Recent RF Development at Fermilab

Weiren Chou and Akira Takagi
Fermilab, U.S.A.
July 7, 2003

Presentation to the FFAG03 Workshop
July 7-12, 2003, KEK

Outline

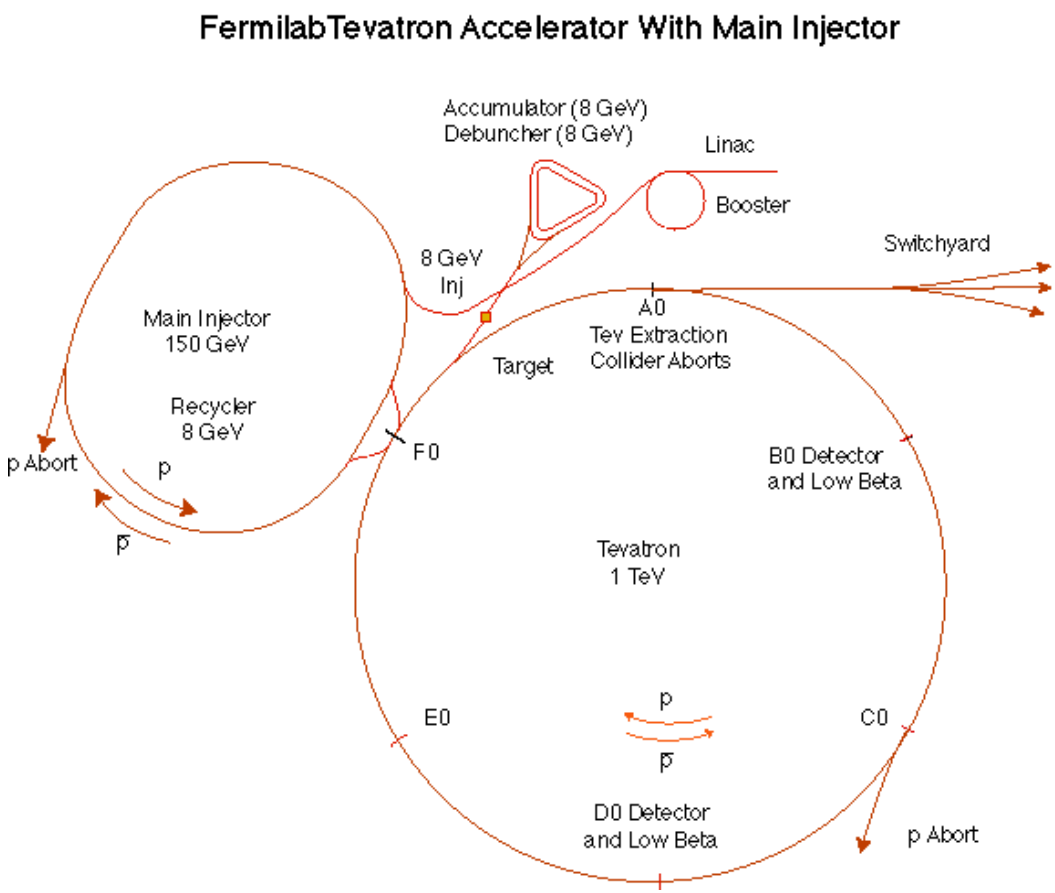
(1) Barrier RF (wideband RF) and stacking

(2) High gradient RF

(1) Barrier RF and Stacking

- Motivation
- Method
- Simulations (K.Y. Ng)
- Barrier RF system and bench test

Fermilab Accelerator Complex

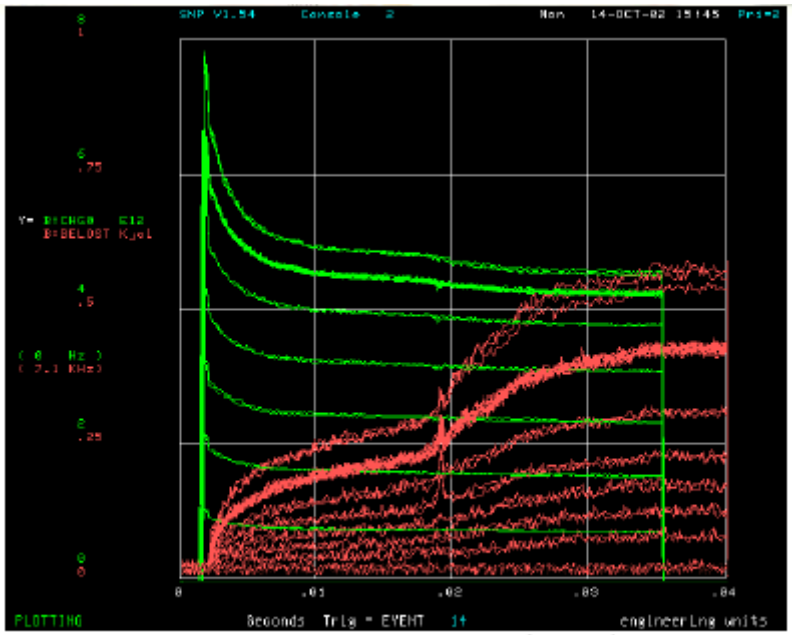


Booster – the Bottleneck

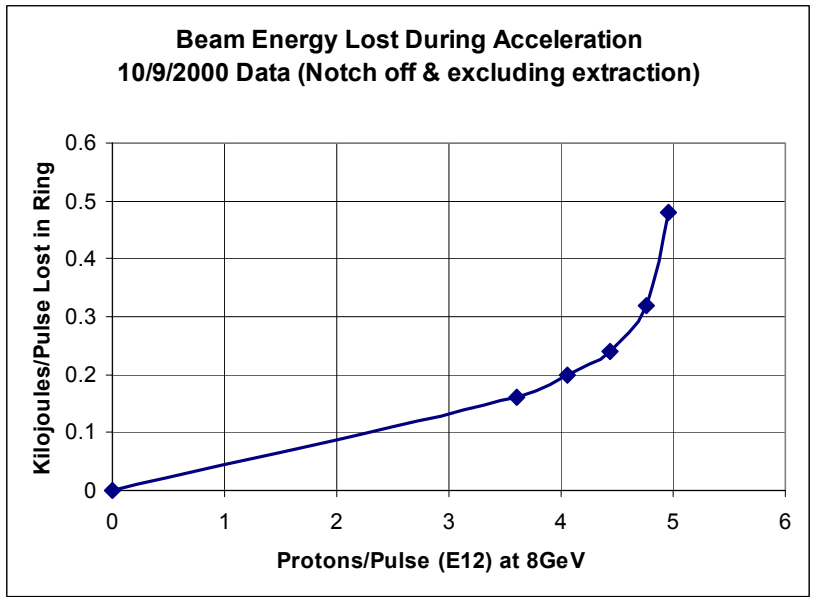
- The Booster is a 30 years old machine and has never been upgraded.
- The 400-MeV Linac can provide 25e12 particles per Booster cycle.
- The 120-GeV Main Injector can accept 25e12 protons per Booster cycle.
- However, the 8-GeV Booster can only deliver 5e12 particles per cycle.

Booster Beam Loss

(courtesy R. Webber)



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



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 beam emittance (0.1 eV-s)

Stacking Goals

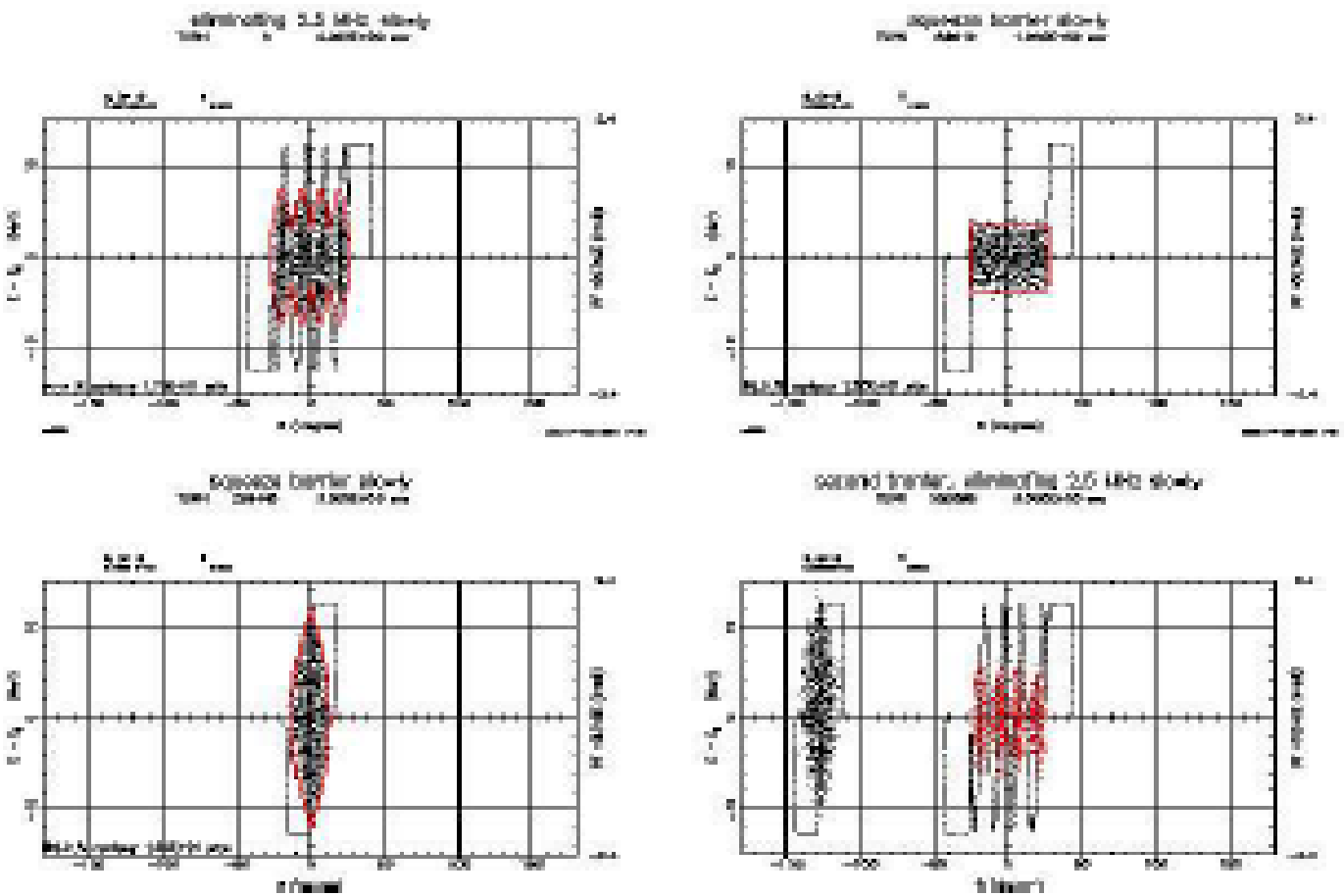
- Goal for Run2 – To increase protons per second (pps) on the pbar target by 50%
  - Baseline: 5e12 every 1.467 sec
  - Goal: 2 x 5e12 every 2 sec
- Goal for NuMI – To increase pps on the NuMI target by 60%
  - Baseline: 3e13 every 1.867 sec
  - Goal: 2 x 3e13 every 2.333 sec

