



Barrier RF Stacking

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Outline



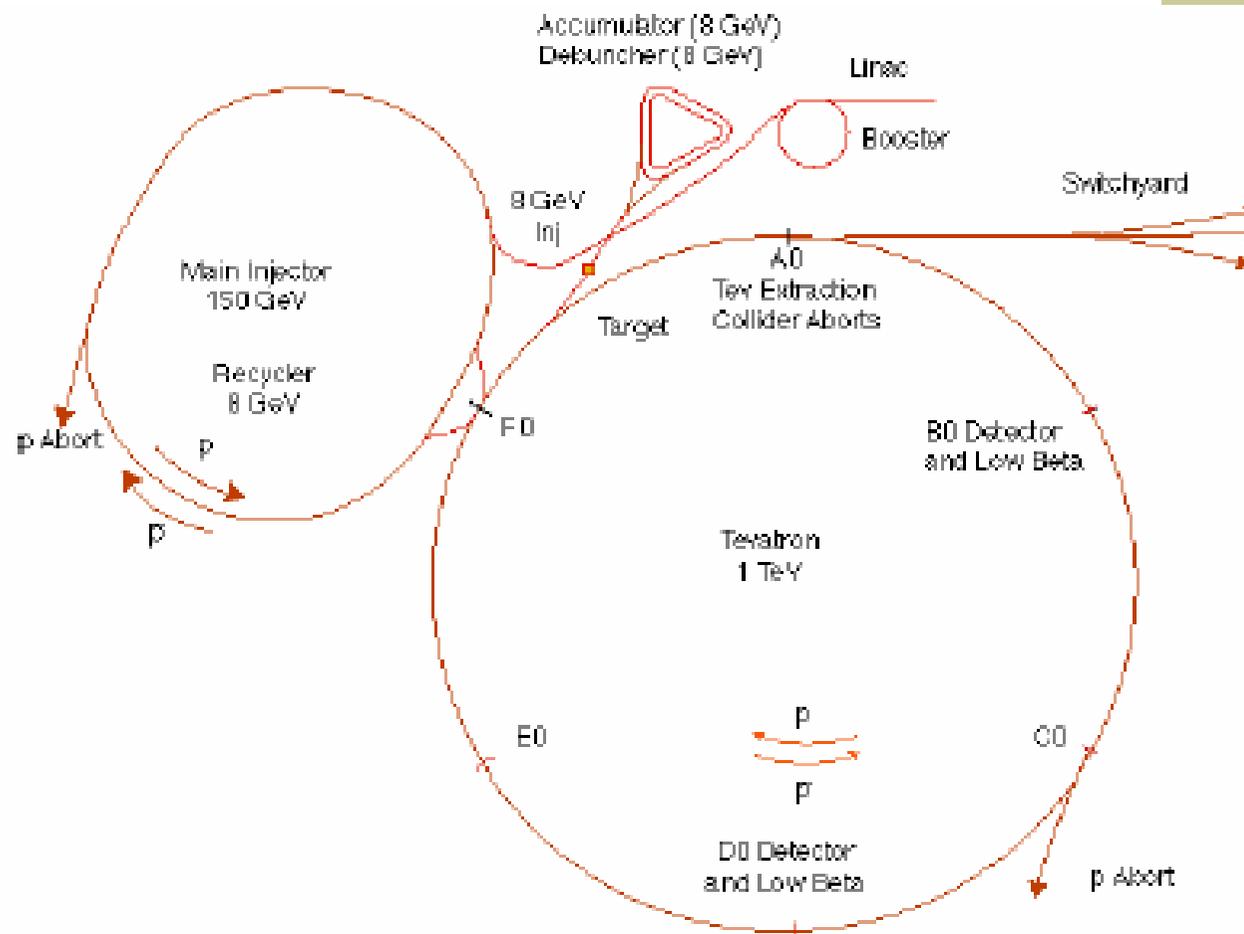
- ◆ Motivation and goals
- ◆ Introduction of the method
- ◆ Hardware requirement and specs
- ◆ Summary

<http://www-bd.fnal.gov/pdriver/barrier/>

Motivation

- ◆ To increase the Tevatron luminosity in **Run2** by increasing the proton intensity on the pbar production target (**2 x 1** Booster batch)
- ◆ To increase the neutrino flux in **NuMI** experiment by increasing the proton intensity on the pion production target (**2 x 6** Booster batches)

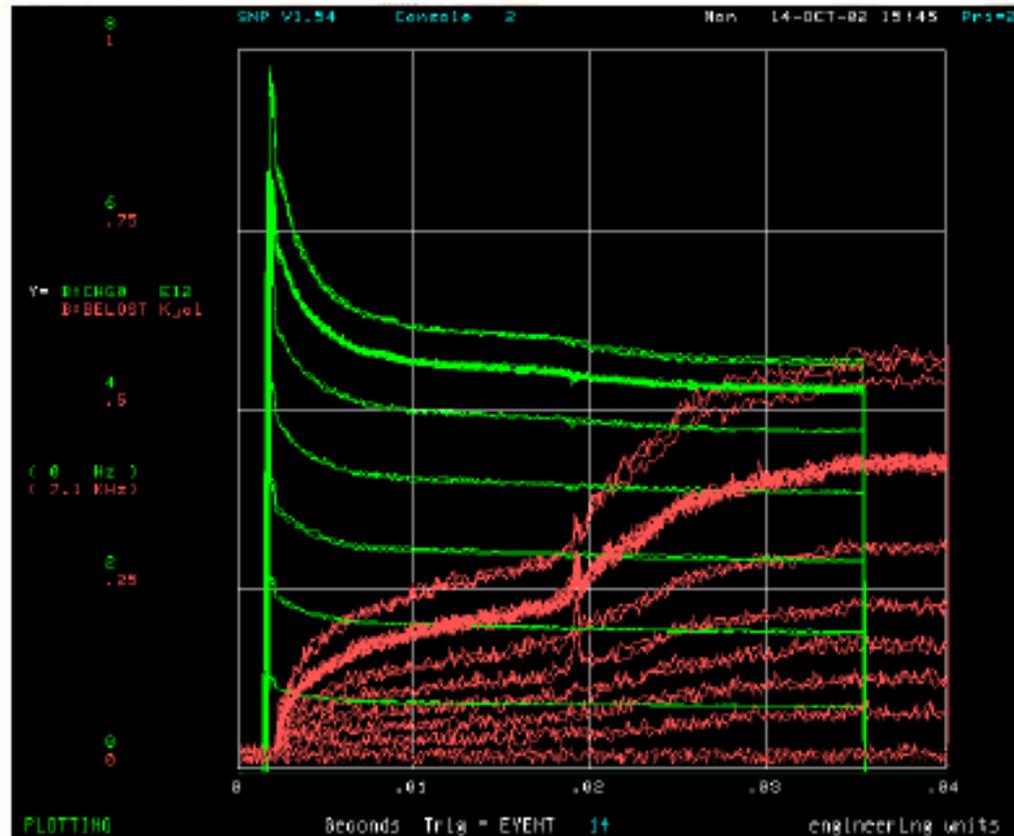
Fermilab Accelerator Complex



Bottleneck - Booster

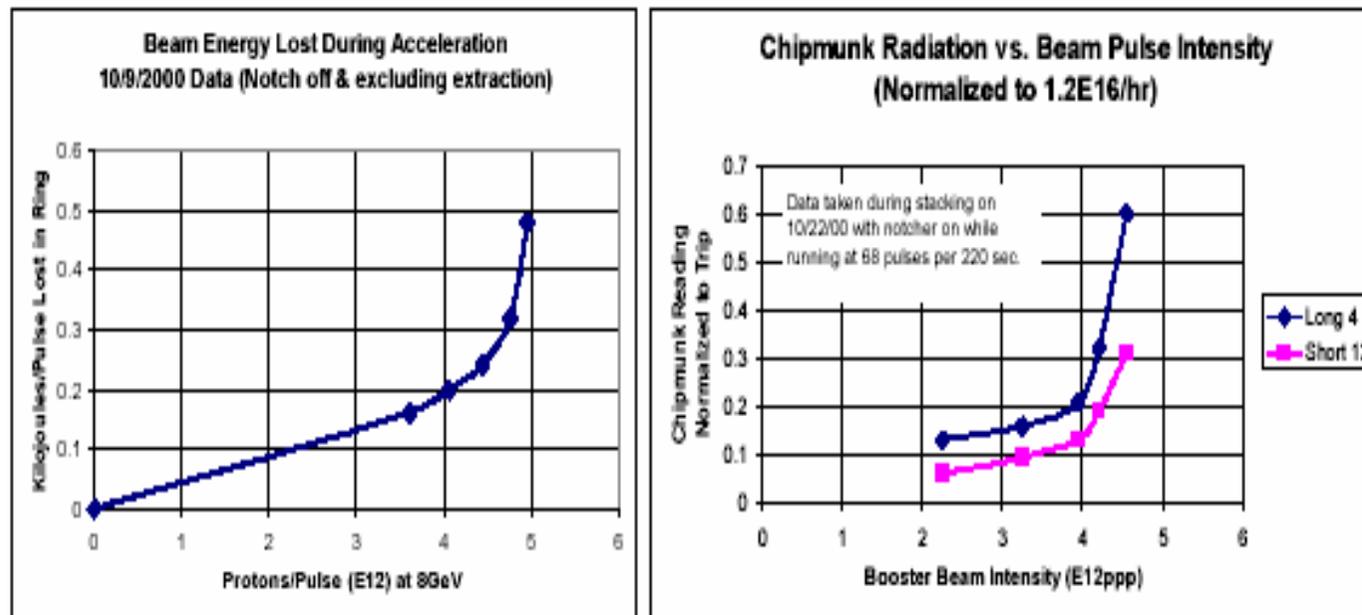
- ◆ The Booster is a bottleneck limiting the proton beam intensity in the Fermilab accelerator complex.
- ◆ The **Linac** can provide **3e13** particles per cycle
- ◆ The **Main Injector** with moderate upgrade can accept **3e13** protons per cycle
- ◆ However, the **Booster** can only accept and deliver **5e12** particles per cycle

Booster Beam Loss



For 0, 2, 4, 6, 8, 10, 12, 14 Injected Turns

Booster Energy Loss



Solution - Stacking

- ◆ A solution is to stack two Booster bunches into one Main Injector RF bucket
- ◆ This is possible because the Main Injector momentum acceptance (0.4 eV-s) is larger than the Booster bunch emittance (0.1 eV-s)

