

# Progress with kicker studies at KEK-ATF

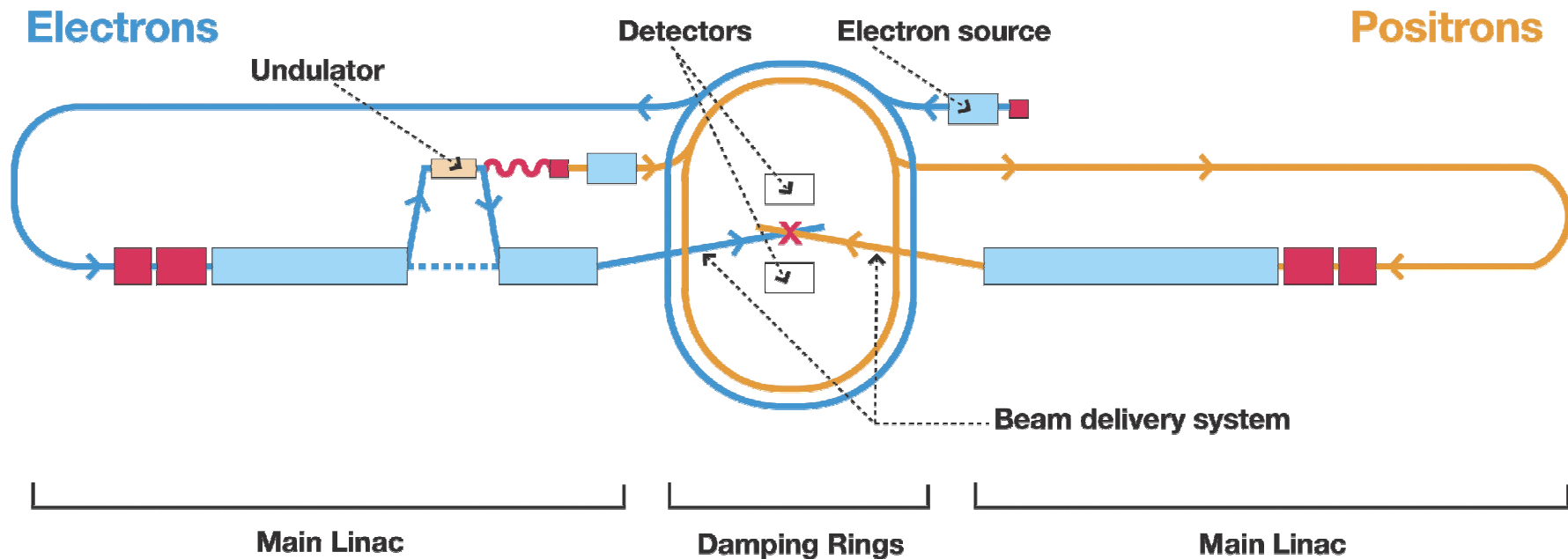
T.Naito(KEK)  
ILCDR07 INFN-LNF

# Parameters of ILC

The length of the bunch train in the linac is  $\sim 300\text{km}$  long which should be compressed in the DR and should be decompressed at the downstream of the DR.

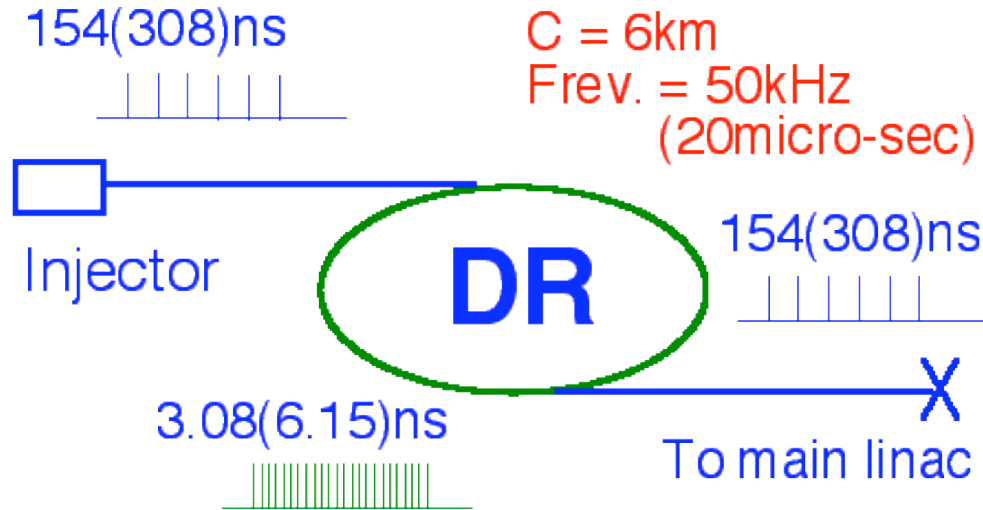
## parameters

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

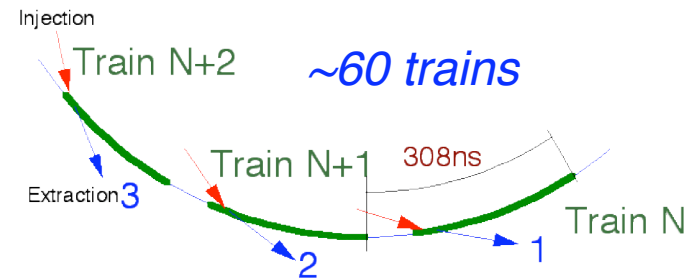
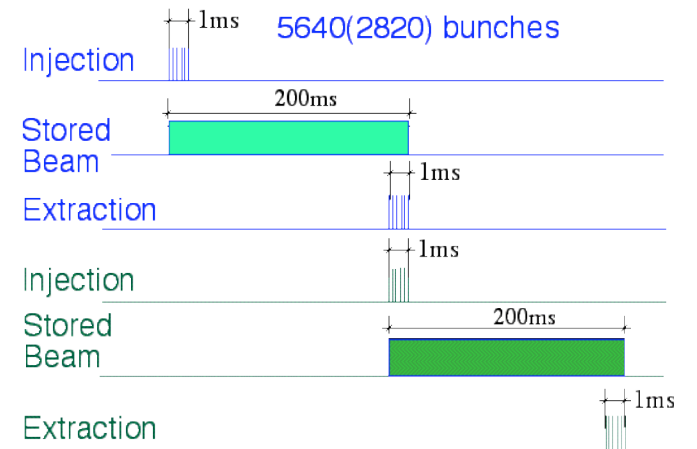


# Beam cycle of DR

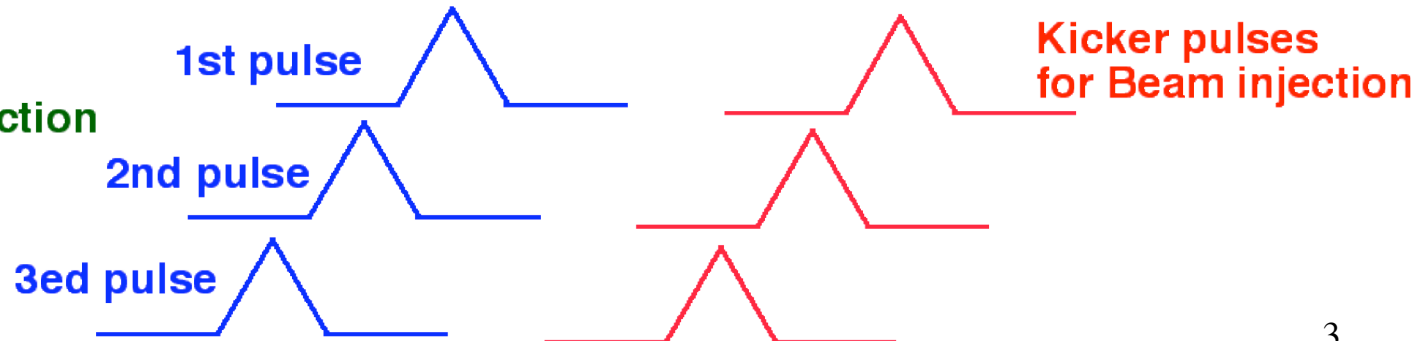
## Bunch spacing



## Beam Storage Sequence in DR

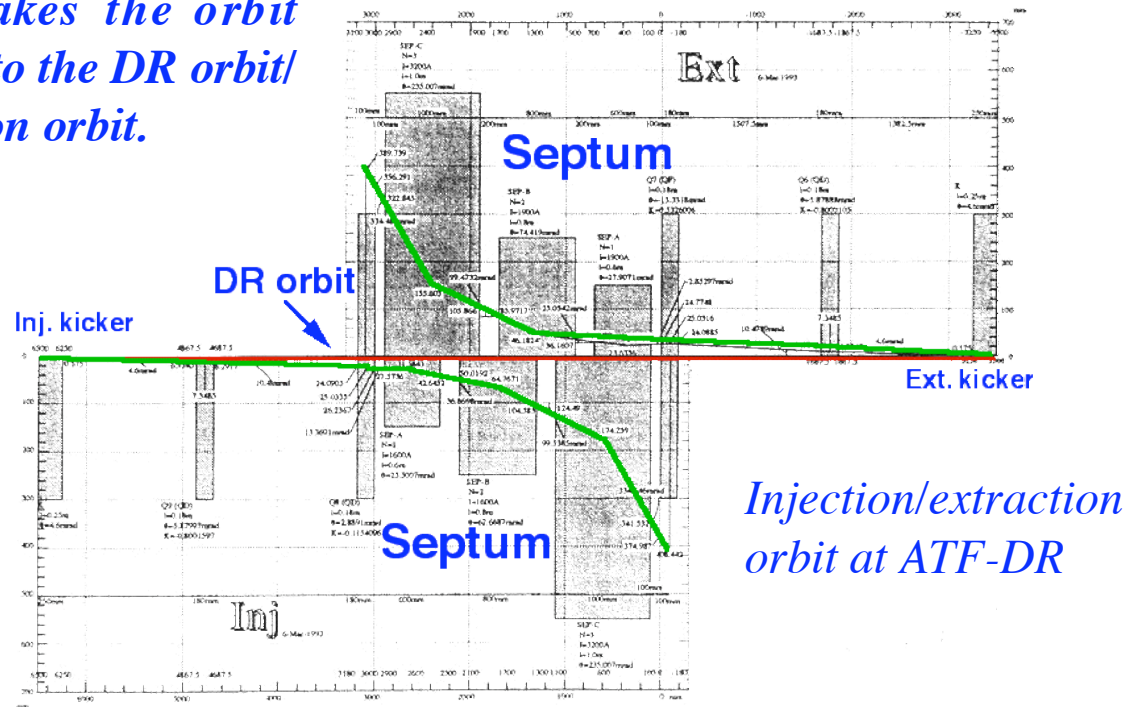


Kicker pulses for Beam extraction



# ILC DR kicker parameters

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



## Specification

Kick angle  $\theta \sim 0.6 \text{ mrad}$  or  $\int B dl \sim 0.01 Tm @ 5 \text{ GeV}$ ,  $\beta \sim 50 \text{ m}$

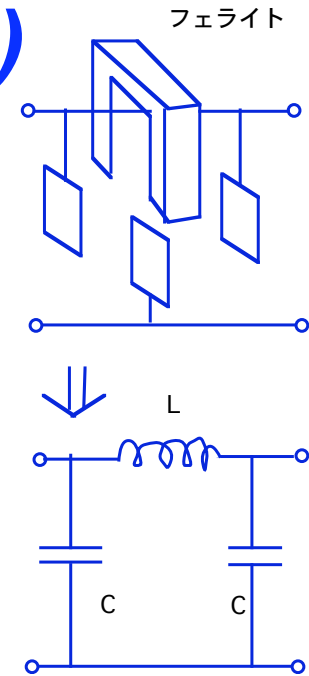
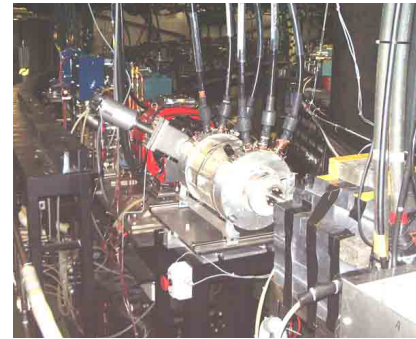
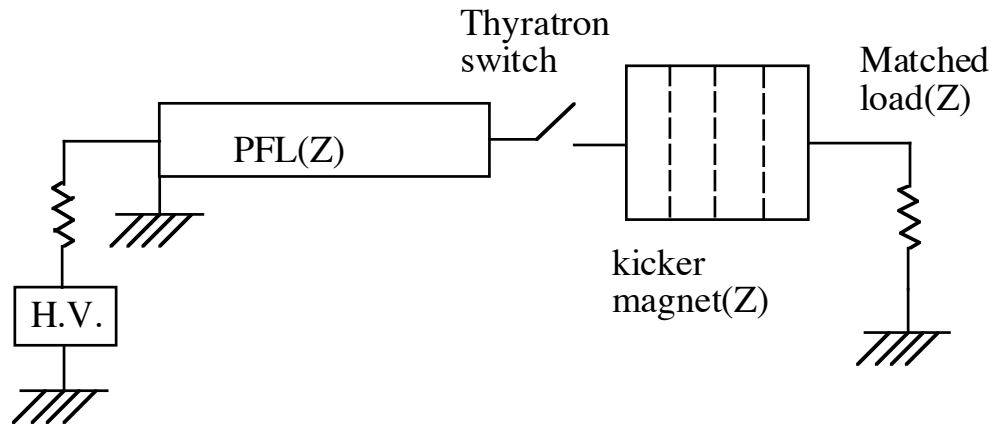
Stability  $7 \times 10^{-4}$

