



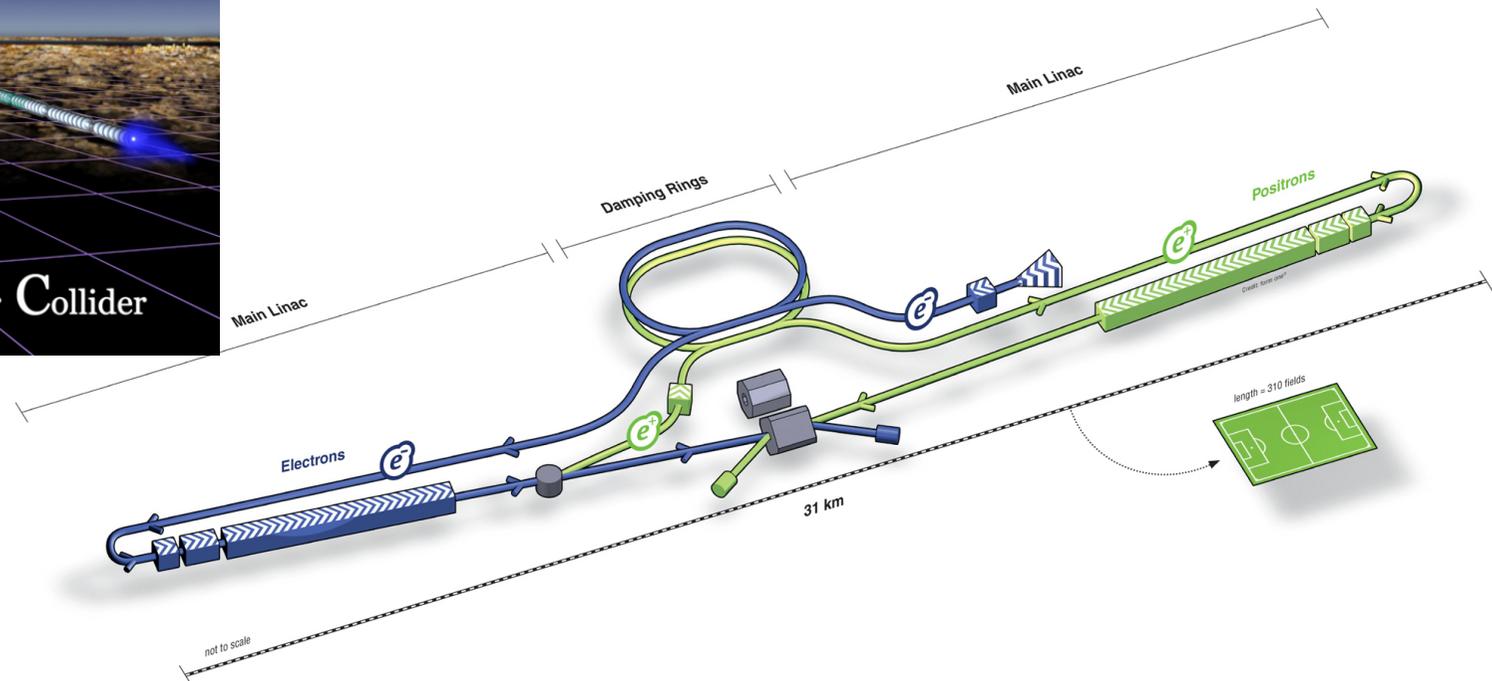
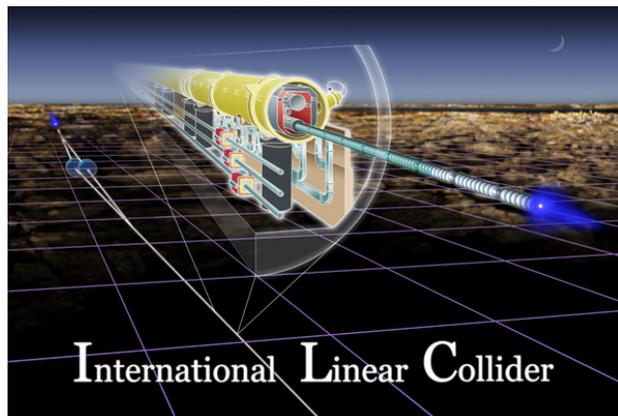
Ultra Fast Kicker Tests at KEK



10/07/2013 LER2013
KEK Takashi Naito

Fast kicker is developing for ILC Damping Ring(DR).

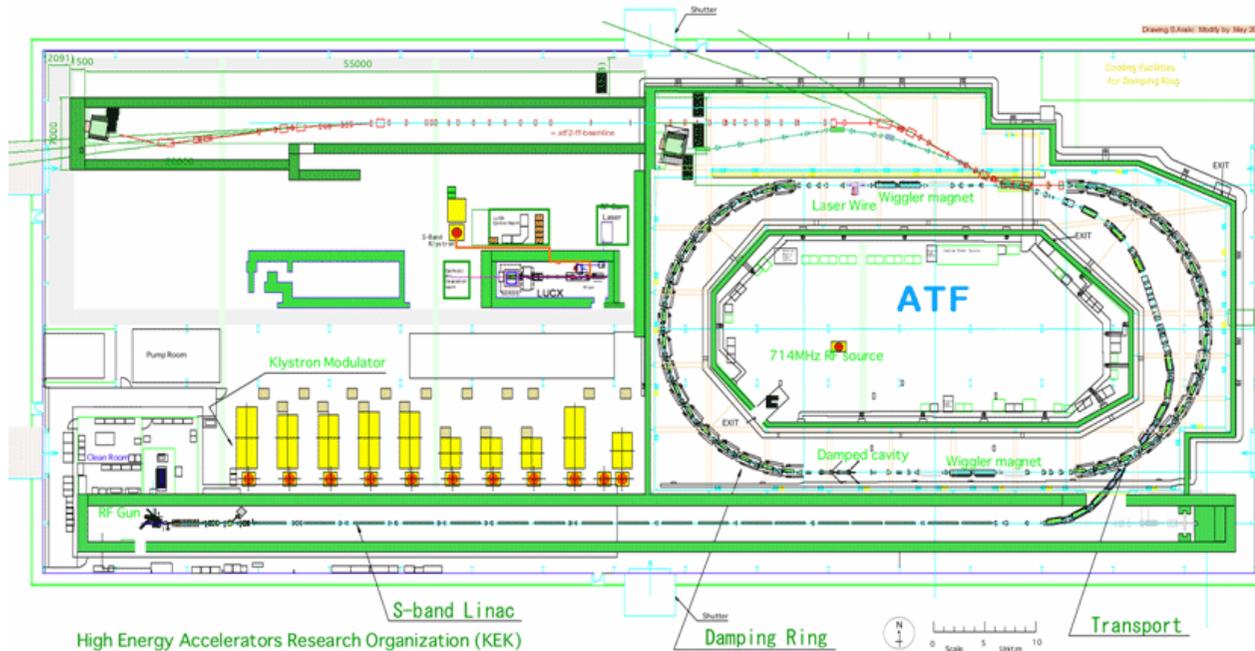
- Super Conducting RF cavity -> long bunch train(200km)
- Short bunch spacing in the DR(3.2km circumference)



ILC Layout



KEK-ATF Test accelerator for Linear Collider



$N_e = 1 \times 10^{10}$ e-/bunch
Bunch#/shot 1 ~ 20
Bunch spacing 2.8~5.6ns
Bunch train 1~3 trains
Inj/ext period ~3Hz

ATF
DR RF frequency 714MHz
(bucket spacing 1.4ns)

ILC
DR RF frequency 650MHz
(bucket spacing 1.5ns)

1. S-band linac(1.28GeV)

Laser triggered RF Gun(CsTe cathode) $\epsilon_{n,x,y} = 3 \times 10^{-5} m$ (measured)

