PAUL SCHERRER INSTITUT PSI

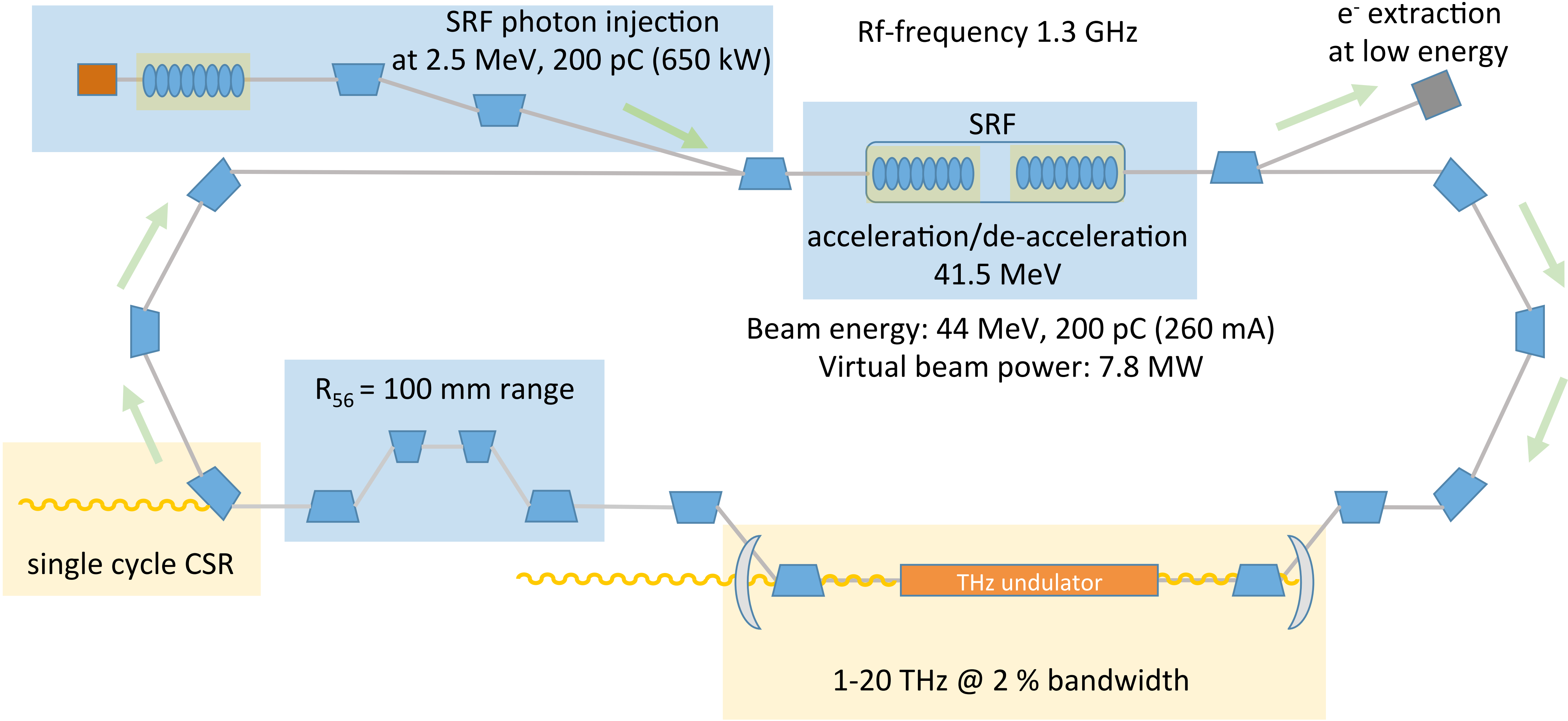
Case 4 – Compact ERL for THz Radiation

- Goal: ***Design a facility to provide high-rep THz radiation in the range of 1 to 20 THz with either single cycle emission or a bandwidth below 2%***

