
Evolution of Pressure

- In Positron Source for future Linear Collider

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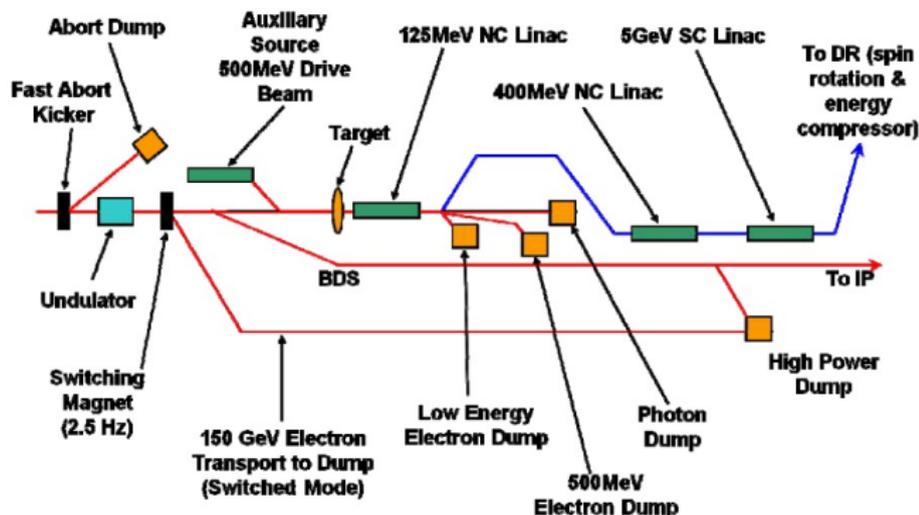
LC FORUM MEETING, MUNICH
July 2011

Outline:

- 1 Introduction
- 2 Fluid Dynamic Model
- 3 Photon interaction with the Target
- 4 Simulation: Parameters and Result
- 5 Observation/Conclusion/Outlook

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

Motivation

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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:

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

- Equation of Motion or Momentum Equation:

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

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

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

(Mikhailichenko, CBN06-1, 2006)

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- Continuity Equation:

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ρ: density
u: Velocity

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P: Pressure

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

Γ: Grisen co-efficient

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

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:

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

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:

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

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

- **Photon Beam (per Bunch) Parameters**

- $\sigma_z = 0.3mm$

- $\sigma_r = 2mm$

- $Q_{bunch} = 0.4J$

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- **Target Material (Tungsten) Parameters**

- 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 : $1.408mm$
- Target Radius: $0.5cm$

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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

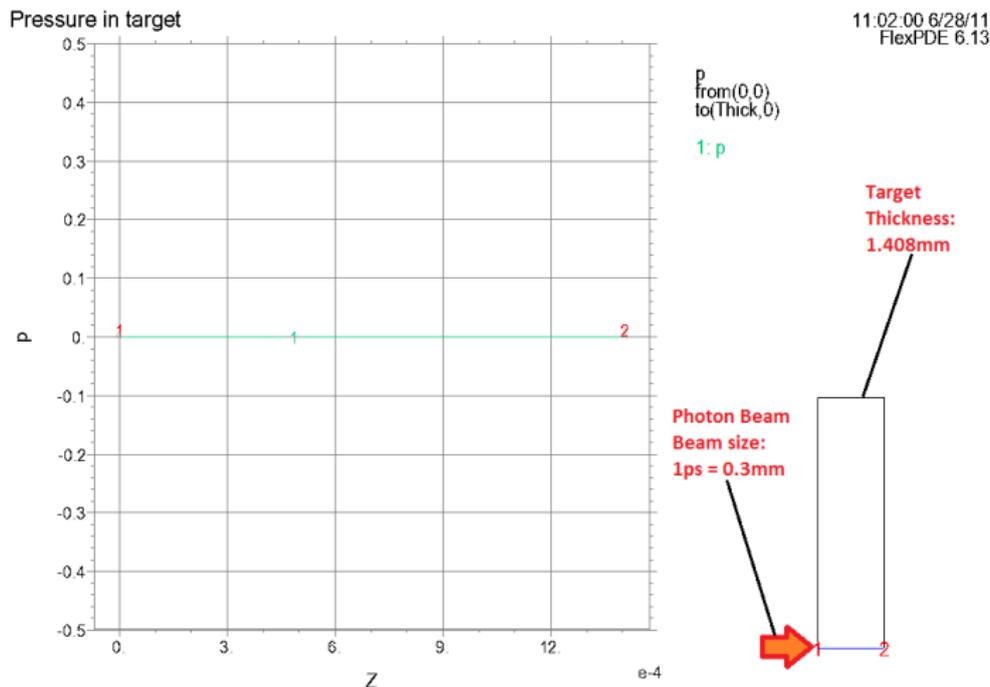
Simulation With FlexPDE

- 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

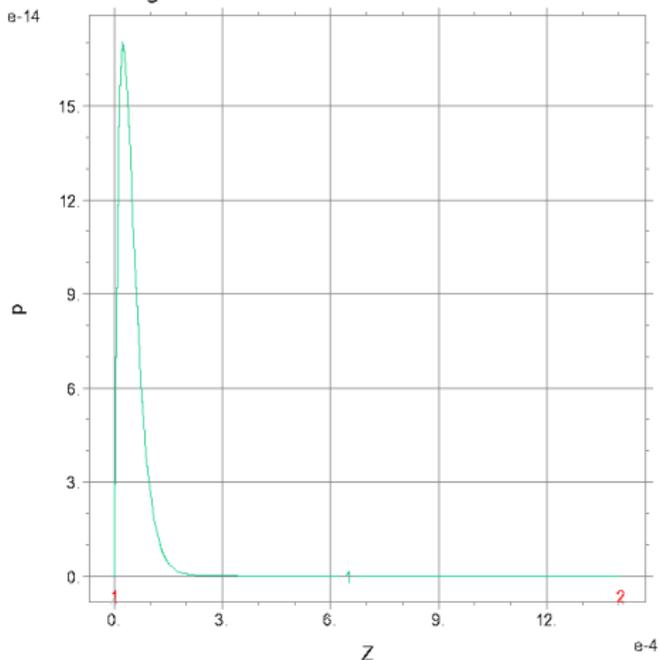


w_target_23062011: Cycle=0 Time= 0.0000 dt= 2.0000e-13 P3 Nodes=611 Cells=158 RMS Err= 1.
Surf_Integral= 0.000000

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

Pressure in target

e-14



P
from(0,0)
to(Thick,0)

1: p

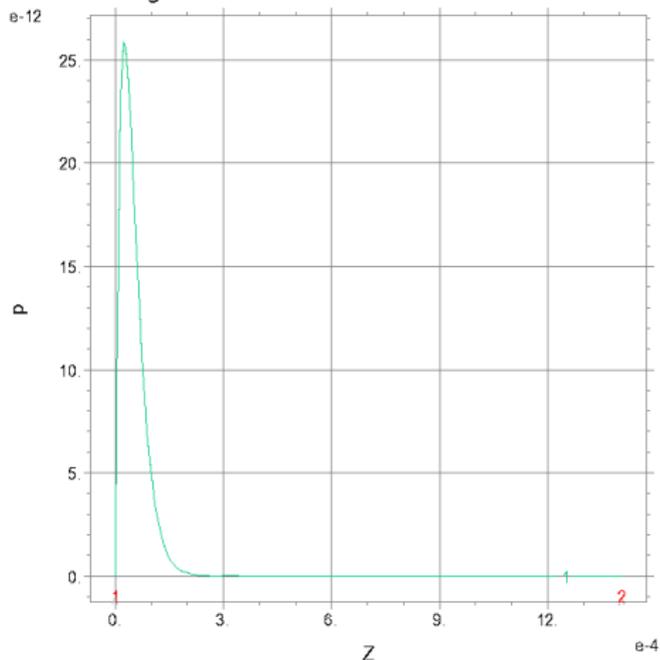
11:02:00 6/28/11
FlexPDE 6.13



w_target_23062011: Cycle=653 Time= 4.0000e-13 dt= 6.2870e-16 P3 Nodes=12769 Cells=3519 RMS Err= 4.9e-8
Surf_Integral= 6.716568e-26

