TESLA

S2E Simulations on Jitter Sensitivity for the European XFEL Project

- Optional Multi-Klystron Operation -

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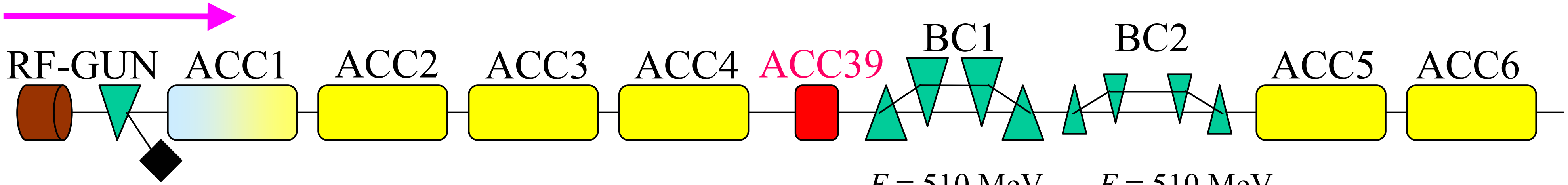
New Lattice for TESLA XFEL – 4th Version

With TESLA XFEL Injector, ε_n= 0.9 μm

σ_z = 1.76 mm → 113 μm → 23 μm →

Q=1.0 nC

e-beam



60 MV/m
38 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

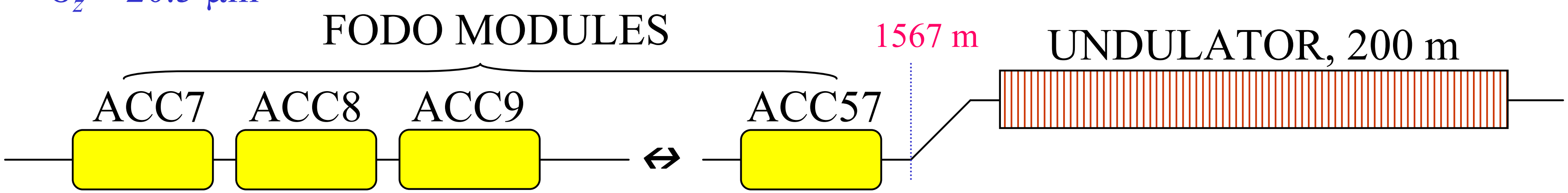
20.65 MV/m
0.0 deg

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 →



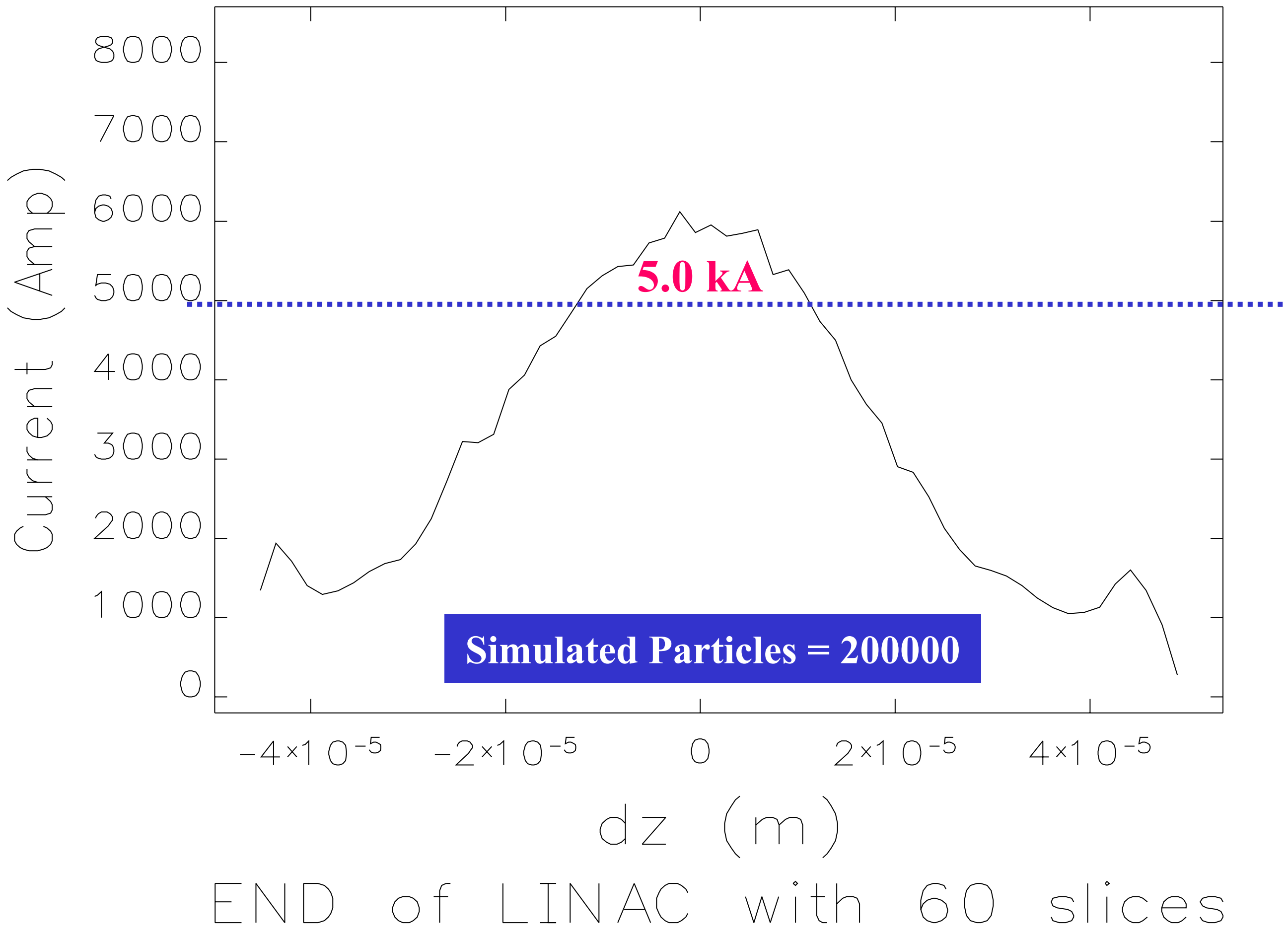
20.65 MV/m
0.0 deg

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 !

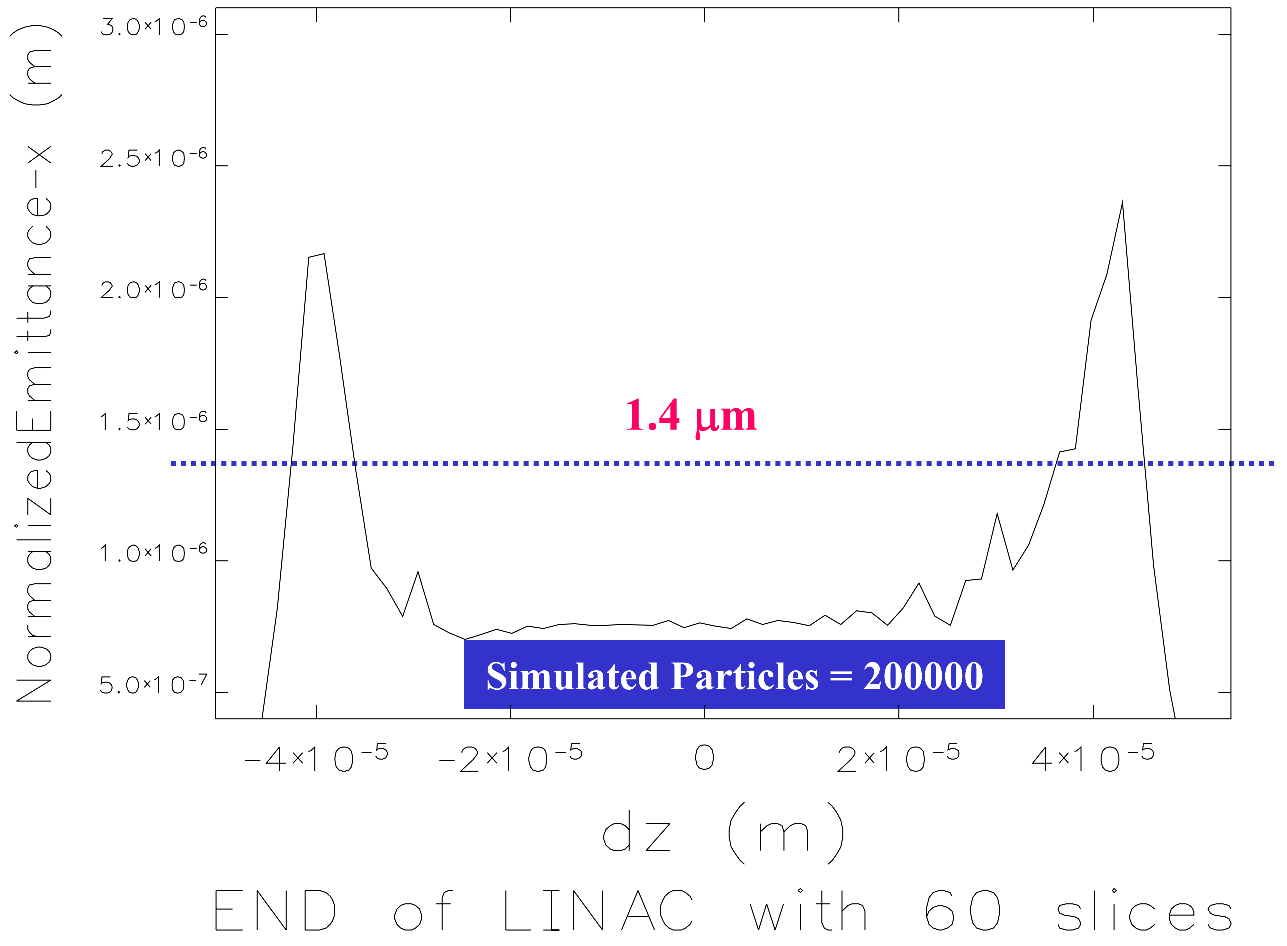
4th Lattice with TESLA XFEL Injector Layout

With TESLA XFEL Injector, ε_n = 0.9 μm



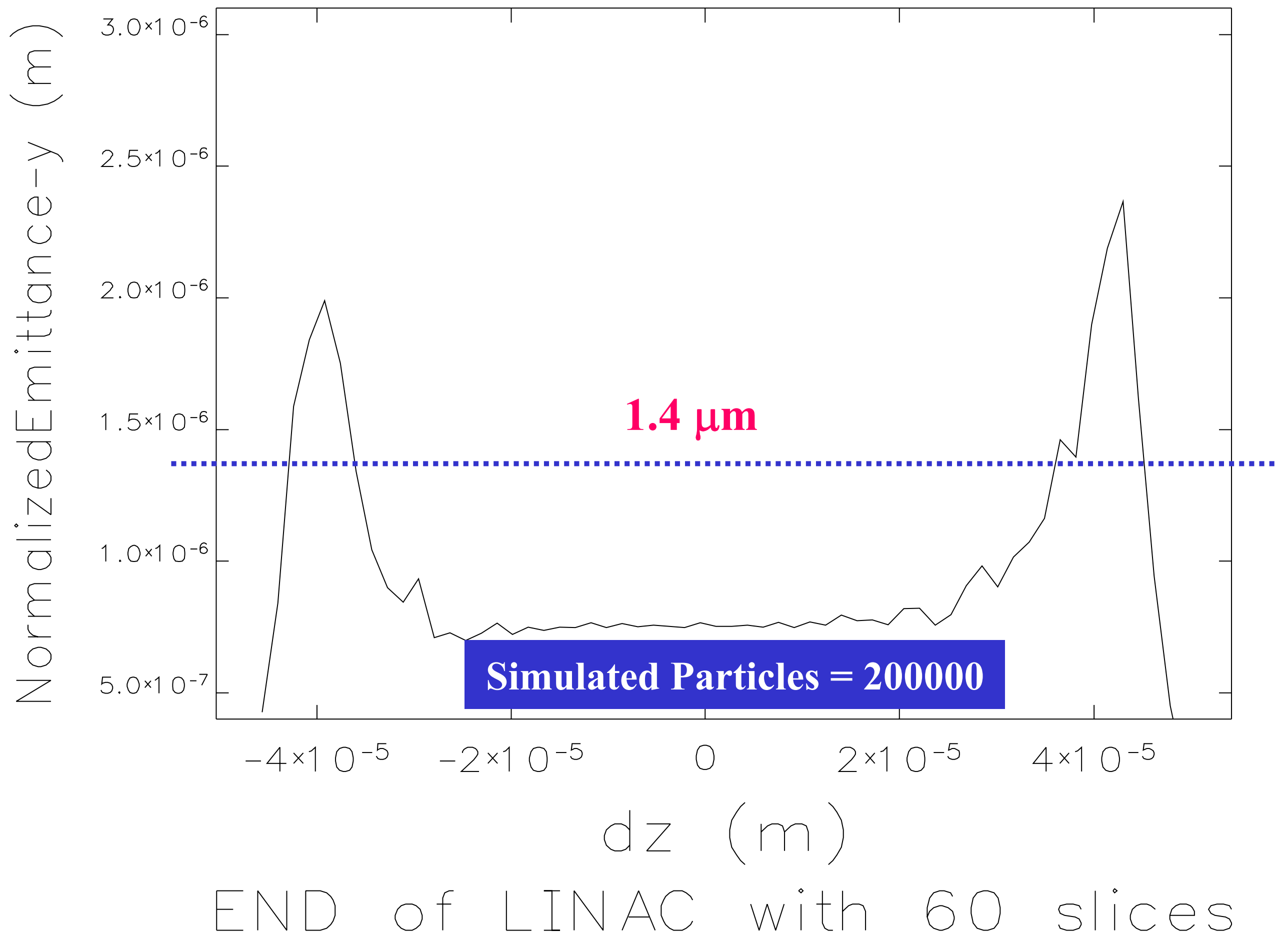
4th Lattice with TESLA XFEL Injector Layout

