Beam-Beam Effects for 4 IP

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Introduction

- Studies on 4 IP started recently and are in progress. The self-consistent list of parameter is not yet ready.
- In this presentation, we discuss the limitations that arise due to the beam-beam effects, propose parameter optimization and estimate achievable luminosity.
- The layout is assumed to be symmetrical, so that 2×2 bunches collide, and a quarter of the ring is a superperiod. This means that between each pair of neighboring IPs there is a straight section where the RF cavities and additional intersection without collision are located.
- Symmetrical scheme with 3 IP implies that 3×3 bunches are coupled, which can cause problems. Almost symmetrical scheme with 3 IP and 2×2 coupled bunches is possible: same as 4 IP, but one IP is missed (no collision, no detector). We will not discuss 3 IP here.

4 IP vs. 2 IP

- Changes in the lattice because of different layout: emittances, momentum compaction, DA, momentum acceptance, etc.

  Not yet taken into account, but these changes should be small – see the previous presentation by K. Oide. The goal now is to compare 4 IP and 2 IP, assuming the basic lattice parameters are the same.

- Do additional coherent instability modes appear in the collisions of 2×2 bunches?

  No additional modes were observed by two independent tracking codes. But these studies are not yet complete.

- Decrease in the synchrotron tune *per superperiod*. This is important for the coherent beam-beam instability and 3D flip-flop.

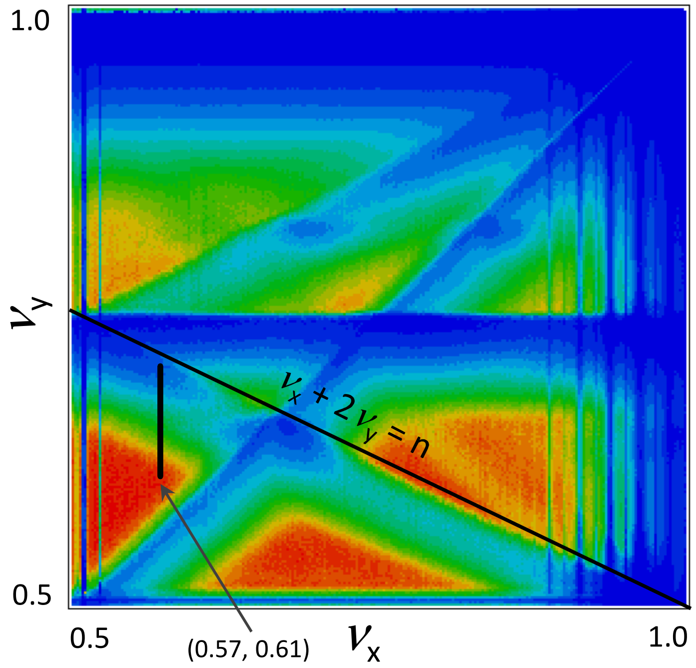
  This affects the choice of working point (betatron tunes). Besides, a decrease in β_x^* is required at low energy.

- Increase in the energy spread and bunch length due to intensified beamstrahlung. The negative consequences:

  1) With the same bunch population, luminosity per IP drops as $L \propto 1/\sigma_z$.
  2) Luminosity at high energies is limited by momentum acceptance. A decrease in the bunch population can be required to maintain acceptable lifetime, that also reduces the luminosity.

Parameter Optimization Issues

Old results for 2 IP at Z pole.