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

Pressure in target

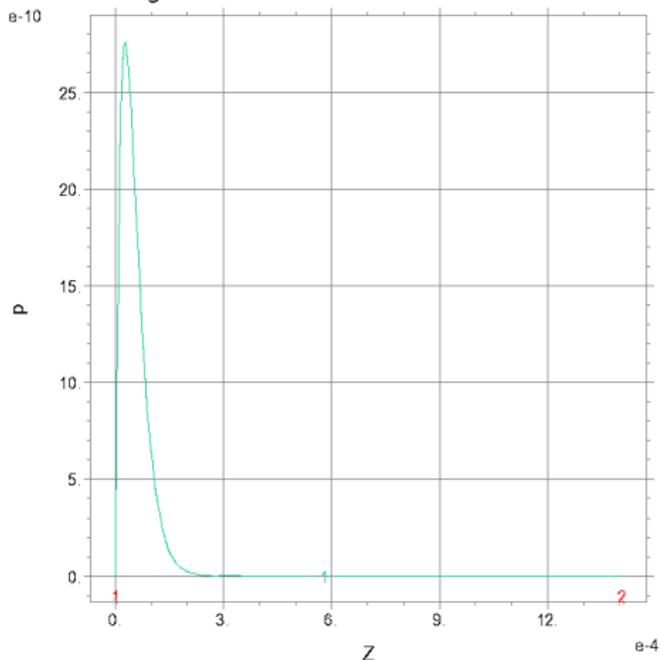
11:02:00 6/28/11
FlexPDE 6.13

w_target_23062011: Cycle=1289 Time= 8.0000e-13 dt= 6.6396e-16 P3 Nodes=12769 Cells=3519 RMS Err= 3.9e-8
 Surf_Integral= 1.083614e-23

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

Pressure in target

e-10



P
from(0,0)
to(Thick,0)

1: p

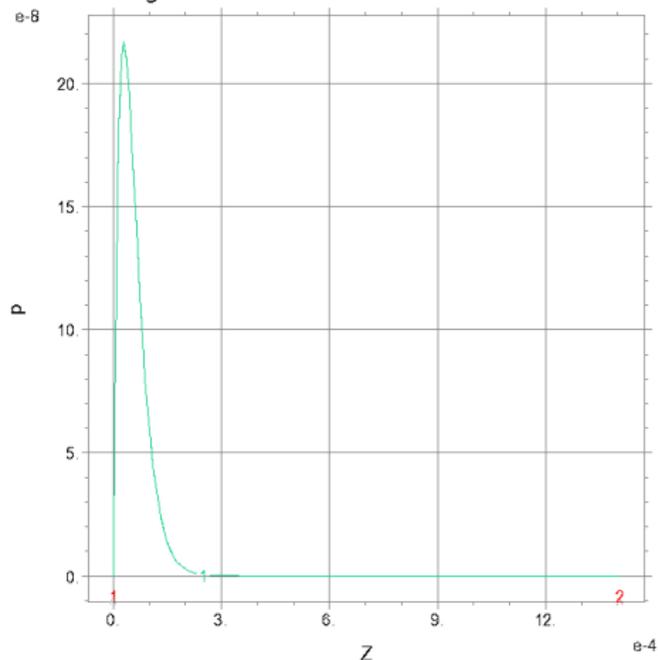
11:02:00 6/28/11
FlexPDE 6.13



w_target_23062011: Cycle=1892 Time= 1.2000e-12 dt= 6.6396e-16 P3 Nodes=12769 Cells=3519 RMS Err= 4. e-8
Surf_Integral= 1.233102e-21

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

Pressure in target



P
 from(0,0)
 to(Thick,0)

1: p

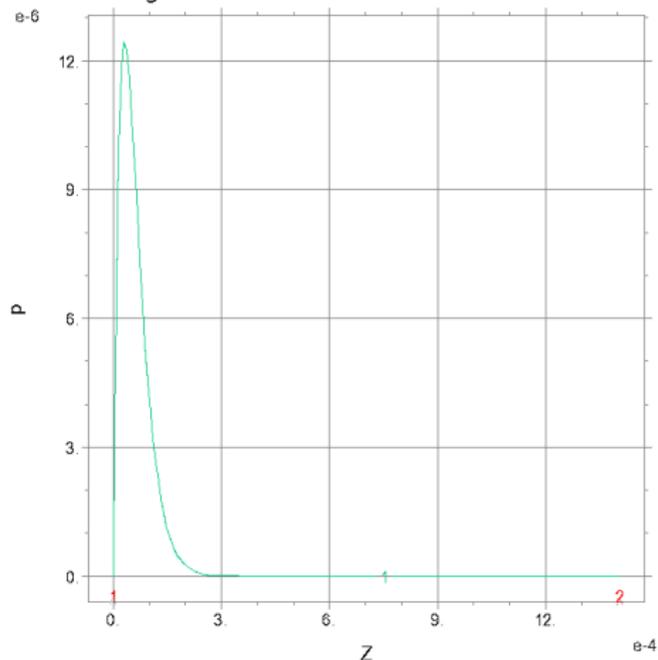
11:02:00 6/28/11
 FlexPDE 6.13



w_target_23062011: Cycle=2495 Time= 1.6000e-12 dt= 6.6396e-16 P3 Nodes=12769 Cells=3519 RMS Err= 4.4e-8
 Surf_Integral= 1.032203e-19

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13

P
from(0,0)
to(Thick,0)

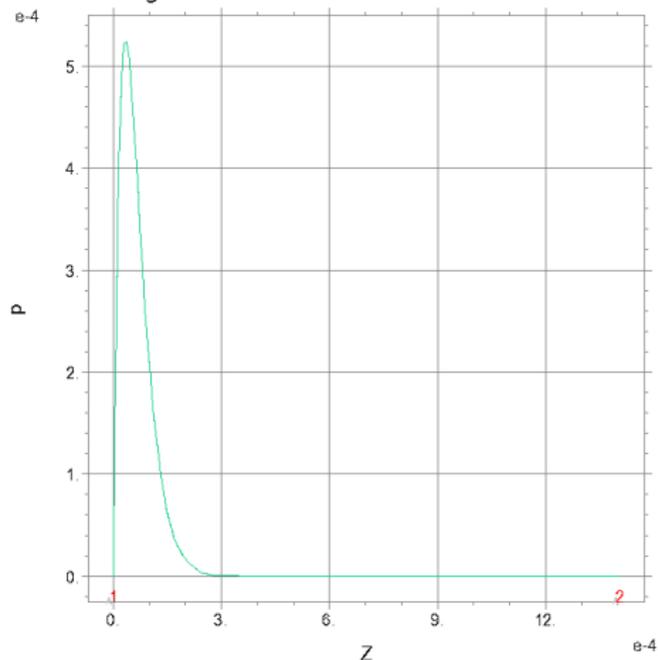
1: p



w_target_23062011: Cycle=3098 Time= 2.0000e-12 dt= 6.6396e-16 P3 Nodes=12769 Cells=3519 RMS Err= 5.2e-8
Surf_Integral= 6.370467e-18

