Beam Loading experiment at KEK ATF

(Multi-train acceleration at KEK-ATF Injector)

KEK
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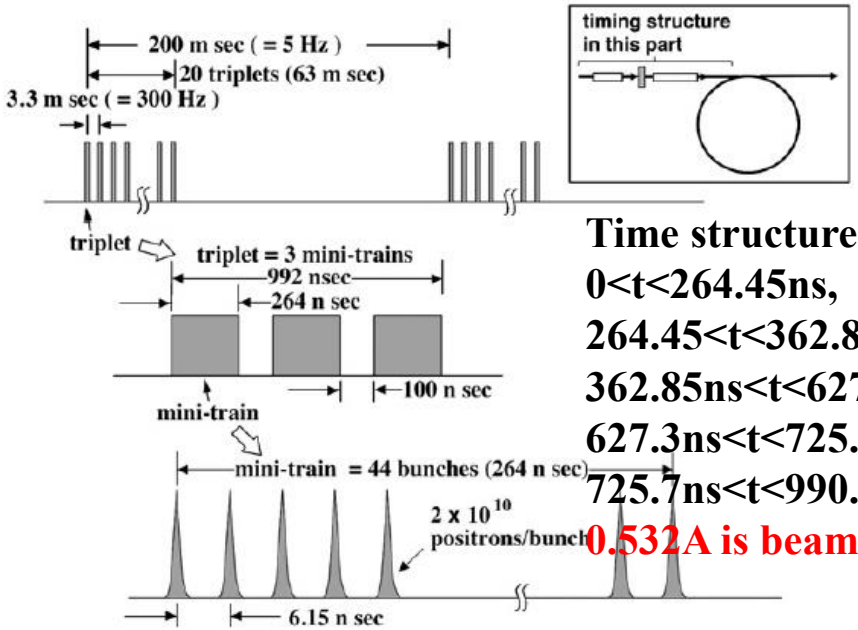
LCWS2014

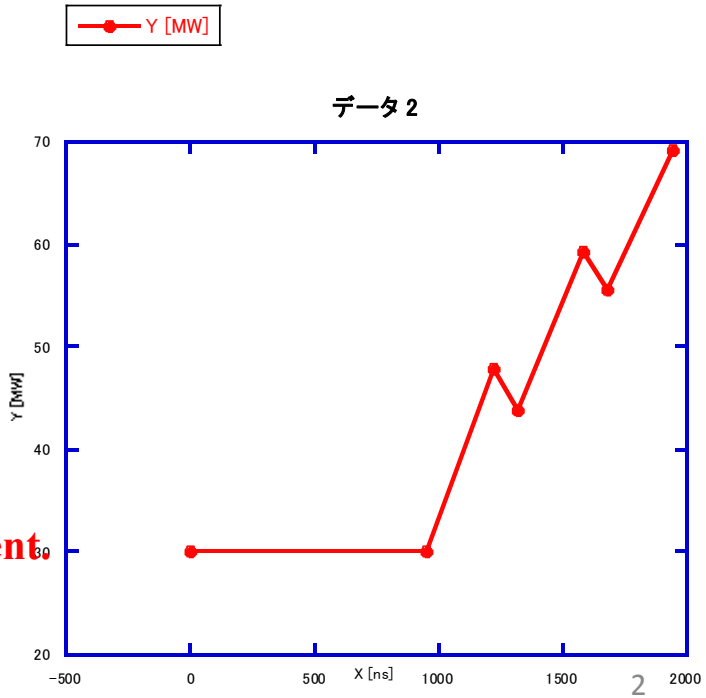
Introduction

- Drive electron positron beams are accelerated with the form of triplet multi-bunch mini-train.
- The beam-loading effect should be compensated to be accepted into the ILC-DR.
  - Beam loading compensation in a mini-train
  - Energy compensation between multi mini-trains

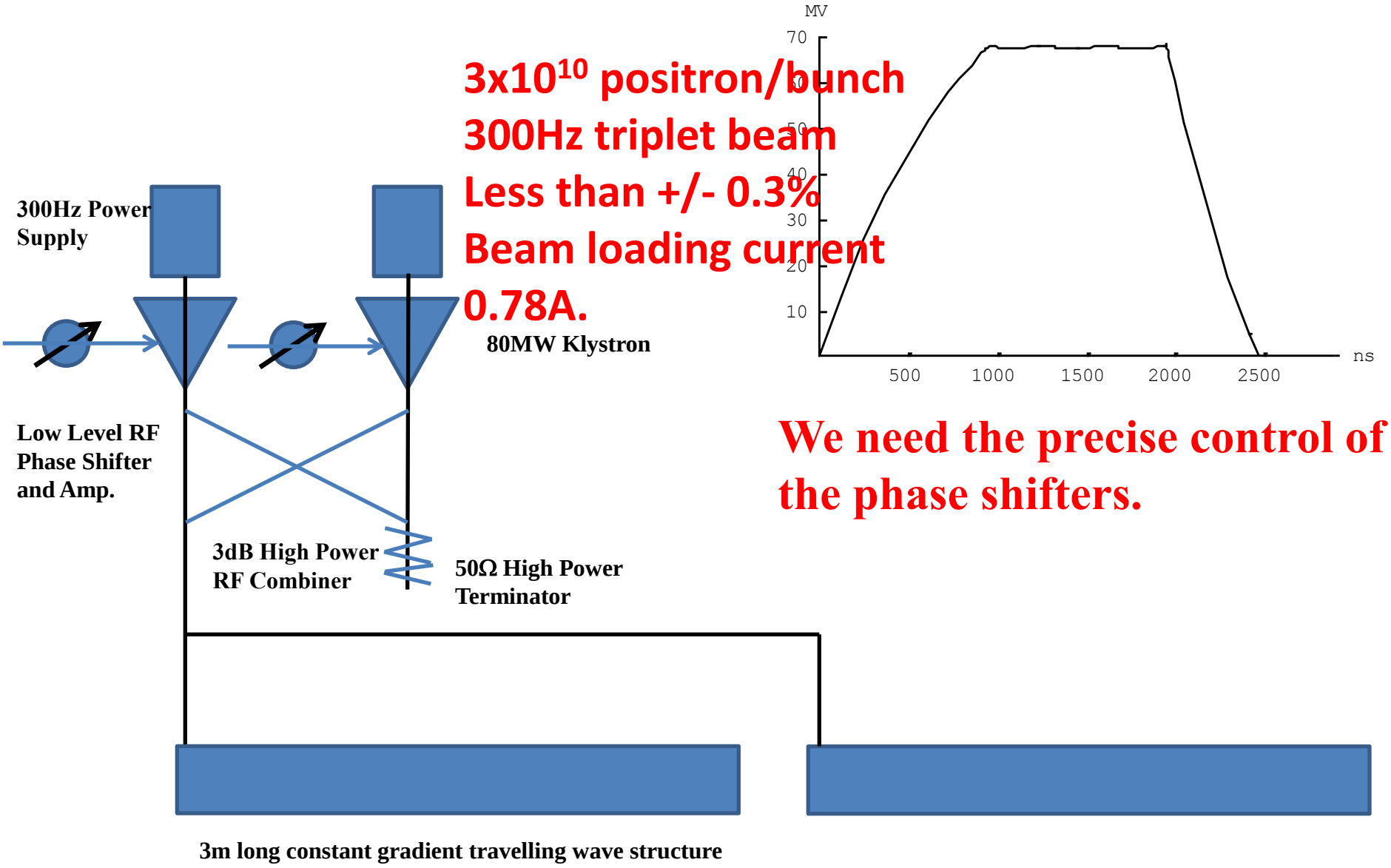
Control of input RF power by phase shifters



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.



T. Omori et al., Nucl. Instrum. Meth. A672 (2012) 52-56.



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 2μs pulse width are necessary.

Beam loading compensation experiment at ATF

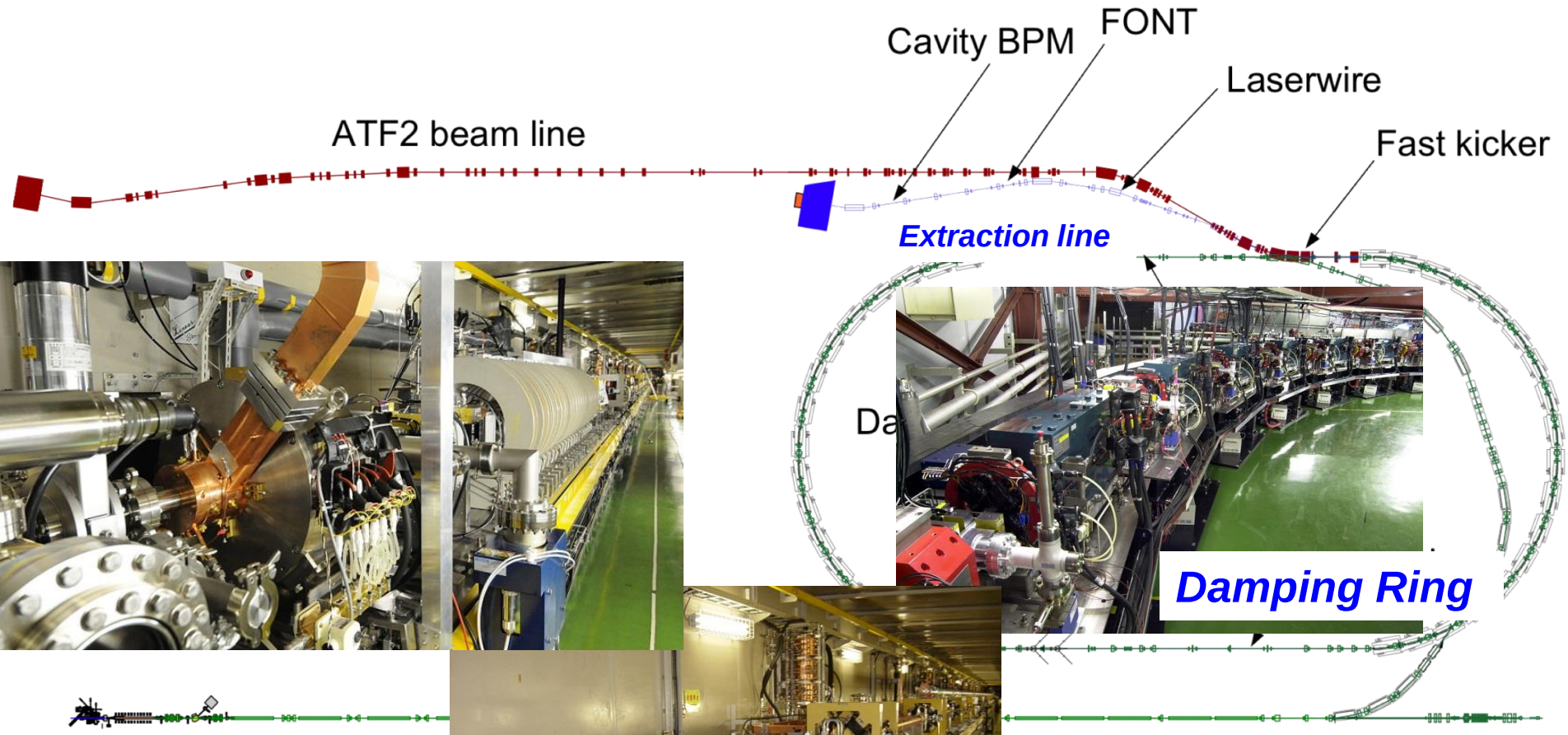
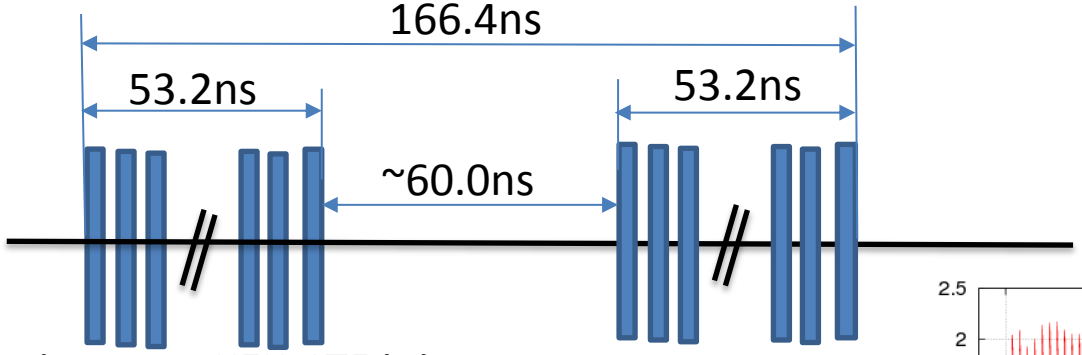