With TESLA XFEL Injector, $\varepsilon_n = 0.9\ \mu m$



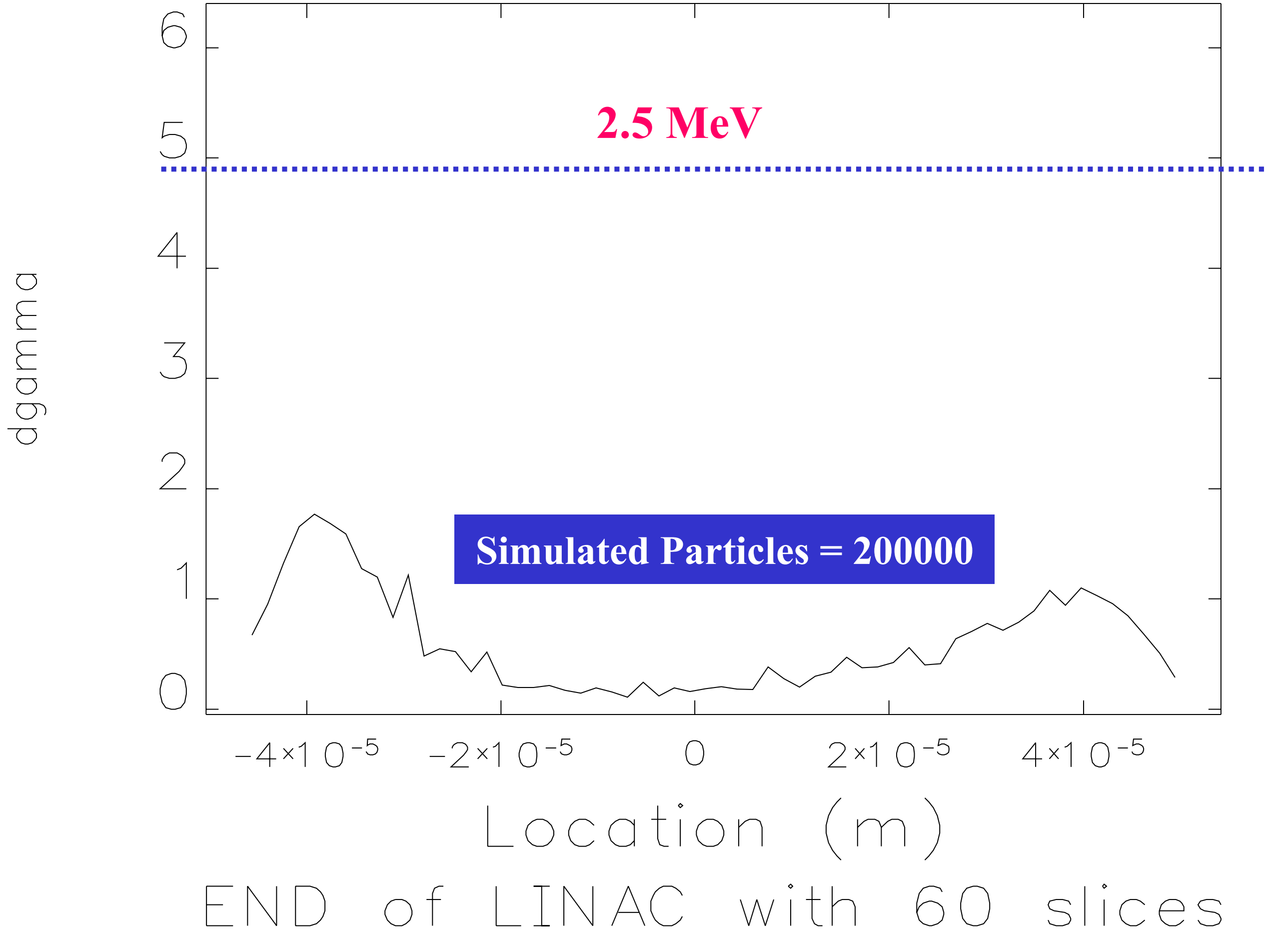
4^{th} Lattice with TESLA XFEL Injector Layout

With TESLA XFEL Injector, $\varepsilon_n = 0.9\ \mu m$



4^{th} Lattice with TESLA XFEL Injector Layout

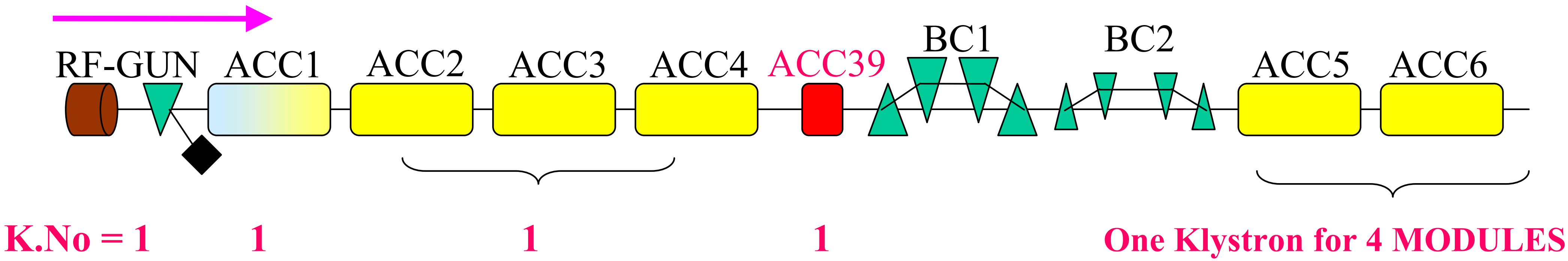
With TESLA XFEL Injector, ε_n= 0.9 µm

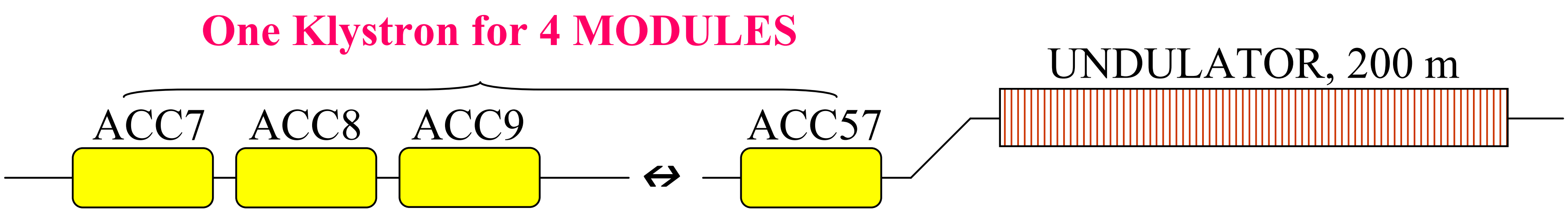


Maximum uncorrelated energy spread : 0.997 MeV @ 20.0 GeV ~ 0.00498% < 0.0125%
Fortunately, the uncorrelated energy spread in the center region is around 0.0005%

Old Klystron Layout for Jitter Study

Here K.No means Klystron number per module !

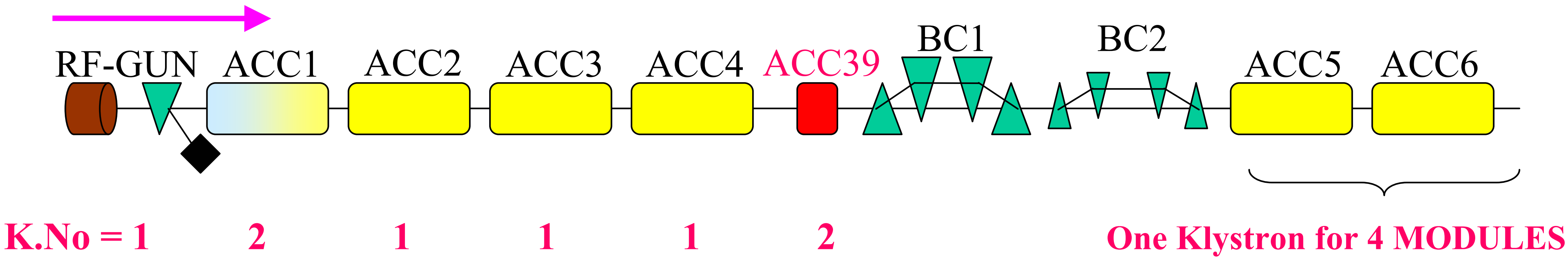


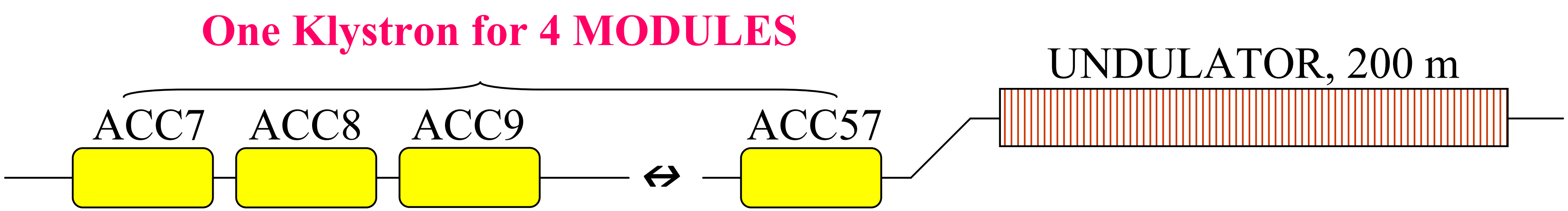


We met difficulity in ACC234 phase (0.02 degree) and ACC39 phase (-0.04 degree) !

New Klystron Layout for Jitter Study

Here K.No means Klystron number per module !





Mliti-Klystron before BC2 reduces the jitter sensitivity in ACC234 and ACC39 modules

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. (Next week will report this !)

Jitter Sensitivity Investigation Method

Used macro particle number for jitter sensitivity investigation : 10000

Considered Collective Effects : Space charge, CSR, Geometric Wakefields.

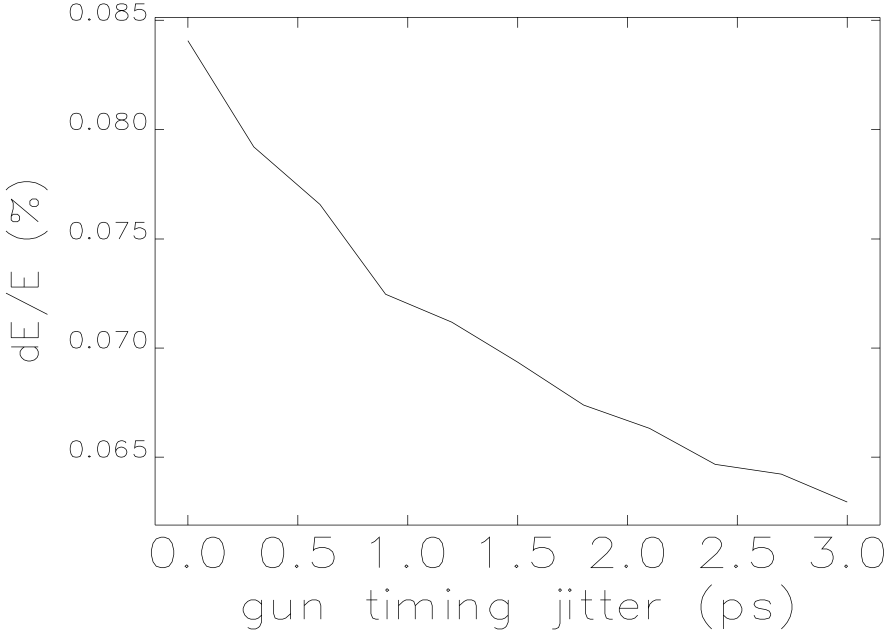
BINs for CSR calculation is reduced to control the artificial modulation at BCs due to small particle number.

