Definition of longitudinal emittance

$$\varepsilon_{\Delta\phi\Delta w} = 2\pi W_p / \lambda \ \varepsilon_{nz}$$

$$\varepsilon_{\Delta\phi\Delta w}(\mathrm{MeV.deg}) = 3.652\mathrm{E}5 \ \varepsilon_{nz}(\mathrm{m})$$

0.13 mm.mrad **0.364E-6**

Required DTL focusing gradient

$$B' \propto \frac{\mathrm{Freq}^2}{\beta}$$

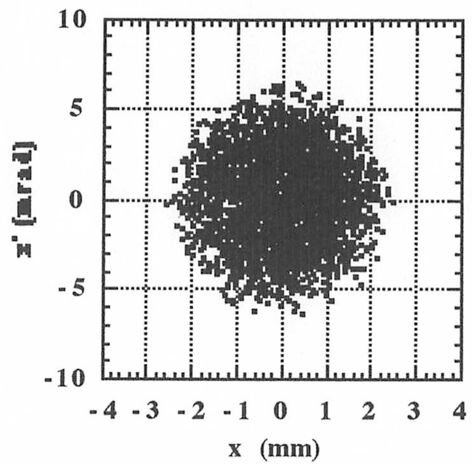
($\beta = v/c$)

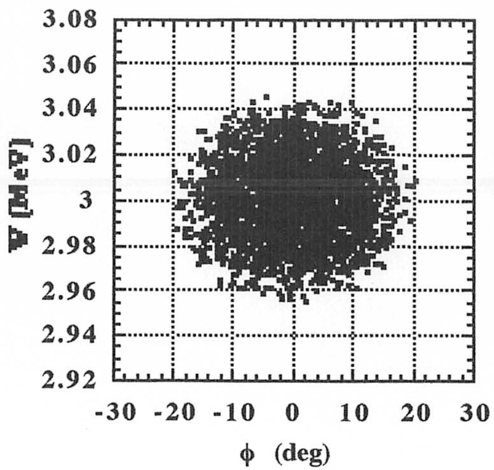
- **make an RFQ of higher output energy**

In JHF design, it was solved by
324 MHz, 3-MeV RFQ and FD focusing scheme in DTL, resulting in some decrease in ZTT in DTL due to rather large DT diameter

