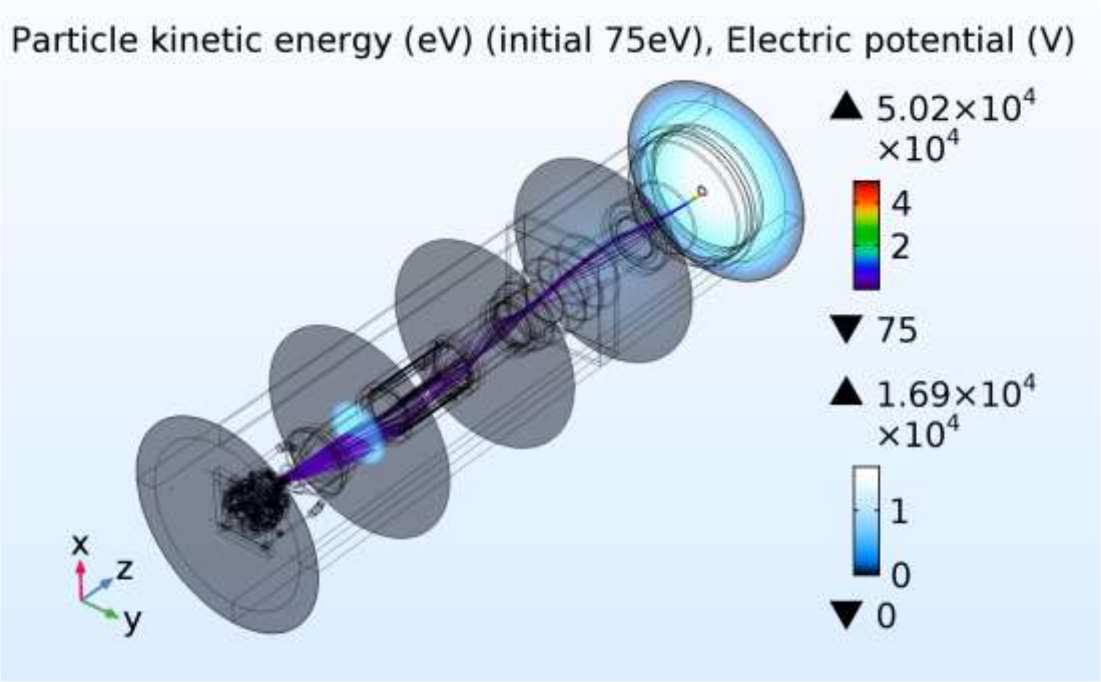


COMSOL
CONFERENCE
2016 MUNICH

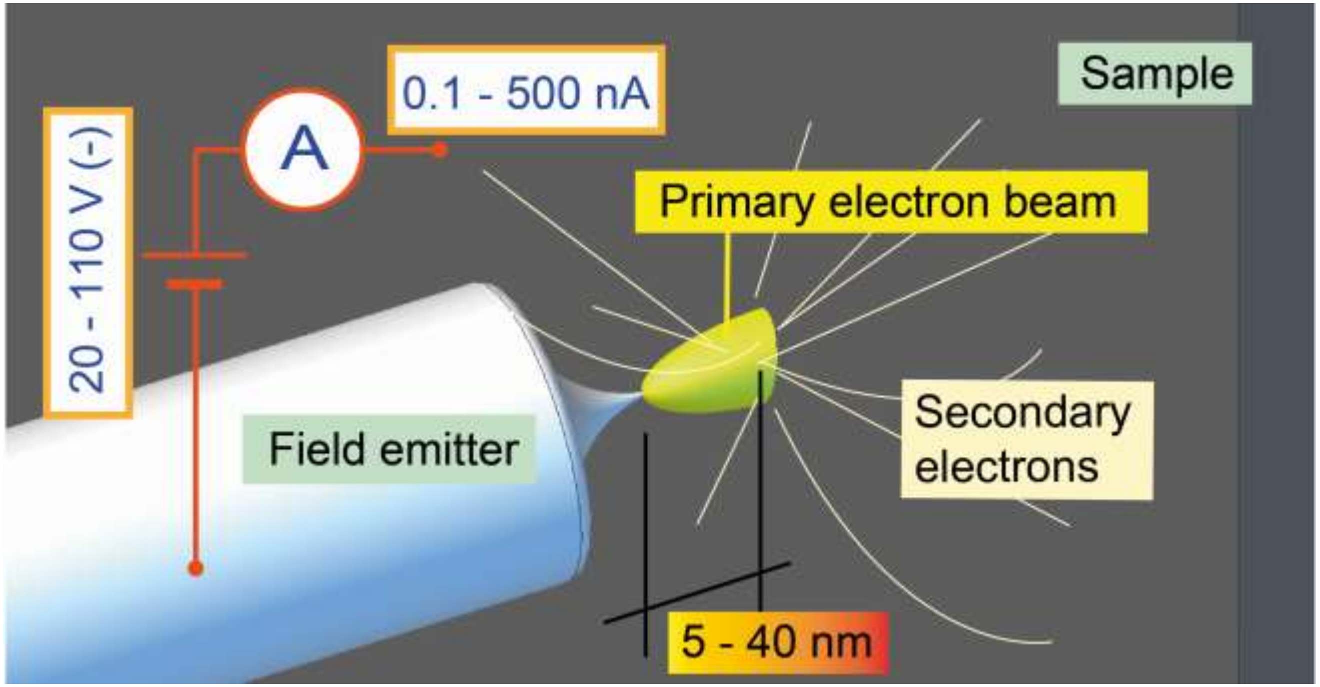
H. Cabrera, L. G. De Pietro and D. Pescia
Swiss Federal Institute of Technology Zurich
ETHZ
Laboratory for Solid State Physics