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

Rise/fall time **< 3.08 (6.15) ns**

<sup>07.3.5</sup> of the field

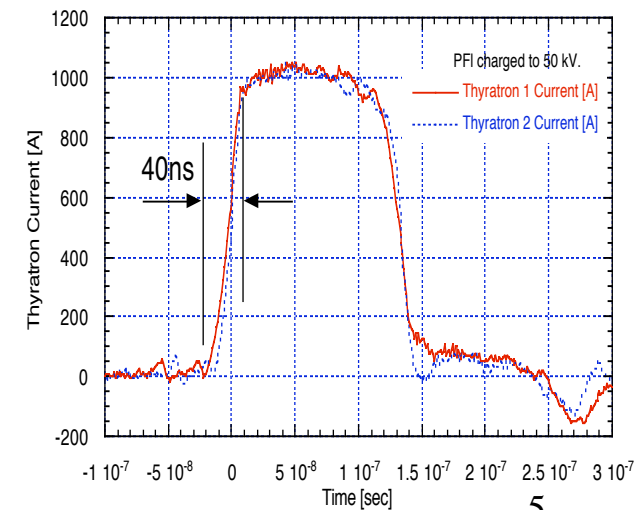
# Ordinary kicker system(pulse magnet)



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

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

Thy2 1 @-20dB[22]

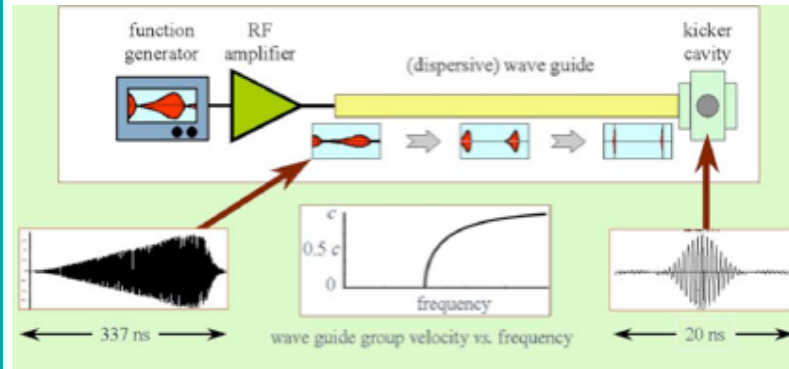


The pulse magnetic field is produced by the LC type pulse magnet. The charged high voltage is switched by the thyatron and the high current goes through the pulse magnet.

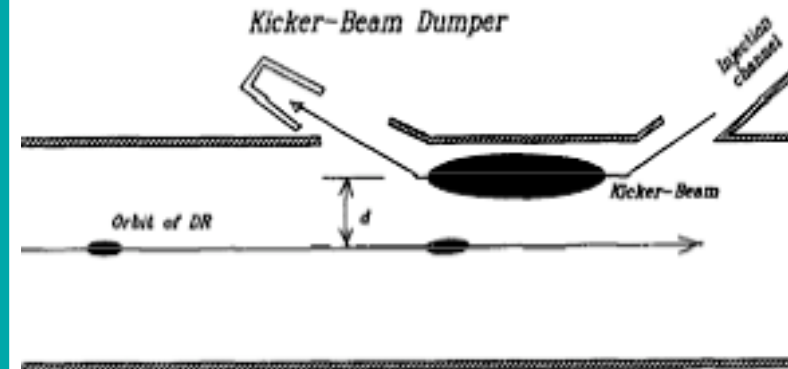
There is a Cutoff frequency ( $\omega_c$ ) for the pulse magnet and the raise time limitation for the thyatron .

# New proposal for the ILC kicker

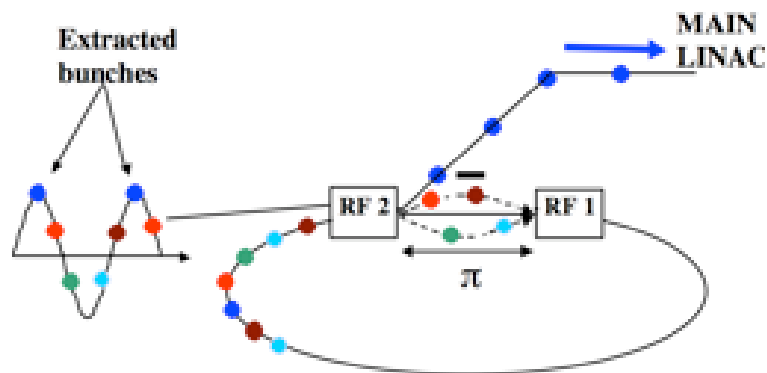
## Fourier series kicker



## Beam-Beam kicker

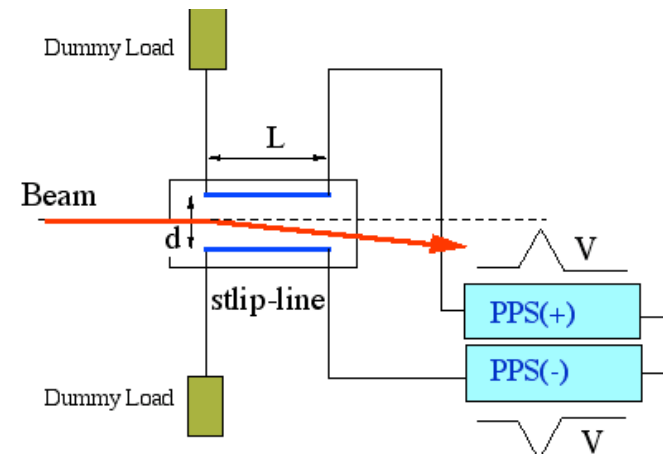


## RF deflector

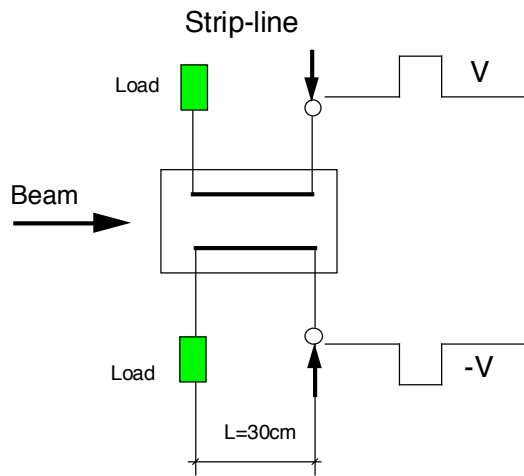


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## Strip-line kicker

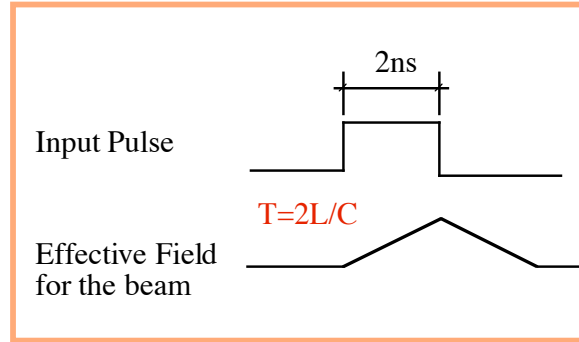


# Kick field of the strip-line kicker

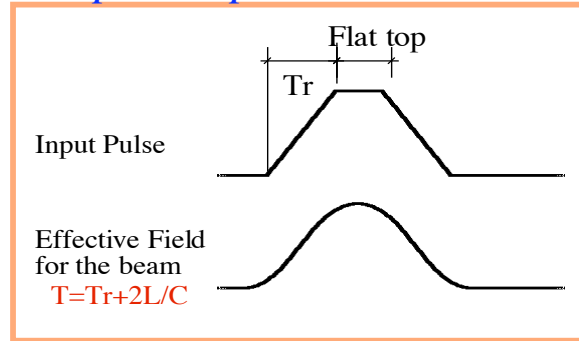


$$\Delta\theta \propto \int_t^{t+2L/c} V(t) dt$$

Rectangular pulse



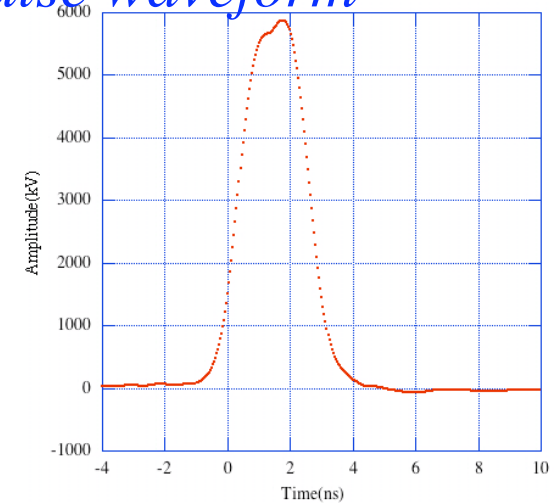
Trapezoid pulse



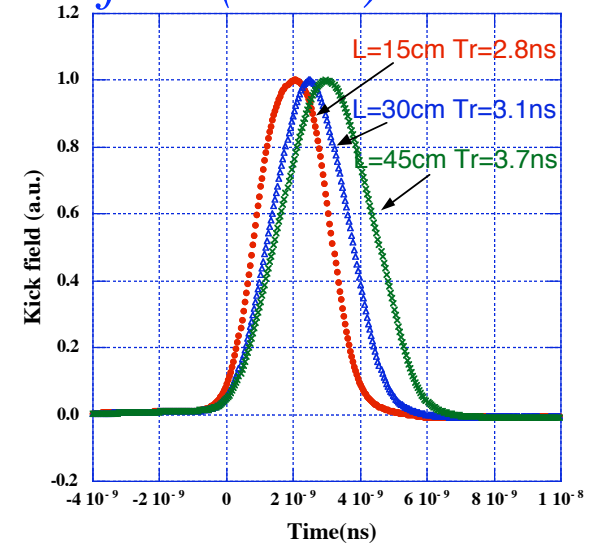
- The counter direction kicker pulse makes the transverse kick to the beam (Panofsky-Wenzel theorem)
- The kick field is defined as the integration of the electromagnetic field when the beam goes through the strip-line.

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Pulse waveform

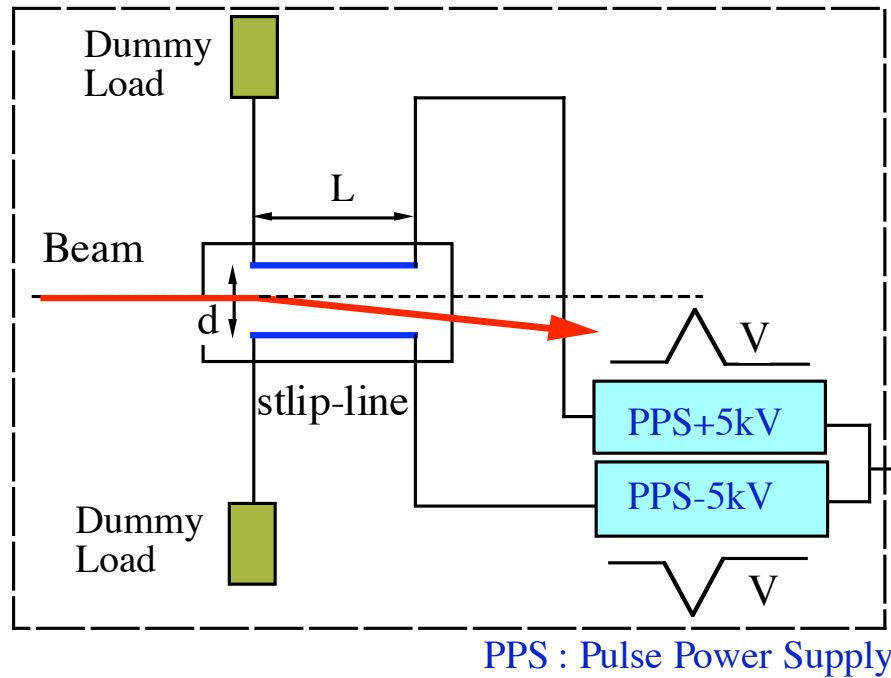
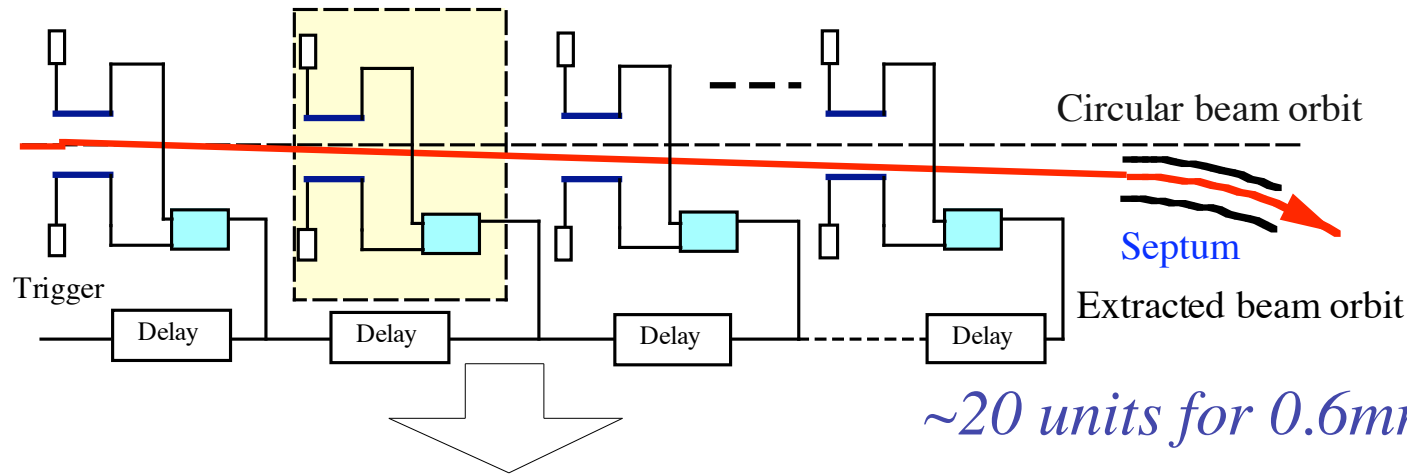


Kick field (calc.)



