The Experimental Plan on Heavy Beam Loading Compensation for ILC Conventional Positron Source

(The status of conventional positron source for ILC)

Beam Physics 2013 at OIST, 28-29 Nov. 2013

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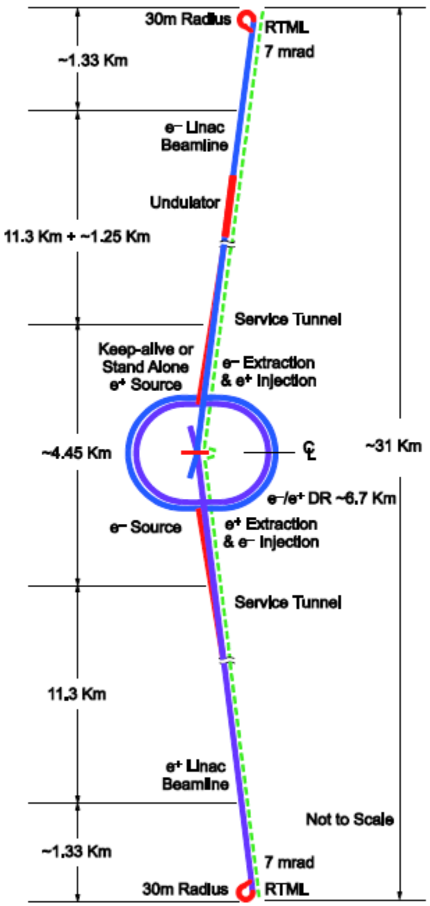
Contents :

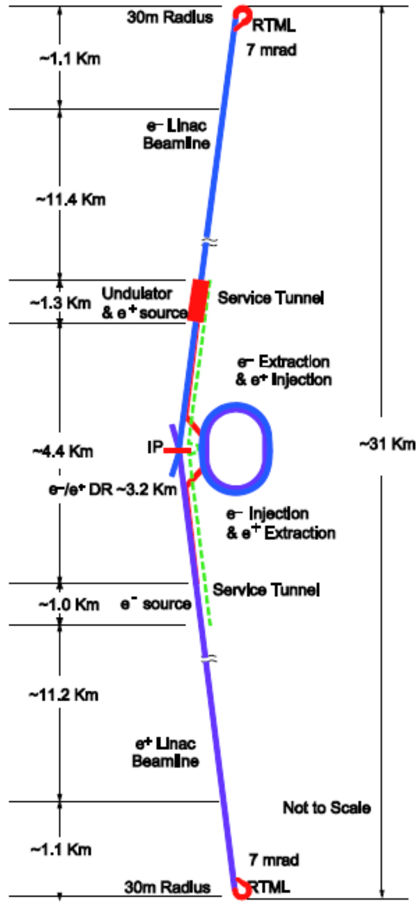
1. Introduction for ILC

TDR(2012) → EDR

RDR(2008)

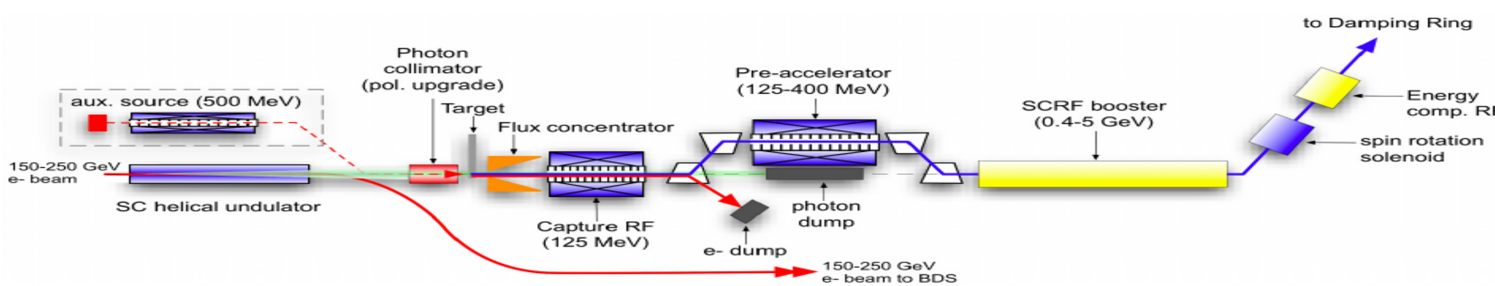


SB2009



- **Single Tunnel for main linac**
- **Move positron source to end of linac *****
- **Reduce number of bunches factor of two (lower power) ****
- **Reduce size of damping rings (3.2km)**
- **Integrate central region**

Baseline positron source : Undulator based scheme



Positron Source: Issues

- ILC positron source is challenging
  - Challenging hardware
    - **Rotating targets, undulators (100m/s, more than 200 m long)**
  - Risk for the electron beam
    - **Electron beam is sent through the smallest aperture**
    - **Significant energy loss for electrons (some GeV)**
    - **Will be hard to commission (compare to FEL)**
    - **Not clear about theoretical studies**
  - Positron beam quality is important
    - Will be hard to commission (comparable to proton source)
  - **Positron damping ring can only be fully commissioned if positron source is commissioned**
    - **Will come after commissioning of electron linac, i.e. late**
    - Positron damping ring is challenging because of electron cloud

From report of Daniel Schulte for LCWS2013

  - Each step appears feasible but tough
  - Total is critical for overall commissioning
    - Adjust construction schedule for this?
  - Use a conventional positron source?

Some more efforts in theoretical studies appear necessary
Should we take the risk?

- Hard to see an integrated system test
  - Can test components, as it has been done/is being done
  - Part tests from FEL, other sources

2. 300Hz Scheme for conventional positron source as backup option

From T. Omori et al. / NIMA 672 (2012) 52–56

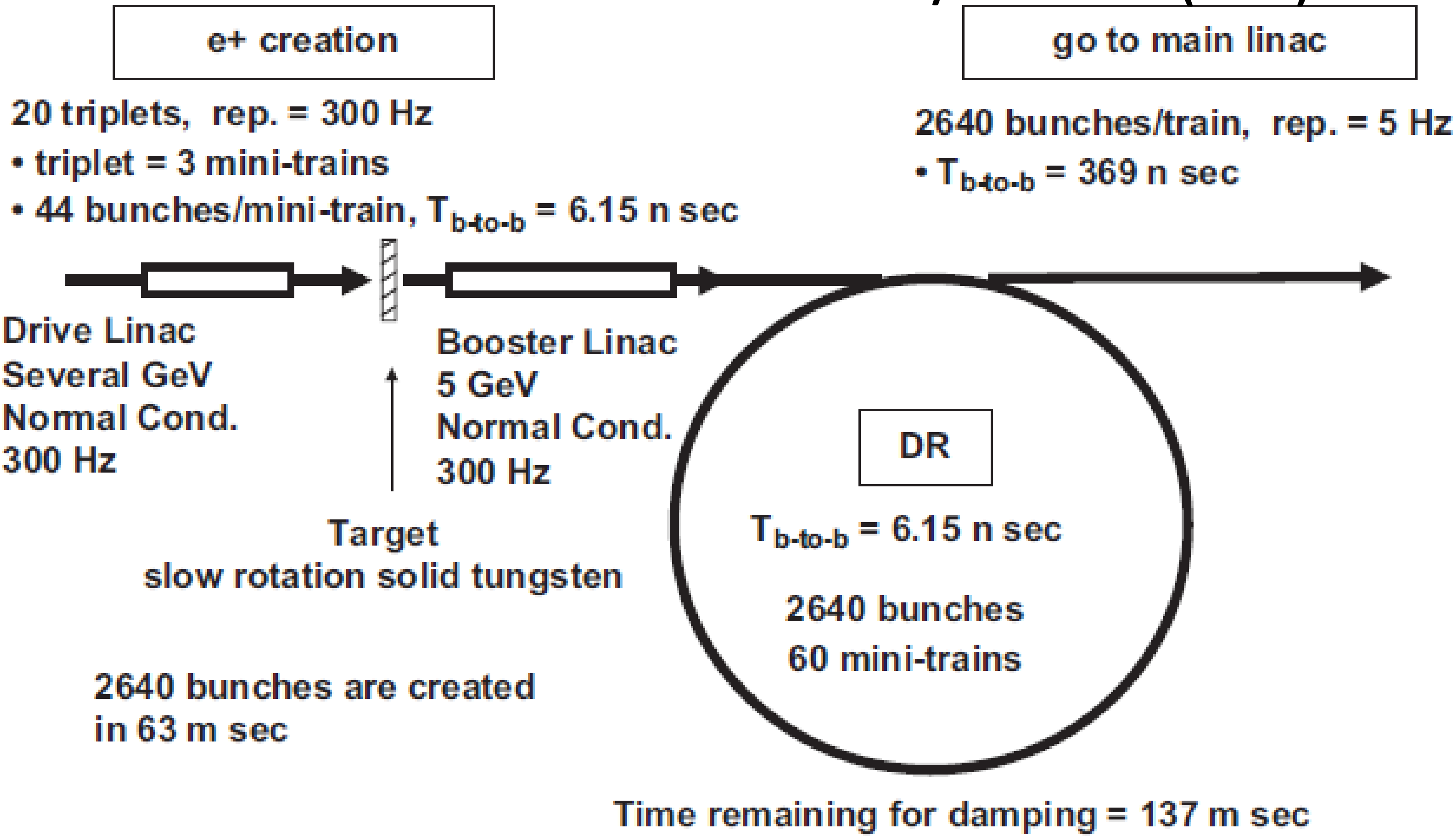
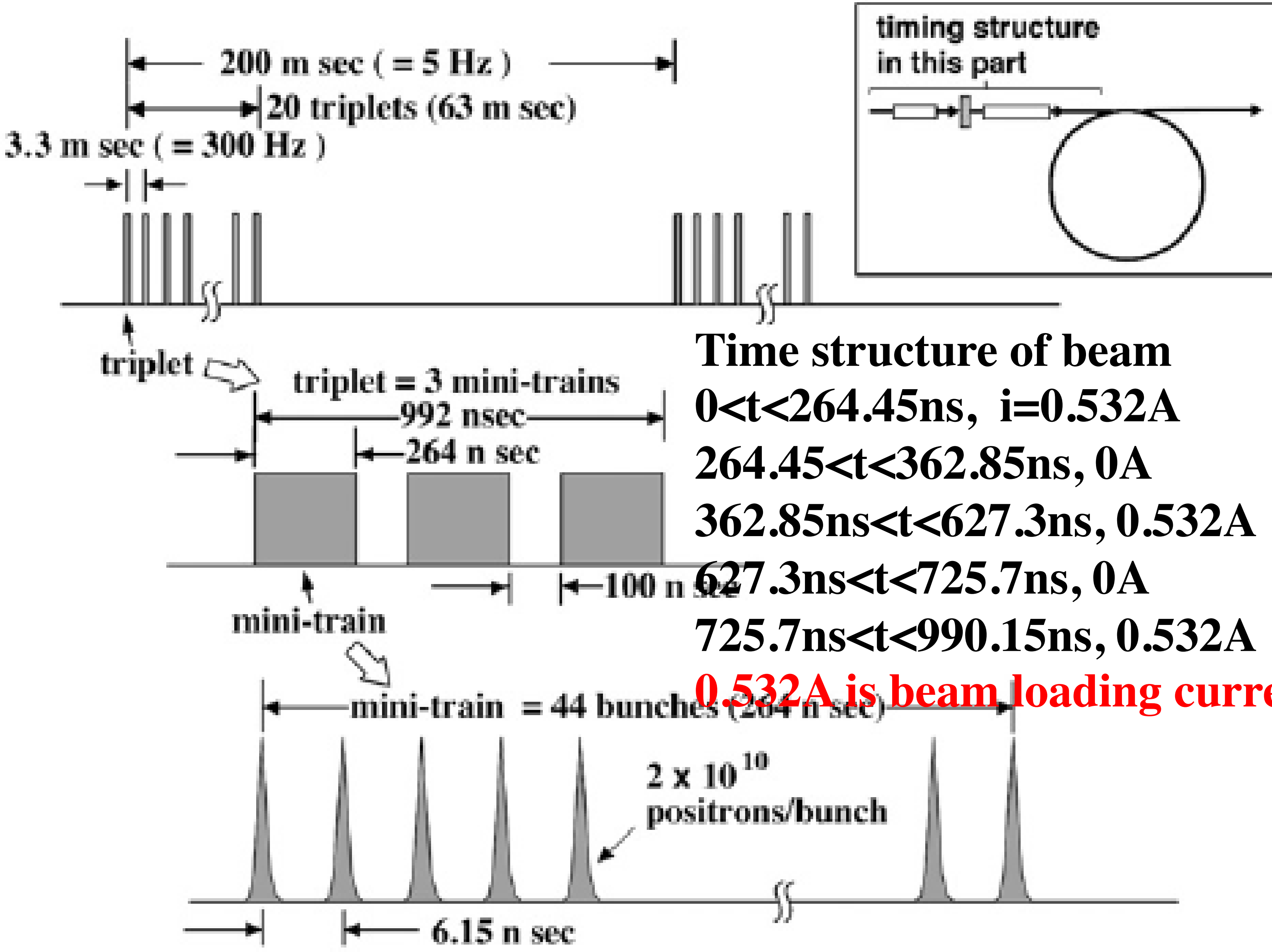


