



Progress with CW 100 mA Electron RF Gun for Novosibirsk ERL 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***

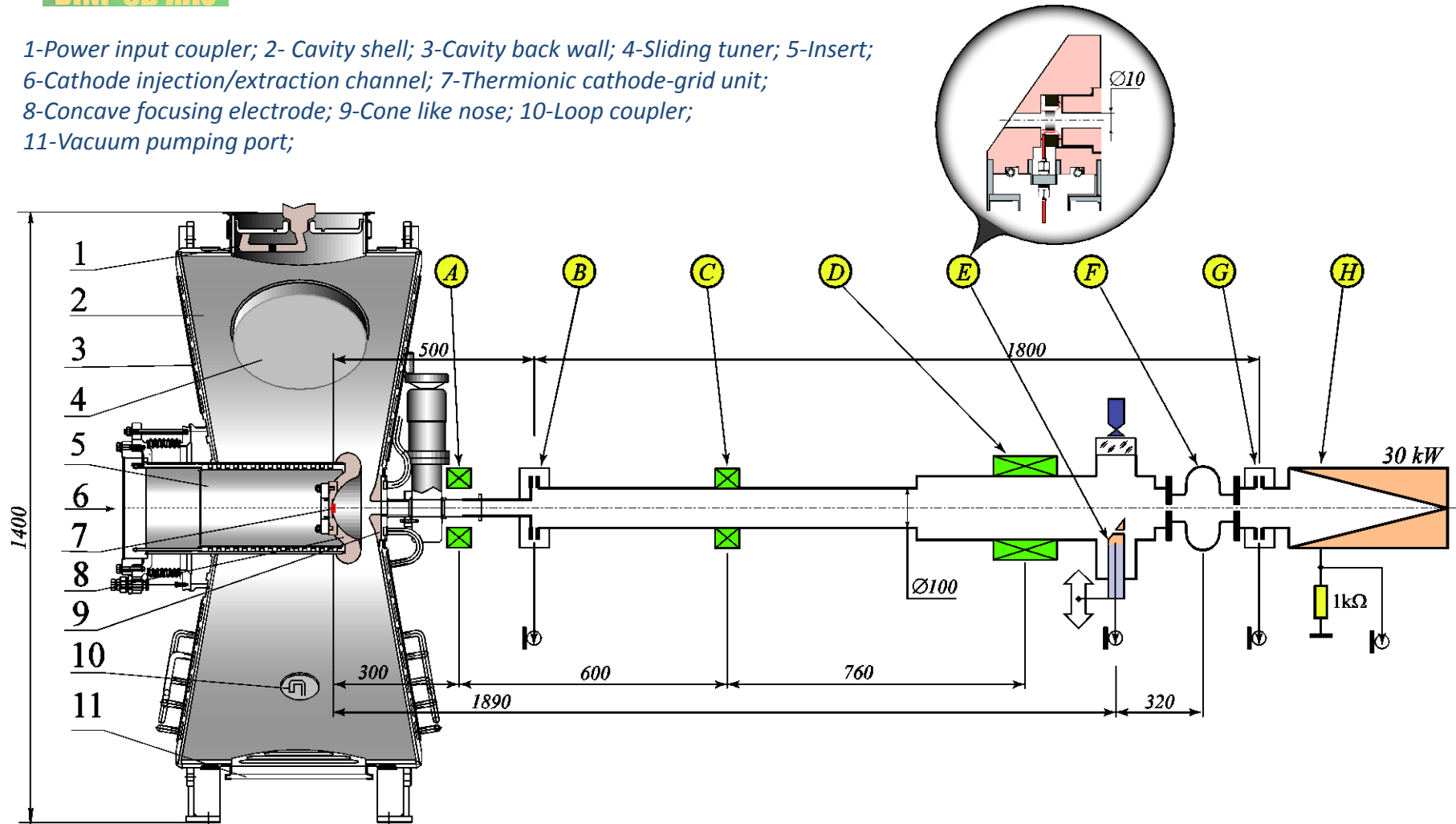


| Measured rf gun characteristics | |
|---------------------------------|-------------------------------------|
| Average beam current, mA | ≤100 |
| Cavity Frequency, MHz | 90 |
| Bunch energy, keV | 100 ÷ 400 |
| Bunch duration (FWHM), ns | 0.06 ÷ 0.6 |
| Bunch emittance, mm mrad | 10 |
| Bunch charge,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

