Evolution of Pressure
- In Positron Source for future Linear Collider

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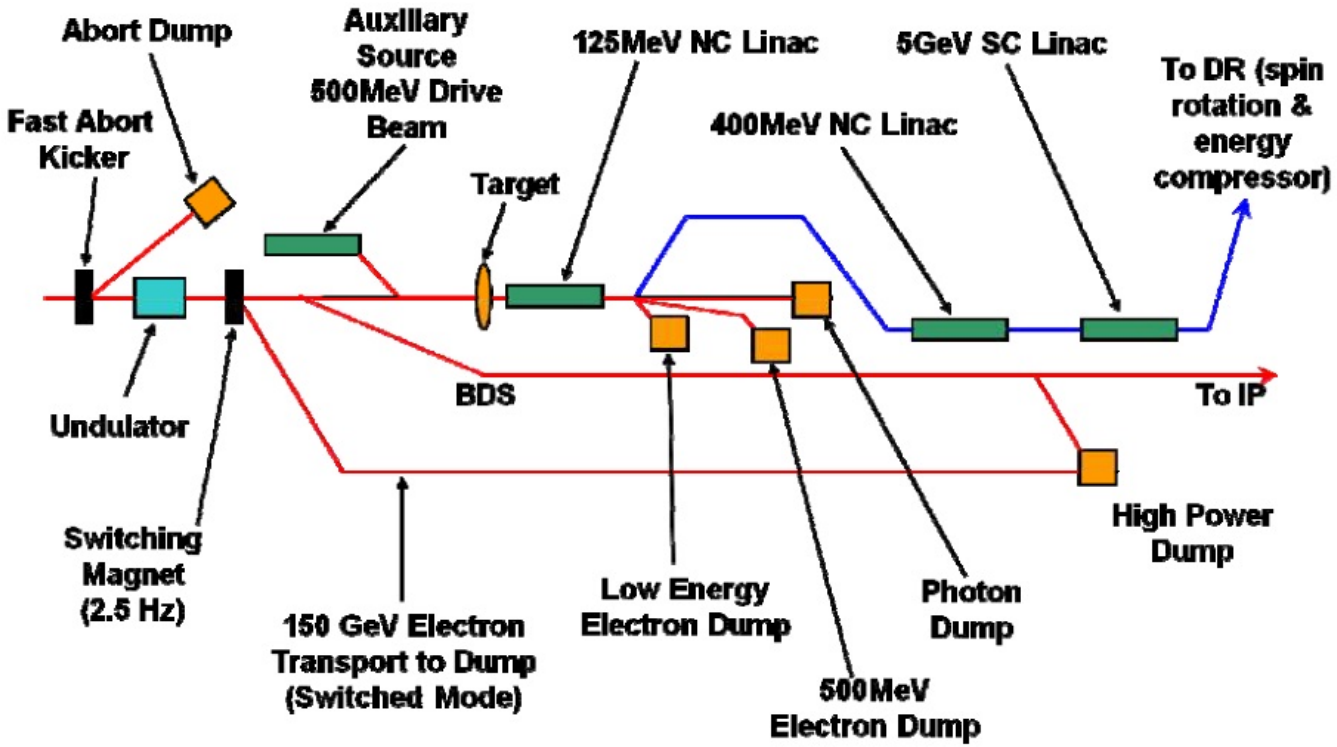
Outline:

Positron Production

The target material is one of the main challenges of the positron source.



Conceptual layout of the positron source region. The electron beam is travelling from left to right. Red lines indicate electrons, blue lines indicate positrons and black lines indicate photons.

Figure: Source: SB2009 Proposal Document, December 2009

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   And in SLC target material for positron source failed after an operation time of about 5 years.
2. Existing simulation result showed huge negative pressure, indicating that the ILC target will not survive a single bunch of photon beam bombardment.

Source: (Vinod Bharadwaj, Workshop on Positron Sources- Daresbury, April 10, 2005)

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Fluid Dynamic Model For Target Material

We investigate the evolution of pressure by using the existing model (i.e. fluid model). The model comprises of:

- Continuity Equation:

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

- Equation of Motion or Momentum Equation:

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

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

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

(Mikhailichenko, CBN06-1, 2006)

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Γ: Grüneisen co-efficient

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Energy deposited on target

(Mikhailichenko, CBN06-1, 2006)

Fluid Dynamic Model For Target Material

From Eqn (1) - Eqn (3) give the Acoustic Waves Equation below:

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

where:

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

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Energy Deposition by Photons

The heat deposited by photons on the target per volume per time is described by Gaussian distribution, for a single bunch we have:

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

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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Parameters of Beam and Target materials

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- $\sigma_z = 0.3mm$
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- Density, ρ: $1.925 \times 10^4 Kg/m^3$
- Sound speed, C_s: $5174m/s$
- Grüneisen co-efficient, Γ: 1.647
- Thickness, l_T: $1.408mm$
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NOTE: Although ILC require Titanium Alloy for the target material, Tungsten is used here because we want to compare result with existing literature

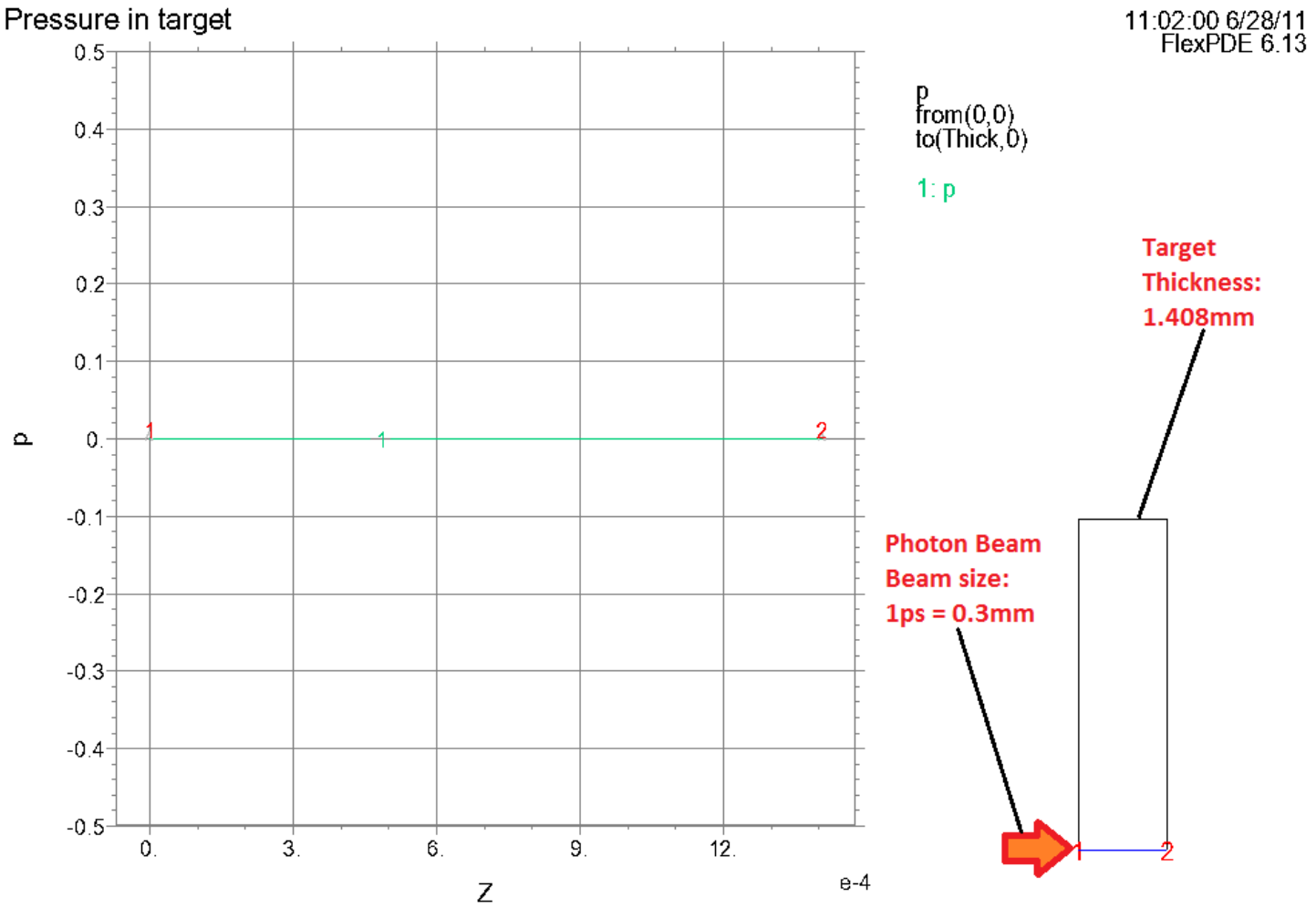
Simulation With FlexPDE

- FlexPDE is a general-purpose software for obtaining numerical solutions to partial differential equations.
- It is based on the Finite Element Method. Simulation was carried out on target material (that is, Tungsten).

In this case, 2-D Cylindrical Co-ordinates were used to describe the Model in FlexPDE

- z-coordinate runs from 0 - Target thickness
- r-coordinate runs from 0 - Target Radius
- Boundary condition: Pressure on the target is taken to be zero, (that is, atmospheric pressure)

Preliminary Results: Pressure (Pascal) vs. target thickness (meter) for a single bunch



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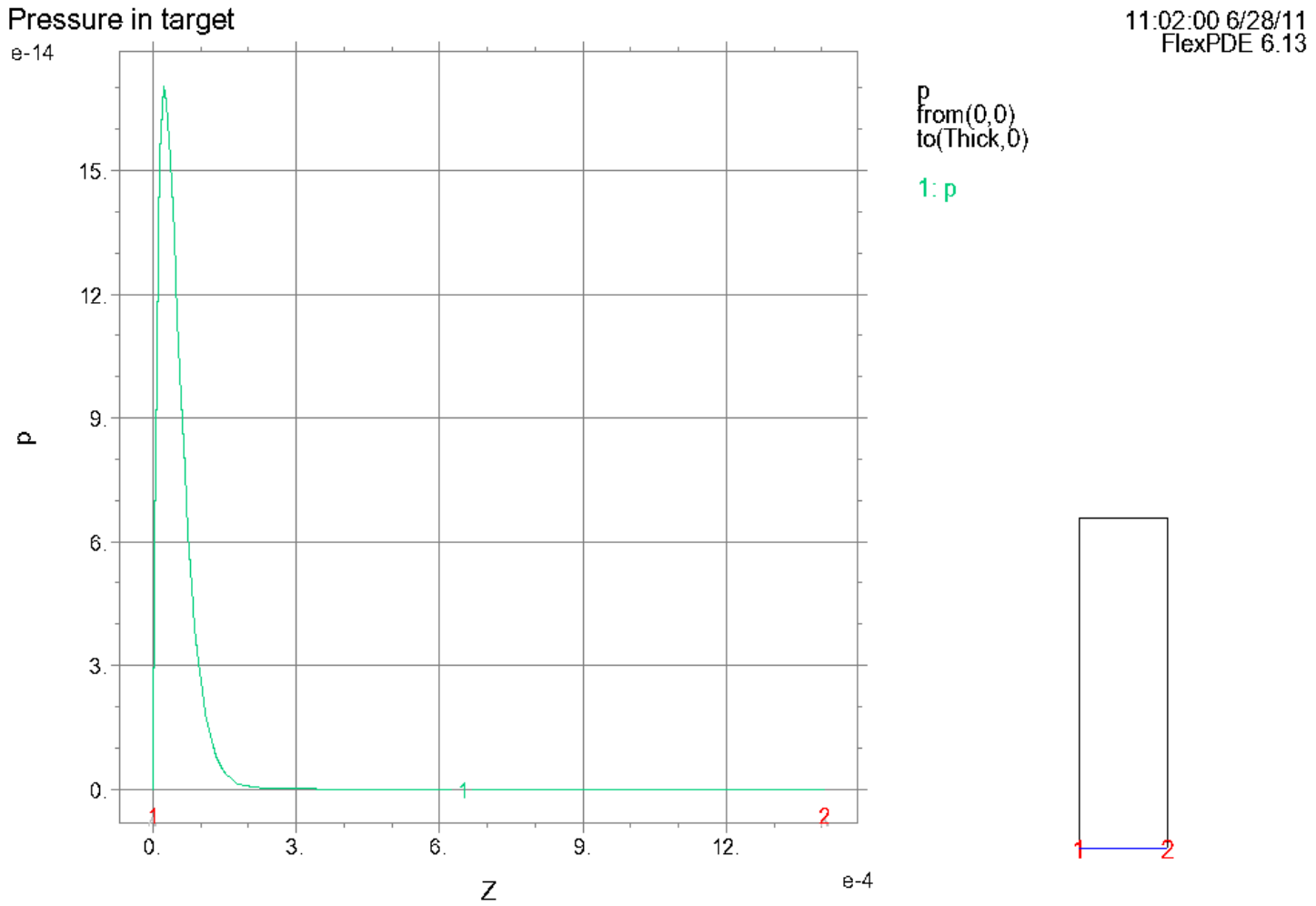

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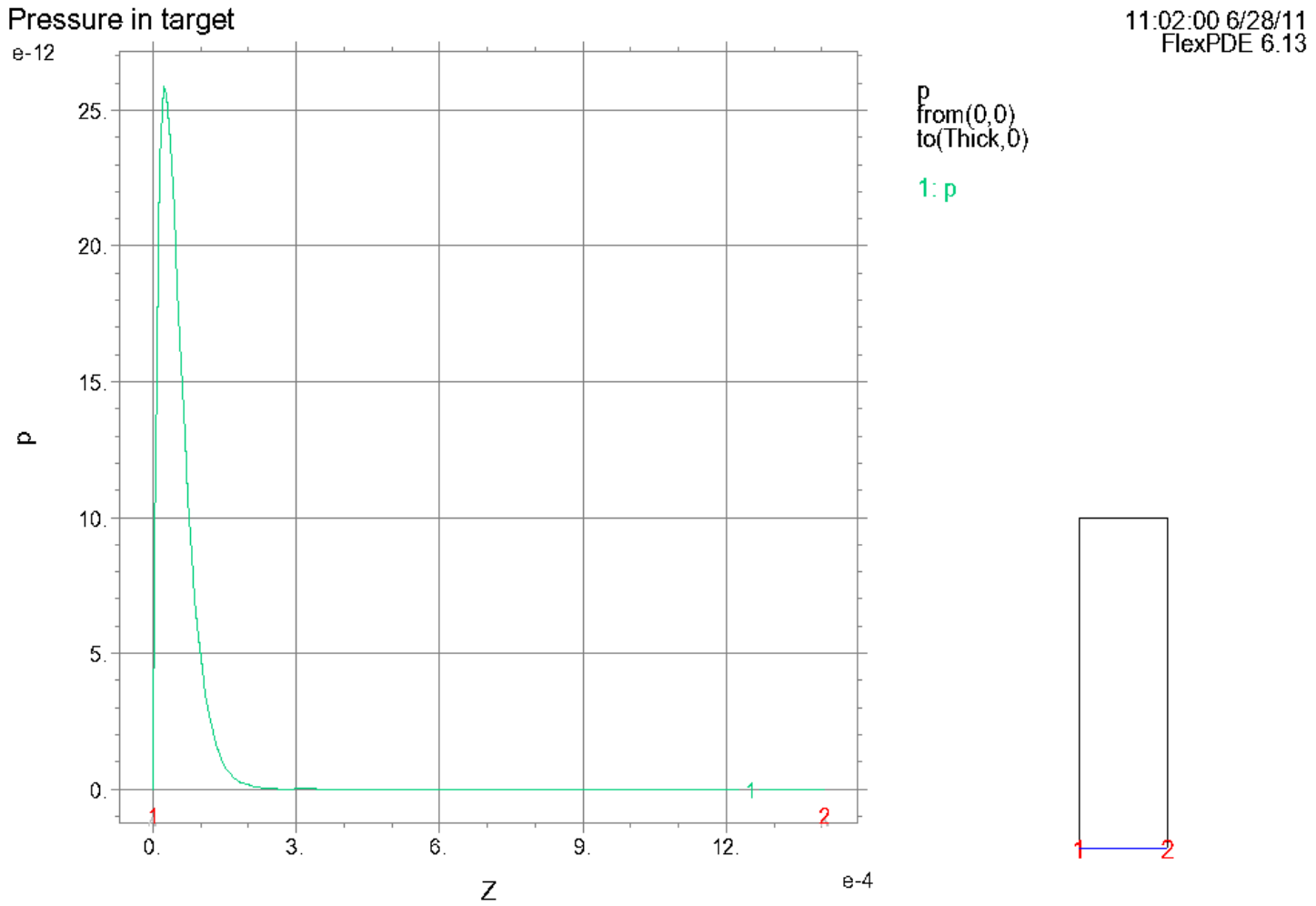

