JHF 200-MeV Proton Linear Accelerator

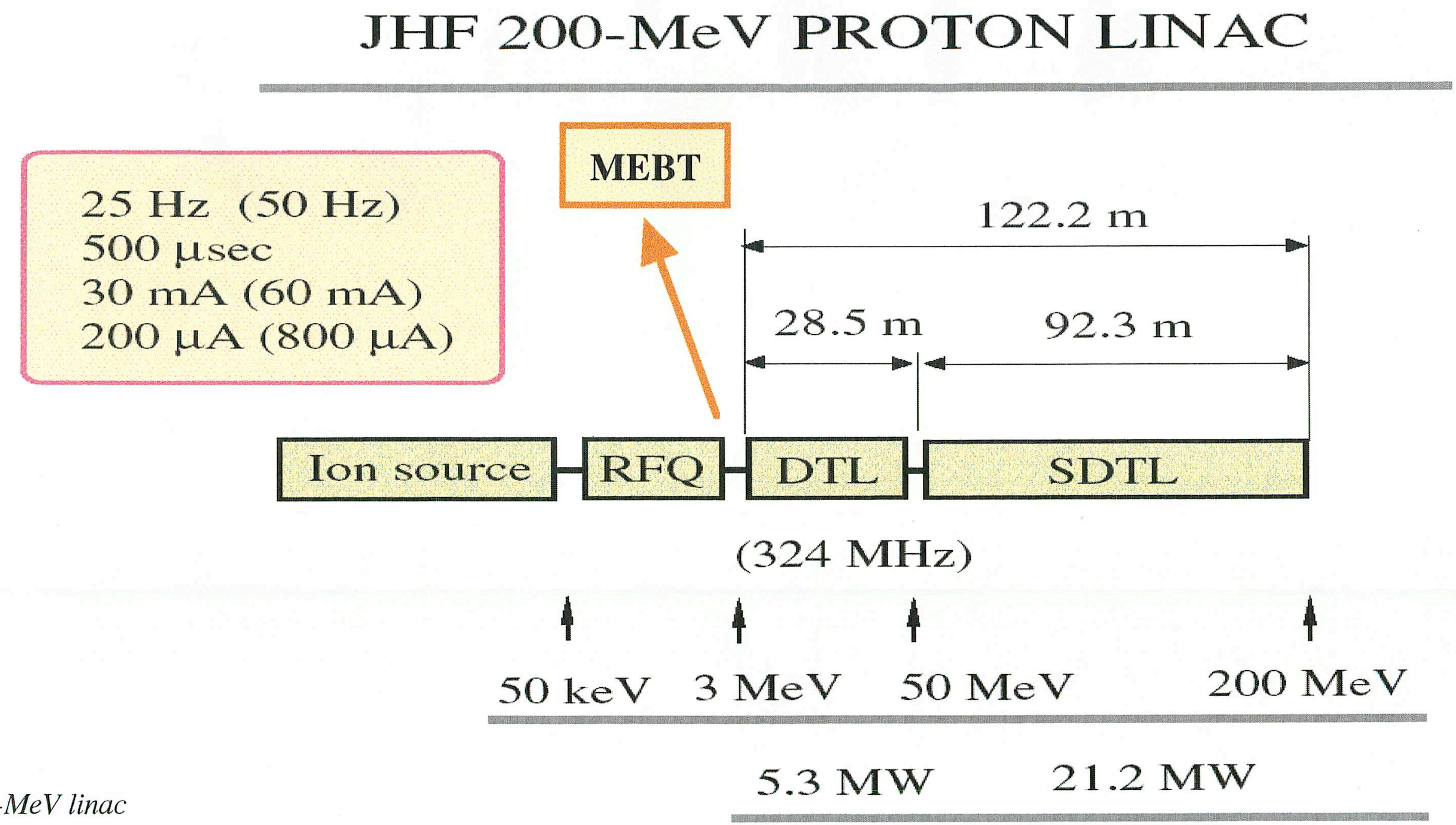
- Requirements
- Configuration
- Focusing scheme
- Frequency selection
- Role of MEBT - beam-loss problem

KEK T. Kato

Requirements

	Initial requirement	Final goal	
Particles	H^-	H^-	
Output energy	200	400	MeV
Peak current	30	60	mA
Beam width	500	500	μsec
Repetition rate	25	50	Hz
Average current	200	800	μA
Length	<150	~220	m
Momentum spread	± 0.1	± 0.1	%
Chopping ratio	0.56	0.56	

The JHF 200-MeV Proton Linear Accelerator



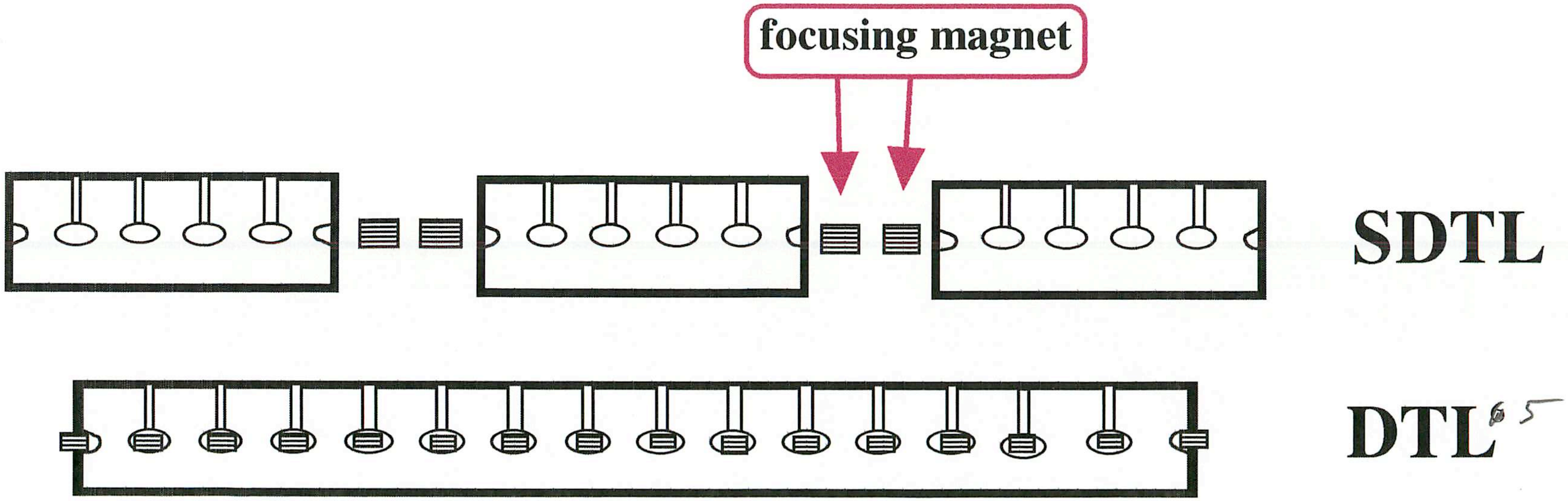
Main parameters

	DTL	SDTL	
Frequency	**324**	**324**	**MHz**
Injection energy	**3.0**	**50.06**	**MeV**
Output energy	**50.06**	**202.5**	**MeV**
Length (structure only)	**27.04**	**65.9**	
Length (including drift space)	**28.51**	**92.4**	**m**
Number of tank	**3**	**31**	
Number of klystron	**3**	**14**	
Rf driving power	**3.92**	**17.4**	**MW**
Total rf power (30 mA)	**5.33**	**22.0**	**MW**
Total length		**122.3**	**m**
Total power (30 mA)		**27.3**	**MW**
Peak current		**30**	**mA**
Beam width		**400**	**μsec**
Repetition rate		**25**	**Hz**
Average current		**200**	**μA**