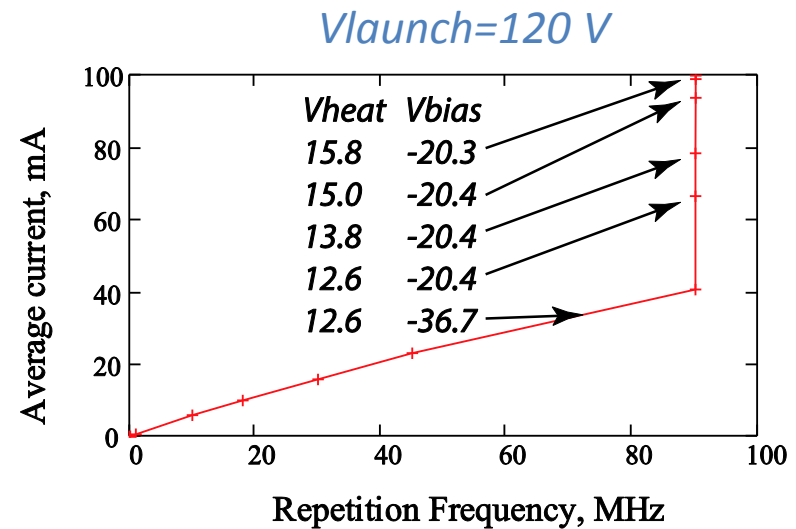
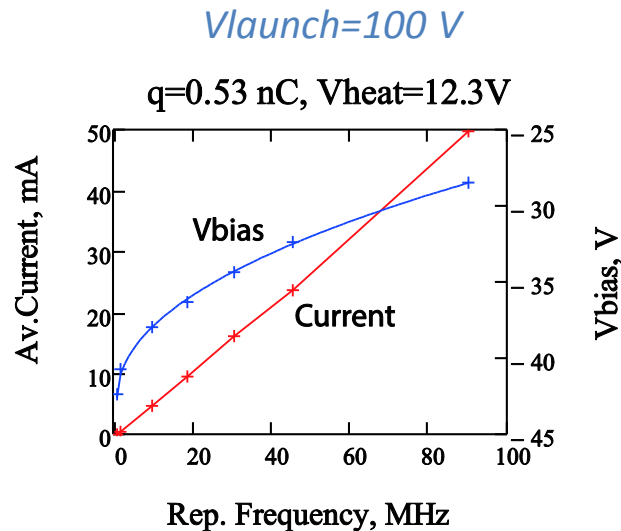
- 1-Power input coupler; 2- Cavity shell; 3-Cavity back wall; 4-Sliding tuner; 5-Insert;
6-Cathode injection/extraction channel; 7-Thermionic cathode-grid unit;
8-Concave focusing electrode; 9-Cone like nose; 10-Loop coupler;
11-Vacuum pumping port;



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



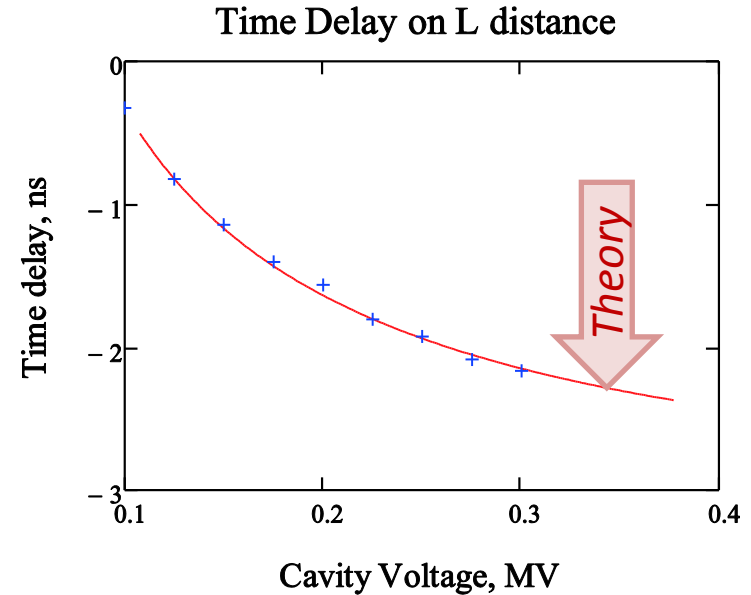
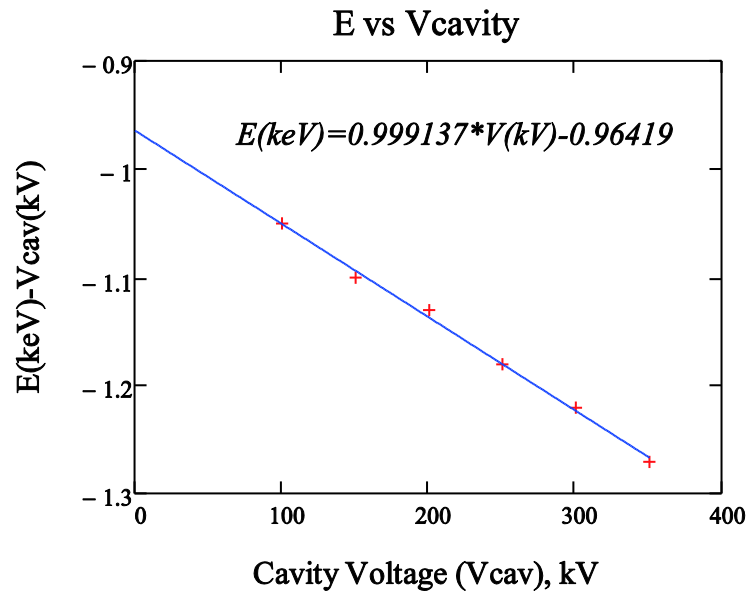
The Typical Mode of current rising is Repetition frequency increasing at $q=1.1 \text{ nC}=\text{const}$

- Cathode thermo-emission current is reverse-acting on the repetition frequency.
- The cathode heating voltage (V_{heat}) and the sum of Launch pulse voltage with the Bias voltage ($V_{\text{launch}} + V_{\text{bias}}$) 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



Bunch velocity (β) vs bunch energy (E)

