

Beam-beam Effects in Inclined Super-bunch Crossing

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AGENDA

1. Introduction
2. Crossing Geometry
3. Calculation Model
4. Calculation Results
5. Summary

[Introduction]

- **Super-bunch Collision** has been proposed

by K.Takayama, J.Kishiro, M.Sakuda, Y.Shimosaki, and M.Wake, Phys. Rev. Let., 88, 144801(2002).

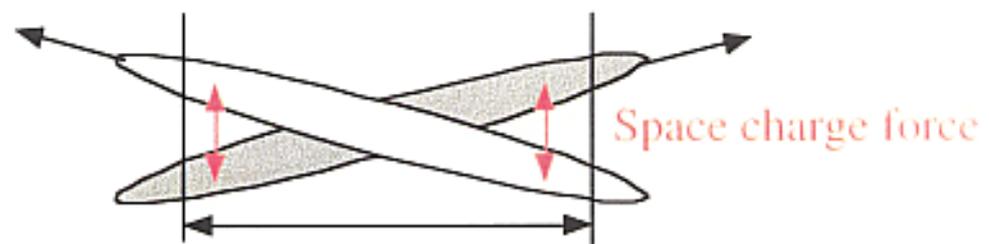
- Super-bunch is VERY LONG !! (450m is planned at VLHC)

Advantage -> High Luminosity

Conventional Hadron Collider : $10^{34} / \text{cm}^2 \text{s}$

Super-bunch Hadron Collider : $1.5 \times 10^{35} \text{cm}^2 / \text{s}$
(Calculated by K. Takayama)

Issue



One super-bunch is exposed to space charge force from the other super-bunch in LONG TIME.

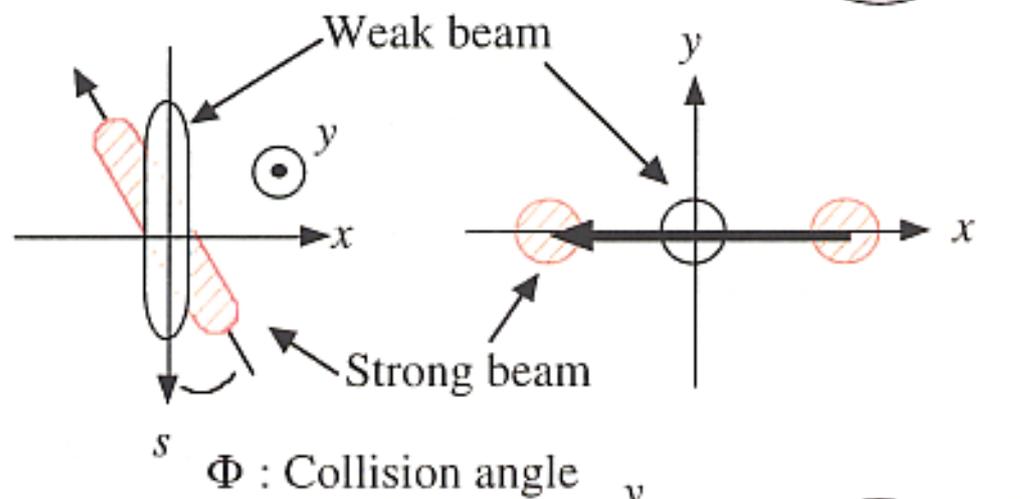
-> Beam-beam effects in **Super-bunch collision** is crucial to realize **Super-bunch Hadron Collider**.

[Our WORK]

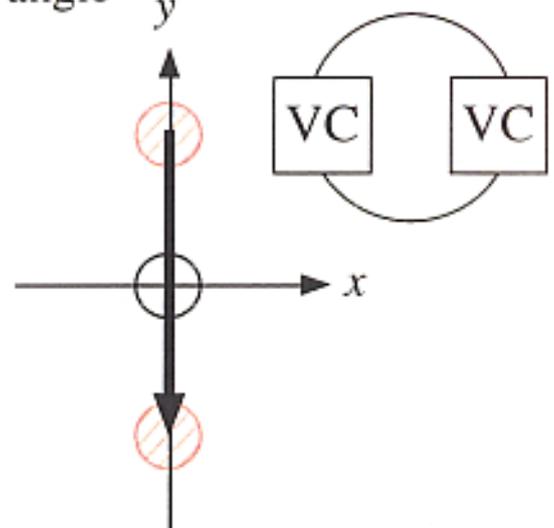
Beam-beam effects have been examined, based on a **weak-strong model** in 4 types of super-bunch crossing .

[Crossing Geometries]

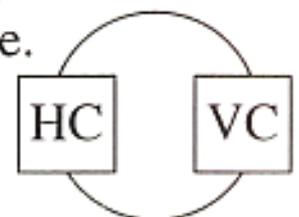
1. Horizontal Crossing (HC).



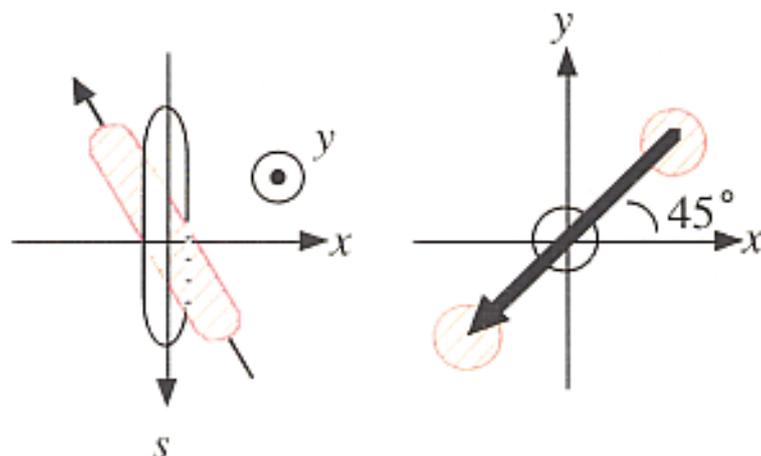
2. Vertical Crossing (VC)