SDTL (Separated-type DTL)

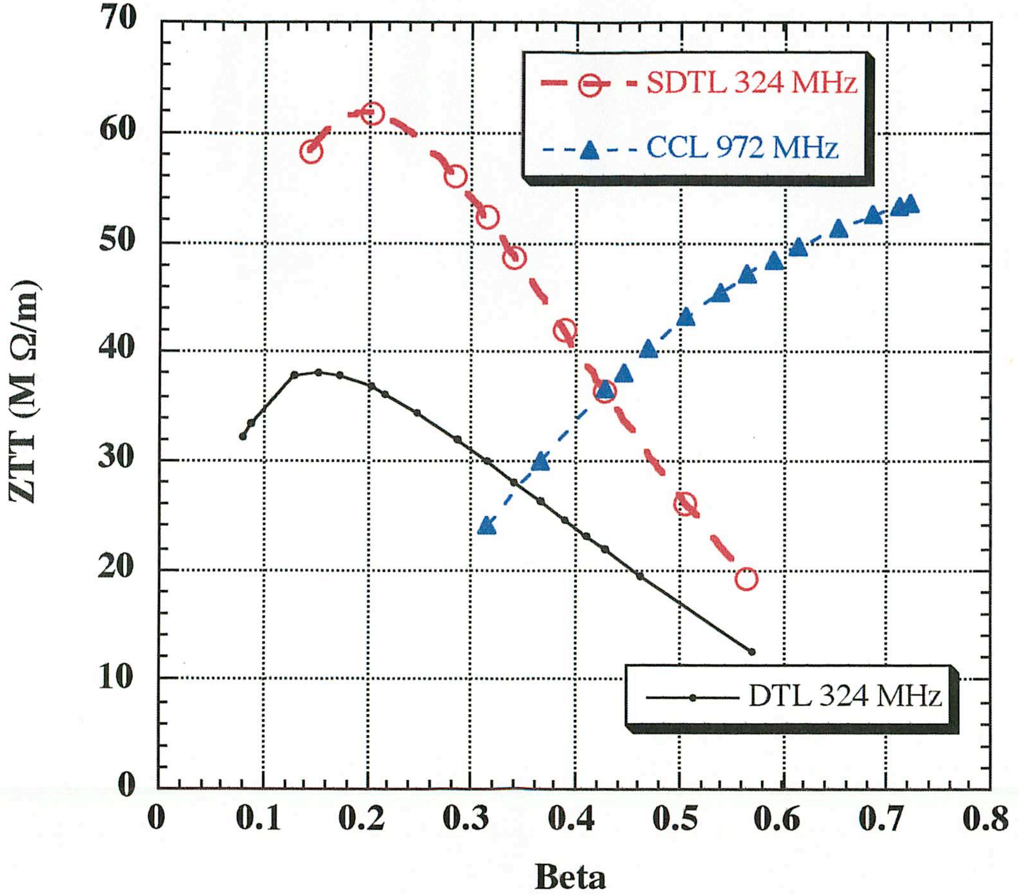
- **SDTL structure for a medium energy range – a new structure concept proposed in 1992**
  - **many advantages of beam dynamics and construction**

Focusing magnets are placed between two SDTL tanks (like a CCL focusing scheme)



200-MeV linac

Shunt impedance



Effective shunt impedances used for the JHF proton linac.

200-MeV Linac Characteristics (1)

- **One rf frequency for all structures**
- **Higher frequency - 324 MHz**
- **3-MeV RFQ - higher output energy with one tank**
- **DTL stabilized post couplers**
- **SDTL structure**
- **Equipartitioning focusing method**
- **Klystron for all structures**

Higher frequency of 324 MHz

201 MHz ⟶ 324 MHz

- Reduce space-charge effects
- Higher shunt impedance
- Easy to use klystrons
- Reduce rf-structure size

Difficulties are

1. RFQ construction
2. DTL focusing magnet

7

Space-charge effects vs. frequency
Simulation results

- **324 MHz vs. 201 MHz (equipartitioning focusing)**

	324	201
σ_x/σ_{x0}	0.84 - 0.77	0.69 - 0.59
σ_z/σ_{z0}	0.72 - 0.62	0.63 - 0.53
Emit. Growth x	0.66 (relative)	1
Emit. Growth z	0.51	1

Injection beam
$\varepsilon_x/\varepsilon_z$=1/2, 30 mA
ε_{xrms}=0.187 πmm-mrad
ε_{x90}=0.804 πmm-mrad

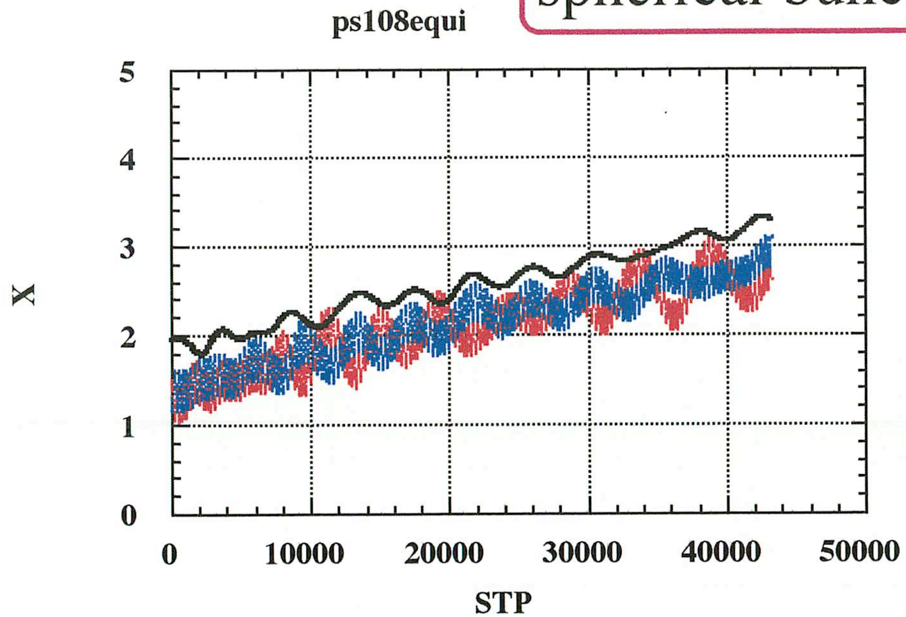
Acceleration from 3 to 148 MeV
E_0=2.1 MV/m for both frequencies

Two types of transverse focusing method

Equipartitioning focusing

$$\frac{k_{x0}}{k_{z0}} \propto \mathrm{const}$$

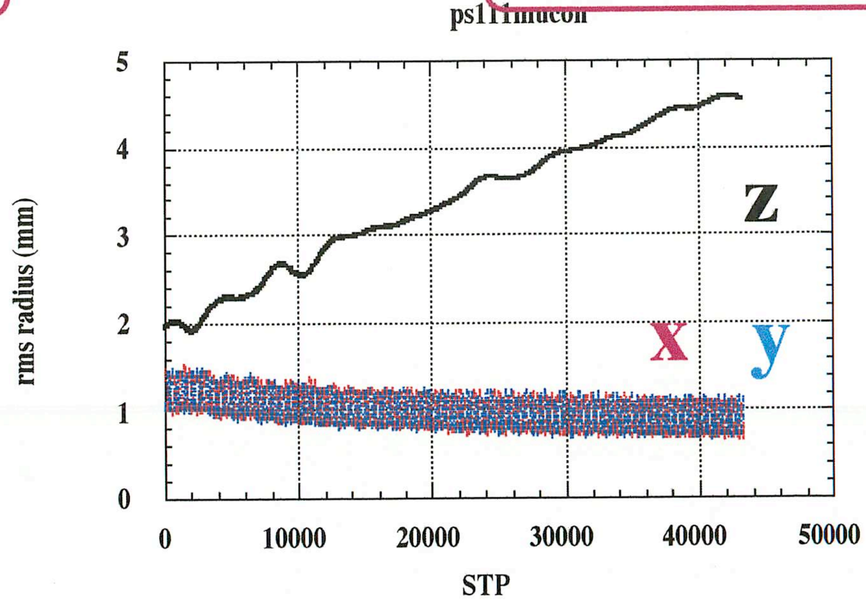
spherical bunch



Constant phase advance

$$\frac{k_{x0}}{k_{z0}} \propto \beta_0^{1/2}\gamma_0^{3/2}$$

asymmetric bunch



rms beam size vs. step number (energy)