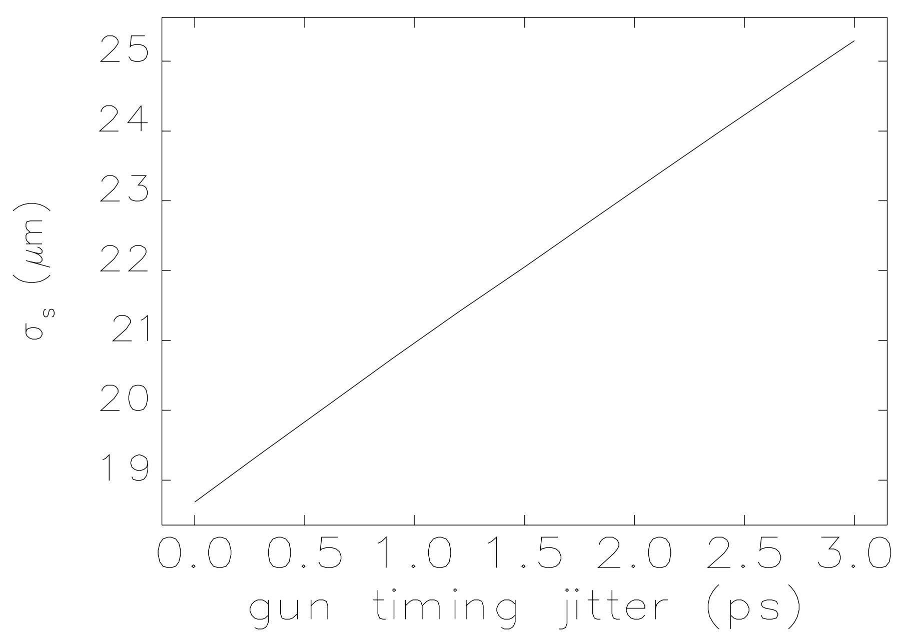
Here dE/E means the relative energy deviation (peak-to-peak) at the end of linac.

For each jitter sensitivity investigation, 10 S2E simulations are used.

S2E simulation Results - Sensitivity

Gun Timing Jitter





Sensitivity in dE/E ~ -11.0 ps

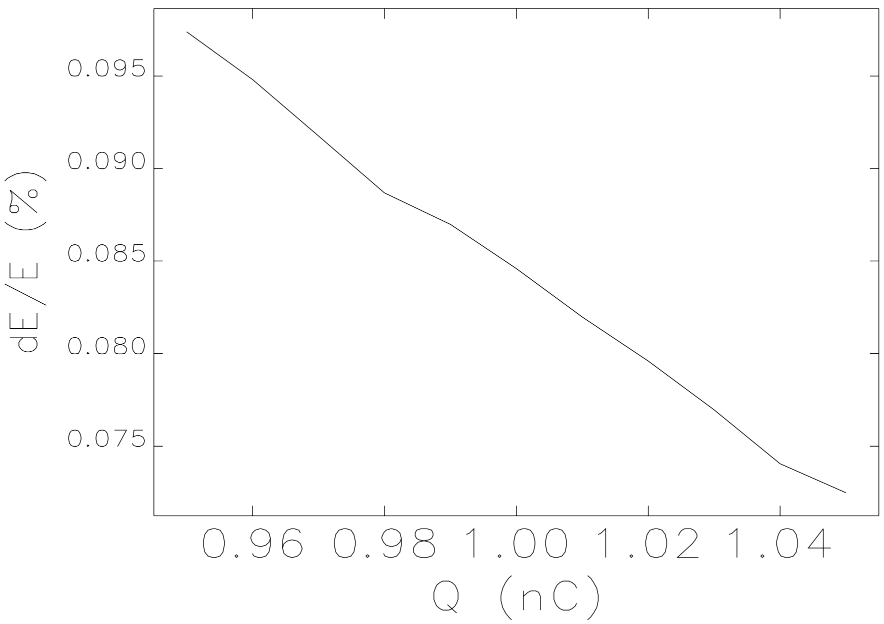
Sensitivity in bunch length ~ 1.0 ps

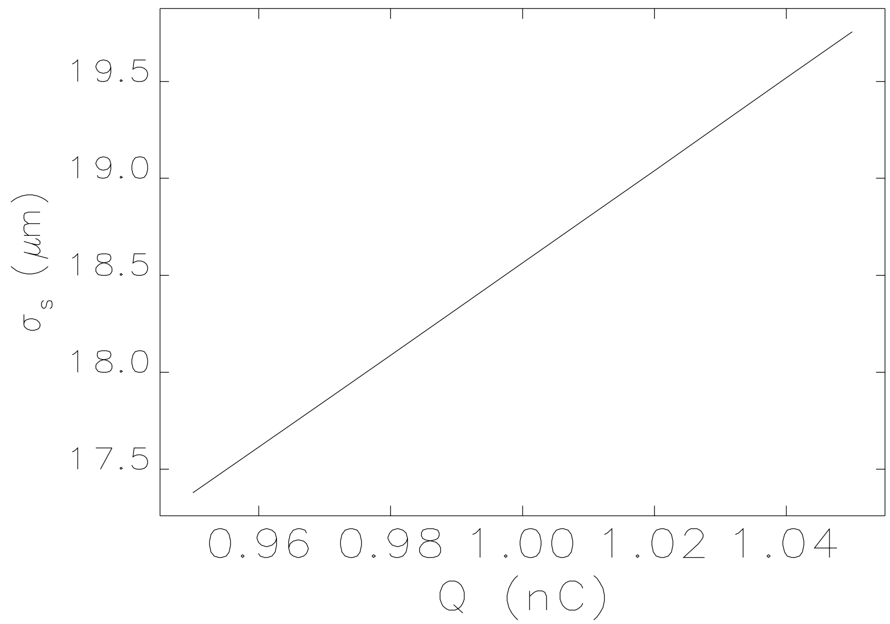
Therefore the tightest sensitivity is about 1.0 ps

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%

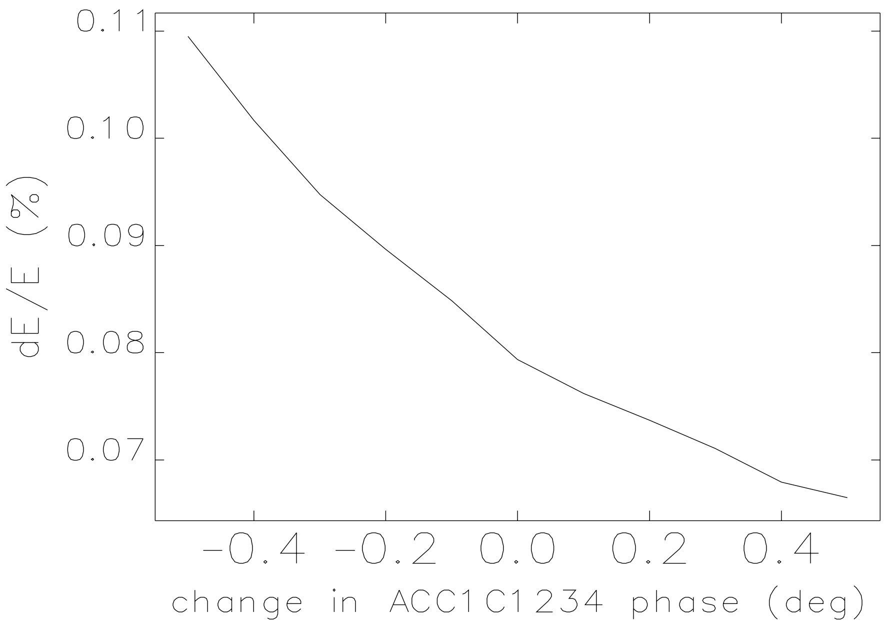
Sensitivity in bunch length ~ 8%

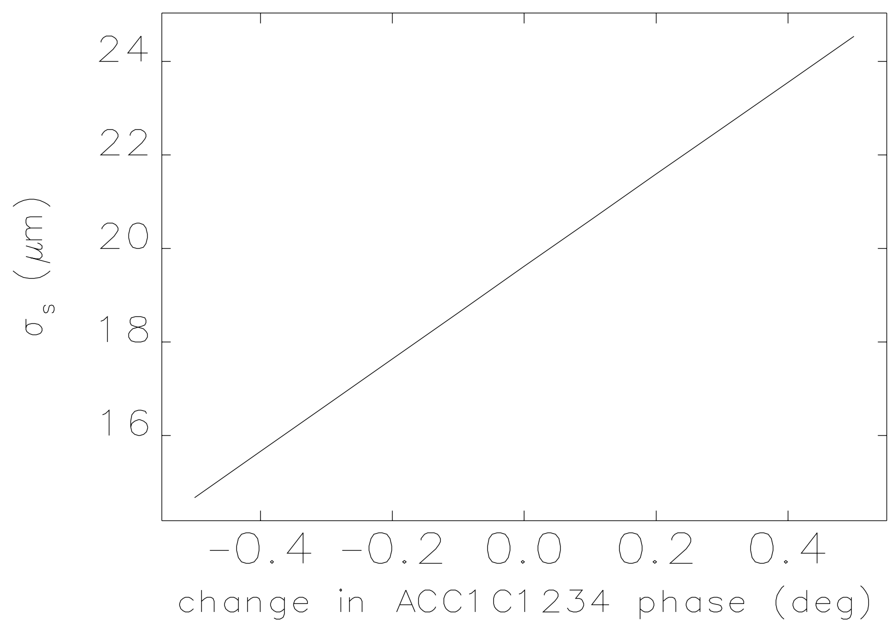
Therefore the tightest sensitivity is about 8%

S2E simulation Results - Sensitivity

ACC1C1234 RF Phase

Here we assumed ACC1C1234 will be driven by one Klystron





Sensitivity in dE/E ~ -2 degree

Sensitivity in bunch length ~ 0.2 degree

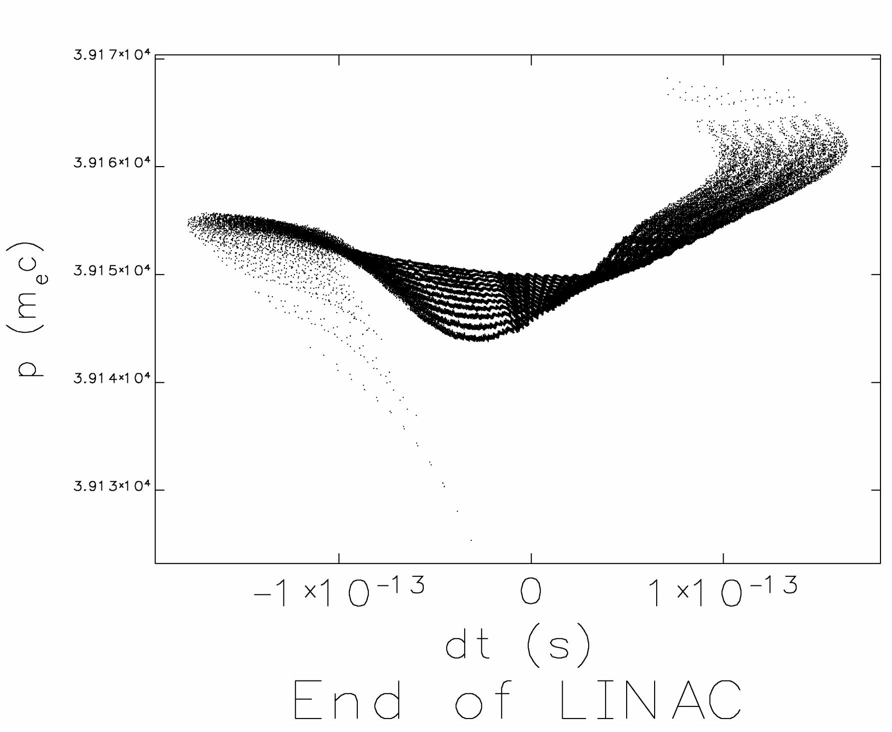
Therefore the new (old) tightest sensitivity is about 0.2 degree (0.1 degree)

