Electron Cloud in Wigglers

considering DAFNE, ILC, and CLIC

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wiggler & beam parameters

photon distributions

e-cloud build-up

e-cloud instabilities

parameters

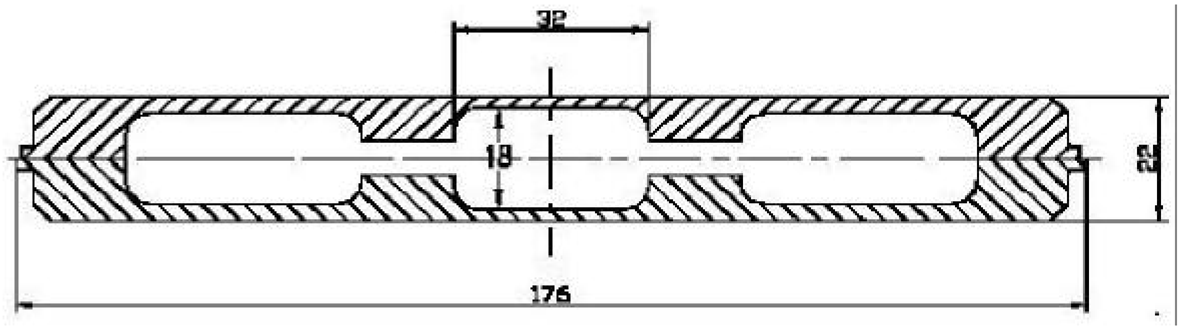
parameter	symbol	TESLA/ILC	CLIC	DAFNE
energy	E	5 GeV	2.424 GeV	0.510 GeV
circumference	C	17 km	357 m	97.69 m
wiggler length	$L_{\text{w-tot}}$	540 m	160 m	8 m
E-loss/turn	U_0	20 MeV	2.19 MeV	9.2 keV
wiggler ρ	ρ_w	9.9 m	4.58 m	1.0 m
bending field	B_w	1.63 T	1.76 T	1.7 T
wiggler period	λ_w	0.40 m	0.20 m	0.65 m
beta x	β_{xw}	10.5 m	4.0 m	5 m
beta y	β_{yw}	10. 5 m	7.0 m	5 m
beam size x	σ_x	93 μm	22.8 μm	1.5 mm
beam size y	σ_y	5 μm	3.6 μm	0.08 mm

parameter	symb.	TESLA/ILC	CLIC	DAFNE
bunch population	N_b	$2.0\text{x}10^{10}$	$4.2\text{x}10^{9}$	$2.1\text{x}10^{10}$
bunch spacing	C	6 m	0.2 m	0.8 m
half width @ wigl.	hx	16 mm	16 mm	60 mm
half height@wigl.	hy	9 mm	9 mm	10 mm
beam line density	λ_b	$3.3\text{x}10^{9}$ m^{-1}	$2.1\text{x}10^{10}$ m^{-1}	$2.6\text{x}10^{10}$ m^{-1}
photon rate / e+	dN_γ/dz	10.4 m^{-1}	10.9 m^{-1}	10.5 m^{-1}
photo-el. rate /e+	dN_e/dz	0.1 m^{-1}	0.3 m^{-1}	<0.03 m^{-1}

simulated incident photon
flux by simulation
+ assumed photoemission
yield Y_{eff}=0.1

0.003 m^{-1}
specified
by DAFNE

model of wiggler vacuum chamber



TESLA or CLIC wiggler chamber

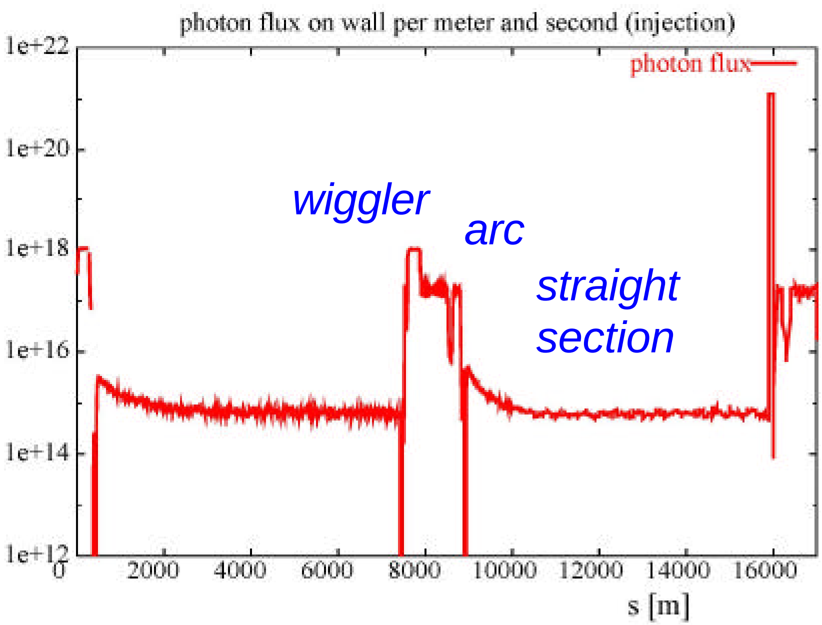
h_x=16 mm, h_y=9 mm (half apertures)

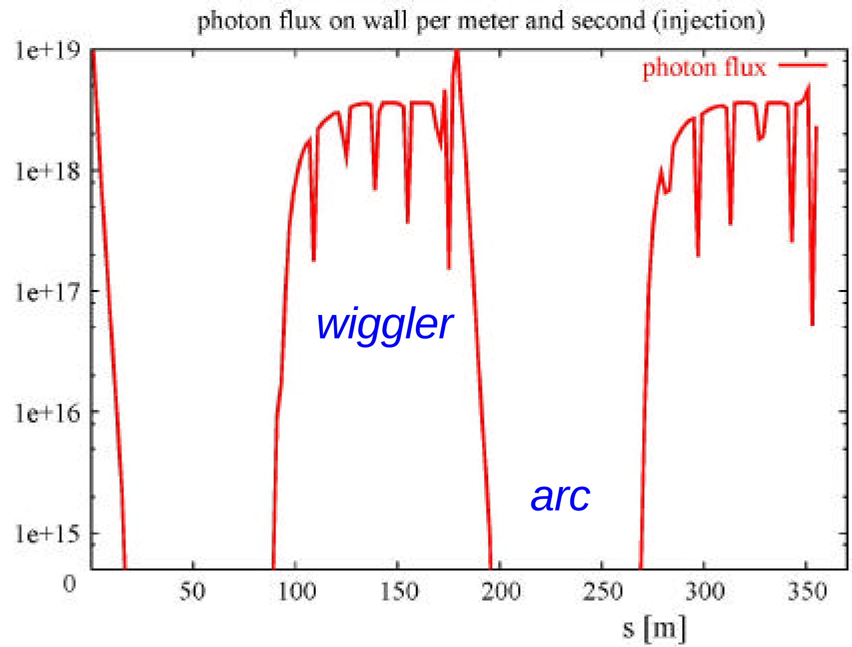
half height of antechamber slot = 3 mm

photons incident at |y|<3 mm are absorbed by antechamber

Monte-Carlo simulations of incident photon distribution

total photon flux incident on beam-pipe wall assuming complete γ absorption at |y|<3 mm by antechamber, and 80% photon reflectivity of other surfaces





TESLA/ILC damping ring

wiggler ~ 10^{18} /m/s

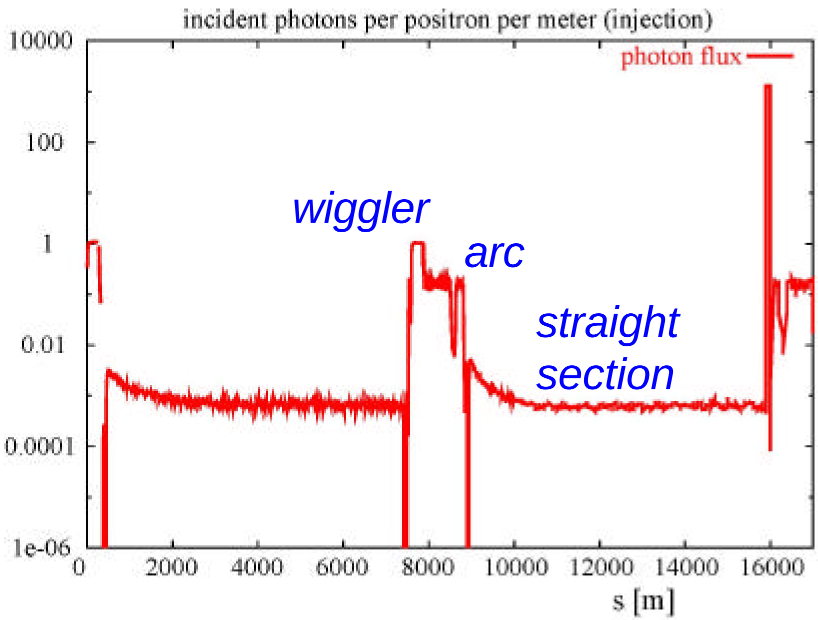
CLIC damping ring

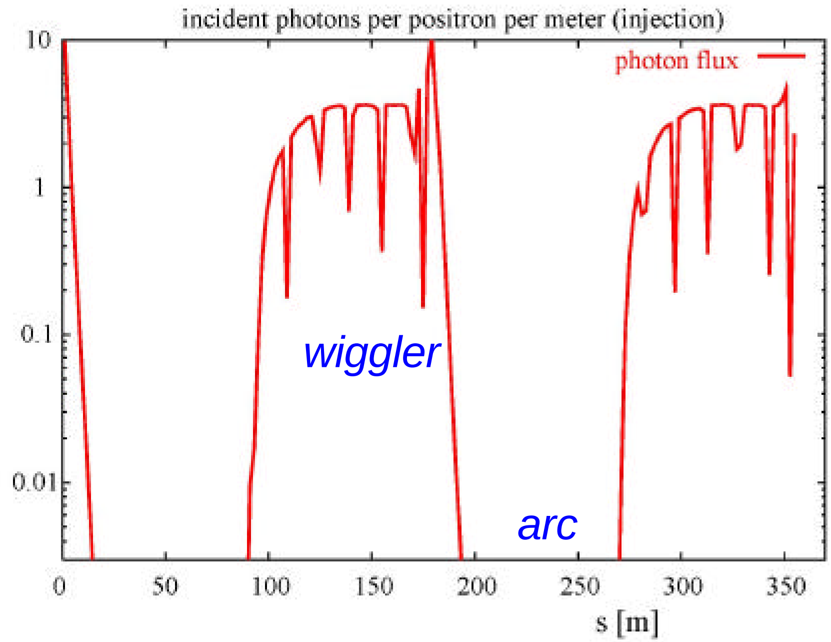
wiggler ~ 3×10^{18} /m/s

injection parameters

PHOTON code

photons per passing e+ incident per metre beam-pipe wall assuming complete γ absorption at |y|<3 mm by antechamber, and 80% photon reflectivity of other surfaces