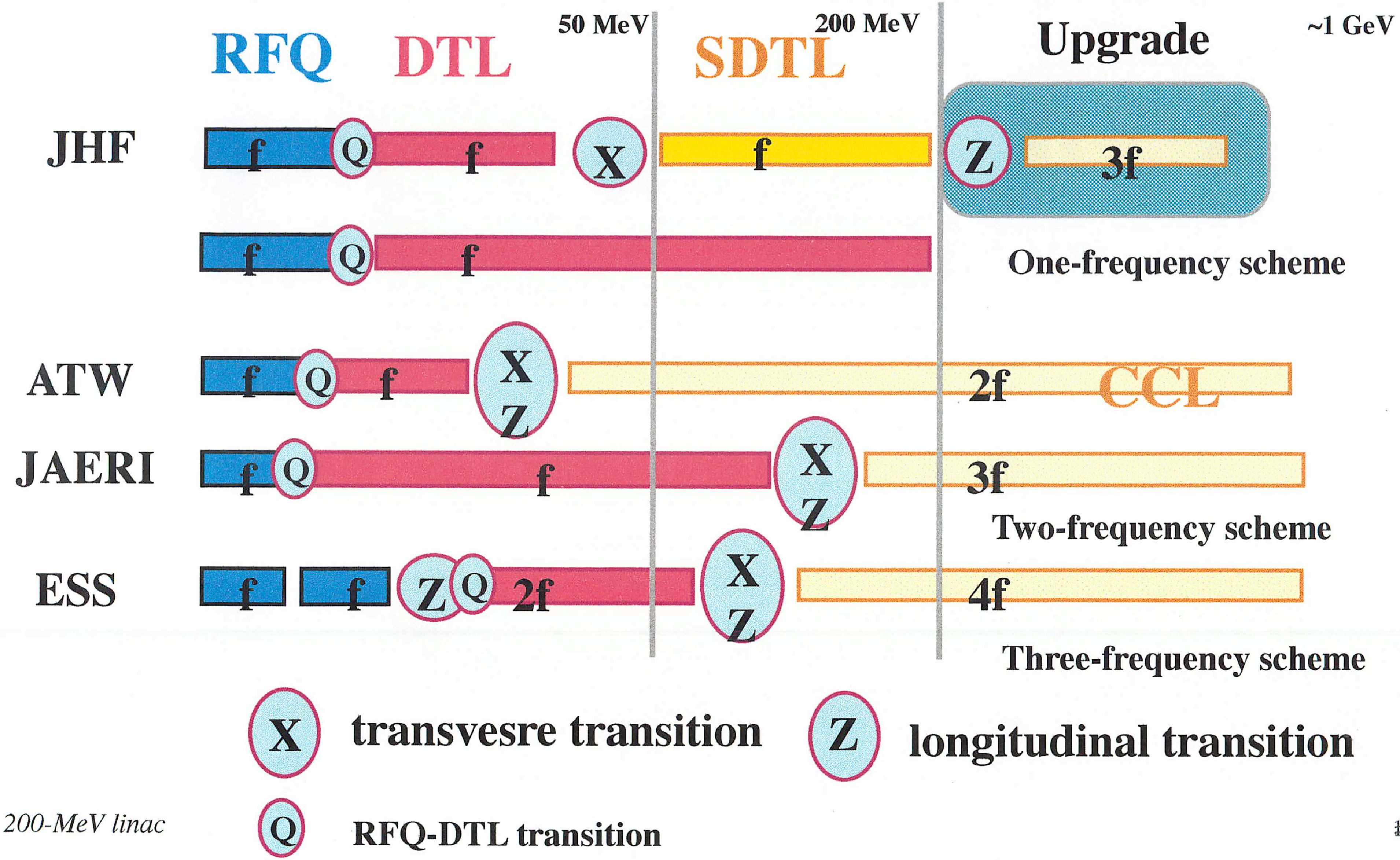
Features of the focusing design

Equipartitioning focusing method
Using LINSAC simulation

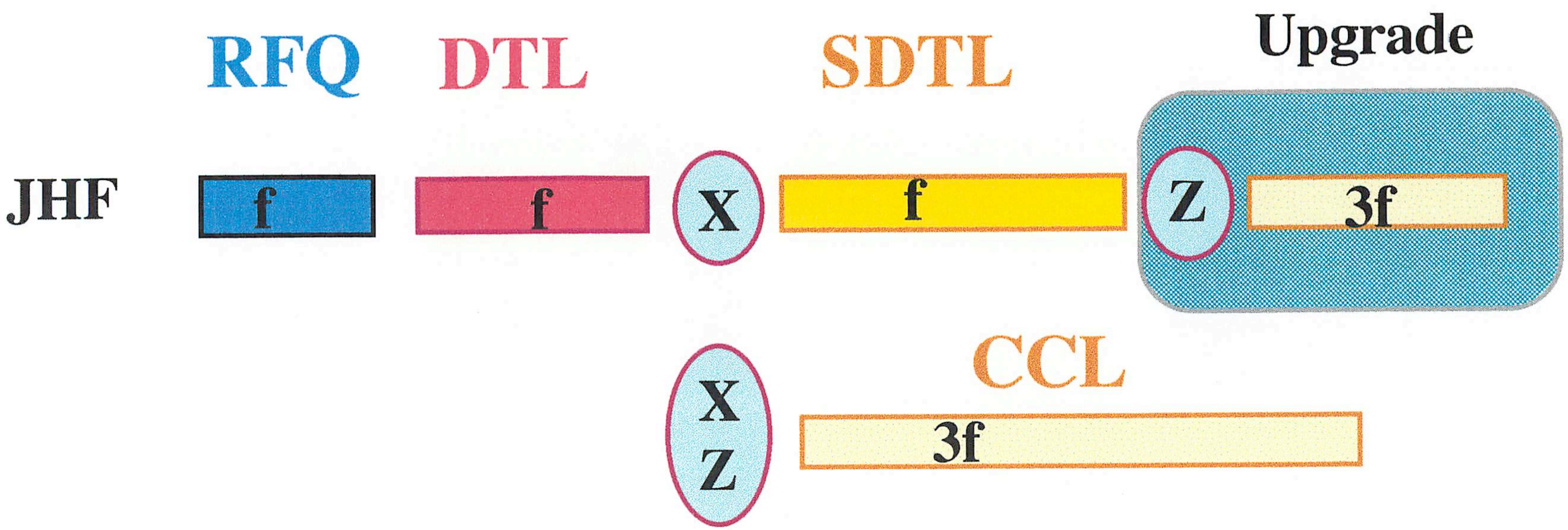
$$\gamma_0 \frac{\varepsilon_{nx}}{\varepsilon_{nz}} \frac{k_x}{k_z} = 1$$

