Extending Storage Ring Beam Performance

K. Soutome (JASRI/SPring-8)

***on behalf of* JASRI Accelerator Division**

Topics:

1) Lower **Emittance** in **Low-Energy (4GeV) Operation**
2) Shorter **Bunch Length** in **Low-Alpha Operation**

Low-Energy Operation

Emittance: $\varepsilon \propto E^2$

3.4 nmrad at 8GeV $\rightarrow$ 0.85 nmrad at 4GeV

Other Parameters

Radiation Loss: $U \propto E^4$

Damping Time: $\tau_{x,y,s} \propto E^{-3}$ $\rightarrow$ **Instability**

Energy Spread: $\sigma_{\Delta p/p} \propto E$

Bunch Length: $\sigma \propto E^{3/2}$ (V_{rf}: fixed)

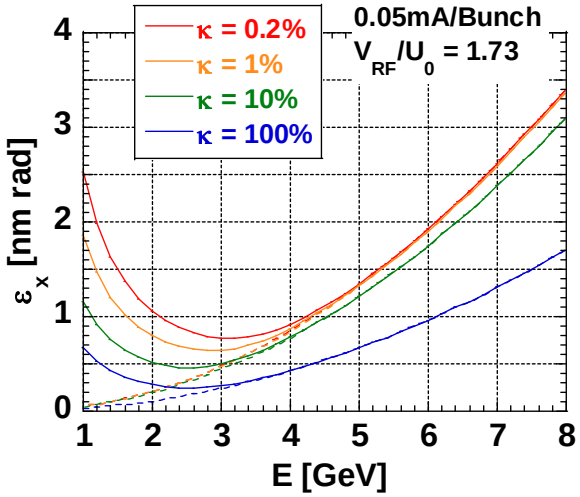
$\propto E^{-1/2}$ (q: fixed, $q=V_{rf}/U$)

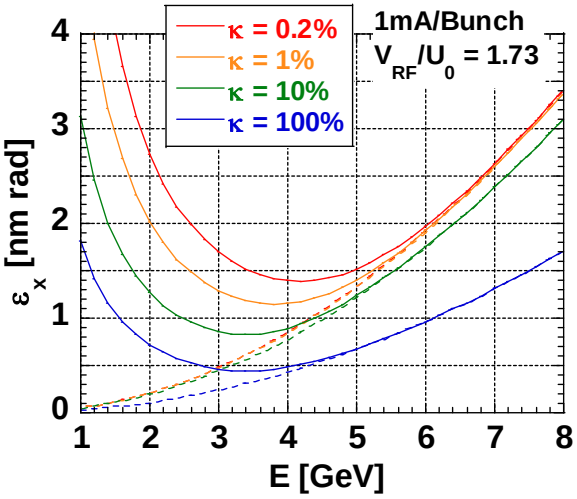
Synchrotron Frequency: $f_s \propto E^{-1/2}$ (V_{rf}: fixed)

$\propto E^{3/2}$ (q: fixed)

Low-E: Intrabeam Scattering Effect

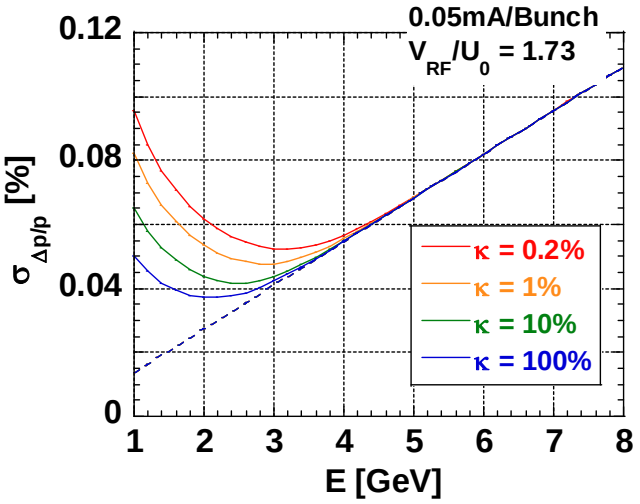
Horizontal Emittance

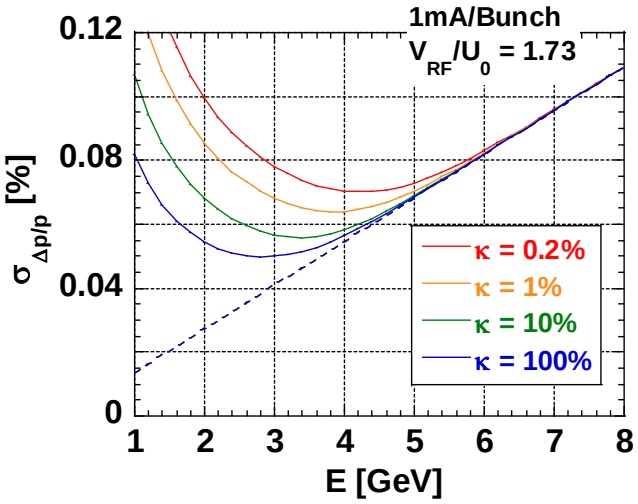




Ref.) K.L.F.Bane, EPAC02, p.1443

Energy Spread





→ **Preliminary target energy was set to be 4GeV.**

Low-E: Beam Size at 4GeV

Measurement:

X-Ray Beam Imager (Fresnel Zone Plate + X-ray Zooming Tube) in Diagnostic Bending BL