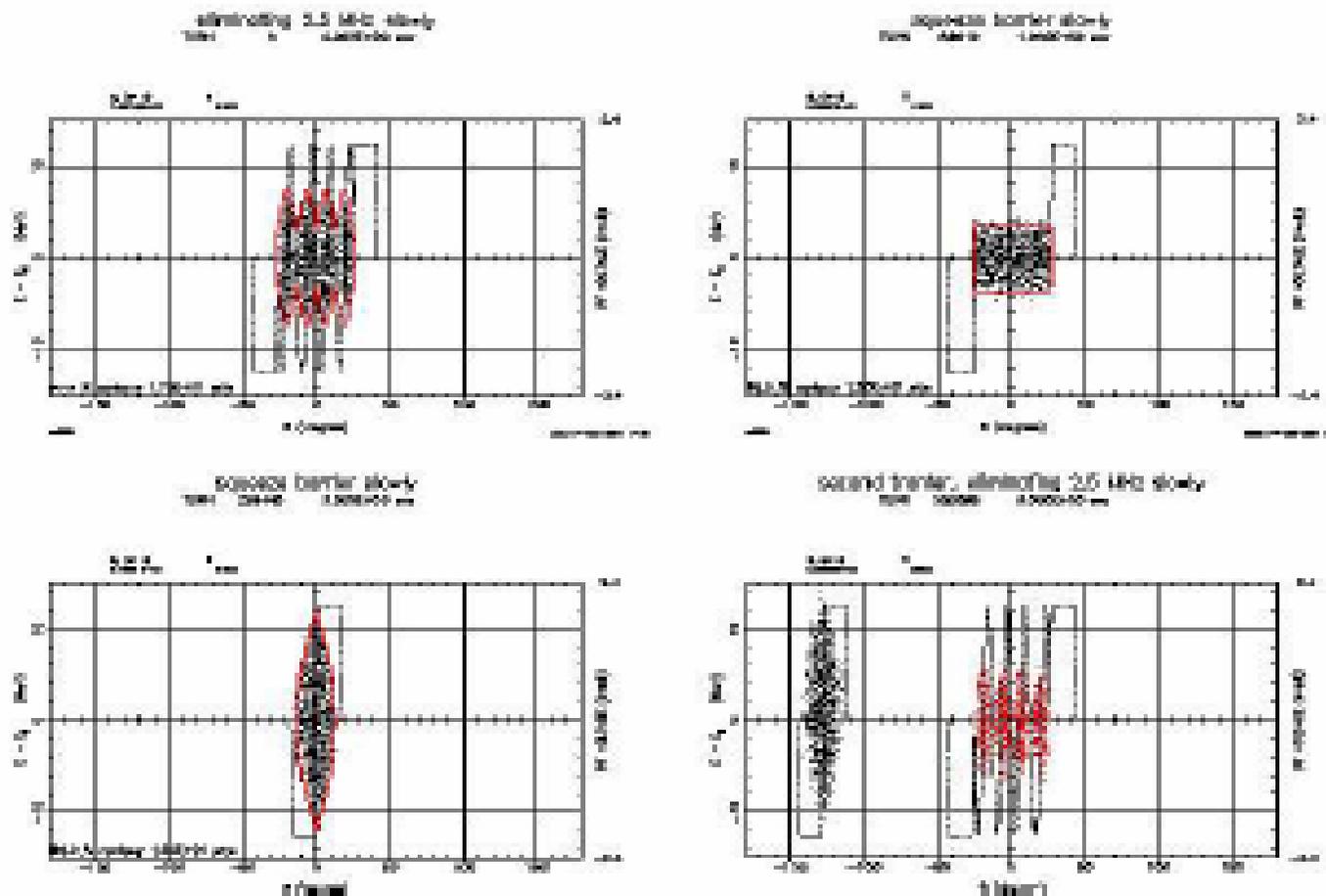
Stacking Goals

- ◆ **Goal for Run2** – To increase protons per second (pps) on the pbar target by **50%**
 - Present: $4.5e12$ every 1.467 sec
 - Goal: $2 \times 4.5e12$ every 2 sec
- ◆ **Goal for NuMI** – To increase pps on the NuMI target by **60%**
 - Baseline: $3e13$ every 1.867 sec
 - Goal: $2 \times 3e13$ every 2.333 sec

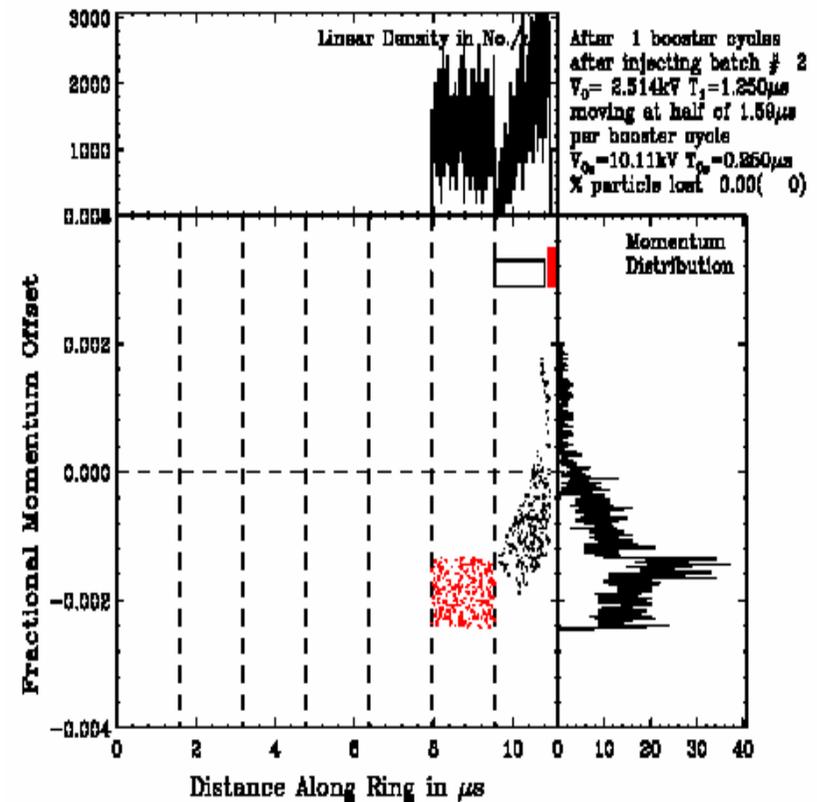
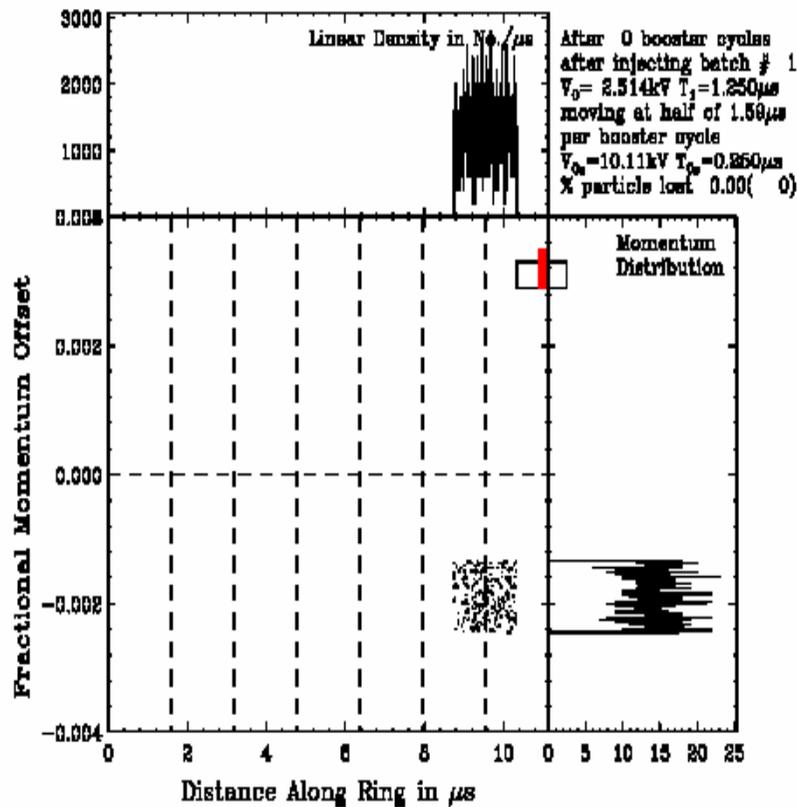
Method

- ◆ A straightforward way is to inject two Booster batches into the MI, confine them by RF barrier buckets, then move the barrier to compress the beam.
- ◆ But the compression must be slow (adiabatic) in order to avoid emittance growth. This would lengthen the injection process and thus reduce protons per second (pps)
- ◆ A better way (first proposed by J. Griffin) is to inject Booster batches off-axis so that the injection can be continuous