TESLA/ILC damping ring

wiggler ~ 1

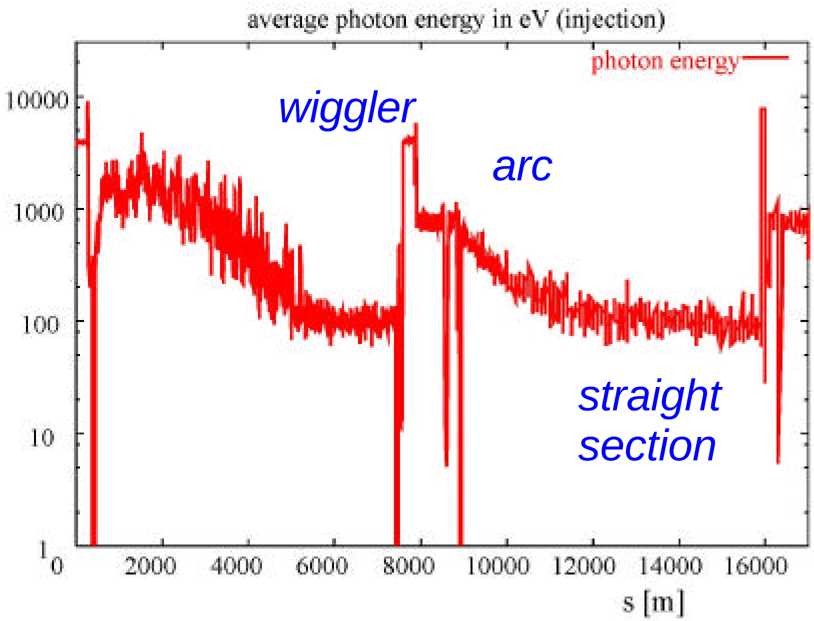
CLIC damping ring

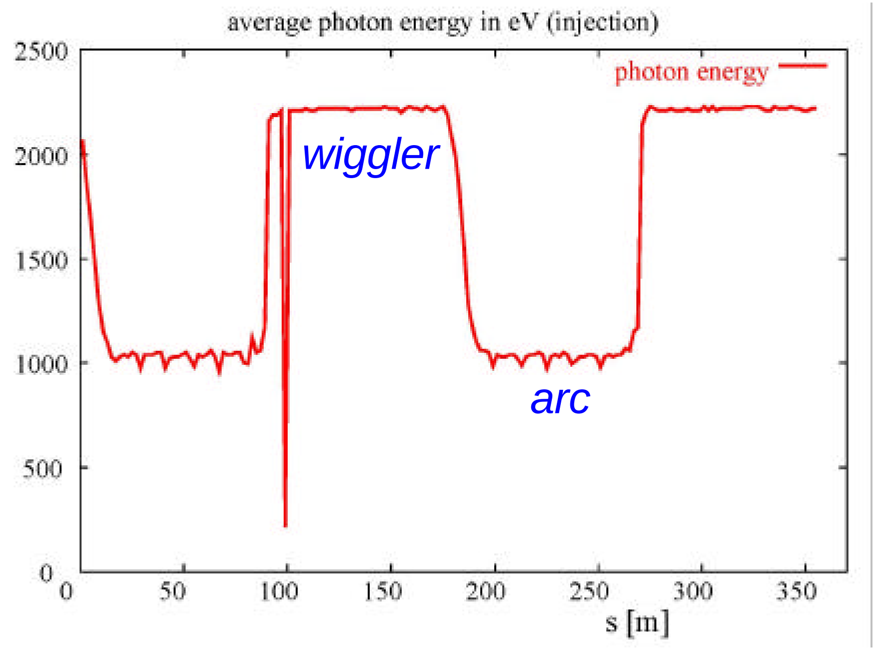
wiggler ~ 3

injection parameters

PHOTON code

average energy of photons incident on beam-pipe wall assuming complete γ absorption at |y|<3 mm by antechamber, and 80% photon reflectivity of other surfaces





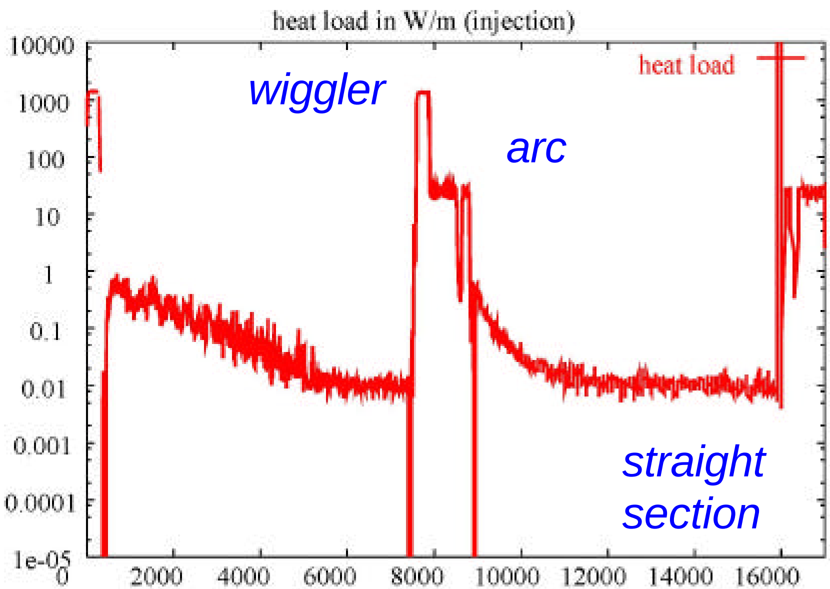
TESLA/ILC damping ring
wiggler ~ 4 keV

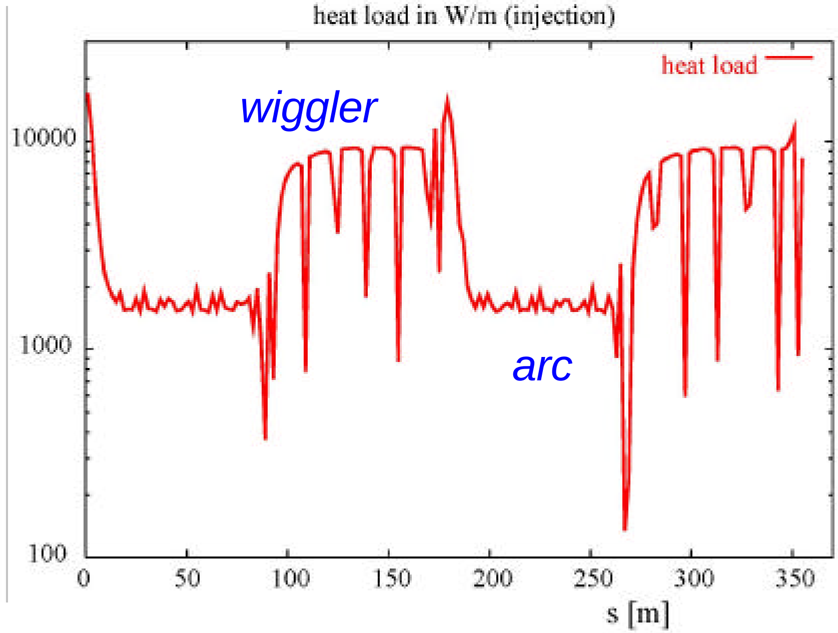
CLIC damping ring
wiggler ~ 2.2 keV

injection parameters

PHOTON code

heat load per metre from g's incident on beam-pipe wall assuming complete γ absorption at |y|<3 mm by antechamber, and 80% photon reflectivity of other surfaces





