Fast kicker performance in ATF

T.Naito(KEK)

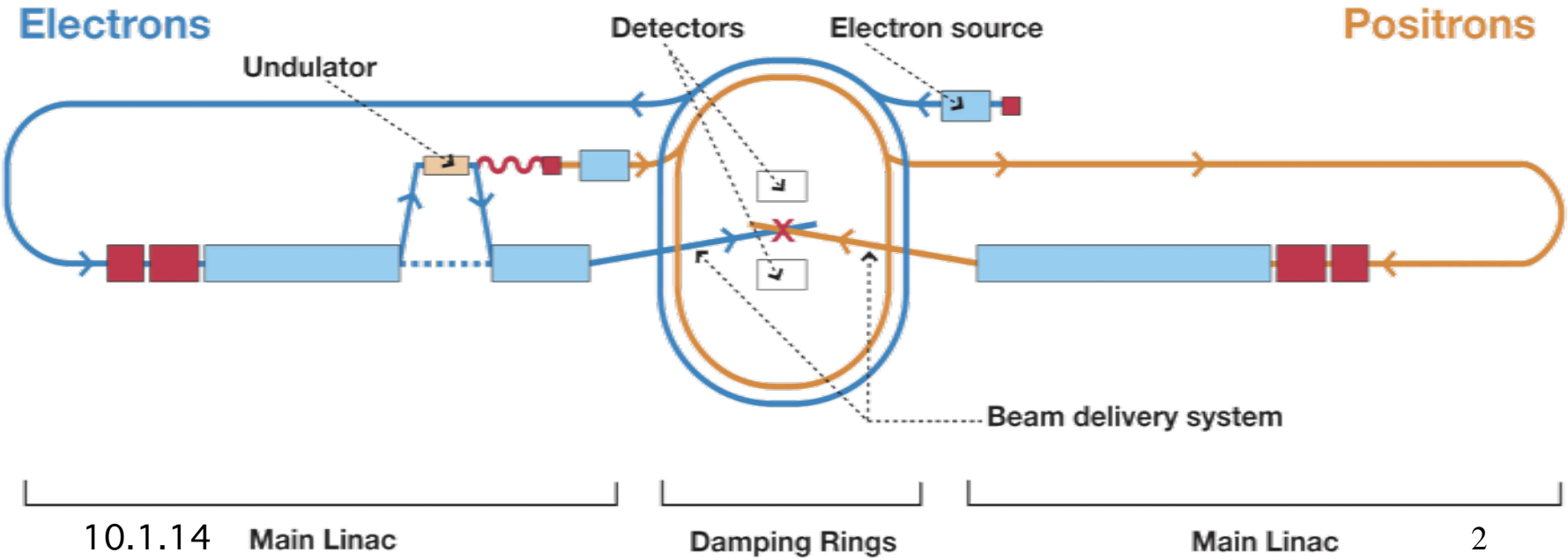
LER2010(2010/01/14)

Parameters of ILC

The length of the bunch train, which consists of 5640 bunches and 154ns bunch spacing, in the linac is ~300km long. 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 of the DR.

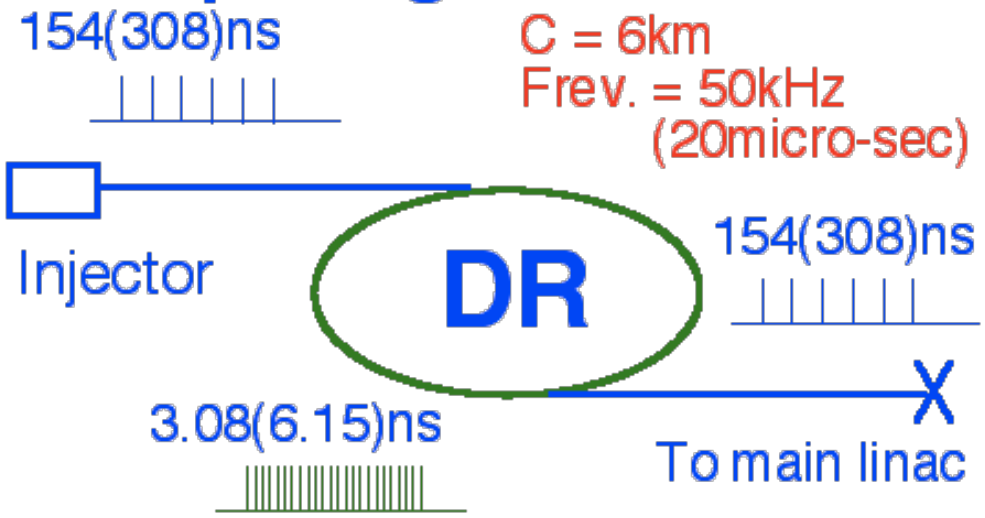
parameters

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

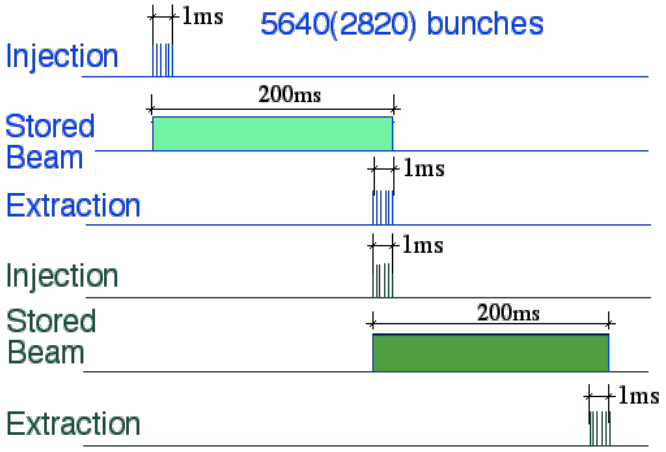


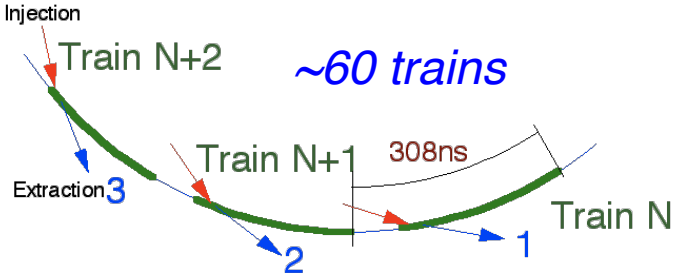
Beam cycle of DR

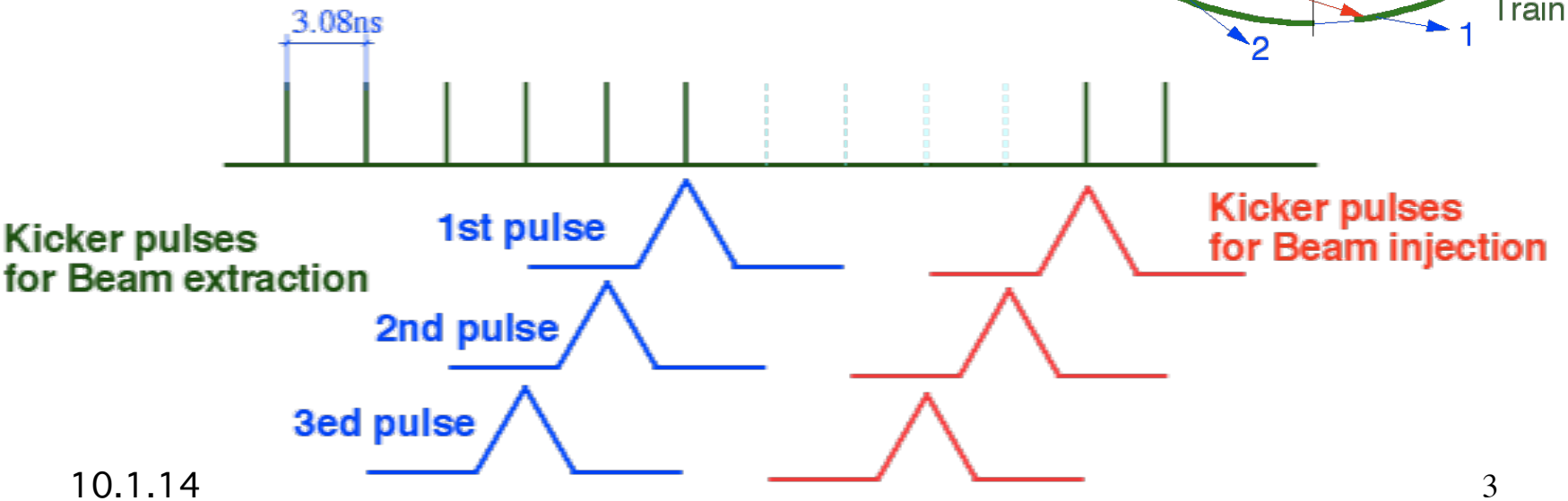
Bunch spacing



Beam Storage Sequence in DR







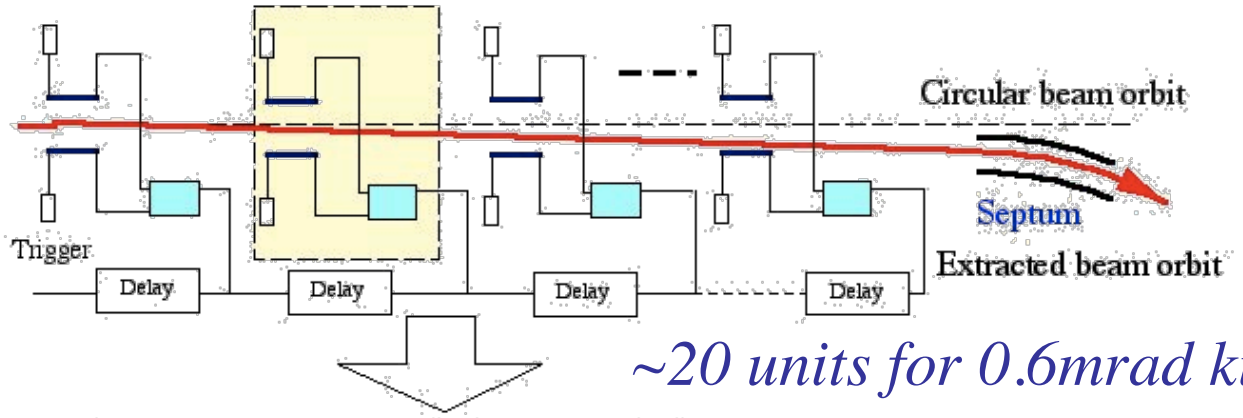
ILC DR kicker parameters

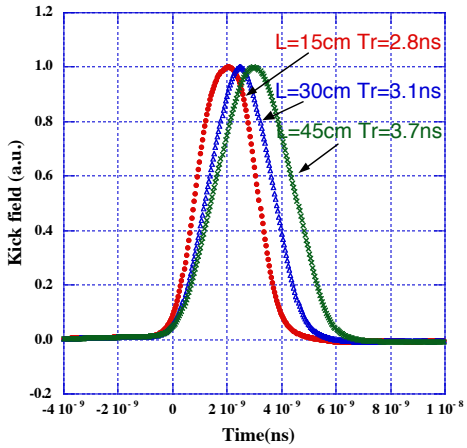
Specification

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

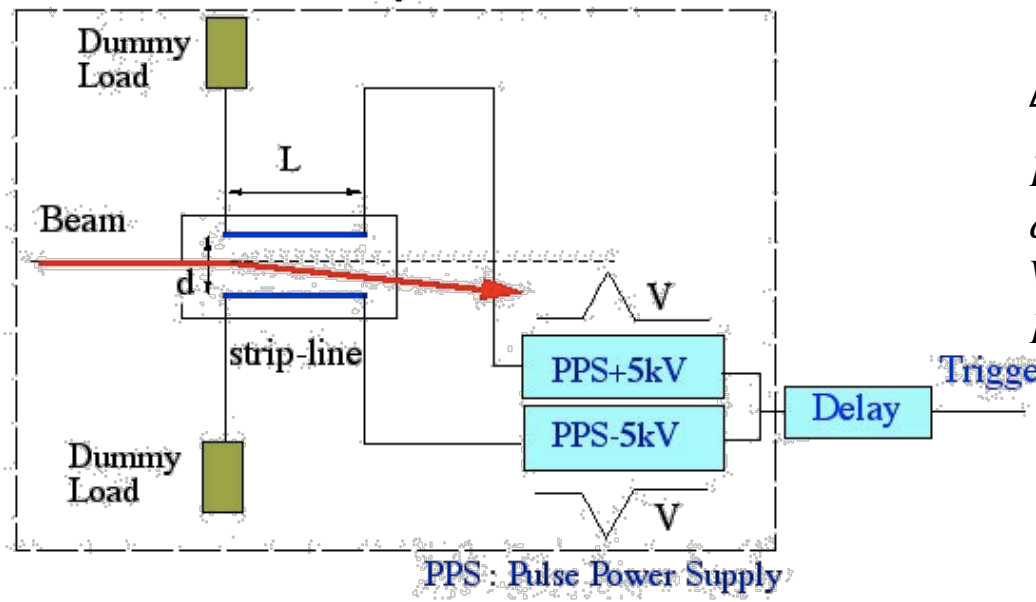
The existing kicker, which consists of a pulse magnet and a thyratron switch, is not be able to realize the parameters, especially, the rise/fall time and the repetition rate.

Design of Strip-line kicker system





~20 units for 0.6mrad kick angle



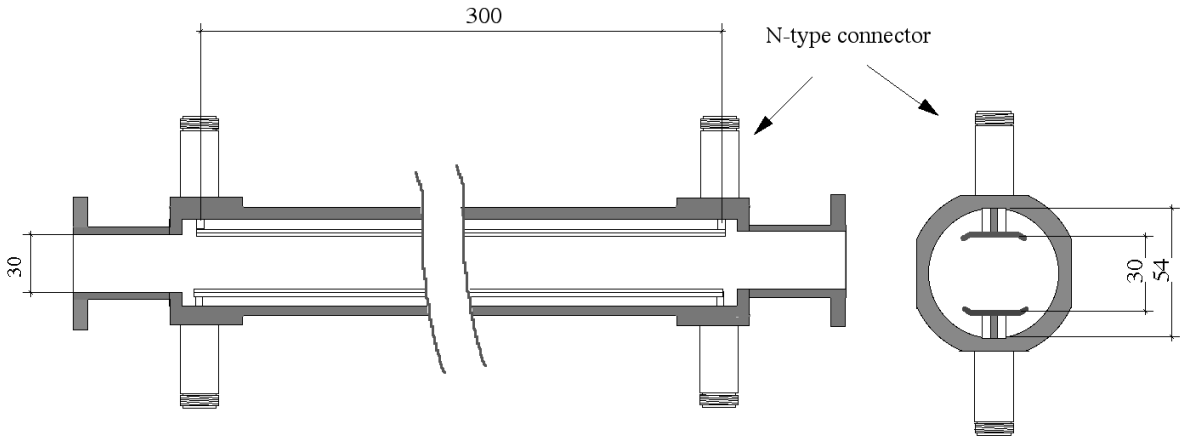
$$\Delta\theta = 2g\frac{eV}{E}\frac{L}{d}$$

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

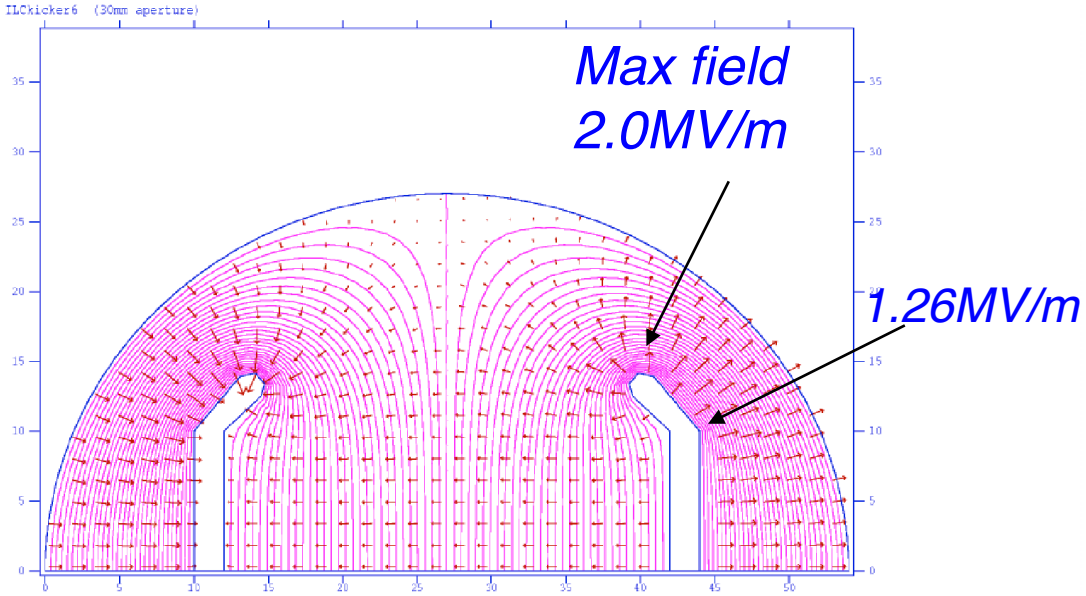
$$g = tanh\left(\frac{\pi\omega}{2d}\right)$$

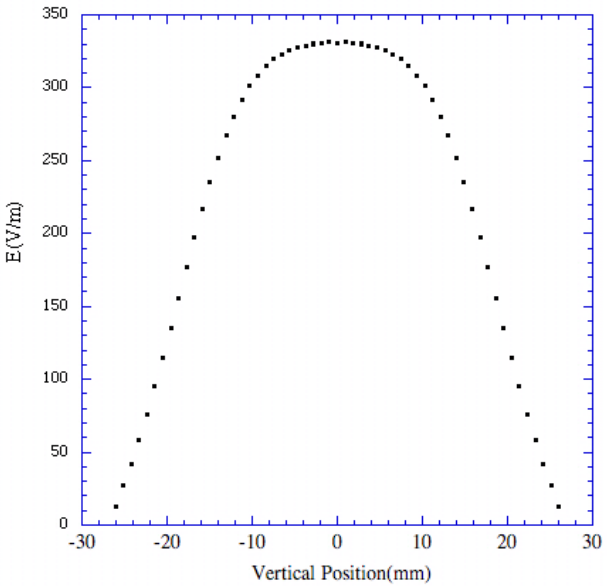
ω = strip – line width
d = distance between the electrodes

Design of Strip-line electrode for ILC



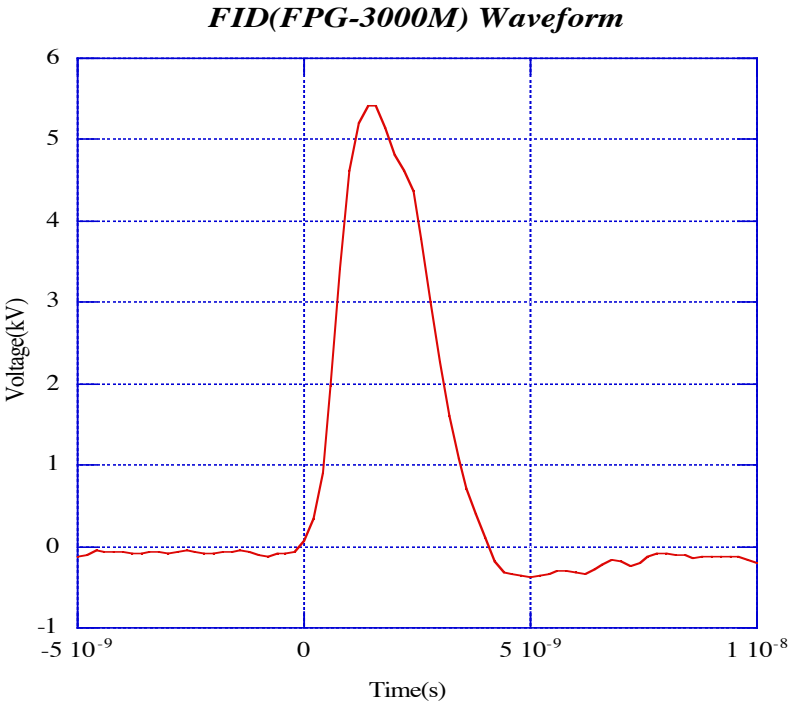
The shape of the electrode is designed to keep good uniformity of the deflecting field. The calculated flatness is 0.07% in the area of +/-1.8mm from the center.

