Target Shock Wave Study

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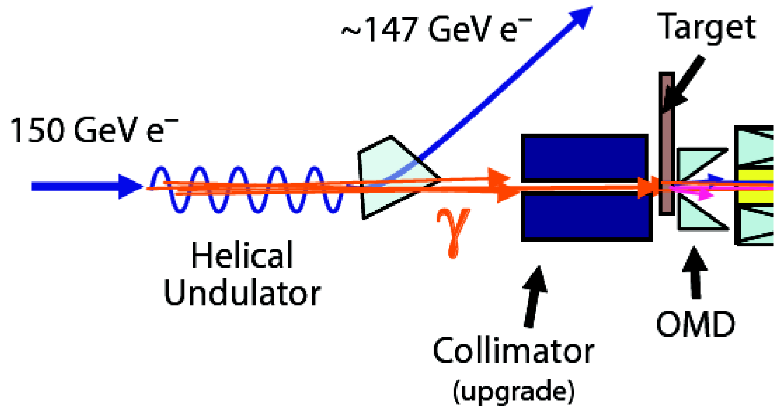
Outline

- Introduction
- Thermal shocks in target
- Energy deposition in target
- Simulations with FlexPDE
- Hydrodynamical model for temperature and pressure
- Summary

Introduction

- Positron source, e.g. ILC RDR:



- Polarized γ on target $\Rightarrow$ polarized e^+
- Leading production process: e^+e^- pair creation
  - Quasi-classical approximations
  - Simulation with e.g. GEANT, FLUKA $\longrightarrow$ tested against data
- Possible problems: heat load, thermal shocks in target, . . .
- Rotating wheel targets
- Prototype in Daresbury (Ti alloy) [Ian's talk]
- Alternatives: Liquid metals (Bi-Pb, Hg) [e.g. A.A. Mikhailichenko, CBN06-1, 2006]

Thermal shocks in target

- Rapid energy deposition of γ beam $\Rightarrow$ pressure shock wave

- Hydrodynamical model [e.g. A.A. Mikhailichenko, CBN06-1, 2006]

  $\longrightarrow$ Temperature $T = T(\vec{x}, t)$, pressure $P = P(\vec{x}, t)$

  described by hydrodynamical equations

- Simulations at LLNL and Cornell

  [talks at Argonne meeting, Sept. 2007, by T. Piggott and A.A. Mikhailichenko, respectively]

- Cornell simulations

  - FlexPDE
  - Large negative pressure at $\mathcal{O}(10^{-10}\ \mathrm{s})$ at target exit
  - Results: *"Ti target not surviving with present margins"*

Thermal shocks in target

Hydrodynamic model behind simulations

E.g. for Cornell simulations [A.A. Mikhailichenko, CBN06-1, 2006, talk at Argonne meeting]

- Temperature: $\nabla(k\nabla T) + \dot{Q} = \rho c_V \dot{T}$

  $\dot{Q}(\vec{x}, t)$: density of energy deposition; c_V: heat capacity

- Pressure: $\ddot{P} - \nabla(c_0^2 \nabla P) = \Gamma / V_0 \dot{Q}$

  c_0: speed of sound; $\Gamma = \Gamma(V) = V/c_V (\partial P/\partial T)_V$

- Gaussian distribution of energy deposition:

$$\dot{Q} = \sum_j \frac{2cQ_{\text{bunch}}}{\pi\sqrt{\pi}\sigma_z \sigma_\perp^2 l_T} \frac{z}{l_T} \exp\left(-\frac{(z + z_0 - c(t - jt_0))^2}{\sigma_z^2}\right) \exp\left(-\frac{r^2}{\sigma_\perp^2}\right)$$

  $\int \dot{Q}(\vec{x}, t) dV dt = Q_{\text{bunch}}$; $\sigma_z, \sigma_\perp$: bunch dimensions; l_T: target thickness

- Density of energy distribution: $Q(\vec{x}) = \int \dot{Q}(\vec{x}, t) dt$

Energy deposition in target

Comparison with FLUKA simulations

[Zeuthen group: S. Riemann, A. Schälicke, A. Ushakov]

Include higher harmonics of undulator radiation

[A. Ushakov, talk at Zeuthen meeting, April 2008]

- γ-beam intensity extends to larger r than for Gaussian distribution
- Energy is distributed in larger volume
- Gaussian approximation underestimates volume for $K \sim 1$
- Better for $K \lesssim 0.5$

Simulations with FlexPDE

- FlexPDE 6.07 available in Zeuthen [S. Riemann, A. Schälicke, A. Ushakov]
- Solves Partial Differential Equations (PDEs)
- 2-dim description of target via cylinder coordinates

```
COORDINATES XCYLINDER
...
BOUNDARIES
REGION 1
START(0,0)
LINE TO (15,0)
LINE TO (15,15)
LINE TO (0,15)
LINE TO CLOSE
```

→ Natural boundary conditions

Simulations with FlexPDE

- For P = 0 on target surface (z = 0 and z = 15 mm)

```
BOUNDARIES
REGION 1
START(0,0)
LINE TO (15,0)
Value(p)=0
LINE TO (15,15)
Natural(p)=0
LINE TO (0,15)
Value(p)=0
LINE TO CLOSE
```

- Read in e.g. energy distribution from FLUKA simulation

```
Q0 = table('energy.tbl')
```

Hydrodynamical model

Heat Equation

$\nabla(k\nabla T) + \dot{Q} = \rho c_V \dot{T}$ $\dot{Q}(\vec{x}, t)$: density of energy deposition; c_V: heat capacity

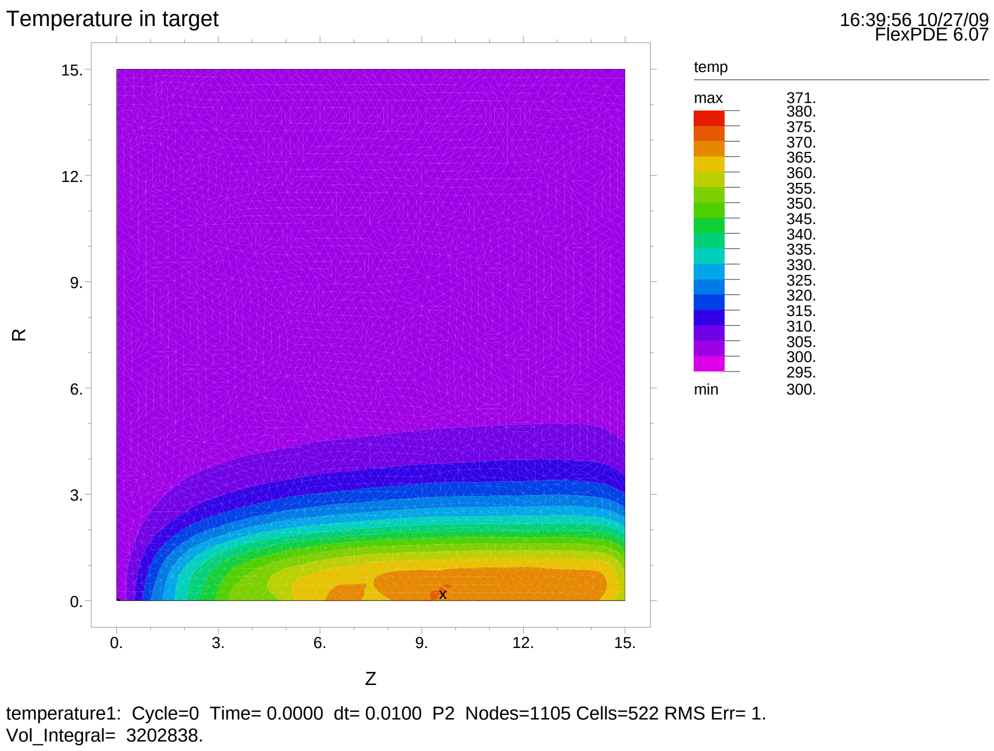
- Heat flow in $\mathcal{O}(1\text{ s}) \longrightarrow$ energy deposition $\dot{Q}$ instantaneous
- FlexPDE:

```
INITIAL VALUES
temp=t0 + cfac*Q0/(C*rho)
EQUATIONS { PDE's, one for each variable }
div(K*grad(temp)) = C*rho*dt(temp) { heat equation }
```

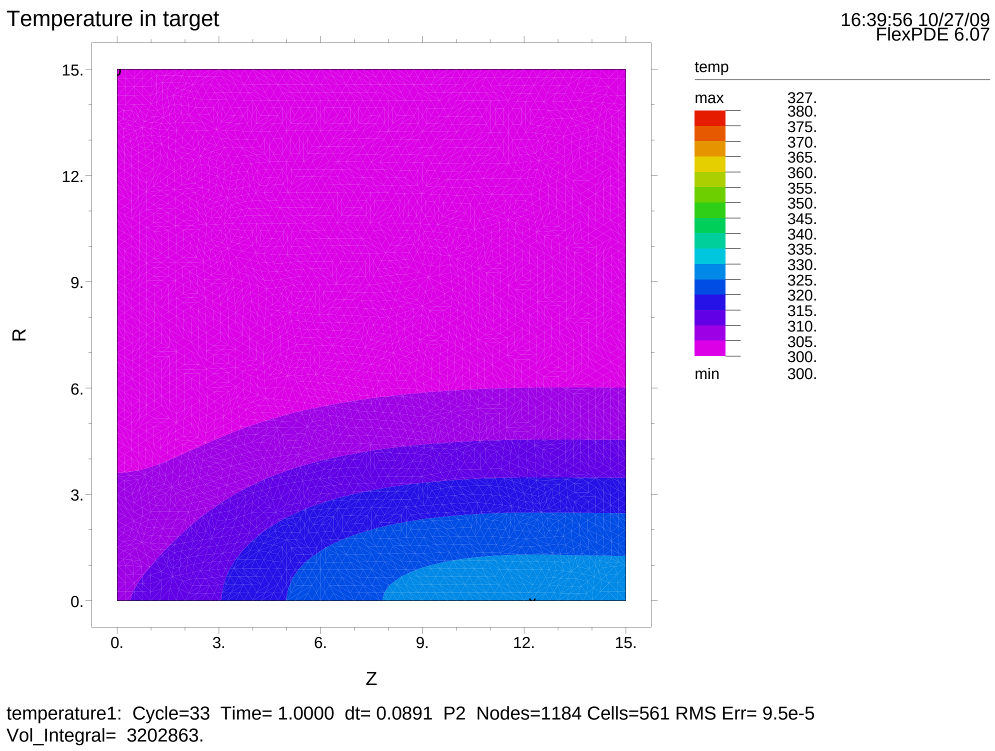
Hydrodynamical model

Heat Equation

$t = 0$



$t = 1$ s



for 100 bunches on 1 spot

Hydrodynamical model

PDE for pressure

$\ddot{P} - \nabla(c_0^2 \nabla P) = \Gamma / V_0 \dot{Q}$ c_0: speed of sound; $\Gamma = \Gamma(V) = V/c_V (\partial P / \partial T)_V$

- 2nd time derivative $\Rightarrow$ split in 2 PDE for FlexPDE:

```
EQUATIONS
pt:  dt(pt) - div(c0*grad(p)) = Gamma*qdot(t)
p:  pt - dt(p) = 0
```

- Analyse pressure at time scale $\mathcal{O}(10^{-10}\ \text{s})$

- Use Gaussian approximation for $\dot{Q}$:

```
qdot(t)=const/sigr^2*z*Exp(-(z-c*t)^2/sigz^2)*Exp(-r^2/sigr^2)
```

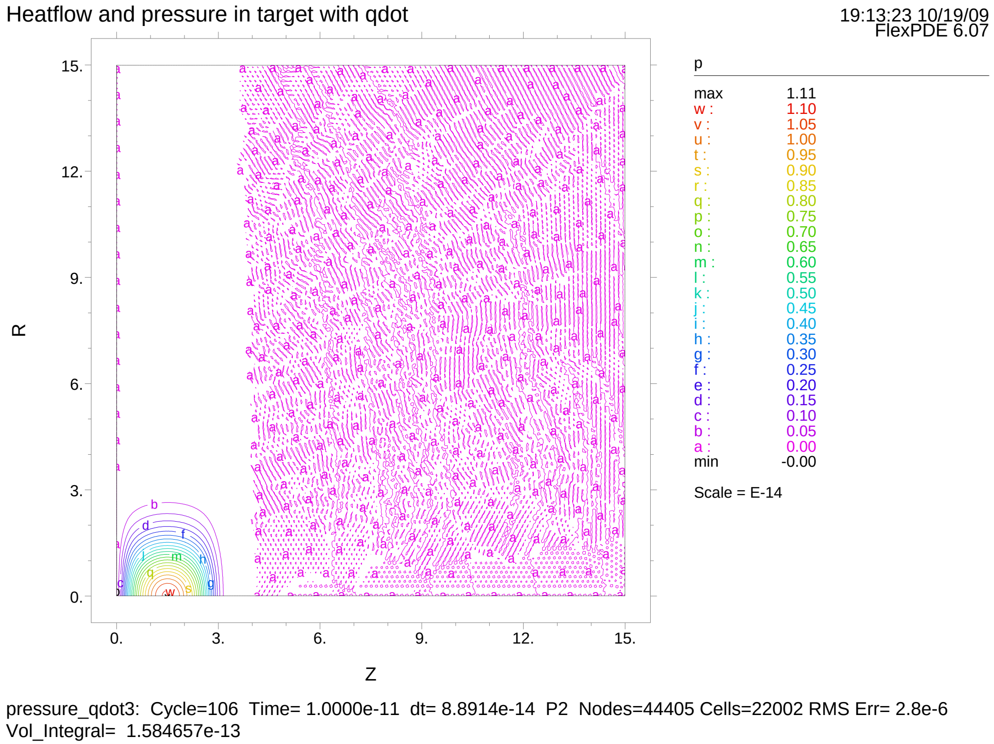
- Time scale of bunch crossing target: $l_T/c \sim 5 \cdot 10^{-11}$ s

Hydrodynamical model

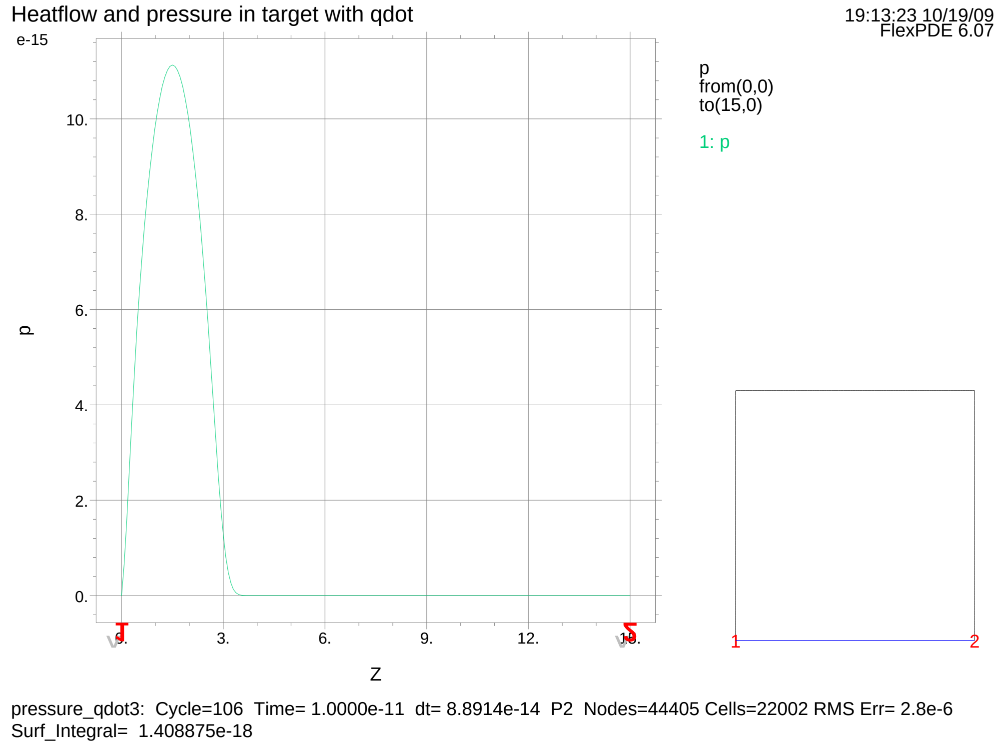
PDE for pressure

$$t = 10^{-11}\ \text{s}$$

Contours of P in a.u.



P on beam axis

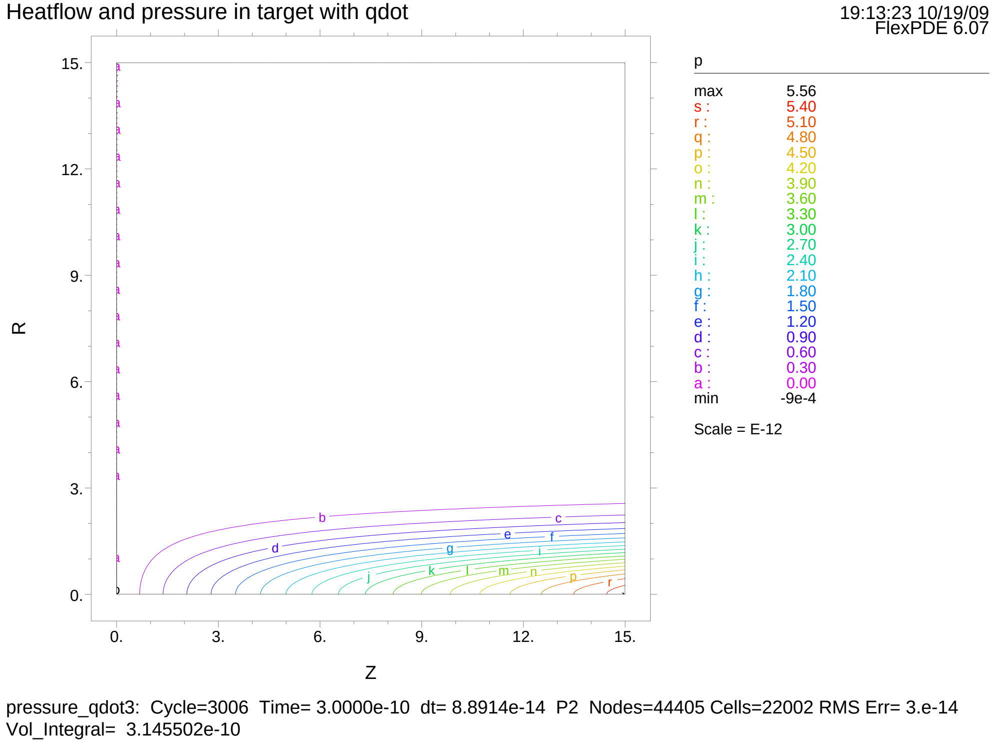


Hydrodynamical model

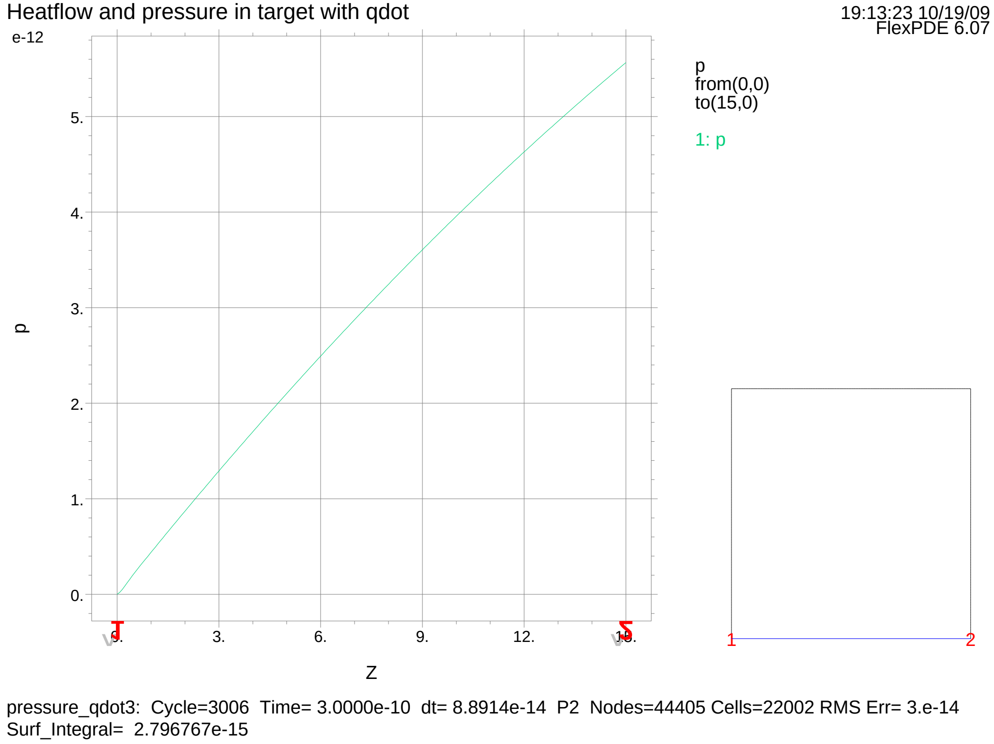
PDE for pressure

$t = 3 \cdot 10^{-10}$ s, natural boundary conditions

Contours of P in a.u.



P on beam axis

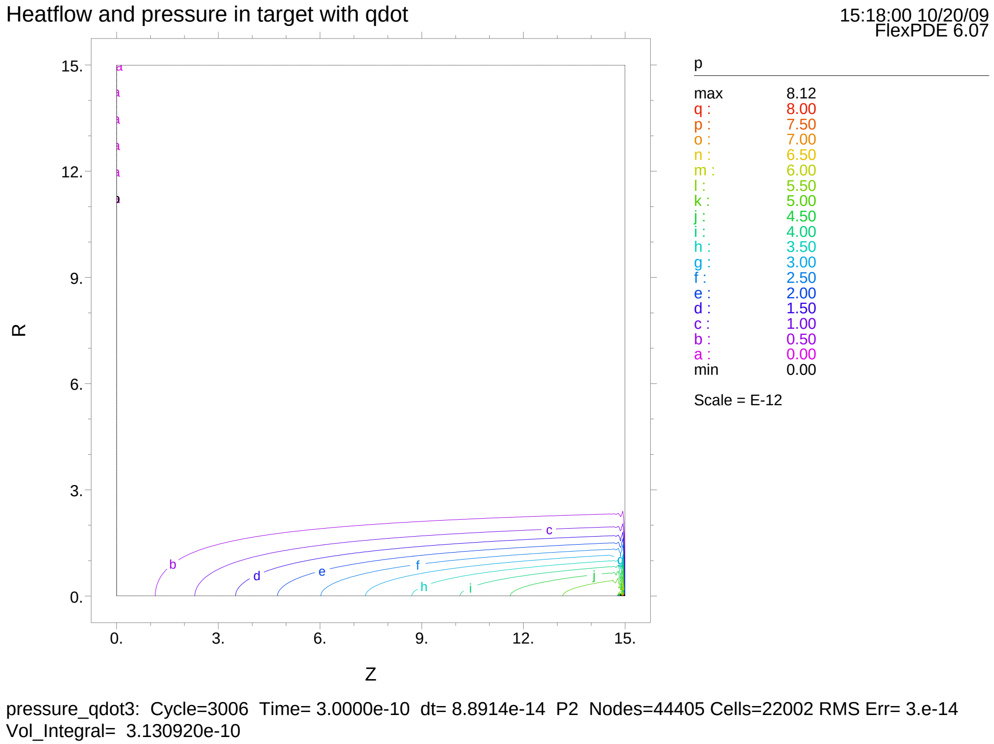


Hydrodynamical model

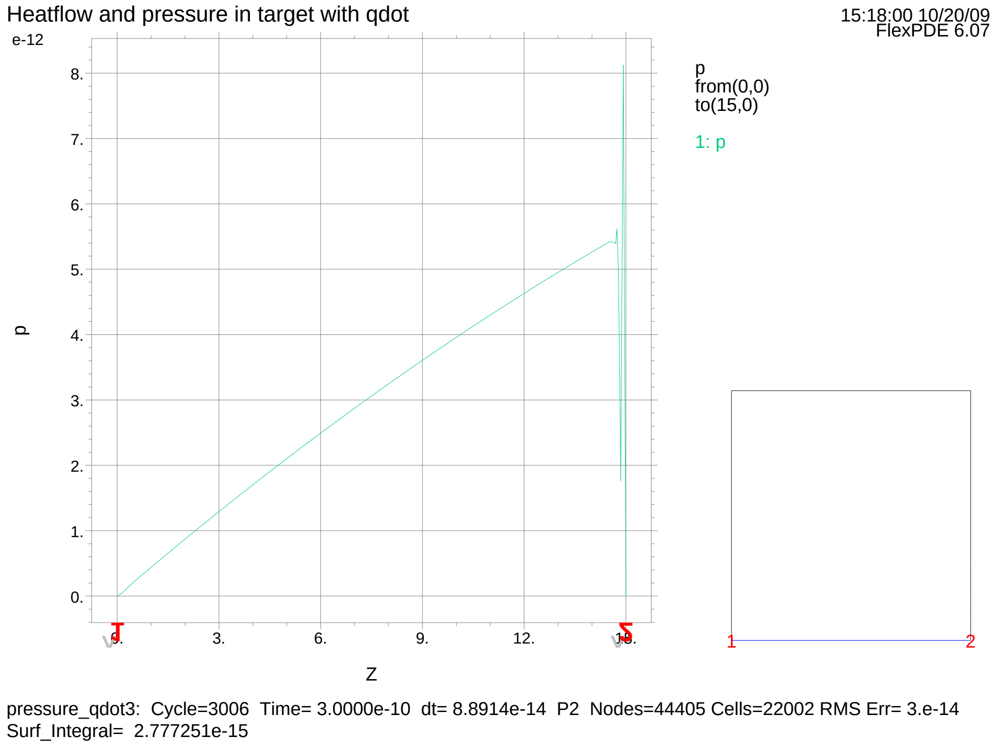
PDE for pressure

$$t = 3 \cdot 10^{-10}\ \text{s},\ P = 0 \text{ for } z = 0, 15\ \text{mm}$$

Contours of P in a.u.



P on beam axis



Hydrodynamical model

Work in progress

- Improvement of simulation
  - Boundary conditions
  - Moving mesh
- Timescales: $\mathcal{O}(10^{-10}\text{ s}) \leftrightarrow \mathcal{O}(10^{-7}\text{ s})$ for pressure waves (speed of sound in $\ddot{P} - \nabla(c_0^2 \nabla P) = \Gamma / V_0 \dot{Q}$)
- Improve description of $\dot{Q}$
- Improvement of hydrodynamical model

Summary

- Goal: Check possible pressure shock waves at target exit at $\mathcal{O}(10^{-10}\text{ s})$

- Simulations with FlexPDE

- Hydrodynamical model
  - Heat equation: $\nabla(k\nabla T) + \dot{Q} = \rho c_V \dot{T} \longrightarrow$ time scale $\mathcal{O}(1\text{ s})$
  - Pressure: $\ddot{P} - \nabla(c_0^2 \nabla P) = \Gamma / V_0 \dot{Q}$
    $\longrightarrow$ time scale $\mathcal{O}(10^{-10}\text{ s})$ for $\dot{Q}$
    and $\mathcal{O}(10^{-7}\text{ s})$ for pressure wave (c_0)

$\longrightarrow$ Work in progress