S2E simulation Results - Sensitivity

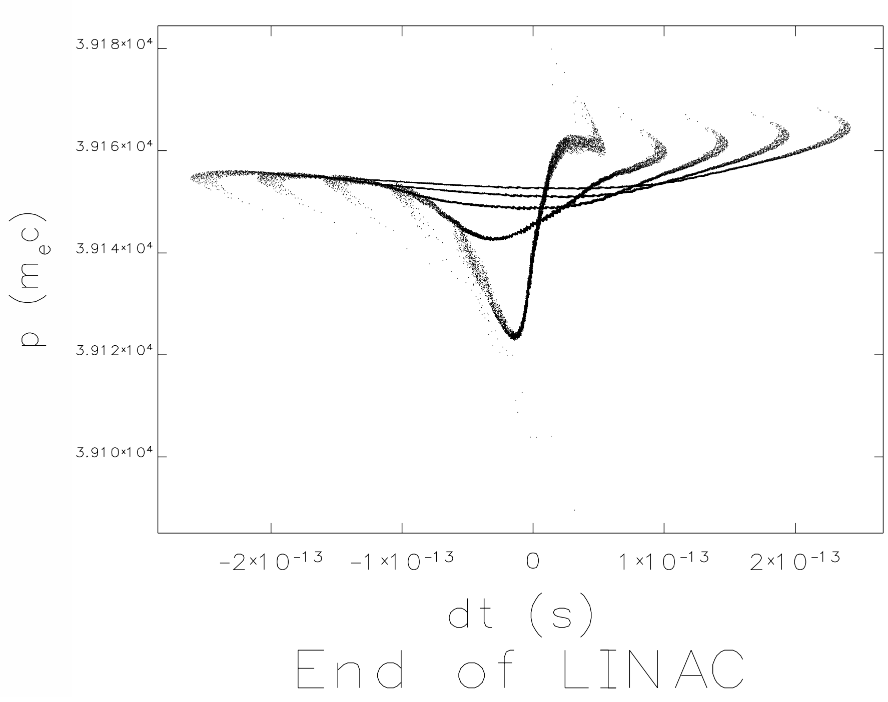
ACC1C1234 RF Phase

Here we assumed ACC1C1234 will be driven by one Klystron

(New Klystron Layout)



(Old Klystron Layout)

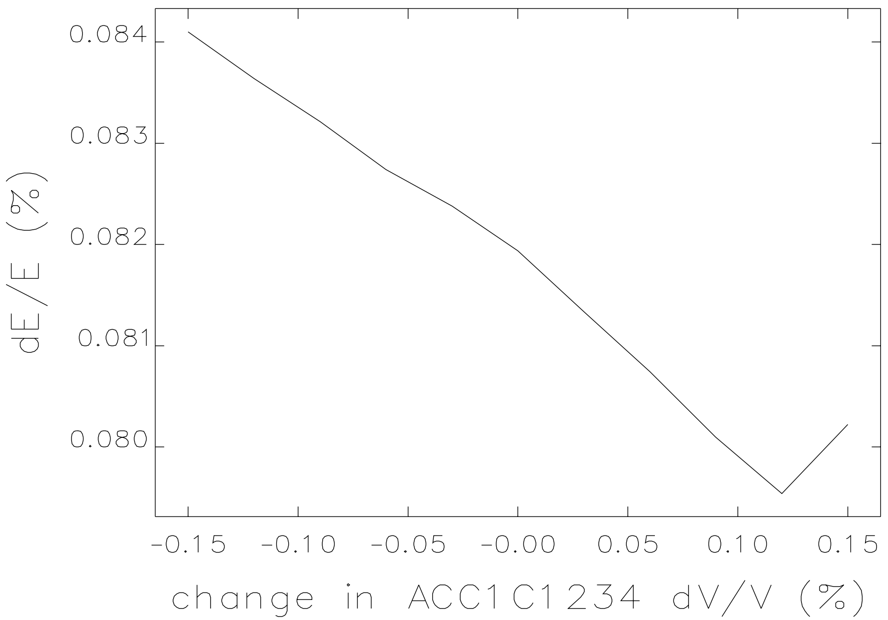


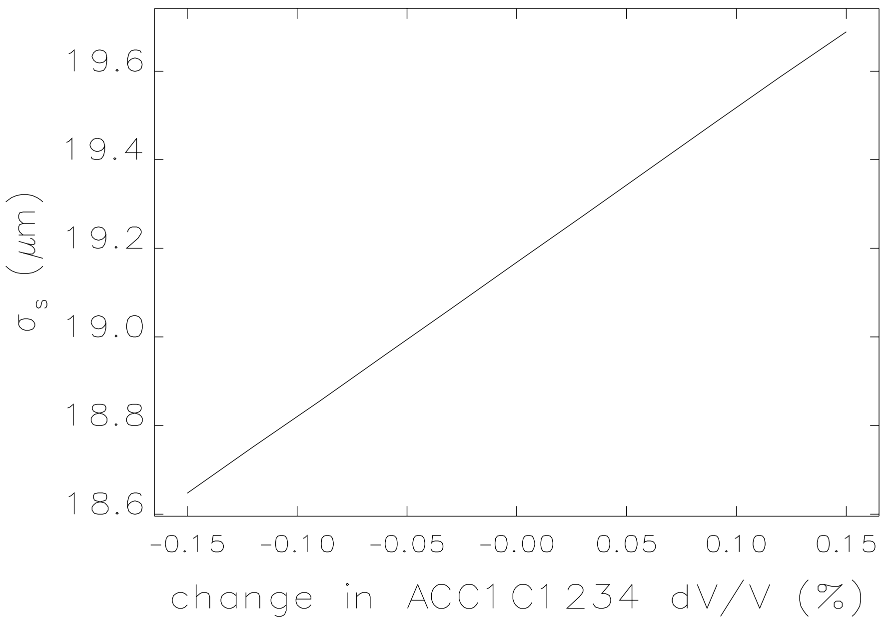
Therefore the tightest sensitivity in ACC1C1234 phase is about 0.2 degree

S2E simulation Results - Sensitivity

ACC1C1234 RF Voltage dV/V

Here we assumed ACC1C1234 will be driven by one Klystron





Sensitivity in dE/E ~ -6.25%

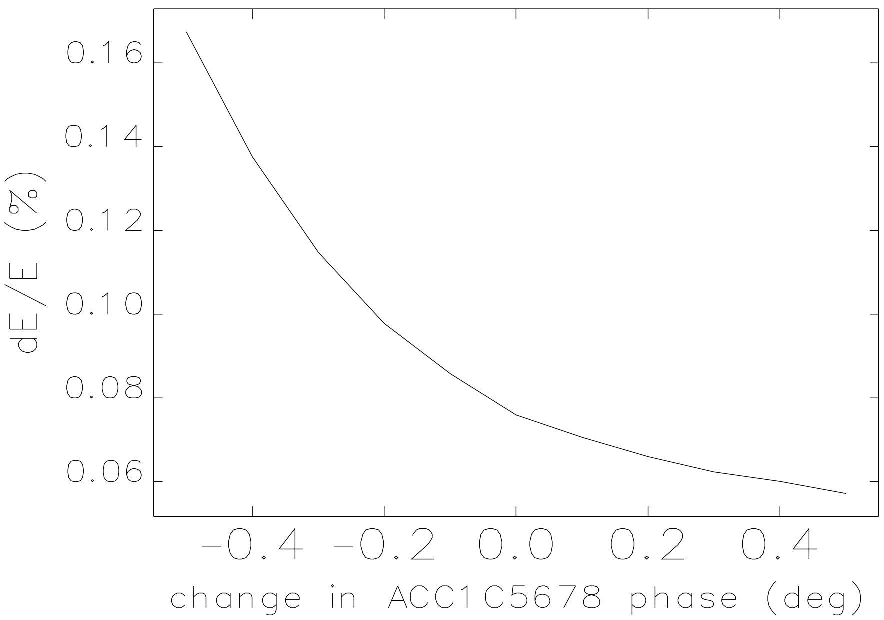
Sensitivity in bunch length ~ 0.6%

Therefore the new (old) tightest sensitivity is about 0.6% (0.15%)

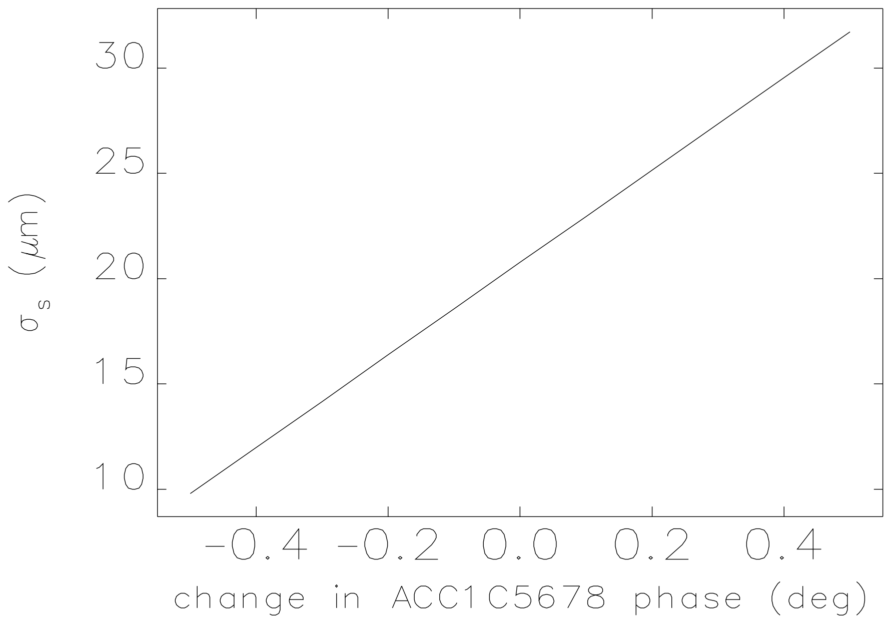
S2E simulation Results - Sensitivity

ACC1C5678 RF Phase

Here we assumed ACC1C5678 will be driven by one Klystron



Sensitivity in dE/E ~ -0.63 degree



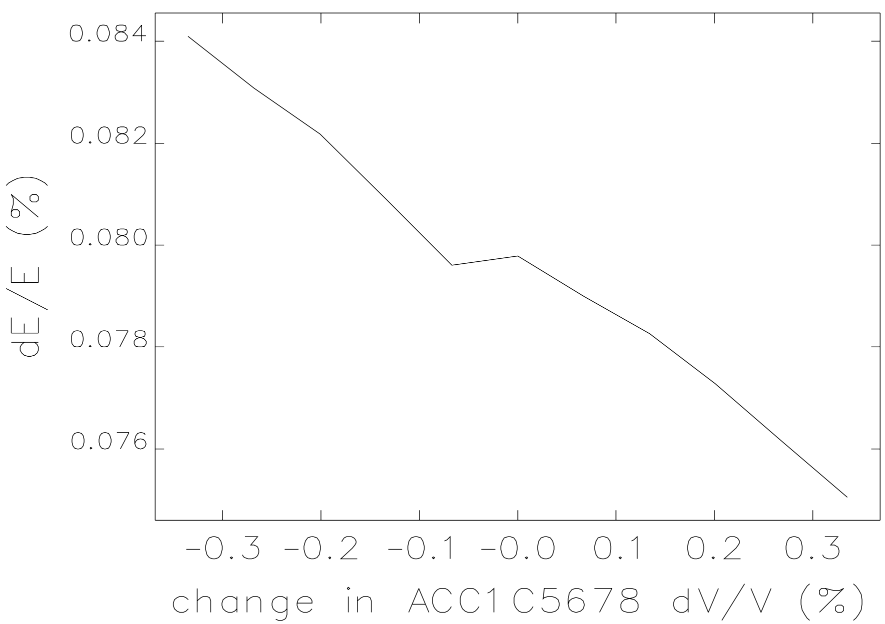
Sensitivity in bunch length ~ 0.1 degree