Secondary Electron Trajectories in Scanning Tunneling Microscopy in the Field Emission Regime

- Setting the electrostatic parameters

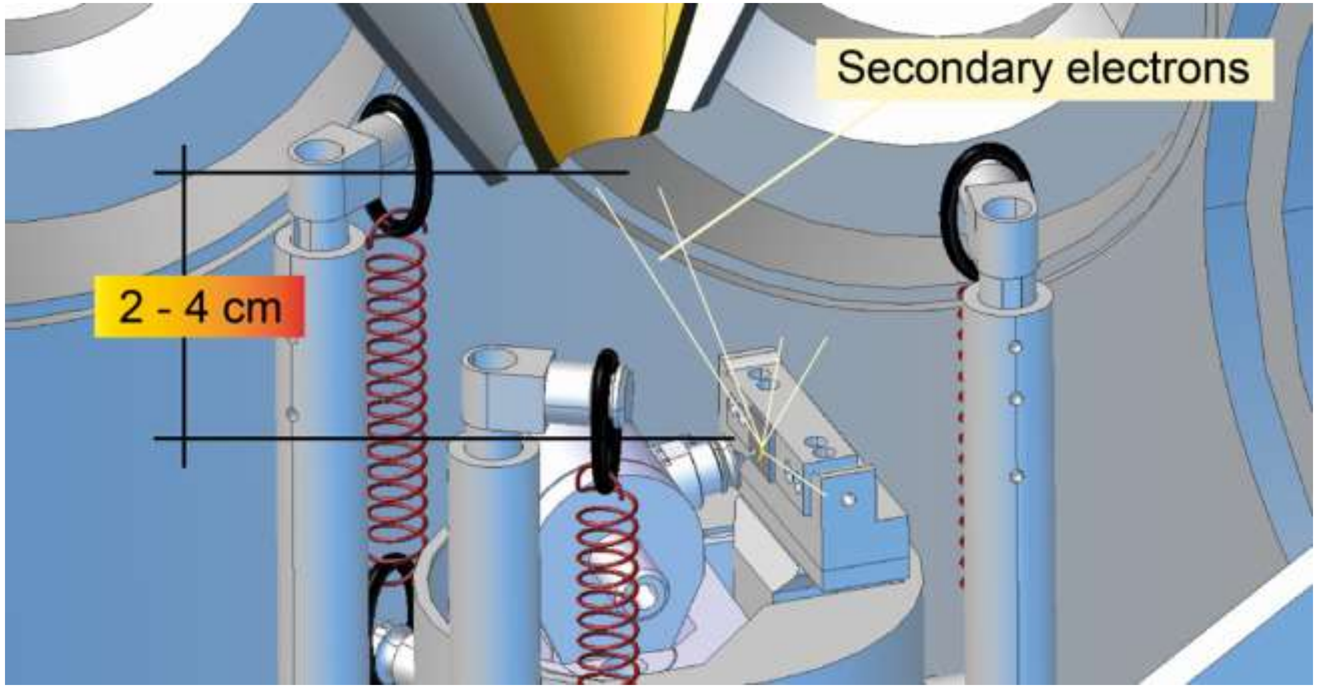
Scanning Tunneling Microscopy in the Field Emission Regime (STM-FE) The electrostatic junction

- A sharp poly crystalline tungsten placed at a distance of few nanometers from the target surface.
- The tip is biased with a negative voltage respect to the planar anode.
- Electrons - forming the primary beam - are emitted from the tip via electric field assisted quantum tunneling.

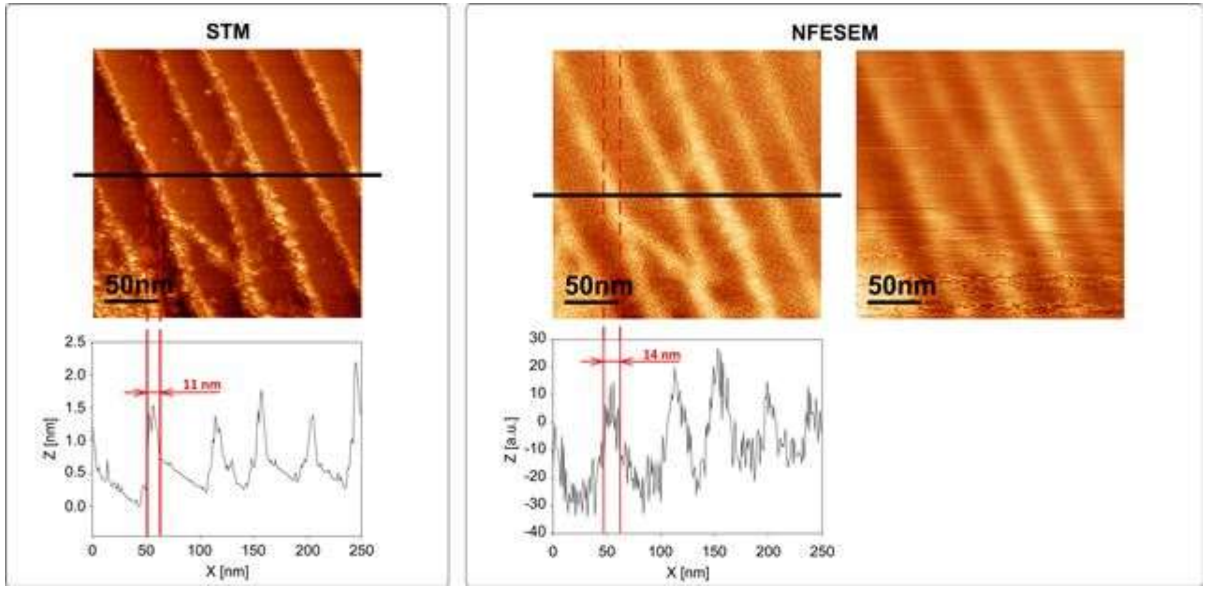


Scanning Tunneling Microscopy in the Field Emission Regime (STM-FE) The electrostatic junction

- The tip is moved parallel to the surface and the low energy primary electron beam is scattered by the target surface generating secondary electrons (SE).
- The SE are sampled by a suitable electron current measuring instrument placed in the vicinity of the tip-surface junction.