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

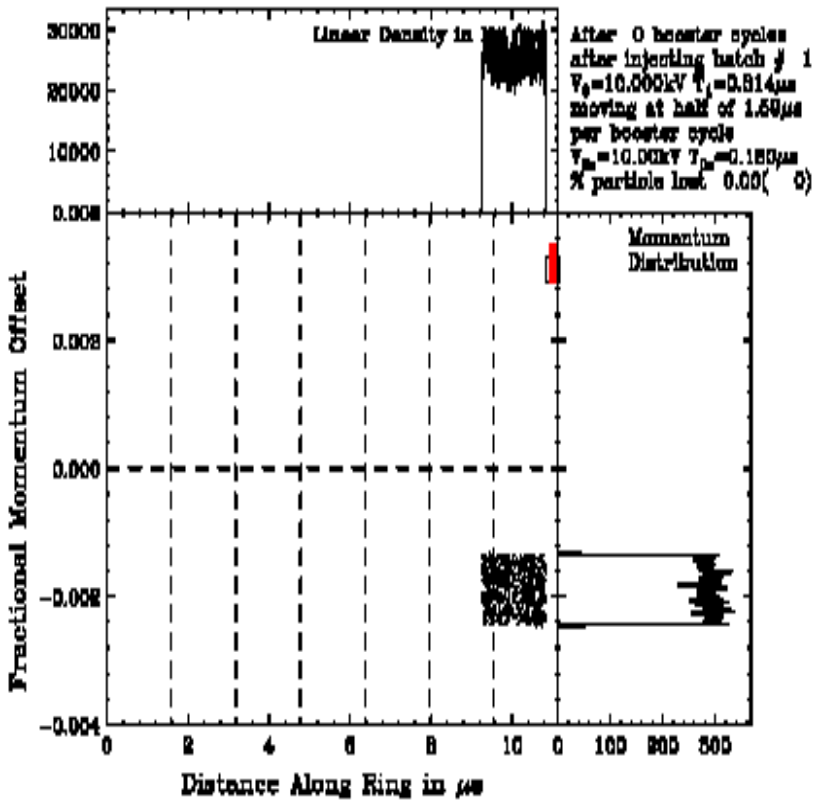
Injection On-Axis

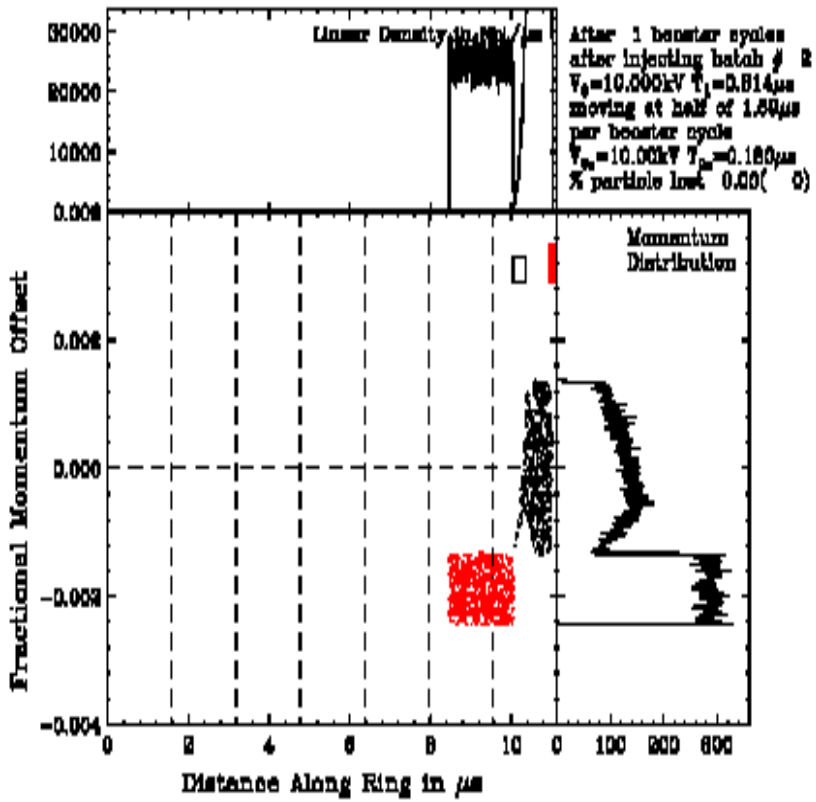
(Recycler, courtesy C. Bhat)



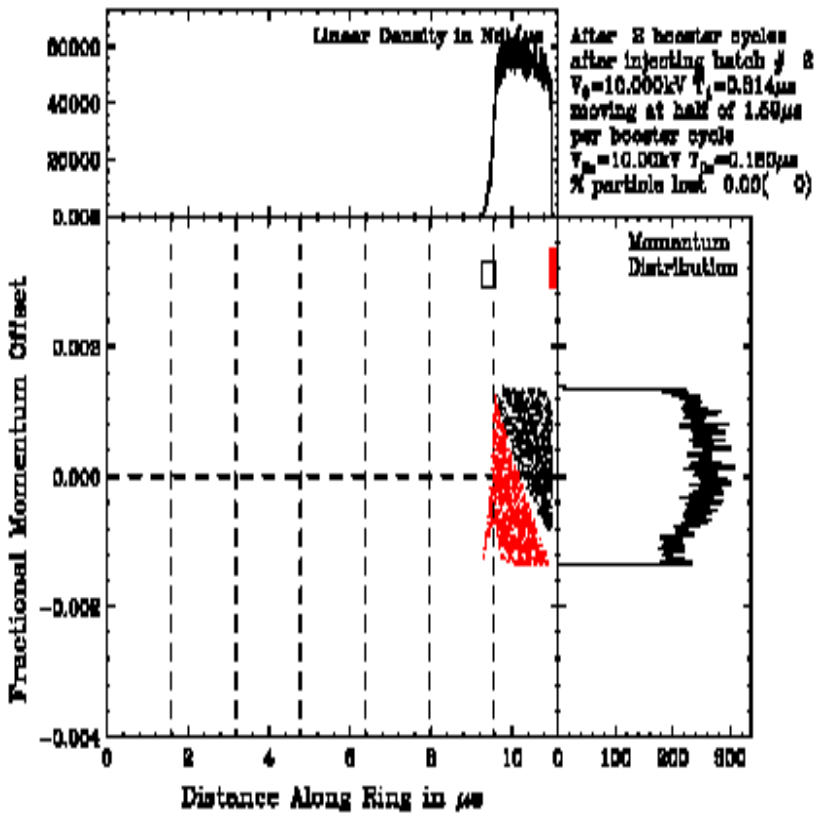
Injection Off-Axis: 2-Batch Stacking

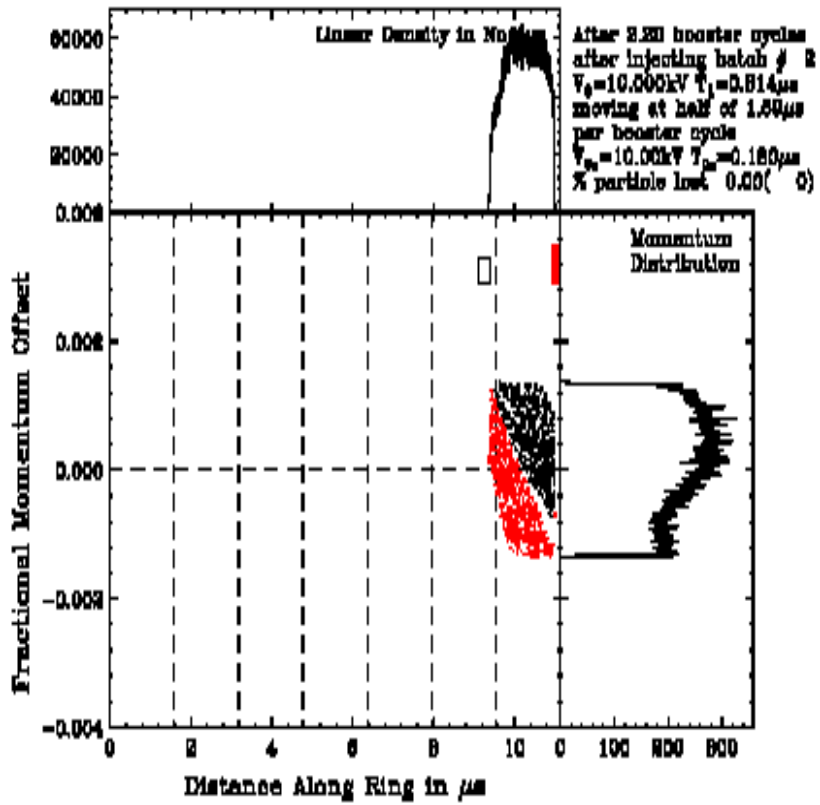
(courtesy K.Y. Ng)





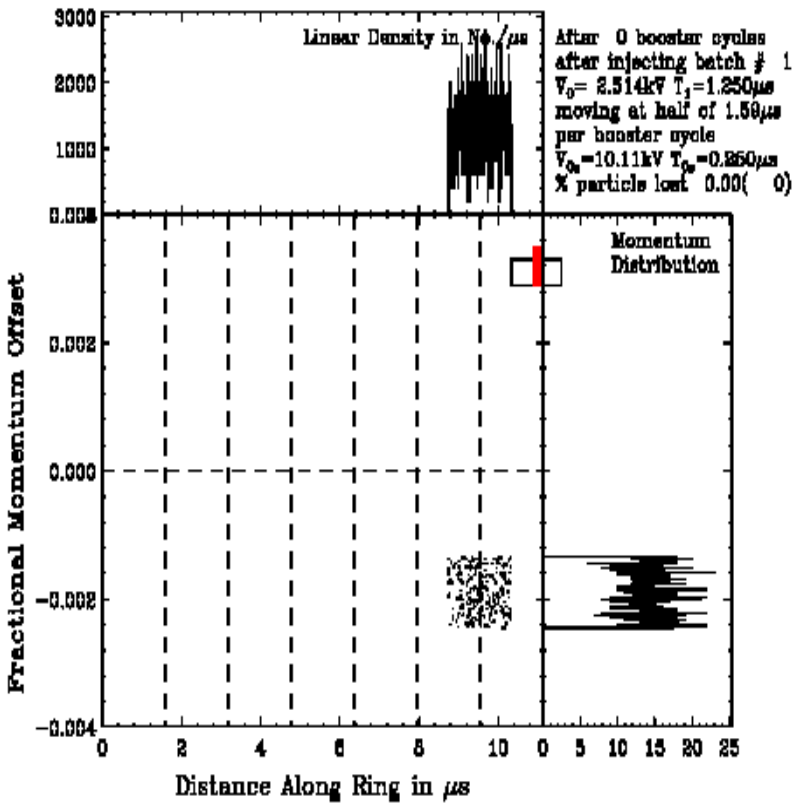
2-Batch Stacking
(cont…)

