Low Emittance Electron Guns Employing the LaB_6 Single Crystal Cathode

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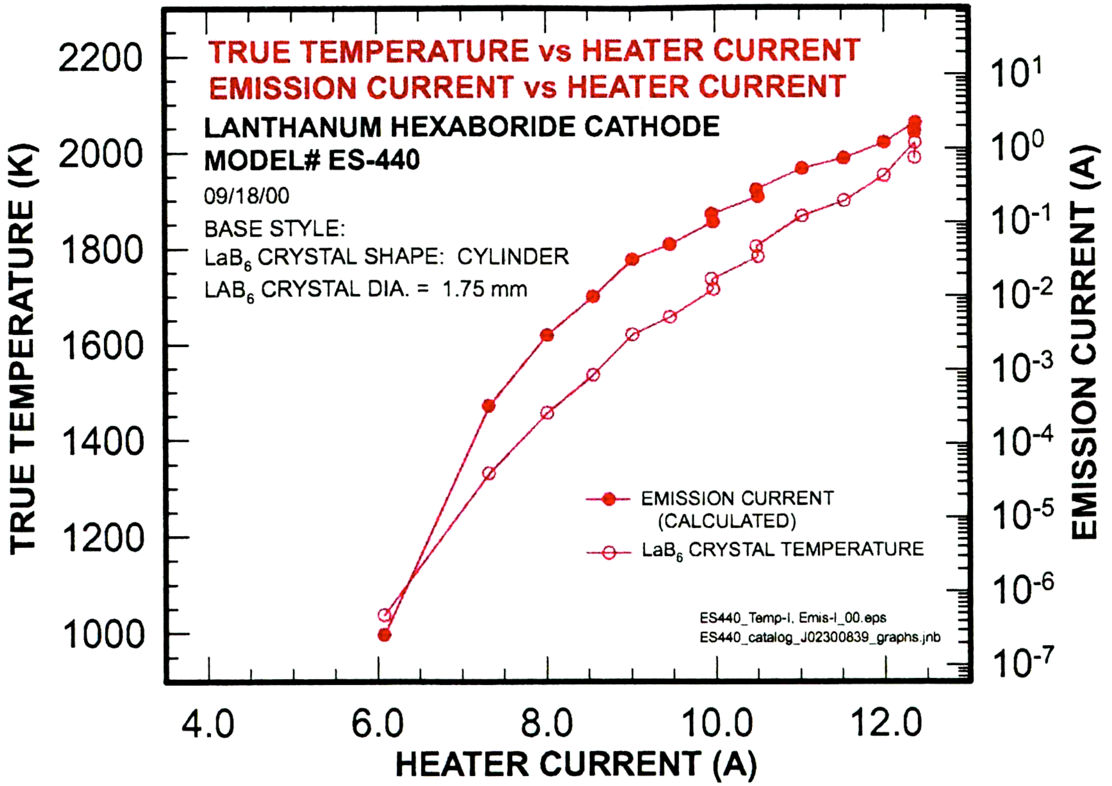
Why LaB_6 Single Crystal Cathode ?

- ☑ **High emission current**
  (Small cathode size creates low emittance beam)
  (Small cathode size may be better against the back-bombardment effect in RF guns)

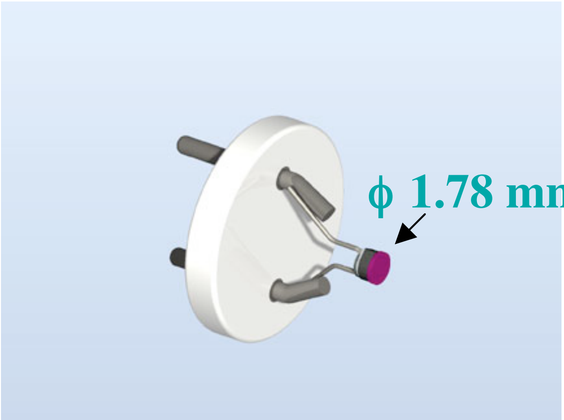
- ☑ **Flat surface because of single crystal**
  (Low intrinsic emittance)

- ☑ **Long lifetime**
  (This is true, but heater assembly is difficult)

High-Temperature Operation of LaB_6 Single Crystal



Single-Crystal LaB6 Cathode



ES-440	
CATHODE MATERIAL	Lanthanum Hexaboride (LaB_6) single crystal
CATHODE SHAPE	Flat cylinder
SIZE	0.070 in dia. x 0.011 in. thick, standard (1.78 mm dia. x 0.25 mm thick)
HEATER	Refractory metal
EMISSION AREA	0.0249 cm^2
TYPICAL HEATING VOLTAGE/CURRENT	Approx. 1 V, 10 A (Voltage measured at cathode)
CATHODE LOADING	Up to 30 A/cm^2 High loadings result in reduced lifetime
WORK FUNCTION	2.69 eV
OPERATING TEMP	Approx. 1700 K to 1900 K
ENERGY SPREAD	Approx. 0.4 eV
LIFETIME	Varies with conditions/vacuum/heating current
VACUUM LEVEL	10^{-7} torr or better, recommended
POWER SUPPLY CAPABILITY	Voltage regulated power supply recommended, 2 V, 12 A


PHYSICS INC.
KPI
HILL RD, WILTON, NH 03086-9742 USA
Fax: (603) 878-3700
ES-440 LaB6 Cathode
1.75 mm, Single Crystal <100>
Custom Mount on AEI w/ Moly pins
OD Ground to 12mm +0.00/-0.02
2005 12 2

Development of thermionic DC gun and RF gun

To extract maximum performance of LaB6, we have developed both DC gun and RF gun.