Photo-cathode RF gu
(electron source)

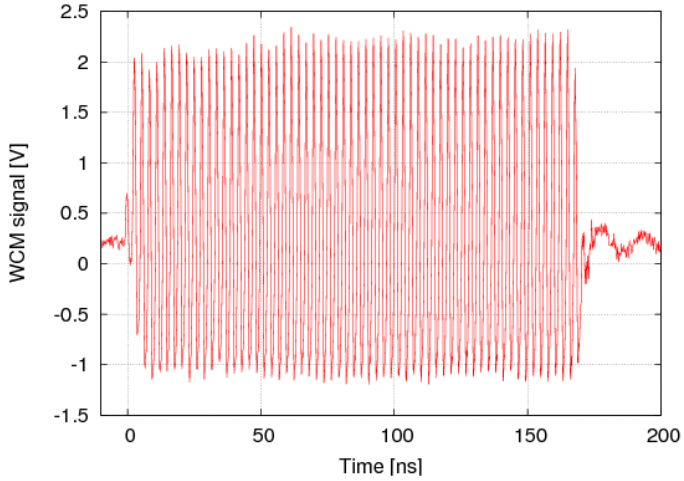
Two train acceleration at KEK-ATF injector

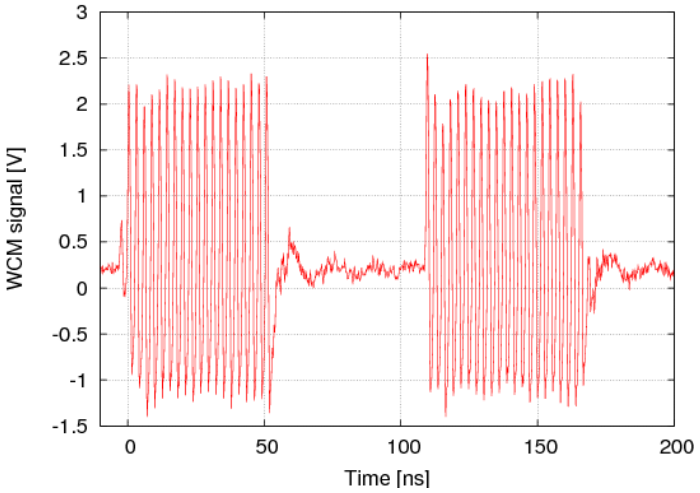


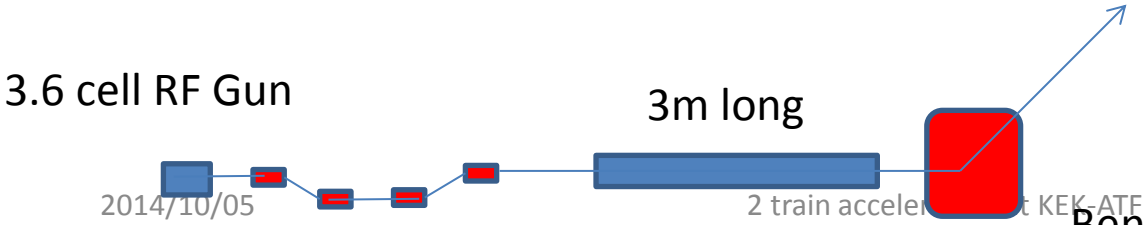
In this experiment at KEK-ATF injector,
2 mini-train beams are accelerated.

Multi-bunch beam:
$2x10^{10}$ with 6.15ns bunch spacing corresponds to $0.9x10^{10}$ in the case of 2.8ns bunch spacing as same beam loading in multi-bunch trains.

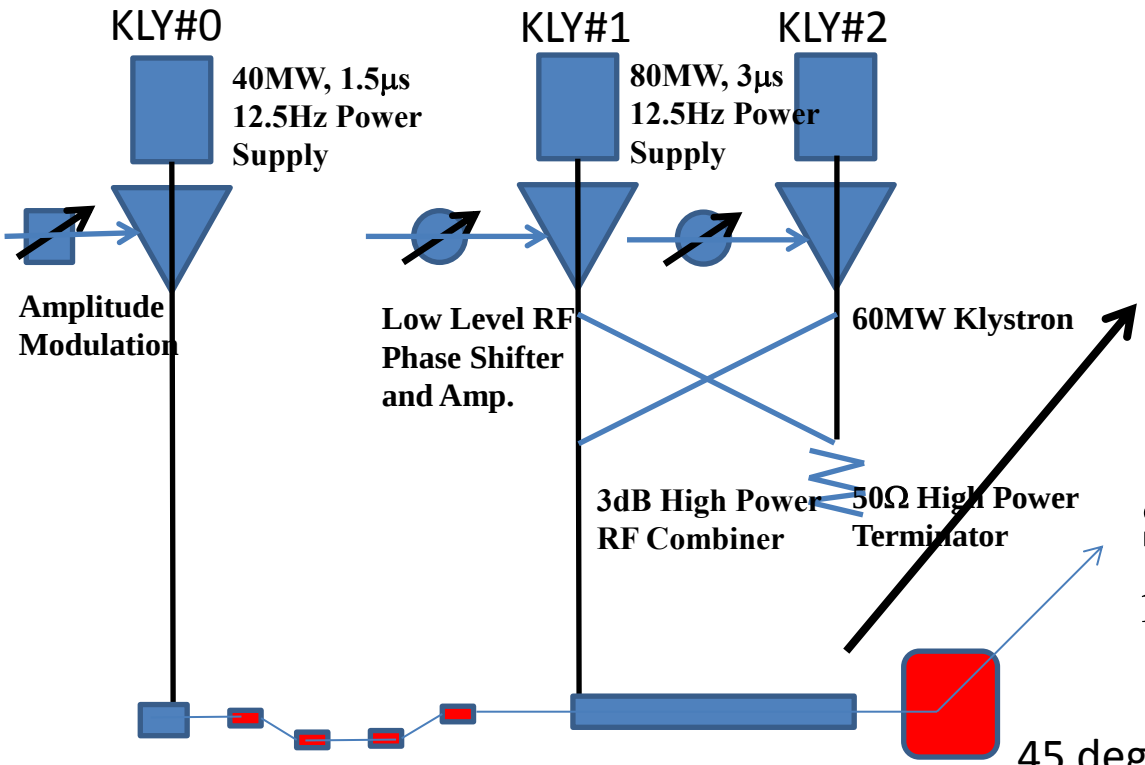
Two mini-train beam :
$3x10^{10}$ with 100nsec train gap and 6.15ns bunch spacing corresponds to $1.4x10^{10}$ in the case of 2.8ns bunch spacing as same beam loading in multi-bunch trains.

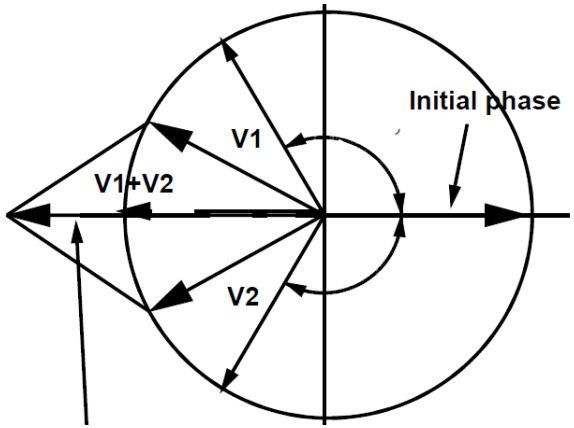






Experimental Setup





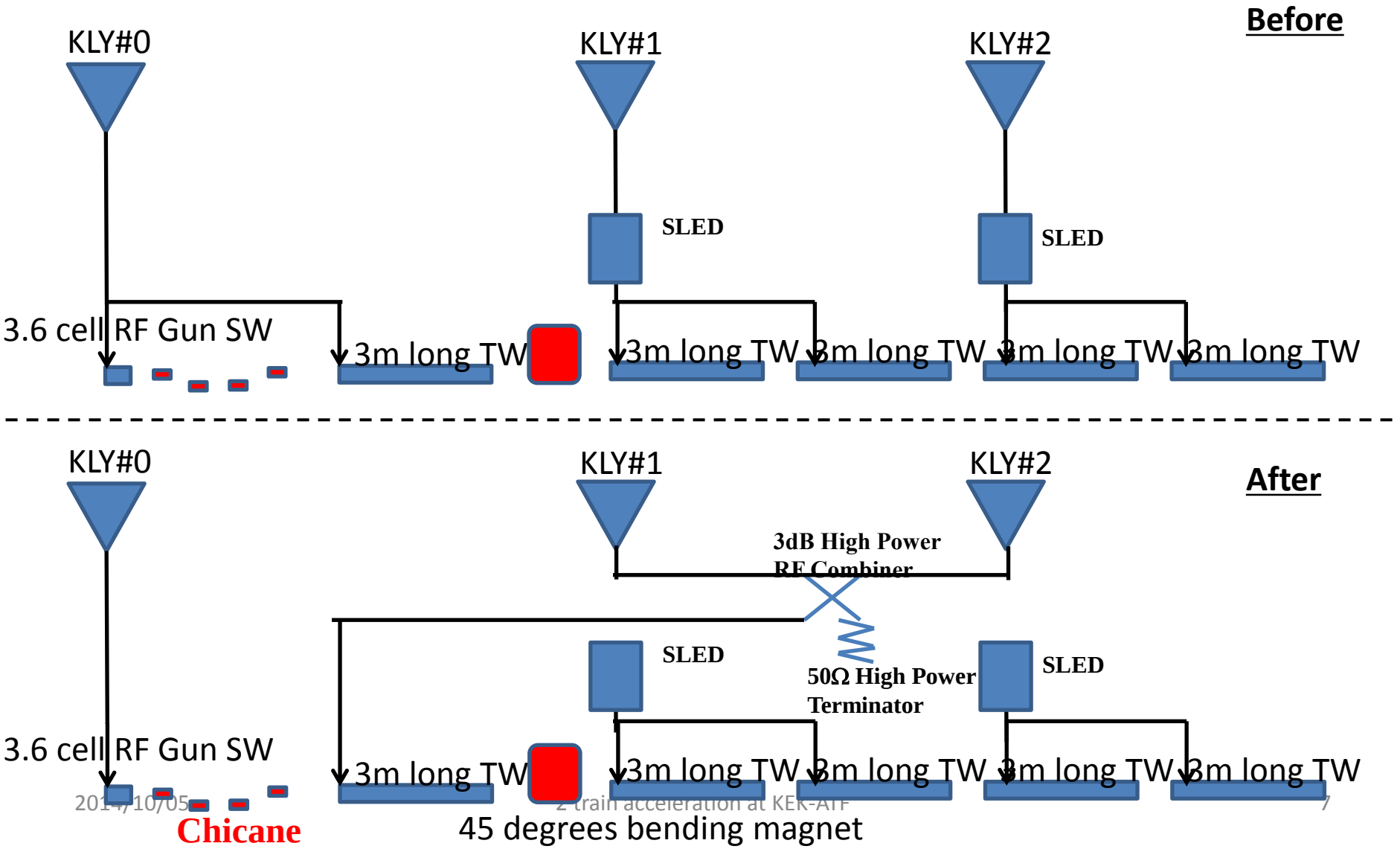
Speed of phase control
is about 100 degrees/10ns.

