Cherenkov Radiation and Transformer Ratio Enhancement in Dielectric Based Accelerator

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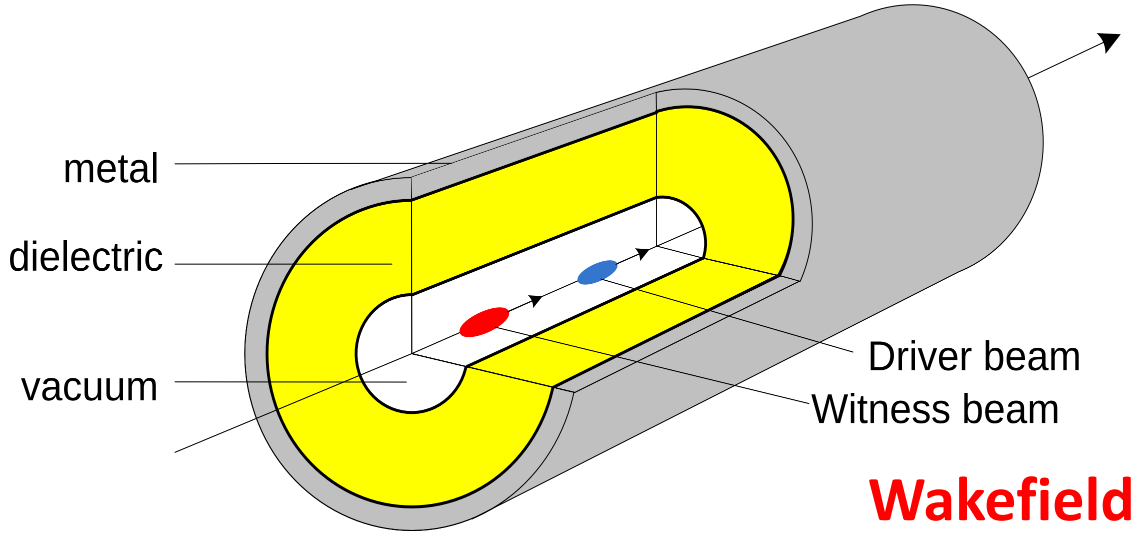
Outline

- Dielectric Loaded Accelerator (DLA)
- Beam Breakup Effects (BBU) at DLA. Code BBU 3000
- Mode Structure of the Dielectric Loaded Accelerator
- Transformer Ratio at DLA
- Coaxial DLA Structure
- Transverse Deflecting Fields of the Coaxial DLA Structure
- Beam Dynamics and BBUs at Coaxial DLA Structure
- Summary

Dielectric Loaded Accelerator (DLA)



$$V = \beta c$$

Wakefield – Cherenkov radiation

Argonne National Laboratory (ANL, USA) /Euclid Techlabs LLC
St.Petersburg Electrotechnical University "LETI"

CLIC (CERN), FACET (Stanford)

Dielectrics: 4.4 (cordierite) - ε = 10 (alumina) – low-loss ceramic,
ε = 5.7 – diamond, ε = 3.7 - quartz

First experiment:

W.Gai, P. Schoessow, B. Cole, R. Conechny, J. Norem, J. Rosenzweig and J.Simpson Experimental Demonstration of Wake-Field Effects in Dielectric Structures, Phys. Rev., V.61,N.24,1988, p.2756-2758

Code BBU 3000

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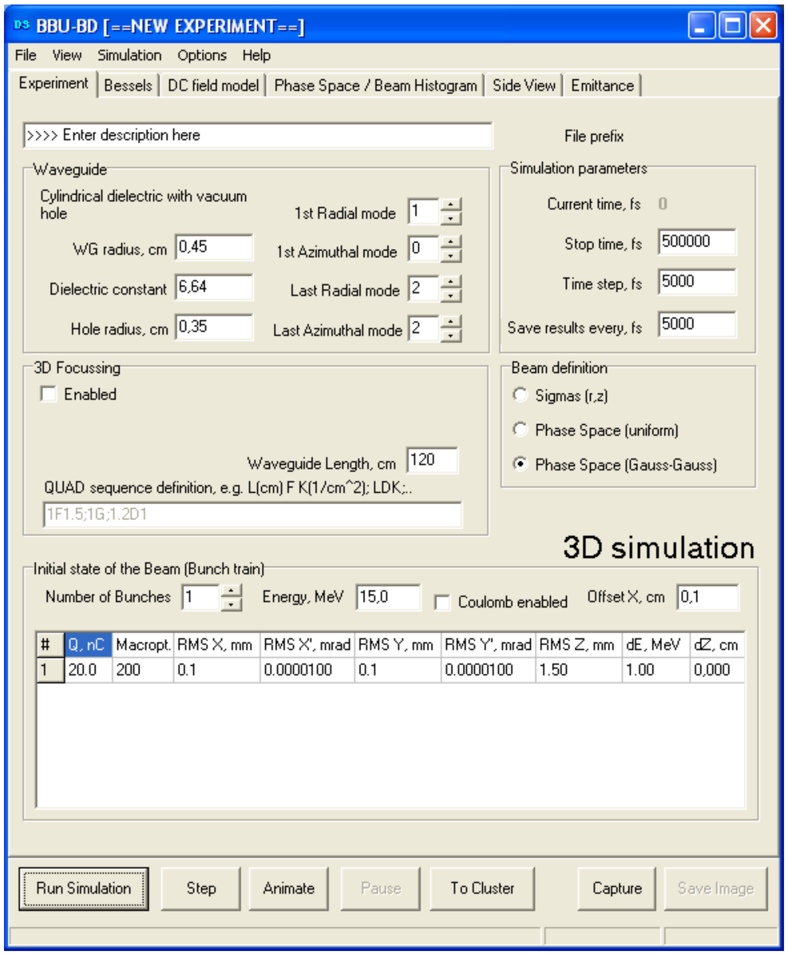
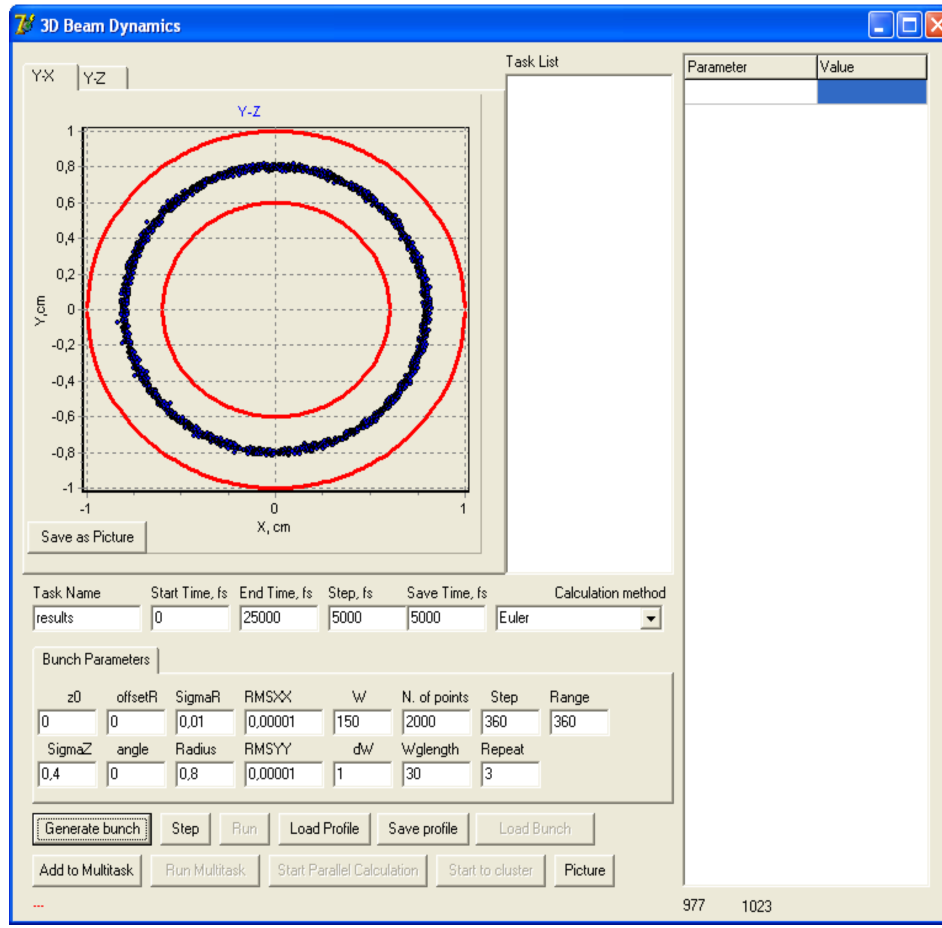
We have developed software for wakefield beam dynamics calculation in DLA – “BBU 3000”

Main window

Dynamics calculation window





The concentration of a point charge

$$n = \frac{q}{e}\delta(z - Vt)\frac{\delta(r - r_0)}{r}\delta(\theta - \theta_0)$$