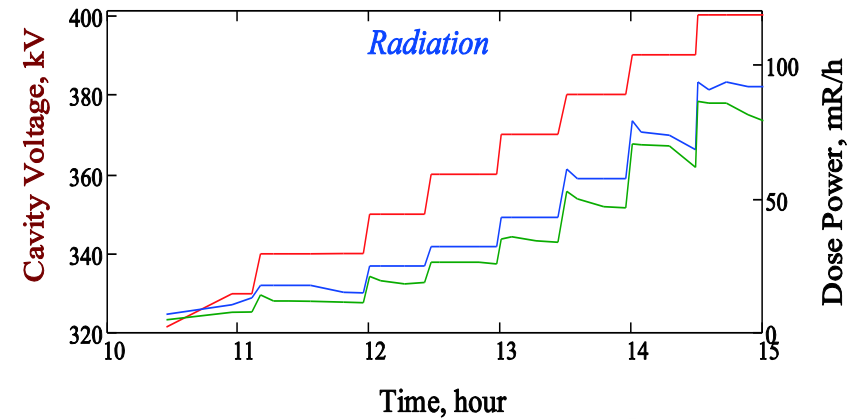
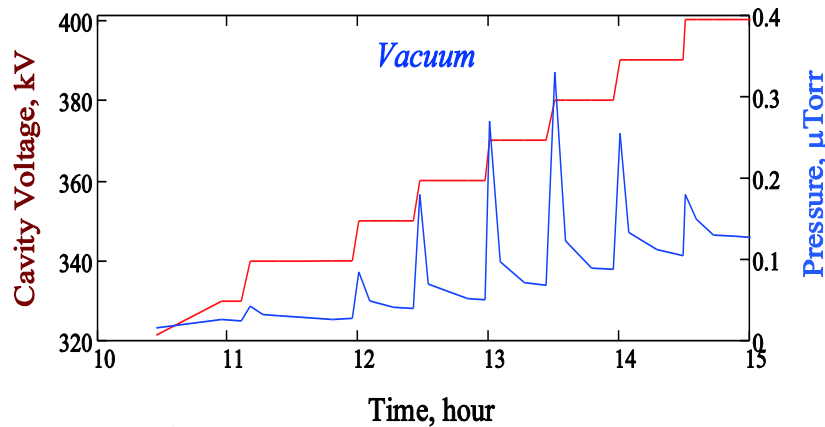
$$\beta(E) := \sqrt{1 - \frac{1}{\left(1 + \frac{E}{mc^2}\right)^2}}$$

