PS/LPNote 95-24 (Min)
8 June 1995

CLIC BEAM DYNAMICS MEETING

Chairman : A. Guignard
Secretary : A. Riche

Minutes of the CLIC Beam Dynamics Meeting hold on
Tuesday May the 30 th
Subject: BEAM DYNAMICS CALCULATIONS FOR CTF
by : M. Dehler

To:		For information	
B. Autin	PS	R. Bossart	PS
H. Braun	PS	F. Chautard	PS
J. Clendenin	PS	M. Comunian	PS
R. Corsini	PS	J.P. Delahaye	PS
J.P. Delahaye	PS	T. E. D'Amico	PS
M. Dehler	PS	C. Fischer	SL
R. Garoby	PS	G. Guignard	SL
K. Huebner	DG-DI	J.H.B. Madsen	PS
A. Millich	SL	G. Parisi	SL
J.P. Potier	PS	W Remmer	PS
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W. Schnell	SL	L. Thorndahl	SL
D. Warner	PS	I. Wilson	SL
W. Wuensch	SL		

The results obtained for Gun N0 4, and with program MAFIA are commented by M.Dehler. They concern the gun followed by a solenoid which reduces the divergence to a value acceptable by the following apertures, followed by a drift.

The important increase of emittance in the drift after the solenoid could be explained by the effects of high non linear fields due to the charge distribution in the bunch at that place. Because the effect is high, the question rises of an artifact caused by discretization errors by finite size of the mesh in space and time, and of having not an adequate number of particles describing the bunch in the mesh.

The constraints are the size of the buffers which have to be contained into available computer memory, and calculation time.

Emittance is (artificially) highly depending on the number of particles used in the simulation, also the energy dispersion, but less, and also the dimensions of the bunch in a smaller degree. Input parameters such as the number of particles are then chosen according to some degree of stability of the solution when they are varied. Here, it is the highest number of particles compatible with calculation time. The effect was already shown by S. Lutgert within a drift tube of 1 m length

The forces in the solenoid and resulting change in (r,r') phase space and variation of emittance with bunch radius are shown for one bunch.

- Effects of multi-bunching are discussed. The different action of the solenoid on bunches of decreasing energies is considered with an elementary optical scheme. For reducing the solenoid strength because its adverse effects, divergence at gun exit should be reduced, or the solenoid installed at a further place.

Emittances, bunch radius, length, divergence, energy spread have been traced along for 70, 85, 100 MV/m fields and .343 T in solenoid. Changing photo-cathode radius from 6 to 9 mm is shown to give better results for all beam parameters.

- In the general discussion about the numerical simulations, some particular points were much commented:

Because of the strong change of the transverse emittance with dicretization and number of particles, a careful scan of the two parameters is requested, for having asymptotic value hopefully close to the real one.

Also important is checking that emittance do not depend too much on halo by elimination points too far away in phase space. The transmission efficiency for a given acceptance (in multi-bunch mode by projection) should be checked).

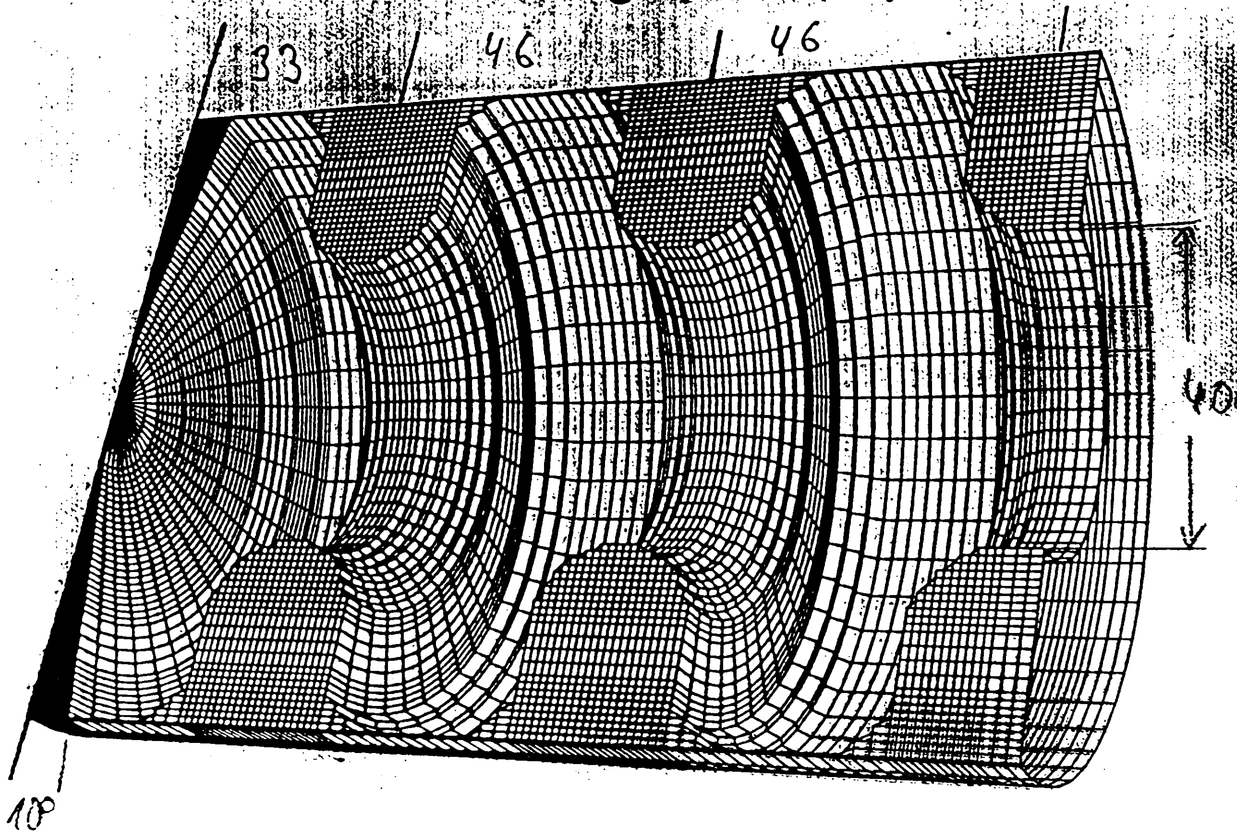
The CTF2 challenge consists in getting a total current of 1 micro C in several bunches, rather than maximizing the current per 1 bunch, therefore solutions to alleviate beam loading and the phase shift generated in the gun should be examined. Solutions for having less beam loading are investigated, as the increase of the fields in the gun, use of mode TM020 allowing for more stored energy. The divergence at gun outlet could be reduced by having more cells.