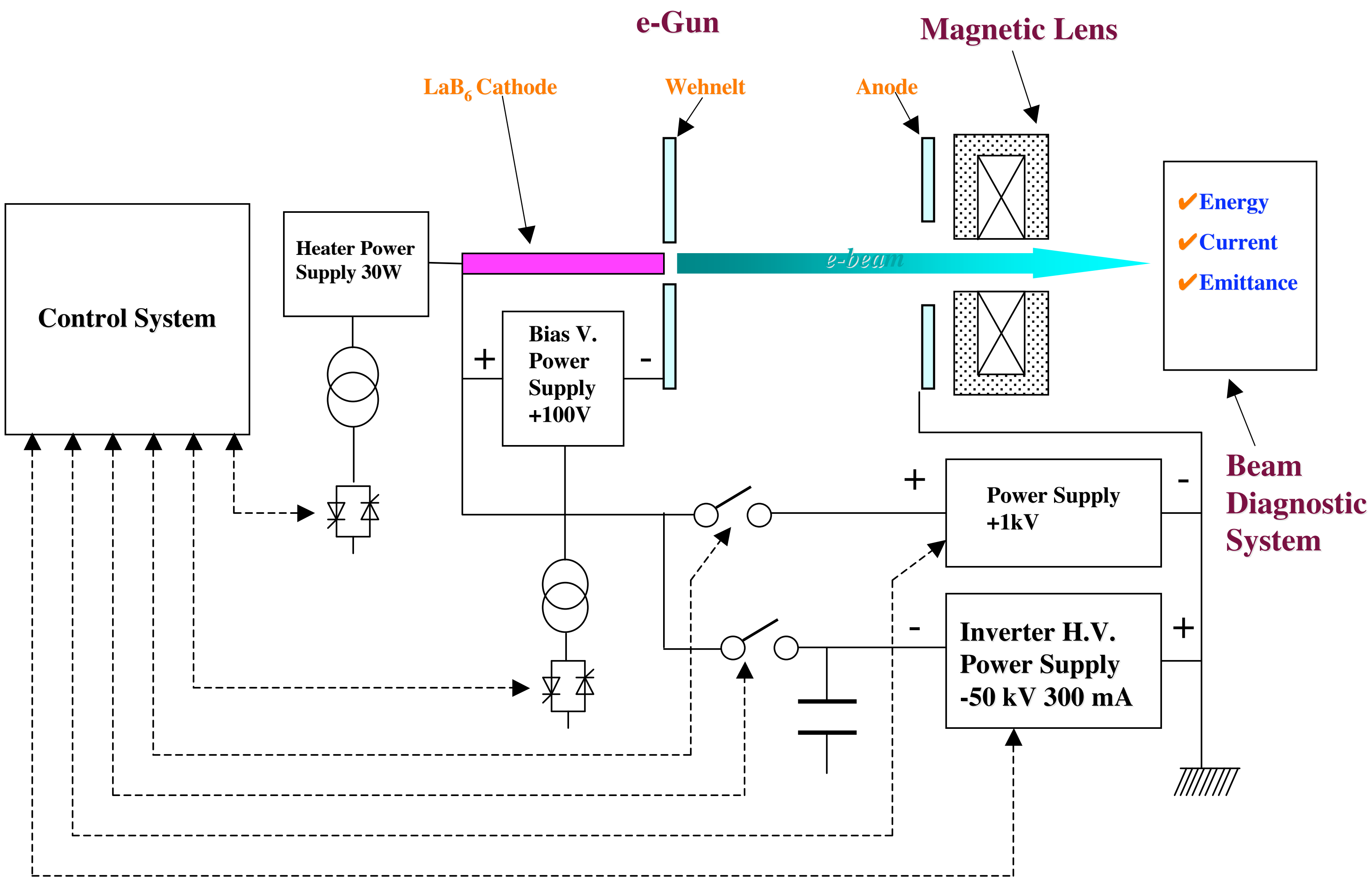
- DC gun -

- ✔**Very low "high-voltage (~50kV)" , no grid and compact.**
- ✔**Low-emittance.**
- ✔**To replace with old thermionic gun ($\varepsilon_n \sim 200\ \pi$ mm mrad).**
- ✔**Smith-Parcel FEL and Teraherz FEL.**

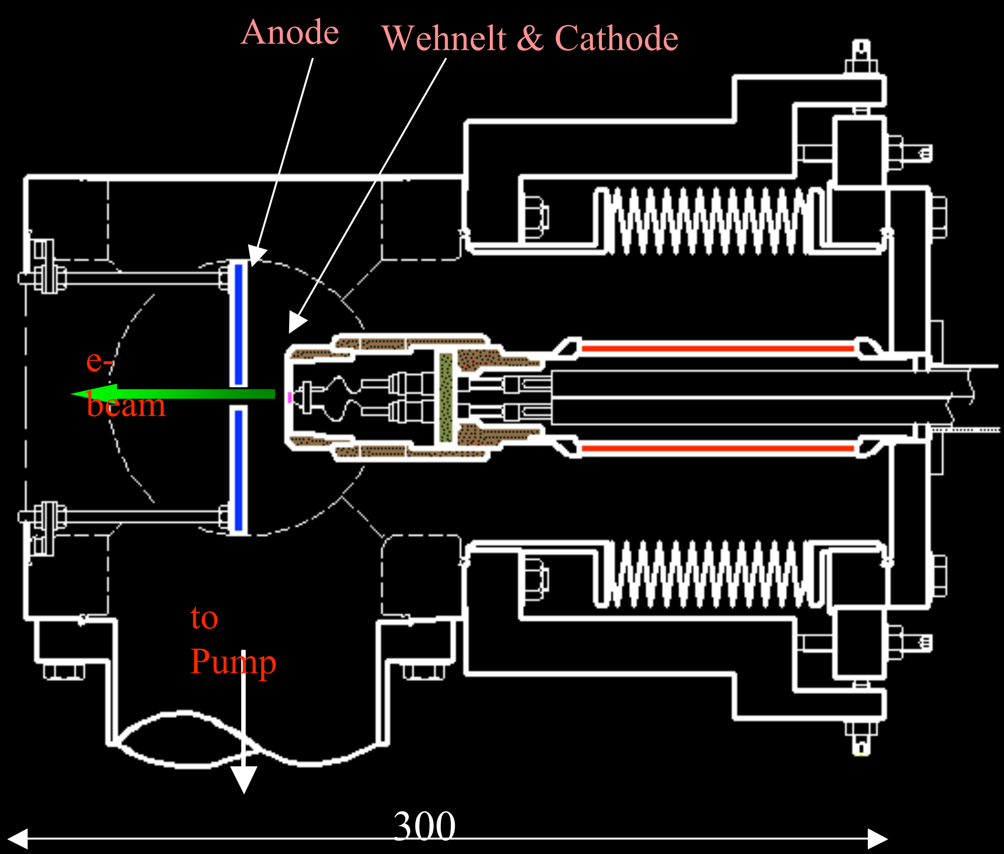
- RF gun -

- ✔**Independently-tunable 2-cell gun.**
- ✔**Low-emittance.**
- ✔**Optimized for production of very short bunches (< 100 fs).**
- ✔**Super coherent THz ring (talk at Group-1 this afternoon).**

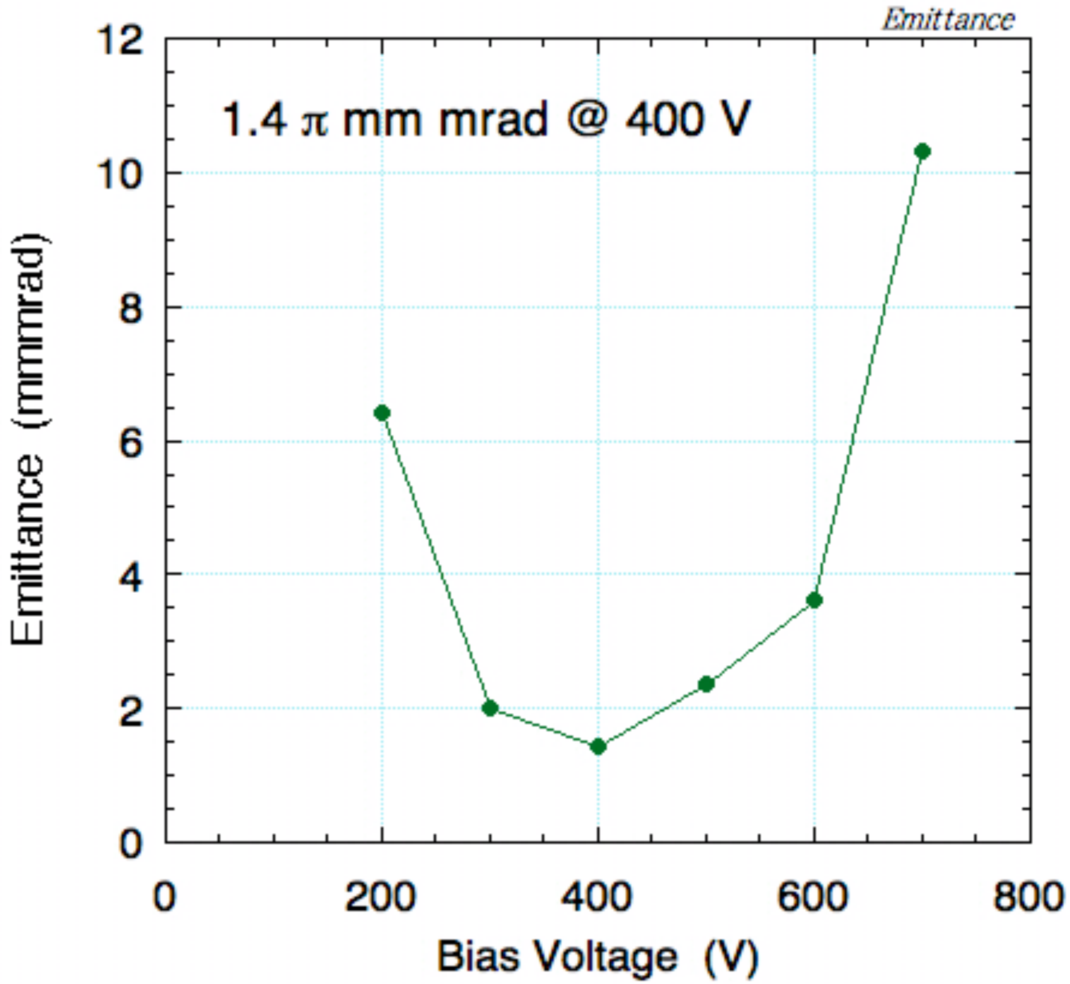
Schematic Diagram of Low Emittance DC-gun



