Booster Linac Design
for ILC Conventional Positron Source

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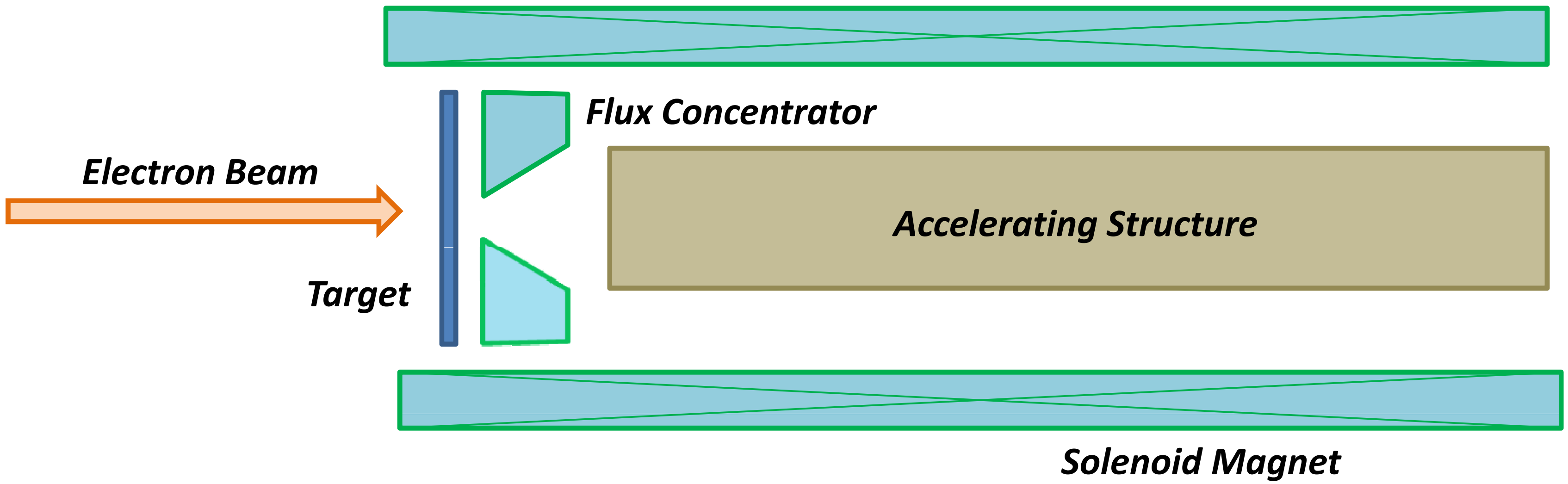
Source Working Group
LCWS2013

Contents

Positron Capture Section



Capture efficiency was evaluated based on the following parameters

*- Nuclear Instruments and Methods in Physics Research **A672** 52 (2011)*

Electron Beam

Beam Energy ; 6GeV

Bunch Population ; 2e10/bunch

Spot Size ; 4 mm (rms.)

Target

Material ; Tungsten

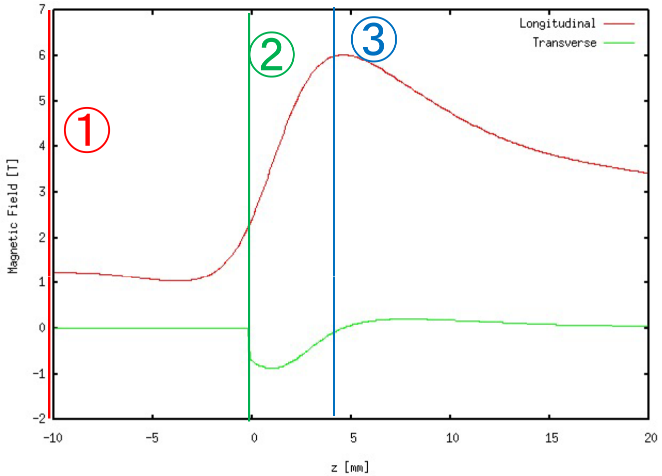
Thickness ; 14mm

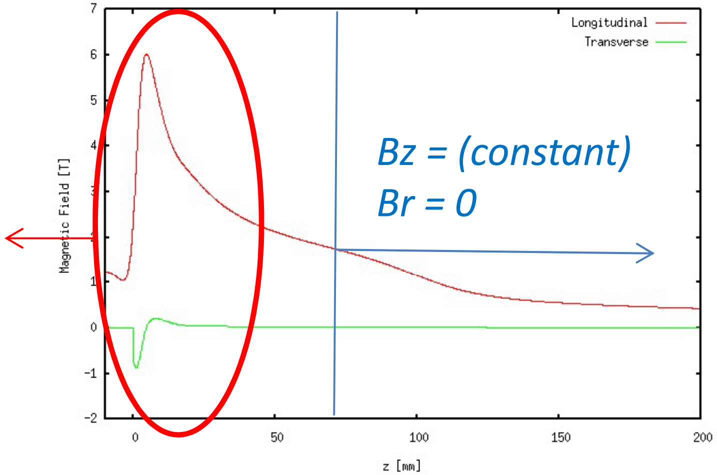
simulated by T. Takahashi (Hiroshima Univ.) with GEANT4.

Capture Simulation

AMD field was scaled from SuperKEKB AMD to ILC (6T peak field) by T. Kamitani.

Solenoid field was assumed to Bz=Bz(z=z0) of AMD and Br=0, when Solenoid is started from z=z0.



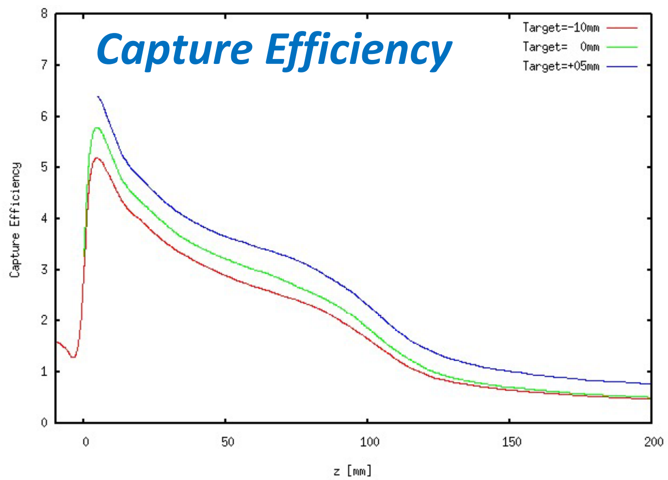


Targets were located at

① ; target = -10mm
(edge of Solenoid)

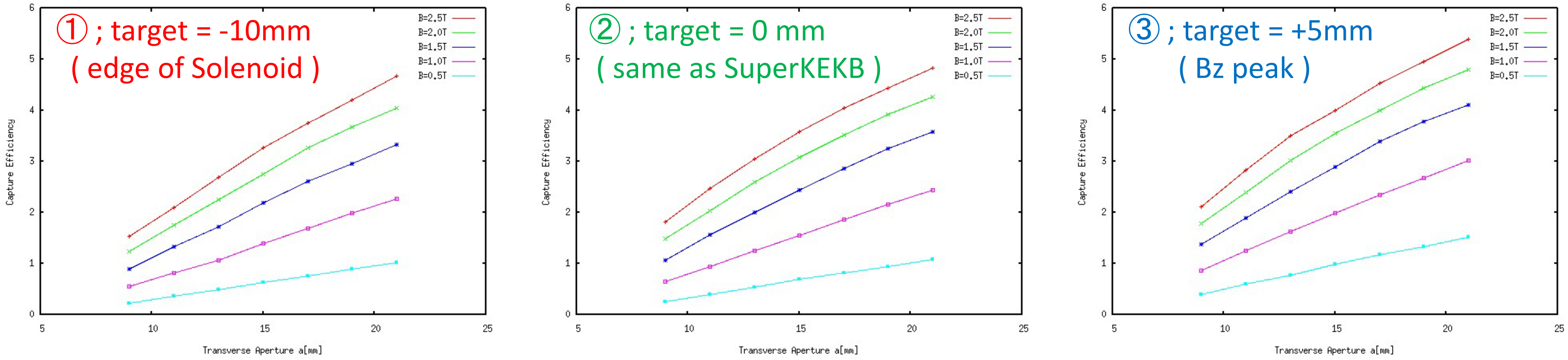
② ; target = 0 mm
(same as SuperKEKB)

③ ; target = +5mm
(Bz peak)

