Barrier RF Systems in Synchrotrons

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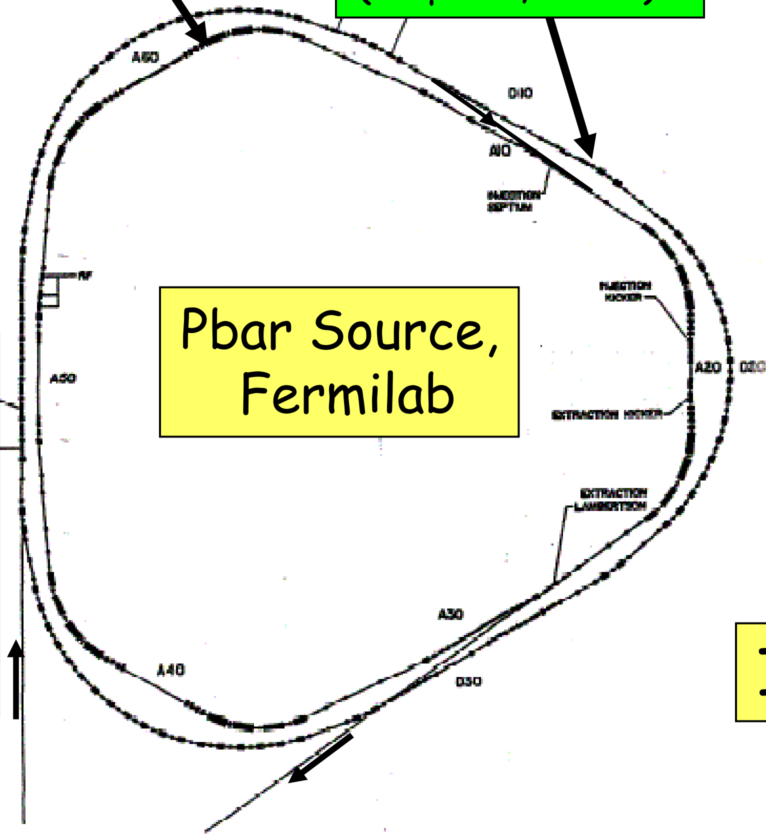
History of Barrier Buckets

Accumulator
(1.59μsec, h=84)

Debuncher
(1.7μsec, h=90)



Pbar Source, Fermilab

Pbars (1.59μsec)

Early stages of antiproton source at Fermilab demanded

1. The bunch length in the Debuncher and the Accumulator should be the same ß **Gap preservation in the Debuncher beam**
2. Necessity of using "**suppressed rf buckets**" during unstacking pbars from the Accumulator

