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

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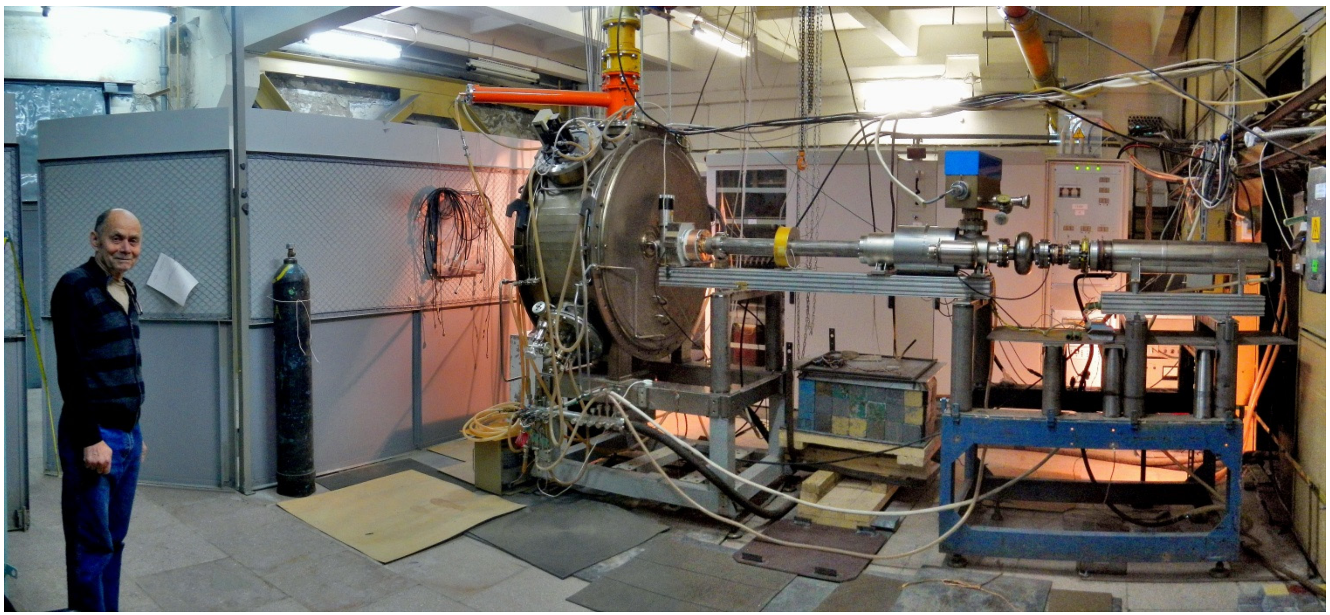
***The most powerful in the world Novosibirsk CW FEL driven by ERL can be more powerful by an order of magnitude with this RF Gun***