E [GeV]	$\sigma_x^{(exp)}$ [μm]	$\sigma_x^{(cal)}$ [μm]
8	110	114
4	57	57

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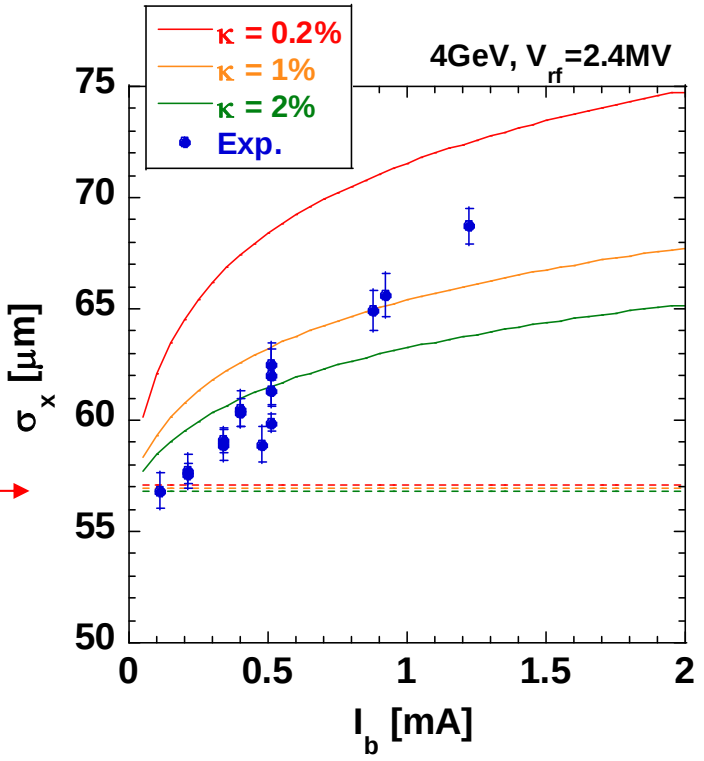
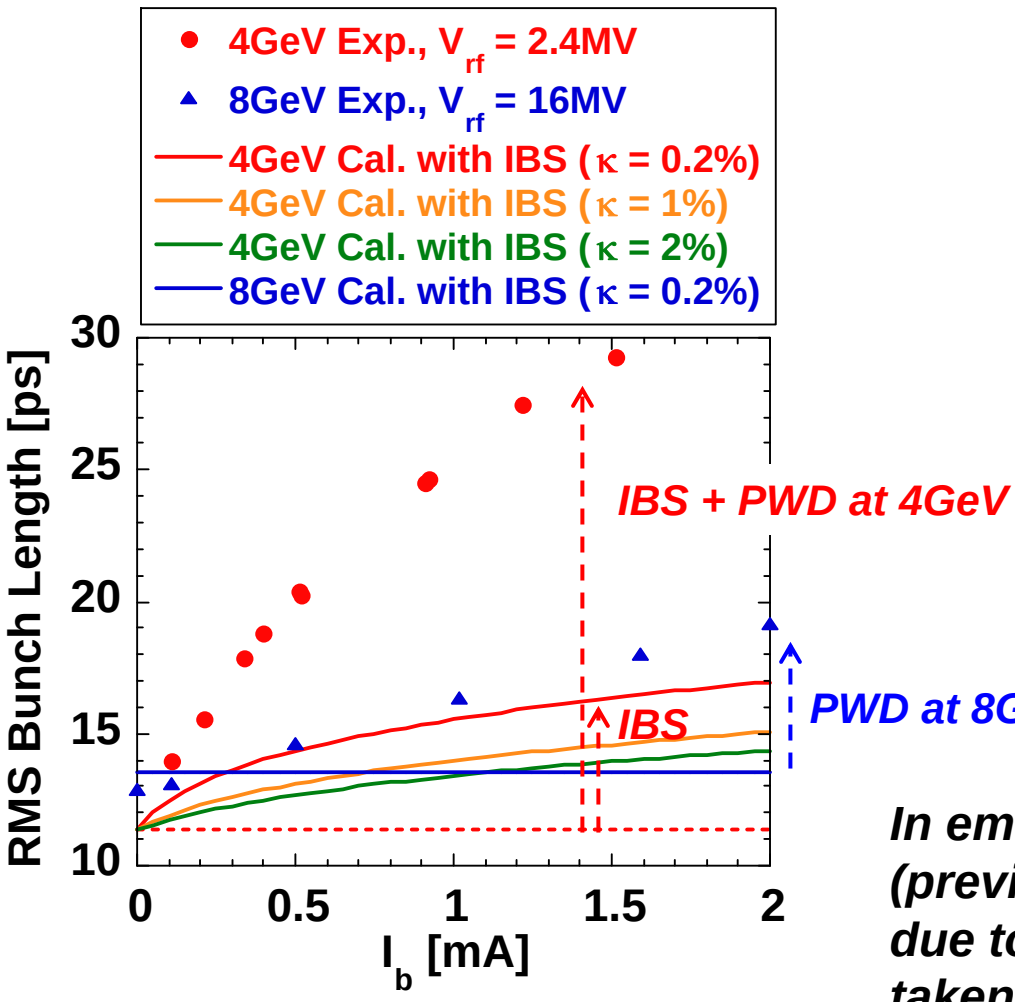
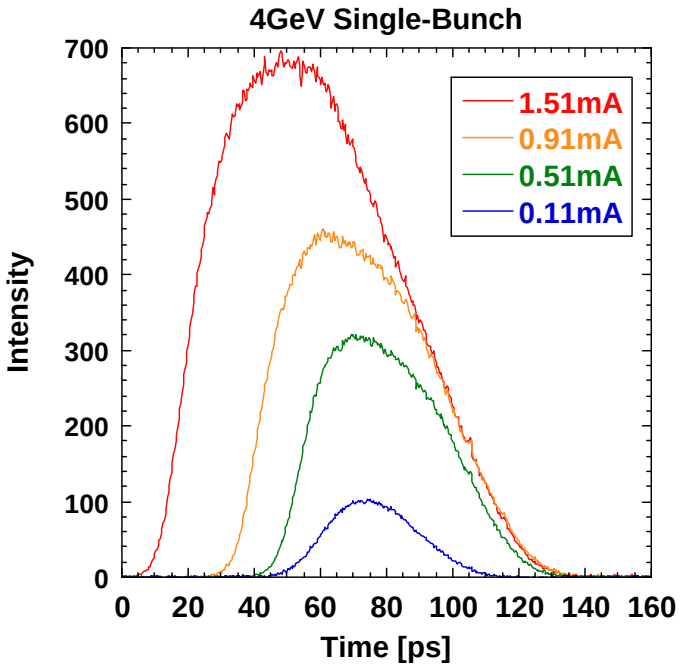
Calculated Beam Size with ε = 0.85 nmrad (w/o IBS) →



Emittance has a bunch current dependence at 4GeV due to IBS.

Low-E: Bunch Length





In emittance calculation of IBS (previous slide), bunch lenghtening due to potential well distortion was taken into account empirically.

