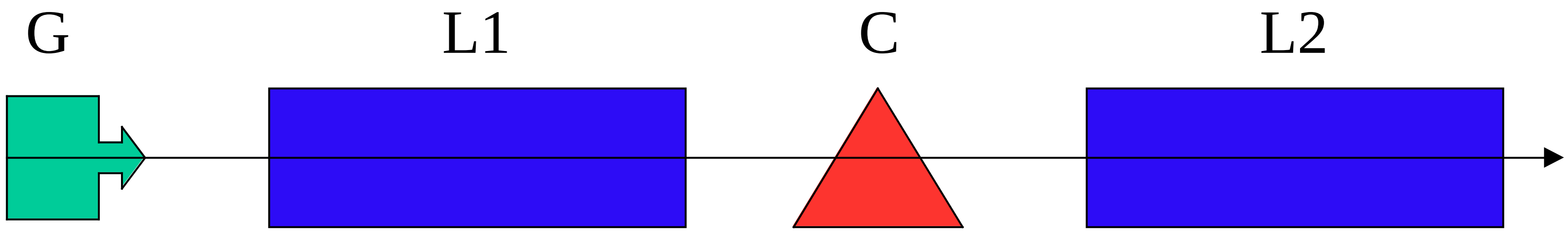
SPARX NOTE 06
October 2001

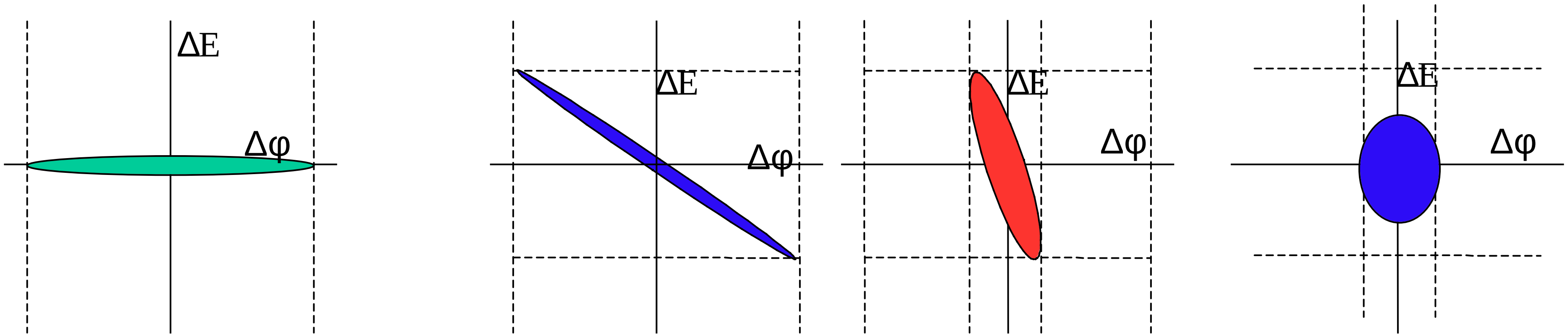
CONTRIBUTIONS TO THE FEL MEETING ON BUNCH COMPRESSOR ISSUES

HOMDYN Study For Possible Sparx Linac Layouts

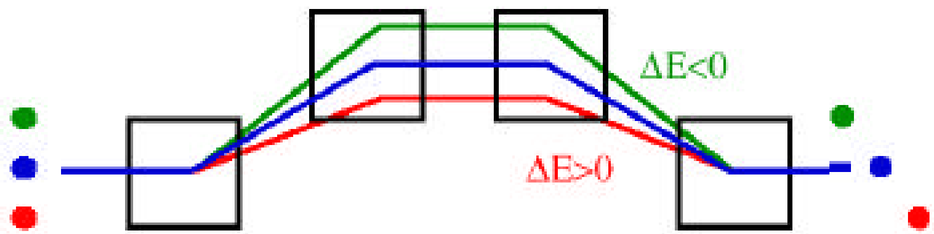
Massimo Ferrario

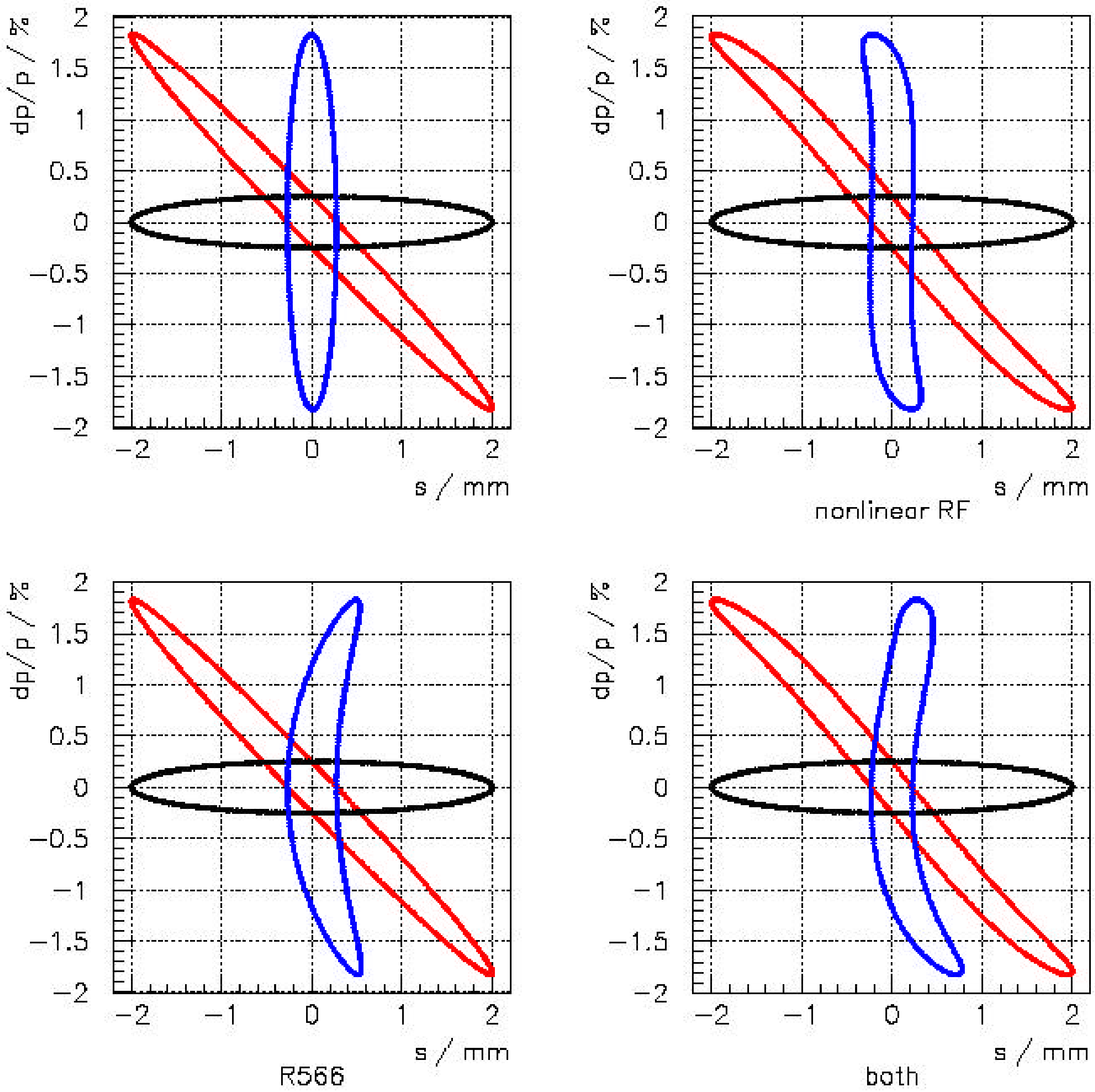
INFN-LNF





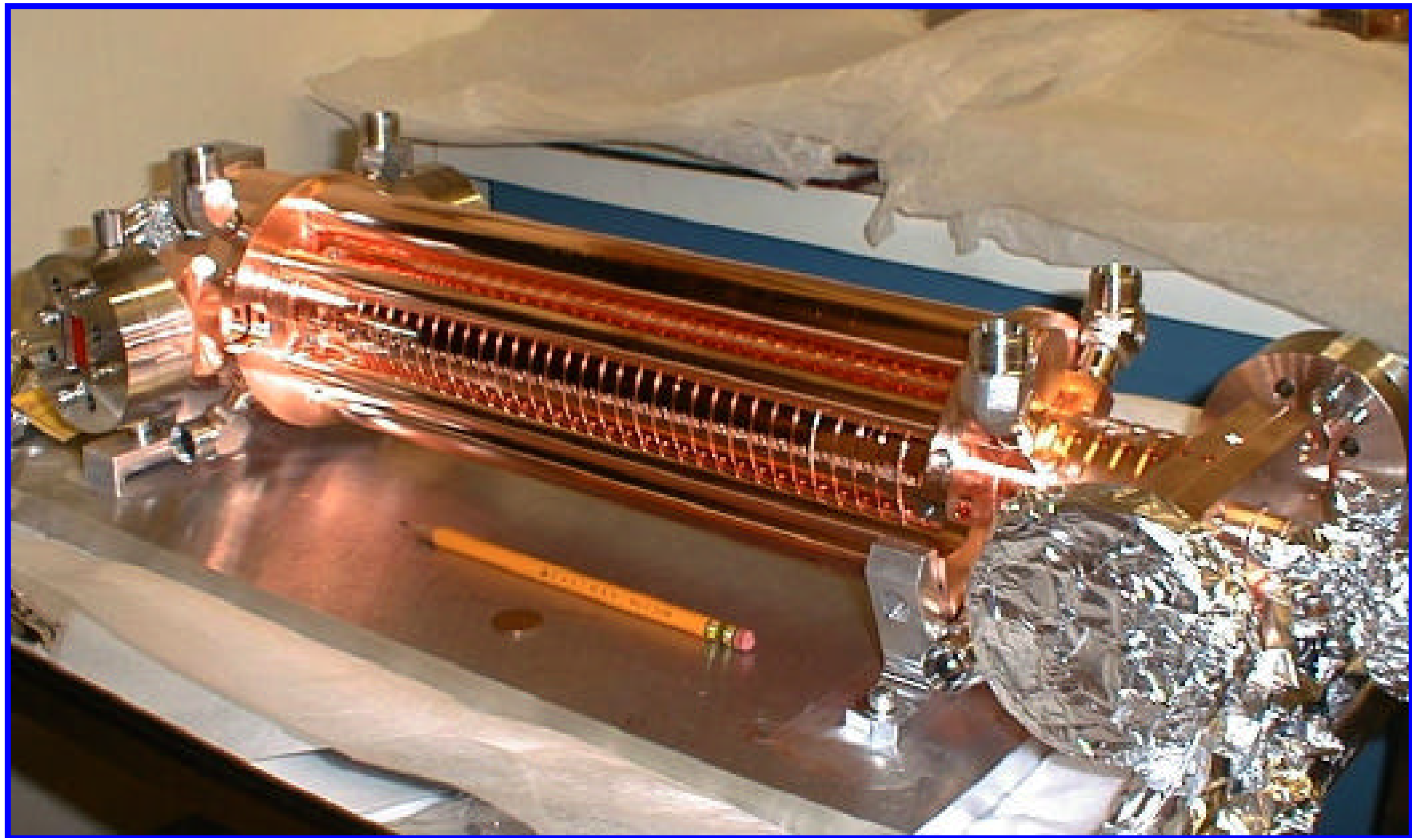
$$\Delta s = R_{56}\ \Delta E / E$$





dp/p / %
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
−2
−1
0
1
2
s / mm
nonlinear RF
R566
both

