Effect of DIFFERENT QUAD CONFIGURATIONS on EMITTANCE DILUTION in ILC LATTICE

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ILC MAIN LINAC

- USCold LC Main Linac Design
  - **Linac Cryogenic system is divided into Cryomodules(CM), with 12 structures / CM**
  - **Magnet Optics : FODO lattice, with phase advance of 60^0 in each plane**
  - **Each quad has a *Cavity style BPM* and a *Vertical Corrector* magnet; horizontally focusing quads also have a nearby *Horizontal Corrector* magnet.**

- Main Linac Design
  - ~11 km length
  - 9 Cell structures at 1.3 GHz and 12 structures per cryostat
  - Total structures : 7920
  - Loaded Gradient : 30 MeV/m
  - Injection energy = 5.0 GeV
  - Initial Energy spread = 2.5 %
  - Extracted beam energy = 250.7 GeV

- Beam Conditions
  - Bunch Charge: 2.0×10^{10} particles/bunch
  - Bunch length = 300 m
  - Normalized injection emittance: $_Y$=20 nm-rad

- Emittance growth in linac $_y \leq$ 10 nm-rad

USColdLC MAIN LINAC

ab initio (Nominal) Installation Conditions

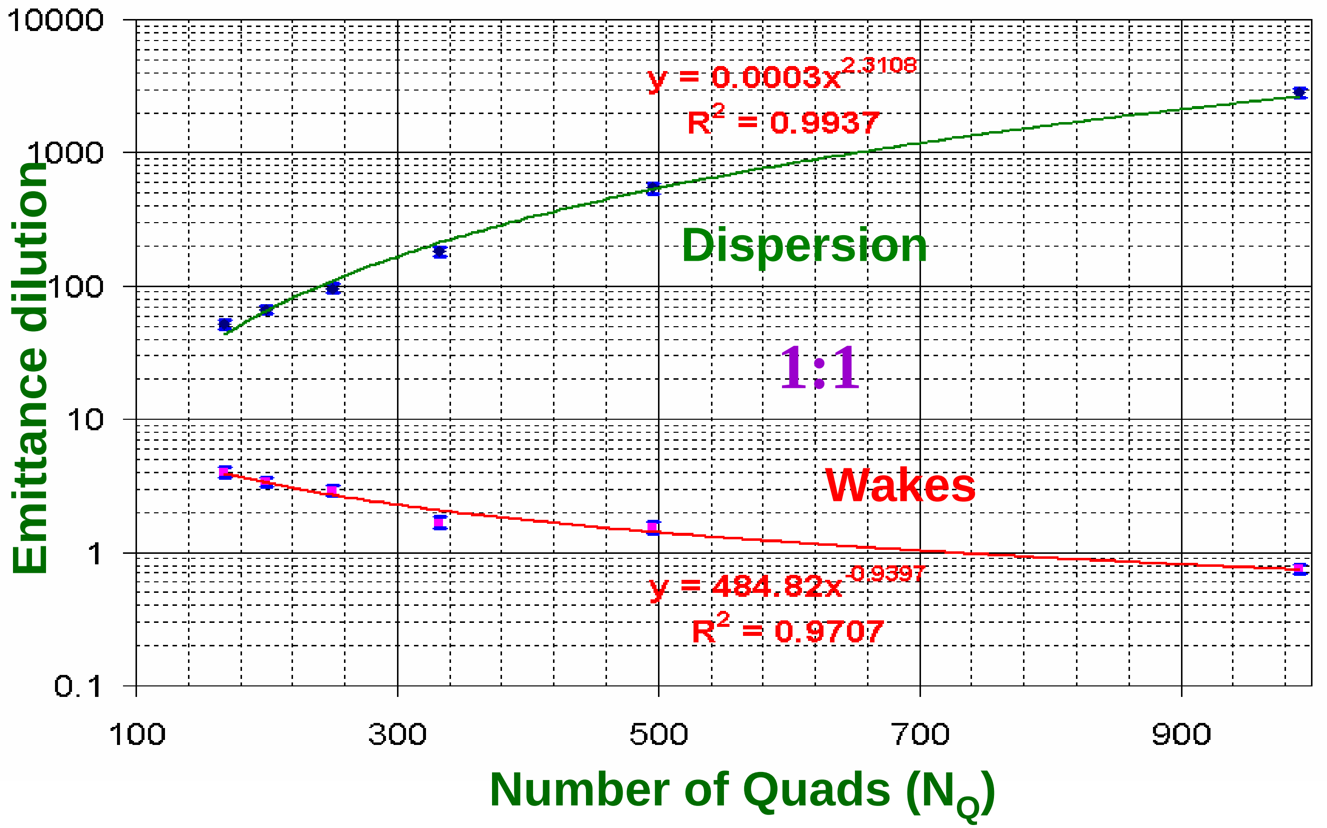
Tolerance	Vertical (y) plane
BPM Offset w.r.t. Cryostat	300 µm
Quad offset w.r.t. Cryostat	300 µm
Quad Rotation w.r.t. Cryostat	300 µrad
Structure Offset w.r.t. Cryostat	300 µm
Cryostat Offset w.r.t. Survey Line	200 µm
Structure Pitch w.r.t. Cryostat	300 µrad
Cryostat Pitch w.r.t. Survey Line	20 µrad
BPM Resolution	1.0 µm

→ 30 µm in launching region (~7 BPM's)

- BPM transverse position is fixed, and the BPM offset is w.r.t. Cryostat
- Only Single bunch used in studies
- No Jitter in position, angle etc.; No Ground Motion and Feedback
- Steering is performed using Dipole Correctors.

QUAD CONFIGURATION

- 8 configurations with diff. quad spacing (from 1 Quad / 1CM to 1 Quad / 8CM)
- Dispersion Case – Quad, BPM Offsets and Structure, CM Pitch
- Wake Case – Structure, CM offset, wakefields

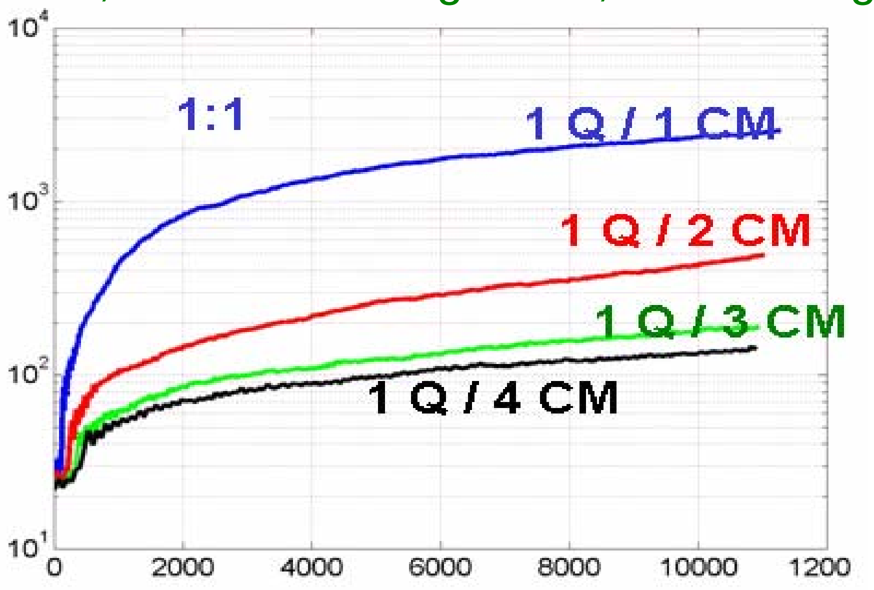


30 MV/m
TTF CM
8 Cavity / CM

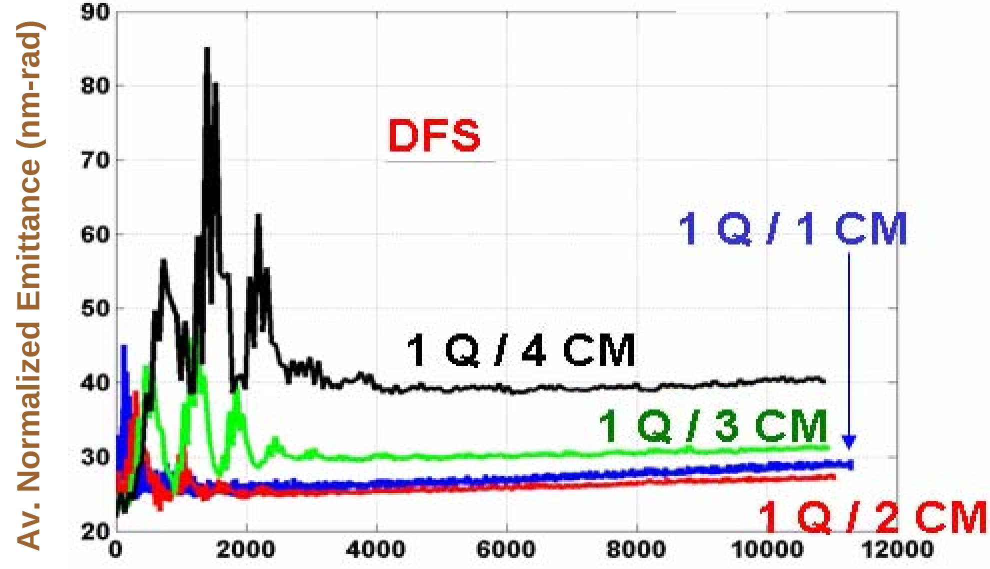
- ☞ Projected emittance growth is dominated by dispersive sources
  - ☞ Large quad spacing seems to be an attractive choice (?)