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

# Design of Strip-line kicker system



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

$L$  = strip - line length

$d$  = distance between the electrodes

$V$  = pulse voltage

$E$  = Beam energy

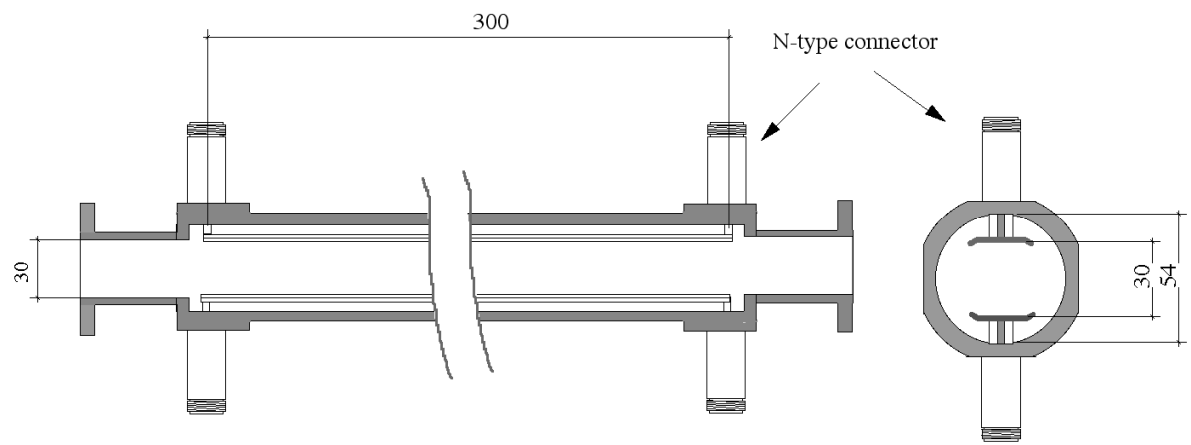
$$g = \tanh\left(\frac{\pi\omega}{2d}\right)$$

$\omega$  = strip - line width

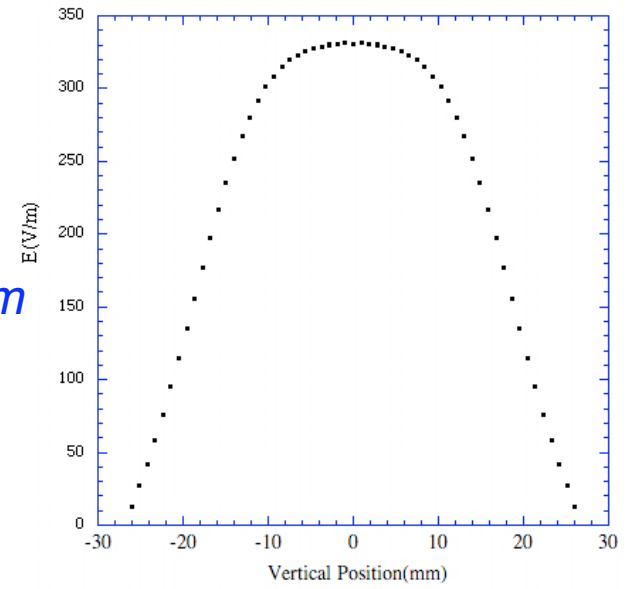
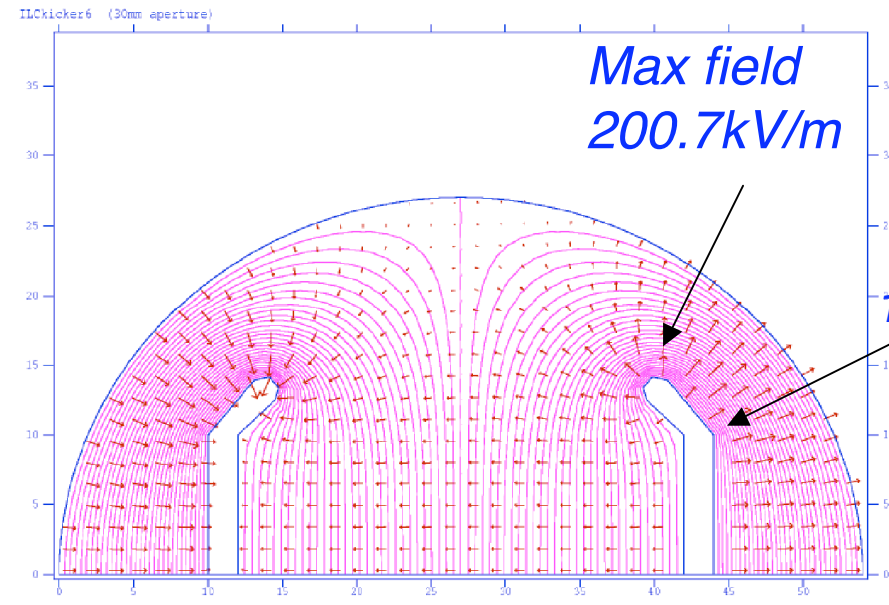
$d$  = distance between the electrodes



# 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

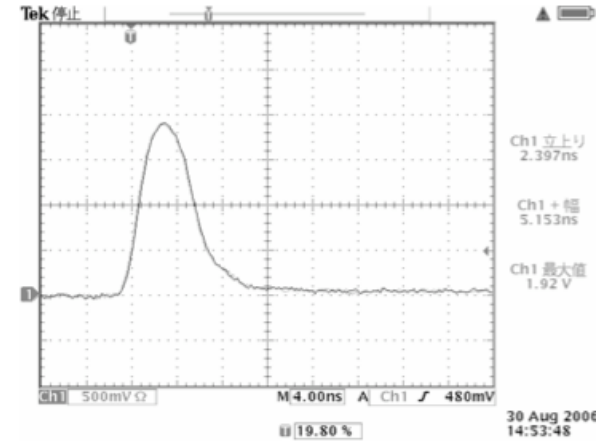
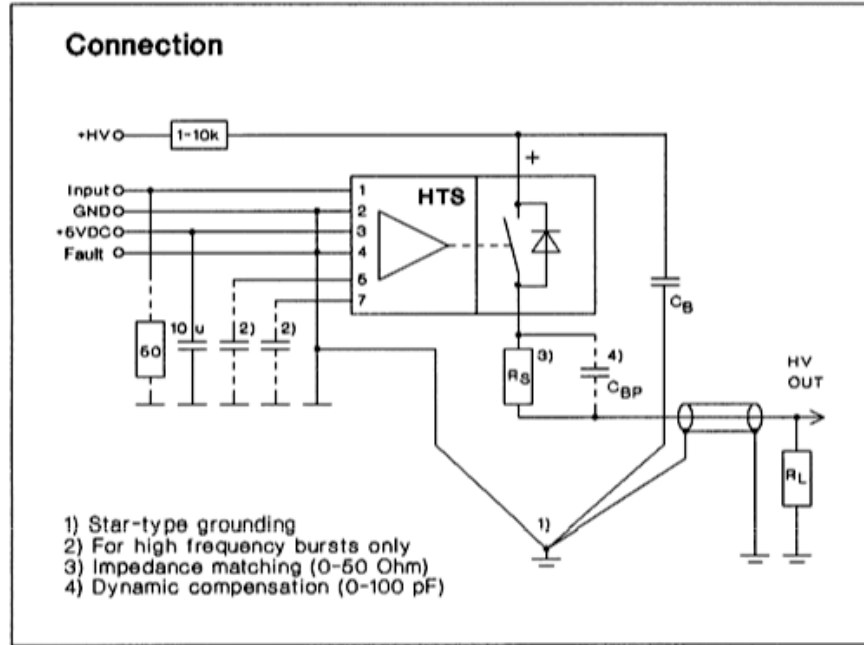
2) Adder Drive Boards(LLNL)

FET ON switch(stacked)

3)FPG 5-3000M(FID GmbH)

Fast Recovery Diode OFF switch

# BEHLKE HTS-50-08-UF

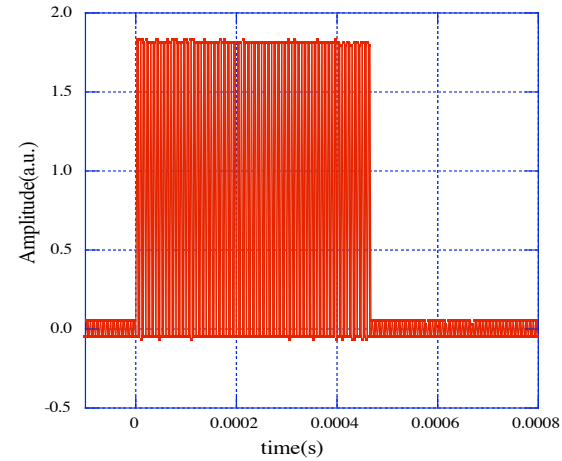


Rise time  $\sim 3\text{ns}$  at 2.5kV output



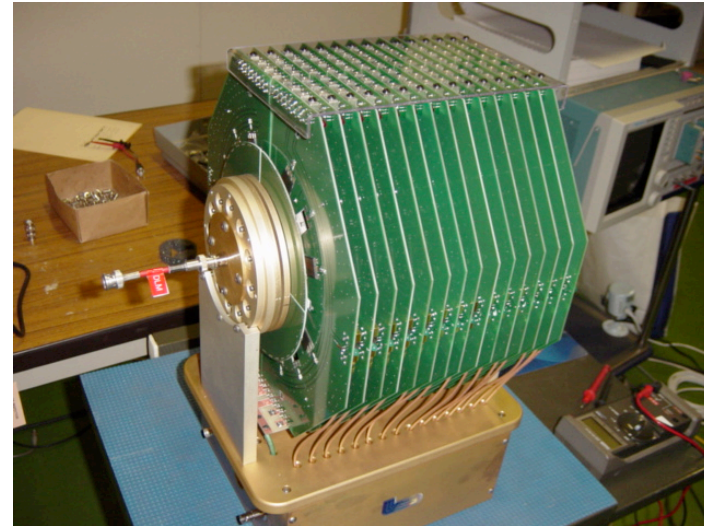
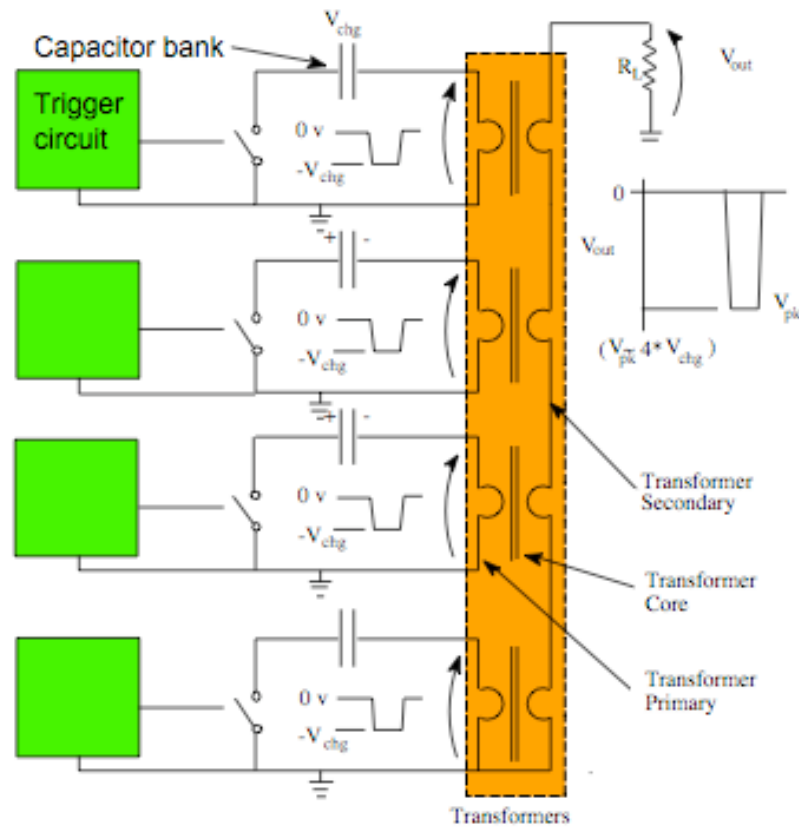
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BEHLKE HTS-50-08-UF (1MHz, 500 pulses)



Burst pulses(1MHz, 500pulses)  
 droop: $5 \times 10^{-3}$

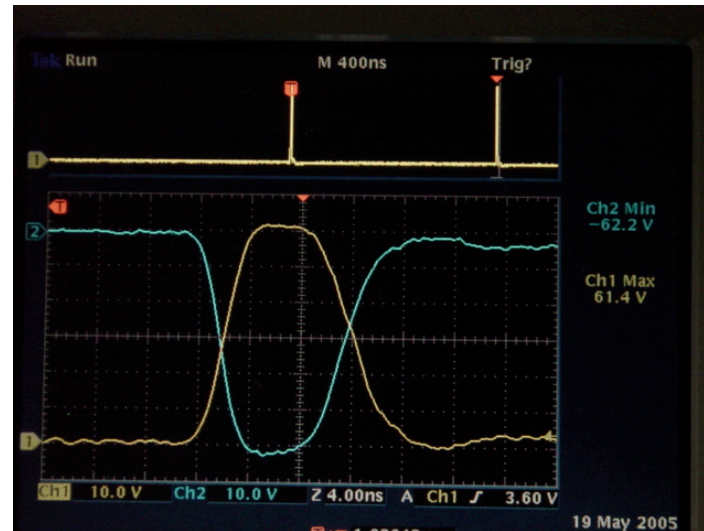
# Adder Drive Board(LLNL:Ed Cook)



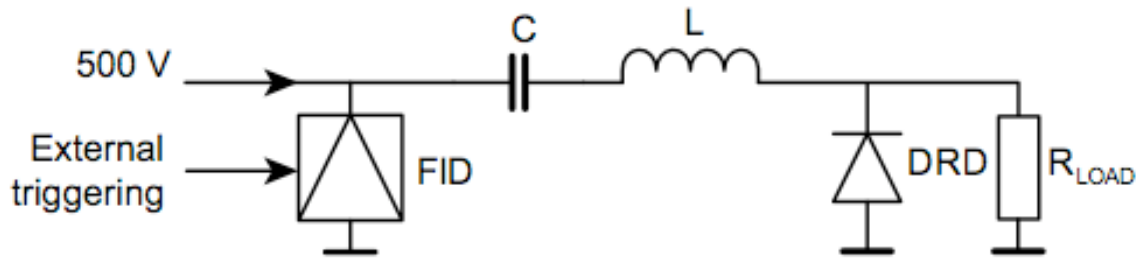
This high voltage pulse power supply is basically developed for the drive pulse of the induction linac.

