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Electrostatic pick-ups for debunched beams at INR linac

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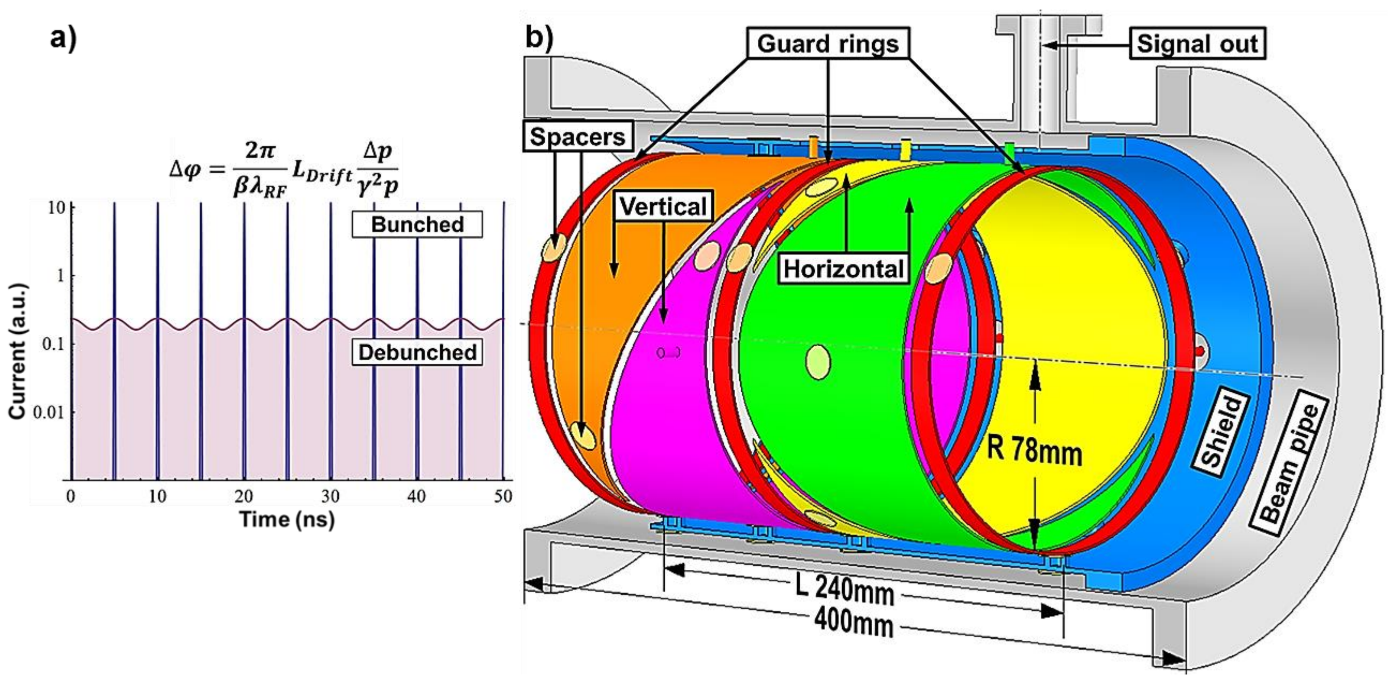
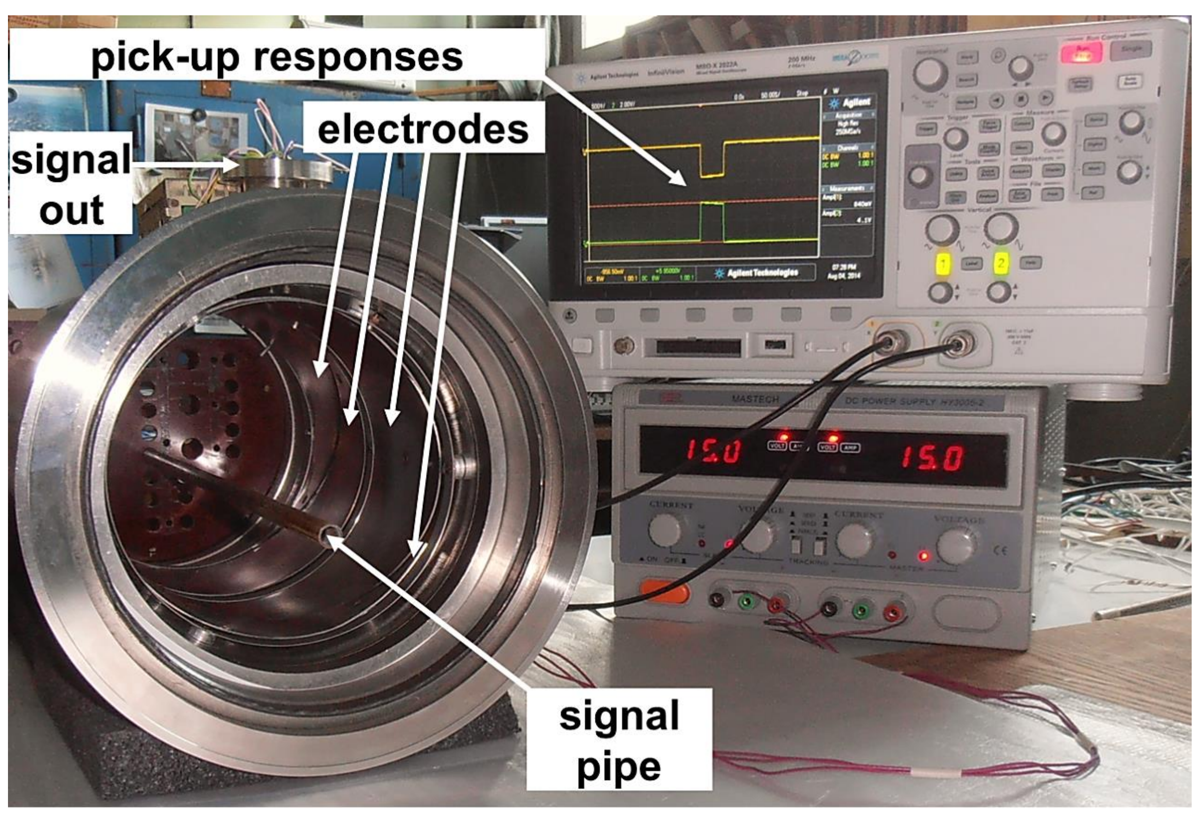
Pick-ups are one of the most widespread non-destructive diagnostics at charged particle accelerators. These detectors, also known as beam position monitors, are generally used for the center-of-mass position measurements of bunched beams. The paper describes the research results for infrequent case of debunched beams operation. Measurement peculiarities and distinctive features of electronics are presented. The results of test bench-based measurements and 3D finite element simulations are discussed.

