Lattice design for Compton ring

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Preliminary Work

- We have calculated a lattice to start to perform beam dynamics calculations
- Compton Interaction (CI) has a pulsed time structuretherefore we need to evaluate beam dynamics with and witout Compton interaction
- Moreover the transition phase when CI is turned on and off has to be studied

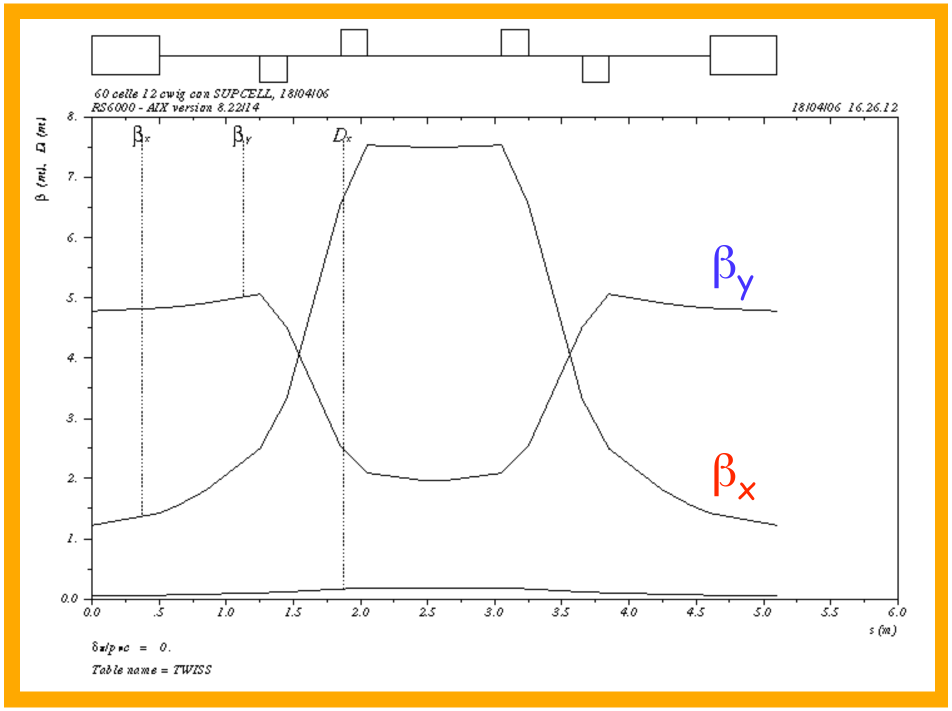
Compton Ring Parameters for CO_2 Laser

Snowmass proposal

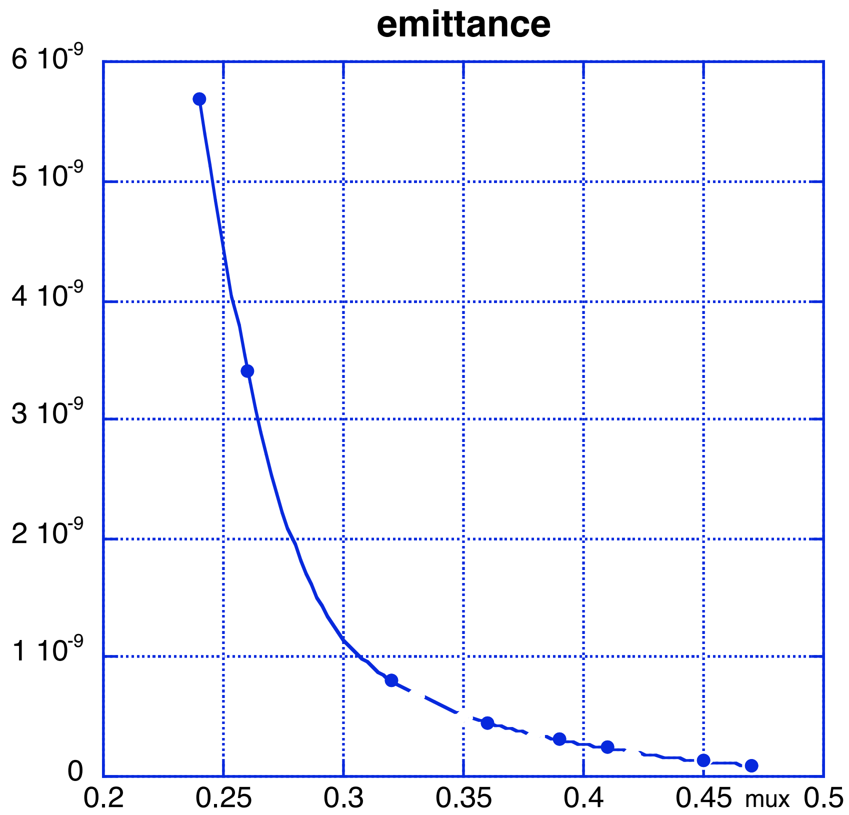
Energy (GeV)	1.3
Circumference (m)	277
Electrons/bunch	$6.2 \cdot 10^{10}$
N of bunches	280
σ_x at IP (μm)	25
σ_z at IP (μm)	5
σ_l at IP (mm)	5
ε_x (m rad)	$5 \cdot 10^{-10}$
κ	0.02
β_x (m)	1.25
β_y (m)	2.5
N of IPs	30