TESLA/ILC damping ring

wiggler ~ 1 kW/m

CLIC damping ring

wiggler ~ 9 kW/m

injection parameters

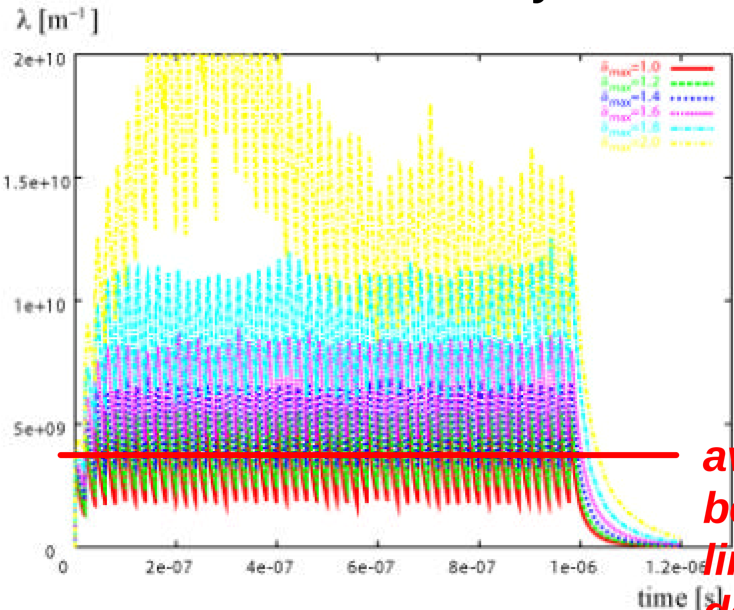
PHOTON code

simulations of electron-cloud build up

constant magnetic dipole field = peak wiggler field

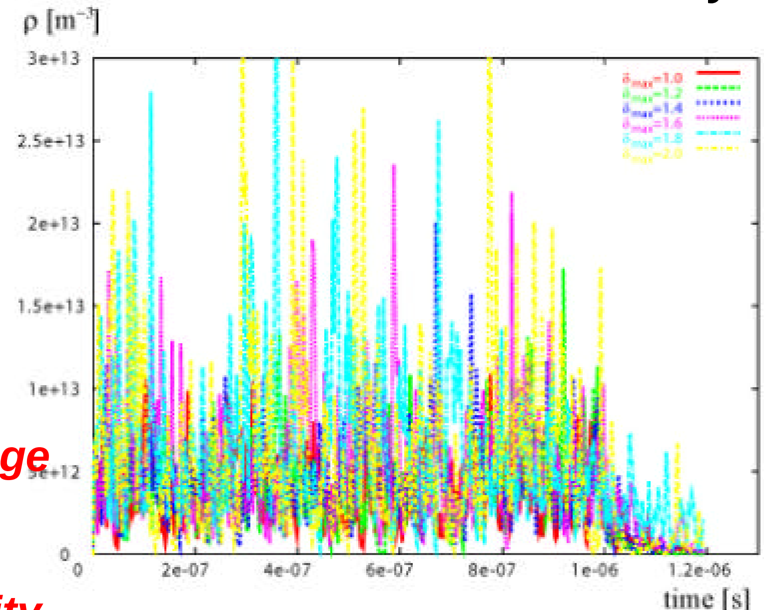
TESLA/ILC

e- line density



average beam line density

central volume density



assumed dN_{e-}/dz=0.2 photo-electrons per positron per meter, 6 different values of δ_{max}

$\lambda_e = 10^{10}$ m^{-1}, $\rho_e \sim 5\times10^{12}$ m^{-3}

ECLOUD code

more realistic wiggler field models

harmonic expansion in cartesian coordinates (Halbach):

$$B_y = B_0 \cosh\left(\frac{2p}{l} y\right)\cos\left(\frac{2p}{l} z\right), \; B_z = B_0 \sinh\left(\frac{2p}{l} y\right)\sin\left(\frac{2p}{l} z\right)$$

expansion in cylindrical coordinates (Venturini):

$$B_r = \sum c_{mn} I_m^{'}(nk_z r)\sin(mf)\cos(nk_z z)$$

$$B_f = \sum c_{mn} \frac{m}{nk_z r} I_m(nk_z r)\cos(mf)\cos(nk_z z)$$

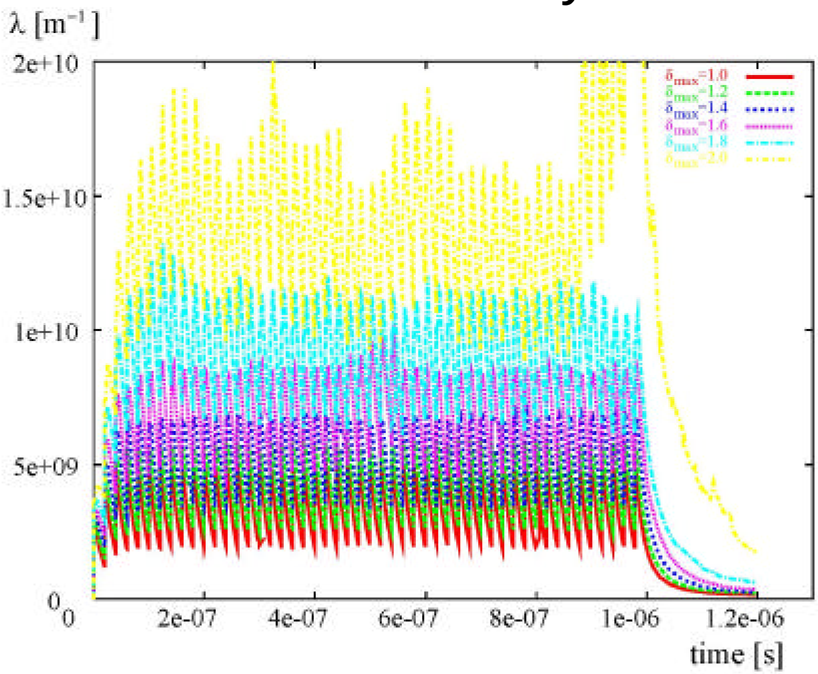
$$B_z = -\sum c_{mn} I_m(nk_z r)\sin(mf)\sin(nk_z z)$$

presently use only the terms n=m=1

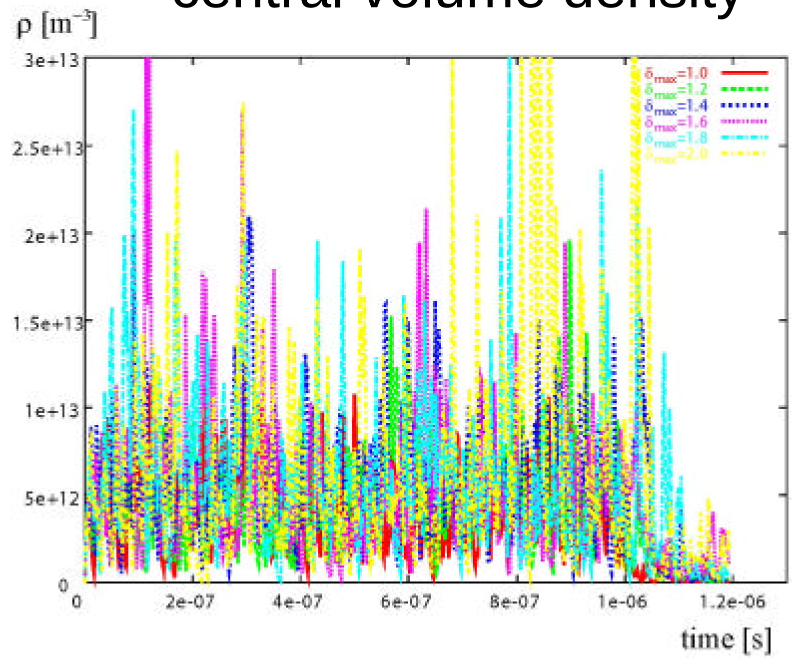
field expansion in cylindrical coordinates

TESLA/ILC

e- line density



central volume density



assumed $dN_{e-}/dz=0.2$ photo-electrons per positron per meter, 6 different values of δ_{max}

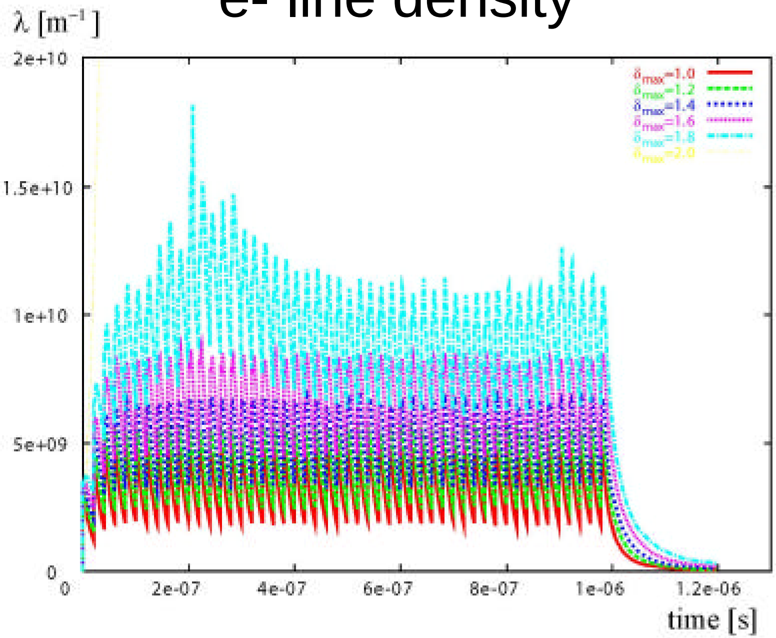
$\lambda_e=10^{10}\,m^{-1}$, $\rho_e \sim 5\text{x}10^{12}\ m^{-3}$

ECLOUD code

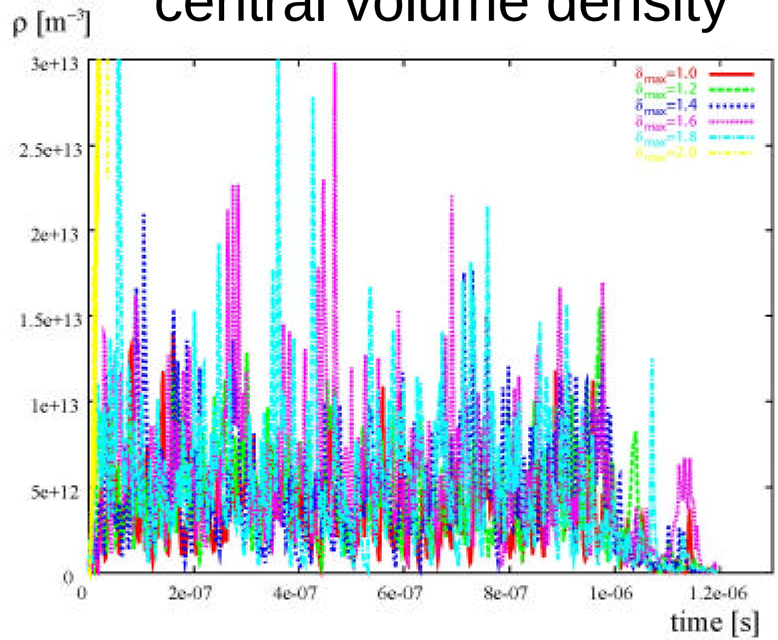
field expansion in cartesian coordinates

