Overview: Status and goals WP2

(let me split hairs….)

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Many thanks to A. Blondel, J. Keintzel, D. Shatilov, J. Wenninger, and all FCC-ee/FCCIS colleagues

Questions:

- We think that the average beam energy can be precisely determined by measuring the spin tune of the pilot bunches.
- I may have several naïve questions, as colliding bunches are different from the colliding bunches:

@Z		pilot	colliding
Collision		N	Y
Bunches/beam		~ 100	10000
Particles/bunch	10^{10}	~ 1	24.3
Energy spread	10^{-4}	3.8	13.2
Bunch length	mm	4.38	15.4
$\varepsilon_y/\varepsilon_x$	%	$\ll 0.2$	0.2
top-up		N	Y

- So the beam orbit, energy, dispersions, emittance can be different in colliding bunches from the pilot bunches, in general.
  - Esp. with impedances, top-up injection, orbit/dispersion/coupling knobs, various feedbacks, etc.

“latest” parameters

Beam energy	[GeV]	45.6	80	120	182.5
Layout		PA31-1.0			
# of IPs		4			
Circumference	[km]	91.174117		91.174107	
Bending radius of arc dipole	[km]	9.937			
Energy loss / turn	[GeV]	0.0391	0.370	1.869	10.0
SR power / beam	[MW]	50			
Beam current	[mA]	1280	135	26.7	5.00
Bunches / beam		10000	880	248	40
Bunch population	[10^{11}]	2.43	2.91	2.04	2.37
Horizontal emittance ε_x	[nm]	0.71	2.16	0.64	1.49
Vertical emittance ε_y	[pm]	1.42	4.32	1.29	2.98
Arc cell		Long 90/90		90/90	
Momentum compaction α_p	[10^{-6}]	28.5		7.33	
Arc sextupole families		75		146	
$\beta^*_{x/y}$	[mm]	100 / 0.8	200 / 1.0	300 / 1.0	1000 / 1.6
Transverse tunes/IP $Q_{x/y}$		53.563 / 53.600		100.565 / 98.595	
Energy spread (SR/BS) σ_δ	[%]	0.038 / 0.132	0.069 / 0.154	0.103 / 0.185	0.157 / 0.221
Bunch length (SR/BS) σ_z	[mm]	4.38 / 15.4	3.55 / 8.01	3.34 / 6.00	1.95 / 2.75
RF voltage 400/800 MHz	[GV]	0.120 / 0	1.0 / 0	2.08 / 0	2.5 / 8.8
Harmonic number for 400 MHz		121648			
RF freuqeuncy (400 MHz)	MHz	399.994581		399.994627	
Synchrotron tune Q_s		0.0370	0.0801	0.0328	0.0826
Long. damping time	[turns]	1168	217	64.5	18.5
RF acceptance	[%]	1.6	3.4	1.9	3.0
Energy acceptance (DA)	[%]	±1.3	±1.3	±1.7	-2.8 +2.5
Beam-beam ξ_x/ξ_y [a]		0.0023 / 0.135	0.011 / 0.125	0.014 / 0.131	0.093 / 0.140
Luminosity / IP	[10^{34}/cm^{2}s]	182	19.4	7.26	1.25
Lifetime (q + BS)	[sec]	–		1065	4062
Lifetime (lum)	[sec]	1129	1070	596	744

[a] incl. hourglass.

