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Bunch length effects

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Motivation

Bunch length of the XFEL beam

Table 3: Properties of the Electron Beam at the Undulator Entrance [6]

Bunch charge	nC	0.02	0.1	0.25	0.5	1
Peak beam current	kA	4.5	5	5	5	5
Normalized rms emittance	mm-mrad	0.32	0.39	0.6	0.7	0.97
rms energy spread	MeV	4.1	2.9	2.5	2.2	2
rms pulse duration	fs	1.2	6.4	16.6	30.6	76.6

from Schneidmiller et al, *Baseline Parameters of the European XFEL*, doi:10.18429/JACoW-FEL2017-MOP033

Bunch compression

- Bunch compression achieved in EUXFEL with **energy chirp** (from RF) and **chicanes** (bending magnets).
  - Bunch length for lasing: <10µm
  - Bunch length for LUXE: (30-50)µm

Stuart Walker's talk, LUXE workshop

- IP simulations in the CDR/technical notes assume an electron-beam bunch length of 24 microns/80 fs (both rms)
- Discussion at last week's workshop suggests actual length will be significantly shorter.
- Leaving aside the question of overlapping the beams, what does reducing the length do to the signal?

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Model

Scaling out bunch length and radius

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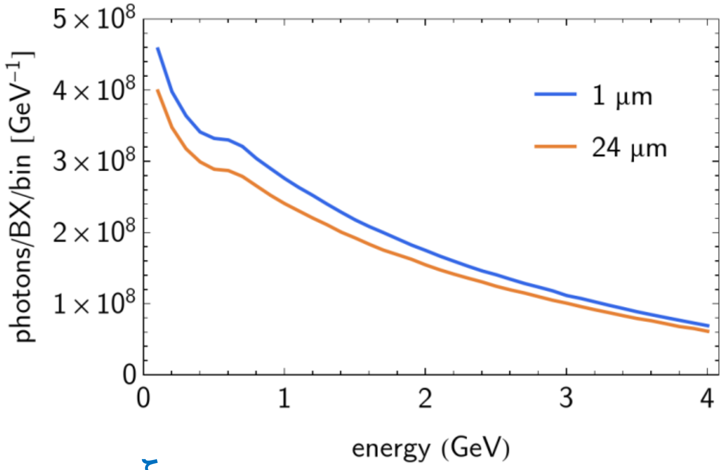
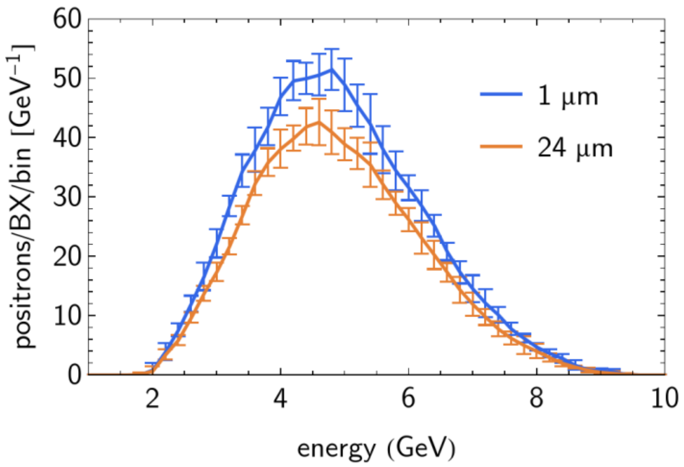
- Ignoring laser Rayleigh range as collision occurs at finite angle $\theta = 17.2^\circ$ (0.3 rad)
- Number of photons scales with "average peak ξ" experienced by the bunch (if $\xi \gg 1$):

$$\langle \xi \rangle = \frac{\xi_{\mathrm{nom}} w_0^2}{\sqrt{\left[w_0^2 + 2\sigma_\perp^2\right]\left[w_0^2 + 2\sigma_\perp^2 + 2\sigma_\parallel^2 \tan^2(\theta/2)\right]}}$$