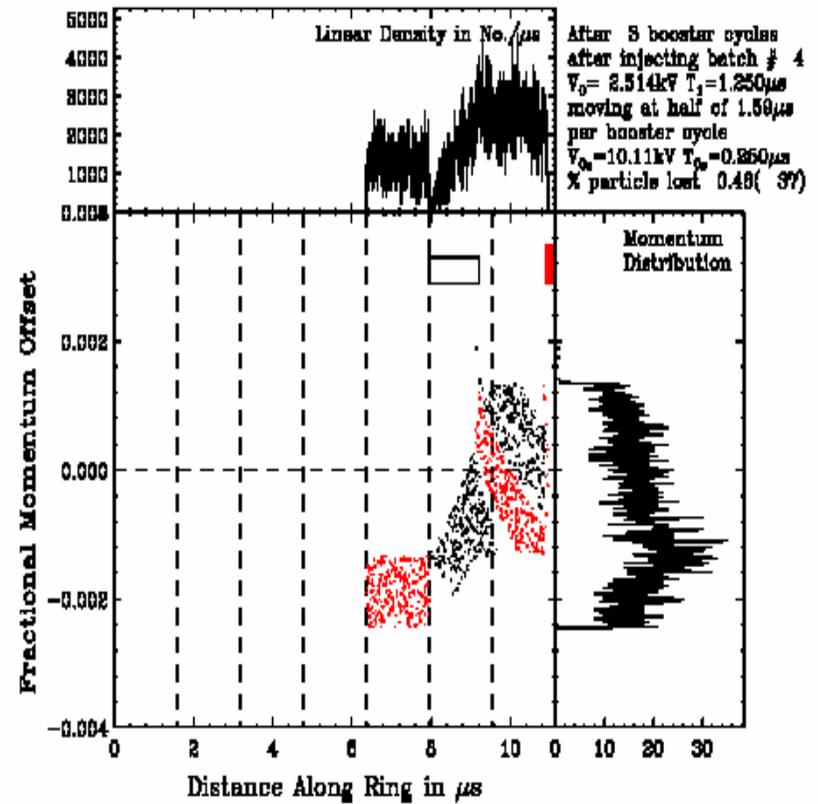
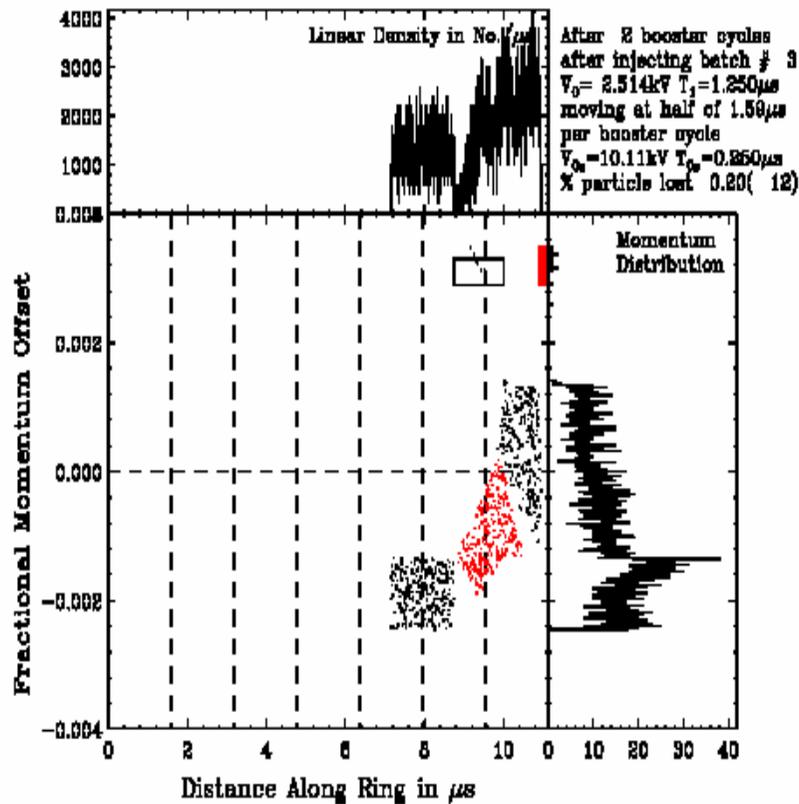
Injection Beam On-Axis (Recycler, courtesy C. Bhat)



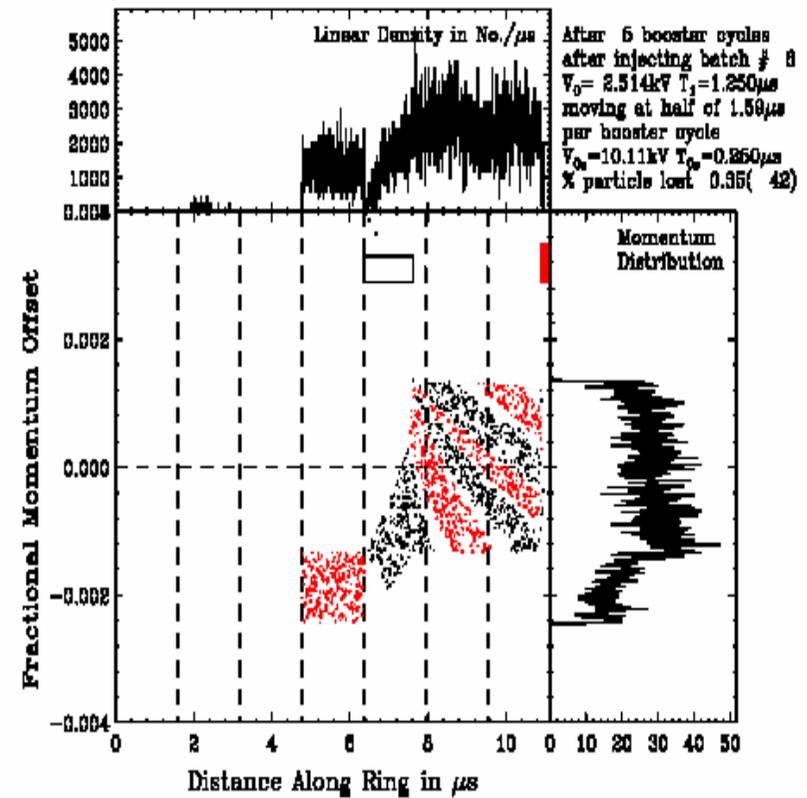
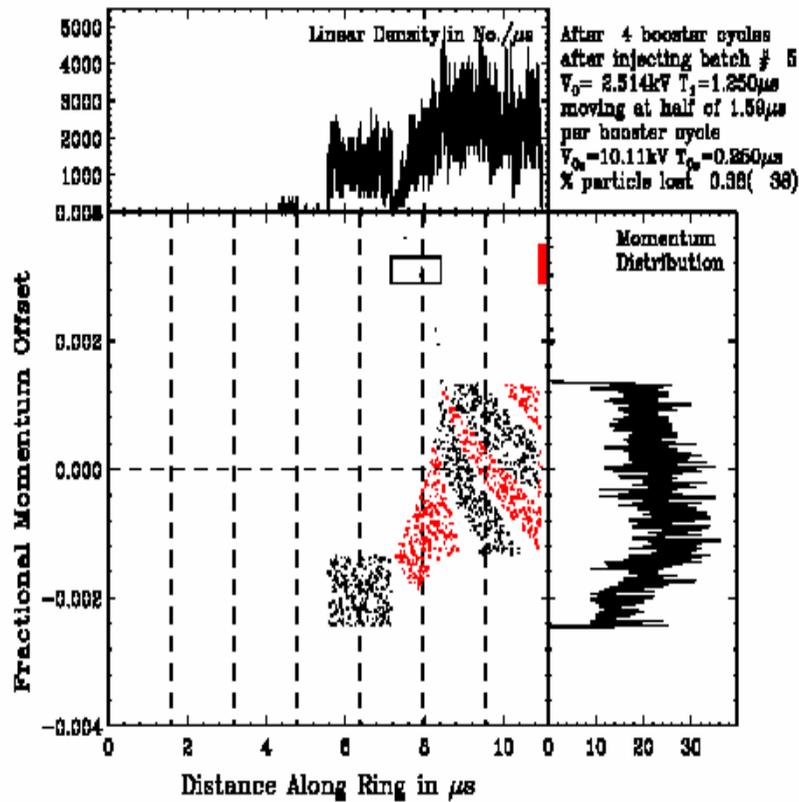
Injection Beam Off-Axis (12-batch stacking, courtesy K-Y. Ng)



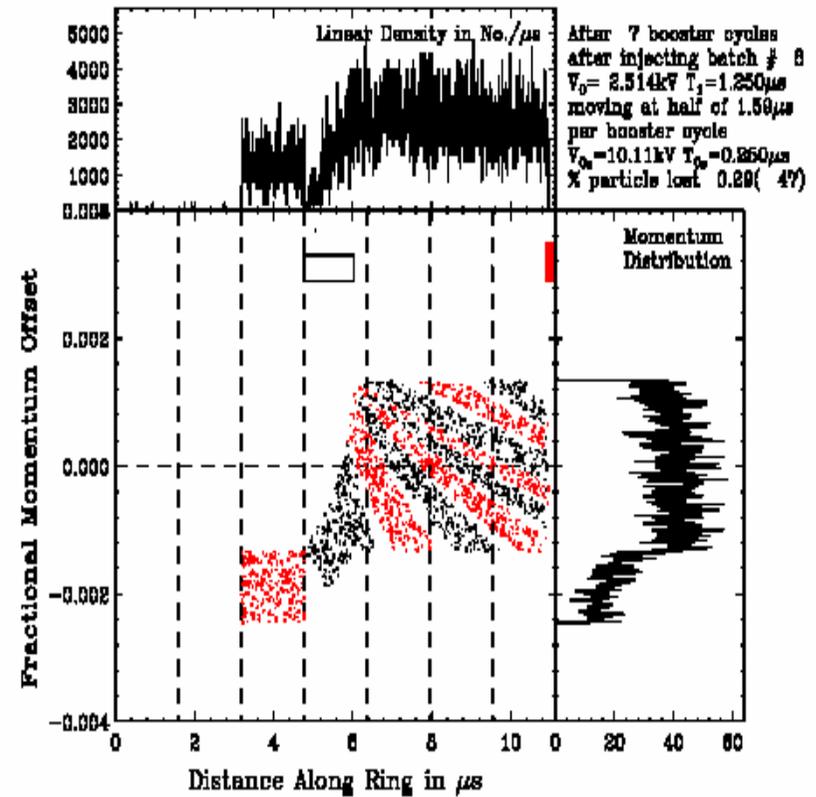
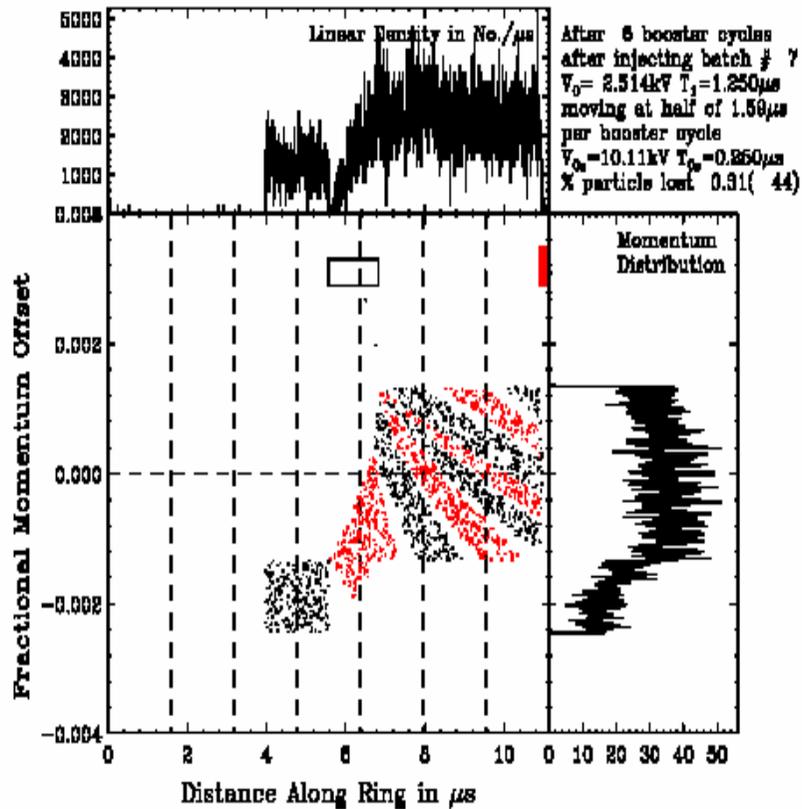
12-Batch Stacking (cont...)