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13

P
from(0,0)
to(Thick,0)

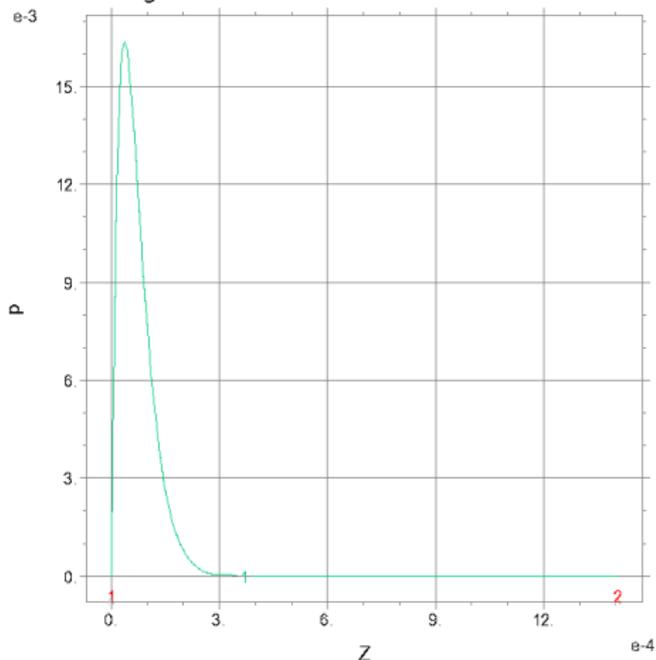
1: p



w_target_23062011: Cycle=3664 Time= 2.4000e-12 dt= 7.8322e-16 P3 Nodes=14610 Cells=4045 RMS Err= 2.9e-8
Surf_Integral= 2.899465e-16

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

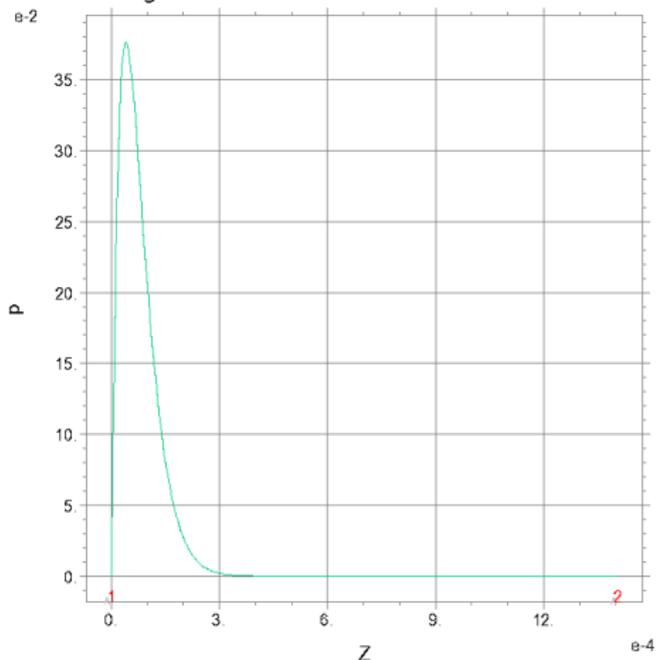
Pressure in target

11:02:00 6/28/11
FlexPDE 6.13

w_target_23062011: Cycle=4180 Time= 2.8000e-12 dt= 8.3469e-16 P3 Nodes=20469 Cells=5713 RMS Err= 4.8e-8
 Surf_Integral= 9.798251e-15

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

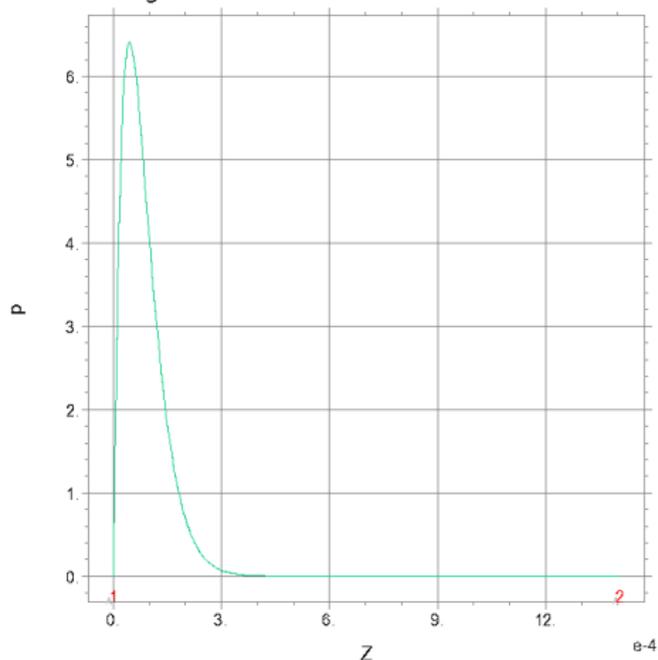
1: p



w_target_23062011: Cycle=4652 Time= 3.2000e-12 dt= 9.0862e-16 P3 Nodes=22113 Cells=6175 RMS Err= 4.8e-8
Surf_Integral= 2.464260e-13

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

Pressure in target



11:02:00 6/28/11
FlexPDE 6.13

P
from(0,0)
to(Thick,0)

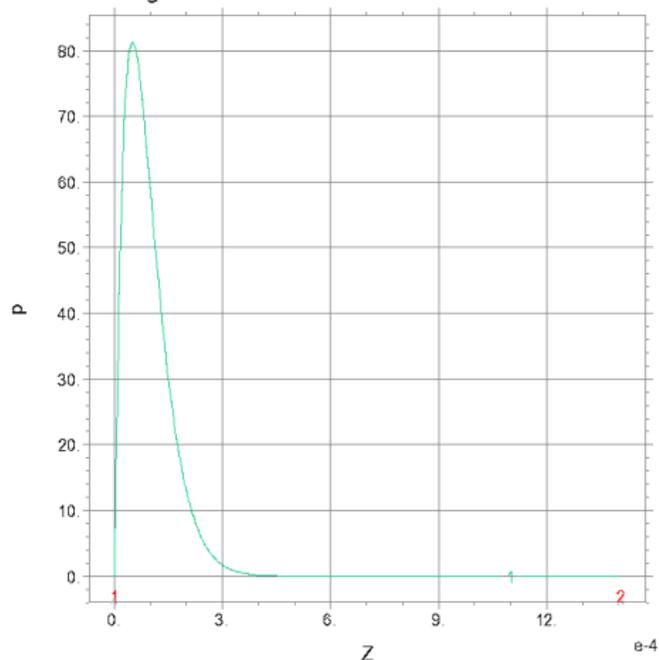
1: p



w_target_23062011: Cycle=5076 Time= 3.6000e-12 dt= 1.0195e-15 P3 Nodes=22113 Cells=6175 RMS Err= 4.9e-8
Surf_Integral= 4.620016e-12