2. Beam Transport

DC septum, Injection kicker(on axis injection)

4. Damping Ring

$\epsilon_{n,x} = 4.3 \times 10^{-6} m$, $\epsilon_{n,y} = 30 \times 10^{-9} m$ (design) $\rightarrow \epsilon_{n,y} = 20 \times 10^{-9} m$ (measured)

5. ATF2(test for the final focus system of ILC)

Vertical beam size **37nm**

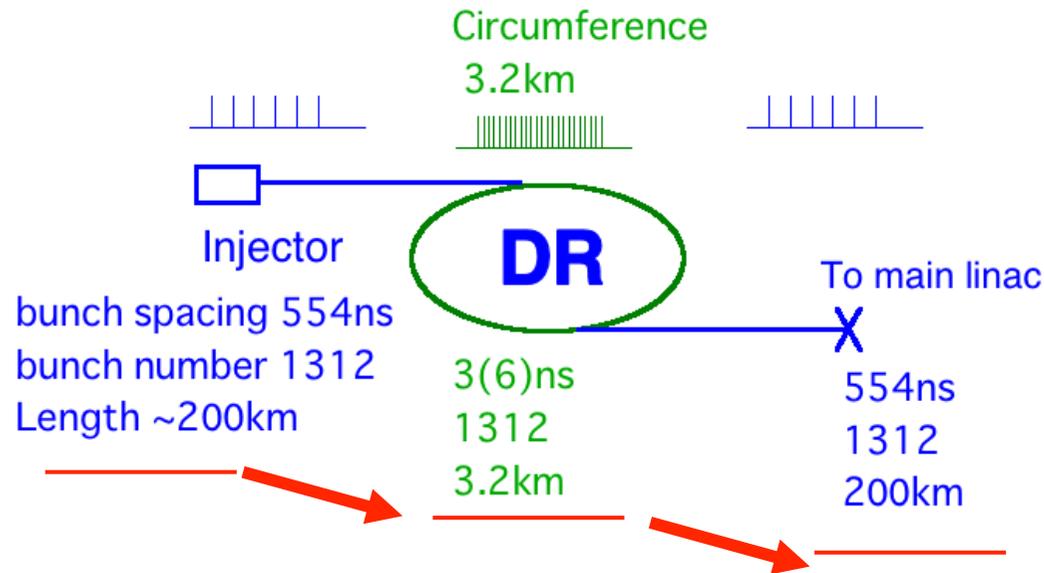


Role of Fast kicker in ILC

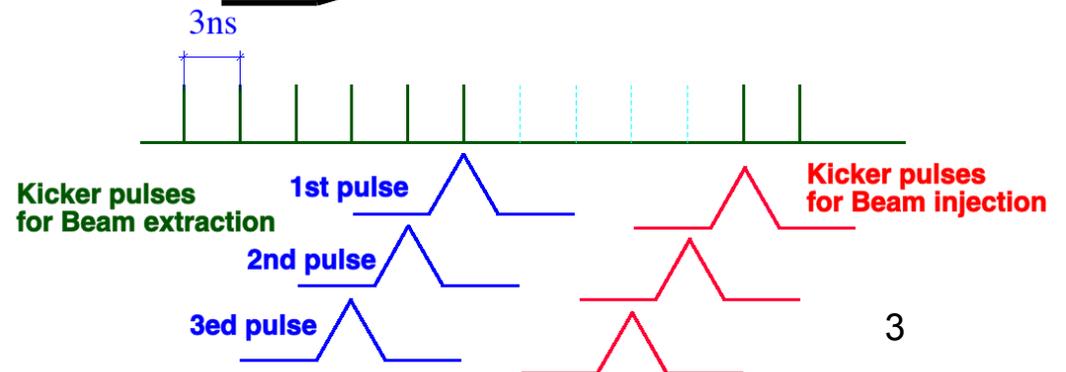


Injection into the DR/Extraction from the DR

The bunch spacing Injector 554ns -> DR 3(6)ns -> Main Linac 554ns



Kick field of pulsed magnet type of the kicker



Requirements of the ILC kicker
 Rise time 3(6)ns
 Rep. rate 3MHz
 Stability 7×10^{-4}



Strip-line kicker for the ILC kicker

We designed the ILC kicker using multi-units of the strip-line kicker.

Parameters

Kick angle 0.6mrad@5GeV

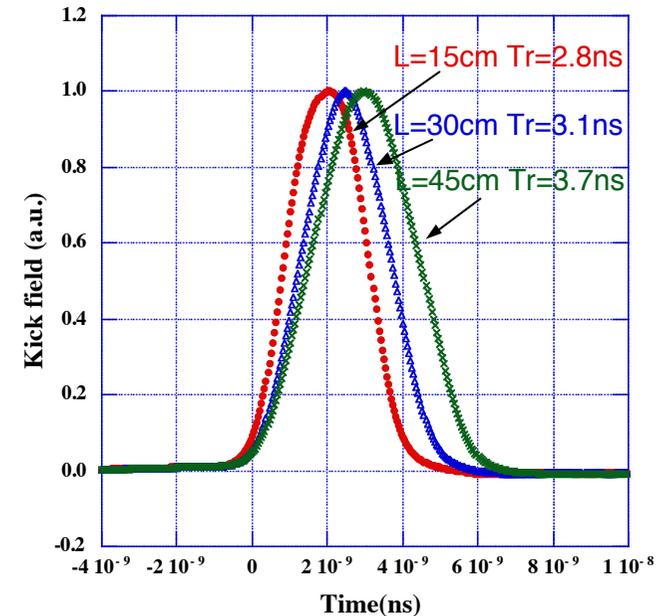
Stability 7×10^{-4}

Rep. rate 6.5(3.25)MHz, 1ms burst, 5Hz

Rise/fall time <3(6)ns

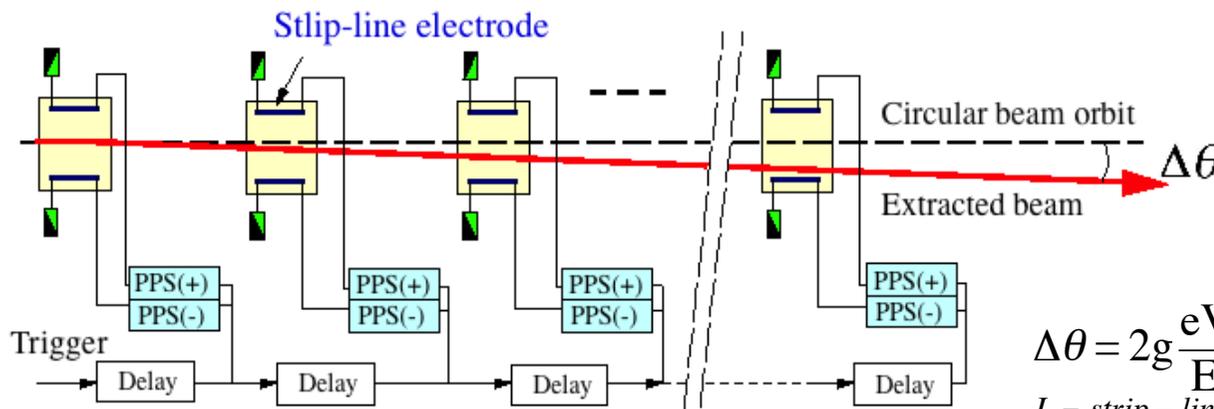
Pulse source +/-5kV, 1ns raise time

Number of units 20~30 units(depends on the strip-line design)



Simulation of the kick fields when apply the pulse(1ns raise time) to the different length of the strip-line.

