CLIC'09 Workshop
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Dielectric Collimators ?

A.Kanareykin
Euclid TechLabs LLC, Rockville, MD

E. Métral, A. Grudiev, G. Rumolo, B. Salvant *(also at EPFL, Lausanne)*, R. Tomàs
CERN, Geneva

Euclid Techlabs

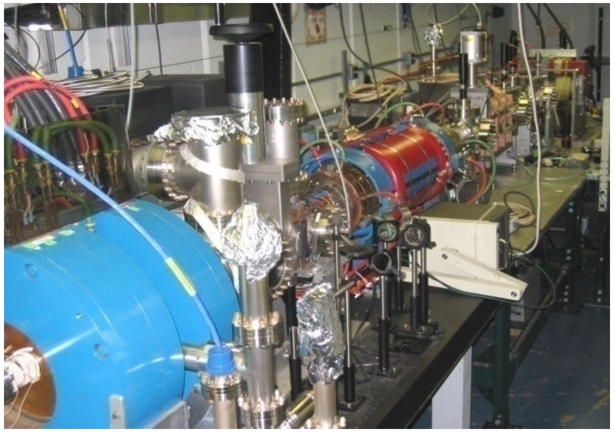
www.beamphysics.com

Euclid TechLabs LLC, founded in 1999 (as Euclid Concepts LLC) is a company specializing in the development of advanced dielectric materials for particle accelerator and other microwave applications. Additional areas of expertise include theoretical electromagnetics; dielectric structure based accelerator development; superconducting accelerating structure design; "smart" materials technology and applications; and reconfigurable computing.

Euclid and the Argonne Wakefield Accelerator group at ANL have a long history of successful collaboration in engineering development and experimental demonstration of high gradient acceleration using a number of different dielectric structures and electron beam configurations.

Collaboration of Euclid Techlabs LLC

AWA of Argonne Nat. Lab, Chicago:
Argonne Wakefield Accelerator:
M.Conde, J.G.Power, R.Conecny, F.Gao
Z.Yusof and W.Gai



Euclid Techlabs, Rockville, MD: C.Jing, P.Schoessow, P. Avrakhov, S.Antipov and A.Kanareykin

Outline

- Why consider dielectrics for LHC collimation?
  - Idea
  - Results and recommendations

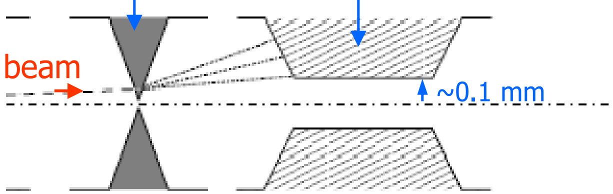
- Extrapolations to the case of the CLIC bunch as an introduction to future work
  - Analytical estimates (A.Grudiev and colleagues)

- Dielectric based accelerator studies: what can be used for CLIC collimator ?:
- materials (quartz, diamond, ceramic)
- software: fields, impedance, beam dynamics

CLIC BDS collimation system

A. Grudiev et al

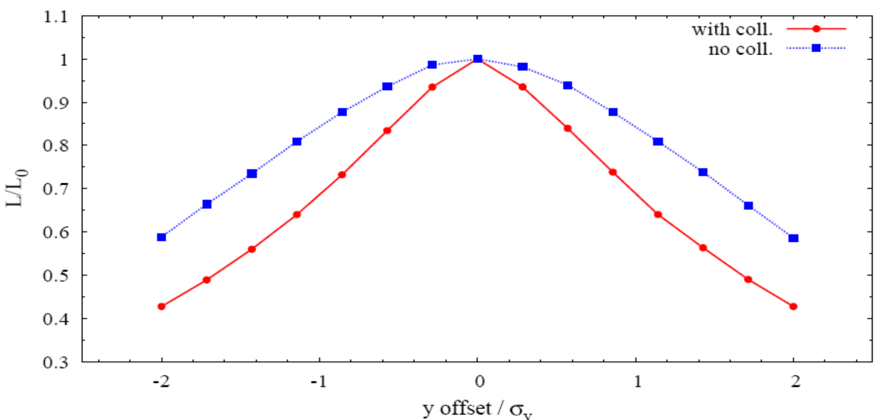
- BDS Collimation System needed for background reduction and machine protection



Courtesy: J. Resta Lopez

- However, collimators may generate strong wakefields and affect the beam quality
  → luminosity limitation

Simulated loss of CLIC luminosity as a function of beam initial vertical offset



Courtesy: J. Resta Lopez

- *CLIC collimation system review: optics issues and wakefield effects*, J. Resta Lopez, 15/01/2009

- *Tracking with Collimator Wake-Fields through the CLIC BDS*, A.Latina, G.Rumolo, D.Schulte, 19/05/2006

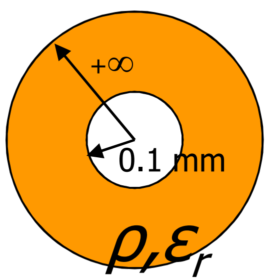
→ Need to minimize the BDS collimation wakefield

Analytical estimates: Resistive wall impedance

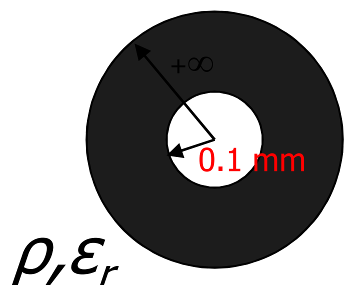
A. Grudiev et al

- CLIC BDS collimator:
  - Length 60 cm, inner radius 0.1 mm, $\gamma = 3\ 10^6$

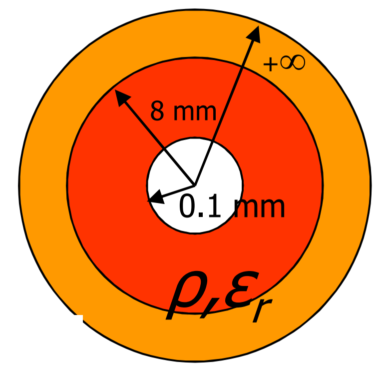
Copper
resistivity $\rho = 1.7\ 10^{-8}\ \Omega.m$
relaxation time $\tau = 2.7\ 10^{-14}$ s)

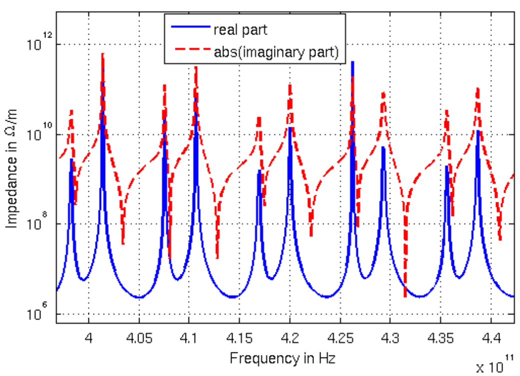


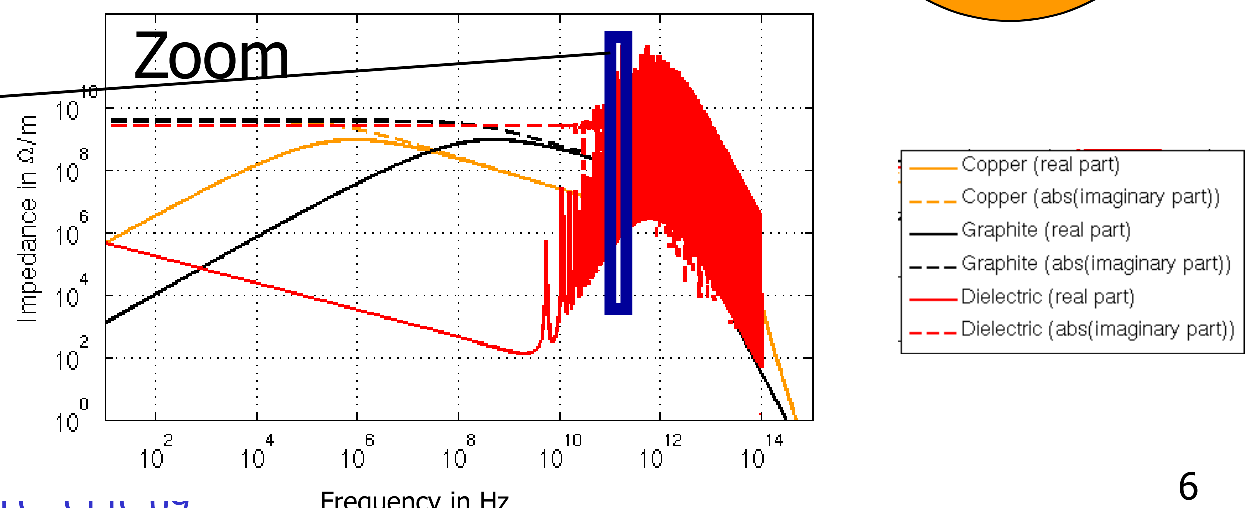
Graphite
resistivity $\rho = 1\ 10^{-5}\ \Omega.m$
relaxation time $\tau = 8\ 10^{-13}$ s)



Dielectric + copper
dielectric resistivity $\rho = 10^{12}\ \Omega.m$
Dielectric permittivity $\varepsilon_r = 5$

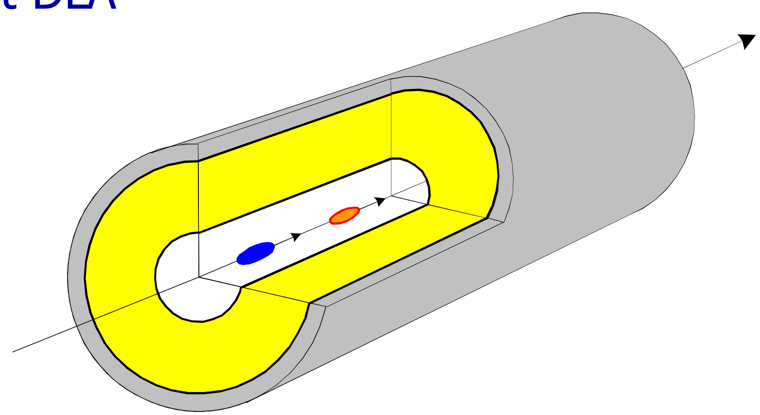






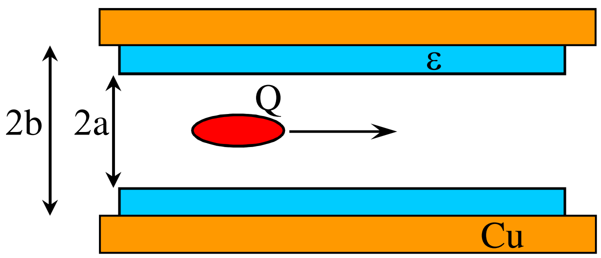
What can be used from the DLA studies ?

- **Drive Beam – Beam Train** - High Gradient DLA
- **Dielectric Material Beam Tests**
- Dielectric - Wakefield Power Extractor
- Tunable Dielectric Based Accelerator
- Energy Transfer: High Transformer Ratio
- **Beam Handling, Beam Breakup (BBU)**
- **Multilayer structure** – High r/Q.



Dielectric Based Accelerator issues: high gradient – drive beam, power extraction, tuning, efficiency, beam control (BBU).

Materials for the Dielectric-Based Accelerator



Low-loss high breakdown strength ceramic for the DLA

Materials	ε (f = 9,4 GHz)	tan δ (f = 9.4 GHz)
Cordierite	4.5±0.2	$\leq 2\times10^{-4}$
Forsterite	6.3±0.3	$\leq 2\times10^{-4}$
Alumina	9.8±0.3	$\leq 1\times10^{-4}$
D-10	9.7±0.2	$\leq 1.5\times10^{-4}$
D-13	13.0±0.5	$\leq 2\times10^{-4}$
D-14	14.0±0.5	$\leq 0.6\times10^{-4}$
D-16	16.0±0.5	$\leq 2\times10^{-4}$
MCT-18	18.0±3%	$\leq 1\times10^{-4}$
MCT-20	20.0±5%	$\leq 1.5\times10^{-4}$
V-20	20.0±5%	$\leq 3\times10^{-4}$
V-37	37.0±5%	$\leq 3\times10^{-4}$

material	ε	tanδ, X-band	Δε/ε, 4 V/μm
BST+MgO	350-500	5×10^{-3}	1.30

Nonlinear ceramic material for the tunable DLA structure

material	ε	tanδ, X-band	thermo-conductivity
TiN, AlN	9.8	3×10^{-3}	180 W/m/^{0}K

Coating,TiN, AlN

and diamond and quartz structures

Loss tangent vs. frequency !

Why is Diamond?

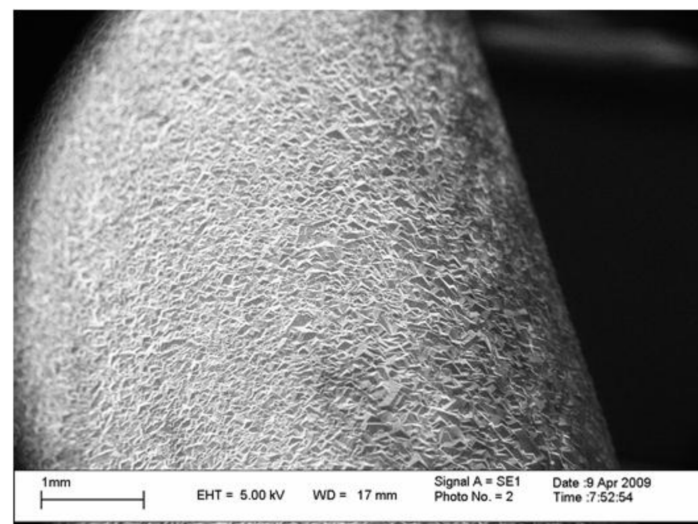
CVD DIAMOND PROPERTIES FOR DLA:

- RF BREAKDOWN THRESHOLD OF ~ 2 GV/m
- LOSS FACTOR DOWN TO 5×10^{-5} AT 30-140 GHz
- HIGHEST THERMAL CONDUCTIVITY
- MULTIPACTING CAN BE SUPPRESSED ,

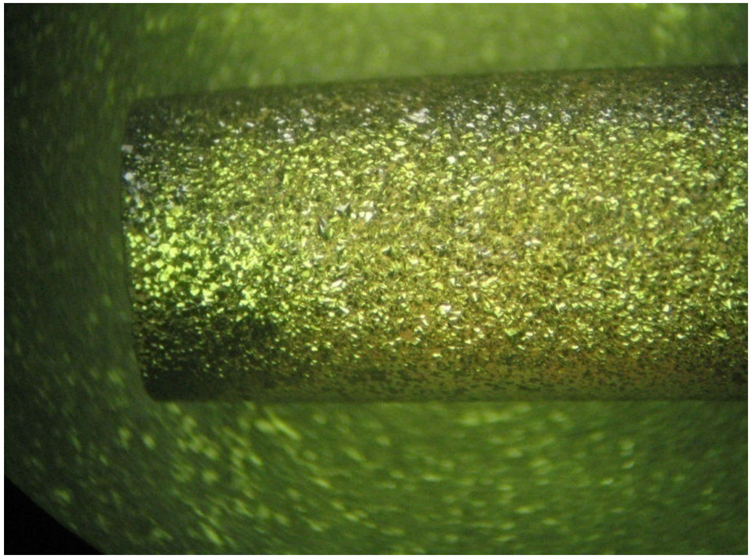
and for Collimator use:

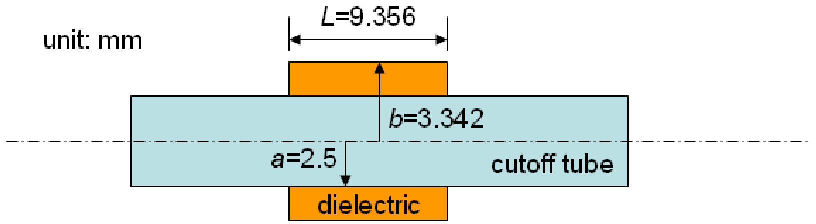
CVD Diamond conductivity can be controlled and adjusted during deposition process.

Planar is easy to fabricate, available commercially

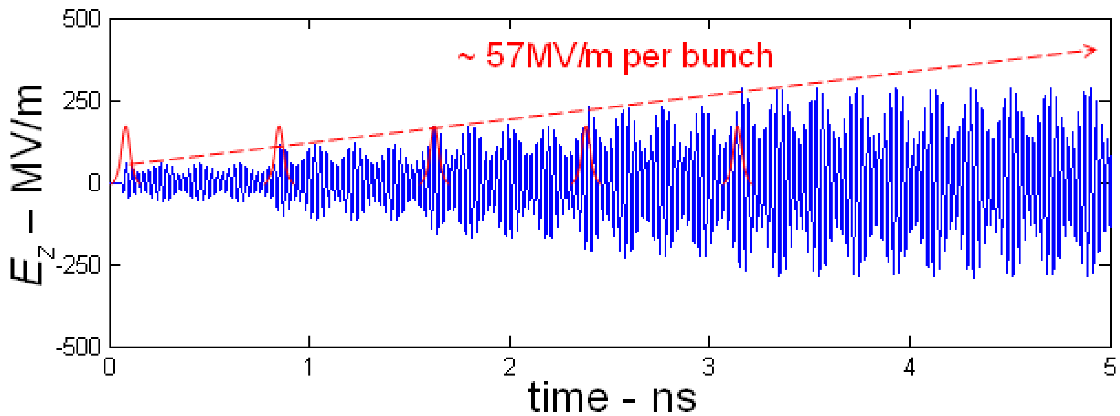


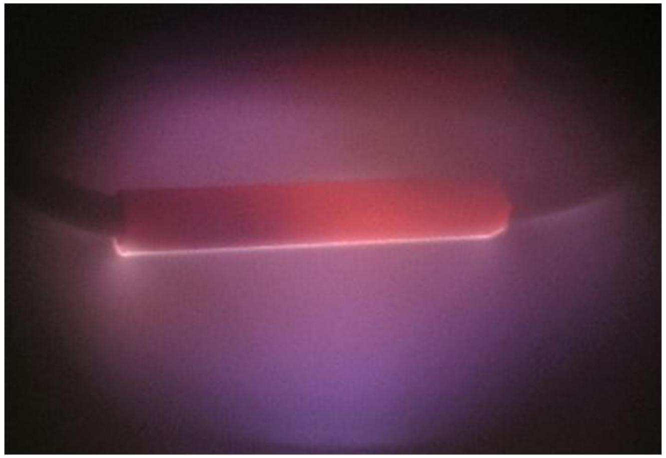
35 GHz Diamond Based DLA Structure





CVD diamond tube fabrication

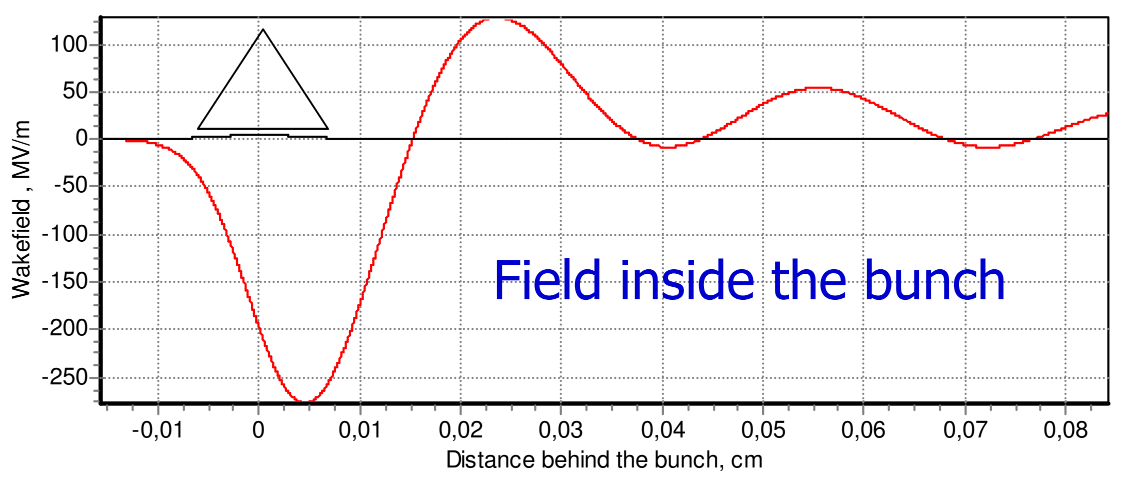


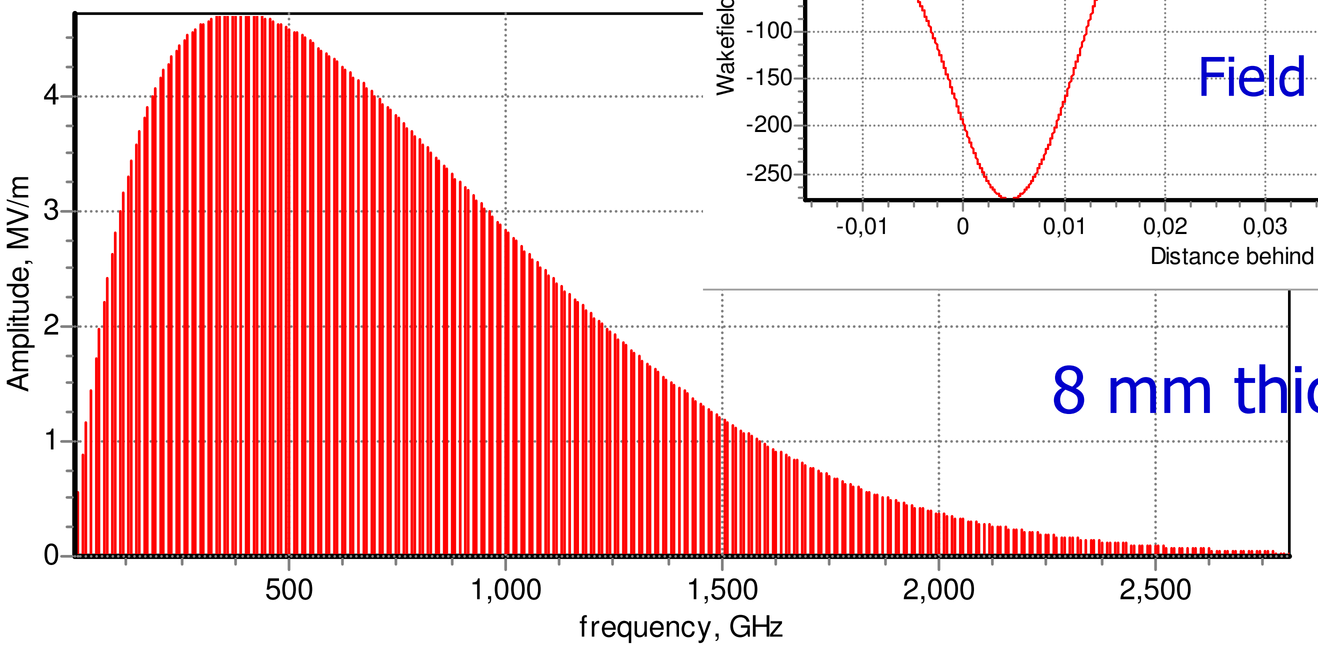


A. Kanareykin, Euclid Techlabs LLC, CLIC'09

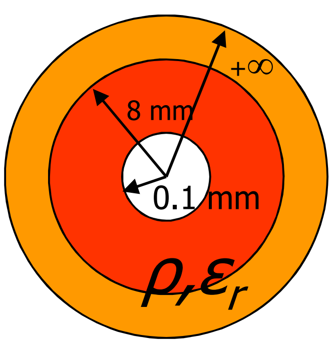
Dielectric Collimator Wakefields, E_z

Dielectric + copper
dielectric resistivity $\rho = 10^{12}\ \Omega.m$
Dielectric permittivity $\varepsilon_r = 5$



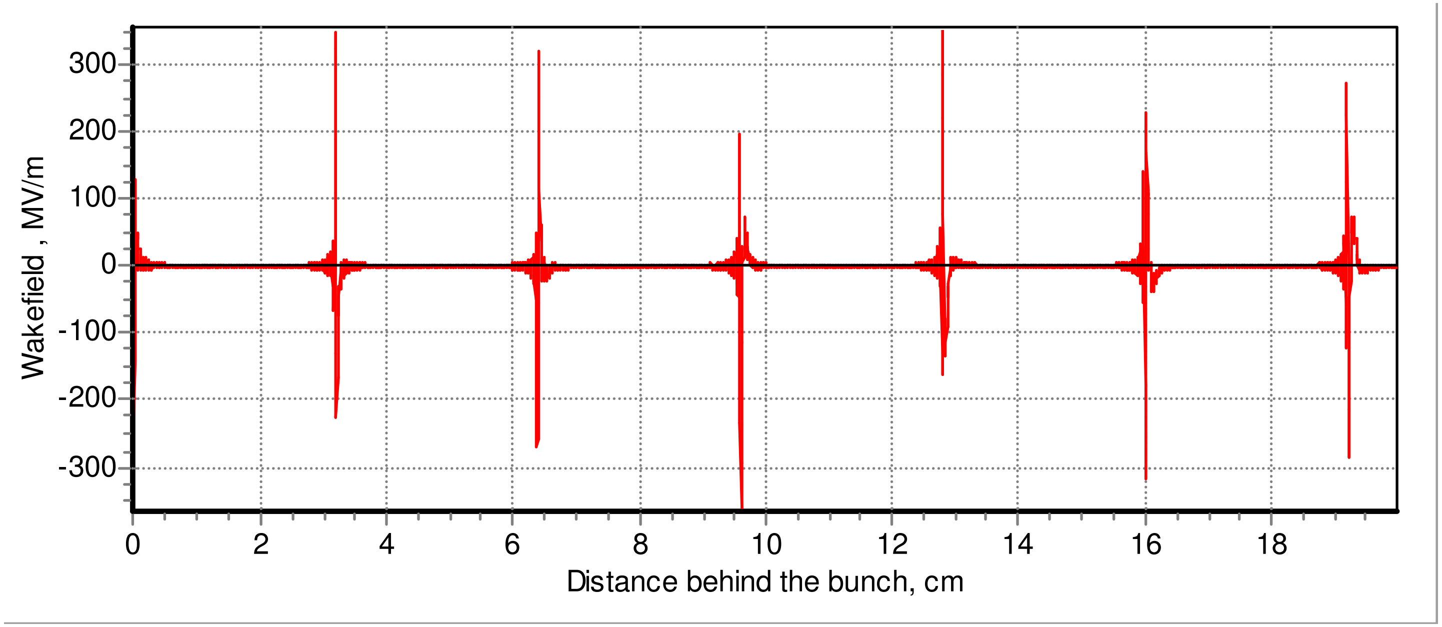


8 mm thickness

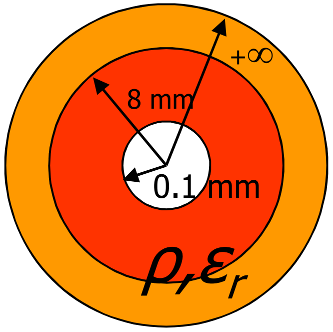


CLIC beam Cherenkov spectrum

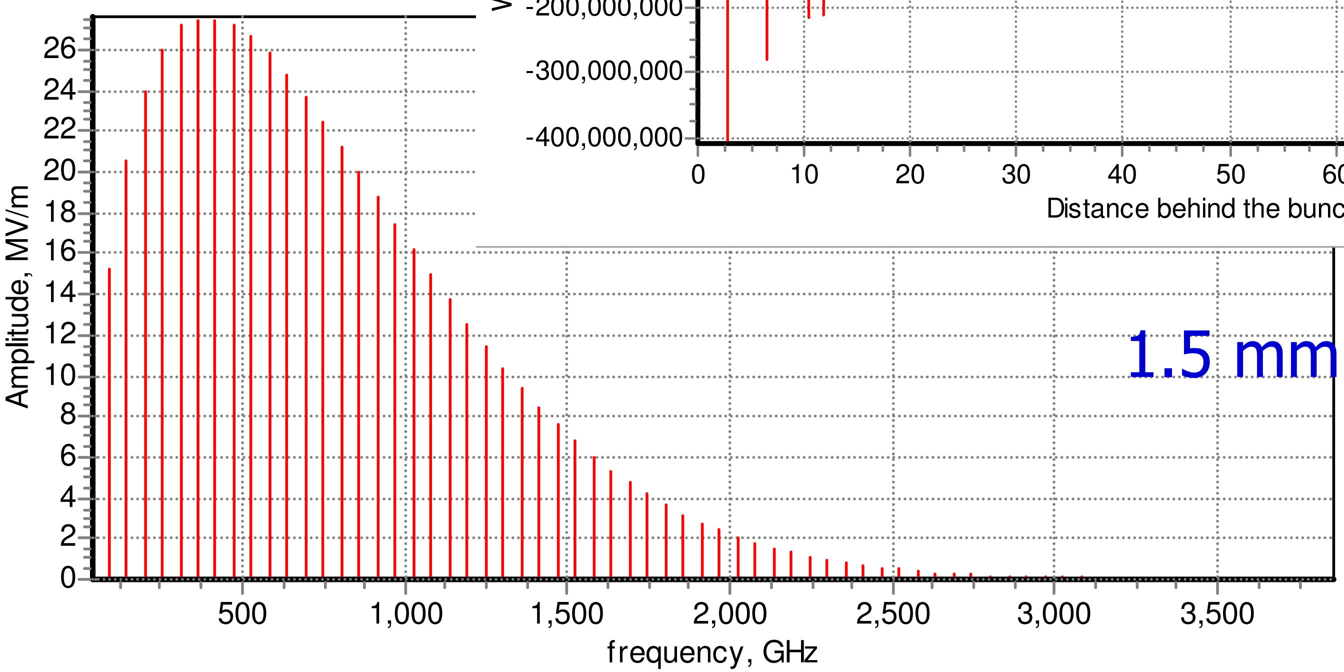
Single Bunch Wakefields, E_z

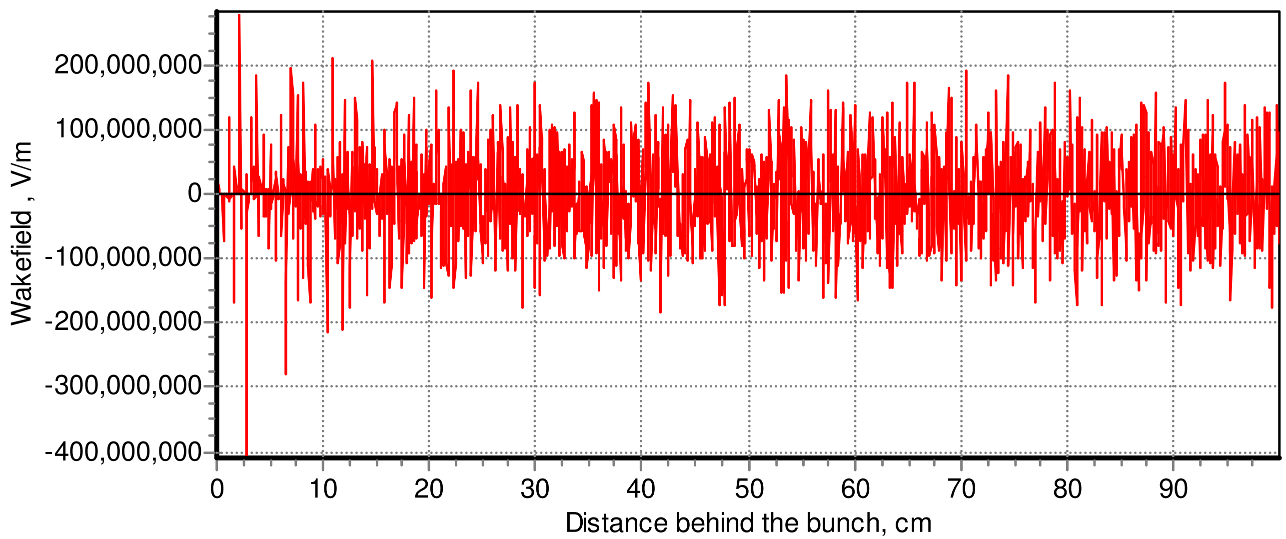


Dielectric + copper
dielectric resistivity ρ = 10^{12} Ω.m
Dielectric permittivity ε_r = 5



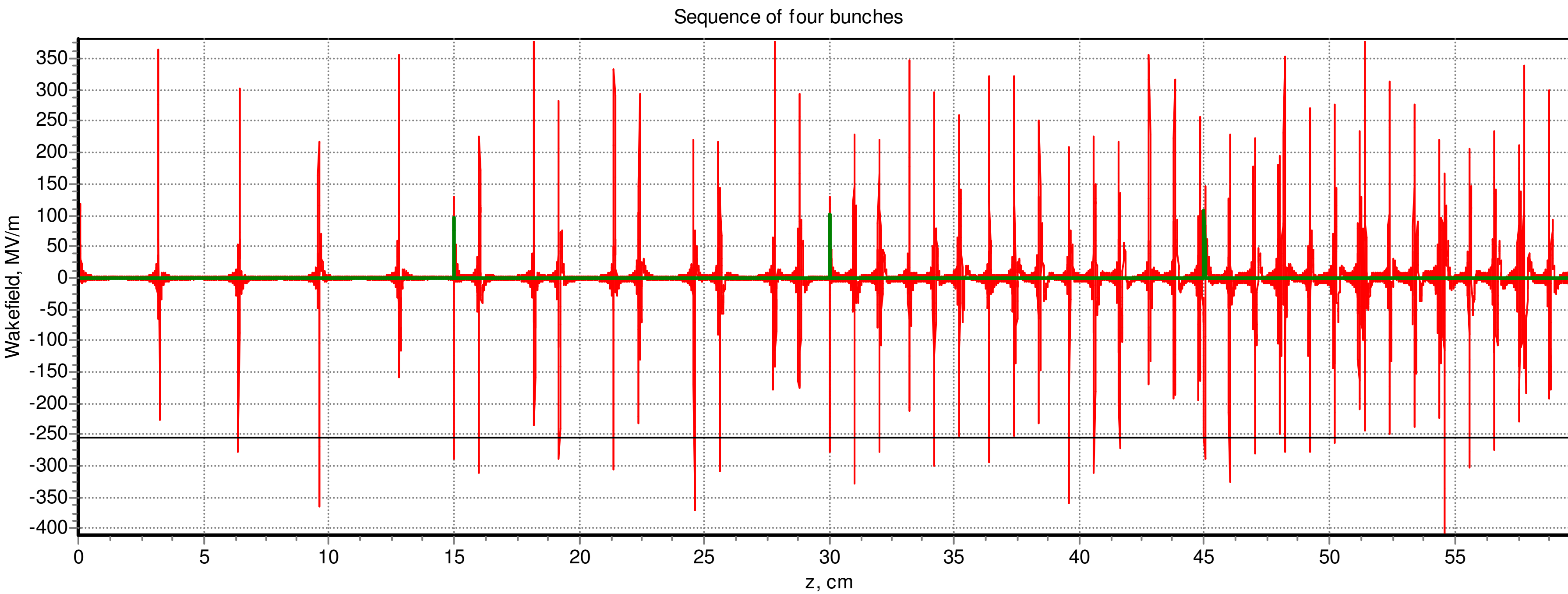
Dielectric Collimator Wakefields, E_z





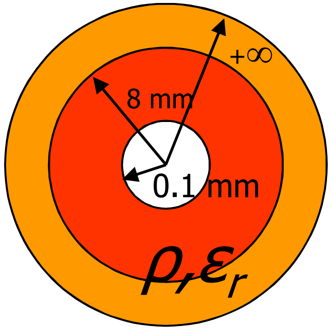
1.5 mm thickness

Multibunch Wakefields, E_z

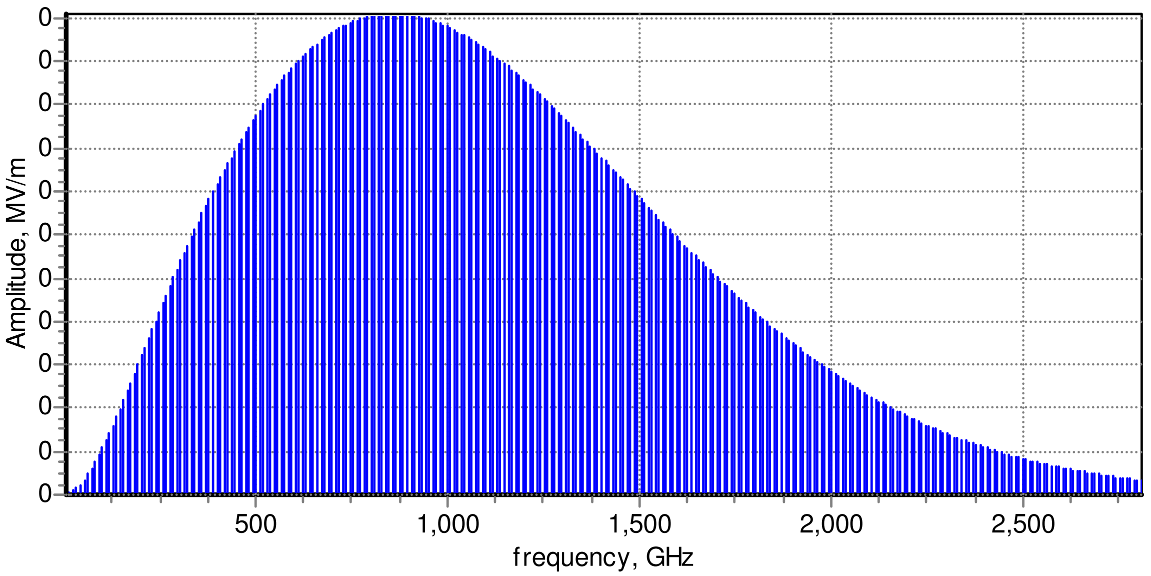


8 mm thickness

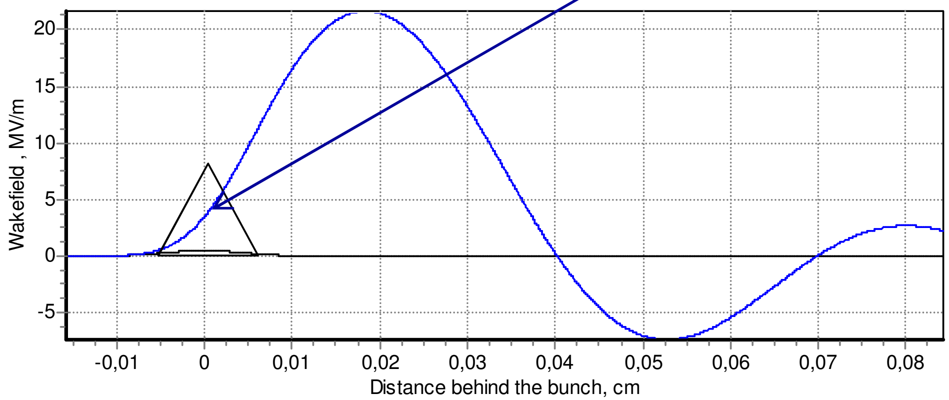
Dielectric + copper
dielectric resistivity $\rho = 10^{12}\ \Omega.m$
Dielectric permittivity $\varepsilon_r = 5$



Transverse Wakefields, E_r

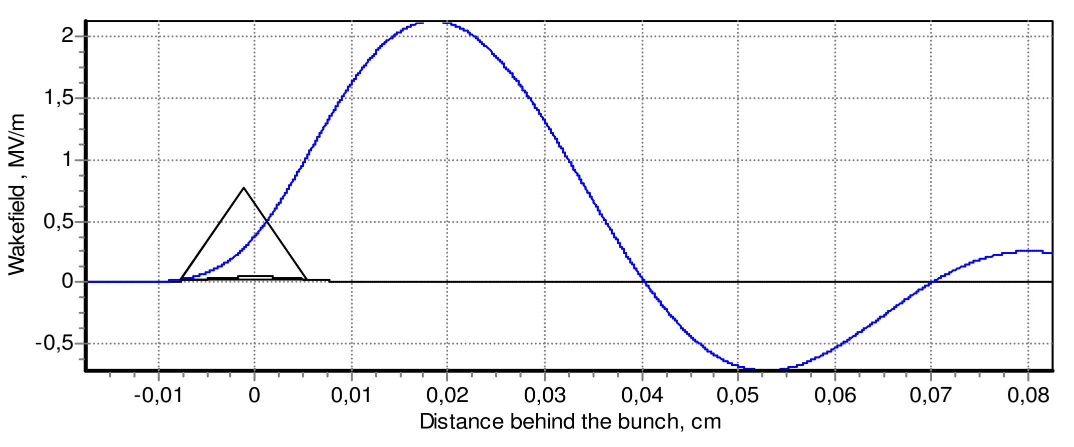


Deflecting Field, Single Bunch

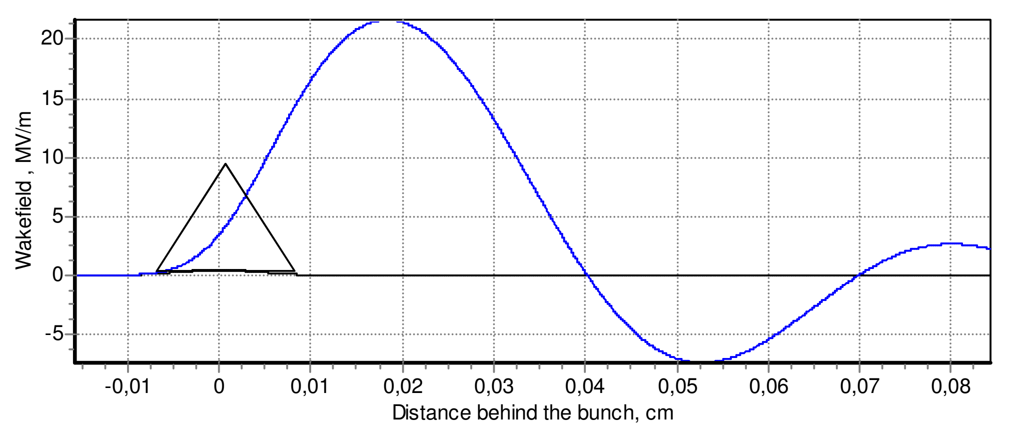


Transverse Cherenkov Spectrum

10 micron offset

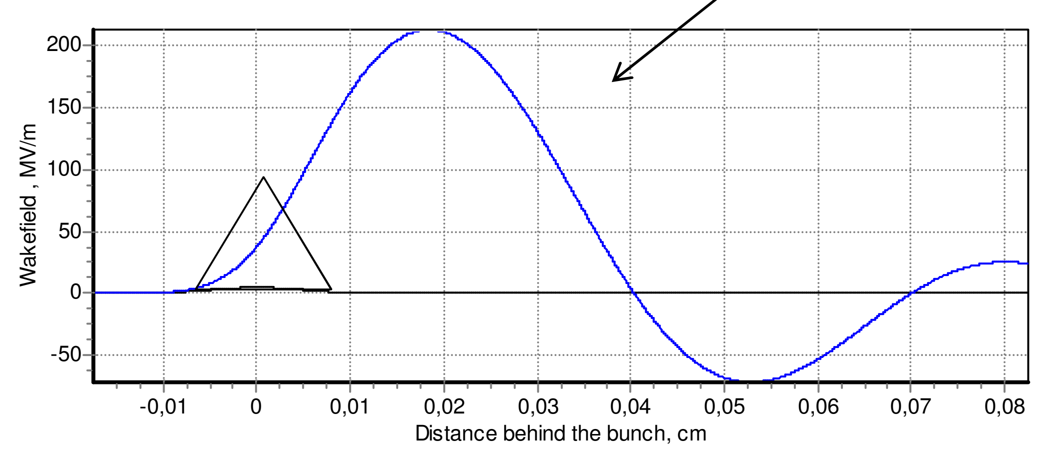


1 micron offset



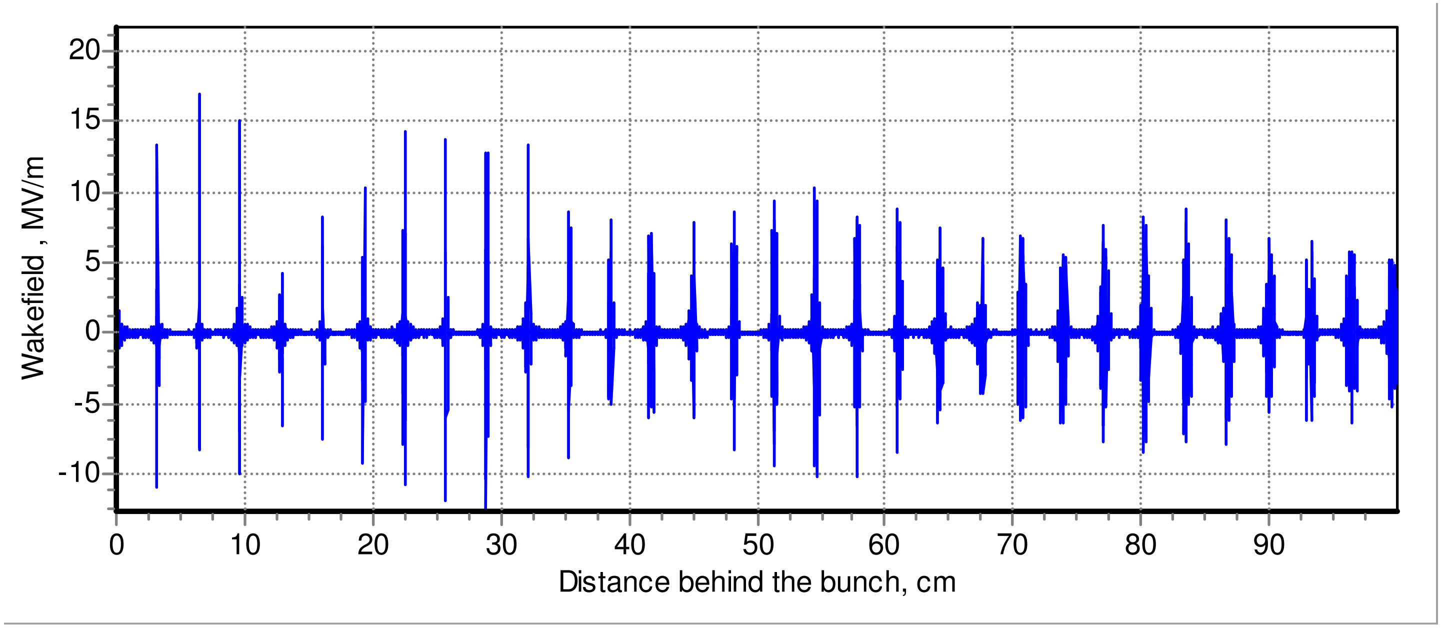
10 micron offset

100 micron offset



Transverse Field inside the Bunch vs. offset

Transverse Wakefields, E_r
Offset 10 um



Dielectric + copper
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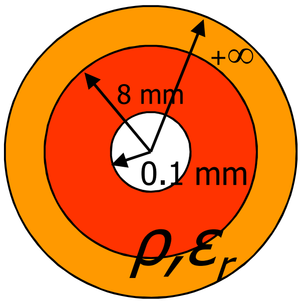


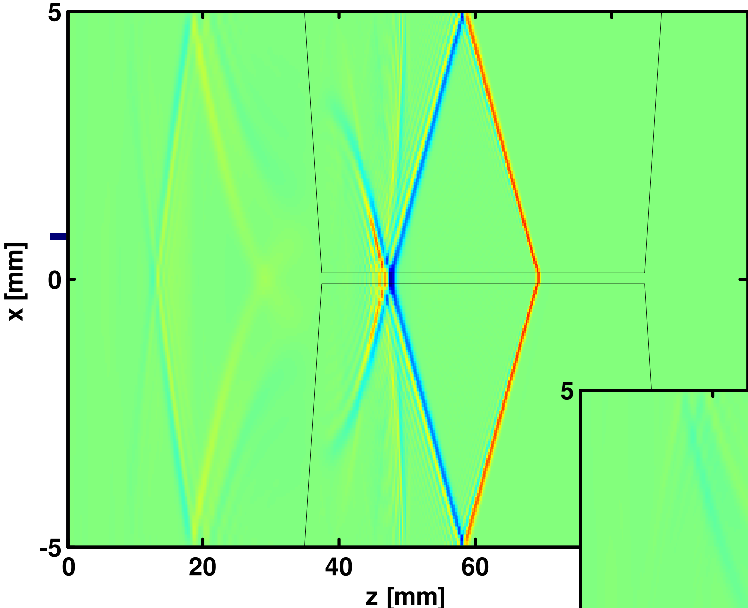
Software for Collimator Simulations

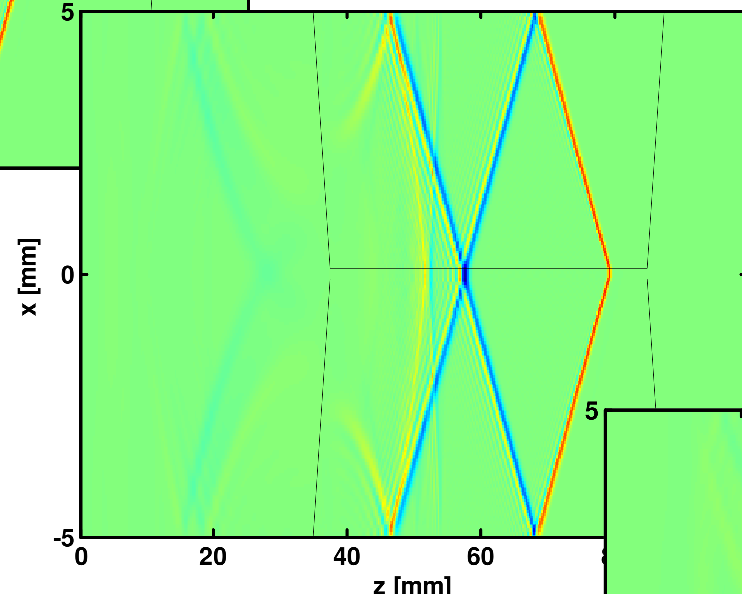
- Large mesh required for problem
- 3D FDTD problematic especially for long range wakes
- Look at specialized codes/algorithms
- SLAB:
  - ❑ 2D FDTD (x,z)
  - ❑ Ribbon beam
  - ❑ Can resolve 3d dimension via expansion in $\exp(ik_y y)$, k_y=transverse wave number. Analogous to $\exp(im\varphi)$ in cylindrical geometry

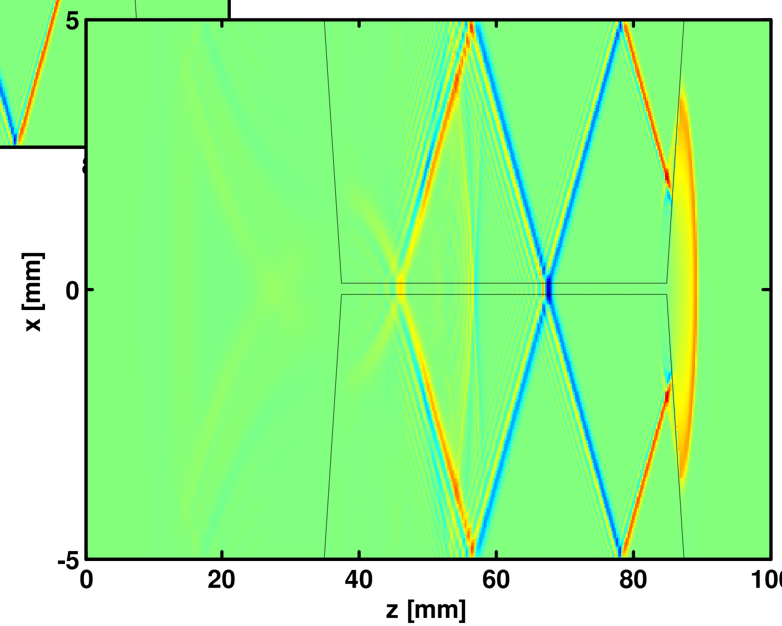
Software for Collimator Simulations

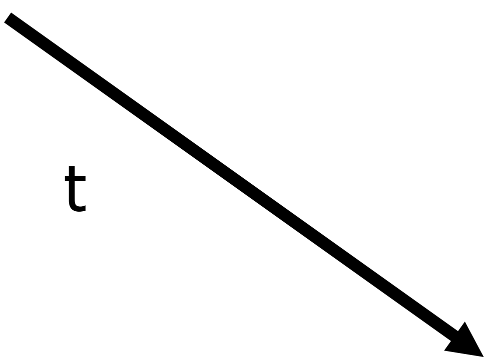
euclid TECHLABS

Diamond collimator 200 um slab, bunch length is 200 um also (mesh)

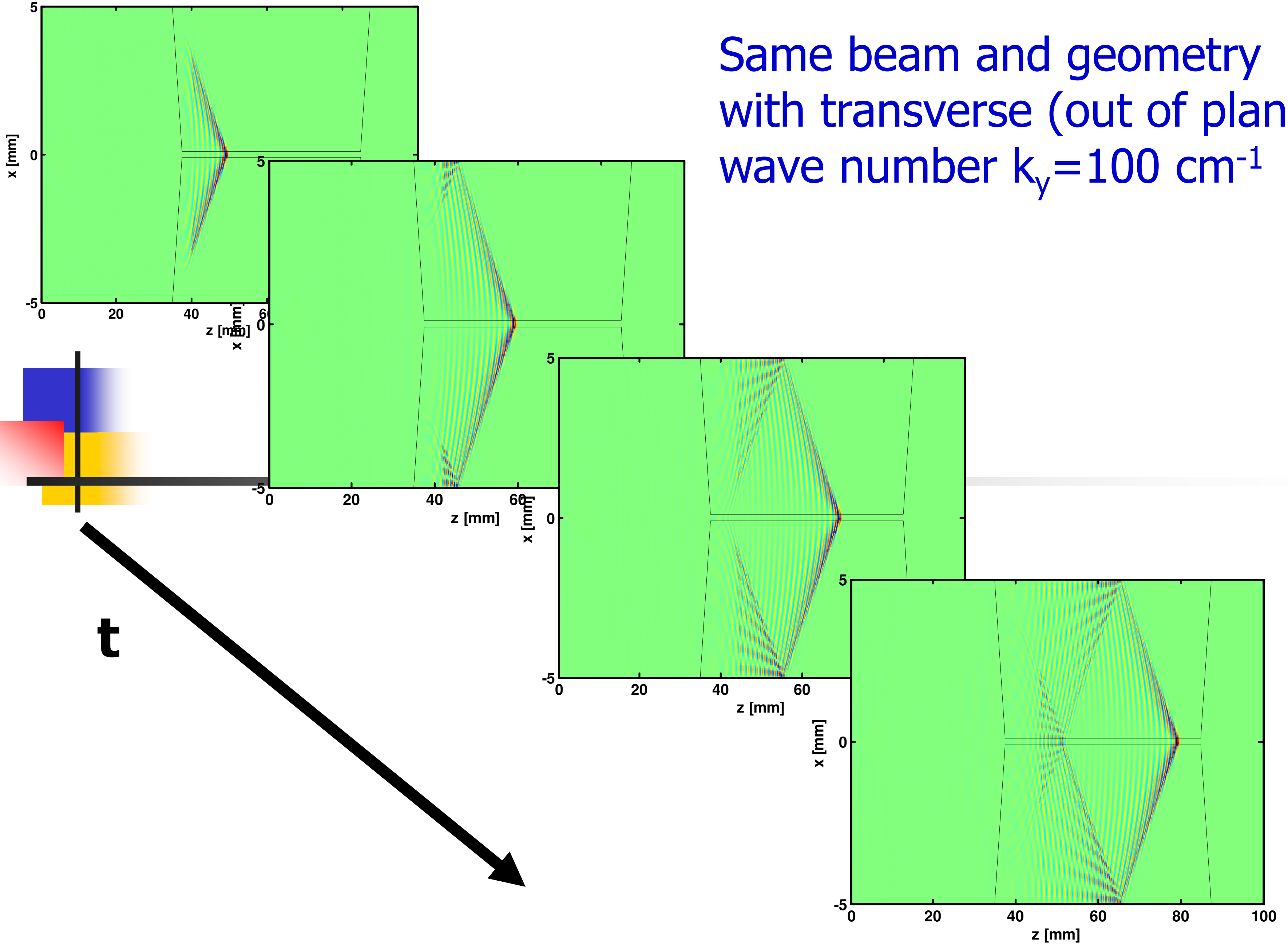




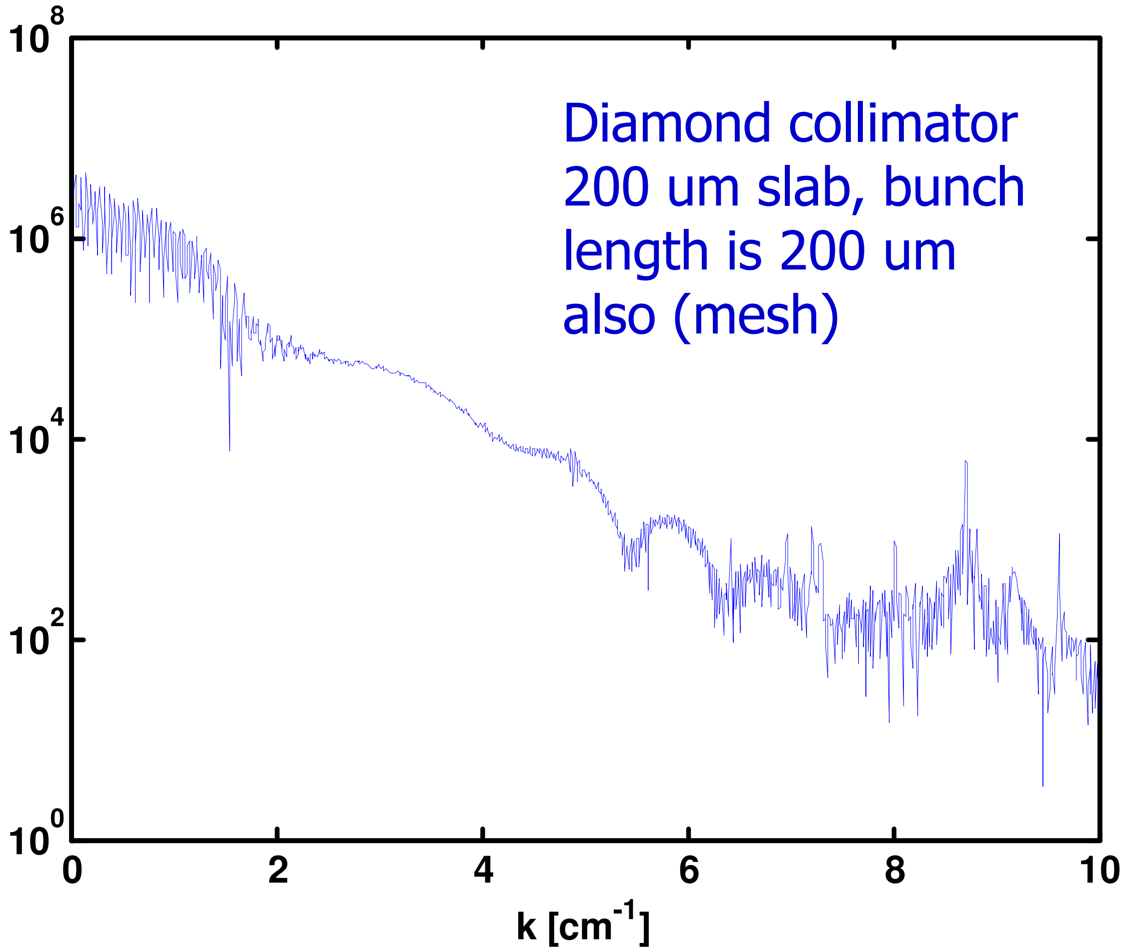




Same beam and geometry with transverse (out of plane) wave number k_y=100 cm^{-1}



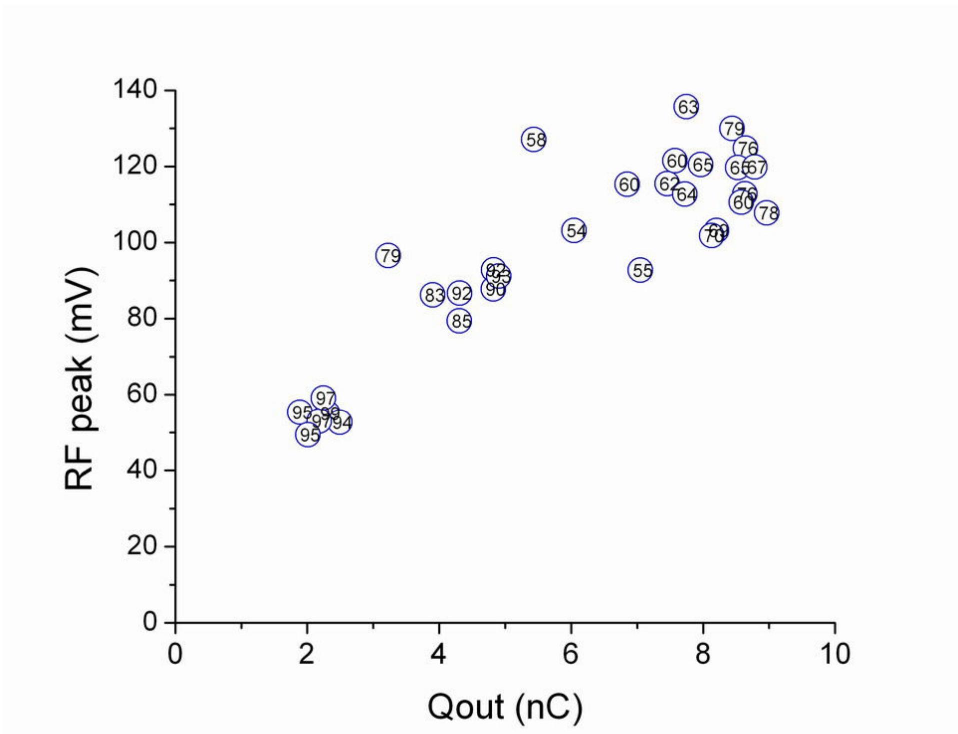
Wake Spectrum

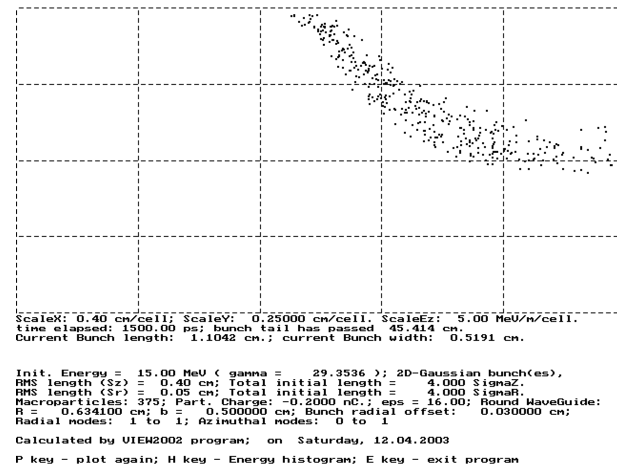


Software for Collimator Simulations (cont.)

- Particle-Green Function codes
  - ❑ BBU-3000
  - ❑ Analytic or numerical Green fns
  - ❑ No mesh required for analytic GFs
  - ❑ Current emphasis on particle dynamics but wakes and impedances also calculable

BBU at Dielectric Accelerator

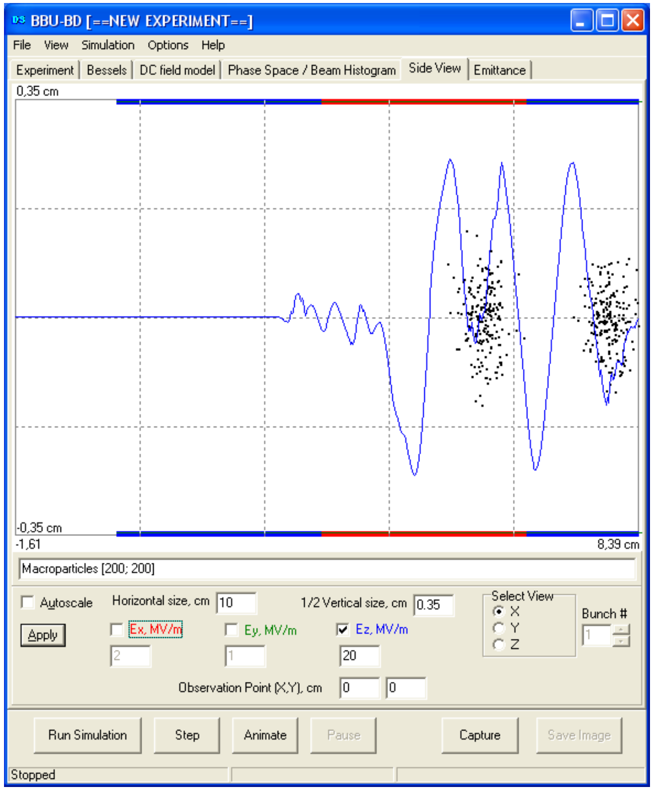


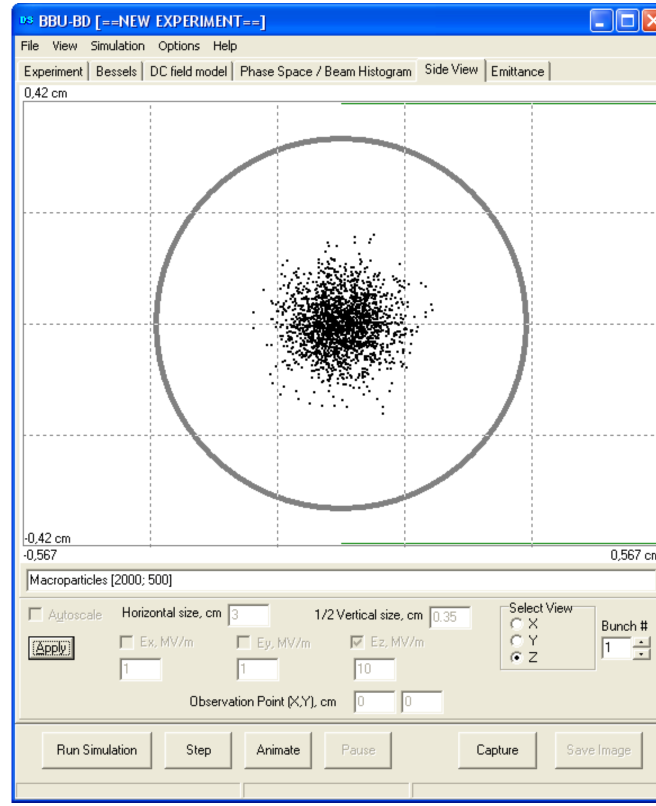


- Deflection of bunch tail by transverse wakefields from head
- Amplification of injection errors as beam propagates
- Especially significant for the high charge bunches used for wakefield acceleration-

BBU Code Development for Dielectric Accelerator

euclid TECHLABS



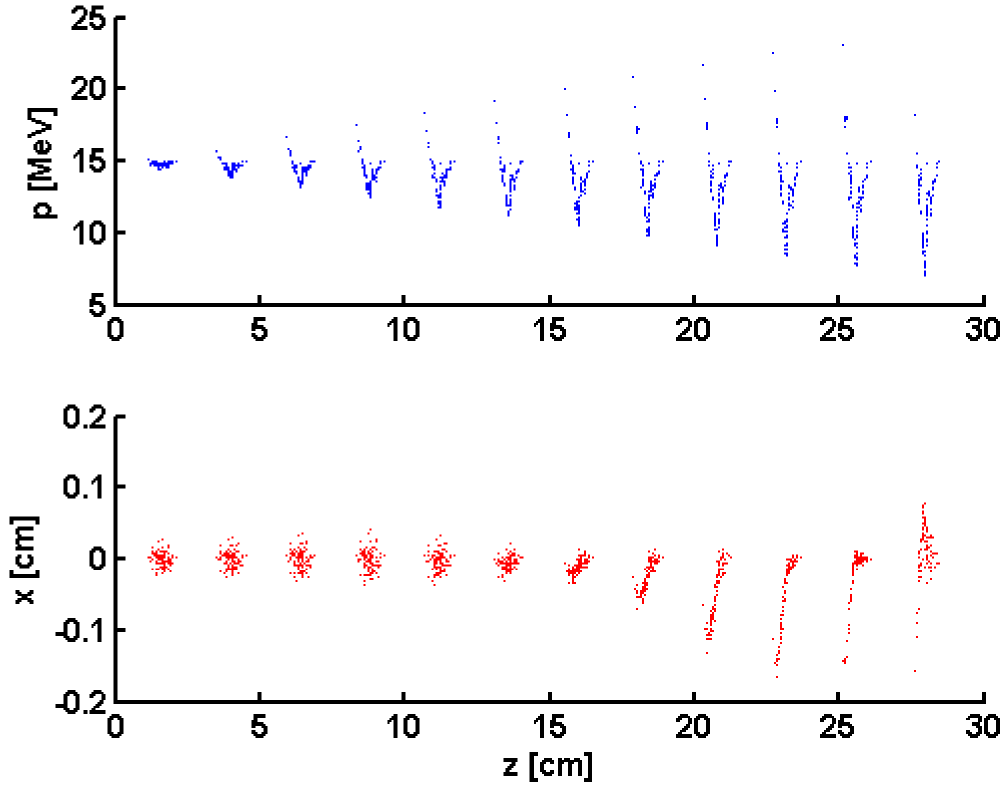


Will be used for Collimator Beam Dynamics

BBB 3000 code interface

Cross-section view (*x-y* plane), Gaussian distribution

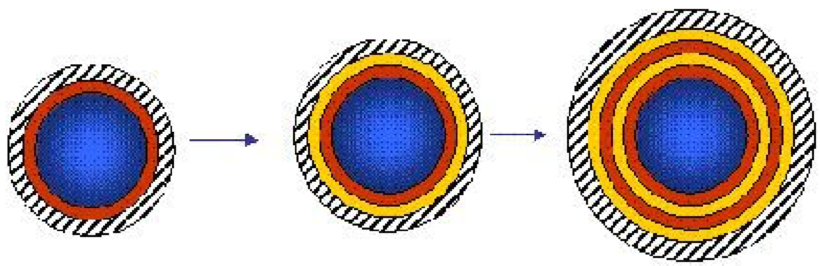
Example of BBU-3000 calculation of time evolution of BBU in a 26 GHz dielectric waveguide

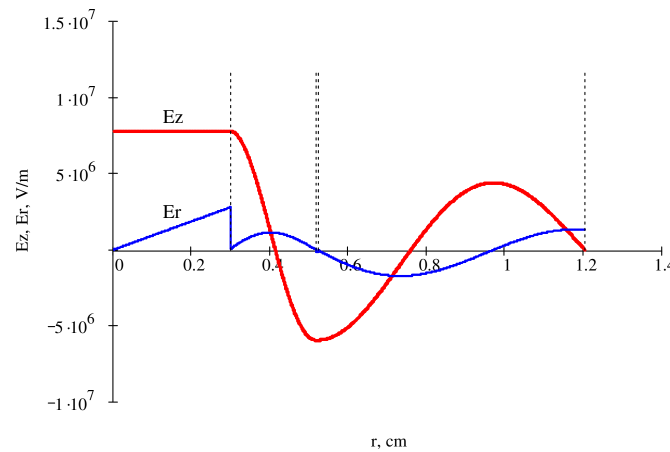


Long. Phase space

X dist.

Multilayer DLA structure





Layers	SINGLE	SINGLE	DOUBLE	4-LAYER
Frequency, GHz	11.424	11.424	11.424	11.424
Mode TM_{0n}	TM_{01}	TM_{03}	TM_{03}	TM_{03}
Group Velocity	0.055	0.033	0,069	0.056
Q	2249	5102	6984	8501
r(MO/m)	15	8.72	15.00	22,00
r/Q	8756	1708	2143	2585
Power Attn (dB/m)	**-14.4**	**-5.86**	**-2.14**	**-2.20**

MULTILAYER DLA

- ALLOWS TO CONFINE E/M FIELDS.

- REDUCES LOSSES DRAMATICALLY

Tasks for Beam Dynamics

- ❑ Additional software modules may be necessary for collimation capability 3D/cartesian geometry for wakefields in BBU-3000
- ❑ Convention for input of numerical Green's functions in BBU-3000
- ❑ Extraction of GFs from electromagnetic simulations (e.g. SLAB)
- ❑ Major issues around 2D vs. 3D capabilities
- ❑ Primarily an issue for electromagnetic simulations (memory), BBU-3000 particle dynamics is already 3D
- ❑ Investigate whether 2D EM with expansion in transverse mode number is useful. Necessary for comparison studies. Relatively easy for collimator geometries.

Motivation for Further Research

Needs :

- At the moment the CLIC collimation system is under revision. The collimator geometry and the lattice are being optimized in terms of wakefield effects, collimation efficiency and collimation material survival. The optimum material so far is Beryllium. Diamond would resist very well the impact of a full CLIC beam wakefields optimizations is needed.

- EM simulations for wakes currently problematic because of mesh/memory requirements (short pulse/large physical system)

- Develop method for extracting GFs from numerical results.

Conclusions

- The reasons that lead CERN to consider dielectrics as low impedance materials for LHC collimations may not be relevant for CLIC.
- However, fine tuning of the material properties is still possible to try and minimize the wakes
- Euclid and AWA group has experience in using different microwave materials for Dielectric Based Accelerator (quartz, diamond, MW ceramics).
- Material properties has to be studied at THz range for CLIC applications.
- Euclid has software tools especially developed for dielectric loaded waveguide/resonator simulations and beam dynamics in dielectric structures as well. This software (with minor upgrade) can be used for collimator simulations (cylindrical and planar both)