

Beam dynamics in the final focus section of the future linear collider

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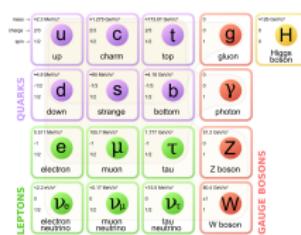


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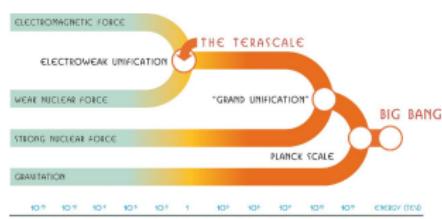
- ▶ Introduction to linear colliders
- ▶ Final focus and small beam size (CLIC, ILC, ATF2)
- ▶ Beam positioning and stabilization (CLIC, ILC, ATF2)
- ▶ Conclusions

The need of colliders to explore particle physics

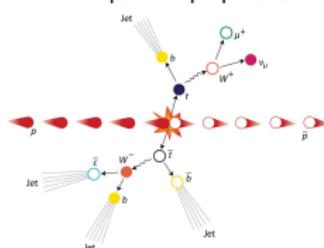
The Standard Model



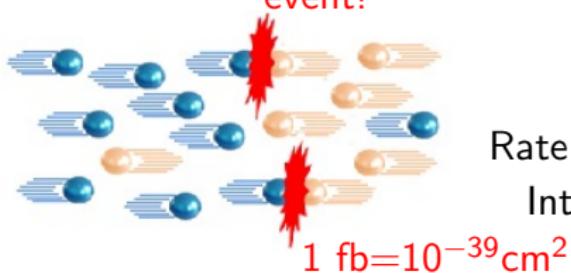
being explored at TeV scale (and beyond)



with enough interactions to measure particle properties



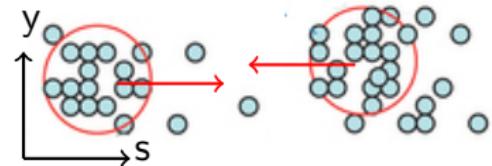
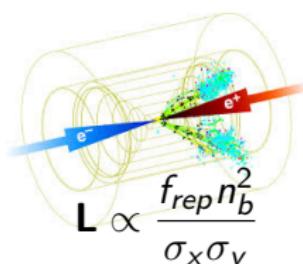
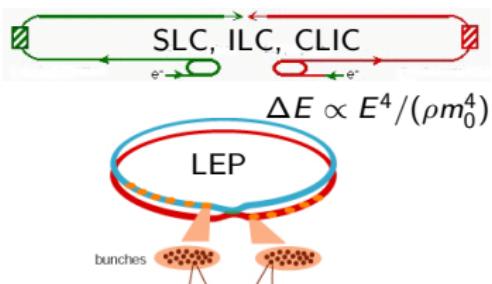
event!



$$R = \sigma L$$

Rate of events Interaction Cross Section Luminosity

Luminosity



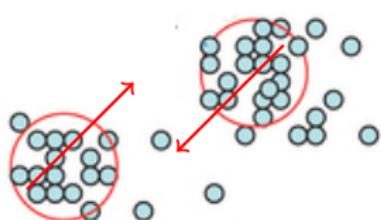
(@LHC, L is of the order of $10^{34} [\text{cm}^{-2} \cdot \text{s}^{-1}]$)

Symbol, [Unit]	LEP	SLC	ILC	CLIC 500 GeV	CLIC 3 TeV
$E, [\text{TeV}]$	0.1046	0.050	0.250	0.250	1.500
n_b	1.7×10^{11}	3.3×10^{10}	2×10^{10}	6.8×10^9	3.72×10^9
$f_{rep}, [\text{Hz}]$	11.2×10^3	120	5	50	50
$\sigma_x / \sigma_y, [\text{nm}]$	$(200/2.5) \times 10^3$	$(2.1/0.6) \times 10^3$	474/5.9	202/2.3	40/1
$L, [\text{cm}^{-2} \cdot \text{s}^{-1}]$	2.1×10^{31}	0.8×10^{30}	1.57×10^{34}	2.3×10^{34}	5.9×10^{34}

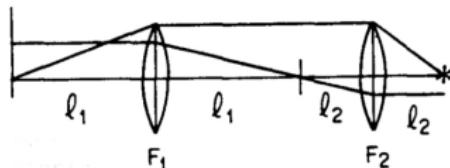
Linear colliders feature **nm beam size** to achieve 10^{34} luminosities.

Challenges for luminosity goals and nm beam size

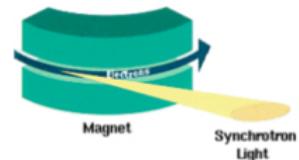
Beam-beam effects



Demagnify the beam



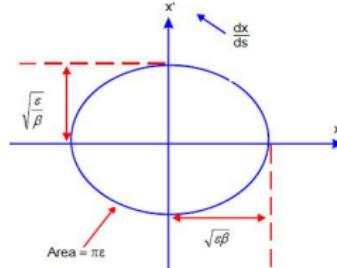
Synchrotron radiation



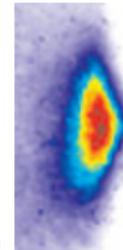
Beam positioning and stabilization



Small emittance beam generation and reduction



Small energy spread in the bunch

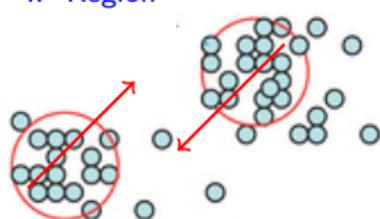


Challenges for luminosity goals and nm beam size

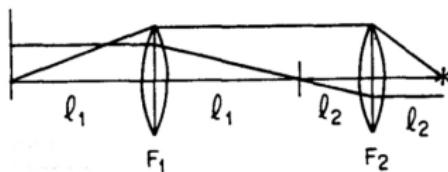
These are addressed in several sections of an accelerator.

Beam-beam effects

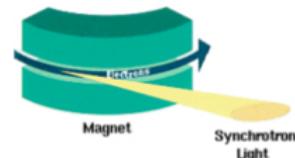
IP Region



Demagnify the beam
Final Focus Section (FFS)

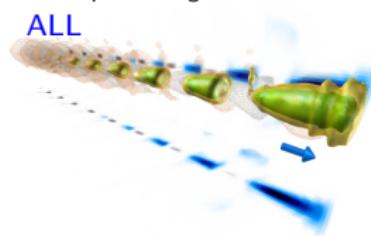


Synchrotron radiation
FFS, Damping Rings
IP Region



Beam positioning and stabilization

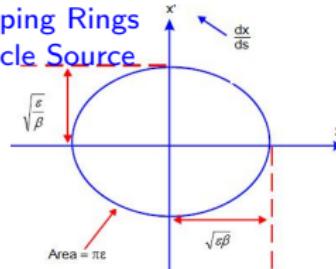
ALL



Small emittance beam generation and reduction

Damping Rings

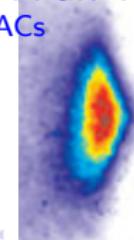
Particle Source



Small energy spread in the bunch

Particle Sources

LINACs



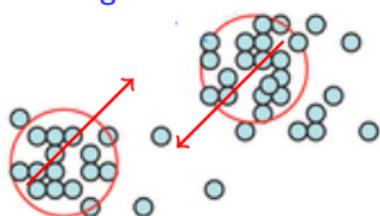
Challenges for luminosity goals and nm beam size

These are addressed in several sections of an accelerator.

Main contributions from this work to the FFS.

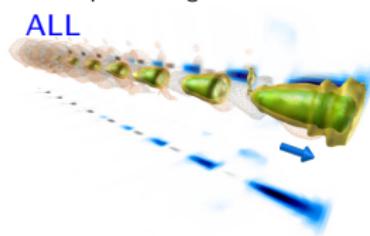
Beam-beam effects

IP Region



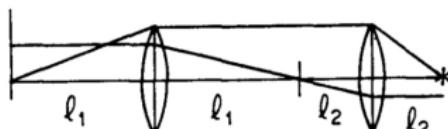
Beam positioning and stabilization

ALL



IP-BPMs @ ATF2

Demagnify the beam
Final Focus Section (FFS)

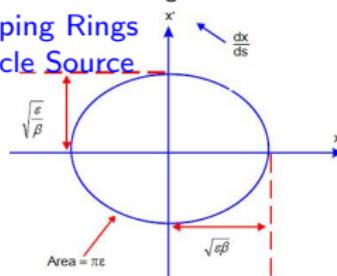


Chromaticity minimization
Chromaticity correction

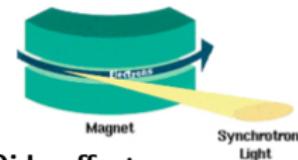
Small emittance beam generation and reduction

Damping Rings

Particle Source



Synchrotron radiation
FFS, Damping Rings
IP Region



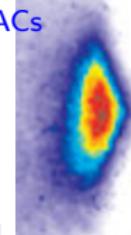
Oide effect

Rad. in bending magnets

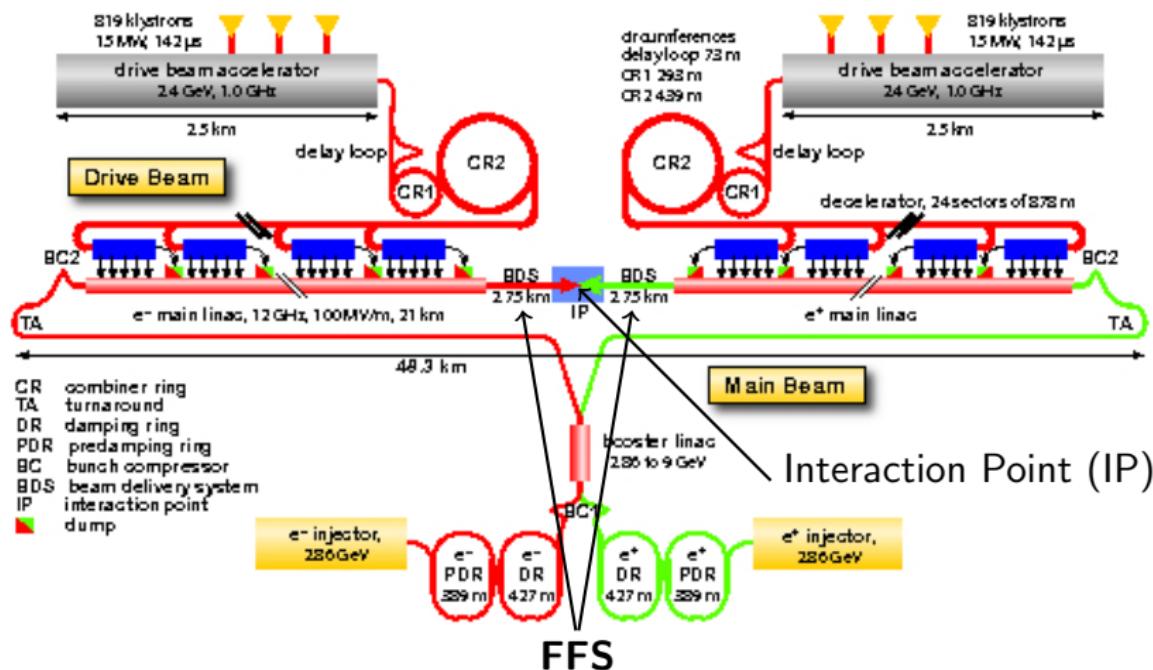
Small energy spread in the bunch

Particle Sources

LINACs

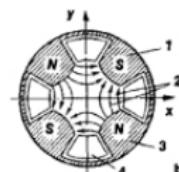
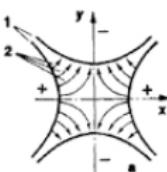


Sections of a Collider (CLIC 3 TeV as an example)



Beam demagnification, positioning and stabilization
with low effect of radiation

Final Focus Section (FFS)

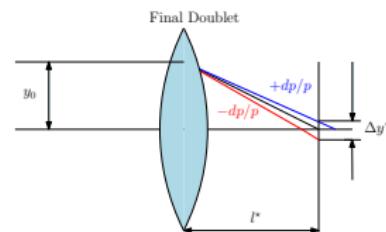
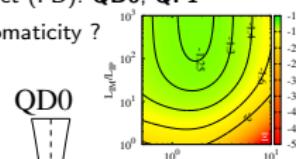
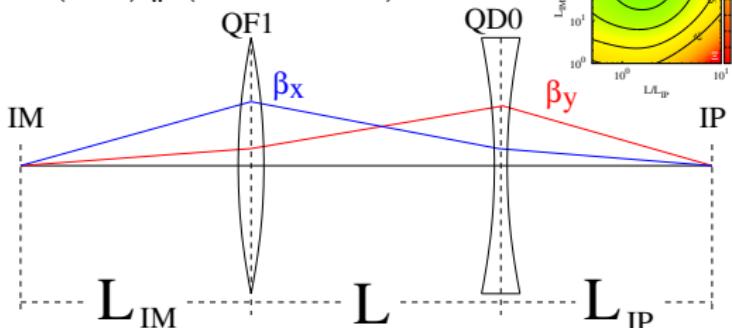


Focusing elements are magnets with 4 poles: quadrupoles

The stronger set of lenses is the Final Doublet (FD): **QD0, QF1**

What are the distances to minimize the chromaticity ?

