

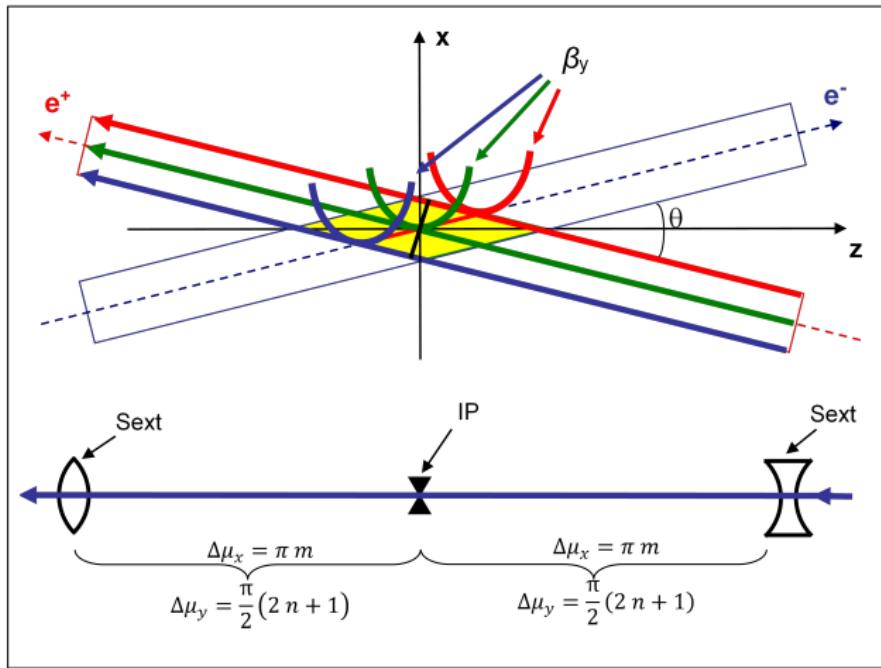
# Review of interaction regions for crab waist colliders

A. Bogomyagkov, E. Levichev

Budker Institute of Nuclear Physics  
Novosibirsk

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# Crab waist [P. Raimondi 2006, tested at DAΦNE]



$$\varphi = \frac{\sigma_z}{\sigma_x^*} \tan\left(\frac{\theta}{2}\right)$$

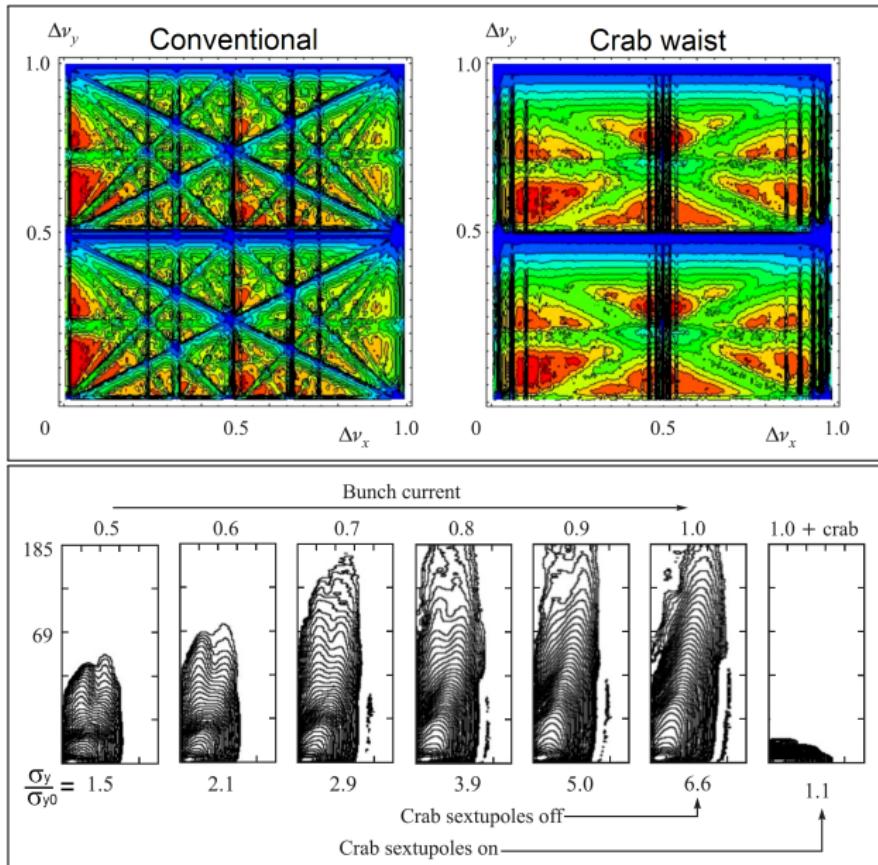
$$L \propto \frac{N\xi_y}{\beta_y^*}$$

$$\xi_y \propto \frac{N\beta_y^*}{\sigma_x^*\sigma_y^*\sqrt{1+\varphi^2}}$$

$$\xi_x \propto \frac{N}{\epsilon_x(1+\varphi^2)}$$

$$K2L[m^{-2}] = \pm \frac{1}{\theta\beta_y^*\beta_y} \sqrt{\frac{\beta_x^*}{\beta_x}}.$$

# Beam-beam resonances [D. Shatilov (lifetrak)]



# Crab waist: summary

## Requirements

- ① large Piwinski angle (small  $\sigma_x^*$ , large  $\theta$ ),
- ② small vertical beta function ( $\beta_y^* \sim \sigma_x^*/\theta \lesssim 1$  mm),
- ③ the sextupoles with proper phase advance and strength.