Lattice Design

- To achieve low emittance we adopt a TME lattice which allows the minimum emittance for a given energy and bending angle
- The value of momentum compaction required depends on the CI beam dynamics
- This lattice allows to change a_c easily by changing the phase advance/per cell

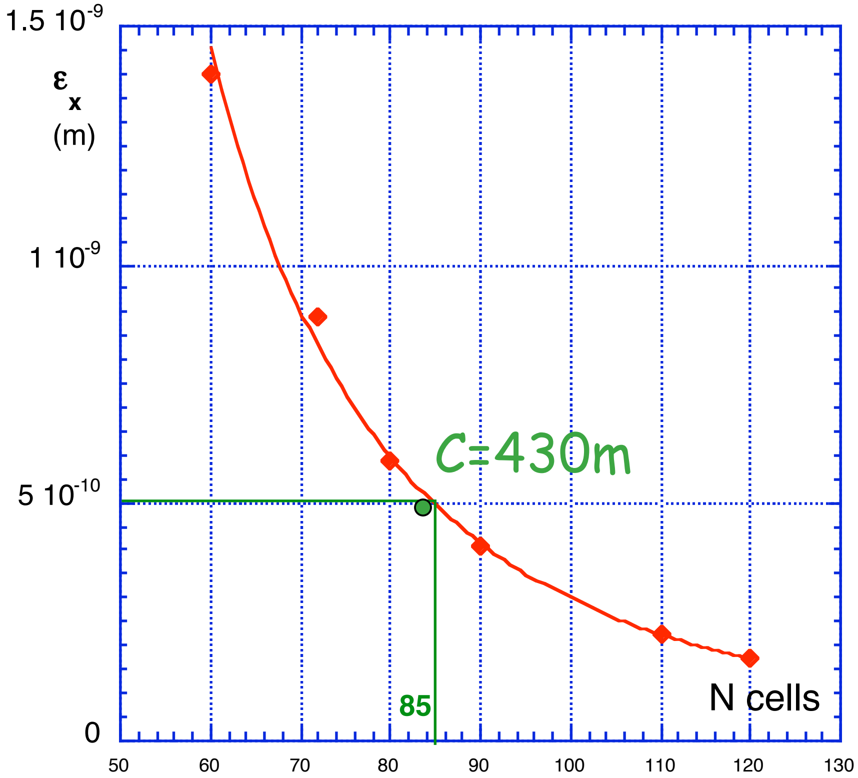


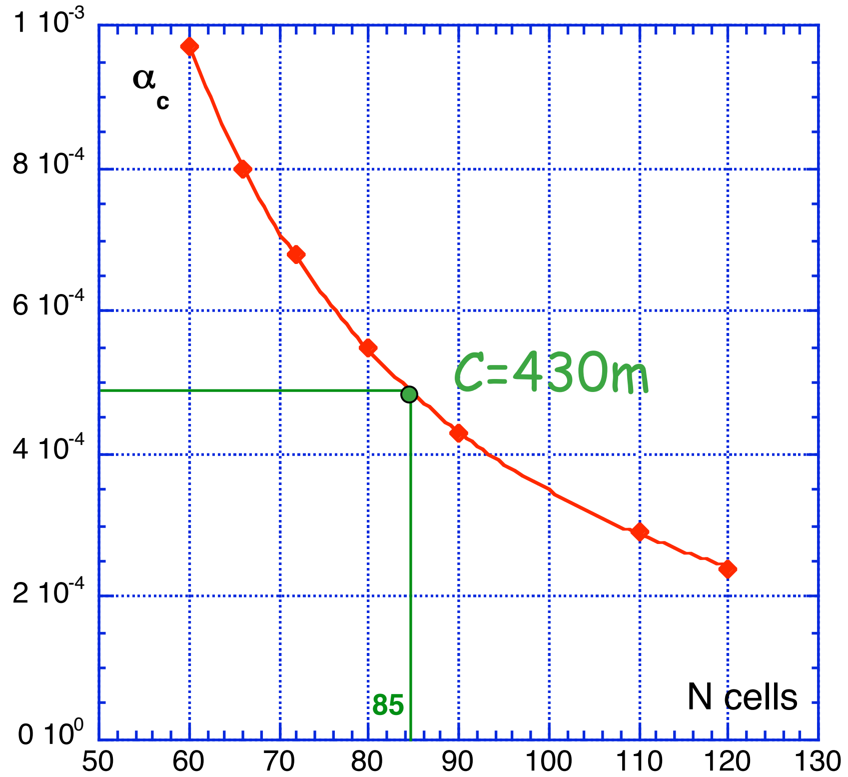
Emittance as a function of phase advance per cell