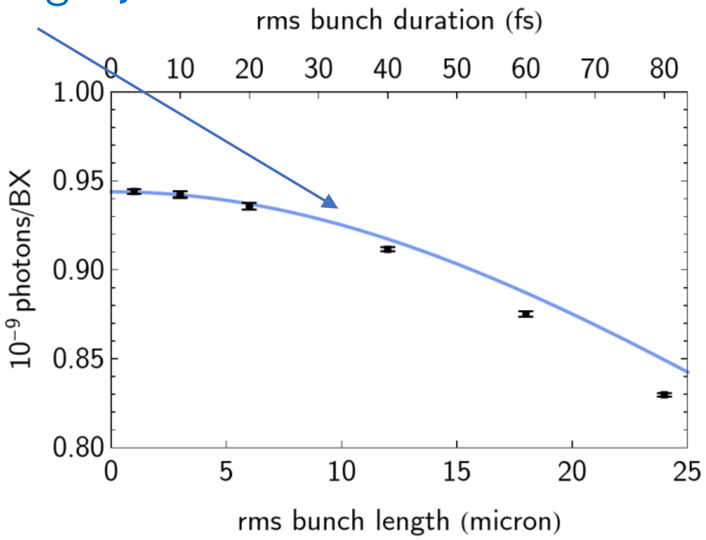
Results

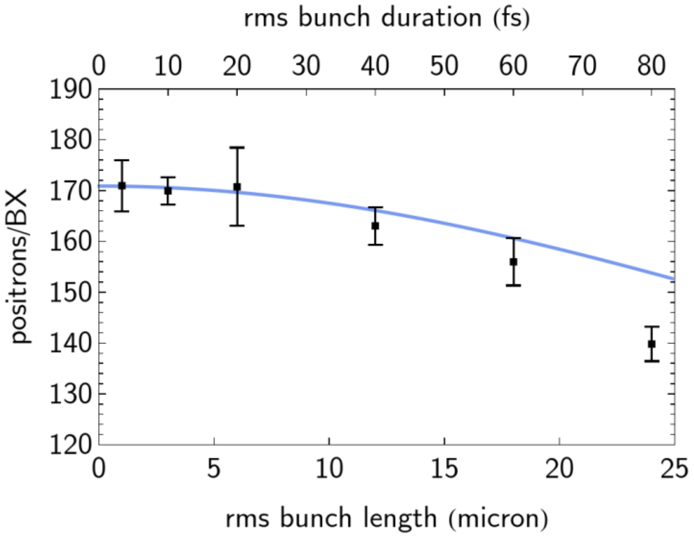
$\xi = 3.0$ (focal spot size 7.9 micron)





ratio of average ξs:
ξ(σ)/ξ(0)





