Latest Results of CW 100 mA Electron RF Gun for Novosibirsk ERL Based FEL

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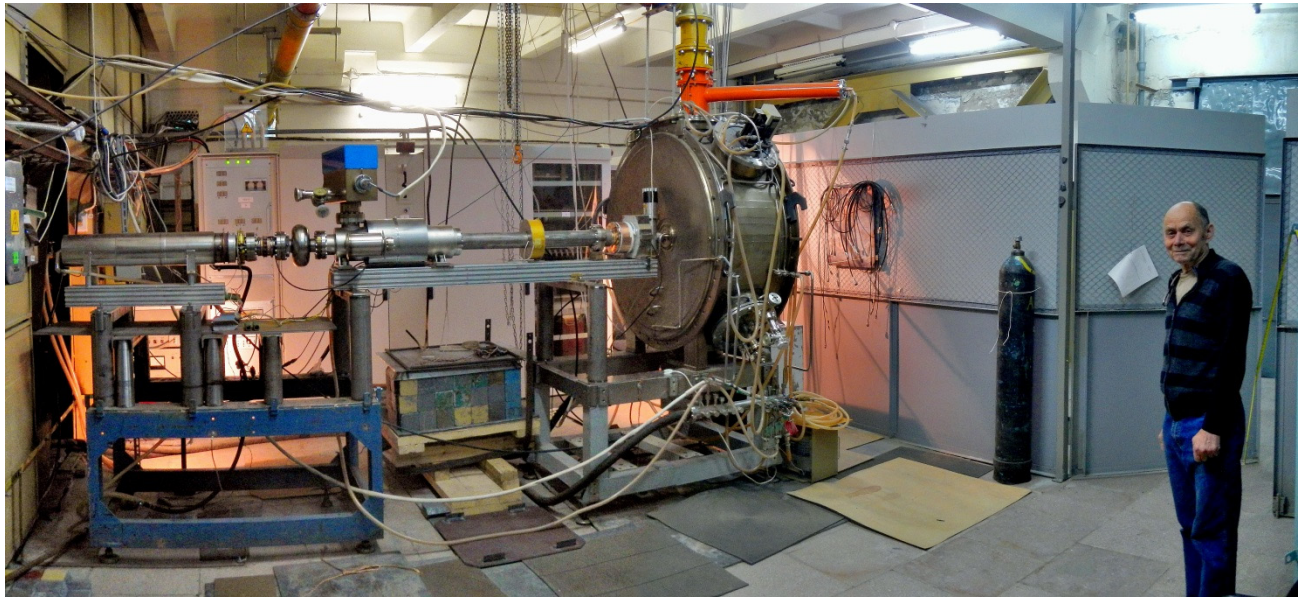
The most powerful in the world Novosibirsk CW FEL driven by ERL can be more powerful by an order of magnitude with this RF Gun

