Intrabeam scattering in ATF Damping ring
- Review of old studies

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References

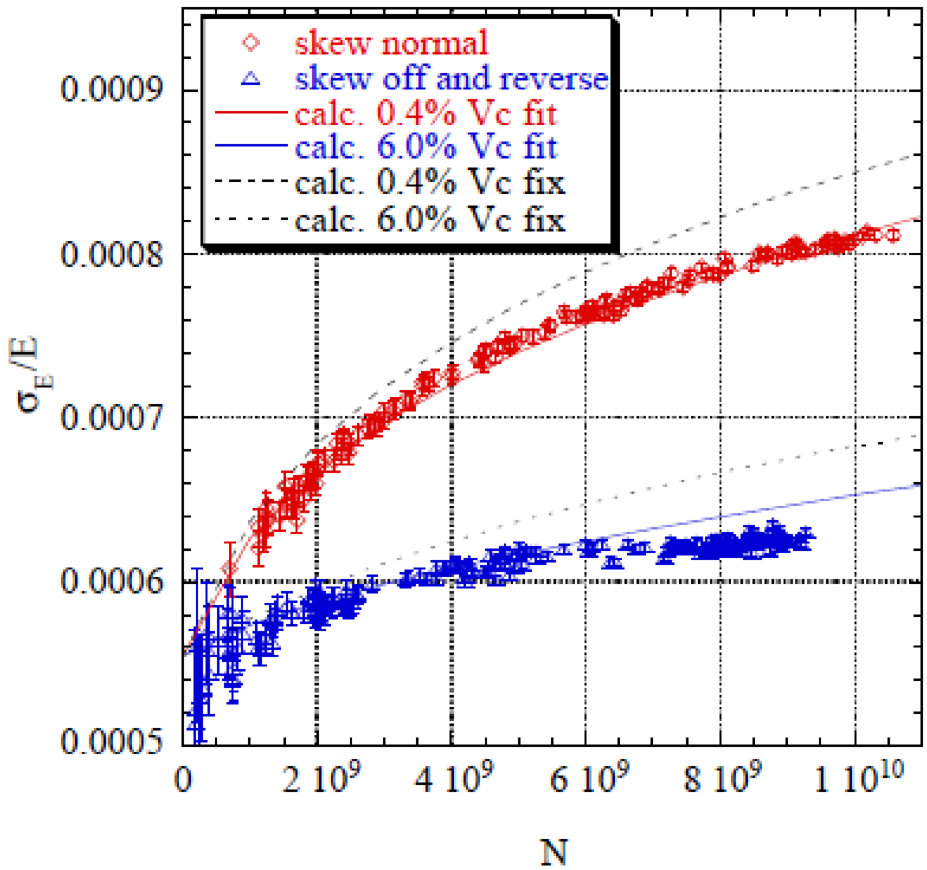
IBS theories and comparison with ATF experiments

- K.Bane, et.al, Phys. Rev. STAB, vol 5, 084403 (2002).

IBS theory, calculation method in SAD used for this report

- K.Kubo and K.Oide, Phys. Rev. STAB, vol 4, 124401 (2001).
  - Based on formula of J.Bjorken and S.K.Mtingwa (Part. Accel. 13, 115 (1983)). With generalization for coupled beam, and different treatment of “log factor”.

