TESLA

S2E Simulations on Jitter Tolerance at the TESLA XFEL Project

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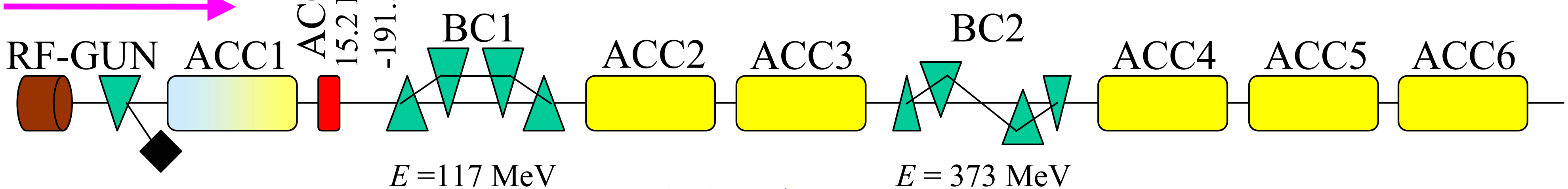
Old Lattice for TESLA XFEL - 2nd Version

Q=1.0 nC
e-beam

σ_z = 1.96 mm → 313 μm → 71 μm →

High gradient by ElectroPolishing Technology

ACC39
15.2 MV/m
-191.5 deg



20 MV/m
-2.773 degree

13 MV/m
20.8 MV/m
-25.0 degree

E =117 MeV
$\sigma_\delta \sim$ 2.14%
R_{56} = 76.2 mm
θ = 12 deg

31.0 MV/m
-60 degree

E = 373 MeV
$\sigma_\delta \sim$ 1.6%
R_{56} = 14.8 mm
θ = 2.1 deg

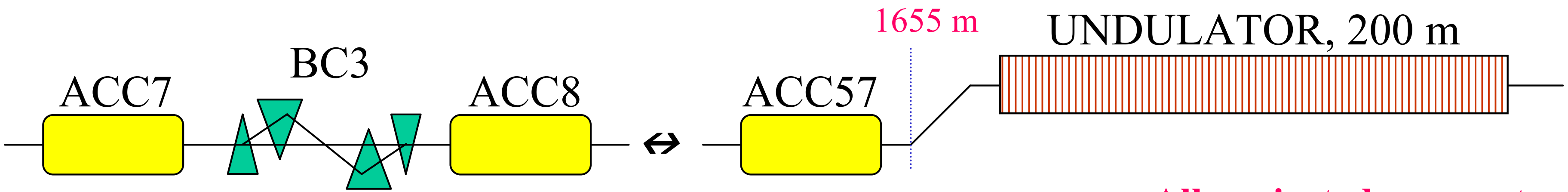
30.0 MV/m
-74 degree

ASTRA with Space Charge

0.0 m — 12.0444 m

To the end of Linac : ELEGANT with CSR
with geometric wakefields
without space charge

σ_z = 71 μm → 25 μm →



E =1.06 GeV
$\sigma_\delta \sim$ 0.9%
R_{56} = 4.7 mm
θ = 1.0 deg

21.0 MV/m
0.0 degree

E = 20.88 GeV
σ_δ = 0.0103%
σ_x = 52.1 μm, σ_y = 15.2 μm, σ_z = 25 μm
ε_{nx} = 1.72 μm, ε_{ny} = 1.28 μm

All projected parameters !

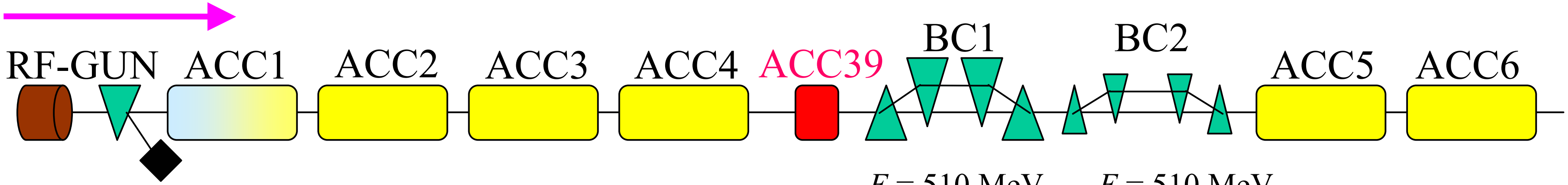
New Lattice for TESLA XFEL – 4th Version

TESLA XFEL Injector, ε_n= 0.9 µm

Q=1.0 nC

e-beam

σ_z = 1.76 mm → 113 µm → 23 µm →



RF-GUN	ACC1	ACC2	ACC39	BC1	BC2	ACC5, ACC6
30 MV/m -0.724 deg	11.5 MV/m 25.0 MV/m -18.3 deg	20.5 MV/m -29.6 deg	34.8 MV/m 160.6 deg	E = 510 MeV $\sigma_\delta \sim$ 1.89% R_{56} = 87 mm θ= 3.95 deg	E = 510 MeV $\sigma_\delta \sim$ 1.88% R_{56} = 4.8 mm θ= 0.93 deg	20.65 MV/m 0.0 deg

ASTRA with Space Charge

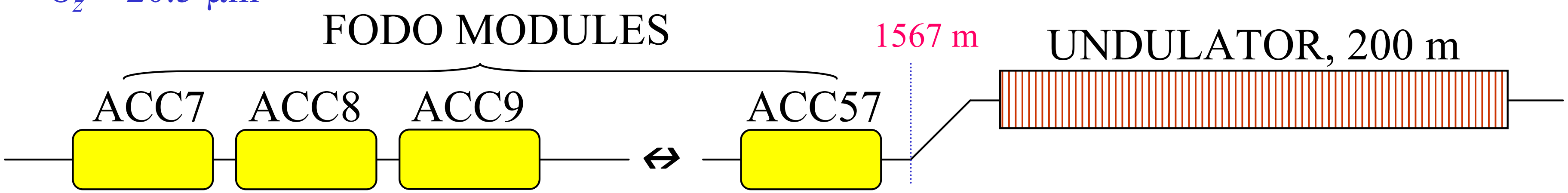
0.0 m — 12.0444 m

To the end of Linac : ELEGANT with CSR

with geometric wakefields

without space charge

σ_z = 20.5 µm →



20.65 MV/m

0.0 deg

E = 20.0 GeV

σ_δ = 0.008%

σ_x= 37.3 µm, σ_y= 31.6 µm, σ_z = 20.5 µm

ε_{nx}= 1.5 µm, ε_{ny}= 0.94 µm

All projected parameters !

Controllable Jitter Tolerance from Dr. Simrock

For both 1.3 GHz TESLA Module & 3.9 GHz 3rd Harmonic Module

For the short term period (1 min)
RF Phase Error < 0.1 degree (rms)
RF Amplitude Error (dV/V) < 0.03% (rms)

Reference !!!

For the mid-term period (1 hour)
RF Phase Error < 0.3 degree (rms)
RF Amplitude Error (dV/V) < 0.09%

For the mid-term period (1 day)
RF Phase Error < 1.0 degree (rms)
RF Amplitude Error (dV/V) < 0.3%

Dr. Simrock will improve these tolerances in the near future !

Jitter Investigation Method with S2E simulation

By the help of S2E simulations, let's apply artificial jitter or error to all important components (GUN, ACC1 ~ ACC57, ACC39, BC1 and BC2) in order to investigate the sensitivity $p_{\text{sensitivity}}$ of those components on the longitudinal phase space at the end of linac (bunch length and dE/E).

After considering FEL performace, let's choose the tightest $p_{\text{sensitivity}}$ by limiting

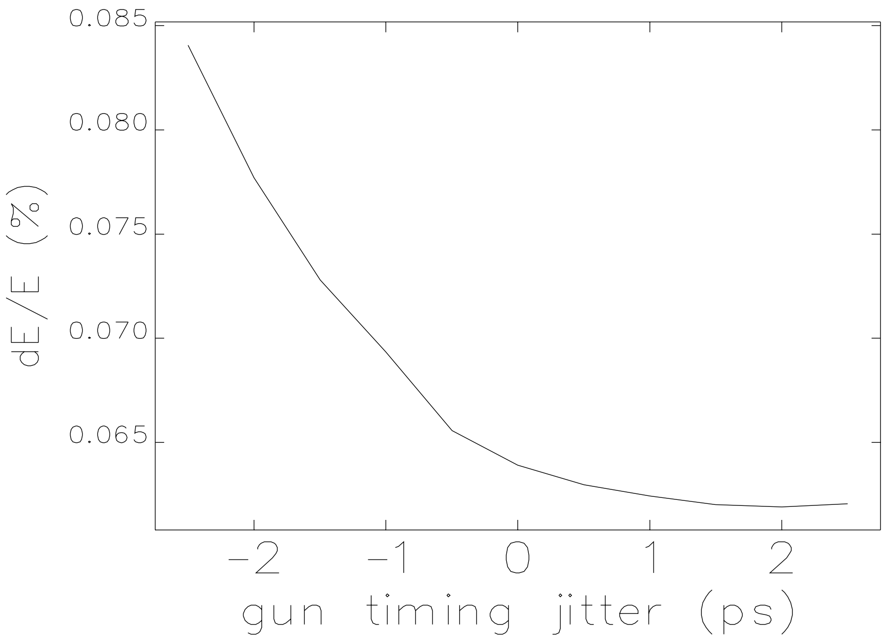
change in bunch length within +10% (~ 2 μm) at the end of linac
change in dE/E within +0.1% at the end of linac