- **both emittance growth and halo-formation are considered**
- **nealy equipartitioned beam is assumed**
- **keep the ratio of transverse focusing strength to longitudinal one constant during acceleration**
  - **less emittance growth in longitudinal motion**
  - **less beam halos in both transverse and longitudinal motion totally**
- **smooth continuation of rms beam size from DTL to SDTL**

Types of linac configurations (longitudinal and transverse transitions)

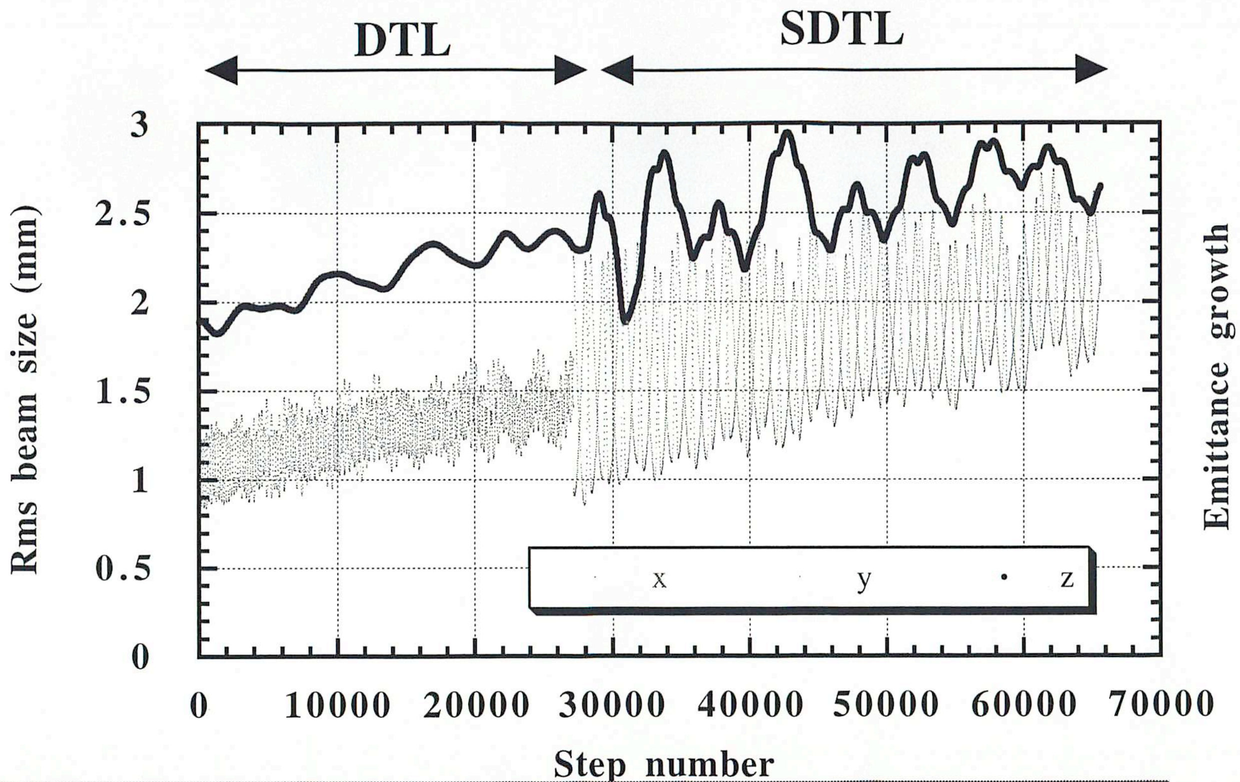


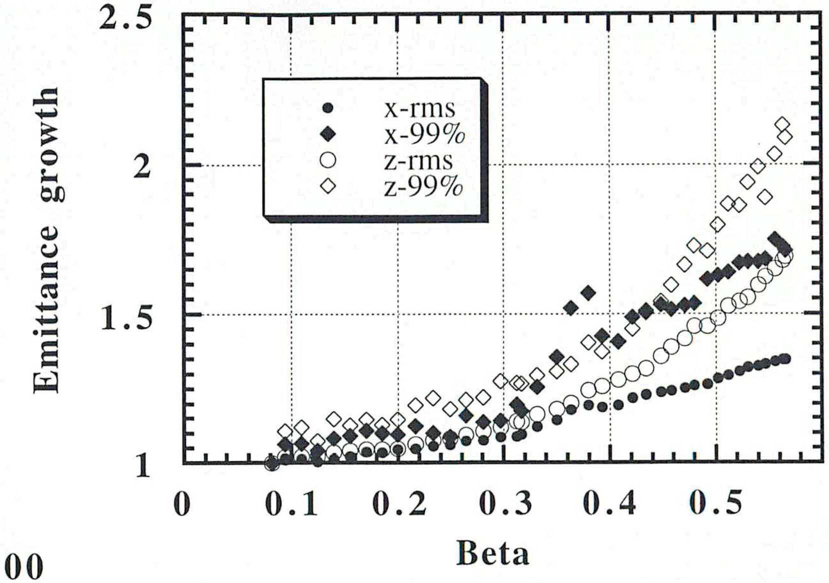
By using SDTL, two transitions are separeted



- **Reduce space-charge effects compared with CCL scheme**
  - **due to beam size difference**
- **Avoid rf-nonlinear effects in CCL of higher frequency**

Beams in the equipartitioning focusing method





An rms beam size in the equipartitioning focusing method is connected smoothly from DTL to SDTL, although there is a transvesre transition of length of focusing periods.

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

Summary of emittance growth

DTL+SDTL vs. all-DTL scheme (equipartitioning is used)