Momentum spread vs. bunch population

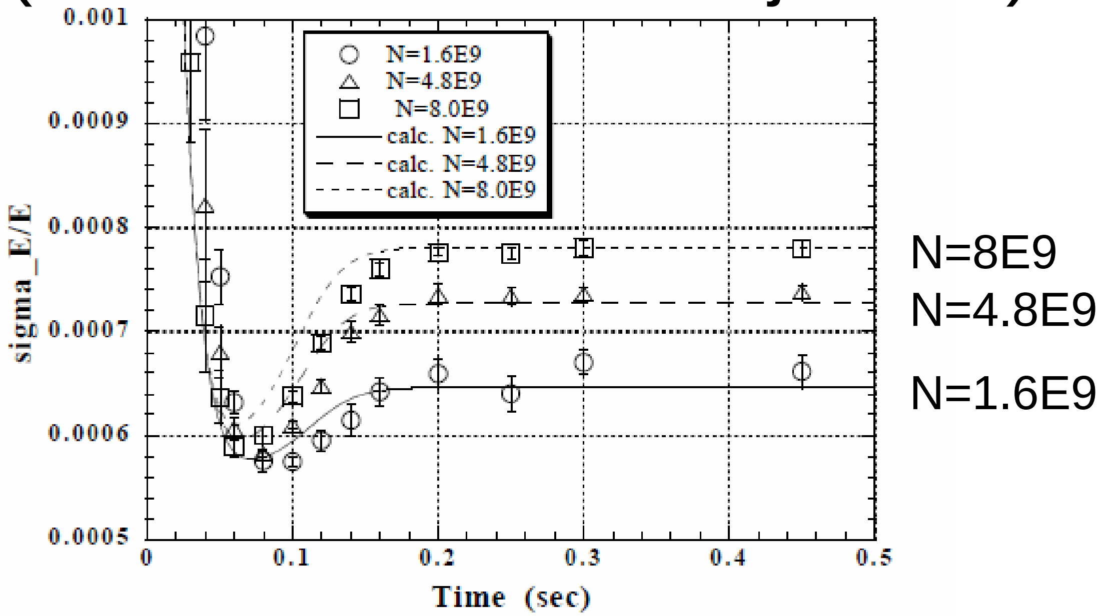


small ε_y (large density)

large ε_y (small density)

See later slides for details.

Momentum spread vs. time (extraction time after injection.)



Longitudinal damping time ~ 1/2 vertical damping time.

And $\varepsilon_{l,injection}/\varepsilon_{l,equilibrium} << \varepsilon_{y,injection}/\varepsilon_{y,equilibrium}$.

→Vertical emittance is still large when momentum spread reaches almost equilibrium.

→Further damping of vertical emittance takes time and gradually makes IBS stronger and increases momentum spread.

See later slides for details of the fitting

- IBS is significant in ATF Damping Ring

→ Experiment and comparison with IBS model(s) were performed.