## Benefits

- ① higher luminosity ( $\times 10 \div 100$ ) for similar beam current and length,
- ② suppression of BB coupling resonances, more freedom for working point.

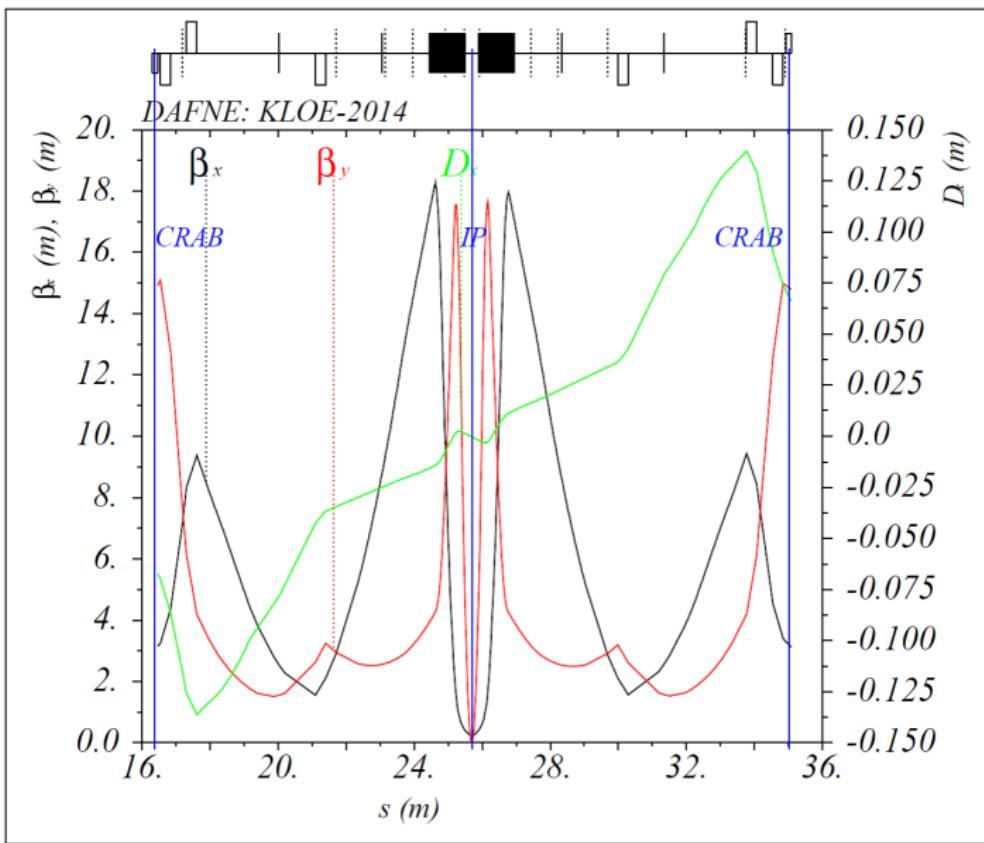
## Difficulties

- ① complex MDI and FF magnets,
- ② raise of linear and nonlinear chromaticities,
- ③ dynamic aperture degradation.

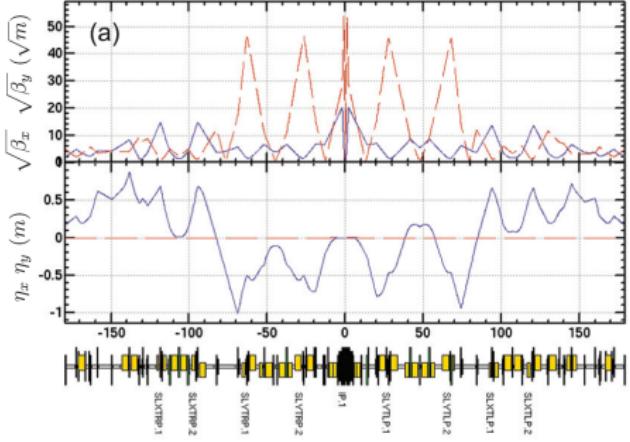
# Present colliders DAΦNE and SuperKEKB

	DAΦNE	SuperKEKB	
Run or ring	SIDDHARTA	LER	HER
Energy, GeV	0.51	4	7.007
Circumference, m	97.69	3016.315	
$\varepsilon_x/\varepsilon_y$ , nm/pm	250/750	3.2/8.64	4.6/12.9
$\beta_x^*/\beta_y^*$ , mm	250/9.3	32/0.27	25/0.3
Crossing angle, mrad	50	83	
$\sigma_z$ , mm	17	6	5
Piwinski angle $\varphi$	1.7	25	19
Beam current $e^-/e^+$ , A	2.45/1.4	3.6	2.6
Beam beam tune shift $\xi_y$	0.03	0.088	0.08
$\mu'_y$	-61	-5400	-5400
Luminosity, $\text{cm}^{-2}\text{s}^{-1}$	Achieved $4.5 \times 10^{32}$	Design $8 \times 10^{35}$	
Luminosity gain	$\times 3$	$\times 40$	