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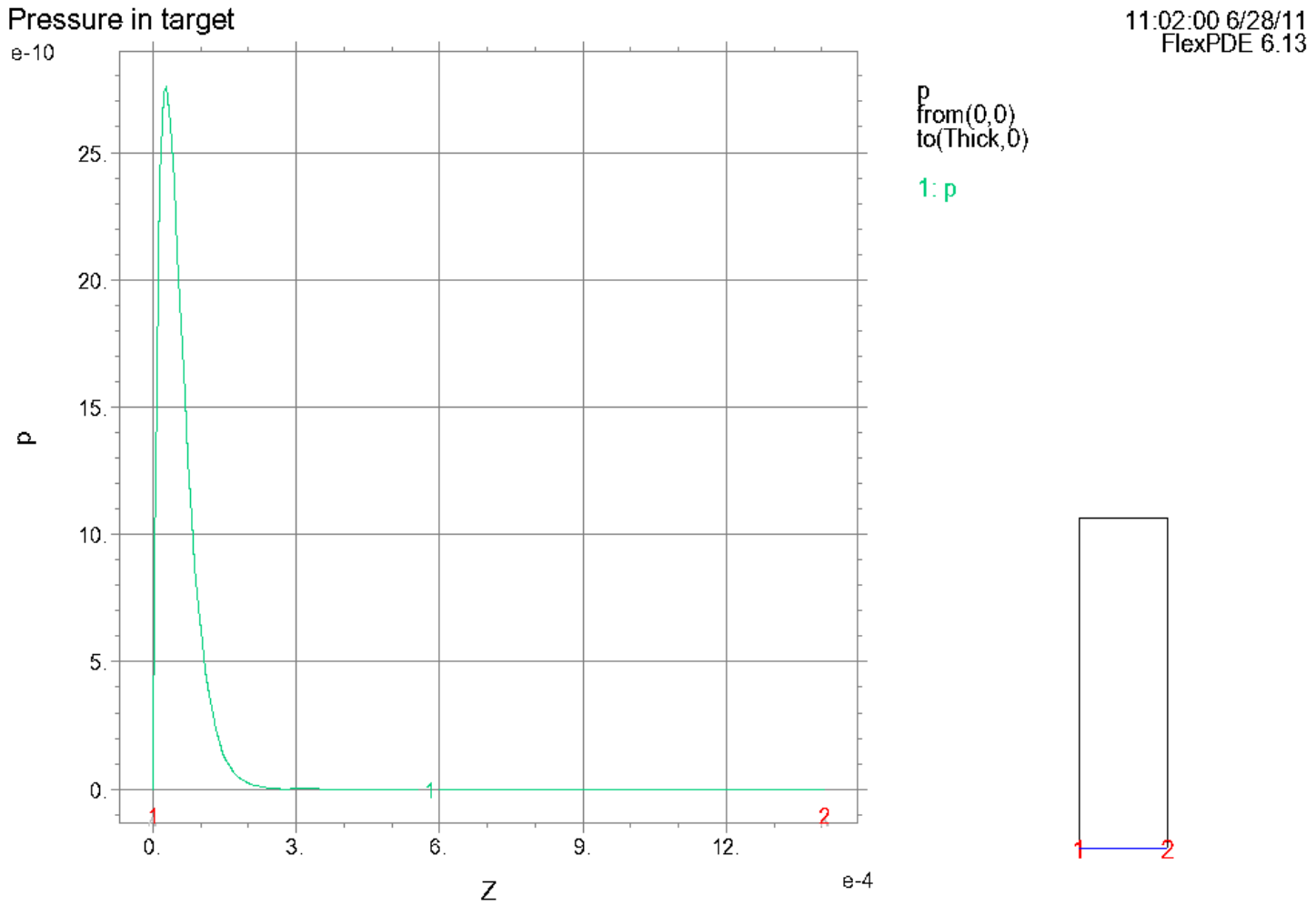

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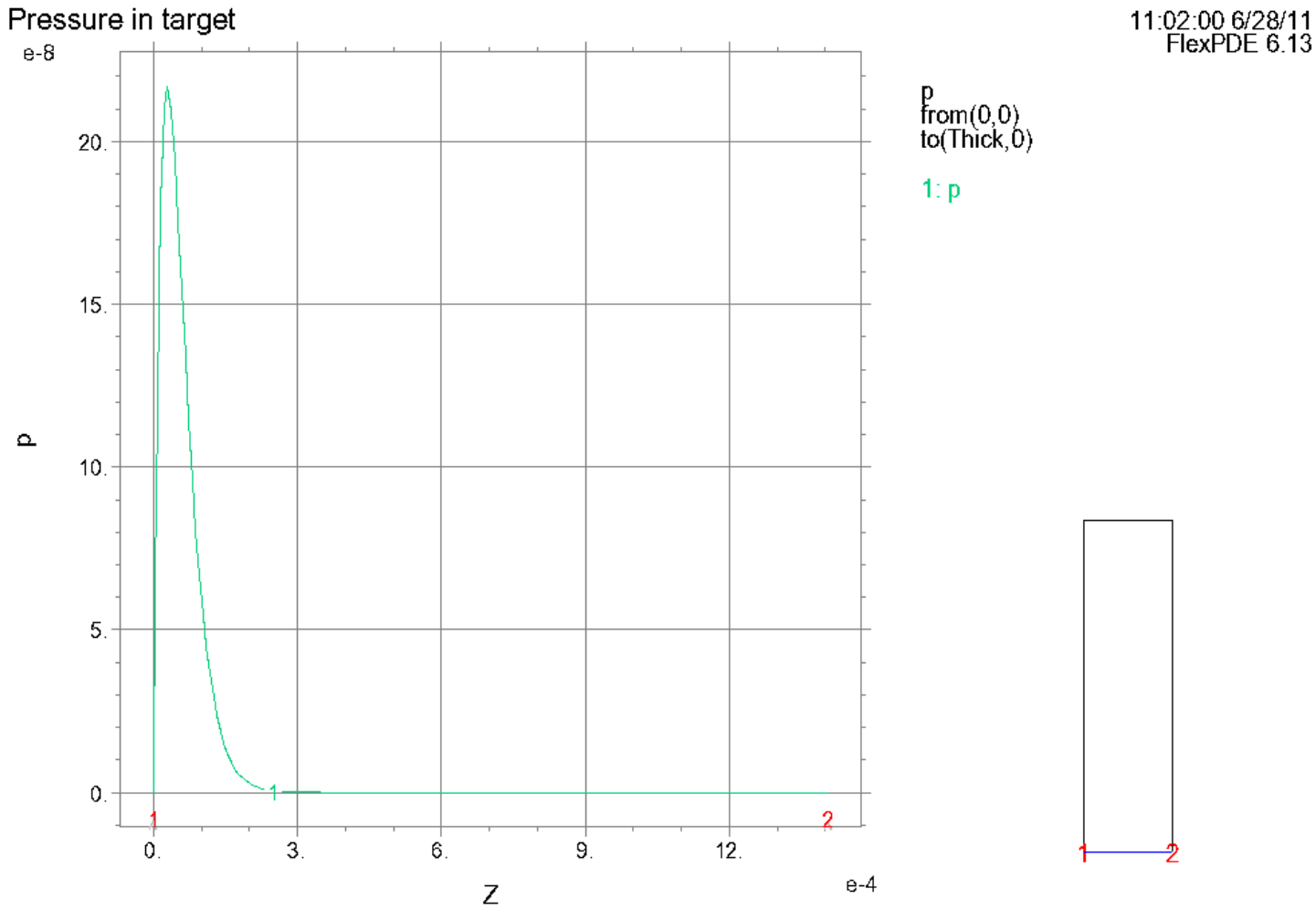

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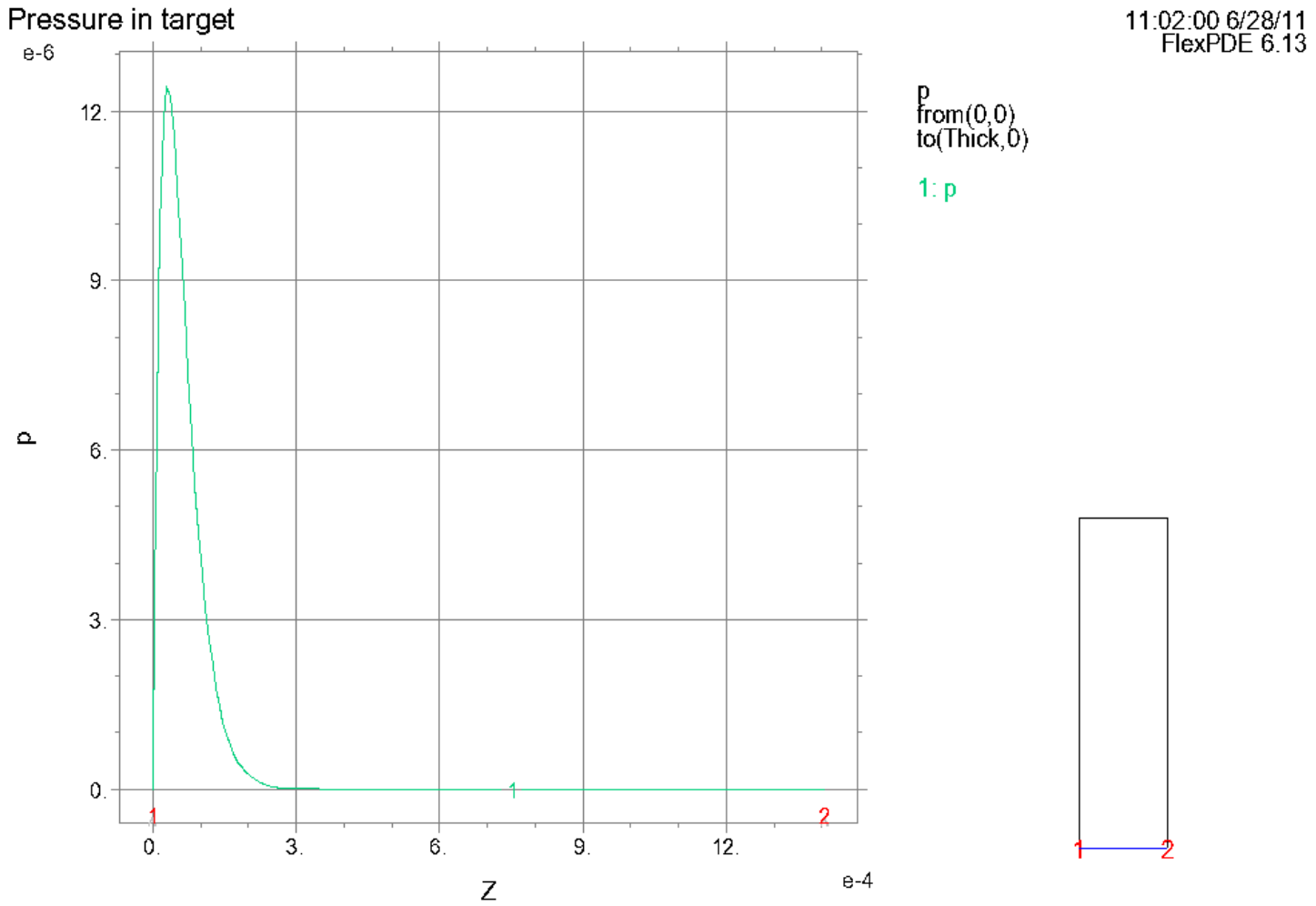

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Surf_Integral= 6.370467e-18

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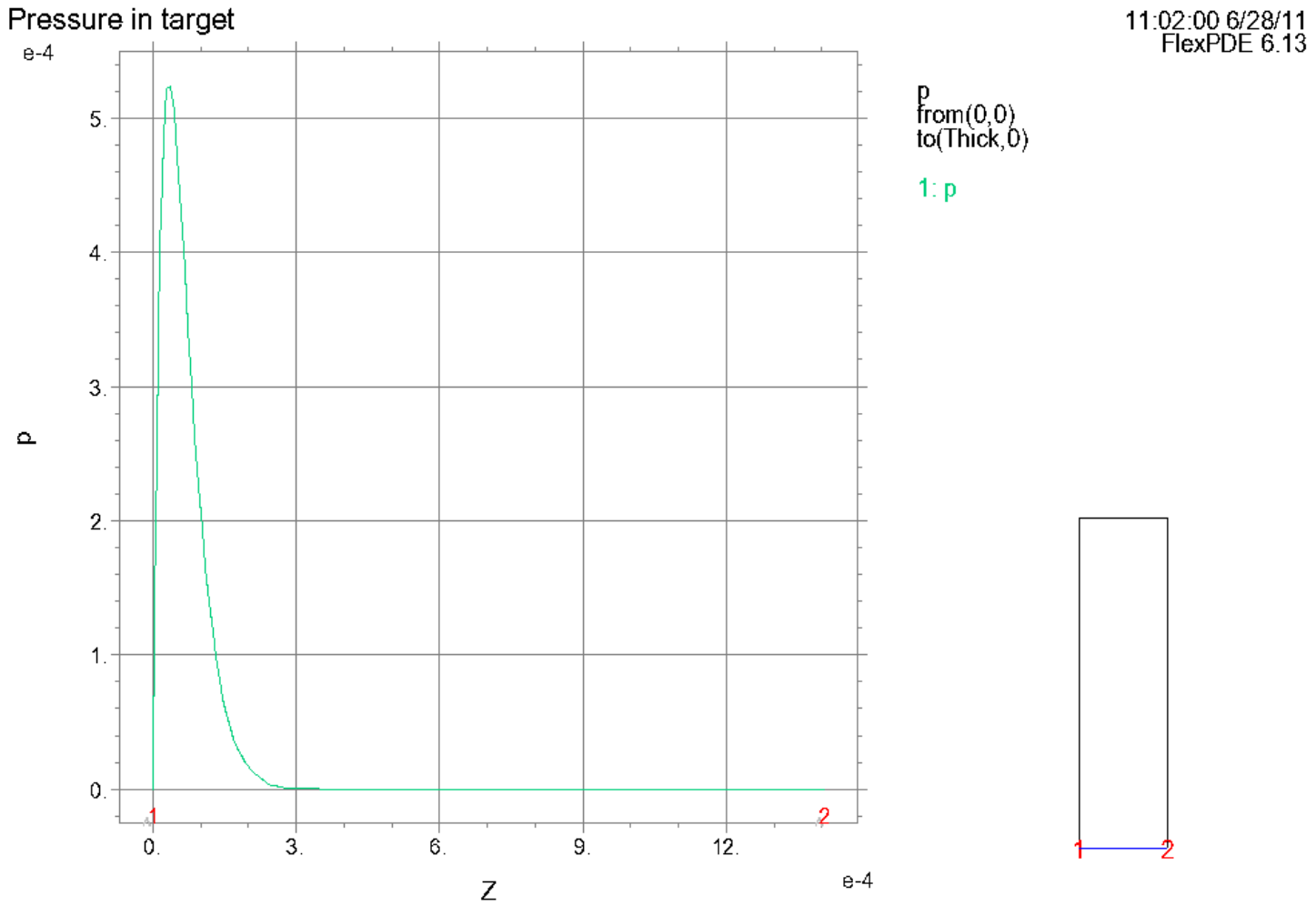

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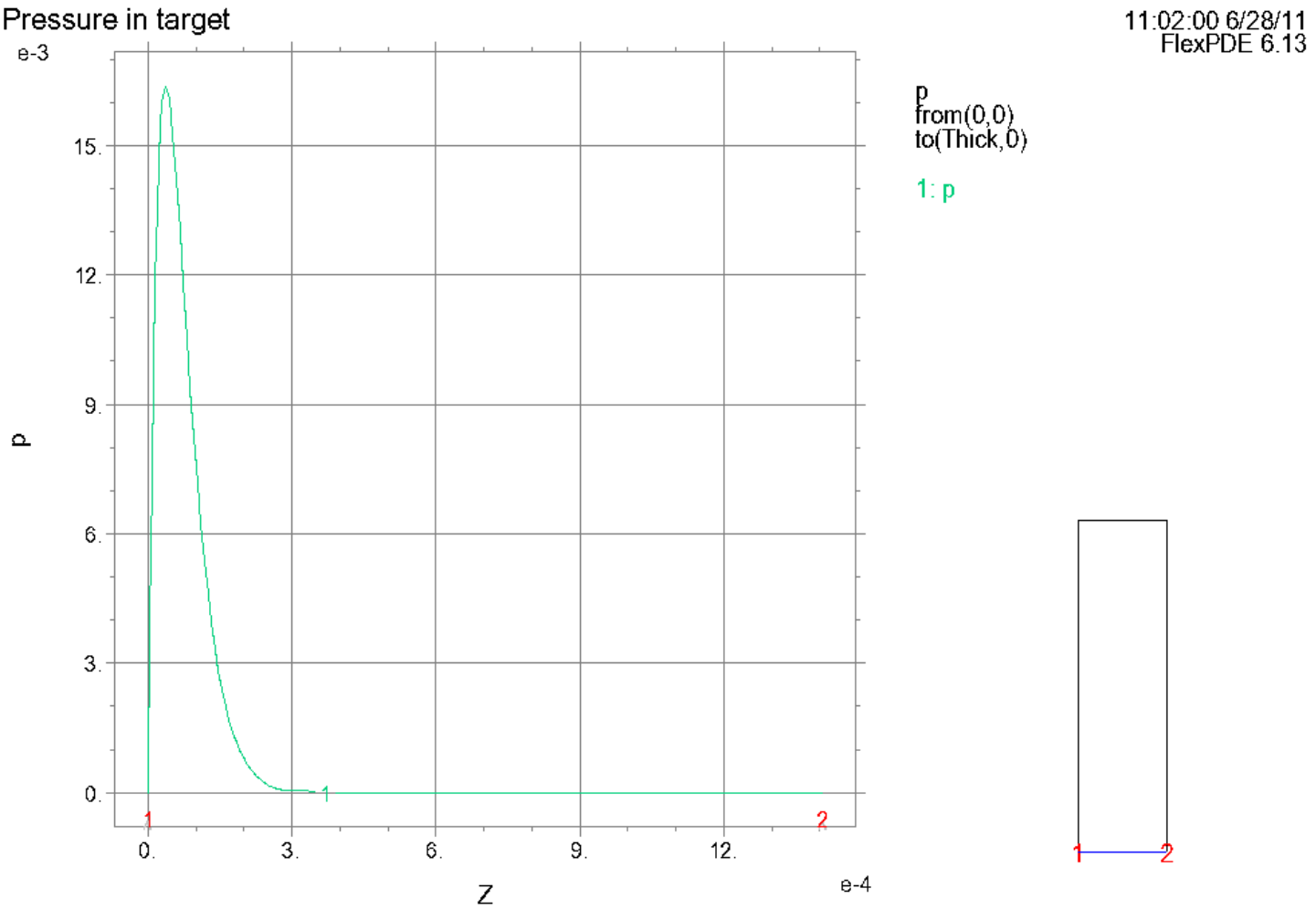

