Low alpha mode for SPEAR3 and a potential THz beamline

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For the SSRL Accelerator Team

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Outline

- The low-alpha mode for SPEAR3
- Potential for a THz beamline
  - Chicane THz source
  - THz power calculation

Parameter	For SPEAR3
Circumference	234 m
Beam energy	3 GeV
Emittance	18 nm (achromat) 10 nm (low emitx)
Momentum spread	0.001
Momentum compaction factor	0.0016 (low emitx) 0.0012 (achromat)
Rf frequency	476.3 MHz
Rf voltage	3.2 MV
Beam current	200 mA (→500mA)

Reasons to go low-alpha

Shorter bunches → short X-ray pulses
→ CSR in THz regime

Bunch length

$$\sigma_T = \frac{\sigma_E / E}{f_{rev}} \left(\frac{\alpha E}{2\pi h} \right)^{1/2} \frac{1}{\left(e^2 V_{rf}^2 - U_0^2 \right)^{1/4}} \qquad \frac{\sigma_E}{E} = \gamma \left(C_q \frac{I_3}{2I_2 + I_4} \right)^{1/2}$$

Ways to get short bunches:
(1) Reduce beam energy
(2) Increase rf voltage
(3) Increase rf frequecy
(4) Reduce momentum compaction factor - alpha

SPEAR3 low alpha optics

First and second order momentum compaction factors:

$$\alpha_1 = \frac{1}{C}\oint \frac{D_{x0}}{\rho} ds$$

$$\alpha_2 = \frac{1}{C}\oint \left(\frac{D_{x1}}{\rho} + \frac{D'^2_{x0}}{2} \right) ds$$

α_1 ↓, QFC ↑, QF ↓

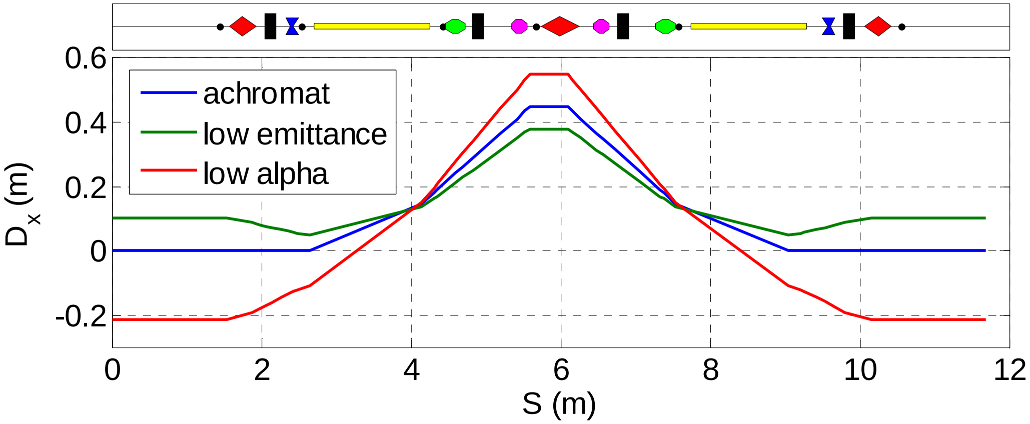
The need to control α_2:

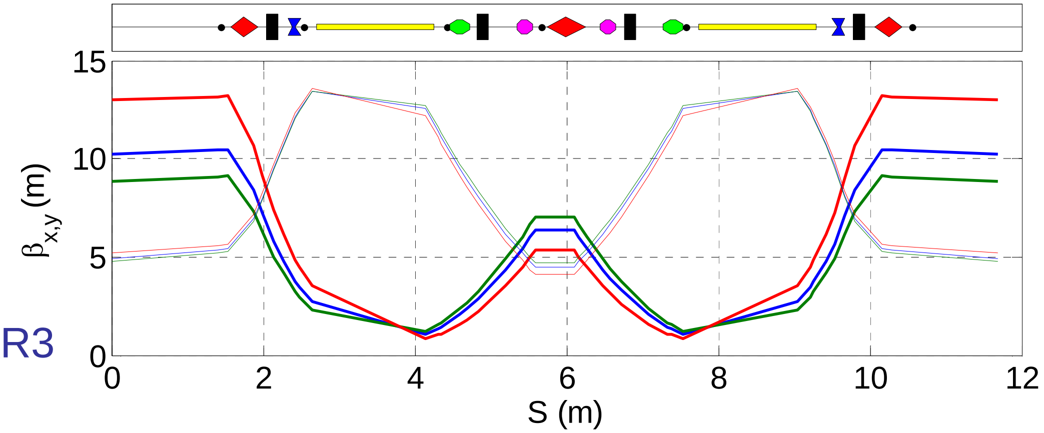
$$\left| \frac{\alpha_1}{\alpha_2} \right| > \text{bucket height}$$

to maintain normal rf buckets

$$|\alpha_2| < 1000 |\alpha_1|^{3/2}$$

is required for SPEAR3





Response matrix for chromaticities

$$\begin{pmatrix} C_x \\ C_y \\ \alpha_2 \end{pmatrix} = \begin{pmatrix} 0.805 & 0.172 \\ -1.144 & -1.314 \\ -1.247\times 10^{-3} & -0.207\times 10^{-3} \end{pmatrix} \times \frac{32.05}{108.33} \begin{pmatrix} I(\mathrm{SF}) \\ I(\mathrm{SD}) \end{pmatrix}$$