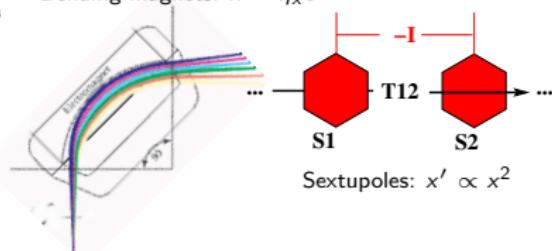
$$L \approx (1 \sim 2)L_{IP}, \text{ (Blanco, IPAC 2014)}$$



Quads behave as lenses: chromatic effect
It is a second order effect, δ^2

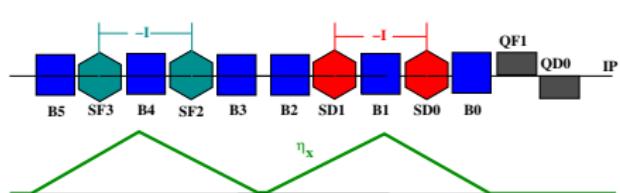
Correction of Chromatic effect

Bending magnets: $x = \eta_x \delta$

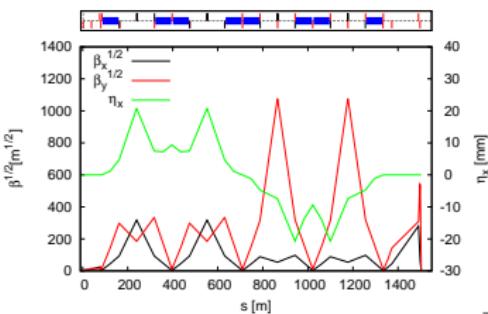


Chromaticity correction

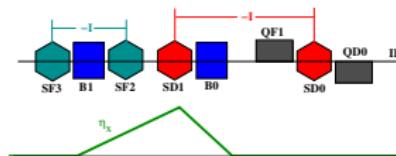
Non-Local chromaticity correction (Brown, 1988)



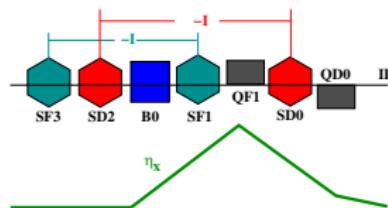
Easier to correct static errors, Longer line



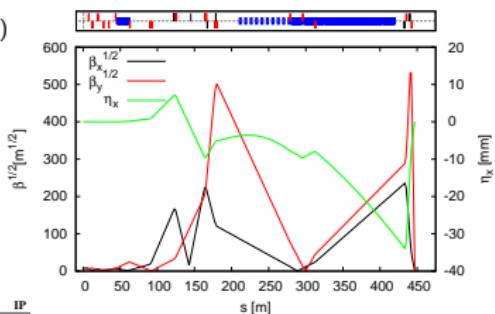
(H. García, PRST-AB 17 101001)



Current CLIC, ILC and ATF2 lines
Local chromaticity correction (Raimondi, 2000)



More difficult to correct static errors, Shorter line

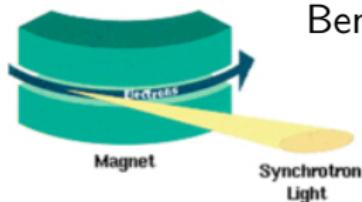


Recent proposal: The non-interleaved line (Tomas, Blanco, Bambade, IPAC 2014)

Final focus and small beam size

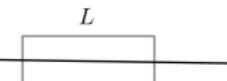
Radiation in bending magnets

Radiation effect in bending magnets



Bending magnets generate energy losses

$$\Delta E \propto \frac{E^4}{\rho m_0^4}$$

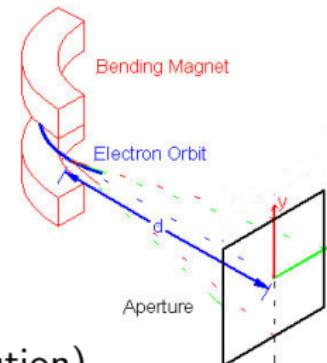


Energy loss is the principal limitation for circular lepton colliders.

The highest energy lepton collision, 209 GeV, have been reached with electron and positron colliding beams in LEP (circular tunnel of 27 km) at CERN.

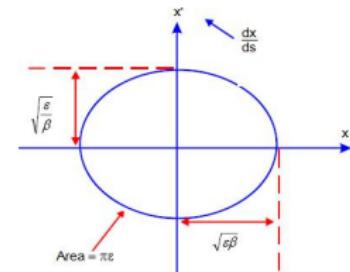
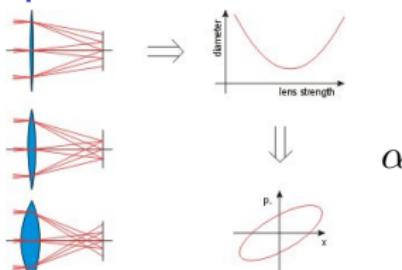
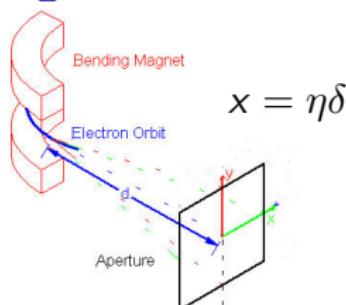
The effect on the beam size was calculated by Sands (SLAC/AP-47, Dec. 1985).

$$x = \sum_{i=1}^{N(T)} \Delta x_{i,total} - x_0$$



N : is the number of photons radiated (Poisson distribution)

A generalization was required



Sands expression was valid for $\alpha_L = 0$, $\eta_L = 0$.

During the design process not always the focus is perfect $\alpha = 0$, nor the η is perfectly corrected.

$$\sigma_{rad}^2 \approx \int E^5 G^3(s) H(s) \cos^2(s) ds$$

It becomes:

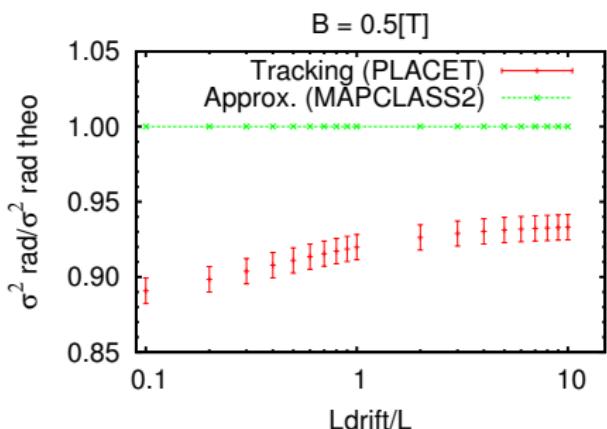
$$\sigma_{rad}^2 \approx \int \frac{E^5}{\rho^3} \left\{ \sqrt{\frac{\beta_L}{\beta_s}} [\eta \cos \Delta\phi(s, L) + (\alpha\eta + \beta\eta') \sin \Delta\phi(s, L)] - \eta_L \right\}^2 ds$$

included in MAPCLASS2, lattice optimization code (published in CLIC-Note-1049).

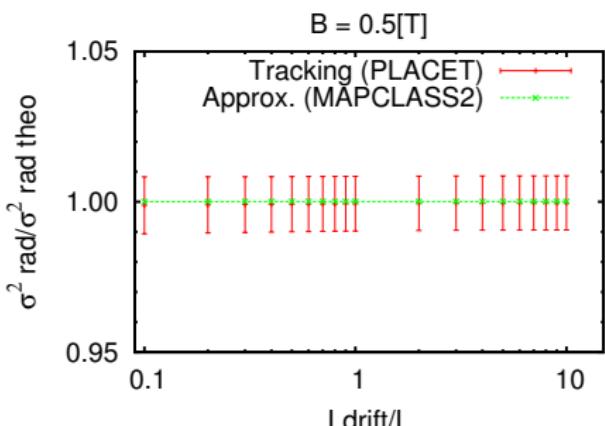


Comparing theory with the tracking code PLACET

PLACET 0.99.01



PLACET 0.99.02

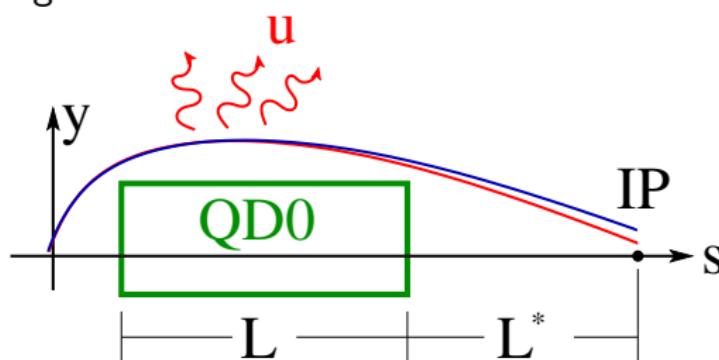


- 1) The lattice optimization of the line's optics now includes radiation!
- 2) This lead to an improvement in the tracking code calculations!

Oide effect

Oide effect

Radiation in a focusing magnet changes the energy of the particle and limits the focusing effect.



Designed particle trajectory, trajectory of a particle due to radiation in the quadrupole.

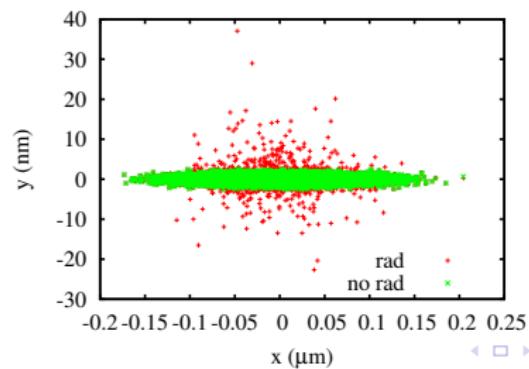
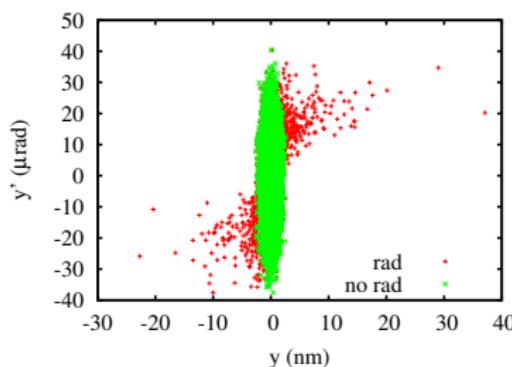
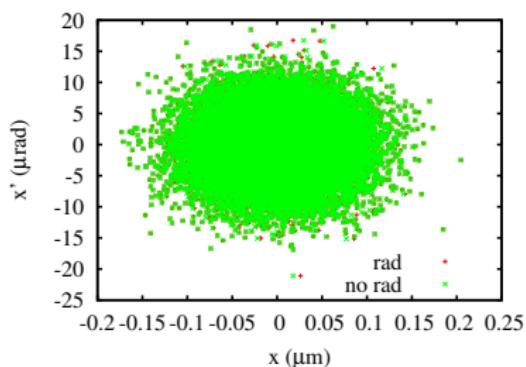
Oide limit

The minimum beam size is independent of energy
 (PhysRevLett.61.1713, 1988).

$$\sigma_y^* \min = c_2 \left[F(\sqrt{KL}, \sqrt{KL}^*) \right]^{\frac{1}{7}} (\epsilon_{Ny})^{\frac{5}{7}}$$

Lattice	ϵ_N (nm)	γ (10^3)	σ_0 (nm)	k (m^{-2})	L (m)	L^* (m)	F	σ_{oide} (nm)	σ (nm)	σ_{min} (nm)
CLIC 3 TeV	20	2935.0	0.70	0.116	2.73	3.5	4.086	0.85	1.10	1.00
CLIC 500 GeV	25	489.2	2.3	0.077	3.35	4.3	4.115	0.08	2.3	1.17
ILC 500 GeV	40	489.2	5.7	0.170	2.20	4.3	9.567	0.04	5.7	1.85

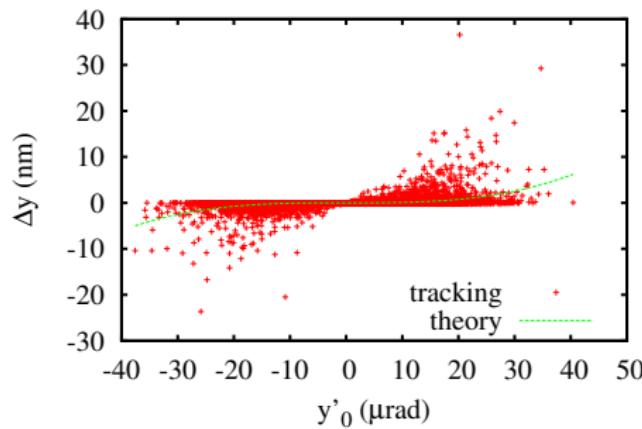
Oide in CLIC 3TeV



Δy due to radiation

Oide averages over u, s, y, y' , obtaining $\langle \Delta y \rangle = 0$.
 But this result hides a correlation between $\Delta y, y'$:

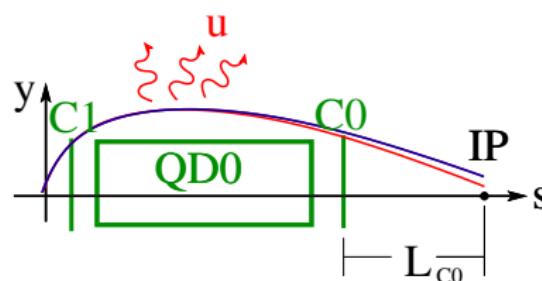
$$\langle \Delta y(y'_0) \rangle = \frac{2}{3} r_e \gamma^3 G(\sqrt{K}L, \sqrt{K}L^*)(y'_0)^3$$



For CLIC 3 TeV parameters it is possible to subtract 10% of the Oide effect.