Beam Dynamics Calculation for CTF

Micha Dehler

- Addendum to results given in March
- Solenoid (Nonlinear Focusing / Multi Bunch Operation)
- Calculation Results for Gun 4 with Solenoid
- Current State of Gun 5

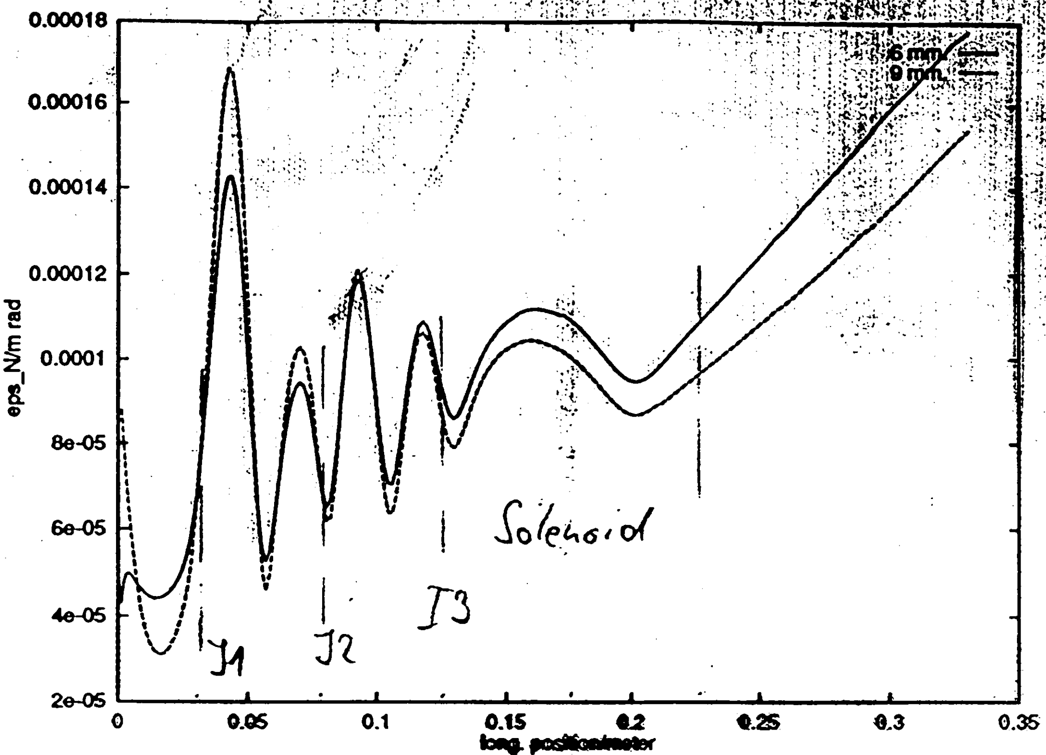
Current design (Gun No 4)



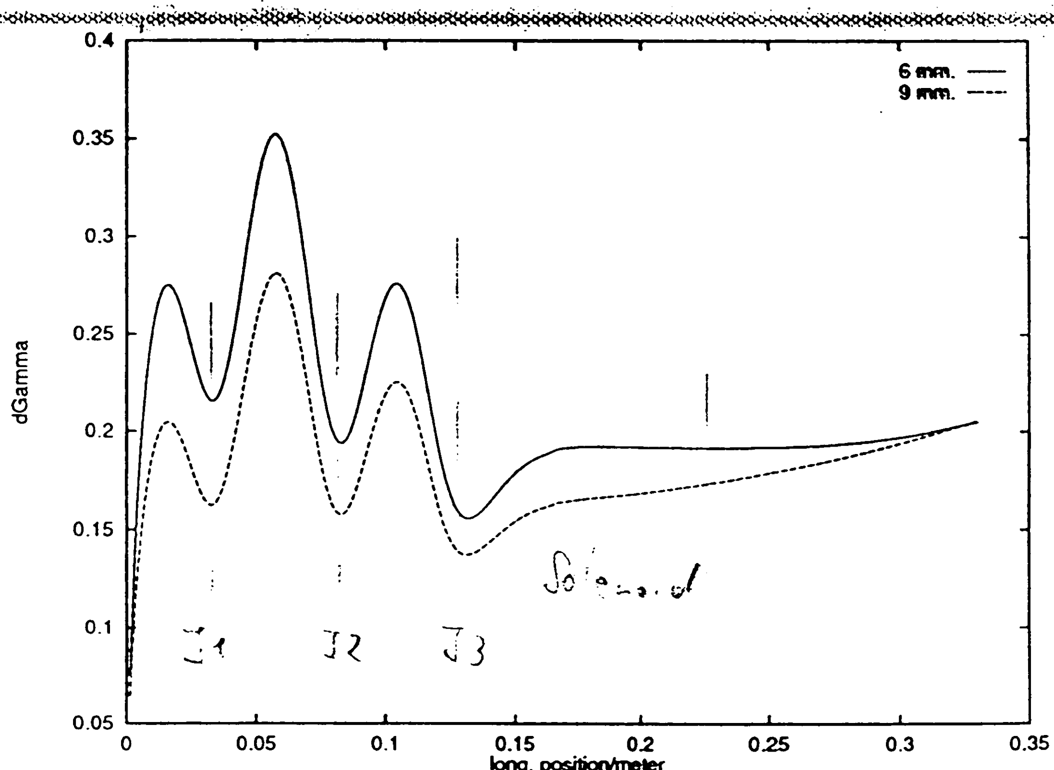
- radius of photocathode: 6mm
- Bunch Charge 30 nC
- Gaussian shape, length (FWHM): 5, 10, 15 psec.
  equiv. r.m.s. values: 4.3, 8.5, 12.8 psec.
- Definition of rf phase with respect to bunch center
- Acceleration by π-mode with maximum electric field of 100 MV/m

