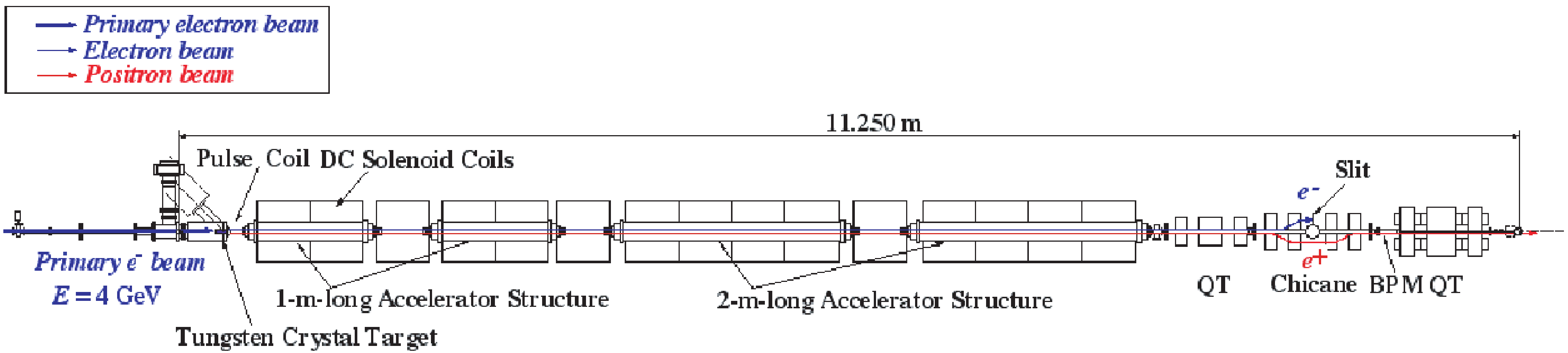
NEW POSITRON SOURCE AT THE KEKB INJECTOR LINAC BASED ON ORIENTED TUNGSTEN CRYSTAL CONVERTER

KEKB Positron Source Layout



Primary Electron Beam Parameters

e^-

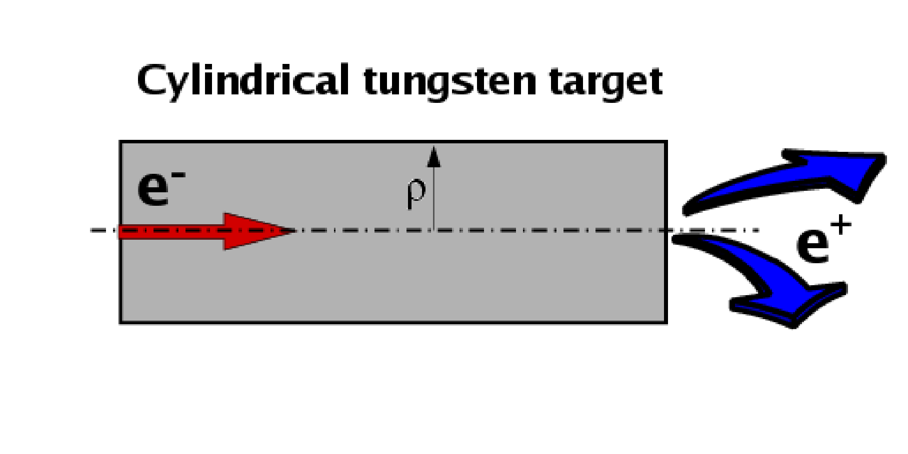
- Energy – 4GeV
- Horizontal Angular Spread (RMS) – 0.2 mrad
- Vertical Angular Spread (RMS) – 0.1 mrad
- Horizontal Emittance – 660 mm mrad
- Vertical Emittance – 360 mm mrad
- Transverse Beam Size – 0.7 mm
- Bunch Duration – 10 ps
- Maximal beam rate – 50 Hz
- Bunch charge – 7.8 nC

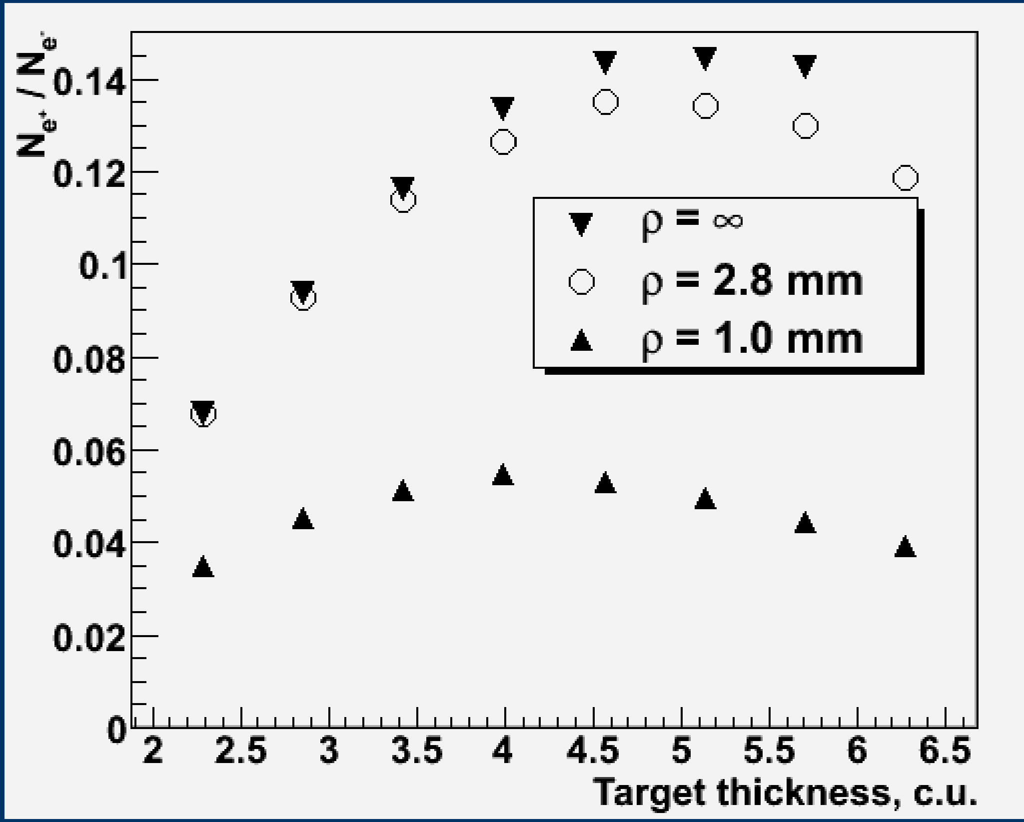
Positron production efficiencies for the first(second) bunch:

- Crystalline 10.5- mm-thick tungsten target – 0.23±0.02(0.24±0.02)
- Amorphous 14-mm-thick tungsten target – 0.20±0.01(0.20±0.01)

Acceptance condition:

$$8.6\frac{MeV}{c} < p < 11.6\frac{MeV}{c},\ p_t < 2.4\frac{MeV}{c}$$





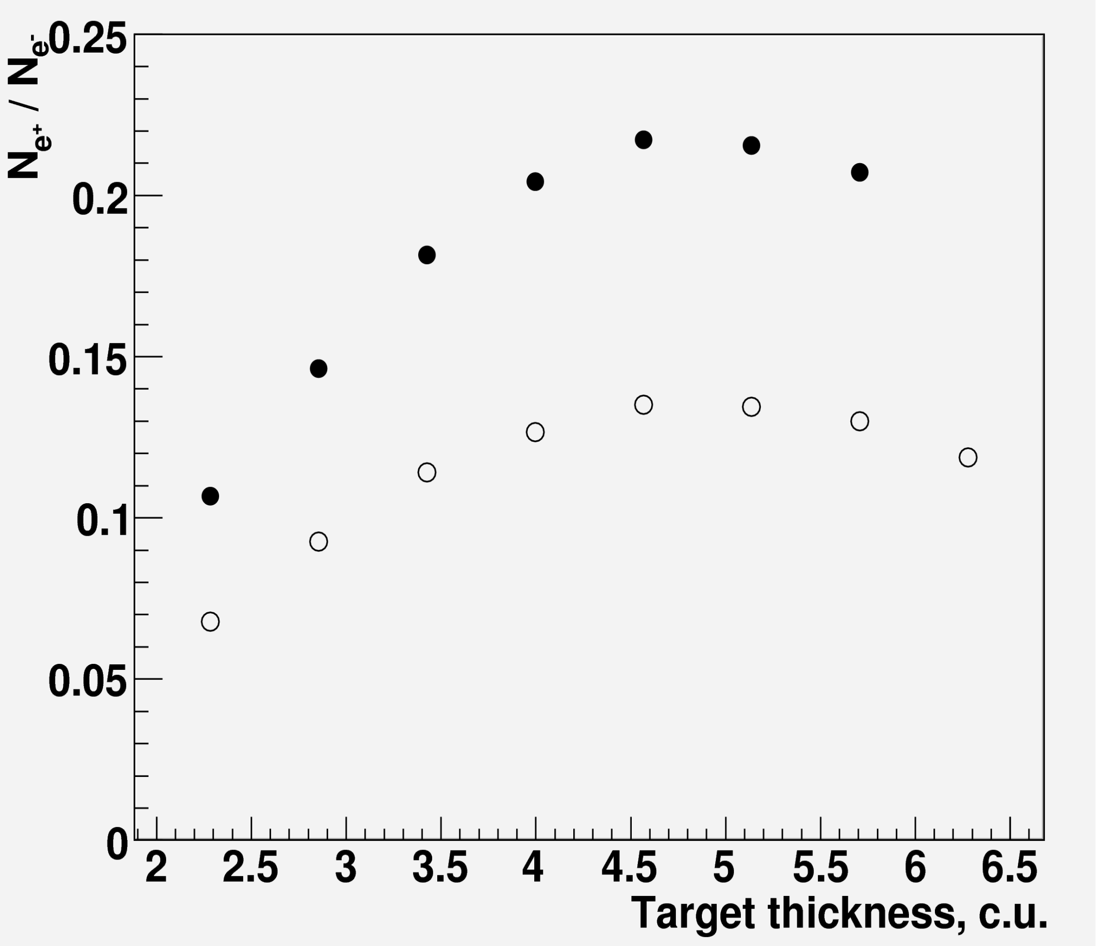
- Number captured positrons is depended on acceptance radius.
- For the given acceptance condition measured positron production efficiency essentialy exceeds results of simulation...

