Progress with kicker studies at KEK-ATF

T.Naito(KEK)

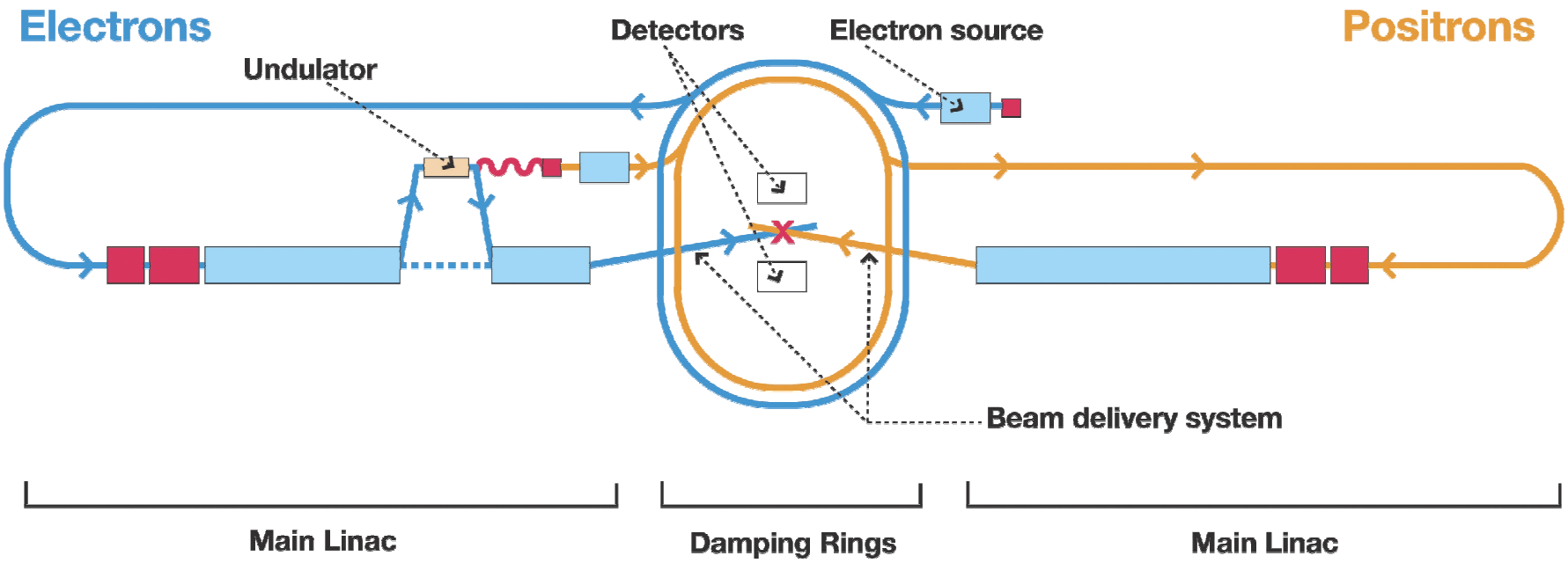
ILCDR07 INFN-LNF

Parameters of ILC

The length of the bunch train in the linac is ~300km long which should be compressed in the DR and should be decompressed at the downstream of the DR.

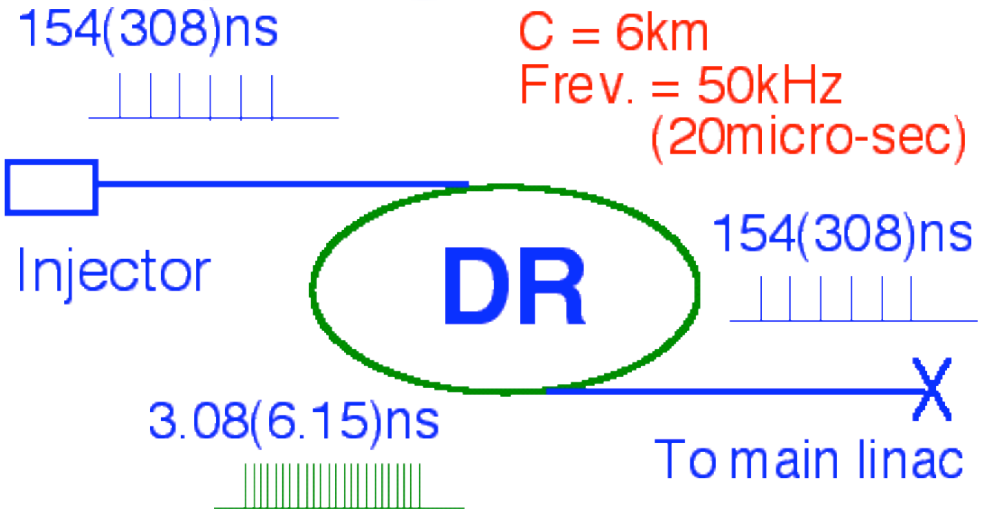
parameters

Bunch train	5640(2820) bunches
Bunch charge	2nC/bunch
Bunch spacing	154(308)ns
Repetition rate	5Hz

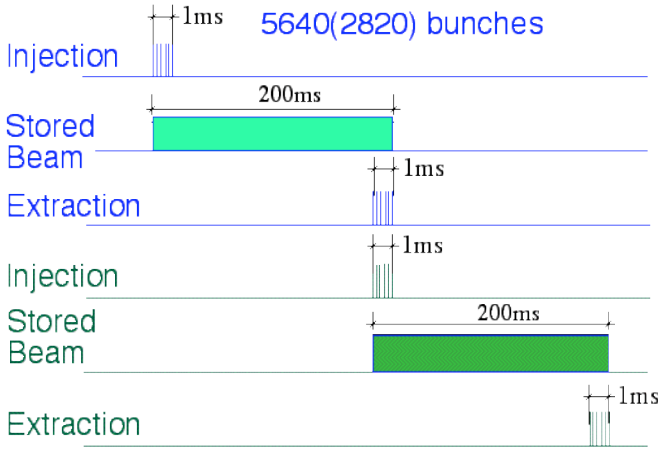


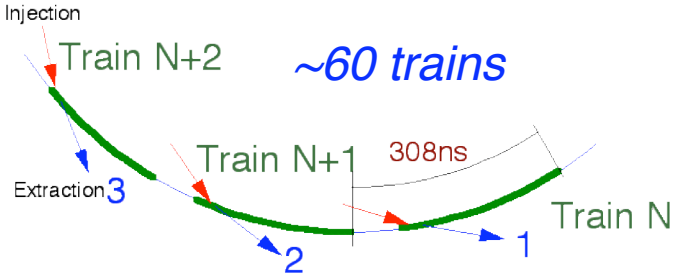
Beam cycle of DR

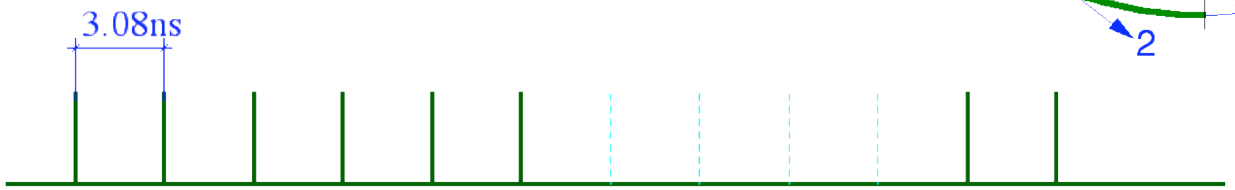
Bunch spacing

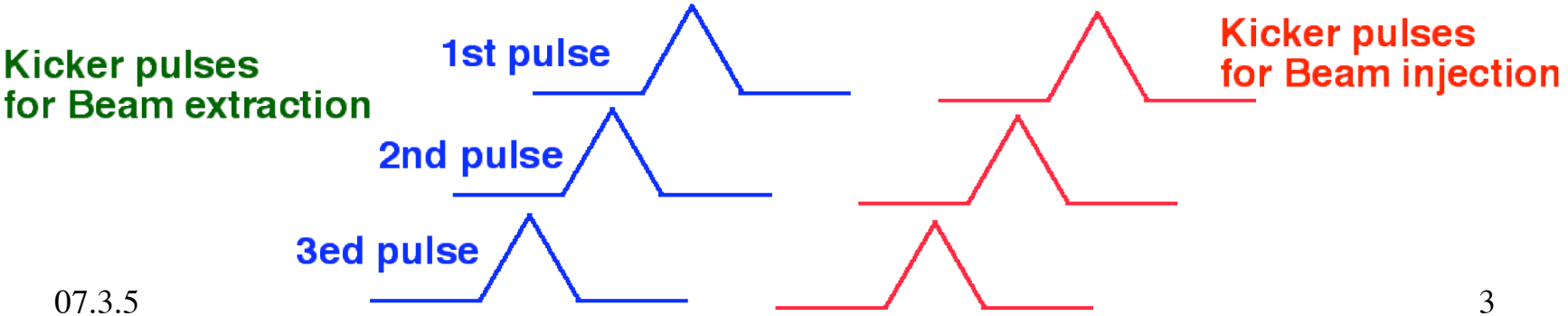


Beam Storage Sequence in DR



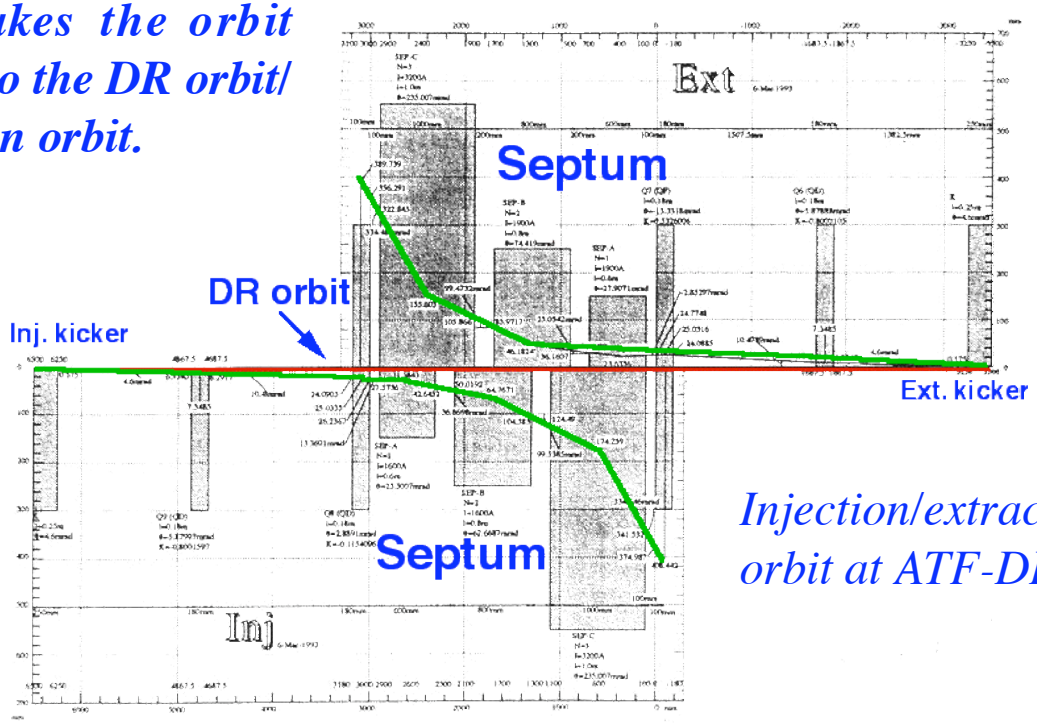






ILC DR kicker parameters

Injection/extraction kicker makes the orbit change form the injection orbit to the DR orbit/ from the DR orbit to the extraction orbit.

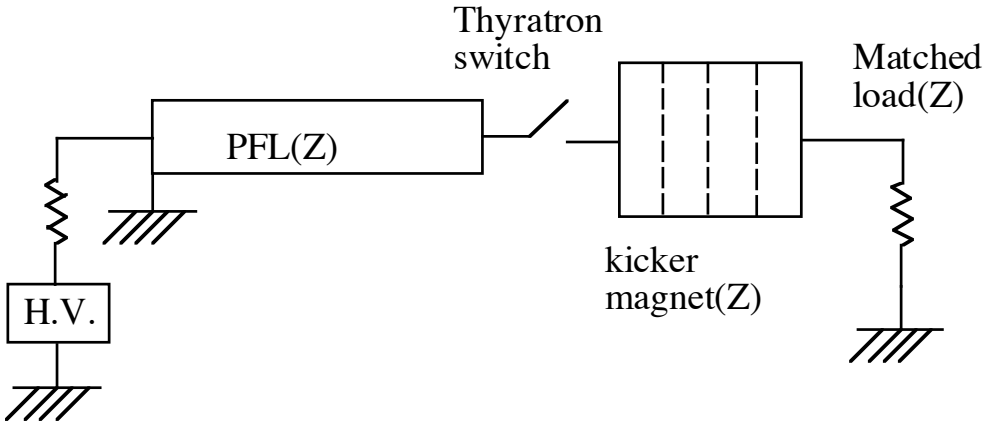


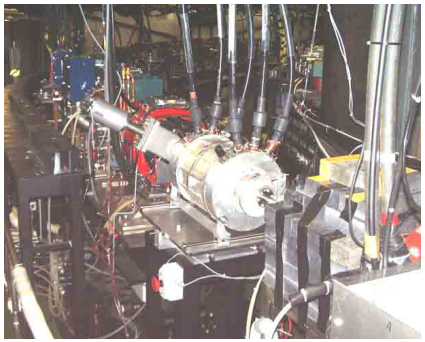
Injection/extraction orbit at ATF-DR

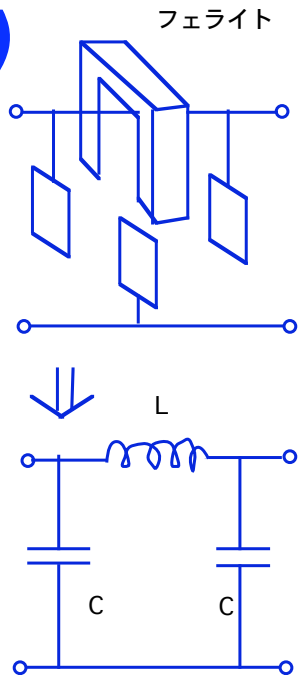
Specification

Kick angle	θ~0.6mrad or $\int Bdl \sim 0.01 Tm$@5GeV, β~50m
Stability	7×10^{-4}
Rep. Rate	6.5(3.25)MHz, 1ms burst, 5Hz
Rise/fall time of the field	**< 3.08 (6.15) ns**

Ordinary kicker system(pulse magnet)