Calibrated L between two WCMs = 0.96078 m

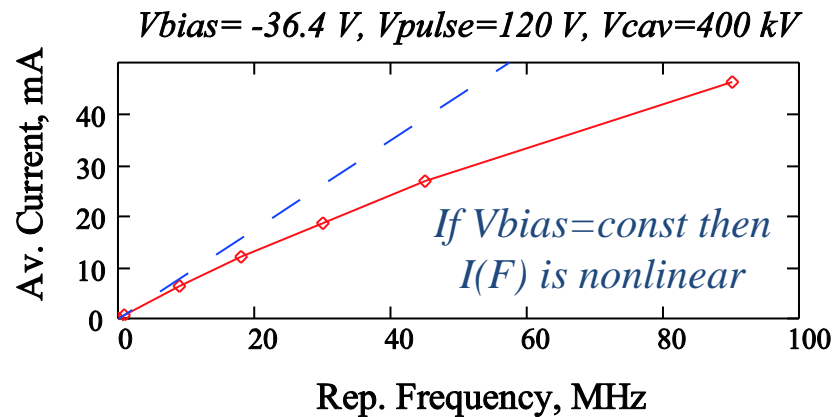
Time delay (T) vs Energy

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

Cavity testing up to 400 kV



$\frac{1}{2}$ hour
operation
time needs to
normalize
pressure level

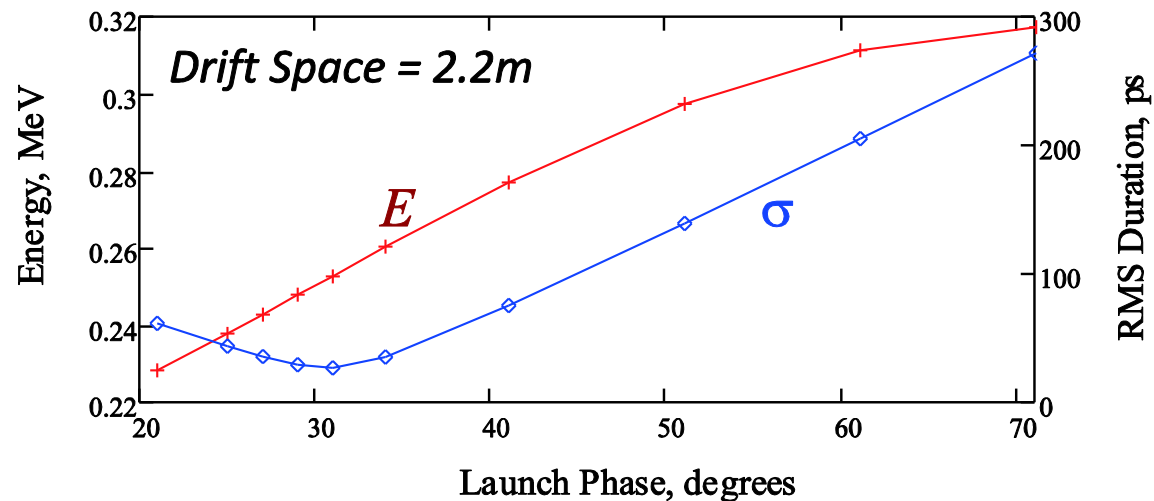
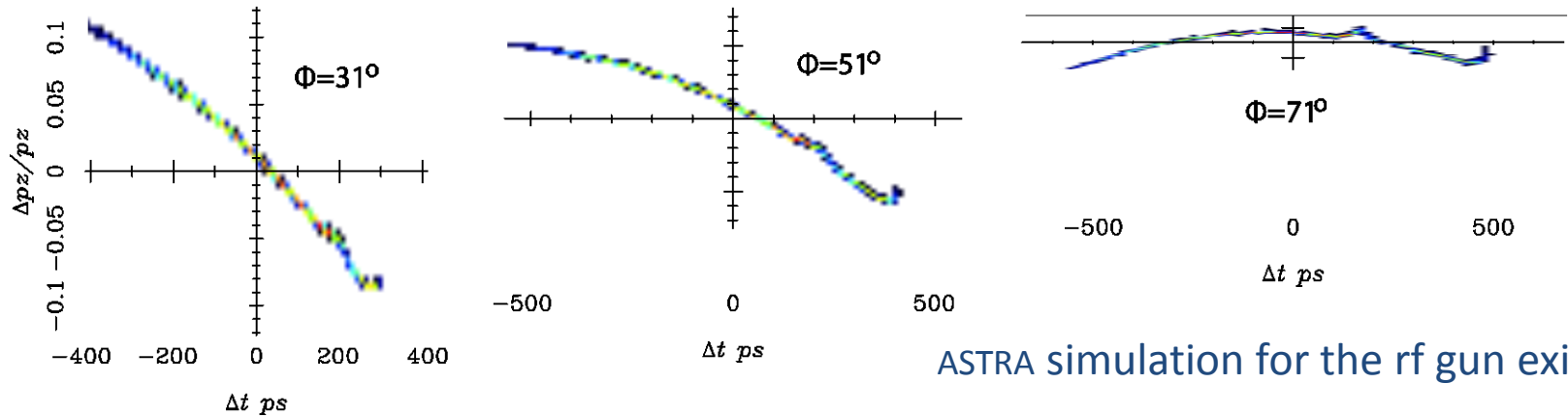


Two radiation
sensors, one
at the
distance of
1.5 m along
axis, second
2 m aside



Launch Phase (Φ) functions

are the reason of velocity bunching and jitter compensation effects



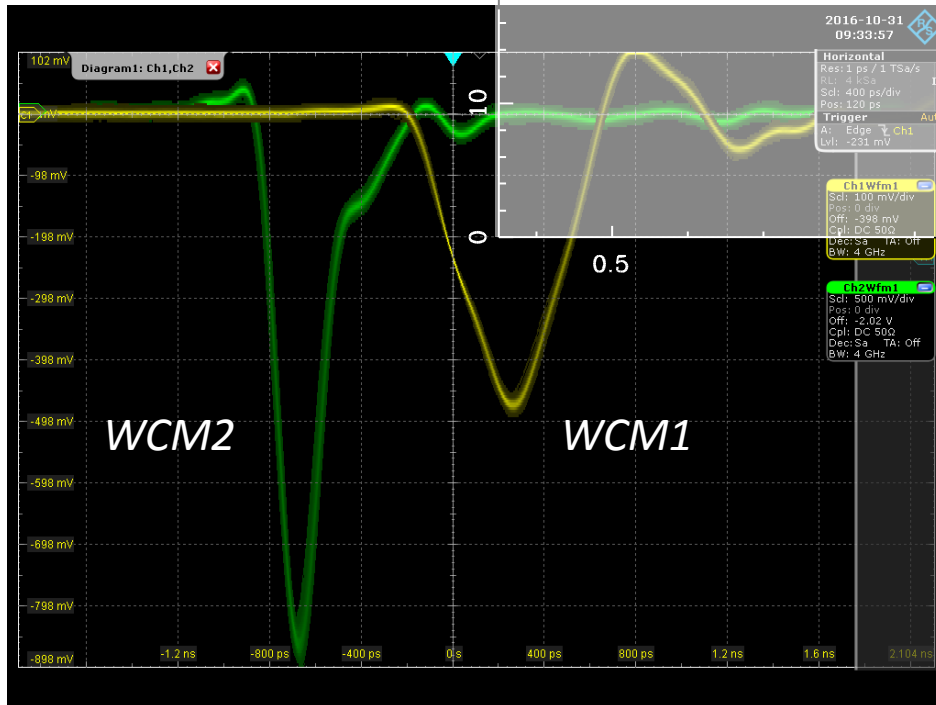
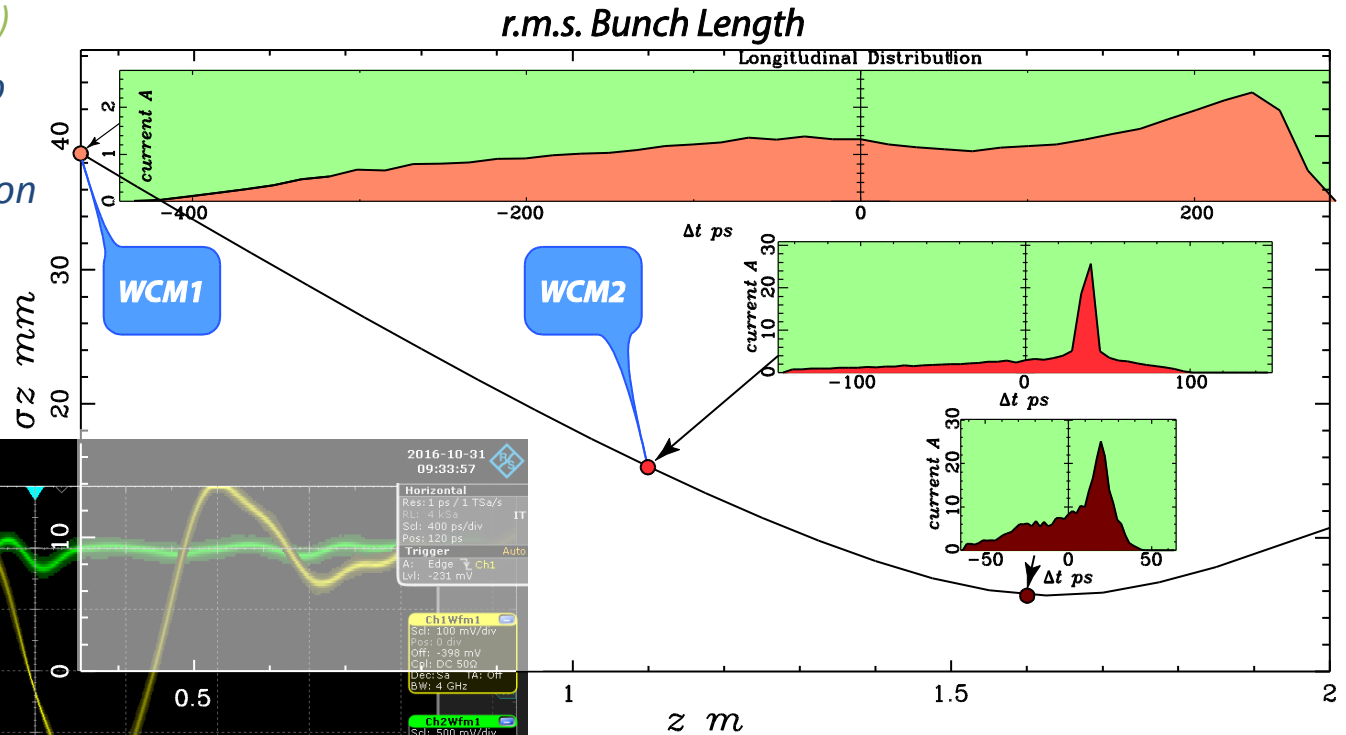


