CORNELL UNIVERSITY LEPP
LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS

CESR-c

D.Rubin for the CESR-c working group

S.Belomestnykh,K.Berkelman,M.Billing,G.Codner, J.Crittenden,A.Devred,
G.Dugan,R.Ehrlich, M.Forster, Z.Greenwald,D.Hartill, Y.He, R.Helms,
G.Hoeffstetter,J.Hylas, Y.Li,V.Medjidzade, R.Meller, A.Mikhailichenko,
N.Mistry,T.Moore,E.Nordberg,M.Palmer, S.Peck, D.Rice, J.Rogers, D.Sagan,
J.Sikora,E.Smith,J.Smith,A.Temnykh,M.Tigner

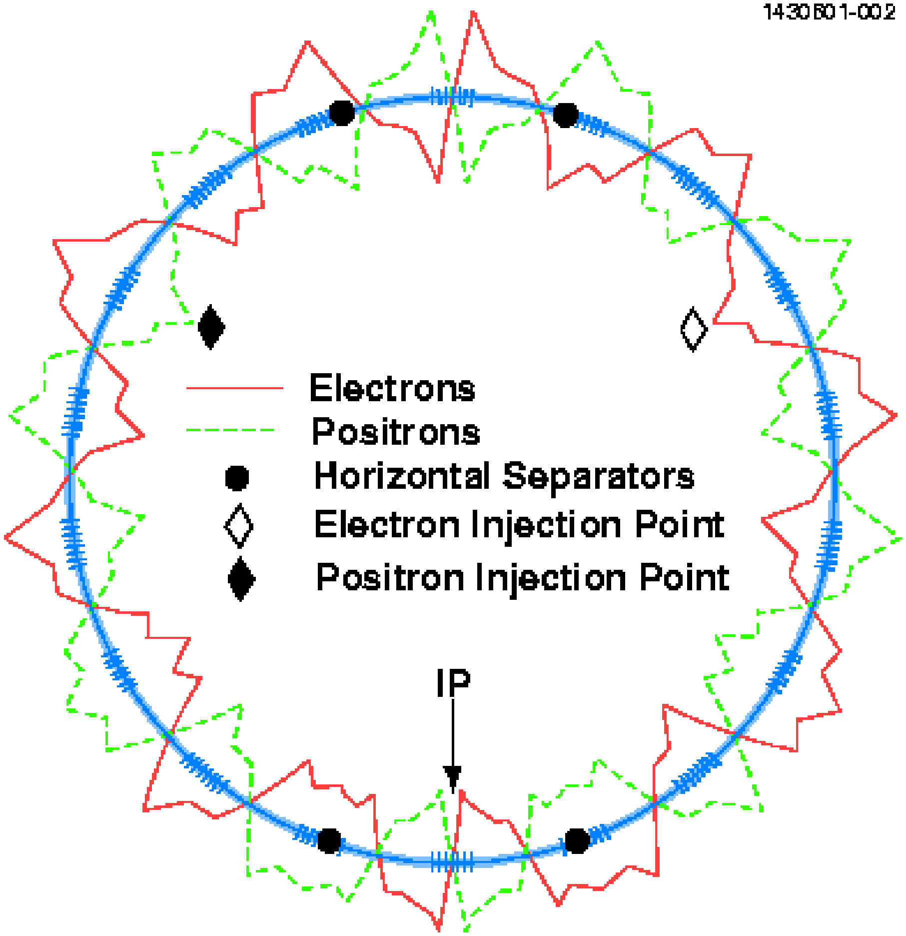
CESR-c

Energy reach 1.5-6GeV/beam

Electrostatically separated electron-positron orbits accomodate counterrotating trains

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

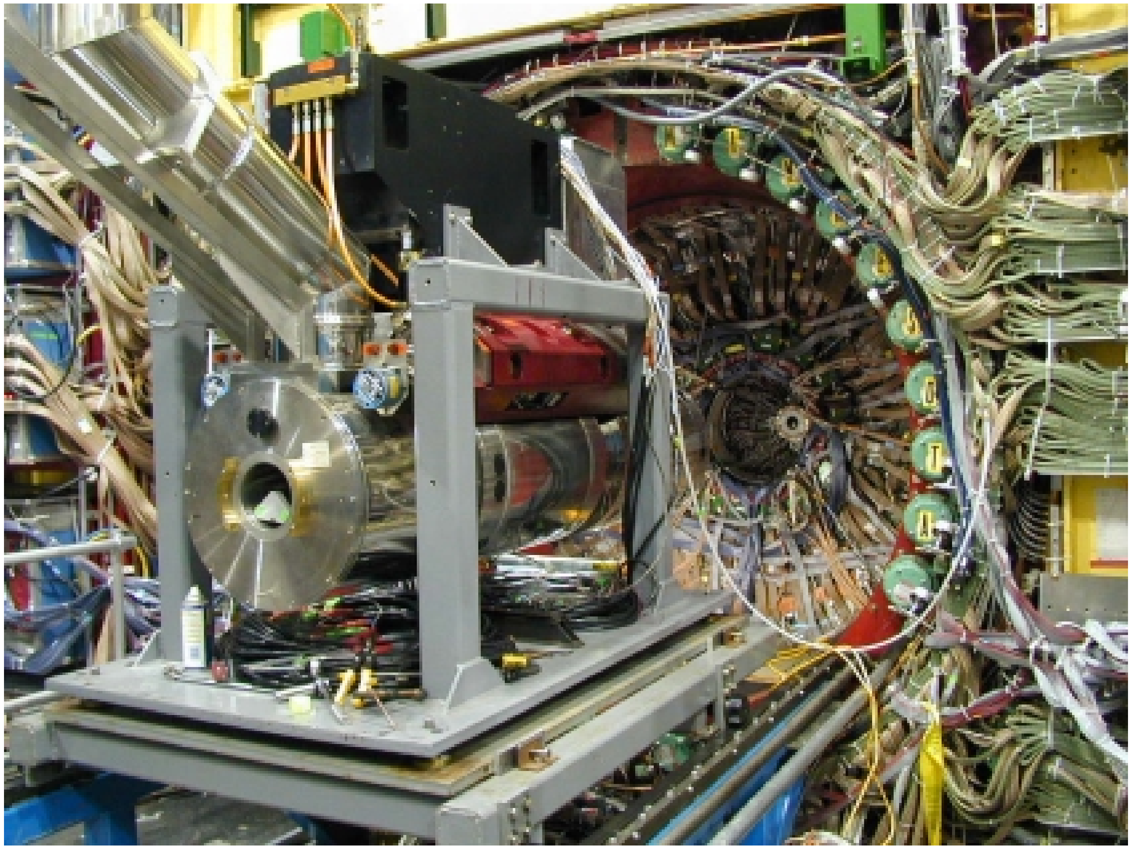
9 5-bunch trains in each beam (768m circumference)



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

β* ~ 10mm

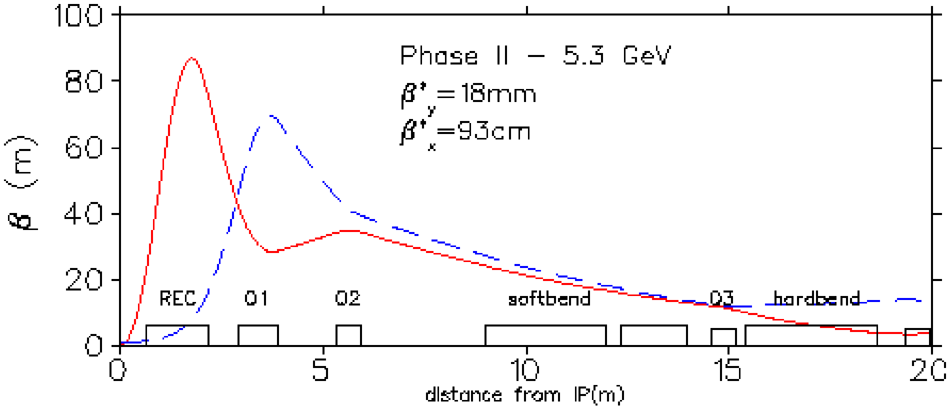
H and V superconducting quads share same cryostat