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

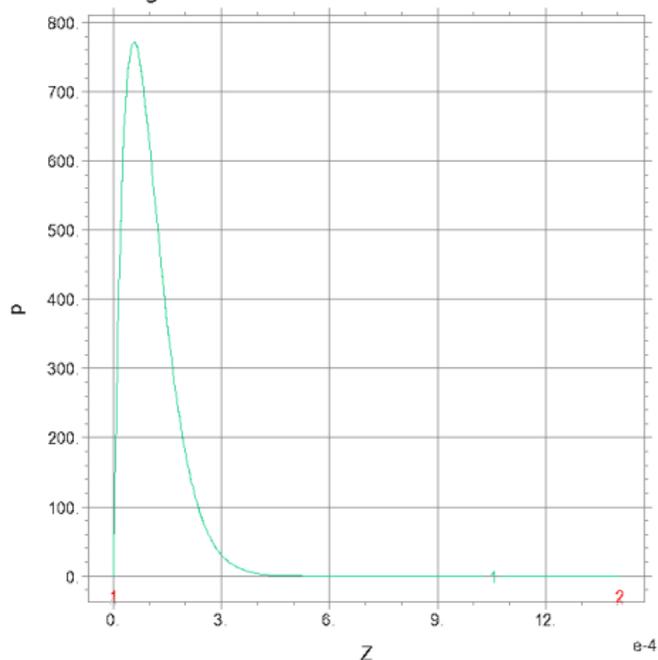
1: p



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

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

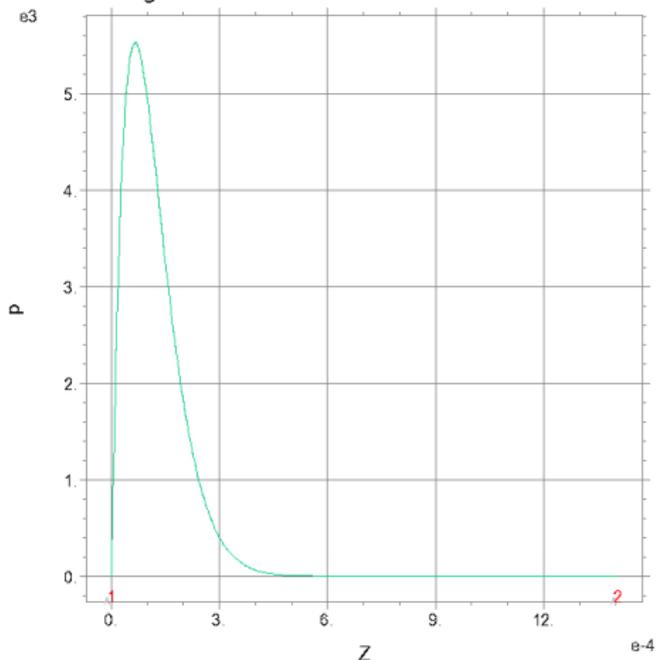
1: p



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

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13

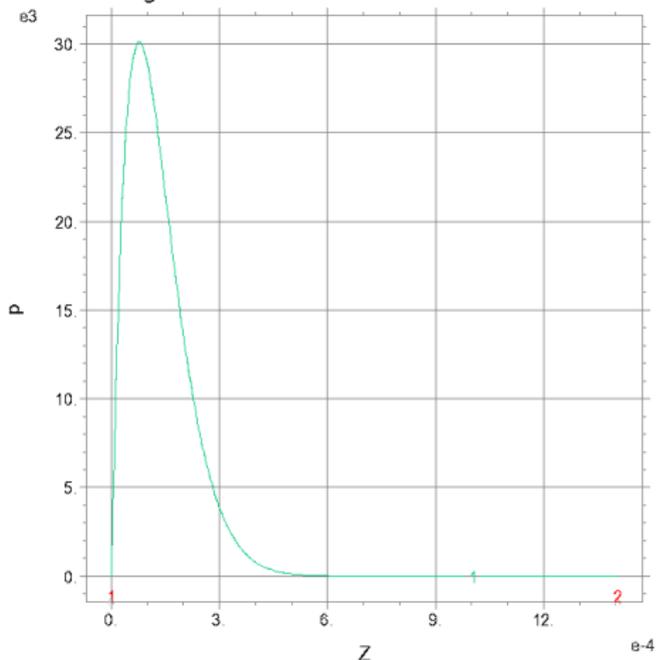
P
from(0,0)
to(Thick,0)
1: p



w_target_23062011: Cycle=6081 Time= 4.8000e-12 dt= 1.6086e-15 P3 Nodes=24475 Cells=6837 RMS Err= 3.e-8
Surf_Integral= 5.568808e-9

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

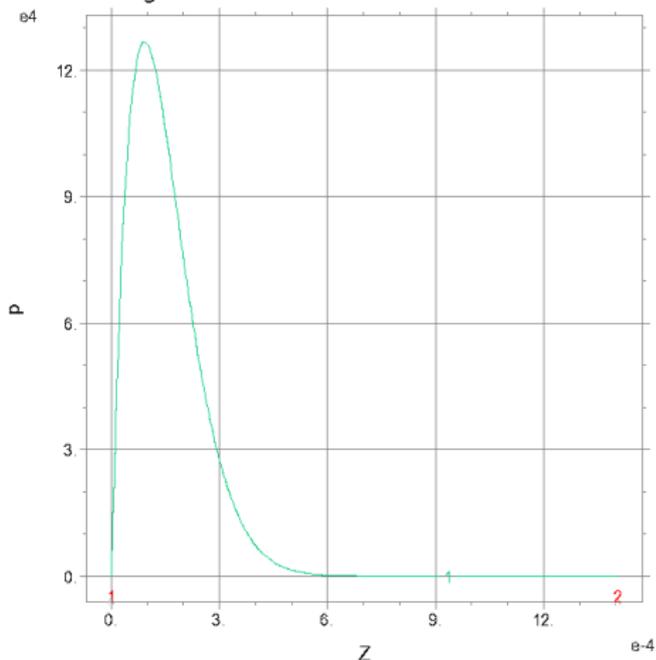
1: p



w_target_23062011: Cycle=6333 Time= 5.2000e-12 dt= 1.8391e-15 P3 Nodes=23982 Cells=6688 RMS Err= 6.1e-8
Surf_Integral= 3.457168e-8

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

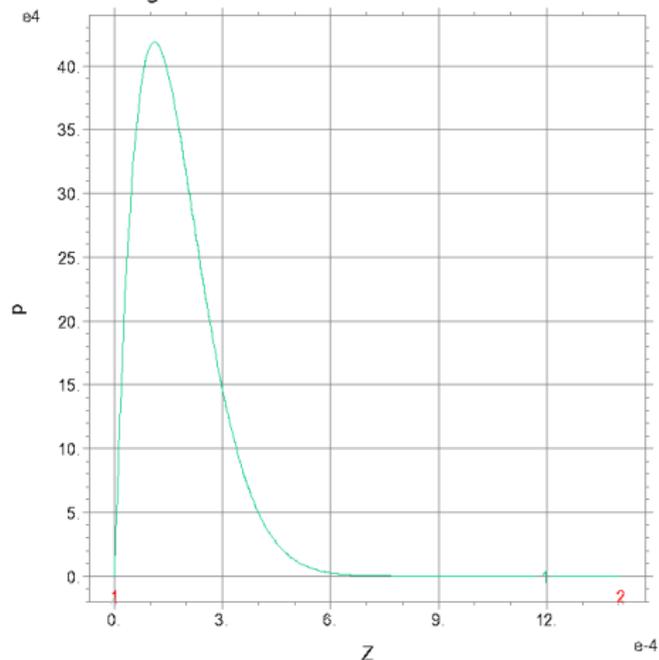
1: p



w_target_23062011: Cycle=6550 Time= 5.6000e-12 dt= 2.1332e-15 P3 Nodes=19325 Cells=5369 RMS Err= 7.2e-8
Surf_Integral= 1.670238e-7