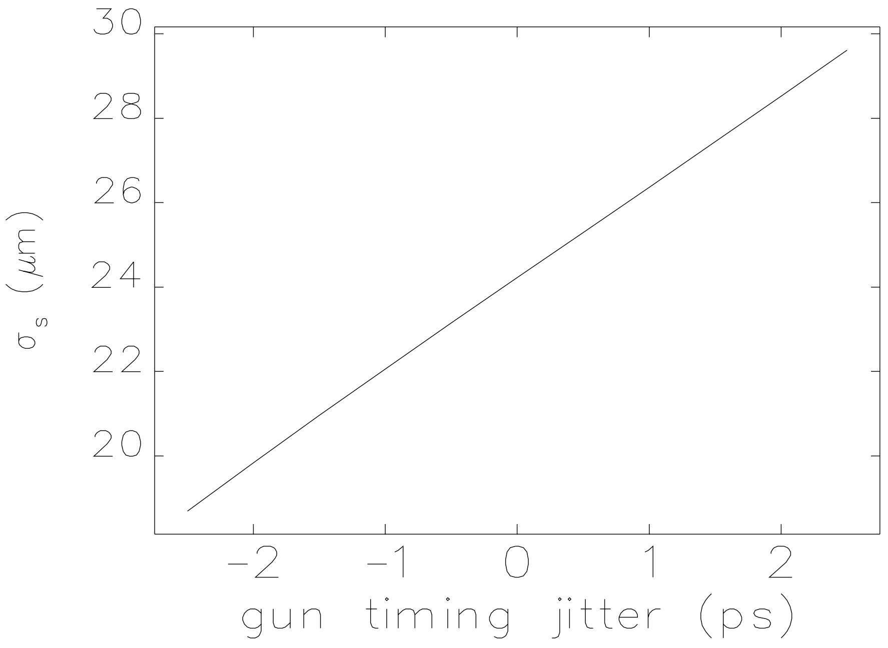
Then choose the tolerance p_{tolence} which gives $\sqrt{\sum_{i=1}^{n}\left(\frac{p_{tolence}}{p_{sensitivity}}\right)^2} < 1$

Let's check FEL performance under above tolerances with S2E simulations.

S2E simulation Results - Sensitivity

Gun Timing Jitter





Sensitivity in dE/E ~ -4.0 ps

Sensitivity in bunch length ~ 1.0 ps

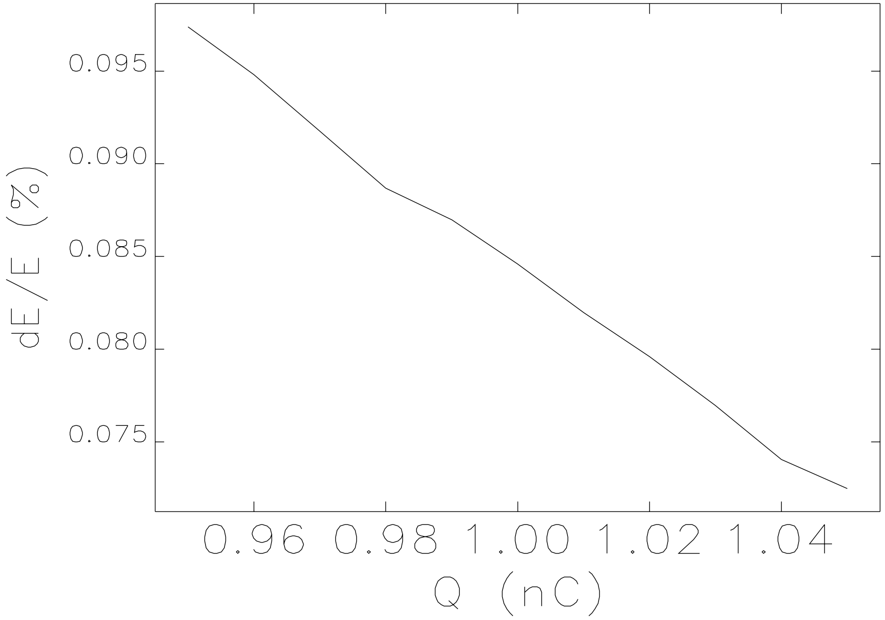
Therefore the tightest sensitivity is about 1.0 ps

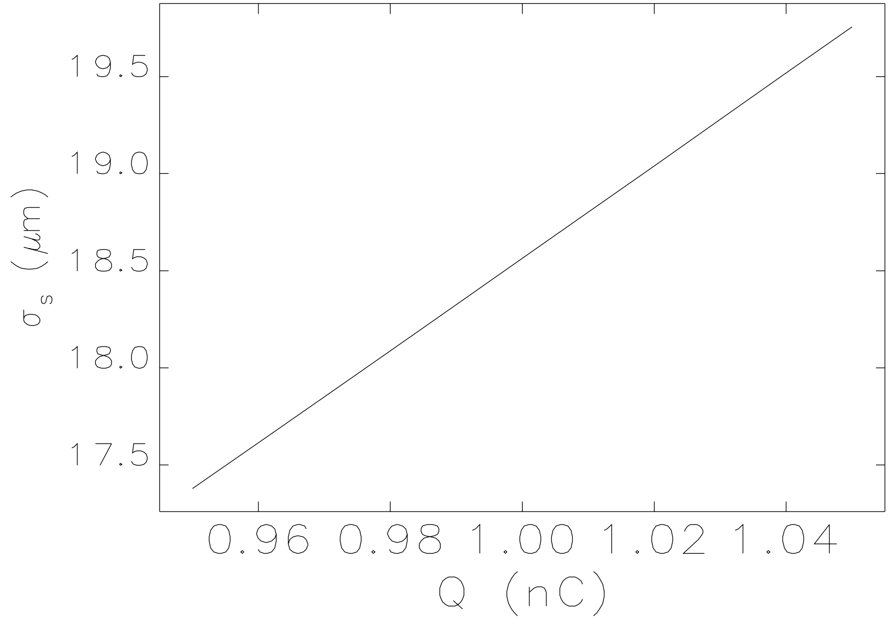
S2E simulation Results - Sensitivity

Change in Charge Q at Gun

From LEUTL's photoinjector experiences,

$$Q = Q_0(1 + 0.03\Delta\phi_l)(1 + (\Delta E / E)_l)(1 + (\Delta V / V)_g)$$





Sensitivity in dE/E ~ -40%

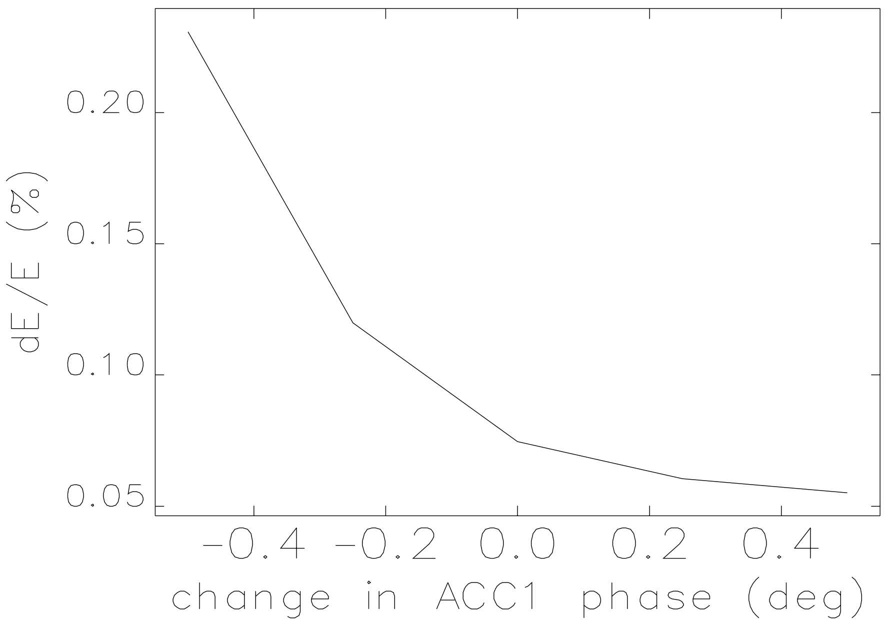
Sensitivity in bunch length ~ 8%

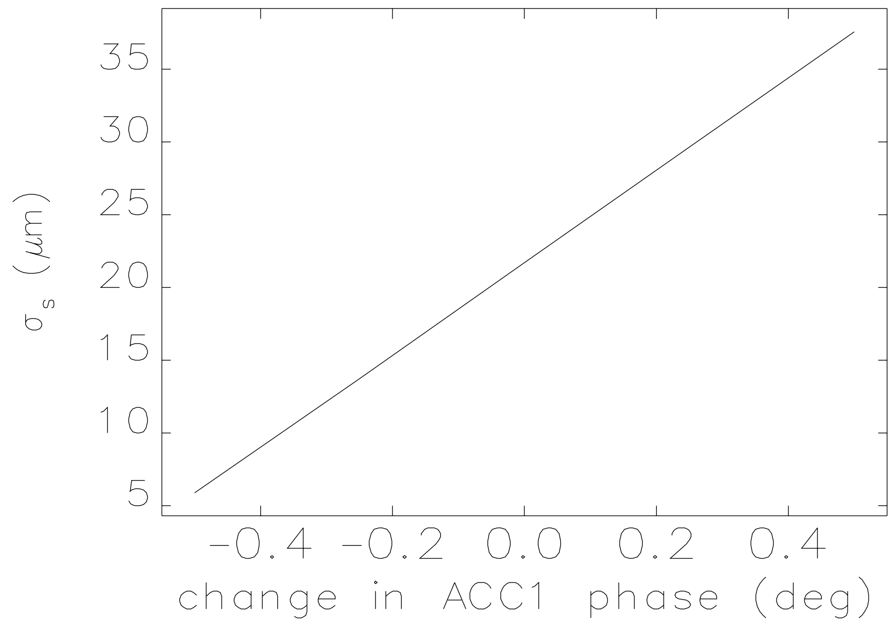
Therefore the tightest sensitivity is about 8%