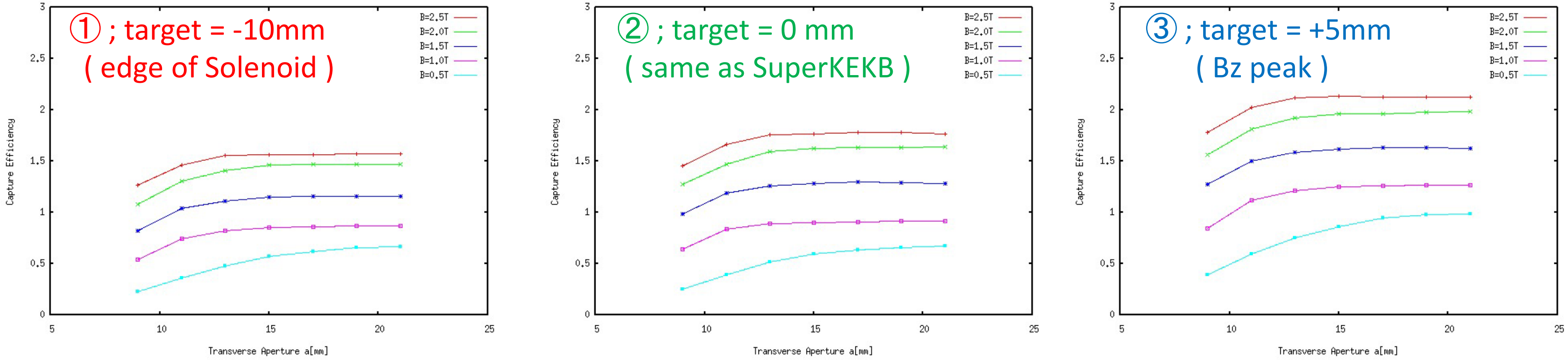


Capture Efficiency within Transverse Acceptance of DR

Capture Efficiency of All Positrons



Capture Efficiency of Positrons after Transverse Cut (Wx+Wy < 0.07m/γ)



- 2.5T
- 2.0T
- 1.5T
- 1.0T
- 0.5T

-Capture efficiency is increased with the Solenoid field.

-Capture efficiency is increased with the Magnetic field at Target.

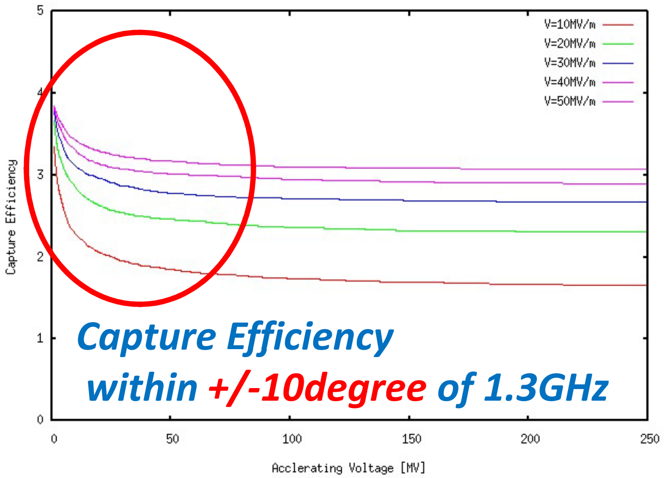
- Capture efficiency of the positrons (Wx+Wy < 0.07) are same for the aperture of the capture section of a > 15mm .

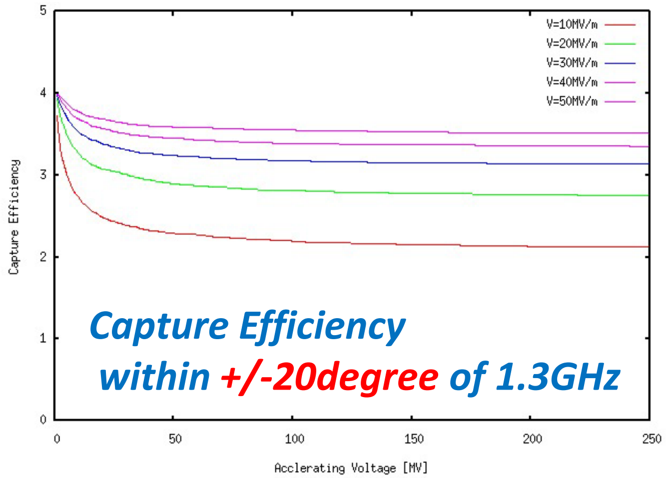
Accelerating Gradient of the Capture Linac

-Solenoid field in capture section generate bunch lengthening.

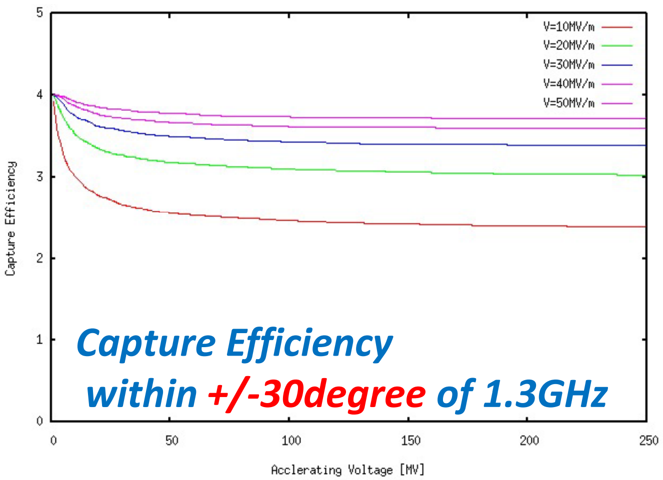
-The long bunch generate a large energy spread in acceleration.

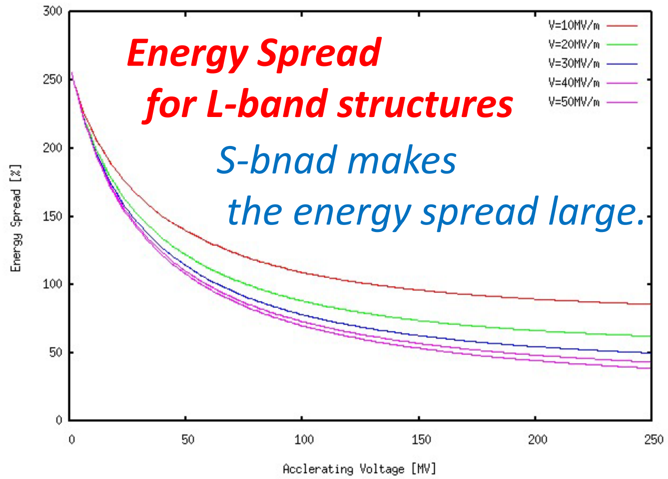
-The most of the particle losses are in the matching to non-Solenoid section, and it strongly depends on the energy spread of injected beam.





10MV/m
20MV/m
30MV/m
40MV/m
50MV/m

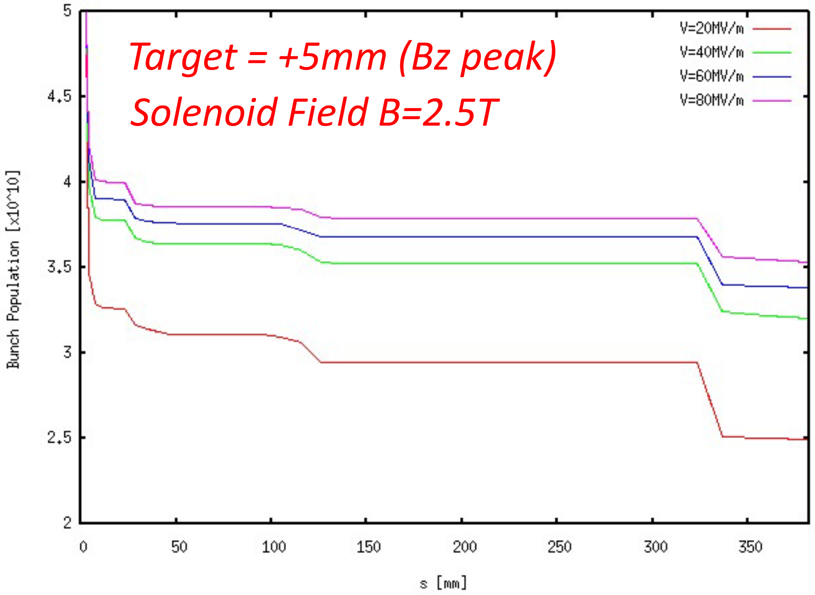


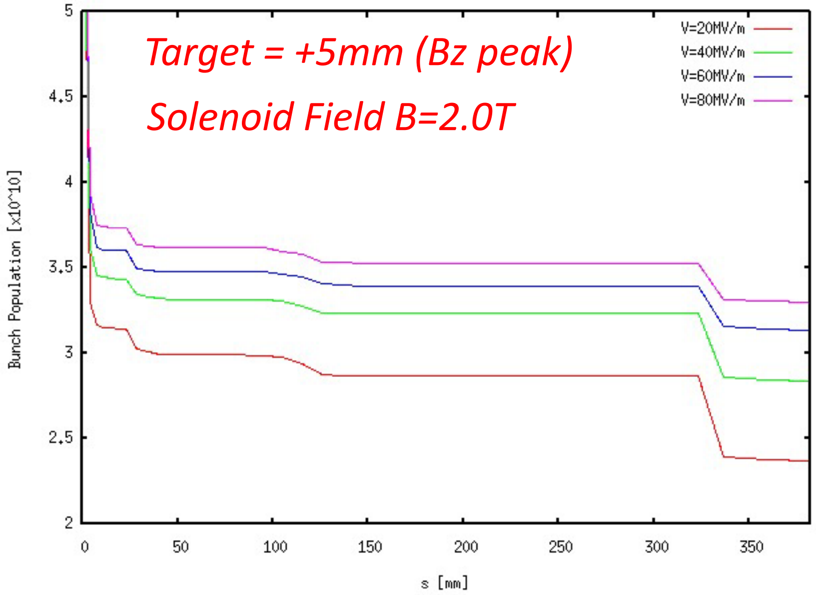


We should accelerate with high gradient structure at least injection of capture linac.