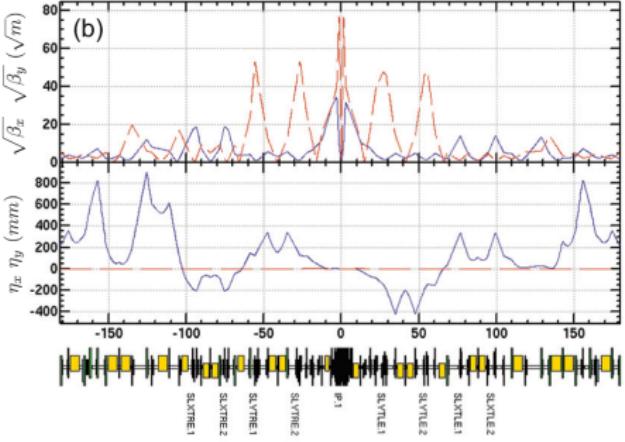
# DAΦNE interaction region



# SuperKEKB interaction region

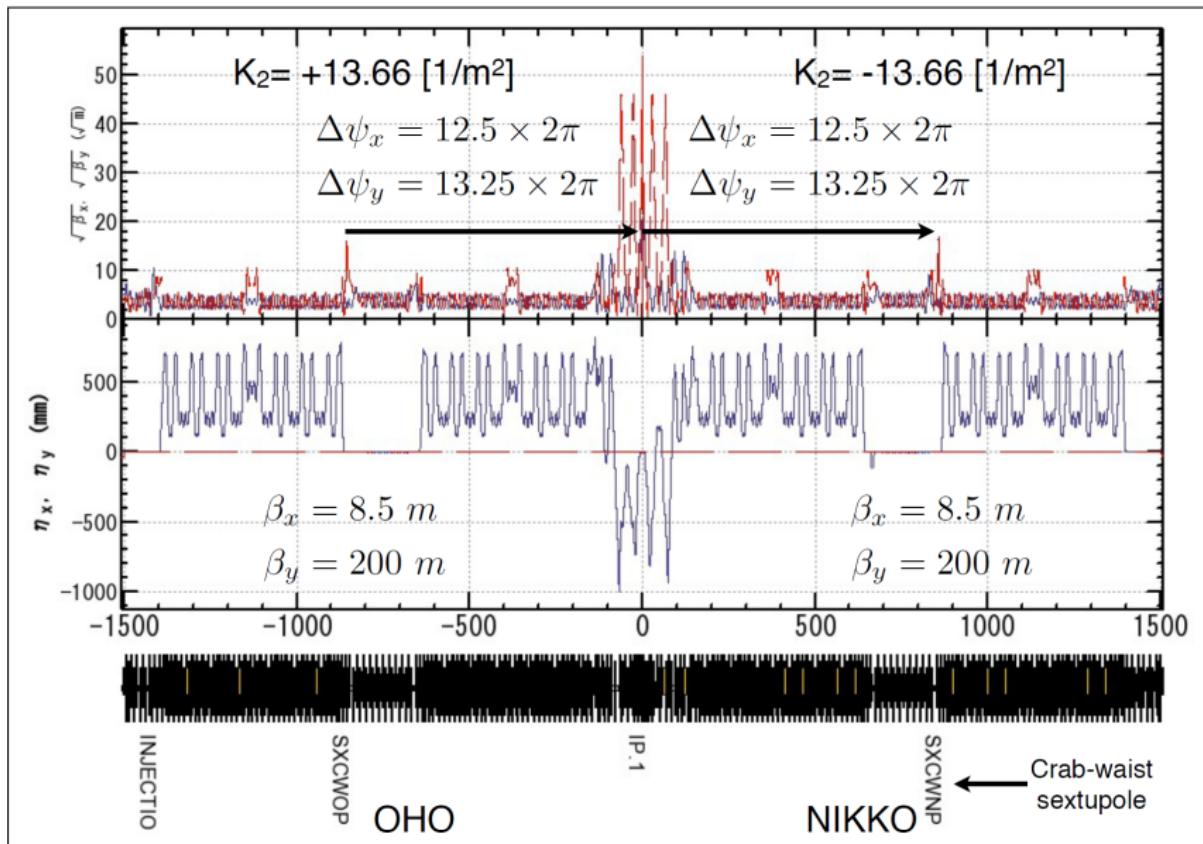


LER

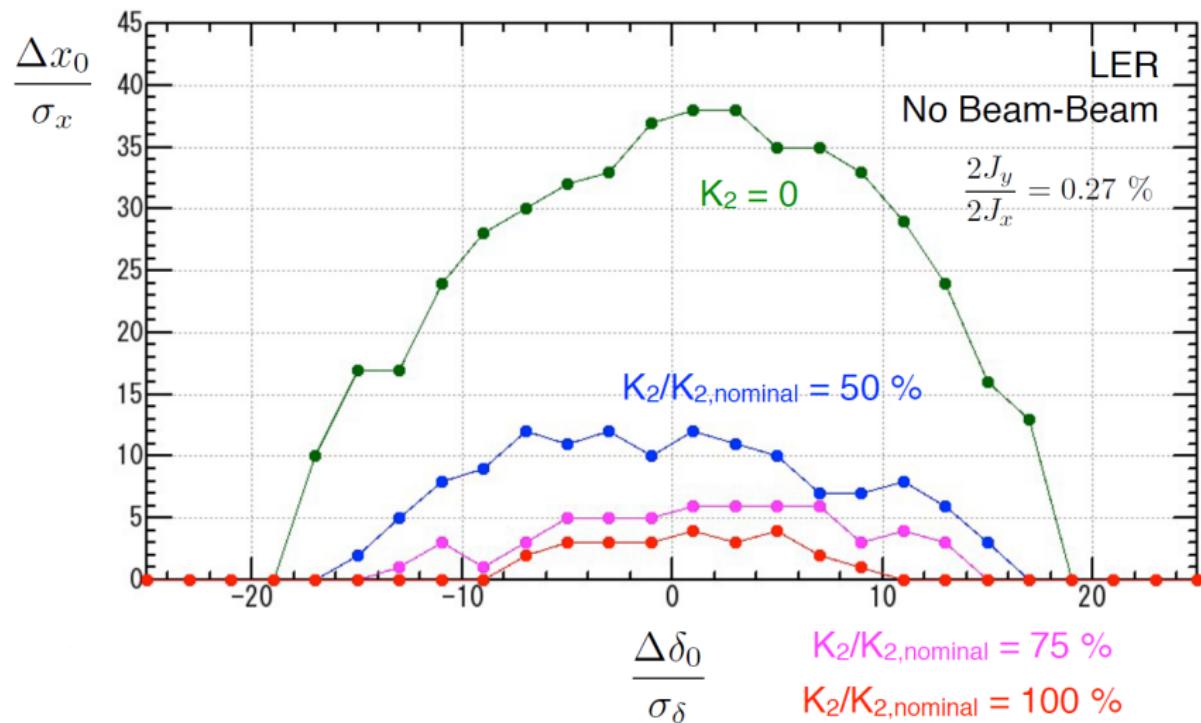


HER

# SuperKEKB crab sextupoles (not installed)



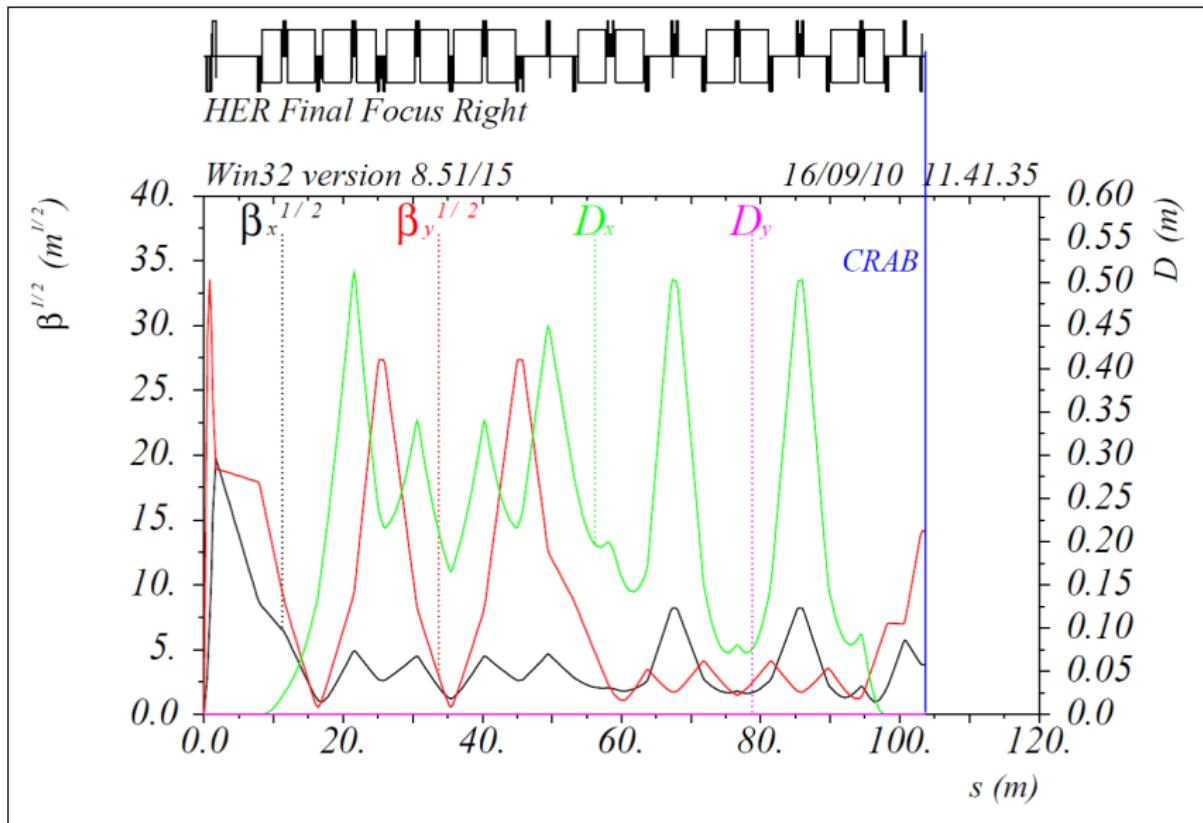
# Dynamic aperture SuperKEKB



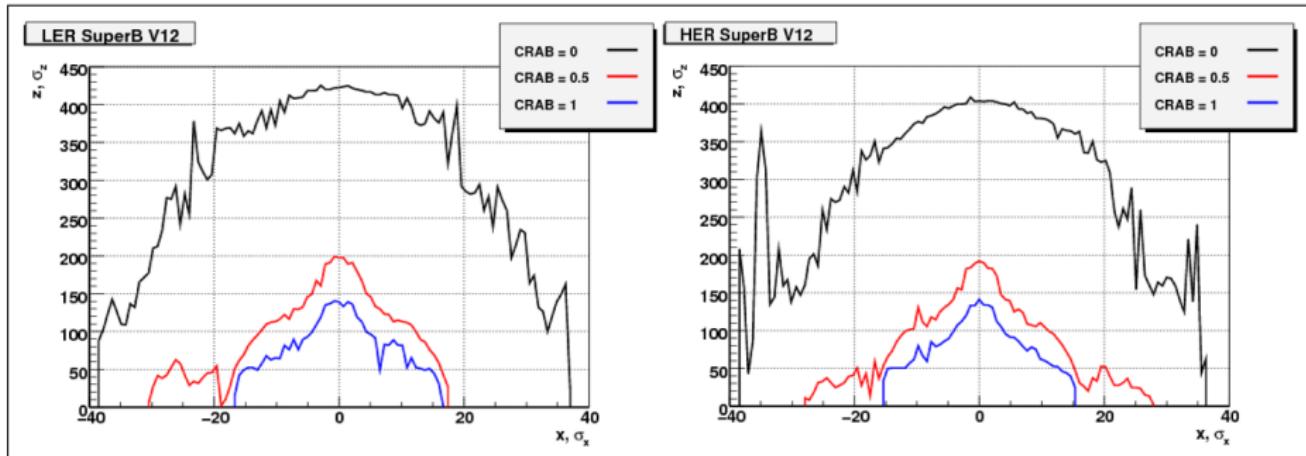
# Projects: SuperB

	SuperB	
Run or ring	LER	HER
Energy, GeV	4.18	6.7
Circumference, m	1258.4	