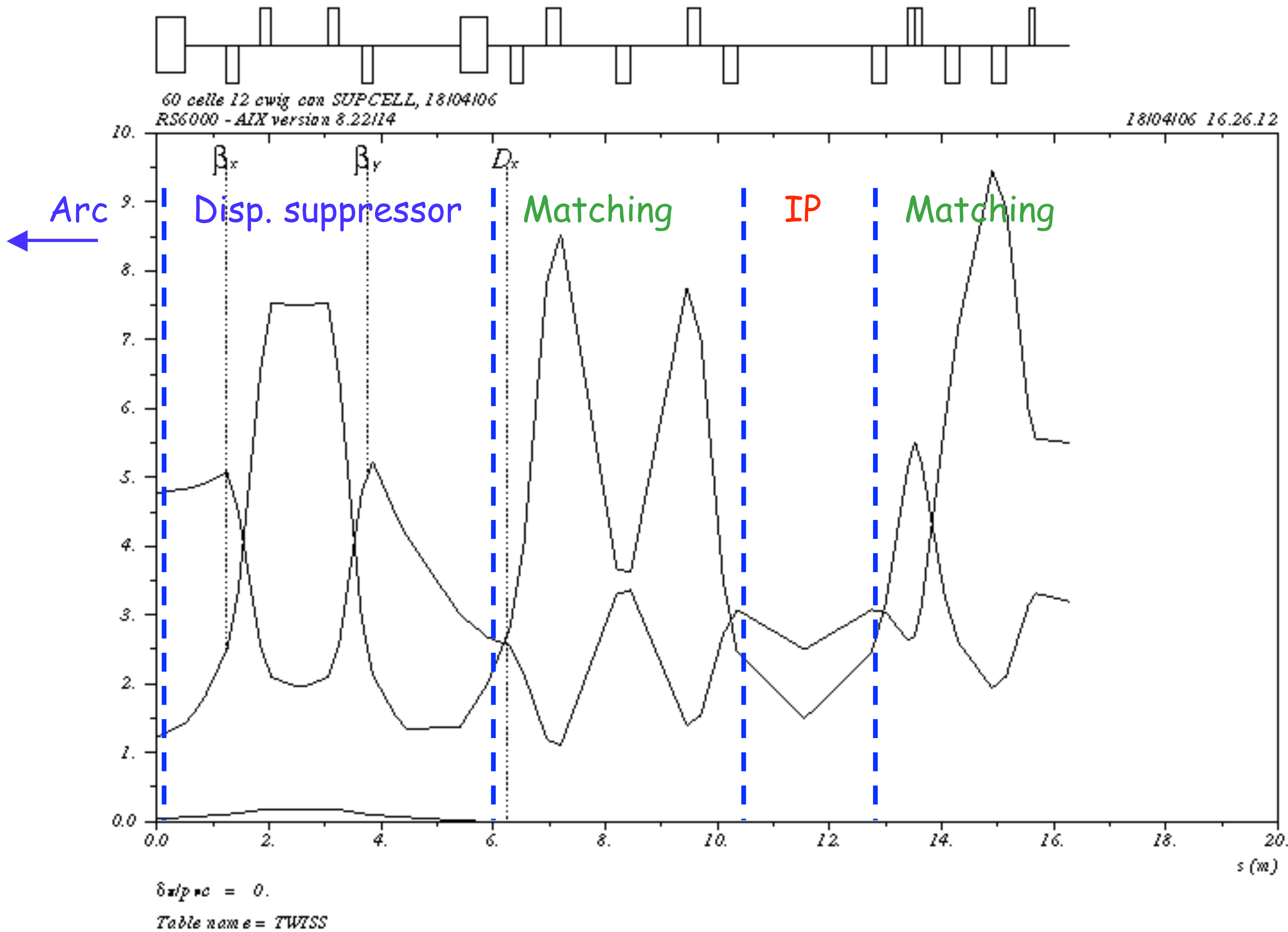
Emittance and a_c as a function of number of cells