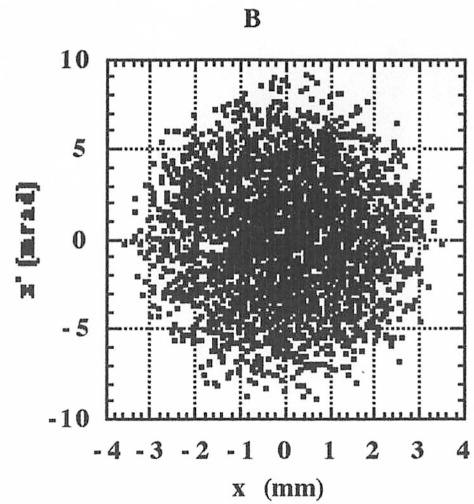
Type A and TypeB input beams

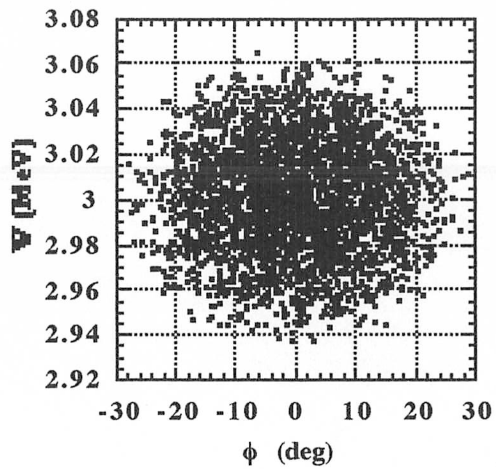
Type A





Type B

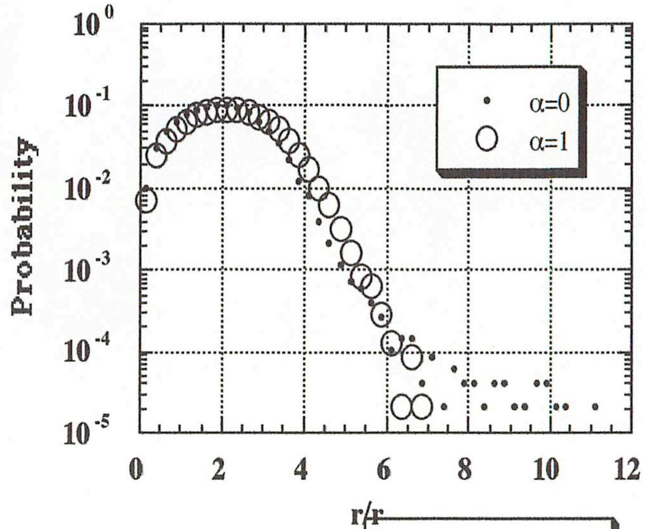




Definition of halos

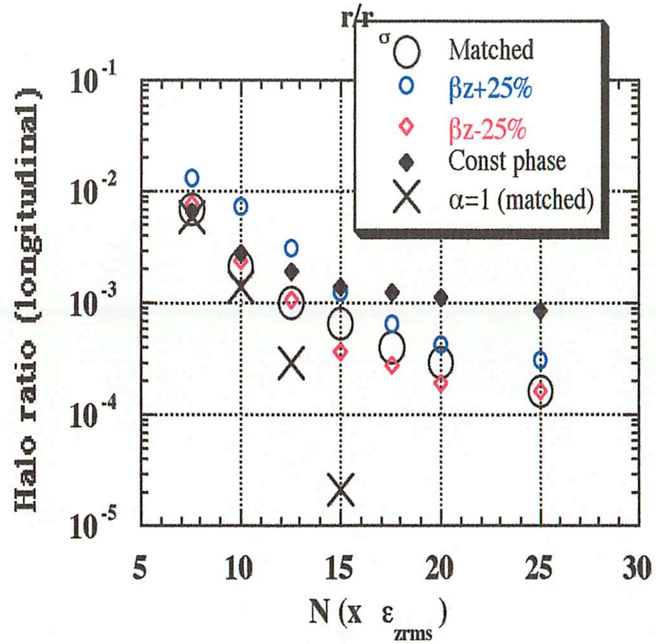
Transverse

Halo-like particles are defined by those in the outside of 6.5 times the standard deviation of the radial distribution of the output beam.

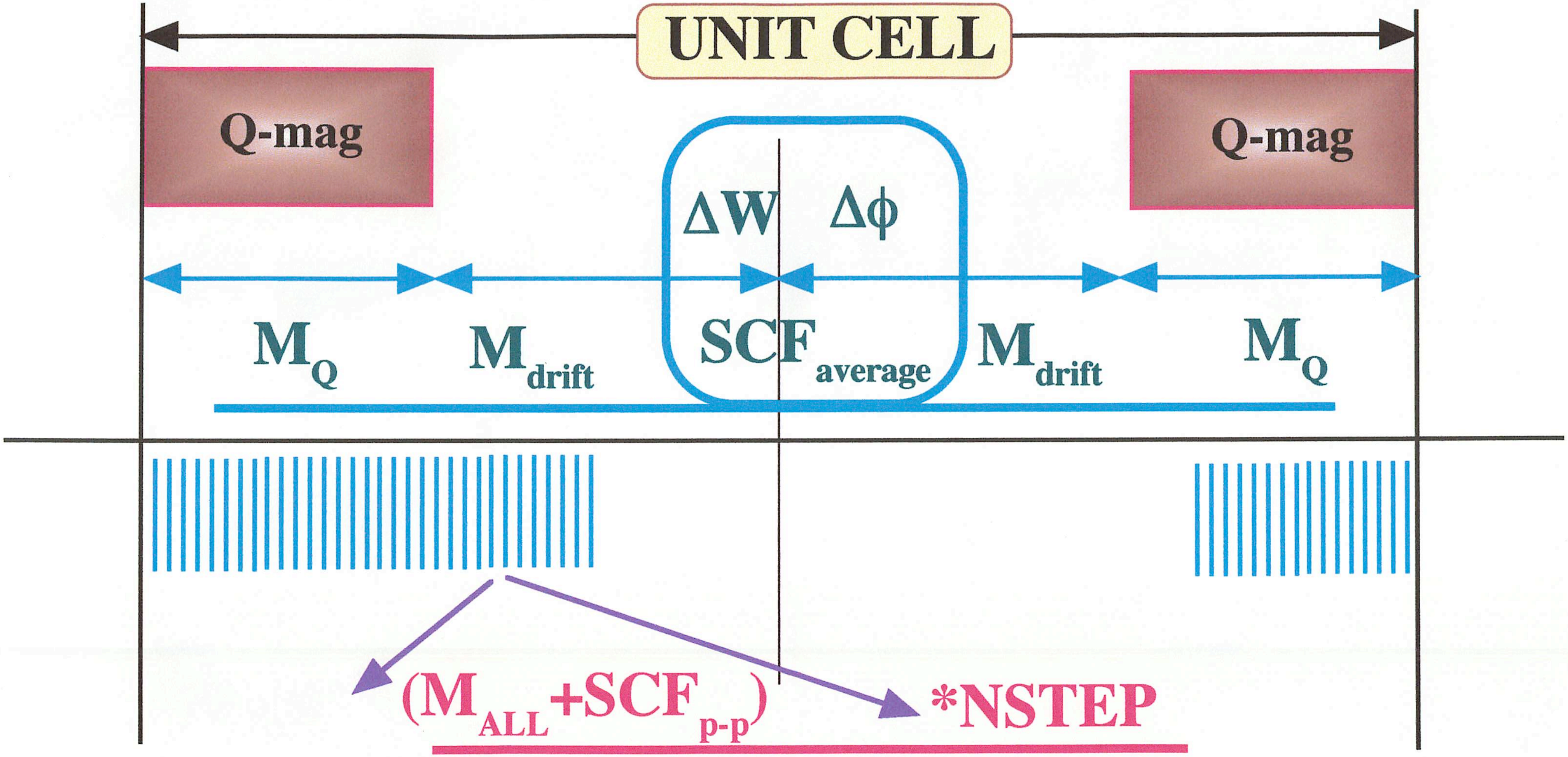


Longitudinal

Halo-like particles are defined by those in the outside of 12.5 times the longitudinal output rms emittance.



Details in calculation (PARMILA vs. LINSAC)



Is emittance growth in LINSAC large?