Transverse	**1.1**	**: 1**
Longitudinal	**1.06**	**: 1**

Equipartitioning vs. Constant phase scheme

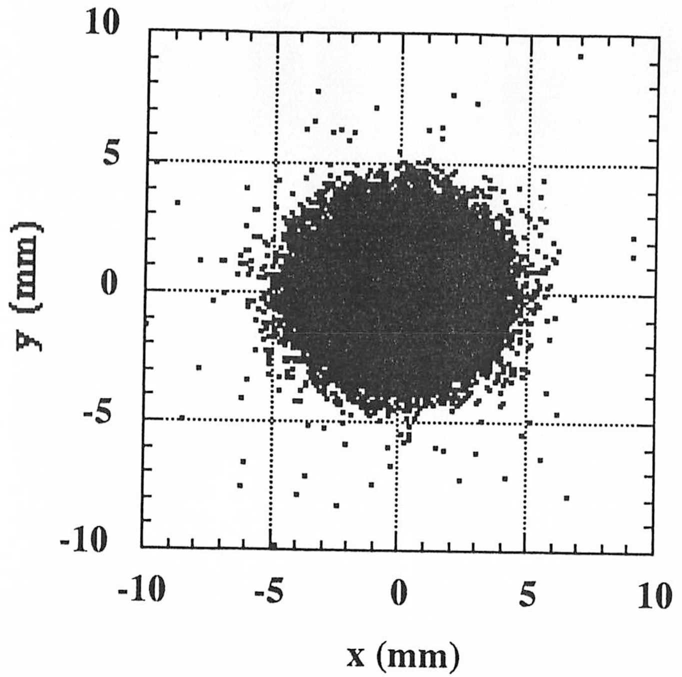
(all-DTL scheme is us

Transverse	**1.22**	**: 1**
Longitudinal	**0.62**	**: 1**

14

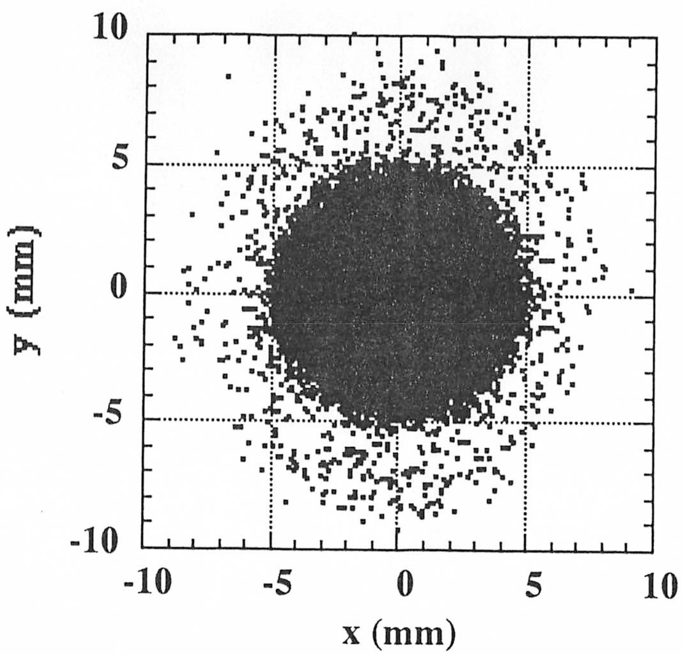
Transverse beam halos in LINSAC

matched injection



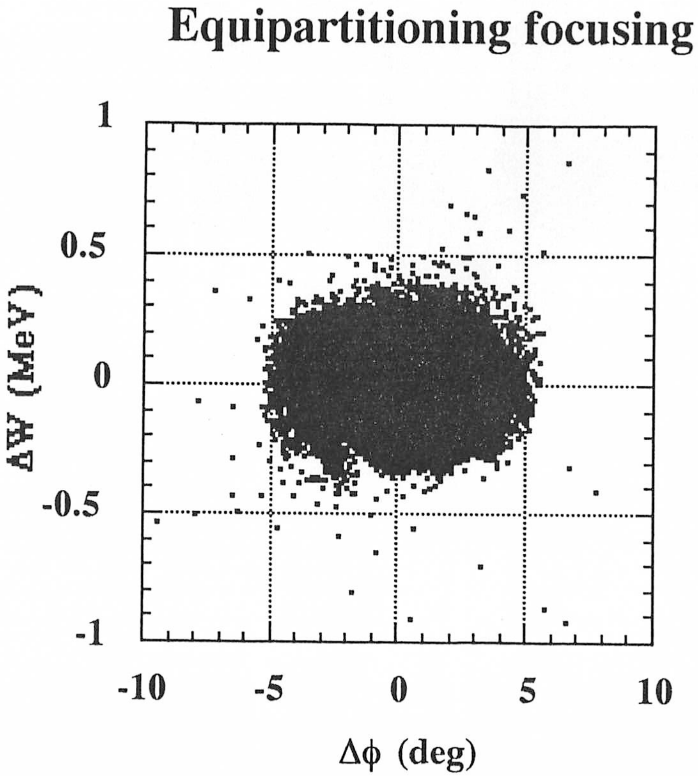
The output profile of the matched injection simulation. The number of particle is 48000. α=0.

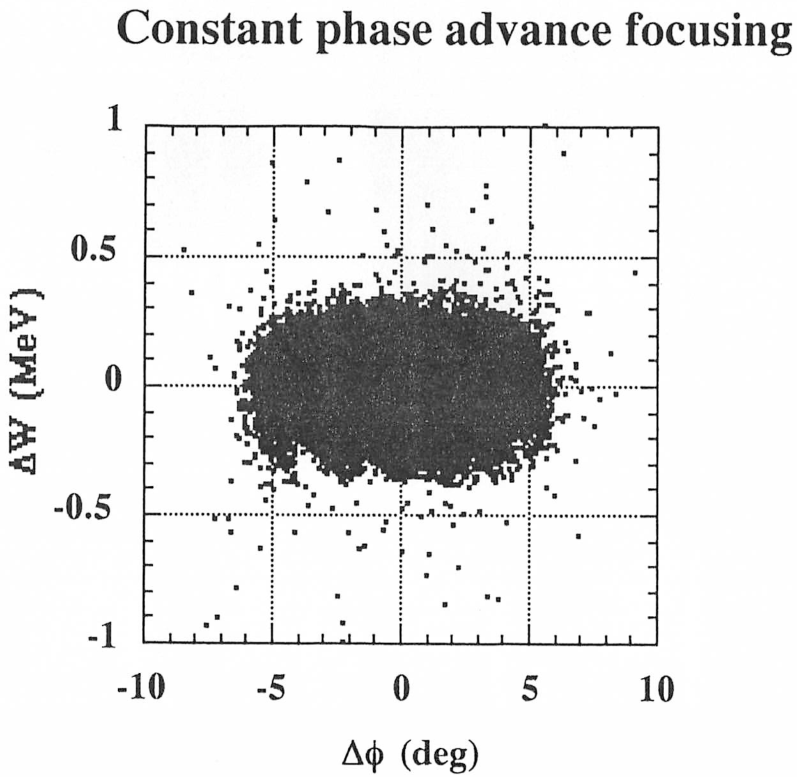
mismatched injection



The output profile of the mismatched injection simulation. The number of particle is 48000. α=0.

Longitudinal beam halos in LINSAC





Longitudinal emittances after acceleration from 3 to 148 MeV. The left is results with the equipartitioning focusing method. The right is results with the constant phase advance method. The number of particles is 48000. The beam current is 30 mA.

Summary of halo-formation

Transverse				
Equipartitioning	**DTL**	**macro**	**0.1**	%
	DTL	**real**	**0.05**	
	DTL+SDTL	**macro**	**0.1**	
Constant phase	**DTL**	**macro**	**0.08**	
Longitudinal				
Equipartitioning	**DTL**	**macro**	**0.098**	
Constant phase	**DTL**	**macro**	**0.19**	

- **Transverse ~ 0.1% due to collision effects**
- **Longitudinal equipartitioning ~ 0.1%**
- **Longitidinal constant phase ~ 0.2%**
- **Mismatched injection causes additional halos**