Results of group 8

Jörn Boedewadt, Raimund Kammering (DESY)
Ben Ledroit (Johannes Gutenberg-Universitaet Mainz)
Alberto Petralia (ENEA Frascati)
Angela Saa-Hernanddez (PSI)
Martin Schmeisser (Helmholtz-Zentrum Berlin)

General layout of the ERL THz facility



Design consideration for the FEL

- FEL for low bandwidth (2%)
- high gain FEL would require very short bunch length and peak current
  - low gain FEL oscillator → compact
  - fixed (ERL) beam energy and constrain on wavelength 1 – 20 THz
  - Use permanent magnet undulator with variable gap for wavelength tuning

$$\lambda_{FEL}(E, \lambda_u, K) = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

$$K = 93.6\, B[T]\, \lambda_u[m]$$

  - start with **K > 1**, **B** on axis **< 1.0T**, reasonable dimensions of gap/undulator
  - gap / vacuum chamber diameter > 30 mm (see next slide)

$$B_0 = 1.8\, B_r \exp\left[-\pi \frac{gap}{\lambda_u}\right]$$

  - -> λ_u = 10 cm

B_r = 1.4 T

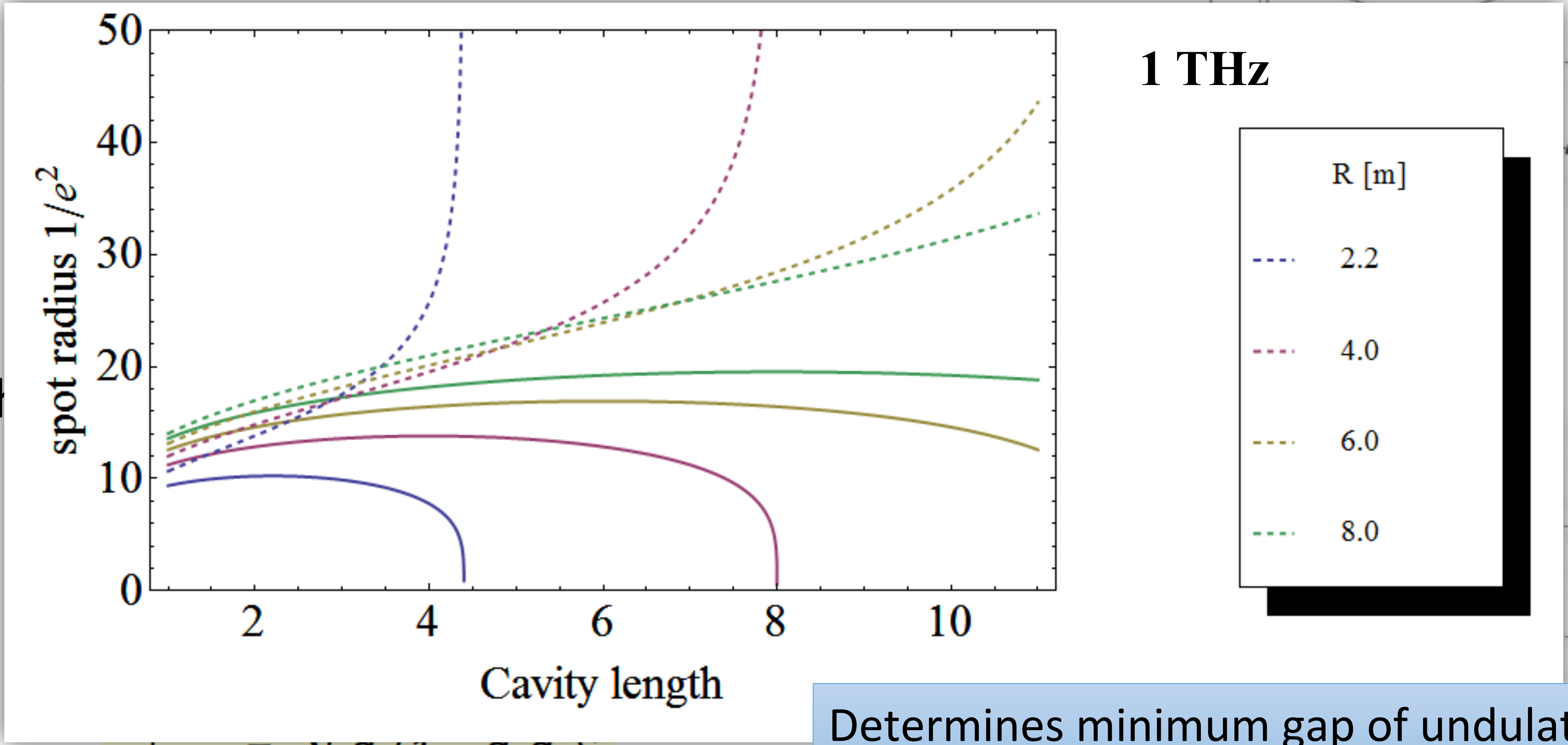
Design consideration for the FEL

- Re
- Wh

At waist:

At mirror:

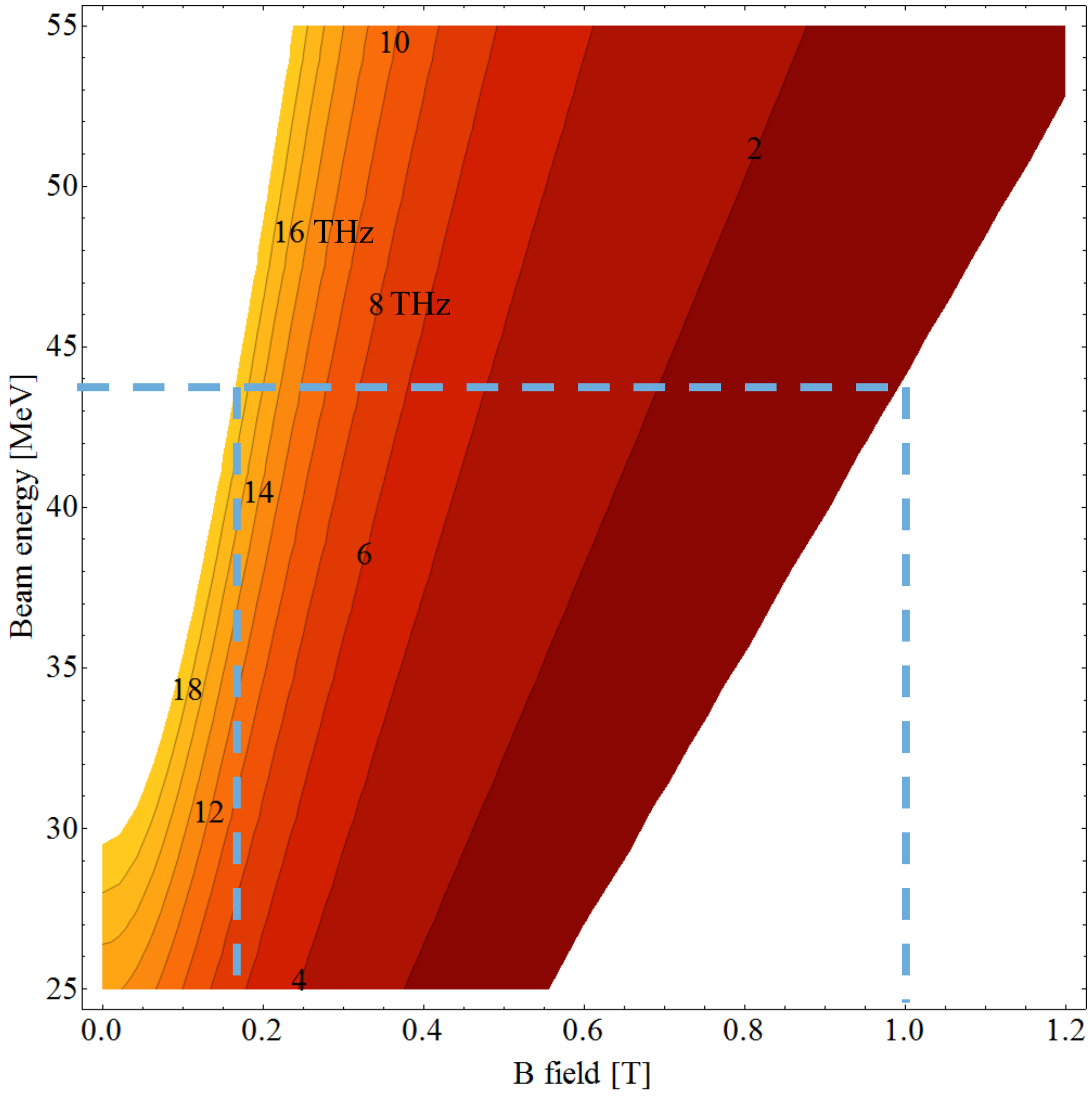
$\pi \sqrt{g_1(1 - g_1 g_2)}$



Determines minimum gap of undulator

Tuning range and undulator give beam energy

Beam energy ~ 44 MeV