Rise time 1%~100%



■ : Load

PPS(+) : +5kV Pulse Power-Supply
PPS(-) : -5kV Pulse Power-Supply

$$\Delta\theta = 2g \frac{eV}{E} \frac{L}{d}$$

L = strip - line length

d = distance between the electrodes

V = pulse voltage

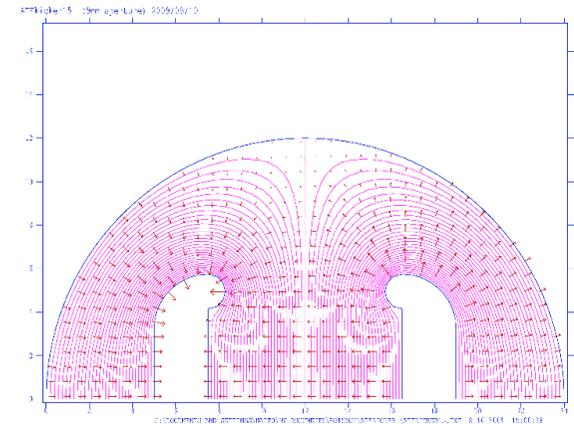
E = Beam energy



Strip-line and Pulse source

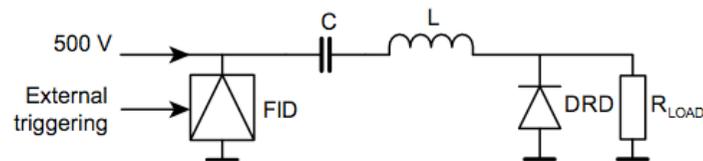


30cm long strip-line electrodes are designed and fabricated.

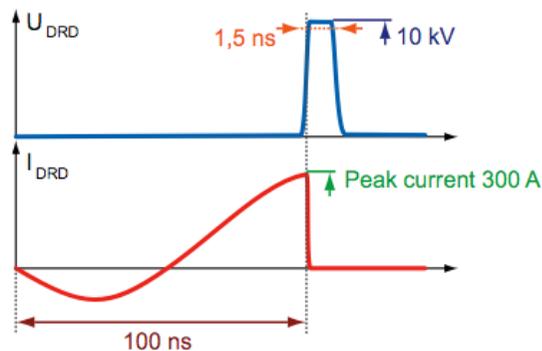


Electric field

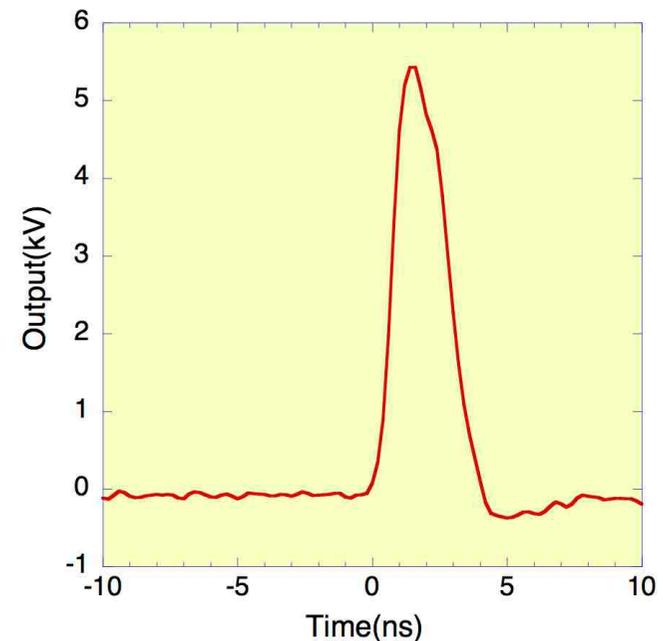
Pulse source (fabricated by FID Co.)



FID : Fast Ionization Dynistor
DRD : Drift step Recovery Diode



Peak 5kV,
Rise time 1ns
Rep rate 3MHz
Burst 3000 pulses



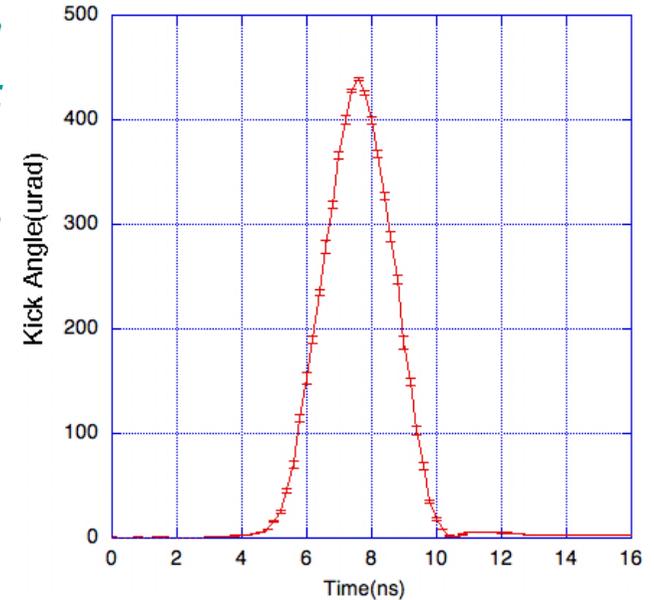
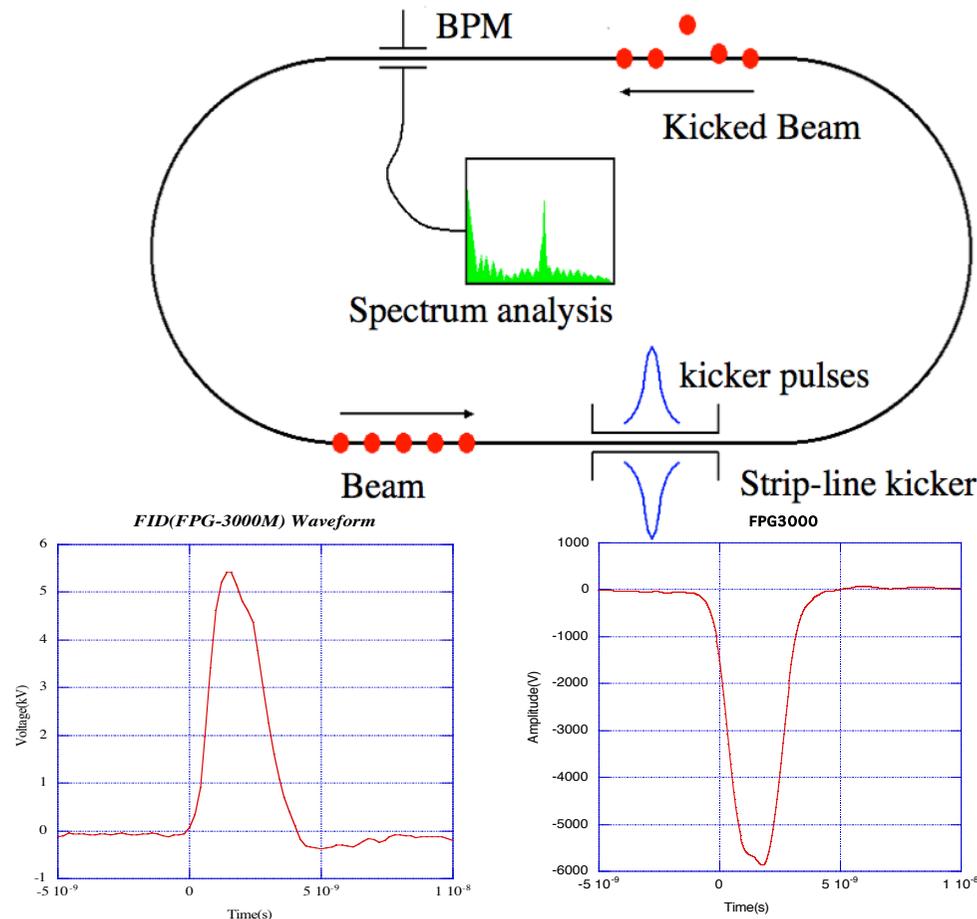


Kick field measurement



It is very difficult to measure a very fast EM field in the strip-line kicker. One turn pick up coil doesn't respond such a fast signal.