45 degrees bending magnet
to measure the energy of multi-bunch

3.6 cell RF Gun **Chicane**
(Standing wave)

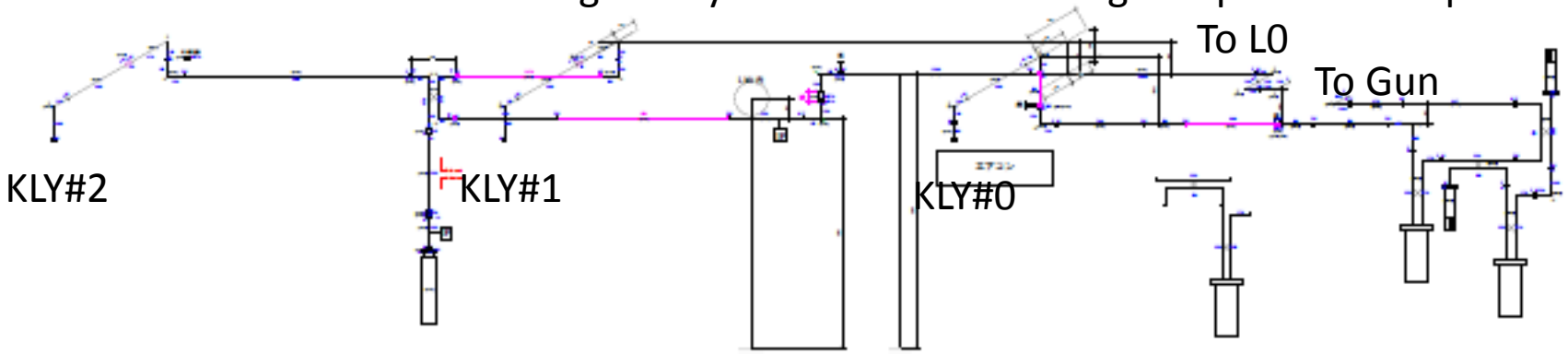
3m accelerating tube
(Traveling wave)

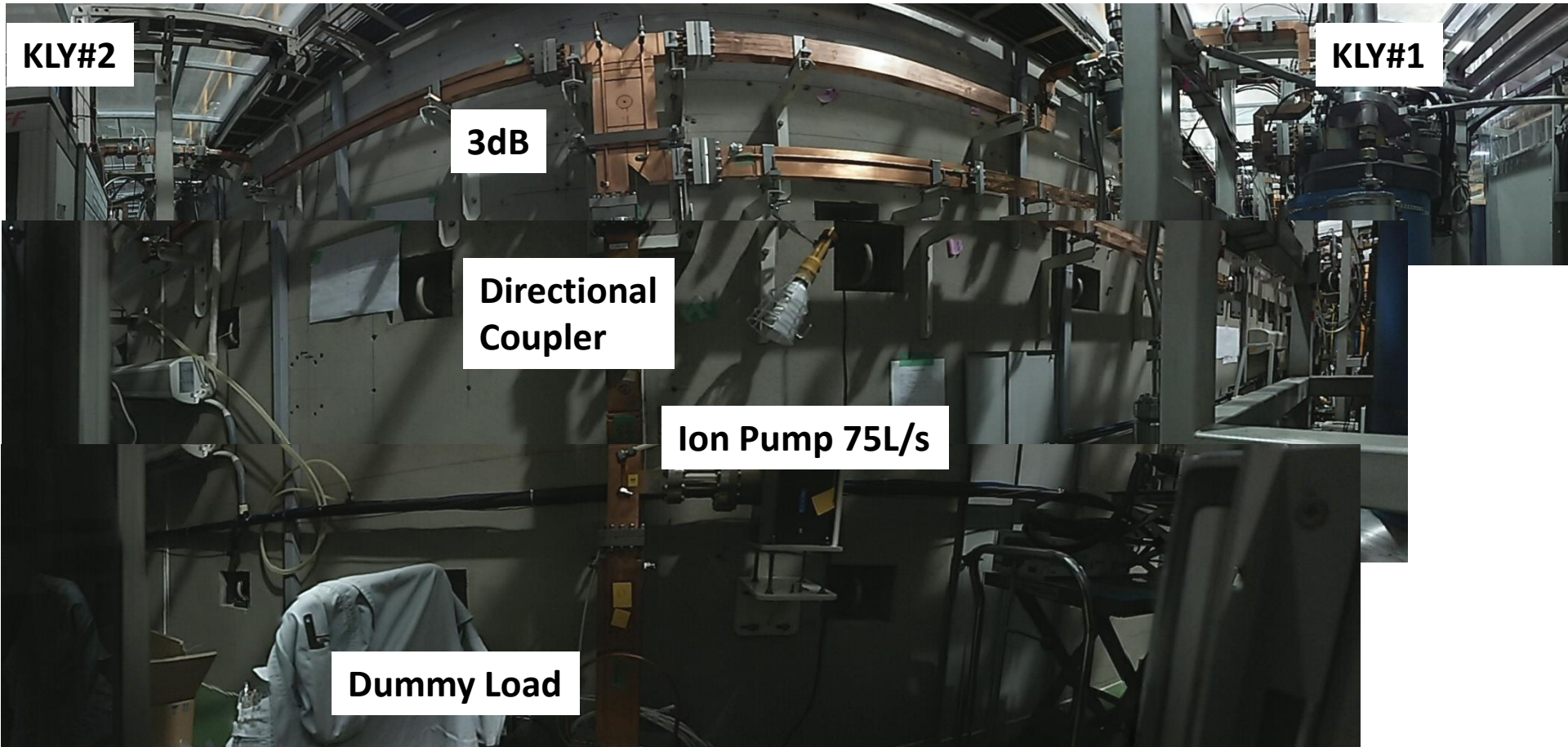
Waveguide circuit

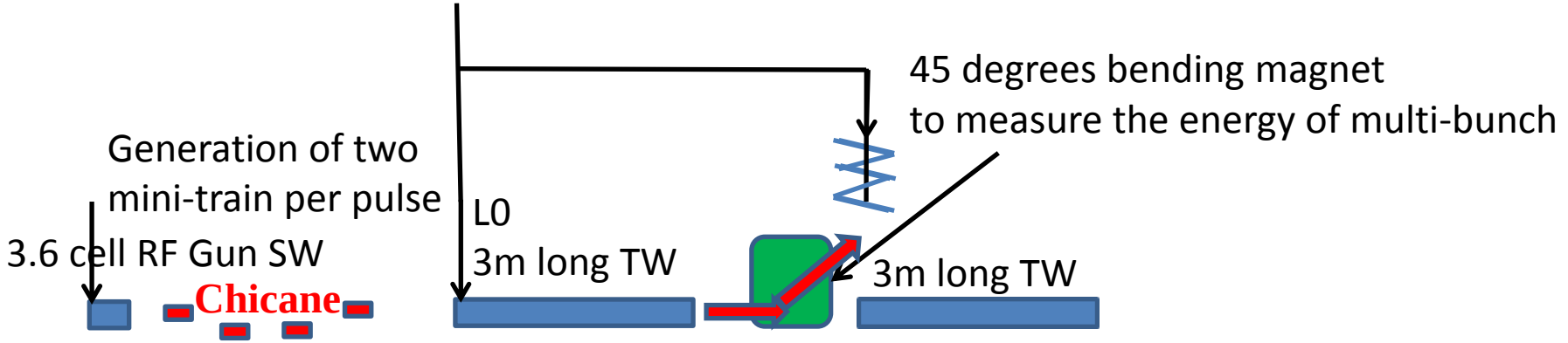


We completed the change of the waveguide system by 21st August. Vacuum level around both klystrons is 5-6x10^{-6}Pa.

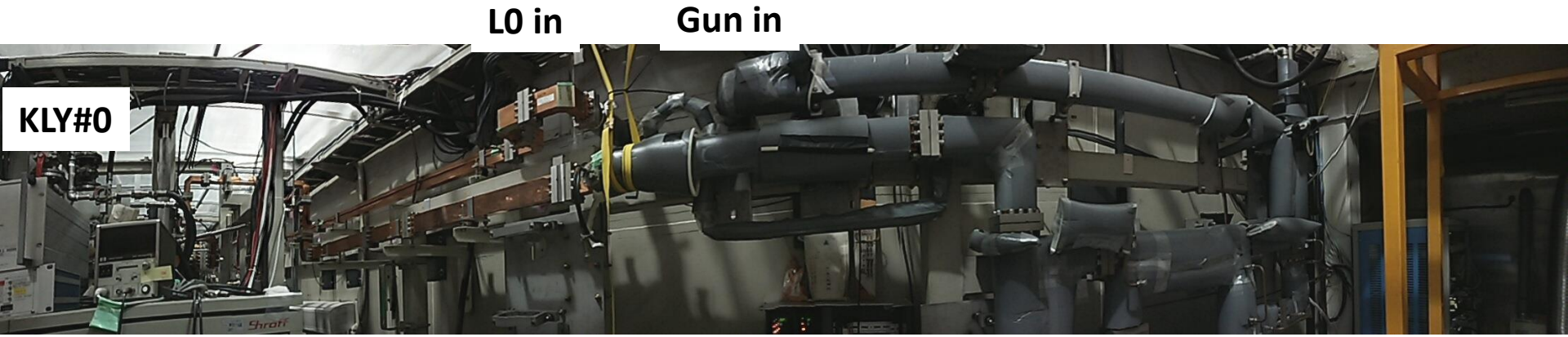
New waveguide system for beam loading compensation experiment






45 degrees bending magnet
to measure the energy of multi-bunch
Generation of two
mini-train per pulse
3.6 cell RF Gun SW
L0
3m long TW
Chicane
3m long TW

