Present status of the BDS tunnel layout

Toshiyuki OKUGI, KEK

2015/11/03

Accelerator Plenary

LCWS2015, Whistler (CANADA)

Future Change Requests related to BDS tunnel

1. ***Philosophical decision of compatible tunnel both for undulator and e-driven positron source (CR from Source group)***

   - This CR is topics of this session.

2. ***Twin tunnel -> Kamaboko tunnel (CR from CFS or BDS group?)***

   - This topics is proposed at ILC review(LAL) in 2015 April by M. Miyahara.

   - In order to make the optimum tunnel,
   I reviewed the positron and electron sources at first.

   *Then, some beamline modifications of **undulator positron source** was proposed at POSIPOL2015.*

   - The tunnel is designing and should be discussed with global group (CFS, BDS, MDI, detector and source etc.).

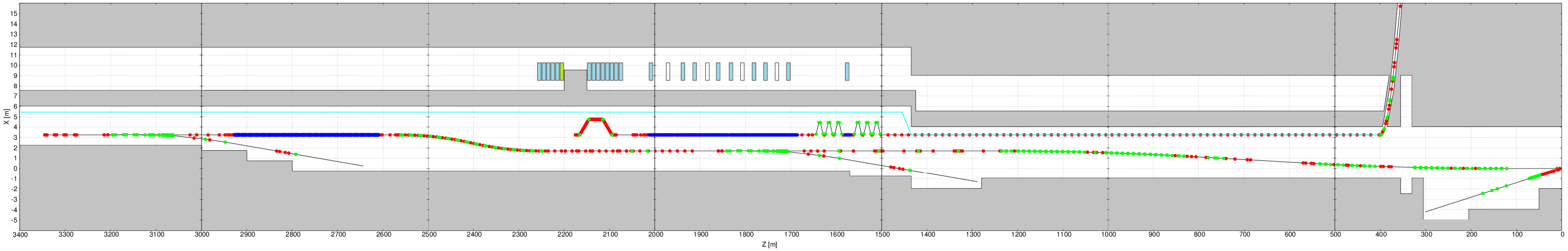
   - The tunnel layout will not include the e-driven positron source at the time.

   - The target of the CR submission is spring 2016 (?).

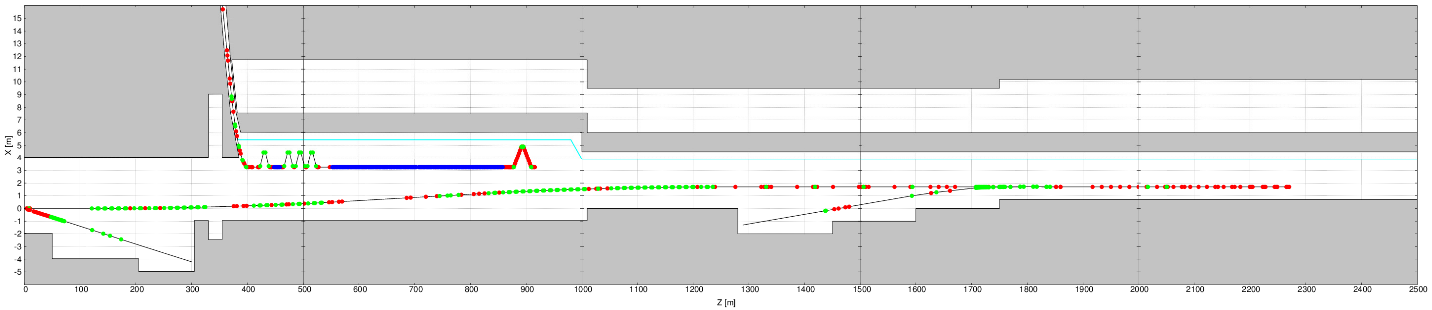
3. ***Engineering design with the compatible tunnel (CR from 2.), if 1. will be approved.***

BDS tunnel layout

Electron BDS



Positron BDS



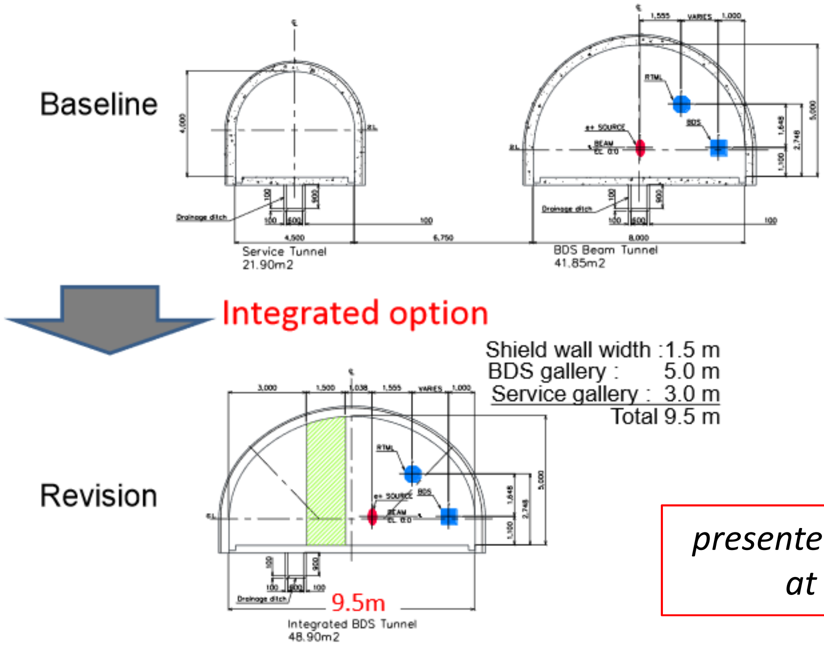
We have a lot of beamlines in BDS tunnel.
We must make the BDS tunnel to be better for all beamlines.

- electron BDS
- undulator positron source
- (e-driven positron source)
- electron RTML ***for electron BDS***.

- positron BDS
- electron source
- positron RTML ***for positron BDS***.

Tunnel layout around undulator PS

Cheaper



presented by M.Miyahara
at ALCW2015

We need many number of waveguide penetrations in between two tunnels.

- *Tunnel drilling*
- *Maintenance of the waveguide*
- *Radiation shielding of the penetration hole*

It is easy to make the tunnel Kamaboko-shape as well as Main Linac.

Proposed beamline layout of Undulator positron source

(not related to this CR, presented at CFS session at 11/3 8:30)

Electron BDS (undulator positron source)

The SC cavities for undulator positron source were moved to upstream in order to reduce the chromaticity of the long transport line.

The R56 for energy compressor was increased and the energy compressor was moved to upstream.

The path length adjuster was put just after energy compressor.

Muon Background to detector

We need the muon background simulation to fix the BDS tunnel shape.

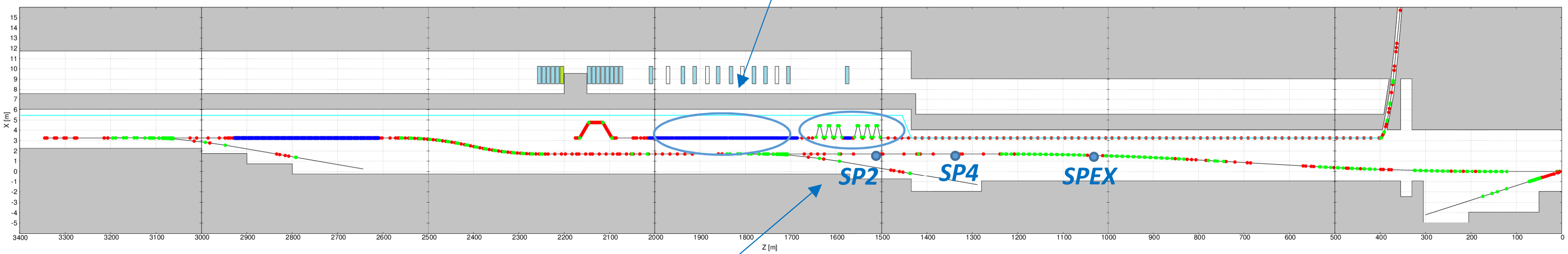
Radiation Wall Thickness

We need careful evaluation of the thickness of the radiation shield to protect PS.

Monitor Stations and Cable Penetrations

Beamline layout of undulator positron source

Booster linac was moved to upstream.



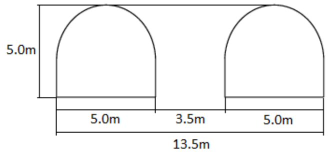
Energy compressor and path length adjuster was put before the long transport line.

The super-conducting devices can be moved to the upstream of BDS beamline.

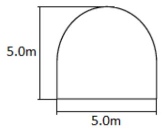
- *SC devices can be put with same to ML Kamaboko tunnel.*
- *SC cavities are located upstream of collimators.*
- *It is easy to arrange the cold system, because the devices are close together.*

Case 1 ; Twin Tunnels

Accelerator Tunnel

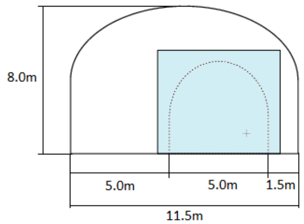


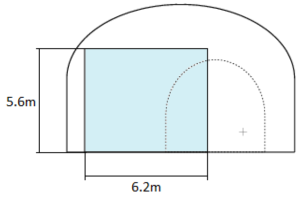
Neck



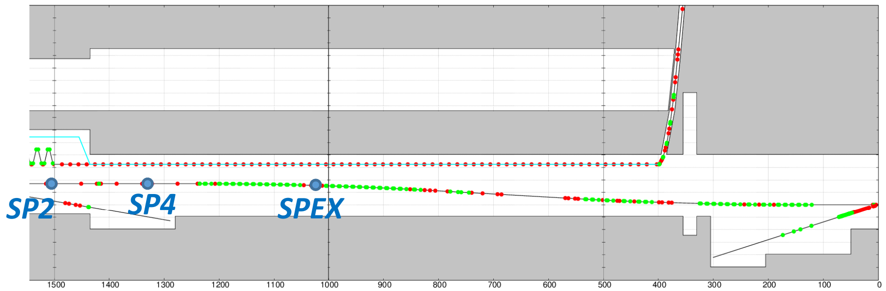
Since the smaller tunnel also is expensive, the tunnel widths was set to 5m for twin tunnel.

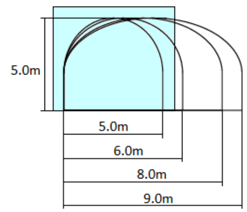
Muon Hall





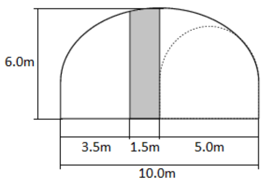
- *Same tunnel shape for entire BDS tunnel*
- *The size of muon spoiler is defined only by the cress section of BDS tunnel.*
- *We should take care of the cable penetrations in between service and accelerator tunnels.*



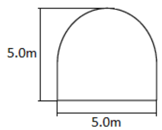


Case 2 ; Single Tunnels

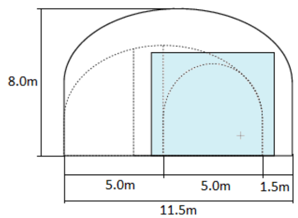
Accelerator Tunnel

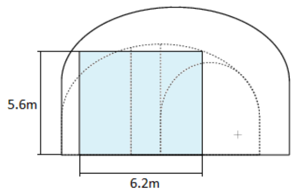


Neck

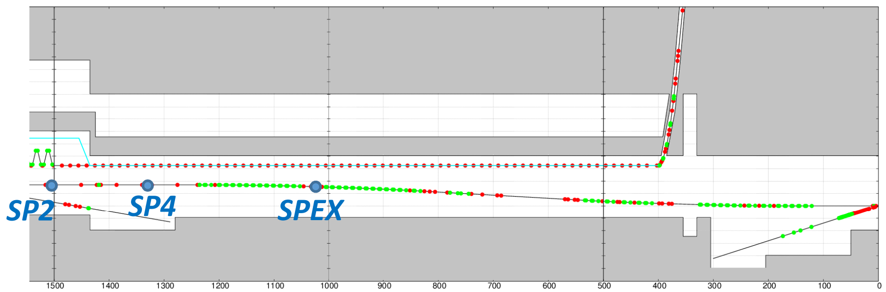


Muon Hall



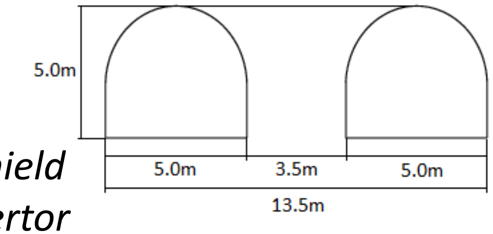


- *Is large muon spoiler required to cover all of cress section for BDS tunnel?*
- *Is the tunnel cheaper than twin tunnel ?*

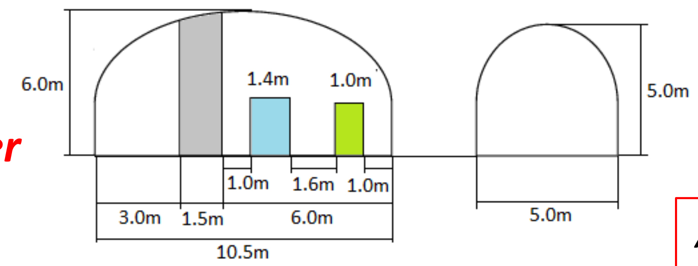


Tunnel expansion for e-driven positron source

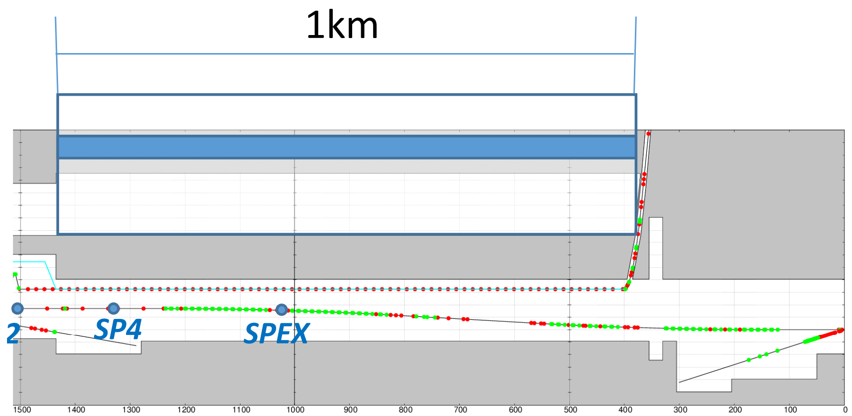
Twin Tunnel



Thickness of radiation shield
Cavern for voltage convertor
(next slide)



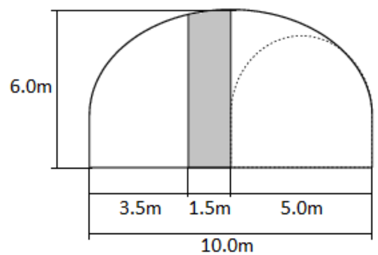
cheaper



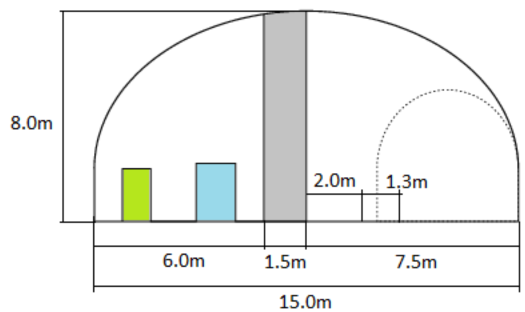
Almost 1km space is available for both tunnels after undulator PS in present BDS tunnel design.