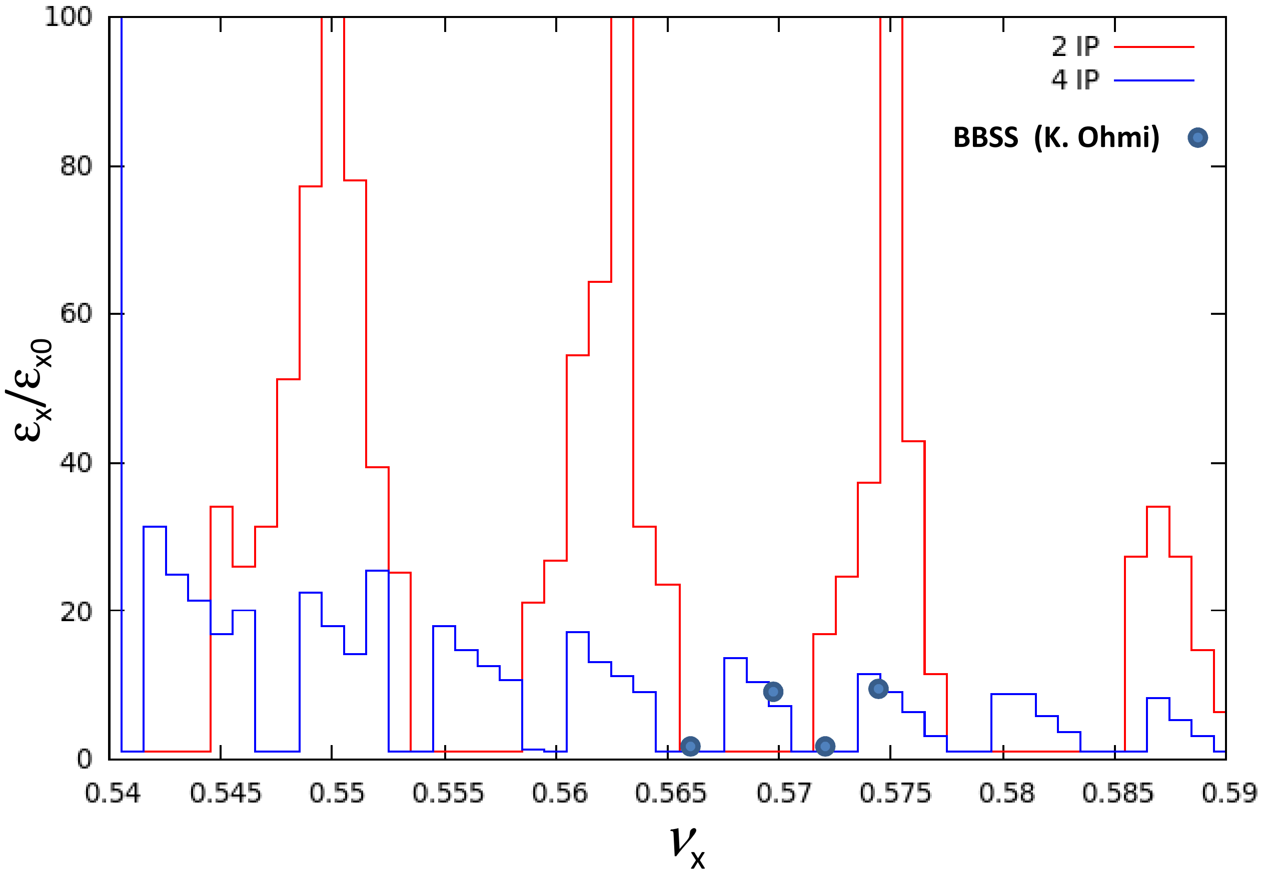


Luminosity vs. betatron tunes, simplified model, weak-strong simulations. Colors from zero (blue) to $2.3 \cdot 10^{36}$ cm^{-2}c^{-1} (red).

All tunes – per superperiod!

- The main problems (esp. at low energies) come from the coherent beam-beam instability and 3D flip-flop. Both effects are associated with the synchro-betatron resonances: $2\nu_x + 2k\nu_z = n$.
- Important parameter, which needs to be minimized: ξ_x / ν_z. Increase in RF voltage does not help!
- The major steps for mitigation of both instabilities:
  1) Increase in the momentum compaction factor: $\nu_z\uparrow$, $\sigma_z\uparrow$ => $\xi_x\downarrow$
  2) Decrease in β_x^* => $\xi_x\downarrow$
  3) Some increase in ν_x to increase the orders of synchro-betatron resonances. But we are limited here, if we want to achieve large ξ_y
  4) Decrease in RF voltage (and ν_z), which does not affect the ξ_x / ν_z ratio but decreases the order of synchro-betatron resonances.
- With 2 IP, luminosity is limited by ξ_y + asymmetry in the bunch population + large enough ν_x.
- With 4 IP, ν_z is halved while ξ_x is *slightly* decreased. Thus we have ξ_x / ν_z increased and the old problems came back…