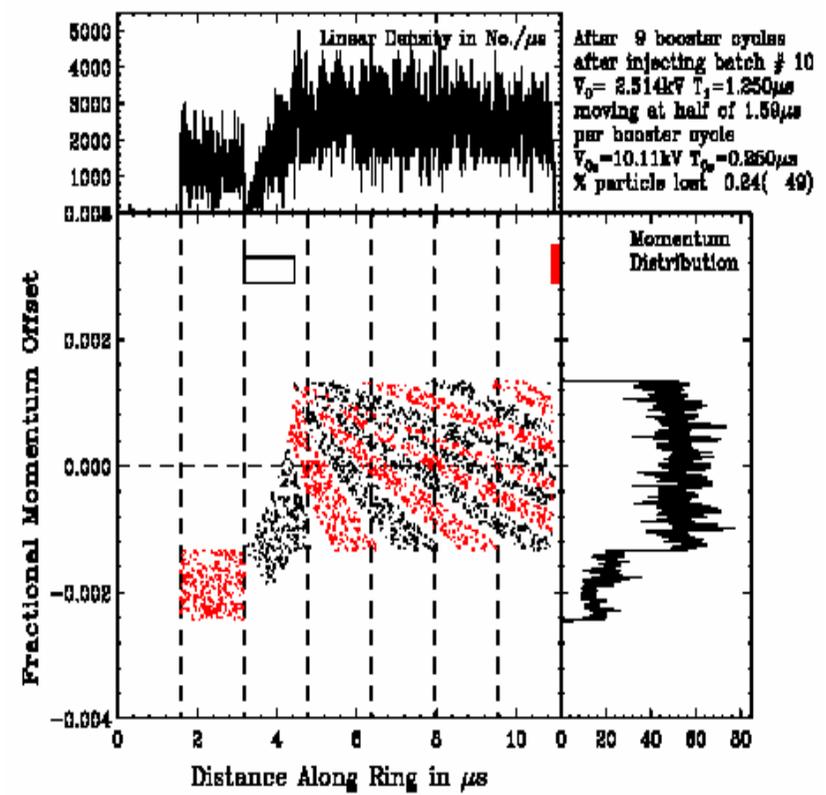
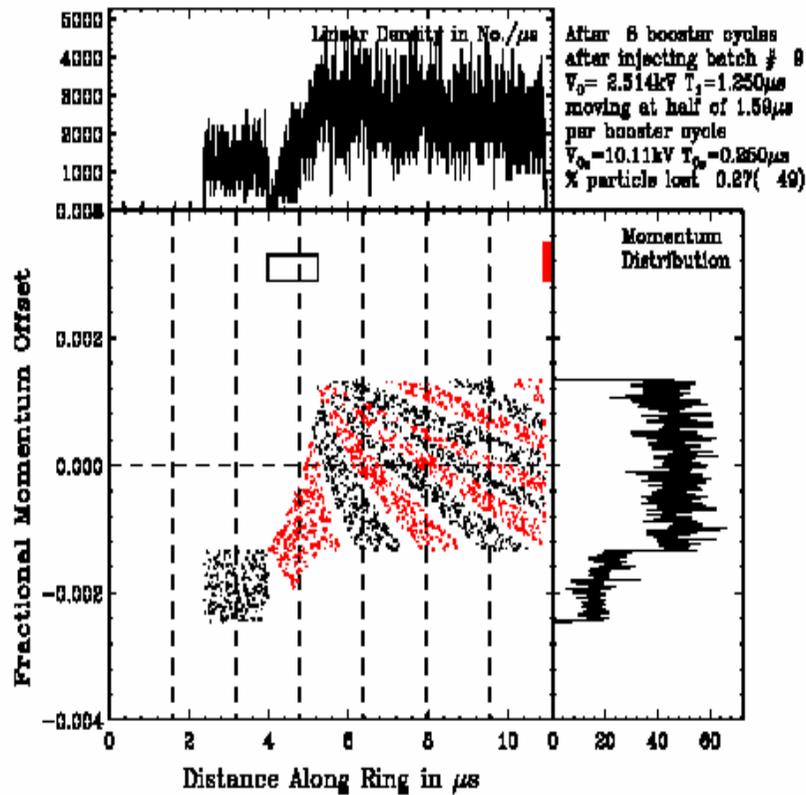
12-Batch Stacking (cont...)



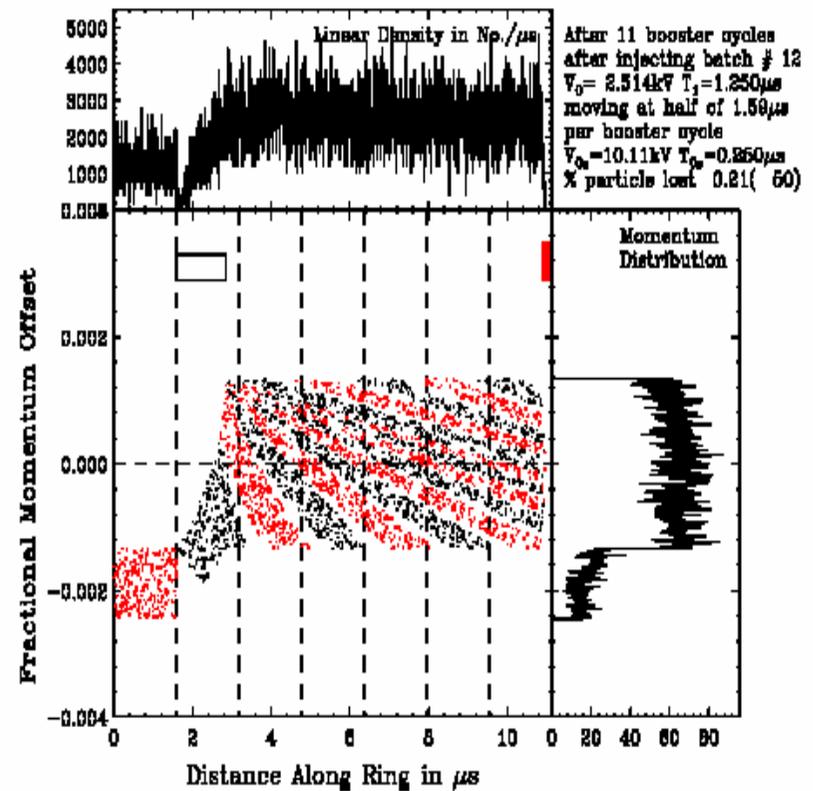
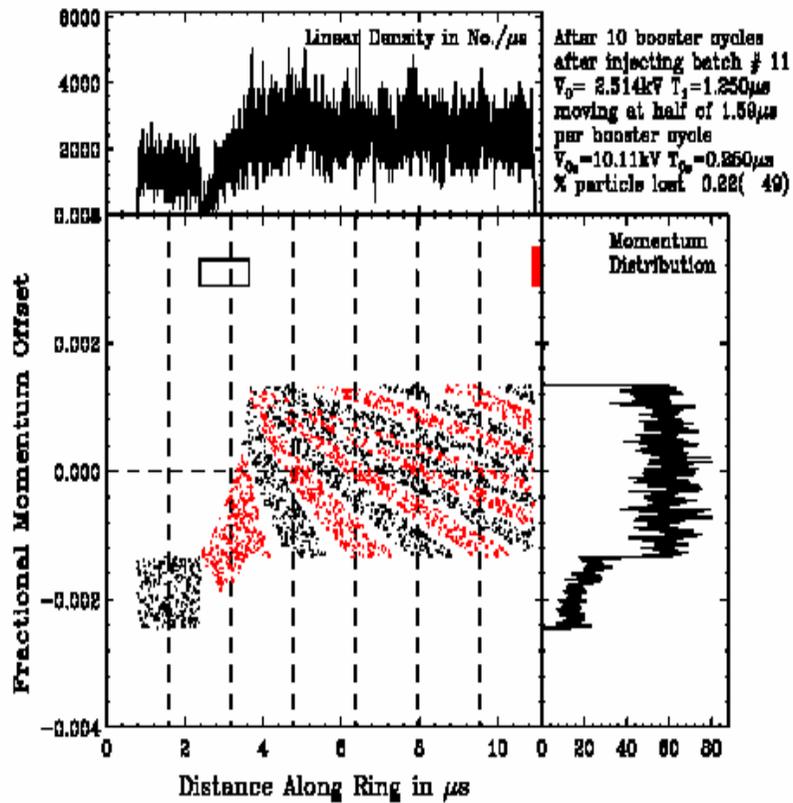
12-Batch Stacking (cont...)