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

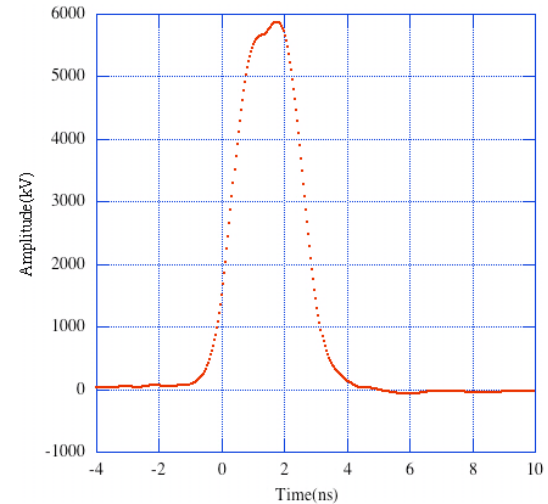
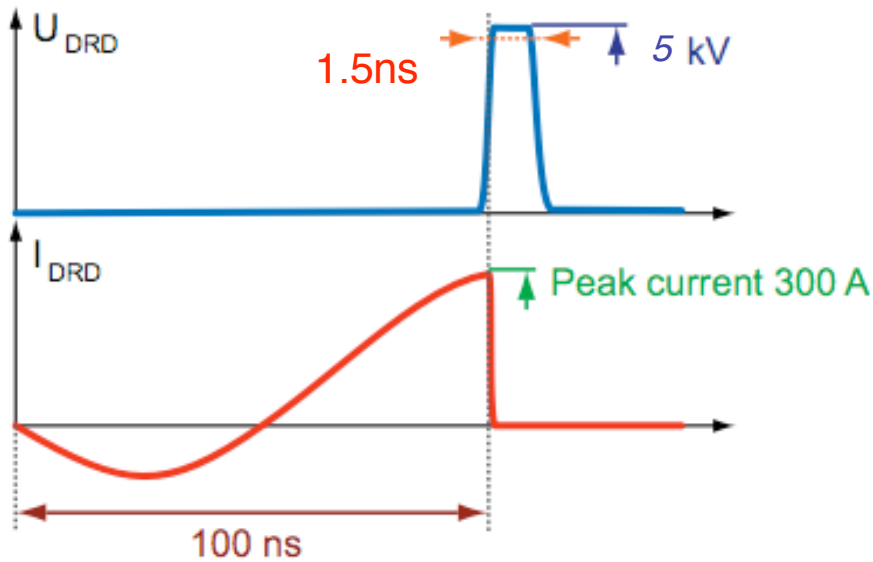
FET(DE275) on time: 2ns



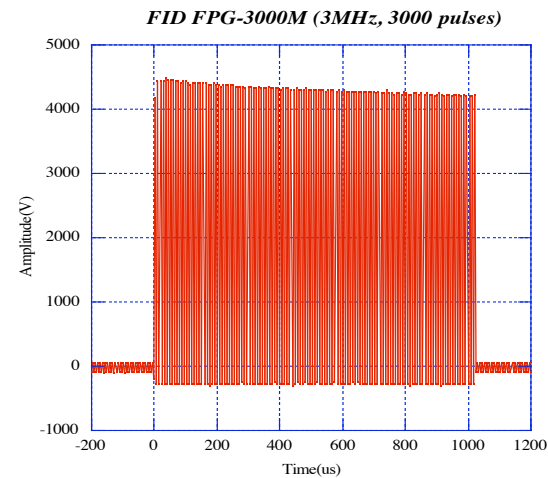
# FID FPG5-3000M(1)



FID : Fast Ionization Dynistor  
 DRD : Drift step Recovery Diode

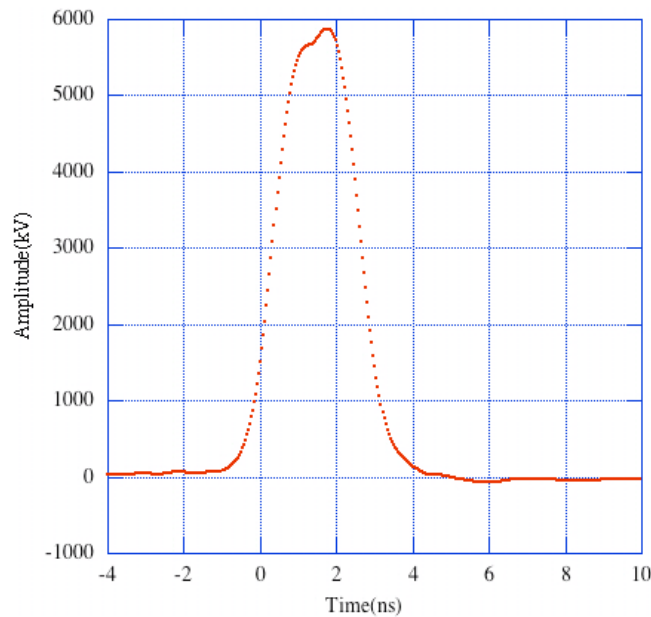


Single pulse waveform

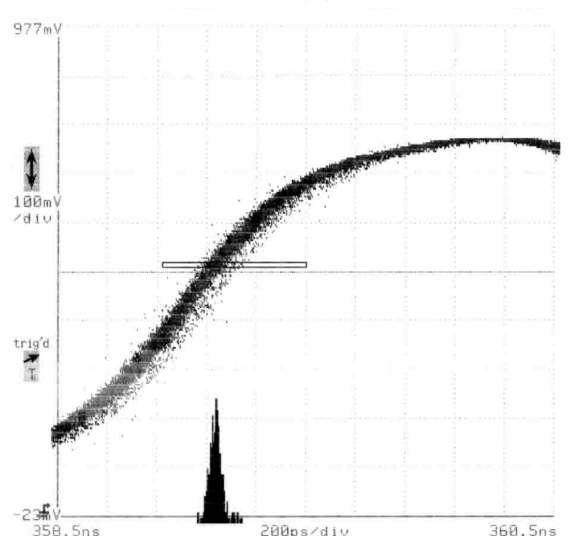


Burst pulses(3MHz, 3000pulses)  
 droop : ~3%

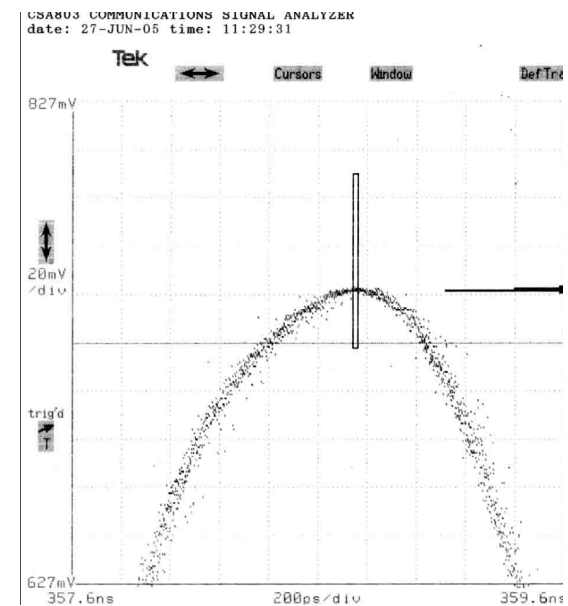
# FID FPG5-3000M(2)



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












07.3.5 *Timing jitter measurement*  
*29ps(1 $\sigma$ )*

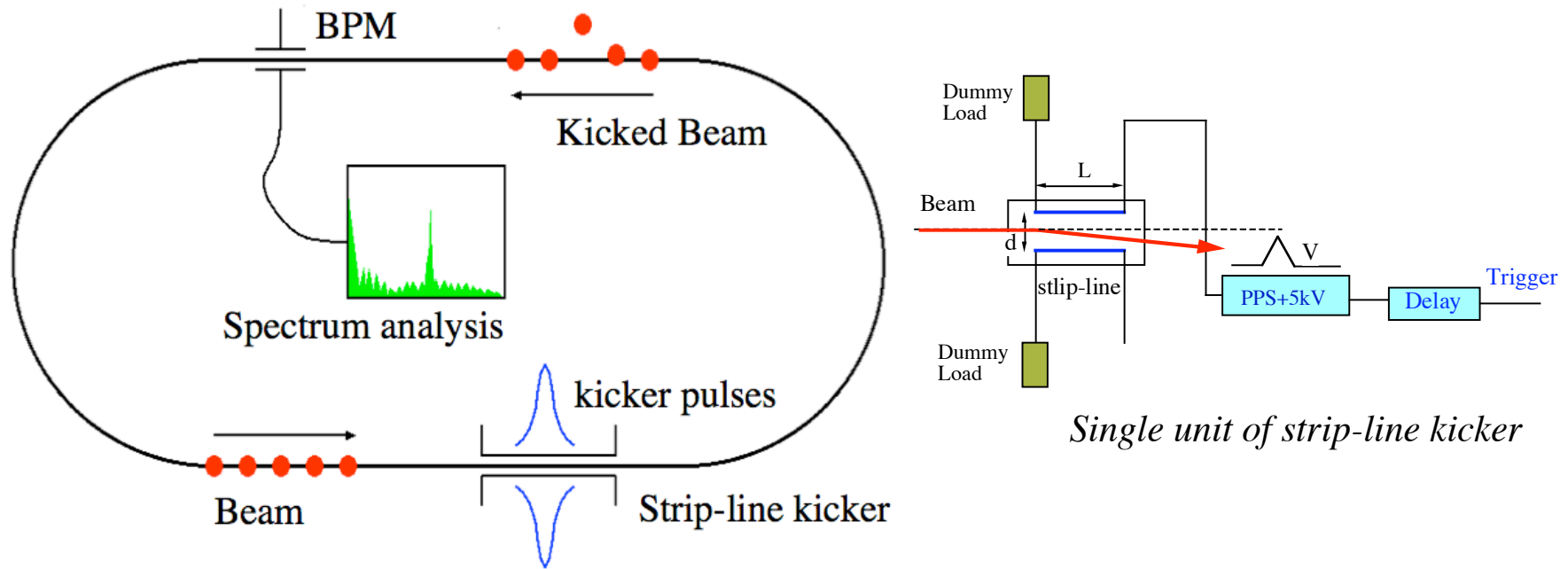


*Amplitude jitter measurement*  
*0.72%(1 $\sigma$ )* 14

## 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



- 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



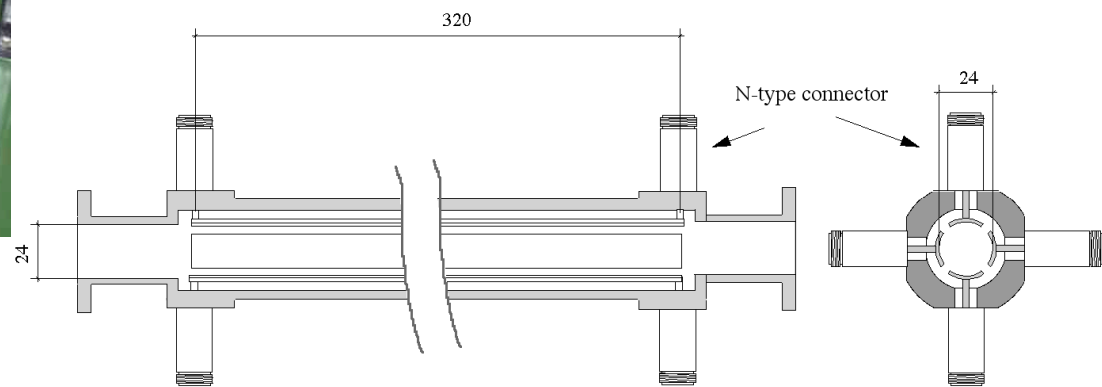
# Strip-line electrode for ATF-DR experiment