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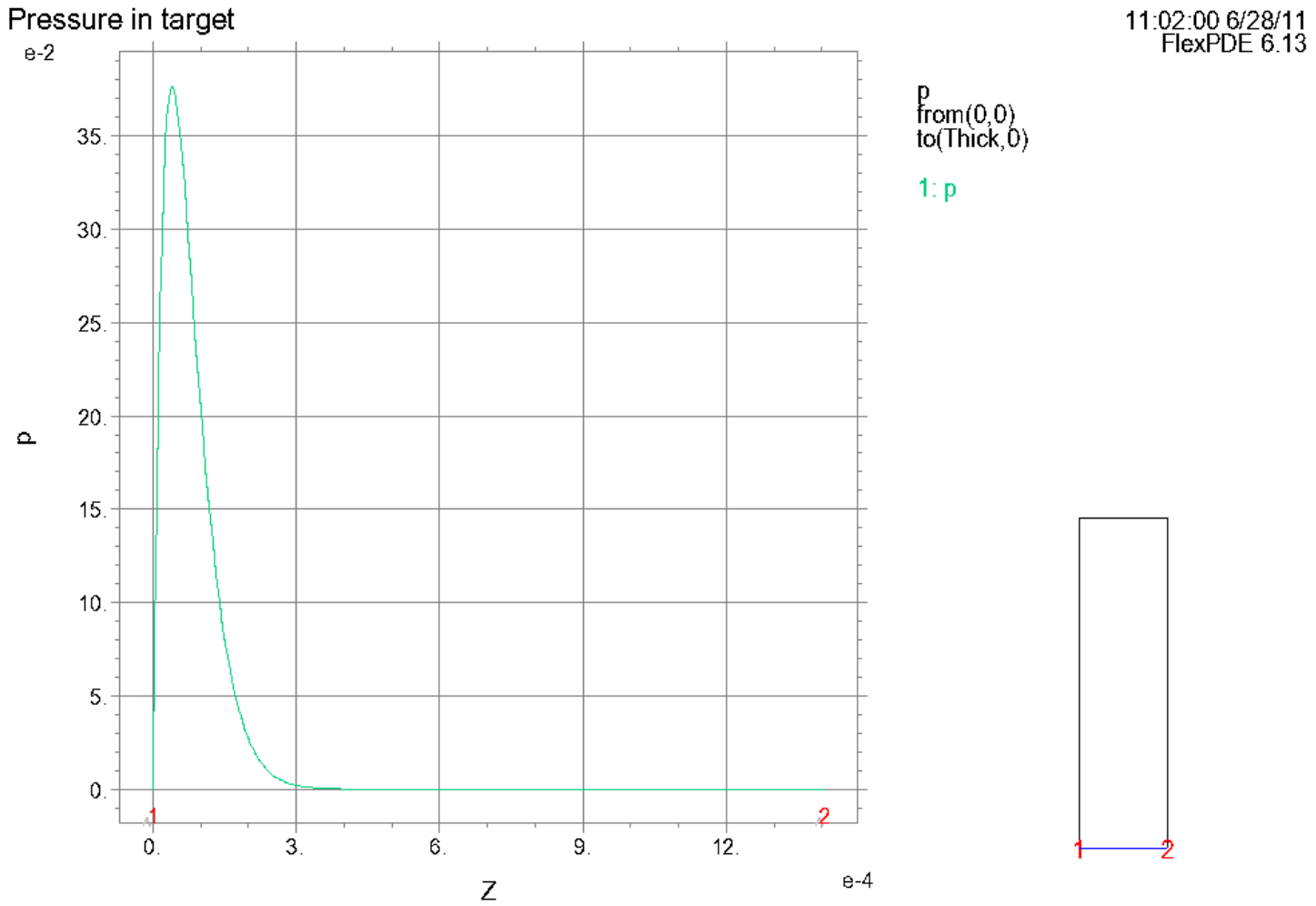

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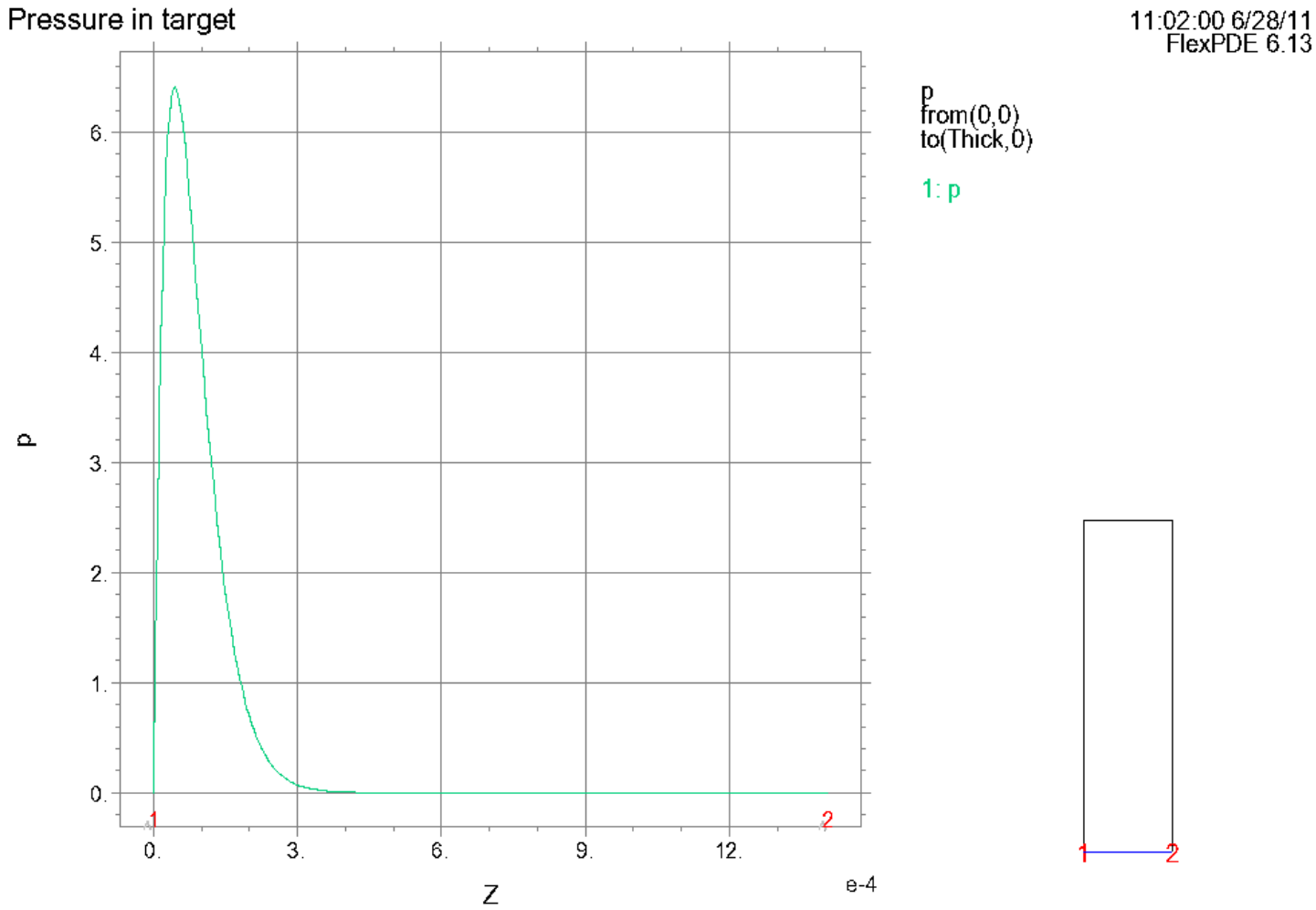

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Surf_Integral= 4.620016e-12

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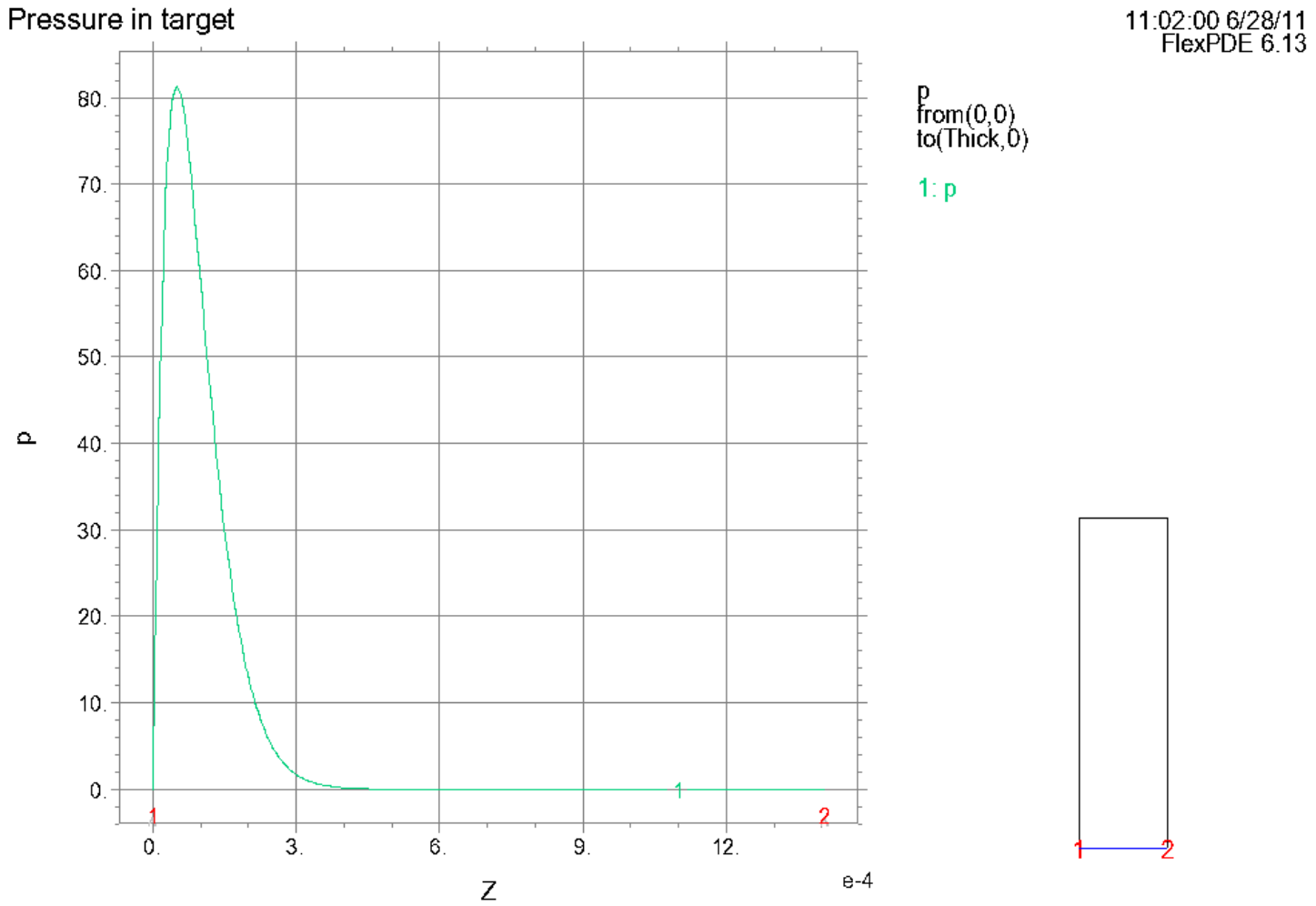

w_target_23062011: Cycle=5463 Time= 4.0000e-12 dt= 1.0848e-15 P3 Nodes=22814 Cells=6374 RMS Err= 4.8e-8
Surf_Integral= 6.496006e-11

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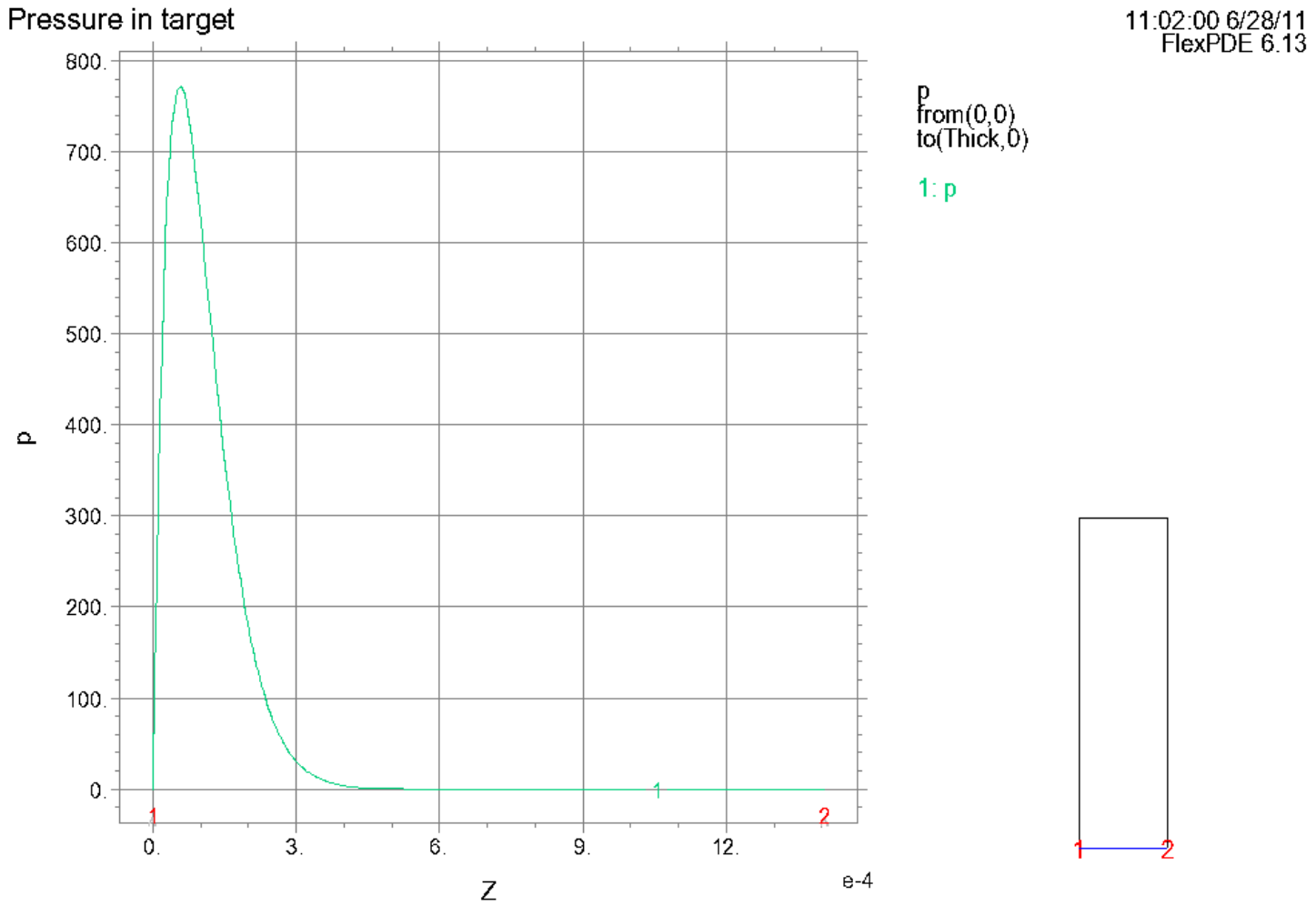

w_target_23062011: Cycle=5788 Time= 4.4000e-12 dt= 1.3657e-15 P3 Nodes=22814 Cells=6374 RMS Err= 5.3e-8
Surf_Integral= 6.894320e-10

