Study on Resistive Wall Instability in CSNS/RCS

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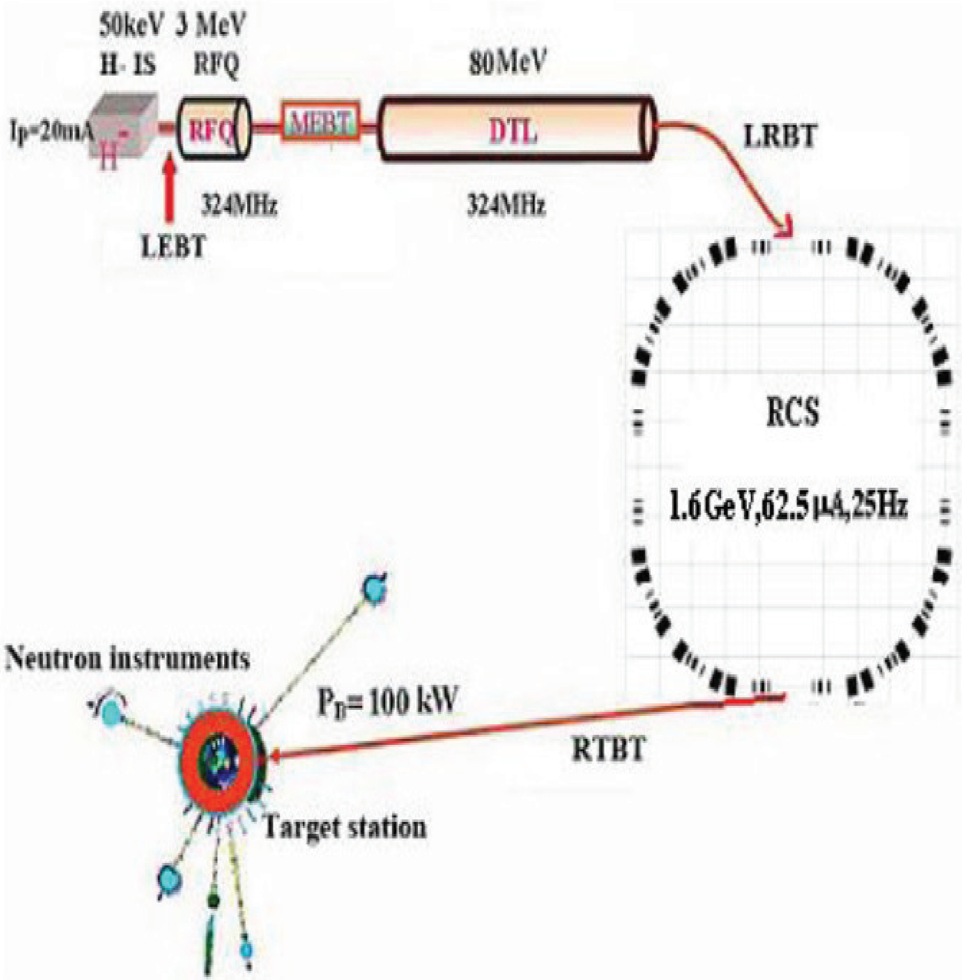
Outline

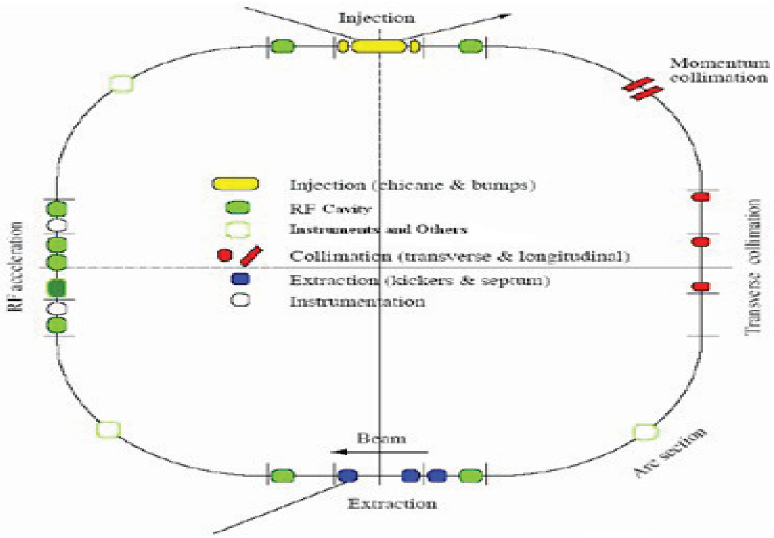
- The CSNS and RCS
- Simulation process and result
- Theoretical estimation and Compared
- The influence of chromaticity
- summary