2 1/2 cells w. solenoid 0.3 Tesla

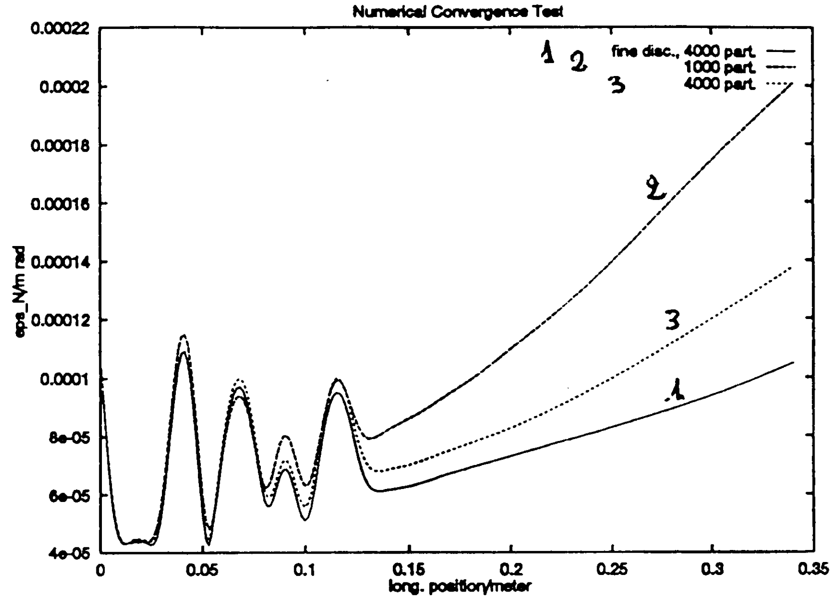
M. Dehler

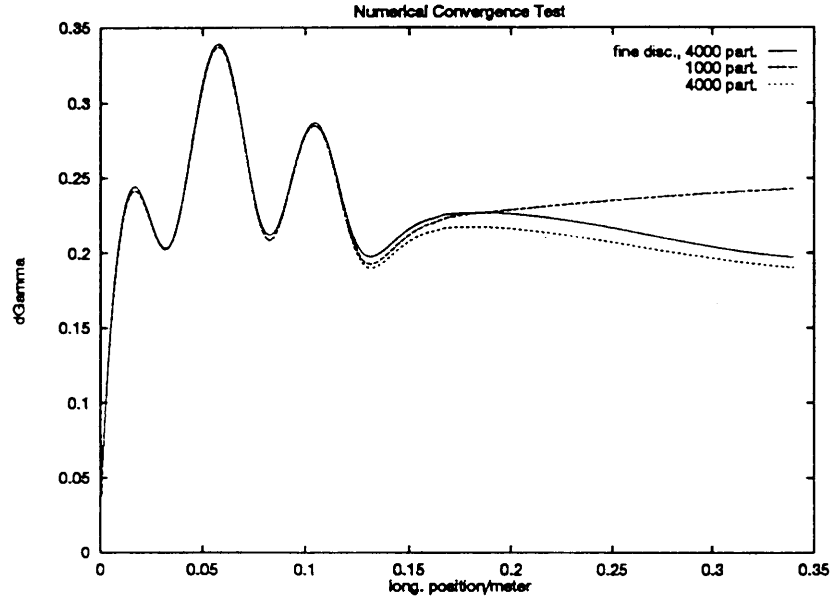


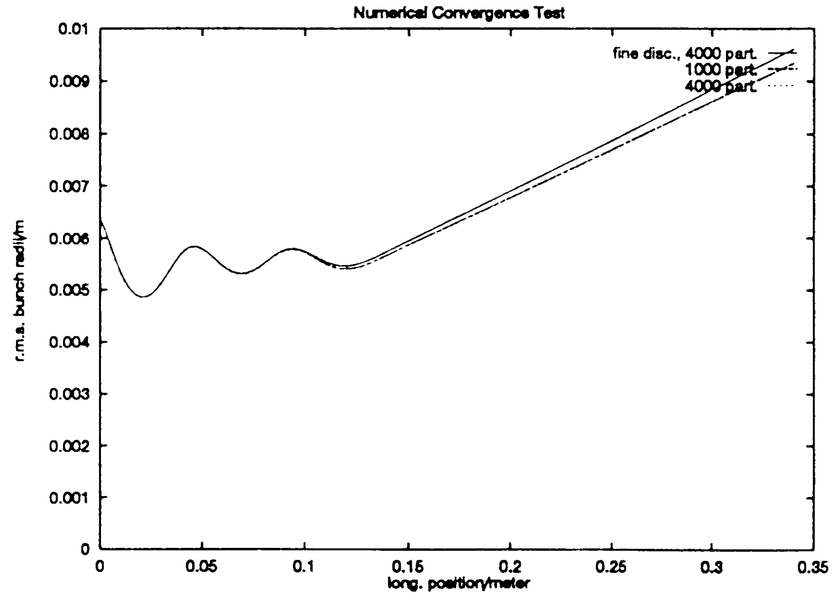
normed emittance ϵ_N



absolute energy spread $\Delta\gamma$


Numerical Convergence Test
fine disc., 4000 part.
1000 part.
4000 part.
1
2
3
eps_N/m rad
long. position/meter


Numerical Convergence Test
fine disc., 4000 part.
1000 part.
4000 part.
dGamma
long. position/meter


Numerical Convergence Test
fine disc., 4000 part.
1000 part.
4000 part.
r.m.s. bunch radii/m
long. position/meter

Similar Effects seen by S. Lütgert

Calculation of Drift Tube, length = 1m

pos./mm	$\Delta\gamma/\gamma$ (%)	ε_N (mm mrad)
400	1,25	82
600	1,39	86
800	1,62	101
1000	1,89	122
1200	2,25	152
1400	2,78	202

Solenoidal Forces

- Generalized Conservation of Angular Momentum:

$$P_\varphi = Q r A_\varphi + \gamma m_0 r^2 \dot{\varphi} = \text{const.}$$

(A_φ: Azimuthal Vektorpotential; $\dot{\varphi}$: Azimuthal Rotation)