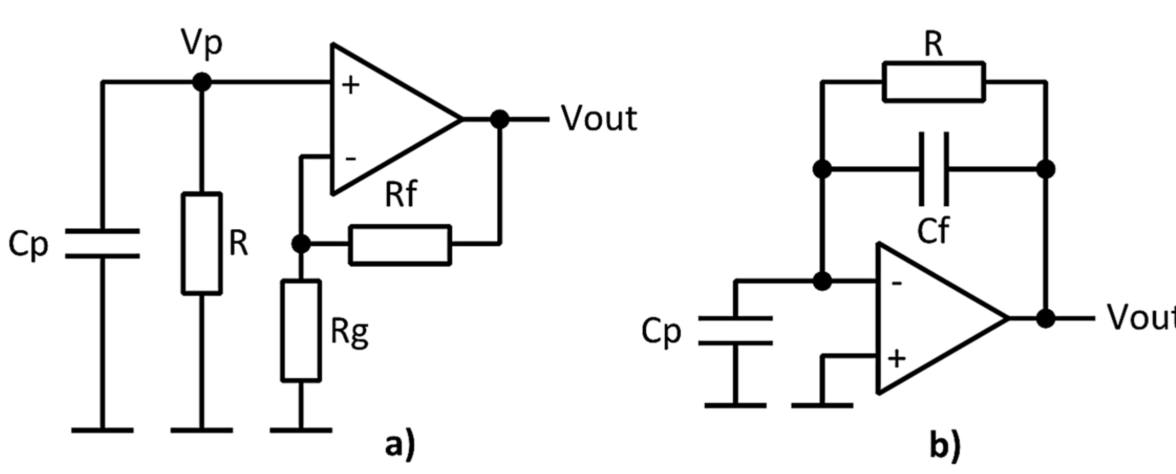
INTRODUCTION

For some time passed by mainly economic reasons the beam is accelerated up to 209 MeV of 600 MeV and is transported near $L_{Drift} \approx$ 400 m to the research facilities without acceleration. Due to the momentum spread ($\Delta p/p \approx \pm 3.5 \cdot 10^{-3}$ at the base) the beam bunch structure ($T_{Bunch} \approx$ 200 ps, f_{RF} = 198.2 MHz) is lost and the measurements are done for the debunched coasting beam.





Pick-up electronics operation modes: (a) voltage amplifier, (b) charge amplifier.



TEST BENCH AND SIMULATIONS

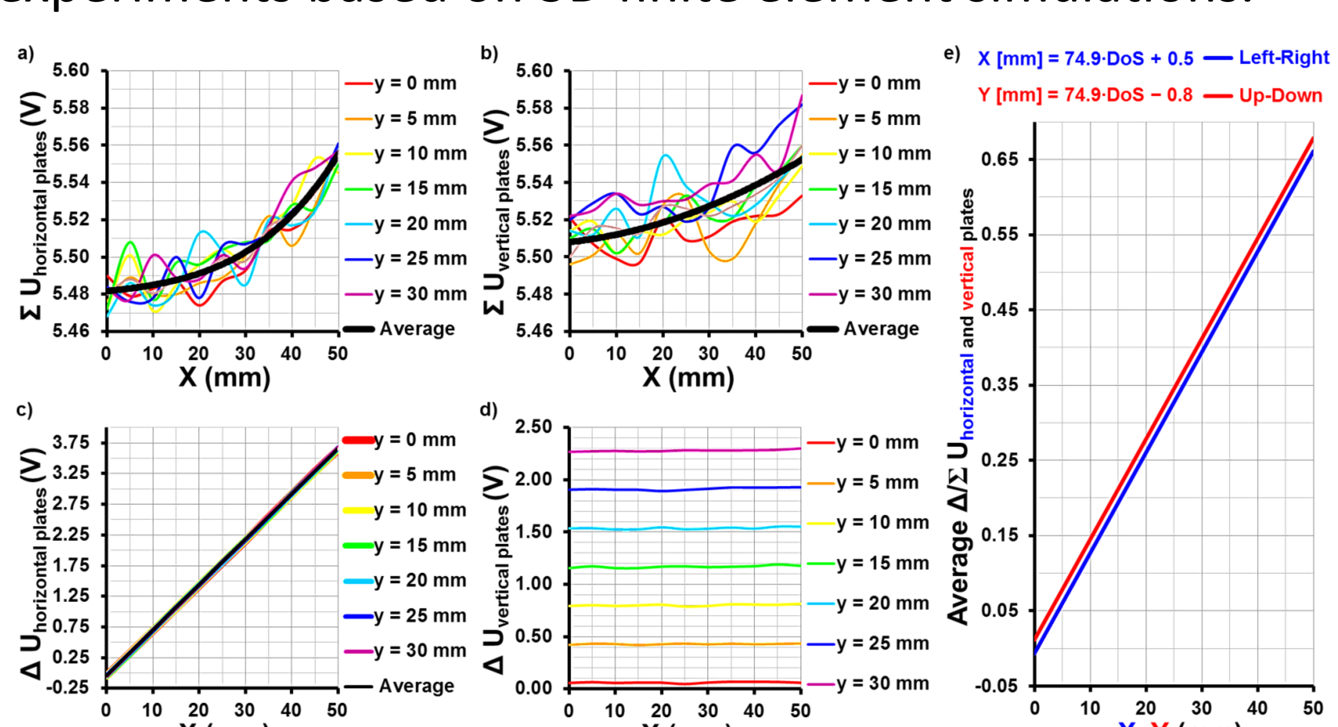
The test bench consists of a copper pipe (D = 10 mm) placed between two grid plates. A signal generator produces a voltage pulse (500 mV, 100 µs, 50 Hz) at the pipe, imitating the debunched proton beam.