We measured the kick field by measuring the betatron beam oscillation amplitude in the ATF-DR.

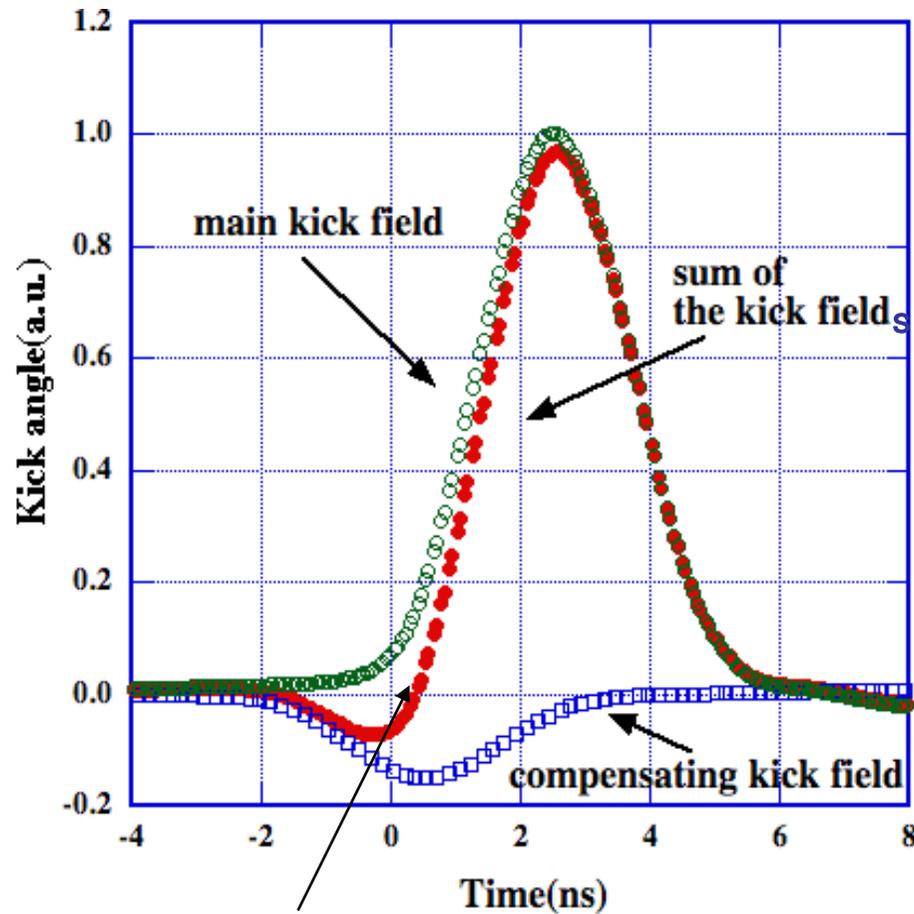


Measured time response of the kick field. The kick pulse timing is scanned with 200ps step. The measured raise time was less than 3ns.

Waveform of the positive/negative pulse(5kV, 1ns rise time)

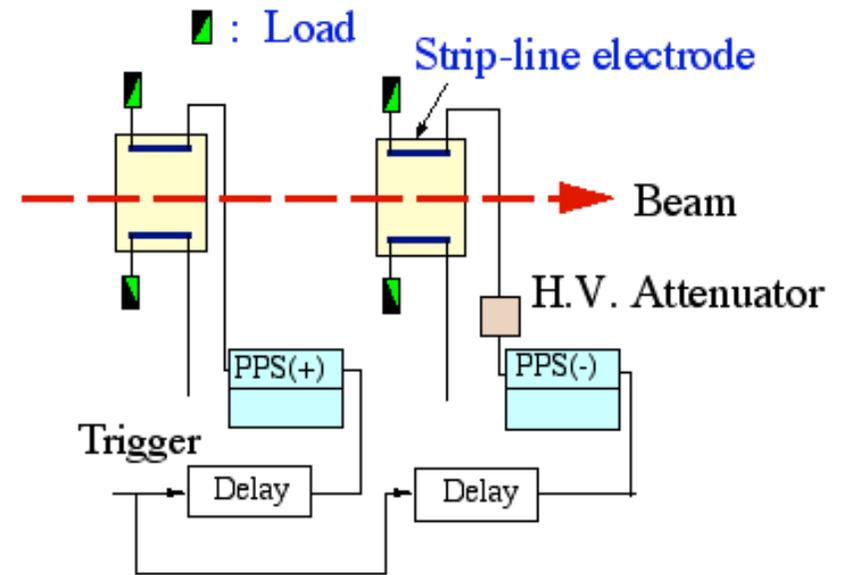


Rise time improvement



Zero Cross field

Simulation of waveform compensator

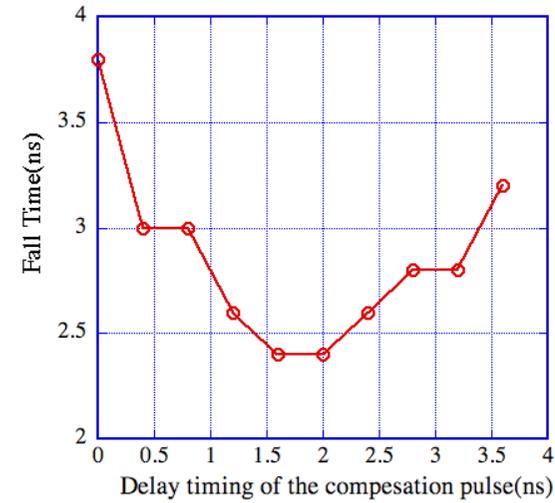
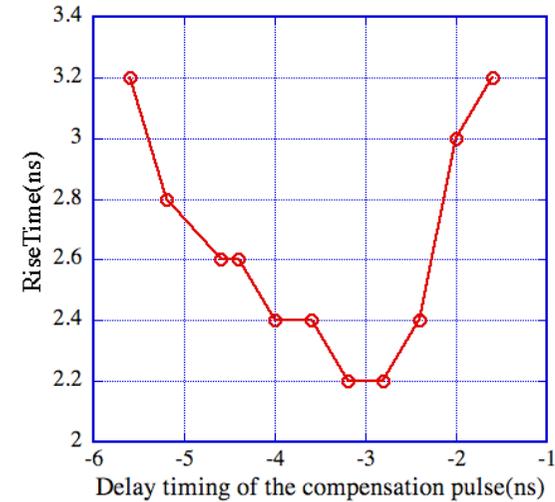
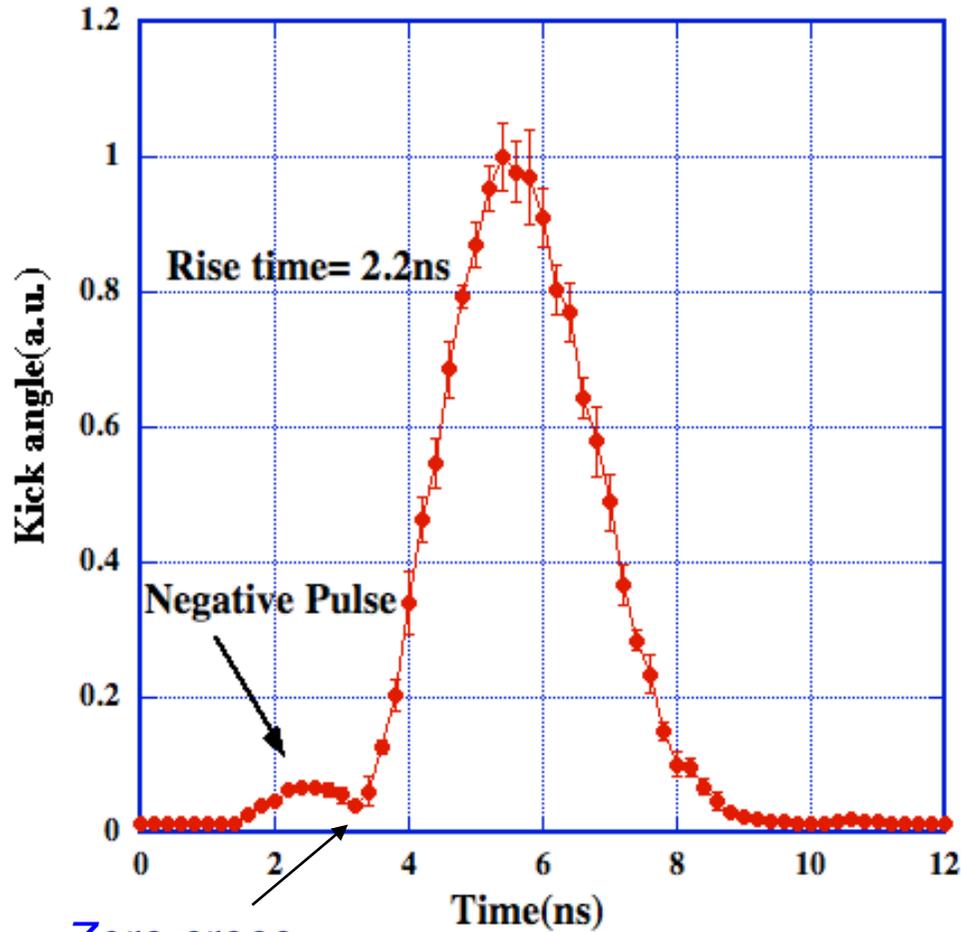