Temporal Parameters of Capture Linac to calculate Booster Linac

Capture Efficiency through the booster linac



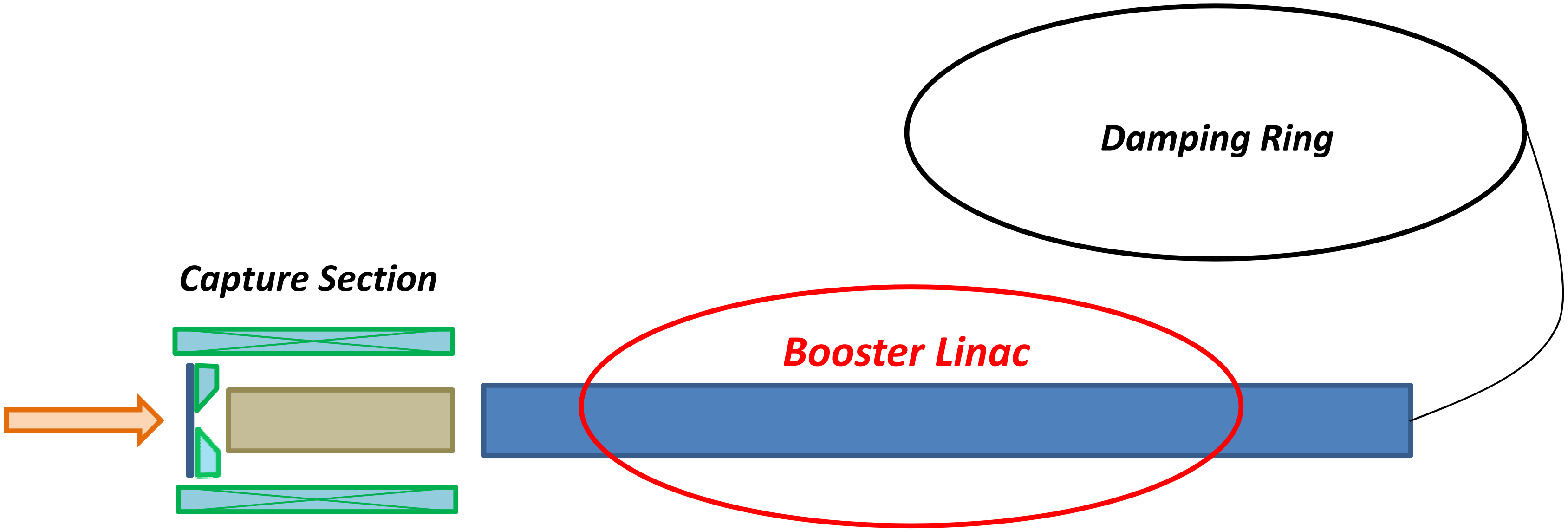


Gradient of L-band Linac	B = 2.5T	B=2.0T
20MV/m	2.23e10	2.20e10
40MV/m	2.96e10	2.64e10
60MV/m	3.09e10	2.88e10
80MV/m	3.19e10	3.02e10

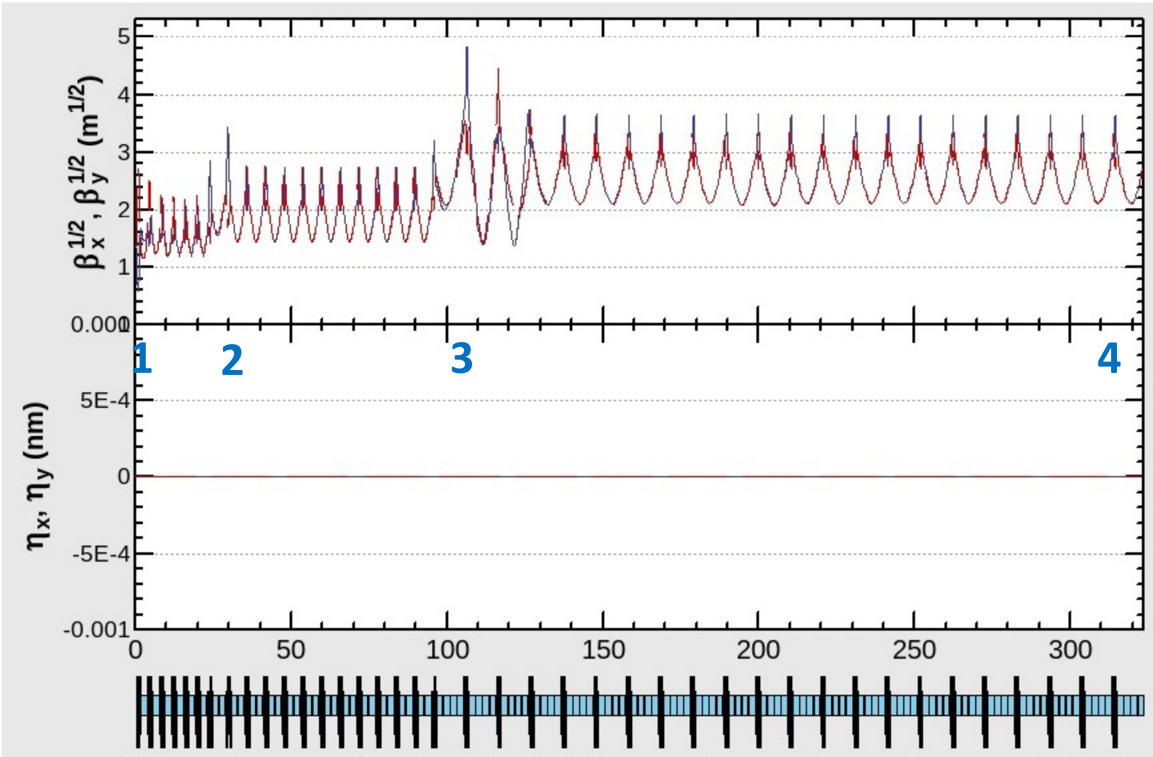
Temporally, I will use this parameter for the following presentation, even though it seems difficult to realize.

Design of the Booster Linac

Accelerating the positron beam to 5GeV to inject to DR



Design of Booster Linac



From 250MeV to 5GeV

If we assumed to

Wx+Wy= 0.07/γ and βx = βy = 2.0 m,

sqrt (βx Wx + βx Wx) = 0.0189 m at 200MeV

sqrt (βx Wx + βx Wx) = 0.0169 m at 250MeV

sqrt (βx Wx + βx Wx) = 0.0154 m at 300MeV

RF System (1.3GHz)

L = 2m each

a = 0.017-0.014m (minimum)

V = 35-45MV / structure

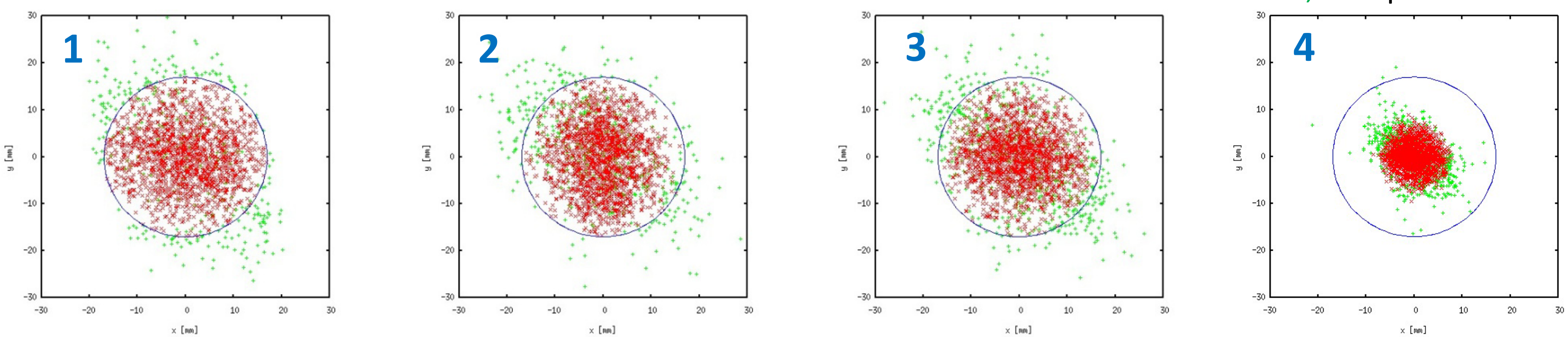
with Beam Loading Compensation
(Beam Current) = 3.5e10/bunch