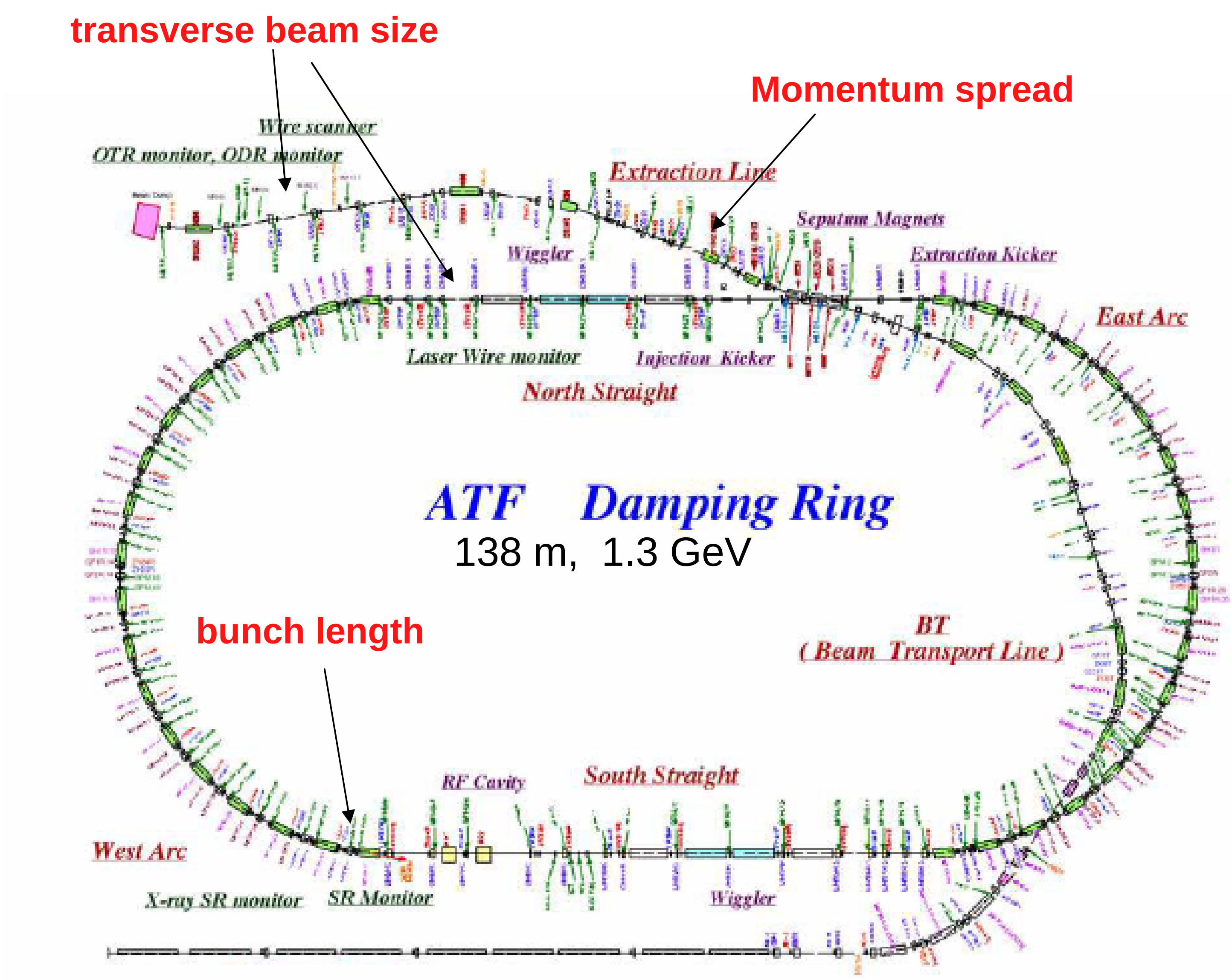
Experiment

Measured beam parameters

- Momentum spread (extracted beam)
  - Screen monitor at large dispersion in extraction line
- Bunch length (in DR)
  - Streak camera
- Horizontal and vertical emittance (in DR and extracted beam)
  - Laser wire in DR
  - Wire scanners in Extraction line
  - We have other beam size monitors but not used in this report.

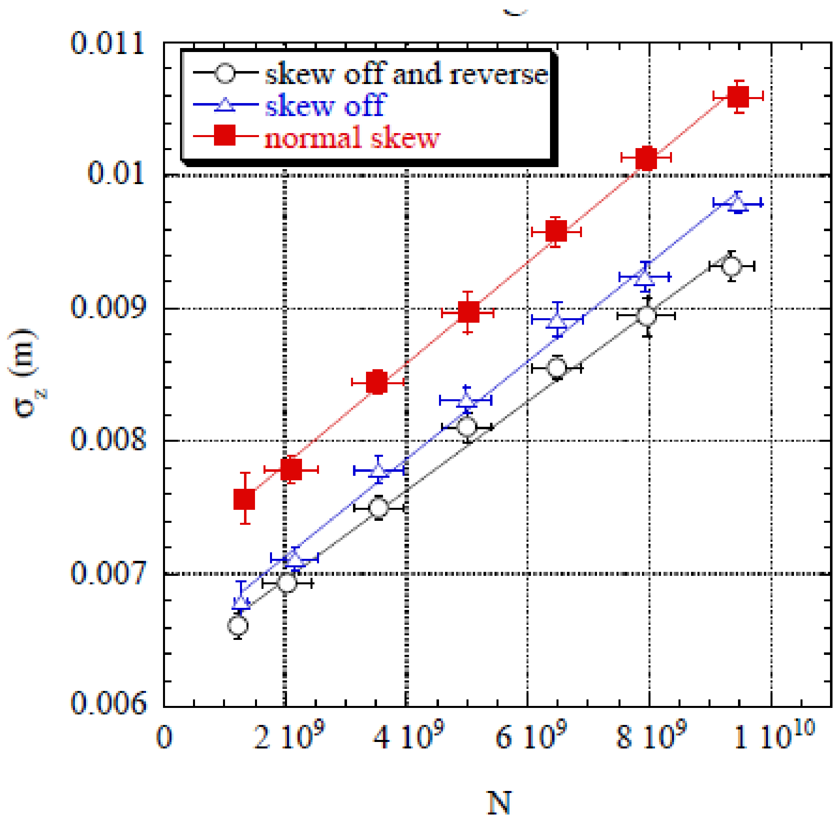
As function of

- Bunch intensity
- x-y coupling
  - Normal skew quad correctors (small ε_y →strong IBS)
  - All skew correctors off
  - Half off and half reversed (large ε_y → very weak IBS)
- Results are compared with calculations using SAD


transverse beam size
Momentum spread
Wire scanner
OTR monitor, ODR monitor
Extraction Line
Septum Magnets
Wiggler
Extraction Kicker
East Arc
Laser Wire monitor
Injection Kicker
North Straight
ATF Damping Ring
138 m, 1.3 GeV
bunch length
BT
(Beam Transport Line)
RF Cavity
South Straight
West Arc
X-ray SR monitor
SR Monitor
Wiggler

Comparison with Calculation
Need to include impedance effect

Bunch length vs. intensity



Strong intensity dependence even for large vertical emittance, where IBS should be very weak.

This came from impedance.

Because Longer bunch length reduces IBS, effect of impedance should be included in calculations

How to include impedance effect

Because SAD is not ready to include impedance, we changed RF cavity voltage for simulating impedance effect.