Experimental set up

The rise/fall time can be improved by the combination of the positive and negative pulses which have different timings and different amplitudes.



Rise time improvement with Waveform compensator



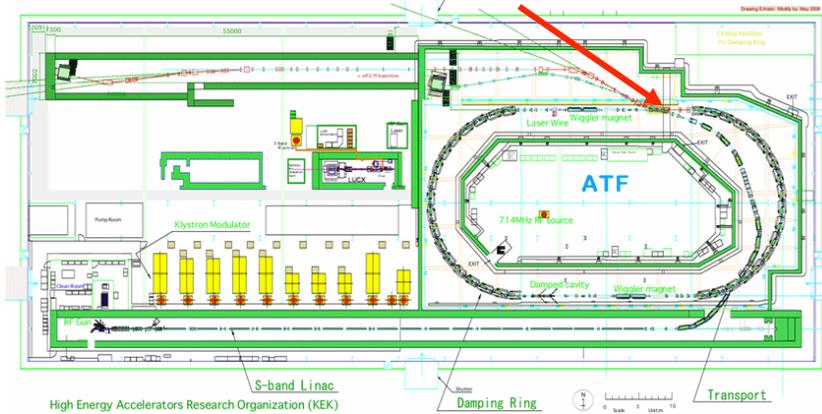
Rise/fall time improvement v.s. timing



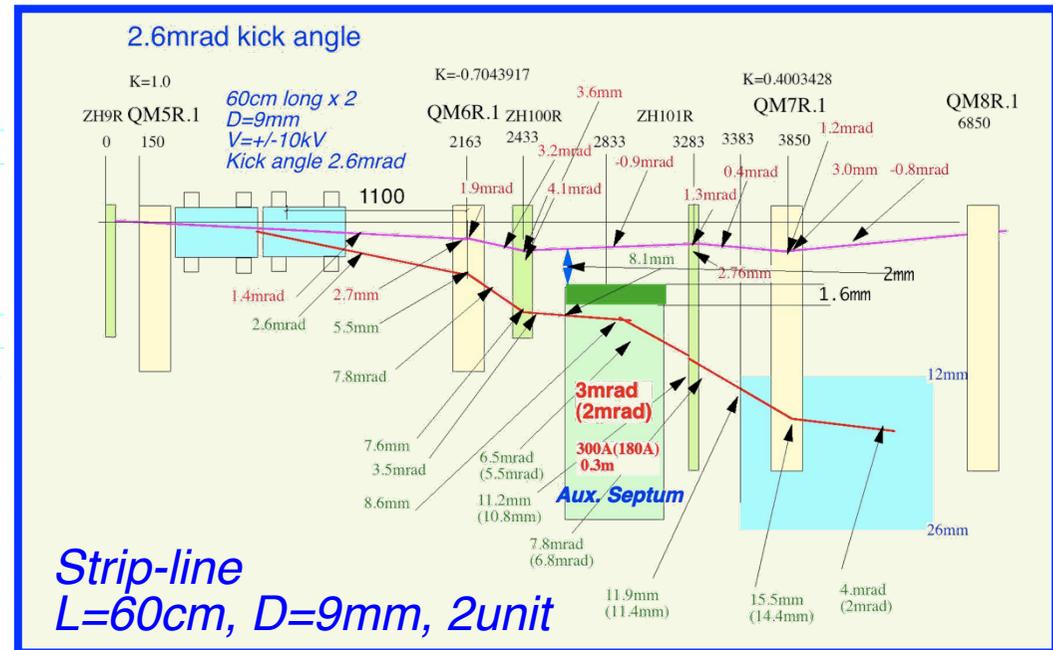
Beam Extraction at KEK-ATF



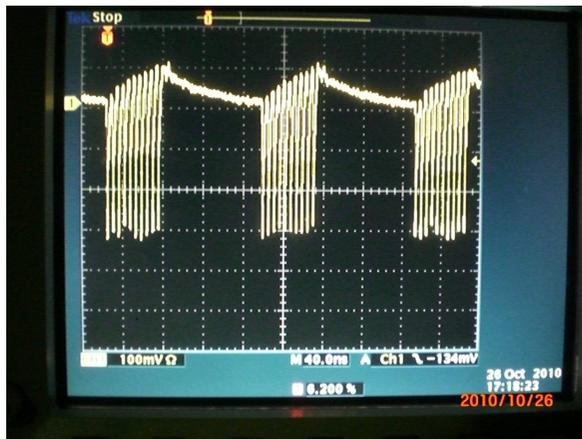
Extraction kicker



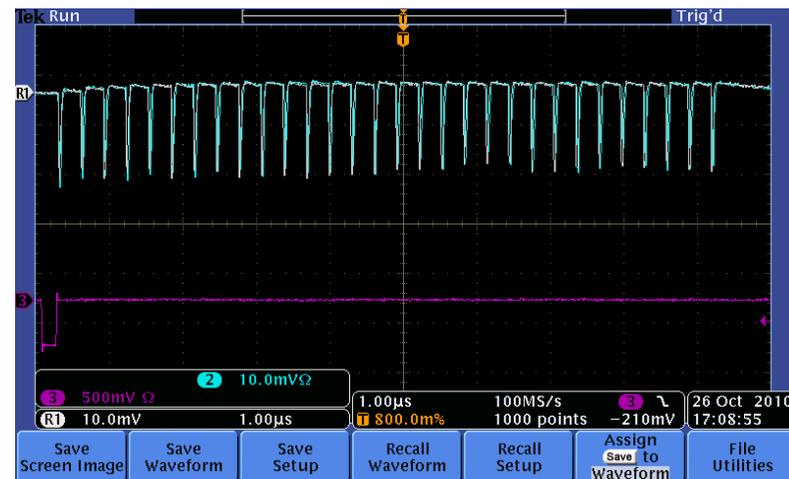
The demonstration of the beam extraction using the strip-line kicker was carried out successfully. To clear the geometrical restriction, the local bump orbit and the additional septum magnet are used with the kicker.