QUAD CONFIGURATIONS

⇨ Constant phase advance of 60^0; No Autophasing considered; G=30MV/m; 660 CM; Nominal misalignment; 18 DFS segments; 7 BPMs in launch region; 100 seeds



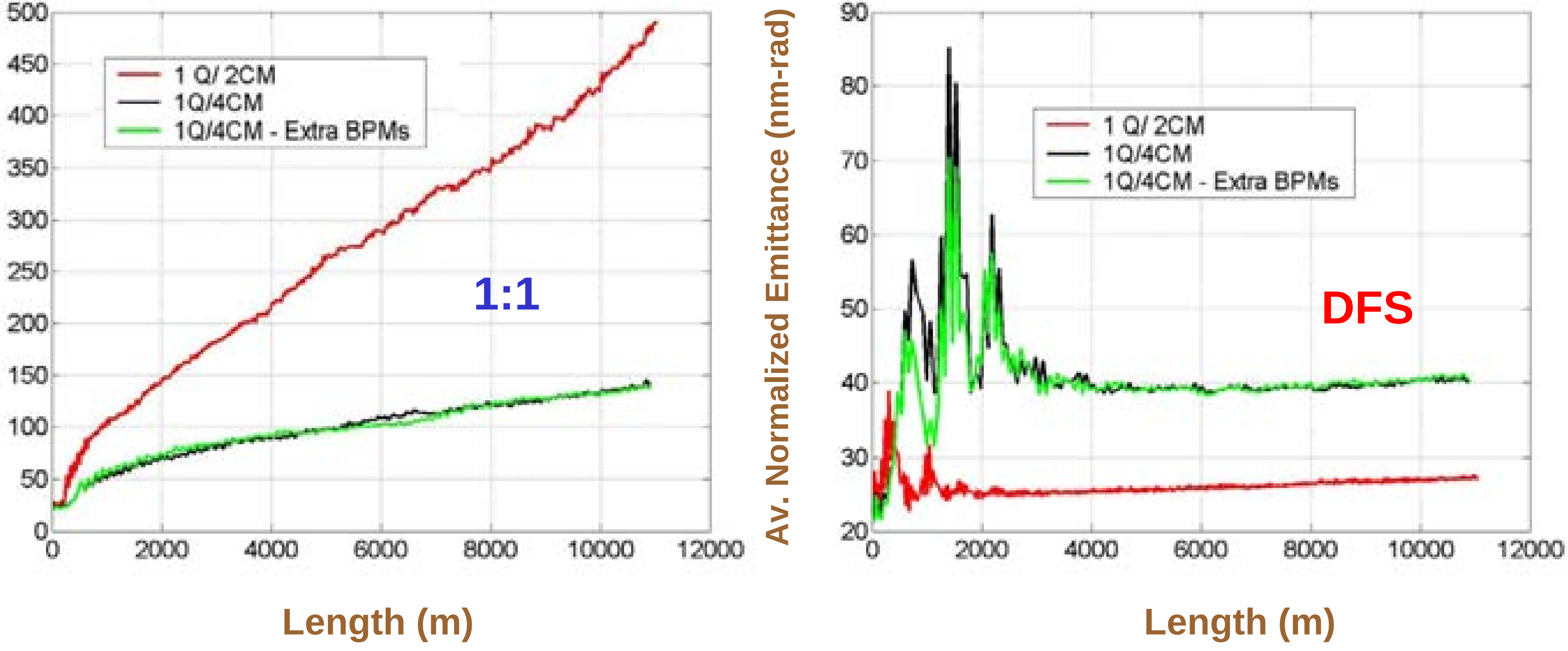
Length (m)



Length (m)

	Mean dilution (nm)		90% dilution (nm)	
	1:1	DFS	1:1	DFS
1 Q / 1CM	2537	8.3	5252	15.3
1 Q / 2CM	470.9	6.9	940.1	13.1
1 Q / 3CM	170.7	11.0	367.3	21.2
1 Q / 4CM	120.8	20.2	232.5	39.4