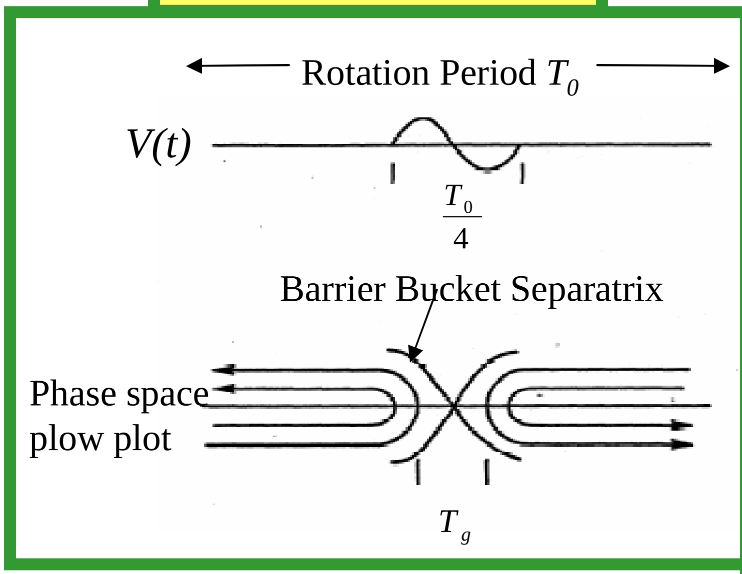
Invention of Barrier RF system

J. Griffin et. al. IEEE Transactions on Nuclear Science, Vlo. NS30 No. 4. 3502

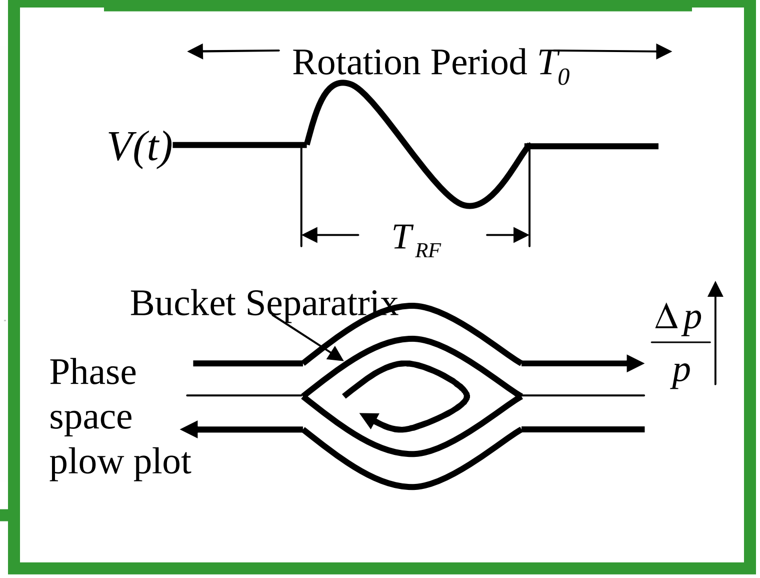
Barrier Buckets - Concepts

A barrier rf system is a broad-band rf system comprising of ferrite loaded rf cavities.

Gap Preserving barrier buckets



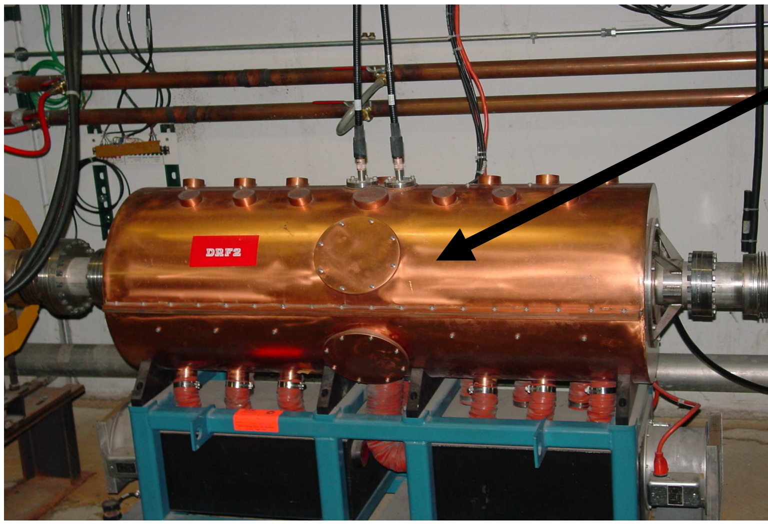
Isolated barrier buckets



$$V(t) = V_0 \frac{2h}{\pi} \sum_{n=0}^{\infty} \frac{Sin(n\pi / h)}{h^2 - n^2} \sin(n\omega t)$$

$$T_0 = h T_{RF}$$

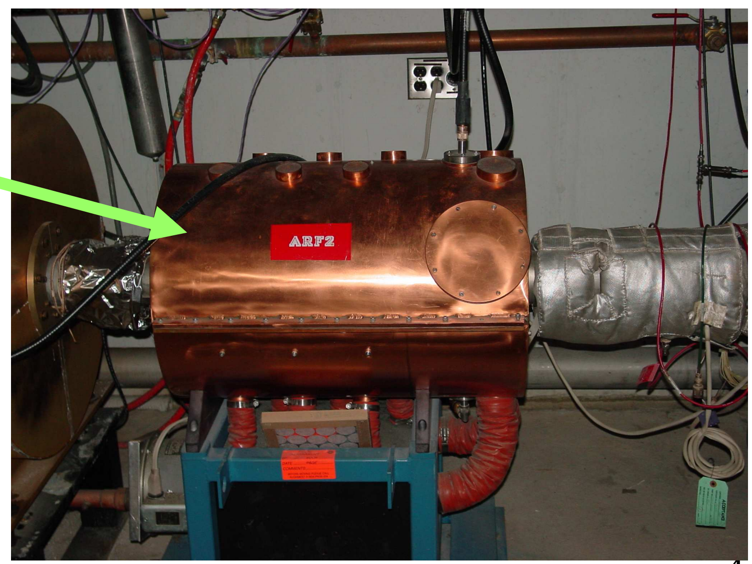
The Earliest Barrier RF System at Fermilab