Strip-line
 $L=60\text{cm}$, $D=9\text{mm}$, 2unit



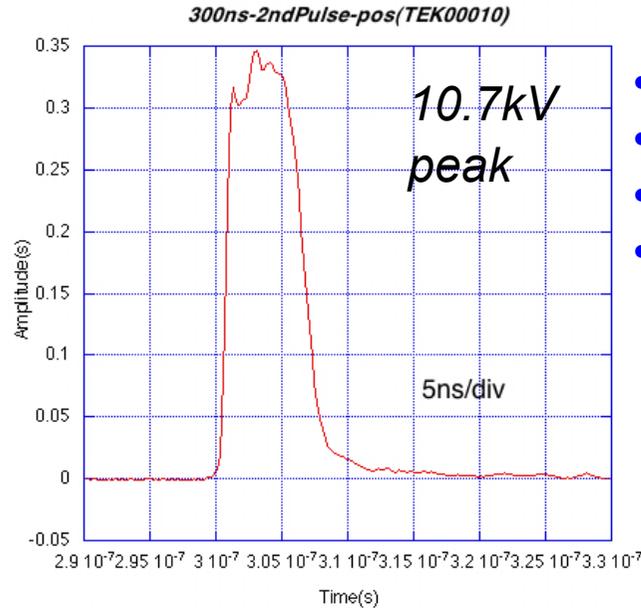
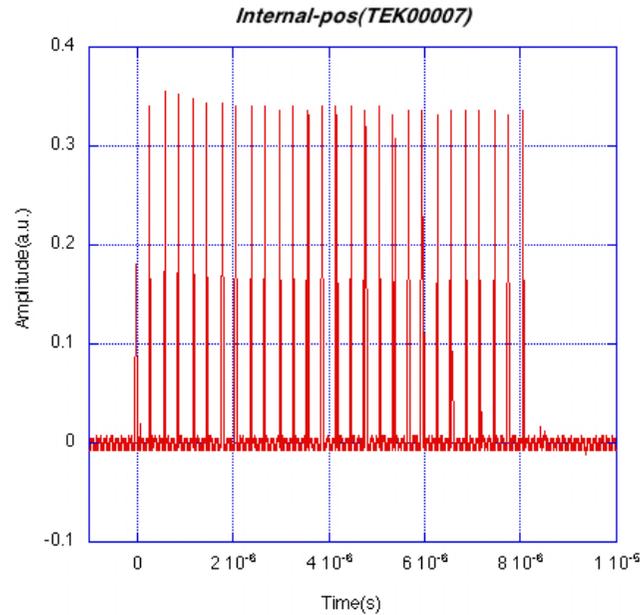
Bunch current in the ring
 (3train, 10bunches, 5.6ns bunch spacing)



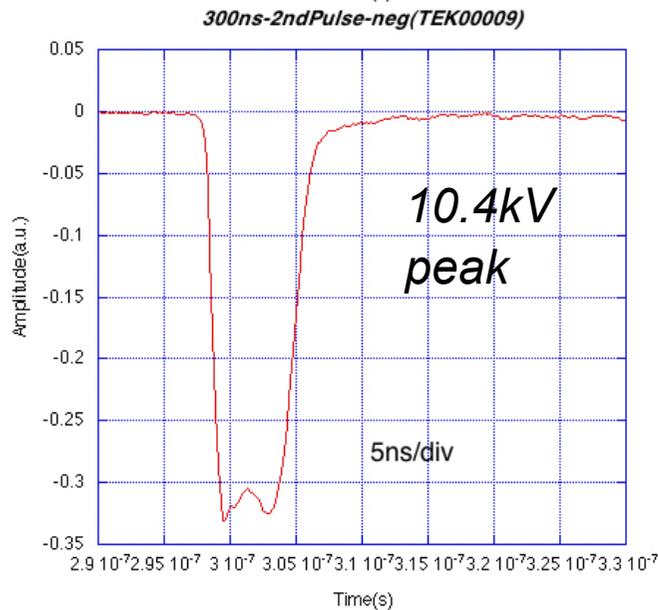
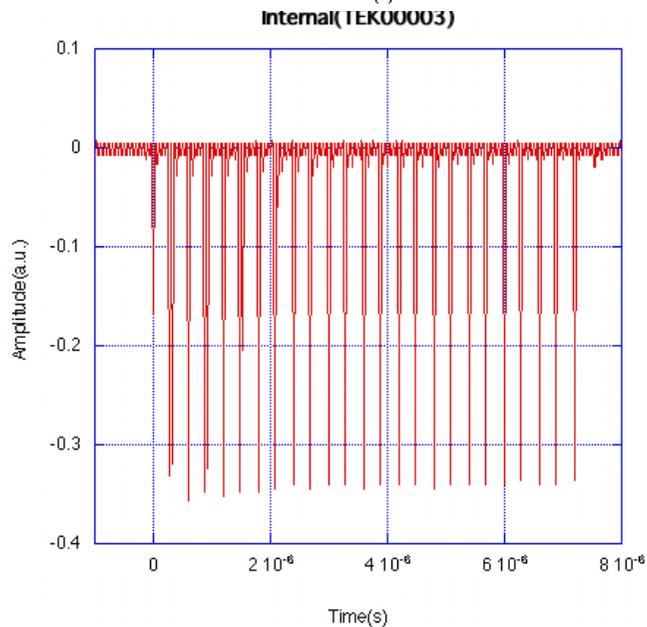
Bunch current of the Extracted beam
 (308ns bunch spacing, 30 bunches)



10kV, 4ns pulser

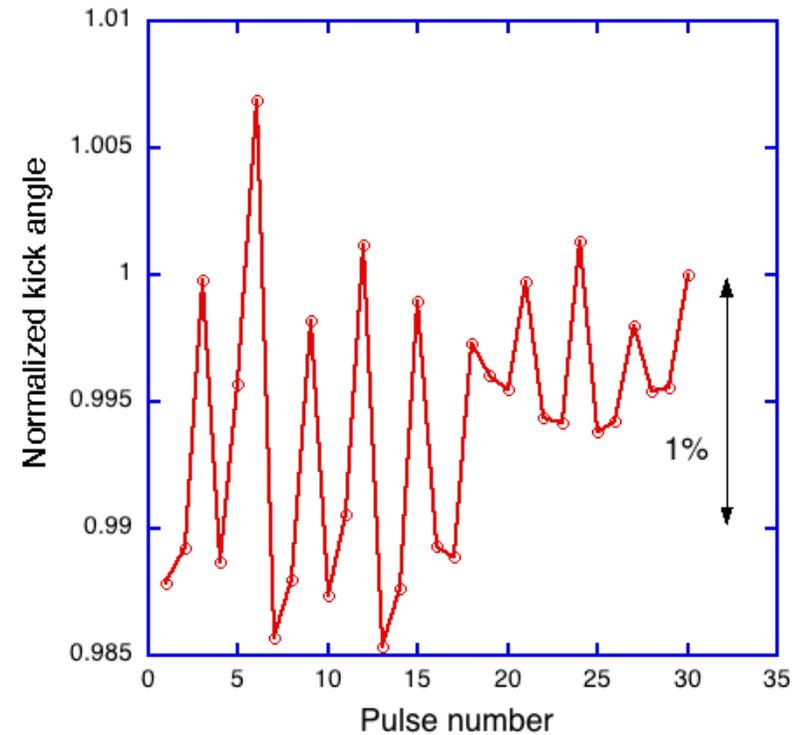
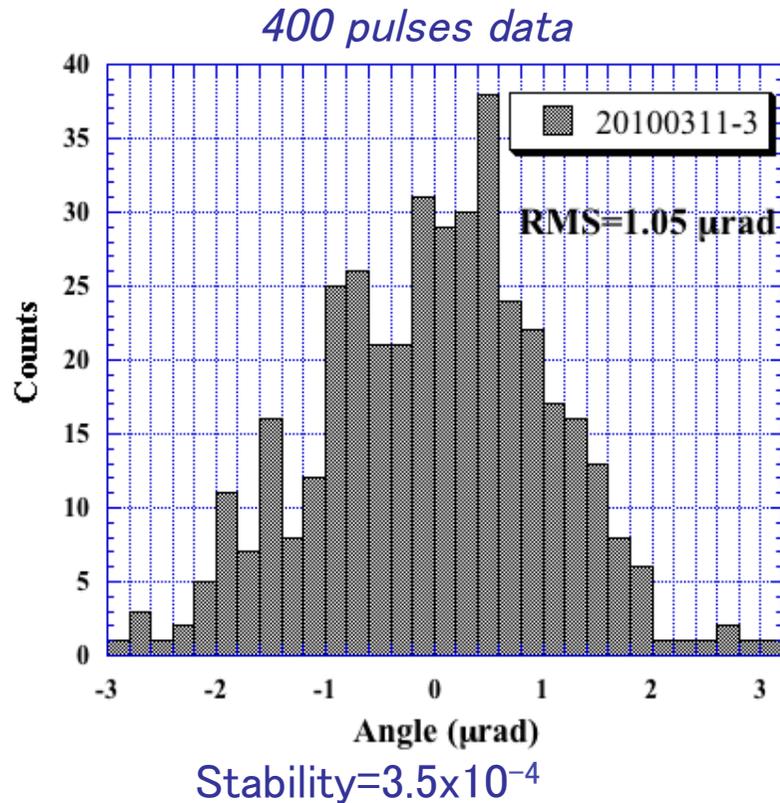


