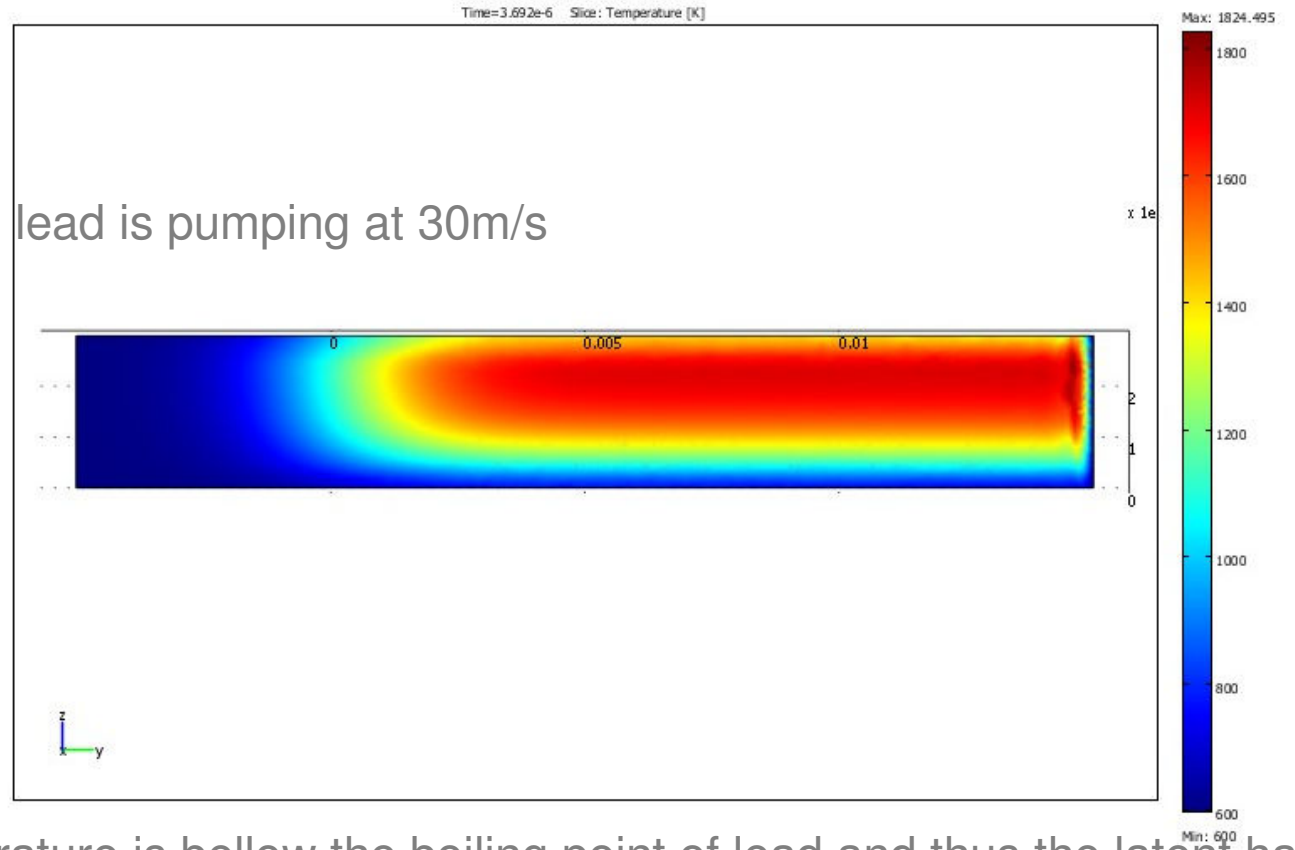
Temperature on surface of window:~1800K

Current brazing material melting point: ~1200K

The temperature on window surface without considering the effect of energy deposition in window is about 600K above the melting point of brazing material when pumping speed is at 20m/s.