Acceptance condition:

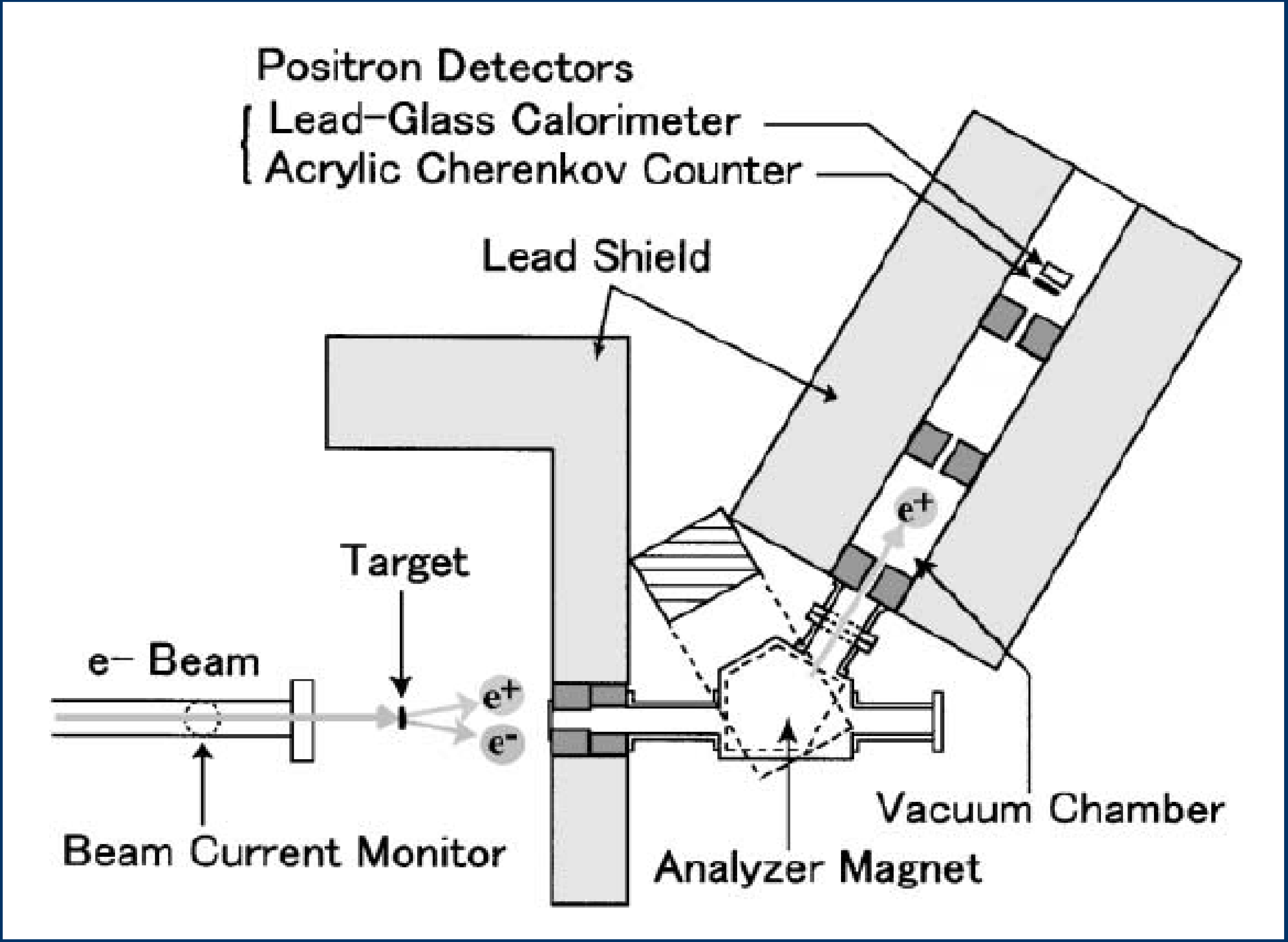
Old : $8.6\frac{MeV}{c} < p < 11.6\frac{MeV}{c}\,,\ p_t < 2.4\frac{MeV}{c}$

New: $7.8\frac{MeV}{c} < p < 12.0\frac{MeV}{c}\,,\ p_t < 2.8\frac{MeV}{c}\,,\ \rho = 2.8\,mm$

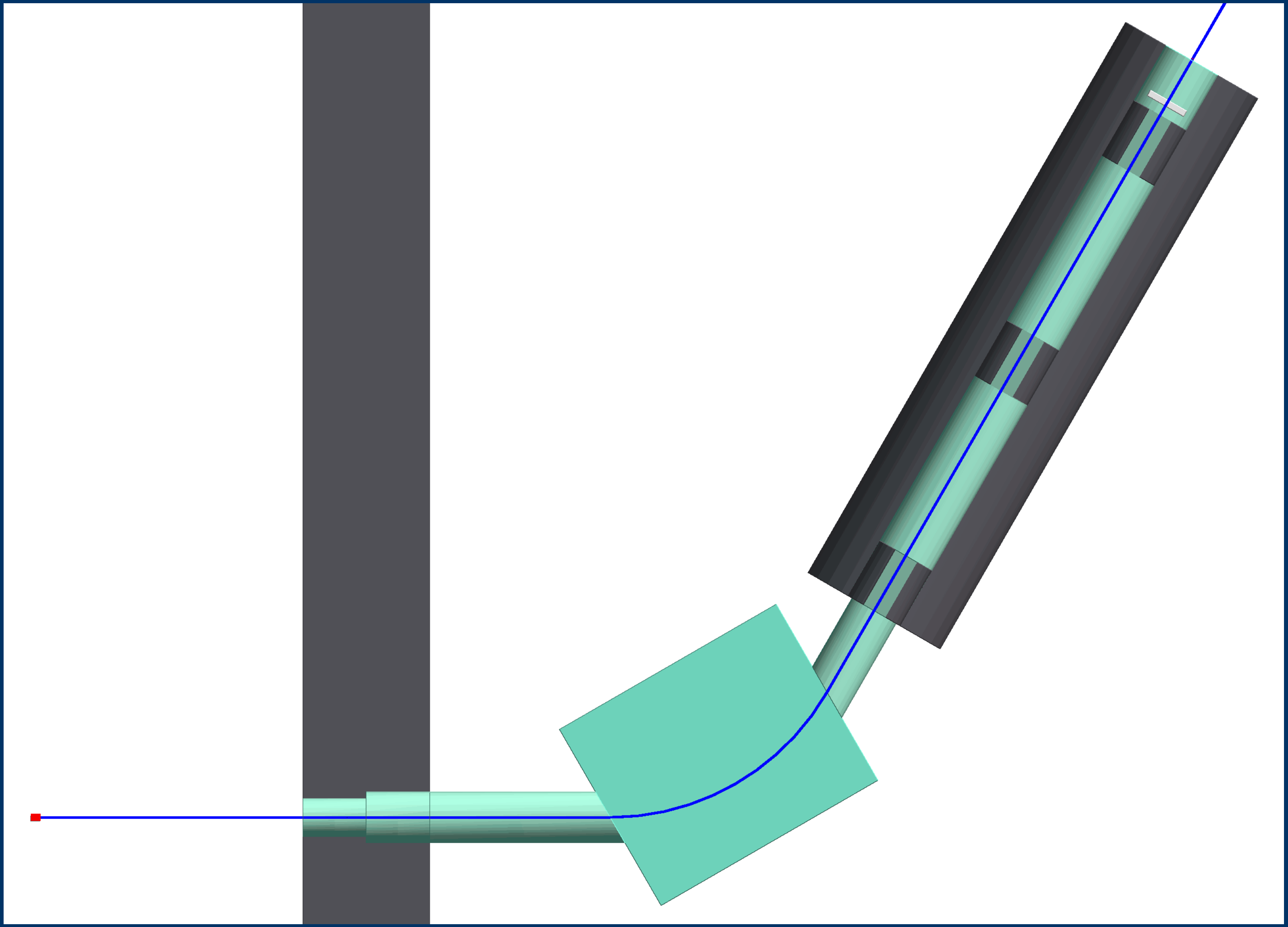
Accept. condition	Spatial spread σ, mm	Ang. spread σ', mrad	Norm. emittance ϵ_n, mm·mrad
Old	0.866 ± 0.003	0.123 ± 0.003	1240
New	0.873 ± 0.004	0.145 ± 0.001	1520



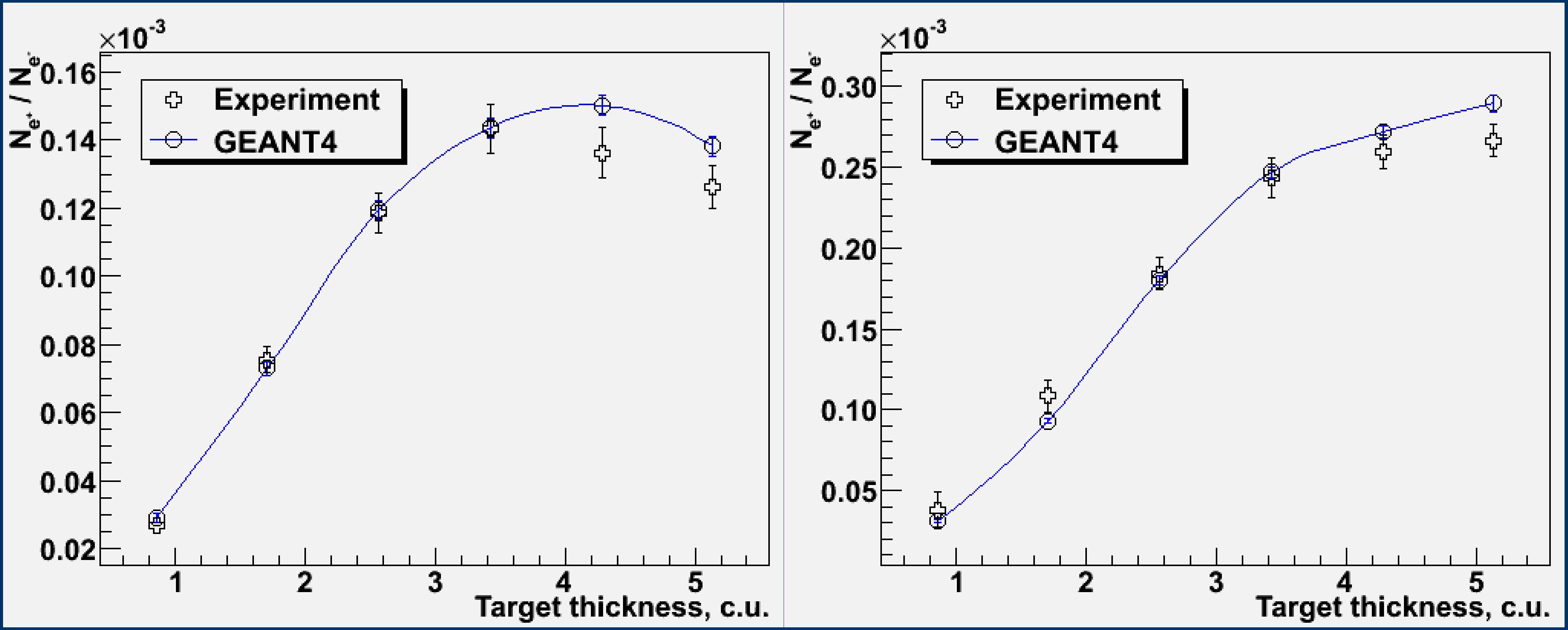
KEK experimental setup:



Geometry of the GEANT4 model



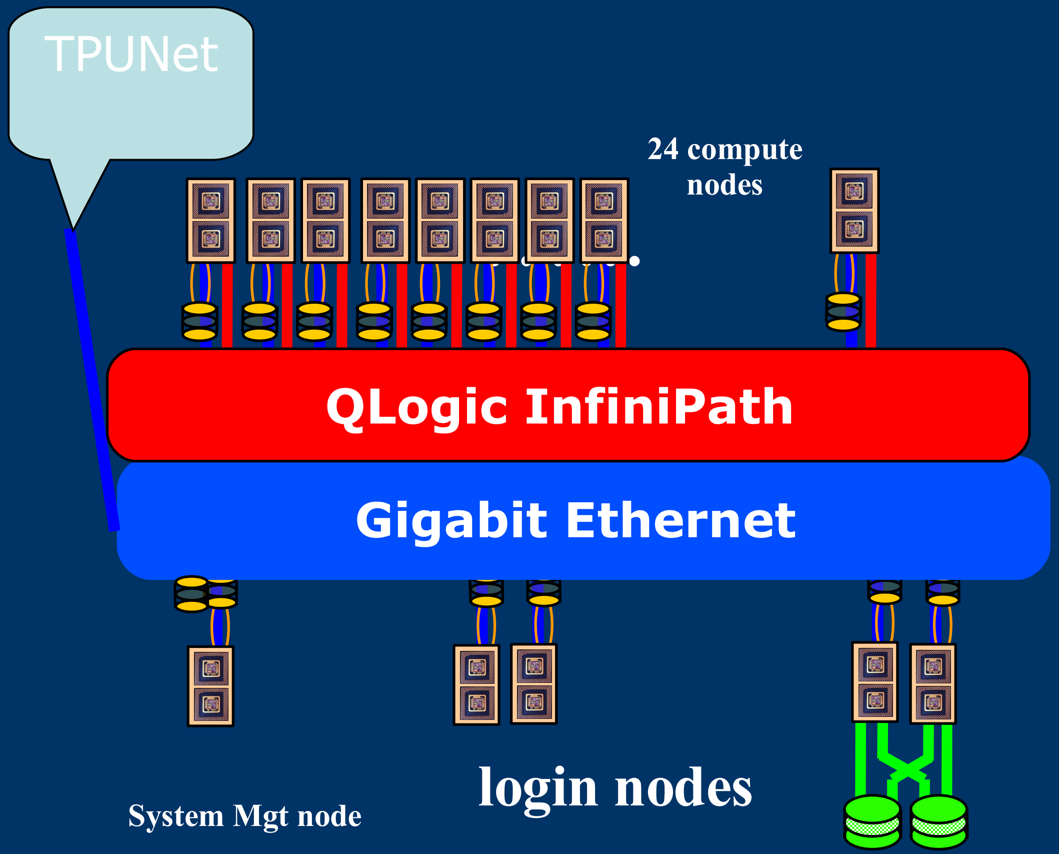
Positron yield from Wa targets



4 GeV beam

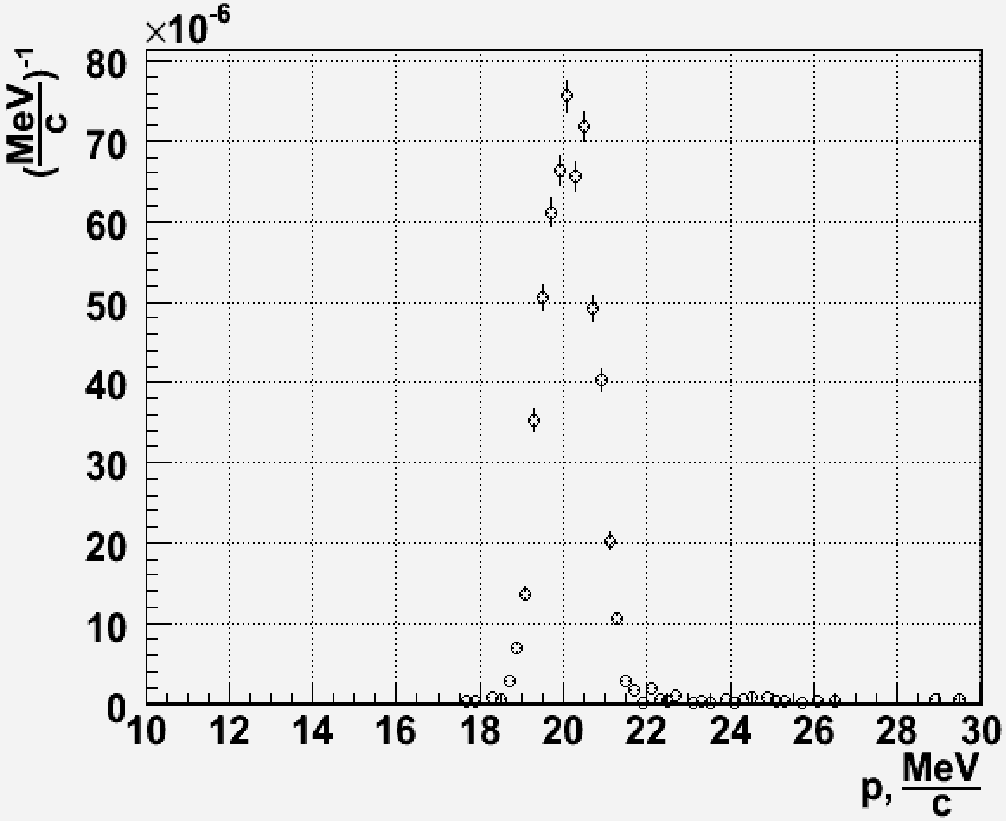
8 GeV beam

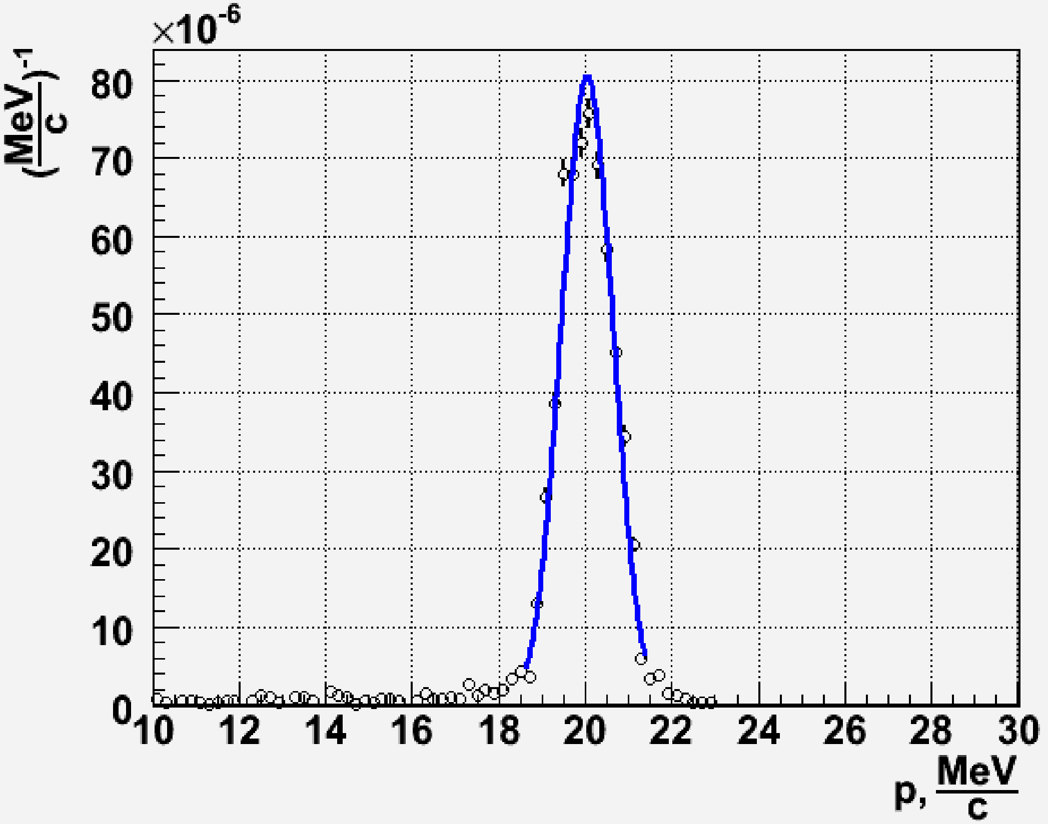
HPC Cluster SKIF-Polytech



- 24 dual processor nodes
- Processors type : dual core Intel Xeon 5150, 2.667GHz
- MPI throughput: 800 Mb/c
- MPI latency : 2.5 usec.
- Peak performance: 1TFlop
- Network data storage system: 5TB.

