



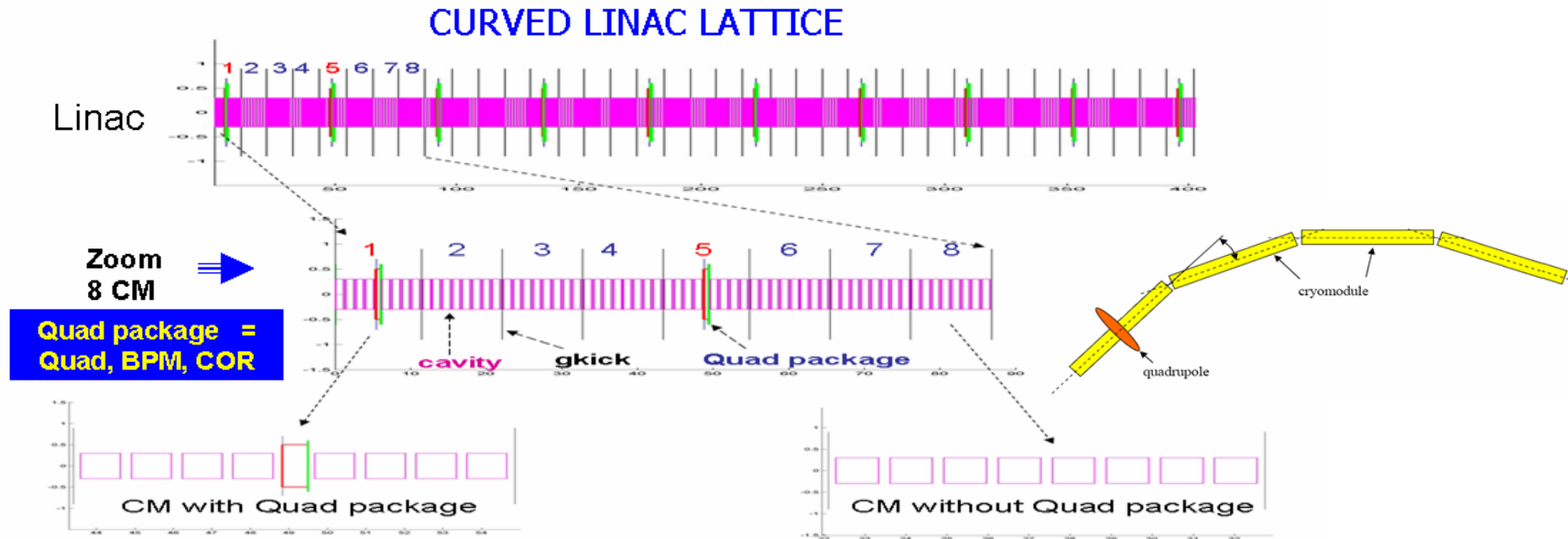
# ILC Curved Linac Simulation

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*Fermilab*

+

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*SLAC*

# Curved ILC-BCD LINAC



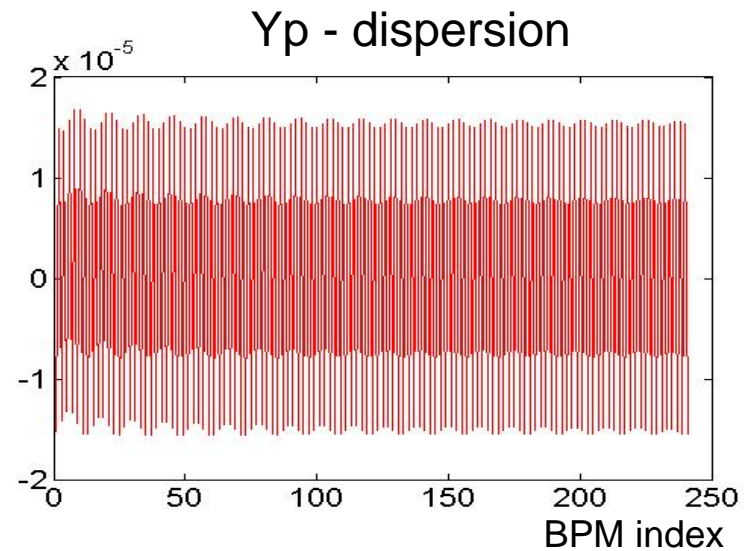
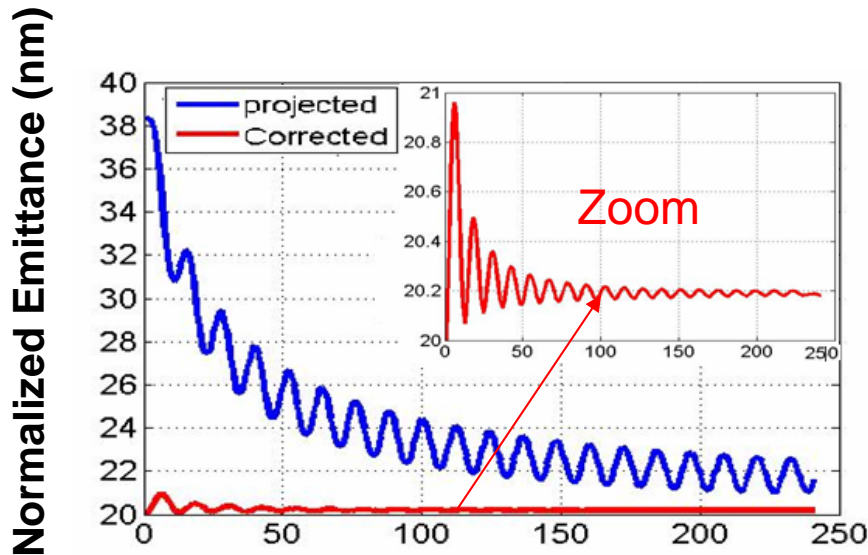
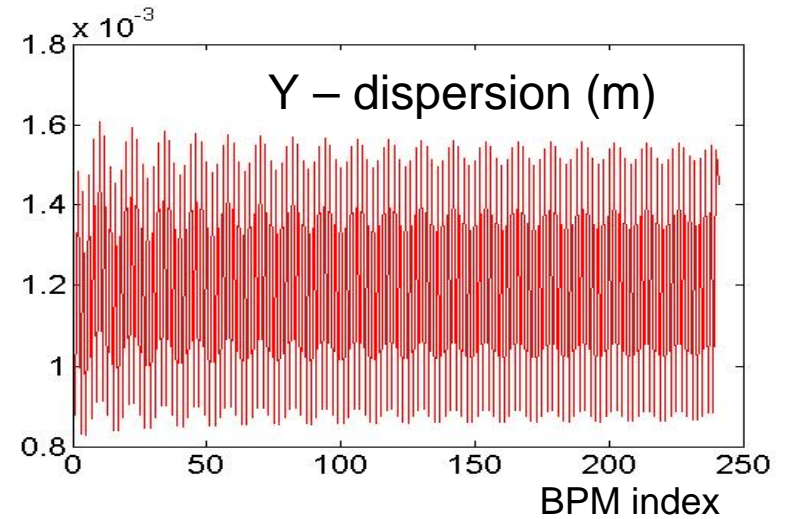
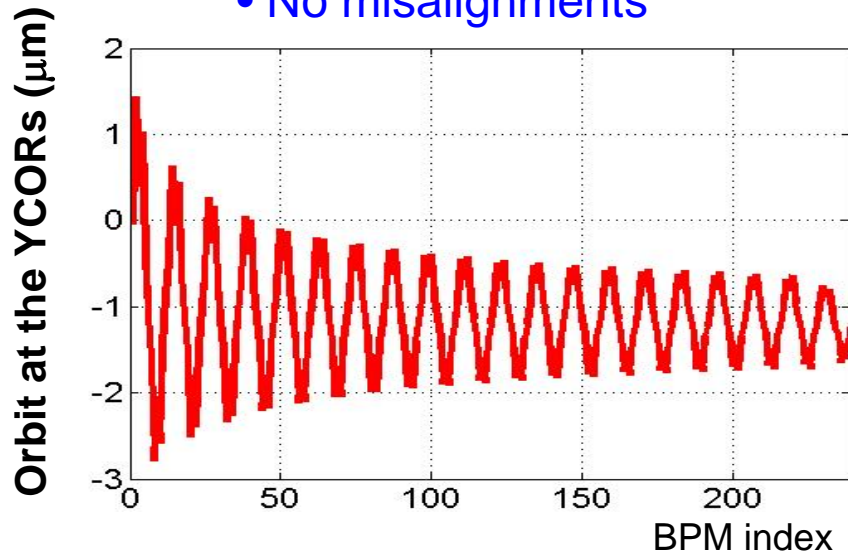
- PT's ILC BCD-like lattice distributed during ILC-LET workshop at CERN.
- A constant focusing lattice with a quadrupole spacing of 32 cavities and x/y phase advance of 75/60 per cell ( ILC BCD - 1Q / 4CM)
- Modifications in LIAR code to simulate the earth curvature:
  - The curvature is simulated by adding kinks between the cryo-modules - **GKICK**
  - The matched dispersion condition at the beginning of the linac is artificially introduced into the initial beam and is propagated through linac using transfer matrices

