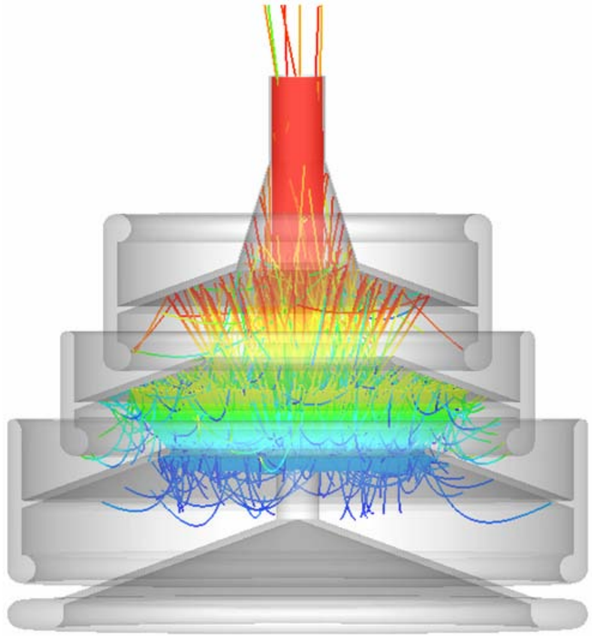
Simulation of Secondary Electron Emission with CST PARTICLE STUDIO™



Frank Hamme, Ulrich Becker and Peter Hammes
Computer Simulation Technology GmbH, 3 October 2006

Outline

- CST Particle Studio™
- Secondary electron emission model
- Simulation results for a
  - depressed electron collector
  - TeV-Energy superconducting linear accelerator (TESLA) cavity
- Conclusions
- Outlook

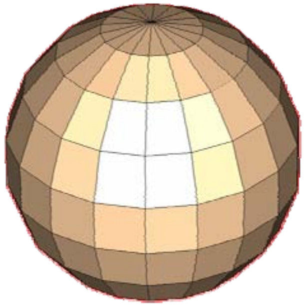
Introduction

- CST PARTICLE STUDIO™ is a software package for the design and analysis

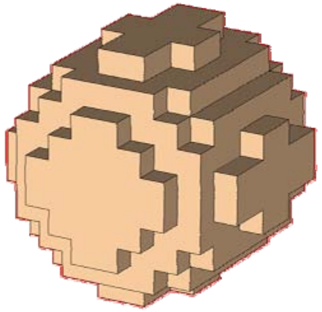
  of 3D electromagnetic components for accelerating and guiding charged particles beams

- It includes an electrostatic, magnetostatic, eigenmode and wakefield solver

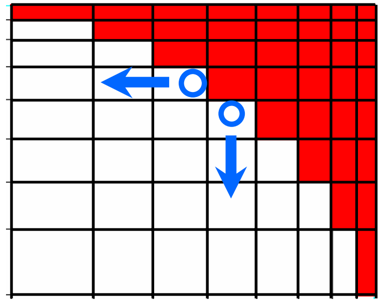
Used discretization technique

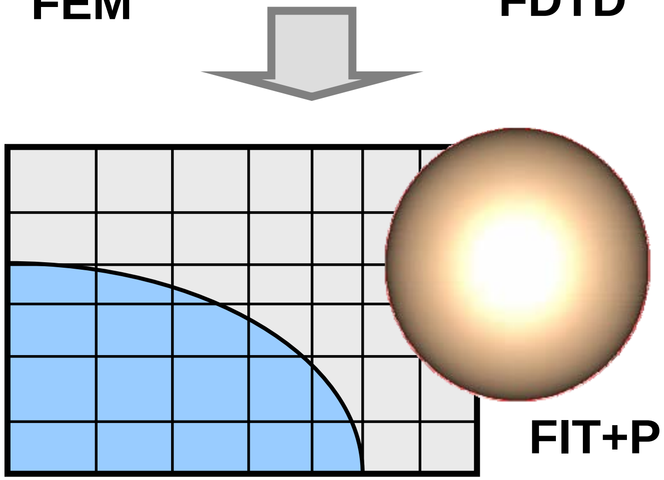


FEM

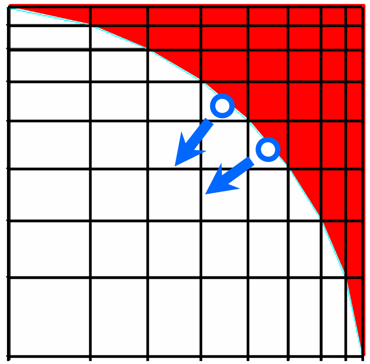


FDTD





FIT+PBA



FIT = Finite Integration Technique
PBA = Perfect Boundary Approximation

☺ **Representation and Emission from rounded objects**

☺ ***Explicit* Time Algorithm without staircase approximation**

Tracking Solver (Leapfrog)

Workflow:

1. Calculate electro- and magnetostatic fields
2. Calculate force on charged particles
3. Move particles according to the previously calculated force → trajectory

$$m\frac{dv}{dt} = q\left(\vec{E} + v \times \vec{B}\right)$$

Velocity update

$$m^{n+1} v^{n+1} = m^n v^n + \Delta t\left(\vec{E}^{n+1/2} + v^{n+1} \times \vec{B}^{n+1/2}\right)$$