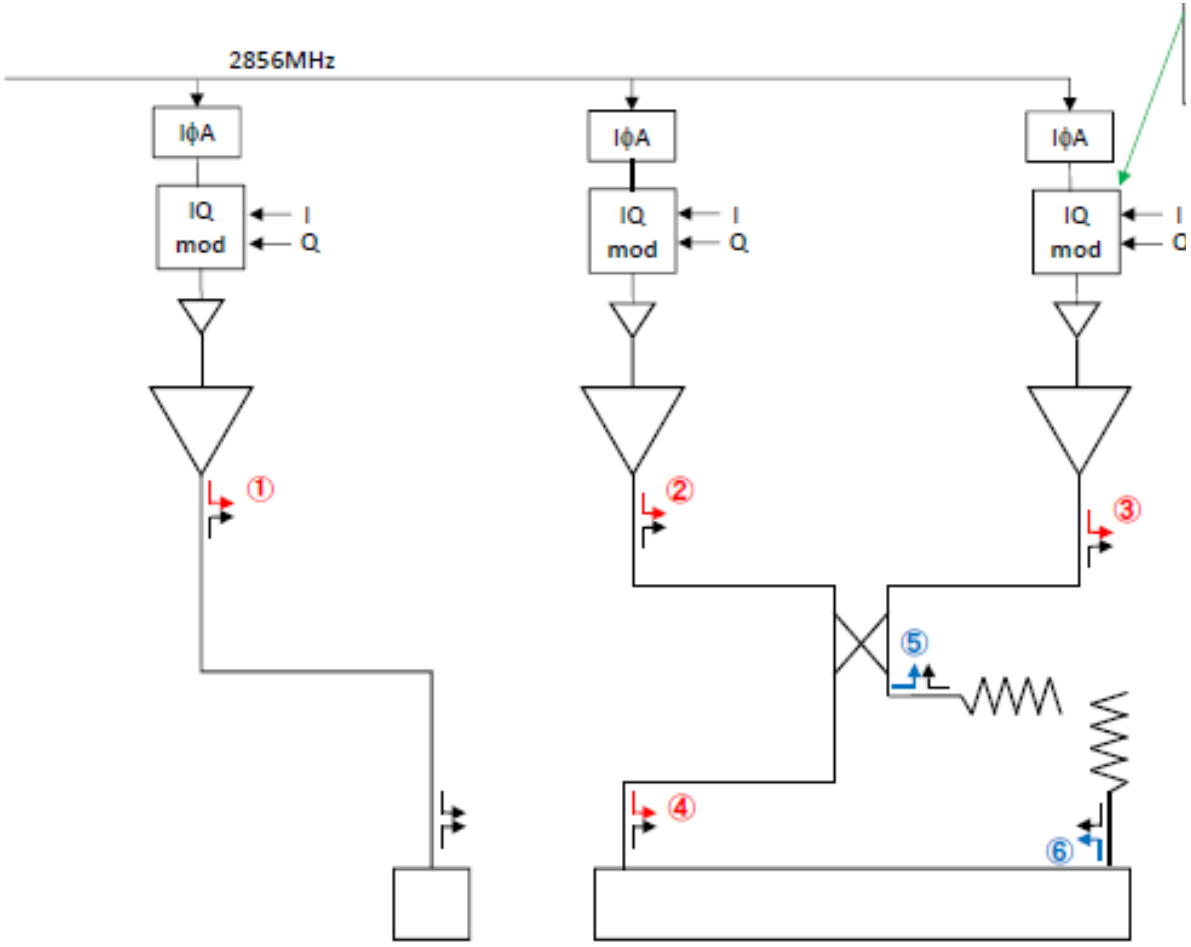

KLY#1
L1,L2 in
KLY#0

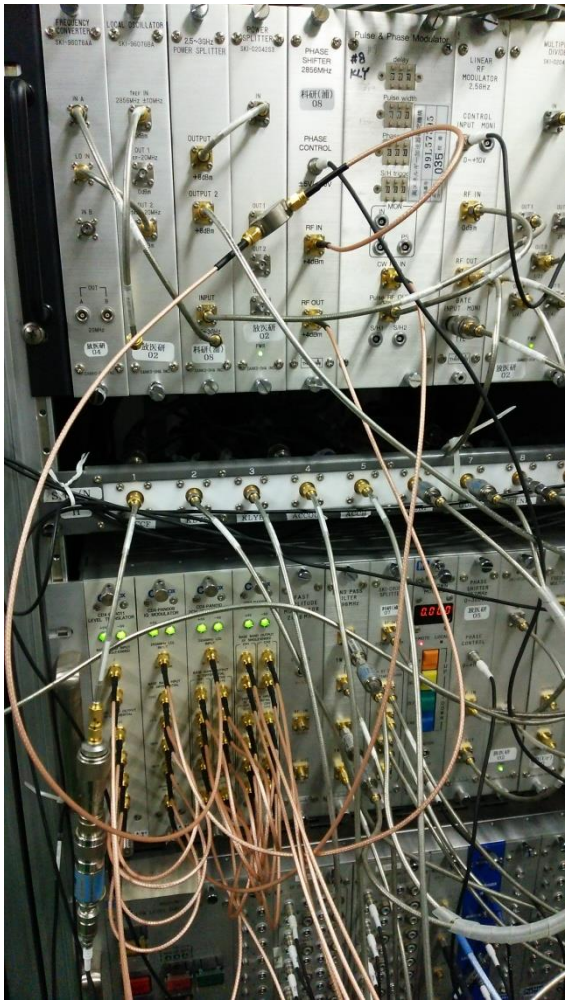

L0 in
Gun in
KLY#0

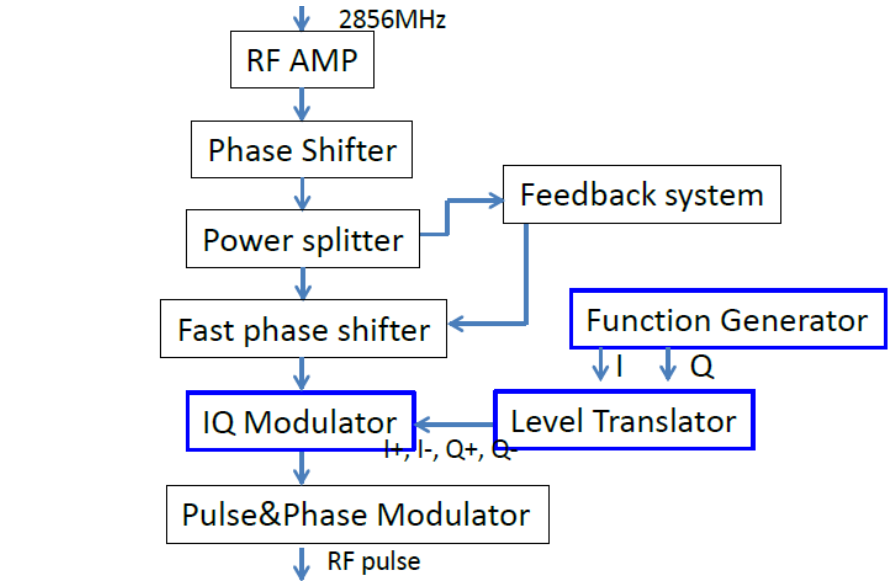
Several modules and function generators were prepared for the control of RF phase and amplitude which are necessary for the beam loading compensation experiment. Then, we started the RF aging and test new instrumentation from end of August.

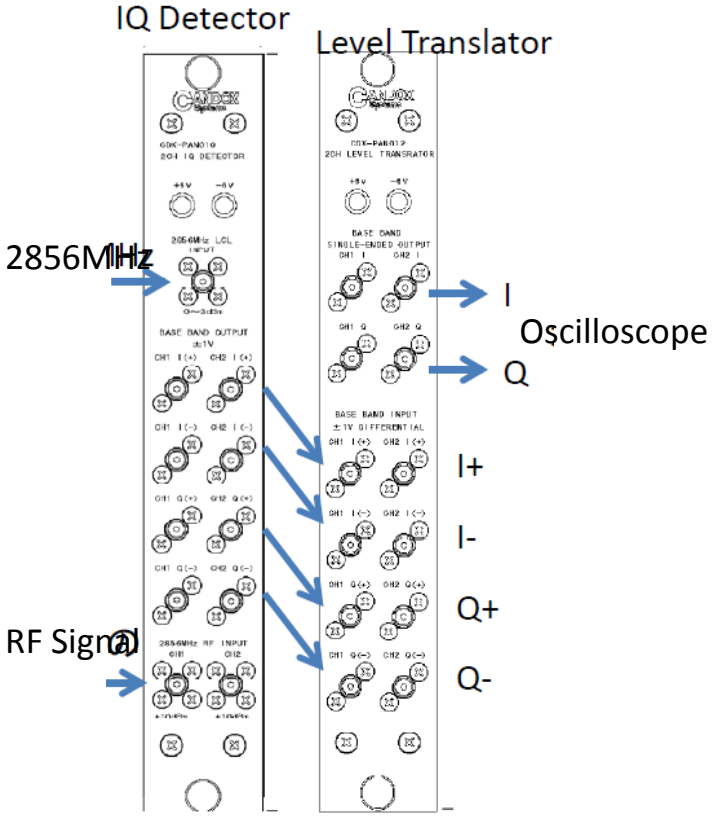
Test of I-Q modulation & detection was done by using LLRF at LUCX and the enough performance was confirmed.

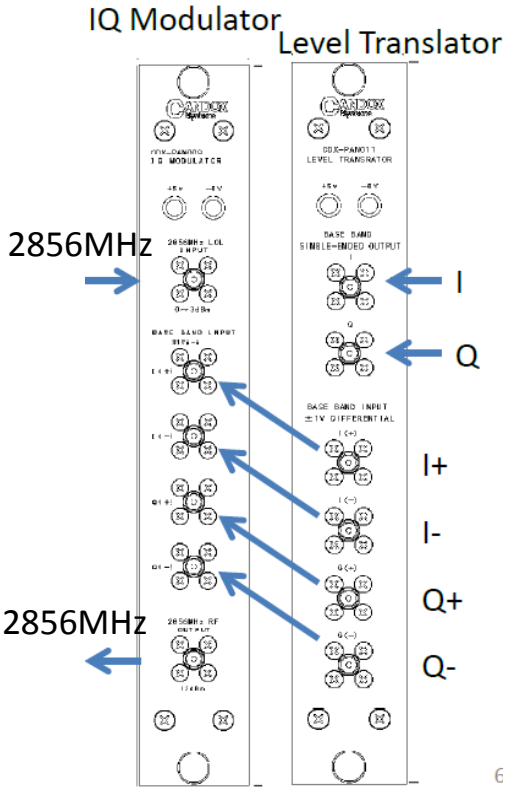
Function Generator (AFG3000C)





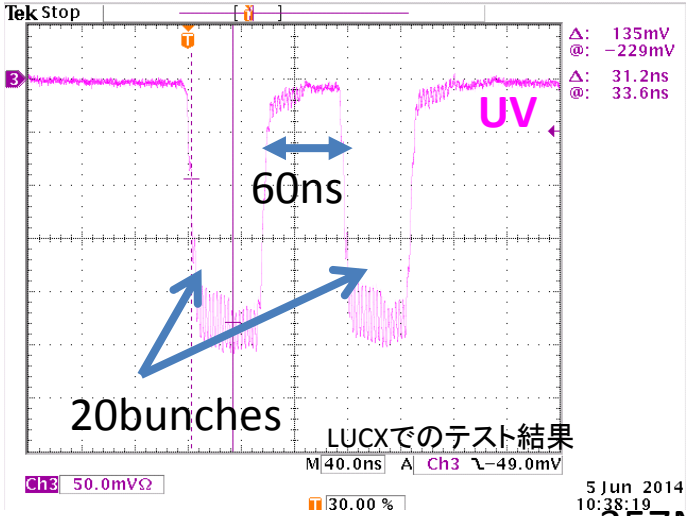


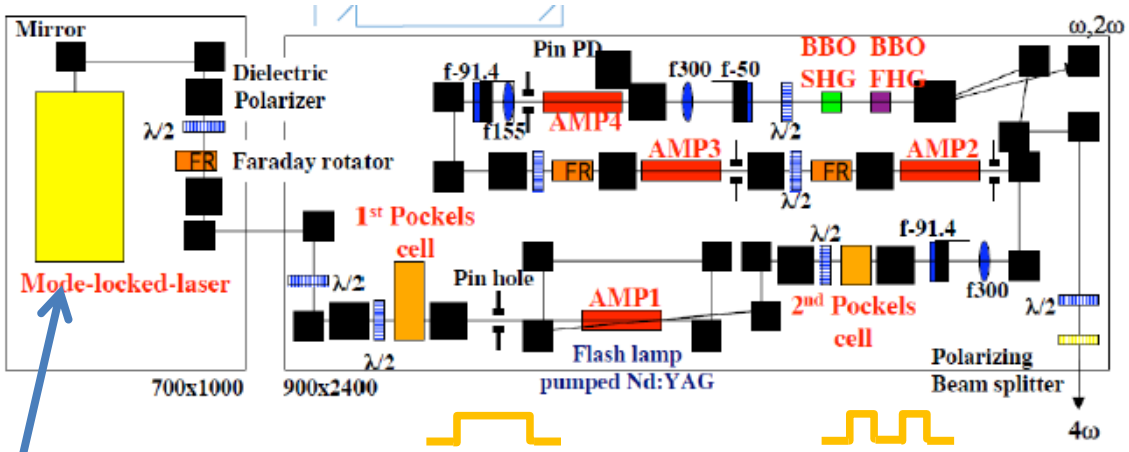




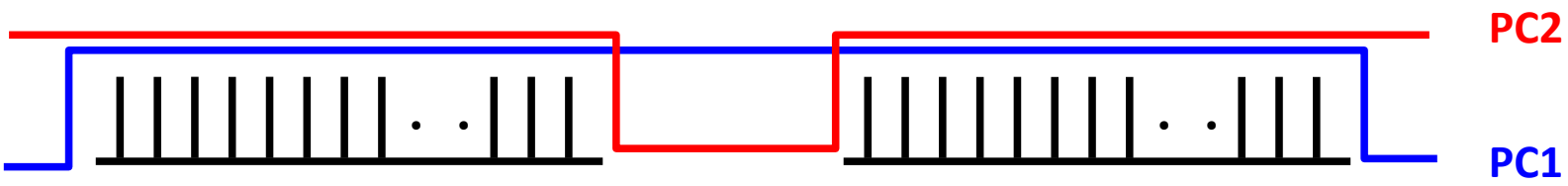
All modules were checked.
The performance was confirmed by measurements of setting accuracy and linearity.

