

Subterahertz Radiation from Corrugated Pipe

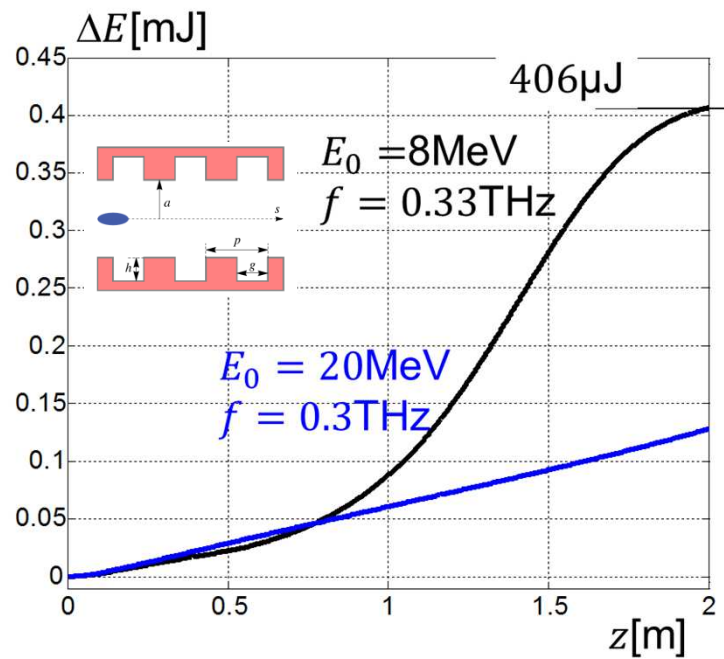
Self-Consistent Simulation of Longitudinal Dynamics

Igor Zagorodnov

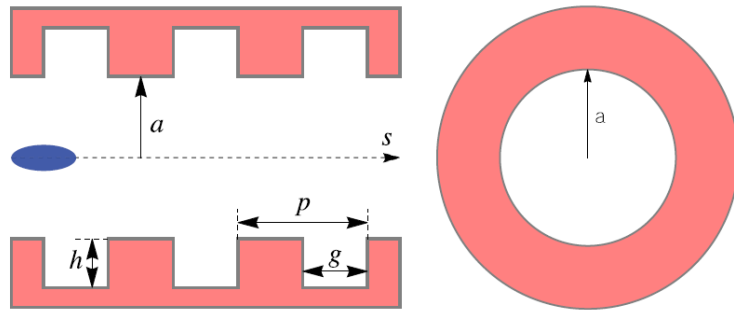
Mini-workshop on THz option at
PITZ (piTHz)

Zeuthen

22. September 2015



Problem fomulation. Relativistic bunch.



Nuclear Instruments and Methods in Physics Research A 677 (2012) 67–73



Contents lists available at SciVerse ScienceDirect
**Nuclear Instruments and Methods in
 Physics Research A**
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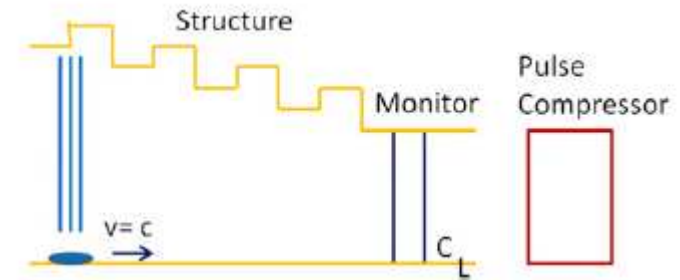


Table 1

Parameters for the standard tapered, corrugated structure and for the exciting bunch, to be used in simulations given in the next section.

Pipe radius a , mm	2–1
Pipe length L , cm	50
Depth δ , μm	50
Period p , μm	40
Gap g , μm	20
Bunch charge Q , nC	1
Bunch length σ_2 , μm	100

Table 2

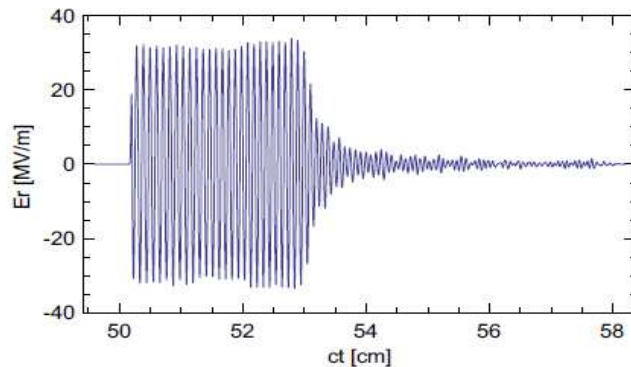
Radiation properties (numerical results).

Frequency f , THz	0.30–0.44
Pulse energy U , mJ	2.3
Pre-compression	
Peak power P , MW	20
Pulse length ℓ , cm	3.5
Post-compression	
Peak power P , MW	250
Pulse length ℓ , cm	0.3

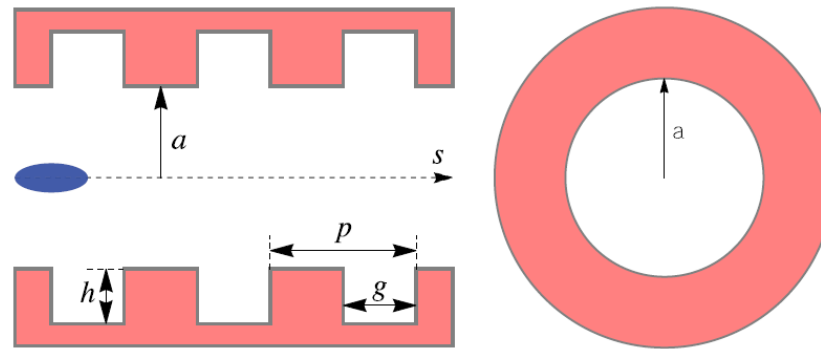
Terahertz radiation from a pipe with small corrugations[☆]

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Problem fomulation. Low energy



PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 18, 030709 (2015)

Using pipe with corrugated walls for a subterahertz free electron laser

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(Received 1 January 2015; published 18 March 2015)

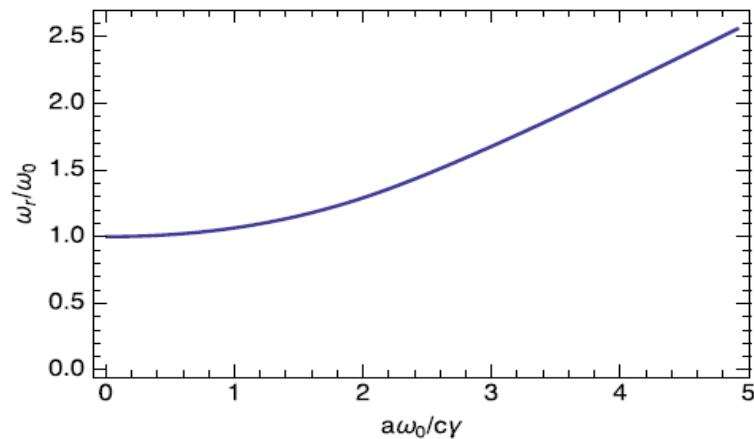
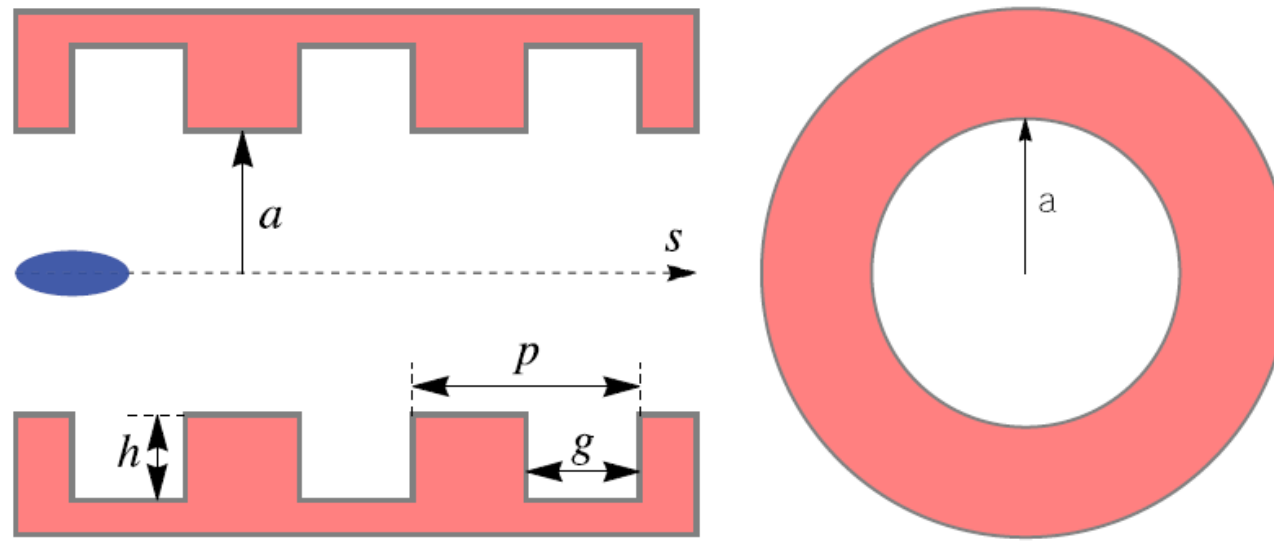


TABLE I. Corrugation and beam parameters.

Pipe radius (mm)	2
Depth h (μm)	50
Period p (μm)	40
Gap g (μm)	10
Bunch charge (nC)	1
Energy (MeV)	5
Bunch length (ps)	10

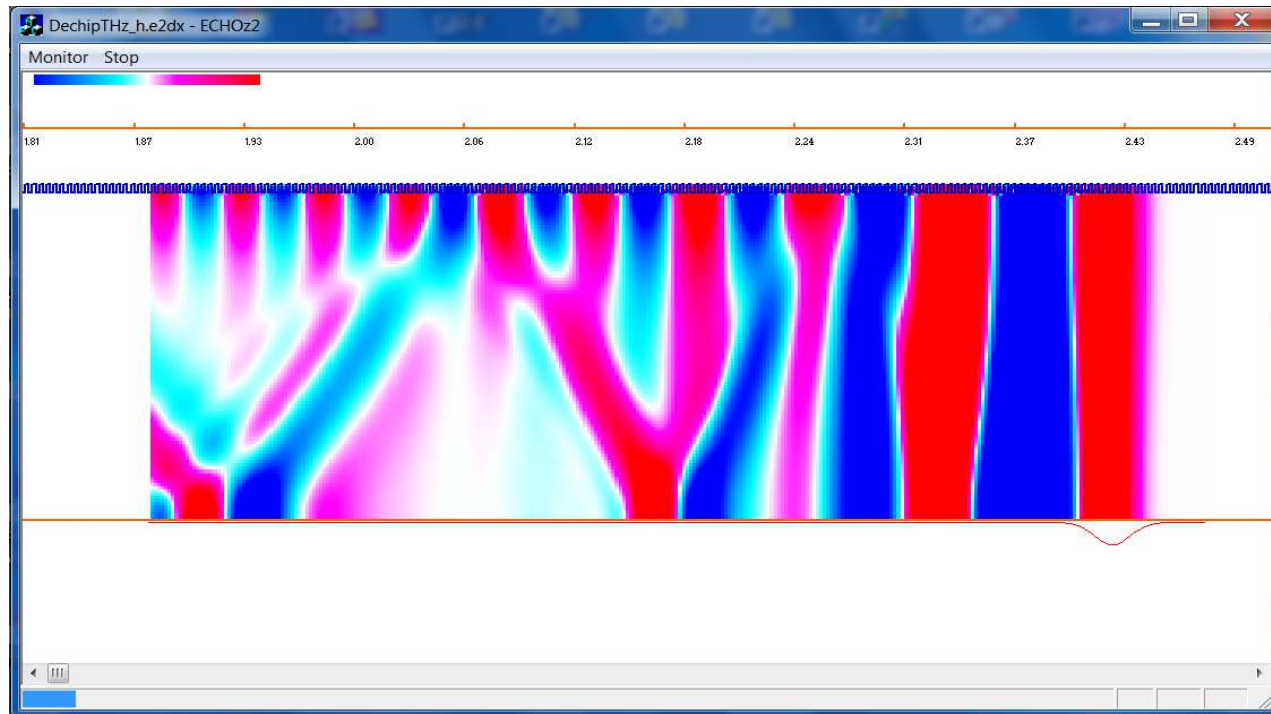


Problem fomulation. Geometry



Pipe radius a , mm	2
Pipe length L , m	0.5-2
Corrugation depth h , mm	0.05
Corrugation period p , mm	0.04
Corrugation gap g , mm	0.02
Gaussian bunch rms σ , mm	0.1-0.3(*8)