CSNS

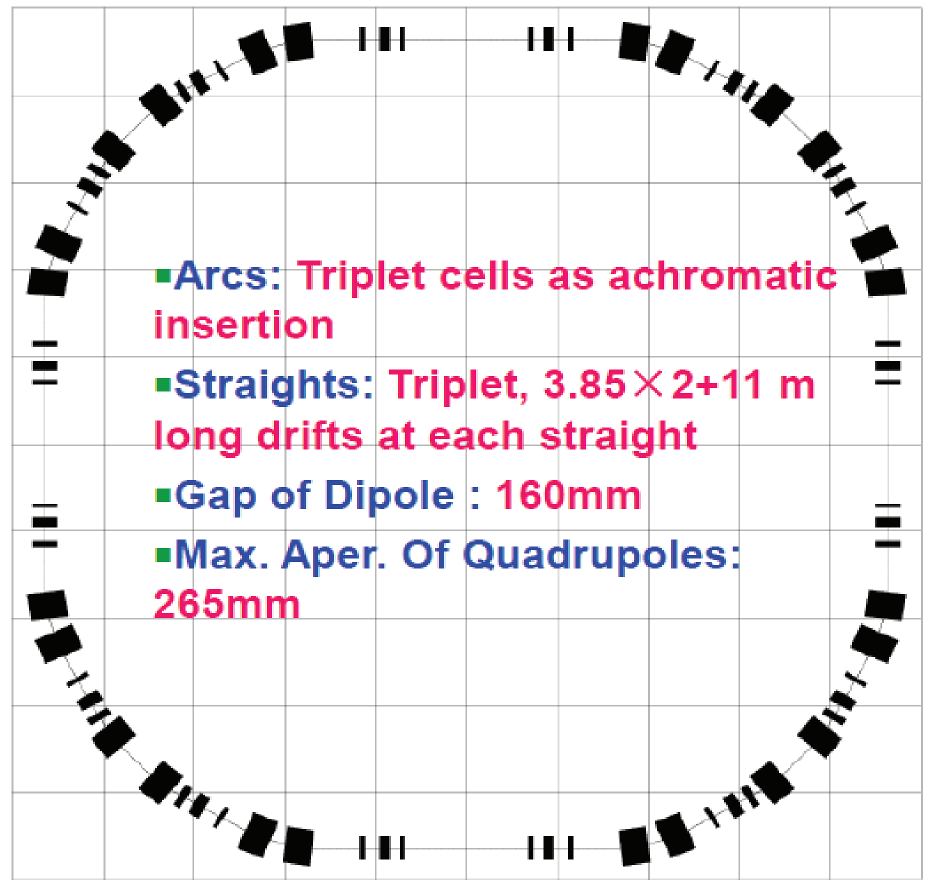


	CSNS/UPGRADES
Beam power(kW)	100/200/500
Proton energy(GeV)	1.6
Linac energy(MeV)	80/130/250
Repetition rate(Hz)	25
Average current(μ A)	62.5/125/312
Target number	1

RCS



Parameters	Values
Circumference/m	227.92
Stainless steel length /m	140
Average beta (H/V)/m	9.5/10.5
Nominal tune(H/V)	4.86/4.78
Natural chromaticity(H/V)	-4.64/-8.27
Bunch number	2
Particles per bunch(e13)	0.78/1.56/3.9
Trans. acceptance (π mm.rad)	540
RF voltage(KV)	165



- Arcs: Triplet cells as achromatic insertion
- Straights: Triplet, 3.85×2+11 m long drifts at each straight
- Gap of Dipole : 160mm
- Max. Aper. Of Quadrupoles: 265mm

Lattice consists of 16 triplet cells, with a gap in the middle of arc and dispersion free straight section .

Why study resistive wall?

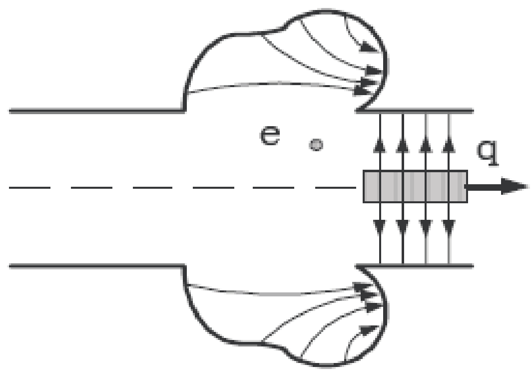
CSNS/RCS critical components impedance estematied value, $n=\omega/\omega_0$, ω_0 is angular revolution frequency.

Item / Component	Injection longitudinal (Ω/m)	Injection transverse(kΩ/m)	Extraction longitudinal(Ω/m)	Extraction transverse(kΩ/m)
Space charge	–j811.45	–j16.77k	–j96.62	–j3.30k
Resistive wall	$1.68(1+j)/n^{1/2}$	$36.12(1+j)/n^{1/2}$	$2.61(1+j)/n^{1/2}$	$23.23(1+j)/n^{1/2}$
Step	j0.23	j57.67+0.025n	j0.55	j151.07+1.0n
RF cavity	j0.014	j4.74	j0.033	j4.74
Collimator	j0.17	j0.23	j0.42	j0.23
bellows	j0.17	j12.38	j0.40	j12.38
Vacuum pump	j0.083	j1.72	j0.083	j1.72
Flanges	j1.12	j0.86	j2.67	j0.36
Kicker	j16.16	j16.63	j38.65	j16.63