$\varepsilon_x/\varepsilon_y$ , nm/pm	2.46/6.15	2/5
$\beta_x^*/\beta_y^*$ , mm	32/0.205	26/0.253
Crossing angle, mrad	66	
$\sigma_z$ , mm	5	5
Piwinski angle $\varphi$	19	23
Beam current, A	2.4	1.9
Beam beam tune shift $\xi_y$	0.097	0.097
$\mu'_y$	-1068	-1056
Luminosity, $\text{cm}^{-2}\text{s}^{-1}$	$1 \times 10^{36}$	

# SuperB interaction region (HER)



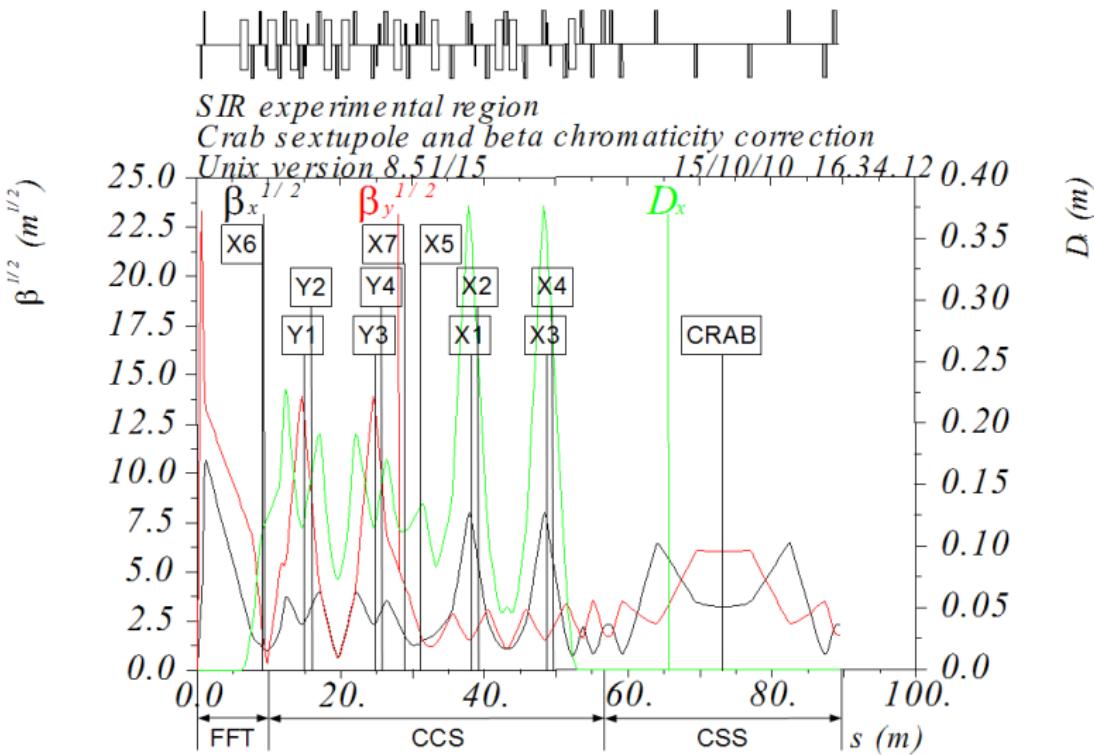
# Dynamic aperture SuperB [P. Piminov]



# Projects: CTau (Novosibirsk)

	CTau			
Energy, GeV	1	1.5	2	2.5
Circumference, m	813.4			
$\varepsilon_x/\varepsilon_y$ , nm/pm	8/40			
$\beta_x^*/\beta_y^*$ , mm	40/0.8			
Crossing angle, mrad	60			
$\sigma_z$ , mm	16.5	11	10	10
Piwinski angle $\varphi$	27	19	17	17
Beam current, A	1.65			
Beam beam tune shift $\xi_y$	0.15	0.15	0.12	0.1
$\mu'_y$	-697			
Luminosity, $\text{cm}^{-2}\text{s}^{-1}$	$0.6 \times 10^{35}$	$0.9 \times 10^{35}$	$1 \times 10^{35}$	$1 \times 10^{35}$

