An Improved Model for Photoemission of Space Charge Dominated Picosecond Electron Bunches: Theory and Experiment.

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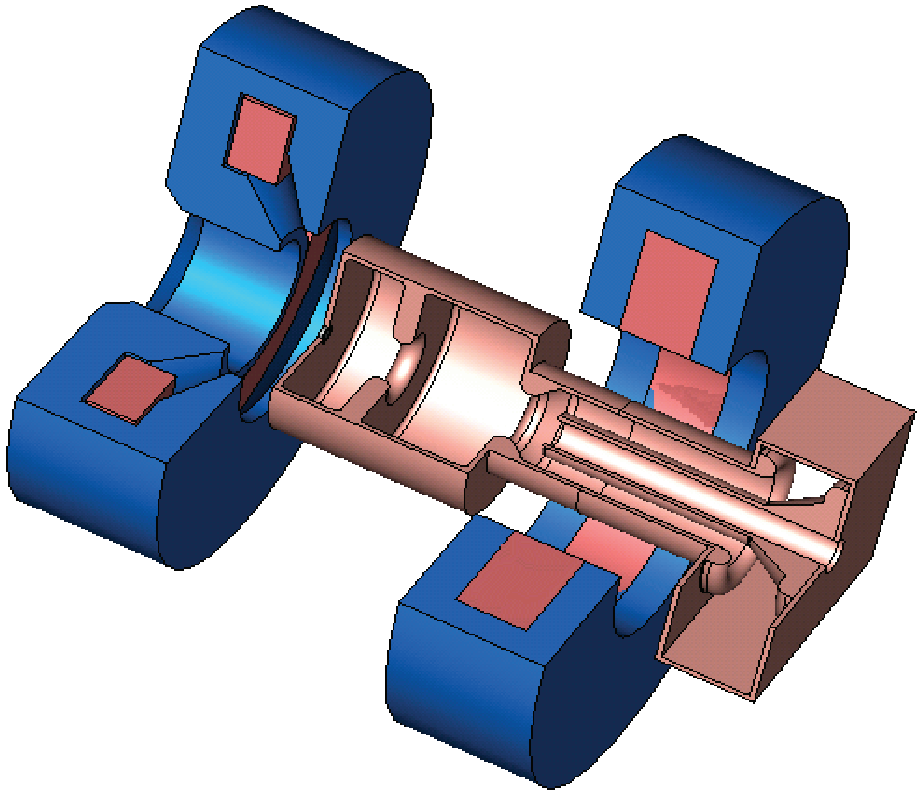
Photo Injector Test facility at DESY, Zeuthen site

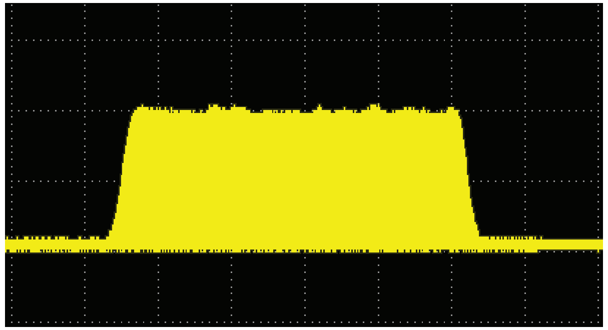


RFgun: L-band (1.3 GHz) nc (copper)
standing wave 1½-cell cavity
Peak rf power: up to 7MW
Ez@cathode: > 60MV/m

Photo cathode (Cs_2Te) QE~0.5-20%

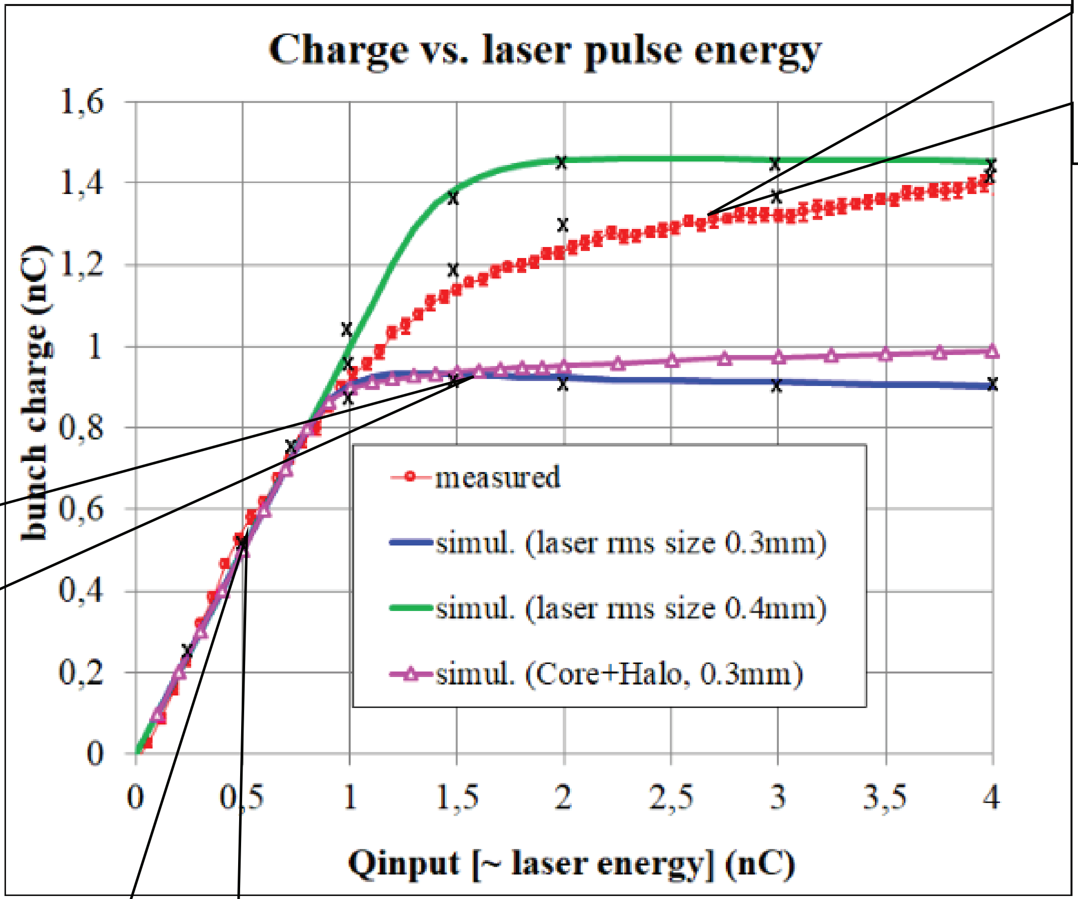
Bunch charge up to 5nC

Cathode laser 257nm ~20ps (FWHM)



Emission curves

Typical characteristic measurement at a photo injector: emission curve – accelerated bunch charge as a function of the photocathode laser pulse energy (~input charge at the cathode)



