Positron target modelling

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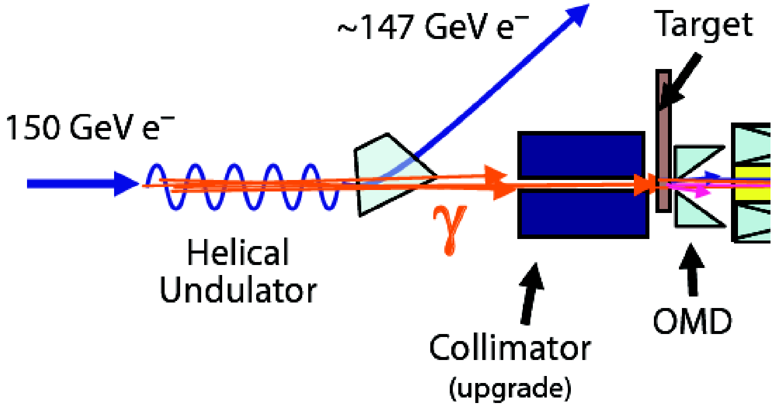
Outline

- Introduction
- Positron creation in target
- Thermal shocks in target
  - Initial energy deposition
  - Hydrodynamic model for heat flow
- Summary and outlook

Introduction

- Positron source, e.g. ILC RDR:



- Polarized γ on target $\Rightarrow$ polarized e^+
- Leading production process: e^+e^- pair creation
- Possible problems: thermal shocks in target
- Rotating wheel targets
- Prototype in Daresbury (Ti alloy)

[I. Bailey, L. Jenner, talks at Zeuthen meeting, April 2008]

- Alternatives: Liquid metals (Bi-Pb, Hg) [e.g. A.A. Mikhailichenko, CBN06-1, 2006]

Positron creation in target

[e.g. A.A. Mikhailichenko, PhD Thesis, 1986 (CBN 02/13, 2002)]
[K. Flöttmann, PhD Thesis, 1993]
[V.N. Baier, V.M. Katkov, Phys. Rept. **409** (2005) 261]

- Leading process: e^+e^- pair creation
- Quasi-classical approximations
- Simulation with e.g. GEANT, FLUKA
  $\longrightarrow$ tested against data
- Program CONVERSION.EXE [A.A. Mikhailichenko]
  - Includes: undulator → target → lens → acceleration
  - Output: efficiencies, effective polarizations
    $\longrightarrow$ hard to test/compare details of processes in target

Thermal shocks in target

- Rapid energy deposition of γ beam $\Rightarrow$ pressure shock wave
- Hydrodynamic 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
  - Results: *“Ti target not surviving with present margins”*

Thermal shocks in target

Plan: Check 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:

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

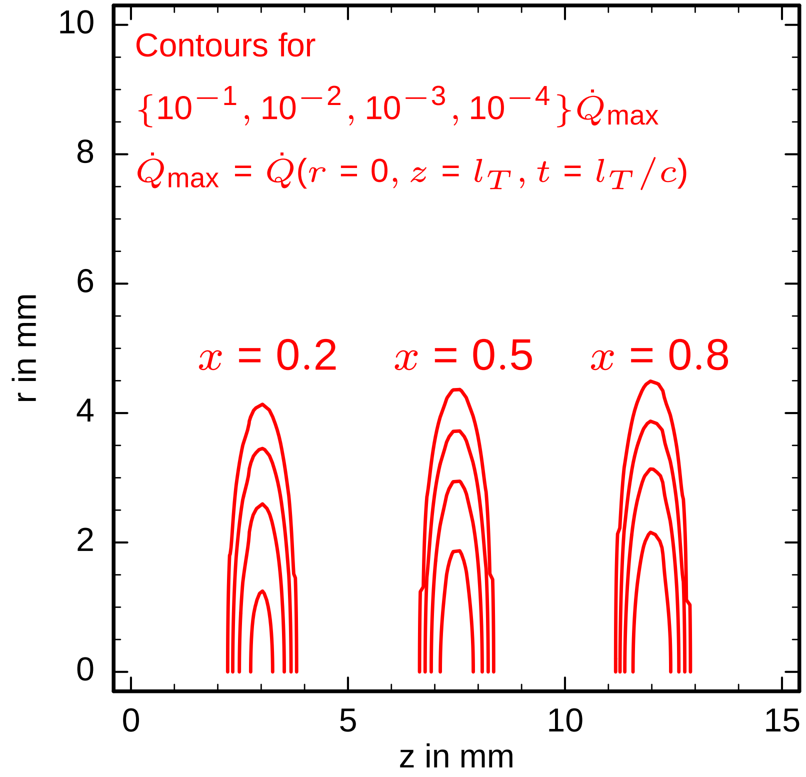
  $\int \dot{Q}(\vec{x}, t) dV dt = Q_{\text{bunch}}$; $\sigma_z, \sigma_\perp$: bunch dimensions; l_T: target thickness