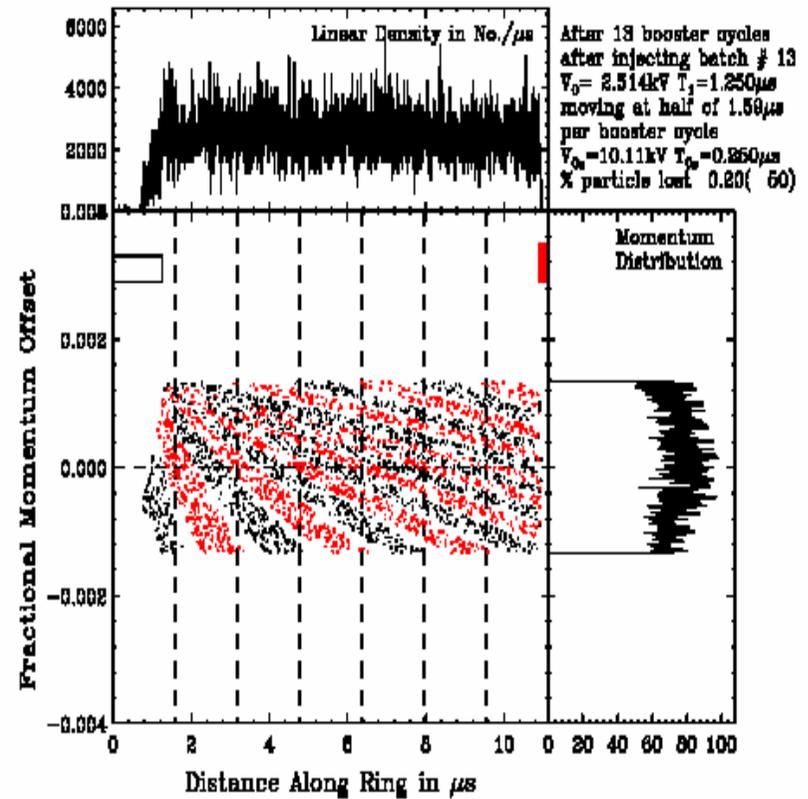
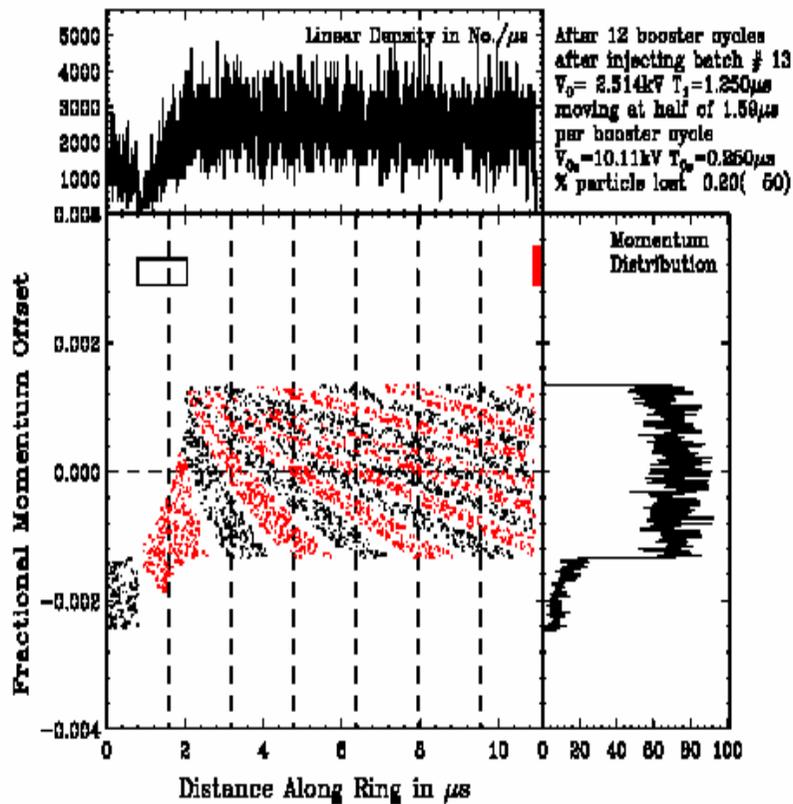
12-Batch Stacking (cont...)

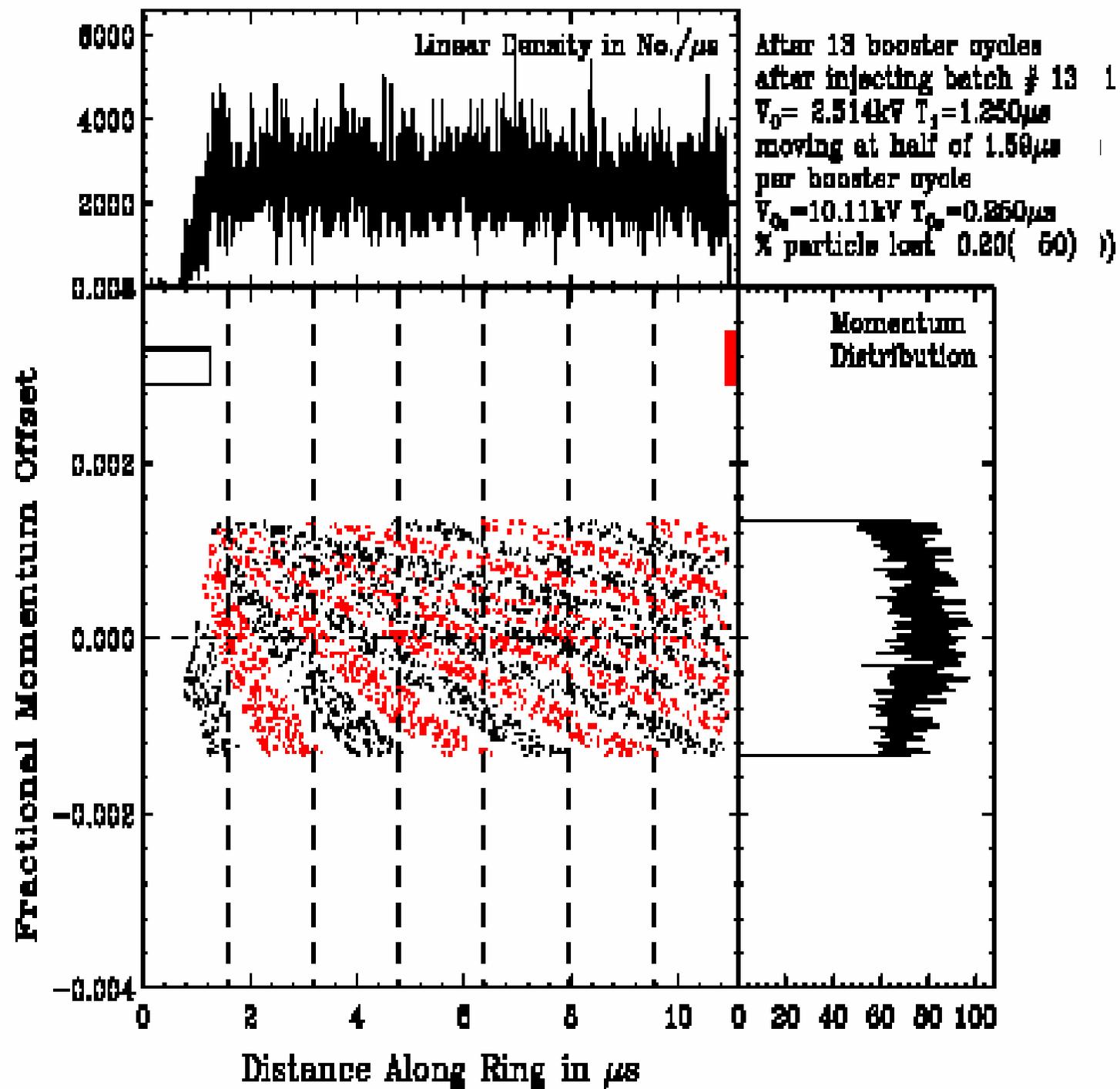


12-Batch Stacking (cont...)

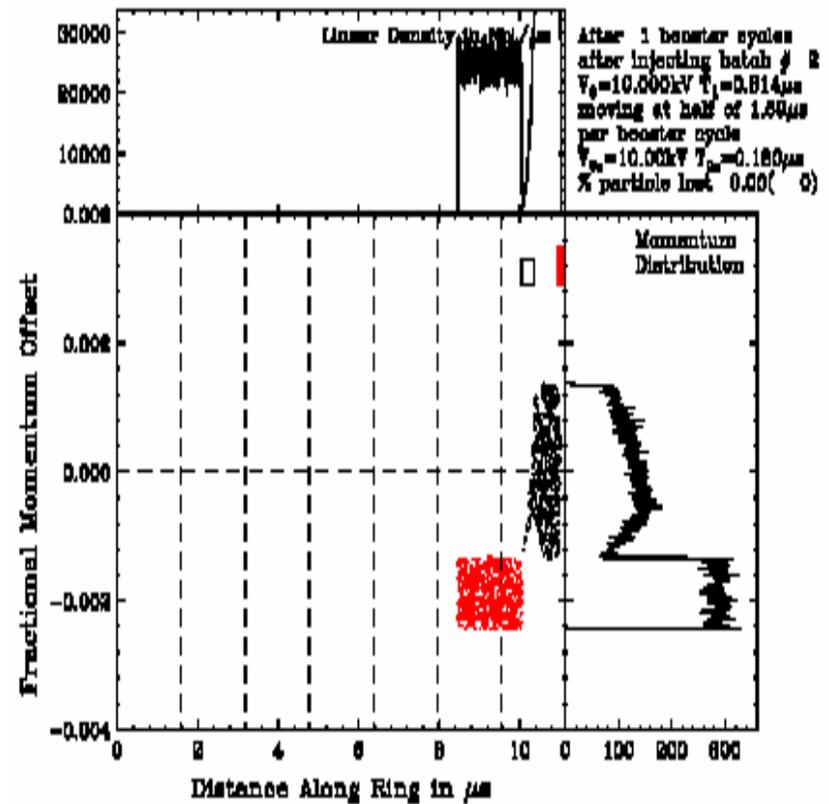
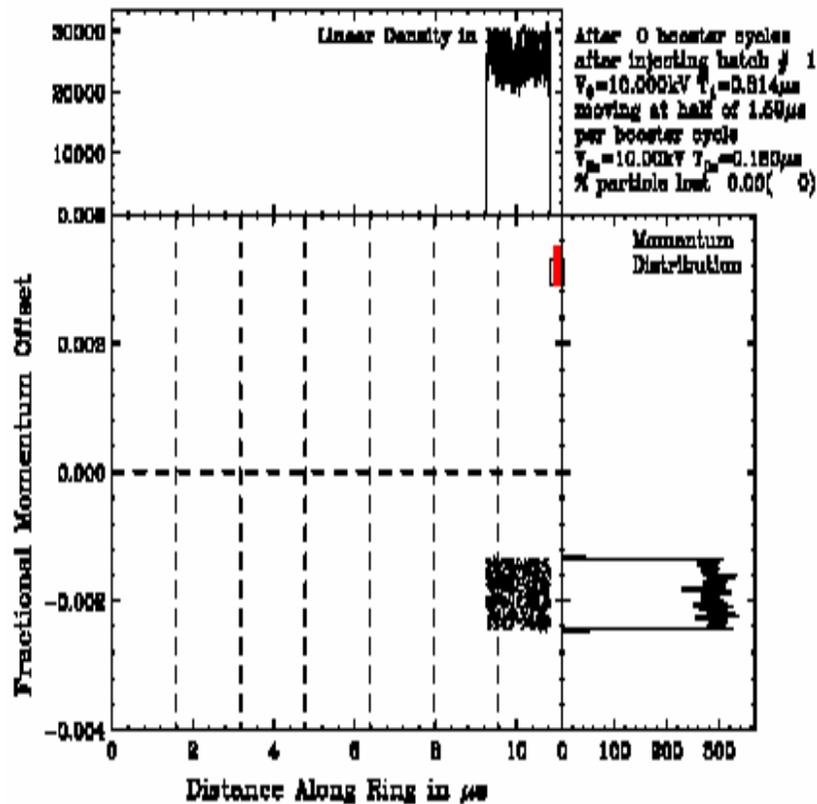


12-Batch Stacking (cont...)