Constant phase advance of 60 deg, 30 mA, 3 - 148 MeV

Type A input beam ε_x=0.187, ε_z=0.364

transverse emittance growth with α=1 ----> ~ 10%

transverse emittance growth with α=0 ----> ~ 20%

- **field energy**
- **nonlinear space-charge effects**
- **injection mismatch**
- **something arising from the code**
  - **true**
  - **insufficient approximation**
  - **error**

Emittance ratio and emittance growth

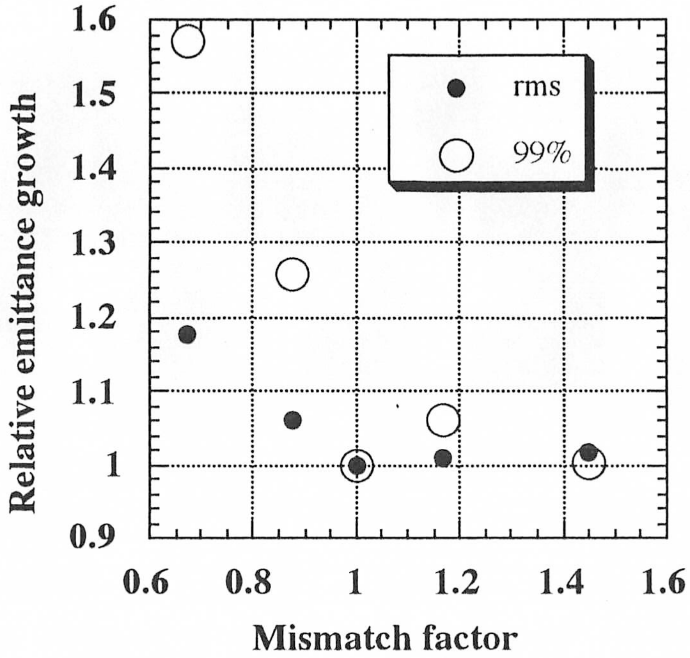
Beam	ε_{nx}	ε_{nz}	$\varepsilon_{nz}/\varepsilon_{nx}$	EGF-x	EGF-z
Type A	0.187	0.364	2	1.4	1.3
Type B	0.372	0.728	2	1.3	1.1
4L-beam	0.744	0.364	0.5	1.2	1.4

α-dependence of emittance growth

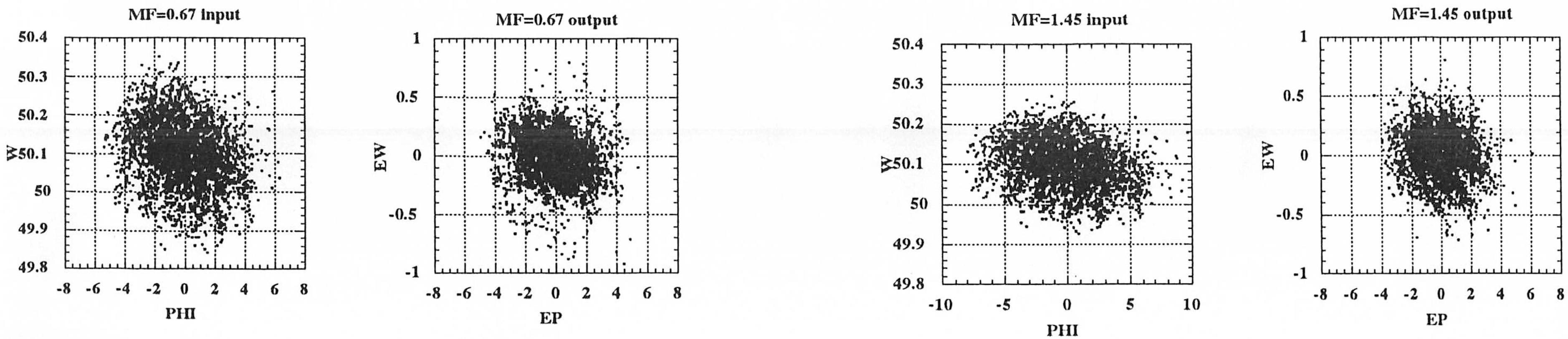
Macro simulation			
	Transverse	**1.53**	**(α=0)**
		1.43	**(α=1)**
Real simulation			
	Transverse	**1.46**	**(α=0)**
		1.40	**(α=1)**

Although there are large differences in the Q-value for the macro and real simulations (Q~12000 and Q=1), the α-dependence of the change in the transverse emittance is nearly the same for the macro and real simulations. Therefore, it is concluded that the effects of large Q-value in the macro simulation upon the growth of rms transverse emittance is very small. A similar situation can be expected in the growth of the longitudinal emittance, suggesting that the large longitudinal emittance growth obtained in the constant phase advance simulations is not due to the effects of large Q-value, although the effects of α on the longitudinal emittance growth is very large.

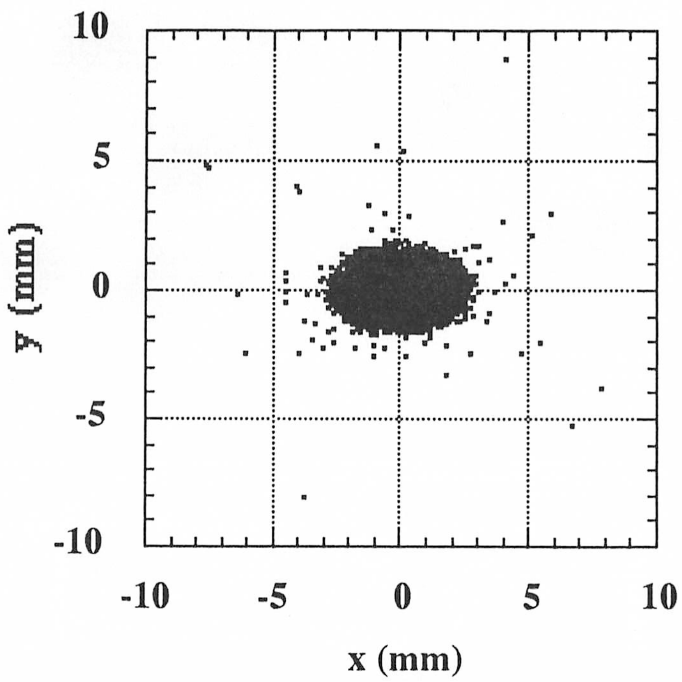
Longitudinal matching in HEBT (2)



Type A beam is used.
MF=0.86 is DTL output.