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

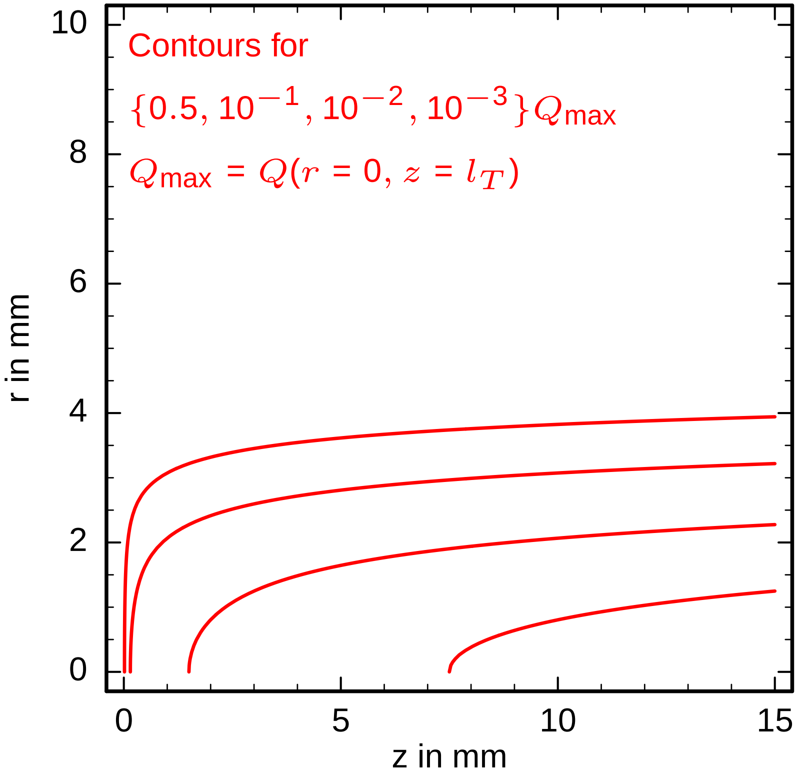
Thermal shocks in target

For l_T = 15 mm, σ_z = 0.3 mm, $\sigma_\perp$ = 1.5 mm

$\dot{Q}(\vec{x}, t = x \cdot l_T/c)$



$Q(\vec{x})$



→ Energy deposition of one bunch

