# Target Shock Wave Study

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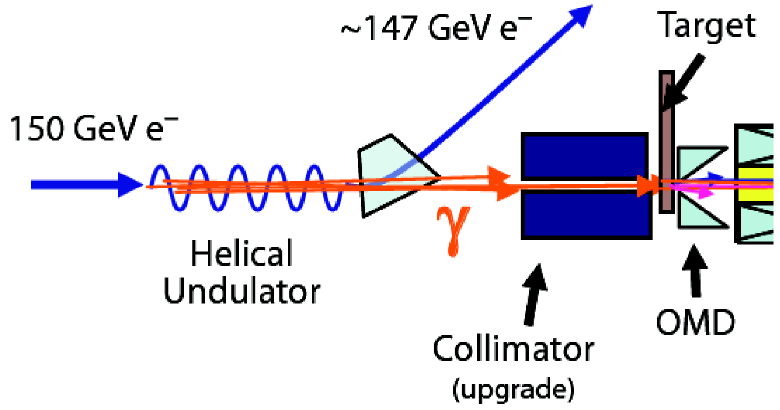
# Outline

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

# Introduction

- Positron source, e.g. ILC RDR:




- Polarized $\gamma$ 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 $\gamma$ 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
  - 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: $Q(\vec{x}) = \int \dot{Q}(\vec{x}, t) dt$