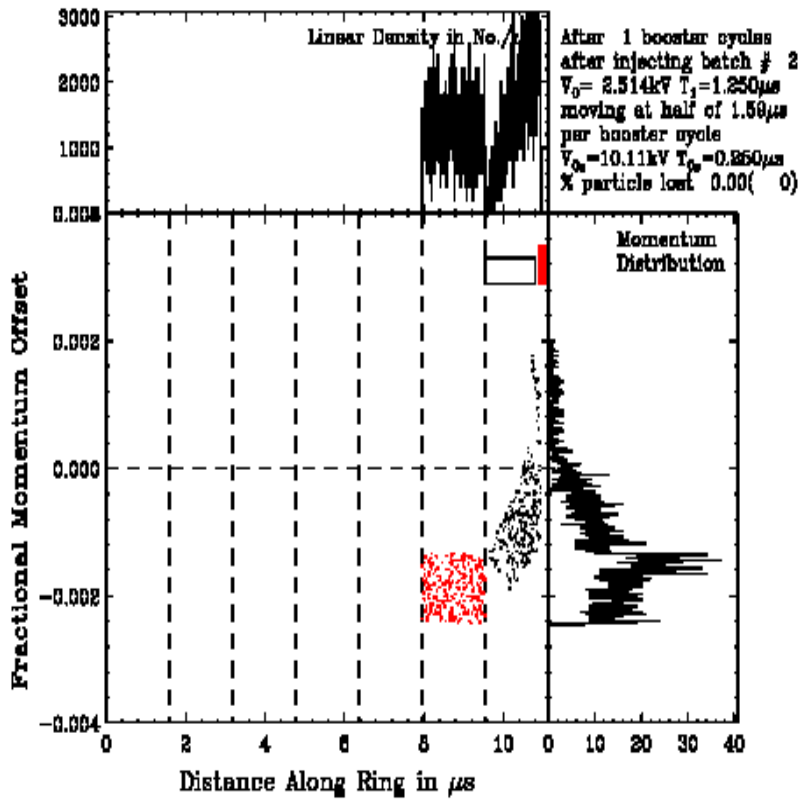




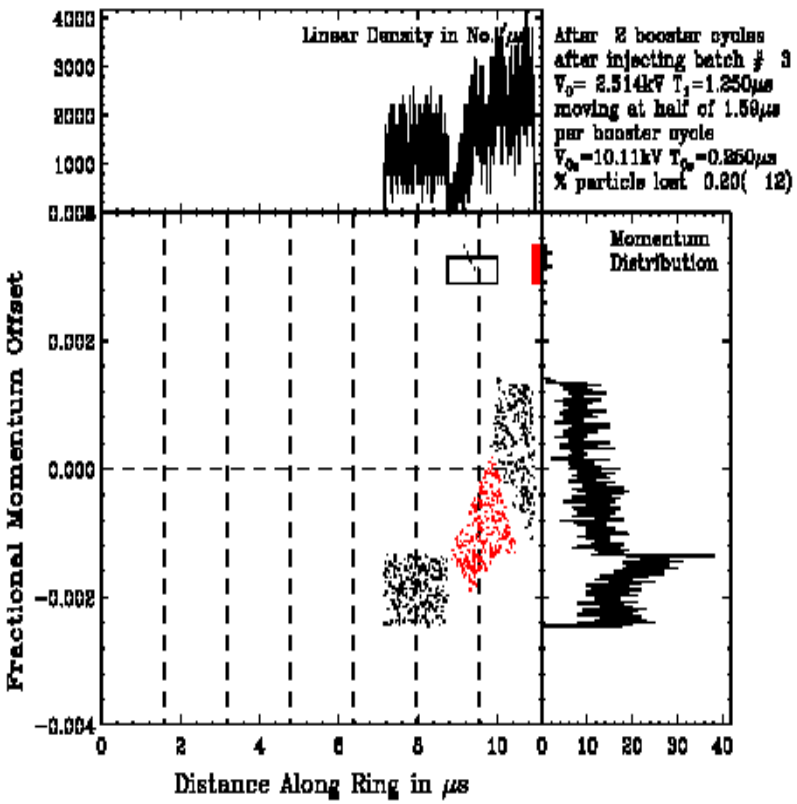
Injection Off-Axis: 12-Batch Stacking

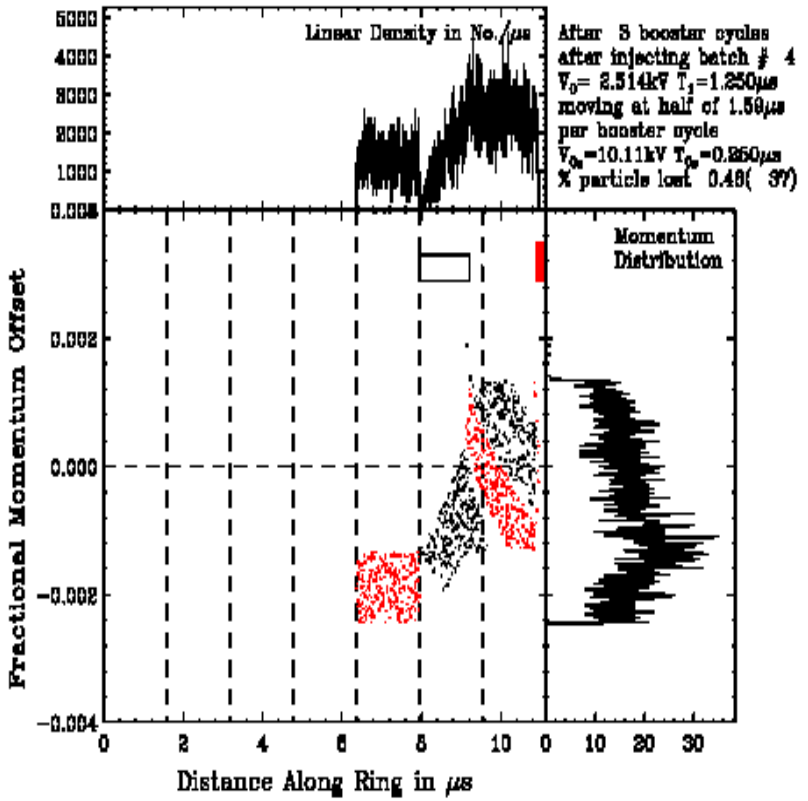
(courtesy K.Y. Ng)



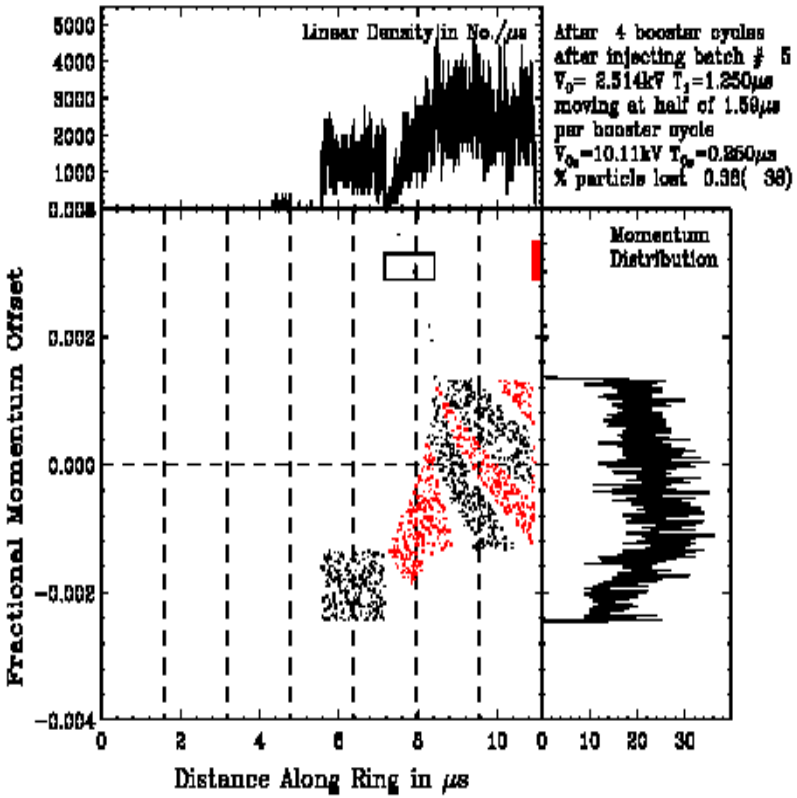


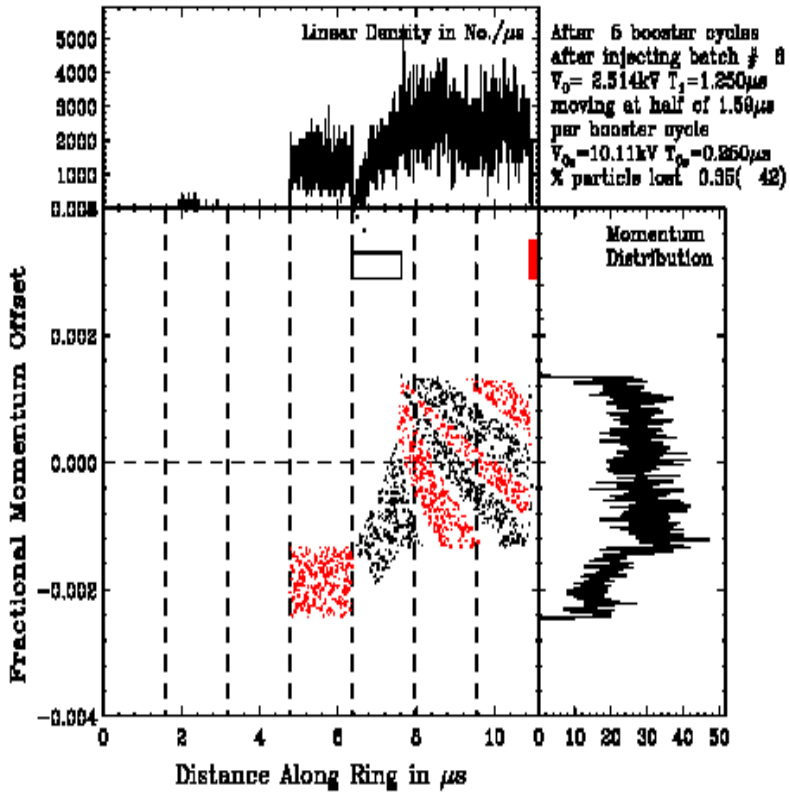
12-Batch Stacking
(cont…)



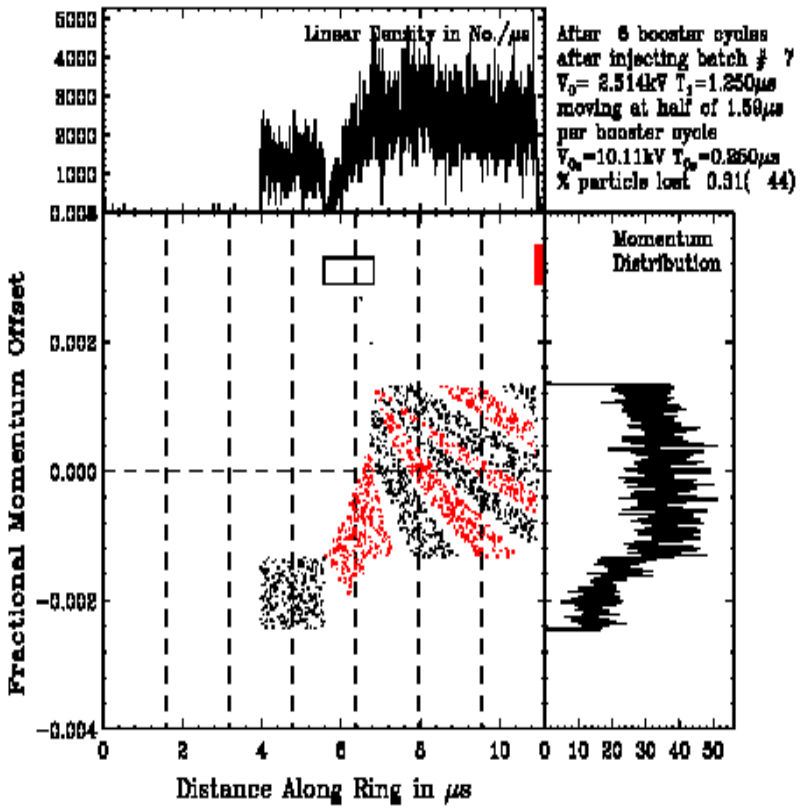


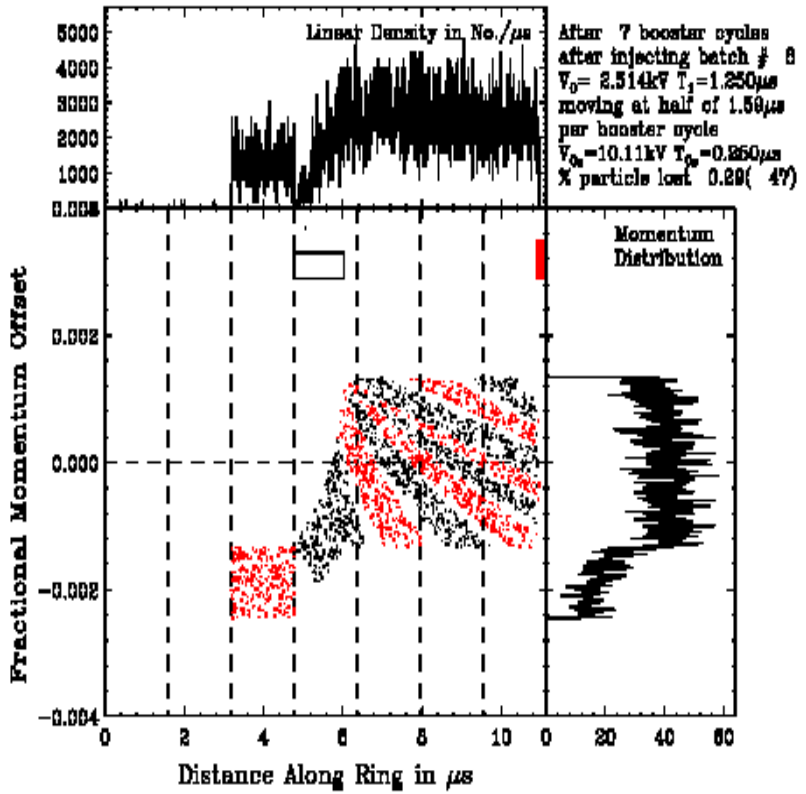
12-Batch Stacking
(cont…)