Experimental Setup

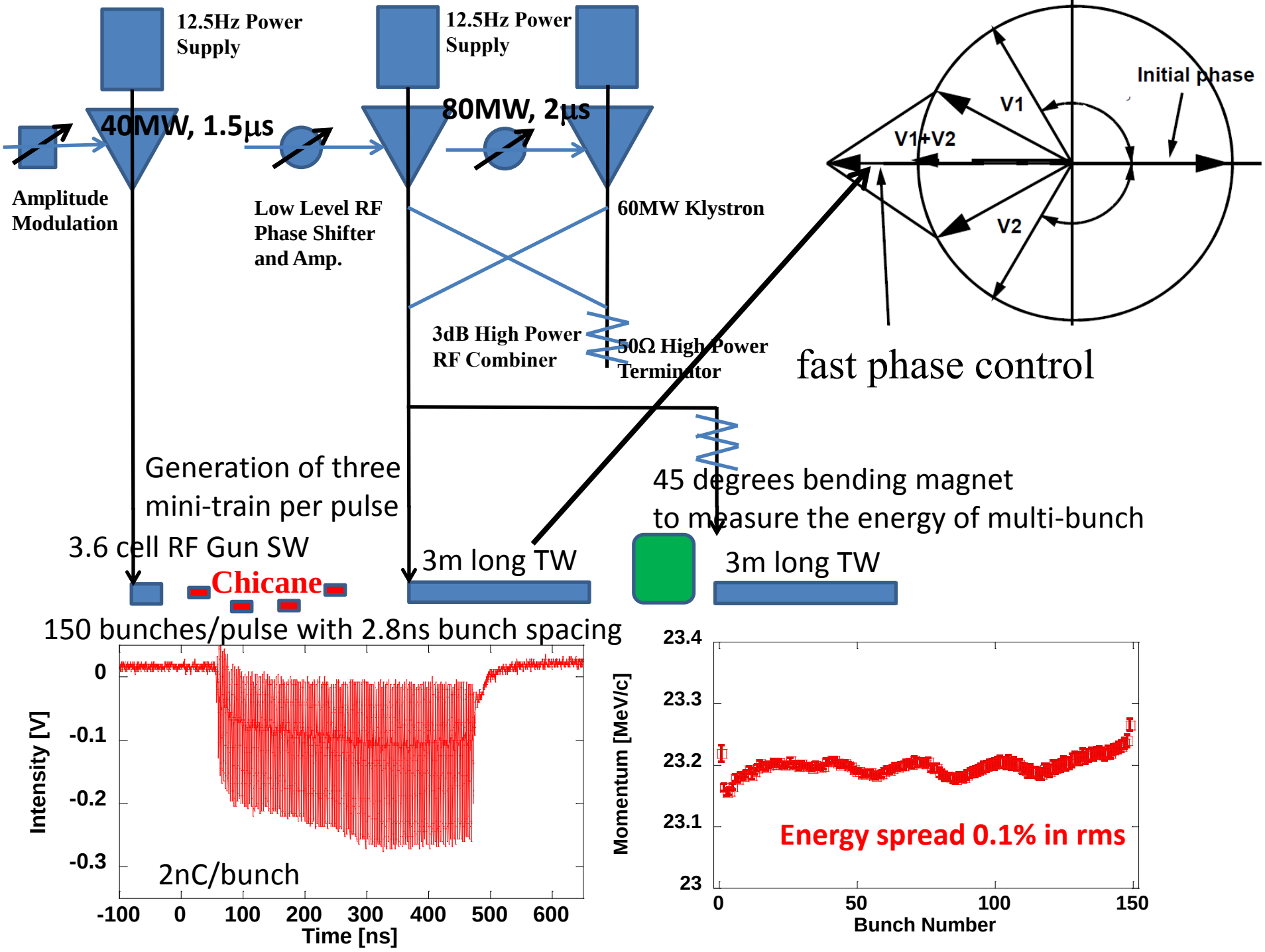




357MHz mode-locked laser

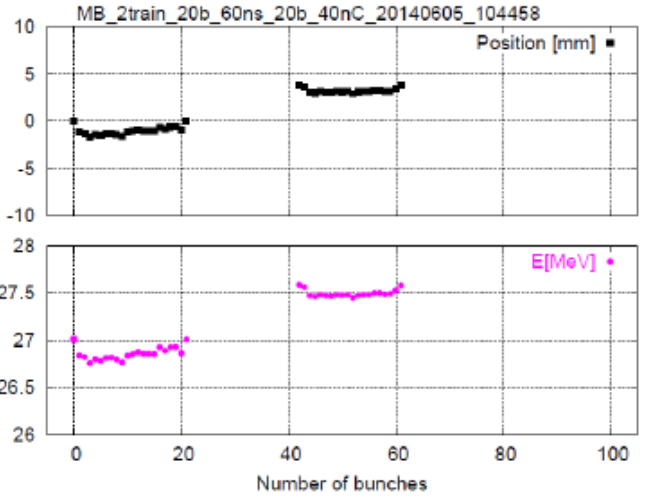


Pockels cell1: 60 pulses are clipped out from pulse train with 357MHz (2.8ns pulse spacing).
Pockels cell2: Train gap with 60ns is made by this pockels cell.

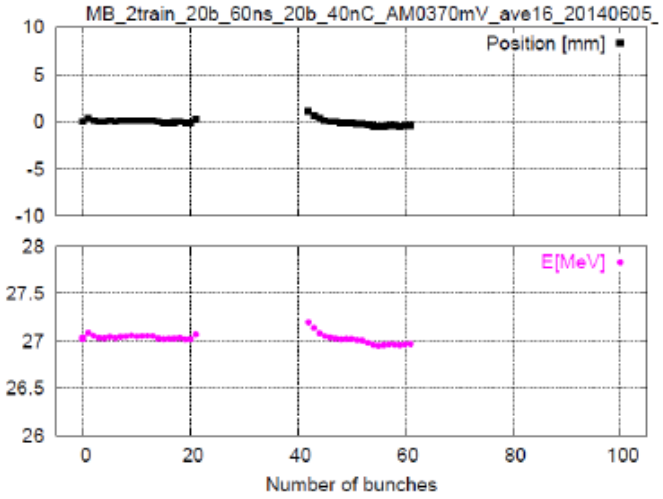

12.5Hz Power Supply
12.5Hz Power Supply
40MW, 1.5μs
80MW, 2μs
Amplitude Modulation
Low Level RF Phase Shifter and Amp.
60MW Klystron
3dB High Power RF Combiner
50Ω High Power Terminator
Initial phase
V1
V1+V2
V2
fast phase control
Generation of three mini-train per pulse
45 degrees bending magnet to 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