Equations

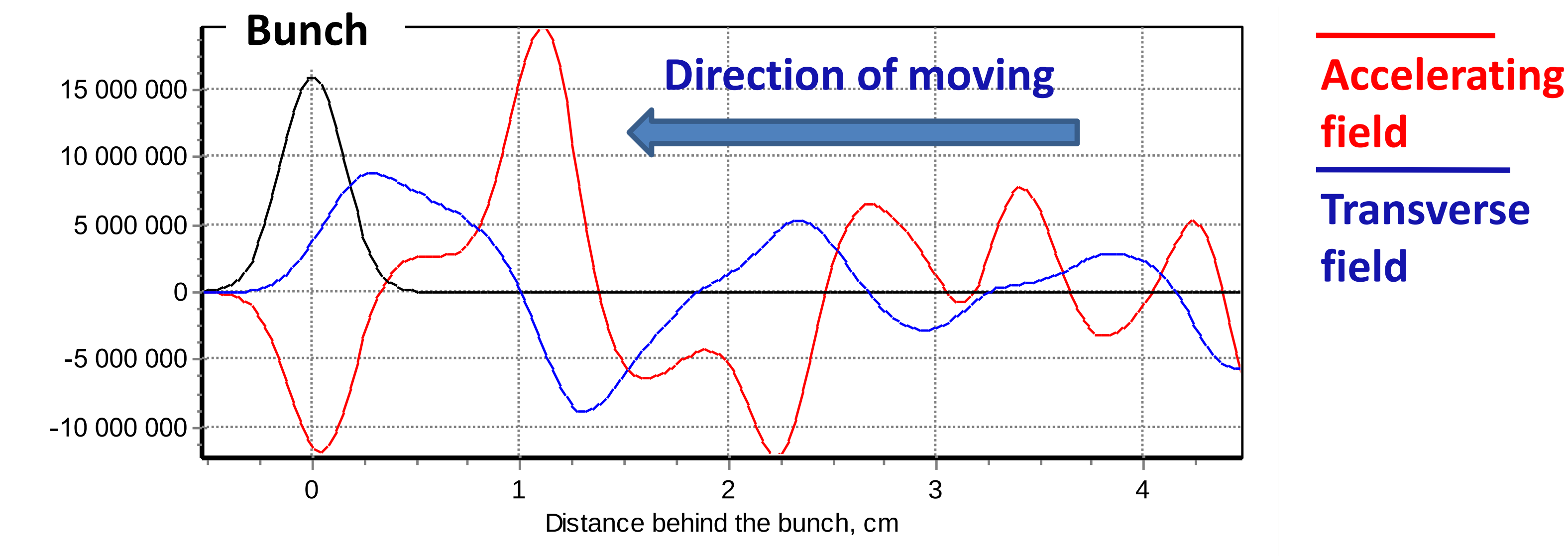
$$\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)E_z = -4\pi e\left(\frac{\beta}{c}\frac{\partial n}{\partial t} + \frac{\partial n}{\partial z}\right) \qquad \left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)H_z = 0$$

Border conditions

1) continuity $E_z, H_z, H_\theta, E_\theta$ on borders

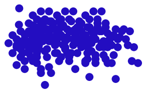
2) $E_z = 0, \ \frac{\partial H_z}{\partial r} = 0$ on outer metal

- Wakefield
  - Accelerating field
  - Transverse field



The tail of the bunch experiences strong deflecting (transverse field)

Wakefield Acceleration (BBU effect)



Driver bunch
(high charge low energy)

Witness bunch
(low charge high energy)

Main problem: dynamics of driver bunch (BBU effect)

BBU (Beam Breakup effect)

Wavegude’s modes

Waveguide modes

- **TM (Transverse magnetic)**
  - -axially symmetric modes
  - - main contribution to the accelerating field
- **HEM(Hybrid Electro Magnetic)**
  - -axially asymmetric modes
  - -main contribution of dipole mode to the transverse field

Dipole mode

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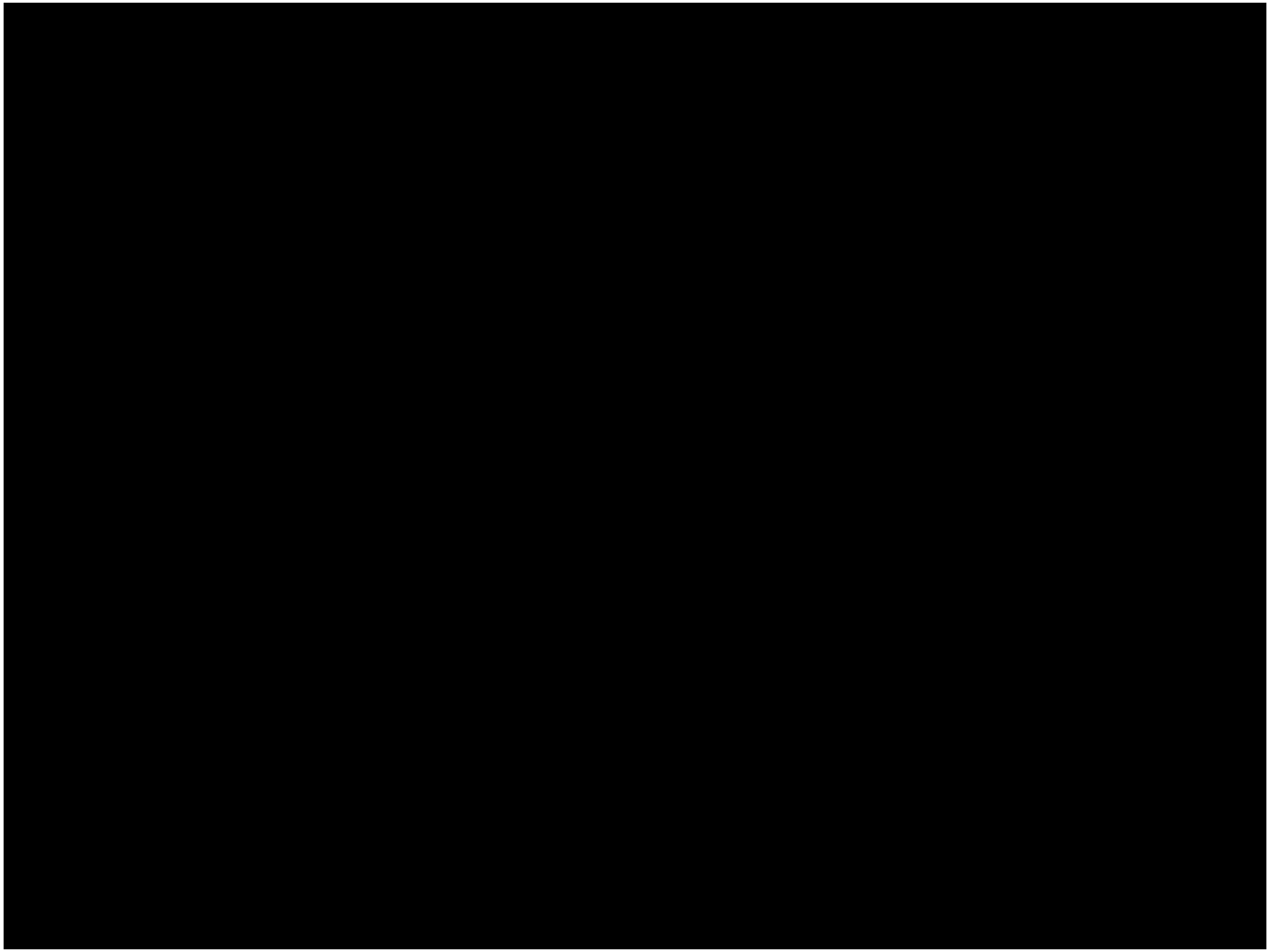
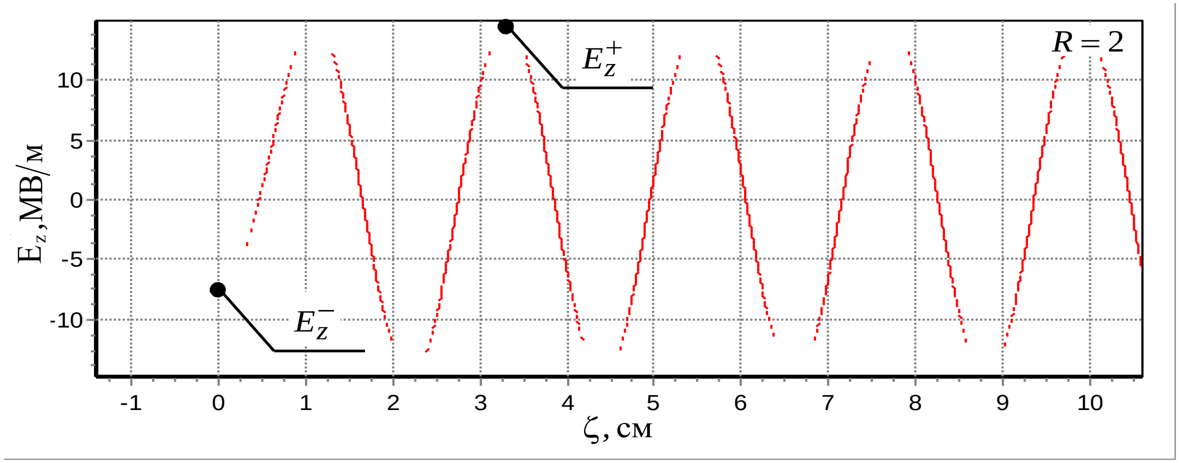
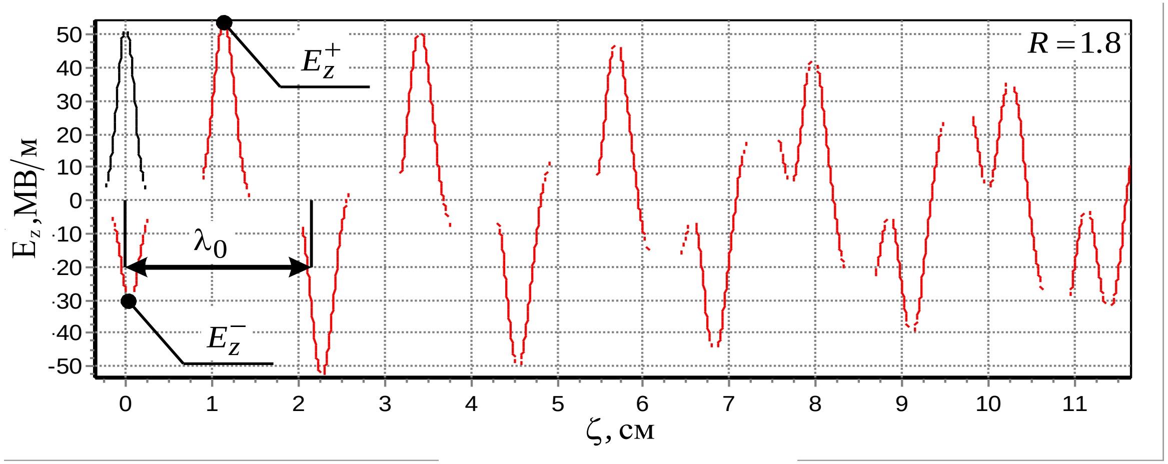


Transformer ratio at DLA

$$R_0 = \frac{\text{Maximum energy gain behind the bunch}}{\text{Maximum energy loss inside the drive bunch}} \le 2$$



Singlemode regime.