Low-E: Summary

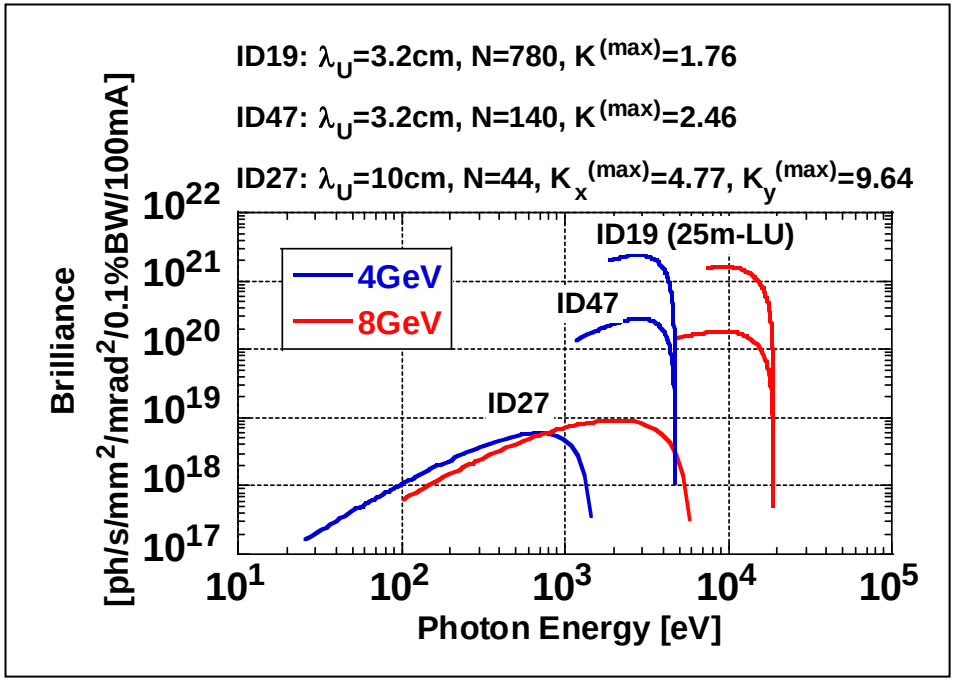
* Emittance of 0.85 nmrad was achieved at low current in 4GeV operation.

* Intrabeam scattering affects the emittance and bunch length.
  → This can be relaxed by coupling control.

* Longitudinal instability was observed above 20mA at 4GeV.
  → This was cured by RF voltage modulation by f_{rev}. *(T.Nakamura)*

* Possibility of higher beam current at 4GeV.

* Possibility of high-brilliance Soft X-ray BL, though beamlines are currently optimized to 8GeV operation.



Low-Alpha Operation

$$\Delta f_{rf} / f_{rf} = -\alpha\delta$$
$$\delta = \Delta p/p$$
$$\alpha = \alpha_0 + \alpha_1\delta + \alpha_2\delta^2 + \alpha_3\delta^3 + \ldots$$

Perturbative Formula: H.Tanaka, et al., NIMA431 (1999) 396
Erratum: NIMA440 (2000) 259

Bunch length scales as $\alpha^{1/2}$ at low bunch curent.

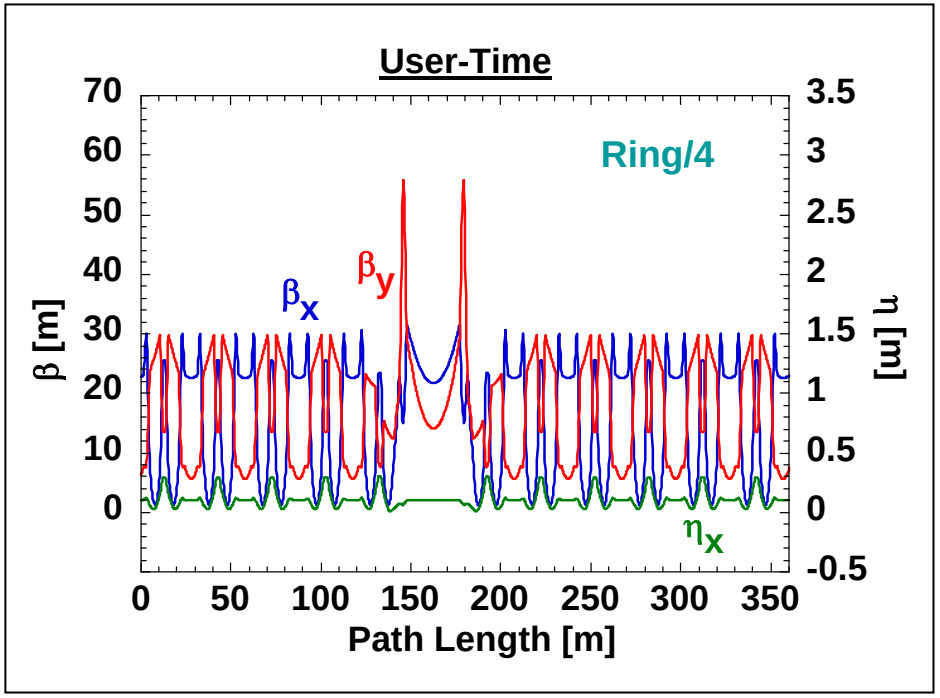
Main Knob to Control α

α_0: Quadrupoles in the arc
(Betatron tune is adjusted with other quadrupoles.)

α_1: Sextupoles in the arc
(Chromaticity is adjusted with other sextupoles.)

α_2: Octupoles in the arc (*no octupoles at present*)
(This term is important in extremely low-alpha regime.)