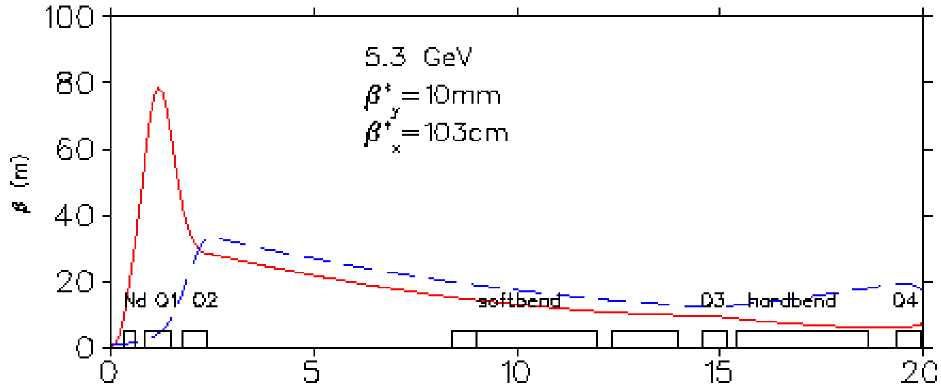
20cm pm vertically focusing nose piece

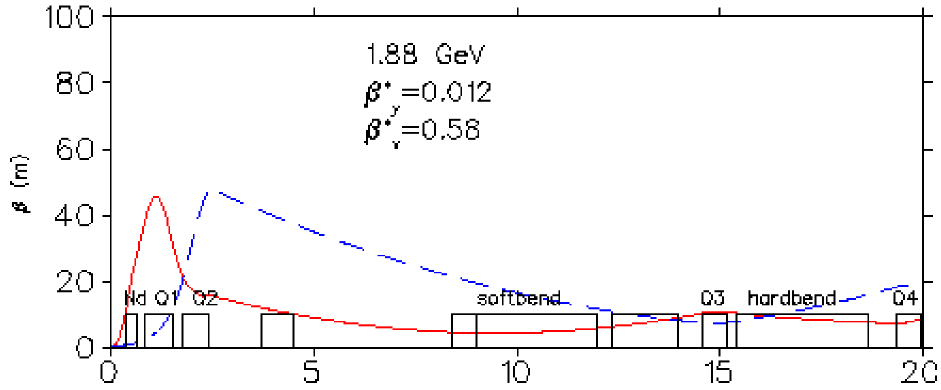
Quads are rotated 4.5^0 inside cryostat to compensate effect of CLEO solenoid

Superimposed skew quads permit fine tuning of compensation

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



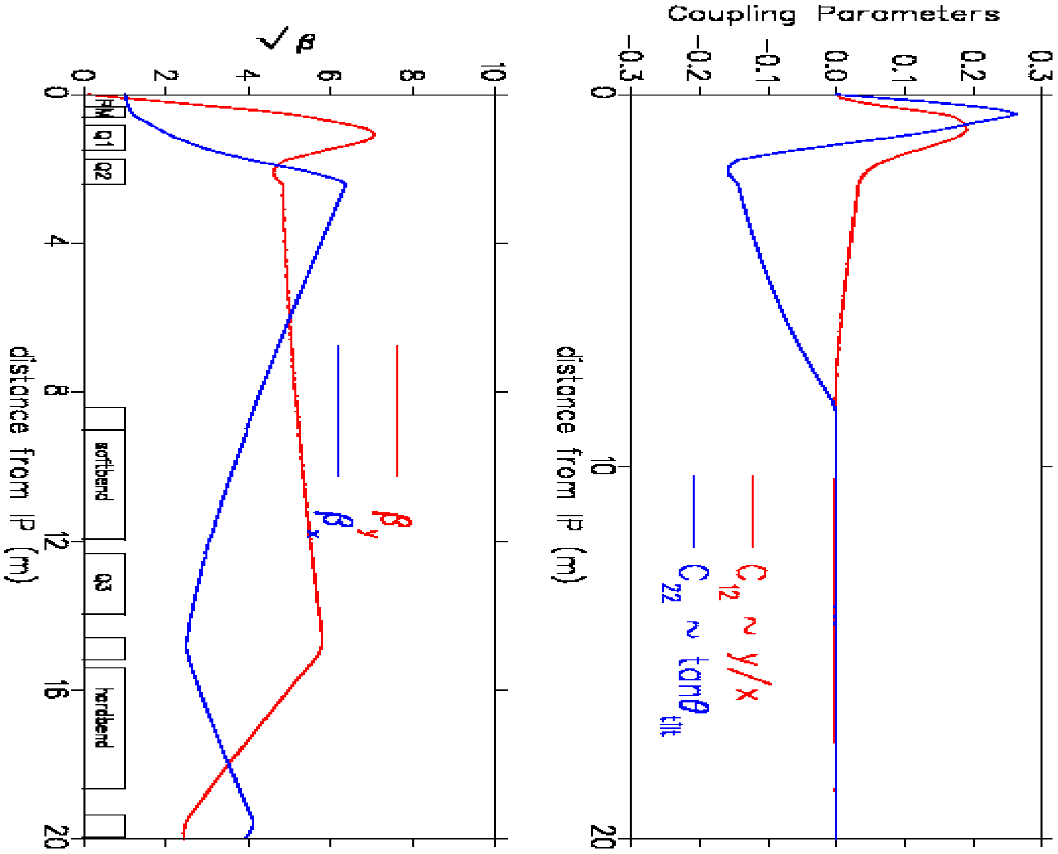




CLEO solenoid
1T(ψ)-1.5T(ϒ)

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

Solenoid readily compensated even at lowest energy



$\beta^*(V)=10mm$ E=1.89GeV
$\beta^*(H)=1m$ 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 $\Delta P_t/P_t = \Delta P/P$
- RF accelerating cavities restore energy only along design orbit, $P \to P + \Delta P$ so that transverse momentum is radiated away and motion is damped
- Damping time $\tau \sim$ 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

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

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 $x(s) = \eta(s)\delta$
- Energy changes abruptly with radiation of synchrotron photon
- Electron begins to oscillate about closed orbit generating emittance, $\sigma = (\epsilon\beta)^{1/2}$
- Lower energy -> fewer radiated photons and lower photon energy

- Emittance $\epsilon \sim E^2$

CESR-c Energy dependence

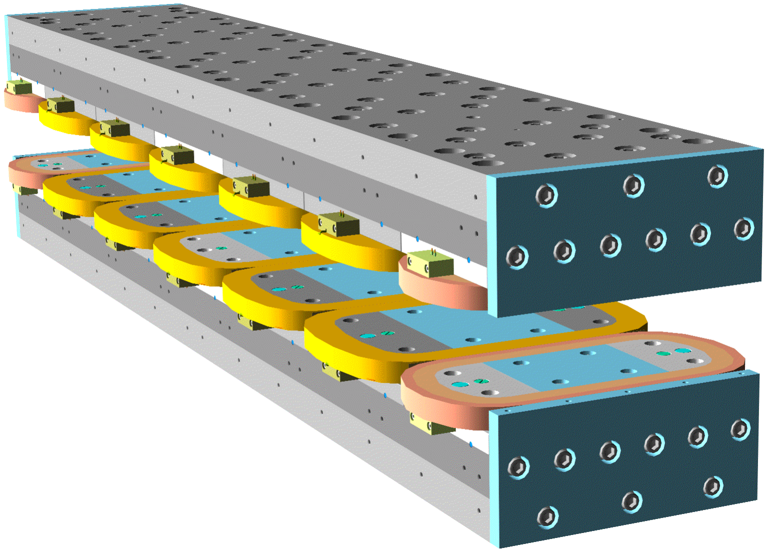
Emittance

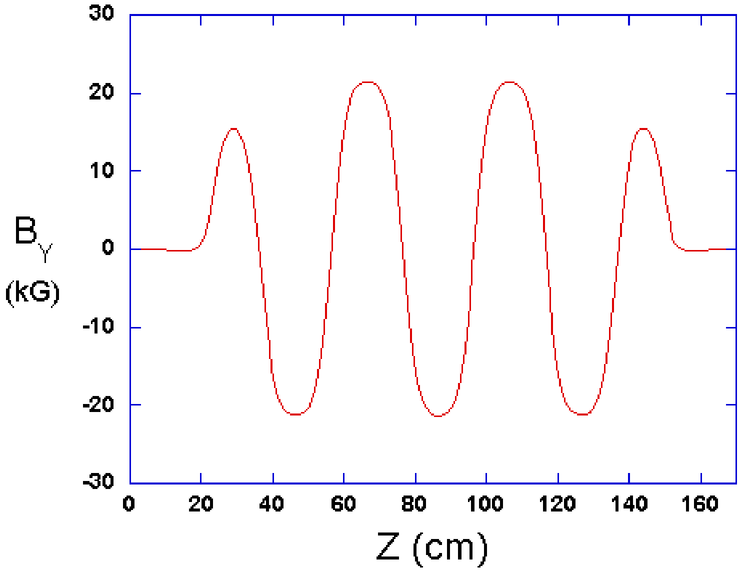
- $L \sim I_B^2 / \sigma_x \sigma_y = I_B^2 / (\varepsilon_x \varepsilon_y \beta_x \beta_y)^{1/2}$
- $\varepsilon_x \sim \varepsilon_y$ (coupling)
- I_B / ε_x limiting charge density
- Then I_B and therefore $L \sim \varepsilon_x$

