Feasibility of double diffraction radiation target interferometry for compact linear accelerator micro-train bunch spacing diagnostics

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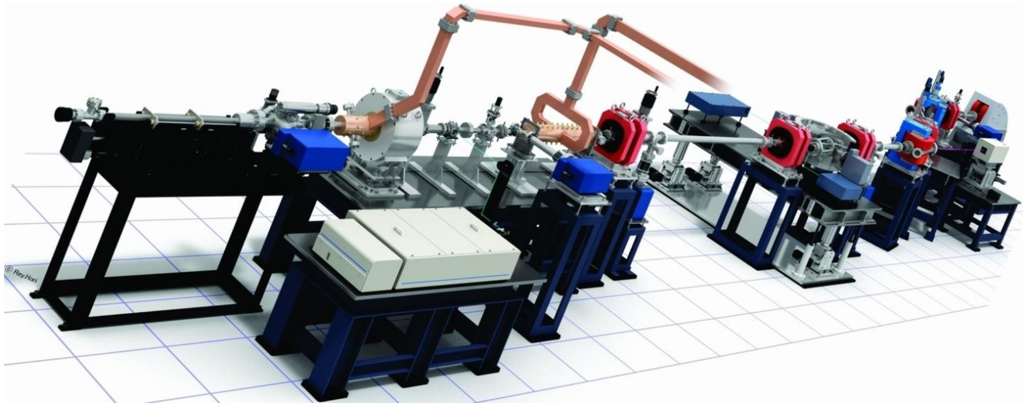
Introduction

There are a few ways to generate intense beams of THz radiation: optically pumped terahertz lasers, photomixing of near-IR lasers, backward-wave oscillators, direct multiplied sources and nonlinear optical processes occurring when an intense laser beam interacts with a material.

Another promising candidate is to generate short, high-brightness THz-frequency coherent radiation pulses using a micro-train electron beam (THz sequence of a several fs-length electron bunches) of a compact accelerator.

Accelerator

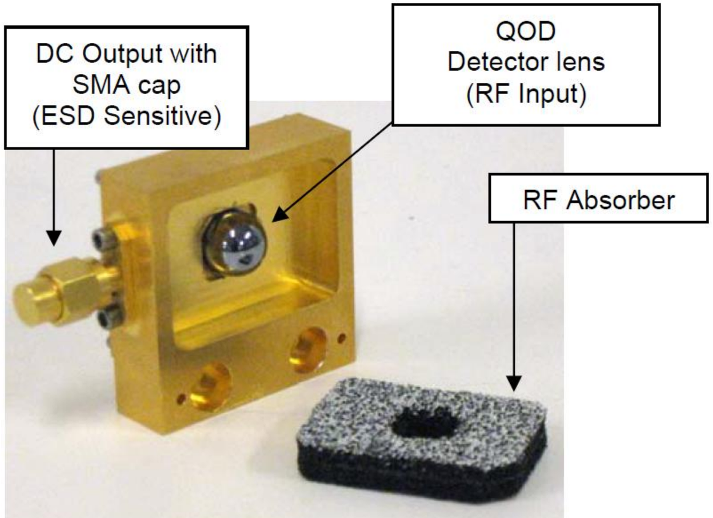


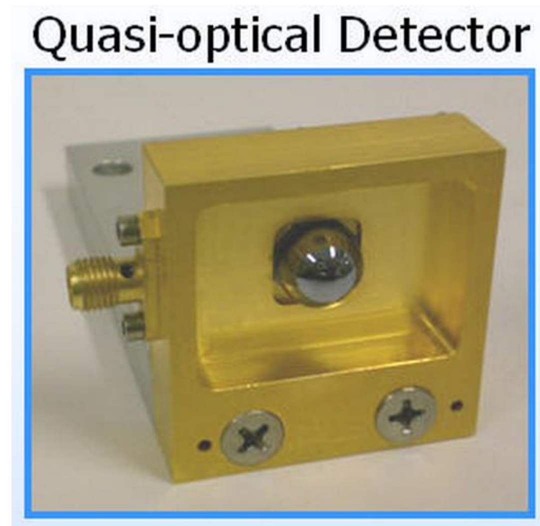
LUCX accelerator facility

<table>
<tr><th>Parameters:</th><th>THz chamber</th><th>CDR chamber</th></tr>
<tr><td>Electron energy</td><td>8.25 MeV</td><td>30 MeV</td></tr>
<tr><td>Micro-bunch length</td><td>100 fs</td><td>200-300 fs</td></tr>
<tr><td>Transverse size (x, y)</td><td colspan="2">200 μm</td></tr>
<tr><td>Micro-bunch spacing</td><td colspan="2">0 – 10 ps</td></tr>
<tr><td>Normalized emittance (x, y)</td><td colspan="2">5π mm×mrad</td></tr>
<tr><td>Micro-bunch charge</td><td colspan="2">100 pC</td></tr>
<tr><td>Number of micro-bunches</td><td colspan="2">2 – 16</td></tr>
<tr><td>Electron energy spread</td><td colspan="2">~1%</td></tr>
</table>