10 cm undulator period

Estimate on FEL peak power

Gain per turn:

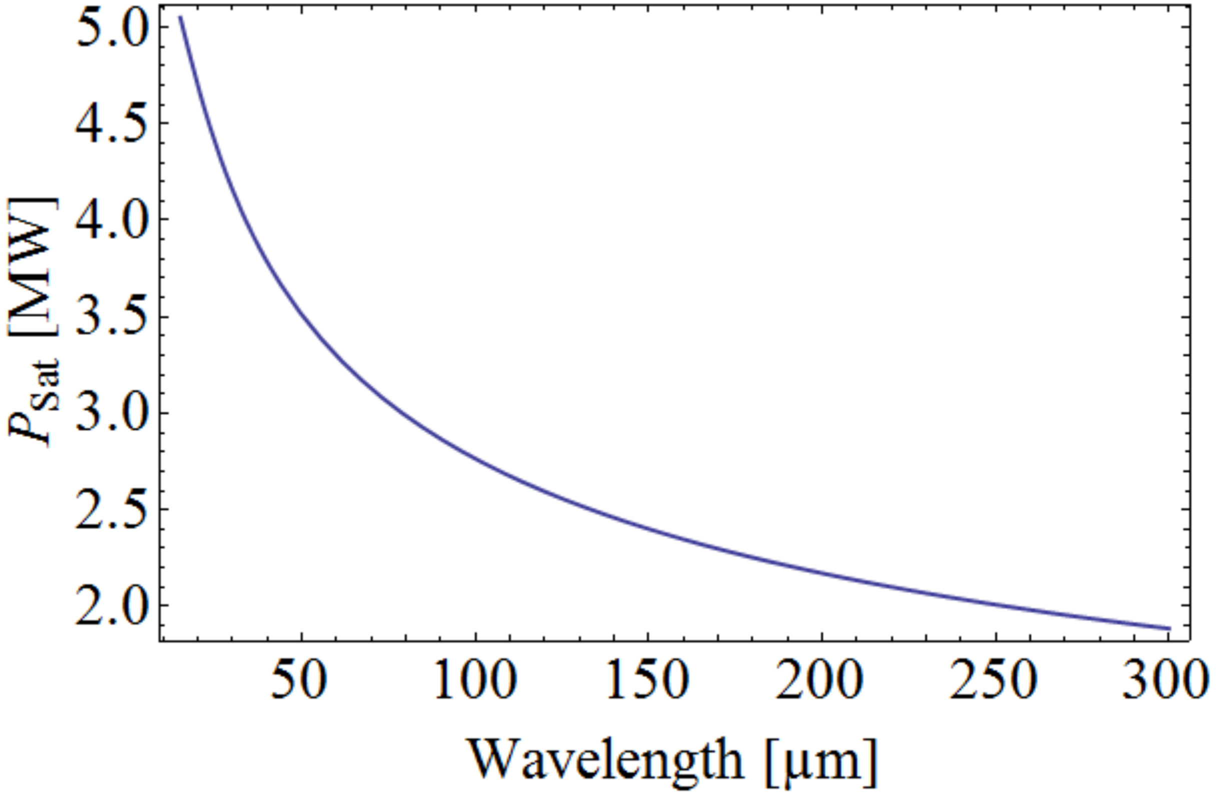
$$G_0 = \frac{(4\pi\rho N_u)^3}{\pi}$$

Saturation power:

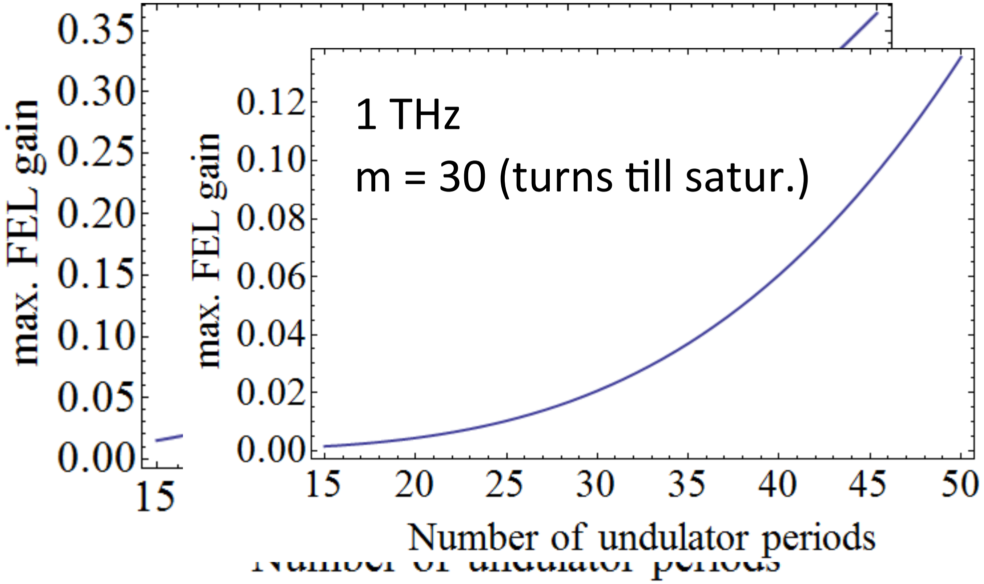
$$P_{sat} = P_0(1 + G_{net})^m$$

$$G_{net} = G_{max} - G_{loss}$$

$$G_{max} = 0.85 G_0 \cdot F + 0.19 (G_0 \cdot F)^2$$



Single pulse energy: **48 – 118 µJ**
Optical beam power: **150 kW**



Length of cavity is 6m

B. Qin et al., Design considerations of a planar undulator applied in a tera hertz FEL oscillator, NIM A 727 (2013) 90–96