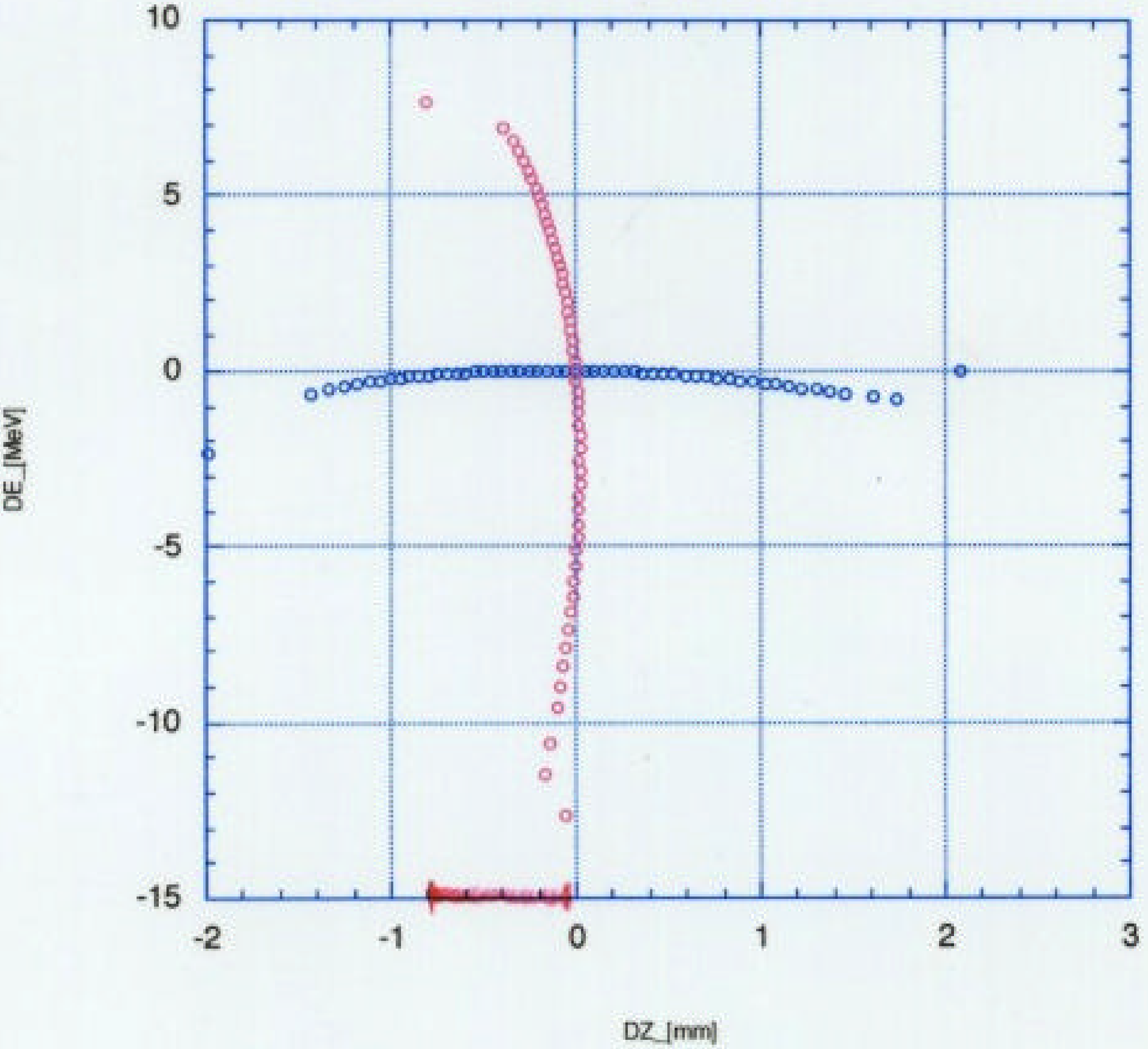
0.5-Meter X-Band RF Accelerating Structure



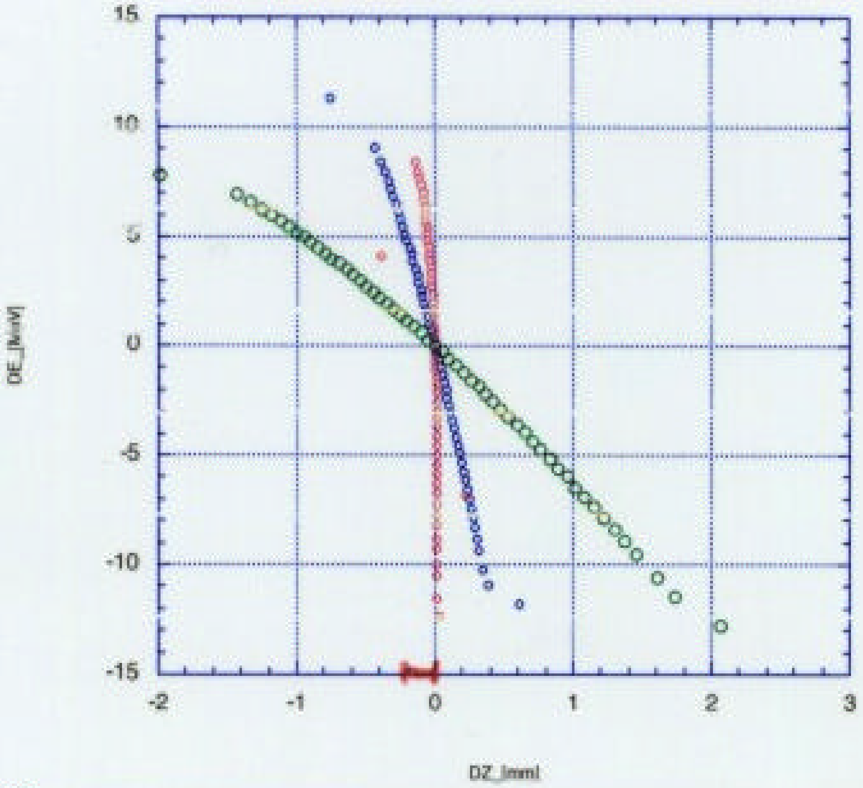
V = 22 MV
f = 11.4 GHz
P = 30 MW
L = 0.6 m
E = 250 MeV