Low-α: Optics

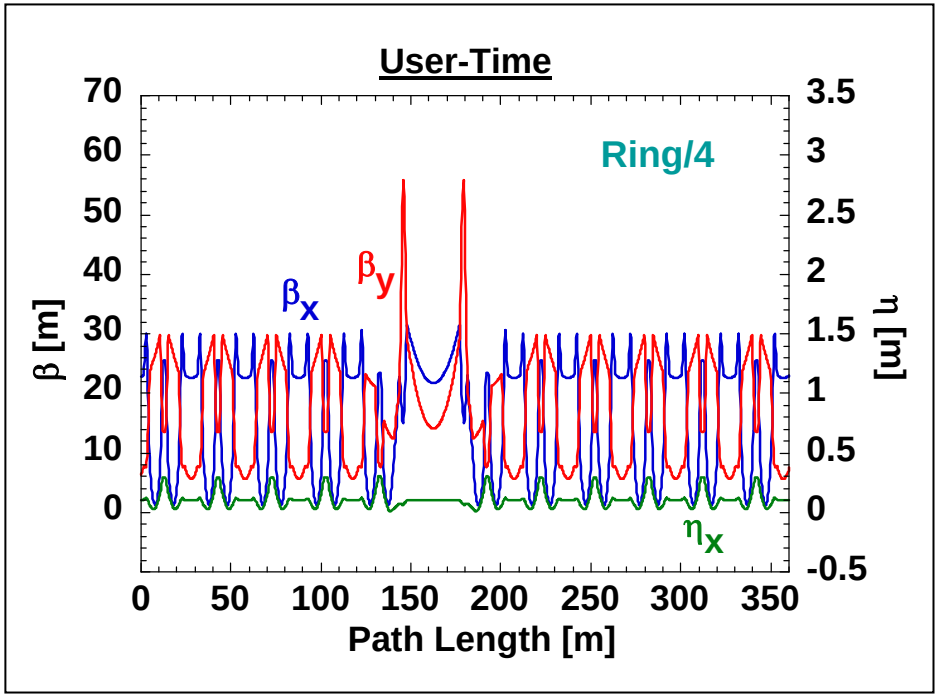


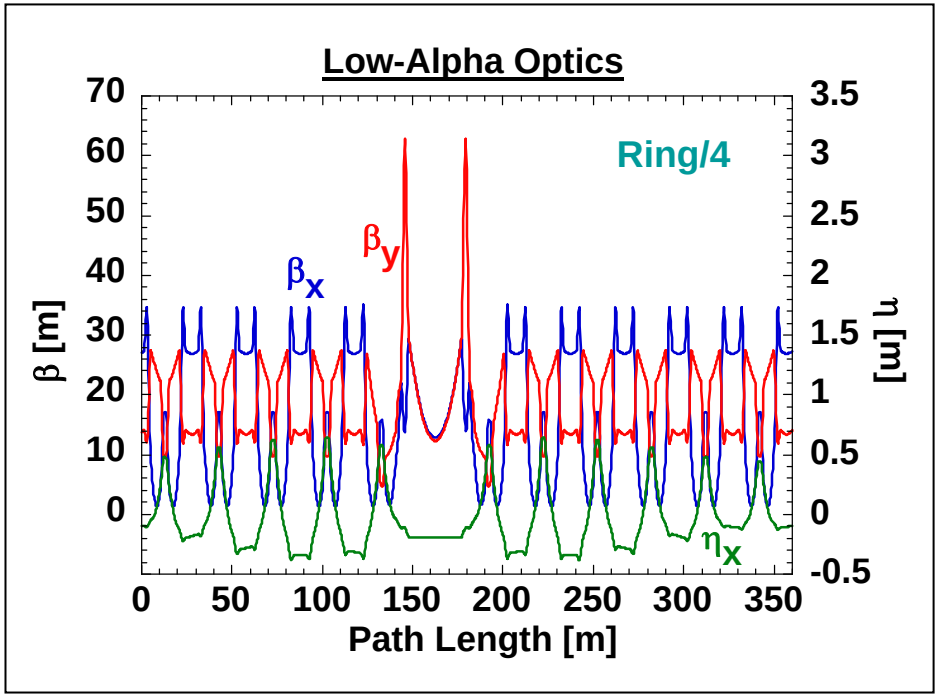
$\alpha_0^{(nominal)} = 1.68\ e\text{-}4$

$\varepsilon = 3.4$ nmrad

$(\nu_x, \nu_y) = (40.15, 18.35)$

Low-α: Optics





$\alpha_0^{(nominal)}$ = 1.68 e-4 $\xrightarrow{\alpha_0^{(nominal)}/11}$ α_0 = 0.158 e-4

ε = 3.4 nmrad → ε = 24.8 nmrad

(ν_x, ν_y) = (40.15, 18.35) → (ν_x, ν_y) = (39.15, 14.35)

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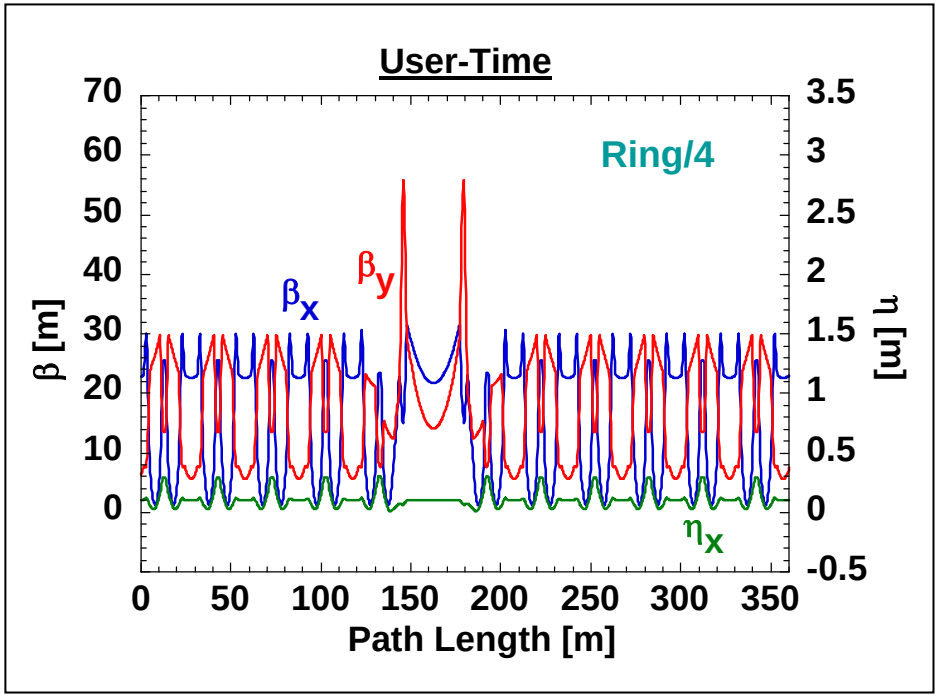

