SIMULATIONS OF OTR, ODR AND CERENKOV RADIATION

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Outline

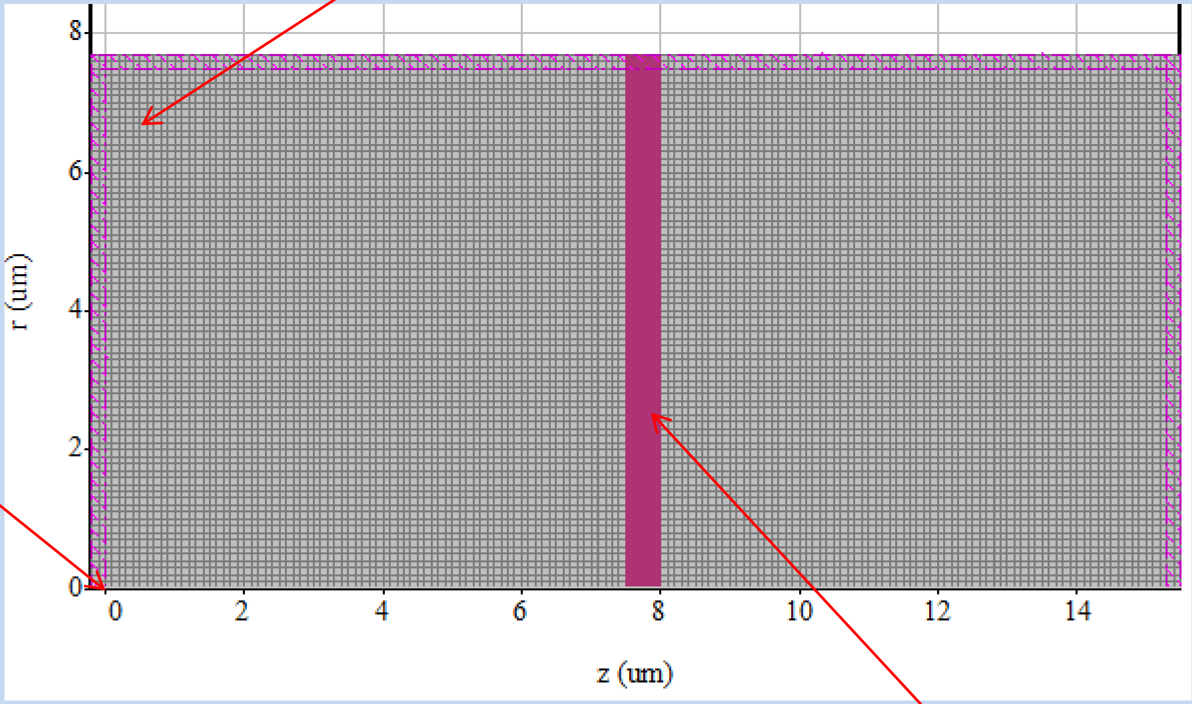
I -	OTR/ODR MAGIC simulations
II -	Simulations of a Cerenkov radiator (Expt at Cornell)
III -	Dielectric-loaded waveguide (DLW)
	- beam bunching
	- extraction
	- Interaction of a single bunch in a DLW
IV-	Example with CST-PS

The results presented here come from an exploratory study of MAGIC capabilities

MAGIC simulations of Optical Transition Radiation OTR/ODR

Observation point
z = 0,75 µm, r = 6,755 µm

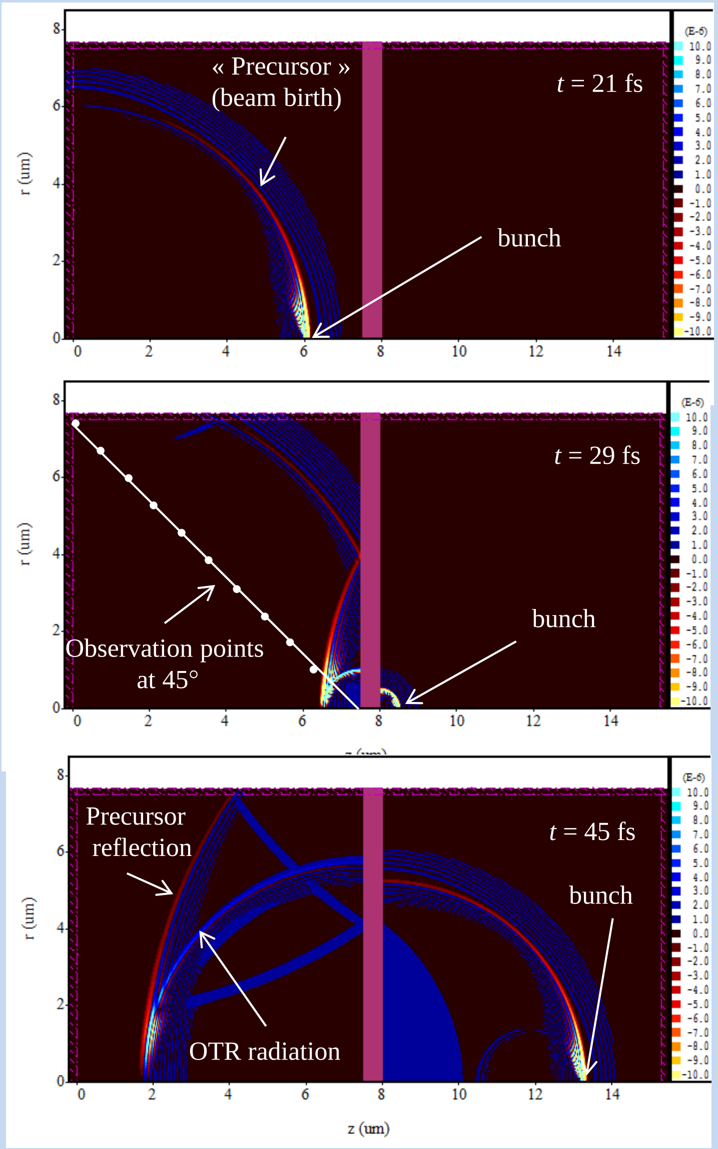
Cathode



Metallic film (Al)
(Central hole for ODR)

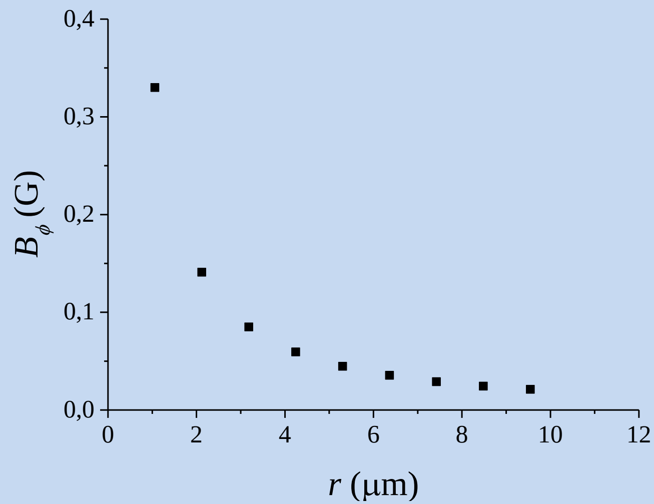
Geometry: 2D axisymetric
Mesh size: 10 x10 nm^2