We should take care of the radiation effect from e-driven positron source for both tunnels, when we will make the compatible tunnel design.

Single Tunnel

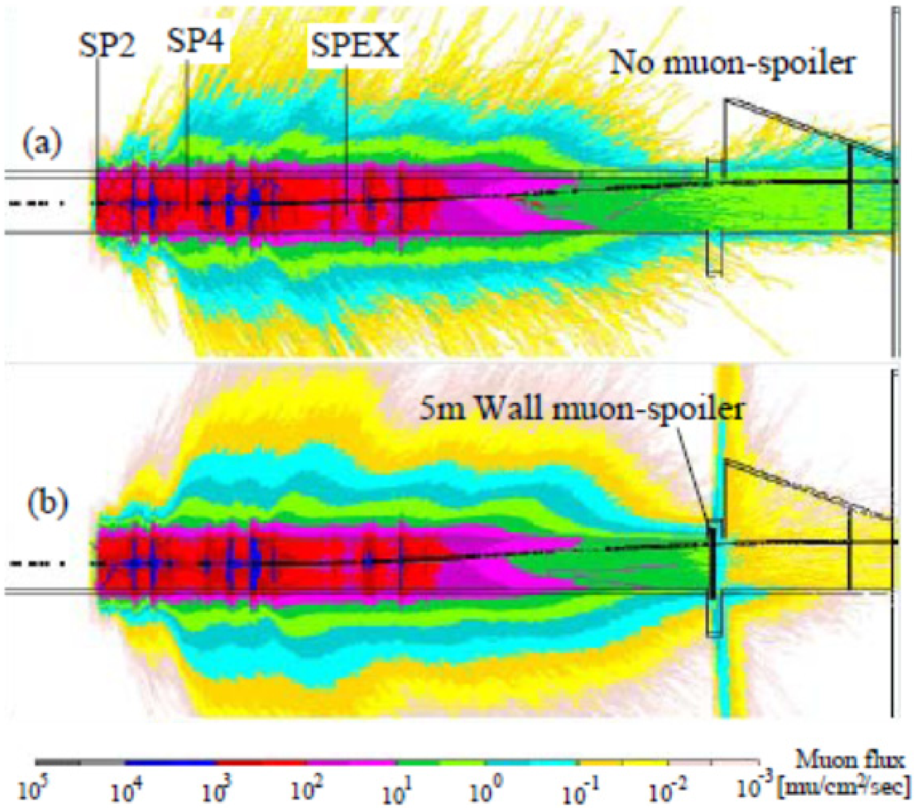


Thickness of radiation shield
Muon background ??

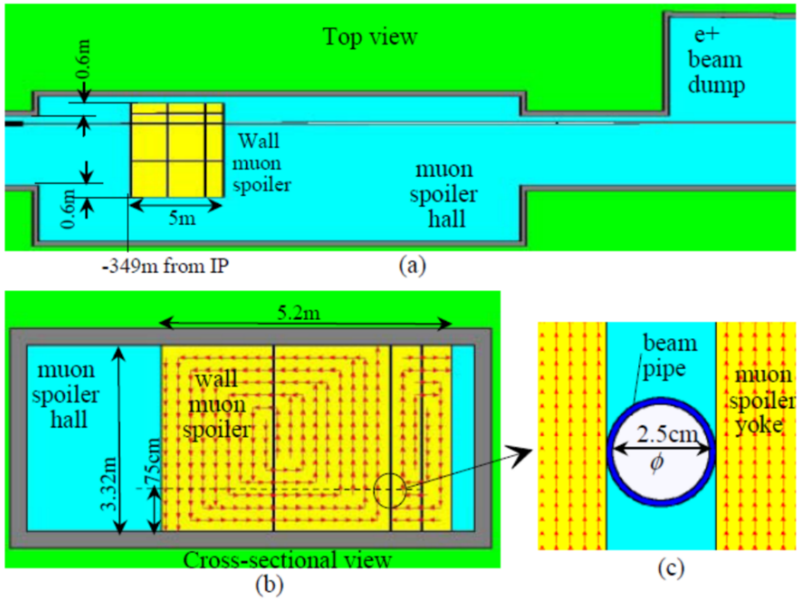


Muon Spoiler

It is better to make the tunnel cross section small
- in order to make the muon spoiler small
- in order to reduce the muon transmission in the tunnel .



The evaluation of muon background by SLAC will be restarted.



slac-pub-12741

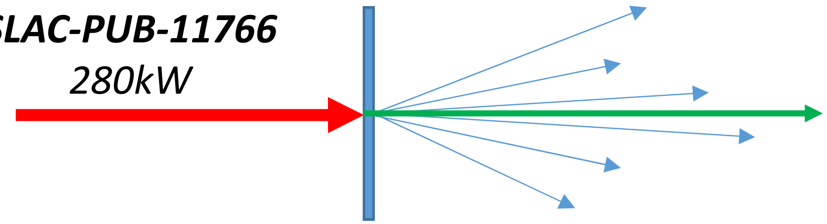
Radiation dose for capture section of positron source

The power loss was evaluated at PAC'05 by V. Bharadwaj et al. (SLAC-PUB-11766).

Electron driven Scheme

SLAC-PUB-11766

280kW



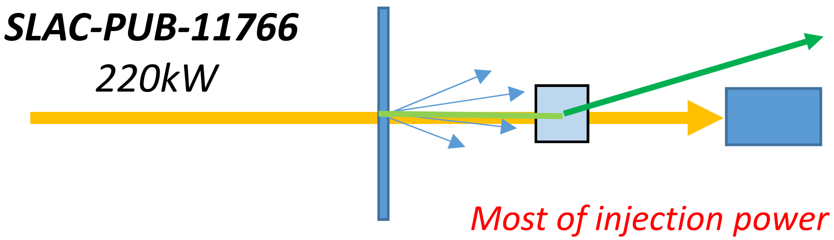
Most of injection power will be sprayed around target.

One of the motivation for photon based source

Undulator Scheme

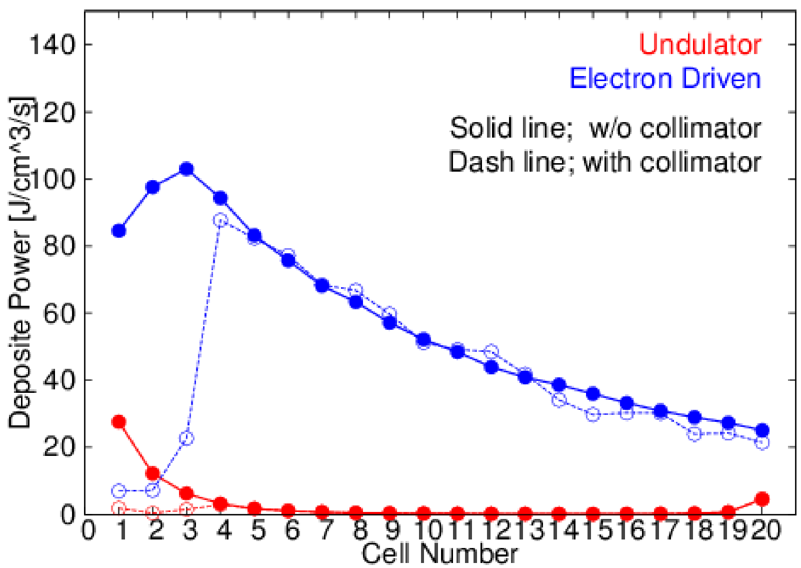
SLAC-PUB-11766

220kW



Most of injection power will be dumped to photon dump.

Power deposit of Innermost iris.



Injection beam power deposition

undulator scheme

6.1% in RF structure

1.5% in innermost iris for structures

Main radiation source is restricted around target.

Halo collimator between target and structure is effective.

electron driven scheme

53% in RF structure

22% in innermost iris for structures

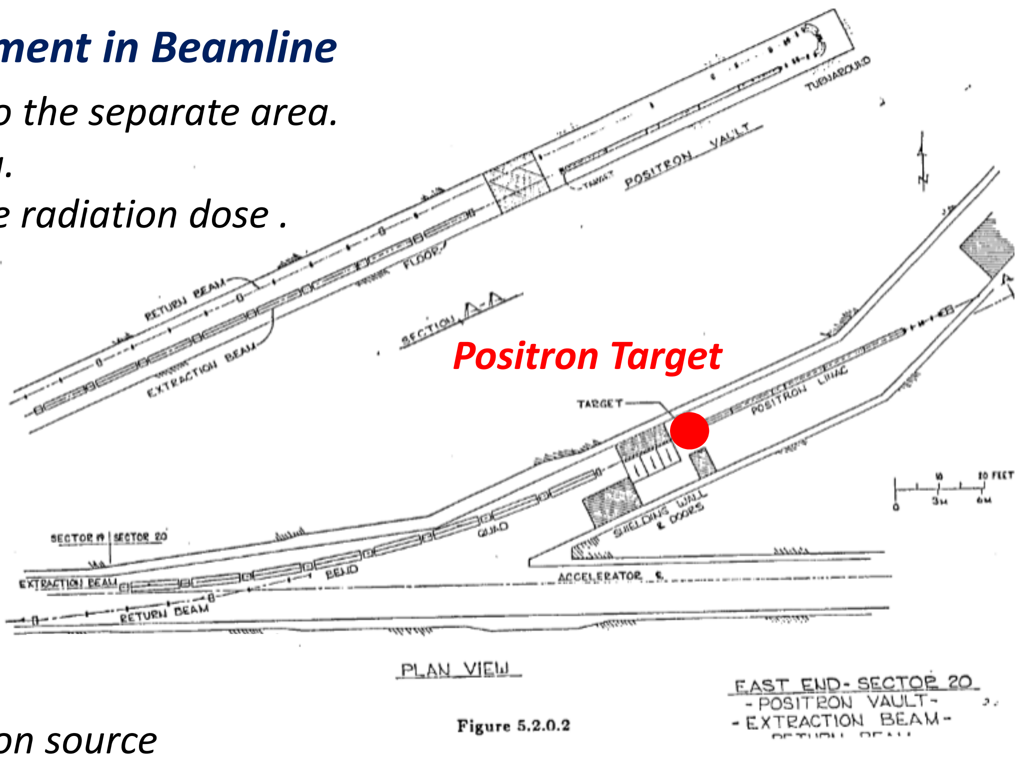
Radiation source is distributed to wide area.

Radiation dose around target section

	SLC maximum	ILC e-driven PS	ILC undulator PS [300GeV]	
			unpolarized	polarized
Beam power to target	40kW	146kW	63.1kW	94.7kW
1st acc. structure	**13kW**	**> 50kW**	3.8kW	5.8kW
Target	9kW	**18kW**	**7kW**	**10kW**

SLC Positron Target Arrangement in Beamline

The positron target was located to the separate area.
- to restrict the radioactive area.
- to protect the devices from the radiation dose .



SLC Design Handbook

Undulator Positron Source

The radiation dose for undulator source also should be taken care, even though it will be smaller than SLC. Radiation loss will be located around target.

Electron Driven Positron Source

The radiation dose for ILC electron driven positron source is 3-4 times larger than SLC.
(twice more for high luminosity option)

Target area for undulator positron source

The radiation loss for undulator source is located only around target area.

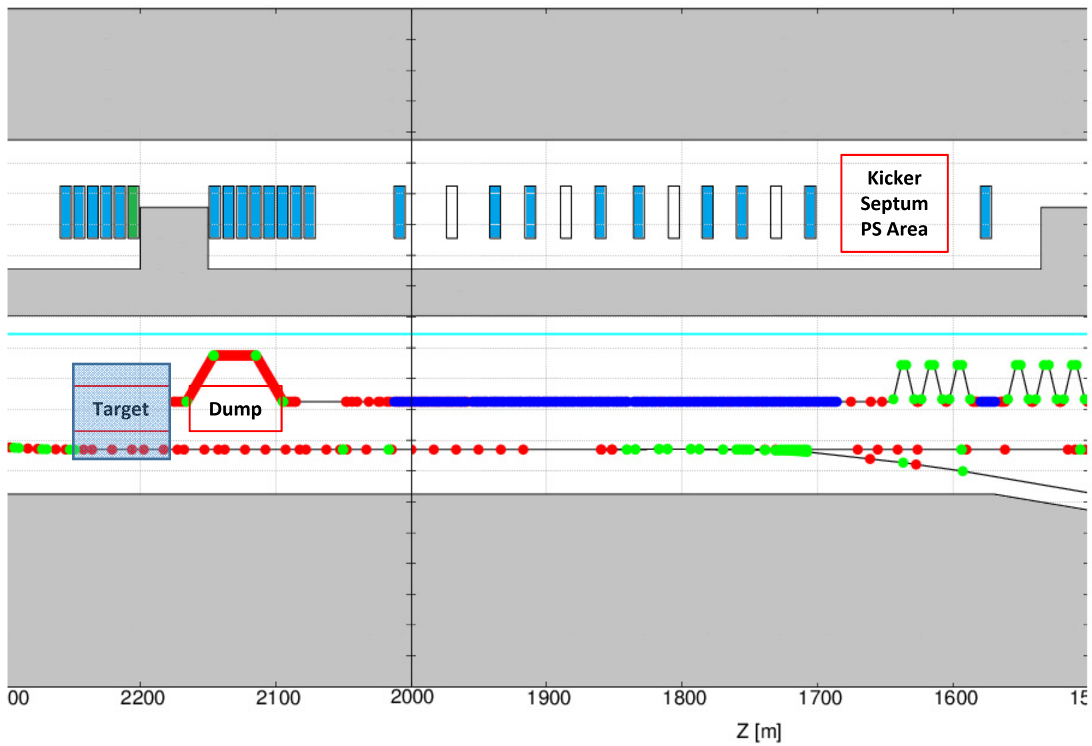
I heard the positron target was covered with radiation shield.