Coherent Instability at 45.6 GeV

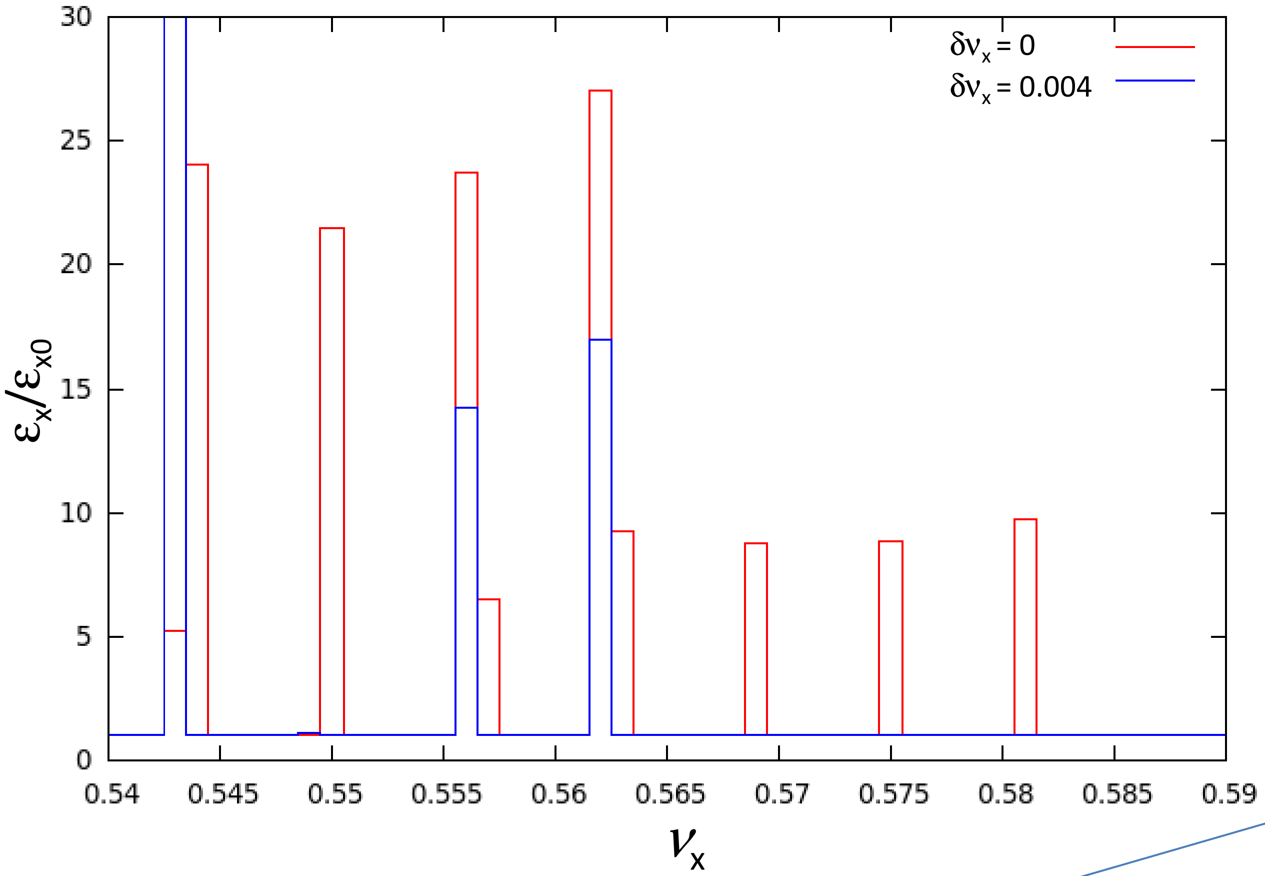


- The orders of resonances doubled, the distance between them halved, and the height of peaks decreased.
- The width of the stable areas between the peaks is important, and NOT the height of the peaks.
- In the case of 4 IP, the width of stable areas is too small. We need additional optimization of parameters.