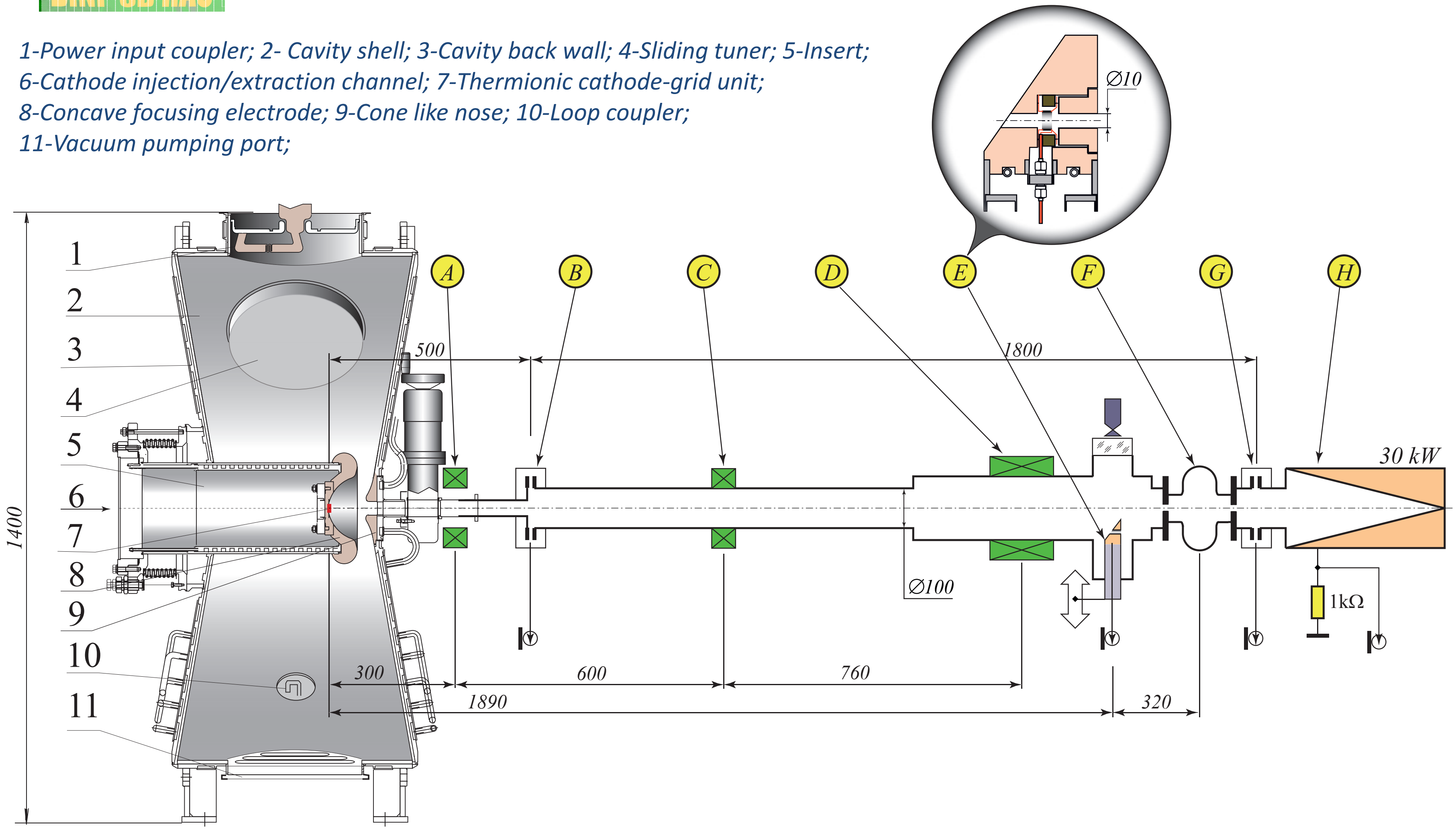


| *Measured rf gun characteristics* | |
|---|---|
| Average beam current, mA | ≤100 |
| Cavity Frequency, MHz | 90 |
| Bunch energy, keV | 100 ÷ 400 |
| Bunch duration (FWHM), ns | 0.06 ÷ 0.6 |
| Bunch emittance, mm mrad | 10 |
| Bunch charge, nC | 0.3 ÷ 1.12 |
| Repetition frequency, MHz | 0.01 ÷ 90 |
| 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;*

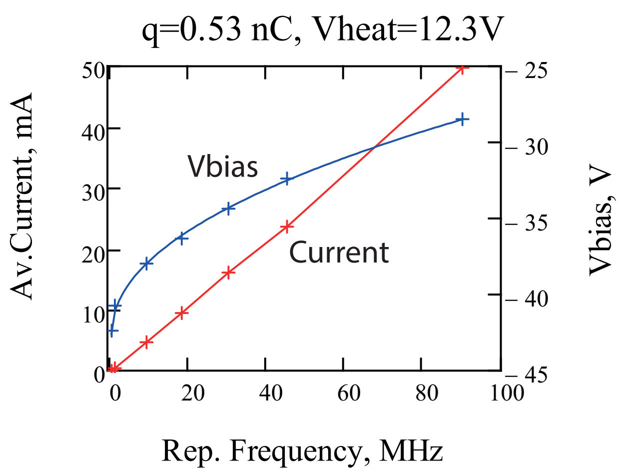



*A-Emittance compensation solenoid; B-First Wall Current Monitor (WCM); C, D -Solenoids ; E-Wideband WCM and transition radiation target; F – Test Cavity; G-third WCM; H-Faraday cup and Water-cooled beam dump*