MAGIC simulations of Optical Transition Radiation OTR



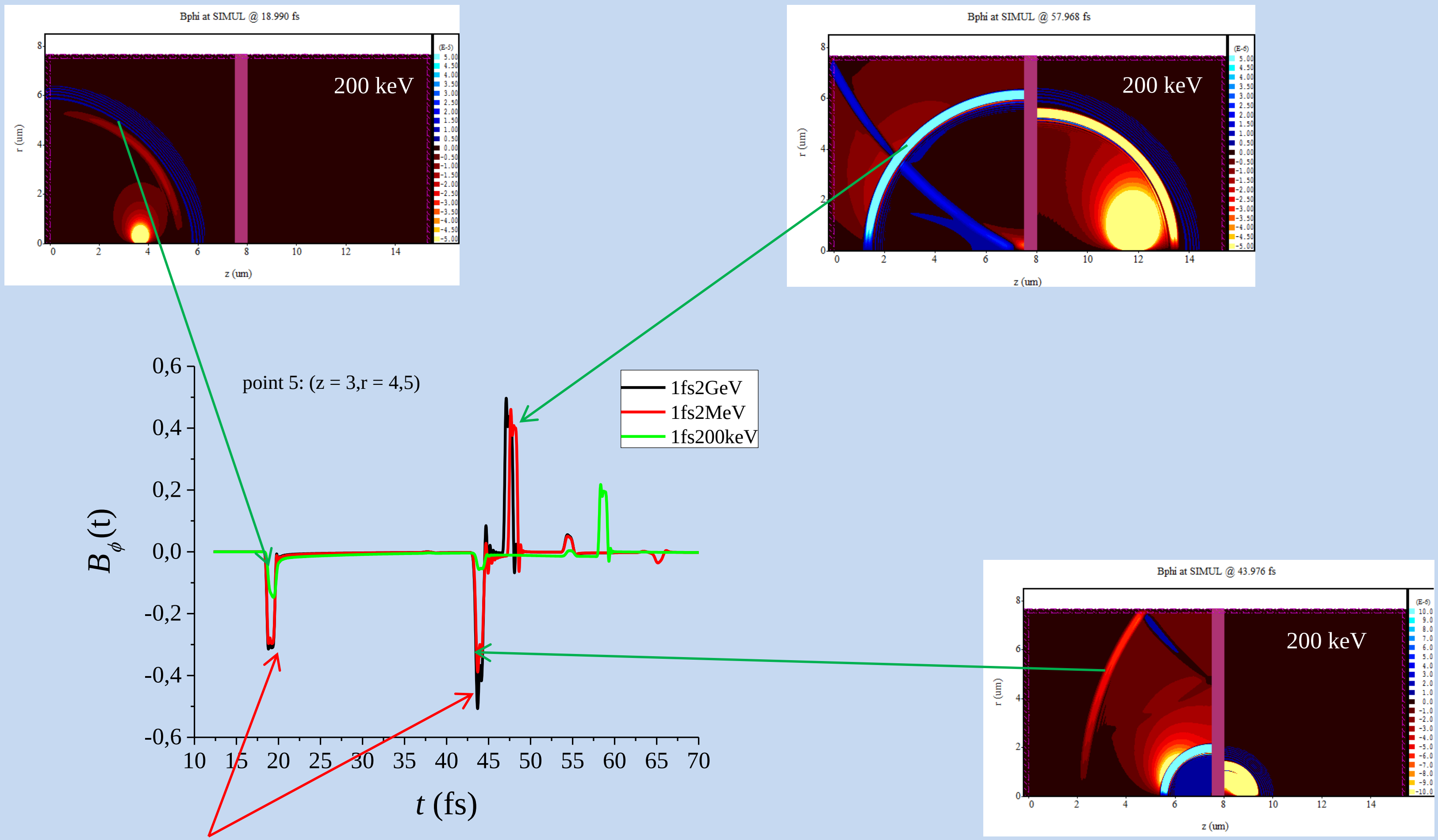
Very short bunch: 2 GeV, $\tau = 0{,}02$ fs, $q = 0{,}02$ aC

The amplitude of the B_ϕ field component on peaks # 3 decreases as $1/r$ *(Along the line at 45°)*



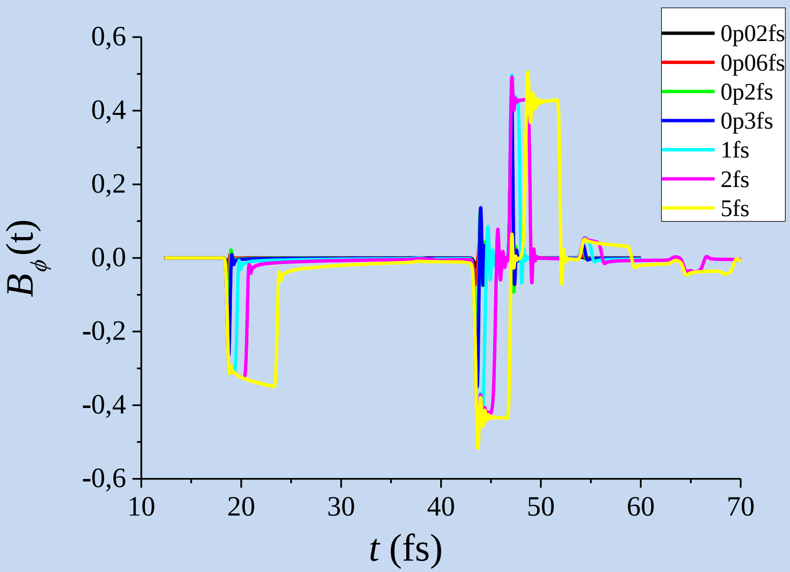
MAGIC simulations of Optical Transition Radiation OTR

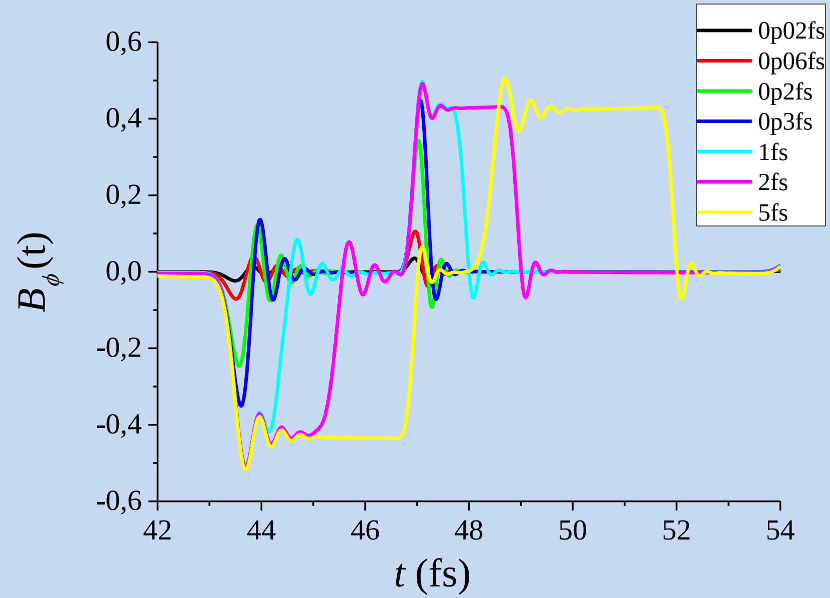
At low energy, one can separate the precursor from the actual OTR radiation.