$\Rightarrow$ Rotational Velocity does not depend on the Trajectory

R. V. is unique Function of A_φ:

$$\dot{\varphi} = \dot{\varphi}_0 - \frac{Q A_\varphi}{\gamma m_0 r}$$

- Longitudinal / Radial Forces independent of Path:

$$F_r = Q \dot{\varphi} B_z + \frac{1}{2} \dot{\varphi}^2 m_0 \gamma r$$

($\frac{1}{2} \dot{\varphi}^2 m_0 \gamma r$: Centrifugal Force)

$$F_z = - Q \dot{\varphi} B_r$$

MAFIA

FRAME: 11 29/03/95 - 10:50:48 VERSION[V320.0] SOL.DRD

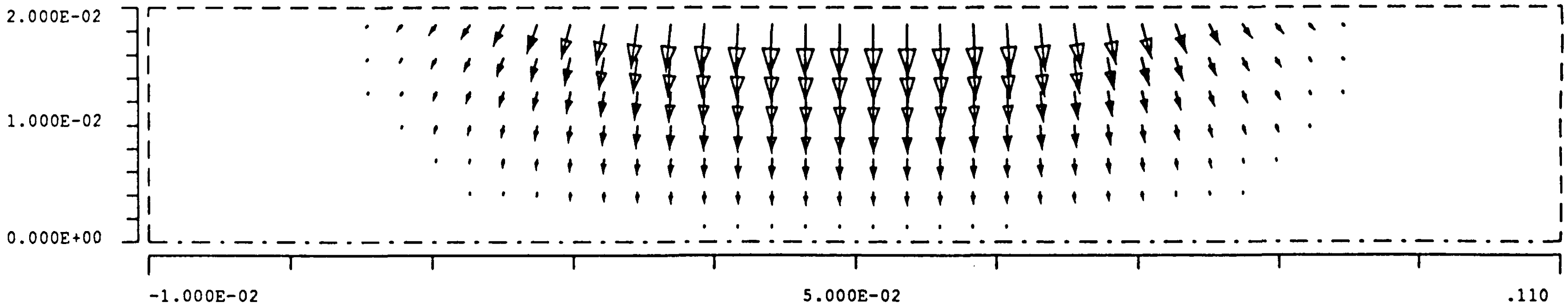
P--:3.20

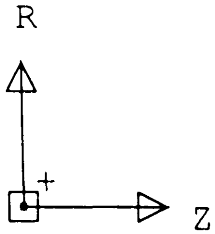
#ARROW

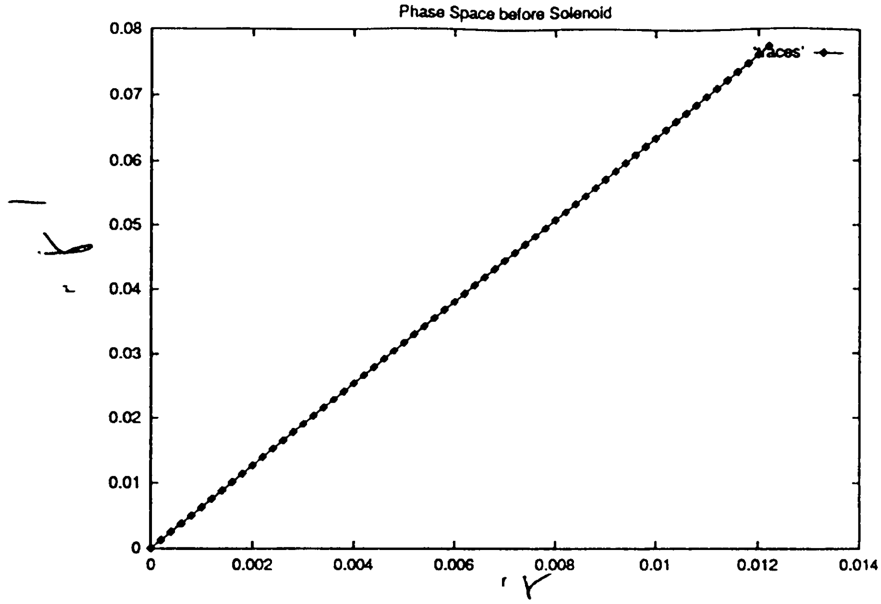
COORDINATES/M
FULL RANGE / WINDOW
R[.0000, .23500]
[.0000, .020000]
Z[-.066500, .16500]
[-.0100000, .11000]

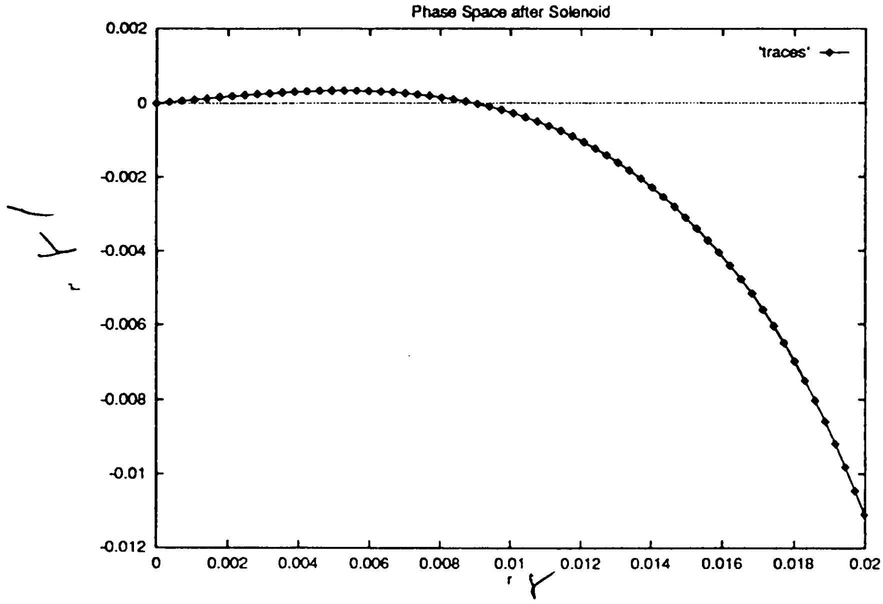
SYMBOL - FORCE
INTERPOLATE.- 0
LOGSCALE....- 0.00000E+0
MAX ARROW - 5.11612E-03

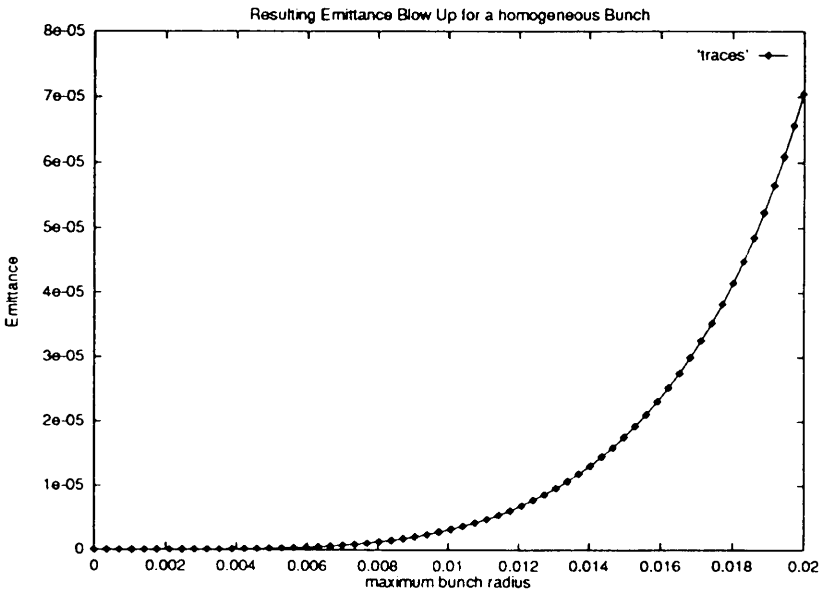
Radial / Longitudinal Forces inside the Solenoid