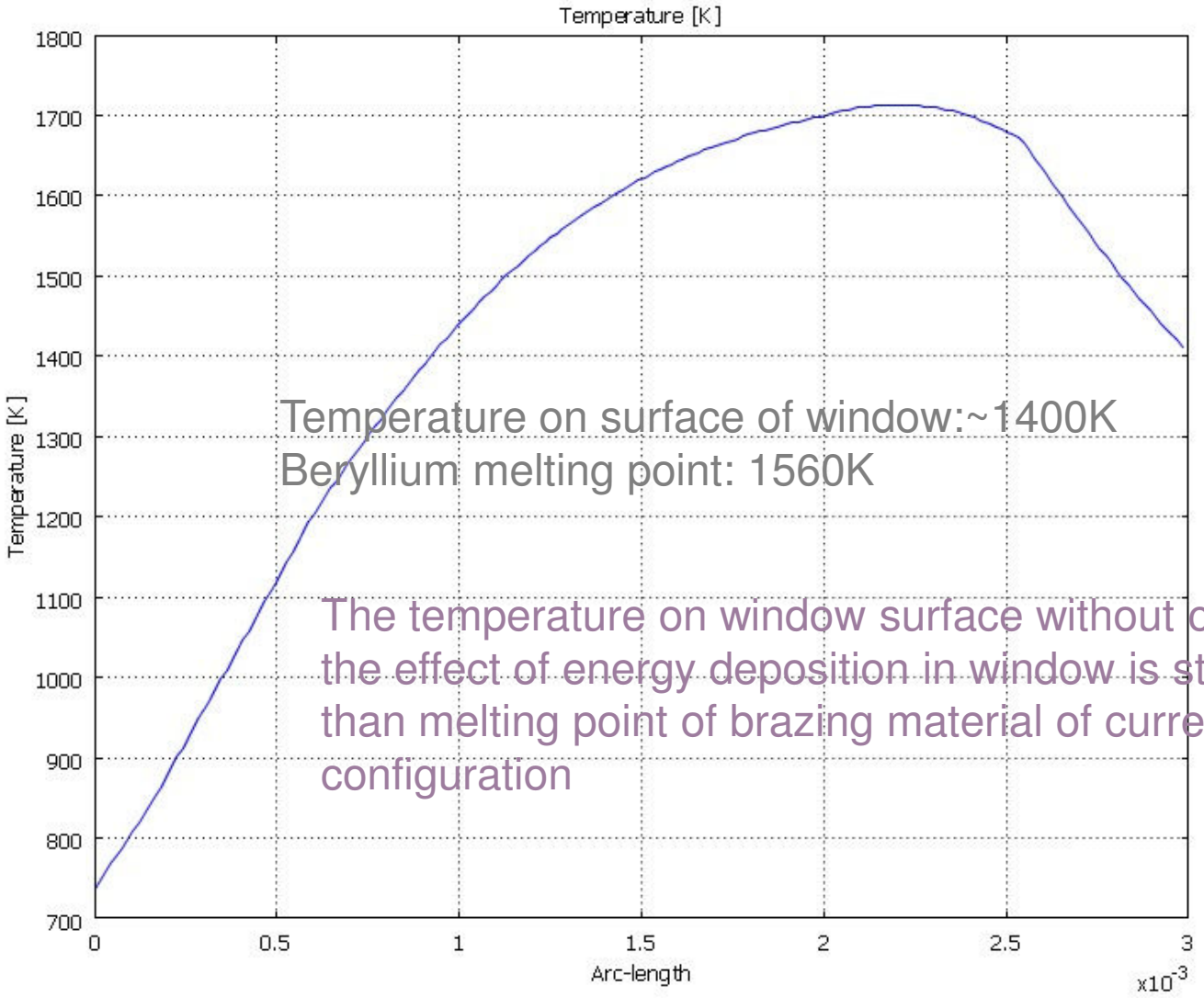
Heat transfer simulation result without considering the latent heat

The liquid lead is pumping at 30m/s



The temperature is bellow the boiling point of lead and thus the latent has no effect here