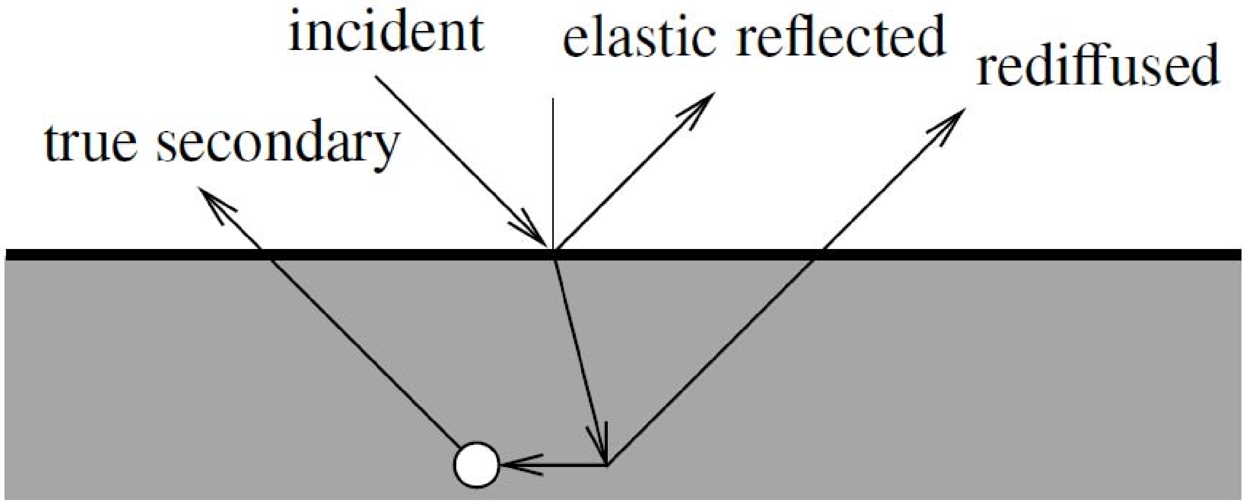
$$\frac{dr}{dt} = v$$

Position update

$$\vec{r}^{\,n+3/2} = \vec{r}^{\,n+1/2} + \Delta t \vec{v}^{\,n+1}$$

Secondary emission model

- Three types of secondary electrons are included in our model

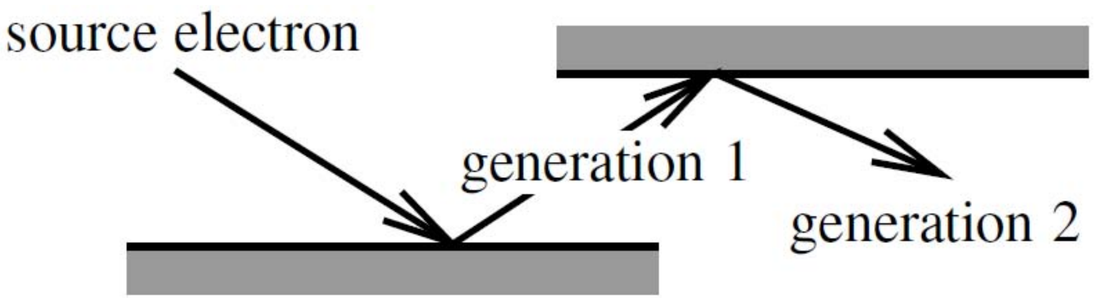


- Secondary electron emission yield

SEY = $\delta = I_s / I_0, \; I_s = I_{ts} + I_e + I_r$

Secondary Emission Model

- It should be possible to define
  - the number of electron generations a source electron is able to produce
  - how many secondary electrons can be maximally emitted due to one electron-wall interaction
  - which material is used for secondary emission



SEE – A Probabilistic Model

- Requirements for the model we need
  - material based, energy and angle dependent
  - probabilistic model
  - fulfillment of basic conservation laws, e.g. that the energy of emitted electrons should not exceed the energy of the primary electron

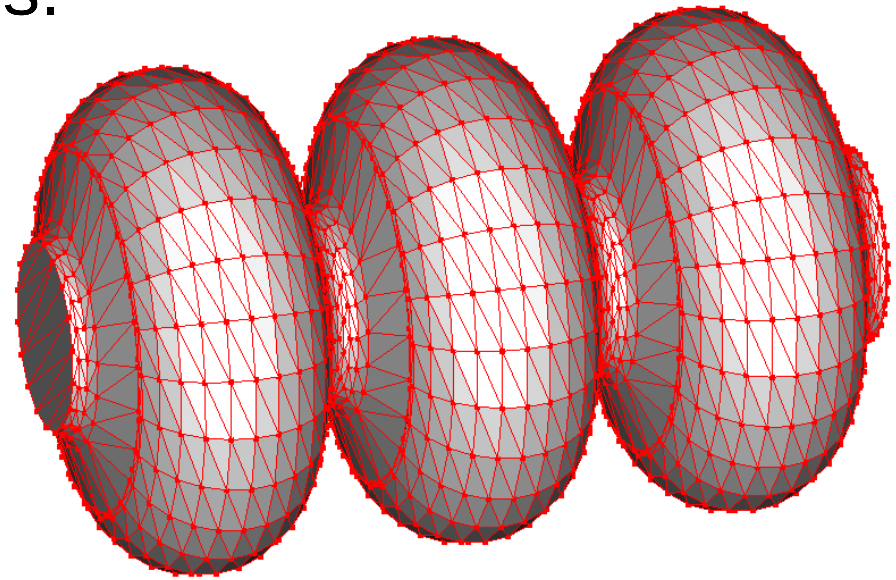
➢ Our implementation is based on a model developed by Furman and Pivi