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

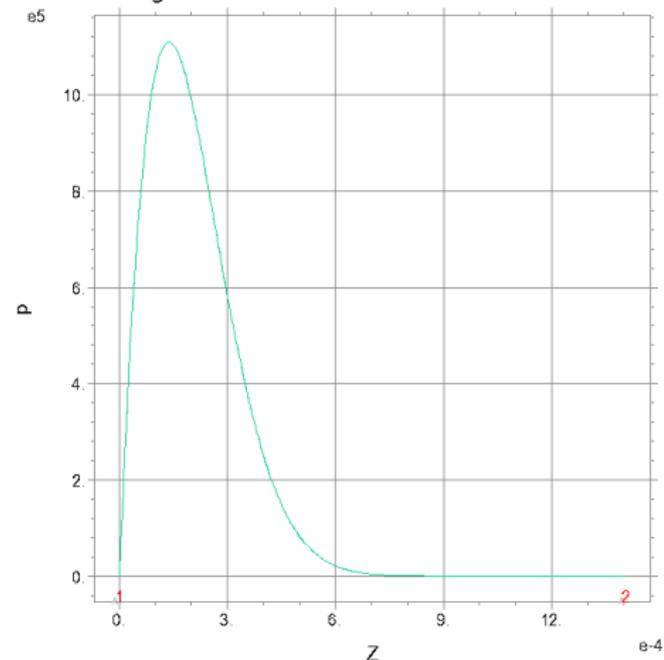
1: p



w_target_23062011: Cycle=6733 Time= 6.0000e-12 dt= 2.8452e-15 P3 Nodes=17902 Cells=4971 RMS Err= 5.4e-8
Surf_Integral= 6.382833e-7

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

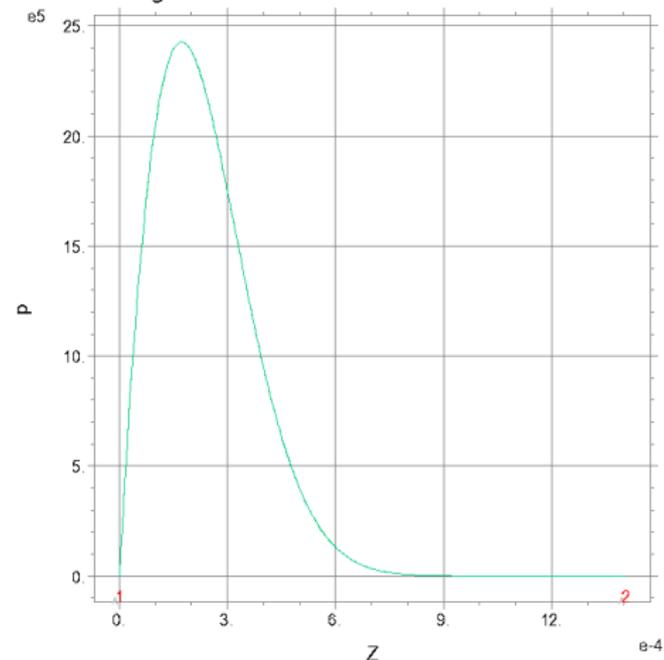
1: p



w_target_23062011: Cycle=6908 Time= 6.4000e-12 dt= 2.6089e-15 P3 Nodes=18819 Cells=5230 RMS Err= 4. e-8
Surf_Integral= 1.966903e-6

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

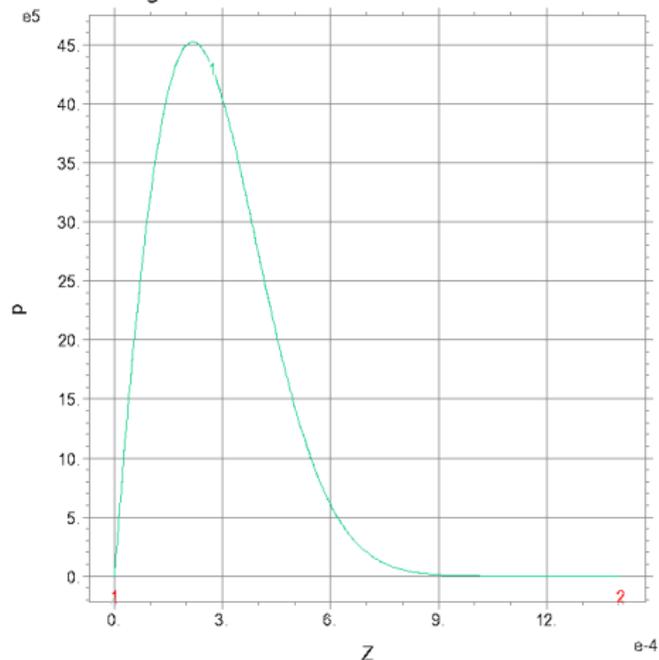
1: p



w_target_23062011: Cycle=7042 Time= 6.8000e-12 dt= 4.0185e-15 P3 Nodes=18908 Cells=5255 RMS Err= 5.4e-8
Surf_Integral= 5.002224e-6

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

Pressure in target

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FlexPDE 6.13

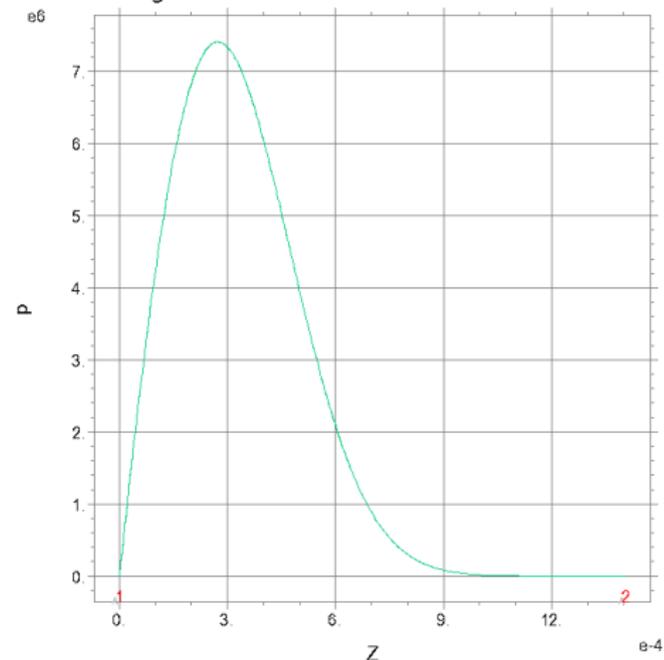
P
from(0,0)
to(Thick,0)
1: p



w_target_23062011: Cycle=7174 Time= 7.2000e-12 dt= 3.8737e-15 P3 Nodes=19233 Cells=5344 RMS Err= 5.4e-8
Surf_Integral= 1.077915e-5

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

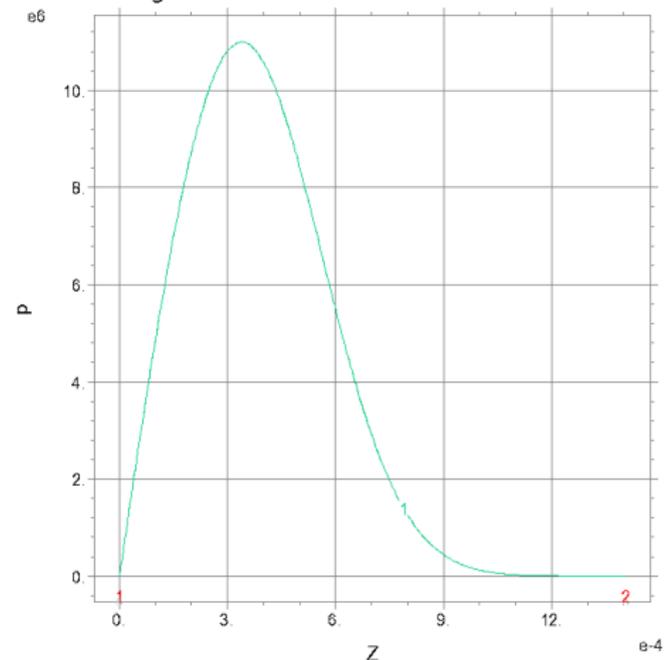
1: p



w_target_23062011: Cycle=7293 Time= 7.6000e-12 dt= 3.7823e-15 P3 Nodes=20393 Cells=5681 RMS Err= 3.6e-8
Surf_Integral= 2.023471e-5