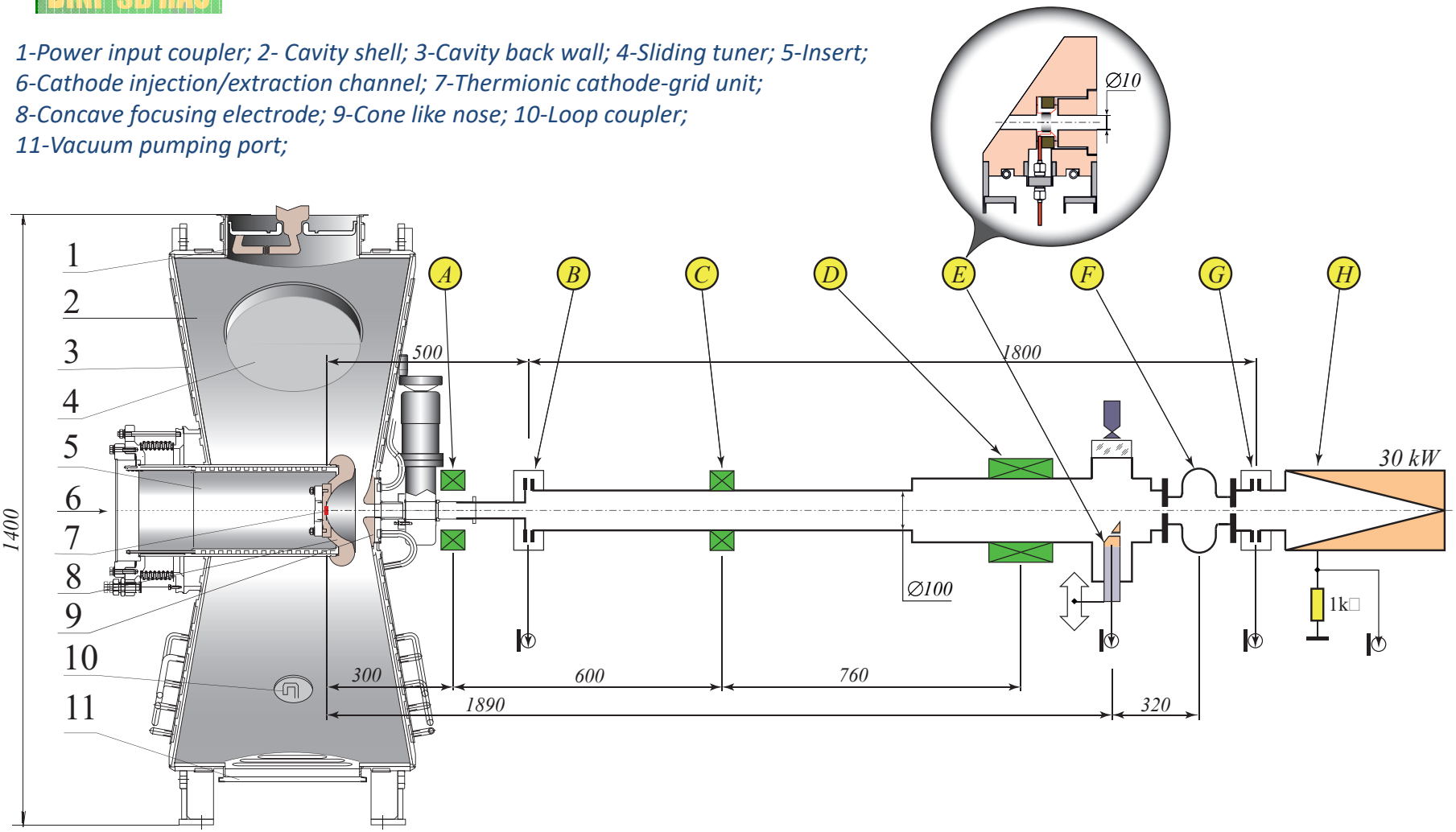


Measured rf gun characteristics	
Average beam current, mA	≤100
Cavity Frequency, MHz	90
Bunch energy, keV	100 ÷ 400
Bunch duration (FWHM), ns	0.06 ÷ 0.6
Bunch emittance, mm mrad	10
Bunch charge, nC	0.3 ÷ 1.12
Repetition frequency, MHz	0.01 ÷ 90
Dark Current Impurity, mkA	0
Radiation Dose Power, mR/h	100/2m
Operating pressure , Torr	~10^{-9}-10^{-7}
Cavity rf loses, kW	20

RF Gun Features: *Gridded thermionic dispenser cathode driven by special modulator with GaN rf transistor;*
Strong rf focusing of the beam just near the cathode;
Absolute absence of dark and leakage currents in the beam.

RF Gun and Diagnostic stand sketches

1-Power input coupler; 2- Cavity shell; 3-Cavity back wall; 4-Sliding tuner; 5-Insert;
6-Cathode injection/extraction channel; 7-Thermionic cathode-grid unit;
8-Concave focusing electrode; 9-Cone like nose; 10-Loop coupler;
11-Vacuum pumping port;

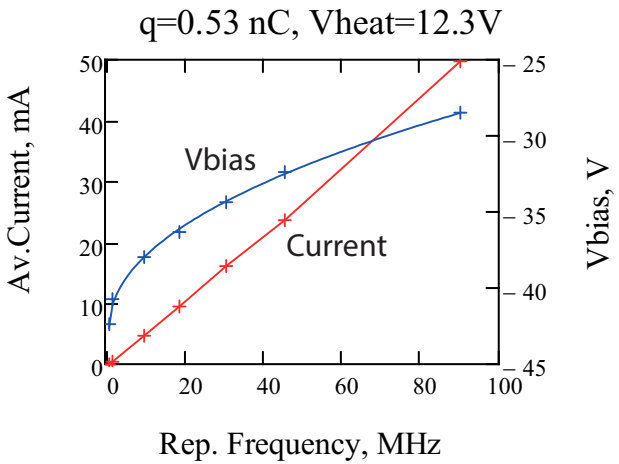


A-Emittance compensation solenoid; B-First Wall Current Monitor (WCM);
C, D -Solenoids ; E-Wideband WCM and transition radiation target;
F – Test Cavity; G-third WCM; H-Faraday cup and Water-cooled beam dump