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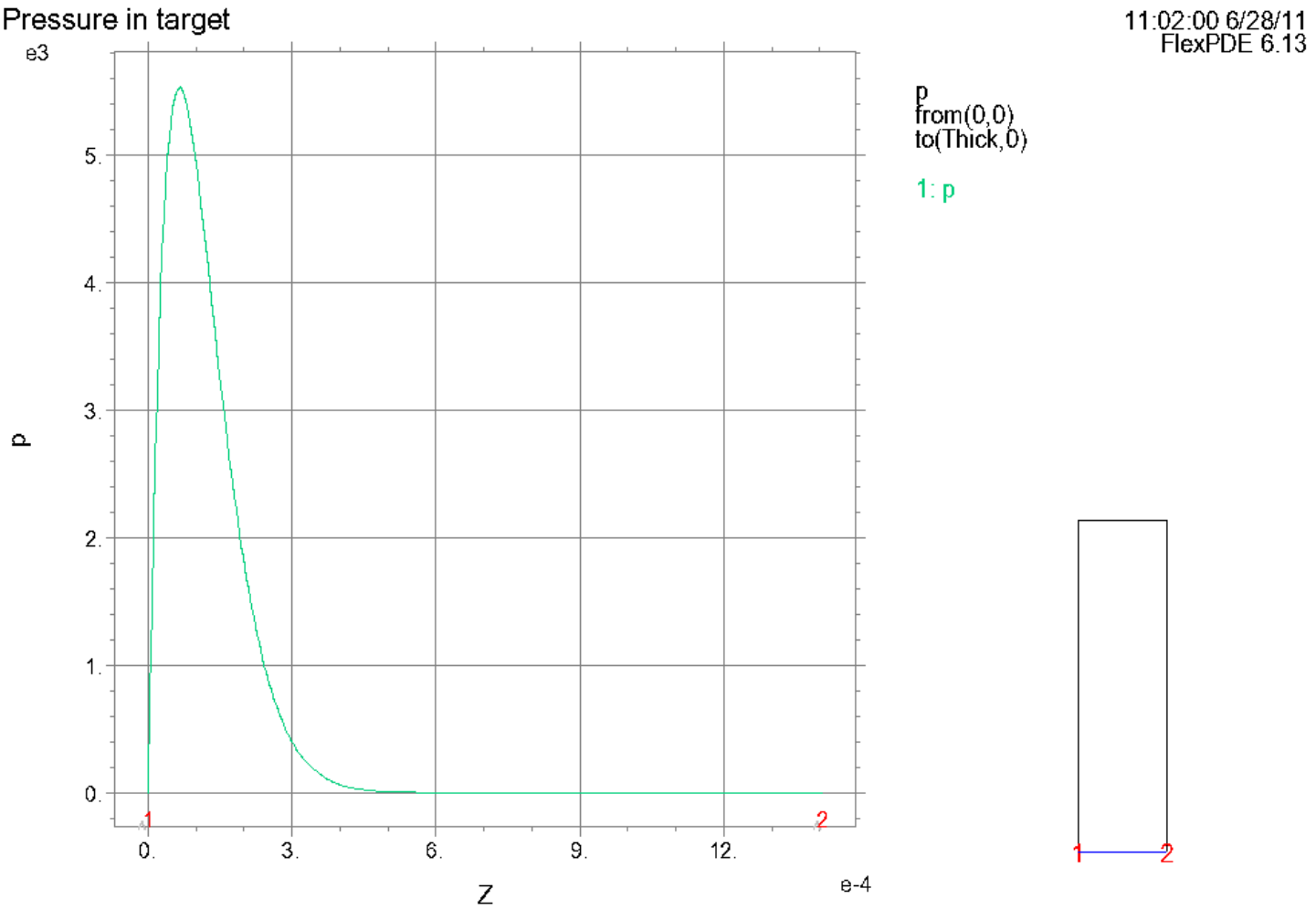

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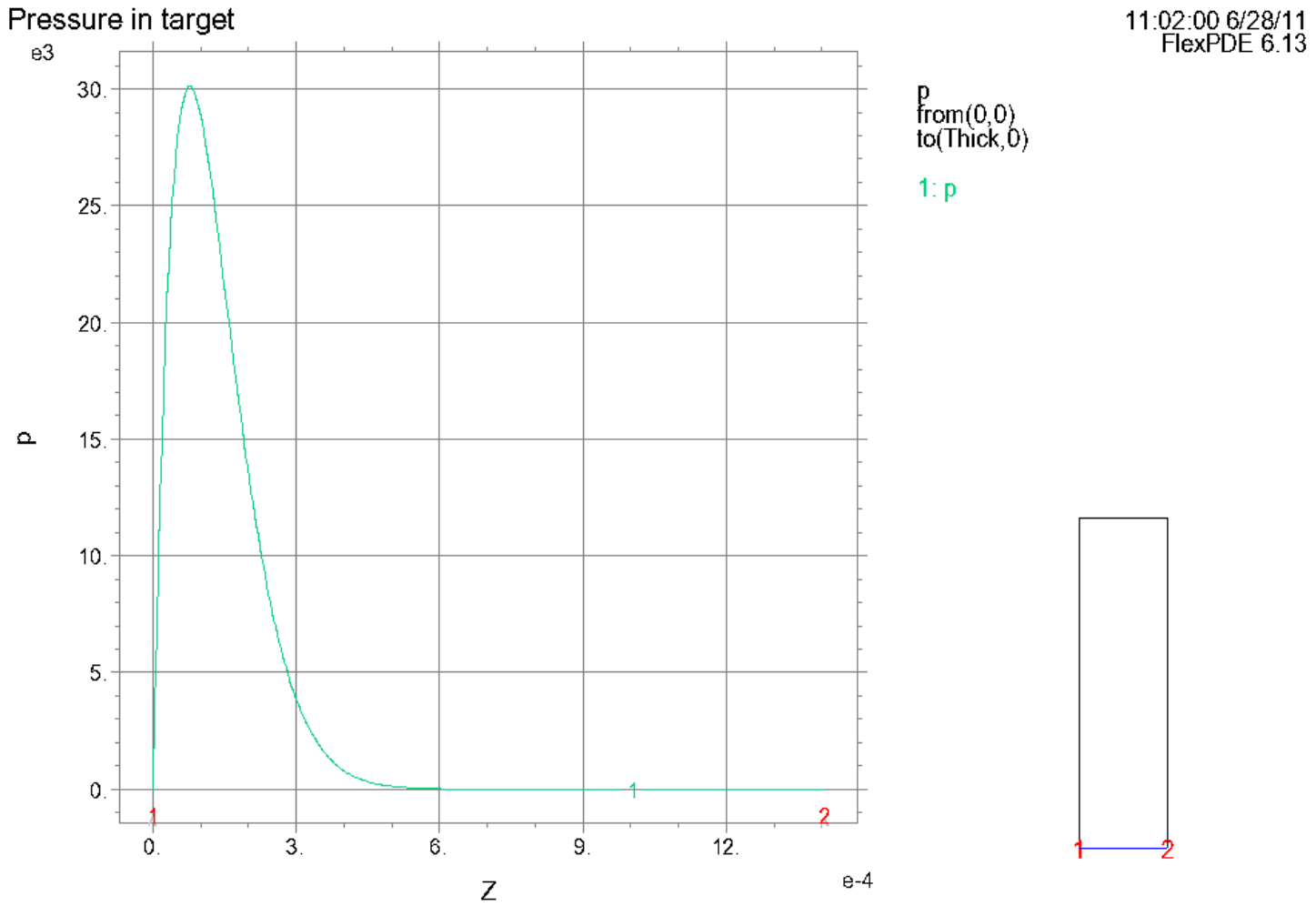

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Surf_Integral= 3.457168e-8

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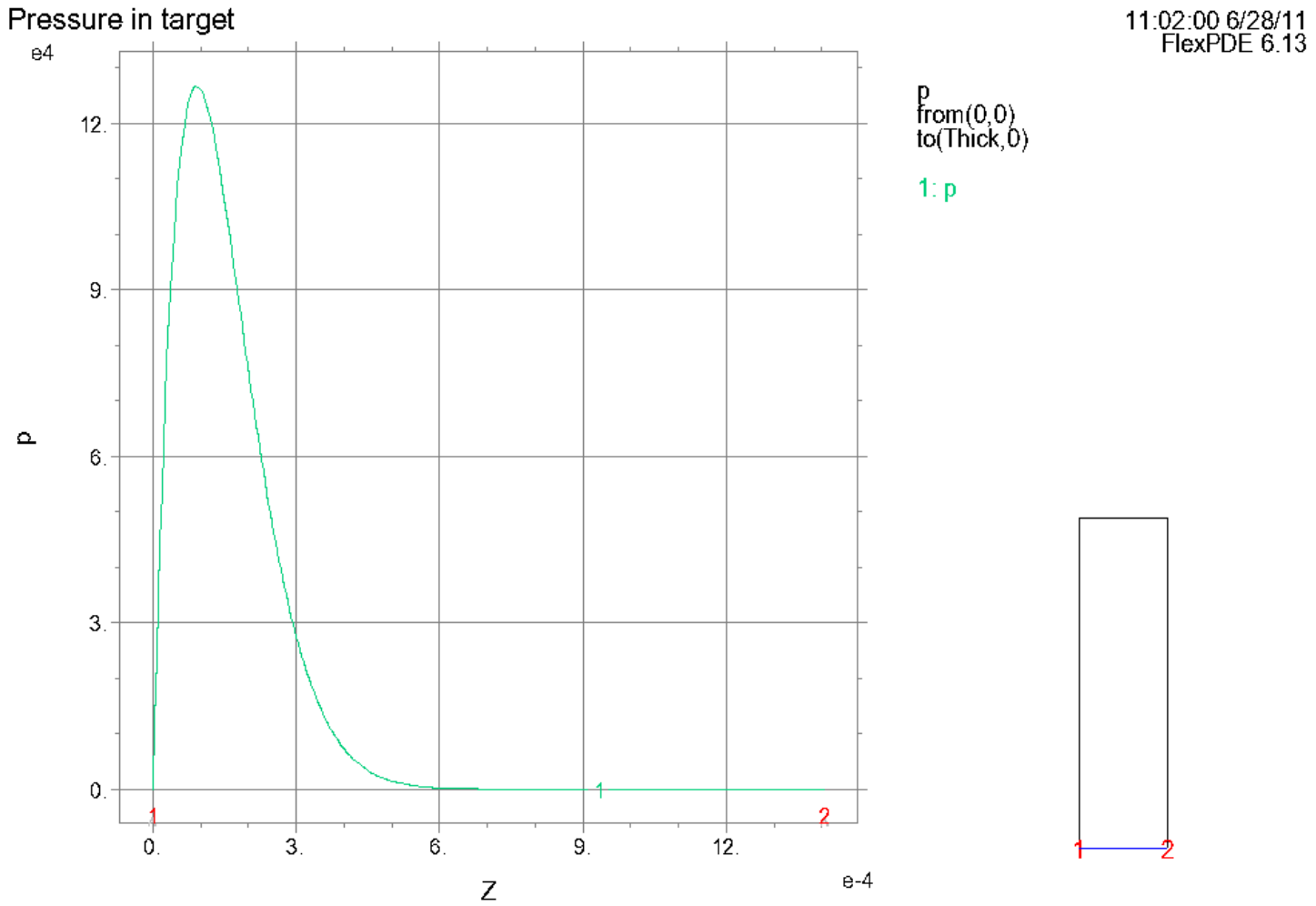

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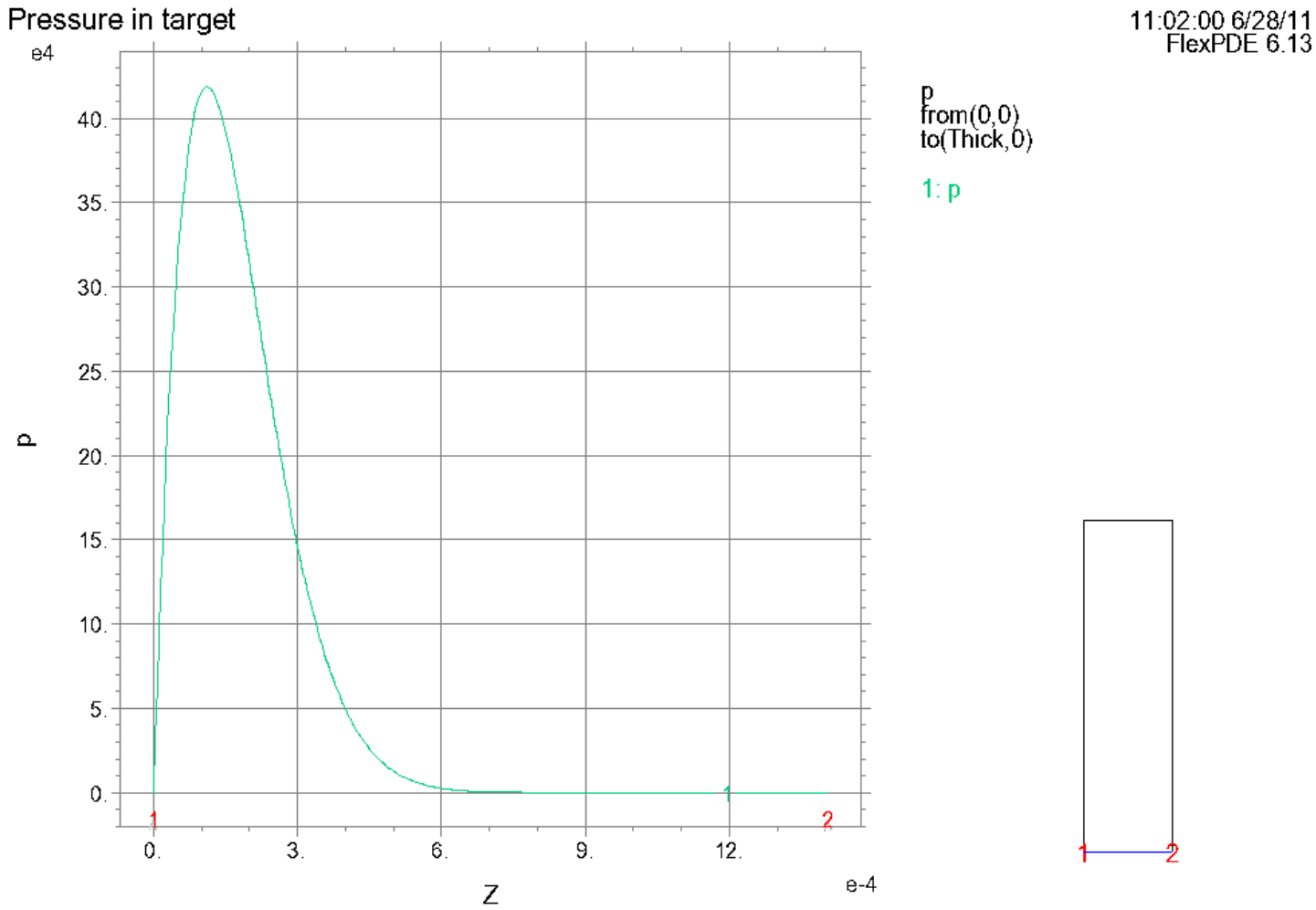