Length (m) :	10417.2m
N_quad :	240
N_cavity :	7680
N_bpms :	241
N_Xcor :	240
N_Ycor :	241
N_gkicks :	1920

# LIAR Simulation: CURVED LINAC



- No misalignments



# Nominal Misalignment tolerances



Tolerance	Vertical (y) plane
BPM Offset w.r.t. Cryomodule	300 $\mu\text{m}$
Quad offset w.r.t. Cryomodule	300 $\mu\text{m}$
Quad Rotation w.r.t. Cryomodule	300 $\mu\text{rad}$
Cavity Offset w.r.t. Cryomodule	300 $\mu\text{m}$
Cryostat Offset w.r.t. Survey Line	200 $\mu\text{m}$
Cavity Pitch w.r.t. Cryomodule	300 $\mu\text{rad}$
Cryostat Pitch w.r.t. Survey Line	20 $\mu\text{rad}$
BPM Resolution	1.0 $\mu\text{m}$

→ 1<sup>st</sup> 7 BPMs have 30  $\mu\text{m}$  RMS offset w.r.t. Cryostat

- BPM transverse position is fixed, and the BPM offset is w.r.t. Cryostat
- Only Single bunch used
- Steering is performed using Dipole Correctors

# Dispersion Free (or Matched) Steering



- 1:1 steering is performed - steer to obtain the nominal, design readings of the BPMs
- DFS -
- Linac is divided into 18 segments (w/ 50% overlap) & 1<sup>st</sup> DF segment starts from 8<sup>th</sup> BPM
- Measure two orbits –
  - (i)  $y(0)$  : one for the nominal energy.
  - (ii)  $y(\delta)$  : other by switching off cavities upstream of the segment (maximum energy change for a given segment is 20% of the nominal energy at the upstream end of the segment, or 18 GeV, whichever is smaller.)
- In both cases 3 BPMs upstream of each segment (used for fitting the incoming beam trajectory) are included in the measurement.
- Simultaneously minimize the Measured dispersion and RMS value of BPM readings

$$\chi^2 = \frac{\Delta y(\delta) \cdot \Delta y(\delta)}{\sigma_{res}^2} + \frac{y(0) \cdot y(0)}{\sigma_{BPM}^2}$$

$$\sigma_{res} = \text{sqrt}(2) * \text{BPM resolution}$$
$$\sigma_{BPM} = \text{BPM offset}$$

Where  $\Delta y(\delta) = y(\delta) - y(0) - \Delta y_{nom}(\delta)$

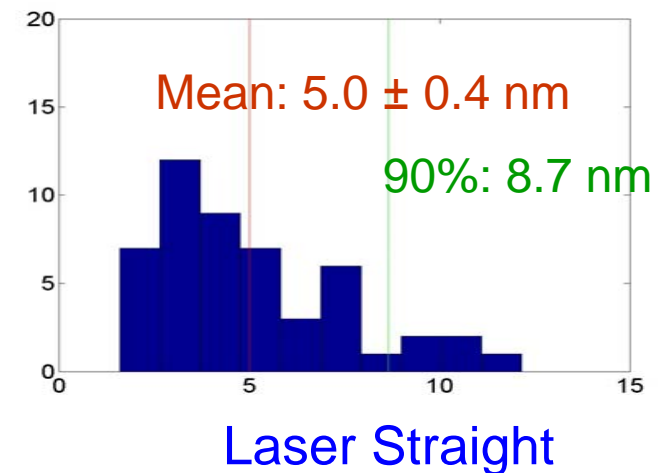
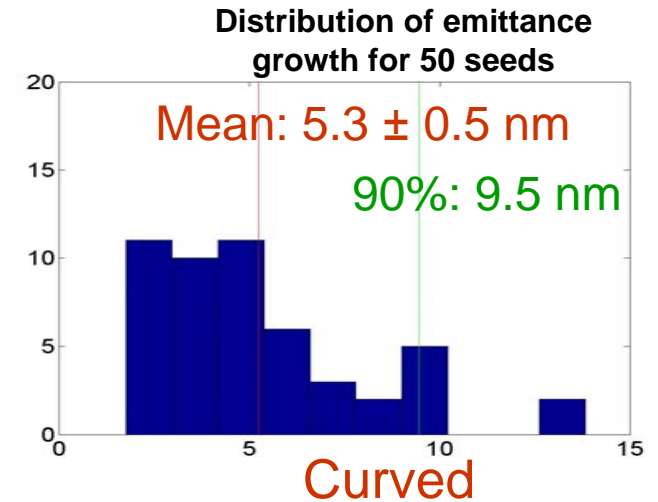
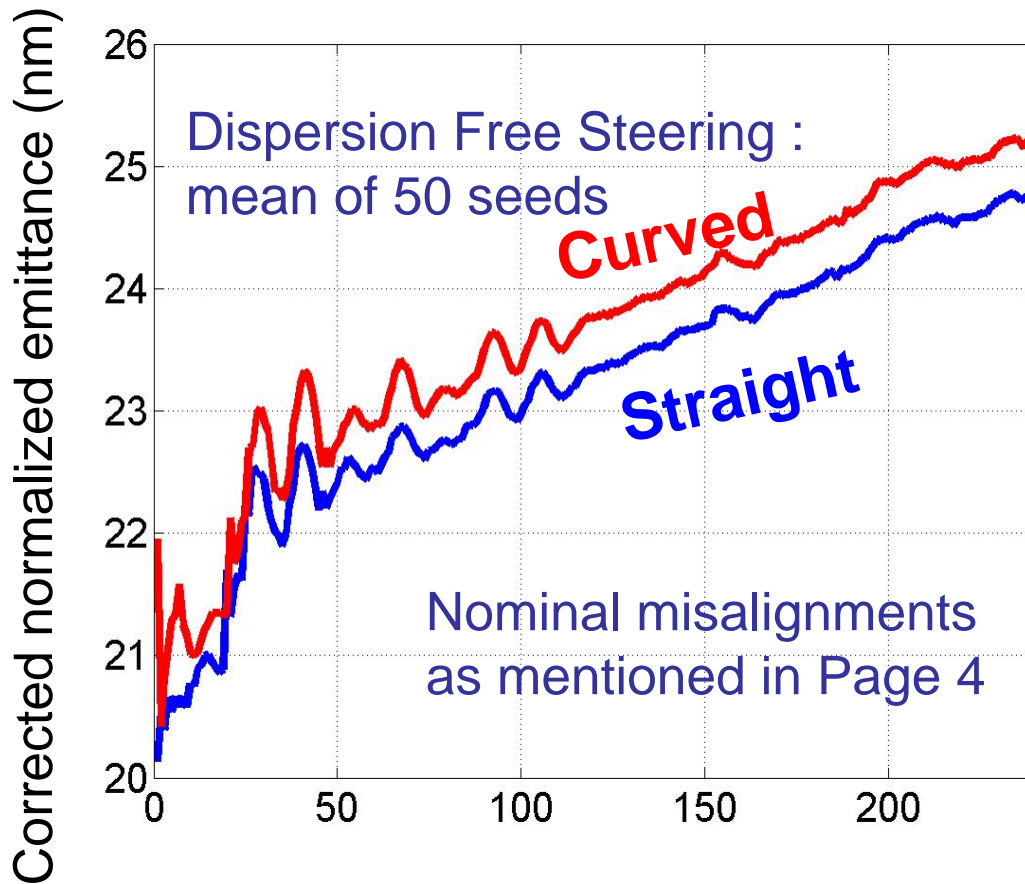
$\Delta y_{nom}(\delta)$  is the nominal or design difference orbit for the momentum error  $\delta$ .