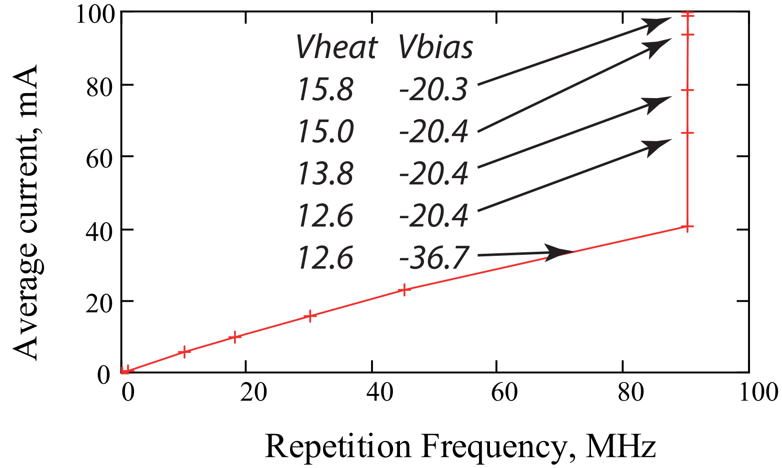
# Beam current vs Repetition frequency

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

*Vlaunch=100 V*




*Vlaunch=120 V*

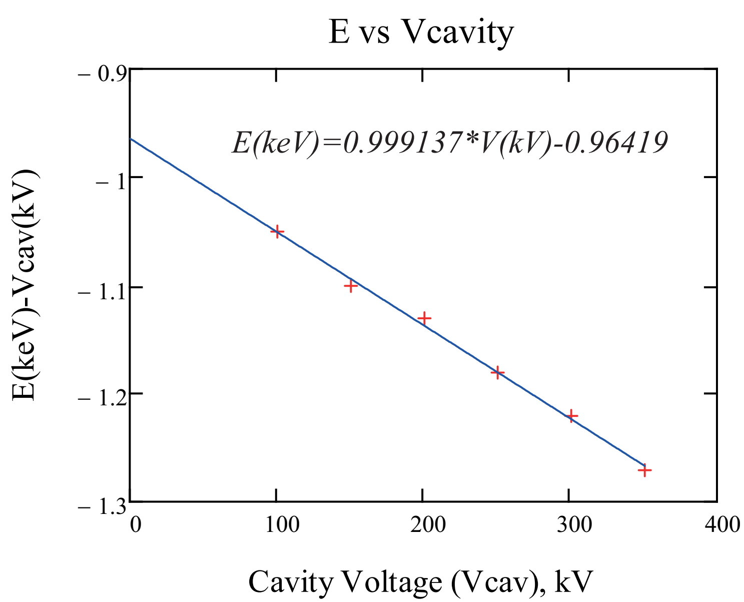


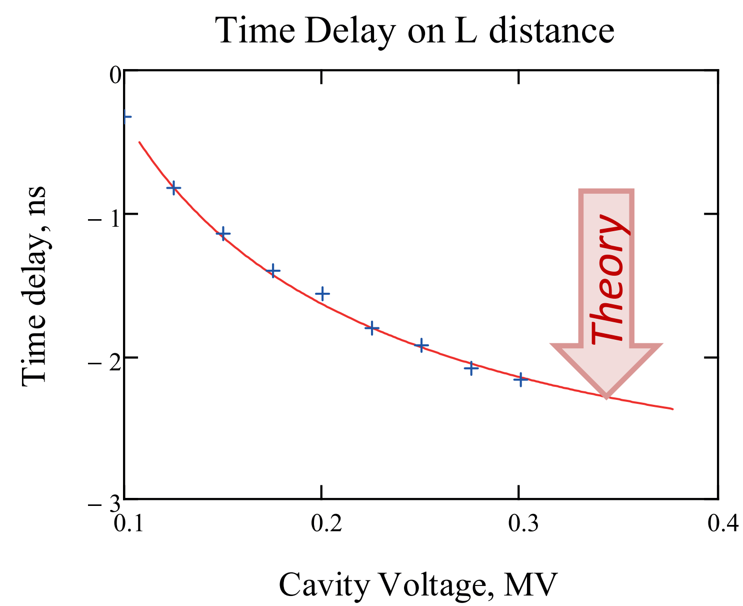

*The Typical Mode of current rising is Repetition frequency increasing at q=1.1 nC=const*

- 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*

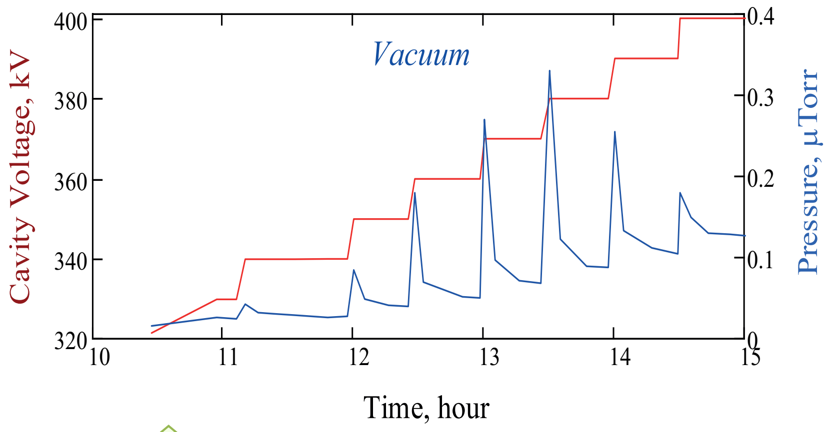
*Bunch velocity (β) vs bunch energy (E)*

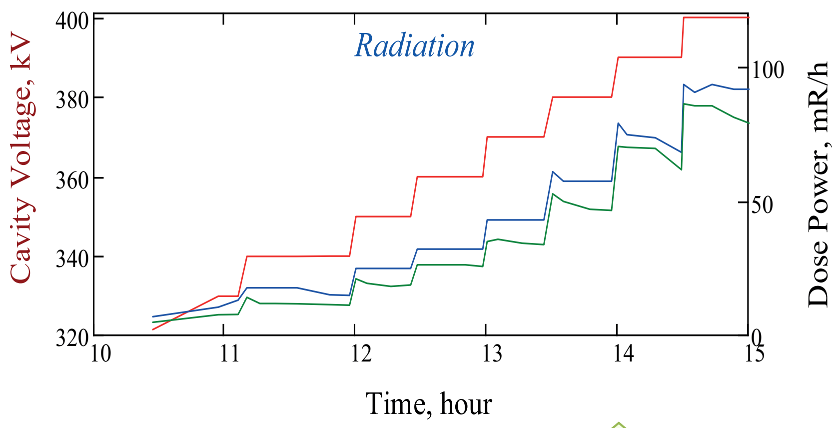
$$\beta(E) := \sqrt{1 - \frac{1}{\left(1 + \frac{E}{mc2}\right)^2}}$$