Velocity modulation bunching effect

measured with wideband WCM2 and 4 GHz oscilloscope ($\Phi=27^\circ$, 300 keV)

Wall Current Monitor (WCM)

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



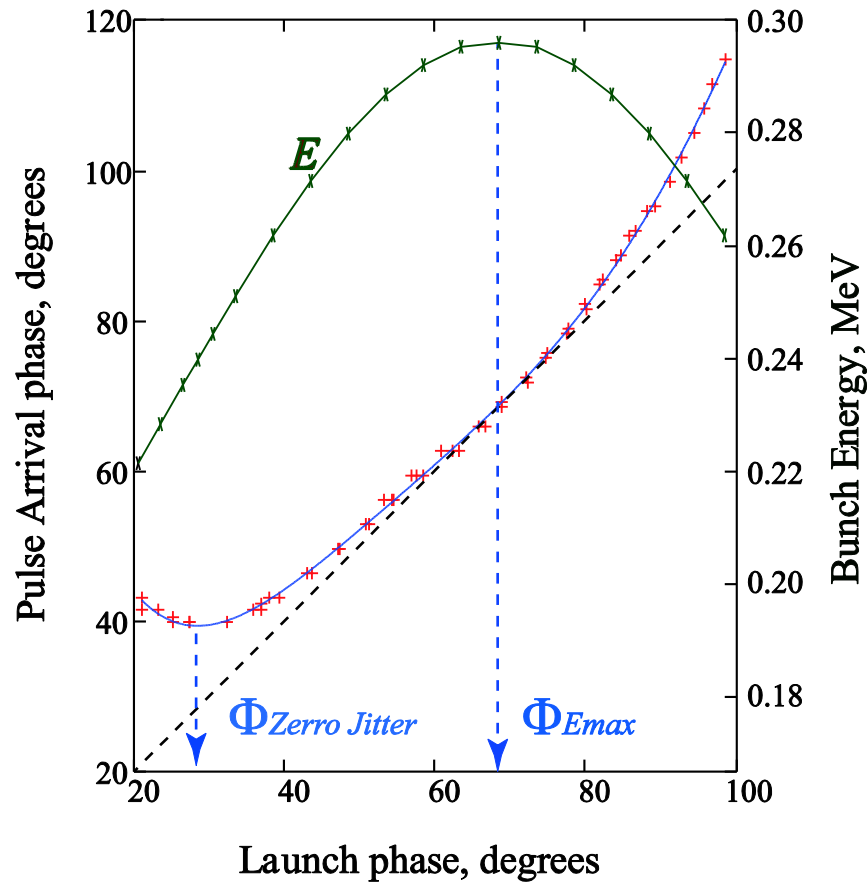
r.m.s. and FWHM be differ a lot

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 $\Phi_{\text{Zero Jitter}}=27^\circ$ degrees, i.e. jitter there is equal to zero, i.e. it has compensated