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

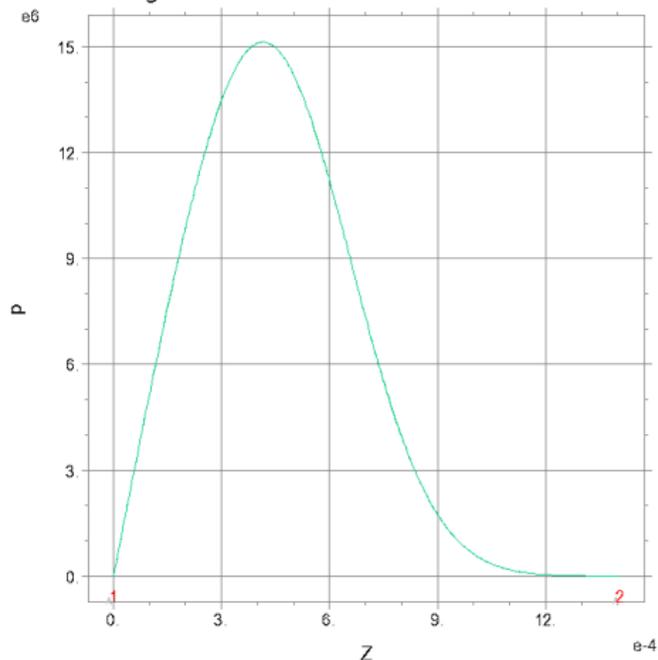
1: p



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

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

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FlexPDE 6.13P
from(0,0)
to(Thick,0)

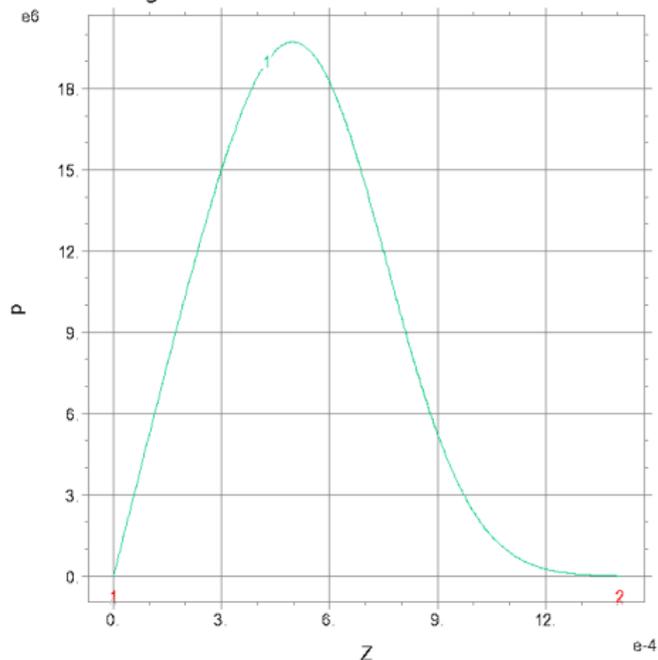
1: p



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

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

Pressure in target

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FlexPDE 6.13P
from(0,0)
to(Thick,0)

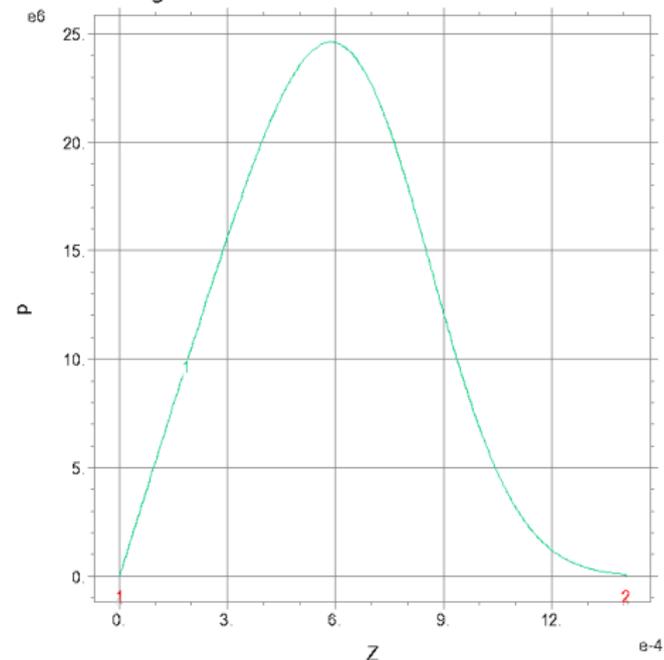
1: p



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

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

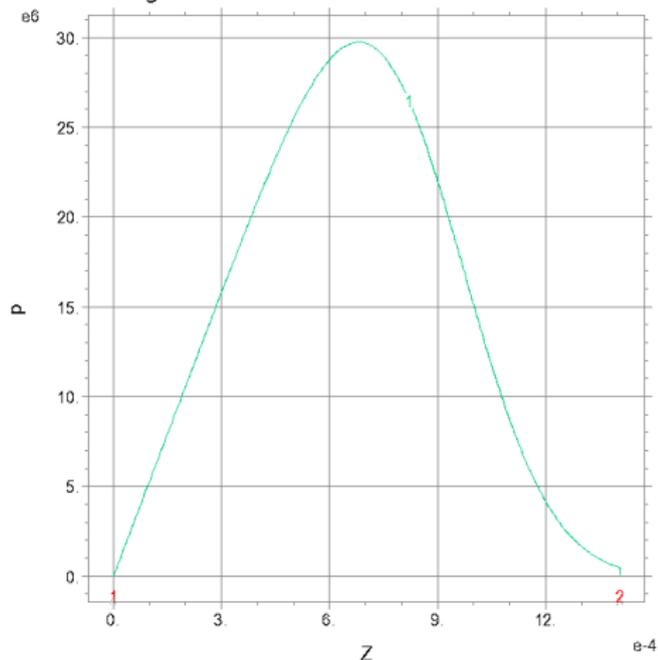
1: p



w_target_23062011: Cycle=7857 Time= 9.2000e-12 dt= 4.4194e-15 P3 Nodes=52661 Cells=14216 RMS Err= 6.7e-8
Surf_Integral= 1.034093e-4

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

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11:02:00 6/28/11
FlexPDE 6.13