We should make careful consideration about radiation shielding from positron target and dumps.

We have 2 choices for undulator PS.

- to make separated area ?

- to cover only around target and increase the shield thickness around the target?



Furthermore, the policy of radiation shielding is one of large issues for e-driven PS.

The radiation dose for e-driven is
- much larger than SLC.
- large along the capture cavities as well as SLC.

We must make a separated area for capture section.

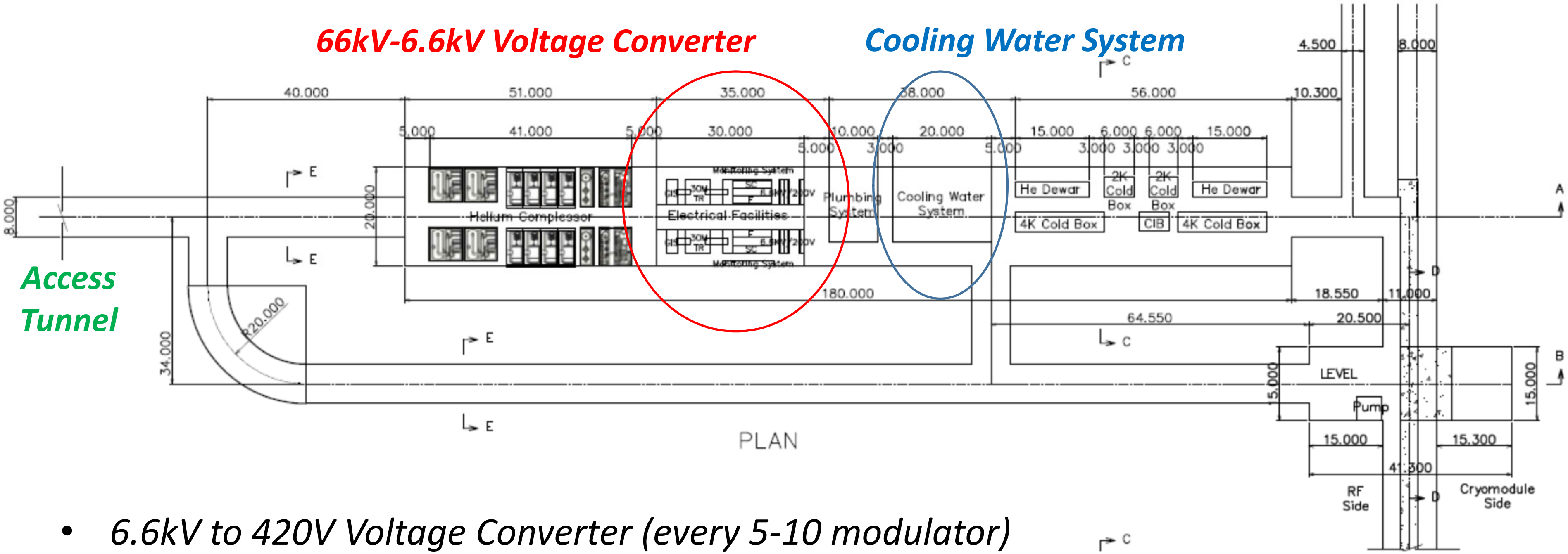
The items of CFS modifications

1. *Widen the tunnel width and modification around capture section*
2. *Access tunnel for installation*
   - We need the installation schedule evaluation.
   But since we must install more than 200 klystrons and modulators, we have a large possibility to make it.
3. *Voltage Converter (66kV main AC to 6.6kV)*
4. *Voltage Converter (6.6kV to 420V for modulators)*
5. *Cooling water Facilities*

Additional CFS for e-driven positron source

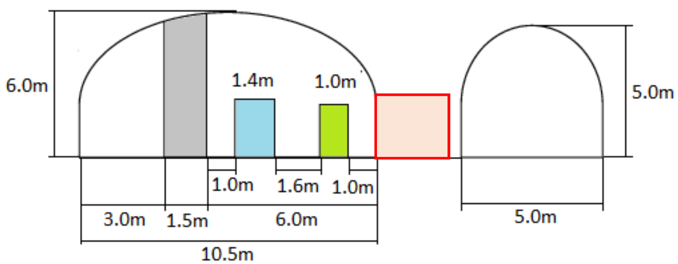
- Access tunnel (> 200 kly&mod etc.)
- 66kV to 6.6kV Voltage Converter (15-30MW)
- Cooling water facility

Large Cavern



- 6.6kV to 420V Voltage Converter (every 5-10 modulator)

➡ *We should consider how to put the cavern for twin tunnel?*



Cavern?
Shield thickness?

Present status of the compatible tunnel design

(Just only my impression)

We have almost 1km space after the undulator PS.
It is possible to make very rough compatible tunnel design at this area.

But we could not proceed more, because there are no consistent beamline design.
It is very important to check whether the space is enough to put the e-driven PS or not.
In order to check it, we should complete the consistent e-driven PS beamline design.

I quick reviewed the present design of the e-driven positron source.
Then, I think we should consider the following issues for the present e-driven PS design.

1. *Radiation Shielding*
2. *RF structure in capture section*
   - *Beam current is 2A (Beam loading compensation)*
   - *Beam loss power in structure is more than 50kW.*
3. *Timing system*
4. *Laser for e-gun of drive beam*
5. *Injection kicker*
6. *Klystron bandwidth for beam loading compensation with triplet bunches*
   (The beam loading evaluation is only without gaps)
7. *Transient beam loading in DR*
8. *Transmission efficiency evaluation with realistic alignment errors*
9. *Evaluation of achievable positron yield*

My suggestion for e-driven positron CR

The present design of e-driven PS is constructed only by the local group.
Therefore, it still contains some technical considerations, and it was not yet a consistent design.

- *My suspicions of the present design will be presented in source session (Thu 8:30 -).*
  Please come and join the session, if interest.

It is very important to have scientific considerations not only within the local group,
but also with the specialists of many field (RF, timing, beam dynamics etc.)

- *I believe my suspicions are also one of the considerations about the e-driven PS.*

I think this CR will be start-point to review the e-driven PS design by global point of view.

But, we still have a lot of works to realize the e-driven positron source.

- *make a consistent design.*
- *design the tunnel and CFS to fit the design.*
- *make a R&D schedule.*
- *evaluate the costs and human resources both for R&D and construction.*

Therefore, I recommend CMB(LCC) should decide whether the tunnel design will be compatible or not after when the consistent design will be established at least, if CR will be submitted.

Otherwise, we will not be able to design the tunnel and so on.

Thank you for your attention.

backup

Present design of positron yield evaluation

Positron yield for single bunch beam

	SLC (experiment)	SuperKEKB (design)	ILC e-driven PS (design)
Electron beam energy	33 GeV	3.3 GeV	6 GeV
Beam size at target	0.6 mm	0.7 mm	4.0 mm
Aperture for 1st cavity	18 mm	30 mm	60 mm
Gradient for 1st cavity	40 MV/m	14 MV/m	8 MV/m
Positron yield	1.1 e+/e- at DR (1.4 e+/e- at LTR)	0.89 (0.30 at now) e+/e- at Capture Out	1.5 e+/e- at DR
Energy acceptance	+/-2.5%	I could not find the number at DR	+/-0.75 %
Transverse acceptance	0.01 m		0.07 m

The present design of the ILC e-driven positron source is

- *the beam energy is much smaller than SLC.*
- *beam spot size at target is much larger than SLC .*
- *accelerating gradient is much smaller than SLC*

But, the positron yield is designed to be higher than SLC (and superKEKB).

Comparison with SuperKEKB

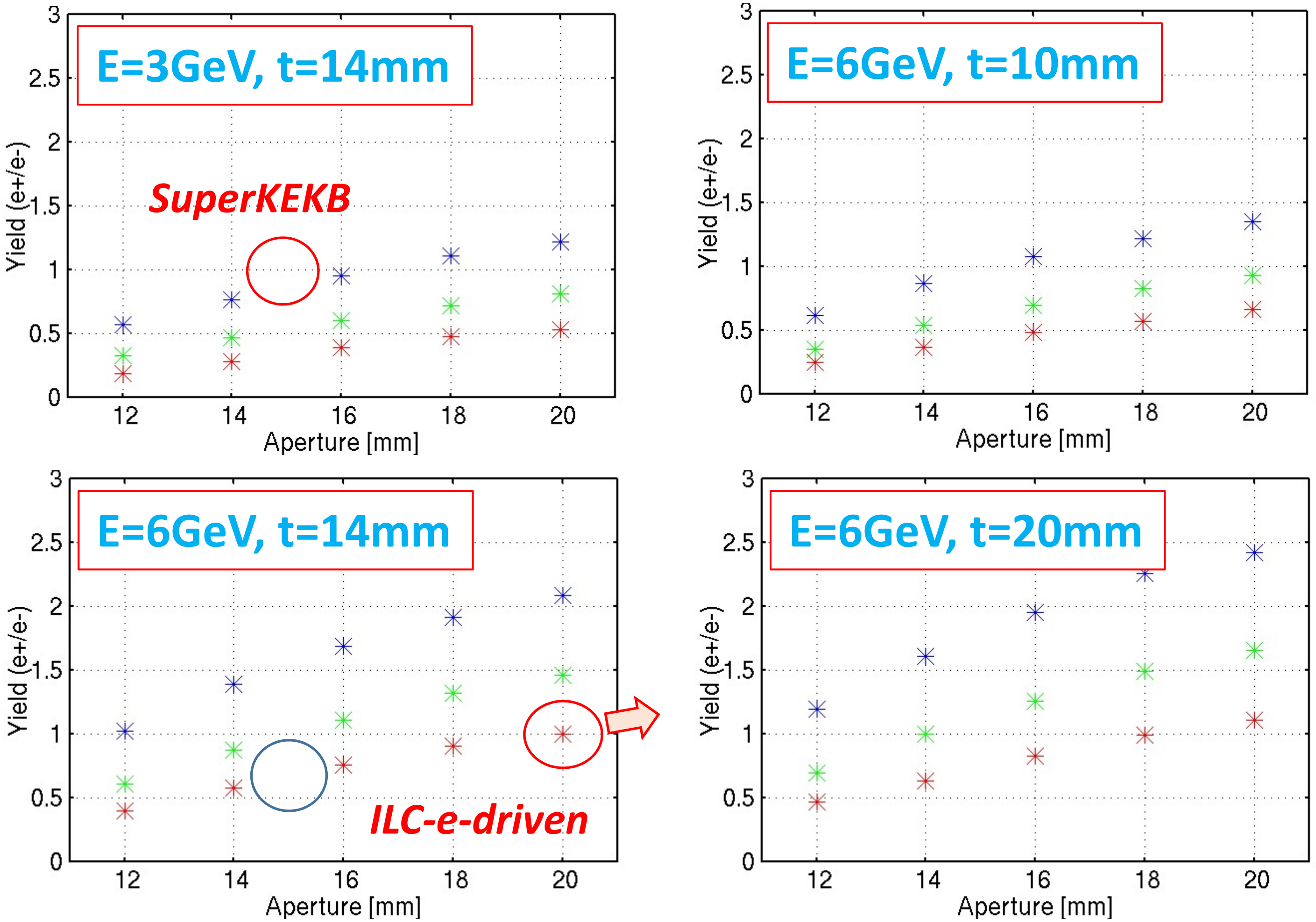
Electron Spot Size Dependence

after Energy Compressor with Longitudinal & Transverse Cut

(1) Electron Beam Size = 4mm ;
used for the GEANT4 data set

(2) Electron Beam Size = 3mm ;
X=3*X/4, Y=3*Y/4 for (1)

(3) Electron Beam Size = 2mm ;
X=2*X/4, Y=2*Y/2 for (1)



Capture Section

E=250MeV
V = 16.6MV/m
B= 0.5T

Flux Concentrator

r=12mm

When we assumed the same aperture,
superKEKB has larger positron yield than ILC e-driven source

T.Okugi, ILC positron phone meeting
(2013/01/30)

Key issue is large aperture

	SLC (experiment)	SuperKEKB (design)	ILC e-driven PS (design)
Electron beam energy	33 GeV	3.3 GeV	6 GeV
Beam size at target	0.6 mm	0.7 mm	4.0 mm
Aperture of flux concentrator	7mm	7mm	16mm
Aperture for 1st cavity	18 mm	30 mm	60 mm
Gradient for 1st cavity	40 MV/m	14 MV/m	8 MV/m
Positron yield	1.1 e+/e- at DR (1.4 e+/e- at LTR)	0.89 (0.30 at now) e+/e- at Capture Out	1.5 e+/e- at DR
Energy acceptance	+/-2.5%		+/-0.75 %
Transverse acceptance	0.01 m		0.07 m

Key point to get such a large number of positron is the wide aperture of the beamline to be transport the large transverse emittance beam to large acceptance DR.

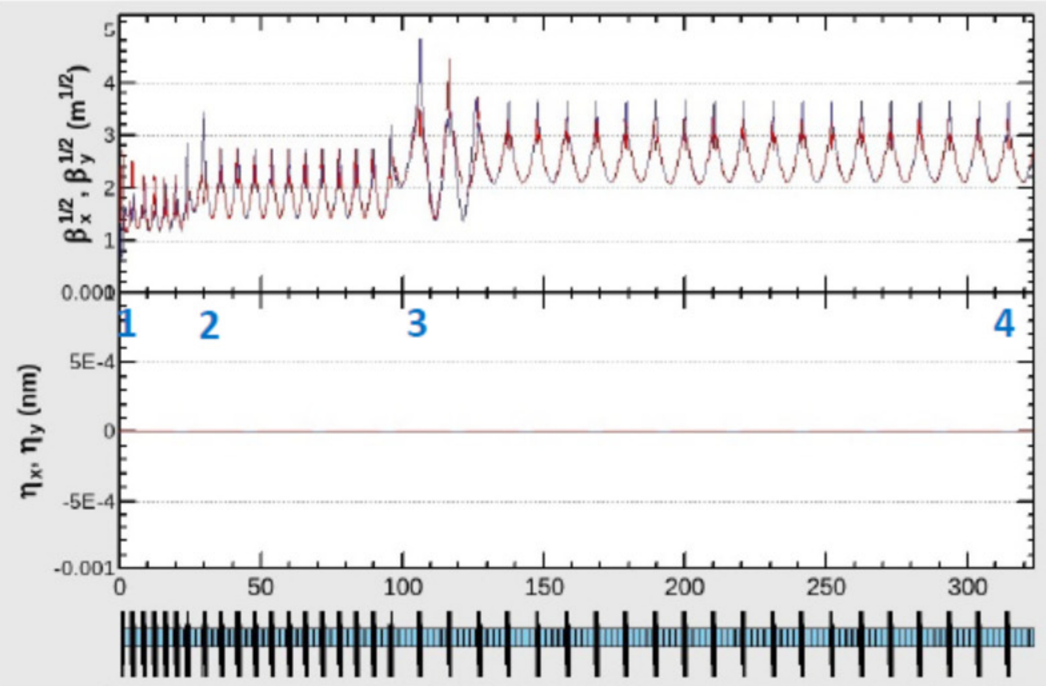
But, we have difficulties to widen the apertures.