Transverse halos in constant phase advance



DTL + SDTL (30-mA simulation)

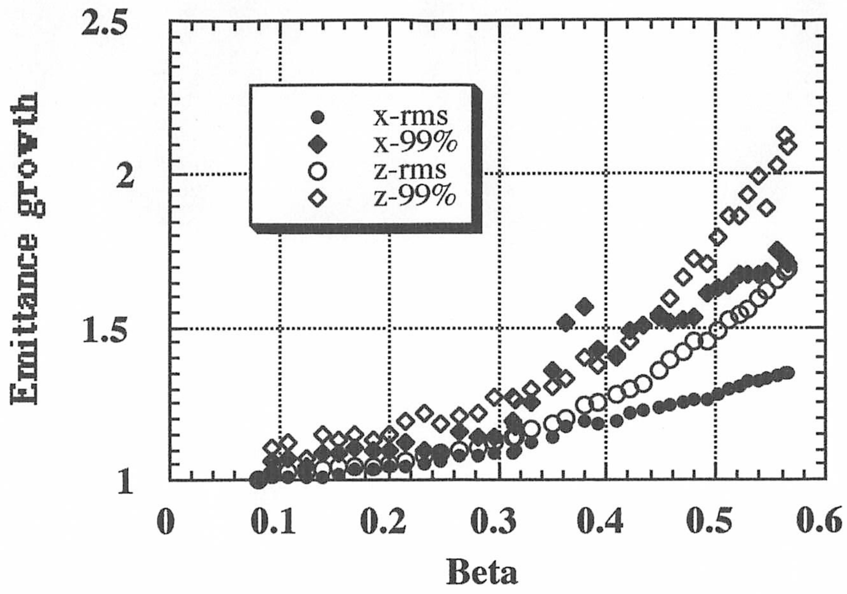
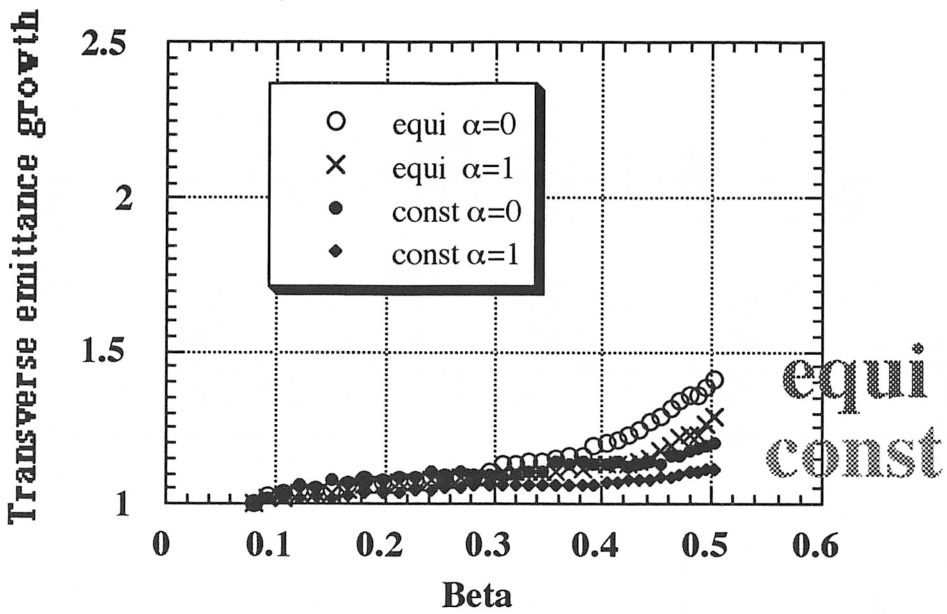
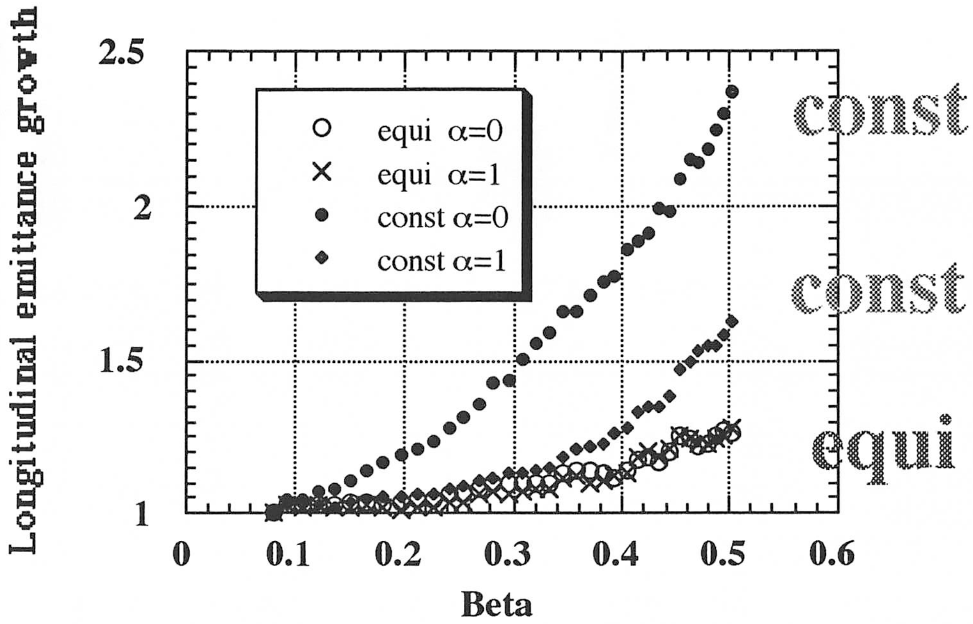


Fig. 4.25 Emittance growth (rms and 99%) along the linac. A 30-mA type-B injection beam is used.