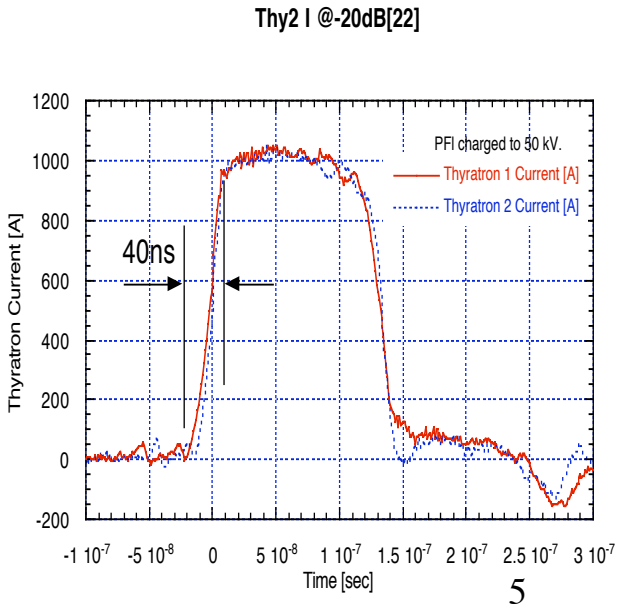




$$\tau = \beta/\omega \approx 2/\omega_c = \sqrt{2LC}$$

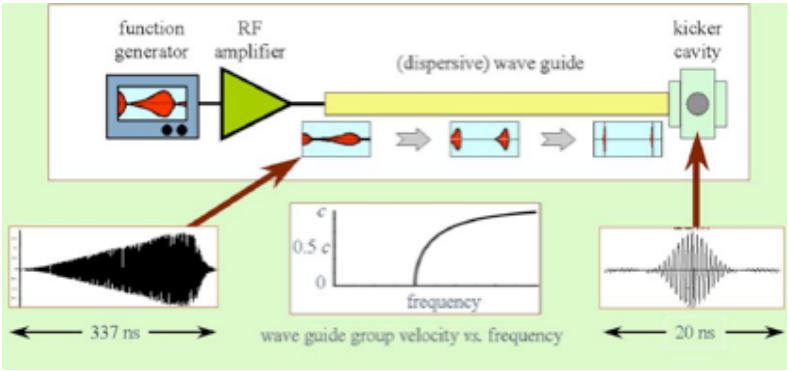
$$Z_o = \sqrt{\frac{L}{2C}}, \quad \omega_c = \sqrt{\frac{2}{LC}}$$

The pulse magnetic field is produced by the LC type pulse magnet. The charged high voltage is switched by the tyratron and the high current go through the pulse magnet.
There is a Cutoff frequency (ω_c) for the pulse magnet and the raise time limitation for the tyratron .

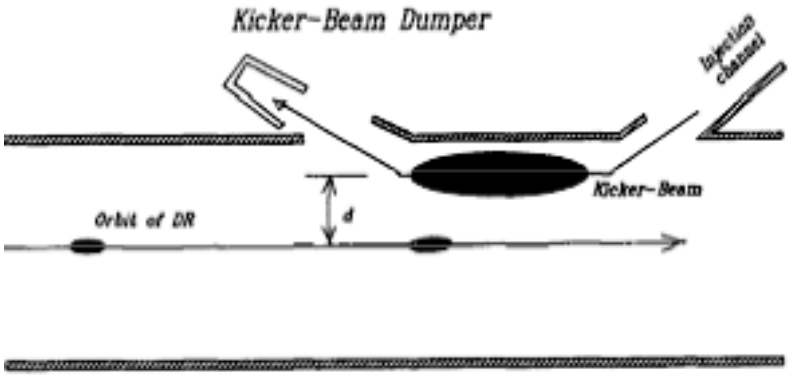


New proposal for the ILC kicker

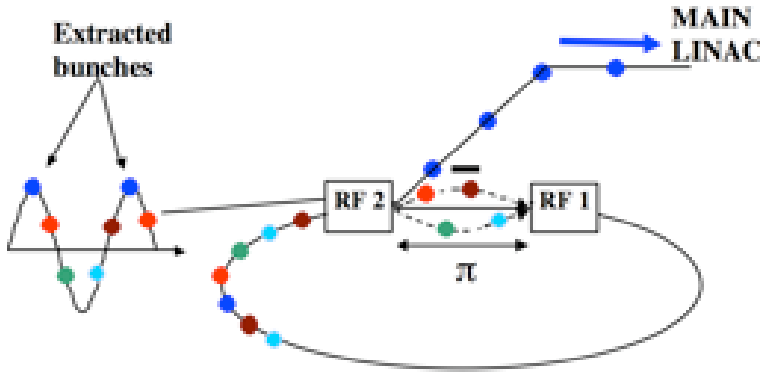
Fourier series kicker



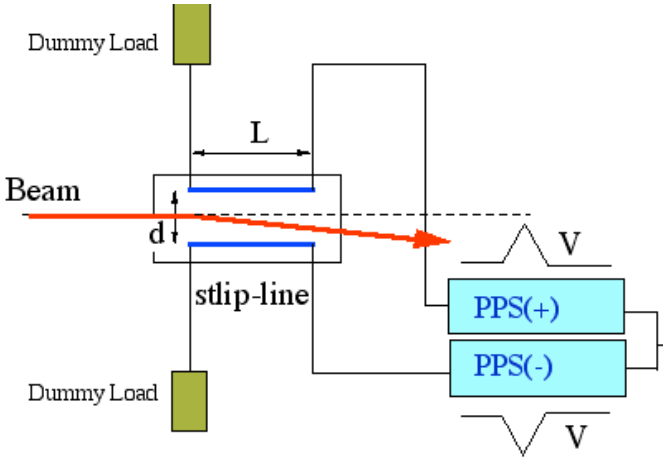
Beam-Beam kicker



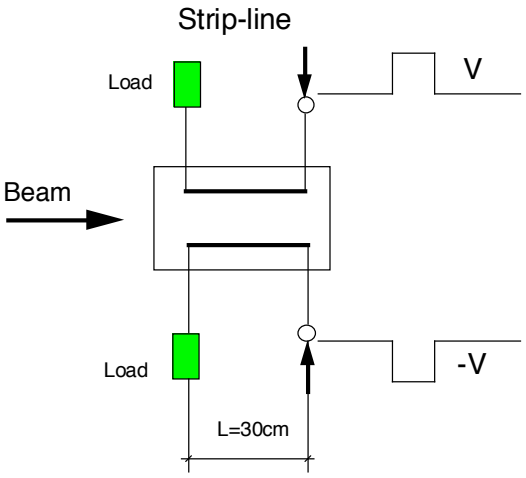
RF deflector



Strip-line kicker

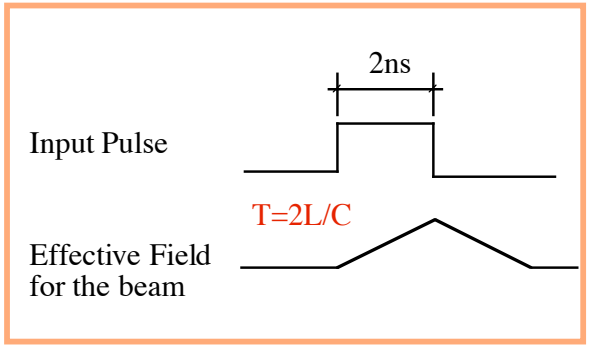


Kick field of the strip-line kicker

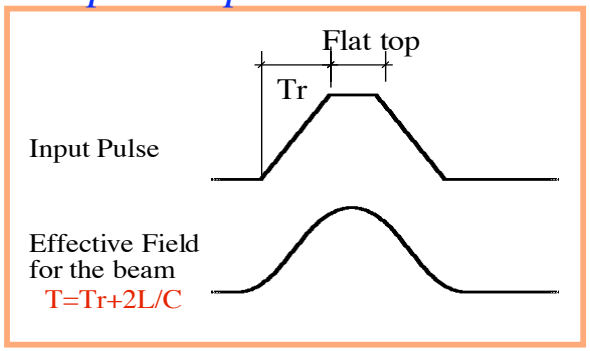


$$\Delta\theta \propto \int_{t}^{t+2L/c} V(t)dt$$

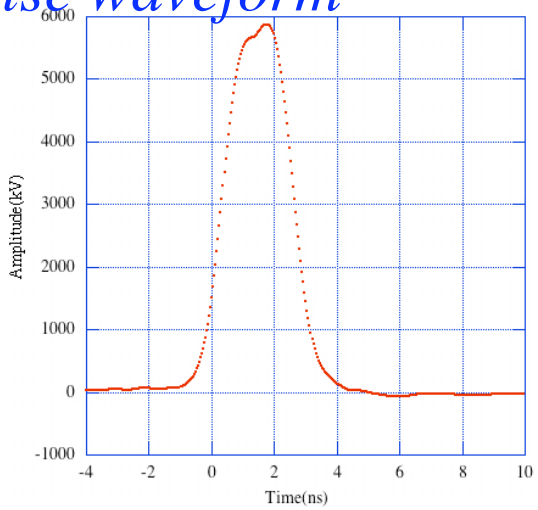
Rectangular pulse



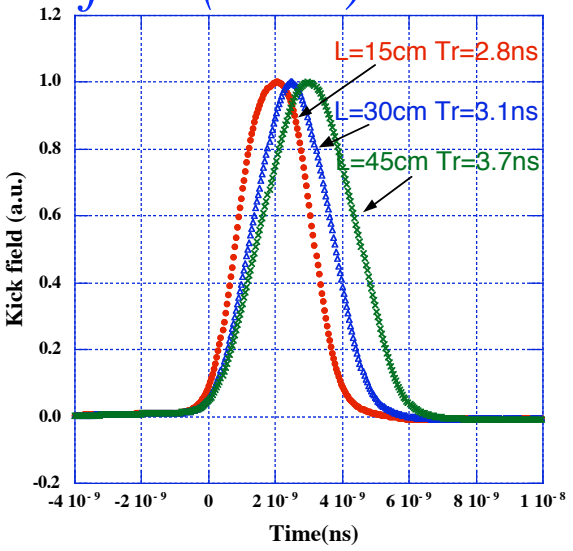
Trapezoid pulse



Pulse waveform



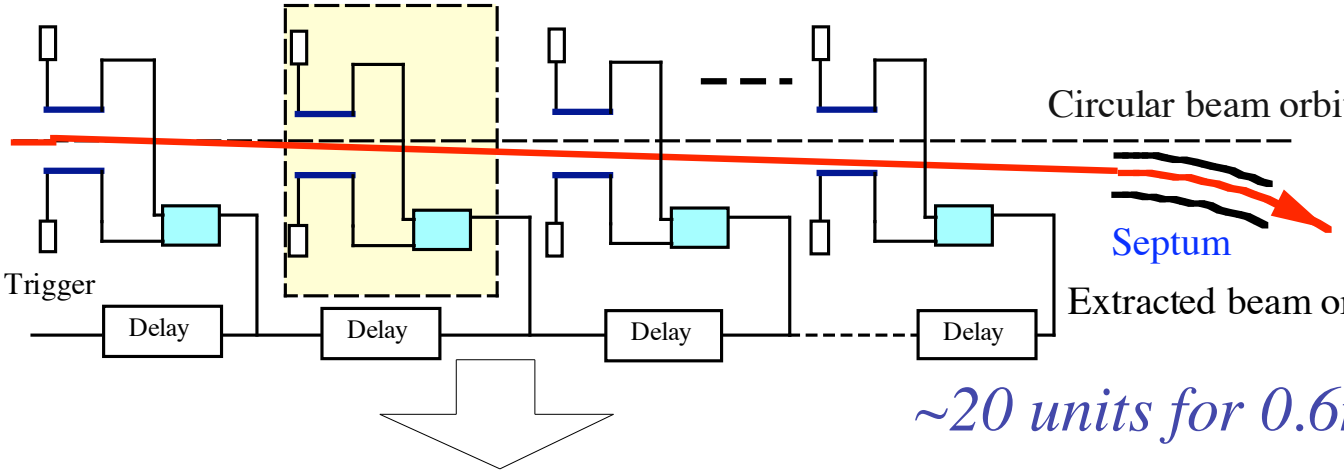
Kick field(calc.)



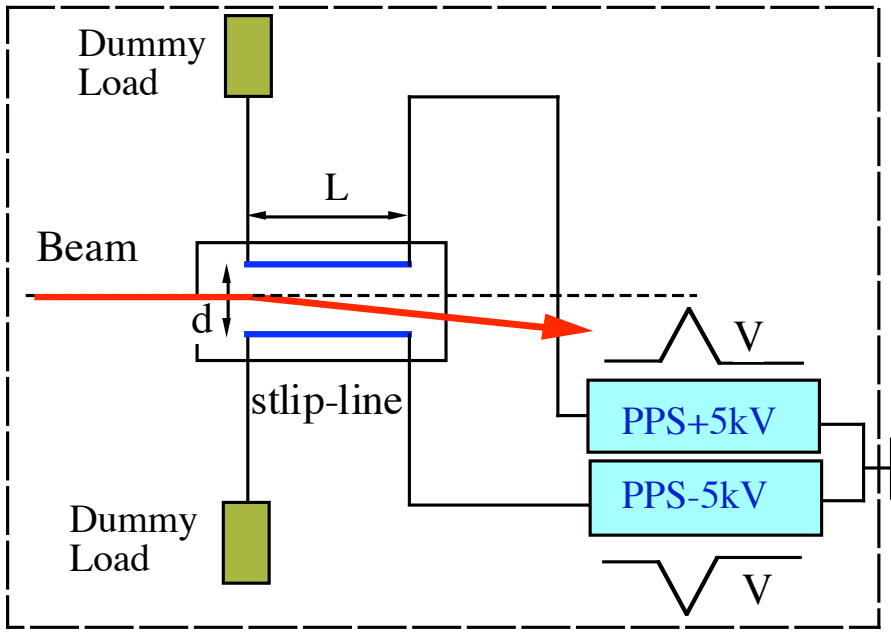
Rise time :1%~100%
Fall time : 100%~1%

- *The counter direction kicker pulse makes the transverse kick to the beam (Panofky-Wenzel theorem)*
- *The kick field is defined as the integration of the electromagnetic field when the beam go through the strip-line.*