TESLA/ILC

e- line density



central volume density



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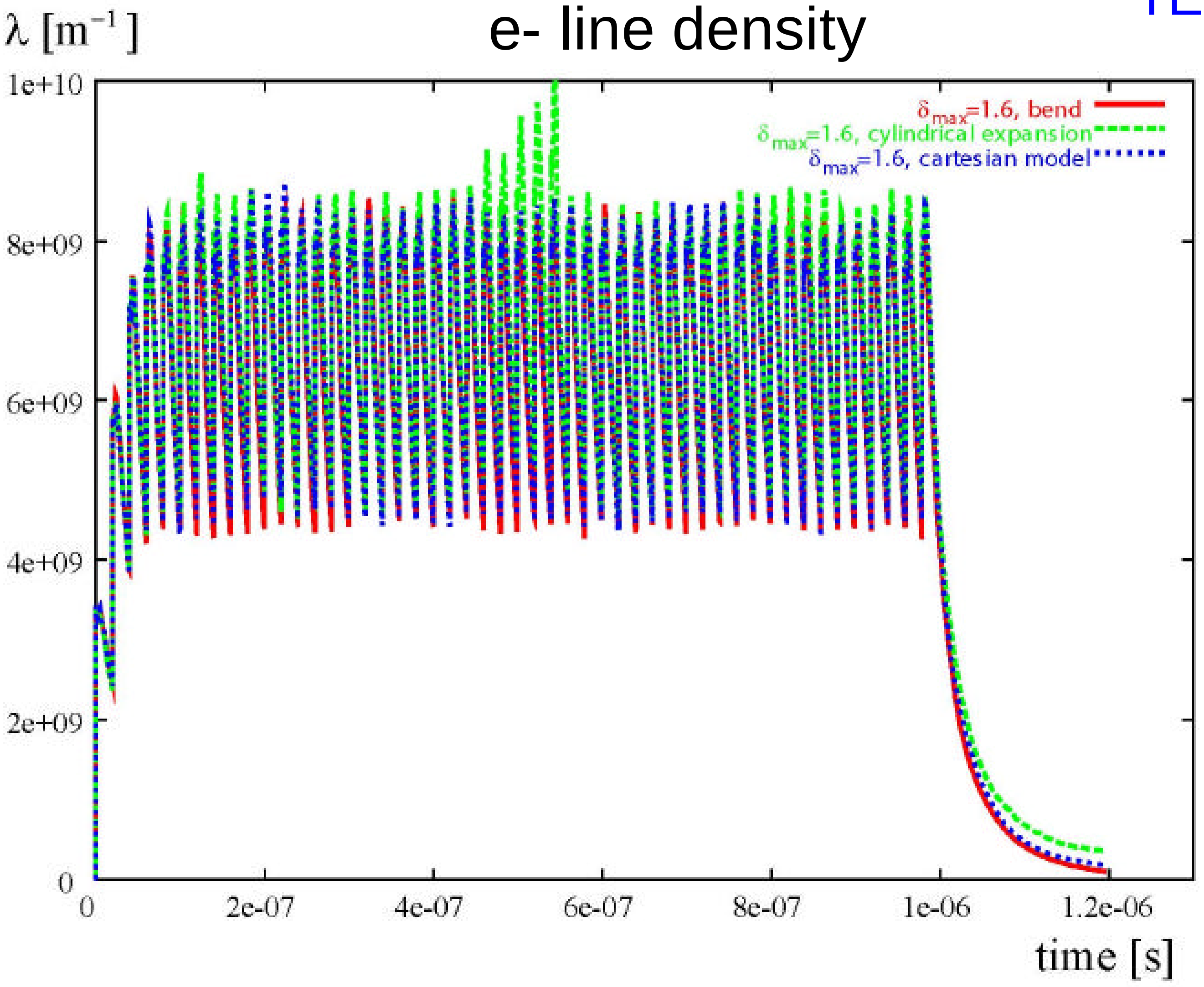
ECLOUD code