⇨ Effect of ADDING 3 extra BPMs and COR in 1Q/4CM b/w Quads 1-2; 2-3; 3-4

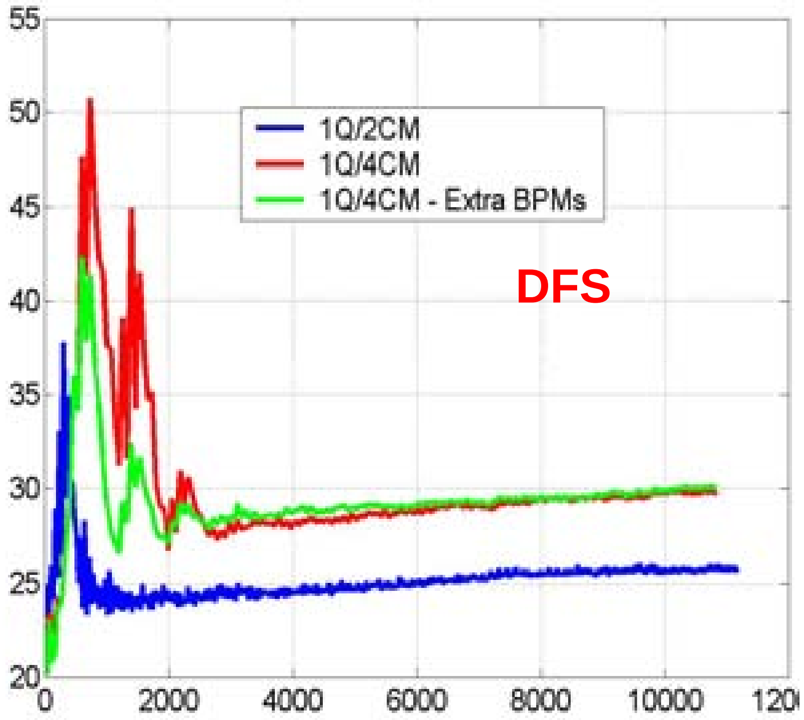


☞Almost no effect of adding extra BPMs / YCOR

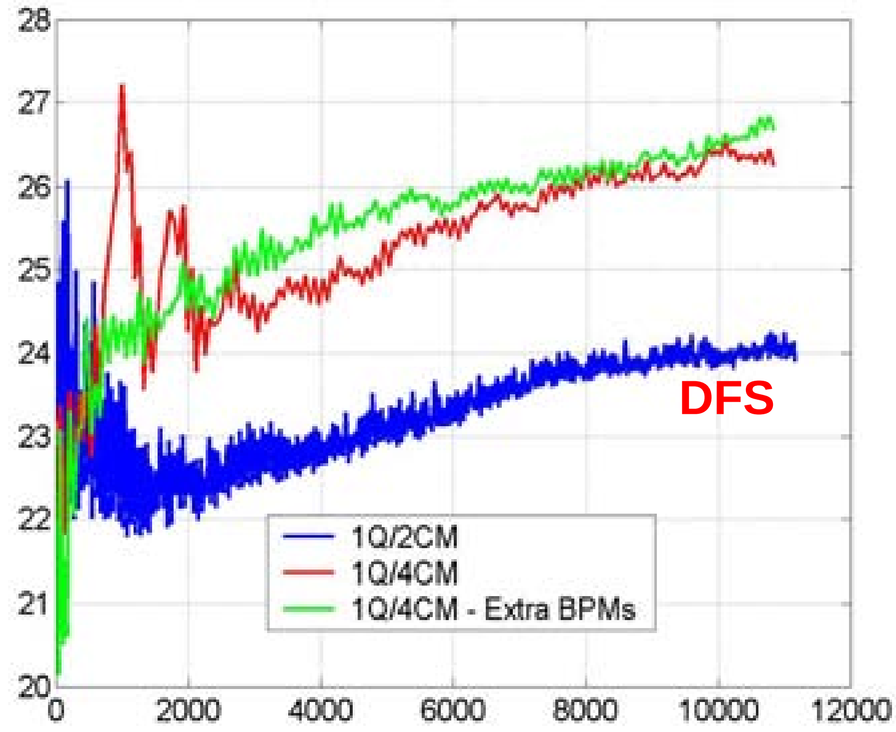
QUAD CONFIGURATIONS

⇨ To avoid the possible systematic effects

RF structure and CM Pitch : OFF



RF structure and CM Pitch : OFF
Launch region BPM RMS OFFSET ~ 0

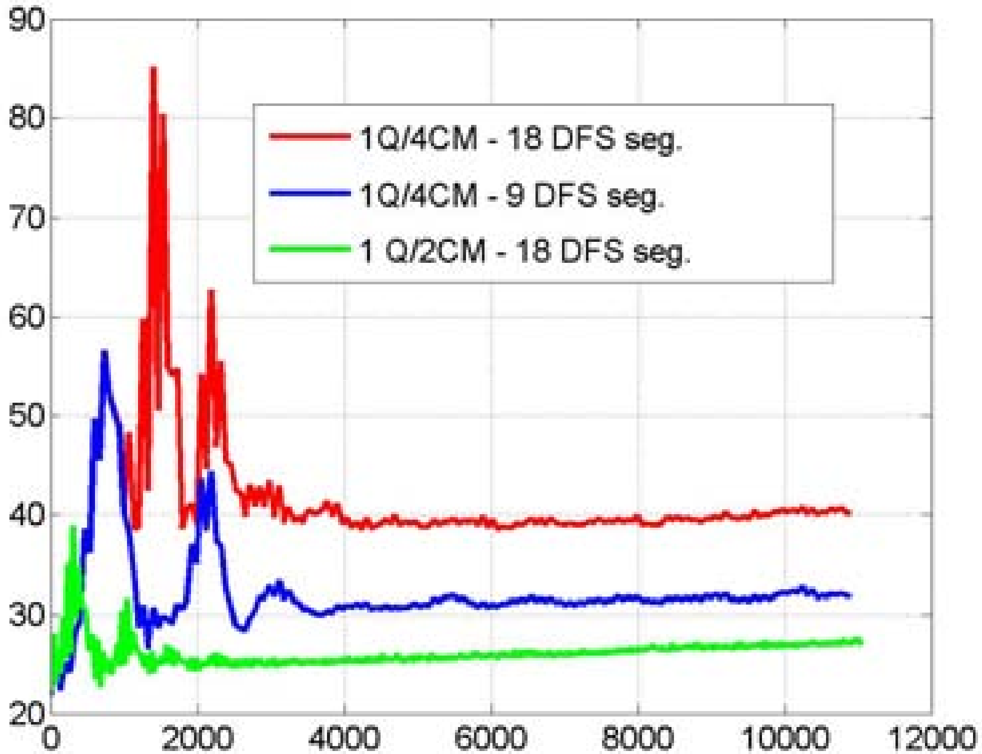


- 1 Q / 4CM is more sensitive to RF / CM pitches
- Extra BPMs not improve final emittance

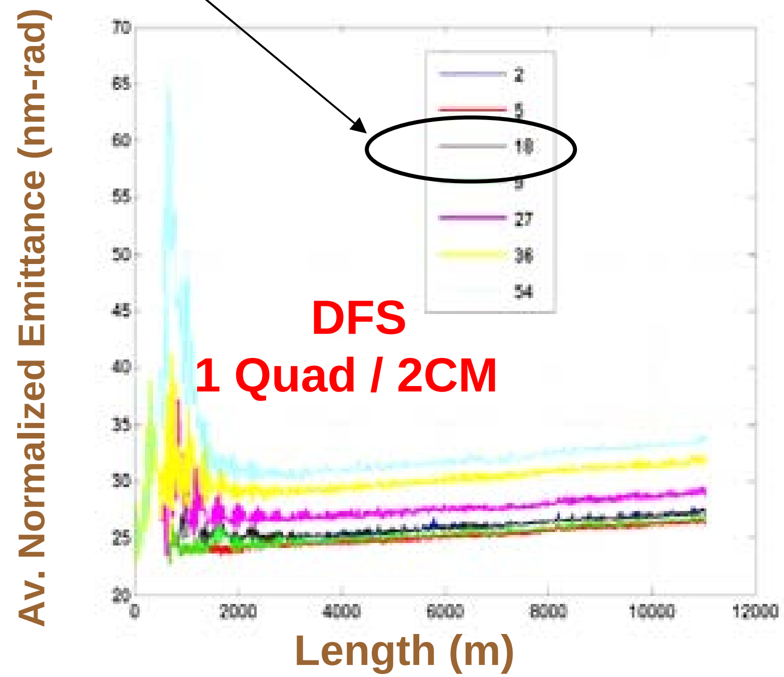
QUAD CONFIGURATIONS. Segmentation

⇨ Effect of varying No. of DFS segments for 1 Q / 4 CM ;
⇨ Nominal misalignment; 100 seeds

Effect of No. of quads per DFS segment



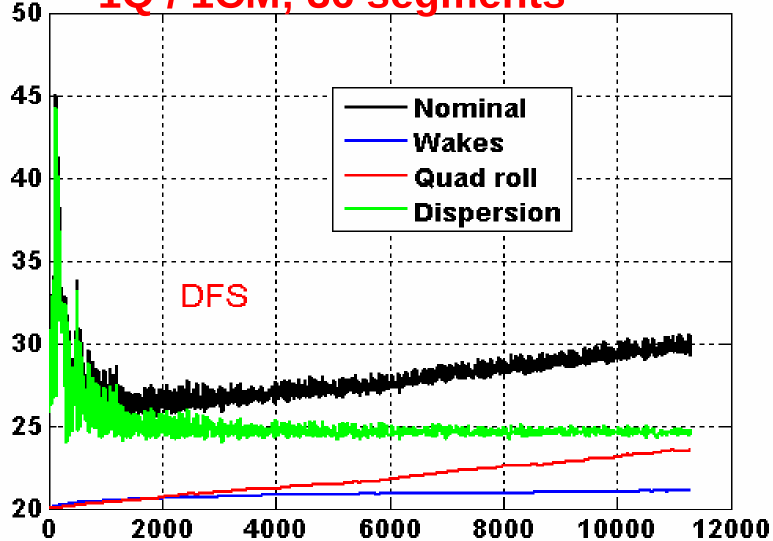
Nominal



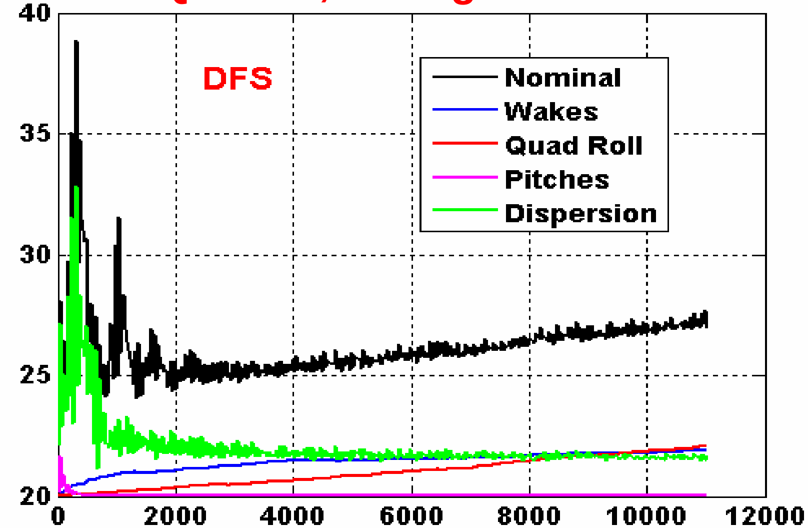
➢ Better for larger number of DFS segment (2,5,9,18 give almost comparable results)