When we transport the beam to 2m long L-band structure without Solenoid field,

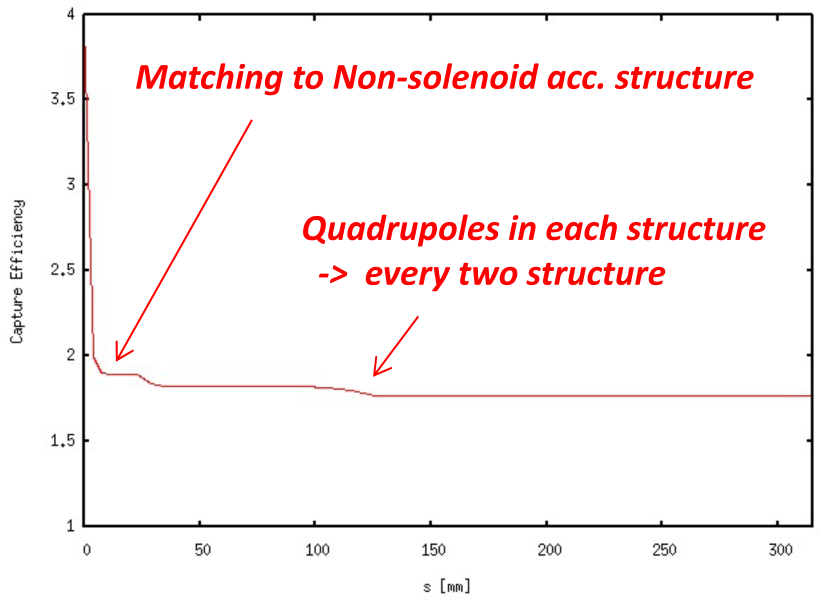
the beam energy should be E>250MeV.

Red ; trasmitted particle

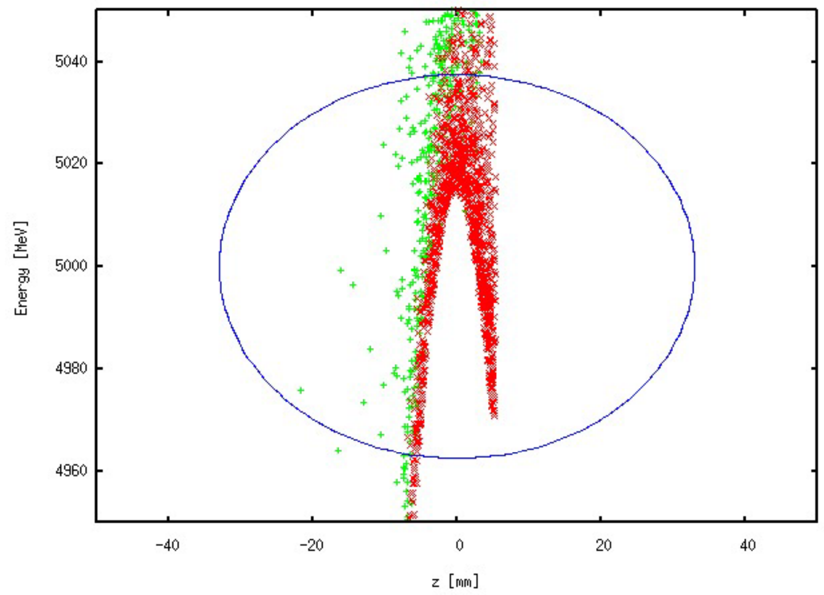
Green ; lose particle



Capture Efficiency after Booster Linac



Longitudinal Phase Space Distribution



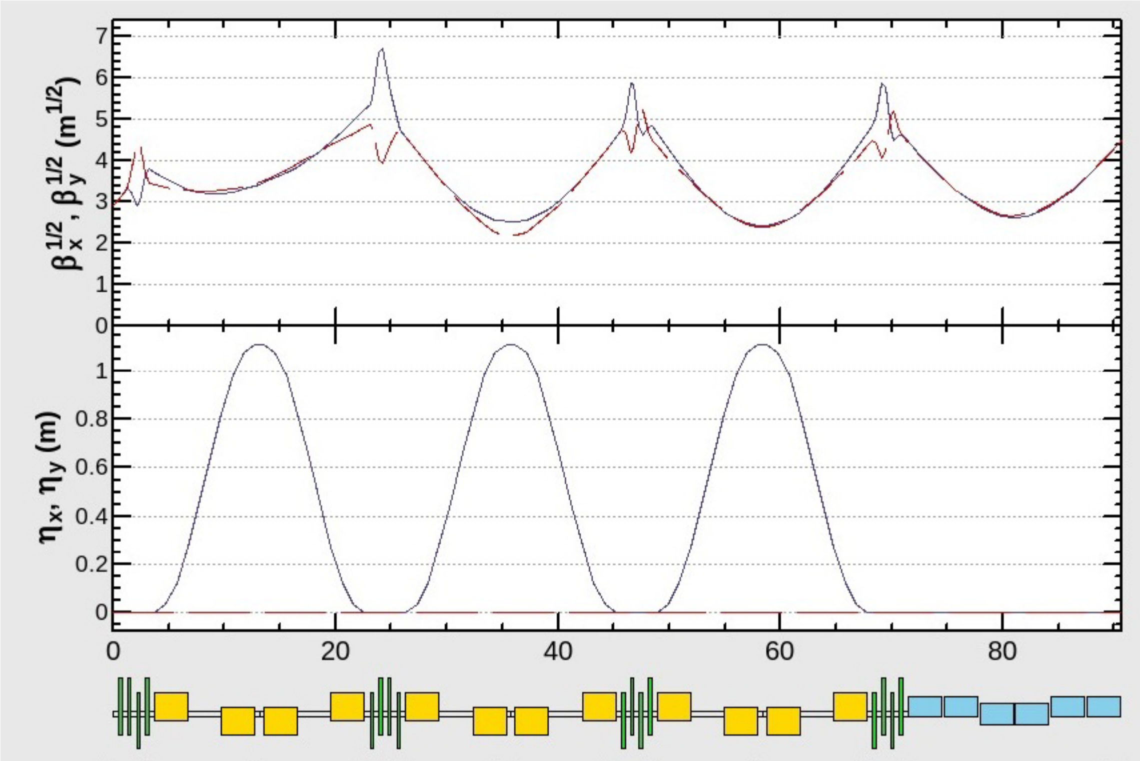
Location	Capture Efficiency
Injection	3.957
After Booster Linac	1.678
Longitudinal Cut	1.147
Longitudinal & Transverse Cut	1.117

Longitudinal Acceptance

33mm ×37.5MeV

Capture efficiency after booster linac is 1.12.

Energy Compression System (ECS)



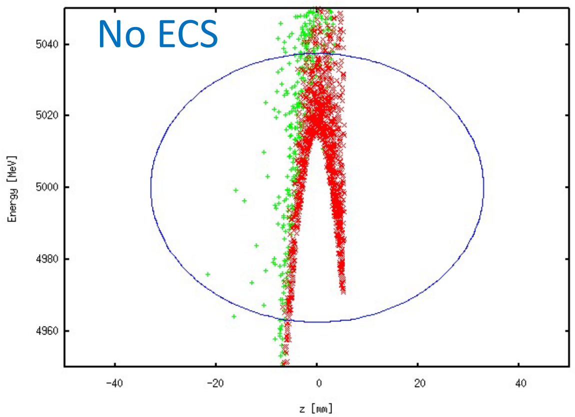
Bending System

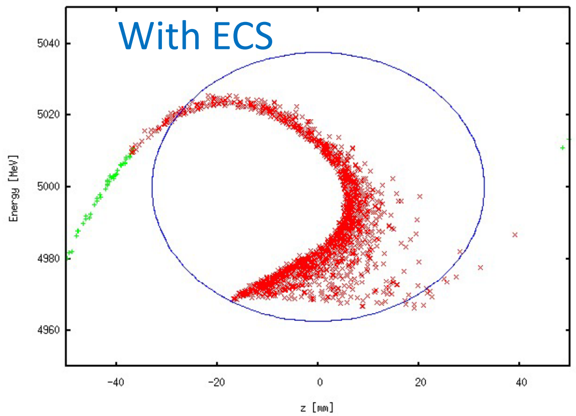
12 Bending Magnets
B=1T each
L=3m each
R56 = 1m
Maximum horizontal offset = 1m

RF System (1.3GHz)