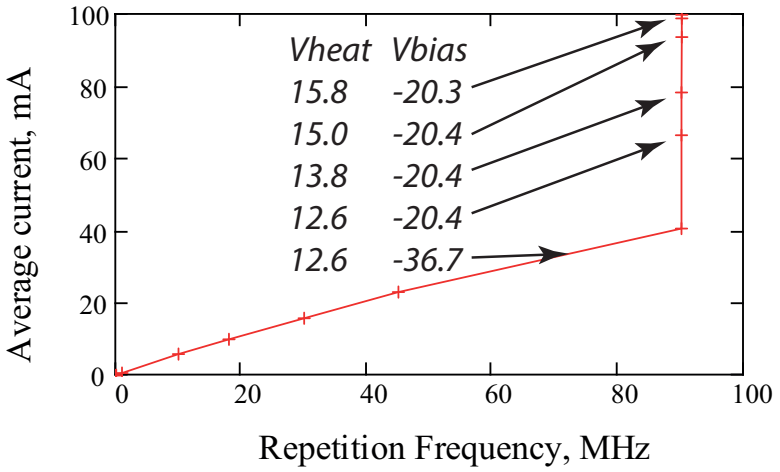
Beam current vs Repetition frequency

Dispenser cathode thermo-emission ability is reverse-acting by beam current

Vlaunch=100 V



Vlaunch=120 V

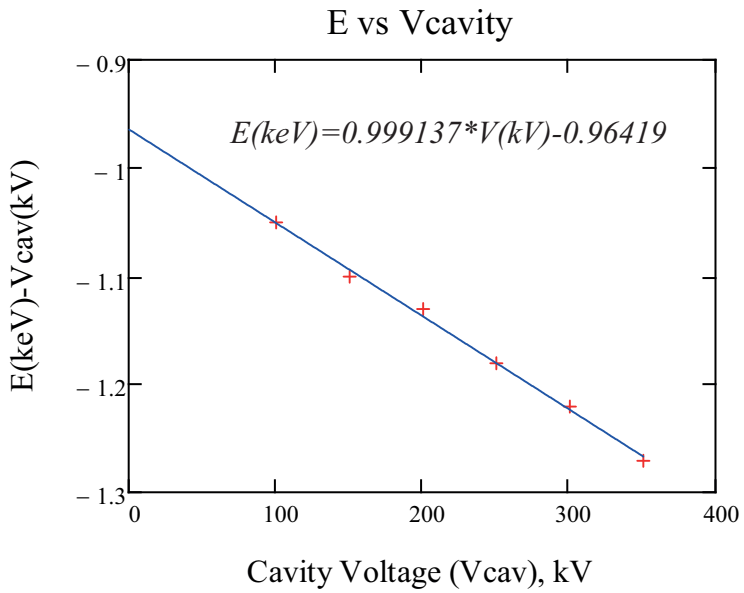


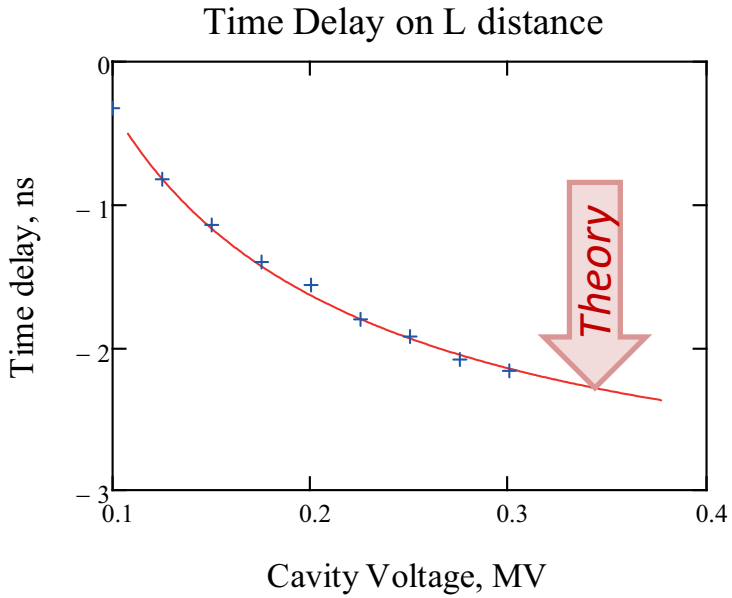
The Typical Mode of current rising is Repetition frequency increasing at q=1.1 nC=const

- Cathode thermo-emission current is reverse-acting on the repetition frequency.
- The cathode heating voltage (Vheat) and the sum of Launch pulse voltage with the Bias voltage (Vlaunch + Vbias) must be enhanced to compensate this.
- Remember, the cathode-grid gap inversely changed on the heating power due to the thermal elongation.

Calibration of Cavity Voltage meter

through the time delay measuring between two wall current monitors





Calibrated L between two WCMs=0.96078 m

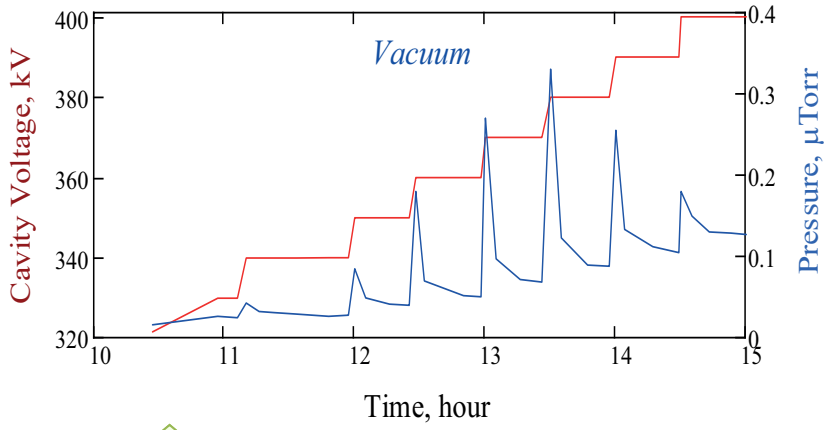
Bunch velocity (β) vs bunch energy (E)

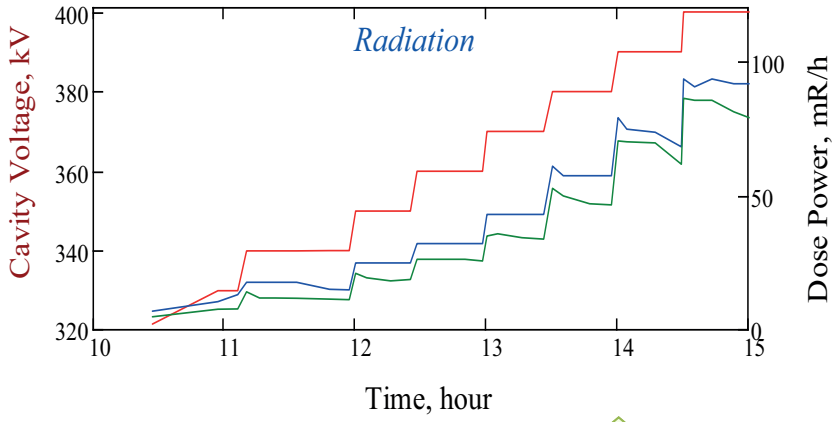
$$\beta(E) := \sqrt{1 - \frac{1}{\left(1 + \frac{E}{mc2}\right)^2}}$$

Time delay (T) vs Energy

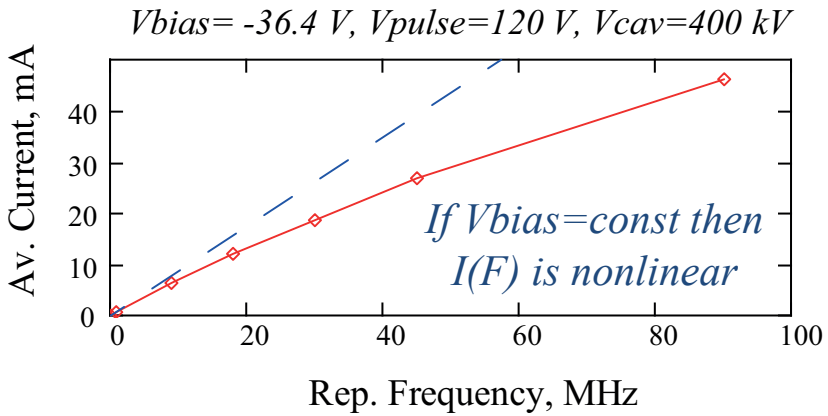
$$T(E) := \frac{L \cdot 10^9}{299792458\beta(E)}$$