S2E simulation Results - Sensitivity

ACC1 RF Phase

Here we assumed ACC1 will be driven by one Klystron





Sensitivity in dE/E ~ -3 degree

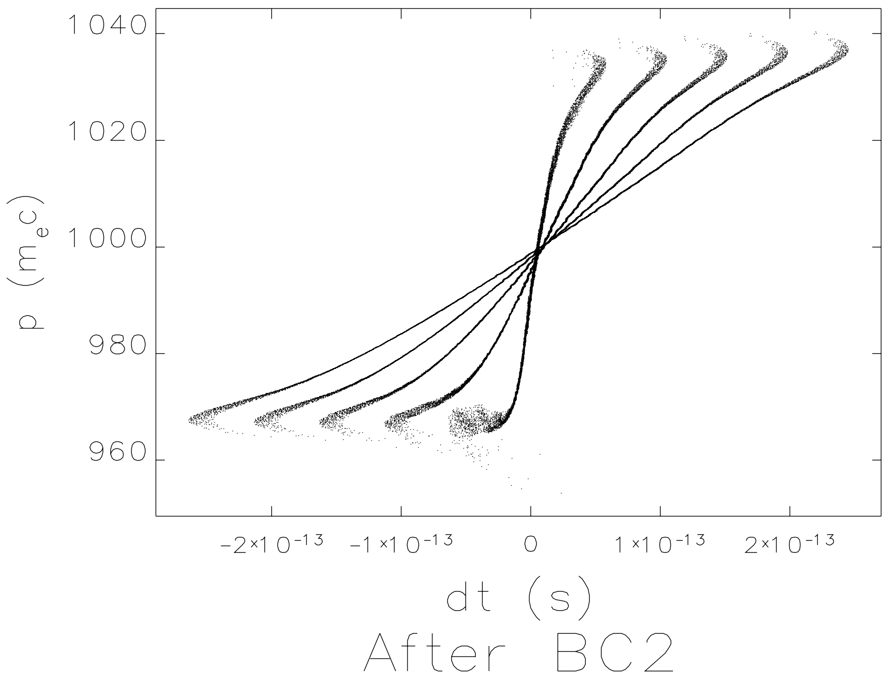
Sensitivity in bunch length ~ 0.1 degree

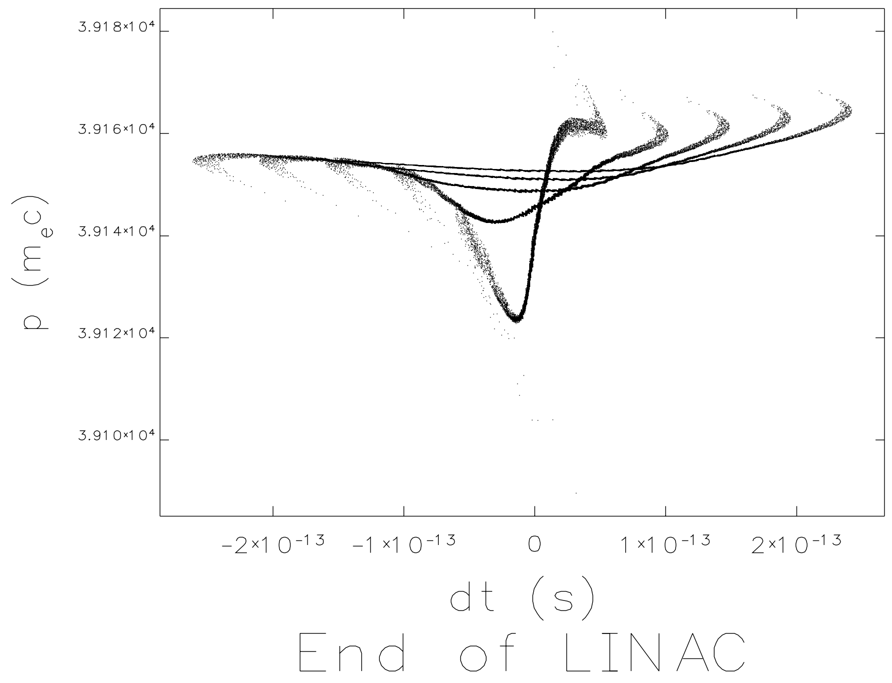
Therefore the tightest sensitivity is about 0.1 degree

S2E simulation Results - Sensitivity

ACC1 RF Phase

Here we assumed ACC1 will be driven by one Klystron



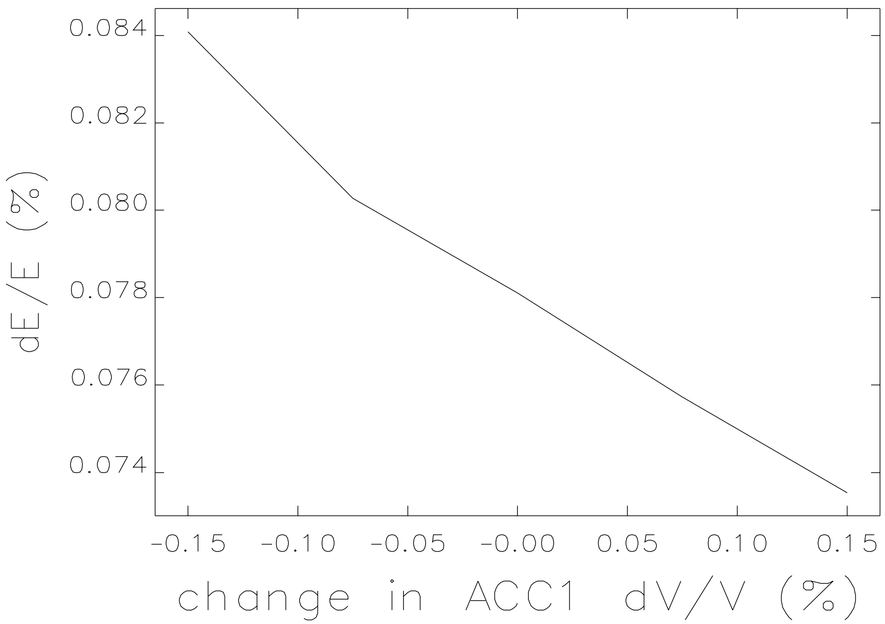


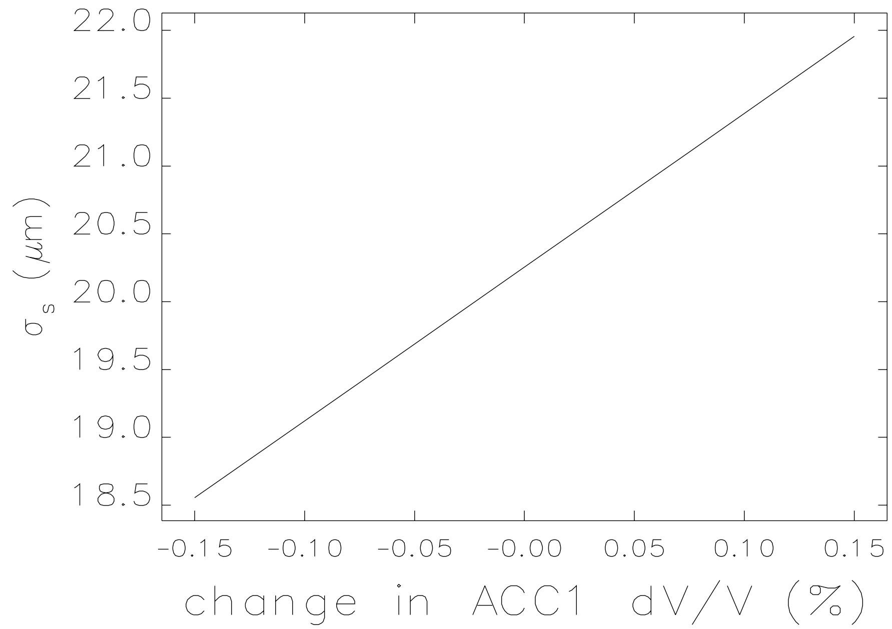
Therefore the tightest sensitivity is about 0.1 degree