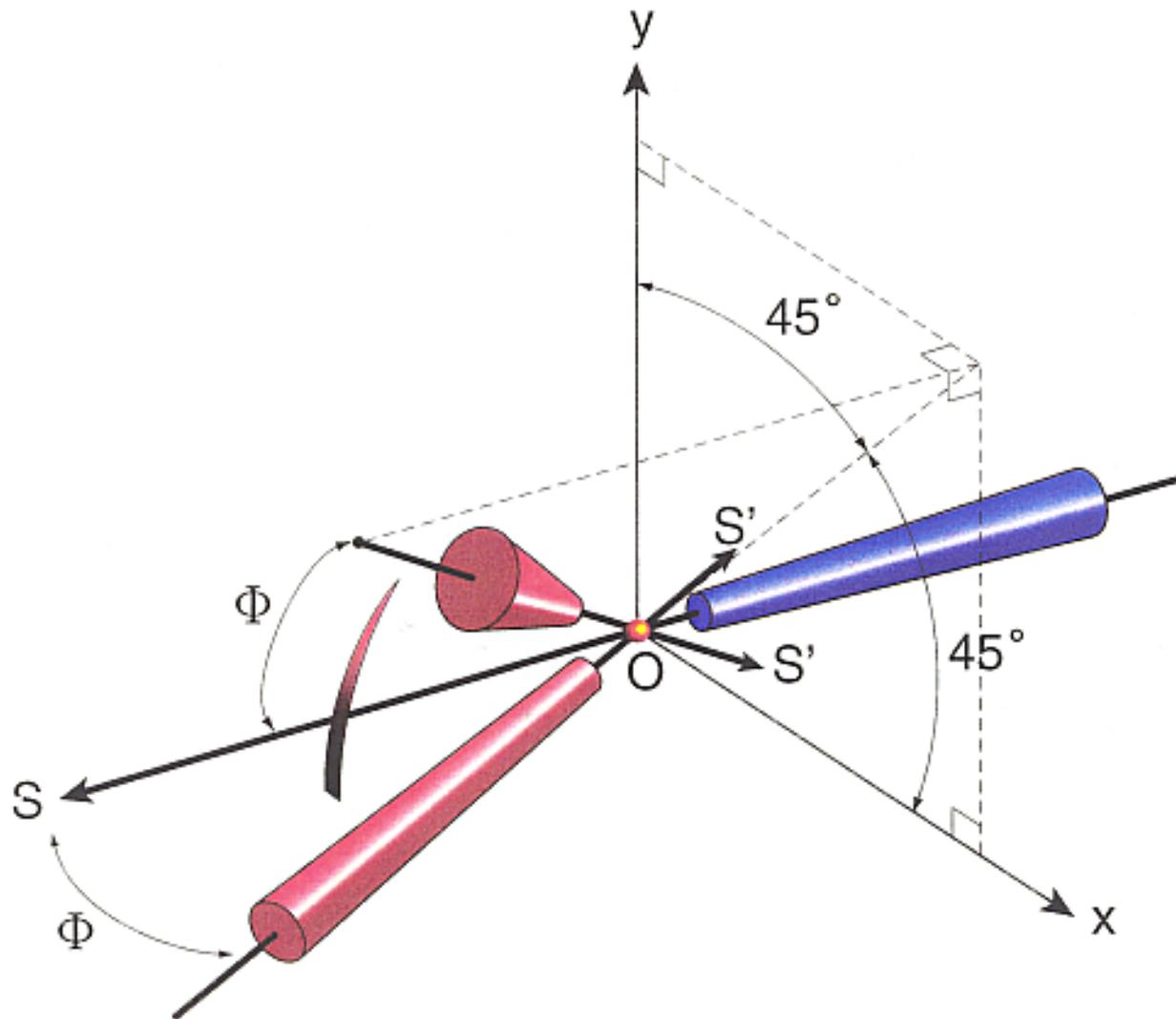
3. Hybrid Crossing (HyC) (or Mixed Crossing)
-> HC in one side + VC in the other side.



4. Inclined Hybrid Crossing (IHyC).



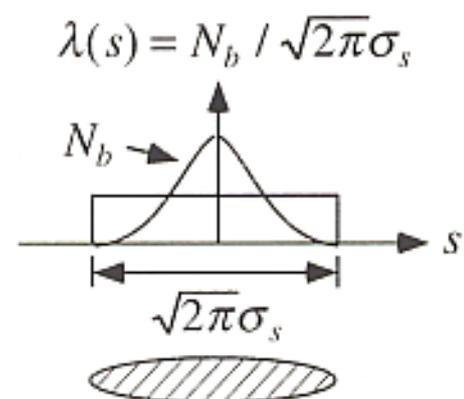
Horizontal Crossing & Inclined Crossing



[Model & Parameters for Simulation]

- 2D Round Gaussian beam.
- Weak-Strong model.
- A particle is tracked by transfer matrix and space charge kick every 10cm.
- LHC's Parameters are examined.

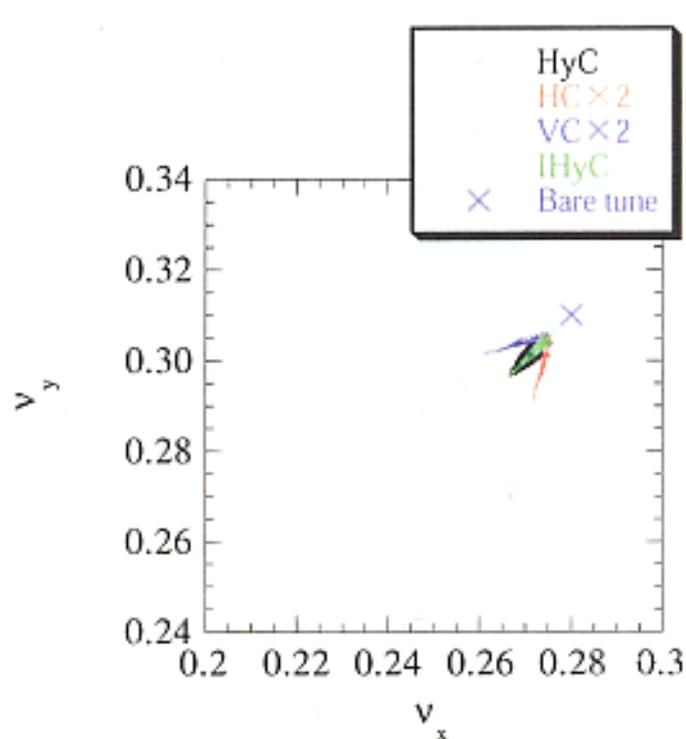
Collision angle, Φ	200	μrad
Interaction region, $2l_{\text{int}}$	50	m
RMS normalized emittance, ϵ_n	3.75	$\pi \text{ mm mrad}$
Bare tune	(68.28, 63.31)	
Line density, N	5×10^{11}	particle/m
Lorentz factor, γ	7460	
β^*	0.5	m