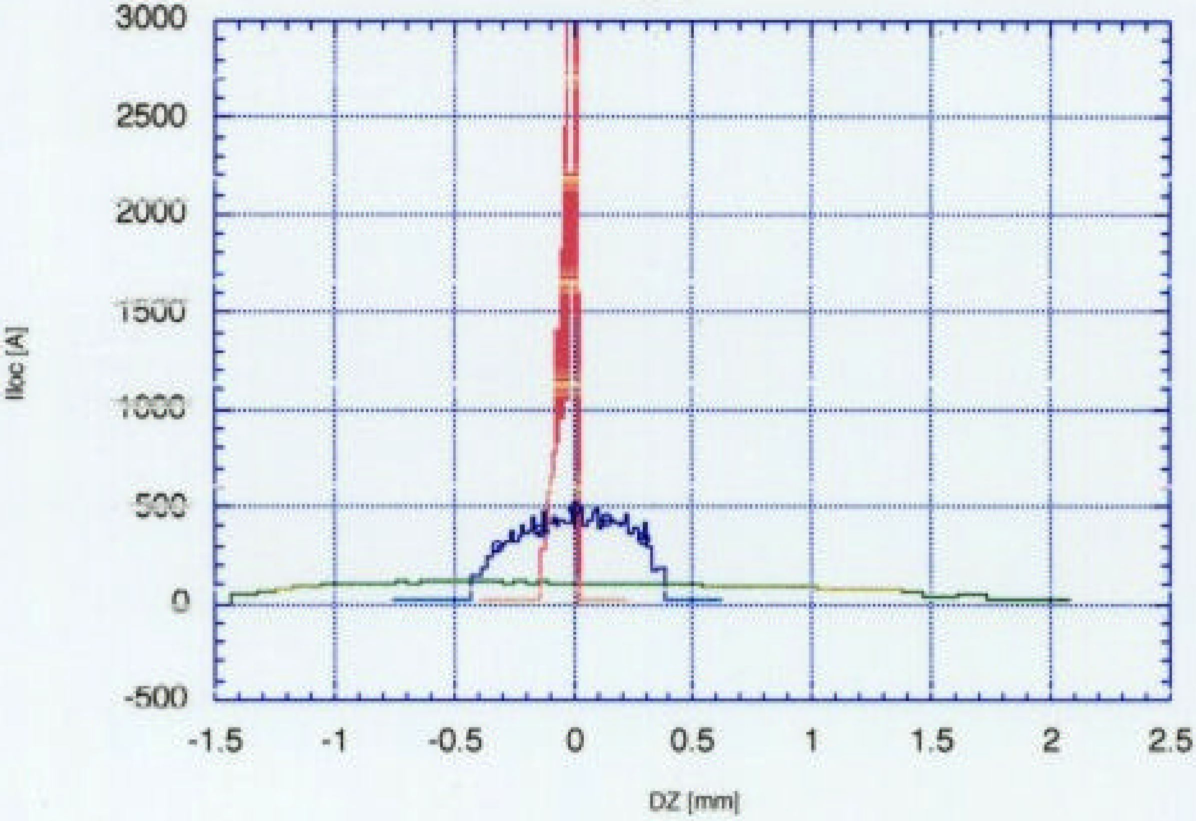
Courtesy of P. Emma, SLAC

SENZA III ARMONICA



CON III ARMONICA



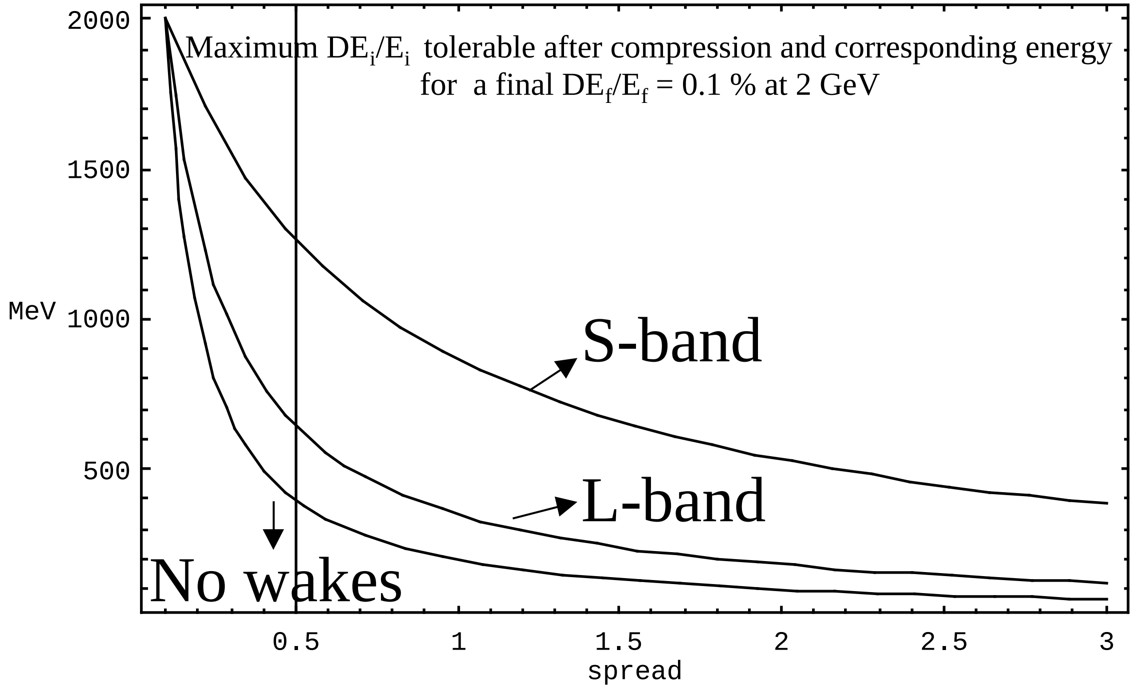


POST COMPRESSION

ENERGY SPREAD COMPENSATION

$$\frac{\Delta E_f}{E_f} = \left(\frac{\Delta E_i}{E_i}\right)\frac{E_i}{E_f} - \frac{Ne^2}{2}\frac{W(\sigma_z)}{E_f}\left(\frac{E_f - E_i}{G}\right)$$

Adiabatic damping — Short range longitudinal wake fields

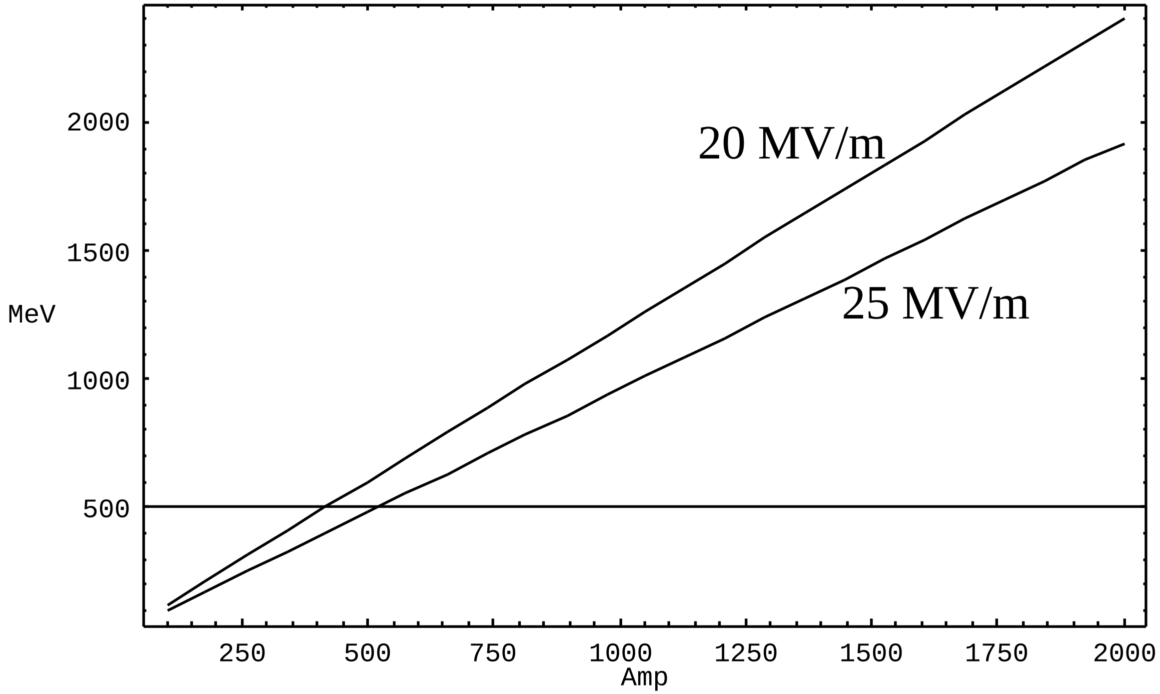


$$\left(\frac{\Delta\varepsilon}{\varepsilon_0}\right)_{\mathrm{CSR}} \sim \frac{N^2 |R_{56}|^{5/3}}{\varepsilon_N \sigma_z^{8/3}},$$

$$\left(\frac{\Delta\varepsilon}{\varepsilon_0}\right)_{\mathrm{ISR}} \sim E^6 \frac{|R_{56}|^{5/2}}{\varepsilon_N},$$

SPACE CHARGE DOMINATED BEAMS
(Serafini, Rosenzweig PRE 55 (97))

$$\gamma = \sqrt{\frac{2}{3}}\,\frac{\hat{I}}{I_o \varepsilon_{th} \gamma'} \qquad \gamma' = \frac{2}{\sigma}\sqrt{\frac{\hat{I}}{2 I_0 \gamma}}$$

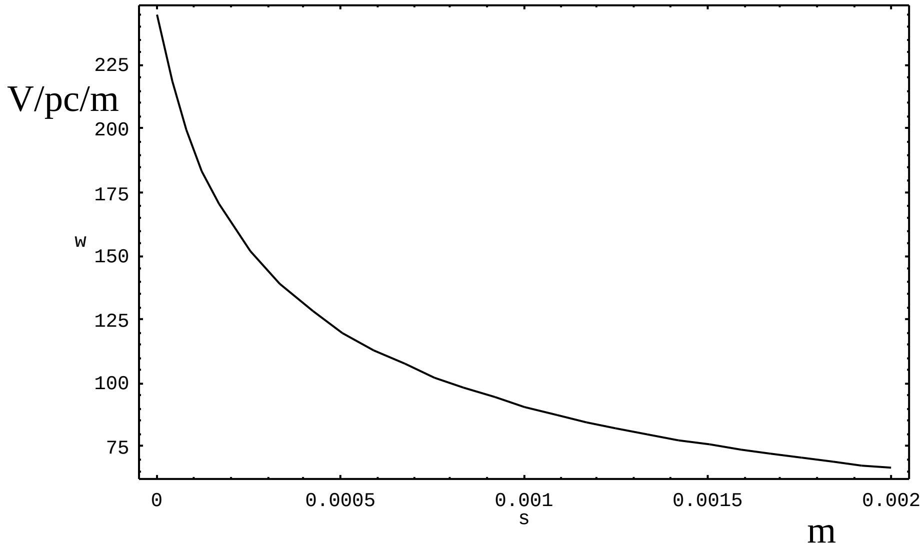


Warning: the 2 kA beam is space charge dominated untill ~ 2 GeV

WAKE FIELDS IN HOMDYN

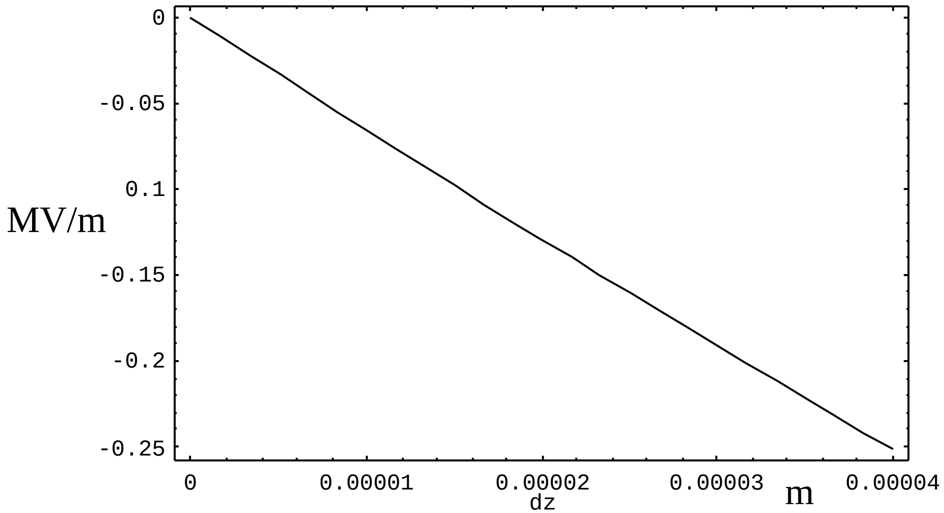
Delta Wake Function

$$W_{//}(s) = \frac{Z_o c}{\pi a \sqrt{a^2 + 8.6 s\lambda}}$$



Convolution with a Uniform charge distribution

$$E_z(s) = \frac{2QcZ_o}{l_b 8.6 \lambda\pi}\left(1 - \sqrt{1 + \frac{8.6\lambda s}{a^2}}\right)$$



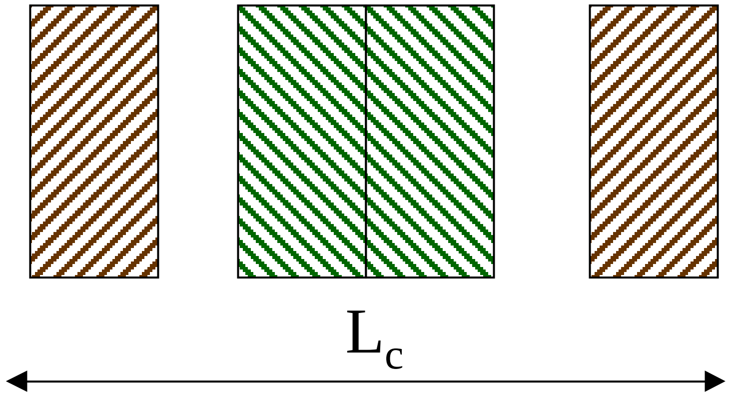
Wake field along a 40 μm bunch

COMPRESSOR/WIGGLER MODEL

IN HOMDYN

$$\dot{z} = c\left(\beta - \frac{K^2}{\gamma^2}\left(1 - \cos\left(2k_z z\right)\right)\right)$$