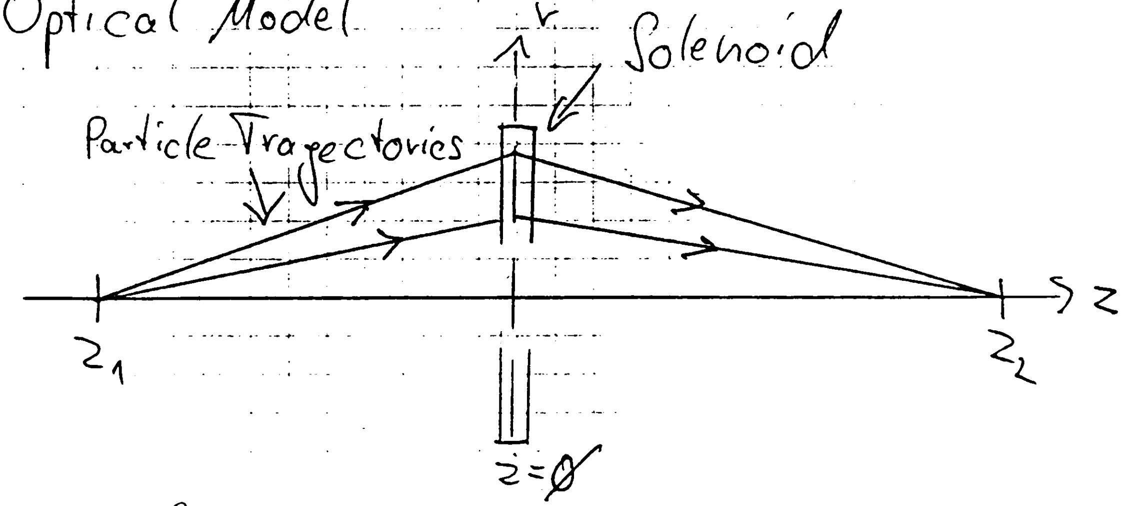

Phase Space before Solenoid
'traces'
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
r


Phase Space after Solenoid
'traces'
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
r

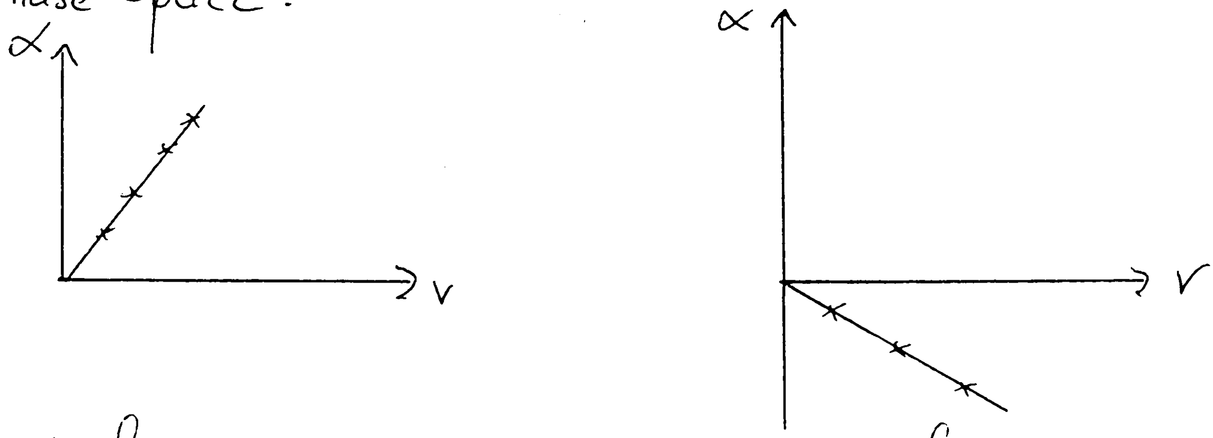

Resulting Emittance Blow Up for a homogeneous Bunch
'traces'
Emittance
8e-05
7e-05
6e-05
5e-05
4e-05
3e-05
2e-05
1e-05
0
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
maximum bunch radius

Effects of the Solenoid on Multibunch Operation

Optical Model



Phase Space:



$\alpha = f_1 \cdot r$ $\qquad\qquad$ $\alpha = f_2 \cdot r$

$f_1 = -\frac{1}{z_1}$ $\qquad\qquad$ $f_2 = -\frac{1}{z_2}$

Solenoidal Strength: $f_S = f_1 - f_2$

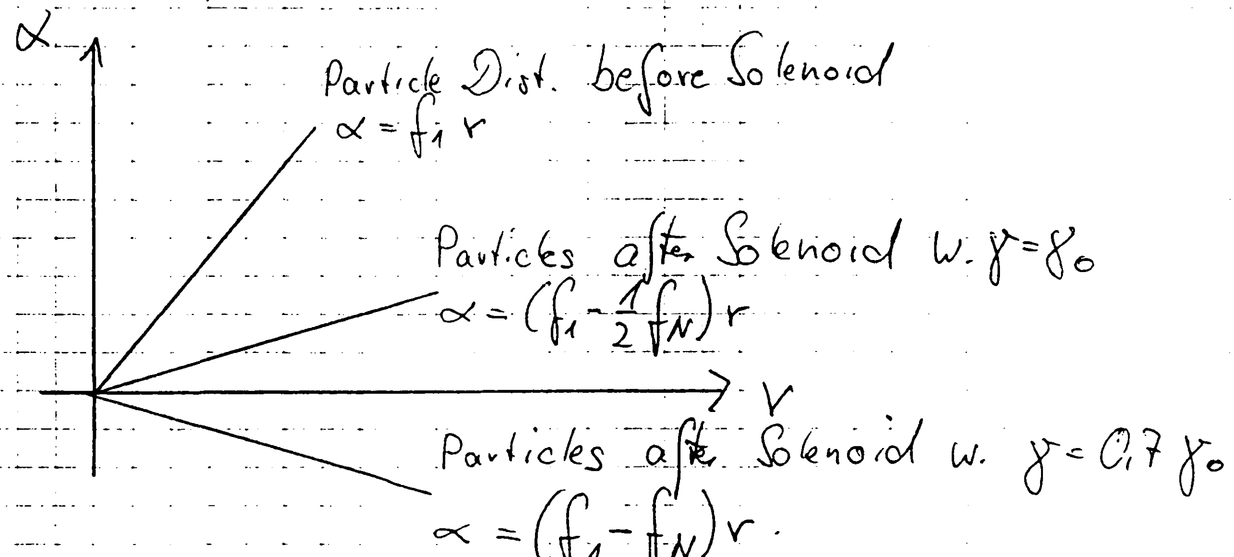
- Multibunch Operation:

Strength: $f_S \sim \frac{1}{\gamma^2}$

Beam Loading: $\gamma = 0{,}7\,\gamma_0 \cdots \gamma_0$

$f_S = 0{,}5\, f_N \cdots f_N$

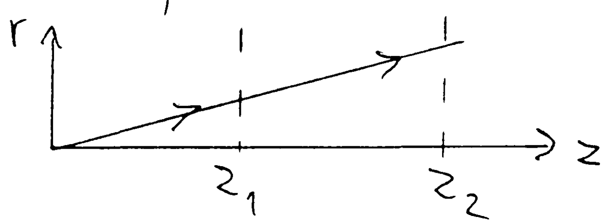
Objective: Small Variation of Beam Divergence with γ

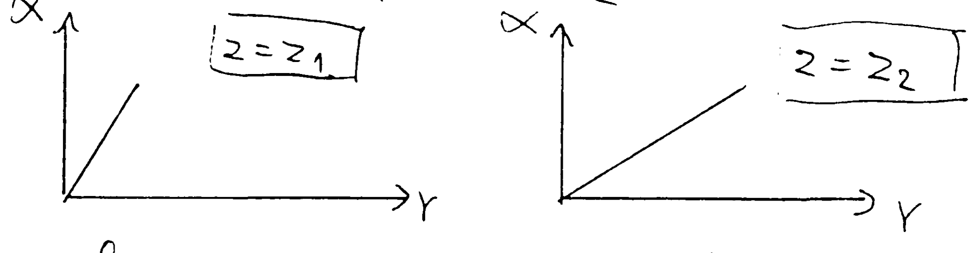


Effect independent of Bunch Radius and mean Flight Angle!

1. Possibility: Reduce $\frac{\alpha}{r}$ of bunches at Gun Exit

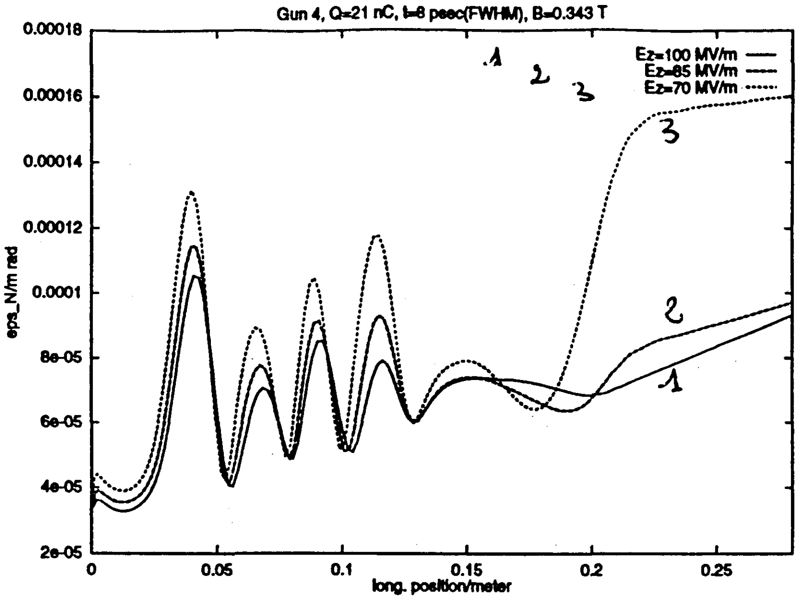
2. Possibility: Small Bunch Radius / Shift Solenoid