Fig. 1. Schematic view of the 300 Hz scheme.



Time structure of beam

0<t<264.45ns, i=0.532A

264.45<t<362.85ns, 0A

362.85ns<t<627.3ns, 0.532A

627.3ns<t<725.7ns, 0A

725.7ns<t<990.15ns, 0.532A

0.532A is beam loading current.

Fig. 2. Timing structure in the positron source and in the booster linac.

Bunch by bunch extraction from Damping Ring to make ILC beam train.

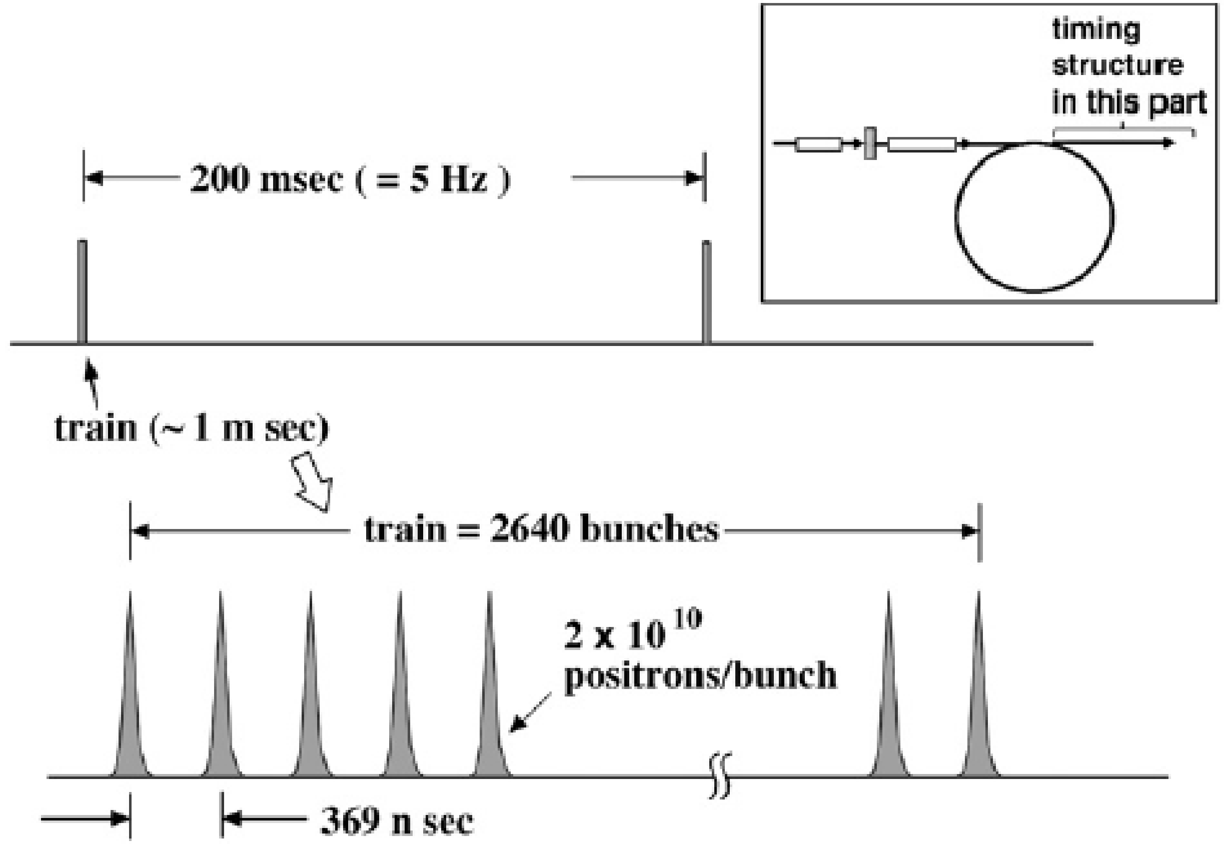
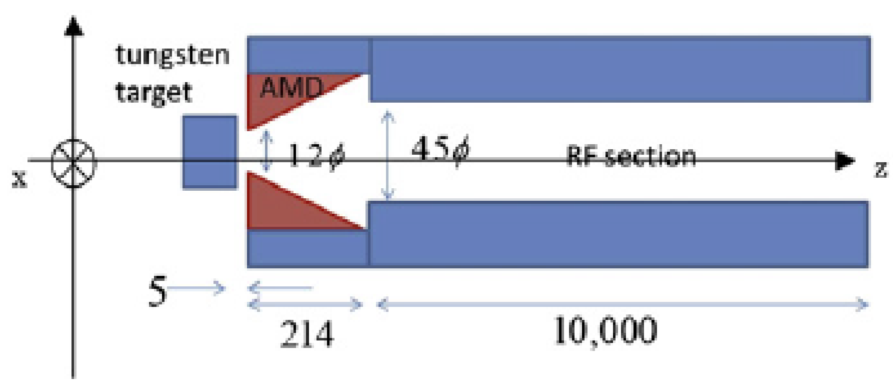


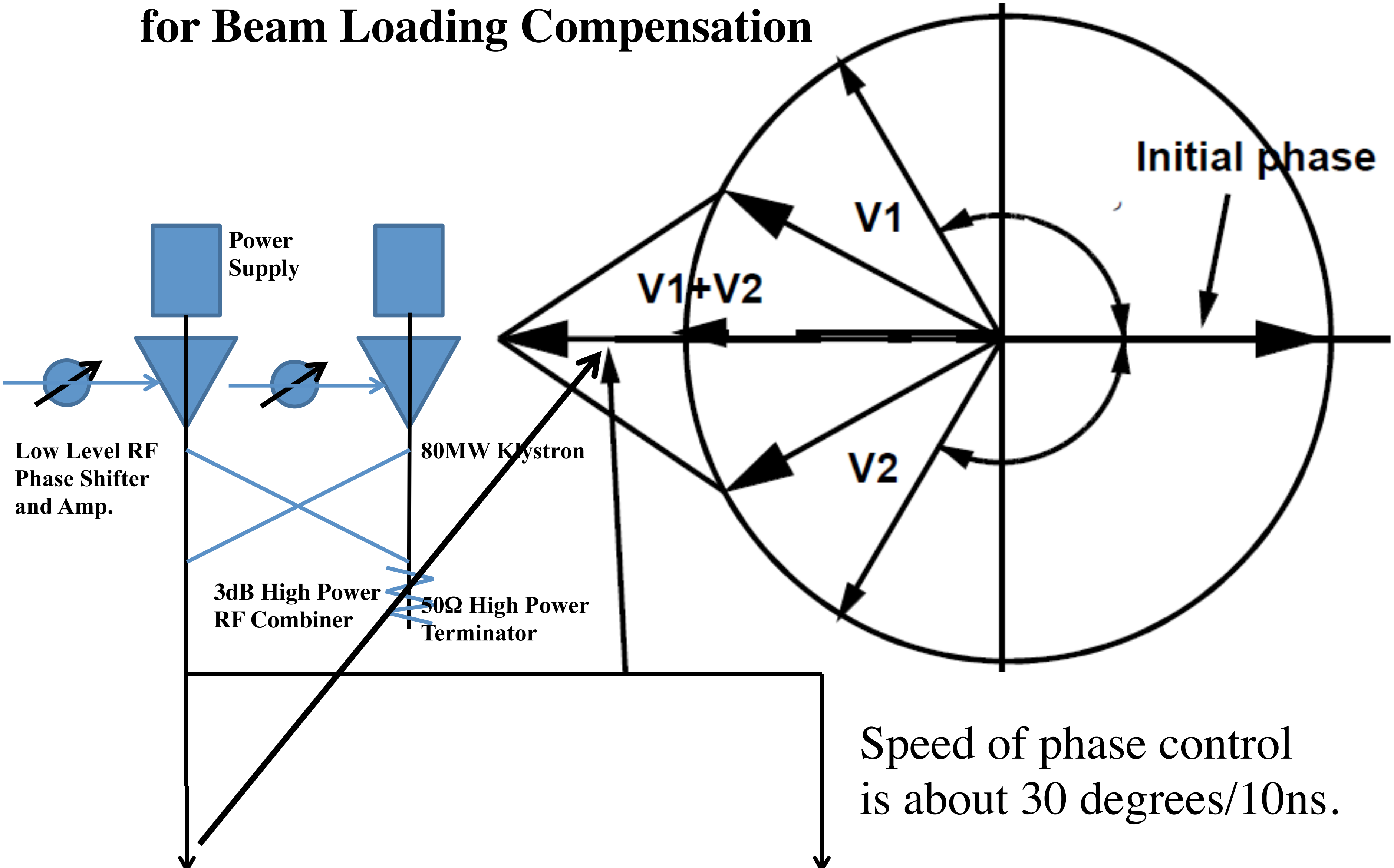
Fig. 4. Time structure after the damping ring.

This is the model for positron target system to confirm the generation of ILC positron beam.

