CORNELL UNIVERSITY LEPP

LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS

CESR-c

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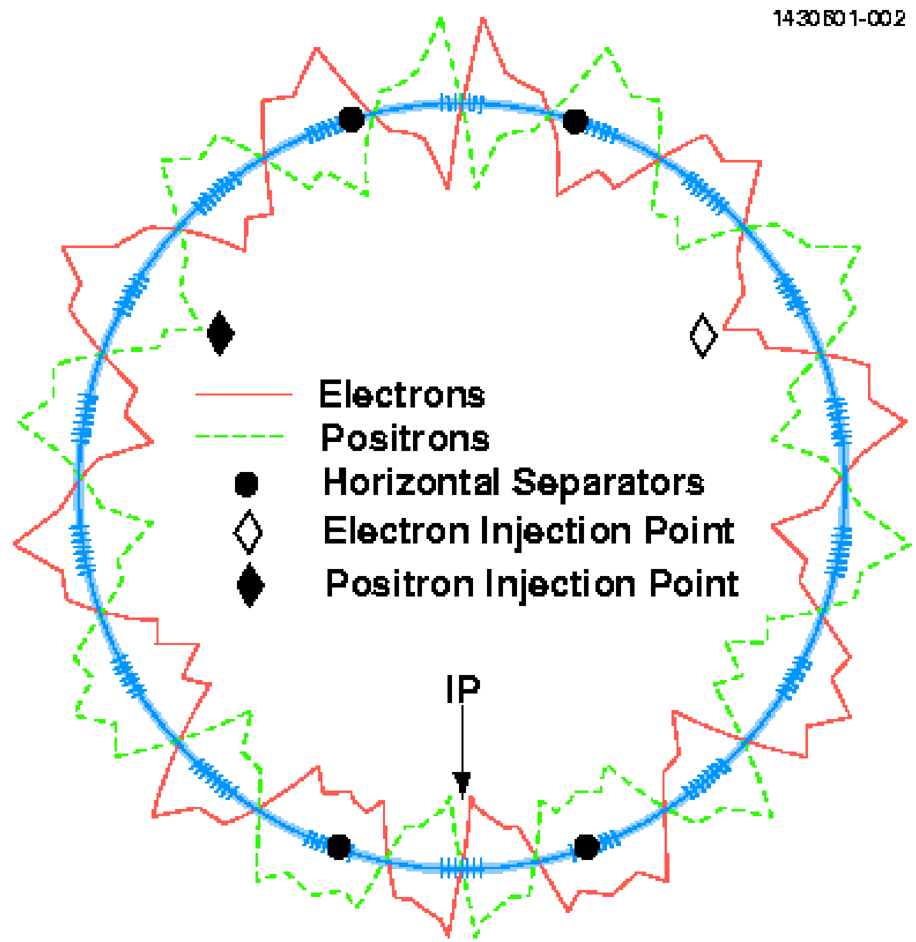
CESR-c

Energy reach 1.5-6GeV/beam

Electrostatically separated electron-positron orbits accomodate counterrotating trains

Electrons and positrons collide with ±~3 mrad horizontal crossing angle

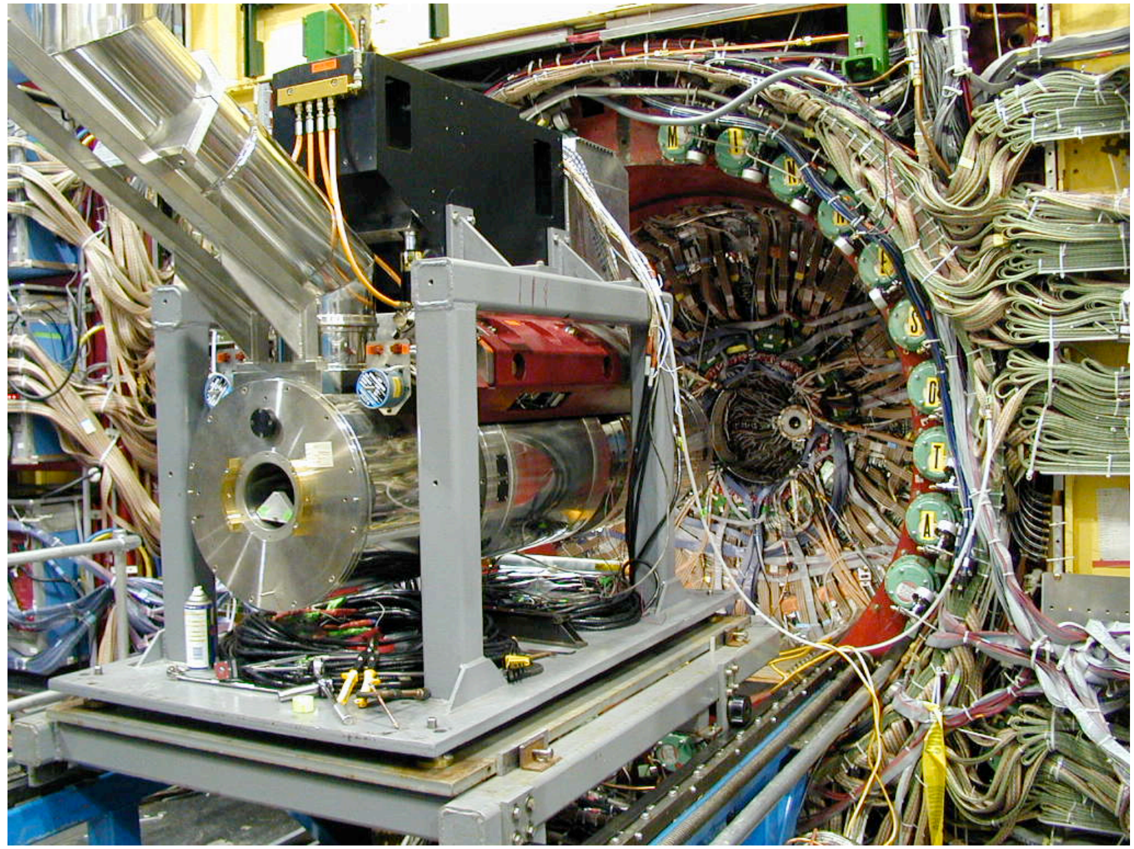
9 5-bunch trains in each beam (768m circumference)



CESR-c IR

Summer 2000, replace 1.5m REC permanent magnet final focus quadrupole with hybrid of pm and superconducting quads

