



# Multi-bunch Beam Extraction by using Strip-line Kicker at KEK-ATF

T.Naito<sup>#</sup>, S.Araki, H.Hayano, K.Kubo, S.Kuroda,  
N.Terunuma, T.Okugi, J.Urakawa(KEK)

*IPAC10(2010/05/26)*

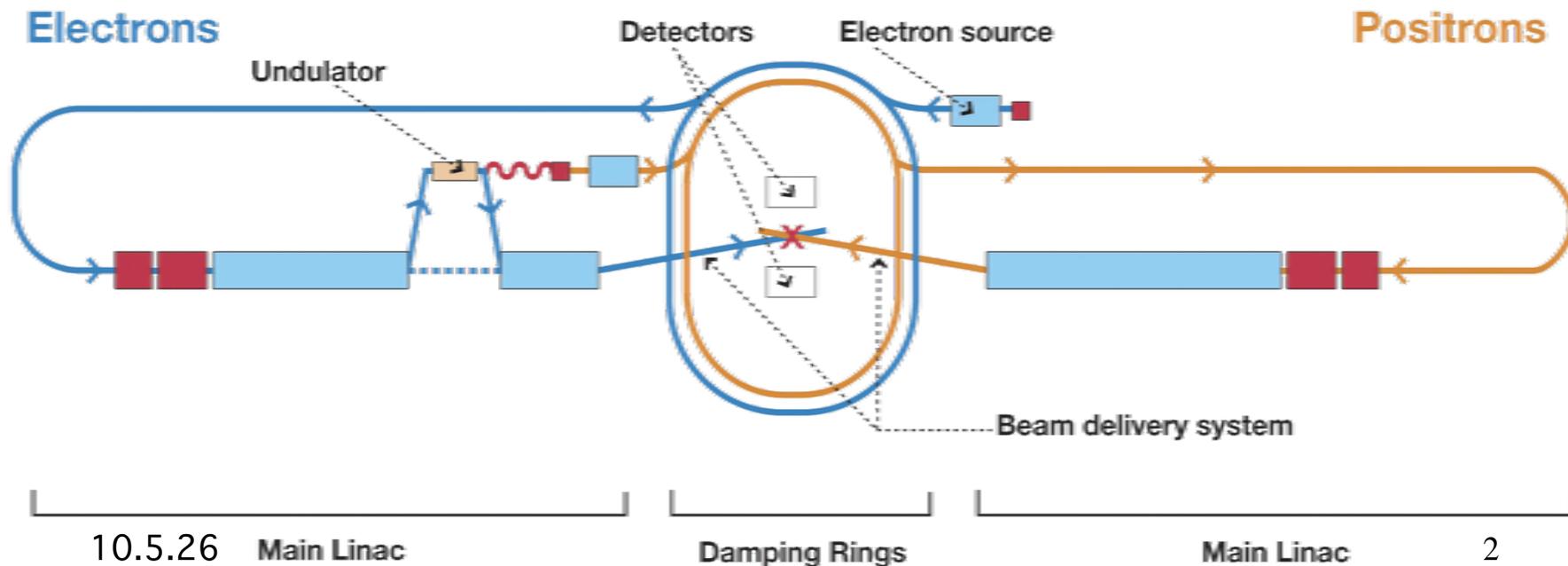


# Parameters of ILC

The length of the bunch train in the ILC linac is  $\sim 300\text{km}$ . The long bunch train should be compressed in the DR and should be decompressed at the downstream of the DR for the appropriate circumference size ( $\sim 6\text{km}$ ) of the DR.

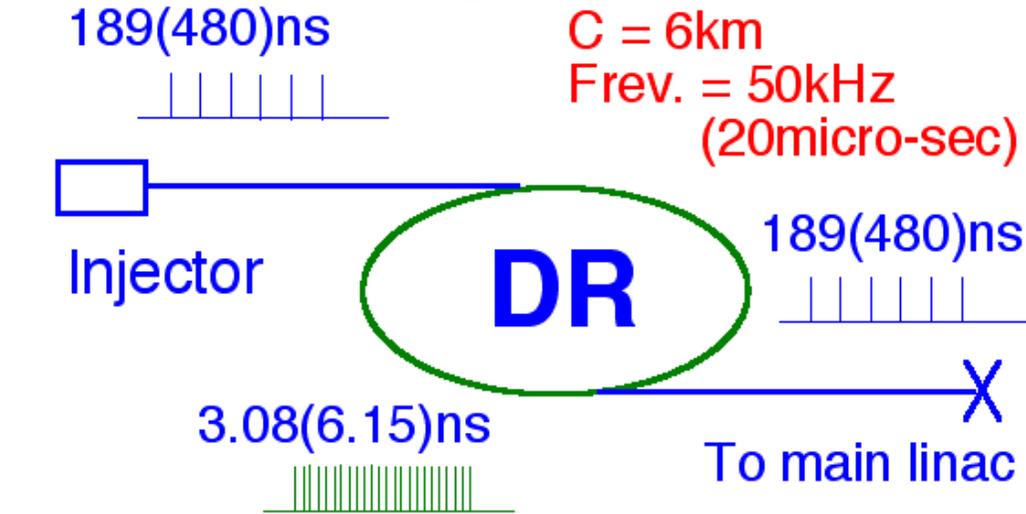
## parameters

Bunch train	5120(1320) bunches
Bunch charge	2nC/bunch
Bunch spacing	189(480)ns
Repetition rate	5Hz

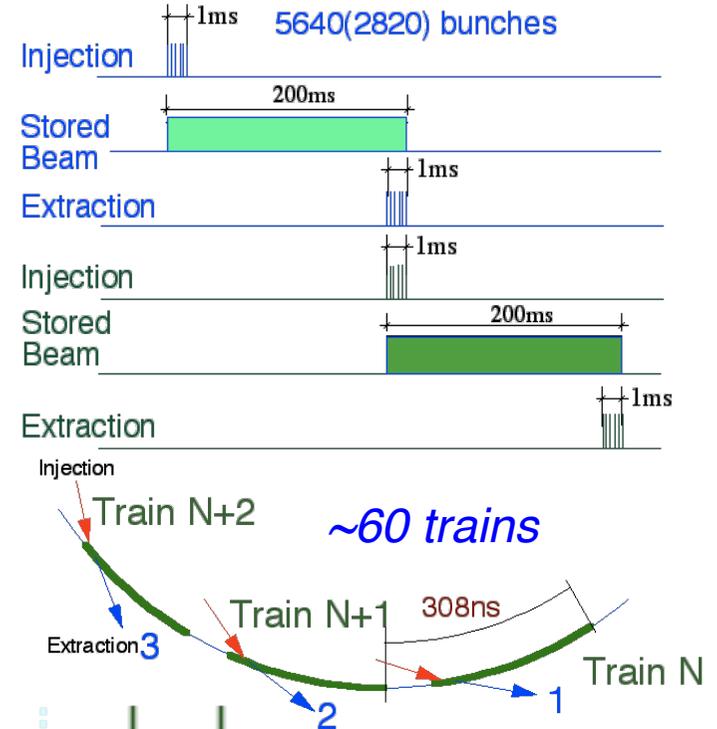


# Beam cycle of DR

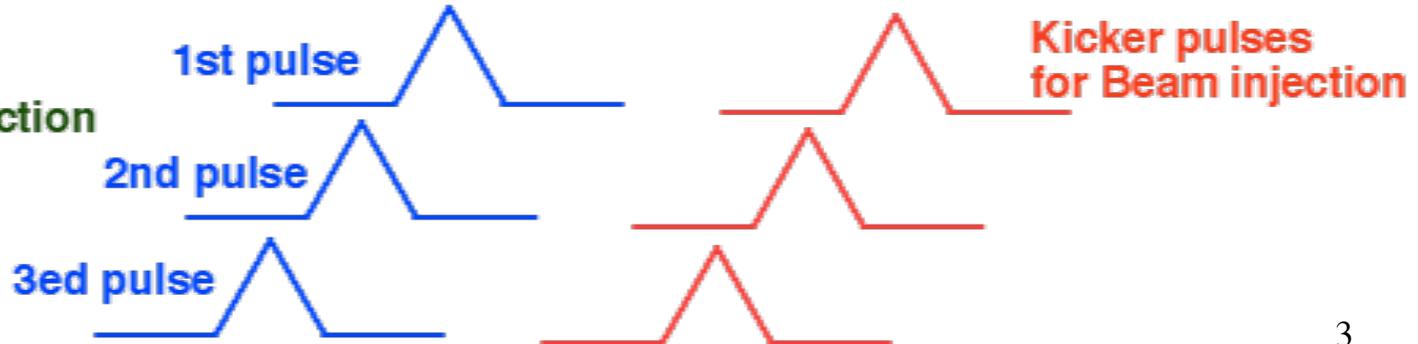
## Bunch spacing



## Beam Storage Sequence in DR



Kicker pulses for Beam extraction





# *ILC DR kicker parameters*

## Specification

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

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

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

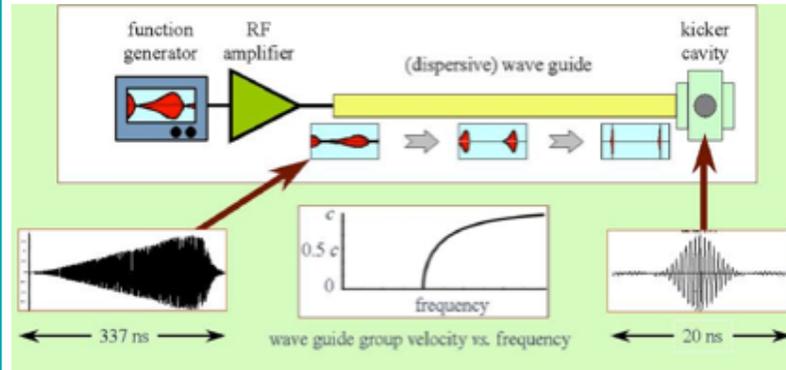
Rise/fall time **< 3 (6) ns**  
of the field

*The conventional kicker can not realize these parameters, especially, the rise/fall time and the repetition rate.*

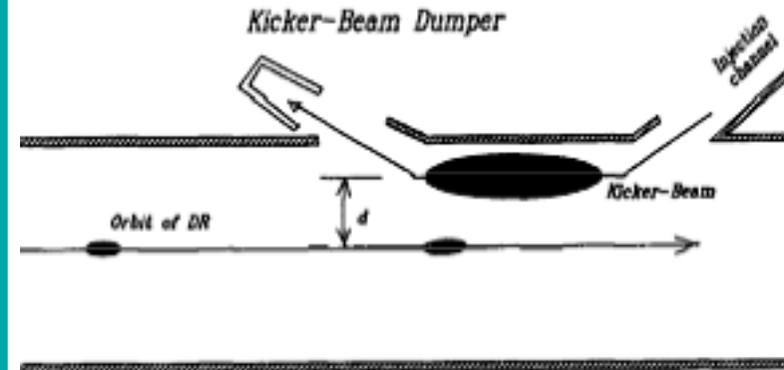
# New proposal for the ILC kicker



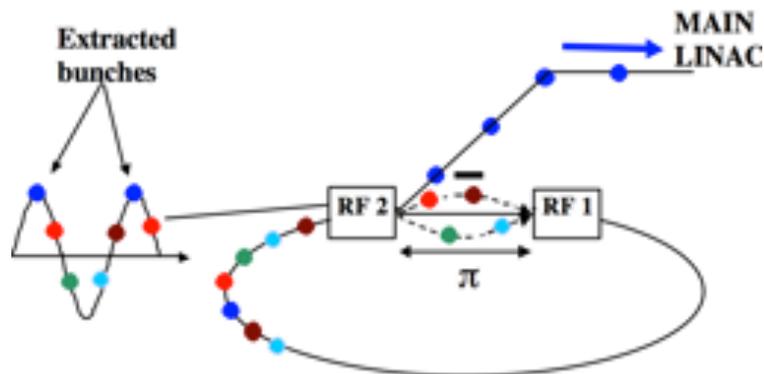
## Fourier series kicker



## Beam-Beam kicker

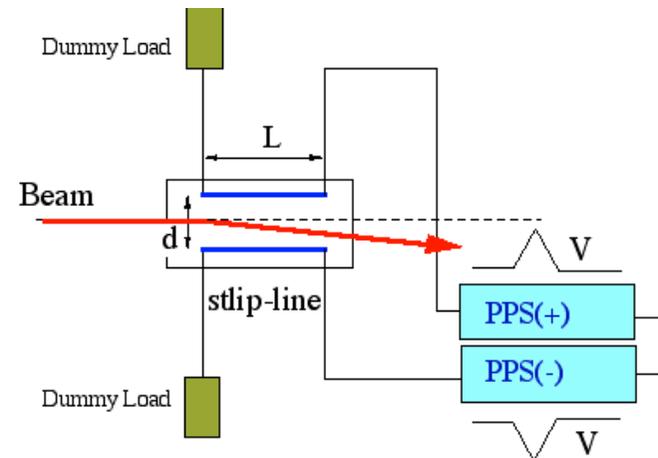


## RF deflector

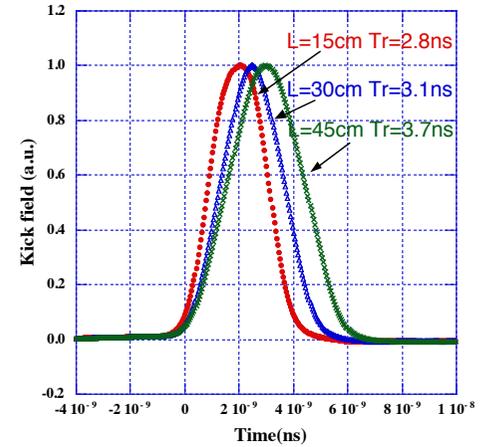
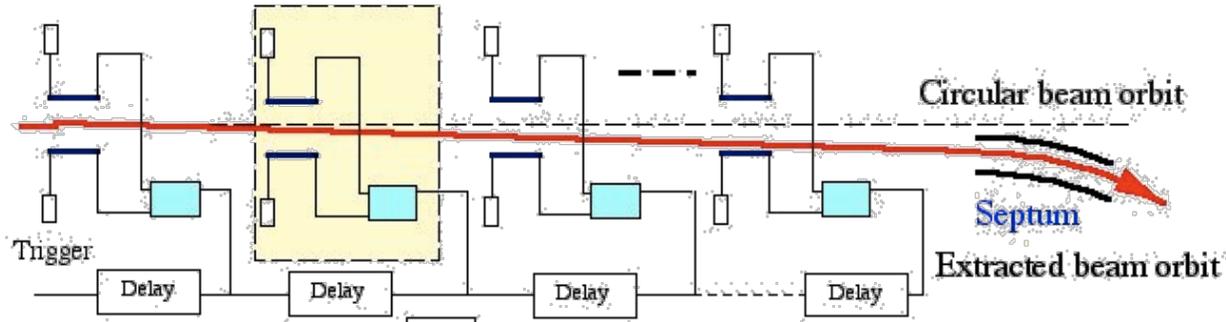