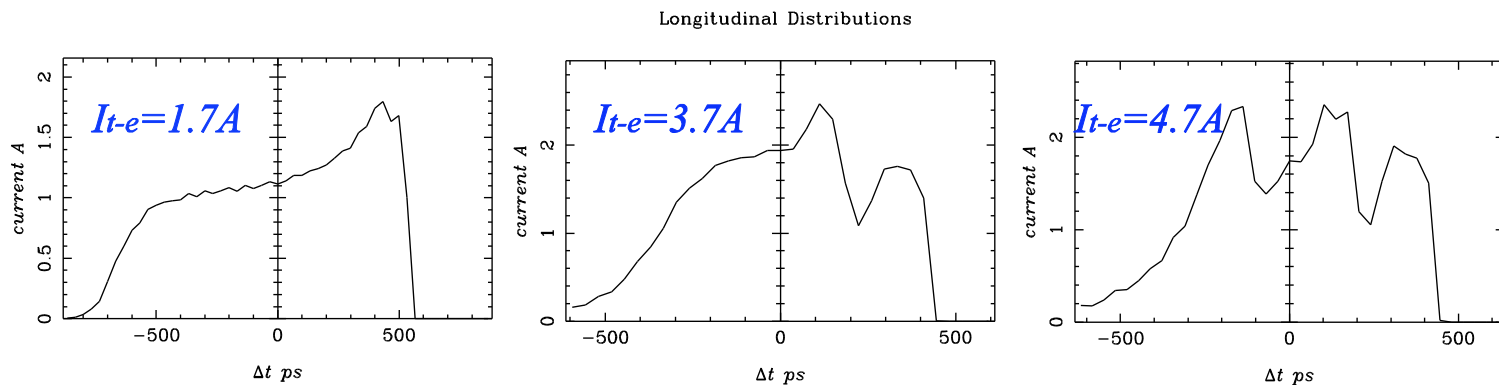


Maximal bunch energy is at $\Phi_{\text{Emax}}=68^\circ$ where it is equal to the arrival phase by accurate within some constant.

Cathode-grid plasma oscillation effect

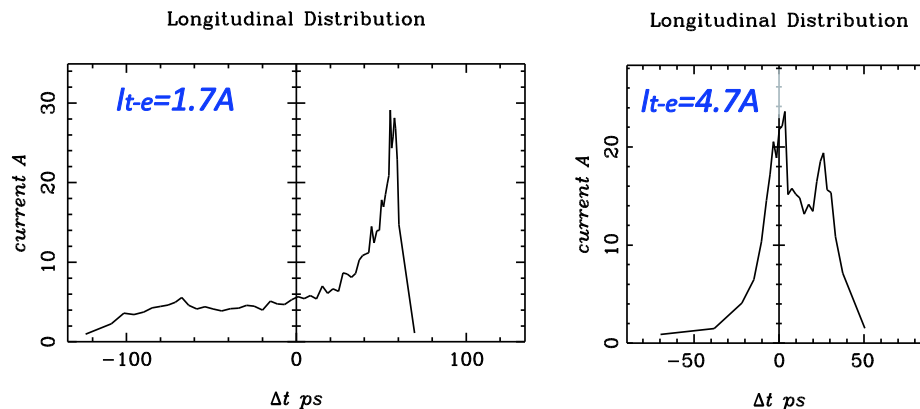
observed with Test Cavity high order modes (HOMs) excited by the beam and already simulated by ASTRA cod

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



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

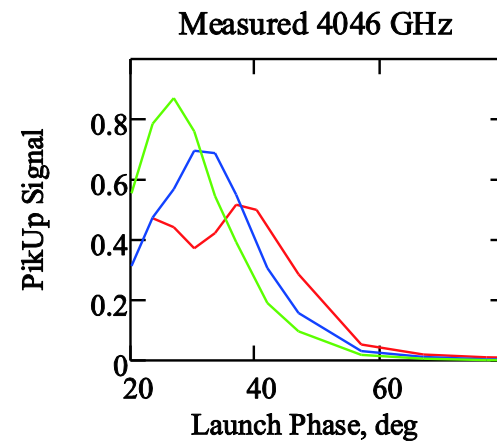
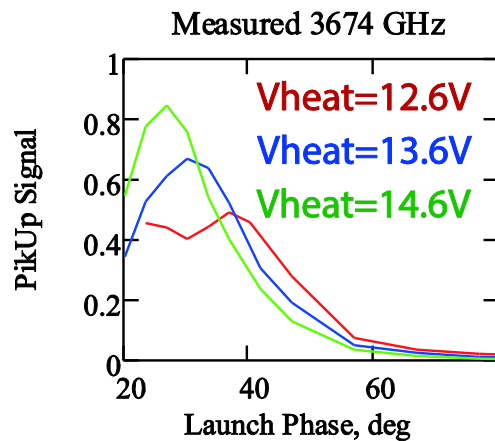
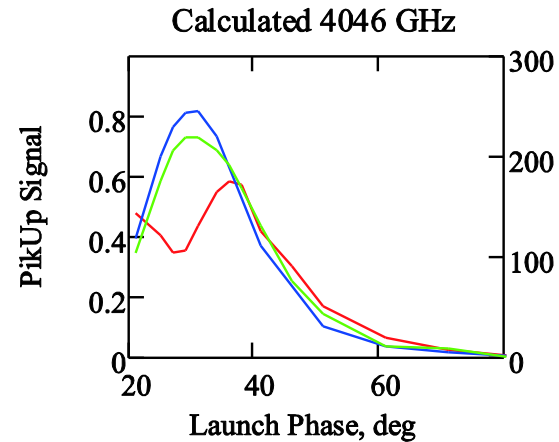
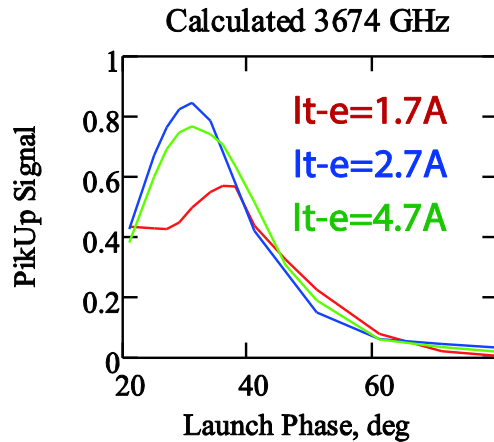
Allegedly, this bunch consists from two bunches that can *interfere* to each other