We have to run with a negative C_x

Implementation of the low alpha optics

Store beam in usual lattice

↓

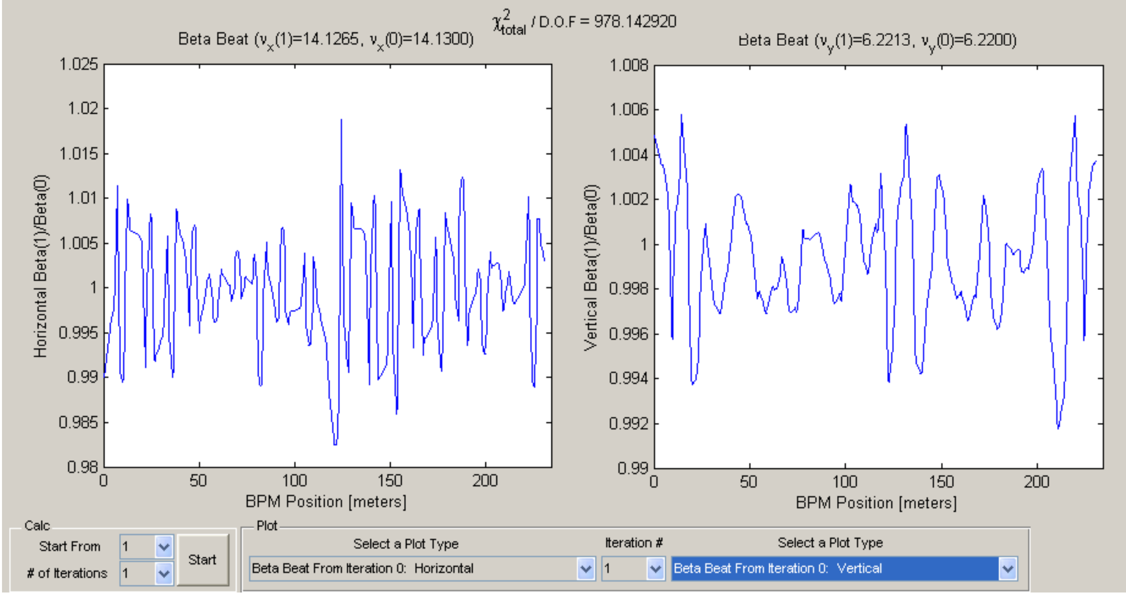
Ramp quadrupoles to new lattice

↓

Correct optics with LOCO

↓

Save new lattice



Start From: 1

# of Iterations: 1

Select a Plot Type: Beta Beat From Iteration 0: Horizontal

Iteration #: 1

Select a Plot Type: Beta Beat From Iteration 0: Vertical

Sextupole SF is set to minimize α_2

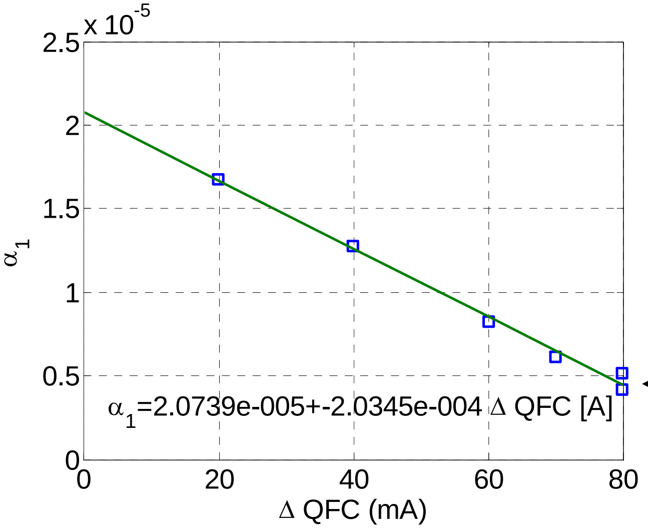
Chromaticity [-2 x, 0.5 y]

Two calibrated low alpha lattice:

α/21,

α/59,

Adjust QFC to get lower alpha



After LOCO measurement and then orbit correction.

Injection is more sensitive to rf frequency and injected beam timing error.