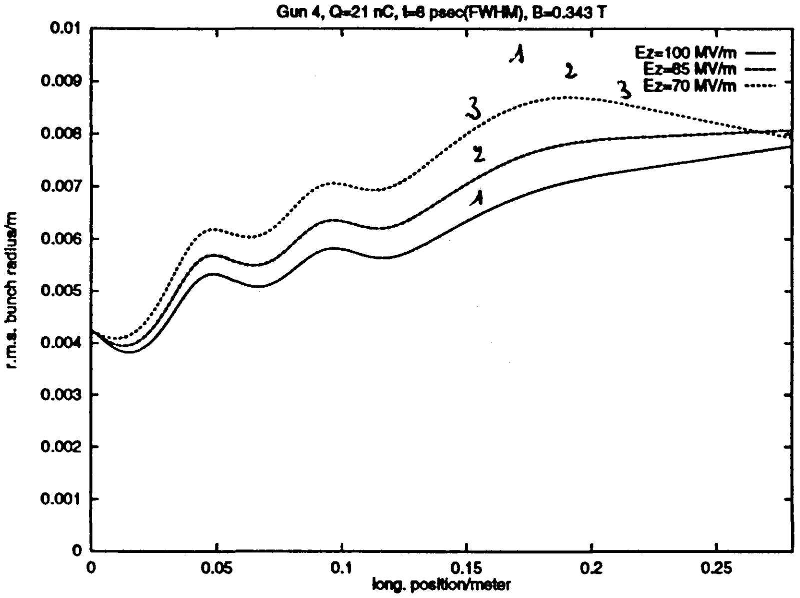


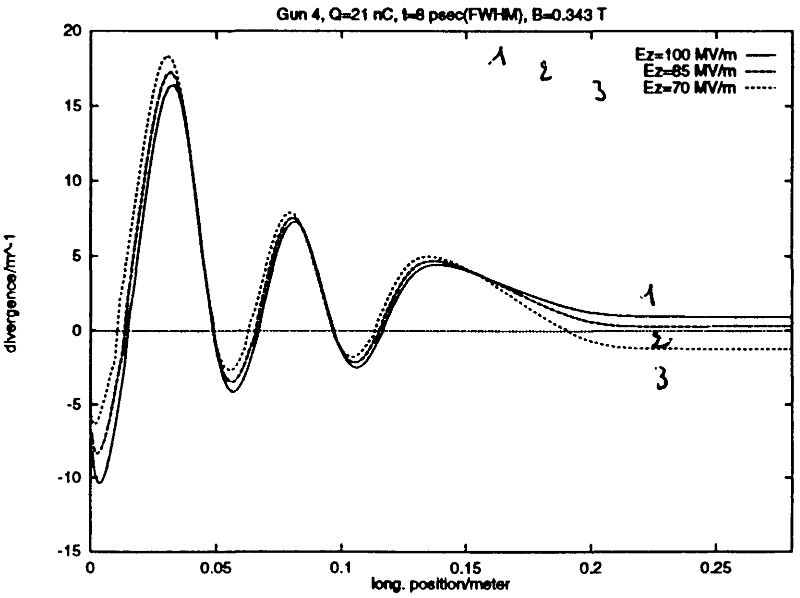


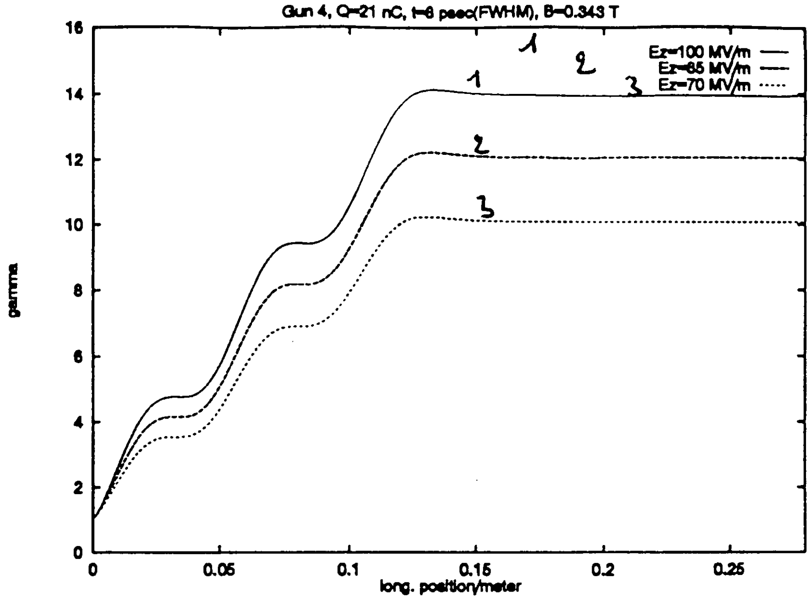
$f = \frac{\alpha}{r}$ gets smaller with increasing z

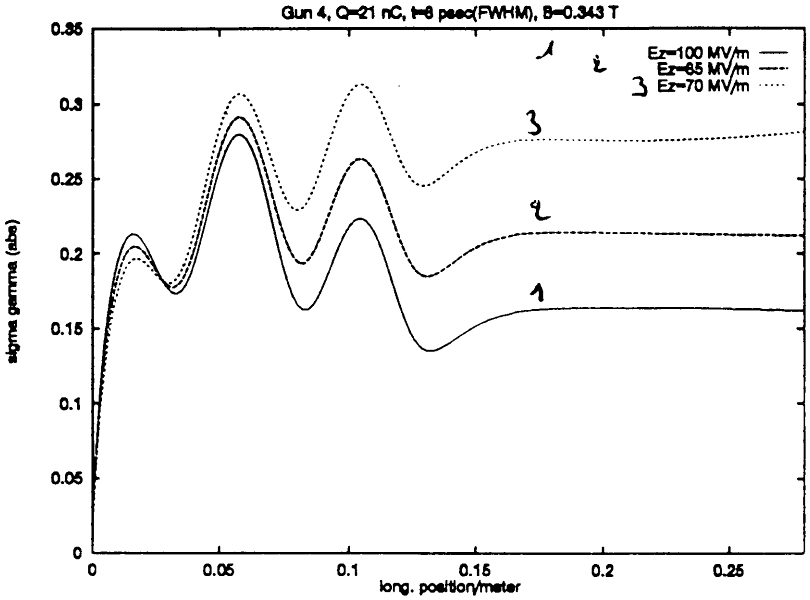
Limit given by beam pipe radius

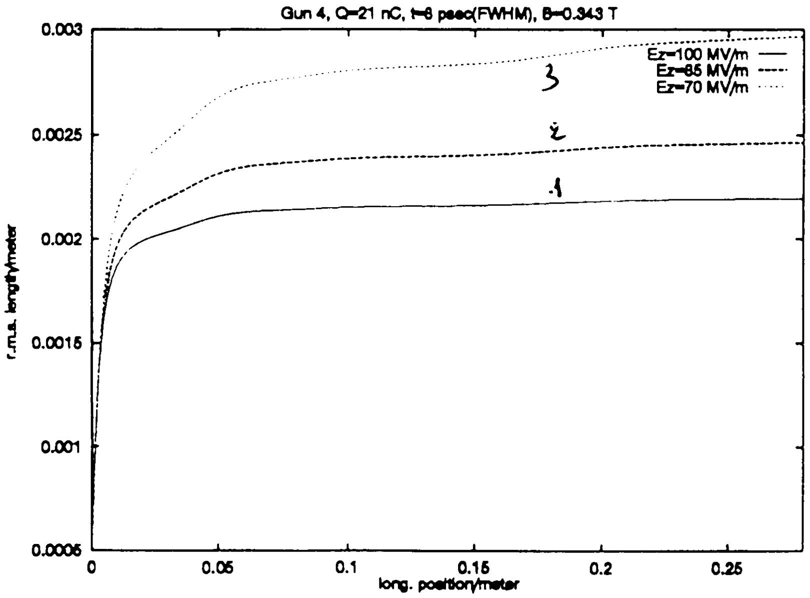

Gun 4, Q=21 nC, t=8 psec(FWHM), B=0.343 T
Ez=100 MV/m
Ez=85 MV/m
Ez=70 MV/m
eps_N/m rad
long. position/meter
1
2
3