Corrector

A pair of correctors is added to the strong focusing in order to mitigate the radiation effect.



nominal trajectory: the kick in C_1 must cancel the kick in C_0 .

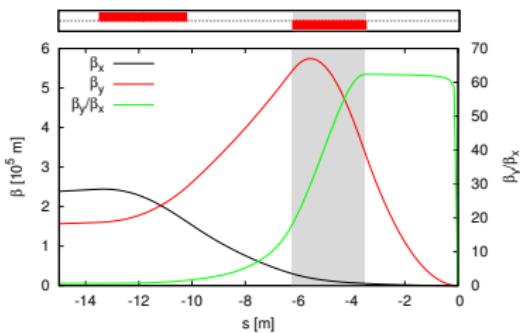
all particles that radiate: the difference in kicks should cancel Δy .

Result

A 4% of beam size reduction was possible for CLIC 3 TeV (6%~7% of Oide effect reduction).

	OD1		OD0		σ_x [nm]	σ_y [nm]	L_{tot} [$10^{34} \text{cm}^{-2} \cdot \text{s}^{-1}$]	L_{peak} [$10^{34} \text{cm}^{-2} \cdot \text{s}^{-1}$]
	l [m]	k_3 [m^{-4}]	l [m]	k_3 [m^{-4}]				
NO RAD	0.01	0	0.01	0	47.45	0.69	7.7	2.9
RAD	0.01	0	0.01	0	47.45	1.18	7.5	2.7
RAD	0.01	0	0.01	-3900	47.45	1.13	7.4	2.7
RAD	0.01	1502	0.01	-3900	47.45	1.17	7.1	2.7

(Blanco IPAC15, to be submitted to PRST-AB next week).



Why it was not possible to reduce the correlation even more ?
 (β_y / β_x) ratio needs to be equal for both correctors,
and the phase advance between correctors (Xu, PRST-AB.8.104002).

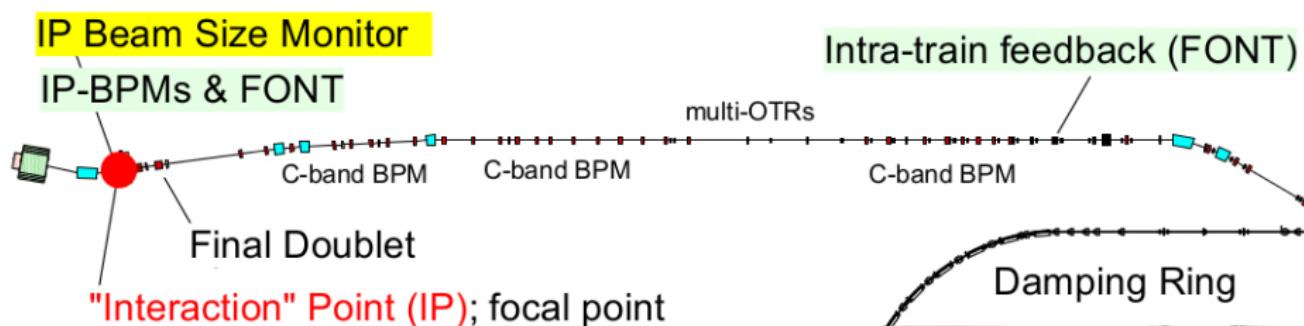
Partial Conclusions...

- ▶ Three theoretical and computational contributions have been given to the FFS design and optimization at 3 TeV
 - ▶ chromaticity minimization: distance between QD0 and QF1 between 1~2 times L_{IP}
 - ▶ Oide effect: Oide beam size contribution reduced by (6~7)%
 - ▶ Radiation in Bending Magnets: Generalization of theoretical formula for lattice design including radiation effects, and an improvement in the tracking code PLACET.
- ▶ One new chromaticity correction method has been proposed and initially studied.

Beam positioning and stabilization

ATF2 line

ATF2 is an extension of ATF (Accelerator Test Facility Test) for the linear colliders R&D.
 The FFS in ILC (~ 700 m) was scale down to ~ 38 m
 Beam of e^- at 1.3 GeV



Goal 1: 37 nm of vertical beam size at the IP
 44 nm beam size has been achieved by systematic tuning.

Goal 2: beam stabilization at the nm level
Measured beam position with nm resolution close to the IP

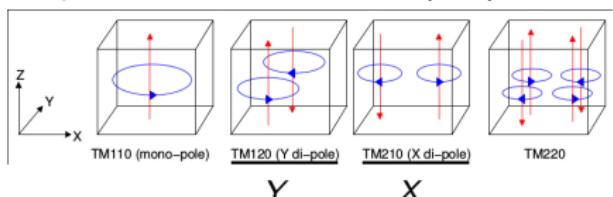


Cavity for 1 nm resolution

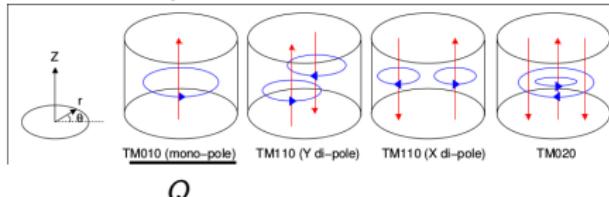
Sensitivity

X: $2.2 \mu\text{V}/\text{nm}/\text{nC}$, Y: $3.7 \mu\text{V}/\text{nm}/\text{nC}$, Ref: $3.27 \text{ V}/\text{nC}$

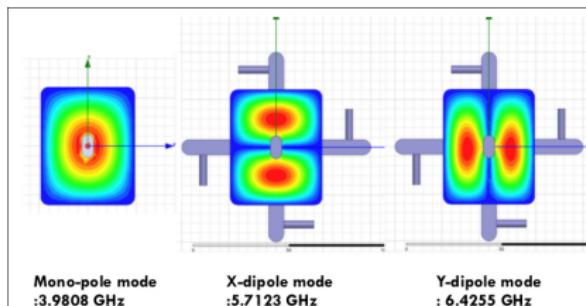
Cavity for Beam Position Measurement (BPM)



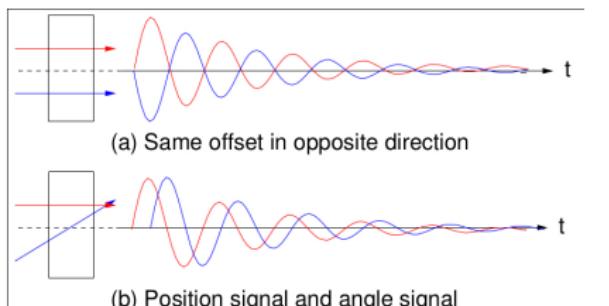
Reference Cavity



Separation of resonant frequencies



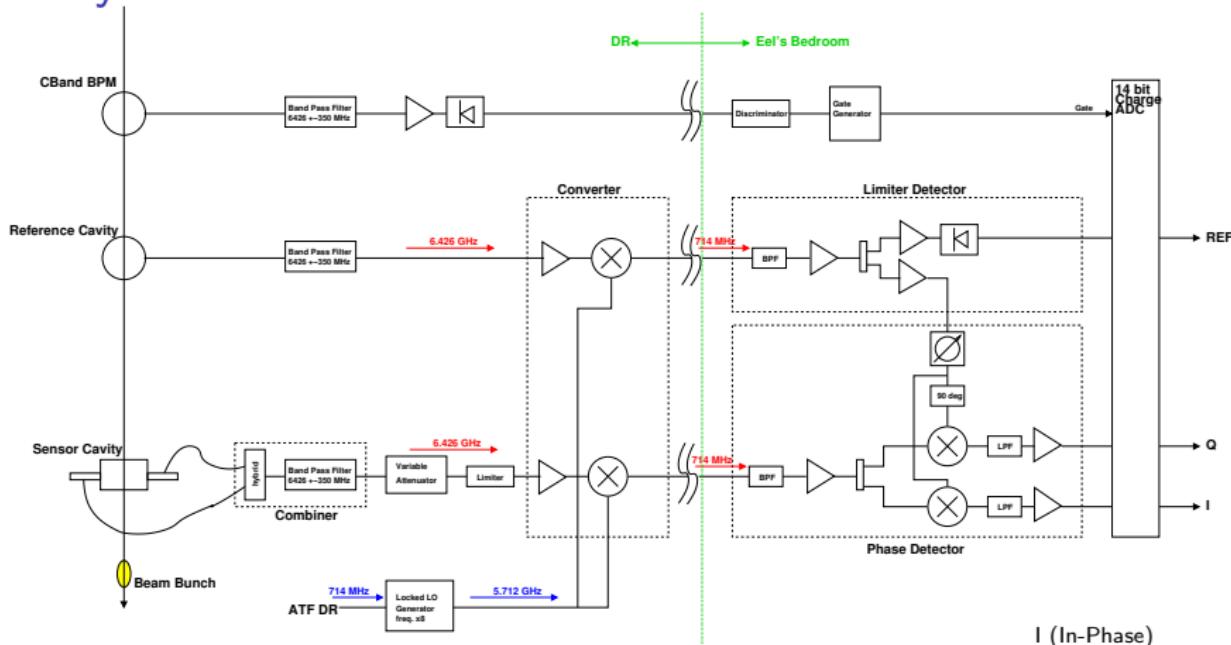
Position and angle



System Measurements

- ▶ **Calibration:** cavity signal/displacement
Piezo movers and cavity response
- ▶ **BPMs resolution:** minimum beam position measurable
- ▶ **Cavities alignment:** finding the center of the BPMs

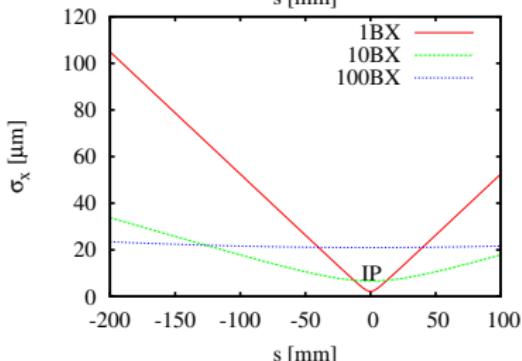
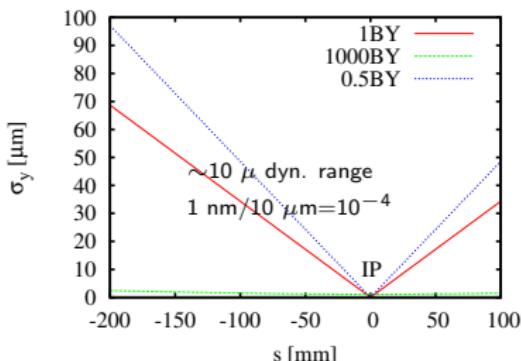
Cavity Electronics



Beam passes through the cavities → 1st stage of downconversion → 2nd stage of downconversion → Q (Quadrature-Phase)
Ref (Reference)

To measure and stabilize

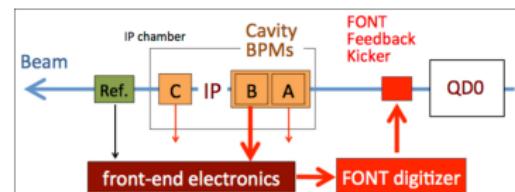
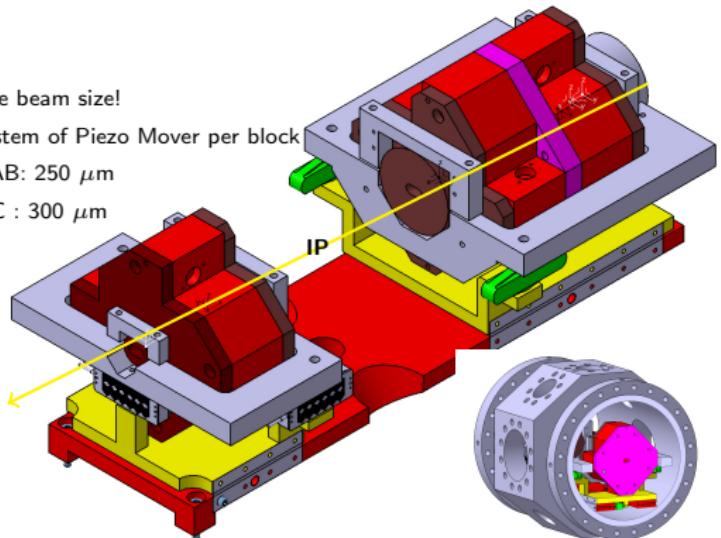
Fluctuations in the beam position are (10~20%) of the beam size!