Parameters:	THz chamber	CDR chamber
Output window (polished)	crystal quartz/sapphire	fused silica
Diameter	100/155 mm	50 mm
Thickness		10 mm

Detector

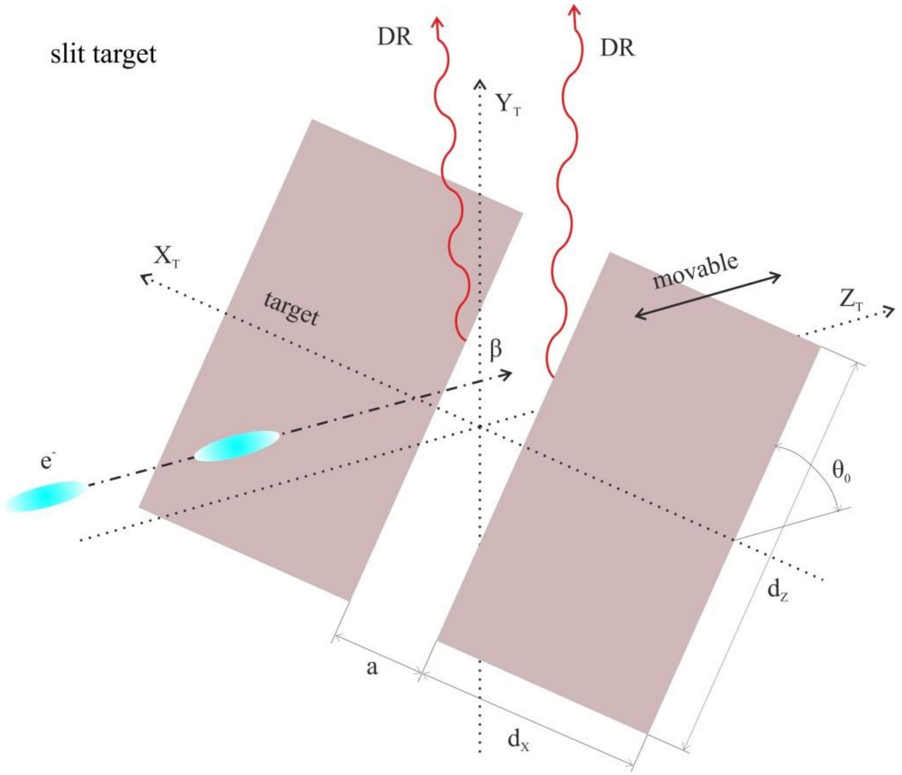




Parameters:	
Detector	QOD (quasi-optical detector) VDI
Spectral range	0.1 – >1.0 THZ*
Sensitivity	500 V/W
Aperture	10 mm
Minimum distance from output window	60 cm
Maximum distance	a few meters

* 0.1 – >1.0 THz correspond to 3 – <0.3 mm.

Double DR target



When bunched electron beam passes through the double DR target it emits coherent radiation with intensity being dependent on double target parts relative position (interferogram).

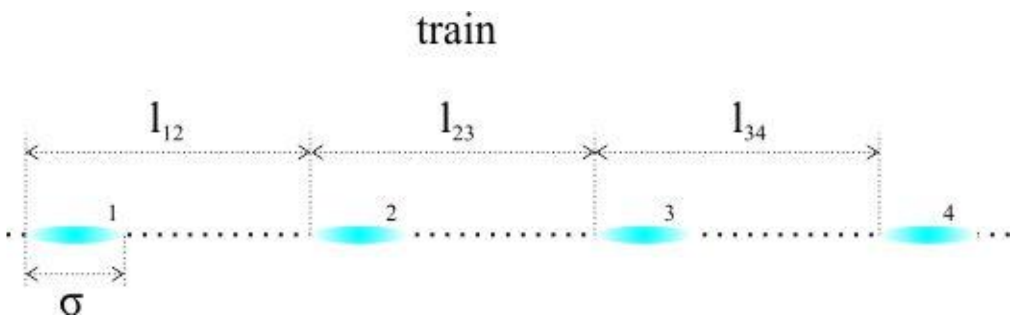
This interferogram can be measured when one part of the target moves relative to another one along the beam trajectory.

Assumptions

The simulations was performed with several assumptions. There are following:

- we do not take into account detector effect (spectral sensitivity);
- we do not take into account influence of output window (glass transmission);
- calculation is done for one point on detector (0,0);
- we use pseudophoton approach;
- EM field have only transverse component;
- we take into account only longitudinal size of bunches;

Train structure



l_{ij} – distance between bunch “i” and “j”
σ – micro-bunch length
β – speed of electrons
θ_0 – angle between beam trajectory and target

