Target survivability studies

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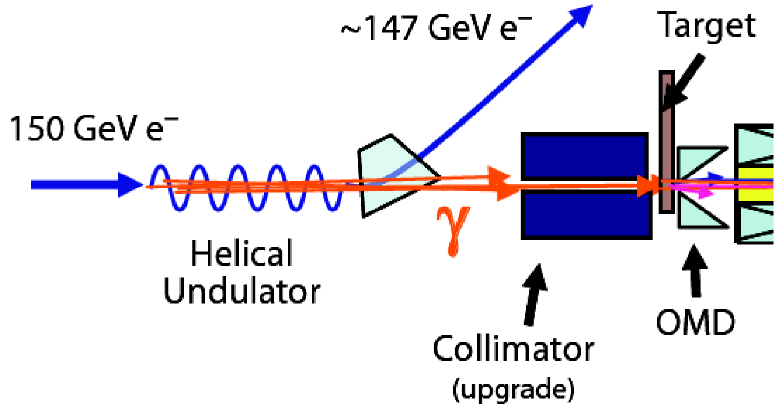
Outline

- Introduction
- Positron creation in target
- Thermal shocks in target
- Initial energy deposition in target
- Outlook: Hydrodynamic model for heat flow
- Conclusions

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) [L. Jenner's talk]
- 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 KONN (CONVERSION.EXE) [A.A. Mikhailichenko]
  - Includes: undulator $\rightarrow$ target $\rightarrow$ lens $\rightarrow$ 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: $Q(\vec{x}) = \int \dot{Q}(\vec{x}, t) dt$