Compression

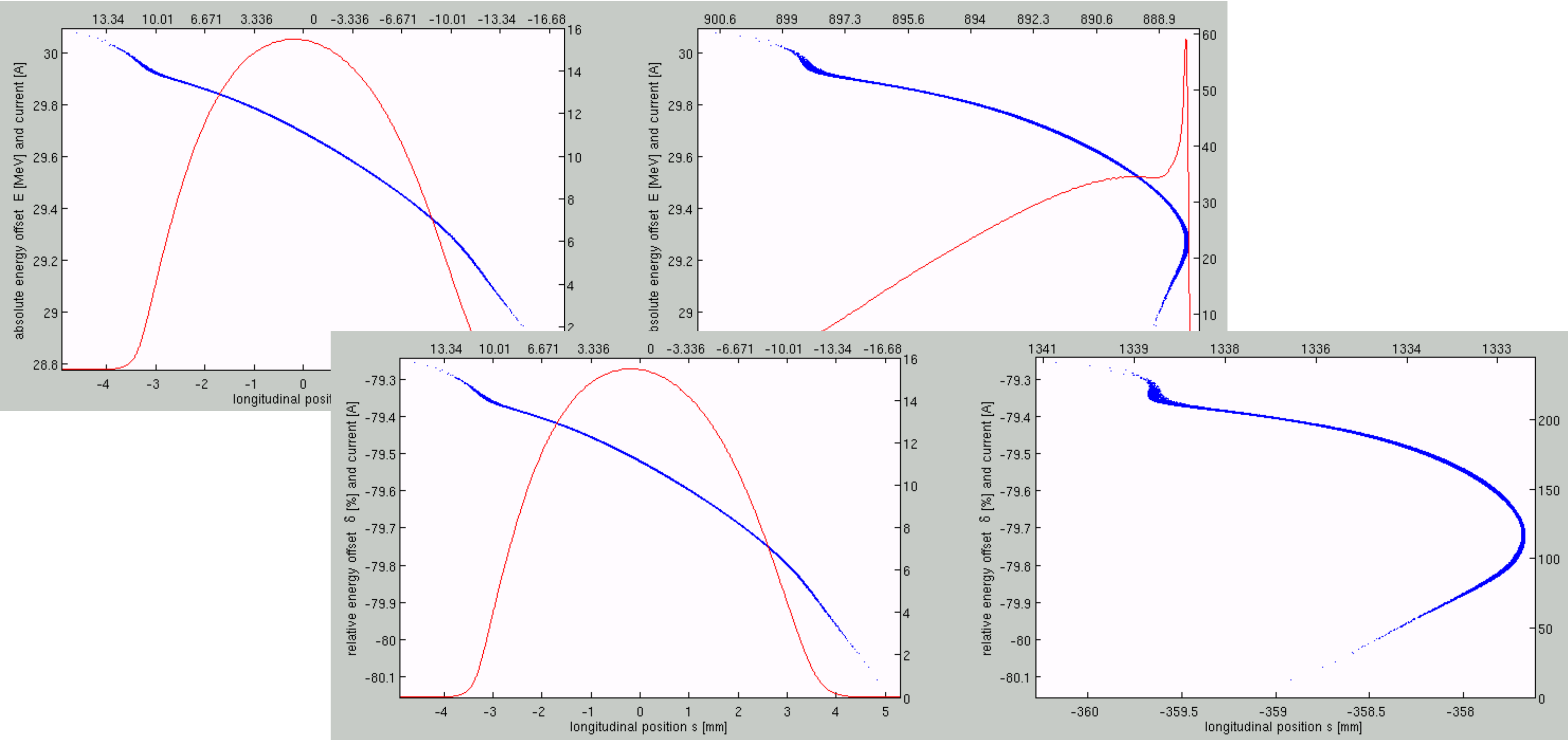
- initial bunch length 20 ps (needed for FEL oscillator)
- final bunch length to get reasonable CSR in THz needs 0.5 ps
- this gives a compression factor of 40 which is challenging using a single compression stage
- other alternatives to get a short radiating pulse: foil, corrugated structure… not possible with ERL design

➔ use non linear compression schema – use “spike mode”