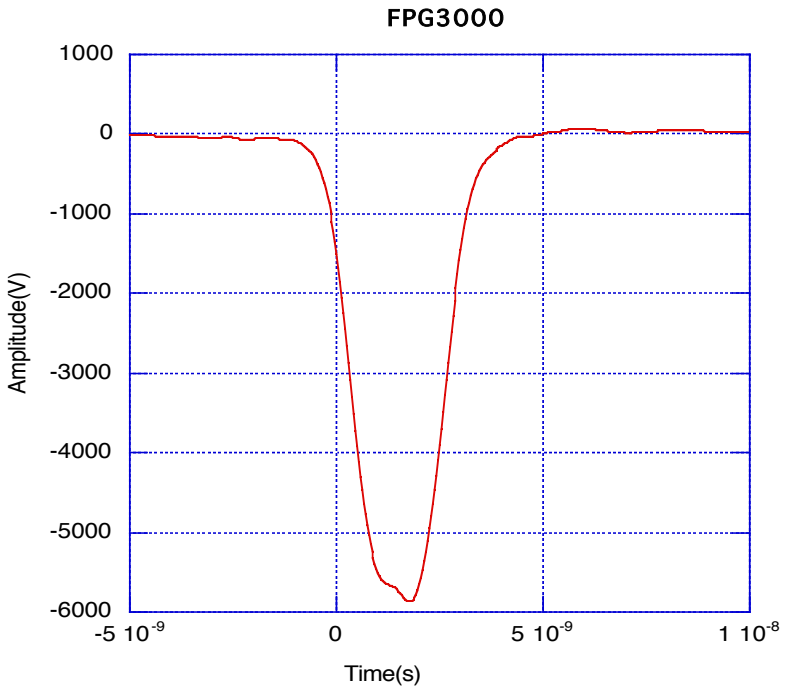




Geometric factor(analytical) =0.955

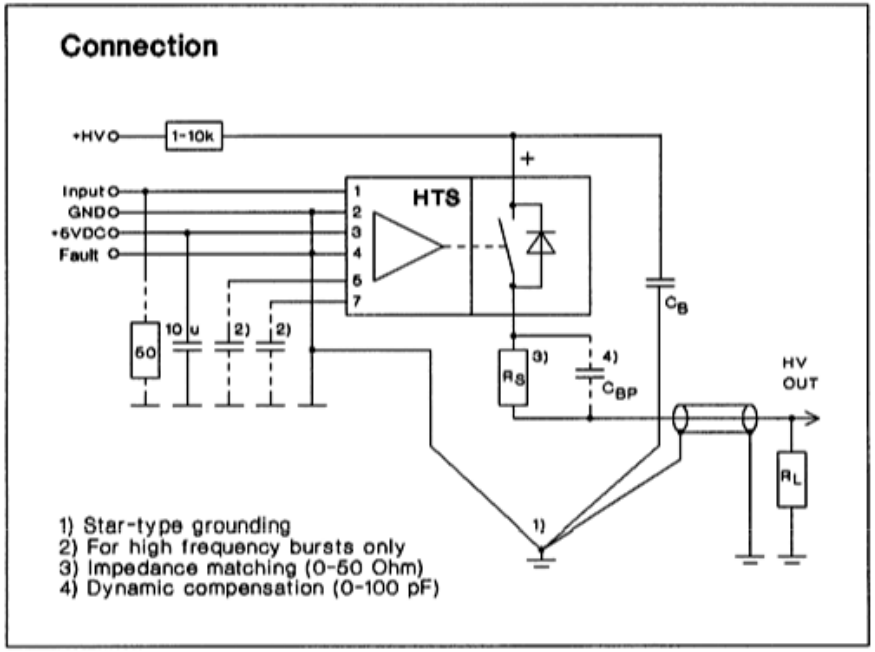
Pulse power supply (FID FPG5-3000M)

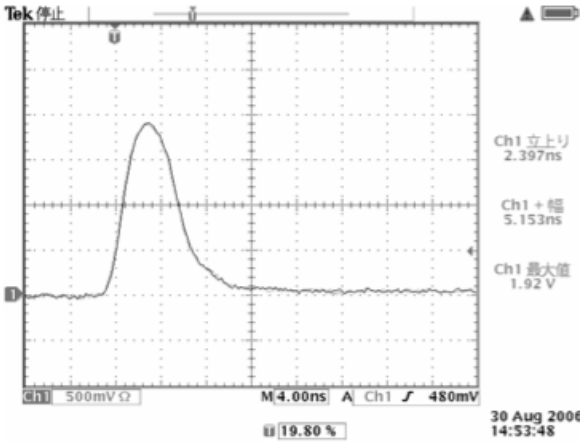




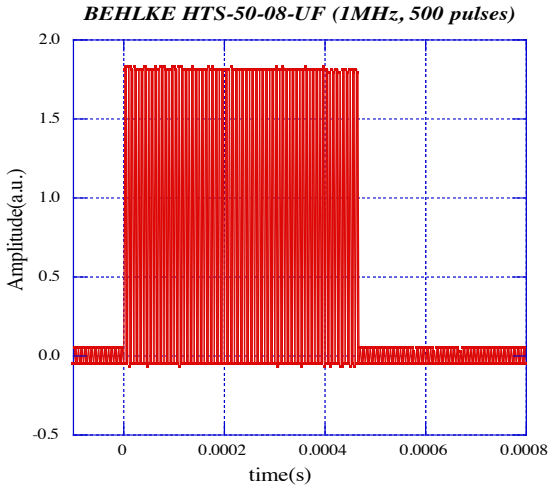
Pulse width(FWHM) = 2ns
Pulse height = 5.8kV
Rise time = ~1.5ns(5%~95%)
Time jitter = ~29ps
Amplitude Jitter = 0.72%
(limited by the scope resolution)

BEHLKE HTS-50-08-UF



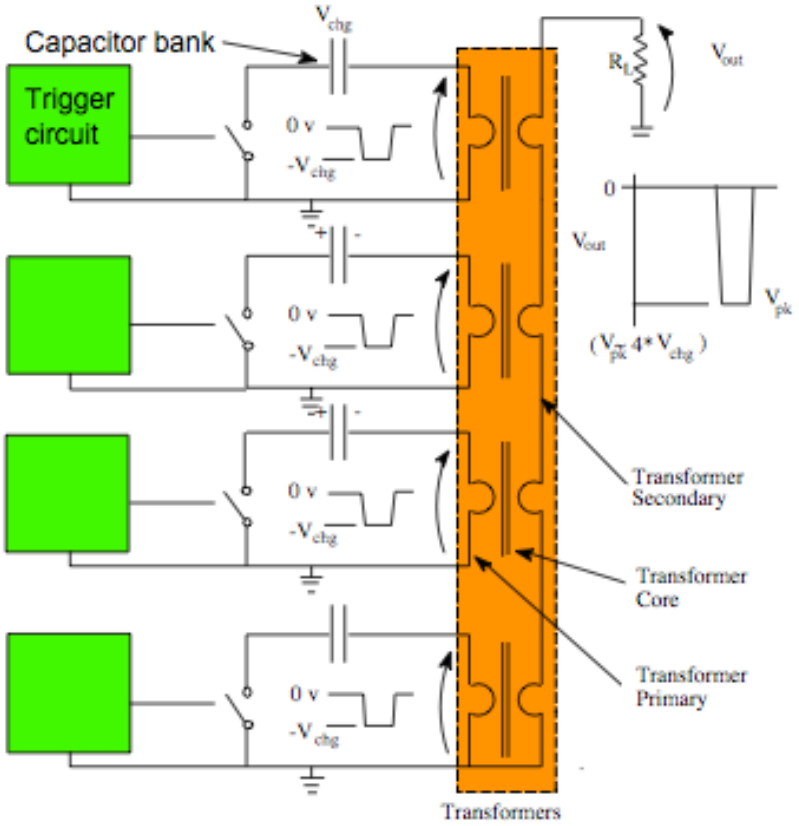


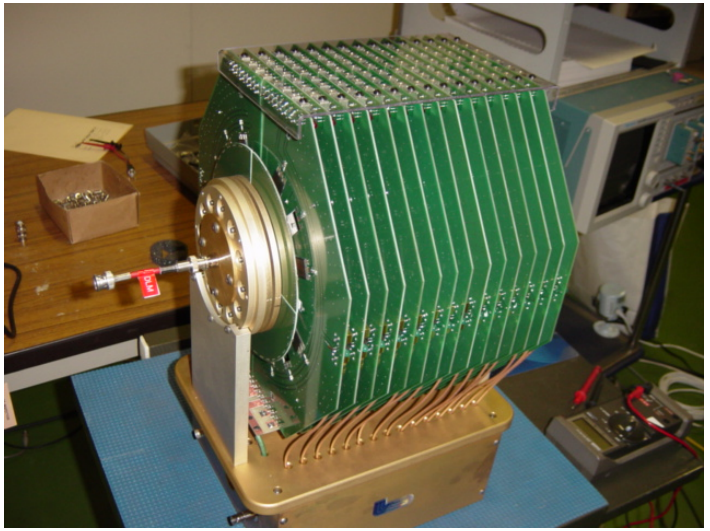
Rise time ~3ns at 2.5kV output

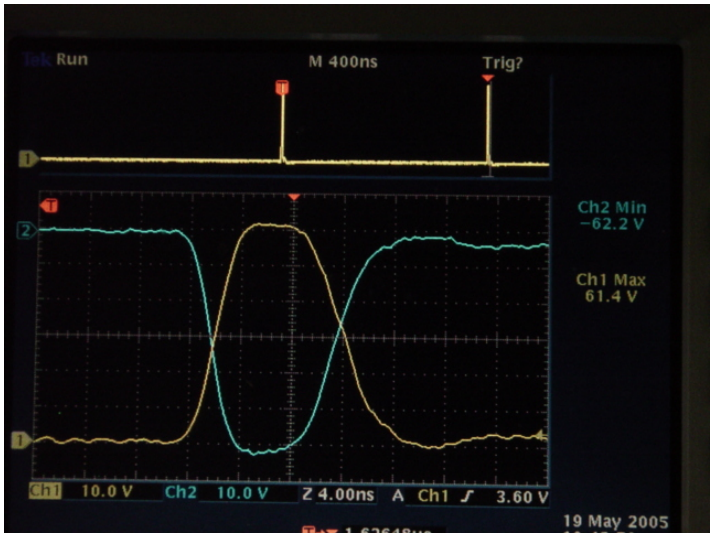


Burst pulses(1MHz, 500pulses)
droop:5x10^{-3}

Adder Drive Board(LLNL:Ed Cook)





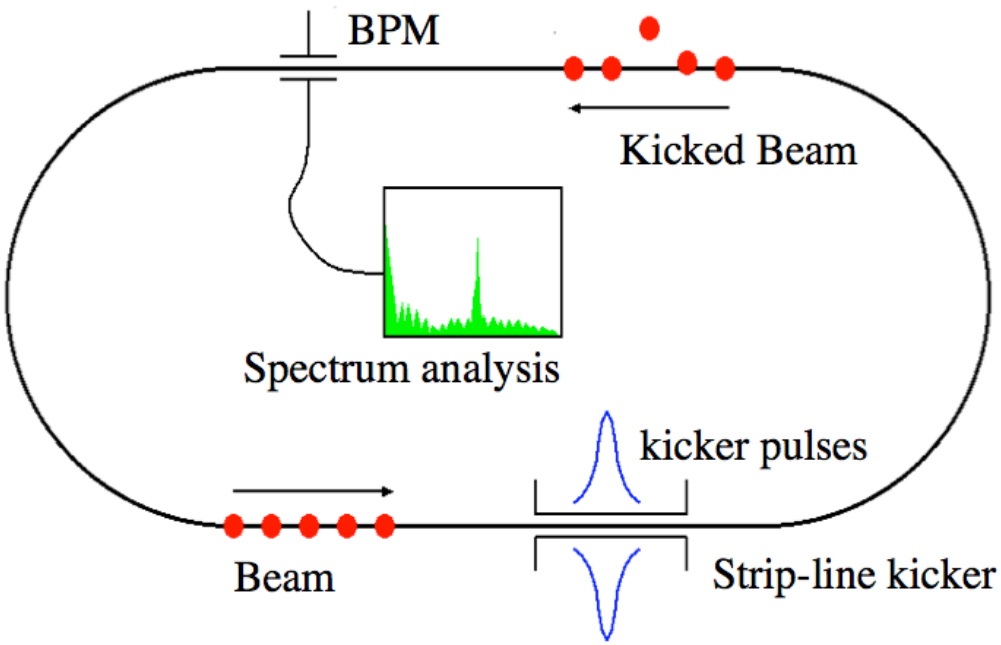


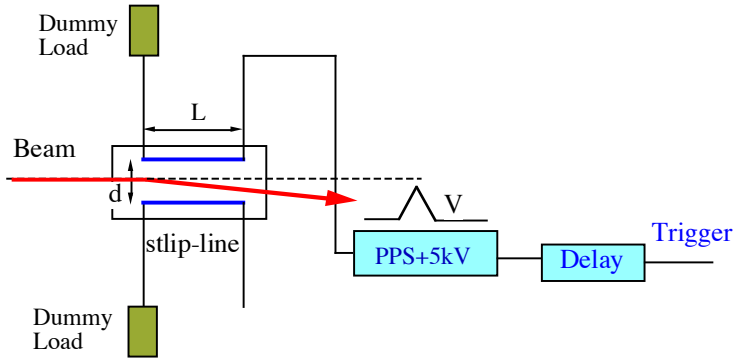
This high voltage pulse power supply is basically developed for the drive pulse of the induction linac.