- Rise time 1.5ns
- Peak voltage +/- 10kV
- 3.2MHz
- Up to 60pulses





Kick angle stability and difference of burst pulse



The kick angle jitter was calculated from the 20 BPMs data at the ATF2 beam line. The graph shows the kick angle distribution for the mean value.

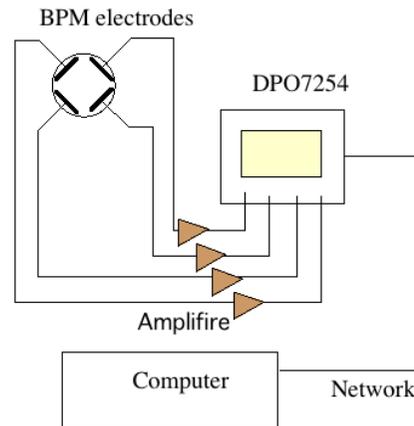
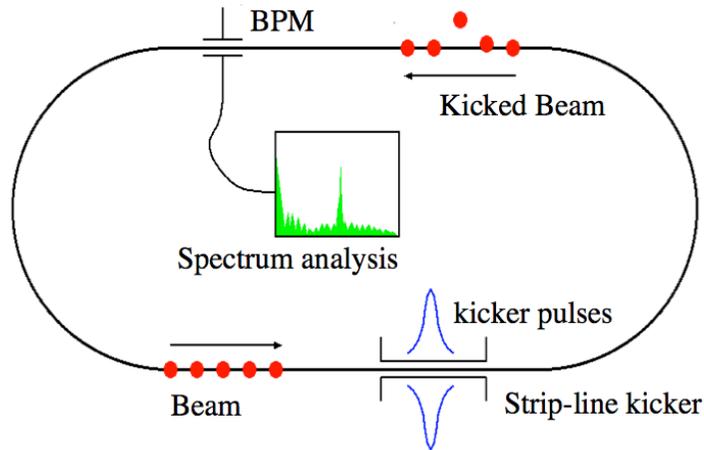
The kick angle difference as a function of the pulse number from the 1st pulse to the 30th pulse. The kick angle is affected the pulse amplitude and the pulse timing of each pulse. This difference can be compensated at the downstream.¹¹



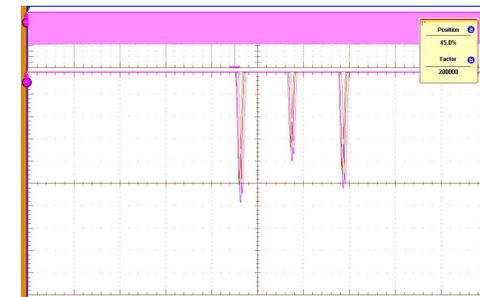
Bunch Oscillation Measurement using fast kicker



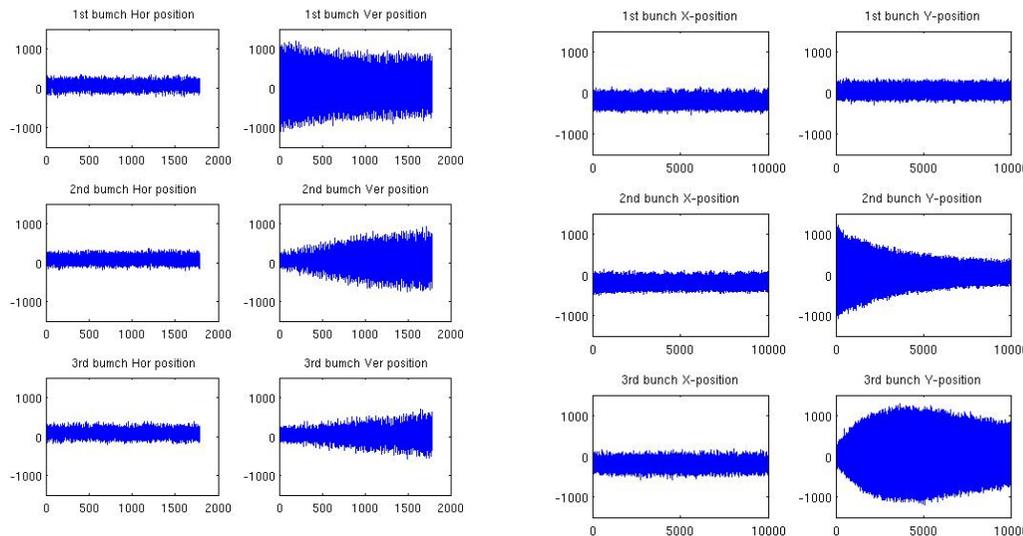
When apply the beam kick to one of the multi-bunch beam, the transverse wakefield effect can be measured.



Multi-bunch, multi-turn beam positions are recorded to 10Gsample/s oscilloscope and the long waveform memory.



3-bunches, 2.8ns bunch spacing

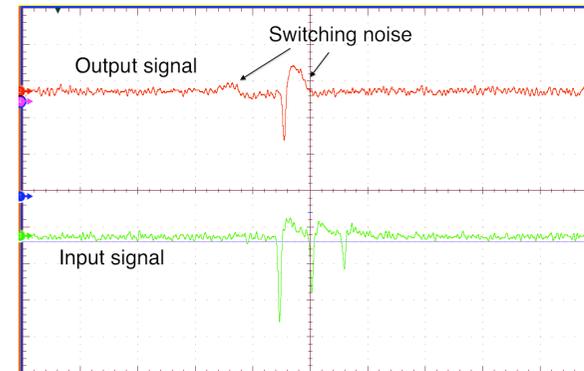
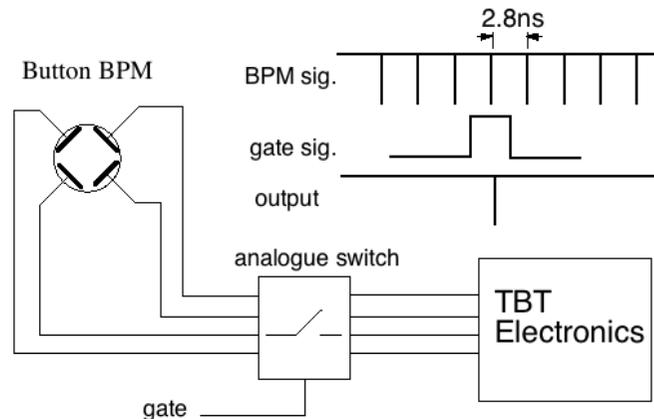