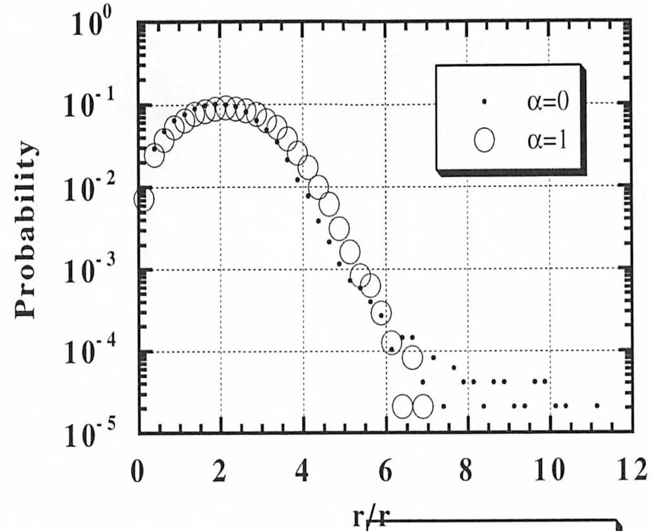
Definition of halos

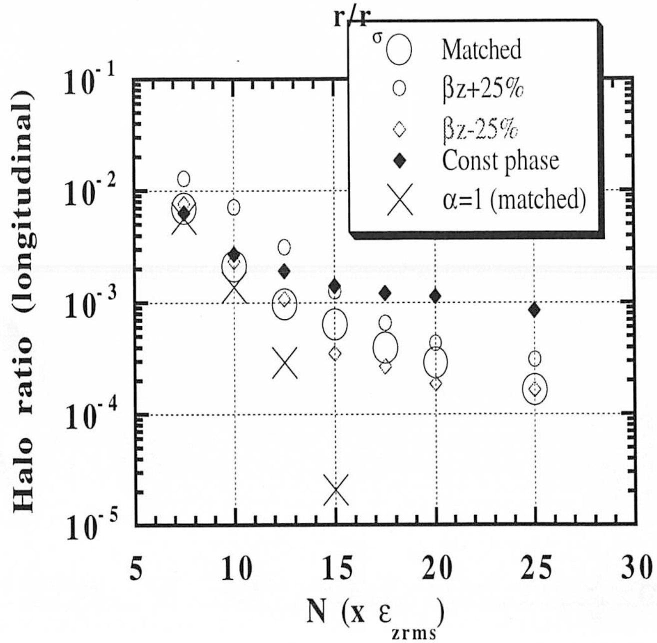
Transverse

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 difined by those in the outside of 12.5 times the longitudinal output rms emittance.





Summary of halo-formation

Transverse					
Equipartitioning	**DTL**	**macro**	**0.1**	%
	DTL	**real**	**0.05**	
	DTL+SDTL	**macro**	**0.1**	
Constant phase	**DTL**	**macro**	**0.08**	
Longitudinal				
Equipartitioning	**DTL**	**macro**	**0.098**	
Constant phase	**DTL**	**macro**	**0.19**	

- **Transverse ~ 0.1% due to collision effects**
- **Longitudinal equipartitioning ~ 0.1%**
- **Longitidinal constant phase ~ 0.2%**
- **Mismatched injection causes additional halos**

Beam-loss problem in a high-intensity proton acclerator about chopper operation

- Reduce beam losses after injection into the ring
- make beam losses in the low-energy region along the linac instead of the ring

Use chopped beam

Use scraper in the DTL

5nA/m/GeV

--> localize the beam-loss along DTL

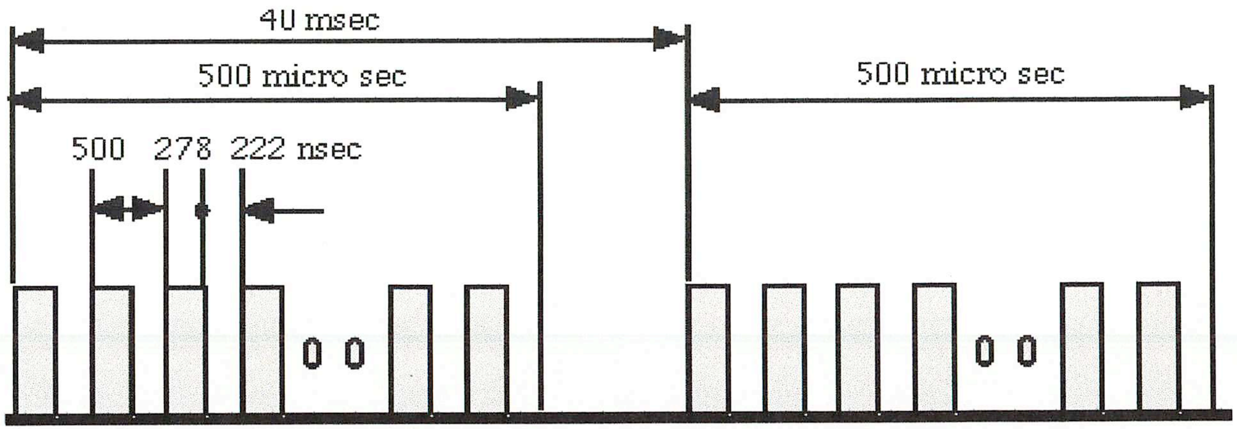
A beam fraction, which has a possibility of becoming unstable in the ring, is less than 0.08%.

20

Beam transport line from RFQ to DTL (MEBT)

Three purposes of MEBT

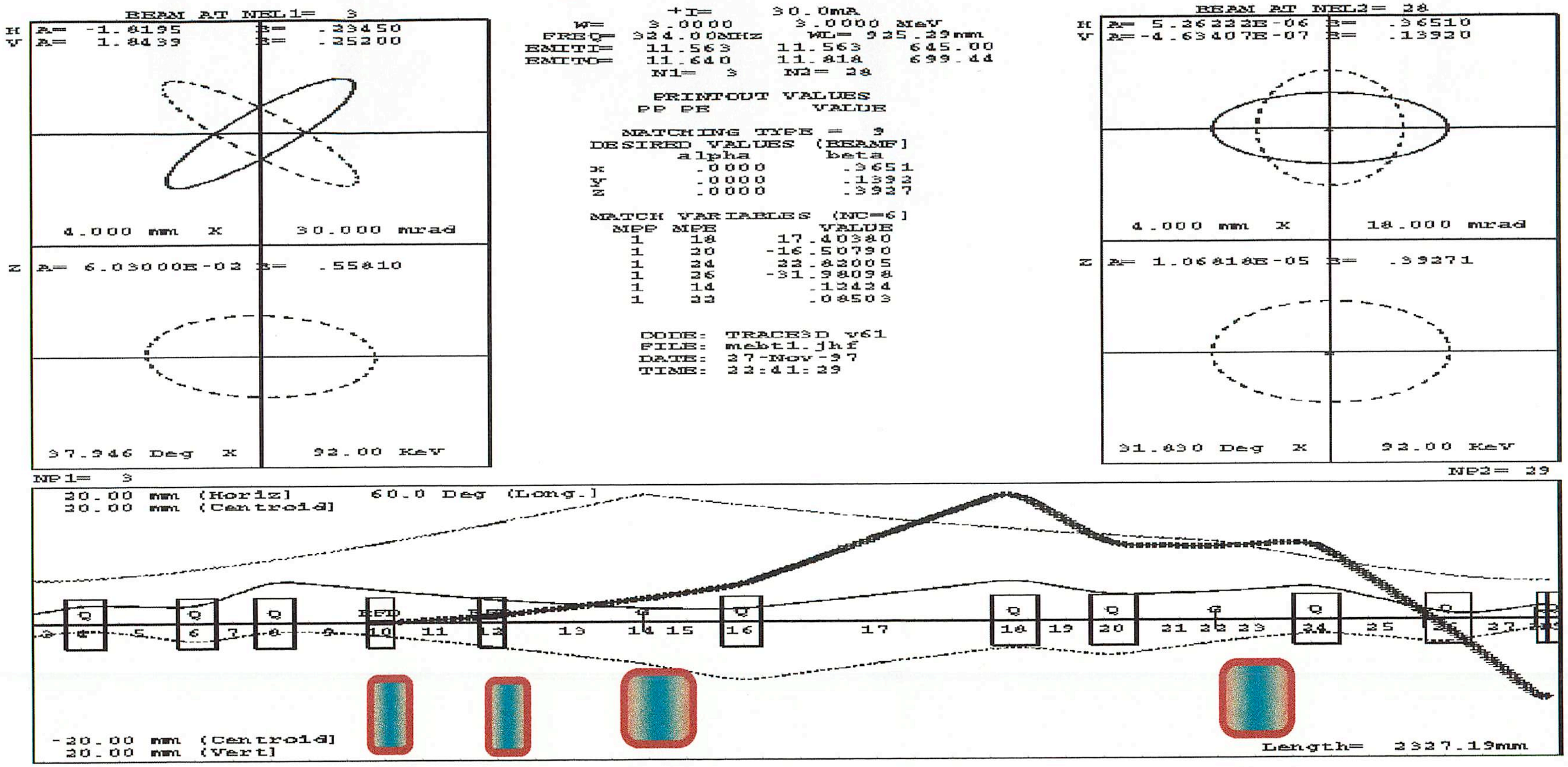
Transverse matching	→	Eight focusing magnets
Longitudinal matching	→	Two buncher ~120 kV
Beam chopping	→	Two rf choppers ~ 50 kW