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

→ instantaneous for hydrodynamical heat flow

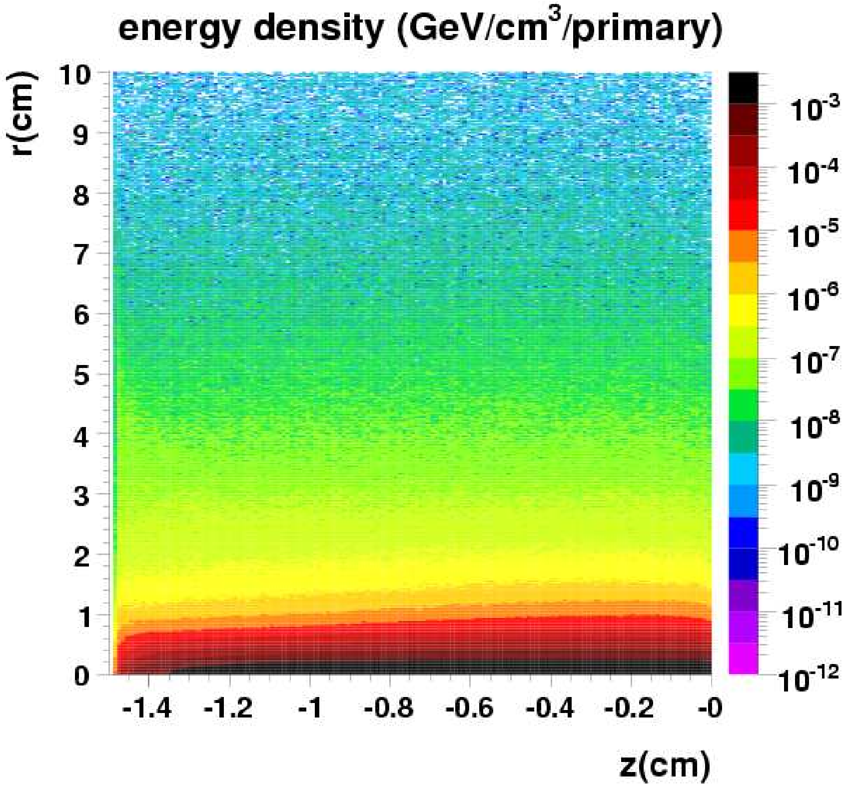
Thermal shocks in target

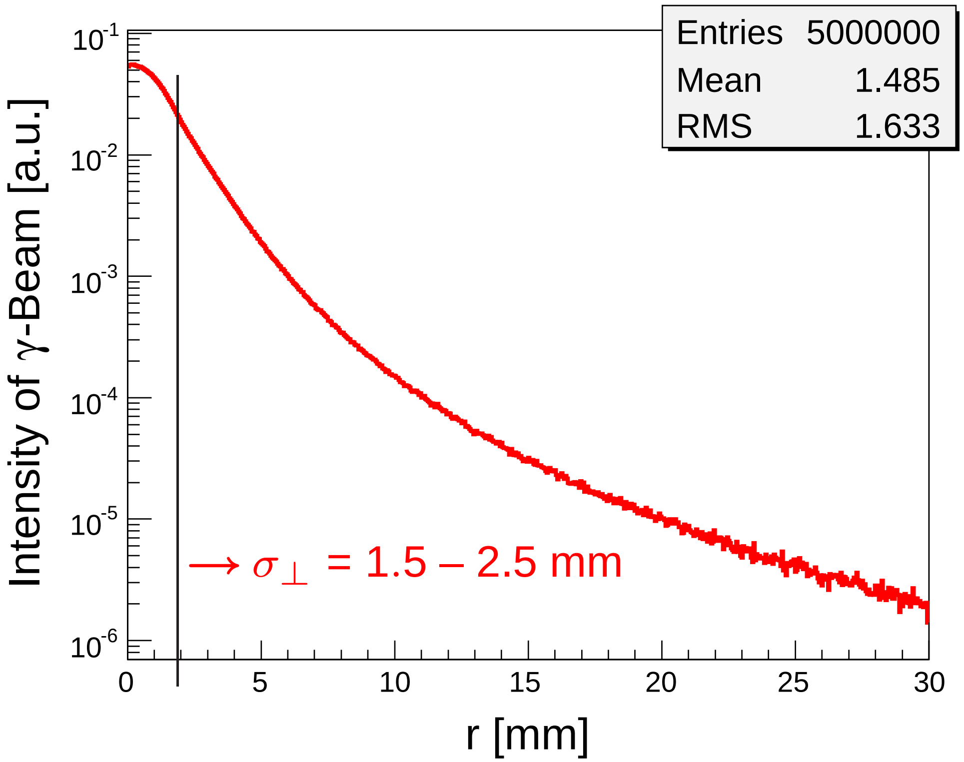
Simulation with FLUKA [Zeuthen group: S. Riemann, A. Schälicke, A. Ushakov]