TESLA/ILC

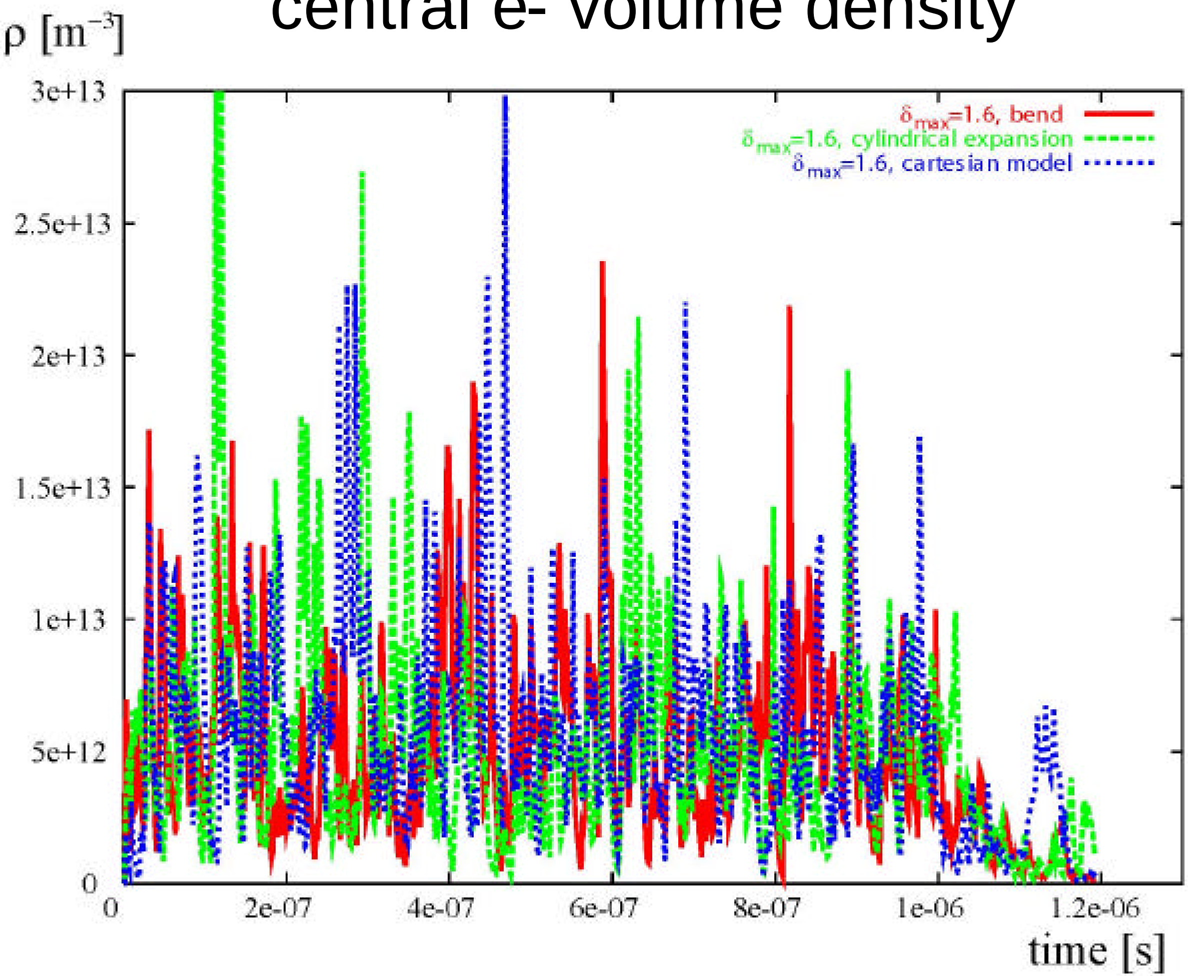
e- line density



comparison of three field models

ECLOUD code

central e- volume density



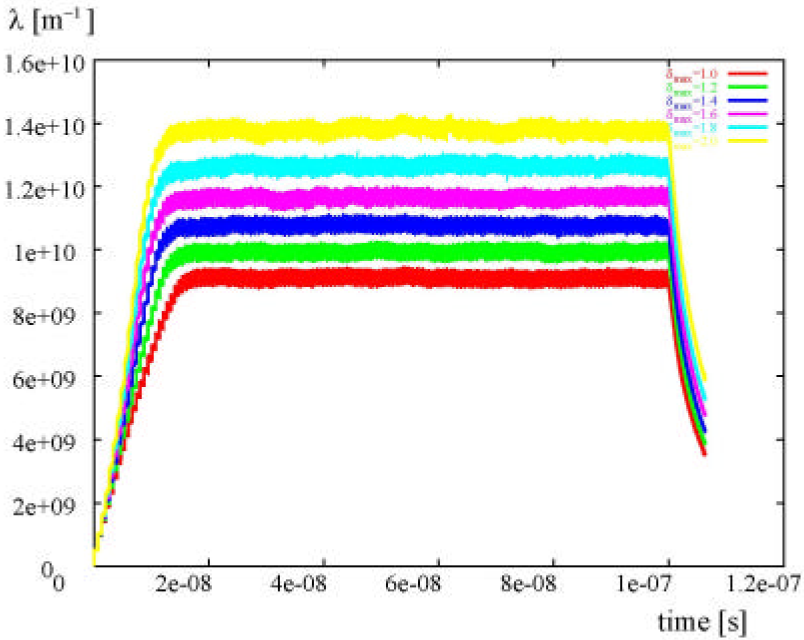
comparison of three field models

ECLOUD code

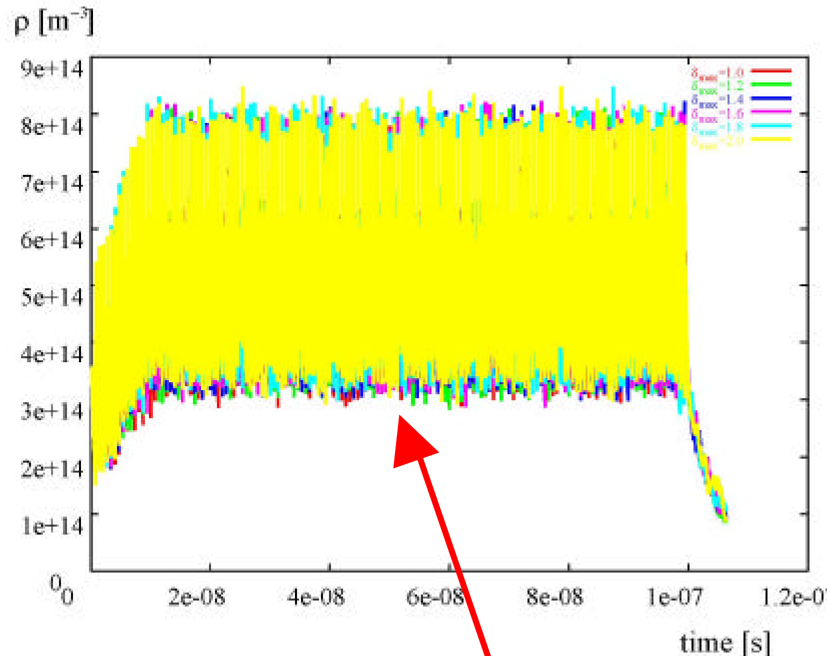
constant magnetic dipole field = peak wiggler field

CLIC

e- line density



central volume density



assumed dN_{e-}/dz=0.11 photo-electrons per positron per meter,
6 different values of δ_{max}

e- trapped inside the beam

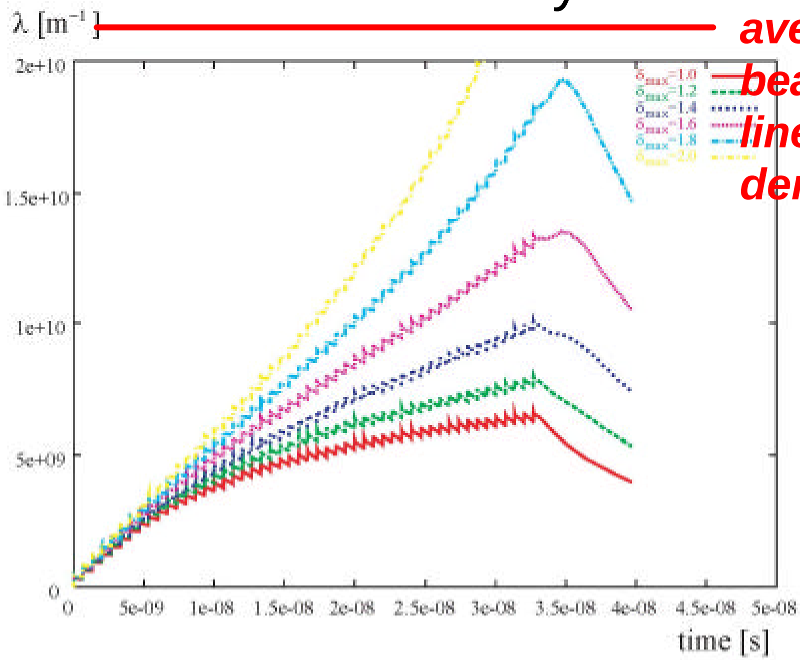
$\lambda_e = 10^{10}\ m^{-1}$, $\rho_e \sim 6\times10^{14}\ m^{-3}$

ECLOUD code

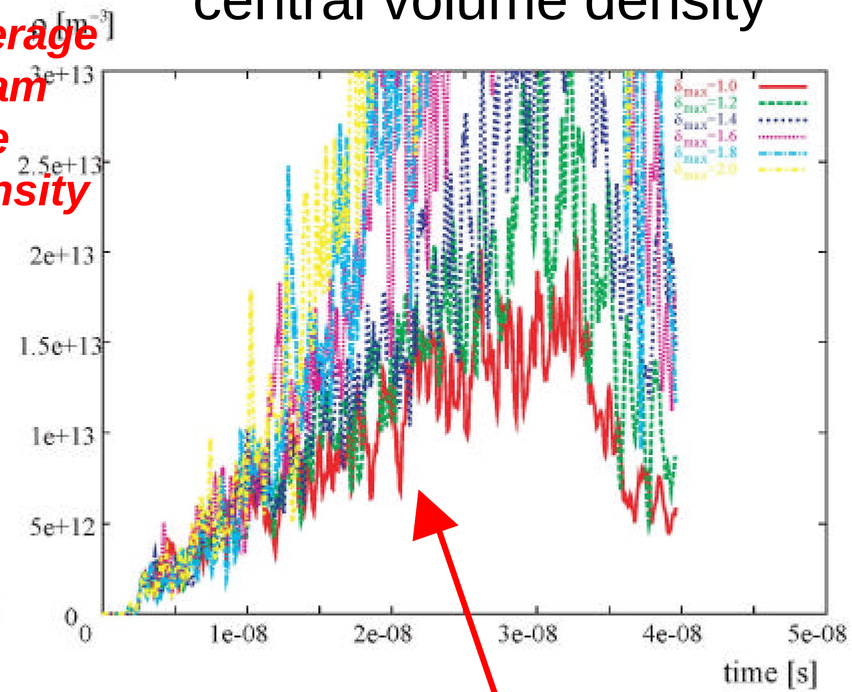
field expansion in cartesian coordinates

CLIC

e- line density



central volume density



assumed $dN_{e-}/dz=0.11$ photo-electrons per positron per meter,

6 different values of δ_{max}

$\lambda_e=10^{10}\ m^{-1}$, $\rho_e\sim 2\times10^{13}\ m^{-3}$

`ECLOUD code`

most e- outside the beam, slow inward migration next step: *include higher-order terms in CLIC wiggler field* –

Fourier-transform radial field on cylinder surface computed by MERMAID code for CLIC hybrid wiggler design (P. Vobly)

$$B_r\left(r=R,f,z\right)=\sum_{m=0}^{\infty}B_m\left(R,z\right)\sin\left(mf\right)$$

$$b_{m,p}=\frac{l_w}{2pp}\frac{\tilde{B}_{m,p}}{I'_m\left(2ppR/l_w\right)}$$

$$\tilde{B}_{m,p}=\frac{1}{l_w}\int_0^{l_w}dz\,e^{-i2ppz/l_w}B_m\left(R,z\right)$$

to fit field expansion coefficients à la M. Venturini (M. Korostelev)

$$\vec{B}=\vec{\nabla}\cdot y$$

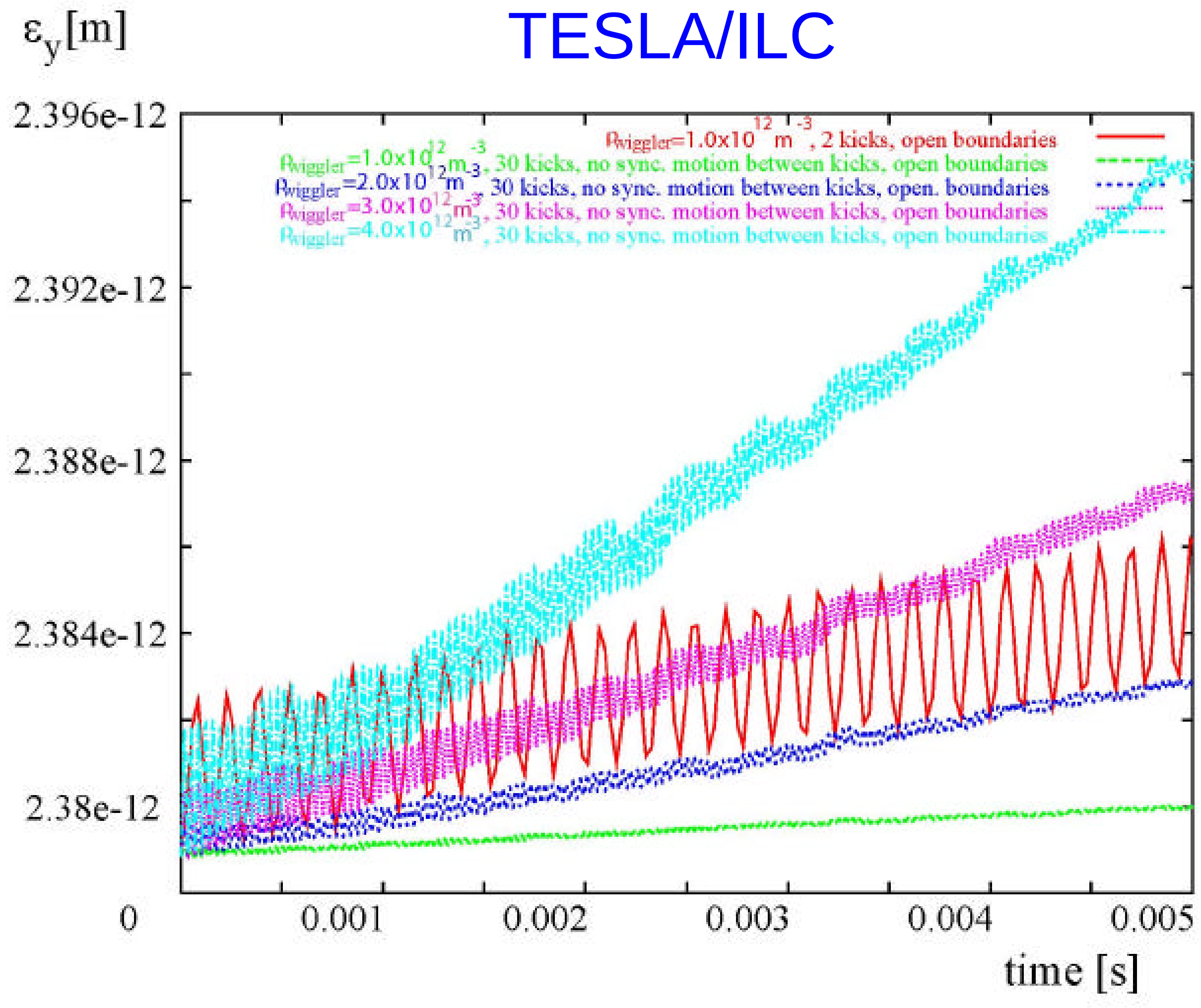
scalar potential

$$y=\sum_{m=0}^{\infty}\sum_{p=-\infty}^{\infty}e^{2pipz/l_w}I_m\left(\frac{2pp}{l_w}r\right)b_{m,p}\sin\left(mf\right)$$