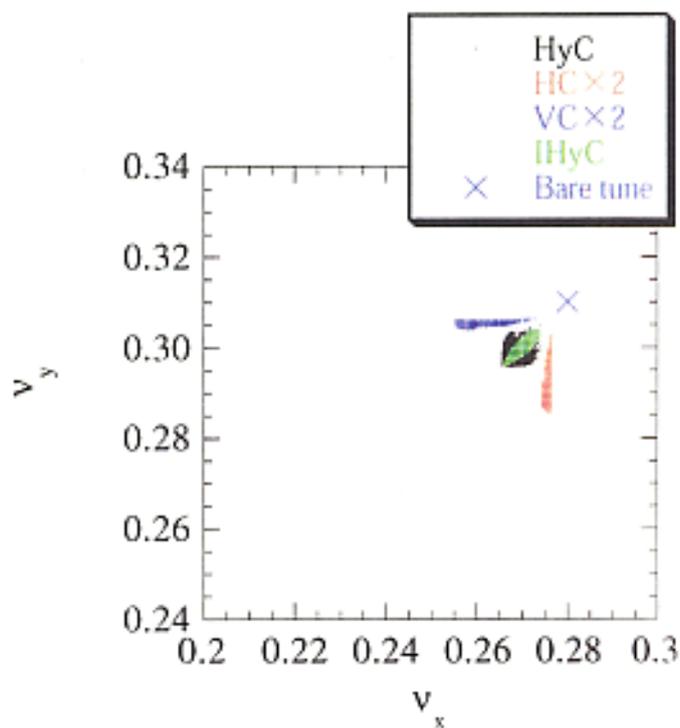
RF bunch @ LHC

[Footprints on the tune diagram - Short interaction region]

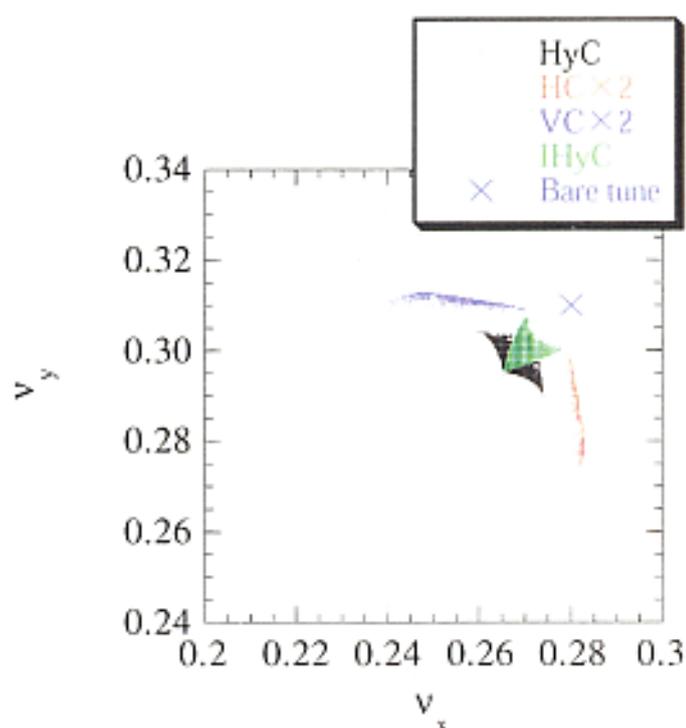
$\Phi = 200 \mu\text{rad}$, (68.28, 63.31)



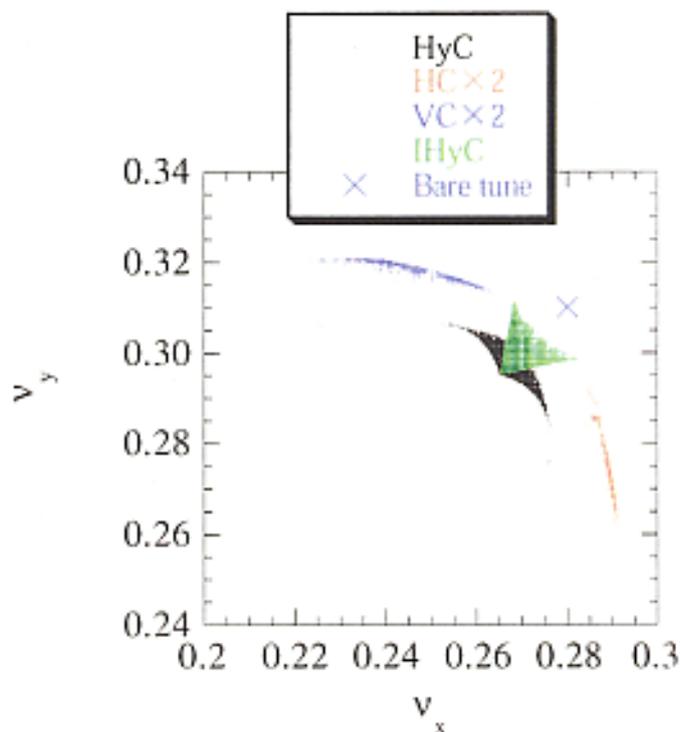
$2l_{\text{int}} = 0.4$ [m]



$2l_{\text{int}} = 0.8$ [m]