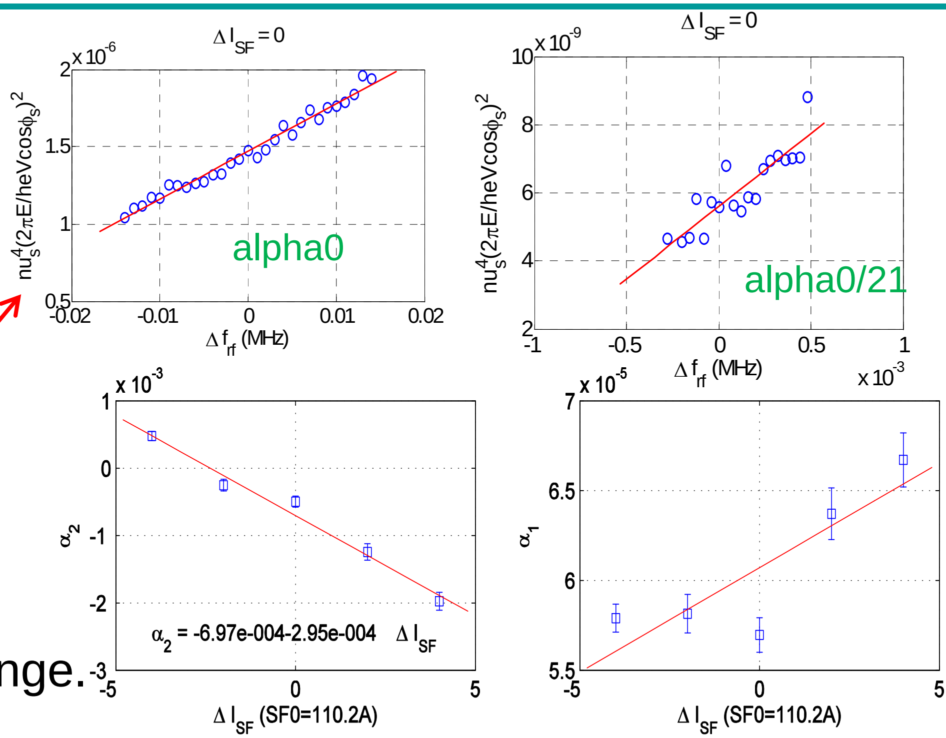
Measurements of alpha

1. Synchrotron tune measurements

$$\nu_s = \sqrt{\frac{heV_{\rm rf}\cos\phi_s}{2\pi E}}\left(\alpha_1^2 - 4\alpha_2\frac{\Delta f_{\rm rf}}{f_{\rm rf}}\right)^{1/4}$$

Nadji et al, NIMA (1996)

Longitudinal motion driven by rf noise, not an intentional excitation.



2. Orbit offset from rf frequency change.

$$\Delta x = D_{x,1}\delta + D_{x,2}\delta^2,$$

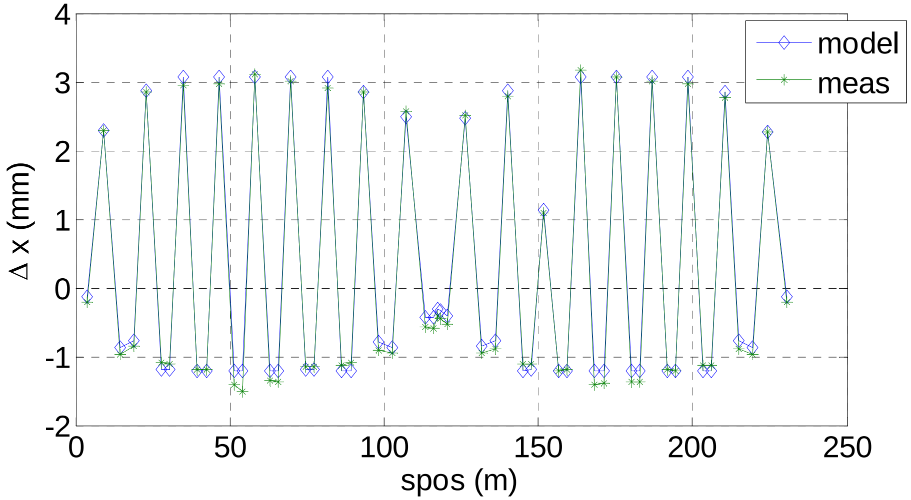
ignore

$$\delta = \frac{\sum \Delta x_i D_i}{\sum D_i^2}$$

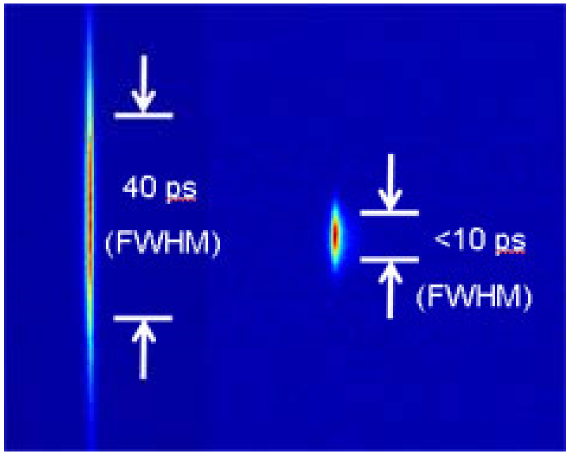
$<D_2D_1>/<D_1\text{^}2>=1.50$ for low alpha lattice, delta<0.006.