Lcell = 5.1 m

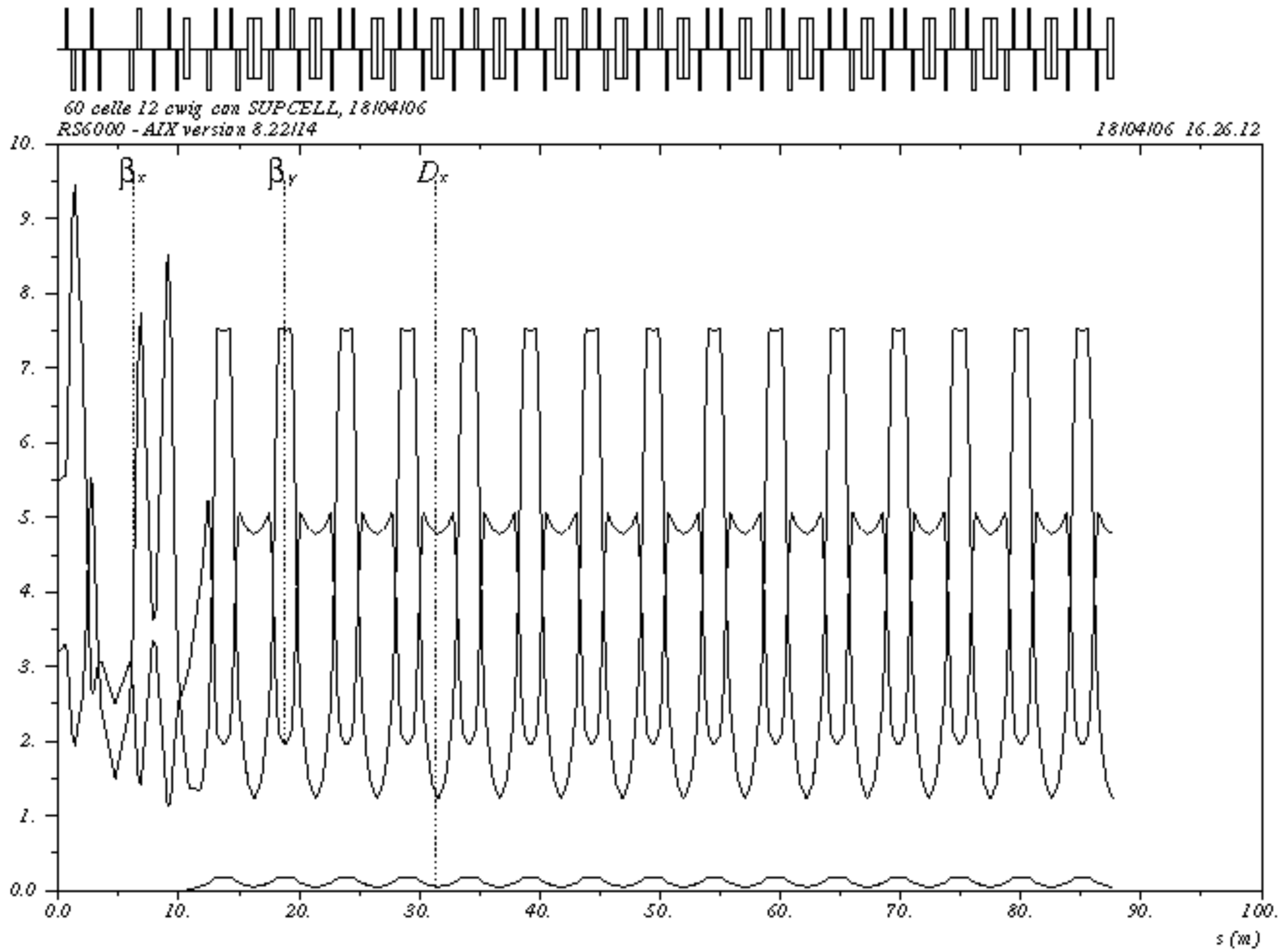