4 Cavities at 180 degree phase
L = 3m each
V = 40MV each

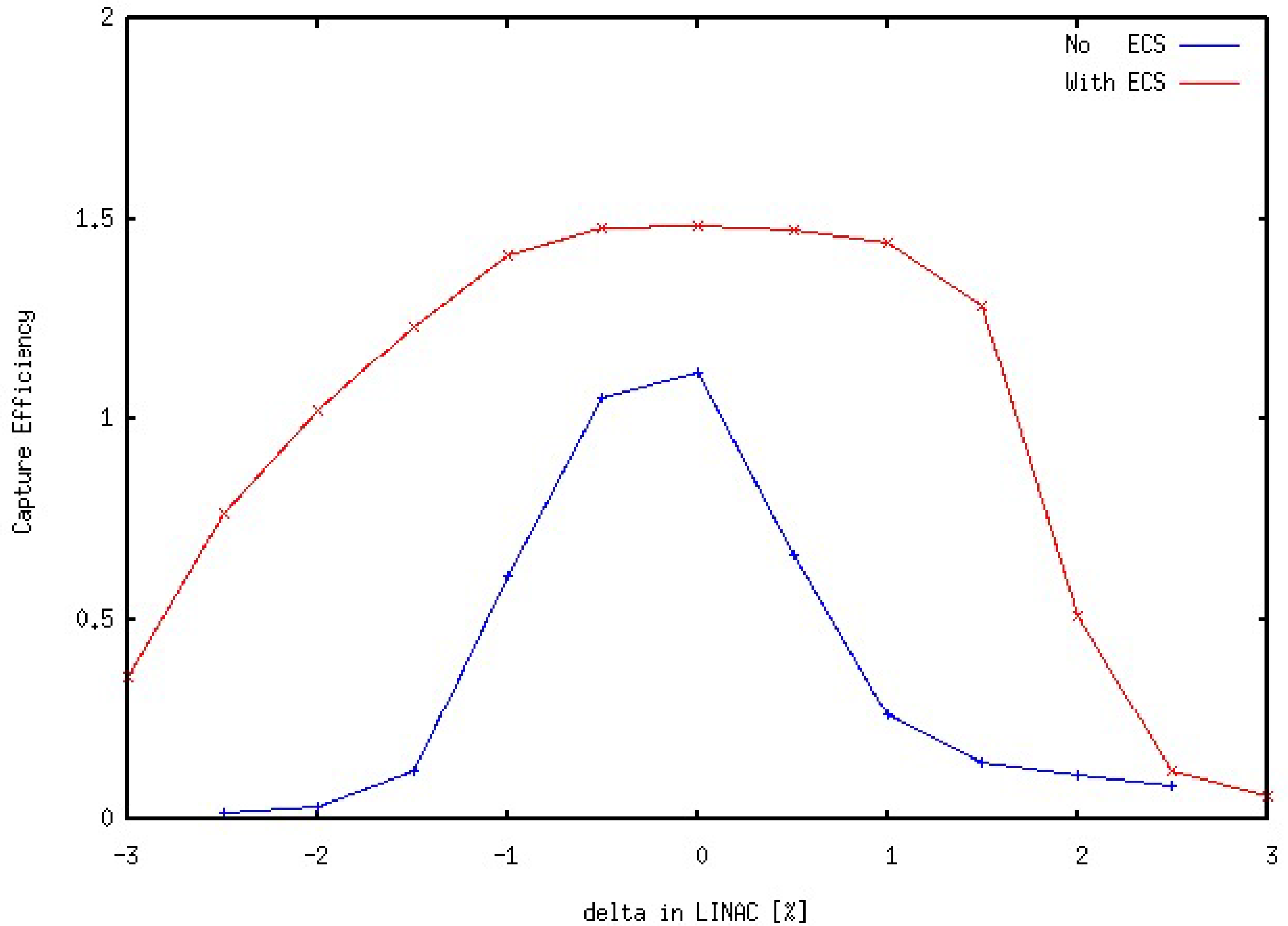
2 Cavities
for Beam Loading Compensation
L = 3m each





Location	Efficiency
Injection	3.957
After Booster	1.678
After ECS	1.604
Long. Cut	1.551
Long. & Trans. Cut	1.482

Requirement of Beam Loading Compensation

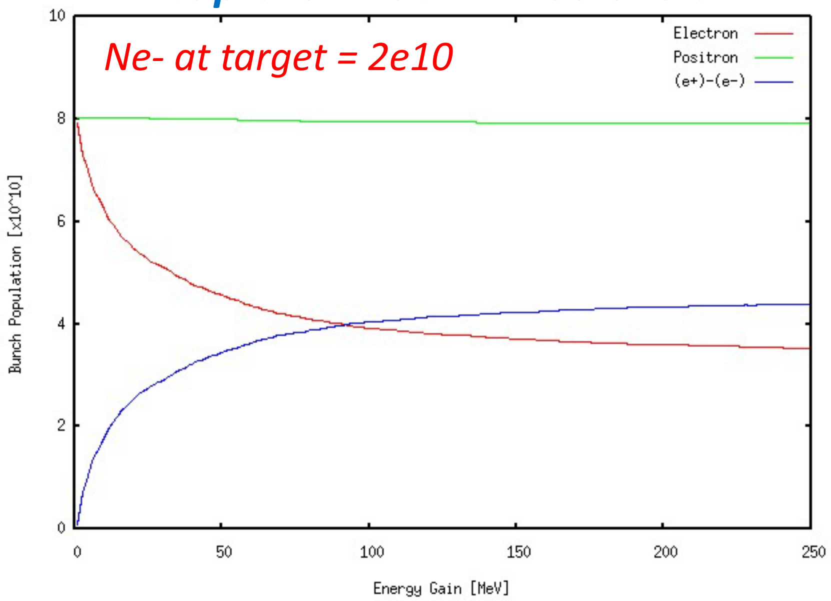


Energy compressor system is not only increase the capture efficiency,
but also increase the tolerance of the multi-bunch energy difference in booster linac.

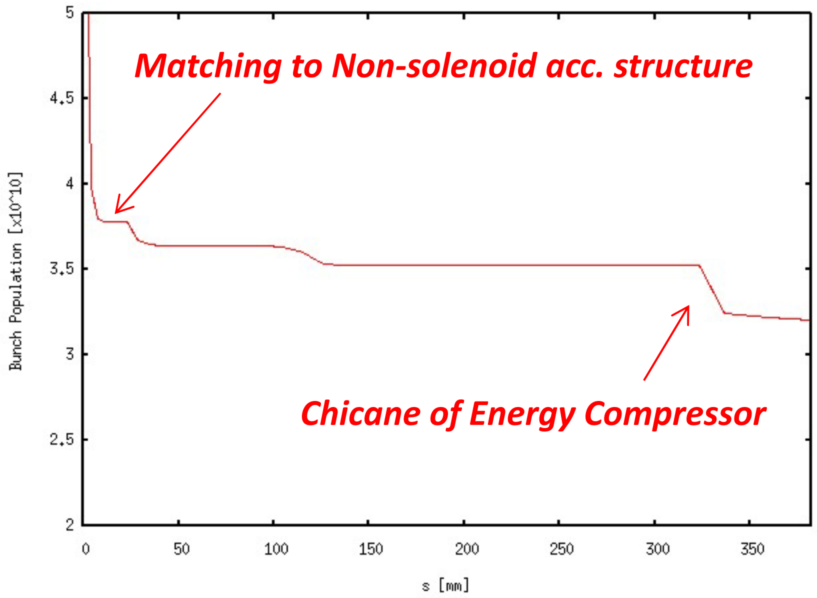
Beam Loading Compensation

Beam Current Propagation

Capture Linac with Solenoid



Booster Linac



(Number of positron) = 8e10
(Number of electron) = 4e10
in Capture Linac with Solenoid

(Number of positron) = 3.5e10
in Booster Linac

We must compensate the beam loading for 4-5e10 positrons in capture linac.
The loading is strongly depends on the parameter of capture section.
The beam loading should be compensated by N=3.5e10 bunch charge in the booster linac.