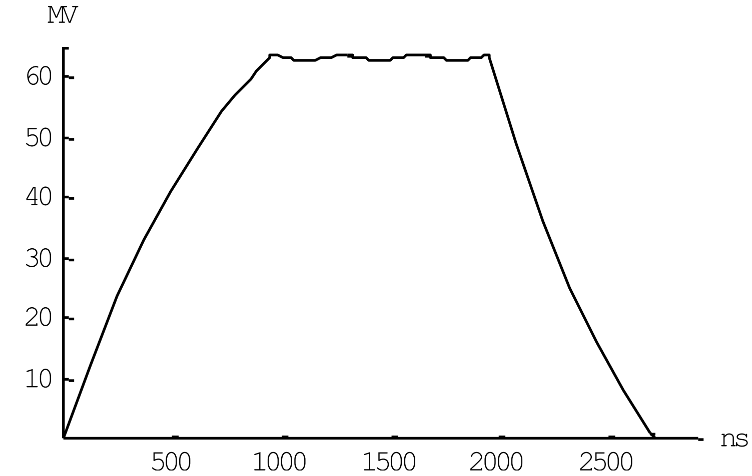


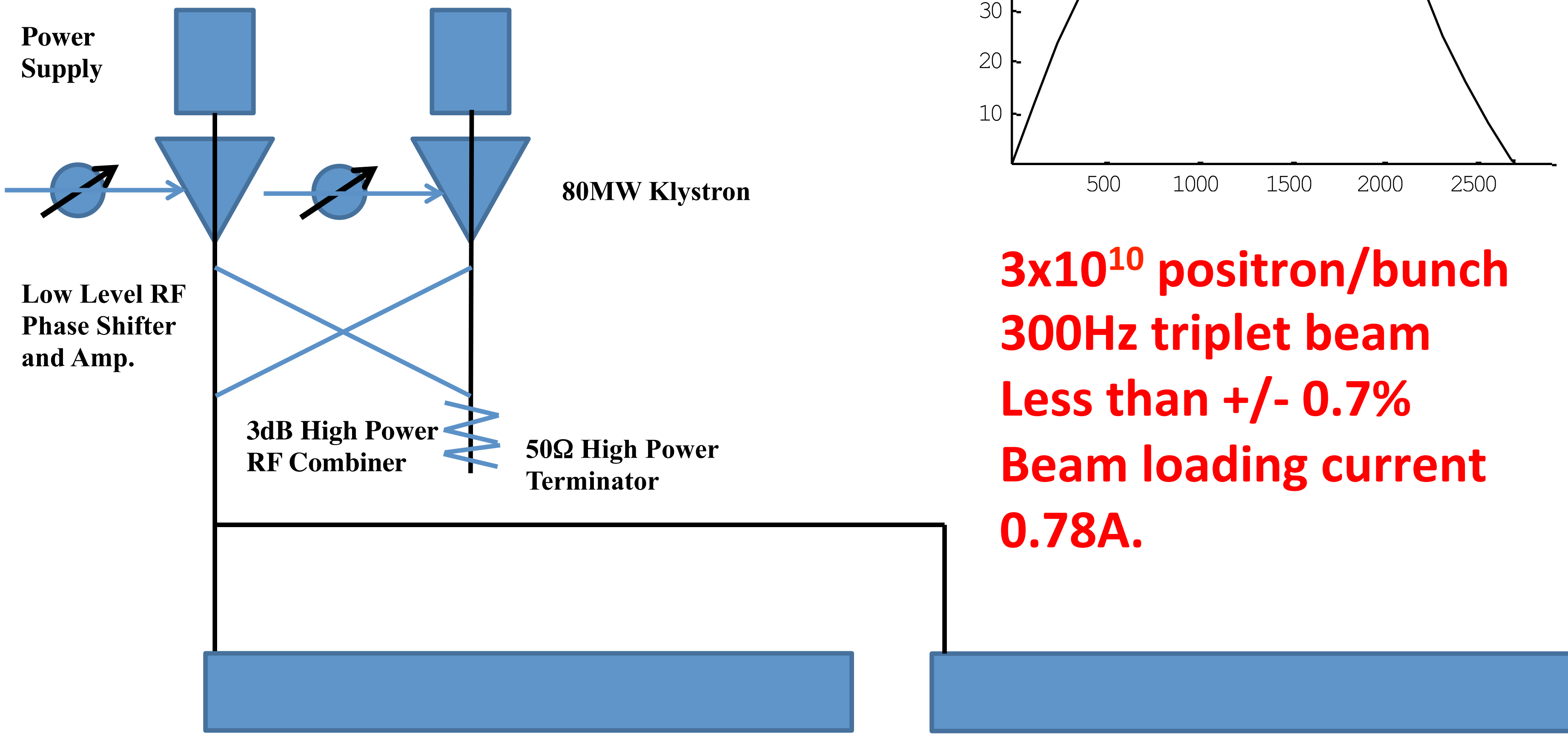
3. 300Hz Linac Scheme for Beam Loading Compensation

Phase to Amplitude Modulation Method for Beam Loading Compensation



Speed of phase control is about 30 degrees/10ns.





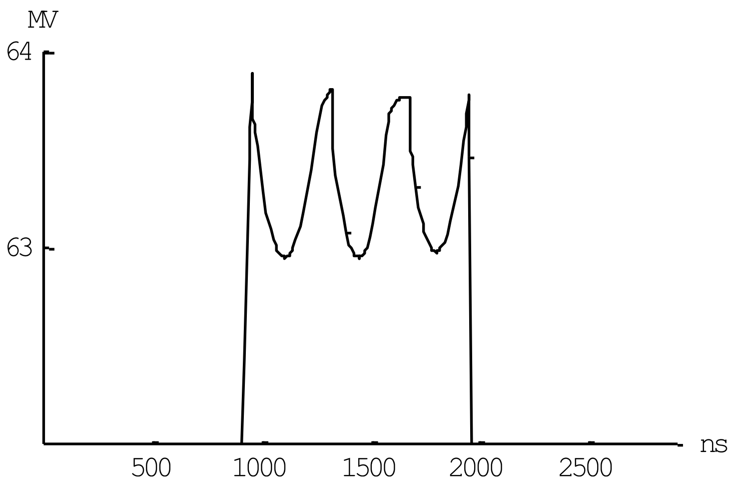
3m long constant gradient travelling wave structure

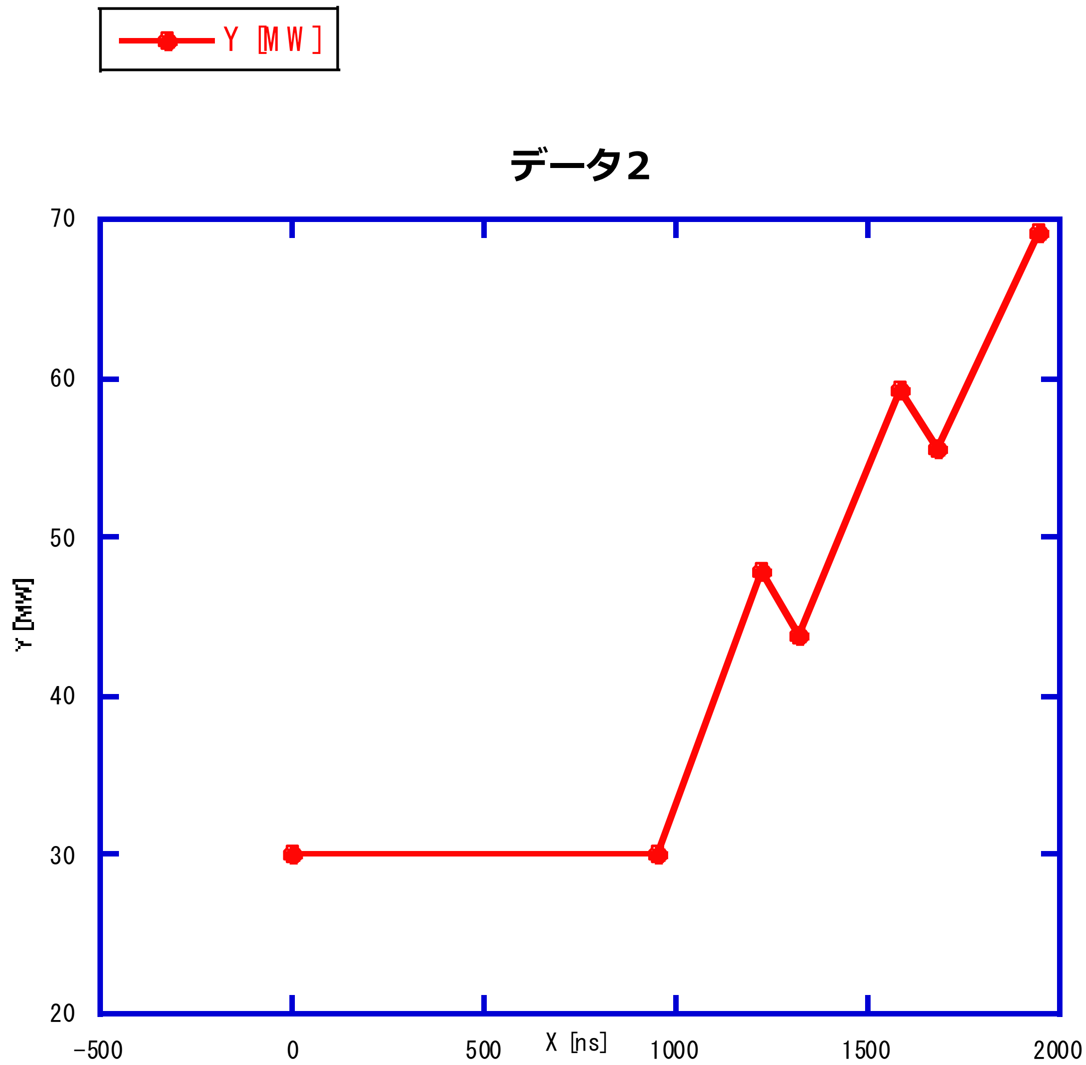
3x10^{10} positron/bunch
300Hz triplet beam
Less than +/- 0.7%
Beam loading current 0.78A.

Also, I assume 10% margin as wave guide loss and so on because of the experience at ATF Linac. So, klystron output power 80MW and 3μs pulse width are necessary.

Control of input RF power by phase shifters

Detail of beam loading compensation:
Less than ±0.7% is possible For ILC 300Hz multi-bunch beam.