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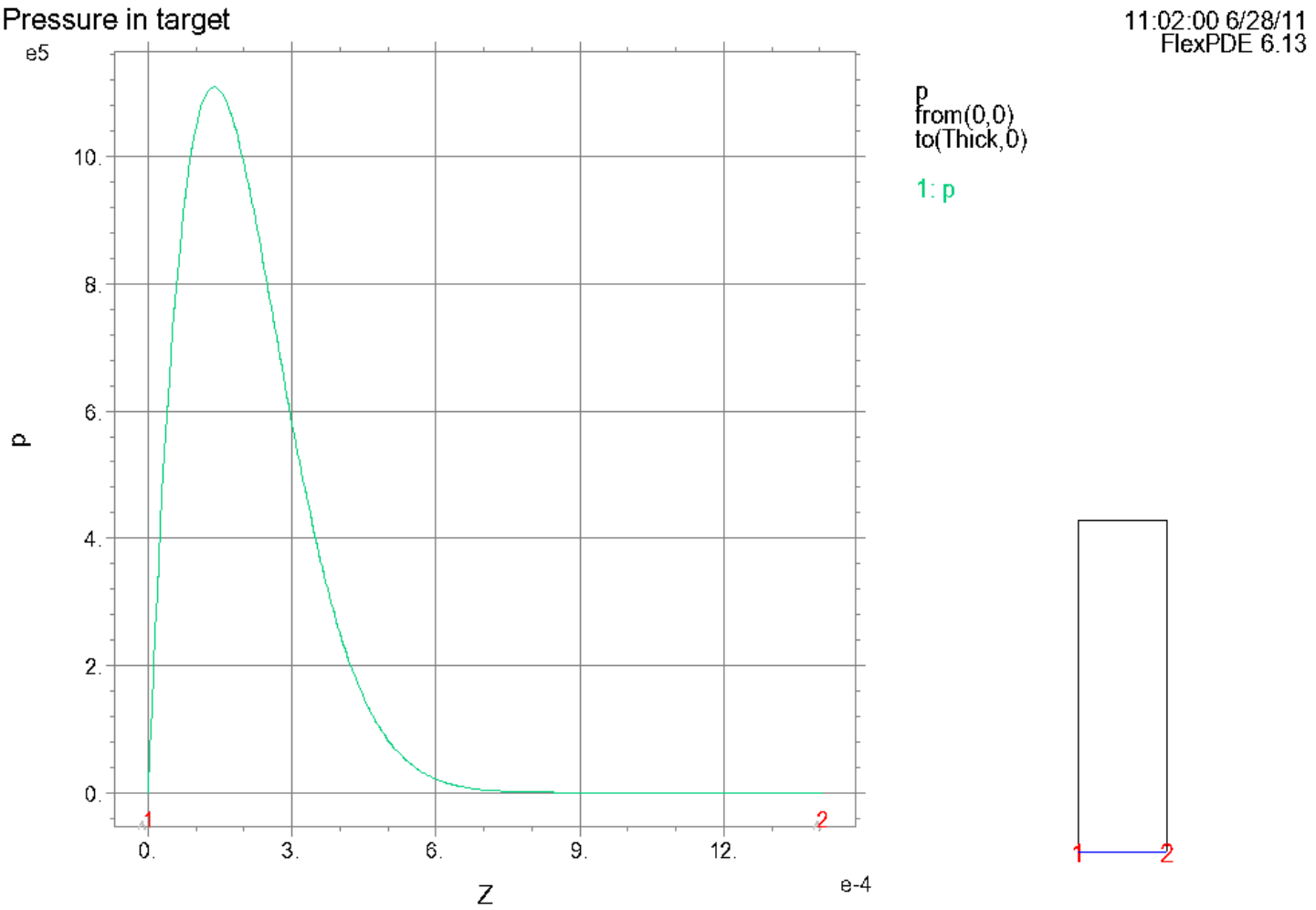

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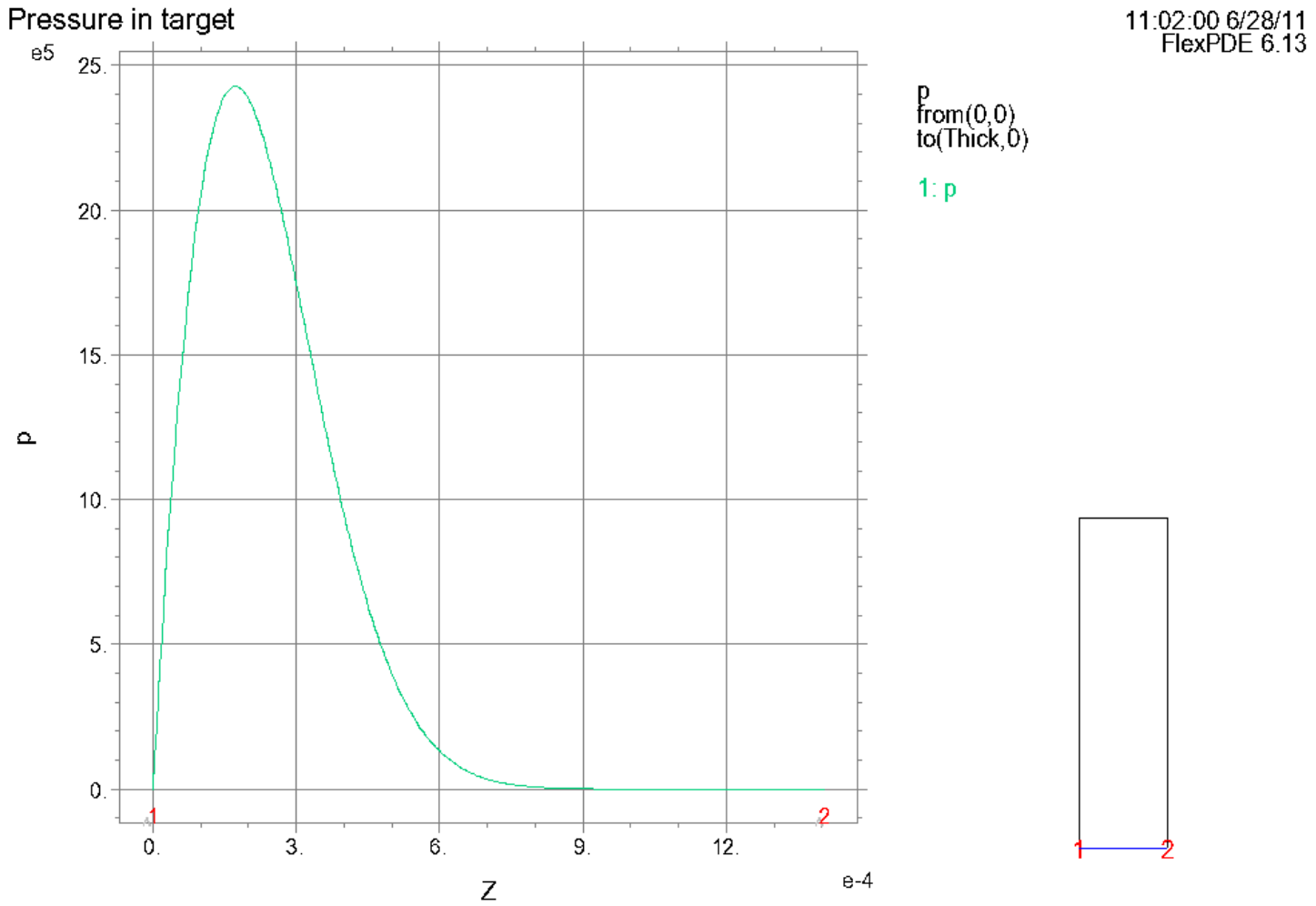

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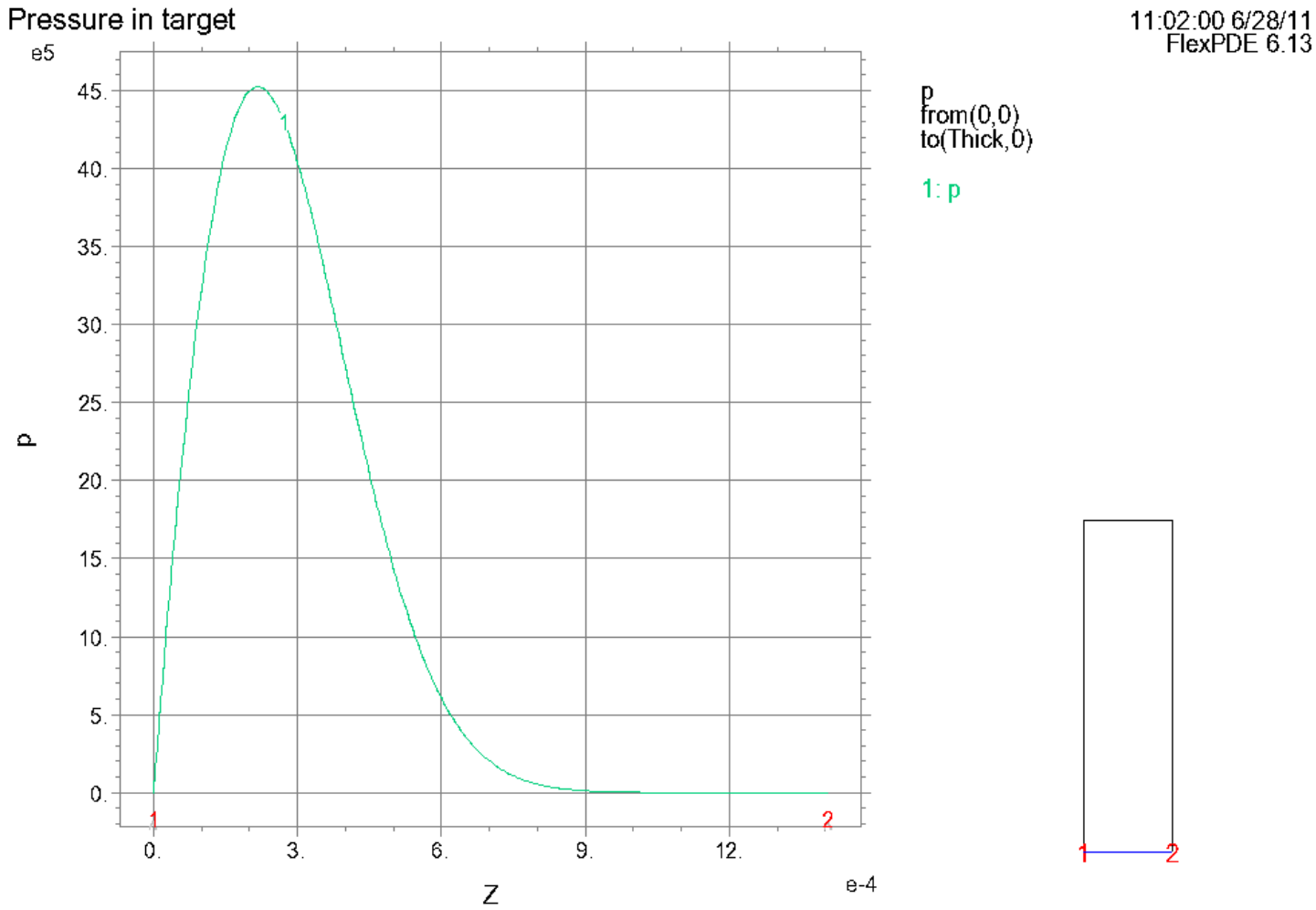

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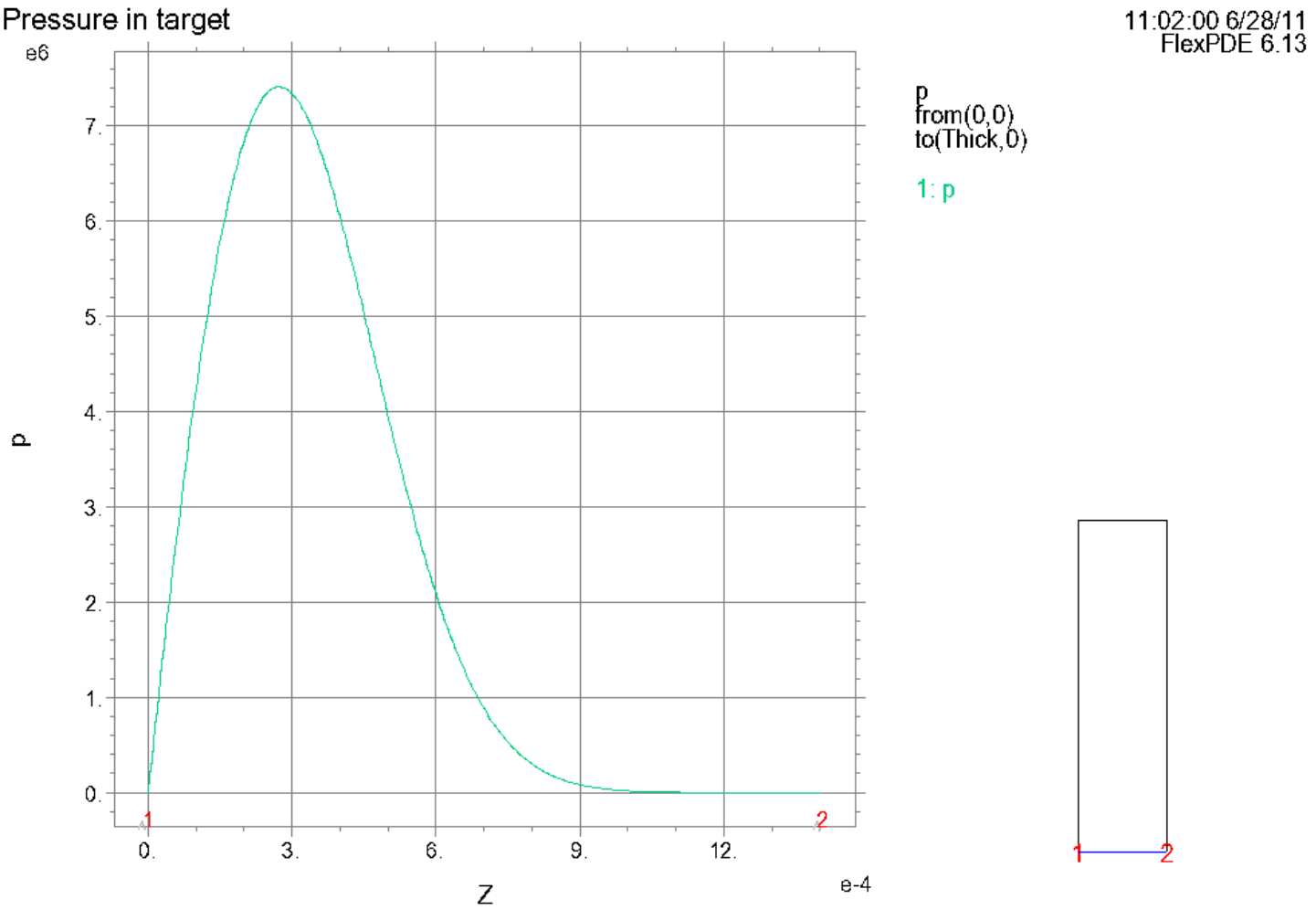

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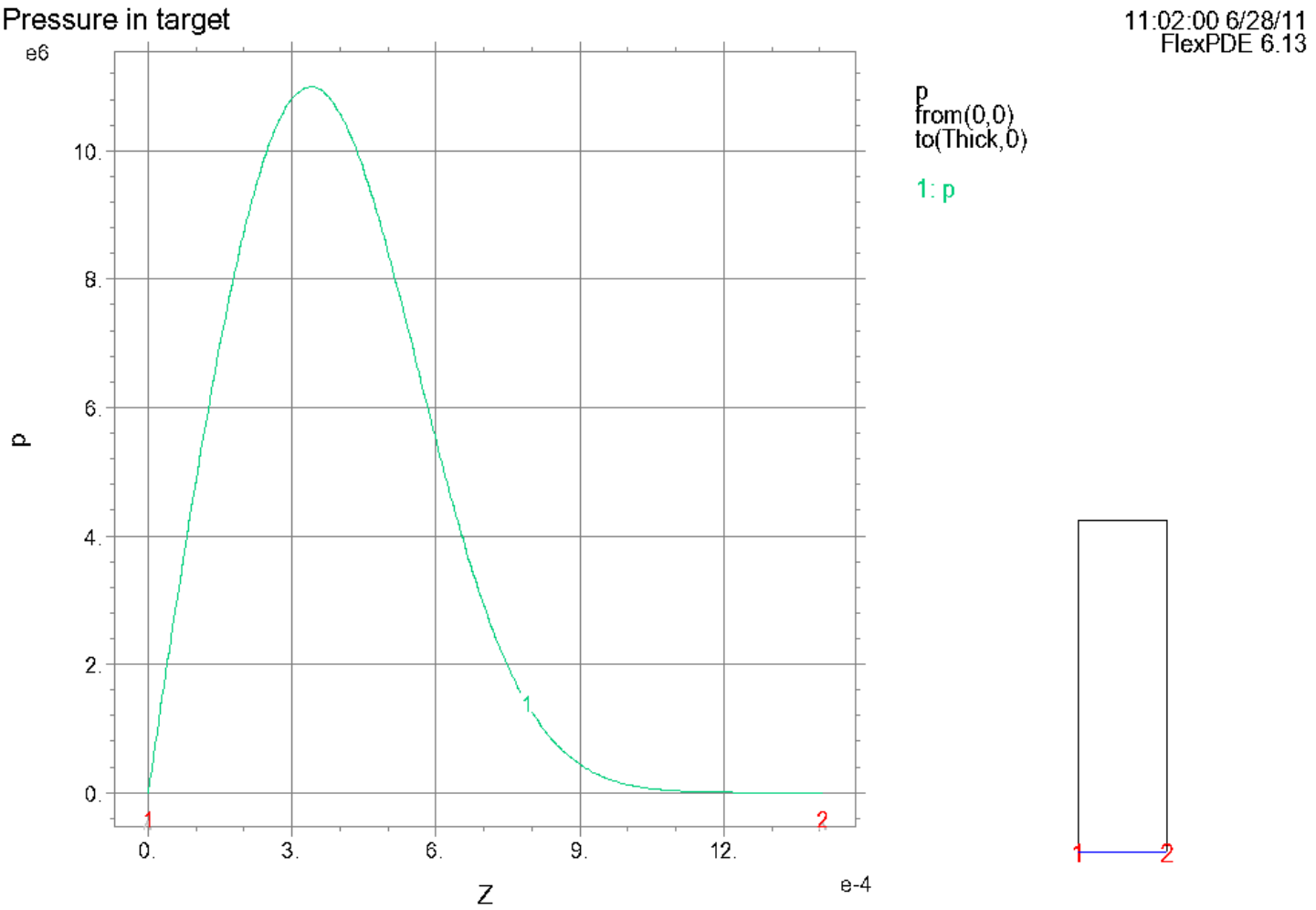

w_target_23062011: Cycle=7407 Time= 8.0000e-12 dt= 3.0685e-15 P3 Nodes=21287 Cells=5939 RMS Err= 4.9e-8
Surf_Integral= 3.400003e-5