This bunch mostly resembles a Gaussian one

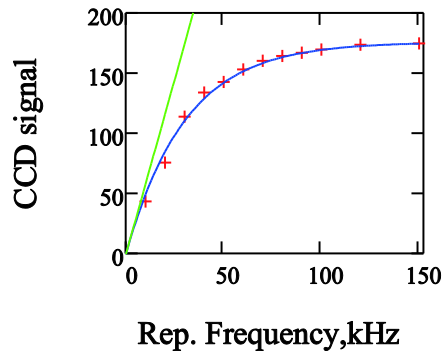
Cathode-grid plasma oscillation effect

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



Emittance measurements

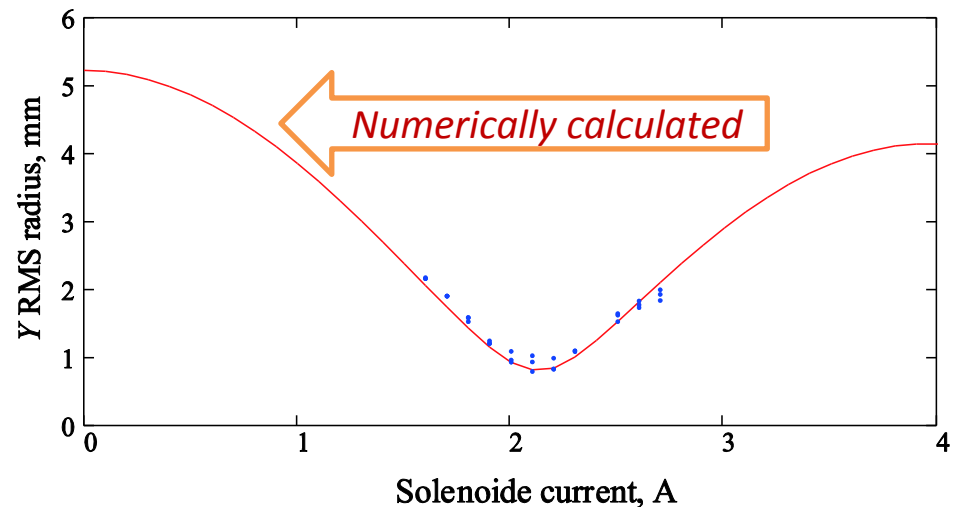
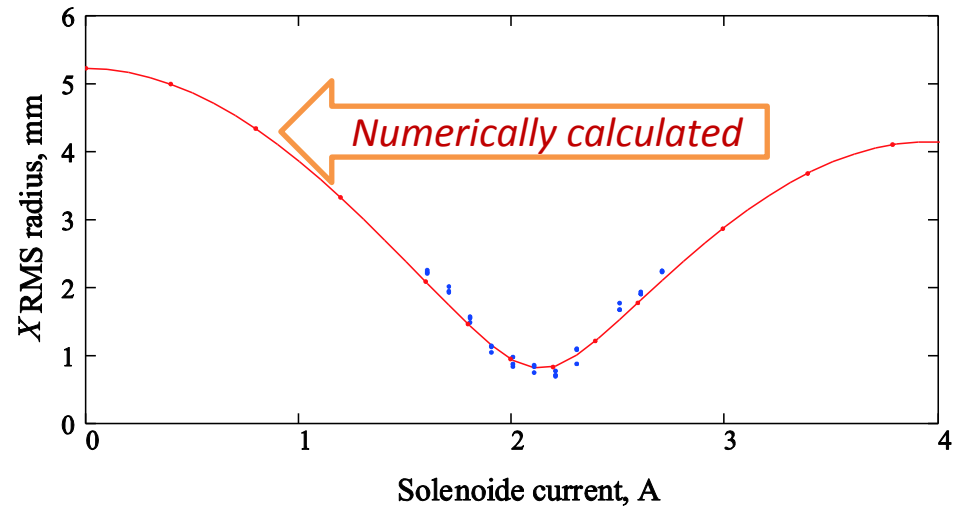
by solenoid focusing method with using transition radiation sensor



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

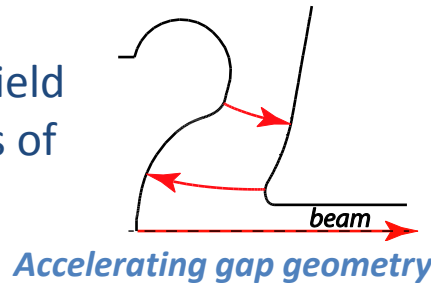
Numerical data processing of CCD camera image and distortion compensated optics were used.