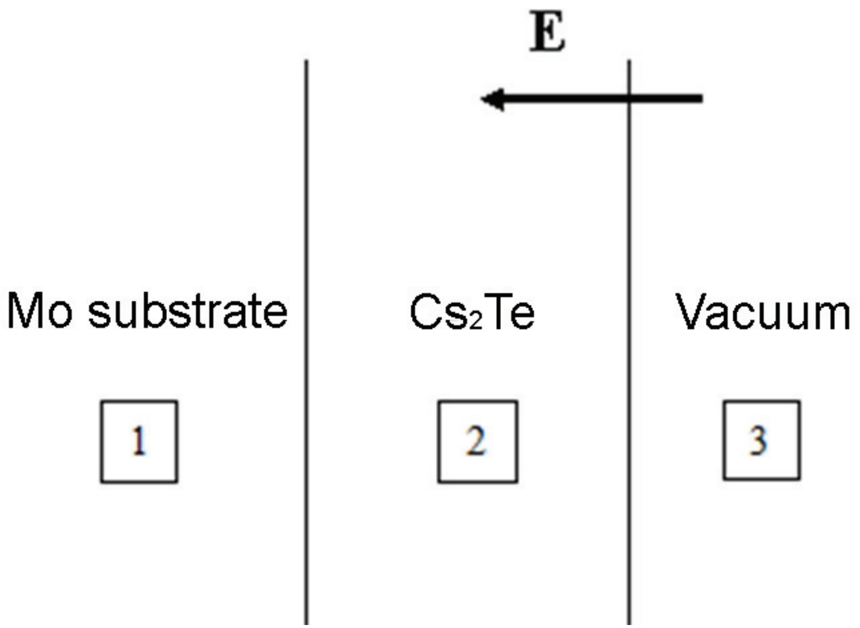
1nC experimen-tally optimized emittance

Saturation due to the space charge-limited emission → charge losses at the photocathode due to a partial virtual cathode formation during emission process

Linear part: QE-limited emission

Emission curves measured at PITZ (red curve) compared to the simulation results from ASTRA (green, blue and magenta curves)

Photocathodes inside the high gradient RF gun



Field penetration depth

$$E = \frac{\sigma}{2\varepsilon\varepsilon_0} = \frac{qN}{2\varepsilon\varepsilon_0}$$

To compensate $E \sim 10^7 V/m$

$$\varepsilon \approx 10; N = 10^{11} cm^{-2}; \rho = 10^{15} cm^{-3}$$

$$d = N/\rho = 1\,\mu m$$

The field penetrates the entire depth of the semiconductor film <0.1μm

Charge balance in a semiconductor film

The electron exit rate is determined by the magnitude of the electric field

$$v_{-} = \frac{eEt}{\varepsilon\gamma m}$$

The rate of positive charge inflow is determined by the difference in carrier concentrations (Fick law)

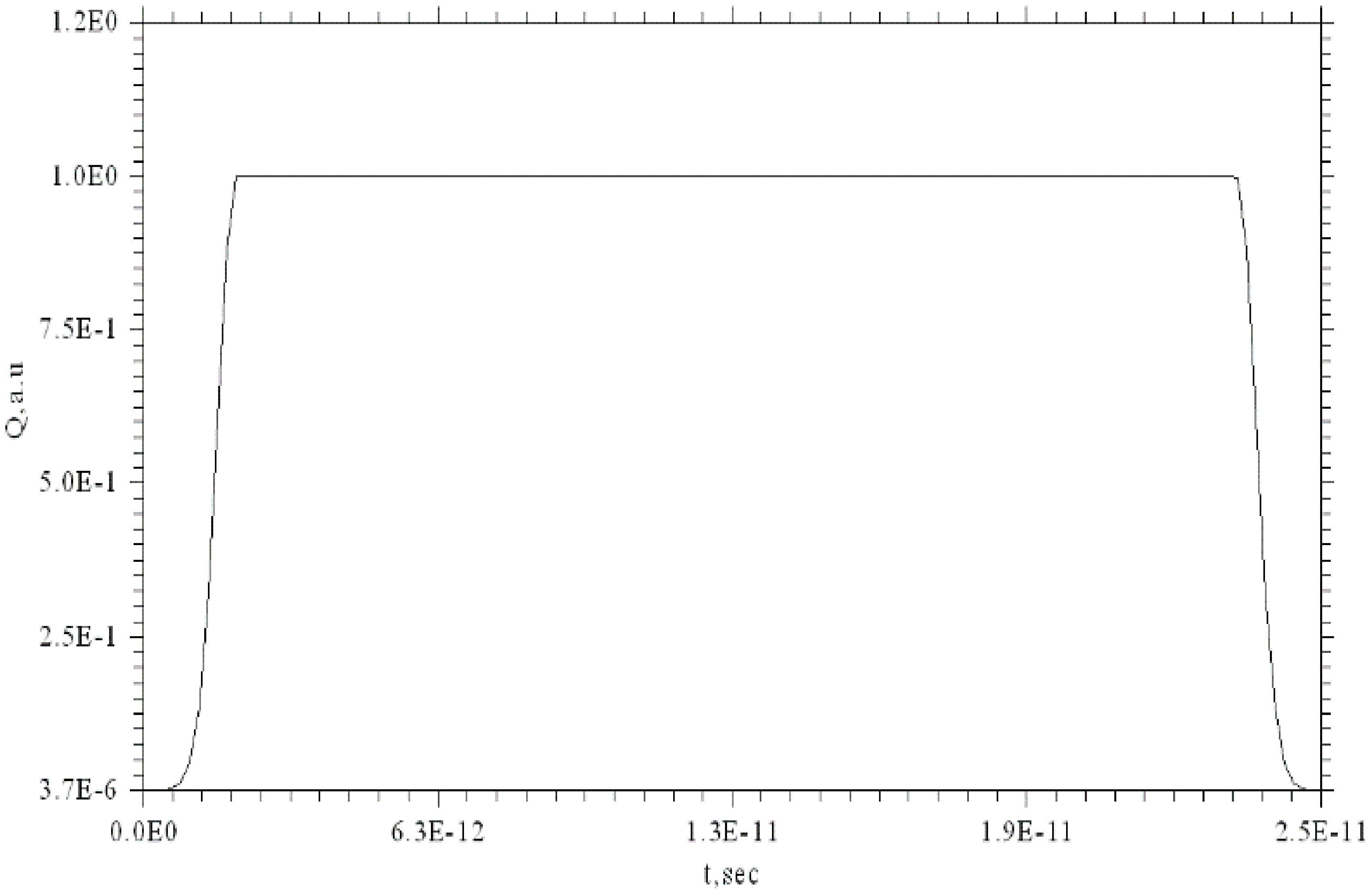
$$\vec{j} = \rho\vec{v}_{+} = -eD\,\mathrm{grad}\,n$$

The diffusion coefficient D is related to the mobility of charge carriers μ by the Einstein relation