10.5.26

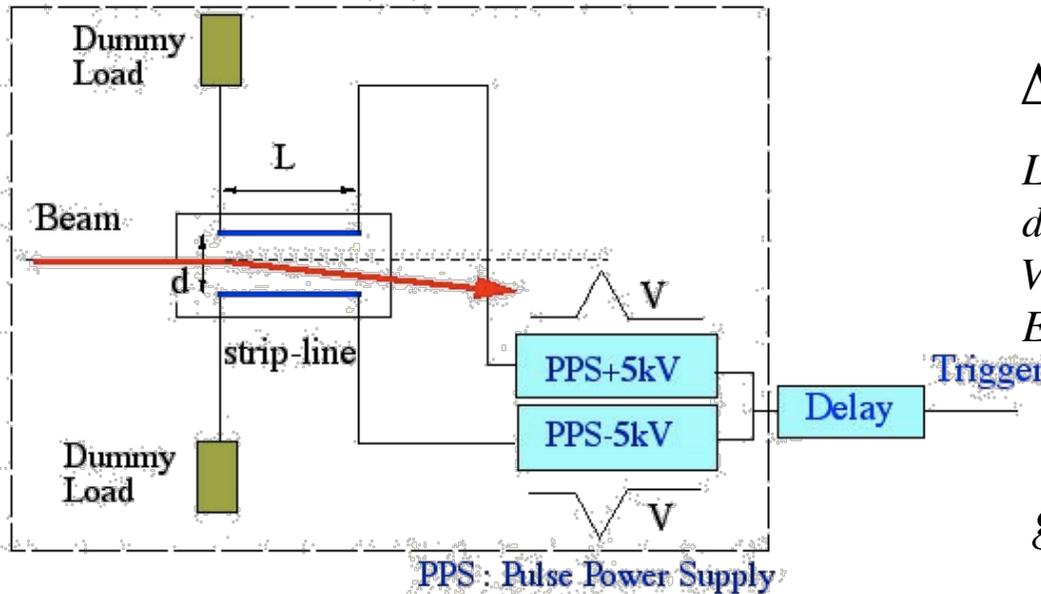
## Strip-line kicker



# Design of Strip-line kicker system



*~20 units for 0.6mrad kick angle*



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

$L$  = strip - line length

$d$  = distance between the electrodes

$V$  = pulse voltage

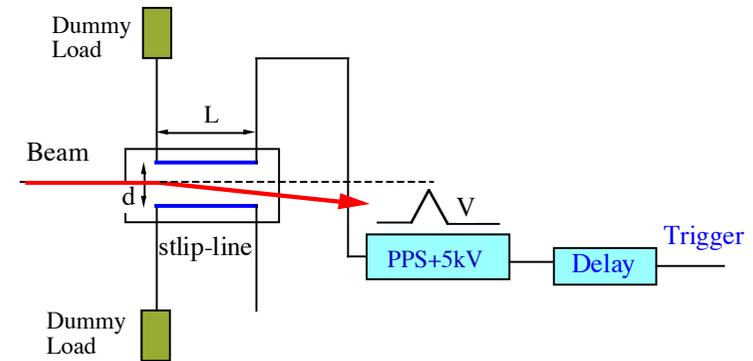
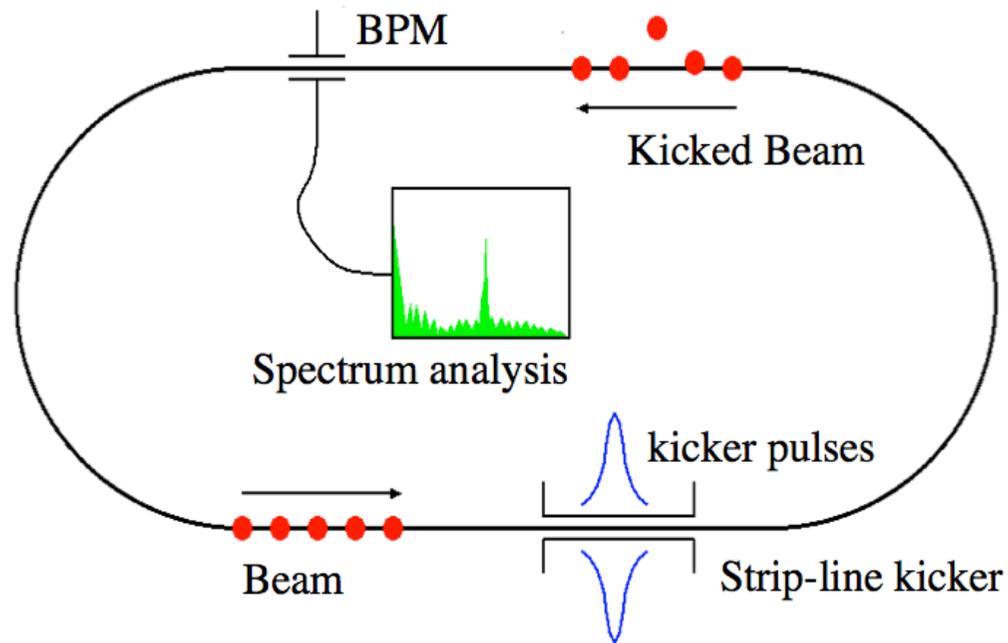
$E$  = Beam energy

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

$\omega$  = strip - line width

$d$  = distance between the electrodes

# Single unit beam test in ATF-DR

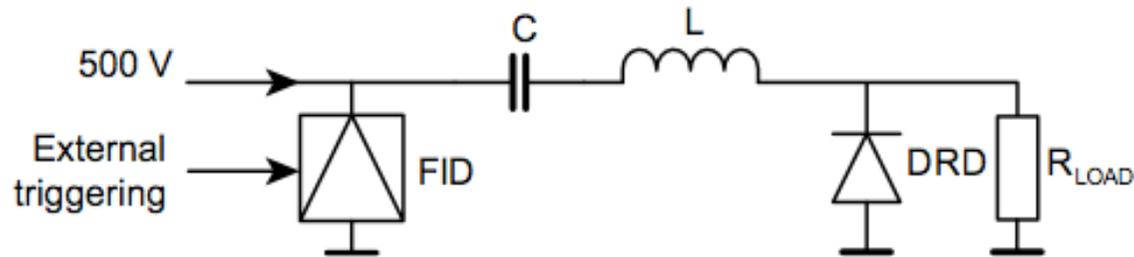


*Single unit of strip-line kicker*

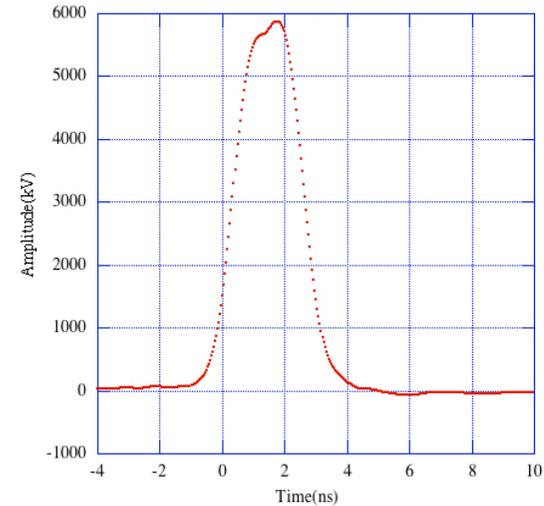
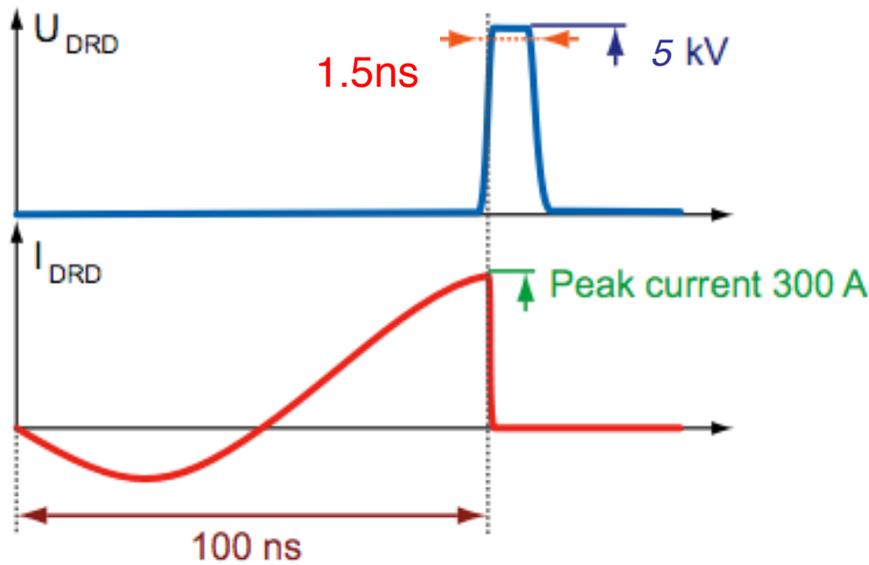
- **Rise/fall time measurement by using Turn-by-Turn BPM**  
the profile of the kick field is estimated from the betatron amplitude
- **Rise/fall time improvement by Waveform compensator**  
the combination of two kick field improve the Rise/fall time



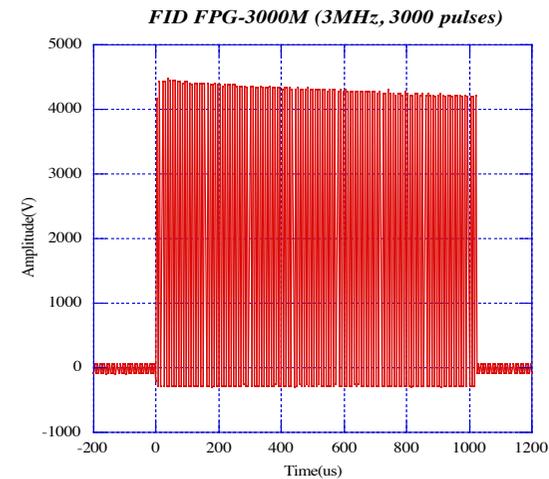
# Pulse source(FID FPG5-3000M)