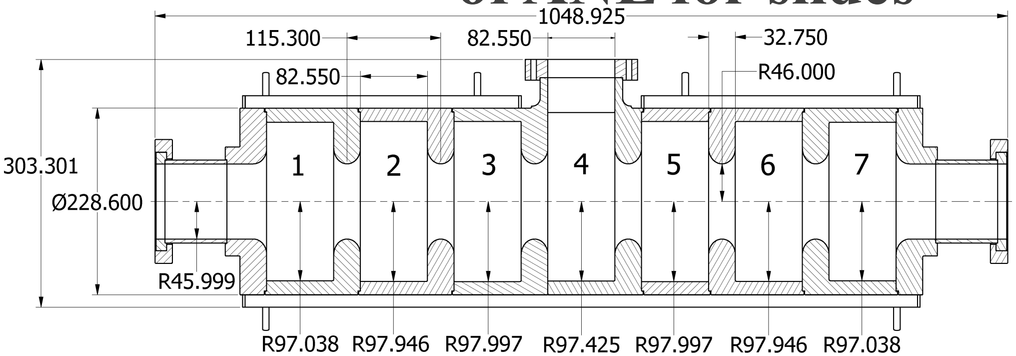




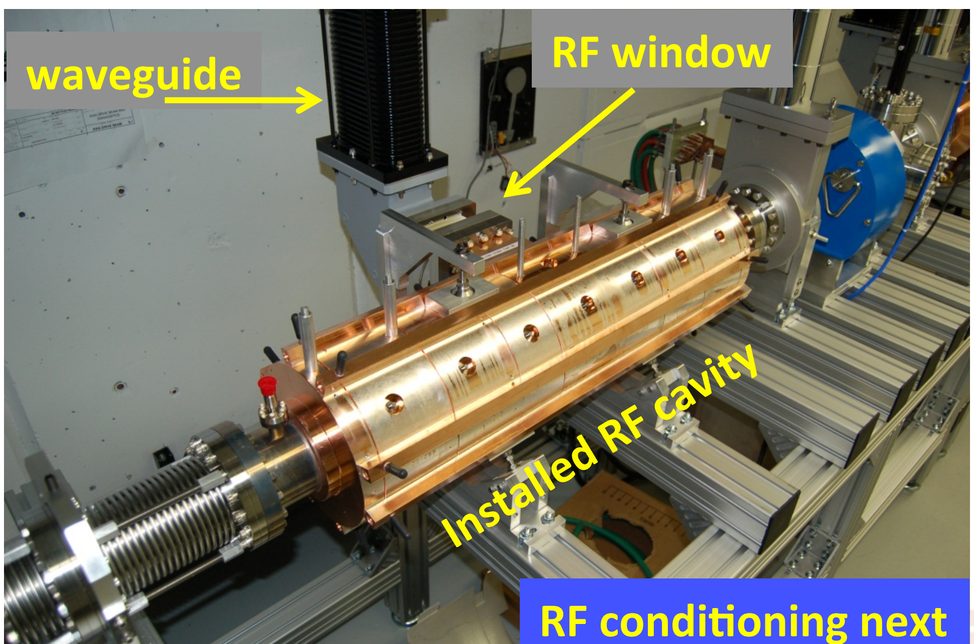
1300 MHz rf cavity

Thank to J. Power of ANL for slides

from design …



…to installed in beamline



Parameter (unit)	Value
unloaded voltage gain, V (MV)	**11.8**
$\varepsilon = U_b/U_0$ @ 1 μC (%)	43.15
energy droop along beam[1] (%)	27
σ = rms energy spread due to wakes[1] (keV)	159
μ = mean energy loss due to wakes[1] (keV)	394
E_{surf} (MV/m)	33.5
H_{surf} (kA/m)	58.8
pulsed heat temp. rise (°C)	1.5
Q_0	25147
U_0 (J)	**27.49**
coupling parameter, β	1.28
mode separation (MHz)	14.7
power flow phase shift (°)	0.17

[1]for P_{in} = 10 MW and Q_b = 100 nC, σ_z = 2 mm.

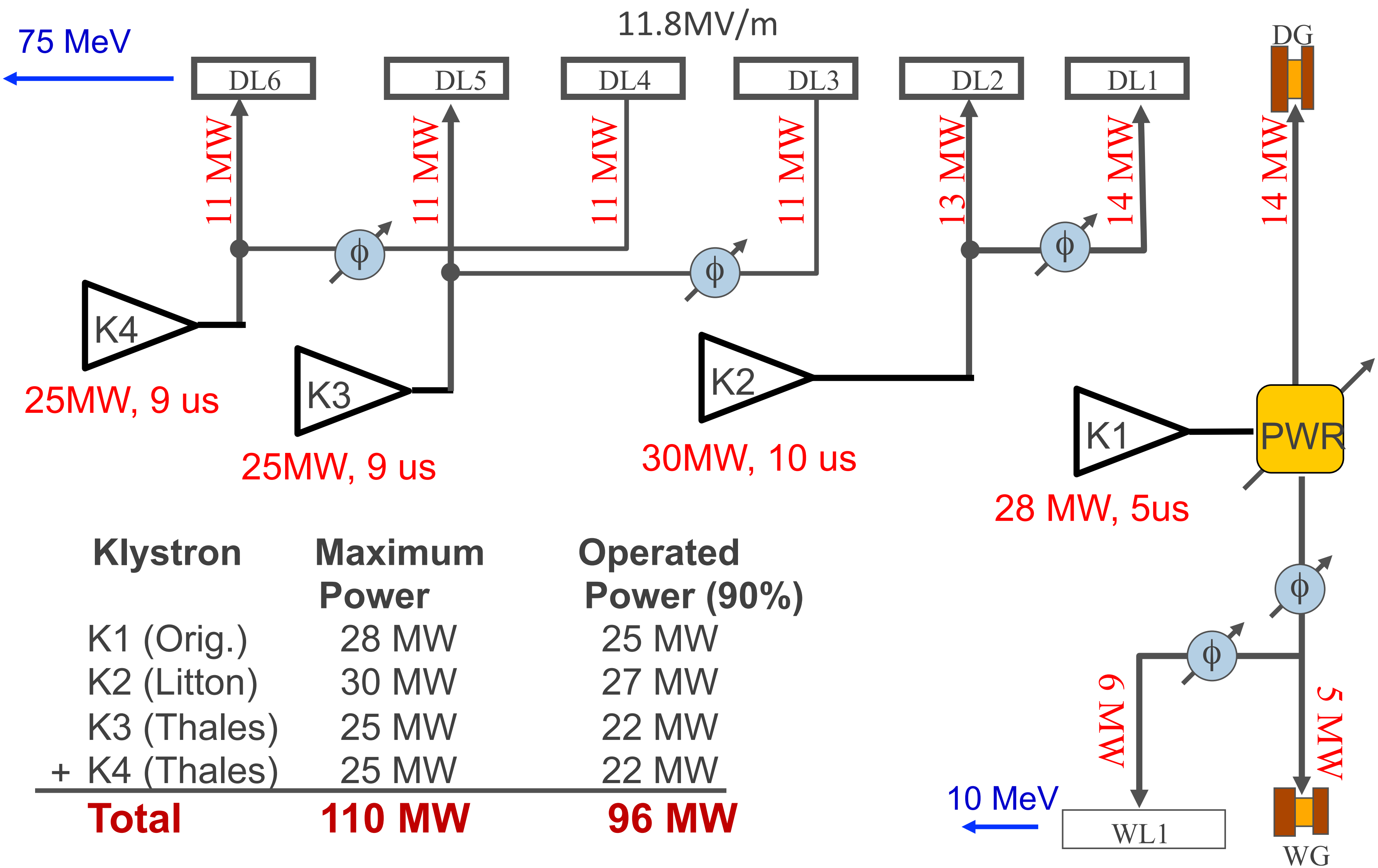
*Designed by ANL/SLAC

*fabrication by local vendor (Hi Tech)

*tuned and balanced at Argonne

RF power distribution

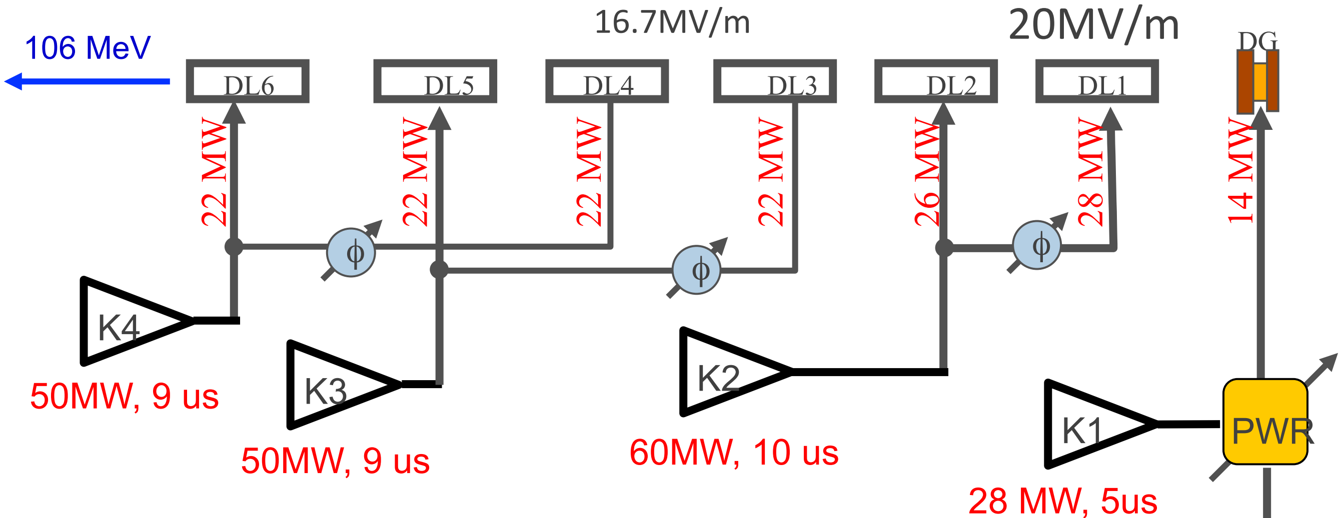
Total Power Budget = 96 MW

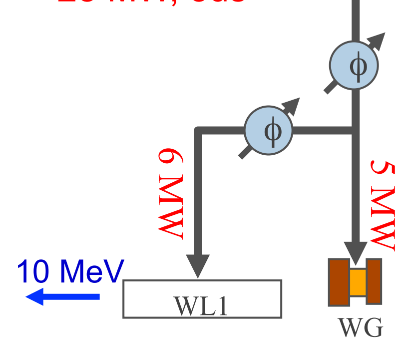


Klystron	Maximum Power	Operated Power (90%)
K1 (Orig.)	28 MW	25 MW
K2 (Litton)	30 MW	27 MW
K3 (Thales)	25 MW	22 MW
+ K4 (Thales)	25 MW	22 MW
Total	**110 MW**	**96 MW**