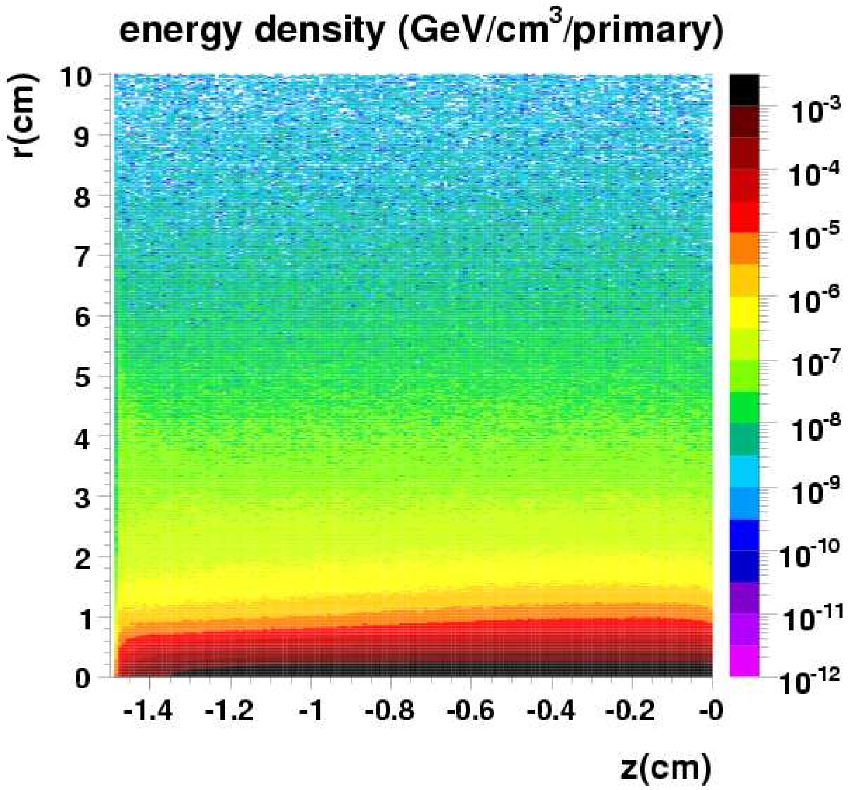
Energy deposition in target

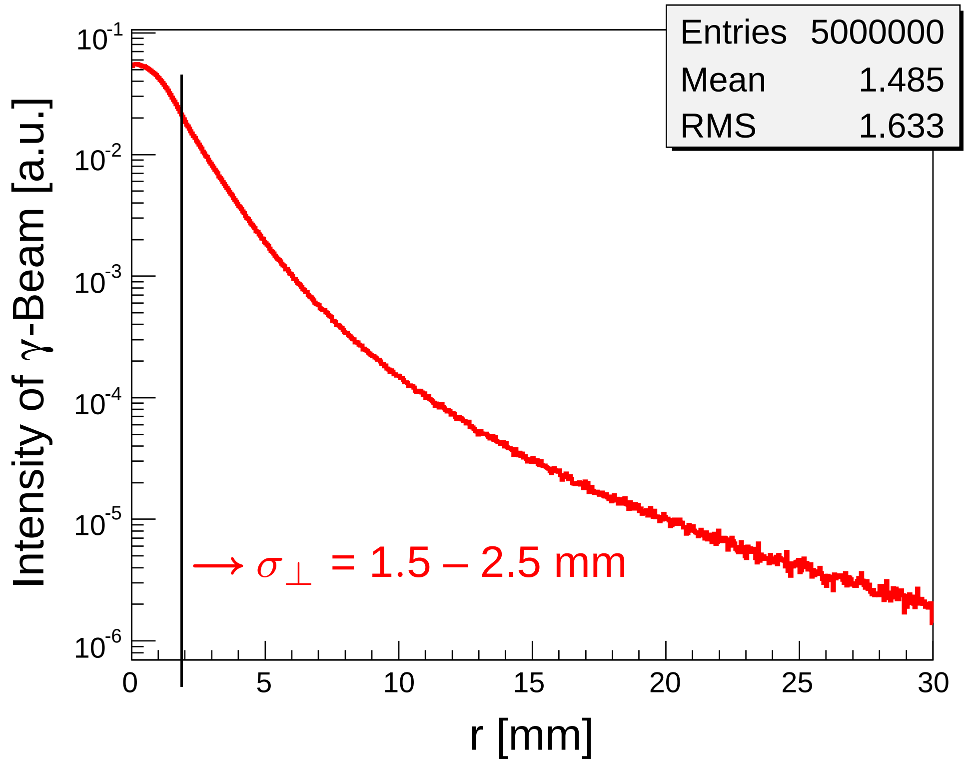
Simulation with FLUKA [Zeuthen group: S. Riemann, A. Schälicke, A. Ushakov]

Includes higher harmonics of undulator radiation

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

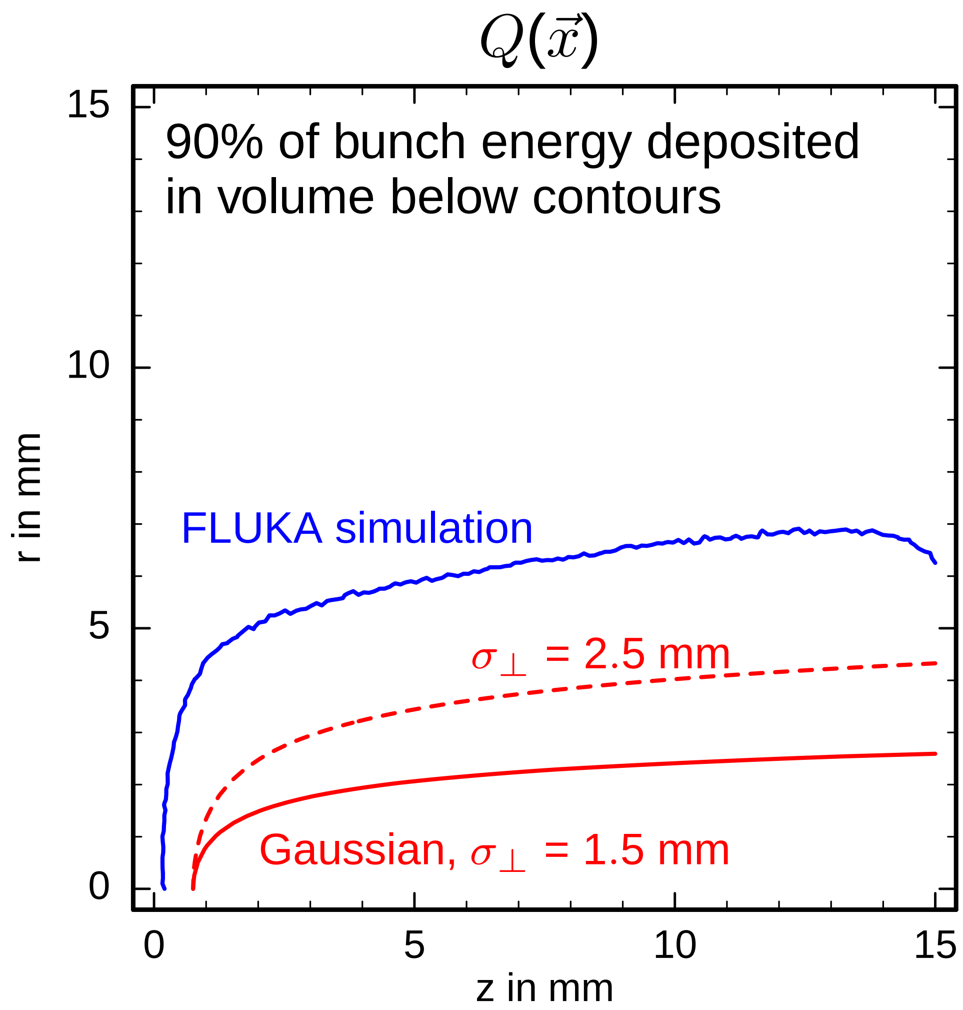
$\longrightarrow$ γ-beam intensity extends to larger r than for Gaussian distribution