$$\vartheta = \frac{K}{\gamma}$$



$$R_{56} = L_c \vartheta^2$$

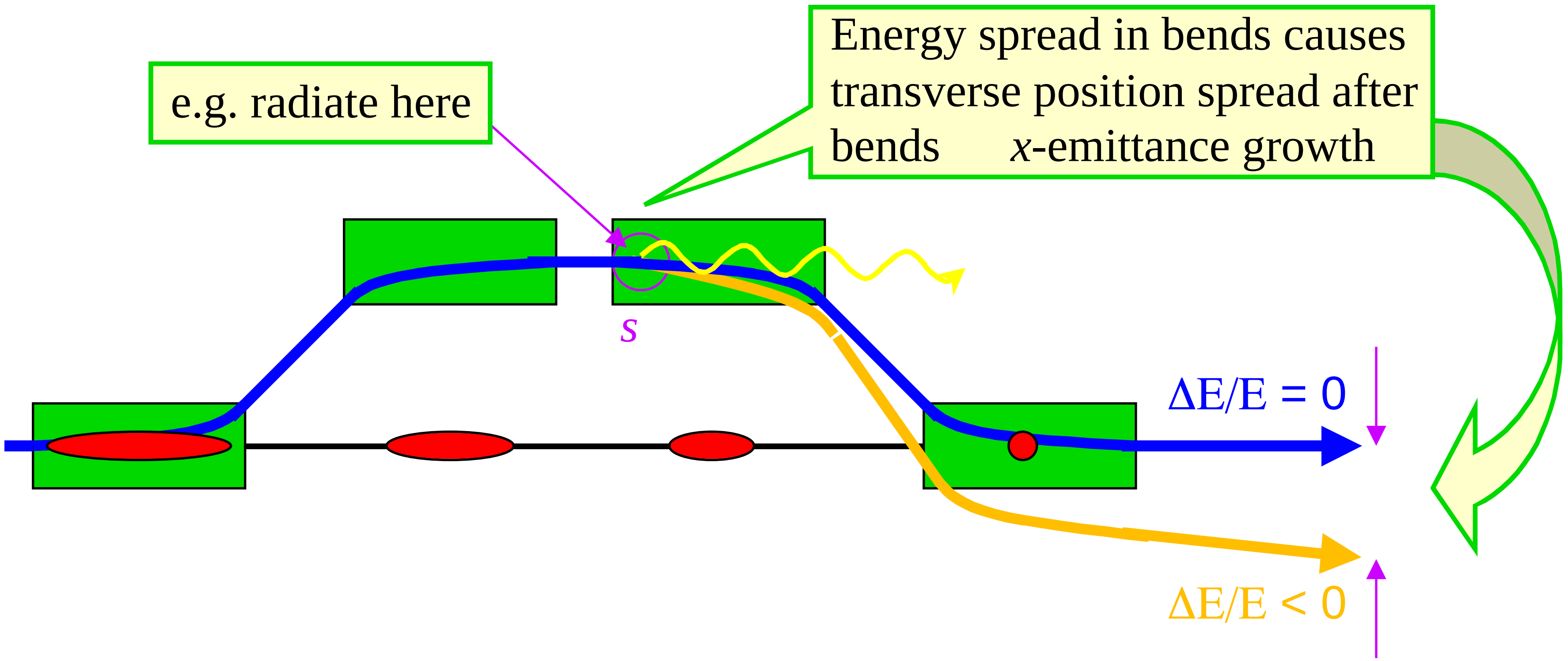
$$\ddot{X} = -\left(\frac{cKk_x}{\gamma}\right)^2 X$$

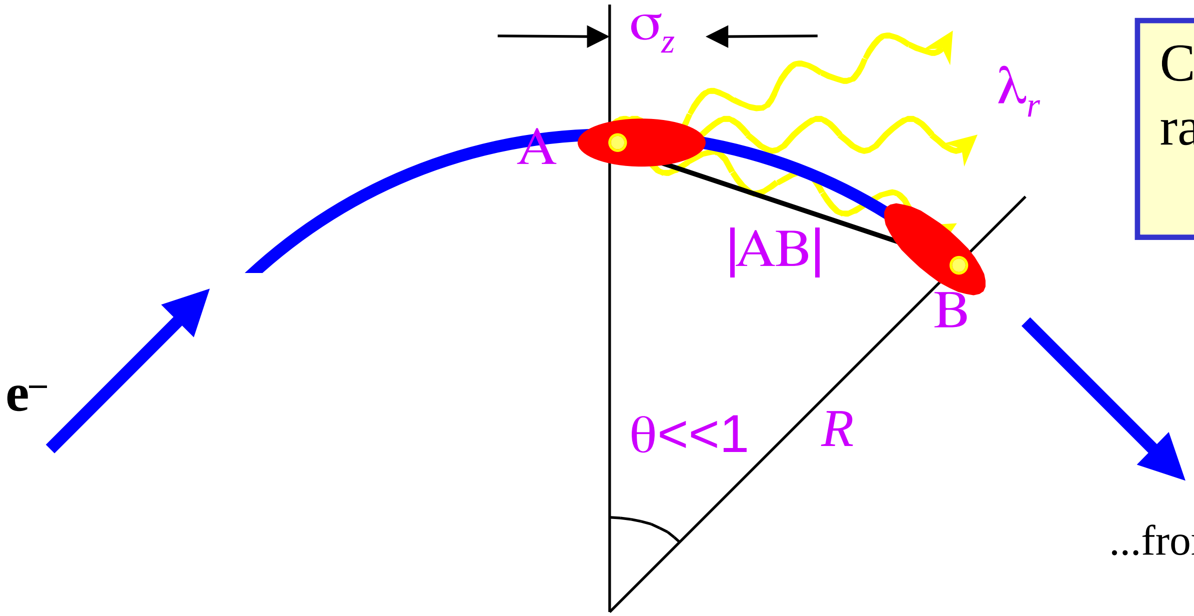
$$K = \frac{e\hat{B}}{\sqrt{2}\, mck_z}\left(1 + \frac{k_x^2}{2}X^2 + \frac{k_y^2}{2}Y^2\right)$$

$$\ddot{Y} = -\left(\frac{cKk_y}{\gamma}\right)^2 Y$$

$$k_x^2 + k_y^2 = k_z^2 = \left(\frac{2\pi}{\lambda_u}\right)^2$$

CSR Effects - Emittance Growth





Coherent radiation for:
$\lambda_r >> \sigma_z$

...from Derbenev, et. al.

Free space radiation from bunch tail at point ***A*** overtakes bunch head, a distance s ahead of the source, at the point ***B*** which satisfies...

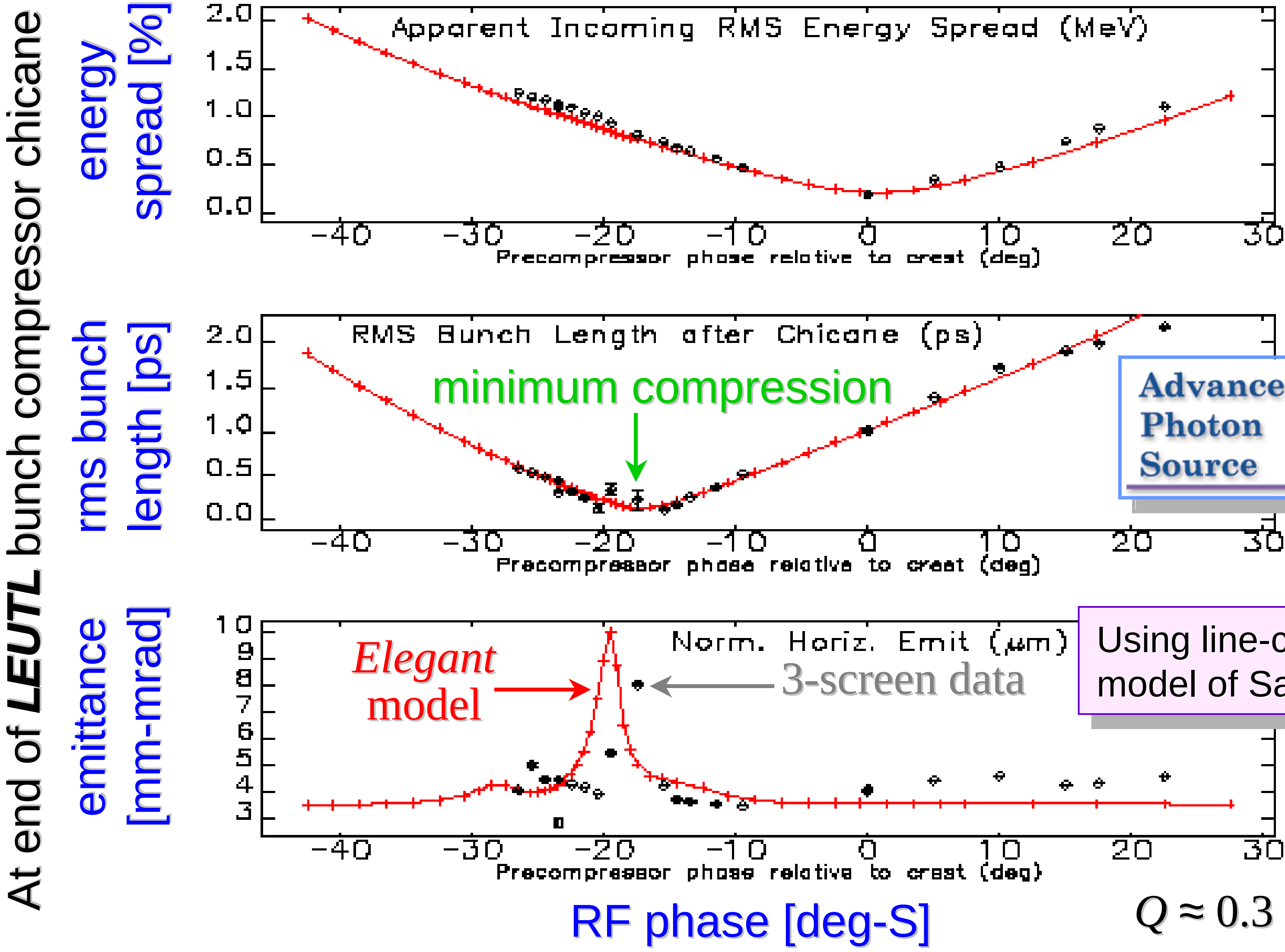
$$s = \mathrm{arc}(\boldsymbol{AB}) - |\boldsymbol{AB}| = R\theta - 2R\sin(\theta/2) \approx R\theta^3/24$$

and for $s = \sigma_z$ (rms bunch length) the overtaking distance is

$$L_0 \equiv |\boldsymbol{AB}| = R\theta \approx (24\sigma_z R^2)^{1/3}$$, (HERA: $L_0 > 100$ m, LCLS: $L_0 \sim 1$ m)

Courtesy of P. Emma, SLAC

LEUTL CSR Measurements (*ANL*)



Advanced Photon Source

Using line-charge CSR model of Saldin, et. al.