e+ spectra beyond target and in counter , 4GeV beam, 9mm Wa

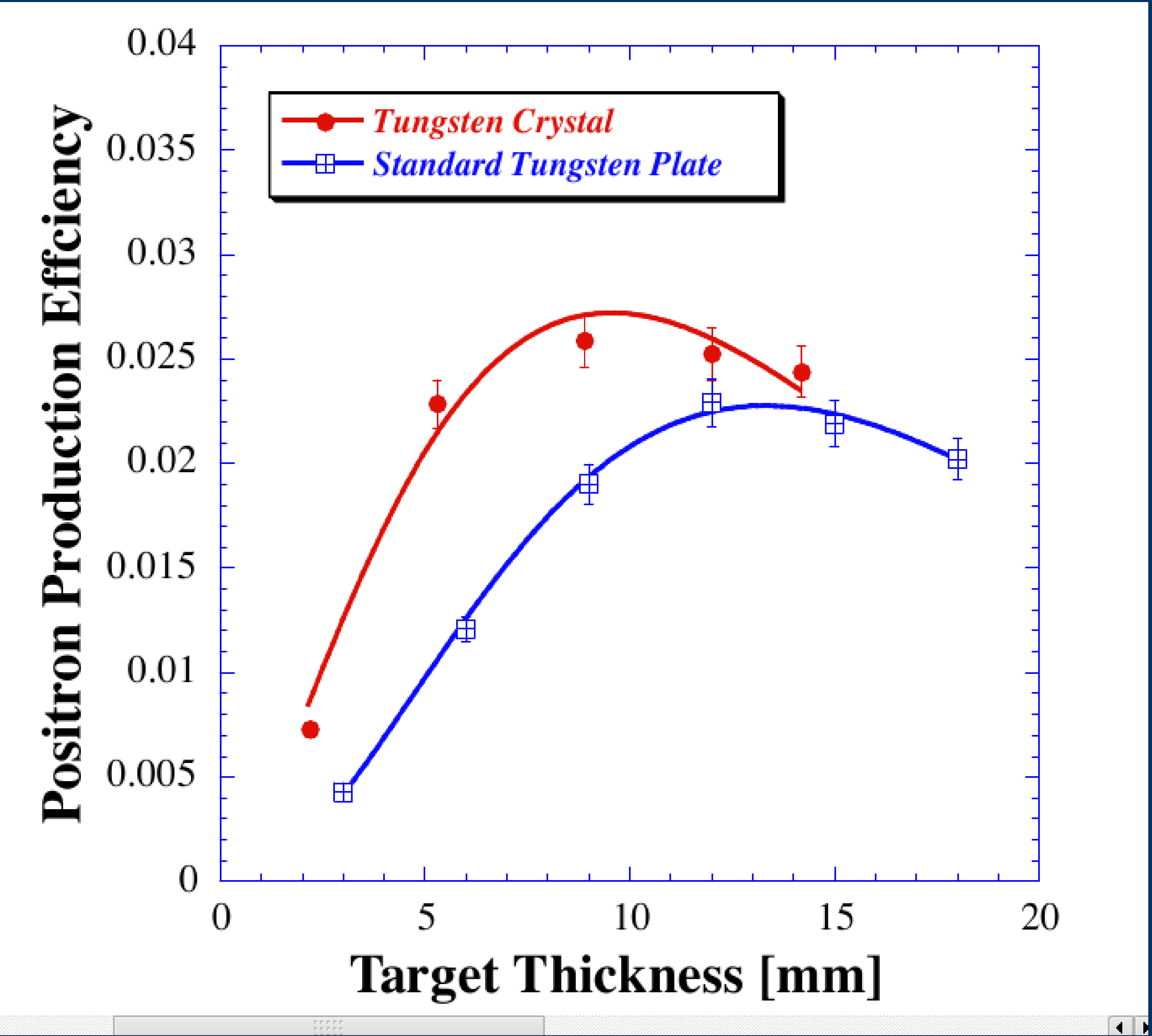




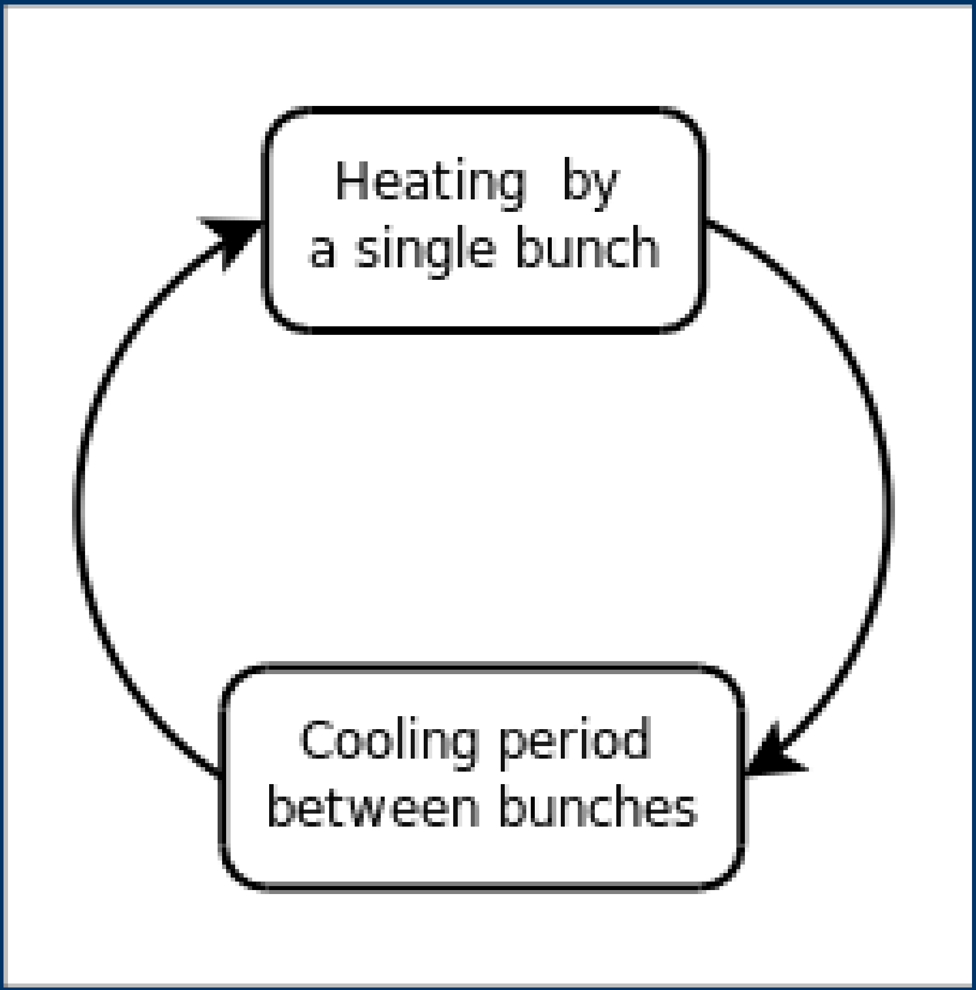
Calorimeter window : 18.6 – 21.4 MeV/c

Peak rms : 0.6 MeV/c

Positron-production efficiencies measured for the tungsten crystal as a function of the crystal thickness (The solid curve through the data are gamma-function fits of the data.

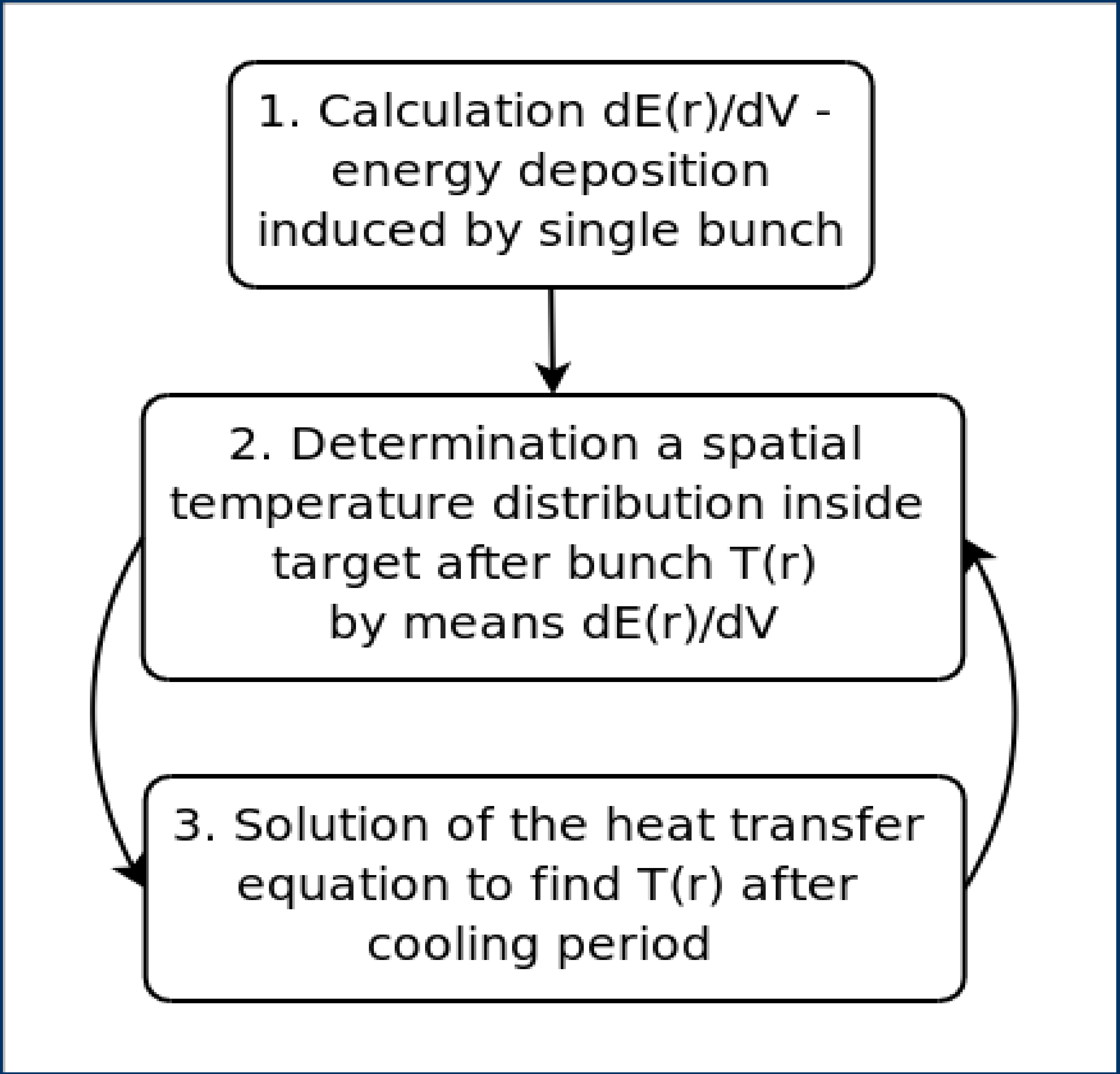


Life cycle of target:



- In the model an energy deposition induced by single bunch considered as instant.
- Cooling period between bunches assumed to be 1/f, where f – beam repetition rate.