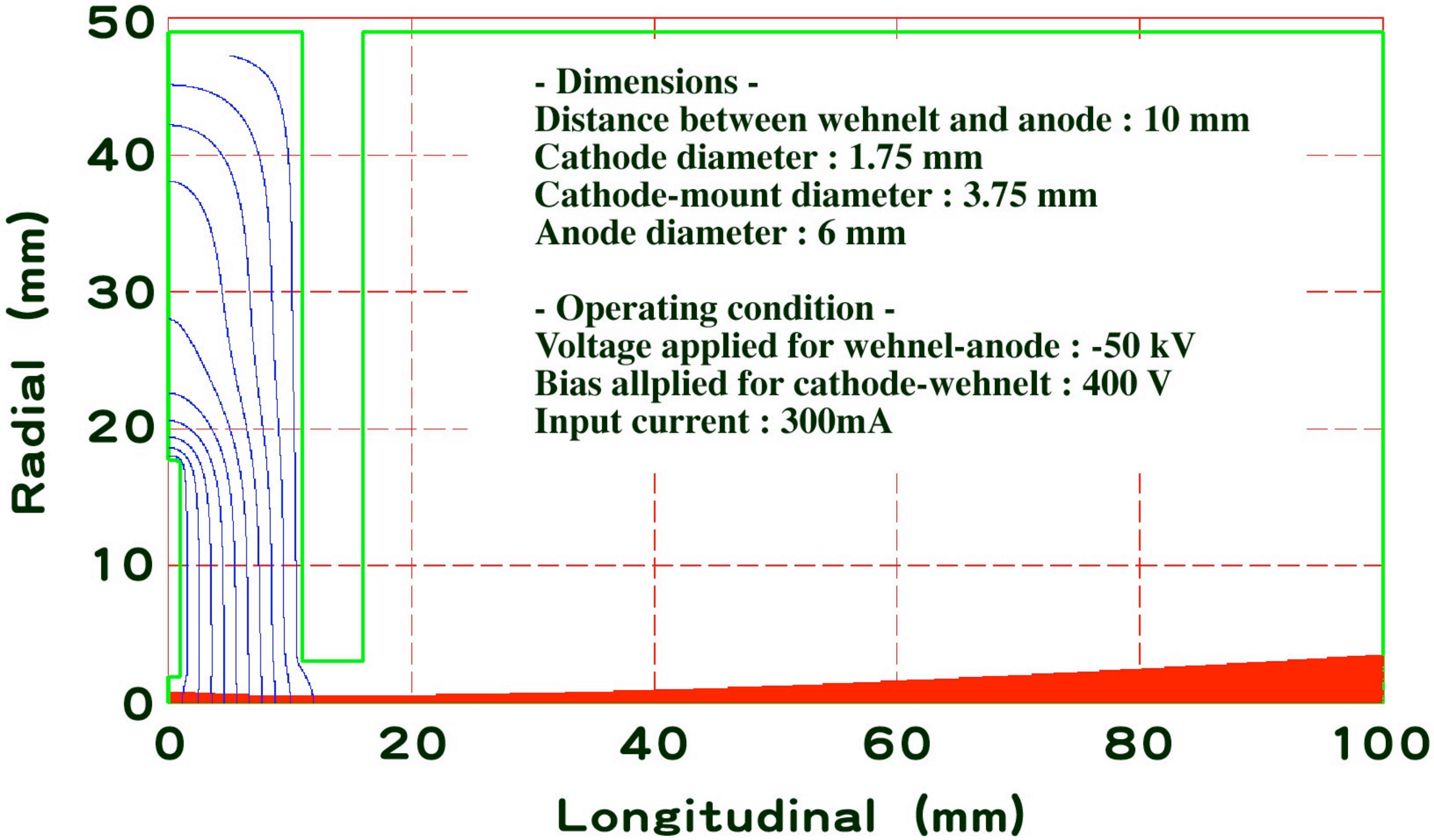
Structure of Compact DC-Gun



Bias Voltage Dependence of the Emittance
I = 300 mA



Result of EGUN Simulation for Minimum Emittance



Why thermionic RF Gun ?

Simple ! No buncher. No high-voltage stage

Photo cathode RF gun hae been getting popular, while thermionic one is not well studied.

Back-bombardment effect can be reduced by introducing small size cathode and shot macropulse operation.

There seems to be a possibility to create very short bunches less than 100 fs, in addition to low emittance.

Thermionic RF Gun

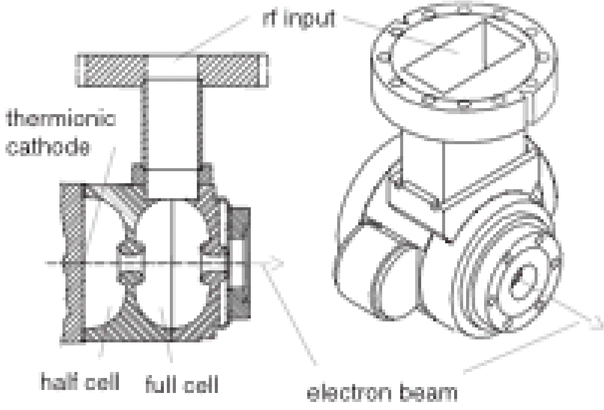


Fig. 1. RF-gun cross-section and 3D-view.

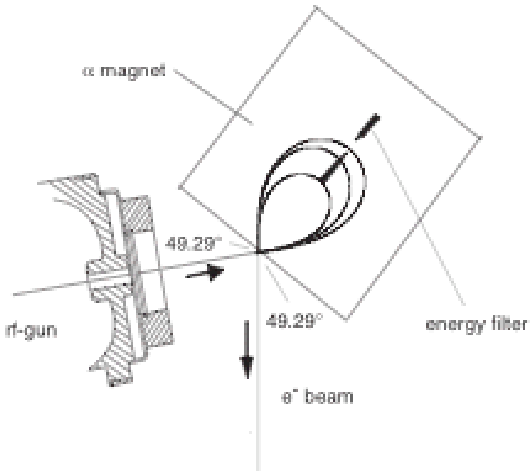


Fig. 3. Rf-gun and α-magnet layout (schematic).