Simulation

$$\ddot{y}_0(t)+\omega_\beta^2 y_0(t)=-\frac{N_p r_p v}{\gamma T_0}\sum_{k=0}^{\infty}[W_1(-kC-\frac{C}{2})y_1(t-kT_0-\frac{T_0}{2})+W_1(-kC)y_0(t-kT_0)]$$

ω_β the frequency of betatron motion, N_p the number of particles in a bunch,
r_p classical radius of proton, v velocity of particle, γ is relative energy factor,
T_0 angular revolution time, W_1 transverse wake function.
β average betatron function, $\nu_{x,y}$ horizontal or vertical tune,
b the radius of chamber, $/z/$ distance from beam to test charge
σ the permittivity, μ_r the relative permeability



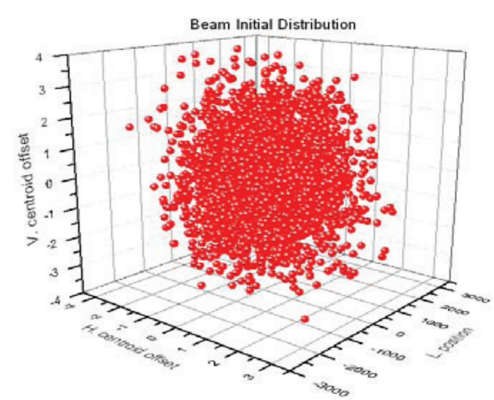
Schematic of wake field*

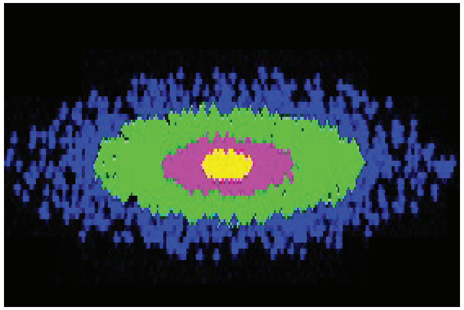
$$\begin{pmatrix} x \\ x' \end{pmatrix}_{i+1}=\begin{pmatrix} \cos(2\pi\nu_{x,y}) & \beta_{x,y}\sin(2\pi\nu_{x,y}) \\ -\frac{1}{\beta_{x,y}}\sin(2\pi\nu_{x,y}) & \cos(2\pi\nu_{x,y}) \end{pmatrix}\begin{pmatrix} x \\ x' \end{pmatrix}_i+\begin{pmatrix} 0 \\ dx' \end{pmatrix}.$$

- **Beam initial distribution is Gaussian.**

$$dx'=\sum_n\sum_j-\frac{eq<\overline{x_{nj}}>W_{nj\perp}N_{nj}L}{\beta^2 E}.$$

$$W_{nj\perp}=-\beta^{3/2}cZ_0\frac{1}{\pi^2 b^3}\sqrt{\frac{\mu_r c}{\sigma}}[\frac{1}{|z|^{1/2}}+\frac{3}{8}\frac{b^2-\frac{3}{2}x^2}{\gamma^2|z|^{5/2}}].$$