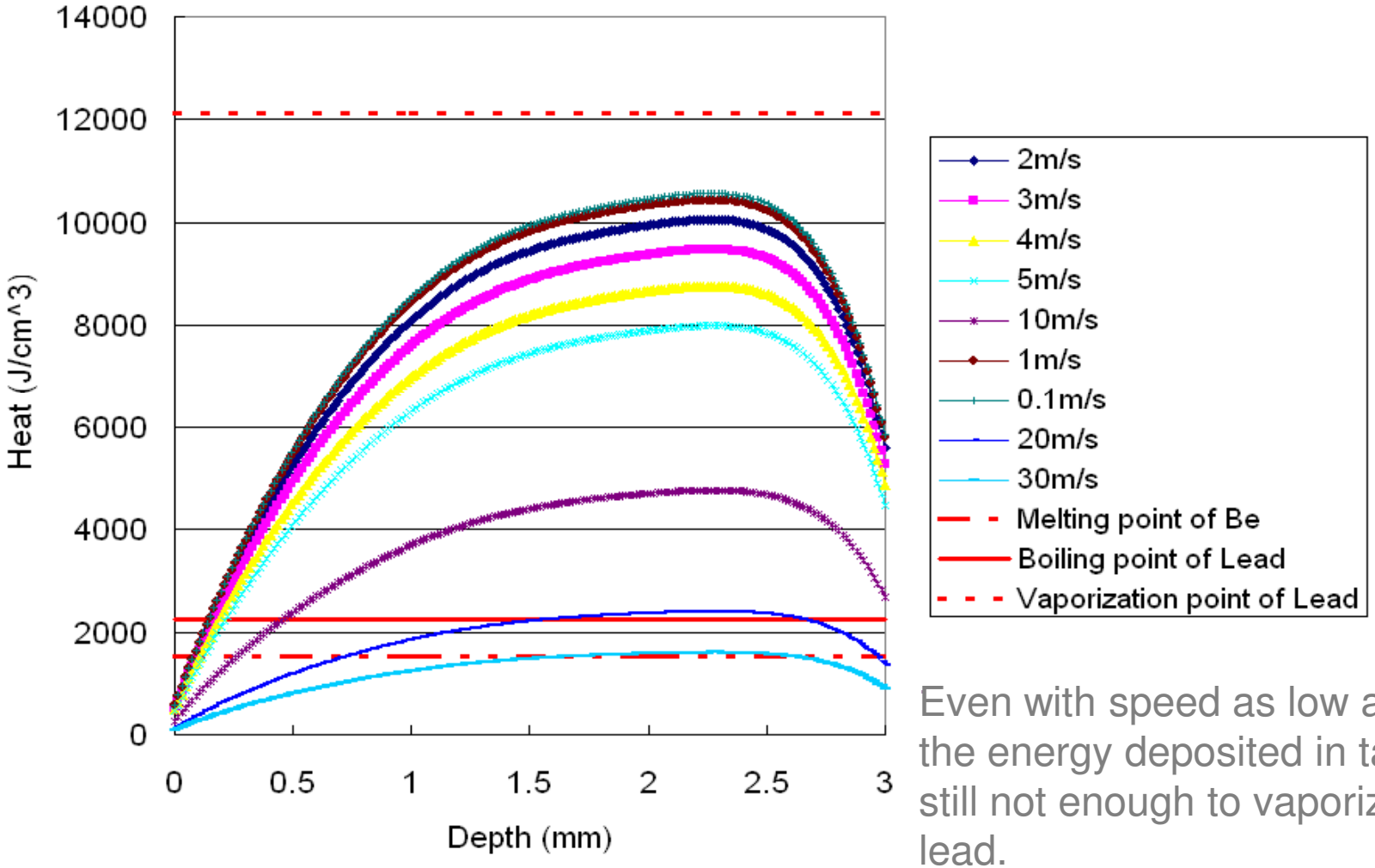
Temperature distribution along the depth of target at the middle of bunch train