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

FET(DE275) on time: 2ns

Beam kick experiment in ATF-DR





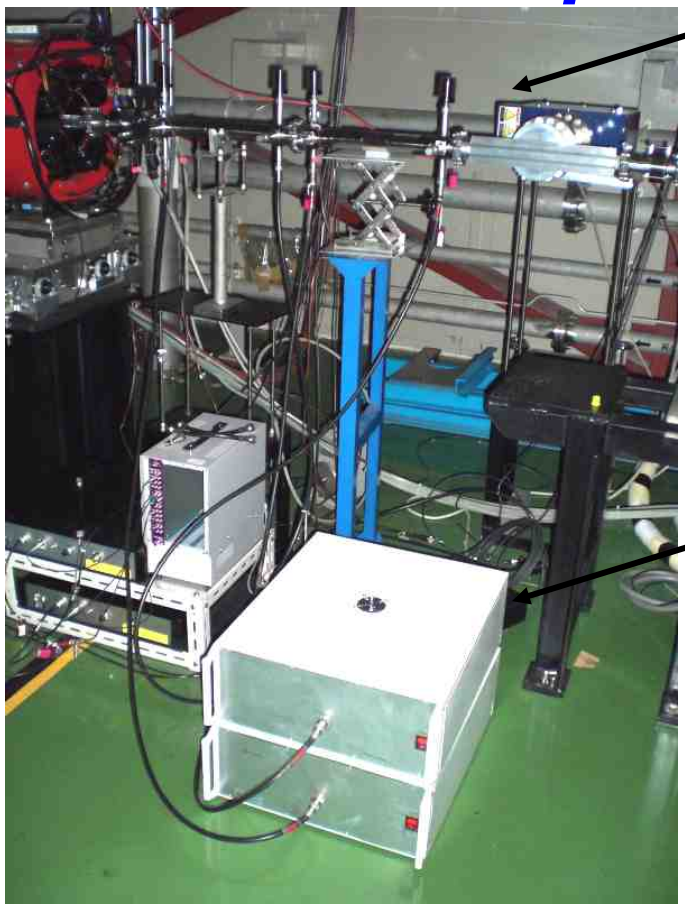
Single unit of strip-line kicker

A) Kick angle measurement by Single-shot BPM

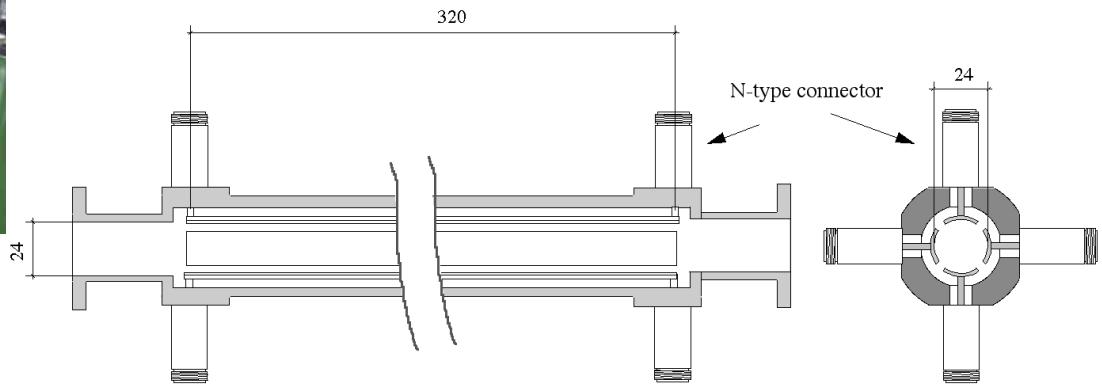
B) Rise/fall time measurement by Turn-by-Turn BPM

C) Rise/fall time improvement by Waveform compensator

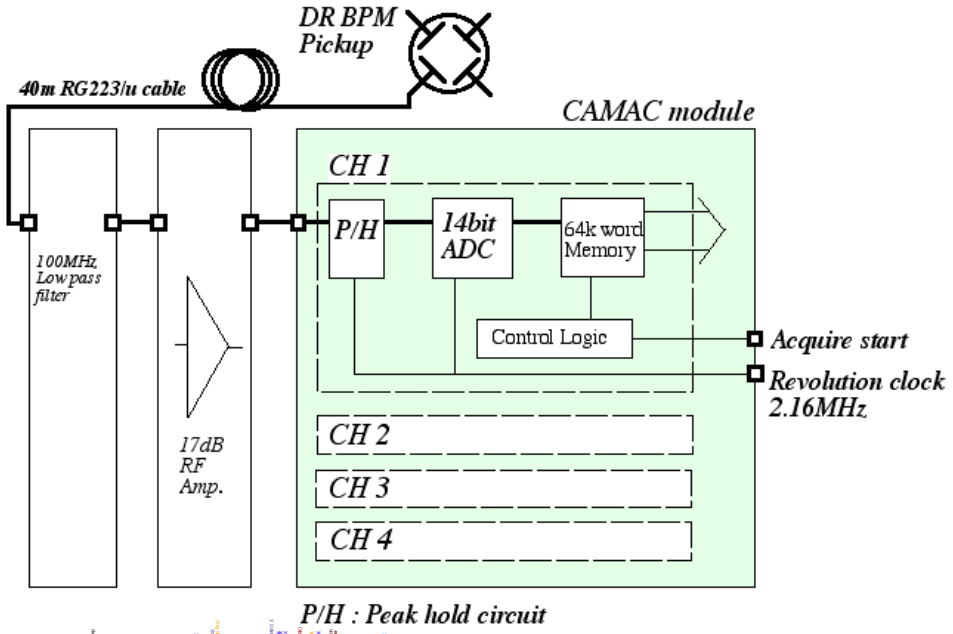
Strip-line electrode for ATF-DR experiment

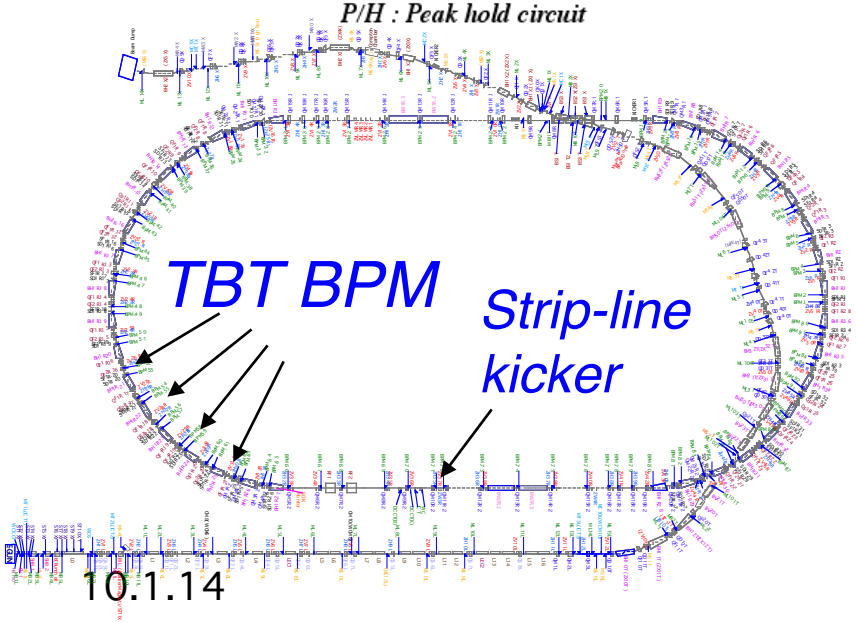


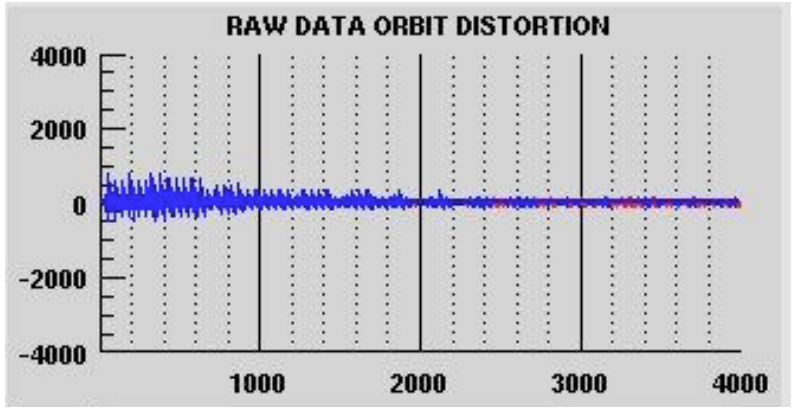
Two strip-line electrodes are used for the experiment. These electrodes was designed for the beam excitation in DR to measure the tune.



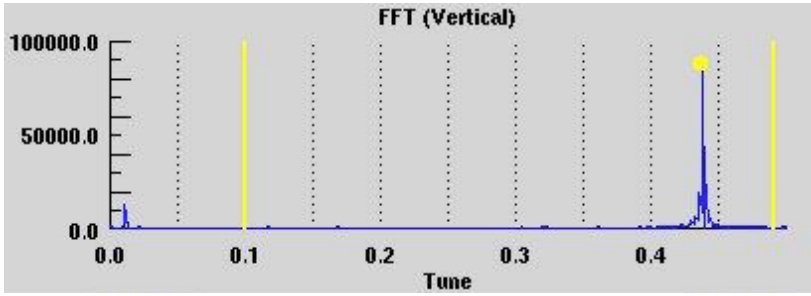
Turn-By-Turn(TBT) BPM system







Beam oscillation during 4000 turn

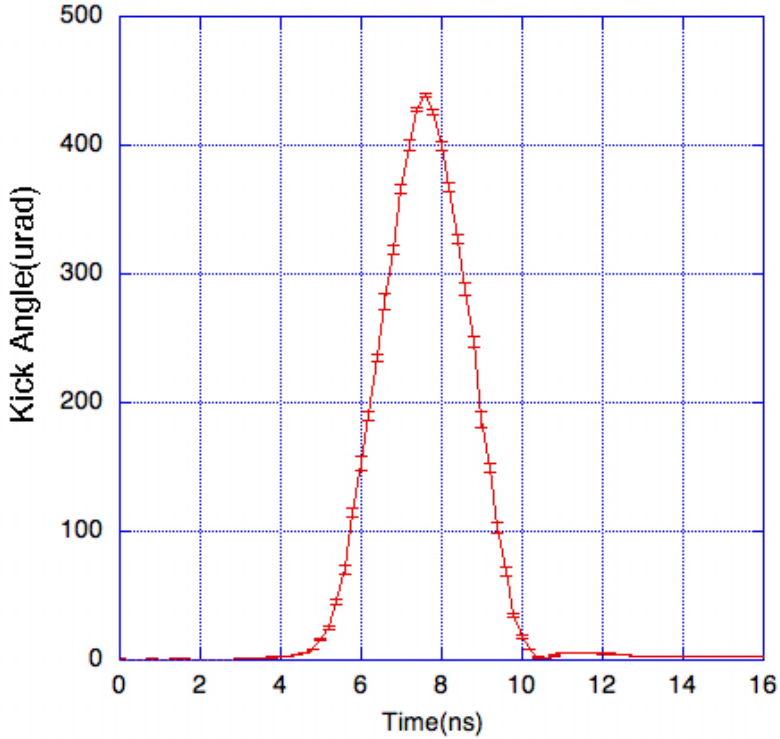


Frequency spectrum

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

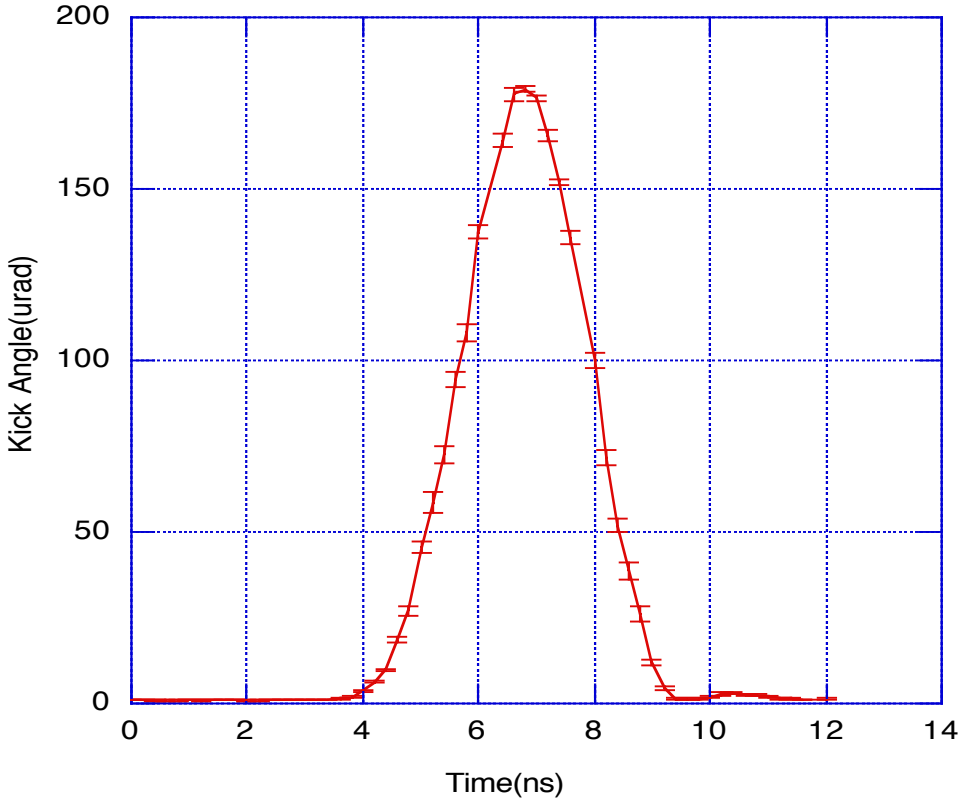
This measurement can avoid the noise effect from the other frequencies.

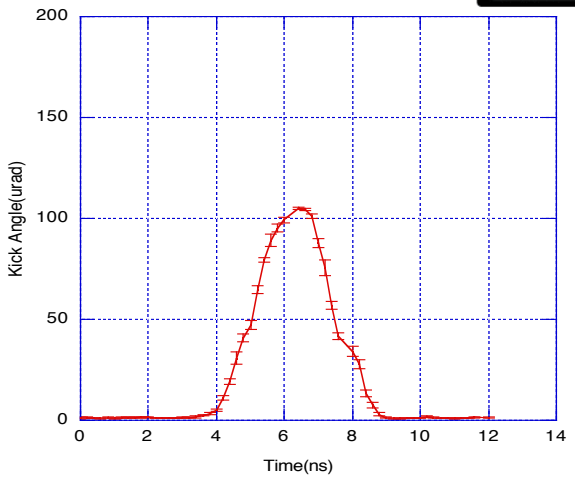
Beam kick profile with 5kV FID pulsers and a 30cm long strip-line kicker



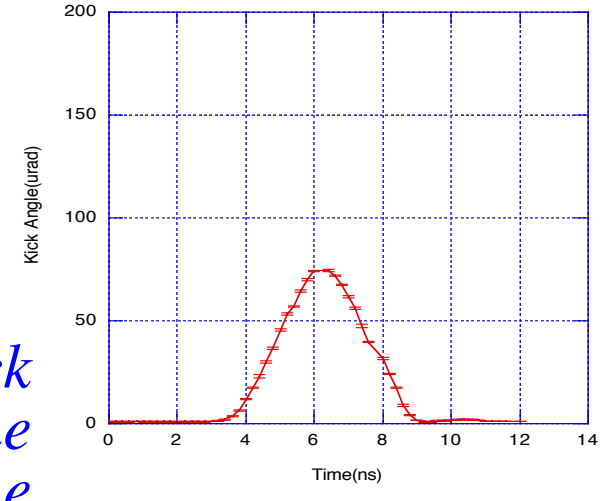
The beam kick test in the DR had been carried out by using a 30cm strip-line and a pair of 5kV FID pulsers. The picture shows the timing scan of the kick pulse to the beam, when the Positive and Negative pulses(5kV) are applied at the same timing. The peak kick angle is 0.44mrad and the rise time of the kick field is 3ns, which agreed with the estimation from the kick voltage and the strip-line dimensions.

Timing scan of the kick pulse





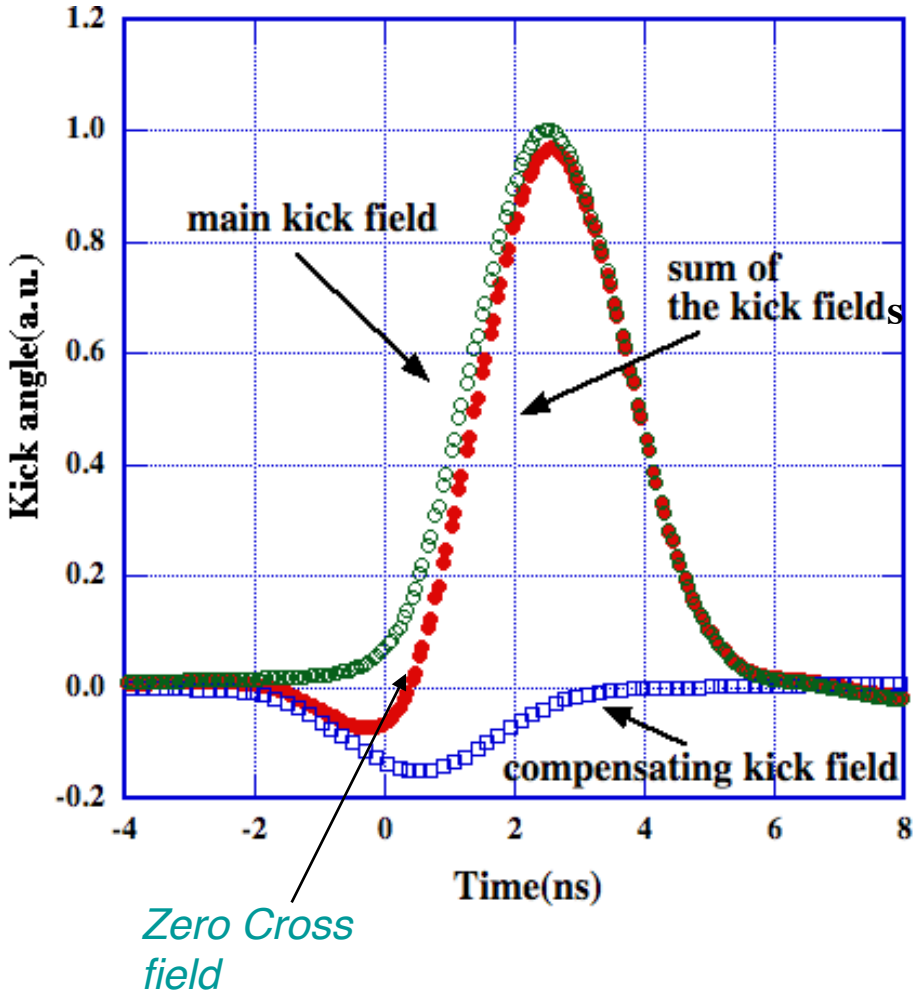
Negative kick pulse

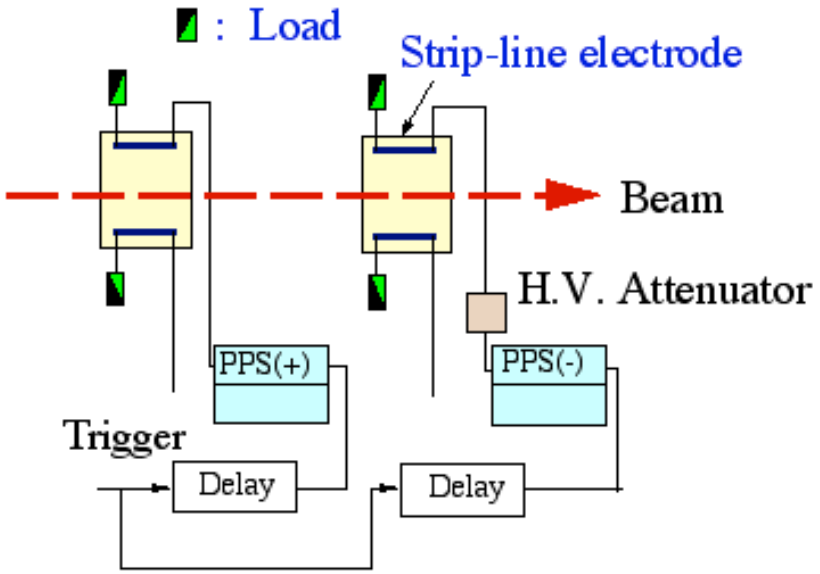


Positive kick pulse

When the negative and the positive kick pulse is applied to the electrodes at the same timing, the kick angle is same as the sum of the kick pulses. There is no affect for the the rise and fall time of the kick field.