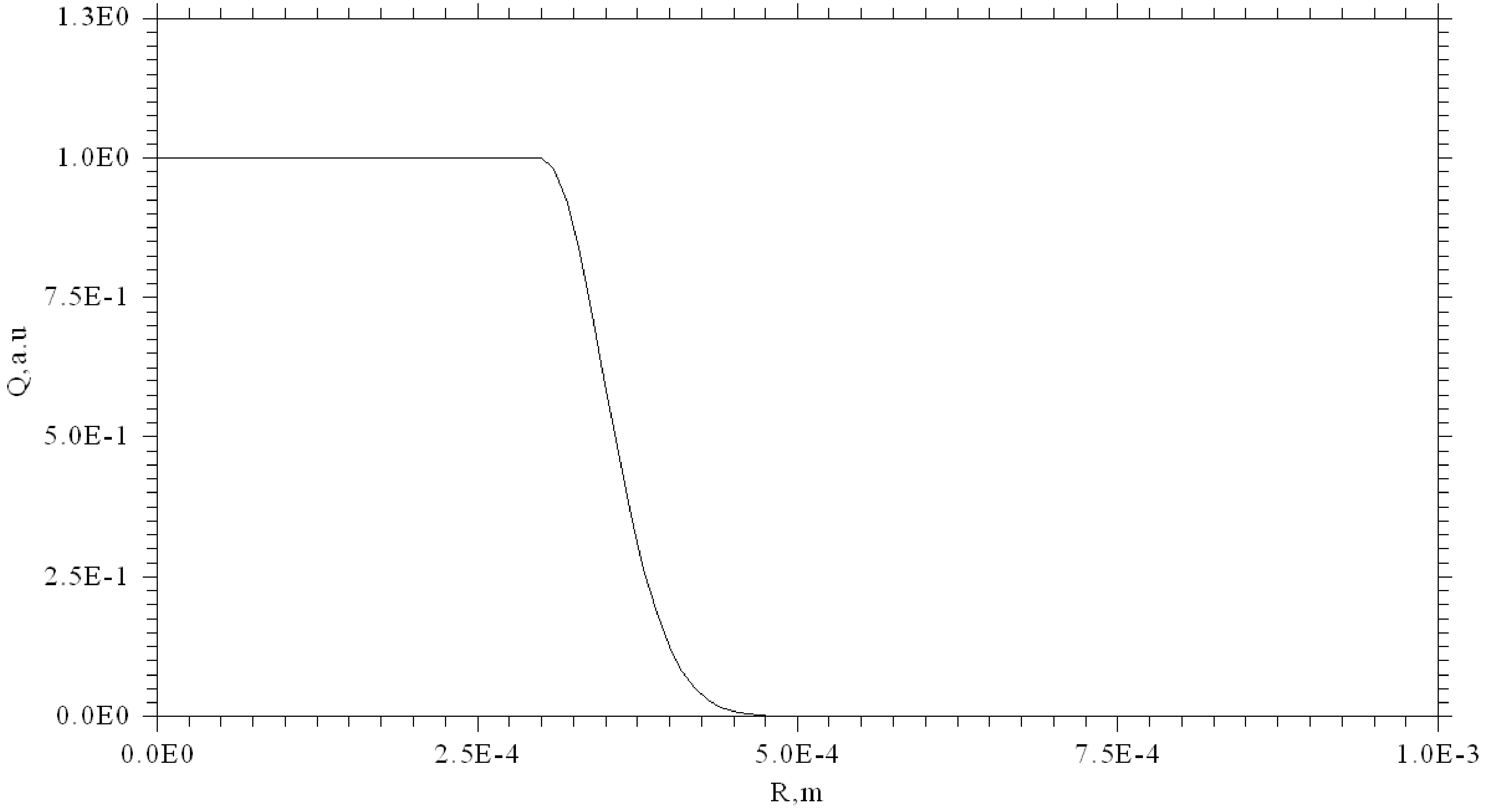
$$D = \frac{kT}{e}\mu$$

In the picosecond time range $v_{-} > v_{+}$

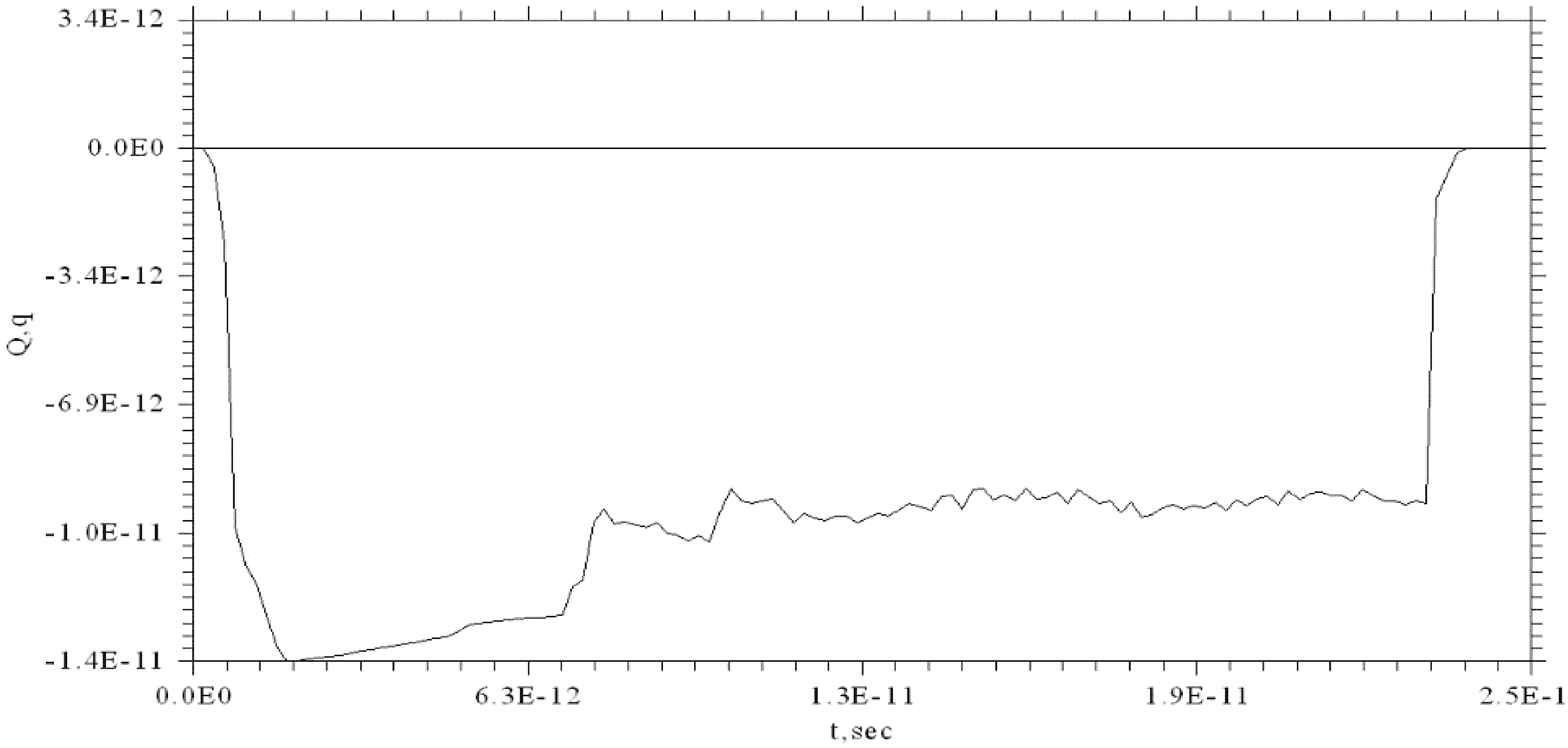
Photocathode laser pulse temporal profile