Simulation

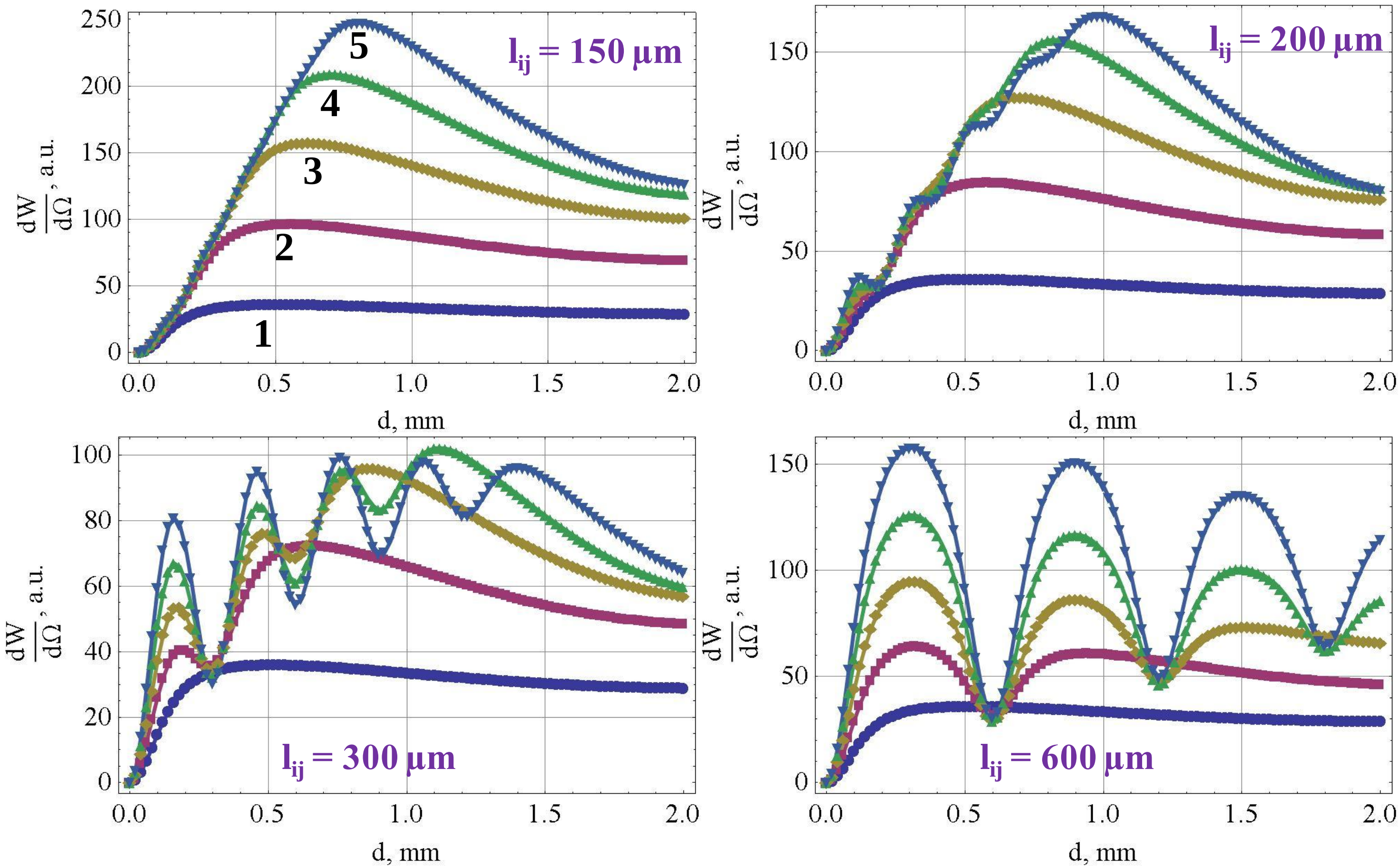
Parameters:	THz chamber	CDR chamber
Electron energy	8.25 MeV ($\gamma \approx 16$)	30 MeV ($\gamma \approx 58.7$)
Micro-bunch length	100 fs (30 μm)	300 fs (90 μm)
Micro-bunch spacing	1 ps (300 μm)	
Radiation wavelength range	0.03 – 3.0 mm (step 5 μm)	
Target slit width	2 mm	
Target-to-detector distance	700 mm far-field zone	700 mm near-field zone
Target dimensions (z, x)	46×20 mm^2	
Target tilt angle	$\pi/4$	
Point of detector	(0,0)	
Interferograms step	20 μm	

Note:

$\gamma\lambda = 16*3$ mm $= 48$ mm
$\gamma^2\lambda = 16^2*3$ mm $= 768$ mm

$\gamma\lambda = 58.7*3$ mm ≈ 176 mm
$\gamma^2\lambda = 58.7^2*3$ mm ≈ 10300 mm

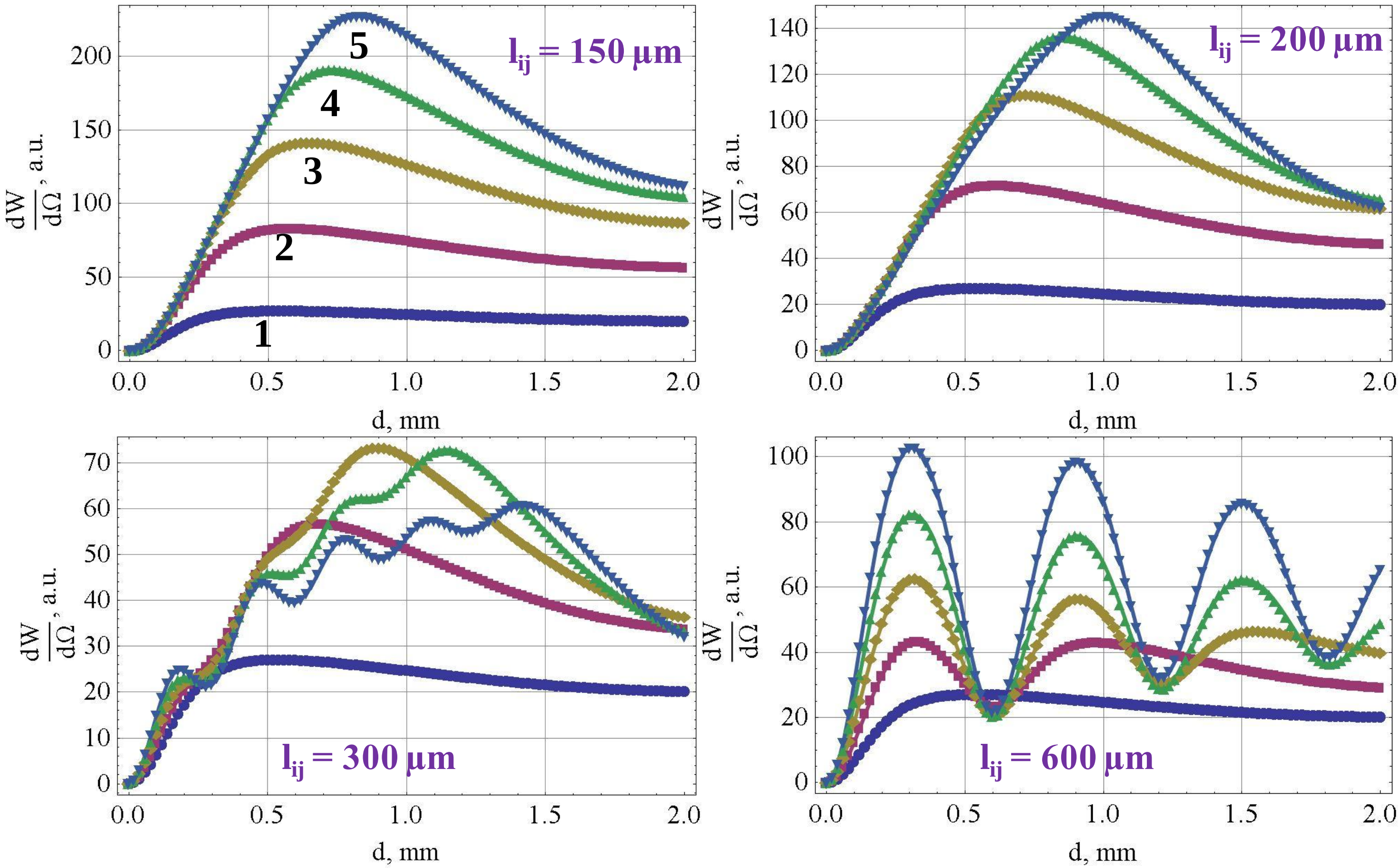
Interferograms 8.25 MeV|30 μm



4 picture of interferograms for different micro-bunch spacing $\mathbf{l_{ij}}$ with number of bunches per train from 1 to 5