Comparison with S-band and L-band

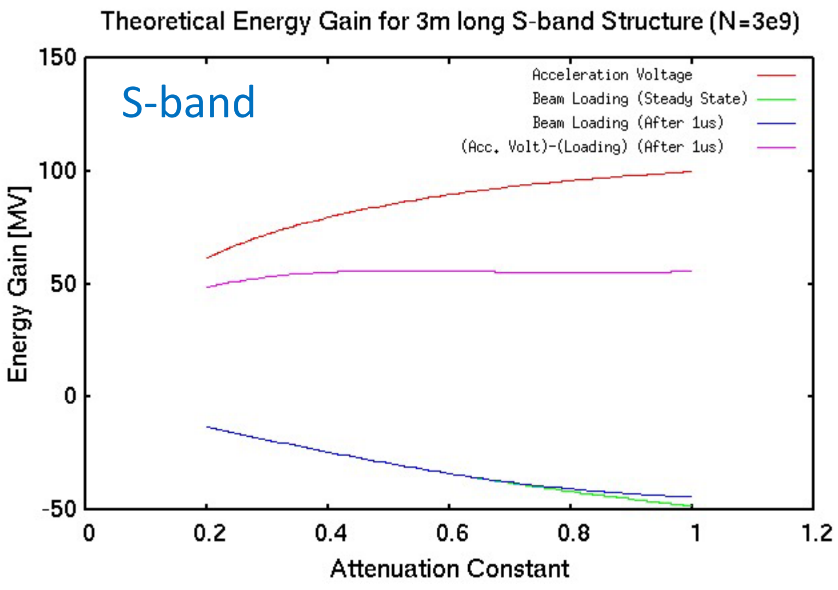
Accelerating Voltage

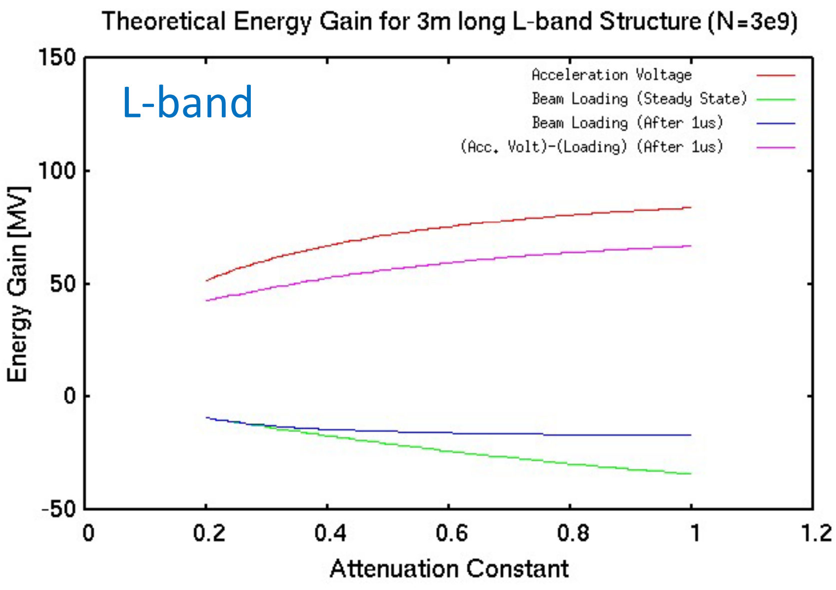
Since S-band structure has a large Shunt Impedance,
accelerating voltage is sqrt(2) times larger than L-band for same input power.

Beam Loading

Since S-band structure has a large R/Q,
the beam loading in steady state is twice as larger than L-band.

Since L-band structure has a long filling time,
the all of bunches pass through within transient beam loading.



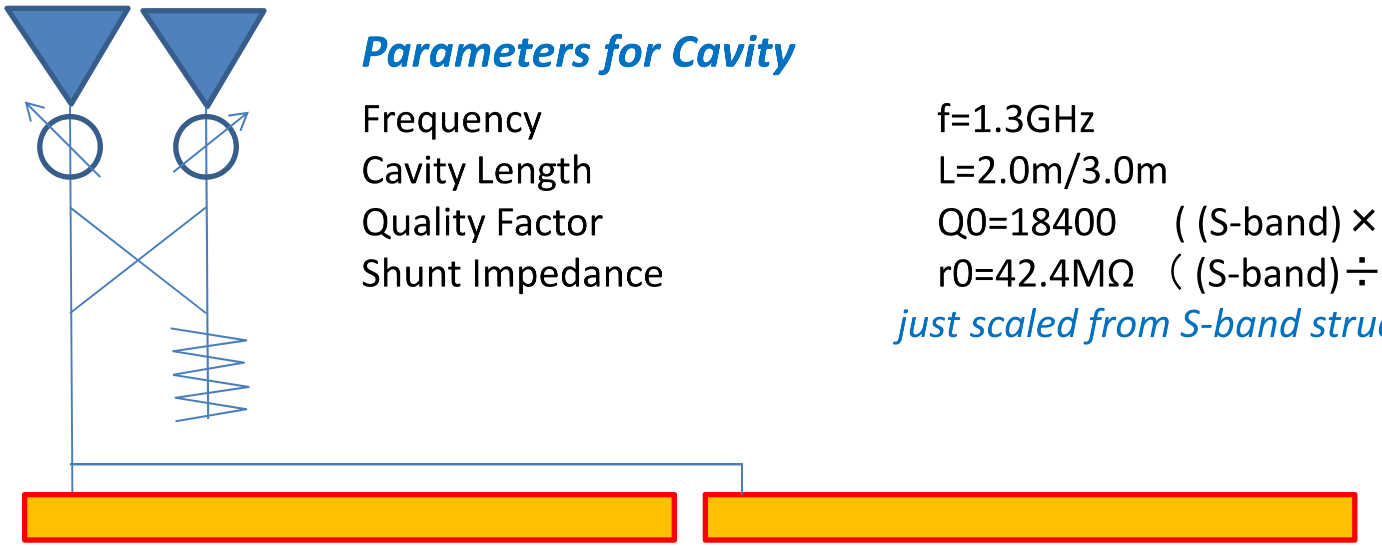


In simple calculation, the accelerating voltage subtracted the beam loading of L-band structure is comparable to the that of S-band structure.

Beam Loading Compensation for L-band Structure

Parameters for Klystron

Frequency	f = 1.3GHz
Maximum Klystron Power	Pmax = 80MW
Transmission Loss	10%
Margin	10%
Effective Input Power	Pin = 64MW



Parameters for Cavity

Frequency	f=1.3GHz
Cavity Length	L=2.0m/3.0m
Quality Factor	Q0=18400 ((S-band) × 1.4)
Shunt Impedance	r0=42.4MΩ （(S-band) ÷ 1.4)

just scaled from S-band structure

Optimistic Scenario to develop High Power L-band Kystron

Specification of TOSHIBA Klystron

	Name	Frequency	Peak Power	Pulse Width	Pulse Rate	Vk [kV]	Ik [A]	Average Power	Corrector Power
L-band	E37501	1,300MHz	0.75MW	1,500us	5pps	66	50	6kW	25kW
	E3736	1,300MHz	10MW	1,500us	10pps	115	132	150kW	228kW
	E37612	1,428MHz	30MW	6us	60pps	295	260	11kW	28kW
S-band	E37307	2,856MHz	5.0MW	18us	600pps	135	95	54kW	138kW
	E37308	2,856MHz	25MW	4us	200pps	245	255	20kW	50kW
	E3729	2,856MHz	34MW	12.5us	50pps	304	316	21kW	60kW
	E3712	2,856MHz	80MW	4us	50pps	400	488	16kW	39kW

The peak power is limited by the Klystron voltage, especially for long pulse.

The average power is limited by the power to the corrector.

If we assumed same perveance of E3736 (multi-beam klystron, 65% efficiency), and reduce the pulse length.

Efficiency	Peak Power	Pulse Width	Pulse Rate	Vk [kV]	Ik [A]	Average Power	Corrector Power
40%	80MW	4us	300pps	304	657	96kW	240kW
45%				290	613		213kW
50%				278	575		192kW

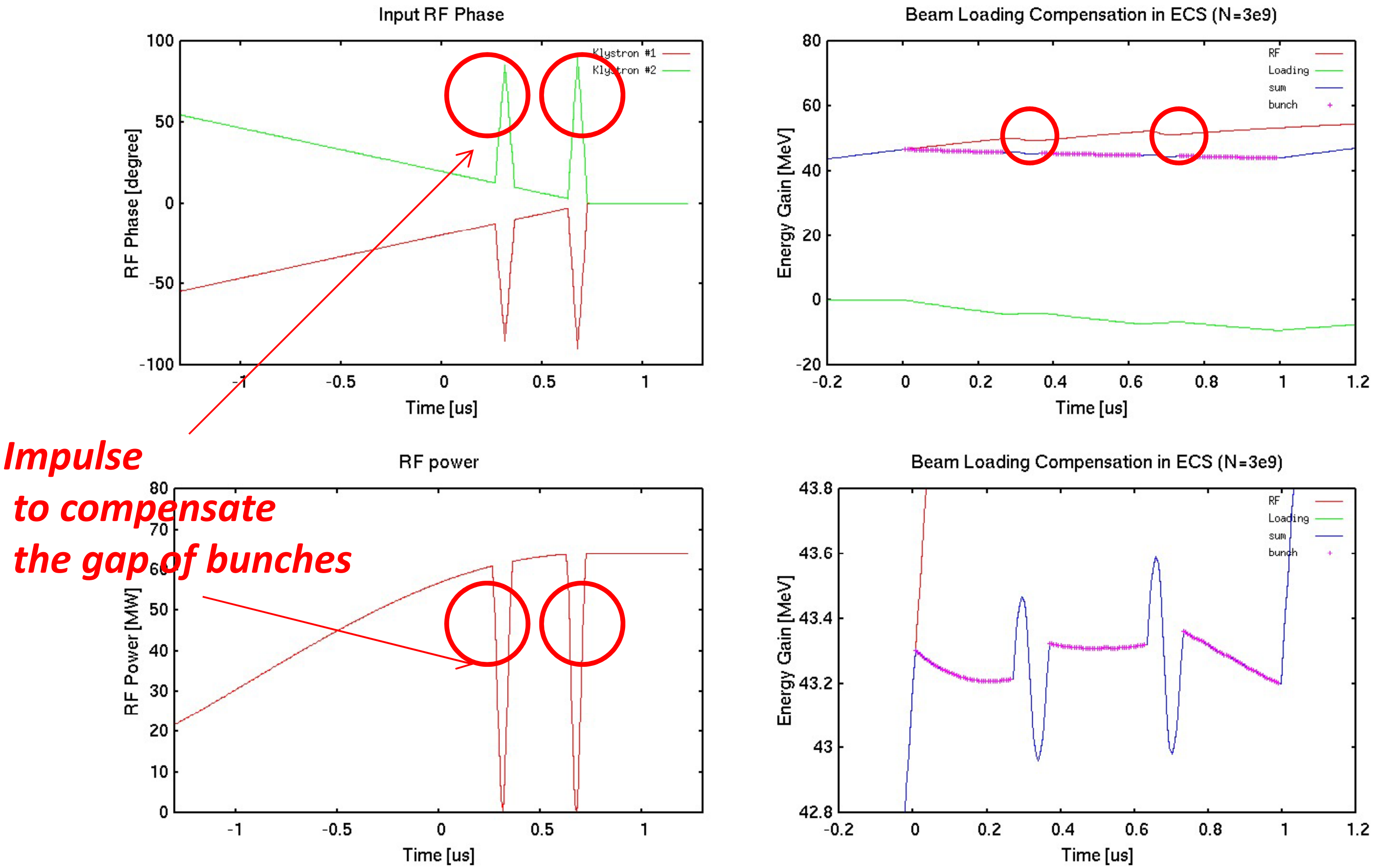
We can develop the 300pps high power L-band klystron based on multi-beam klystron.