Energy deposition in target

Comparison



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

Energy deposition in target

Angular distribution of undulator radiation

[B.M. Kincaid, J. Appl. Phys. **48** (1977) 2684]

$$\frac{dW}{d\Omega} = \frac{8Ne^2\omega_0K^2\gamma^4}{c(1+K^2+\gamma^2\theta^2)^3}\sum_{n=1}^{\infty} n^2 \left[J_n'^2(x_n) + \left(\frac{\gamma\theta}{K} - \frac{n}{x_n}\right)^2 J_n^2(x_n) \right]$$

where $J_n(x)$: Bessel function of the first kind

$$\gamma = \frac{E_{e^-}}{m_e}, \quad x_n = \frac{2Kn\gamma\theta}{(1+K^2+\gamma^2\theta^2)}, \quad \omega_0 = \frac{2\pi\beta^* c}{\lambda_0}, \quad \beta^* = \beta\sqrt{1-\left(\frac{K}{\gamma}\right)^2}$$

for undulator with K, period λ_0, number of periods N

and e^- beam energy E_{e^-}

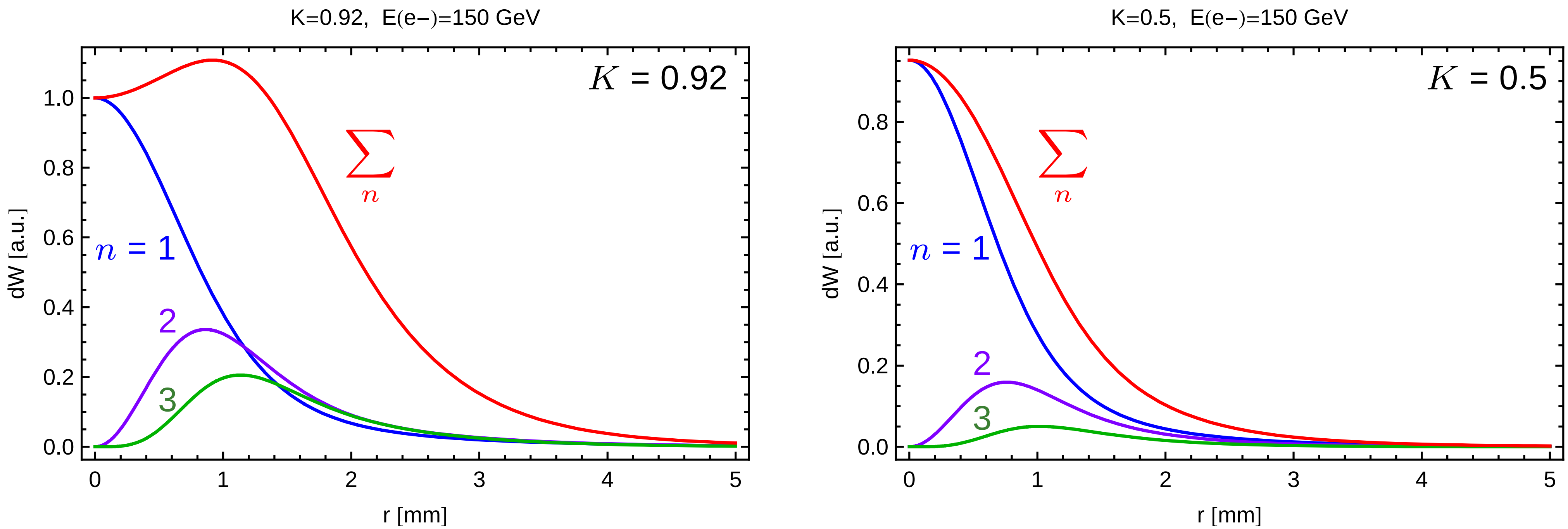
In the following:

Normalisation $\quad dW(K = 0.92, E_{e^-} = 150\text{ GeV}, \theta \to 0) \equiv 1$

Energy deposition in target

Energy distribution $dW(r)$ at target surface

for $r = \theta\, d_{\rm UT}$, undulator-target distance $d_{\rm UT}$ = 500 m, E_{e^-} = 150 GeV



$\Rightarrow K \sim 1$:

Gaussian approximation (n = 1) underestimates volume of initial energy deposition

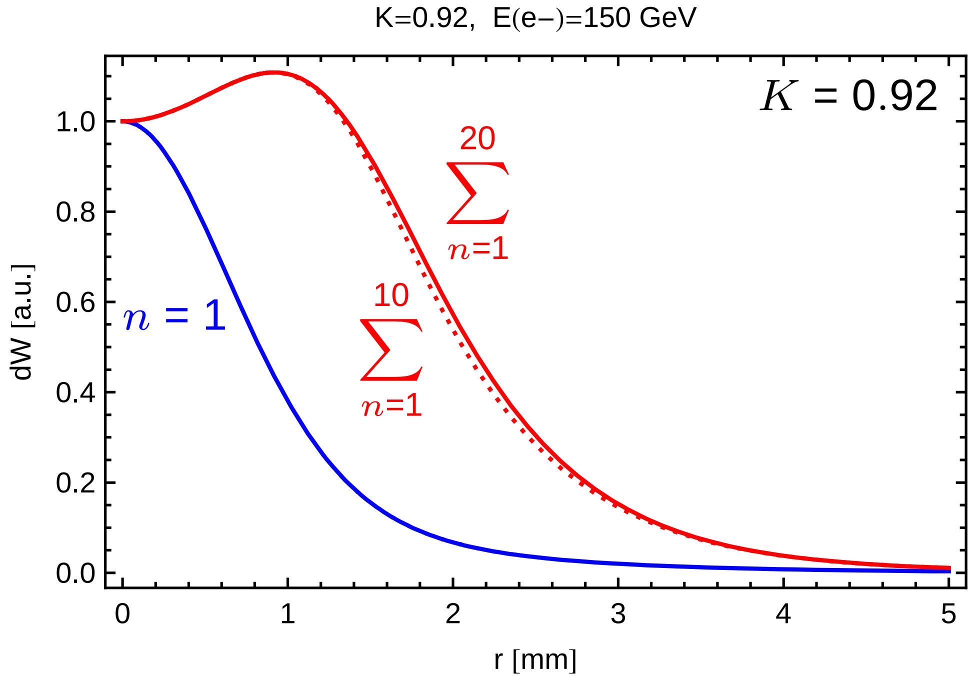
$\Rightarrow K \lesssim 0.5$:

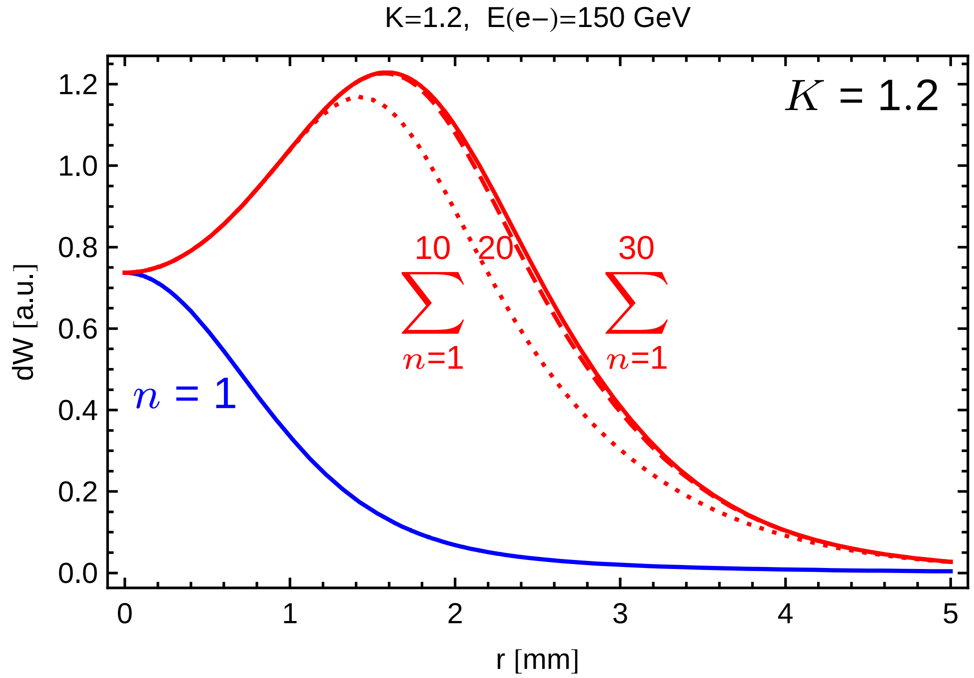
Gaussian approximation better

Energy deposition in target

Higher harmonics in $dW(r)$

(d_{UT} = 500 m)