*Strip-lines*

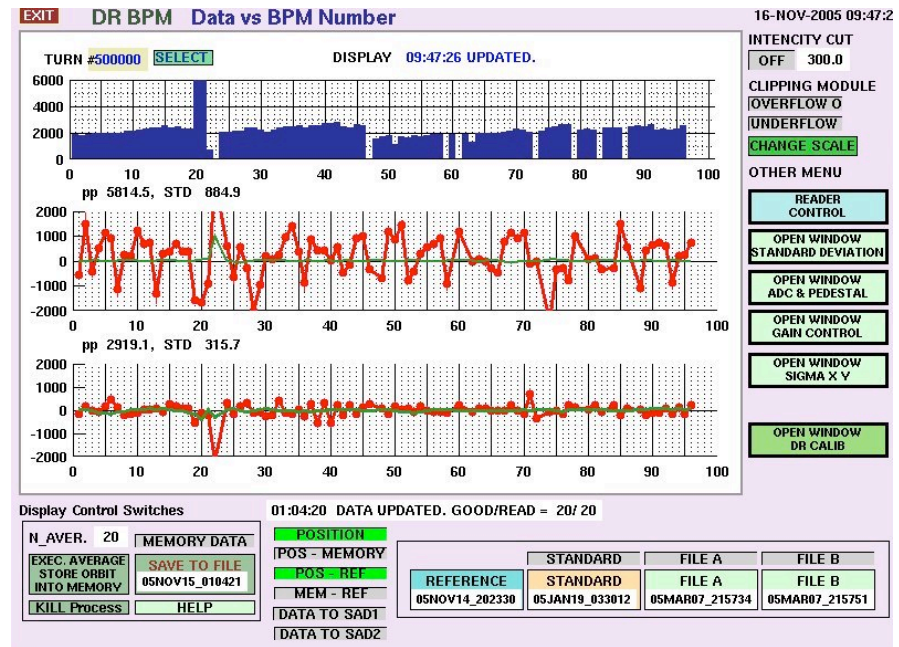
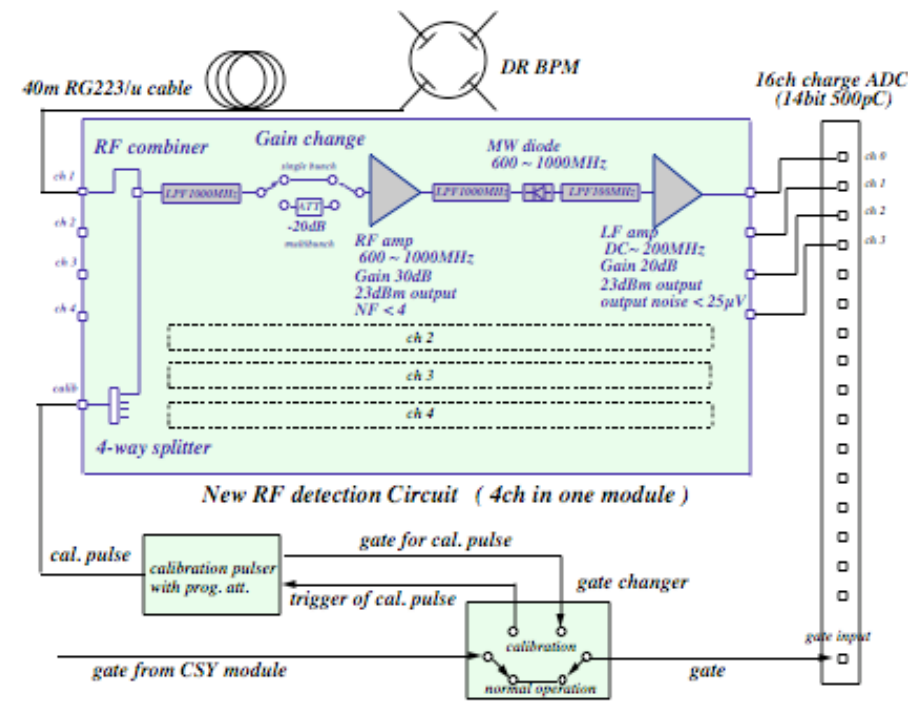
*Two strip-line electrodes are used for the experiment which was designed for tune measurement of ATF-DR.*

*Pulse power supplies*



# Single-shot BPM system

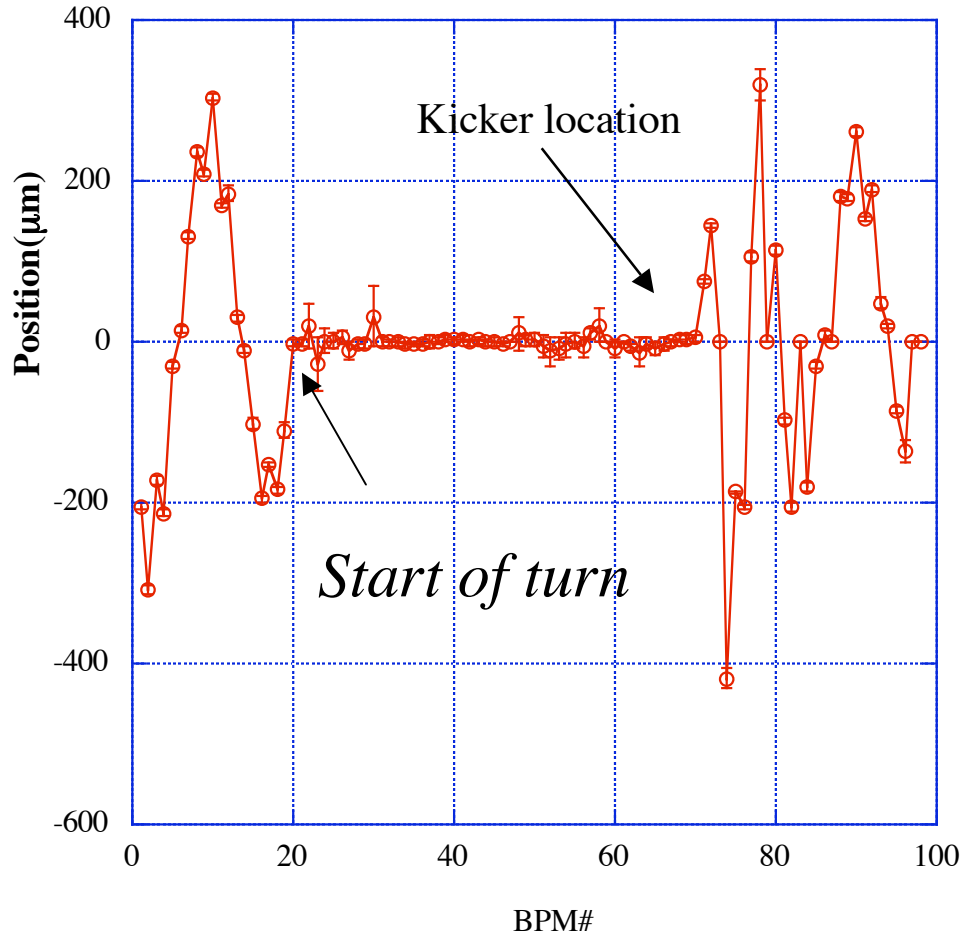
## 96 BPMs in DR



Resolution :  $\sim 2\mu\text{m}(\text{rms})$  at  $1 \times 10^{10}e$   
(Electronics)

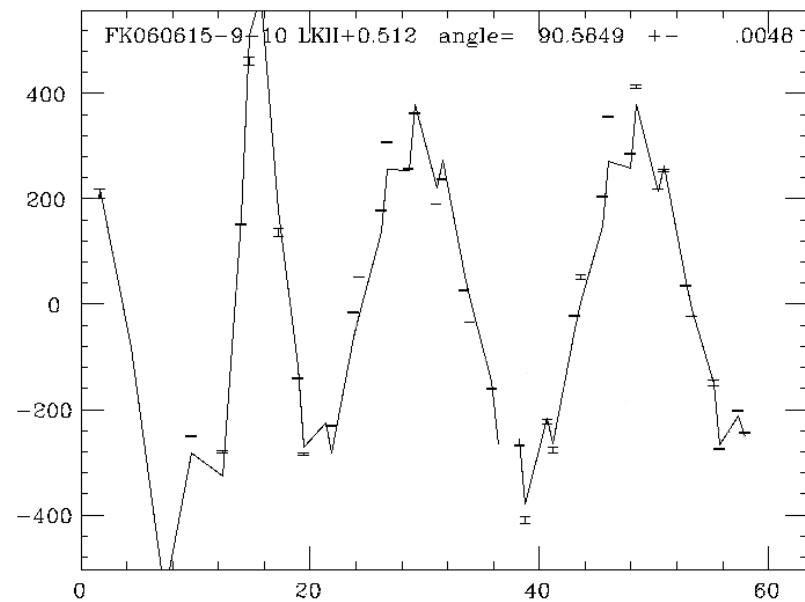
# Result of kick angle measurement

*First turn orbit of the excited beam*



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 below graph shows the kick angle calculation by SAD.

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

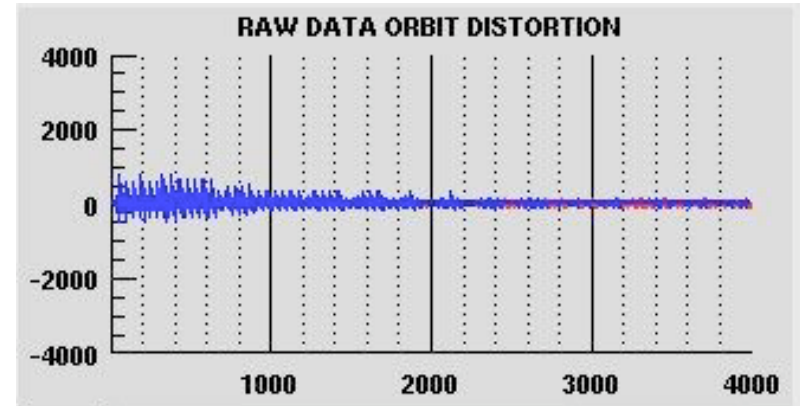
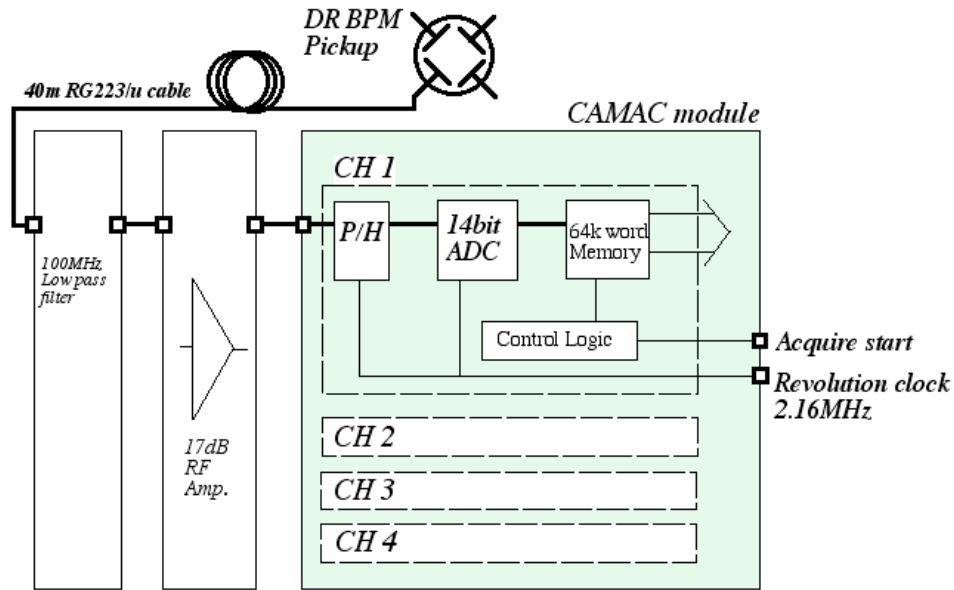


*Kick angle = 91.1 +/- 1.8 μrad*

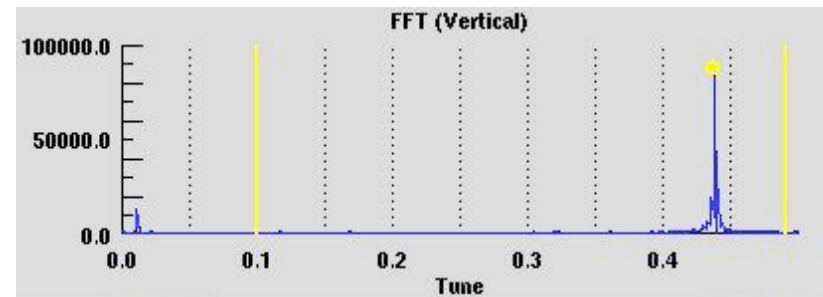
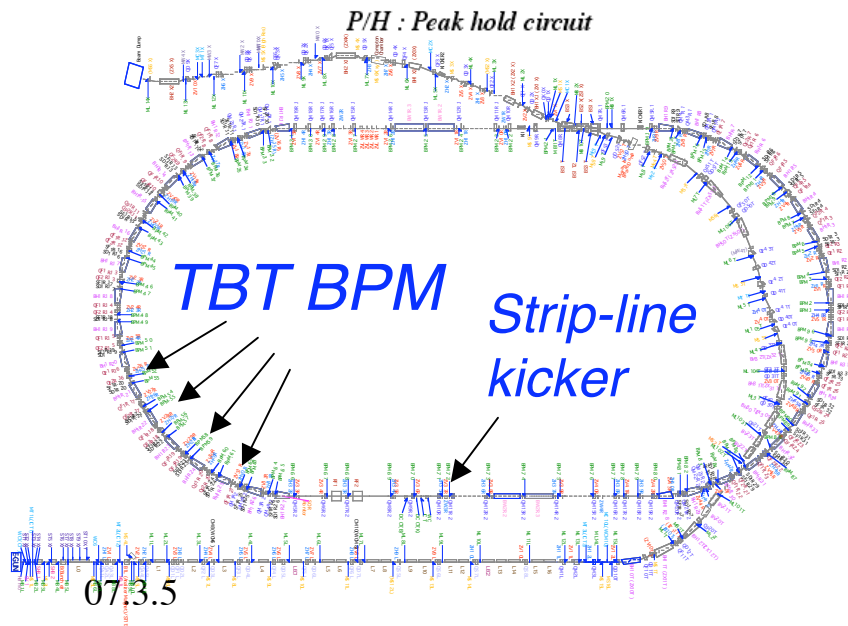
*BPM Error(1σ) mean = 6.6 μm*