- Power supply for flux concentrator

- RF structure with large aperture etc.

No margin for transverse acceptance

T.Okugi LCWS13



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

Same acceptance to DR (twice for undulator)

RF System

L = 2m each

a = 0.017 m (minimum)

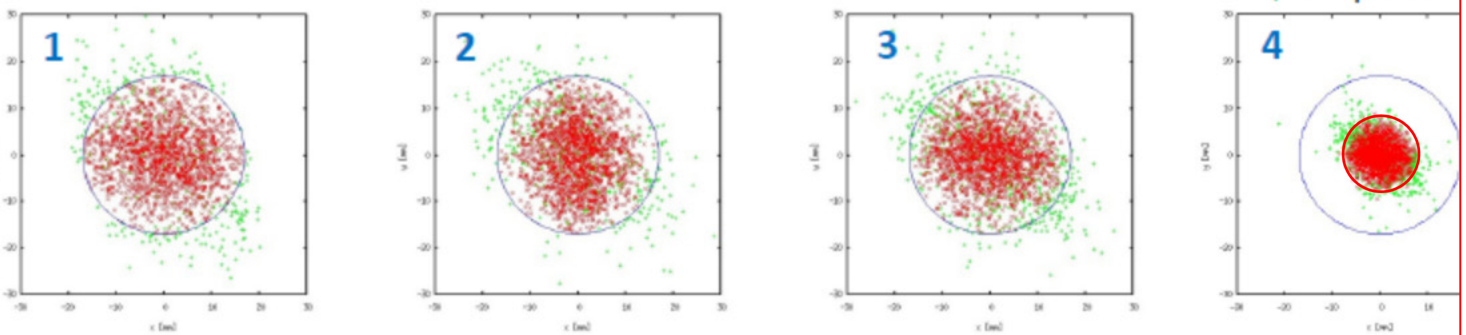
V = 35-45MV / structure

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



Now the aperture was smaller than LCWS2013 to use S-band

- *Make tolerance small*
- *Make transverse wake large !*

Beam loss was generated by optics mismatch, misalignment, transverse wake etc.

RF structures in capture section

The beam loading current in capture section (2A)
is 2 order larger than undulator PS and much larger than any machine in the world.

The radiation dose for capture structure
is much larger than undulator PS and any machine in the world.
- *Cell-to-cell frequency shift by temperature rise by beam loss*
- *Breakdown for high radiation condition*
- *Vacuum pumping*

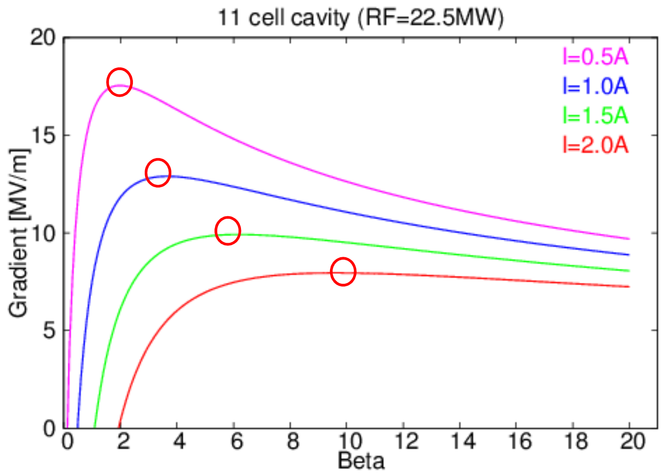
The largest technical difficulty is in capture section for present e-driven positron source.

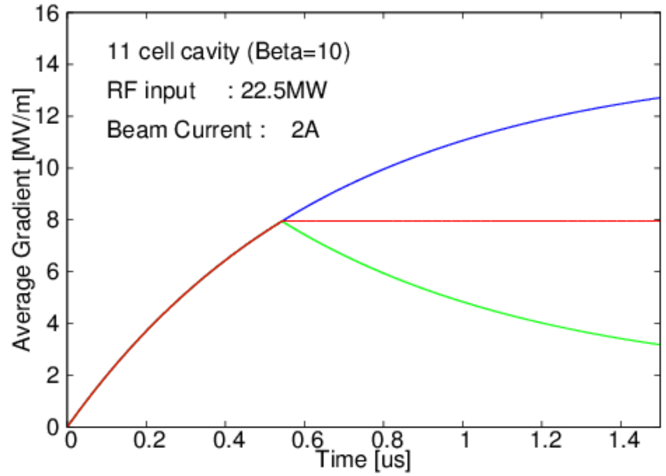
In present design, the multi-cell standing wave structure
is assumed in the capture section to make the aperture wide.

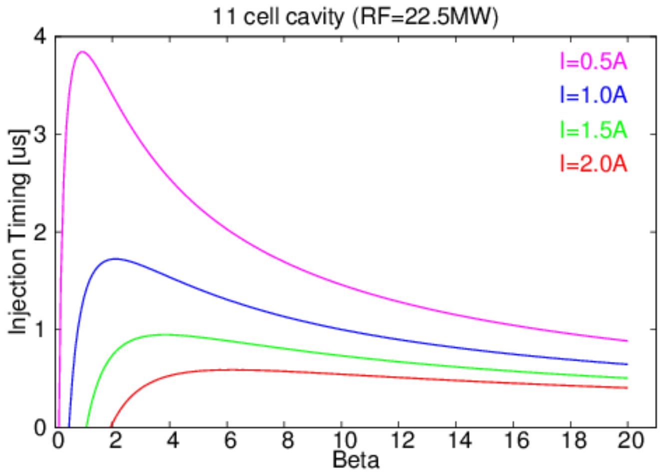
Present candidate RF structure of the capture section for e-driven positron source

The transient beam loading for multi-cell standing wave structure was evaluated only by using formula of "single-cell standing wave structure"

Is the assumption OK ?





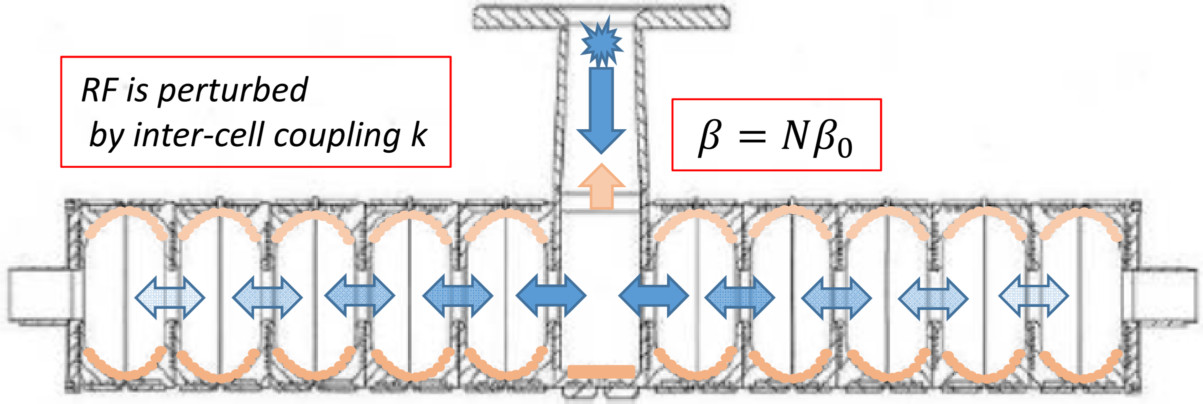


Comment

In the report (9/30), the accelerating gradient was assumed to be optimized by changing the coupling constant (β) for each beam current.

But, it is difficult to change the coupling constant (iris of the coupling hole) so much for normal conducting structure.

Multi-cell standing wave structure

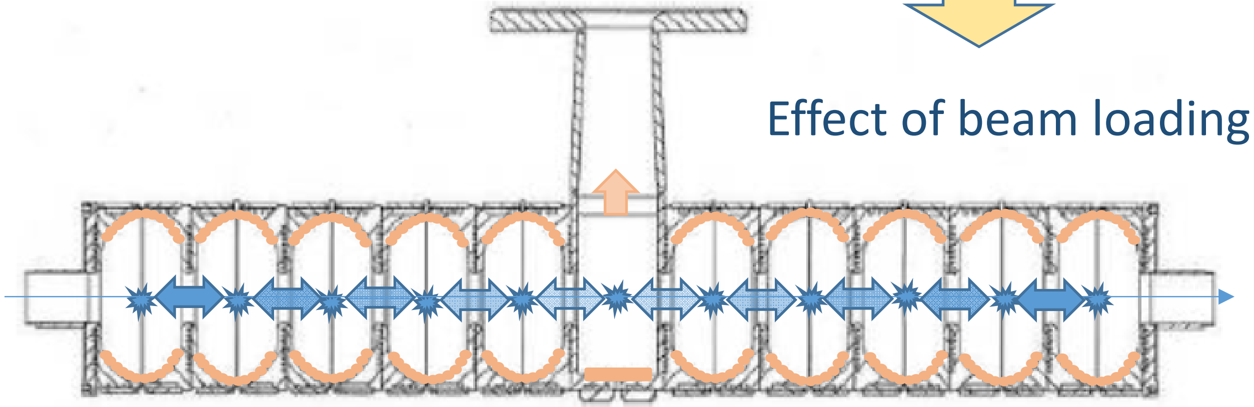


Single Cell formula

Effect of RF power

$$V(t) = \frac{2\sqrt{\beta P_0 r L}}{1+\beta}\left(1 - e^{-\frac{t}{T_0}}\right) - \frac{rIL}{1+\beta}\left(1 - e^{-\frac{t-t_b}{T_0}}\right)$$

Effect of beam loading



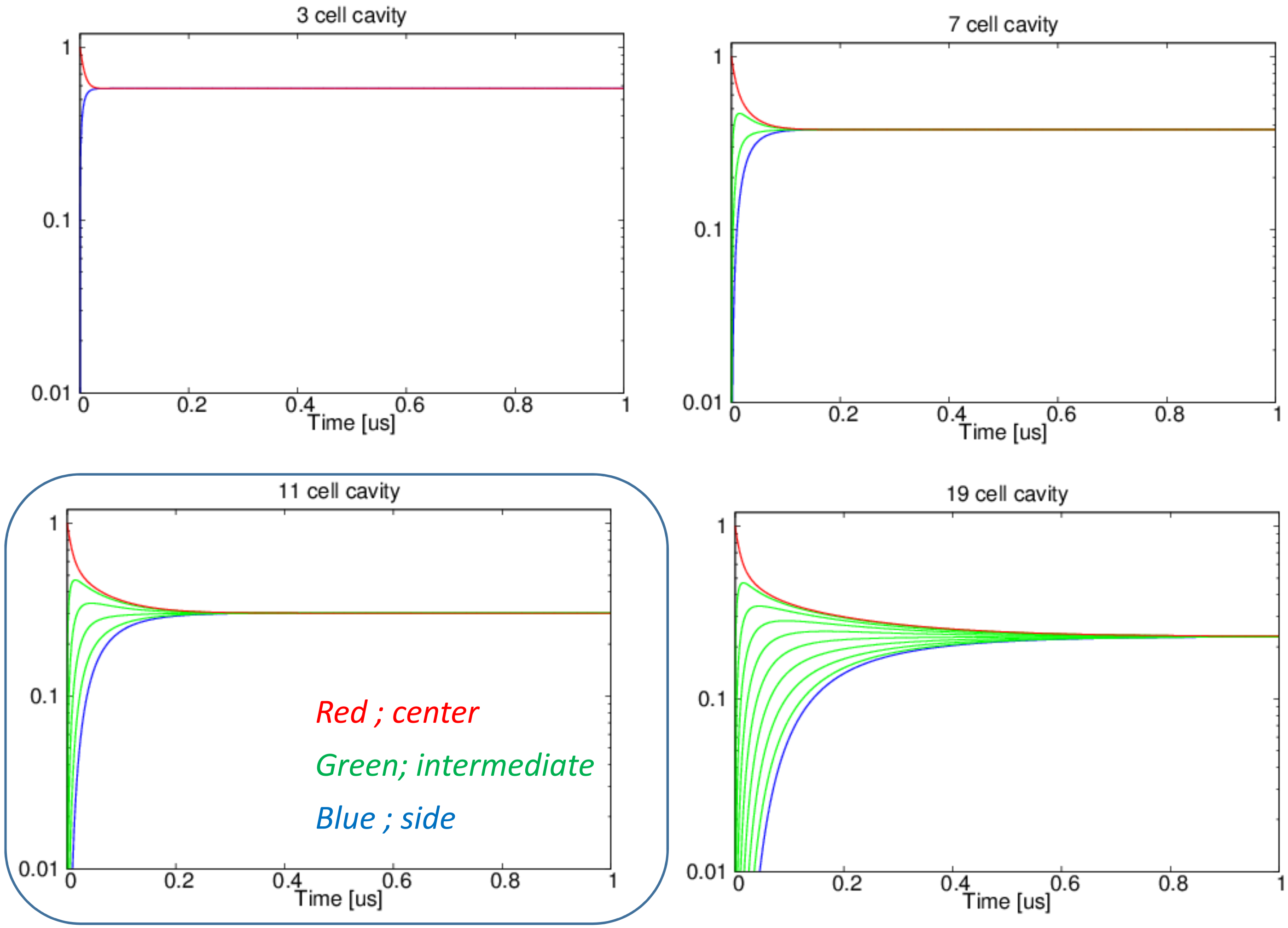
Cavity loss for center cell
(1+β) Qo

Cavity loss for other cell
Qo

RF perturbation in the multi-cell structure

inter-cell coupling constant ;   k = 0.0125

(capture structure for undulator source)



- *RF power was stored only center-cell for t < 0.*
- *RF power will perturb for t > 0.*
- *No wall loss*

The time to be steady state is proportional to N^2.