Stages of simulation:



Calculation of energy deposition induced by beam bunch

- Math. model : Set of Boltzmann equations:

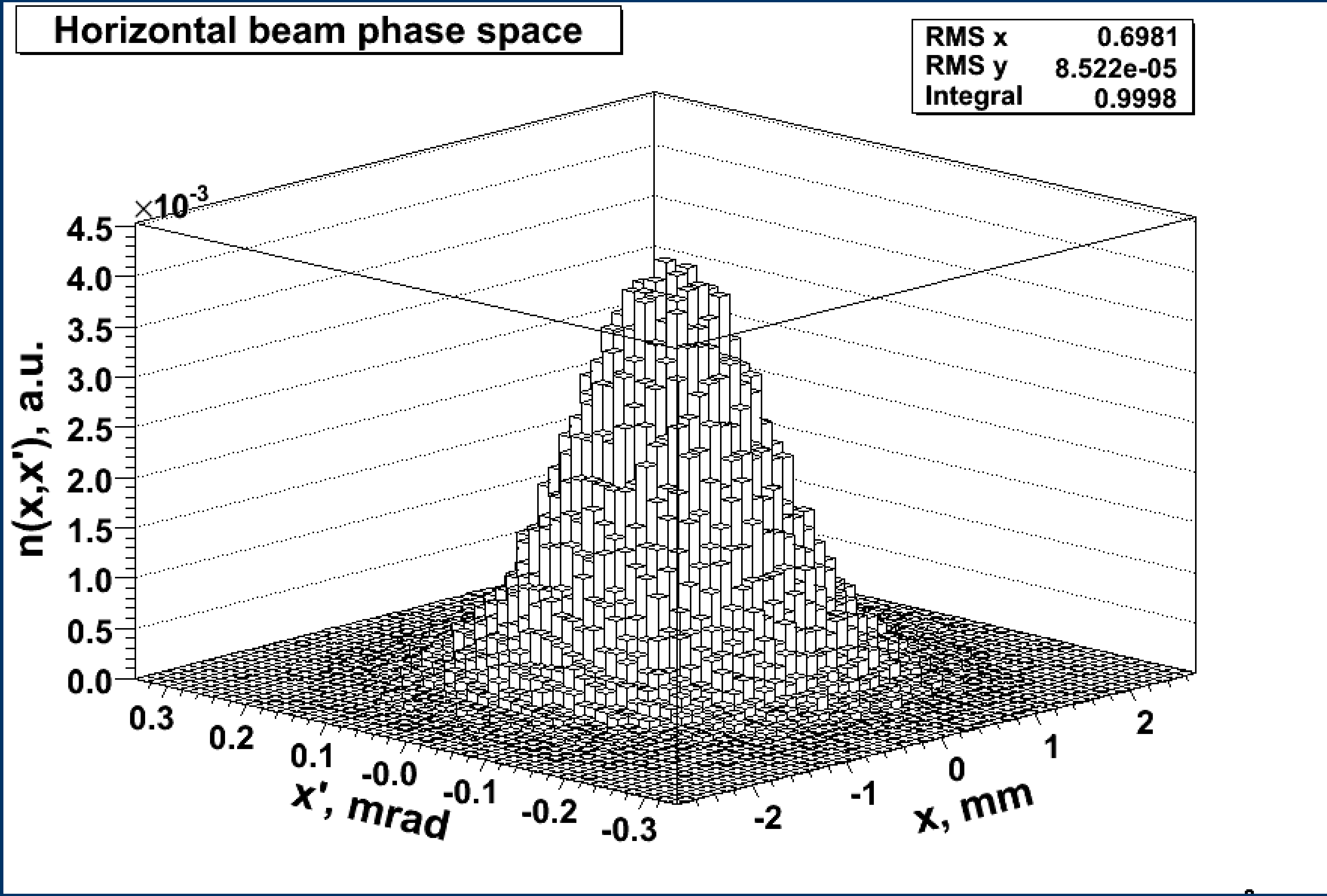
$$\vec{\Omega}\nabla\Phi_i(\vec{r},\vec{\Omega},E)+\Sigma_i(\vec{r},E)\Phi_i(\vec{r},\vec{\Omega},E)+$$
$$\sum_j\int d\Omega'\int dE'\,\Sigma_{j,i}(\vec{r},\vec{\Omega}'\rightarrow\vec{\Omega},E'\rightarrow E)\Phi_j(r,\vec{\Omega}',E')=$$
$$S(\vec{r},\vec{\Omega},E),$$
$$J=\int d\vec{r}\int dE\int d\vec{\Omega}\,\Phi(\vec{r},\vec{\Omega},E)D(\vec{r},\vec{\Omega},E)$$

- Particles in effect : photons (photo, Compton, pair production), electrons, positrons (bremsstrahlung, ionization)
- Solution method: statistical testing – Monte Carlo
- Tools : GEANT4, CASCADE

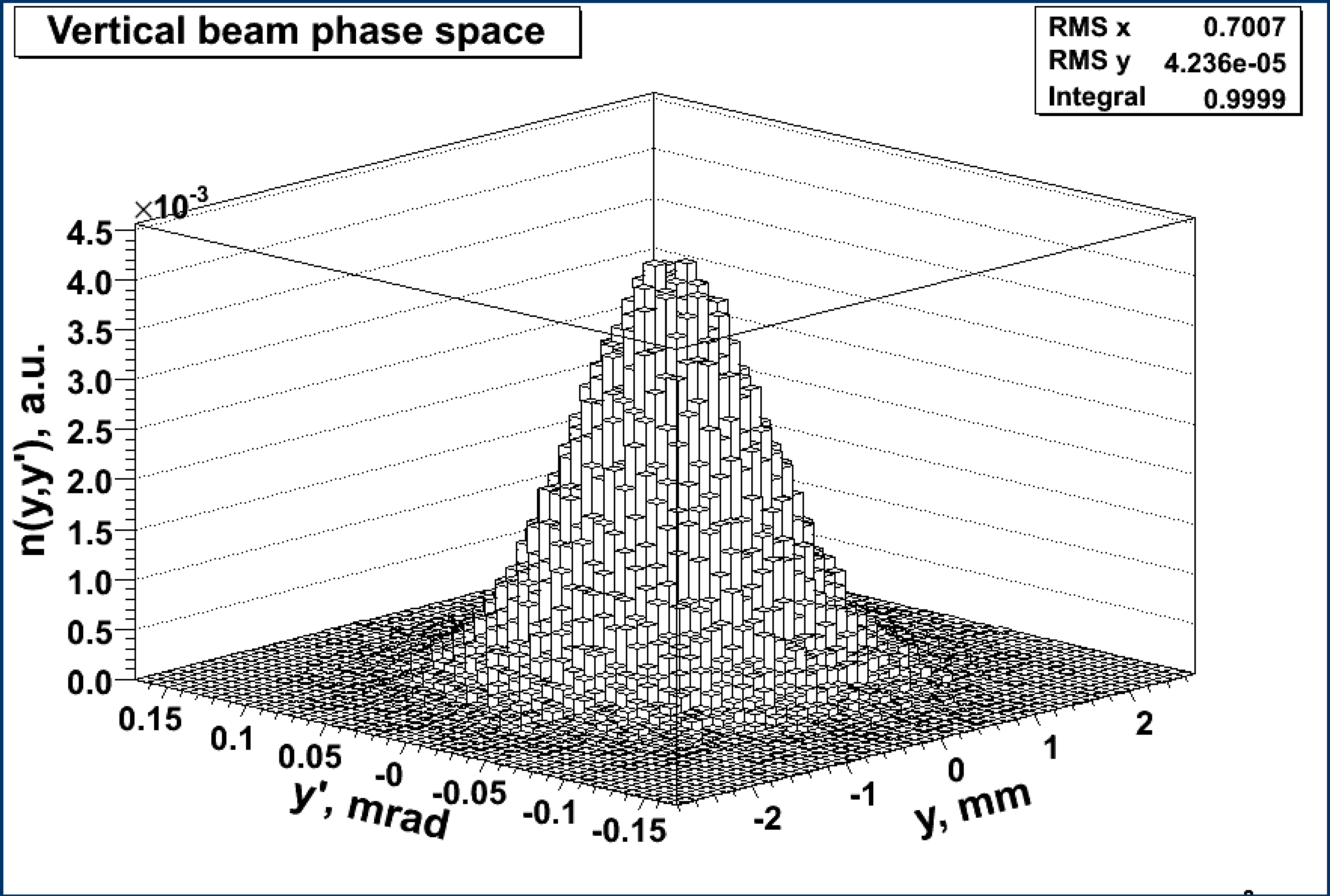
Beam model parameters:

- Beam energy – 4 GeV .
- Bunch charge – 7.8 nC .
- Gaussian model is used for spatial – angular distribution of electrons .

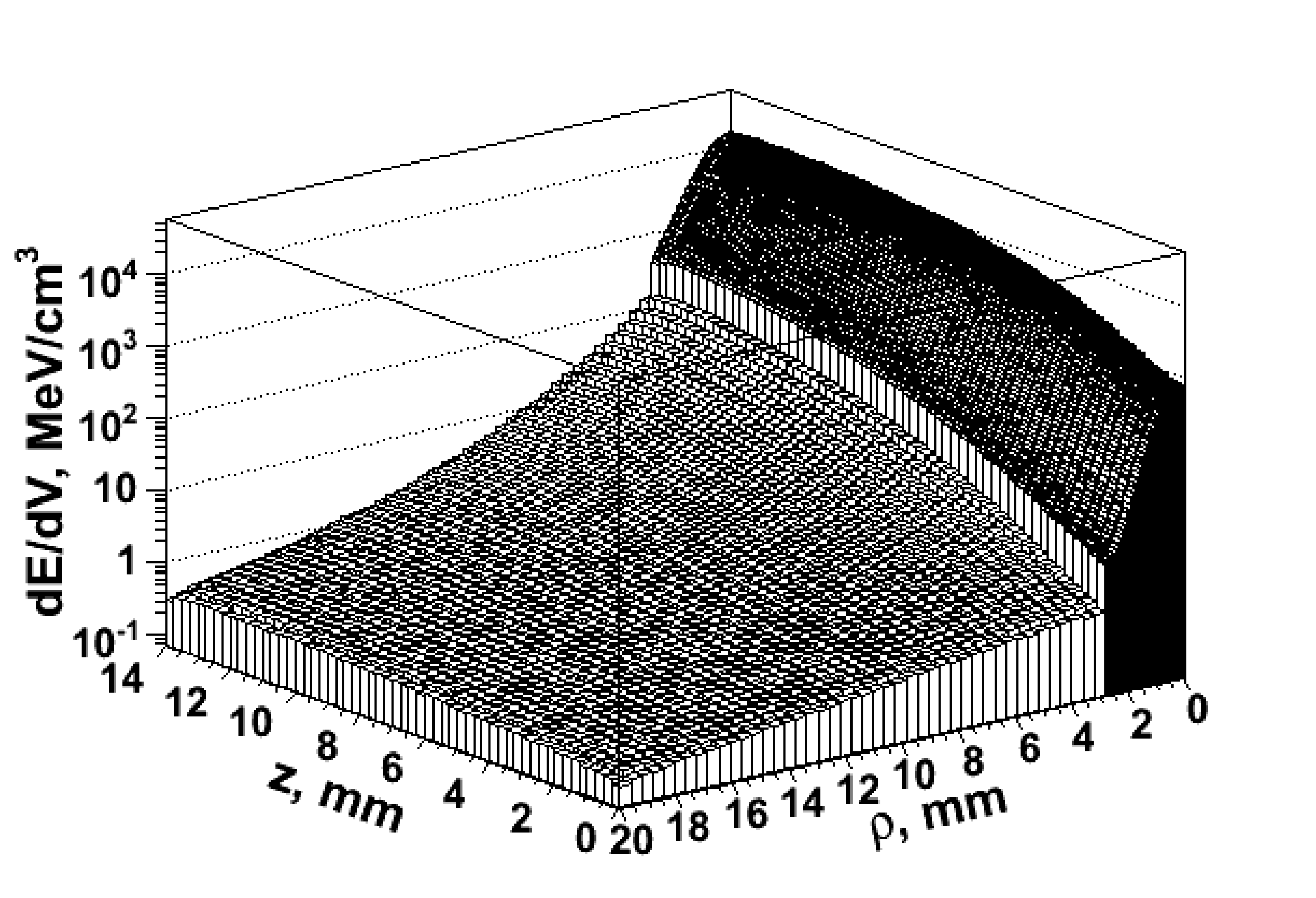
Beam model:


Horizontal beam phase space
RMS x 0.6981
RMS y 8.522e-05
Integral 0.9998
×10-3
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
n(x,x'), a.u.
0.3
0.2
0.1
-0.0
-0.1
-0.2
-0.3
x', mrad
-2
-1
0
1
2
x, mm

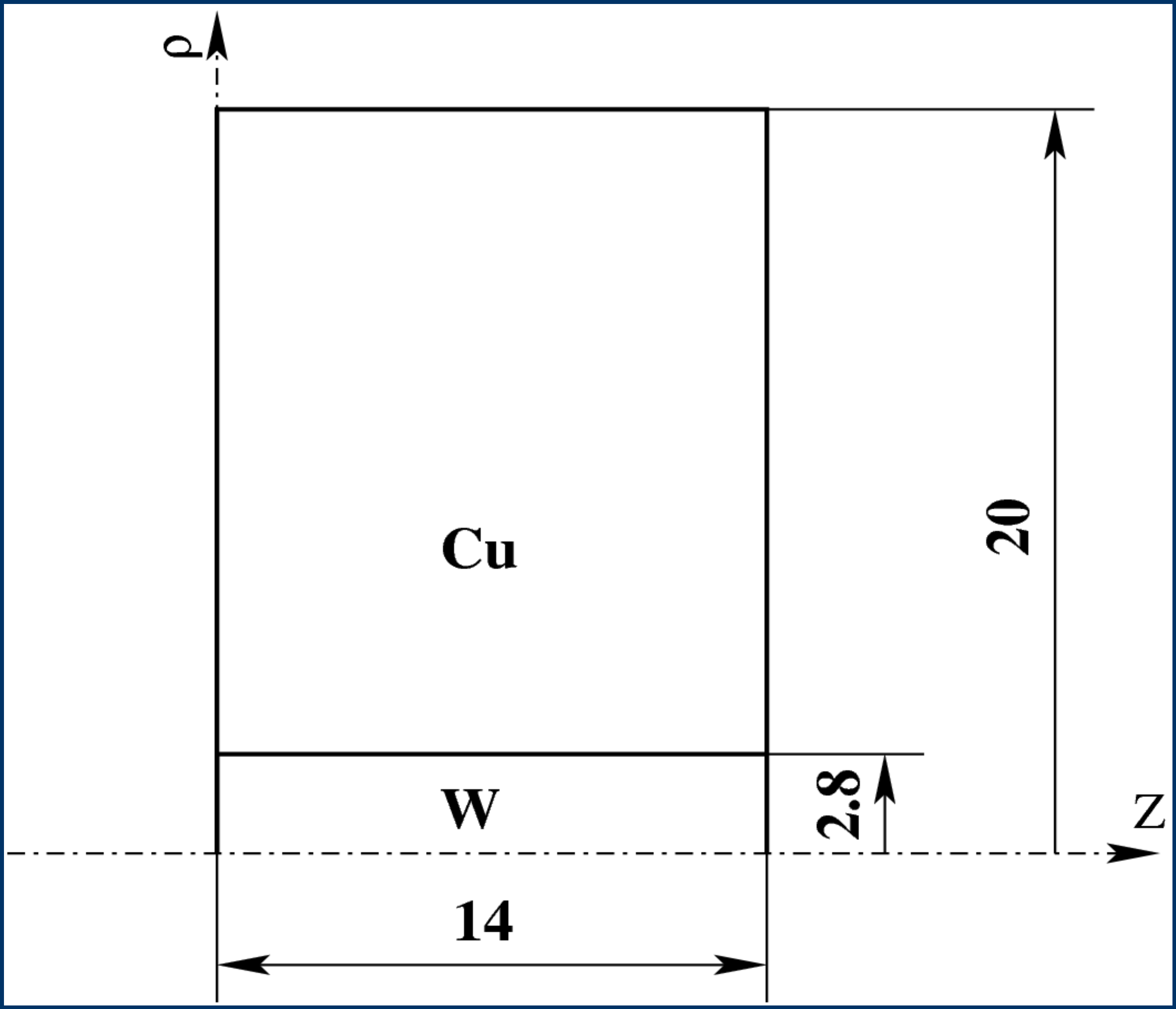
Beam model:


Vertical beam phase space
RMS x 0.7007
RMS y 4.236e-05
Integral 0.9999
×10-3
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
n(y,y'), a.u.
0.15
0.1
0.05
-0
-0.05
-0.1
-0.15
y', mrad
-2
-1
0
1
2
y, mm

Energy deposition induced by single bunch (GEANT4) :



Geometry model for the heat transfer problem:



Determination a spatial temperature distribution after bunch:

- Math. Model: $$\frac{d\,E(\vec{r})}{dV} = \rho \int_{T_0(\vec{r})}^{T(\vec{r})} du\, c(u)$$

  where ρ - density, $c(u)$ - specific heat , $T_0(\vec{r}), T(\vec{r})$ - temperatures at $\vec{r}$ before and after bunch, respectively.

- Method: Iterative procedure

Heat transfer between bunches

- Math. model: $$c(T)\rho\frac{\partial T}{\partial t}=div(k\,grad\,T)$$
- Boundary conditions : convective heat flux on upstream plane and side cylindrical surface of copper body:

$$k\frac{\partial T}{\partial n}+h(T-T_c)=0,\quad T_c=25^0C,\quad h=0.93\times10^{-2}\,W/mm^2K$$

- Initial condition: defined from solution of

$$\frac{dE(\vec{r})}{dV}=\rho\int_{T_0(\vec{r})}^{T(\vec{r})}du\,c(u)$$

with respect to the upper limit $T(\vec{r})$, $T_0(\vec{r},t=0)=25^0C$

- Solution method : Finite Volume Method (FVM)

Test example: Heat transfer in infinite tungsten cylinder.

- Initial condition: $T(\rho, t=0) = 100\, exp(-\frac{\rho^2}{2\sigma^2}) \quad , \sigma = 0.7\, mm$
- Boundary condition: convective flux,

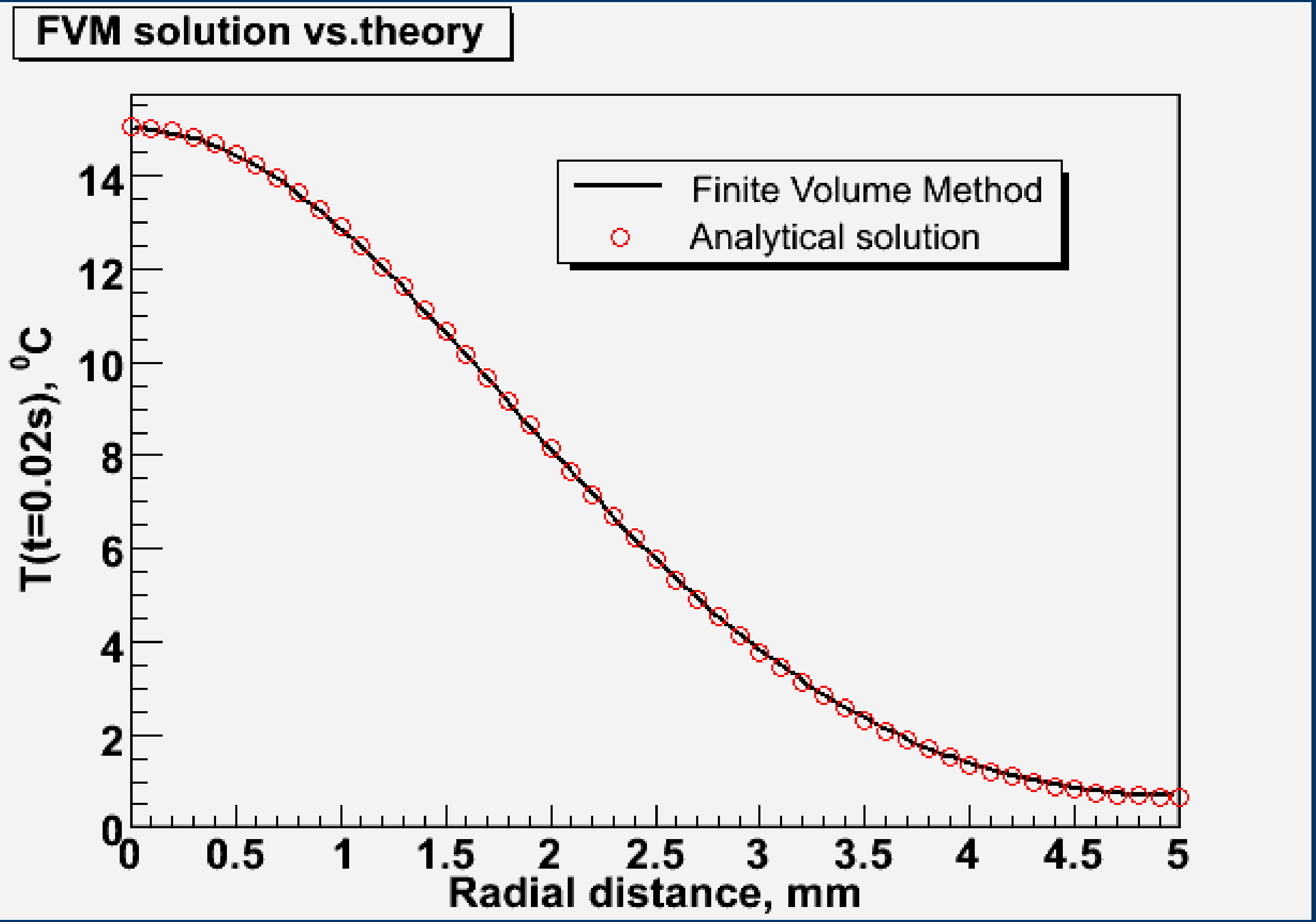
$$T_c = 0^0 C, \quad h = 0.015\, W/mm^2 K$$