Probabilistic model for the simulation of secondary electron emission, Physical Review Special Topics, Accelerators and Beams, Volume 5, 2002

SEE Model – Basics

1. Check each timestep, if an electron collides with solids or faces, face normals are needed
   → problem: time-consuming.

   The solution is a collision detection based on triangulated surfaces and axis-aligned bounding box (aabb) trees.



SEE Model – Basics

2. If an electron collides, generate random numbers to get the kind of emission (elastic, etc.) and the number of new secondary electrons.

Collision Information

- At each collision point (triangle/trajectory intersection) detailed collision information for primary and secondary electrons is calculated: power, current, energy
- Additionally so called particle monitors can be defined to get particle/trajectory information

SEE – Rediffused Electrons

- The secondary electrons are characterized by probability distribution functions

$$f_{1,\mathrm{r}} = \theta(E)\theta(E_0 - E)\delta_{\mathrm{r}}(E_0, \theta_0)\,\frac{(q+1)E^q}{E_0^{q+1}}$$

- Integration over energy yields the SEY

$$\delta_{\mathrm{r}}(E_0, \theta_0) = \delta_{\mathrm{r}}(E_0, 0)\,[1 + r_1(1 - \cos^{r_2}\theta_0)]$$

$$\delta_{\mathrm{r}}(E_0, 0) = P_{1,\mathrm{r}}(\infty) + [1 - \exp(-(E_0/E_{\mathrm{r}})^r)]$$

- The angle dependency is identical for all emission types

SEE – Elastic Reflected Electrons

- Gaussian distribution
- Incident angle θ_0
- Incident energy E_0

$$f_{1,\mathrm{e}}(E) = \theta(E)\theta(E_0 - E)\delta_\mathrm{e}(E_0, \theta_0)\frac{2\exp\left(-(E - E_0)^2/(2\sigma_\mathrm{e}^2)\right)}{\sqrt{2\pi}\sigma_\mathrm{e}\operatorname{erf}\left(E_0/(\sqrt{2}\sigma_\mathrm{e})\right)}$$

$$\delta_\mathrm{e}(E_0, 0) = P_{1,\mathrm{e}}(\infty) + \left[\hat{P}_{1,\mathrm{e}}(\infty) - P_{1,\mathrm{e}}(\infty)\right]\exp\left(-\frac{|E_0 - \hat{E}_\mathrm{e}|^p}{pW^p}\right)$$

- Other parameters are material dependent

SEE – True Secondary

- Only due to true emission more than one secondary electron can be emitted

$$f_{n,\mathrm{ts}} = \theta(E) F_n E^{p_n - 1} \exp(-E/\epsilon_n)$$

$$F_n^n = \frac{P_{n,\mathrm{ts}}(E_0)}{\left[\epsilon_n^{p_n}\Gamma(p_n)\right]^n P(np_n, E_0/\epsilon_n)}$$

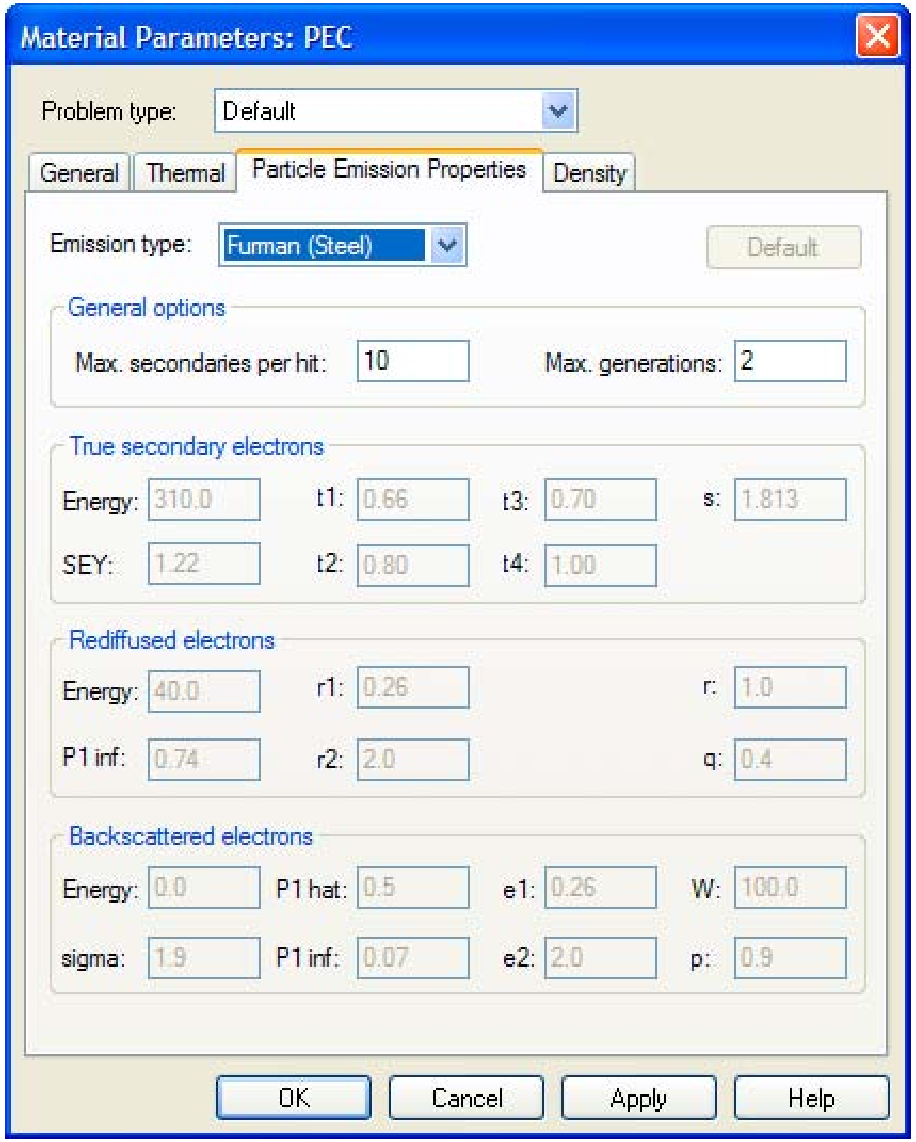
- The probability is chosen as binominal distribution