Intended for 5.3GeV operation but perfect for 1.5GeV as well



CESR-c IR

□* ~ 10mm

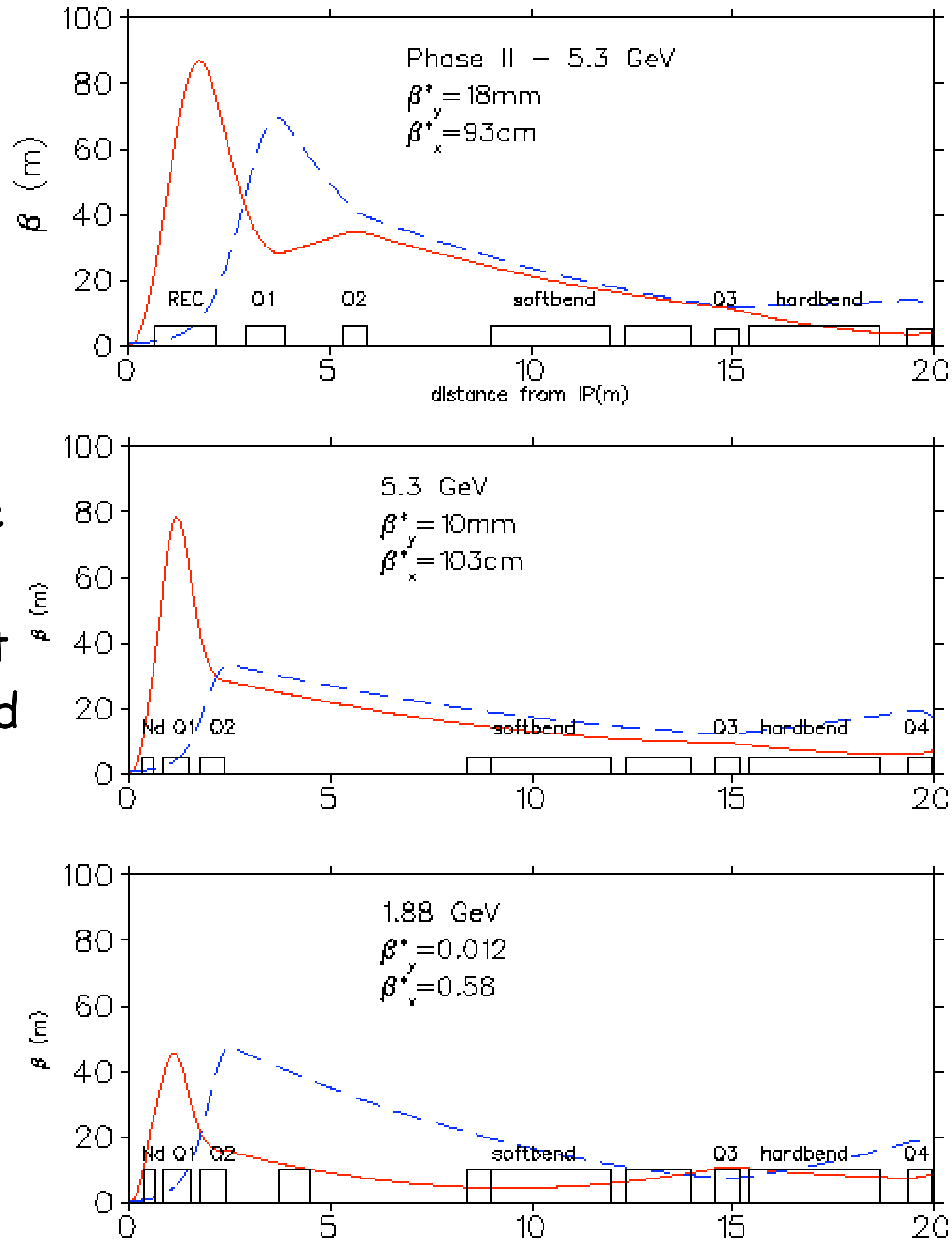
H and V superconducting quads share same cryostat

20cm pm vertically focusing nose piece

Quads are rotated 4.5^0 inside cryostat to compensate effect of CLEO solenoid

Superimposed skew quads permit fine tuning of compensation

At 1.9GeV, very low peak □ =>
  Little chromaticity, big aperture

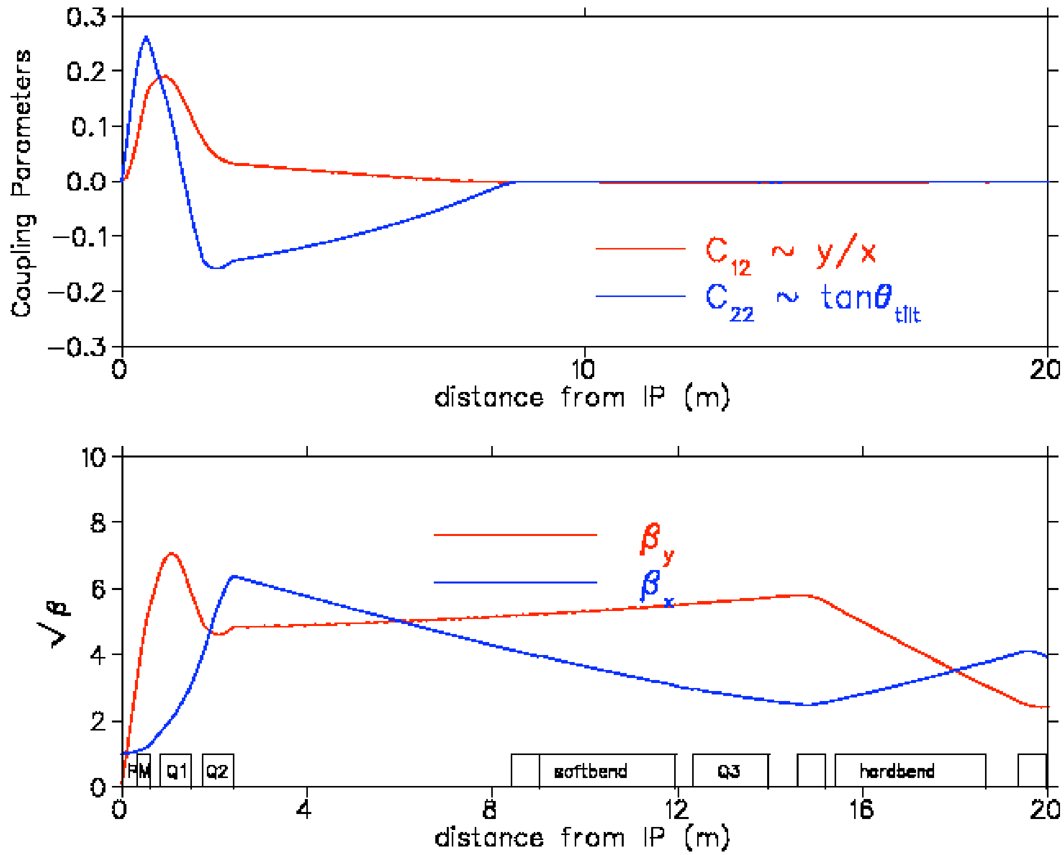


CLEO solenoid

1T(□)-1.5T( )

Good luminosity requires zero transverse coupling at IP
(flat beams)

Solenoid readily compensated even at lowest energy



□*(V)=10mm E=1.89GeV
□*(H)=1m B(CLEO)=1T

CESR-c Energy dependence

Beam-beam effect

- In collision, beam-beam tune shift parameter ~ I_b/E
- Long range beam-beam interaction at 89 parasitic crossings ~ I_b/E (for fixed emittance)
  (and this is the current limit at 5.3GeV)

Single beam collective effects, instabilities

- Impedance is independent of energy
- Effect of impedance ~I/E

CESR-c Energy dependence

(scaling from 5.3GeV/beam to 1.9GeV/beam)

Radiation damping and emittance

Damping

Circulating particles have some momentum transverse to design orbit (P_t/P)

In bending magnets, synchrotron photons radiated parallel to particle momentum □P_t/P_t = □P/P

RF accelerating cavities restore energy only along design orbit, P-> P+ □P so that transverse momentum is radiated away and motion is damped

Damping time □ ~ time to radiate away all momentum

CESR-c Energy dependence

Radiation damping

In CESR at 5.3 GeV, an electron radiates ~1MeV/turn

~> τ ~ 5300 turns (or about 25ms)

SR Power ~ $E^2B^2 = E^4/\rho^2$ at fixed bending radius

$1/\tau$ ~ P/E ~ E^3

so at 1.9GeV, τ ~ 500ms

Longer damping time

- Reduced beam-beam limit
- Less tolerance to long range beam-beam effects
- Multibunch effects, etc.
- Lower injection rate