Cavity testing up to 400 kV





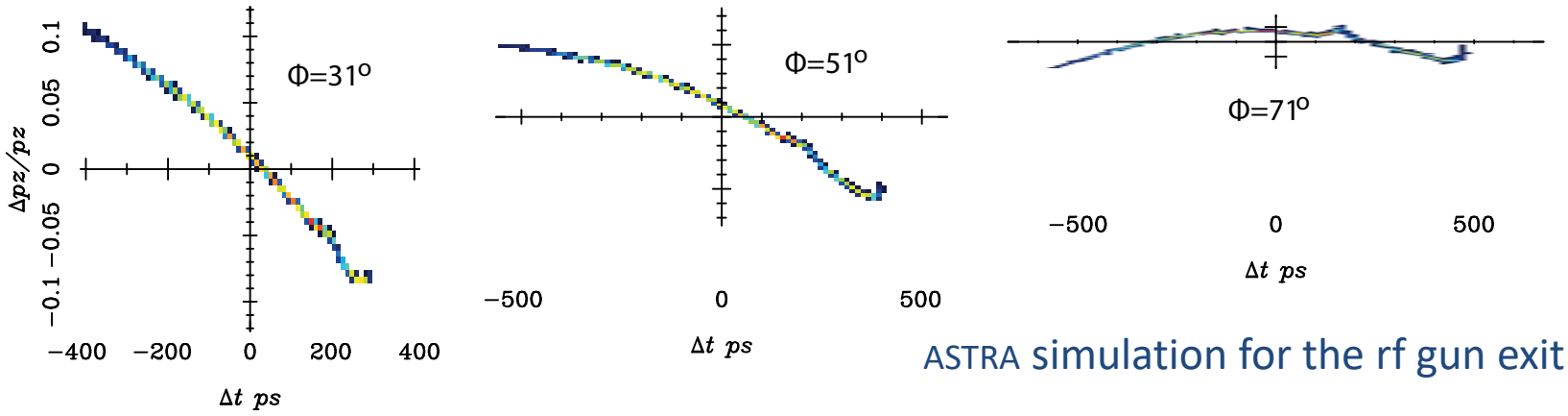
½ hour operation time needs to normalize pressure level



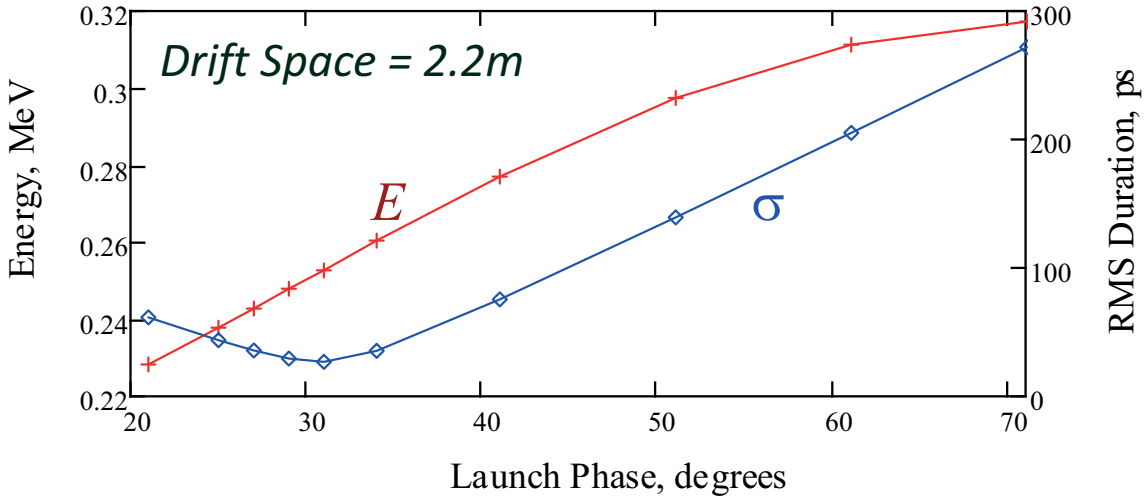
Two radiation sensors, one at the distance of 1.5 m along axis, second 2 m aside