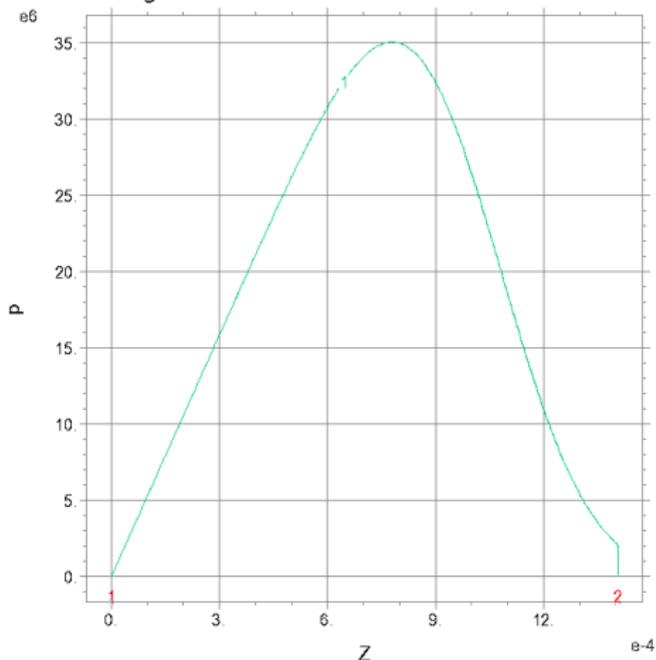
P
from(0,0)
to(Thick,0)
1: p



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

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

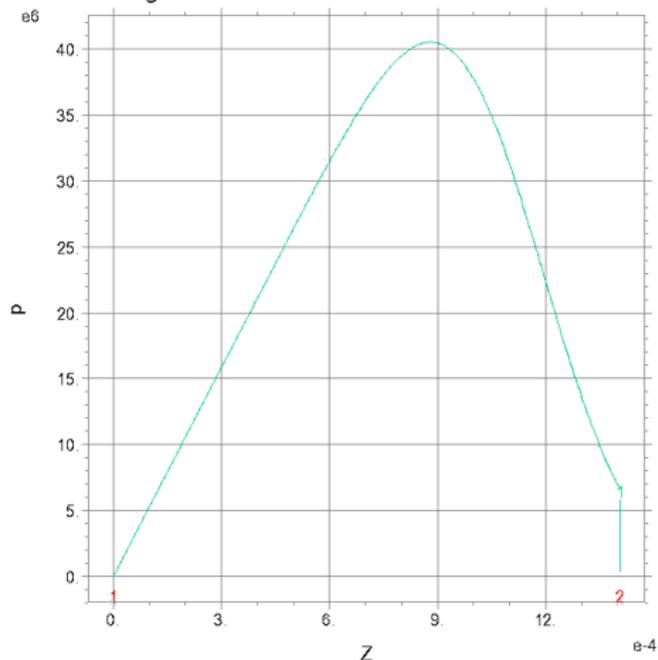
Pressure in target

11:02:00 6/28/11
FlexPDE 6.13
 P
 from(0,0)
 to(Thick,0)
1: p 

w_target_23062011: Cycle=8462 Time= 1.0000e-11 dt= 4.3038e-15 P3 Nodes=410553 Cells=110653 RMS Err= 3.1e-8
 Surf_Integral= 1.725365e-4

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13

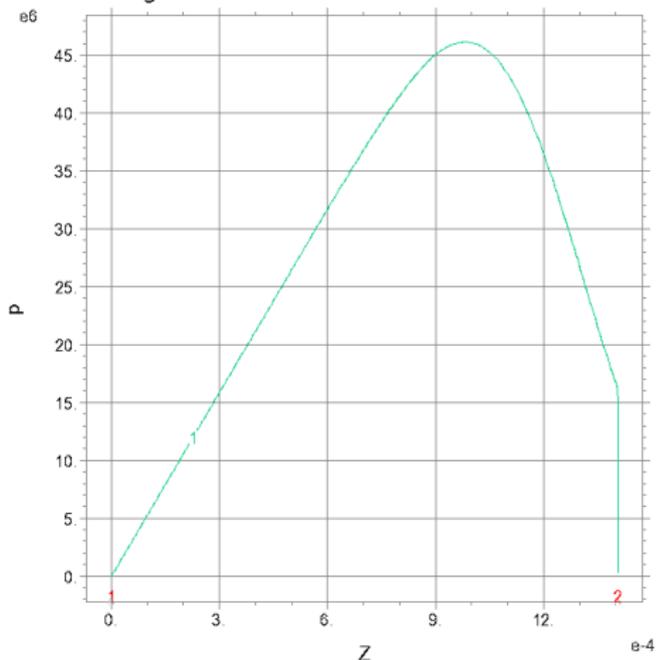
P
from(0,0)
to(Thick,0)
1: p



w_target_23062011: Cycle=8803 Time= 1.0400e-11 dt= 3.6359e-15 P3 Nodes=1151933 Cells=302351 RMS Err= 2.1e-8
Surf_Integral= 2.116213e-4

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

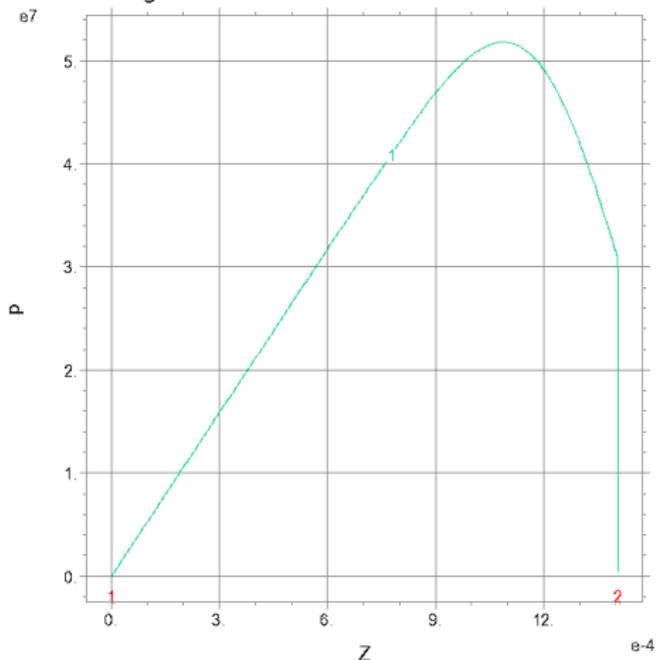
1: p



w_target_23062011: Cycle=9105 Time= 1.0800e-11 dt= 3.3135e-15 P3 Nodes=156019 Cells=41055 RMS Err= 2.4e-6
Surf_Integral= 2.498615e-4

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

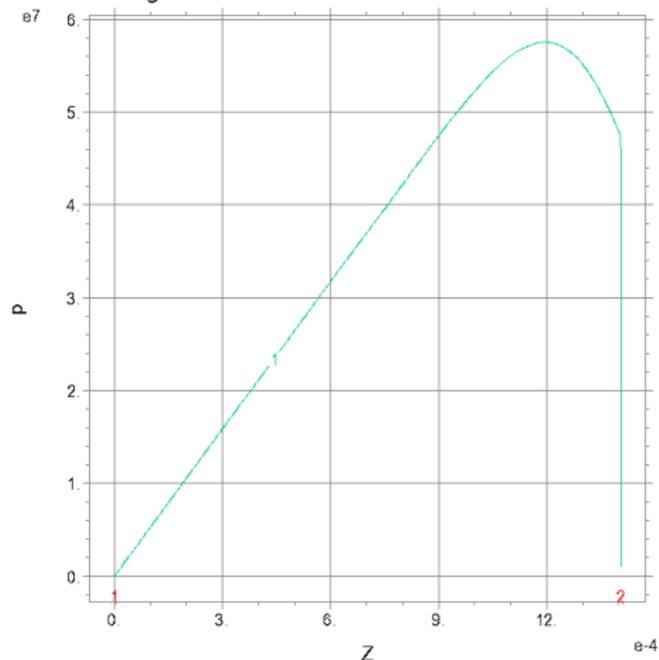
1: p



w_target_23062011: Cycle=9379 Time= 1.1200e-11 dt= 4.8186e-15 P3 Nodes=60780 Cells=16342 RMS Err= 1.7e-9
Surf_Integral= 2.826898e-4

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13P
from(0,0)
to(Thick,0)