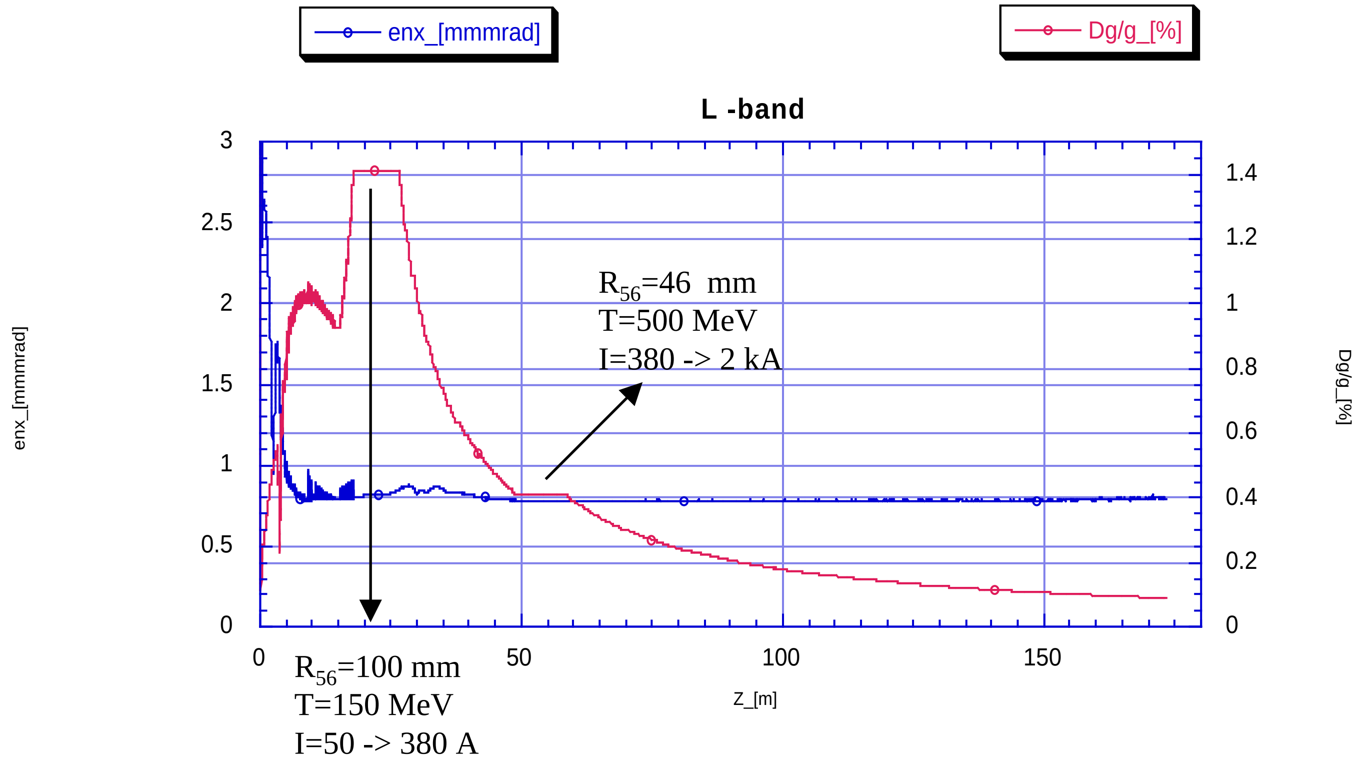
$Q \approx 0.3$ nC

← over-compression

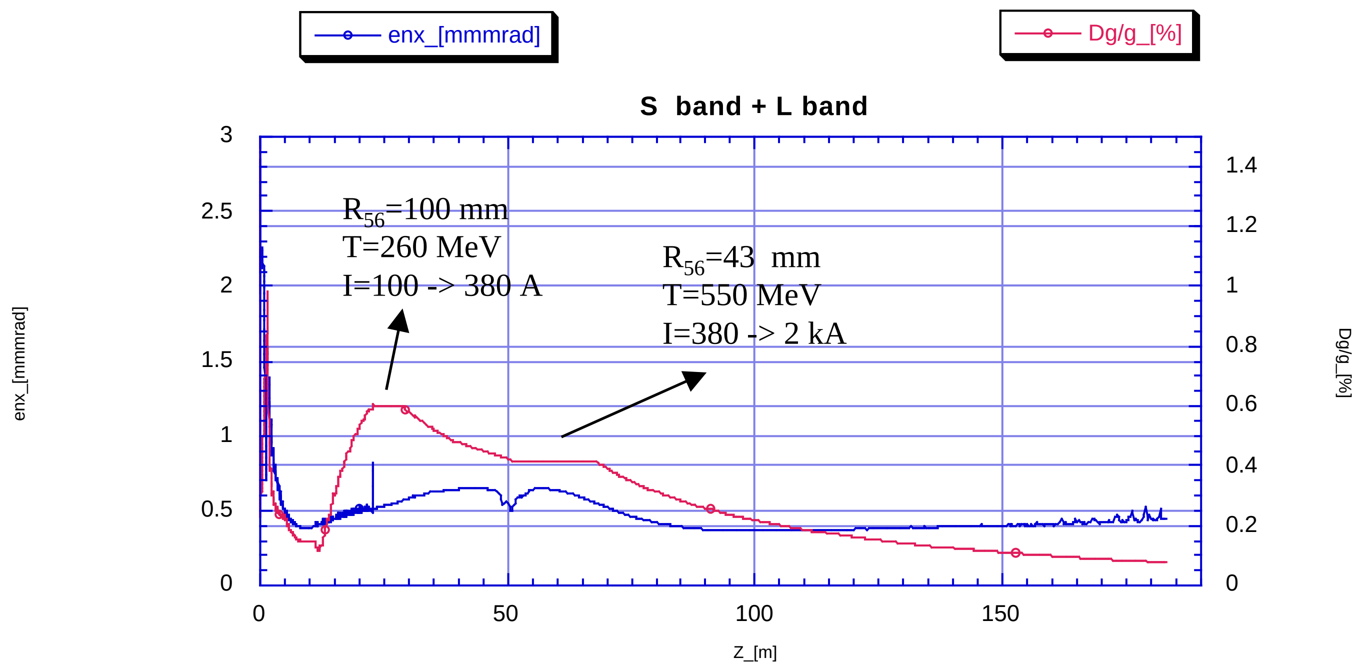
Courtesy M. Borland, J. Lewellen, ***ANL***