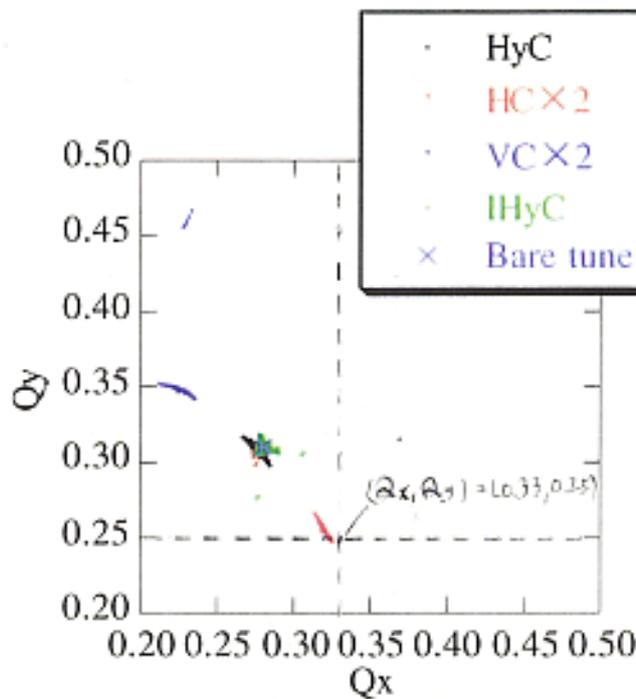
$2l_{\text{int}} = 2$ [m]



$2l_{\text{int}} = 4$ [m]

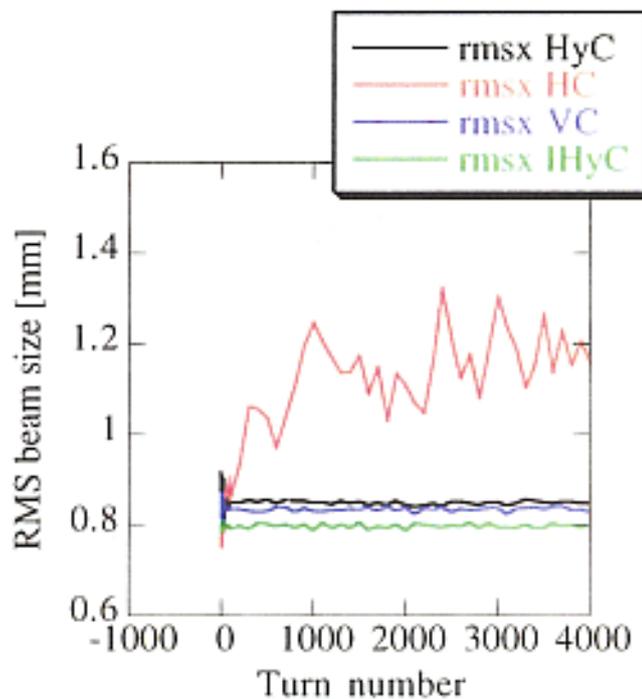
[Long interaction region 1]

$2l_{int} = 50\text{ m}$, $\Phi = 400\ \mu\text{rad}$, (68.28, 63.31).

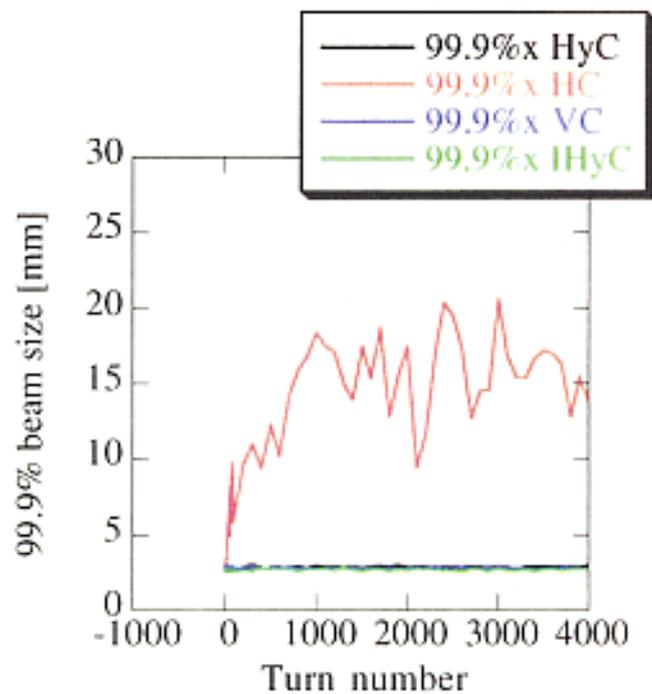


HyC or IHyC is indispensable to suppress beam-beam effects in super-bunch collision.

Footprints on the tune diagram
 $2k_{int} = 50\text{m}$, $\Phi = 400\ \mu\text{rad}$



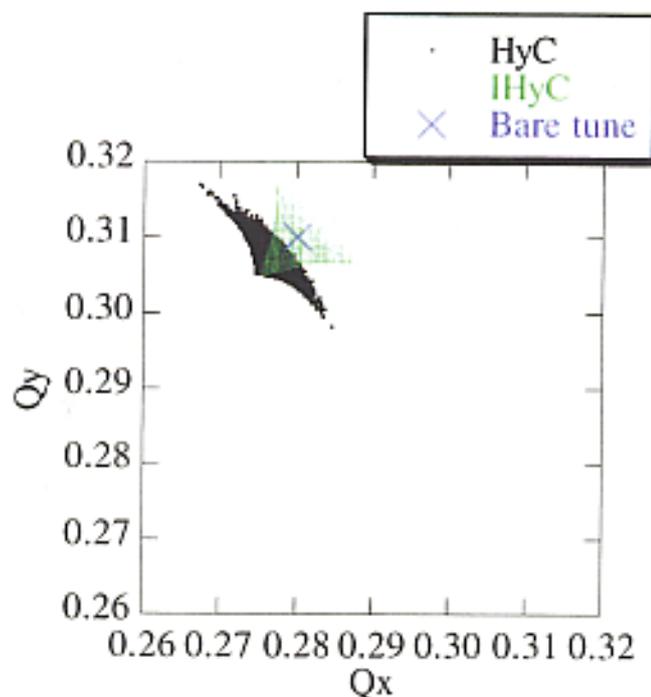
Horizontal rms beam size
 $2l_{int} = 50\text{m}$, $\Phi = 400\ \mu\text{rad}$



Horizontal 99.9% beam size
 $2l_{int} = 50\text{m}$, $\Phi = 400\ \mu\text{rad}$

[Long interaction region 2]

$2 l_{\text{int}} = 50 \text{ m}$, $\Phi = 400 \mu\text{rad}$, (68.28, 63.31).