Energy sawtooth → J. Keintzel

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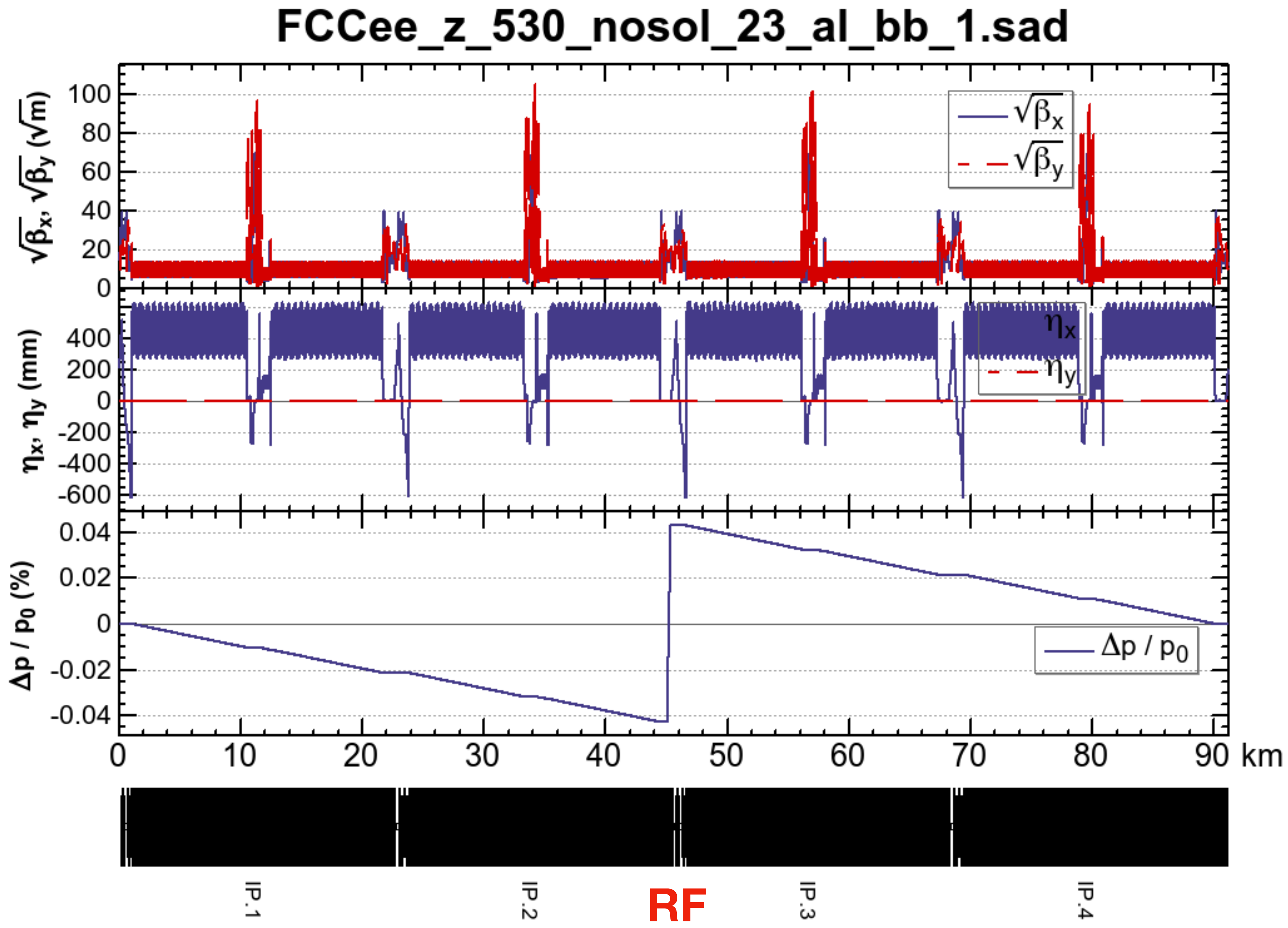
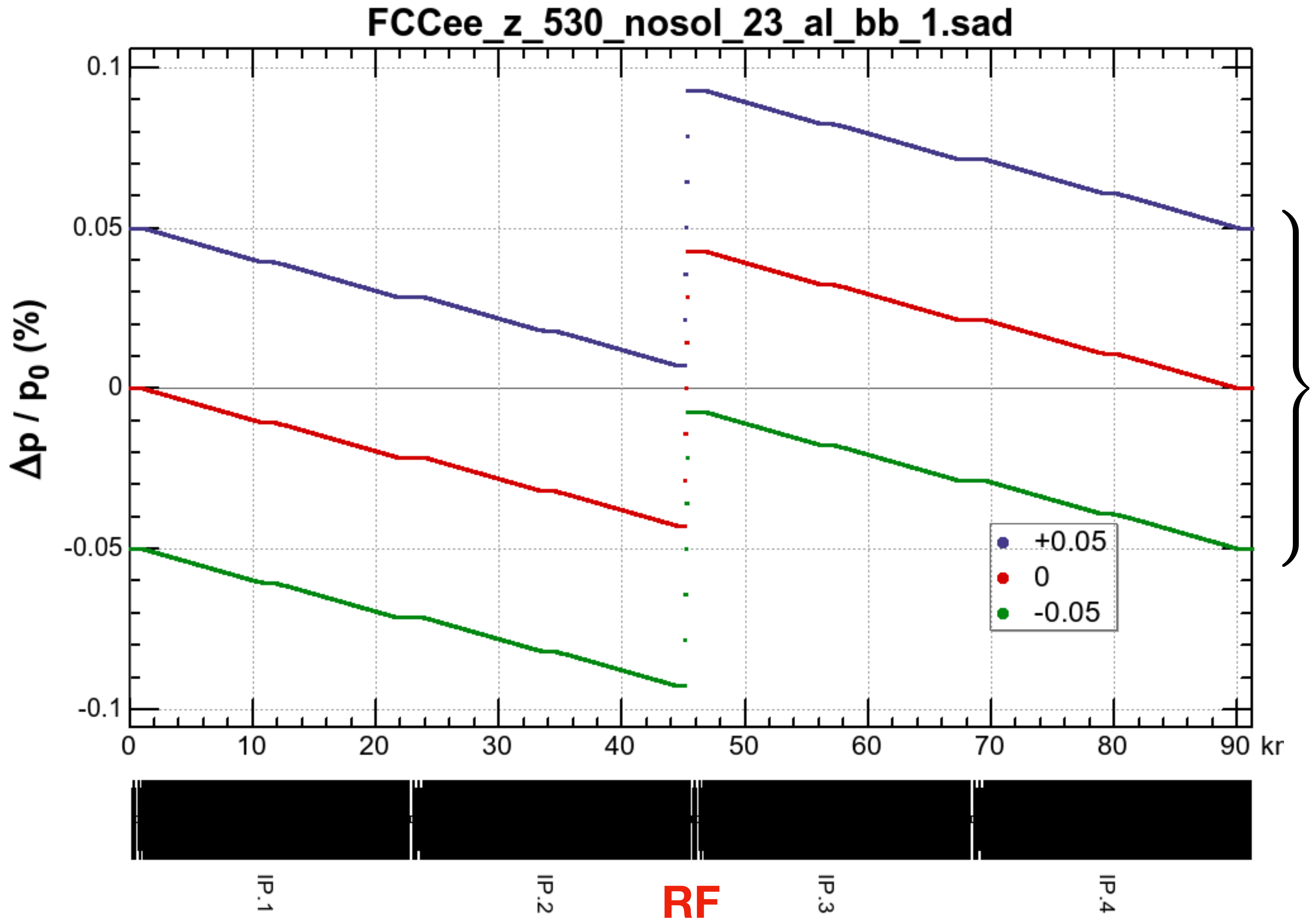