Code modification



Wakefield code ECHO
(with resistivity)



Particle-in-Cell code ECHO-PIC
(only longitudinal dynamics)

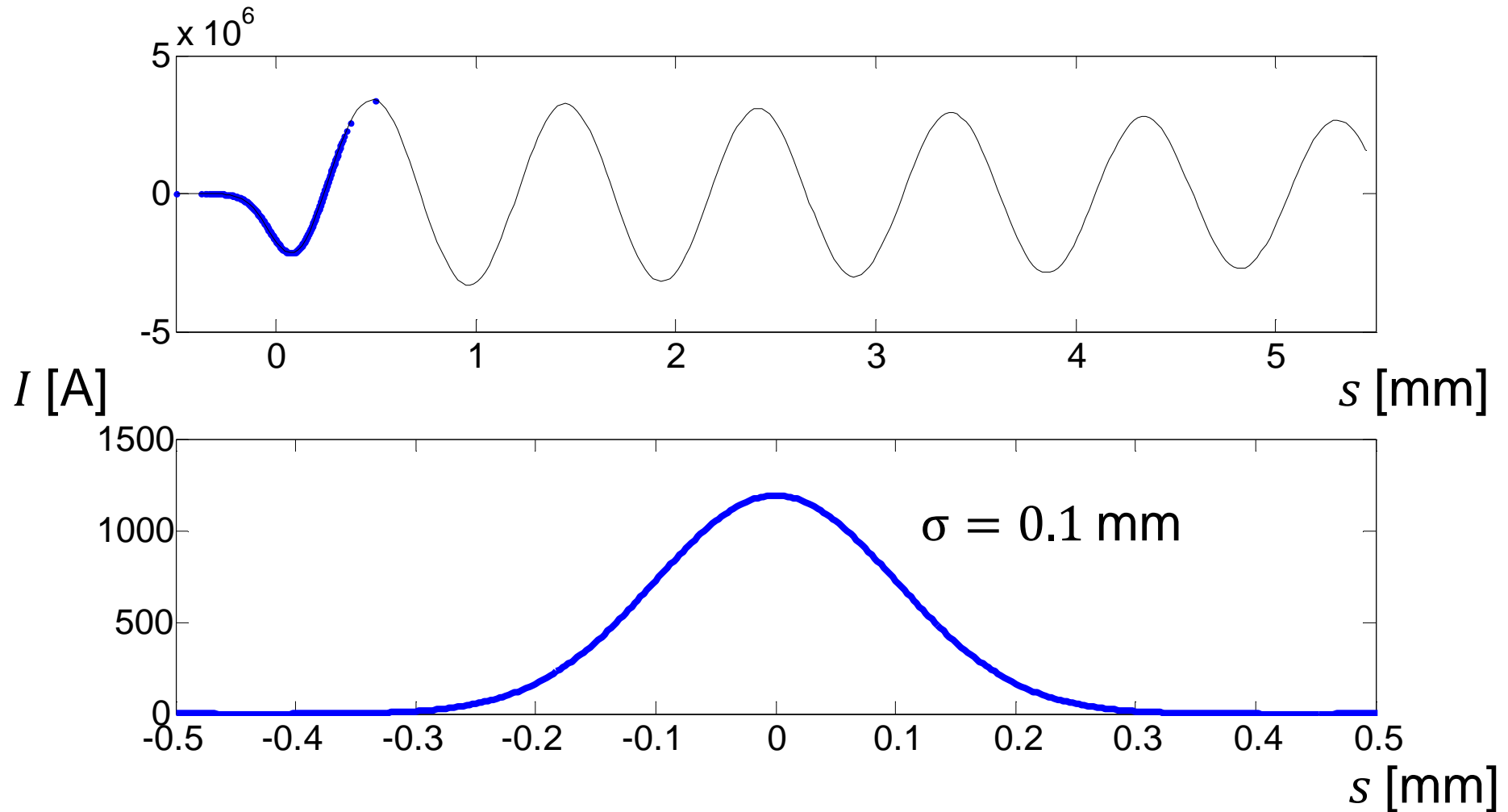
Short bunch. High charge. High Energy

Pipe length L , m	0.5
Bunch energy E_0 , MeV	14000
Gaussian bunch rms σ , mm	0.1
Charge Q , nC	1



Short bunch. High charge. High Energy

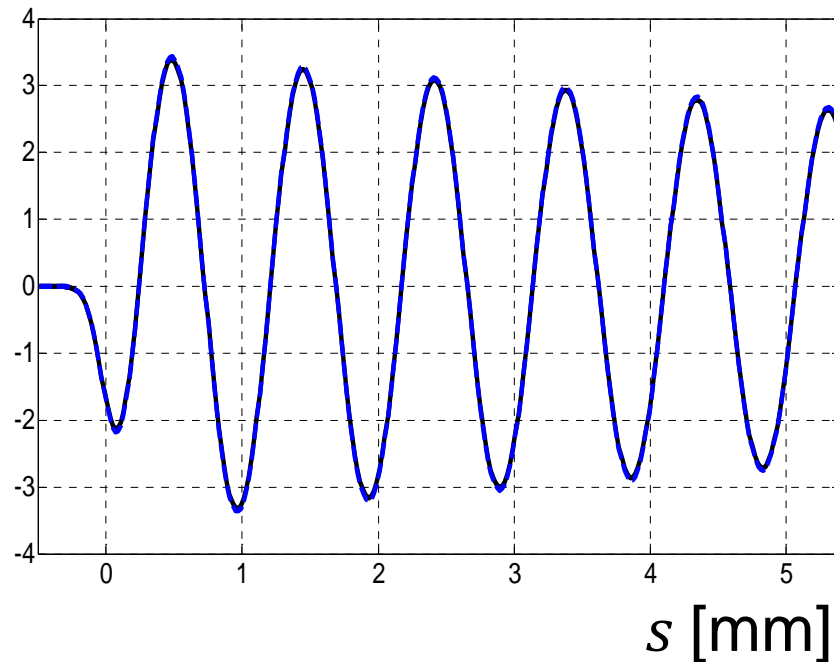
$2\Delta E$ [eV/m] $Q = 1$ nC $E_0 = 14$ GeV



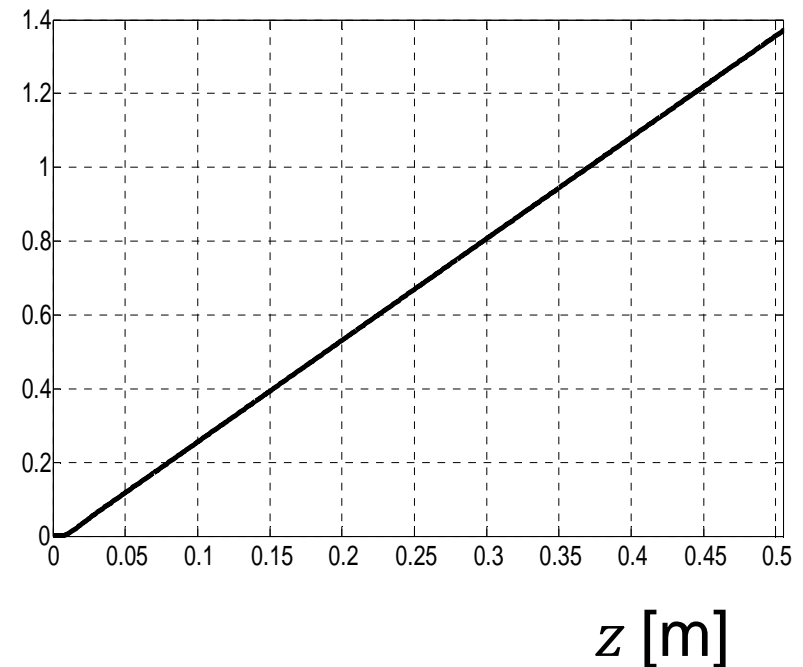
Short bunch. High charge. High Energy

$$Q = 1 \text{ nC} \quad E_0 = 14 \text{ GeV} \quad \sigma = 0.1 \text{ mm}$$

ΔE [MeV]



ΔE [mJ]



Short bunch. High charge. Low Energy

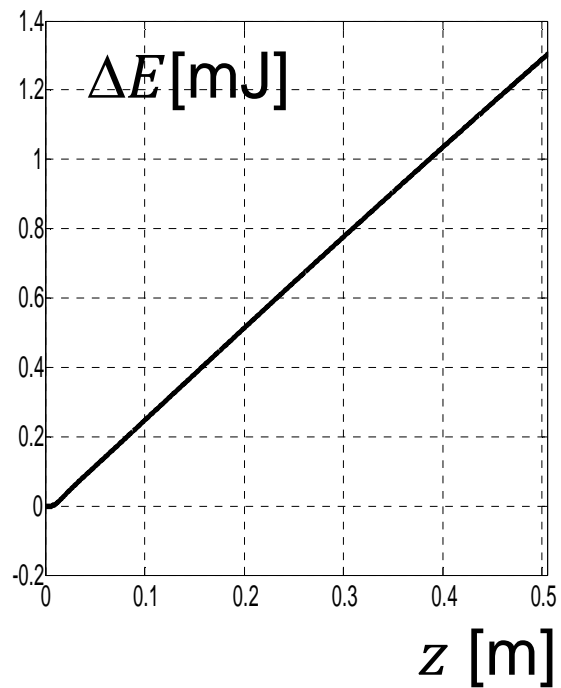
Pipe length L , m	0.5
Bunch energy E_0 , MeV	5-20
Gaussian bunch rms σ , mm	0.1
Charge Q , nC	1