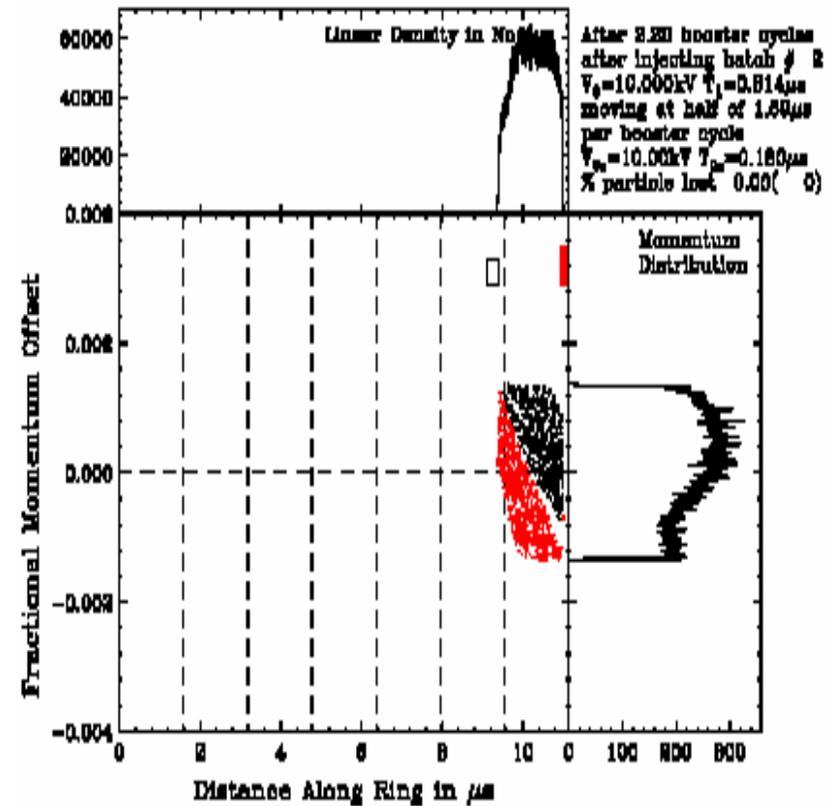
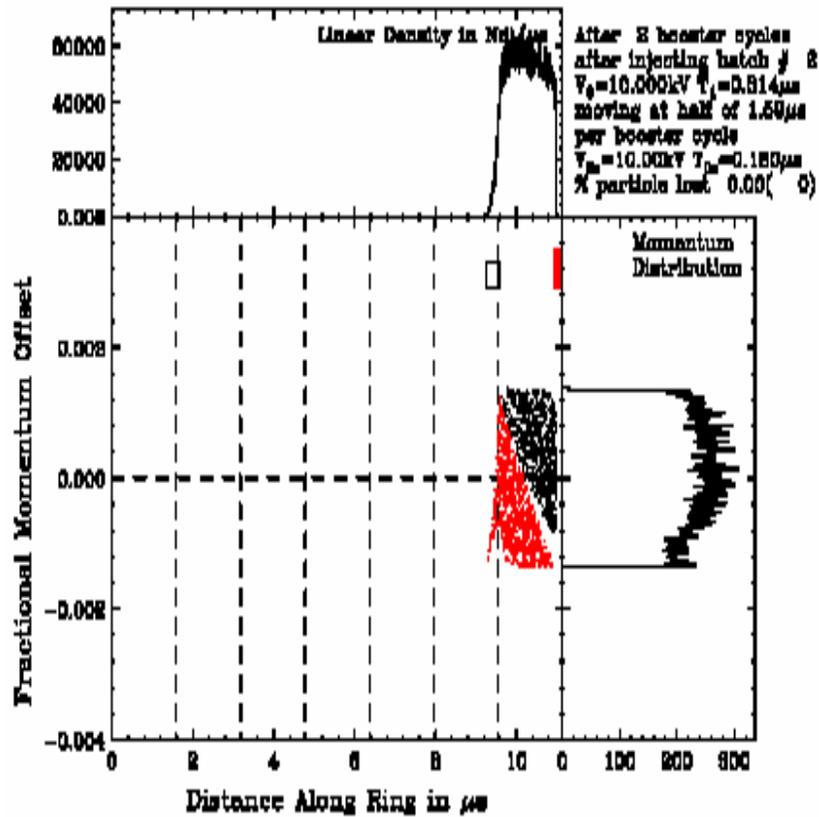




Injection Beam Off-Axis (2-batch stacking, courtesy K-Y. Ng)



2-Batch Stacking (cont...)



Barrier RF Stacking *vs.* Slip Stacking

- ◆ One main advantage of barrier RF stacking is smaller beam loading effect thanks to lower peak beam current
- ◆ Another “advantage” is that we didn’t know much about this method and have never tried. (By contrast, we already know how hard slip stacking is.)

Key Issue

- ◆ Booster beam must have a small $\Delta p/p$ to start with (required ΔE about ± 6 MeV)
- ◆ This means one has to control the instability of the Booster beam by means of: (a) longitudinal damper, (b) RF frequency modulation, and to perform a bunch rotation prior to extraction

Hardware

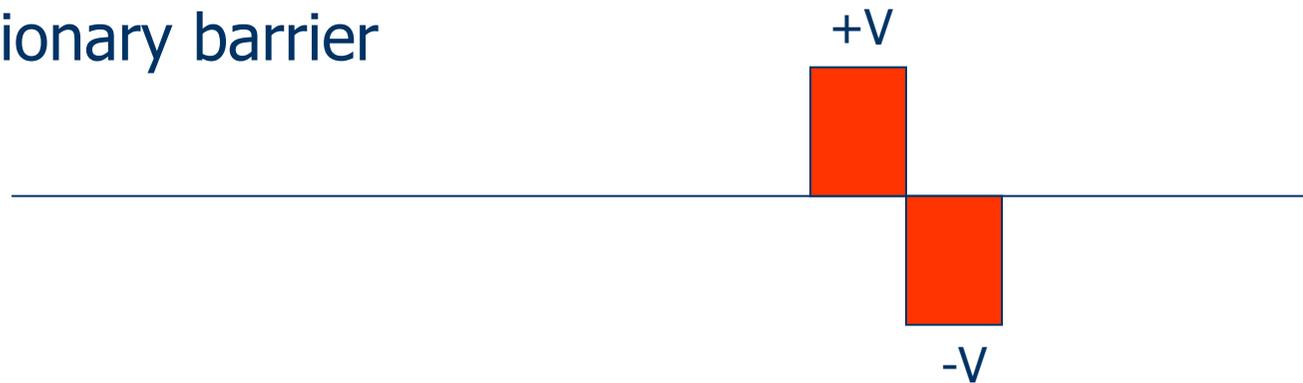
- ◆ Task: To build a ± 6 kV wideband RF system (i.e, the barrier RF) using Finemet cavities and high voltage fast switches
- ◆ Cavity: Based on the design of an RF chopper that was built by a Fermilab-KEK collaboration via a US-Japan Accord. Hitachi Metals Ltd. (Japan) will supply the Finemet cores

Hardware (cont...)

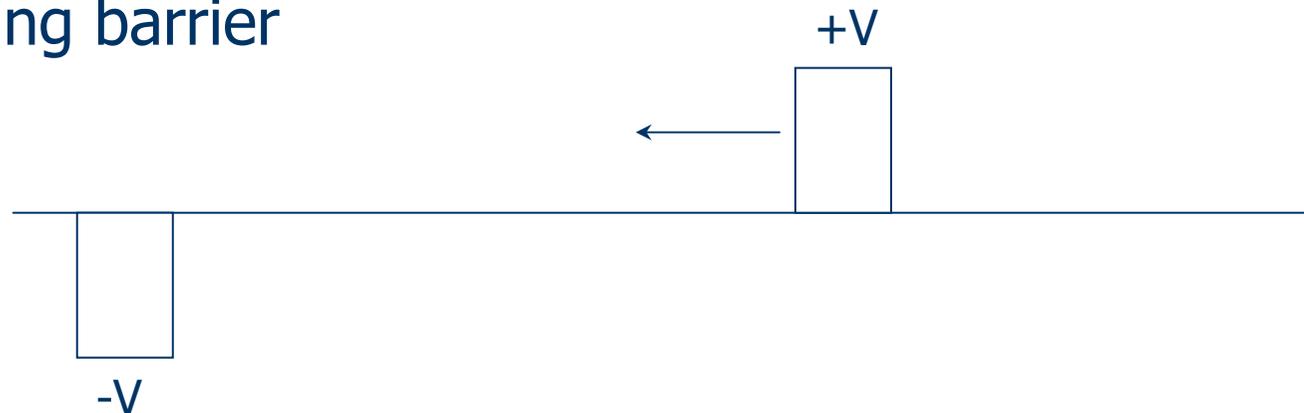
- ◆ Switch circuit: Also based on the design of the RF chopper. Behlke Co. (Germany) will supply the switches (solid state HTS series).
- ◆ However, there is an important difference between the chopper circuit and the barrier RF circuit. The former uses a pair of +V and -V pulses. The latter has two types. One of them requires a zero-voltage gap between +V and -V pulses. Therefore, the circuit must be modified. (No good design yet; Help welcome)