Design of Strip-line kicker system



~20 units for 0.6mrad kick angle



PPS : Pulse Power Supply

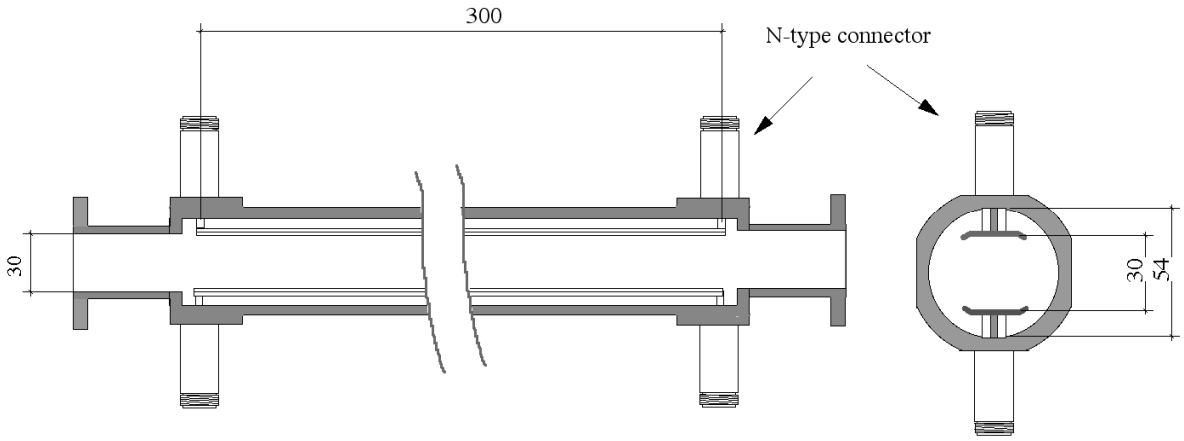
$$\Delta\theta = 2g\frac{eV}{E}\frac{L}{d}$$

L = strip – line length
d = distance between the electrodes
V = pulse voltage
E = Beam energy

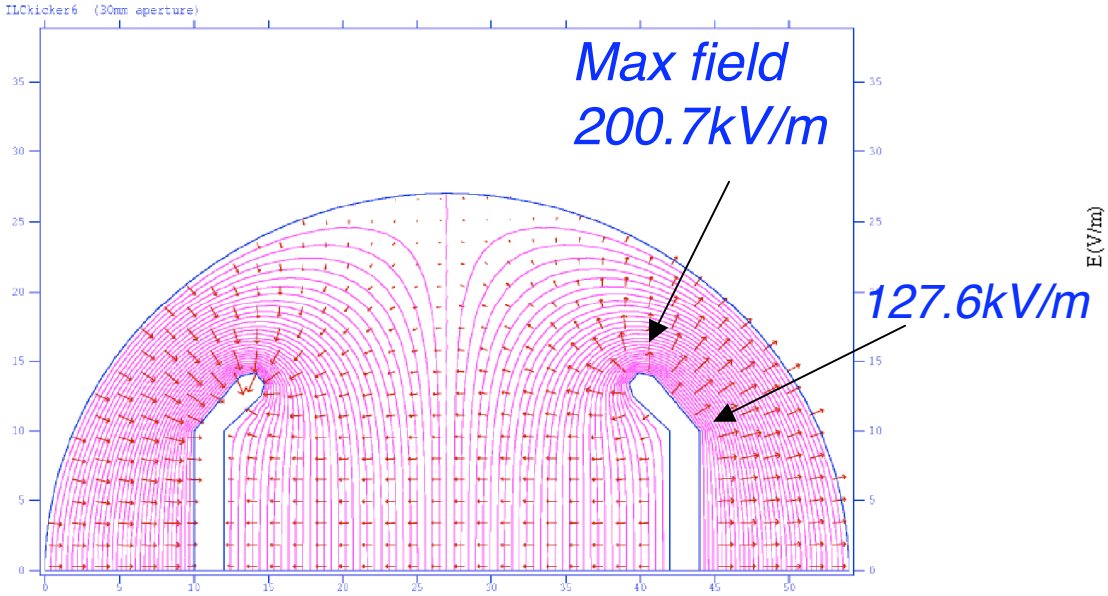
$$g = tanh\left(\frac{\pi\omega}{2d}\right)$$

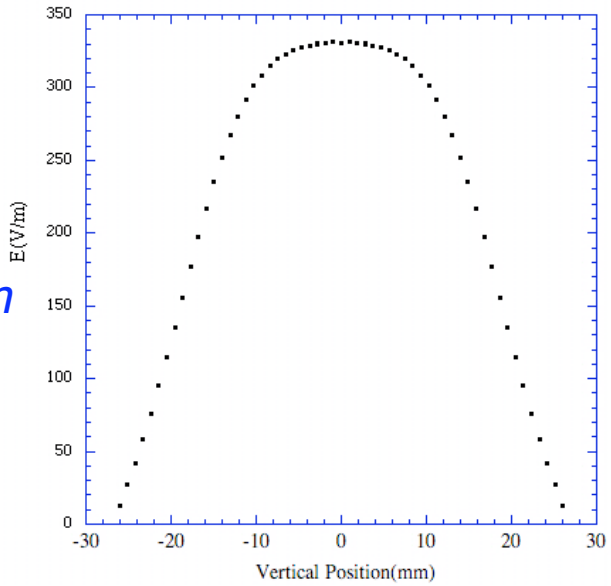
ω = strip – line width
d = distance between the electrodes

Design of Strip-line electrode



The shape of the electrode is designed to keep good uniformity of the deflecting field. The calculated flatness is 0.07% in the area of +/-1.8mm from the center.





Geometric factor(analytical) =0.955

Pulse power supply

There is 3 types of candidates for the kicker pulse source.

1) HTS-50-08-UF(BEHLKE GmbH)

FET ON switch module

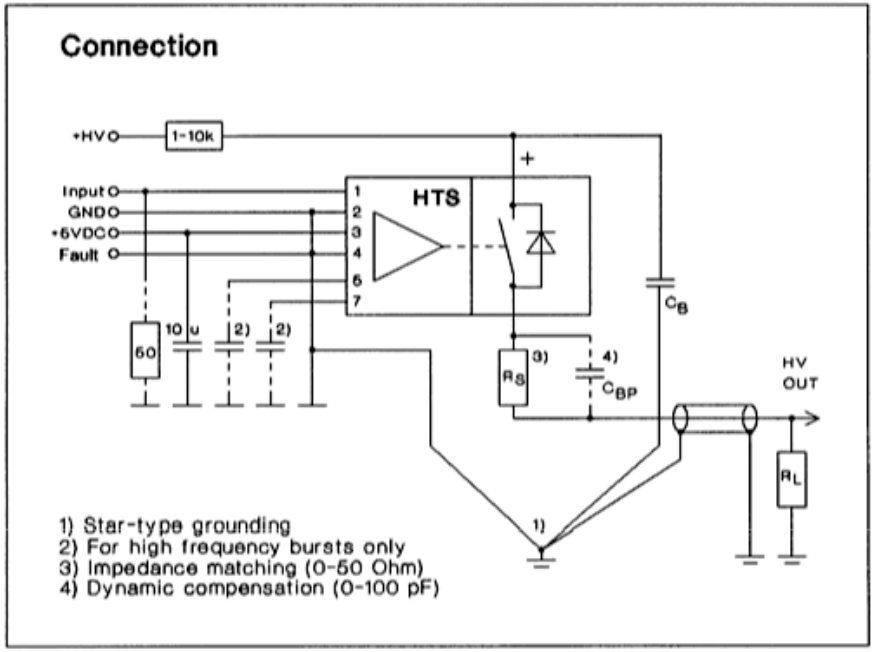
2) Adder Drive Boards(LLNL)

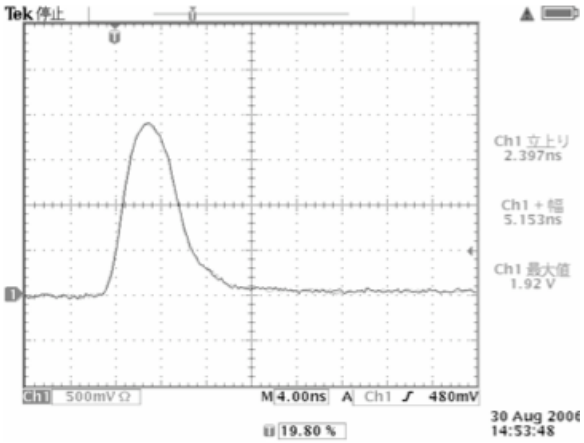
FET ON switch(stacked)

3)FPG 5-3000M(FID GmbH)

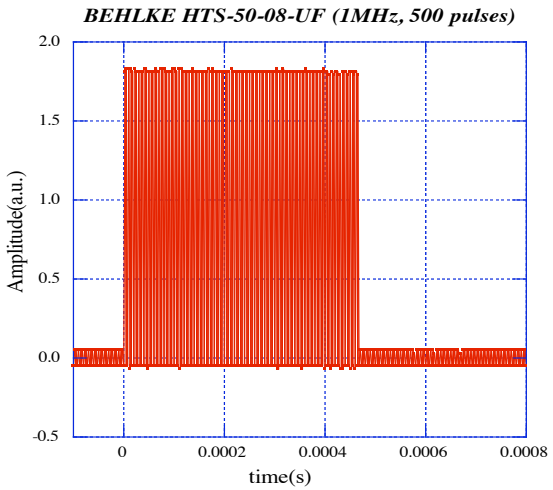
Fast Recovery Diode OFF switch

BEHLKE HTS-50-08-UF



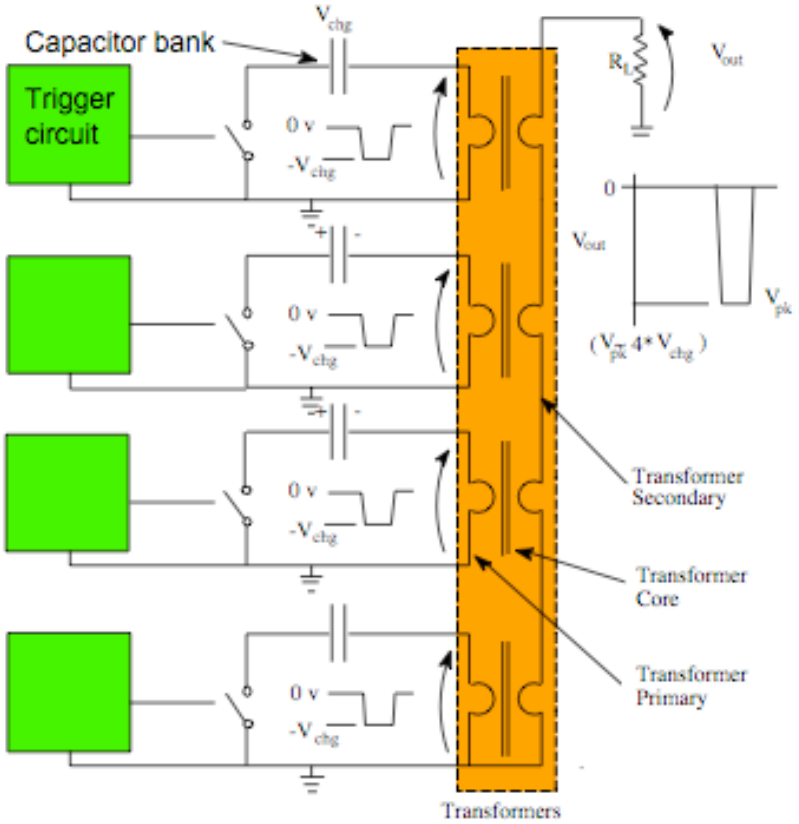


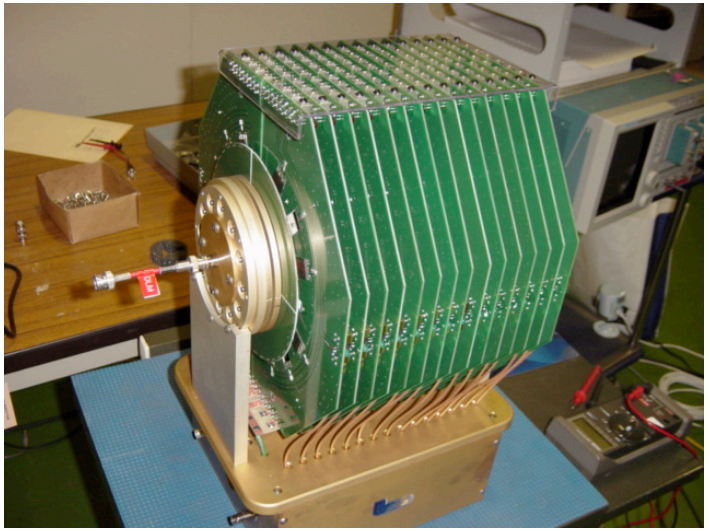
Rise time ~3ns at 2.5kV output

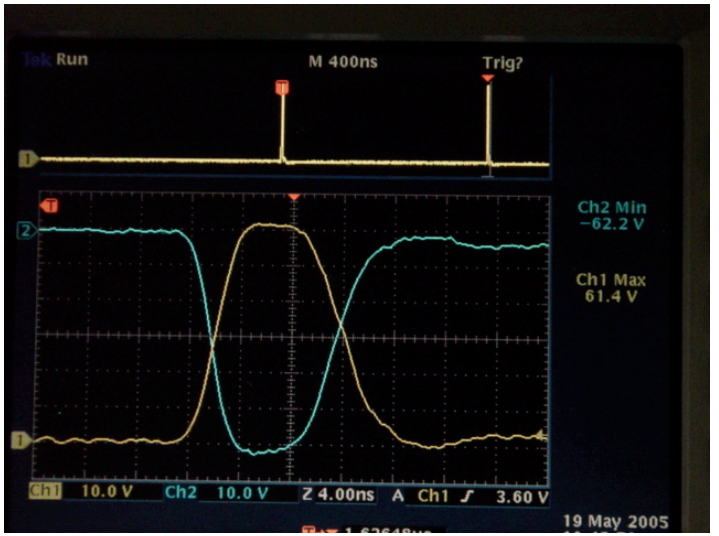


Burst pulses(1MHz, 500pulses)
droop:5x10^{-3}

Adder Drive Board(LLNL:Ed Cook)





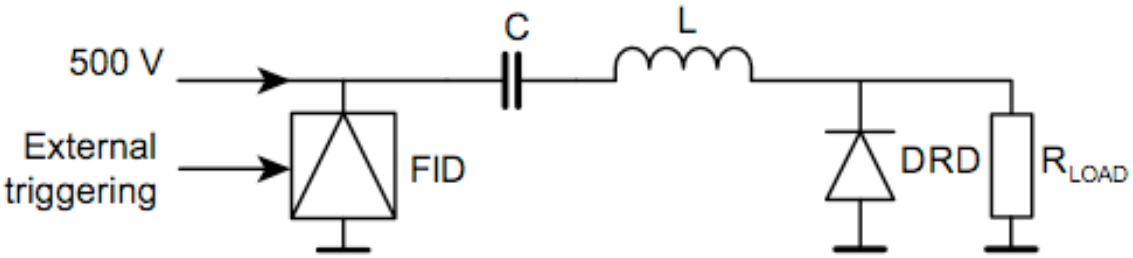


This high voltage pulse power supply is basically developed for the drive pulse of the induction linac.