- The two first negative spikes come from the radiation appearing during beam emission
- OTR is the third peak

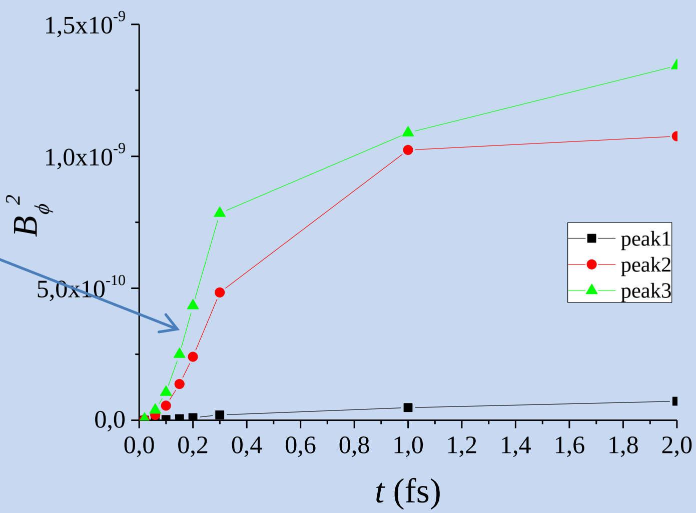
MAGIC simulations of Optical Transition Radiation OTR





For short bunches, the power scales with n^2

Coherent radiation for short pulses

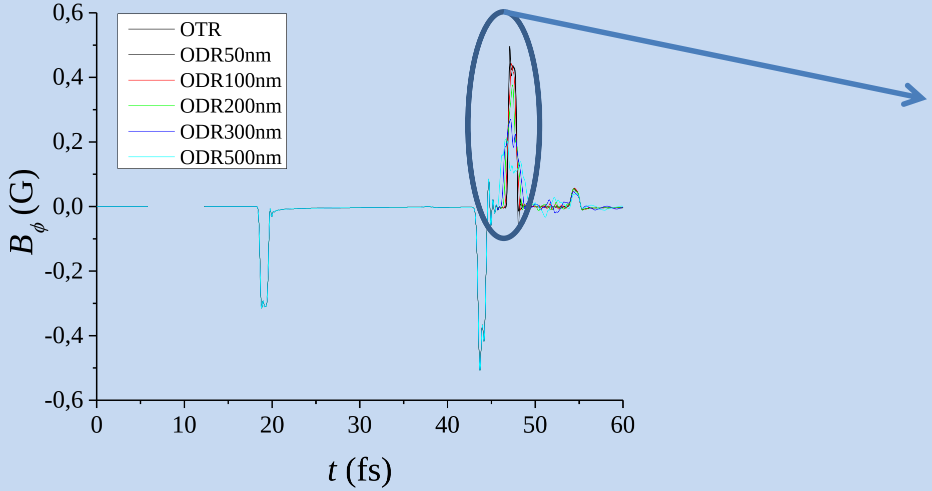


2 GeV, constant current 1 mA, variable bunch length

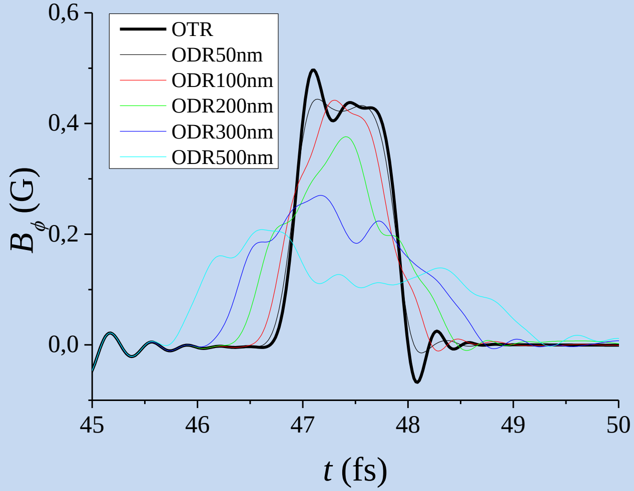
Optical Diffraction Radiation ODR

A small hole of variable radius is cut in the metallic foil

Point #5 z = 3 µm, r = 4,5 µm



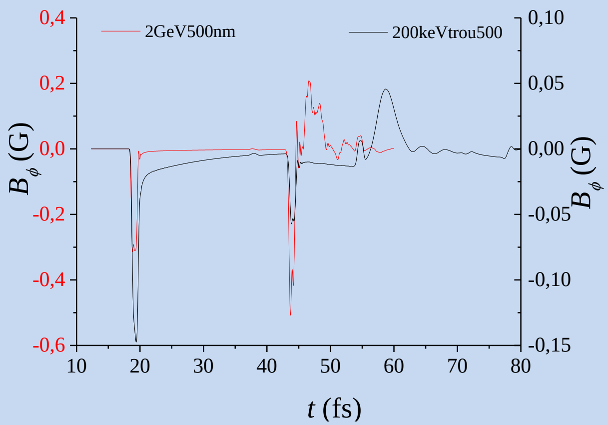
Effect of the hole size at 2 GeV

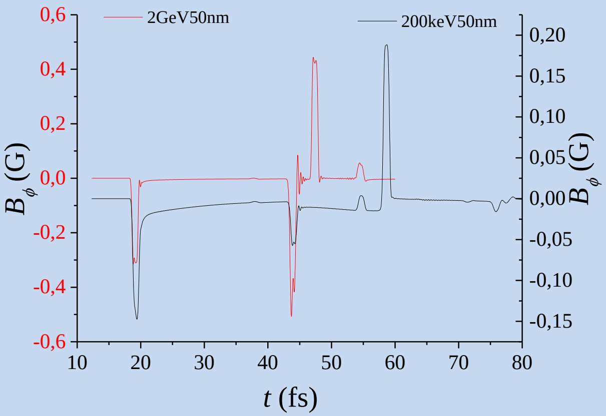


Close-up around peak#3

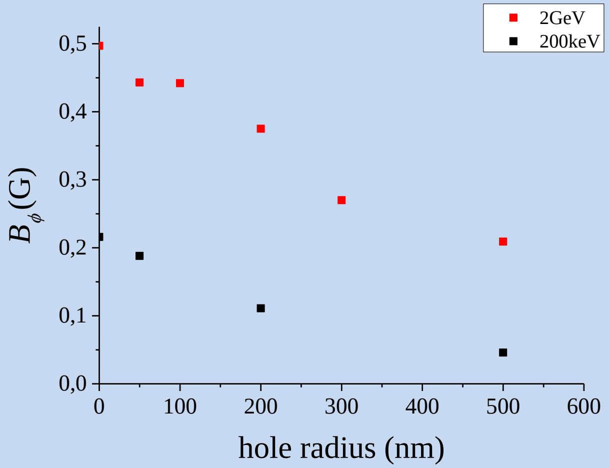
Optical Diffraction Radiation ODR

z = 3 µm, *r* = 4,5 µm,





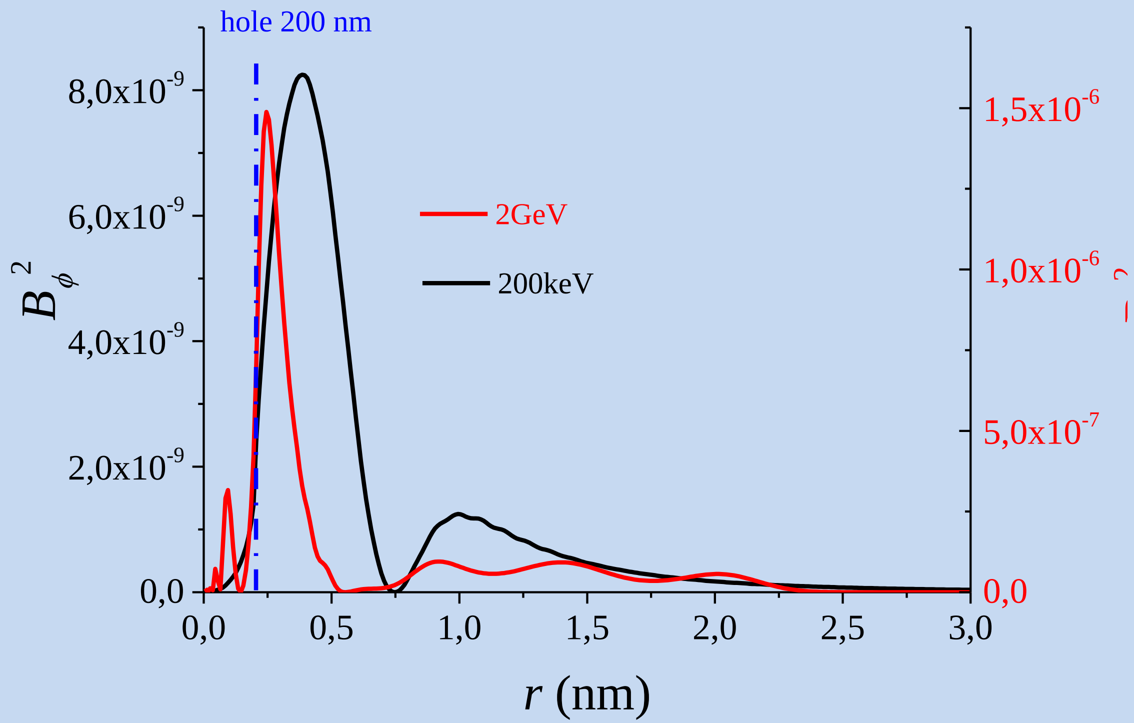
Effect of the beam energy for two sizes (50 and 500 nm)