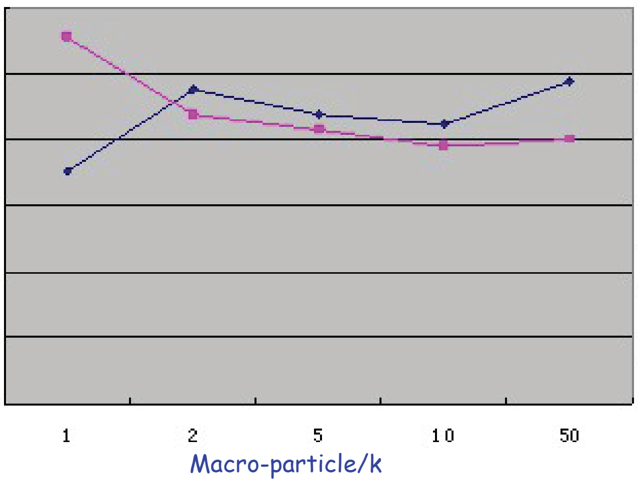


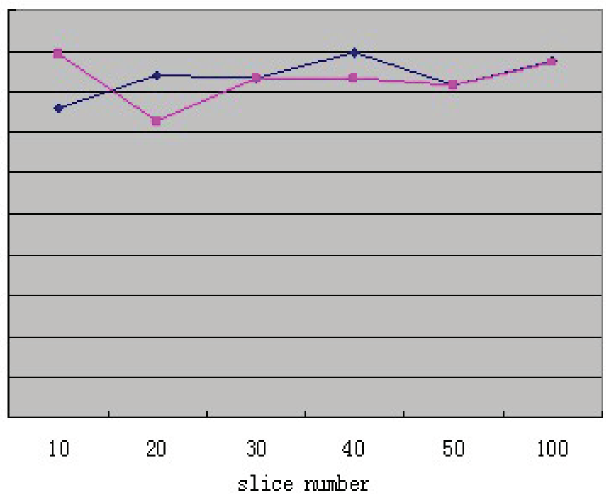


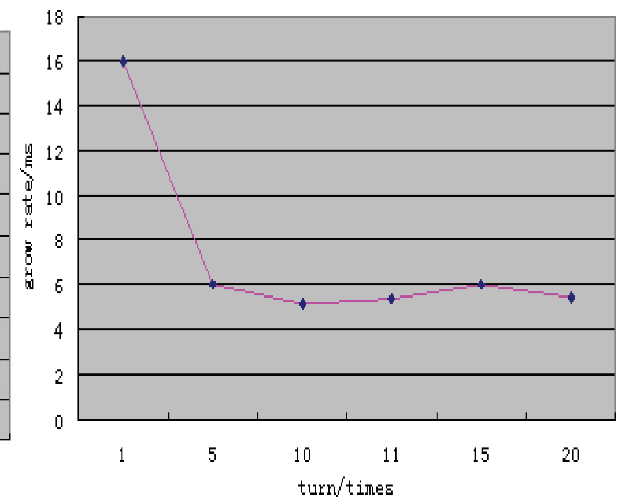
* come from Physics of Collective Beam Instability in High Energy Accelerators by Alex. Wu Chao

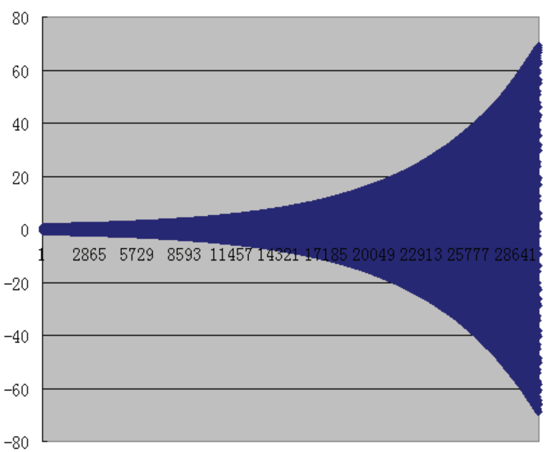
Simulated parameters

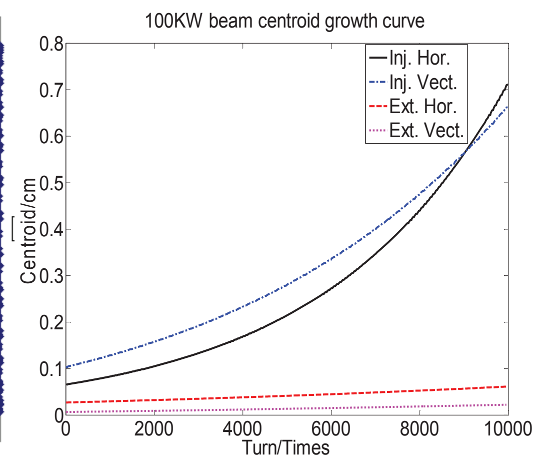
- 3 thousands macro-particles were considered, 50 slices, wake field was cut off after 10 turns.











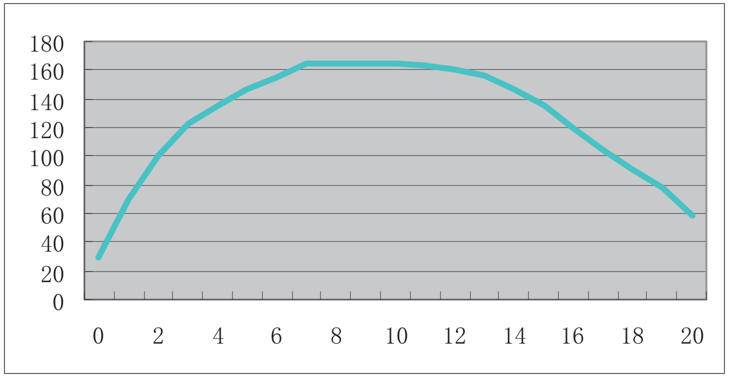
Power/Inj. Energy kW/MeV	Injection(ms)		Extraction(ms)	
	Hor.	Ver.	Hor.	Ver.
100/80	9.3	9.2	18.9	19.1
200/130	5.1	4.7	9.2	8.2
500/250	2.1	1.9	3.1	3.0

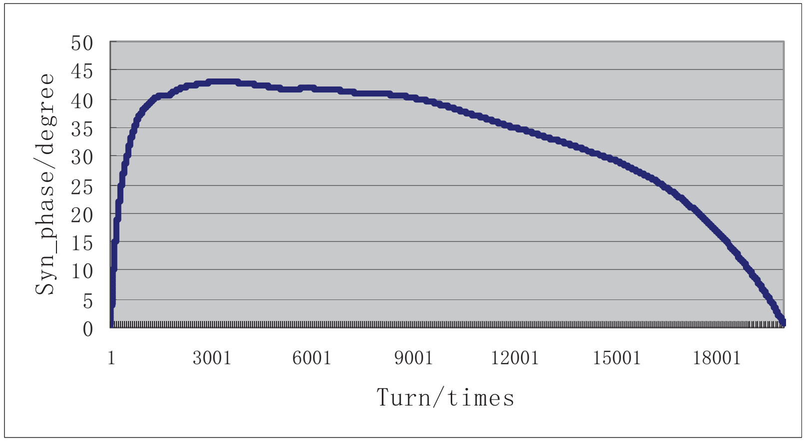
$$\begin{pmatrix}\Delta z\\ \delta\end{pmatrix}_{i+1} = \begin{pmatrix} \cos(2\pi\nu_s) & \dfrac{\eta\beta c}{\nu_s\omega_0}\sin(2\pi\nu_s) \\ -\dfrac{\nu_s\omega_0}{\eta\beta c}\sin(2\pi\nu_s) & \cos(2\pi\nu_s)\end{pmatrix}\begin{pmatrix}\Delta z\\ \delta\end{pmatrix}_{i}.$$