CESR (5.3GeV), $\varepsilon_x = 200$ nm-rad
CESR (1.9GeV), $\varepsilon_x = 30$ nm-rad

CESR-c Energy dependence

Damping and emittance control with wigglers





CESR-c Energy dependence

In a wiggler dominated ring

- $1/\tau \sim B_w^2 L_w$
- $\epsilon \sim B_w L_w$
- $\sigma_E/E \sim (B_w)^{1/2}$ nearly independent of length
  (B$_w$ limited by tolerable energy spread)

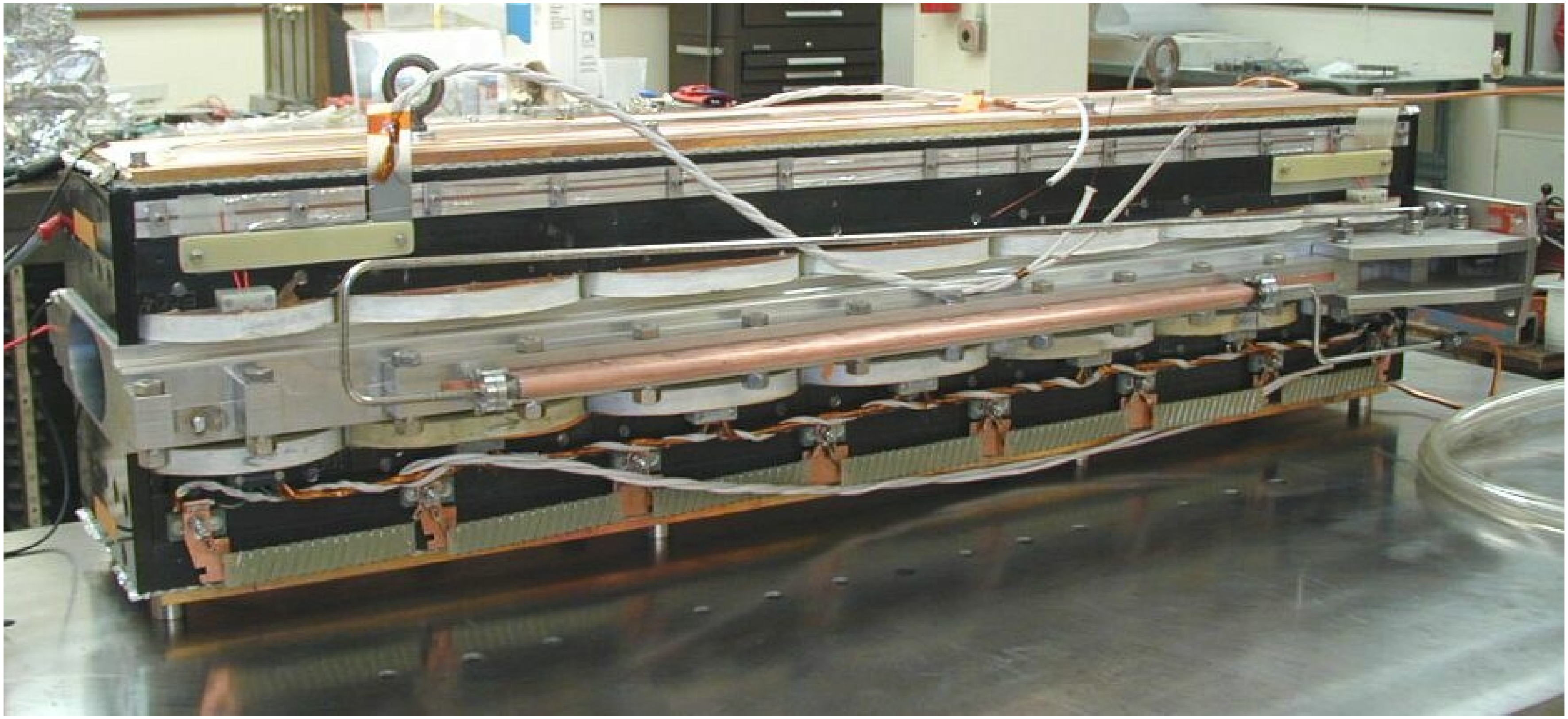
Then 18m of 2.1T wiggler

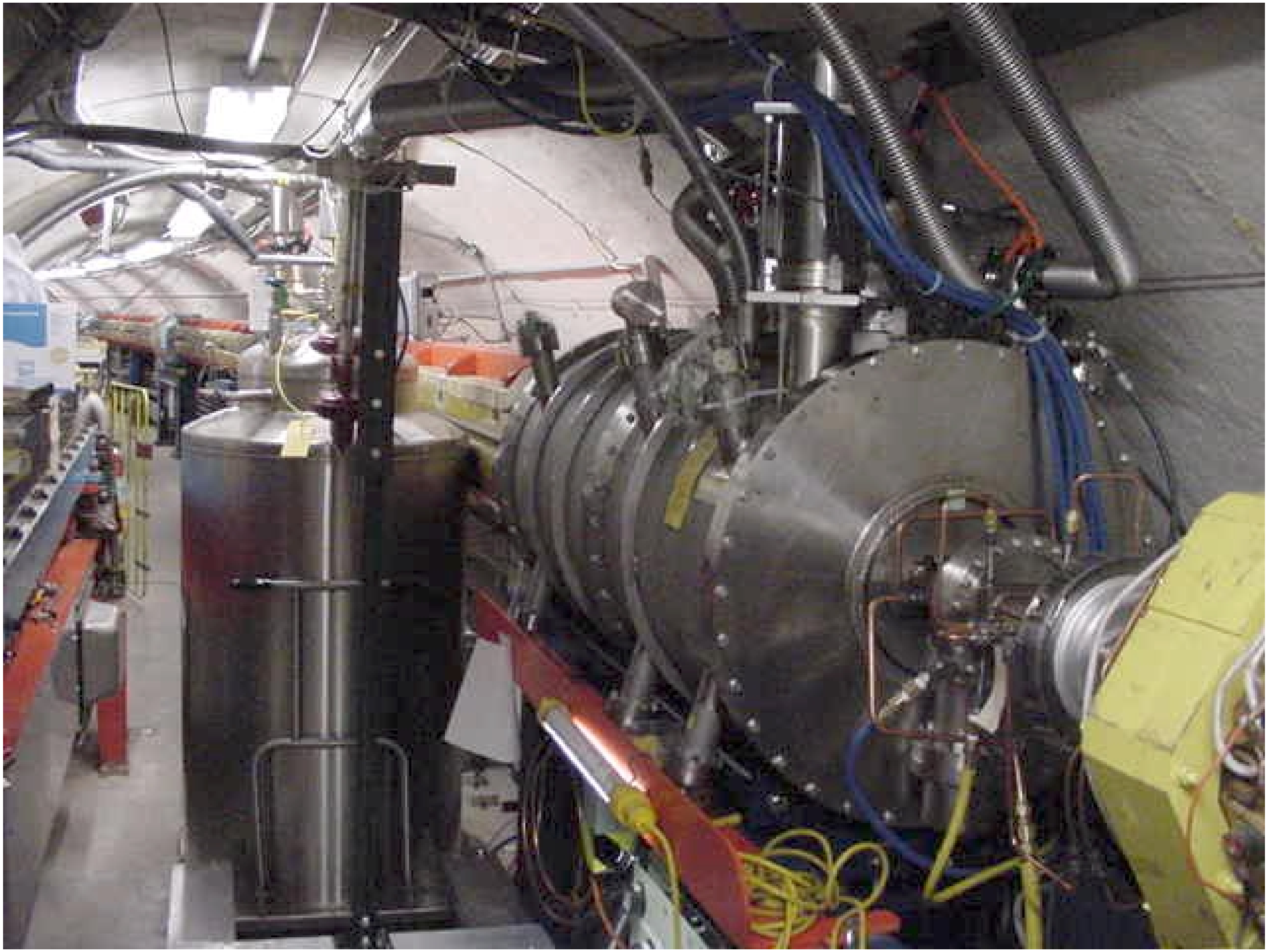
-> $\tau \sim 50$ms

-> 100nm-rad $< \epsilon <$300nm-rad

Superconducting wiggler