Scanning Tunneling Microscopy in the Field Emission Regime (STM-FE) First results



Top left: STM image of a nanostructured W(110) surface, with accumulation of matter along the surface steps (running along the diagonal of the image).
Top center: The same surface spot imaged by recording the intensity of the backscattered electrons.
Right: The same surface spot imaged by recording simultaneously with the middle image the field emission current I while scanning the tip at fixed tip-surface distance of 40 nm and at fixed voltage.
Bottom left: Line scan through the STM image: plotted is the height of the surface structures along the black line indicated in top.
Bottom center: Line scan through the NFESEM image: plotted is the detector signal along the black line. The recording of both STM and NFESEM images can be used to calibrate the NFESEM height. A vertical spatial resolution of less than 10-1 nm has been observed at distances of about 20 nanometers.

D.A. Zanin, M. Erbudak, L.G. De Pietro, H. Cabrera, A. Redmann, A. Fognini, T. Michlmayr, Y.M. Acremann, D. Pescia, and U. Ramsper, Proceeding of the 26th International Vacuum Nanoelectronics Conference, IEEE (2012).

Scanning Tunneling Microscopy in the Field Emission Regime (STM-FE) First results

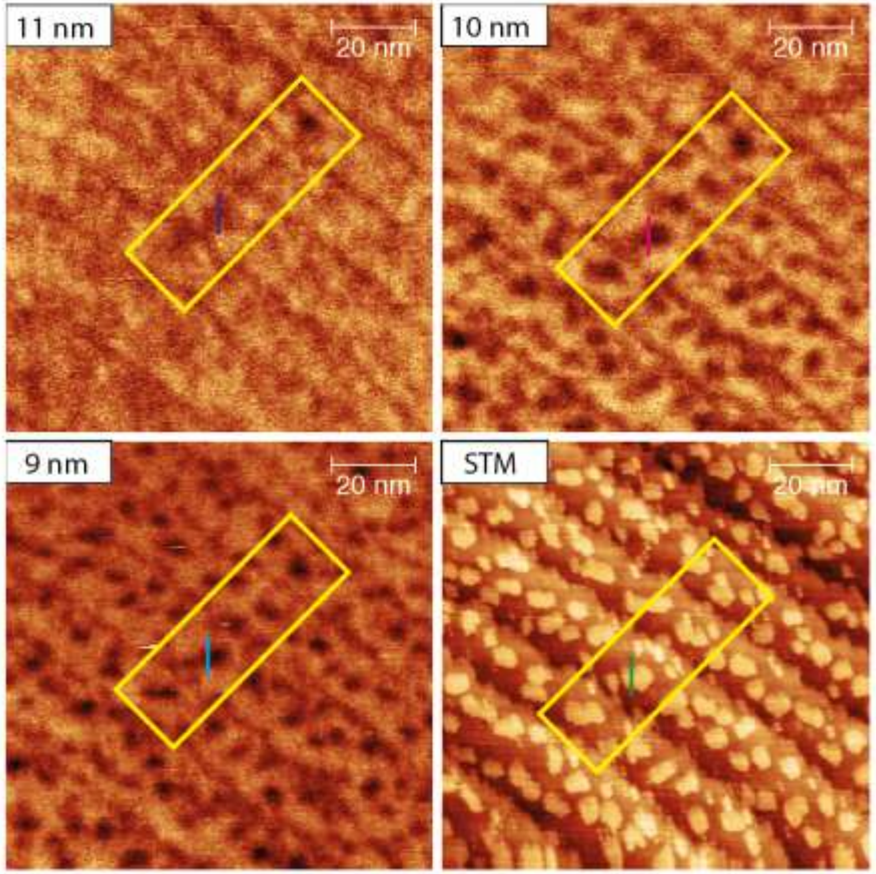


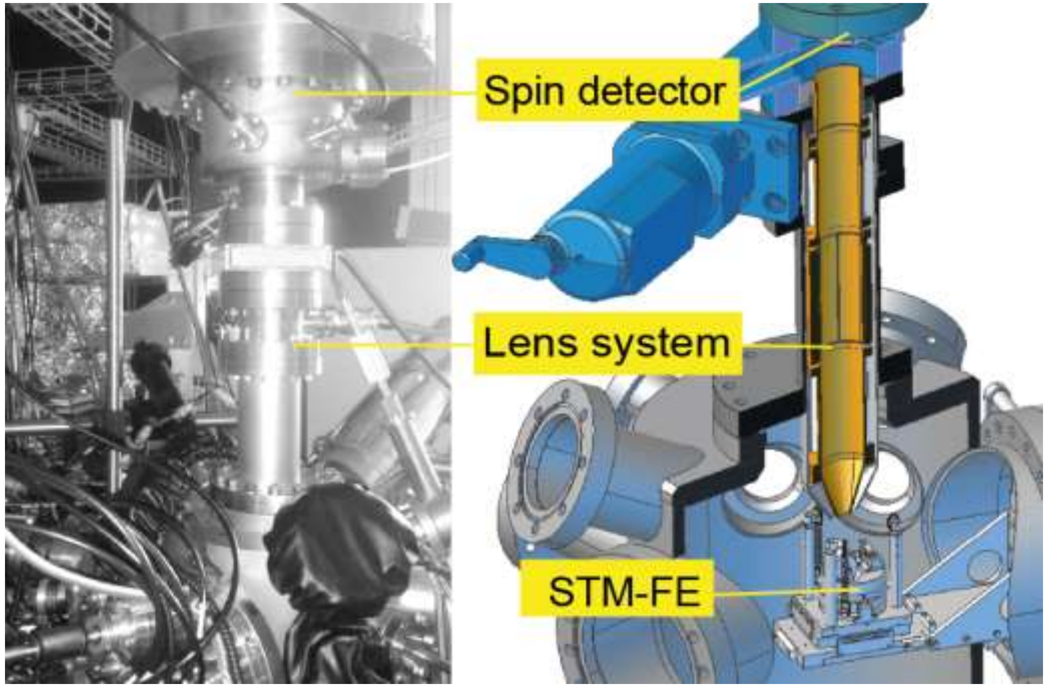