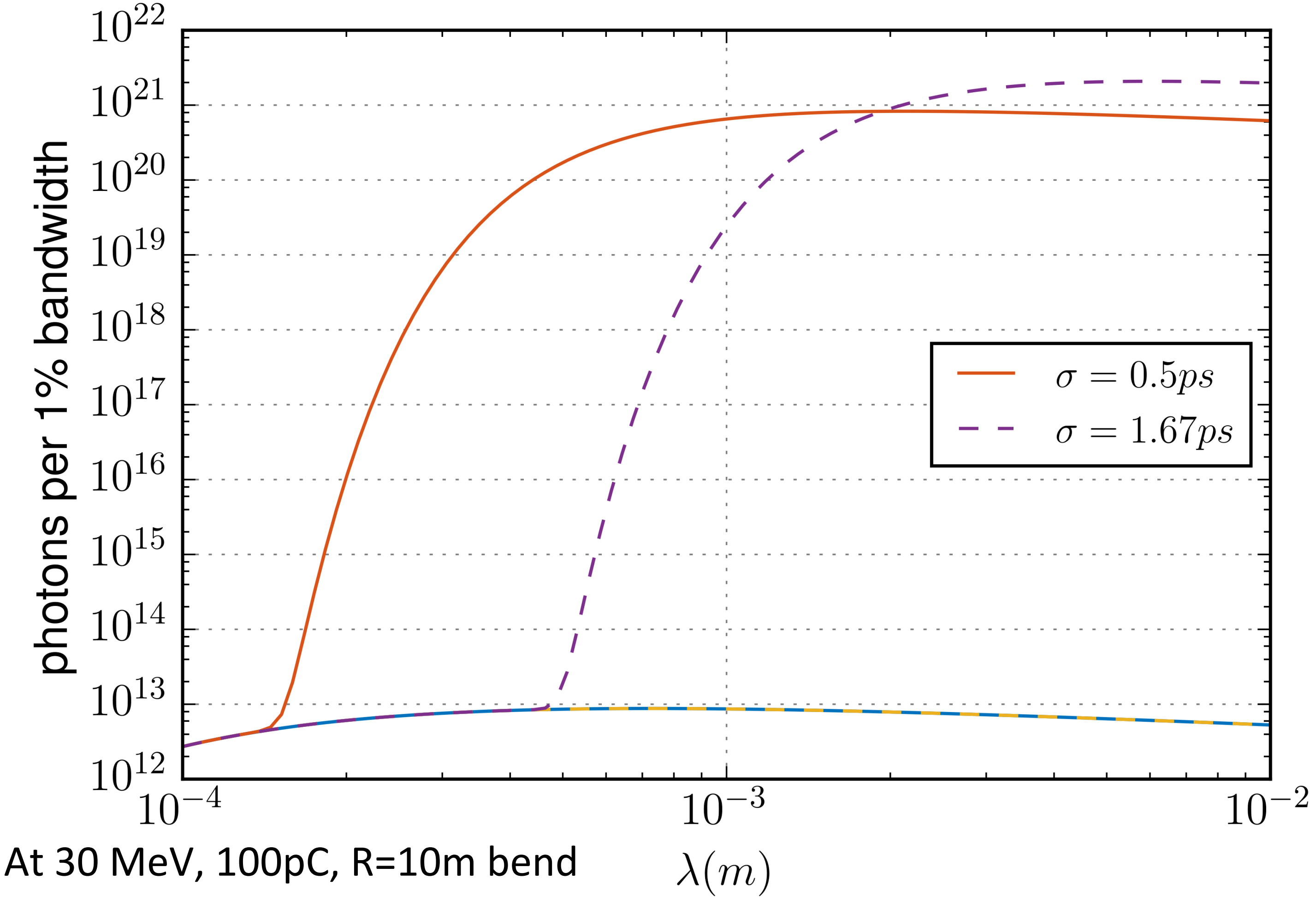
$$E(s) = E_0 + eV_{RF}\cos(ks+\varphi_{RF}) = E_0 + eV_{RF}[\cos(\varphi_{RF}) - k\sin(\varphi_{RF})s - k^2\cos(\varphi_{RF})\,s^2 + \cdots]$$

$$s_f = s_i + \frac{R_{56}}{E_0}(-keV_{RF}\sin(\varphi_{RF})\,s_i - k^2 eV_{RF}\cos(\varphi_{RF})\,s_i^2)$$

Compression



single cycle CSR



At 30 MeV, 100pC, R=10m bend

Incoherent synchrotron radiation flux

$$\frac{\mathrm{d}\dot{N}_{\mathrm{ph}}}{\mathrm{d}\psi} = \frac{4\alpha}{9}\gamma\frac{I}{e}\frac{\Delta\omega}{\omega}S\left(\frac{\omega}{\omega_{\mathrm{c}}}\right)$$

$$S\left(\frac{\omega}{\omega_{\mathrm{c}}}\right) = \frac{9\sqrt{3}}{8\pi}\frac{\omega}{\omega_{\mathrm{c}}}\int_{\omega/\omega_{\mathrm{c}}}^{\infty} K_{5/3}(\bar{x})\,\mathrm{d}\bar{x}$$