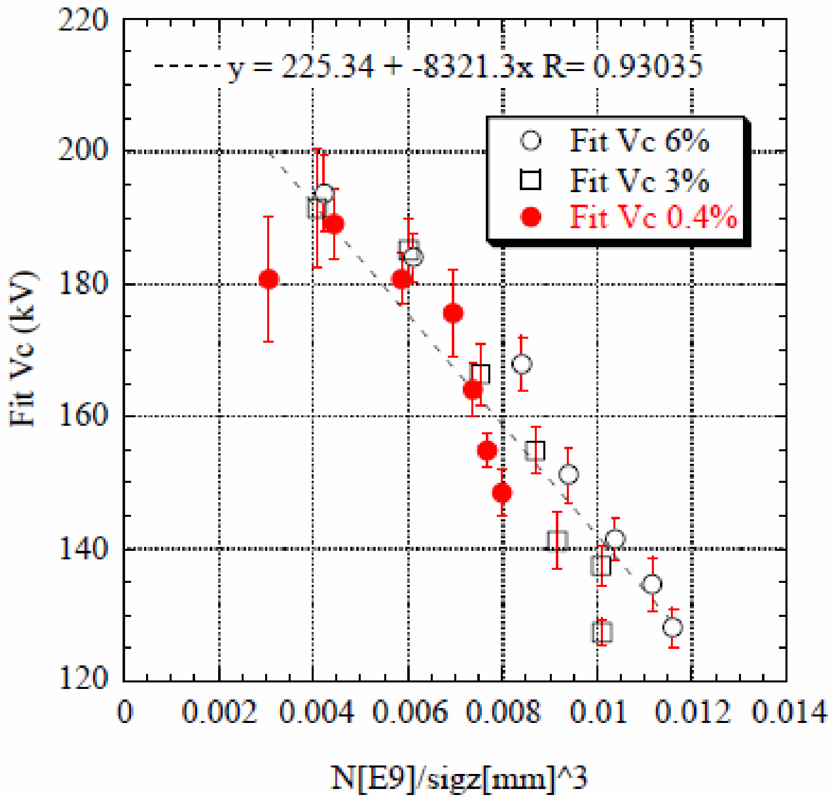
- Assuming pure inductive impedance, the voltage reduction should be a function of

$$N/\sigma_z^{\ 3}$$

- Find Vc with which SAD reproduces experimental data of bunch length.
- Then fit Vc as a function of $N/\sigma_z^{\ 3}$.

How to include impedance effect (3)

Vc with which SAD reproduces experimental data of bunch length vs. N/σ_z^3. *($\varepsilon x/\varepsilon y$ was assumed to be 0.4, 3 and 6%.)*

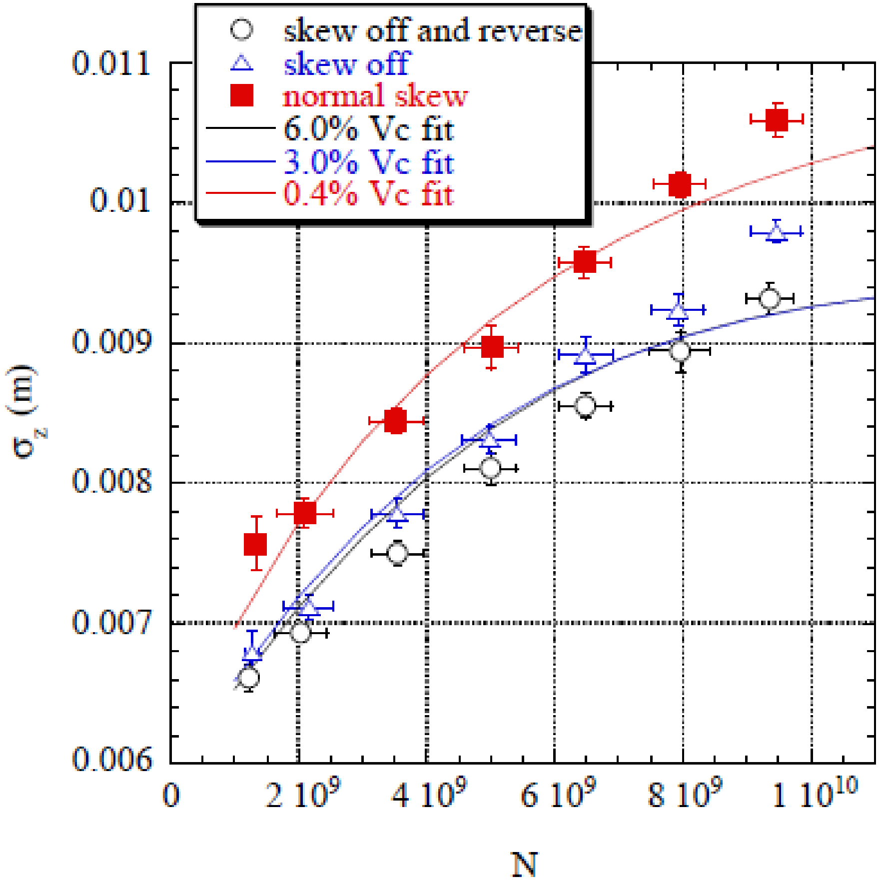


From this plot,

$$Vc[\mathrm{keV}] = 225 - 8321\, N/\sigma_z^3$$

was used for following calculations.
(Need some iterations because σ_z depends on *Vc*)