Generally, plate charge Q_p is integrated on the total pick-up capacitance C_p, producing voltage $V_p = Q_p/C_p$. Then voltage amplifier is used to provide gain. C_p is composed of a pick-up plate-to-ground capacitance plus the capacitance of the interconnecting cable.

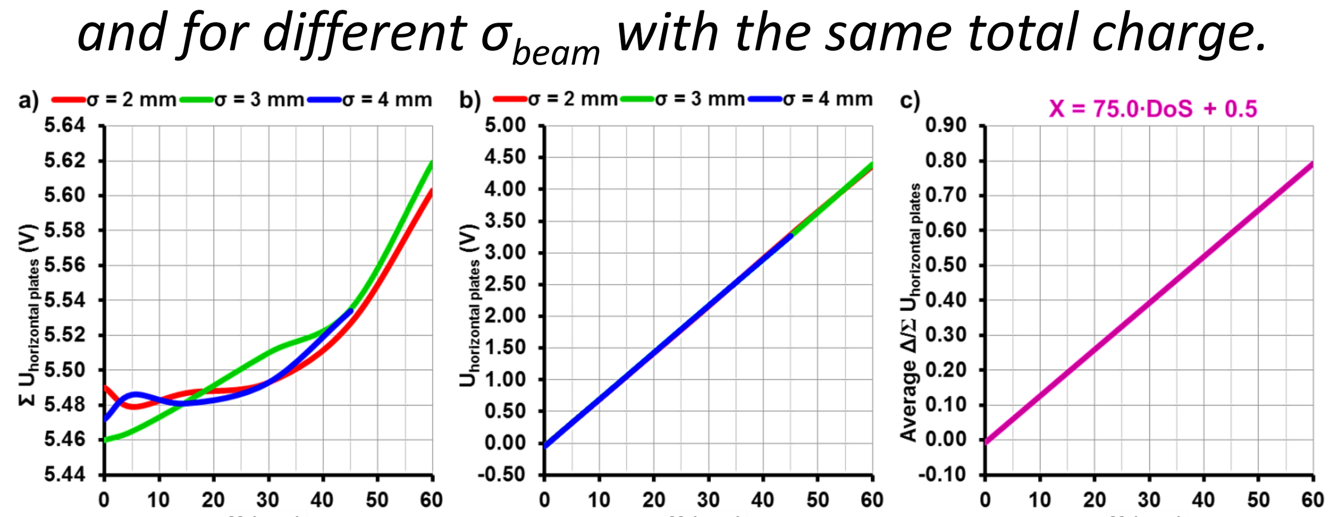
Unlike floating potentials of the electrodes in case of voltage amplifier, charge amplifier actively keeps the electrodes at zero potential. Its output voltage is always $V_{out} = -Q_p/C_f$, so pick-up calibration can be done with an arbitrary cable length.

Taking into account electronics noise ±7.5 mV, one can estimate the pick-up resolution ΔX specifying the ability to measure small beam position displacements.

A conductive pipe with uniform surface distribution of a fixed voltage cannot be an equivalent of a beam. Therefore we need a complementary numerical experiments based on 3D finite element simulations.