Fig. 1. (Top left and right, bottom left) NFESEM images of the same spot of the sample surface for three different tip-sample distances (11 nm, 10 nm and 9 nm). All NFESEM images show atomic thick Fe patches (dark) residing on the terraces and decorating the W steps (originally the steps are straight). The primary electron beam energy was varied between 24 eV and 35 eV for achieving a set field emission current at varying tip-surface distance. The overall average field emission current is 300 nA. (Bottom right) STM reference topography of the same location acquired after the NFESEM series. Tip-sample voltage is 200 mV, the preset current is 70 pA and the z-amplitude is 1.3 nm. The yellow rectangle highlights a group ofisland clearly visible in all topographies. The red line in the STM image indicates the location of the profile shown in Fig.2.

D.A. Zanin, L.G. De Pietro, H. Cabrera, A. Kostanyan, A. Vindigni,
D. Pescia, and U. Ramsperger
Proceeding of the 27th International Vacuum Nanoelectronics Conference 2014 ,IEEE (2014)

Task: Optimize the Amount of Detected SE

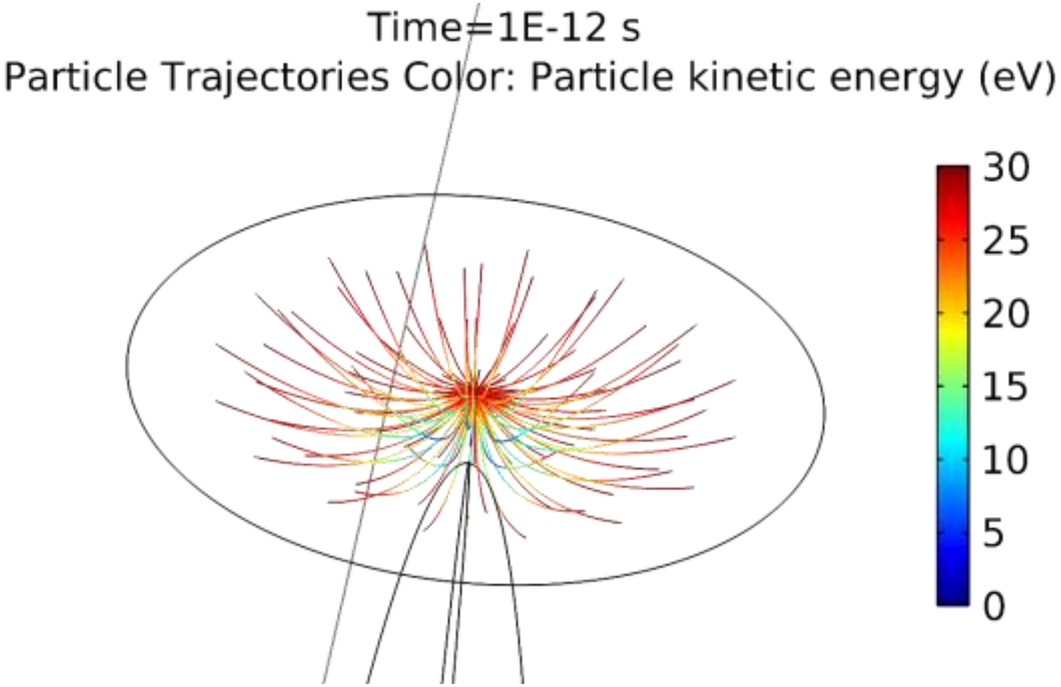
The System Set-up

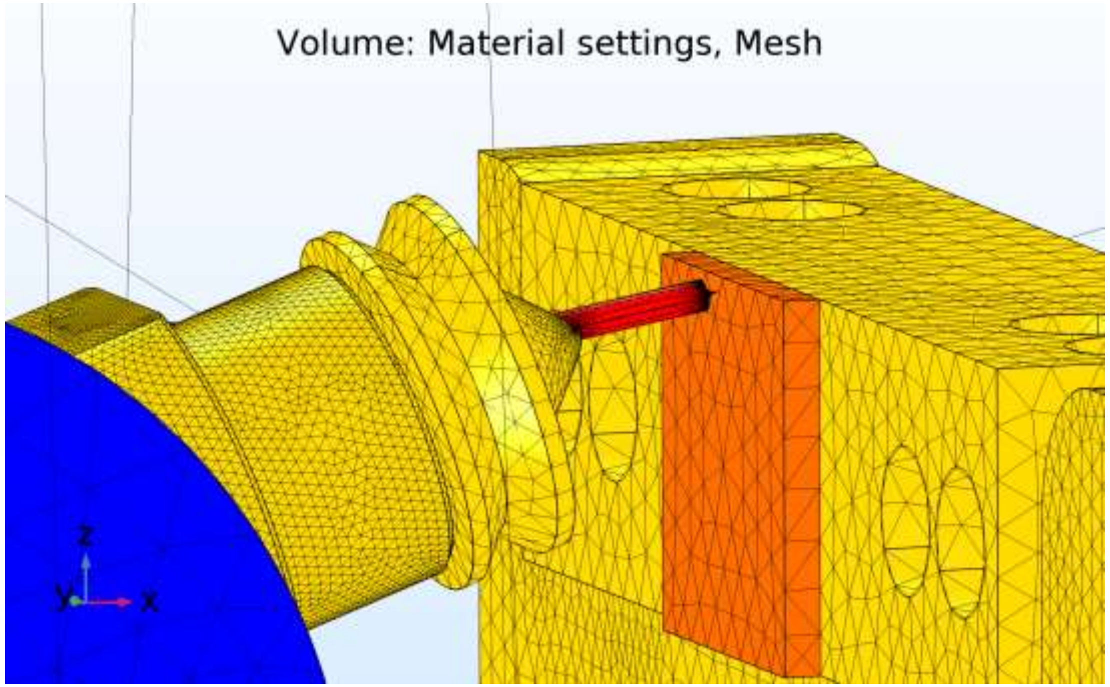
- Expanding the technology to other pourposes: nm-scale imaging of electron spin polarisation.
- Adjust the lens system to collect more SE.
- Improve the geometry of the system.
- Analyze the trajectories of the secondary electrons from the emission point on the surface of the samples to its final position at the entrance to the detectors.