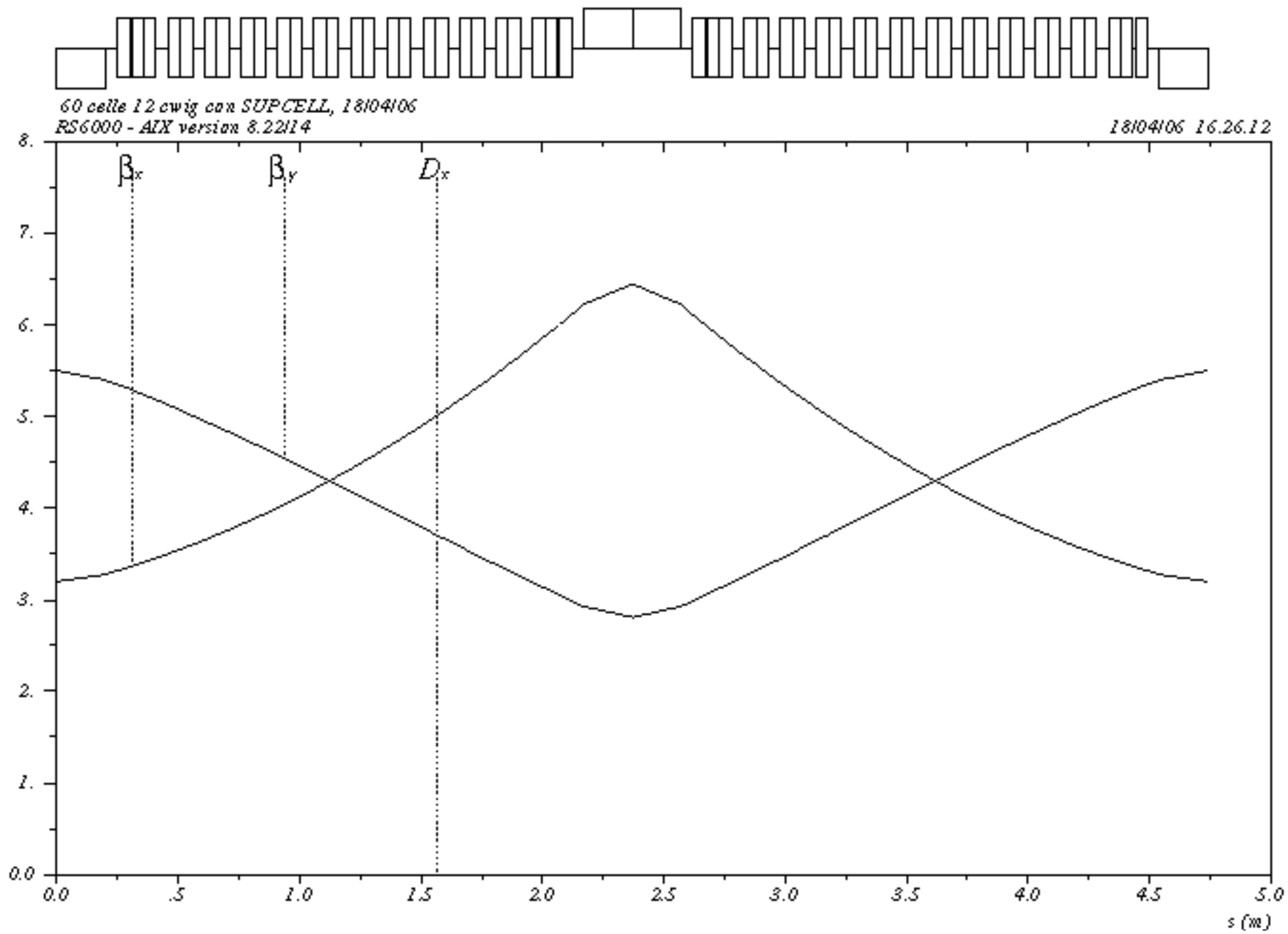
Dispersion suppressor and half straight section