*Time delay (T) vs Energy*

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

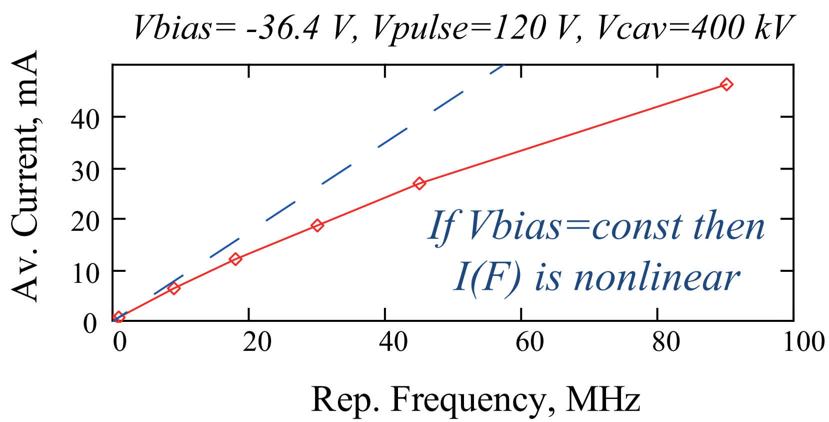
# Cavity testing up to 400 kV



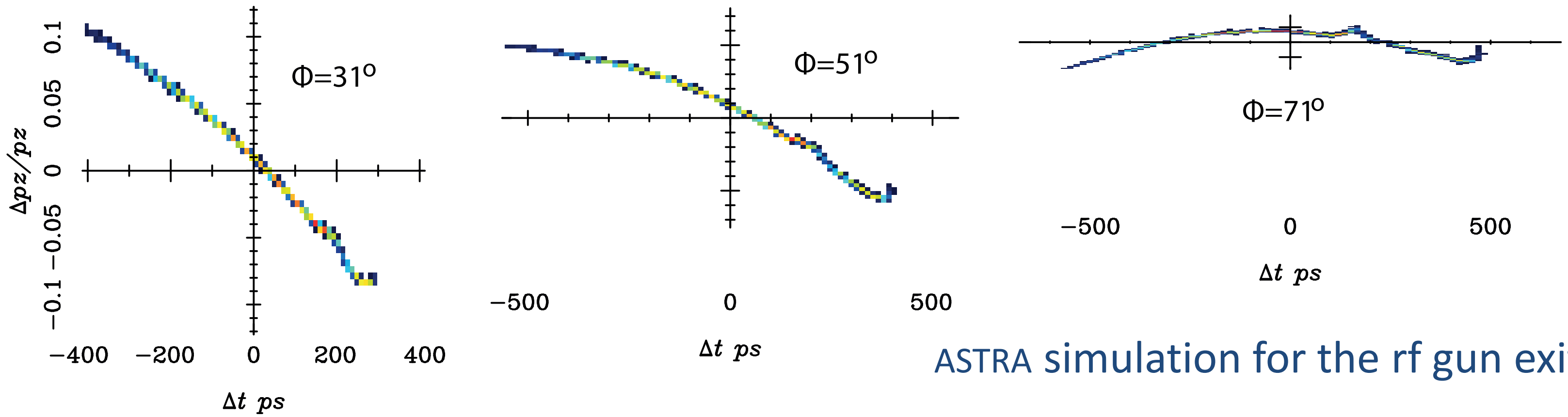

½ hour operation time needs to normalize pressure level

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

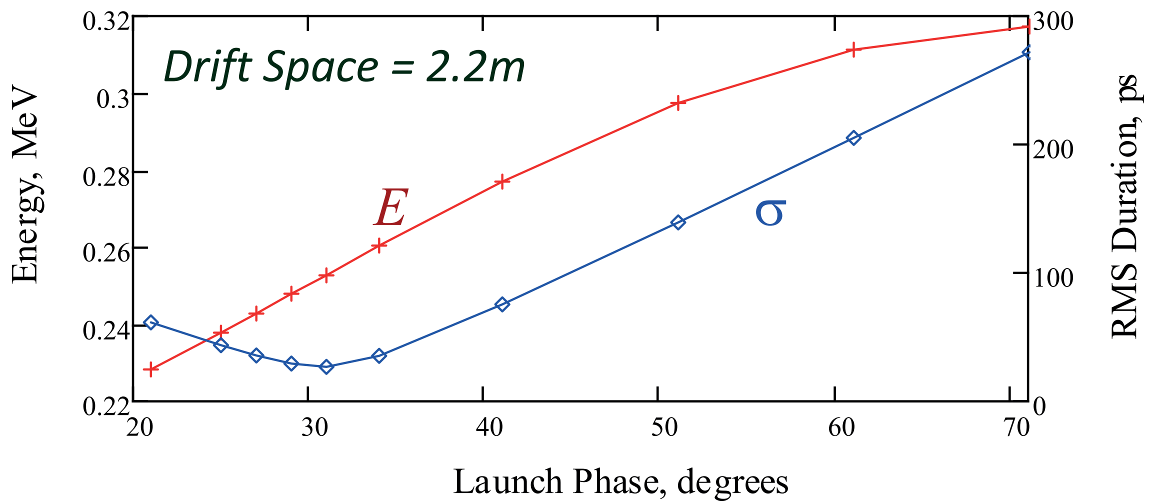


# Launch Phase (Φ) functions

*are the reason of velocity bunching and jitter compensation effects*




ASTRA simulation for the rf gun exit

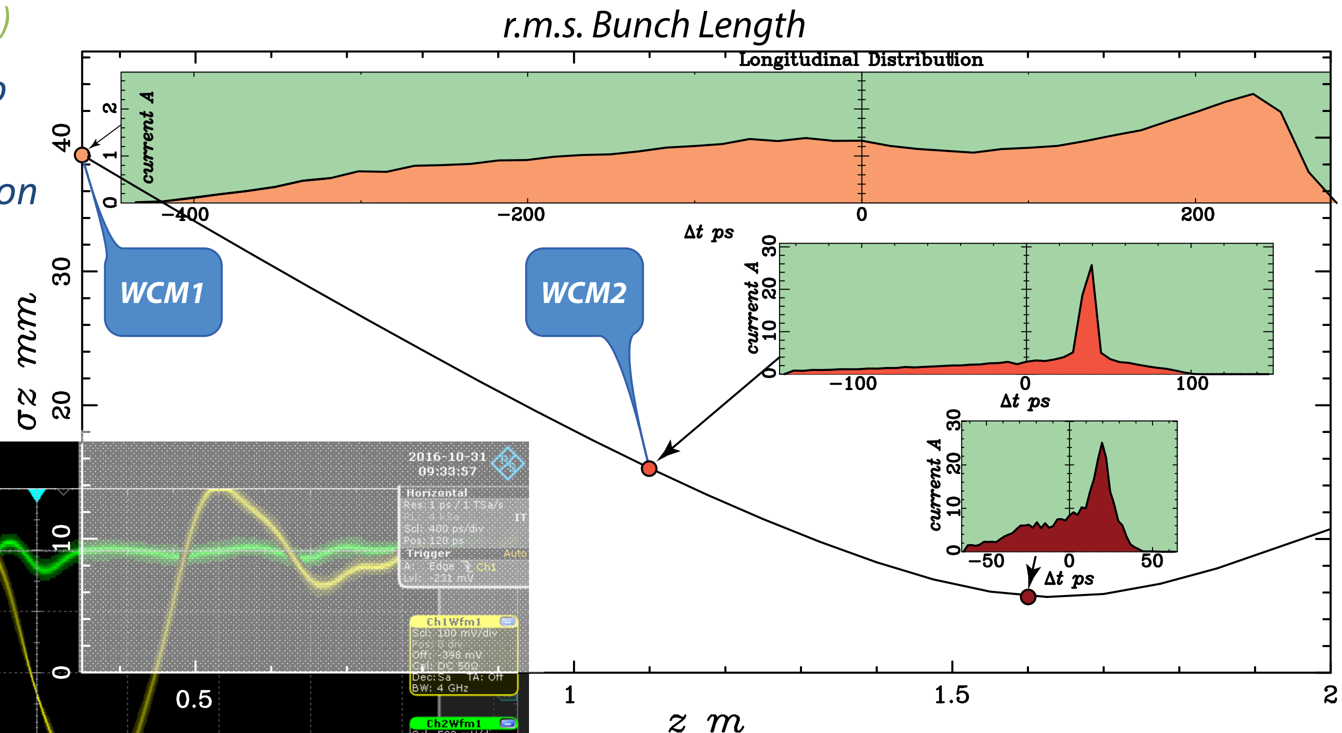