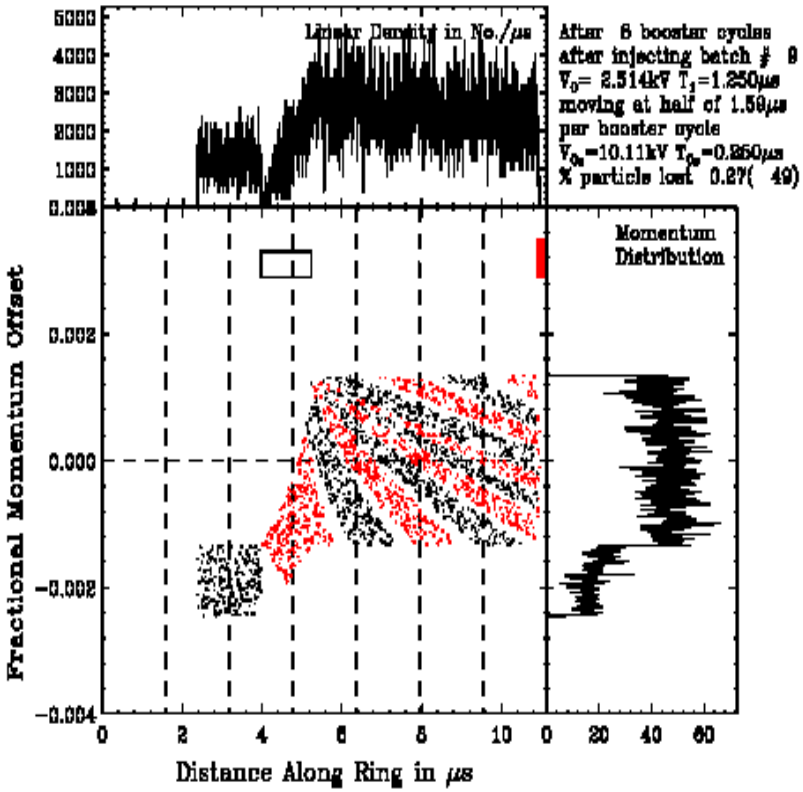


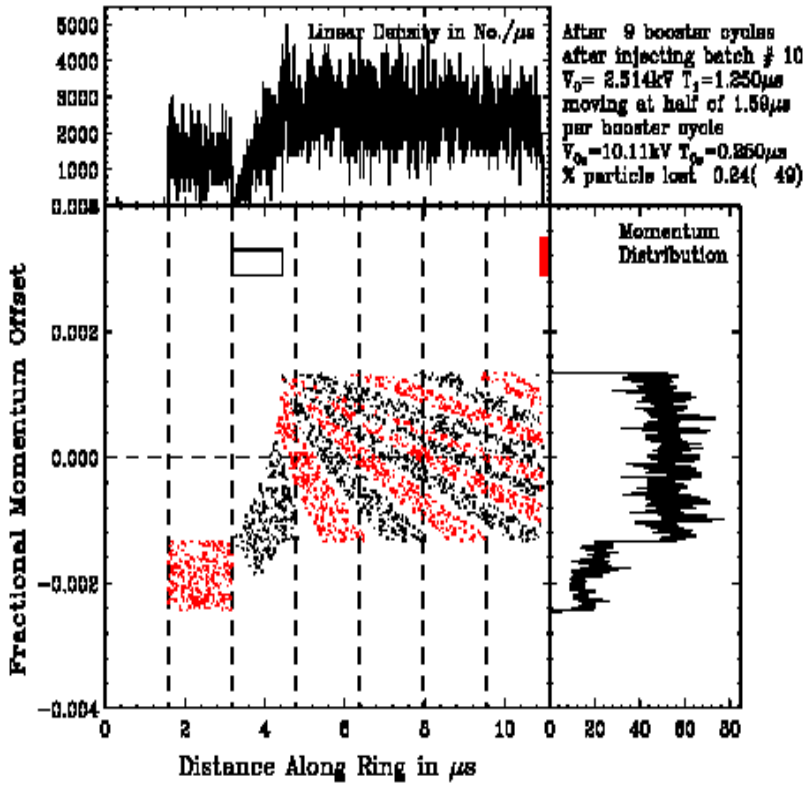
12-Batch Stacking
(cont…)



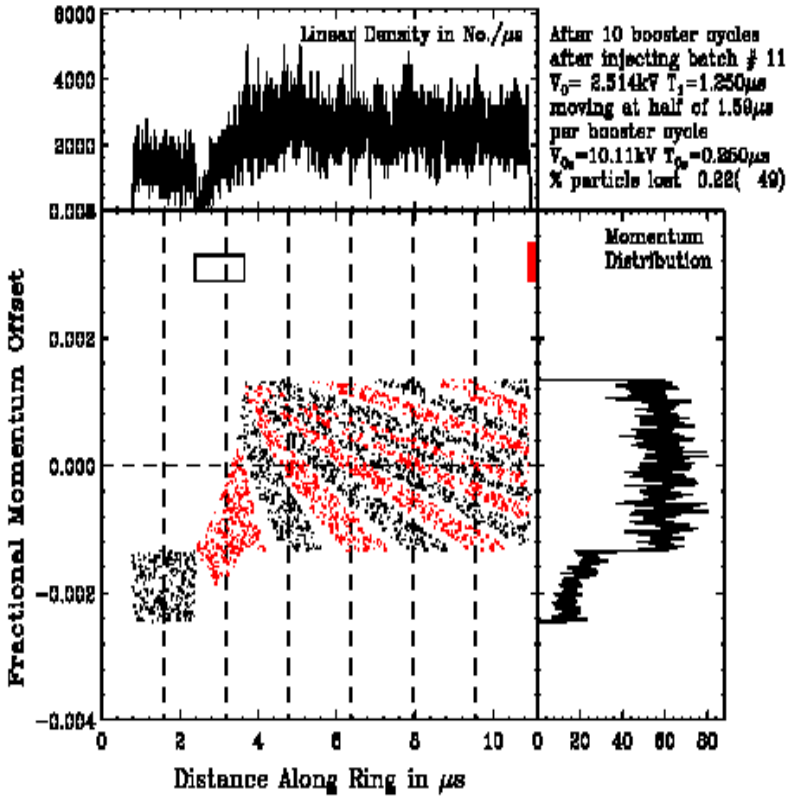


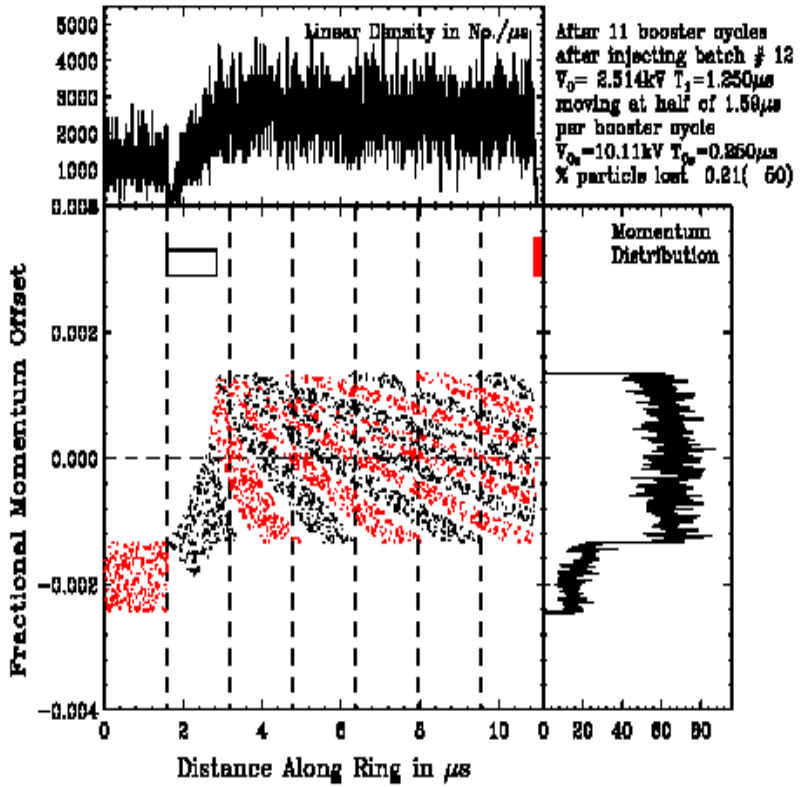
12-Batch Stacking
(cont…)



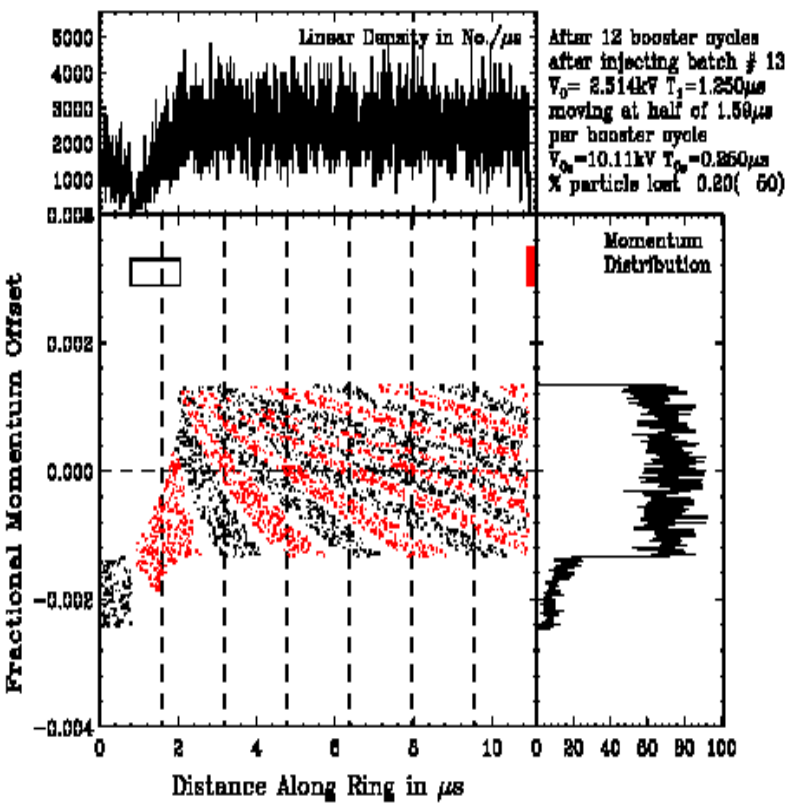


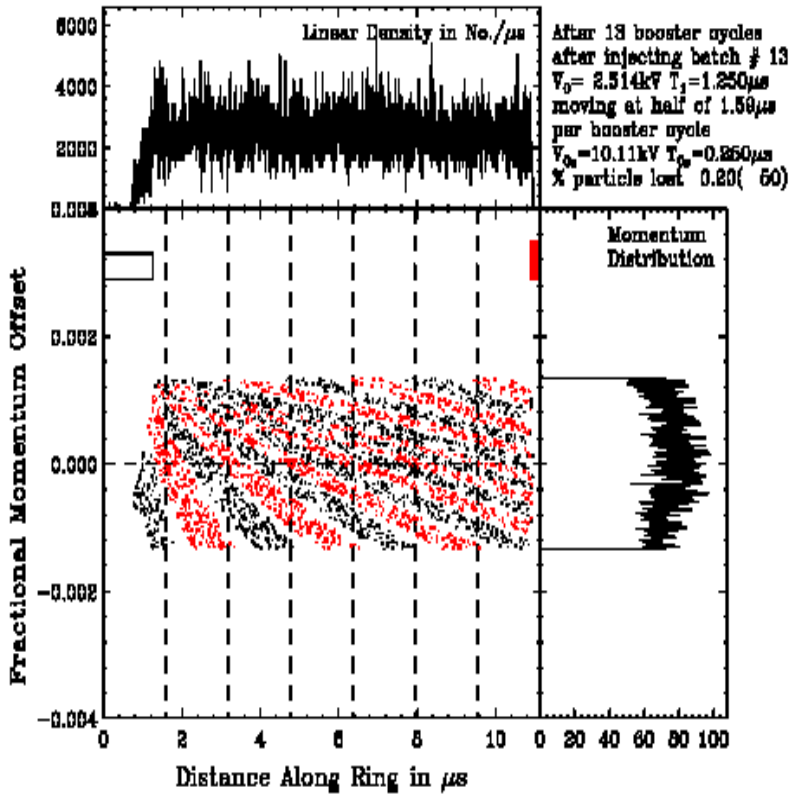
12-Batch Stacking
(cont…)