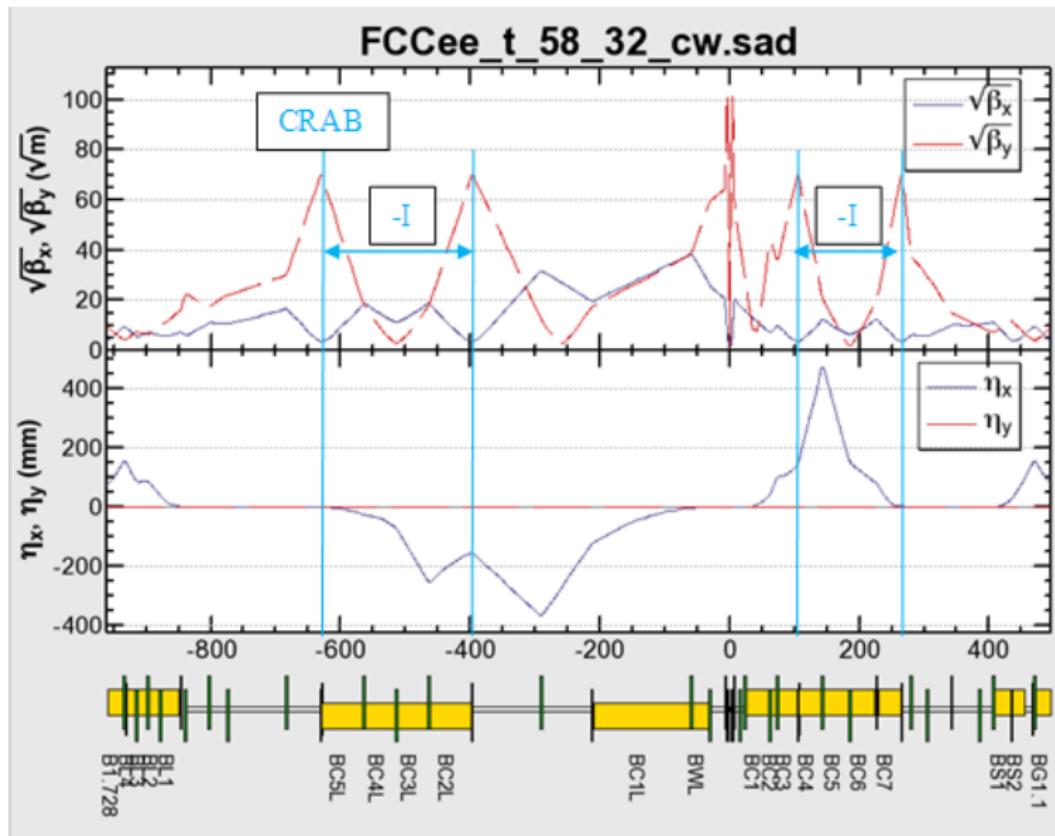
# Interaction region CTau



# Projects: FCCee

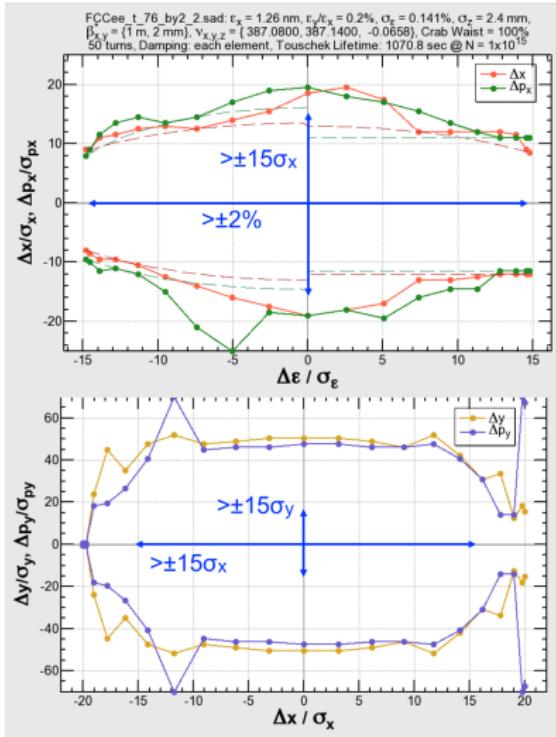
	FCC-ee			
Experiment	Z	W	H	tt
Energy, GeV	45	80	120	175
Circumference, m	$100 \times 10^3$			
$\varepsilon_x/\varepsilon_y$ , nm/pm	0.14/1	0.44/2	1/2	2.1/4.3
$\beta_x^*/\beta_y^*$ , mm	500/1			
Crossing angle, mrad	30			
$\sigma_z$ , mm	5.9	9.1	8.2	6.6
Piwinski angle $\varphi$	11	9	6	3
Beam current, A	1.4	1.4	0.3	0.06
Beam beam tune shift $\xi_y$	0.175	0.187	0.16	0.08
$\mu'_y$	-2805			
Luminosity, $\text{cm}^{-2}\text{s}^{-1}$	$211 \times 10^{34}$	$36 \times 10^{34}$	$9 \times 10^{34}$	$1.3 \times 10^{34}$