Footprints on the tune diagram
 $2k_{\text{int}} = 50\text{m}$, $\Phi = 400\mu\text{rad}$

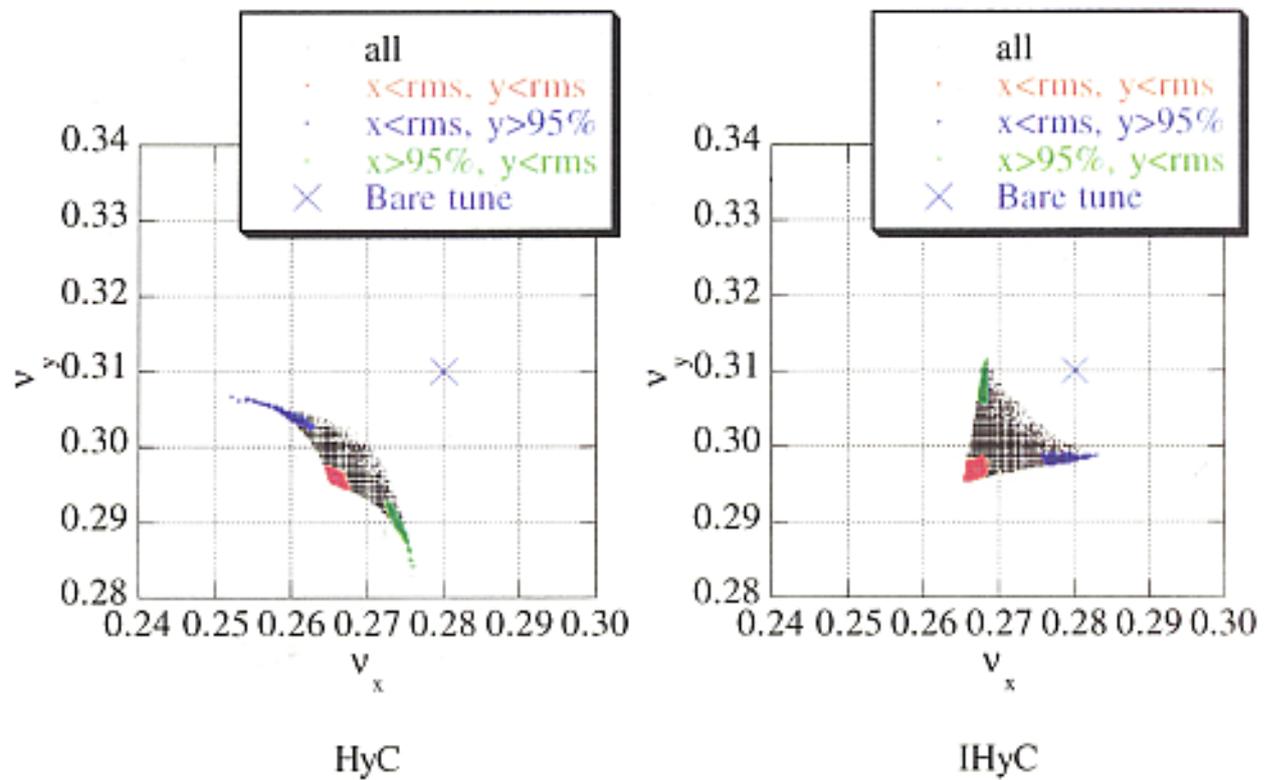
By the way....

Why is footprints like

bird-wing shape (HyC)?

fish-tail fin shape (IHyC)?

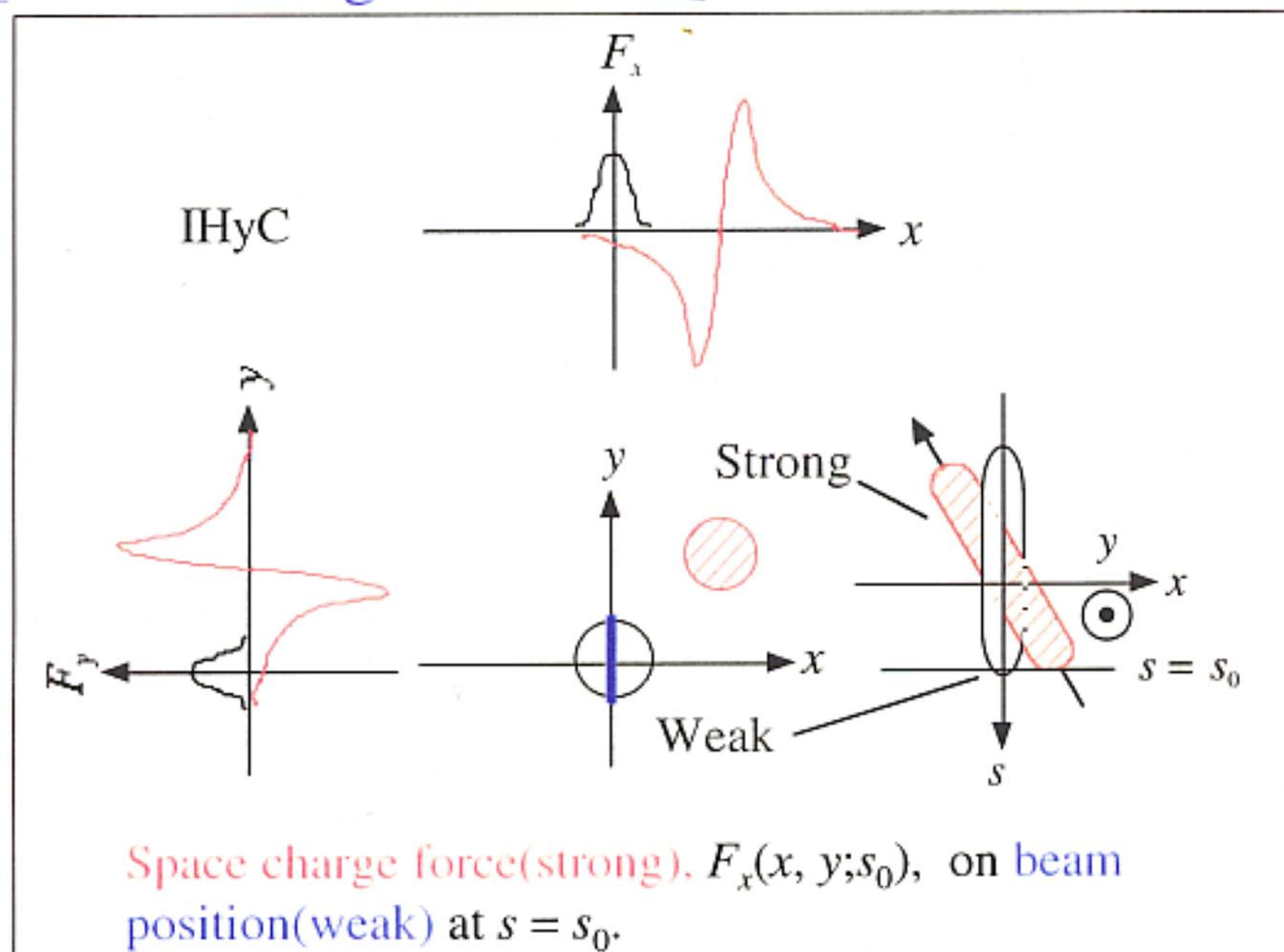
[Dependence of footprints on emittance]