	σ_δ (SR)	σ_δ (SR+BS)	σ_z (SR)	σ_z (SR+BS)	N_p	ξ_x	L / IP
2 IP	3.8E-4	1.32E-3	3.5 mm	12.1 mm	1.7E+11	0.0038	2.3E+36
4 IP	3.8E-4	1.48E-3	3.5 mm	13.7 mm	1.7E+11	0.0030	2.0E+36

-13%

β_x^* reduced from 15 to 10 cm [45.6 GeV]



- Beamstrahlung becomes stronger, since σ_x drops. As a result, σ_z increases and ξ_x drops even more:

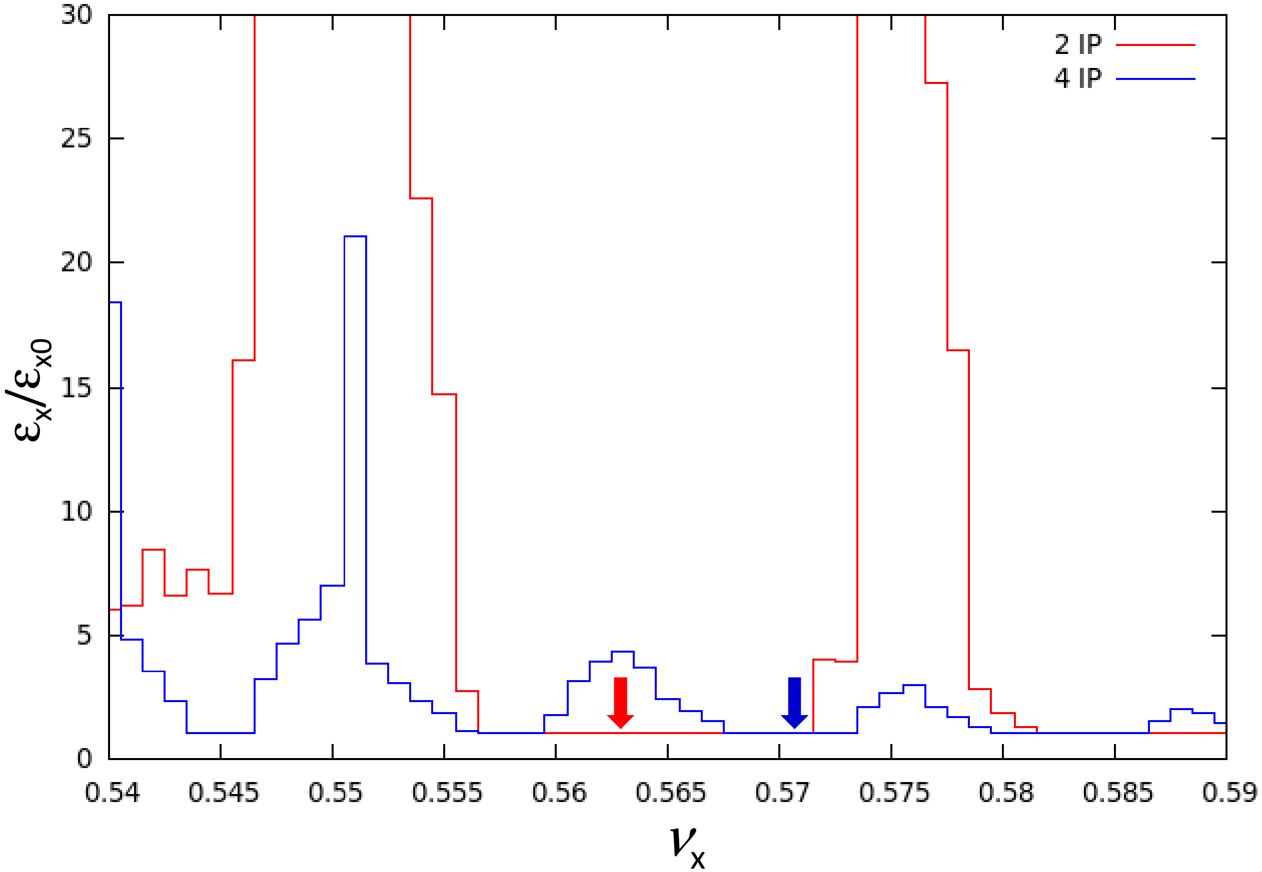
$$\xi_x \propto \beta_x^* / \sigma_z^2$$