EMITTANCE DILUTION – SOURCES

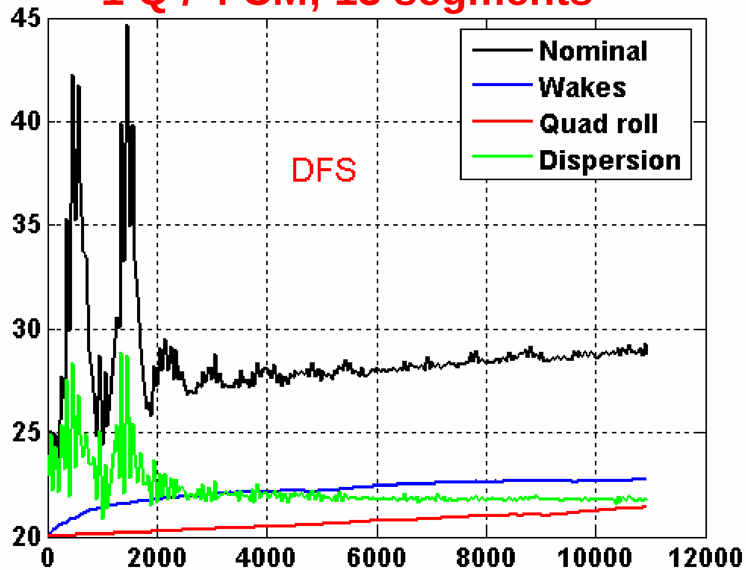
1Q / 1CM; 36 segments



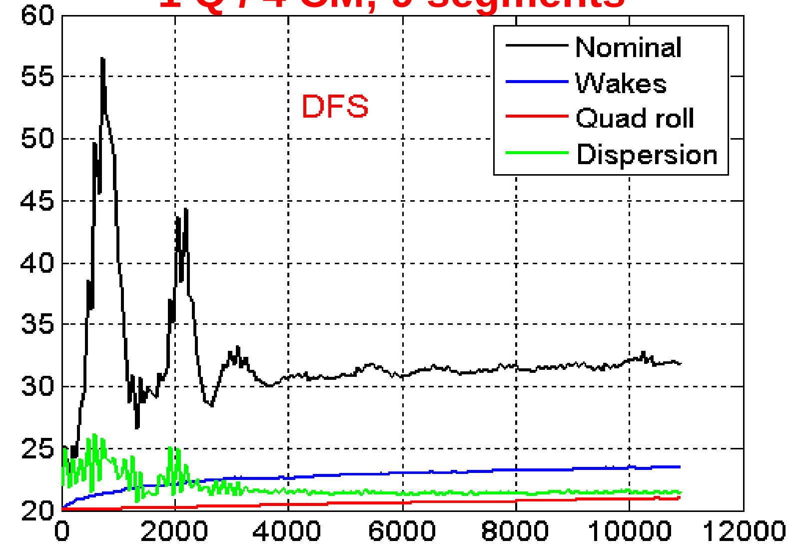
1Q / 2CM; 18 segments



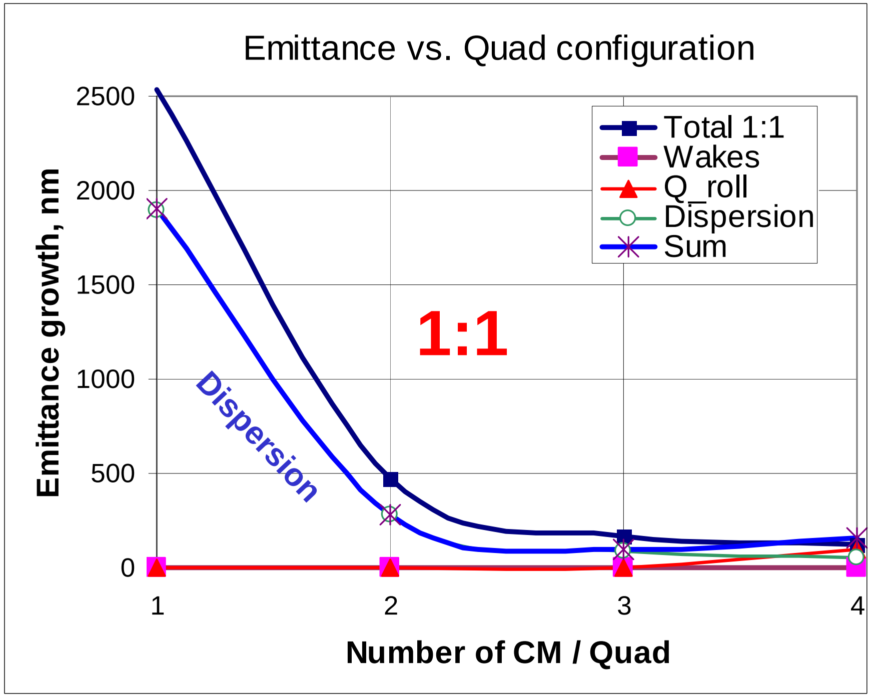
1 Q / 4 CM; 13 segments

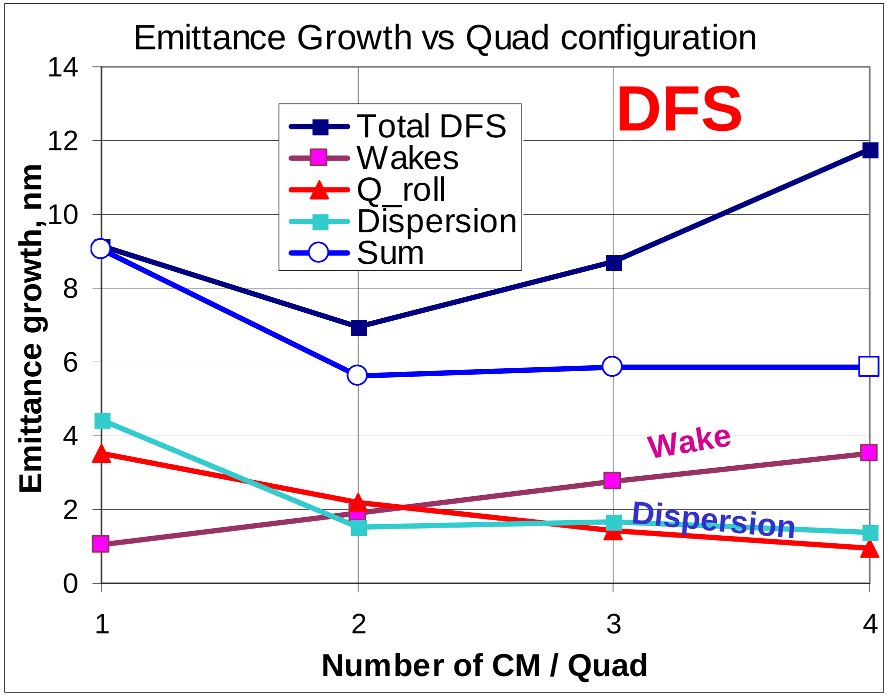


1 Q / 4 CM; 9 segments



EMITTANCE DILUTION – SOURCES





DFS:

1Q/2CM is equilibrium optics with equal contribution from each source. Optics with larger quad spacing is wakefield dominated with the systematic wake-related contribution (Sum of all three contributions is smaller that the total calculated emittance growth).

EMITTANCE DILUTION – SOURCES

1 Quad / 4 CM

1:1 Steering

Nominal[nm]:	1.208e+002
No Wakes[nm]:	5.828e+001
No Quad roll[nm]:	1.194e+002
No Quad Offset[nm]:	1.204e+002
No BPM Offset[nm]:	4.692e+001
No Front BPM Offset[nm]:	1.118e+002
No CM Offset[nm]:	8.799e+001
No Cavity Offset[nm]:	1.212e+002
No Cavity Pitch[nm]:	1.195e+002
No CM pitch[nm]:	1.207e+002

DFS

Nominal[nm]:	1.177e+001
No Wakes[nm]:	2.332e+000
No Quad roll[nm]:	1.077e+001
No Quad Offset[nm]:	1.113e+001
No BPM Offset[nm]:	4.694e+001
No Front BPM Offset[nm]:	8.904e+000
No CM Offset[nm]:	9.314e+000
No Cavity Offset[nm]:	1.153e+001
No Cavity Pitch[nm]:	8.564e+000
No CM pitch[nm]:	1.132e+001

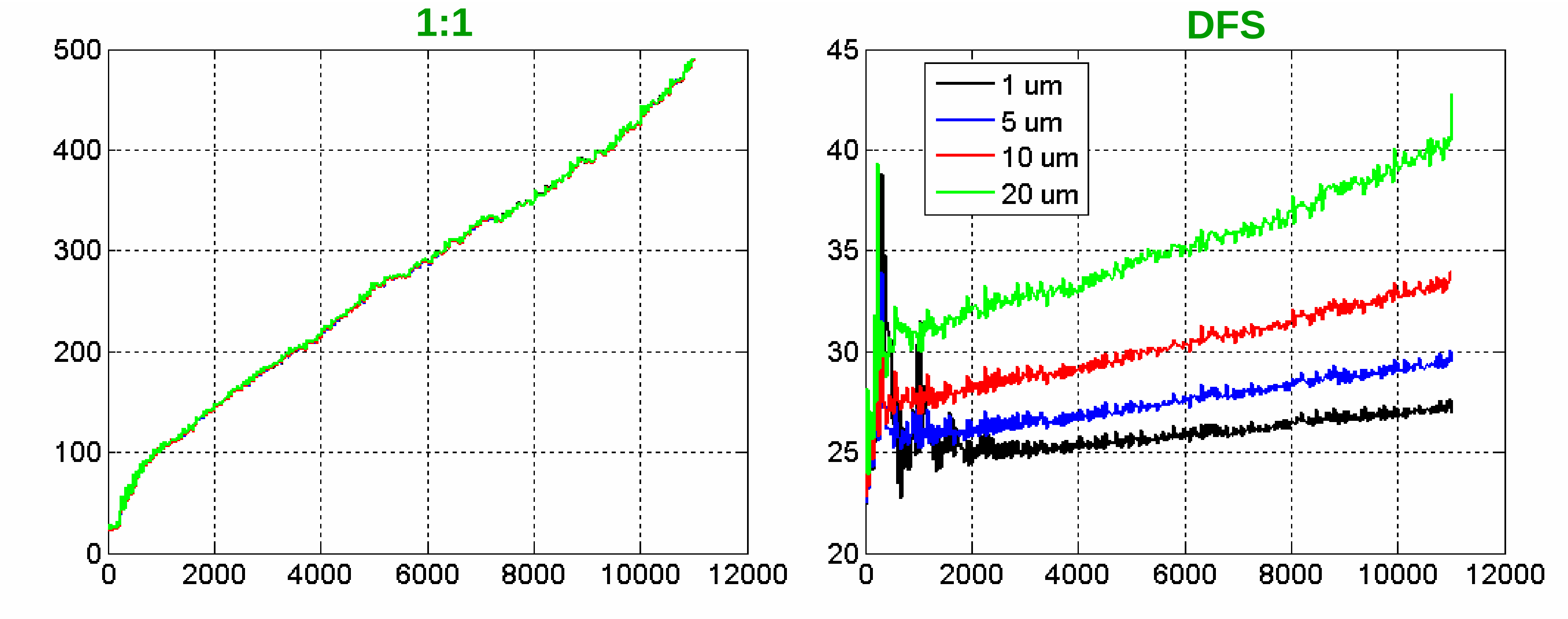
Screw DFS ← (No BPM Offset)