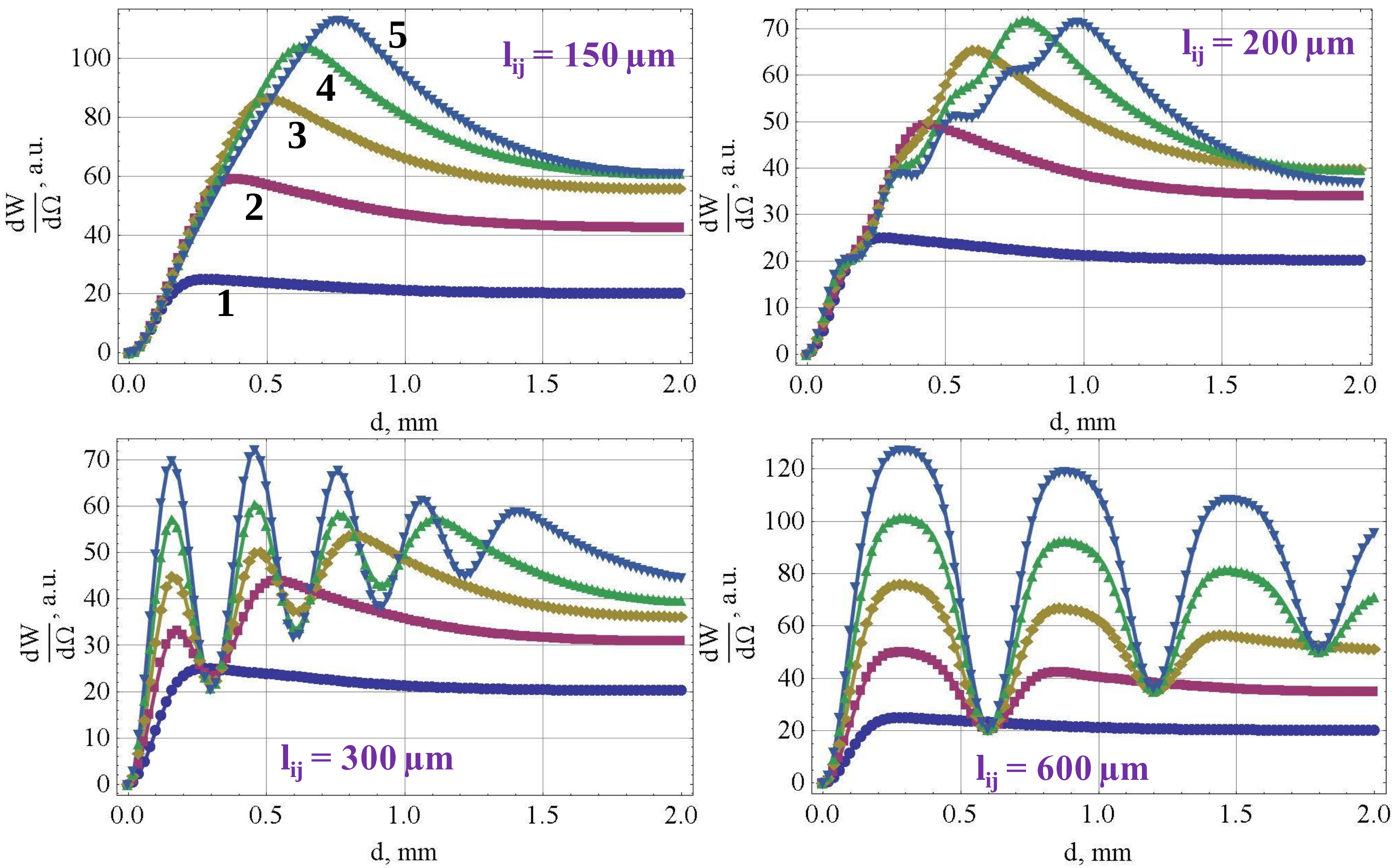
Number of peaks in the interferograms correspond to the number of bunches in micro-train

Interferograms 8.25 MeV|90 μm



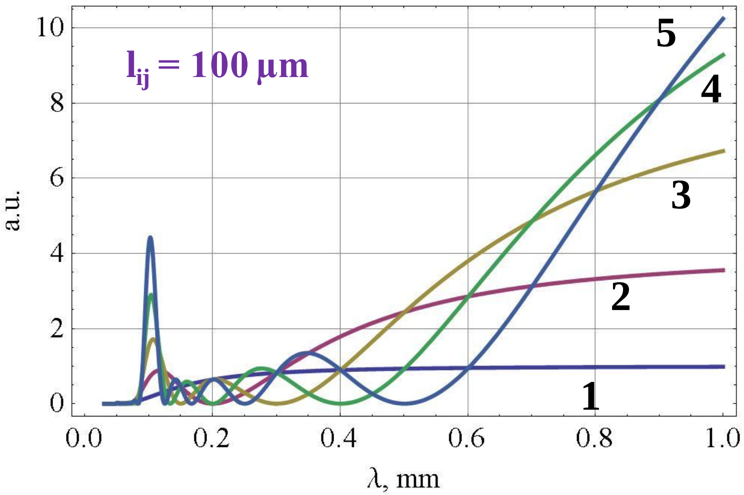
4 picture of interferograms for different micro-bunch spacing l_{ij} with number of bunches per train from 1 to 5