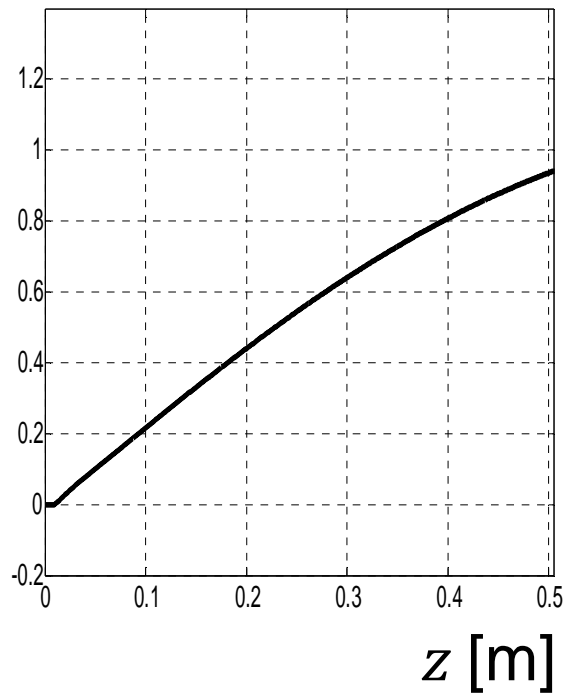
Short bunch. High charge. Low Energy

$$Q = 1 \text{ nC} \quad \sigma = 0.1 \text{ mm}$$

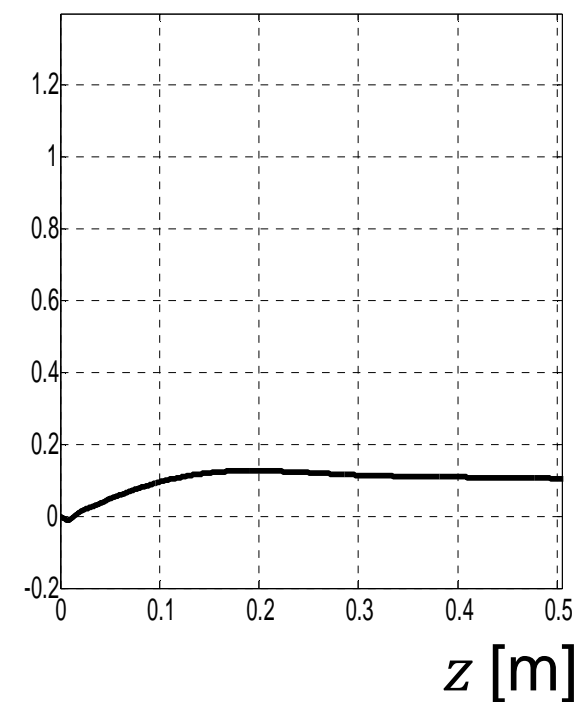
$$E_0 = 20 \text{ MeV}$$



$$E_0 = 10 \text{ MeV}$$

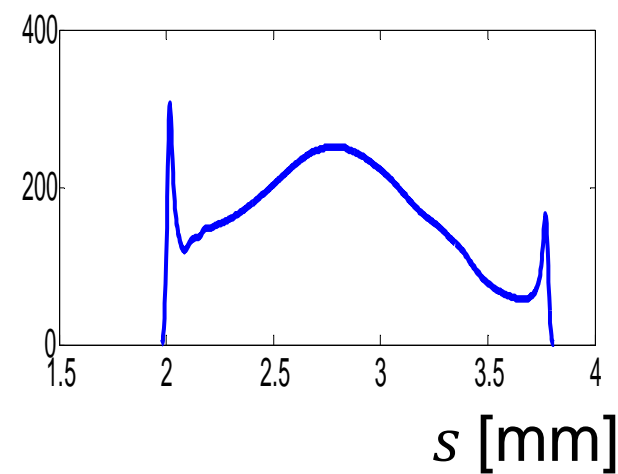
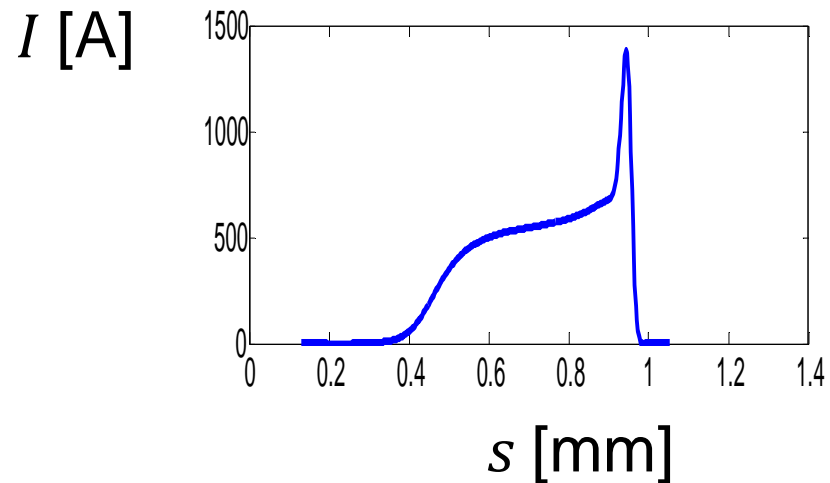
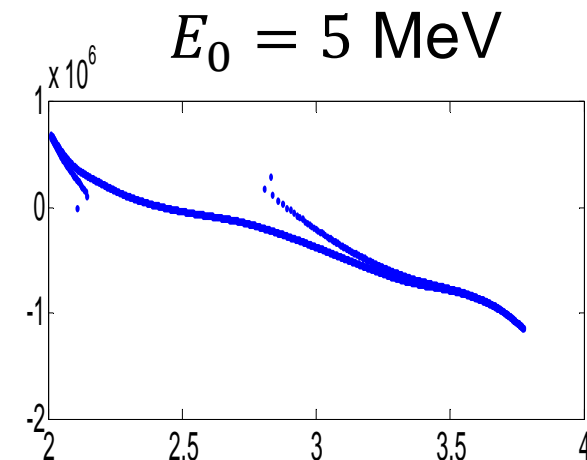
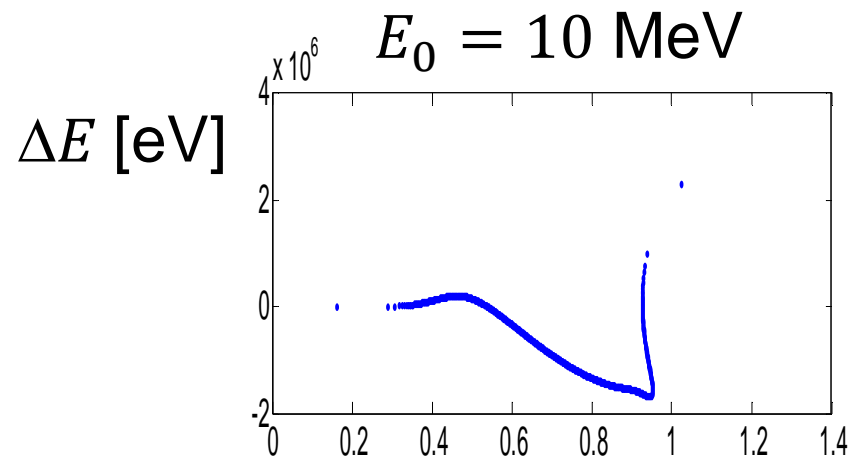


$$E_0 = 5 \text{ MeV}$$



Short bunch. High charge. Low Energy

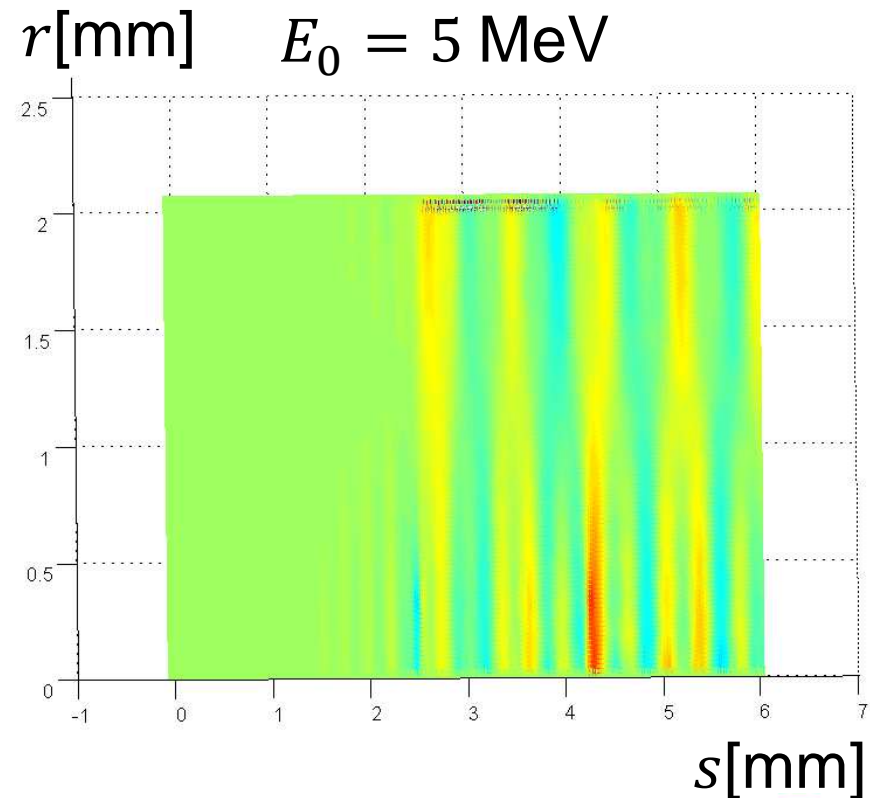
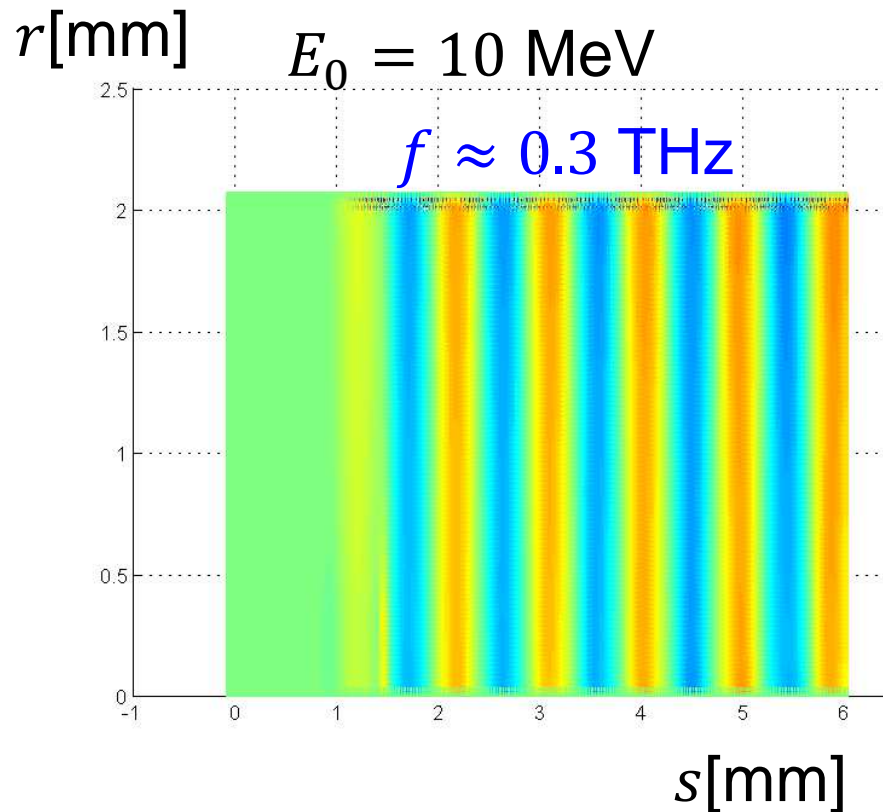
$$Q = 1 \text{ nC} \quad \sigma = 0.1 \text{ mm} \quad I_0 = 1200 \text{ A}$$



Short bunch. High charge. Low Energy

Longitudinal electric field component E_z

$$Q = 1 \text{ nC} \quad \sigma = 0.1 \text{ mm}$$



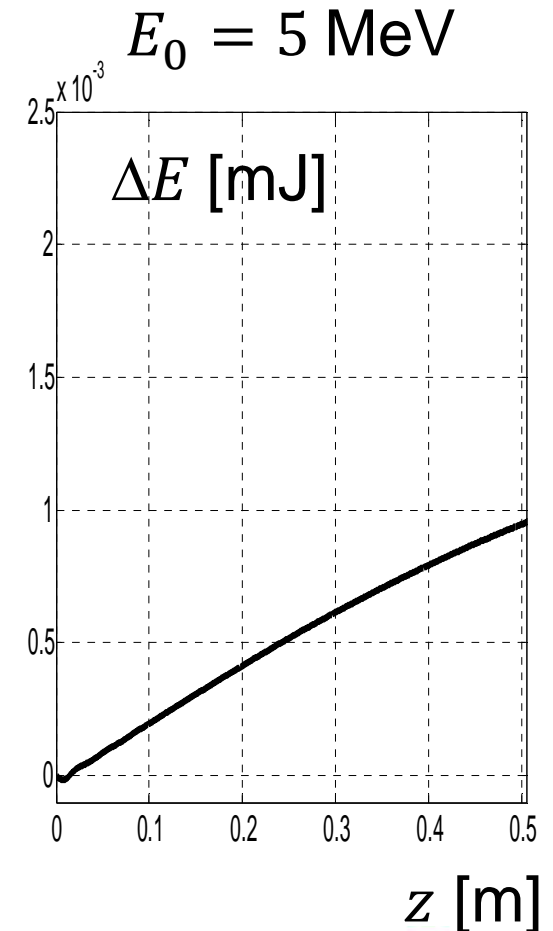
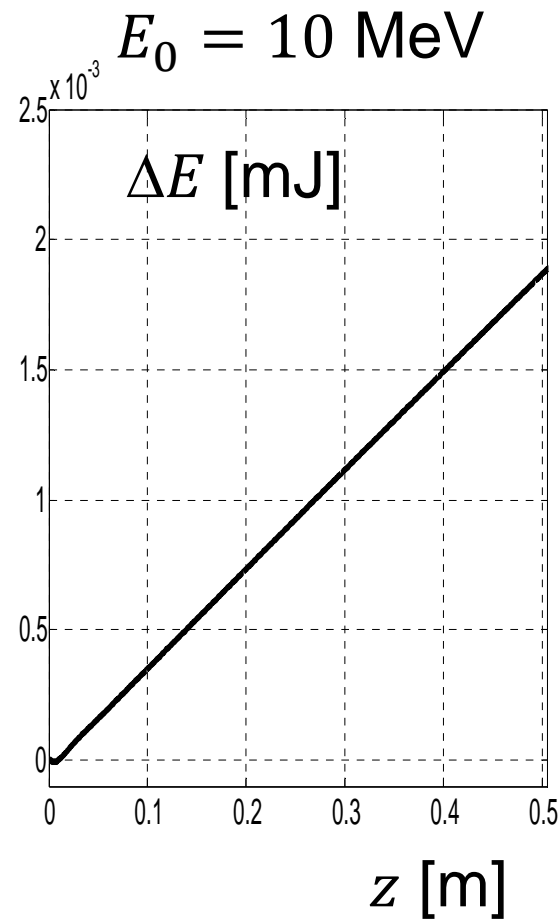
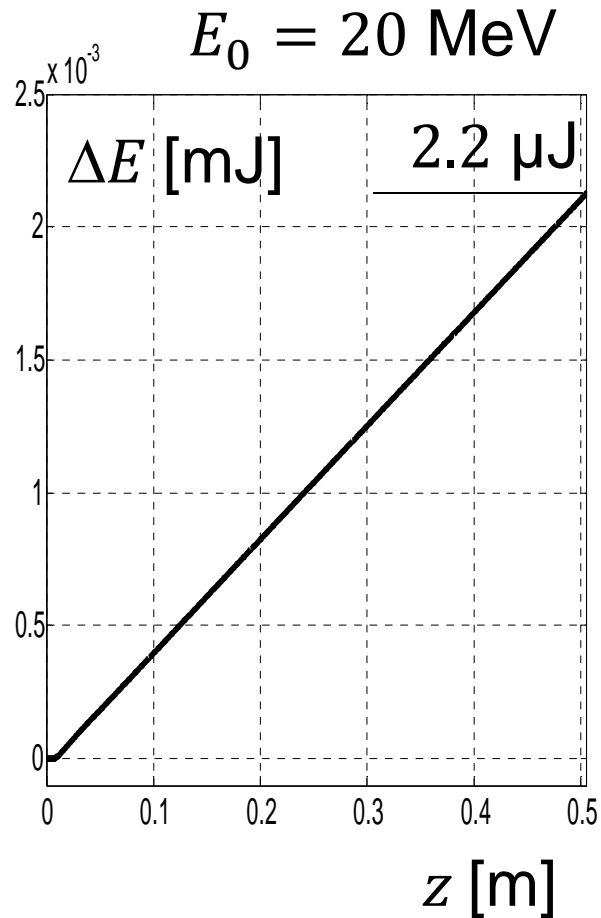
Short bunch. Low charge. Low Energy