Two Types of Barrier

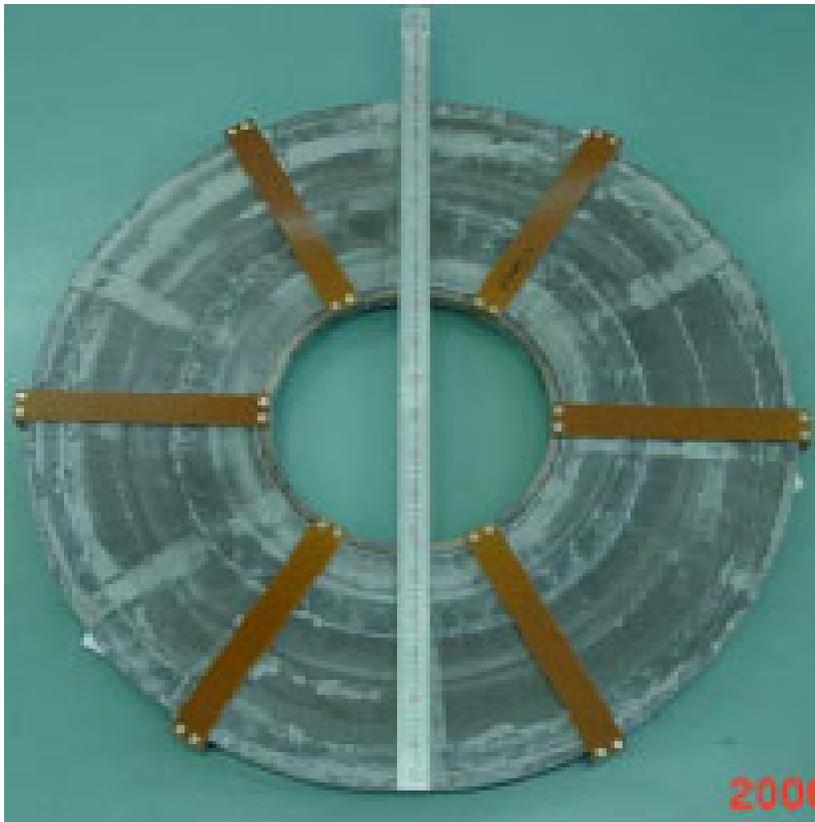
Stationary barrier



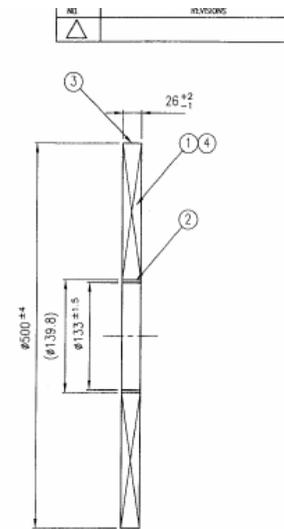
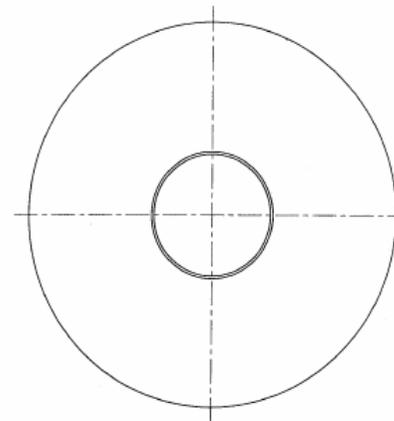
Moving barrier



Finemet Core



DIMENSIONS
外觀寸法



ELECTRICAL CHARACTERISTICS
電気特性

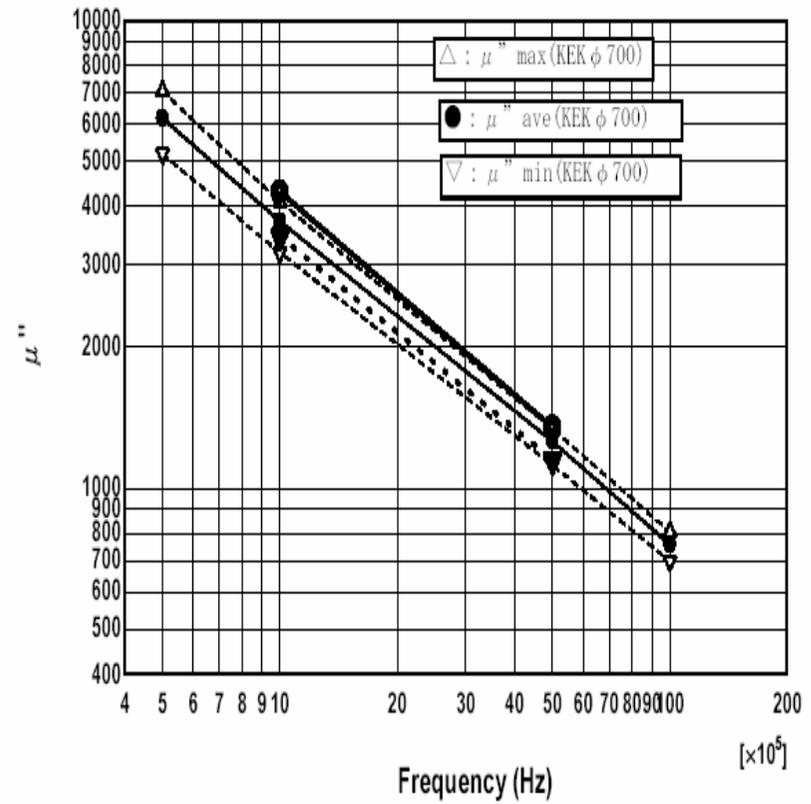
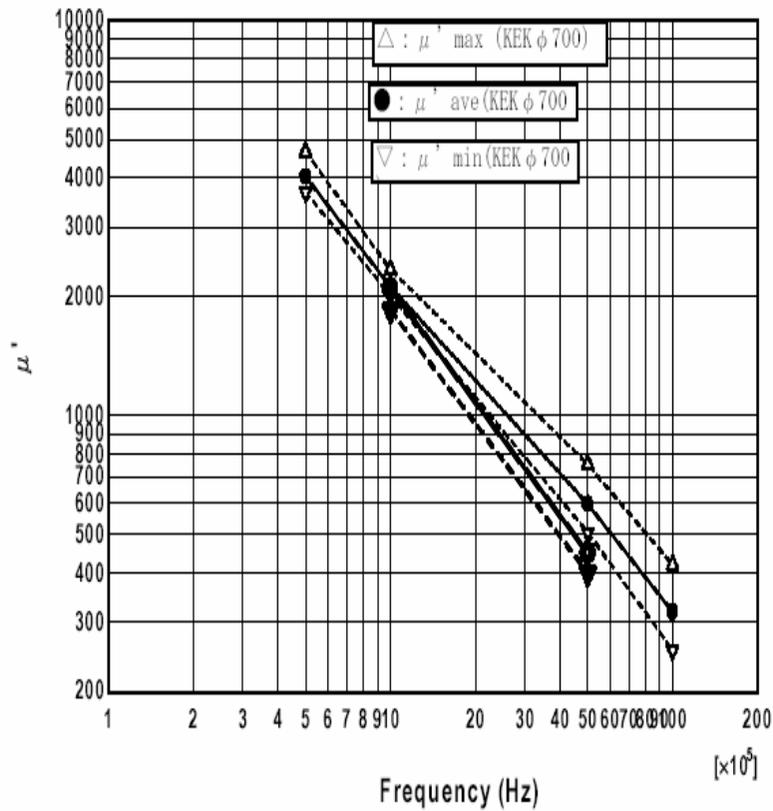
COMPLEX PERMEABILITY 複素透磁率	Frequency	1MHz	5MHz
	μ'	≥ 1700	≥ 350
μ''	≥ 3000	≥ 1000	

EQUIPMENT : LCR METER HP-4284A or EQUIVALENT
CONDITION : 0.5Vrms
MEASURING MODE: SERIES MODE

SCALE	UNIT(mm)	QTY	NO.	GENERAL DIMENSION	TOLERANCE	MARK
ϕ		1	④			
		1	③			
		1	②			
		1	①			
DWN	R. Ogawa	02-9-20				
CHD	J. Saito	02-9-20				
CHD	J. Shirose	02-9-20				
APPR.						
				TITLE	FT-3M	
					TD 500-	

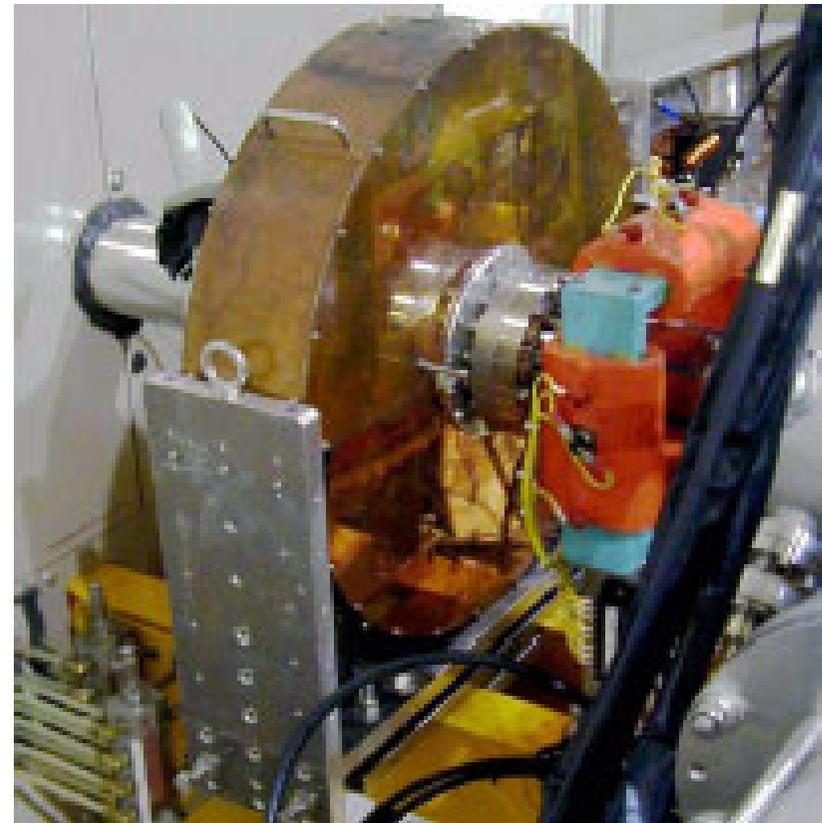
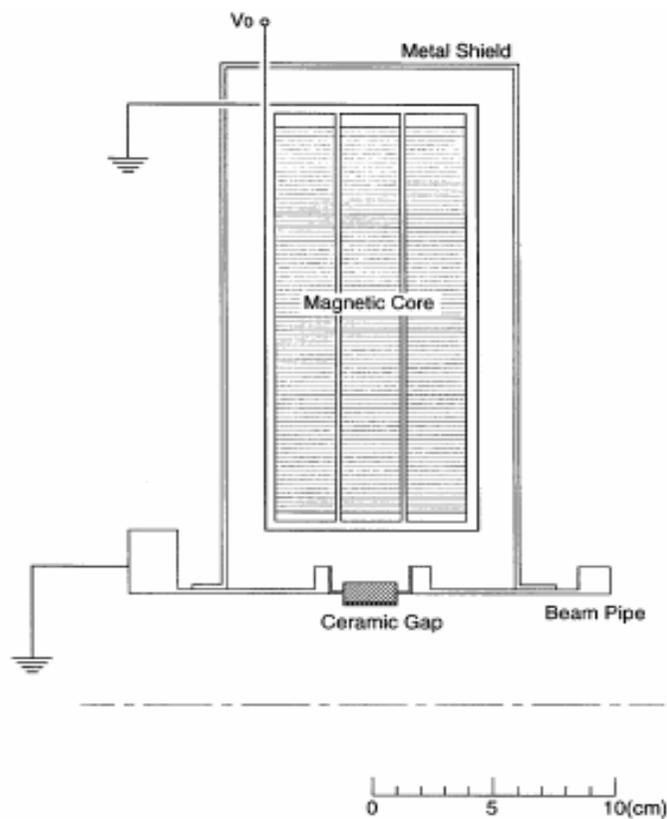
Hitachi Metals, Ltd. FM

Finemet Core (cont...)