simulations of electron-cloud single-bunch instabilities

emittance growth for various e- densities in wiggler only

TESLA/ILC

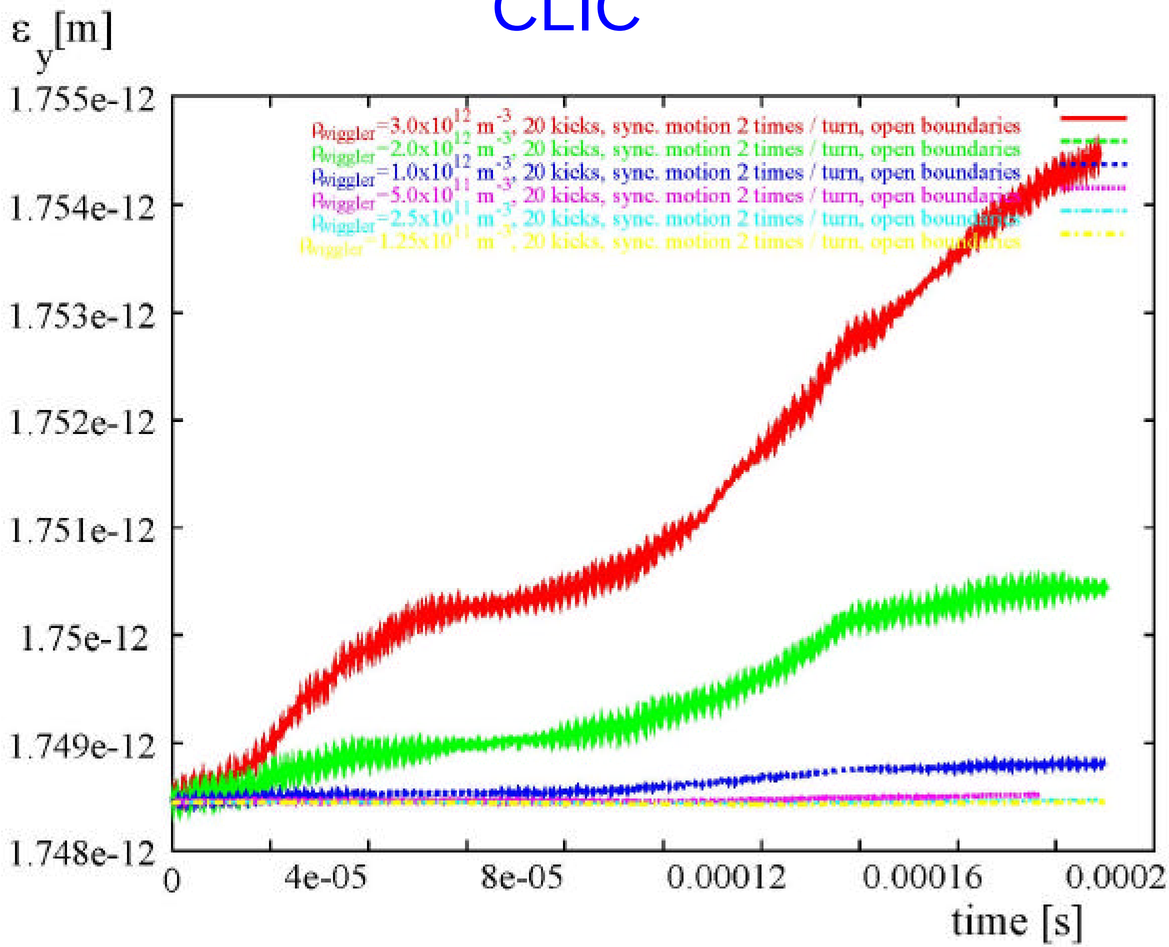


HEADTAIL code

threshold density for weak instability $\rho_w \sim 2x10^{12}$ m^{-3}

emittance growth for various e- densities along the ring

CLIC



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threshold density for weak instability $\rho_{ring} \sim 1 \times 10^{12}\ m^{-3}$

DAFNE observations

from discussions with P. Raimondi and M. Zobov

- e+ current limited to 1.2 A in collision by strong instability (~10 μs rise time); in previous years reached 2.5 A
- large positive tune shift with current in e+ ring, not seen in e- ring
- wound solenoids in field-free sections w/o any effect
- main change for 2004 was wiggler field modification; suspicion that e- are created and trapped by the wiggler field
- instability sensitive to orbit in wiggler (few mm)
- instability depends on bunch current (not total current)
- instability strongly increases along the train
- rise time is faster than the synchrotron period
- instability sensitive to injection conditions
- instability threshold scales w. transverse emittance

grow-damp measurement of transverse e+ instability

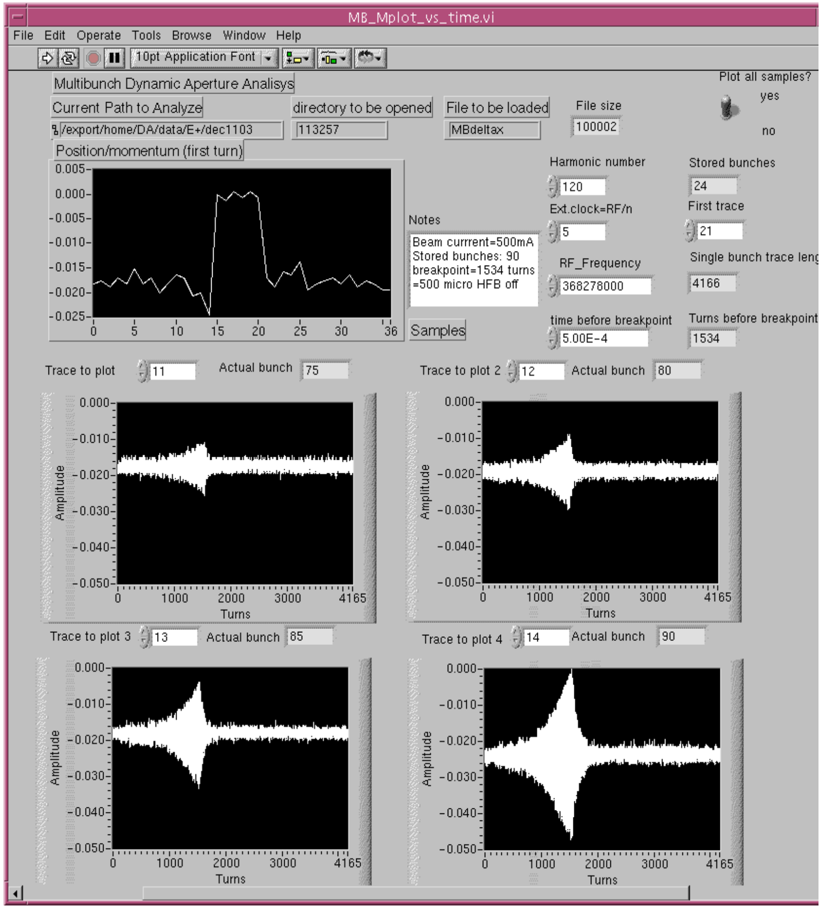
DAFNE

Bunches at the train end:75, 80, 85,90

90 consecutive bunches
+ 20 bucket gap

beam current = 500 mA

single- or multi-bunch instability?



A. Drago
M. Zobov
C. Vaccarezza

model of DAFNE wiggler field in ECLOUD simulations:

magnetic field (B_x, B_y, B_z) inside the wiggler as a function of x,y,z coordinates is obtained from a bi-cubic fit of the measured 2-dimensional field-map data $B_y\,(x,y=0,z)$; field components B_x and B_z are approximated by

$$B_x = \frac{\partial B_y(x, y=0, z)}{\partial x} y$$

$$B_z = \frac{\partial B_y(x, y=0, z))}{\partial z} y$$

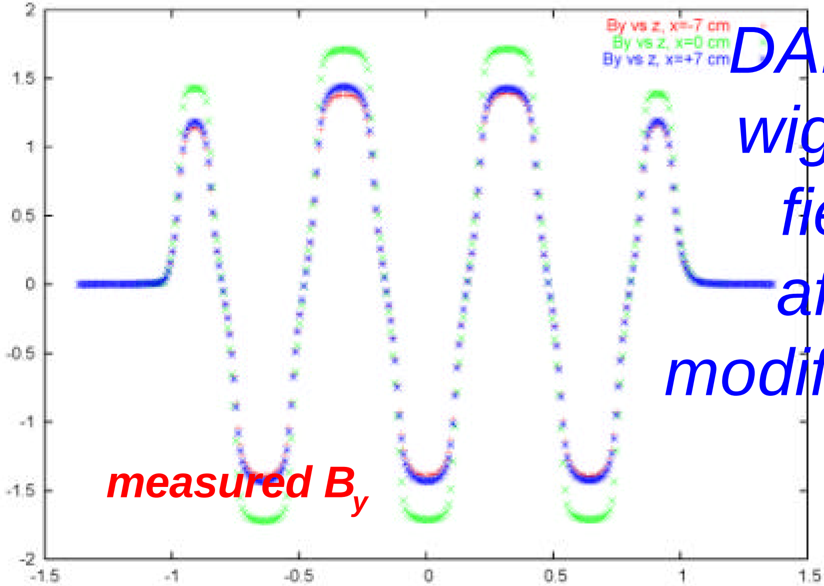
$$B_y(x,y,z) = B_y(x, y=0, z) - \frac{y^2}{2}\left(\frac{\partial^2 B_y(x, y=0, z)}{\partial x^2} + \frac{\partial^2 B_y(x, y=0, z)}{\partial z^2} \right)$$