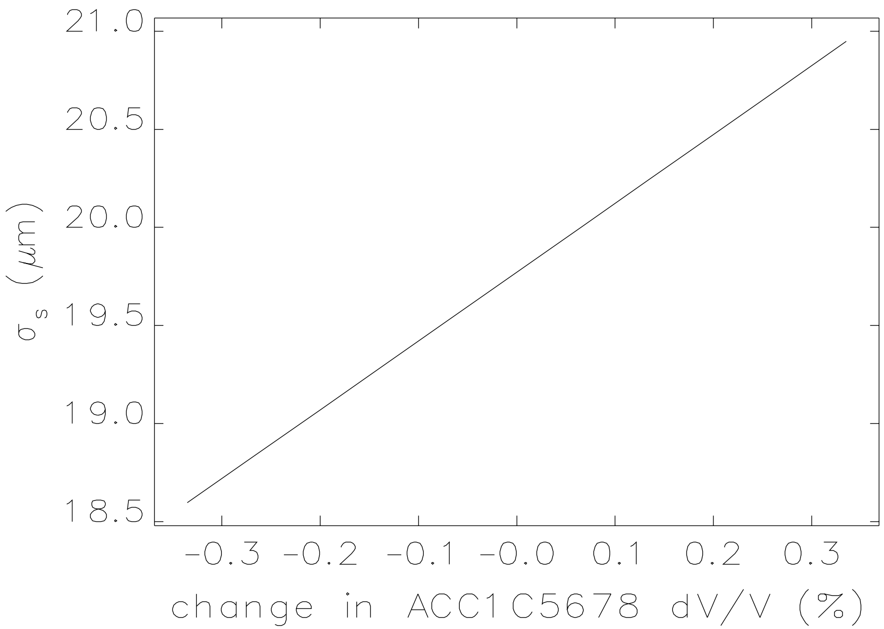
Therefore the tightest sensitivity is about 0.1 degree

S2E simulation Results - Sensitivity

ACC1C5678 RF Voltage dV/V

Here we assumed ACC1C5678 will be driven by one Klystron





Sensitivity in dE/E ~ -6.0%

Sensitivity in bunch length ~ 0.6%

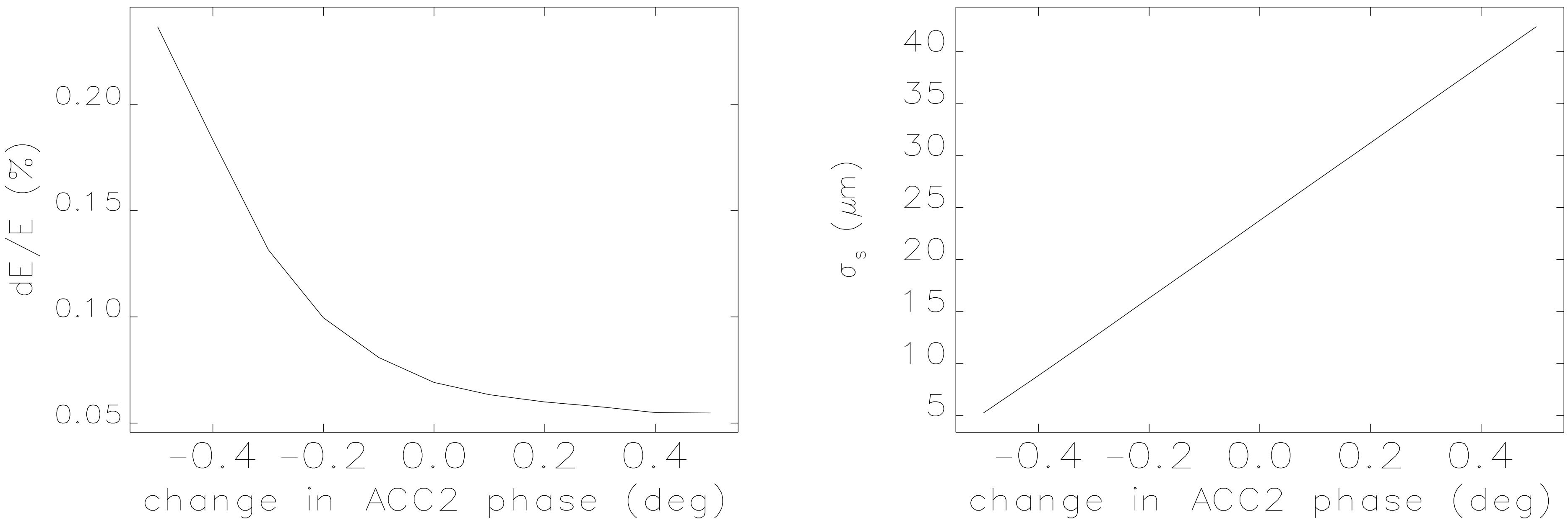
Therefore the tightest sensitivity is about 0.6%

S2E simulation Results - Sensitivity

ACC2, ACC3, and ACC4 RF Phase

Here we assumed ACC2, ACC3, and ACC4 will be driven by three Klystrons

ACC3 and ACC4 have the same sensitivity



Sensitivity in dE/E ~ -0.4 degree

Sensitivity in bunch length ~ 0.05 degree

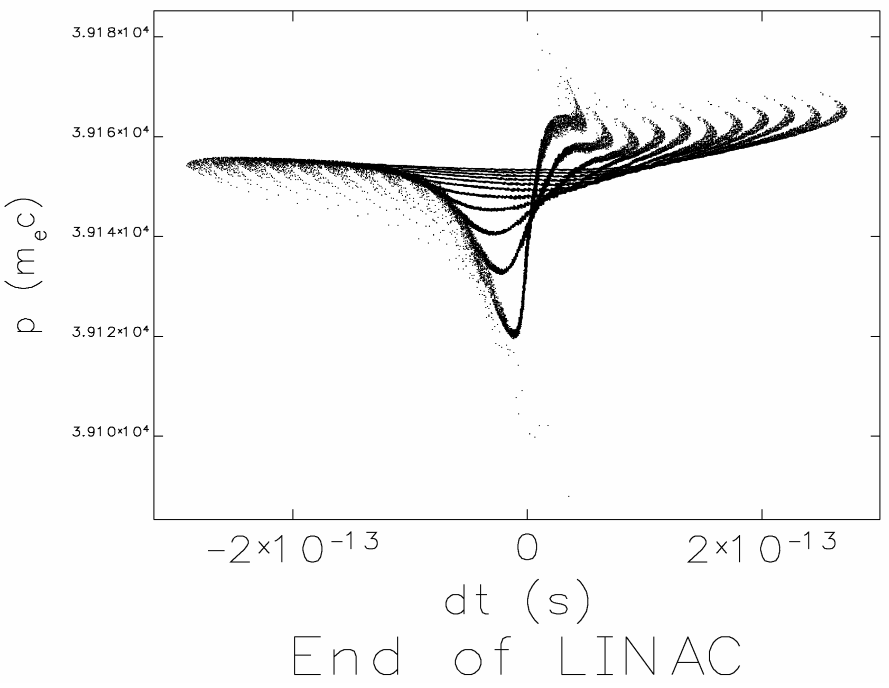
Therefore the new (old) tightest sensitivity is about 0.05 degree (0.02 degree)

S2E simulation Results - Sensitivity

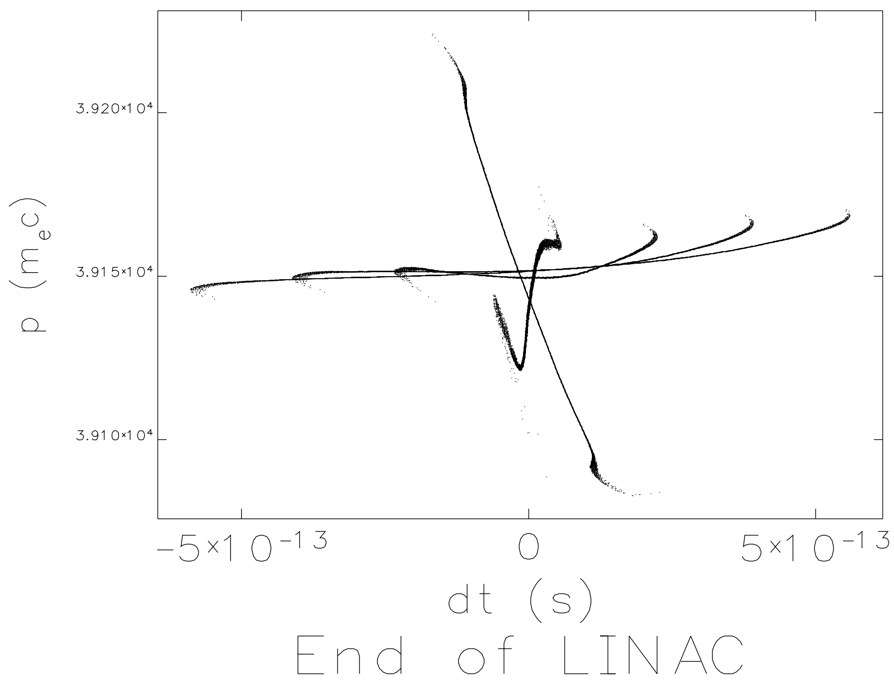
ACC2, ACC3, and ACC4 RF Phase

Here we assumed ACC2, ACC3, and ACC4 will be driven by three Klystrons

(New Klystron Layout)



(Old Klystron Layout)



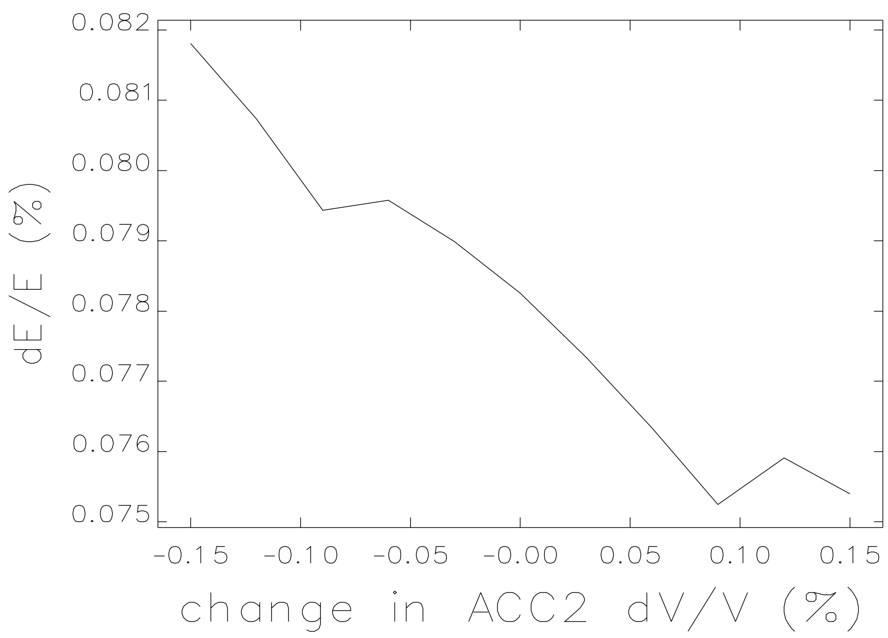
Therefore the tightest sensitivity is about 0.05 degree