FID : Fast Ionization Dynistor  
DRD : Drift step Recovery Diode



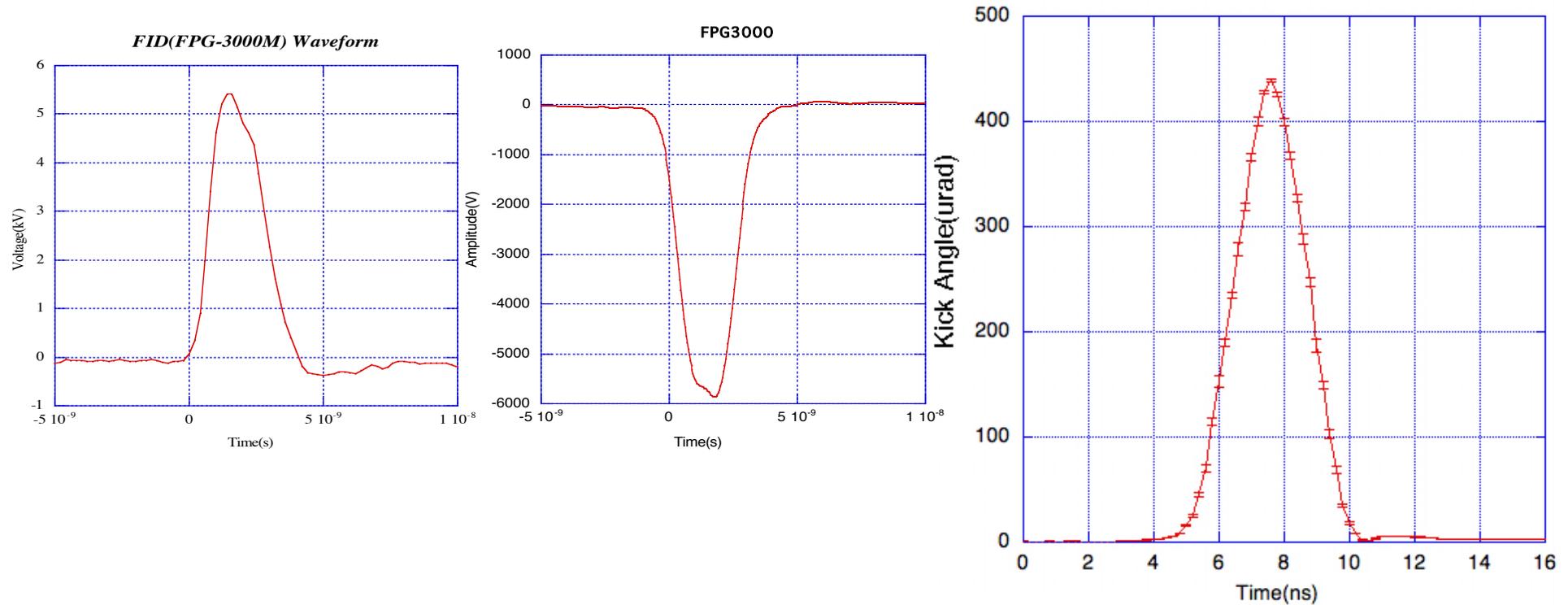
Single pulse waveform



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

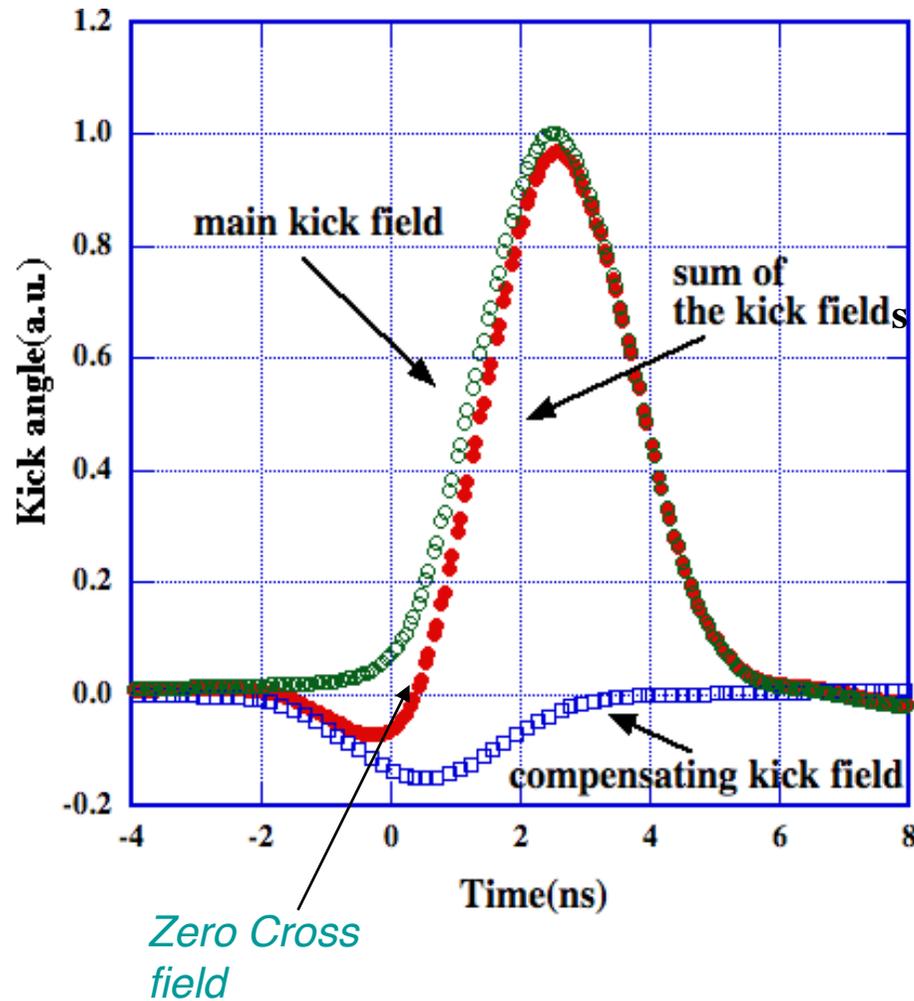


## Beam kick profile with 5kV FID pulsers and a 30cm long strip-line kicker



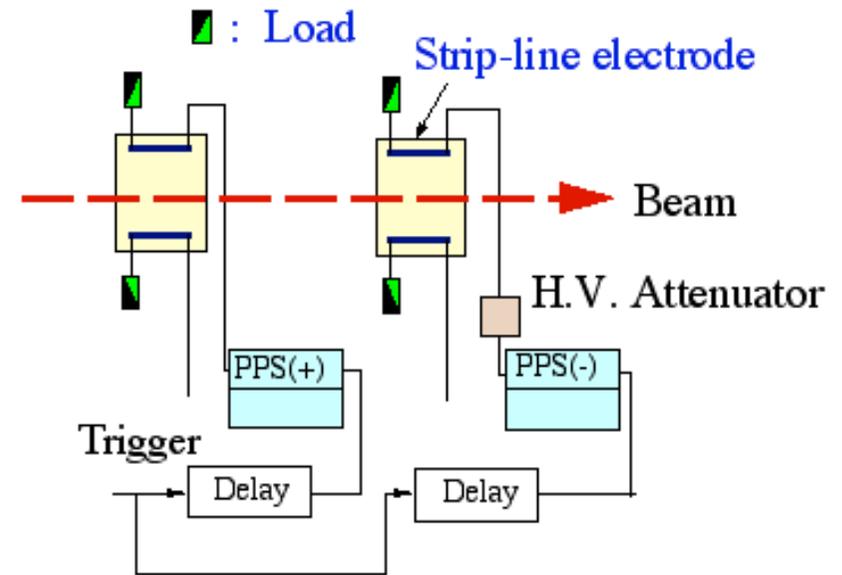
The picture shows the timing scan of the kick pulse to the beam, when the Positive and Negative pulses(5kV) are applied at the same timing. The peak kick angle is 0.44mrad and the rise time of the kick field is 3ns, which agreed with the estimation from the kick voltage and the strip-line dimensions.

# Waveform compensator



*Simulation of waveform compensator*

10.5.26

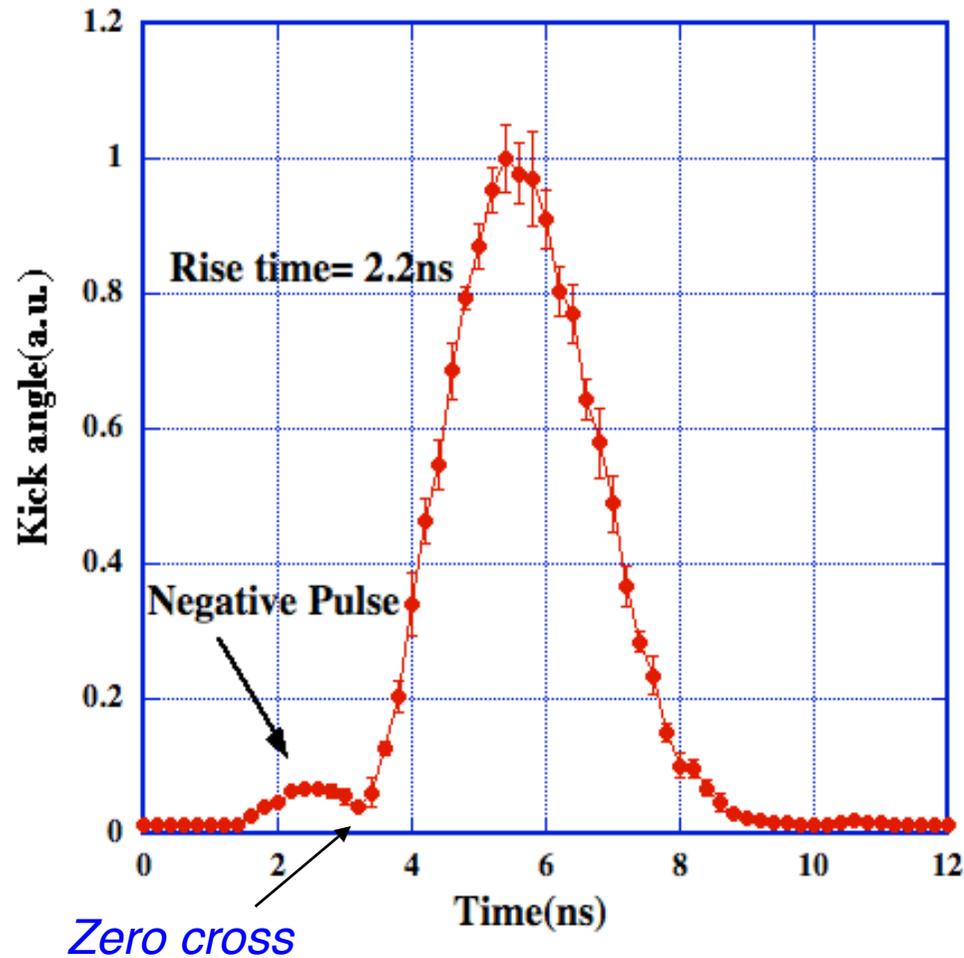


*Experimental set up*

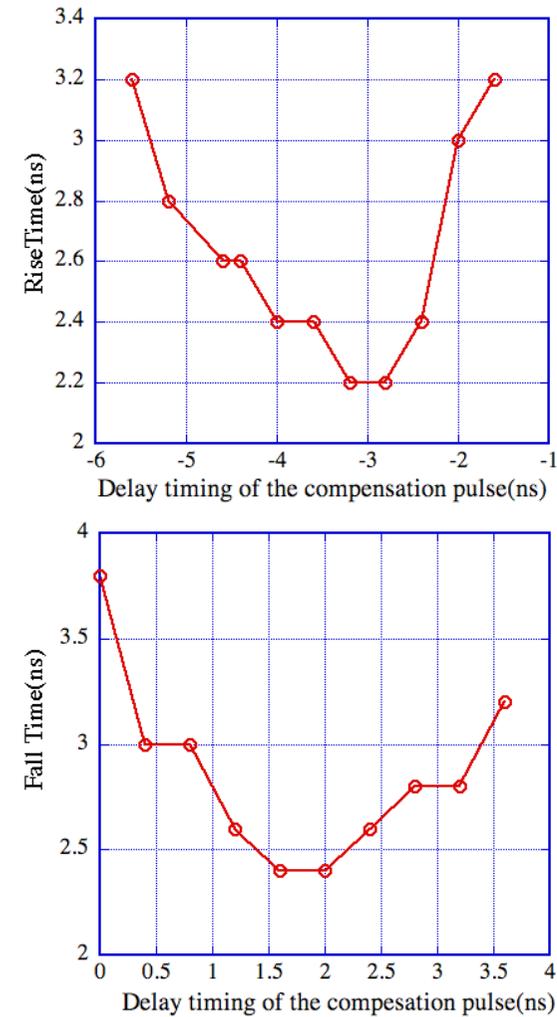
*The rise/fall time can be improved by the combination of the positive and negative pulses which have different timings and different amplitudes.*