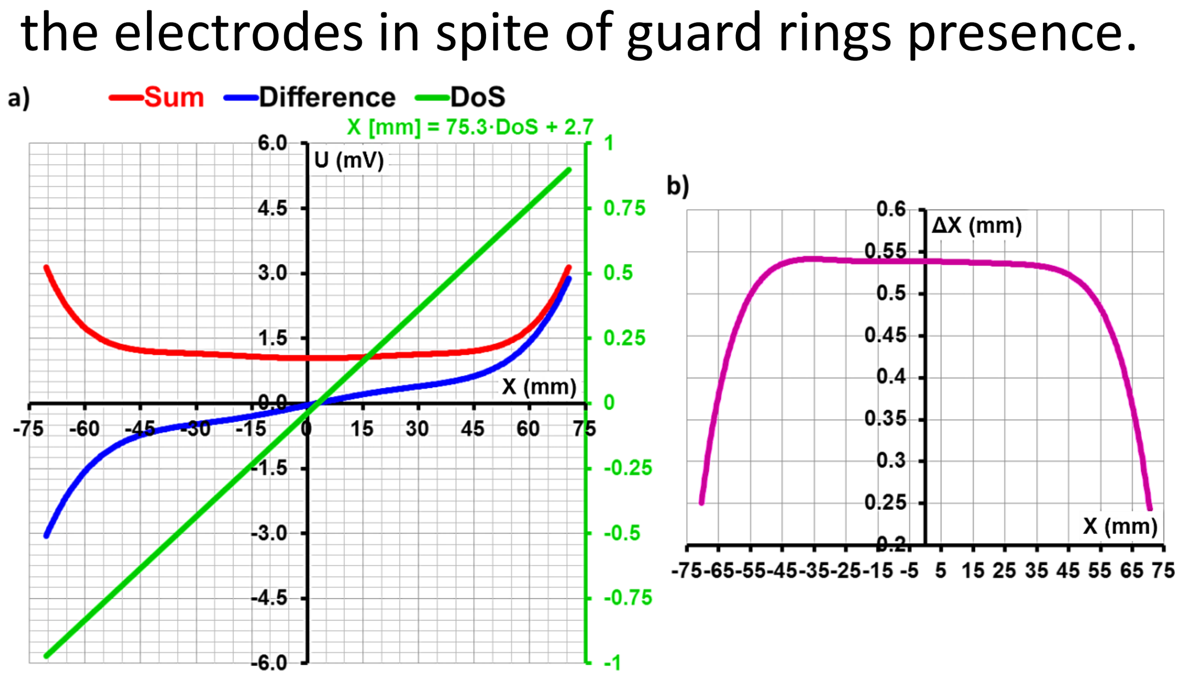


The comparative results for different position offsets and for different σ_{beam} with the same total charge.



TEST RESULTS

Results of bench-based measurements show expected DoS linearity across the whole aperture of the pick-up, though the sum and the difference are nonlinear per se. Deviations from the linear fit are smaller than ±0.5%. Constant $K_X = K_Y$ = 75.3 mm is 3.5% better than 2D-ideal approximation and is primarily caused by variation of beam pipe shape and size near the electrodes in spite of guard rings presence.