$$P_{n,\mathrm{ts}} = \binom{M}{n} p^n (1-p)^{M-n}$$

M = max. number of secondary electrons

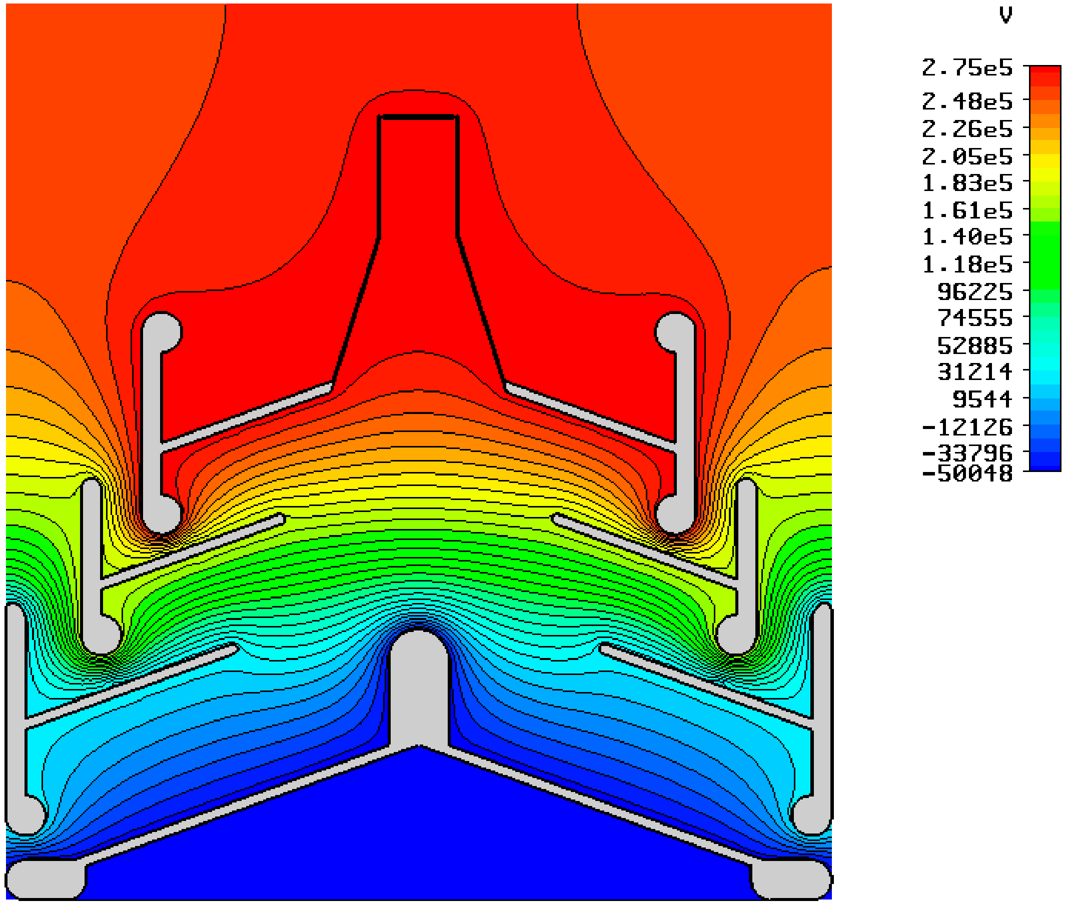
$$\delta_{\mathrm{ts}}(E_0, \theta_0) = \hat{\delta}(\theta_0) D(E_0/\hat{E}(\theta_0)), \quad D(x) = \frac{sx}{s - 1 + x^s}$$