Waveform compensator



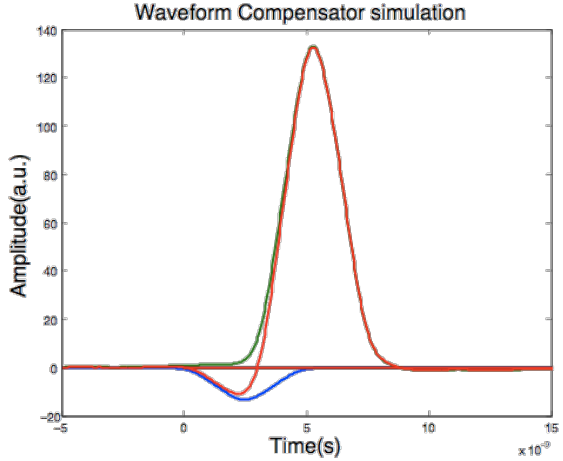


Experimental set up

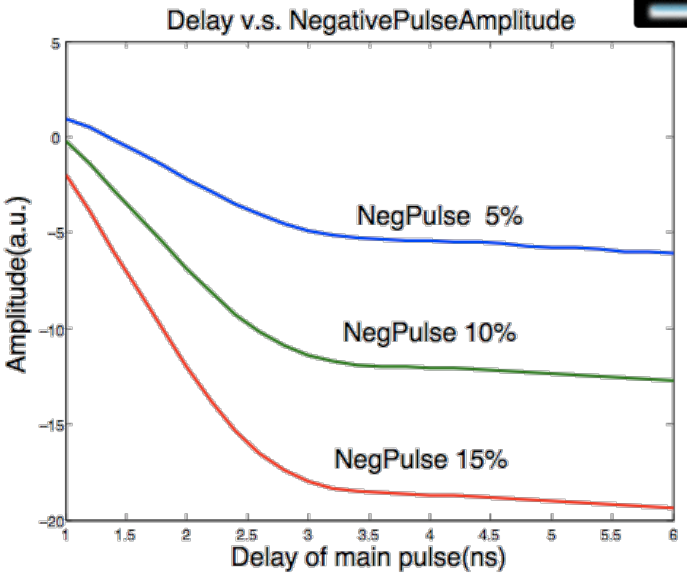
The rise/fall time can be improved by the combination of the positive and negative pulses which have different timings and different amplitudes.

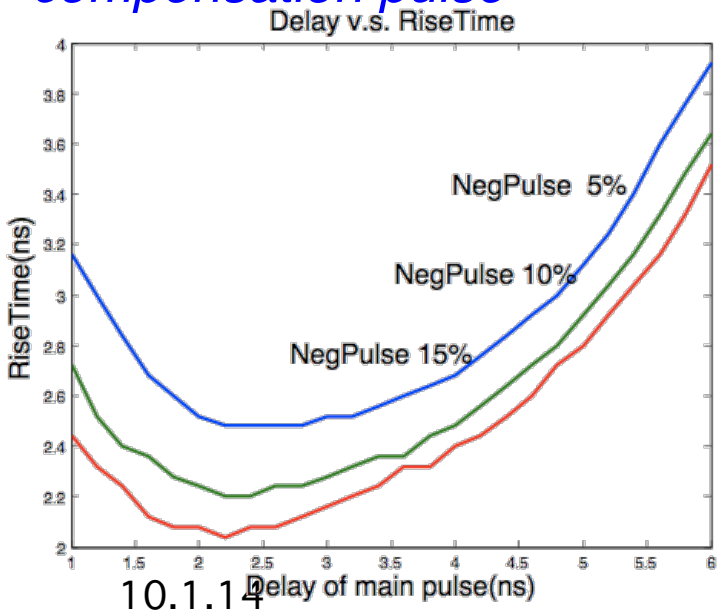
Simulation of waveform compensator

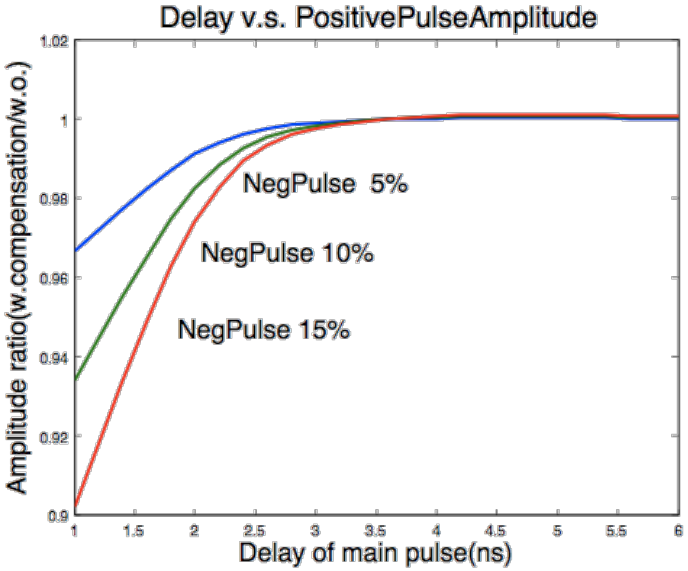
Waveform simulation



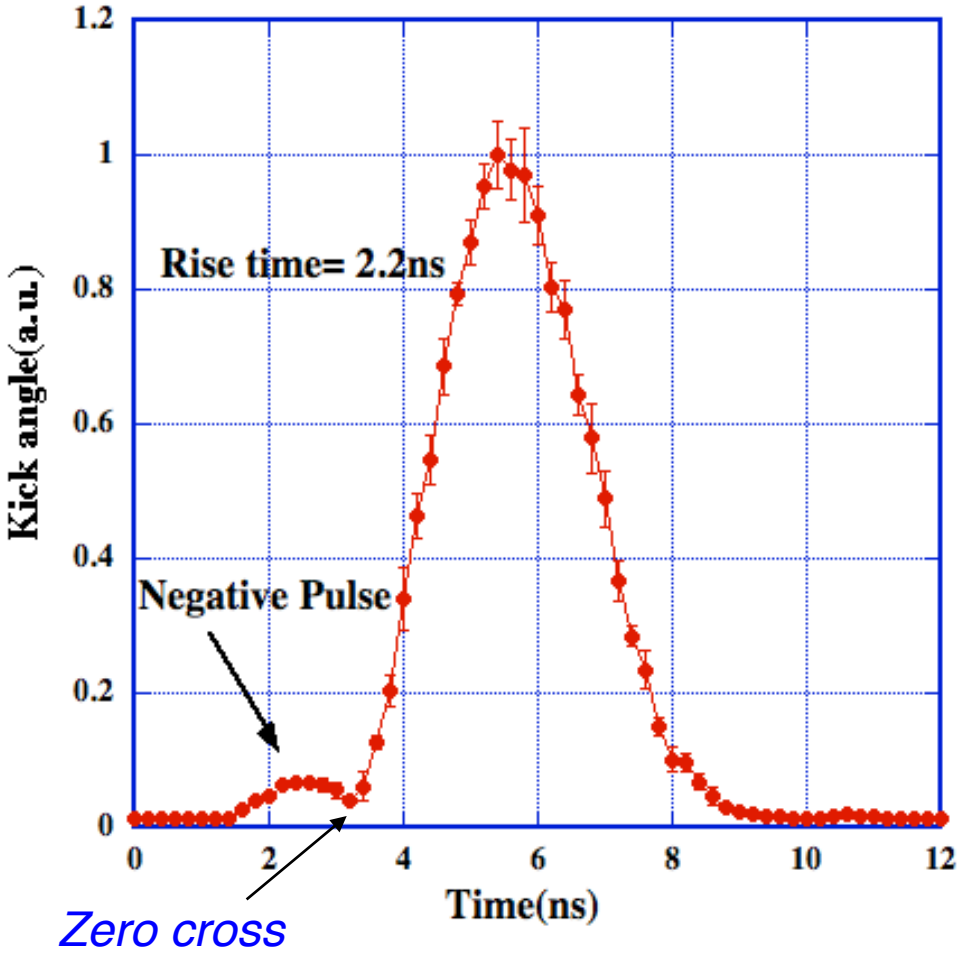
The rise time simulation for the timing and the amplitude of the compensation pulse

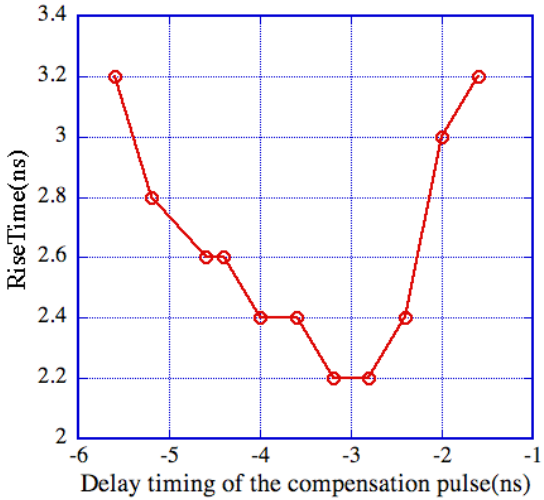


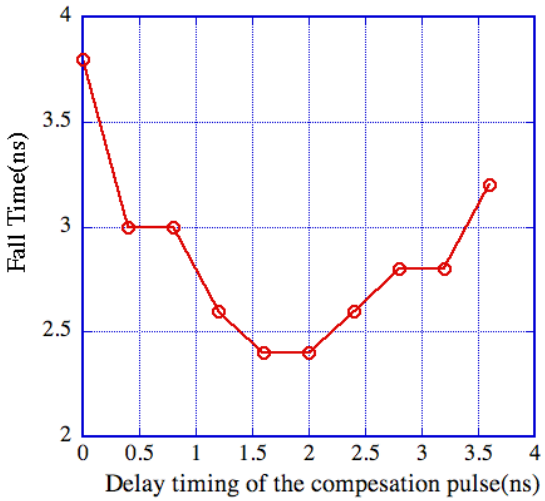




Rise time improvement with Waveform compensator





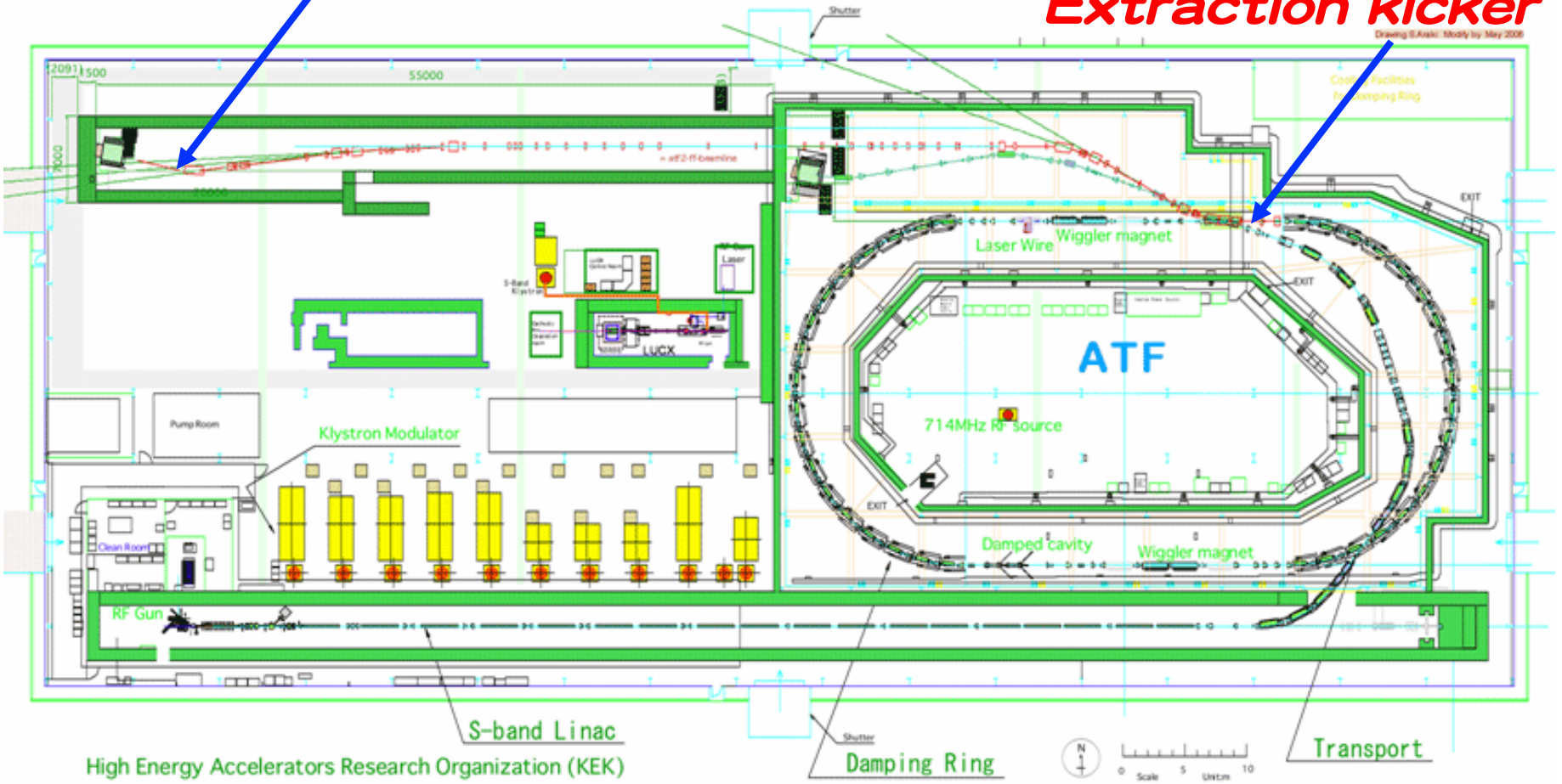


Rise/fall time improvement v.s. timing

Experiment at ATF2

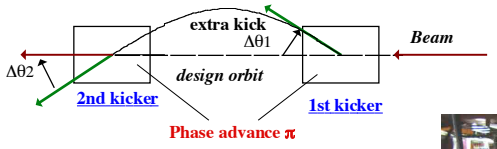
ATF2 - 40nm beam production, measurement

Extraction kicker

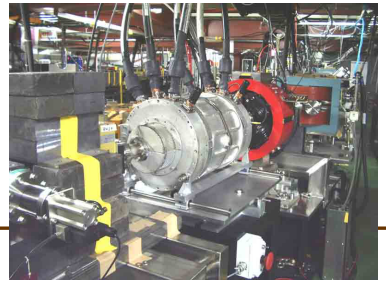


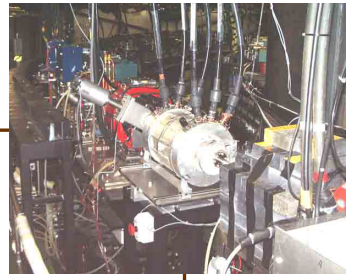
The beam extraction test of the strip-line kicker is being carried out by replacing the pulse magnet of the extraction kicker. The difficulty is that the kick angle of strip-line kicker is not enough compared to the kick angle of the existing pulse magnet.