Pipe length L , m	0.5
Bunch energy E_0 , MeV	5-20
Gaussian bunch rms σ , mm	0.1
Charge Q , nC	0.04



Short bunch. Low charge. Low Energy

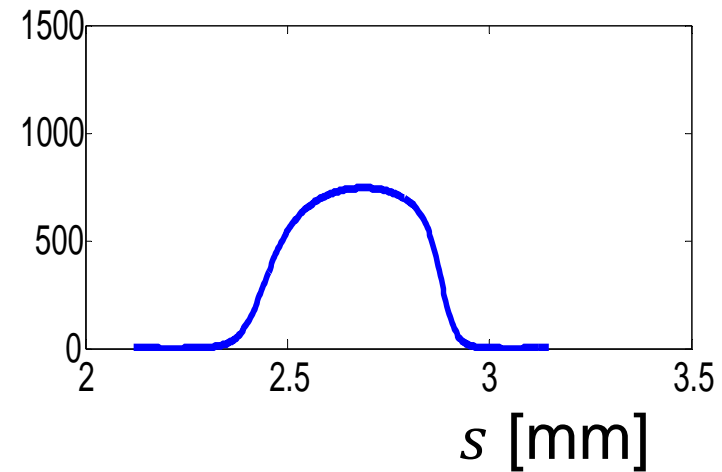
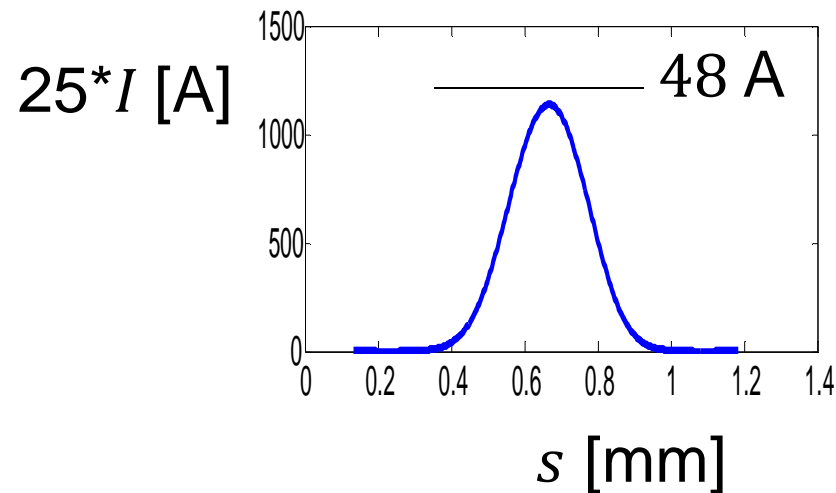
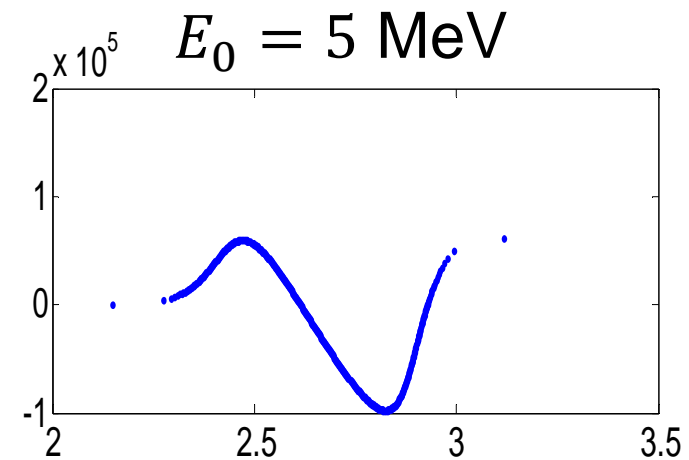
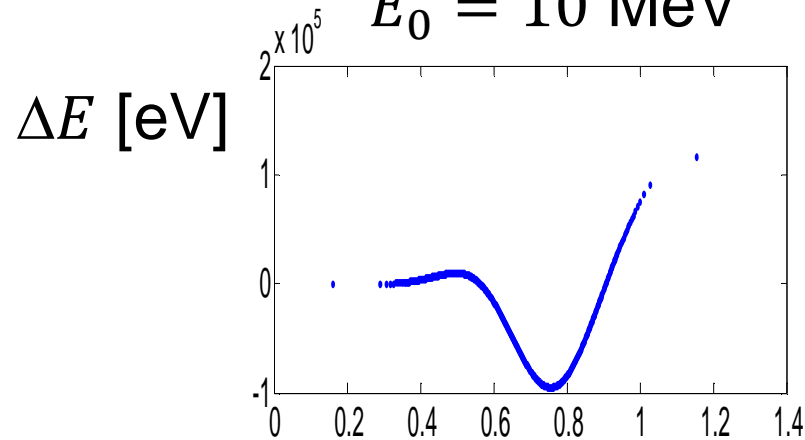
$$Q = 40 \text{ pC} \quad \sigma = 0.1 \text{ mm} \quad I_0 = 48 \text{ A}$$



Short bunch. Low charge. Low Energy

$$Q = 40 \text{ pC} \quad \sigma = 0.1 \text{ mm} \quad I_0 = 48 \text{ A}$$

$$E_0 = 10 \text{ MeV}$$

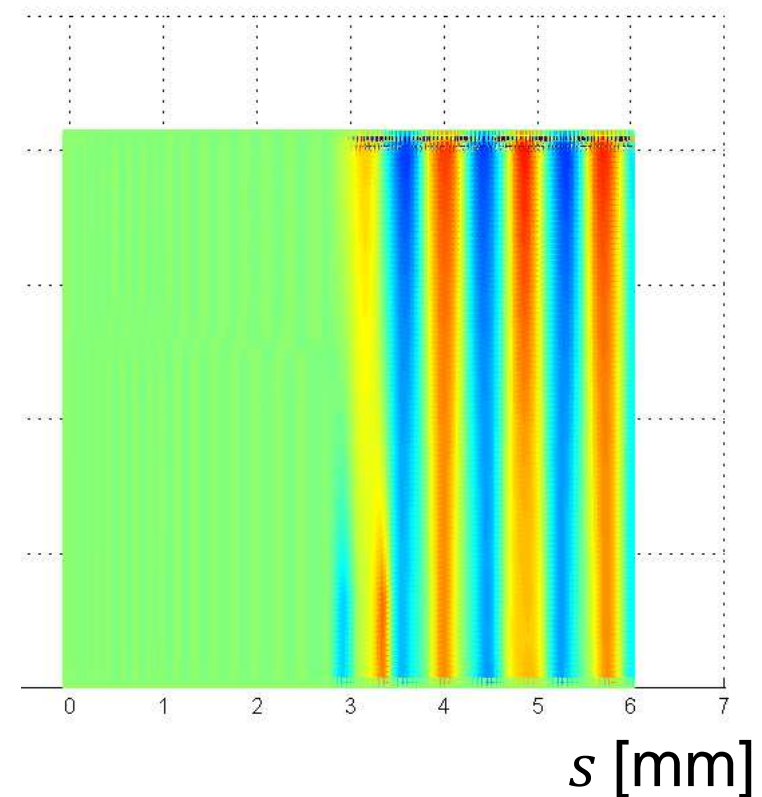
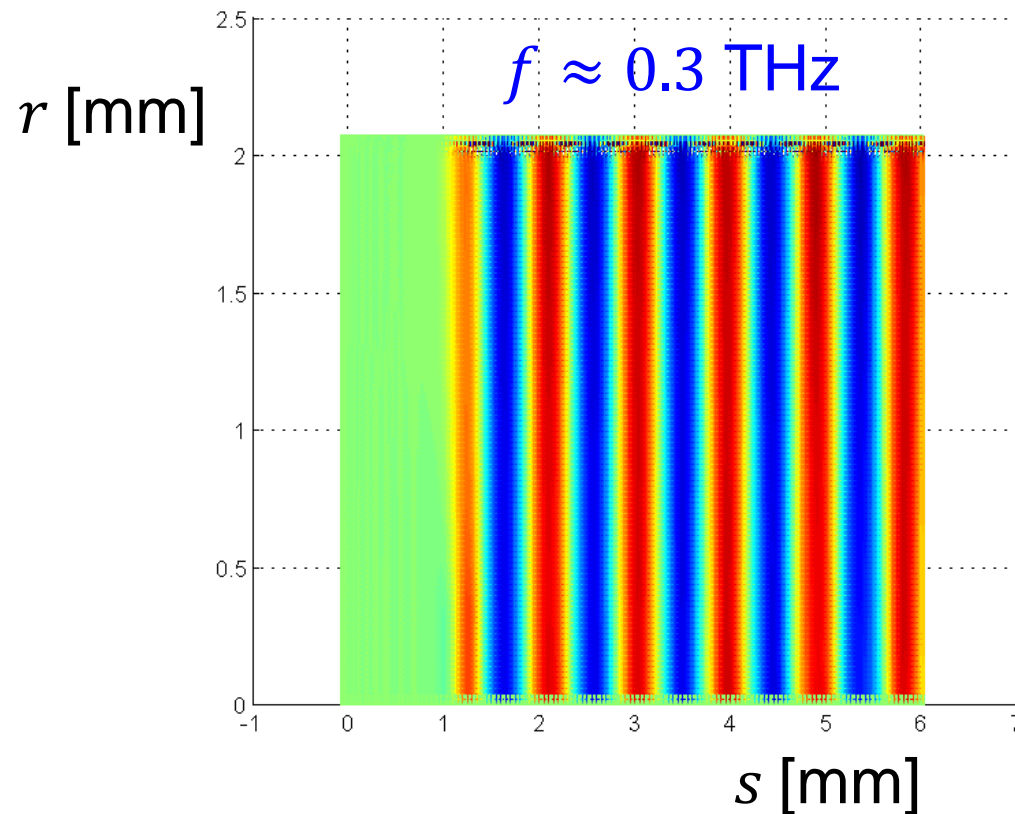