DFS

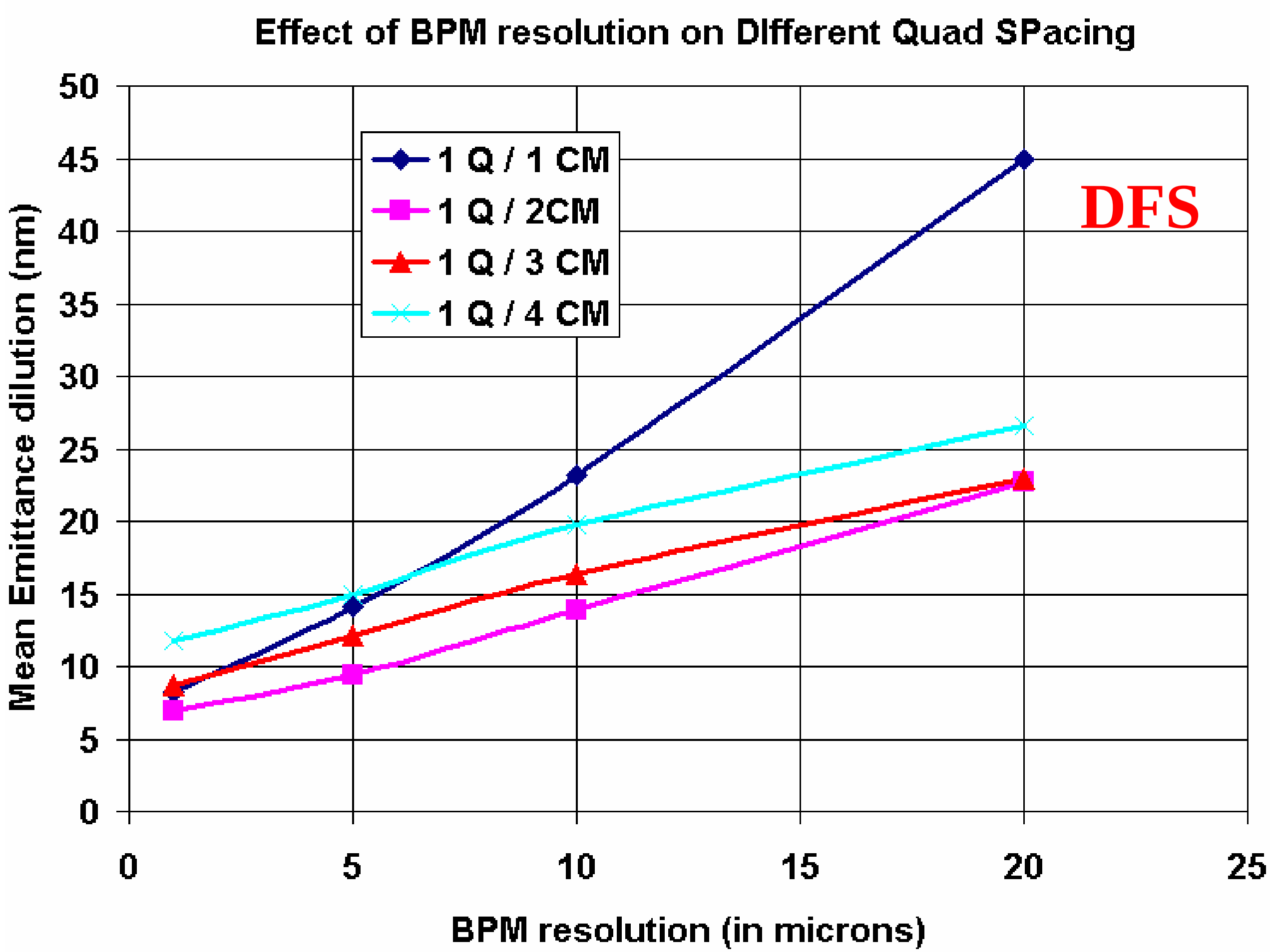
Nominal	11.77
No wake	2.33
No Disp	3.51
No Quad roll	10.77

EMITTANCE DILUTION – Effect of BPM Resolution

1 Quad / 2CM – 30 MV/m – No Autophasing



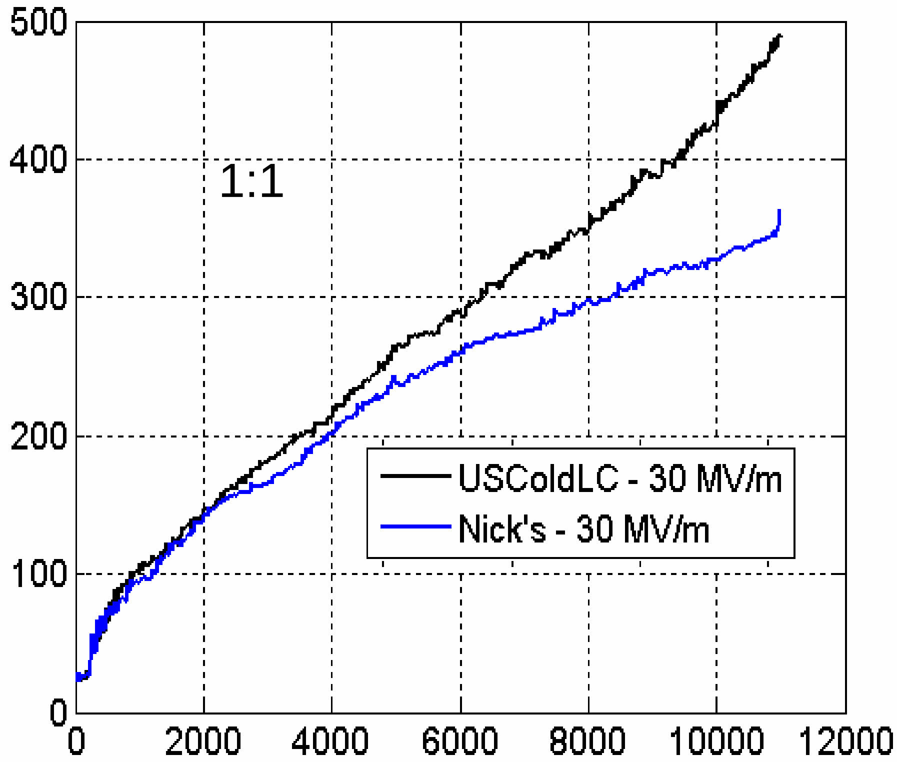
EMITTANCE DILUTION – Effect of BPM Resolution