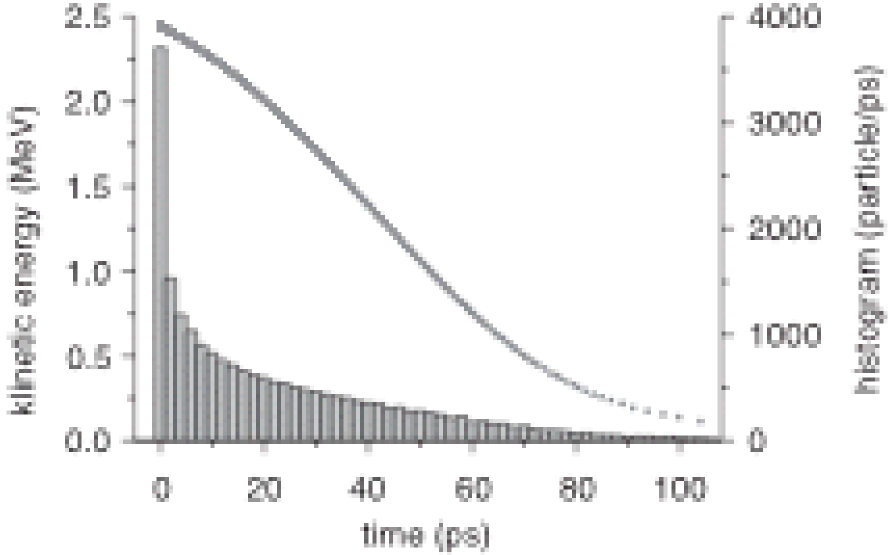
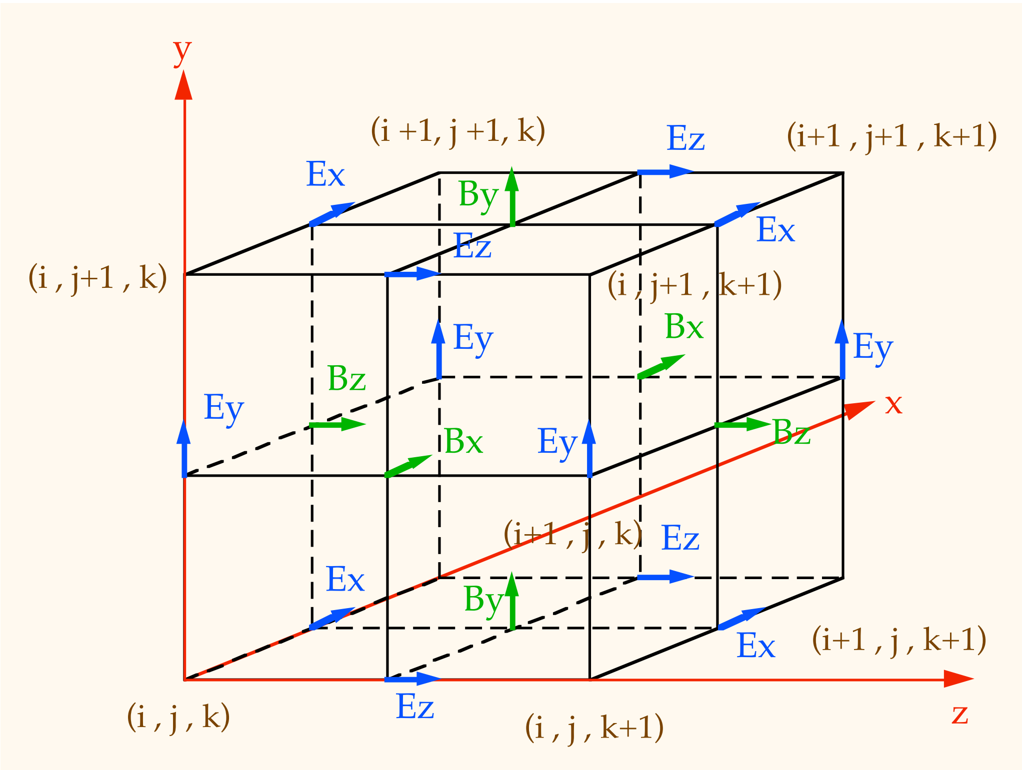


Fig. 2. Particle distribution in energy-time phase space for a single S-band bunch at the RF-gun exit with histogram. The units of the histogram are macroparticles (each representing 6.34×10^4 electrons) per picosecond.

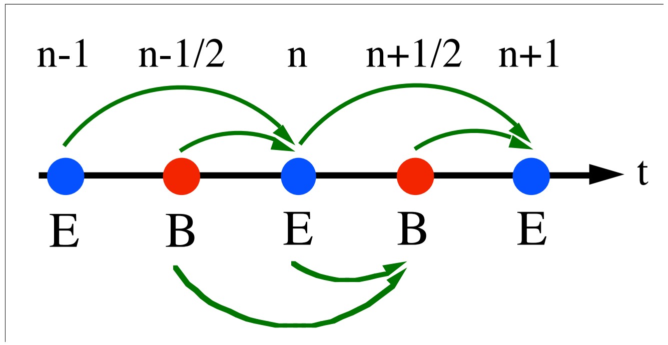
Courtesy S. Rimjaem, H. Wiedemann et al., NIM A 533 (2004) 258-269

FDTD (Finite Difference Time Domain) Method as a 3-D Maxwell's equations solver

Cubic mapping (Lee cell)



Leap-frog step



Finite Difference Equation

Spatial domain

$$\frac{\partial F^n(i,j,k)}{\partial x} = \frac{F^n\left(i+\frac{1}{2},j,k\right) - F^n\left(i-\frac{1}{2},j,k\right)}{\Delta x} + O\left(\Delta x^2\right)$$

Time domain

$$\frac{\partial F^n(i,j,k)}{\partial t} = \frac{F^{n+\frac{1}{2}}(i,j,k) - F^{n-\frac{1}{2}}(i,j,k)}{\Delta t} + O\left(\Delta t^2\right)$$

First order of Taylor expansion of differential equation
Error comes from 2nd order expansion
Symplectic ! within 1 st order

Maxwell's eqs. $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ $\nabla \times \vec{B} = \frac{1}{c^2}\frac{\partial \vec{E}}{\partial t} + \mu_0 \vec{J}$

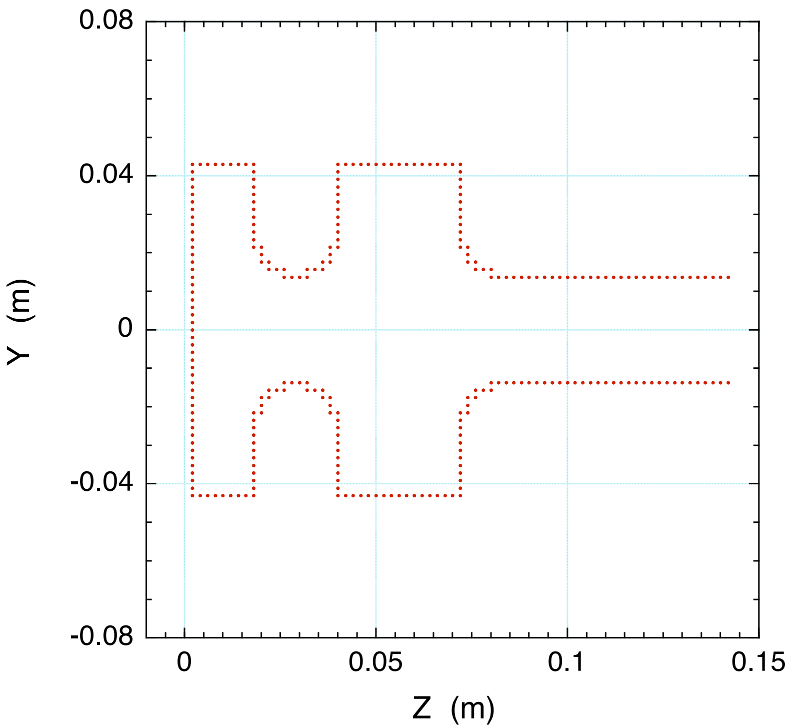
Example solution (E_x) of finite difference equation,