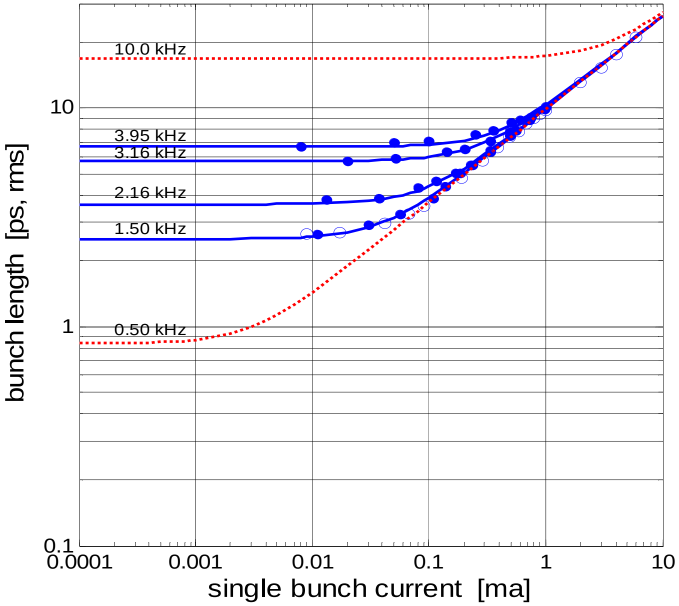
$$\frac{\Delta f_{\rm rf}}{f_{\rm rf}} + \alpha_1\delta + \alpha_2\delta^2 = 0.$$

Fit for α_1 ,α_2



Short bunches observed





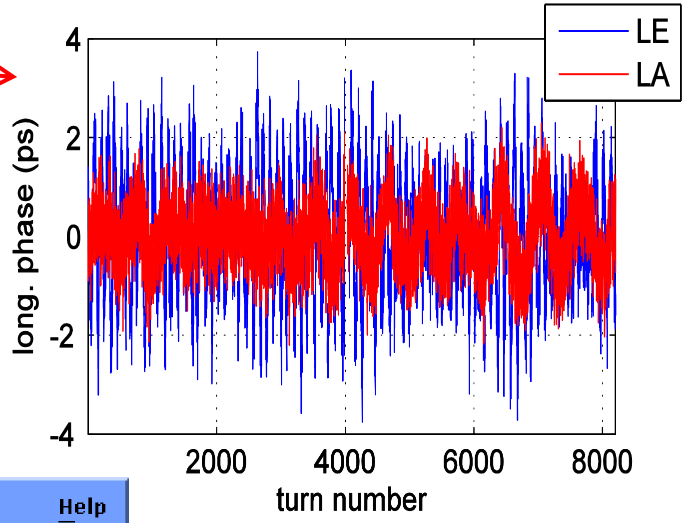
$$\left(\frac{\sigma}{\sigma_1}\right)^4 = \left(\frac{f_s}{f_{s,o}}\right)^4 + \left(\frac{I}{I_1}\right)^{1.7}$$