Bunch length vs. intensity



small ε_y

(y/x emittance ratio 0.4%)

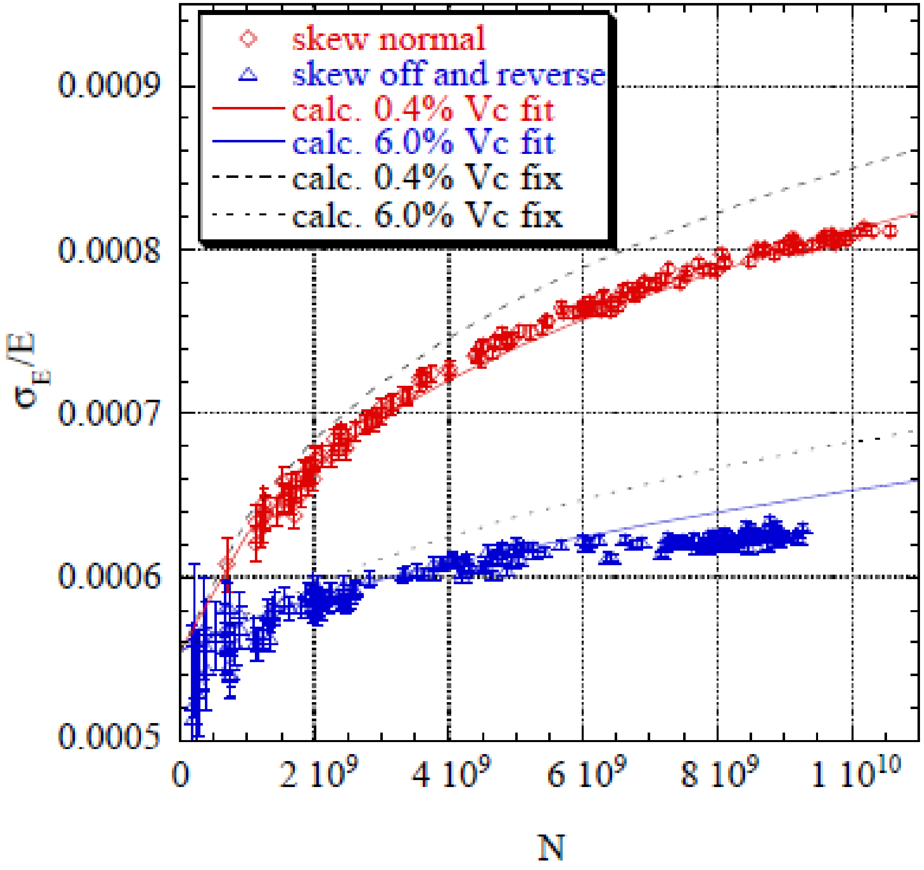
large ε_y

(y/x emittance ratio 3% and 6%)

Difference between calculation and measurement may come from non-inductive components of impedance.

Details of impedance model do not significantly affect calculation of momentum spread and transverse emittance.