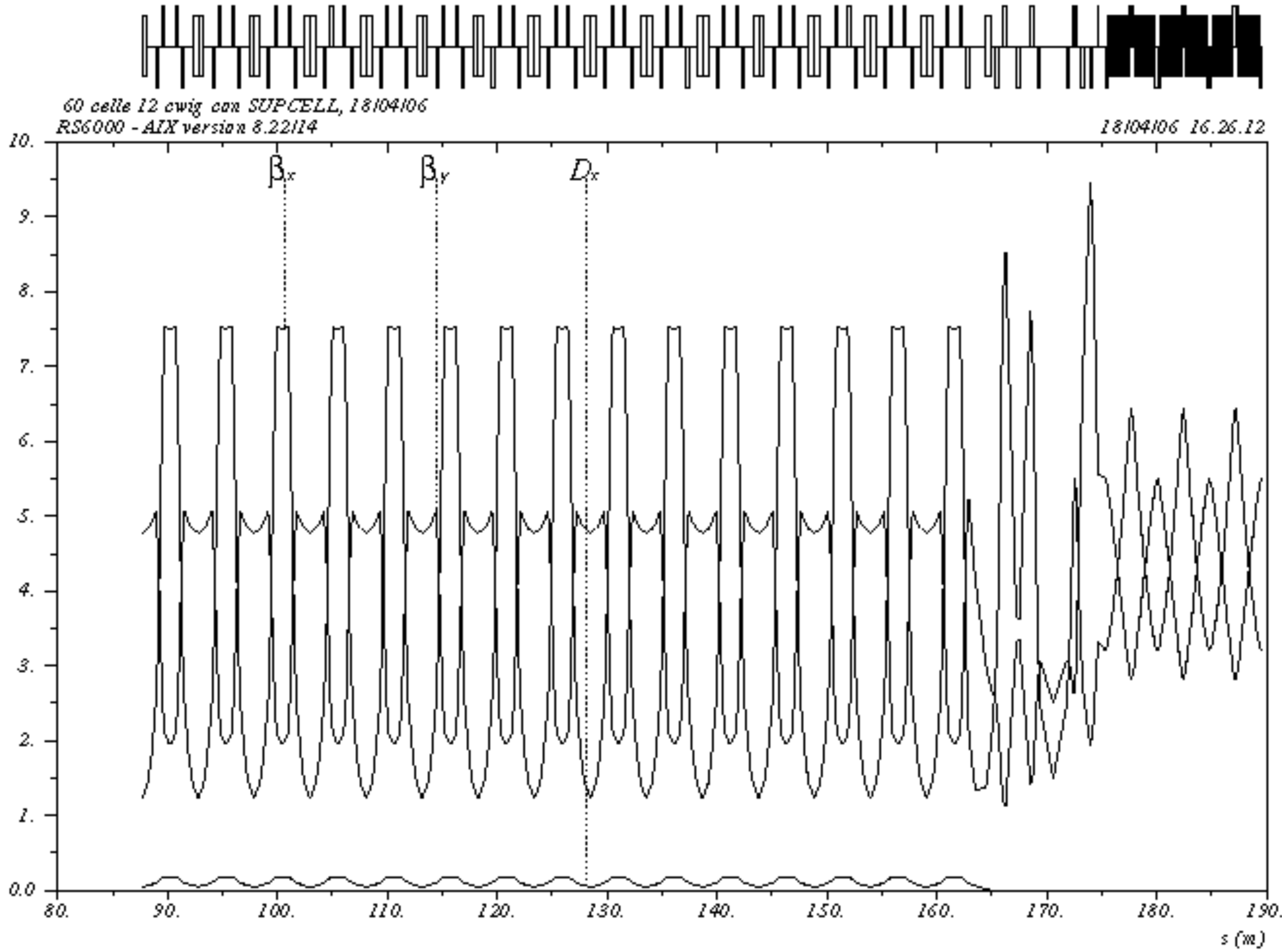
One quarter of ring - no wigglers



Wiggler cell



One quarter of ring - with wigglers



Ring Parameters

	A
K	0.008
sigma_x (μm)	44
sigma_y (μm)	5
$\sigma_x\sigma_y$ **(μm^2)**	220
alpha_c	8.07E-04
C (m)	345
V_RF (MV)	0.35
f_RF (MHz)	500
sigma_s (mm)	5.08
N part/bunch	6.20E+10
Touschek (min)	0.79
sigma_buck	1.7E-02
E_0 (GeV)	1.3
emittance (m)	1.3E-09
τ_ε **(ms)**	28.2
Wigglers	no

A - 60 cells

C = 345 m

$\varepsilon = 1.3 \cdot 10^{-9}$ m

σ_x > 25 mm - reduce β_x

Touschek lifetime is less than one minute

To increase Touschek lifetime we increase the vertical emittance

	A	B
K	0.008	0.237
sigma_x (μm)	44	40
sigma_y (μm)	5	25
$\sigma_x \sigma_y$ (μm^2)	220	1000
alpha_c	8.07E-04	8.07E-04
C (m)	345	345
V_RF (MV)	0.35	0.35
f_RF (MHz)	500	500
sigma_s (mm)	5.08	5.08
N part/bunch	6.20E+10	6.20E+10
Touschek (min)	0.79	3.7
sigma_buck	1.7E-02	1.7E-02
E_0 (GeV)	1.3	1.3
emittance (m)	1.3E-09	1.3E-09
τ_ε (ms)	28.2	28.2
Wigglers	no	no