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



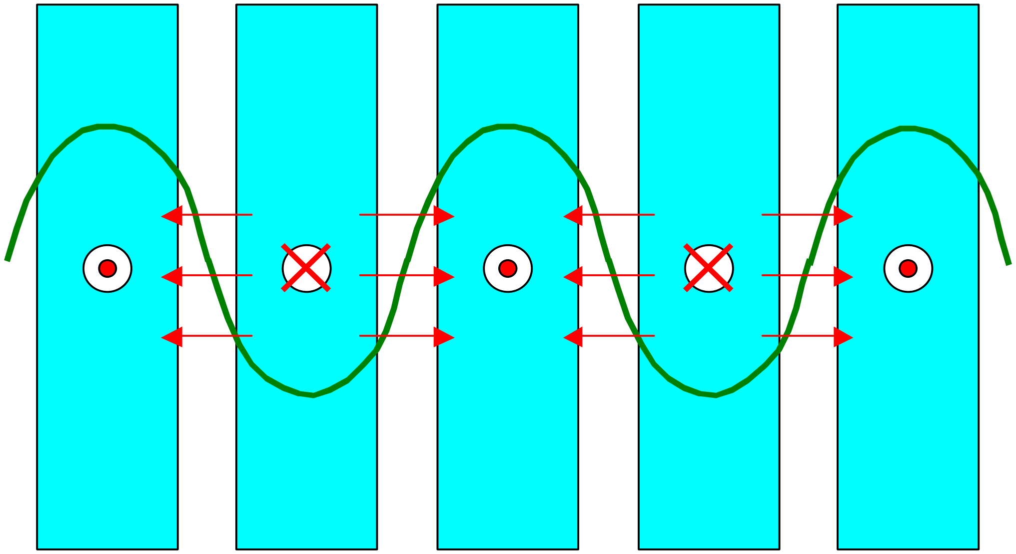


Optics effects - Ideal Wiggler

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

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

Vertical kick ~ θB_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, $\Delta Q \sim 0.1$/wiggler

But is readily compensated by adjustment of nearby quadrupoles

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

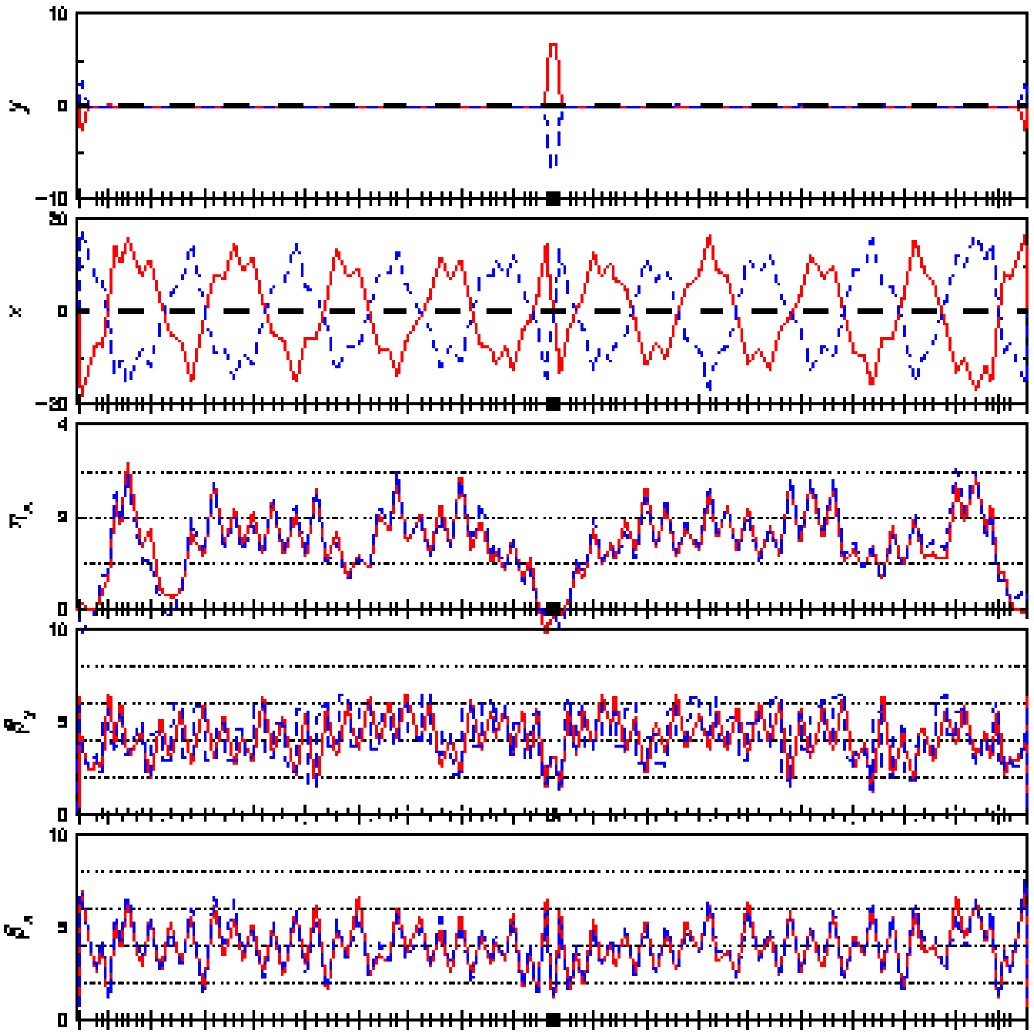
We choose the relatively long period -> $\lambda = 40$cm