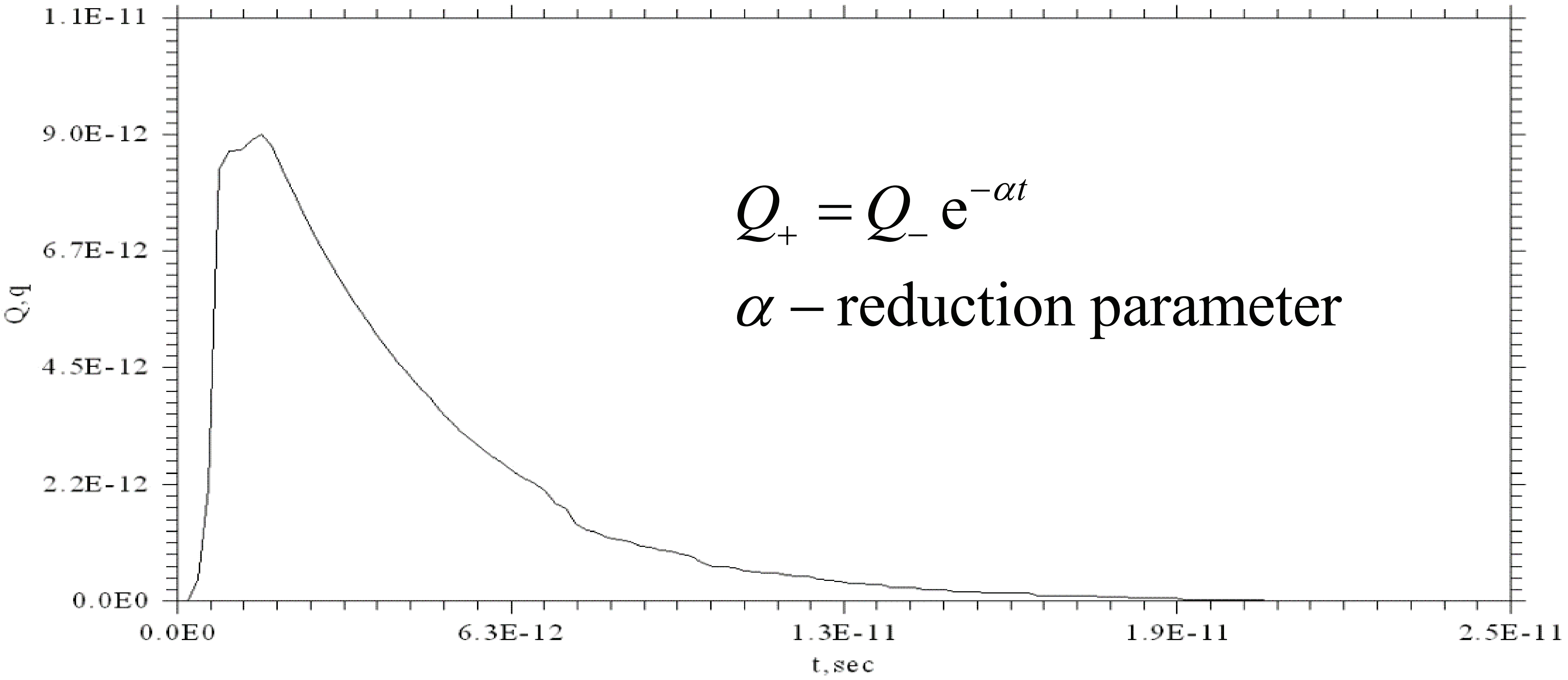
Radial charge distribution in the photocathode



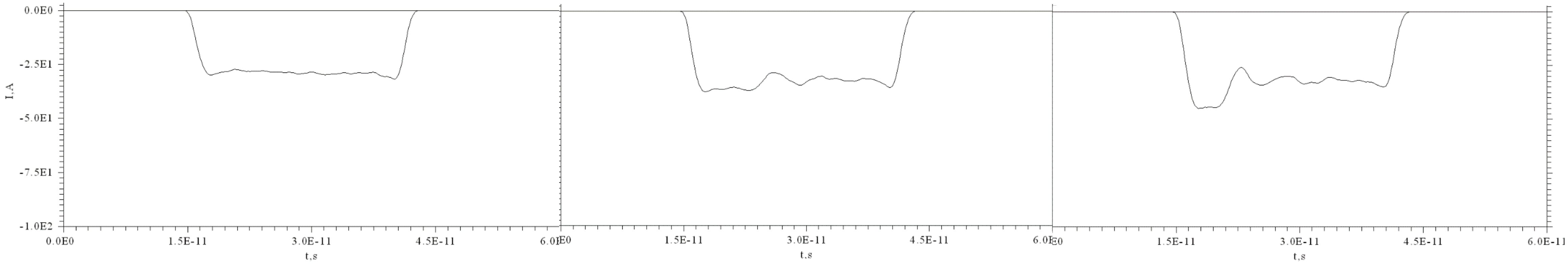
Emitted charge temporal profile



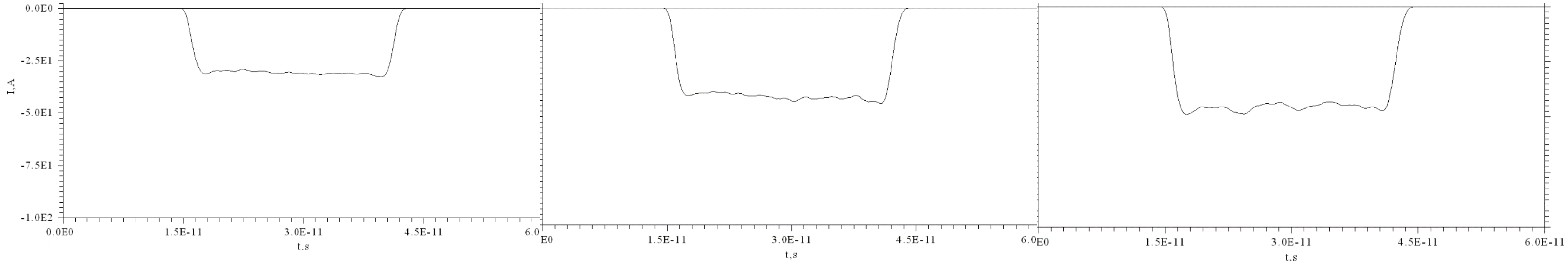
Positive charge temporal profile in a semiconductor film