I_1 =3.8mA, σ_1 = 16.8ps,
f_{s0}=10.8 kHz

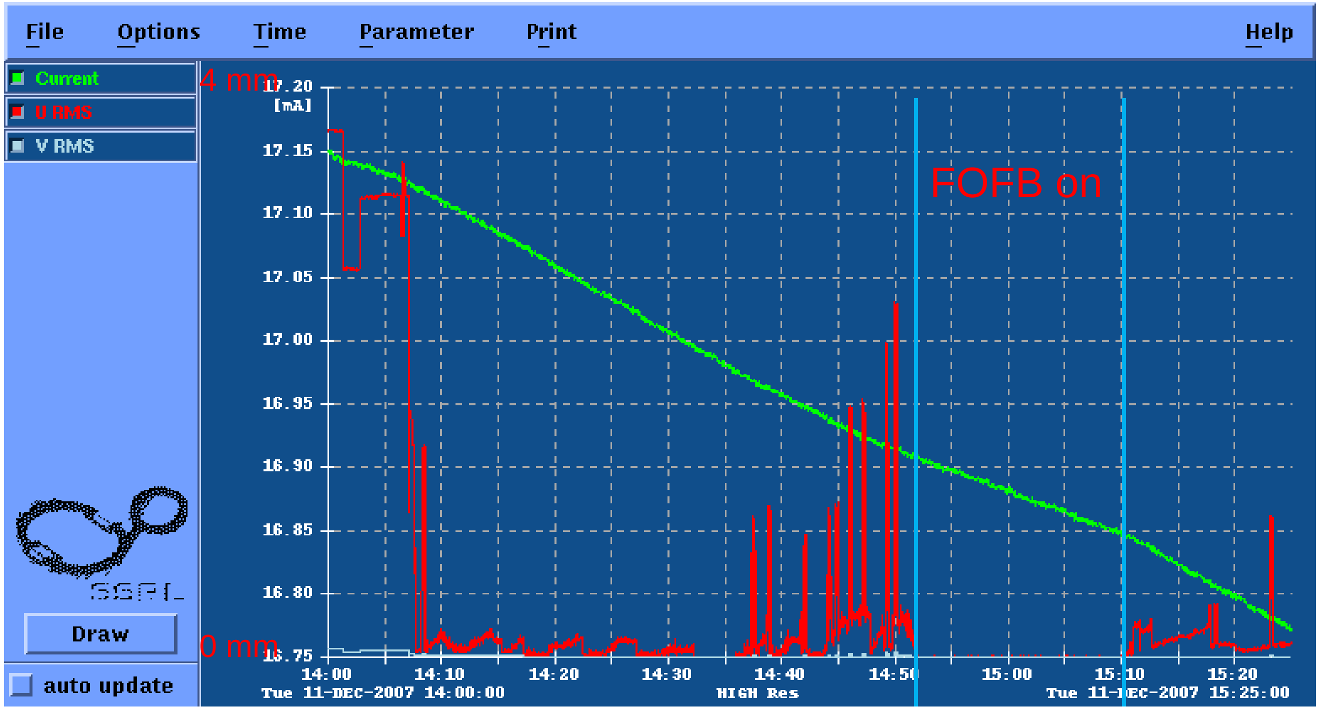
Streak camera measurement by J. Corbett, et al

Orbit stability

Better longitudinal phase stability in low alpha mode

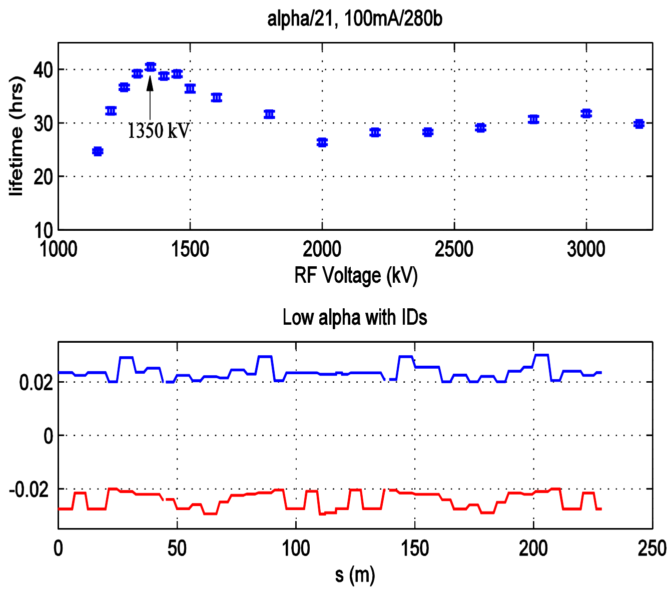


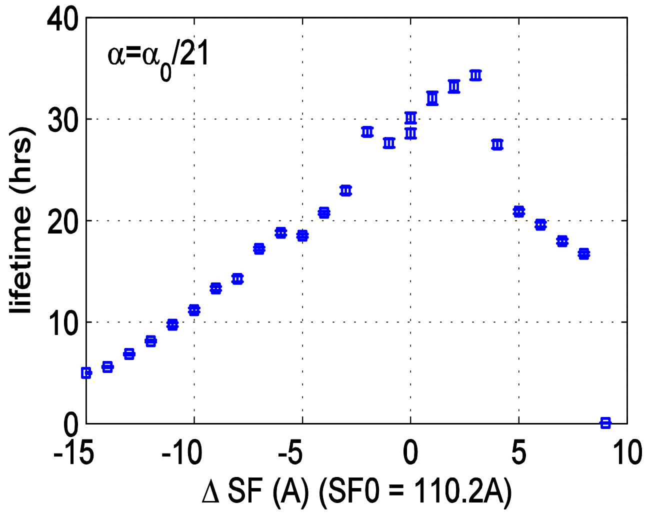
Horizontal orbit stability is worse, but can be kept under control by fast orbit feedback.



FOFB on for $\alpha/340$ lattice

Lifetime





Lifetime is 30 hrs at 100 mA, alpha/21, dominated by Touschek lifetime.

A positive α_3 (=0.05) helps stabilize the beam (Y. Shoji, NewSUBARU).