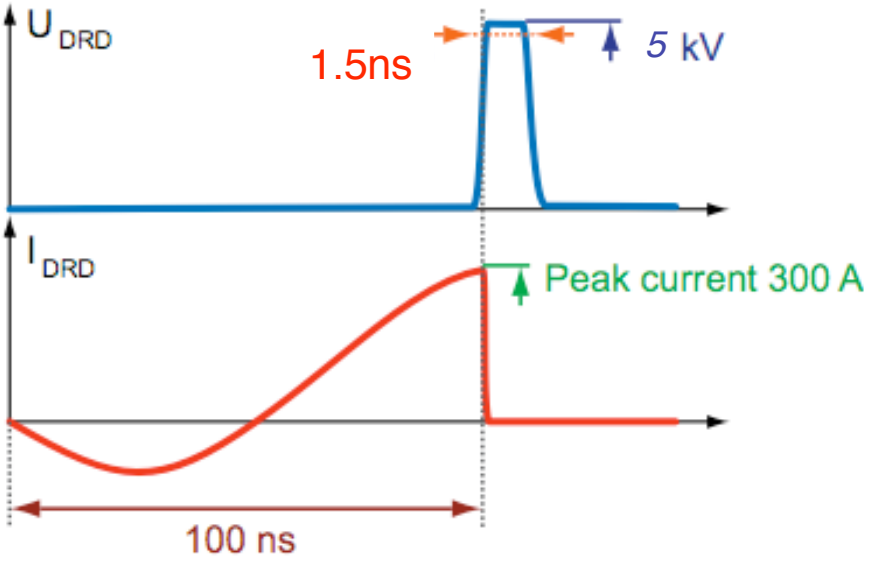
+/-3.1kV, 500kHz, 500 pulses, ~4ns rise time, 10ns pulse width

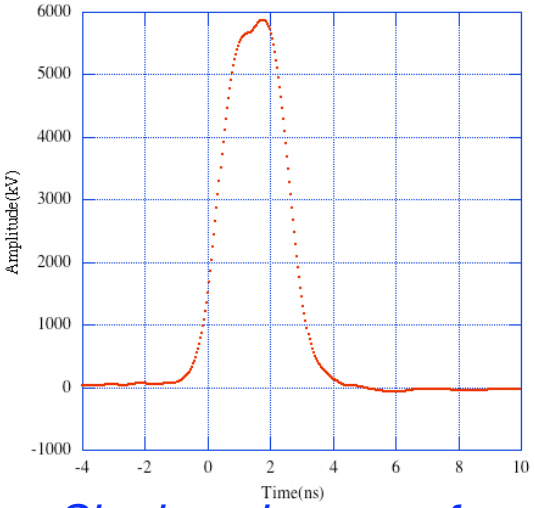
FET(DE275) on time: 2ns

FID FPG5-3000M(1)

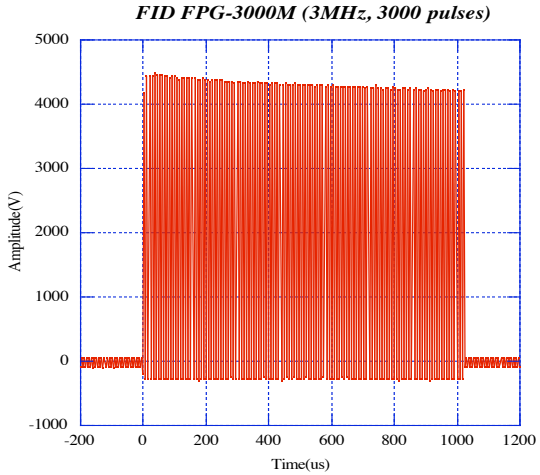


FID : Fast Ionization Dynistor
DRD : Drift step Recovery Diode



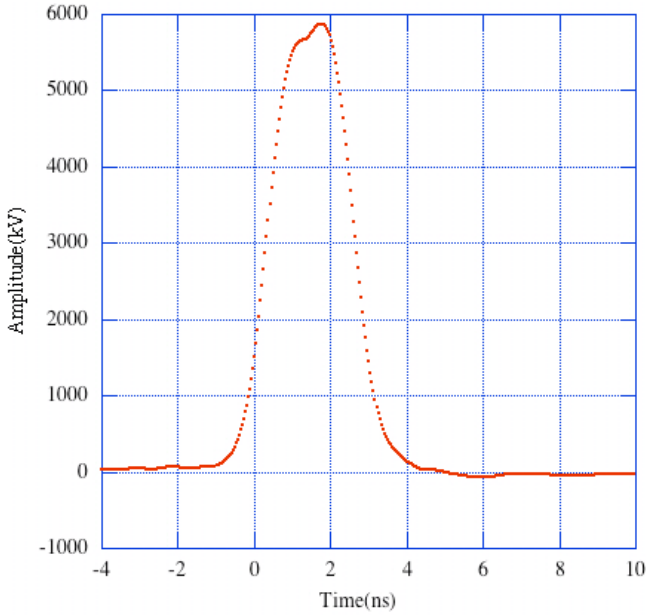


Single pulse waveform

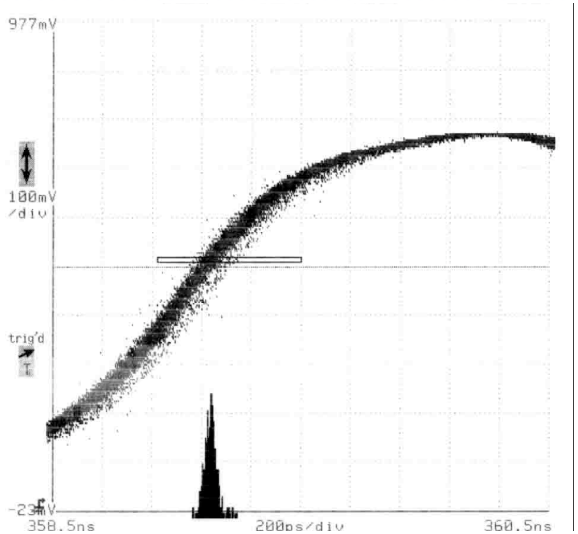


Burst pulses(3MHz, 3000pulses)
droop : ~3%

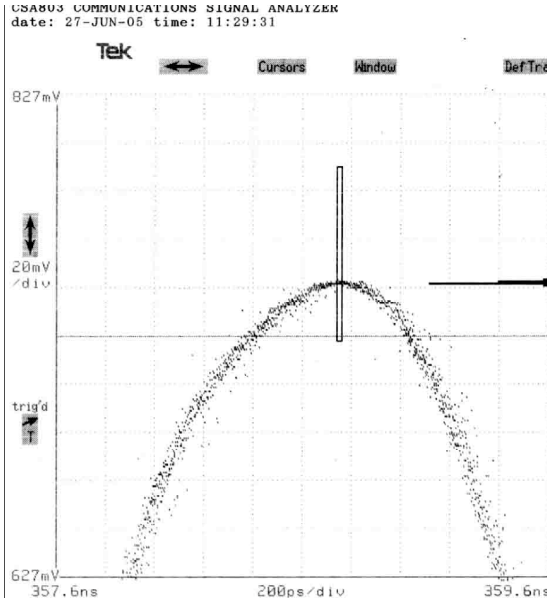
FID FPG5-3000M(2)



Pulse width(FWHM) = 2ns
Pulse height = 5.8kV
Rise time = ~1.5ns(5%~95%)
Time jitter = ~29ps
Amplitude Jitter = 0.72%
(limited by the scope resolution)



Timing jitter measurement
29ps(1σ)

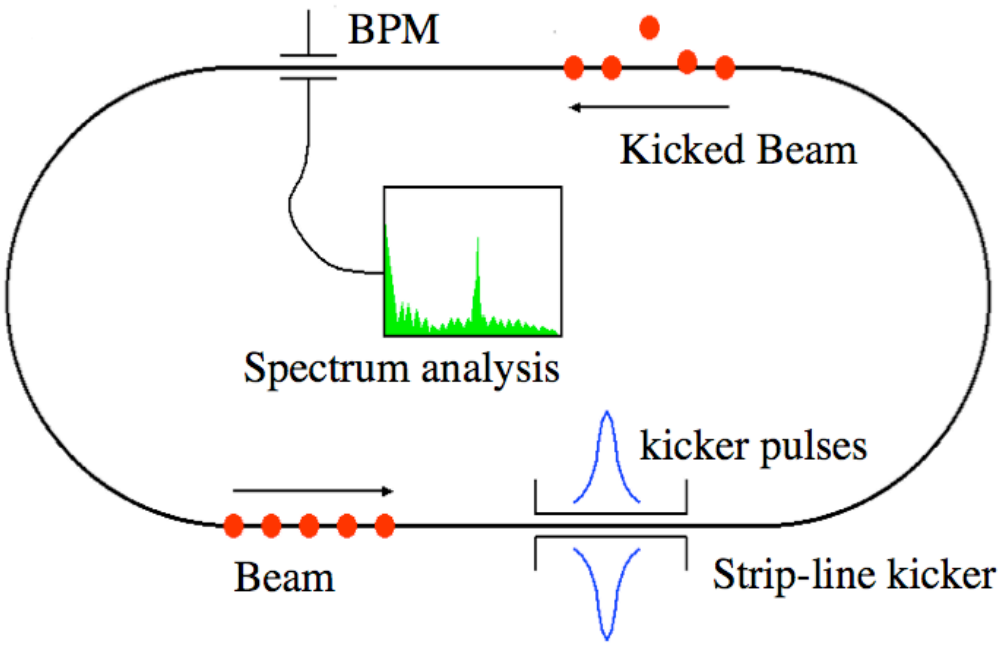


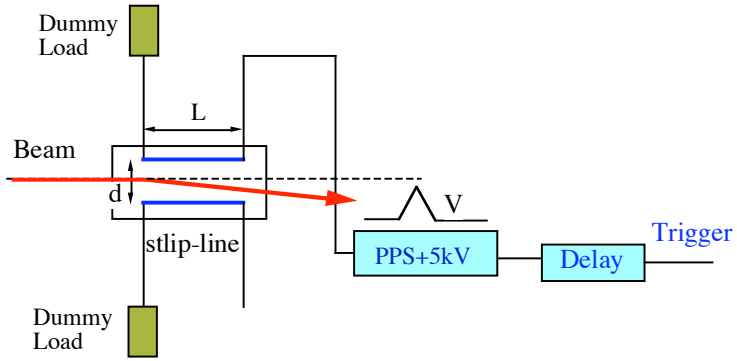
Amplitude jitter measurement
0.72%(1σ)

Comparison of pulse power supplies

	Rise Time	High Voltage	Rep. rate
HTS-50-08	3ns △	2.5kV △	1MHz △
Adder Drv.	4ns △	>+/-3.1kV ◎	>500kHz △
FPG5-3000M	1.5ns ◎	5kV ○	3MHz ◎

Beam kick experiment at ATF-DR





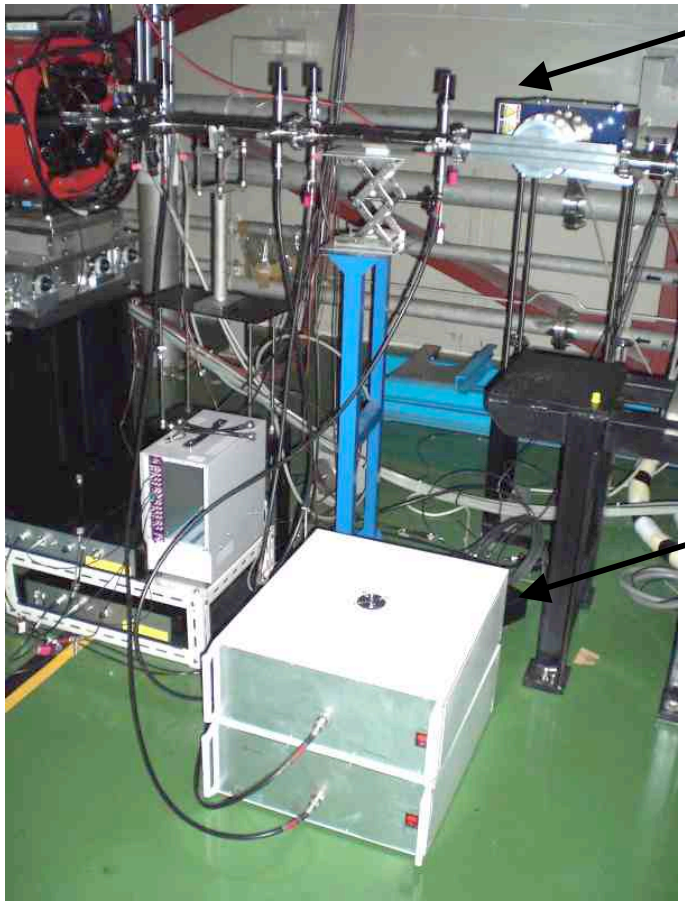
Single unit of strip-line kicker

A) Kick angle measurement by Single-shot BPM

B) Rise/fall time measurement by Turn-By-Turn BPM

C) Rise/fall time improvement by Waveform compensator

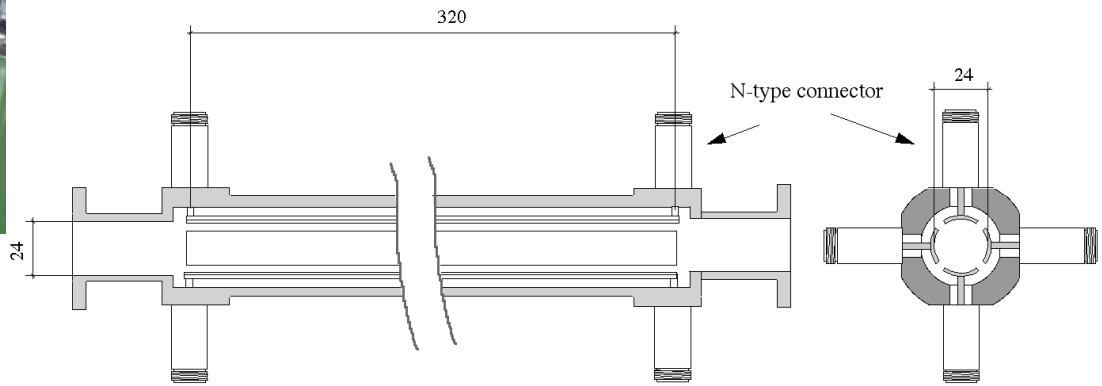
Strip-line electrode for ATF-DR experiment