bunch charge held constant

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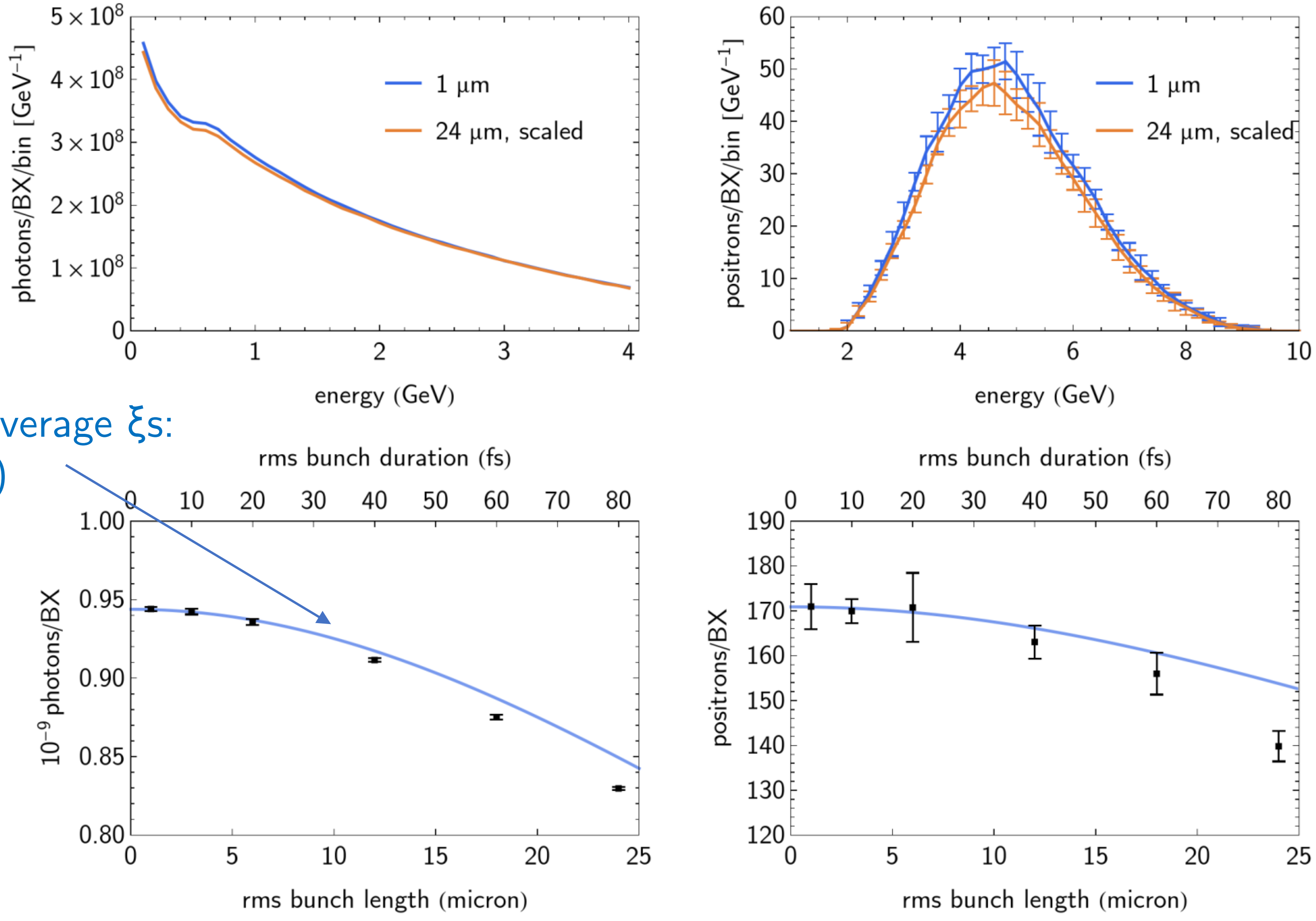
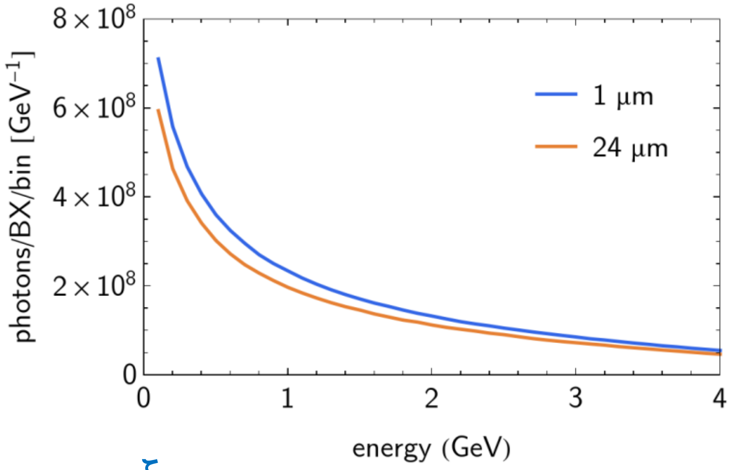
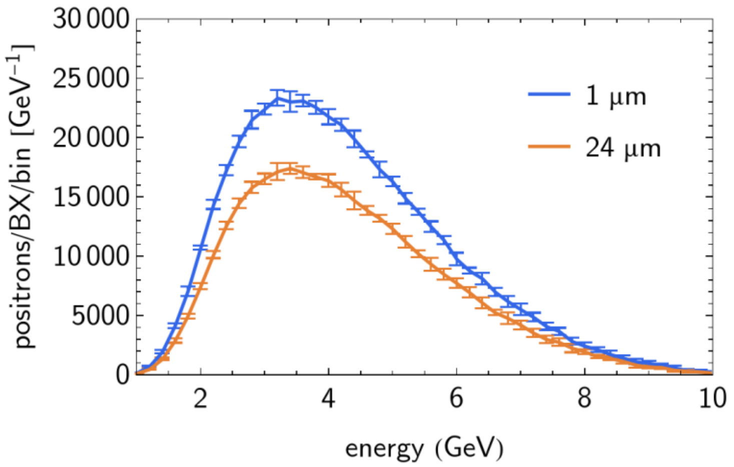


bunch charge held
constant

Results

$\xi = 7.0$ (focal spot size 3.3 micron)