Left, The first bunch is kicked, vertically. (1~2000turns)

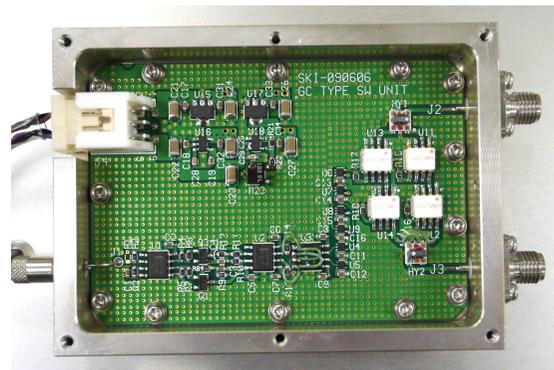
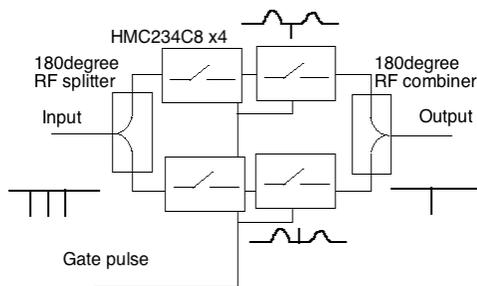
Right The second bunch is kicked, vertically. (1~10000turns)



Signal Processing for Bunch-by-Bunch Beam Position Measurement



Fast analogue switch has the switching noise at the on and off timing, which deteriorate the position sensitivity.



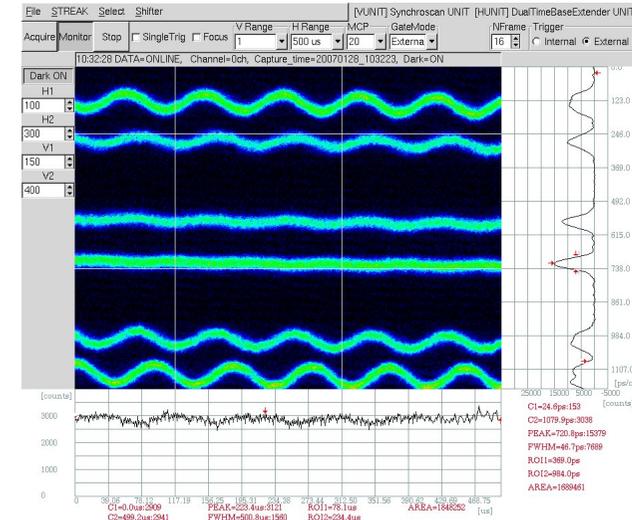
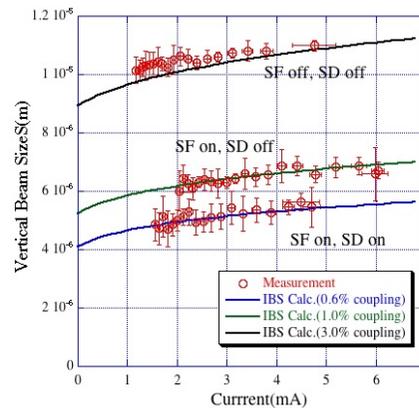
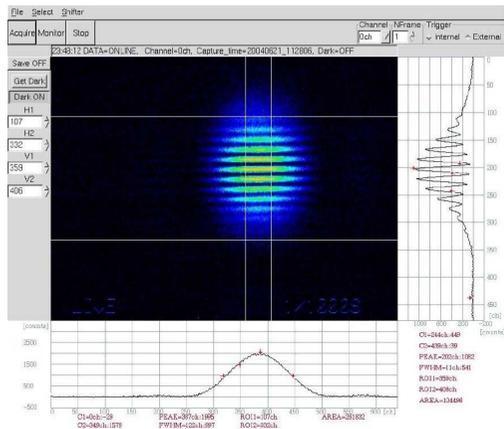
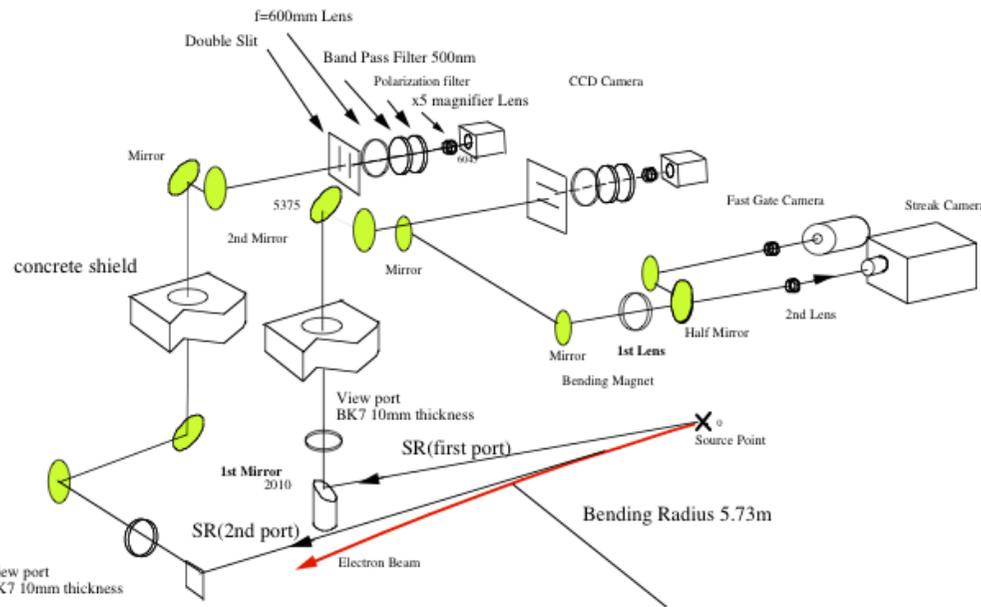
One of the bunch signal can be selected by using fast analogue switches. The problem of the switching noise of the analogue switch was cured by developing the compensation circuit. Super KEKB employed this circuit.



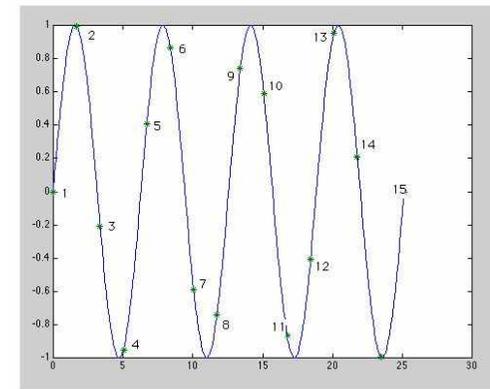
The compensation circuit canceled out the switching noise, completely.



SR monitors



10th
5th
3rd
1st
7th
8th



Sweep freq.=357MHz * 4/15=95.2MHz

Bunch-by-bunch bunch length measurement using streak camera:
By using the gate function of the MCP and the non-integer sweep frequency, we can measure bunch-by-bunch longitudinal profile.

SR interferometer less than 5um(vertical) can be measured.
Naito, et. al. PRST-AB 14,051002(2011)



Summary



The fast kicker development has been carried out in KEK for the ILC kicker.

- The measured rise/fall time of the kick field was $\sim 3\text{ns}$.*
- The rise/fall time improved up to 2.2ns with the waveform compensator. 2ns raise time will be realized using this method.*
- Multi-bunch beam extraction was demonstrated from ATF-DR to ATF2 beam line.*
- Stability of the kick angle for single bunch was 3.5×10^{-4} , which is enough for ILC requirement.*
- The fast kicker can be applicable for the investigation of the transverse wakefield measurement and the longitudinal instability measurement.*