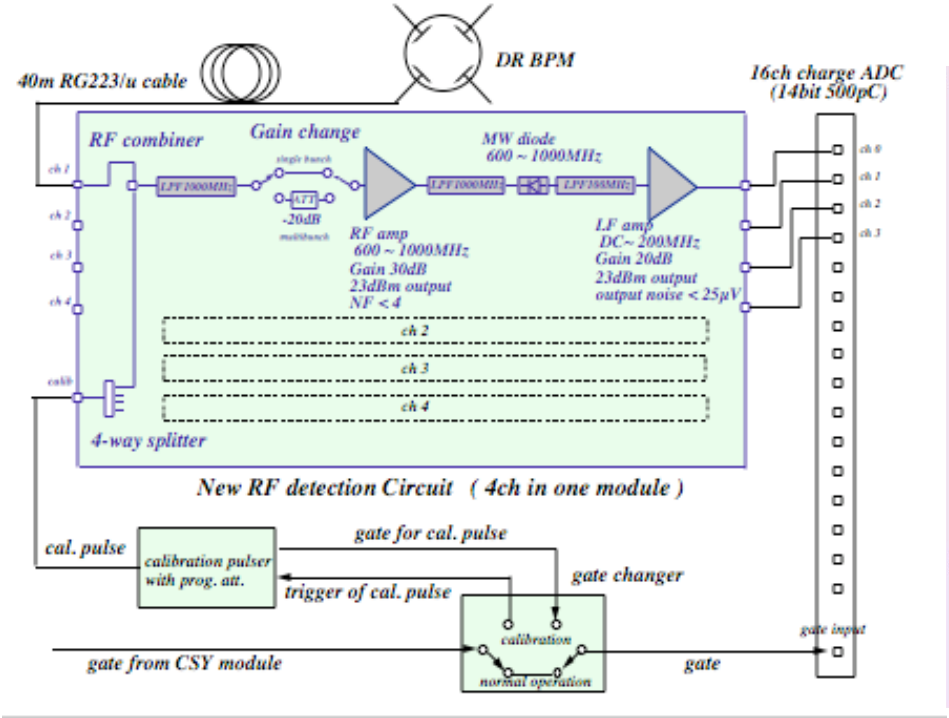
Strip-lines

Pulse power supplies

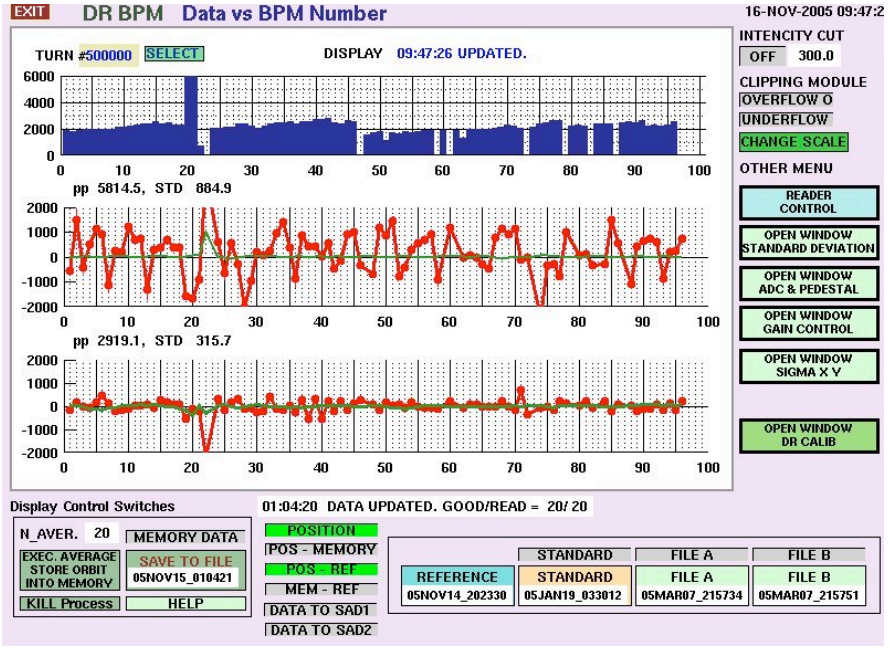
Two strip-line electrodes are used for the experiment which was designed for tune measurement of ATF-DR.



Single-shot BPM system

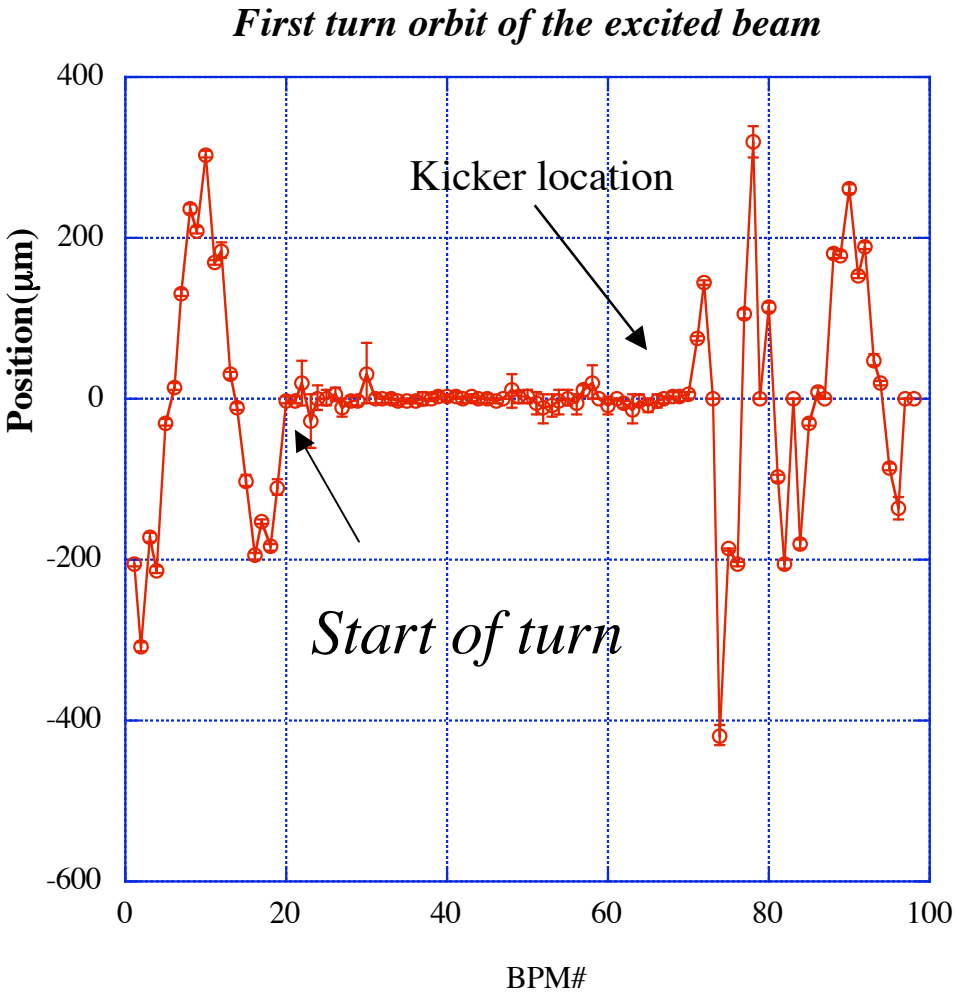


96 BPMs in DR



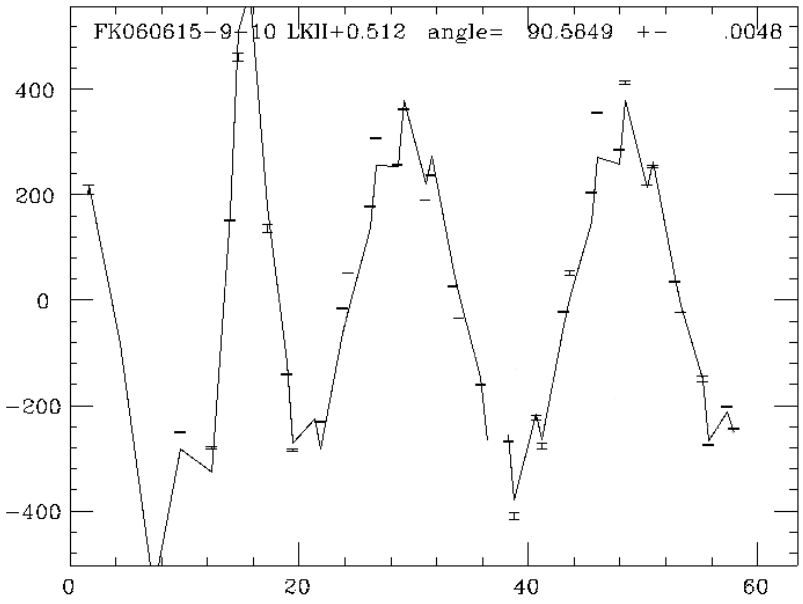
Resolution : ~2μm(rms) at 1x10¹⁰e
(Electronics)

Result of kick angle measurement



The kick angle is estimated from the kicked orbit and R12. The graph shows one turn orbit just apply the beam kick. The kicked orbit starts from #70 BPM. The bellow graph shows the kick angle calculation by SAD.