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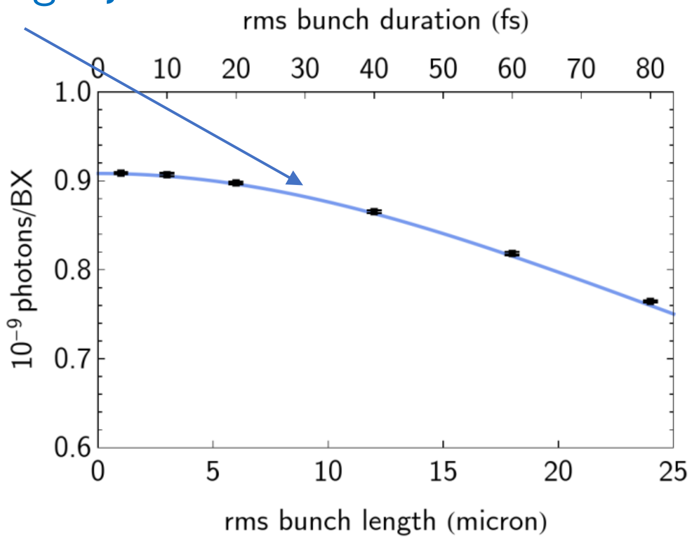

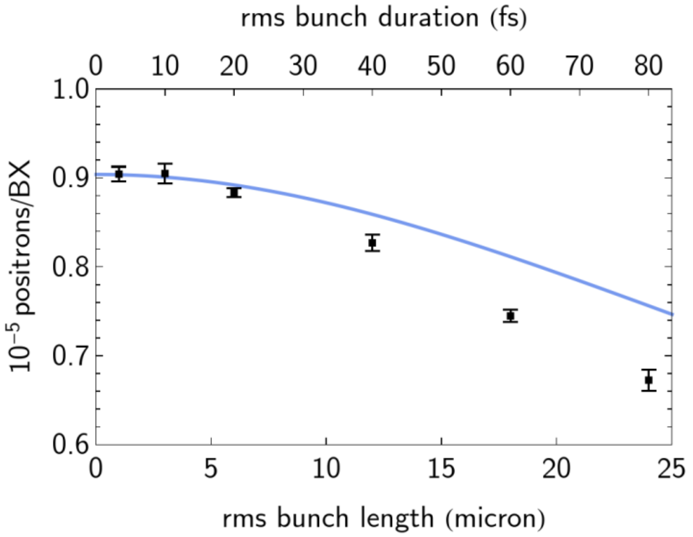

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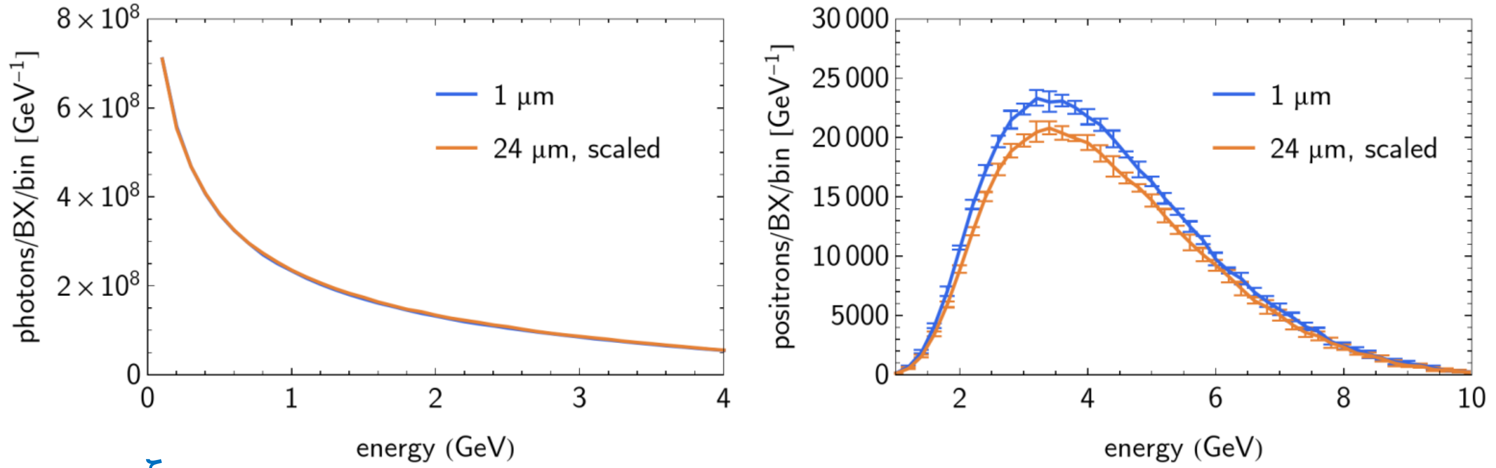