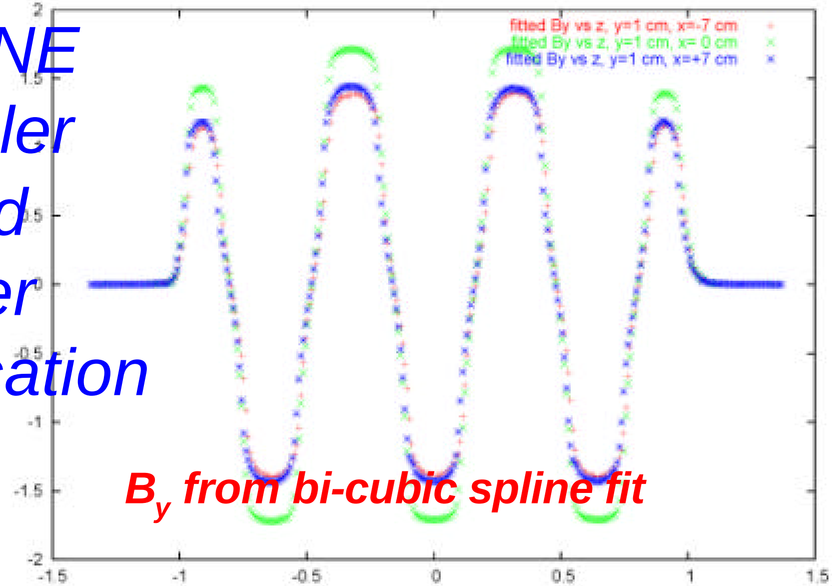
consistent with Maxwell's equations $\vec{\nabla} \times \vec{B} = 0, \quad \vec{\nabla} \cdot \vec{B} = 0$