CESR-c Energy dependence

Emittance

- Closed orbit depends on energy offset x(s) = □(s)□
- Energy changes abruptly with radiation of synchrotron photon
- Electron begins to oscillate about closed orbit generating emittance, □= (□□)$^{1/2}$
- Lower energy -> fewer radiated photons and lower photon energy

- Emittance □~ E^2

CESR-c Energy dependence

Emittance

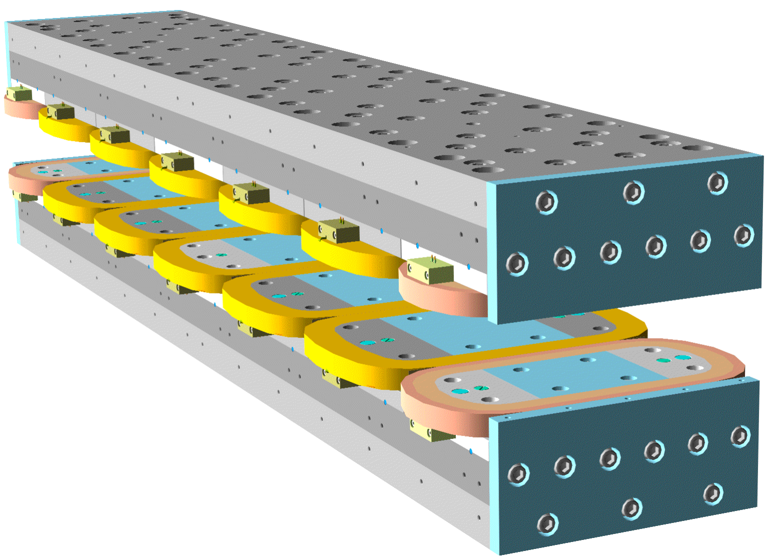
- $L \sim I_B^2 / \square_x \square_y = I_B^2 / (\square_x \square_y \square_x \square_y)^{1/2}$
- $\square_x \sim \square_y$ (coupling)
- $I_B / \square_x$ limiting charge density
- Then I_B and therefore $L \sim \square_x$

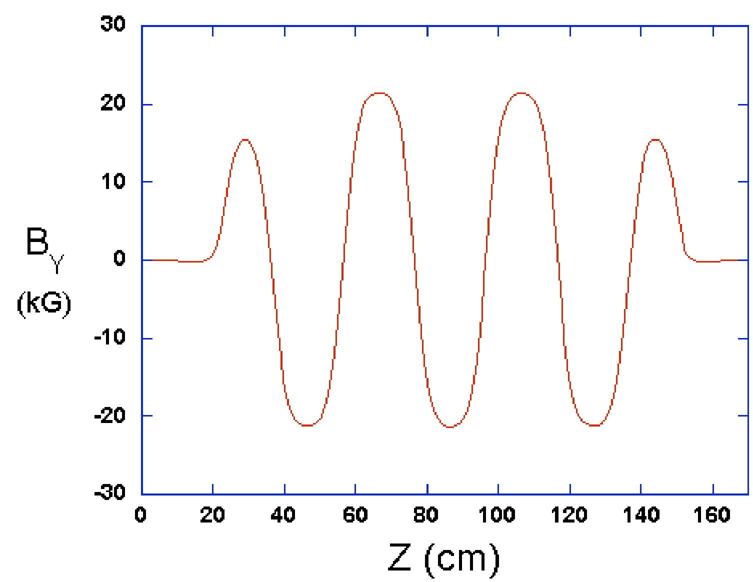
CESR (5.3GeV), $\square_x$ = 200 nm-rad

CESR (1.9GeV), $\square_x$ = 30 nm-rad

CESR-c Energy dependence

Damping and emittance control with wigglers





CESR-c Energy dependence

In a wiggler dominated ring

- 1/ □ ~ $B_w{}^2 L_w$
- □ ~ B_w L_w
- $□_E/E$ ~ $(B_w)^{1/2}$ nearly independent of length
  (B$_w$ limited by tolerable energy spread)