Old model

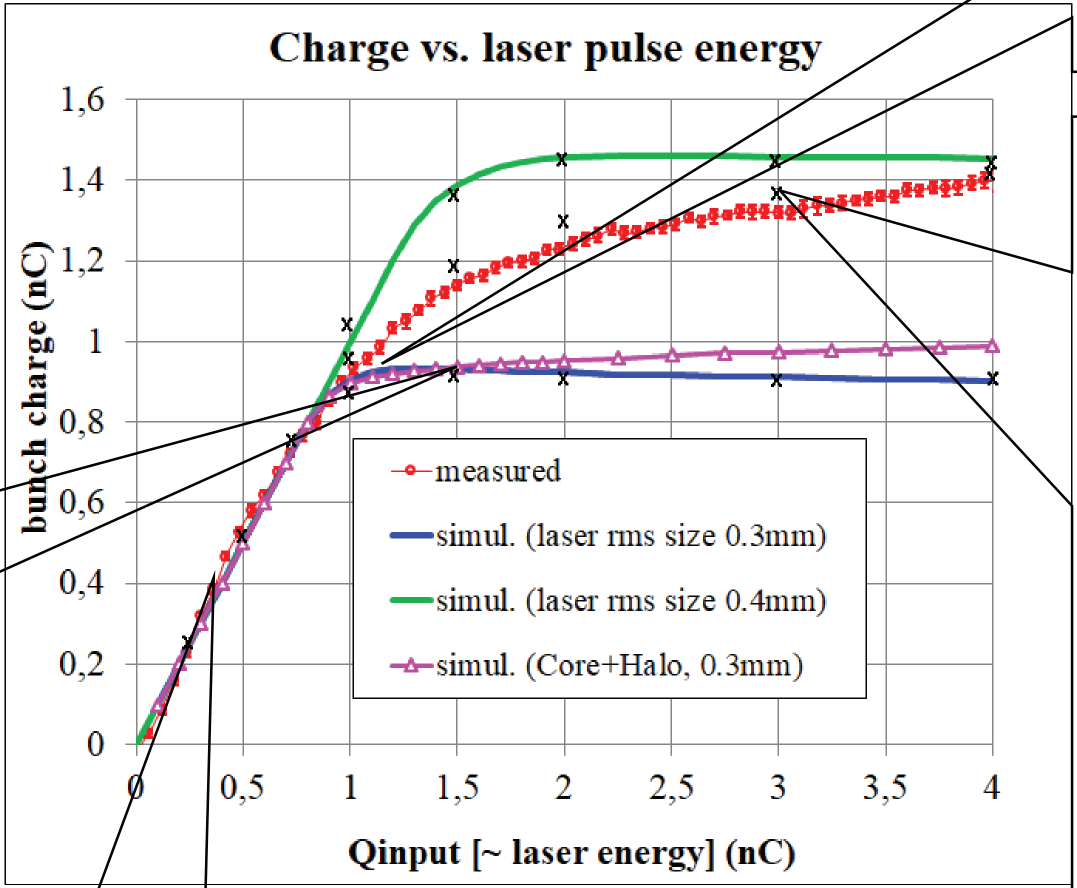


New model



Emission curves

Typical characteristic measurement at a photo injector: emission curve – accelerated bunch charge as a function of the photocathode laser pulse energy (~input charge at the cathode)



1nC experimentally optimized emittance

x - SUMA simulation

α - once fitted for one point of the emission curve → fixed as a material constant

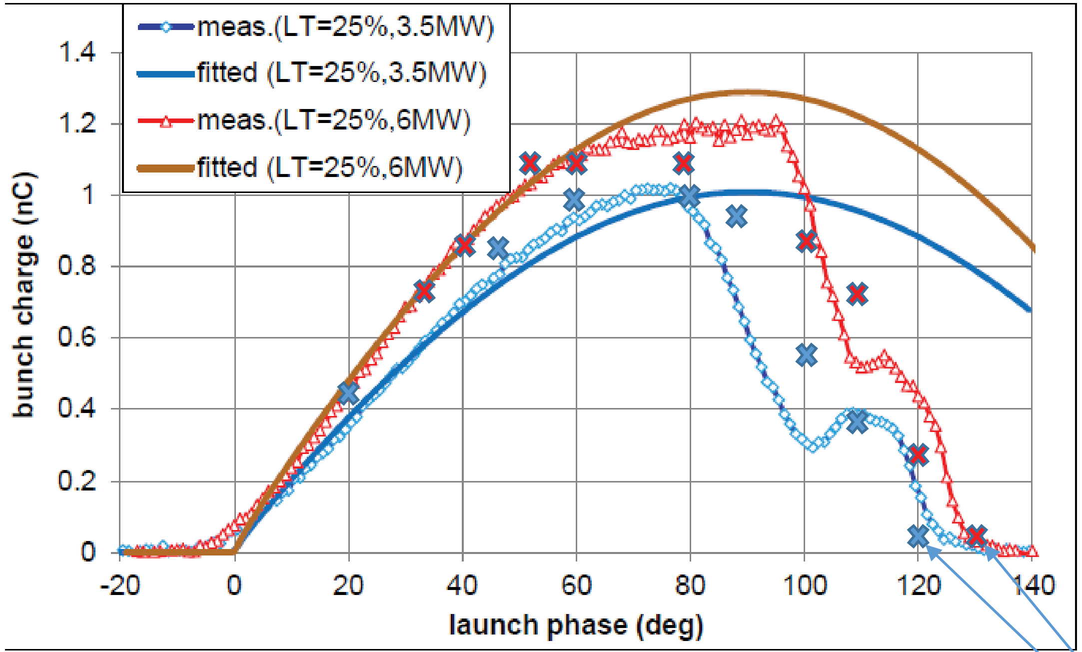
Saturation due to the space charge-limited emission → charge losses at the photocathode due to a partial virtual cathode formation during emission process

Linear part: QE-limited emission

Emission studies: modeling → RF field influence (LT=25%)

$$Q \propto \eta \cdot LT \cdot \left(1 + b\sqrt{E}\right)^m$$

LT = laser transmission (%)
E – field at the cathode (MV/m)
η, b, m – fitting parameters



$LT = LT0$ = 25% (1nC at MMMG phase for 6MW)

RF power (MW)	Ecath (MV/m)	max <Pz> (MeV/c)
6.02	62.0	6.83
3.54	47.6	5.43

Fitting:
Phase range: 10→70deg
$E = E_{cath} \cdot sin\varphi_0$
η=1.2148E-5
b=10.9222
m=1.8705 (1.8977-2.1081)→2
+convolution with laser temporal profile

Measurements:

Laser:

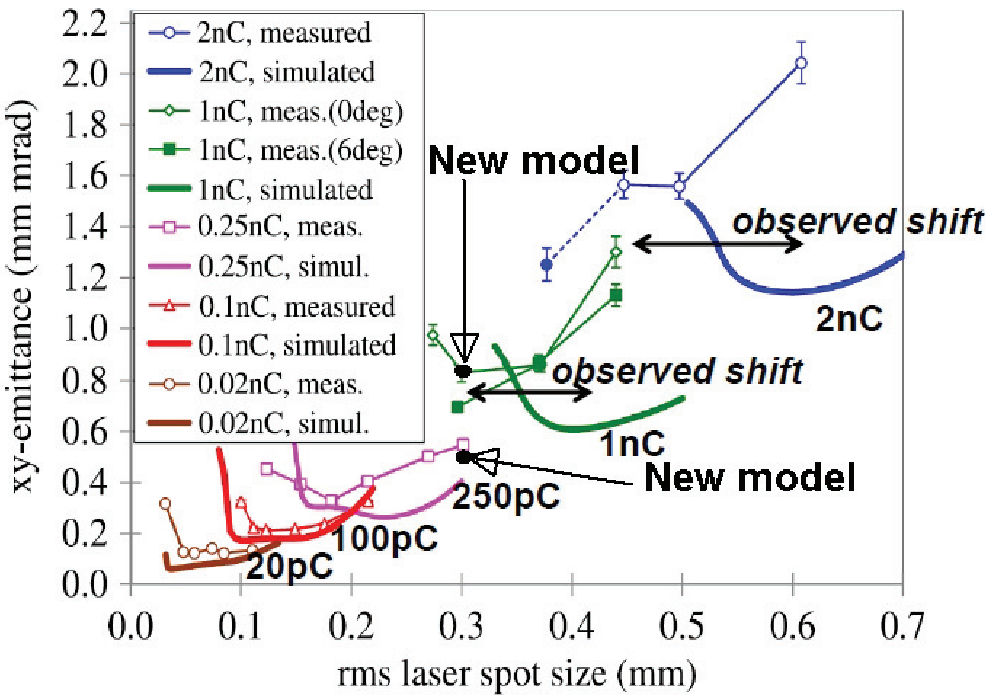
- *Temporal → flattop 2/20\2ps*
- *Transverse → 0.3 mm rms*