M. Borland, **RPAH001**

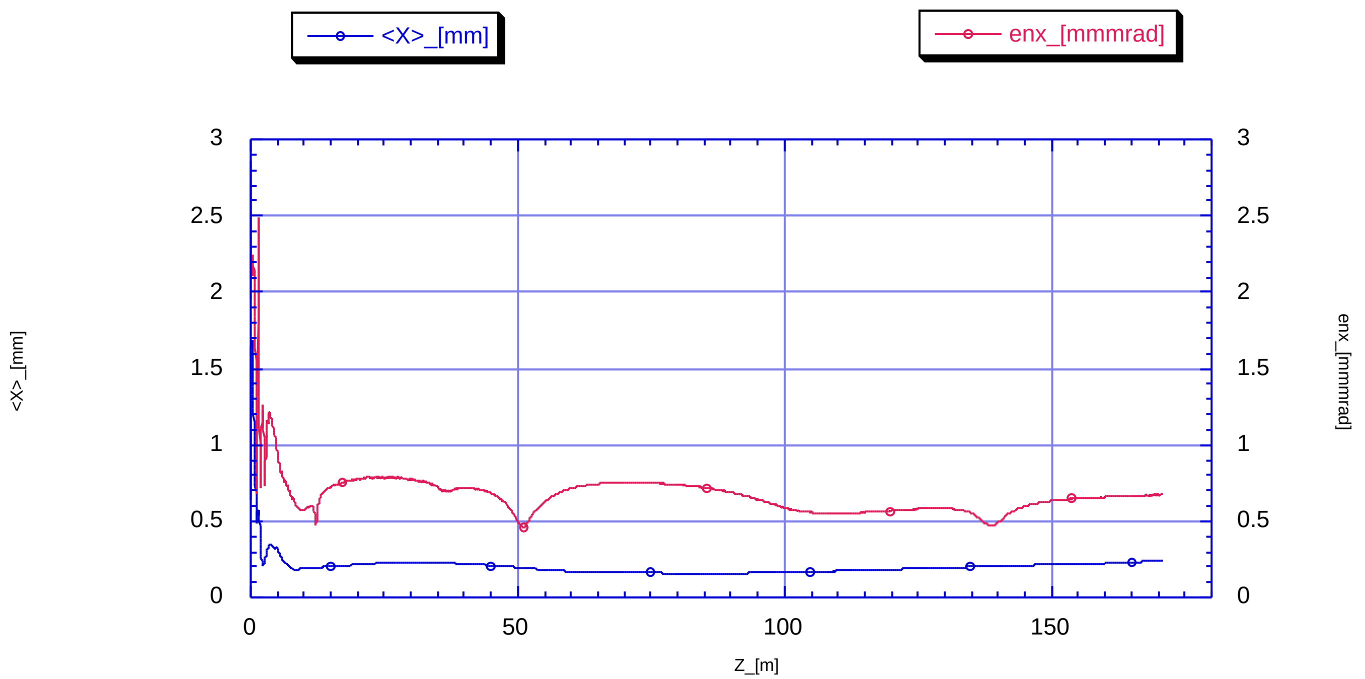
L-band injector + Linac



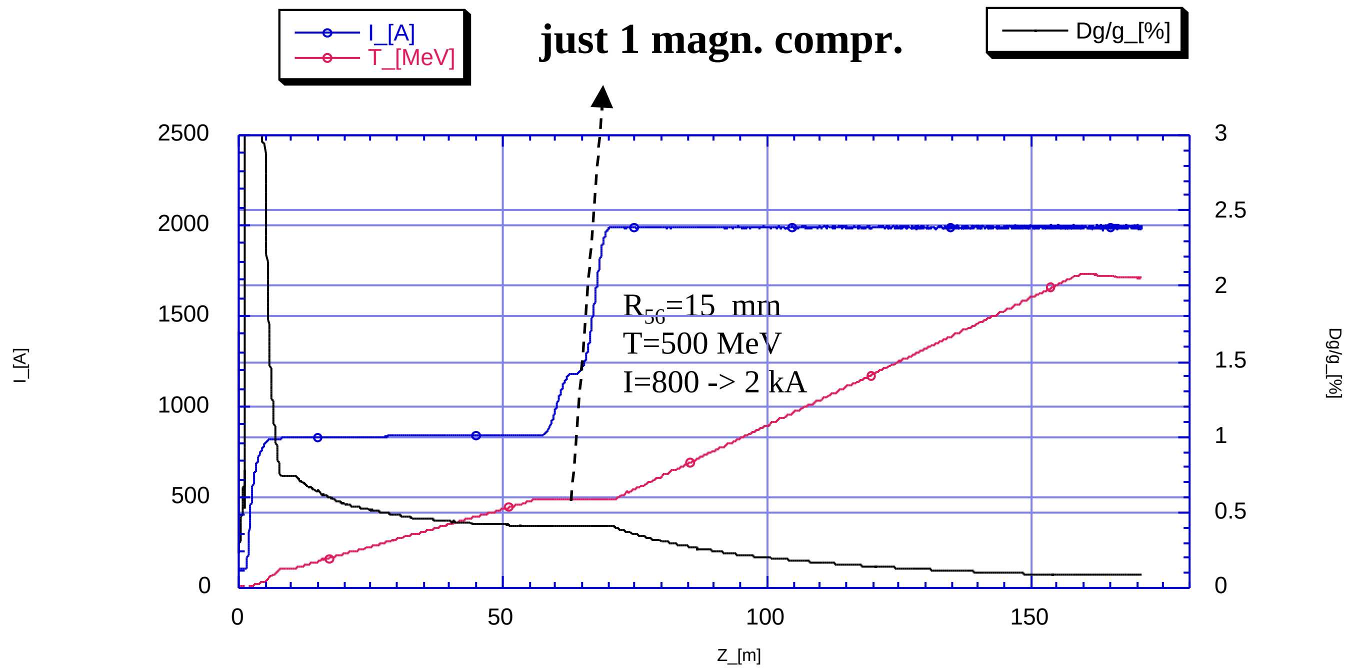
S-band inj. + L-band Linac



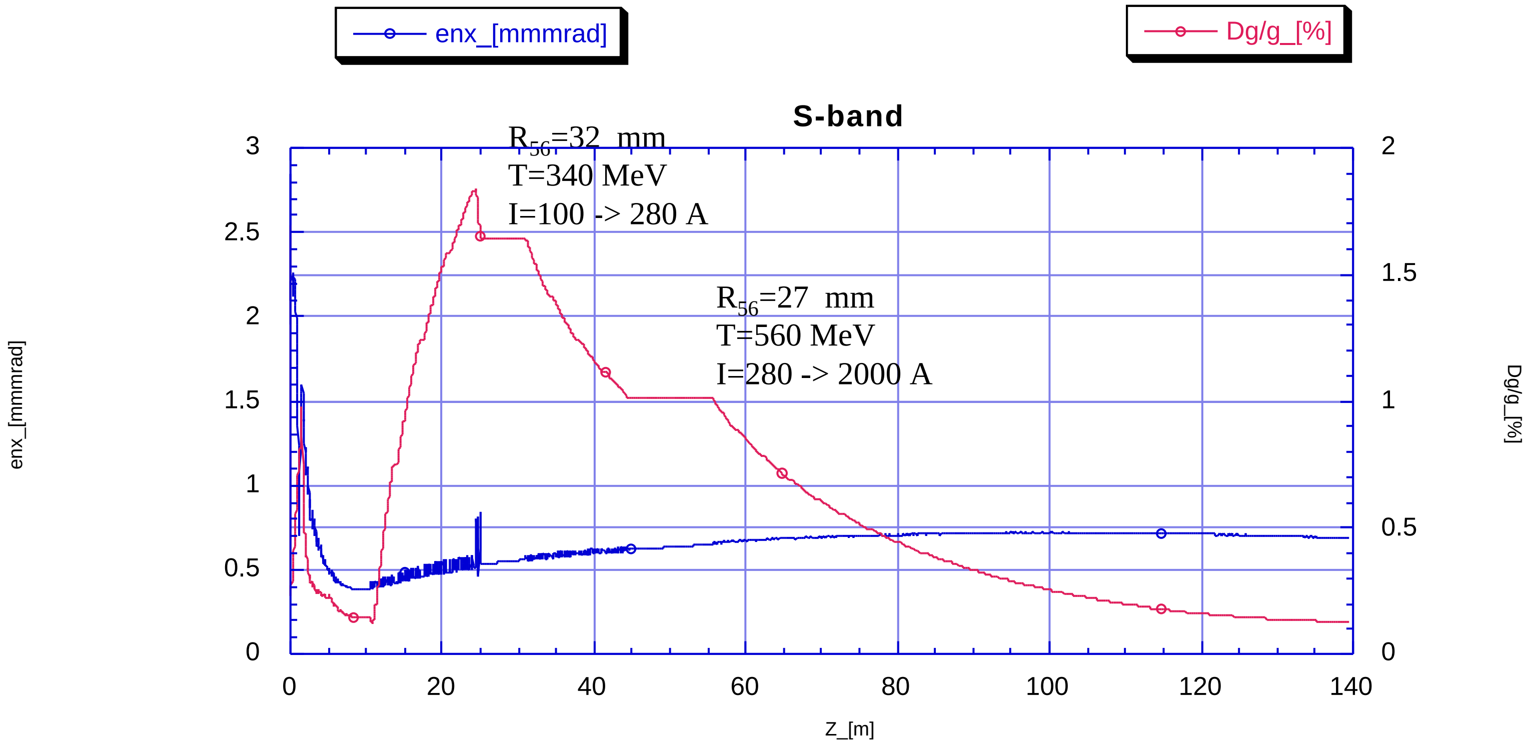
S-band inj. + L-band Linac with RF compressor (velocity bunching)

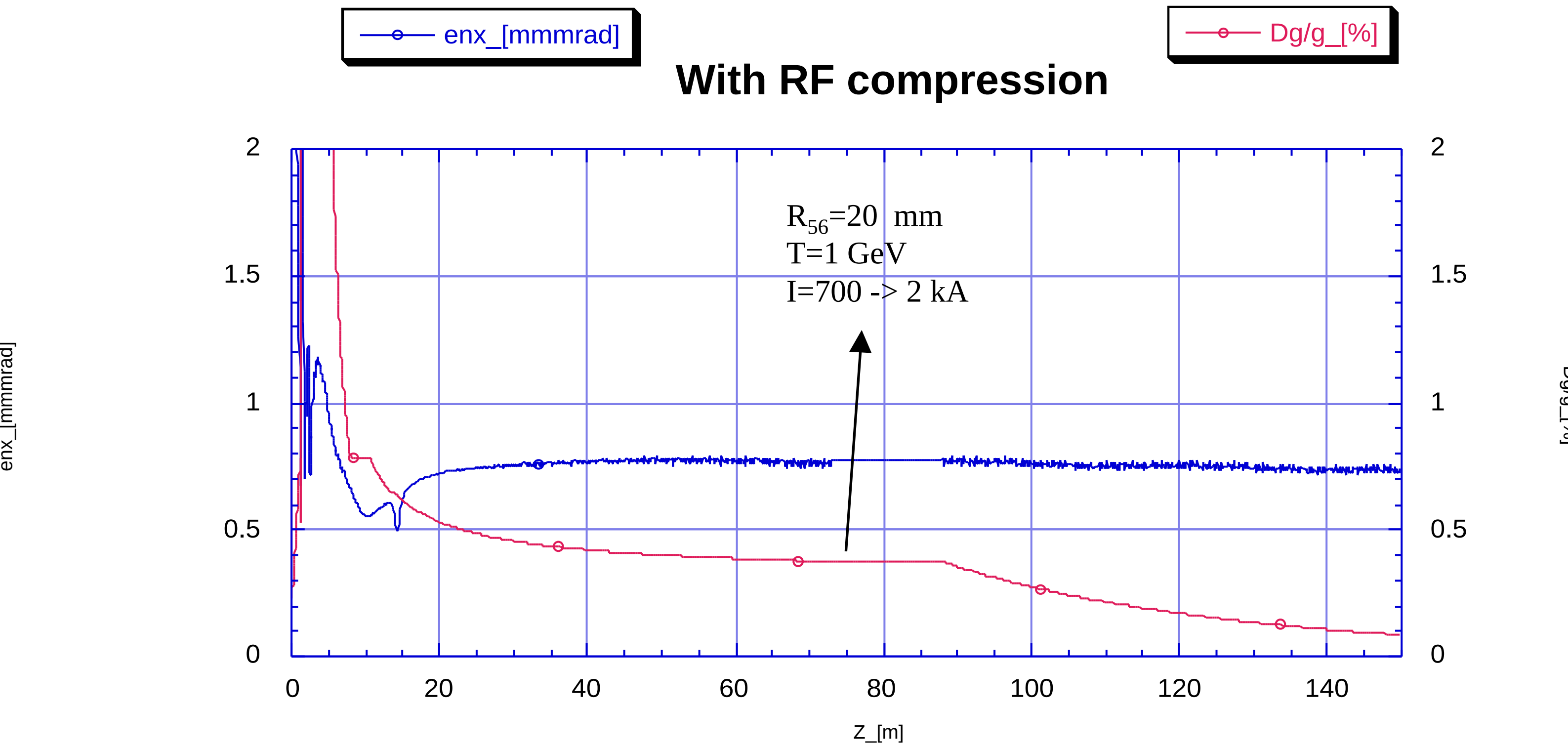


just 1 magn. compr.



S-band inj. + S-band Linac

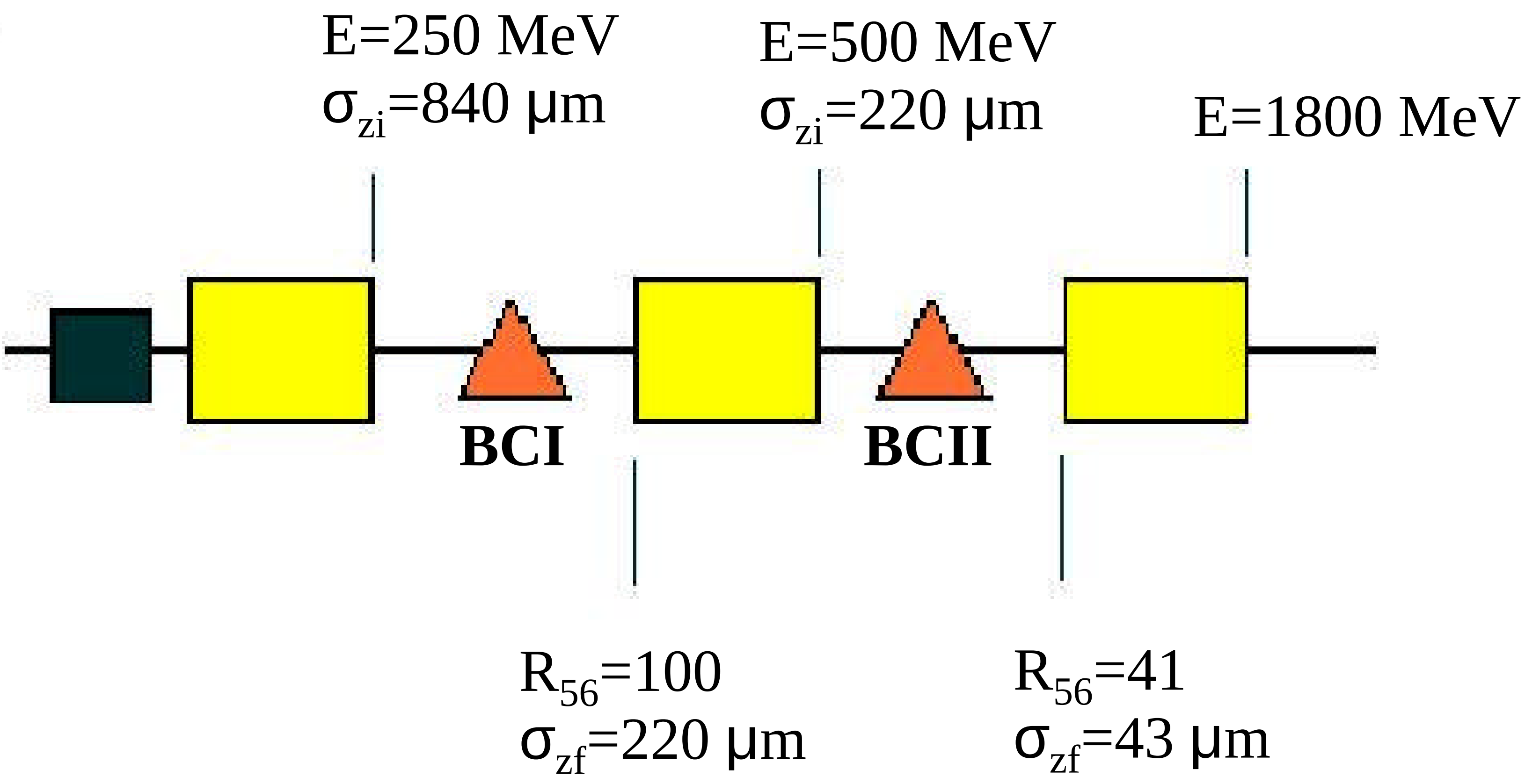




Bunch Compressor preliminary scheme

Cristina Vaccarezza (INFN-LNF)