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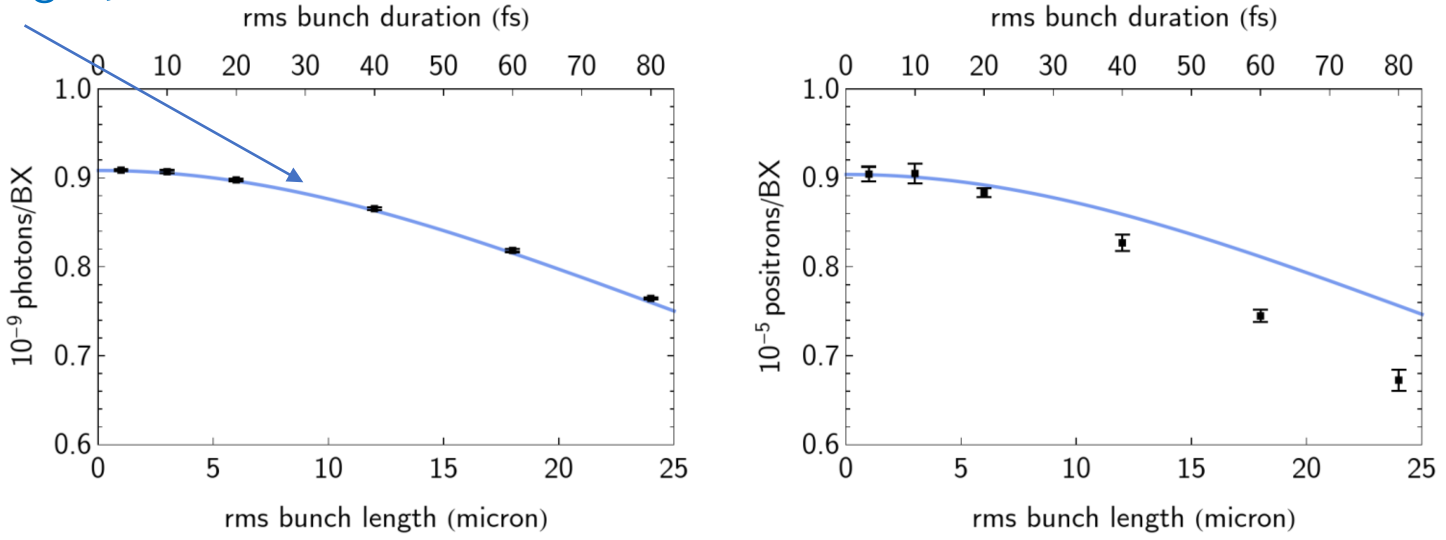

bunch charge held constant

Summary

- Smaller bunch length increases the number of photons and positrons per (successful) collision, as more electrons fit inside the high-intensity region.
- For phase-0 collision parameters, the increase in the signal is at most 20%.
- Change in the number of photons can be scaled away with reasonable accuracy.
- Data here: /nfs/dust/luxe/group/MCProduction/Signal/ptarmigan-v0.8.1/e-laser/phase0/blen