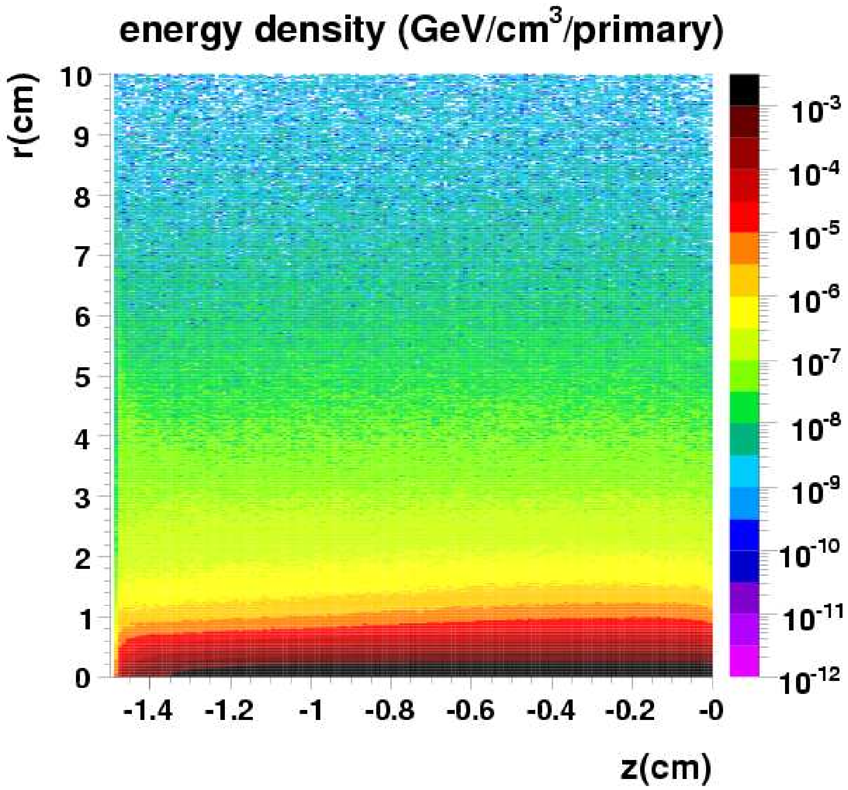
# Energy deposition in target

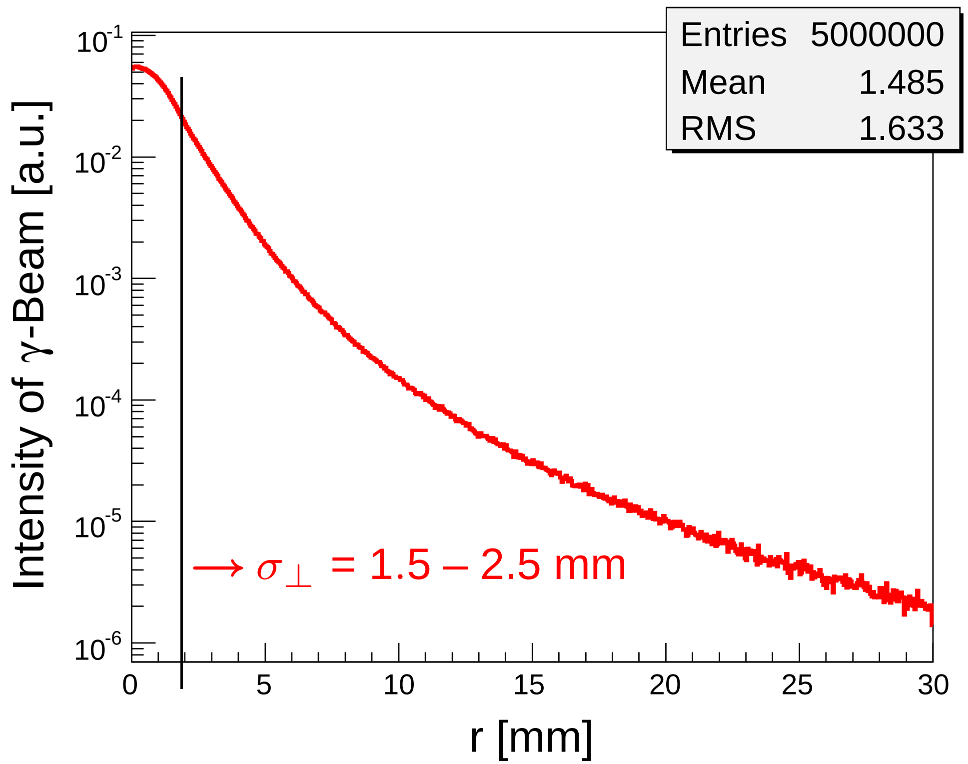
**Simulation with FLUKA** [Zeuthen group: S. Riemann, A. Schälicke, A. Ushakov]

Includes higher harmonics of undulator radiation

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

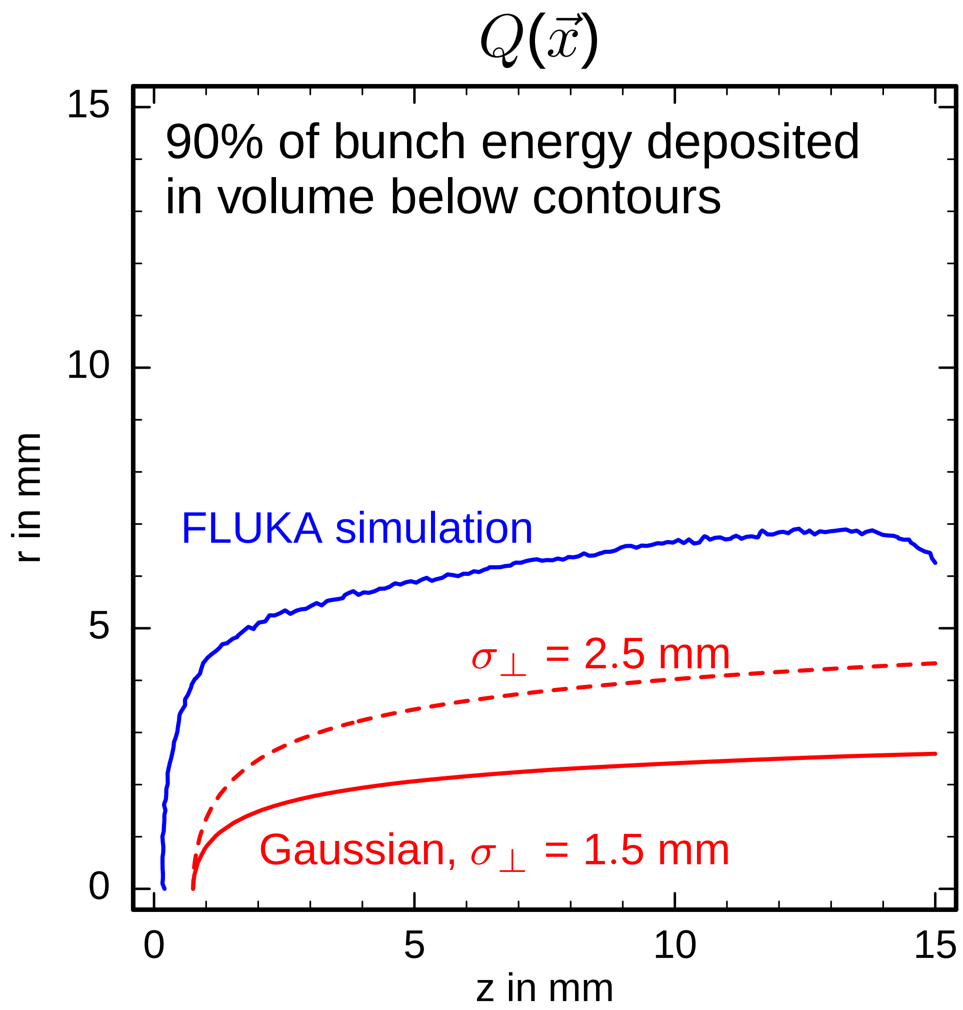
$\longrightarrow$ $\gamma$-beam intensity extends to larger $r$ than for Gaussian distribution