Temperature on surface of window:~1400K
Beryllium melting point: 1560K

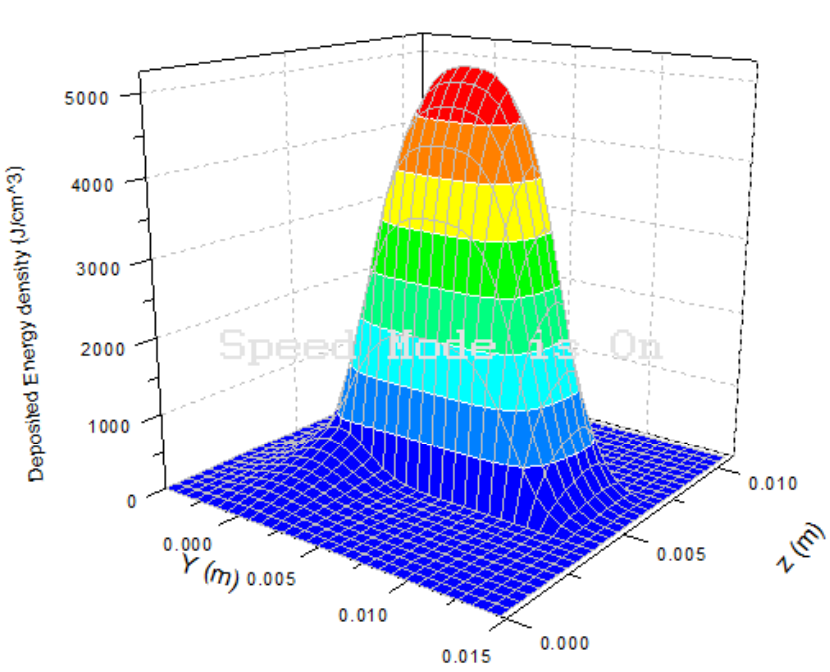
The temperature on window surface without considering the effect of energy deposition in window is still higher than melting point of brazing material of current configuration

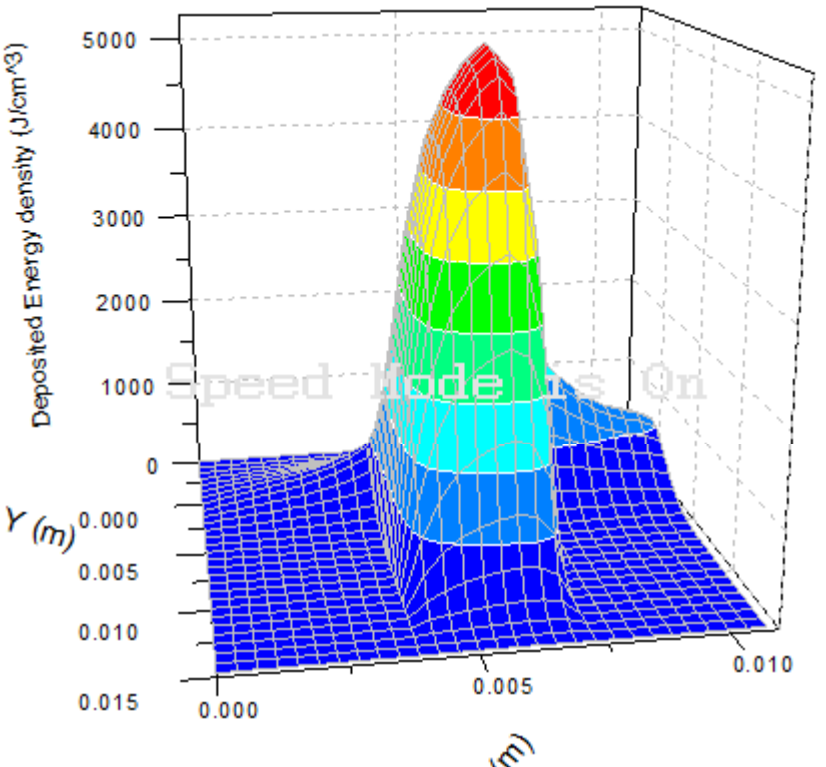
Heat density at the middle of bunch train for different pumping speeds



Even with speed as low as 10cm/s the energy deposited in target is still not enough to vaporize the lead.

Energy deposition density in both window and target Pumping speed is 10m/s





4mm thick BN window applied on both upstream and downstream of liquid lead target. Energy deposition profile for a train of 2625 bunches shows that the energy deposition in window is < 2000 J/cm^3 which can only increase the temperature of window by ~700K which is far bellow the maximum working temperature of BN,3000^{o}C.

With 10cm/s pumping, the lead will be at its boiling point 2022K, adding 700K to the downstream window only bring the window up to 2722K. It is still more than about 500K bellow the maximum using temperature of BN

Summary

- Numerical simulations shows that the undulator based ILC e+ with liquid lead target with BN window will work (if the issue of melting of brazing joint can be overcome).
- The pumping speed can be as low as 10cm/s without vaporizing the liquid lead or melting the BN window.