$$\Delta E_{i+1} = \Delta E_i + eV(\sin(\phi_i) - \sin(\phi_s)),$$

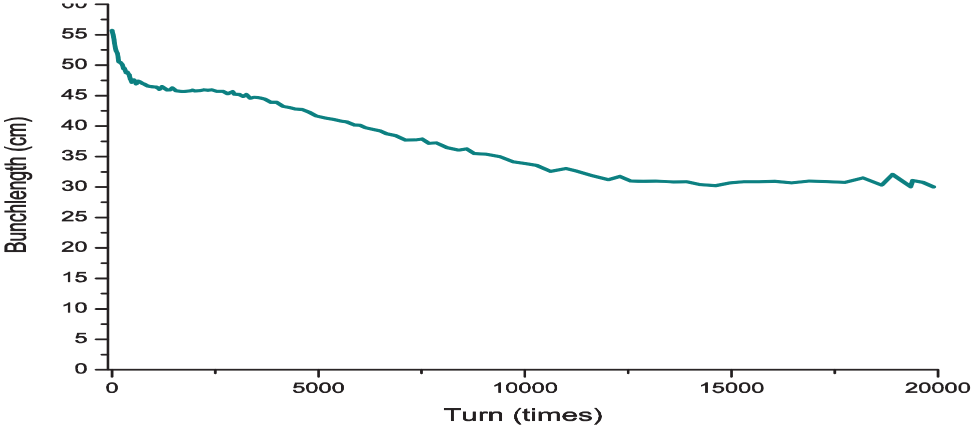
$$\phi_{i+1} = \phi_i + \frac{2\pi h\eta}{\beta^2 E}\Delta E_{i+1}.$$

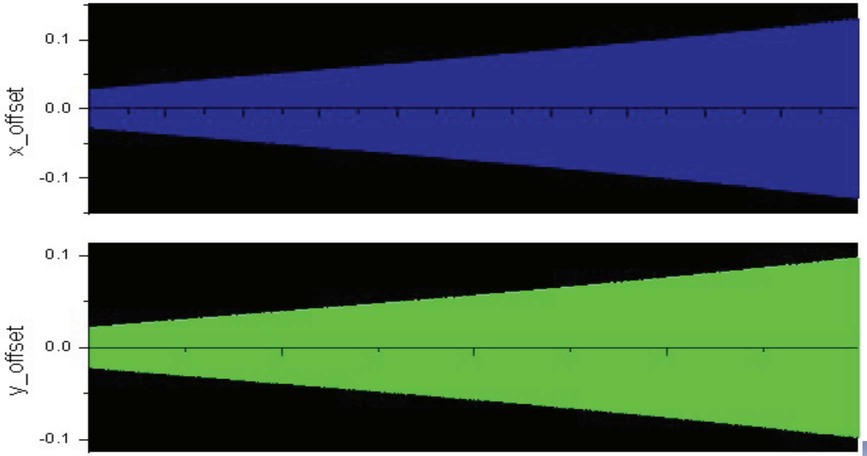
- **Longitudinal wake is not considered.**
- **Simulation process is the same with above.**





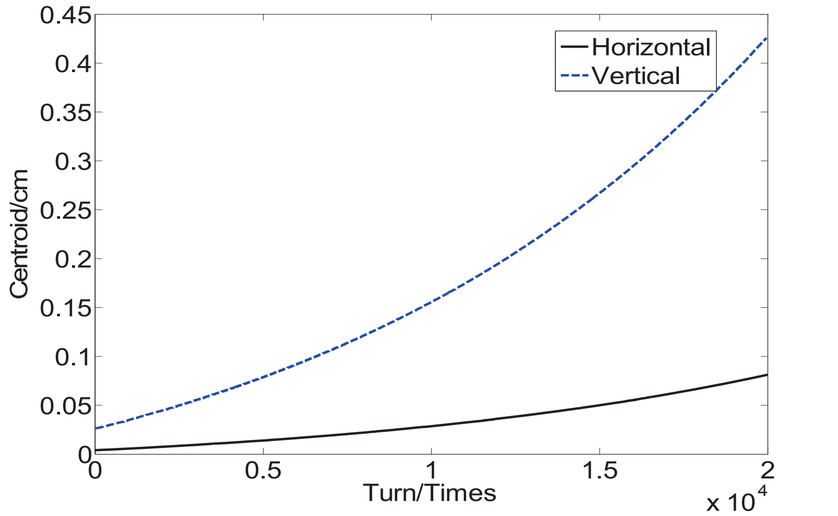
Voltage and synchrotron phase curve with time