Cavity in the Debuncher

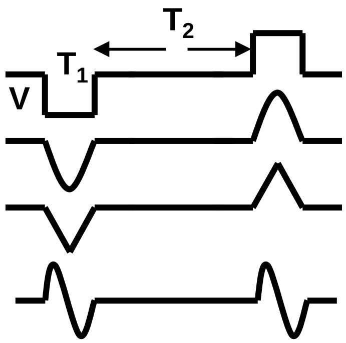
Peak Voltage: 160V (700V) **Power:** 2.4 kWatts
Type of Ferrite: MnZn+NiZn
Shunt Impedance: 104 Ω /cavity
Band Width : 10kHz -10MHz
Dimension: ~ 1 meters
Amplifier : IFI3100S

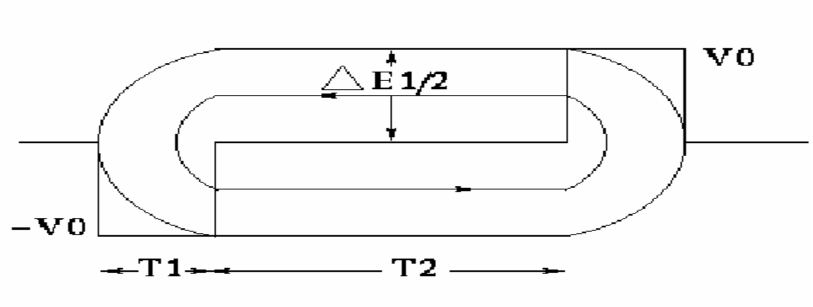
Cavity in the Accumulator



Peak Voltage: 70 V **Power:** 100W
Type of Ferrite: MnZn+NiZn
Shunt Impedance: 50 Ω /cavity
Band Width : 10kHz -10MHz
Dimension: 1 meter
Amplifier : ENI2100

Properties of Barrier Buckets





Bucket height :

$$\Delta E_b = 2\sqrt{\frac{2\beta^2 E_0}{|\eta|}\frac{\int_0^{T_1} eV_{rf}(t)\,dt}{T_0}}$$

Synchrotron Period :

$$T_s = 2\frac{T_2}{|\eta|}\left[\frac{\beta^2 E_0}{|\Delta \hat{E}|}\right] + 4\frac{|\Delta \hat{E}|}{eV_0}T_0$$