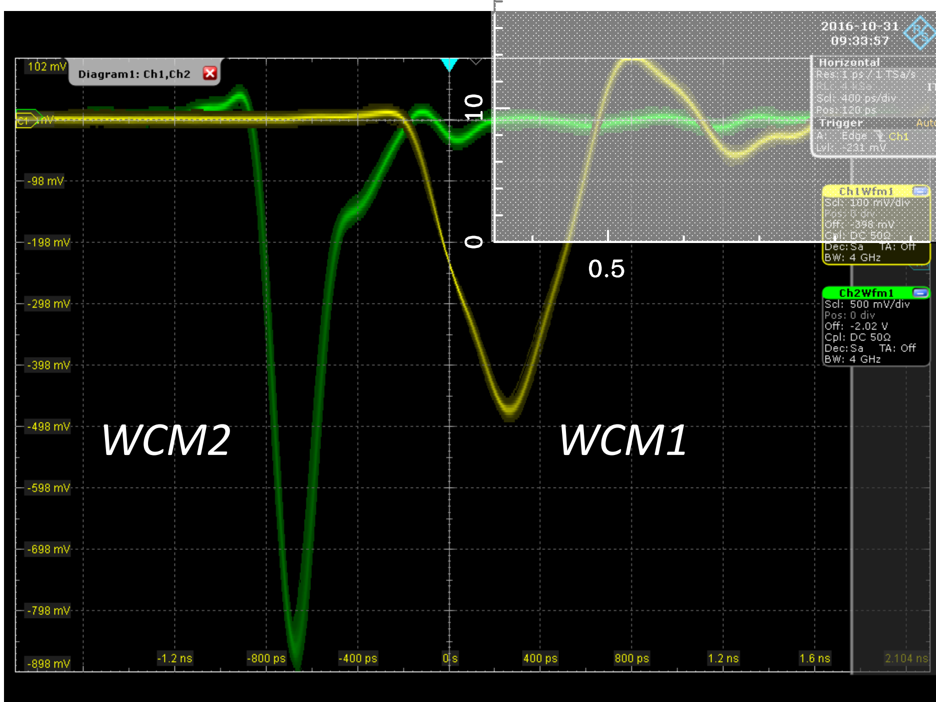
# Velocity modulation bunching effect

## 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.*



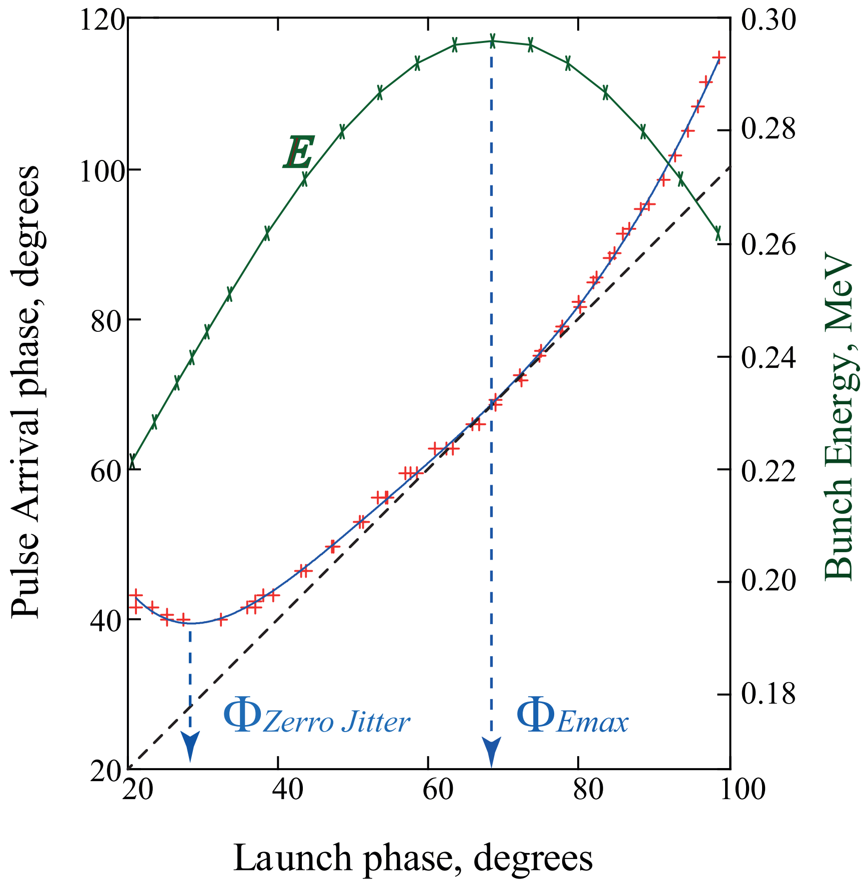

r.m.s. and FWHM be differ a lot

*Numerical ASTRA calculations predicts FWHM $\tau_{FWHM}$=20 ps, unfortunately the 4 GHz oscilloscope cannot show pulses $\tau$<200 ps, it all viewed as $\tau$=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* $\Phi_{Zerro\ Jitter}$*=27° degrees, i.e. jitter there is equal to zero, i.e. it has compensated*