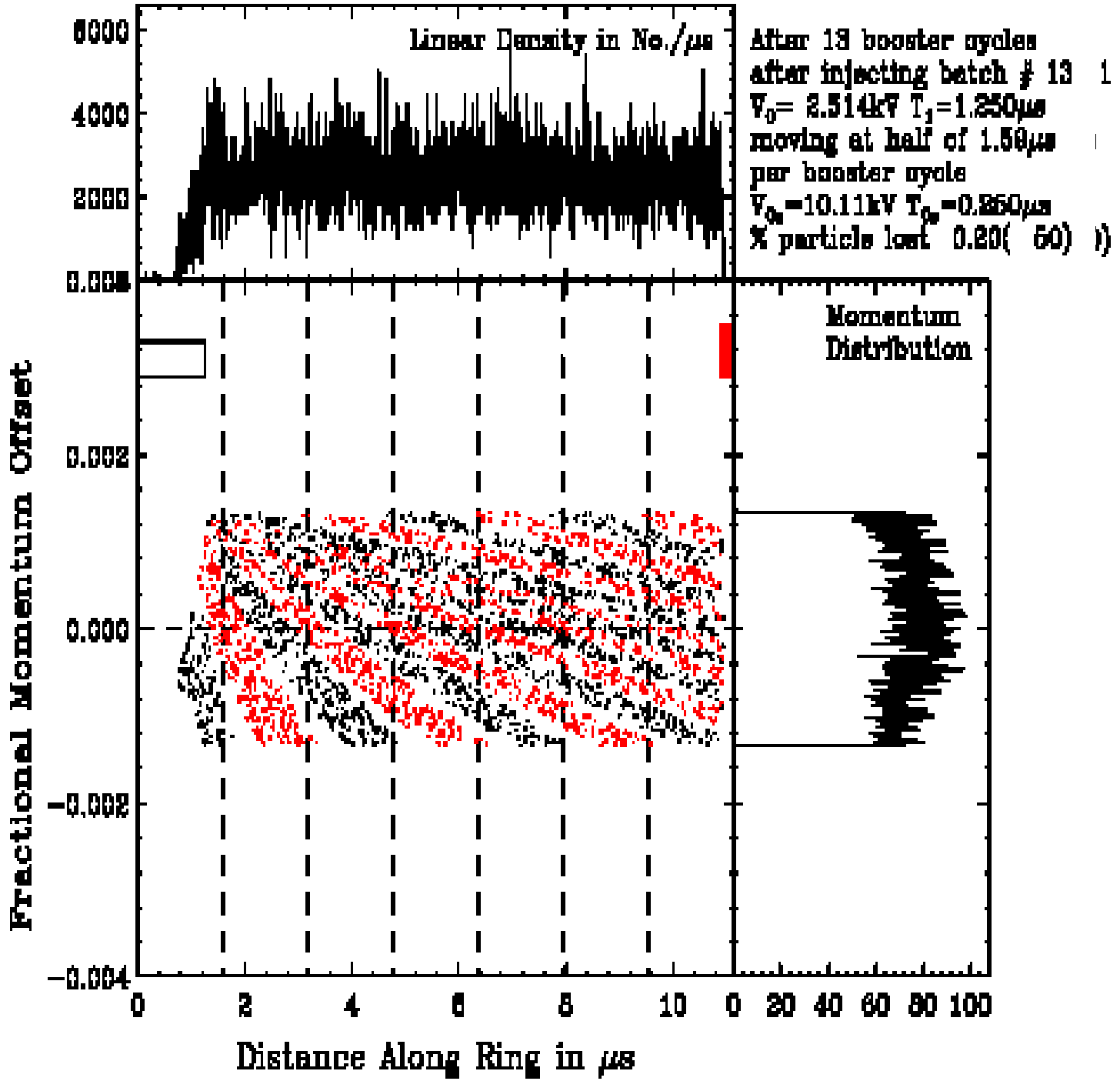




12-Batch Stacking
(cont…)





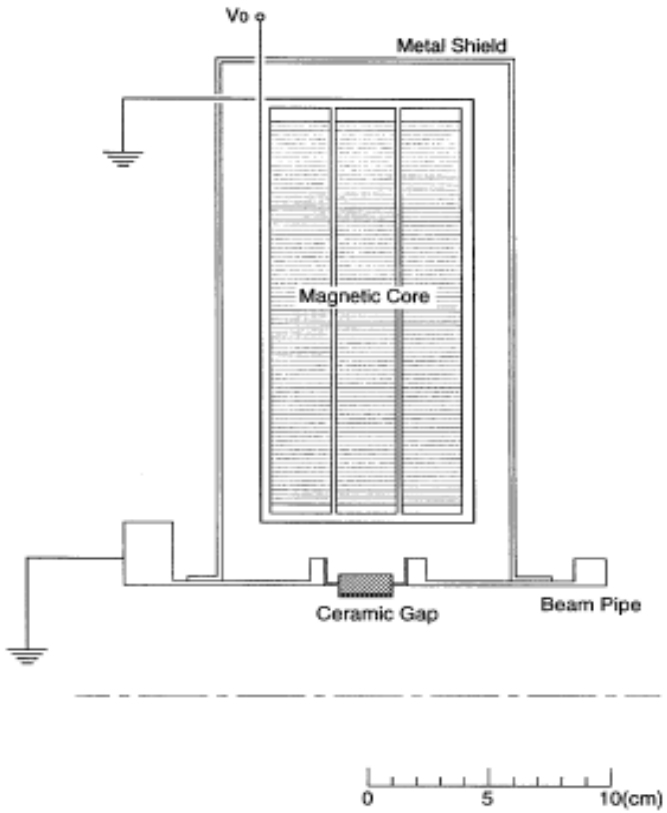

Linear Density in No./μs
6000
4000
2000
0.000
After 13 booster cycles
after injecting batch # 13 1
V0= 2.514kV T1=1.250μs
moving at half of 1.58μs
per booster cycle
V0=10.11kV T0=0.250μs
% particle lost 0.20(60))
Momentum
Distribution
0.002
0.000
−0.002
−0.004
Fractional Momentum Offset
0
2
4
6
8
10
0
20
40
60
80
100
Distance Along Ring in μs

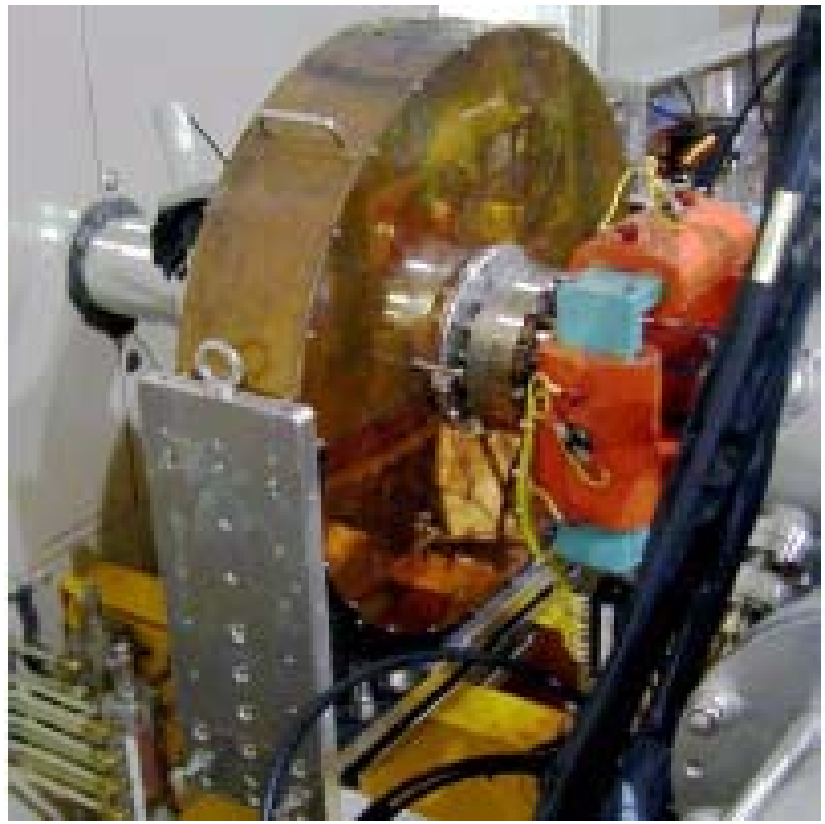
Hardware

- Task: To build a $\pm$ 6 kV wideband RF system (i.e, the barrier RF)
- Cavity: Based on the design of an RF chopper built at Chiba by a KEK-Fermilab team; using Finemet cores made by Hitachi Metals
- Switch circuit: Also based on the design of the RF chopper; using high voltage solid-state switches made by Behlke Co. (Germany)

Finemet Cavity as a Chopper

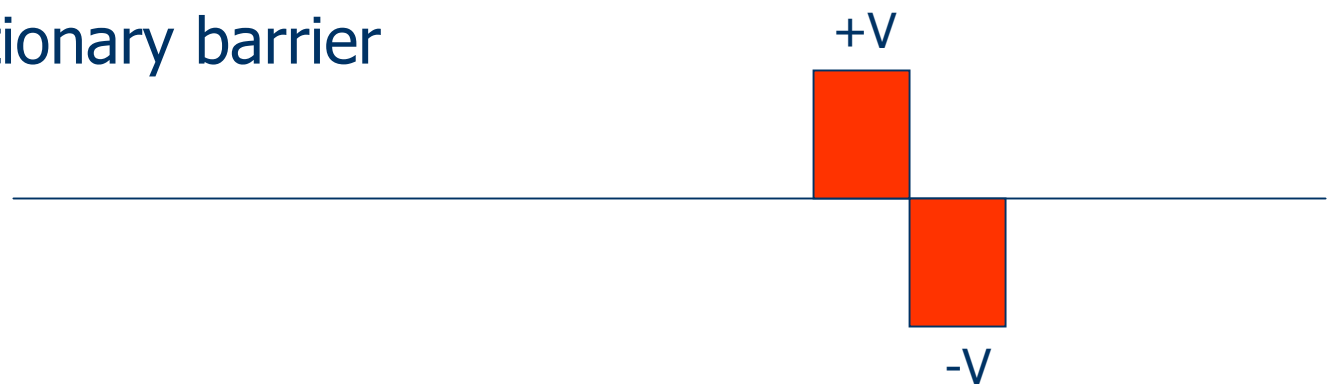
(installed on the linac of HIMAC in Chiba)