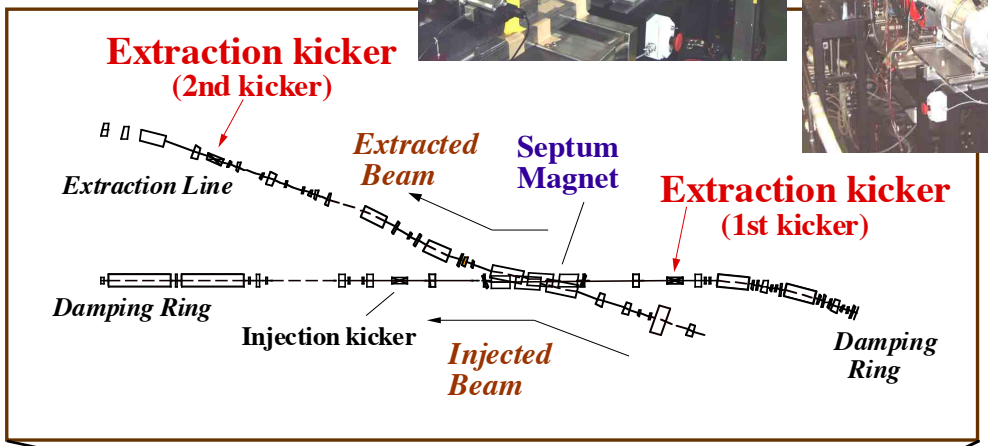
Present beam extraction (Pulse magnet kicker system)

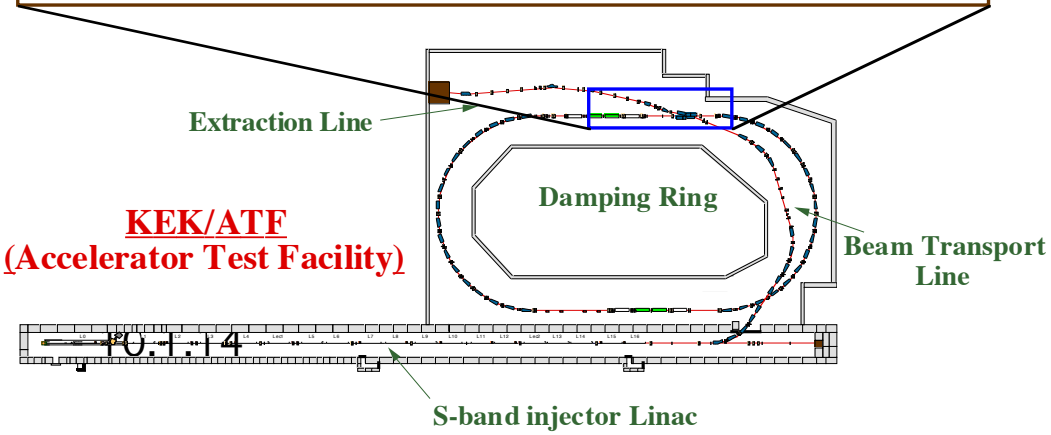


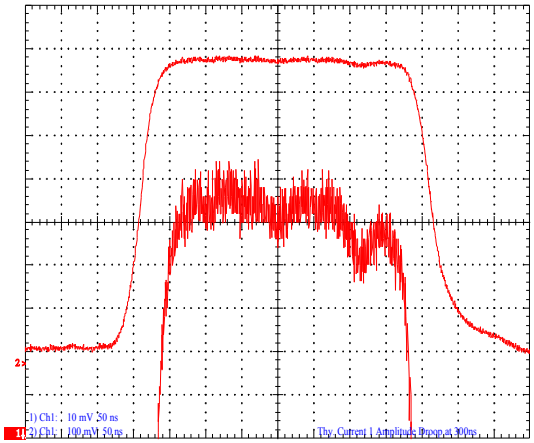
Kick angle Stability
1×10^{-3} -> 2.8×10^{-4}



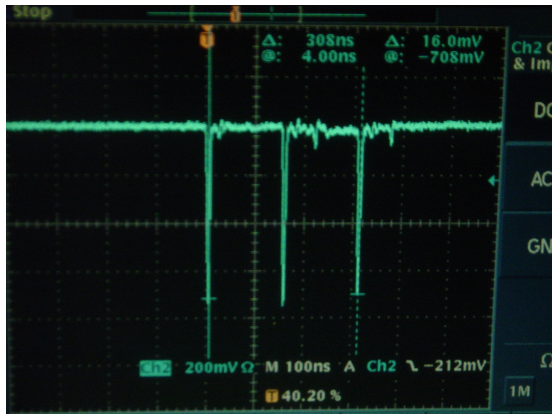








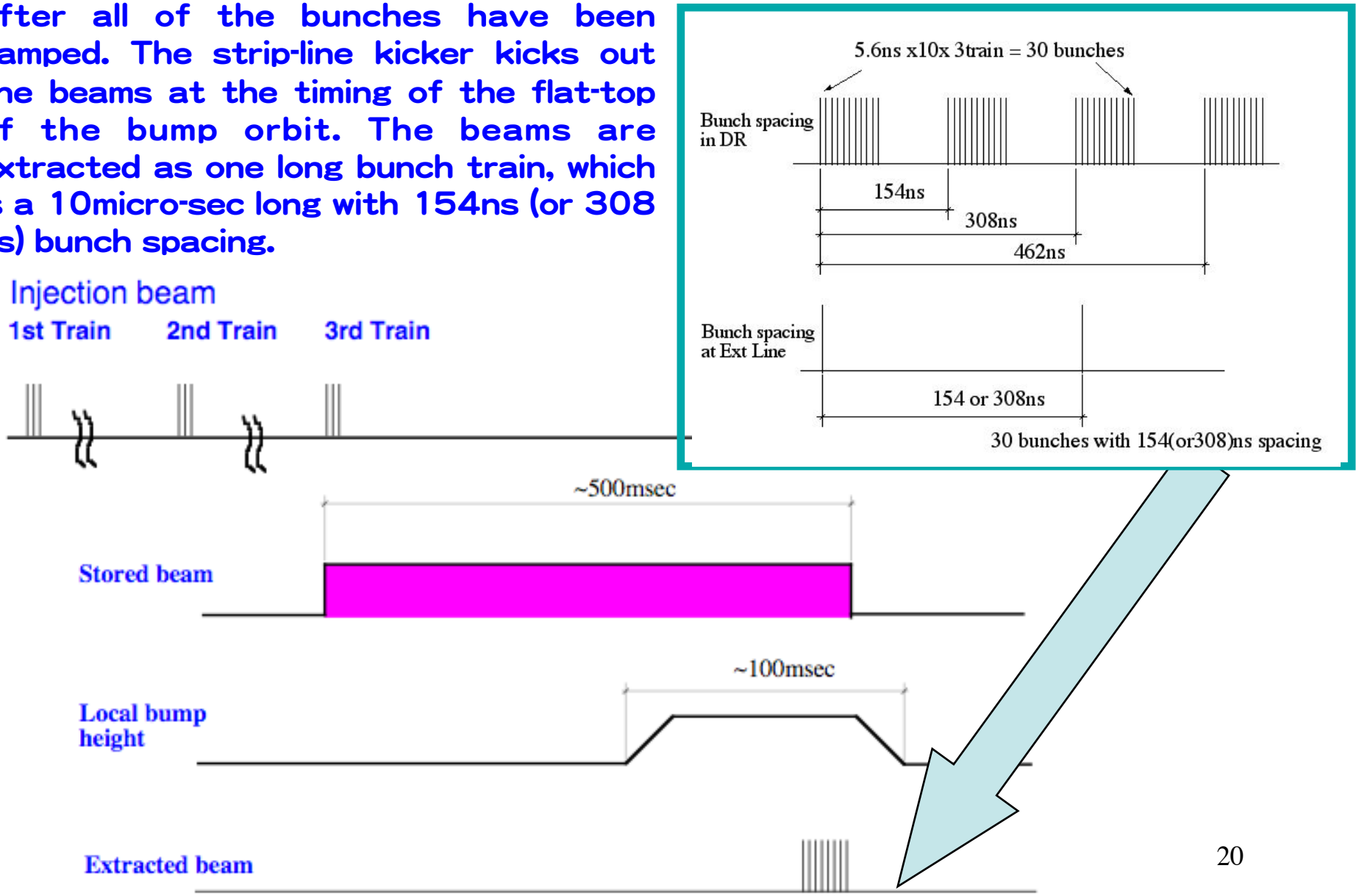
308ns pulse width



3 bunches, 154ns spacing

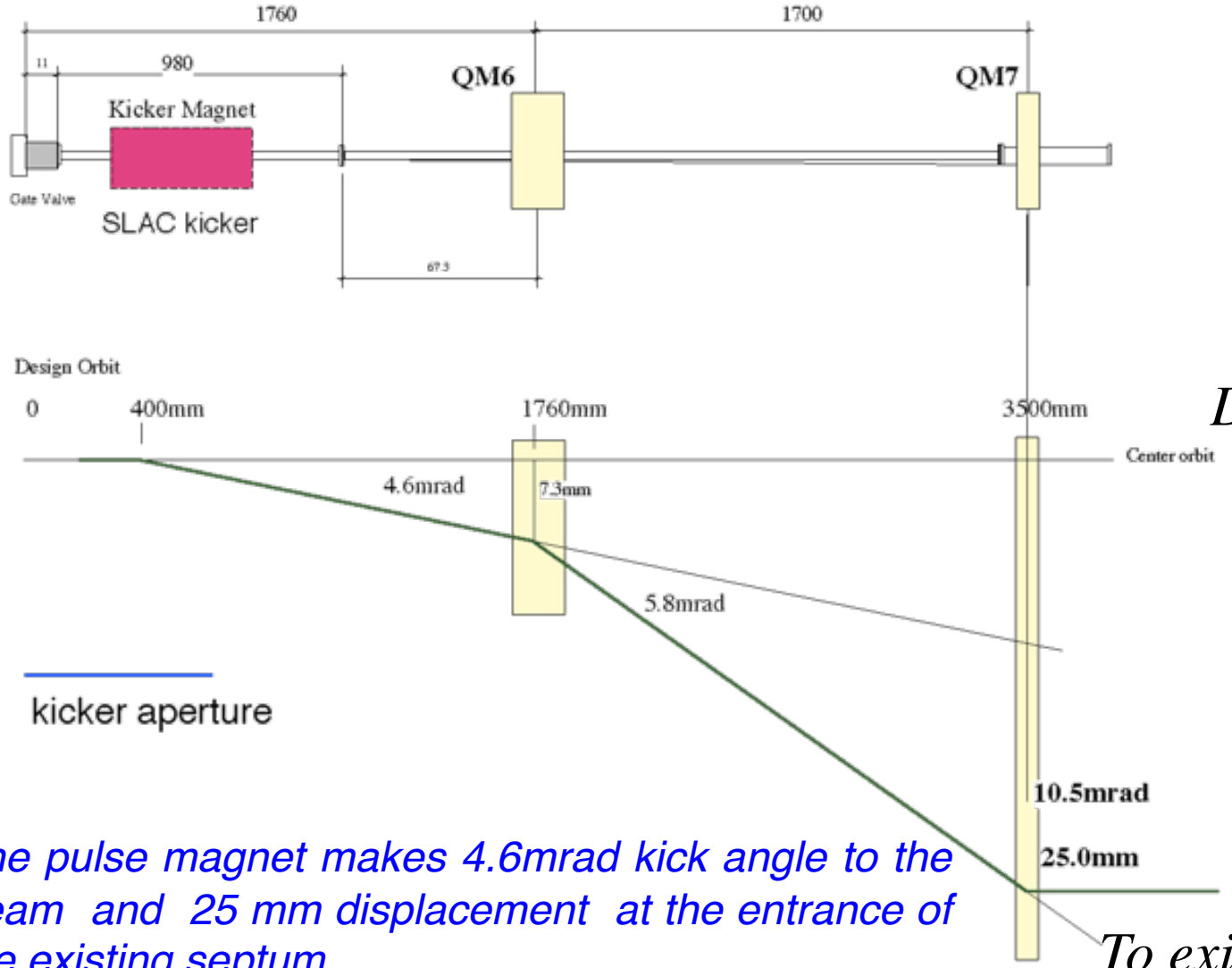
Timing chart of 30 bunches beam extraction

The bump orbit is gradually changed after all of the bunches have been damped. The strip-line kicker kicks out the beams at the timing of the flat-top of the bump orbit. The beams are extracted as one long bunch train, which is a 10micro-sec long with 154ns (or 308 ns) bunch spacing.



Present layout

20051221 T.Naito

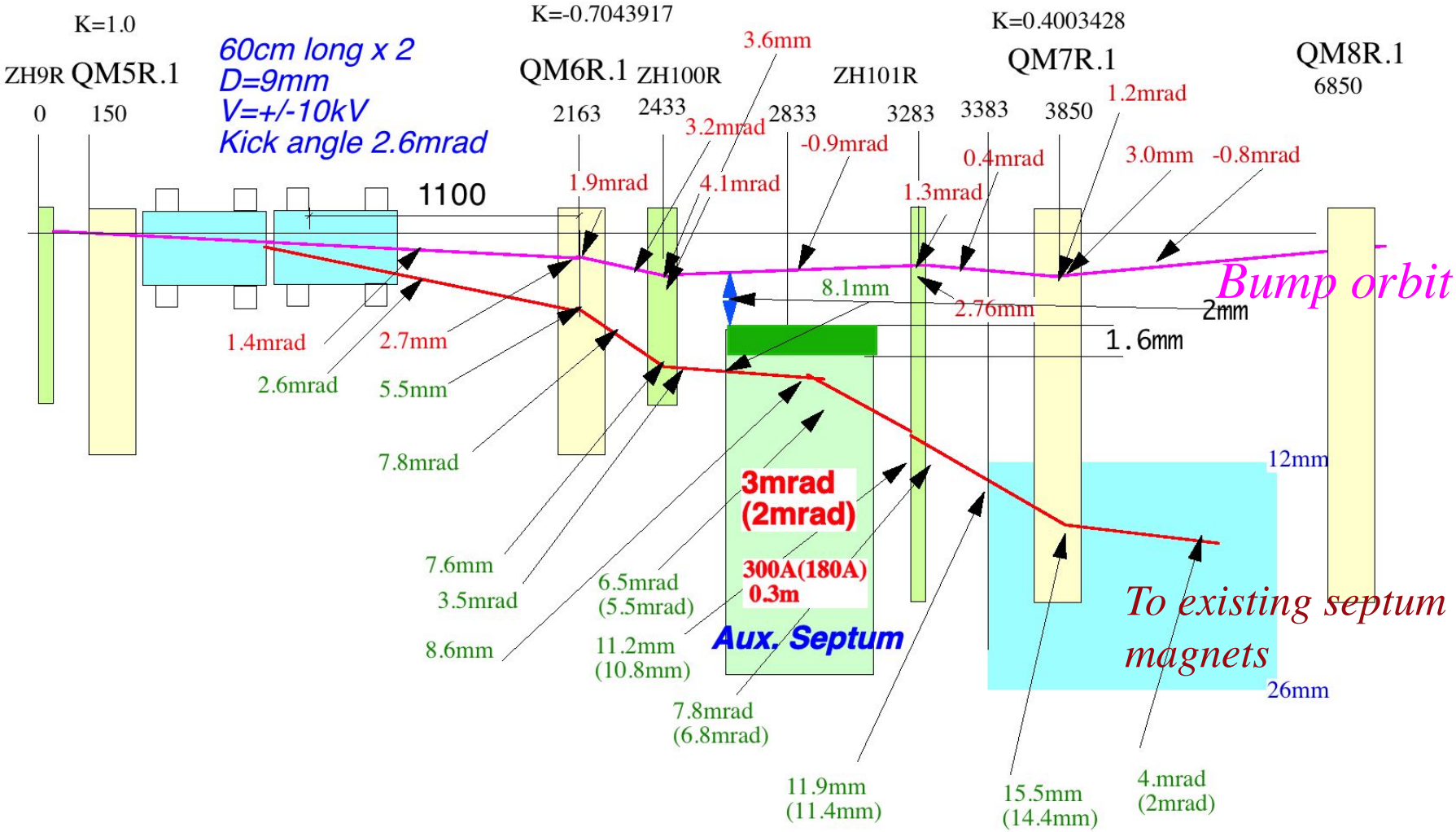


DR orbit

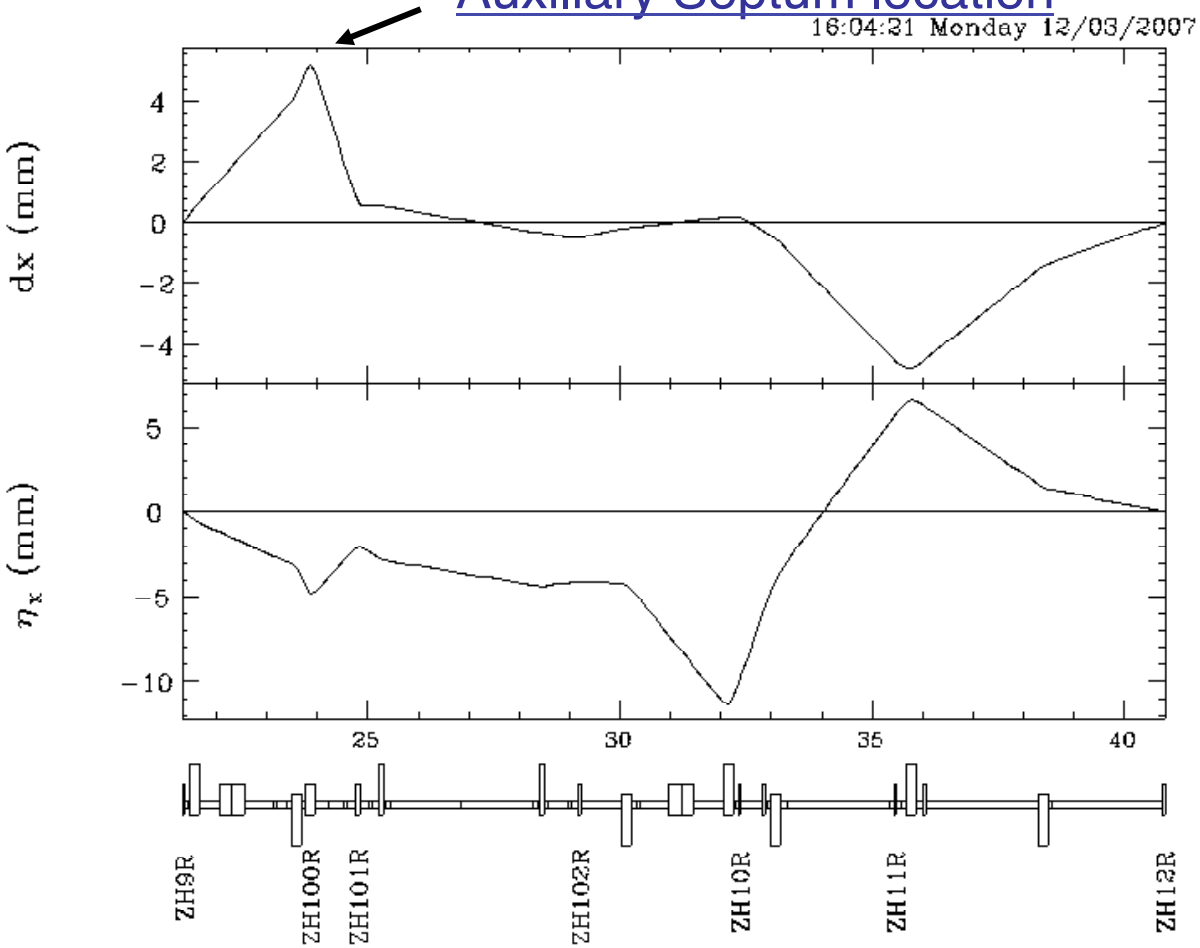
The pulse magnet makes 4.6mrad kick angle to the beam and 25 mm displacement at the entrance of the existing septum.