S2E simulation Results - Sensitivity

ACC1 RF Voltage dV/V

Here we assumed ACC1 will be driven by one Klystron





Sensitivity in dE/E ~ -3.0%

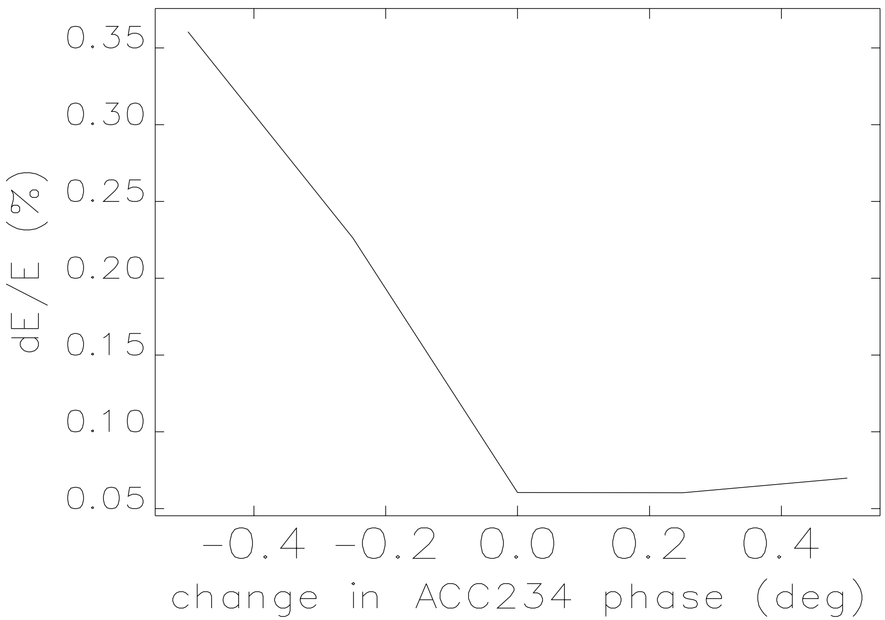
Sensitivity in bunch length ~ 0.15%

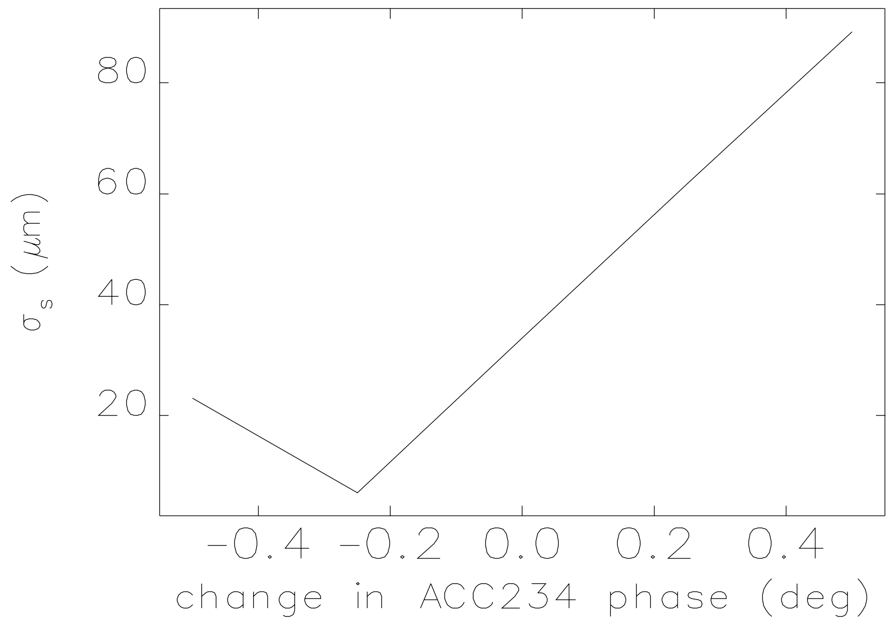
Therefore the tightest sensitivity is about 0.15%

S2E simulation Results - Sensitivity

ACC234 RF Phase

Here we assumed ACC2, ACC3, and ACC4 will be driven by one Klystron





Sensitivity in dE/E ~ -0.2 degree

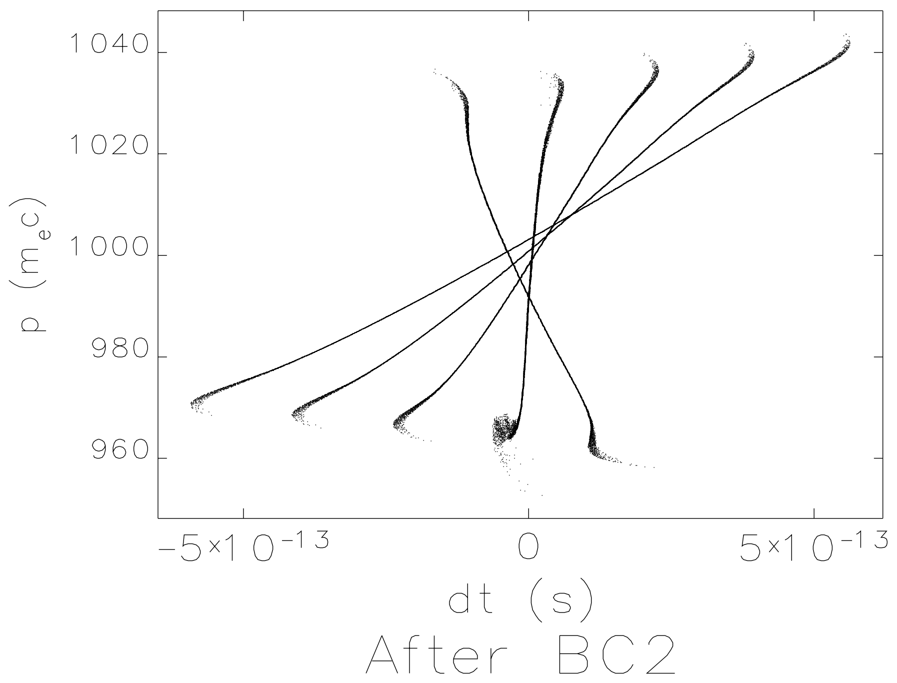
Sensitivity in bunch length ~ 0.02 degree