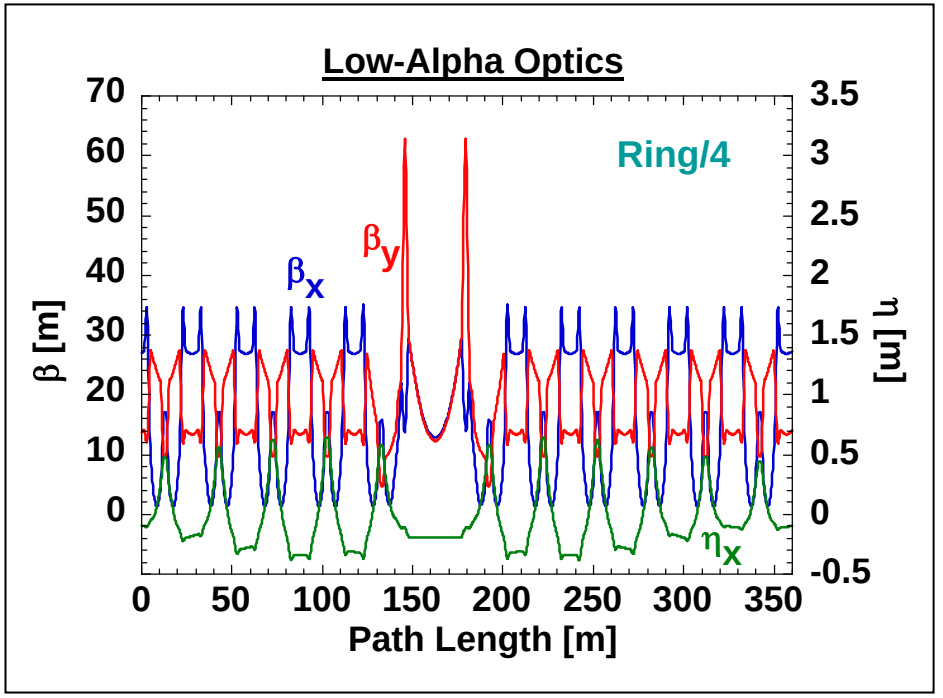

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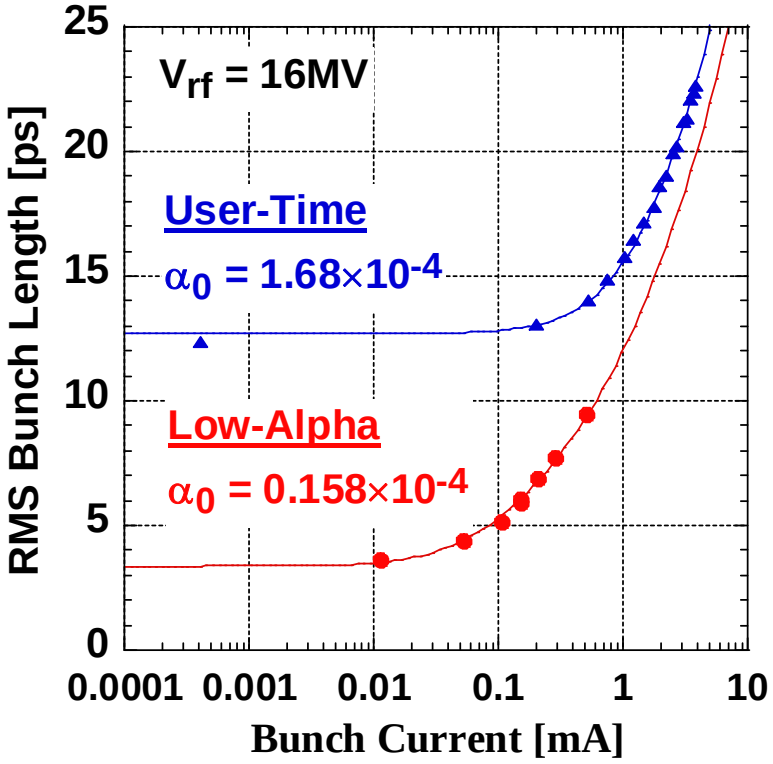
Gradual Change, Tune Fixed