Required time structure of the bunch. A pulse length is 500 μsec. A repetition rate is 25 Hz.
(An rf frequency of the ring is 2 MHz ---> 500 μsec)

Beam transport line from RFQ to DTL (MEBT)

Matching and chopping the beam



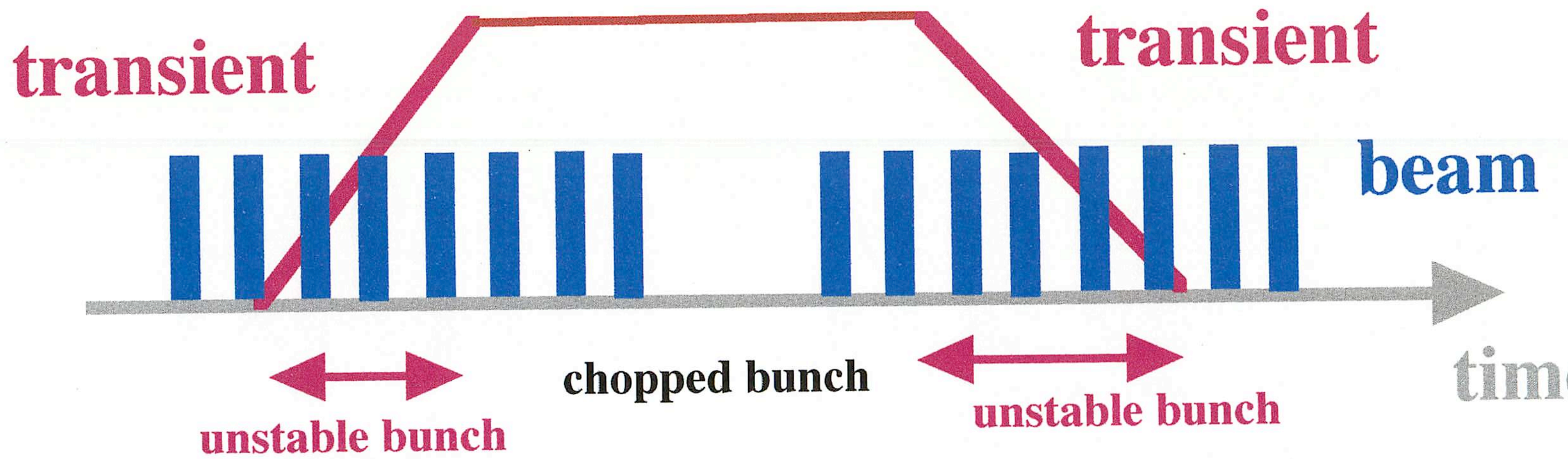
RFQ chopper chopper buncher buncher DTL

Q1 Q2 Q3 Q4 Q5 Q6 Q7 Q8

High performance in chopping operation

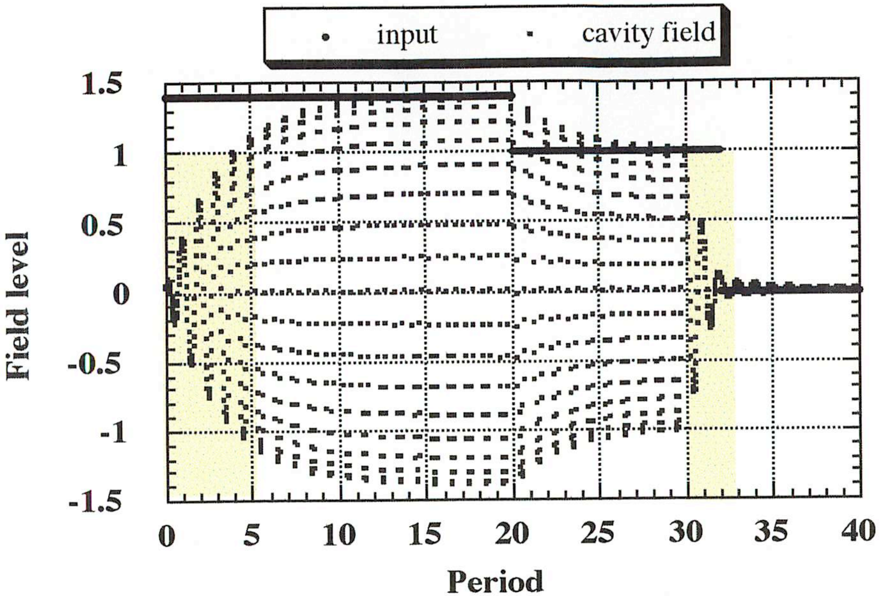
A fraction of the unstable transmitted particles through the DTL with the scrapers during transient times was reduced to as small as 0.08% of the total injection beam into the MEBT.

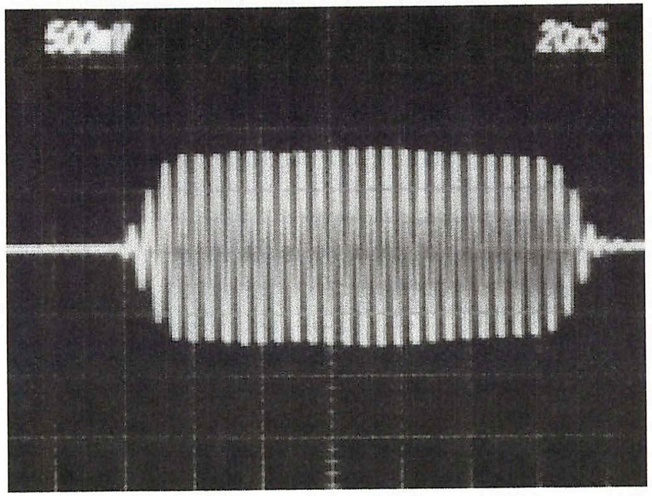
Amplitude of the chopping rf electric field



RF deflecting field during transient times

Use rf deflectiong cavity with low loaded Q-value





Calculated cavity field with an improved method. The initial amplitude (Em) of the incident power is 1.4 times higher. After some time, Em is adjusted to 1. A rapid phase shift is added at a timing of turn-off. After some time (at about 33-th periods in this figure), the incident power is turned off.

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.