- Analytical solution:

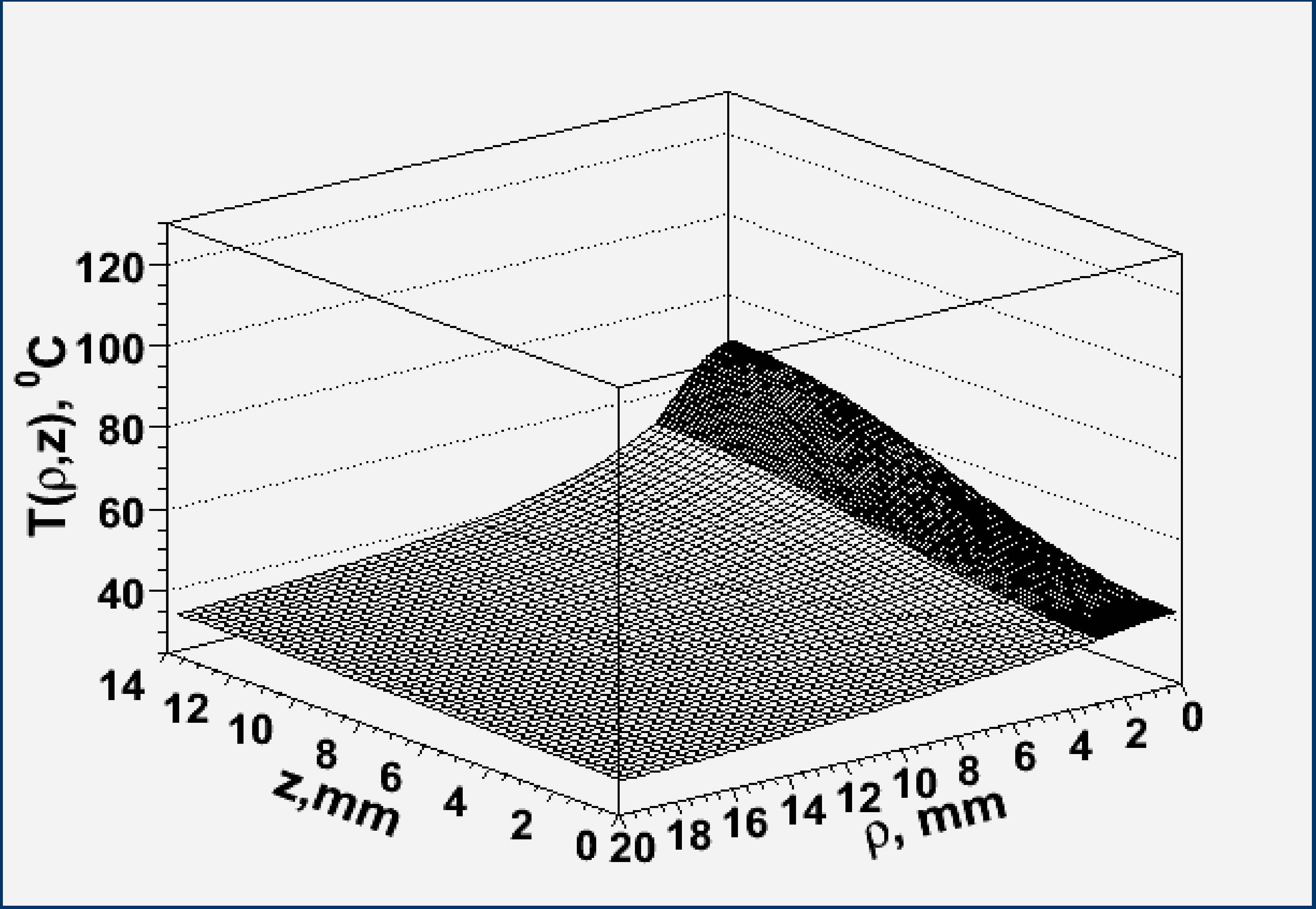
$$T(\rho, t) = \frac{2}{\rho_0} \sum_{i=0}^{\infty} \exp(-\lambda_n^2 \alpha t) \frac{J_0(\lambda_n \rho)}{J_0^2(\lambda_n \rho_0) + J_1^2(\lambda_n \rho_0)}$$

$$\int_0^{\rho_0} \rho T(\rho, t=0) J_0(\lambda_n \rho) d\rho, \quad \lambda_n: \quad \lambda \rho_0 \frac{J_1(\lambda \rho_0)}{J_0(\lambda \rho_0)} = \frac{h \rho_0}{k}$$

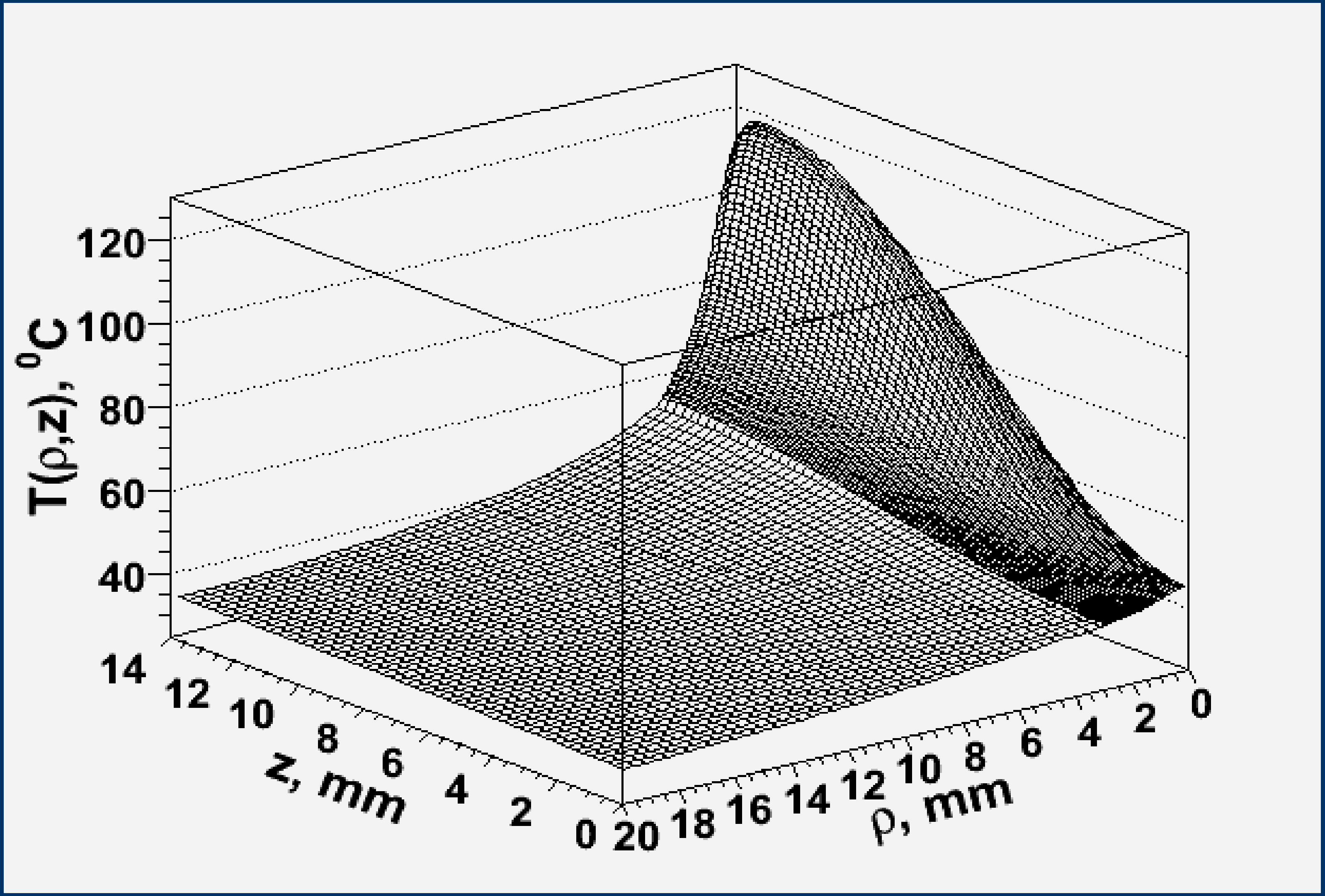
Test example: Heat transfer in infinite tungsten cylinder.