# Rise time improvement with Waveform compensator



10.5.26



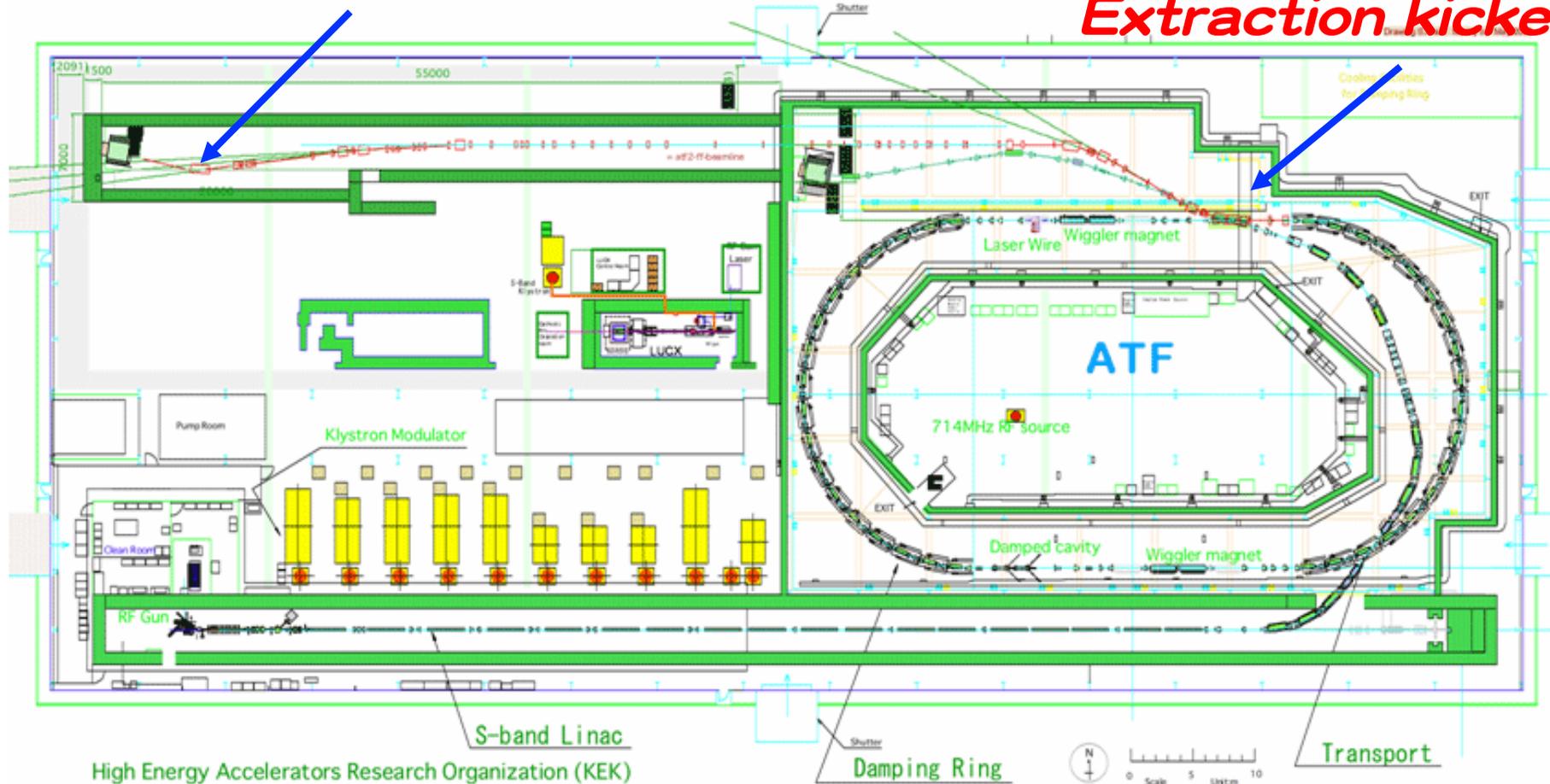
Rise/fall time improvement v.s. timing



# Experiment at ATF2

ATF2 - 37nm beam production and measurement

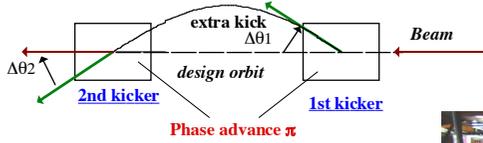
**Extraction kicker**



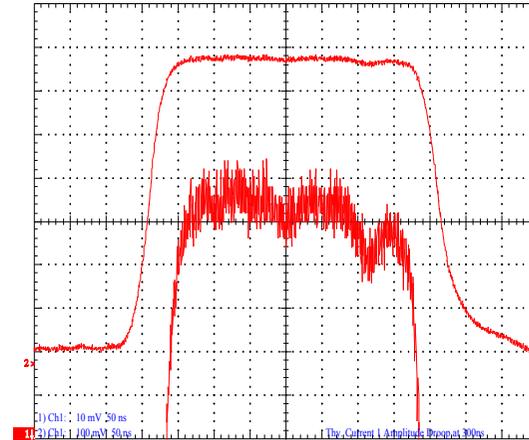
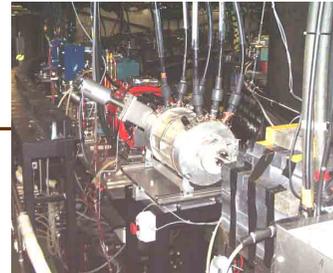
To demonstrate the performance of the strip-line kicker. The beam extraction test of the strip-line kicker is being carried out by replacing the conventional kicker.



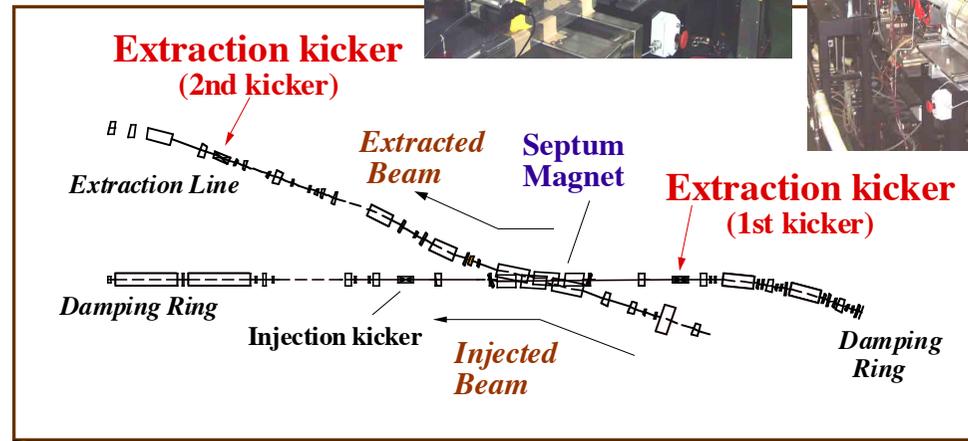
# Present beam extraction (Conventional kicker)



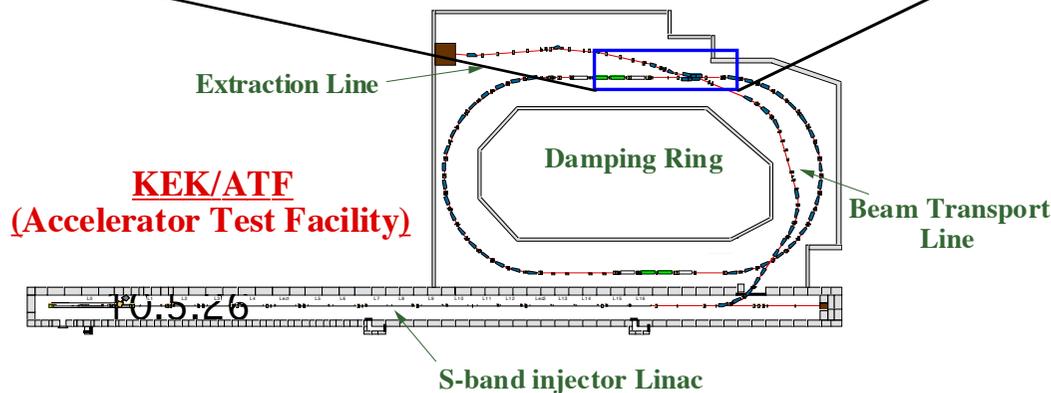
Kick angle Stability  
 $1 \times 10^{-3} \rightarrow 2.8 \times 10^{-4}$



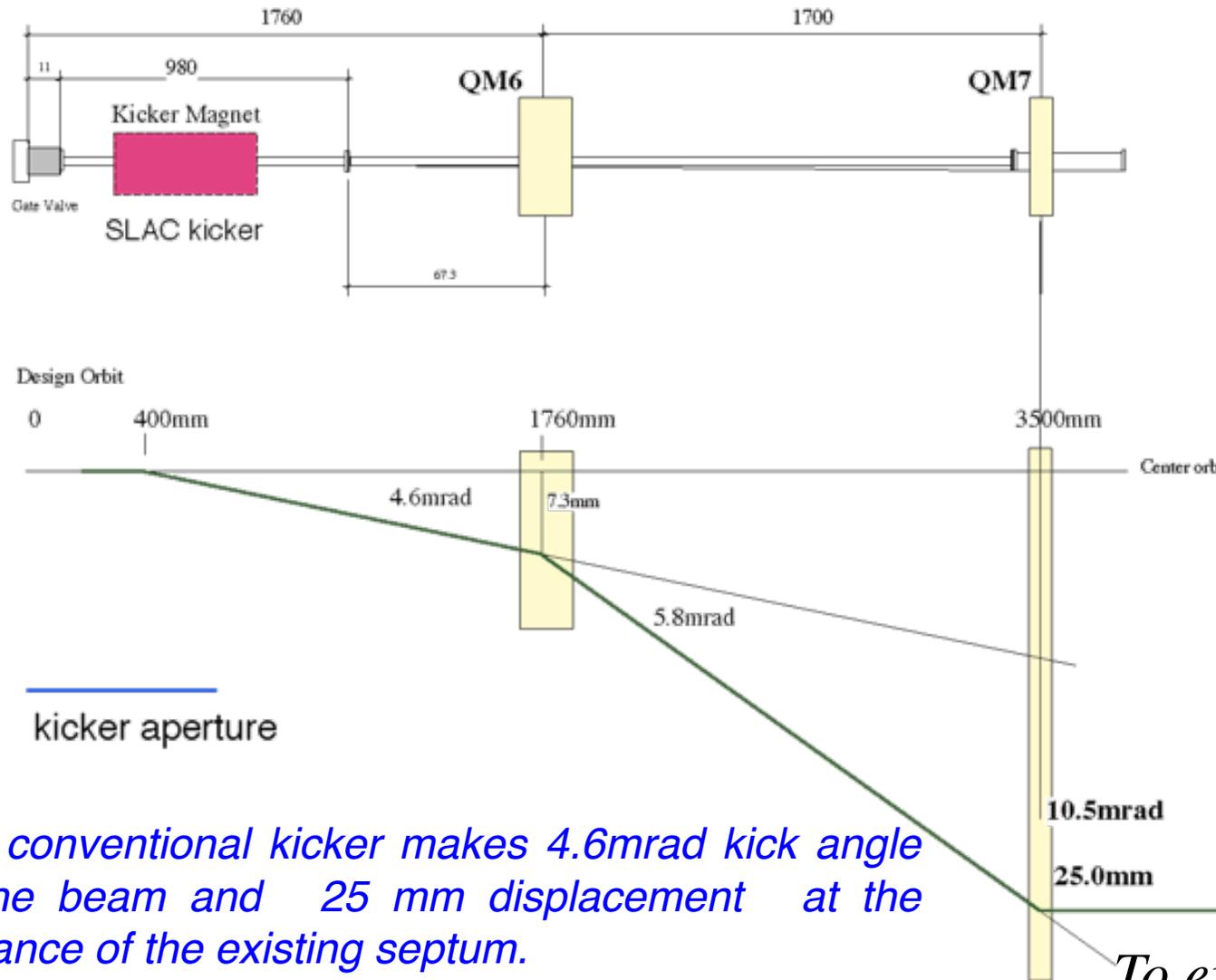
308ns pulse width



3 bunches, 154ns spacing



# Present layout



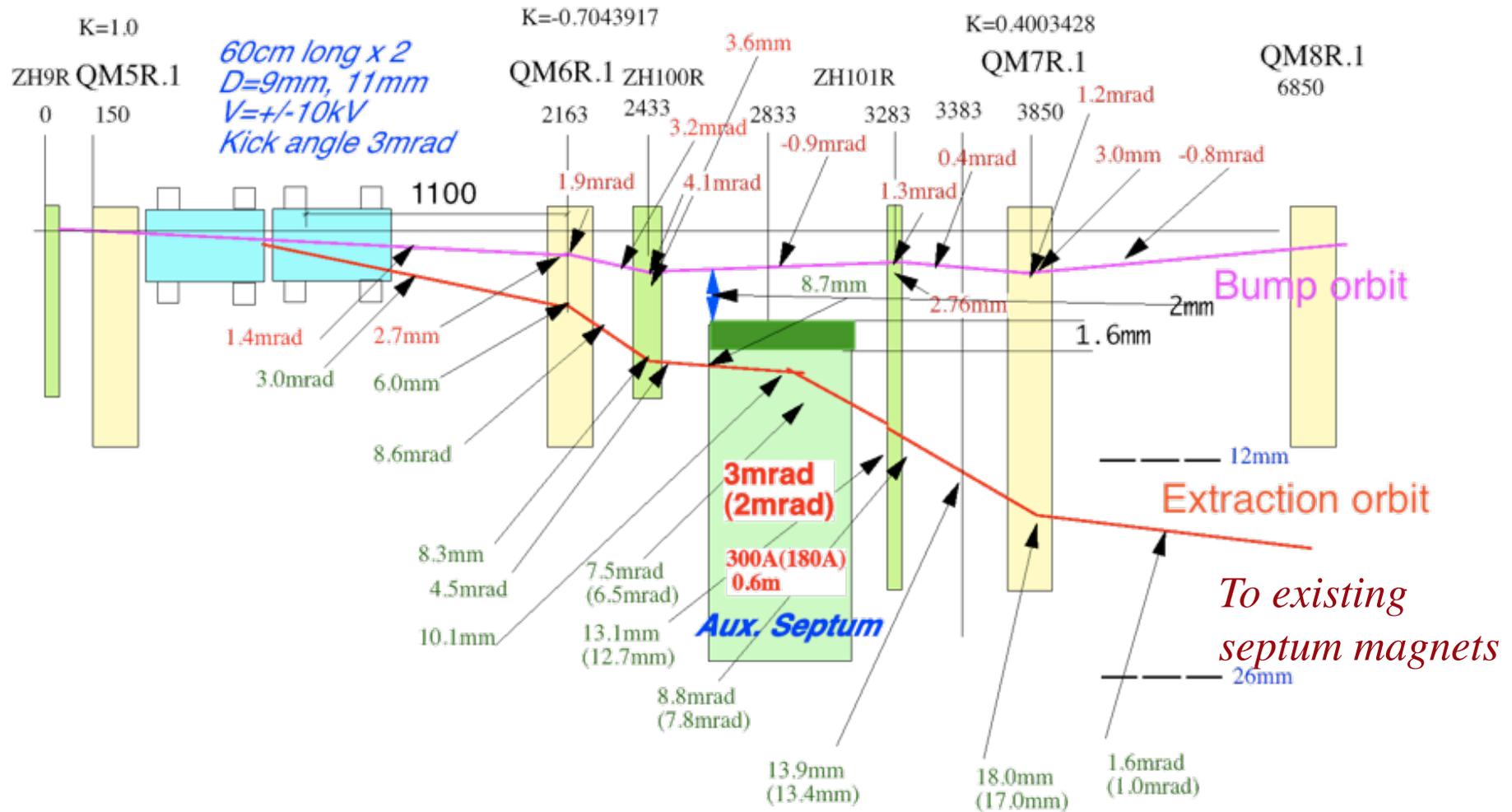
*The conventional kicker makes 4.6mrad kick angle to the beam and 25 mm displacement at the entrance of the existing septum. There is no enough space to install strip-line kicker to get same kick angle.*