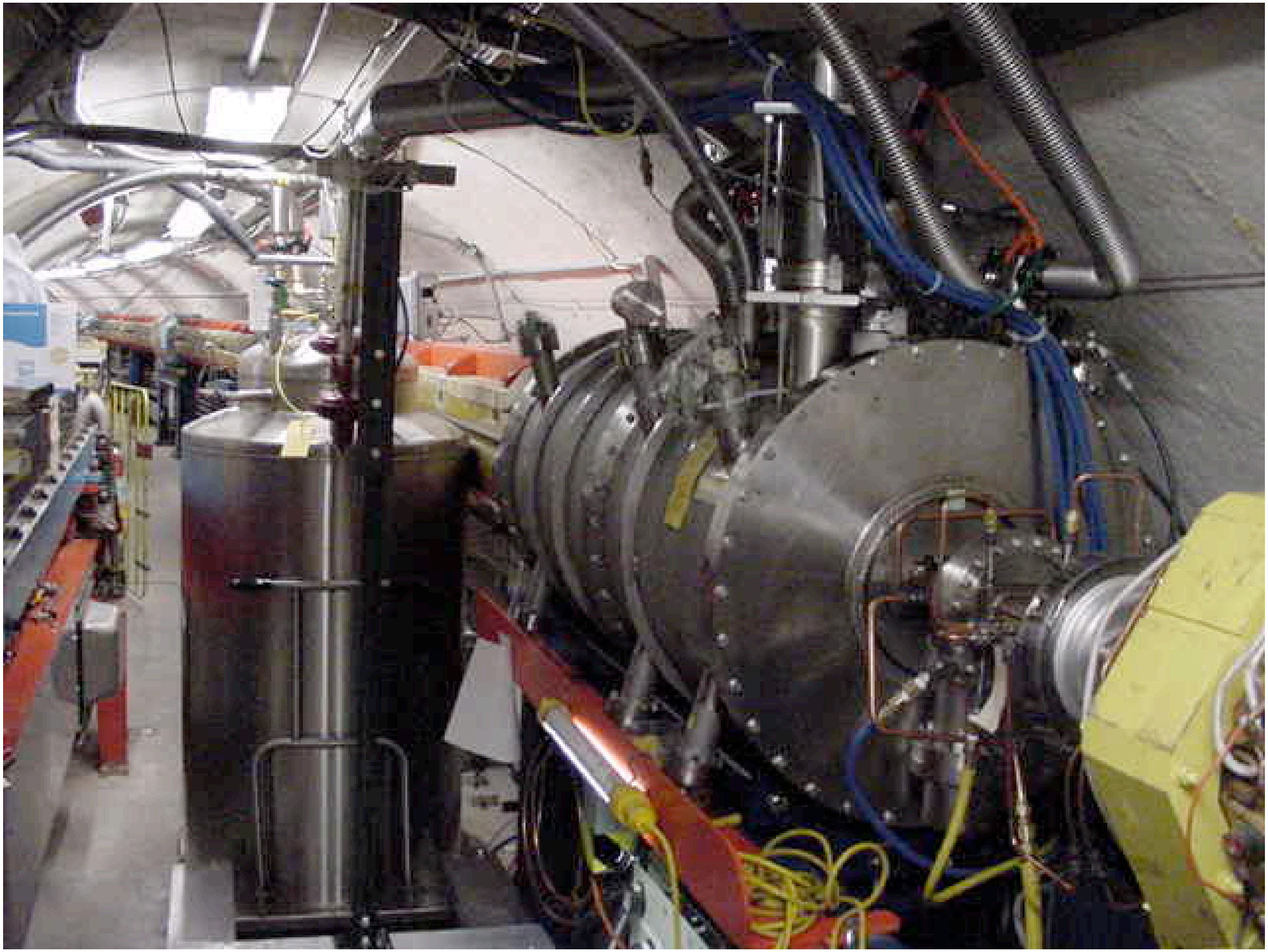
Then 18m of 2.1T wiggler

-> □ ~ 50ms

-> 100nm-rad < □<300nm-rad

Superconducting wiggler

7-pole, 1.3m
40cm period,
161A, B=2.1T

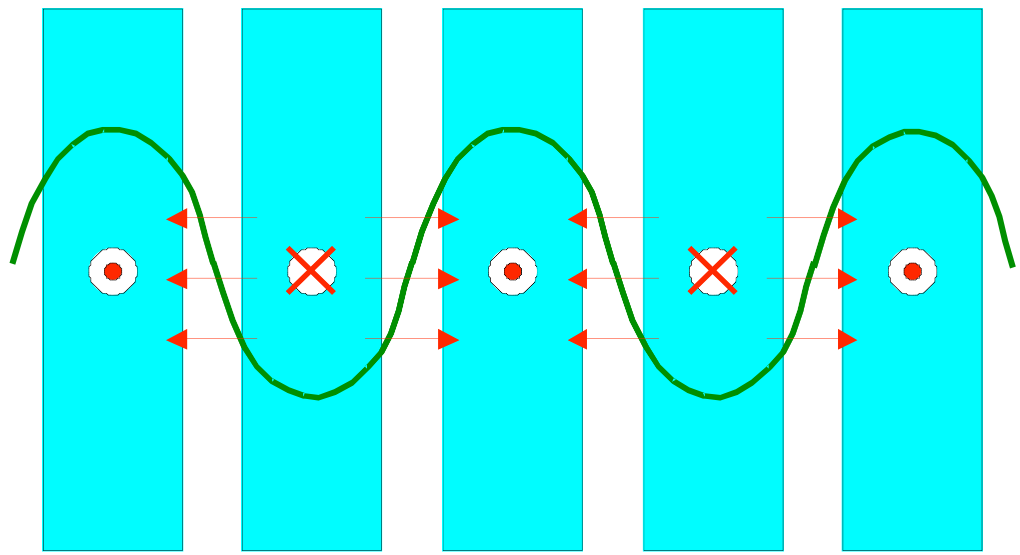


Optics effects - Ideal Wiggler

$$B_z = -B_0 \sinh k_w y \ \sin k_w z$$

$$\theta = \frac{ceB_0}{E_0}\frac{\lambda_w}{2\pi}$$

Vertical kick ~ $\int B_z$



$$\Delta y' = -\frac{B_0^2 L}{2(E_0/ce)^2}\left[y + \frac{2}{3}\left(\frac{2\pi}{\lambda}\right)^2 y^3 + \ldots\right]$$

Optics effects - Ideal Wiggler

Vertical focusing effect is big, ΔQ ~ 0.1/wiggler

But is readily compensated by adjustment of nearby quadrupoles

Cubic nonlinearity ~ $(1/\lambda)^2$

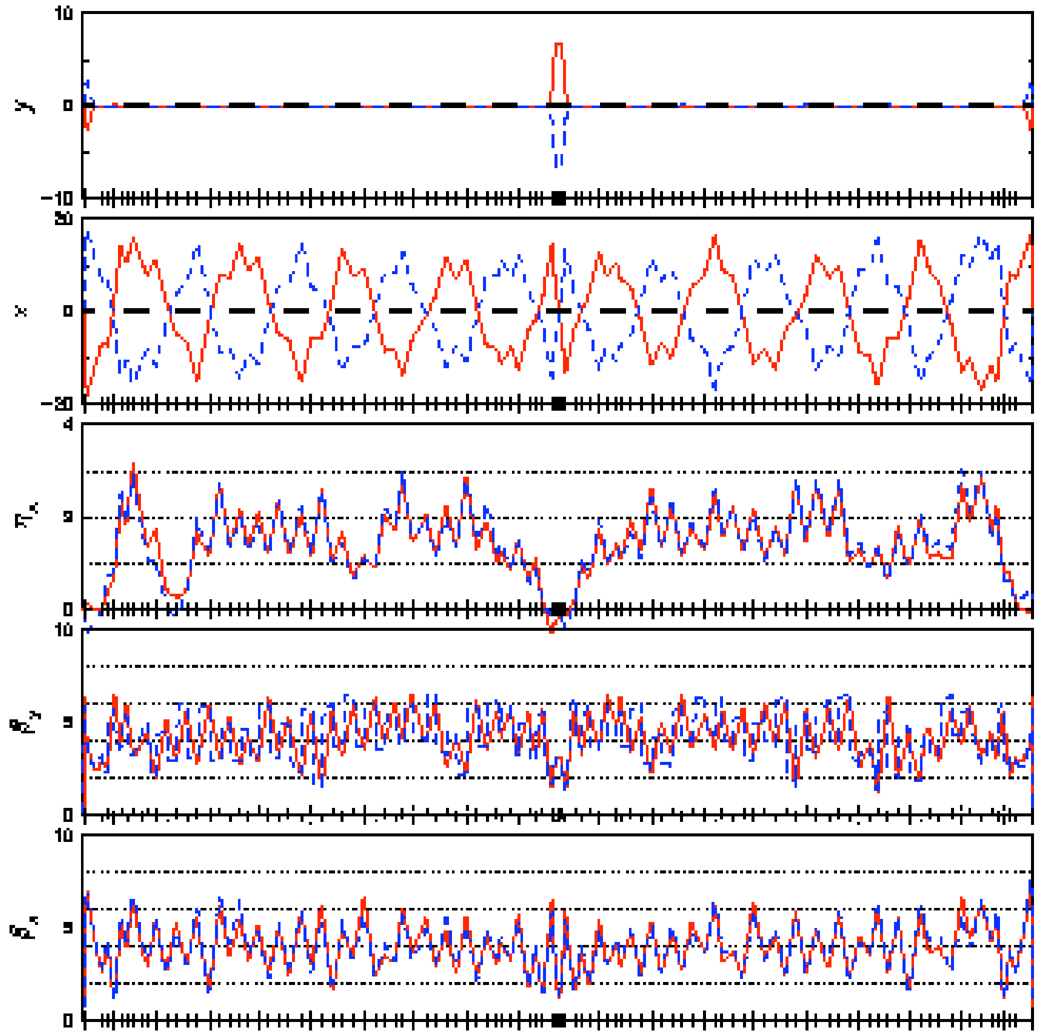
We choose the relatively long period -> λ = 40cm

Finite width of poles leads to horizontal nonlinearity

6 Wiggler Linear Optics

Lattice parameters

Beam energy[GeV]	1.89
β^*_v[mm]	12
β^*_h[m]	0.56
Crossing angle[mrad]	3.8
Q_v	9.59
Q_h	10.53
Number of trains	9
Bunches/train	4
Bunch spacing[ns]	14
Accelerating Voltage[MV]	10
Bunch length[mm]	9
Wiggler Peak Field[T]	2.1
Wiggler length[m]	1.3
Number of wigglers	6
ϵ_x[mm-mrad]	0.15
σ_E/E[%]	0.08