Is this true ?? (Questions for RF expert)

Example of Beam Loading Compensation

Cavity Length	Attenuation Constant	Speed of Phase Shift (Required Klystron BW)	
		Gap 1	Gap 2
2m	0.50	50 ns / 90degree (+/- 5.0MHz)	50 ns / 90degree (+/- 5.0MHz)

Wide bandwidth is important.

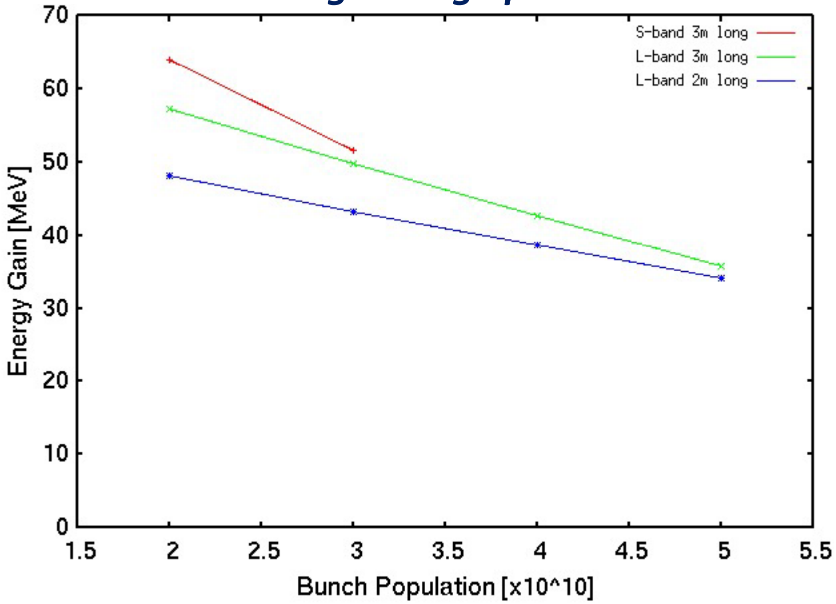


Accelerating Gradient for L-band Structure with beam loading compensation

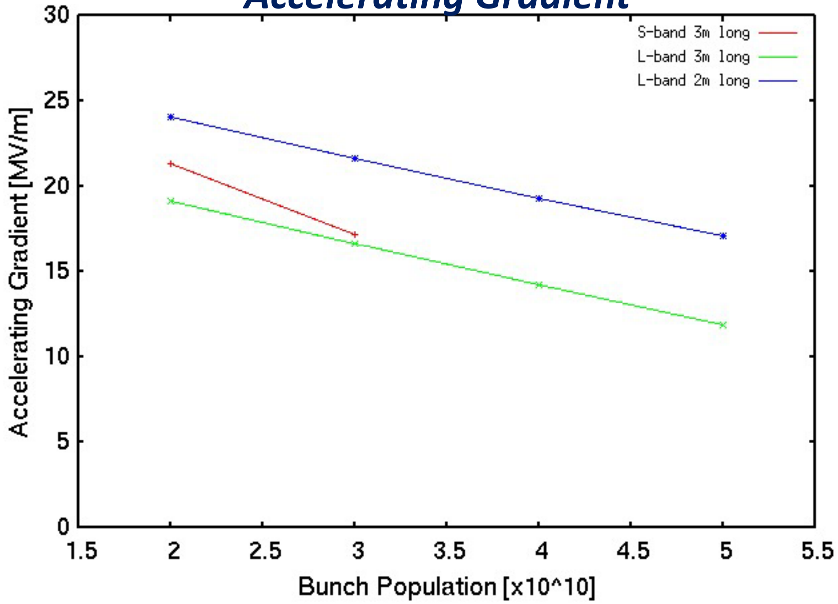
τ = 0.59 for S-band structure

τ = 0.50 for L-band structure

Accelerating Voltage per structure



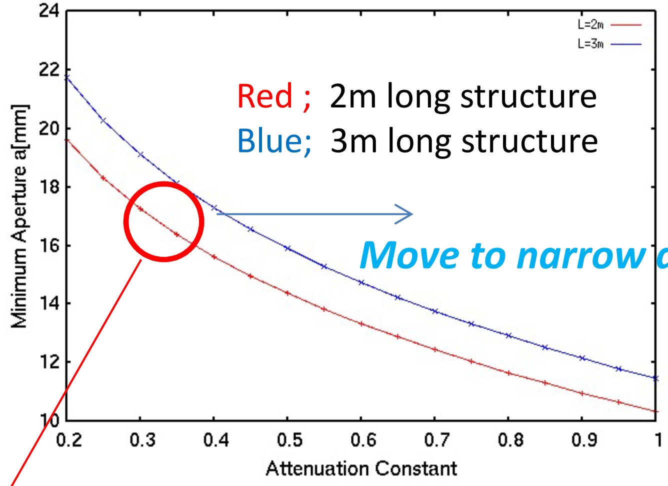
Accelerating Gradient



Total accelerating voltage of 2m long structure is lower than that of 3m long structure, but the accelerating gradient is larger than 3m long structure.