RF power distribution

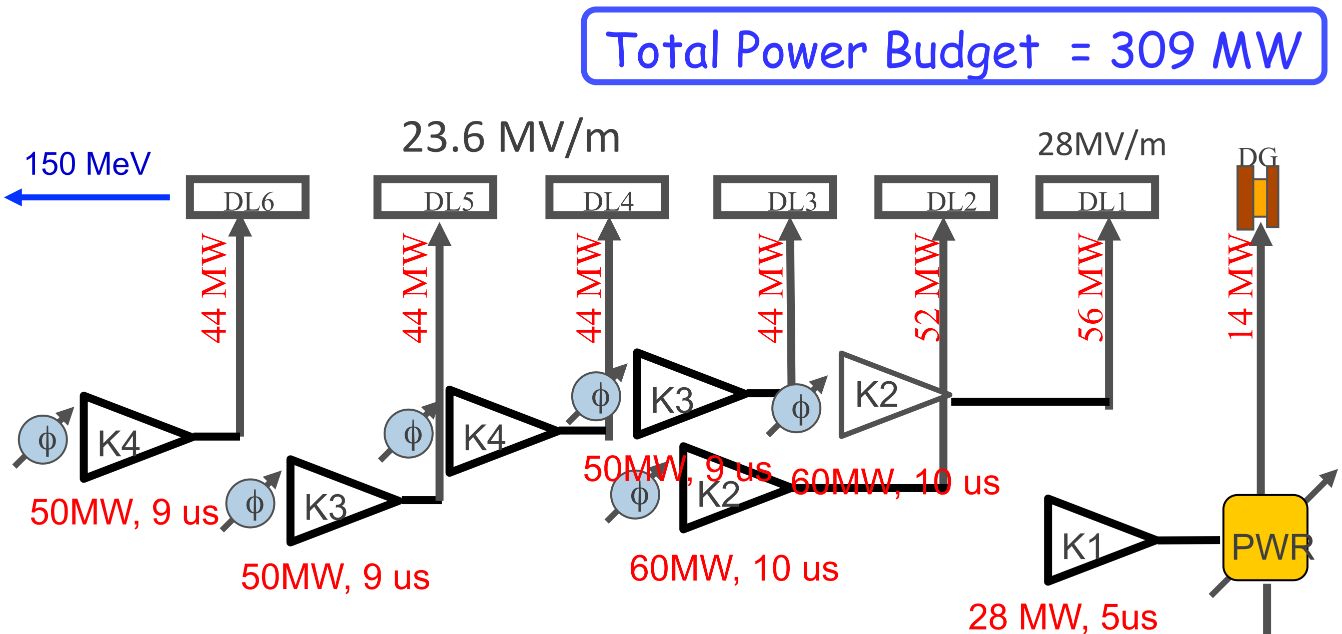
Total Power Budget = 167 MW

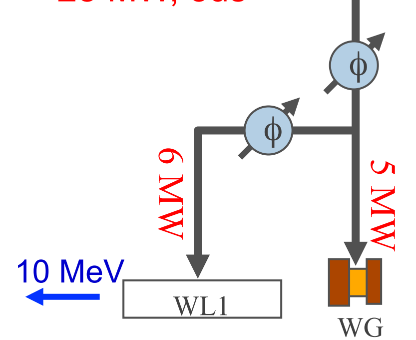




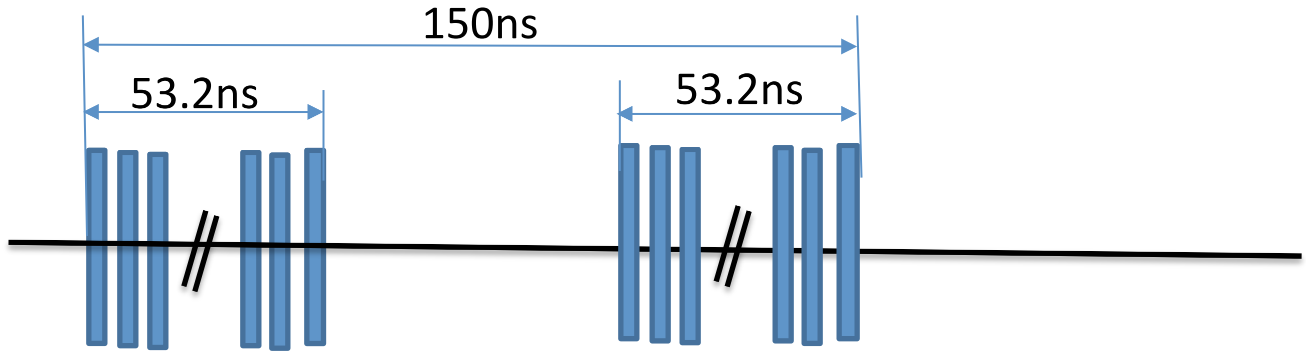
Klystron	Maximum Power	Operated Power (90%)
K1 (Orig.)	28 MW	25 MW
K2 (Litton)	60 MW	54 MW
K3 (Thales)	50 MW	44 MW
+ K4 (Thales)	50 MW	44 MW
Total	**188 MW**	**167 MW**

RF power distribution

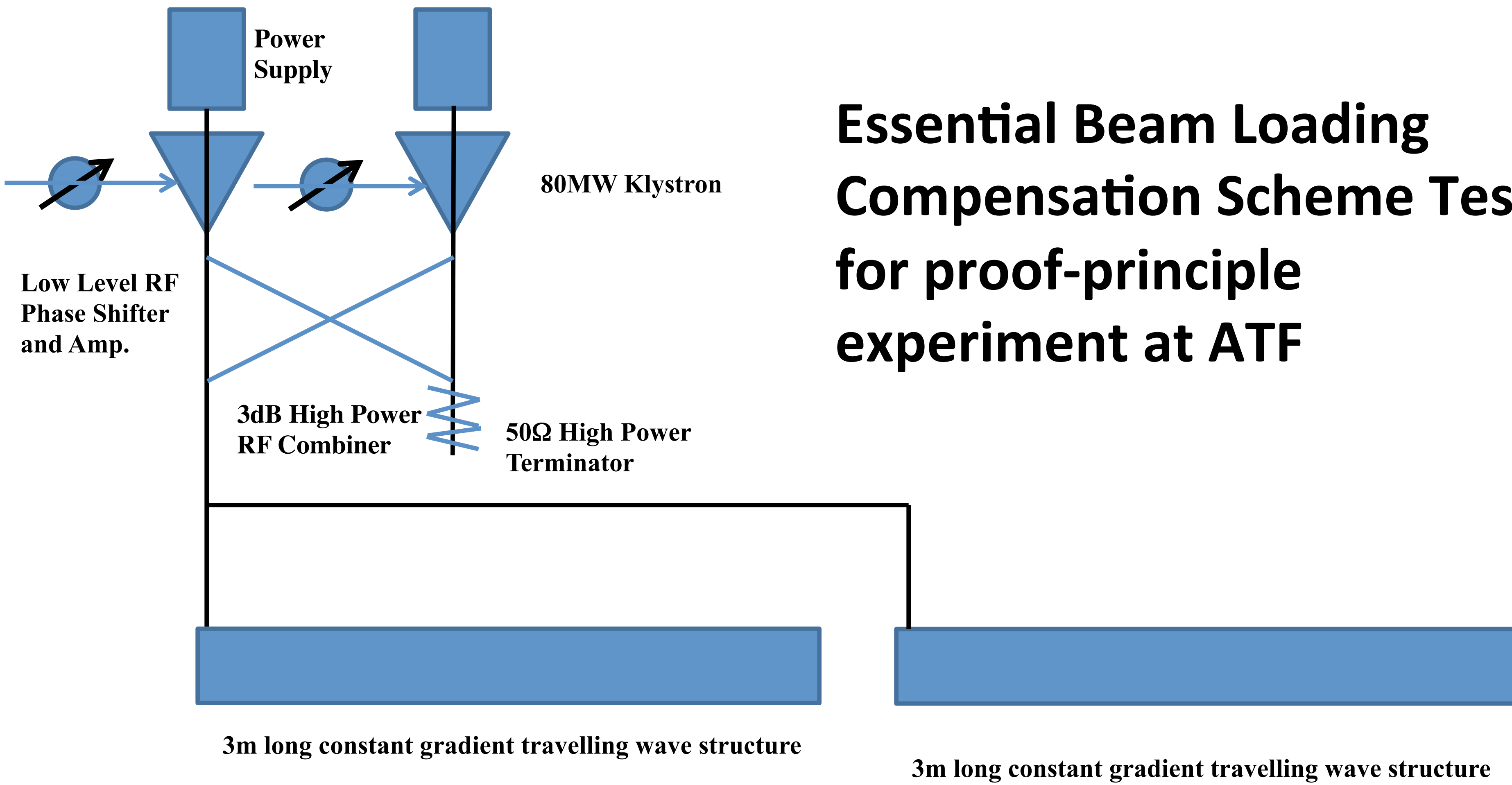




Klystron	Maximum Power	Operated Power (90%)
K1 (Orig.)	28 MW	25 MW
2*K2 (Litton)	120 MW	108 MW
2*K3 (Thales)	100 MW	88 MW
+ 2*K4 (Thales)	100 MW	88 MW
Total	**348 MW**	**309 MW**



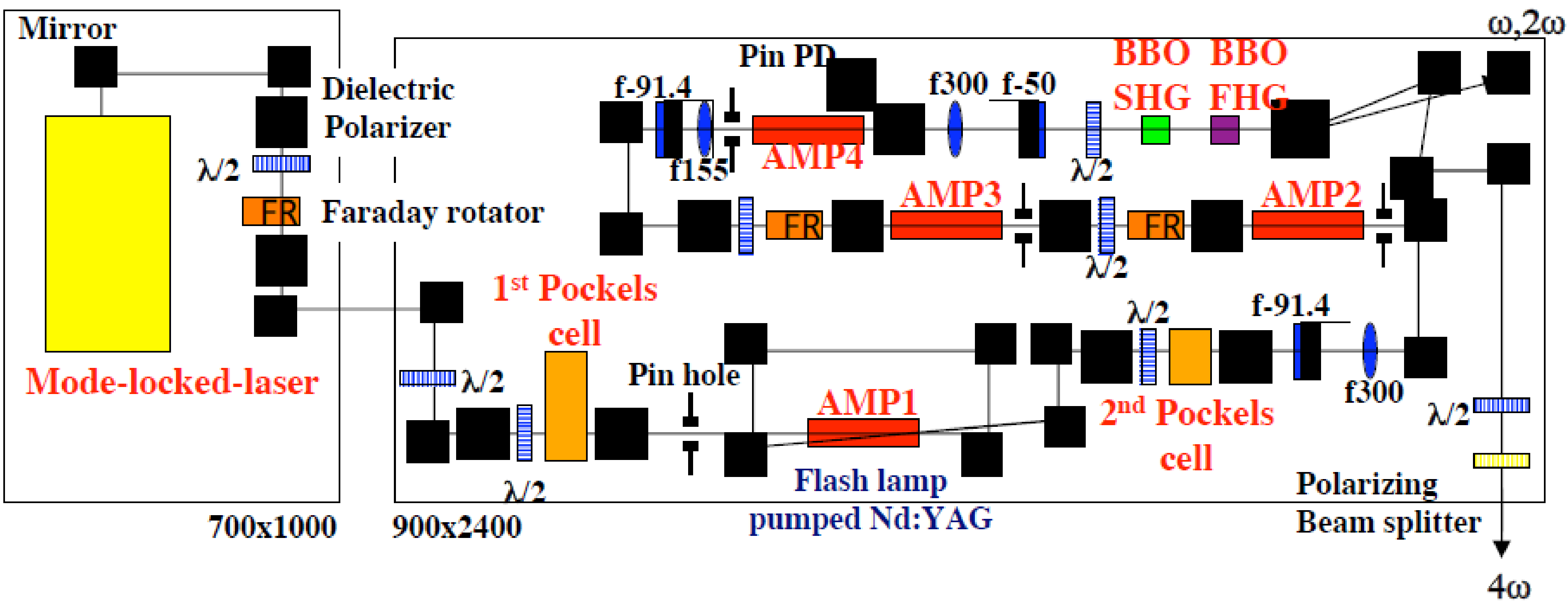
Essential Beam Loading Compensation Scheme Test for proof-principle experiment at ATF