Momentum spread vs. intensity



small ε_y

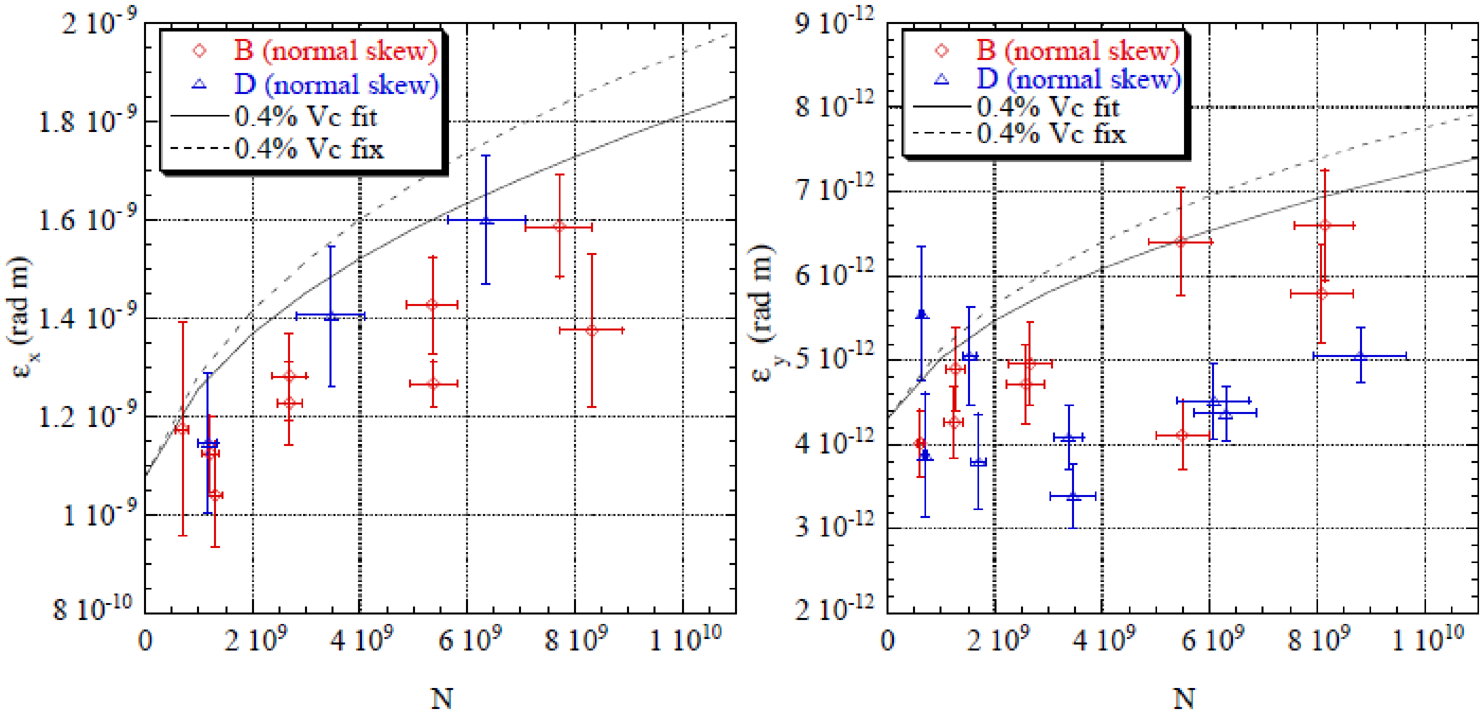
(y/x emittance ratio 0.4%)

large ε_y

(y/x emittance ratio 6%)

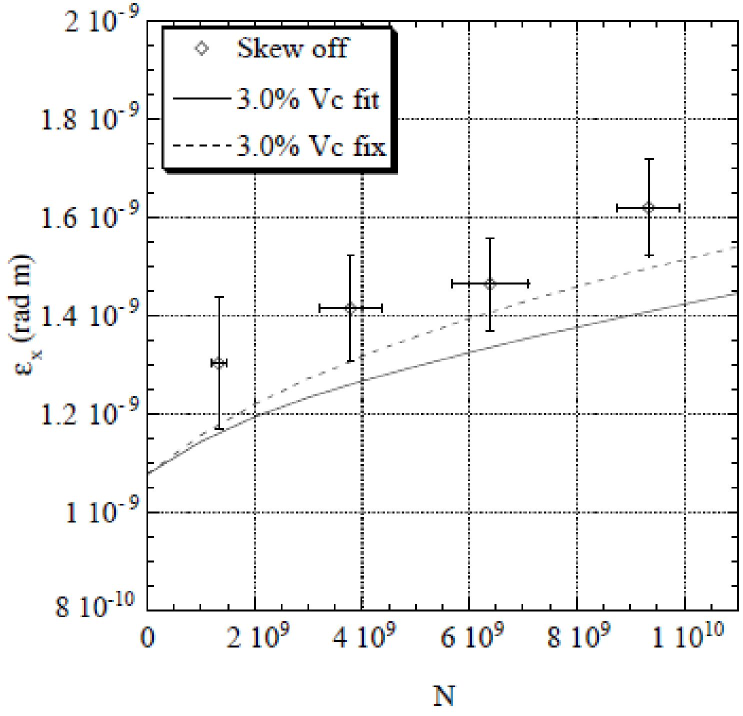
Calculation with fitted *Vc* (which was fitted to reproduce measured bunch length) agree with measured momentum spread data much better than fixed VC.