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

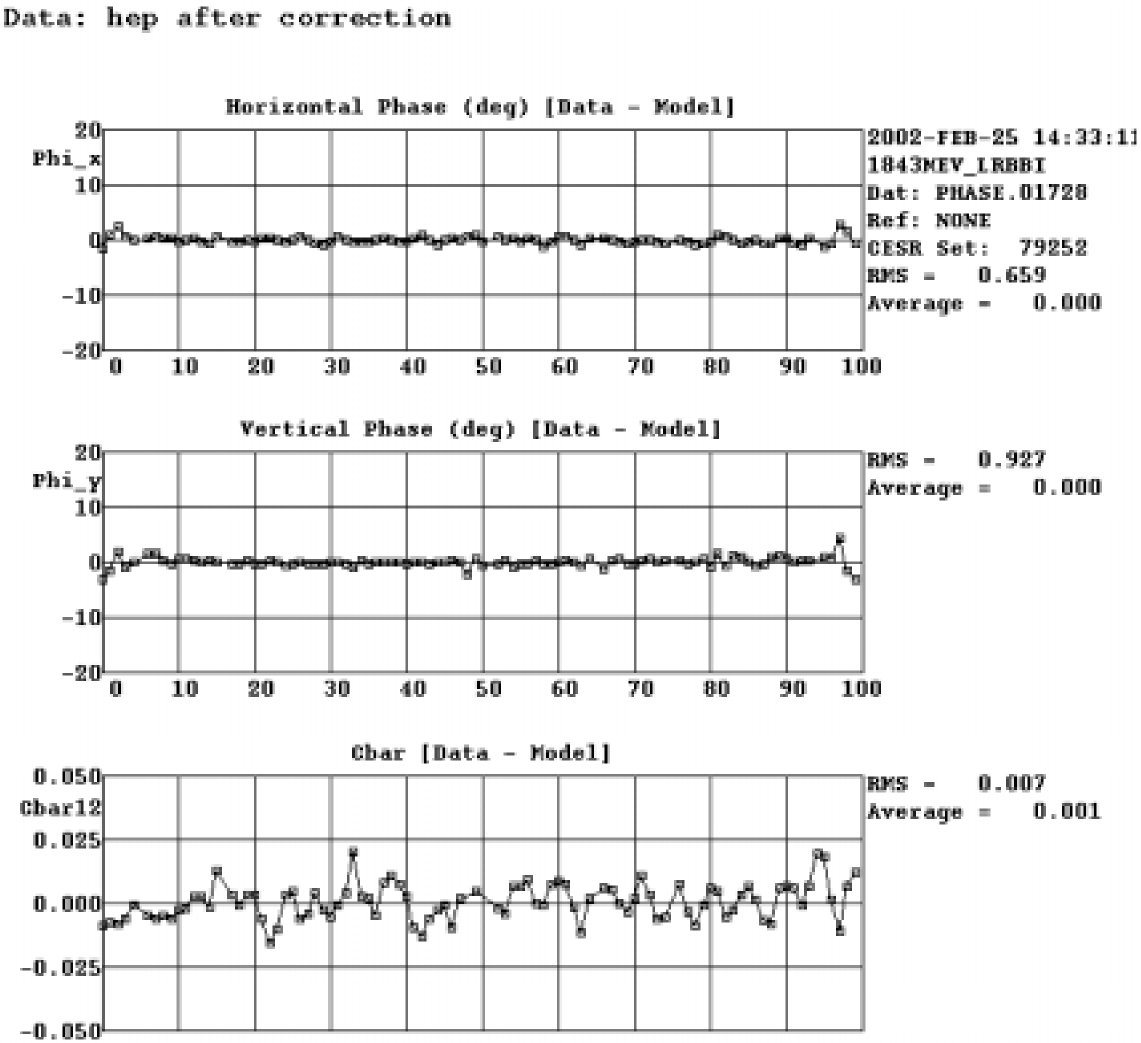


Wiggler Beam Measurements

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



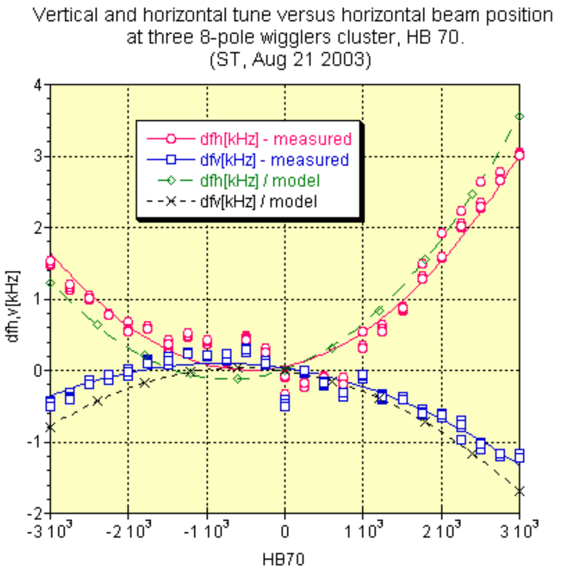
```
2002-FEB-25 14:33:1
1843MEV_LRBBI
Dat: PHASE.01728
Ref: NONE
CESR Set:  79252
RMS =     0.659
Average =    0.000
```

```
RMS =     0.927
Average =    0.000
```

```
RMS =     0.007
Average =    0.001
```

Wiggler Beam Measurements

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

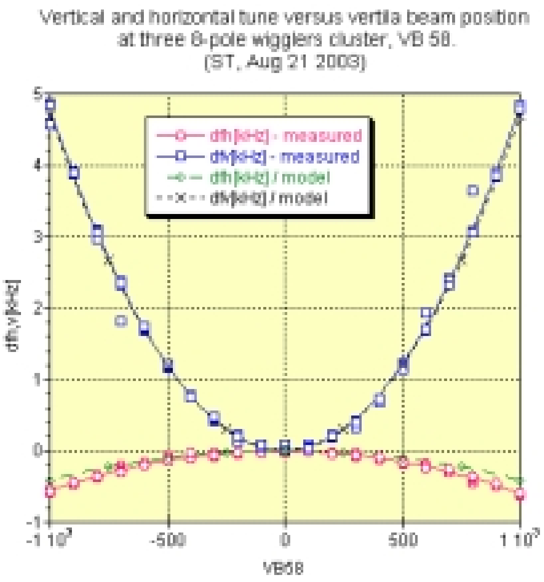

Vertical and horizontal tune versus horizontal beam position
at three 8-pole wigglers cluster, HB 70.
(ST, Aug 21 2003)

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

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

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

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


Vertical and horizontal tune versus vertila beam position
at three 8-pole wigglers cluster, VB 58.
(ST, Aug 21 2003)

$Y = M0 + M1^*x + \ldots M8^*x^8 + M9^*x^9$	
M0	-0.0022589
M1	-1.9531e-05
M2	-5.7511e-07
R	0.99344

$Y = M0 + M1^*x + \ldots M8^*x^8 + M9^*x^9$	
M0	0.00051816
M1	1.983e-05
M2	4.8043e-06
R	0.99829

$Y = M0 + M1^*x + \ldots M8^*x^8 + M9^*x^9$	
M0	0.0035498
M1	0
M2	-4.1365e-07
R	0.99994

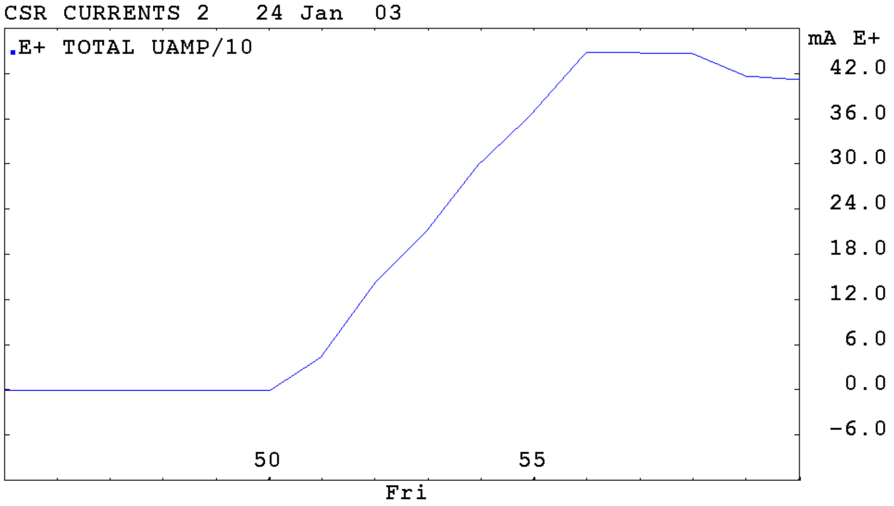
$Y = M0 + M1^*x + \ldots M8^*x^8 + M9^*x^9$	
M0	0.015455
M1	-2.5555e-08
M2	4.5909e-06
R	0.99997