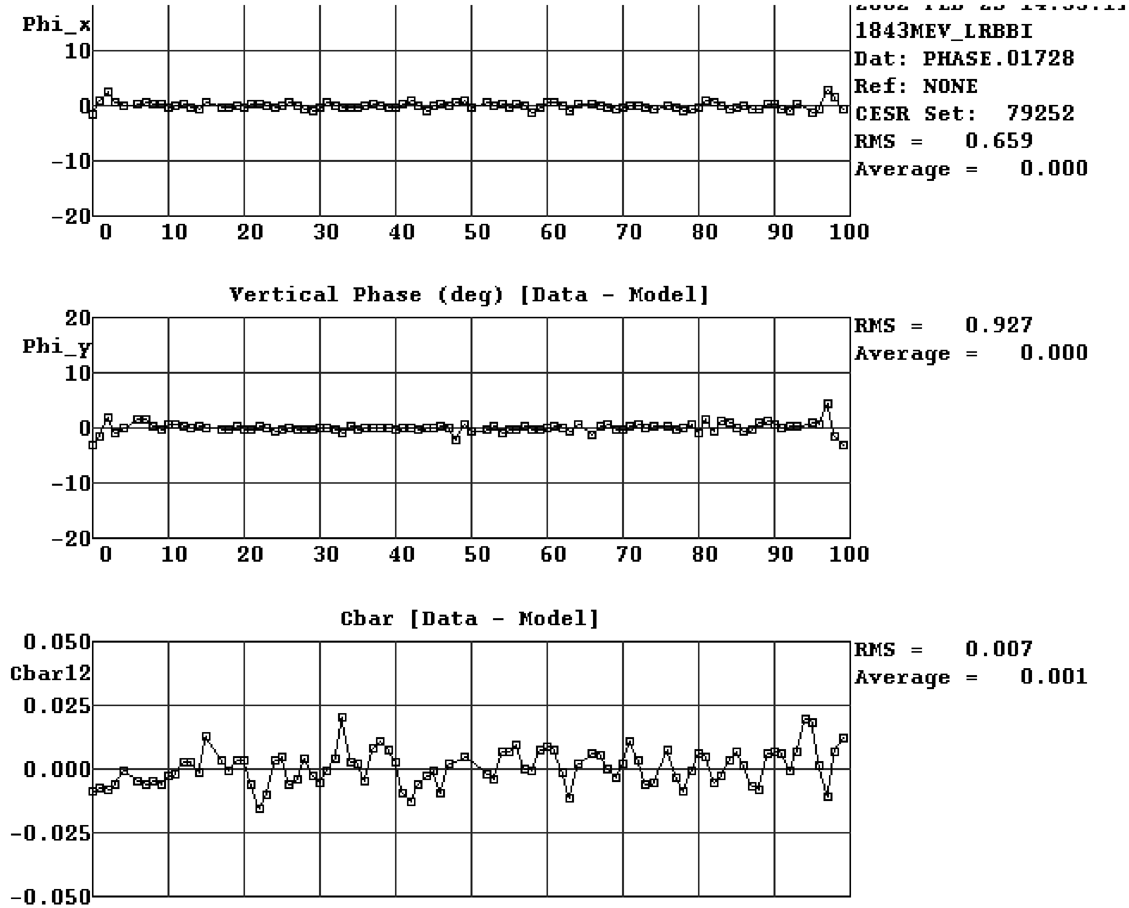


Wiggler Beam Measurements

First wiggler installed 9/02

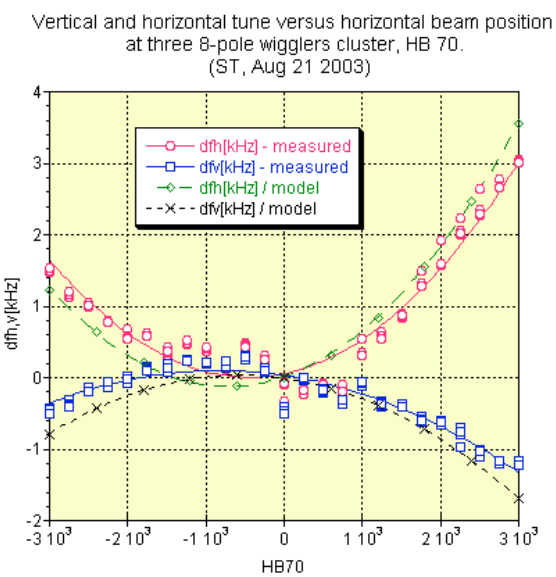
Beam energy = 1.84GeV

- -Optical parameters in IR match CESR-c design
- -Measure and correct betatron phase and transverse coupling
- - Measurement of lattice parameters (including emittance) in good agreement with design



Wiggler Beam Measurements

-Measurement of betatron tune vs displacement consistent with modeled field profile and transfer functon

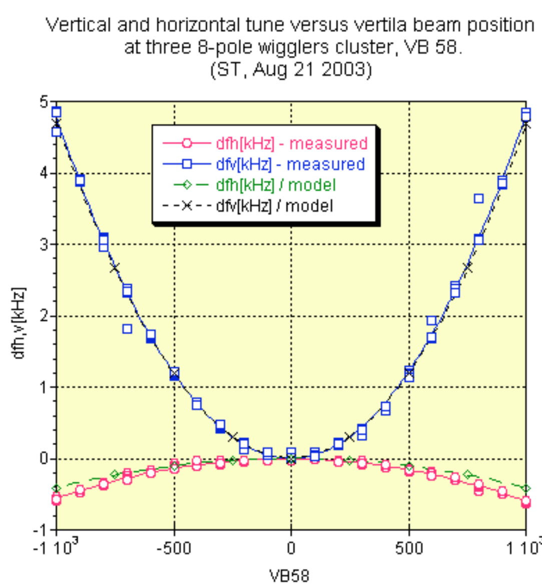


Y = M0 + M1*x + ... M8*x^8 + M9*x^9	
M0	0.059295
M1	0.00022736
M2	2.5315e-07
R	0.95831

Y = M0 + M1*x + ... M8*x^8 + M9*x^9	
M0	0.033497
M1	-0.00016229
M2	-9.7726e-08
R	0.9352

Y = M0 + M1*x + ... M8*x^8 + M9*x^9	
M0	0.014522
M1	0.00038242
M2	2.6541e-07
R	0.99985

Y = M0 + M1*x + ... M8*x^8 + M9*x^9	
M0	-0.0040093
M1	-0.00015152
M2	-1.3727e-07
R	0.99997



Y = M0 + M1*x + ... M8*x^8 + M9*x^9	
M0	-0.0022588
M1	-1.9531e-05
M2	-5.7511e-07
R	0.99344

Y = M0 + M1*x + ... M8*x^8 + M9*x^9	
M0	0.00051815
M1	1.983e-05
M2	4.8043e-06
R	0.99829

Y = M0 + M1*x + ... M8*x^8 + M9*x^9	
M0	0.0035498
M1	0
M2	-4.1385e-07
R	0.99994

Y = M0 + M1*x + ... M8*x^8 + M9*x^9	
M0	0.015455
M1	-2.6666e-06
M2	4.6909e-06
R	0.99997