SEE - User Interface



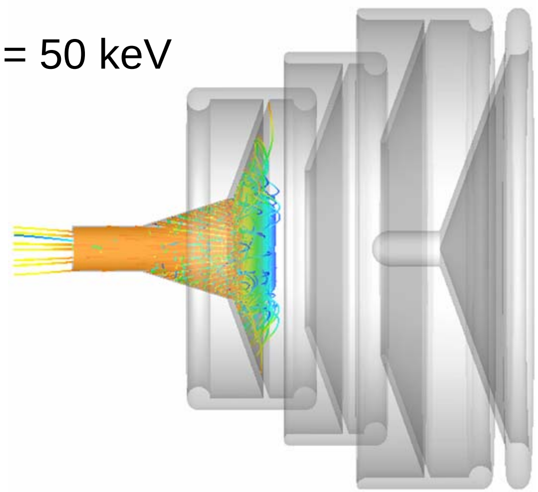
Depressed Electron Collector

- Potential field

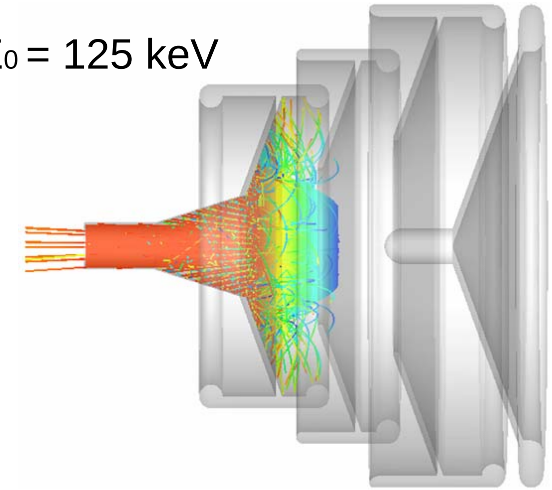


Electron Collector

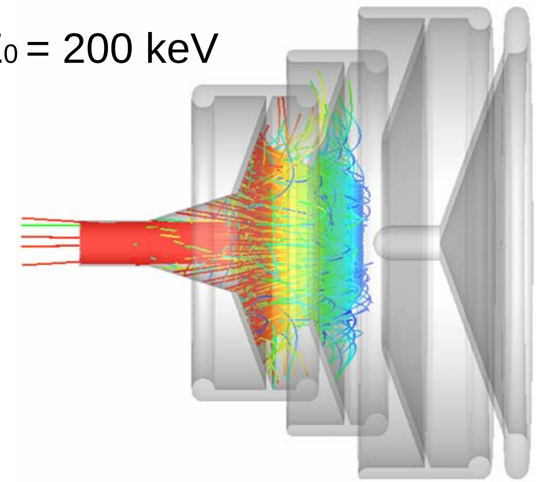
$E_0 = 50$ keV



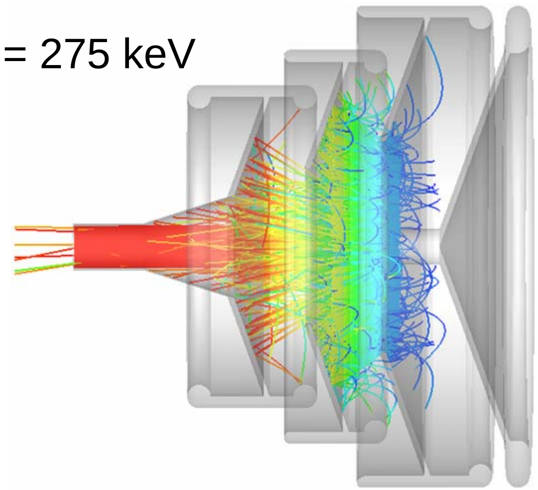
$E_0 = 125$ keV



$E_0 = 200$ keV