- Only 1 RF station/per ring at the same straight section for both beams.
- The center of mass at each IP (≈IP1+IP4, IP2+IP3) will be nearly the same between 4 IPs.

Tapering



All satisfy the tapering condition.

- “Tapering” is to scale the magnetic fields with the local energy of the beam.
- However, this definition is in ***underdetermination***.
  - For instance, any one of above energy sawtooth satisfies the tapering condition.
- So to avoid the complexity, let us ***turn off tapering*** in the following discussions.

Beam energy deviation due to machine errors

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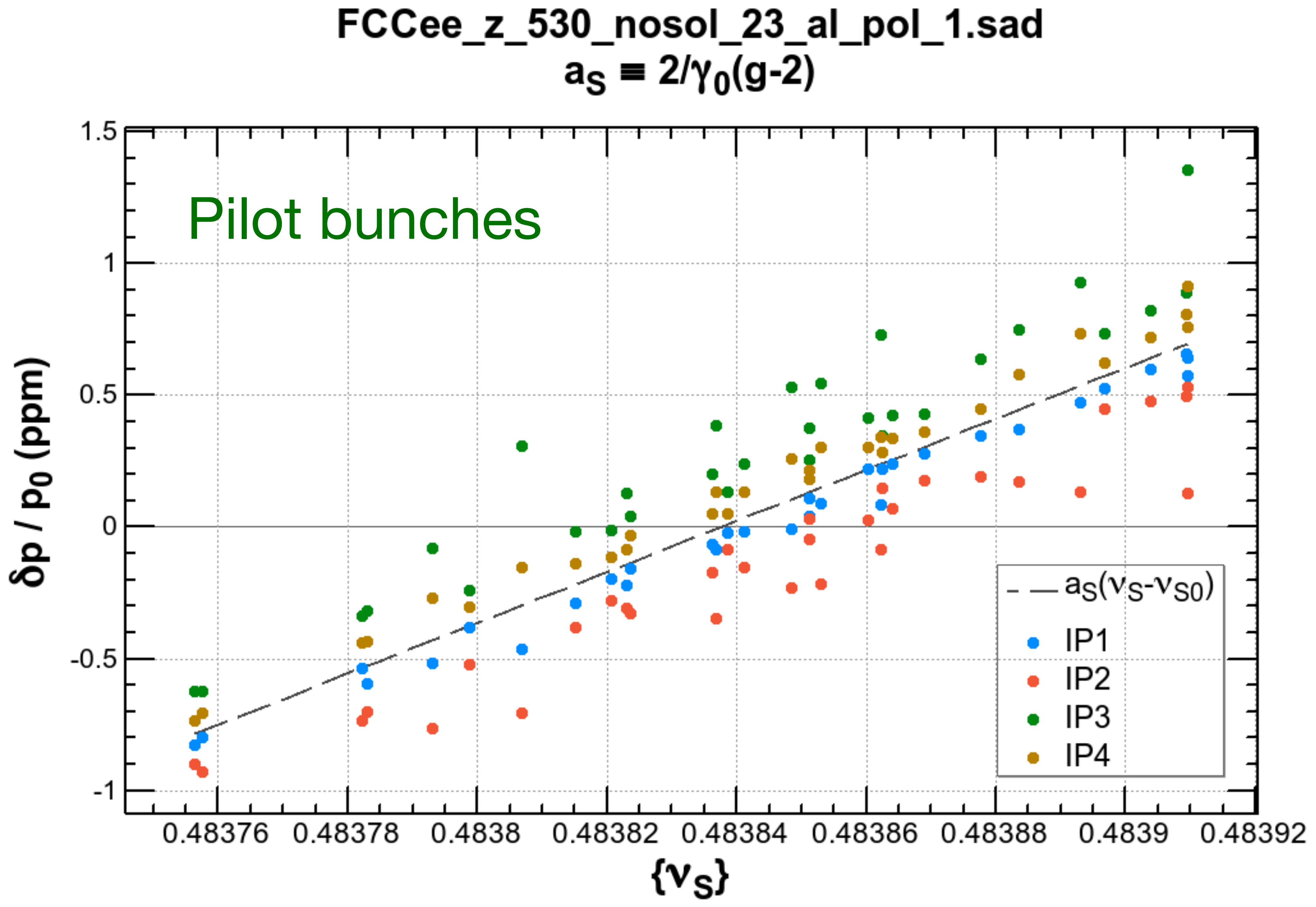
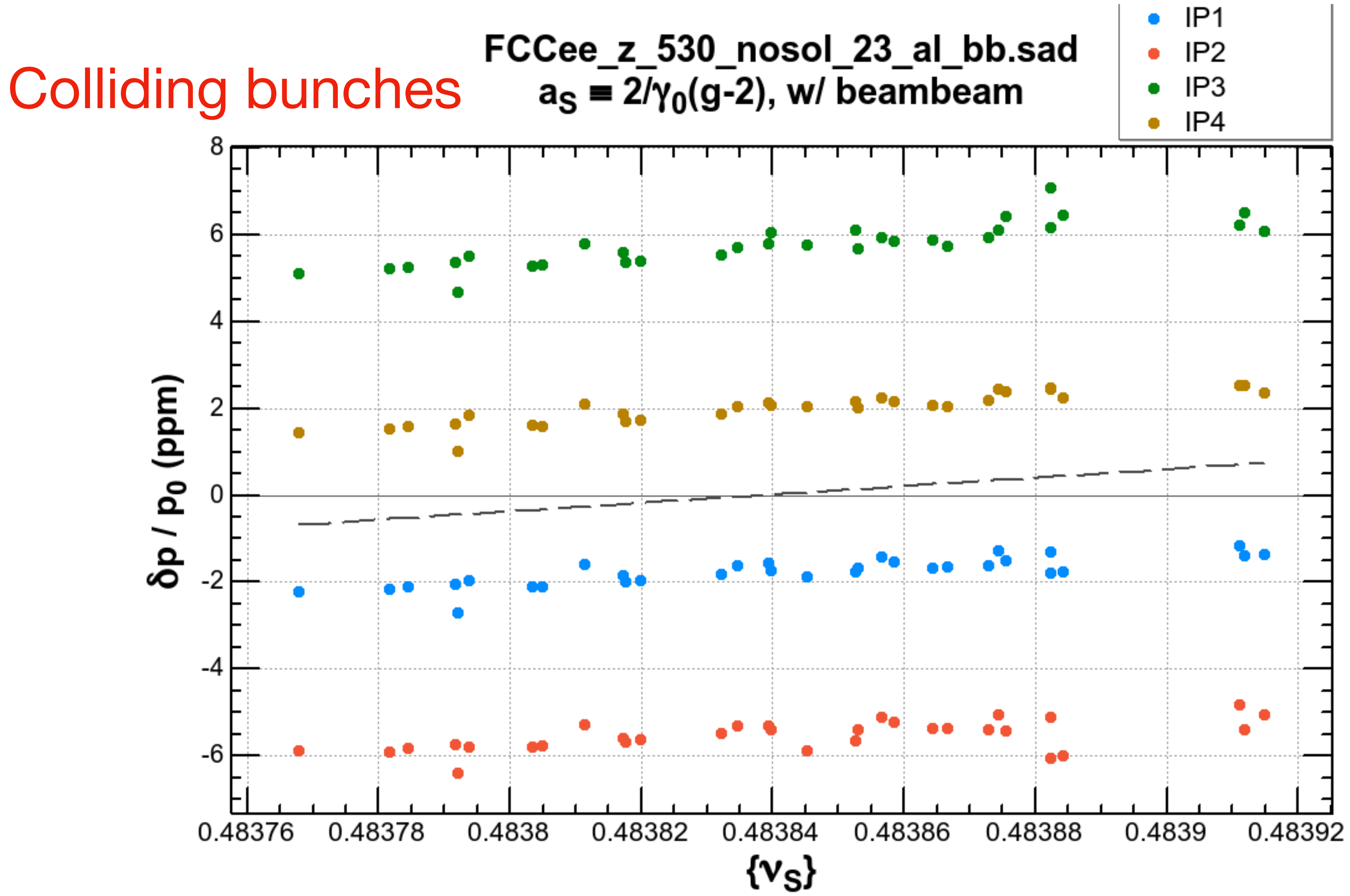
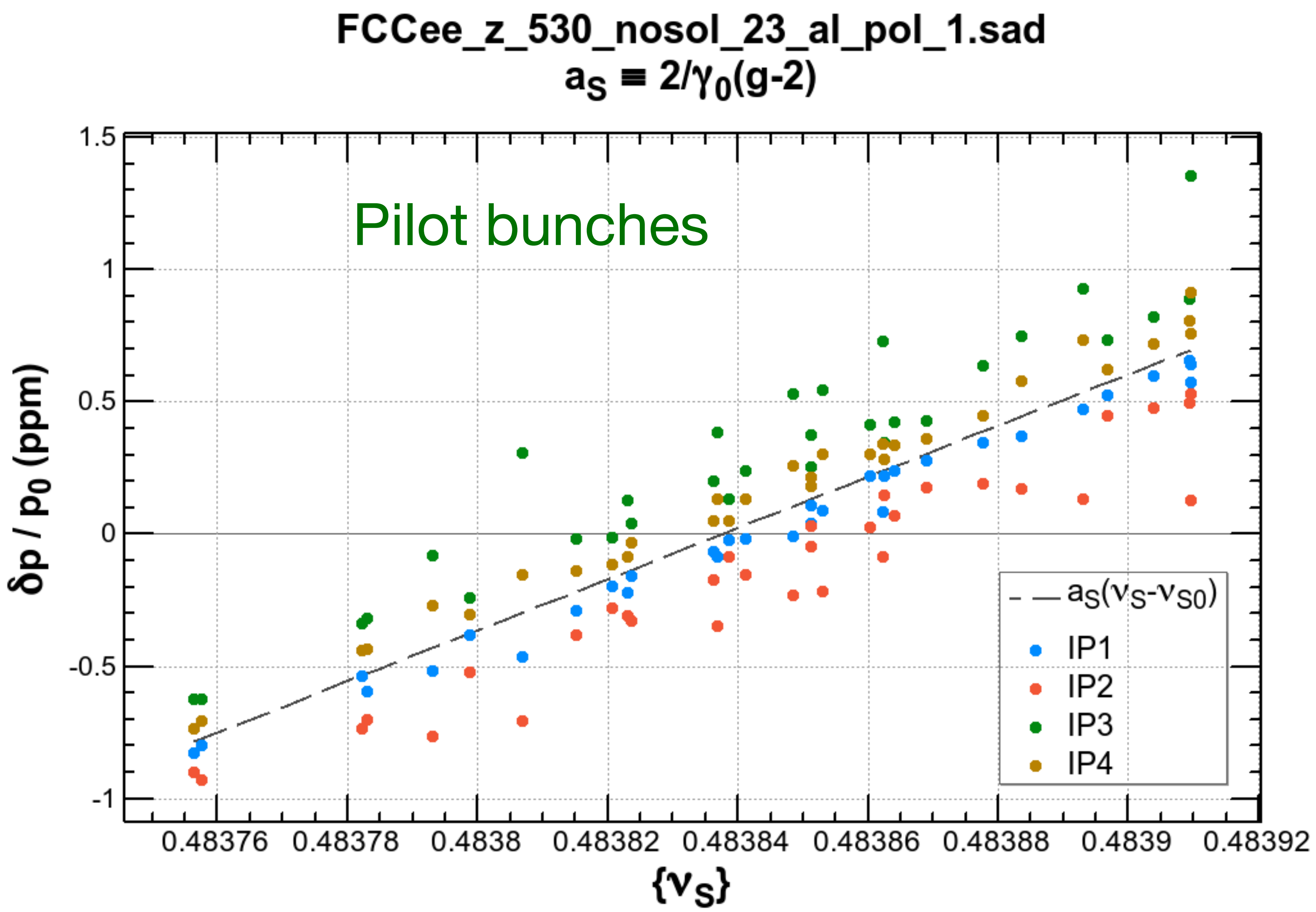