*Kicked orbit fit by SAD 19*

# Turn-By-Turn (TBT) BPM system



*Beam oscillation during 4000 turn*

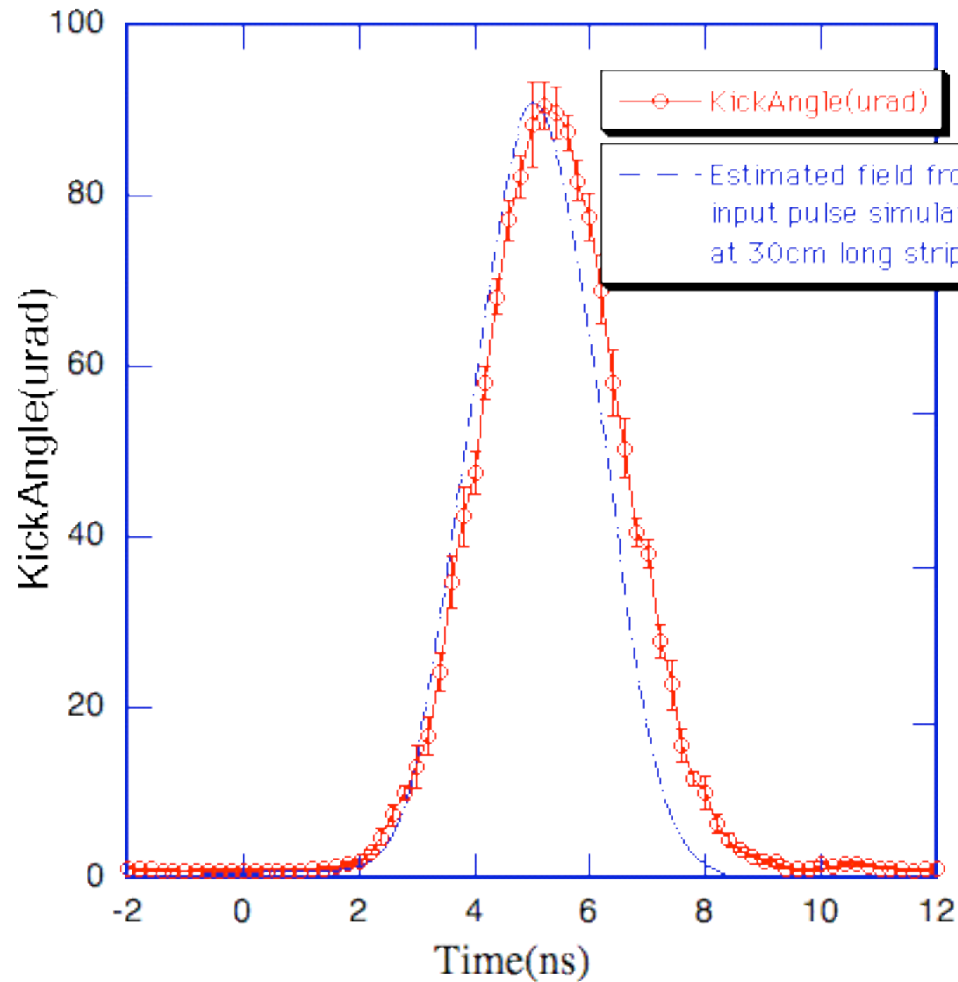


*Frequency spectrum*

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

*This measurement can avoid the noise effect from the other frequencies. 20*

# Timing scan of the kick pulse



*Beam kick profile*

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

*Rise time = 3.2ns*

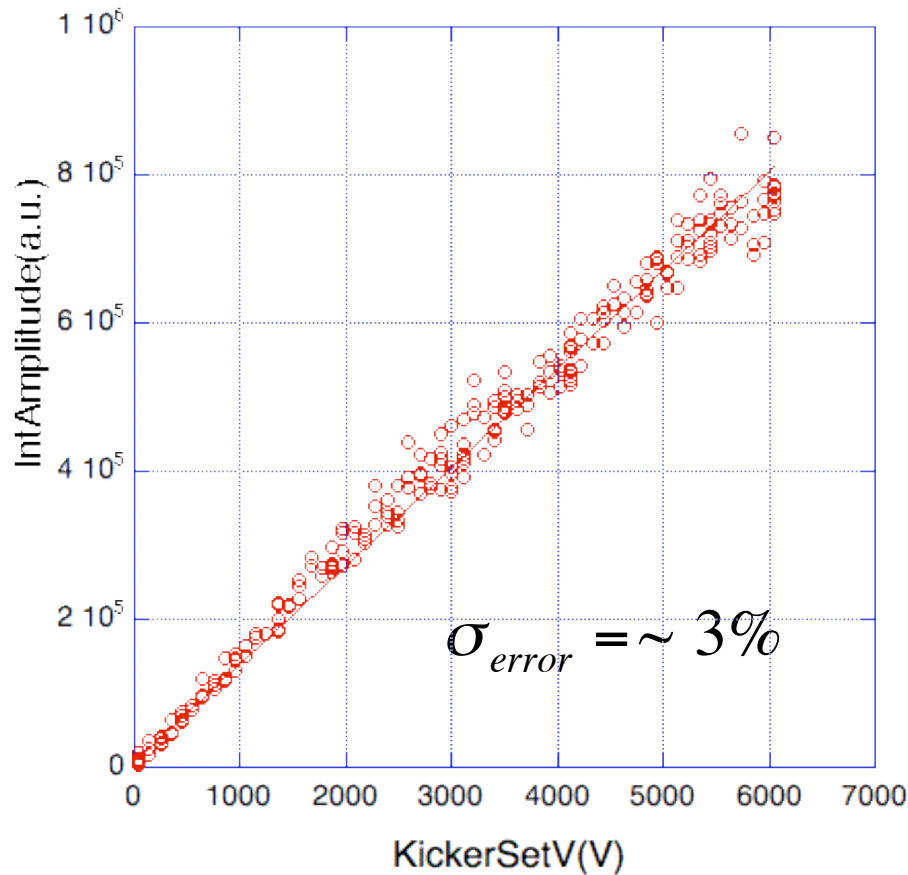
*(1%~100%)*

*Fall time = 4.0ns*

*(100%~1%)*

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

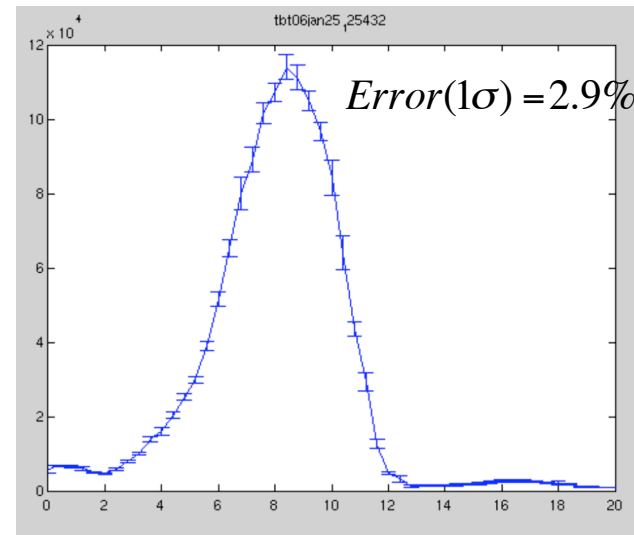
# Measurement error



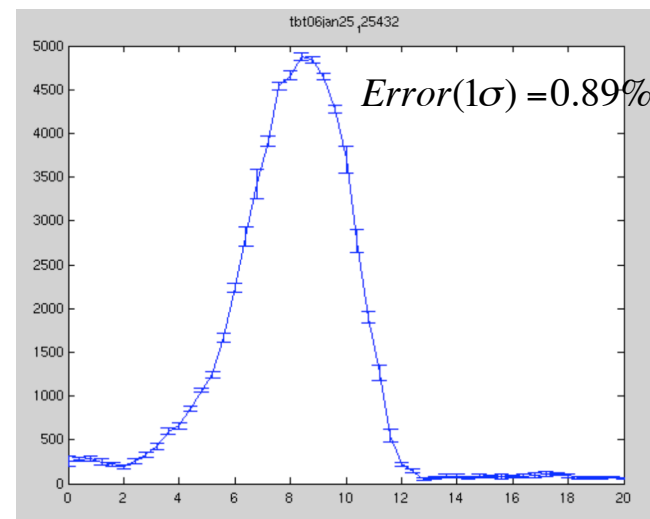
## Linearity of the oscillation amplitude

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

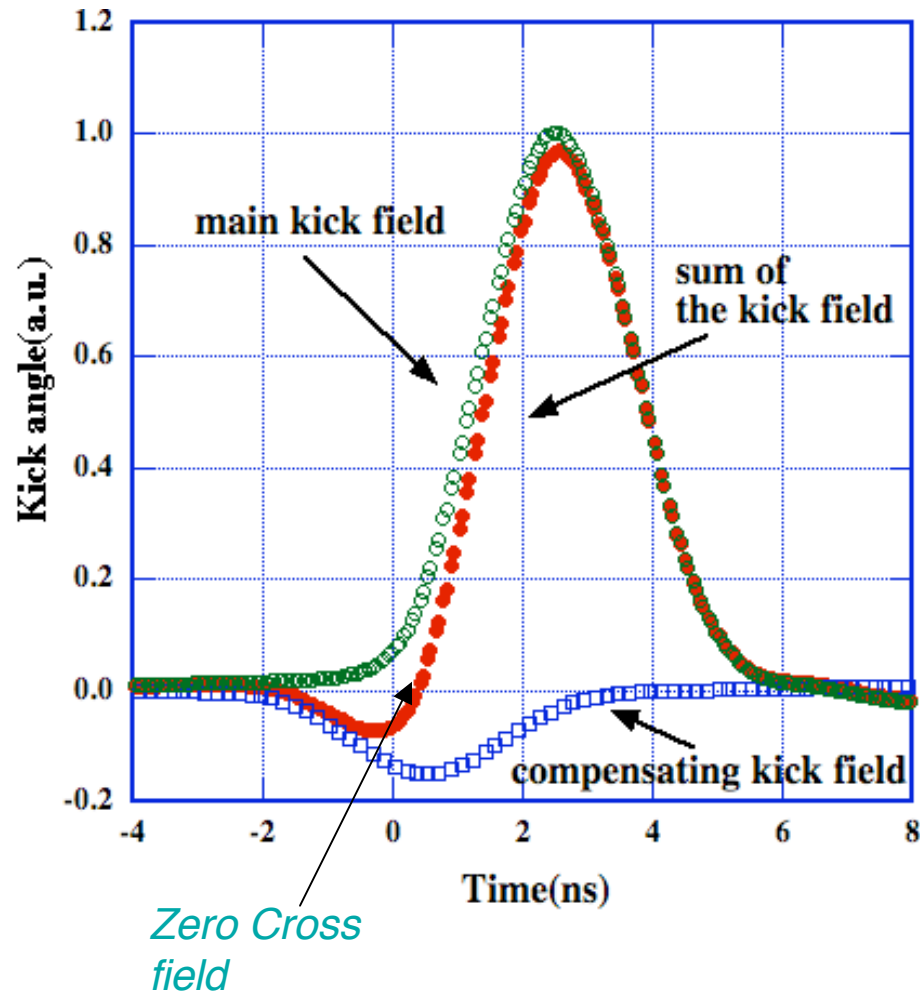


Beam kick profile(4096 turns data)

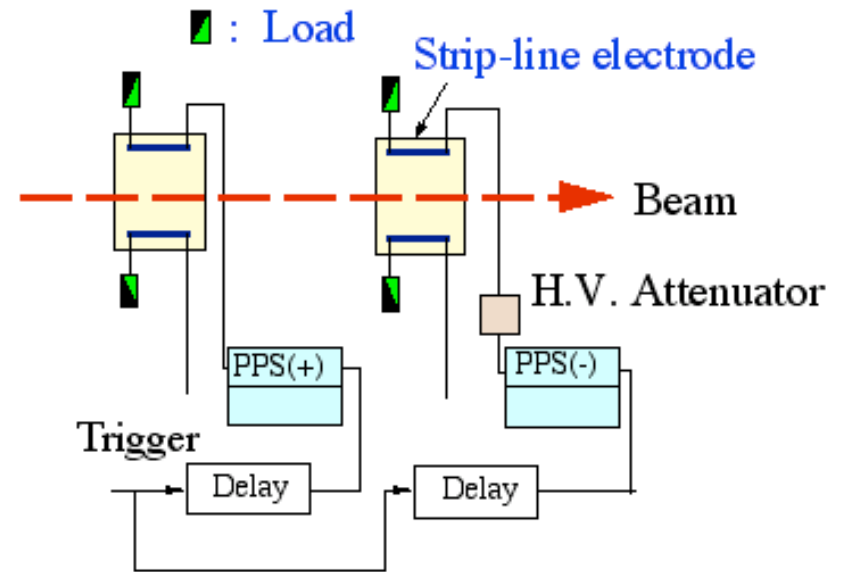


Beam kick profile(64 turns data)

