Modeling CESR-c

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Weak strong beambeam simulation

- Motivation
  - Identify component or effect that is degrading beambeam tuneshift
  - Establish dependencies on details of lattice design
  - Including
    - Wiggler nonlinearity
    - Localization of radiation in wigglers
    - Crossing angle
    - Pretzel (off axis closed orbit)
    - Parasitic interactions
    - Sextupole distribution
    - Bunch length
    - Tunes
    - Coupling
    - Rfcavity deployment (finite dispersion)
    - Solenoid compensation

Weak strong beambeam simulation

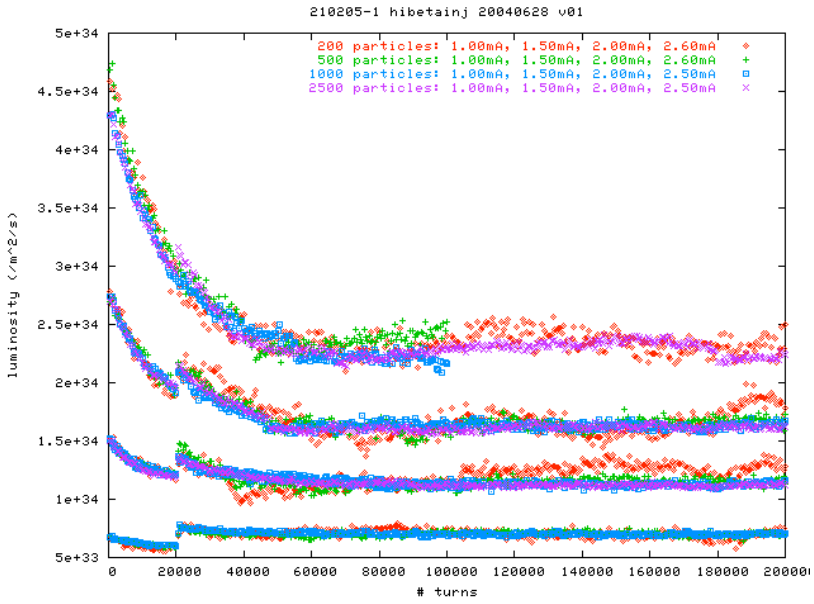
- Model
  - Machine arc consists of a line of individual elements each represented by a nonlinear map, a matrix, or thin kicks
  - Solenoid, rotated quads, quads, sextupoles, electrostatic separators, RF cavities
  - Wigglers - field is analytic function fit to field table generated by finite element code
  - Interaction region
    - Superimposed/ rotated quadrupoles, skew quadrupoles, solenoid represented by exact linear superposition
  - Radiation damping and excitation
    - Damping and radiation excitation at beginning and end of each element => beam size, length, energy spread
  - Parasitic beambeam interactions
    - Compute closed orbit, □-functions, emittance for strong beam
    - Add 2-d beam beam kick at each crossing point
  - Beam beam kick
    - Strong beam has gaussian distribution in x,y,z
    - Parameters of closed orbit and focusing functions of strong beam => orientation, size
    - Beambeam kick is 2-d, Longitudinal slices => sensitivity to crossing angle, bunch length, synchrotron tune

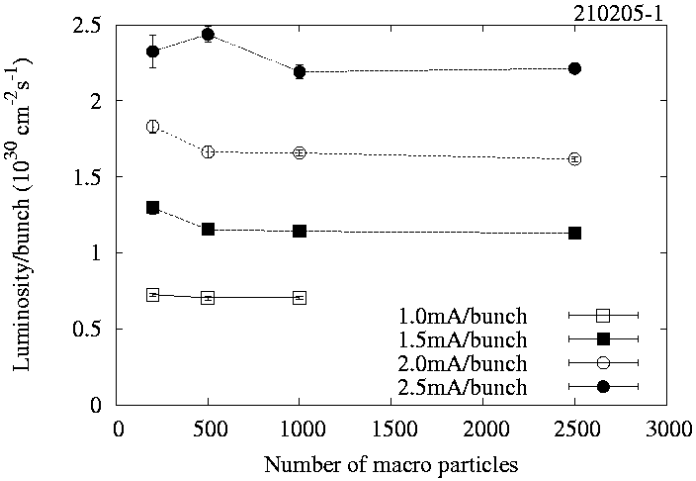
Weak strong beambeam simulation

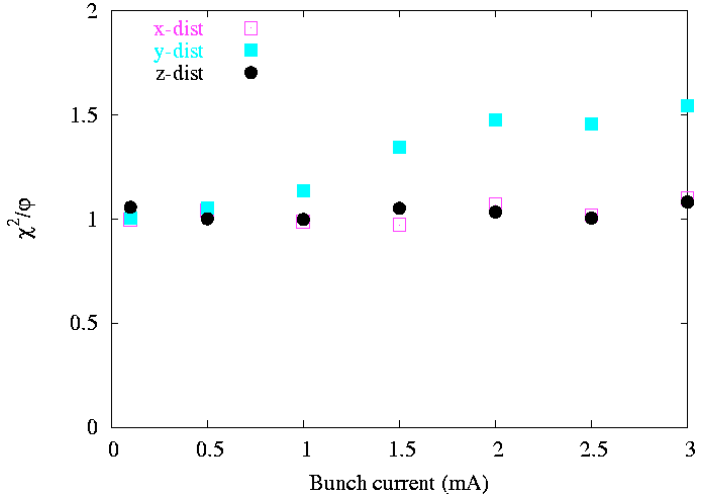
- Procedure
  - Initialization
    - Add beambeam elements at parasitic crossing points, and at IP
    - Adjust horizontal separators to zero differential horizontal displacement at IP
      (PRETZING 13)
    - Adjust vertical separators and vertical phase advance between separators to zero differential vertical displacement and angle at the IP
      (VNOSEING 1 and 2)
    - Turn off beambeam interaction at IP and set weak beam tunes.
    - Restore beambeam interaction at IP
  - Track 500 macro particles of weak beam
    - Beginning after 1 damping time (20k turns)
      - Fit weak beam distribution as gaussian
      - Set strong beam size equal to fitted parameters of weak beam

Weak strong beambeam simulation

- Parameters of simulation
  - Number of macroparticles (500)
  - Number of turns (5 damping times)
  - Weak strong approximation
  - Lifetime



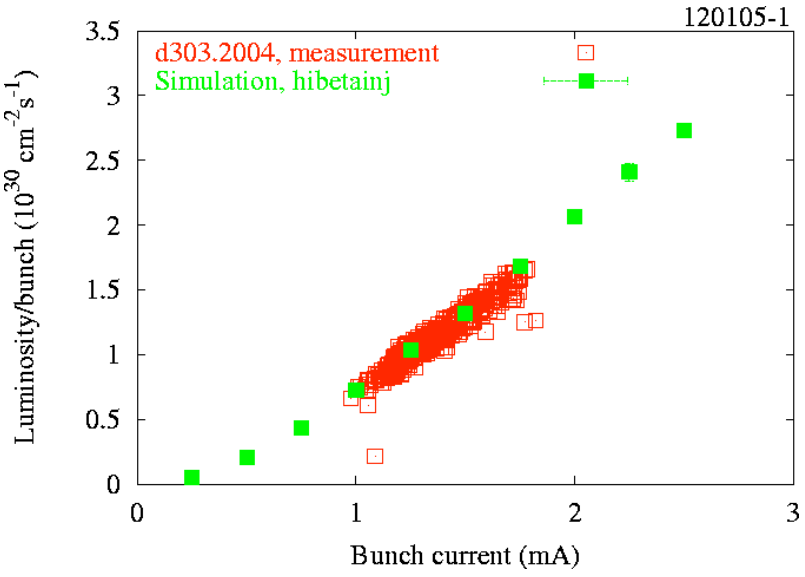




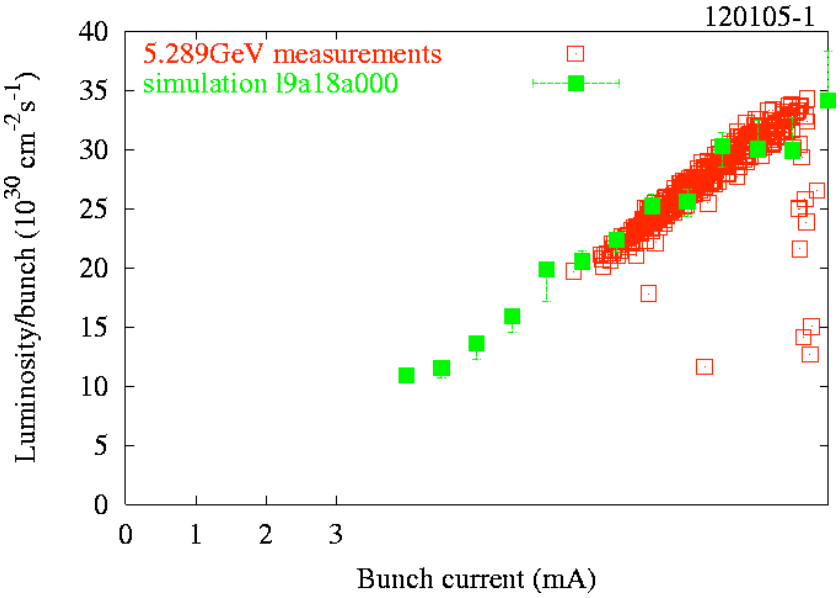
Weak strong beambeam simulation

- Comparison with measurements
  - In simulation, tune scan yields *operating* point
  - Data: Assume all bunches have equal current and contribute equal luminosity

CESR-c
1.89 GeV, 12 2.1T wigglers
Phase III IR



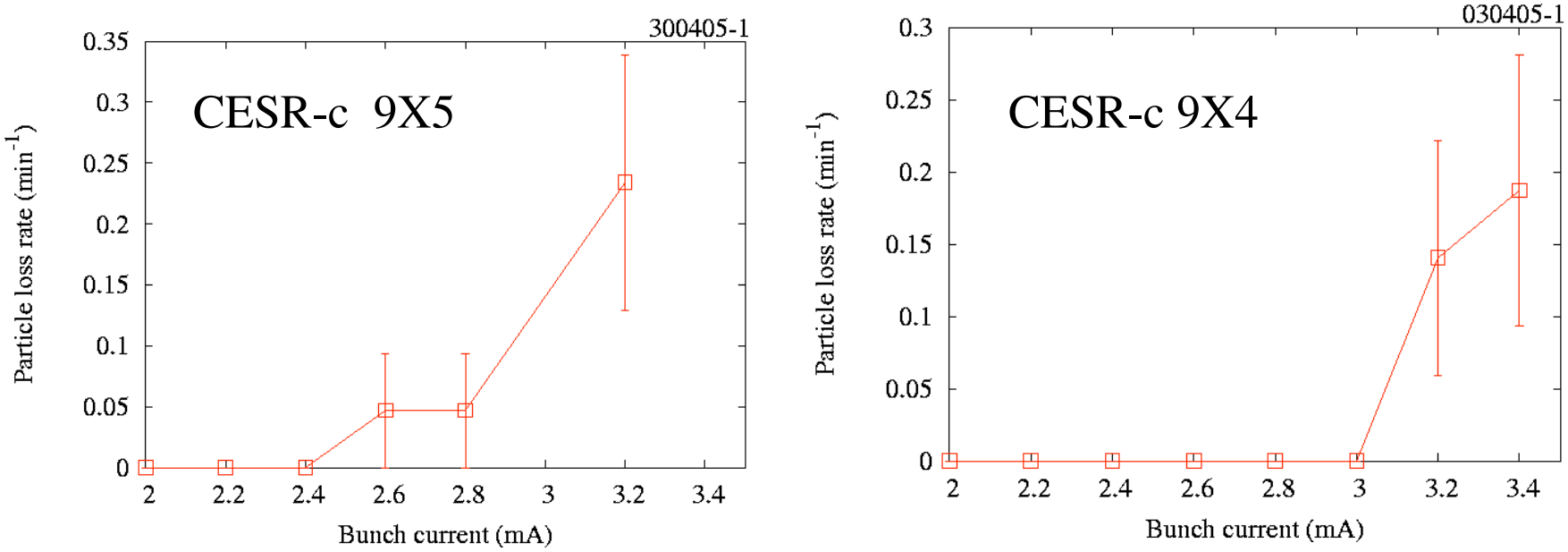
5.3GeV
Phase II IR



Weak strong beambeam simulation

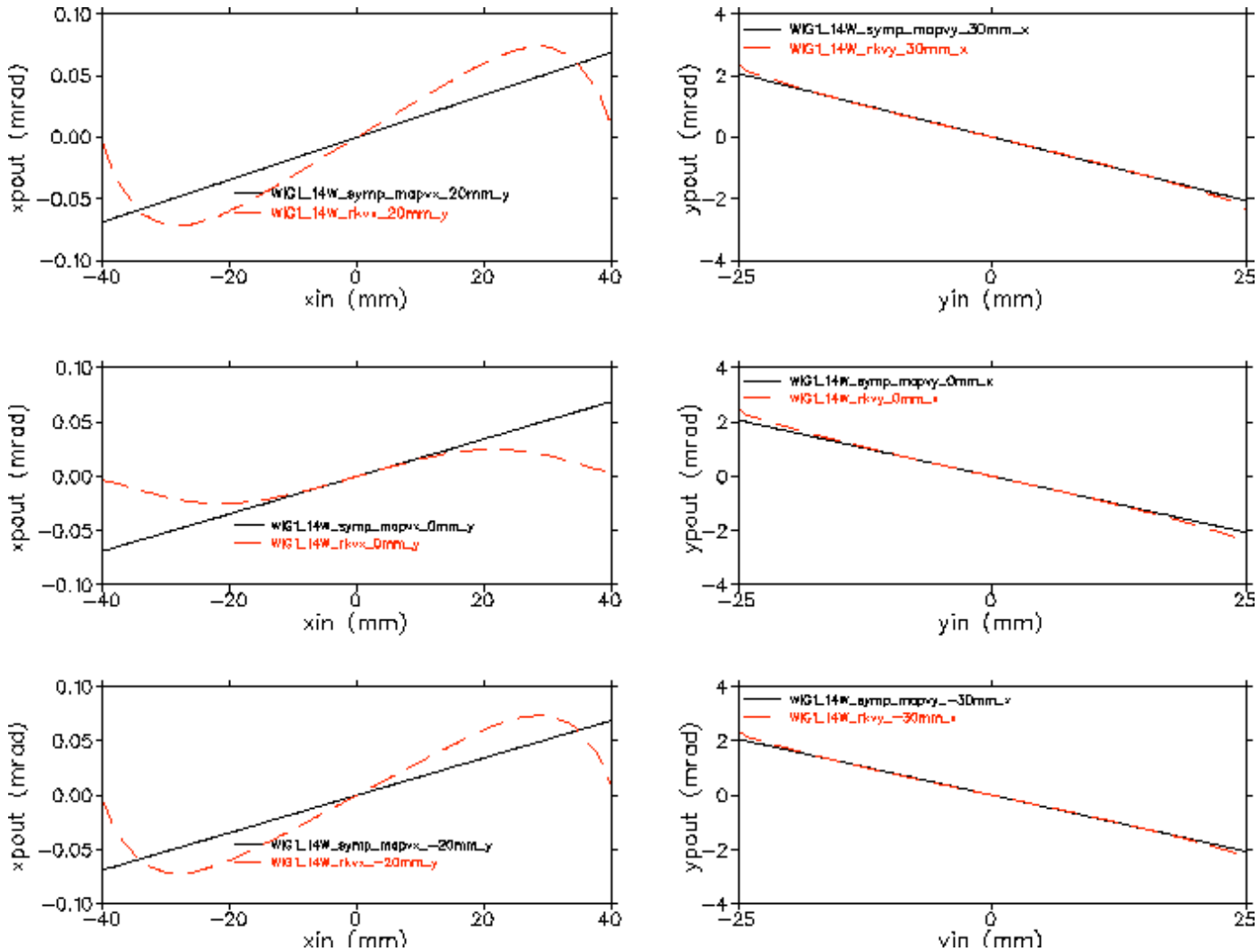
- Lifetime $\frac{1}{\tau} = \frac{1}{N}\frac{dN}{dt} = \frac{1}{N}\frac{\Delta N}{n_{turns}} f_{rev}$

Loss of 1 of 5000 particles in 100 k turns => 20 minute lifetime



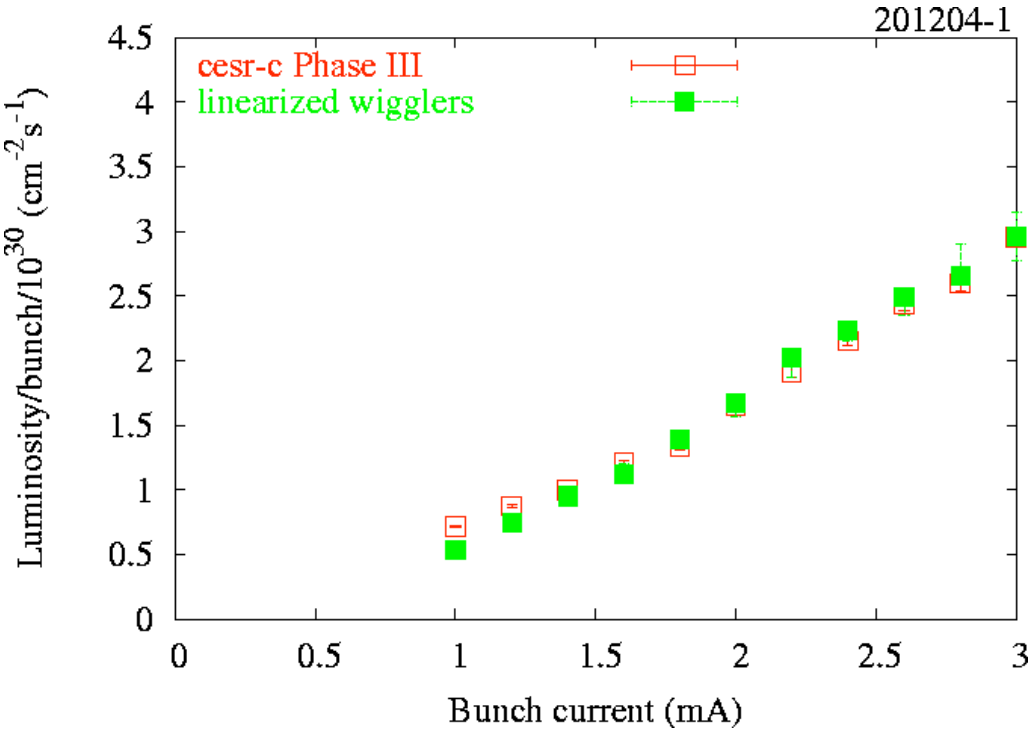
Measure lifetime limited current ~ 2.2mA/bunch(9X5), ~2.6mA/bunch(9X4)

Linearized wiggler map



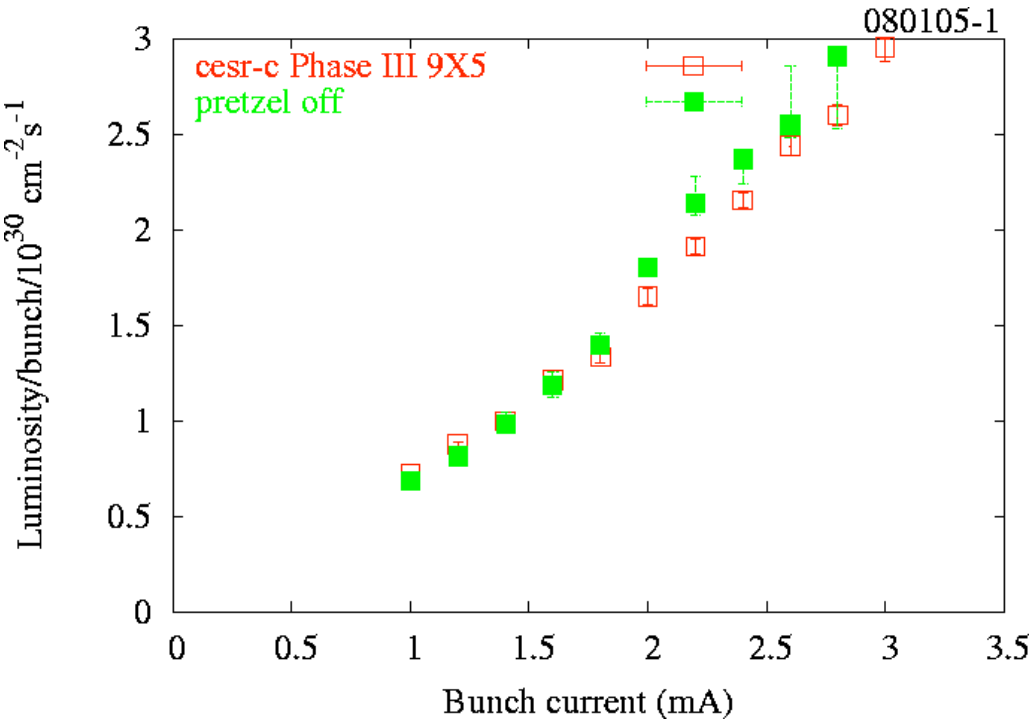
Weak strong beambeam simulation

- Specific luminosity.
  - Wiggler nonlinearities



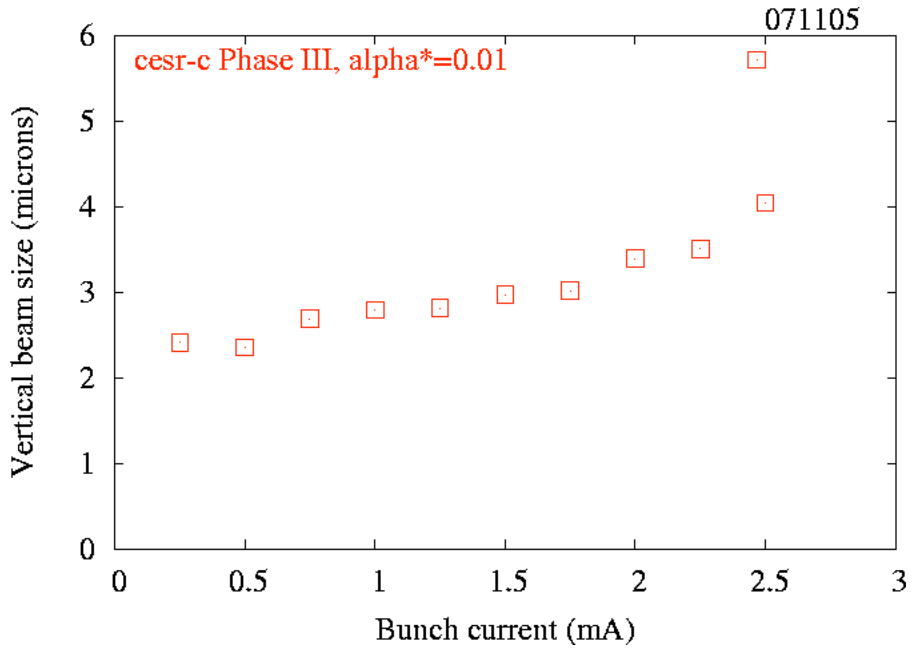
Weak strong beambeam simulation

- Specific luminosity.
  - Pretzel/crossing angle
  - Parasitic crossings



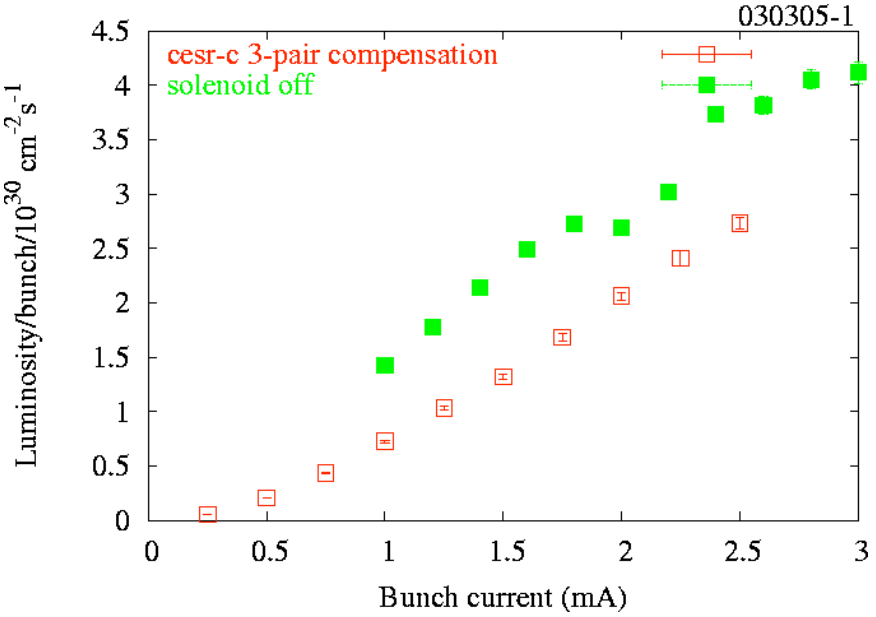
Weak strong beambeam simulation

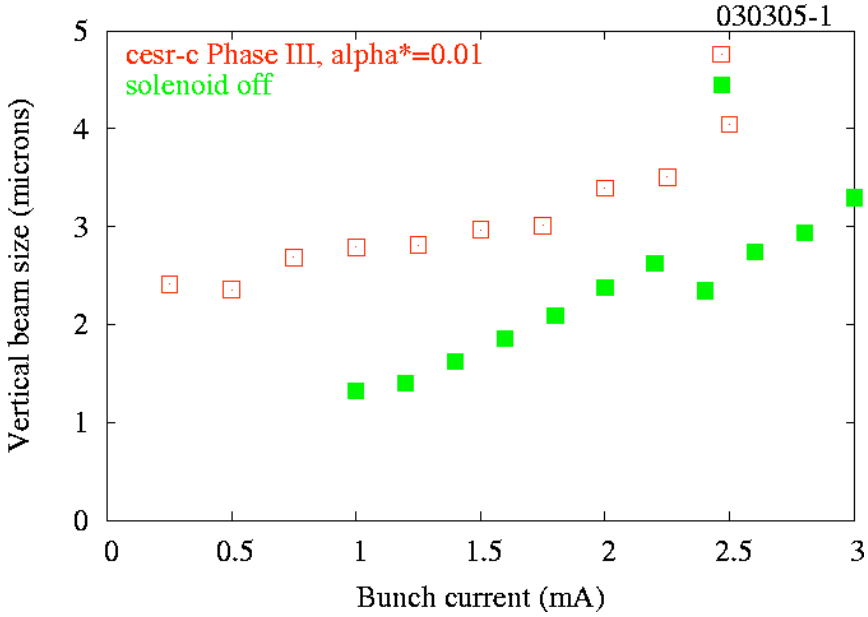
- In Zero current limit, beam size is big
  - No alignment errors
  - No coupling errors
  - Analytic single beam emittance ~0.05nm



Weak strong beambeam simulation

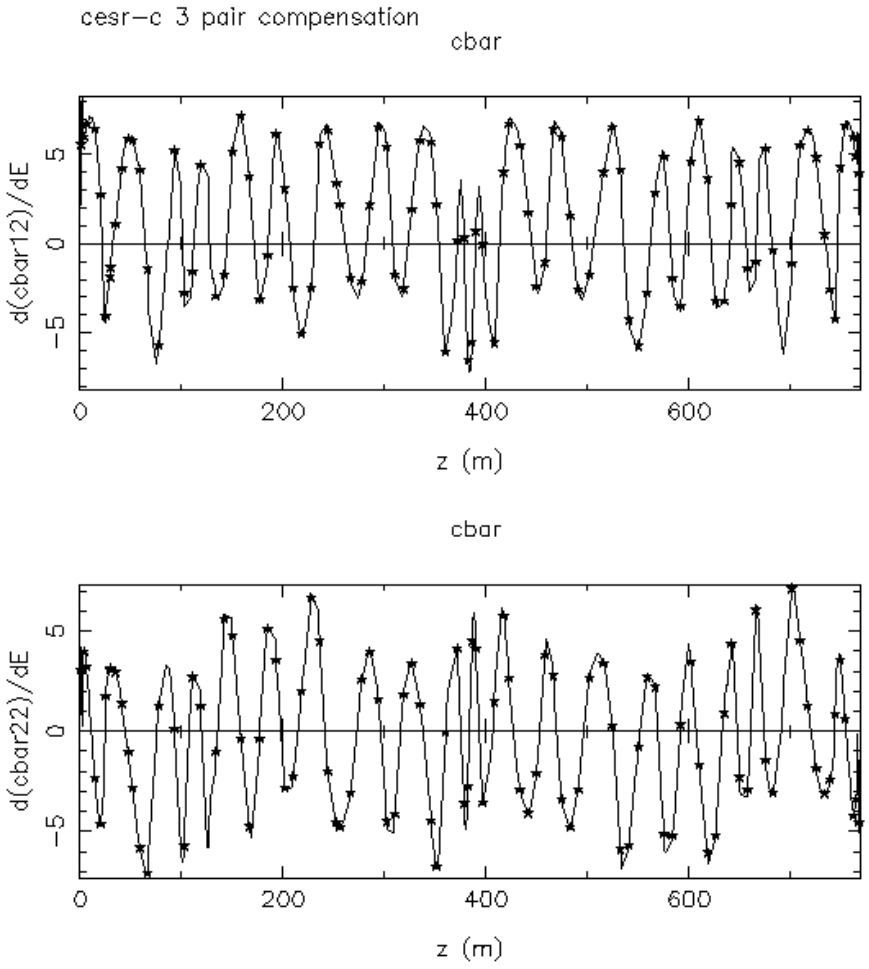
- Solenoid compensation
  - Simulation with no solenoid
  - Beam size vs current





Weak strong beambeam simulation

- Solenoid compensation
  - Energy dependence of coupling parameters



$$\frac{\Delta E}{E} = 0.00084 \Rightarrow C_{ij} \sim 0.6\%$$

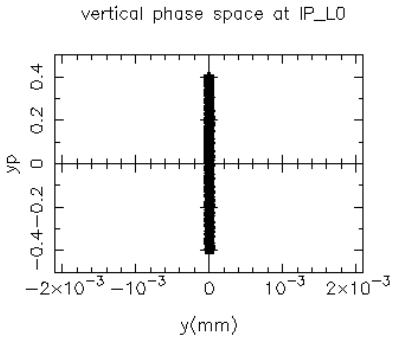
- Solenoid compensation
  - Phase space

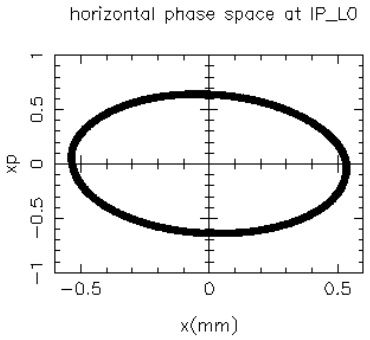
CESR-c 3 pair compensaton

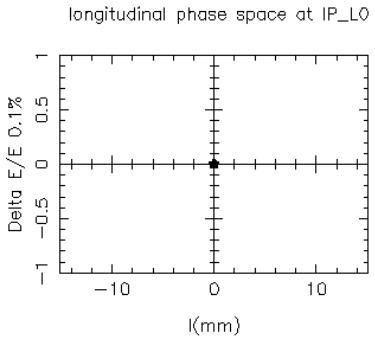
Q_x=0.52
Q_y=0.58
Q_z=0.089

Separators off
Begin tracking outside
Of compensation region
X_{init} =2mm

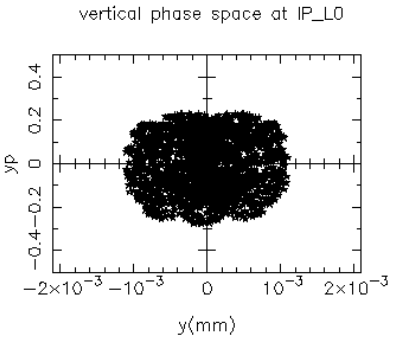
□=0.0

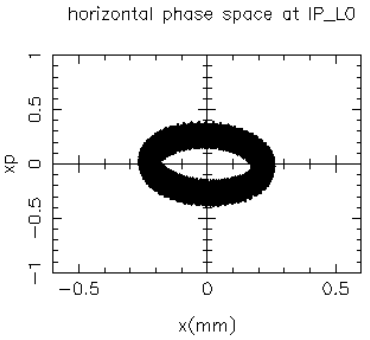


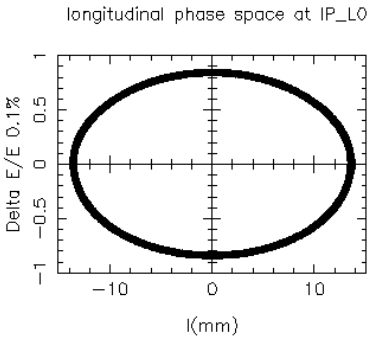




□=0.00084





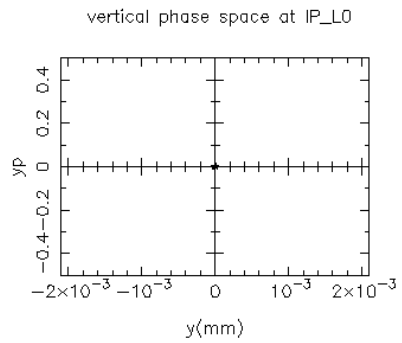


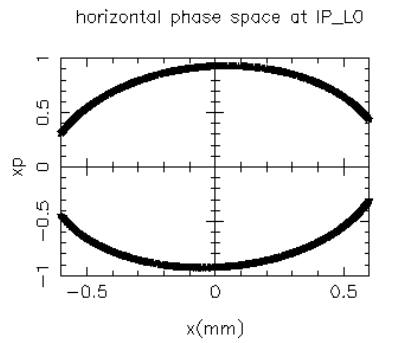
No solenoid

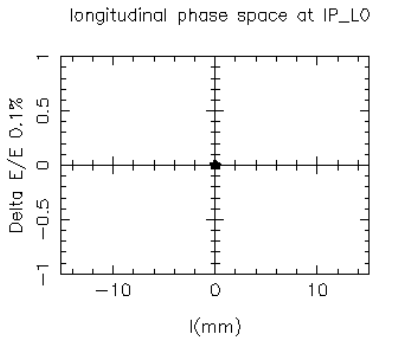
Q_x=0.52
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Separators off
Begin tracking outside
Of compensation region
X_{init} =2mm

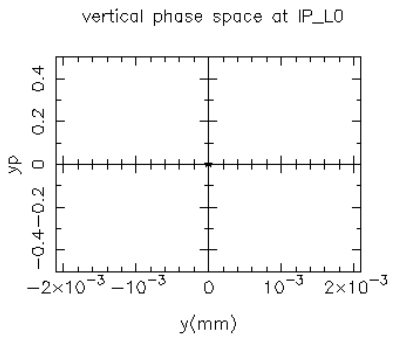
□=0.0

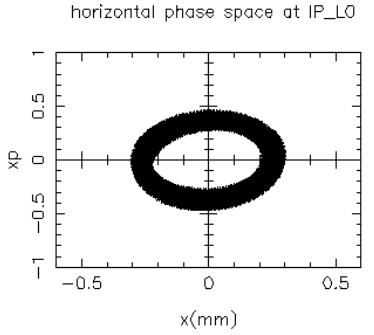


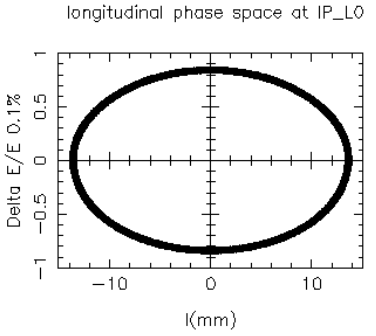


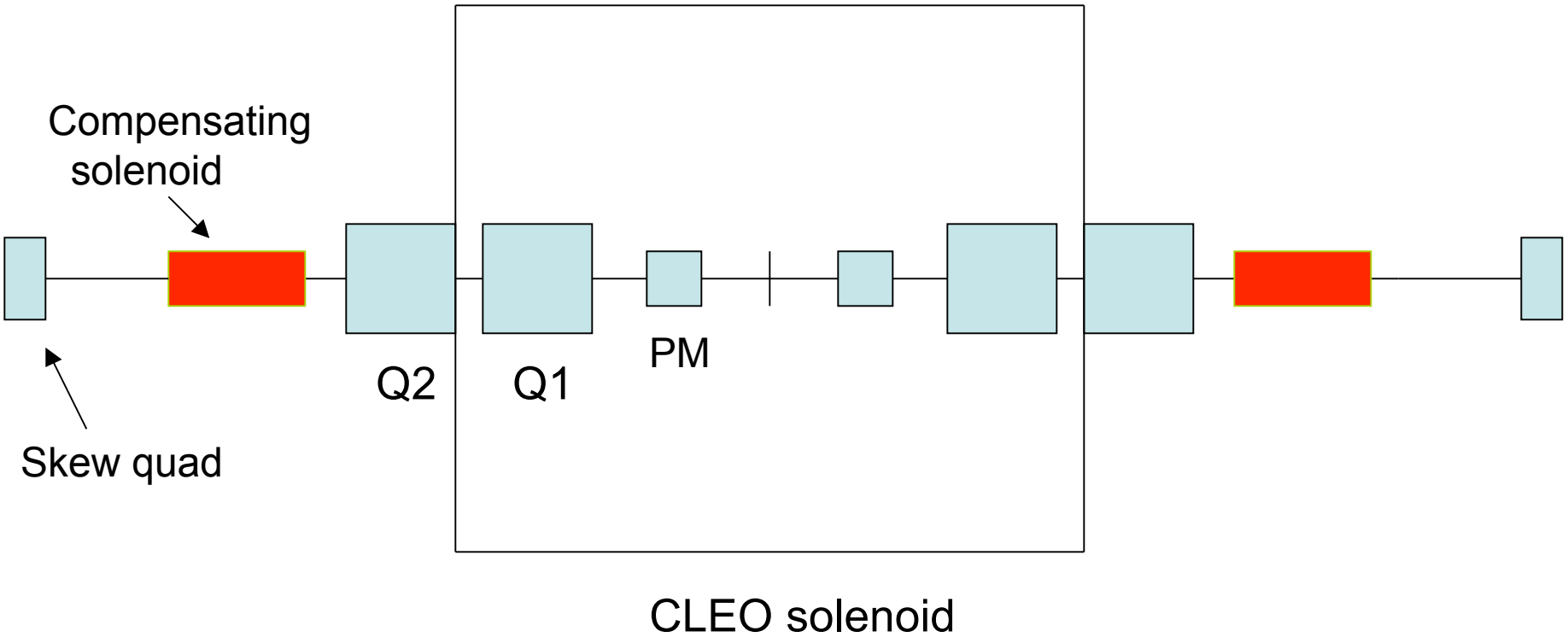


□=0.00084








Compensating
solenoid
Skew quad
Q2
Q1
PM
CLEO solenoid

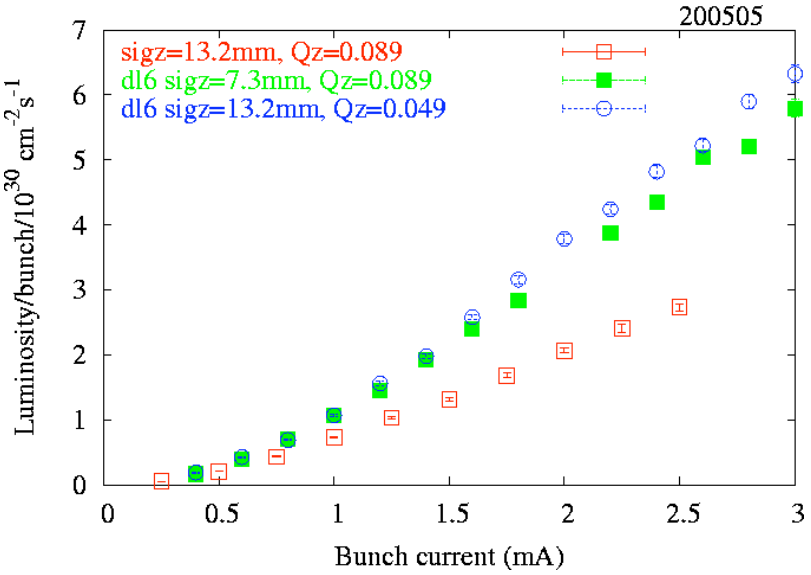
Longitudinal emittance

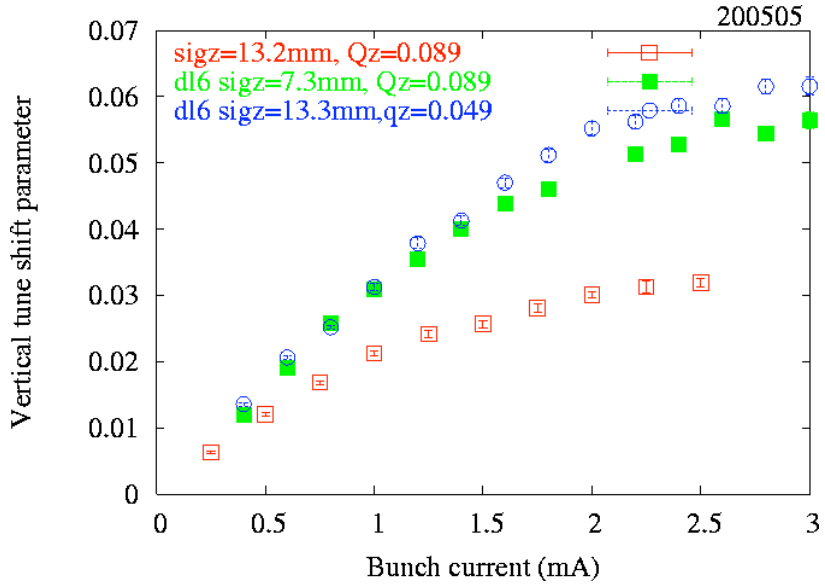
- 12 wigglers, 1.89GeV/beam
  - σ_E/E ~ 0.084%, τ ~ 50 ms, ε_h = 112nm
  - α_p = 0.0113
  - β_v^* = 12mm
  - Then σ_l = 12mm => Q_s= 0.091
- Imagine, momentum compaction so reduced that
  - σ_l = 12mm => Q_s= 0.049 / Q_s =0.091 => σ_l = 7.3mm
- To achieve this miracle insert element

$$M = \begin{bmatrix} I & 0 & 0 \\ 0 & I & 0 \\ 0 & 0 & \begin{matrix} 1 & 6 \\ 0 & 1 \end{matrix} \end{bmatrix}$$

Longitudinal emittance

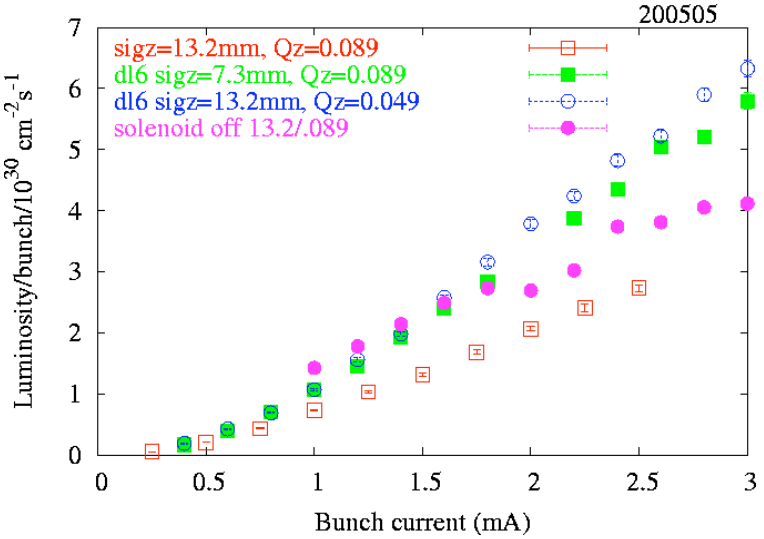
- 12 wigglers, 1.89GeV/beam
  - σ_E/E ~ 0.084%, τ ~ 50 ms, ε_h = 120nm
  - α_p = 0.0113
  - β_y^* = 12mm
  - Then σ_l = 12mm => Q_s= 0.089
- Element M inserted in ring opposite IP
  - Then σ_l = 12mm => Q_s= 0.049 or Q_s =0.089 => σ_l = 7.3mm