Wiggler Beam Measurements

-Injection

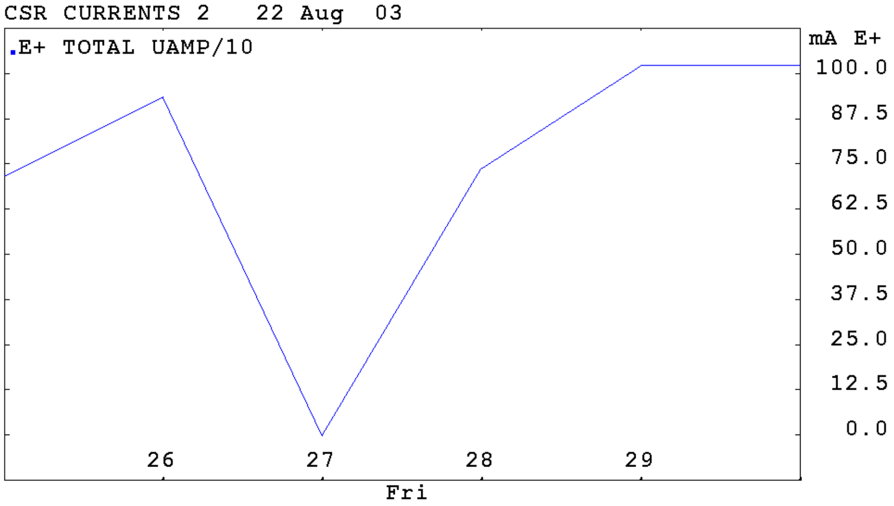
1 sc wiggler -> 8mA/min

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



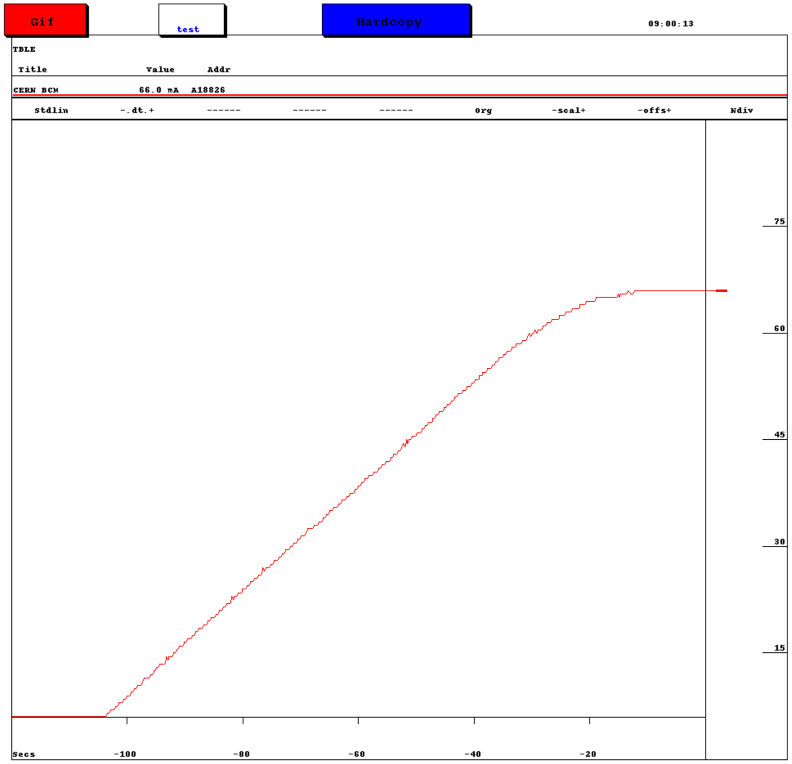
6 sc wiggler -> 50mA/min

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



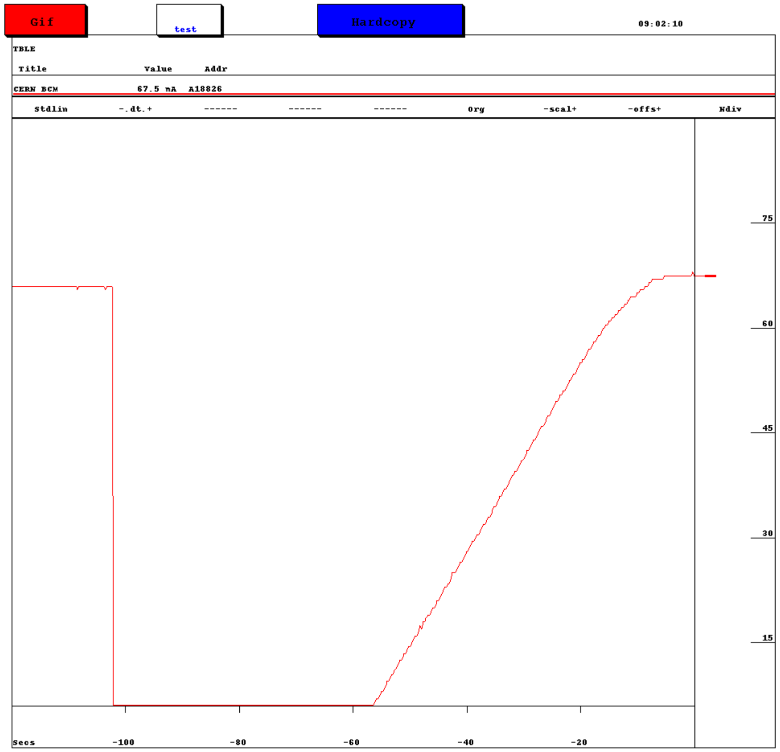
Wiggler Beam Measurements

-Injection



Title	Value	Addr
CERN BCM	66.0 mA	A18826

30 Hz 68mA/80sec



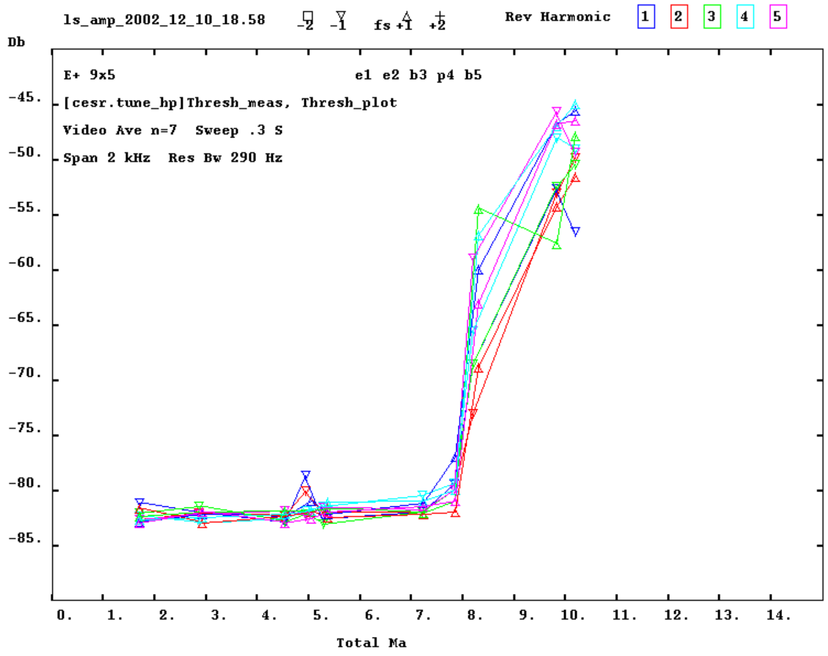
Title	Value	Addr
CERN BCM	67.5 mA	A18826