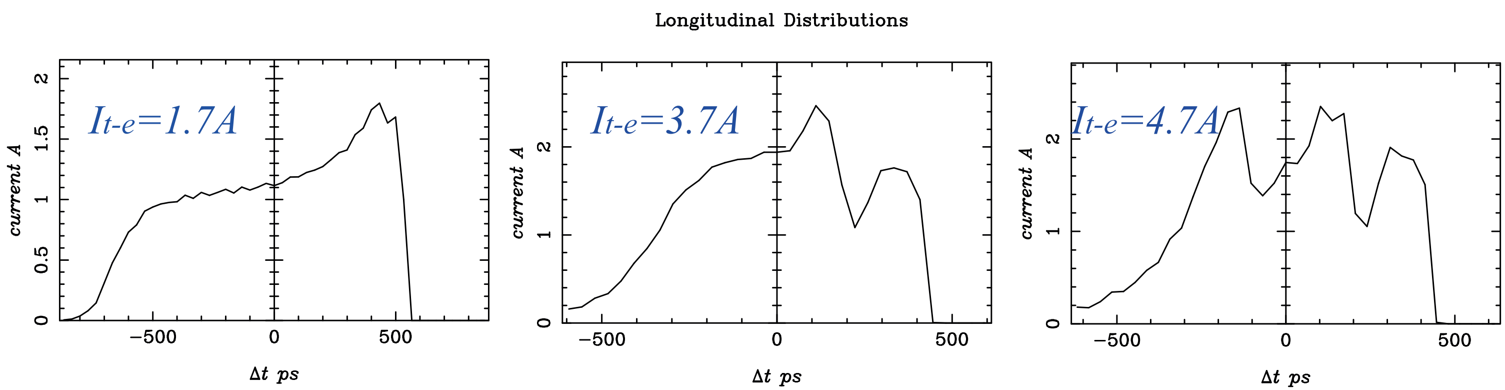



*Maximal bunch energy is at* $\Phi_{Emax}$*=68° where it is equal to the arrival phase by accurate within some constant.*

# *Cathode-grid plasma oscillation effect*

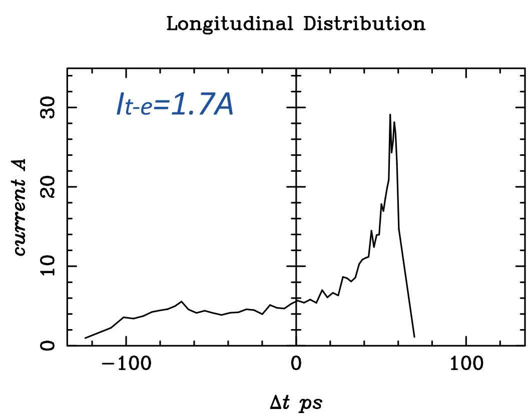
*observed with Test Cavity high order modes (HOMs) excited by the beam and already simulated by ASTRA cod*

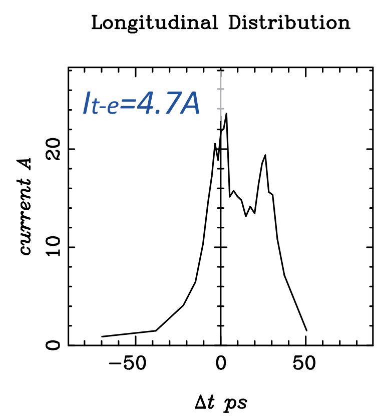
Electron plasma oscillation effect depends on cathode thermo- emission current ($I_{t\text{-}e}$)