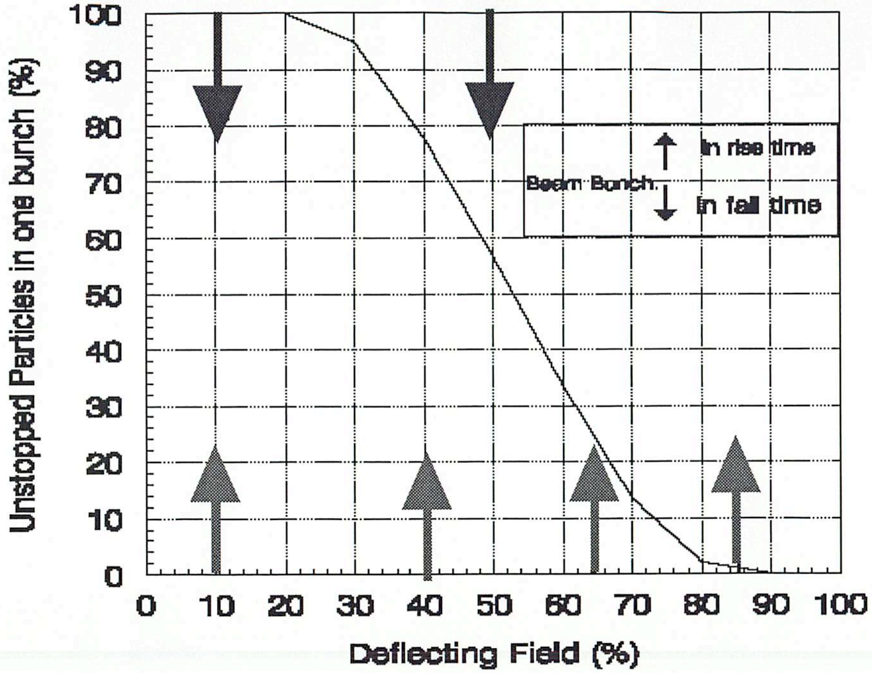
How to decrease unstable portion?

- **Decrease periods of transient** $\exp\left(-\frac{\omega t}{2Q_L}\right)$
  - **Low loaded Q-value of 10 ~ 20**
  - **Higher voltage at the beginning of the pulse**
  - **Phase change at the end of pulse**
- **Analysys of unstable-beam behavior in the DTL**
- **Using scrapers in the DTL is very effective**

25

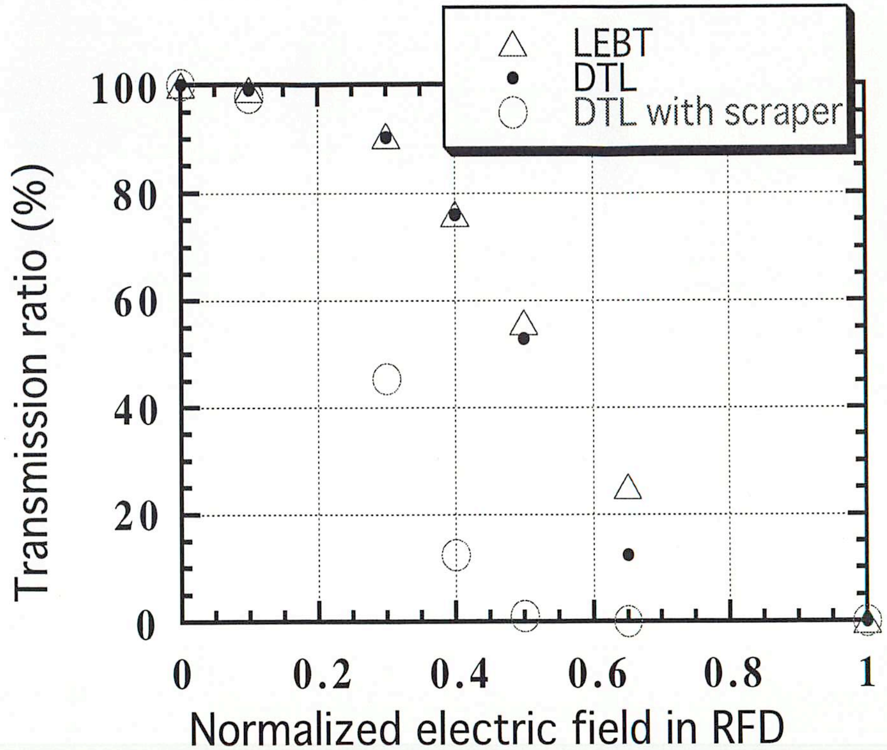
Analysys of unstable-beam behavior in the DTL

falling time



rising time

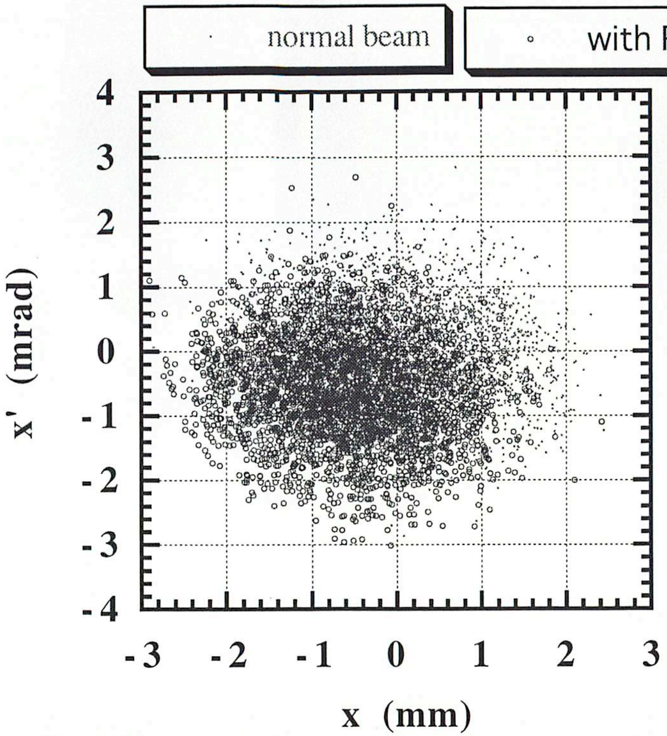
Micro bunch during transient periods

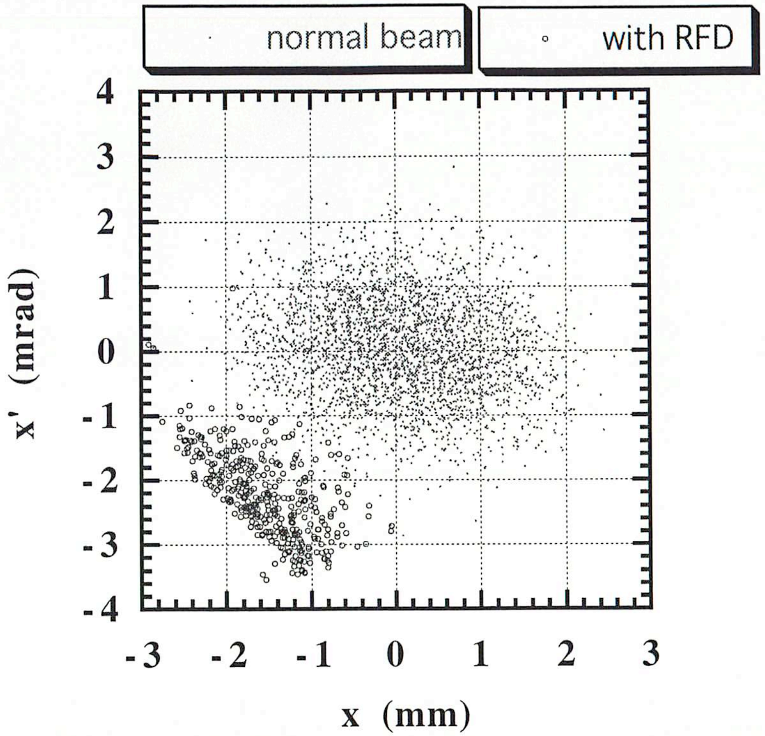


Transmission ratio through MEBT and DTL vs. RFD field during transient periods

26

Analysys of the chopper operation





The transmission ratio for the micro bunch with a 10%-RFD field is more than 97%.

Output emittances for the normal-unchopped bunch and the chopped one with a 40%-RFD field at the DTL exit. Two scrapers after DTL tank-1 and tank-2 are used for eliminating the outer part of the chopped bunch. The ratio of number of particles of the chopped bunch is 12.4% of the normal one.