# Dispersion Free Steering - Results



Misalign the beamline components and perform the DF steering

**CURVED vs. STRAIGHT LINAC**

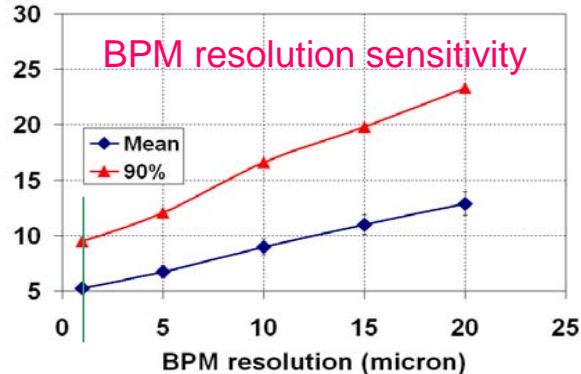
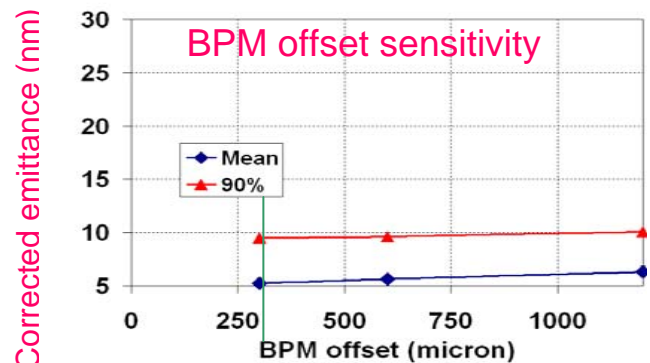
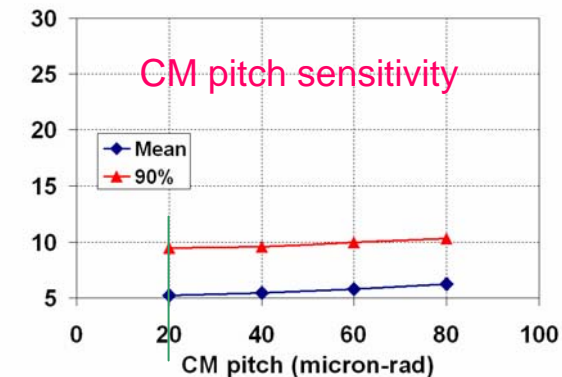
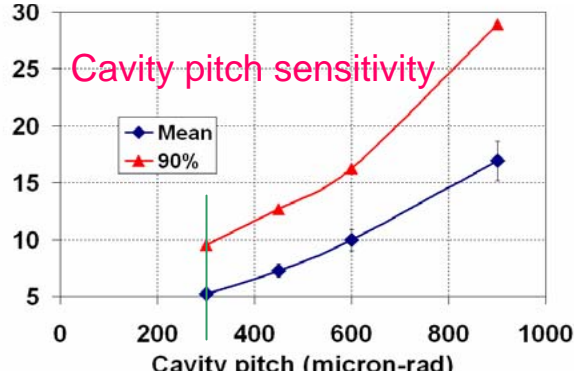
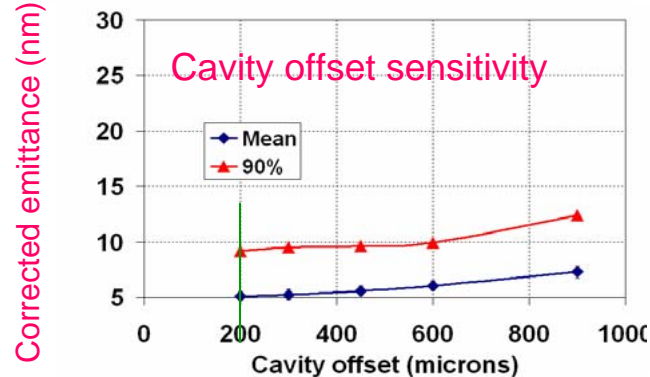
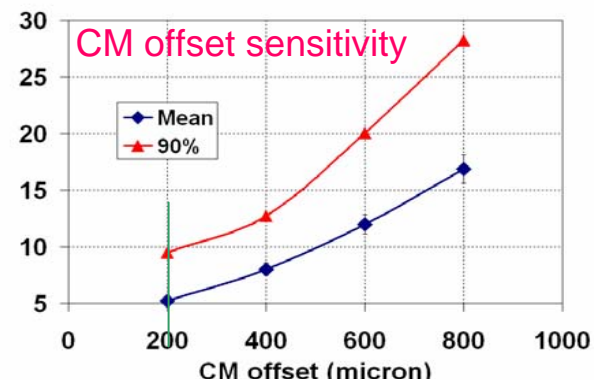
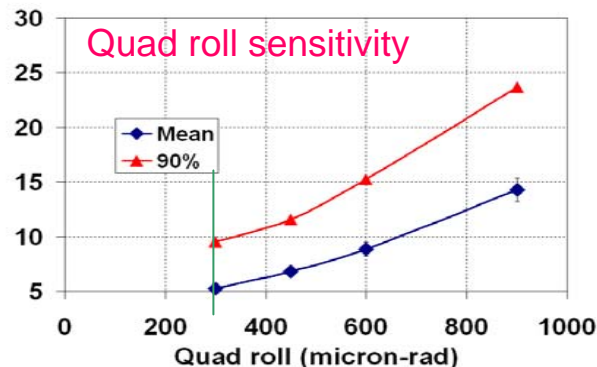
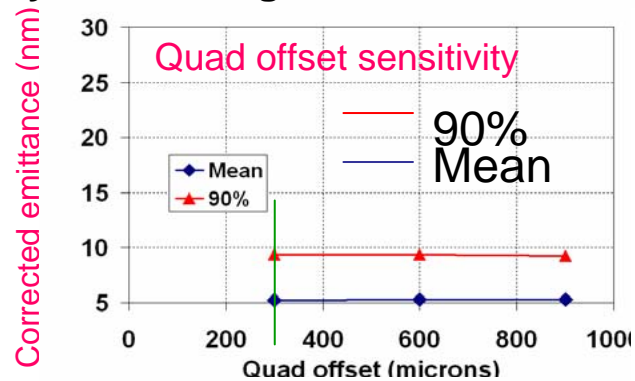


DFS parameters not optimized for Curved Linac

# DFS: Sensitivity studies



Vary one misalignment from its nominal value - keeping all other misalignments at their nominal values



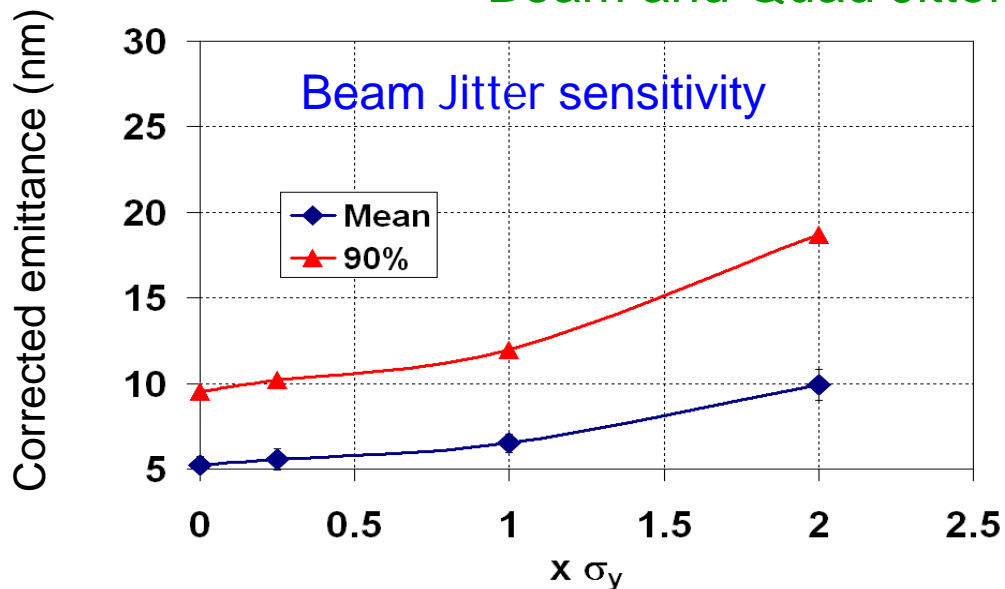
**Sensitive to**  
**Cavity pitch,**  
**BPM resolution,**  
**CM offset,**  
**Quad roll**