Short bunch. Low charge. Low Energy

Longitudinal electric field component E_z

$$E_0 = 10 \text{ MeV}$$

$$E_0 = 5 \text{ MeV}$$



Middle bunch. Middle charge. Low Energy

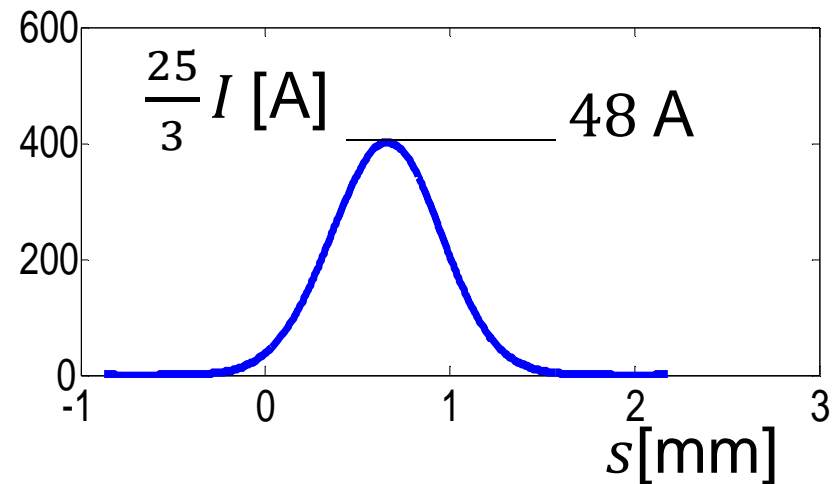
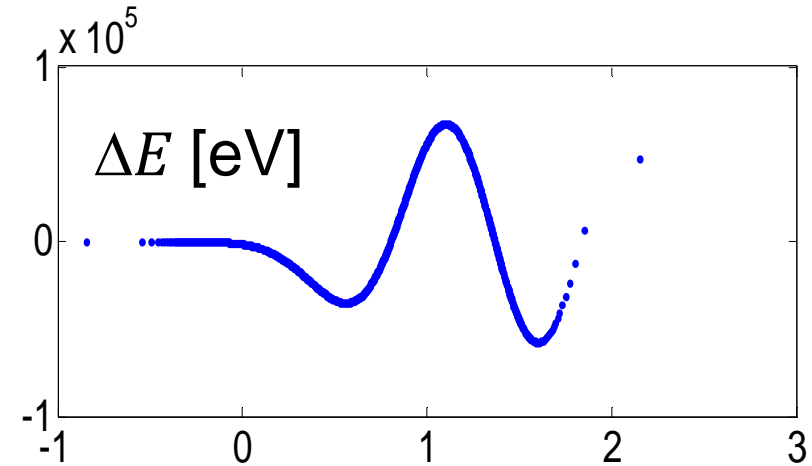
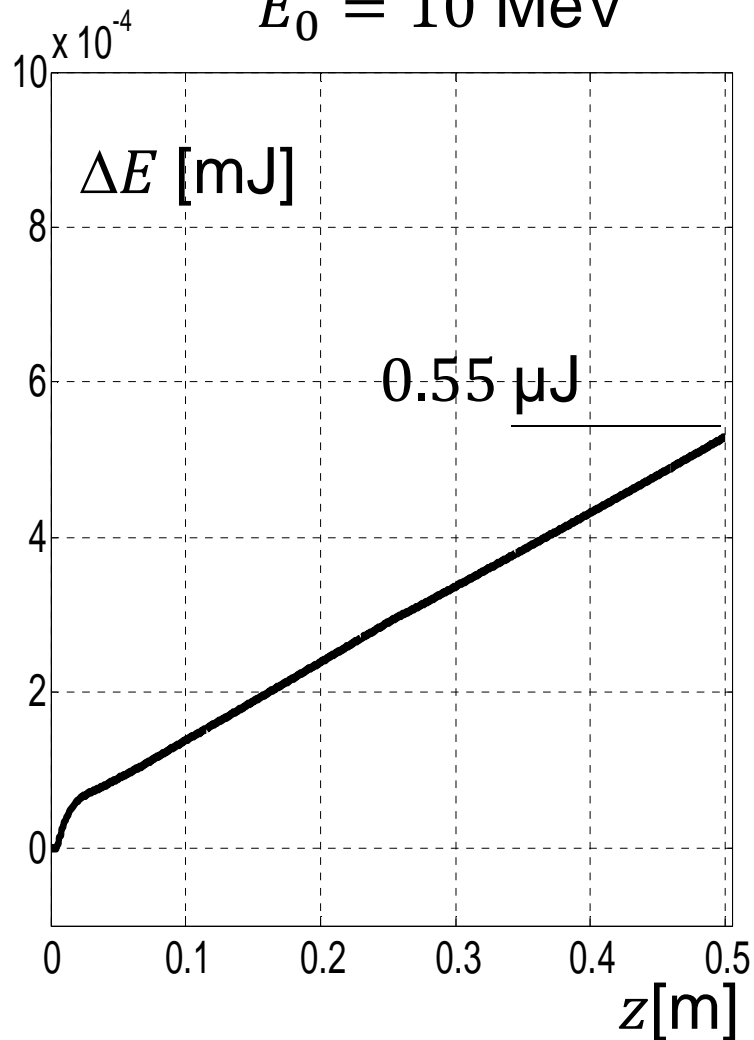
Pipe length L , m	0.5
Bunch energy E_0 , MeV	10
Gaussian bunch rms σ , mm	0.3
Charge Q , nC	0.12



Middle bunch. Middle charge. Low Energy

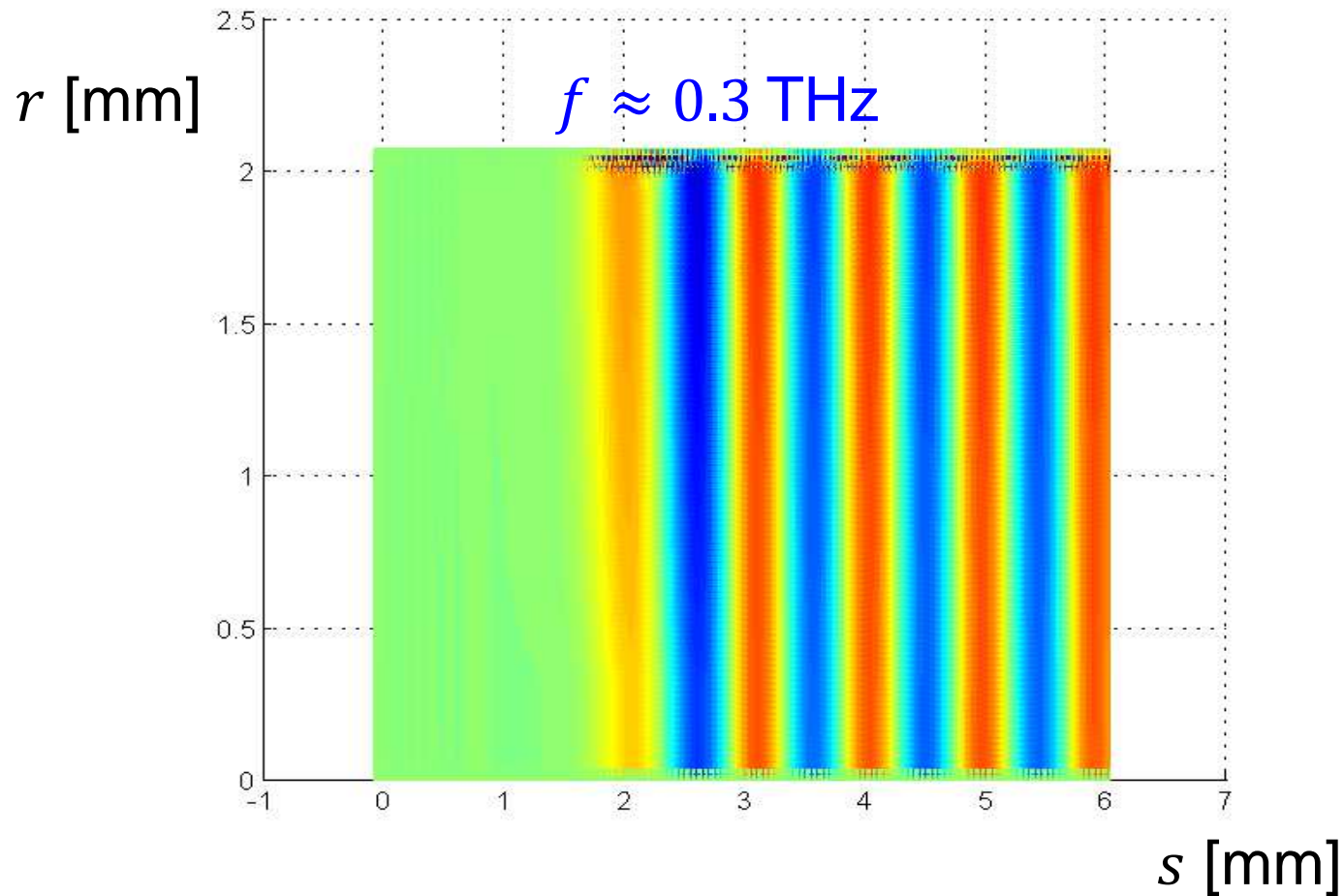
$$Q = 120 \text{ pC} \quad \sigma = 0.3 \text{ mm} \quad I_0 = 48 \text{ A}$$

$$E_0 = 10 \text{ MeV}$$

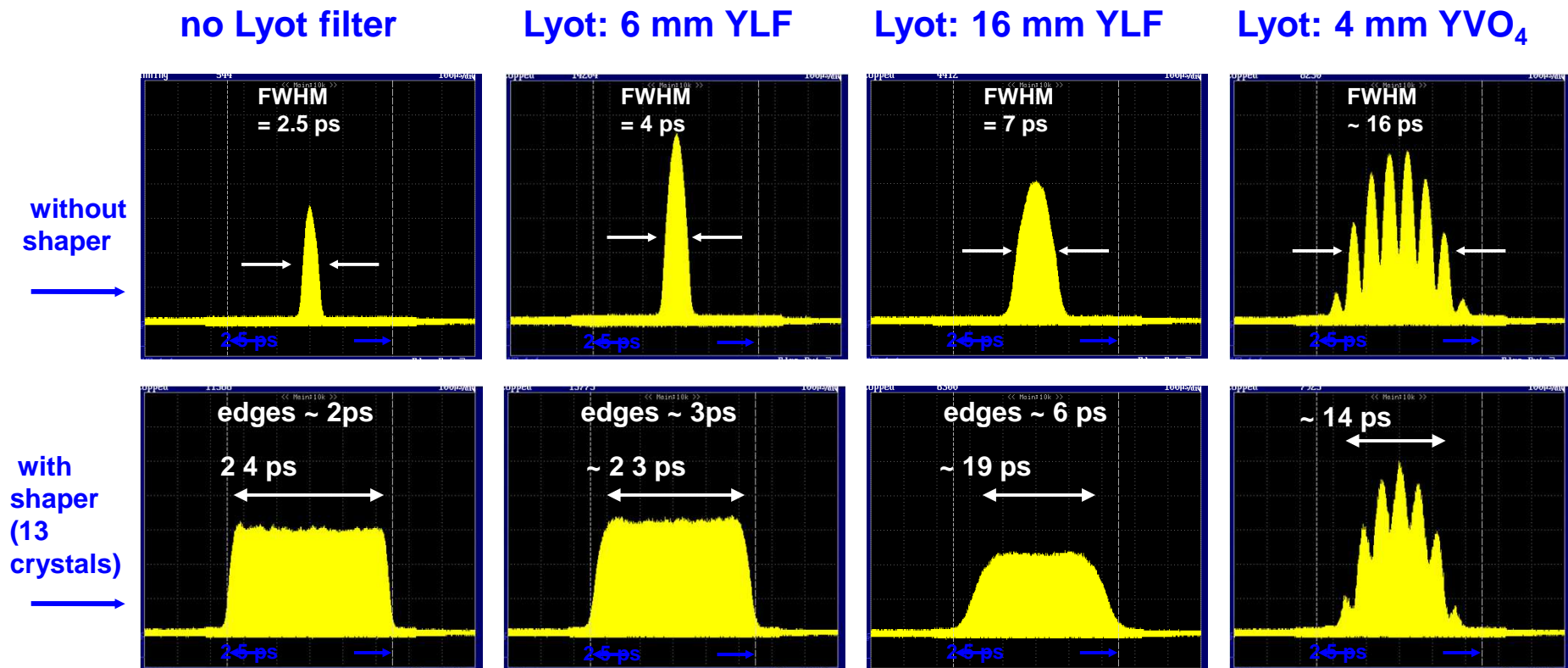


Middle bunch. Middle charge. Low Energy

Longitudinal electric field component E_z



Premodulated bunch (from M. Krasilnikov)