$$min.\sum[\theta \bullet R12 - \Delta x]$$

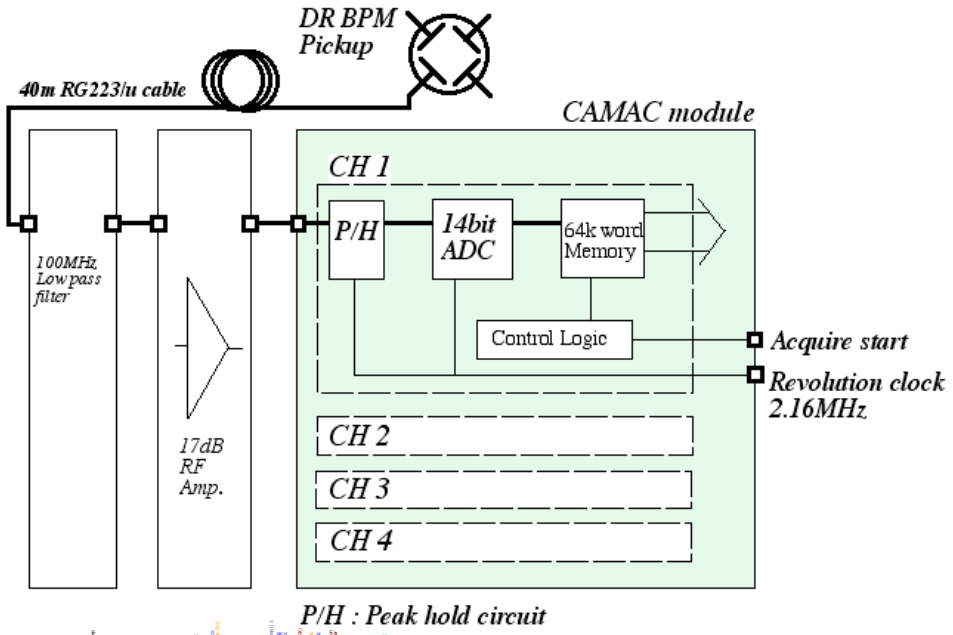


Kicked orbit fit by SAD

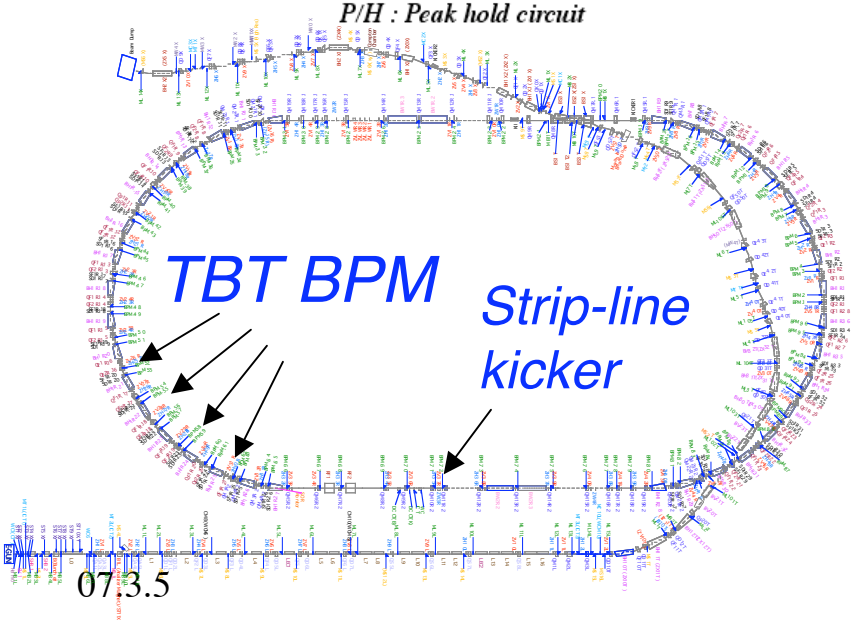
Kick angle =91.1+/-1.8μrad

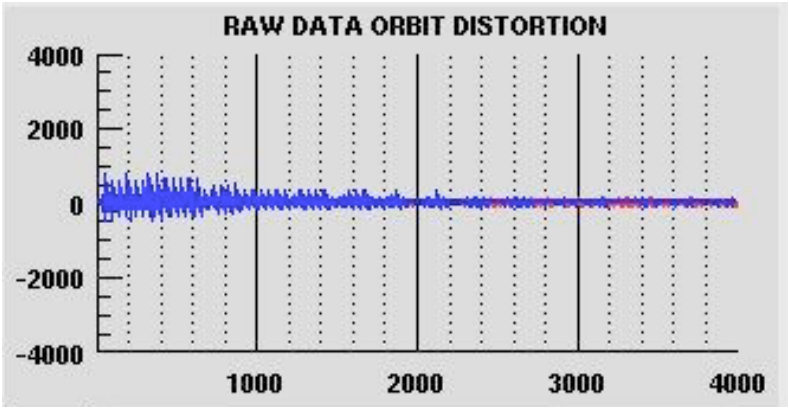
BPM Error(1σ) mean =6.6μm

Turn-By-Turn(TBT) BPM system

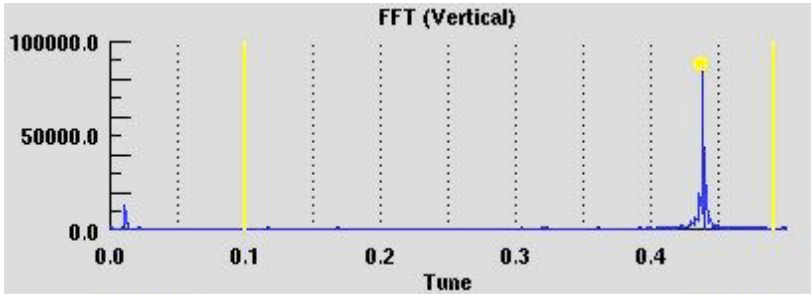


P/H : Peak hold circuit





Beam oscillation during 4000 turn

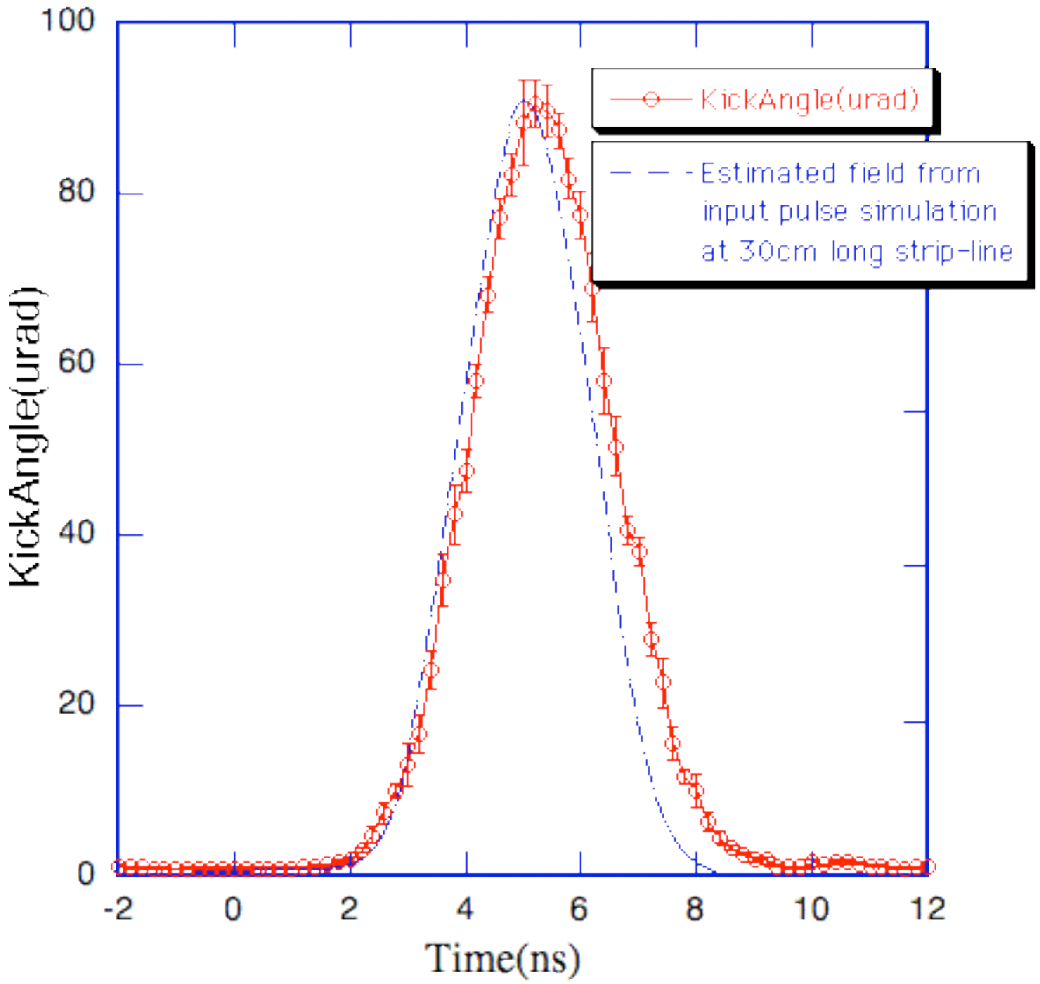


Frequency spectrum

$$y' \propto F(f)$$

This measurement can avoid the noise effect from the other frequencies.

Timing scan of the kick pulse

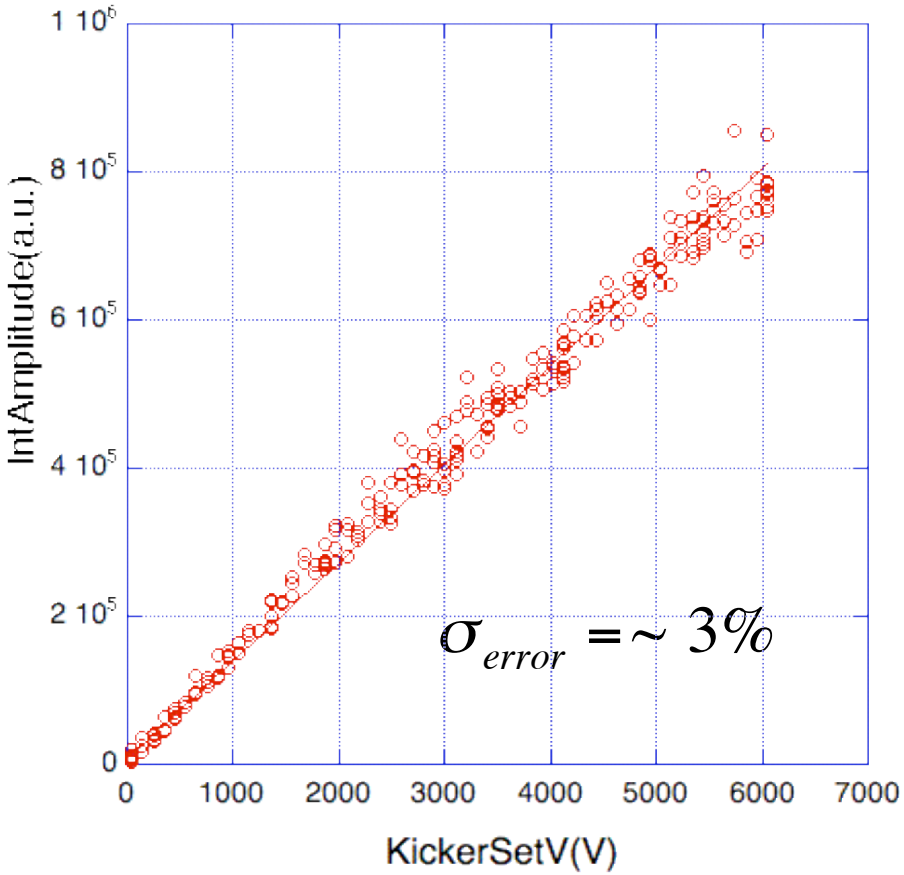


Kick angle is estimated from the amplitude of the betatron frequency of the FFT signal.

Beam kick profile
The timing of the kick pulse is scanned for the beam timing with 200ps steps.

Rise time = 3.2ns
(1%~100%)
Fall time = 4.0ns
(100%~1%)

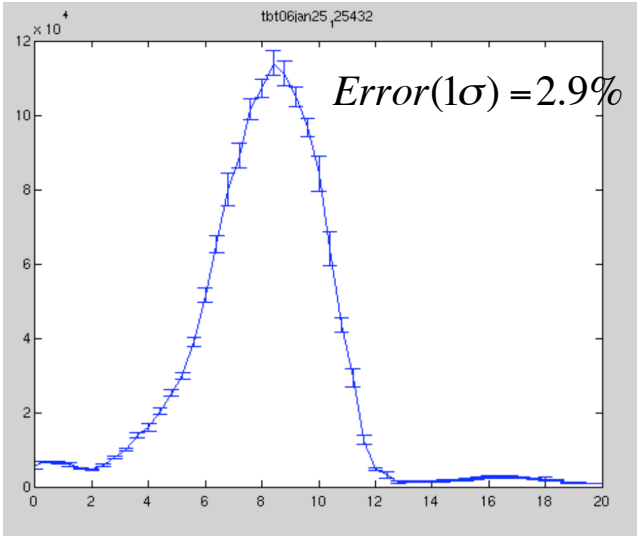
Measurement error



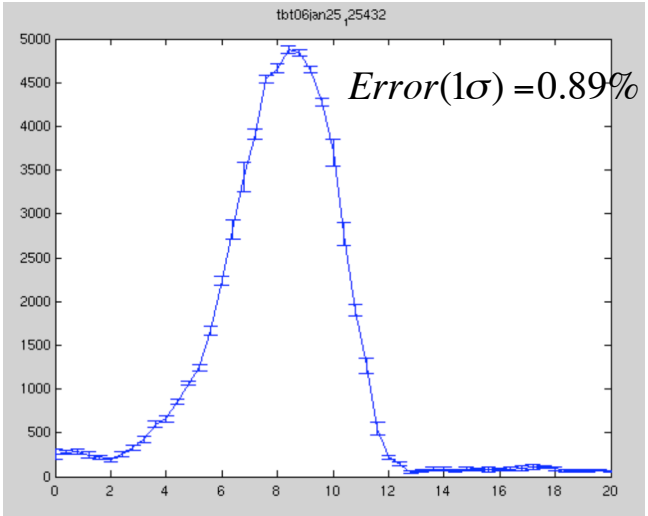
Linearity of the oscillation amplitude

The Betatron amplitude of FFT is affected by the impedance effect , chromaticity, dynamic aperture, etc,. The measurement need to chose minimize these effects.

Difference of turn number for FFT

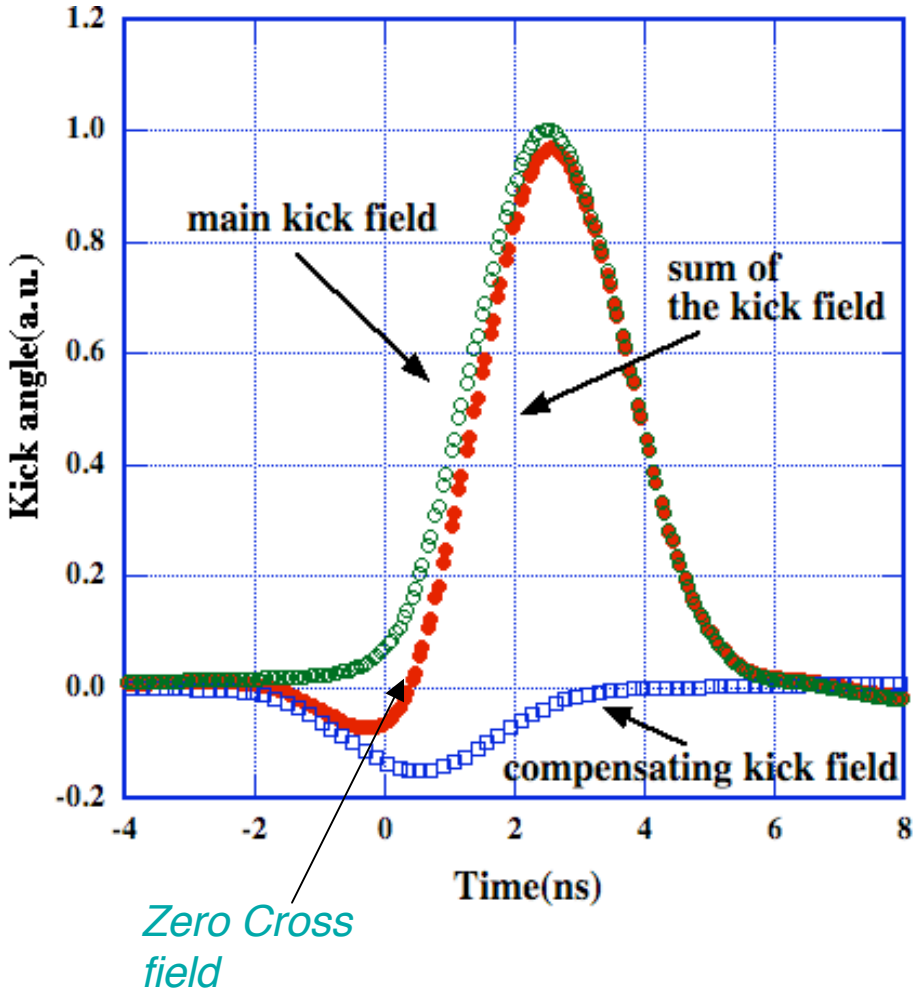


Beam kick profile(4096 turns data)

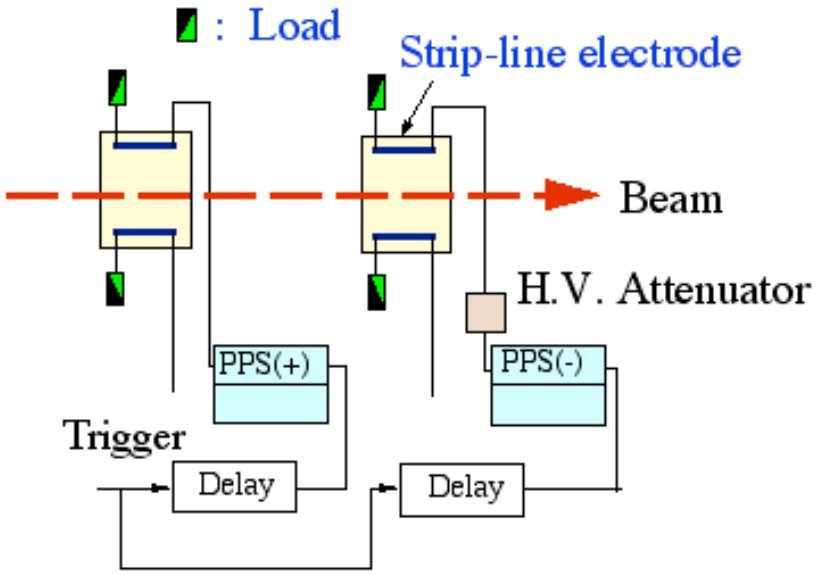


Beam kick profile(64 turns data)