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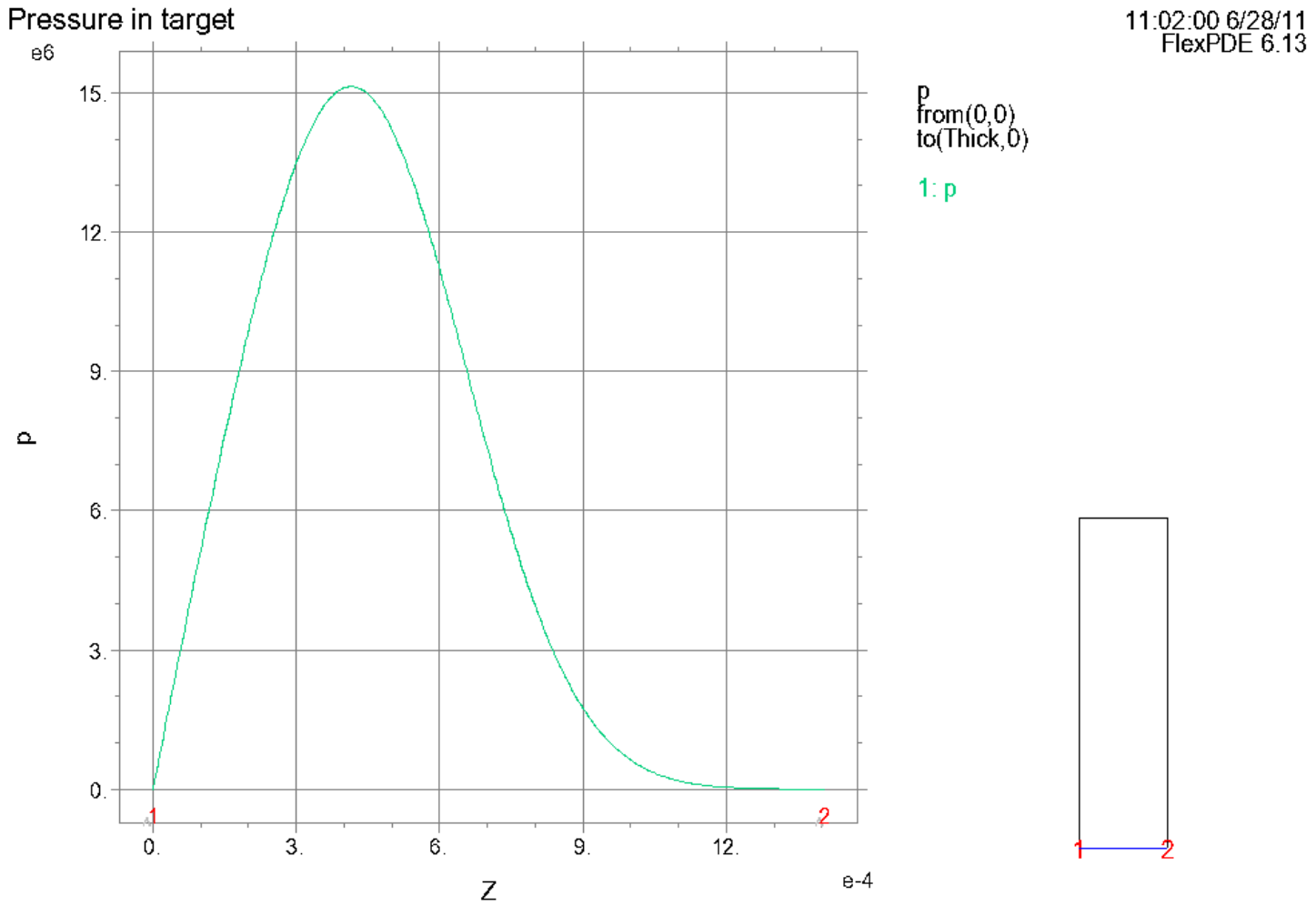

w_target_23062011: Cycle=7514 Time= 8.4000e-12 dt= 3.9845e-15 P3 Nodes=20583 Cells=5734 RMS Err= 5.7e-8
Surf_Integral= 5.239138e-5

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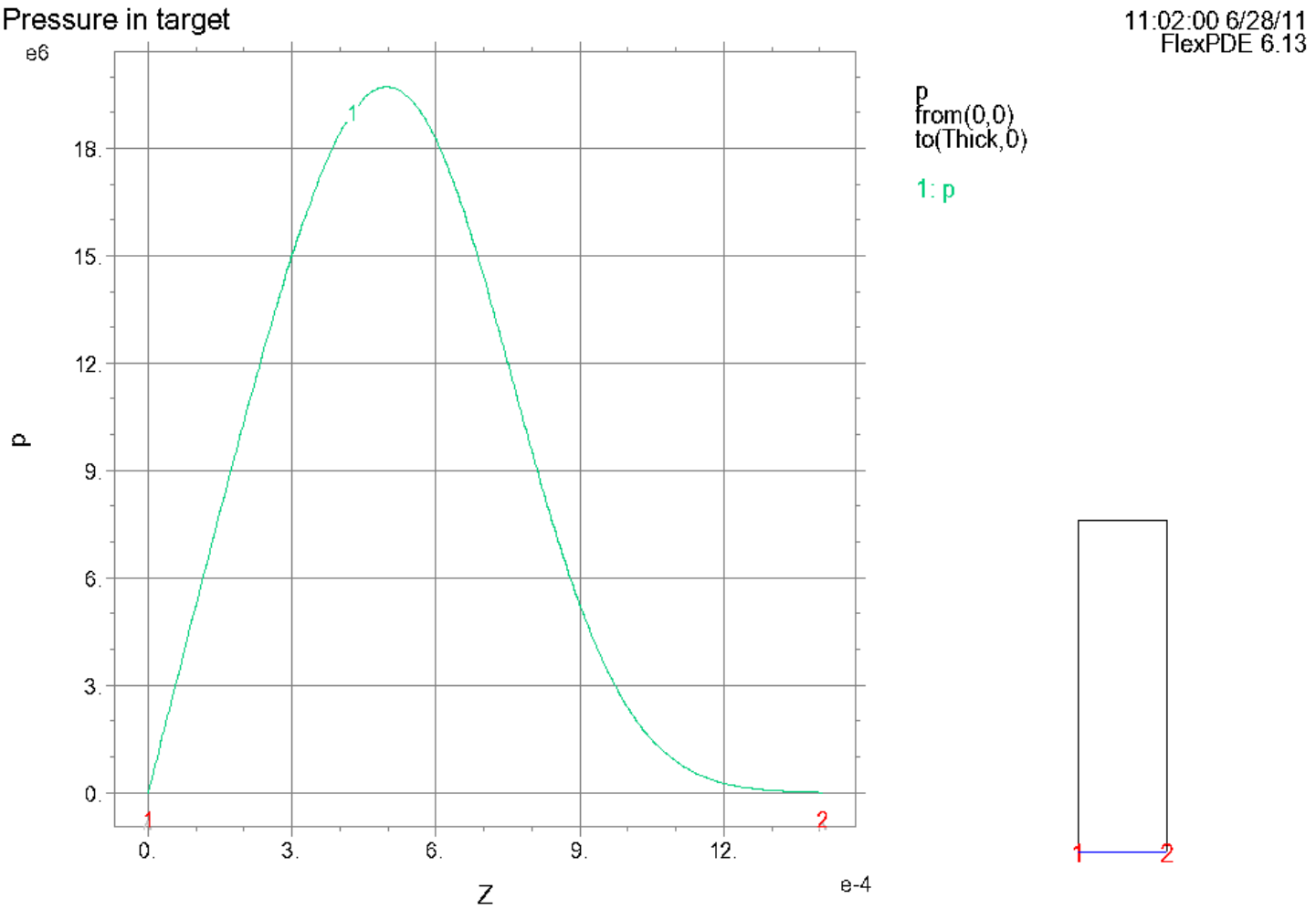

w_target_23062011: Cycle=7652 Time= 8.8000e-12 dt= 2.3305e-15 P3 Nodes=24870 Cells=6847 RMS Err= 3.8e-8
Surf_Integral= 7.552412e-5

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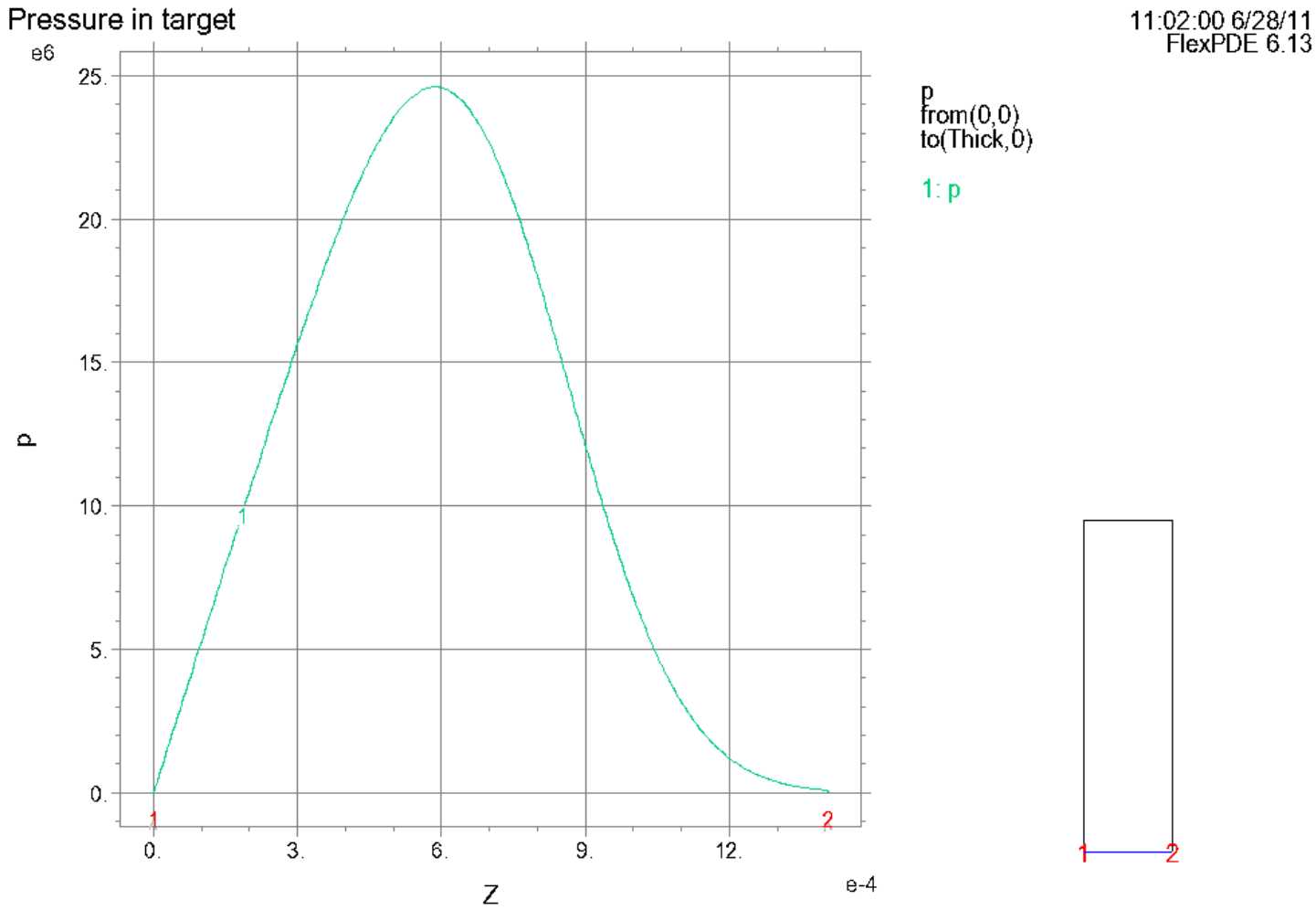

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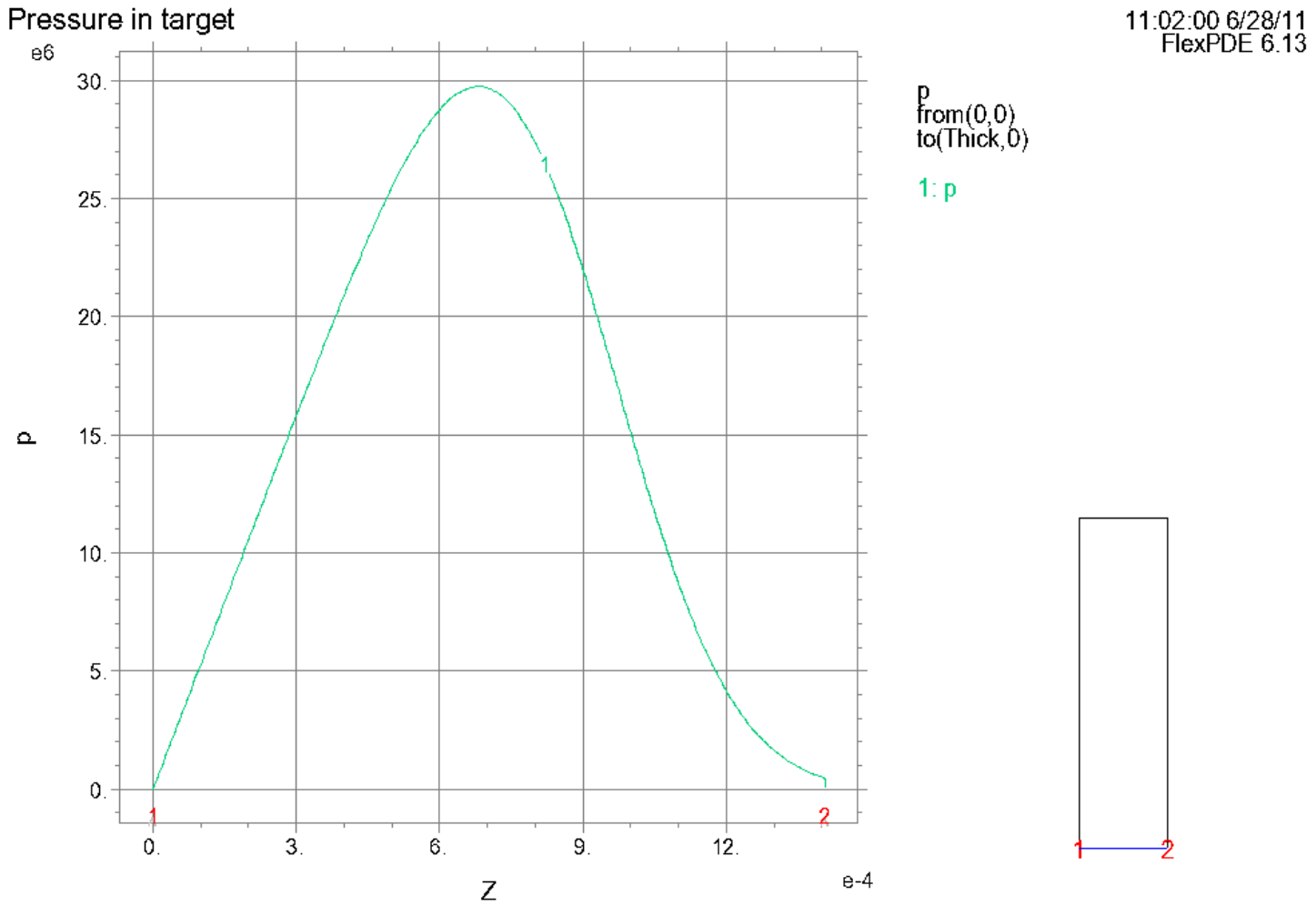

w_target_23062011: Cycle=8138 Time= 9.6000e-12 dt= 8.4152e-16 P3 Nodes=518128 Cells=134775 RMS Err= 3.2e-8
Surf_Integral= 1.359266e-4