Radiated B-field at point#5 for two energies as a function of the hole size

Optical Diffraction Radiation ODR

Squared *B*-field profile as a function of *r* at the film entry



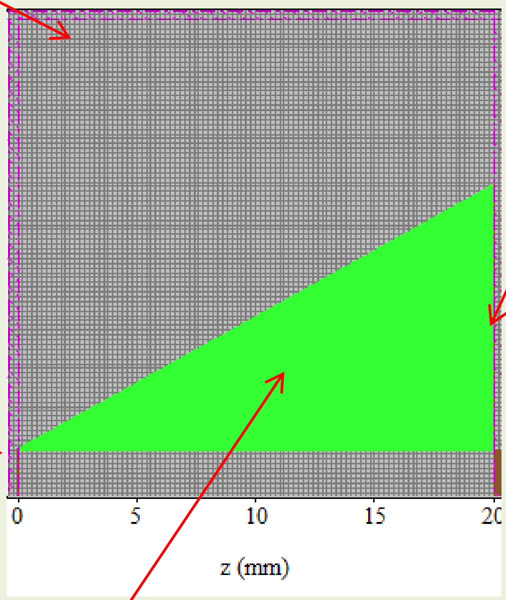
will be improved in 2D cartesian (and ultimately in 3D) in order to compare simulation results with experimental data (in particular, misaligned beam effects could be adressed)

Preliminary MAGIC simulation of a Cerenkov radiator

Main observation point (z = 4 mm, r = 20 mm)

Metallic plate

r_d



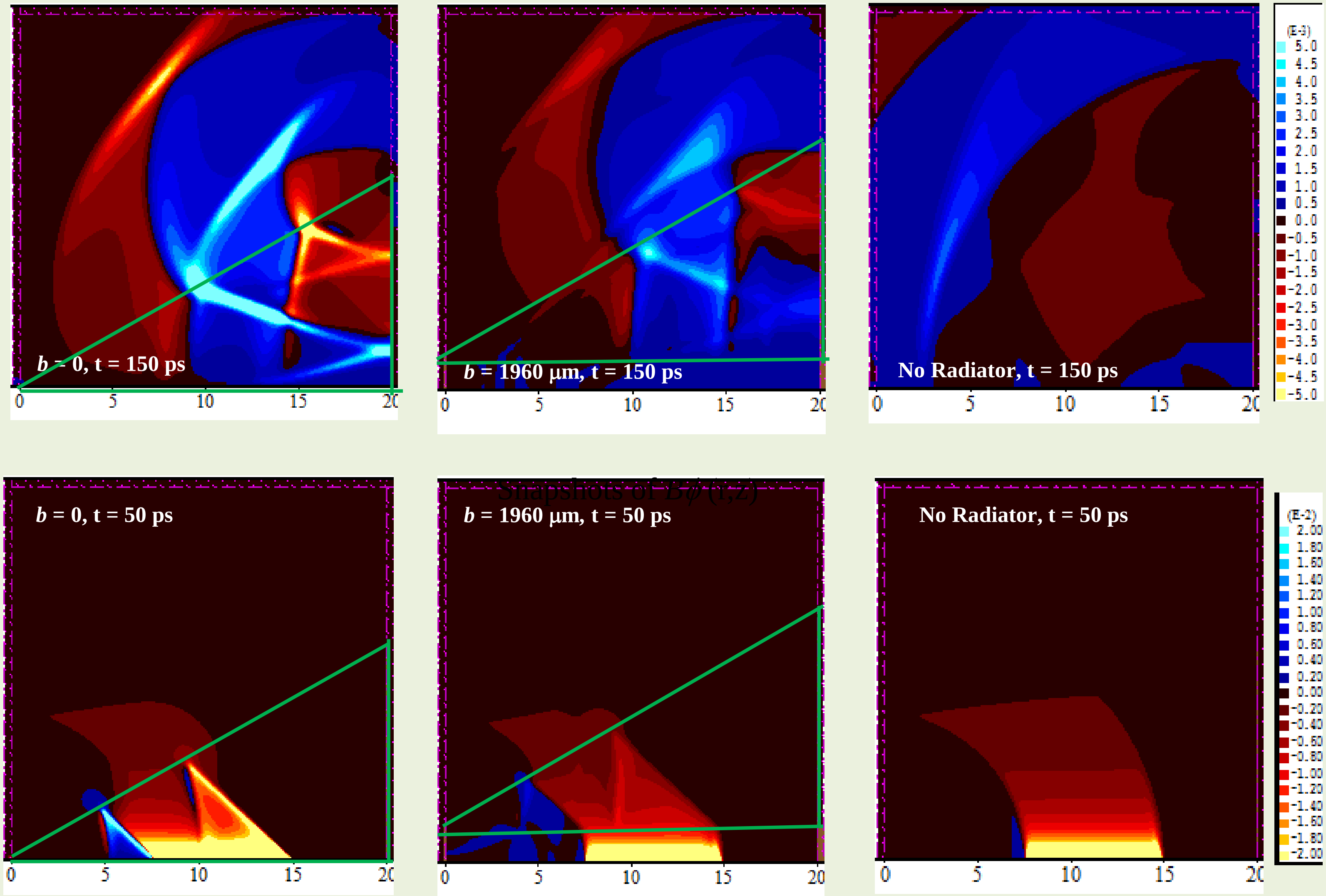
Beam:
Kinetic energy: 2 GeV
Bunch length (trapezoidal shape): 25 ps
Rise time: 1 ps
Peak current: 100A
Bunch charge: 2.5 nC
Beam radius: 40 µm (homogeneous)

Conical Cerenkov radiator:
-Length: 20mm
-Internal radius r_d from 40 µm to 2 mm (adjustable to simulate the effect of the impact parameter)
-Dielectric:fused silica $\varepsilon_r = 2.1$
-Metallic plate at z = 20 mm

Geometry: 2D axisymetric
Boundaries freespaces (not prefectly absorbing)
Mesh size $dz = dr$ = 20 µm
Electromagnetic time step: 33.3 fs
Runtime 500 ps
Job duration 1h 30