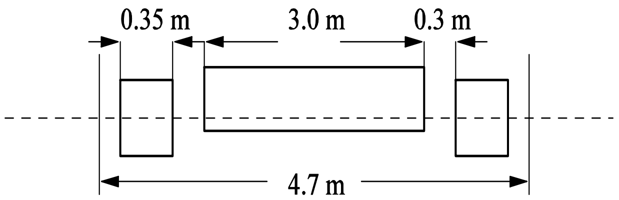
User interests in low alpha mode

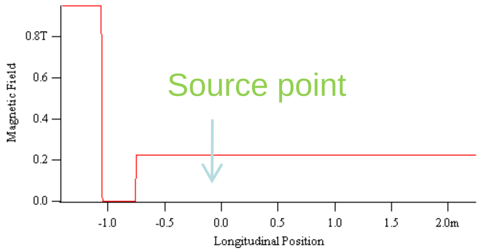
- Timing experiment
  - 1 ps rms beam for a user group in several experimental sessions.
- THz?

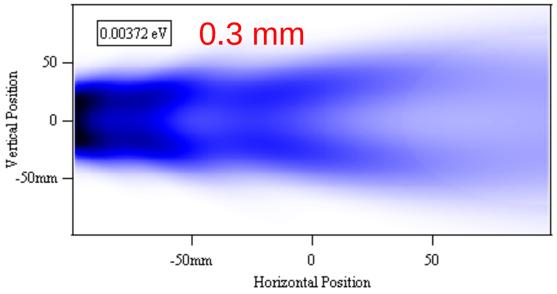
Plan for a THz beamline

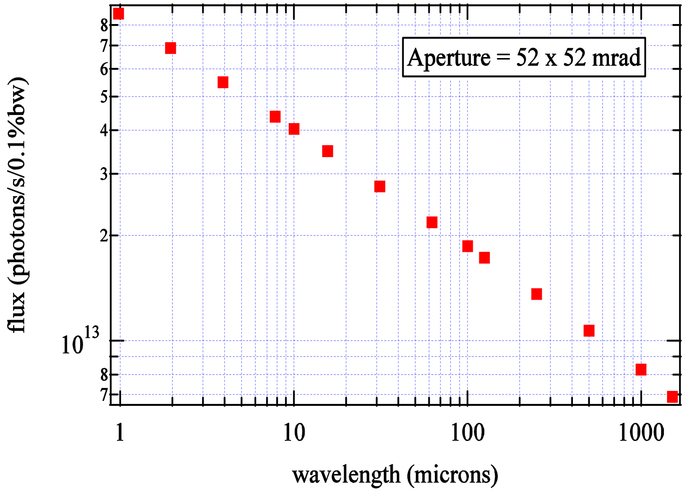
- Edge radiation or dipole radiation?
- The chicane dipole source
- Incoherent synchrotron radiation flux

Parameter	Value
Bending radius	45 m
Bending angle	66.7 mrad
Aperture	52 x 52 mrad^2









Calculated with SRW

Consideration for bending radius

- Opening angle of SR
- Shielding of vacuum chamber
- THz flux
- Horizontal size of first mirror
- cost

$$\sigma_\theta = 0.62\left(\frac{\lambda}{\rho}\right)^{1/3} \quad [\mathrm{rad}],$$

$$\lambda_{\mathrm{cutoff}} = 2h\sqrt{\frac{h}{\rho}}$$

$$\mathrm{flux} \propto \rho^{1/3}$$

We need to optimize the design (not done yet)

Calculation of THz power

Considerations:

- Incoherent THz flux
- CSR amplification factor
    - Single bunch current limit
    - Equilibrium distribution
- Vacuum chamber shielding at the port

Current – bunch length scaling law (for SPEAR3):

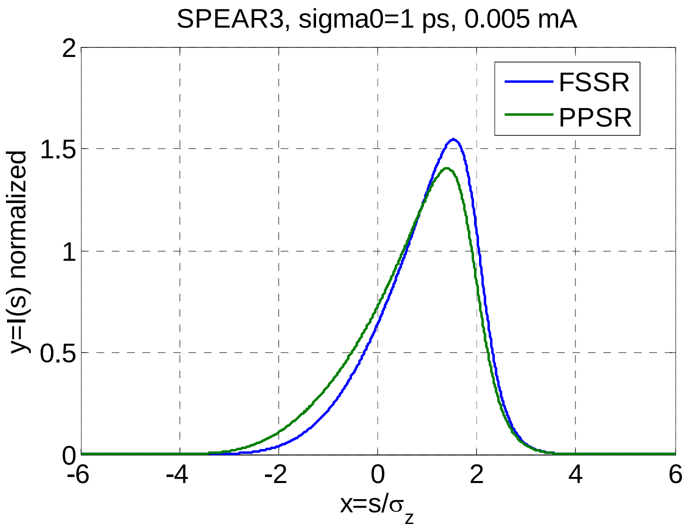
$$I[\text{mA}] = 0.0094\sigma[\text{ps}]^{7/3}$$