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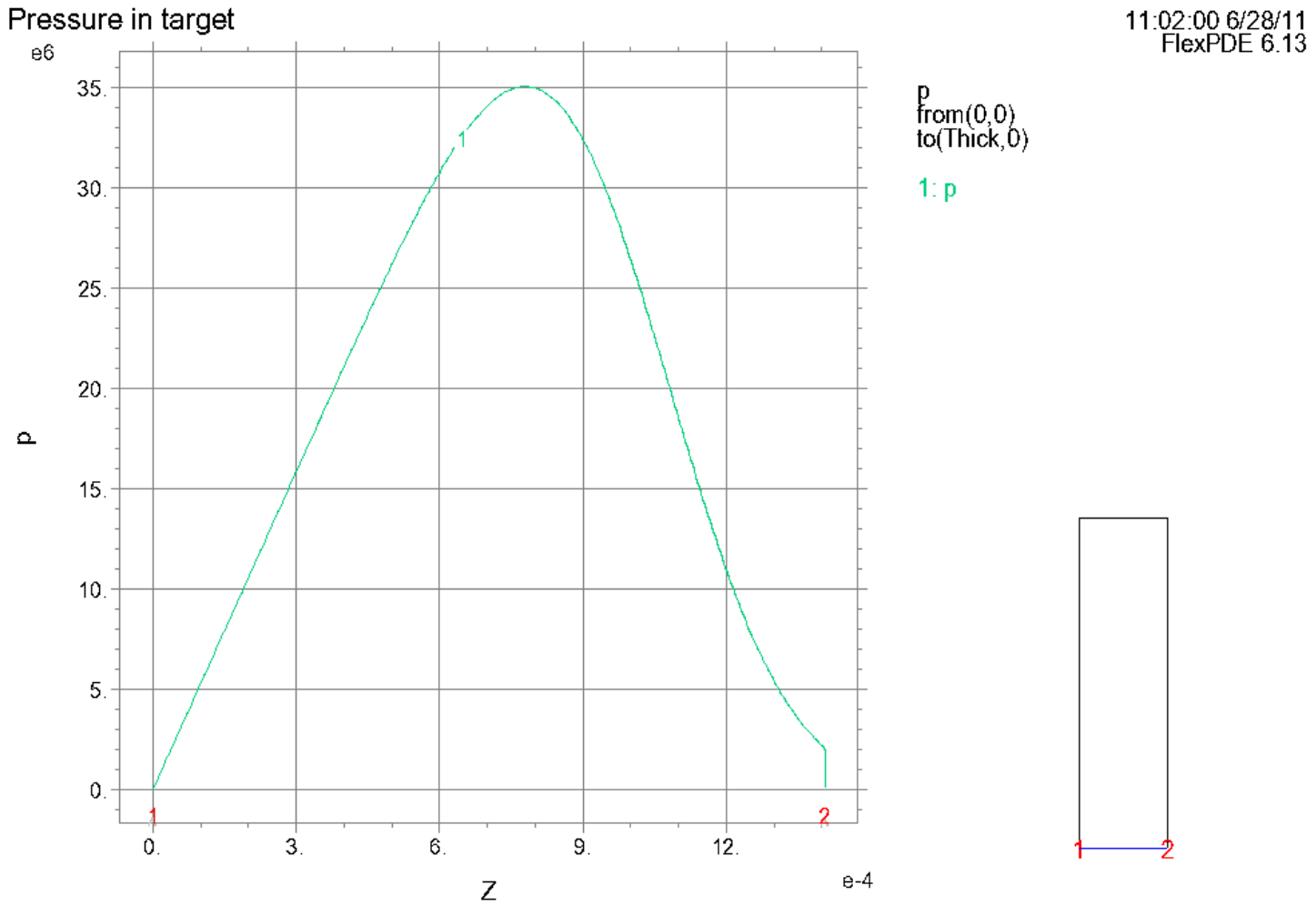

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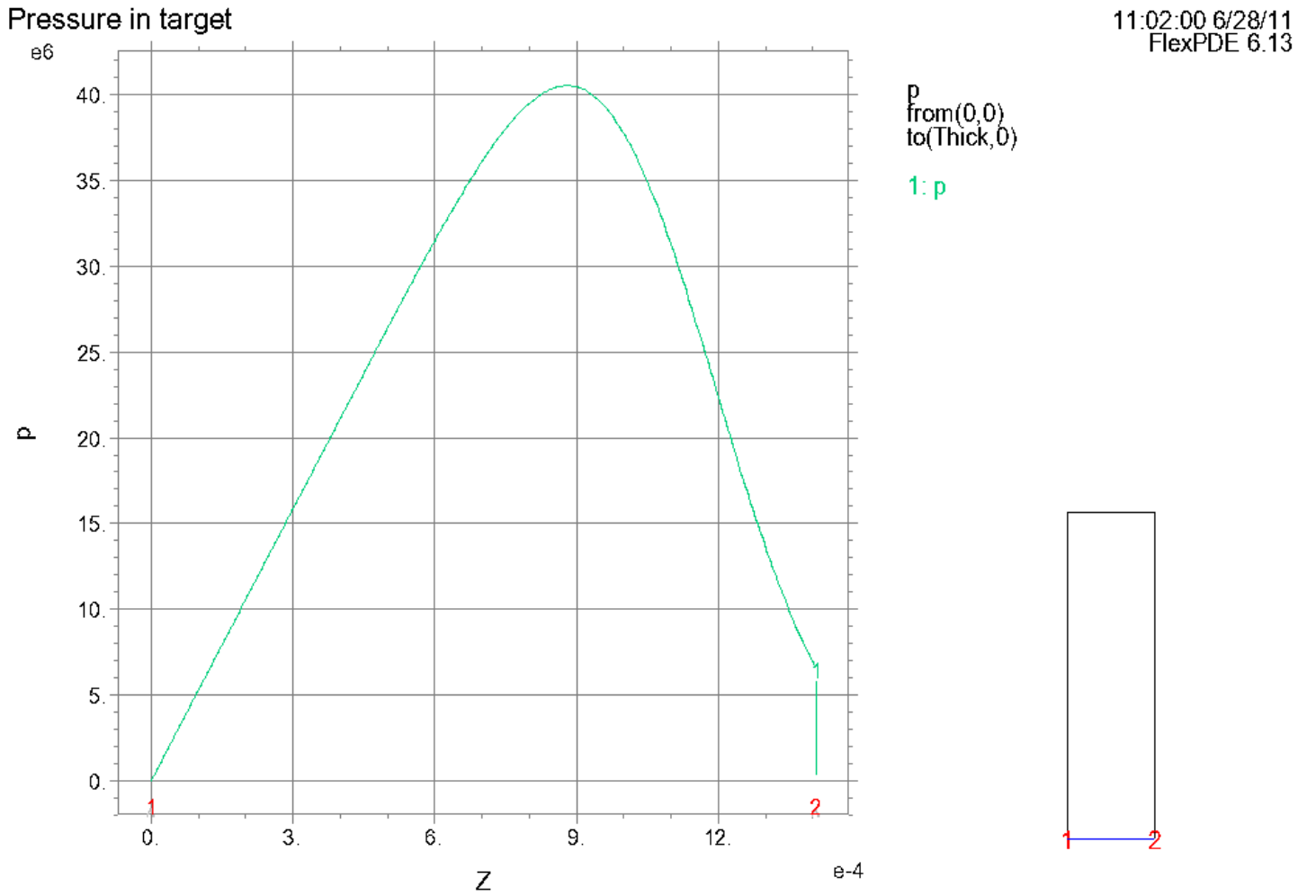

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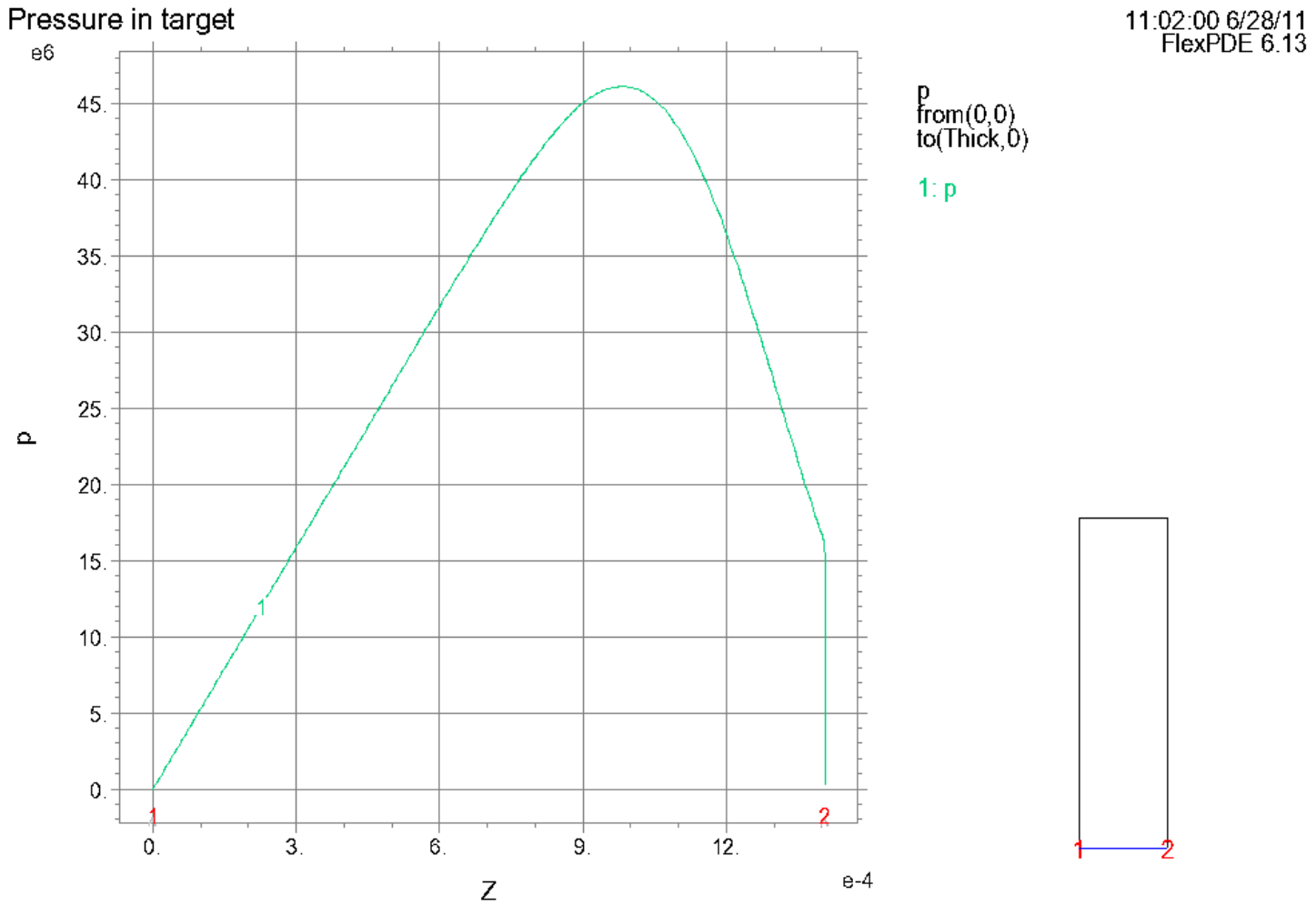

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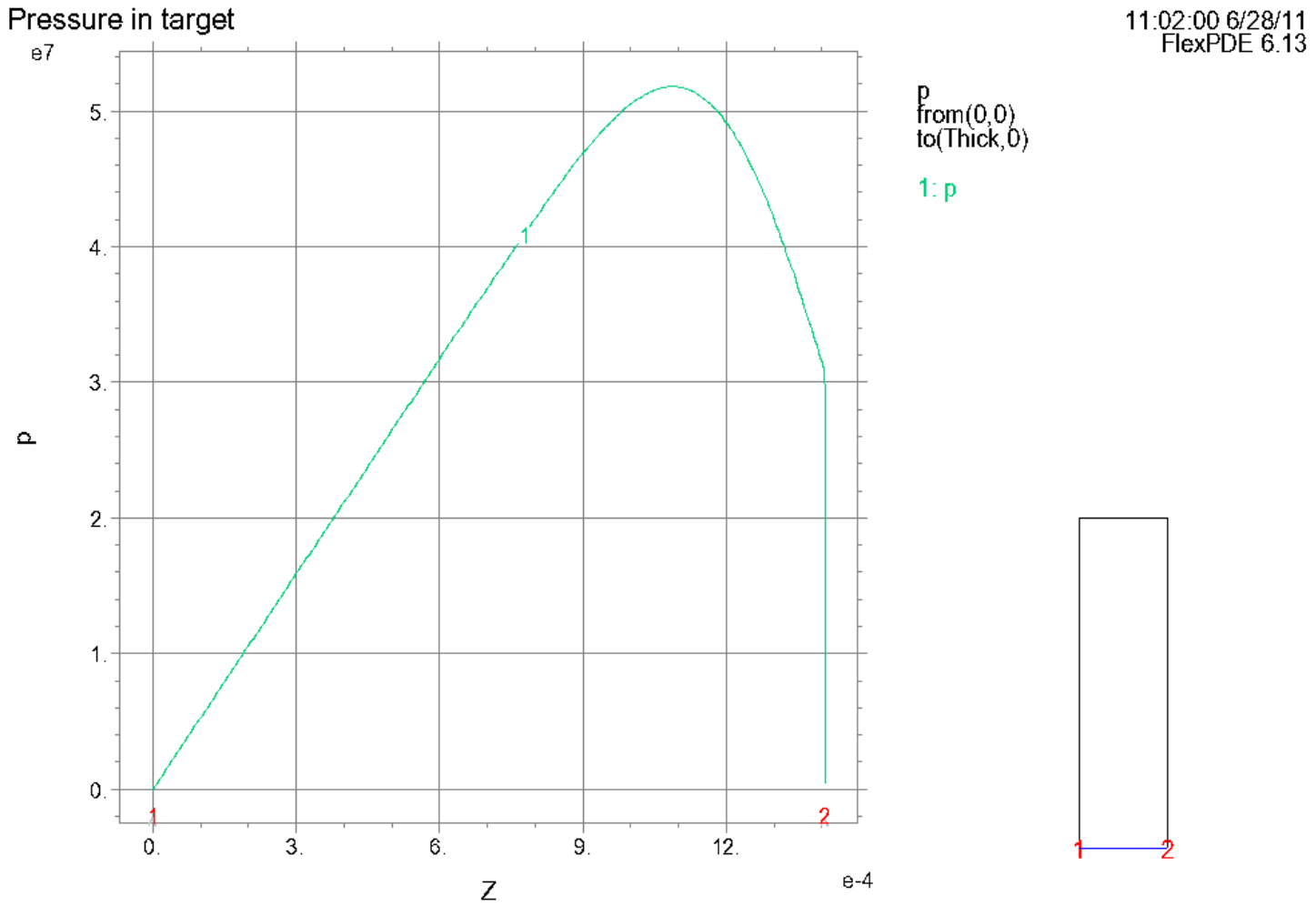

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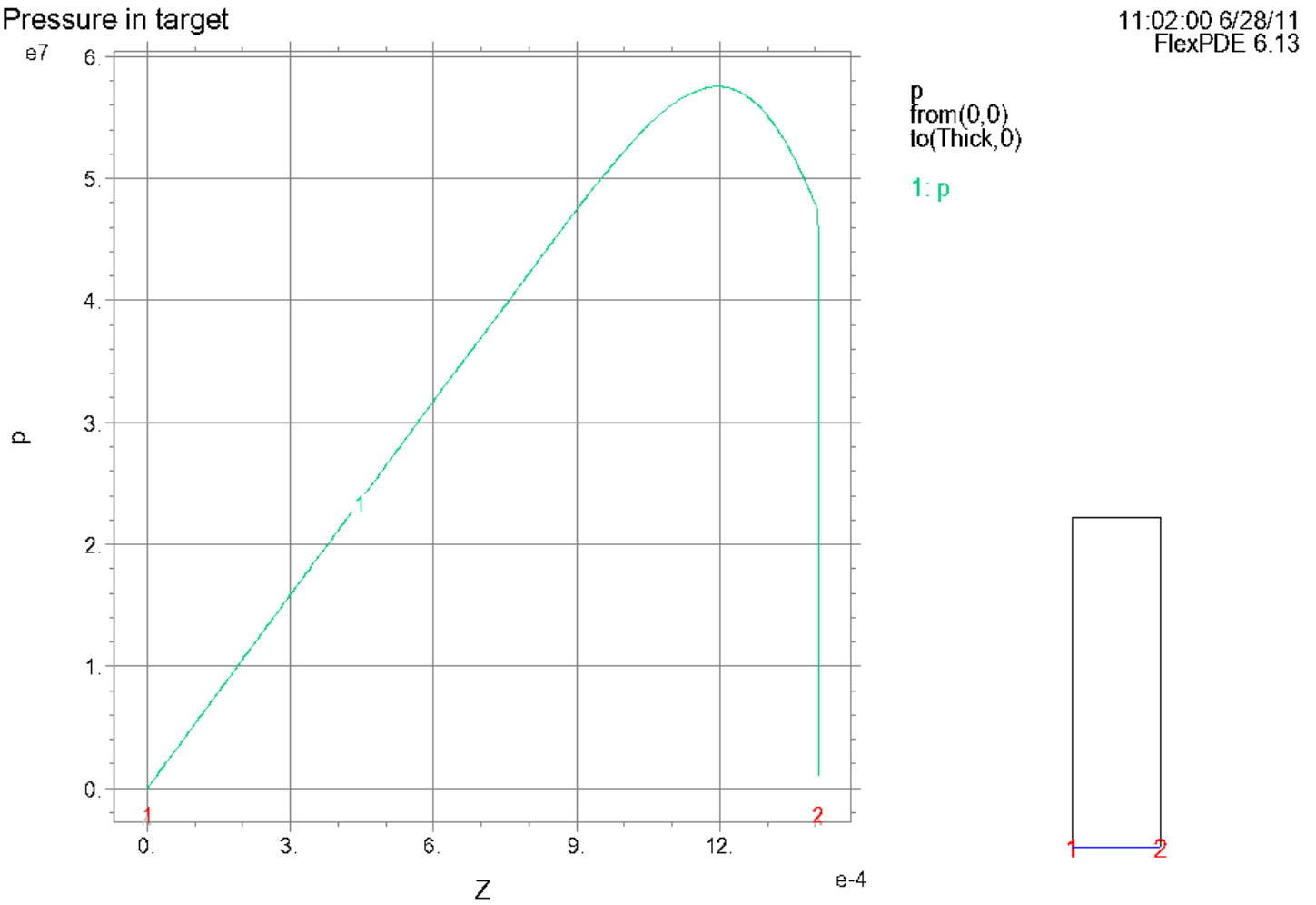