Therefore the tightest sensitivity is about 0.02 degree

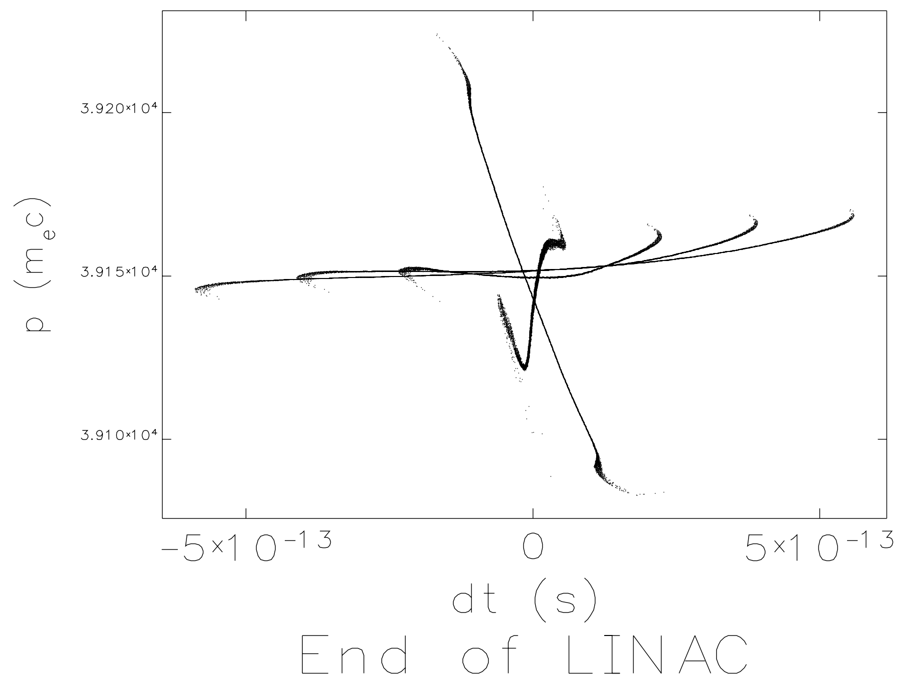
S2E simulation Results - Sensitivity

ACC234 RF Phase

Here we assumed ACC2, ACC3, and ACC4 will be driven by one Klystron



Sensitivity in dE/E ~ -0.2 degree



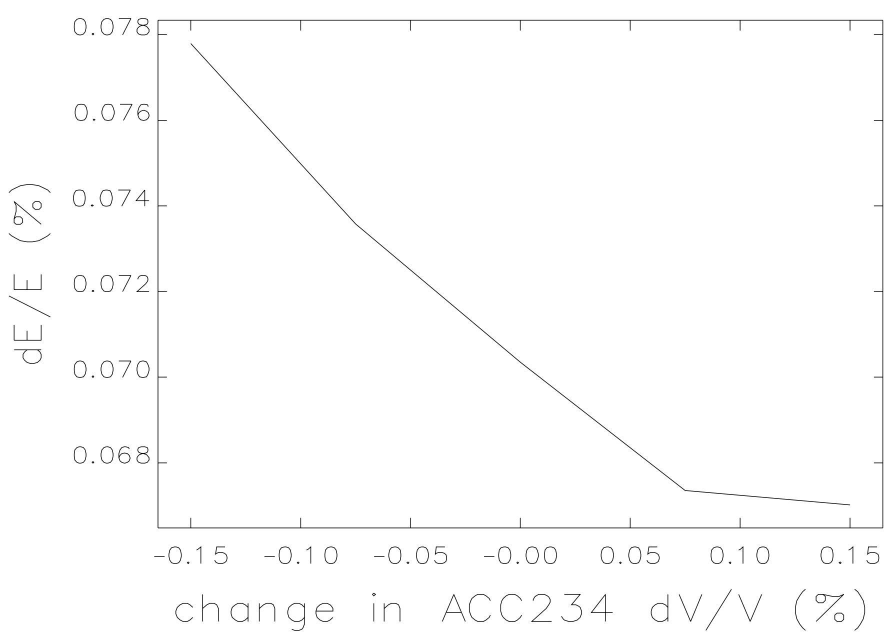
Sensitivity in bunch length ~ 0.02 degree

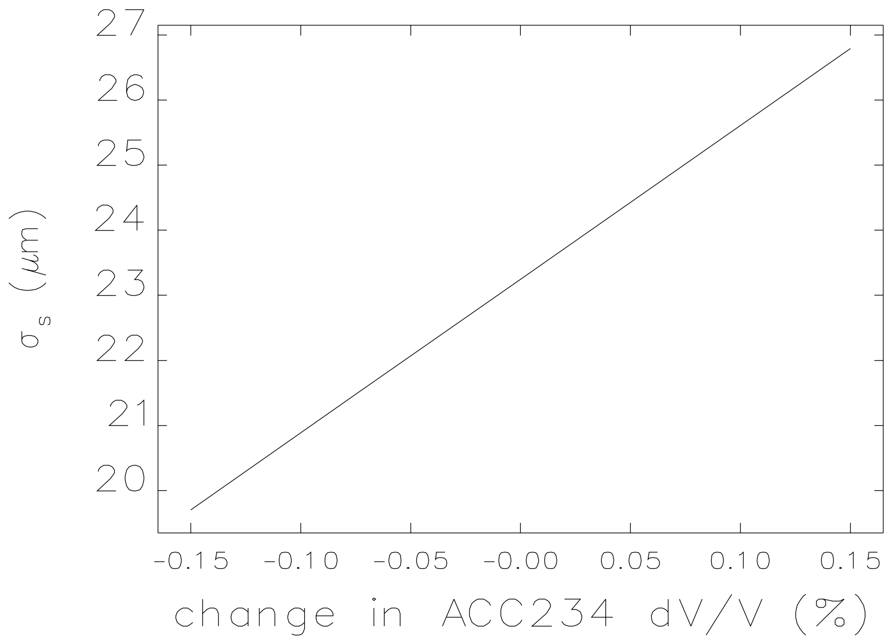
Therefore the tightest sensitivity is about 0.02 degree

S2E simulation Results - Sensitivity

ACC234 RF Voltage dV/V

Here we assumed ACC2, ACC3, and ACC4 will be driven by one Klystron





Sensitivity in dE/E ~ -2%

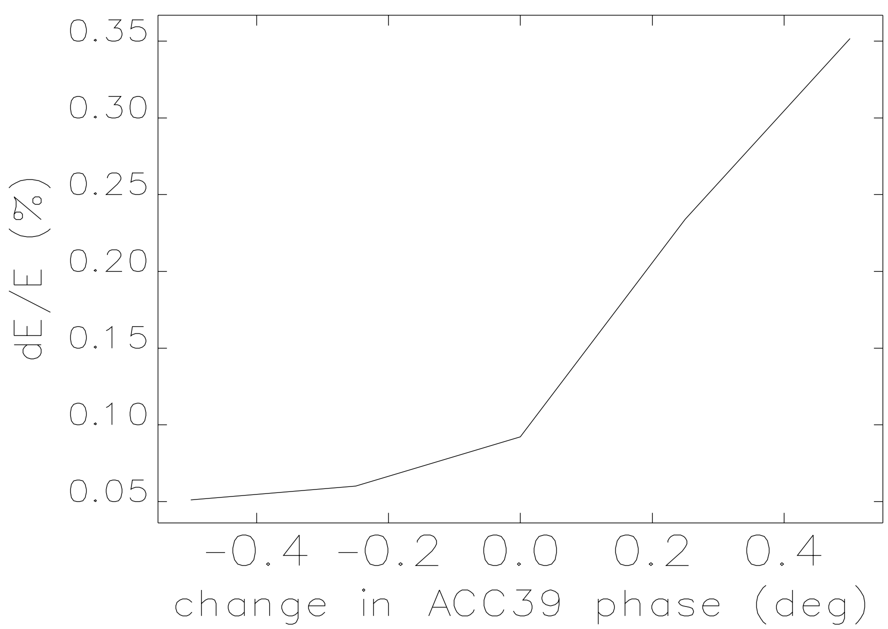
Sensitivity in bunch length ~ 0.1%

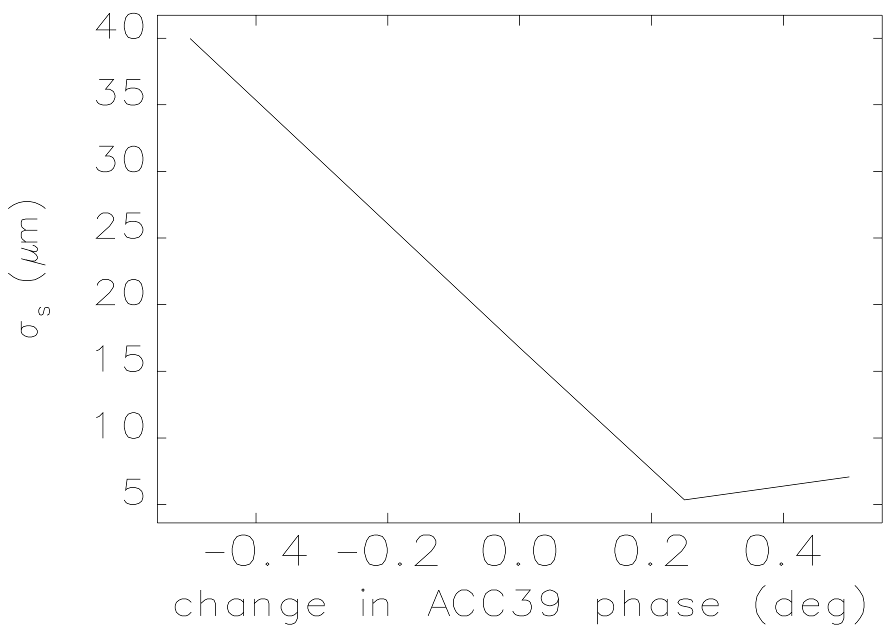
Therefore the tightest sensitivity is about 0.1%

S2E simulation Results - Sensitivity

ACC39 RF Phase

Here we assumed ACC39 will be driven by one Klystron





Sensitivity in dE/E ~ 0.2 degree

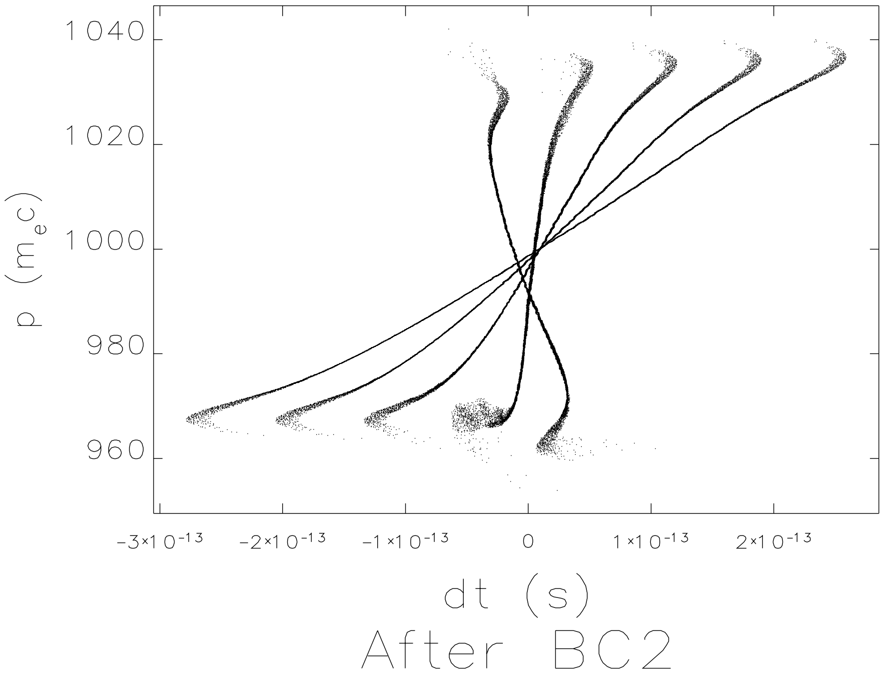
Sensitivity in bunch length ~ -0.04 degree