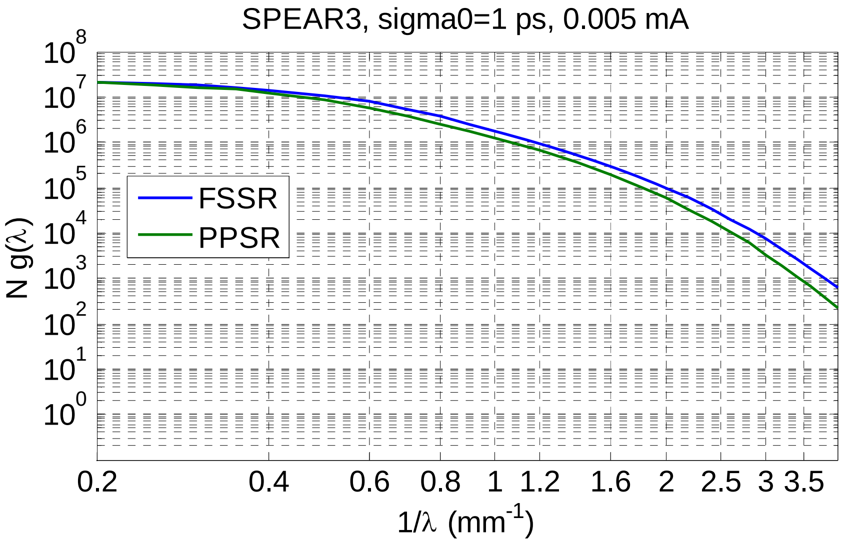
F. Sannibale model with $\lambda \sim 2\pi/5\ \sigma$

$$I[\text{mA}] = 0.005\sigma[\text{ps}]^{2.354}$$

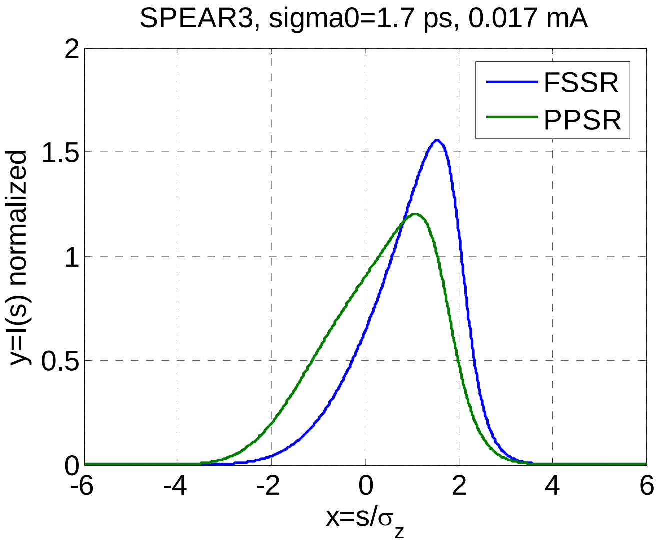
J. Corbett measurement

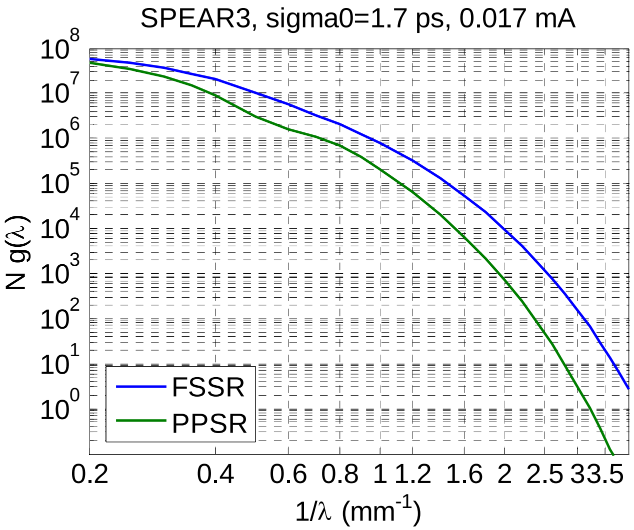
Hassinski eq. with free space CSR
F(k=0.29)=3.3 (FSSR)