The Coupled Simulations

A Multiscale Problem





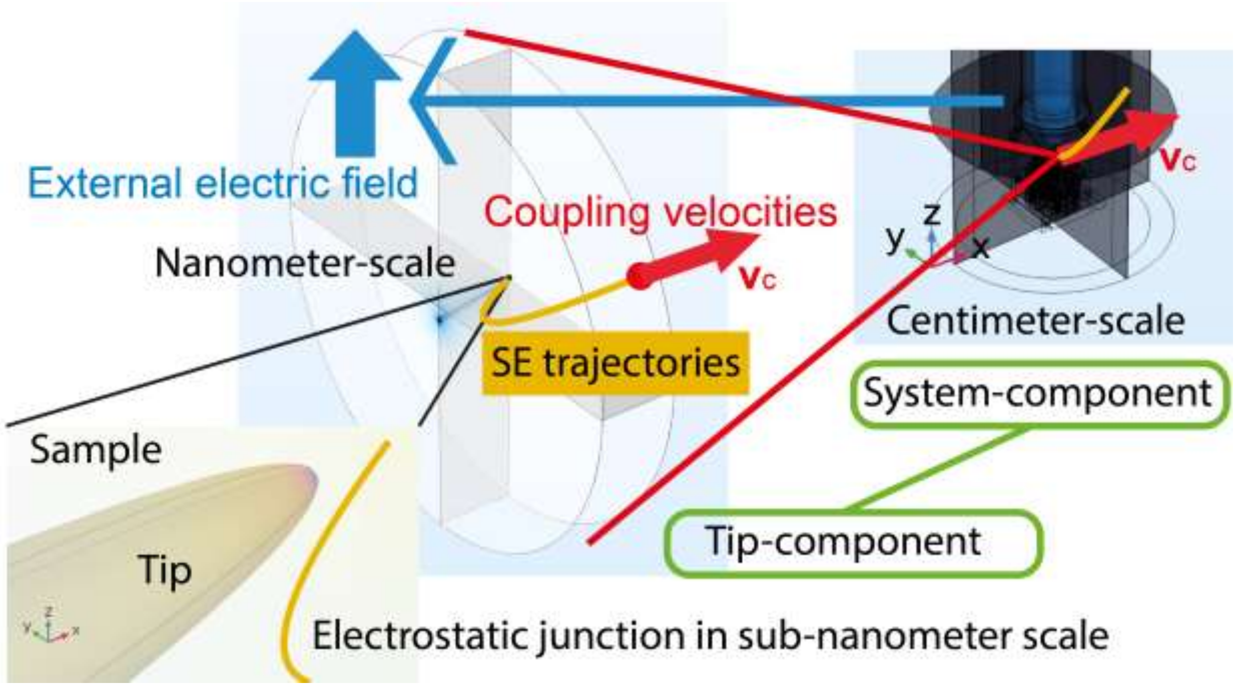
- Fundamental question: which electrons leave the junction? Fine simulation is needed.
- Not feasible considering the dimensions of the mesh and the singularity of the field emitter.

The Coupled Simulations
Junction and System-Components

- Junction-Component in a nanometer-scale.