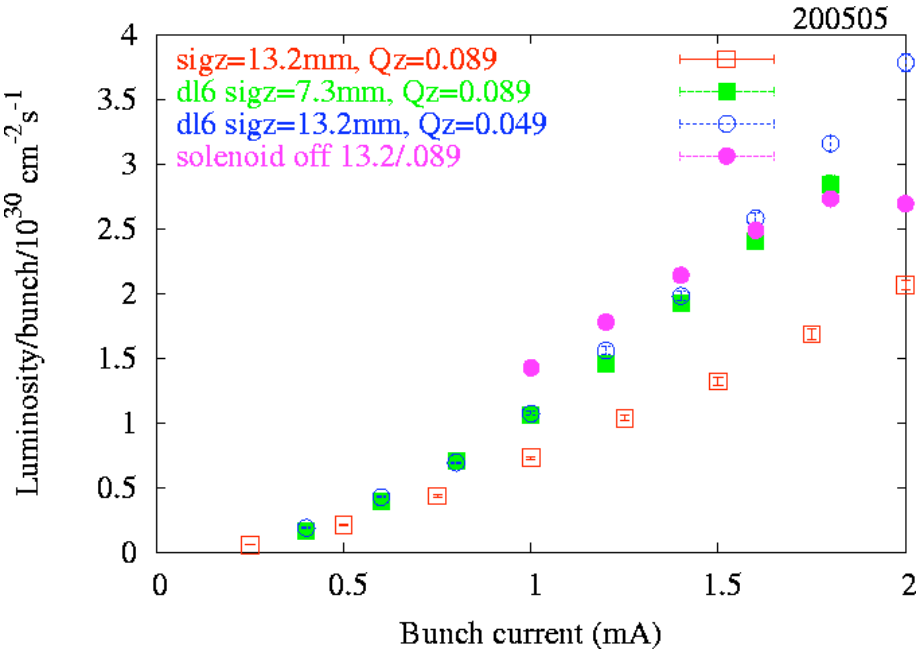




Longitudinal emittance

- Reduced momentum compaction and no solenoid





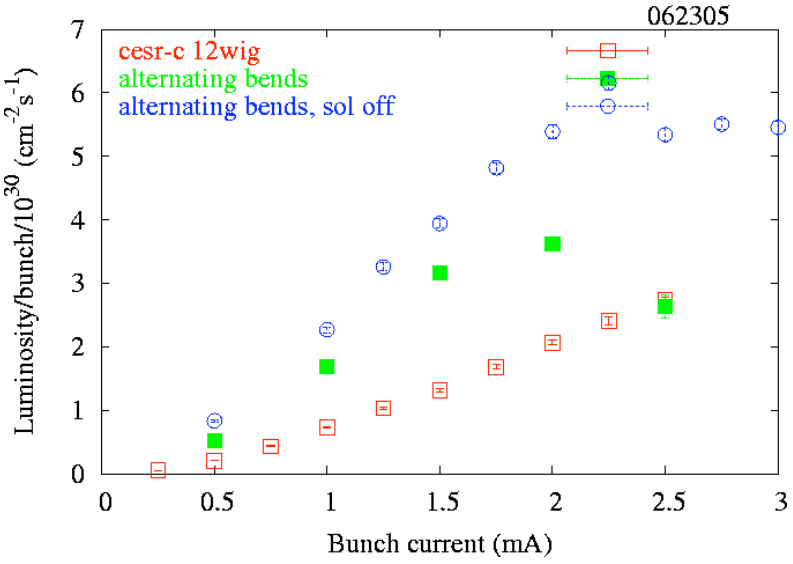
Longitudinal emittance

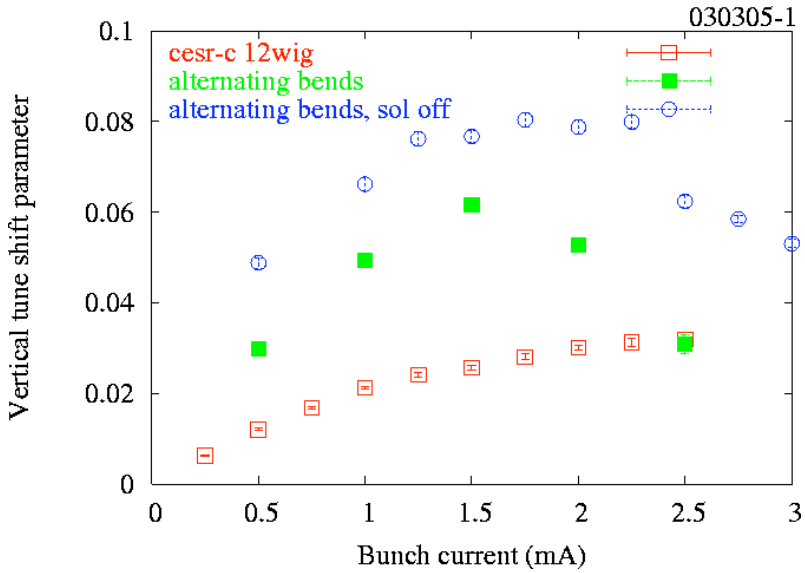
- 0 wigglers, 1.89GeV/beam, alternating bends
  - Replace each CESR dipole with 5 sections of alternating field
    -where the length of each section is 1/5 CESR dipole
    -and B = $5B_{cesr}$
    no change in bending angle

- Then
  - $\sigma_E/E \sim 0.0386\%$, $\tau \sim 43$ ms, $\varepsilon_h = 64$nm (CESR-c, $\varepsilon_h = 120$nm)
  - $\alpha_p = 0.0108$
  - $\beta_v^* = 12$mm
  - Then $\sigma_l = 5.8$mm => $Q_s = 0.089$

Longitudinal emittance

- 0 wigglers, 1.89GeV/beam, alternating bends
  - σ_E/E ~ 0.0386%, τ ~ 43 ms, ε_h = 64nm
  - α_p = 0.0108
  - β_y^* = 12mm
  - Then σ_l = 5.8mm => Q_s= 0.089



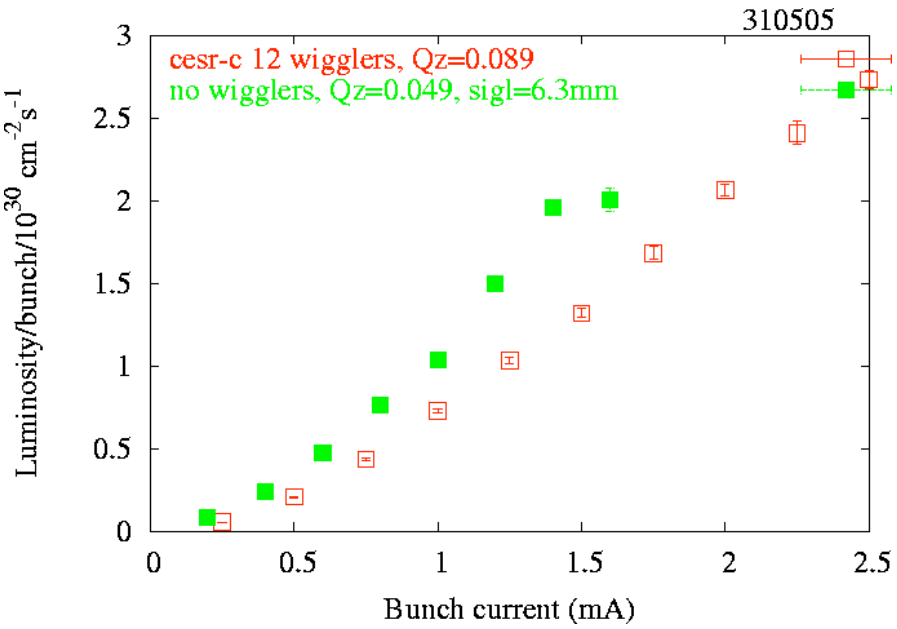


Longitudinal emittance

- Luminosity and damping decrement
- CESR-c, wigglers off, 1.89GeV/beam
  - σ_E/E ~ 0.022%, τ ~ 556 ms, ε_h = 20nm (CESR-c, ε_h = 120nm)
  - ε_p = 0.0111
  - β_v^* = 12mm
  - Then Q_s= 0.049 => σ_l = 6.2mm

Longitudinal emittance

- 0 wigglers, 1.89GeV/beam
  - σ_E/E ~ 0.022%, τ ~ 556 ms, ε_h = 20nm
  - α_p = 0.0111
  - β_v^* = 12mm
  - Then σ_l = 6.2mm => Q_s= 0.049
  - Current limited by low emittance < 1.4mA



Luminosity lifetime
< 2minutes at 1.4mA

Summary

- Weak strong simulation of luminosity in good agreement with measurement
- Specific luminosity (L/I) at low current is insensitive to:
  - Wiggler nonlinearity
  - Pretzel/crossing angle
  - Parasitic crossings
  - Radiation damping time
- Simulation of lifetime indicates limit is parasitic beam beam interactions. Particles are lost to horizontal aperture
- Strong dependence on energy spread/bunch length/synchrotron tune
  - Energy dependence of solenoid compensation dilutes vertical emittance
  - Long bunch/ High synchrotron tune limit beambeam tune shift