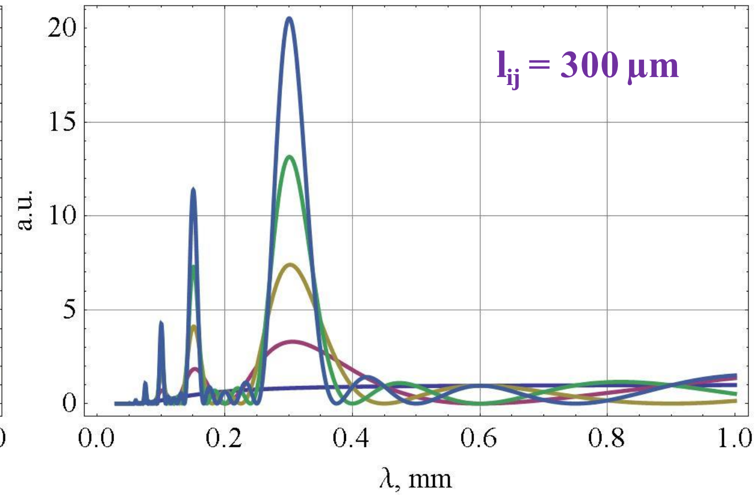
Interferograms 30 MeV|90 μm

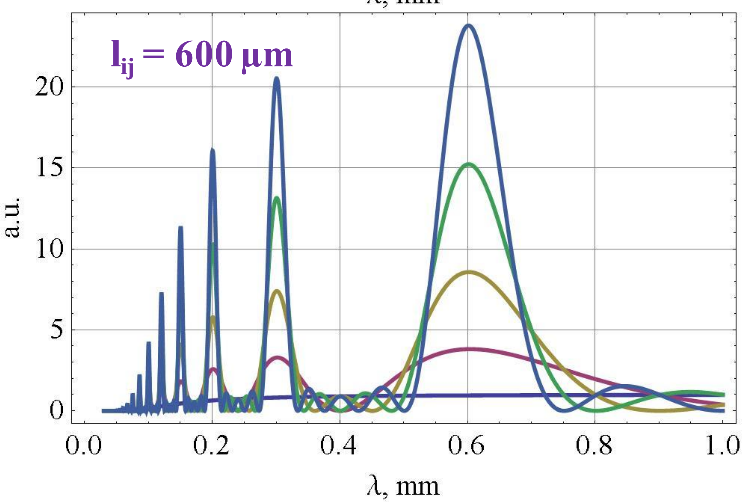


4 picture of interferograms for different micro-bunch spacing **l_{ij}** with number of bunches per train from 1 to 5

Form-factor 8.25 MeV|30 µm







Form-factor for different micro-bunch spacing **l_{ij}** with number of bunches per train from 1 to 5

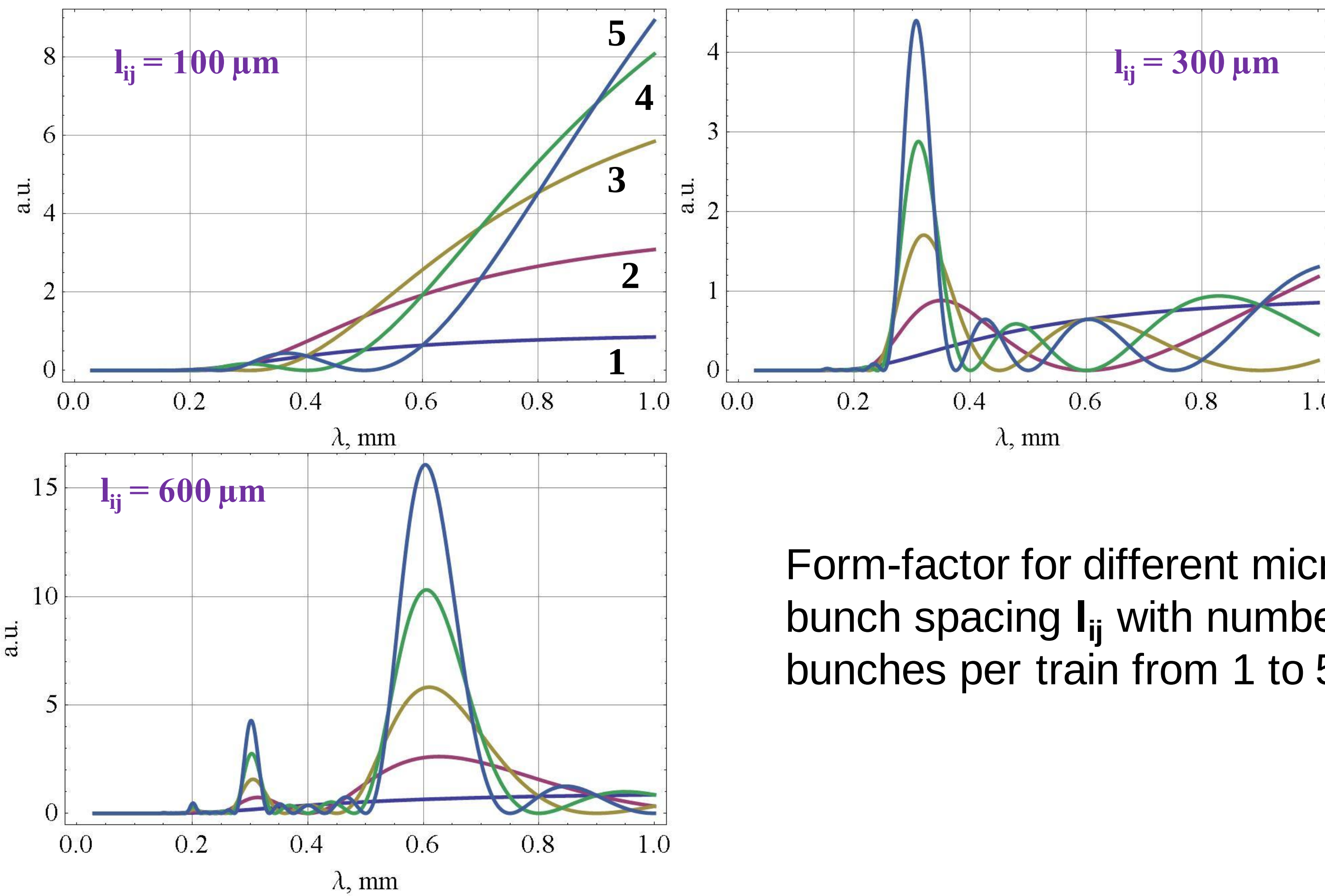
$$e^{-\frac{2\pi^2\sigma^2}{\lambda^2}}\left|1+e^{\frac{2i\pi l_0}{\beta\lambda}}\right|^2 \qquad 2$$