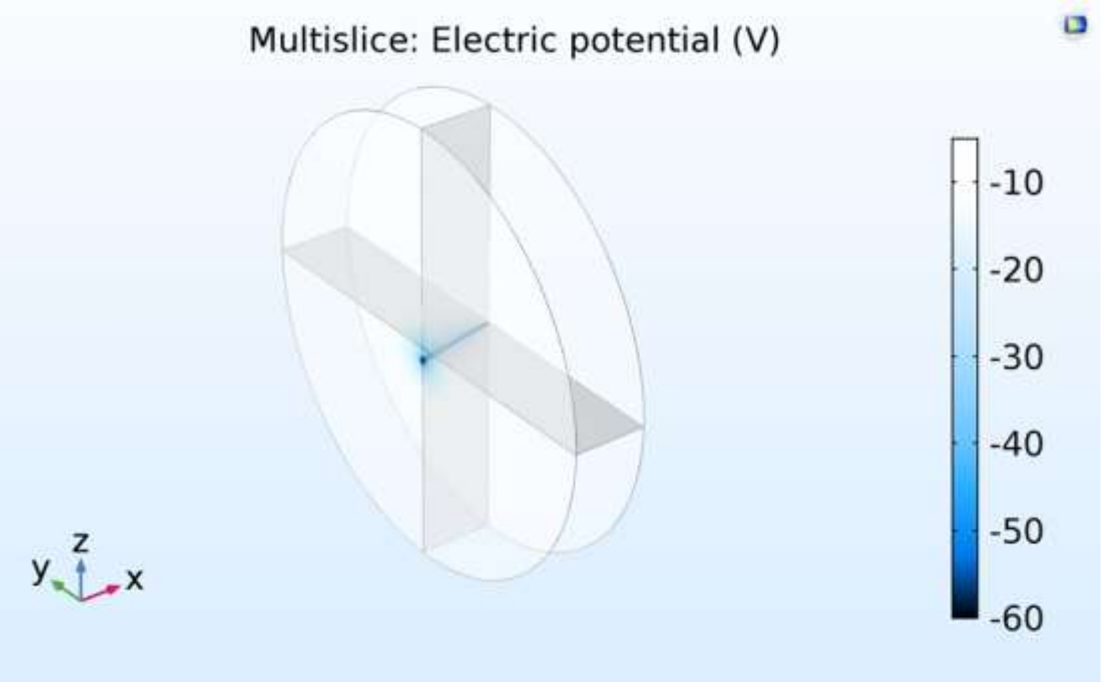
  Hyperboloide of revolution model for the field-emitter.
- System-Component for the STM-FE set-up (centimeter scale).

  Import construccion CAD-files.
- In the Junction-Component add an external electric field from the System-Component.
- Coupling the velocities using the Bondary Condition Freeze feature.



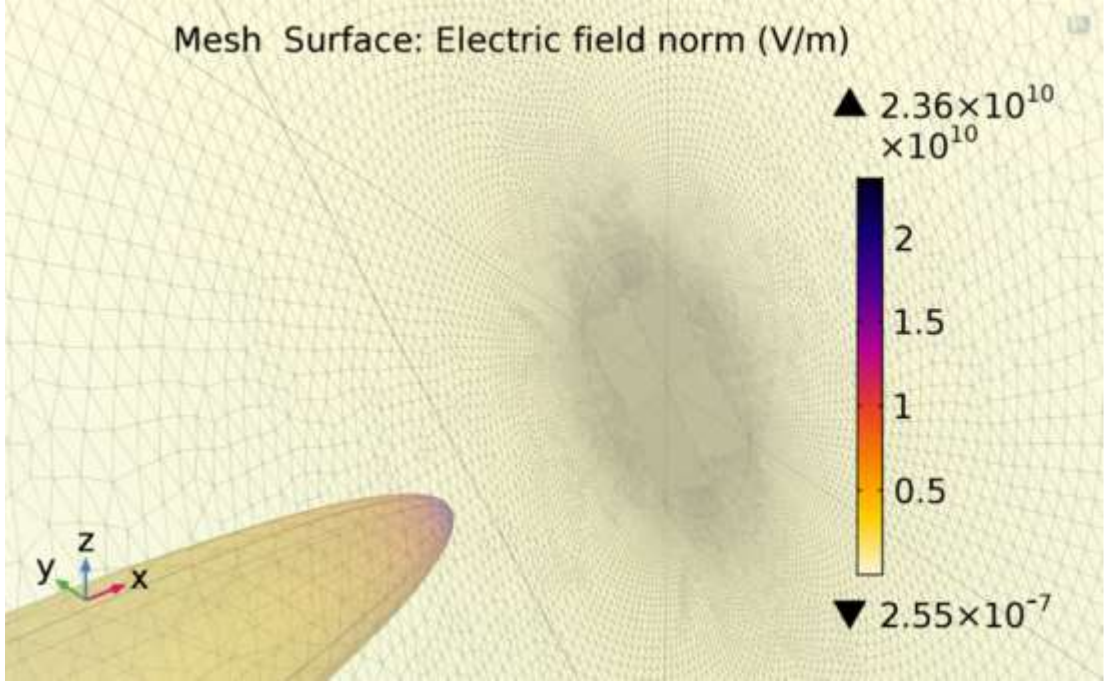
The Junction-Component

- AC/DC Module.
  - Solve Laplace equation and calculate the electric potentials and fields.
  - Inputs: Bias-voltage, distance between tip and sample and tilt angle of the tip.
  - Stationary Study.
- Particle Tracing Module.
  - Calculate trajectories for 2500 electrons by solving the movement equations.
  - Inputs: initial kinetic energy an positions of the secondary electrons.
  - Time Dependent Study.