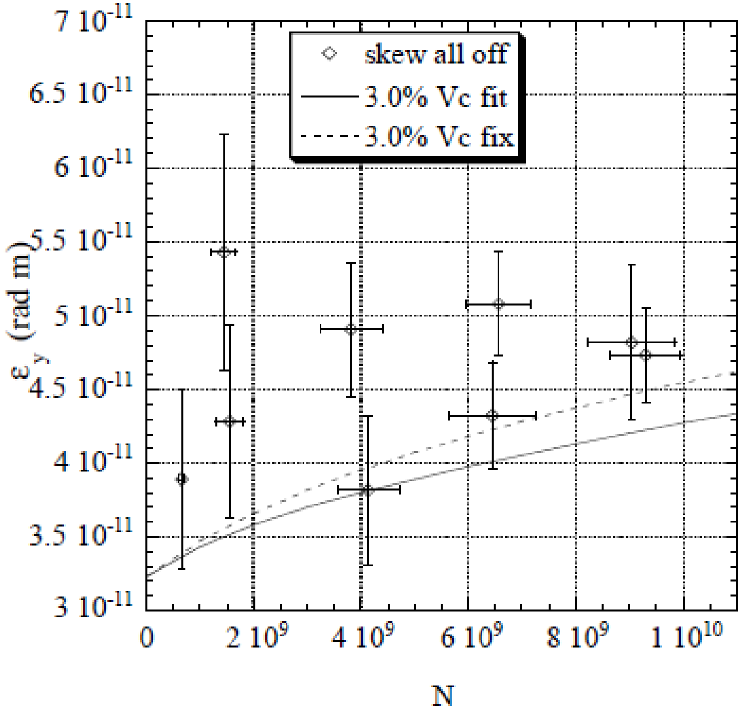
Emittance vs. intensity - normal skew correctors ($\varepsilon_y/\varepsilon_x \sim 0.4\%$)



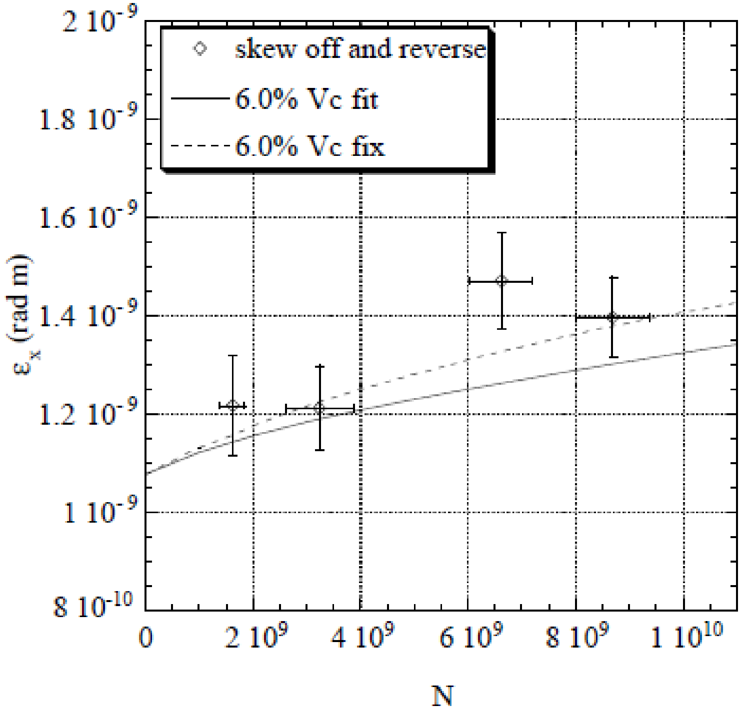
Too large error of measurements to check the model accurately.

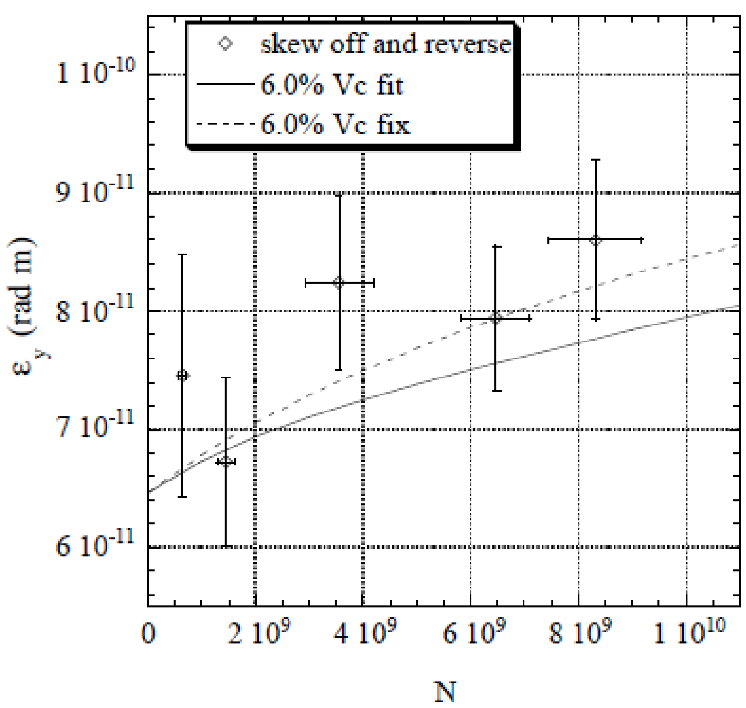
Emittance vs. intensity - skew correctors off ($\varepsilon_y/\varepsilon_x \sim 3\%$)