System of Piezo Mover per block

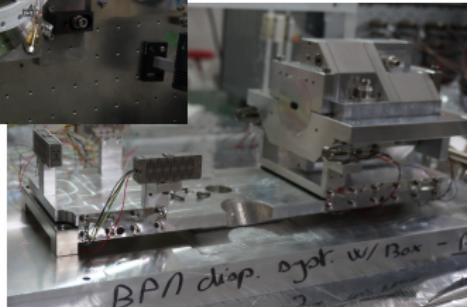
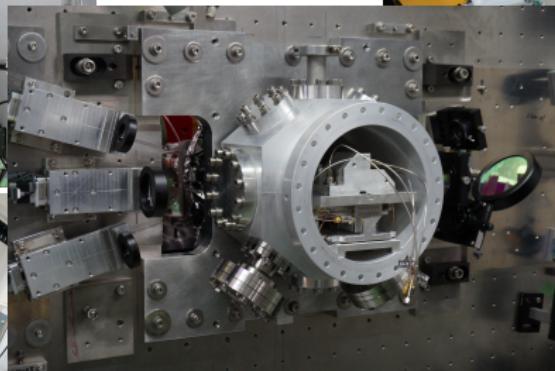
IPAB: 250 μm

IPC : 300 μm



Measure one packet of particles and kick the second

The installation



IPBPMs alignment

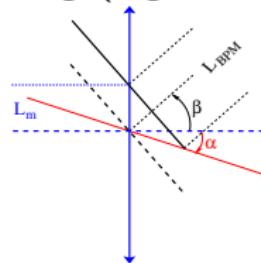
The alignment goal is:

1. to keep calibration constants within $10^{-3} \sim 10^{-4}$ relative precision.
2. to put the three BPMs inside the **electronics** dynamic range with lowest possible attenuation.

$$I' = L_{BPM}$$

$$Q' \propto 3.2\mu\text{m}/\text{mrad}(\alpha + \beta) + \text{bunch tilt?} + \text{monopole-like modes?}$$

$$A = \sqrt{I' + Q'} < \text{elect. dyn. range} (\text{e.g. } 0.3 \sim 0.6\mu\text{m @0dB@}10^{10} \text{ particles})$$



Movers axis, BPM, beam

Signal Acquisition and Analysis

$3 \text{ BPMs} \times 2 \text{ planes (x,y)} \times 2 \text{ signals (I,Q)} + 2 \text{ Ref (x,y)} = 14 \text{ signals}$



SIS3316

16 channels, 14 bits, 238 MS/s, 2V or 5V dynamic range, parallel acquisition

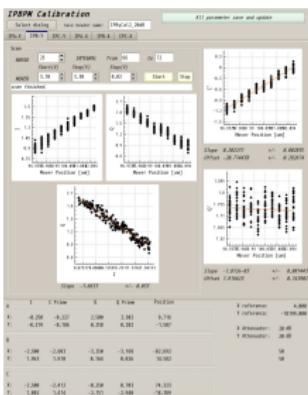
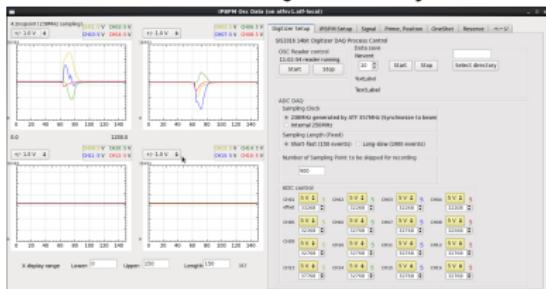
To sample within the 20 ns of signal decay

$$2^{13} = 8192, 2^{14} = 16384$$

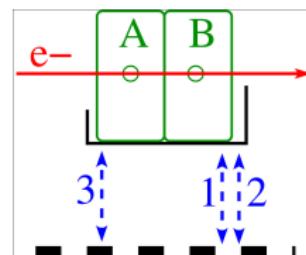
$$1/238 \text{ MHz} = 4.2 \text{ ns}$$

Calibration = Signal/Displacement

Waveform and jitter analysis

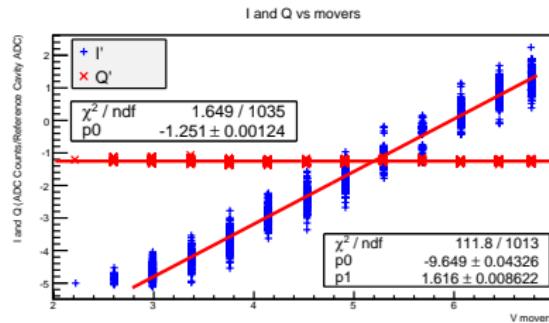
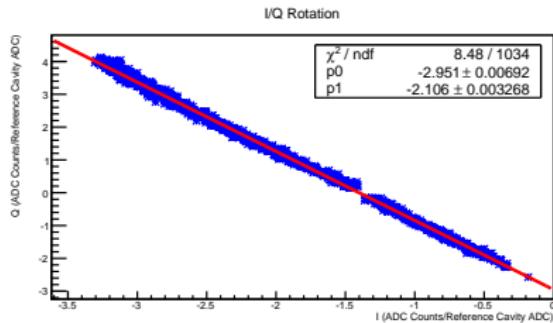
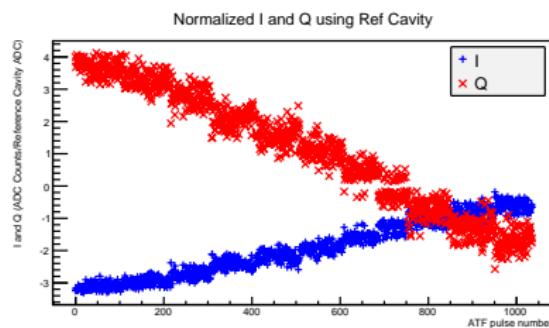
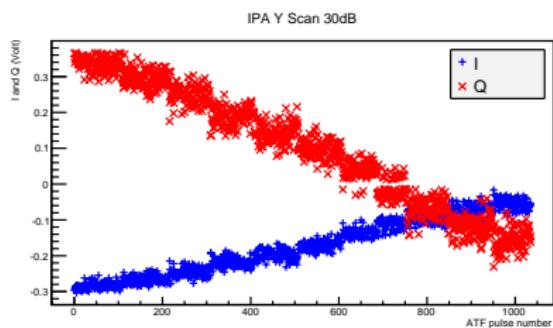


Systematic change of movers 1,2,3 while the beam is running

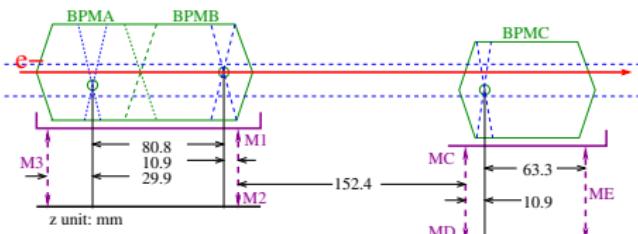
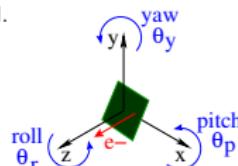


Progress towards the integration with the ATF tuning instrumentation

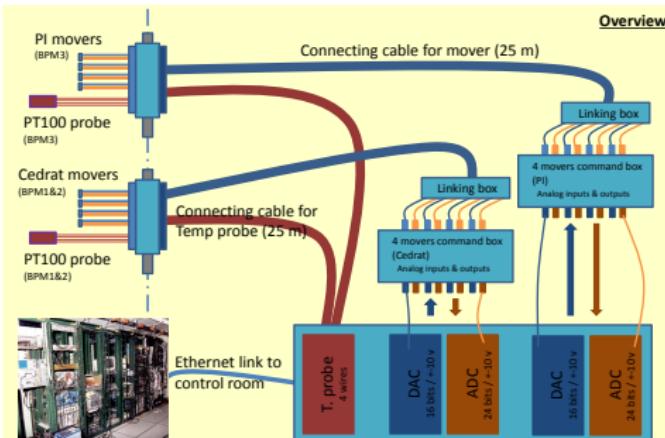
Calibration



Displacing the blocks (piezo-movers)

IPAB: 250 μm , ± 1 mrad.IPC : 300 μm , ± 2 mrad.

Movers can change vertical and horizontal position, or pitch.



Laptop running NI VI.

DACs 16 bits/ADC 24 bits → Step resolution.

Control Boxes (PI, Cedrat) → Feedback.

Two PT100 temperature probes → Thermal expansion.

3 vertical/1 horizontal movers per block → Alignment.

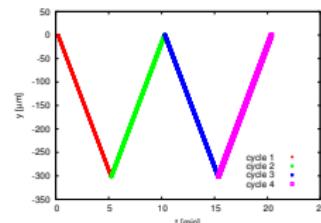
Measurements

Movers calibration

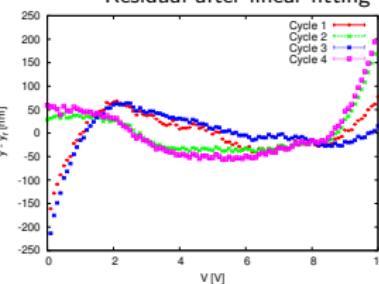
Interferometer better than 1 nm resolution



Four cycles over the entire range of vertical movers

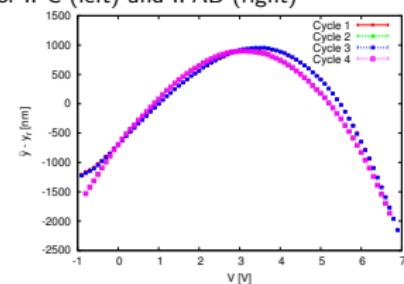


Residual after linear fitting for IPC (left) and IPAB (right)



$$\text{Cal} = (30.002 \pm 0.007) \mu\text{m/V}$$

Stability ~ 1 nm

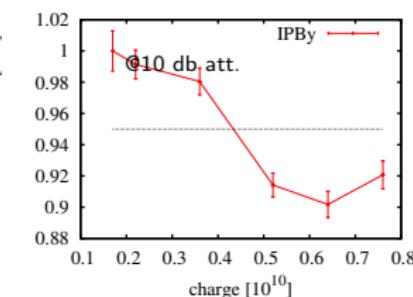
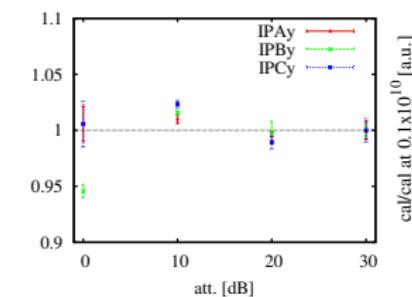
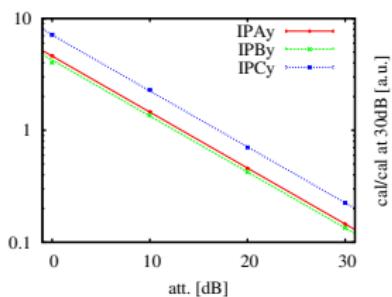
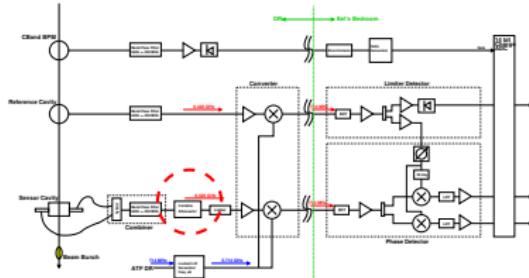
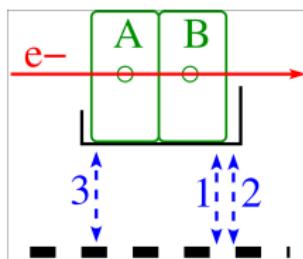


$$\text{Cal} = (31.0015 \pm 0.012) \mu\text{m/V}$$

Stability ~ 1 nm

Cavity calibration

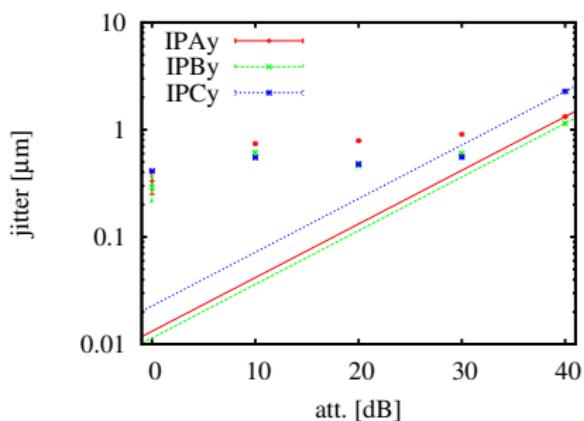
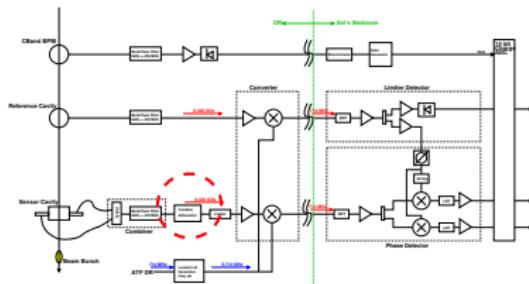
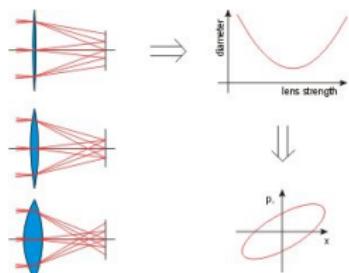
The block position is systematically changed in steps to obtain signal/displacement ratio.