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



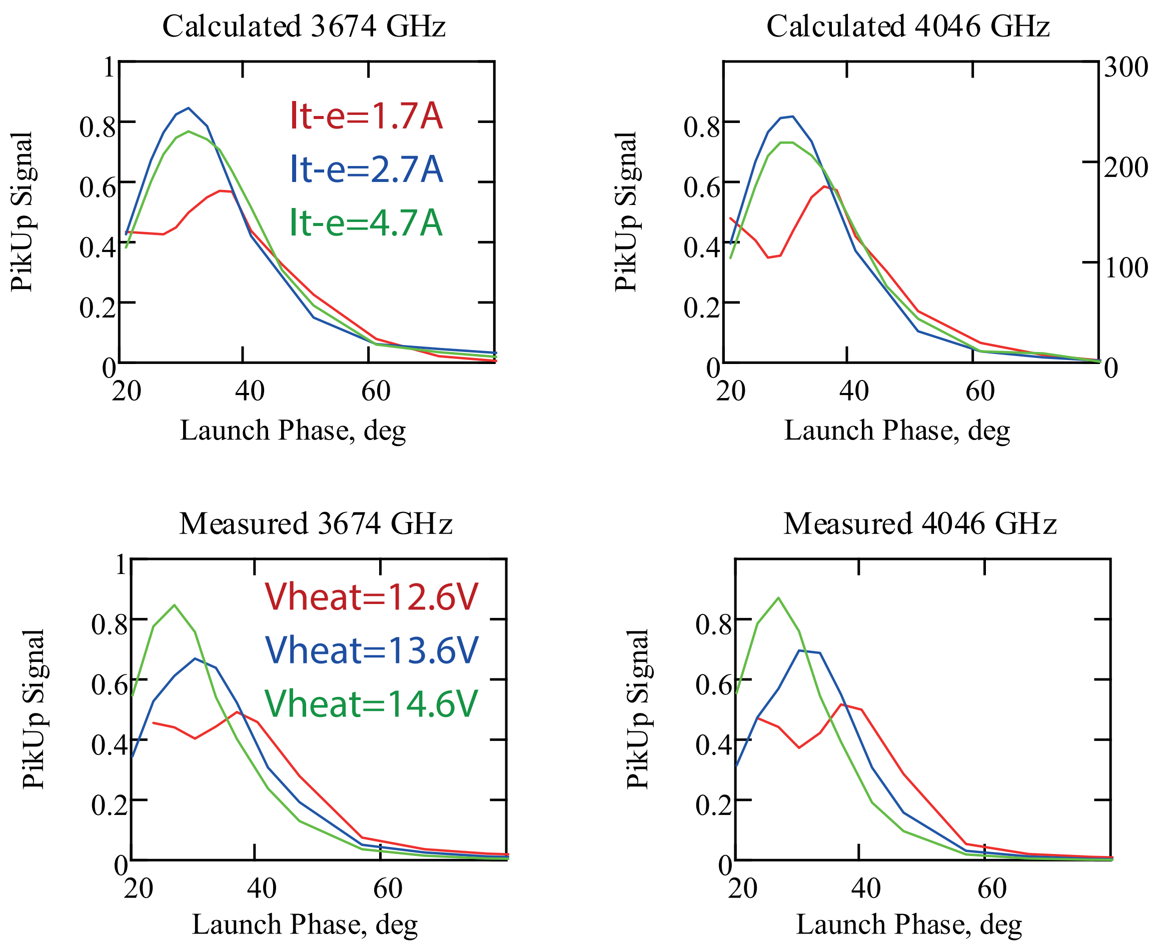




This bunch mostly resembles a Gaussian one

# Cathode-grid plasma oscillation effect

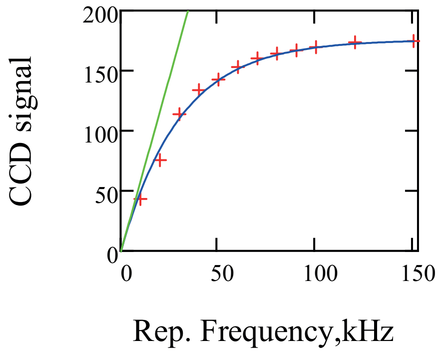
*ASTRA simulations and experiments with HOMs excited by bunched beam*