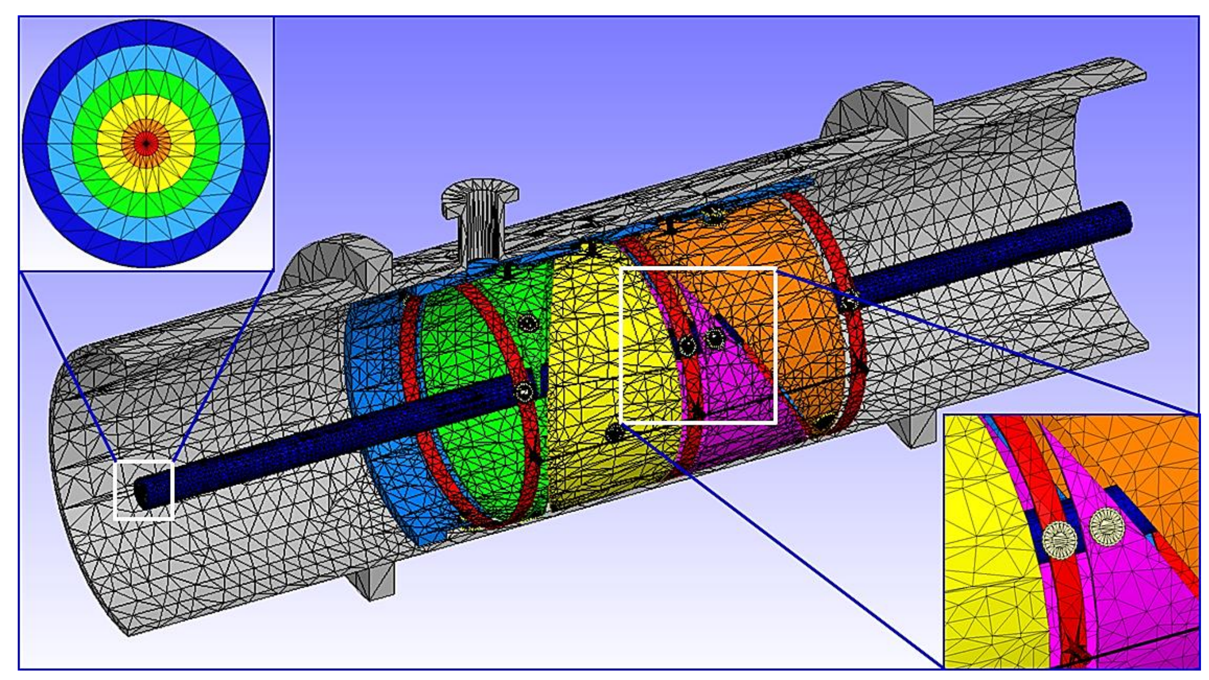


(a) DoS calibration. (b) Position resolution.

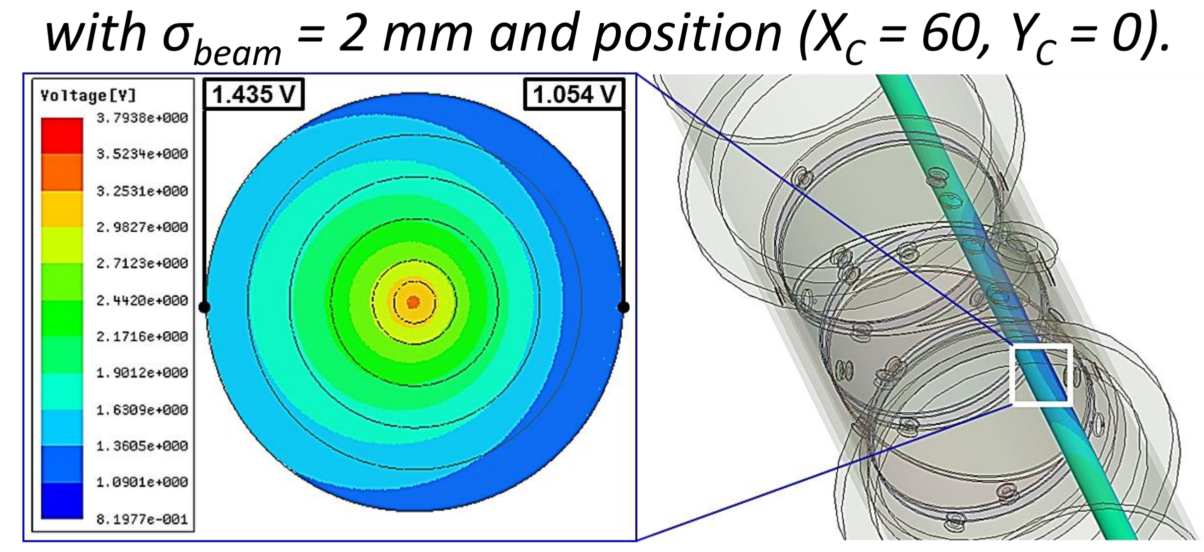
THEORY FORMALISM

In ideal 2D electrostatic approximation for cylindrical split-electrodes with inner radius R beam positions are determined by Difference of the charges over their Sum (DoS). In practice, because of the capacitive coupling between the adjacent electrodes and asymmetry of the electric field at their edges, positions are:

$$X = K_X \frac{\Delta Q_{Horizontal}}{\sum Q_{Horizontal}} + \delta_X, Y = K_Y \frac{\Delta Q_{Vertical}}{\sum Q_{Vertical}} + \delta_Y.$$

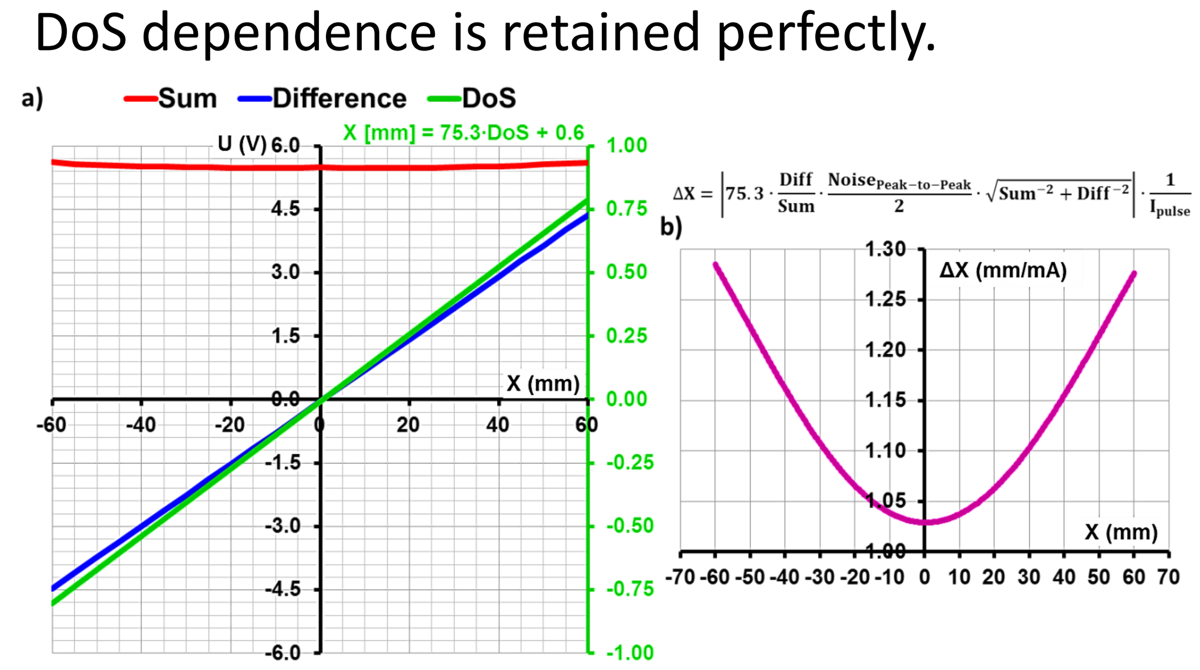


ANSYS tetrahedral meshing for INR pick-up and beam models. Voltage distribution in the beam with σ_{beam} = 2 mm and position (X_C = 60, Y_C = 0).



SIMULATION RESULTS

Simulations show that a beam "surface" voltage distribution differs considerably from the uniform surface voltage distribution of a conductive pipe, and this difference increases with a beam offset. This effect provides expected qualitative changes of the electrodes responses. The sum and the difference signals dependences lose non-linear tails, whereas the DoS dependence is retained perfectly.



(a) DoS calibration. (b) Position resolution.