$$e^{-\frac{2\pi^2\sigma^2}{\lambda^2}}\left|1+e^{\frac{2i\pi l_0}{\beta\lambda}}+e^{\frac{4i\pi l_0}{\beta\lambda}}\right|^2 \qquad 3$$

$$e^{-\frac{2\pi^2\sigma^2}{\lambda^2}}\left|1+e^{\frac{2i\pi l_0}{\beta\lambda}}+e^{\frac{4i\pi l_0}{\beta\lambda}}+e^{\frac{6i\pi l_0}{\beta\lambda}}\right|^2 \qquad 4$$

$$e^{-\frac{2\pi^2\sigma^2}{\lambda^2}}\left|1+e^{\frac{2i\pi l_0}{\beta\lambda}}+e^{\frac{4i\pi l_0}{\beta\lambda}}+e^{\frac{6i\pi l_0}{\beta\lambda}}+e^{\frac{8i\pi l_0}{\beta\lambda}}\right|^2 \qquad 5$$

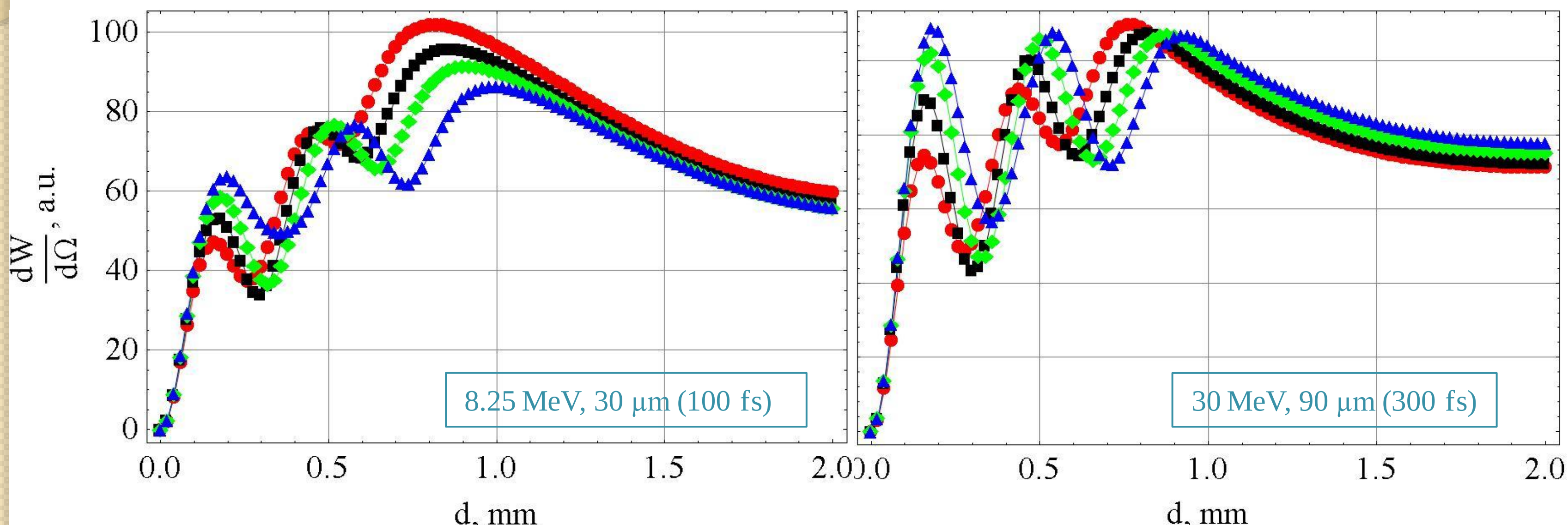
Form-factor 30 MeV|90 μm



Form-factor for different micro-bunch spacing $\mathbf{l_{ij}}$ with number of bunches per train from 1 to 5

Interferograms (spacing)