Emittance vs. intensity - half of skew correctors reversed ($\varepsilon_y/\varepsilon_x \sim 6\%$)





Issue in Calculations:
"log factor" in SAD (1)

log factor is

$$(\log) \equiv \frac{1}{2}\log\frac{1-\cos\theta_{\max}}{1-\cos\theta_{\min}} = \log\frac{b_{\max}}{b_{\min}}$$

where $\theta_{\max}$ and $\theta_{\min}$ are considered maximum and minimum scattering angle.

Approximately,

$b_{\max}$ is maximum impact parameter.

$b_{\min}$ is minimum impact parameter if $b_{\min} >> \sqrt{2}m\alpha \big/ \left|p^2\right|$.

(p is momentum of the particle in CMS.)

“log factor” in SAD (2)

- Maximum scattering angle (or b_{min}) - “Tail cut”
  - To calculate core (Gaussian) part of beam, large angle scattering, of which rate is smaller than radiation damping rate, should not be included. (T.Raubenheimer SLAC Report No. SLAC-387(1991) and Part. Accel. 45, 111(1994))
  - The angle cannot be larger than *90 degree*.

$$\int_{\theta_{\rm cut}}^{\pi/2} (\text{Event rate})\, d\theta = (\text{radiation damping rate})$$

- Minimum scattering angle (or b_{max})
  - Interaction only with the nearest particle should be considered as “scattering” .
  - No particles farther than beam size.

“log factor” in SAD (3)

scattering angle 90 deg → $\frac{\sqrt{2}m\alpha}{\langle p^2 \rangle}$; “tail cut” → $\sqrt{\frac{1}{\pi\rho\sqrt{\langle v^2 \rangle}\max(\tau_1,\tau_2,\tau_3)}}$

$$b_{\min} = \max\left(\frac{\sqrt{2}m\alpha}{\langle p^2 \rangle},\ \sqrt{\frac{1}{\pi\rho\sqrt{\langle v^2 \rangle}\max(\tau_1,\tau_2,\tau_3)}} \right)$$

$\langle p^2 \rangle$: Average p^2, ρ : density of beam,

$\langle v^2 \rangle$: average of square of velosity, in CMS of beam.

typical distance to nearest particle → $\rho^{-1/3}$; beam sizes → $\sqrt{\langle x_1^2 \rangle}$, $\sqrt{\langle x_2^2 \rangle}$, $\sqrt{\langle x_3^2 \rangle}$

$$b_{\max} = \min\left(\rho^{-1/3}, \sqrt{\langle x_1^2 \rangle}, \sqrt{\langle x_2^2 \rangle}, \sqrt{\langle x_3^2 \rangle} \right)$$

$\langle x_{1,2,3}^2 \rangle$: average of x^2 of an eigen mode 1, 2, 3 $(\approx \sigma_x, \sigma_y, \sigma_z)$

“log factor” in SAD (4)

Typical values in ATF DR :

$$b_{\min} = \sqrt{\frac{1}{\pi\rho\sqrt{\langle v^2\rangle}\max(\tau_1,\tau_2,\tau_3)}} \approx 2\times10^{-10}\,\mathrm{m}$$

$$\frac{\sqrt{2}m\alpha}{\langle p^2\rangle} \approx 1\times10^{-12}\,\mathrm{m},$$

$$b_{\max} = \rho^{-1/3} \approx 3\,\mu\mathrm{m},$$

$$\sigma_y \approx 5\,\mu\mathrm{m}$$

$\rightarrow (\log) \approx 10 \quad$ (without "Tail cut", $\;(\log) \approx 15$)

Summary

- We observed strong IBS in ATF Damping Ring
- Calculation using SAD is mostly consistent with experimental data.
  - Momentum spread: Agreed well
    - Choice of log factor seems reasonable
    - Need to include Impedance effect. (Not very accurate and introduce some ambiguities.)
  - Bunch length: Hard to use for model test because it was affected by impedance.
  - Transverse emittance: Hard to have clear conclusion due to large error of measurement.
    - Possible discrepancy is not large.