Geometry and main parameters: experiment at Cornell

Effect of the impact parameter

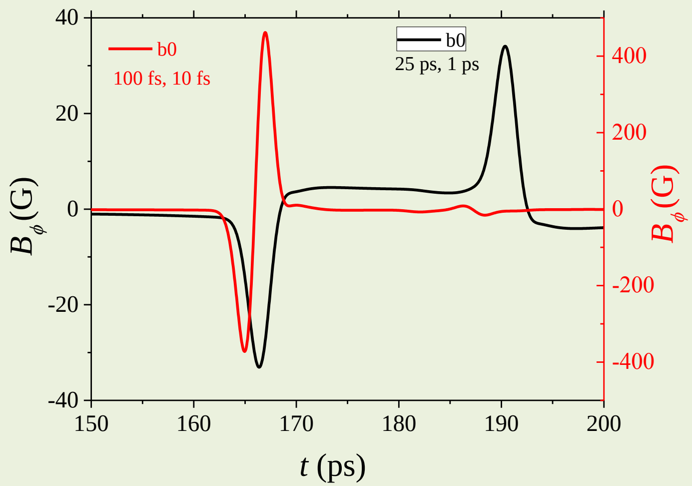


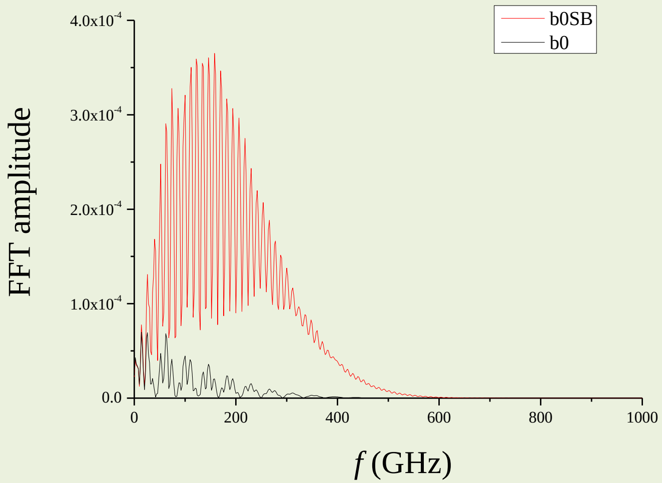
- The dielectric medium is not shown for visibility, it has been replaced by green lines.
- The impact parameter b is 0 in the left figures and is maximum (1.96 mm) in the middle ones.
- On the two right figures, we see the wakefield of the bunch at 50 ps and its reflection on the metallic plate at t = 150 ps

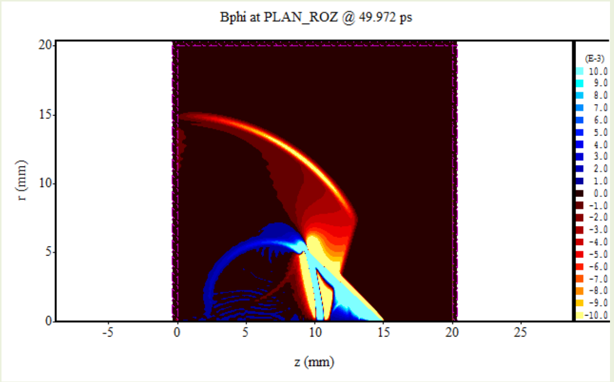
Effect of the bunch length

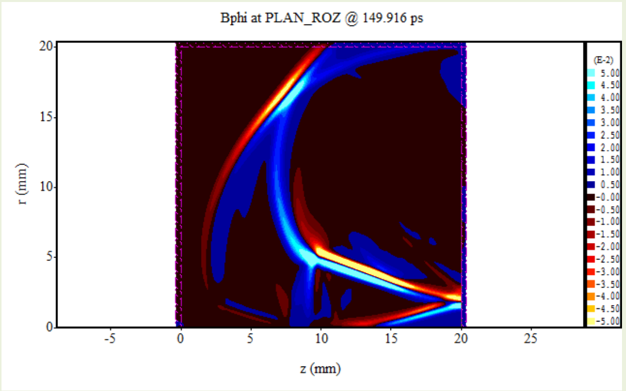
Comparison for a long bunch (25 ps) and a short bunch (100 fs), Impact parameter $b = 0$

B_ϕ (t) at observation point (z = 4 mm, r = 20 mm)



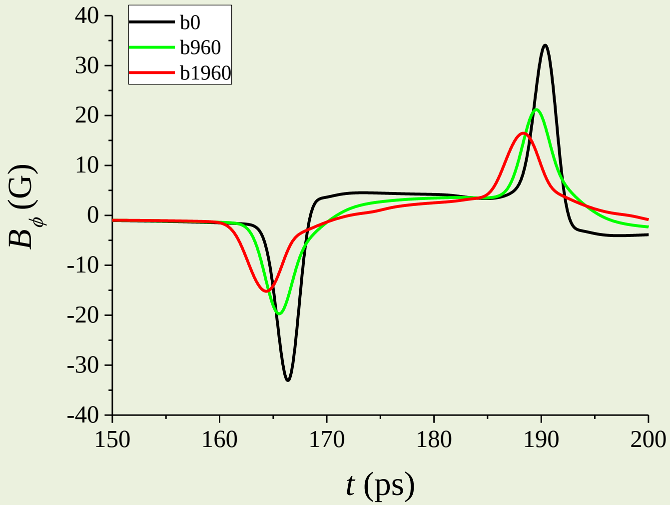






Snapshots for the short bunch (100 fs)

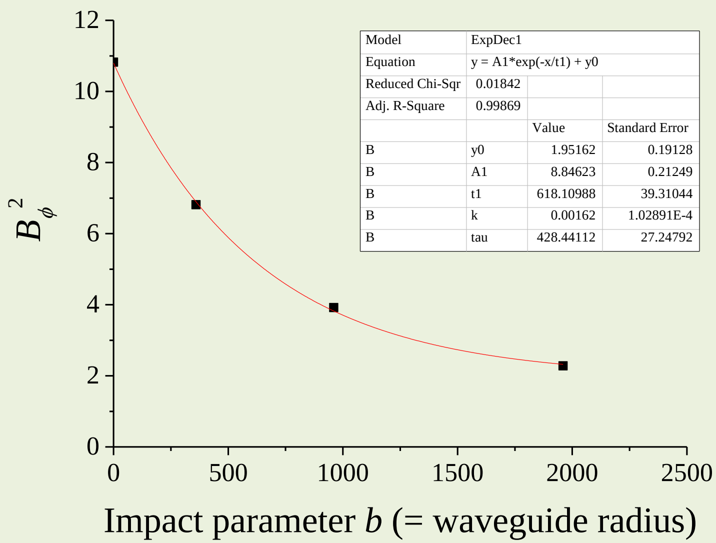
Effect of the impact parameter



Effect of the impact parameter.
Risetime 5ps
mesh size 20 μm

-With these 3 values of *b*, I have squared the max B_ϕ values and I got a perfect exponential decay.

Remenbering that 1 G corresponds to a radiated field of 120 W/cm^2, the simulation gives a large amount of power !!



Model	ExpDec1		
Equation	y = A1*exp(-x/t1) + y0		
Reduced Chi-Sqr	0.01842		
Adj. R-Square	0.99869		
		Value	Standard Error
B	y0	1.95162	0.19128
B	A1	8.84623	0.21249
B	t1	618.10988	39.31044
B	k	0.00162	1.02891E-4
B	tau	428.44112	27.24792

Beam bunching in a dielectric-loaded circular waveguide

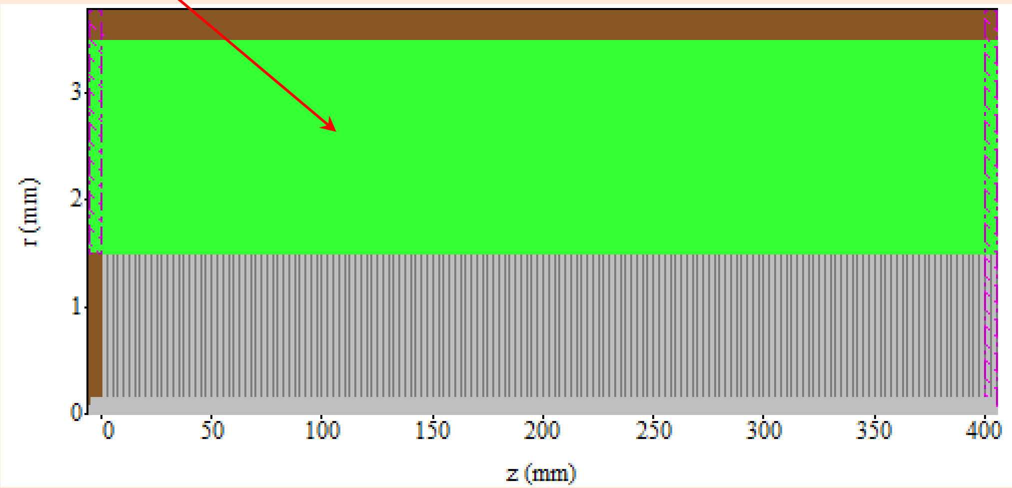
Geometry: 2D axi

Dielectric Loaded Waveguide (DLW)