X-FEL Layout



Bunch Compressor main parameters

$$R_{56} \quad 2\theta_B^2 \left(\Delta L + \frac{2}{3} L_B\right)$$

$$\sigma_\delta = (.22)\frac{N r_e L_B}{\gamma R^{2/3} \sigma_z^{4/3}}$$

$$\frac{\varepsilon}{\varepsilon_0} = \sqrt{1 + \frac{(0.22)^2}{36} \frac{r_e^2 N^2}{\gamma \varepsilon_N \beta} \left(\frac{\theta^5 L_B}{\sigma_z^4}\right)^{2/3} \left[L_B^2 \left(1+\alpha^2\right) + 9\beta^2 + 6\alpha\beta L_B\right]}$$

Beam energy	E	GeV
charge	q	nC
Initial rms bunch length	σ_{zi}	μm
Final rms bunch length	σ_{zf}	μm
rms energy spread throughout chicane	σ_δ	%
Momentum compaction	R_{56}	mm
Total chicane length	L_{tot}	m
Length of each of four dipole magnets	L_B	m
Drift between the dipoles	ΔL	m
Bend angle of each dipole	$\lvert \theta_B \rvert$	deg
Emittance dilution due to CSR (no shielding)	$\Delta\varepsilon_{CSR}/\varepsilon_o$	%
rms CSR relative energy spread (at 250 MeV)	$\sigma_{\delta\ CSR}$	10^{-4}

Bunch Compressor preliminary scheme

type	***E*** (GeV)	$\boldsymbol{R_{56}}$	σ_{zi} (μm)	σ_{zf} (μm)	$\boldsymbol{L_B}$ (m)	$\Delta\boldsymbol{L}$ (m)	L_{tot} (m)	$\lvert\theta_B\rvert$ (deg)	β_x (m)	$\sigma_{\delta\ CSR}$ 10^{-4}	$\Delta\varepsilon_{CSR}/\varepsilon_o$ %
BCI a	.25	100	843	220	.4	1.8	7	8.9	.9	1.3	5.2
BCI b	.25	100	843	220	.2	2.0	6.8	8.9	.9	1.0	3.3
BCII a	.5	41	220	43	.3	5.5	17.7	3.4	.9	2.7	6.9
BCII b	.5	41	220	43	.2	8.0	24.8	2.9	.9	2.3	2.9

Elegant 14.5 (June 2001)
ELEctron Generation And Tracking

- Tracking code in 6-dimensional space thate uses matrices of selectable order, canonical kick elements, numerical integrated elements and any combination thereof.
- The particles distributions can be generated internally or externally by other programs and stored in external files.
- The CSR model used by ELEGANT derives from the results of Saldin *et al* .

  Each dipole is splitted into a user-specified number of pieces (e.g. 100), for each piece the entire beam (e.g. 40000 particles) is propagated using a second or fourth-order canonical integrator, the CSR wake is computed, finally the CSR energy kick is applied.
- The CSR in the drift space is included, different methods are compared.

General Considerations about Compressor Optics

Catia Milardi LNF - INFN

Bunch compressor main issues:

- **bunch length tuning**
- **low $\beta_{x,y}$ to minimize chromatic effects**
- **low η_x to have small contribution to second order isochronicity as well as to transverse emittance.**
- **matching section**
- **isochronicity (for beam diagnostic)**

Bunch Length Tuning

The path length variation with energy is:

$$c\Delta t = R_{51}x + R_{52}x' + R_{56}\Delta p/p + T_{566}(\Delta p/p)^2 + \ldots$$

the first order approximation neglects contribution from T matrix

the achromatic condition implies

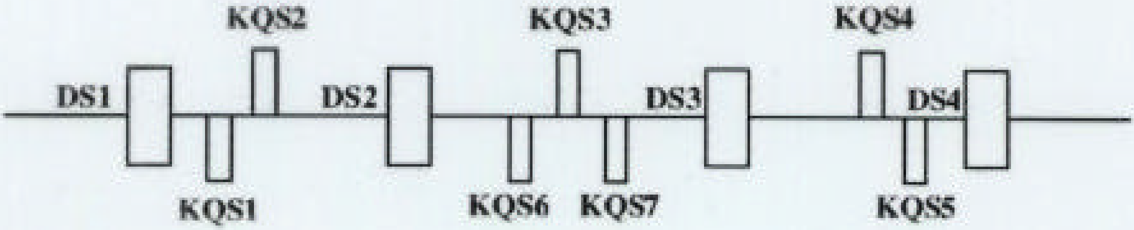
$$R_{51} = R_{52} = 0$$

$$c\Delta t = R_{56}\Delta p/p$$

If $R_{56} = 0$ the section is isochronous

Four-Bends Achromat

$-.16\ [m] \le R_{56} \le .16\ [m]$

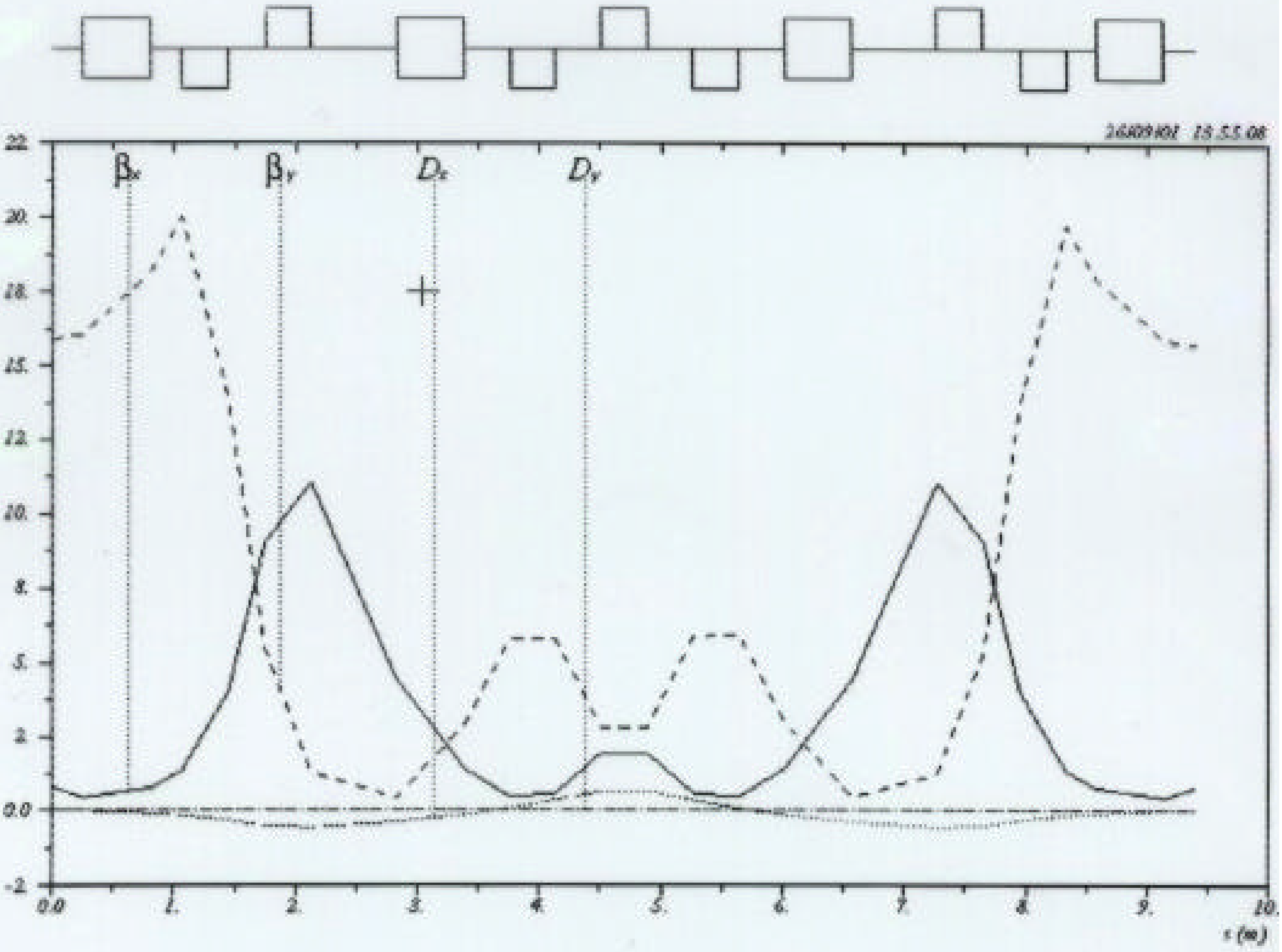


	R_{56} = -.16 [m]	R_{56} = 0 [m]	R_{56} = .16 [m]
KQS1 K [m^{-1}]	-1.04	- .99	-1.28
KQS2	2.18	1.89	1.53
KQS3	1.73	1.84	2.4
KQS4	1.82	1.89	1.53
KQS5	1.50	- .99	-1.28
KQS6	- .86	- .79	-1.55
KQS7	- .91	- .79	-1.55