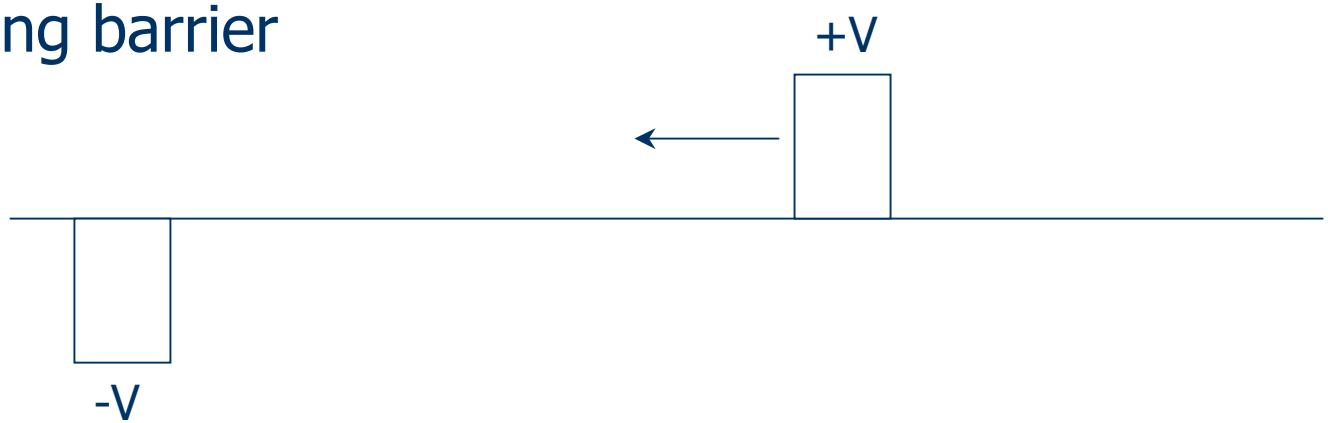


Two Types of Barrier

Stationary barrier

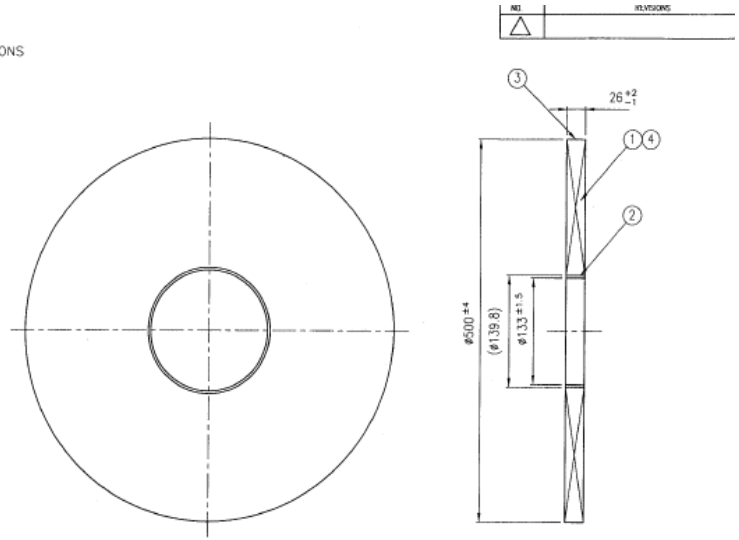


Moving barrier



Finemet Core

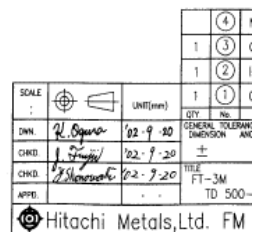
DIMENSIONS
外観寸法



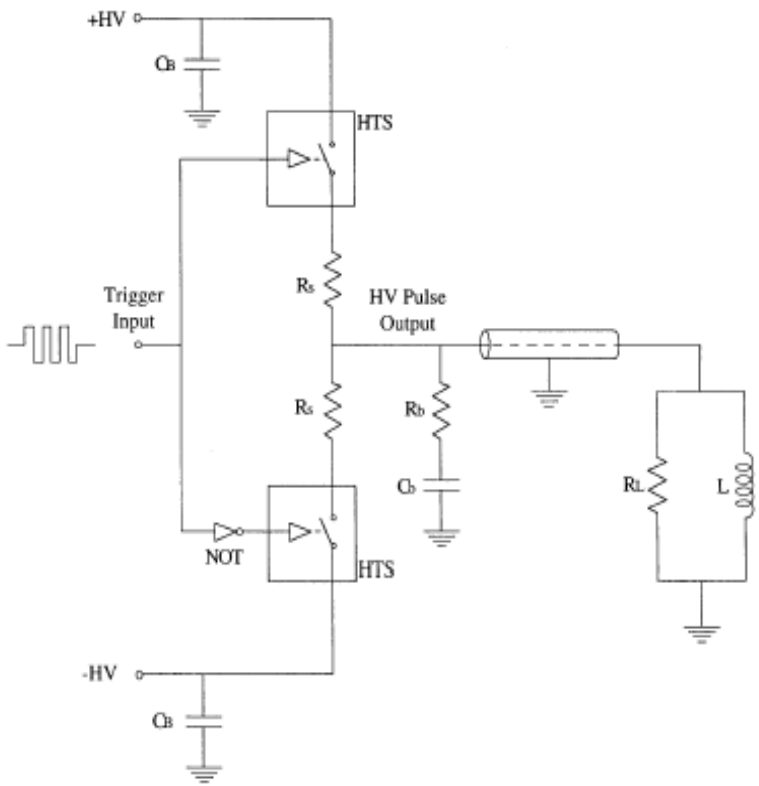
ELECTRICAL CHARACTERISTICS
電気特性

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

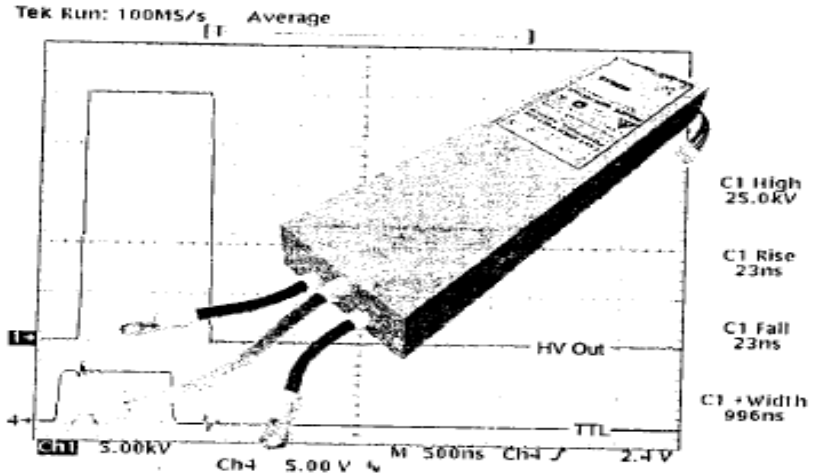
EQUIPEMENT :LCR METER HP-4284A or EQUIVALENT
CONDITION :0.5Vrms
MEASURING MODE: SERIES MODE



High Voltage Fast Switch



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

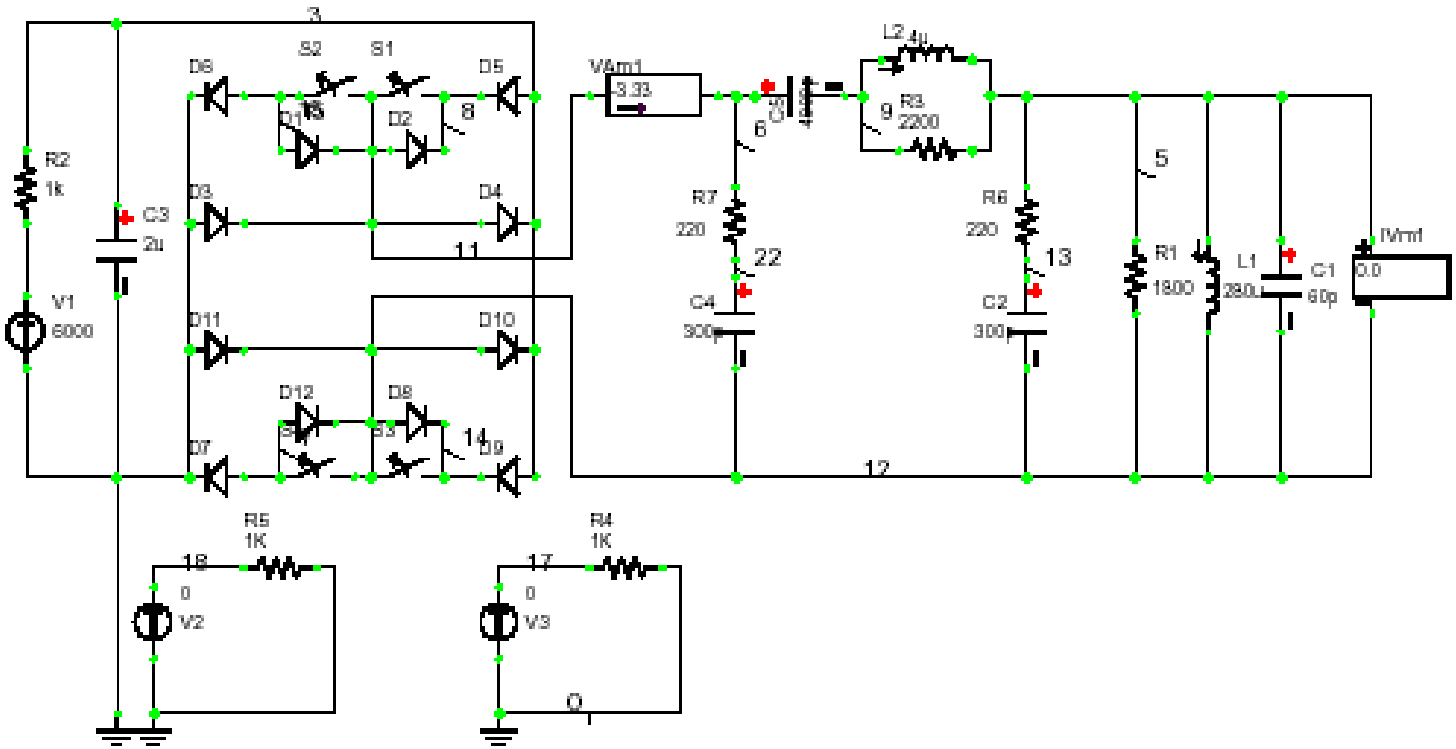


- Fast transition times, rise time and fall time ~20 ns
- Variable pulse width from 200 ns to infinity
- No pulse droop and very low ripple on the pulse top
- No working resistor power, small buffer capacitors