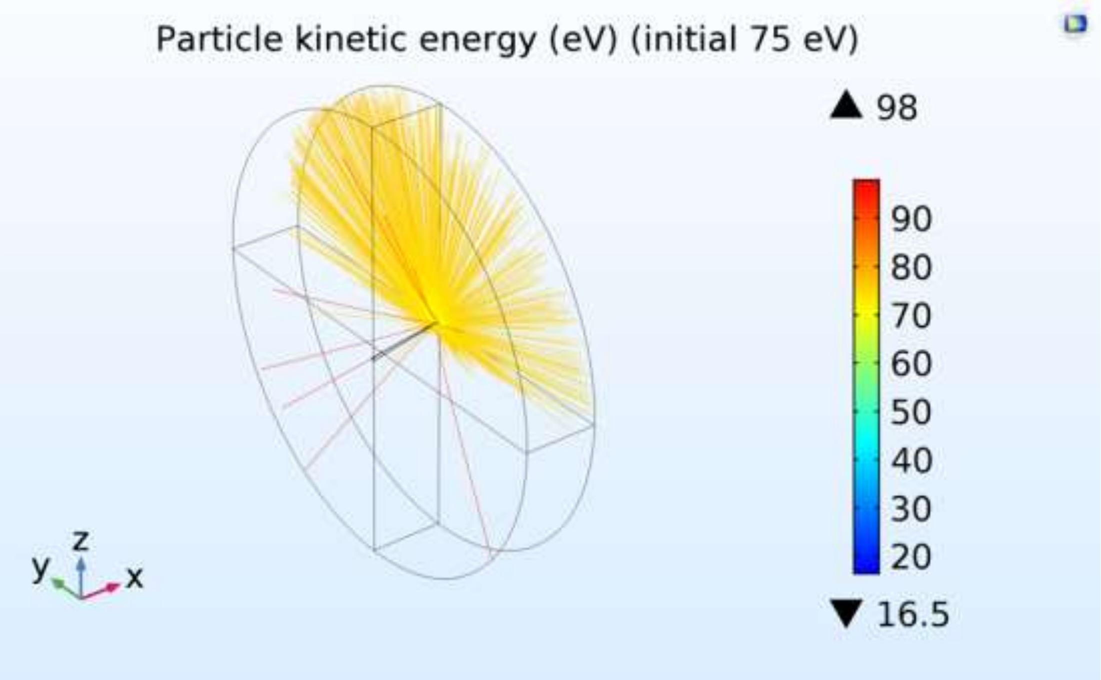
The Junction-Component

- AC/DC Module.
  - Solve Laplace equation and calculate the electric potentials and fields.
  - Inputs: Bias-voltage, distance between tip and sample and tilt angle of the tip.
  - Stationary Study.
- Particle Tracing Module.
  - Calculate trajectories for 2500 electrons by solving the movement equations.
  - Inputs: initial kinetic energy an positions of the secondary electrons.
  - Time Dependent Study.



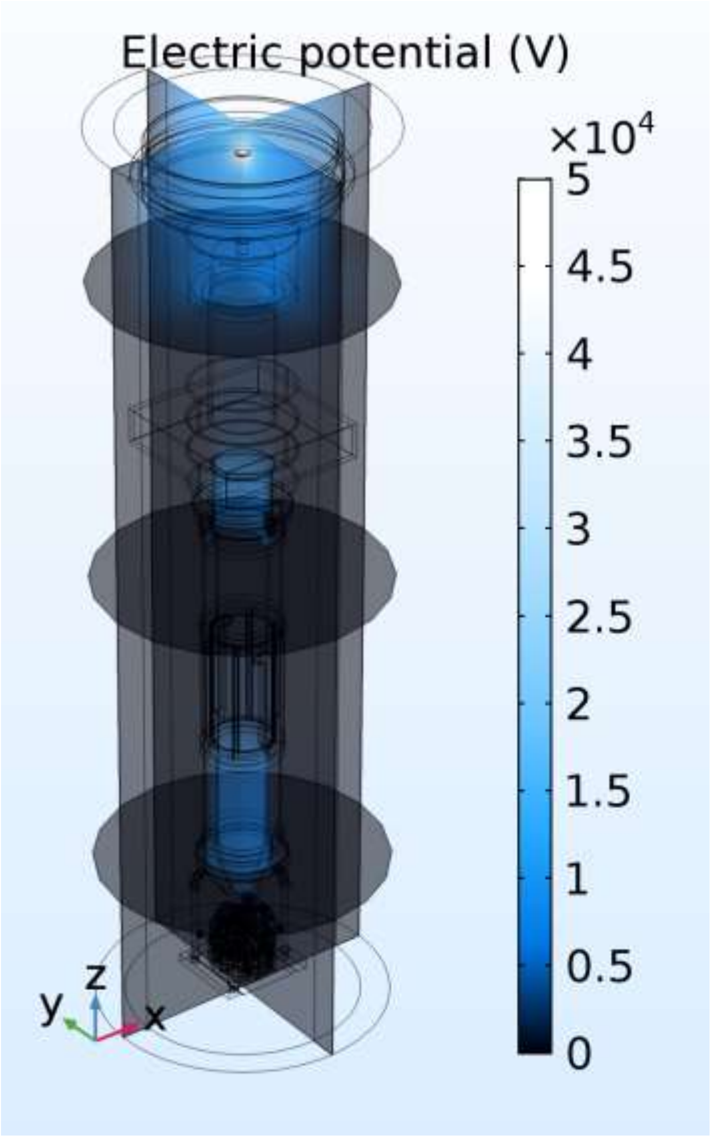
The Junction-Component

- AC/DC Module.
  - Solve Laplace equation and calculate the electric potentials and fields.
  - Inputs: Bias-voltage, distance between tip and sample and tilt angle of the tip.
  - Stationary Study.
- Particle Tracing Module.
  - Calculate trajectories for 2500 electrons by solving the movement equations.
  - Inputs: initial kinetic energy an positions of the secondary electrons.
  - Time Dependent Study.