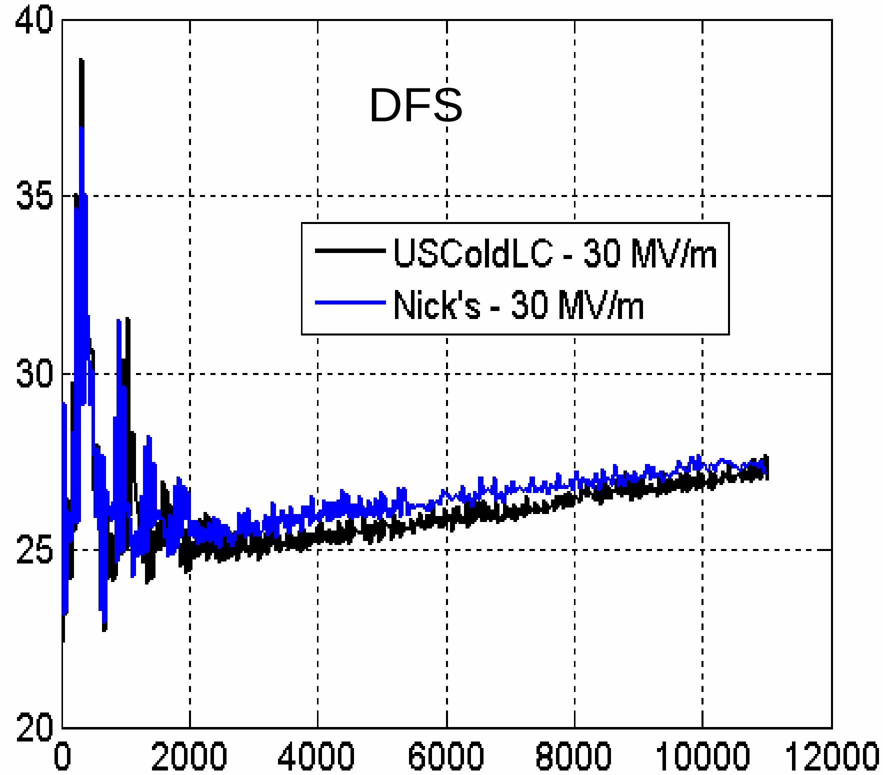


- Almost no effect for 1:1 steering
- 1Q/1CM is more sensitive
- No bumps

Non-regular Lattices. Nick vs. PT

30 MV/m Lattice, No autophasing

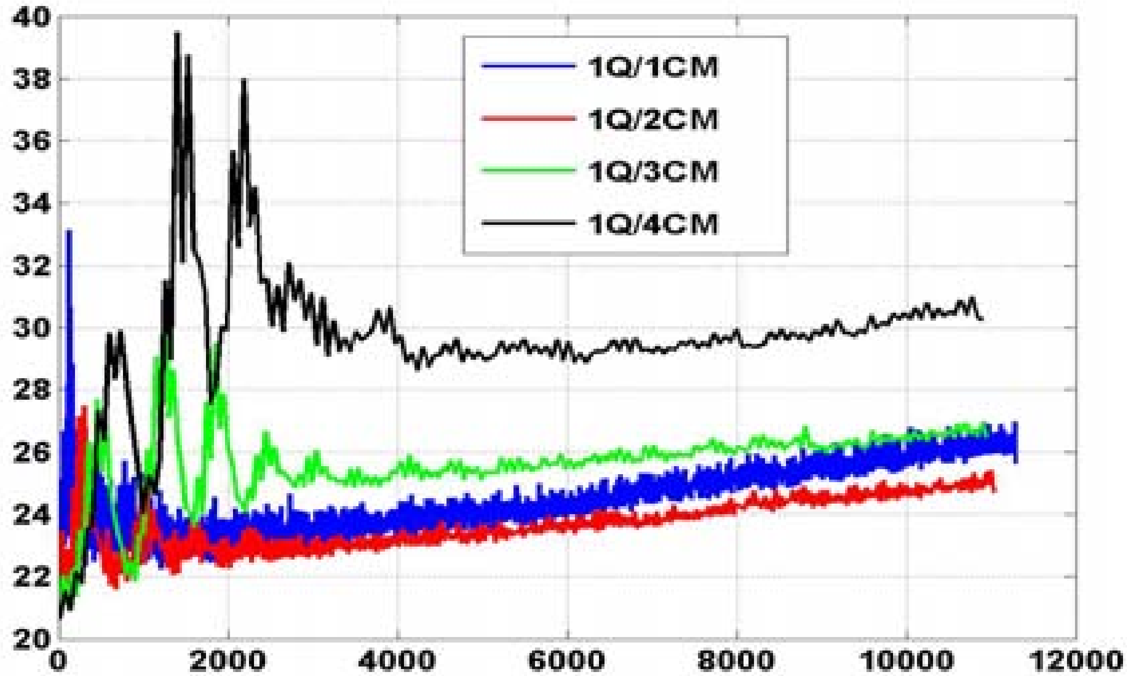




- Nick Walker Lattice: 1Quad / 2CM +Matching section+ 1Q/3CM (280 Quads)
- Higher emittance growth at the first half-linac for the Nick Lattice id due to non-optimal segmentation ? (18 segments in both cases)

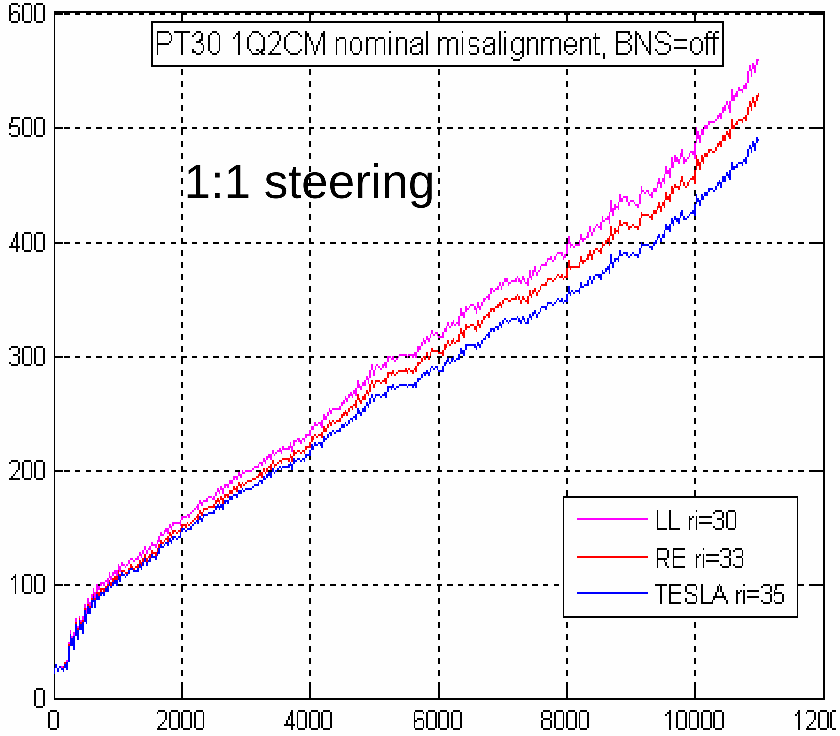
QUAD CONFIGURATIONS. Energy spread

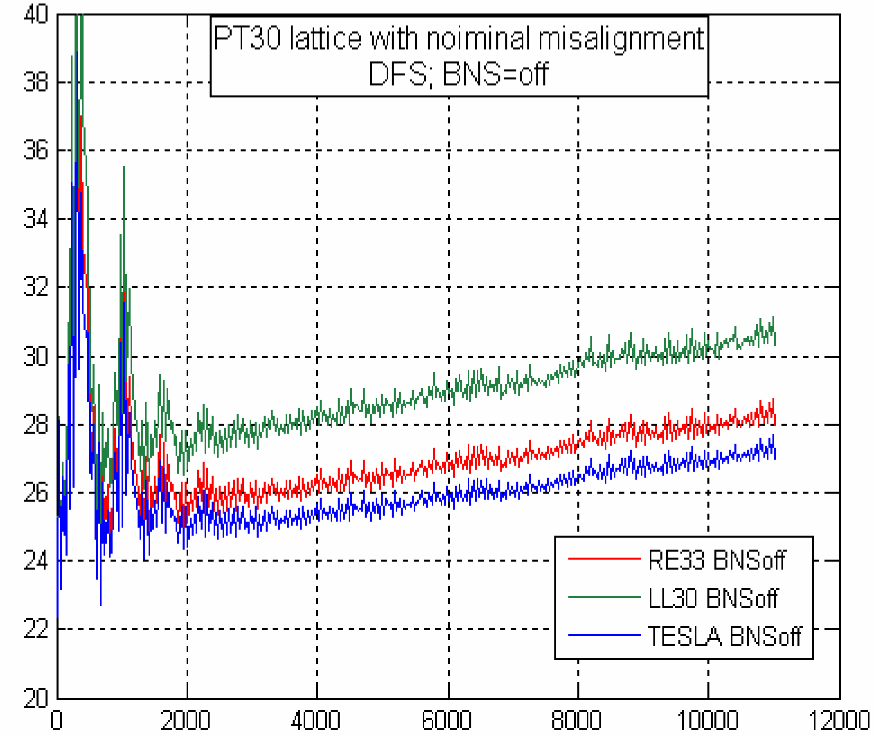
⇨ **Initial Energy = 15 GeV (energy spread 130 MeV); Nominal misalignment; 100 seeds**



Injection energy →	Mean dilution (nm) DFS		90% dilution (nm) DFS	
	5 GeV	15 GeV	5 GeV	15 GeV
1 Q / 1CM	8.3	5.6	15.3	9.1
1 Q / 2CM	6.9	4.7	13.1	9.3
1 Q / 3CM	11.0	6.5	21.2	13.6
1 Q / 4CM	20.2	10.2	39.4	19.3

Emittance in Linac with new HG cavities (RE or LL)