Waveform compensator



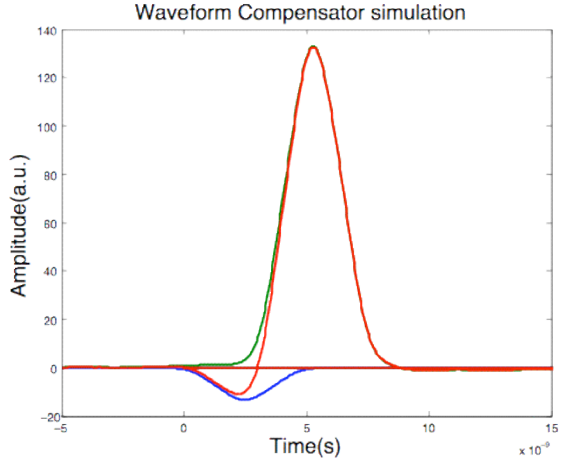
Simulation of waveform compensator



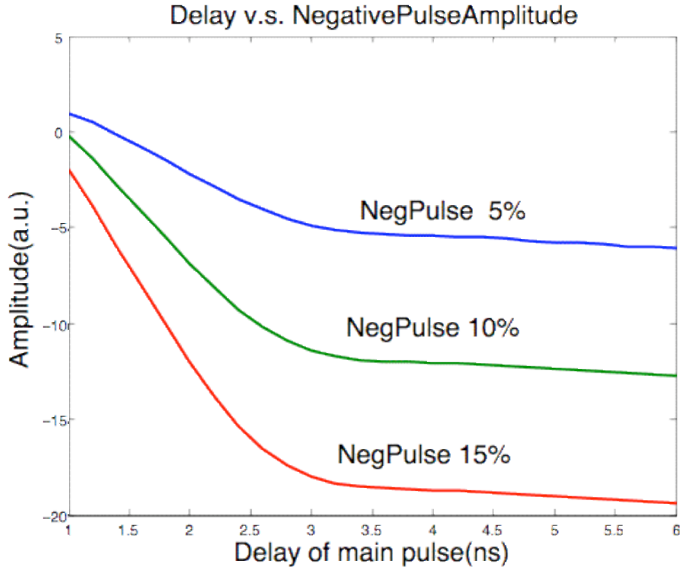
Experimental set up

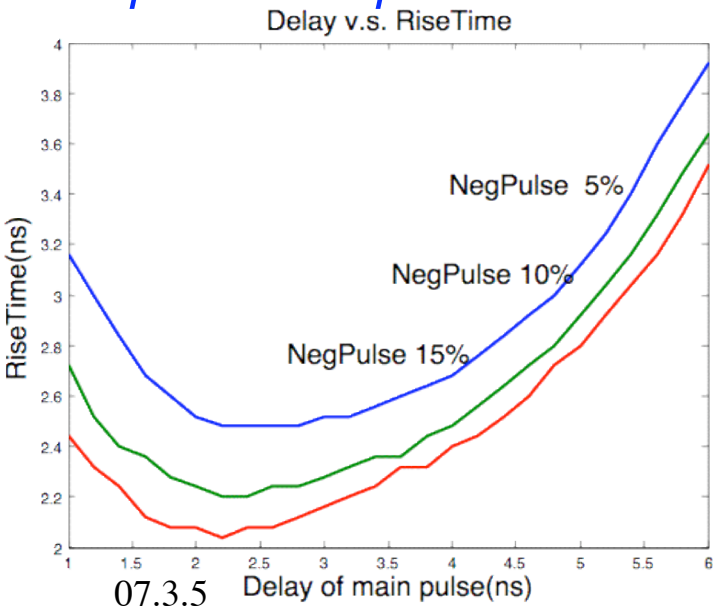
The rise/fall time can be improved by the combination of the positive and negative pulses which have different timings and different amplitudes.

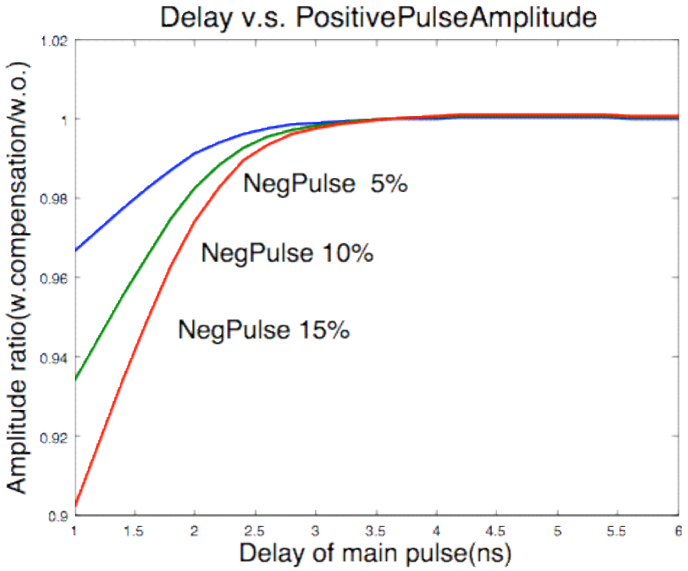
Waveform simulation



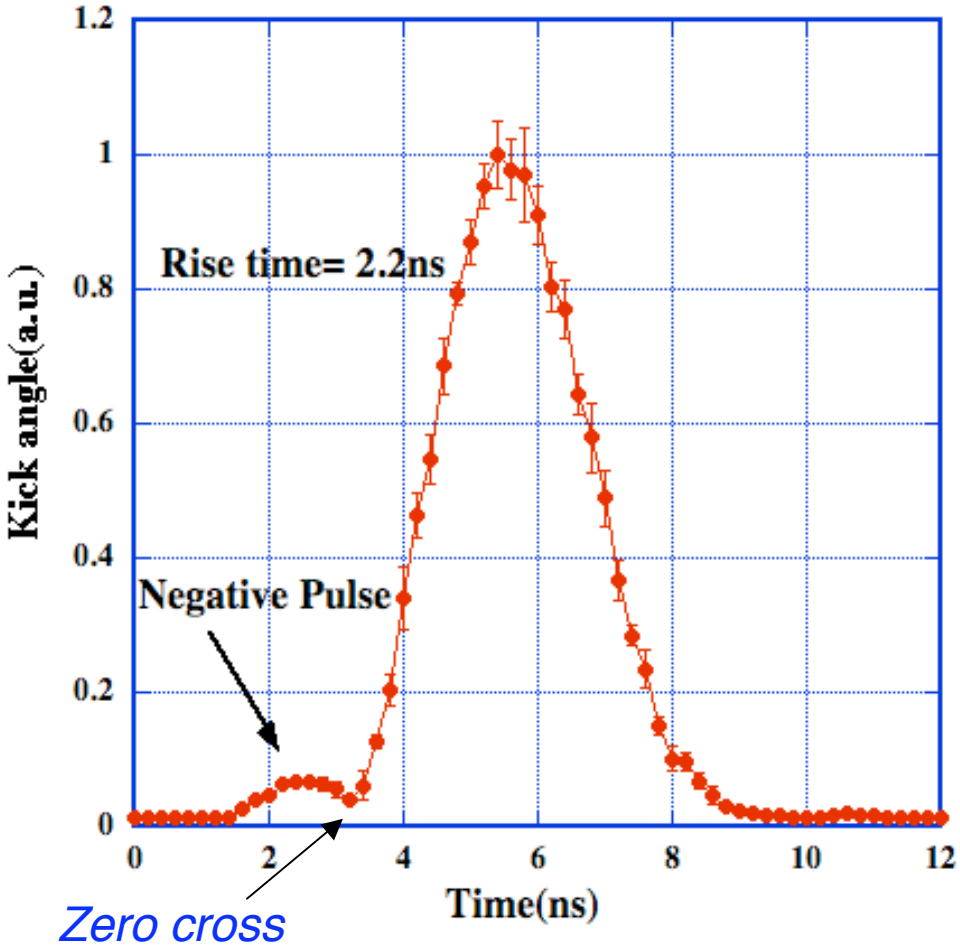
The rise time simulation for the timing and the amplitude of the compensation pulse

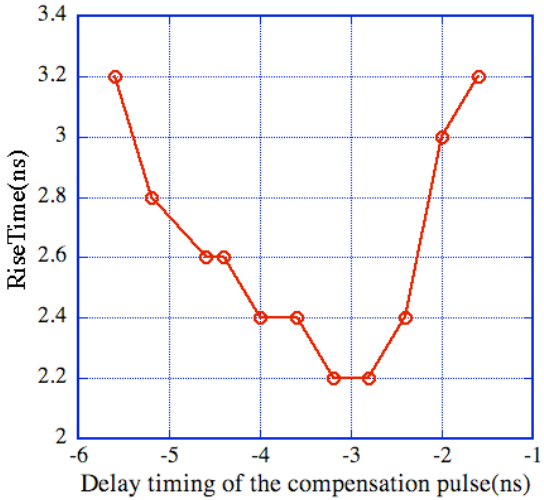


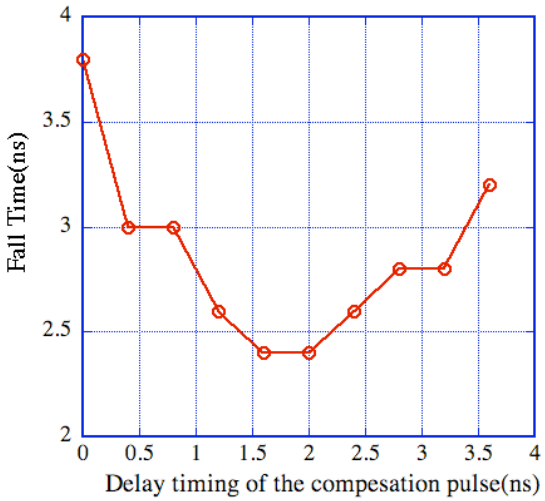




Rise time improvement with Waveform compensator

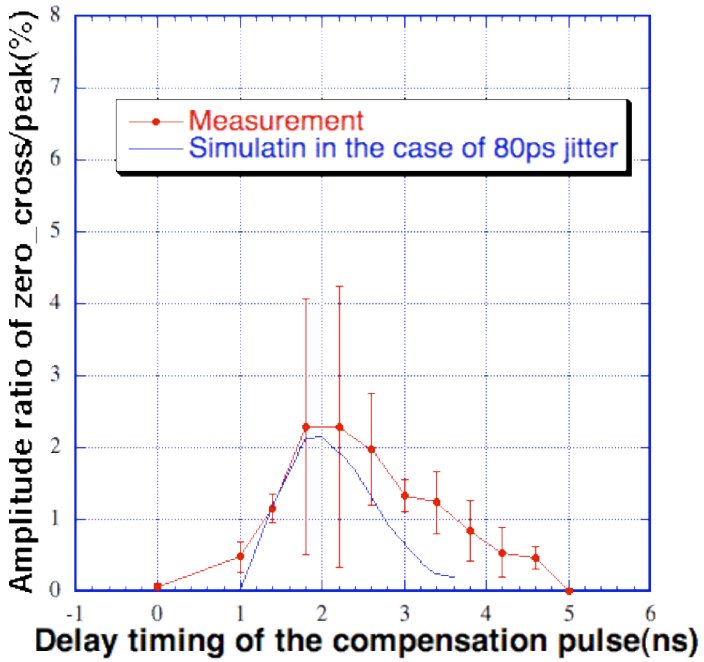


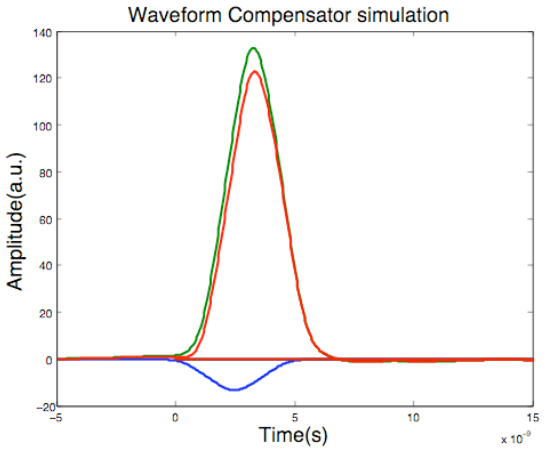




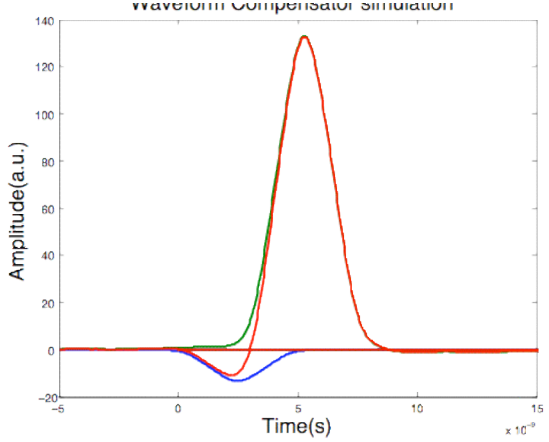
Rise/fall time improvement v.s. timing

Timing jitter

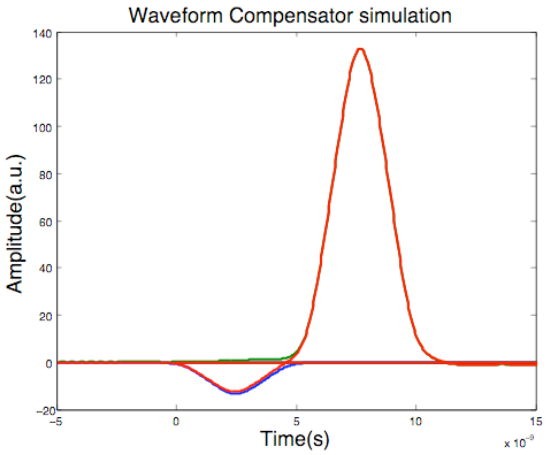




1ns delay



2ns delay



5ns delay

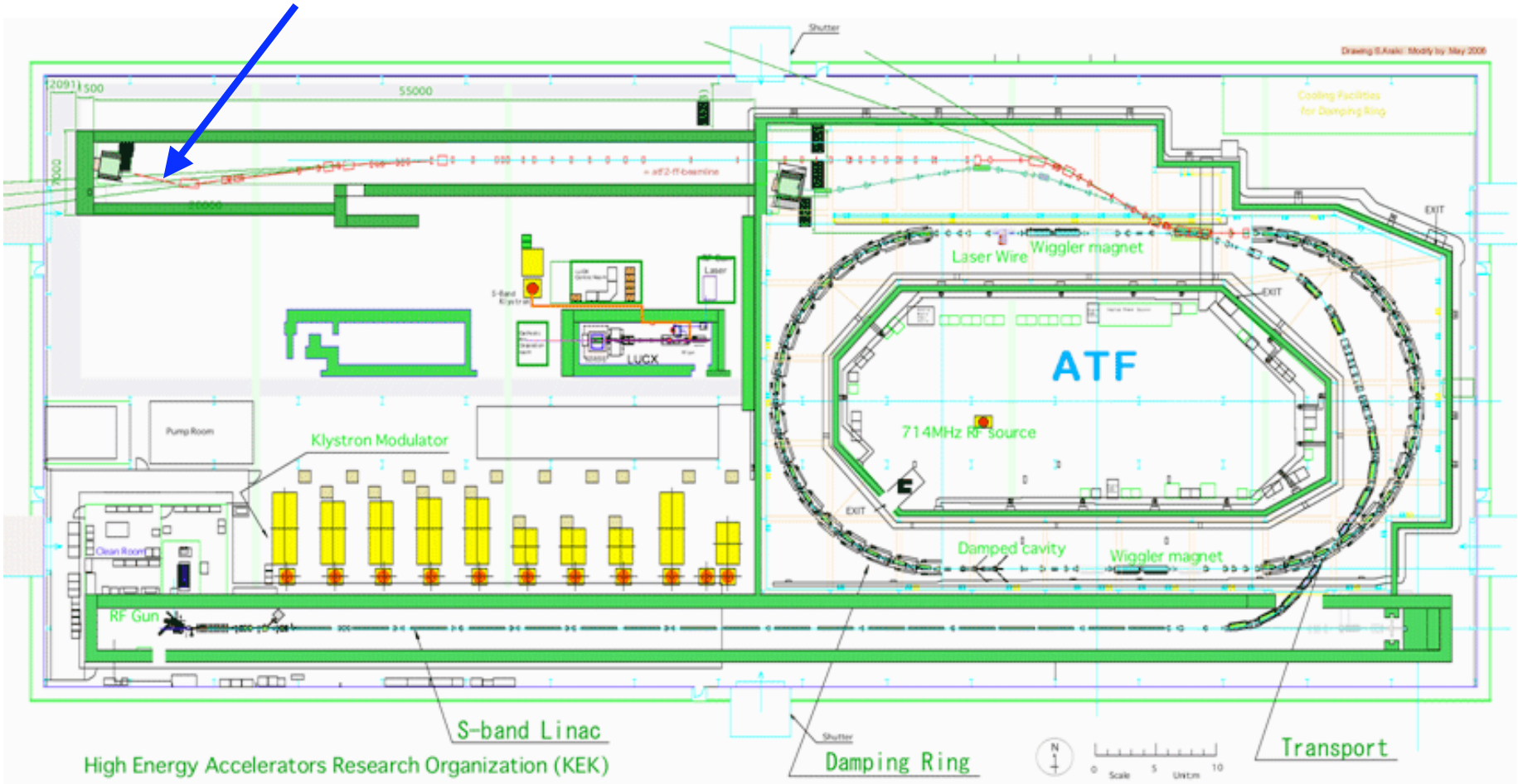
The zero cross point of two pulses didn't reach to zero in the measurement. The reason comes from,