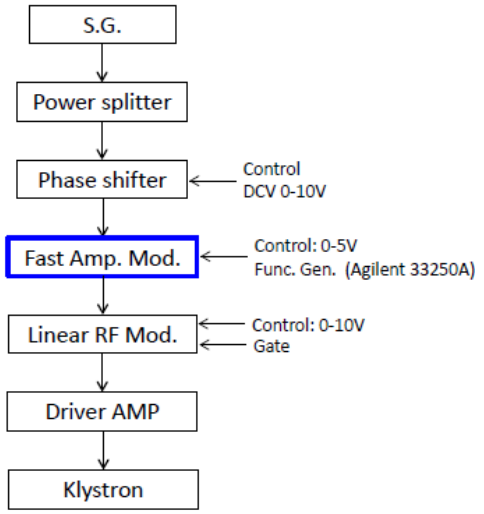
20 bunch – 60ns – 20 bunch at 1nC/bunch

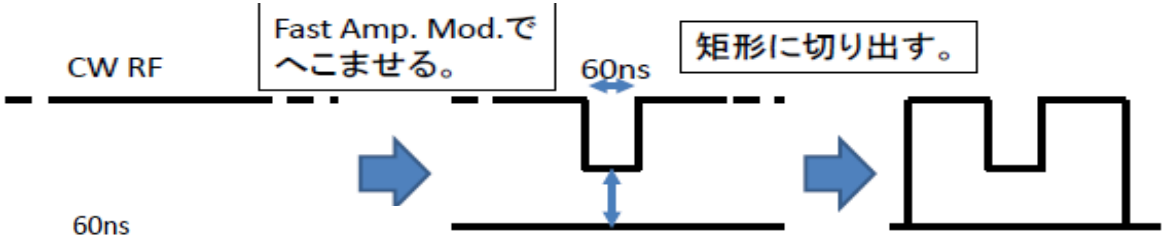
Fast amplitude modulator off

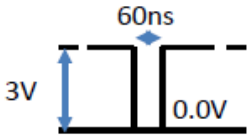


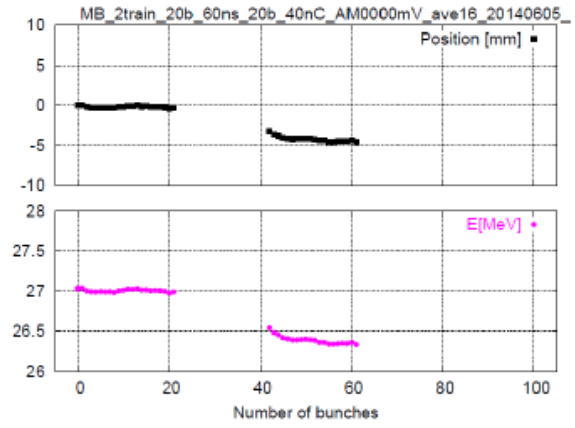
Fast amplitude modulator on

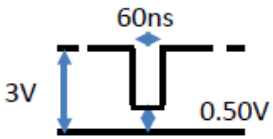


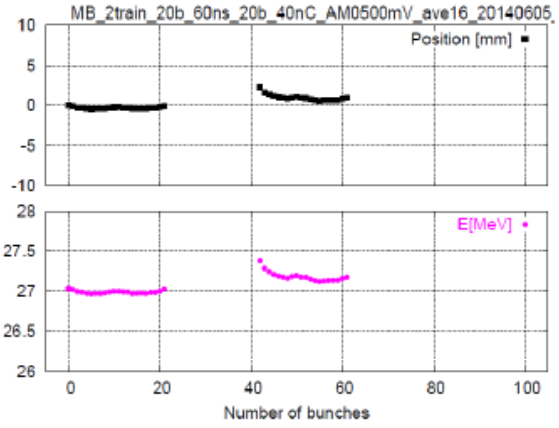




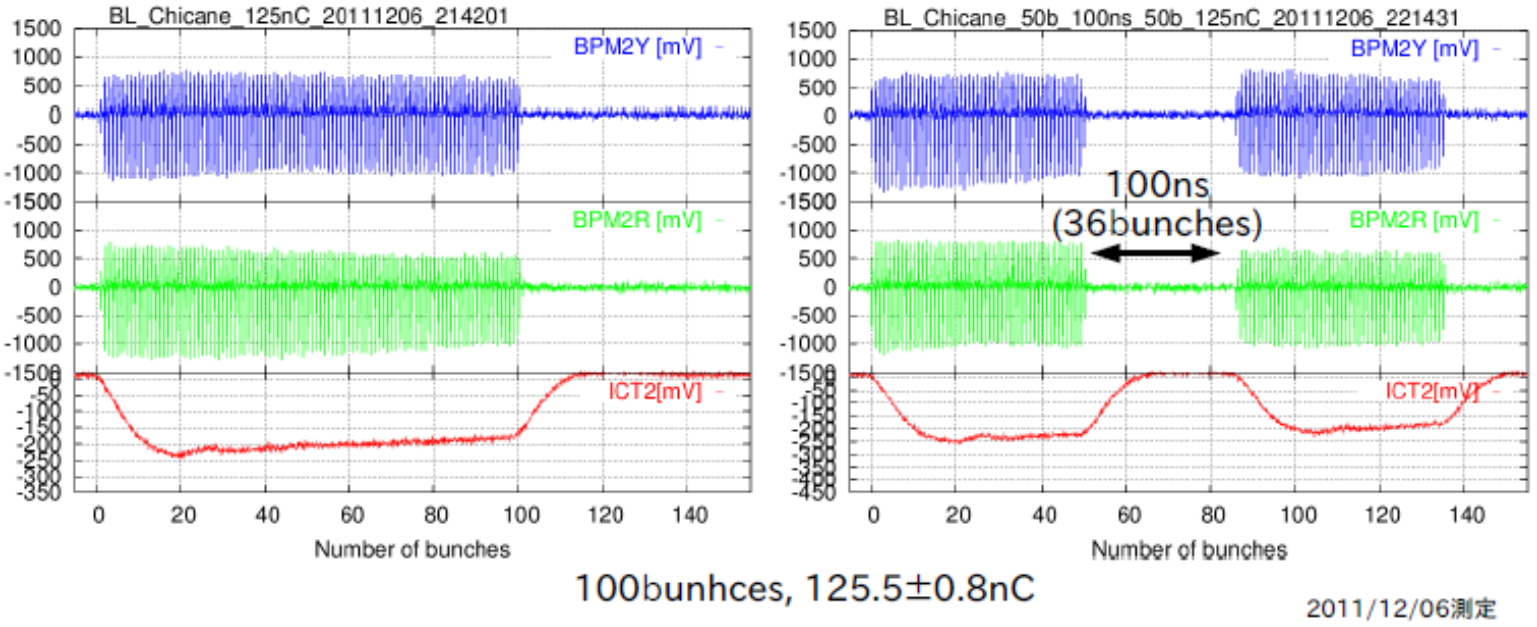




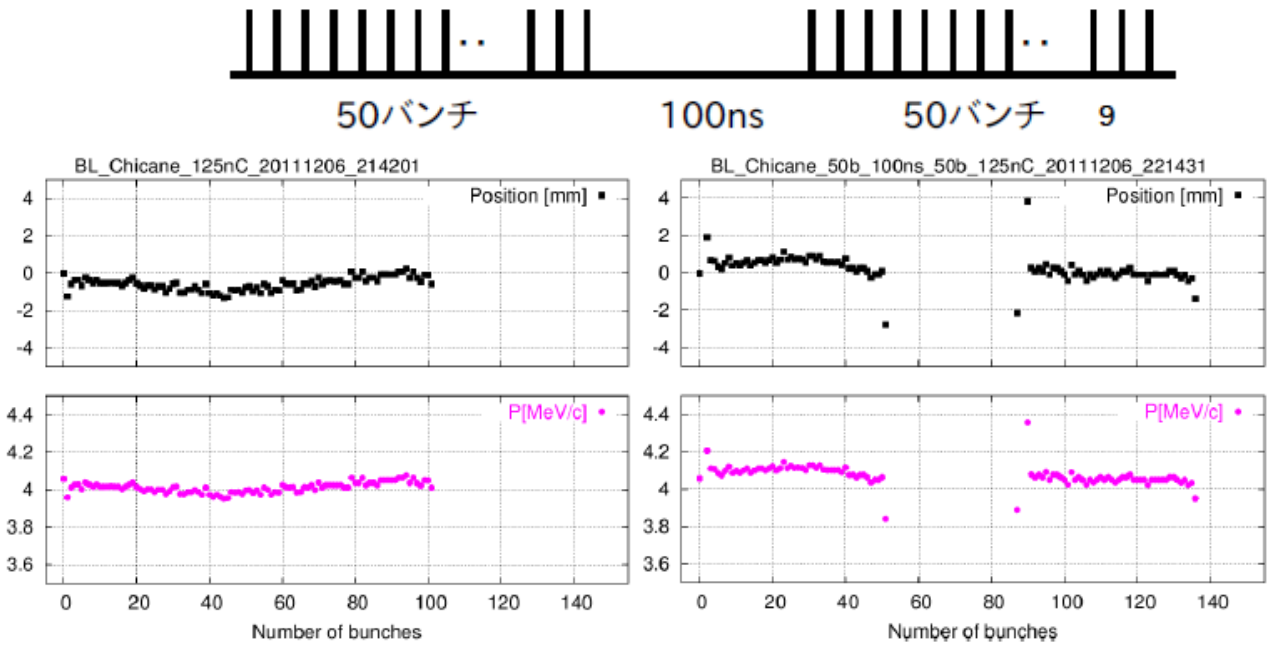




Checked amplitude control accuracy.



Present laser system,
Two Pockels cells,
1.6 cell RF Gun, Chicane
and BPM were used
to generate doublet
pulse train and to measure
energy of each bunch.
0.78 x10^{10} electrons per
bunch were checked at
LUCX.



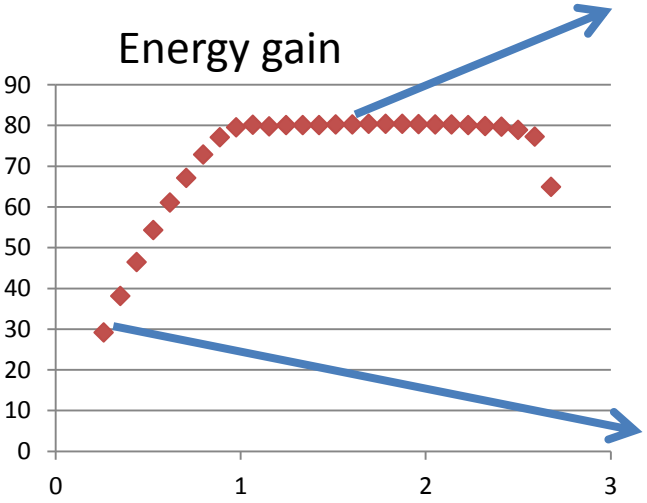
Beam loading compensation

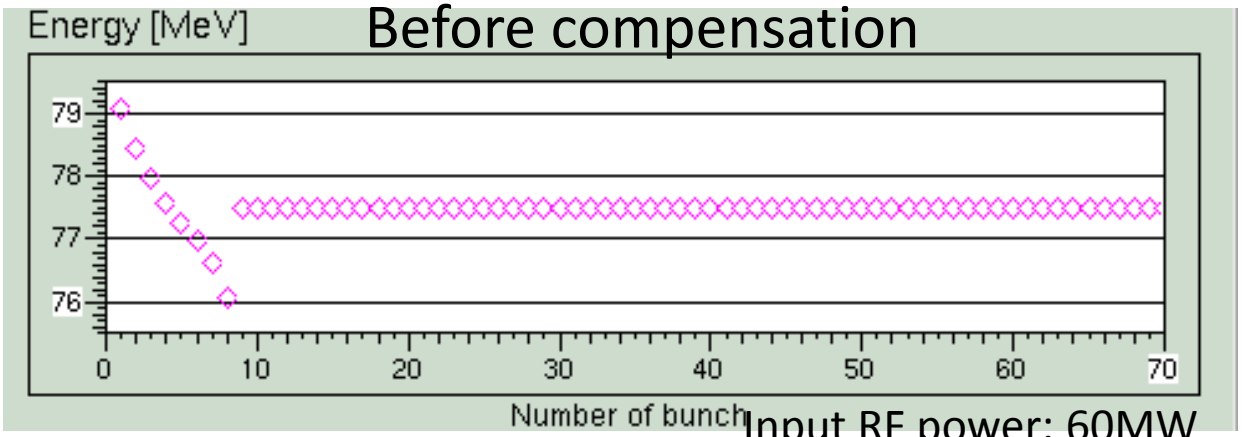
A train with 1.5x10^{10} e^-/bunch and 60 bunches is accelerated.

Beam loading is compensated by using Δt method.

5nC/bunch

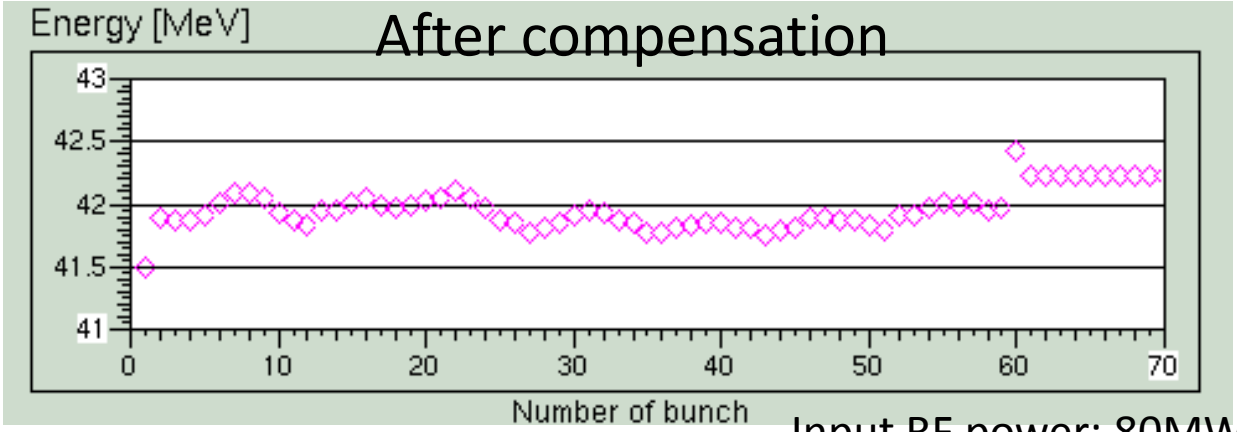
Big beam loading





Input RF power: 60MW

Only 8 bunches are observable in this case.

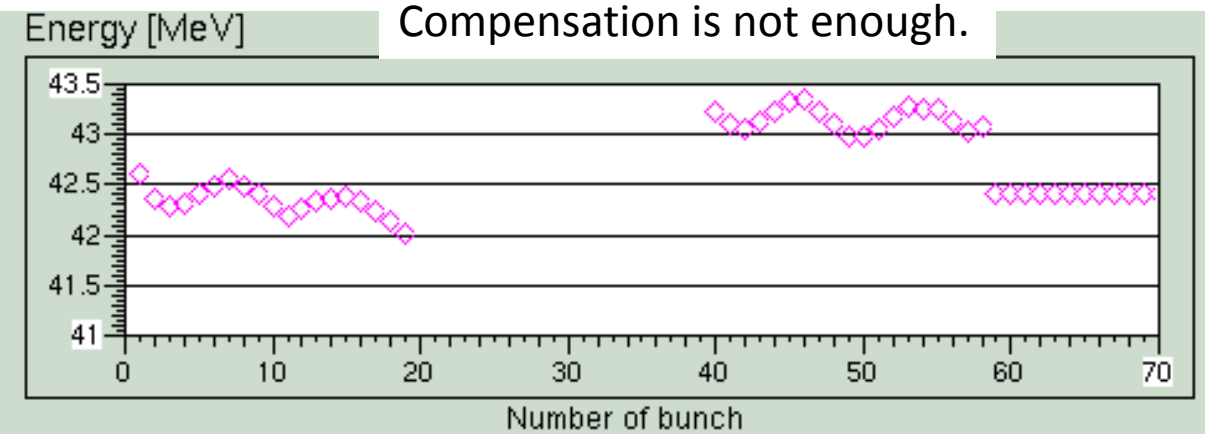


Input RF power: 80MW

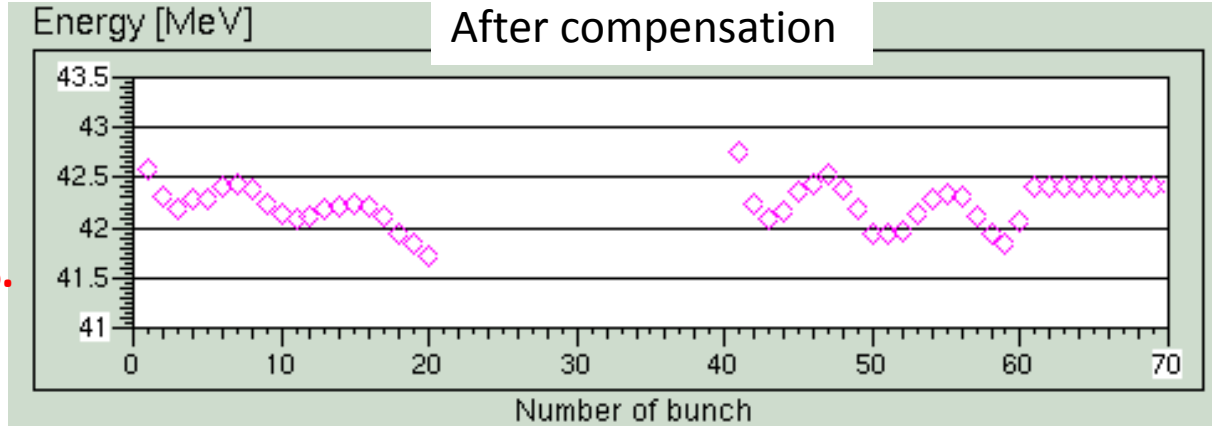
2 train acceleration

Two trains with 1.5x10^{10} e$^-$/bunch and 20 bunches are accelerated. Energy difference at the train gap is compensated by amplitude modulation by phase control.