IPBy shows saturation and it is used to determine the dynamic range ($10\mu\text{m}@10\text{dB}$ att. @ 0.4×10^{10}).

Resolution (noise floor)

The block position is **fixed** and the beam position is measured using the calibrations.



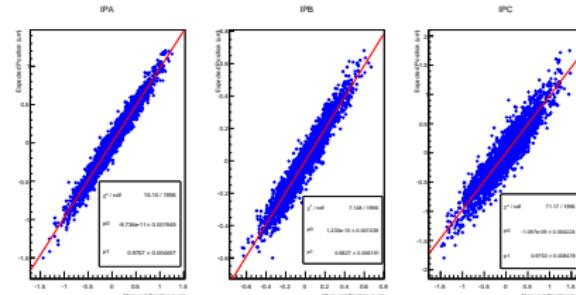
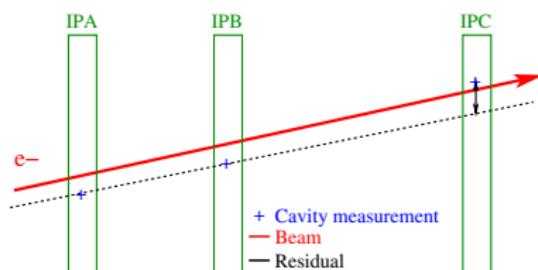
Electronics Noise imposes a limit on resolution.

IPA,IPB: 10 nm.

IPC: 20 nm ?!

Resolution (3 BPMs)

The block position is **fixed** and the beam position is measured using the calibrations.

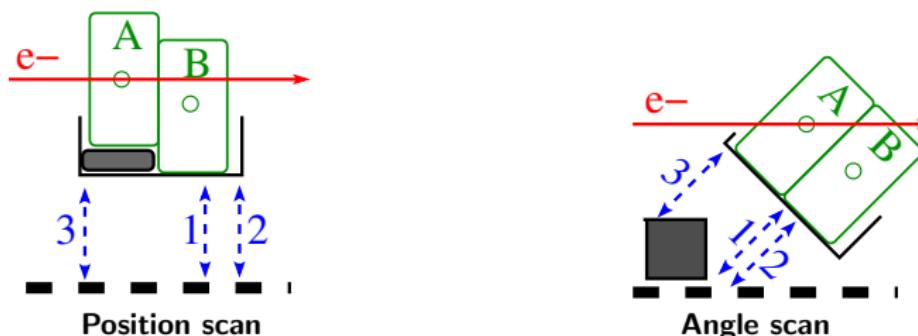


Parameter	IPAY	IPBY	IPCY
Jitter [μm]	0.437	0.216	0.498
Slope	0.9757 ± 0.0044	0.9827 ± 0.0062	0.9753 ± 0.0085
Correlation	0.9798	0.9626	0.9322
Geometrical factor	0.5457	0.7988	0.2531
R [nm]	87.2 ± 1.4	59.7 ± 1.0	185.3 ± 2.9
Resolution [nm]	47.6 ± 0.8	47.7 ± 0.8	46.9 ± 0.7

Resolution ~ 47 nm.

Alignment

The initial installation was corrected by tilting the optical table (S. Jang, IPAC14)



Try to find the center of the cavity ($I'=0$)

Find the center and try to make the cavity perpendicular to the beam ($I'=0, Q'=0$)

After a second installation, using $I'=0$, the alignment results have been:

Vertical	IPA	IPB	IPC
Y [μm]	-7	+79	-
θ_p [mrad]	0.024	1.0	-

Currently, this is not a limitation.

Status of the IP-BPMs

PARAMETER	REQUIREMENT	STATUS	Comments
Resolution	$\sim \text{nm} @ 1 \times 10^{10}$	$< 50 \text{ nm} @ 0.4 \sim 0.5 \times 10^{10}$	Cal. factors within 5% linearity Elect. noise: 10 nm/BPM IPC sens. and/or gain : +20nm X to Y coupling?
Dynamic Range	$\sim 10 \mu\text{m} + \text{extra} @ 0 \text{ dB att.}$	$9 \sim 11 \mu\text{m} @ 10 \text{ dB att.}$	Response is linear within 5% Electronics starts to saturate at $0.4 \times 10^{10} @ 10 \text{ dB att.}$ IPBy Q' signal sats. at 0 dB
Compatibility	IPBSM, EPICS	In progress	Cal. Software : Initial version. Requires comp. w offline results. Jitter Software: Initial version. Requires comp. w offline results. IP-BSM, requires study of res. at low charge, $0.1 \sim 0.5 \times 10^{10}$
Feedback	Operative	Tested	Jitter reduction to 67 nm. Limited by BPM resolution.

(IPAC15)

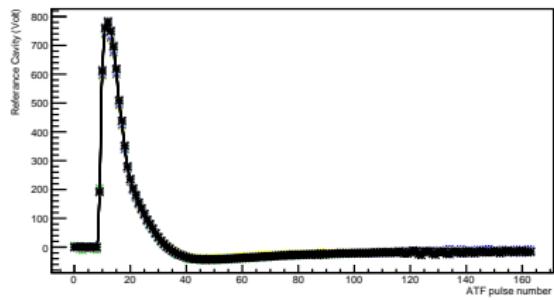
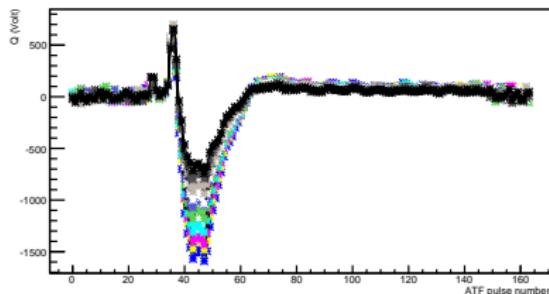
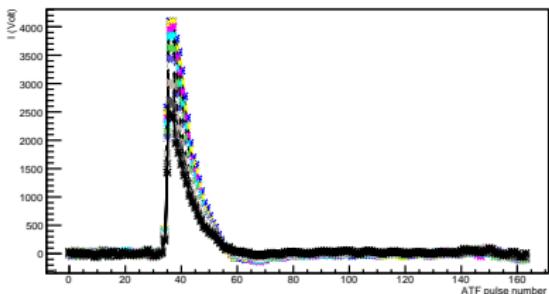
Conclusions

- ▶ Three theoretical and computational contributions have been given to the FFS design and optimization at 3 TeV
 - ▶ chromaticity minimization: distance between QD0 and QF1 between 1~2 times L_{IP}
 - ▶ Oide effect: Oide beam size contribution reduced by (6~7)%
 - ▶ Radiation in Bending Magnets: Generalization of theoretical formula for lattice design including radiation effects, and an improvement in the tracking code PLACET.
- ▶ One new chromaticity correction method has been proposed and initially studied.
- ▶ The measured resolution of the IPBPMs is below 50 nm. The system characterization points to upgrade the electronics to reach better resolution.
- ▶ This work is relevant for high energy colliders in the TeV energy scale and beyond.

Thank you!

I,Q,Ref

Extra slides



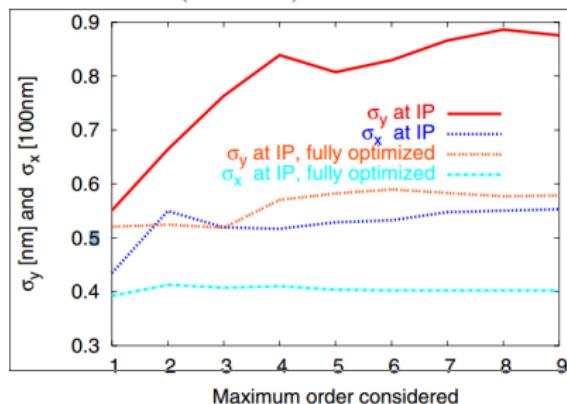
Mapclass

$$x_f = \sum_{jklmn} X_{jklmn} x_0^j P_x^k y_0^l P_y^m \delta_0^n$$

$$\langle x_f^2 \rangle = \sum_{jklmn} X_{jklmn}^2 \Gamma\left(\frac{1+2j}{2}\right) \Gamma\left(\frac{1+2k}{2}\right) \Gamma\left(\frac{1+2l}{2}\right) \Gamma\left(\frac{1+2m}{2}\right) \frac{2^{j+k+l+m}}{(2n+1)\pi^2} \sigma_x^{2j} \sigma_{p_x}^{2k} \sigma_y^{2l} \sigma_{p_y}^{2m} \Delta_\delta^{2n}$$

$$+ \sum_{jklmn > j'k'l'm'n'} 2X_{jklmn} X_{j'k'l'm'n'} \Gamma\left(\frac{1+j+j'}{2}\right) \Gamma\left(\frac{1+k+k'}{2}\right) \Gamma\left(\frac{1+l+l'}{2}\right) \Gamma\left(\frac{1+m+m'}{2}\right)$$

$$\times \frac{2^{[(j+k+l+m+j'+k'+l'+m')/2]-n-n'}}{(n+n'+1)\pi^2} \sigma_x^{j+j'} \sigma_{p_x}^{k+k'} \sigma_y^{l+l'} \sigma_{p_y}^{m+m'} \Delta_\delta^{n+n'}.$$



Geometric factor

$$\frac{\sigma_{Rm}}{\sqrt{\langle R_t^2 \rangle}} = 1 \quad (1)$$

$$\frac{\sigma_{Rm}}{\sqrt{\left(\frac{\partial R_t}{\partial y_A}\right)^2 r_A^2 + \left(\frac{\partial R_t}{\partial y_B}\right)^2 r_B^2 + \left(\frac{\partial R_t}{\partial y_C}\right)^2 r_C^2}} = 1 \quad (2)$$

$$\frac{\sigma_{Rm}}{\sqrt{\left(\frac{\partial R_t}{\partial y_A}\right)^2 + \left(\frac{\partial R_t}{\partial y_B}\right)^2 + \left(\frac{\partial R_t}{\partial y_C}\right)^2}} = r \quad (3)$$

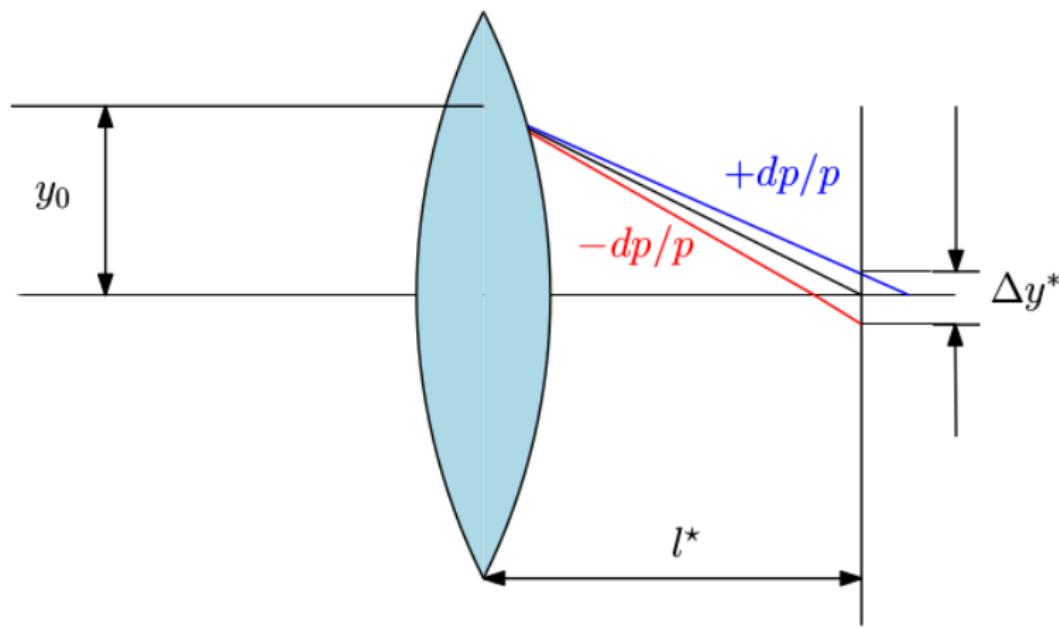
$$g\sigma_{Rm} = r \quad (4)$$

The equations used for position prediction are shown in Eq. (5), where the coefficients are calculated from the longitudinal distance among BPMs.

$$\begin{aligned} f_A(y_B, y_C) &= 1.463y_B - 0.463y_C \\ f_B(y_A, y_C) &= 0.683y_A + 0.317y_C \\ f_C(y_A, y_B) &= -2.156y_A + 3.156y_B \end{aligned} \quad (5)$$

Telescope Design

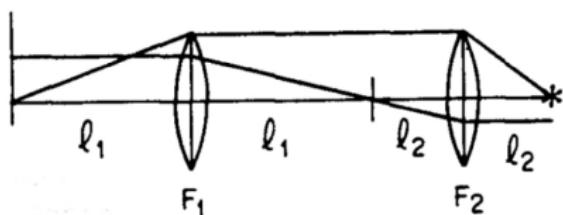
Chromaticity



The focal point changes as a function of the energy.
This generates an increase of the beam size.