Length 400 mm, wall radius r_w = 3.5 mm
Mesh size: 0.25 mm x 0.25 mm

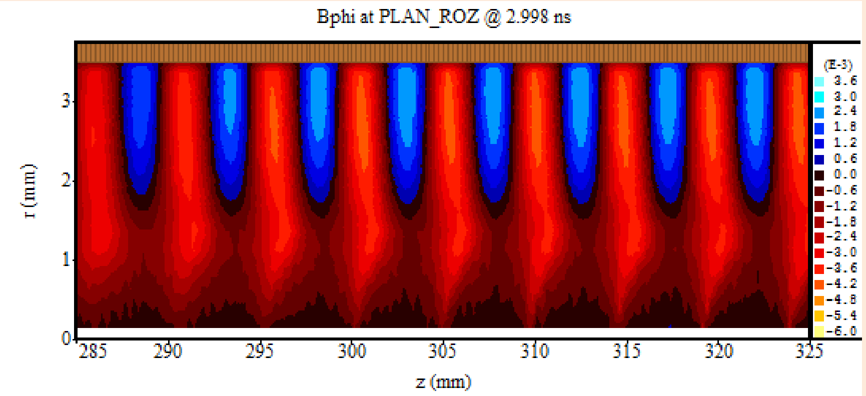
Incident CW electron beam emitted from the left : T = 140 keV, I = 15 A, r_b = 1.25 mm

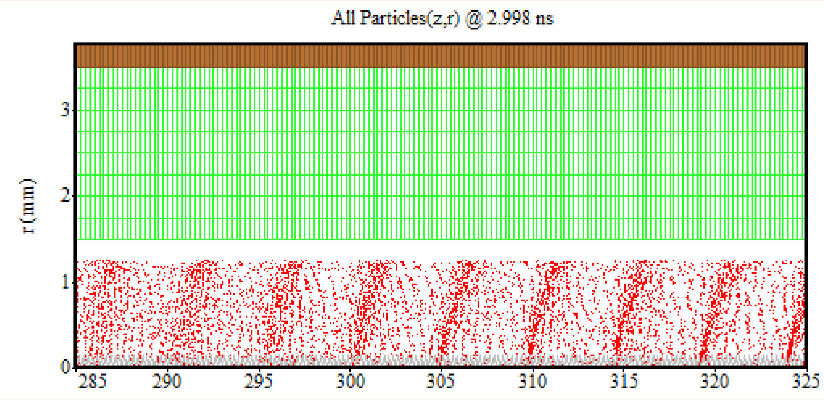
Dielectric cylinder: ε = 3.8, r_{d1} = 1.5 mm, $r_{d12}=r_w$

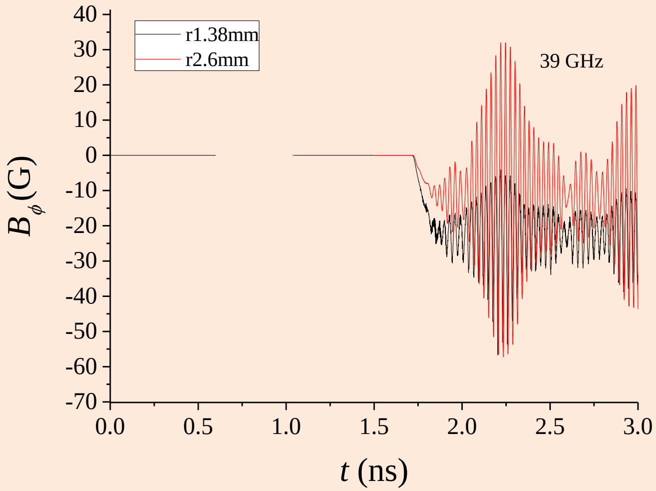


Beam bunching in a dielectric-loaded circular waveguide

Excitation of the DLW fundamental TM01 mode



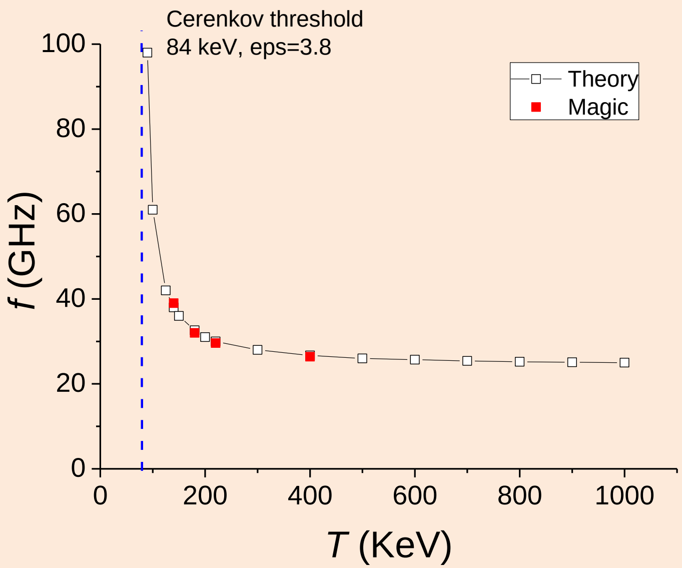




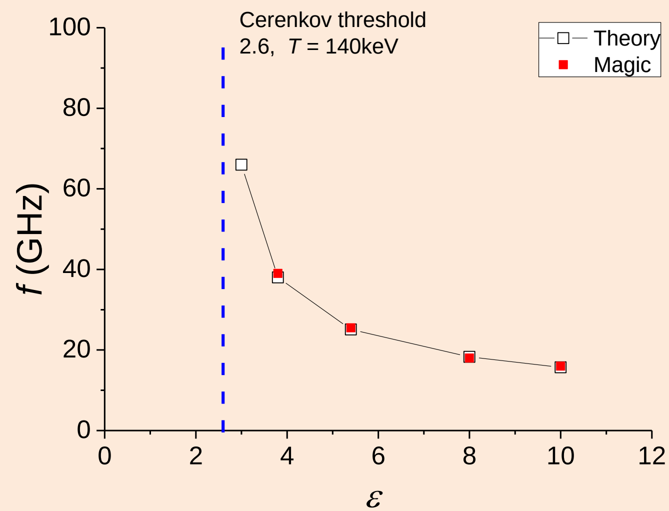
Beam bunching in a dielectric-loaded circular waveguide

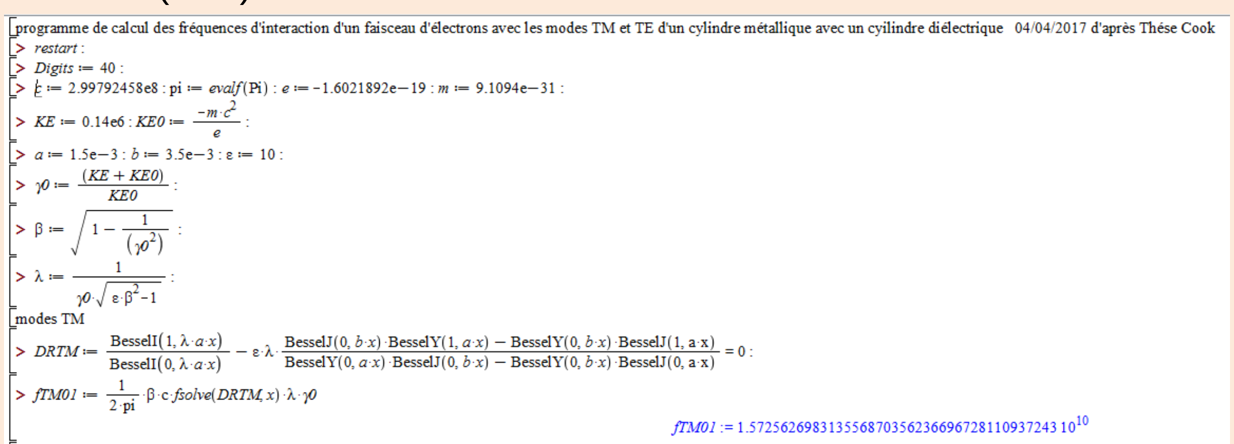
Comparison with Theory (Cook’s thesis)