Emittance growth for both focusing methods



Transverse



Longitudinal

LINSAC results

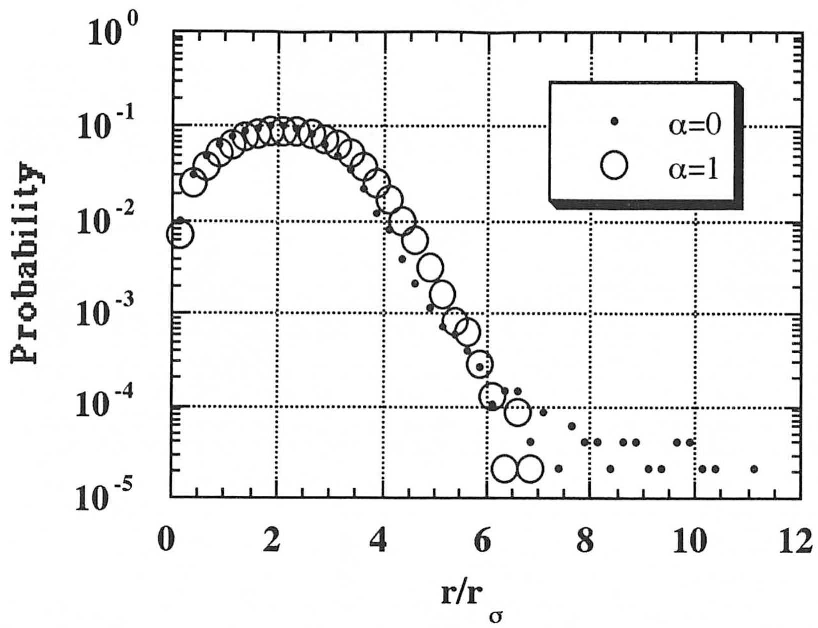
DTL acceleration from 3 to 148 MeV, 30-mA beam

$\alpha=0$ means with collision effects

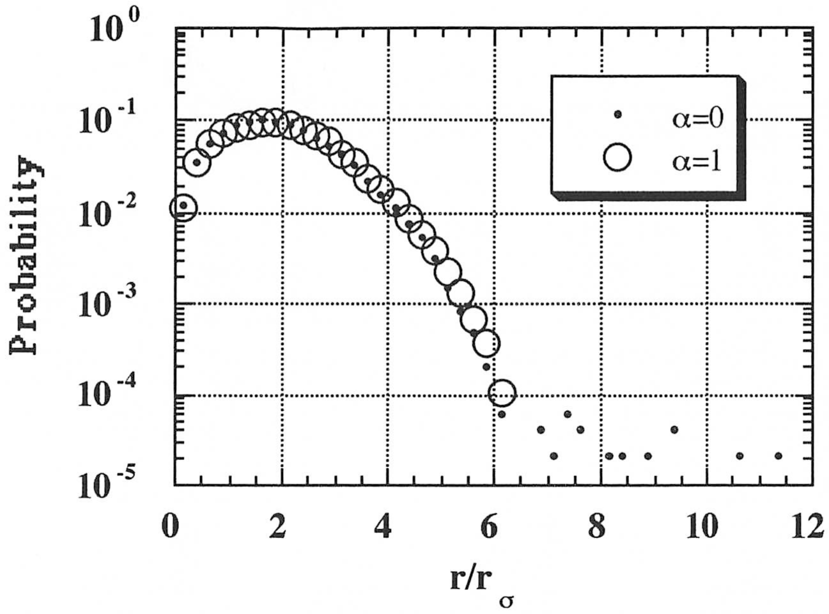
$\alpha=1$ means without collision effects

Radial distribution (macro and real sim.)

MACRO



REAL



Comparison of the radial distribution for the matched macro simulations of α=0 and α=1. The radii were normalized by the standard deviation (r_σ) for each profile. The number of particles is 48000.

Comparison of the radial distribution for the matched real simulations of a=0 and a=1. The number of particles is 48000. Q=1.

Acceptance

Acceptance of the DTL (normalized, 90%)
x: 43 πmm-mrad
z: 9.3 πMeV-deg

Acceptance of the SDTL (normalized, 90%)
x: 21 πmm-mrad
z: 40 πMeV-deg

Equi. vs Const phase

	rms	90%	99%	99.9%
EQUI	0.25263E-01	0.10969E+00	0.20726E+00	0.41796E+00
CONST	0.23442E-01	0.10052E+00	0.21223E+00	0.43362E+00

Reducing beam losses in the linac

- less increase in emittance growth with higher frequency
- equal increase in both emittance growth
- less halo formation by equipartitioning focusing
- keep ratio between transverse and longitudinal focusing strength through the linac
- avoid longitudinal transition up to 200 MeV
  - In upgrade, two or three times the frequency for CCL instead of more than four
- sufficiently large bore radii and acceptances
- Stabilized rf structures and short SDTL unit tank
- Simple DTL injection scheme, avoiding tuning errors
- small repetition frequecy, reducing transient loss