Therefore the tightest sensitivity is about -0.04 degree

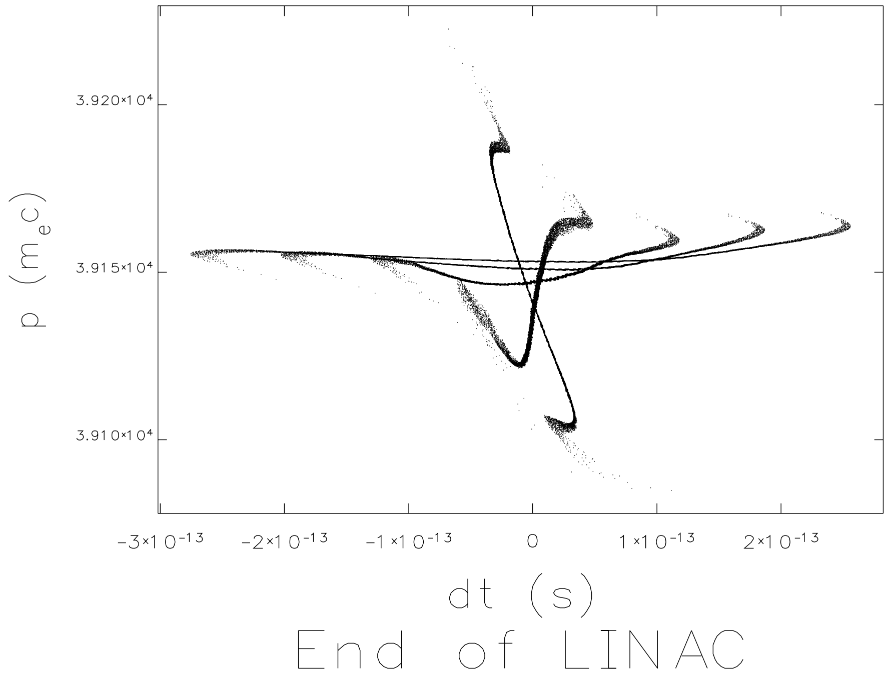
S2E simulation Results - Sensitivity

ACC39 RF Phase

Here we assumed ACC39 will be driven by one Klystron



Sensitivity in dE/E ~ 0.2 degree



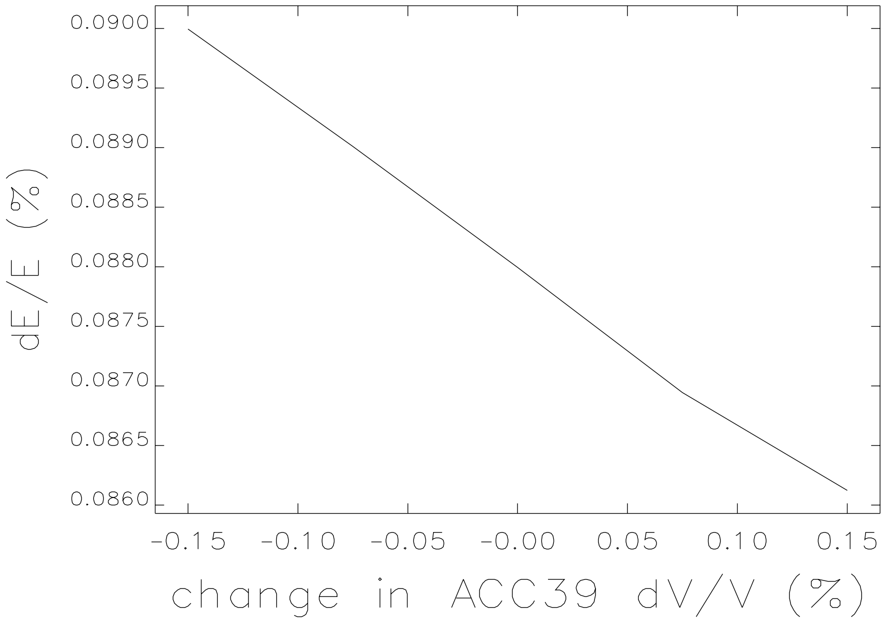
Sensitivity in bunch length ~ -0.04 degree

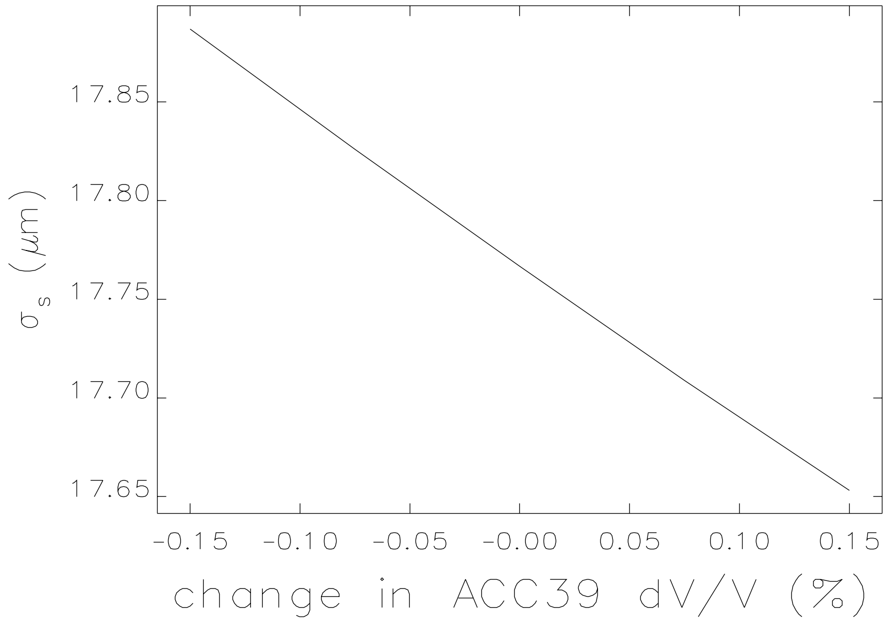
Therefore the tightest sensitivity is about -0.04 degree

S2E simulation Results - Sensitivity

ACC39 RF Voltage dV/V

Here we assumed ACC39 will be driven by one Klystron





Sensitivity in dE/E ~ -15%

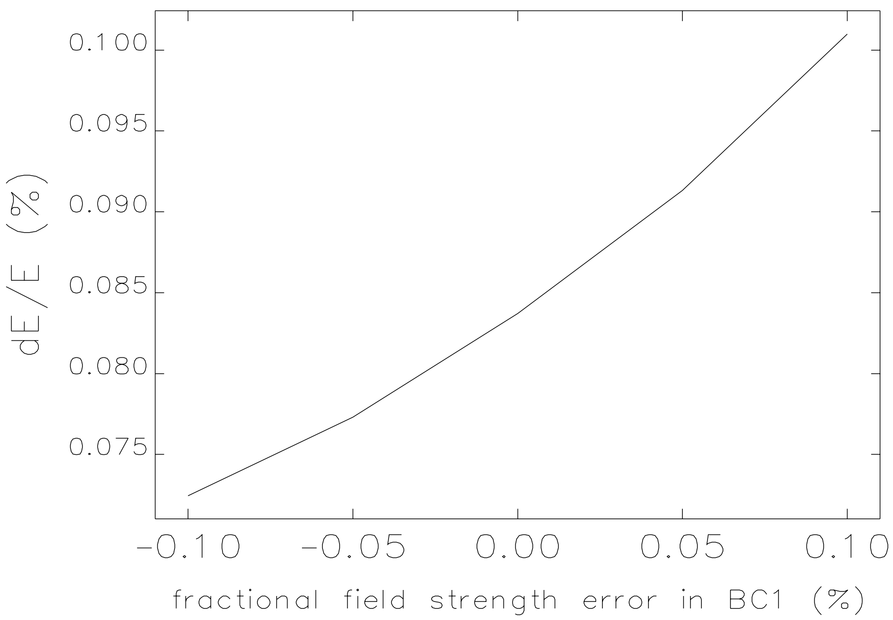
Sensitivity in bunch length ~ -3%

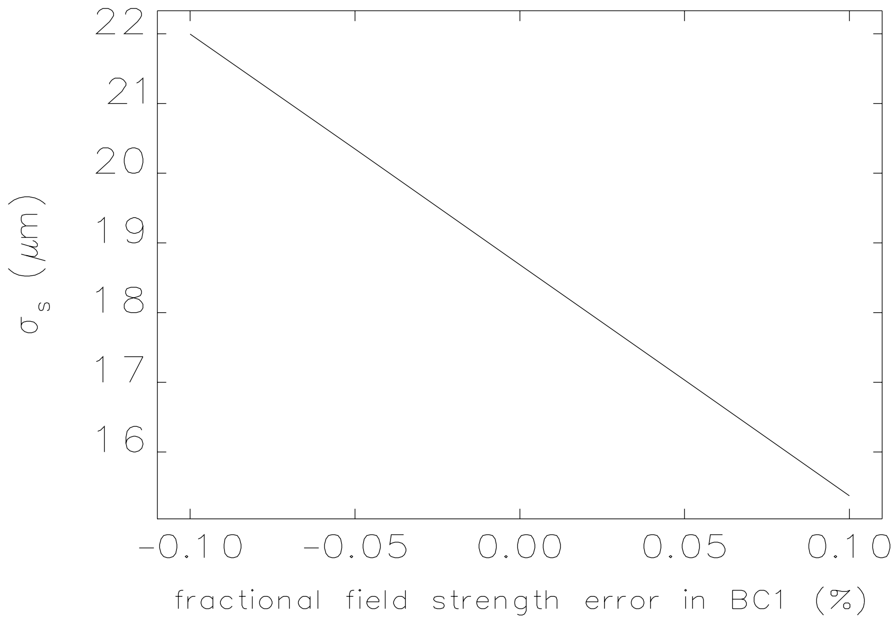
Therefore the tightest sensitivity is about -3%