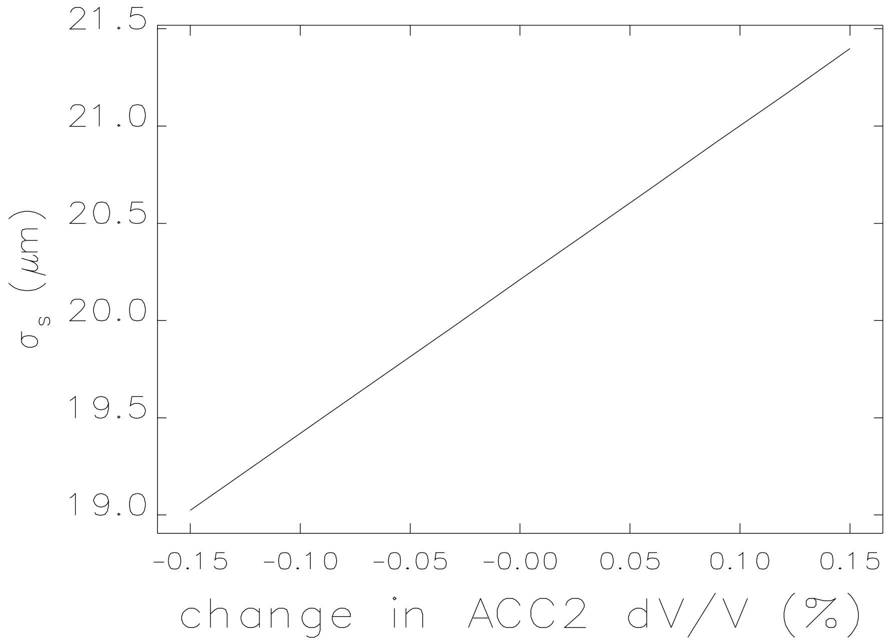
S2E simulation Results - Sensitivity

ACC2, ACC3, and ACC4 RF Voltage dV/V

Here we assumed ACC2, ACC3, and ACC4 will be driven by three Klystrons

ACC3 and ACC4 have the same sensitivity





Sensitivity in dE/E ~ -4%

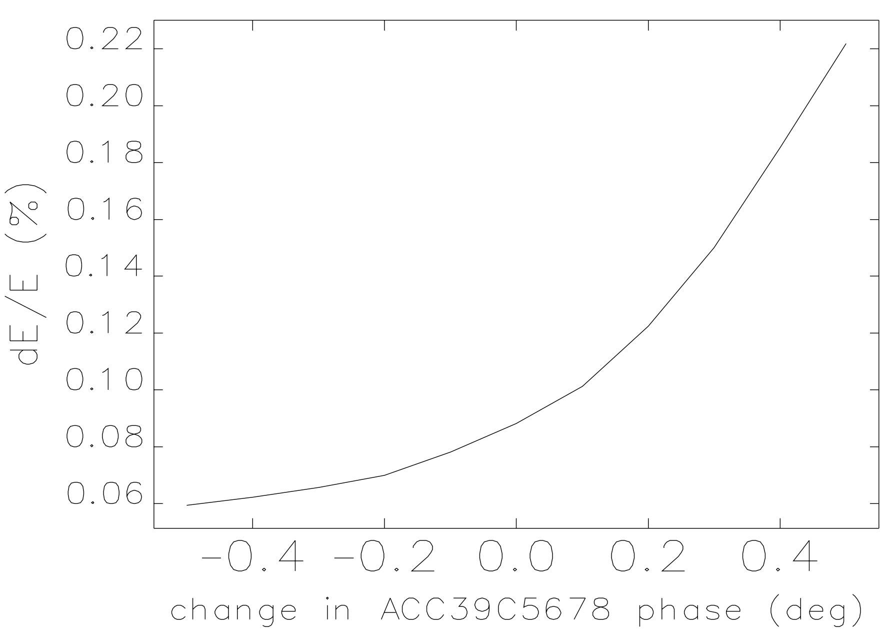
Sensitivity in bunch length ~ 0.25%

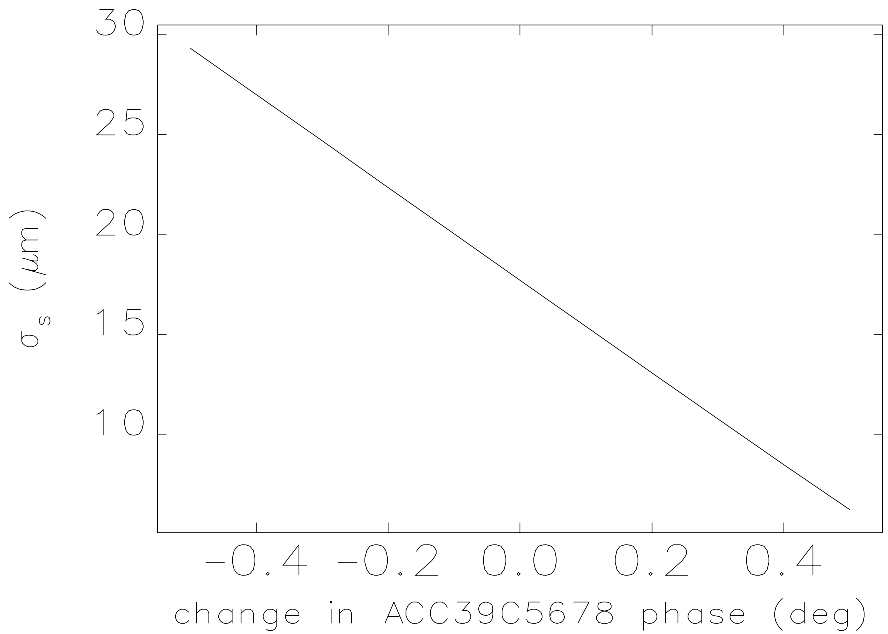
Therefore the new (old) tightest sensitivity is about 0.25% (0.1%)

ACC39C1234 and ACC39C5678 RF Phase

Here we assumed ACC39 will be driven by two Klystrons

ACC39C1234 has the same sensitivity





Sensitivity in dE/E ~ 0.4 degree

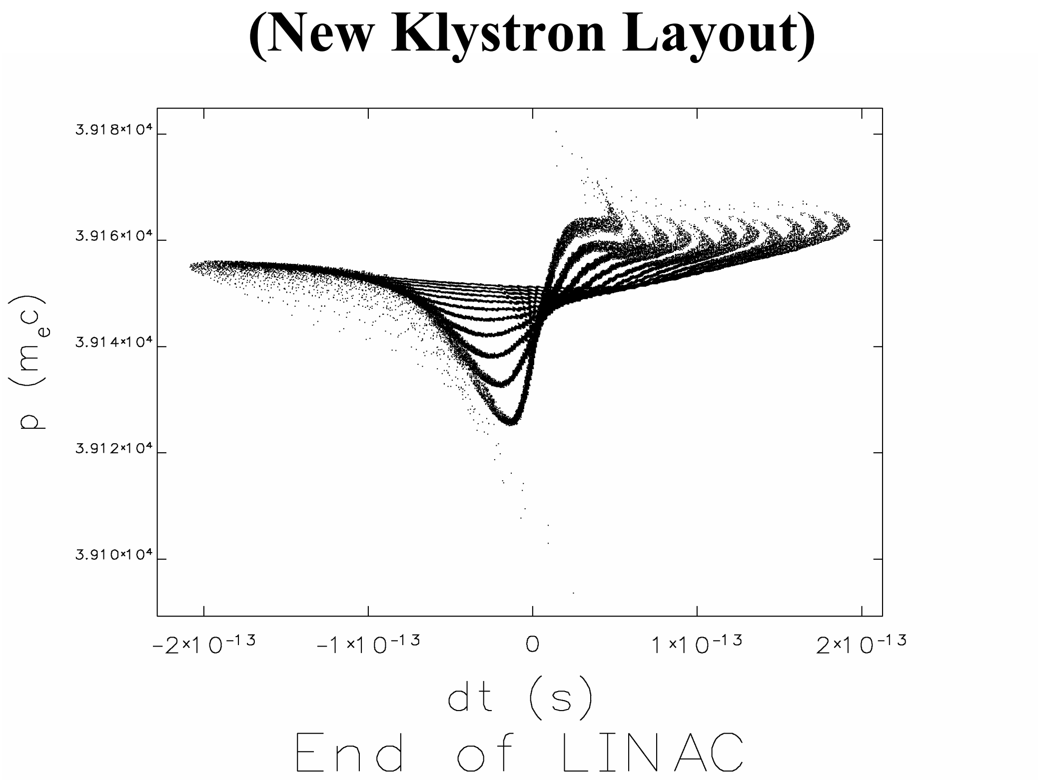
Sensitivity in bunch length ~ -0.1 degree

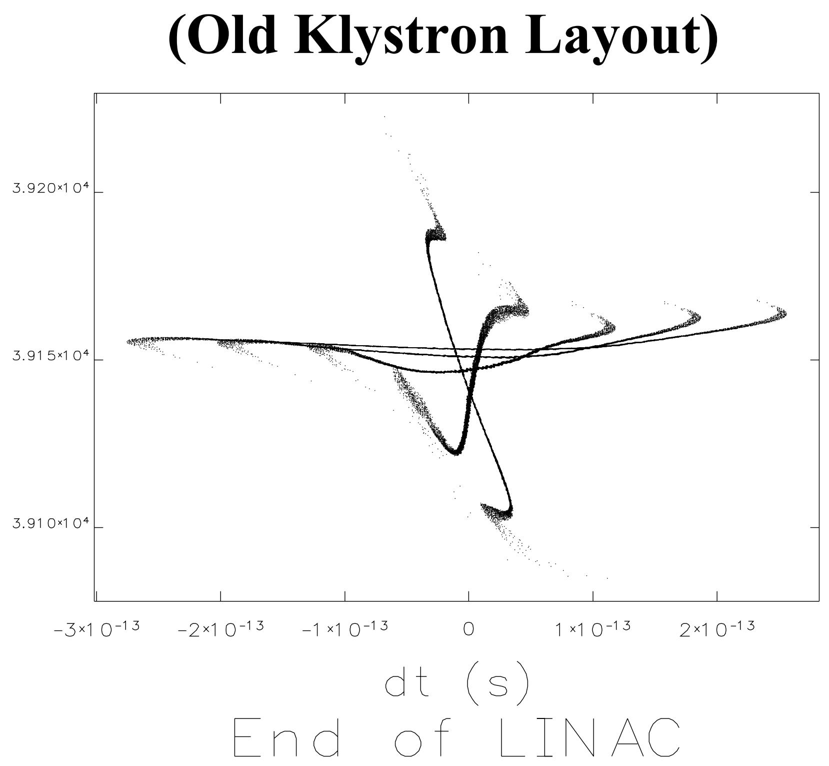
Therefore the new (old) tightest sensitivity is about -0.1 degree (-0.04 degree)

S2E simulation Results - Sensitivity

ACC39C1234 and ACC39C5678 RF Phase

Here we assumed ACC39 will be driven by two Klystrons





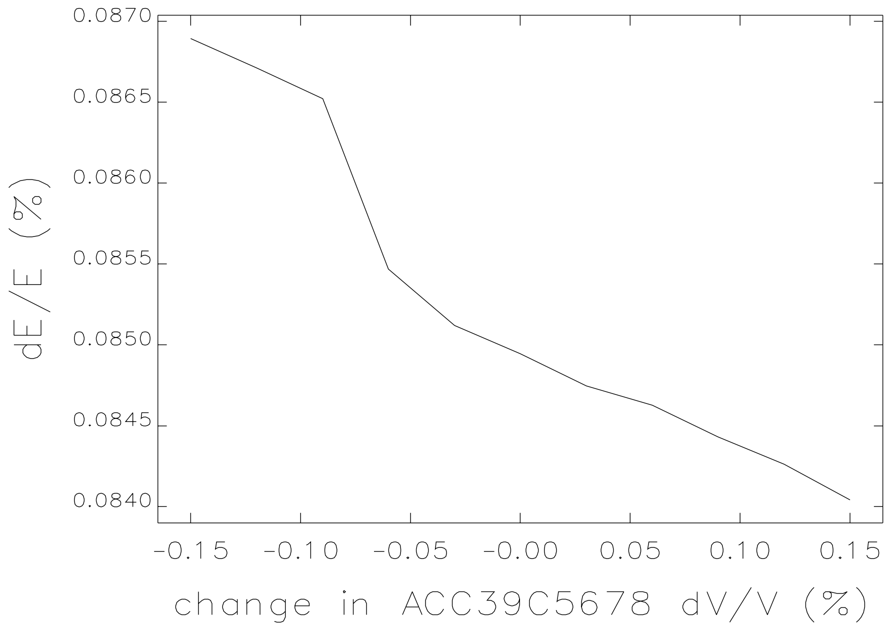
Therefore the tightest sensitivity is about -0.1 degree