# Waveform compensator



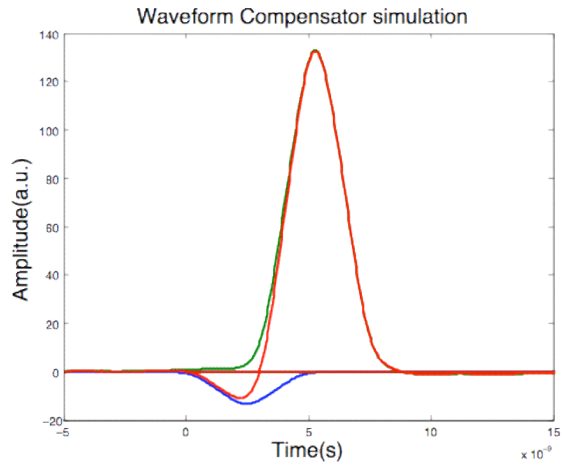
*Simulation of waveform compensator*



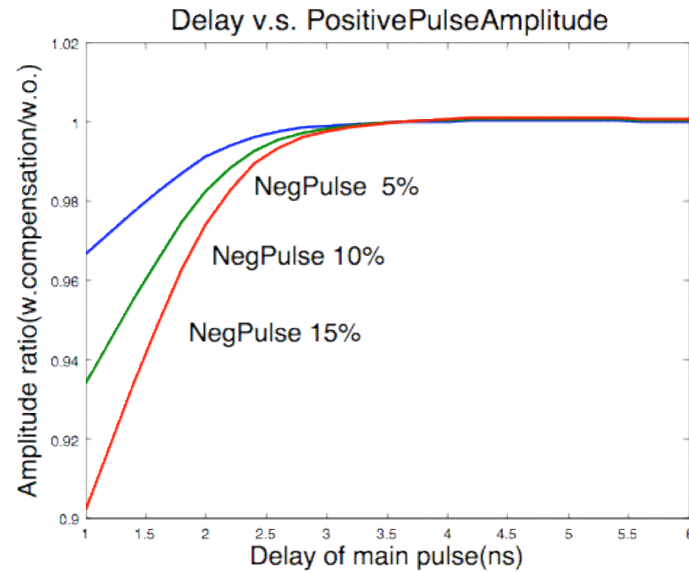
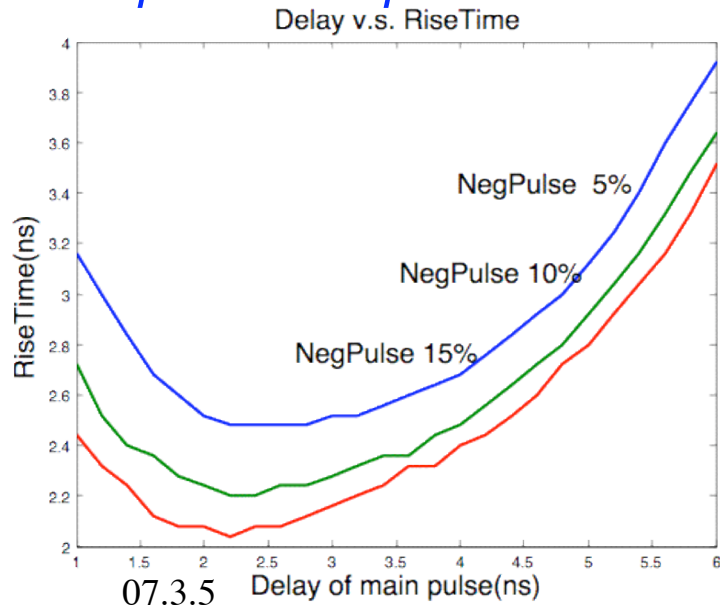
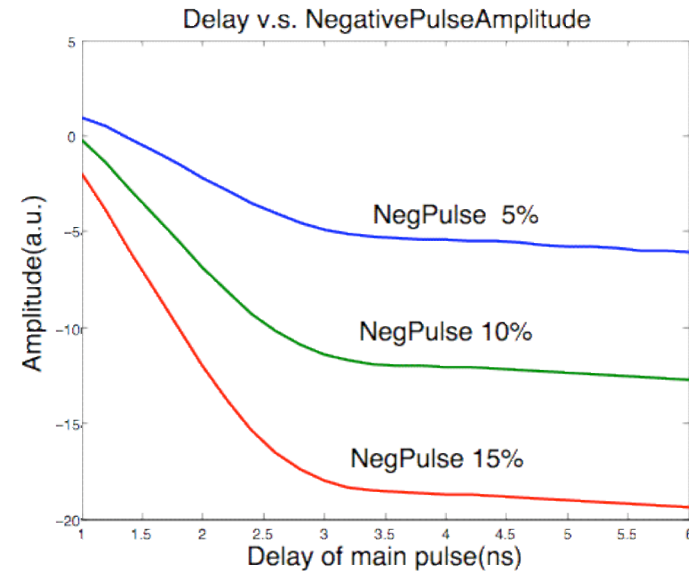
*Experimental set up*

*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

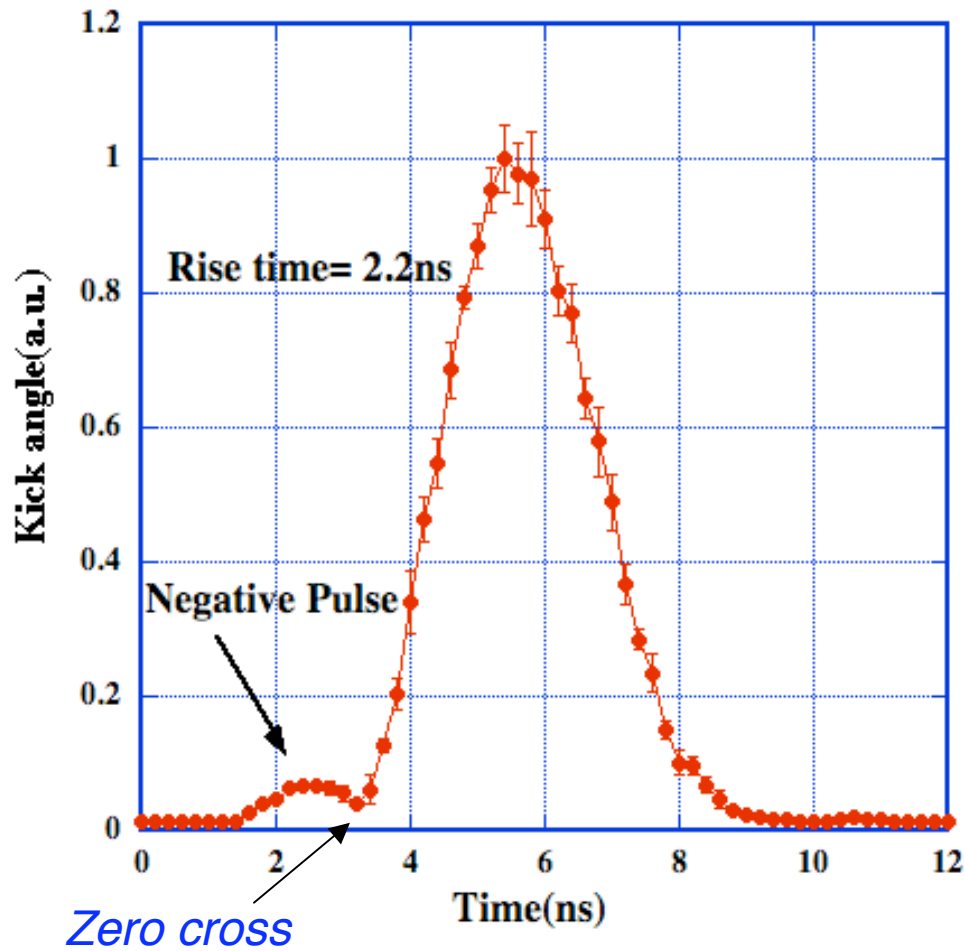


*The rise time simulation for the timing and the amplitude of the compensation pulse*

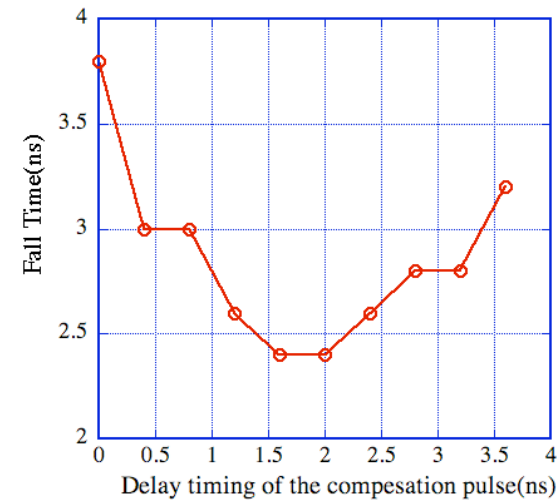
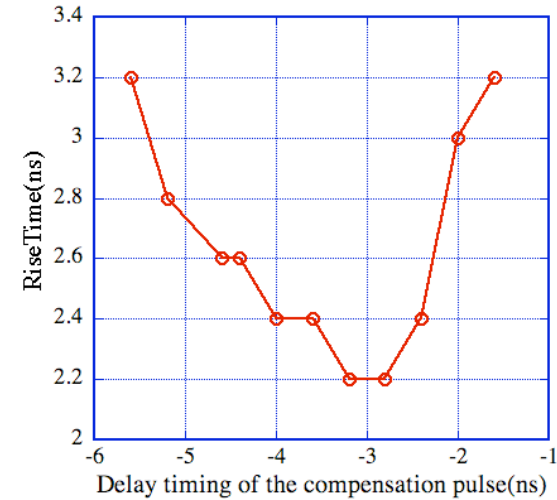




# Rise time improvement with Waveform compensator

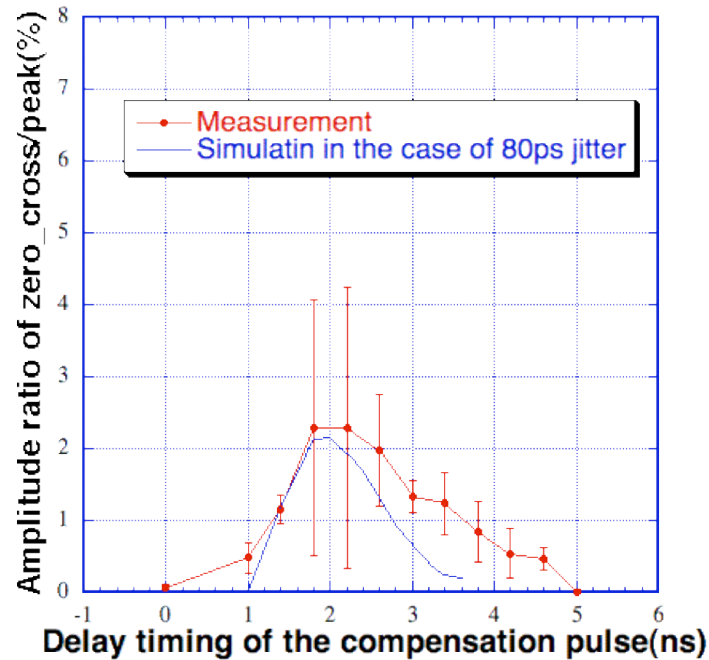


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Rise/fall time improvement v.s. timing

# Timing jitter

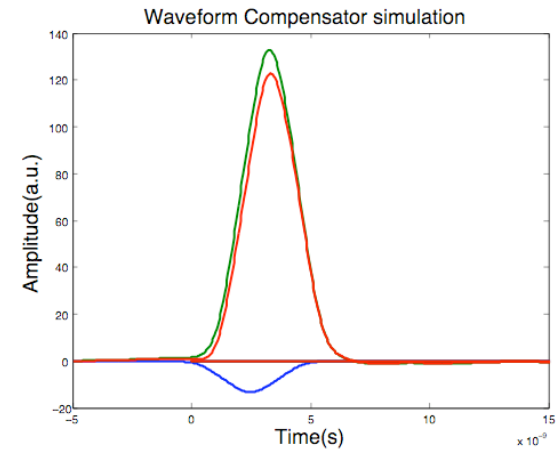


The zero cross point of two pulses didn't reach to zero in the measurement. The reason comes from,

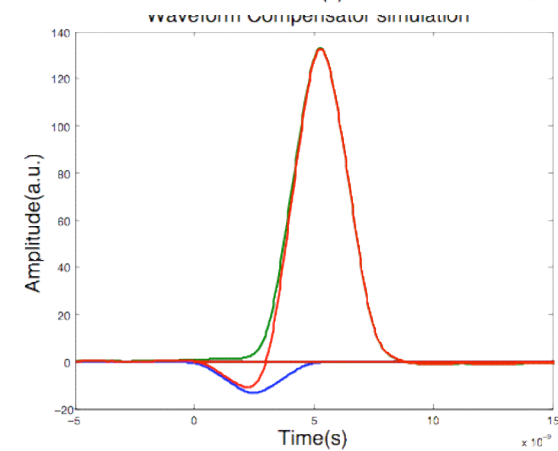
- the timing jitter between the beam and the kick pulse.
- the amplitude depends on the slope of the kick field.
- it is agreed with the simulation in the case of the 80ps time jitter