$E_0 = 275$ keV



Electron collector

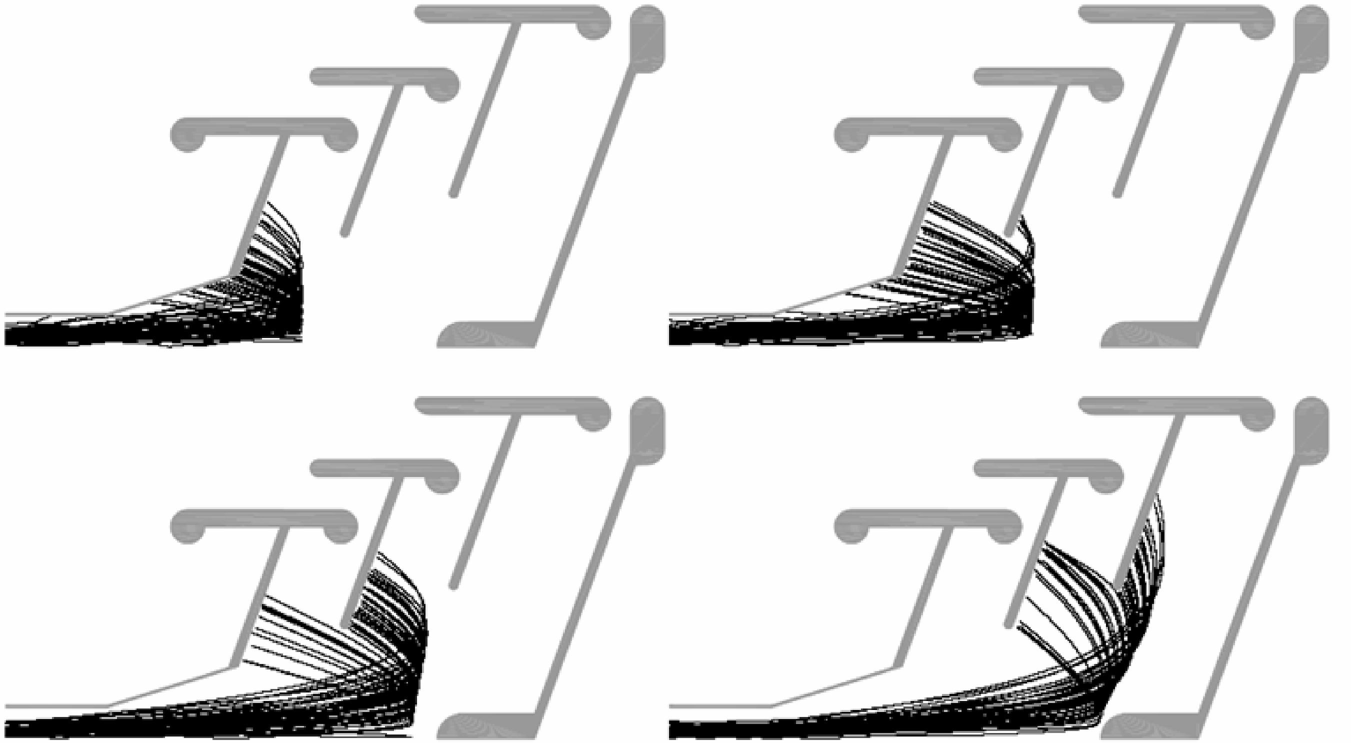
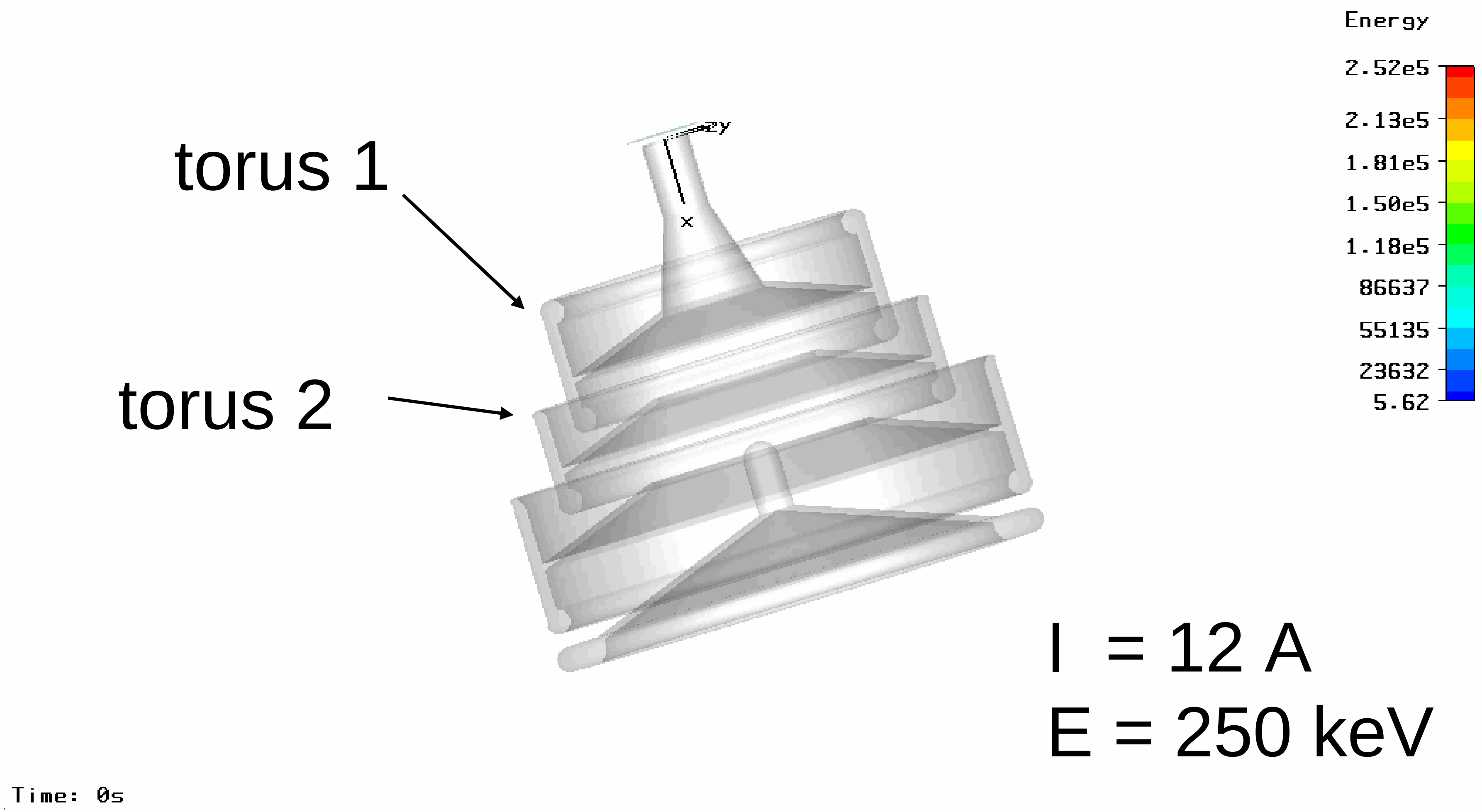


Figure 5-16: 50 Sample trajectories for 50, 125, 200 and 275 keV electrons. The electrons with the highest energies are collected on the electrodes with the lowest potential.