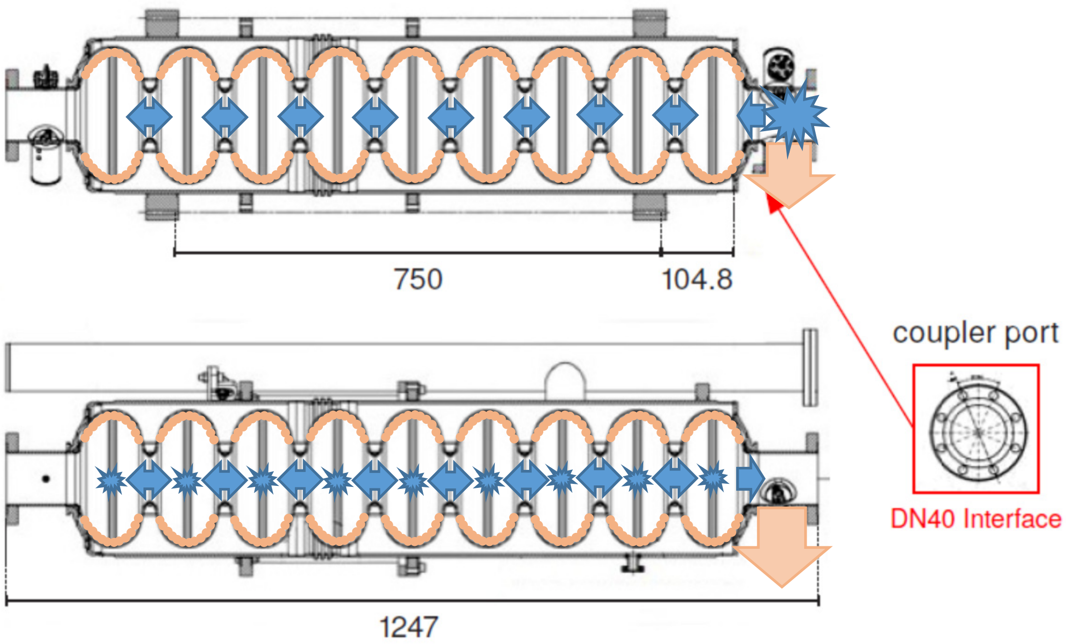
For 11 cell cavity, the perturbation time is roughly O(0.1us).

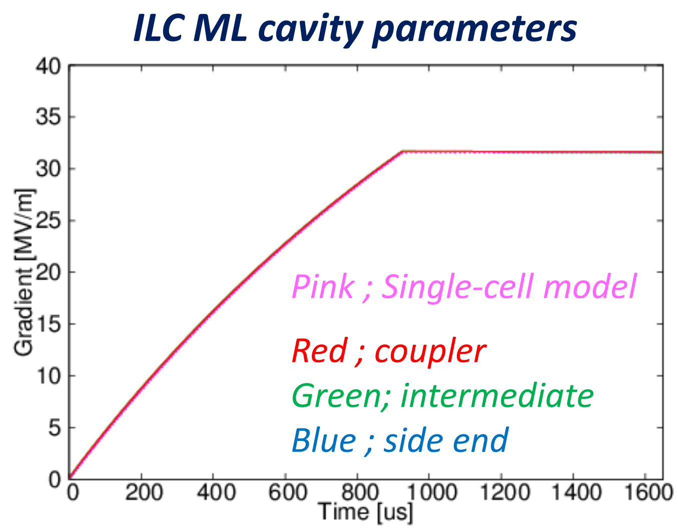
Evaluation of transient beam loading for super-conducting structure

- *Filling time of RF is O(ms) (Q-value for super-conducting structure is O(10^{10}))*
- *Perturbation time within multi-cell structure is O (0.1us)*

Inter-cell RF perturbation can be ignored.

Wall loss in the cavities can be ignored, because the coupling constant (β) is O(1000).





$$V(t) = \frac{2\sqrt{\beta P_0 r L}}{1+\beta}\left(1 - e^{-\frac{t}{T_0}}\right) - \frac{rIL}{1+\beta}\left(1 - e^{-\frac{t-t_b}{T_0}}\right)$$

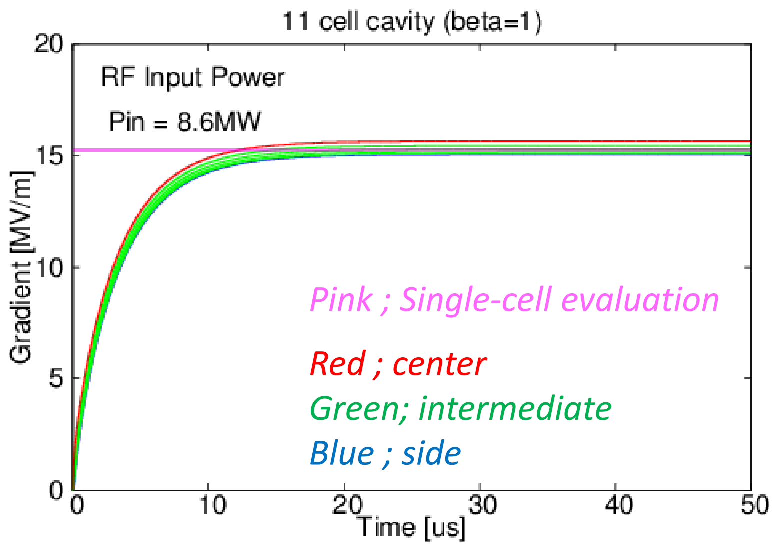
It is no problem to use the single cavity formula for super-conducting multi-cell structure.

OK

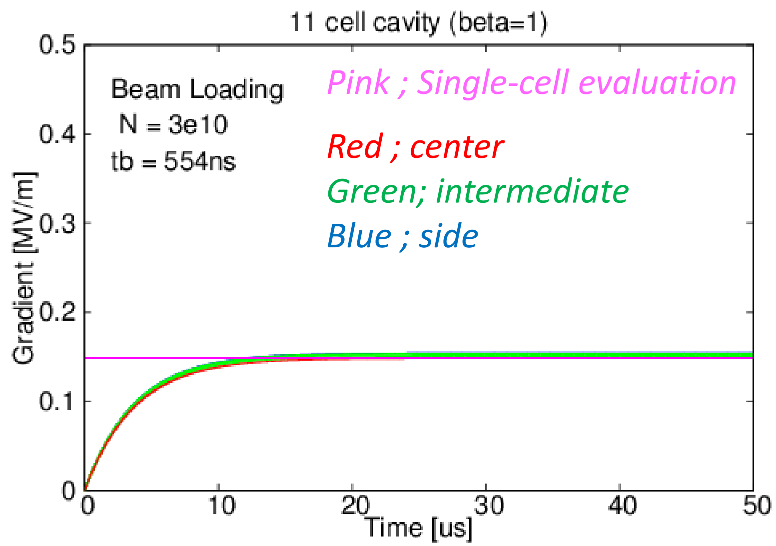
Evaluation of steady state for normal conducting cavity

Capture cavity for Undulator positron source

RF input



Beam Loading



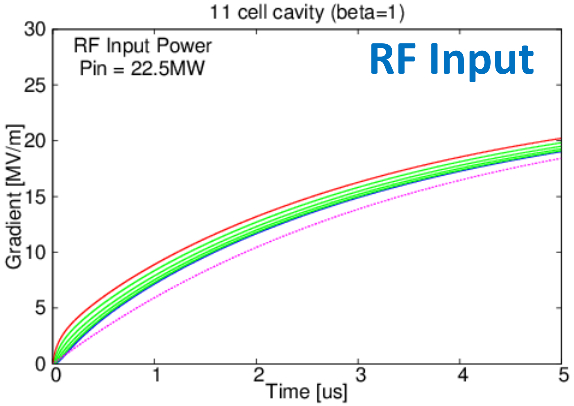
Since the beam current is very small for the capture cavity of undulation positron source, the effect of beam loading is only 1% of accelerating voltage.

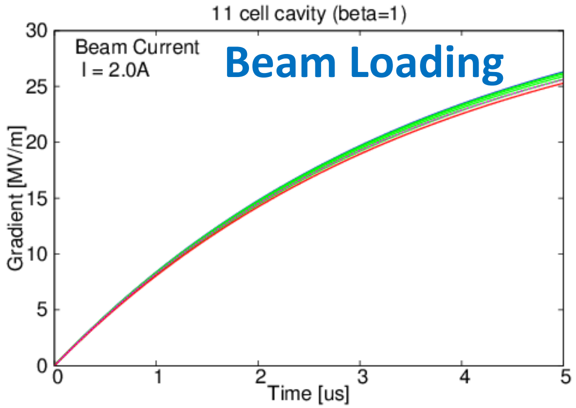
The accelerating voltage and beam loading for steady state are same to the evaluation with single cell formula for undulator PS parameter.

OK for undulator PS capture cavities

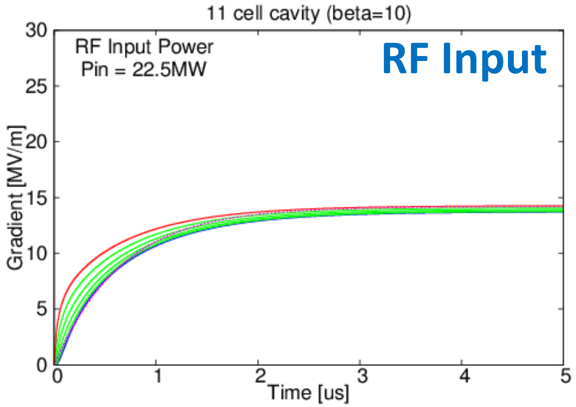
Behavior of RF perturbation for normal conducting cavity

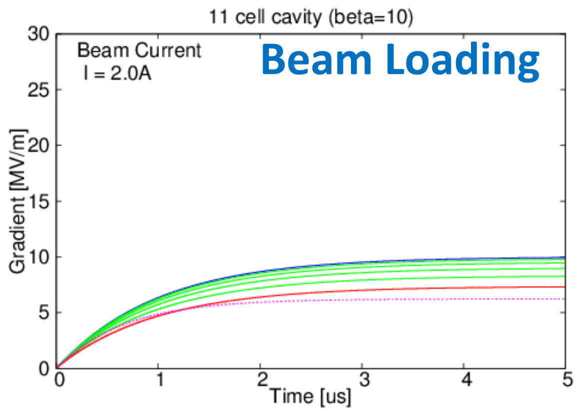
beta=1





beta=10





Parameter for the capture cavity of e-driven PS.

Pink ; Single-cell evaluation

Red ; center

Green; intermediate

Blue ; side

The time constant of input RF is different.

The time profile of input RF is not exponential.

Beam loading is larger than accelerating field.

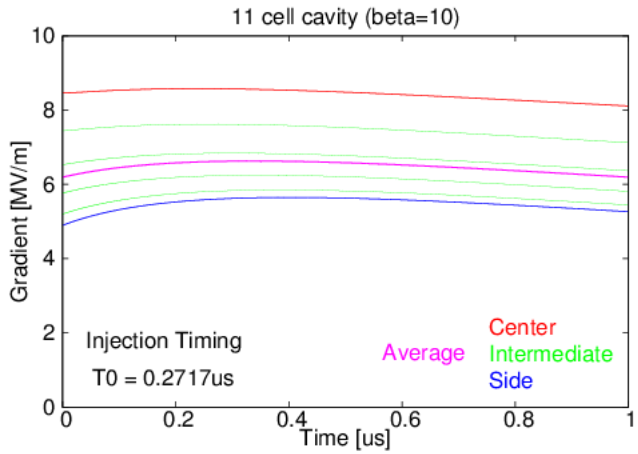
By increasing the beta,
beam loading will be smaller than accelerating field.

But,
- the reduction of beam loading was smaller than the evaluation of single cell formula.
- cell-to-cell field balance for beam loading will be large.

Transient beam loading compensation with multi-cell model

Performance for candidate structure

Cavity parameters were assumed to standing wave cavity for undulator source except for 11cell and $\beta = 10$.
(design at 9/30 report is 11cell and $\beta = 10.3$)



	Single cell model	Multi-cell model
Average Gradient	8.0 MV/m	6.2 MV/m
Injection Timing	0.543us	0.272us
Field def. in train	0 %	7 % peak-to-peak
Cell-to-cell field def.	0 %	50% peak-to-peak

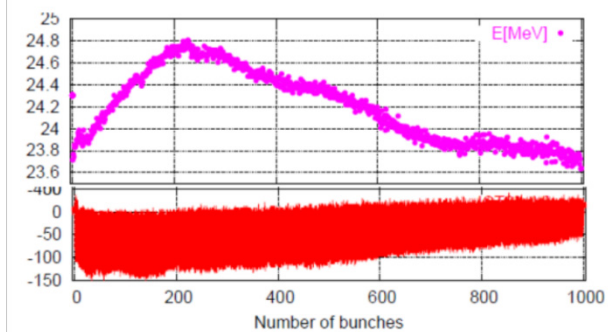
The transient beam loading for multi-cell standing wave structure is not evaluated by single cell formula.