Launch Phase (Φ) functions

are the reason of velocity bunching and jitter compensation effects



ASTRA simulation for the rf gun exit

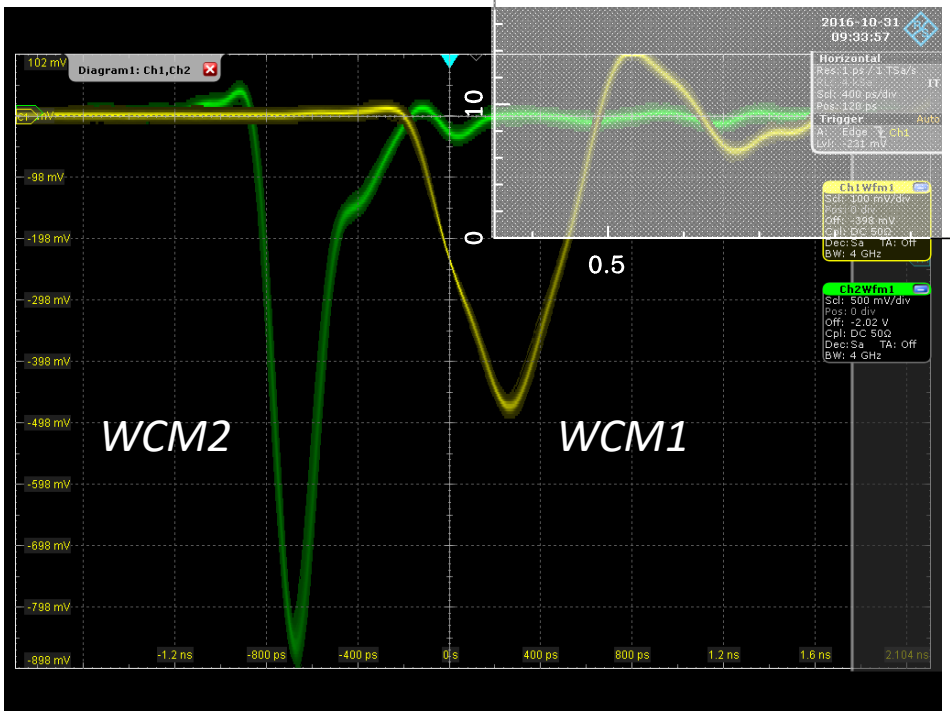


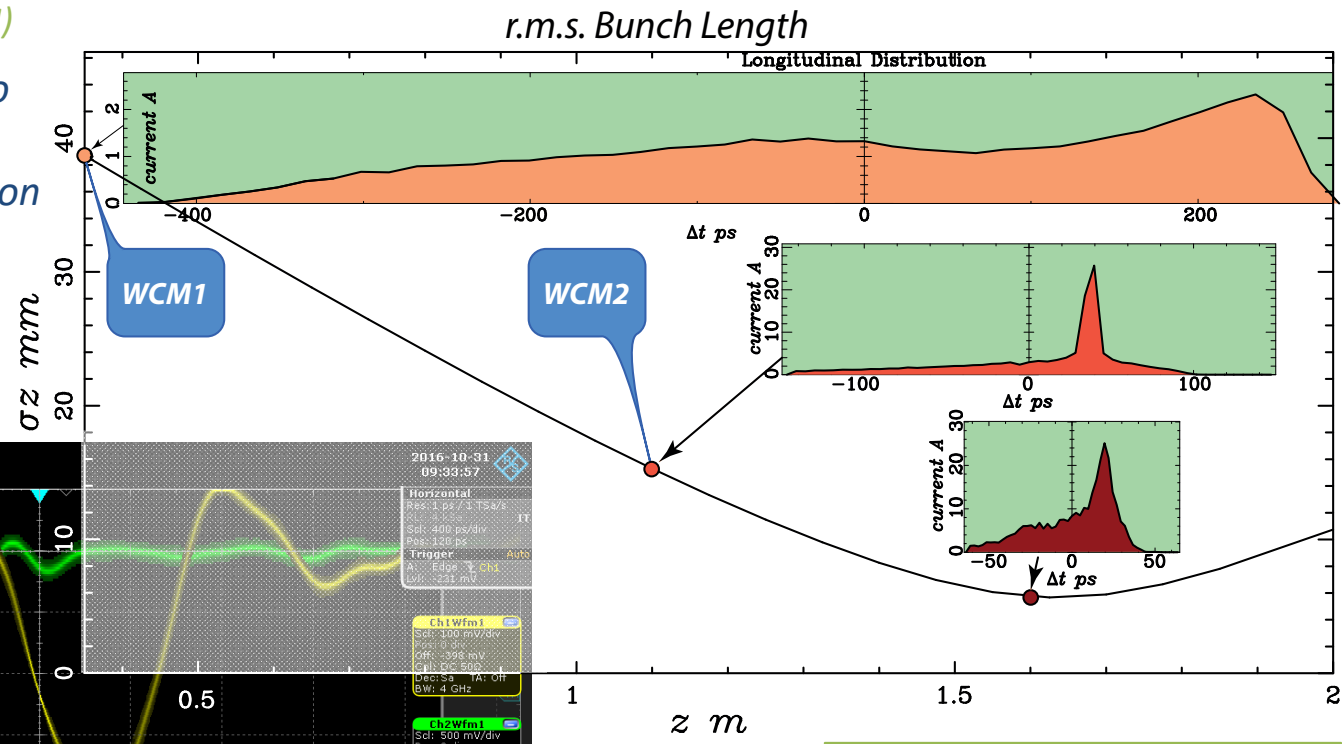
Velocity modulation bunching effect

measured with wideband WCM2 and 4 GHz oscilloscope (*Φ=27°, 300 keV*)

Wall Current Monitor (WCM)

Frontal spike formed into cathode-grid gap due to electron plasma oscillation there.





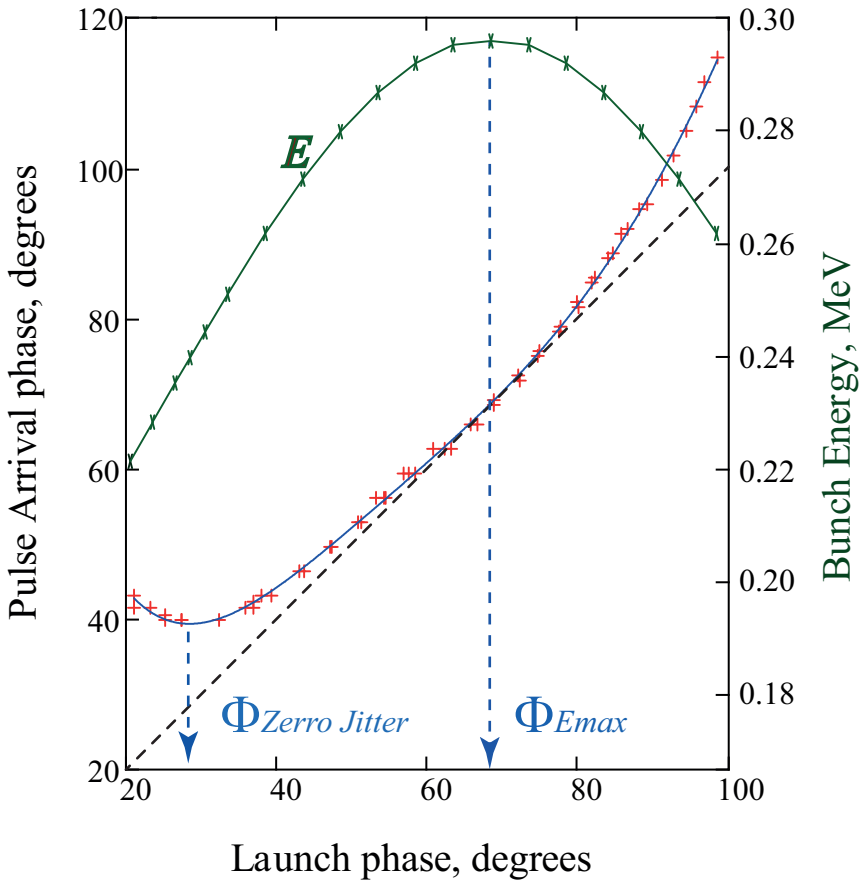
r.m.s. and FWHM be differ a lot

Numerical ASTRA calculations predicts FWHM τ_{FWHM}=20 ps, unfortunately the 4 GHz oscilloscope cannot show pulses τ<200 ps, it all viewed as τ=200 ps