peak field ~1.7 T, period ~65 cm

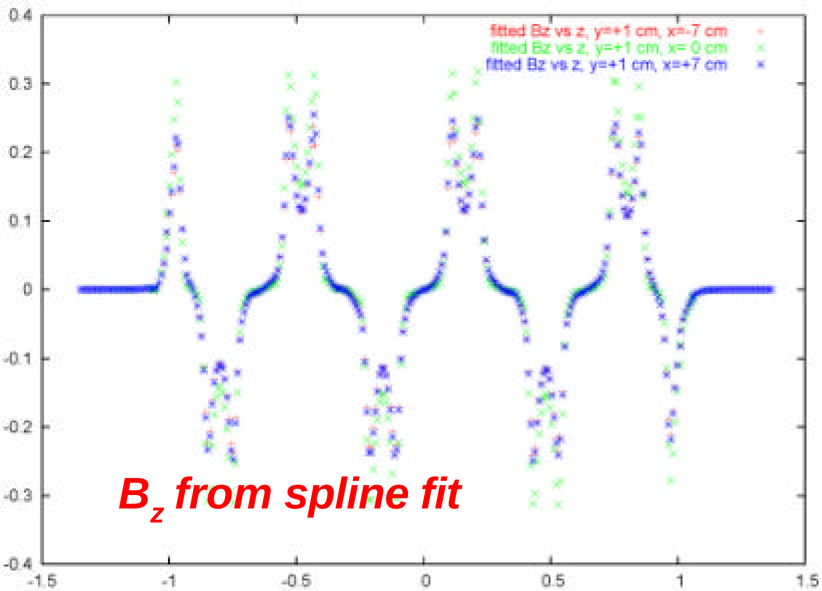
C. Vaccarezza

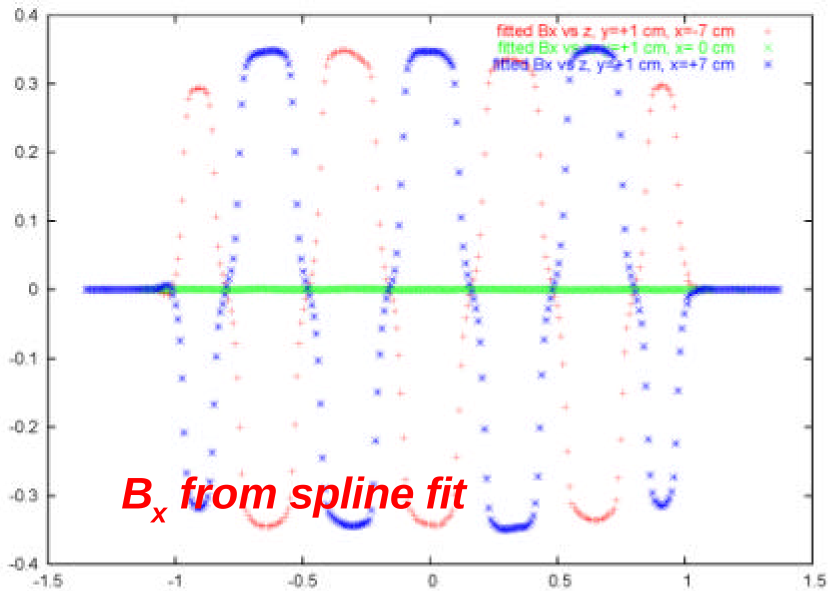
DAFNE wiggler field after modification



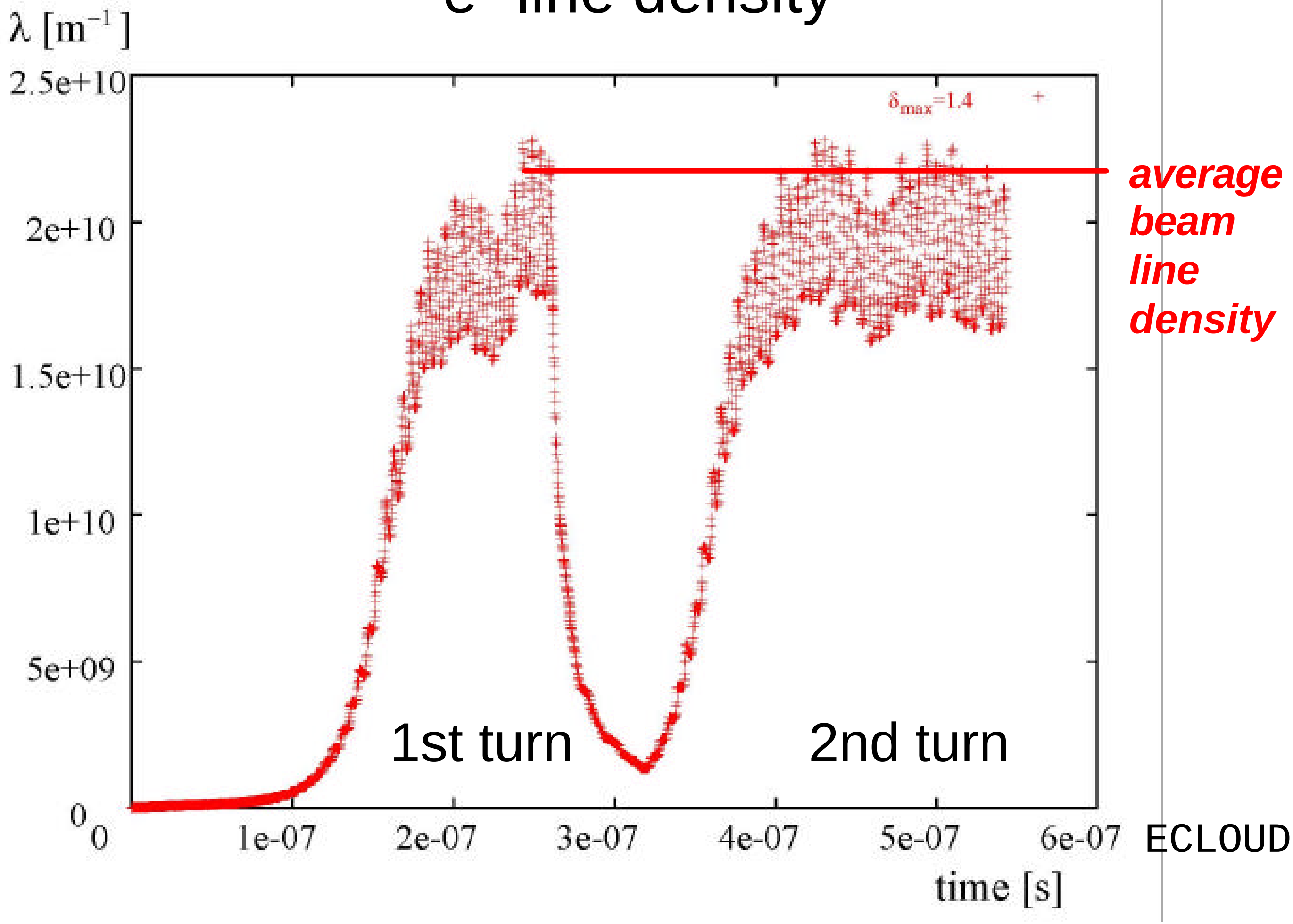


3 curves refer to x = -7, 0, +7 cm





e- line density

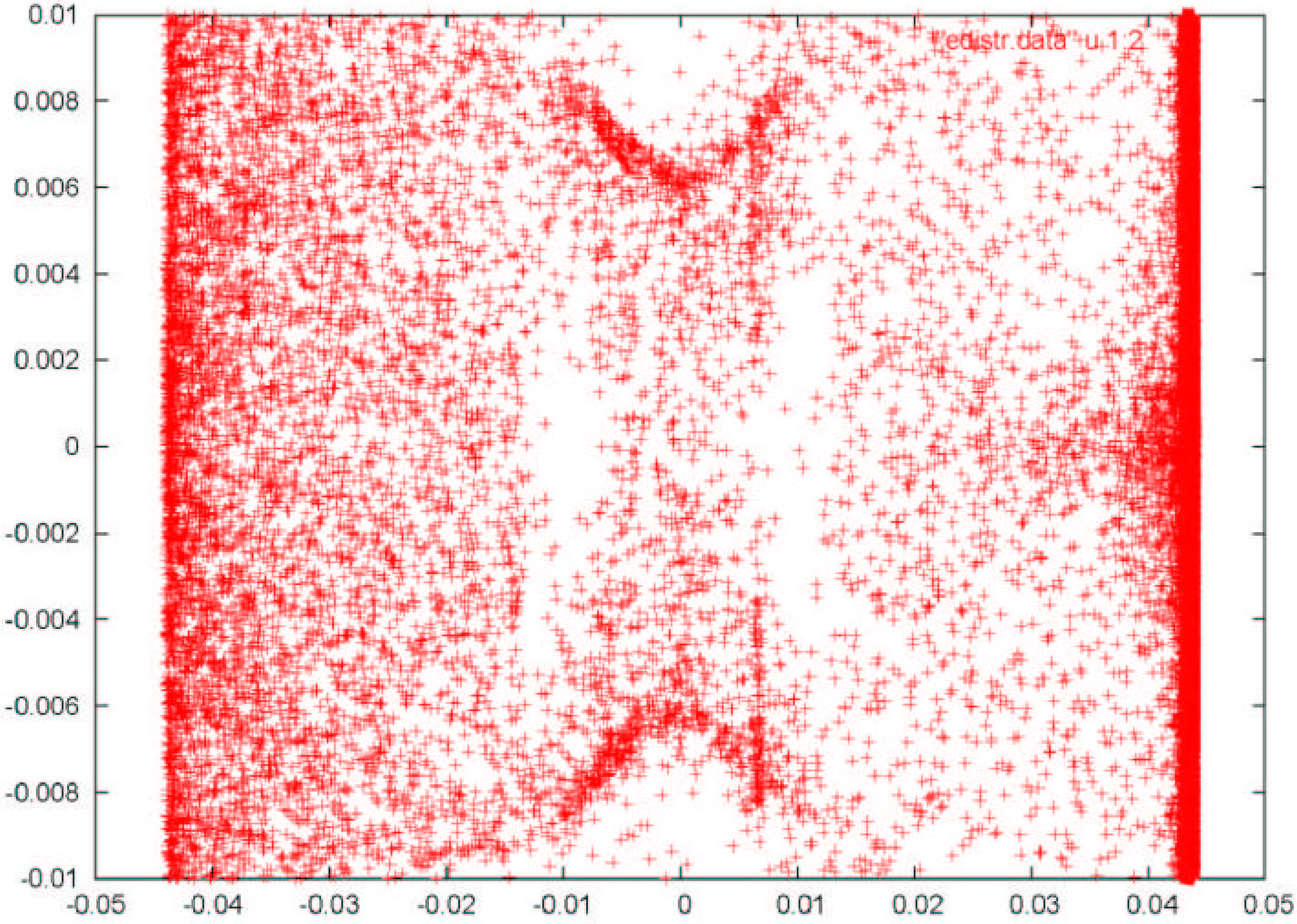


ECLOUD code

parameters: 1.6 m spacing, $N_b=3.5\text{x}10^{10}$, 49 bunches + 11 b. gap, $\delta_{max}=1.4$, $dN_\gamma/dz=0.00051\ m^{-1}$ with 20% photon reflectivity & $\cos^2\phi$ distribution

e- x-y distribution

DAFNE



ECLOUD code

parameters: 1.6 m spacing, N_b=5.0x10^{10}, 49 bunches + 11 b. gap, δ_{max}=1.4, dN_γ/dz=0.00051 m^{-1} with 20% photon reflectivity & $\cos^2 \phi$ distribution

coupled-bunch e-cloud instability

multibunch wake field W [m^{-2}] is computed by introducing bunch offset Δx & recording electric field E field at subsequent bunches:

$$W = \frac{1}{r_e}\left(\frac{eE}{m_e}\right) L_w \frac{1}{N_b \Delta x}\frac{1}{c^2}$$

$$\approx 6\times 10^{-10}\ \mathrm{s}^2\mathrm{m}^{-3}\left(\frac{eE}{m_e}\right)$$

(numerical value for offset Δx=2.5 mm, N_b=2.1x10^{10}, L_w=8 m)

instability rise time:

$$t \approx \frac{2gCw_b}{N_b r_p c^2 W\left(L_{sep}\right)} \approx 3.7\frac{\mathrm{s}}{\mathrm{m}^2}\frac{1}{W\left(L_{sep}\right)}$$

ECLOUD code

single-bunch e-cloud instability

DAFNE

variable	symbol	value
bunch population	N_b	2.1×10^{10}
rms bunch length	σ_z	17.2 cm
rms x size	σ_x	1.5 mm
rms y size	σ_y	0.08 mm
x beta	β_x	5 m
y beta	β_y	5 m
chromaticity	$Q'_{x,y}$	2
momentum compaction	α	0.023
synchrotron tune	Q_s	0.0083
rf voltage	V_{rf}	80 kV
rms momentum spread	$\Delta p/p$	4×10^{-4}

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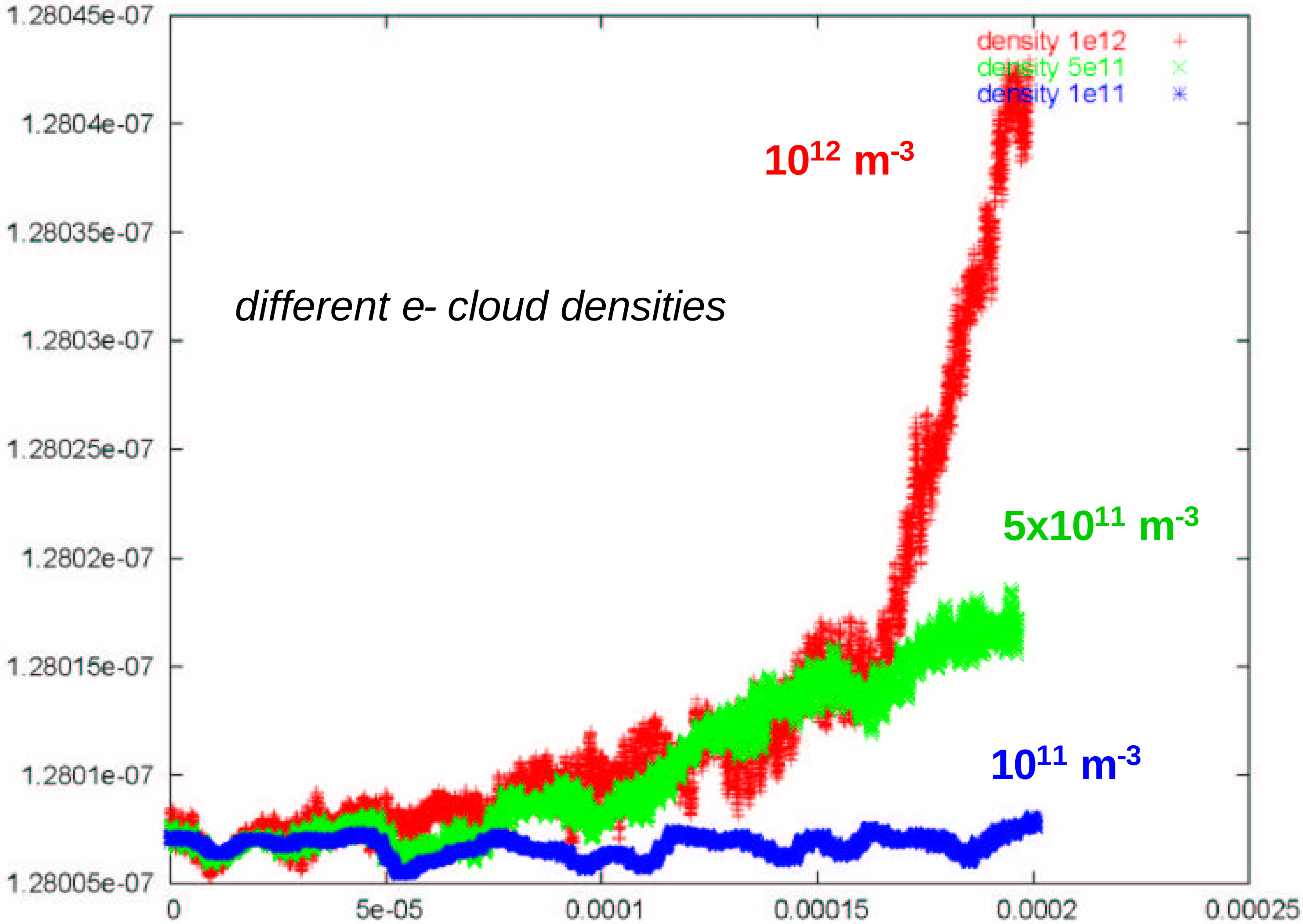
vertical emittance vs. time

DAFNE



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conclusions

- significant fraction of **photons not absorbed by wiggler antechamber**
- together with high primary photon flux, this yields a **large rate of primary photo-electrons**
- in consequence, simulated **e-cloud density for wiggler much higher than for arcs** and straights
- for CLIC a more **realistic wiggler field** reduces the e-cloud ρ near beam; but for TESLA ρ identical to uniform field
- e-cloud in the wiggler likely causes **single- & multi-bunch e-cloud instabilities**; e-cloud **might be responsible for current limitation in DAFNE e+ ring**
- possible **countermeasures**: clearing electrodes, grooved surfaces (?), photon absorbers/radiation masks with low reflectivity & low photoemission yield
- more precise field models in future simulations
- **e-cloud effects to be considered in wiggler design**

thank you for your attention!