$\alpha_0^{(nominal)}$ /29 →

α_0 = 0.058 e-4

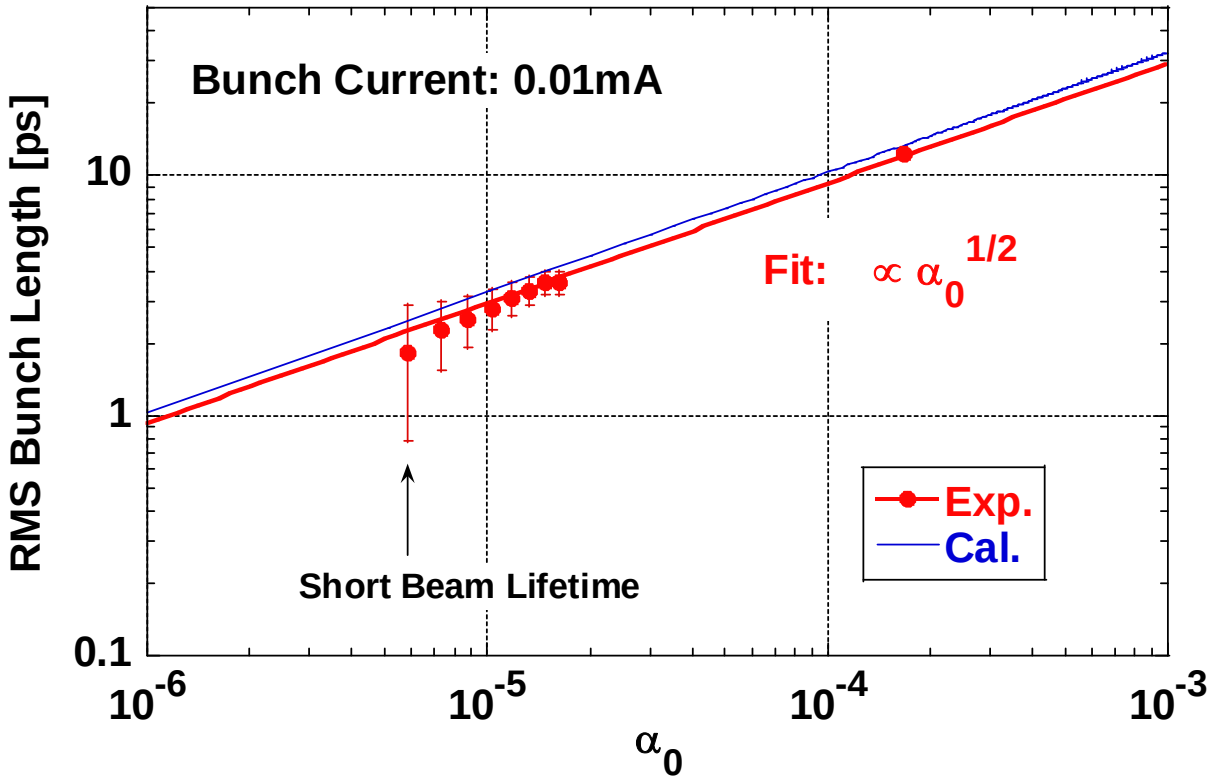
Low-α: Bunch Length vs Current



Measurement:
Streak Camera (Hamamatsu C5680)

2.5ps Error Assumed (estimated by measuring bunch length as a function of synchrotron frequency)

Low-α: Bunch Length vs α_0



α_0	σ_{meas} [ps]
1.68e-4	12.4
0.16e-4	3.6
0.073e-4	2.3
0.058e-4	1.8*

***Beam lifetime was short.**

NB: Measured bunch length is slightly shorter than calculation.

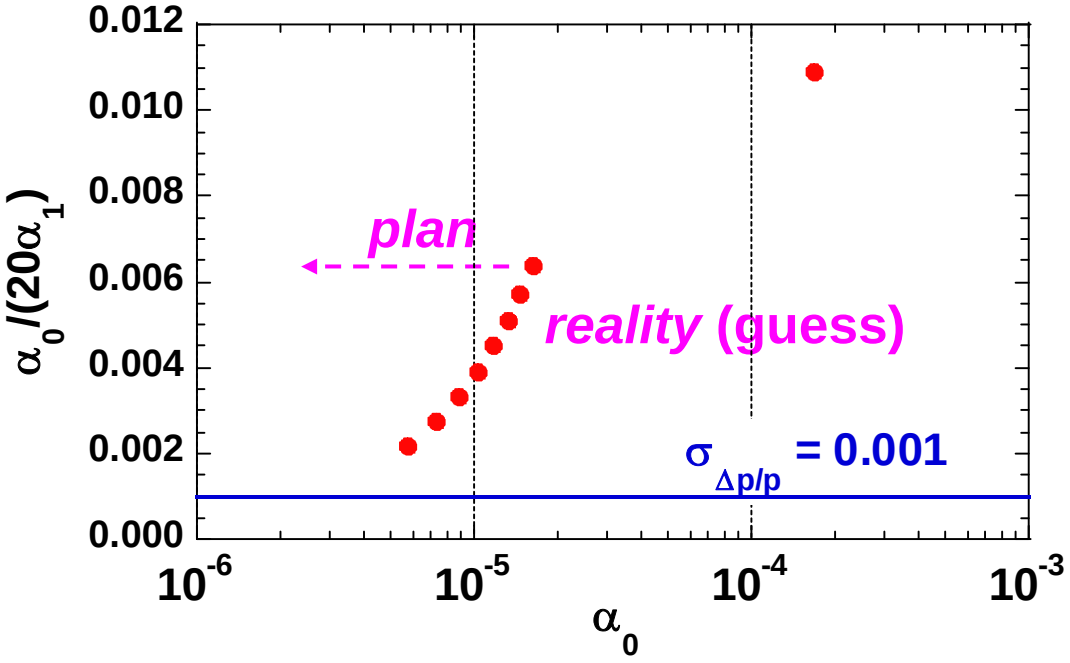
$\rightarrow$ Calibration of streak camera with a beam is planned.

Low-α: "Alpha-Bucket"

Beam lifetime was short at α_0 = 5.8e-6.

Possible Reason:

(1) Control of α_1 was not perfect in the experiment and the acceptance was small. ($\rightarrow$ Check df_{sy}/df_{rf} = 0.)



$\sigma_{\Delta p/p} < |\alpha_0/(20\alpha_1)|$

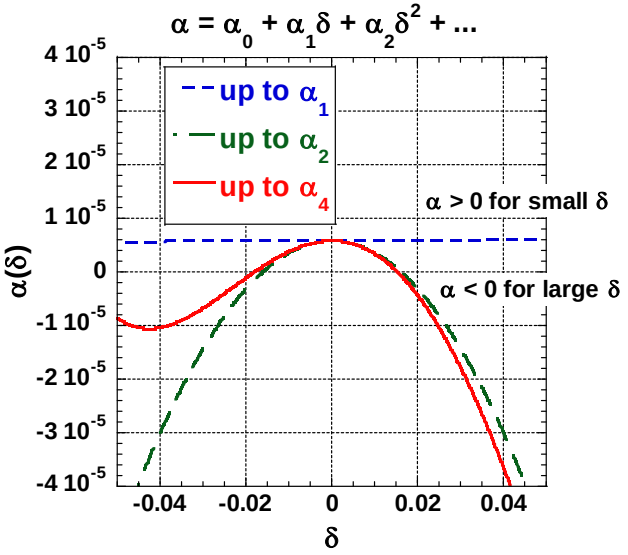
for good lifetime

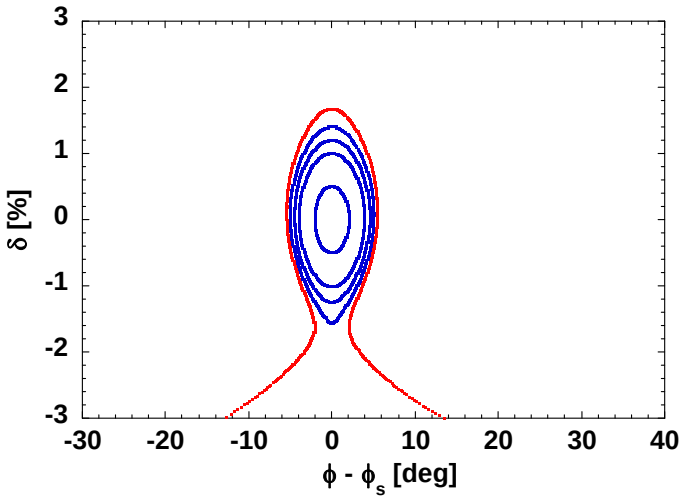
REF.) D.Robin, et al., PR E48 (1993) 2149

(2) Control of α_2 will be effective (needed for smaller α_0).