S2E simulation Results - Sensitivity

BC1 Power Supply Error dI/I=dB/B

Here we assumed BC1 will be driven by one power supply





Sensitivity in dE/E ~ 0.5%

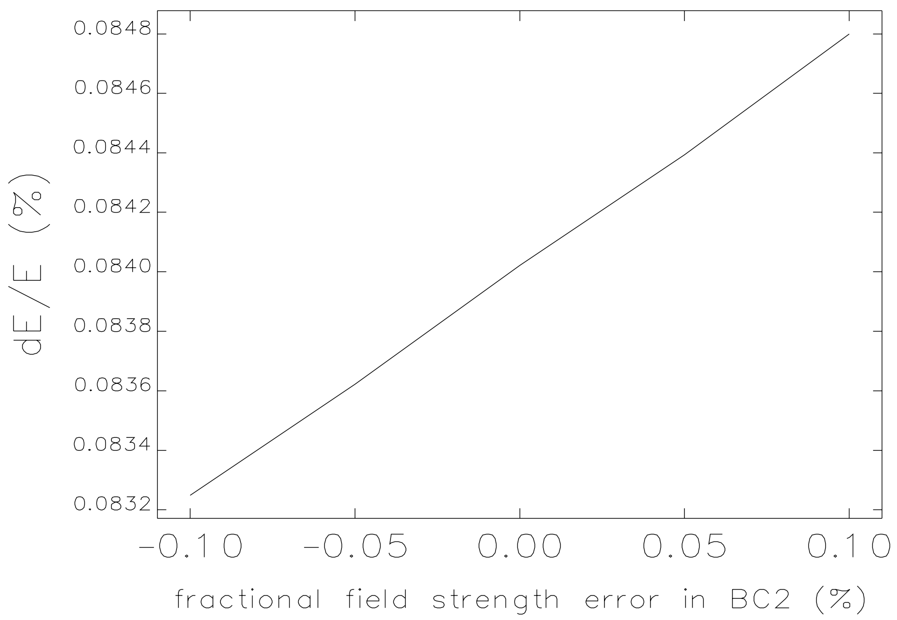
Sensitivity in bunch length ~ -0.05%

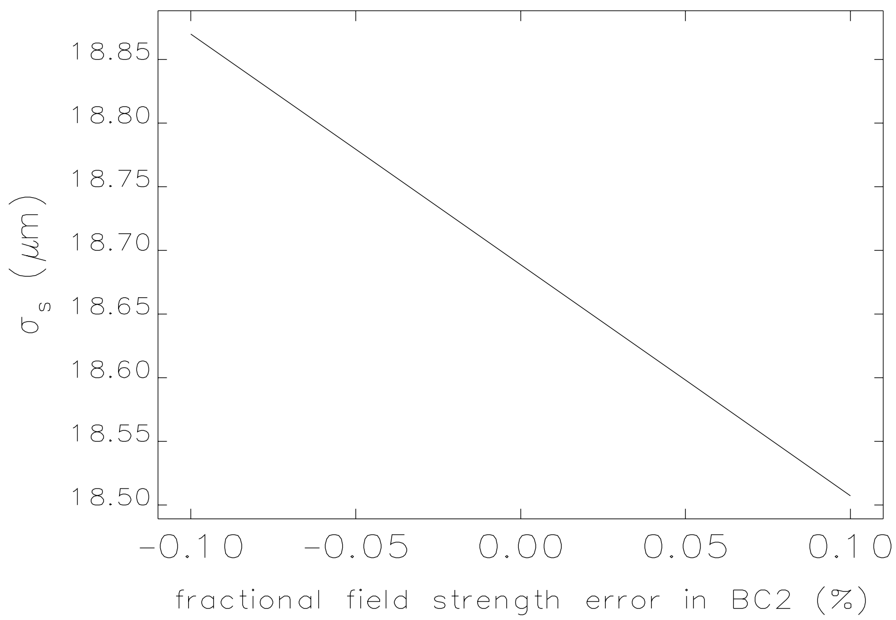
Therefore the tightest sensitivity is about -0.05%

S2E simulation Results - Sensitivity

BC2 Power Supply Error dI/I=dB/B

Here we assumed BC2 will be driven by one power supply





Sensitivity in dE/E ~ 125%

Sensitivity in bunch length ~ -1%

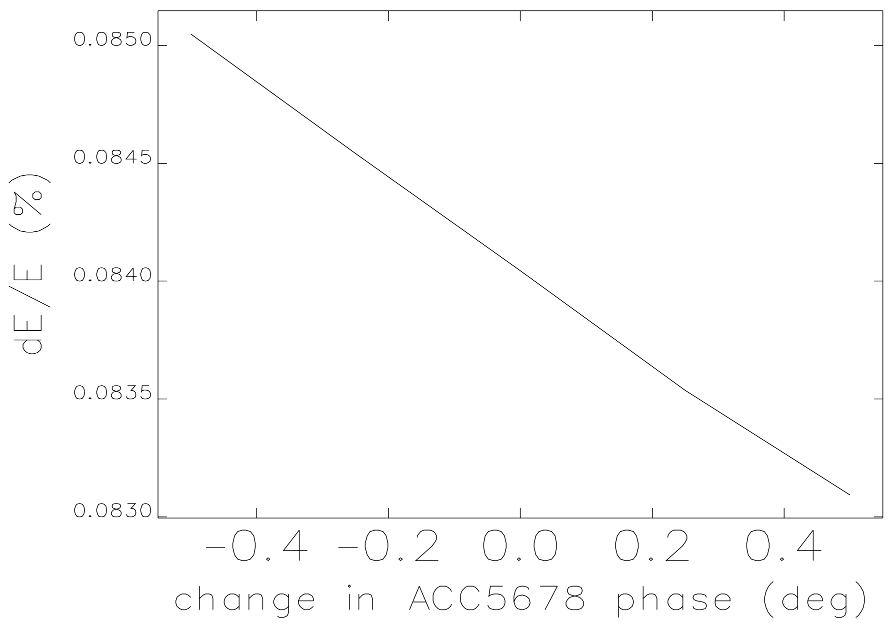
Therefore the tightest sensitivity is about -1%

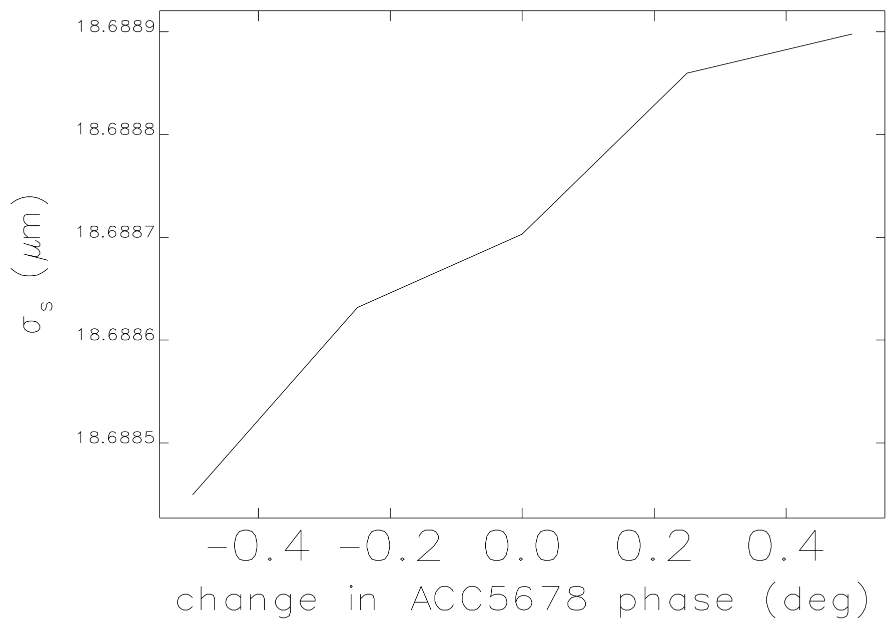
S2E simulation Results - Sensitivity

ACC5678 RF Phase

We assumed ACC5, ACC6, ACC7, and ACC8 will be driven by one Klystron

Since there are about 26 Klystrons after BC2, this region is safe against jitter.