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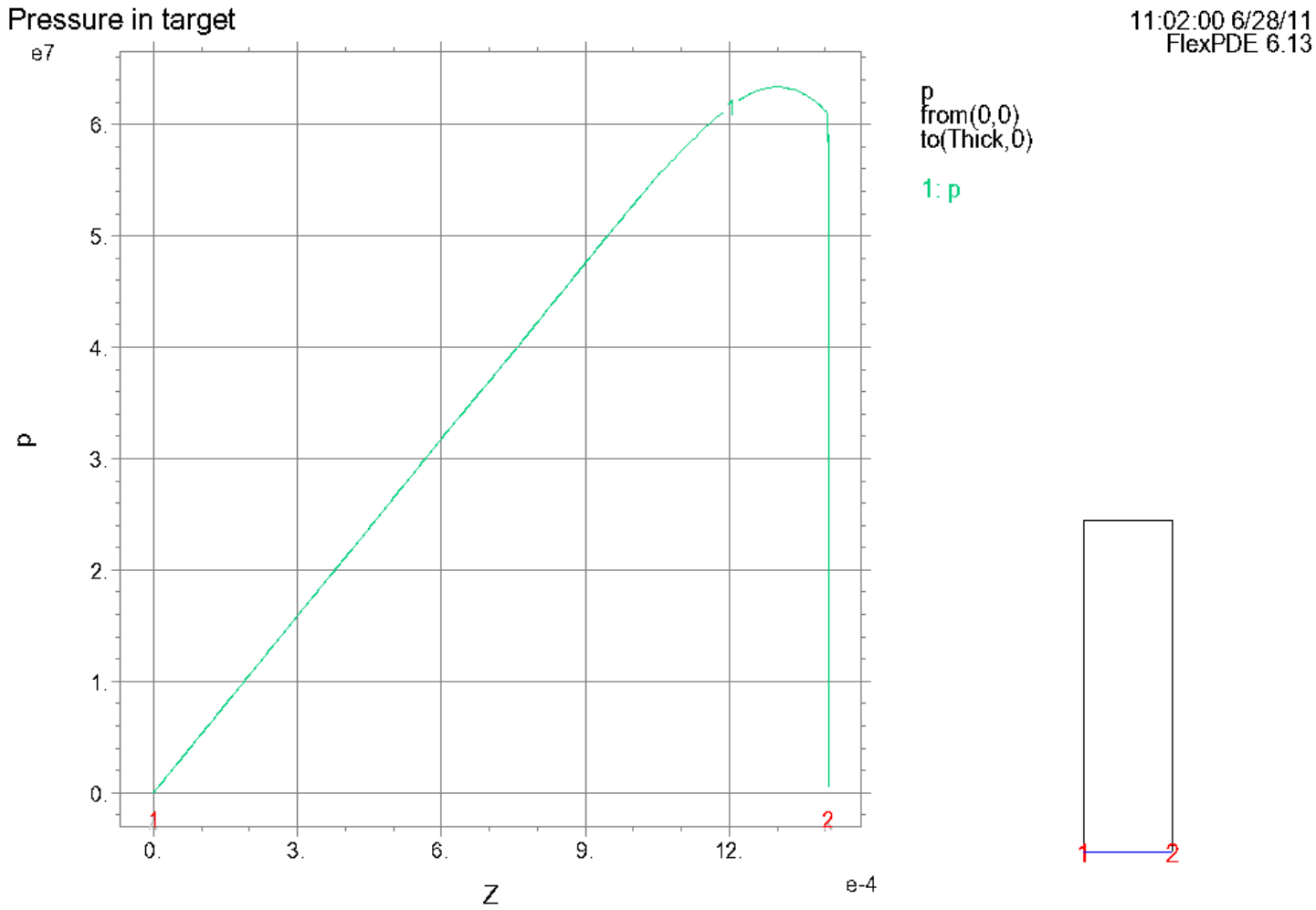

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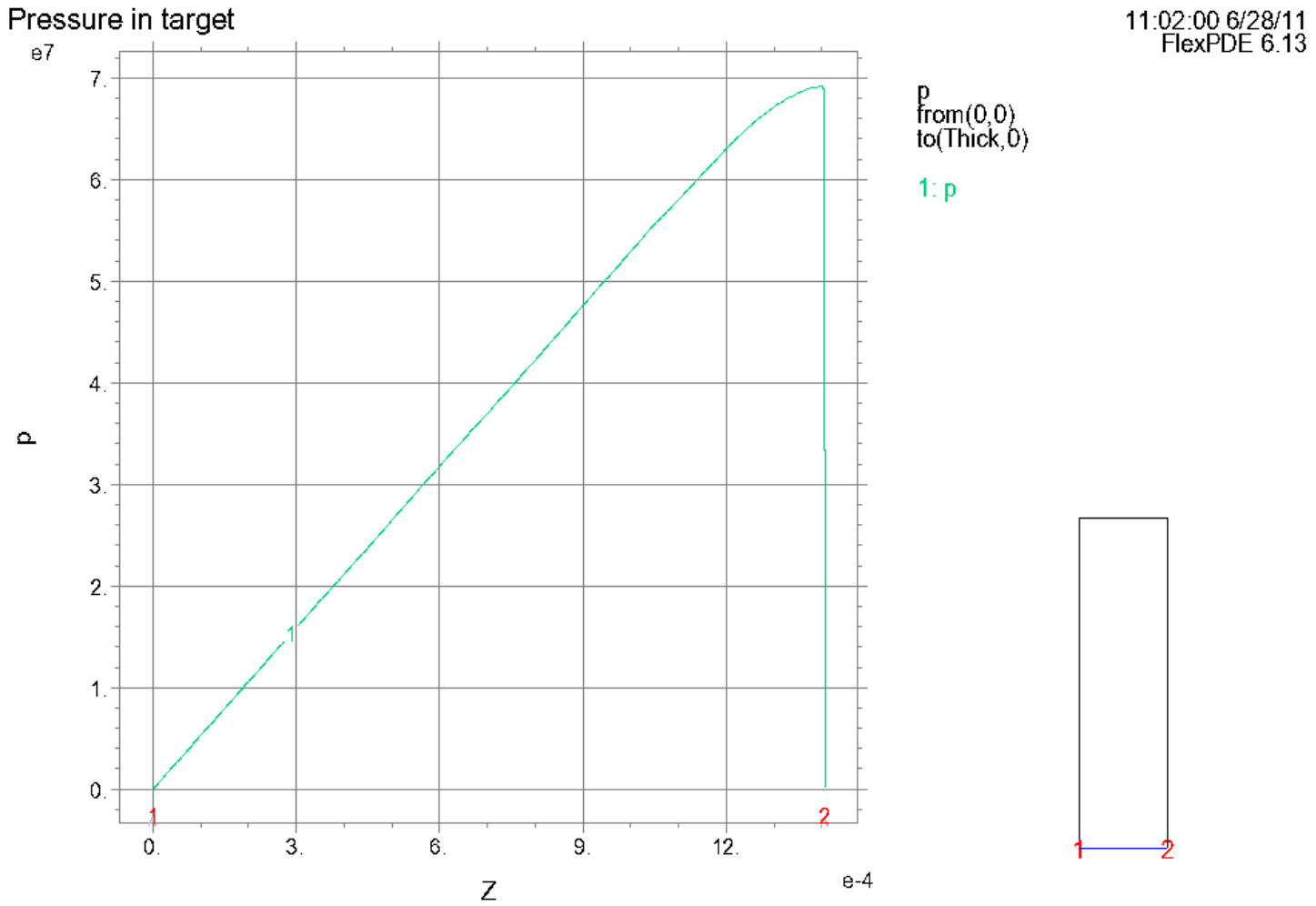

w_target_23062011: Cycle=10135 Time= 1.2400e-11 dt= 5.2951e-15 P3 Nodes=17040 Cells=4582 RMS Err= 1.4e-9
Surf_Integral= 3.260388e-4

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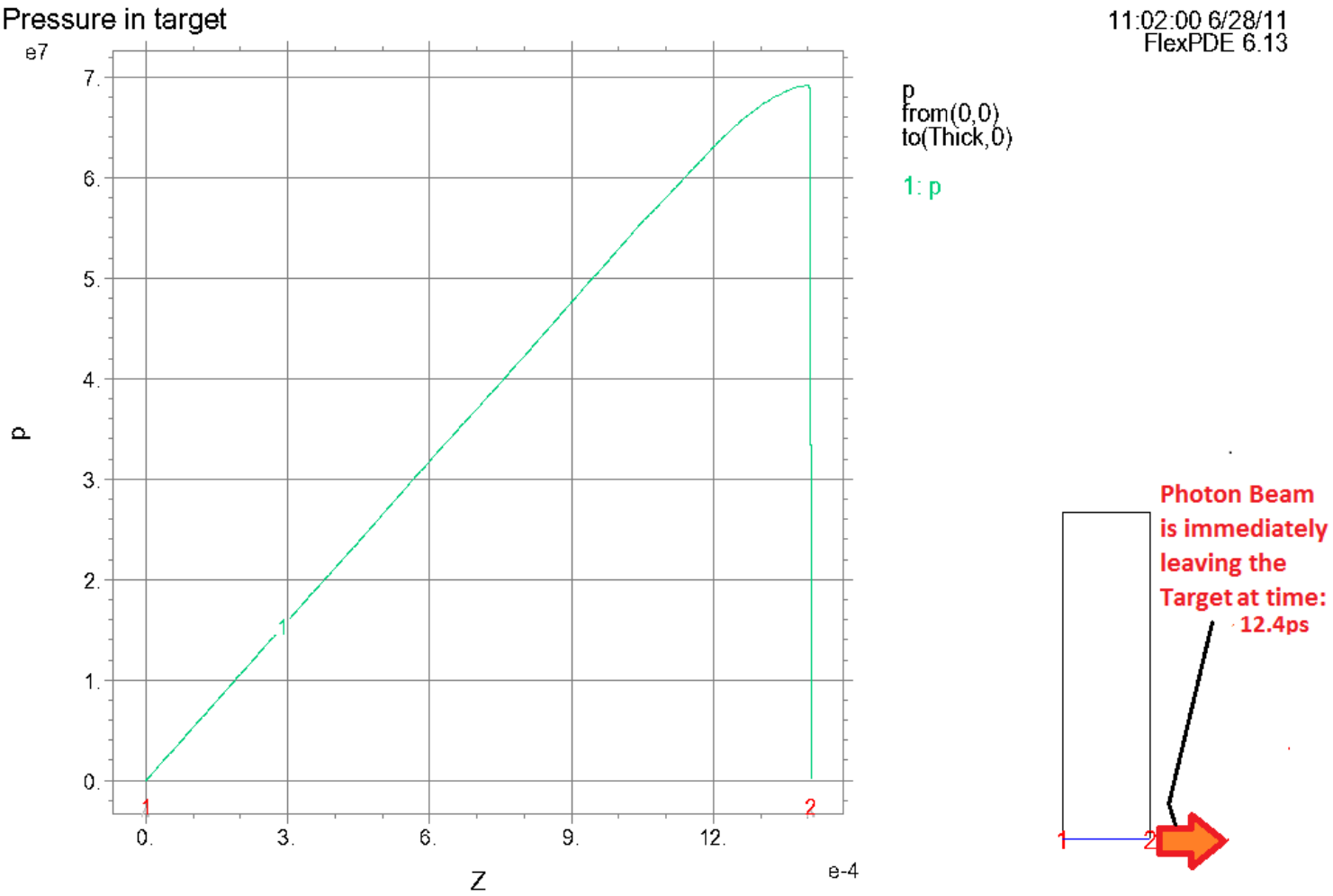

Preliminary Results (Pa Vs. meter):This is the result obtained by extending the time of simulation to $1ns$.

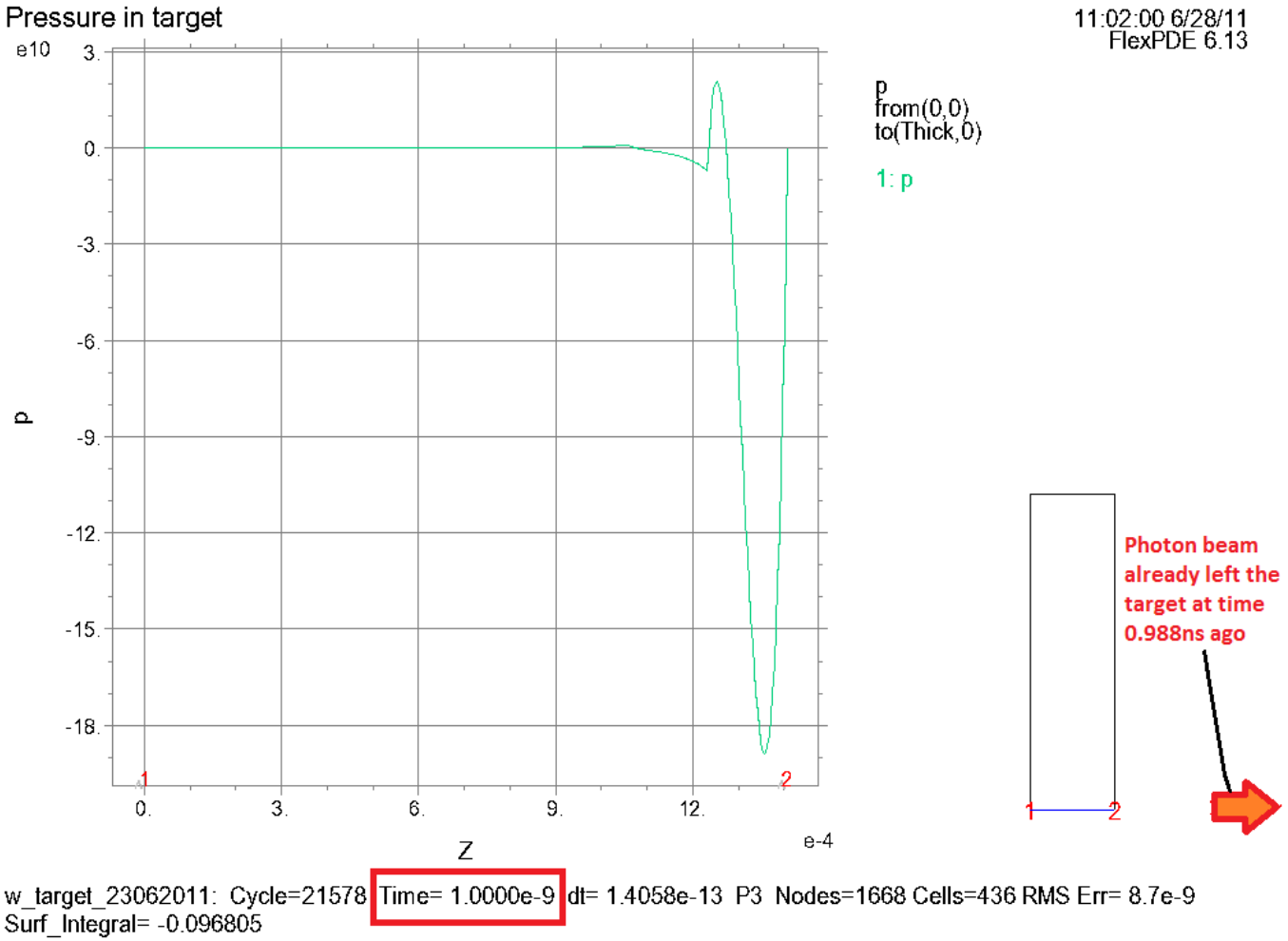

Figure: **Maximum Pressure induce is -190GPa**

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Observation/Conclusion

- From this preliminary report we observed that simulation results is very sensitive to the time, because pressure magnitude is continuously growing with time!!!

Hence it is physically reasonable to simulate within the time taken for the photon beam to cross the target.

Observation/Conclusion

- Also, based on this we can conclude that the peak pressure generated in the target will not destroy the target, because the induced pressure ($= 70 MPa$) is less than the material tensile strength ($= 750 MPa$).

Outlook

This is not the end of the story, more is still needed to be done. Because so far we have considered:

- Gaussian distribution for energy deposition on the target;
- Linear effects; and
- Single bunch of the beam.

We still need more analysis and simulation, which will include the following:

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- Rotation of the target

Thank You!