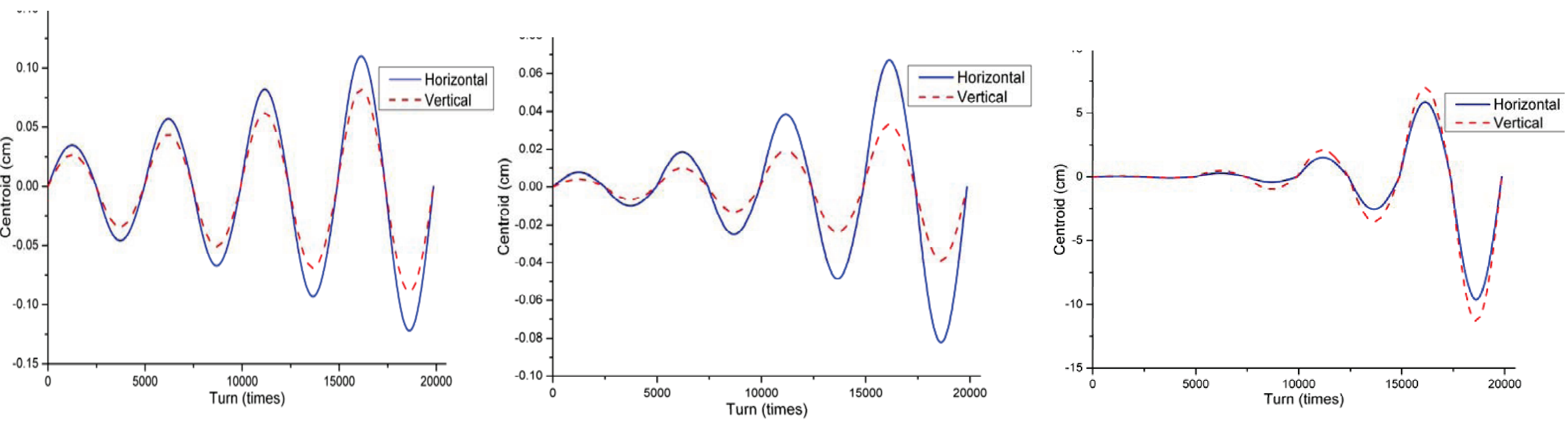




- **The growth times are obtained by calculating the time when transverse offsets increased e(2.71828) times of initial offsets.**

Power/Inj. Energy kW/MeV	Ramping(ms)	
	Horizontal	Vertical
100/80	11.5	12.3
200/130	5.4	6.2
500/250	2.7	2.8



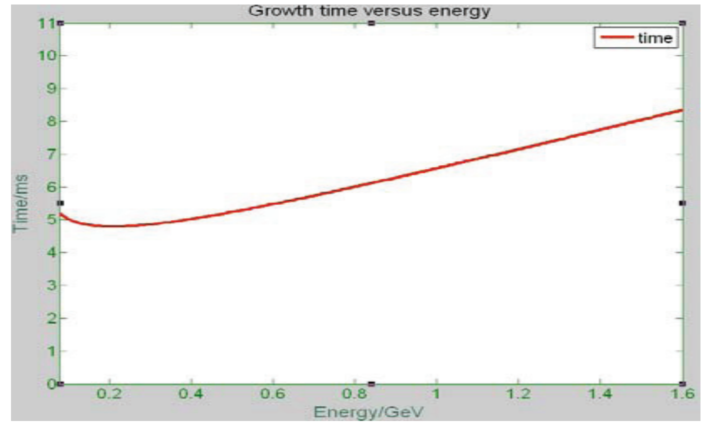


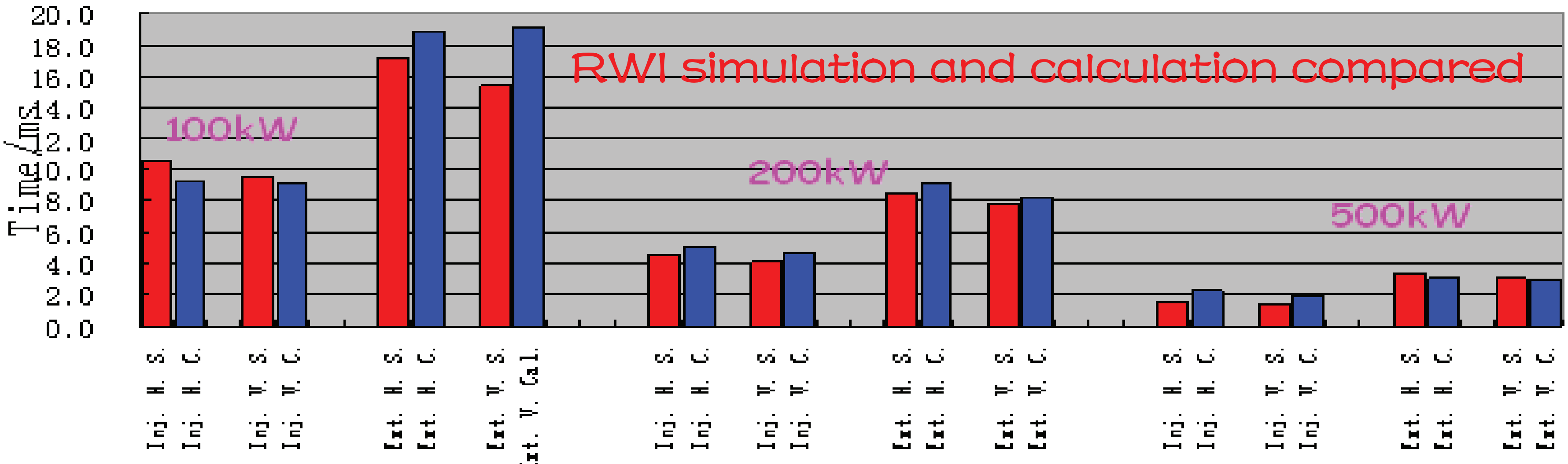
schematic of transverse oscillation for CSNS and upgrades