Main solenoid: 400A
Charge measured by LOW.ICT1 → z=0.9m

SUMA simulation

Emittance experimental curves and SUMA simulation

Simulated optimum laser spot size ≠ measured one



M. Krasilnikov, et al., Phys. Rev. ST Accel. Beams 15, 100701 (2012)

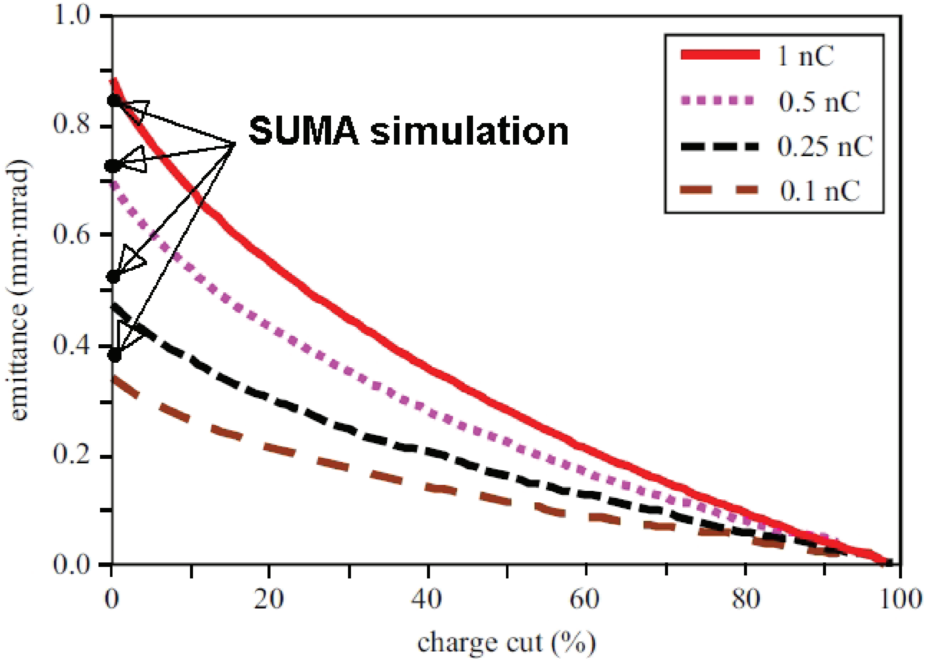
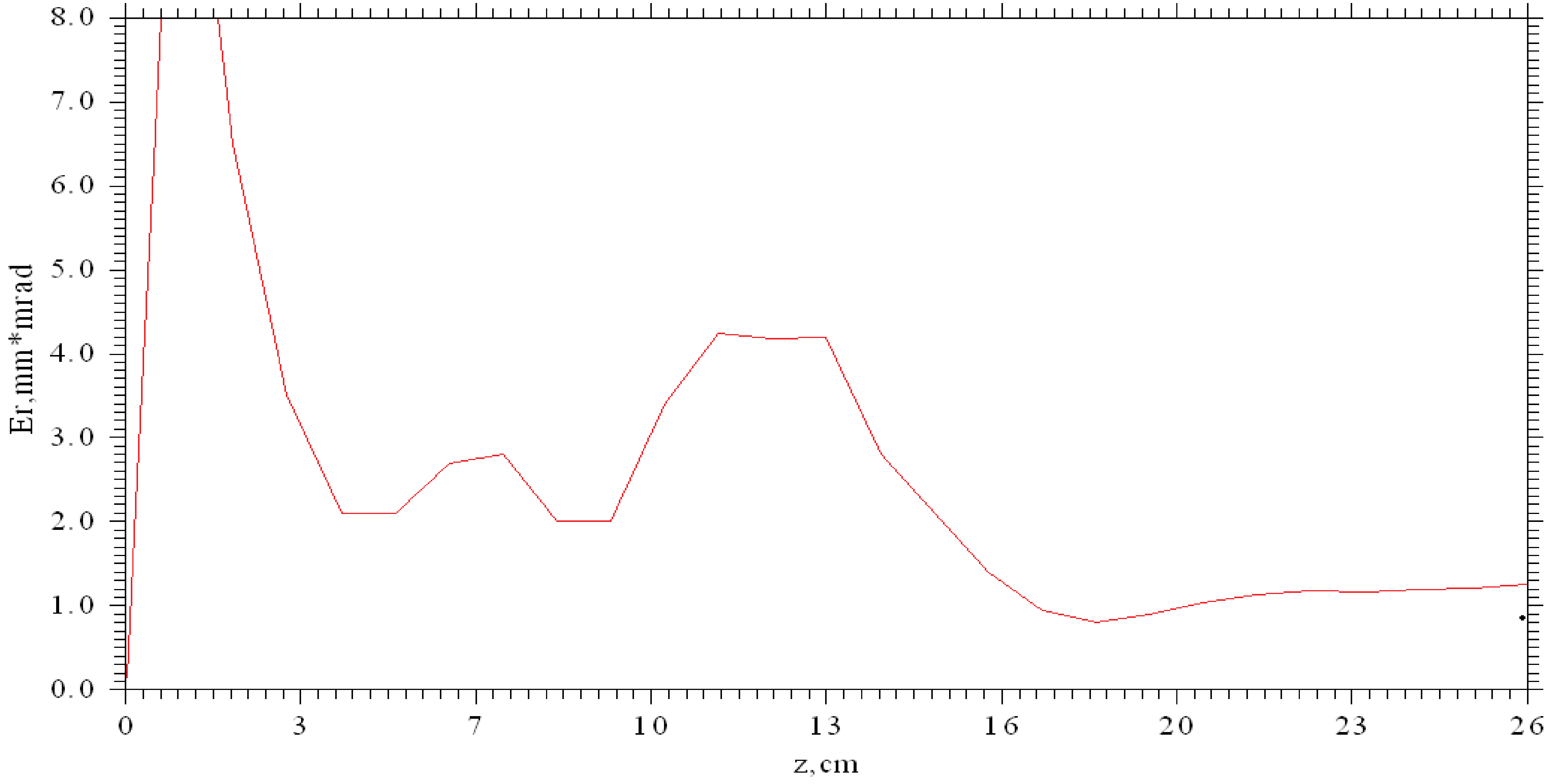