*To existing septum magnets*

# Orbit by using Strip-line Kicker & bump



3mrad kick angle





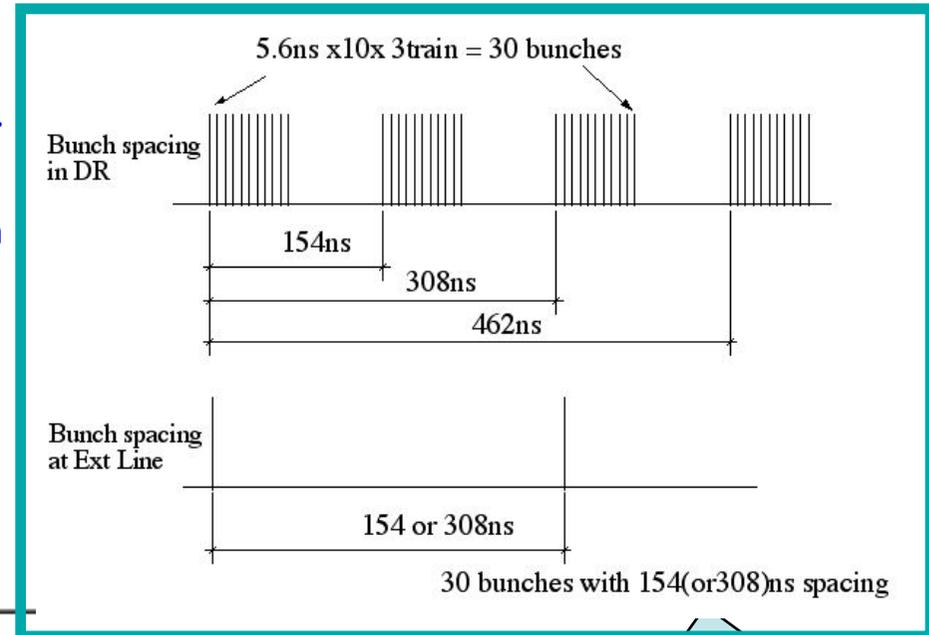
# Timing chart of 30 bunches beam extraction

## Beam injection/extraction sequence

- 10 bunches, 3 trains injection
- Pulse bump excites gradually after damping
- Beam kick out bunch-by-bunch with 308ns spacing

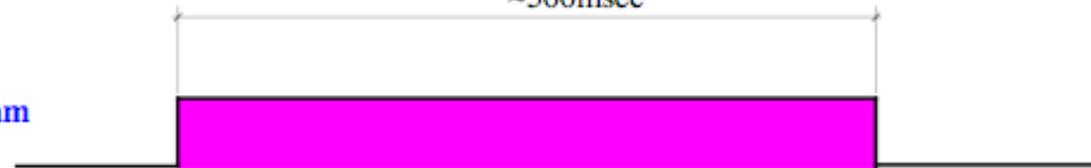
Injection beam

1st Train    2nd Train    3rd Train



~500msec

Stored beam



Local bump height

~100msec



Extracted beam

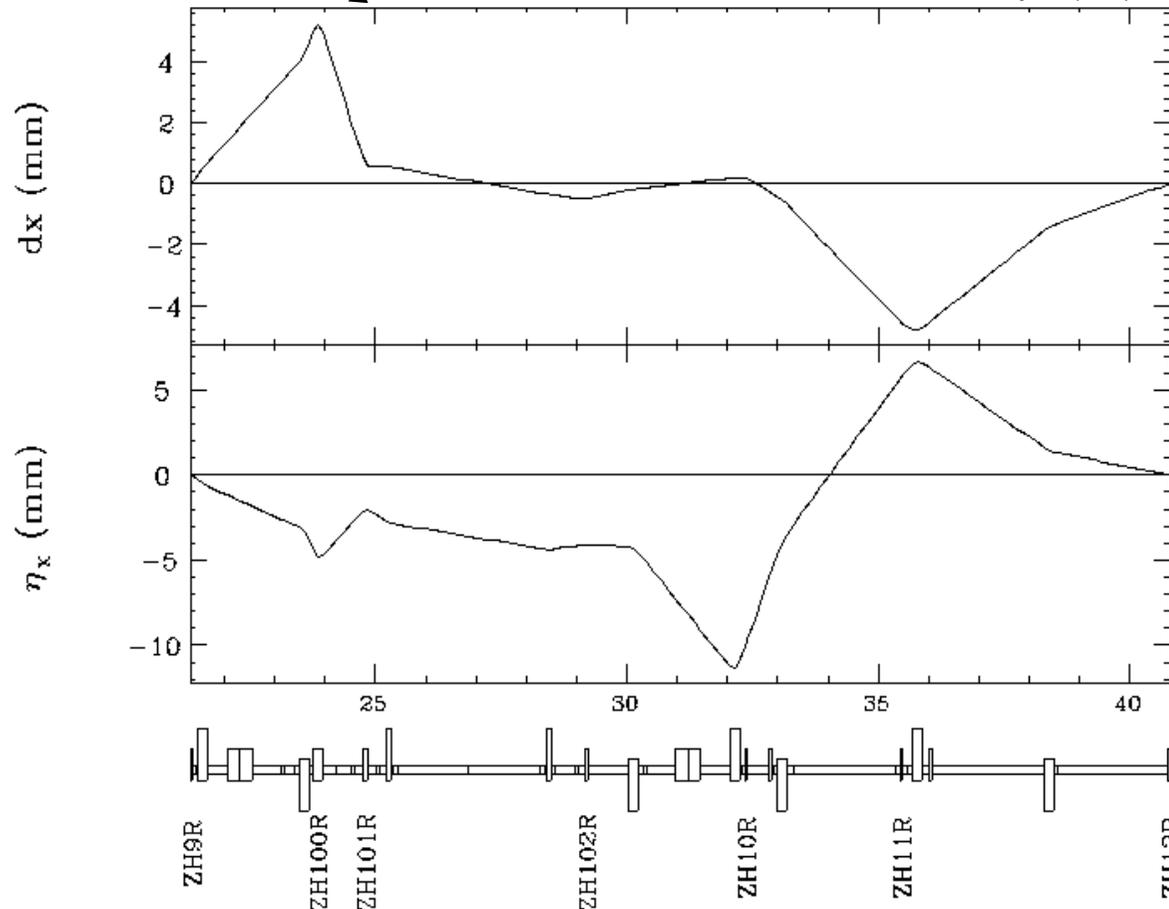




# Optics design of Orbit Bump with 7 Correctors

Auxiliary Septum location

16:04:21 Monday 12/03/2007



$dx=5\text{mm}@ZH100R$

ZH9R -.002320433716

ZH100R .010028367995

ZH101R -.005102712636

ZH102R -5.52689273E-4

ZH10R .001010243282

ZH11R -7.88468363E-4

ZH12R 5.883103424E-4

**Abs[dx] between septum and INJ.Kicker**

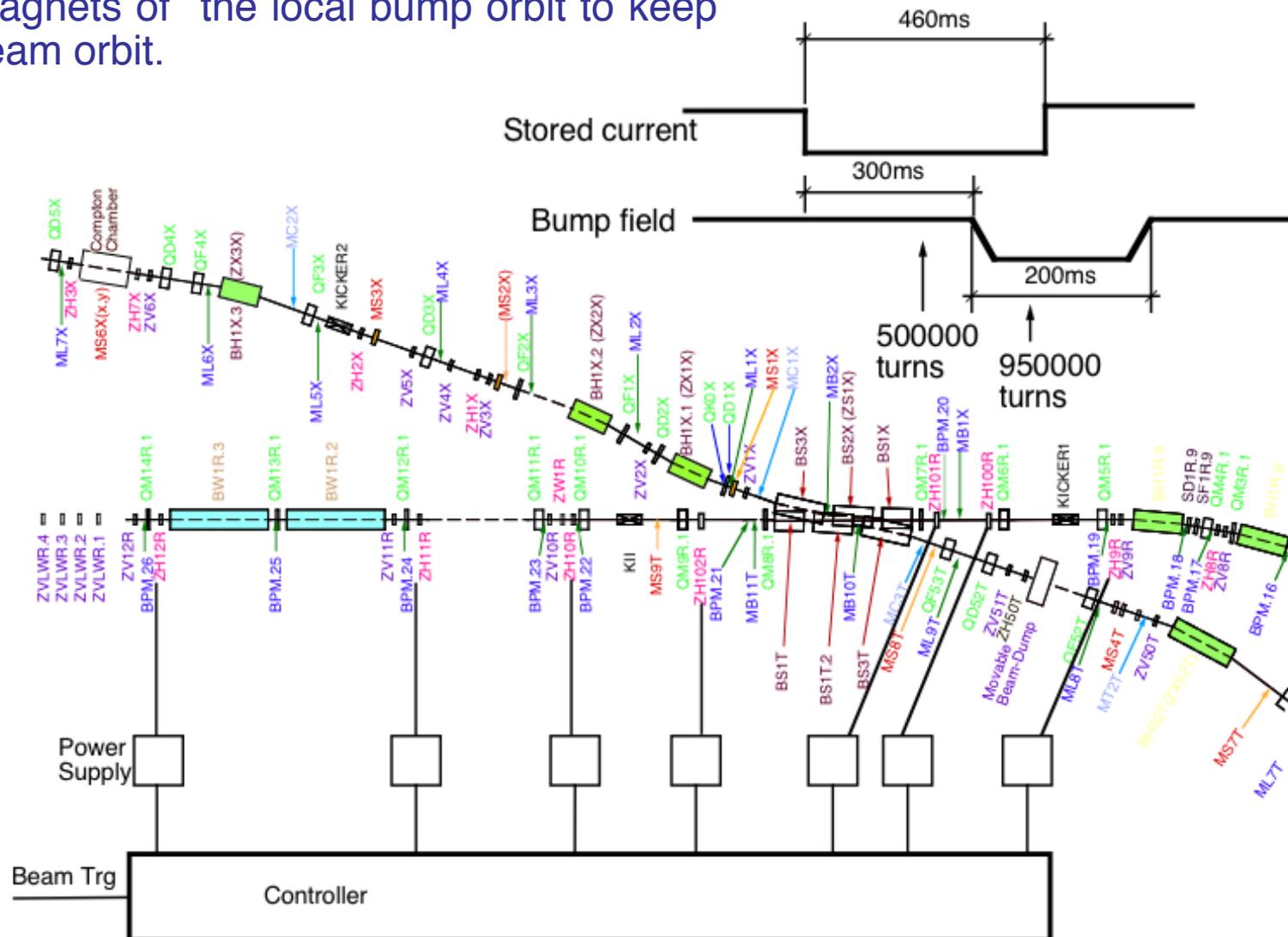
**10.5.26 ( from LSEP.1to IIN) < 0.5 mm**