- The resonances become very narrow. If we apply some asymmetry, e.g. slightly different ν_x, their widths decrease even more.
- Now the width of stable areas is sufficient.
- Luminosity is *almost* limited by increased σ_δ.

	σ_δ (SR)	σ_δ (SR+BS)	σ_z (SR)	σ_z (SR+BS)	N_p	ξ_x	L / IP
2 IP	3.8E-4	1.32E-3	3.5 mm	12.1 mm	1.7E+11	0.0038	2.3E+36
4 IP	3.8E-4	1.63E-3	3.5 mm	15.0 mm	1.7E+11	0.0017	1.9E+36

-18%

80 GeV



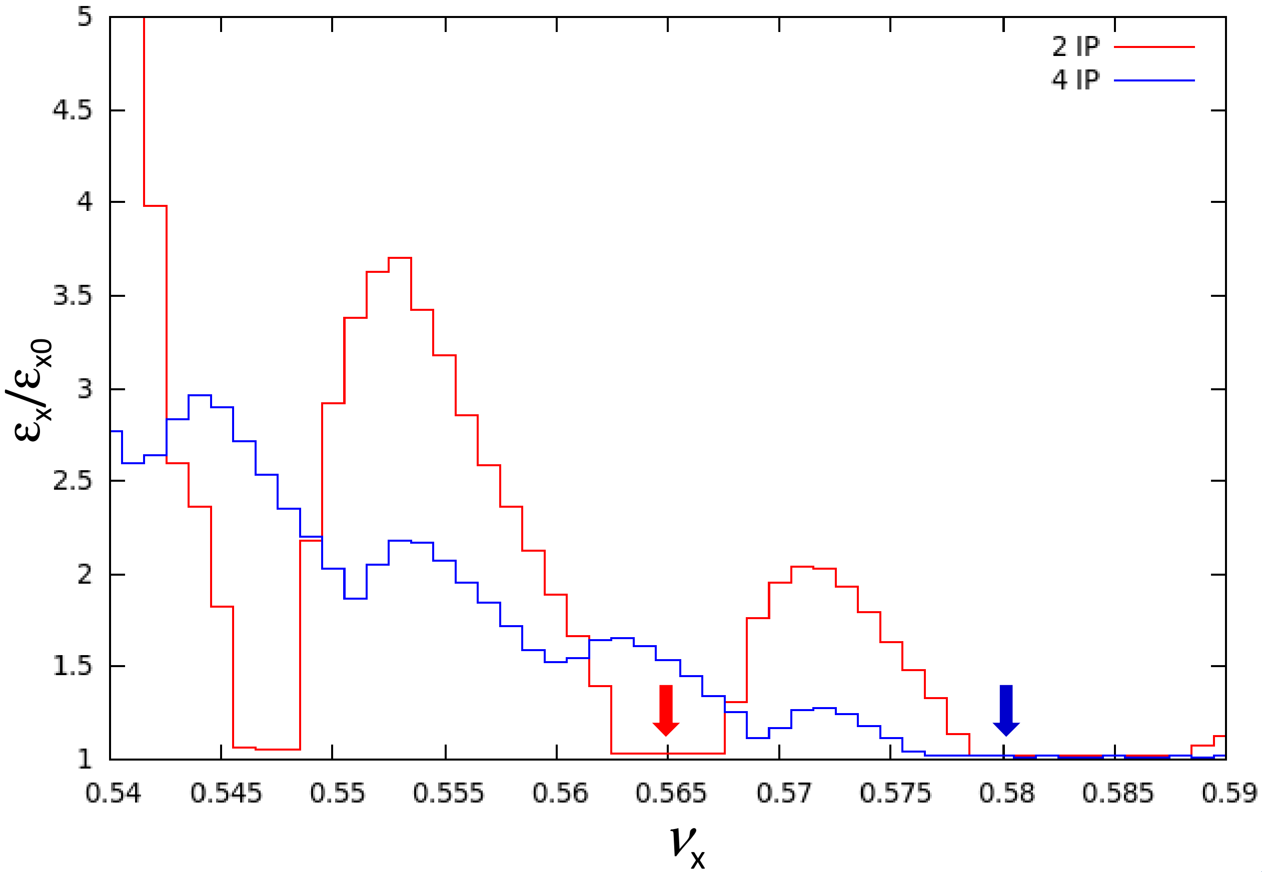
The width of stable areas is sufficient. We only need to change ν_x, and that will be enough.