Theoretical calculation

$$(\Delta\omega_\beta)_{coh} = -\frac{ir_p k_b N_p v Z_T}{2\omega_\beta \gamma T_0^2},$$

$$\frac{1}{\tau} = \frac{N_p k_b r_p \omega_0^2}{2\pi\beta\gamma c Z_0}\beta_{av}\,\mathrm{Re}(Z_T).$$

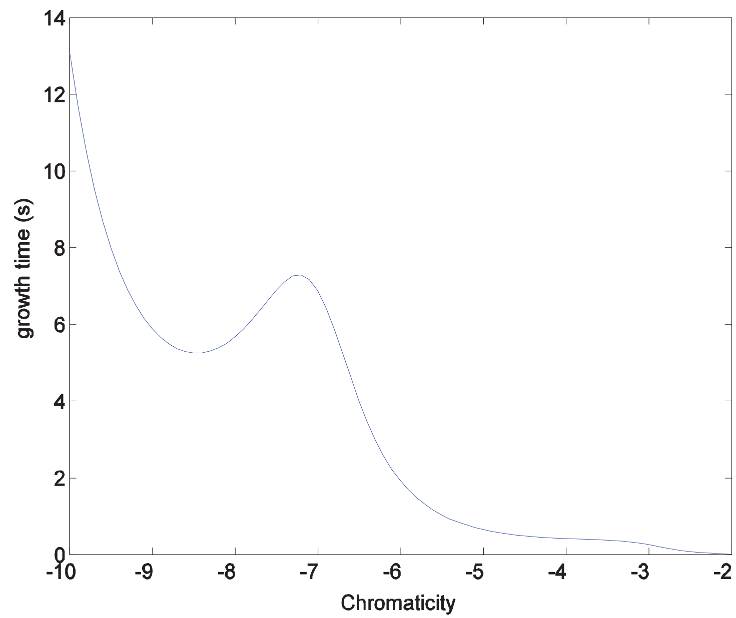




- Resistive wall instability would happen if any another damping.
- How about with natural chromaticity?

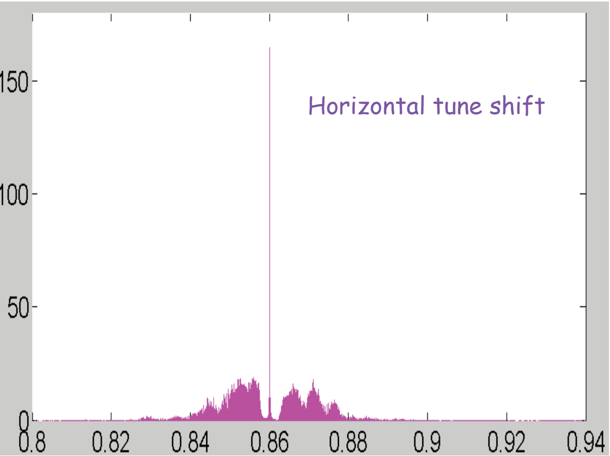
Chromaticity

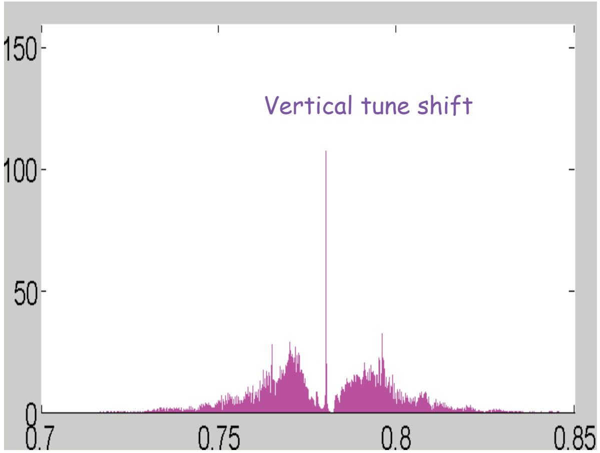
$$\frac{1}{\tau}=\frac{N_p k_b r_p \omega_0^2}{2\pi\beta\gamma c Z_0}\beta_{av}\,\mathrm{Re}(Z_\mathrm{T})F_m(\omega_\xi).$$