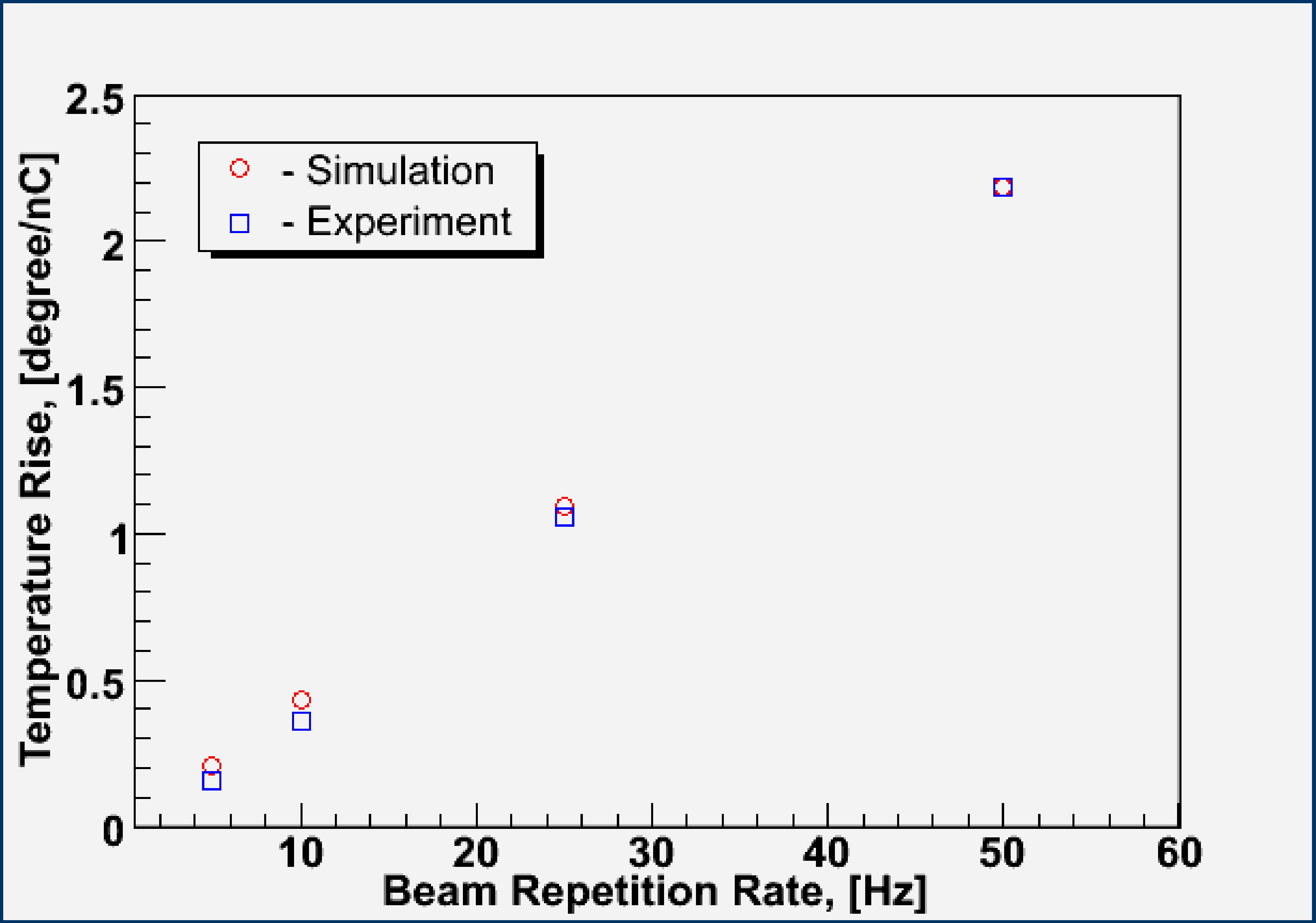
Steady state temperature distribution just before bunch for 14 mm amorphous target:



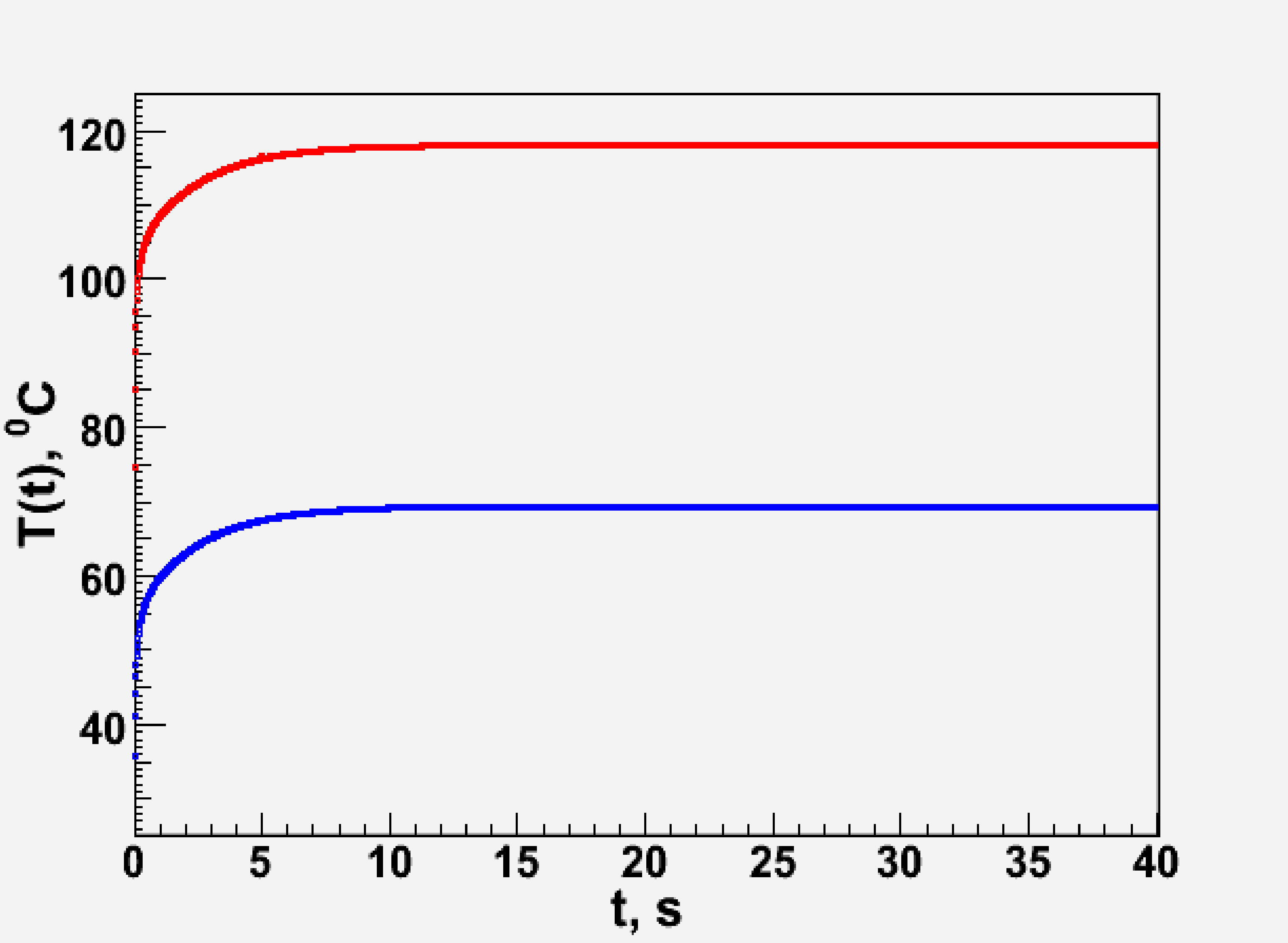
Steady state temperature distribution immediately after bunch:

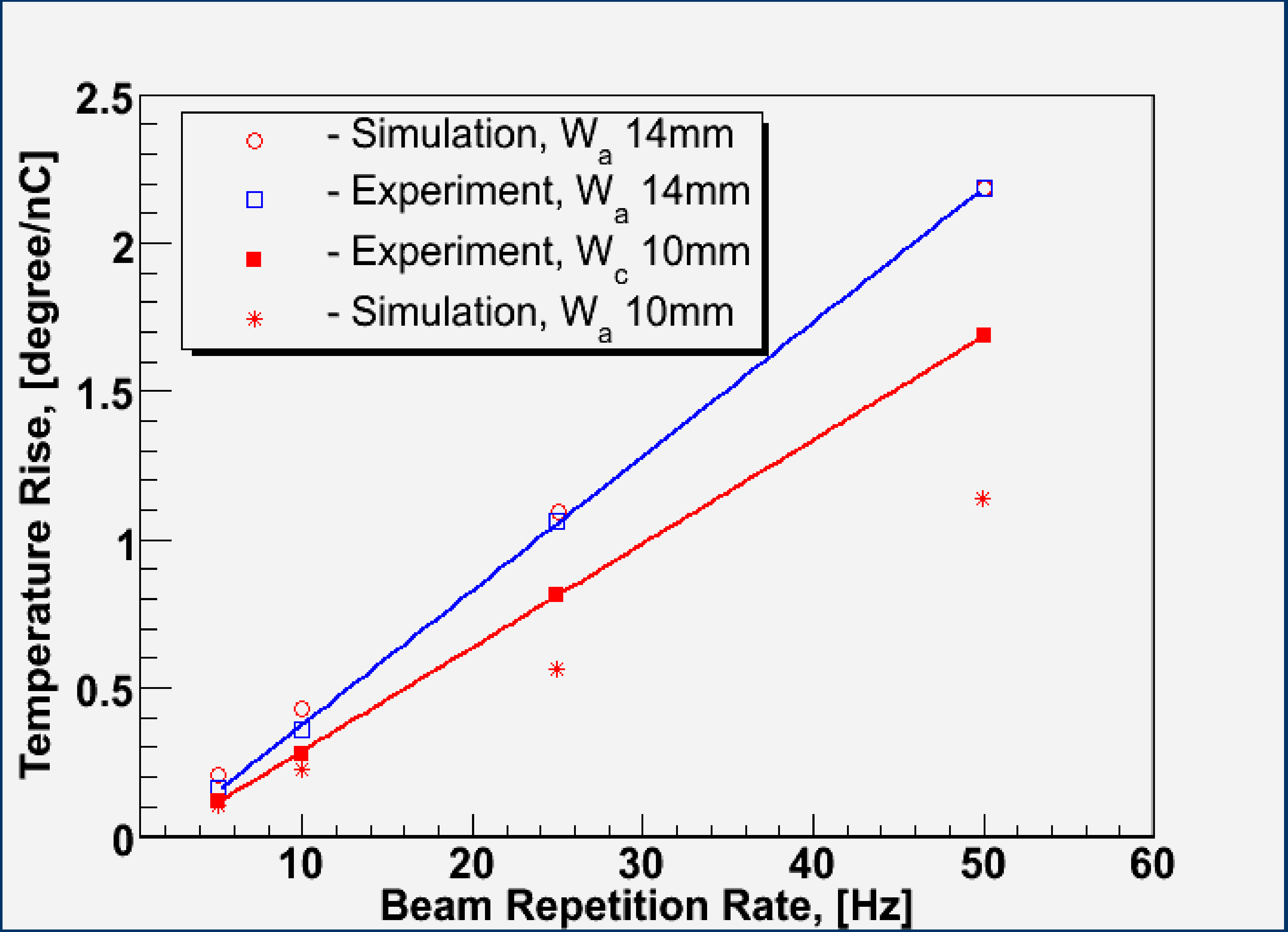


Temperature rise at downstream side of the 14 mm Wa target



Max. temperatures before and after bunch as function of irradiation time for the 14mm Wa target





- Simulation, W a 14mm
- Experiment, W a 14mm
- Experiment, W c 10mm
- Simulation, W a 10mm
Temperature Rise, [degree/nC]
Beam Repetition Rate, [Hz]
0
0.5
1
1.5
2
2.5
10
20
30
40
50
60

Target model for simulation: