Jitter amplification in booster linac

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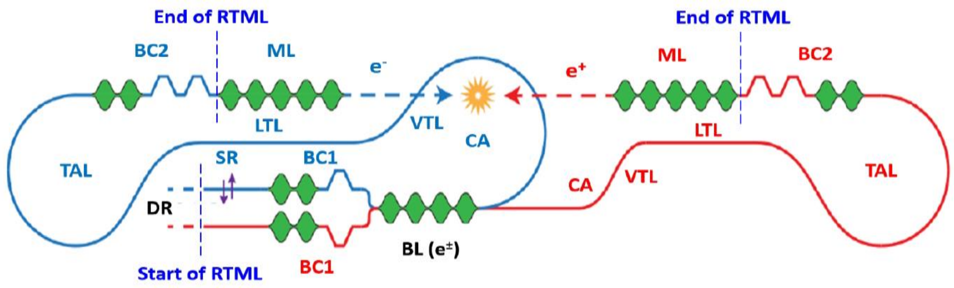
For discussion only

25/09/2024

Introduction

- CLIC RTML layout



- Baseline Booster Linac (BL) lattice
  - CLIC "L-band" structure
  - 8 structures per FODO cell
  - Distance between quadrupoles: 7.5 m
  - 272 structures. G = 15.089 MV/m

- Beam parameters

Parameter	Unit	Entrance	Exit
Number of bunches per train		352	
Number of particles per bunch		5.2×10^9	
Beam energy	GeV	2.86	9
Bunch length (σ_z)	μm	1800	$\sim$70
Energy spread (σ_E/E)	%	0.12	< 1.7
Horizontal emittance ($\epsilon_{n,x}$)	nm·rad	700	< 800
Vertical emittance ($\epsilon_{n,y}$)	nm·rad	5	< 6

- Emittance budgets (full RTML)

Emittance budgets	$\epsilon_{n,x}$	$\epsilon_{n,y}$
Perfect machine	< 800	< 6
Static imperfections	< 820	< 8
Static and dynamic imperfections	< 850	< 10

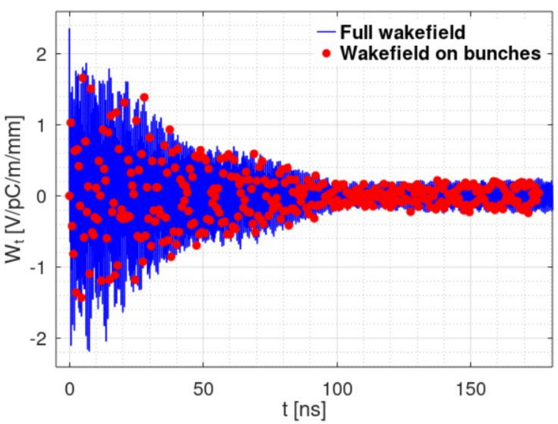
- CLIC "L-band" structure parameters

Parameter	Unit	BC1
Structure name		CLIC L-band
RF frequency	GHz	1.999
Structure length	m	1.5
Number of cells		30
Phase advance per cell	°	120
Working RF phase	°	90
First iris radius	mm	20
Last iris radius	mm	14
First iris thickness	mm	8
Last iris thickness	mm	8

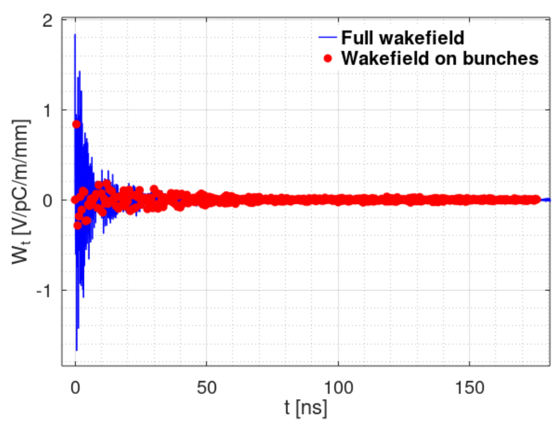
Long-range wakefield

- Using wakefields directly from Adnan:
  - Version 0: Wakefield not used
  - ~~Version 1: a0 = 13 mm. Wakefield with sum(|Wt|) = 93.38 V/pC/m/mm~~
  - Version 2: a0 = 15 mm. Wakefield with sum(|Wt|) = 9.86 V/pC/m/mm
  - Version 3: a0 = 16 mm. Wakefield with sum(|Wt|) = 9.36 V/pC/m/mm

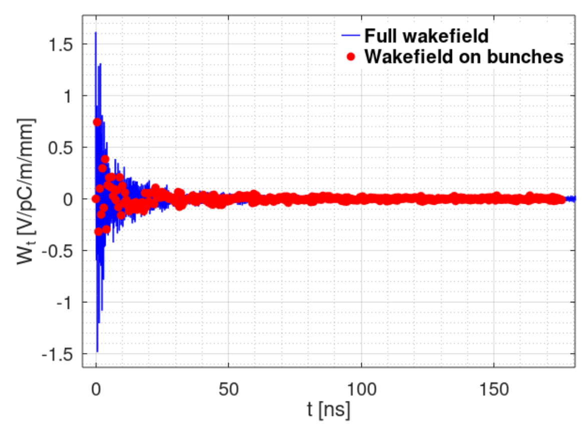
Version 1



Version 2



Version 3

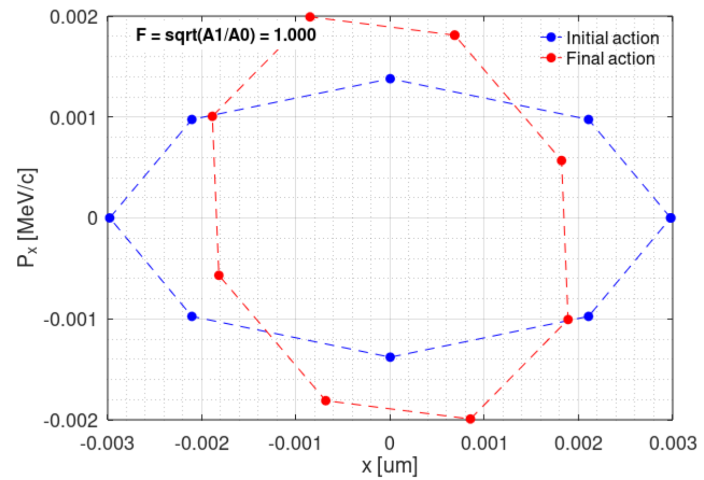


Coherent jitter

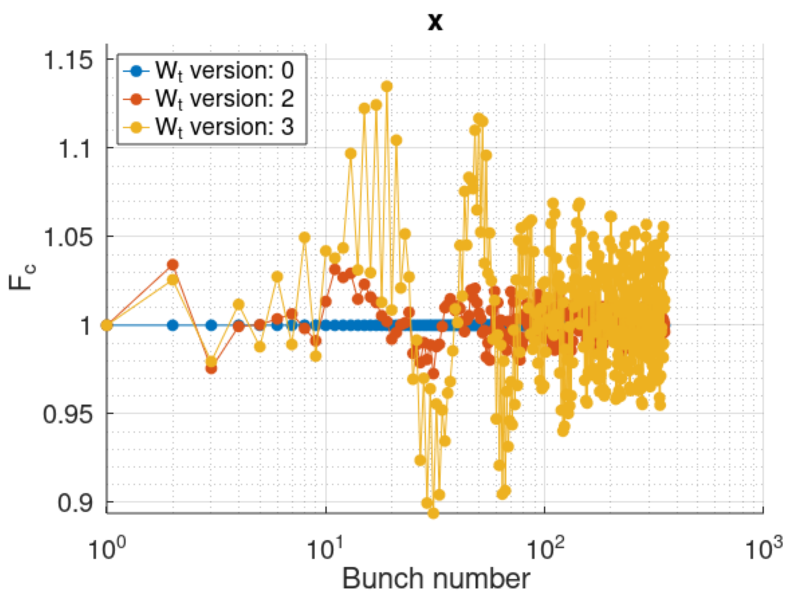
- **Single particle tracking** simulation
- Jitter considered: J = **10%** * σ(x, px)
- 8 trains evenly spaced on ellipse
- 352 bunches per train
- Jitter amplification factor (F) definition in this case:

$$F_c = \frac{F_{W\neq 0}}{F_{W=0}} \text{ , where } F = \max_{\text{bunches}}\left(\frac{J_{\text{final}}}{J_{\text{initial}}}\right) = \max_{\text{bunches}}\left(\sqrt{\frac{A_{\text{final}}}{A_{\text{initial}}}}\right)$$

Action of last bunch, wakefield not used



A: action (area of ellipse)



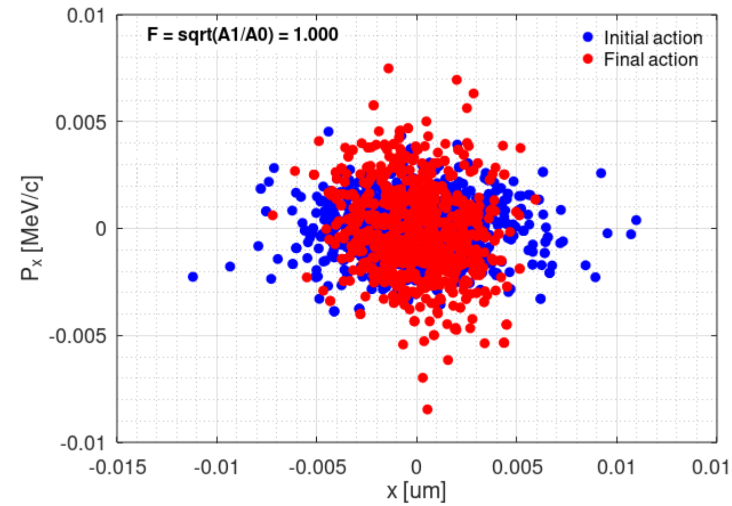
Version	Average F	Maximum F
2	1.001	1.034
3	1.007	1.135

Incoherent jitter

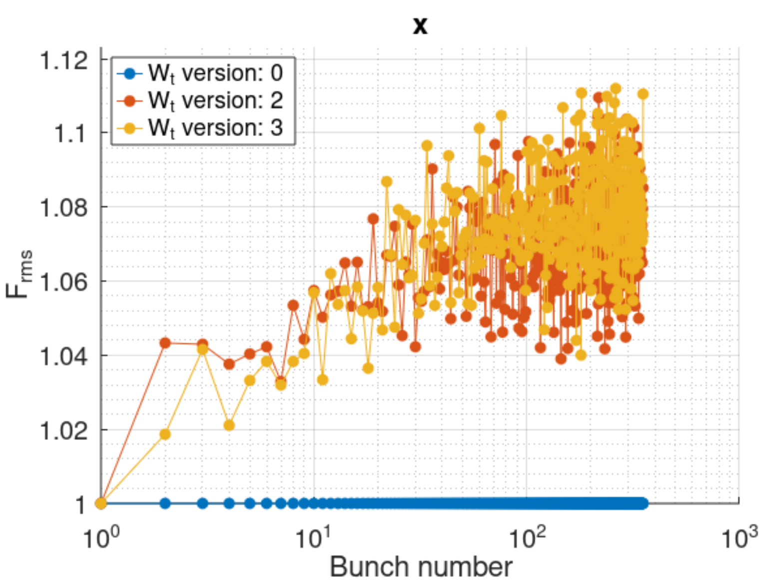
- **Single particle tracking** simulation
- Jitter considered: J = **10%** * σ(x, px)
- 1000 trains randomly spaced in phase space
- 352 bunches per train
- Jitter amplification factor (F) definition in this case:

$$F_{\text{rms}} = \frac{F_{W\neq 0}}{F_{W=0}} \text{ , where } F = \frac{1}{N_{\text{bunches}}} \sum \frac{J_{\text{final}}}{J_{\text{initial}}} = \frac{1}{N_{\text{bunches}}} \sum \sqrt{\frac{A_{\text{final}}}{A_{\text{initial}}}}$$

Action of last bunch, wakefield not used



A: action (area of ellipse)



Version	Average F	Maximum F
2	1.070	1.110
3	1.076	1.112

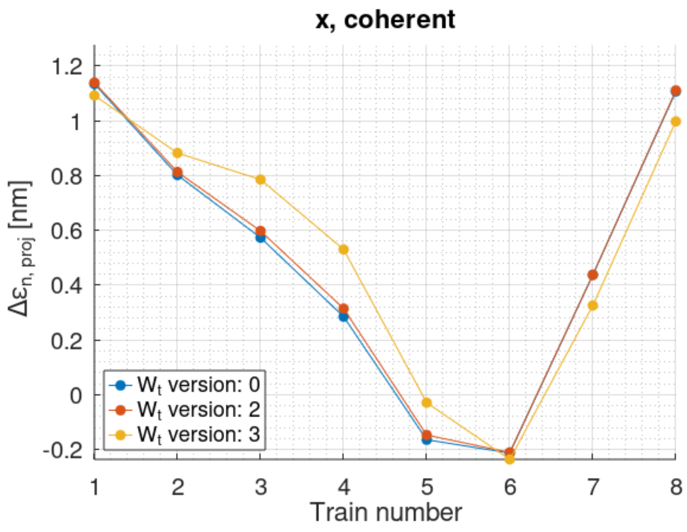
Full bunch tracking

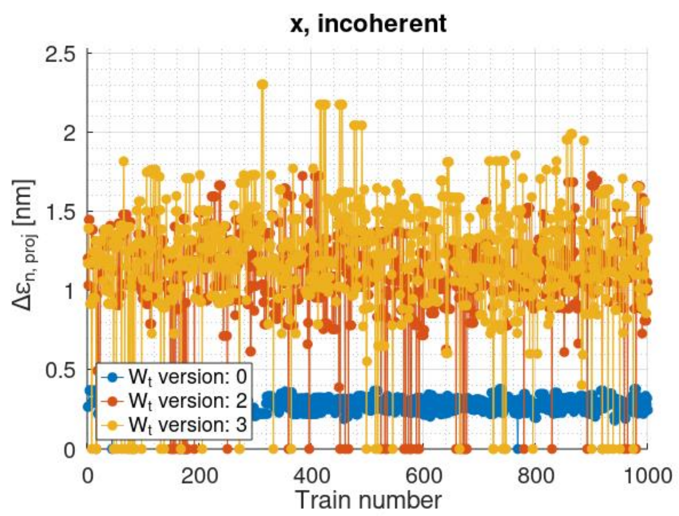
- Full bunch tracking also performed
- Consistent with single particle tracking

Jitter amplification	V2 (a0 = 15 mm)	V3 (a0 = 16 mm)
Single particle tracking, max(F_c)	1.034	1.135
Full bunch tracking, max(F_c)	1.035	1.140
Single particle tracking, mean(F_{rms})	1.070	1.076
Full bunch tracking, mean(F_{rms})	1.073	1.081

- Conclusions:
  - a0 = 15 mm has smaller jitter amplifications than a0 = 16 mm
  - F_c ~ 1.03, F_{rms} ~ 1.07

Projected emittance growth





Projected emittance growth [nm]	V0 (no wake)	V2 (a0 = 15 mm)	V3 (a0 = 16 mm)
Coherent, average	0.5	0.5	0.5
Coherent, maximum	1.1	1.1	1.1
Incoherent, average	0.3	1.1	1.2
Incoherent, maximum	0.4	1.7	2.3
Incoherent, average (calculated)	0	1.0	1.2

Consistent with calculation!

- Calculated incoherent emittance growth:

$$\Delta\varepsilon_{\mathbf{projected}} = \varepsilon_{\mathbf{projected}}^{\mathbf{final}} - \varepsilon_{\mathbf{projected}}^{\mathbf{ininal}} = \varepsilon_0 \cdot \left(1 + J_1^2\right) - \varepsilon_0 \cdot \left(1 + J_0^2\right) = \varepsilon_0 \cdot J_0^2 \cdot \left(F^2 - 1\right)$$

Conclusions

- Latest wakefield from Adnan looks much better now. a0 = 15 mm is better than a0 = 16 mm
- Jitter amplifications: F_c ~ 1.03, F_{rms} ~ 1.07, which is small
- Projected emittance growth (full train): ~1.1 nm, which is small and consistent with the calculation

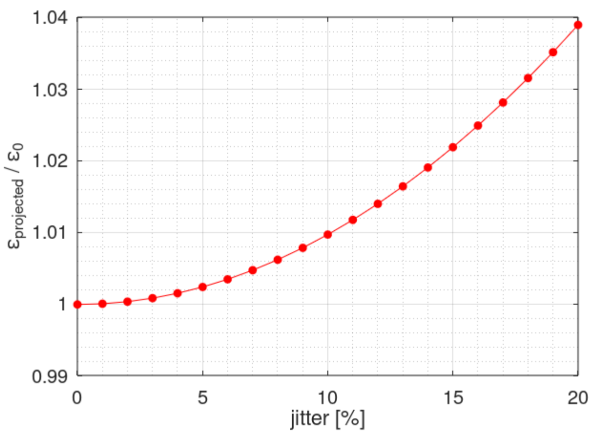
BACKUP

Jitter tolerance

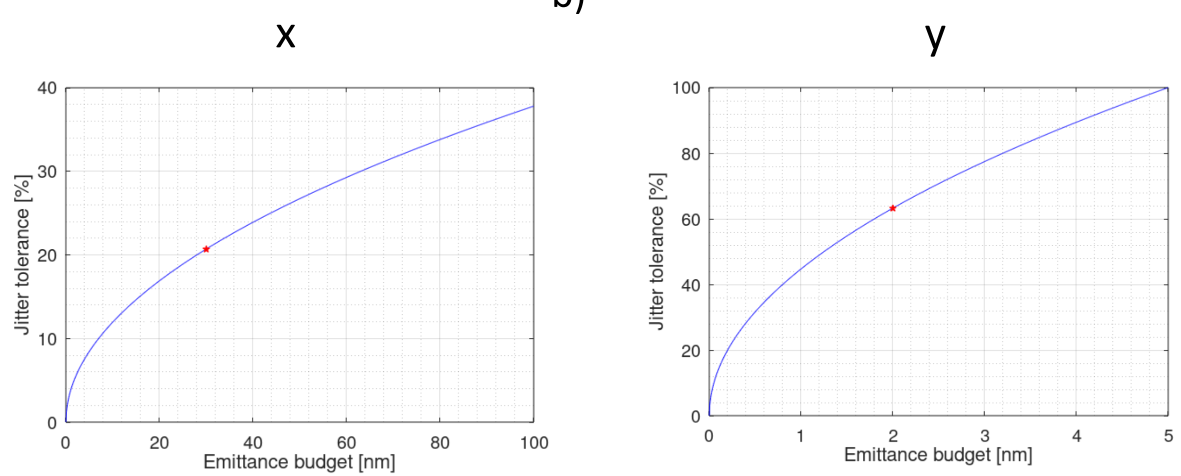
Test 0

- No tracking. Average of 5 randomly jittered trains (352 random bunches per train)
- Plotting
  - a) projected emittance growth as a function of jitter
  - b) jitter tolerance for x & y

a)



b)



Jitter tolerance definition in this case:

$$\Rightarrow \frac{\boldsymbol{\varepsilon}_{\mathbf{projected}}}{\boldsymbol{\varepsilon}_{\mathbf{0}}} \approx \mathbf{1} + \mathbf{J}^{\mathbf{2}}$$

$$\Rightarrow J \approx \sqrt{\frac{\boldsymbol{\varepsilon}_{\mathbf{projected}}}{\boldsymbol{\varepsilon}_{\mathbf{0}}} - \mathbf{1}}$$

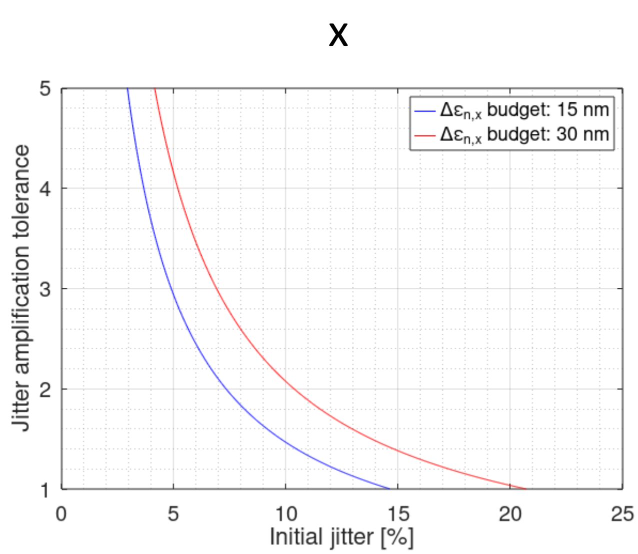
$$\Rightarrow J_{\mathbf{max}} = \sqrt{\frac{\boldsymbol{\varepsilon}^{\mathbf{max}}_{\mathbf{projected}}}{\boldsymbol{\varepsilon}_{\mathbf{0}}} - \mathbf{1}} = \sqrt{\frac{\Delta\boldsymbol{\varepsilon}^{\mathbf{max}}_{\mathbf{projected}}}{\boldsymbol{\varepsilon}_{\mathbf{0}}}} = \sqrt{\frac{\mathbf{Budget}}{\boldsymbol{\varepsilon}_{\mathbf{0}}}}$$

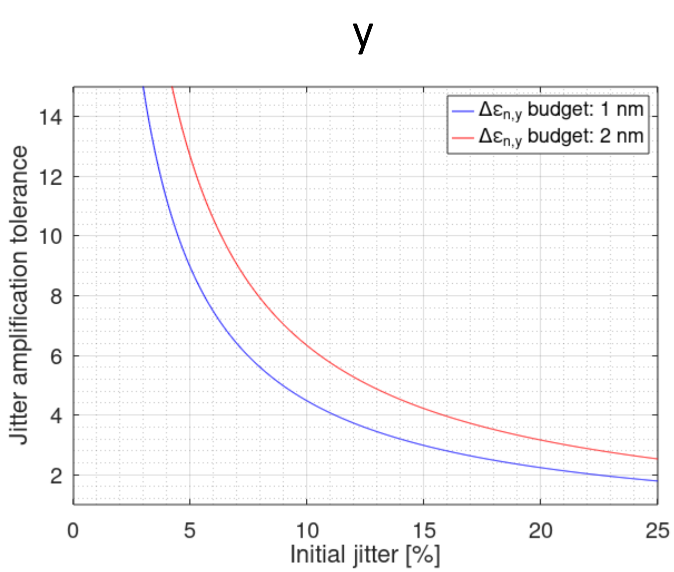
➡ **$J_{x,max}$ ~ 20%, $J_{y,max}$ ~ 60% (for given budgets)**

Test 0

- No tracking. Average of 5 randomly jittered trains (352 random bunches per train)
- Plotting
  - c) jitter amplification tolerance for x & y

c)





Jitter amplification tolerance definition in this case:

$$\Rightarrow \quad F = \frac{J_{\max}}{J_{\text{initial}}} = \sqrt{\frac{\text{Budget}}{\varepsilon_0 \cdot J_{\text{initial}}^2}} \quad \Rightarrow$$

$F_{x,max}$ ~ 4, $F_{y,max}$ ~ 12 @ $J_{initial}$ = 0.05 (budgets: 30 nm, 2 nm)

$F_{x,max}$ ~ 2, $F_{y,max}$ ~ 5 @ $J_{initial}$ = 0.1 (budgets: 30 nm, 2 nm)

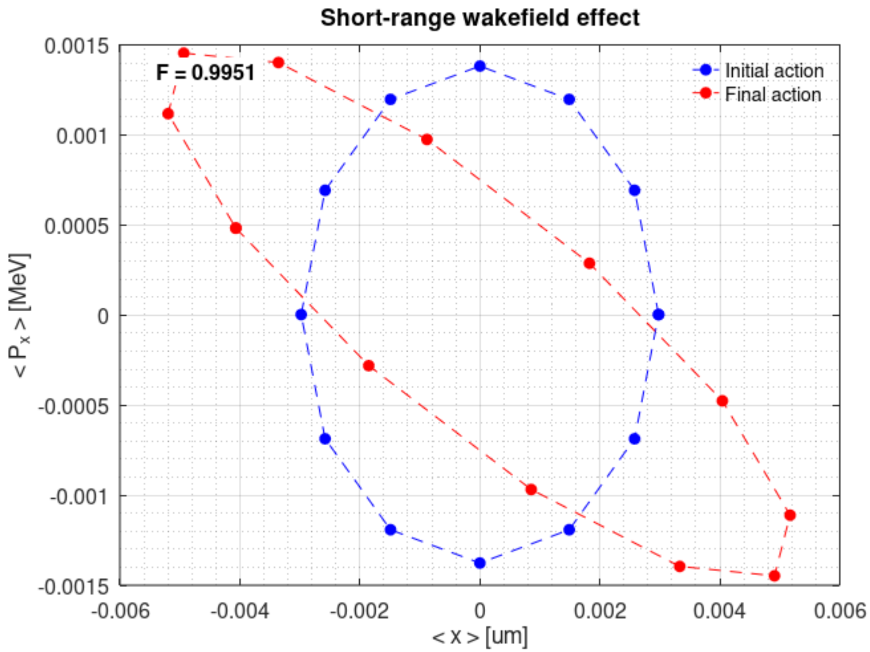
Short-range wakefield effect

Test 1

- **Short-range** wakefield effect in BL. Full **single bunch tracking simulation**
- Jitter considered: J = 10% * σ(x,px)
- Jitter amplification factor definition in this case:

$$F_s = \frac{J_{\text{final}}}{J_{\text{initial}}} = \sqrt{\frac{A_{\text{final}}}{A_{\text{initial}}}}$$

J: jitter, A: action (area)



- W/o SRWF, zero E spread: $F_{x,s}$ = 1.0000
- W/o SRWF, 1.2% E spread: $F_{x,s}$ = 0.9862
  - E spread helps to damp the effect (BNS damping)
- W/ SRWF, 1.2% E spread: **$F_{x,s}$ = 0.9951** (Nominal)

Long-range wakefield effect – kick on next bunch only

Test 2.0

- **Long-range** wakefield effect in BL. **Single particle calculation using Daniel's formulae**
- Transverse **kick on next bunch only (a_k = 0 when k ≠ 1)**
- Jitter amplification factor definition in this case:

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MULTI-BUNCH CALCULATIONS IN THE CLIC MAIN LINAC

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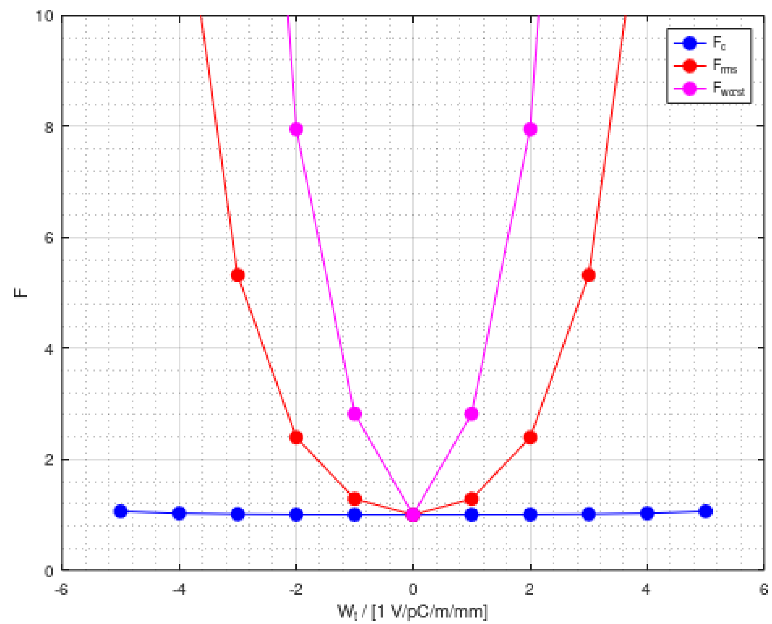
$$A = \lim_{m\to\infty}\left(1+\frac{a}{m}\right)^m = \exp(a) = \sum_{k=0}^{\infty}\frac{a^k}{k!} = \sum_{k=0}^{n-1}\frac{a^k}{k!}$$

$$a_k = \sum_i \frac{L_i\beta_i}{2E_i}W(z_k)Ne^2$$

$$F_c = \frac{1}{n}\sum_k\left|\sum_j A_{kj}\right|^2$$

$$F_{rms} = \frac{\sum_{k=0}^{n-1}\sum_{j=1}^{k} A_{k,j}A^*_{k,j}}{n}$$

F_{worst} = svd(A)(1)^2



$F_{x,c}$ = 1.062 @ ±5 V/pC/m/mm

$F_{x,rms}$ = 31.9 @ ±5 V/pC/m/mm

$F_{x,worst}$ = 178.4 @ ±5 V/pC/m/mm

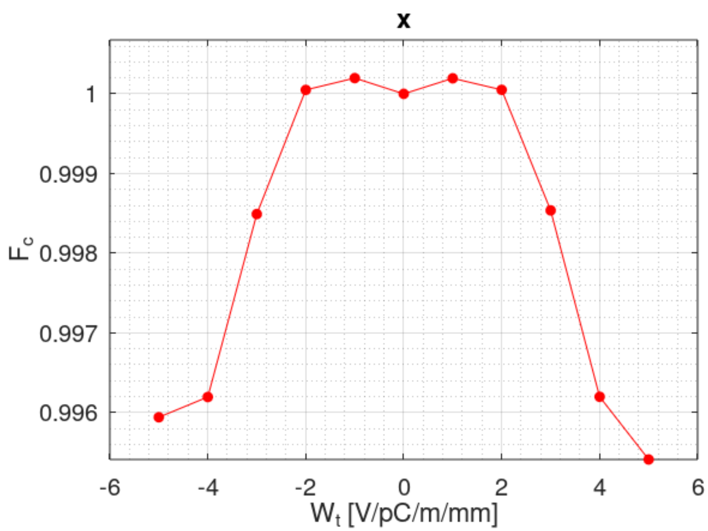
Test 2.1.1a

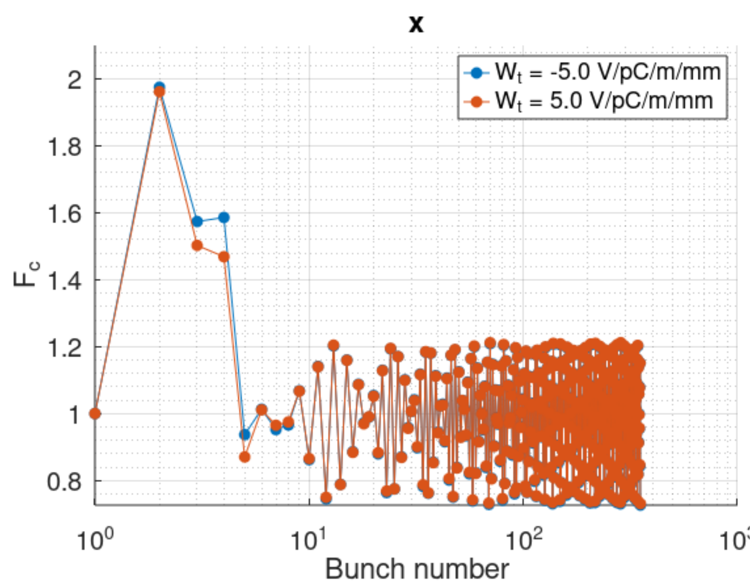
- **Long-range** wakefield effect in BL. **Single particle tracking simulation**
- Jitter considered: J = 0.10, that is, <x,px> = 0.10*σ(x,px)
- Transverse **kick on next bunch only**. **Coherent** jitter with 8 specific trains (like Test 1)
- Jitter amplification factor definition in this case:

Using average F of all bunches

$$F_c = \frac{F_{W\neq 0}}{F_{W=0}} \text{ , where } F = \frac{1}{N_{\text{bunches}}}\sum\frac{J_{\text{final}}}{J_{\text{initial}}} = \frac{1}{N_{\text{bunches}}}\sum\sqrt{\frac{A_{\text{final}}}{A_{\text{initial}}}}$$

A: action (area)





$F_{x,c}$ ~ 0.996 @ ±5 V/pC/m/mm

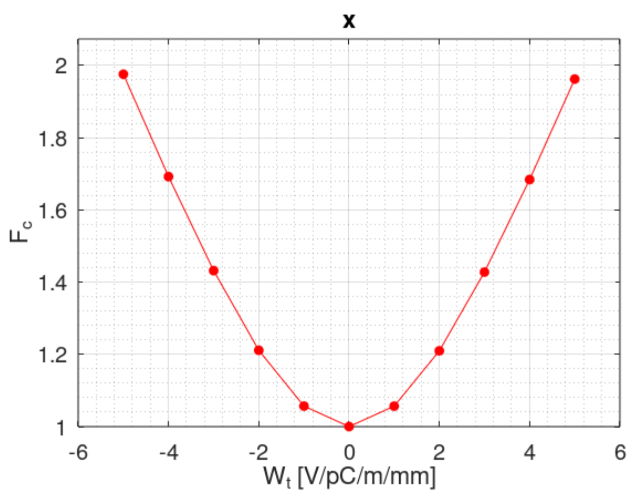
Test 2.1.1b

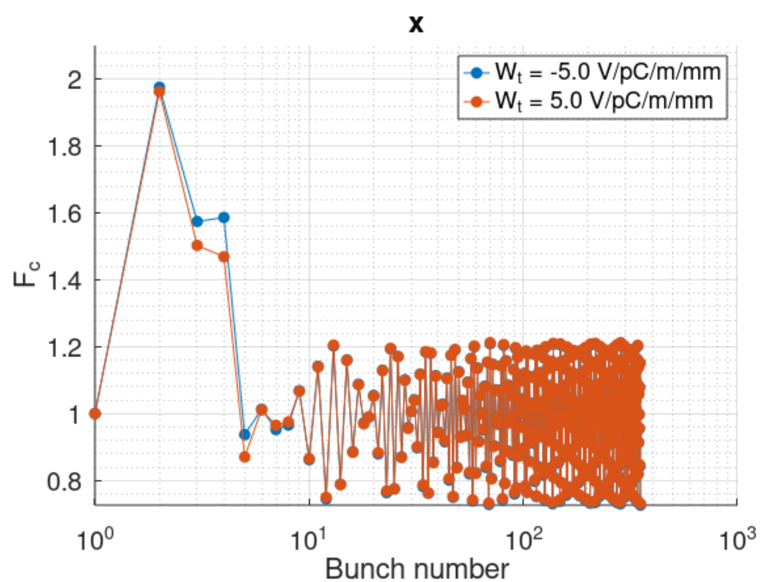
- **Long-range** wakefield effect in BL. **Single particle tracking simulation**
- Jitter considered: J = 0.10, that is, <x,px> = 0.10*σ(x,px)
- Transverse **kick on next bunch only**. **Coherent** jitter with 8 specific trains (like Test 1)
- Jitter amplification factor definition in this case:

Using maximum F of all bunches

$$F_c = \frac{F_{W\neq0}}{F_{W=0}} \text{ , where } F = \max_{\text{bunches}}\left(\frac{J_{\text{final}}}{J_{\text{initial}}}\right) = \max_{\text{bunches}}\left(\sqrt{\frac{A_{\text{final}}}{A_{\text{initial}}}}\right)$$

A: action (area)





$F_{x,c}$ ~ 2.0 @ ±5 V/pC/m/mm

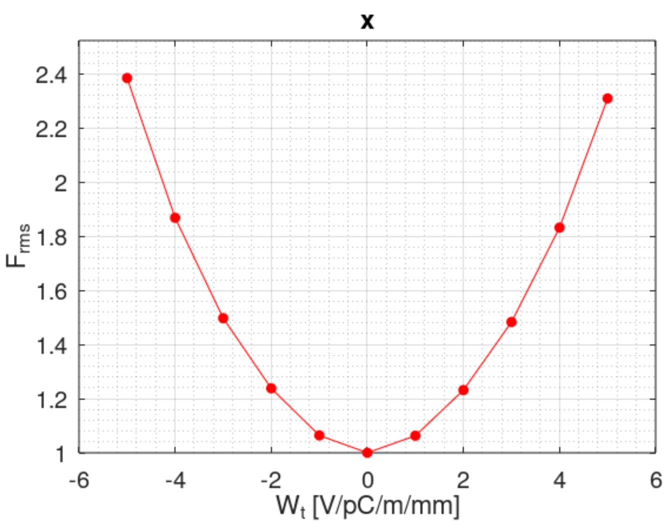
Test 2.1.2a

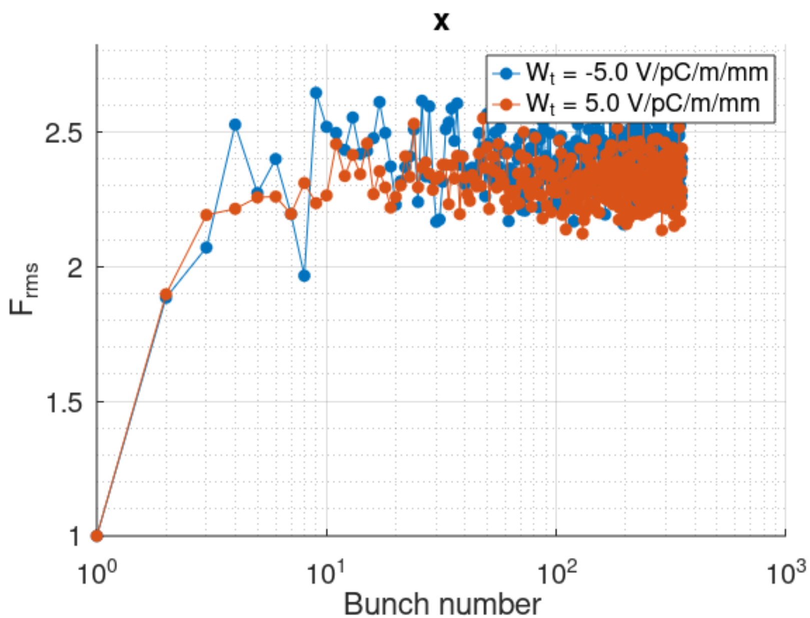
- **Long-range** wakefield effect in BL. **Single particle tracking simulation**
- Jitter considered: J = 0.10, that is, <x,px> = 0.10*σ(x,px)
- Transverse **kick on next bunch only**. **Incoherent** jitter with 1000 random trains
- Jitter amplification factor definition in this case:

Using average F of all bunches

$$F_{\mathrm{rms}} = \frac{F_{W\neq 0}}{F_{W=0}} \;, \text{ where } F = \frac{1}{N_{\mathrm{bunches}}}\sum \frac{J_{\mathrm{final}}}{J_{\mathrm{initial}}} = \frac{1}{N_{\mathrm{bunches}}}\sum \sqrt{\frac{A_{\mathrm{final}}}{A_{\mathrm{initial}}}}$$

A: action (area)





$F_{x,c}$ ~ 2.4 @ ±5 V/pC/m/mm

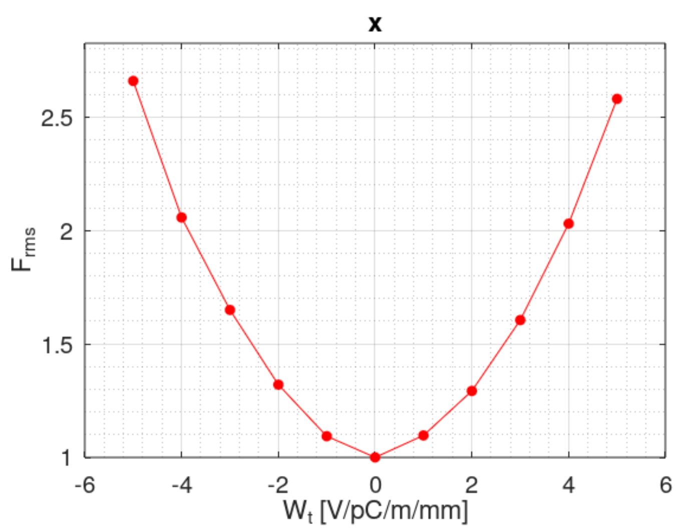
Test 2.1.2b

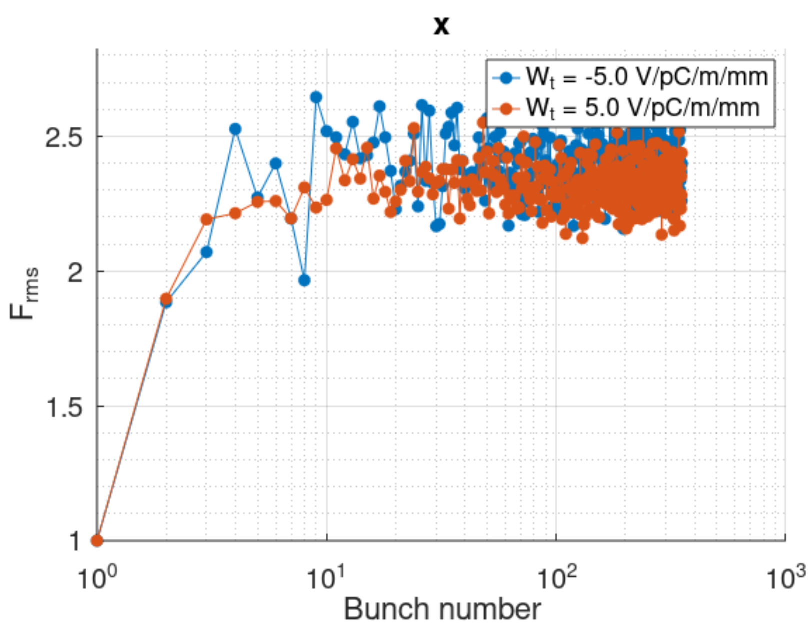
- **Long-range** wakefield effect in BL. **Single particle** **tracking** **simulation**
- Jitter considered: J = 0.10, that is, <x,px> = 0.10*σ(x,px)
- Transverse **kick on next bunch only**. **Incoherent** jitter with 1000 random trains
- Jitter amplification factor definition in this case:

Using maximum F of all bunches

$$F_{rms} = \frac{F_{W\neq 0}}{F_{W=0}} \text{ , where } F = \max_{bunches}\left(\frac{J_{final}}{J_{initial}}\right) = \max_{bunches}\left(\sqrt{\frac{A_{final}}{A_{initial}}}\right)$$

A: action (area)





$F_{x,c}$ ~ 2.7 @ ±5 V/pC/m/mm

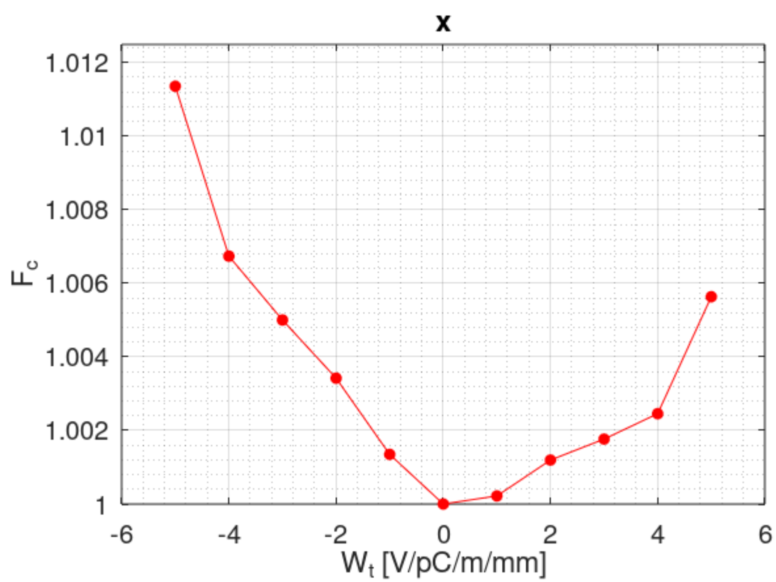
Test 2.2.1a

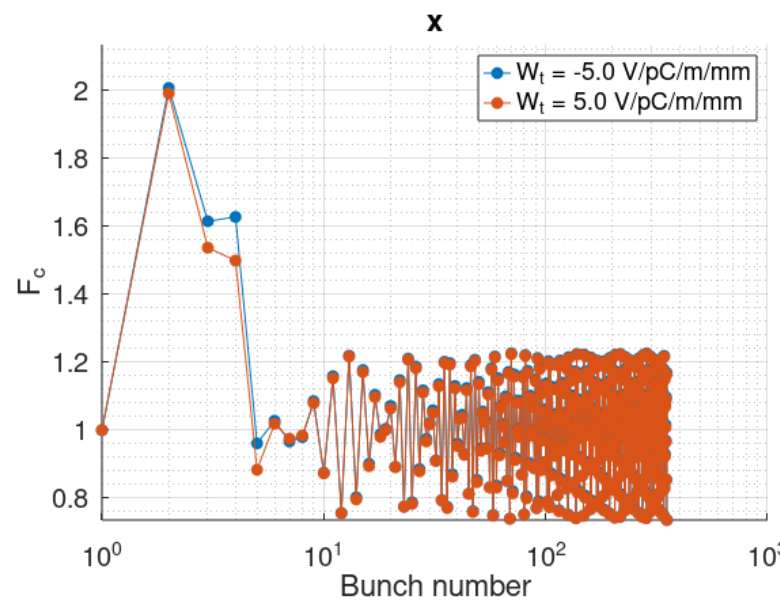
- **Long-range** wakefield effect in BL. **Full bunch** **tracking** **simulation**. Short-range wake considered
- Jitter considered: J = 0.10, that is, <x,px> = 0.10*σ(x,px)
- Transverse **kick on next bunch only**. **Coherent** jitter with 8 specific trains
- Jitter amplification factor definition in this case:

Using average F of all bunches

$$F_c = \frac{F_{W\neq 0}}{F_{W=0}}\ , \text{ where } F = \frac{1}{N_{\text{bunches}}}\sum \frac{J_{\text{final}}}{J_{\text{initial}}} = \frac{1}{N_{\text{bunches}}}\sum \sqrt{\frac{A_{\text{final}}}{A_{\text{initial}}}}$$

A: action (area)





$F_{x,c}$ ~ 1.01 @ ±5 V/pC/m/mm

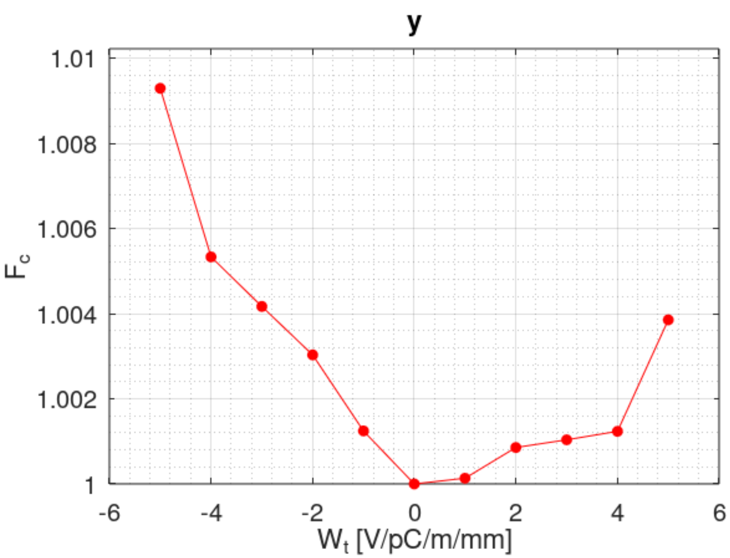
Test 2.2.1a (checking vertical plane)

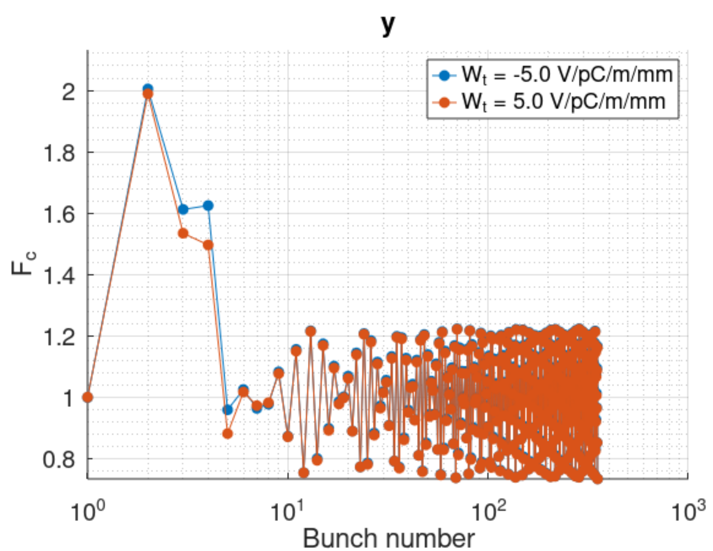
- **Long-range** wakefield effect in BL. **Full bunch tracking simulation**. Short-range wake considered
- Jitter considered: J = 0.10, that is, <x,px> = 0.10*σ(x,px)
- Transverse **kick on next bunch only**. **Coherent** jitter with 8 specific trains
- Jitter amplification factor definition in this case:

Using average F of all bunches

$$F_c = \frac{F_{W\neq 0}}{F_{W=0}} \text{ , where } F = \frac{1}{N_{\text{bunches}}}\sum \frac{J_{\text{final}}}{J_{\text{initial}}} = \frac{1}{N_{\text{bunches}}}\sum \sqrt{\frac{A_{\text{final}}}{A_{\text{initial}}}}$$

A: action (area)





$F_{x,c}$ ~ 1.01 @ ±5 V/pC/m/mm

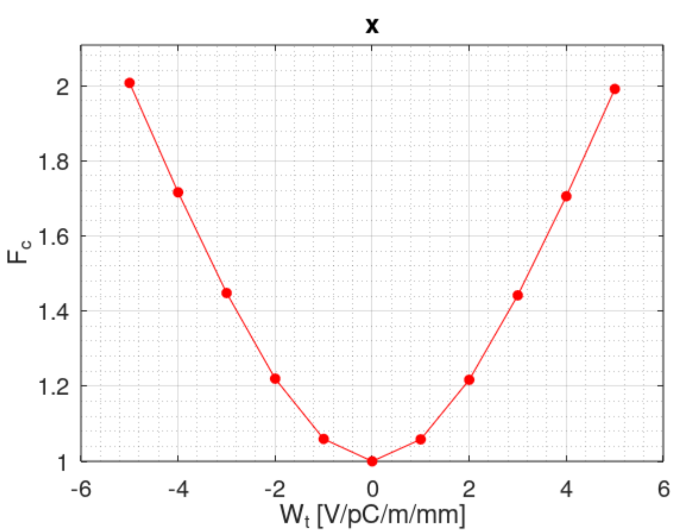
Test 2.2.1b

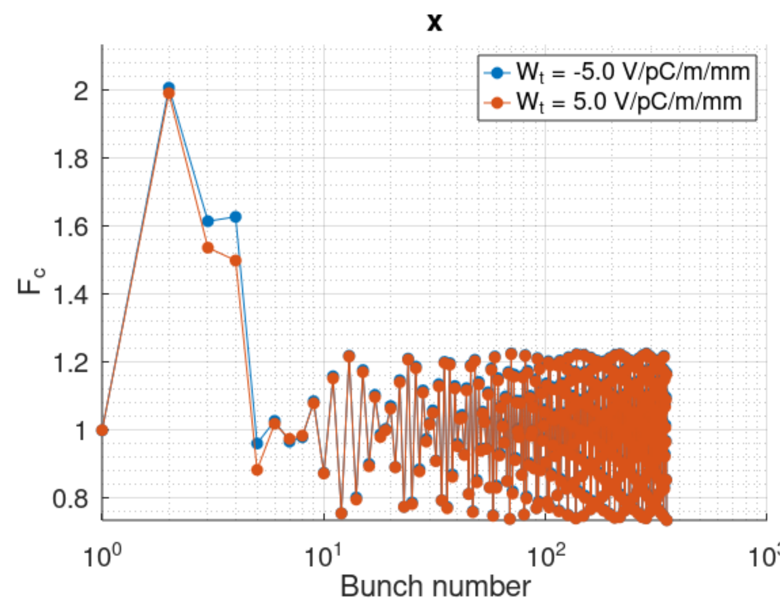
- **Long-range** wakefield effect in BL. **Full bunch** **tracking** **simulation**. Short-range wake considered
- Jitter considered: J = 0.10, that is, <x,px> = 0.10*σ(x,px)
- Transverse **kick on next bunch only**. **Coherent** jitter with 8 specific trains
- Jitter amplification factor definition in this case:

Using maximum F of all bunches

$$F_c = \frac{F_{W\neq 0}}{F_{W=0}} \text{ , where } F = \max_{\text{bunches}}\left(\frac{J_{\text{final}}}{J_{\text{initial}}}\right) = \max_{\text{bunches}}\left(\sqrt{\frac{A_{\text{final}}}{A_{\text{initial}}}}\right)$$

A: action (area)





$F_{x,c}$ ~ 2.0 @ ±5 V/pC/m/mm

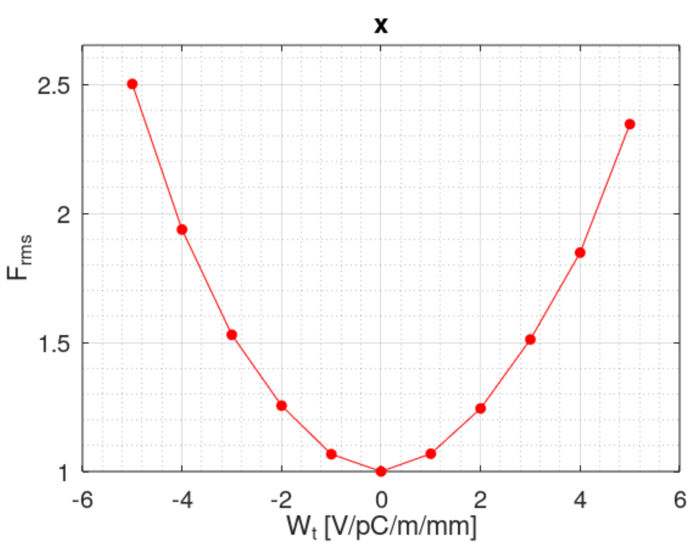
Test 2.2.2.1a

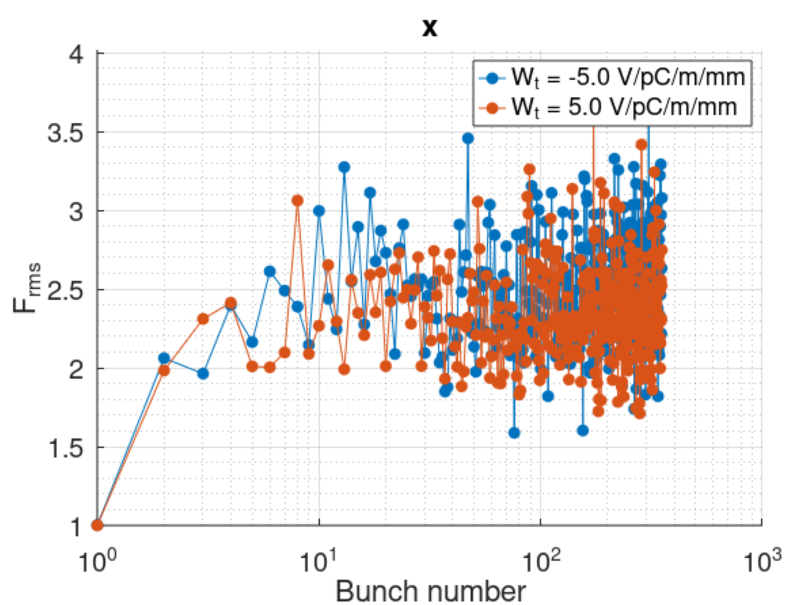
- **Long-range** wakefield effect in BL. **Full bunch tracking simulation**. Short-range wake considered
- Jitter considered: J = 0.10, that is, <x,px> = 0.10*σ(x,px)
- Transverse **kick on next bunch only**. **Incoherent** jitter with 100 random trains
- Jitter amplification factor definition in this case:

Using average F of all bunches

$$F_{\mathrm{rms}} = \frac{F_{W\neq 0}}{F_{W=0}}, \text{ where } F = \frac{1}{N_{\mathrm{bunches}}}\sum \frac{J_{\mathrm{final}}}{J_{\mathrm{initial}}} = \frac{1}{N_{\mathrm{bunches}}}\sum \sqrt{\frac{A_{\mathrm{final}}}{A_{\mathrm{initial}}}}$$

A: action (area) of bunch centers





$F_{x,rms}$ ~ 2.5 @ ±5 V/pC/m/mm

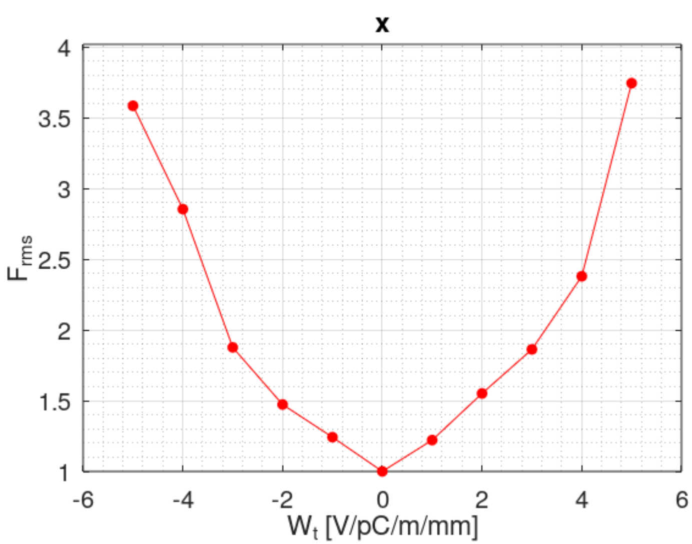
Test 2.2.2.1b

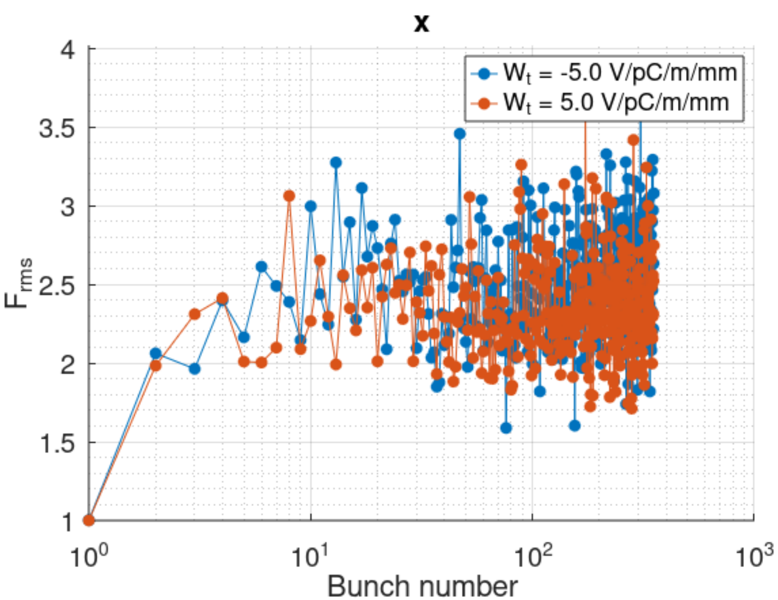
- **Long-range** wakefield effect in BL. **Full bunch tracking simulation**. Short-range wake considered
- Jitter considered: J = 0.10, that is, <x,px> = 0.10*σ(x,px)
- Transverse **kick on next bunch only**. **Incoherent** jitter with 100 random trains
- Jitter amplification factor definition in this case:

Using maximum F of all bunches

$$F_{\mathrm{rms}} = \frac{F_{W\neq 0}}{F_{W=0}} \text{ , where } F = \max_{\mathrm{bunches}}\left(\frac{J_{\mathrm{final}}}{J_{\mathrm{initial}}}\right) = \max_{\mathrm{bunches}}\left(\sqrt{\frac{A_{\mathrm{final}}}{A_{\mathrm{initial}}}}\right)$$

A: action (area) of bunch centers





$F_{x,rms}$ ~ 3.7 @ ±5 V/pC/m/mm

Test 2.2.2.2a

- **Long-range** wakefield effect in BL. **Full bunch tracking simulation**. Short-range wake considered
- Jitter considered: J = 0.10, that is, <x,px> = 0.10*σ(x,px)
- Transverse **kick on next bunch only**. **Incoherent** jitter with 100 random trains
- Jitter amplification factor definition in this case:

Using average F of all bunches

$$F_{\text{rms}} = \frac{F_{W\neq 0}}{F_{W=0}} \quad , \text{ where } F = \frac{1}{N_{\text{bunches}}}\sum \frac{J_{\text{final}}}{J_{\text{initial}}} = \frac{1}{N_{\text{bunches}}}\sum \frac{\sqrt{\frac{\varepsilon_{\text{total}}^{\text{final}}}{\varepsilon_{\text{single}}^{\text{initial}}}-1}}{\sqrt{\frac{\varepsilon_{\text{total}}^{\text{initial}}}{\varepsilon_{\text{single}}^{\text{initial}}}-1}} = \frac{1}{N_{\text{bunches}}}\sum \sqrt{\frac{\varepsilon_{\text{total}}^{\text{final}}-\varepsilon_{\text{single}}^{\text{initial}}}{\varepsilon_{\text{total}}^{\text{initial}}-\varepsilon_{\text{single}}^{\text{initial}}}}$$

$\varepsilon_{\text{total}}$: projected emittance of all trains for same bunch

$\varepsilon_{\text{single}}$: single bunch emittance

In progress ...

Seems quite difficult. Need to store very huge data on disk and much longer time for each train or Condor job. I will see if it's possible.

Instead of using projected emittance of all trains, it's much easier to use projected emittance of all bunches in a train, where I just need to store a number instead of all bunches. See Test 2.2.2.3.

Test 2.2.2.2b

- **Long-range** wakefield effect in BL. **Full bunch** **tracking** **simulation**. Short-range wake considered
- Jitter considered: J = 0.10, that is, <x,px> = 0.10*σ(x,px)
- Transverse **kick on next bunch only**. **Incoherent** jitter with 100 random trains
- Jitter amplification factor definition in this case:

Using maximum F of all bunches

$$F_{\text{rms}} = \frac{F_{W\neq 0}}{F_{W=0}} \text{ , where } F = \max_{\text{bunches}}\left(\frac{J_{\text{final}}}{J_{\text{initial}}}\right) = \max_{\text{bunches}}\left(\frac{\sqrt{\frac{\varepsilon_{\text{total}}^{\text{final}}}{\varepsilon_{\text{single}}^{\text{initial}}}-1}}{\sqrt{\frac{\varepsilon_{\text{total}}^{\text{initial}}}{\varepsilon_{\text{single}}^{\text{initial}}}-1}}\right) = \max_{\text{bunches}}\left(\sqrt{\frac{\varepsilon_{\text{total}}^{\text{final}}-\varepsilon_{\text{single}}^{\text{initial}}}{\varepsilon_{\text{total}}^{\text{initial}}-\varepsilon_{\text{single}}^{\text{initial}}}}\right)$$

$\varepsilon_{\text{total}}$: projected emittance of all trains for same bunch

$\varepsilon_{\text{single}}$: single bunch emittance

In progress ...

Seems quite difficult. Need to store very huge data on disk and much longer time for each train or Condor job. I will see if it’s possible.

Instead of using projected emittance of all trains, it’s much easier to use projected emittance of all bunches in a train, where I just need to store a number instead of all bunches. See Test 2.2.2.3.

Test 2.2.2.3a

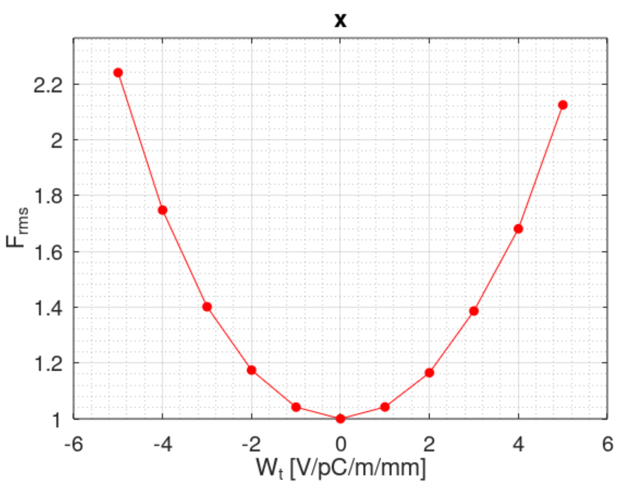
- **Long-range** wakefield effect in BL. **Full bunch tracking simulation**. Short-range wake considered
- Jitter considered: J = 0.10, that is, <x,px> = 0.10*σ(x,px)
- Transverse **kick on next bunch only**. **Incoherent** jitter with 100 random trains
- Jitter amplification factor definition in this case:

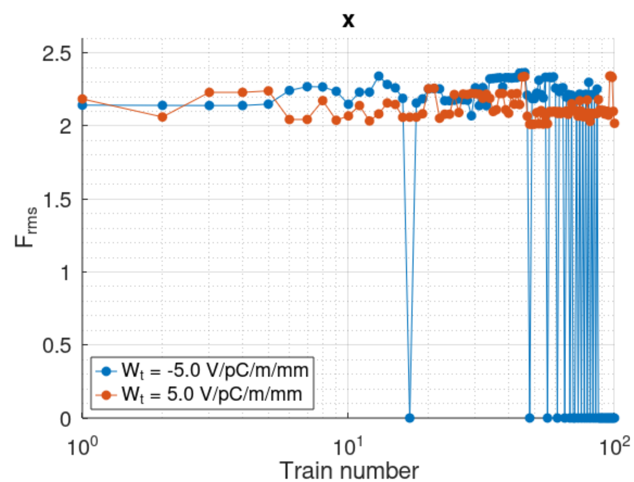
Using average F of all trains

$$F_{\mathrm{rms}} = \frac{F_{W\neq 0}}{F_{W=0}} \;, \text{ where } F = \frac{1}{N_{\mathrm{trains}}}\sum \frac{J_{\mathrm{final}}}{J_{\mathrm{initial}}} = \frac{1}{N_{\mathrm{trains}}}\sum \frac{\sqrt{\frac{\varepsilon_{\mathrm{total}}^{\mathrm{final}}}{\varepsilon_{\mathrm{single}}^{\mathrm{initial}}}-1}}{\sqrt{\frac{\varepsilon_{\mathrm{total}}^{\mathrm{initial}}}{\varepsilon_{\mathrm{single}}^{\mathrm{initial}}}-1}} = \frac{1}{N_{\mathrm{trains}}}\sum \sqrt{\frac{\varepsilon_{\mathrm{total}}^{\mathrm{final}}-\varepsilon_{\mathrm{single}}^{\mathrm{initial}}}{\varepsilon_{\mathrm{total}}^{\mathrm{initial}}-\varepsilon_{\mathrm{single}}^{\mathrm{initial}}}}$$

$\varepsilon_{\mathrm{total}}$: projected emittance of all bunches for same train

$\varepsilon_{\mathrm{single}}$: single bunch emittance





$F_{x,rms}$ ~ 2.2 @ ±5 V/pC/m/mm

F = 0 means job is killed probably due to long simulation time. Not considered in calculation

Test 2.2.2.3b

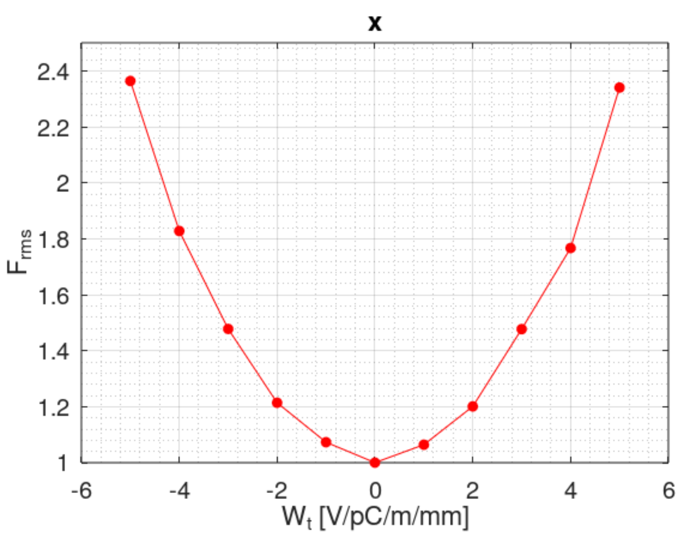
- **Long-range** wakefield effect in BL. **Full bunch tracking simulation**. Short-range wake considered
- Jitter considered: J = 0.10, that is, <x,px> = 0.10*σ(x,px)
- Transverse **kick on next bunch only**. **Incoherent** jitter with 100 random trains
- Jitter amplification factor definition in this case:

Using maximum F of all trains

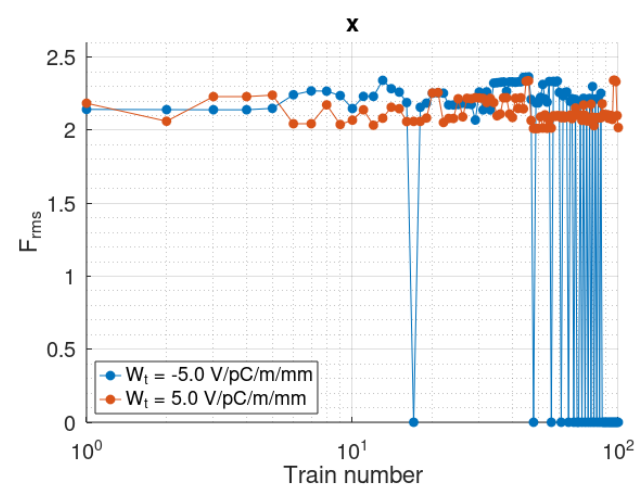
$$F_{\text{rms}} = \frac{F_{W\neq 0}}{F_{W=0}} \text{ , where } F = \max_{\text{trains}}\left(\frac{J_{\text{final}}}{J_{\text{initial}}}\right) = \max_{\text{trains}}\left(\frac{\sqrt{\frac{\varepsilon_{\text{total}}^{\text{final}}}{\varepsilon_{\text{single}}^{\text{initial}}}-1}}{\sqrt{\frac{\varepsilon_{\text{total}}^{\text{initial}}}{\varepsilon_{\text{single}}^{\text{initial}}}-1}}\right) = \max_{\text{trains}}\left(\sqrt{\frac{\varepsilon_{\text{total}}^{\text{final}}-\varepsilon_{\text{single}}^{\text{initial}}}{\varepsilon_{\text{total}}^{\text{initial}}-\varepsilon_{\text{single}}^{\text{initial}}}}\right)$$

$\varepsilon_{\text{total}}$: projected emittance of all bunches for same train

$\varepsilon_{\text{single}}$: single bunch emittance



$F_{x,rms}$ ~ 2.4 @ ±5 V/pC/m/mm

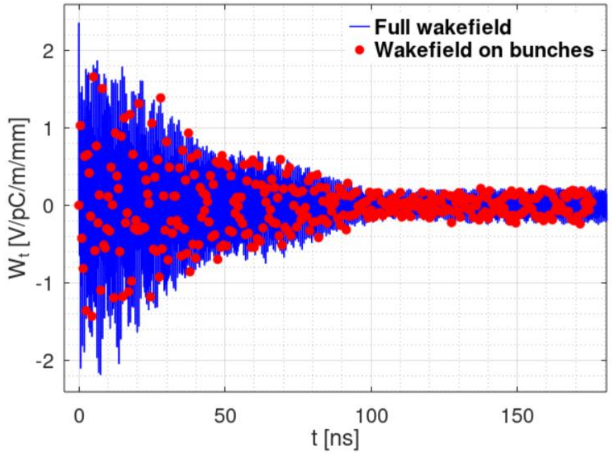


F = 0 means job is killed probably due to long simulation time. Not considered in calculation

Long-range wakefield effect – kick on all bunches

Test 3.0

- Using wakefield (V1) directly from Adnan:



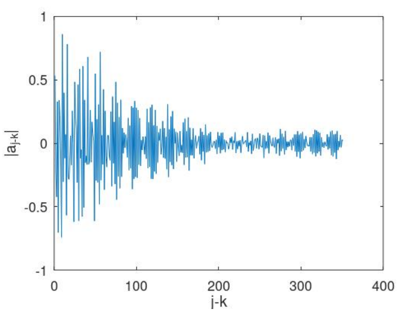
Single particle calculation using Daniel's formulae. Same definitions and conifgurations as Test 2.0

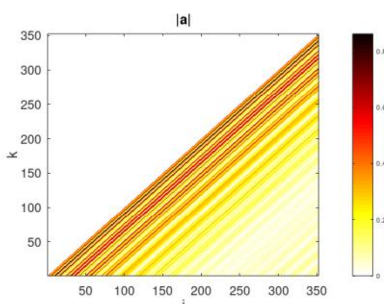
Sum(Abs(W)) = 93.4 V/pC/m/mm

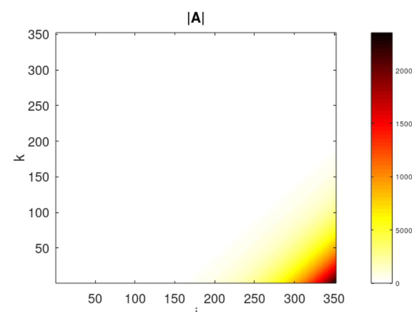
$$a_{j-k} = i\int_0^{\hat{s}} \frac{W(z_j - z_k, s) N e^2 \beta(s)}{2E(s)} ds$$

$$a_{jk} = a_{j-k} \text{ for } j > k$$

$$A = \lim_{m\to\infty}\left(1+\frac{a}{m}\right)^m = \exp(a) = \sum_{k=0}^{\infty}\frac{a^k}{k!} = \sum_{k=0}^{n-1}\frac{a^k}{k!}$$







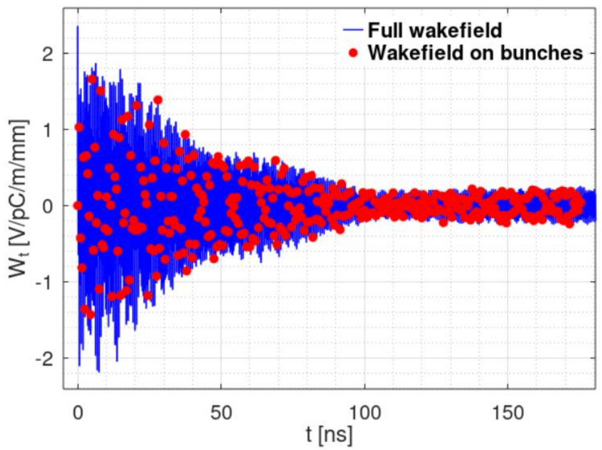
- $F_{x,c}$ = 1.0E+07
- $F_{x,rms}$ = 1.0E+09
- $F_{x,worst}$ = 3.6E+11

a1 = 0.53

Very very large jitter amplifications!

Test 3.1.1

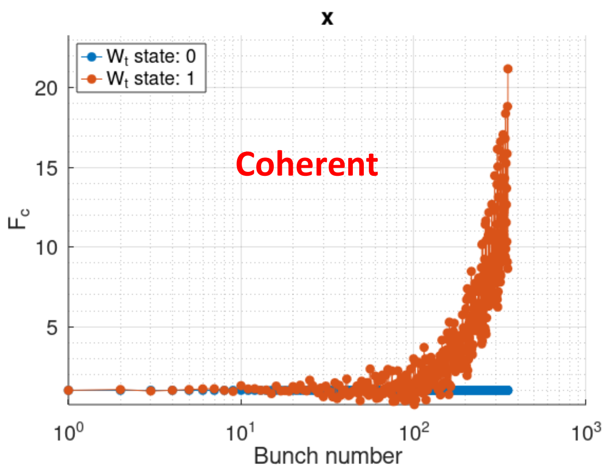
- Using wakefield (V1) directly from Adnan:

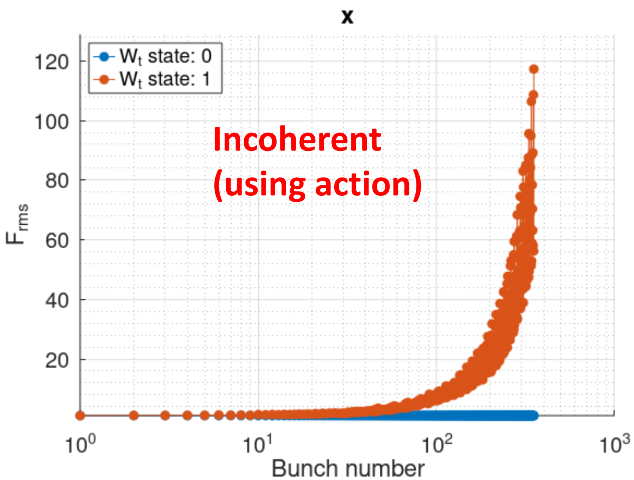


Sum(Abs(W)) = 93.4 V/pC/m/mm

Single particle tracking simulation

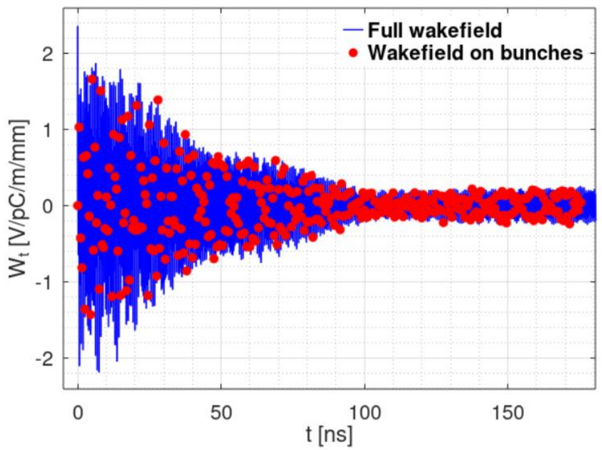
- **$F_{x,c}$ = 4.9 (average) or 21.2 (maximum)**
- **$F_{x,rms}$ = 24.4 (average) or 117.3 (maximum)**





Test 3.1.2

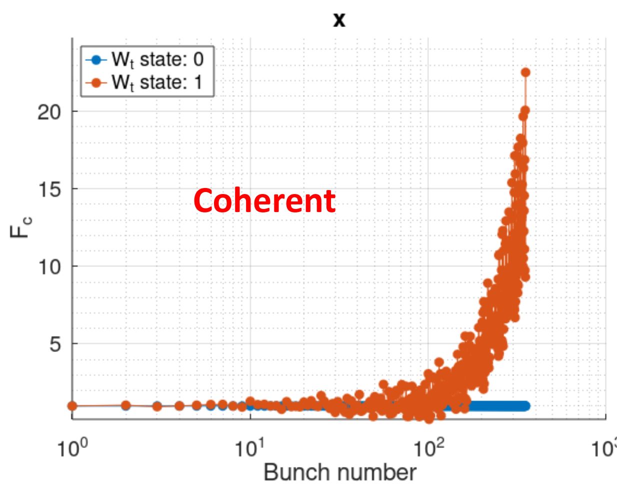
- Using wakefield (V1) directly from Adnan:

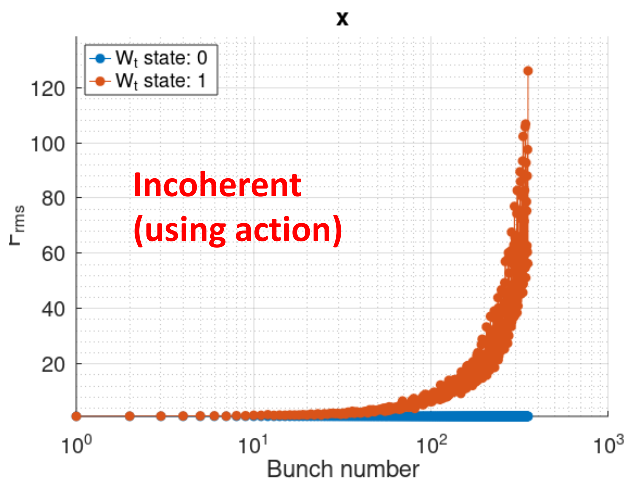


Sum(Abs(W)) = 93.4 V/pC/m/mm

Full bunch tracking simulation

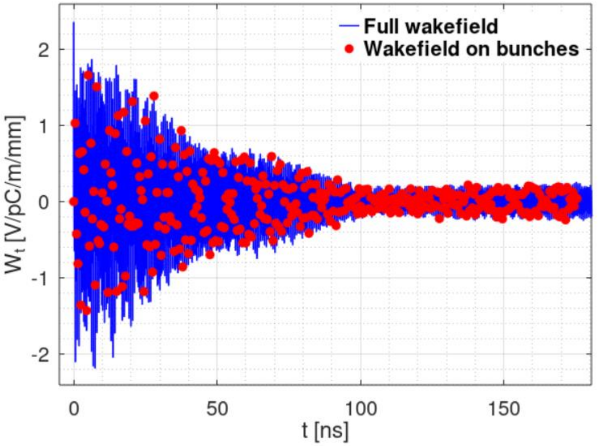
- **$F_{x,c}$ = 5.1 (average) or 22.5 (maximum)**
- **$F_{x,rms}$ = 24.9 (average) or 126.0 (maximum)**





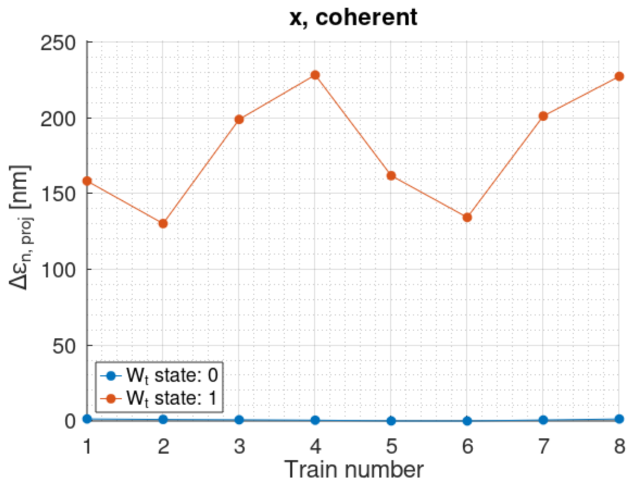
Test 3.1.2

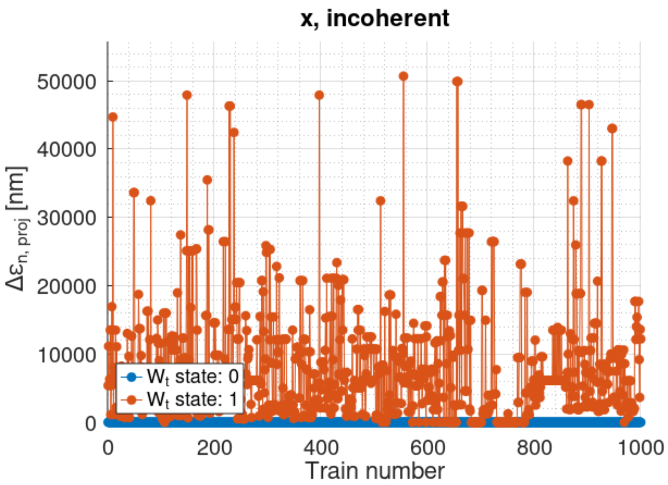
- Using wakefield (V1) directly from Adnan:



Sum(Abs(W)) = 93.4 V/pC/m/mm

Full bunch tracking simulation





Test 3.1.1 & 3.1.2

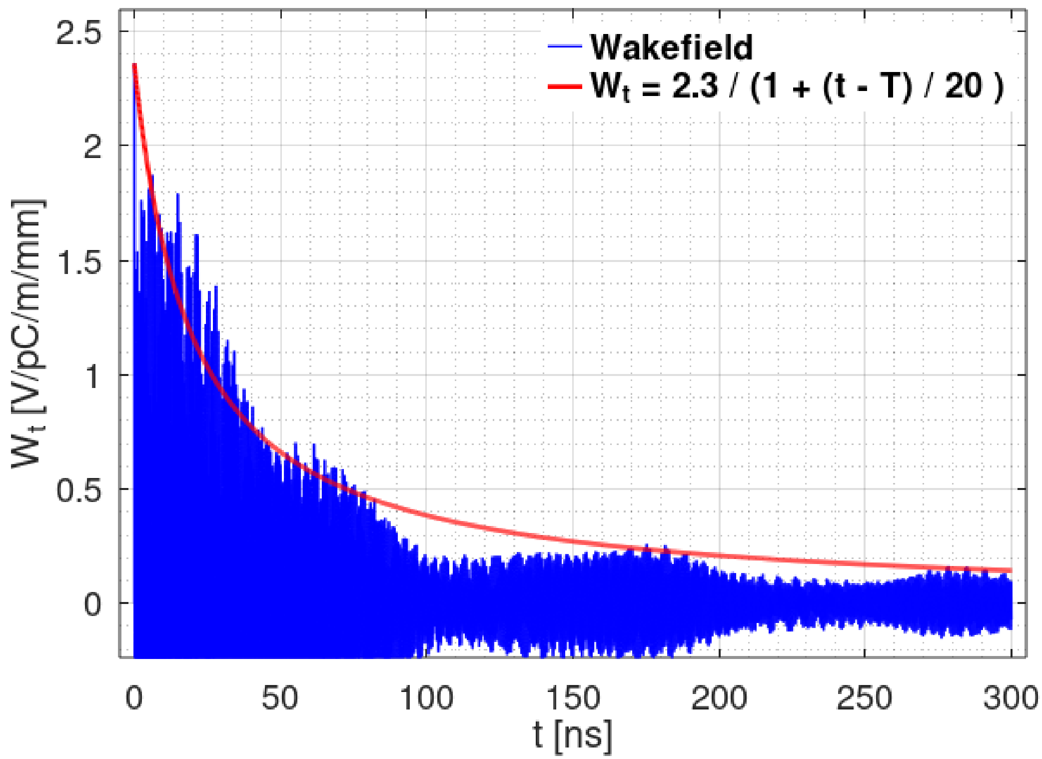
- Comparison between single particle & full bunch
  - Consistent with very small difference

x	Average Fc	Maximum Fc	Average Frms	Maximum Frms
Single particle	4.9	21.2	24.4	117.3
Full bunch	5.1	22.5	24.9	126.0

Test 3.2 – Wake scan

- Wake formula assumption:

$$W_{\perp(t)} = \frac{k}{1 + \frac{t - T}{\alpha}}, \qquad t \geq T = 0.5 \text{ ns}$$

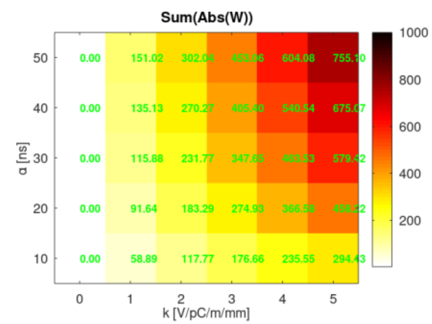


Test 3.2 – Wake scan

- Range
  - k: [0:1:5] V/pC/m/mm
  - alpha: [10:10:50] ns

$$W_{\perp(t)} = \frac{k}{1+\dfrac{t-T}{\alpha}}, \qquad t \geq T = 0.5\ \text{ns}$$

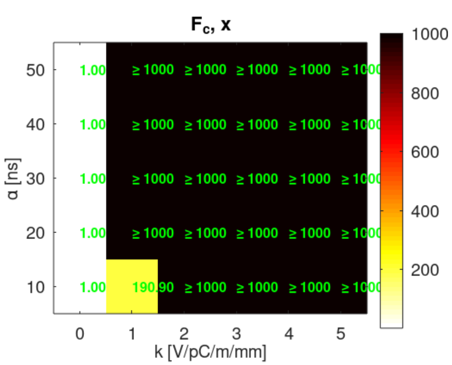
Full bunch tracking simulation. Same definitions and conifgurations as Test 2.2.1 and Test 2.2.2.3 (but only 10 trains simulated)



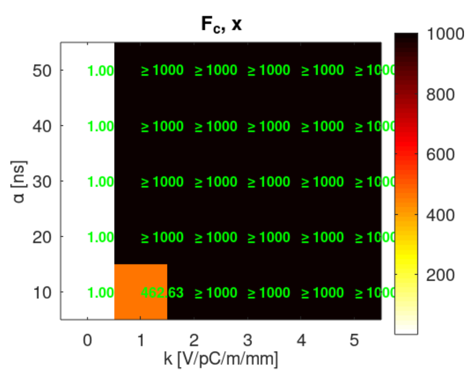
Coherent

Incoherent

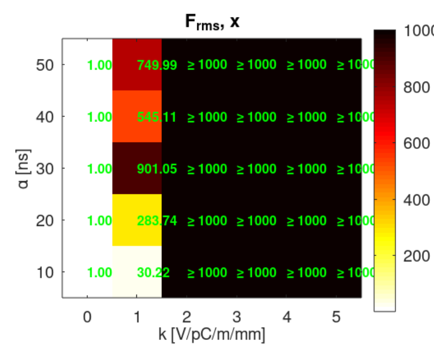
Average



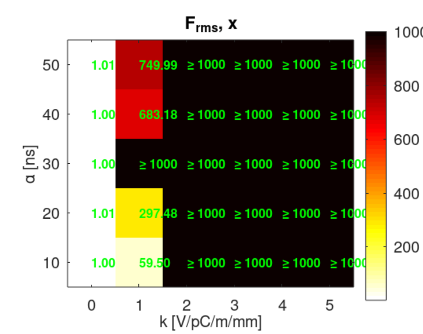
Maximum



Average



Maximum



Very very large jitter amplifications!

Summary (table in next slide)

- Test 0: general study. Jitter budgets are 0.2σ for x and 0.6σ for y (assuming projected emittance budgets are same with budget numbers in PIP report). Jitter amplification (F) budgets are plotted as functions of initial jitter, e.g. Fx < 4, Fy < 12 @ 0.05σ, Fx < 2, Fy < 5 @ 0.1σ
- Test 1: F = 0.995 due to short-range wakefield for full bunch tracking (w/ BNS damping)
- Test 2.0: F plotted as kick on next bunch only using Daniel's analytic formulae for single particle, for x. E.g. Fc = 1.06, Frms = 32, Fworst = 178 @ 5 V/pC/m/mm
- Test 2.1.1a: Fc (average of all bunches) plotted as kick on next bunch only for single particle tracking, using action (area), for x. E.g. Fc = 0.996 @ 5 V/pC/m/mm
- Test 2.1.1b: Fc (maximum of all bunches) plotted as kick on next bunch only for single particle tracking, using action (area), for x. E.g. Fc = 2.0 @ 5 V/pC/m/mm
- Test 2.1.2a: Frms (average of all bunches) plotted as kick on next bunch only for single particle tracking, using action (area), for x. E.g. Frms = 2.4 @ 5 V/pC/m/mm
- Test 2.1.2b: Frms (maximum of all bunches) plotted as kick on next bunch only for single particle tracking, using action (area), for x. E.g. Frms = 2.7 @ 5 V/pC/m/mm
- Test 2.2.1a: Fc (average of all bunches) plotted as kick on next bunch only for full bunch tracking, using action (area), for x. E.g. Fc = 1.01 @ 5 V/pC/m/mm
- Test 2.2.1b: Fc (maximum of all bunches) plotted as kick on next bunch only for full bunch tracking, using action (area), for x. E.g. Fc = 2.0 @ 5 V/pC/m/mm
- Test 2.2.2.1a: Frms (average of all bunches) plotted as kick on next bunch only for full bunch tracking, using action (area), for x. E.g. Frms = 2.5 @ 5 V/pC/m/mm
- Test 2.2.2.1b: Frms (maximum of all bunches) plotted as kick on next bunch only for full bunch tracking, using action (area), for x. E.g. Frms = 3.7 @ 5 V/pC/m/mm
- Test 2.2.2.2a and Test 2.2.2.2b (average and maximum of all bunches) using projected emittance of all trains in progress (seems difficult technically)
- Test 2.2.2.1a: Frms (average of all trains) plotted as kick on next bunch only for full bunch tracking, using projected emittance of all bunches, for x. E.g. Frms = 2.2 @ 5 V/pC/m/mm
- Test 2.2.2.1a: Frms (maximum of all trains) plotted as kick on next bunch only for full bunch tracking, using projected emittance of all bunches, for x. E.g. Frms = 2.4 @ 5 V/pC/m/mm
- Test 3.0: F calculated using Daniel's analytic formulae for single particle calculation, with full wakefield map, for x. E.g. Fc = 1.0E+07, Frms = 1.0E+09, Fworst = 3.6E+11
- Test 3.1: F estimated for full bunch tracking, with full wakefield map, and plotted as function of bunch number, for x. E.g. Fc = 5.1 (average) or 22.5 (maximum), Frms = 26.2 (average) or 62.2 (maximum)
- Test 3.2: F estimated for full bunch tracking, with wakefield envelop assumption, and plotted as function of parameters 2D scan, for x. Very very large F is found

Summary table

F for x @ 5 V/pC/m/mm due to long-range wake (with kick on next bunch only)	Fc	Frms	Fworst
Analytic usingDaniel's formulae	1.06	32	178
Single particle tracking	0.996 (average) 2.0 (maximum)	2.4 (average) 2.7 (maximum)	-
Full bunch tracking - Using action for Frms (100 trains, to increase statistics?)	1.01 (average) 2.0 (maximum)	2.5 (average) 3.7 (maximum)	-
Full bunch tracking - Using projected emittance for Frms – Using projection emittance of all trains	-	In progress (difficult)	-
Full bunch tracking - Using projected emittance for Frms – Using projection emittance of all bunches	-	2.2 (average) 2.4 (maximum)	-

F for x due to long-range wake (full fieldmap)	Fc	Frms	Fworst
Analytic usingDaniel's formulae	1.0E+07	1.0E+09	3.6E+11
Single particle tracking	-	-	-
Full bunch tracking - Using action for Frms (100 trains, to increase statistics?)	5.1 (average) 22.5 (maximum)	26.2 (average) 62.2 (maximum)	-

F for x due to long-range wake (2D scan)	Fc	Frms	Fworst
Full bunch tracking - Using action for Frms (10 trains, to increase statistics?)	>> 100	>> 100	-

Follow-up study

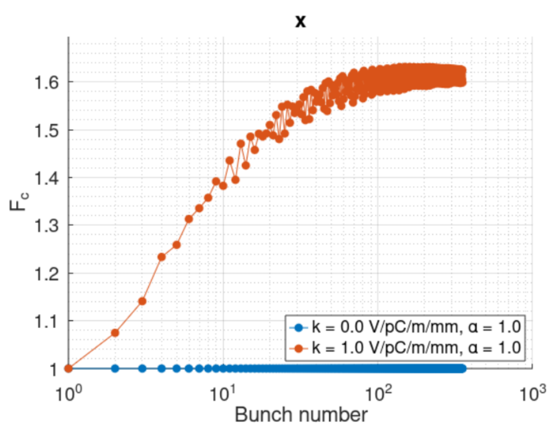
Strategy

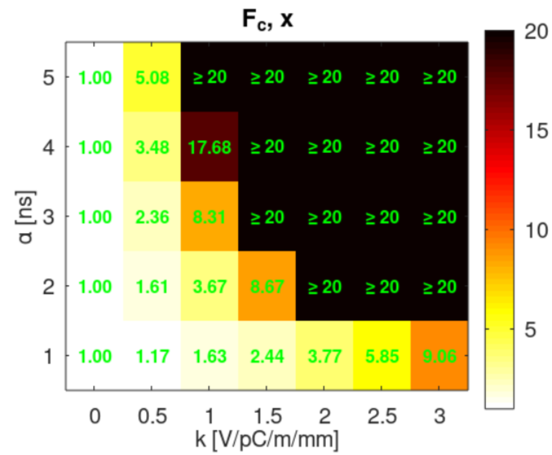
- The analytic formulae are being verified
- For the moment, the most fast, reliable and conservative way to estimate jitter amplification might be using single particle tracking and maybe better to take the maximum number if statistics allows
- To be conservative, envelop of wakefield is also used and assumed to be the $k/[1+(t-T)/\alpha]$ function, with a 2D scan of k and α, but with small numbers (corresponding to wakefield after damping)

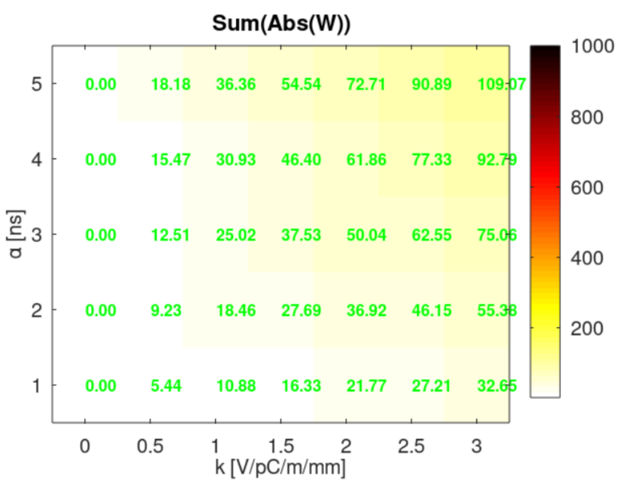
Test 3.3.1

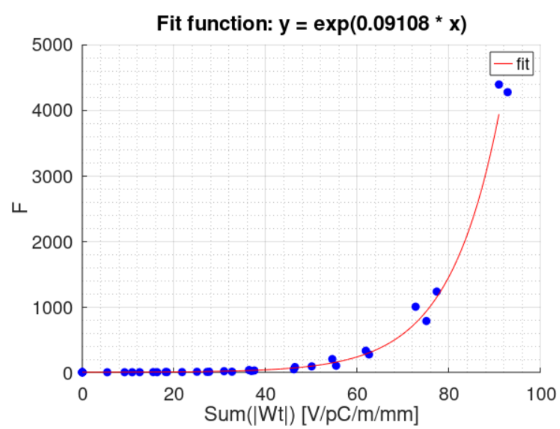
- Following strategy in last slide (single particle tracking)

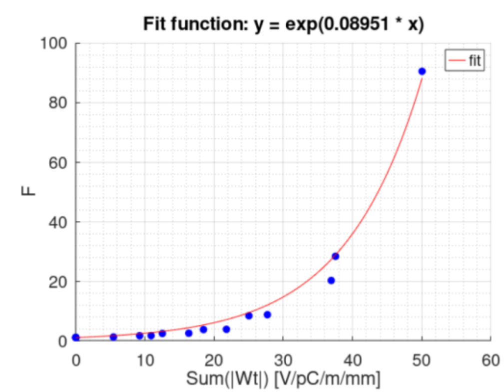
Coherent case. 8 trains (evenly spaced on ellipse)
Using maximum number











Test 3.3.2

- Following strategy in last slide (single particle tracking)

Incoherent case. 1000 trains (randomly spaced in phase space)
Using average number (due to large fluctuations)