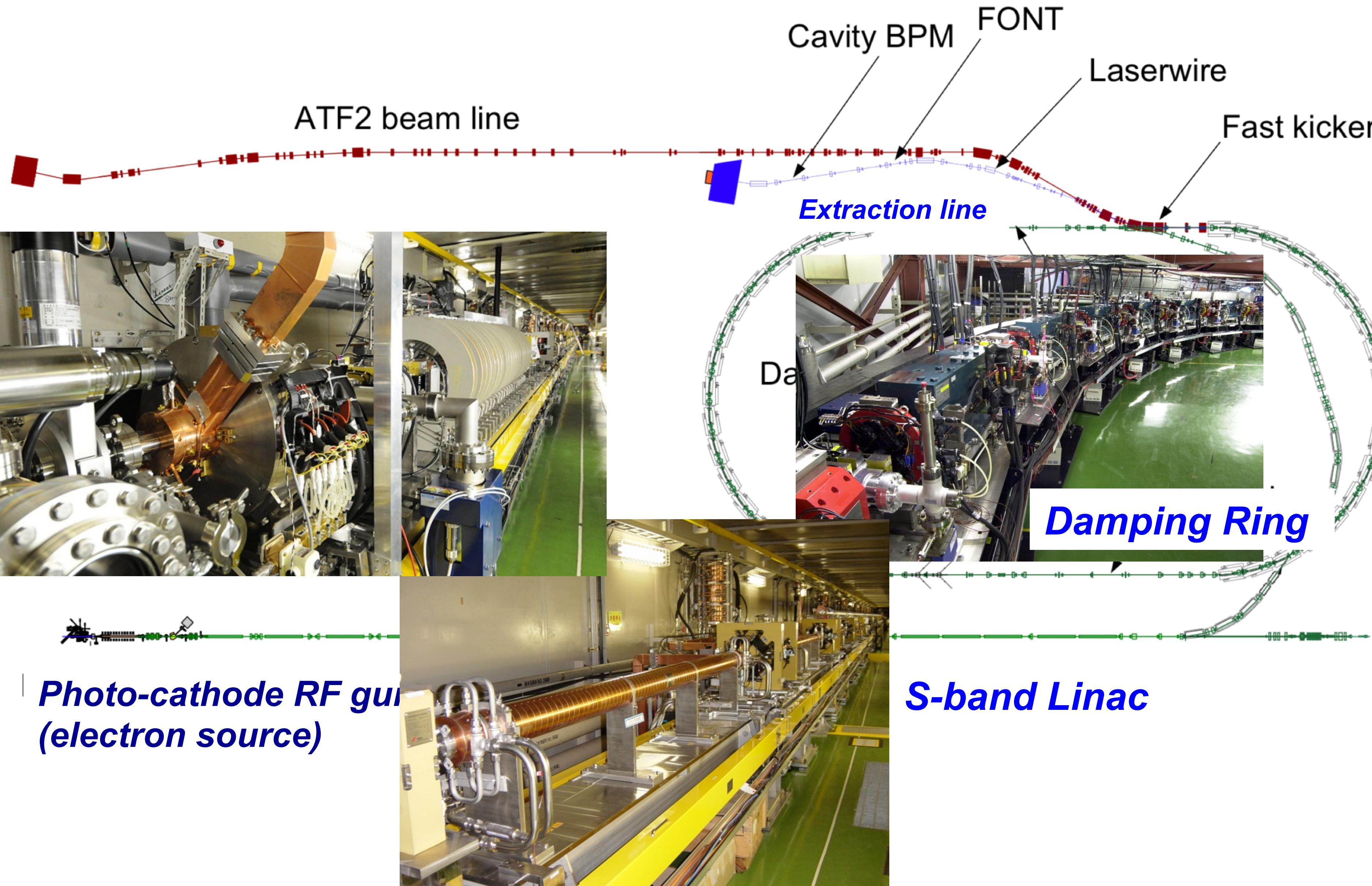
ATF laser system for photo-cathode RF Gun can generate doublet laser beam of 20 pulse with 2.8ns bunch spacing and about 100ns gap by minor modifications.

357MHz Laser oscillator	Pockels cell to make triplet laser pulse train	12.5Hz Amp.	4th higher harmonics generator (crystal:BBO)

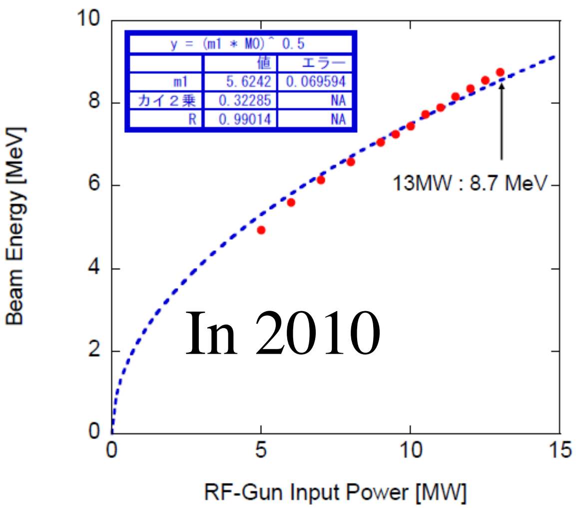
Delay loop

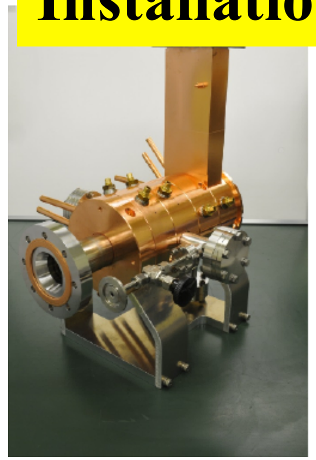


4. Plan for beam loading compensation experiment at ATF

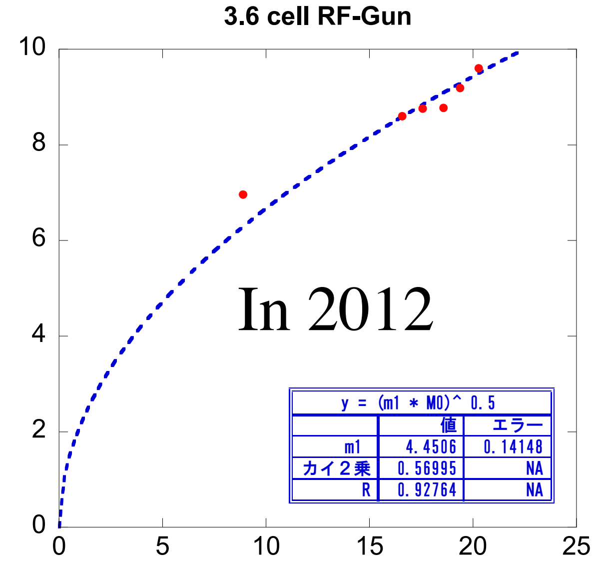


3.6 cell RF Gun Installation

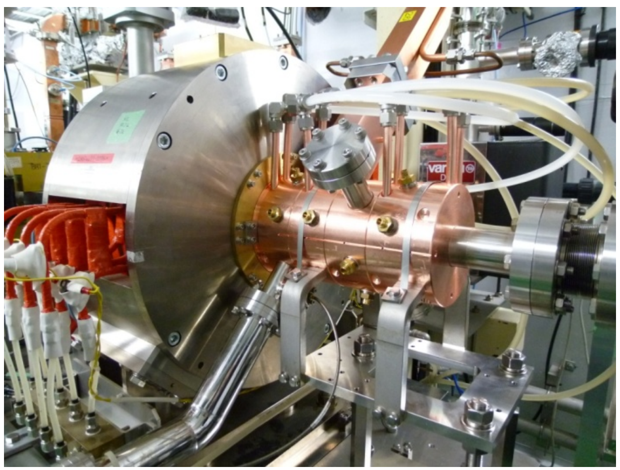




ATF インストールの様子

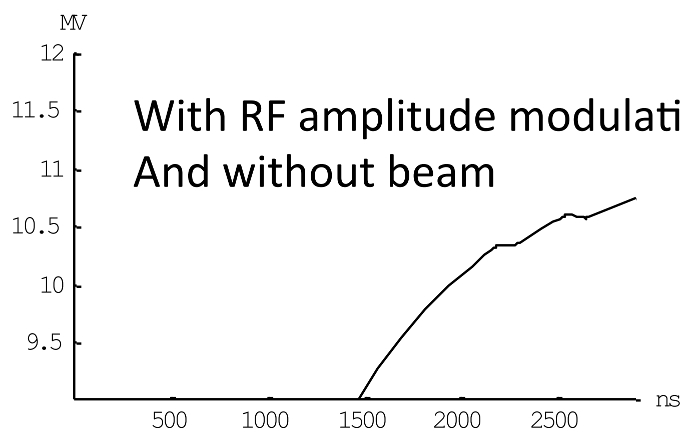


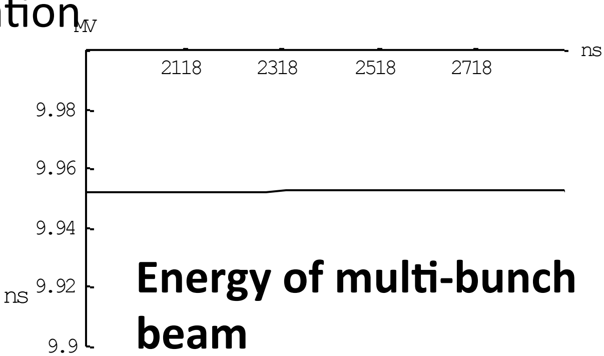
9.6MeV beam in one week RF aging with ~20.3MW RF input power



3.6 cell RF-Gun started beam acceleration test from 1/11,2012.

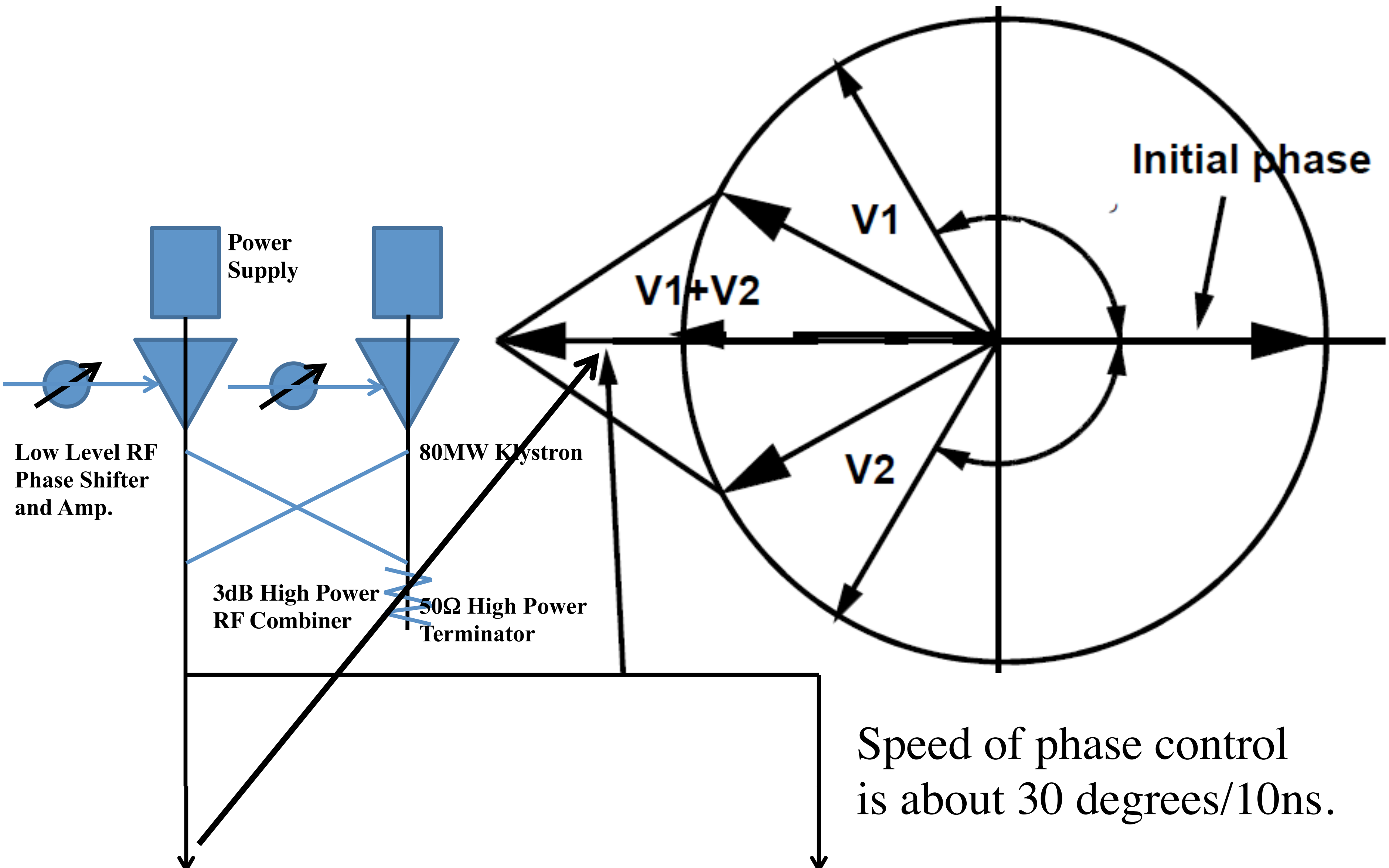
Now, 10MeV multi - bunch trains are generated and accelerated.