Effect of the the beam KE



Effect of the dielectric constant ε





programme de calcul des fréquences d'interaction d'un faisceau d'électrons avec les modes TM et TE d'un cylindre métallique avec un cyilindre diélectrique 04/04/2017 d'après Thése Cook

> restart :

> Digits := 40 :

> $c := 2.99792458e8 : pi := evalf(\mathrm{Pi}) : e := -1.6021892e-19 : m := 9.1094e-31 :$

> $KE := 0.14e6 : KE0 := \frac{-m \cdot c^2}{e} :$

> $a := 1.5e-3 : b := 3.5e-3 : \varepsilon := 10 :$

> $\gamma 0 := \frac{(KE + KE0)}{KE0} :$

> $\beta := \sqrt{1 - \frac{1}{(\gamma 0^2)}} :$

> $\lambda := \frac{1}{\gamma 0 \cdot \sqrt{\varepsilon \cdot \beta^2 - 1}} :$

modes TM

> $DRTM := \frac{\mathrm{BesselI}(1, \lambda \cdot a \cdot x)}{\mathrm{BesselI}(0, \lambda \cdot a \cdot x)} - \varepsilon \cdot \lambda \cdot \frac{\mathrm{BesselJ}(0, b \cdot x) \cdot \mathrm{BesselY}(1, a \cdot x) - \mathrm{BesselY}(0, b \cdot x) \cdot \mathrm{BesselJ}(1, a \cdot x)}{\mathrm{BesselY}(0, a \cdot x) \cdot \mathrm{BesselJ}(0, b \cdot x) - \mathrm{BesselY}(0, b \cdot x) \cdot \mathrm{BesselJ}(0, a \cdot x)} = 0 :$

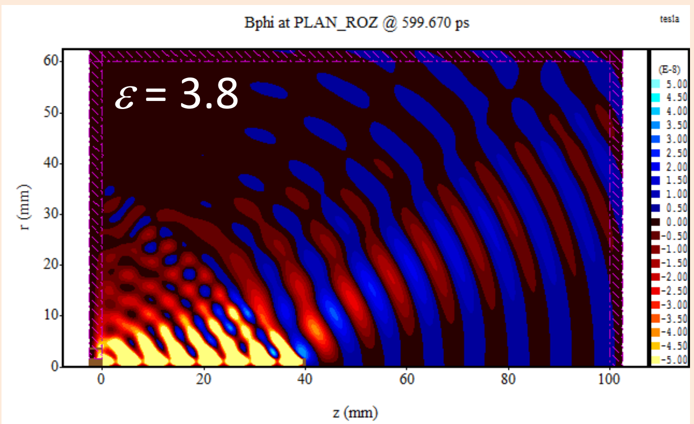
> $fTM01 := \frac{1}{2 \cdot pi} \cdot \beta \cdot c \cdot fsolve(DRTM, x) \cdot \lambda \cdot \gamma 0$

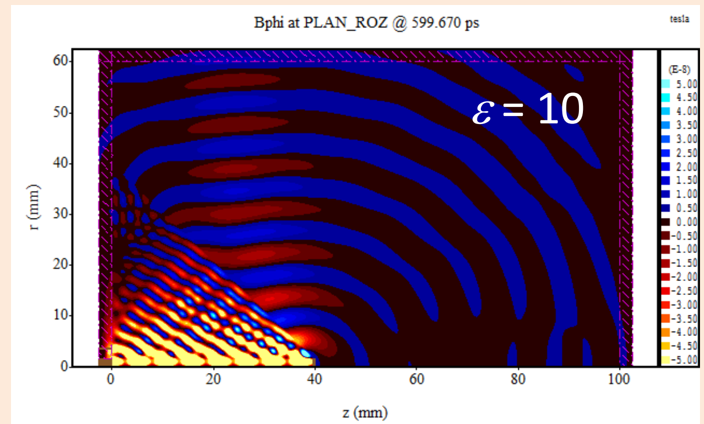
$fTM01 := 1.572562698313556870356236696728110937243 \; 10^{10}$

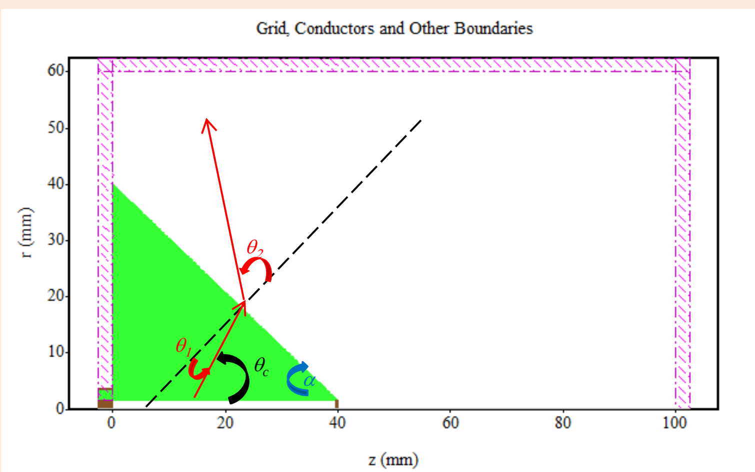
Extraction from a DLW

….checking Snell-Descartes law with MAGIC

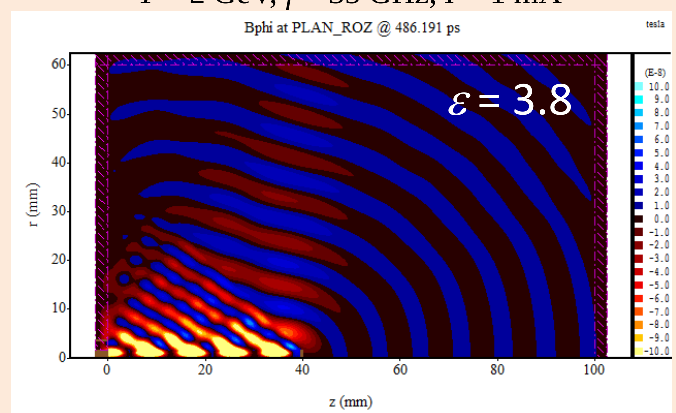
Prebunched beam: T = 140 keV, f = 35 GHz, I = 1 mA