Launch Phase Jitter compensation

measured with Wall Current Monitor 3 (L=1.2 m)

Pulse arrival phase is independent on Launch phase at $\Phi_{\text{Zerro Jitter}}$*=27° degrees, i.e. jitter there is equal to zero, i.e. it has compensated*

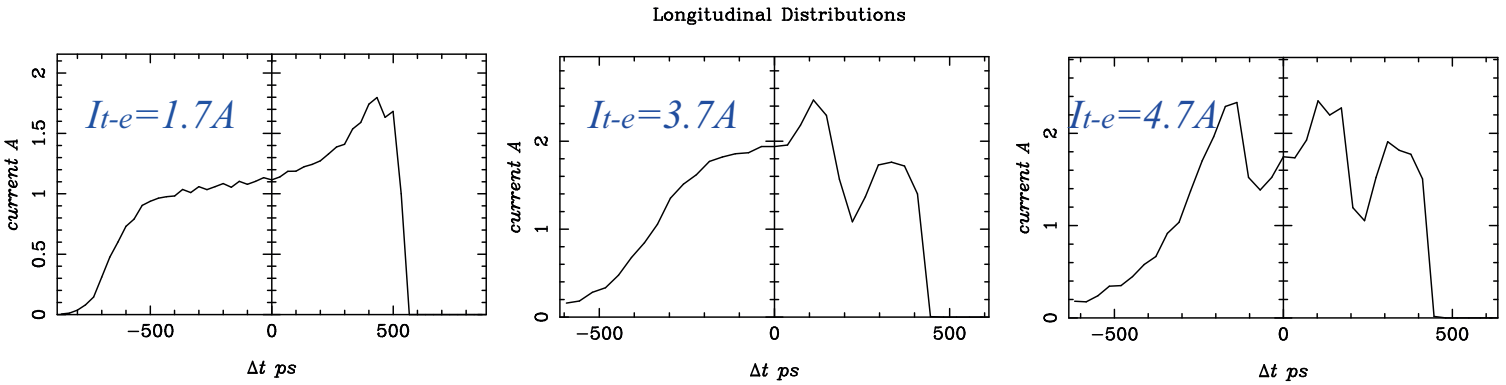


Maximal bunch energy is at Φ_{Emax}*=68° where it is equal to the arrival phase by accurate within some constant.*

Cathode-grid plasma oscillation effect

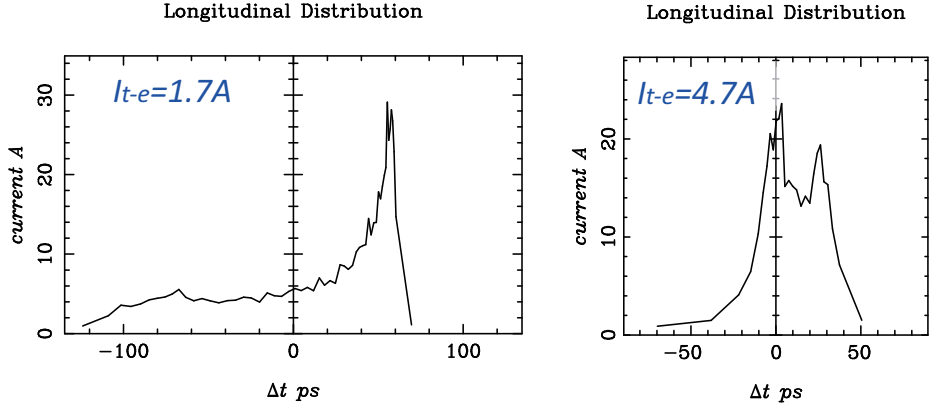
observed with Test Cavity high order modes (HOMs) excited by the beam and already simulated by ASTRA cod

Electron plasma oscillation effect depends on cathode thermo- emission current ($I_{t\text{-}e}$)



Current distributions for bunched beam at the end of the drift space (*2.2 m, Φ=31*) are not Gaussian one