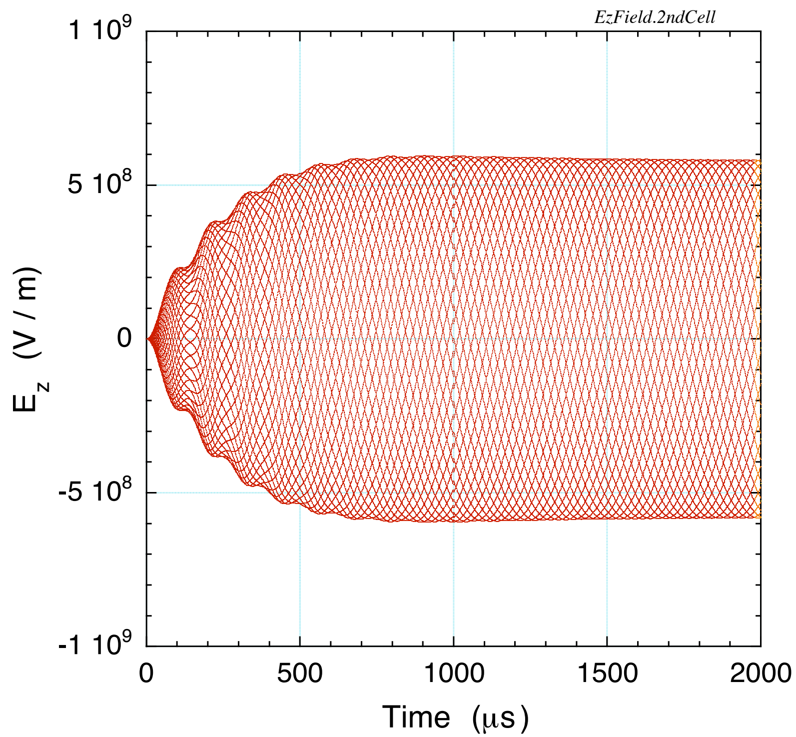
$$E_x^{n+1}\left(i+\frac{1}{2}, j, k\right) = E_x^{n}\left(i+\frac{1}{2}, j, k\right) + c^2 \Delta t \left[\frac{B_z^{n+\frac{1}{2}}\left(i+\frac{1}{2}, j+\frac{1}{2}, k\right) - B_z^{n+\frac{1}{2}}\left(i+\frac{1}{2}, j-\frac{1}{2}, k\right)}{\Delta y} - \frac{B_y^{n+\frac{1}{2}}\left(i+\frac{1}{2}, j, k+\frac{1}{2}\right) - B_y^{n+\frac{1}{2}}\left(i+\frac{1}{2}, j, k-\frac{1}{2}\right)}{\Delta z}\right] - \frac{\Delta t}{\varepsilon_0} J_x^{n+\frac{1}{2}}\left(i+\frac{1}{2}, j, k\right)$$

Δx, Δy, Δz ; spatial step length Δt ; step time n ; number of steps

$\left(c\,\Delta t\right)^{-1} \geq \sqrt{\Delta x^{-2} + \Delta y^{-2} + \Delta z^{-2}}$ should be satisfied to avoid instability

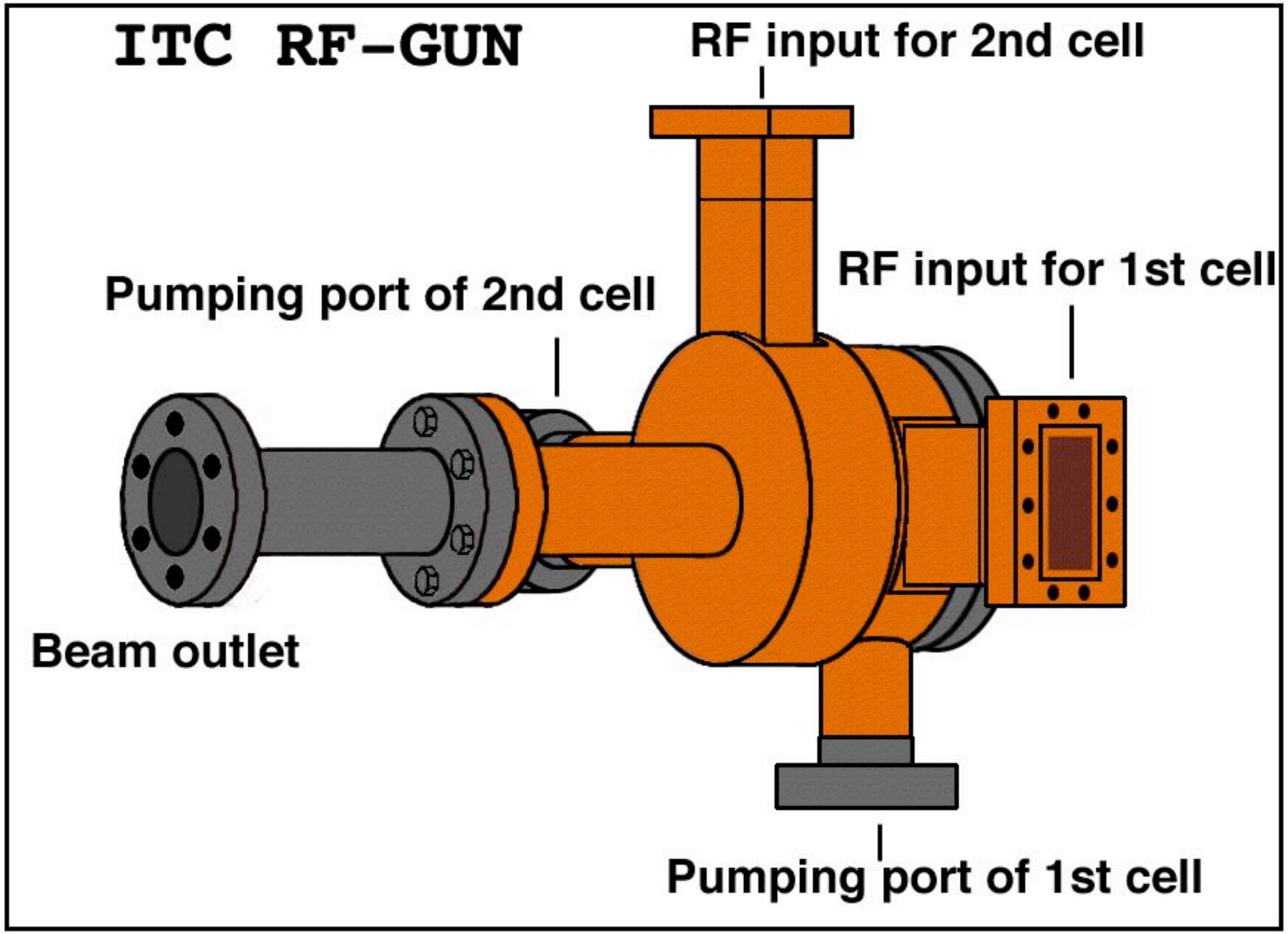
Example : 1.5-cell RF gun (on-axis coupled)