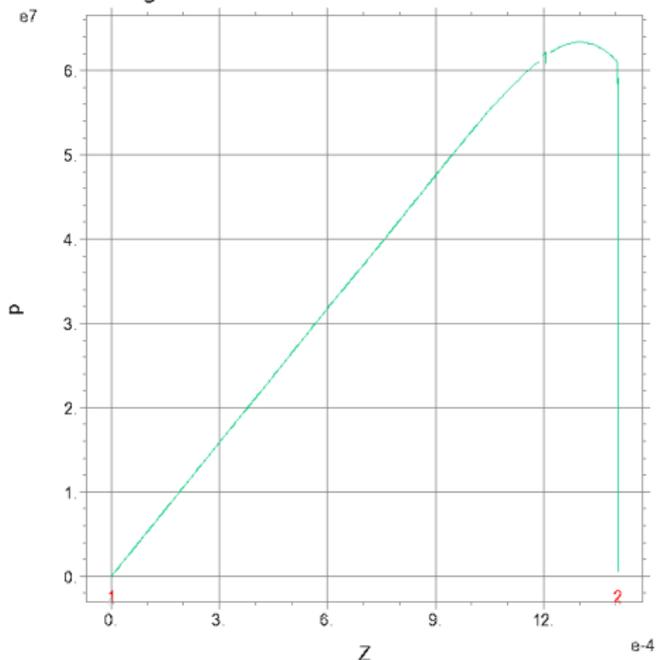
1: p



w_target_23062011: Cycle=9538 Time= 1.1600e-11 dt= 4.9047e-15 P3 Nodes=459657 Cells=123292 RMS Err= 3.7e-8
Surf_Integral= 3.062939e-4

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13

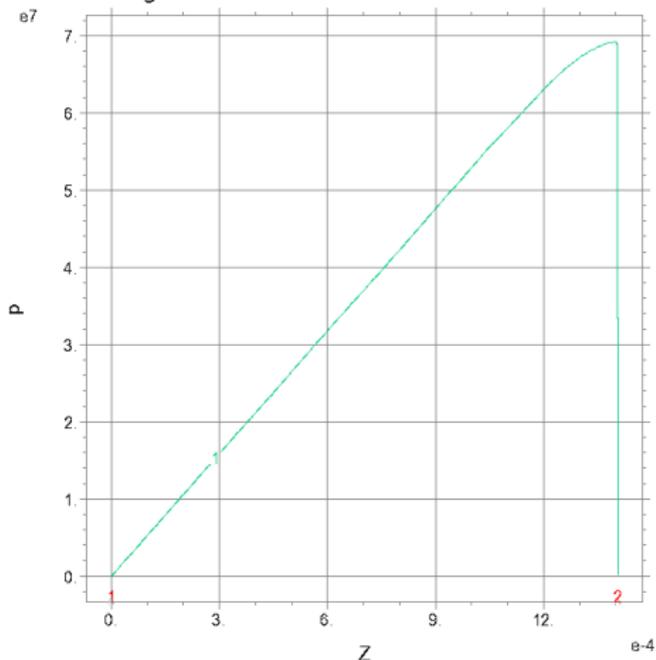
P
from(0,0)
to(Thick,0)
1: p



w_target_23062011: Cycle=9811 Time= 1.2000e-11 dt= 3.8932e-15 P3 Nodes=66268 Cells=17841 RMS Err= 2.2e-8
Surf_Integral= 3.199779e-4

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

Pressure in target

11:02:00 6/28/11
FlexPDE 6.13

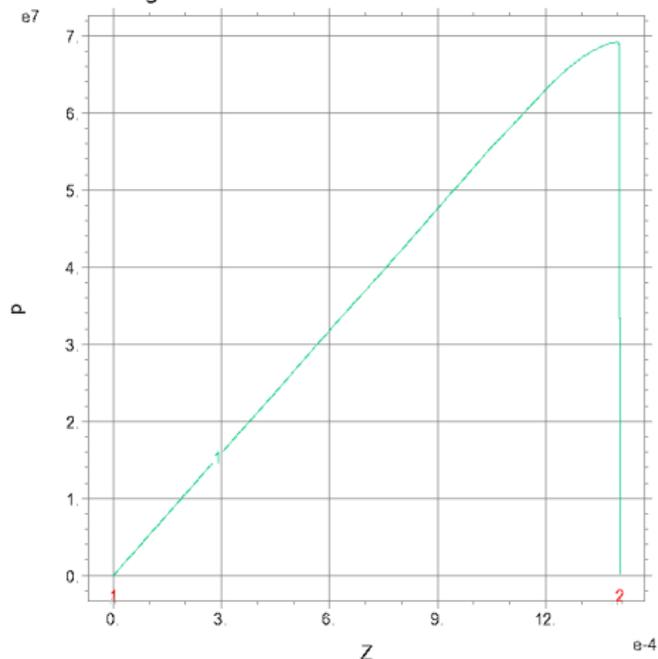
P
from(0,0)
to(Thick,0)
1: p



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

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

Pressure in target



P
from(0,0)
to(Thick,0)
1:p

11:02:00 6/28/11
FlexPDE 6.13

Photon Beam
is immediately
leaving the
Target at time:
12.4ps



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

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

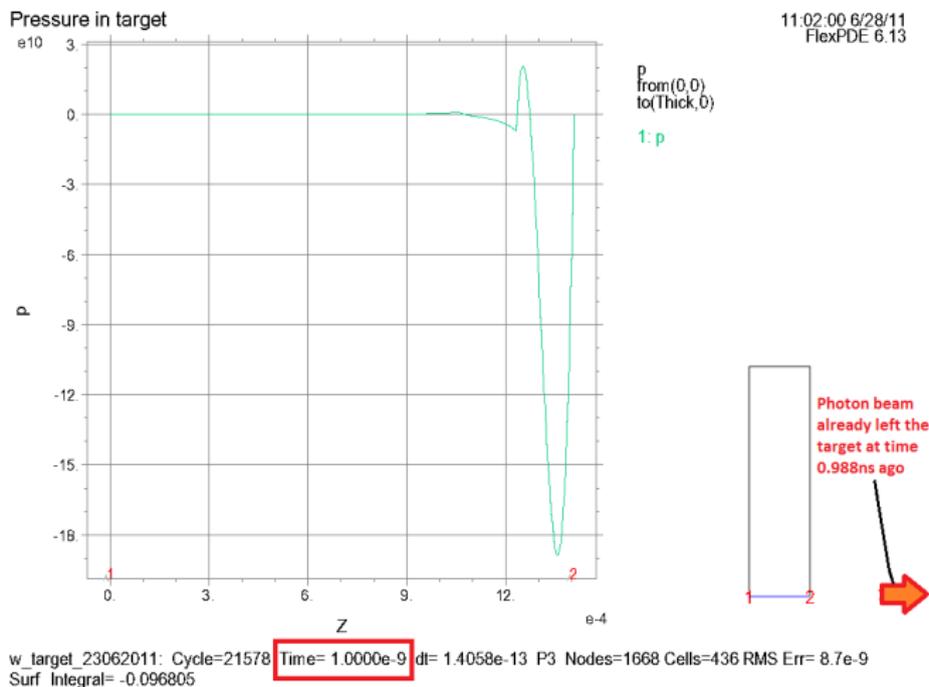


Figure: **Maximum Pressure induce is -190GPa**

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- 1 Introduction
- 2 Fluid Dynamic Model
- 3 Photon interaction with the Target
- 4 Simulation: Parameters and Result
- 5 Observation/Conclusion/Outlook**

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 ($= 70\text{MPa}$) is less than the material tensile strength ($= 750\text{MPa}$).

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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- realistic photon beam profile, generated in helical undulator
- non-Linear effects
- multi-Bunch effects (1312 bunches per train)
- Rotation of the target

Thank You!