To existing septum magnets

Orbit by using Strip-line Kicker & bump



Optics design of Orbit Bump with 7 Correctors



dx=5mm@ZH100R

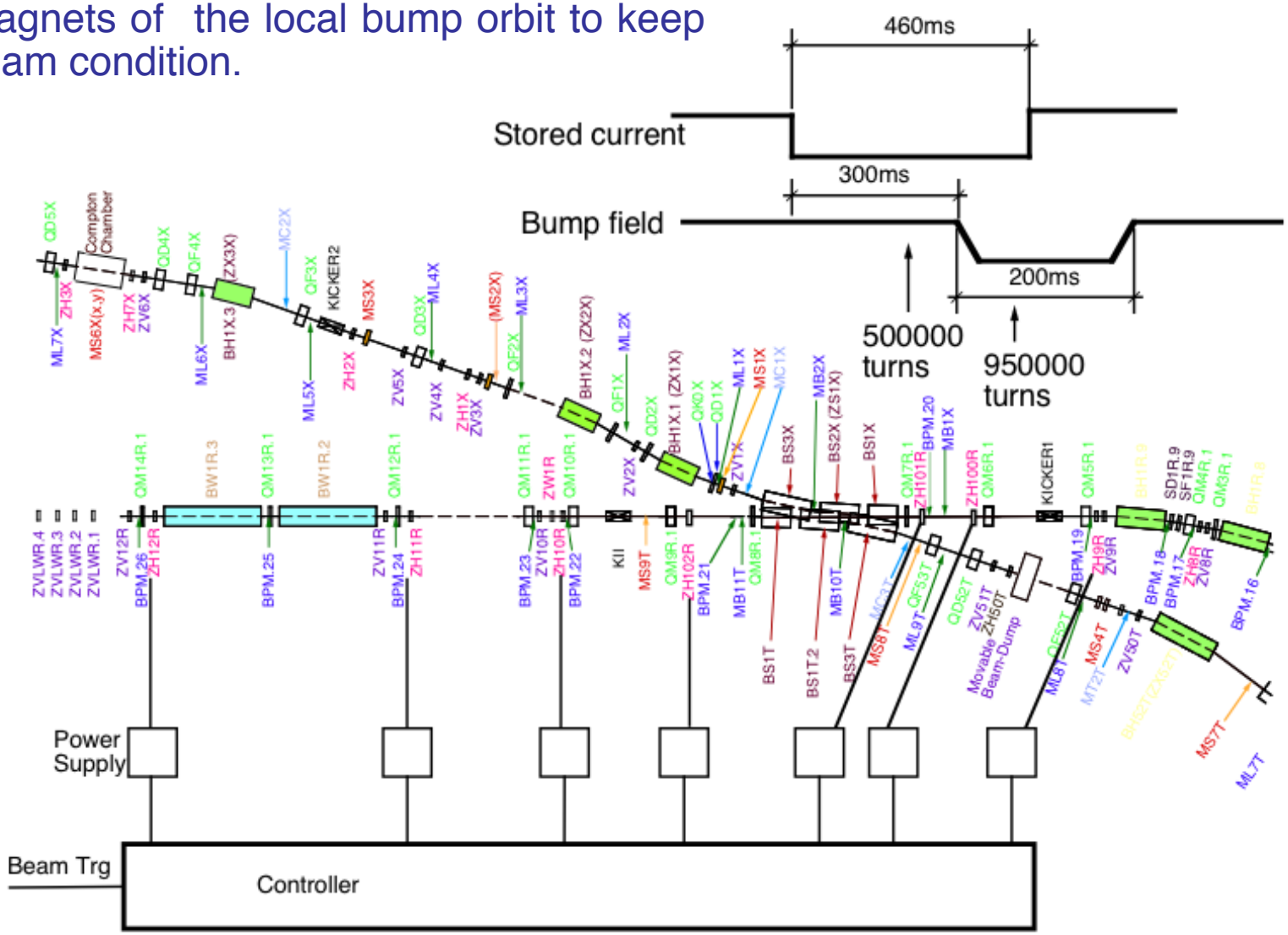
ZH9R	-.002320433716
ZH100R	.010028367995
ZH101R	-.005102712636
ZH102R	-5.52689273E-4
ZH10R	.001010243282
ZH11R	-7.88468363E-4
ZH12R	5.883103424E-4

Abs[dx] between septum and INJ.Kicker (from LSEP.1to IIN) < 0.5 mm

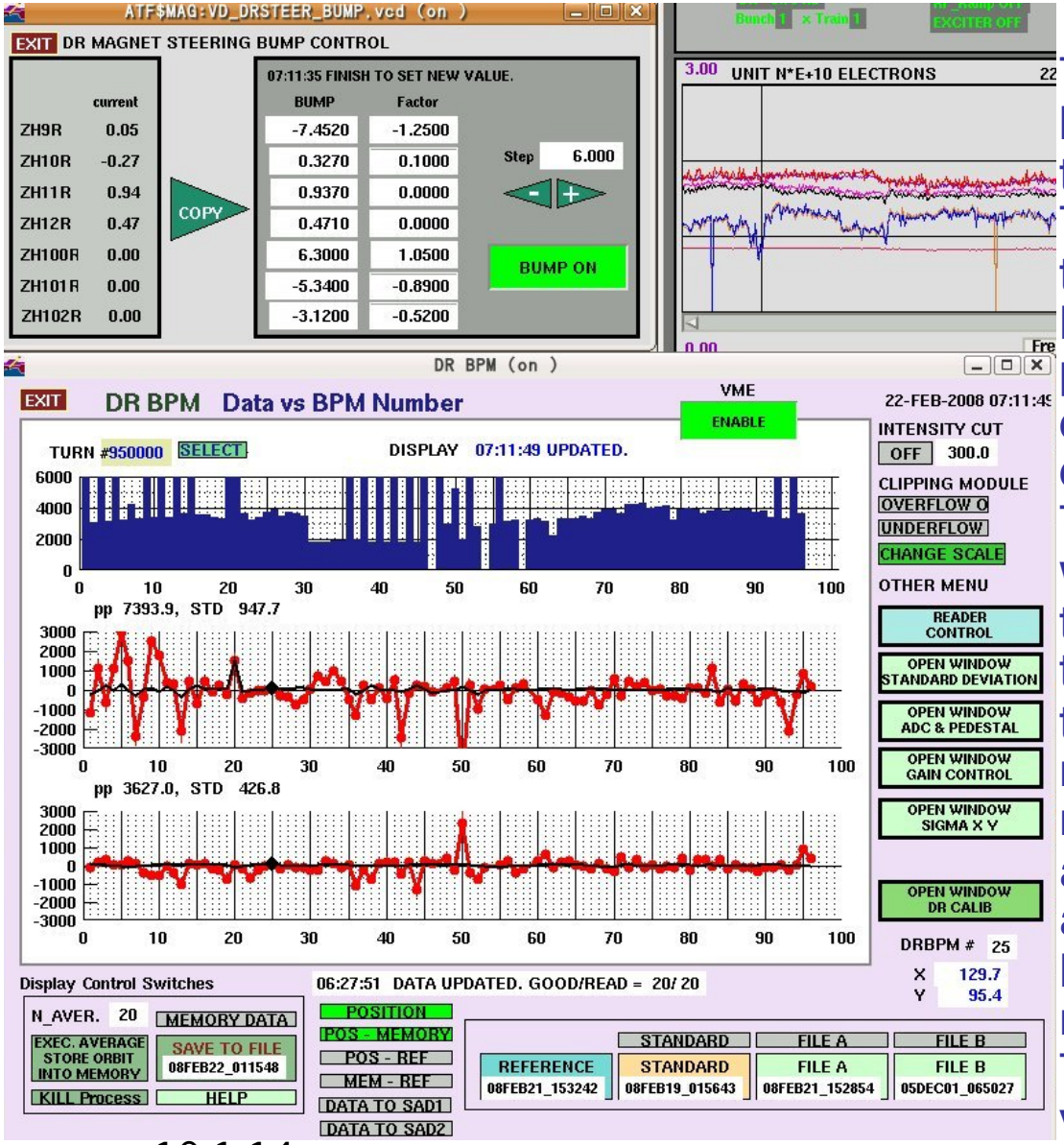
S.Kuroda

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 condition.



Bump Orbit Test Result



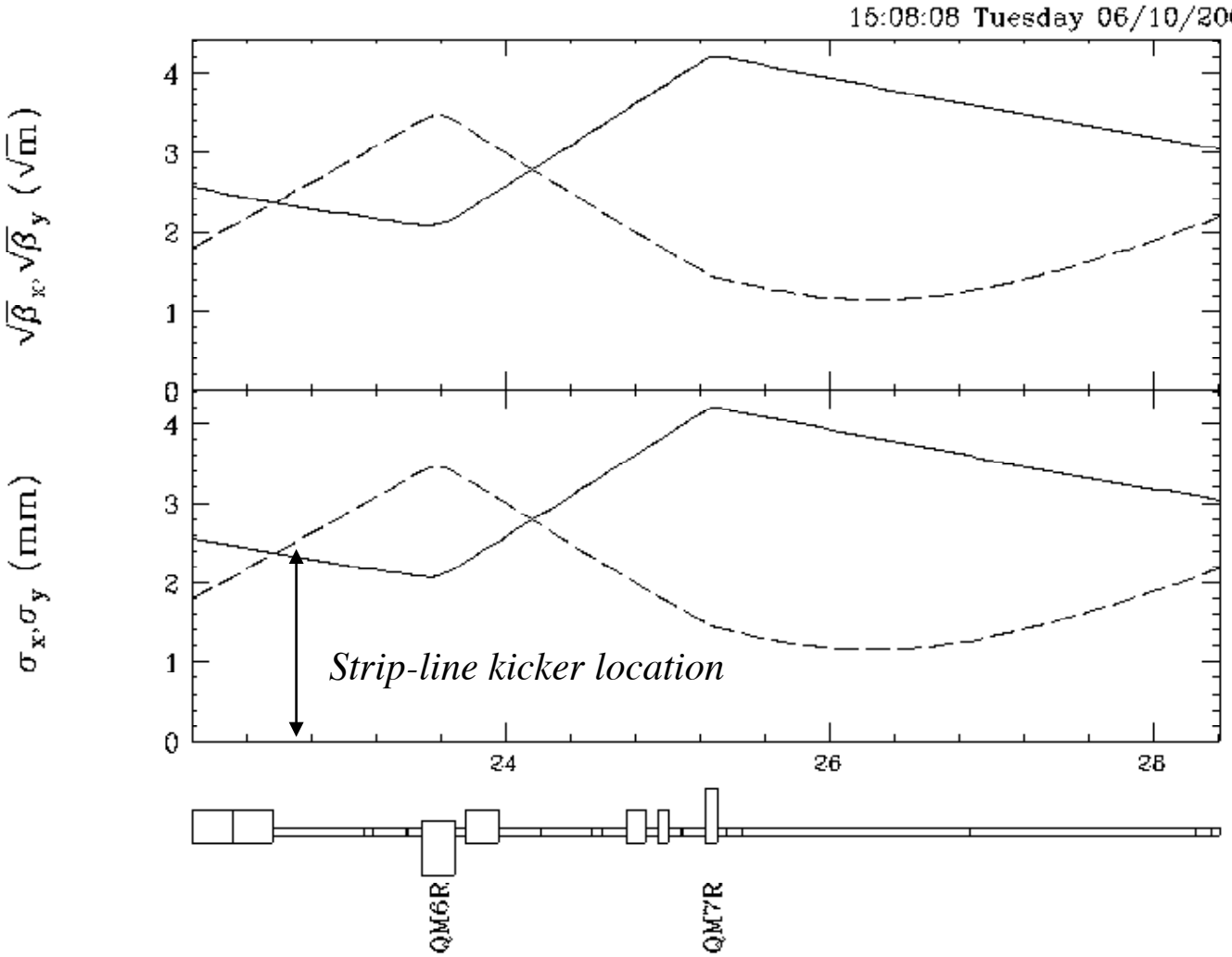
The height of the bump is confirmed by the displacement at BM20 and the magnet currents.

There is no BPM at the location of the peak of the bump. BPM20 is located at 1m downstream of the peak of the bump. The calculation depicted about 2mm of displacement at the BPM20.

The picture shows the control window and the beam position of the damping ring. The black line in the horizontal beam position shows the displacement by the bump magnet from the COD. The measurement results show good agreement with the calculation and almost no leakage orbit at the other location. The dispersion correction is not enough at this condition.

There was no beam blow up for the vertical emittance and no beam loss at this experiment.

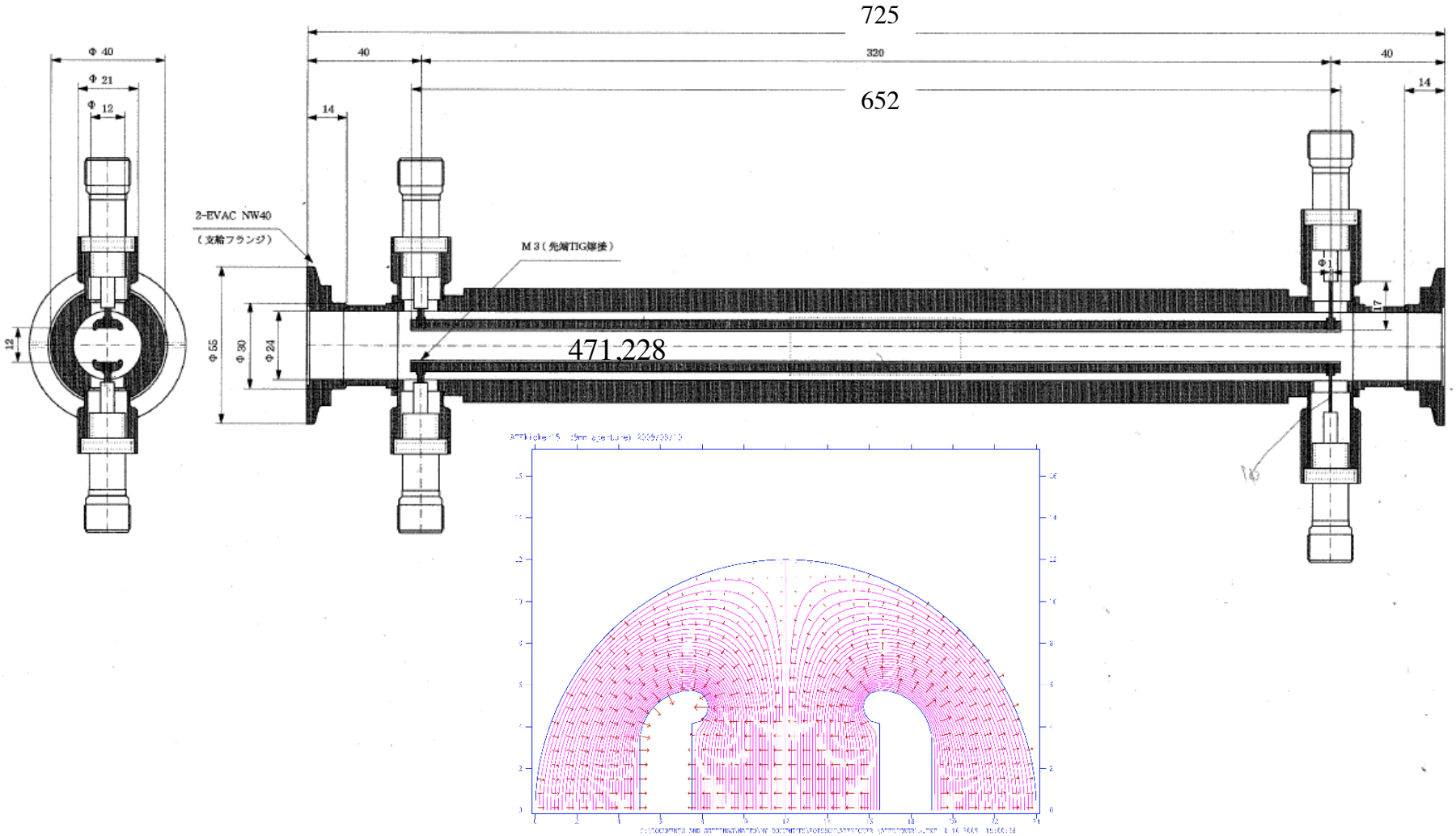
Aperture



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

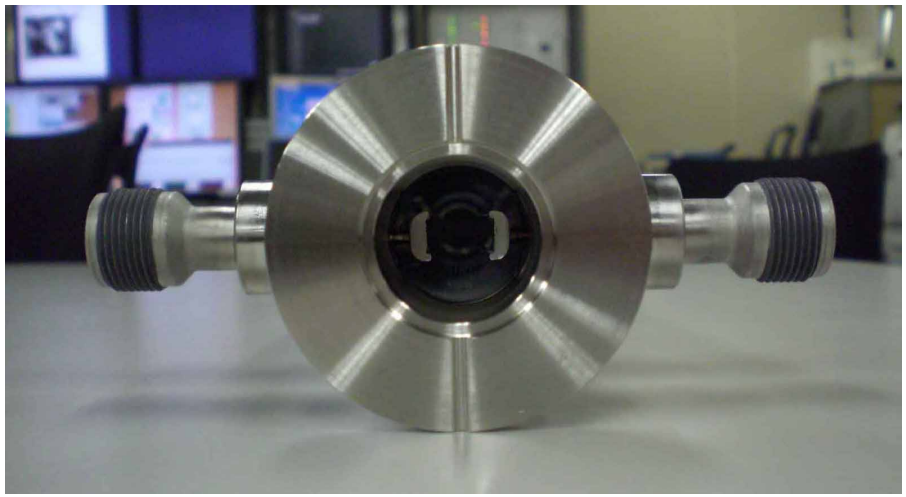
Horizontal aperture is limited by the strip-line electrode. 3σ of the injection beam can get through a 12mm gap of the strip-line kicker section.