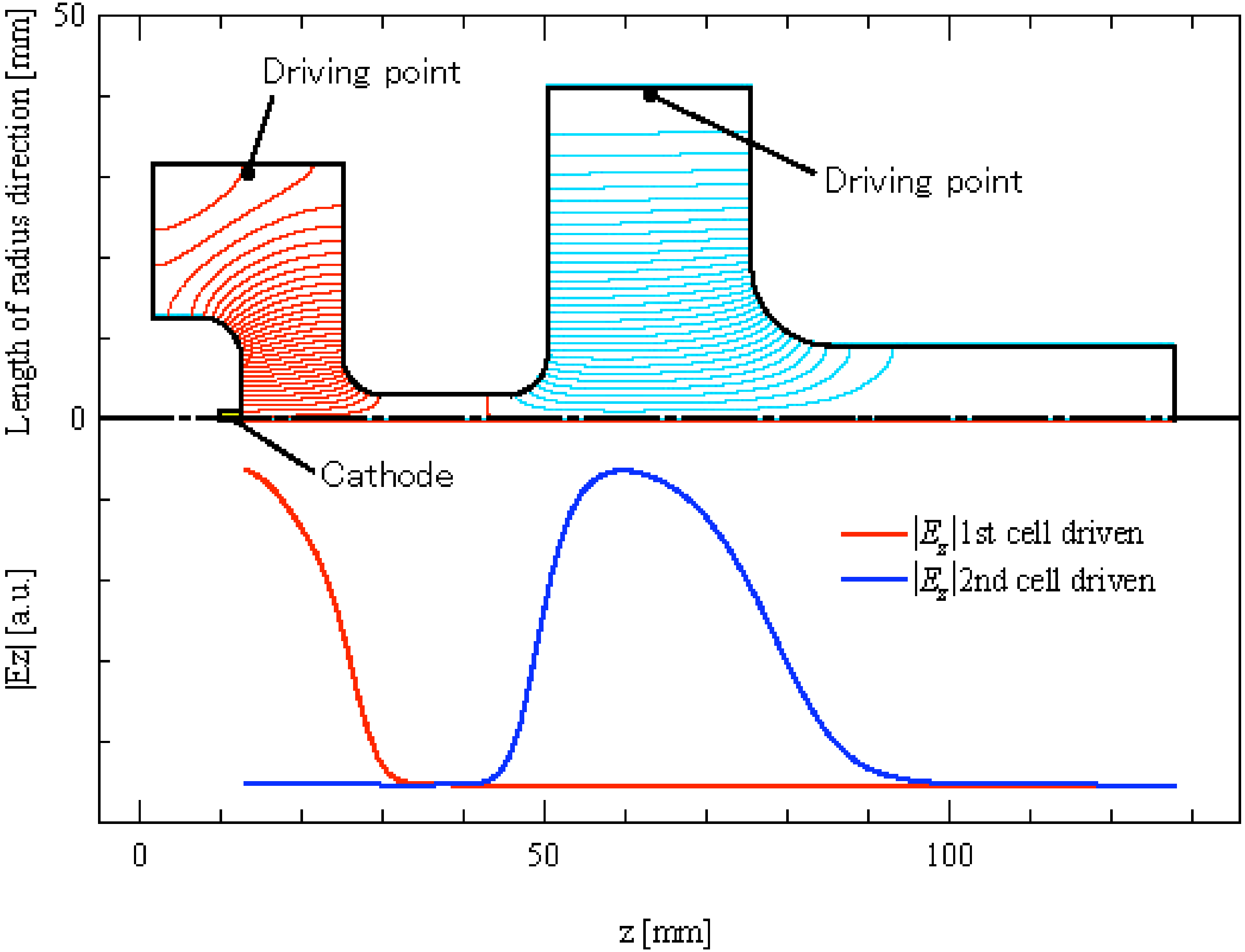


0-mode is also excited at the beginning of power feed
Frequency separation : ~ 7 MHz (0 -π modes)

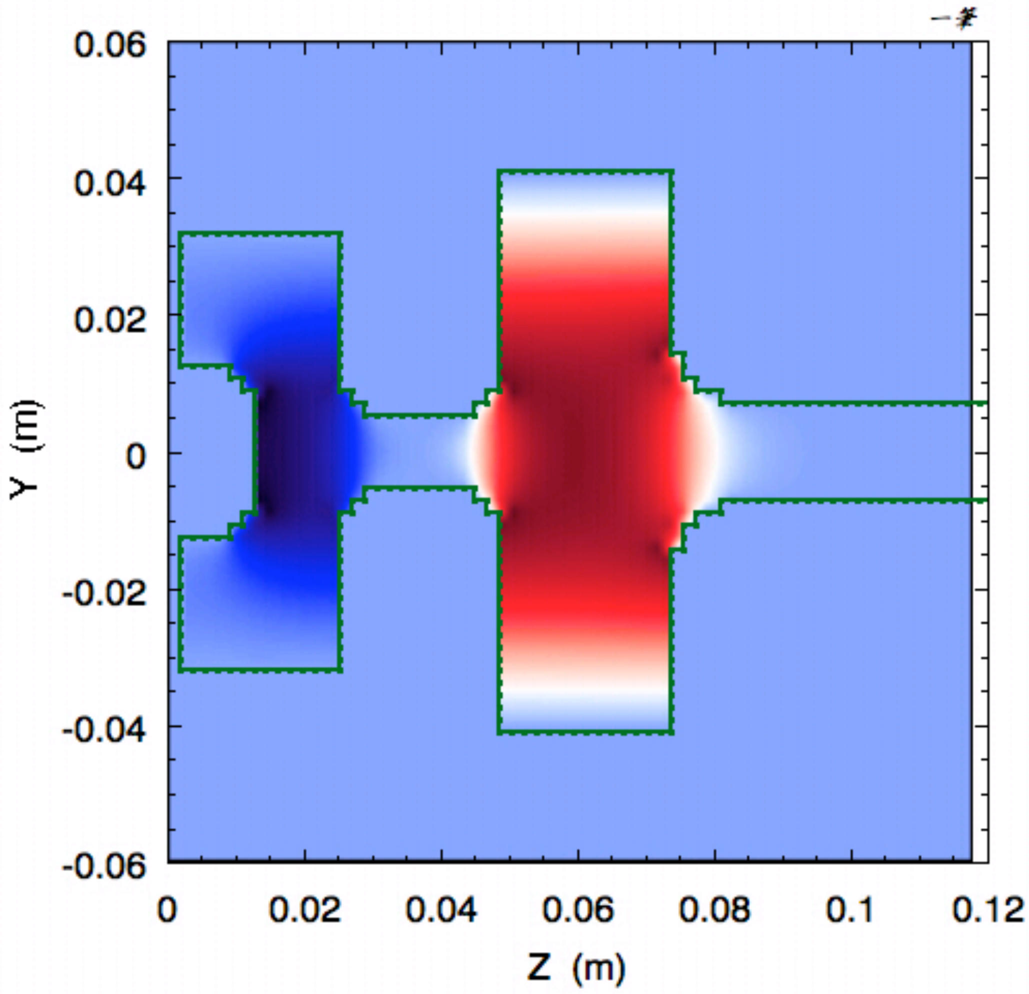
ITC (Independently-Tubanle Cells) RF-Gun



Q1 = 13000,   Q2 = 12500 (SUPERFISH)