60 Hz 67ma/50sec

Wiggler Beam Measurements

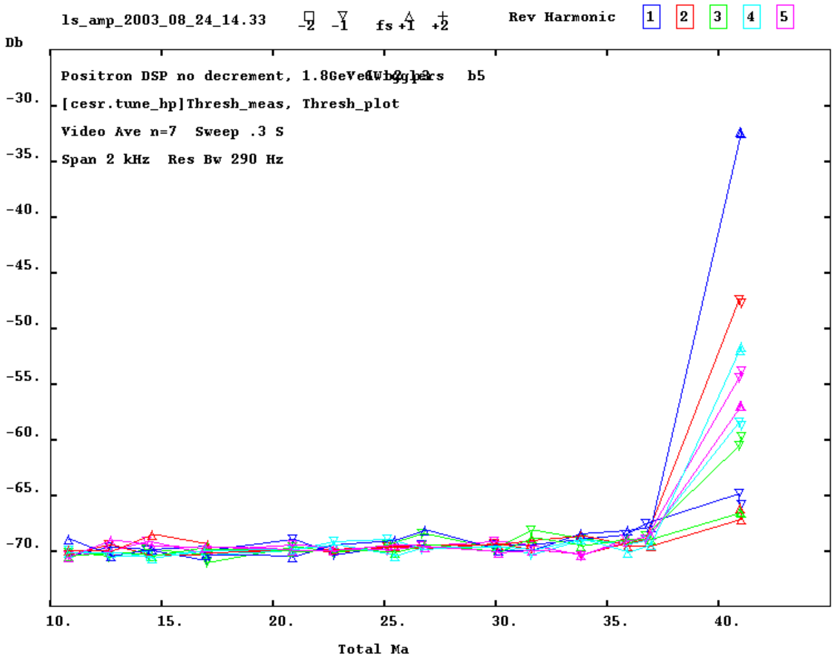
-Single beam stability

2pm + 1 sc wigglers



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

6 sc wigglers



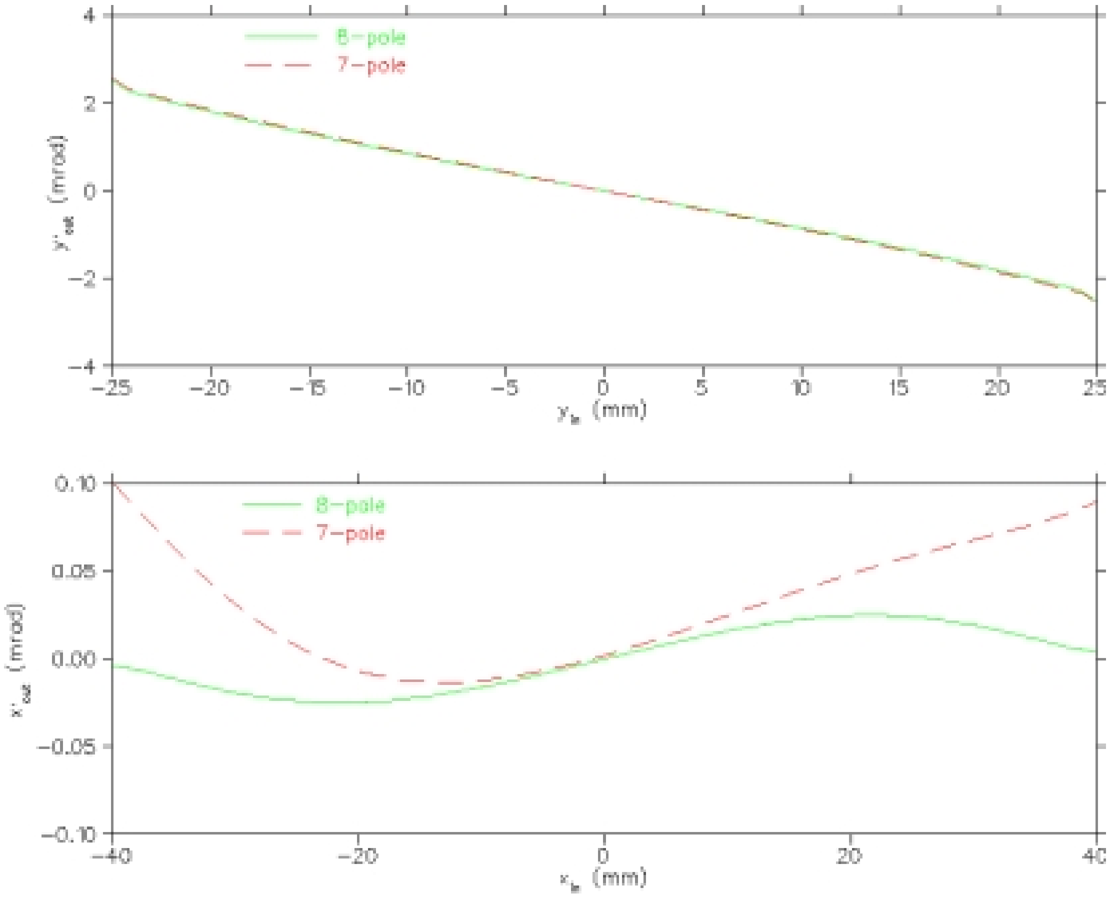
$1/\tau = 10.9s^{-1}$

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

$$B_{fit} = \Sigma_{n=1}^{N} B_n(x, y, s; C_n, k_{xn}, k_{yn}, k_{sn}, \phi_n)$$

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

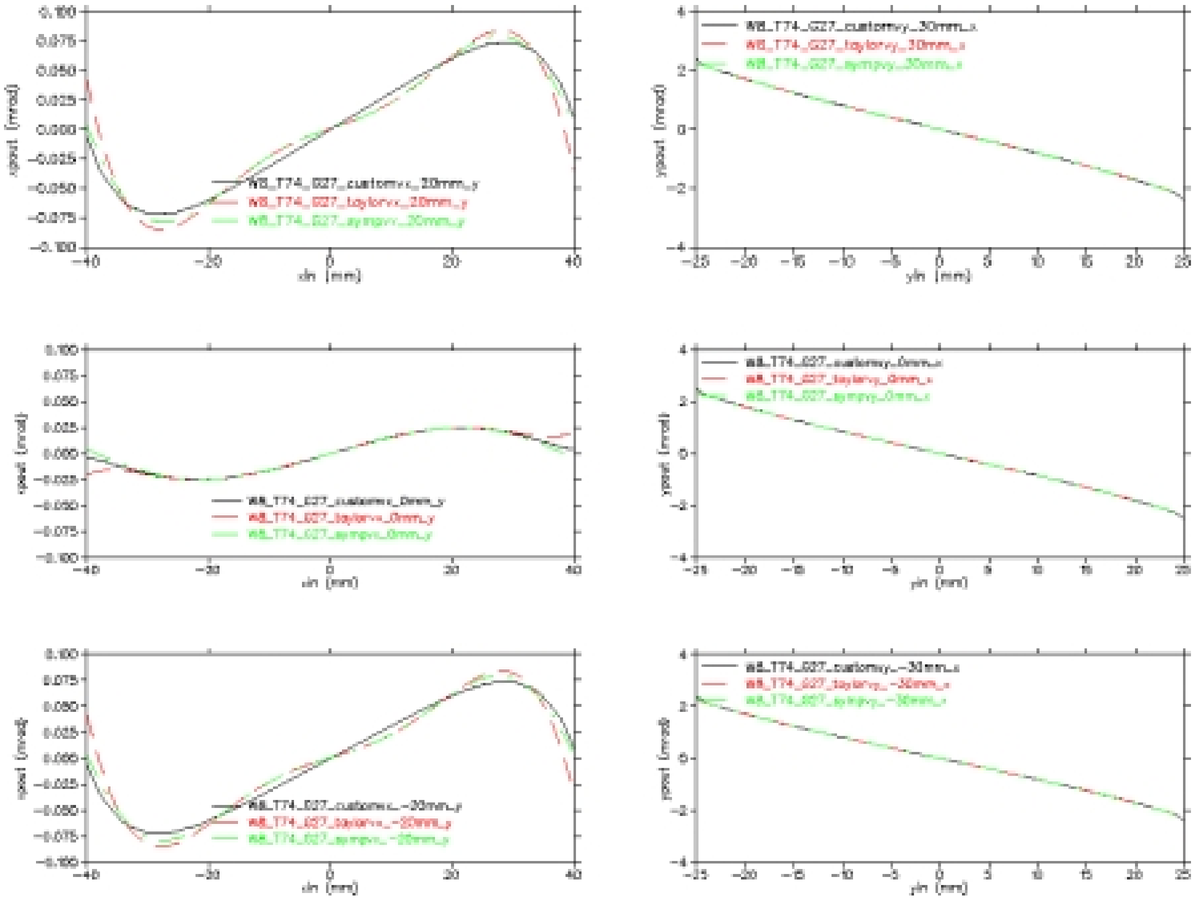
with $k_y^2 = k_x^2 + k_s^2$

Machine modeling

-Wiggler map

Fit parameters of
 series to field table

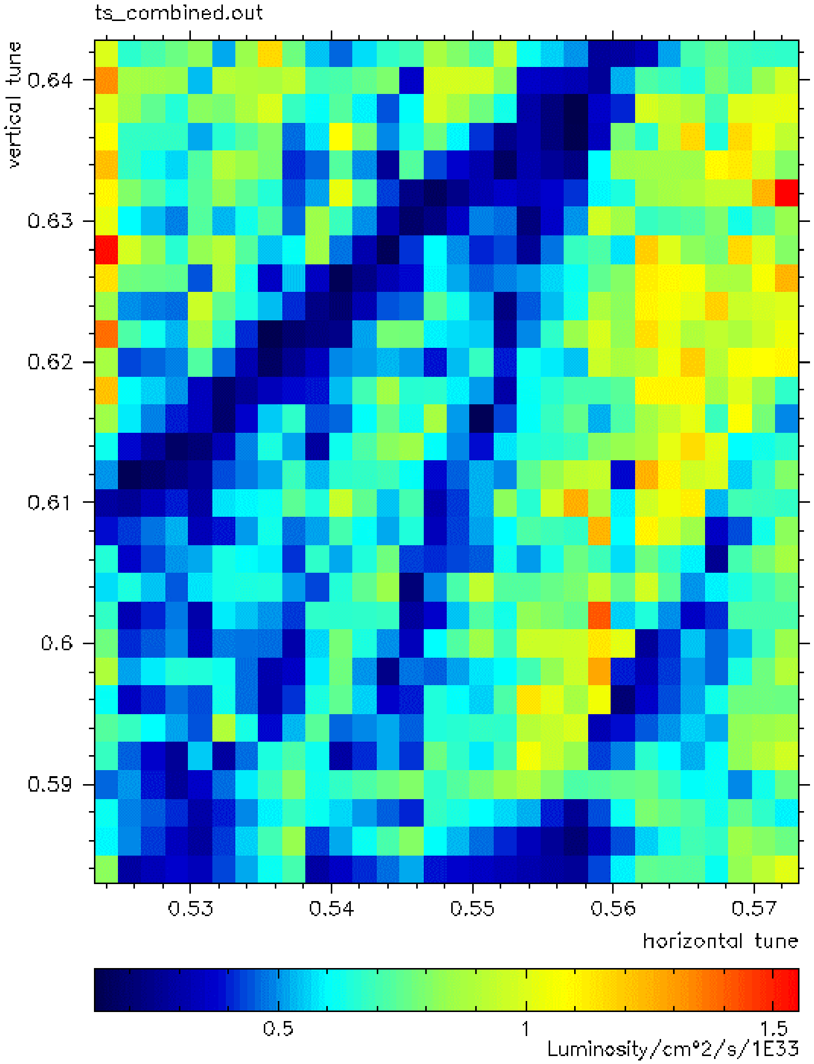
Analytic form of
Hamiltonian
   -> symplectic integration
   -> taylor map