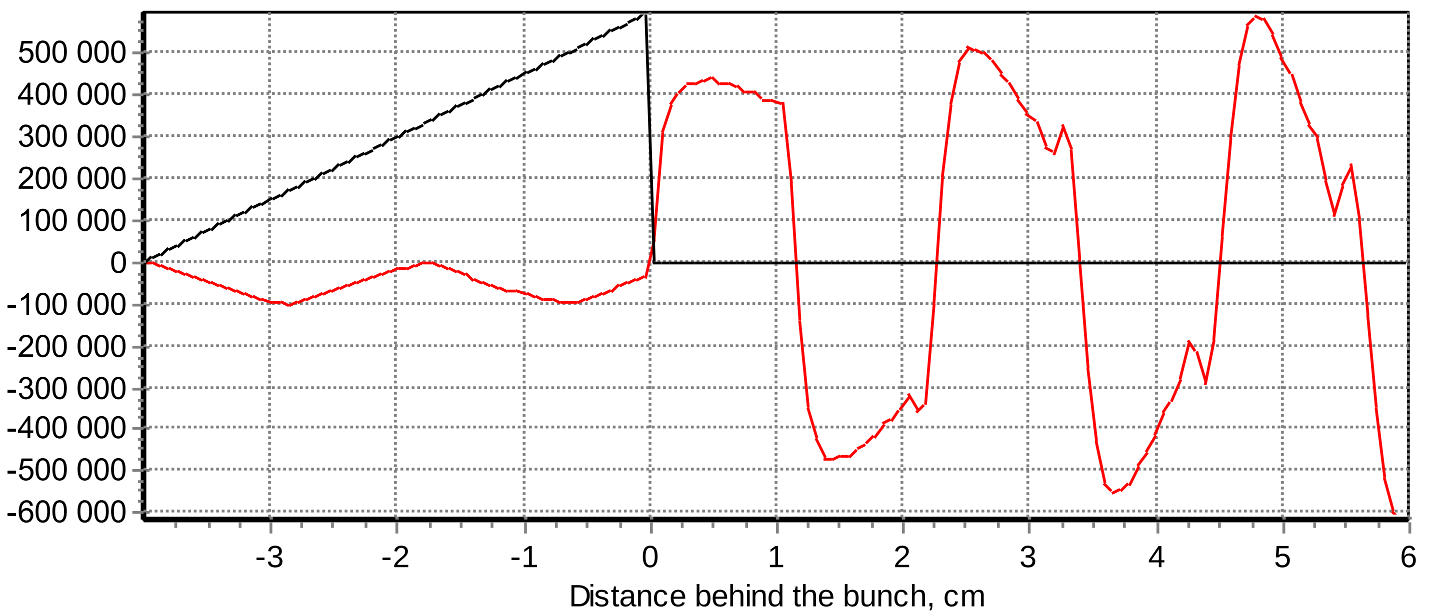


Multimode regime.

Several schemes have been proposed to obtain *R > 2* .

Asymetric bunch

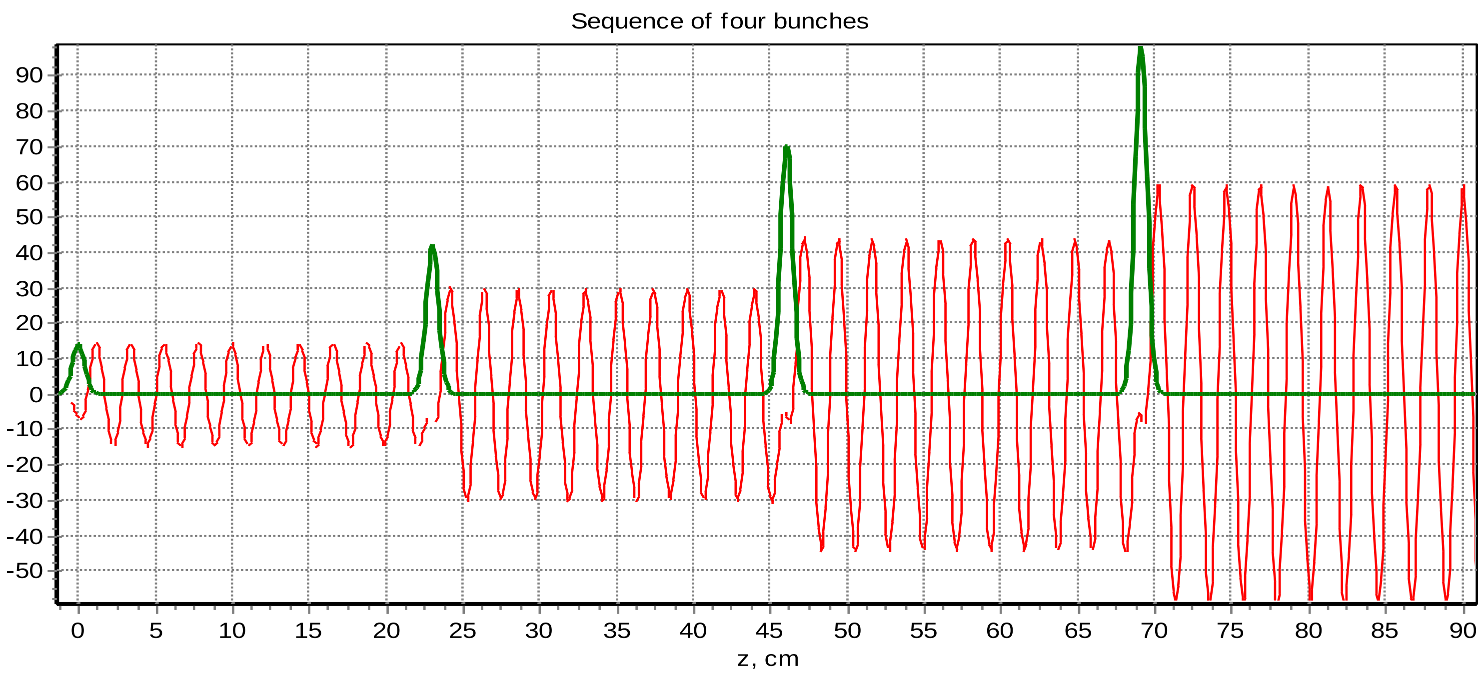
The bunch with asymmetric distribution (triangle slope)



Main problem: lack of suitable techniques to produce this bunch.

Multibunch wakefield acceleration

The sequence of four bunch (Ramped Bunch Train method)



$R \approx 7 - 8.$

- Bunches have the same decelerating field
- Accelerating field after 4 bunches is increased