1.5x10^{10} e$^-$/bunch
20bunches/train
60ns train gap
2.8ns bunch spacing

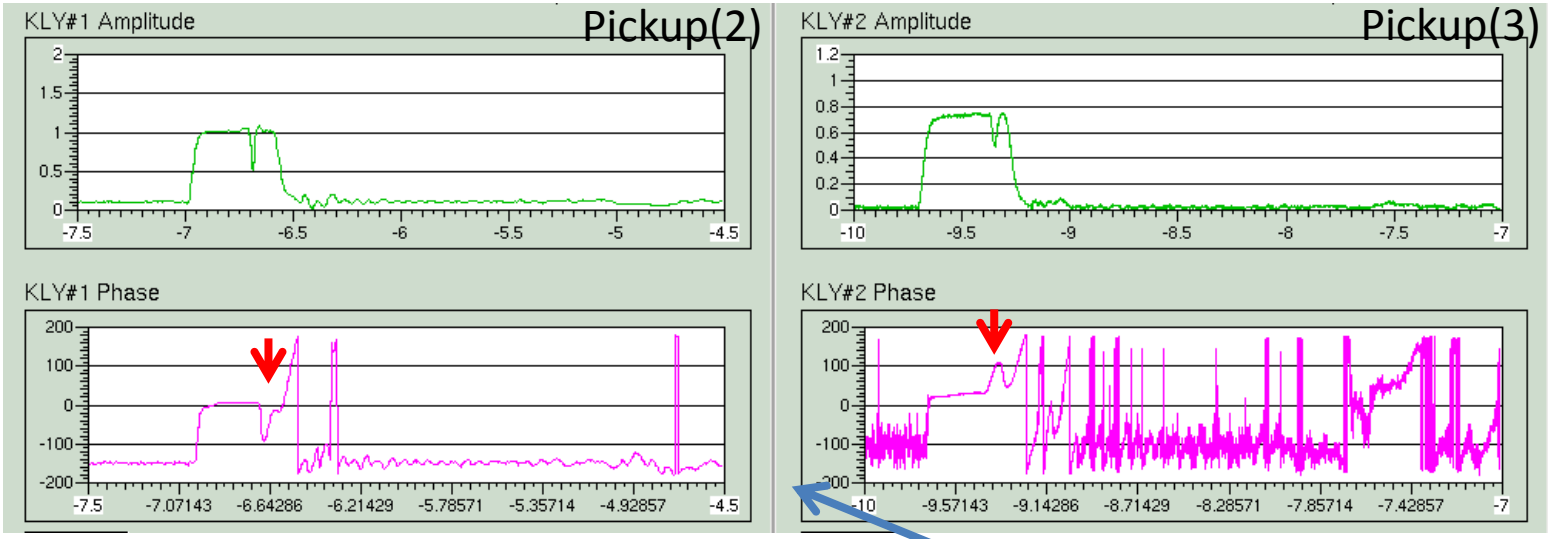


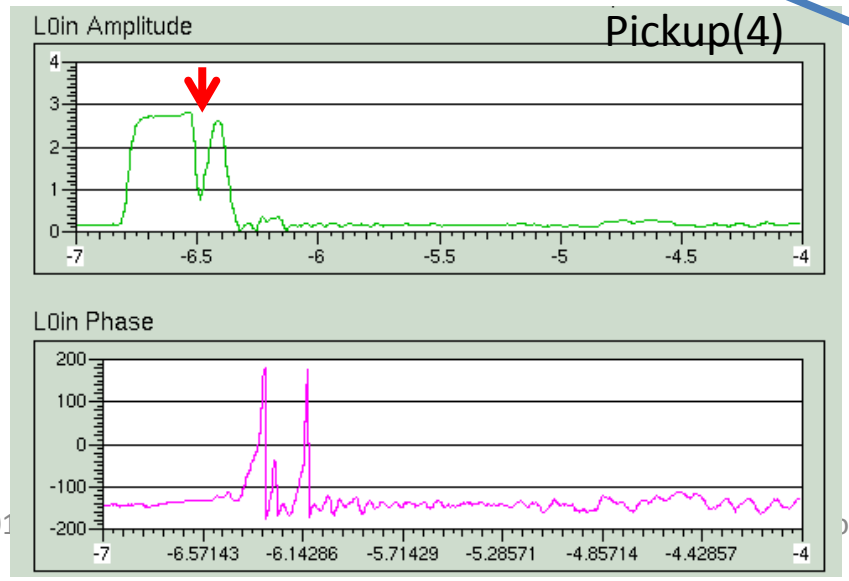
After compensation, the energy differnce is within 0.5MeV (pk-pk) which correspond 1.2% (Peak to Peak). This is less than +/-0.3%.

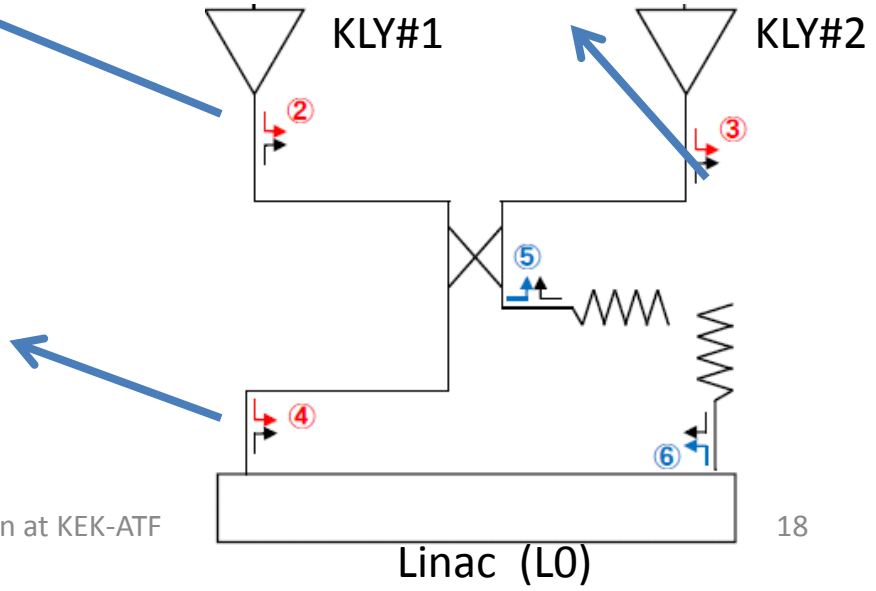


RF pulse

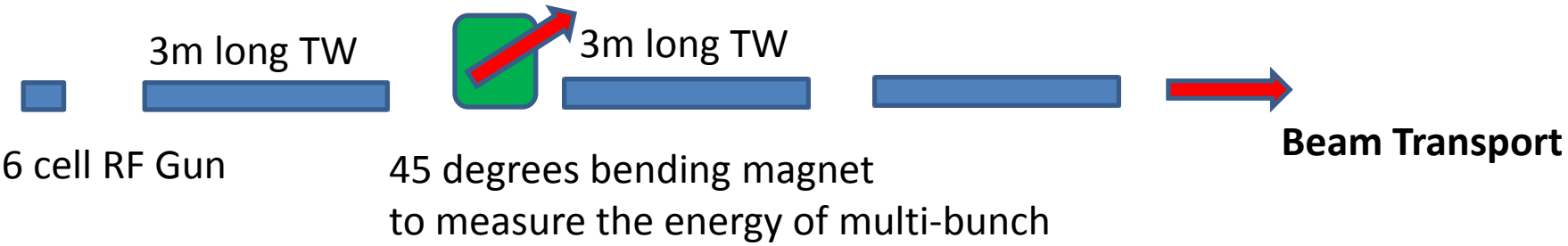
Phase of KLY#1 and KLY#2 was modulated at the timing of train gap.







Summary



$3x10^{10}$ with 6.15nsec bunch spacing corresponds to $1.4x10^{10}$ in the case of 2.8nsec bunch spacing with same beam loading in multi-bunch trains.

Amplitude modulation technique for beam loading compensation was confirmed by test at LUCX successfully.

Δt and phase amplitude modulation technique for beam loading compensation was confirmed by test at KEK-ATF.

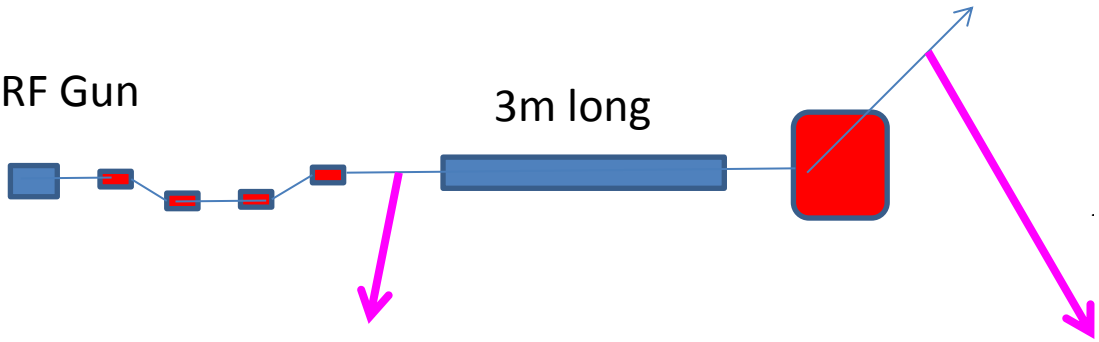
Thank you for your attention.