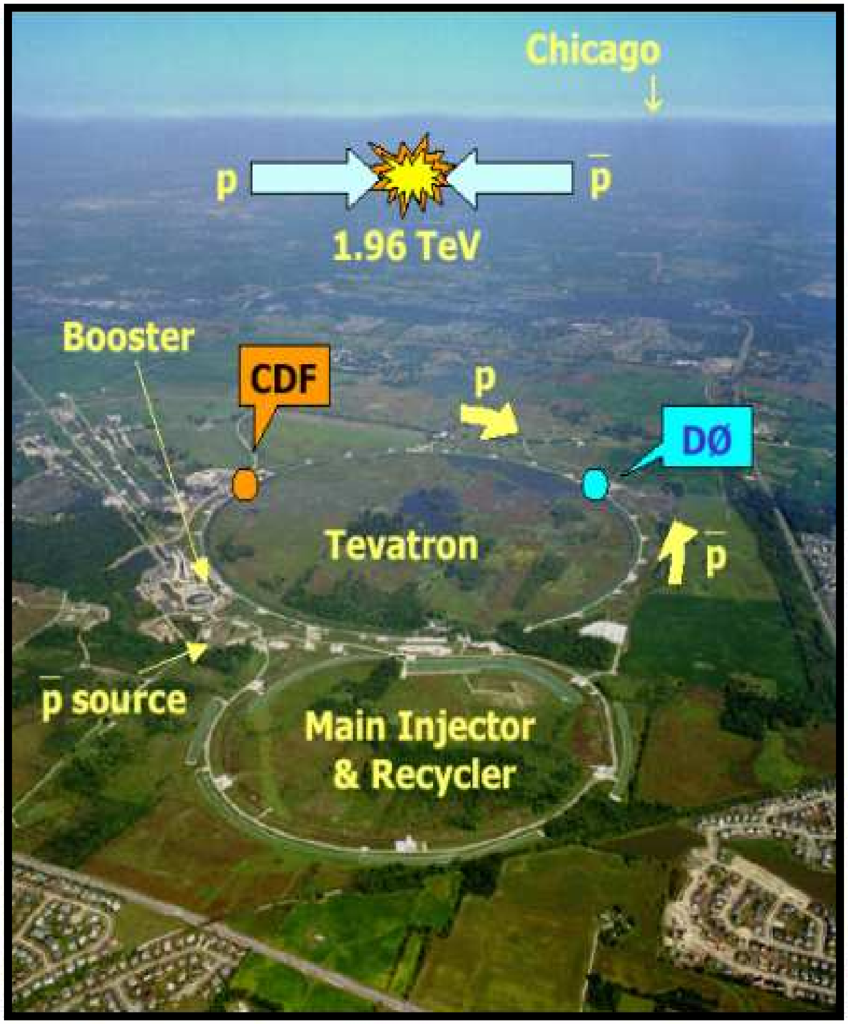
Bucket area :

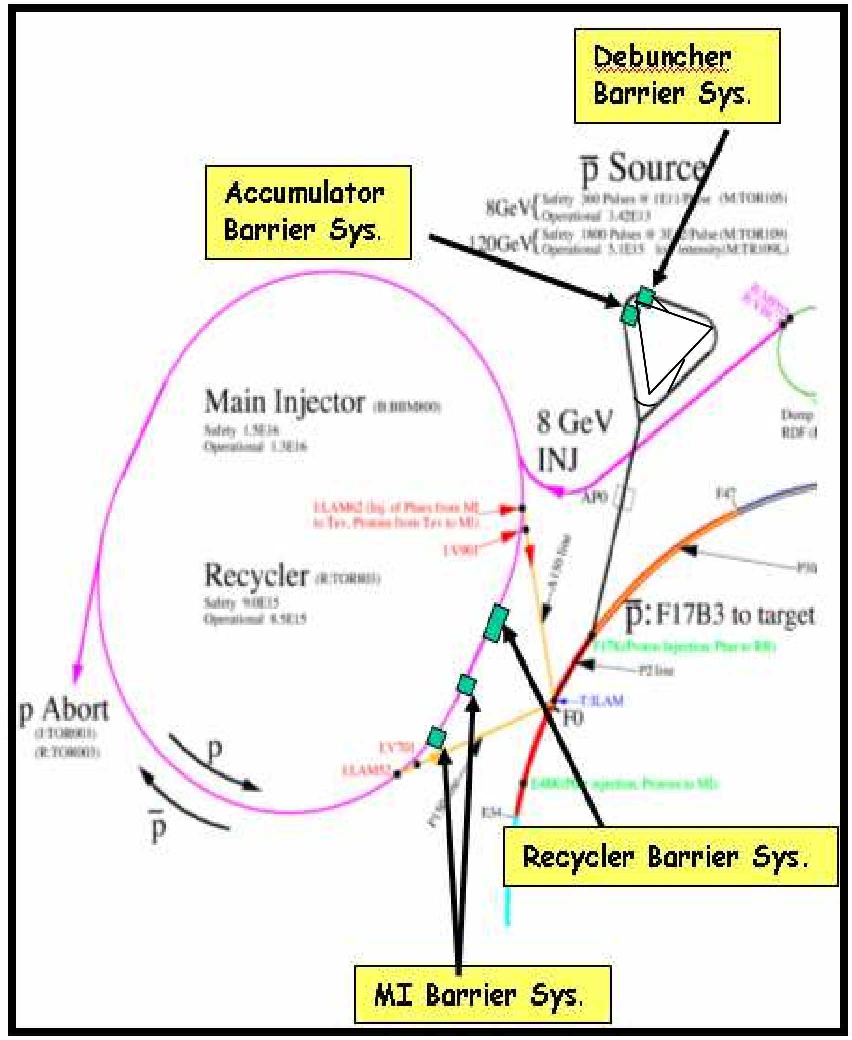
$$\varepsilon_l = T_2 \Delta E_b + \frac{8\pi|\eta|}{3\omega_o \beta^2 E_o eV_{rf}}\left[\frac{\Delta E_b}{2}\right]^3$$