## Interaction region FCC-1 [K. Oide]

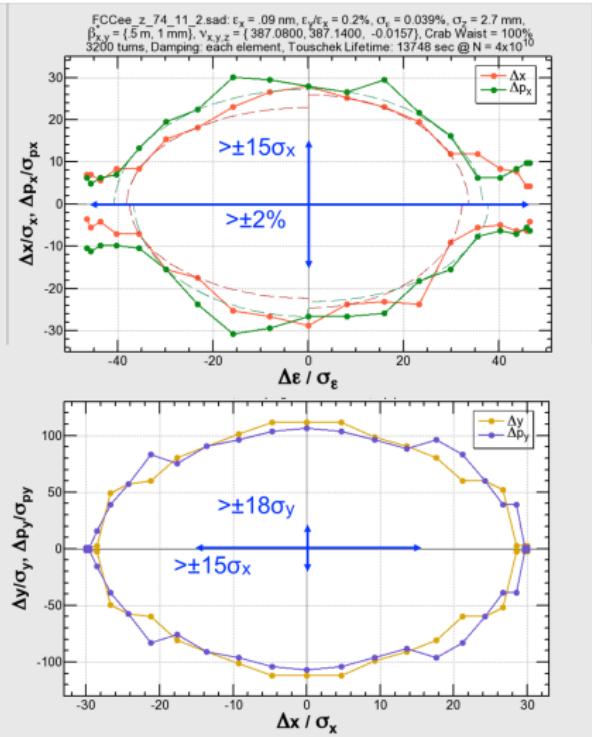


# Dynamic aperture FCC-1 [K. Oide]

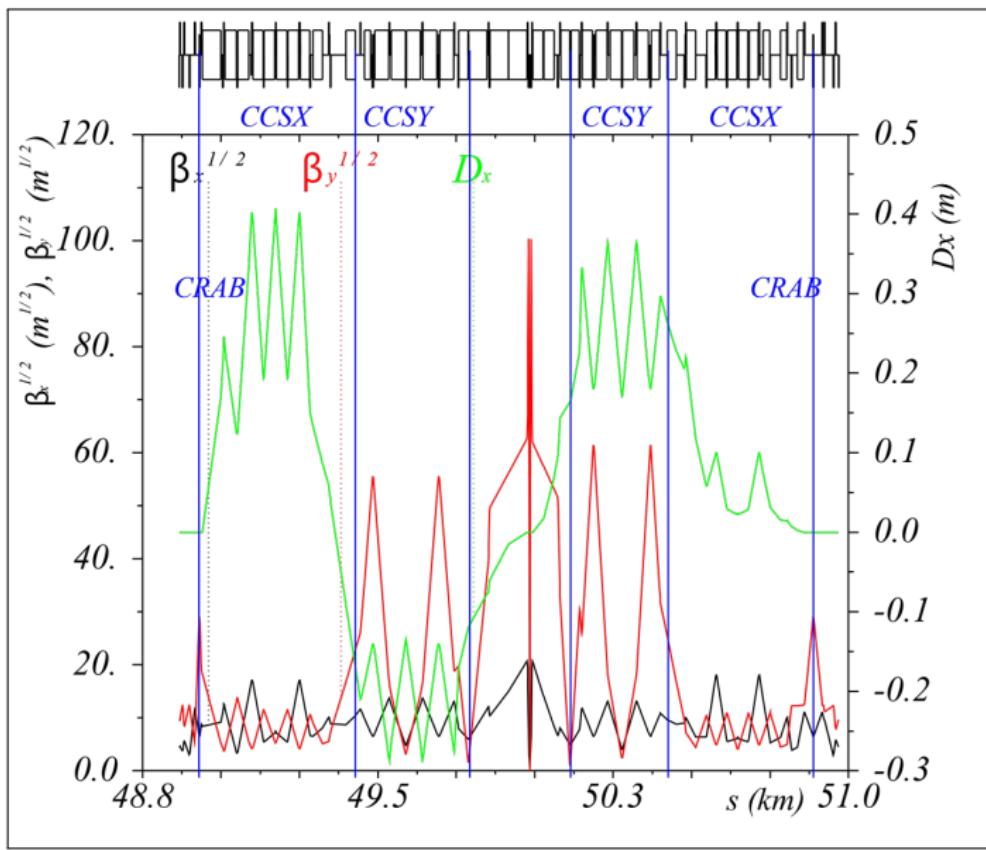
175 GeV,  $\beta^*_{x,y} = (1 \text{ m}, 2 \text{ mm})$



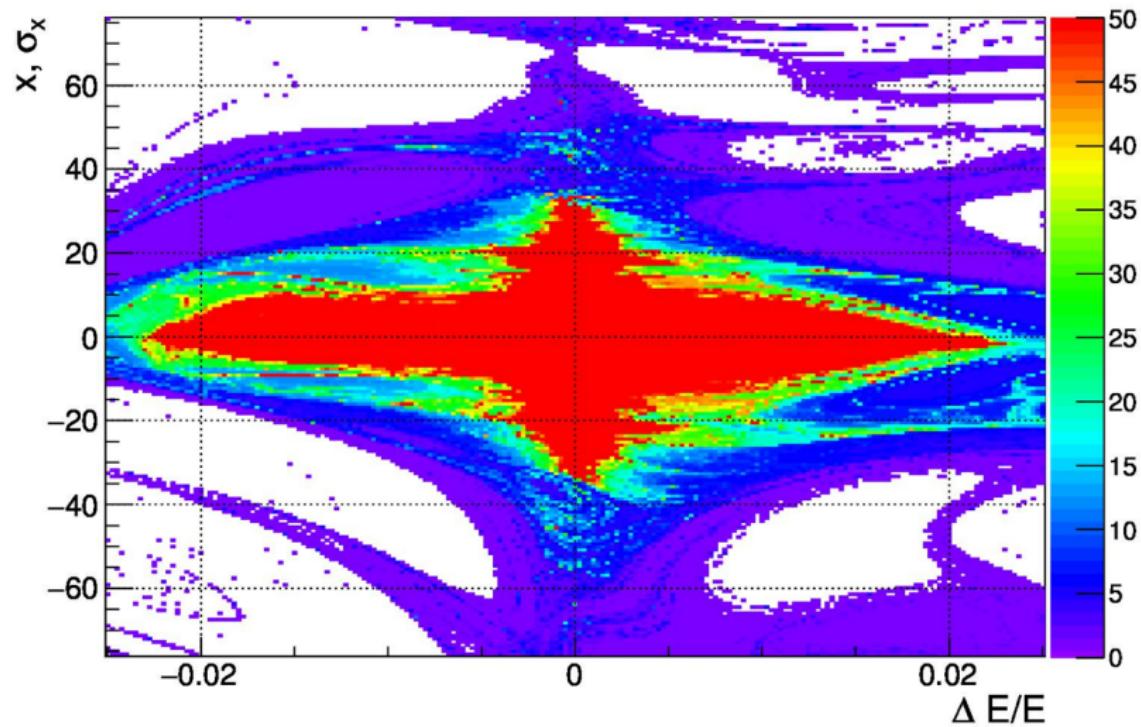
45.6 GeV,  $\beta^*_{x,y} = (0.5 \text{ m}, 1 \text{ mm})$