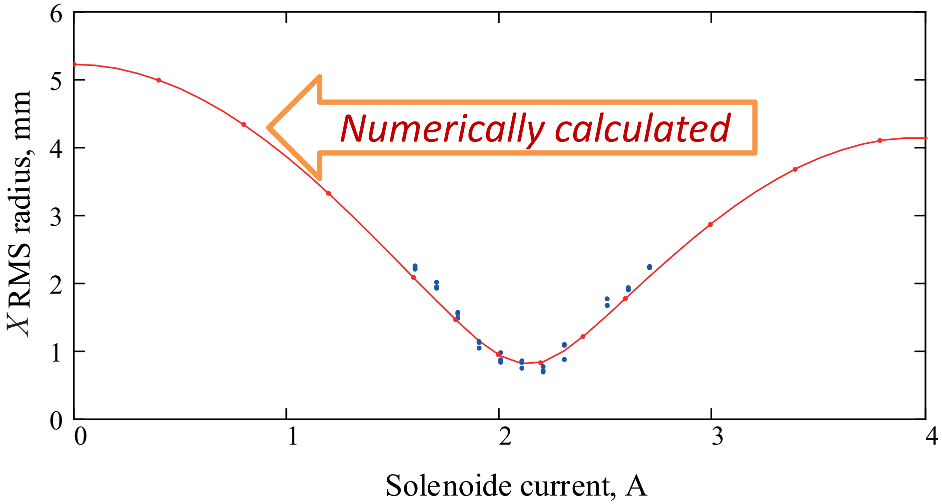
***have shown this interference***

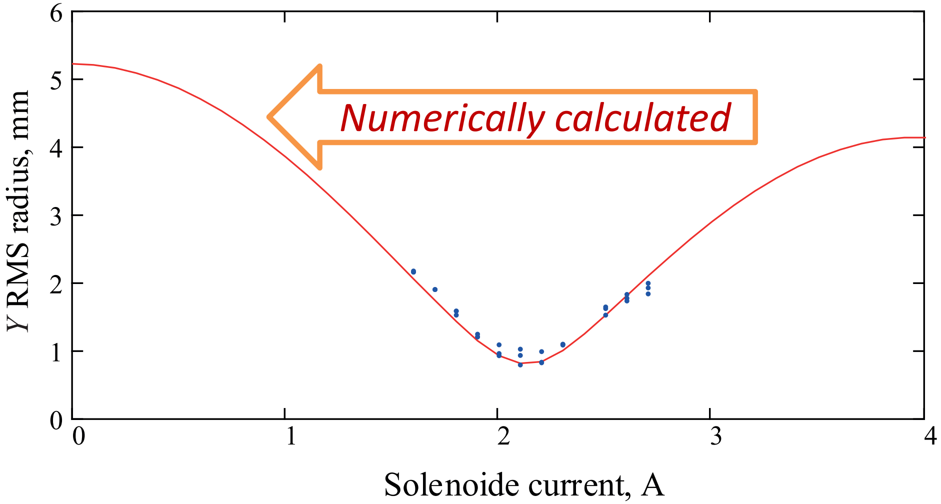


# Emittance measurements

*by solenoid focusing method with using transition radiation sensor*



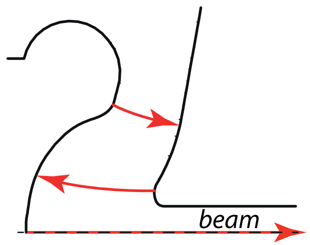

Measured normalized emittance ε=15.5 mm mrad can be compensated by solenoid focusing to ε=10 mm mrad.

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

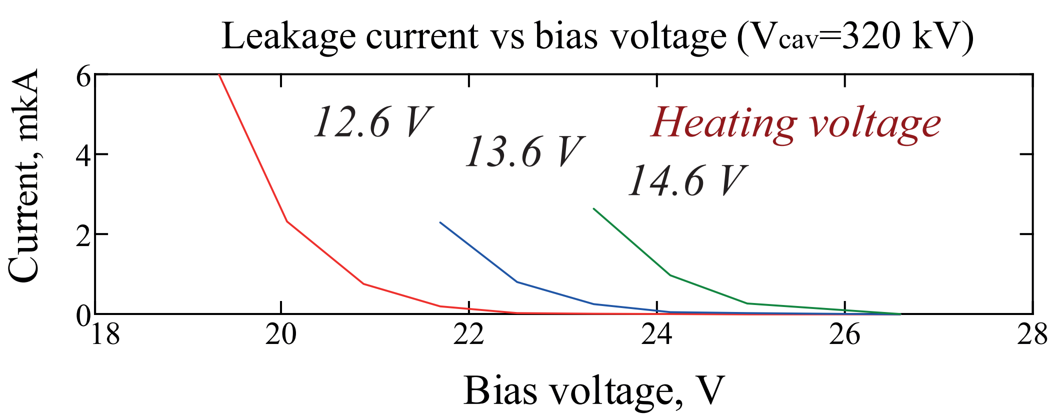



*Accelerating gap geometry*

There are no dark currents in the beam absolutely

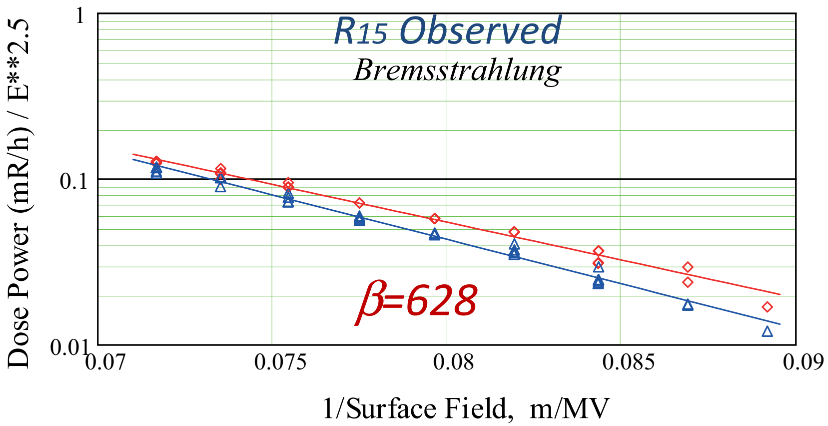
*Leakage current (at Vpuls=0) depends on heating voltage because cathode-grid gap is changed under the thermal elongation.*

*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*



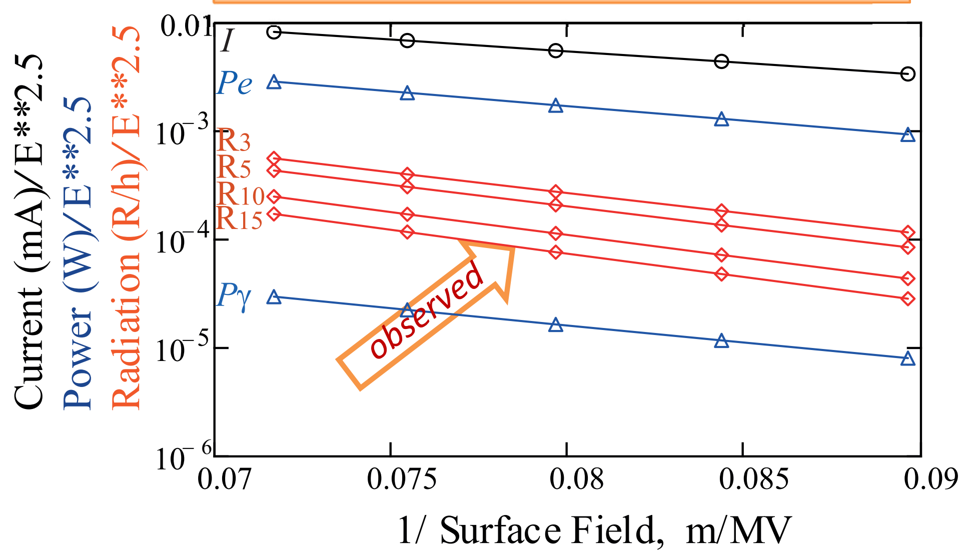

*Fowler-Nordheim (F-N) equation*
*$\phi$=4.5 eV, B=6830, E (MV/m)*

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

*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