- Machine errors may change the beam energy.
- For example, here we set random field error in arc dipole field by 10^{-4}, and horizontal misalignment of all quads (except QC{12} around each IP) + "ideal" orbit correction.
  - Then for the pilot bunches, the beam energy at 4 IPs deviate, but they are well correctable using the spin tune measurement.
  - The residual after the pilot bunch correction, the variation is well below 0.5 ppm.

Beam energy deviation due to machine errors with beam-beam, beamstrahlung → D. Shatilov





- If a toy model of the beam-beam & beamstrahlung is applied to each IP, there appear deviations of beam energy at each IP.
- However, the center of mass energy (≈IP1+IP4, IP2+IP3) still look close to 0, and well scales with the spin tune.
- The residual error after scaling seems below 0.5 ppm, if all beamstrahlungs are identical at four IPs.

Vertical dispersion at IP

It is known[a] that the spread of the center-of-mass energy, divided by the beam energy, is written as

$$\sigma_{E_{\rm CM}}^2 = 2\sigma_\epsilon^2 \left[1 + (D_{y1}^* + D_{y2}^*)^2 \frac{\sigma_\epsilon^2}{\sigma_y^{*2}}\right] , \tag{1}$$

where σ_ϵ and σ_y are the beam energy spread and the vertical beam size, which we have assumed equal for both beams. The vertical dispersions are $D_{y1,2}^*$. Then we can consider two extremes:

$$\sigma_{E_{\rm CM}}^2 = \begin{cases} 2\sigma_\epsilon^2 & (D_{y1}^* = -D_{y2}^*) \,, \\ 2\sigma_\epsilon^2 \left[1 + \dfrac{4D_y^{*2}\sigma_\epsilon^2}{\sigma_y^{*2}}\right] & (D_{y1}^* = D_{y2}^* = D_y^*) \,. \end{cases} \tag{2}$$

On the other hand since

$$\sigma_y^{*2} = \sigma_{y\beta}^2 + D_y^{*2}\sigma_\epsilon^2 \,, \tag{3}$$

we can say

$$2\sigma_\epsilon^2 \le \sigma_{E_{\rm CM}}^2 \le 10\sigma_\epsilon^2 \,. \tag{4}$$

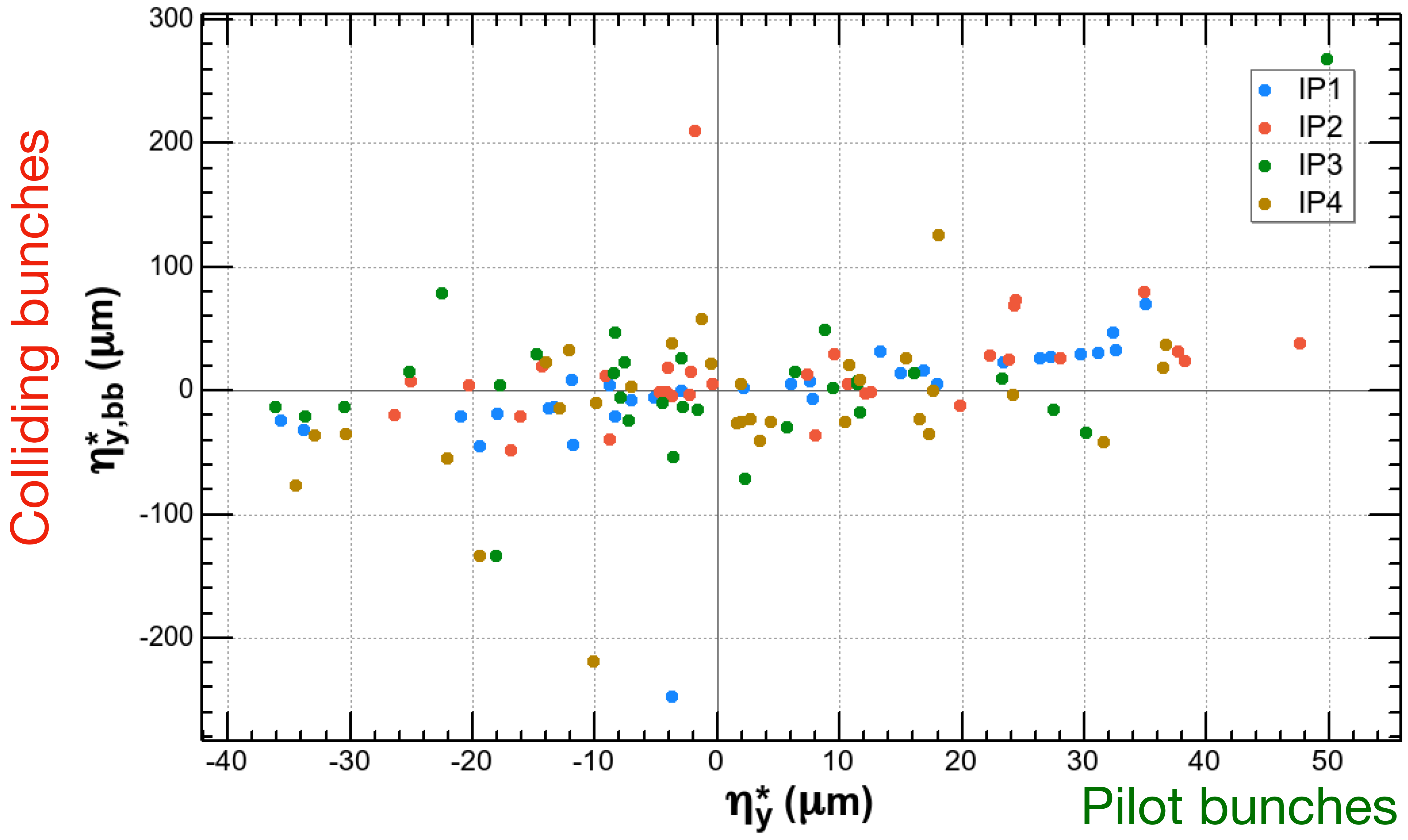
Therefore to minimize σ_ϵ^2, two strategies are possible: (1) make the IP dispersion antisymmetric and/or (2) reduce the vertical dispersion at the IP as small as possible. Both can be done by a *vertical dispersion knob* at the IP. Also to adjust the vertical beam sizes at the IP, knobs with *coupling bump* orbits in the arc without dispersion leak are necessary.