Why a telescope ?

Demagnify the beam with minimal chromaticity generation



$$x_i \in x, x', y, y', \tau, \delta$$

$$R = \begin{pmatrix} M_x & 0 & 0 & 0 \\ 0 & 1/M_x & 0 & 0 \\ 0 & 0 & M_y & 0 \\ 0 & 0 & 0 & 1/M_y \end{pmatrix}$$

A Conceptual Design of Final Focus Systems for Linear Colliders

$$\dots R_{12}(0) = 0, T_{116} = 0 \dots$$

$$\beta(\delta)\beta_0 = R_{11}^2\beta_0^2 + 2[0]\delta + [2R_{11}U_{1166}\beta_0^2 + T_{126}^2]\delta^2 + \dots$$

So for telescopic systems ... the derivative with respect to δ vanishes...

The problem

A Conceptual Design of Final Focus Systems for Linear Colliders

...

The principal problem in designing Final Focusing Systems (FFS) for linear colliders is the elimination or minimization of the chromatic distortions introduced by the final lens system nearest to the interaction point (I.P.).

...

There are several possible approaches ...

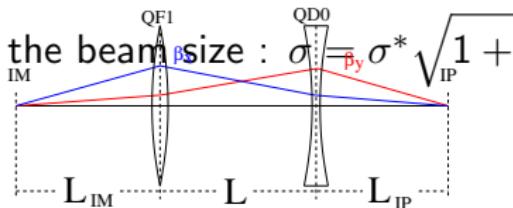
3. Sextupoles can be introduced into the optical design to cancel the principal second-order chromatic aberrations ...
4. Alternatively one might choose to 'live with' the small residual second-order chromatic aberrations

...

Chromaticity minimization

$$\xi_x = \frac{1}{\beta_x^*} \left(T_{116}^2 \beta_{x0} + T_{126}^2 \frac{1}{\beta_{x0}} \right) \quad \xi_y = \frac{1}{\beta_y^*} \left(T_{336}^2 \beta_{y0} + T_{346}^2 \frac{1}{\beta_{y0}} \right)$$

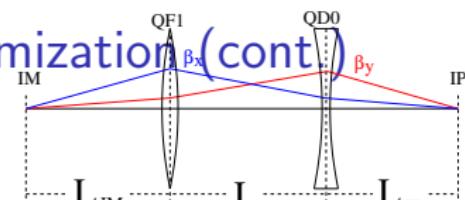
Chromaticity increases the beam size : $\sigma = \sigma^* \sqrt{1 + \xi^2 \sigma_\delta^2}$



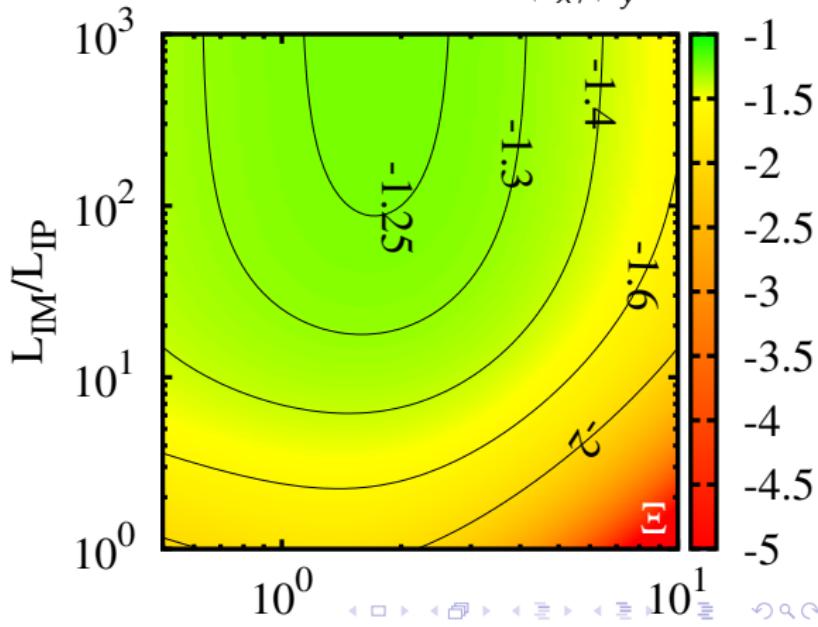
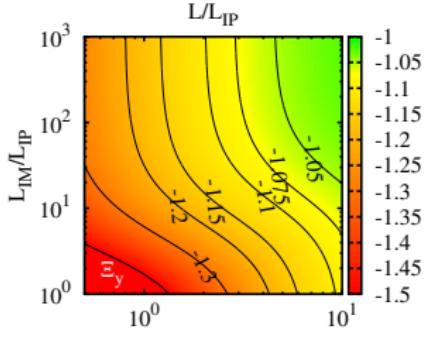
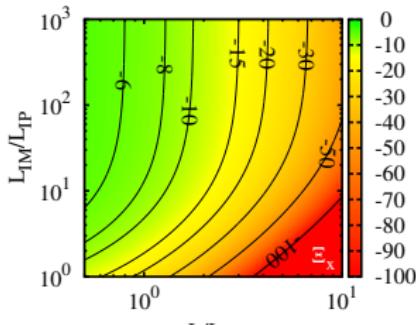
$$\xi_y = \mp \frac{1}{4\pi} \int \beta_y k dl = \mp \frac{1}{4\pi} \left(\beta_{y1} k_1 l_1 - \beta_{y0} k_0 l_0 \right) = \frac{1}{4\pi} \frac{L_{IP}}{\beta_x^*} \Xi_y(r, r_{im})$$

with

Chromaticity minimization (cont.)



$$\Xi = \frac{\Xi_x}{\beta_x^*/\beta_y^*} + \Xi_y$$



Chromaticity correction

Second order terms reduction

Quadrupoles generate chromaticity ($k_1\delta x, k_1\delta y$) and in dispersive regions also generate second order dispersion ($k_1\eta_x\delta^2$).

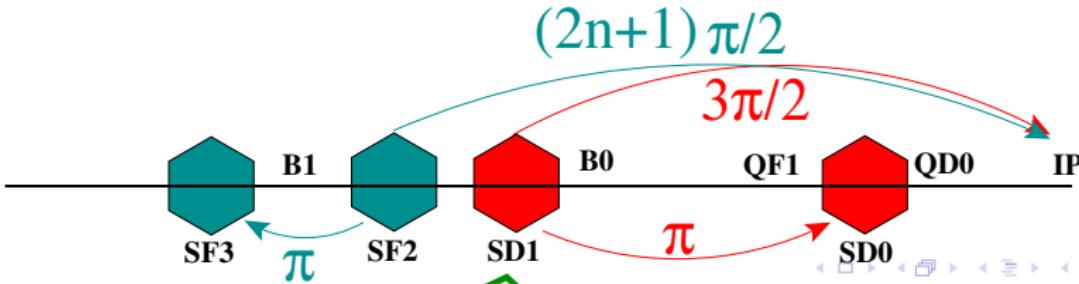
One of the paired sextupoles is in a horizontal dispersive region ($\eta_x \neq 0$).

This will correct second order dispersion ($\eta_x^2\delta^2$), twice the h. chromaticity ($\eta_x\delta x_1$) and the total v. chromaticity ($\eta_x\delta y$).

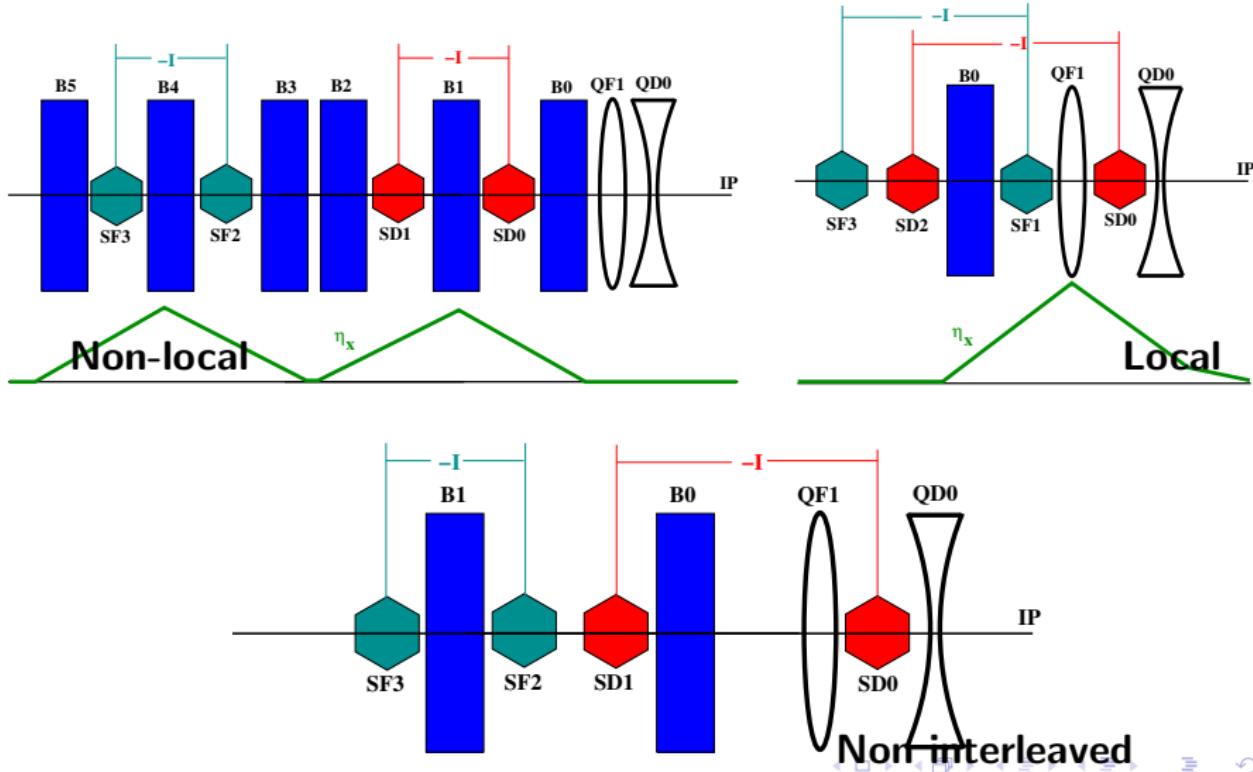
The sextupoles in non-dispersive regions ($\eta_x = 0$) will correct the geometrical components from sextupoles (x^2, y^2, xy).

$$x'_2 = \frac{k_2}{2}(x_1 + \eta_x\delta)^2 - y_1^2 = \frac{k_2}{2}(x_1^2 + 2x_1\eta_x\delta + \eta_x^2\delta^2 - y_1^2)$$