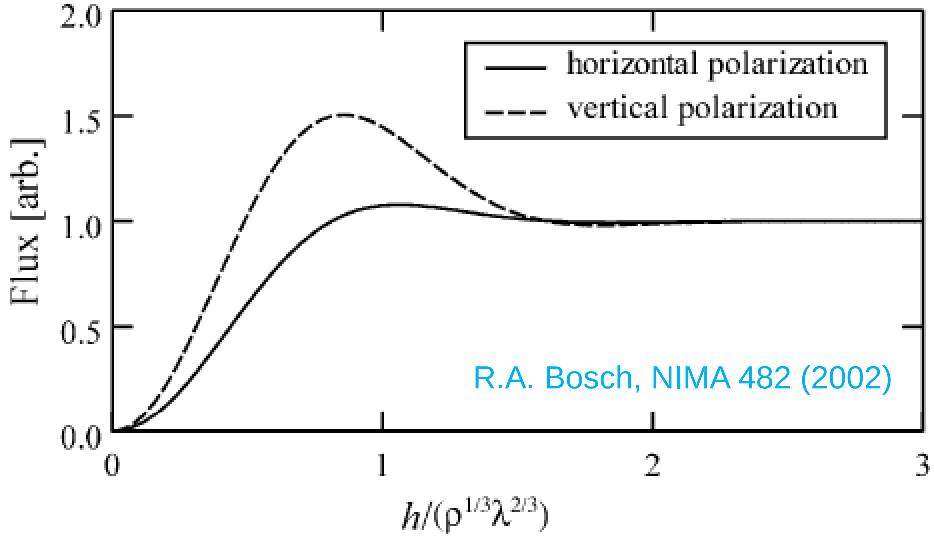




Shielding



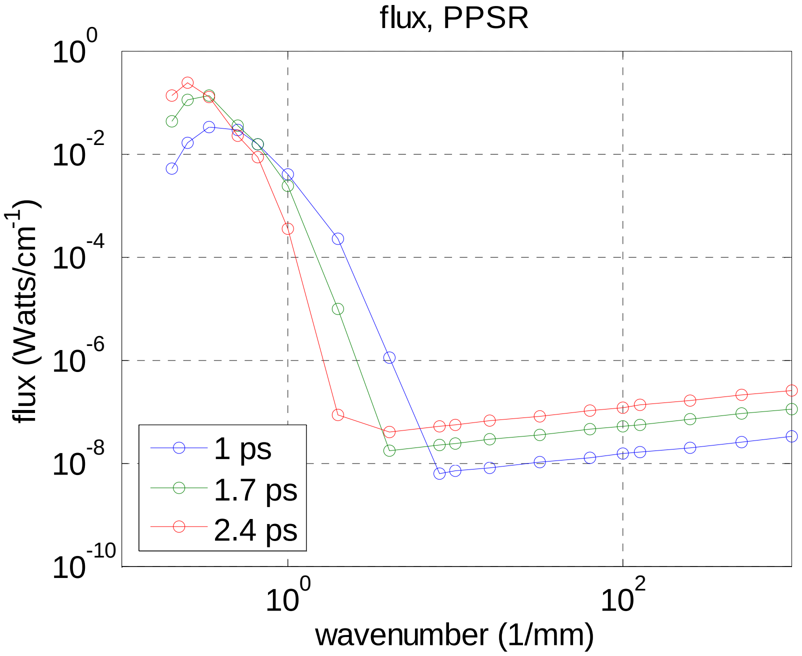




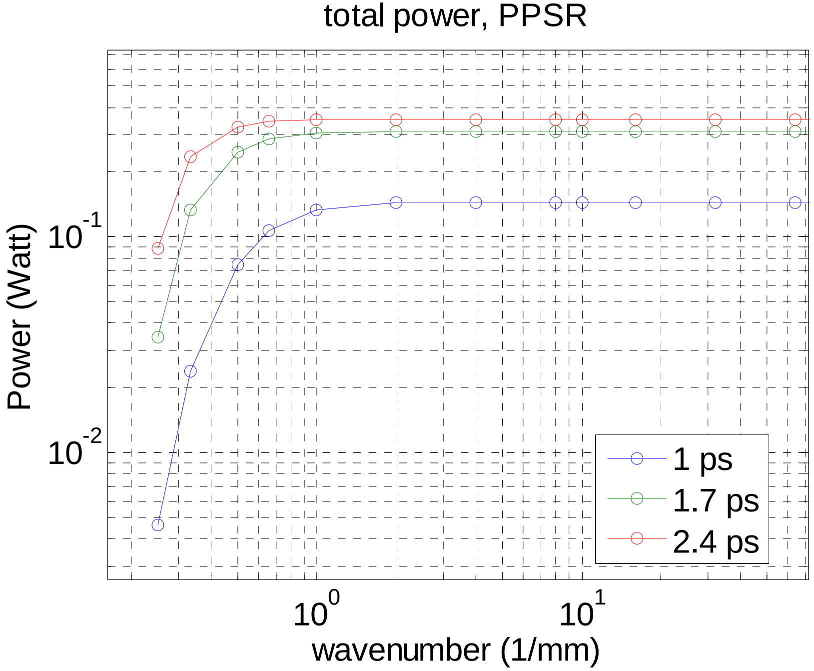
R.A. Bosch, NIMA 482 (2002)

Assume chamber height 52 mm

THz power



Flux through a 52 x 52 mrad^2 aperture



Total power through the aperture

Integration is numerically over data points shown on the left plot..

The measured current-bunch length scaling law is used.
Parallel plate shielding model is used to calculate bunch shape deformation.

The total THz power is 144 mW for the 1ps mode, mainly from wavelengths between 3 mm and 0.5 mm. The power can reach 300 mW for longer bunch modes, but concentrated in longer wavelengths.

Summary

- Low alpha mode for SPEAR3 was developed and is deliverable to users.
- A plan for a THz beamline is in its early stage.
- Questions:
  - Scaling law
  - Single bunch current limit – may be 2-4 times higher than assumed.
  - CSR impedance with shielding