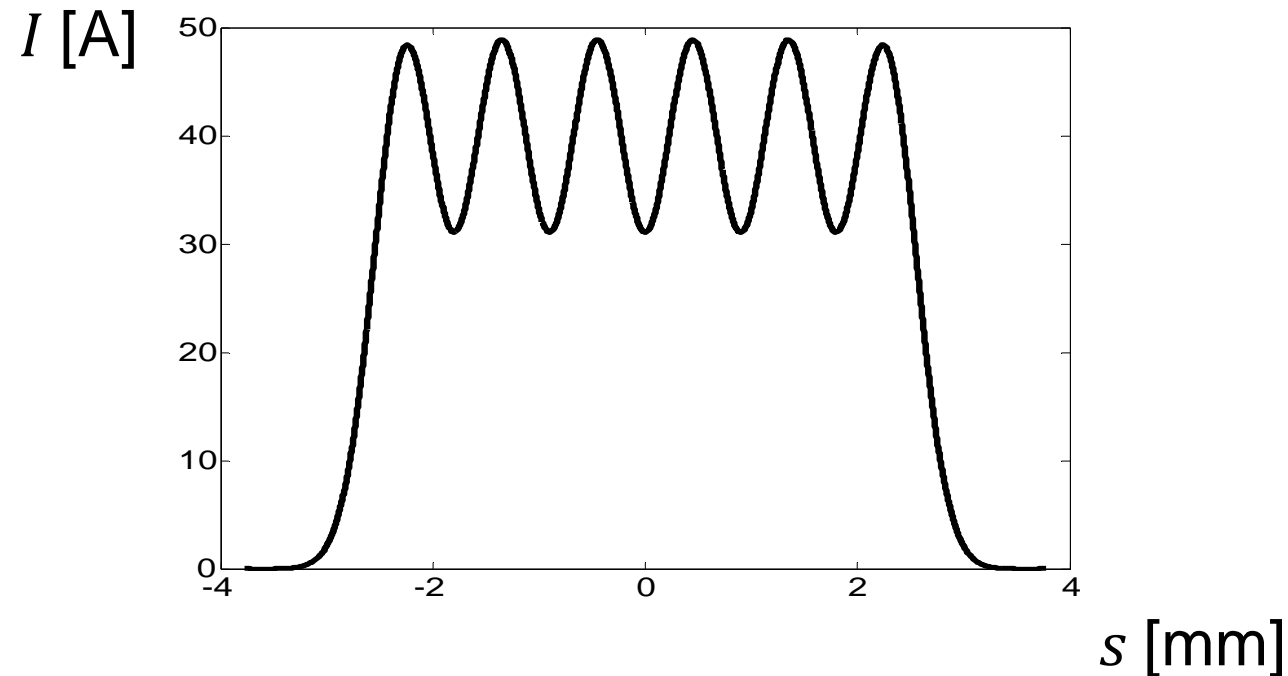


- Edges of the flat-top pulses are slightly shorter than FWHM of the Gaussian pulse (measured without shaper)
- **“Smoothing” of the Modulations** in the flat-top region of the pulse

I. Will, G. Klemz „Increasing the flexibility in pulse shape of a Yb:YAG photocathode laser” 20.06.2009

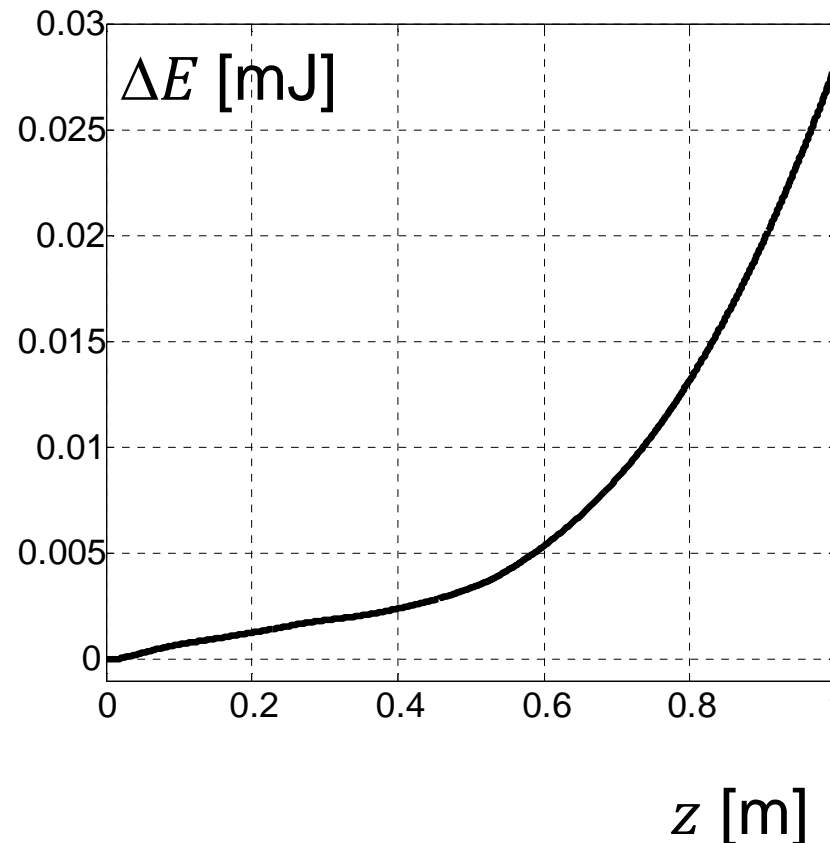
Premodulated bunch. 6 microbunches

Pipe length L , m	0.5
Bunch energy E_0 , MeV	5
Gaussian bunch rms σ , mm	$0.3*6$
Charge Q , nC	$0.12*6$

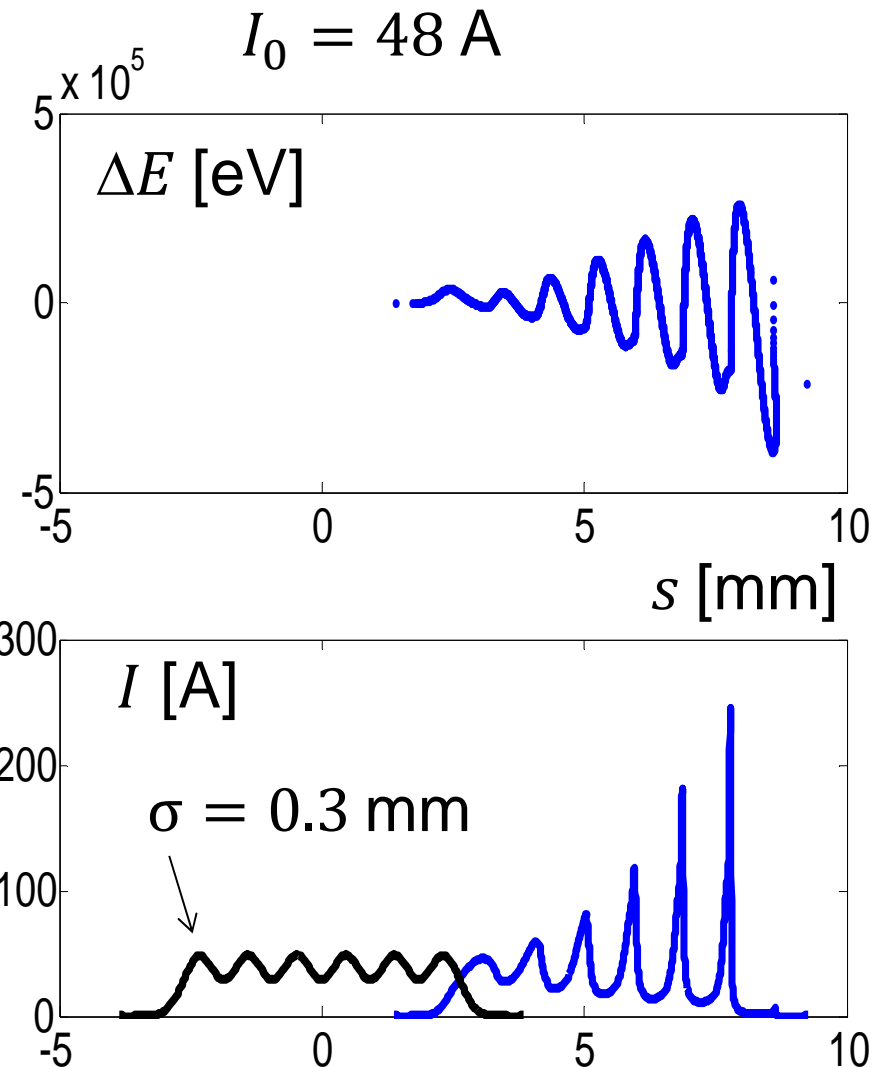


Premodulated bunch. 6 microbunches

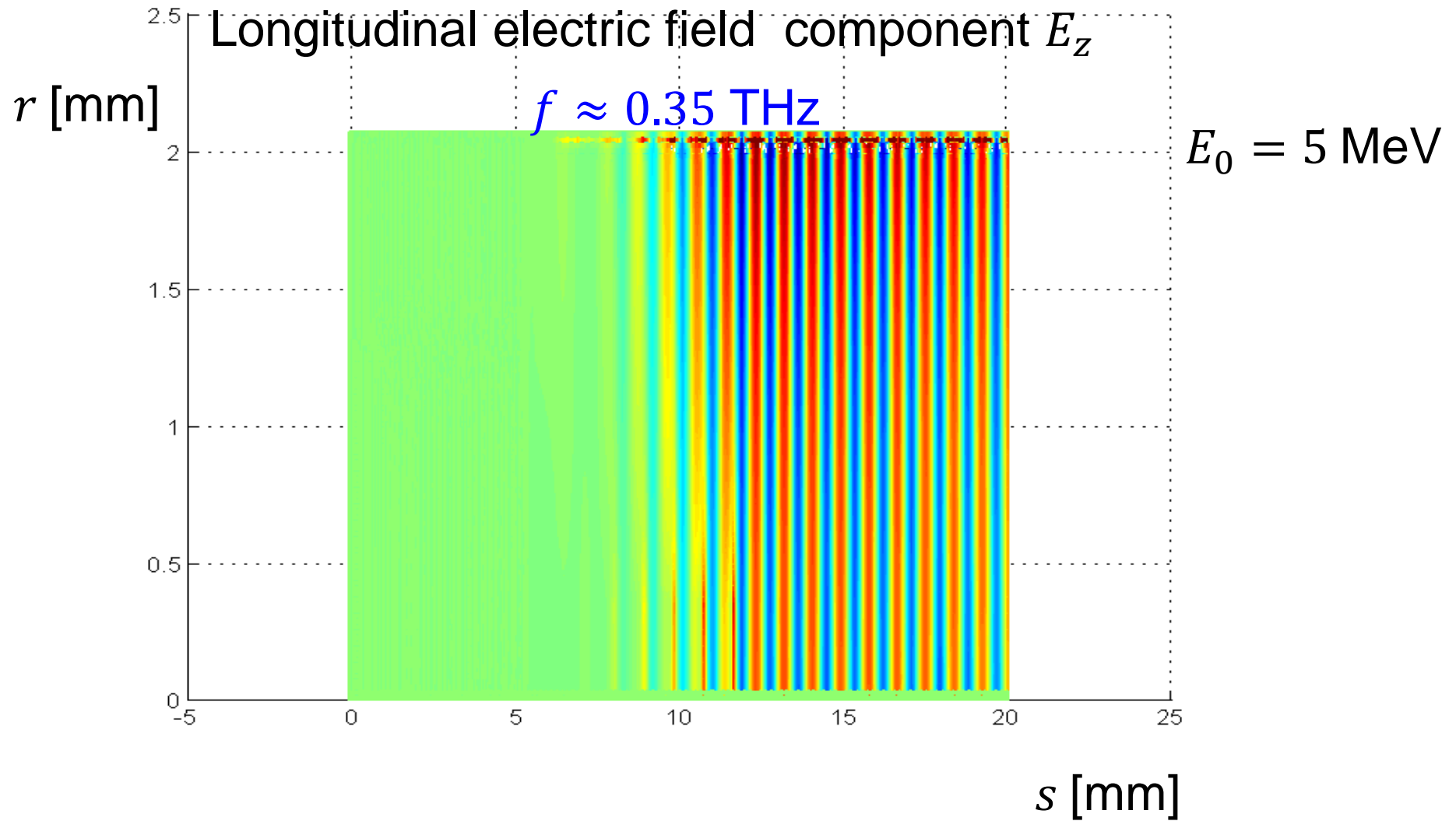
$$E_0 = 5 \text{ MeV}$$
$$Q = 6 * 120 \text{ pC}$$