Wiggler Beam Measurements

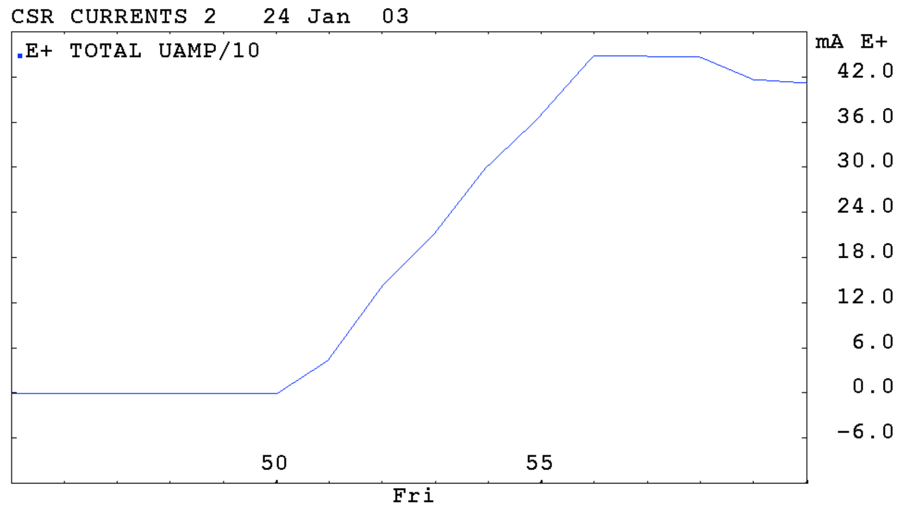
-Injection

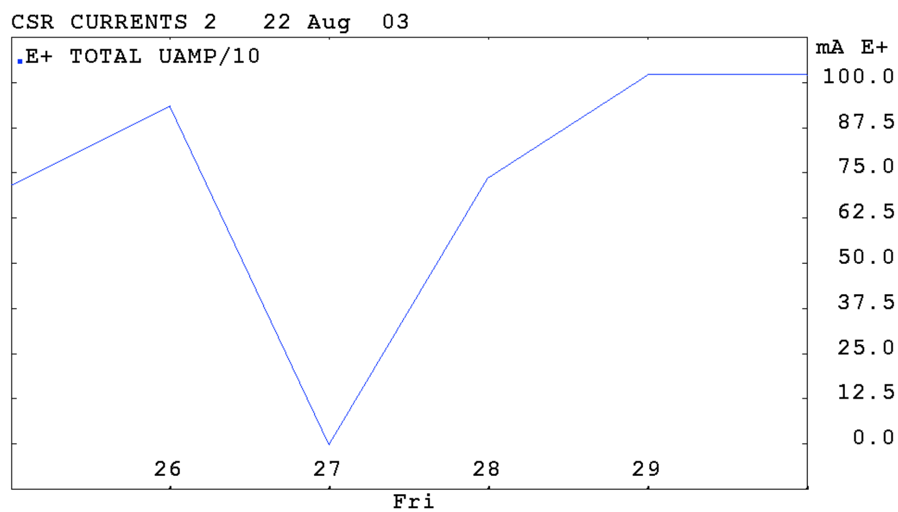
1 sc wiggler -> 8mA/min

$1/\tau = 4.5\ s^{-1}$

6 sc wiggler -> 50mA/min

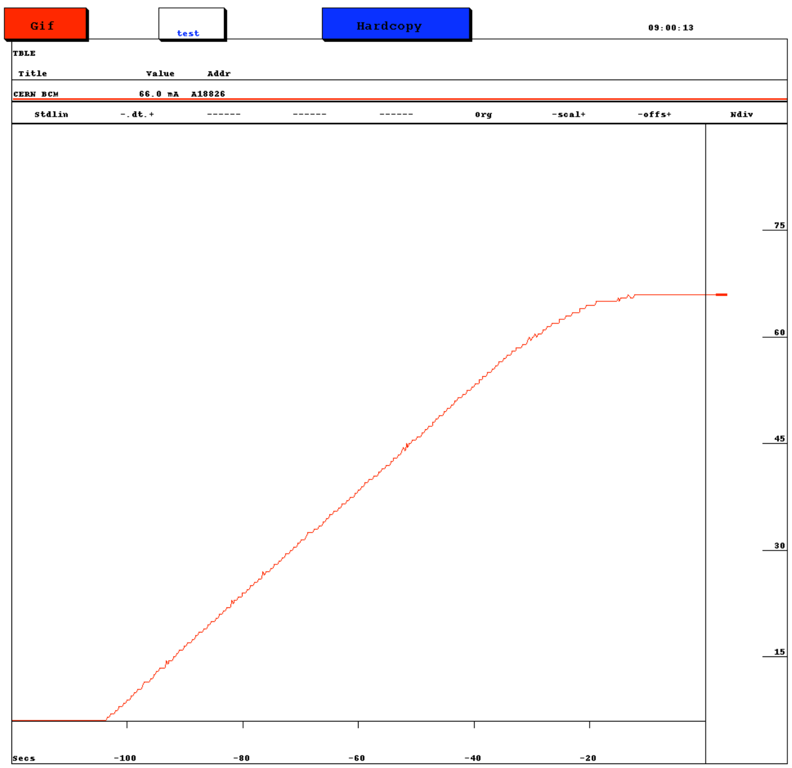
$1/\tau = 10.9 s^{-1}$



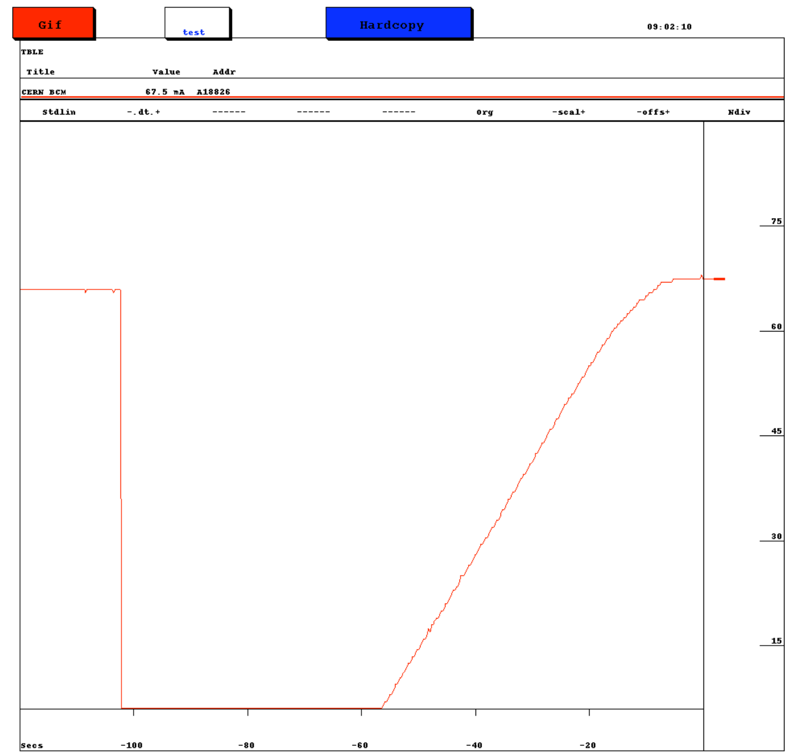


Wiggler Beam Measurements

-Injection



30 Hz 68mA/80sec

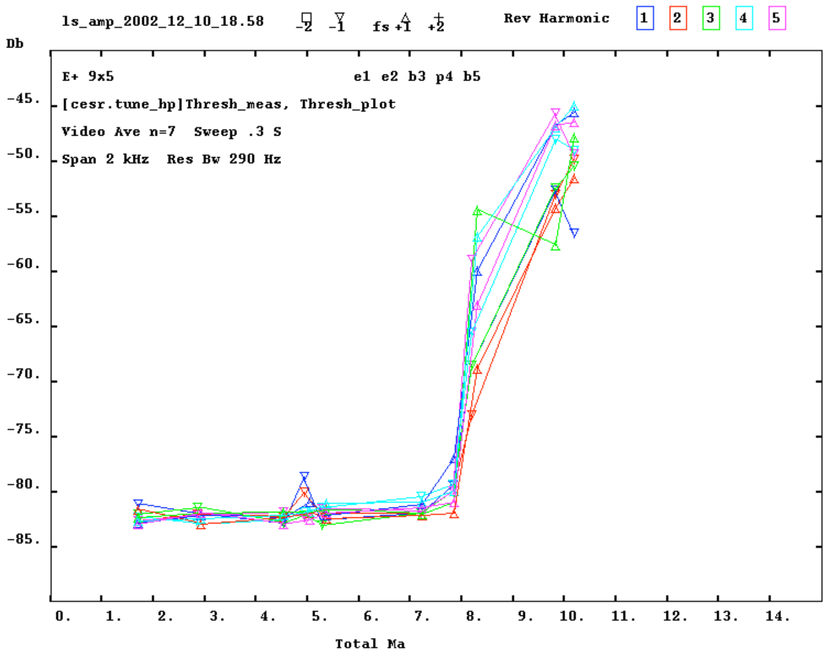


60 Hz 67ma/50sec

Wiggler Beam Measurements

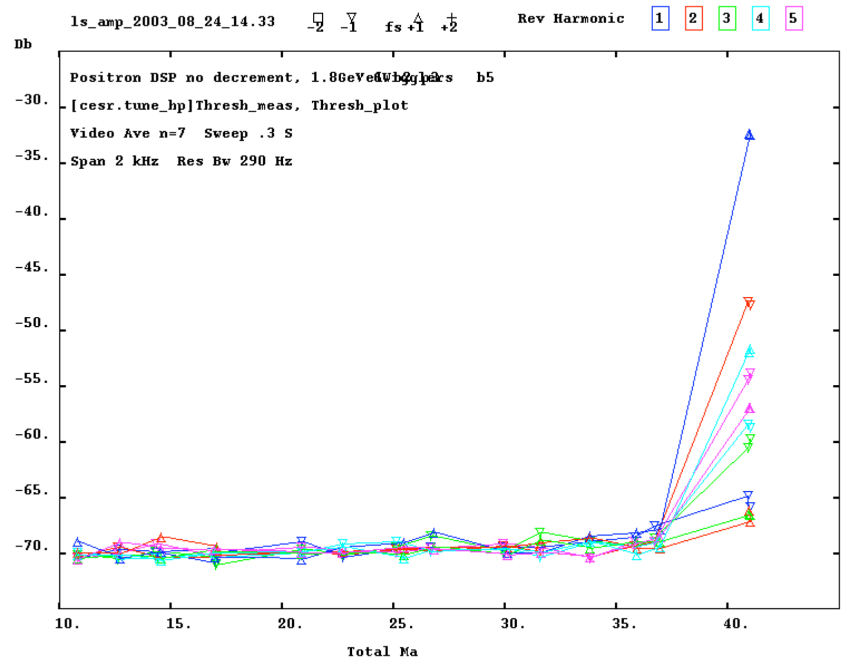
-Single beam stability

2pm + 1 sc wigglers



$1/□ = 4.5\ s^{-1}$

6 sc wigglers



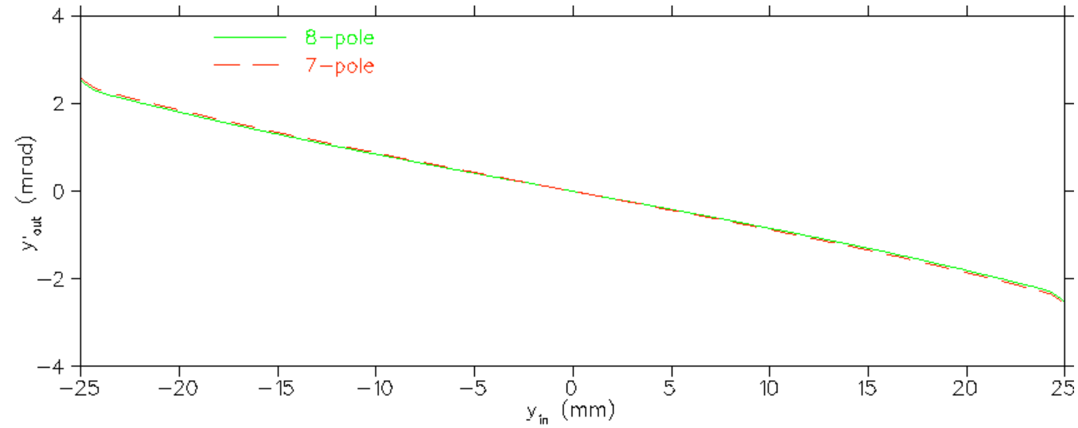
$1/□ = 10.9 s^{-1}$

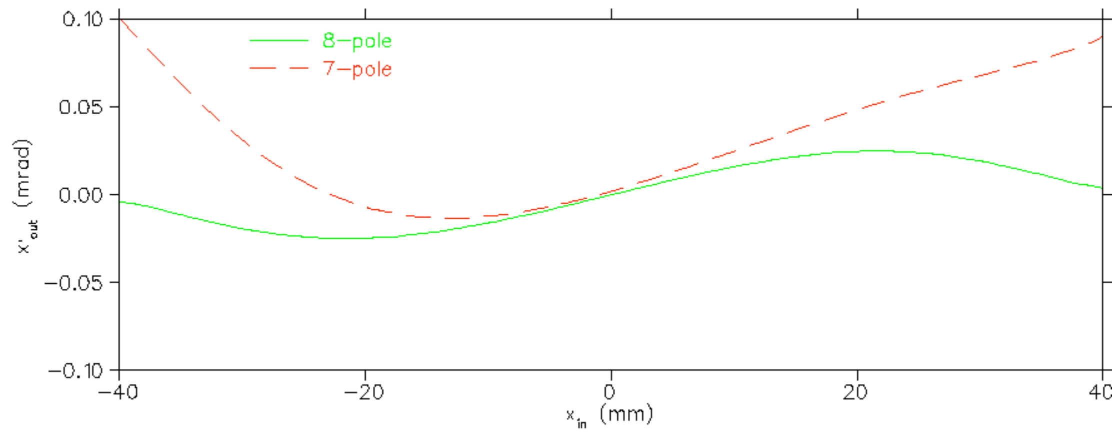
Machine modeling

-Wiggler transfer map

-Compute field table
with finite element code