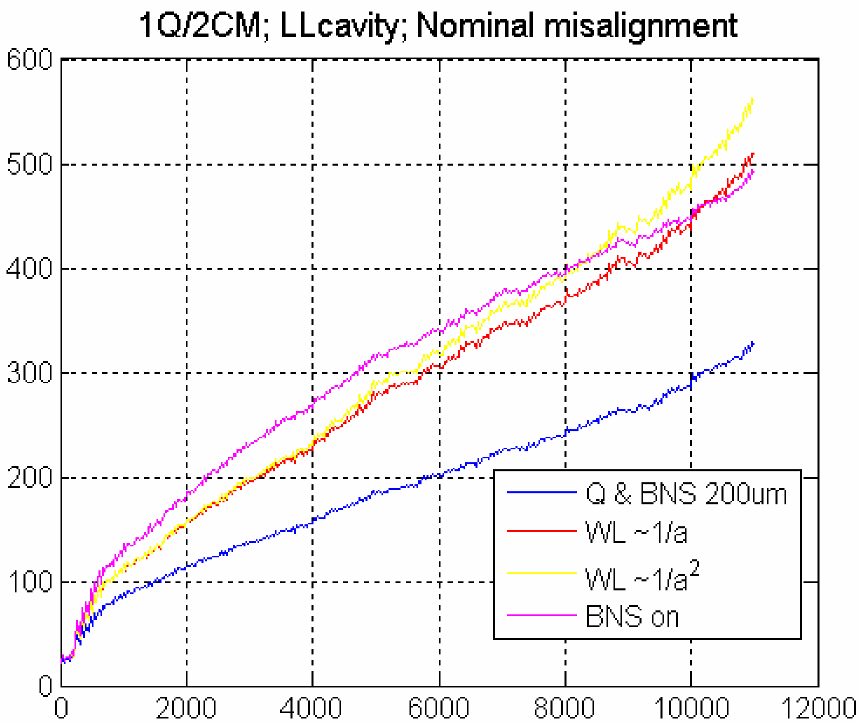


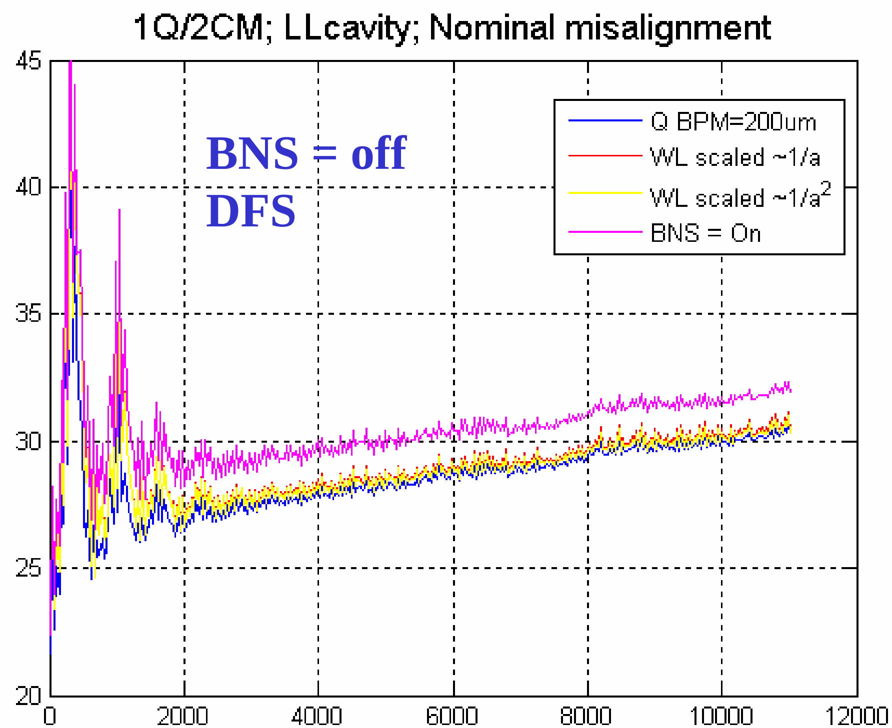
Nominal conditions:

Quad,cavity,BPM offset:	300 µm
Quad roll	300 µrad
Cavity pitch	300 µrad
CM offset:	200 µrad
CM pitch:	200 µrad
BPM resolution	1 µm

- LL30 – Low Loss cavity with 30mm iris
- RE33 – Re-entrant cavity with 33 mm iris
- Transverse wakefield are scaled ~ $1/a^3$ from I.Zagorodnov (K.Bane) calculation for TESLA CM
- Longitudinal wake is scaled ~$1/a^x$, x=x(s)

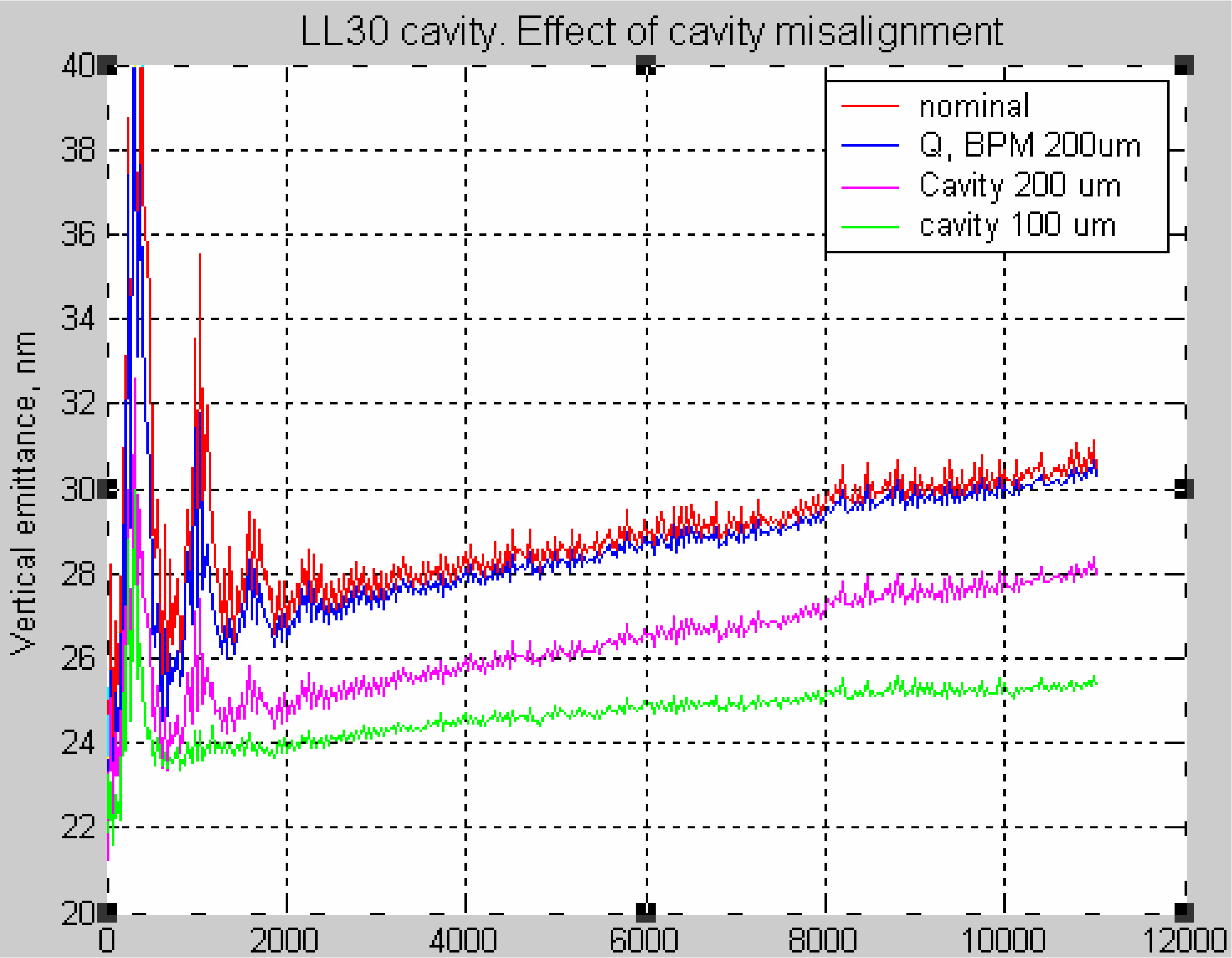
Effect of Longitudinal scaling law





- $_y \approx$11nm
- Small effects of scaling law for longitudinal wake (WL vs. a)
- Reduction of Quad and BPM offset installation tolerances from 300µm to 200µm has big effect to 1:1 steering and small effect on DFS

Effect of cavity and Quad misalignment



Tighter installation tolerances will reduce emittance growth

Using wake bumps should help to reduce emittance growth

CONCLUSION

- Few Lattices with different quad configuration (1Q/1QM ➔ 1Q/6QM) were studied.
- 1Quad / 2 CM lattice seems to be optimal. Contribution of three sources: dispersion, wakefield and x-y coupling for this configuration is almost equal.
- In higher quad spacing lattices the emittance dilution become wakefield dominated.
- Lattice with HG smaller aperture cavities (LL cavity Ri=30mm,

  RE with Ri=33mm) probably will require tighter cavity/duad offset tolerances (~200um for LL cavity)

Scaling of NLC simulations to TESLA cavity

If use normalized parameters: $a^* = \dfrac{a}{L}; \quad g^* = \dfrac{g}{L};$

$$W_Z(s^*) = \frac{Z_0 c}{\pi \cdot a^{*2}} \cdot \exp\left(-\sqrt{\frac{s^*}{s_0^*}}\right) \cdot \frac{1}{L^2}$$

$$W_\perp(s^*) = \frac{4Z_0 c \cdot s_1^*}{\pi \cdot a^{*4}} \cdot \left[1 - \left(1 + \sqrt{\frac{s^*}{s_1^*}}\right)\exp\left(-\sqrt{\frac{s^*}{s_1^*}}\right)\right] \cdot \frac{1}{L^3}$$