*S.Kuroda*

# Power Supply Control for the Pulse Bump



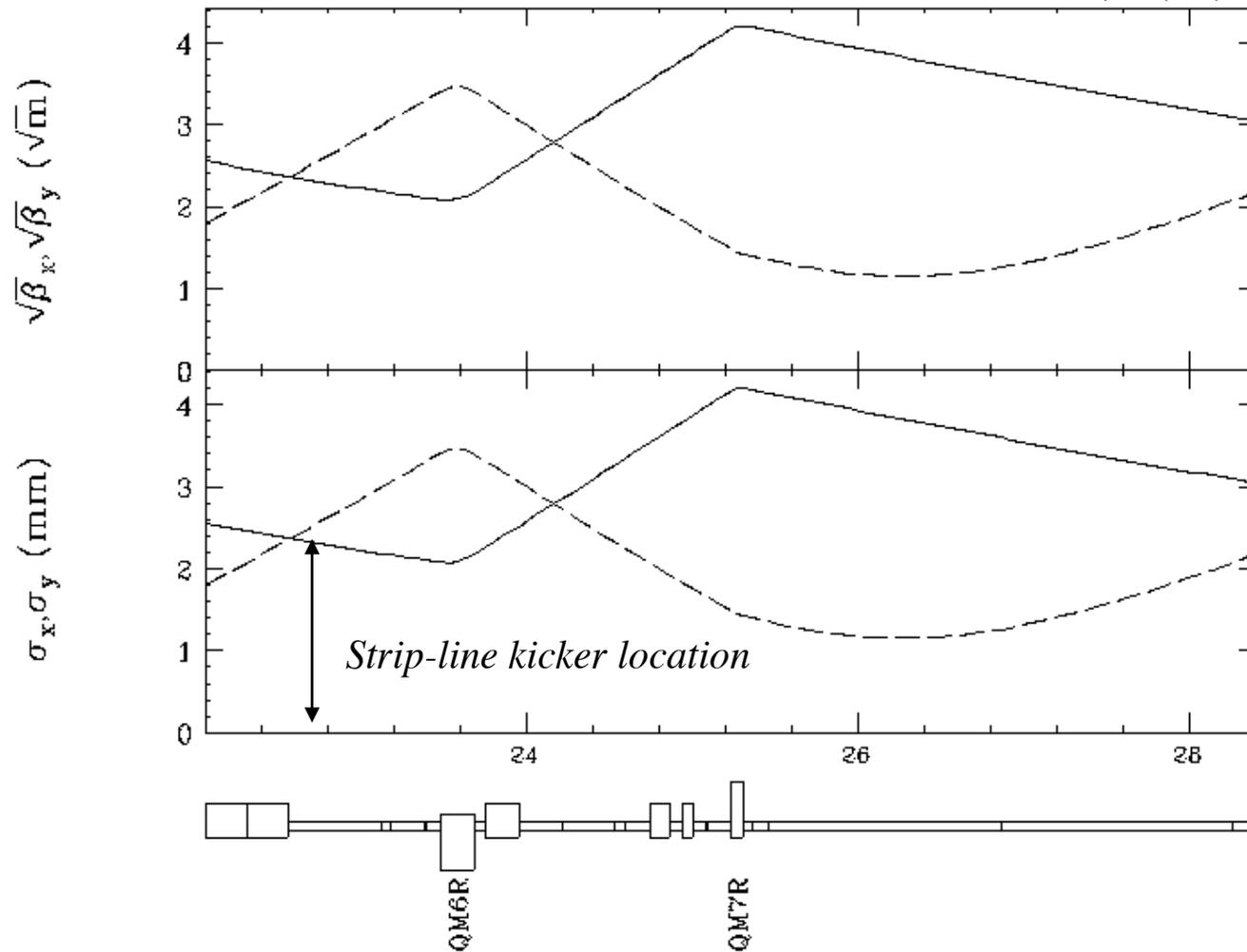
The pulse current control, which is synchronized with the beam injection, is required for the steering magnets of the local bump orbit to keep a stable beam orbit.



# Aperture



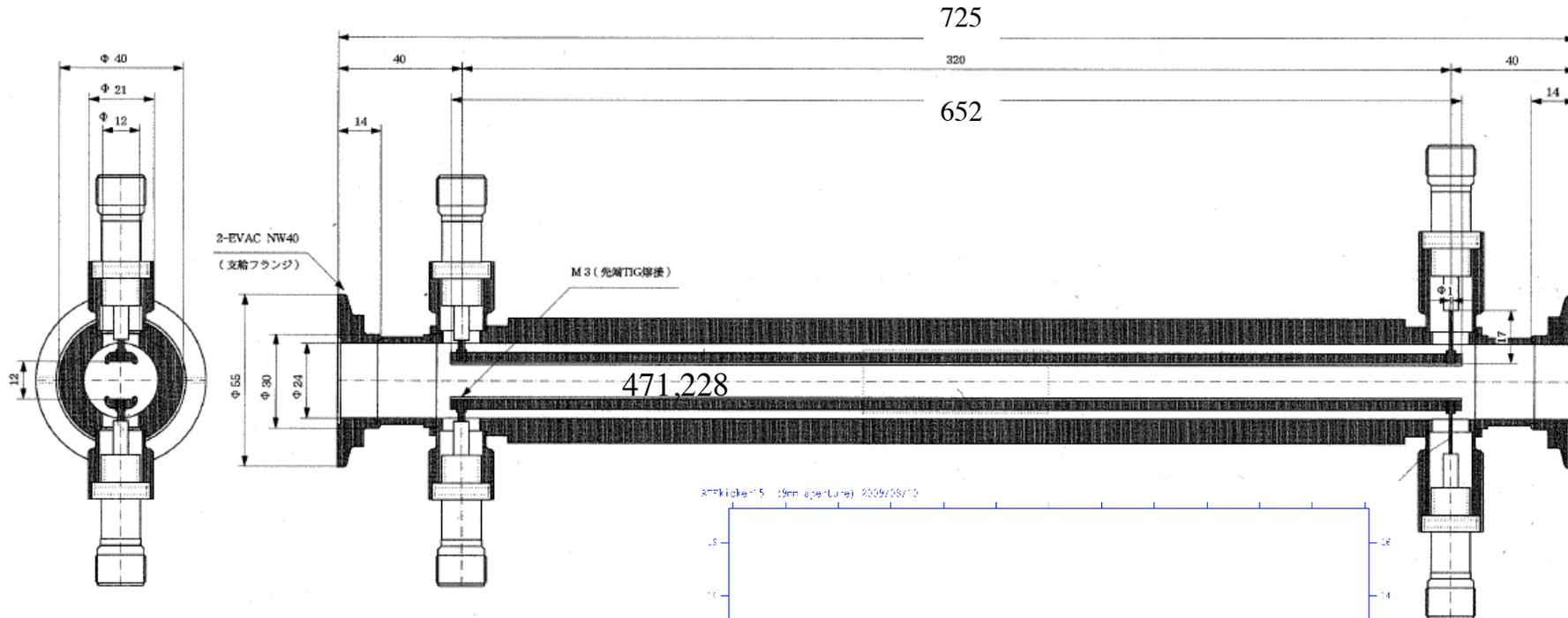
15:08:08 Tuesday 06/10/2008



$Ex(inj.)=1e-6,$   
 $Px(inj.)=1e-2$

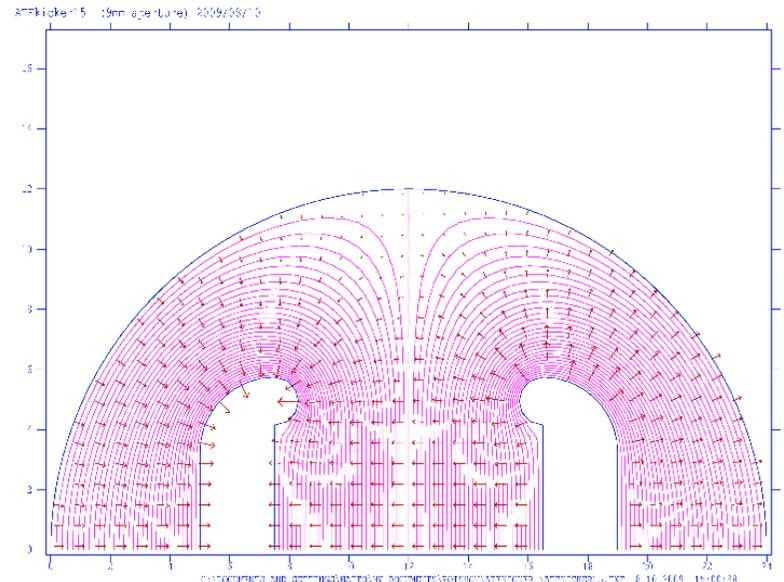
Horizontal aperture is limited by the strip-line electrode gap.  $3\sigma$  of the injection beam can get through a 9mm gap of the strip-line kicker section.

# Proto type strip-line kicker(60cm long)



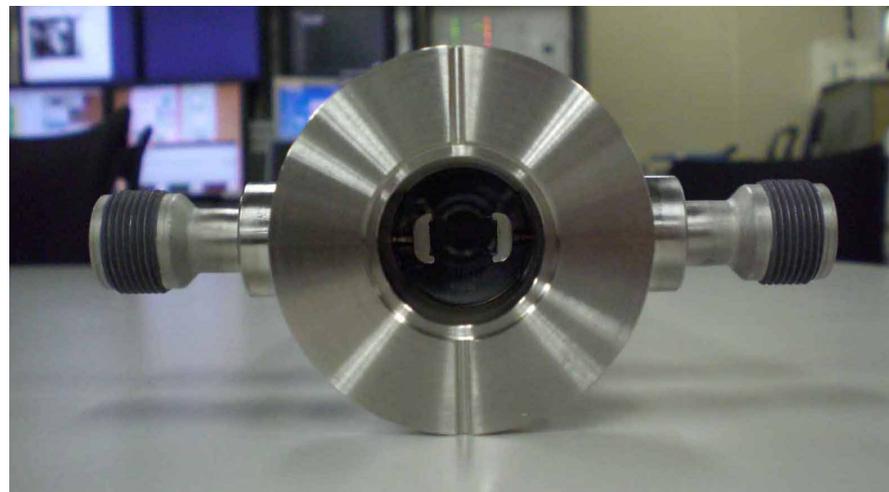
## Fabrication of Strip-line electrode

- Designed by using POISSON
- HN-type connector
- Gap distance 9mm, 11mm





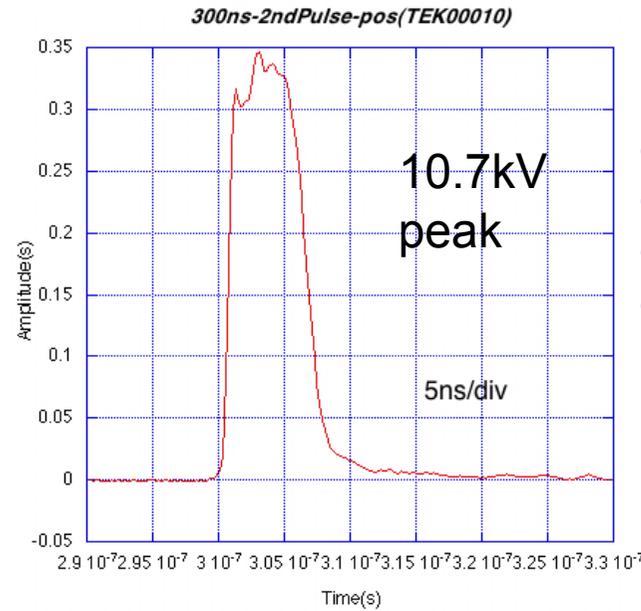
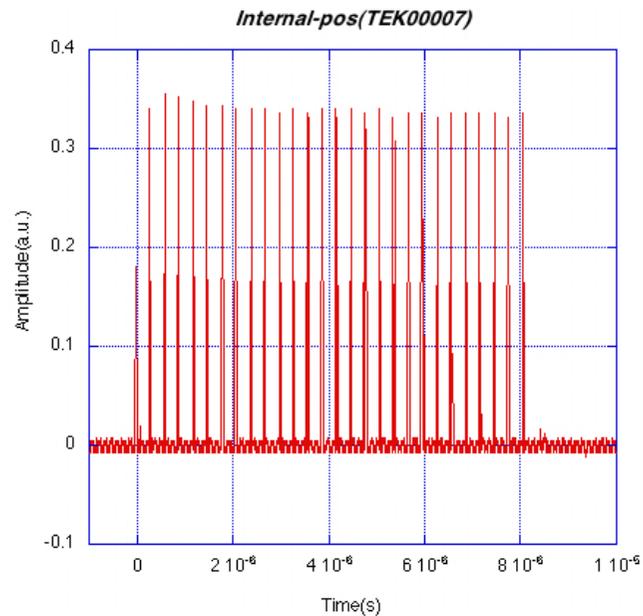
## Photo of the fabricated strip-line kicker



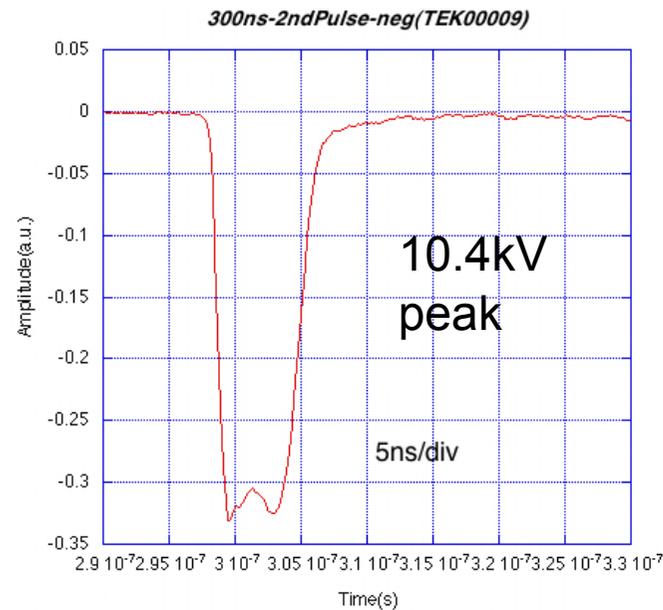
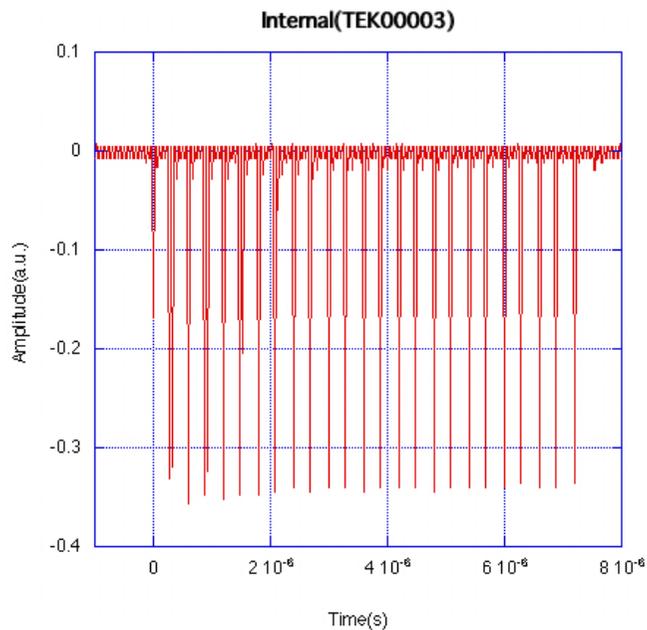
10.5.26