Bas van der Geer, Marieke de Loos. Thesis, Eindhoven University of Technology.
The General Particle Tracer code. Design, implementation and application.

Electron Collector



I = 12 A

E = 250 keV

Electron Collector

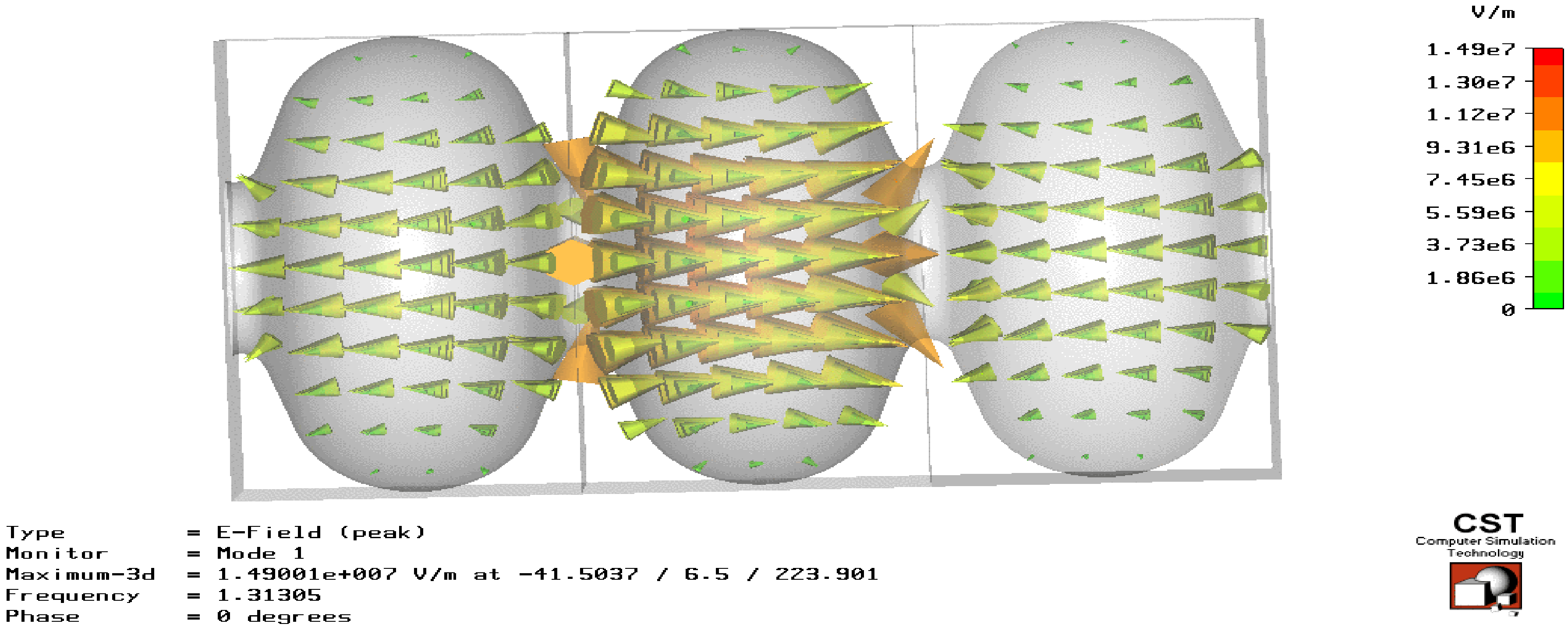
- Simulation with and without secondary emission

	surface	current in A		power in MW	
		incident	emitted	incident	emitted
without SE	torus 1	2.629	0	0.660	0
	torus 2	9.371	0	1.360	0
with SE	torus 1	8.819	4.417	1.602	0.580
	torus 2	18.260	10.680	1.978	0.795