Includes higher harmonics of undulator radiation

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

→ γ-beam intensity extends to larger r than for Gaussian distribution

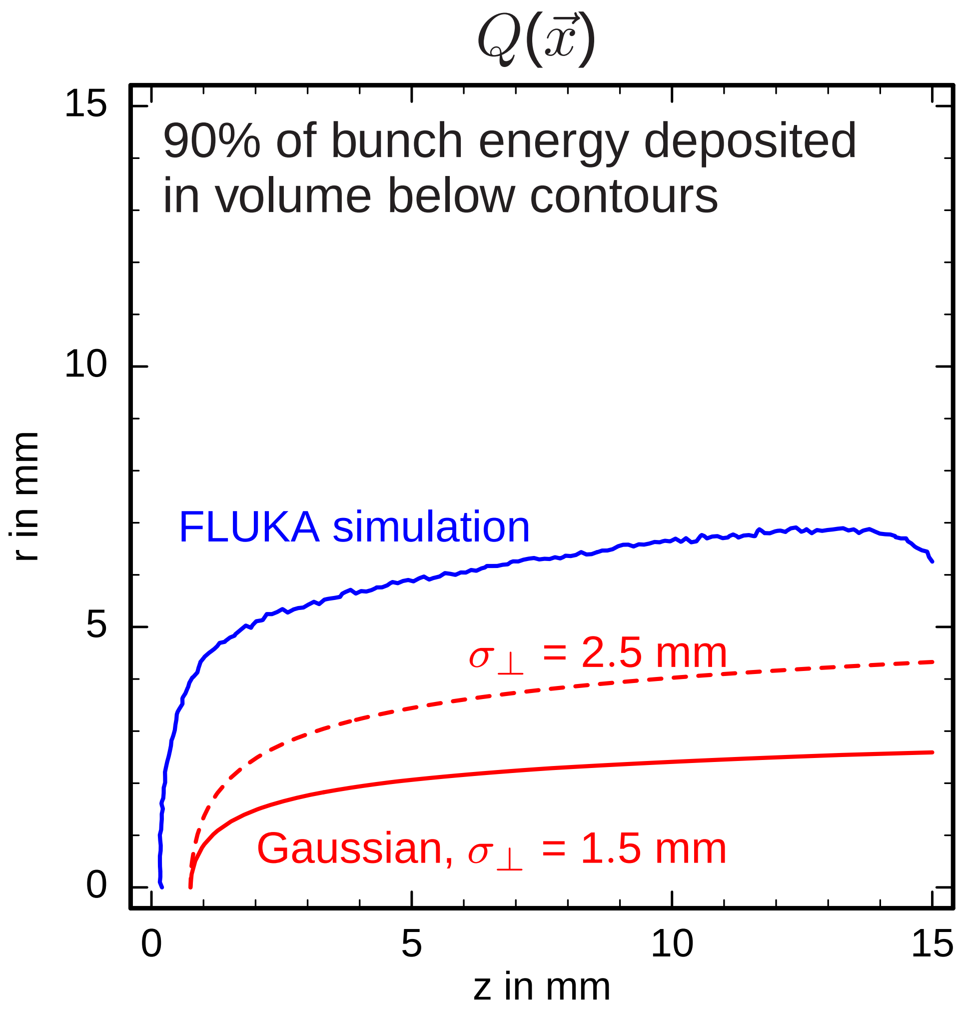




→ $\sigma_\perp$ = 1.5 – 2.5 mm

Thermal shocks in target

Comparison



$\Rightarrow$ In (more realistic) FLUKA simulation the energy is distributed in larger volume than in Gaussian approximation

Thermal shocks in target

To do

Apply hydrodynamical model

- Relevant time scale $\sim 10^{-7}$ s (governed by speed of sound)

  $\Rightarrow$ energy deposition by 1 bunch is instantaneous (time scale $\sim 5 \cdot 10^{-11}$ s)

  $\longrightarrow$ $Q(\vec{x})$ defines initial temperature distribution

- Next step: solve partial differential equations for heat transport:

  $\nabla(k\nabla T) + \dot{Q} = \rho c_V \dot{T}$, $\ddot{P} - \nabla(c_0^2 \nabla P) = \Gamma / V_0 \dot{Q}$

- Within time scale $\sim 10^{-7}$ s also next bunch hits target

Summary and outlook

- Initial energy deposition in target

  Cornell simulations: Gaussian approximation of γ beam intensity

  $\longrightarrow$ bunch energy deposition in smaller volume
  than for FLUKA simulation

  $\longrightarrow$ important issue if target survivability is discussed

- Combine efforts with studies about radiation damage in collimators

  [J.L. Fernandez-Hernando, talk at LCUK Meeting, Birmingham, April 2008]

  $\longrightarrow$ tests at ATF-KEK