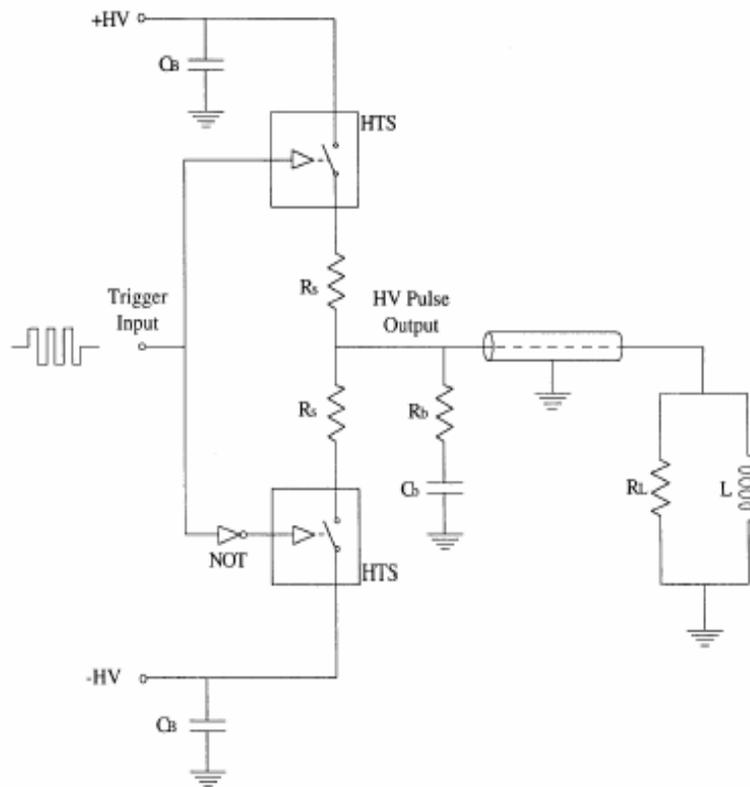


Finemet Cavity as a Chopper

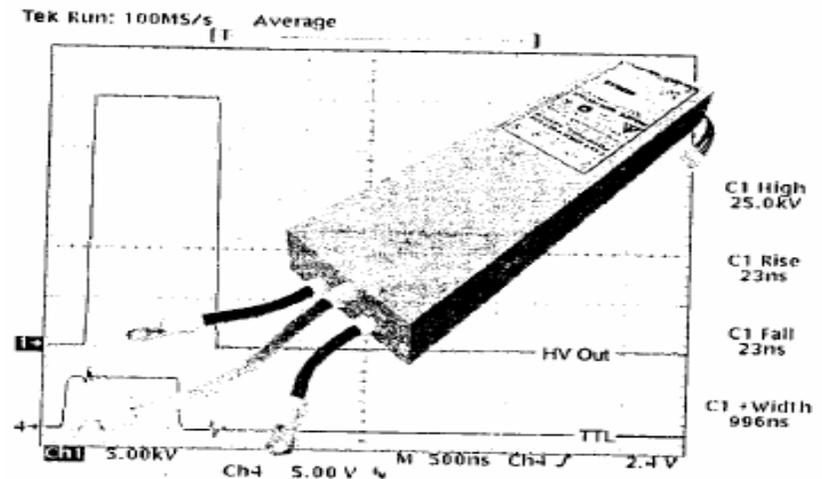
(installed on the linac of HIMAC in Chiba)



High Voltage Fast Switch



HTS 161-06-GSM 2x16kV / 60A
HTS 301-03-GSM 2x30kV / 30A



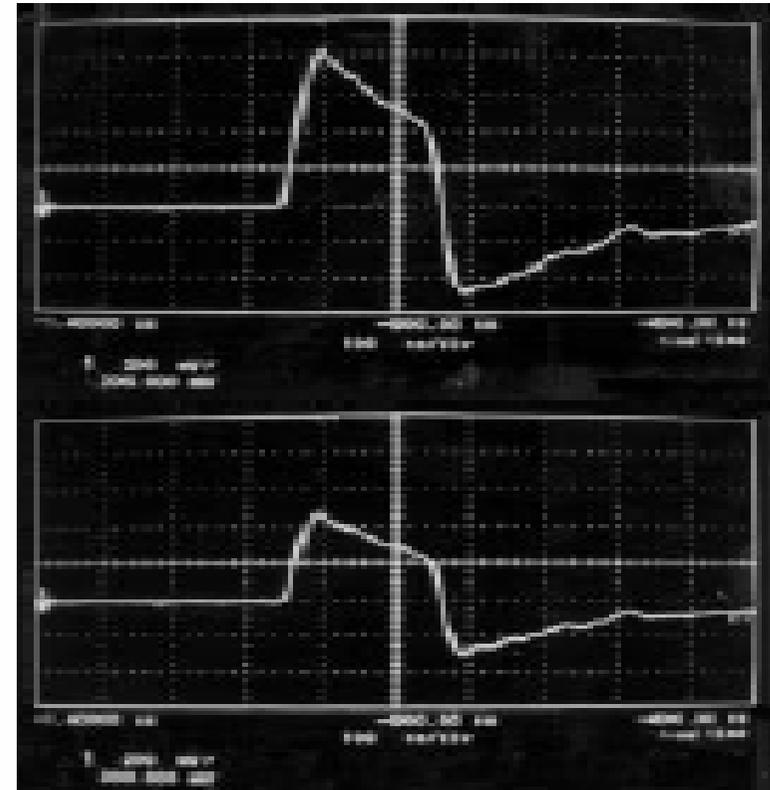
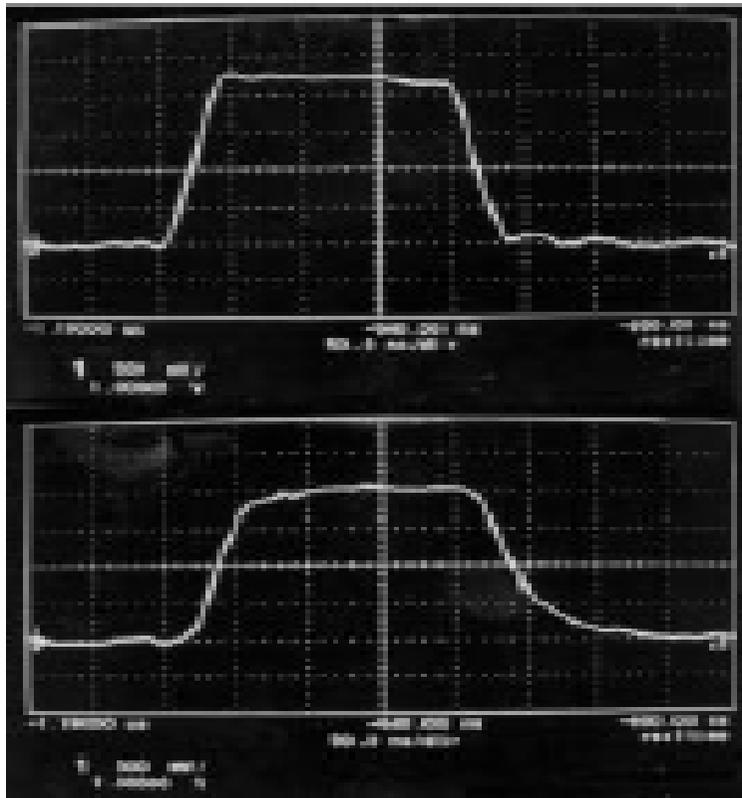
- Fast transition times, rise time and fall time ~20 ns
- Variable pulse width from 200 ns to infinity
- No pulse droop and very low ripple on the pulse top
- No working resistor power, small buffer capacitors

PUSH-PULL

- Patented -
Made in Germany

MOSFET
TECHNOLOGY

Finemet vs. Ferrite (4M2)



Finemet Core Specs

- ◆ OD = 500 mm
- ◆ ID = 139.8 mm
- ◆ t = 25 mm
- ◆ Stainless steel mandrel OD = 139.8 mm
- ◆ Stainless steel mandrel ID = 133 mm
- ◆ t (mandrel) = 3.4 mm
- ◆ Inductance = 56 μH (per core)
- ◆ Resistance = 190 Ω (per core)

Switch Specs

- ◆ Operation peak voltage = ± 6 kV
- ◆ Operation peak current = 13 A
- ◆ HTS 161-06-GSM switch specs:
 - Max peak voltage = $\pm 2 \times 8$ kV
 - Max peak current = 2×60 A
 - Max burst frequency = 2 MHz
 - Rise and fall time = 20 ns
 - Min pulse width = 200 ns
 - Min pulse spacing = 400 ns

Summary

- ◆ Barrier RF for beam stacking is another application of induction devices in accelerators
- ◆ Unlike an acceleration RF, the barrier RF has following features: high peak voltage, high peak current, burst mode operation, low duty factor
- ◆ Finemet cores and HTS switches can meet the requirements
- ◆ A barrier RF system is being built at Fermilab



Questions?