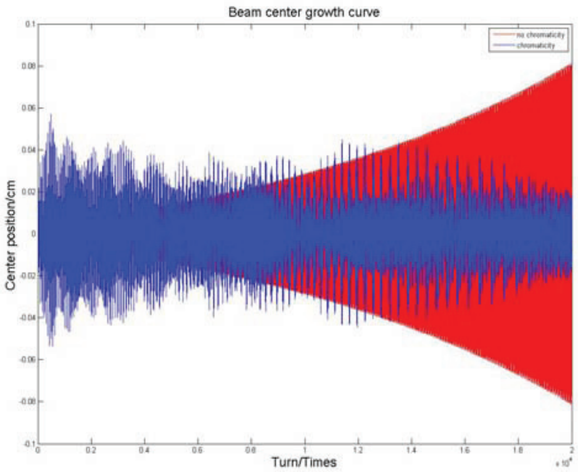
- **Natural chromaticity affect betatron tune and angular revolution frequency. Where, the change of angular revolution frequency was ignored, thus, only betatron tune changed.**

$$\nu_{x,y}{}' = \nu_{x,y} + \xi_{x,y}\delta_{x,y}.$$

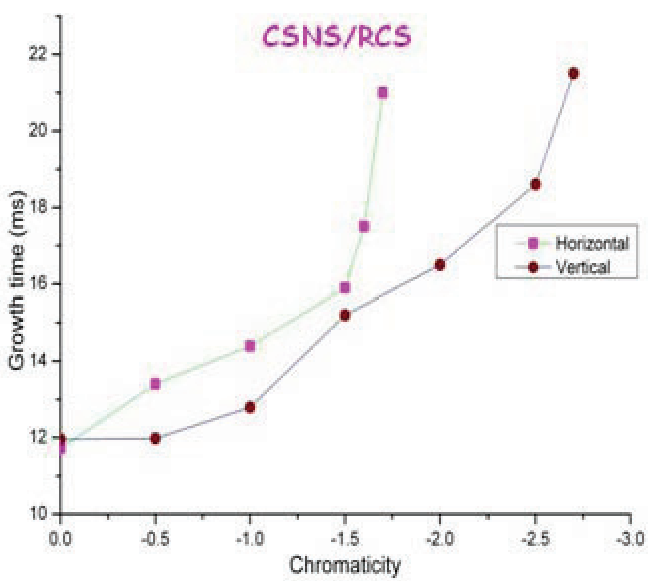


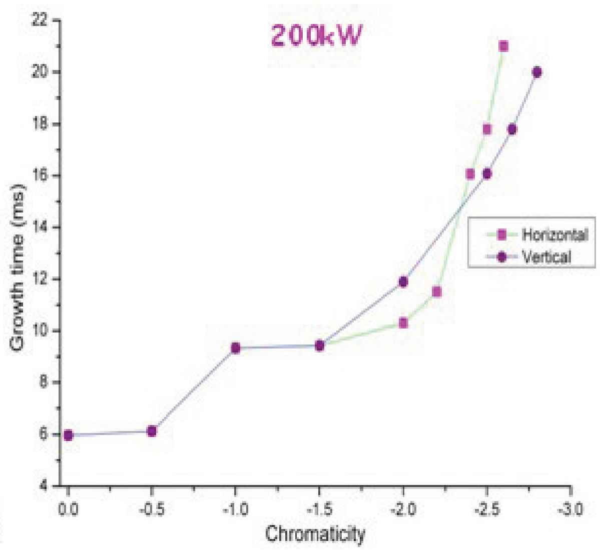


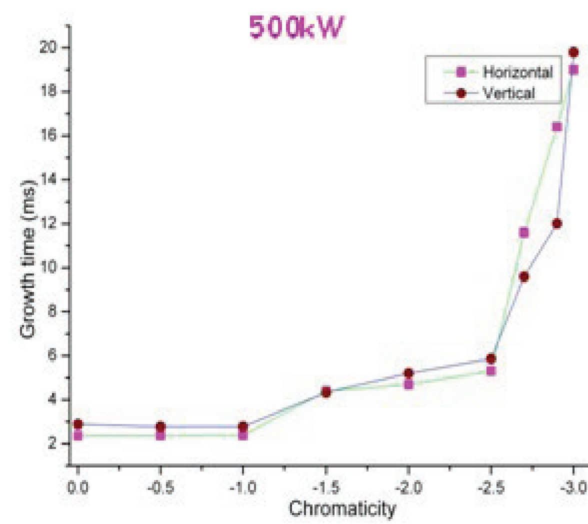
Horizontal and vertical maximum tune shift caused by natural chromaticity are about 0.04 and 0.06.



- The horizontal and vertical instabilities are depressed entirely.
- The sextupoles are designed for the chromaticity correction in CSNS/RCS, and the chromaticity can be corrected to a negative value close to zero.







summary

- Resistive wall instability model is found and simulated code is obtained according to this model.
- Simulation results of transverse two directions during the phase of injection and extraction agree well with theoretical calculation results.
- Ramping program was simulated. Growth time was smaller than ramping time. Resistive wall instability would happen if any another damping.
- The transverse resistive wall instability can be depressed when the chromaticity effect is considered.

Thank you for your attention!