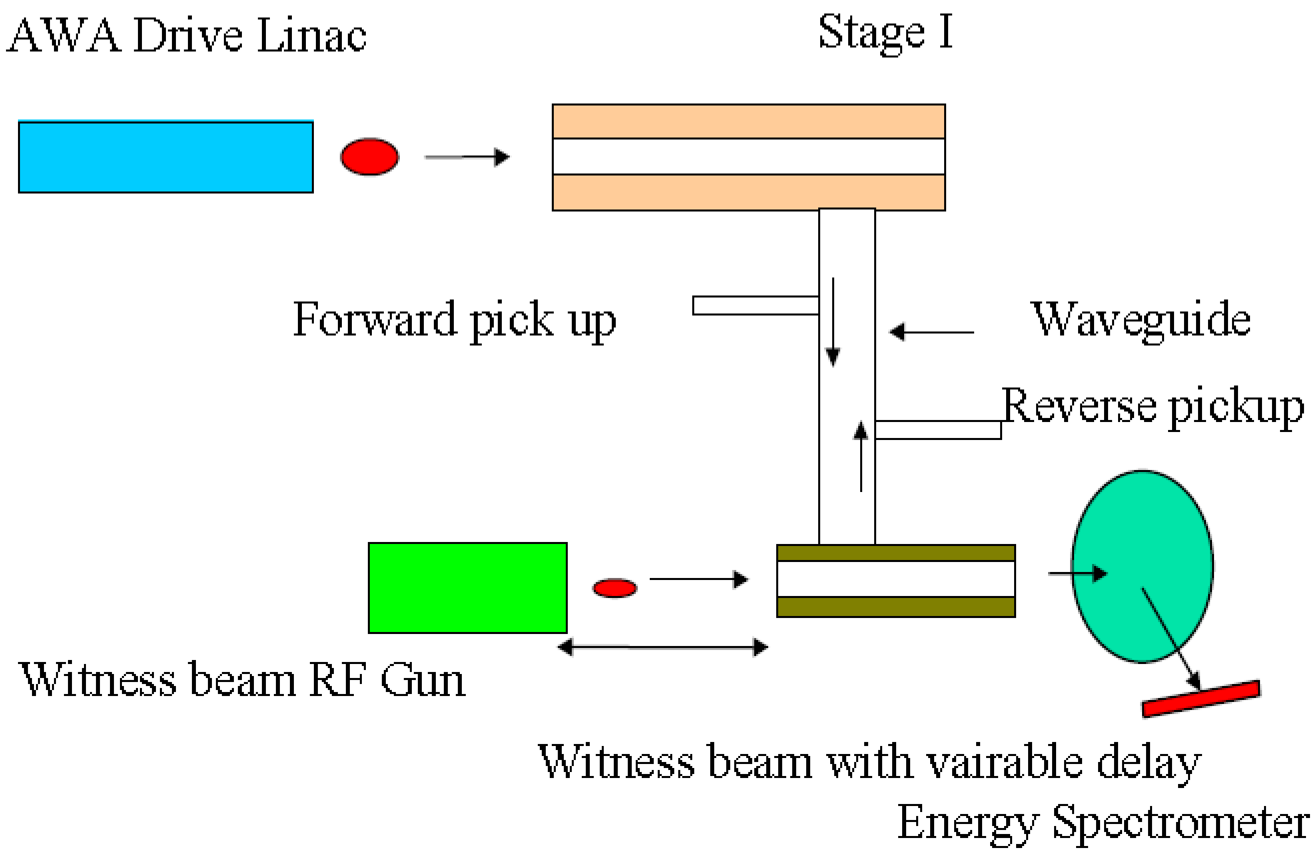
Main problems:

- dielectric waveguides tolerance
- beams precise positions

Experiment:

C. Jing, A. Kanareykin, J. Power, M. Conde, Z. Yusof, P. Shoessow, and W. Gai // Phys. Rev. Lett. 2007. V.98, P. 144801

Step-up transformer at AWA

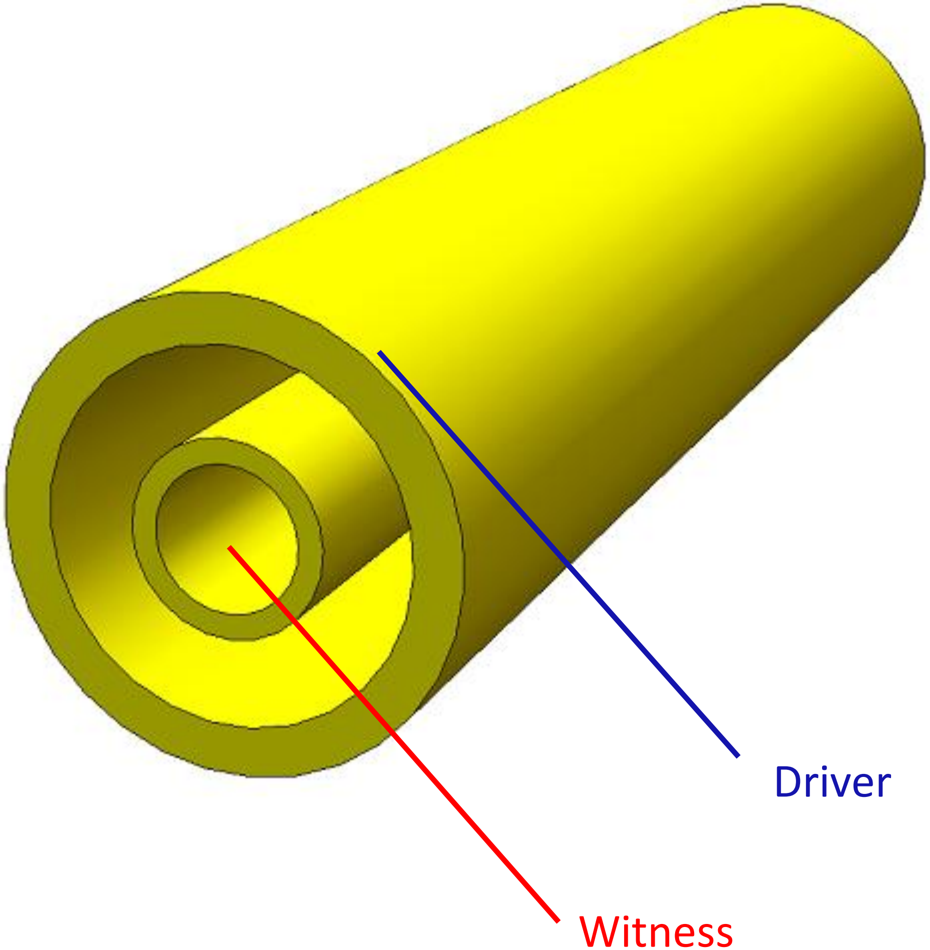


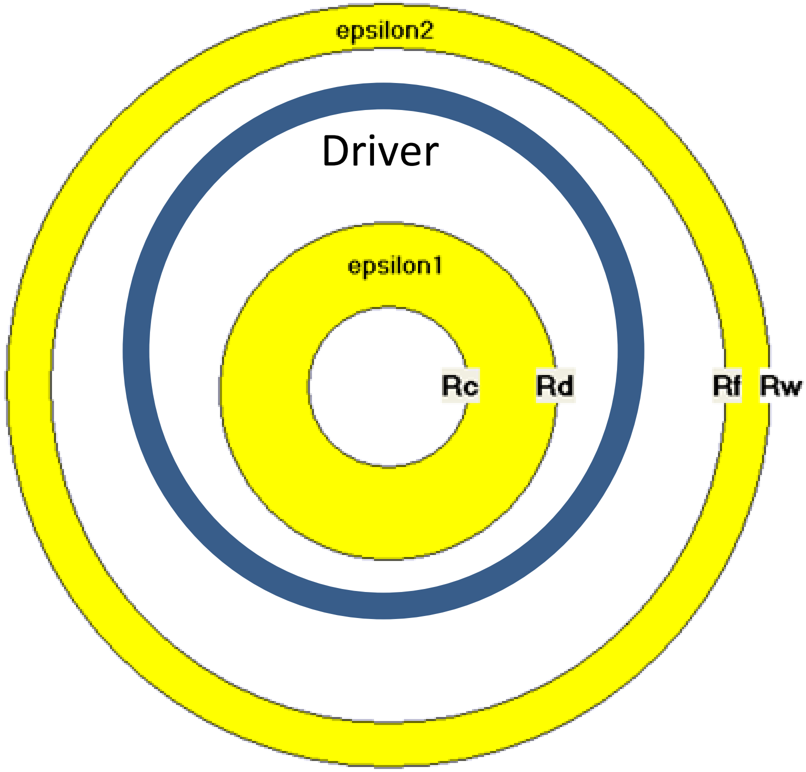
Witness and drive bunches are moving along the different structures

Two beam acceleration is currently under development for CLIC at CERN

Coaxial DLA Structure

Subject of presentation: wakefield generated by ring beam in cylindrical waveguide



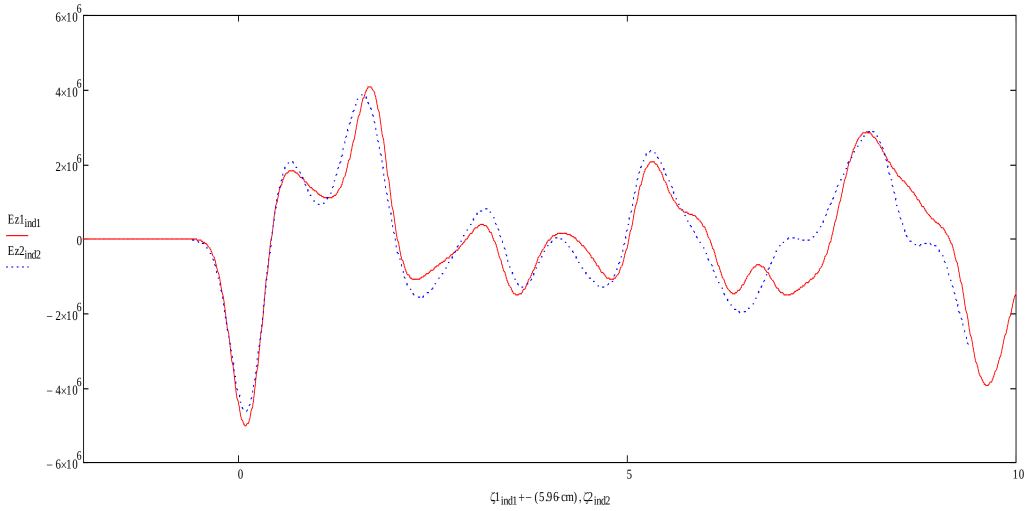


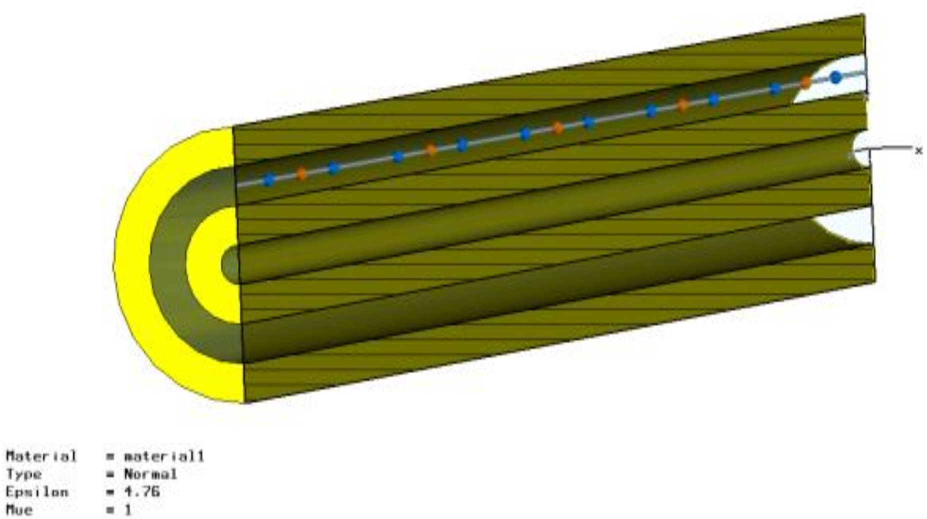
Purpose of study: BBU effect of driver

Wanming Liu and Wei Gai //PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 12, 051301 (2009)