21

# 10kV, 4ns pulser



- Rise time 1.5ns
- Peak voltage +/- 10kV
- 3.2MHz
- Up to 50pulses

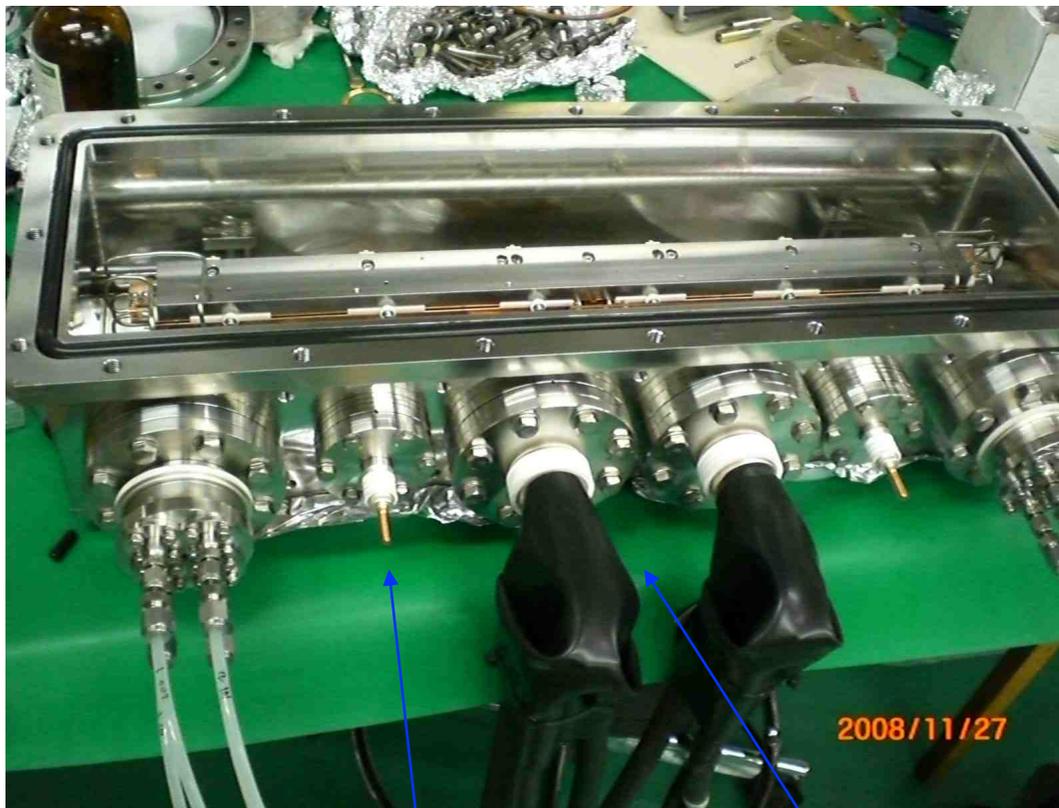
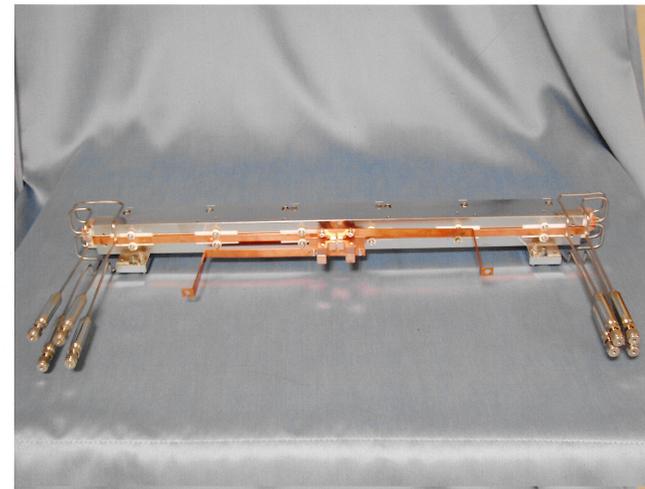


# Auxiliary septum magnet



In vacuum type septum was designed and fabricated.

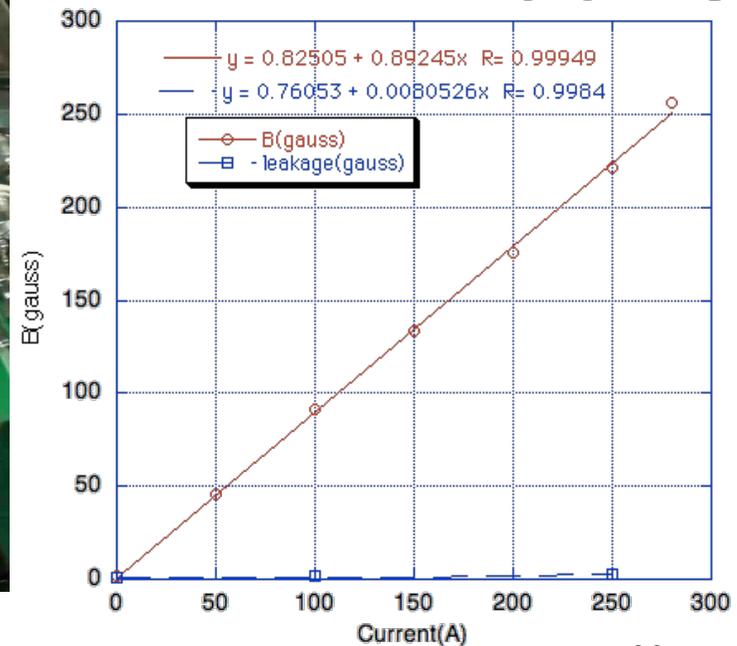
The current test up to 300A was done without any temperature problem. The leakage flux is less than 1%, which can be compensated by the auxiliary coil.



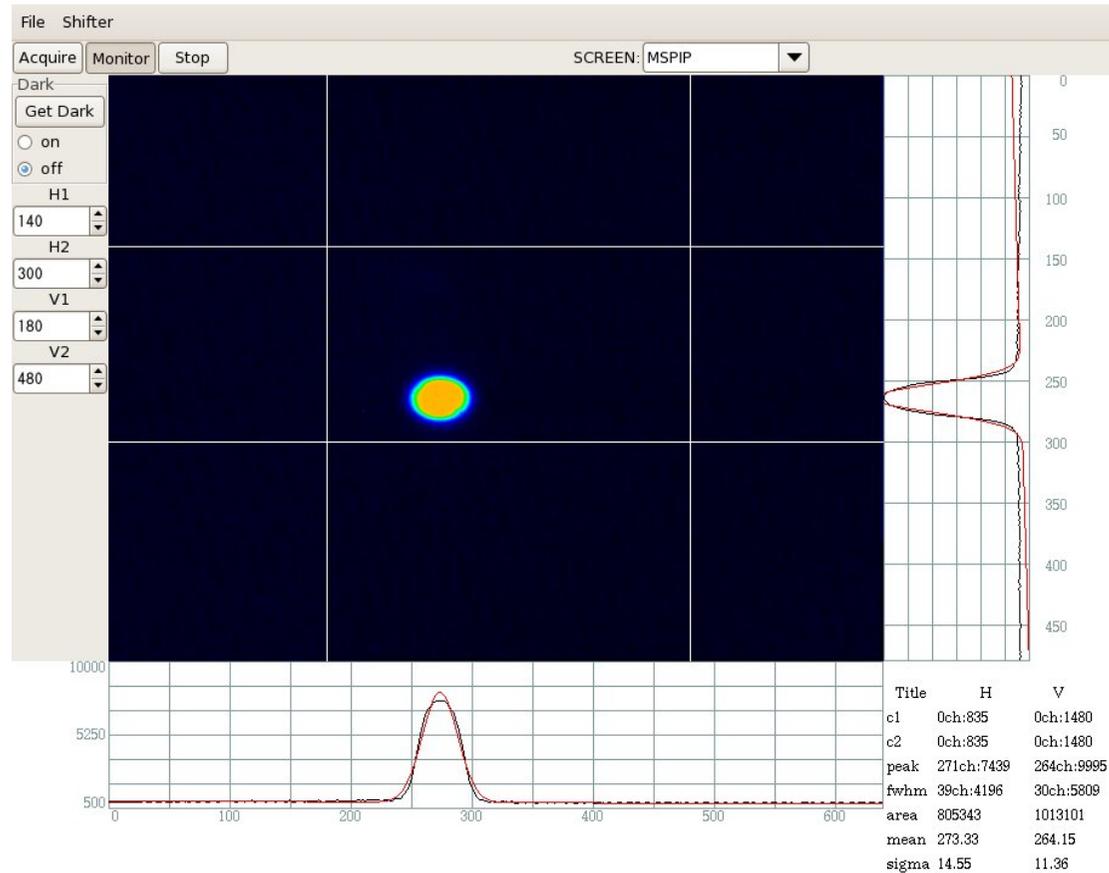
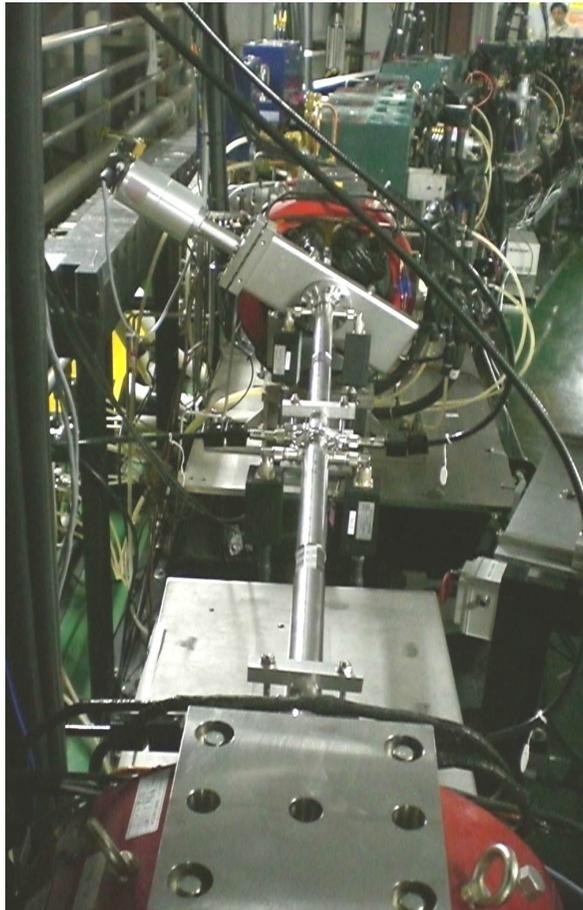
10.5.26 Aux. coil(1turn)

Main coil(1turn)

Field Measurement of the Auxiliary Septum Magnet

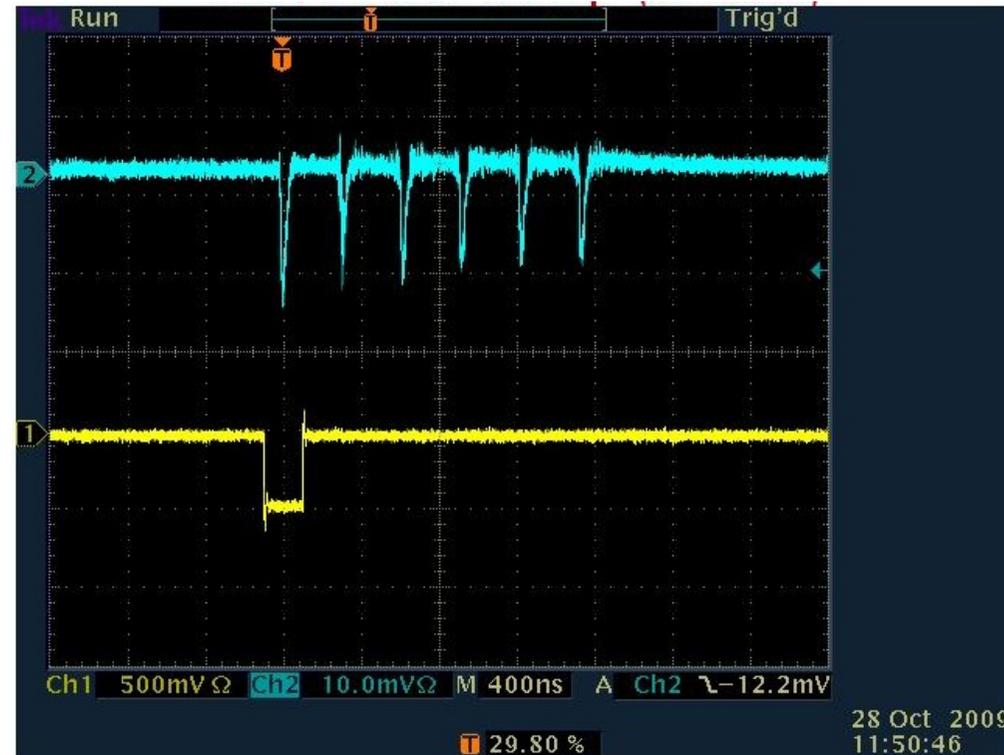
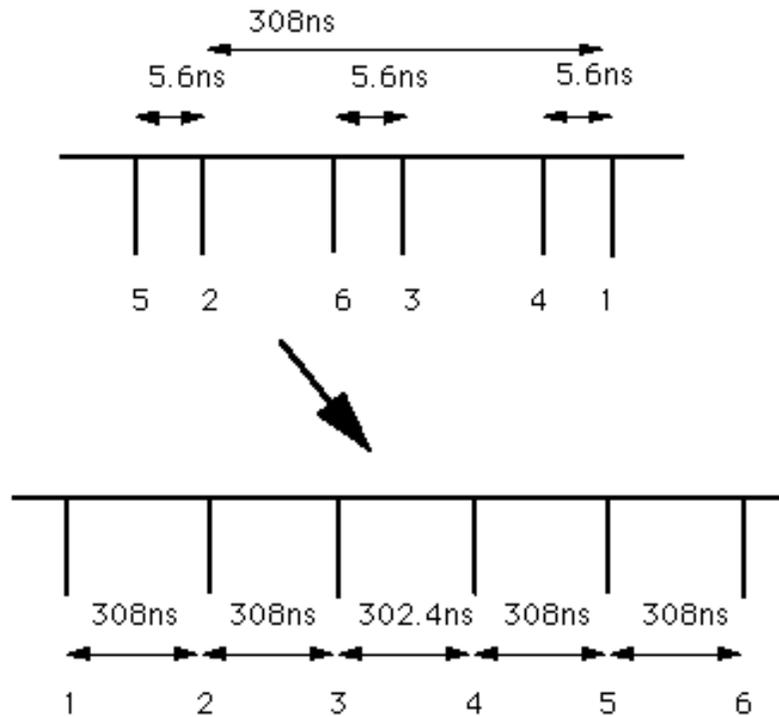