B

σ_x= 40 μm

σ_y = 25 μm

τ_{Tou} = 3.7 min

By = 2.5 m, can be reduced

Insert wigglers to reduce horizontal emittance emittance

	A	B	C
K	0.008	0.237	0.980
sigma_x (μm)	44	40	19
sigma_y (μm)	5	**25**	25
$\sigma_x\sigma_y$ (μm^2)	220	1000	475
alpha_c	8.07E-04	8.07E-04	7.93E-04
C (m)	345	345	408
V_RF (MV)	0.35	0.35	0.7
f_RF (MHz)	500	500	500
sigma_s (mm)	5.08	5.08	4.97
N part/bunch	6.20E+10	6.20E+10	6.20E+10
Touschek (min)	0.79	3.7	4.6
sigma_buck	1.7E-02	1.7E-02	1.95E-02
E_0 (GeV)	1.3	1.3	1.3
emittance (m)	1.3E-09	1.3E-09	5.0E-10
τ_ε (ms)	28.2	28.2	9.0
Wigglers	no	no	**yes**

C

C = 408

$\varepsilon = 0.5 \cdot 10^{-9}$ m

$\sigma_x = 19\ \mu m$

$\sigma_y = 25\ \mu m$

$\tau_{Tou} = 4.6$ min

Increase energy to increase Touschek lifetime

	A	B	C	D
K	0.008	0.237	0.980	0.144
sigma_x (μm)	44	40	19	51
sigma_y (μm)	5	25	25	25
$\sigma_x\sigma_y$ (μm^2)	220	1000	475	1275
alpha_c	8.07E-04	8.07E-04	7.93E-04	8.07E-04
C (m)	345	345	408	345
V_RF (MV)	0.35	0.35	0.7	0.68
f_RF (MHz)	500	500	500	500
sigma_s (mm)	5.08	5.08	4.97	4.98
N part/bunch	6.20E+10	6.20E+10	6.20E+10	6.20E+10
Touschek (min)	0.79	3.7	4.6	12.1
sigma_buck	1.7E-02	1.7E-02	1.95E-02	2.00E-02
E_0 (GeV)	1.3	1.3	1.3	1.6
emittance (m)	1.3E-09	1.3E-09	5.0E-10	2.0E-09
τ_ε (ms)	28.2	28.2	9.0	15.1
Wigglers	no	no	yes	no

D

$E = 1.6$ GeV

$\varepsilon = 2.0\cdot 10^{-9}$ m

$\sigma_x = 51\ \mu m$

$\sigma_y = 25\ \mu m$

$\tau_{Tou} = 12$ min

Touschek lifetime

- At 1.3 GeV with proposed bunch densities Toschek lifetime is very critical
- We expect that also the intrabeam scattering effect is very strong
- Next step is the calculation of IBS emittances growth
- Insertion of wigglers and increase of the energy can reduce both effects

The Touschek half-lifetime according to the formula given by H. Bruck

$$\frac{1}{\tau} = \frac{\sqrt{\pi}\, r_0^2 c N}{\gamma^3 \sigma'_x \varepsilon^2 (4\pi)^{\frac{3}{2}} \sigma_l \sigma_x \sigma_y} C(u_{\min})$$

where:

r_0 = classical electron radius
c = velocity of light
γ = electron energy in units of rest mass
N = number of electrons per bunch
σ_x'= angular divergence of the beam
$(4\pi)^{3/2} \sigma_l \sigma_x \sigma_y$ = beam volume

$$C(u_{min}) = \int_{u_{min}}^{\infty} \frac{1}{u^2}\left[u - u_{min} - \frac{1}{2} ln\left(\frac{u}{u_{min}}\right)\right] e^{-u} du$$