# DFS: Sensitivity studies

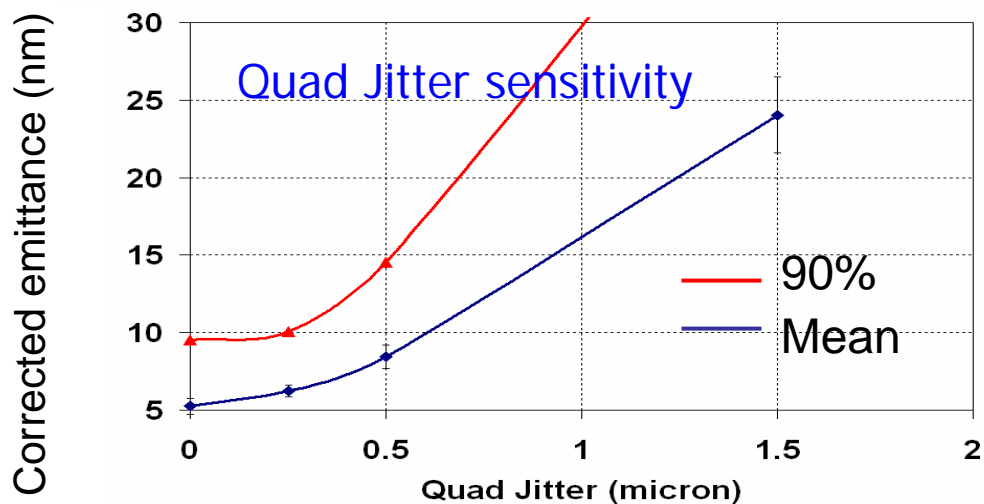


## Beam and Quad Jitter Sensitivity



## Quad Strength error

Quad strength error (dK)	Mean	90%
0.5 e-3	7.43±0.46	11.7
1e-3	7.44±0.46	11.5
2.5e-3	7.50±0.46	11.5
5e-3	7.70±0.46	11.9





# DFS: Contributions



50 seeds	mean	90%	
Nominal	5.26 ± 0.38	9.47	
Dispersion only	1.99 ± 0.24	4.22	Switch off wakes & quad roll
Wakes only	1.8 ± 0.17	3	Cavity offset & wakes only
Quad roll only	1.47 ± 0.13	2.83	quad roll only
Total	5.26	10.05	

Individual misalignment (30 seeds)	mean	err	90%
CM pitch only	0.25	0.036	0.56
Cavity pitch only	2	0.35	4.3
Front bpm offset only	0.41	0.0493	0.77
Quadroll only	1.39	0.13	2.37
Cavity offset only	1.67	0.18	2.98
Bpm resolution only	0.43	0.0548	0.76
Bpm offset only	0.2	0.0107	0.28
Quad offset only	0.17	0.0026	0.19
Sum	6.52		12.2

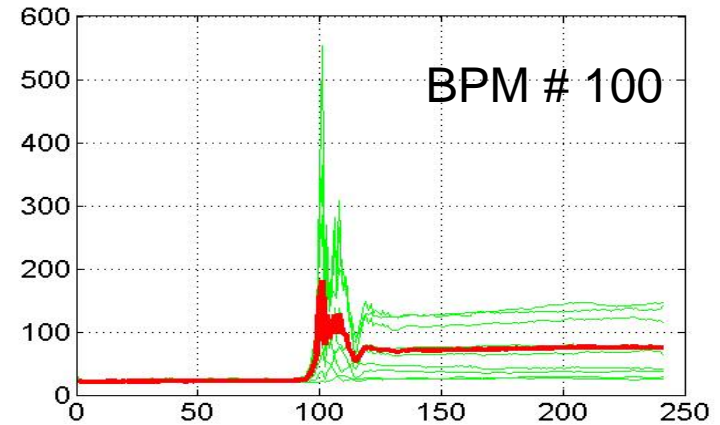
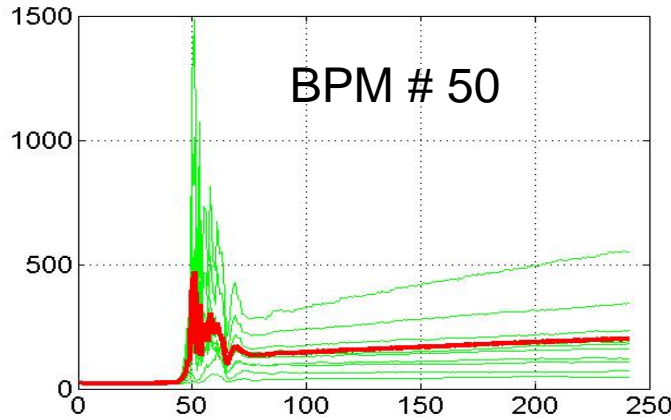
A **systematic contribution** seems to add up in each case, which is added only once when we perform the nominal run



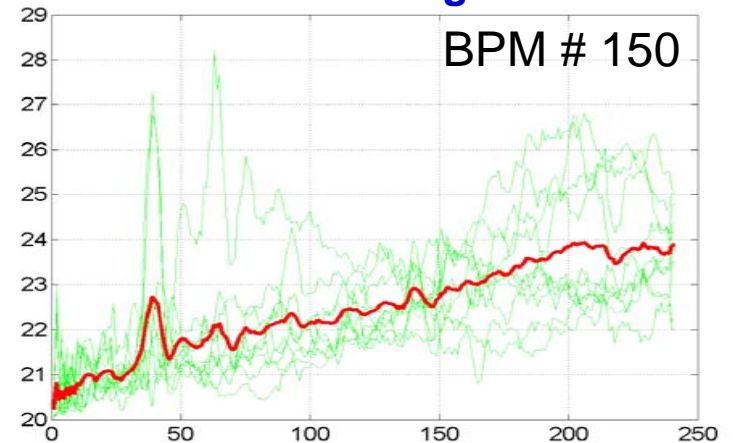
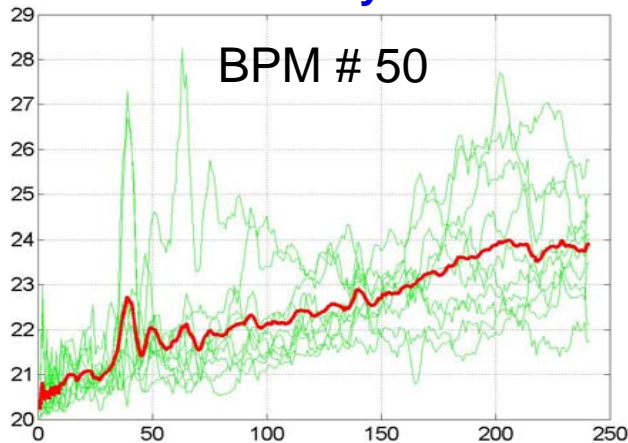
# Failure Mode Analysis (ILC BCD Curved Linac)

10 seeds; Curved Linac; **1 BPM reading = 0** and is used in the DF steering

Dispersion corrected emittance growth (nm-rad) vs. BPM index



**Case2: Faulty BPM and associated YCOR not used in steering**

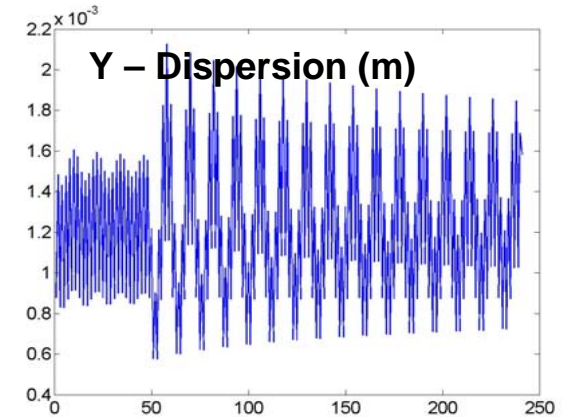
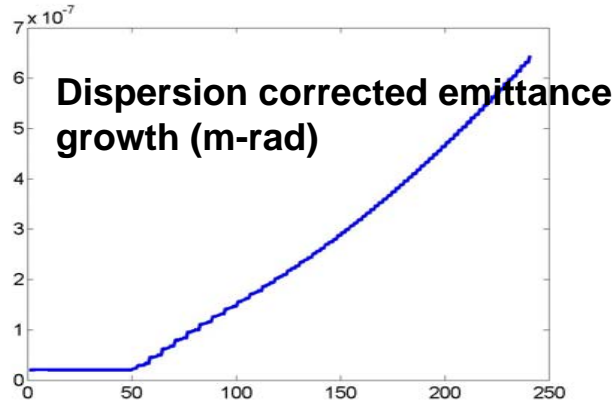
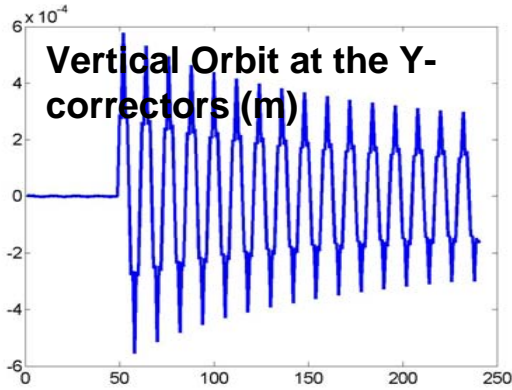


- (1) If you know the position of faulty BPM and exclude it from the steering then the results are fine
- (2) However, if you use that faulty BPM in finding the corrector settings, then the emittance dilution is significant.