Wiedemann

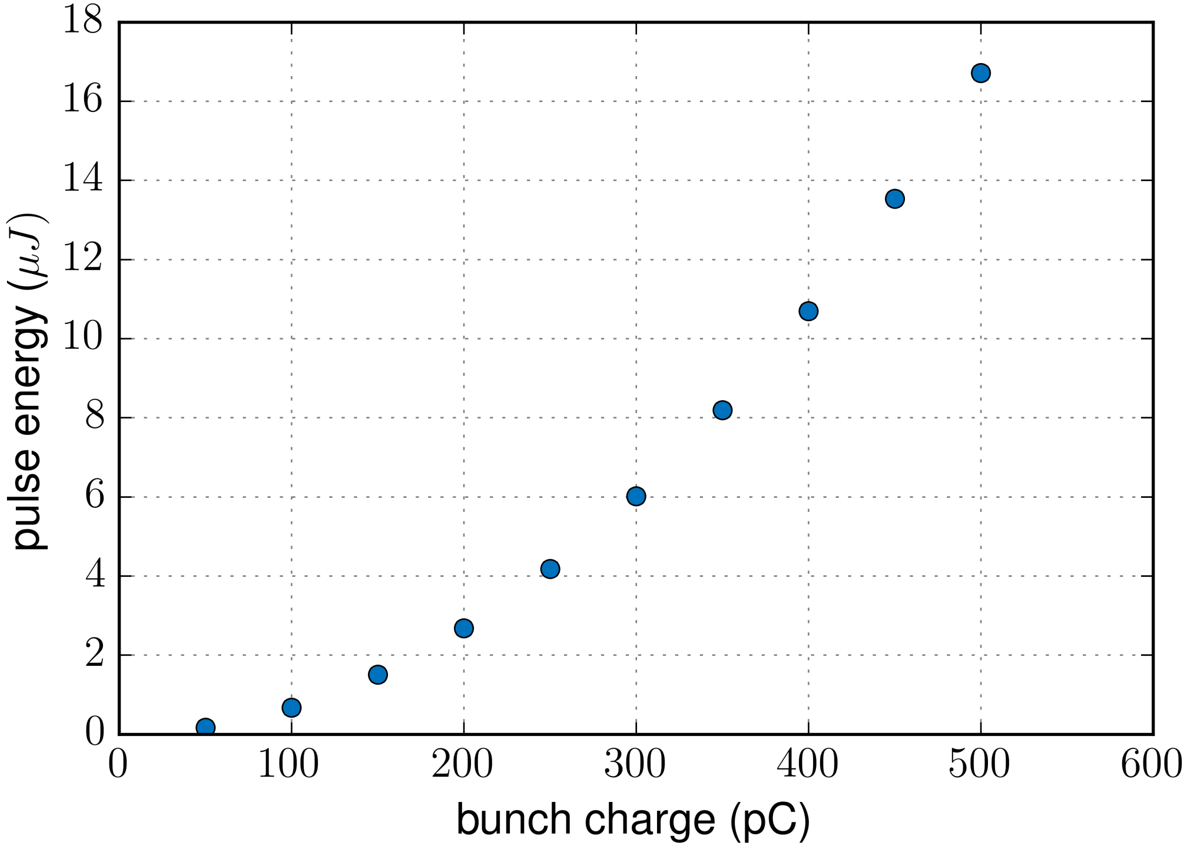
Coherent radiation governed by form factor

$$g_\lambda = \left|\int n(z) e^{2\pi i z/\lambda}\, dz\right|^2$$

$$P_{coh} = N_e\, g_\lambda\, P_{inc}$$

S. Di Mitri, G. Wüstefeld

single cycle CSR



Summary of determined parameters

- Machine parameters:
  - 260 mA average beam current
  - 200 pC @ 1.3 GHz
  - 20 ps bunch length (uncompressed down to 500 fs compressed)
  - Beam energy 44 MeV
- Undulator parameters:
  - gap 30 mm, 10 cm undulator period
  - B = 0.16 … 1.0 T (K = 1.5 ... 9.3)