Intrabeam scattering

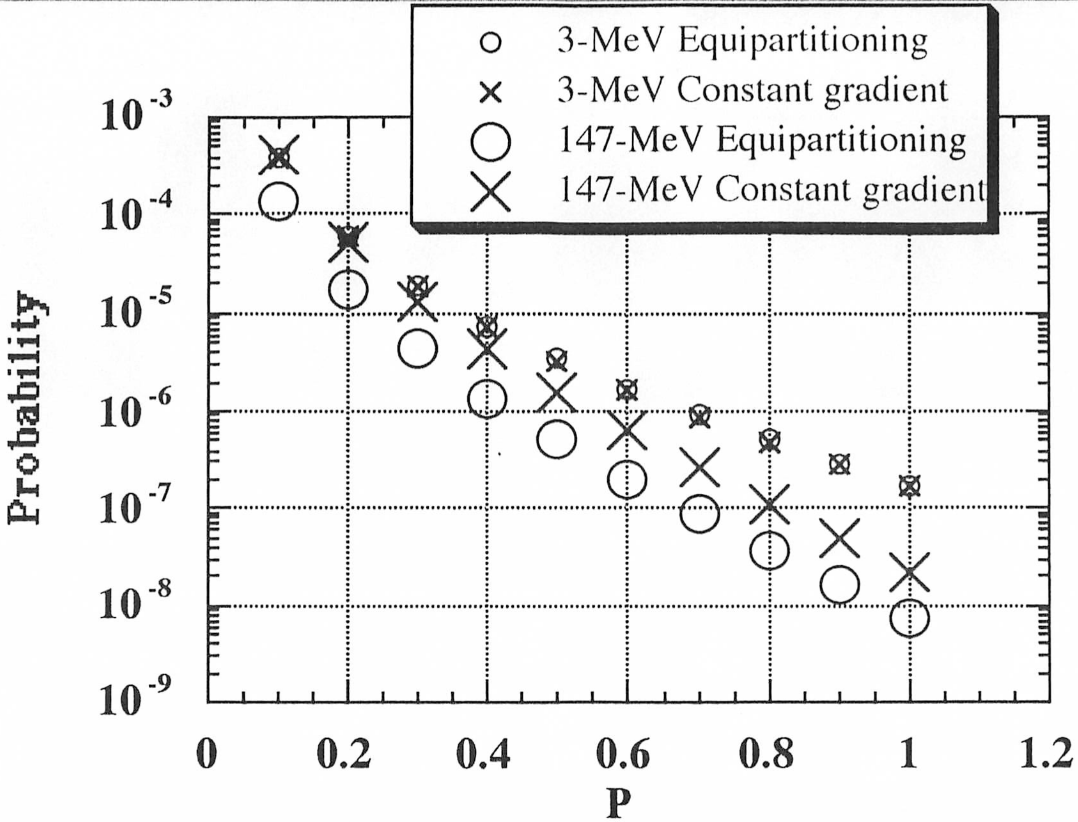
The rate of collisions due to particles having a relative longitudinal velocity of more than v_{th} is given by

$$\left(\frac{dN}{dt}\right)_{collision} = \frac{N^2 r_c^2 c \Lambda^3}{16\pi \sigma_x \sigma_y \sigma_z} D(\xi)$$

$$D(\xi) = \sqrt{\xi}\left\{ -\frac{3}{2} e^{-\xi} + \frac{\xi}{2}\int_{\xi}^{\infty} \frac{\ln(u) e^{-u}}{u} du + \frac{1}{2}\left(3\xi - \xi \ln(\xi) + 2\right)\int_{\xi}^{\infty} \frac{e^{-u}}{u} du \right\}$$

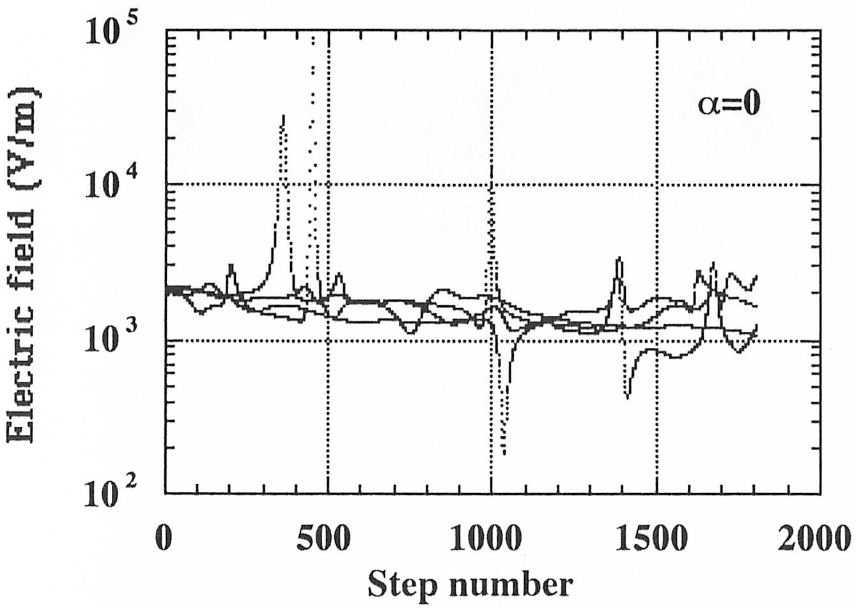
where N is the number of particles in a bunch; $r_c = 1.53 \times 10^{-18}$ m the classical proton radius; $\Lambda = c/v_{th}$; $x = v_{th}/v_{rms}$; v_{rms} the rms longitudinal velocity in the moving frame; and σ_x, σ_y and σ_z the rms radii of the bunch for x, y and z directions, respectively.