# Beam Extraction succeeded from DR to ATF2 2009.Oct. 22.



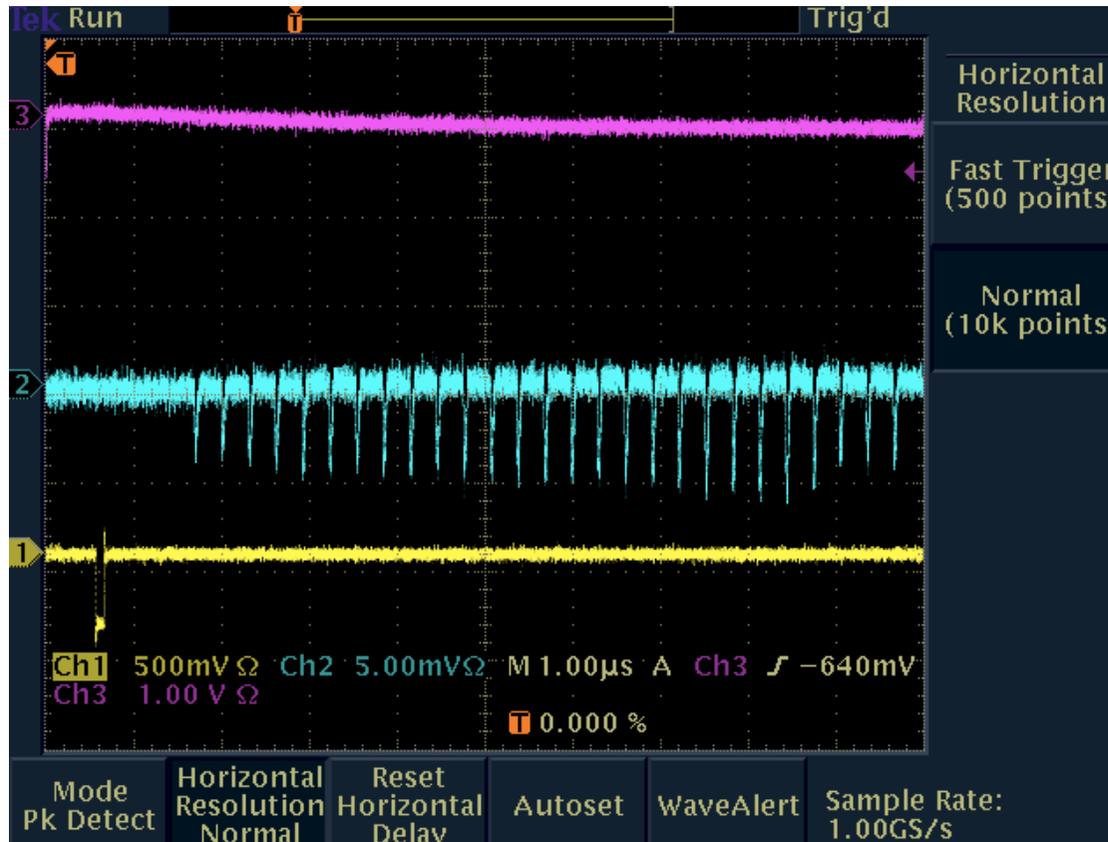
*First beam extraction was confirmed at MSIX screen monitor, which is located at the downstream of the septum magnets.*

# Multi-bunch beam extraction by the Fast kicker(1)



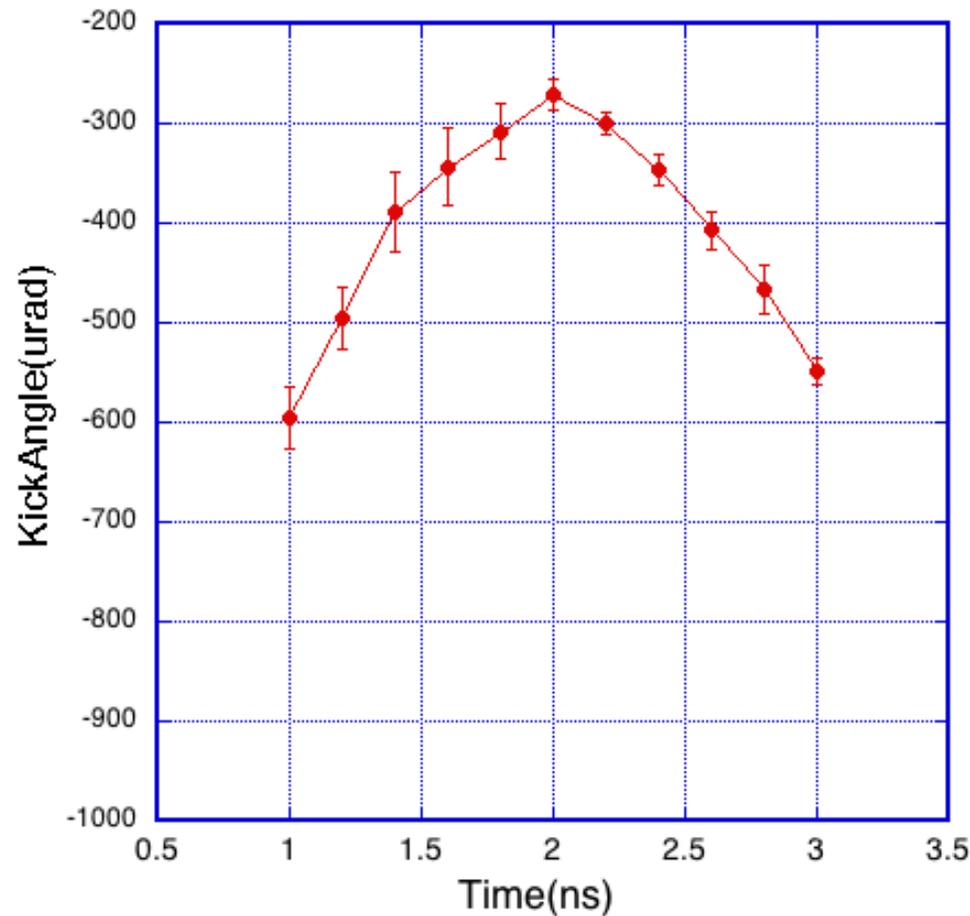
The stored multi-bunch beam, which has short bunch spacing(5.6ns), in the Damping Ring was kicked out bunch-by-bunch with 308ns(302.4ns) interval. The picture shows the case of the 6 bunches beam extraction. The bunch charge was monitored by the current transformer at the location of the middle of the extraction line. The horizontal scale is 400ns/div and the vertical scale is 0.2nC/div.

## Multi-bunch beam extraction by the Fast kicker(2)



Up to 27 bunches of the multi-bunch beam was extracted to the extraction line. Unfortunately, the beam storage in the DR was not good at that time. The last bunch of each train could not store to the DR. The bunch population of the extracted beam was not so flat.

# Kick field profile and the jitter



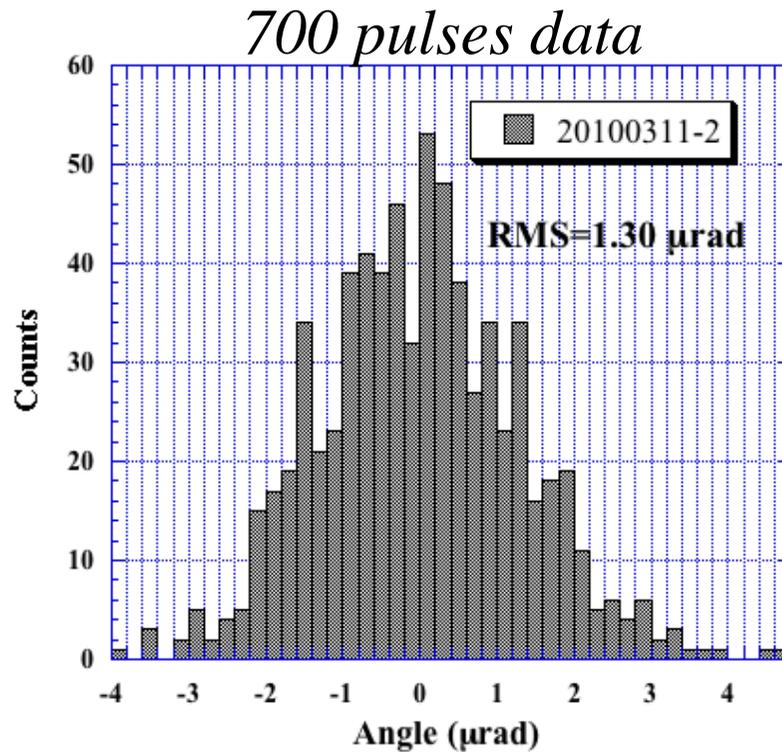
- Kick field measurement by scanning the kicker timing for the single bunch beam.
- There is no flat-top.
- The kick angle jitter increased at steep area of the kick field.
- The trigger jitter was dominant for the kick angle jitter.

*Stability  $2 \times 10^{-3}$*

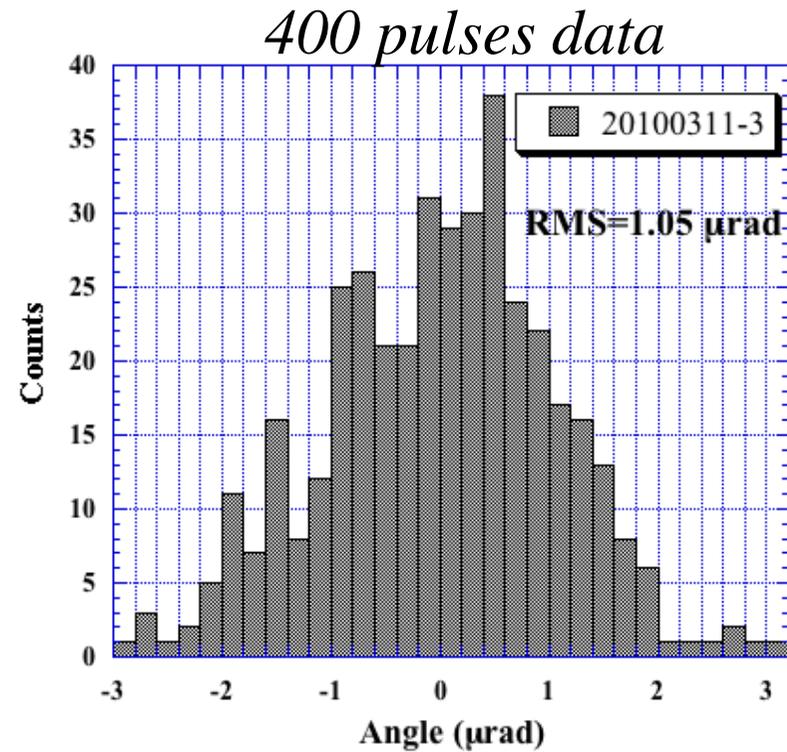
*2009/10/30*



# Kick angle stability



$$\text{Stability}=4.3 \times 10^{-4}$$



$$\text{Stability}=3.5 \times 10^{-4}$$

After trigger jitter reduced to less than 100ps(p-p), the kick angle jitter improved. The kick angle jitter reached to  $10^{-4}$ . The kick angle jitter was estimated from the 20 BPMs data at the ATF2 beam line. The graph shows the kick angle distribution for the mean value.

# 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  $\sim 3$ ns.
- The rise/fall time improved up to 2.2ns with the waveform compensator.
- Multi-bunch beam beam extraction was demonstrated from ATF-DR to ATF2 beam line.
- Stability of the kick angle for single bunch was  $3.5 \times 10^{-4}$ , which is enough for ILC requirement.



Thank you for attention.