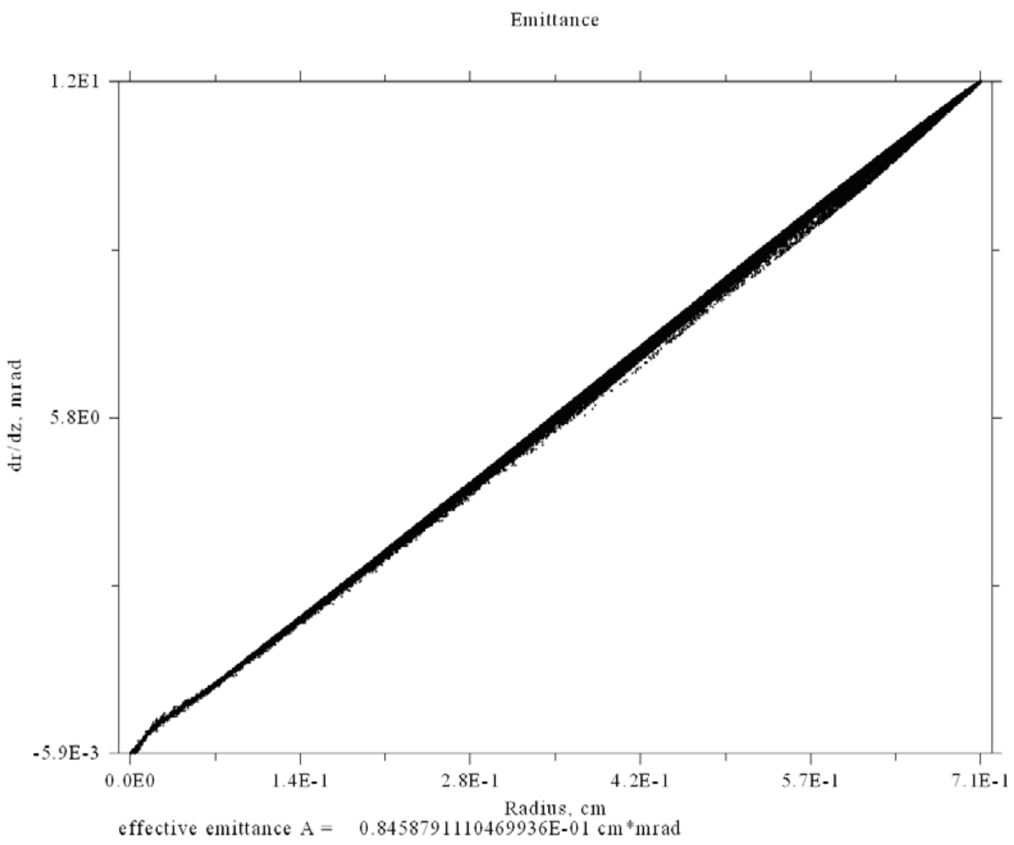
Fig. 13. Minimum geometric mean emittance (ε_{xy}) as a function of a charge cut starting from the lowest density tails in the phase-space distribution for a bunch charge of 1, 0.5, 0.25 and 0.1 nC. The 100% emittance values reported here are for a charge cut 0% (no charge cut).

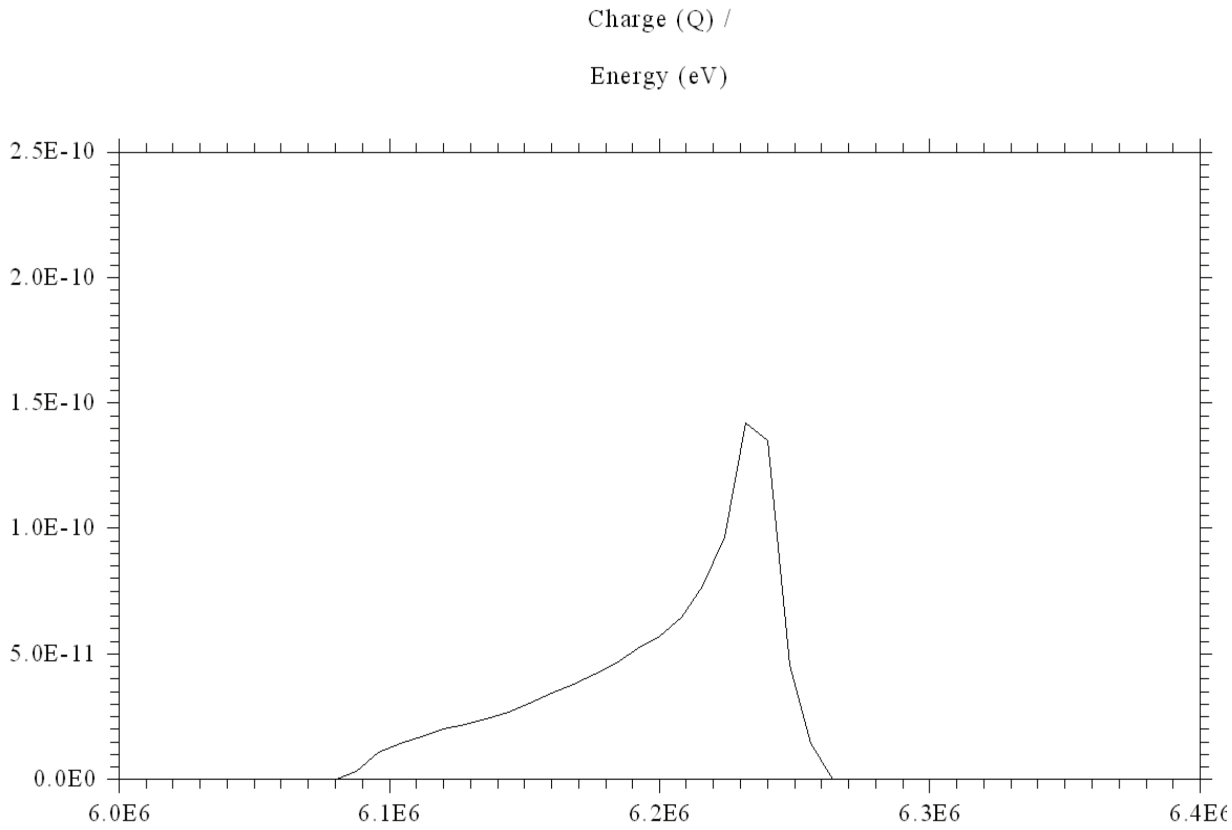
S. Rimjaem, F.Stephan, M.Krasilnikov et al. Nuclear Instruments and Methods in Physics Research A 671 (2012) 62–75