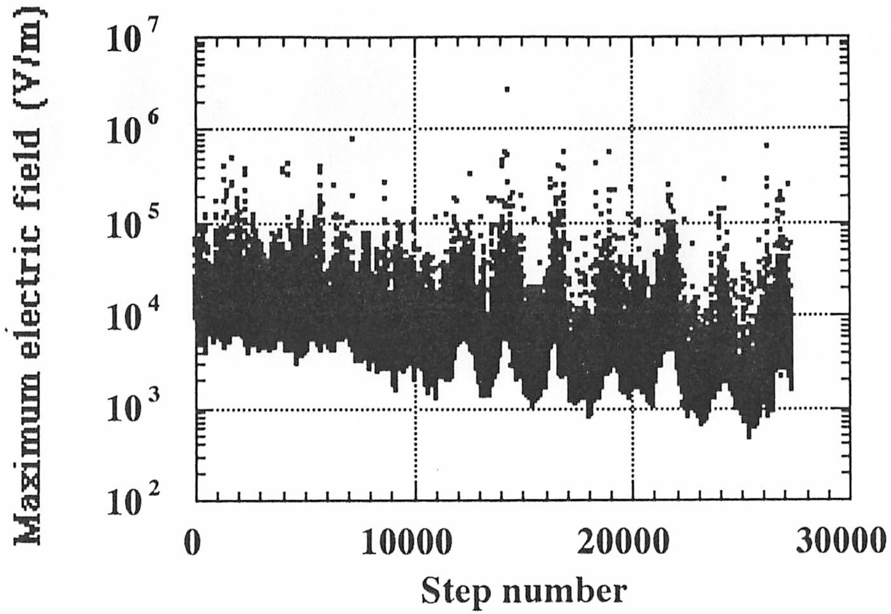
Collision probability



Collision probabilities at two kinds of energies (3 and 147 MeV) for two kinds of focusing methods (the equipartitioning method and the constant gradient method). P expresses the ratio of the relative longitudinal velocity to the threshold longitudinal velocity, which is set to the average of the rms transverse velocities. The probabilities stand for the period for the transit time through the linac.

Collision in the real simulation - Coulmb forces

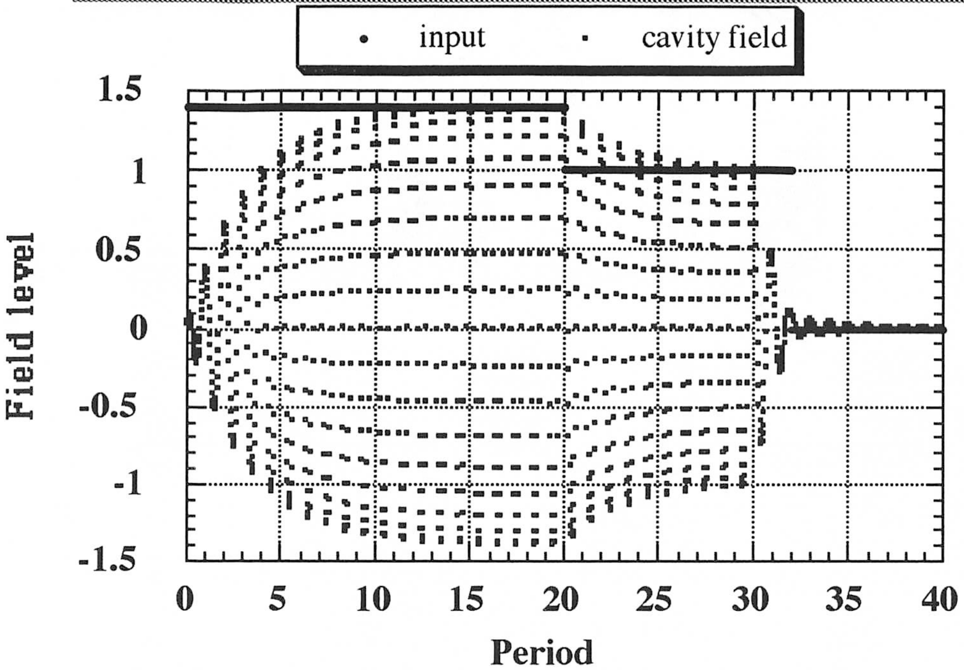




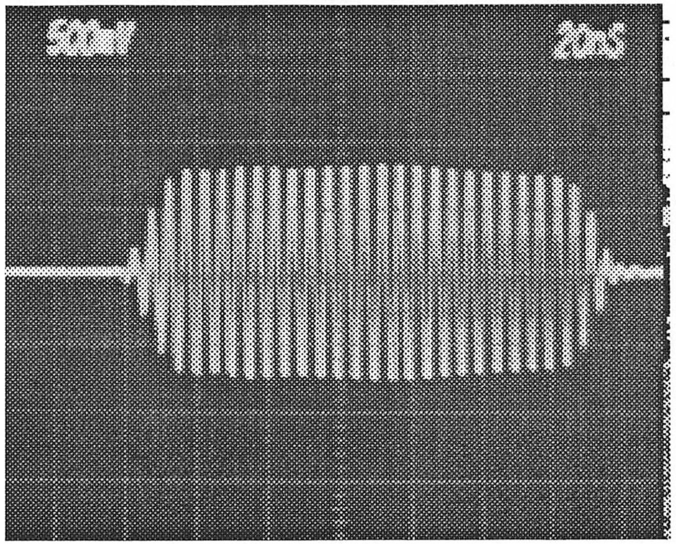
Electric field on four particles among 1600 particles.

Maximum electric fields due to the space-charge effects among all particles in every calculation step up to 27324 for the real simulations.