Rough Evaluation of Accelerator Tube Aperture

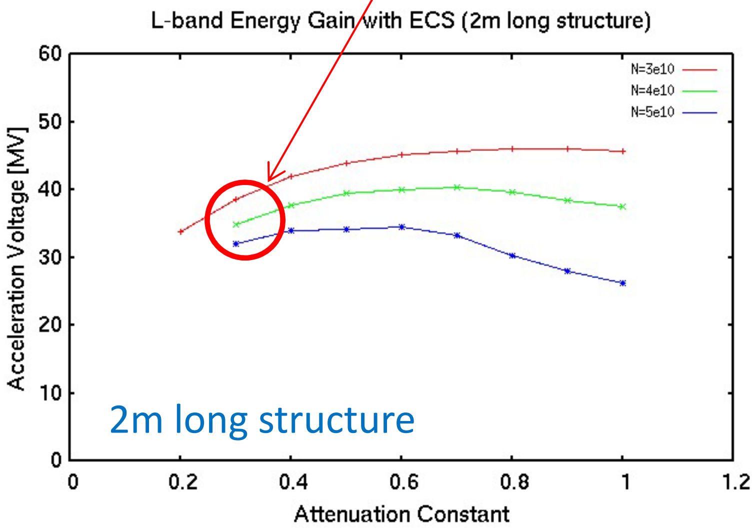
Scaled from SuperKEKB L-band structure

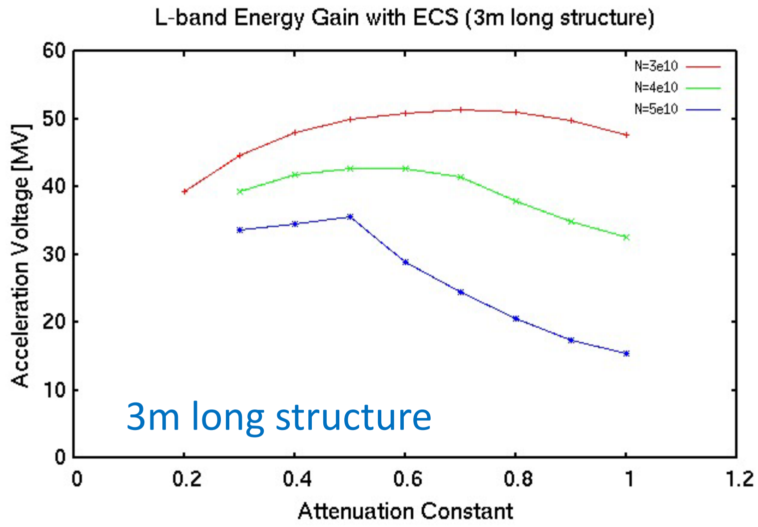


Move to narrow aperture through acceleration

Entrance of Booster Linac

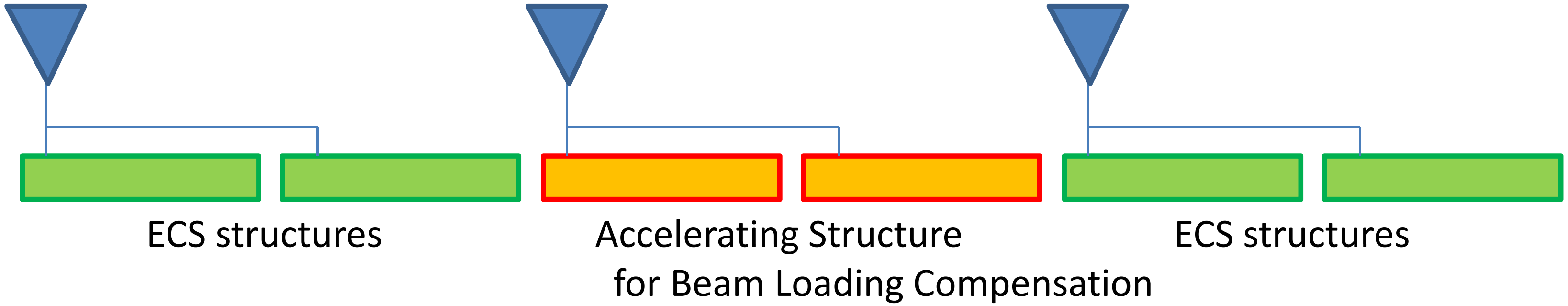
Large aperture required



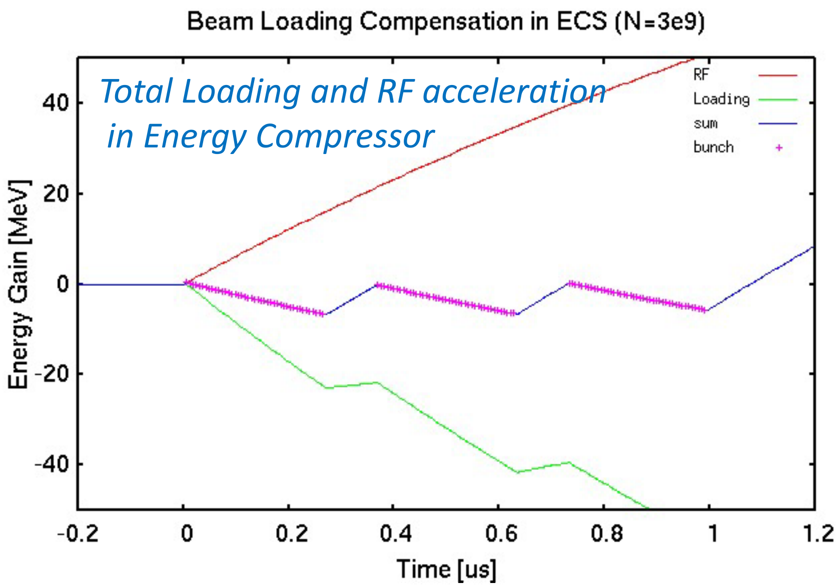


Beam Loading Compensation for the Cavity of ECS

Simple ΔT Energy Compensation Method



RF power is injected to RF structure just after 1st bunch is injected.

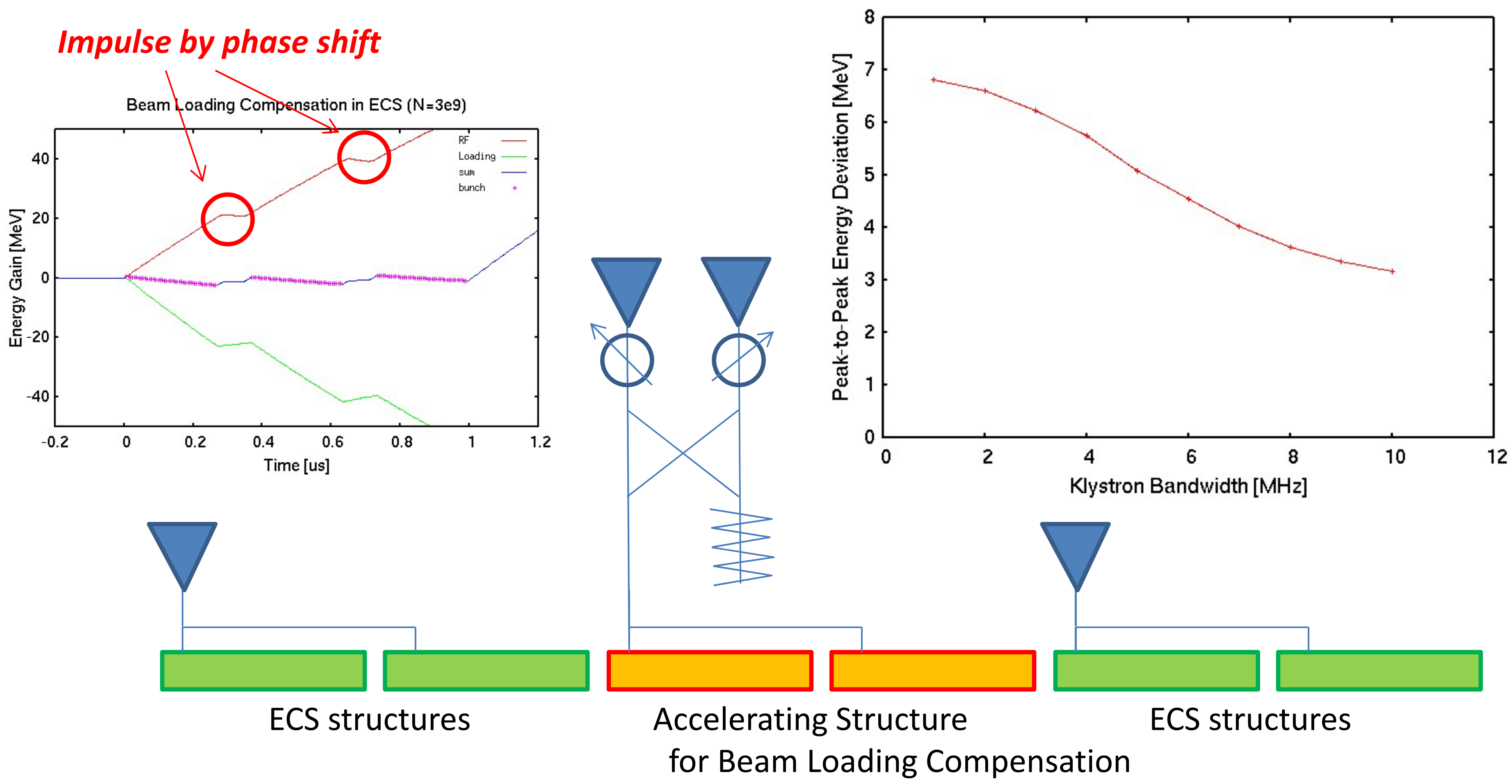


	ECS	Beam Load.
f	1.3 GHz	1.3 GHz
L	3 m	3 m
Q	18400	18400
R	42.4 MΩ	42.4 MΩ
τ	0.40	0.80
P /structure	32MW	32 MW

ΔE = 68MeV -> ΔE = 7MeV

Beam Loading Compensation for the Cavity of ECS 2

When the simple DT method is not enough,
the energy jump can be compensated by 2 klystron.



In this method, the energy deviation is depends on the klystron bandwidth.

Summary

Capture Section

I evaluated the capture efficiency based on the parameters, written in NIM paper.
Then, it was found that …

-Capture efficiency is increased with the ***magnetic field at target.*** ***-> Affect to the eddy current of rotating target !***
-Capture efficiency is increased with the ***solenoid field****.*
-Capture efficiency (Wx+Wy < 0.07) are ***same for the aperture of a > 15mm****.*
-Capture efficiency is strongly depends on the ***accelerating gradient at least injection of capture linac****.*
- Capture efficiency is better for ***L-band structure****.*

But, I have not yet found the realistic solution to get 150% of capture efficiency.

Therefore, we should optimize the design of capture section ***not only for above conditions, but also the following issues***

-The beam energy, current and spot size of the injected electron beam to target
- The target material and thickness
} Affect to the damage of target !

i.e.) electron beam size σ_{e-}*=4mm -> 3*σ_{e-}*=12mm*
aperture within Wx+Wy < 0.07 -> a=15mm ***very tight***

-Design of the flux concentrators.

The design of the capture section is a key issue for the ILC conventional positron source (1 st ***priority) .***

Summary (continued)

Booster Linac

Once we can optimized the capture section, we can transport the positron with small particle loss.

*- Injection to non-Solenoid L-band linac should by **E>250MeV.***

*- **4 Quadrupole magnets are put each 2m long L-band structure** at the entrance of booster linac.*

*-**The energy compressor is essential** not only increasing the capture efficiency,*
but also increasing the tolerance of the beam loading compensation.

Beam Loading Compensation

*-The accelerating voltages included the beam loading for **S-band and L-band are almost same at N=3e10**.*

-2m long structure can accelerate the positron beam by high accelerating gradient than 3m long structure.

*-We had better to use the **klystrons with wide bandwidth** for the beam loading compensation*

*- The beam loading for **energy compressor cavity can be compensated to 7MeV or less.***

We should check whether is it possible to develop 300pps high power L-band klystron. (2nd priority)

We should optimize the structure and beam loading compensation parameters to make cost minimum. (3rd priority)