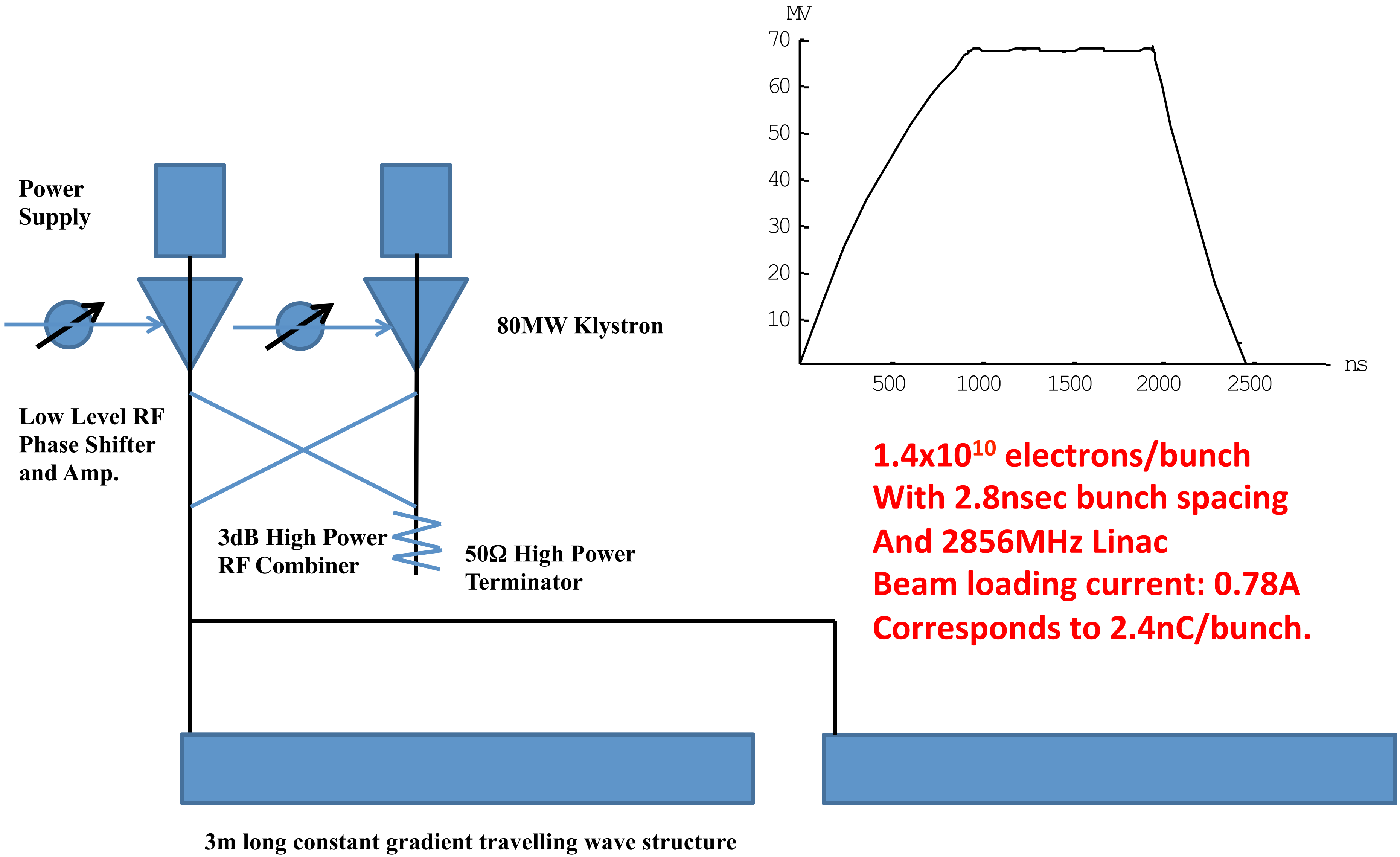


Energy of multi-bunch beam

Phase to Amplitude Modulation Method for Beam Loading Compensation



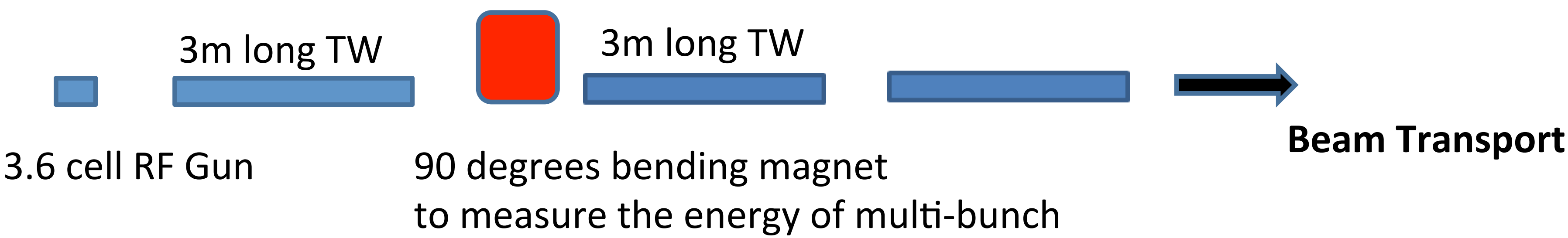
Speed of phase control is about 30 degrees/10ns.



$1.4\text{x}10^{10}$ electrons/bunch
With 2.8nsec bunch spacing
And 2856MHz Linac
Beam loading current: 0.78A
Corresponds to 2.4nC/bunch.

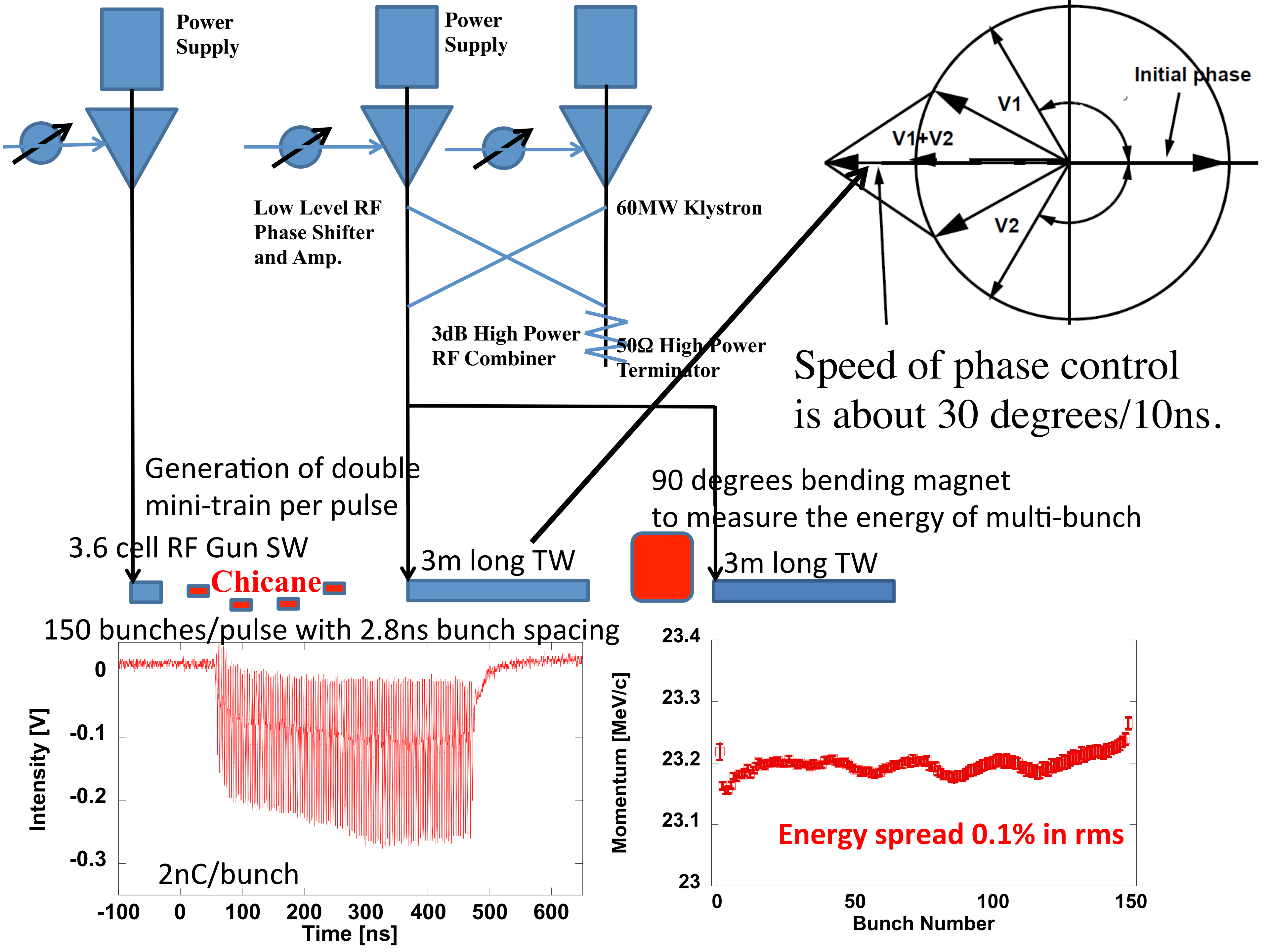
Also, I assume 10% margin as wave guide loss and so on because of the experience at ATF Linac. So, klystron output power 80MW and 3μs pulse width are necessary.

ATF Injector for 1.5GeV ATF Linac will be modified for beam loading compensation experiment in next year.

