Simulating e-cloud induced coherent tuneshifts using POSINST: first results

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Coherent tuneshifts are calculated from 3D averages of e-field over bunch density

\[ \Delta y' = \Delta s \left( \frac{d^2 y}{ds^2} \right)_{EC} = \frac{q}{v_0 p_0} E_y(x, y, s = s_i; t), \]

Kick received by bunch particle at eCloud station \( s = s_i \)

Equation of motion for centroid of k-bunch in train

\[ \frac{d^2 \langle y_k \rangle}{ds^2} + \kappa_y(s) \langle y_k \rangle = \frac{q}{v_0 p_0} \sum_{i=1}^{k} \delta(s - s_i) \Delta s_i \int dx dy dz E_y(x, y, s_i; k, z) \rho_k(x, y, z). \]

Assume interaction with eCloud is dominated by first moments (centroids) of bunches

\[ \frac{q}{v_0 p_0} \int dx dy dz E_y(x, y, s_i; k, z) \rho_k(x, y, z) \simeq \sum_{j=1}^{k} C_{kk}^{(i)} \langle y_j \rangle. \]

Assume coupling coefficient are diagonal

Coefficient is supposed to be independent of centroid offset

Tuneshift contribution from eCloud station \( s = s_i \)

\[ \Delta \nu_y(k) = \frac{1}{4 \pi} \beta_y(s_i) \Delta \kappa_y(s_i) \Delta s \]

\[ \Delta \kappa_y(s_i) = -C_{kk}^{(i)}. \]
Recent POSINST developments

- POSINST has already the capability of determining eCloud induced wake fields by displacing bunches in train one at the time.
  - e-fields generated by e\(^{-}\) calculated using Bassetti-Erskine like formulas (and summing over all electrons) – some approximation to handle image charges.
  - no average on z

- Extend existing capability
  - by allowing for offset of all bunches in train at once
  - for efficiency, option to use for e-fields the solution to the Poisson equation that POSINST already employs to calculate electrons-to-electron space-charge kick
  - do averaging over x,y; option to average over z of bunch densities
  - introduce option to have a witness bunch following bunch train (with same charge as the other bunches). It is possible to have the witness bunch span trailing region in a single run w/o need to start anew.
  - output is
    - Ex and Ey averaged in x and y as a function of z (for each slice)
    - Ex and Ey averaged over x,y, and z for each train bunch and witness bunch
    - Tuneshifts determined by post-processing POSINST output
Simulations Parameters, etc.

- Use CesrTA tuneshift measurement setting of April/2007 (POSINST input deck set up and kindly provided by G. Dugan)
- 1.885 GeV; 11 bunch trains with uniform 14 ns bunch spacing; 0.75 mA/bunch

- In simulations I mostly used SEY=2 and reflectivity 15% (I did some exploration of sensitivity of results to values of these parameters)
- For speed I mostly used 31 kicks (or bunch slices); not big differences found when using 51 kicks.
- 10,000 photo(macro)electrons

- Following simulation results are for positron bunches in DRIFTS and Soft-DIPOLES (for relevant parameters like beta functions, radiation deposition, etc. see spreadsheet LatticeRadiationWeights.xls by G. Dugan)
DRIFTS
**DRIFT:: Vertical motion:**

$<E_y>$ vs. $dy=<y>$ is about linear
**DRIFT:: Vertical** motion: tuneshift largely independent of leading bunches offset

**Only 6th bunch has y-offset**

- $E=1.888$ GeV
- 31 kicks
- bunch spacing = 14 ns
- $\delta_{\text{max}}=2$
- $N_{\text{mp}}=10^4$
- Poisson method = 2
- $d_y=5$ mm

**All bunches have same y-offset**

- $E=1.888$ GeV
- 31 kicks
- bunch spacing = 14 ns
- $\delta_{\text{max}}=2$
- $N_{\text{mp}}=10^4$
- Poisson method = 2
- $d_y=5$ mm

Offset: $dy=5$ mm
DRIFT:: **Vertical** motion: tuneshift not very sensitive to value of reflectivity

Reflectivity 30%

Reflectivity 15%

$\Delta Q_y$ (kHz)

bunch no.

 CESR-TA/POISON/shift

E=1.888 GeV
31 kicks
bunch spacing = 14 ns
$\delta_{\text{max}} = 2$
$N_{\text{mp}} = 10^4$
Poisson method = 2
d$_y$ = 5 mm

$\Delta Q_y$ (kHz)

bunch no.

 CESR-TA/POISON/shift

E=1.888 GeV
31 kicks
bunch spacing = 14 ns
$\delta_{\text{max}} = 2$
$N_{\text{mp}} = 10^4$
Poisson method = 2
d$_y$ = 5 mm
DRIFT:: **Vertical** motion: using 32 or 51 kicks yields about the same results

**51 kicks**

- $E = 1.888$ GeV
- 51 kicks
- bunch spacing = 14 ns
- $\delta_{\text{max}} = 2$
- $N_{\text{mp}} = 10^4$
- Poisson method = 2
- $d_y = 5$ mm

**31 kicks**

- $E = 1.888$ GeV
- 31 kicks
- bunch spacing = 14 ns
- $\delta_{\text{max}} = 2$
- $N_{\text{mp}} = 10^4$
- Poisson method = 2
- $d_y = 5$ mm
DRIFT:: Vertical motion: dependence on SEY apparent only in last bunches of train

- SEY = 1.6
- SEY = 1.8
- SEY = 2.0
- SEY = 2.2
**DRIFT::** Horizontal motion: $<\text{Ex}>$ is not anti-symmetric under inversion of dx sign

**Tuneshift calculated as**

$$\Delta Q_x = -(<\text{Ex}(dx)> - <\text{Ex}(-dx)>)/(2dx)$$

Max $\Delta Q_x$ about $1/5$ of max $\Delta Q_y$
**DRIFT::** Horizontal motion: \(<Ex>\) is about independent of \(dx\) over first 2-3 bunches.

**<Ex> for dx=-0.5mm offset**

- \(E=1.888\ \text{GeV}\)
- 31 kicks
- bunch spacing = 14ns
- \(\delta_{\text{max}}=2\)
- \(N_{\text{mp}}=10^4\)
- Poisson method = 2
- \(d_x=-0.5\text{mm}\)

**<Ex> for dx=-5mm offset**

- \(E=1.888\ \text{GeV}\)
- 31 kicks
- bunch spacing = 14ns
- \(\delta_{\text{max}}=2\)
- \(N_{\text{mp}}=10^4\)
- Poisson method = 2
- \(d_x=-5\text{mm}\)
**DRIFT:** Horizontal motion: confirm insensitivity to reflectivity as in the $y$-plane.

- Reflectivity = 30%
  - $E = 1.888$ GeV
  - 31 kicks
  - bunch spacing = 14 ns
  - $\delta_{\text{max}} = 2$
  - $N_{\text{mp}} = 10^4$
  - Poisson method = 2
  - $d_x = \pm 5$ mm
  - refl. = 0.3

- Reflectivity = 15%
  - $E = 1.888$ GeV
  - 31 kicks
  - bunch spacing = 14 ns
  - $\delta_{\text{max}} = 2$
  - $N_{\text{mp}} = 10^4$
  - Poisson method = 2
  - $d_x = \pm 5$ mm
DRIFT:: Horizontal motion: some sensitivity to presence/absence of offset in leading bunches.

Only 6th bunch has x-offset

Only 11th bunch has x-offset

All bunches have same x-offset

<table>
<thead>
<tr>
<th></th>
<th>All bunches offset</th>
<th>Only 6th bunch offset</th>
<th>Only 11th bunch offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>6th</td>
<td>ΔQx=0.065</td>
<td>ΔQx=0.013</td>
<td></td>
</tr>
<tr>
<td>11th</td>
<td>ΔQx=0.100</td>
<td></td>
<td>ΔQx=0.062</td>
</tr>
</tbody>
</table>
Soft DIPOLES
Soft DIPOLE: Vertical motion: tuneshift sensitive to value of reflectivity

Reflectivity 30%

Reflectivity 15%

- $E = 1.888$ GeV
- 51 kicks
- bunch spacing = 14ns
- $\delta_{\text{max}} = 2$
- $N_{mp} = 10^4$
- Poisson method = 2
- $d_y = 5$ mm
- refl. = 0.3

Reflectivity 15%

- $E = 1.888$ GeV
- 51 kicks
- bunch spacing = 14ns
- $\delta_{\text{max}} = 2$
- $N_{mp} = 10^4$
- Poisson method = 2
- $d_y = 5$ mm
- refl. = 0.15
Soft DIPOLE:: **Vertical** motion: data points become more scattered when offset is smaller

**dy=5mm**

- $E=1.888$ GeV
- 51 kicks
- bunch spacing = 14 ns
- $\delta_{\text{max}}=2$
- $N_{\text{mp}}=10^4$
- Poisson method = 2
- $d_y=5$ mm
- refl. = 0.18

**dy=1mm**

- $E=1.888$ GeV
- 51 kicks
- bunch spacing = 14 ns
- $\delta_{\text{max}}=2$
- $N_{\text{mp}}=10^4$
- Poisson method = 2
- $d_y=1$ mm
- refl. = 0.15

**dy=0.5mm**

- $E=1.888$ GeV
- 51 kicks
- bunch spacing = 14 ns
- $\delta_{\text{max}}=2$
- $N_{\text{mp}}=10^4$
- Poisson method = 2
- $d_y=0.5$ mm
- refl. = 0.15
Soft DIPOLE:: **Vertical** motion: insensitivity to offset of leading bunches

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**Graphs:**

- **All bunches are offset (dy=-0.5mm):**
  - E=1.888 GeV
  - 51 kicks
  - bunch spacing=14 ns
  - $\delta_{\text{max}}=2$
  - $N_{\text{mp}}=10^4$
  - Poisson method=2
  - $d_y=5 \text{ mm}$
  - refl.=0.3

- **Only 6th bunch is offset (dy=-0.5mm):**
  - E=1.888 GeV
  - 51 kicks
  - bunch spacing=14 ns
  - $\delta_{\text{max}}=2$
  - $N_{\text{mp}}=10^4$
  - Poisson method=2
  - $d_y=-5 \text{ mm}$
  - refl.=0.3
Soft DIPOLE: \( \text{Horizontal} \) motion: max x-tuneshift about 1/7 of max y-tuneshift

**Horizontal Tuneshift**

- \( E = 1.888 \text{ GeV} \)
- 51 kicks
- bunch spacing = 14ns
- \( \delta_{\text{max}} = 2 \)
- \( N_{\text{mp}} = 10^4 \)
- Poisson method = 2
- \( d_x = +/− 5\text{mm} \)
- refl. = 0.15

**Vertical Tuneshift**

- \( E = 1.888 \text{ GeV} \)
- 51 kicks
- bunch spacing = 14ns
- \( \delta_{\text{max}} = 2 \)
- \( N_{\text{mp}} = 10^4 \)
- Poisson method = 2
- \( d_y = 5\text{mm} \)
- refl. = 0.15
Soft DIPOLE: Horizontal motion: data points look more scattered at smaller offset.

(dx=+/− 5mm)

(dx=+/− 0.5mm)

E=1.888 GeV
51 kicks
bunch spacing=14 ns
N_{mp}=10^4
Poisson method=2
d_{x} =+/− 5 mm
refl.=0.15

CESR-TA/POSINST/r-dipole

CEL Q_x (kHz)

bunch no.

0.1

0.05

0

−0.05

−0.1

0.1

0.05

0

−0.05

−0.1

0.1

0.05

0

−0.05

−0.1

0.1

0.05

0

−0.05

−0.1

0.1

0.05

0

−0.05

−0.1

0.1

0.05

0

−0.05

−0.1

0.1

0.05

0

−0.05

−0.1

0.1

0.05

0

−0.05

−0.1

0.1

0.05

0

−0.05

−0.1

0.1

0.05

0
Soft DIPOLE:: **Horizontal** motion: tuneshift is sensitive to offset in leading bunches.

- **All bunches are offset** (dy=+/- 0.5mm)

- **Only 6th bunch is offset** (dy=+/- 0.5mm)

Reflectivity=30%