Sensitivity in dE/E ~ -5 degree

Sensitivity in bunch length ~ ∞

Therefore the tightest sensitivity is about -5 degree

S2E simulation Results – Tolerance

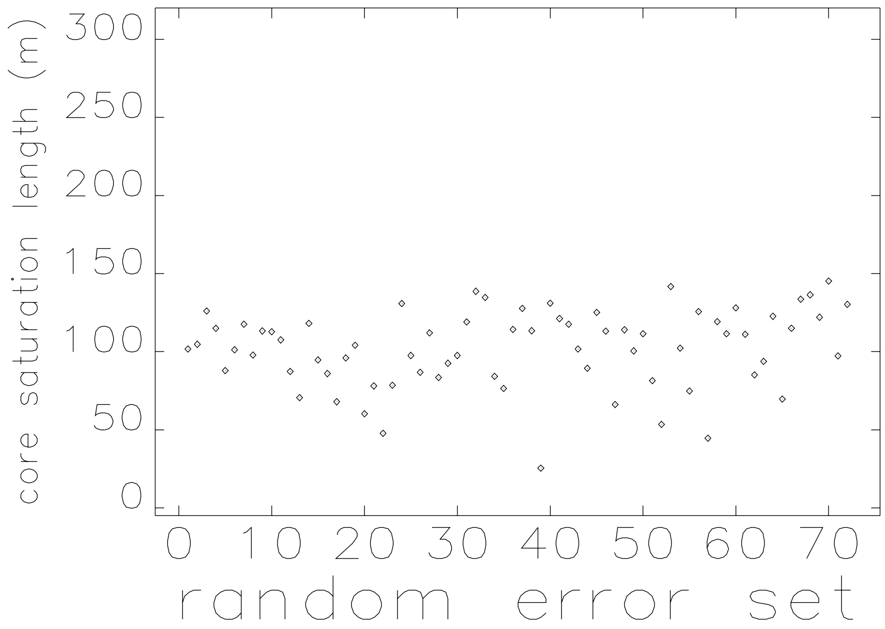
ACC234 phase (0.02 degree) and ACC39 phase (-0.04 degree) are lower than our control range !!!

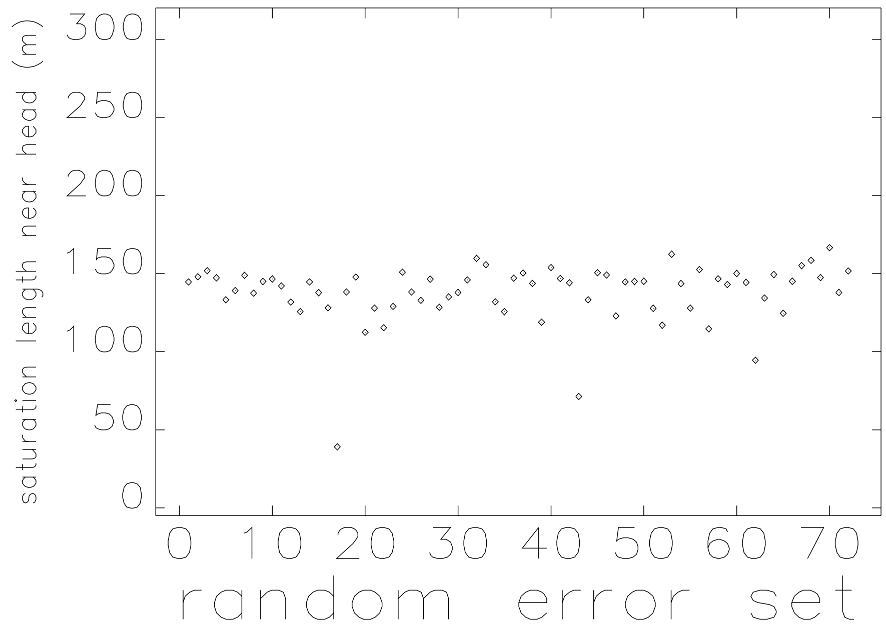
Anyway, I applied 70 random error set with following tolerances to TESLA XFEL linac, and checked FEL performance.
Here error cutoff is 3 sigma !

Gun Timing jitter : 0.3 ps (rms)
Charge change : 1% (rms)
Phase errors for all modules : 0.1 degree (rms)
Amplitude errors for all moduels : 0.03% (rms)
Power suppy error for BC1 and BC2 : 0.02% (rms)

S2E simulation Results – Tolerance

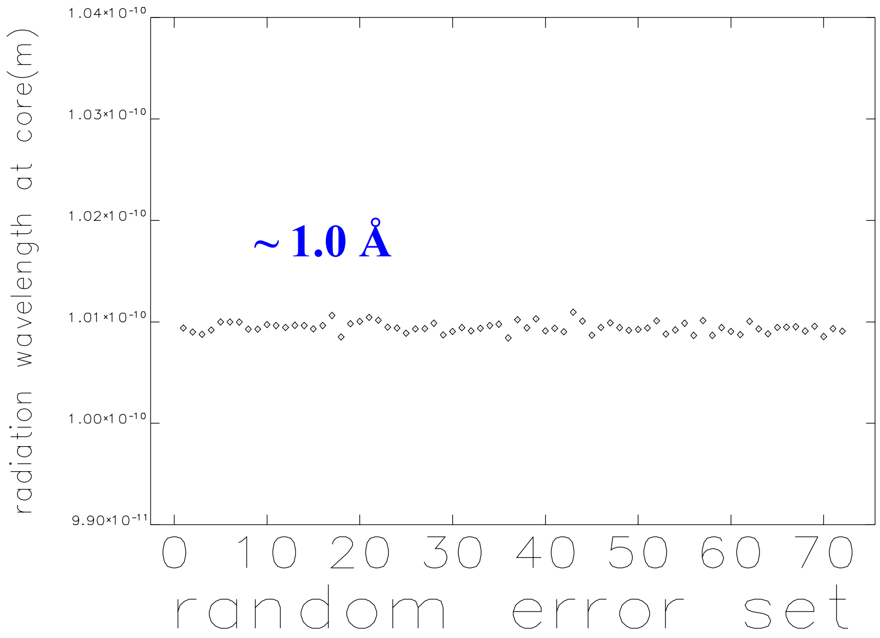
Saturation length is safe enough (< 200 m) under jitters and erros !!!



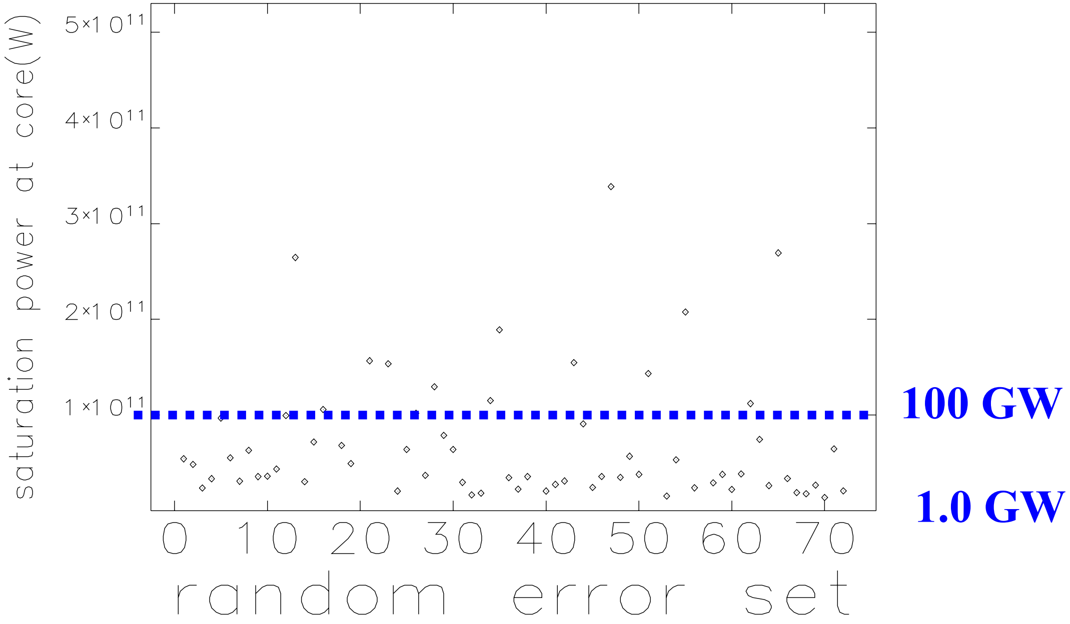


S2E simulation Results – Tolerance

Wavelength is no problem but the jitter in the saturation power is high !!!



Planned Power ~ 24 GW



Summary

After considering the space charge force at Gun, CSR in BCs, and geometric wakefields in linac, we have investigated jitter tolerance in the new TESLA XFEL lattice.

At the moment, it seems that we can not control phase jitters in ACC234 and ACC39 modules.

Under current controllable jitter tolerances, we met strong fluctuations in FEL output power. There is no big problem in all other things.

Continuously, we should study on the jitter tolerance and a new linac lattice for TESLA XFEL with large jitter margin.

Acknowledgments

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