$$y'_2 = k_2(x_1 + \eta_x\delta)y = k_2(x_1y_1 + \eta_x\delta y_1)$$

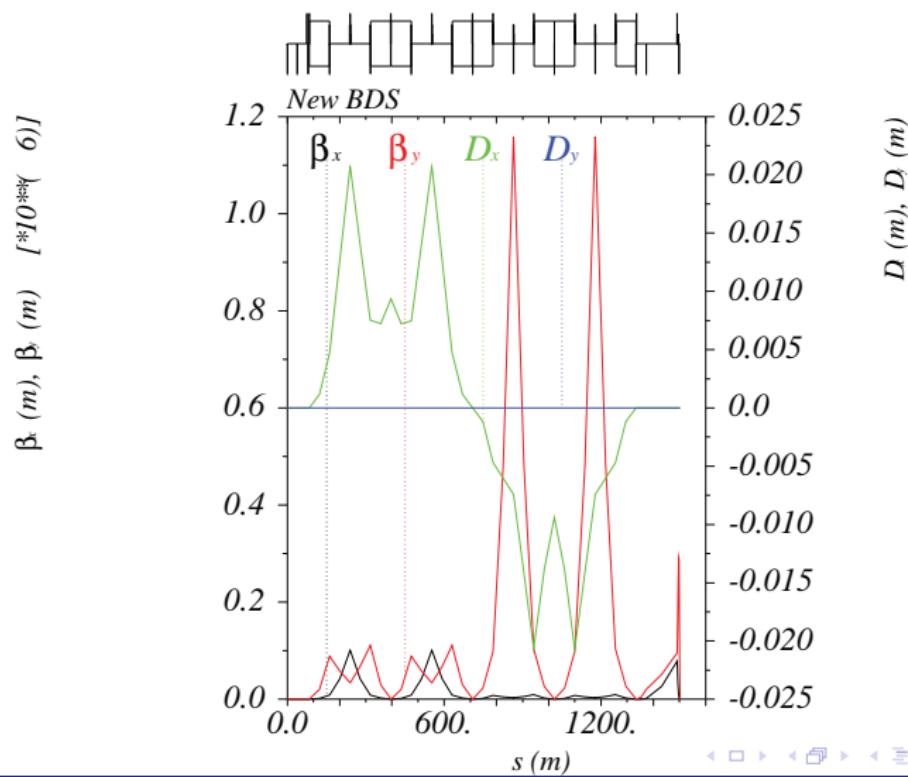


Local, Non-local and Non-interleaved correction

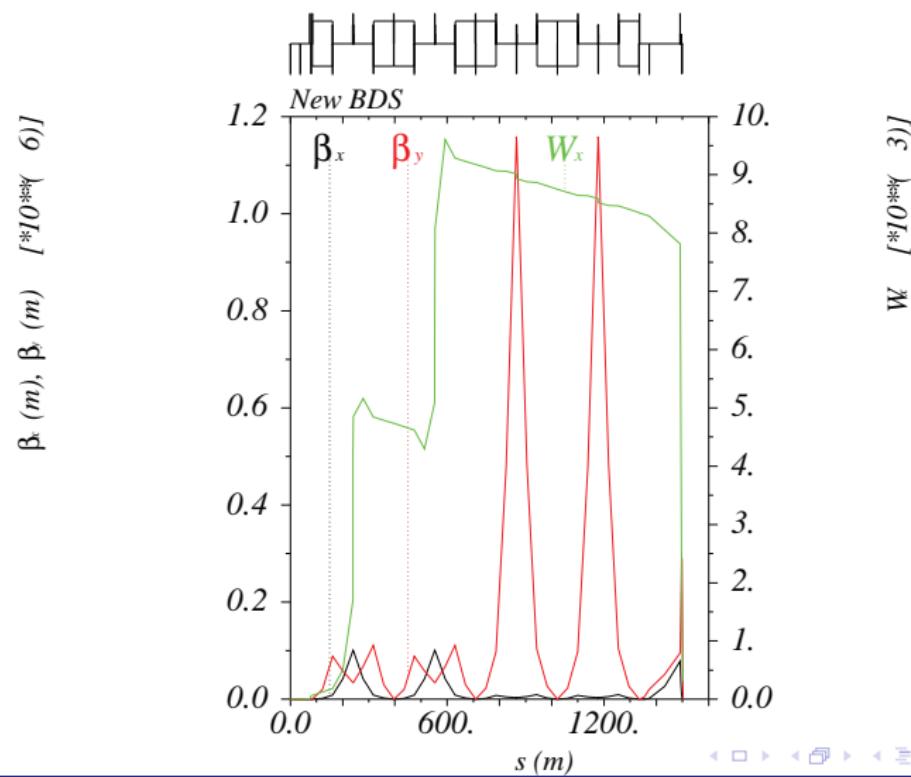


CLIC 3TeV Non-local (trad)

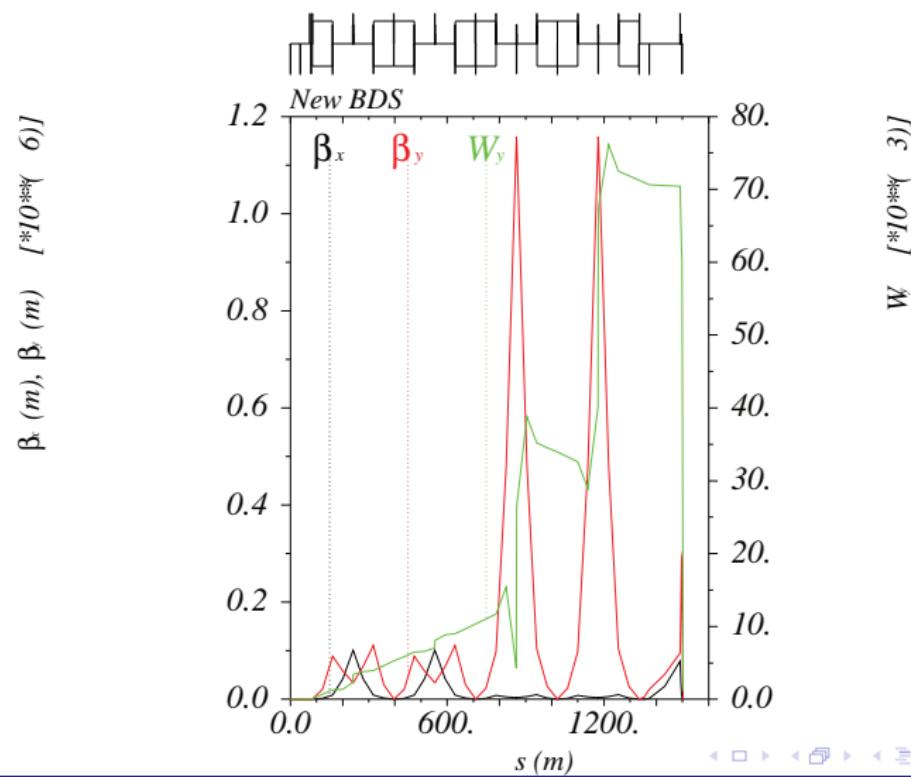
CLIC 3TeV Non-local (trad)



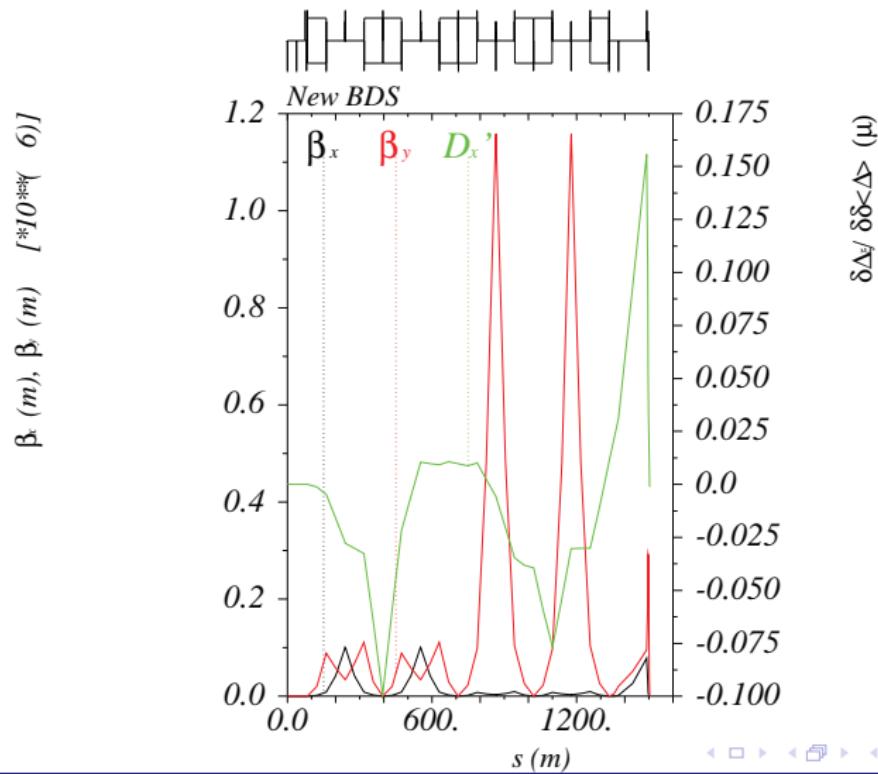
CLIC 3TeV Non-local (trad)



CLIC 3TeV Non-local (trad)

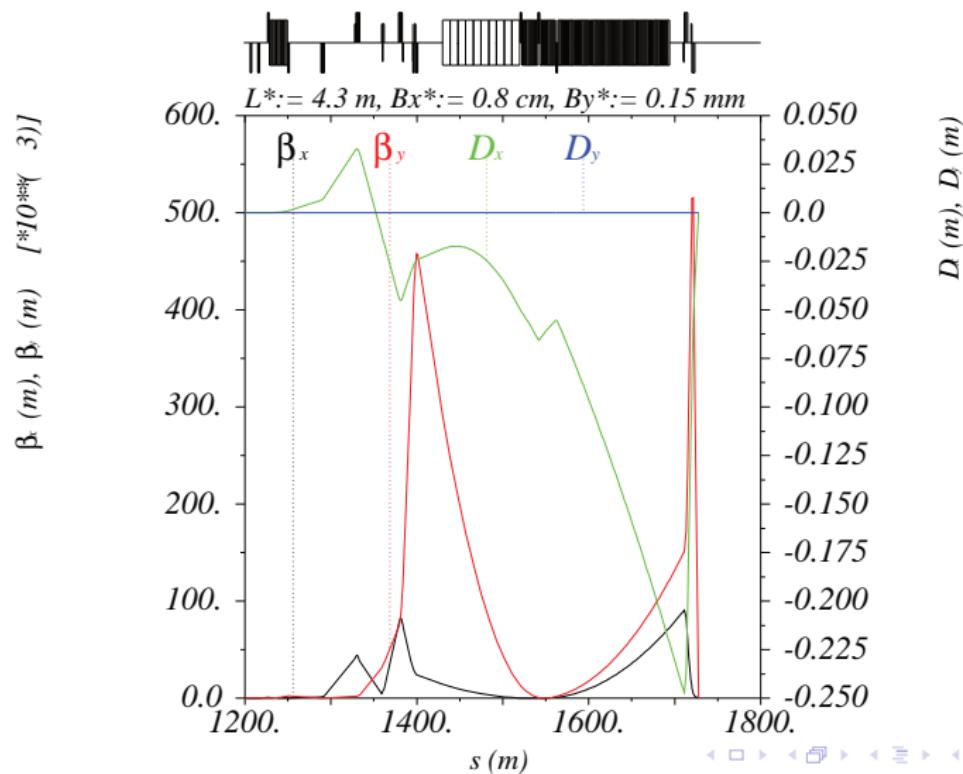


CLIC 3TeV Non-local (trad)

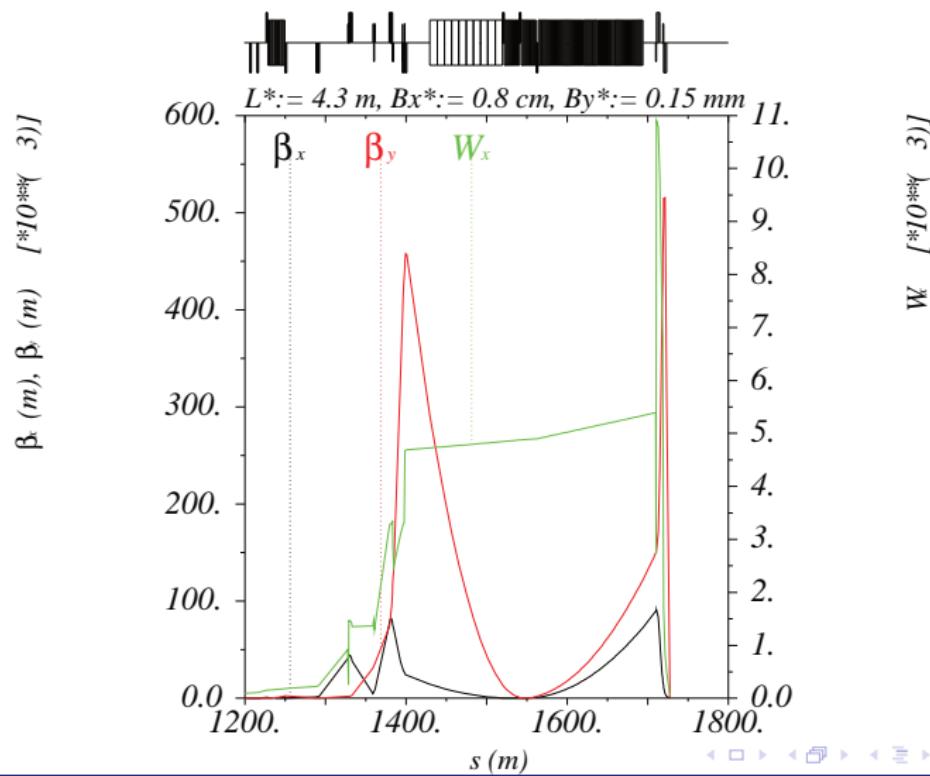


ILC 500 GeV

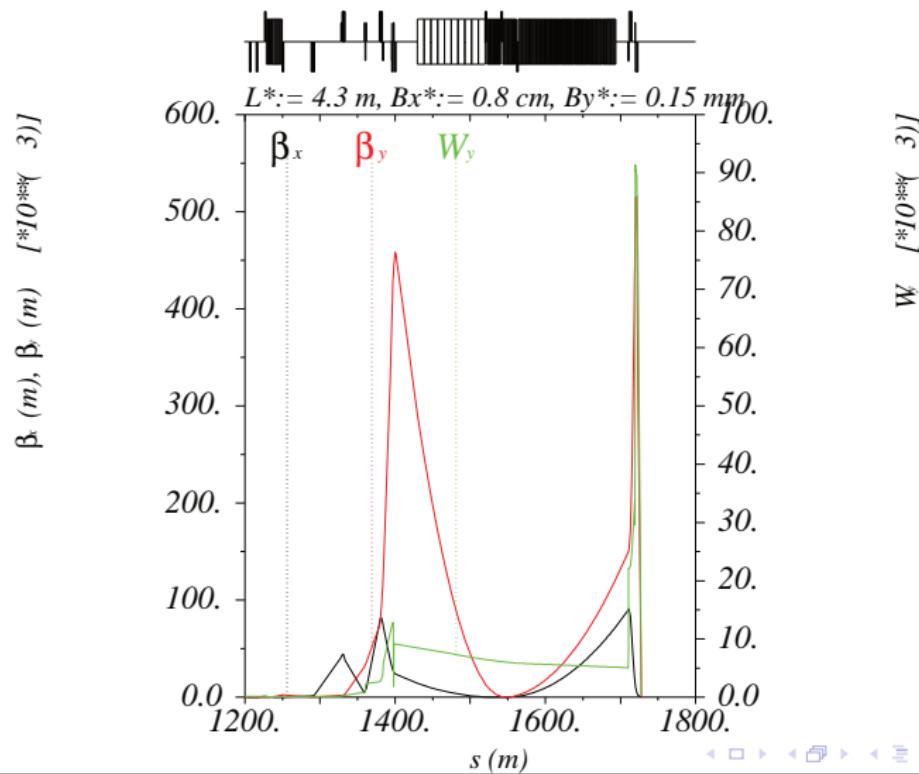
ILC 500 GeV (Local)