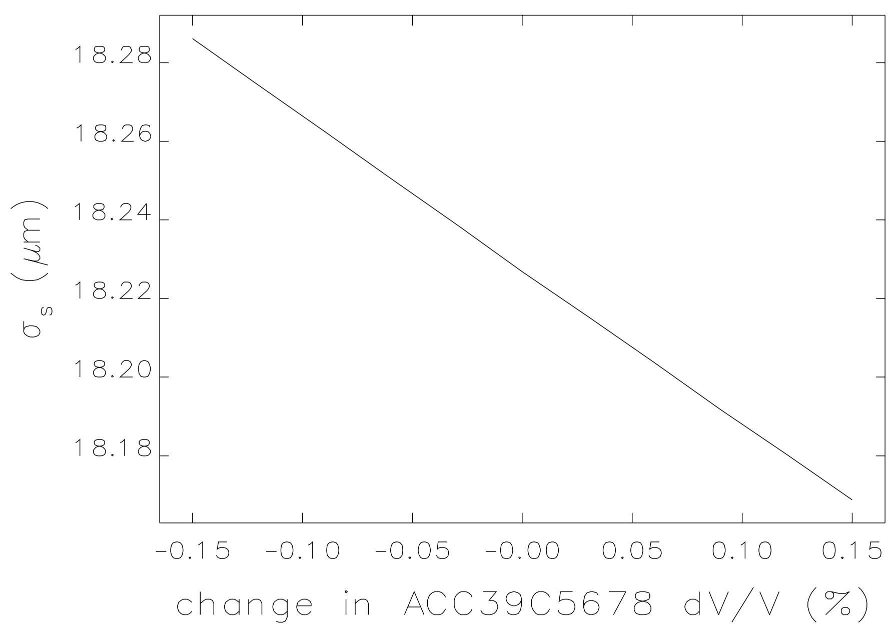
S2E simulation Results - Sensitivity

ACC39C1234 and ACC39C5678 RF Voltage dV/V

Here we assumed ACC39 will be driven by two Klystrons

ACC39C1234 has the same sensitivity





Sensitivity in dE/E ~ -10%

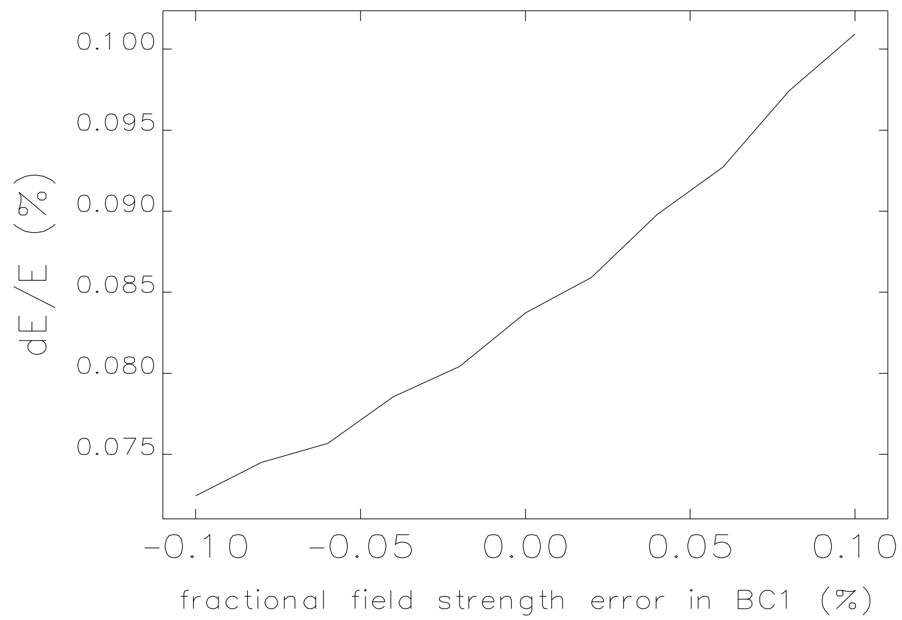
Sensitivity in bunch length ~ -5.4%

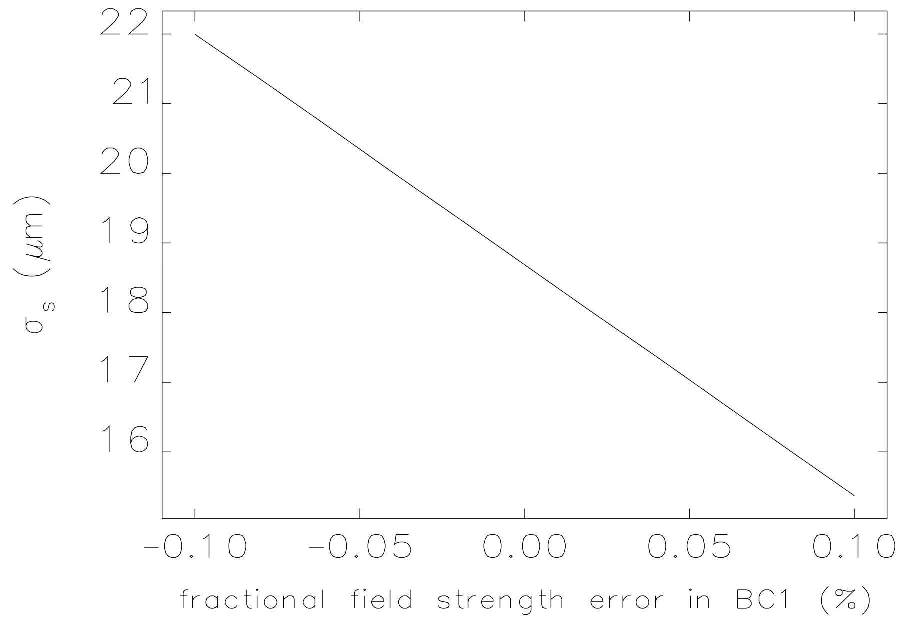
Therefore the new (old) tightest sensitivity is about -5.4% (-3.0%)

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%

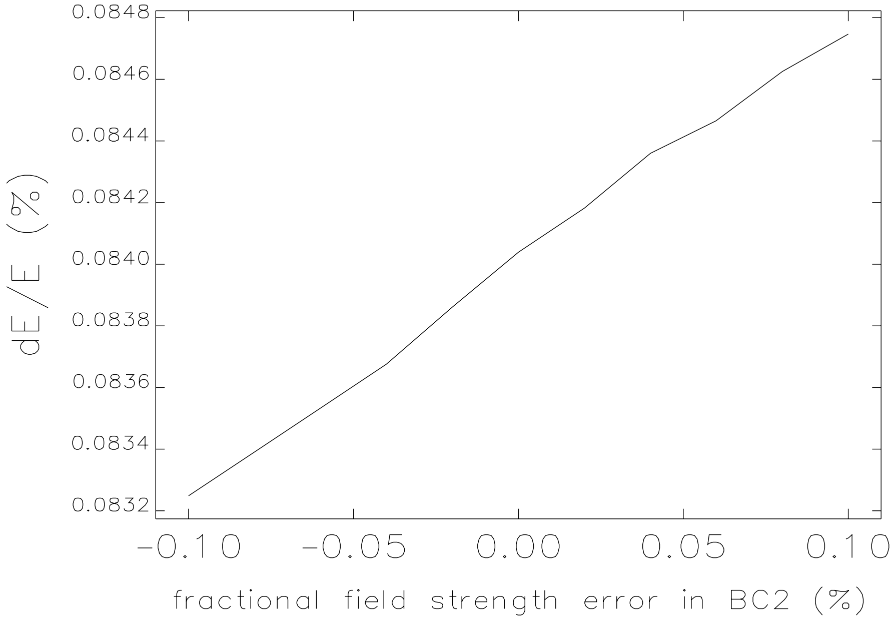
Sensitivity in bunch length ~ -0.05%

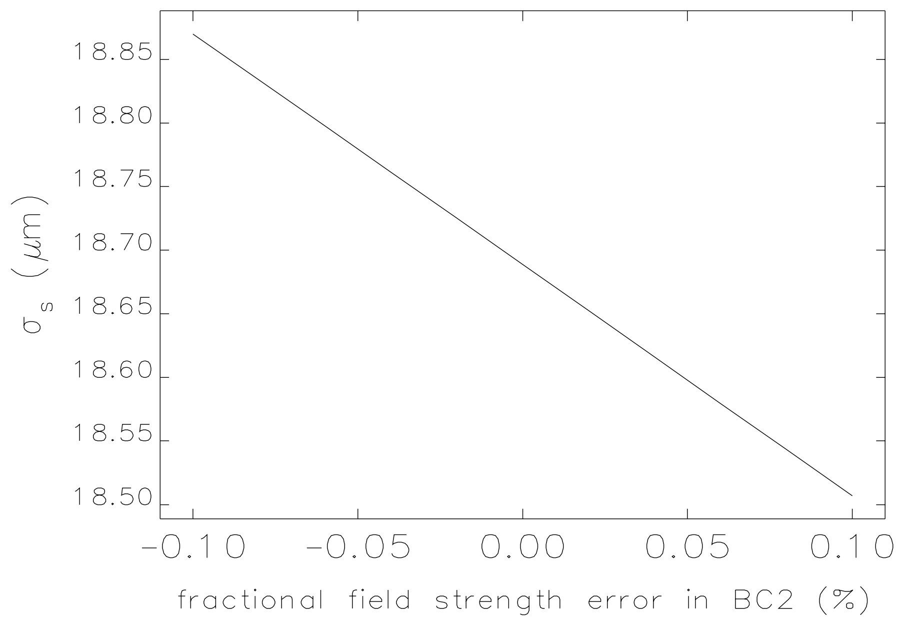
Therefore the tightest sensitivity is about -0.05%

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%

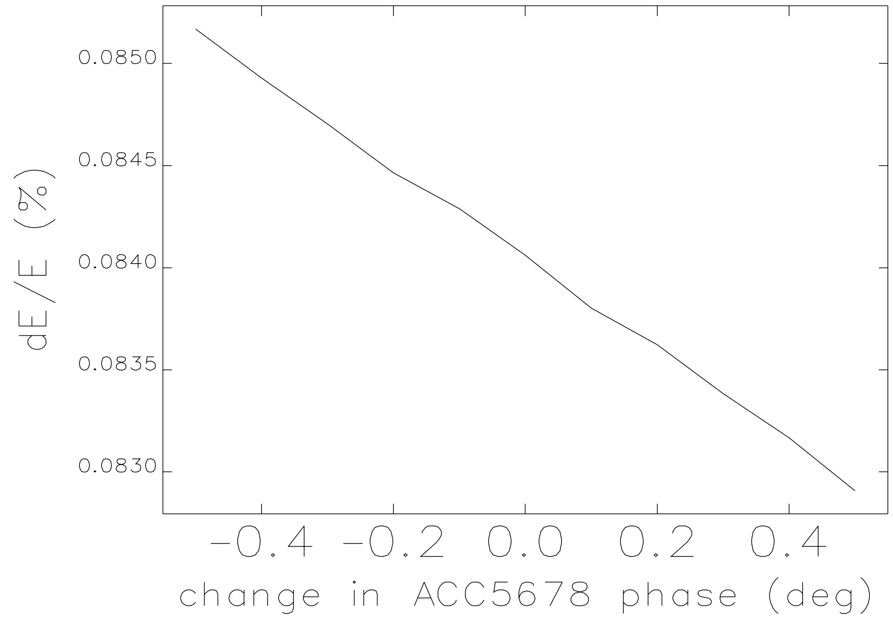
Therefore the tightest sensitivity is about -1%

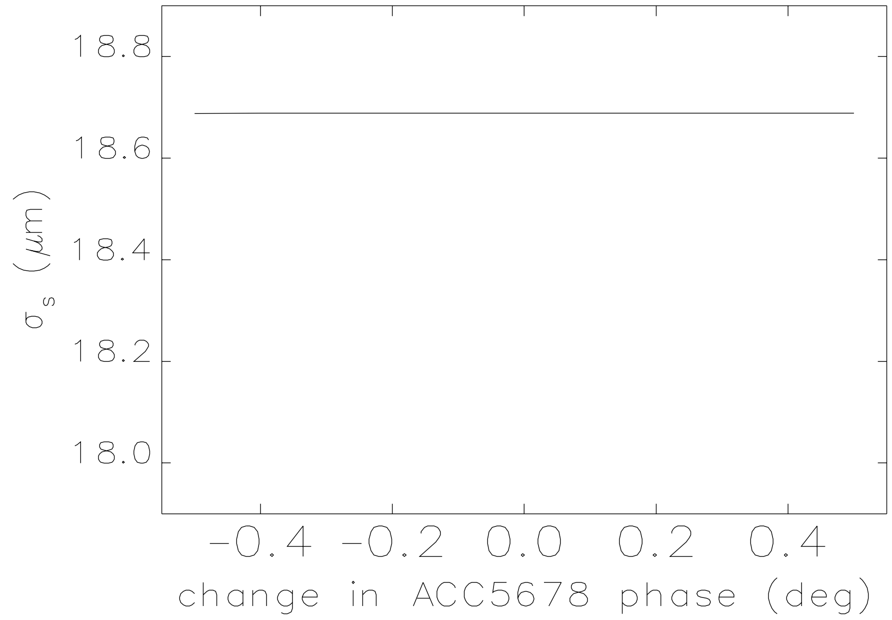
S2E simulation Results - Sensitivity

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 ~ -40 degree

Sensitivity in bunch length ~ ∞

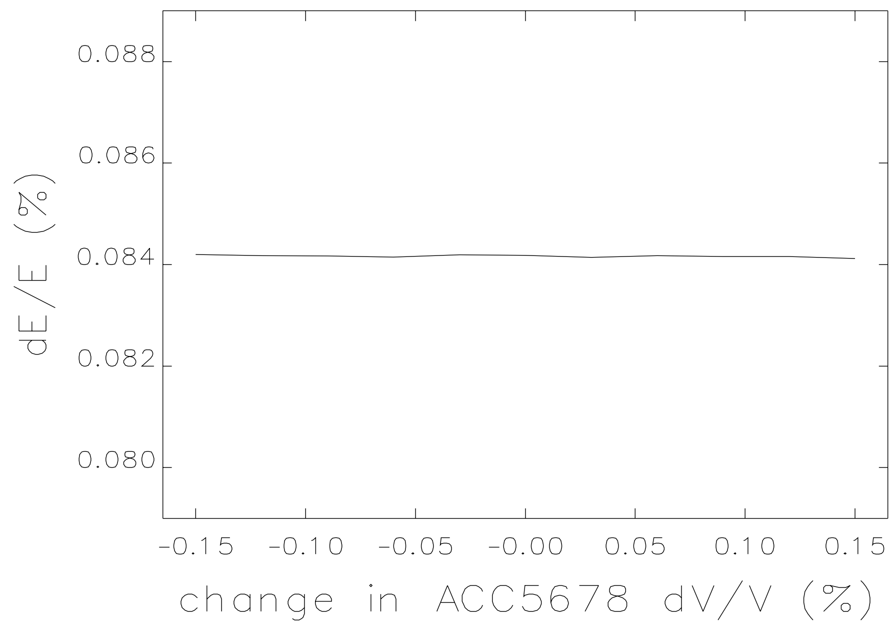
Therefore the tightest sensitivity is about -40 degree