$$u_{\min} = \left(\frac{\varepsilon}{\gamma \sigma'_x}\right)^2$$

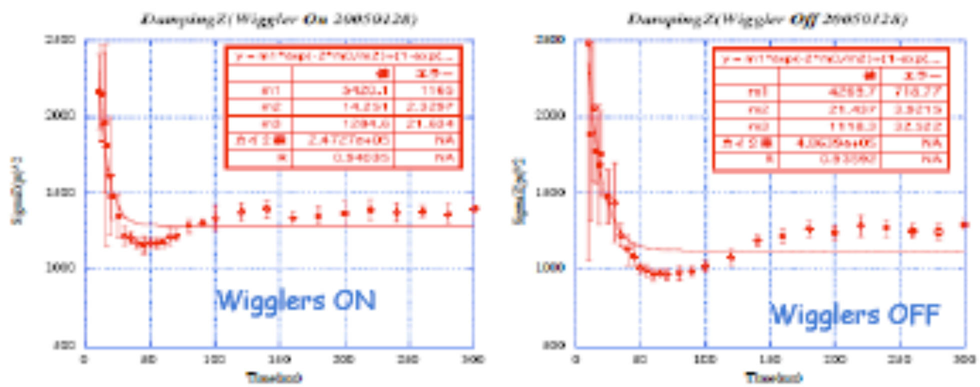
ATF with wigglers

ATF (J.Urakawa)

- Four wigglers (2m long) turned on
- Damping times and emittances were measured and found consistent with calculations
- Horizontal beam size, bunch length and energy spread growth, due to IBS effects after damping, was observed.
- Reduction of the damping time and suppression of IBS effect with wiggler operation observed
- Reduction of emittance with wigglers ON also observed

ATF Damping times

Damping Time	Cal.,wiggler off	Cal.,wiggler on	Meas.wiggler off	Meas.wiggler on
Horizontal τ_x	17.5 ms	15.0 ms	19.3+/-0.63 ms	15.7+/-0.38 ms
Vertical τ_y	28.5 ms	23.0 ms	28.8+/-1.5 ms	25.4+/-0.67 ms
Longitudinal τ_z	20.5 ms	15.5 ms	21.4+/-3.9 ms	14.2+/-2.4 ms



Wiggle05

Collective instabilities

	CR	DR
N part/bunch	$6.2\ 10^{10}$	$1\ 10^{10}$
Bunch distance	3 ns	3 ns
Average current	3.3 A	0.4 A
E	1.3 GeV	5 GeV

Very challenging parameters!

We are worried of:

- Bunch lengthening
- Fast ion instability

Bunch length

Next step:

To achieve very small bunch length at the IP study lattices with

- Negative momentum compaction
- Bunch length modulation

See "Proposal of a Bunch Length Modulation Experiment in DAFNE", LNF-05/4(IR), 22/02/2005 at http://www.lnf.infn.it/sis/preprint/pdf/LNF-05-4%28IR%29.pdf

A few comments on RF Voltage

- The RF voltage required for synchrotron radiation is rather low (<1MV)
- The voltage needed to compensate the "Compton" energy loss (11MeV) is quite high (20 MV)
- Beam power is very high: **11x3.3 = 33MW** many cavities are needed
- For comparison DR has a voltage 19÷48 MeV and a beam power of 4MW (16÷32 SC cavities)

Simulation of the longitudinal dynamics of the bunch

- The electrons are represented by 10^5 macro-particles.
- Longitudinal phase space coordinates:
  - Energy spread $P = (E - E_0)/E_0$
  - Phase $\phi = 2\pi hz / L_0$

Scheme of the code:

- Initial electron distribution is Gaussian.
- Every macro-particle experiences 4 sections:
  - phase advances because of the momentum compaction;
  - scattering with the laser simulated using the Thomson cross section under linear interaction;
  - synchrotron radiation energy loss (radiation damping and quantum excitation);
  - RF cavity.

Laser interaction

- ϕ distribution is binned;
- it is calculated the number of interactions of each bin with the laser;
- for each interaction it is generated a MonteCarlo number for the energy of the scattered photon;
- it is calculated the lost energy by each bin due to Compton effect;
- with a linear interpolation it is calculated the lost energy by the macro-particles;

- Phase advances as $$\phi_f = \phi_i - k_1 P - k_2 P^2 - k_3 P^3$$
- Synchrotron radiation $$P_f = P_i - DP_i - U_0 / E_0 + \frac{\sigma_E \sqrt{2D}}{E_0} \boxed{R}$$

  Gaussian number with rms 1
- RF cavity $$P_f = P_i + \frac{V}{E_0} \cos\left(\arccos\left(U_0 / V\right) - \phi_f\right)$$

Tests are in progress

Conclusions

- A preliminary lattice has been designed
- Insertion of wigglers and/or increase of the energy are needed to get low emittance and reasonable Touschek lifetime
- Still the high bunch density and high current make this ring extremely challanging