# Failure Mode Analysis (ILC BCD Curved Linac)

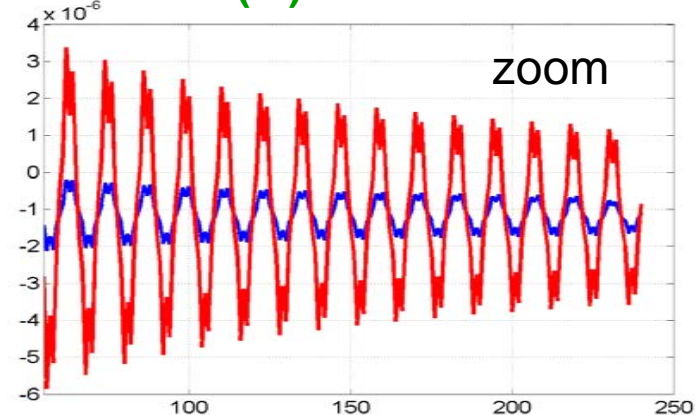
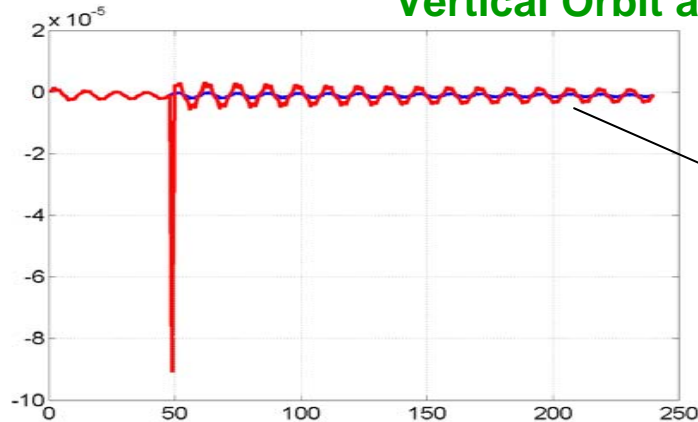
Case 1: Perfectly straight Linac (1 Y - CORRECTOR NOT WORKING (kick =0) :# 49 )



In a perfectly aligned Linac, if one YCOR doesn't work according to it's designed value – then both the trajectory and emittance dilution are significantly worse

- Adjusted the adjacent two correctors (upstream and downstream) to guide the beam on to the designed orbit – we know which corrector is failed!

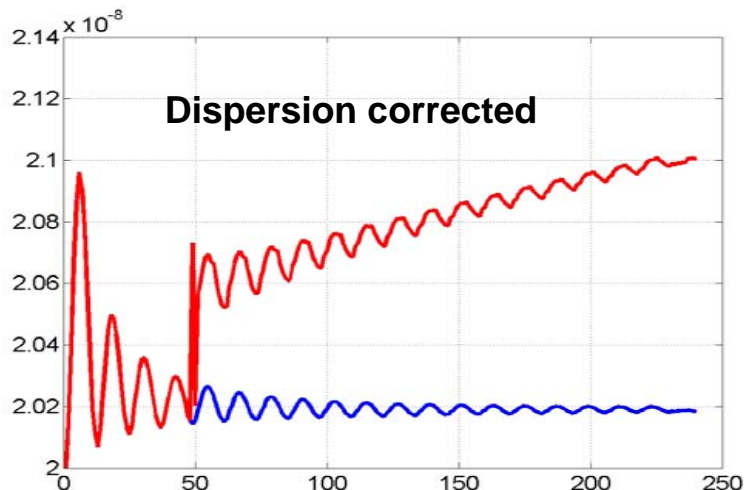
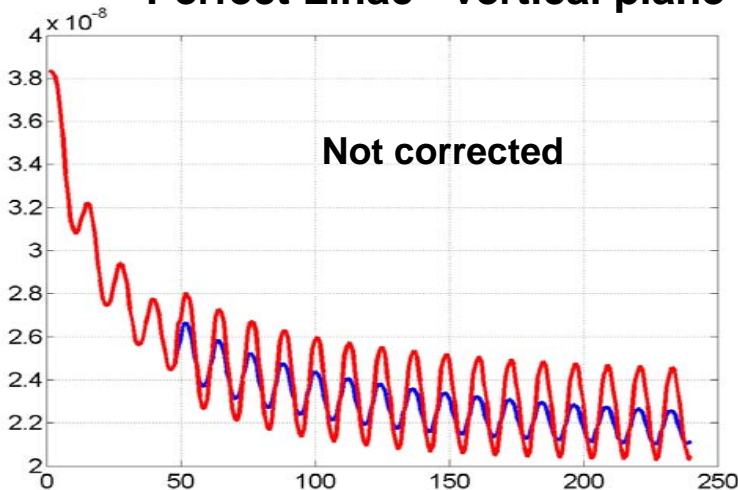
## Vertical Orbit at the Y-correctors (m)





# Failure Mode Analysis (ILC BCD Curved Linac)

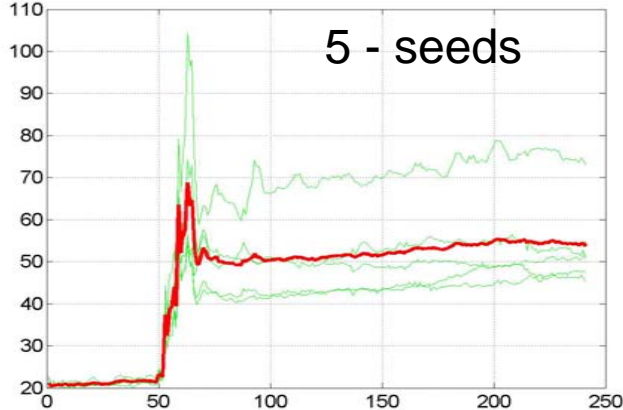
## Perfect Linac - vertical plane - Projected Normalized Emittance (m-rad)



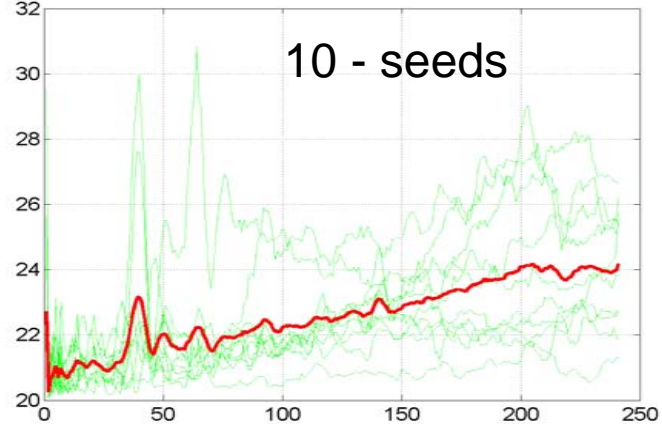
**Nominal misalignment ; Dispersion Free Steering;**

▪ **Case 1: Failed Corrector used in finding the correction-settings; but correction is not applied to the failed corrector**