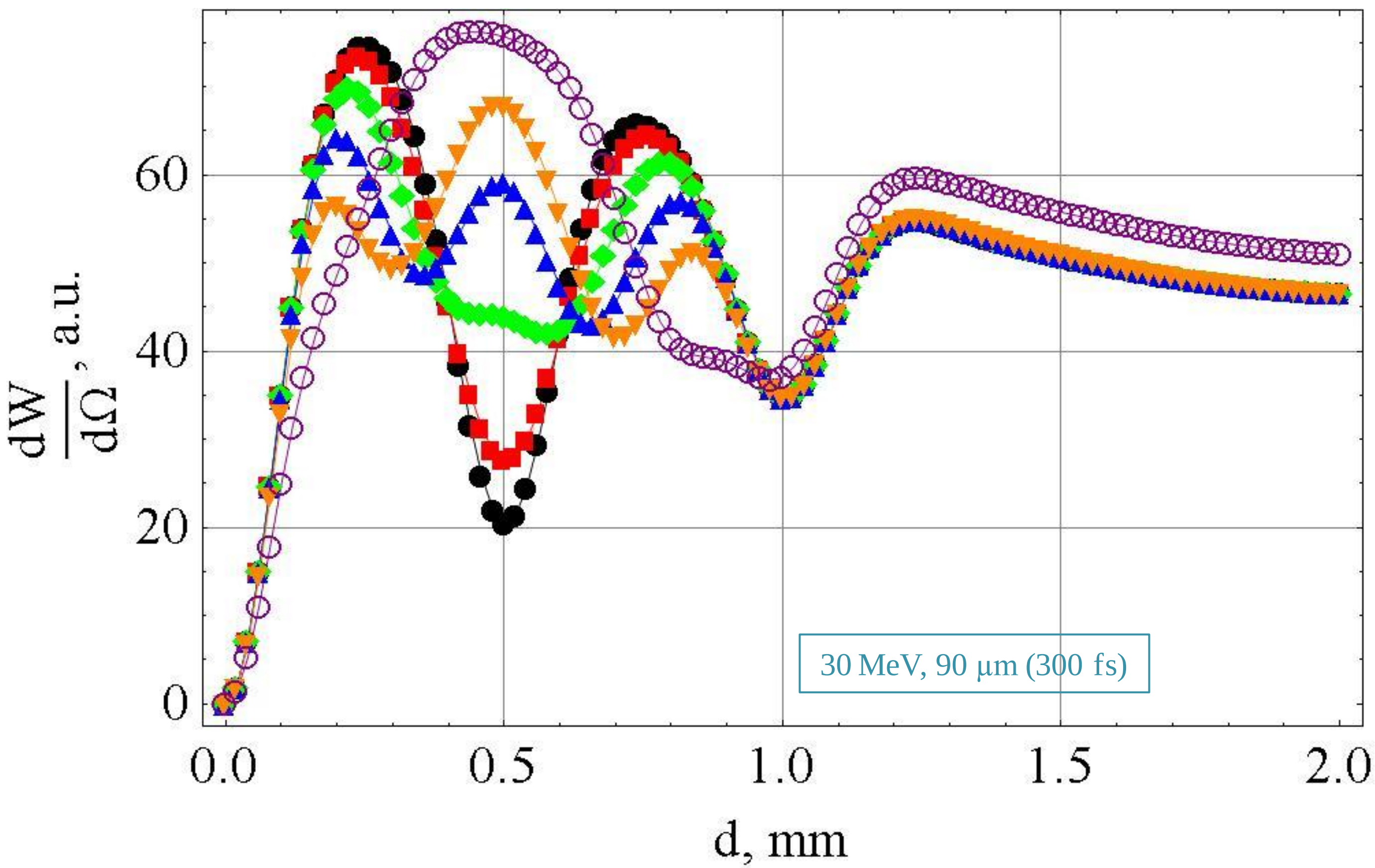
Following interferograms simulated for different spacing between 3 bunches in the micro-train:



	#	1	2	3	4
Graph	Color	Black, mm	Red, mm	Green, mm	Blue, mm
8.25 MeV, 30 μm (100 fs)	$l_{12}\backslash l_{23}$	0.3\0.3	0.3\0.25	0.3\0.35	0.3\0.4
30 MeV, 90 μm (300 fs)	$l_{12}\backslash l_{23}$	0.3\0.3	0.3\0.25	0.3\0.35	0.3\0.4

For reverse values of spacing the interferograms shapes are the same

Interferograms (spacing_2)



	#	1	2	3	4	5	6
Graph	Color	Black, mm	Red, mm	Green, mm	Blue, mm	Orange	Purple
30 MeV, 90 μm (300 fs)	$l_{12}\backslash l_{23}$	0.5\0.5	0.45\0.55	0.4\0.6	0.35\0.65	0.3\0.7	0.2\0.8

Conclusion and plans

- Development of a robust and non-invasive micro-train bunch spacing diagnostics obtains vast importance.
- Double diffraction radiation target interferometry can be used for non-invasive determination of submicron bunch spacing (1. we can distinctly to observe the number of bunches in micro-train through the interferograms shapes 2. we see that the average meaning of bunch spacing in micro-train is came out from the 1st minimum of interferogram)
- We need to carry out additional investigation for better understanding the process of interaction micro-train with double DR target interferometer.
- Cross-check measurements with deflecting cavity and THz Michelson interferometer at KEK, LUCX facility can be considered as an important step.

Thank you

for your attention!