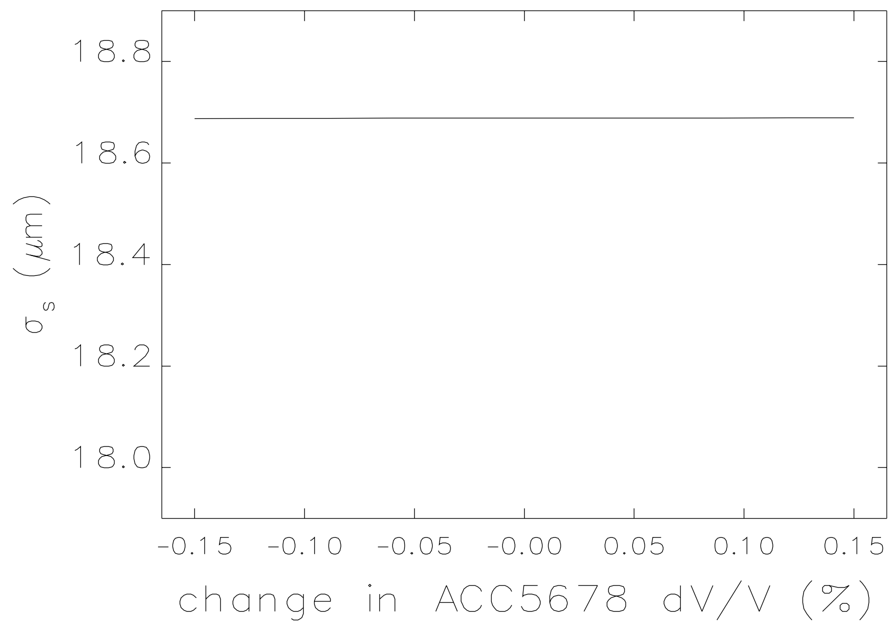
S2E simulation Results - Sensitivity

ACC5678 RF Voltage dV/V

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 ~ ∞ degree

Sensitivity in bunch length ~ ∞

Therefore the tightest sensitivity is about ∞ degree

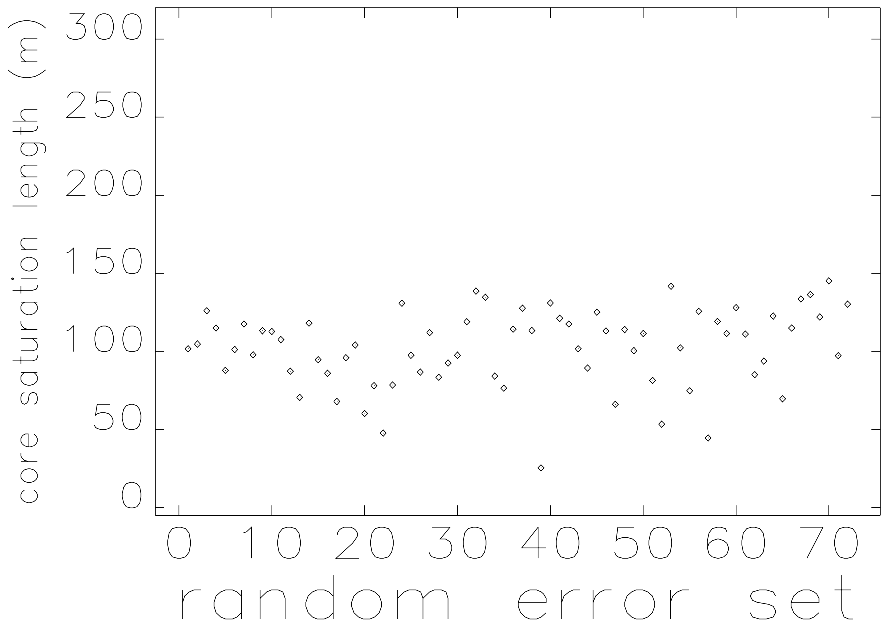
Sensitivity & Tolerance

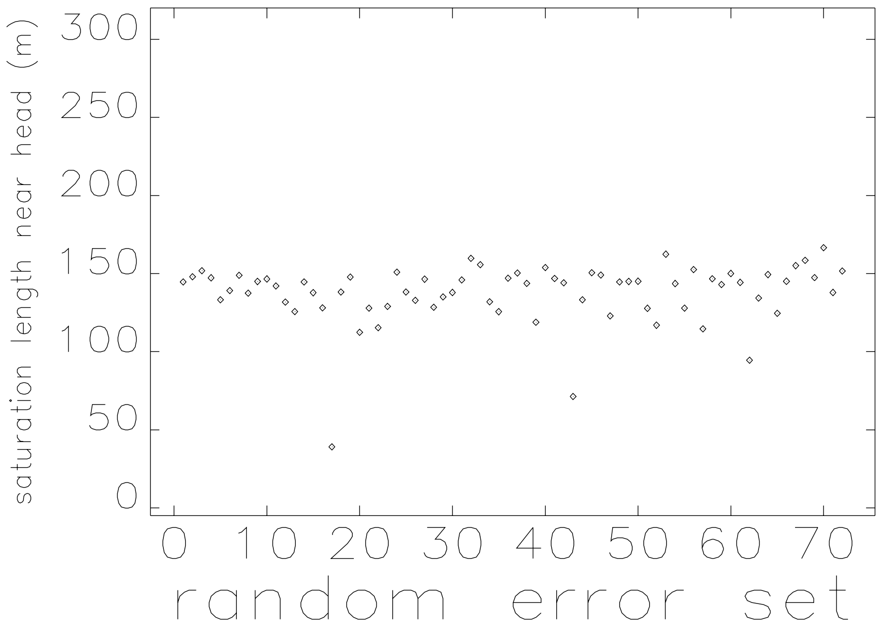
Now ACC2, ACC3, and ACC4 phase (0.05 degree) are close to our control range !

	Sensitivity (rms)	Tolerance (rms) for 1 minute
dT	1.0 ps	0.3 ps
dQ	8.0%	1.0%
ACC1C1234 Phase	0.2 deg	0.05 deg
ACC1C1234 dV/V	0.6%	0.03%
ACC1C5678 Phase	0.1 deg	0.05 deg
ACC1C5678 dV/V	0.6%	0.03%
ACC234 Phase	0.05 deg	0.05 deg
ACC234 dV/V	0.25%	0.03%
ACC39 Phase	0.1 deg	0.05 deg
ACC39 dV/V	5.4%	0.03%
BC1 dI/I	0.05%	0.02%
BC2 dI/I	1.0%	0.02%
ACC5678 Phase	-	0.05 deg
ACC5678 dV/V	-	0.03%

Old S2E simulation Results – Tolerance

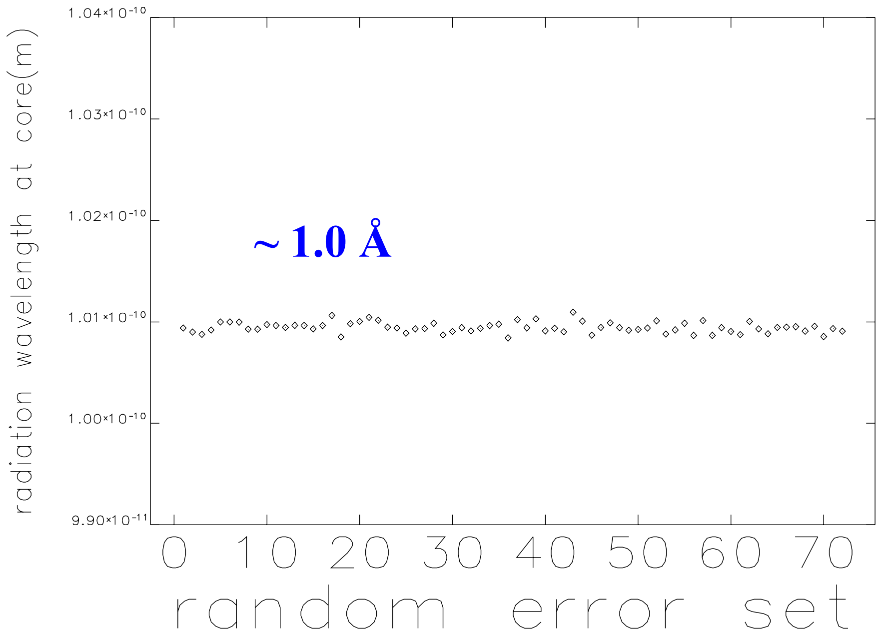
Saturation length is safe enough (< 200 m) under jitters and erros !!!



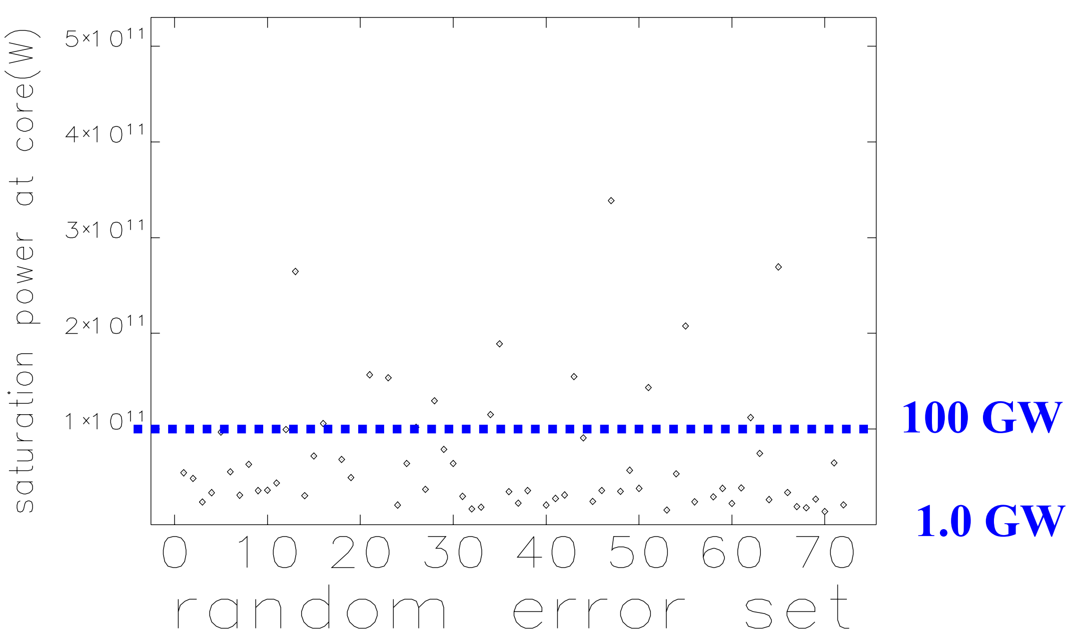


Old S2E simulation Results – Tolerance

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 may control phase jitters by the multi-klystron operation before BC2.

Next week, I will report on the tolerance study with 100 random error set.

Acknowledgments

Y. Kim sincerely thanks S. Simrock, M. Borland, P. Emma, S. Schreiber, J. S. Oh, Professor J. Rossbach, Professor I. S. Ko, and Professor W. Namkung for their encouragements of this work and many useful comments and discussions on the injector and BC layout.