-Tracking through field
table -> transfer maps





Machine modeling

- Fit analytic form to field table

$$B_n x = -C\frac{k_x}{k_y}\sin(k_x x)\sinh(k_y y)\cos(k_s s + \phi_s)$$

$$B_n y = C\cos(k_x x)\cosh(k_y y)\cos(k_s s + \phi_s)$$

$$B_n s = -C\frac{k_s}{k_y}\cos(k_x x)\sinh(k_y y)\sin(k_s s + \phi_s)$$

with $k_y^2 = k_x^2 + k_s^2$

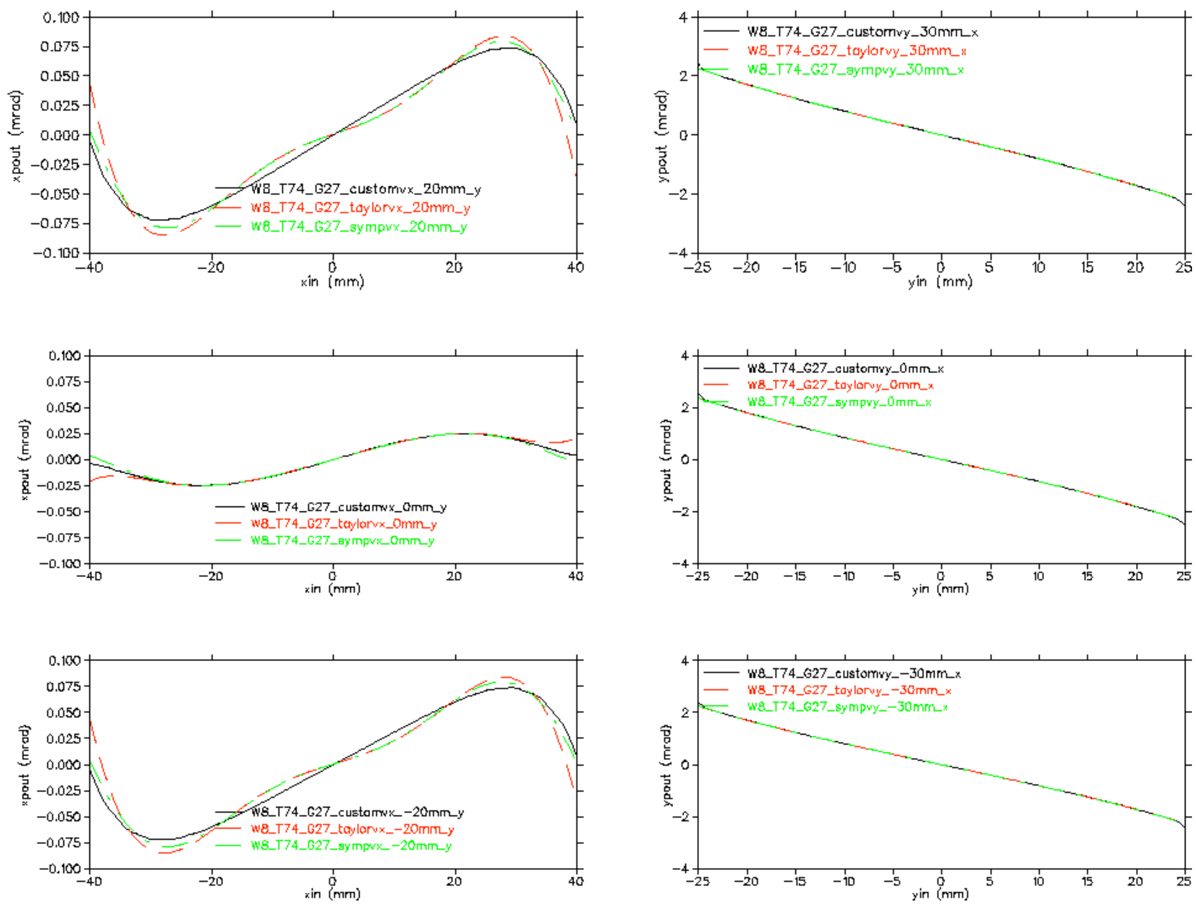
1

Machine modeling

-Wiggler map

Fit parameters of
series to field table

Analytic form of
Hamiltonian
-> symplectic integration
-> taylor map



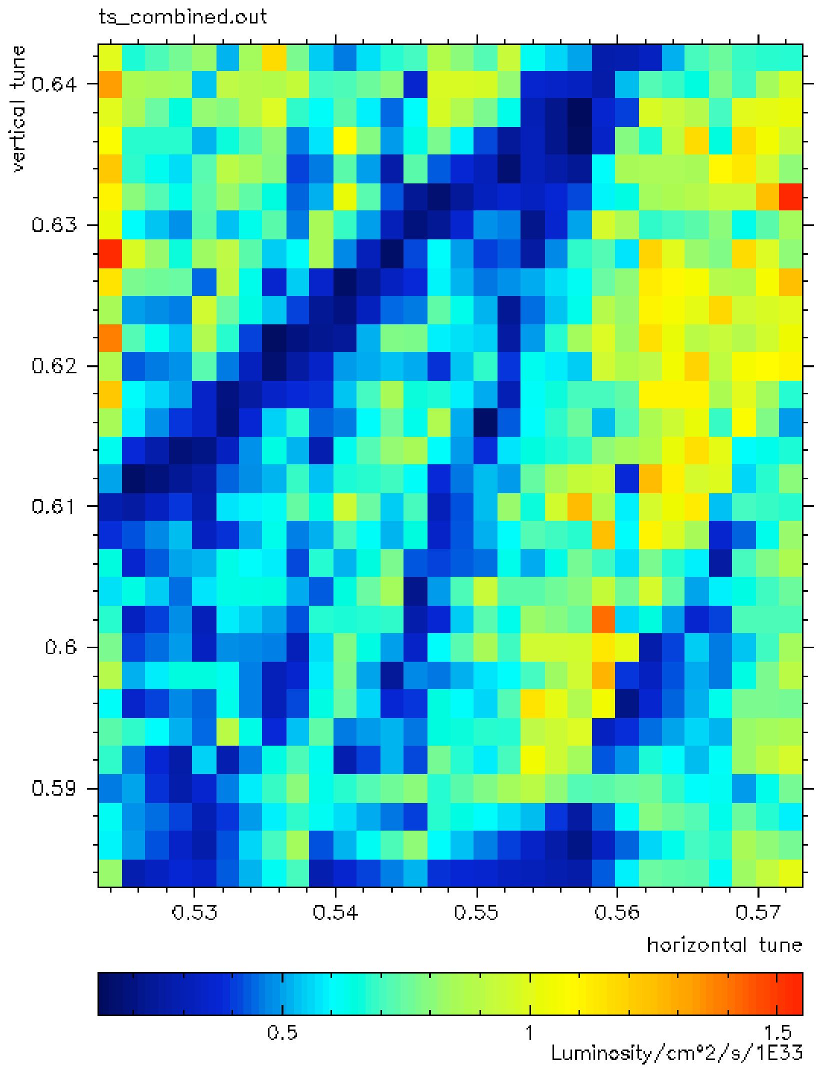
Simulation

-Machine model includes:

- -Wiggler nonlinearities
- -Beam beam interactions (parasitic and at IP)
- -Synchrotron motion
- -Radiation excitation and damping

-Weak beam

- -200 particles
- - initial distribution is gaussian in x,y,z
- - track ~ 10000 turns



Wiggler Status

-Single wiggler installed October 2002 and tested
    October - December 2002
- Five additional wigglers installed Spring 03
    Machine studies with 6 wigglers August 2003

-Remaining 6 wigglers to be installed early 04

CESR-c design parameters

Beam Energy [GeV]	1.55	1.88	2.5	5.3
Luminosity [÷10^{30}]	150	300	500	1250
i_b [mA/bunch]	2.8	4.0	5.1	8.0
I_{beam} [mA/beam]	130	180	230	370
ξ_y	0.035	0.04	0.04	0.06
ξ_x	0.028	0.036	0.034	0.03
σ_E/E_0 [x10^3]	0.75	0.81	0.79	0.64
$\tau_{x,y}$ [msec]	69	55	52	22
B_W [Tesla]	2.1	2.1	1.75	1.2
β_y^* [cm]	1.0	1.0	1.0	1.8
ε_x [nm-rad]	230	220	215	220

Energy Calibration

Collide I_T~ 12 mA and scan

Identification of ψ(2S) yields
calibration of beam energy