NG

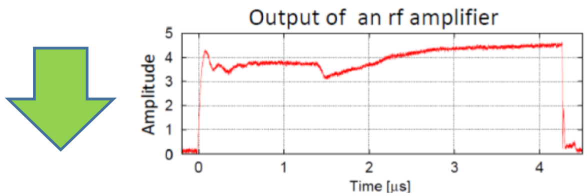
Example of Transient Beam Loading

S-band 12-cell standing wave structure at LUCX, KEK (*0.2A, 2.8us, β=1.1* **)**

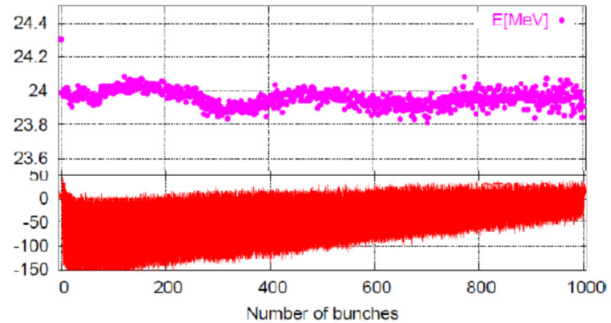
M.Fukuda, Proceedings of IPAC2015



Observation of field def.
(no Amplitude modulation)



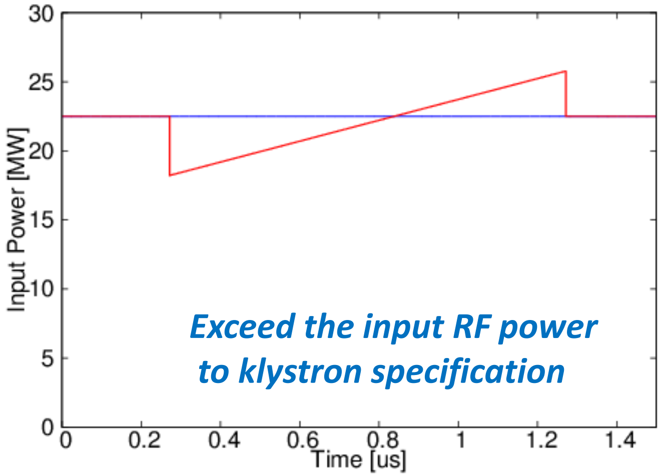
Amplitude modulation

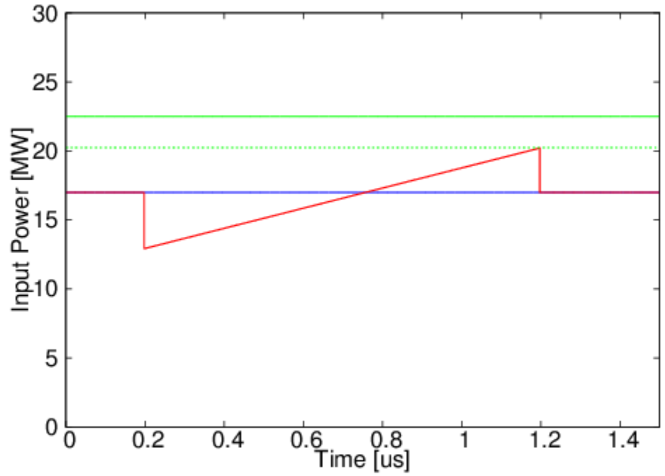


4% -> 1.3% peak to peak

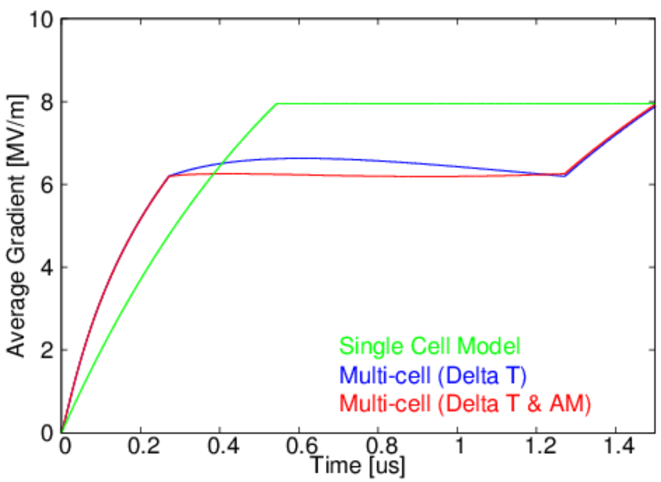
Amplitude Modulation

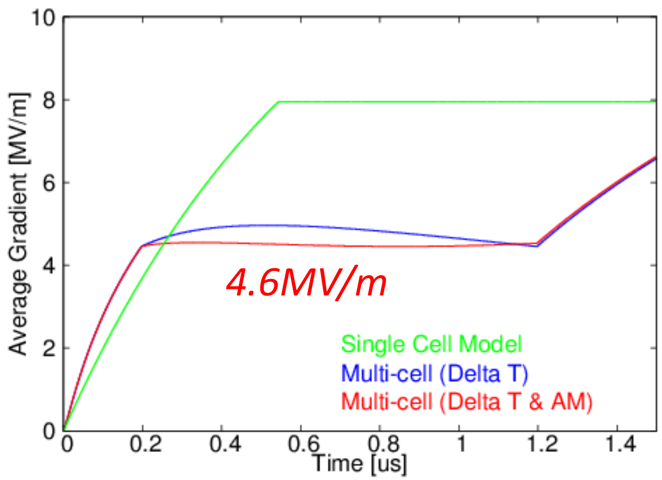
Since we will not operate the klystrons at saturation condition (to apply amplitude modulation), the input RF power should be reduced more (90% for ILC-ML RF).





90% of saturation level





50MW klystron to two 11cell cavities

8.0MV/m
Single-cell model

4.6MV/m
Multi-cell model

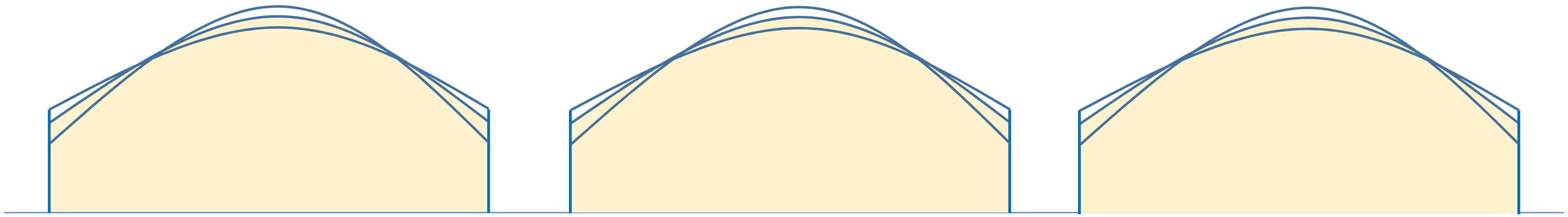
8MV/m can be calculated only when we assumed to the assumption of single cell formula.
The optimum gradient should be > 15MV/m for deceleration capture.

Conditions, should be included the evaluation

Electric Field

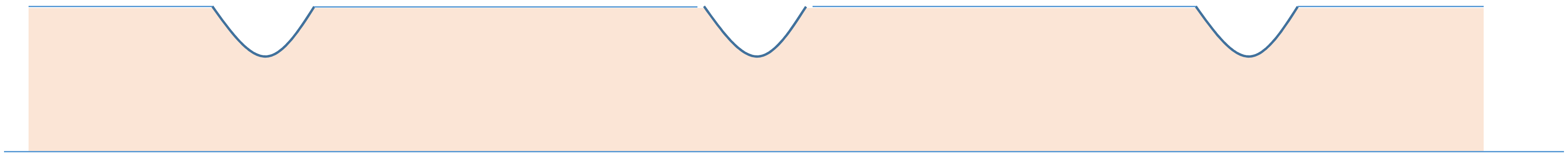
- *Lower gradient → reduction of the yield*
- *Cell-to-cell difference → reduction of the yield*
- *Time variation → the yield change in time*
- *Alignment errors → the effect of transverse wake*

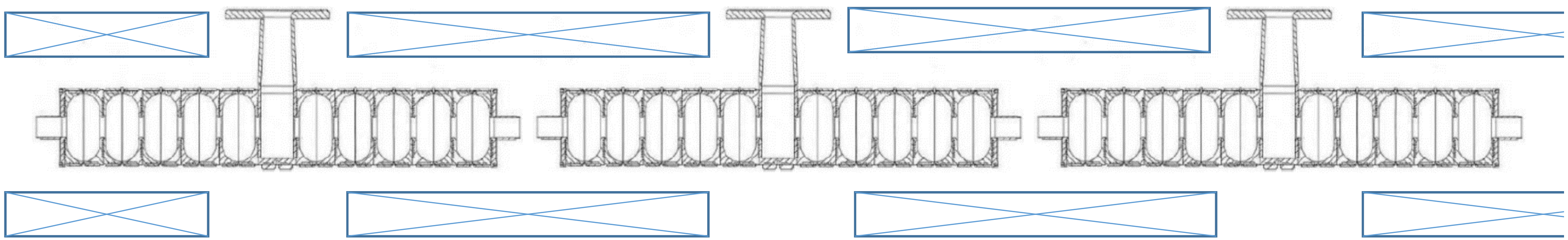
These also strongly affect to positron yield evaluation



Magnetic Field

- *Effect of gap for waveguide → reduction of the yield*
- *Misalignment of solenoid → transverse wake at fringe*





Beam Tuning

Can we tune the beam ?

Beam energy is measured after few 10 structures (beam current is different for every structure) .

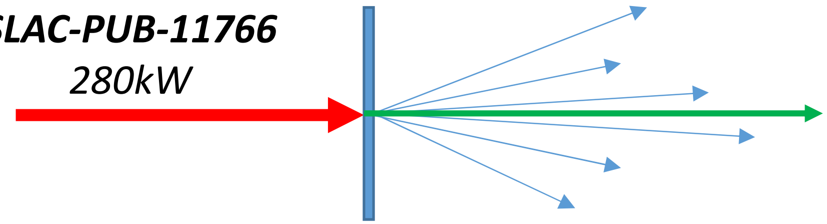
Radiation dose in capture section

The power loss was evaluated at PAC'05 by V. Bharadwaj et al. (SLAC-PUB-11766).

Electron driven Scheme

SLAC-PUB-11766

280kW

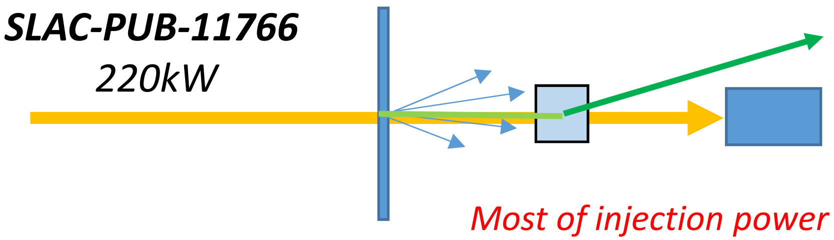


Most of injection power will be sprayed around target.

Undulator Scheme

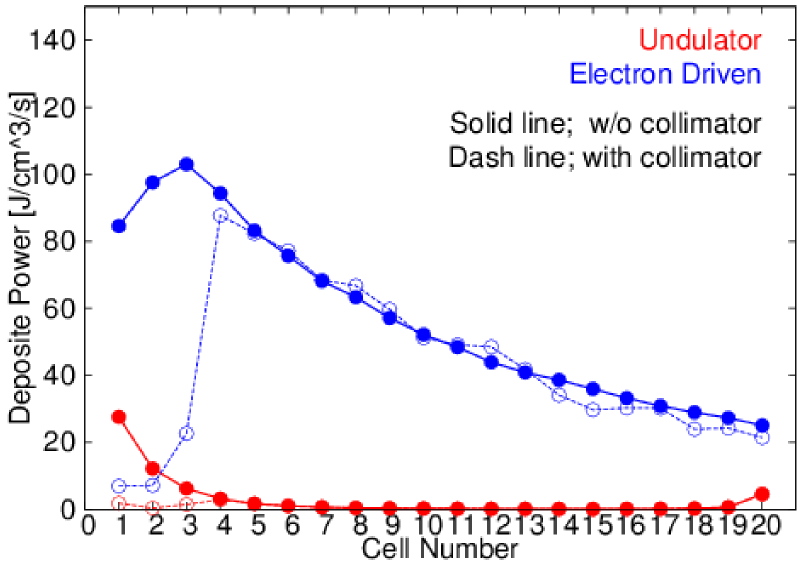
SLAC-PUB-11766

220kW



Most of injection power will be dumped to photon dump.

Power deposit of Innermost iris.



Injection beam power deposition

undulator scheme

6.1% in RF structure

1.5% in innermost iris for structures

Main radiation source is restricted around target.

Halo collimator between target and structure is effective.

electron driven scheme

53% in RF structure

22% in innermost iris for structures

Radiation source is distributed to wide area.

Heating of standing wave structure for ILC positron source

Effect of the capture cavity for undulator positron source was evaluated at PAC'05 by J. Wang et al. (SLAC-PUB-11767).

Table 3: Cavity Detunings for Different Loads

Case	Cavity detuning
Average RF losses only	-20.4 kHz
Average RF and particle losses	-58.6 kHz
Start of RF pulse, RF loss only	-19.5 kHz
End of RF pulse, RF loss only	-23.3 kHz
Transient detuning, RF only	-3.9 kHz
Start of RF pulse, RF and particle loss	-53.8 kHz
End of RF pulse, RF and particle loss	-68.9 kHz
Transient detuning, RF and particle loss	-15.1 kHz

RF only ***RF & beam loss***

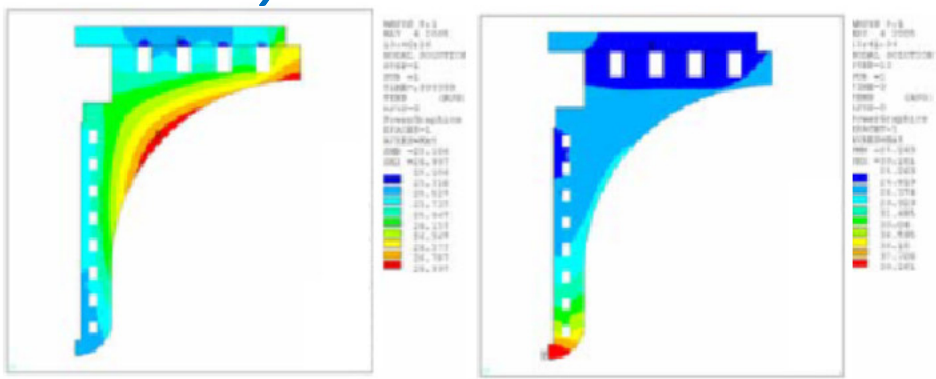
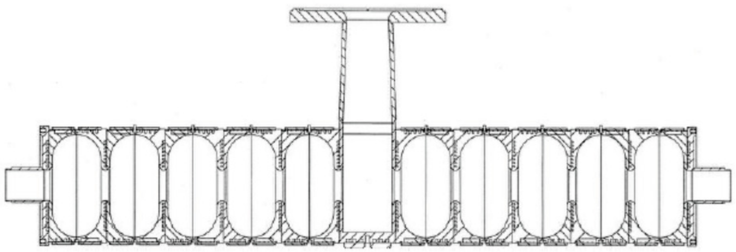


Figure 4: ANSYS thermal model with average RF losses (left) and thermal model with average RF and particle losses (right).