PUSH-PULL - Patented - Made in Germany MOSFET TECHNOLOGY

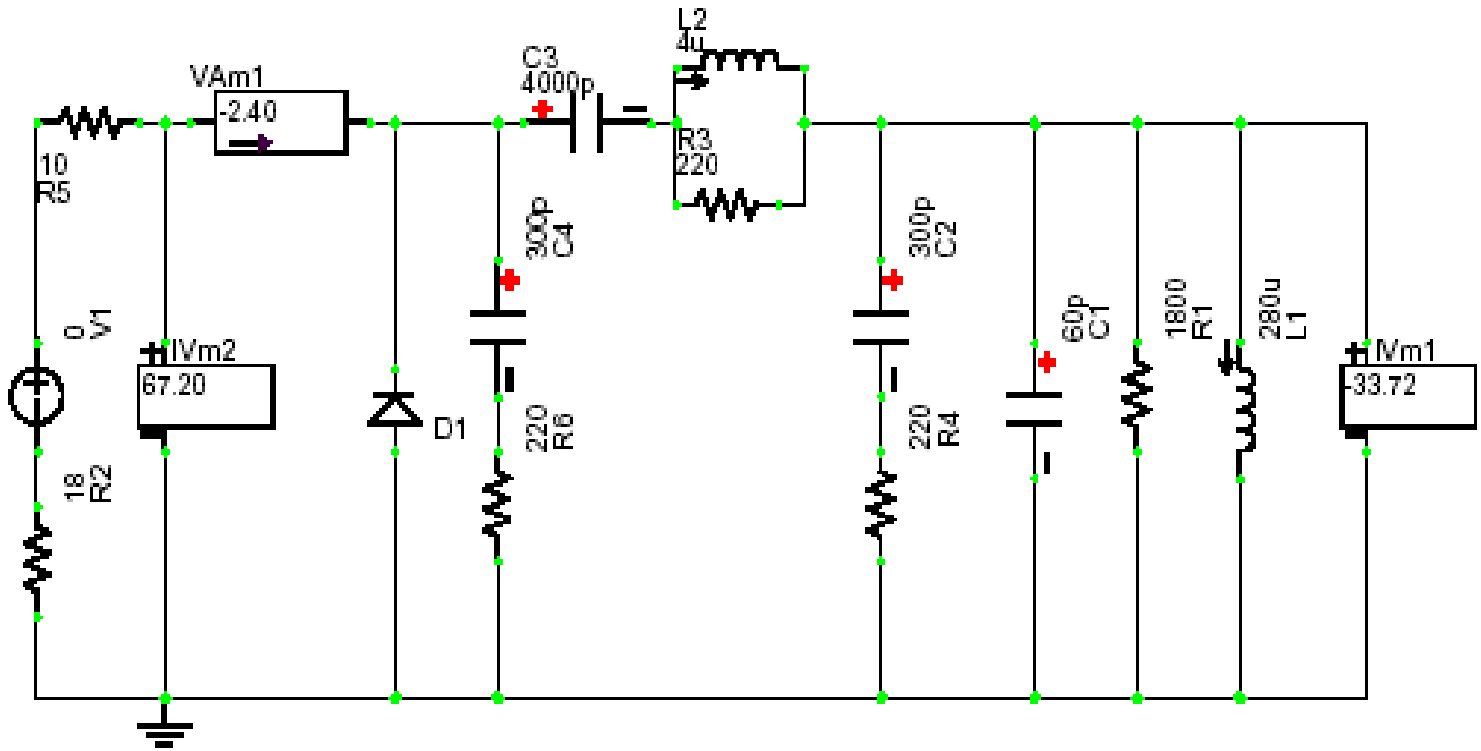
Design Circuit Diagram

Full-bridge push-pull, bipolar pulse



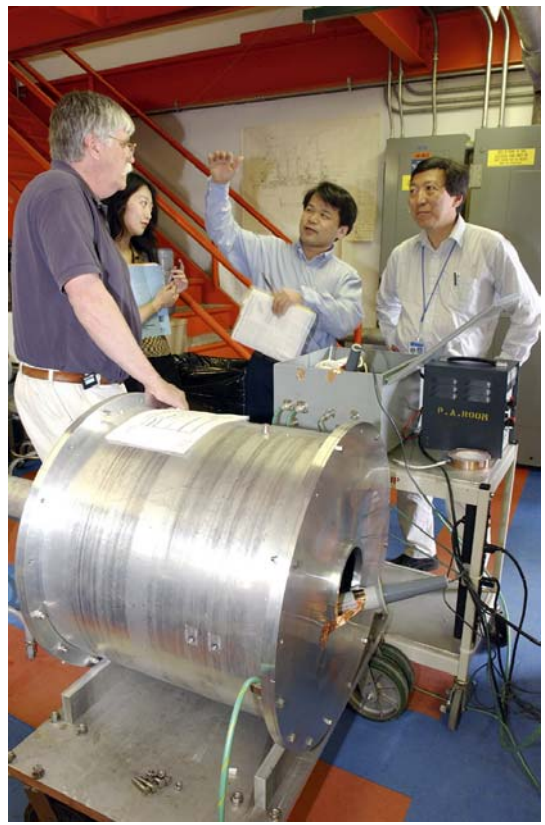
Test Circuit Diagram

One push-pull, mono polar pulse

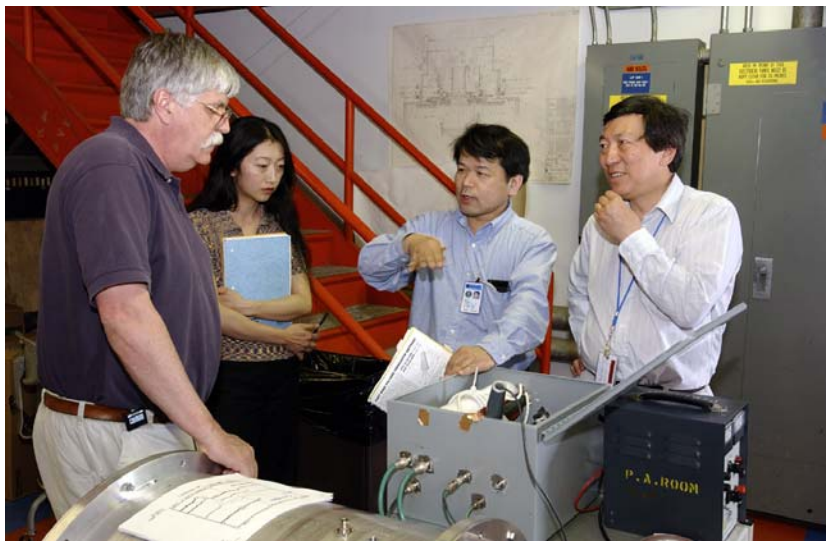


Building a Barrier RF System

A Fermilab-KEK-Caltech team

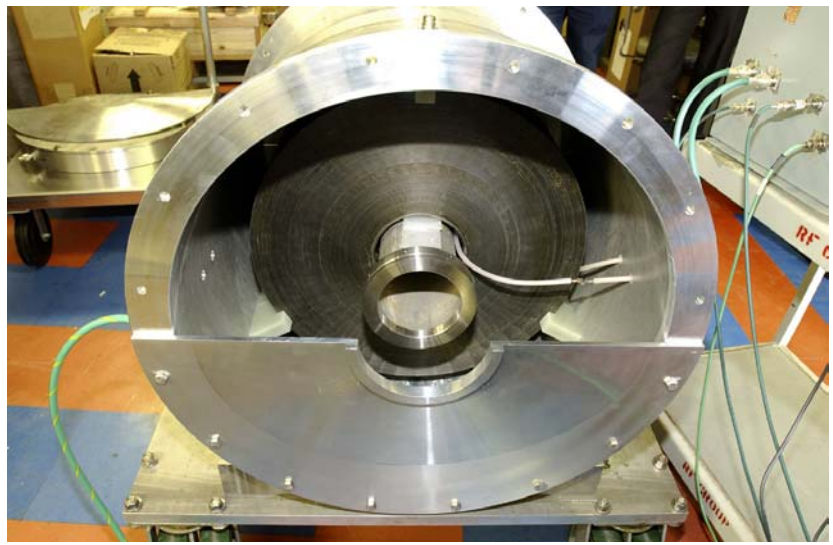


Building a Barrier RF System
(cont…)



Barrier RF power supply

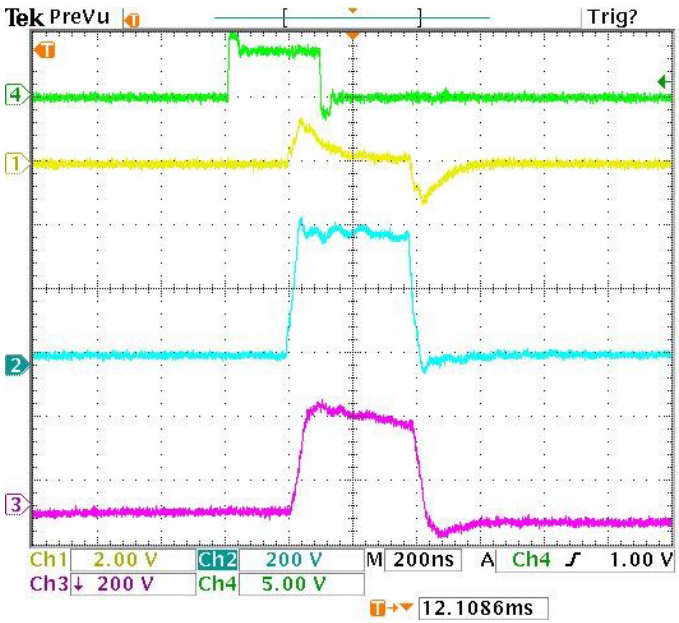
Building a Barrier RF System
(cont…)



Barrier RF cavity

Testing a Barrier RF System

One barrier



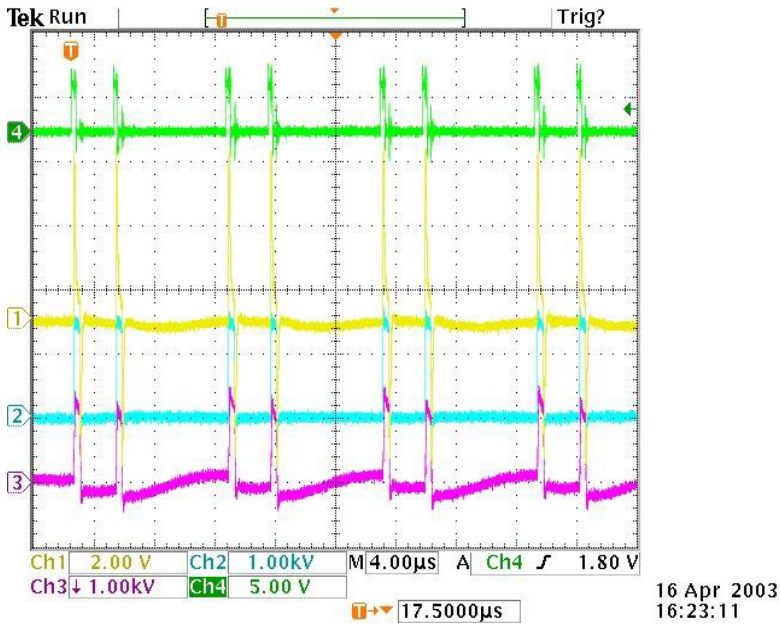
trigger

current

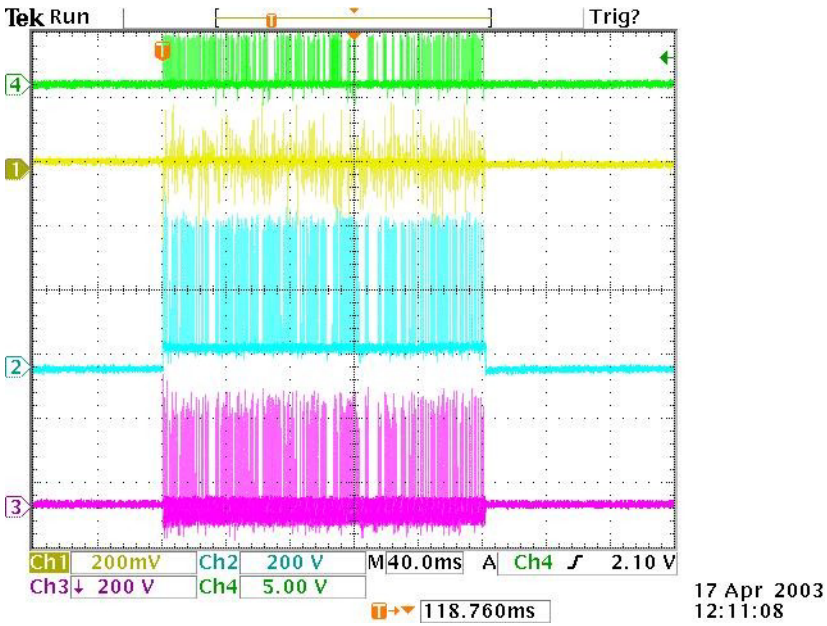
primary voltage

gap voltage

Two barriers per MI period



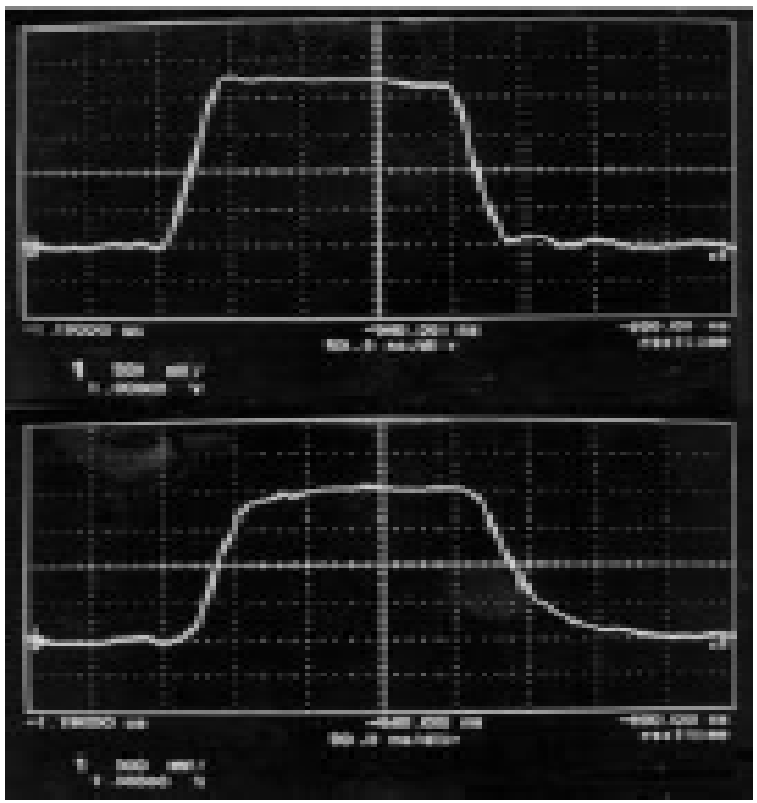
Testing a Barrier RF System
(cont…)