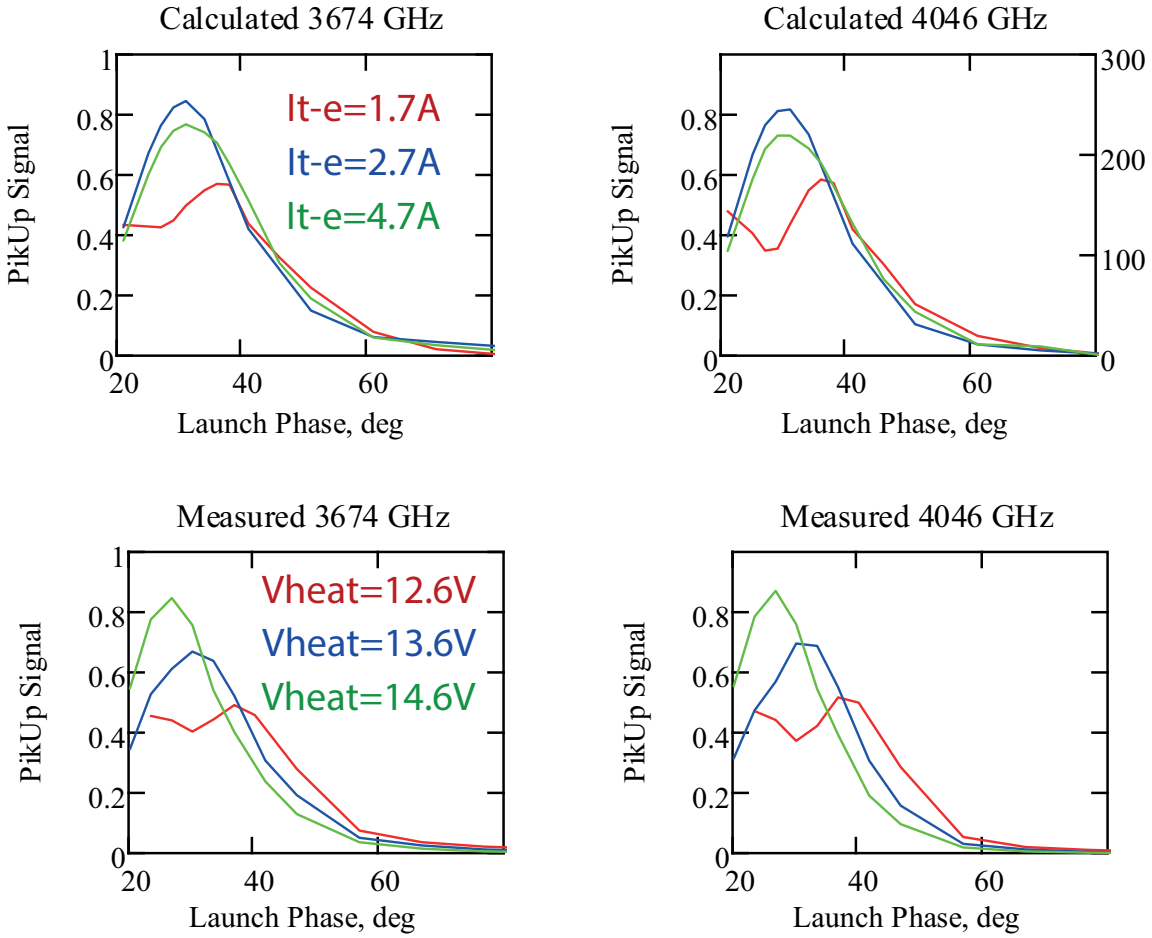
Allegedly, this bunch consists from two bunches that can *interfere* to each other



This bunch mostly resembles a Gaussian one

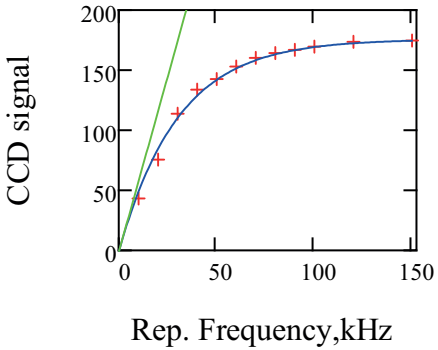
Cathode-grid plasma oscillation effect

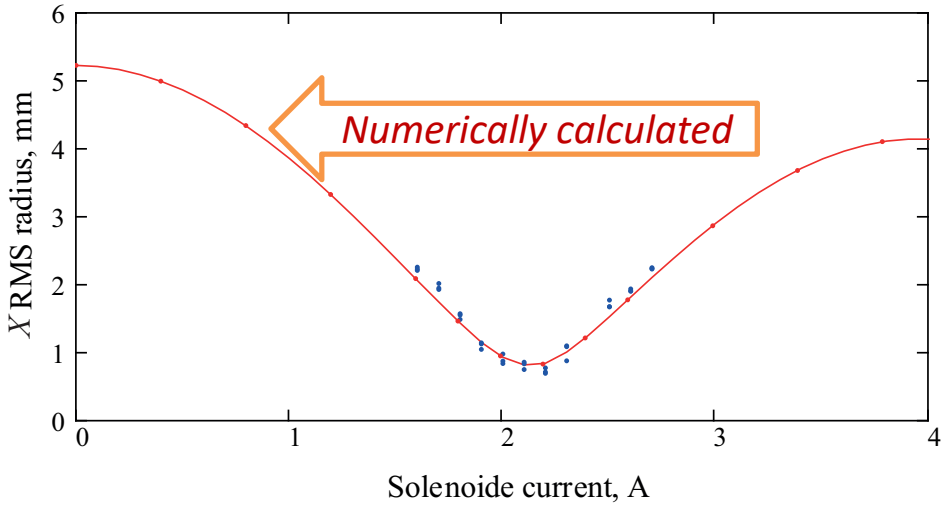
ASTRA simulations and experiments with HOMs excited by bunched beam
have shown this interference

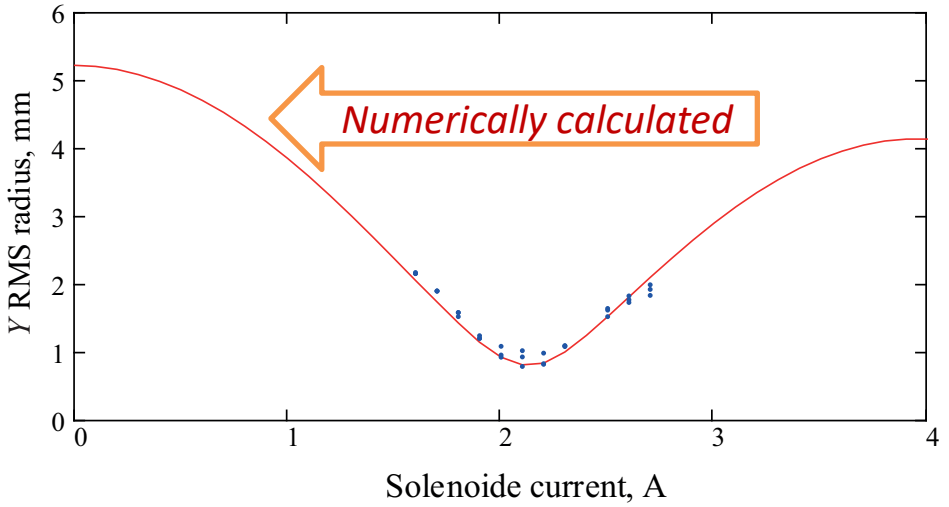


Emittance measurements

by solenoid focusing method with using transition radiation sensor







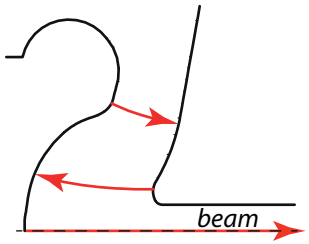
Measured normalized emittance ε=15.5 mm mrad can be compensated by solenoid focusing to ε=10 mm mrad.