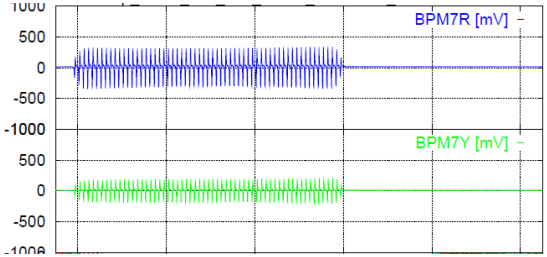
Backup

Energy measurement

3.6 cell RF Gun

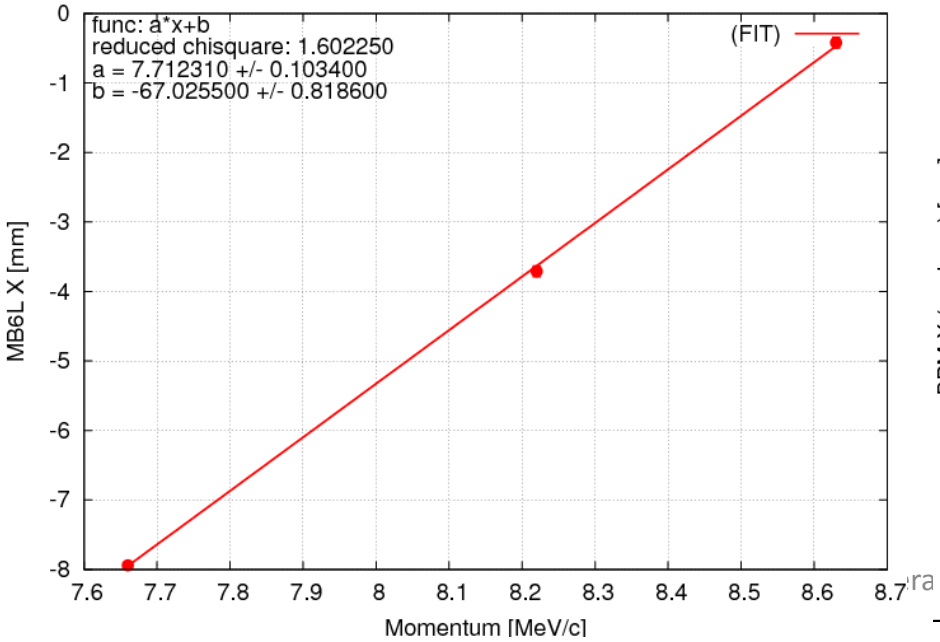
3m long



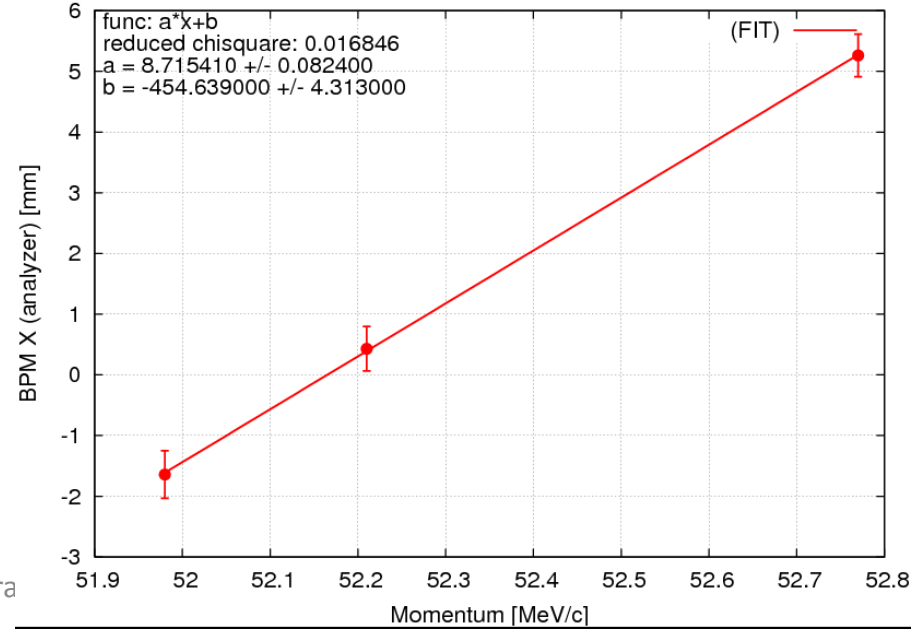


$$Position = S \times \frac{V_G - V_B}{V_G + V_B}[mm]$$

Calibration result (Chicane out)

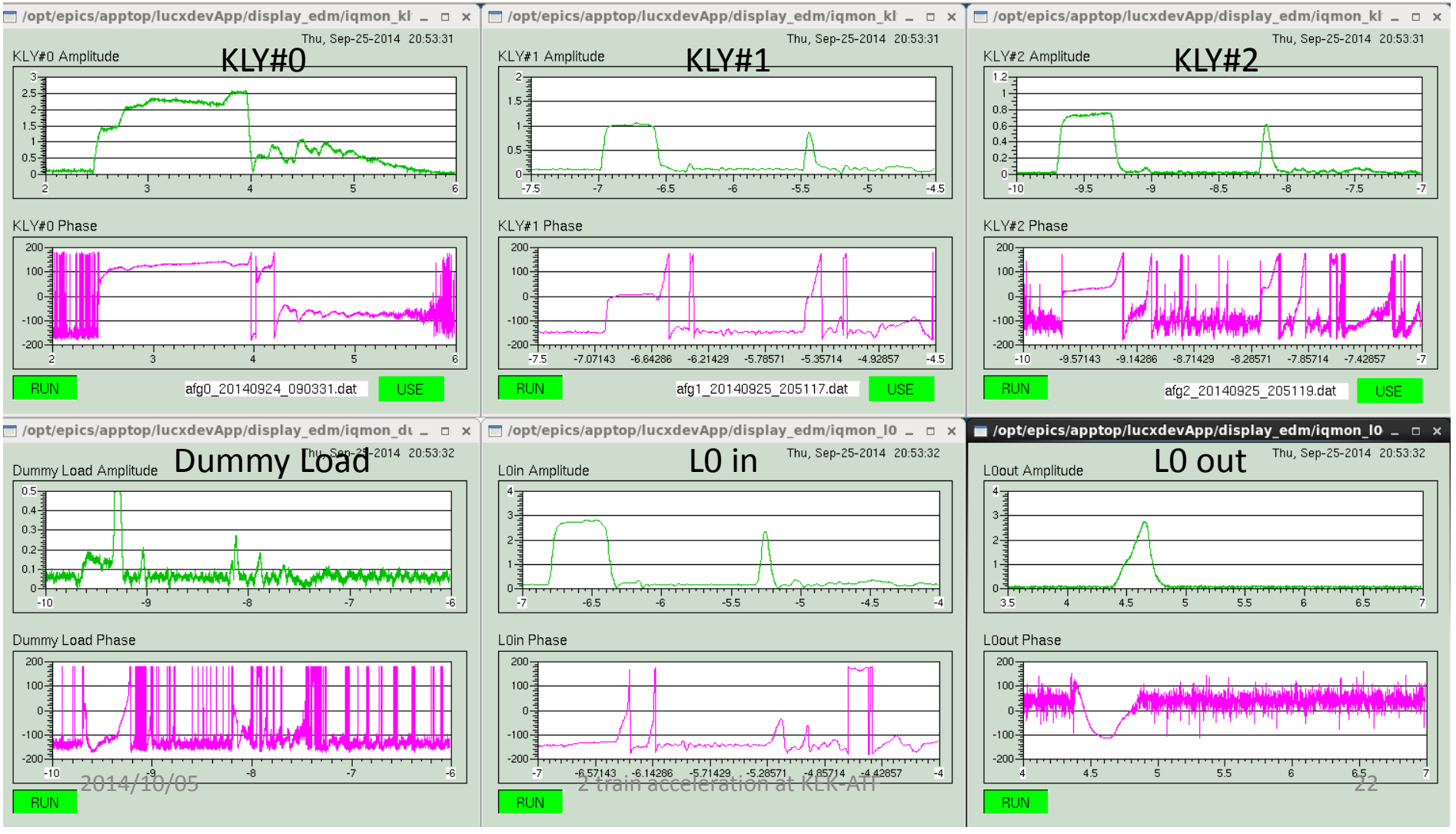


Calibration result (Bending magnet out)



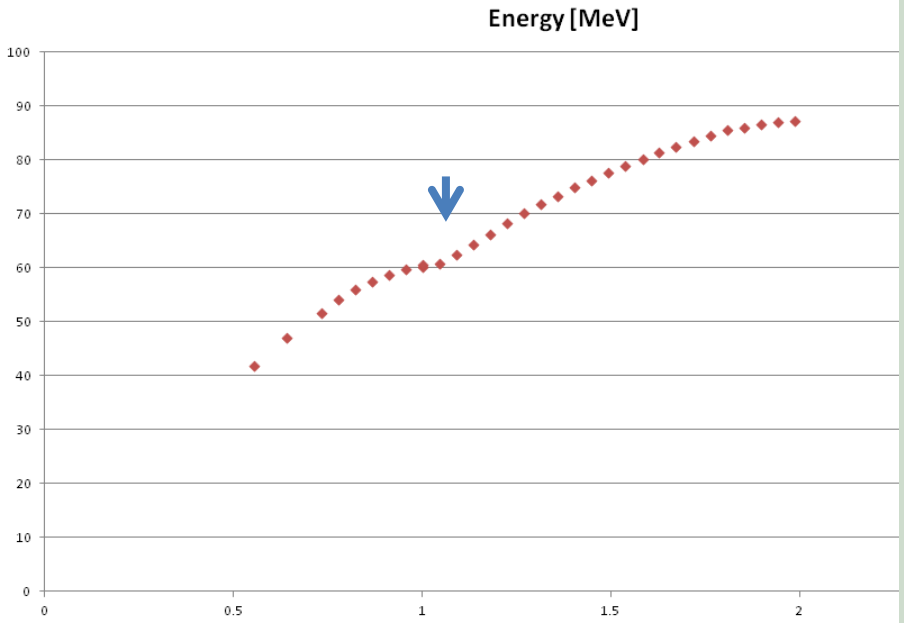
RF pulse

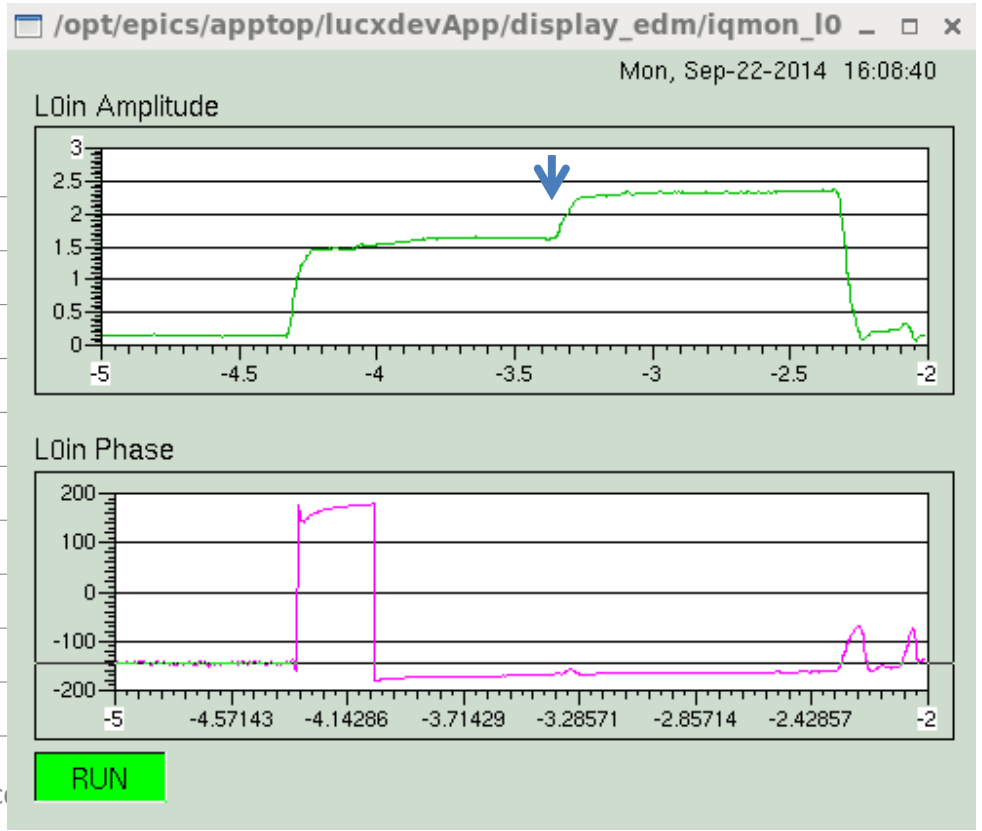
RF pulse shapes during 1train acceleration (60bunches)



Beam loading compensation with step modulation

RF pulse with stepped shape was injected to the accelerating tube.





Beam loading compensation with step modulation

Energy in a train could not be compensated because the response time of klystron was slow.