[a] J.M. Jowett, J. Wenninger, J. Yamartino, CERN SL/Note 95–46 (May 1995)

Vertical dispersion at IP

FCCee_z_530_nosol_23_al_bb_1.sad

$\eta^*_{y,rms}$ = 19.27 µm, $\eta^*_{y,bb,rms}$ = 54.81 µm, ε_y (w/o bb) = .71 pm



- The beam-beam focusing changes the vertical dispersion at the IP.
- The amount depends on the residual dispersion without beam-beam, collision offset at the IP, etc.
- An example above shows an enhancement of the vertical dispersion at t each IP, assuming random vertical misalignments of arc sexts to produce $\varepsilon_y = 0.7\,\mathrm{pm}$, together with random vertical offset at each IP by $0.1\sigma^*_y$.

Dispersion measurement

- Dispersion measurements for non-colliding beam is easily done by a shift of RF frequency, for instance.
- However, it is only possible at low current. We cannot store non-colliding high current beam without collision due to instabilities. → E. Carideo
- Measurement for colliding bunches will be very difficult, as it violates the collision conditions to cause the 6D flip-flop.
- String high current also changes everything: orbit, optics, dispersion, etc.
- The only possibility is to measure the dispersion by exciting the synchrotron motion of the pilot bunches, by special deflector (either longitudinal or transverse at a dispersive location).

Top-up injection

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- The top-up injection shakes the colliding bunches periodically, transversely or longitudinally.
- Then either the bunch-by-bunch or narrowband feedbacks tries to damp such oscillations. Esp. the narrow band feedback shakes the pilot bunches.
    - The magnitude must be estimated.
- Such disturbance on the pilot bunches may affect the spin tune measurement.
- It is not possible to suspend the injection, since the delicate balance between two or *four* colliding bunches easily breaks to result in unrecoverable 6D flip-flop.

Summary

- A few questions are mentioned.
  - Some of them might have been already answered by you.
- There are more:
  - How do we generate the necessary vertical emittance:
    - a closed emittance bump through arc, without affecting the IP dispersion/coupling.
  - The effect of global deformation of the tunnel and the ring on the spin tune.
  - …