Numerical data processing of CCD camera image and distortion compensated optics were used.

Deviation of measured radius from calculated one is 9% so we can trust to our numerical ASTRA calculations.

Dark and Leakage Currents

Two places with peak surface field of 10-14 MV/m are the sources of field emitted dark currents

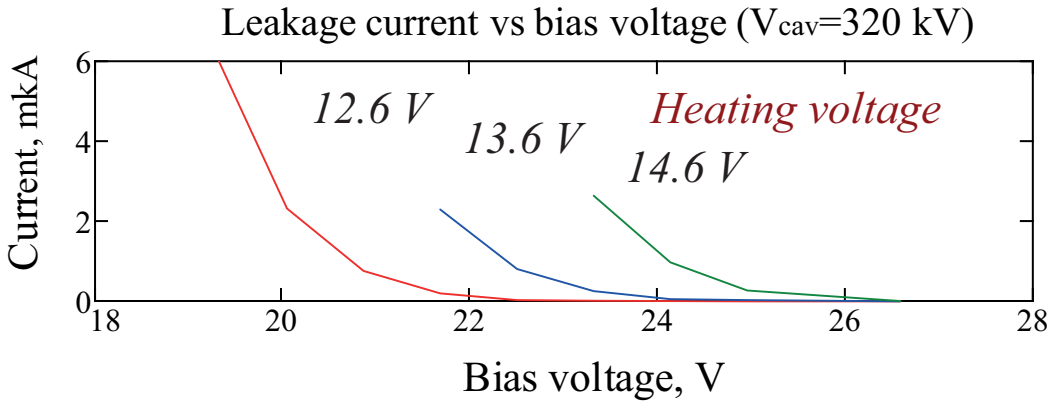


Accelerating gap geometry

There are no dark currents in the beam absolutely

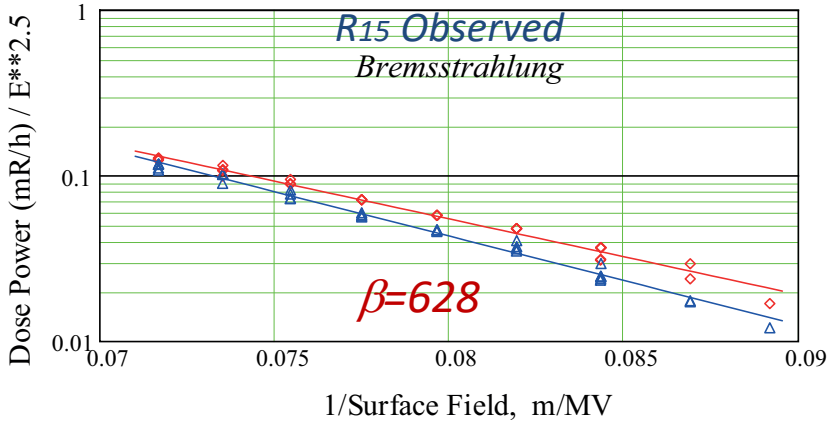
Leakage current (at Vpuls=0) depends on heating voltage because cathode-grid gap is changed under the thermal elongation.

To exclude leakage current from the beam we have to chose proper bias voltage.



Radiation Background

measured with radiation sensor at 1.5 m along axis and 2 m aside one



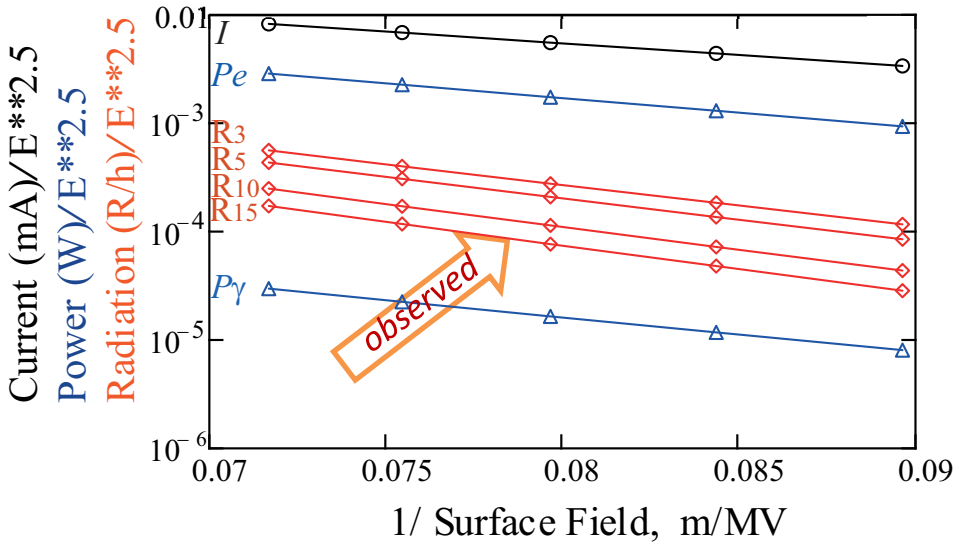
Fowler-Nordheim (F-N) equation
ϕ=4.5 eV, B=6830, E (MV/m)

$$I \approx (\beta E)^{2.5} exp\left(-\frac{B\varphi^{1.5}}{\beta E}\right)$$

Enhancement factors β are differ

Name		label	β
Dark Current of Field Emission		I	1264
Dark Current Power		Pe	1003
Bremsstrahlung Power		Pγ	865
Cu Shielded Dose Power	d=3 mm	R3	721
	d=5 mm	R5	695
	d=10mm	R10	649
	d=15mm	R15	628

All Calculated have F-N nature!



Thank you for your attention