1st Cell frequency change (no collimator) for 220kW Photon Beam

Average frequency change ; 38.2 kHz

Transient frequency change ; 11.2 kHz
(within 1ms interval)

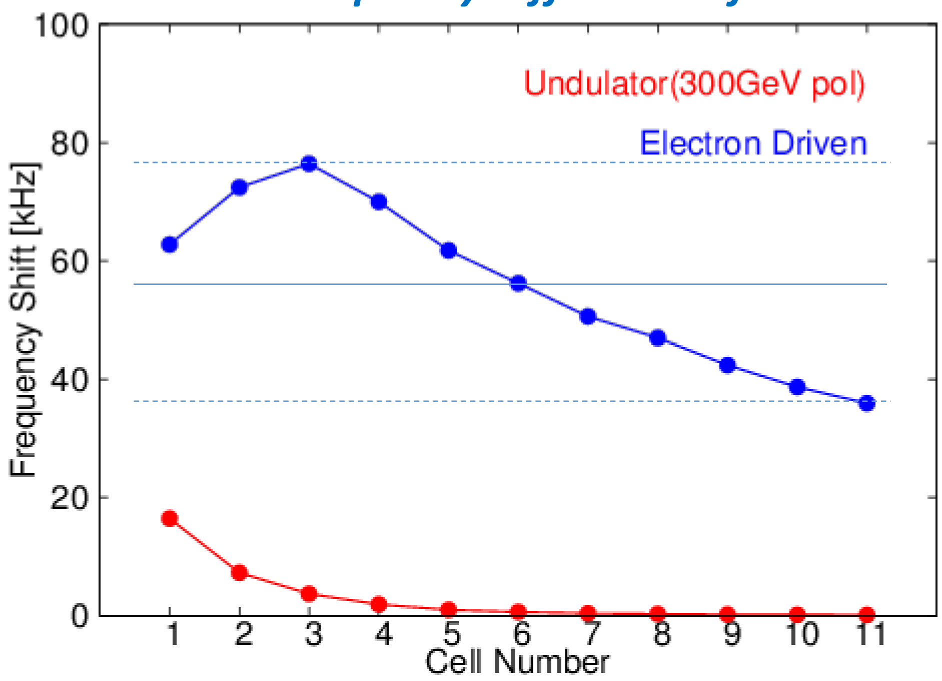
Scaled to present design

Since the parameters were changd from 2005, the power deposition was scaled to present parameter.

	e-driven	Undulator [300GeV]	
		unpolarized	polarized
Beam power to target	146kW *(6GeV & Nb=2.3e10)*	63.1kW	94.7kW
Acc. structure	77kW	3.8kW	5.8kW
Innermost iris only	32kW	0.9kW	1.4kW

Beam power for SLC positron source was < 40kW

Frequency difference of beam loss ON/OFF for e-driven scheme



Average frequency shift for beam loss ON/OFF

55kHz

We could store the RF in the cavity either the beam loss ON or OFF.

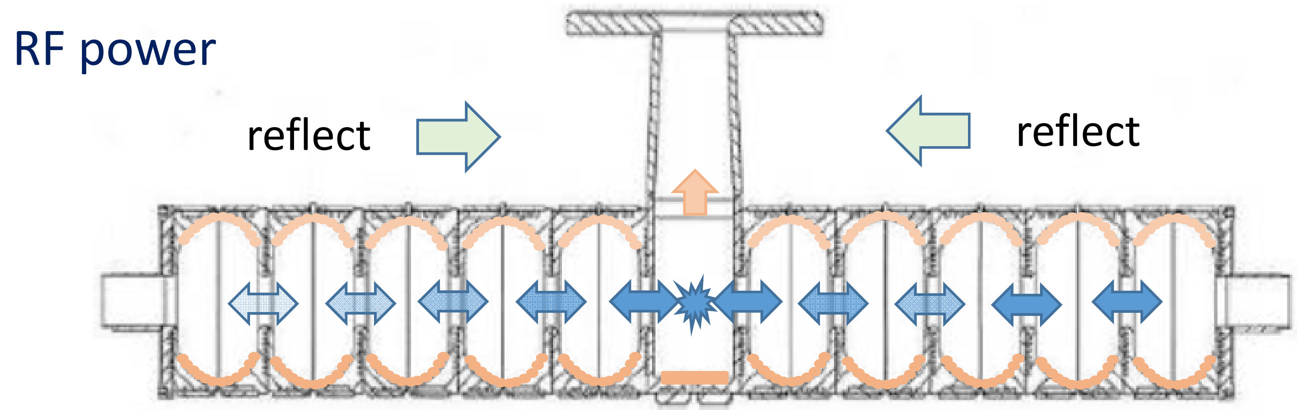
Frequency difference within 1 structure

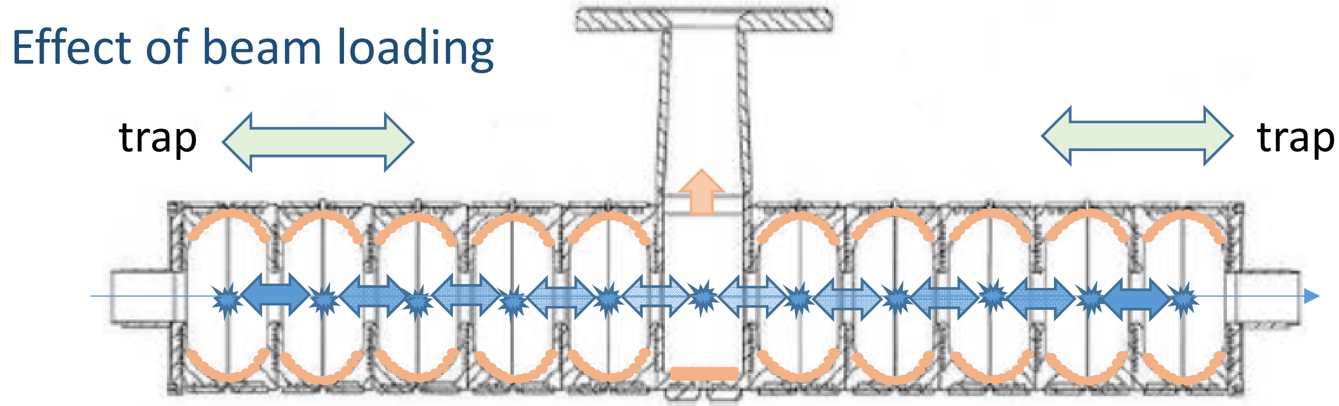
40kHz

The frequency tolerance for RF structure

$$\Delta f = f/Q = 43.8kHz$$

Resonant frequency difference within multi-cell cavity





RF distribution will be changed from the cavity with uniform resonant frequency.

We should evaluate the accelerating voltage both for RF input and beam loading by using the cavity model with different frequency within the structure.

Radiation protection

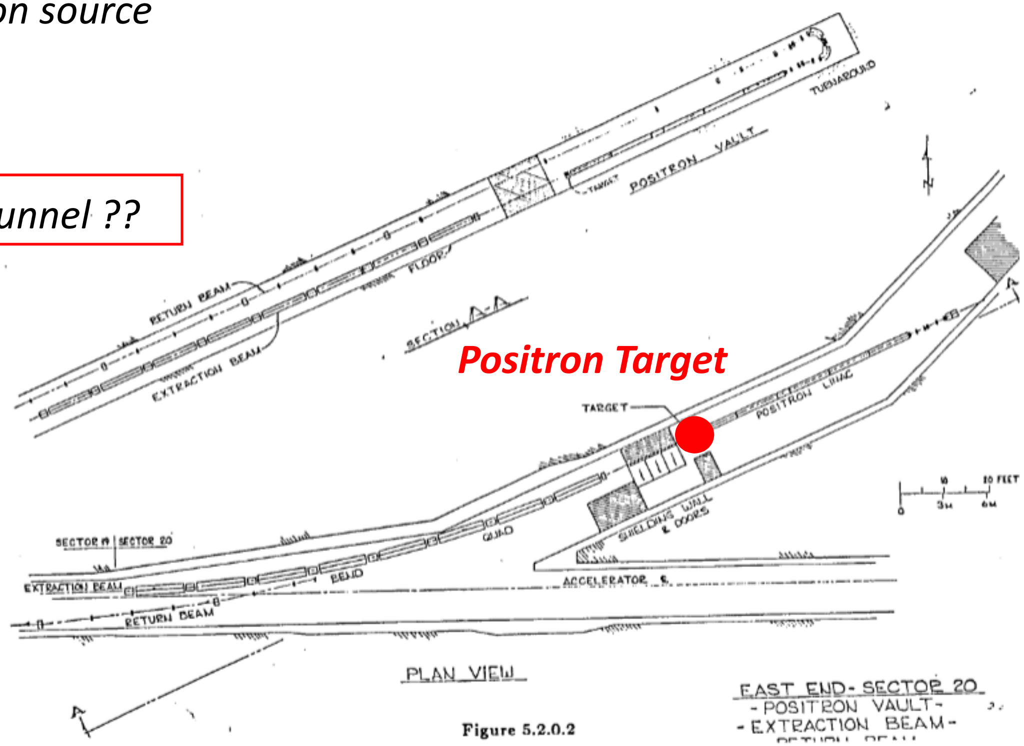
SLC Positron Target Arrangement in Beamline

The positron target was located to the separate area.
- to restrict the radio active area.
- to protect the devices from the radiation dose .

Electron Driven Positron Source

The radiation dose for ILC electron driven positron source is 3-4 times larger than SLC.
(twice more for high luminosity option)

Can the positron target put the target to same tunnel ??



SLC Design Handbook

Undulator Positron Source

The radiation dose for undulator source also should be taken care, even though it will be smaller than SLC.

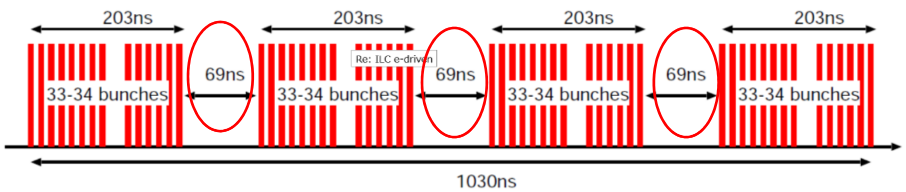
Electron driven bunch pattern to fit the filling pattern in DR

type	h	k_b	N_{bunch}	n_b	g	n_t	N_t	Q_b [$10^{10}e$]	t_b [ns]	I_{ML} [mA]	t_{pulse} [μs]
SB2009 nominal values								$c = 3248$ m			
DRFS	7042	463	1312	–	–	–	–	2.00	712	4.5	935
KCS	7042	347	1312	–	–	–	–	2.00	534	6.0	700
FP(e^-)	7042	231.5	2625	–	–	–	–	2.00	356	9.0	935
FP(e^+)	7042	231.5	1312	–	–	–	–	2.00	356	9.0	935
Solution 1								$c = 3238.68/3239.14$ m			
DRFS	7022	476	1312	4	33	23	59	2.00	732	4.4	961
KCS	7022	360	1312	4	45	34	39	2.00	554	5.8	727
FP(1Ring)	7022	238	2625	2	31	45	59	2.00	366	8.8	961
FP(2Ring)	7022	238	1312	4	75	23	59	2.00	366	8.8	961

In order to inject the electron beam to DR by same filling pattern, train spacing and number of bunch should be changed train-by-train.

- *33 or 34 bunches/train*
- *70.77 ns or 76.92 ns of train gap*

Should be change pulse-by-pulse



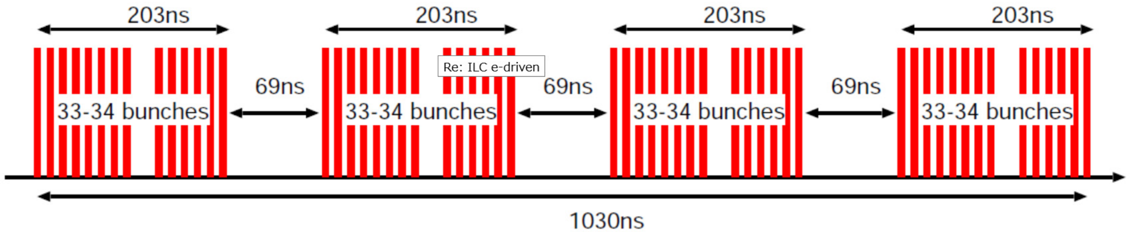
180 degree phase change within 70ns for gun seed laser

Filling Pattern in DR (TDR baseline)

Train in DR	Number of bunch	Train gap in DR (unit; bunch separation)
1	34	12.5
2	34	**11.5**
3	34	12.5
4	34	**11.5**
5	34	12.5
6	34	**11.5**
7	34	12.5
8	34	**11.5**
9	34	12.5
10	34	**11.5**
11	34	12.5
12	**33**	12.5
13	34	12.5
14	**33**	12.5
15	34	12.5
:	:	:
38	**33**	12.5
39	34	12.5

A half and integer

Timing chart in the CR backup report



39 train in DR

(Train Interval)= 74ns (12.00 bunch separation ; one of the proposal at 06/05)
-> 69ns (11.25 bunch separation ; design in report)
-> 90 degree of gun laser phase should be shifted within 69ns.

(Last train gap) = 77ns (one of the proposal at 06/05)
-> 252ns (design in report)

Timing of ML (proposed at 06/05)

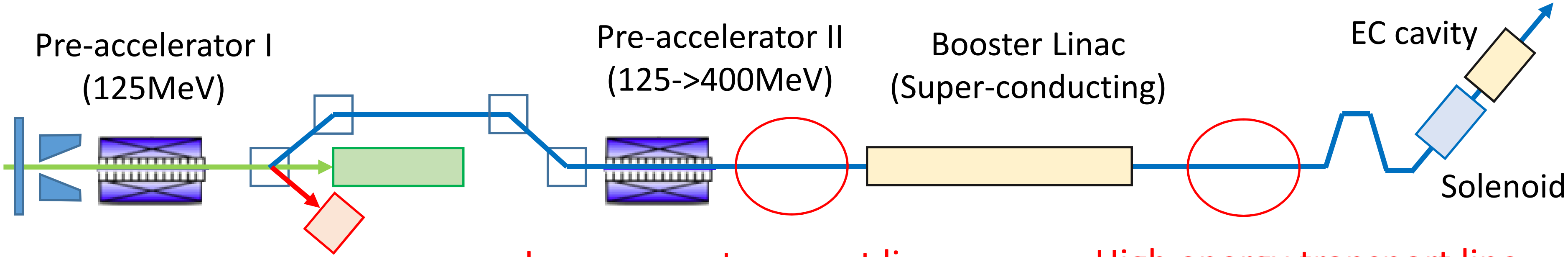
N in ML	RF buckets	Interval (ns)
1	1	
2	361	554 ns
3	721	554 ns
:	:	:
20	6841	554 ns
21	181	557 ns
22	541	554 ns
:	:	:
39	6661	554 ns
40	5	563 ns
41	365	554 ns

Timing of ML (design in report)

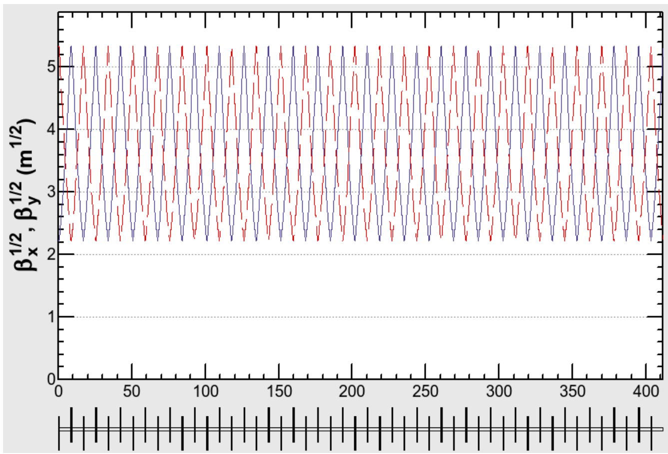
N in ML	RF buckets	Interval (ns)
1	1	
2	355	545 ns
3	709	545 ns
:	:	:
20	6727	545 ns
21	178	728 ns
22	532	545 ns
:	:	:
39	6550	545 ns
40	5	734 ns
41	359	545 ns

The timing system requires
- to modify to be complex timing system for e-gun of electron source and kickers.