Where: *s*=s/L – normalized distance*

$$s_0^* = (s_0 / L) = 0.41 \cdot (a^*)^{1.8} \cdot (g^*)^{1.4}$$

$$s_1^* = (s_1 / L) = 0.169 \cdot (a^*)^{1.79} \cdot (g^*)^{0.38}$$

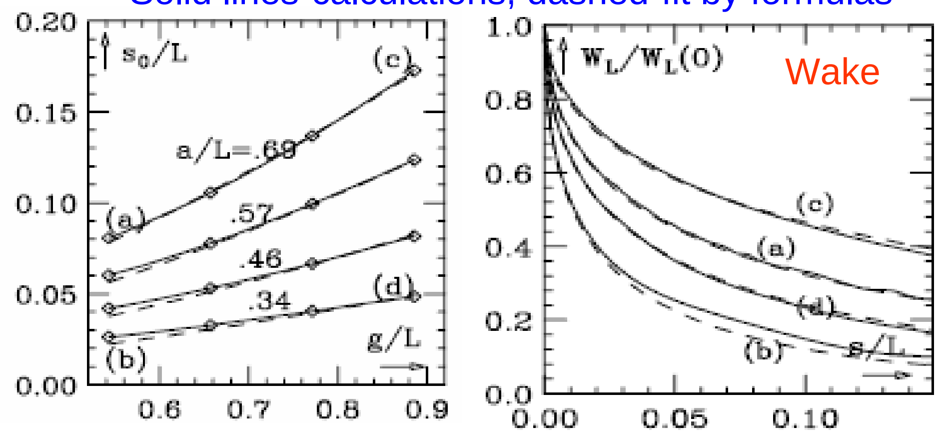
Scaling Laws:

$W_Z \sim \dfrac{1}{L^2} \quad W_\perp \sim \dfrac{1}{L^3}$ *(a*,g* fixed)*

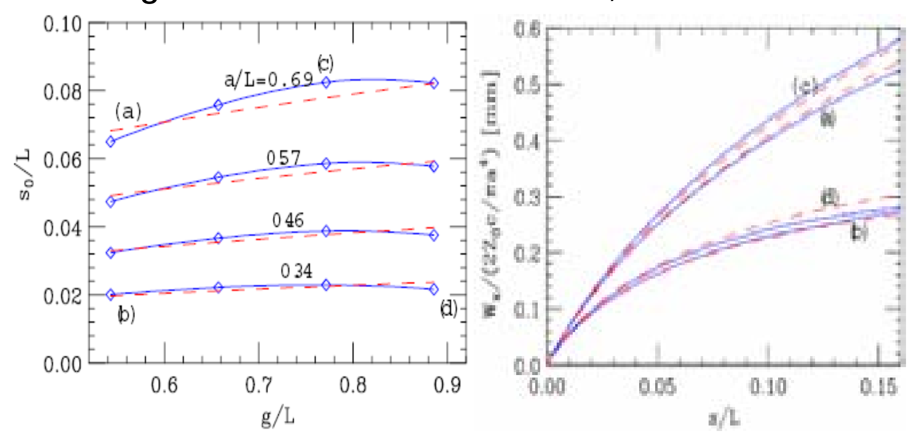
$W_Z \sim \dfrac{1}{a^x} \quad W_\perp \sim \dfrac{1}{a^3}$ *(for fixed L)*

Where *x = x(s/L) = 1÷2,* $x(s^*) \sim 2/(1+0.46\, s^{*0.7})$.

Solid lines-calculations, dashed-fit by formulas



Longitudinal wake: K.Bane.et all, SLAC-PUB-7862

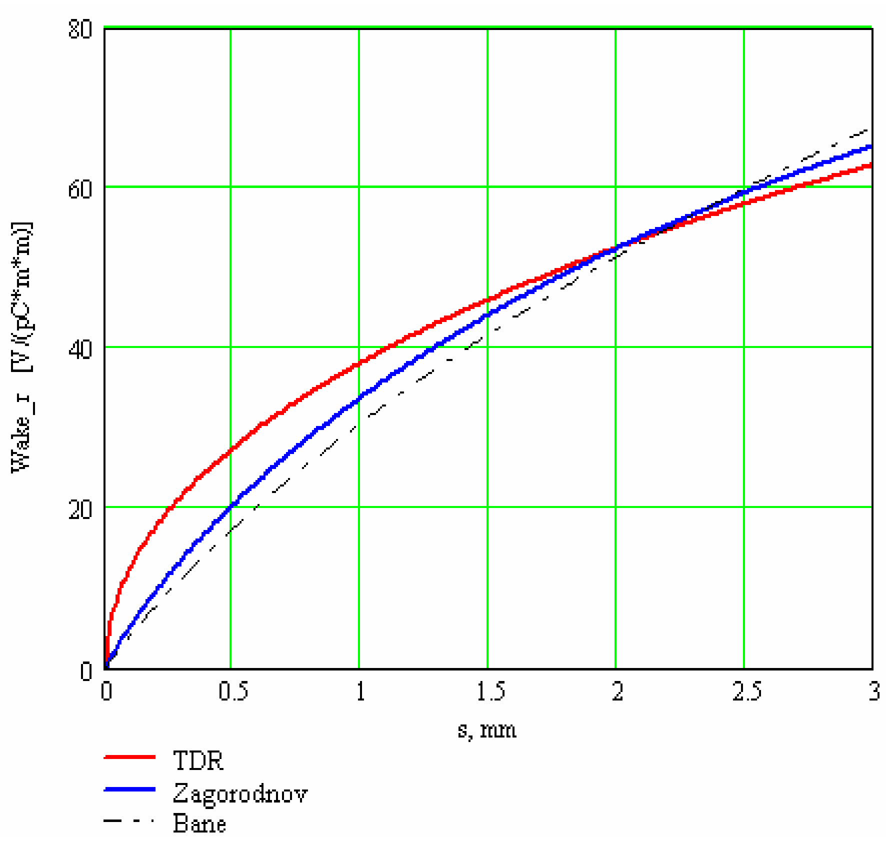


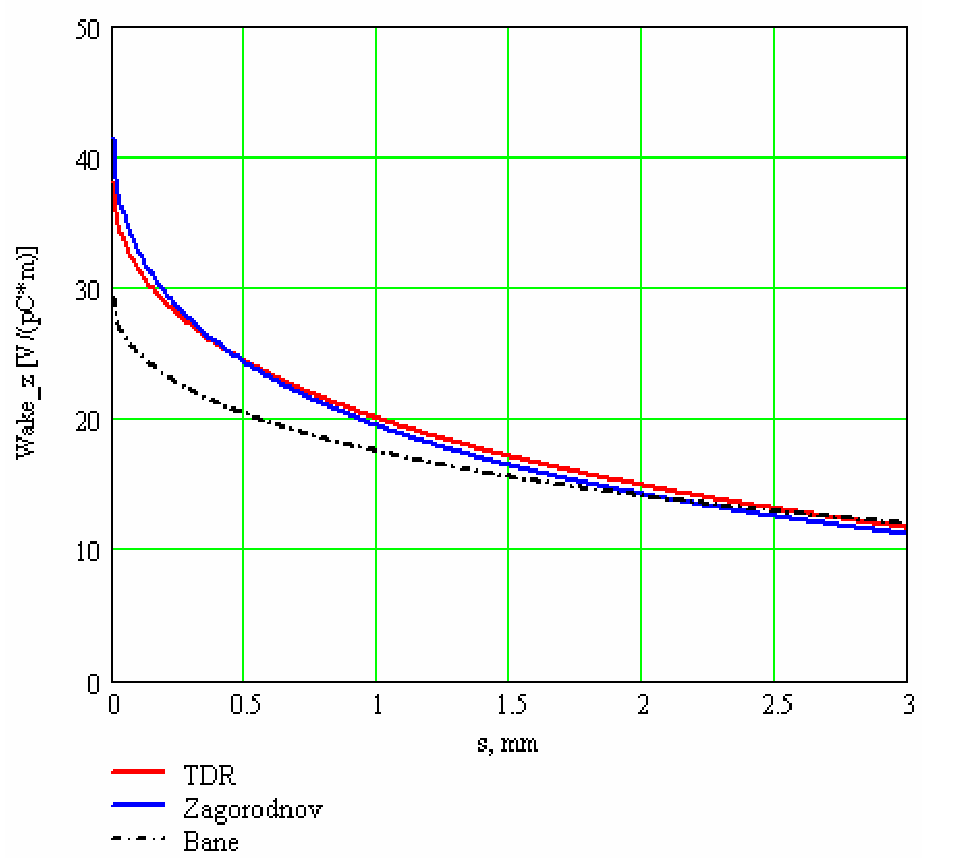
Dipole wake: K.Bane, SLAC-PUB-9663

Calculated for parameters in region:
034 ≤ *a/L* ≤0.69 and 0.54 ≤*g/L* ≤0.89

TESLA cavity: $a^* = 0.3; \; g^* \approx 0.8$ (a* out of range calculated NLC parameters, but…)

Comparison TESLA and NLC calculations





For transverse Wakefield good agreement between K.Bane and Zagorodnov/Weiland calculations.

For Longitudinal wakes some disagreement.

Igor formula gives: $W_Z(0) = 41.5 \left[\frac{\text{V}}{\text{pC}\cdot\text{m}}\right]$

Karl formula gives: $W_Z(0) = \frac{Z_0 c}{\pi \cdot a^2} = 29.4 \left[\frac{\text{V}}{\text{pC}\cdot\text{m}}\right]$