Emittance variation along the gun length



Emittance and energy spectrum at the output of the gun

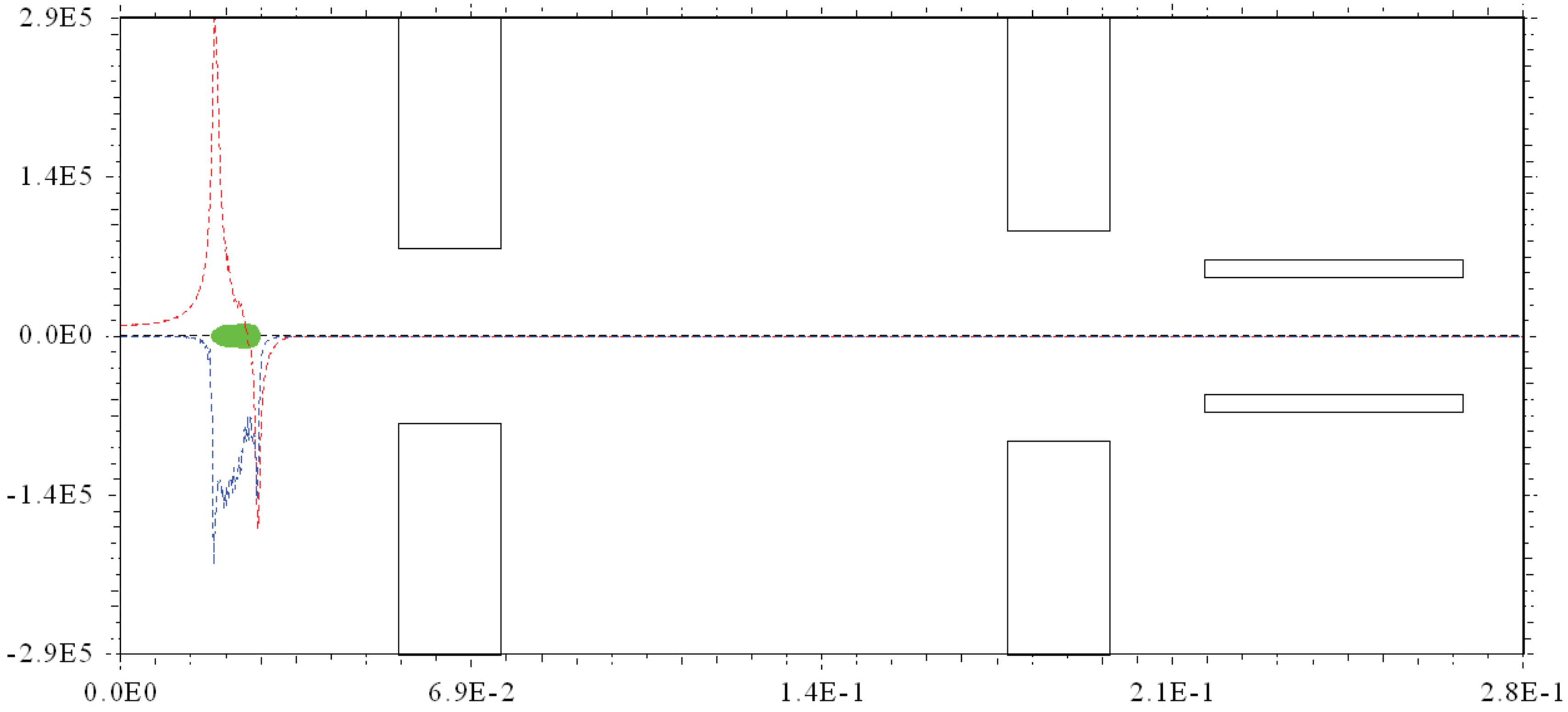




Bunch and fields in the gun

STEP 1197 SORT 1 L=0.00914529 Z=0.02731843 VMAX=284170240. VMIN=0.00000000 W=1281920.00

Ez-red Er-blue R= 6 W1=1522779.3 W0=1025074.5 ZMEN=0.02287590 RMEN=0.00194200 RMAX=0.00313350



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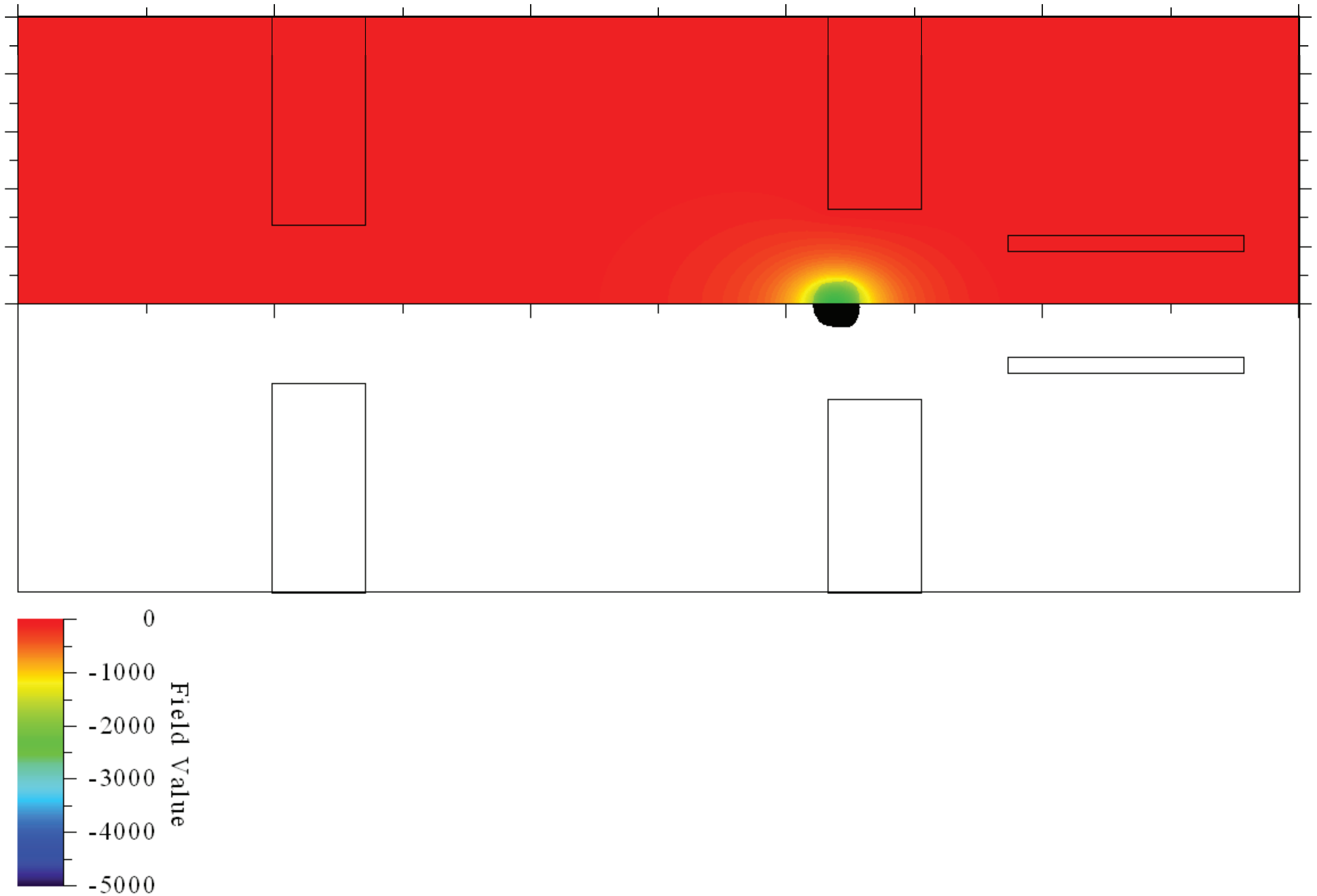

Conclusions

- A new model of the photoemission from a semiconductor photocathode in a space charge dominated regime was proposed and implemented in SUMA code
- It implies a finite rate of the positive charge flow in the photocathode film which (partially) compensates the space charge field of the emitted electrons
- The new model was applied to the experimental data at the PITZ RF photogun operated in a space charge dominated regime corresponding to the high brightness performance of the photoinjector
- The results show better agreement of the newly proposed model with experimental data than the old model
- Further investigations are ongoing..

Thanks for attention !