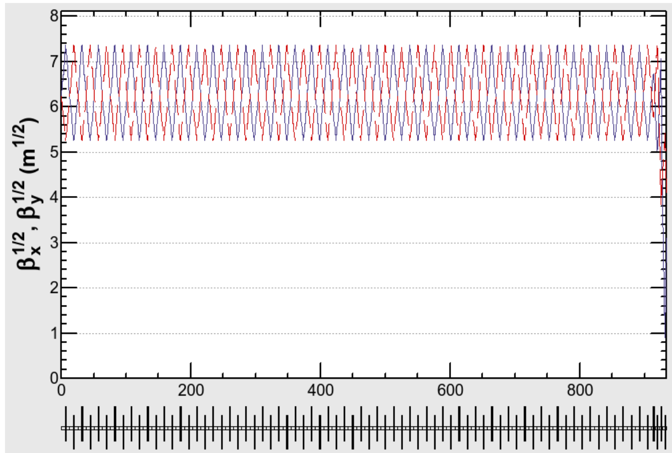
Positron Transport Line in BDS Tunnel



Low energy transport line
(E= 400 MeV)



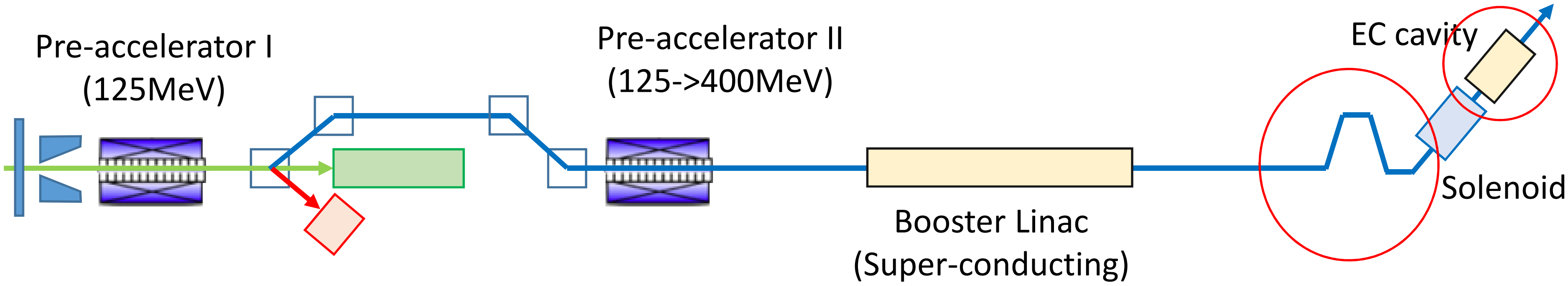
High energy transport line
(E= 5 GeV)

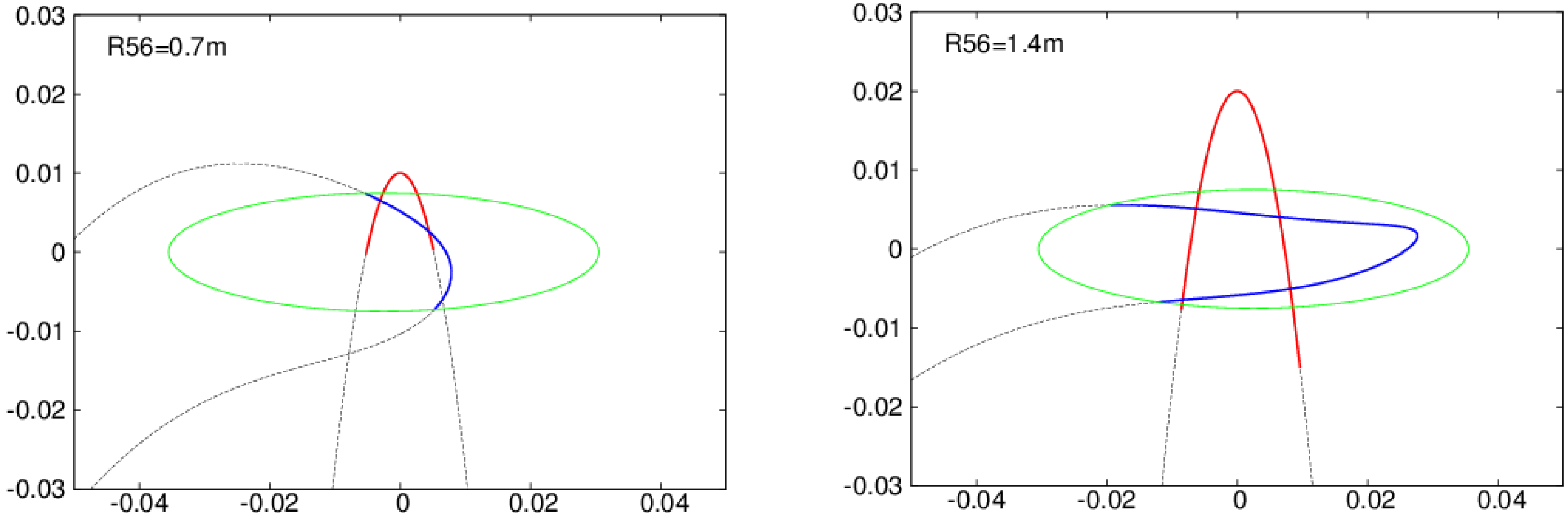


Long transport line
should be put
- after 5GeV acceleration
- after energy compressor

	Low Energy Transport	High Energy Transport (after EC)
Number of quadrupoles	119 quads/km	79 quads/km
Full aperture of DR acceptance	11 cm	5 cm
Chromaticity	- 250 / km	- 60 / km
Momentum Spread	> +/- 2 %	+/- 2 % (**+/- 0.75 % after EC**)
(Chromaticity) x (Momentum Spread)	5 /km	1.2 /km (**0.45 / km**)

Energy Compressor



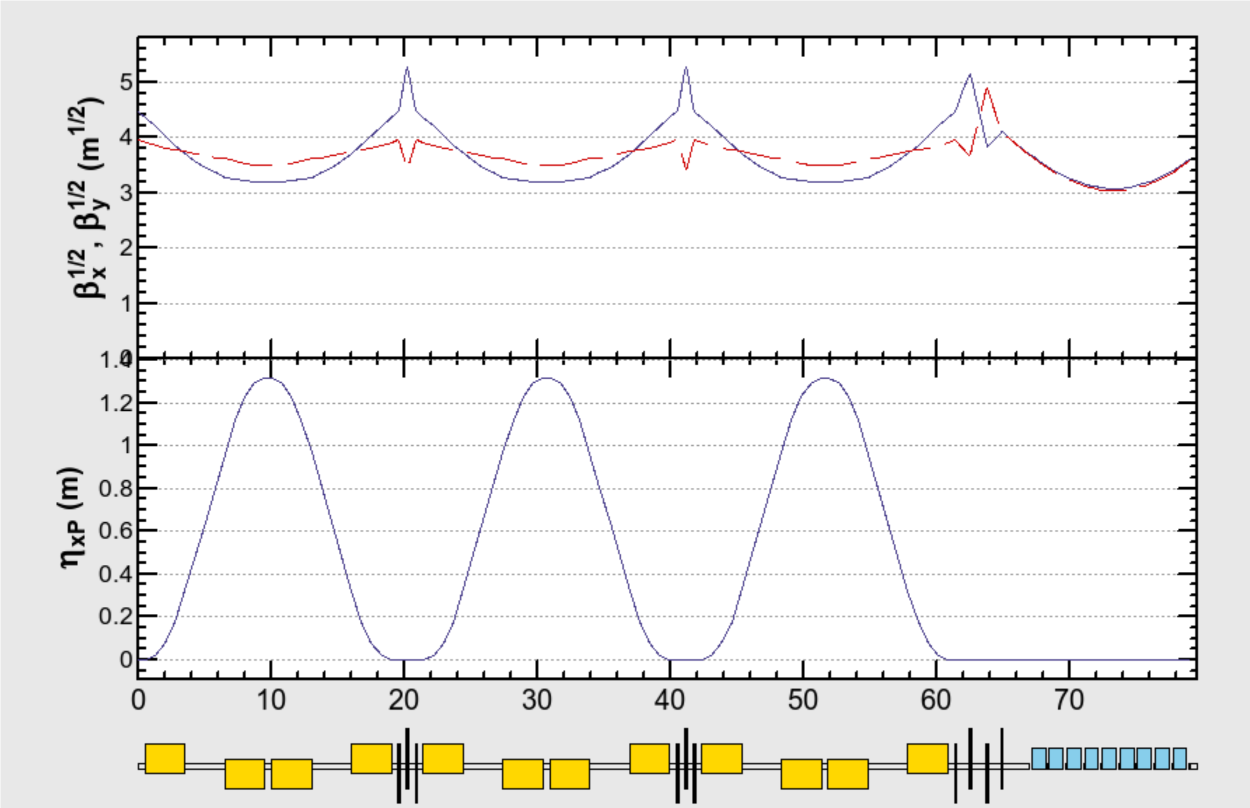


In present optics deck, the R56=0.7m, but the parameter is not effective to energy compress.

When R56 is increased twice as large as the present design (R56=1.4m),
the energy compress was more effective.

I recommend to increase R56 for energy compressor.

Beam Optics for Energy Compressor with R56=1.4m



Bending System

B = 1.2 T
3 chicanes
R56 = 1.4m

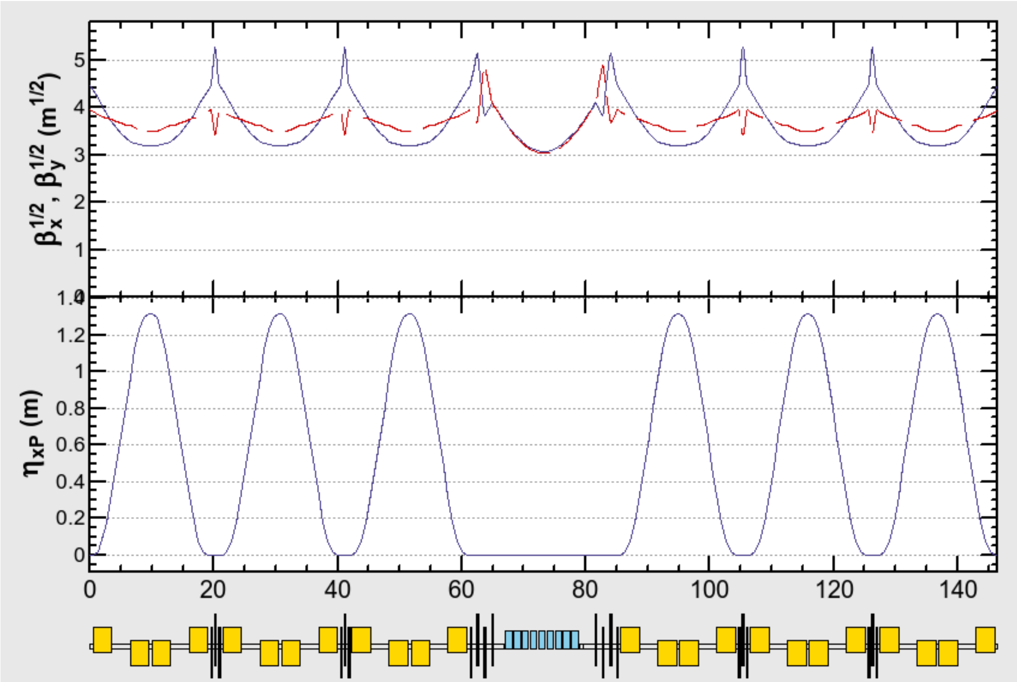
RF voltage
9 x 9cell cavity
（Type A module）

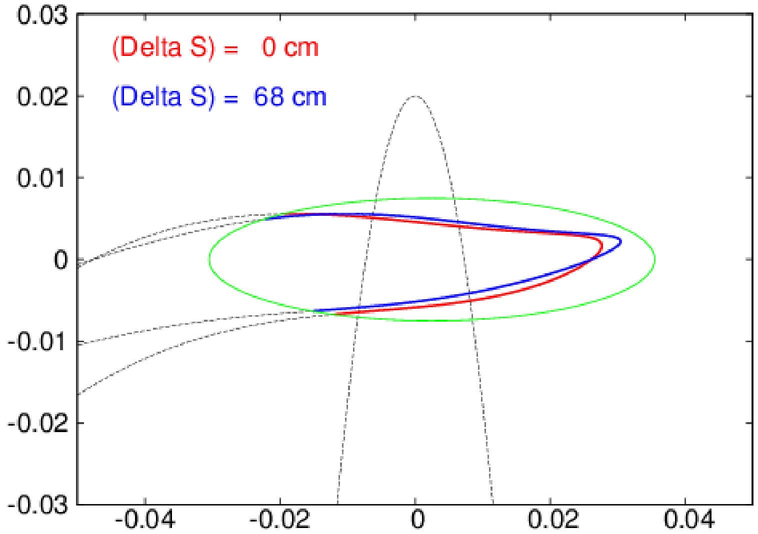
V = 131 MV

Path Length Adjuster

Path length adjuster is required in the positron source beamline in order to adjust the collision timing.

When we put the same chicane to energy compressor just after energy compressor, the path length will be able to change by 68cm by 3 chicanes.





When the path length adjuster put after energy compressor, the longitudinal phase space is not change so much.

I recommend to put the path length adjuster after the energy compressor.