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

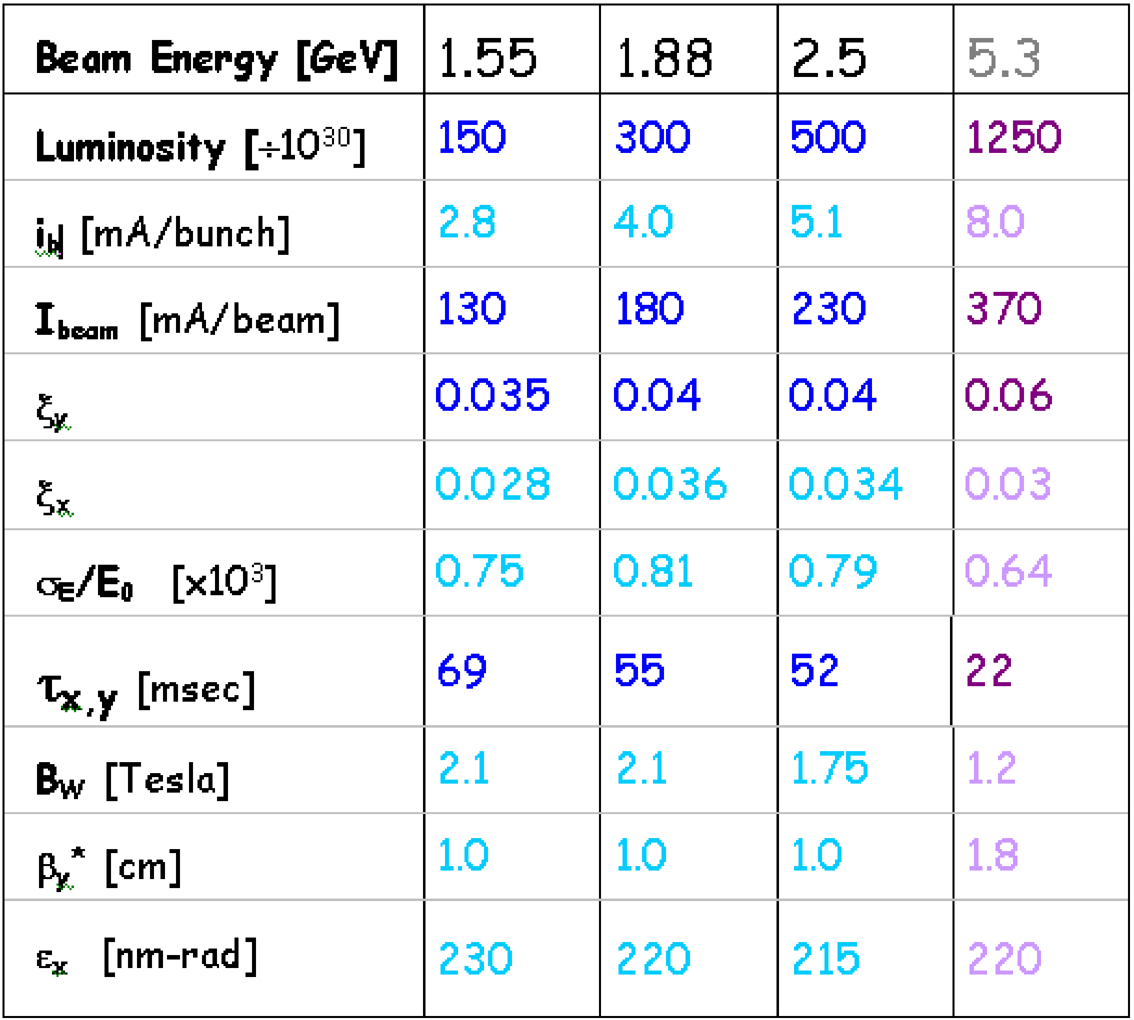
-Single wiggler installed October 2002 and tested October - December 2002

- 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

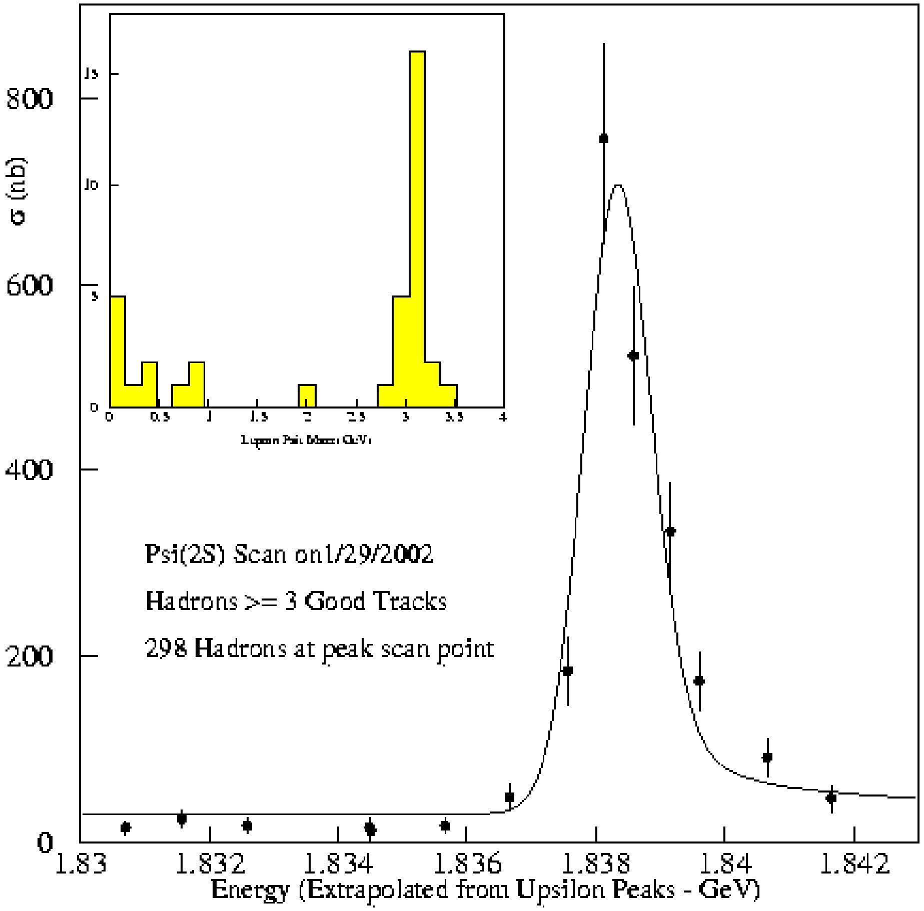


Beam Energy [GeV]	1.55	1.88	2.5	5.3
Luminosity [$\div 10^{30}$]	150	300	500	1250
i_b [mA/bunch]	2.8	4.0	5.1	8.0
I_{beam} [mA/beam]	130	180	230	370
ξ_y	0.035	0.04	0.04	0.06
ξ_x	0.028	0.036	0.034	0.03
σ_E/E_0 [$x10^3$]	0.75	0.81	0.79	0.64
$\tau_{x,y}$ [msec]	69	55	52	22
B_W [Tesla]	2.1	2.1	1.75	1.2
β_y^*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



Psi(2S) Scan on1/29/2002

Hadrons >= 3 Good Tracks

298 Hadrons at peak scan point