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



Dark and Leakage Currents

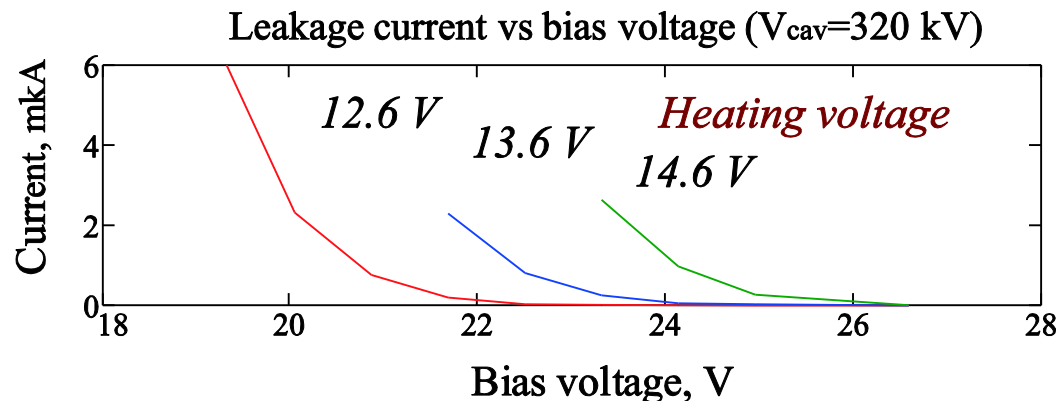
Two places with peak surface field of 10-14 MV/m are the sources of field emitted dark currents



There are no dark currents in the beam absolutely

Leakage current (at $V_{puls}=0$) depends on heating voltage because cathode-grid gap is changed under the thermal elongation.

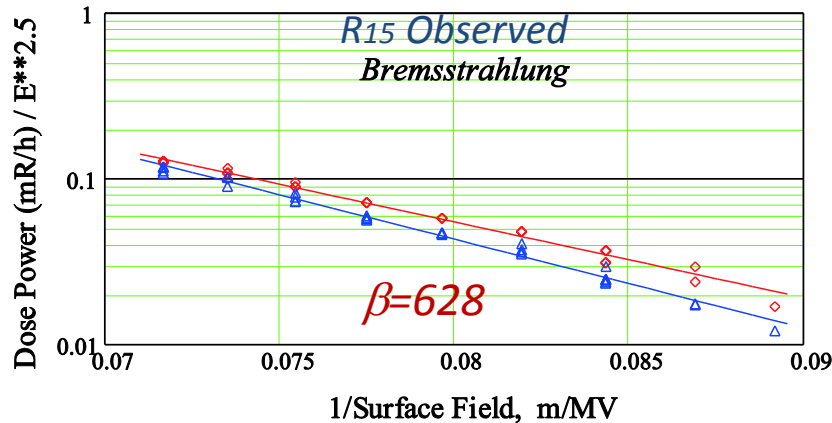
To exclude leakage current from the beam we have to chose proper bias voltage.





Radiation Background

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



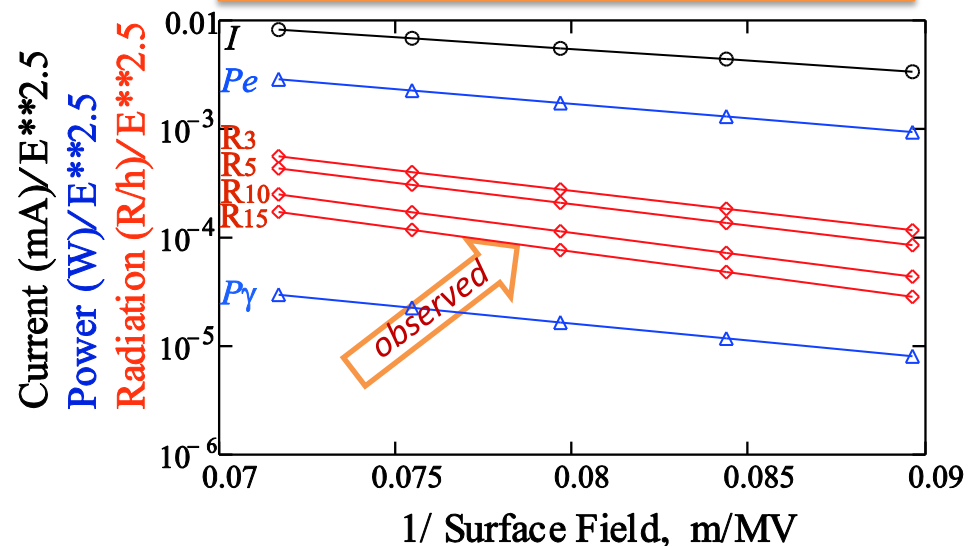
Fowler-Nordheim (F-N) equation
 $\phi=4.5$ eV, $B=6830$, E (MV/m)

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

Enhancement factors β are differ

| Name | | label | β |
|---------------------------------|-----------|------------|---------|
| Dark Current of Field Emission | | I | 1264 |
| Dark Current Power | | Pe | 1003 |
| Bremsstrahlung Power | | P_γ | 865 |
| Cu Shielded Dose Power | $d=3$ mm | R_3 | 721 |
| | $d=5$ mm | R_5 | 695 |
| | $d=10$ mm | R_{10} | 649 |
| | $d=15$ mm | R_{15} | 628 |

All Calculated have F-N nature!





Thank you for your attention