G.V. Sotnikov,, T.C. Marshall, J.L. Hirshfieldb , and S.V. Shchelkunov // AAC 13 Workshop, 2009

Comparison with CST



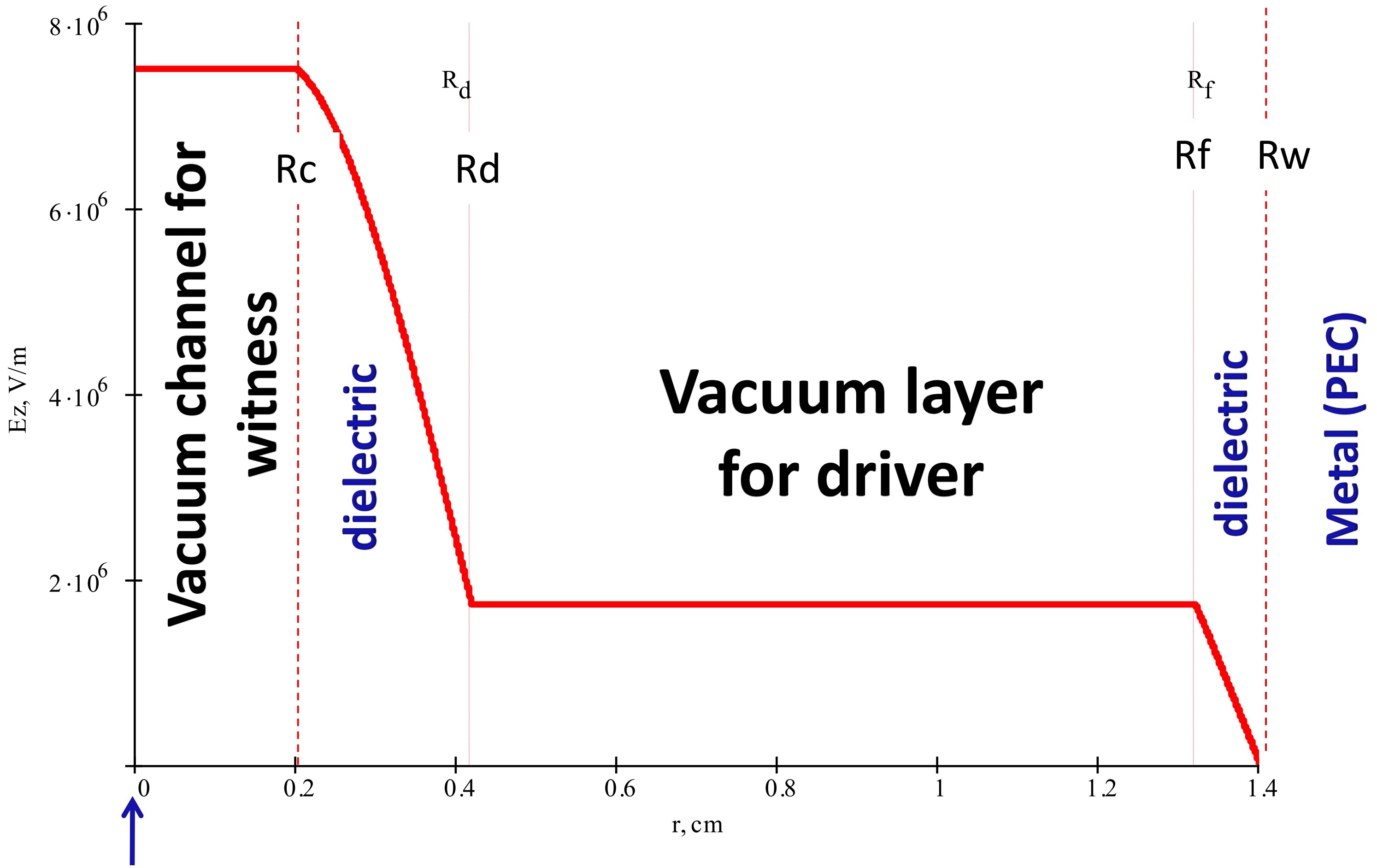


Comparison for point-charge bunch simulations

Good agreement of analytical results with CST

Calculation time while using CST is much more than in our analytical code

Radial structure of accelerating field (TM01-mode)



Center of waveguide

R0 = 0.87cm

Accelerating field in vacuum channel is greater than in vacuum layer

Transverse field

$$Fr = \sum_{m=1}^{Nm} \sum_{n=1}^{Nn} \left(A(r_0,m,n) I'(\chi_{m.n} r) + B(r_0,m,n) K'(\chi_{m.n} r) \right) \cos\left(m(\theta - \theta_0) \right) \sin\left(k_{m,n} \zeta \right)$$

$$F_\theta = \sum_{m=1}^{Nm} \sum_{n=1}^{Nn} \left(C(r_0,m,n) I(\chi_{m.n} r) + D(r_0,m,n) K(\chi_{m.n} r) \right) \sin\left(m(\theta - \theta_0) \right) \sin\left(k_{m,n} \zeta \right)$$

$A(r_0,m,n)$, $B(r_0,m,n)$, $C(r_0,m,n)$, $D(r_0,m,n)$ — **Coefficients which are depended on the waveguides parameters, bunch position, shape and charge.**

(r_0,θ_0), (r,θ) — **Coordinates of the bunch and view point in cylindrical coordinate system**

ζ **- distance behind the bunch**

Transverce structure of dipole mode (Radial force Fr)

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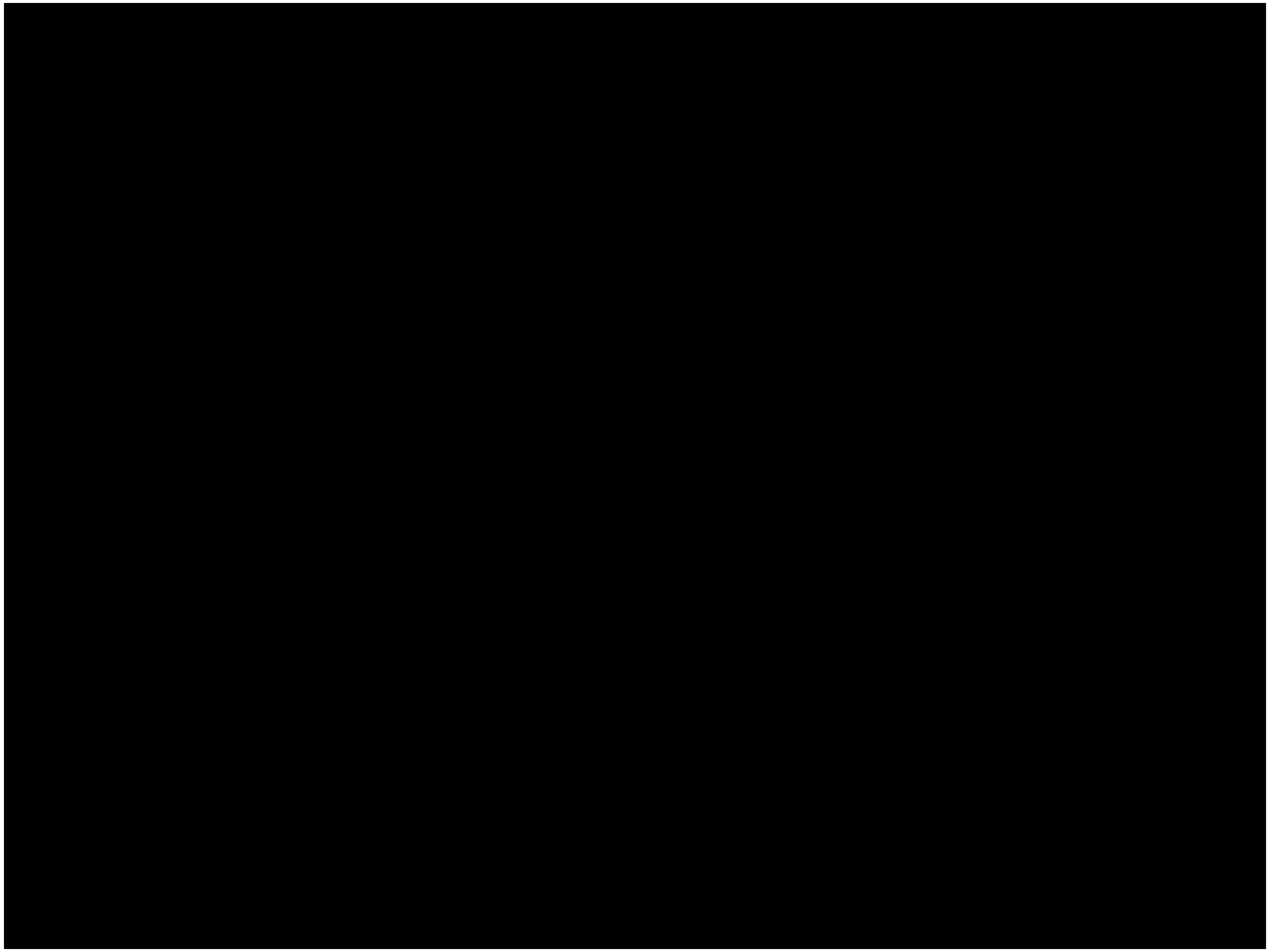
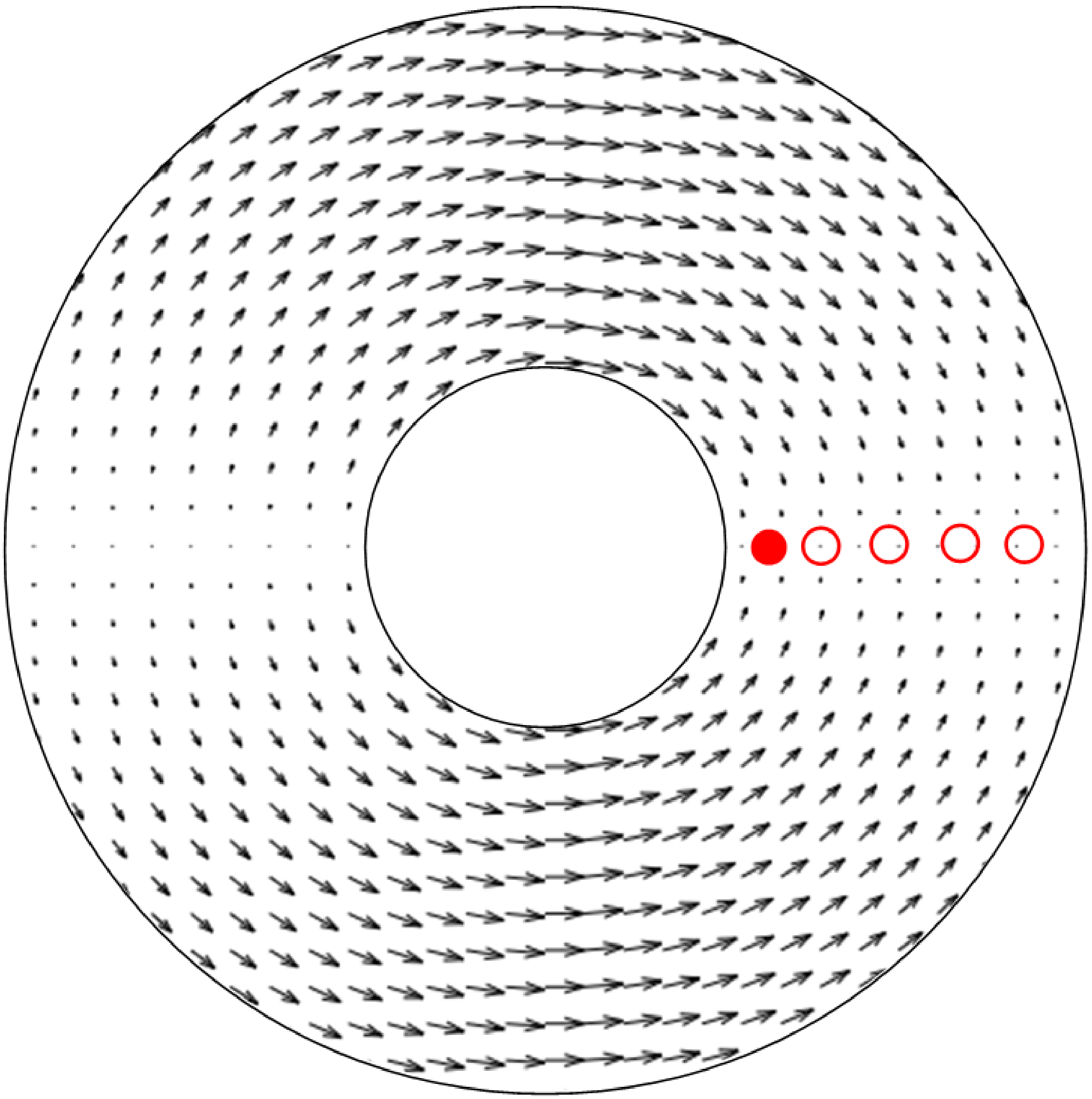
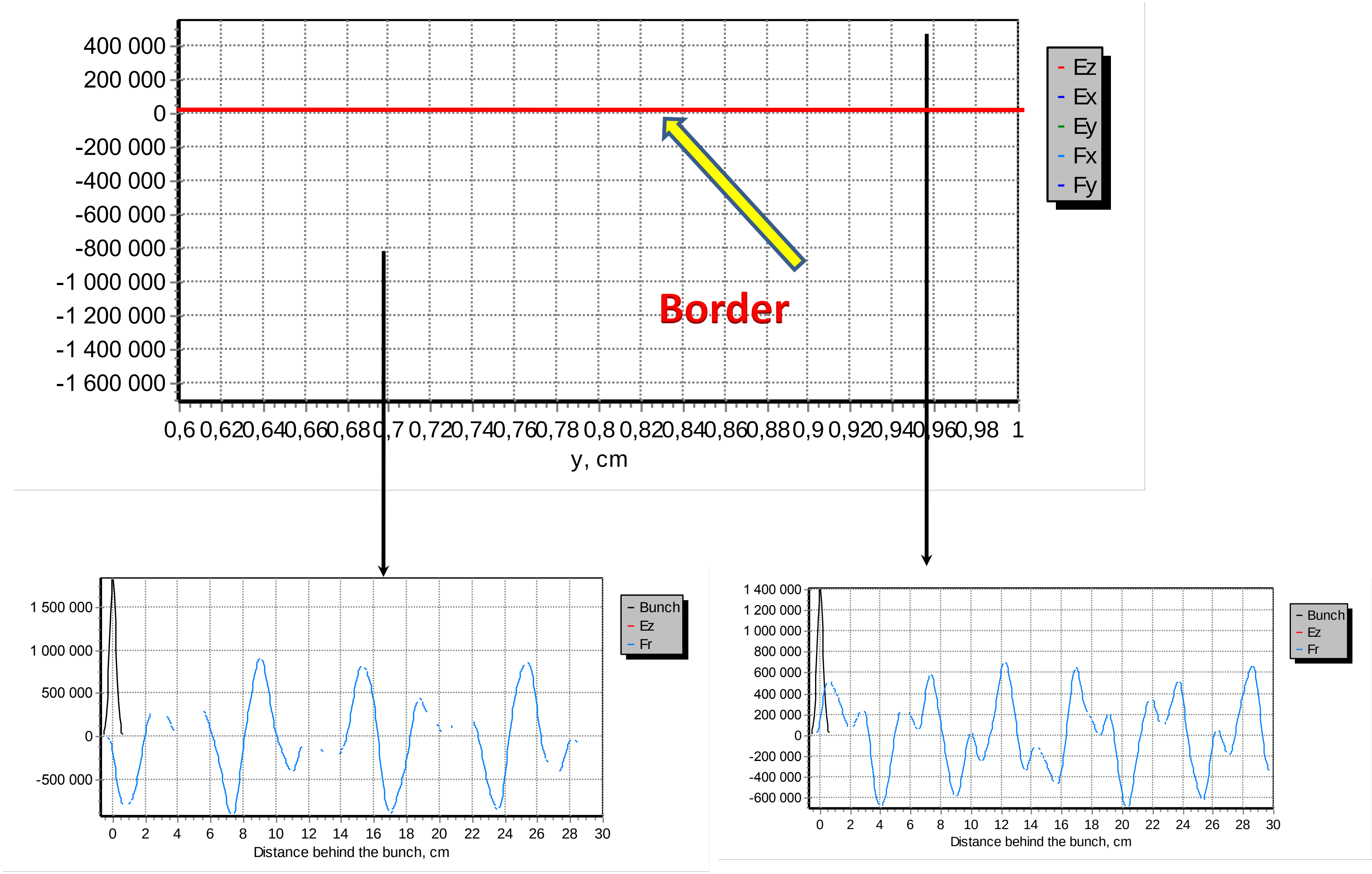


Transverce structure of dipole mode (azimuthal force)

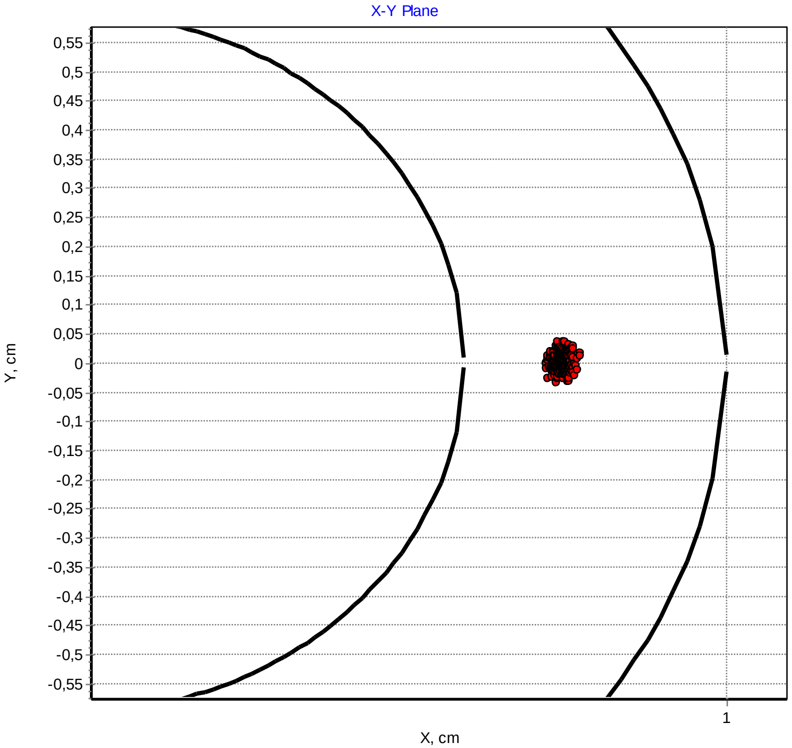


Transverse structure of deflecting force

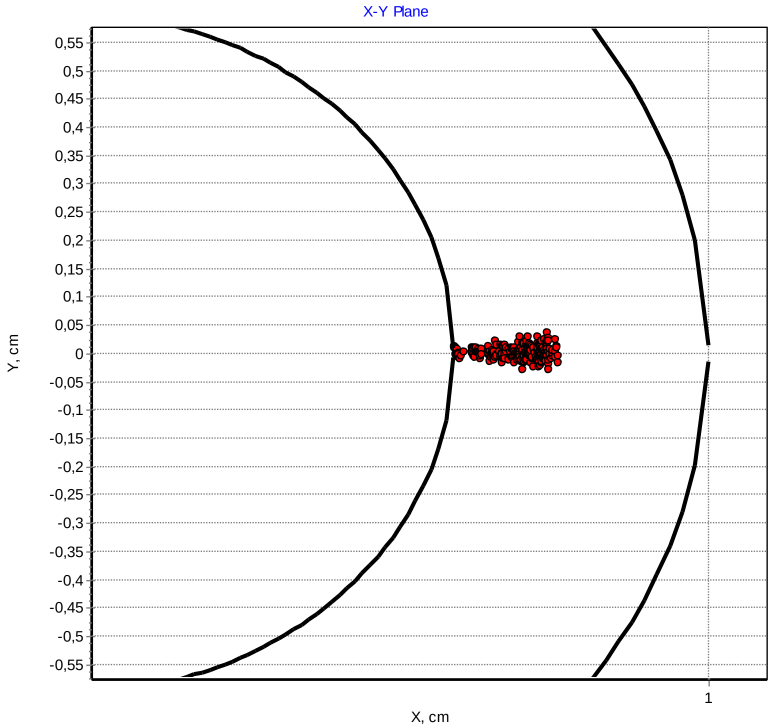


Bunch is close to inner dielectric tube surface

Start



End



Parameters of simulation

B_Charge1:F 100
Rw:F 1,4
Rf:F 1
Rd:F 0,6
Rc:F 0,2
eps1:F 4,76
eps2:F 4,76
Energy:F 15
start_time:I 0
stop_time:I 250000
time_step:I 5000
save_step:I 5000

current time:I 0
Last_az_mode:I 1
Last_rad_mode:I 3
ang:F 0
sigmaR:F 0,01
sigmaz:F 0,2
wglength:F 30
B_rmsXX1:F 1E-5
B_rmsYY1:F 1E-5
B_dE1:F 1
Number of particles: 300

Gaussian bunch is deflected into the inner dielectric tube surface

Bunch is close to outer dielectric layer surface

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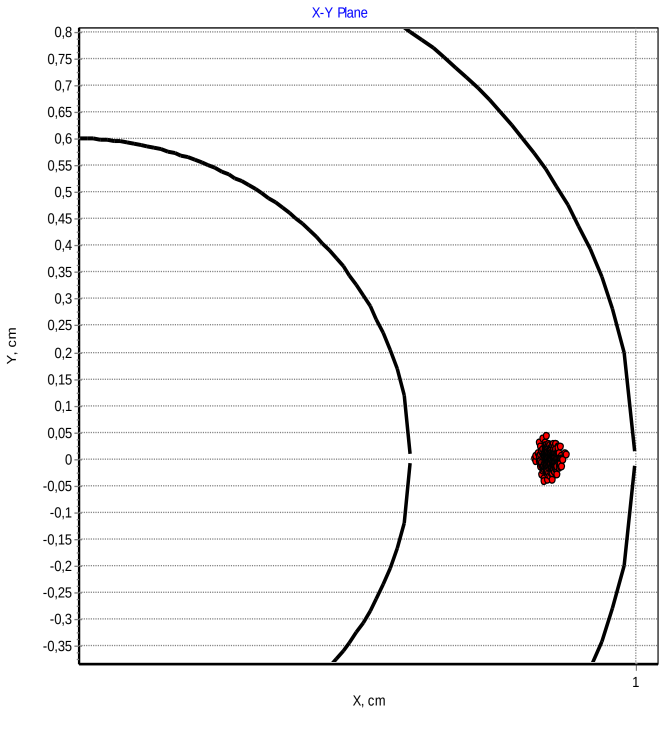
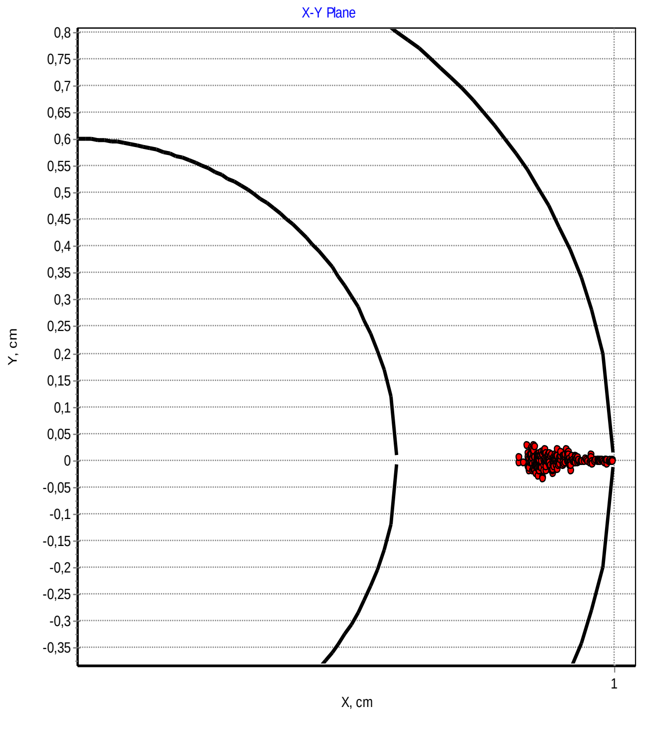
Start



End



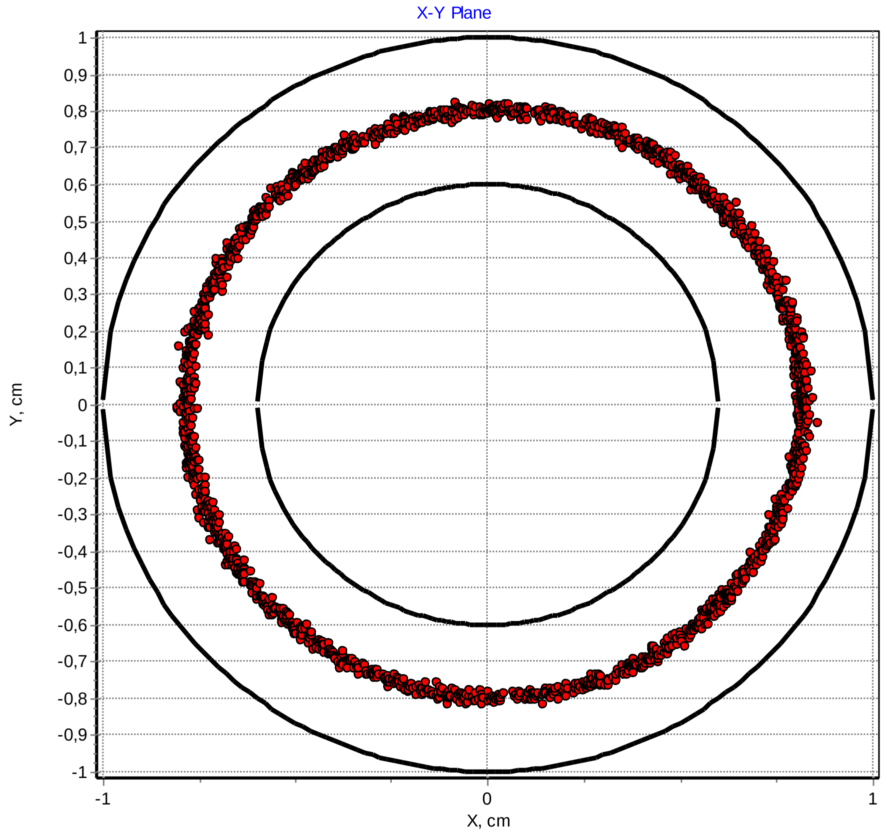
Parameters of simulation

B_Charge1:F 100
Rw:F 1,4
Rf:F 1
Rd:F 0,6
Rc:F 0,2
eps1:F 4,76
eps2:F 4,76
Energy:F 15
start_time:I 0
stop_time:I 500000
time_step:I 5000
save_step:I 5000

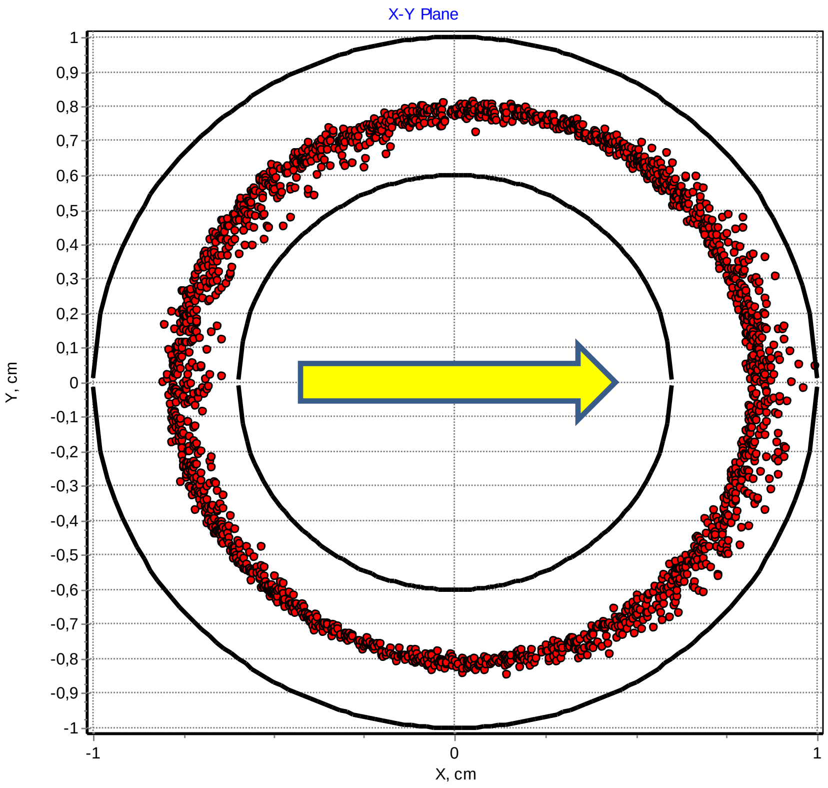
current time:I 250000
Last_az_mode:I 1
Last_rad_mode:I 3
offsetR:F 0
ang:F 0
sigmaz:F 0,2
wglength:F 30
B_rmsXX1:F 1E-5
B_rmsYY1:F 1E-5
B_dE1:F 1
Number of particles: 300

Gaussian bunch deflects into the outer dielectric layer surface

Symmetric ring beam with radial offset



End

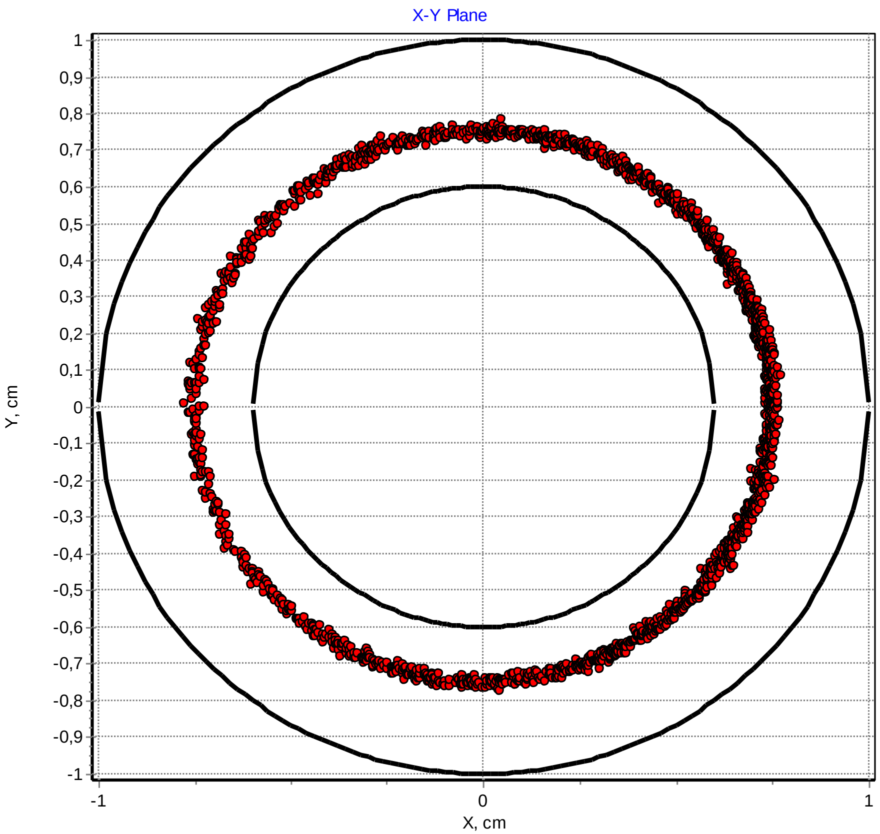


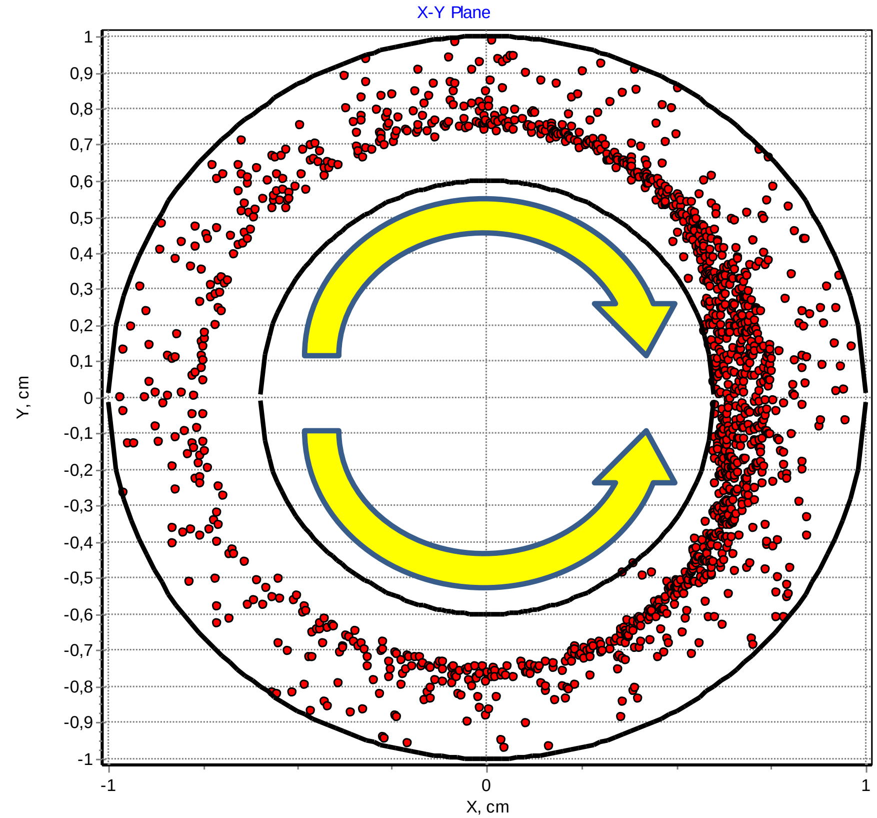
Symmetric bunch with radial offset of 0,02cm

Parameters of simulation

B_Charge1:F 50	Last_az_mode:I 1
Rw:F 1,4	Last_rad_mode:I 2
Rf:F 1	offsetR:F 0,02
Rd:F 0,6	ang:F 0
Rc:F 0,2	sigmaR:F 0,01
eps1:F 4,76	bunchradius:F 0,8
eps2:F 4,76	sigmaz:F 0,2
Energy:F 10	wglength:F 300

Asymmetric ring beam with radial offset





Asymmetric bunch

$$\frac{1367}{633}$$

Parameters of simulation

B_Charge1:F 50	Last_az_mode:I 1
Rw:F 1,4	Last_rad_mode:I 2
Rf:F 1	offsetR:F 0
Rd:F 0,6	ang:F 0
Rc:F 0,2	sigmaR:F 0,01
eps1:F 4,76	bunchradius:F 0,75
eps2:F 4,76	sigmaz:F 0,2
Energy:F 10	wglength:F 30

Summary

- ❑ Transformer Ratio increase is required for the Dielectric Based Accelerator efficiency.
- ❑ BBU effect is a serious issue for the DLA development
- ❑ BBU effect can be now considered using new code “BBU 3000”
- ❑ Coaxial DLA structure can be used for transformer ratio and accelerating gradient increase.
- ❑ Transverse deflecting modes have been studied using “BBU 3000” as well as beam dynamics at coaxial DLA
- ❑ Transverse dynamics is defined by area where beam is located
- ❑ Coaxial DLA can be realized for THz and GHz frequency range but ring shape of the drive bunch exhibits azimuthal instability in addition to the radial one that causes deflecting force increase.

Electron beam for GHz (AWA): σ_z = 1-2 mm, Q = 10-100 nC, field~ 200-300 MV/m at 20-30 GHz

Electron beam for THz (FACET): σz = 20-30 um, Q = 1-3 nC, 0,5-1,0 THz frequency, 1-10 GV/m gradient