# 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]

$$\frac{dW}{d\Omega} = \frac{8Ne^2\omega_0 K^2\gamma^4}{c(1+K^2+\gamma^2\theta^2)^3}\sum_{n=1}^{\infty} n^2 \left[ J_n'^2(x_n) + \left(\frac{\gamma\theta}{K} - \frac{n}{x_n}\right)^2 J_n^2(x_n) \right]$$

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 $\lambda_0$, number of periods $N$

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

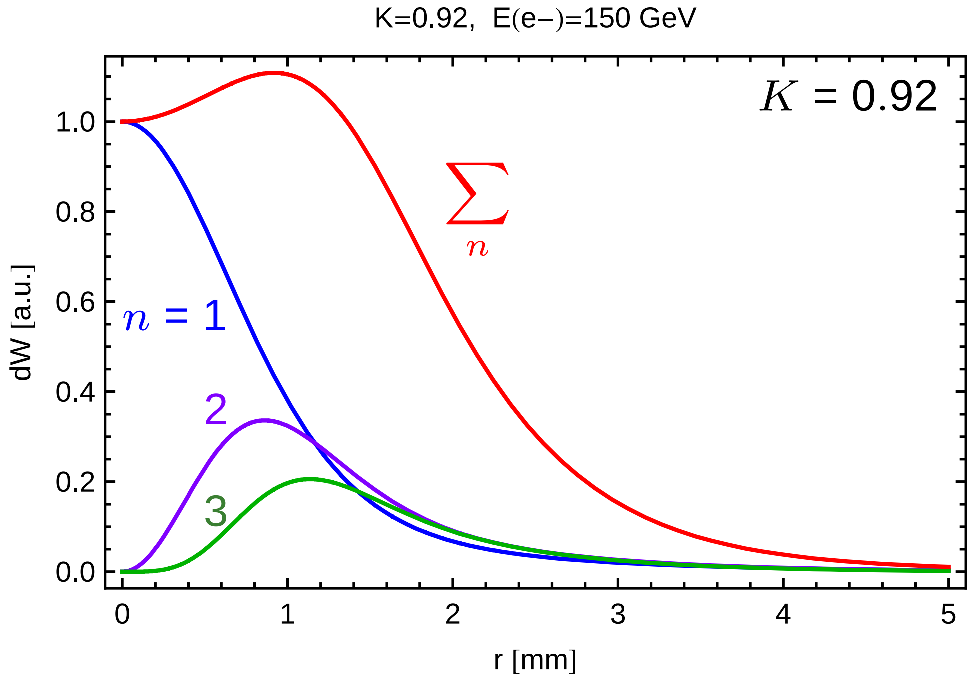
In the following:

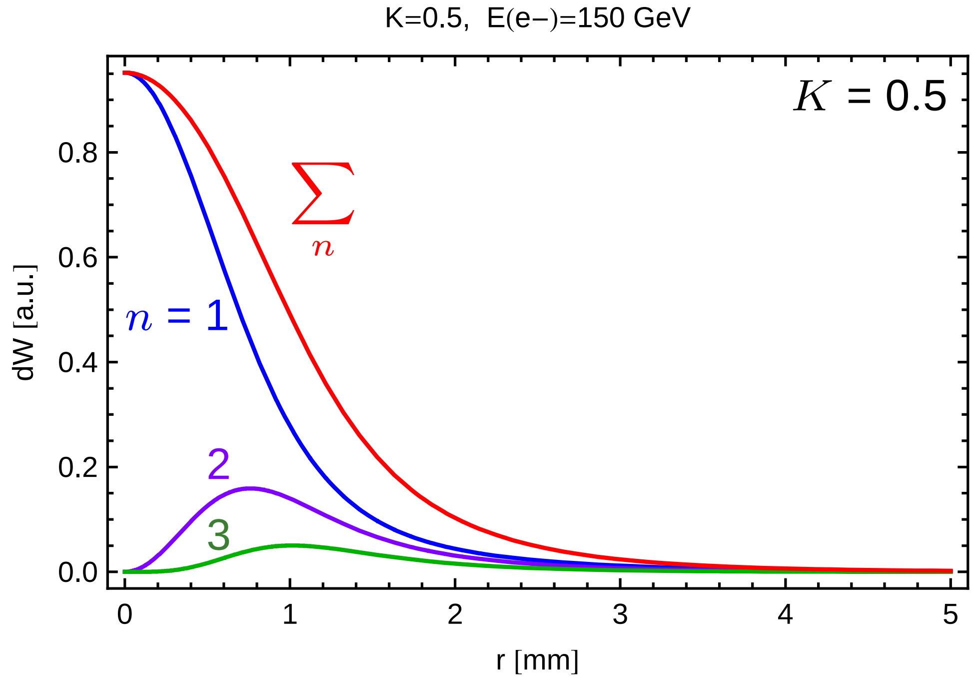
Normalisation $\quad dW(K = 0.92, E_{e^-} = 150\ \text{GeV}, \theta \to 0) \equiv 1$

# Energy deposition in target

## Energy distribution $dW(r)$ at target surface

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




$\Rightarrow K \sim 1$:

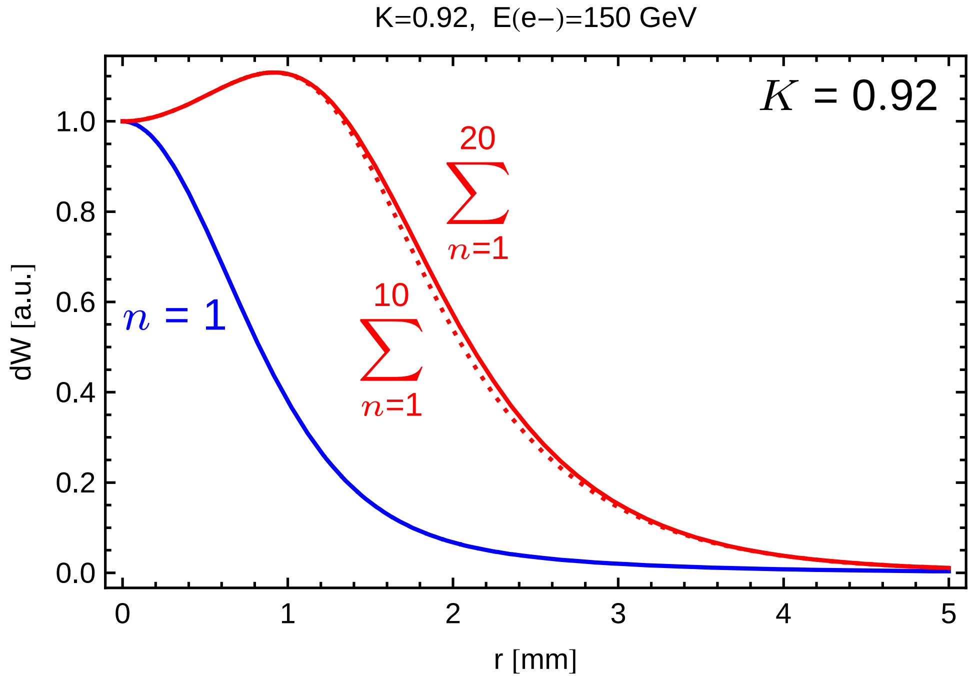
Gaussian approximation ($n = 1$) underestimates volume of initial energy deposition