3-D FDTD Cavity Analysis



$f_1 = 2856.000\ (0.000051)$ *MHz*
$Q_1 \sim 13000$

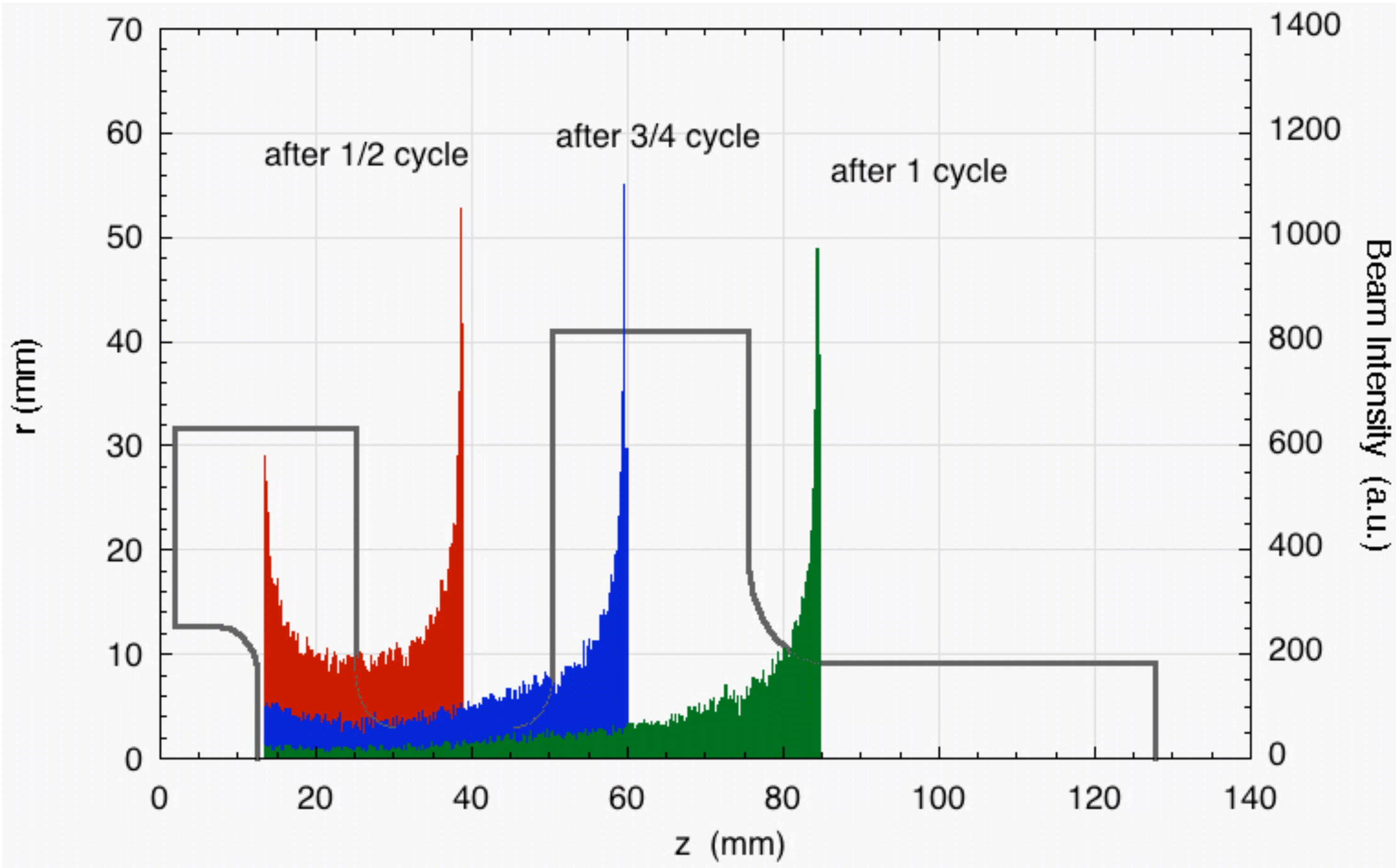
$f_2 = 2856.141\ (0.009700)$ *MHz*
$Q_2 \sim 12500$

Coupling is almost negligible.
$< 10^{-6}$

Velocity Bunching-Like Effect

Electron equation of motion

$$\frac{d\vec{\beta}}{dt} = -\frac{\sqrt{1-\beta^2}\,e}{m_0 c}\left[\vec{E} + c\,\vec{\beta}\times\vec{B} - \left(\vec{E}\cdot\vec{\beta}\right)\vec{\beta}\right]$$