$$2 l_{\text{int}} = 4 \text{ m}, \Phi = 200 \mu\text{rad}, (68.28, 63.31).$$

Footprints can be illustrated by those of particles with $(\epsilon_x, \epsilon_y) = (0, 0), (0, 9\epsilon_{\text{rms}})$ and $(9\epsilon_{\text{rms}}, 0)$.

[Time-averaged K value]



Perturbed betatron equation for particles with $(\epsilon_x, \epsilon_y) = (0, 0), (0, 9\epsilon_{rms})$ of weak beam

$$x'' = F_x(0, y; s)$$

$F_x(x, y; \eta)$ is Taylor expanded; then the linear term for x is remained

$$x'' - \frac{\partial F_x(0, y; s)}{\partial x} x = 0$$

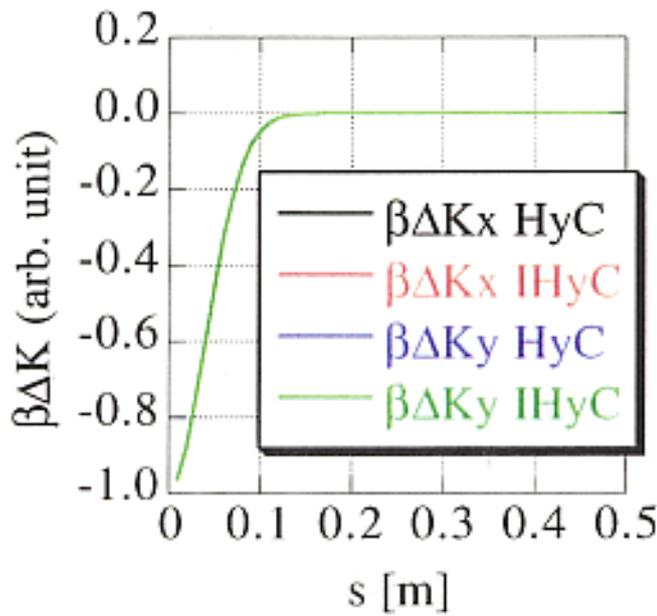
After time-averaging over many turns

$$\Delta v_x \propto \int_0^{int} \beta(s) \Delta K_x(s) ds$$

$$\Delta K_x(s) = -\frac{1}{y_{max} - y_{min}} \int_{y_{min}}^{y_{max}} \frac{\partial F_x(0, y; \eta)}{\partial x} dy$$

[Tune shift for particle with $(\epsilon_x, \epsilon_y) = (0, 0)$]

$2 l_{int} = 4 \text{ m}, \Phi = 200 \mu\text{rad}, (68.28, 63.31).$

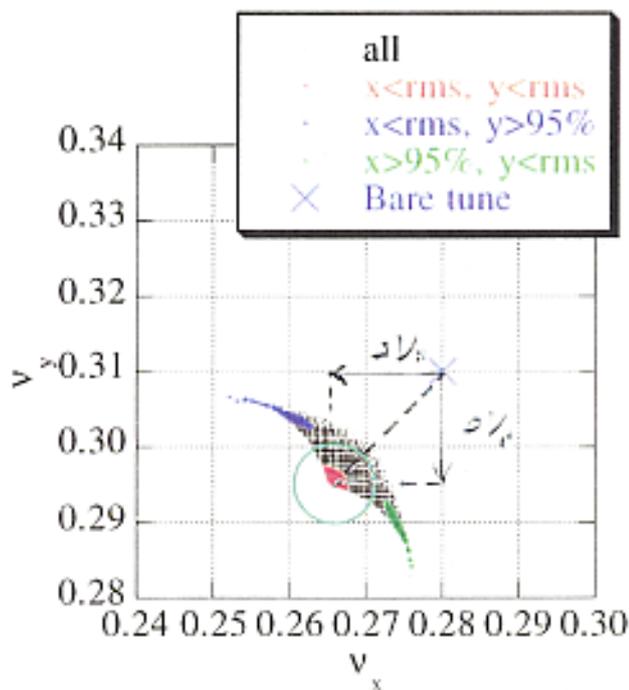


$$\begin{aligned} x'' + \Delta K_x x &= 0 \\ y'' + \Delta K_y y &= 0 \end{aligned}$$