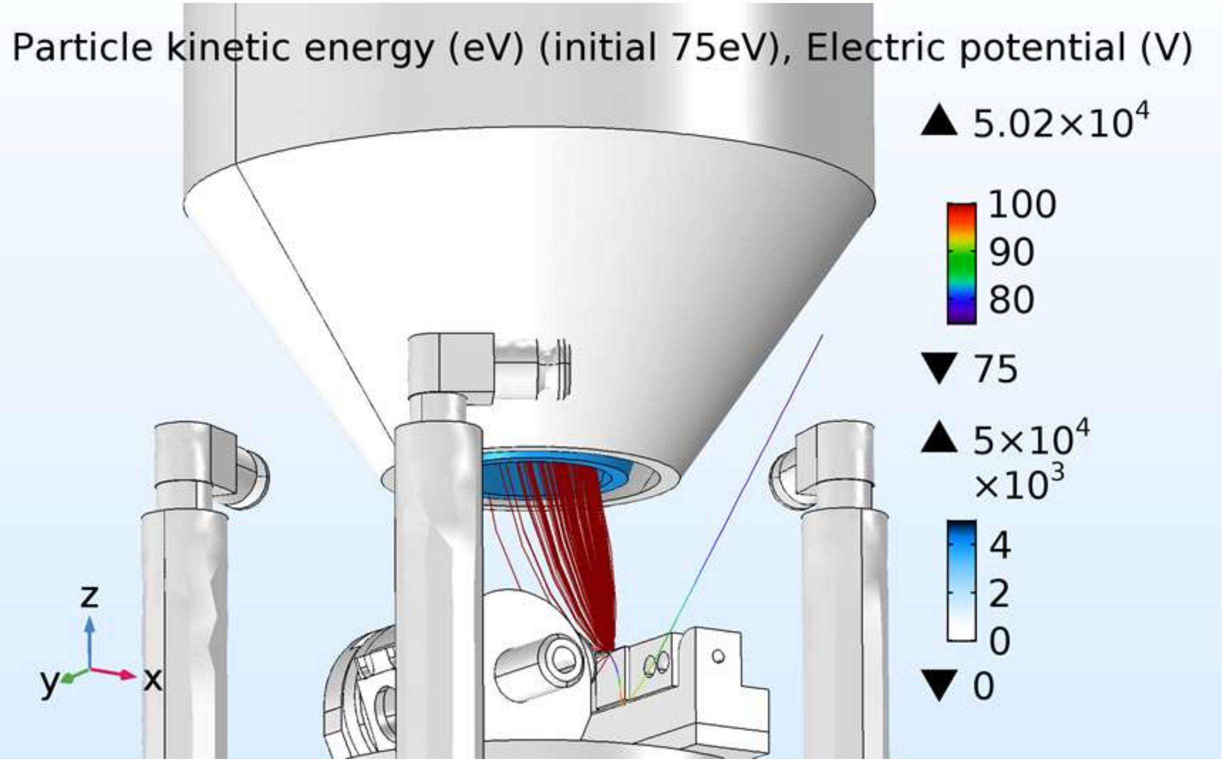
The System-Component

- AC/DC Module.
  - Solve Laplace equation and calculate the electric potentials and fields.
  - Inputs: Bias-voltage, distance between tip and sample and tilt angle of the tip.
  - Stationary Study.
- Particle Tracing Module.
  - Calculate the electron trajectories by solving the movement equations.
  - Inputs: voltages of the lens, detectors and other components of the system, final electron positions and velocities recorded in the Junction-Component.
  - Time-Dependent Study.



The System-Component

- AC/DC Module.
  - Solve Laplace equation and calculate the electric potentials and fields.
  - Inputs: Bias-voltage, distance between tip and sample and tilt angle of the tip.
  - Stationary Study.
- Particle Tracing Module.
  - Calculate the electron trajectories by solving the movement equations.
  - Inputs: voltages of the lens, detectors and other components of the system, final electron positions and velocities recorded in the Junction-Component.
  - Time Dependent Study.



Results: Secondary Electrons Reaching the Detector

- It is posible to estimate the number of electrons reaching the detector for different values of the tip-sample distance, initial kinetic energy and system voltages.
- The simulation allows to observe the importance of the tilt angle of the field-emitter.
- Electrons with energy less than 30 eV return to the sample.

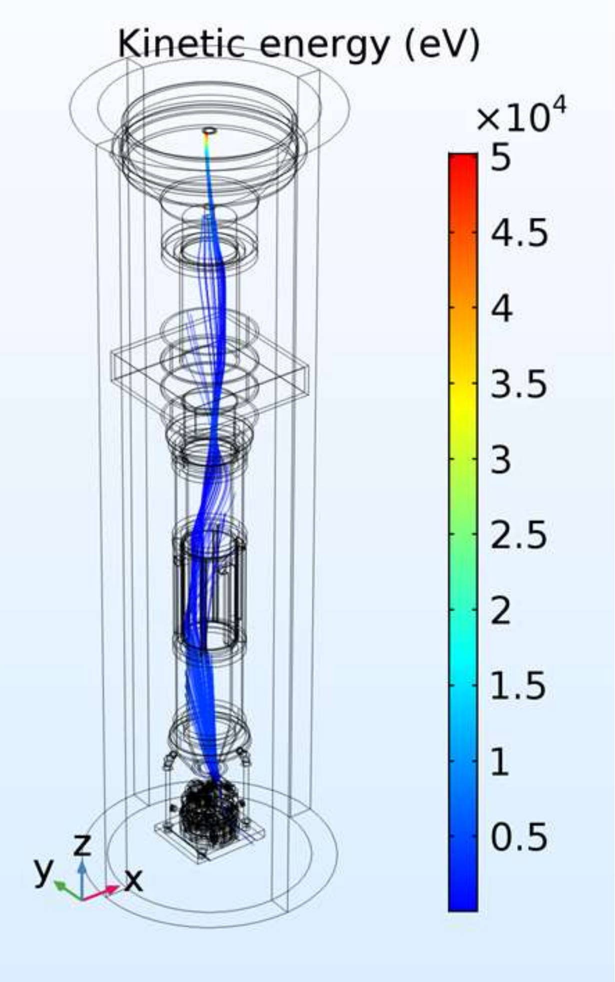


Table 1: Secondary electrons escaping from the junction and reaching the detector for different values of the initial kinetic energy.

Initial kinetic energy (eV)	Escaped electrons	Electrons in detector
35	0	0
45	1	0
55	11	0
65	178	0
75	341	45
85	402	33

Contact Information

ETH Zurich
Laboratory for Solid State Physics
HPT C 2.1, Auguste-Piccard-Hof 1
8093 Zurich

http://www.microstructure.ethz.ch/

Thank you very much for your attention!