Low-α: Control of α_2

Install octupoles to control α_2 (or operate with $\alpha_0 < 0$).





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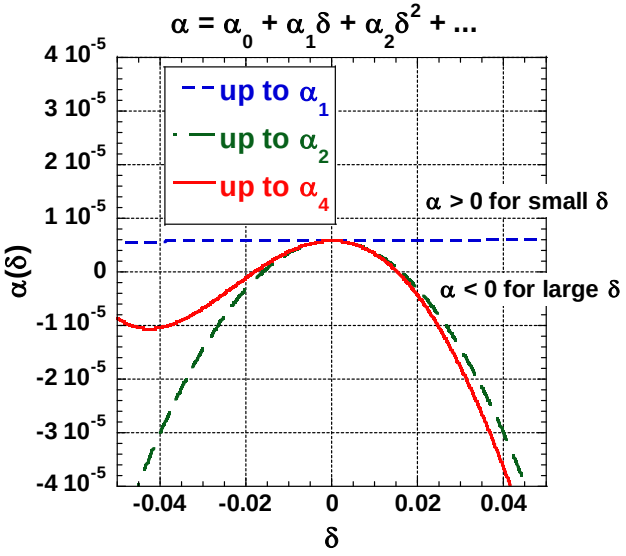
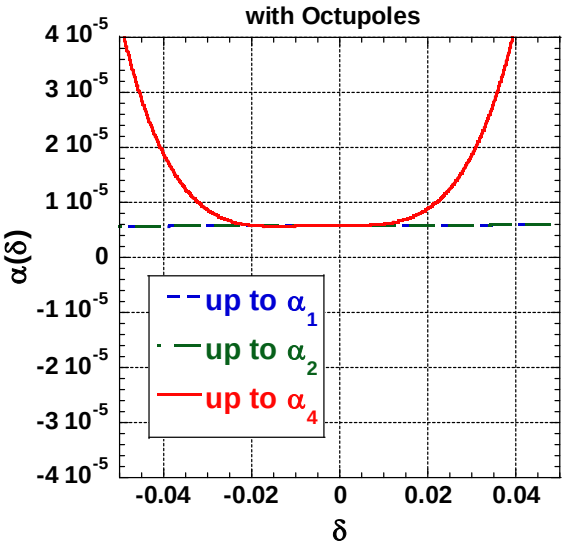
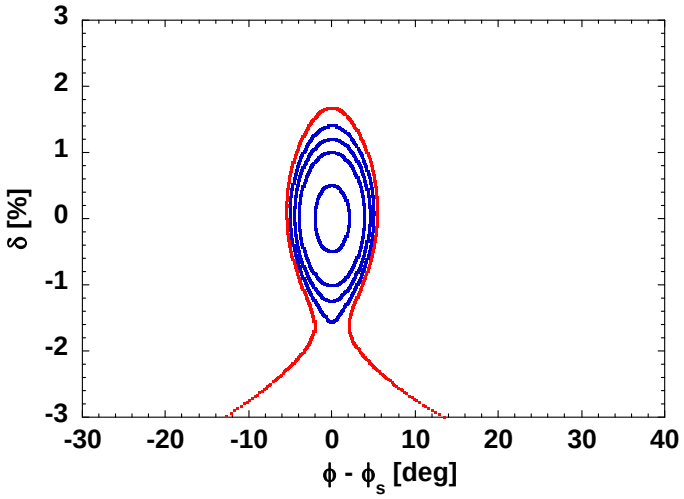


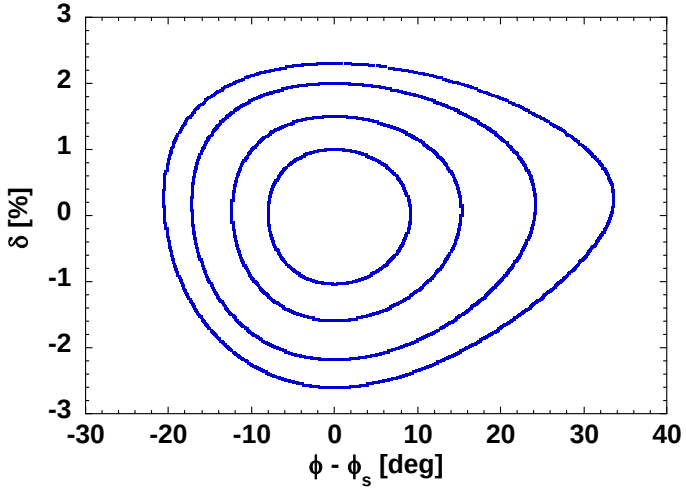
with Octupoles

→

calculation for temporary set of octupoles, not optimized







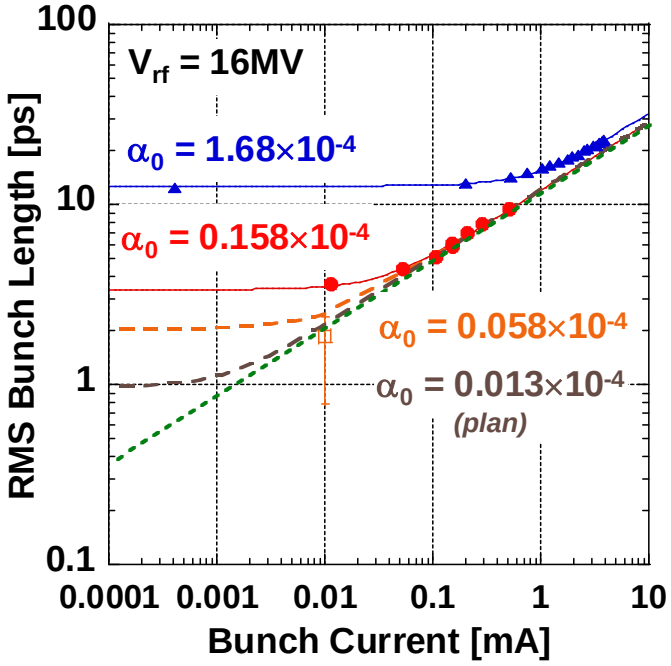
Low-α: Further Reduction?