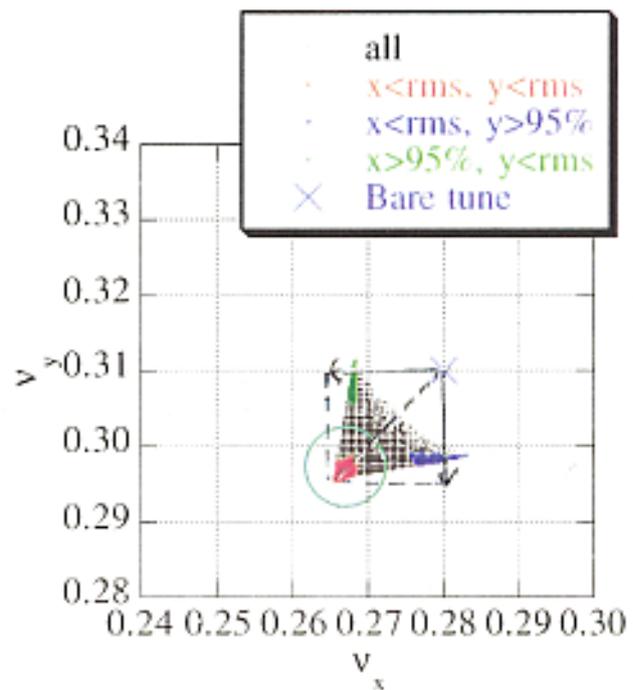
$\Delta K_x = \Delta K_y$ for both crossing.

$\rightarrow \Delta v_x = \Delta v_y$ for both crossing.

$\beta\Delta K_x, \beta\Delta K_y$
 $(\epsilon_x, \epsilon_y) = (0, 0)$



HyC

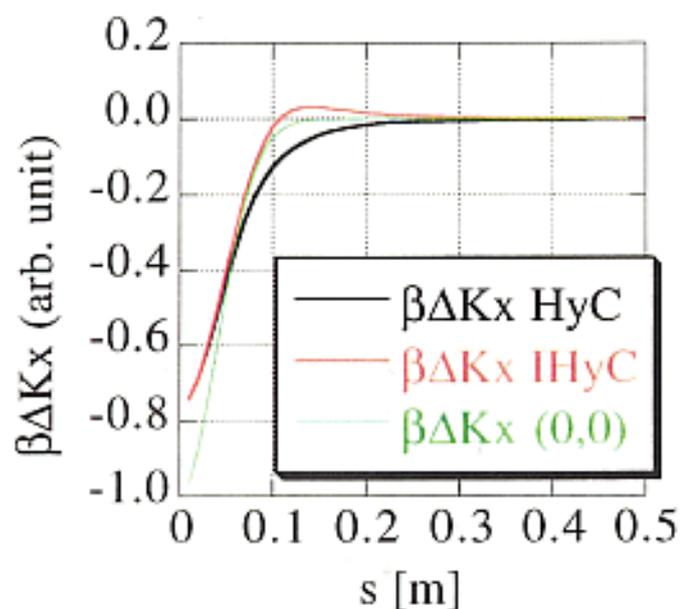


IHyC

[Horizontal tune shift for particle

with $(\epsilon_x, \epsilon_y) = (0, 9\epsilon_{rms})$

$2 l_{int} = 4 \text{ m}, \Phi = 200 \mu\text{rad}, (68.28, 63.31).$



$$\Delta\nu \propto \int_0^{l_{int}} \beta\Delta K ds$$

$$\beta(s) = \beta^* + \frac{s^2}{\beta^*}$$

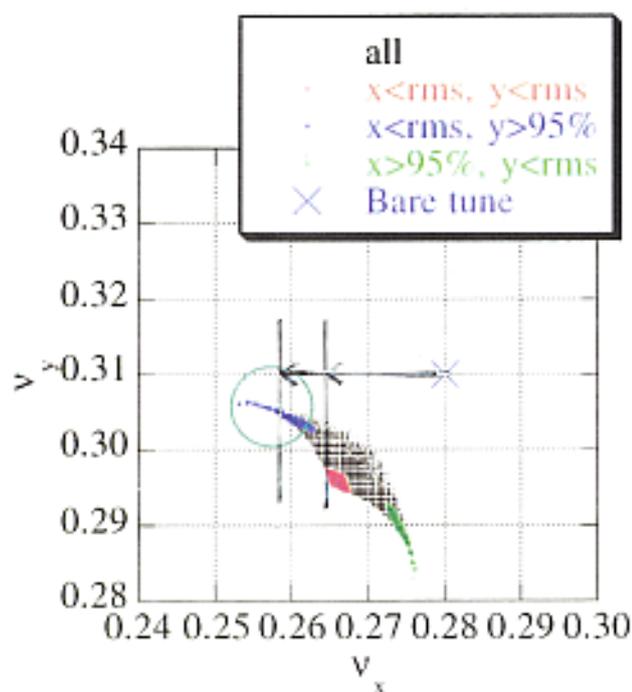
$$\int_0^{l_{int}} \beta\Delta K_x(\text{HyC}) ds > \int_0^{l_{int}} \beta\Delta K_x(0,0) ds$$

$$\cong 5.04 \quad \cong 4.49$$

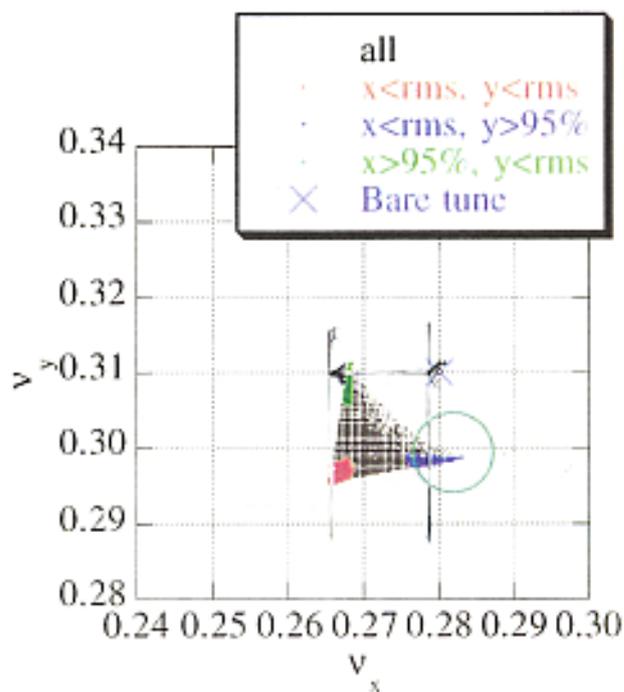
$$> \int_0^{l_{int}} \beta\Delta K_x(\text{IHyC}) ds$$