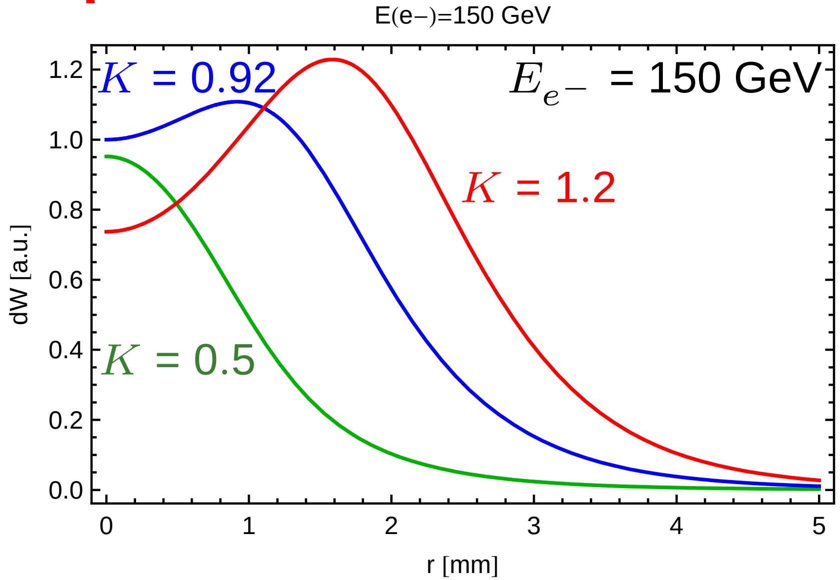


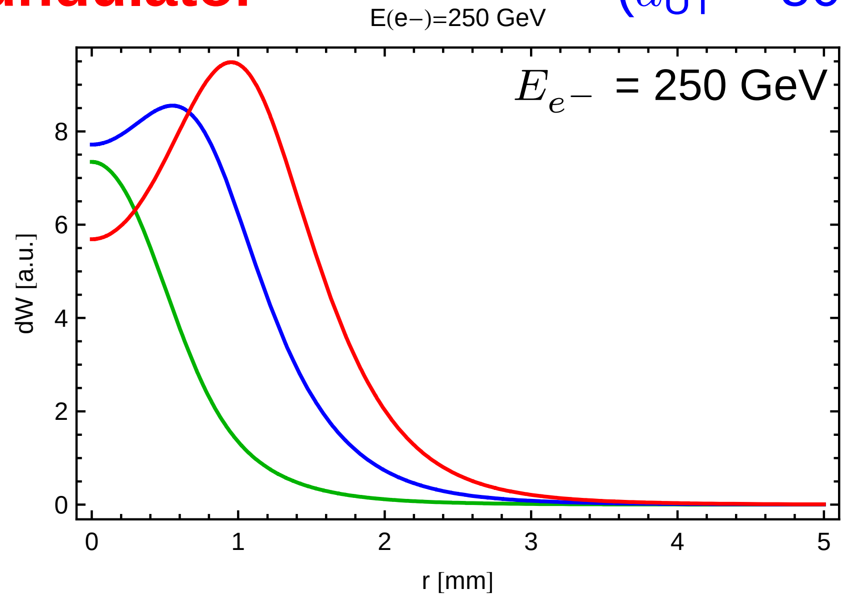
$\Rightarrow K \sim 1$:
First 10 harmonics describe distribution well

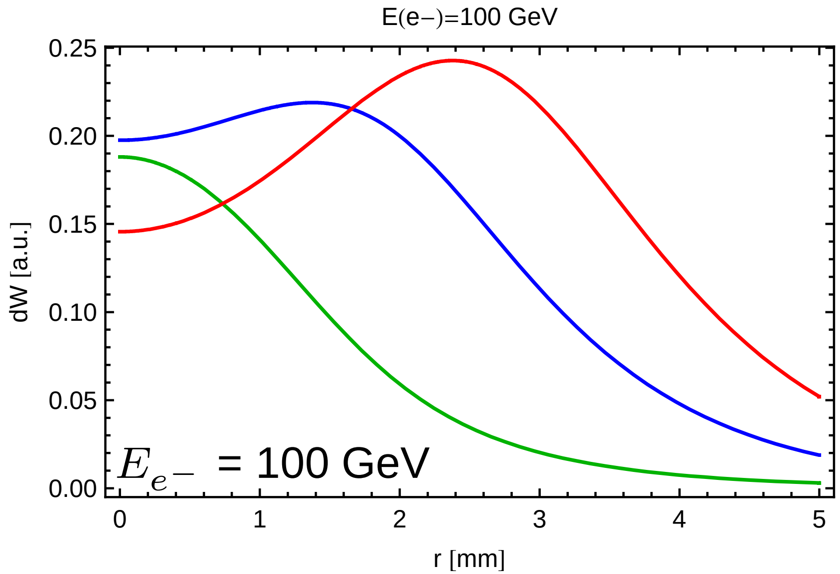
$\Rightarrow K > 1$:
More harmonics necessary

Energy deposition in target

Dependence on e^- beam energy in undulator (d_{UT} = 500 m)







$\Rightarrow$ E_{e^-} = 250 GeV:
Larger energy hits target in smaller volume than for E_{e^-} = 150 GeV

$\longrightarrow$ Steeper temperature gradients?

$\longrightarrow$ Test impact on thermal stress!

Outlook: Hydrodynamical model

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 $l_T/c \sim 5 \cdot 10^{-11}$ 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

Conclusions

- Initial energy deposition in target
  - Cornell simulations $\longrightarrow$ Gaussian approximation (first harmonic)

    $\longrightarrow$ $K \sim 1$ underestimates volume where energy is deposited

    $\longrightarrow$ $K \lesssim 0.5$: Gaussian approximation better
  - Higher E_{e^-} $\Rightarrow$ larger energy hits target in smaller volume

  $\longrightarrow$ Important issues if target survivability is discussed
- To be done: application of hydrodynamical model for heat transport
- 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