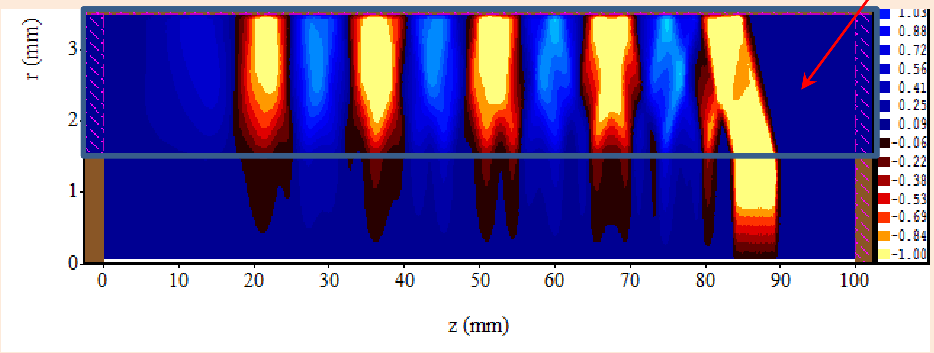


T = 2 GeV, f = 35 GHz, I = 1 mA



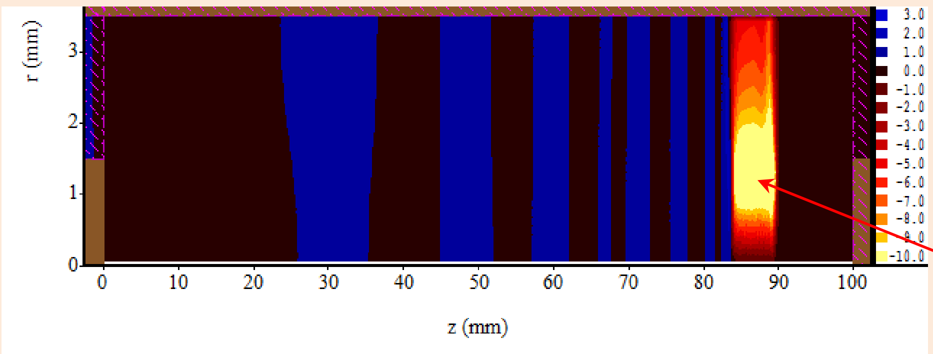
Interaction of a single bunch in a DLW

DLW (not visible):
Diamond $\varepsilon = 5.7$



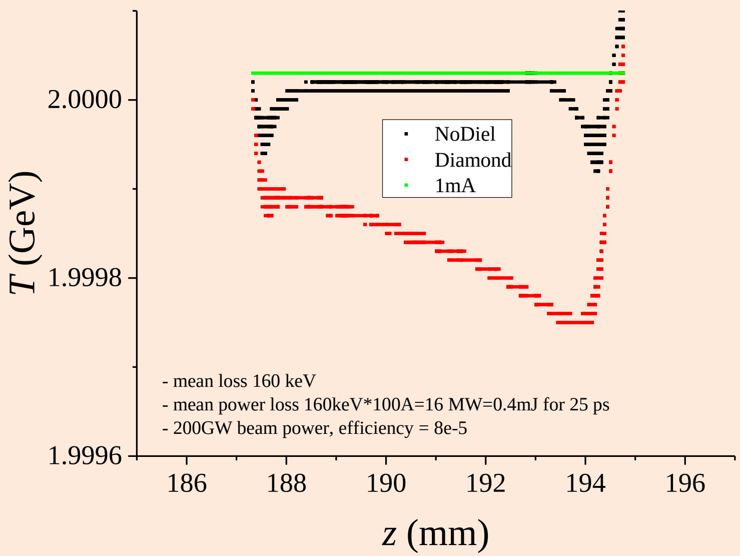
Homogeneous & perfect electron bunch :

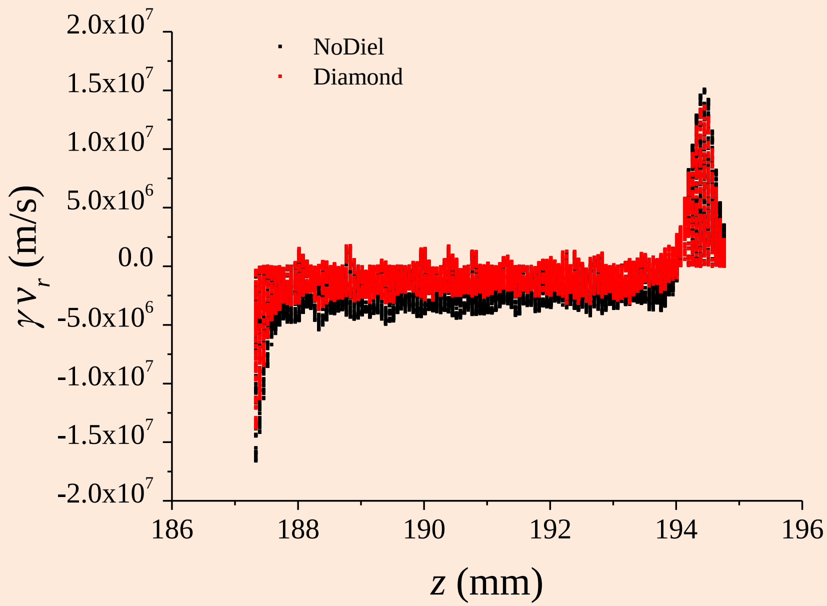
T = 2 GeV, I_p = 100 A,; τ = 25 ps, rt = 1ps



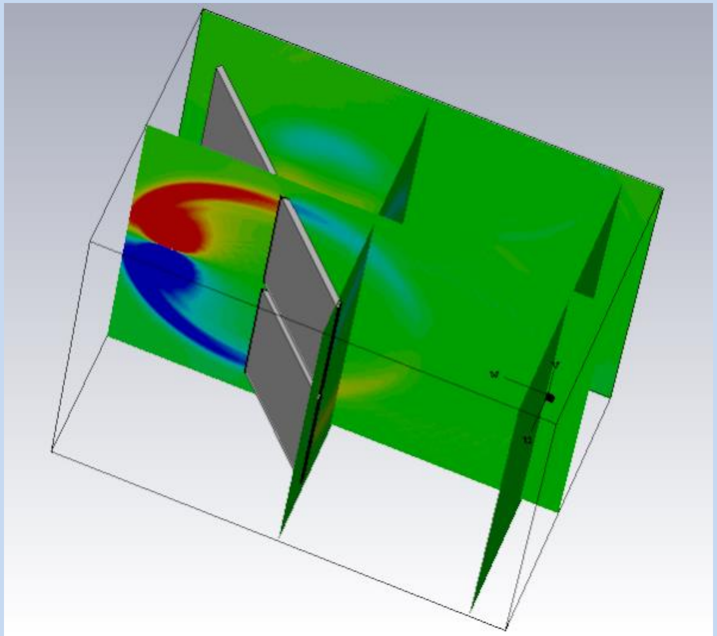
B-field in an empty waveguide

Interaction of a single bunch in a DLW





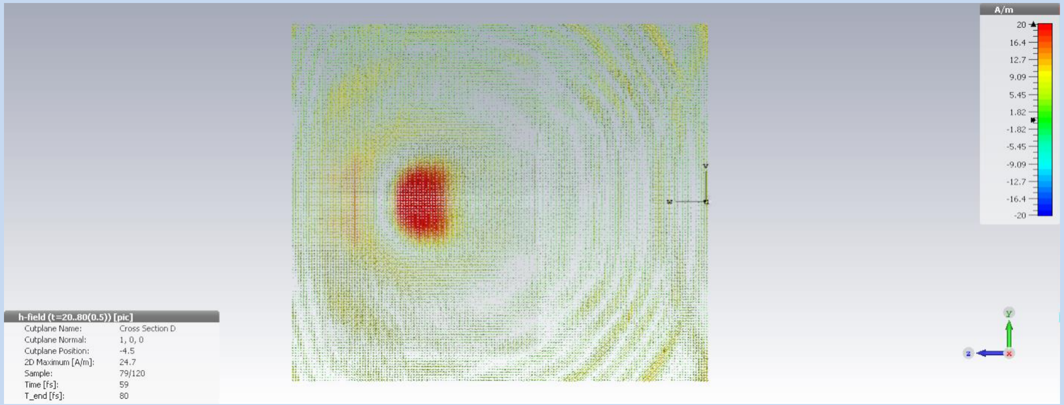
Example with CST (ODR)



beam.mpg

EyX=m4p5 - Copie.mpg

T200VODR45Hz - Copie.mpg



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