Bunch population and number of bunches are limited by HOM power, and are not yet limited by BS lifetime. N_p should be the same for 2 IP and 4 IP.

	σ_δ (SR)	σ_δ (SR+BS)	σ_z (SR)	σ_z (SR+BS)	N_p	ξ_x	L / IP
2 IP	6.6E-4	1.3E-3	3.0 mm	6.0 mm	1.5E+11	0.0097	2.8E+35
4 IP	6.6E-4	1.5E-3	3.0 mm	6.7 mm	1.5E+11	0.0078	2.5E+35

-11%

120 GeV



Synchro-betatron resonances overlap in the case of smaller ν_z, but their orders are higher. Since ξ_y slightly drops, we can allow an increase in ν_x to 0.58.

Bunch population is limited by BS lifetime & momentum acceptance. To maintain the same lifetime, N_p should be reduced for 4 IP.

	σ_δ (SR)	σ_δ (SR+BS)	σ_z (SR)	σ_z (SR+BS)	N_p	ξ_x	L / IP
2 IP	9.9E-4	1.65E-3	3.15 mm	5.3 mm	1.8E+11	0.015	8.5E+34
4 IP	9.9E-4	1.83E-3	3.15 mm	5.6 mm	1.7E+11	0.013	7.4E+34

-13%

182.5 GeV

- Piwinski angle is not large (~1) and damping is very strong, so there are no problems with coherent instabilities. Small ν_z per superperiod is not an issue anymore.
- As compared with 2 IP, σ_δ increases because of intensified beamstrahlung => σ_z increases as well => the charge density decreases => the critical energy of BS photons U_c decreases.
- For the BS lifetime two things are important: σ_δ and U_c. It so happened that the increase in σ_δ is compensated by a decrease in U_c, and we got the same lifetime. There is no need to decrease N_p.

	σ_δ (SR)	σ_δ (SR+BS)	σ_z (SR)	σ_z (SR+BS)	N_p	ξ_x	L / IP
2 IP	1.5E-3	1.92E-3	1.97 mm	2.54 mm	2.3E+11	0.099	1.55E+34
4 IP	1.5E-3	2.17E-3	1.97 mm	2.89 mm	2.3E+11	0.086	1.40E+34

-10%

Summary

- In the case of 4 IP instead of 2, luminosity per IP decreases by 10÷20 % (in assumption that the basic lattice parameters are the same).
- The main limiting factors are beamstrahlung (increase in the energy spread) and reduced synchrotron tune per superperiod (coherent instability at low energy).
- The proposed parameter optimization:
  - Z) Change in ν_x, decrease in β_x^*.
  - W) Change in ν_x.
  - H) Change in ν_x, decrease in N_p.
  - tt) No changes are required.