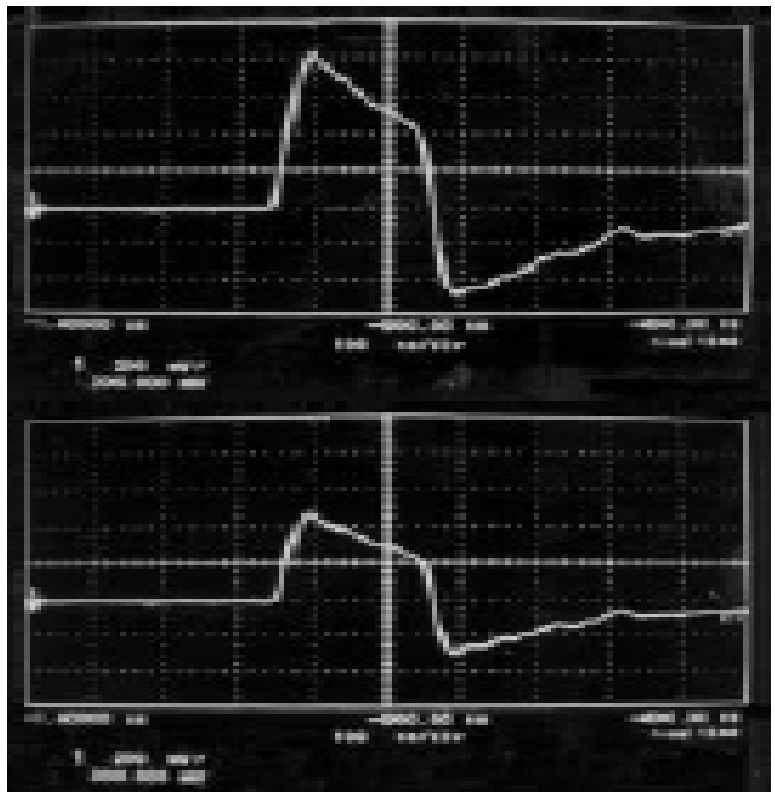


Burst length

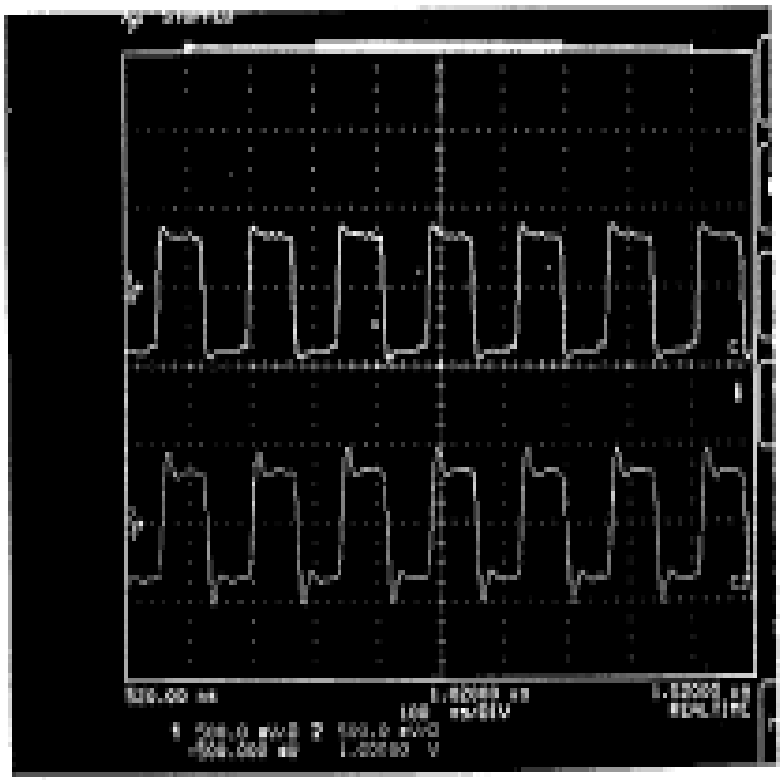
- The required burst length is 150 ms (2.2 Booster cycles); achieved 200 ms.
- The required peak voltage is 6 kV; achieved 4 kV.
- Waiting for two larger switches to raise the voltage to 6 kV.

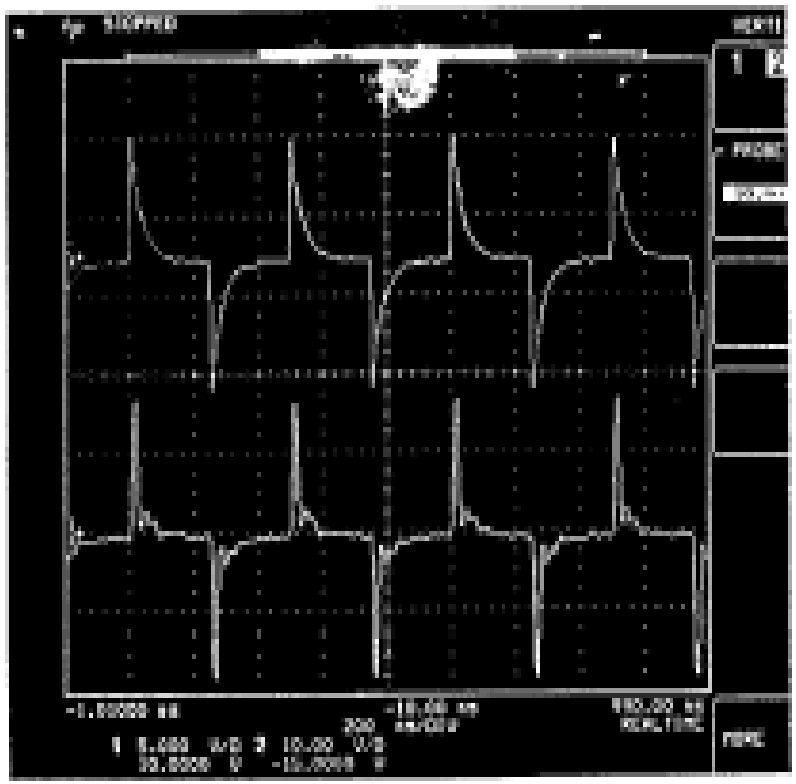
Finemet *vs.* Ferrite (4M2)





Finemet *vs.* Ferrite (4M2)
(cont…)





(2) High Gradient RF

- Goal:

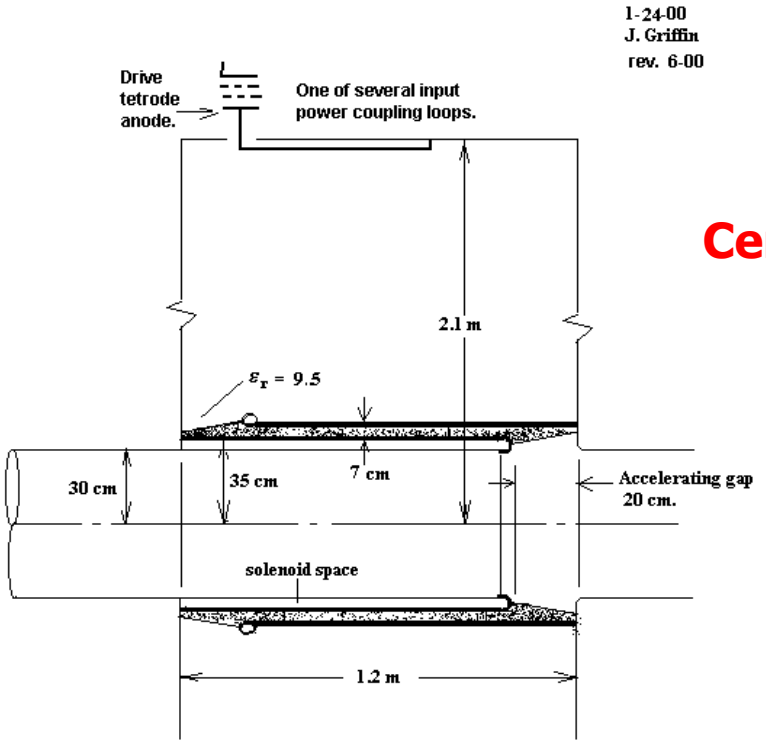
  To provide 0.5-1 MV/m accelerating voltage at low frequency (7.5 MHz) for the purpose of:

  - FFAG-based muon phase rotator (the PRISM Project)
  - bunch rotation in high intensity proton rings.

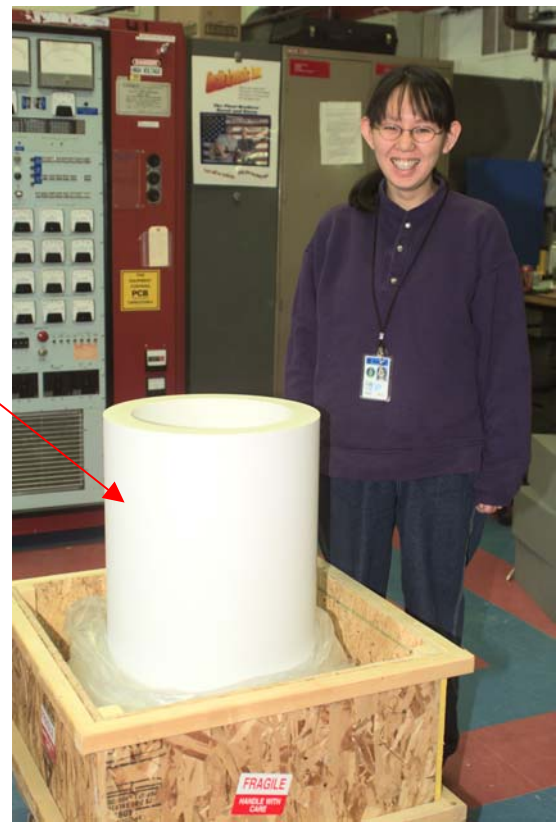
- Design types:

  - Air cavity (similar to CERN's AA cavity)
  - Ceramic loaded cavity (Fermilab)
  - Special ferrite (SY25) loaded cavity (KEK)

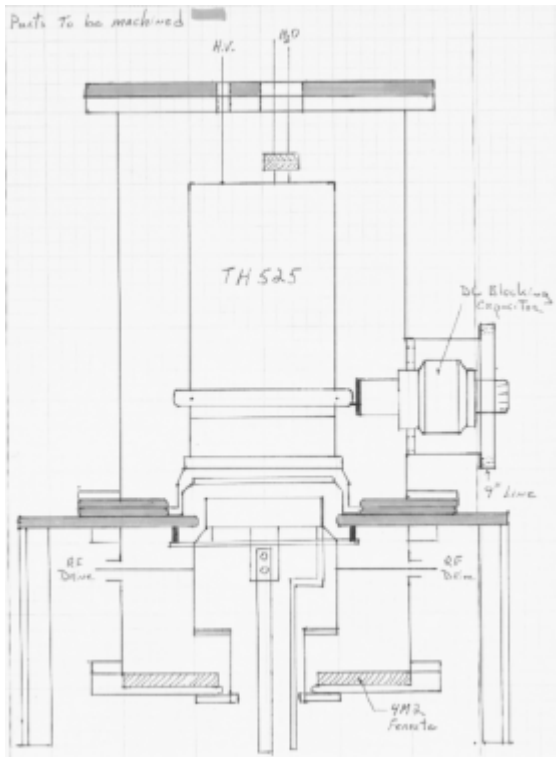
Cavity Sketch



Ceramic pipe



Power Amplifier



TH 525 tube ➡

3 MW, 7.5 MHz

Power Amplifier
(cont…)

Socket components

Power Amplifier
(cont…)

Power supply

50 Ω dummy load

Plan for Ceramic Loaded Cavity

- Phase 1: Design and fabricate a high power amplifier (3MW, 7.5 MHz)
  - 2 kW solid-state driver (purchased)
  - 200 kW driver (built)
  - 3 MW amplifier (under construction)
- Phase 2: Design and fabricate a ceramic loaded cavity
- Phase 3: Test different ceramic material and pipe design

Questions?