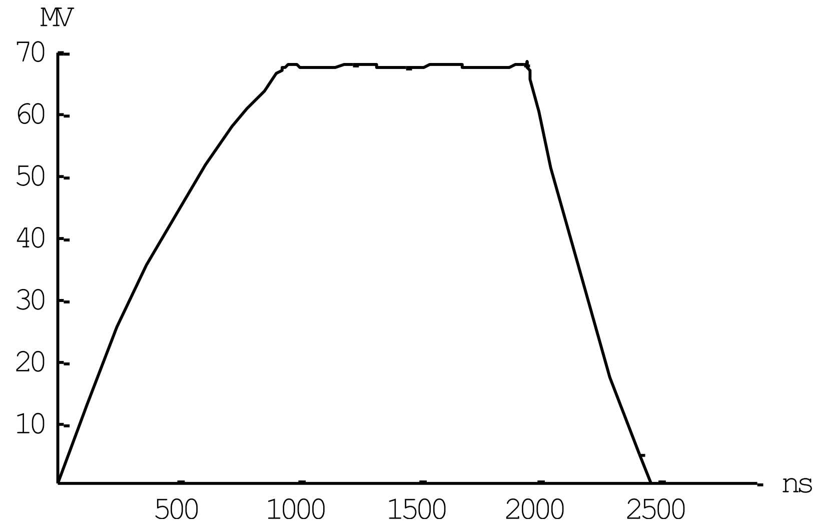


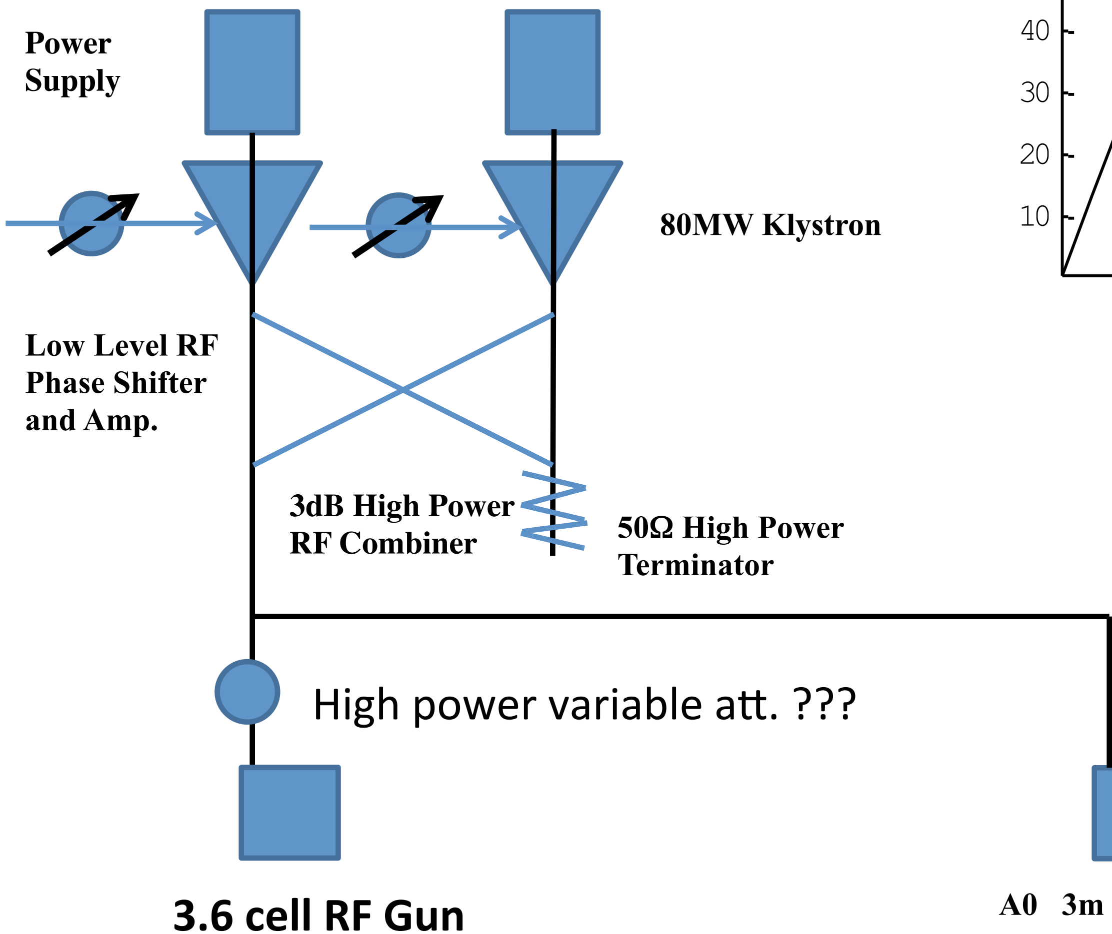
3×10^{10} with 6.15nsec bunch spacing corresponds to 1.4×10^{10} in the case of 2.8nsec bunch spacing as same beam loading in multi-bunch trains.

ATF Doublet Beam : 2x20 bunches/train with 60nsec train gap and 2.8nsec bunch spacing. This operation is possible in the safety of the radiation for ATF injector section.


Power Supply
Power Supply
Low Level RF Phase Shifter and Amp.
60MW Klystron
3dB High Power RF Combiner
50Ω High Power Terminator
Initial phase
V1
V1+V2
V2
Speed of phase control is about 30 degrees/10ns.
Generation of double mini-train per pulse
90 degrees bending magnet to measure the energy of multi-bunch
3.6 cell RF Gun SW
Chicane
3m long TW
3m long TW
150 bunches/pulse with 2.8ns bunch spacing
Intensity [V]
0
-0.1
-0.2
-0.3
2nC/bunch
-100
0
100
200
300
400
500
600
Time [ns]
Momentum [MeV/c]
23.4
23.3
23.2
23.1
23
Energy spread 0.1% in rms
0
50
100
150
Bunch Number

Maybe, this is not realistic.
Last slide scheme is realistic.



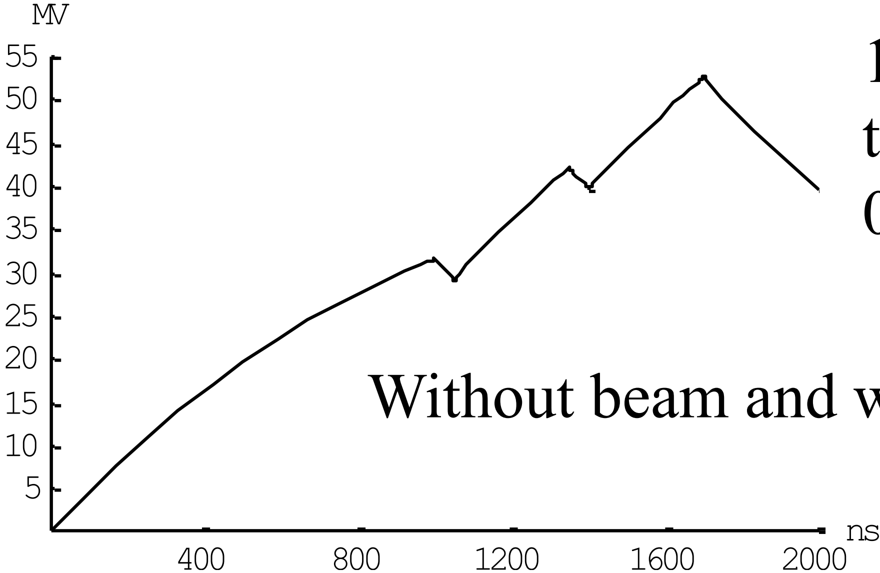


1.4x10^{10} electrons/bunch
With 2.8nsec bunch spacing
And 2856MHz Linac
Beam loading current: 0.78A

Considering the cost reduction for this experiment now.
Single bunch beam loading compensation can be done using off crest acceleration on which we have a lot of experience.

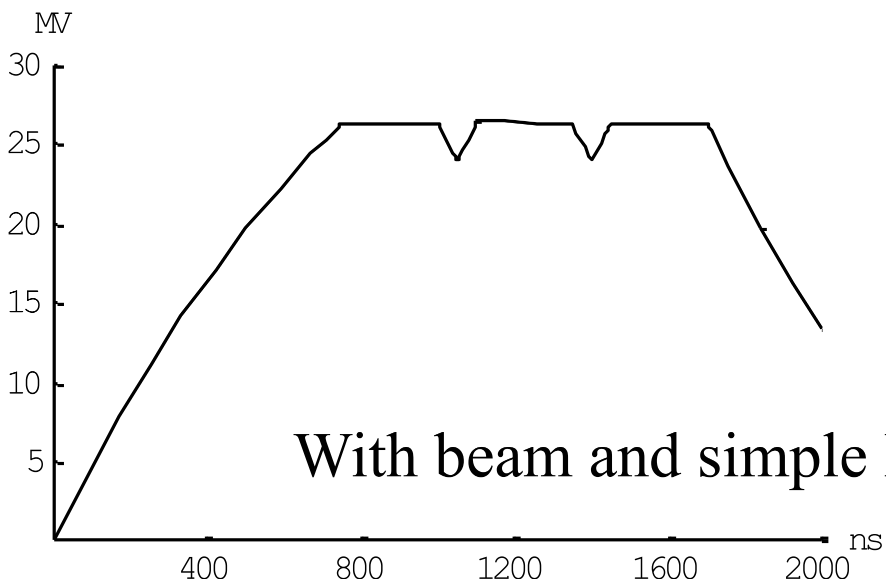
Rough beam loading compensation by simple simulation using standing wave accelerating structures

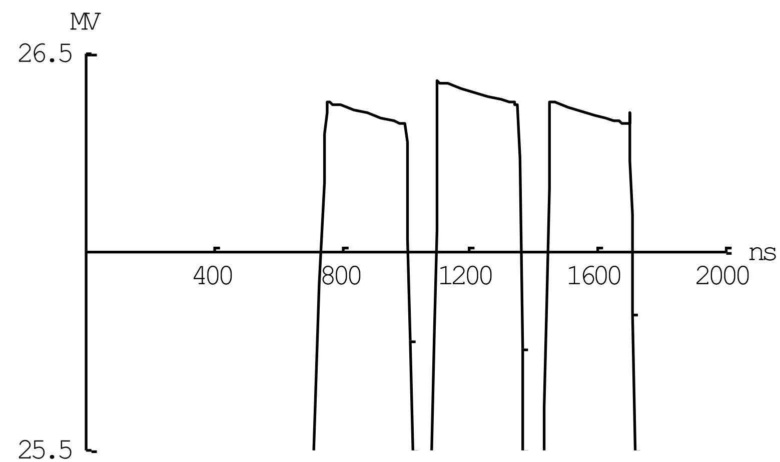
Tentative ILC e+ beam simulation with 20MHz bandwidth



100ns beam gap and 3 x 250ns bunch train with 6.15ns bunch spacing and 0.78A beam loading

Without beam and with simple RF input power control





With beam and simple RF input power control

Increase accelerating gradient to 40MV as unloaded one, then we will make the design of 30MV/m as loaded one with 3×10^{10} positrons/bunch and 6.15ns bunch spacing.
We need the reduction of accelerator structure iris diameter from 46mm to ~40mm.

I hope ANL L-band standing wave tube with minor modification will be applicable to ILC positron booster Linac.

5. Summary

Beam dynamics simulation from the target to DR is necessary.

Target R&D is necessary at KEK.

Simple beam loading compensation experiment is necessary at ATF.