Gun 4, Q=21 nC, t=8 psec(FWHM), B=0.343 T
Ez=100 MV/m
Ez=85 MV/m
Ez=70 MV/m
r.m.s. bunch radius/m
long. position/meter
1
2
3


Gun 4, Q=21 nC, t=8 psec(FWHM), B=0.343 T
Ez=100 MV/m
Ez=85 MV/m
Ez=70 MV/m
divergence/m^-1
long. position/meter
1
2
3


Gun 4, Q=21 nC, t=6 psec(FWHM), B=0.343 T
Ez=100 MV/m
Ez=85 MV/m
Ez=70 MV/m
gamma
long. position/meter
1
2
3


Gun 4, Q=21 nC, t=6 psec(FWHM), B=0.343 T
Ez=100 MV/m
Ez=85 MV/m
Ez=70 MV/m
sigma gamma (abs)
long. position/meter
1
2
3


Gun 4, Q=21 nC, t=6 psec(FWHM), B=0.343 T
Ez=100 MV/m
Ez=85 MV/m
Ez=70 MV/m
r.m.s. length/meter
long. position/meter
1
2
3

Beam Parameters Gun 4

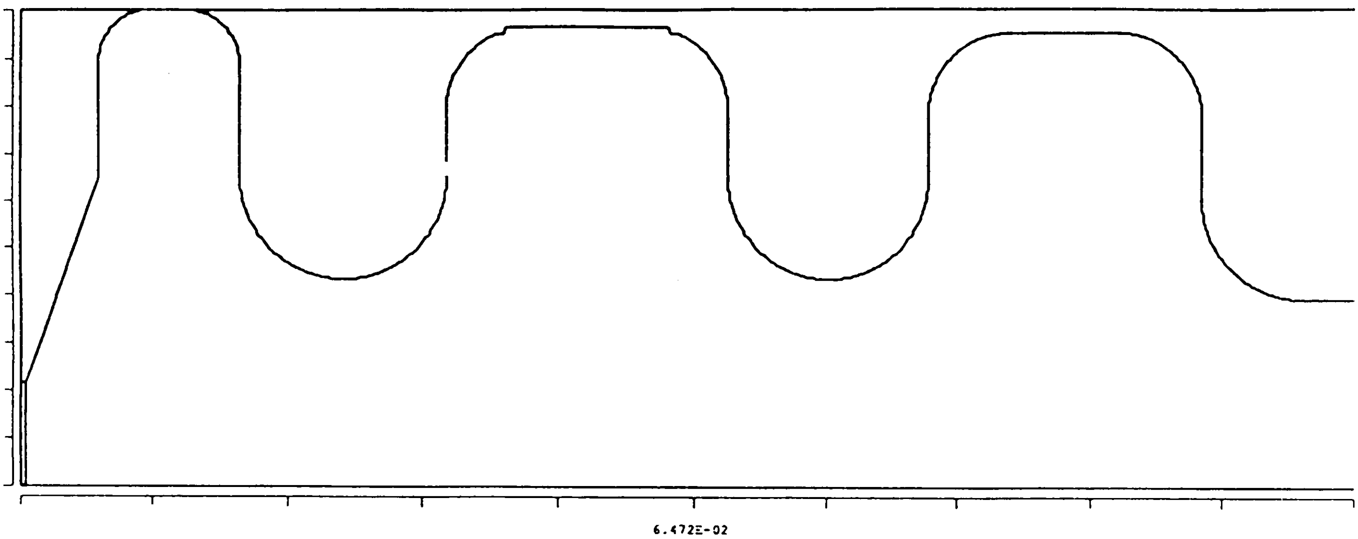
Bunch: 21 nC, 8 psec (FWHM)

Solenoid: 0,343 T

All Values 50 mm behind solenoid

$E_{z,max}$	70 MV/m	85 MV/m	100 MV/m
r.m.s. radius/mm	7,98	8,06	7,73
α/r $\left(\frac{mrad}{mm}\right)$	-1,22	0,329	0,95
α (mrad)	-8,7	2,15	6,70
γ	10,08	12,05	13,94
$\frac{\delta\gamma}{\gamma}$ (%)	2,77	1,74	1,16
r.m.s. length/mm	2,96	2,46	2,20

Current Design



- Refinement of Gun No. 4 (No drastic Changes)
- Rounded Half Cell
- 20 Degree Cone Angle
- Cell Lengths: 31/47/47 mm
- Exit Beam Pipe Ø: 36 mm

Comparison Current Design / Gun #4

Bunch: 21 nC, 8 psec. (FWHM)
No Solenoid
Acc. Field: 85 MV/m (Avg. for Bunchtrain)
Values: 25 mm behind Gun Exit

	Gun 4	Current Design	
Photo Cathode Ø radius/mm	6	6	9
r.m.s. radius/mm	7,08	6,39	6,93
$\frac{\alpha}{r}$ $\left(\frac{mrad}{mm}\right)$	4,46	4,24	3,51
α	29,07	24,91	22,96
γ	12,095	12,105	12,09
$\frac{\delta\gamma}{\gamma}$ (%)	1,68	1,53	1,37
r.m.s. length/mm	2,4	2,52	2,07
ε_N / mm mrad	66	64	52

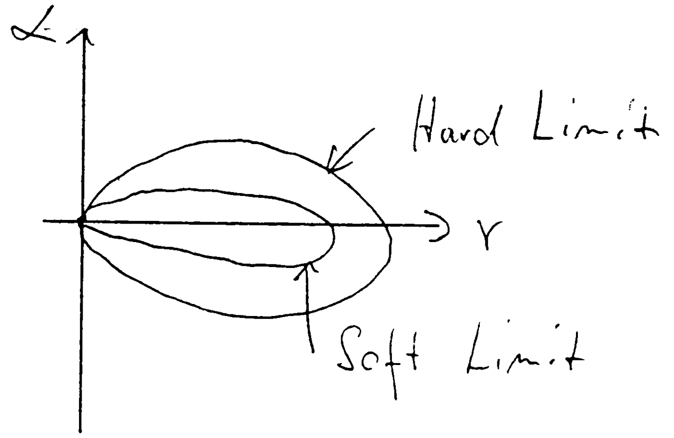
Concluding Remarks

- Laser Spot Size $r = 9\,mm$ Development Aim?

- Variation of Bunch Parameters sufficient for HCAS

- For Modular Design
  Definition of Region of „Acceptance"

  $\gamma \in [10; 14]$



- Limits for Single Bunch Parameters?