**Case 2: Failed Corrector NOT used in finding the correction-settings;**



**Dispersion corrected – emittance growth (nm-rad)**

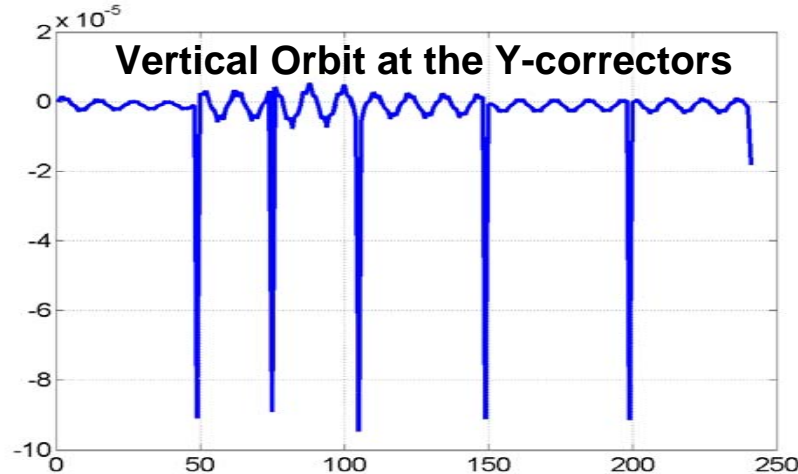




# Failure Mode Analysis (ILC BCD Curved Linac)

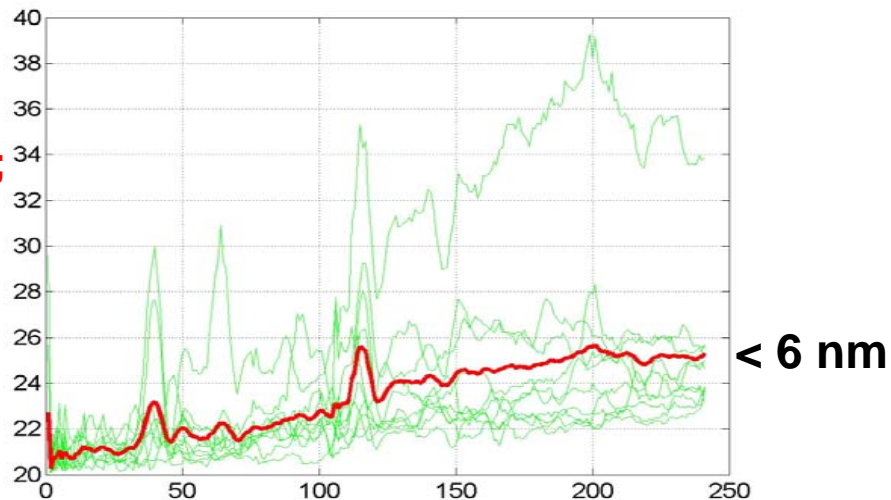
**5 Y-CORRECTORS NOT WORKING – randomly chosen - CORRECTORS NO. 50,76,106,150,200 (one corrector failure in one DF segment)**

- Adjusted the adjacent two correctors to guide the beam on to the correct orbit



**Nominal misalignment ;  
Dispersion Free Steering;**

**Dispersion  
corrected –  
emittance growth  
(nm-rad)**



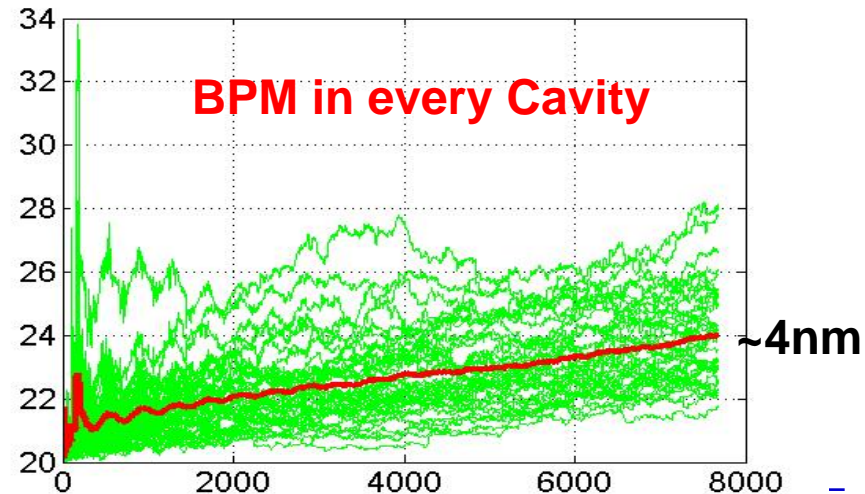
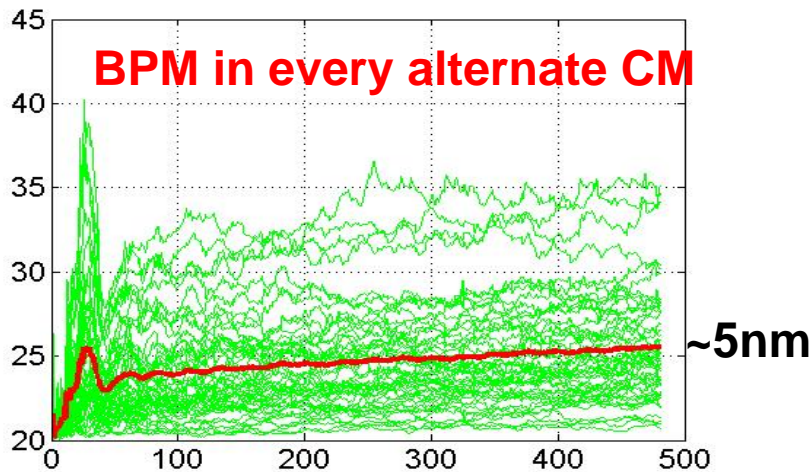
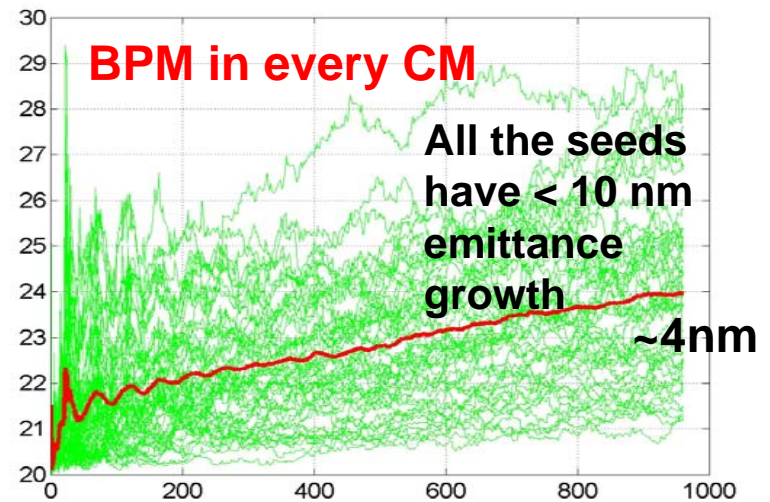
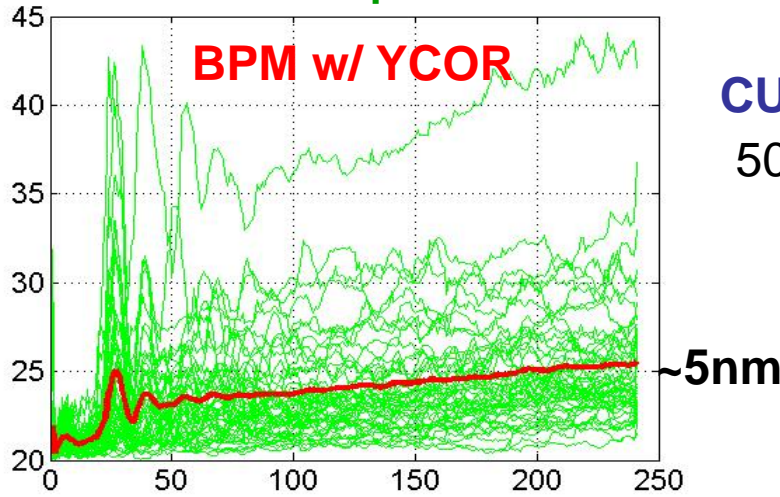


# No. of BPMs



Using BPM in every CM or in every Cavity : Presently we are using BPM in only Quad package along w/ Corrector. (a) What if BPM is there at the centre of every CM? (b) what if each cavity can be read out as BPM – BPM in every cavity?