- the timing jitter between the beam and the kick pulse.
- the amplitude depends on the slope of the kick field.
- it is agreed with the simulation in the case of the 80ps time jitter

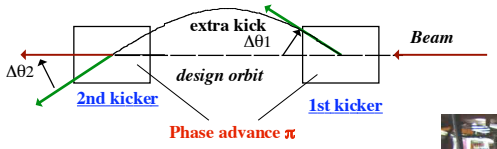
To cure the effect, the timing jitter has to be minimize.

ATF2

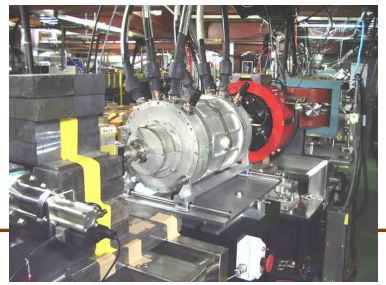
ATF2 - 40nm beam production, measurement ,
single bunch and multi bunch beam handling

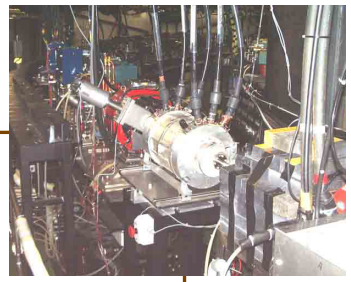


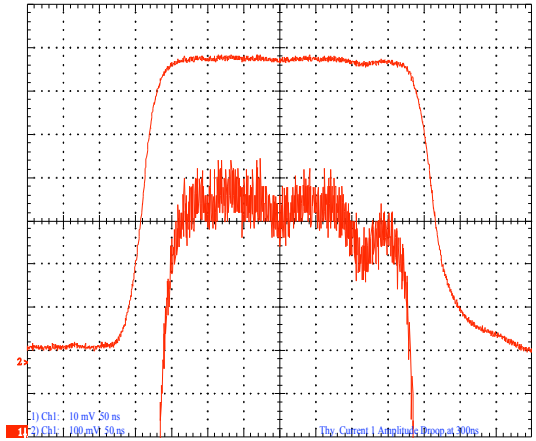
Present beam extraction (Pulse magnet kicker system)



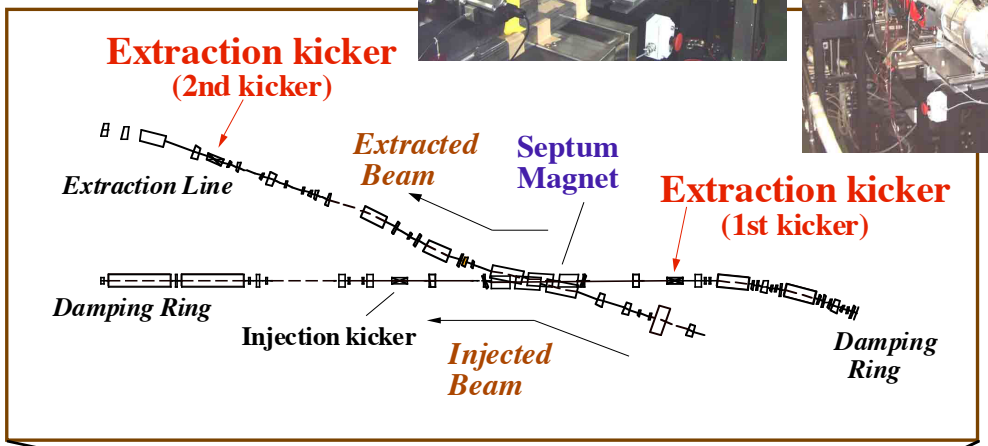
Kick angle Stability
$1x10^{-3}$ -> $2.8x10^{-4}$

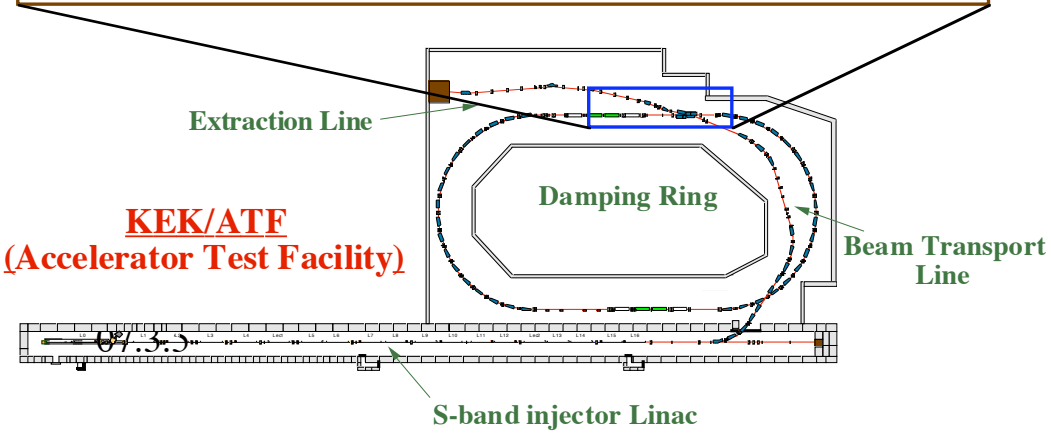


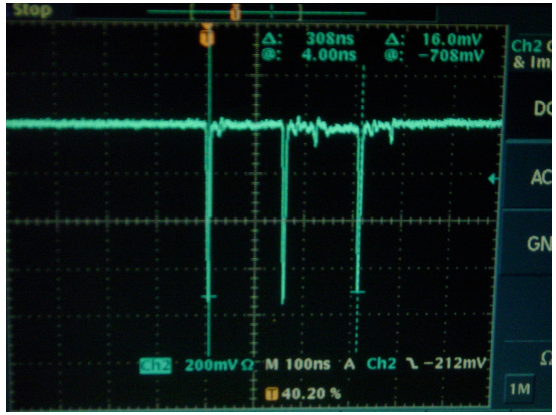




308ns pulse width

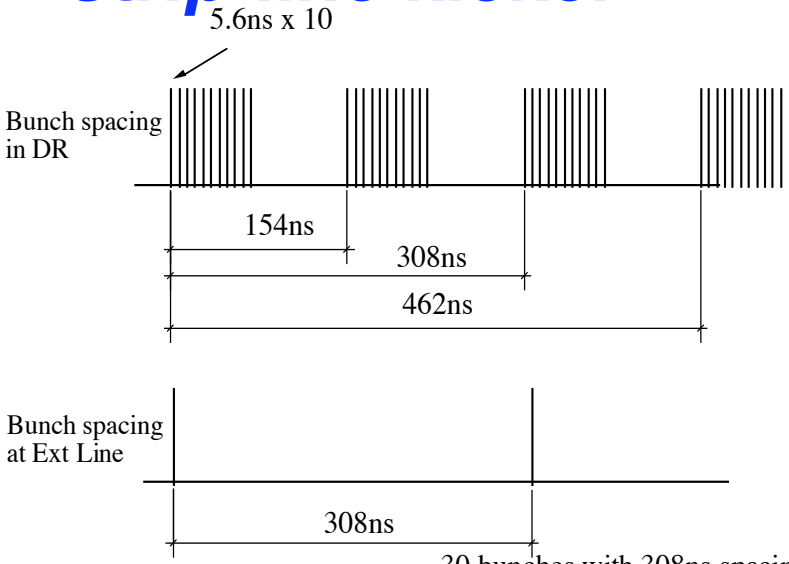






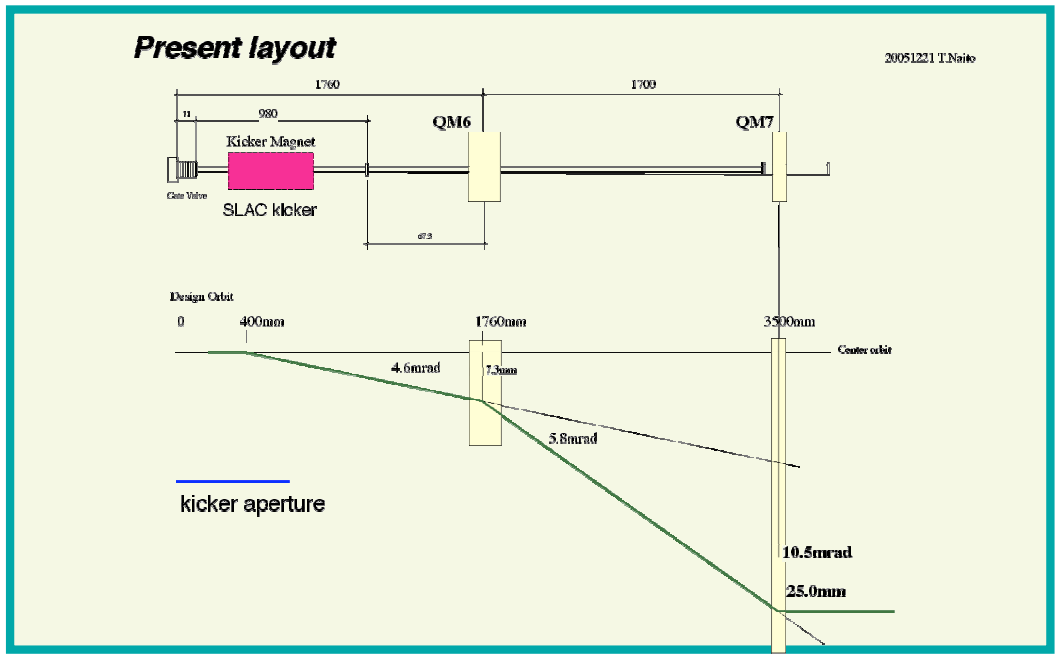
3 bunches, 154ns spacing

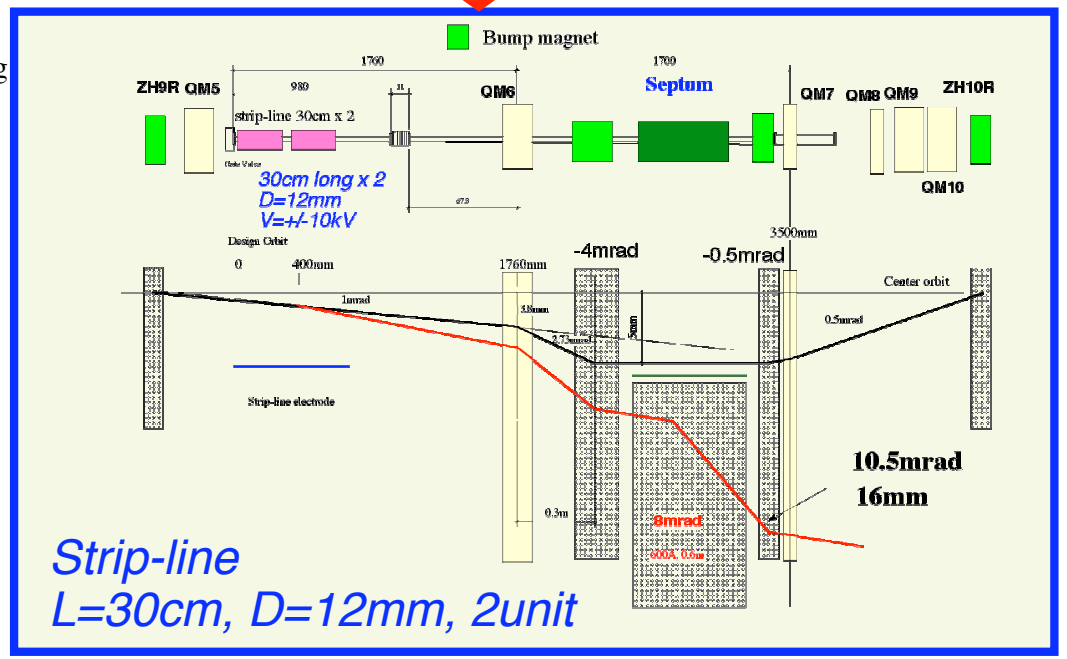
Beam extraction experiment with strip-line kicker



Multi-bunch beam extraction with strip-line kicker is under designing. One of the problem is no space for the strip-line kicker electrodes. We are considering to add the pulse bump orbit.

07.3.5





Summary

1. Development work of Multiple unit strip-line kicker system is carrying out at KEK-ATF. The tentative strip-line electrode shape is designed.
2. Three type of the pulse power supply are evaluated for the strip-line kicker pulse source.
3. The beam kick test of the single unit was carried out in the KEK-ATF DR. The measured rise time is 3.2ns and the fall time is 4.0ns, respectively.
4. The rise/fall time improvement by the waveform compensator was tested. The rise time is improved up to 2.2ns.
5. The beam extraction from the DR to the extraction line is under designing for the multi-bunch extraction which is same scheme of the beam extraction from ILC-DR to RTML.