Proto type strip-line kicker(60cm long)

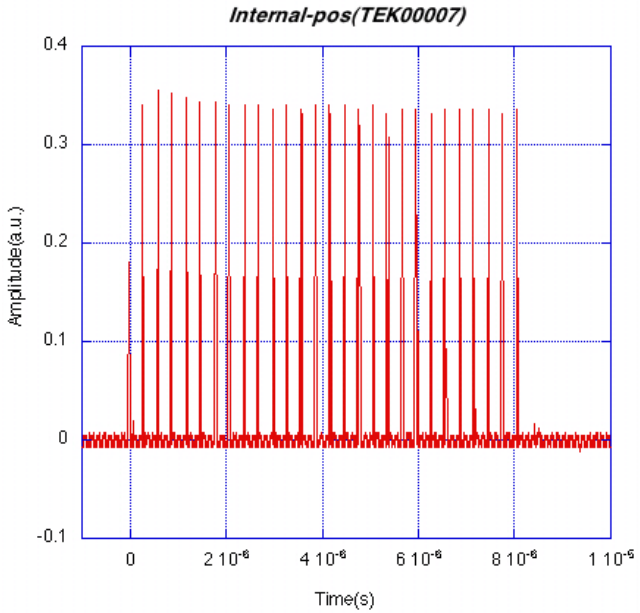


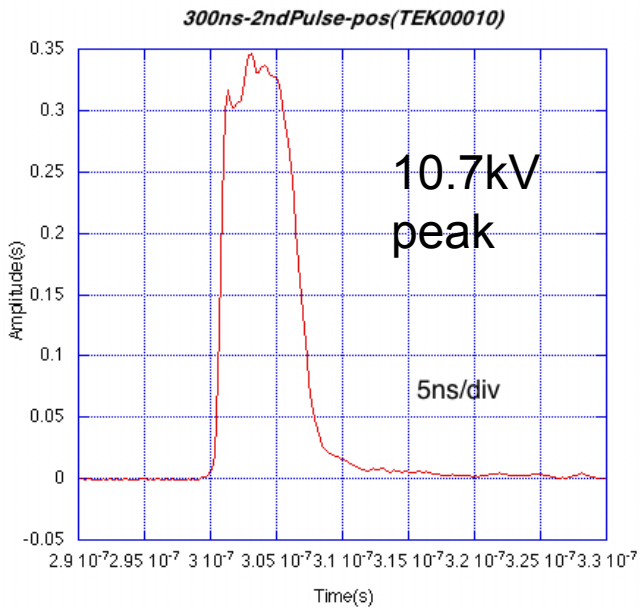
KEK fabricated a proto type 60cm long strip-line kicker, which has 9mm electrode gap. The input/output connectors are HN-type commercially available feed through.

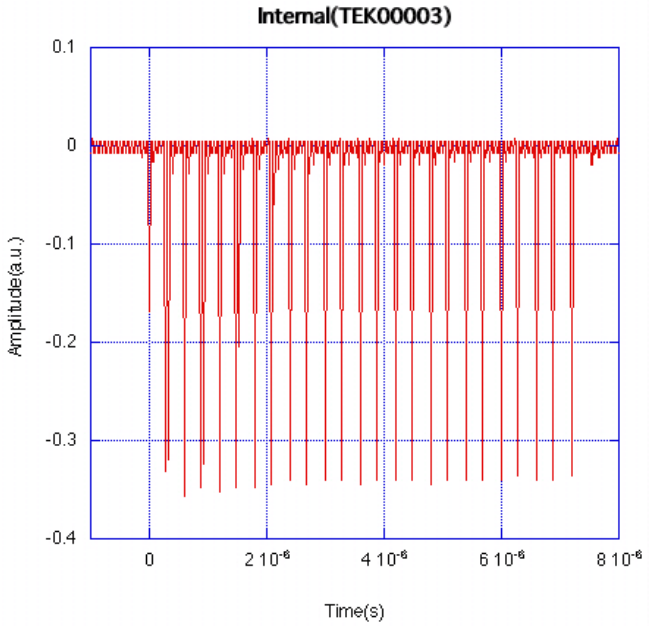
Photo of the fabricated strip-line kicker

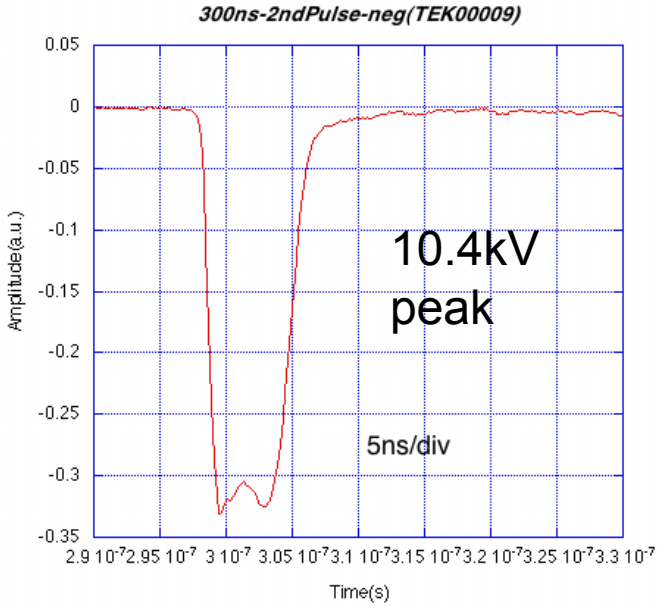


10kV, 4ns pulser



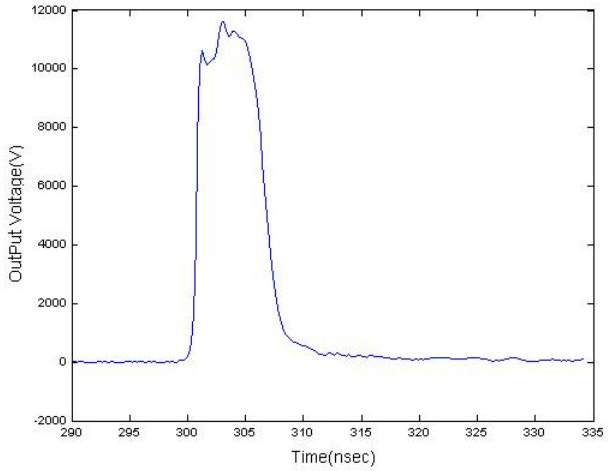


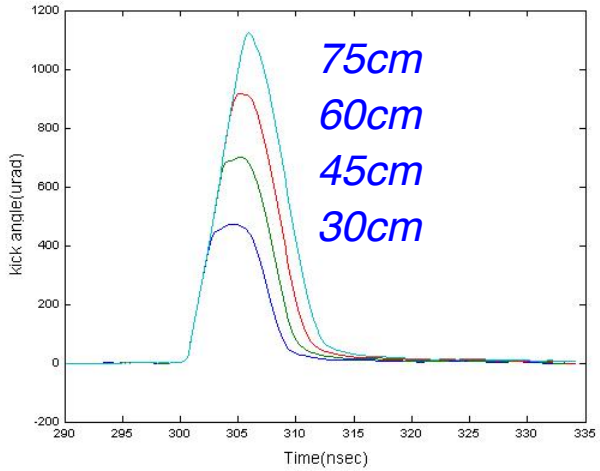


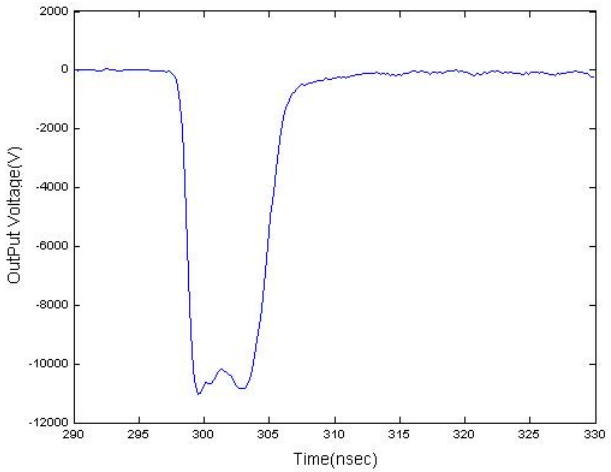


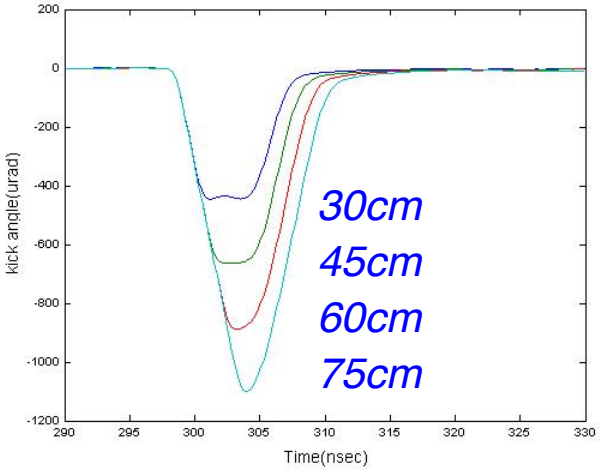
To increase the kick angle, we used 4ns pulse width pulsers, which is fabricated by FID. The waveform looks good. The flatness of the pulse train is defined from 7th pulse to 37th pulse.

Kick angle estimation of the 4ns pulser



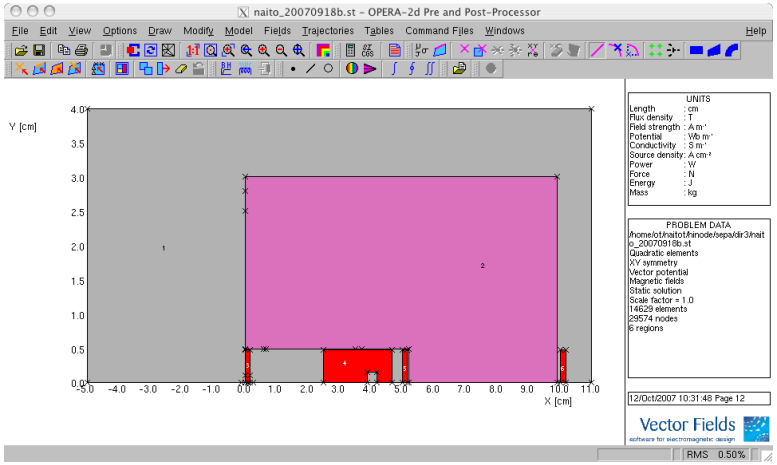


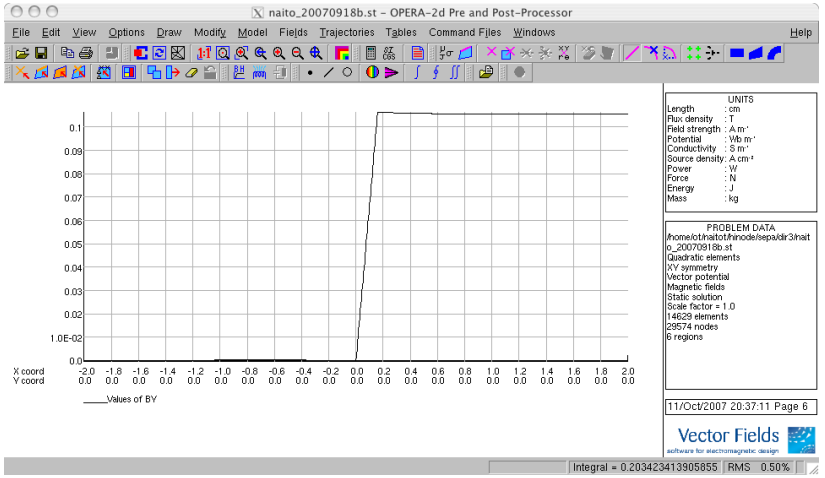


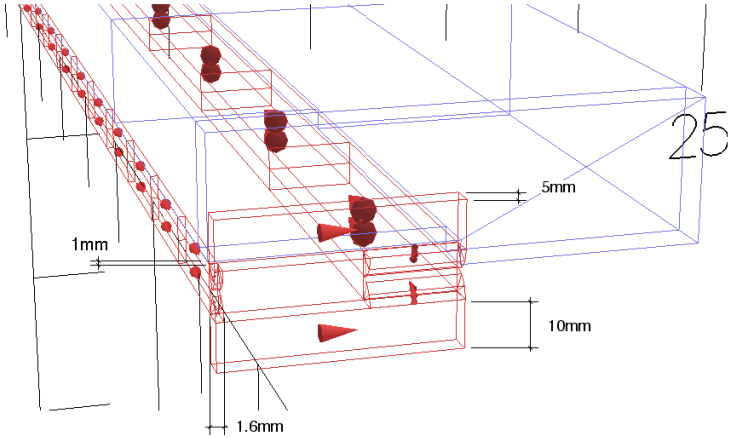


The kick angle of the single pulser is 0.9mrad for 60cm long strip-line. Two pairs of the strip-line will make 3.6mrad kick angle, which will be able to extract the beam without the auxiliary septum magnet.

Auxiliary septum magnet design and fabrication





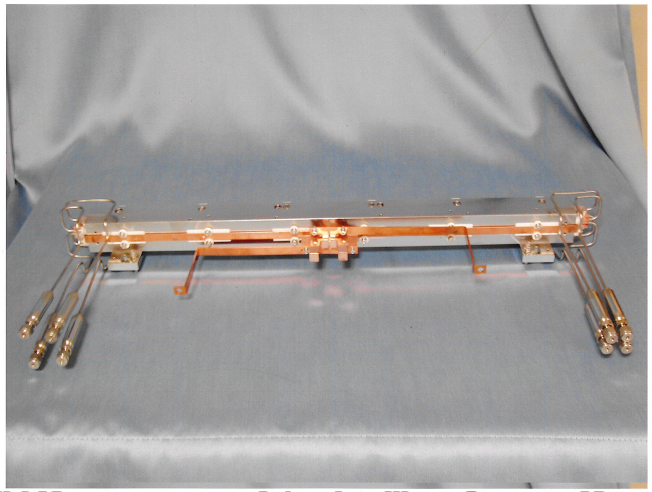


The design work of the auxiliary septum magnet was carried out by using OPER 2D and 3D.

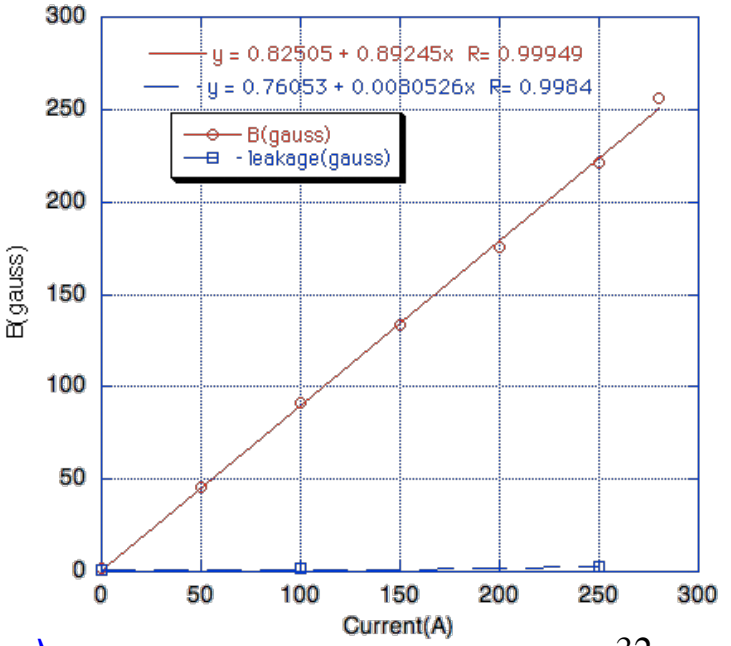
The designed auxiliary septum magnet has 1.6mm of a thin separator and 0.1T of bending field.

Auxiliary septum magnet

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.

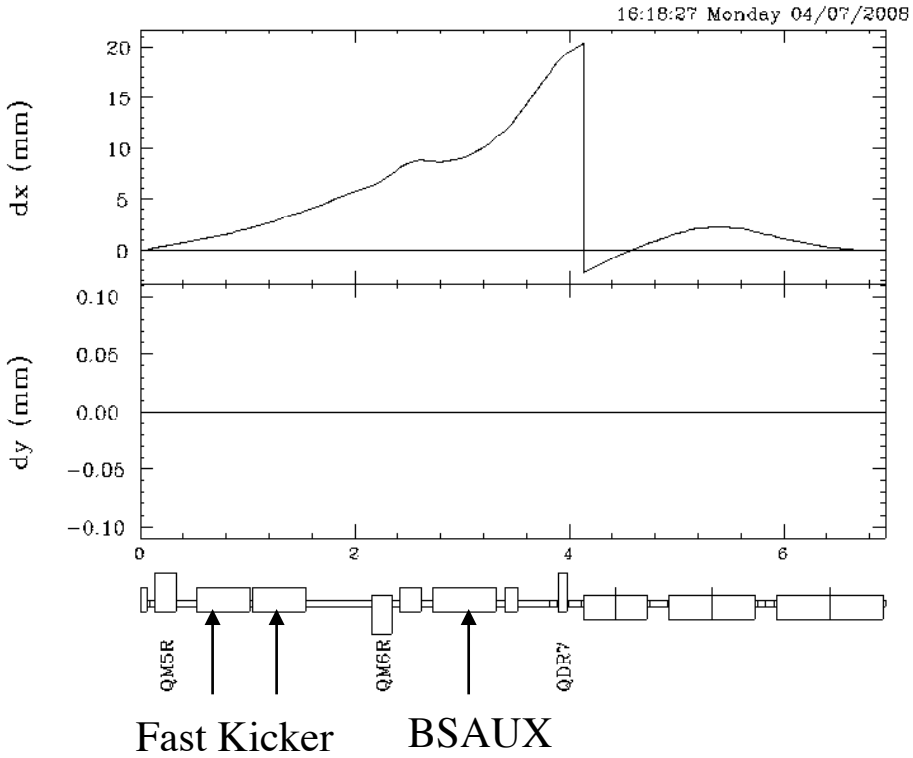


Feild Measurement of the Auxiliary Septum Magnet



EXT Orbit with Fast Kicker

S.Kuroda



Fast Kicker Strength: 1mrad X 2

Correctors K0: ZH9R -0.002320433716
ZH100R 0.009876184722
ZH101R -0.005210348744

Free parameters; K0 of BSAUX, BS1-3X

Imposed Condition;

Abs[dx]< 3 mm in BS1-3X region

dx=dpx=0 at the end of BS3X

Results;

BSAUX K0=-.010280163677

BS1X K0 =.0011826626821

BS2X K0 =.0031361169236

BS3X K0 =-.0013134448462

BS1&2X is weaker by 8.4%, BS3X is stronger by 1.1%.