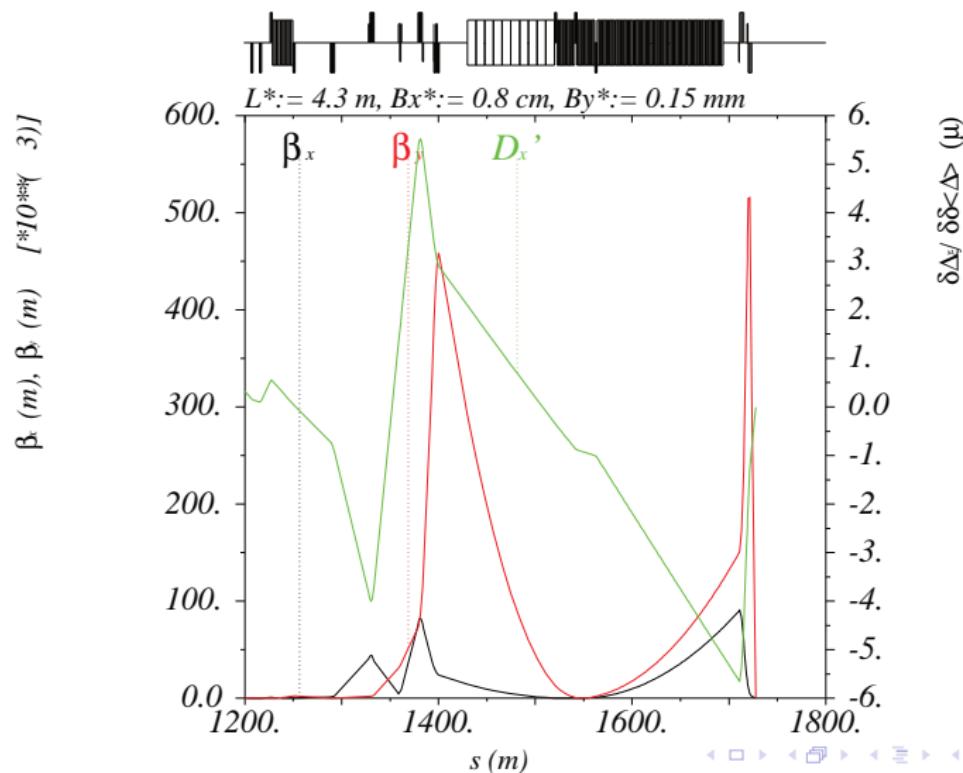
ILC 500 GeV (Local)



ILC 500 GeV (Local)



ILC 500 GeV (Local)

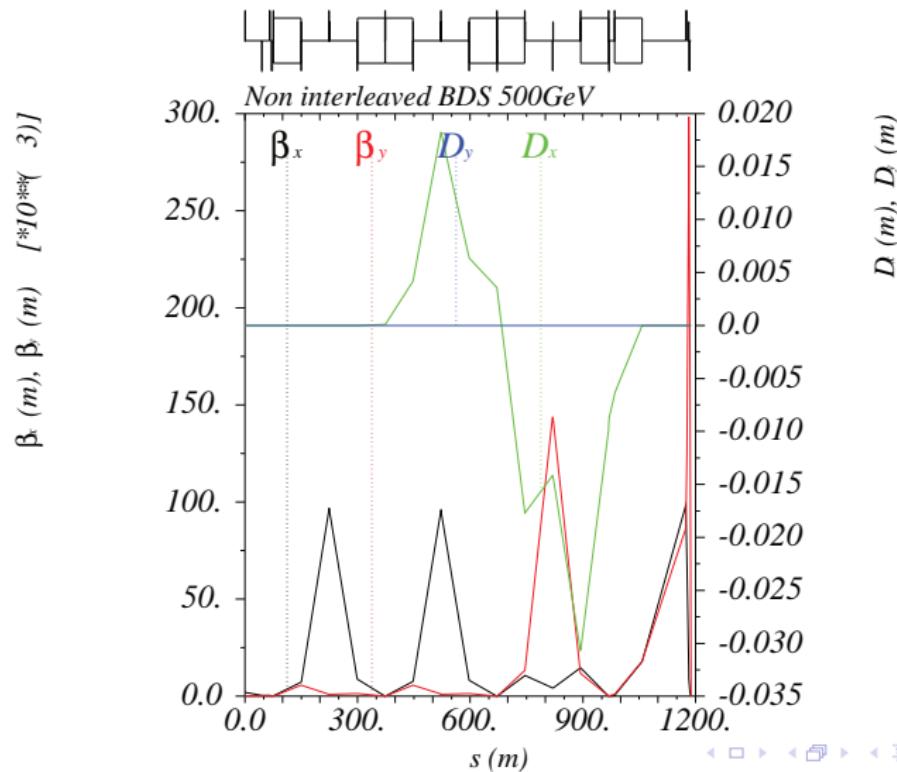


CLIC 500 GeV Non-interleaved Lattice

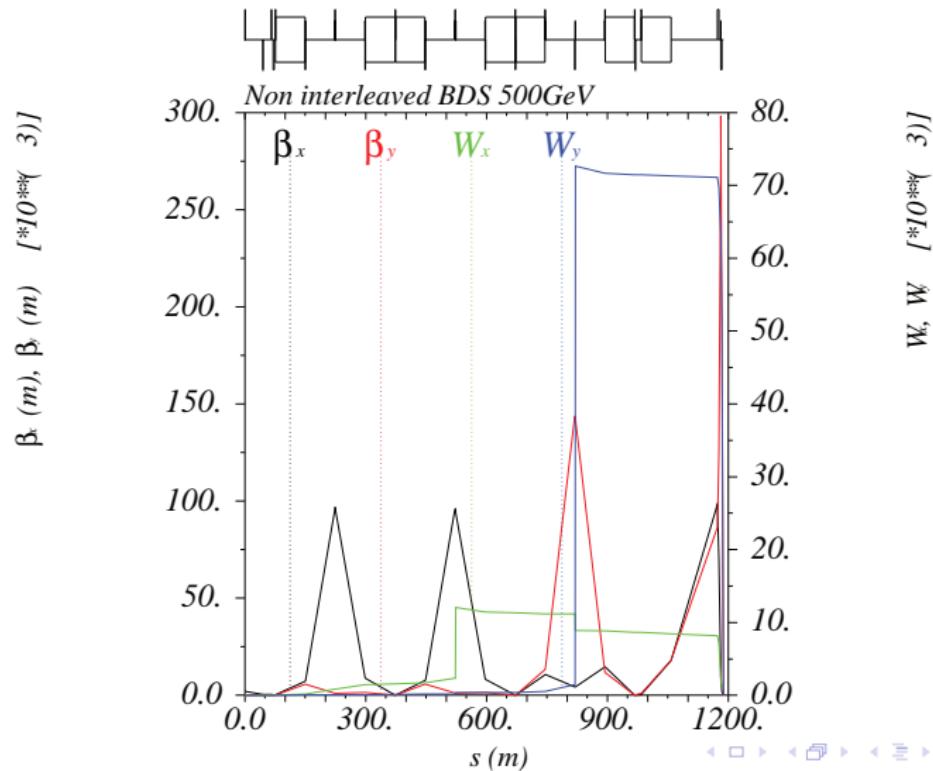
Current 500 GeV Lattice Parameters (from CDR)

Parameter [Units]	Value
Length (linac exit to IP distance/side [m])	1750
Maximum energy/beam [TeV]	0.25
Distance from IP to first quad, L^* [m]	4.3
Crossing angle at the IP [mrad]	18.6
Nominal core beam size at IP, $\sigma^*, x/y$ [nm]	202/2.3
Nominal beam divergence at IP, $\theta^*, x/y$ [μ rads]	25/23
Nominal beta-function at IP, $\beta^*, x/y$ [mm]	8/0.1
Nominal bunch length, σ_z [μ m]	72
Nominal disruption parameters, D , x/y	0.1/12
Nominal bunch population, N	6.8×10^9
Beam power in each beam [MW]	4.9
Preferred entrance train to train jitter [σ]	< 0.2
Typical nominal collimation aperture, x/y [σ_x/σ_y]	10/55
Vacuum pressure level, near/far from IP [10^{-9} mbar]	100/10

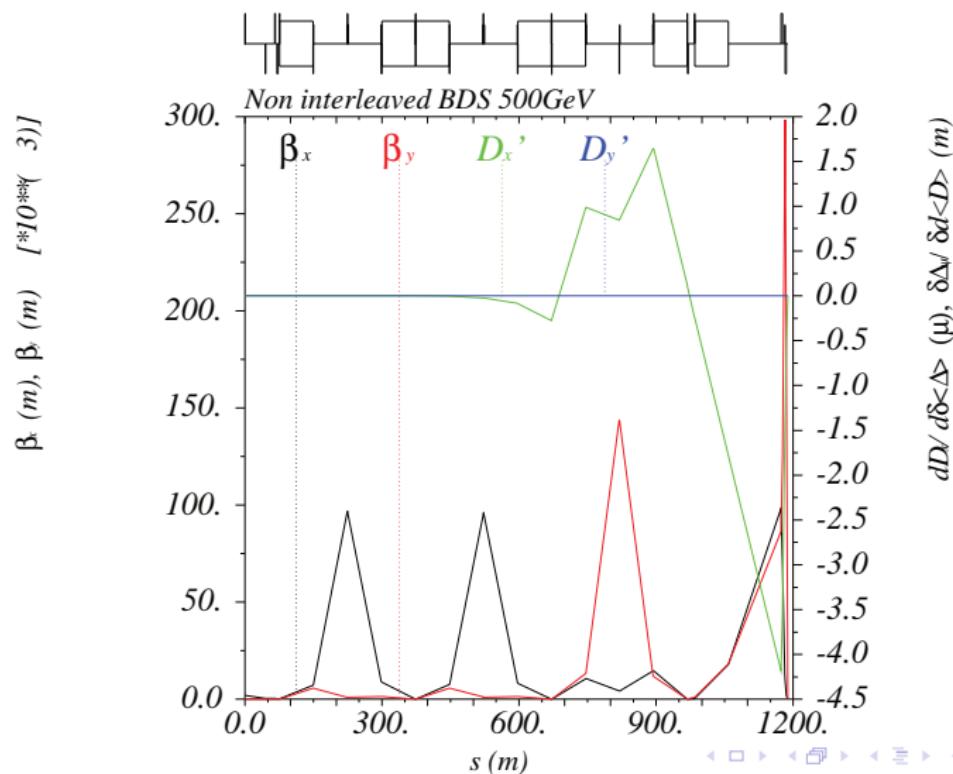
CLIC 500GeV Non-interleaved Lattice



CLIC 500GeV Non-interleaved Lattice



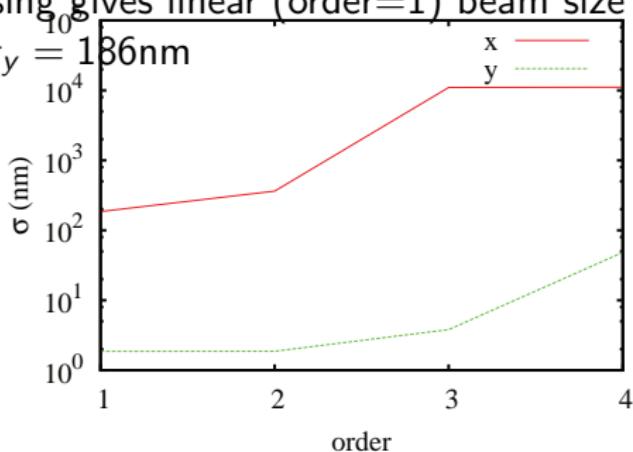
CLIC 500GeV Non-interleaved Lattice



Non-interleaved CLIC 500 GeV (cont.)

The lattice design gives linear (order=1) beam size of :

$$\sigma_x = 1.9 \text{ nm}, \sigma_y = 1.86 \text{ nm}$$



$$\sigma_{bends} = 0.2 \text{ nm}$$

The third order terms U_{1166} and U_{3466} increase the beam size due to second order dispersion at the sextupole inside the Final doublet.

Second order dispersion needs to be corrected before the FD (not only at