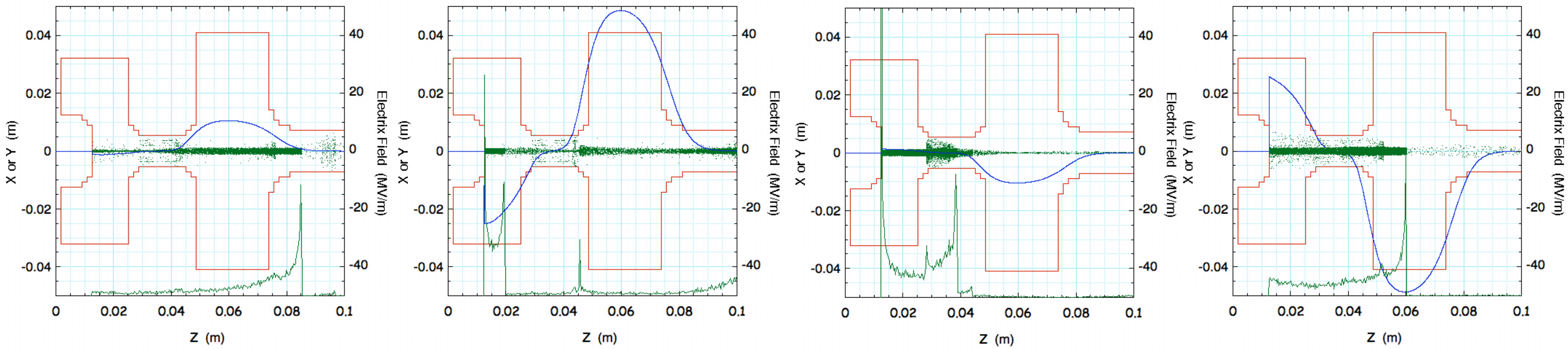


Beam Dynamics in Thermionic RF Gun

E1 = 25 MV/m

E2 = 50 MV/m

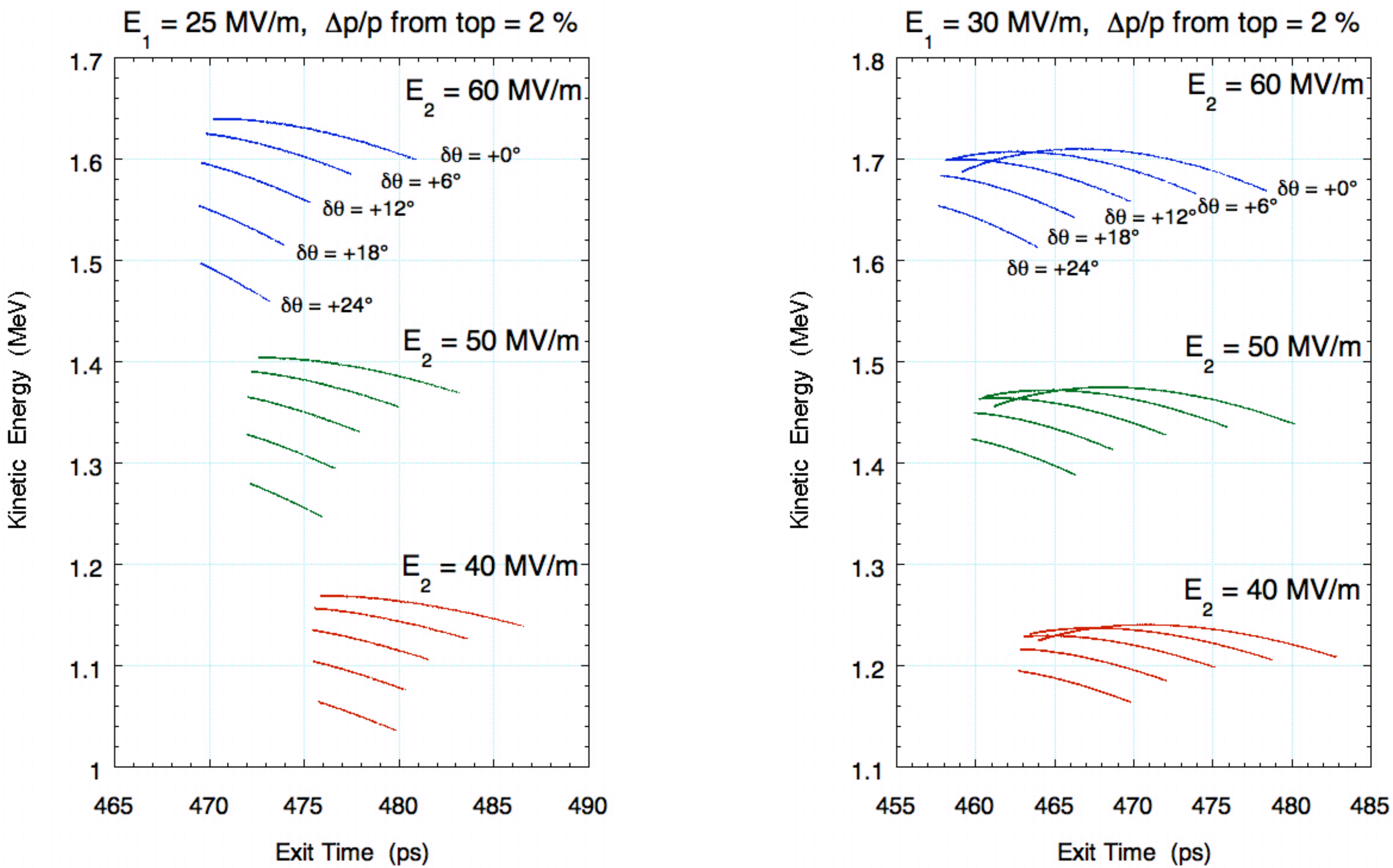
$\Delta\theta$ (cav_1-cav_2) = 18°



n + 0 cycles | **n + 0.25 cycles** | **n + 0.5 cycles** | **n + 0.75 cycles**

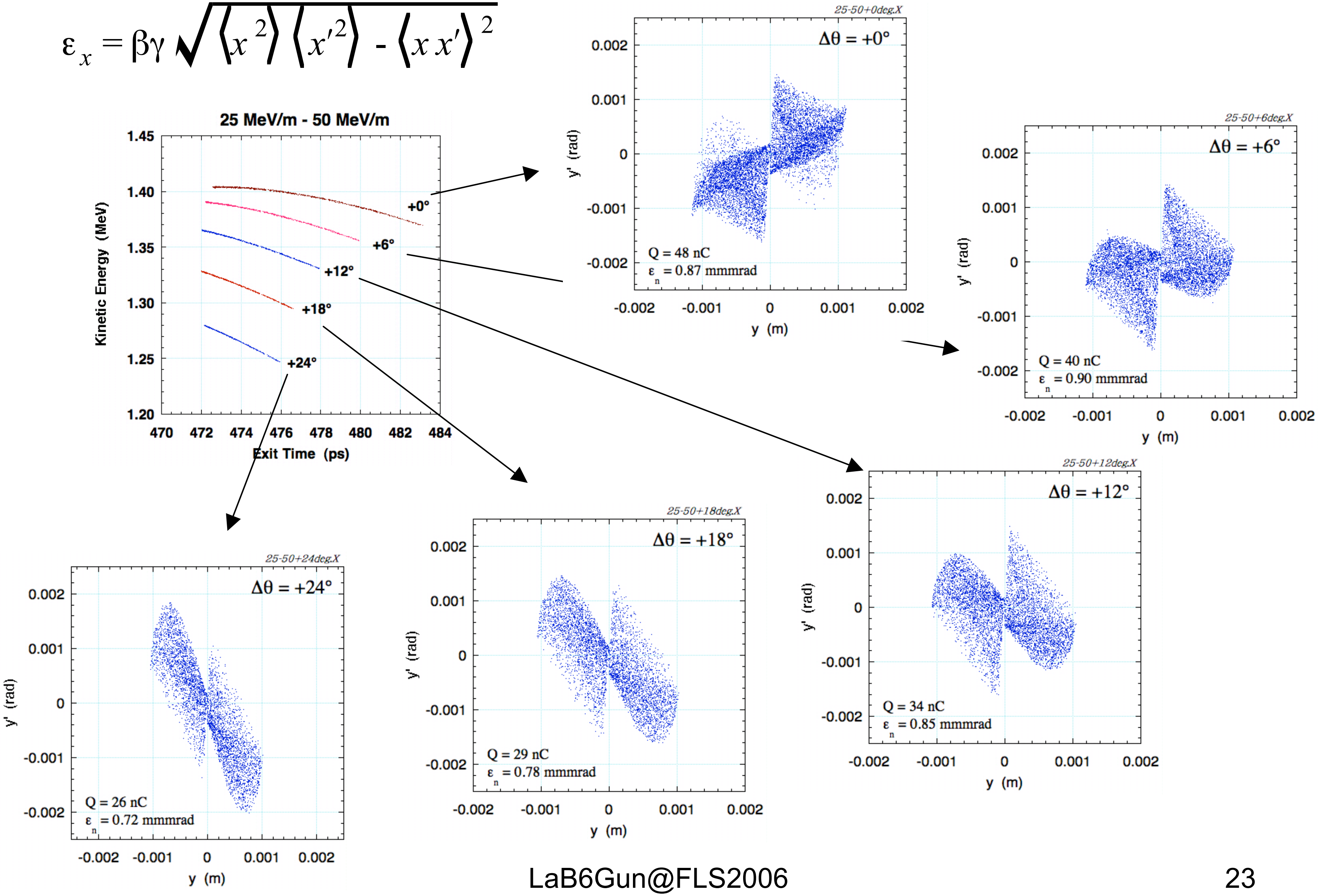
Control of Final Longitudinal Phase Space

$$\Delta\theta = \psi_{cavity\text{-}1} - \psi_{cavity\text{-}1}$$



Transverse Phase Space

$$\varepsilon_x = \beta\gamma \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle x\, x' \rangle^2}$$



Summary of Guns with LaB_6 Cathode

DC Gun:

Low "high-voltage" with short distance between wehnelt and anode and no-grid structure does not simply produce low emittance beam. Require a special bias voltage to manipulate the equi-potential line.

=> 1.4 π mm mrad

ITC-RF Gun:

Longitudinal phase space can be manipulated by adjusting relative phase and E-field. Hope to obtain 100 fs bunchlength. Emittance is still lower but for low bunch charge (< 50 pC).

=> ~ 1 π mm mrad