$$\cong 2.27$$

$\beta\Delta K_x$
 $(\epsilon_x, \epsilon_y) = (0, 9\epsilon_{rms})$



HyC

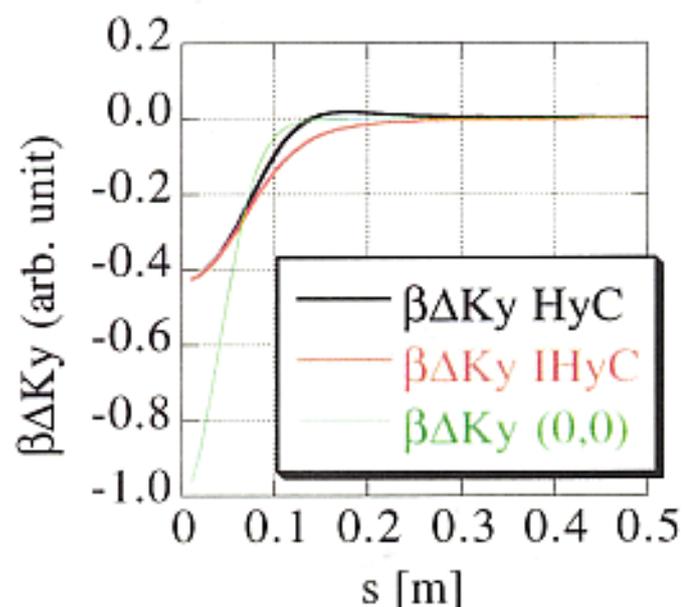


IHyC

[Vertical tune shift for particle

with $(\epsilon_x, \epsilon_y) = (0, 9\epsilon_{rms})]$

$2 l_{int} = 4 \text{ m}, \Phi = 200 \mu\text{rad}, (68.28, 63.31).$



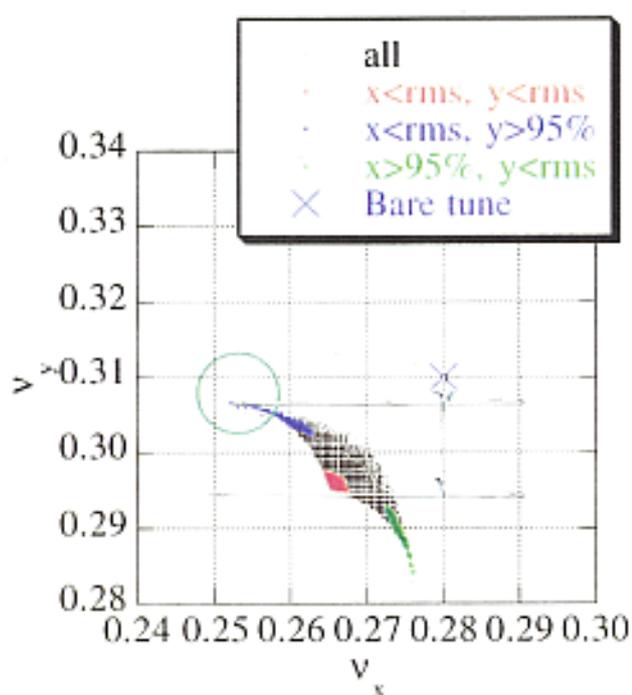
$$\int_0^{l_{int}} \beta\Delta K_y(0,0)ds > \int_0^{l_{int}} \beta\Delta K_y(\text{IHyC})ds$$

$$\cong 4.49 \qquad \cong 3.06$$

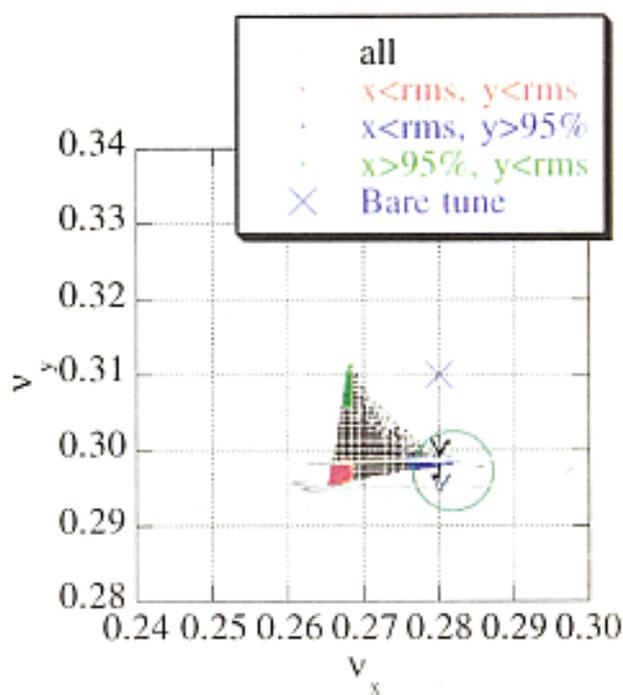
$$> \int_0^{l_{int}} \beta\Delta K_y(\text{HyC})ds$$

$$\cong 1.77$$

$\beta\Delta K_y$
 $(\epsilon_x, \epsilon_y) = (0, 9\epsilon_{rms})$



HyC



IHyC

[Summary]

- Beam-beam effects for 4 types of super-bunch crossing have been examined based on the weak-strong model.
- It turned out that choice of HyC or IHyC is crucial to suppress beam-beam effects in super-bunch collision.
- Footprints of HyC and IHyC have been calculated. Behavior of extreme particles $(\epsilon_x, \epsilon_y) = (0, 0), (0, 9\epsilon_{\text{rms}})$ has been manifested.

[Next step]

- Strong-strong model should be developed as soon as possible for more precise estimation .