## Dispersion Corrected Emittance Growth vs. BPM index



# PLAN

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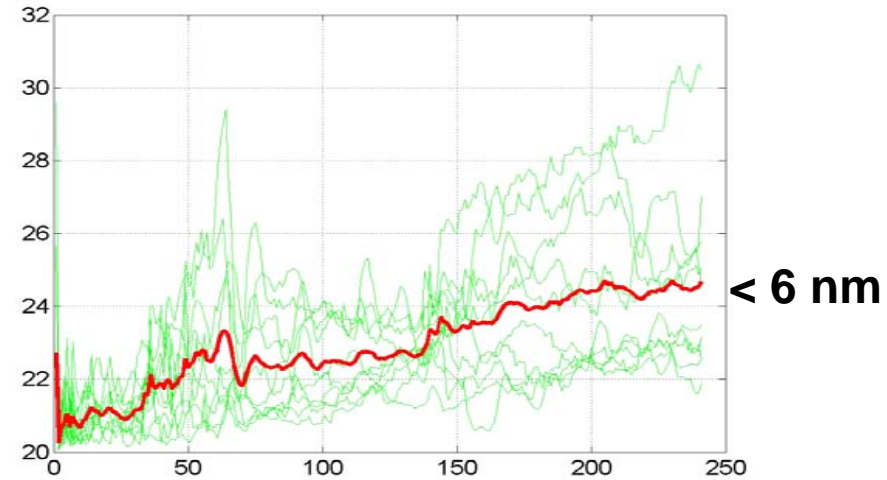
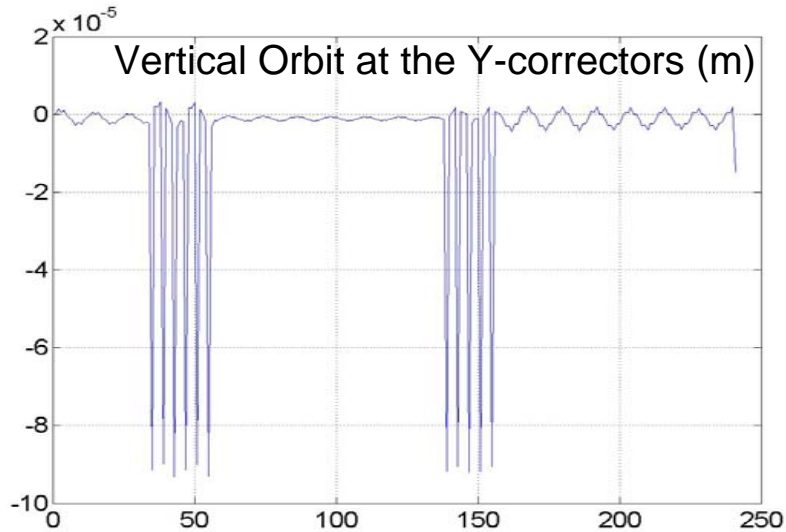
- **Use dispersion + wake bumps in curved linac**
- **Perform the studies in the Final Main Linac Lattice**



# Several Y-CORRECTORS NOT WORKING – randomly chosen Correctors not used in the steering



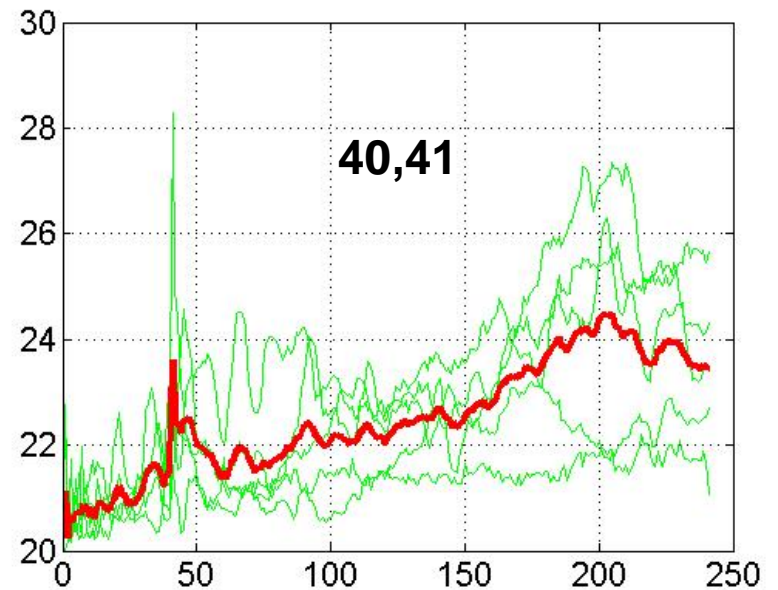
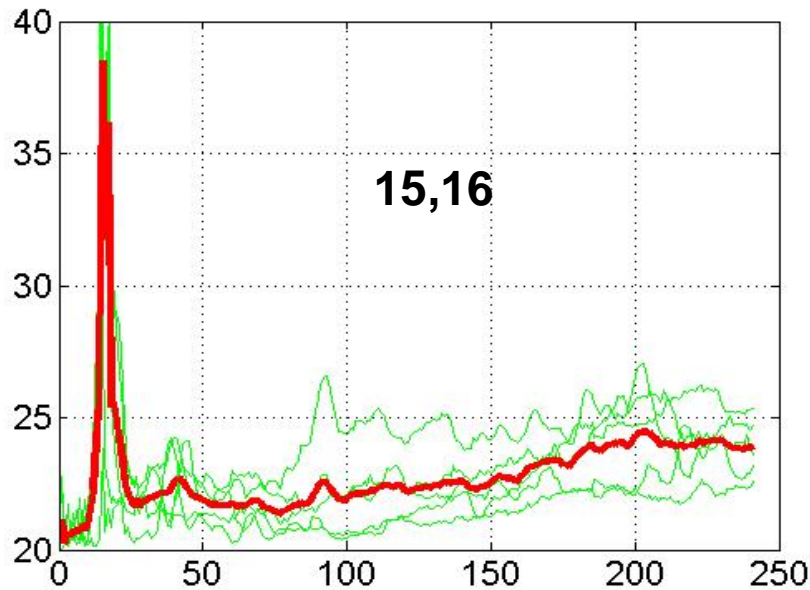
Nominal misalignment; DMS  
Dispersion corrected emittance dilution (nm-rad);



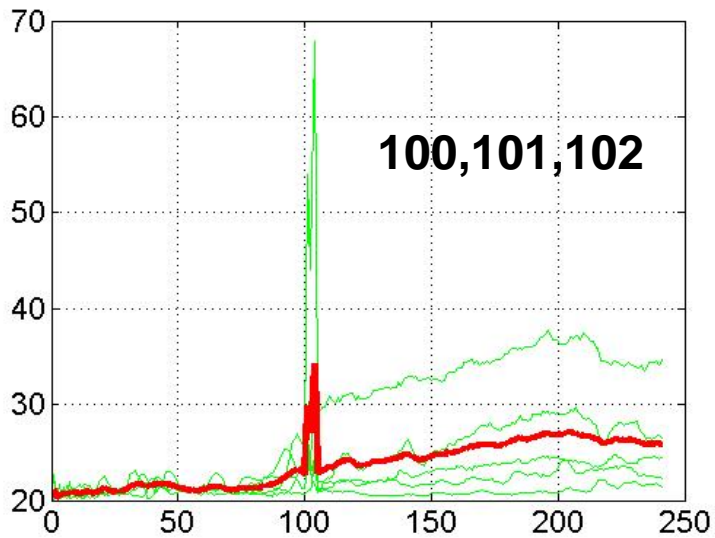
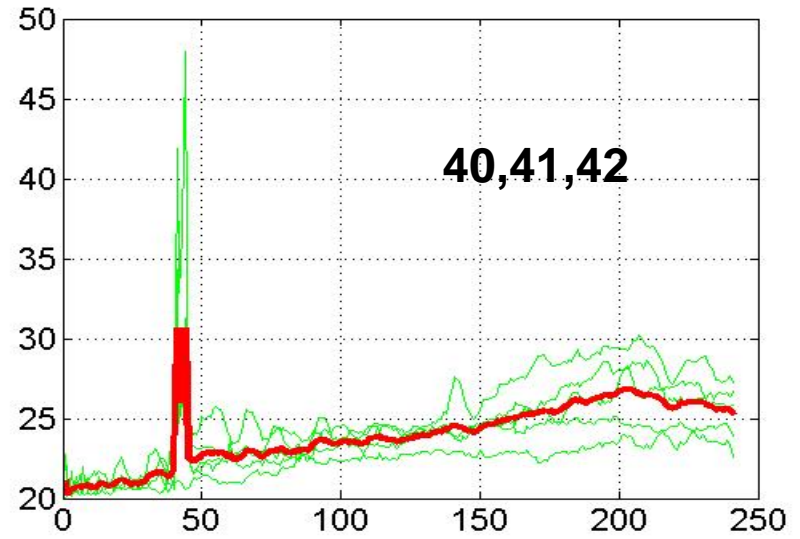
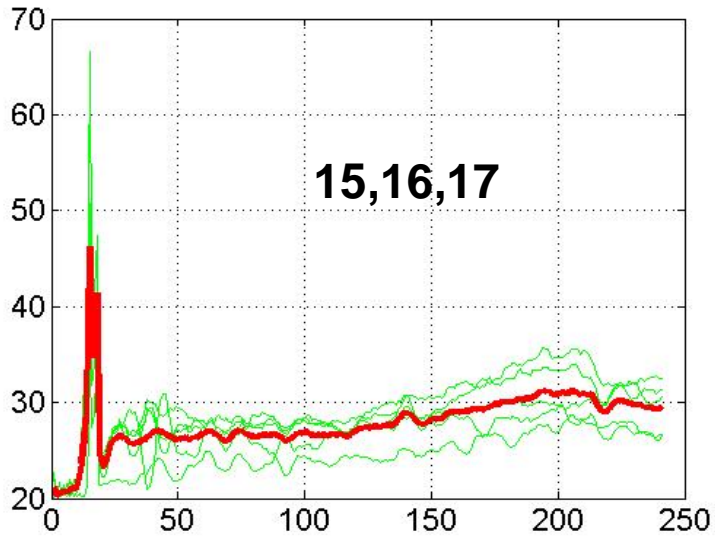