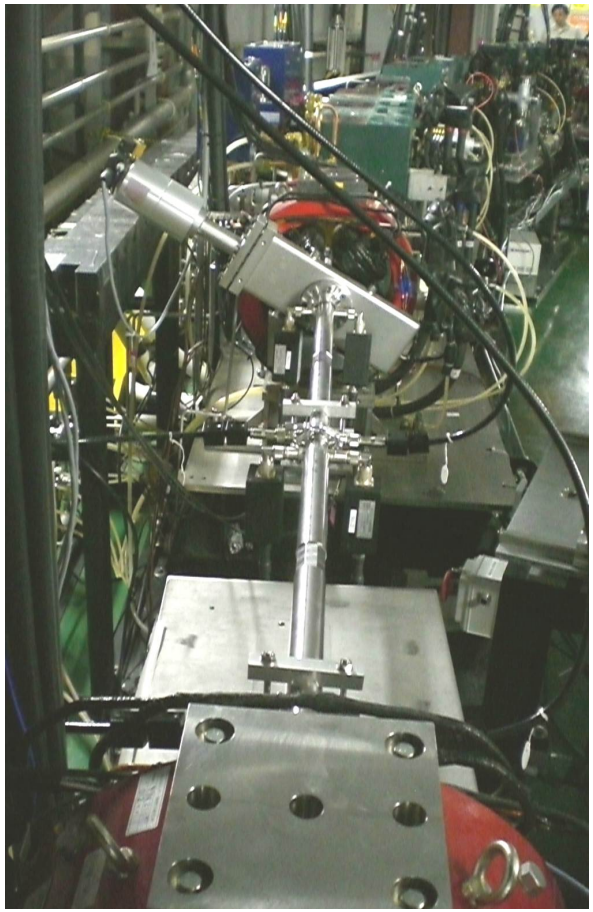
Orbit is measured from DR design orbit
+ toward EXT

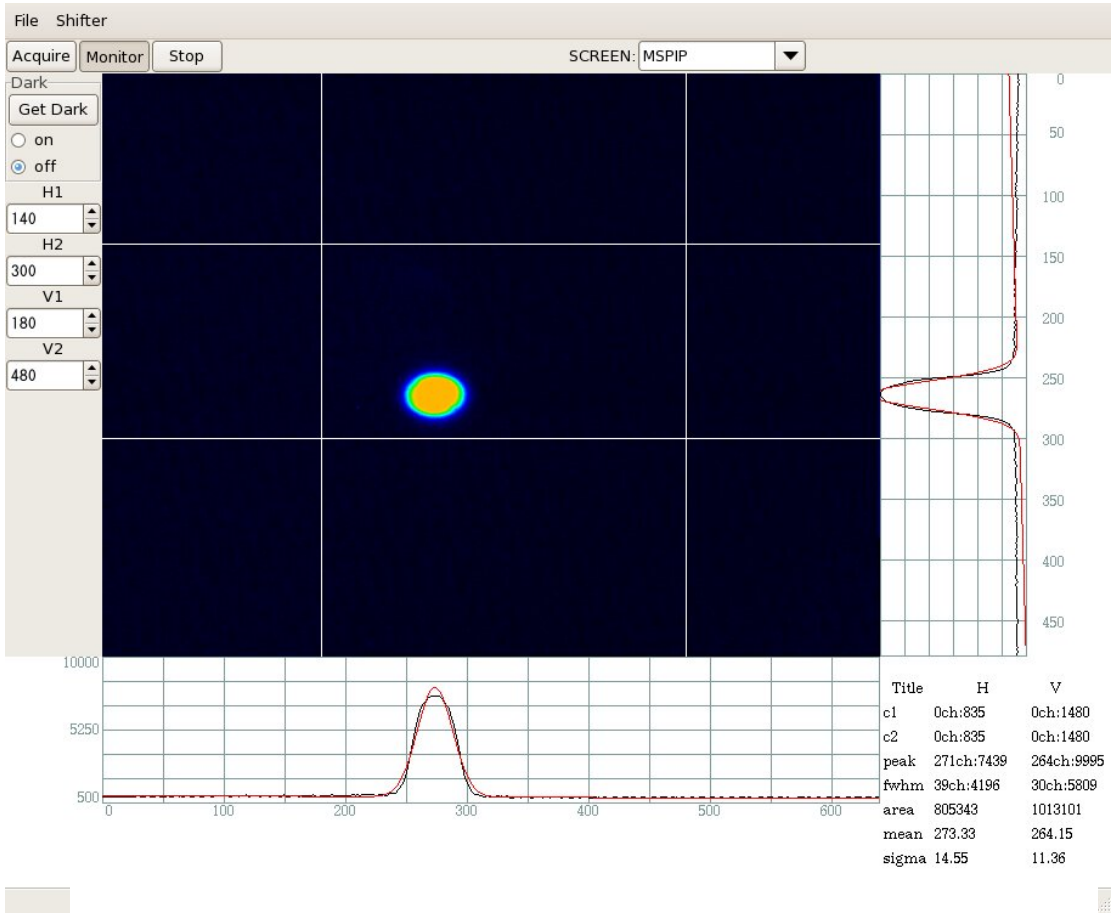
Orbit is measured from EXT design orbit
- toward DR

Physical aperture in septum region must be larger than
3mm+orbit distortion(+beam size)

10.1.14

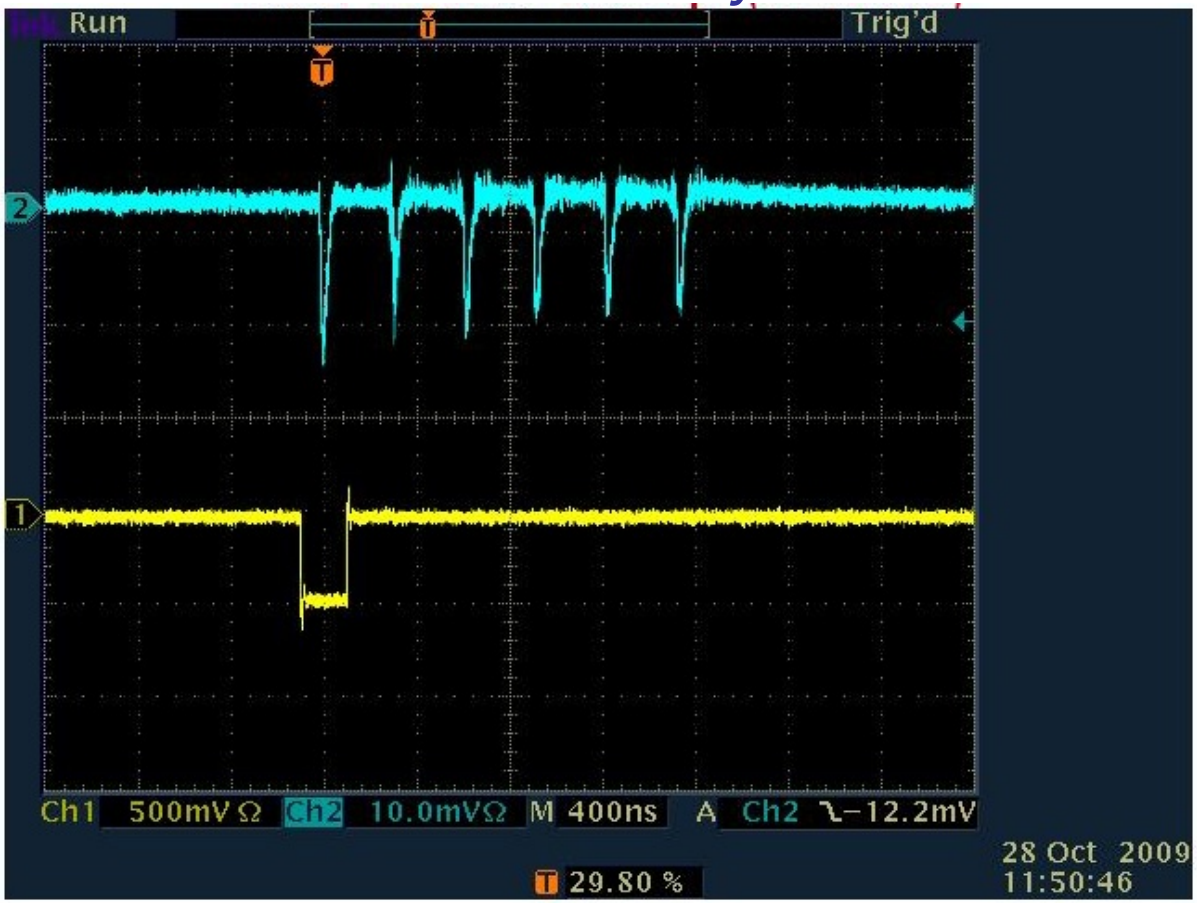
Beam Extraction succeeded from DR to ATF2 2009.Oct. 22.





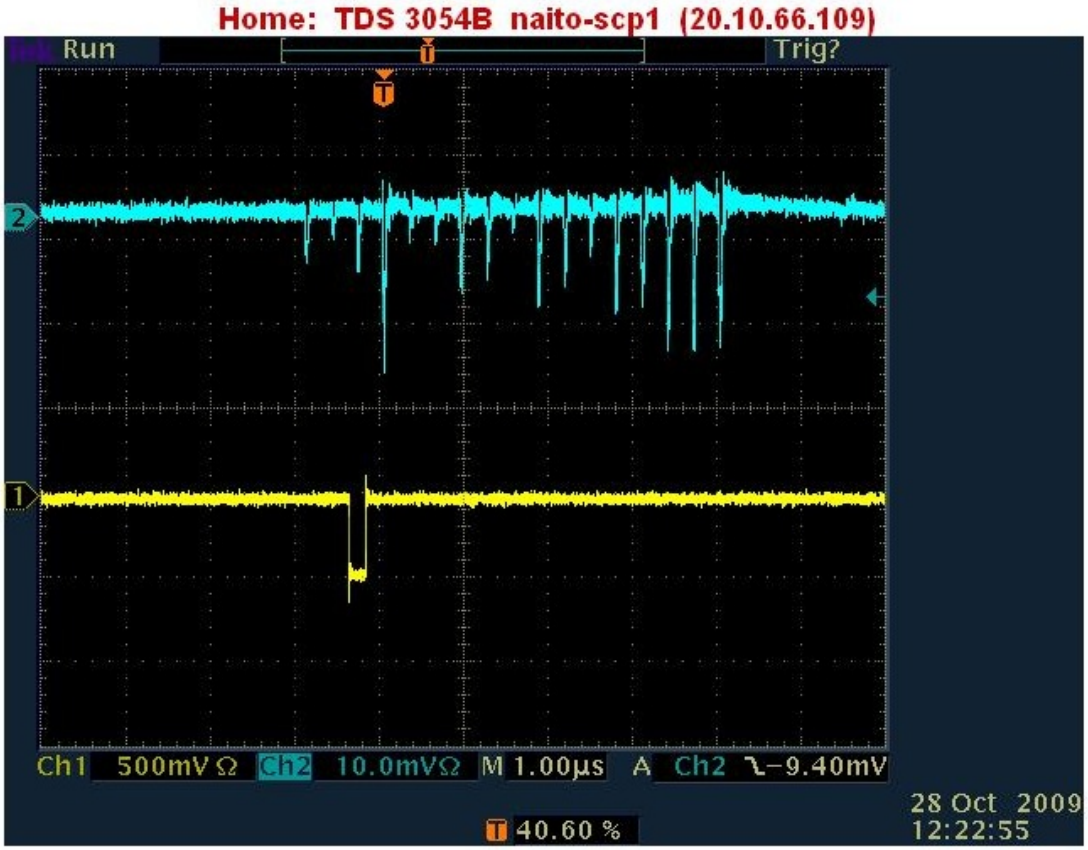
Beam profile at MS1X screen monitor, which is located at the downstream of the septum magnets.

Multi-bunch beam extraction by the Fast kicker



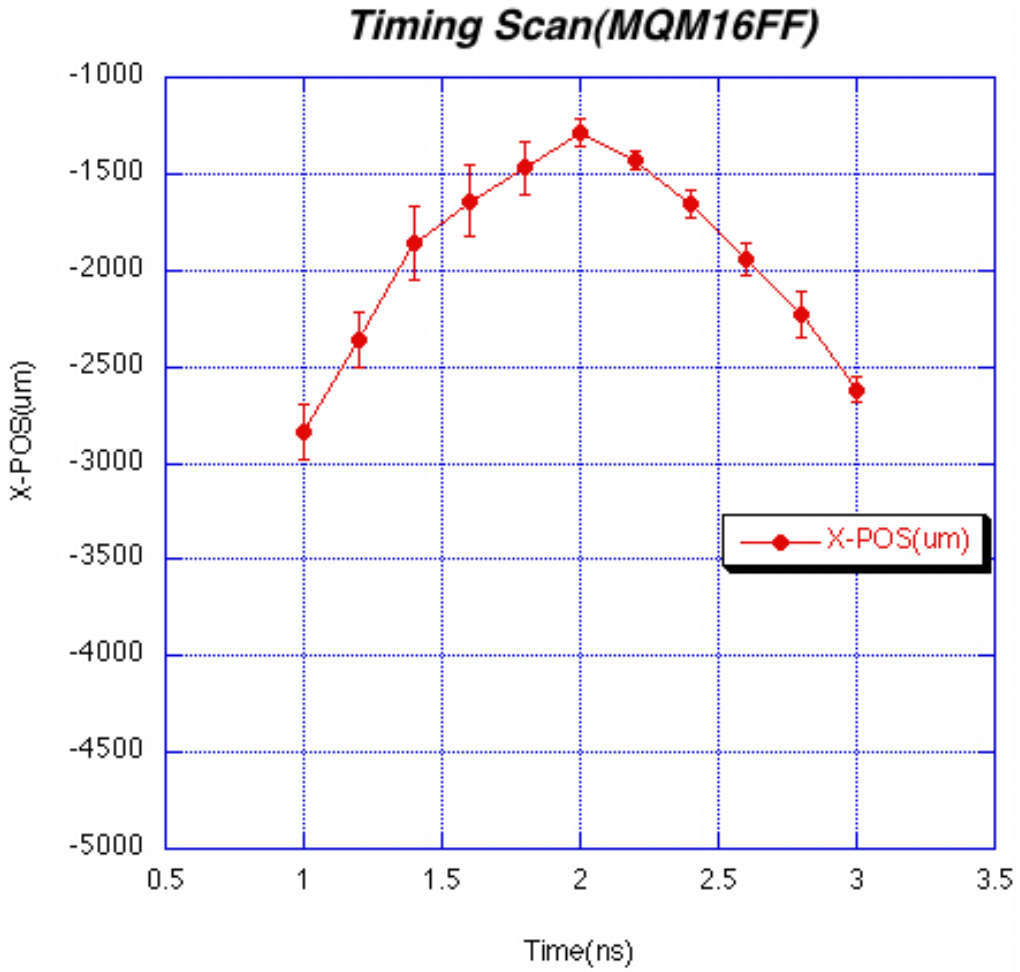
The stored multi-bunch beam, which has short bunch spacing(5.6ns), in the Damping Ring is kicked out bunch-by-bunch with 308ns interval by the fast kicker. The picture shows the case of the 6 bunches beam extraction. In the picture, the blue line shows the bunch charge monitored by the current transformer 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 17 bunches of the multi-bunch beam was extracted to the extraction line. Unfortunately, the bunch population of the extracted beam was not so flat. The timing system had a trouble at that time, which was caused by the unstable beam storage in the DR. The timing system will be improved for the next beam test.

Kick field profile and Timing jitter



The graph shows the measured horizontal beam position at the extraction line, when the kicker pulse timing was scanned with 200ps interval. The position displacement corresponds to the kick field difference. A cavity BPM(MQM16FF) at the ATF2 beam line was used for the measurement.

There is no flat-top for the kick field of the strip-line kicker. The estimated kick angle jitter is about 2x10^-3, when the designed R12 is used. We suspect the trigger timing jitter was caused by the kick angle jitter. One of four pulses had a large timing jitter(~500ps) compare to the others. We are trying to reduce the timing jitter.

Summary

The fast kicker development has been carried out in KEK. The multi-unit of the strip-line kicker system driven by fast pulsers is most promising candidate of the ILC kicker. The performance of the single unit was tested in ATF DR. The measured rise/fall time of the kick field was 3ns each, which depends on the shape of the kick pulse waveform. The waveform compensator was proposed and tested to improve the rise/fall time. The rise time improved from 3ns to 2.2ns with the waveform compensator.

The beam extraction test has been done from the ATF-DR to the extraction line. The circulated bunches with 5.6ns bunch spacing was kicked out bunch-by-bunch with 308ns bunch spacing. The beam extraction scheme is same as ILC kicker. Up to 17 bunches of the bunch train could be made at the extraction line. The measured stability of the kick angle was 2x10^-3.