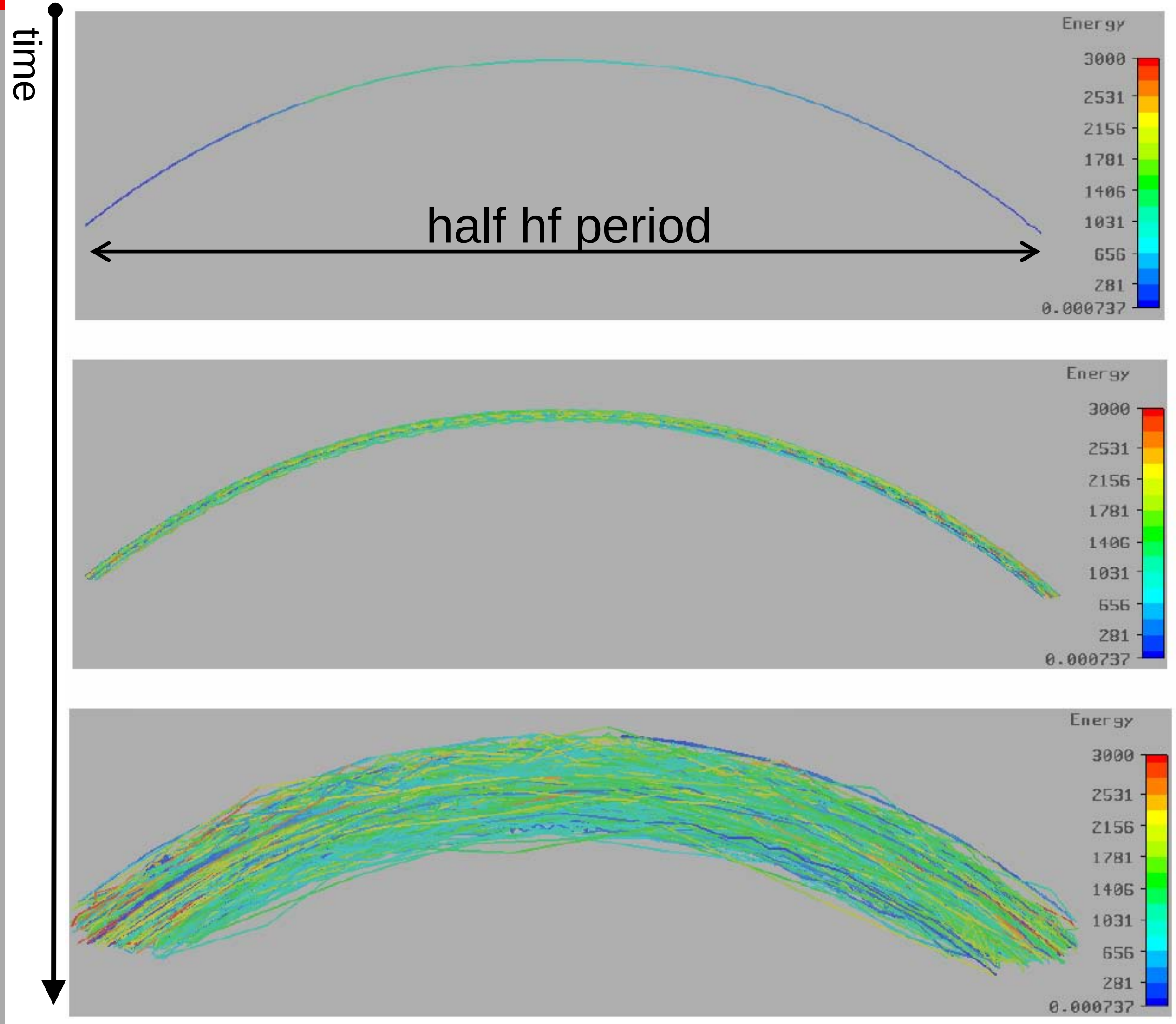
- The total current sum equals in both cases 12 A
- There is increase of total power of 10%

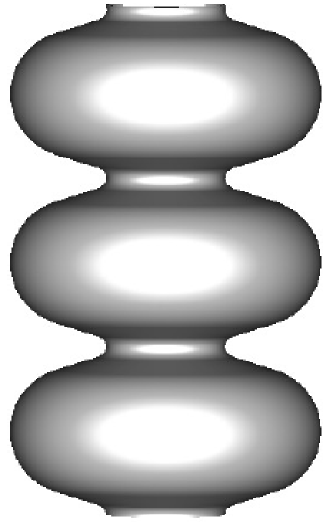
TESLA Cavity

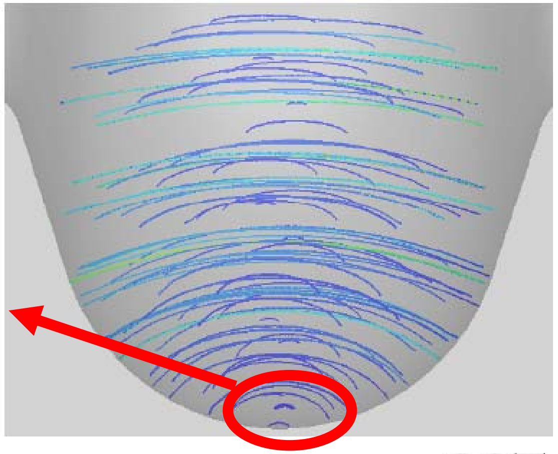
- Eigenmode at 1.3 GHz
- E_{max} = 45 MV/m



TESLA – Two-Point Multipacting







Conclusions

- Furman SE model is implemented
- Very important are accurate input secondary emission material parameters
- The principals of two-point (and one-point) multipacting can be simulated with CST Particle Studio™
- Secondary electron emission is a heating mechanism for the depressed collector

Outlook

- Post processing analysis of the secondary emission heating with a thermal solver
- More material data to get better secondary emission simulation results

Thank you !