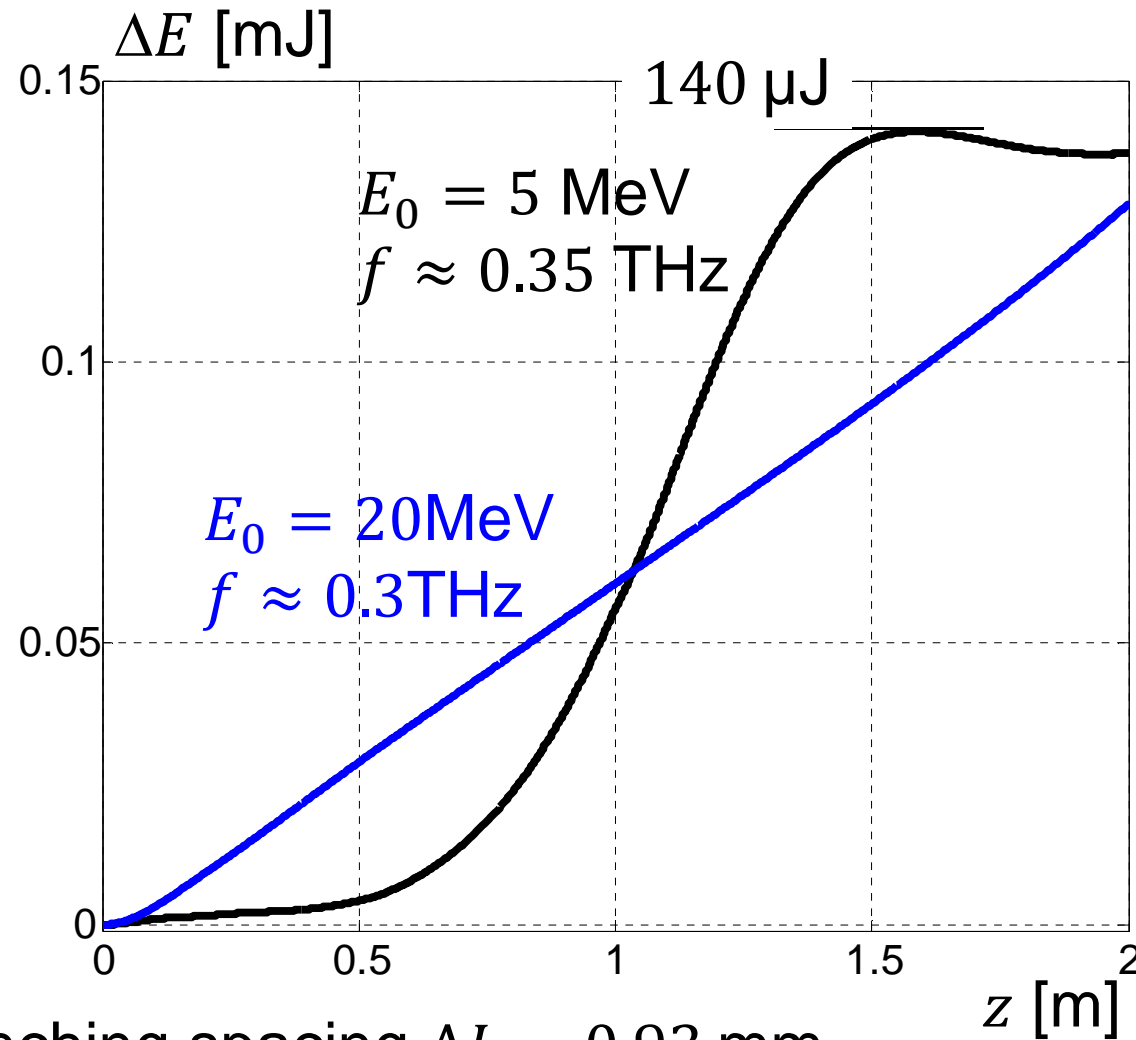
Microbunching spacing $\Delta L = 0.93 \text{ mm}$



Premodulated bunch. 6 microbunches



Premodulated bunch. 8 microbunches



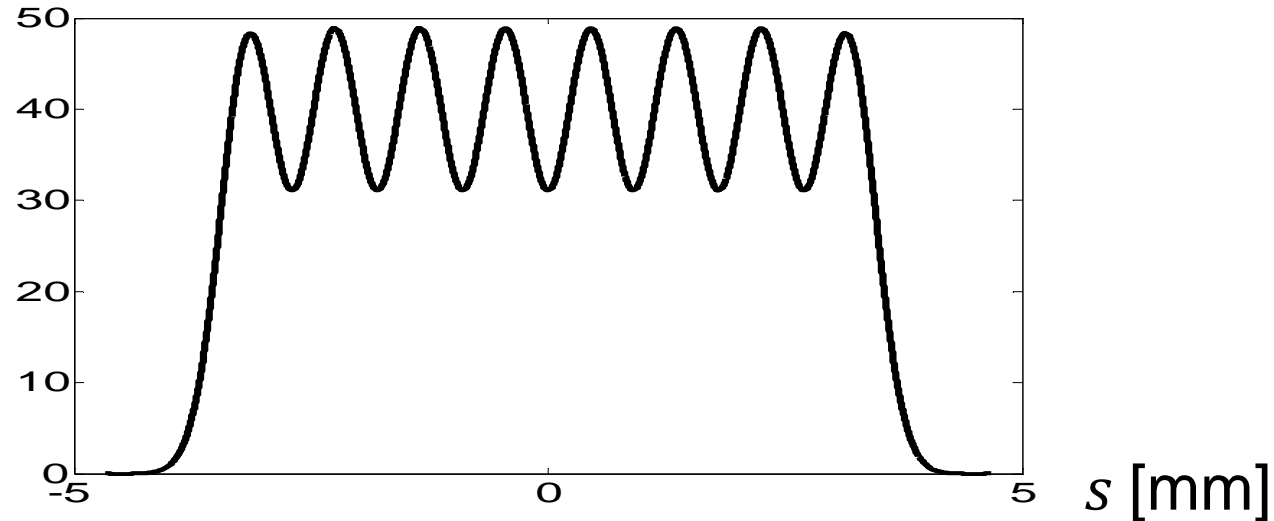
Microbunching spacing $\Delta L = 0.93 \text{ mm}$



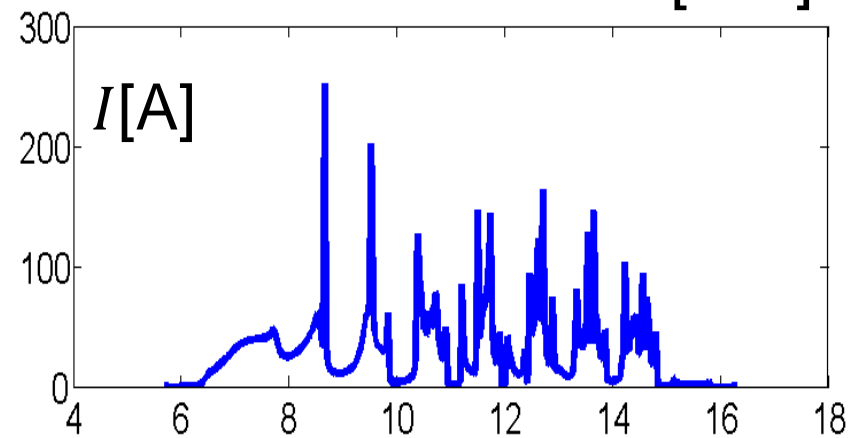
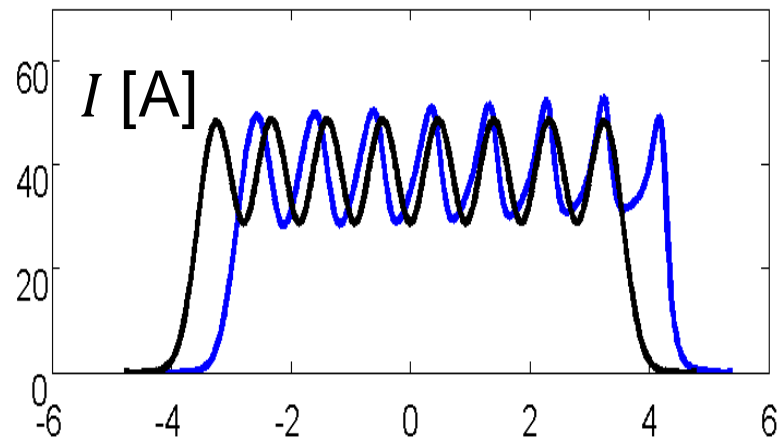
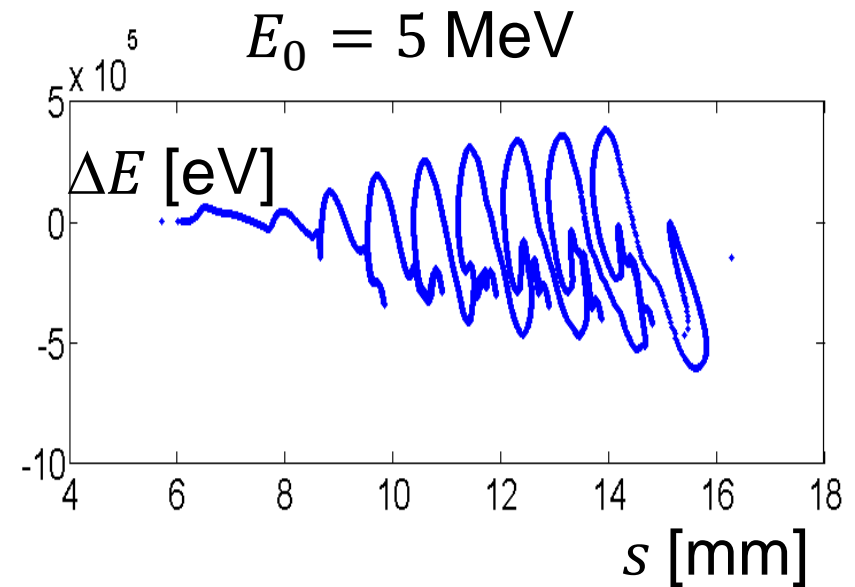
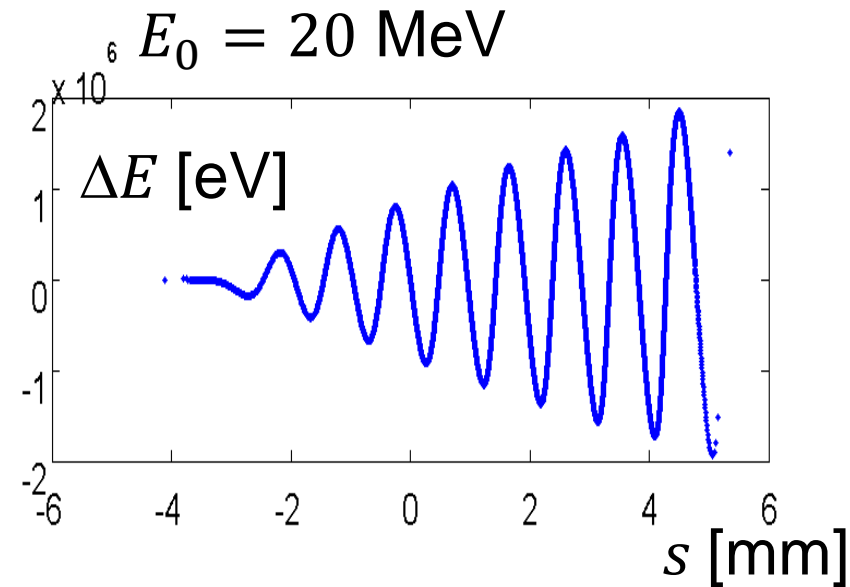
Premodulated bunch. 8 microbunches

Pipe length L , m	1.5-2
Bunch energy E_0 , MeV	5
Gaussian bunch rms σ , mm	$0.3 \cdot 8$
Charge Q , nC	$0.12 \cdot 8$

I [A]