# Interaction region FCC-2



# Dynamic aperture FCC-2 [P. Piminov]



# Detuning coefficients: $\Delta\nu_y = \alpha_{yy}J_y + \alpha_{xx}J_x$

Quadrupole of length  $L_q$ :

$$K1L[m^{-1}] = -\frac{2}{L^* + L_q/2}.$$

Chromaticity by FF quadrupole:

$$\mu'_y = \frac{1}{2} \sum_i K1L_i \beta_{i,y}.$$

Kinematic:  $H = \frac{(P_x^2 + P_y^2)^2}{8}$ ,  $\alpha_{yy}^k \approx \frac{3}{16\pi} \frac{L^* + L_q/2}{\beta_y^{*2}}$ .

Fringe:  $H \approx -K1'' \frac{(x^4 - y^4)}{48}$ ,  $\alpha_{yy}^f \approx \frac{1}{2\pi} \frac{L^{*3}}{L_q(L^* + L_q/2)\beta_y^{*2}}$ .

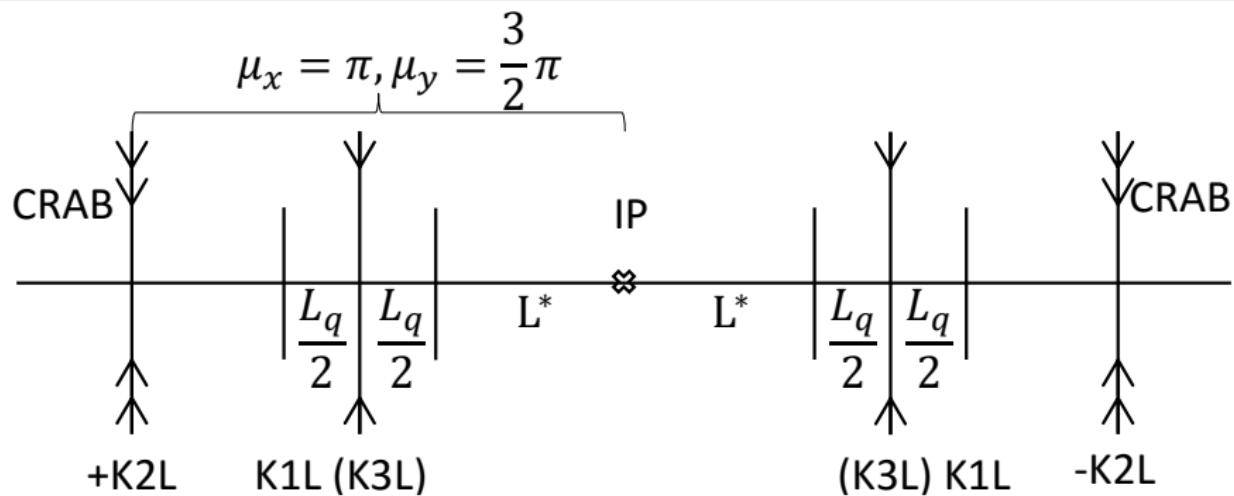
-I sextupole pair:

$$\alpha_{yy}^s \approx -\frac{1}{16\pi} (K2L_s)^2 L_s \beta_{s,y}^2.$$

# Comparison of detuning coefficients

	$\mu'_y$	$\alpha_{yy}^k [m^{-1}]$	$\alpha_{yy}^f [m^{-1}]$	$\alpha_{yy}^s [m^{-1}]$
DAΦNE	-61	694	218	
SuperKEKB	-5400	$1.8 \times 10^6$	$9.8 \times 10^6$	$-7 \times 10^5$
SuperB	-1060	$1 \times 10^6$	$2.8 \times 10^5$	$-5.4 \times 10^6$
CTau	-700	$1.3 \times 10^5$	$7.7 \times 10^5$	$-7.2 \times 10^5$
FCC-2	-2800	$4.5 \times 10^5$	$1.9 \times 10^5$	$-1.2 \times 10^7$

# Map calculation layout



# Comparison of maps coefficients

$$x = V_{11111}x_0^4 + V_{11133}x_0^2y_0^2 + V_{13333}y_0^4$$

	$V_{11111}[m^{-3}]$	$V_{11133}[m^{-3}]$	$V_{13333}[m^{-3}]$
DAΦNE	-16500	$-5.5 \times 10^4$	$6.8 \times 10^3$
SuperKEB	-496	$-1.2 \times 10^6$	$1.2 \times 10^6$
SuperB	-980	$-6.5 \times 10^5$	$6.5 \times 10^5$
CTau	-1800	$-2.6 \times 10^6$	$2.6 \times 10^6$
FCC-2	-60	$-9.3 \times 10^3$	$9.4 \times 10^3$

# Observations over interaction regions

- ① High linear and nonlinear chromaticity, because of high beta values in final focus quadrupoles.
- ② Substantial influence of kinematic term and fringe fields of final focus quadrupoles on dynamic aperture.
- ③ Reduction of dynamic aperture due to interference of crab sextupoles with final focus quadrupole fringes and kinematic term.