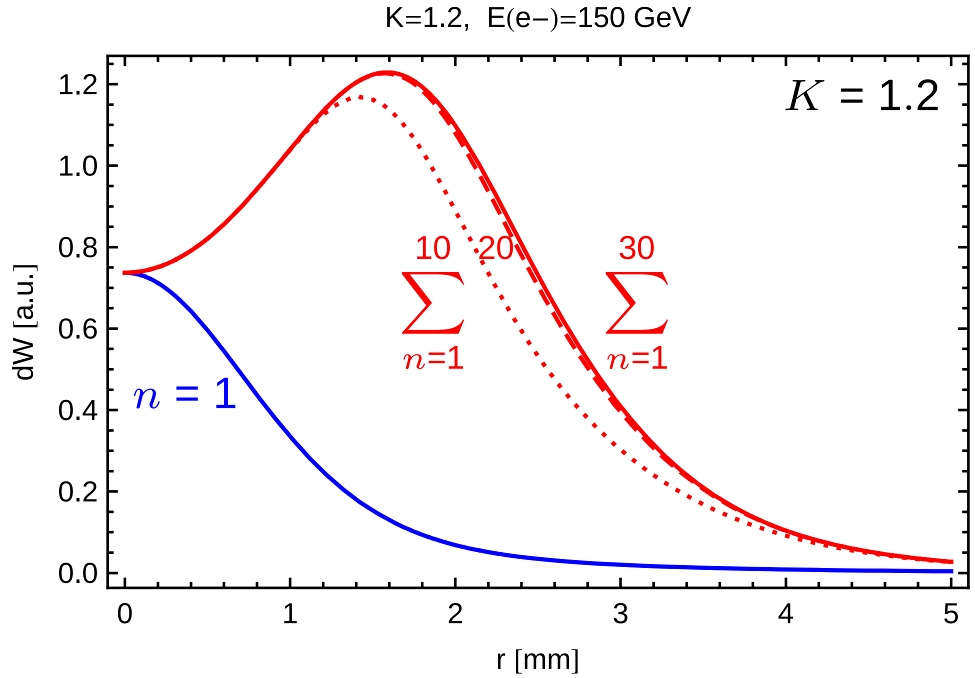
$\Rightarrow K \lesssim 0.5$:

Gaussian approximation better

# Energy deposition in target

## Higher harmonics in $dW(r)$ ($d_{\mathrm{UT}}$ = 500 m)



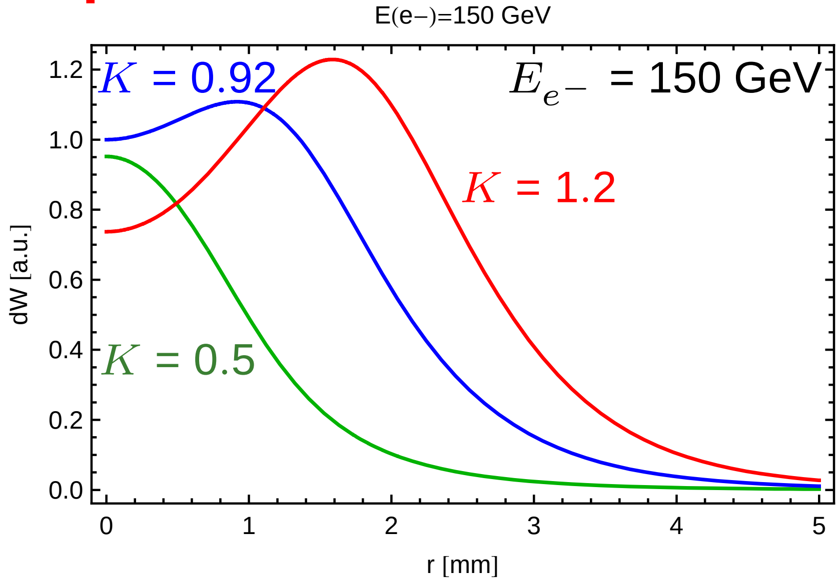



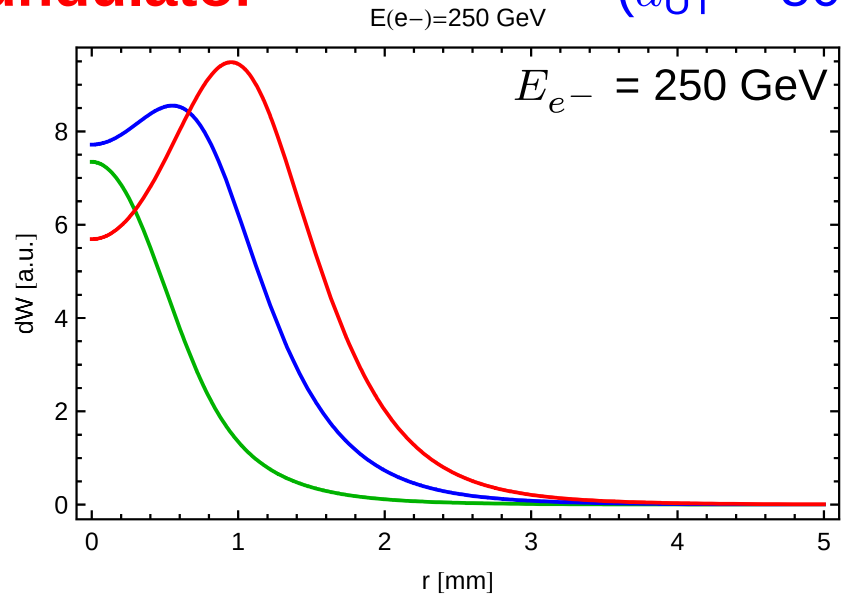

$\Rightarrow K \sim 1$:
First 10 harmonics describe distribution well

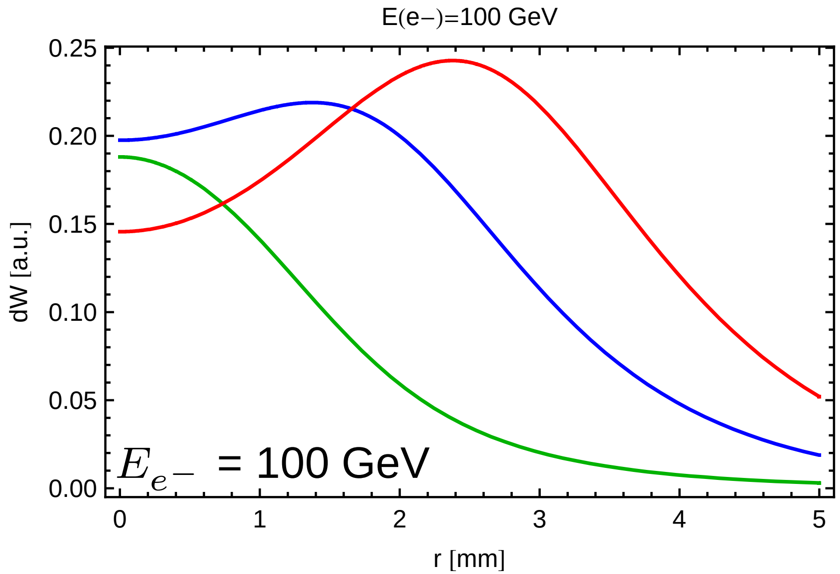
$\Rightarrow K > 1$:
More harmonics necessary

# 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

$\rightarrow$ Steeper temperature gradients?

$\rightarrow$ Test impact on thermal stress!

# 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

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

- Application of hydrodynamical model for heat transport

  $\longrightarrow$ solve partial differential equations with FlexPDE

# Hydrodynamical model

## Work underway

- Read FLUKA simulated initial energy deposition into FlexPDE
- Calculate time evolution of temperature and pressure distributions using
  - Heat equation: $\nabla(k\nabla T) + \dot{Q} = \rho c_V \dot{T}$
  - Pressure: $\ddot{P} - \nabla(c_0^2 \nabla P) = \Gamma / V_0 \dot{Q}$
- Resulting shock waves can be analysed

- Outlook: improvement of hydrodynamical model

# 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
- Application and test of hydrodynamical model for heat transport

  $\longrightarrow$ Work underway
- 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