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

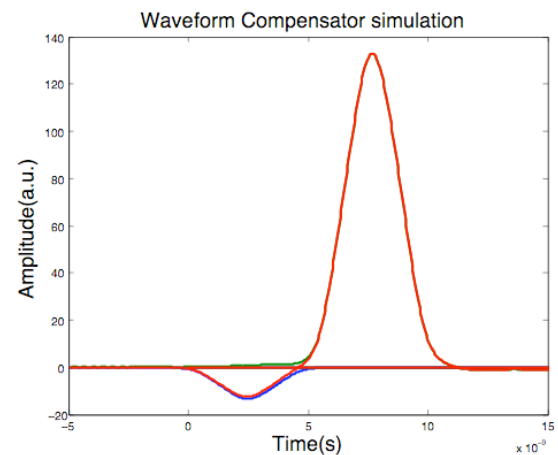
07.3.5



*1ns delay*



*2ns delay*

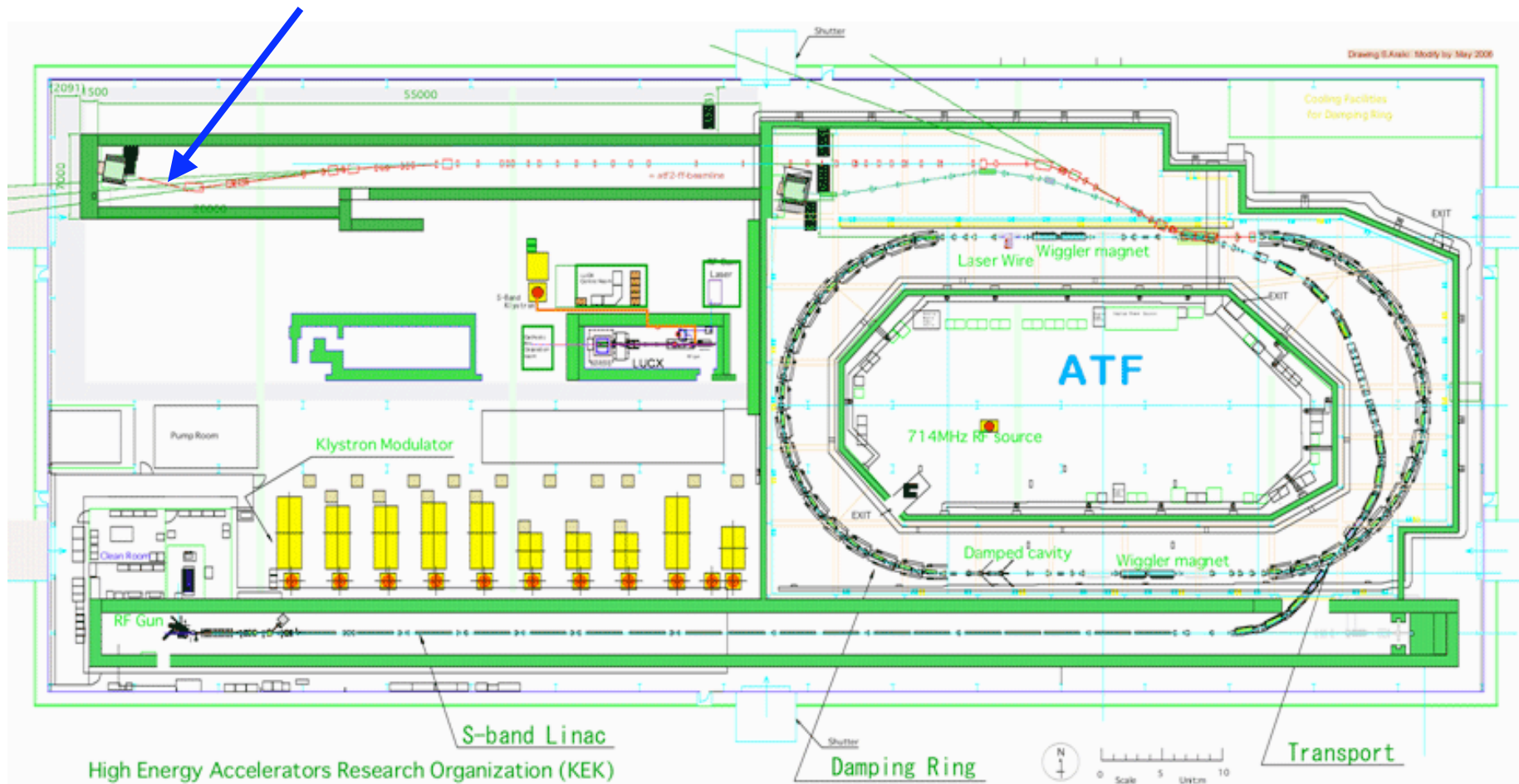


*5ns delay*

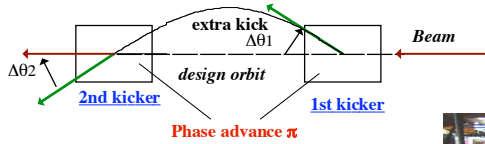
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# ATF2

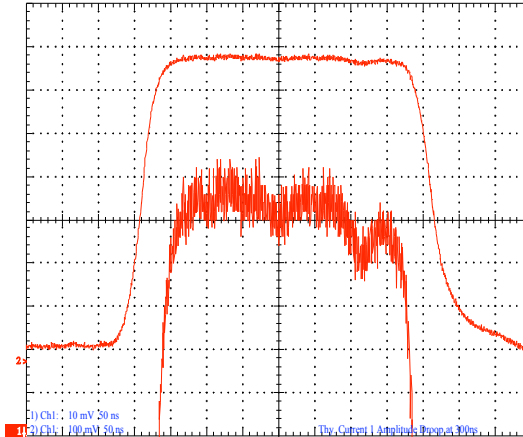
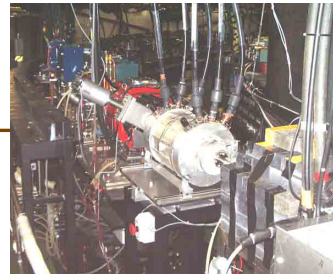
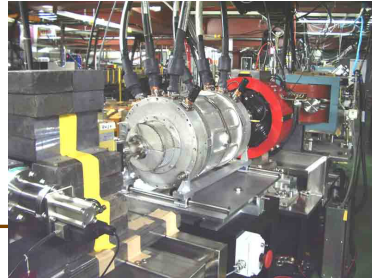
*ATF2 - 40nm beam production, measurement ,  
single bunch and multi bunch beam handling*



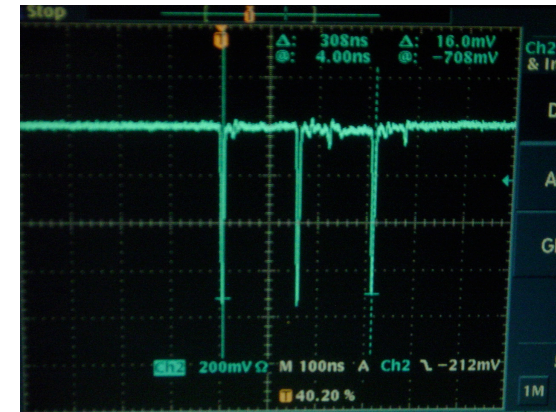
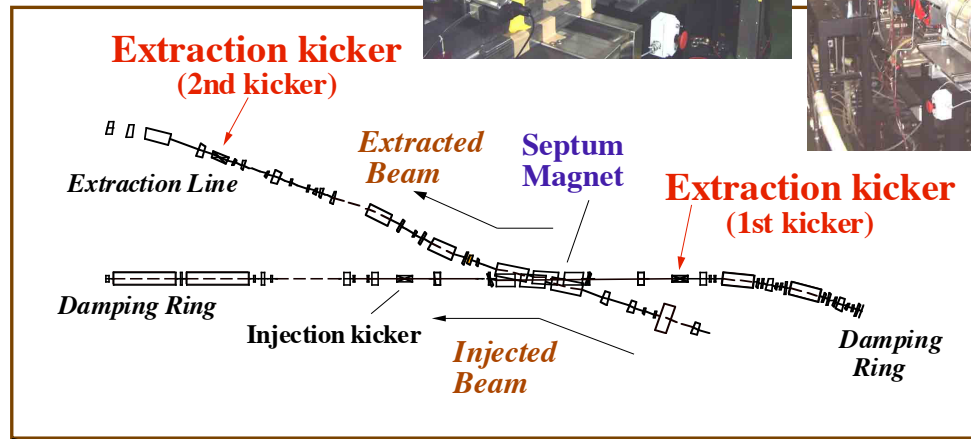
# Present beam extraction (Pulse magnet kicker system)



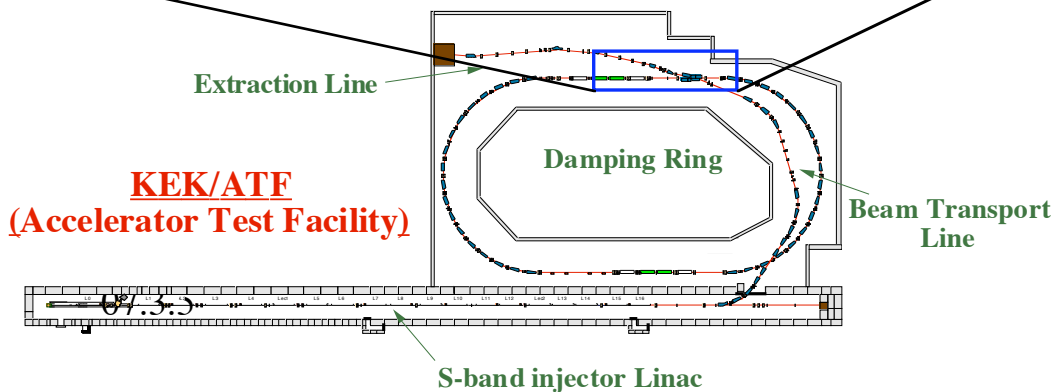
Kick angle Stability  
 $1 \times 10^{-3} \rightarrow 2.8 \times 10^{-4}$



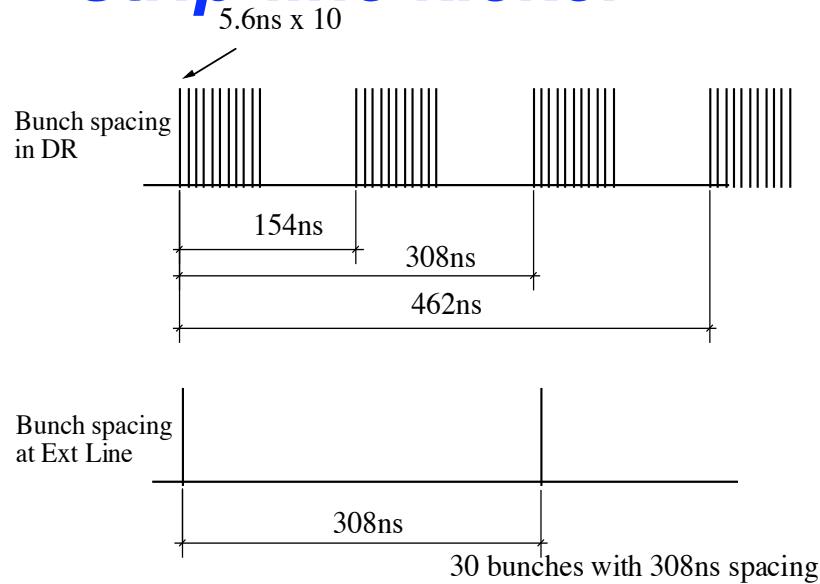
308ns pulse width



3 bunches, 154ns spacing

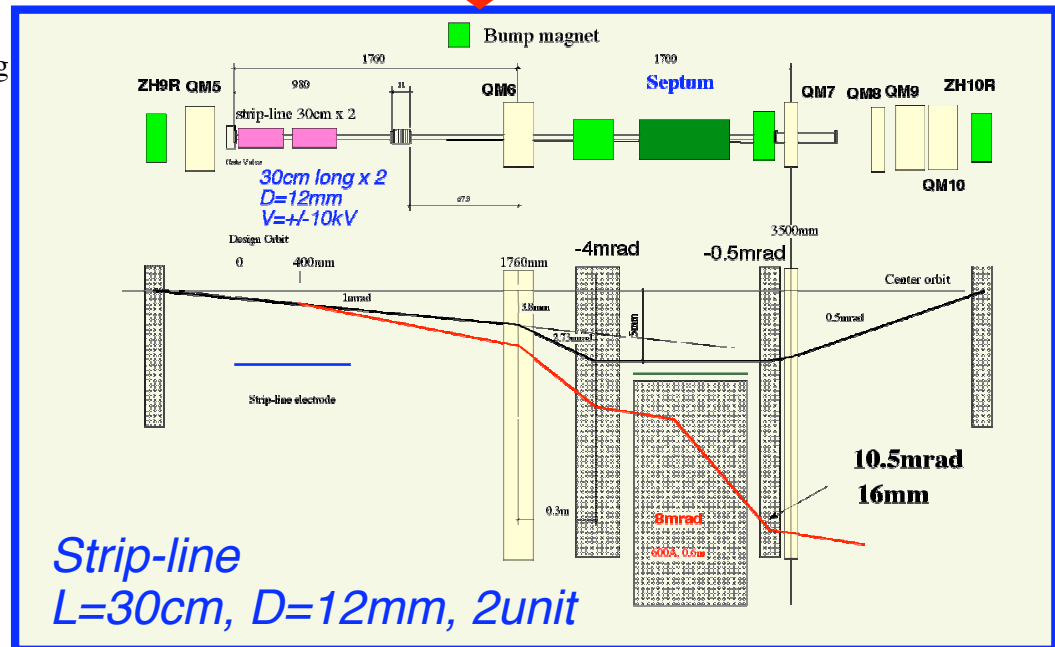
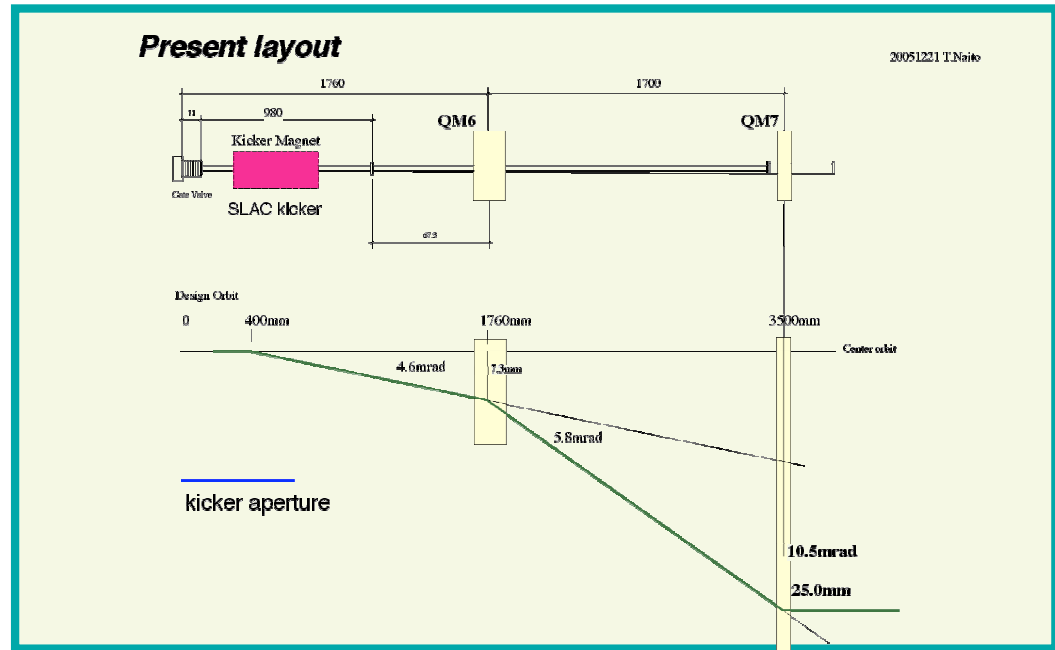


# Beam extraction experiment with strip-line kicker



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.