**WHAT IF Consecutive BPM / YCORs are not working and not used in finding the corrector settings?**

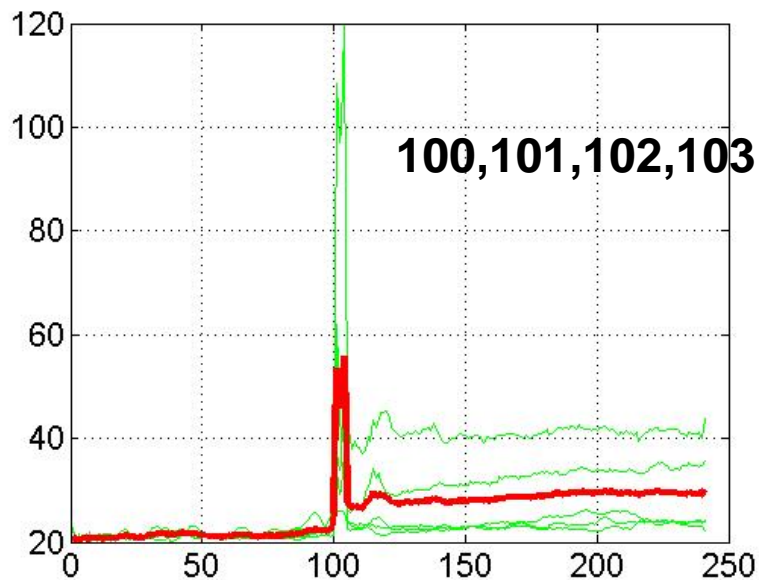
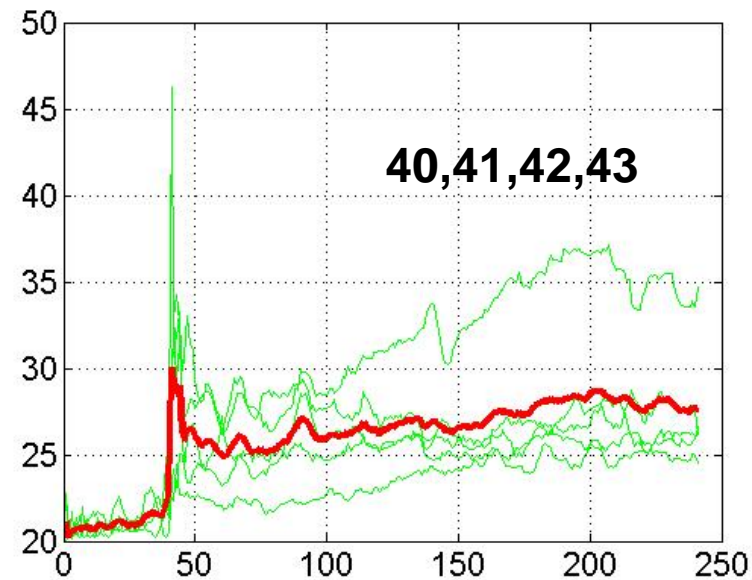
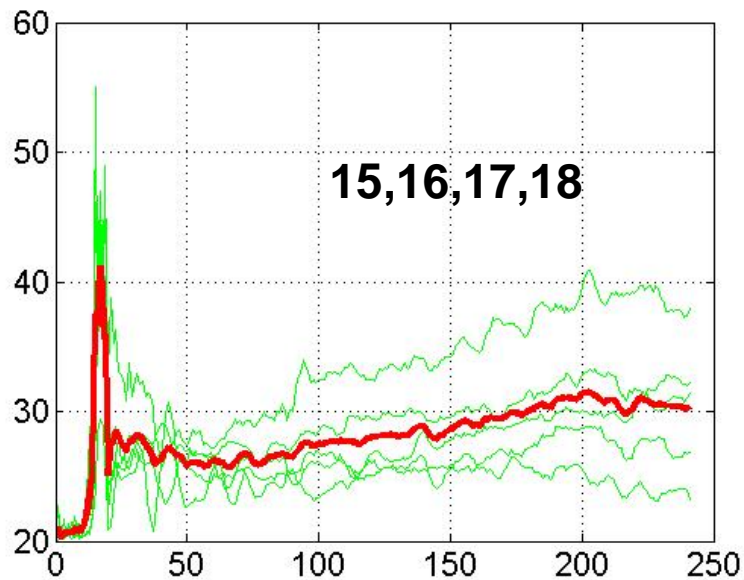
### 2 consecutive BPM/YCOR removed



# 3 consecutive BPM/YCOR removed



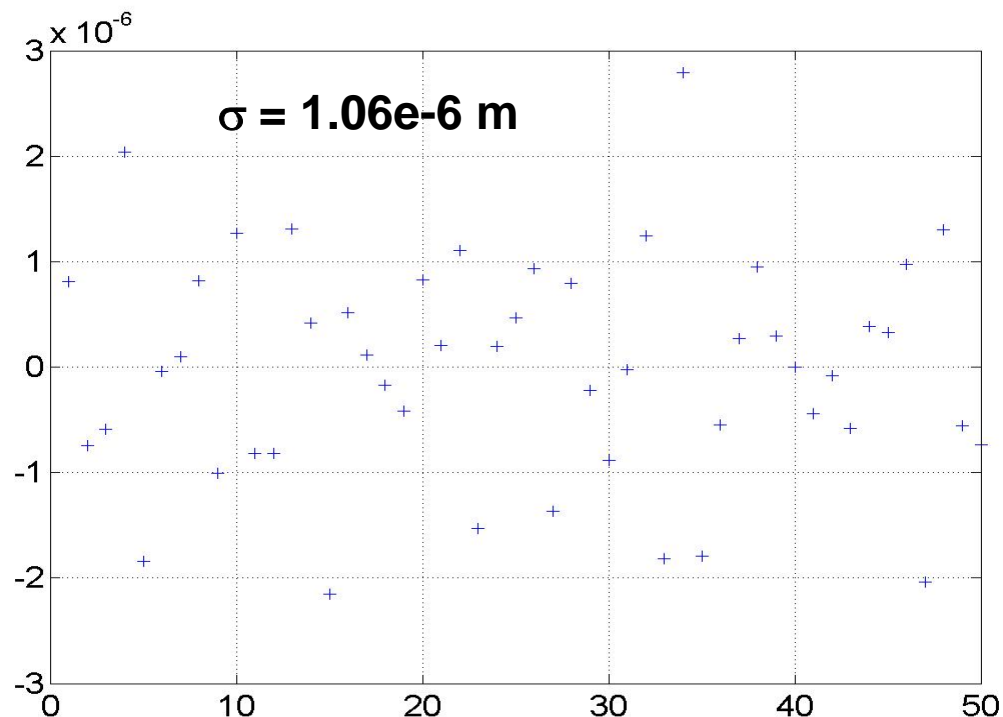
# 4 consecutive BPM/YCOR removed





Straight Linac; 30nm RMS (white noise) Quad vibration (no other error); 50 seeds

Ybpm\_readings at the end of the linac vs. seed no.



Y\_beam\_size at the end of the linac=  $2.5 \text{ e } -6 \text{ m}$