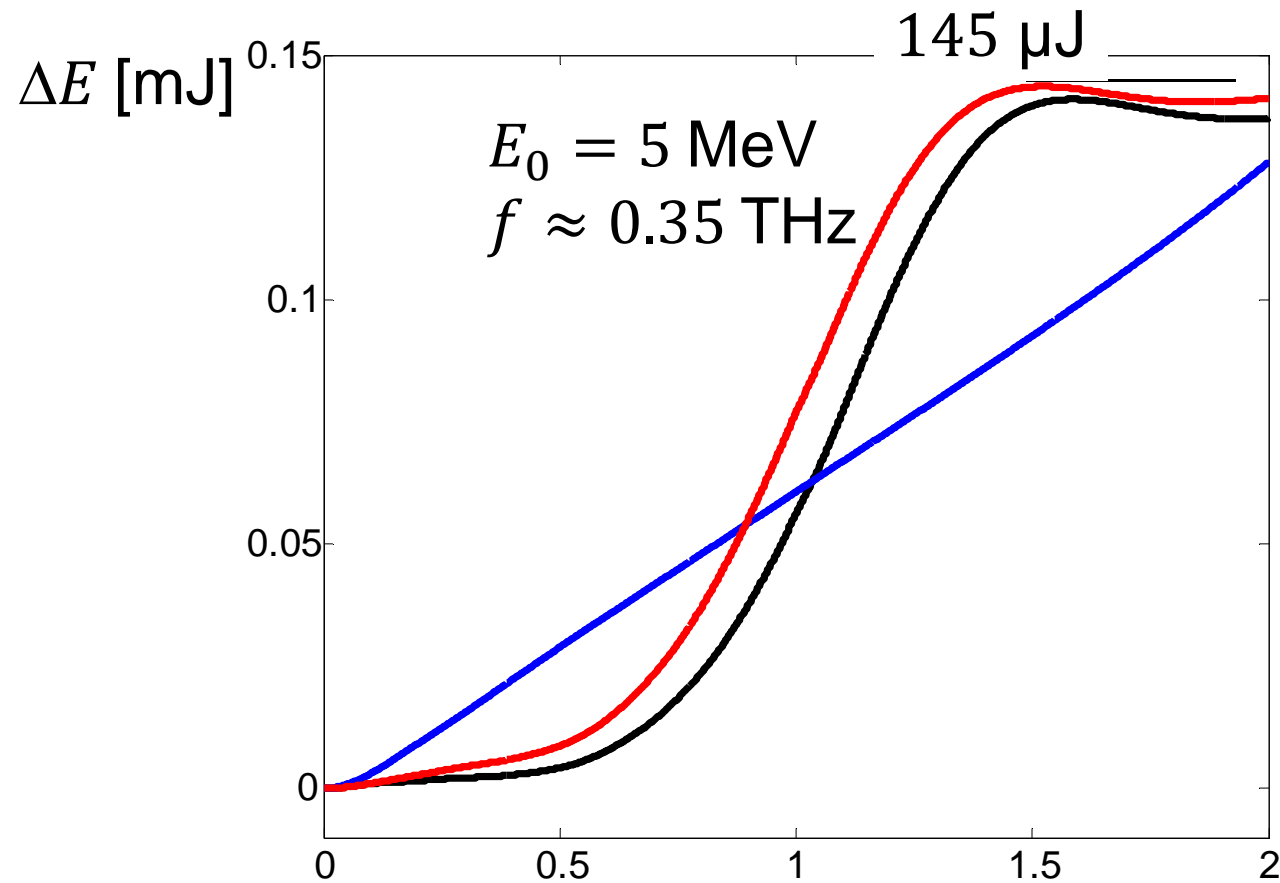


Premodulated bunch. 8 microbunches



Microbunching spacing $\Delta L = 0.93 \text{ mm}$

Premodulated bunch. 8 microbunches



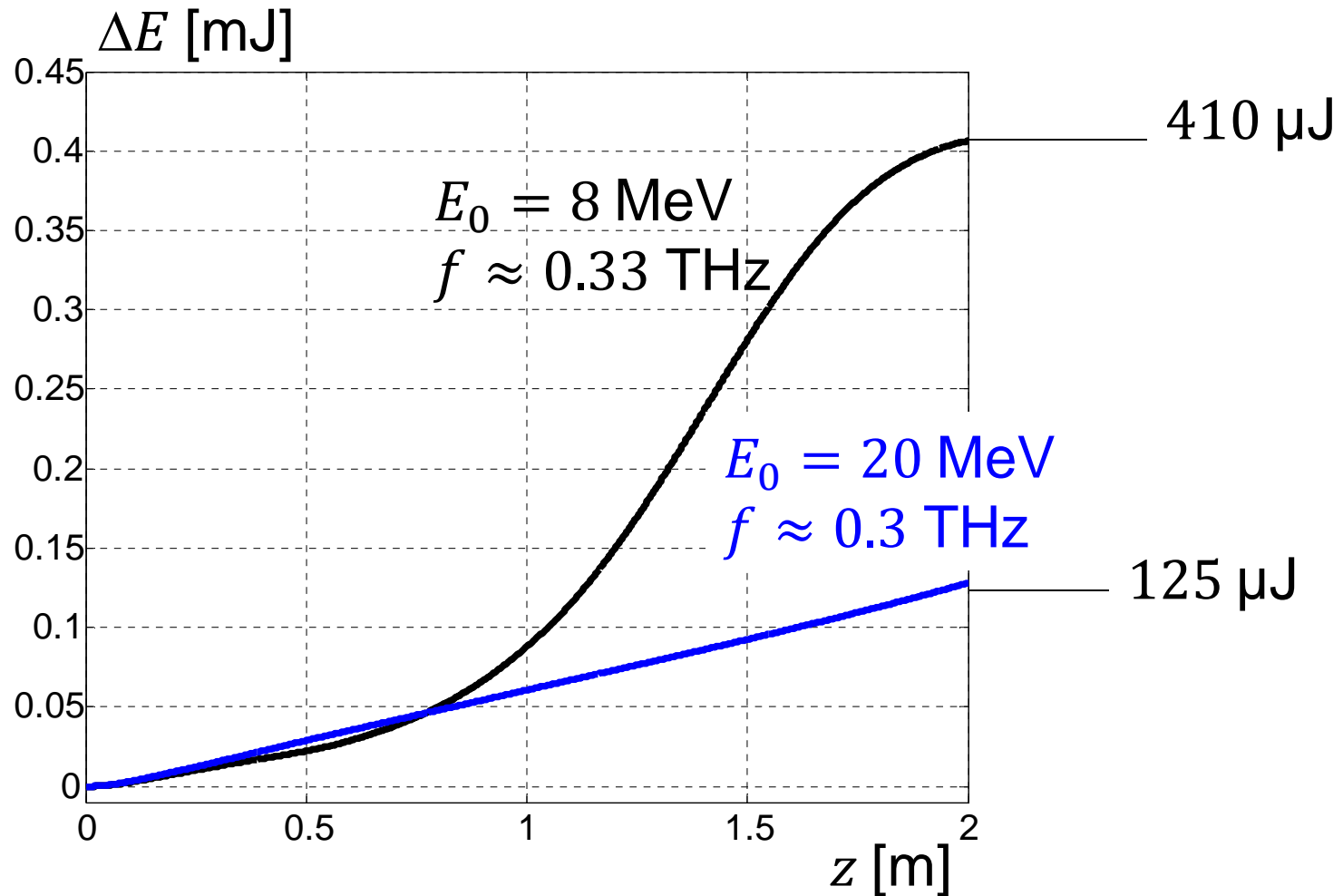
Microbunching spacing $\Delta L = 0.88$ mm z [m]

Premodulated bunch. 8 microbunches

Pipe length L , m	2
Bunch energy E_0 , MeV	8
Gaussian bunch rms σ , mm	$0.3 \cdot 8$
Charge Q , nC	$0.12 \cdot 8$



Premodulated bunch. 8 microbunches



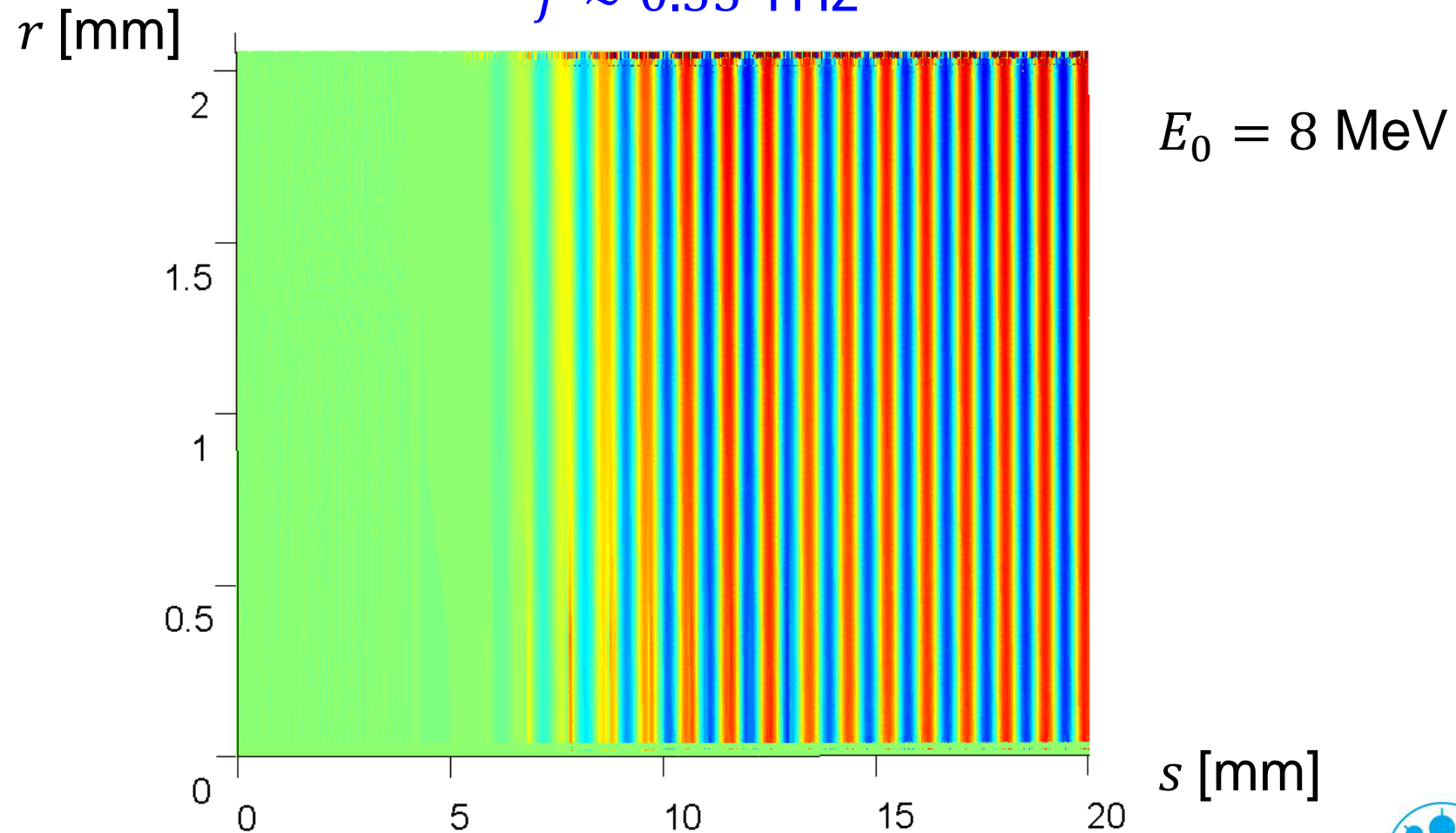
Microbunching spacing $\Delta L = 0.93$ mm



Premodulated bunch. 8 microbunches

Longitudinal electric field component E_z

$$f \approx 0.33 \text{ THz}$$



Summary

Charge, [pC]	Beam energy, [MeV]	RMS length, [mm]	Number of bunches	Pipe Length [m]	Field energy, [uJ]	Frequ-ency, [THz]
1000	14000	0.1	1	0.5	1400	0.3
1000	20	0.1	1	0.5	1300	0.3
40	10	0.1	1	0.5	2	0.3
120	10	0.3	1	0.5	0.55	0.3
120*8	20	0.3	8	1.5	85	0.3
120*8	5	0.3	8	1.5	140	0.35
120*8	8	0.3	8	2	410	0.33



Summary

To consider:

- transverse dynamics,
- tapering, resonance condition,
- resistivity (already implemented in code),
- rectangular pipe (wakefield code available),
- start from shot noise,
- Start with short driving bunch,
- optimal prebunching, optimal energy.