RF chopper - waveform



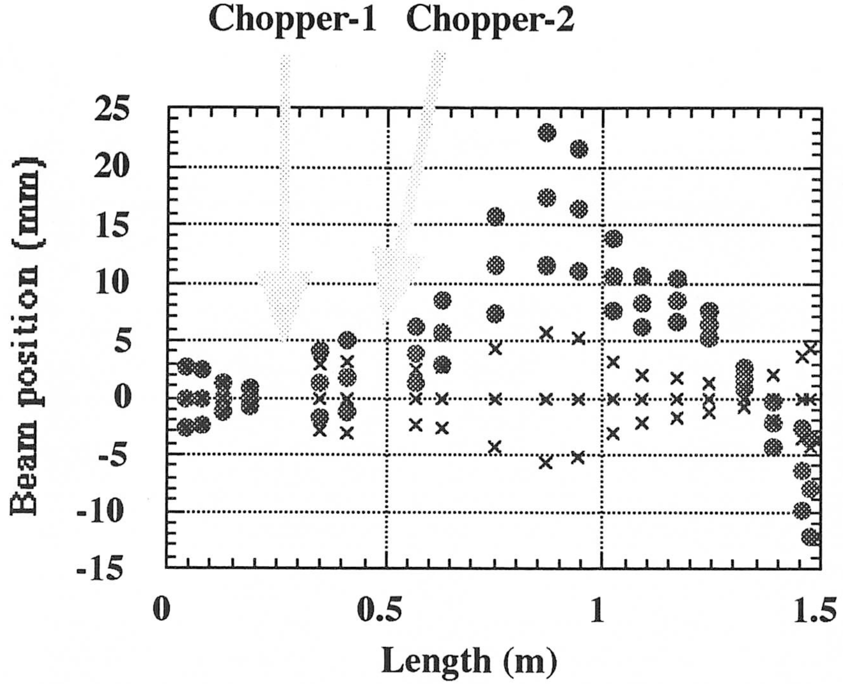
8.5 kW peak power



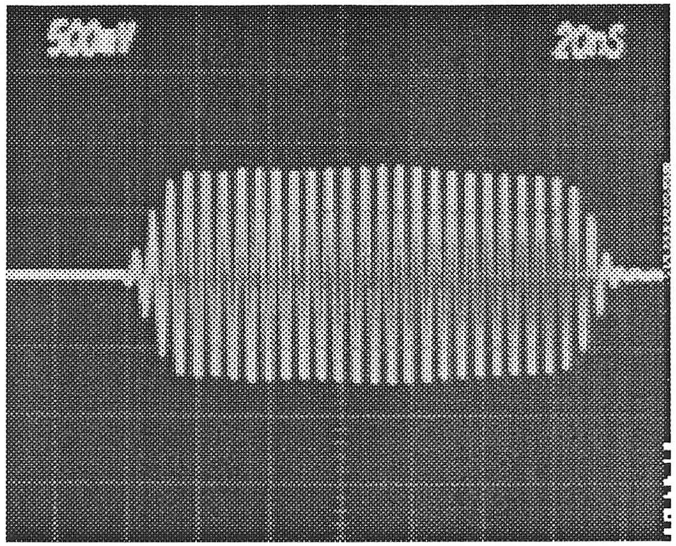
Results of rf-field simulation in a low-Q cavity

In order to reduce losses during rise and falling time, modulation in the ion source is desirable.

RF chopper

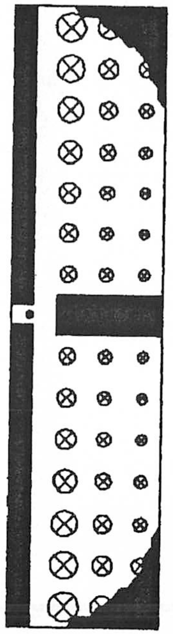


Traces of the chopped (circles) and normal (cross) beams along the MEBT. The symbols indicate the outermost points and the center of the beam. Each chopper gives 15mrad defelection.



Shape of an rf pulse for the chopper cavity, measured in the preliminary experiment at a frequency of 201 MHz. A peak power is about 8.5 kW. 20nsec/div.

Chopper cavity



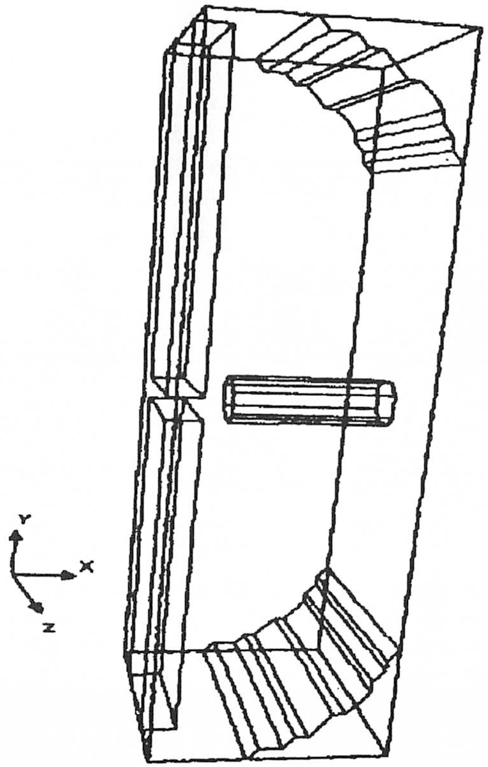


Fig. 2 RFD cavity shape (half cell).

Required rf parameters for the chopper system (432 MHz).

Number of cavities	Deflection mrad	Pc/cavity kW	Total power kW
1	14	58.2	58.2
2	6	11.0	22.1
4	4	7.1	28.5