DS1
DS2 $\alpha = 18^0$
DS3 $\rho = 1.79$ m
DS4

DS1, ..,DS4 are the EPA TL magnets

Four-bends achromat twiss functions



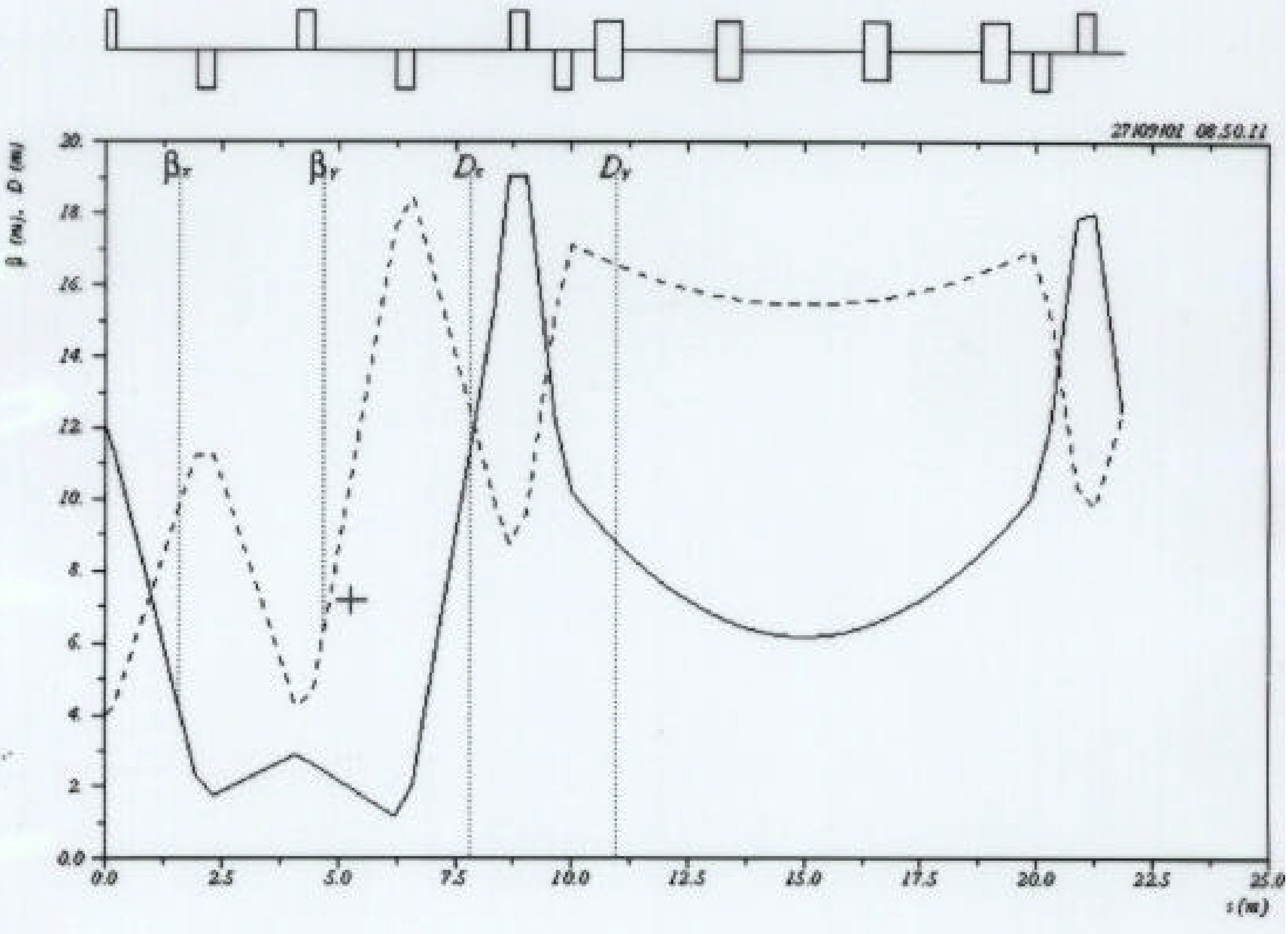
R_{56} ~ .16

assuming no E, z correlation the rsm bunch lenght σ_l is

$$\sigma^2_l = \sigma^2_{l0} + R_{56}\sigma^2_e$$

the achromat can be used to stretch the bunch

Four-bends achromat off twiss functions



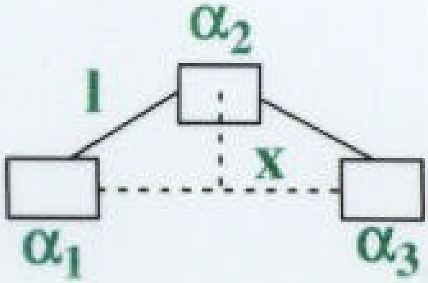
R_{56} = 0. !!

Three-bends achromat

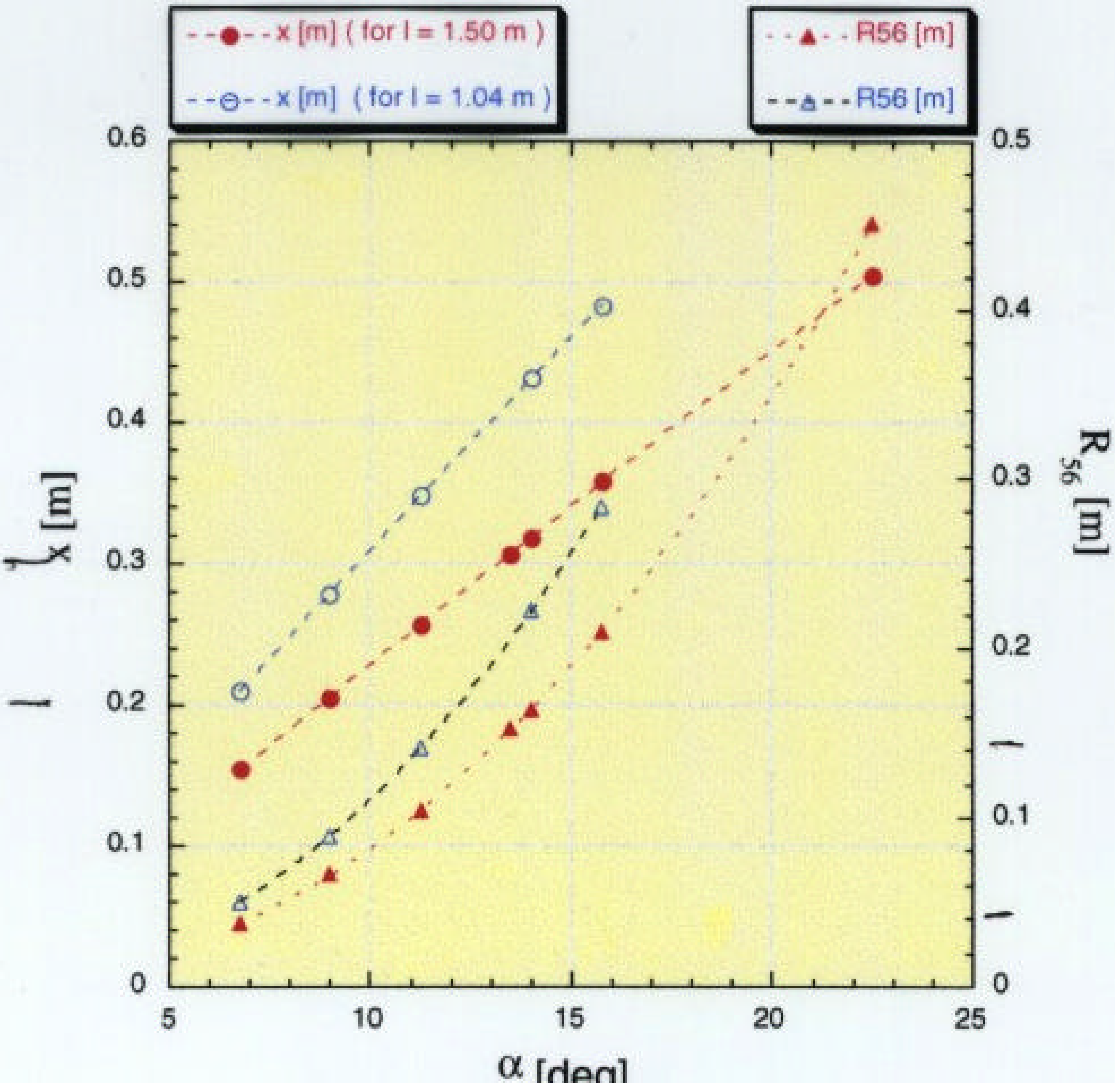
$\alpha_1 = \alpha_3$

$\alpha_2 = 2\,\alpha_1$

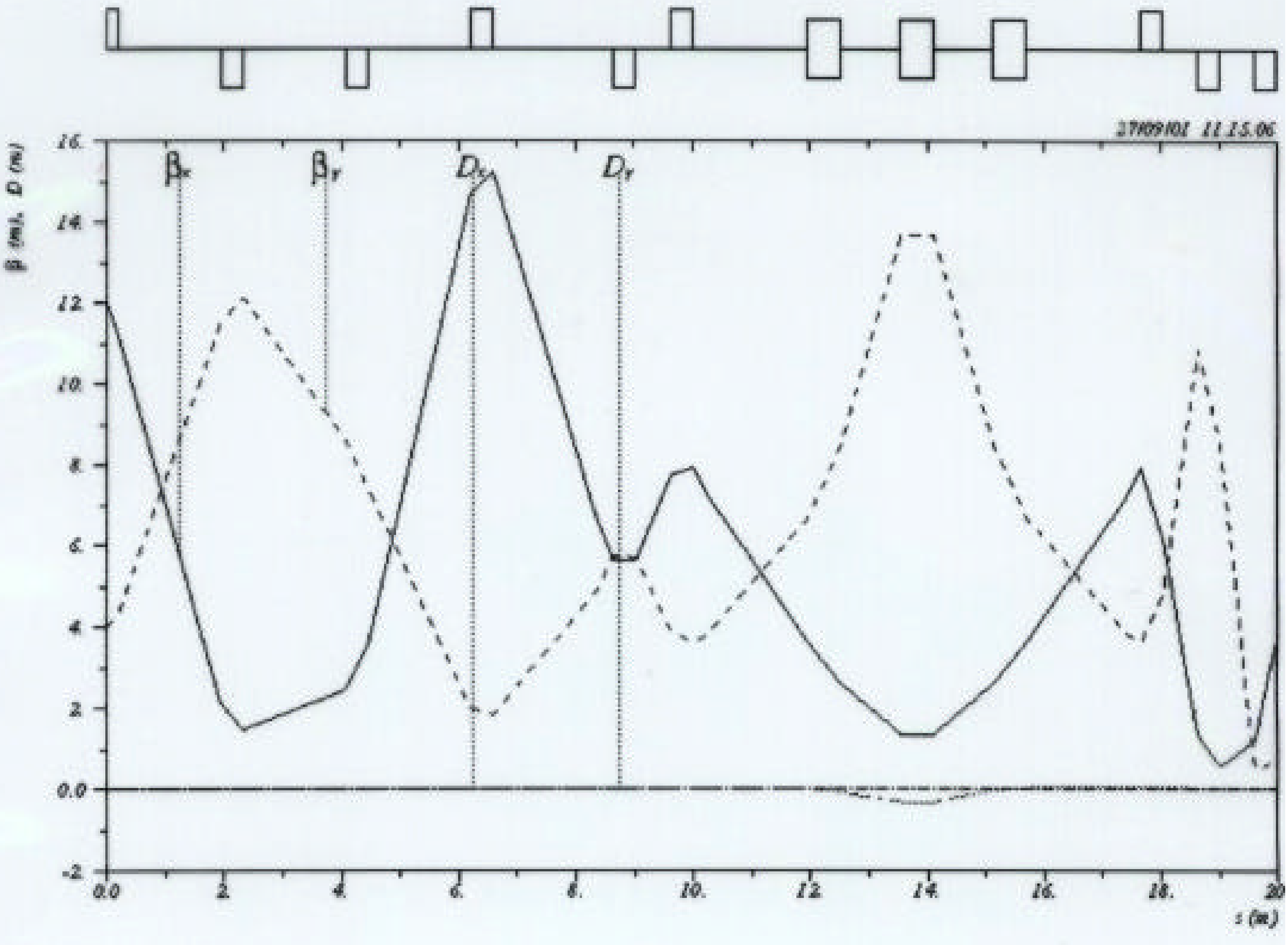
$.06\ [m] \le R_{56} \le .16\ [m]$



$\alpha_1 = \alpha_2 = \alpha_3 = 0 \qquad R_{56} = 0.$



Three-bends achromat twiss functions



$R_{56} \sim .16$