Further Reduction Beyond a Few ps ?

→ Current must be low anyway.

Combination with ...

* 4 GeV Operation
  → *factor 1/3 naively*
* Damping Partition Control
* Higher RF Voltage
* RF Voltage or Phase Modulation
  (Bunch Length Modulation at kHz)



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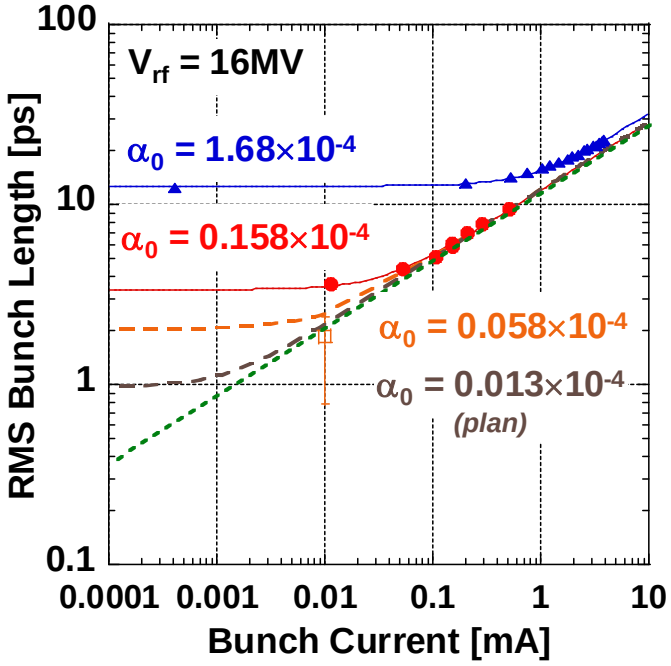


Other Approaches

* Bunch Deflection with Crab Cavities
* Bunch Deflection by Dipole Kick (W.Guo)
  (Short X-Ray Pulses at kHz)

Low-α: Summary

* The first order term α_0 was reduced by 1/29 in machine study.

* RMS bunch length of about 2ps was achieved at 0.01mA.

* Control of α_1 was done but not perfect. ... *to be improved*

* Control of α_2 is important in extremely low-α_0 regime.
  ... *Installation of octupole magnets (or negative-α_0 operation) is under consideration.*

* Plan (dream?) to reduce α_0 by 1/129.

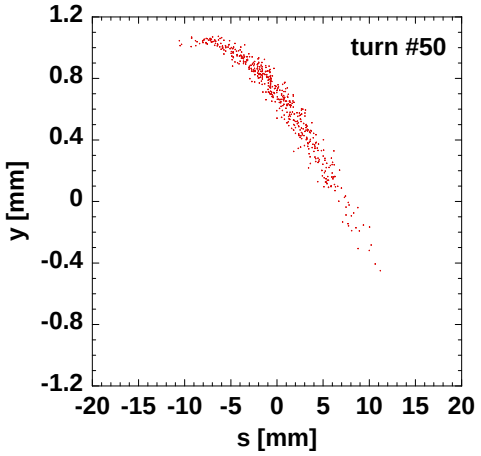
* Reproducibility of optics should be checked.

* Shorter bunch below 1ps is very difficult.
  Combination with other methods like RF modulation ?

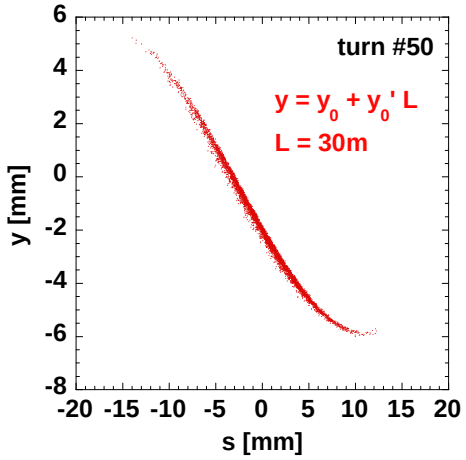
Bunch Deflection by Dipole Kick (W.Guo)

Simulation with Chromaticity (ξ_x, ξ_y) = (+2, +2), κ = 0.1%
Vertical Kick with 1mm Oscillation Amplitude

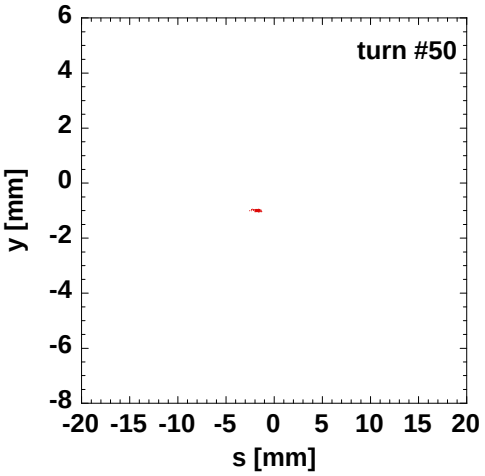
Bunch after 50 Turns

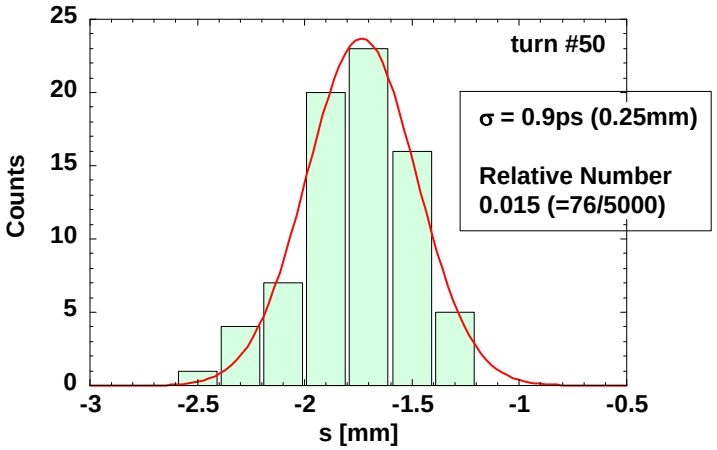


Transferred Position at 30m



Vertical Slit 0.1mm





σ = 0.9ps