- η is phase slip factor,
- E_o is synchronous energy,
- ω_o=2p f_{rev} with f_{rev}= beam circulation frequency.

Ref: S. Y. Lee, *Accelerator Physics*, (World Scientific, Singapore, 1999)

Barrier RF Systems at Fermilab Accelerators



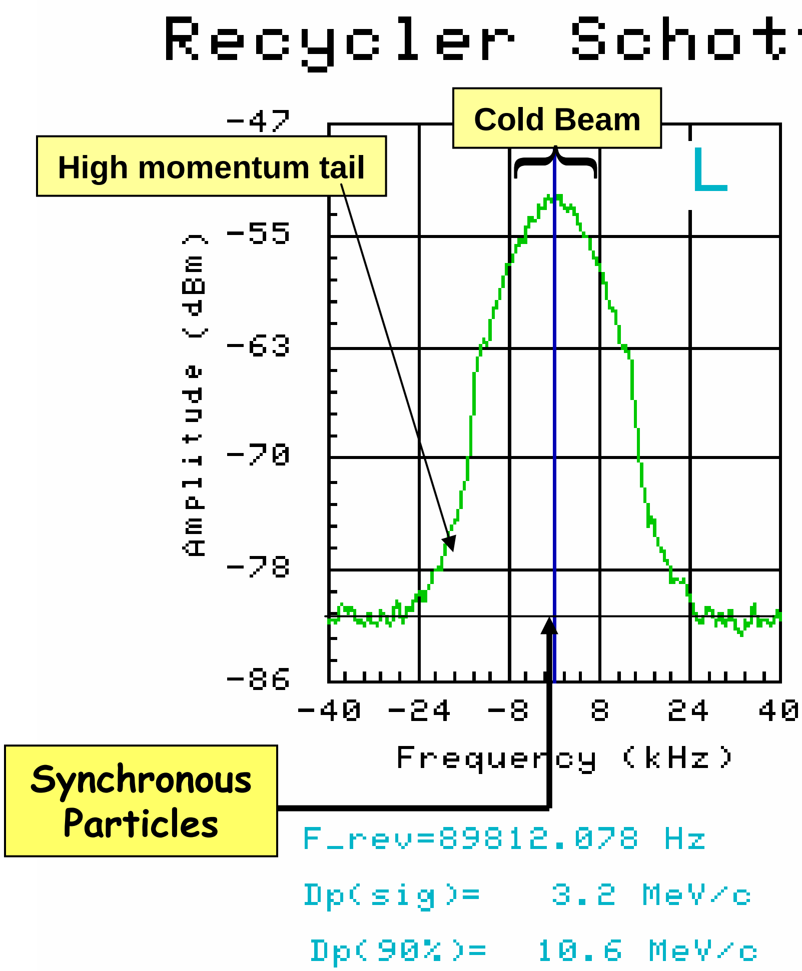


Applications of Barrier RF Systems at Fermilab

- **Longitudinal Momentum Mining**
- New Schemes to **produce intense beam** in accelerators Barrier Stacking

Longitudinal Momentum Mining

Ref: C. M. Bhat, LANL Physics/0406013 & FERMILAB-FN-746 (2004)

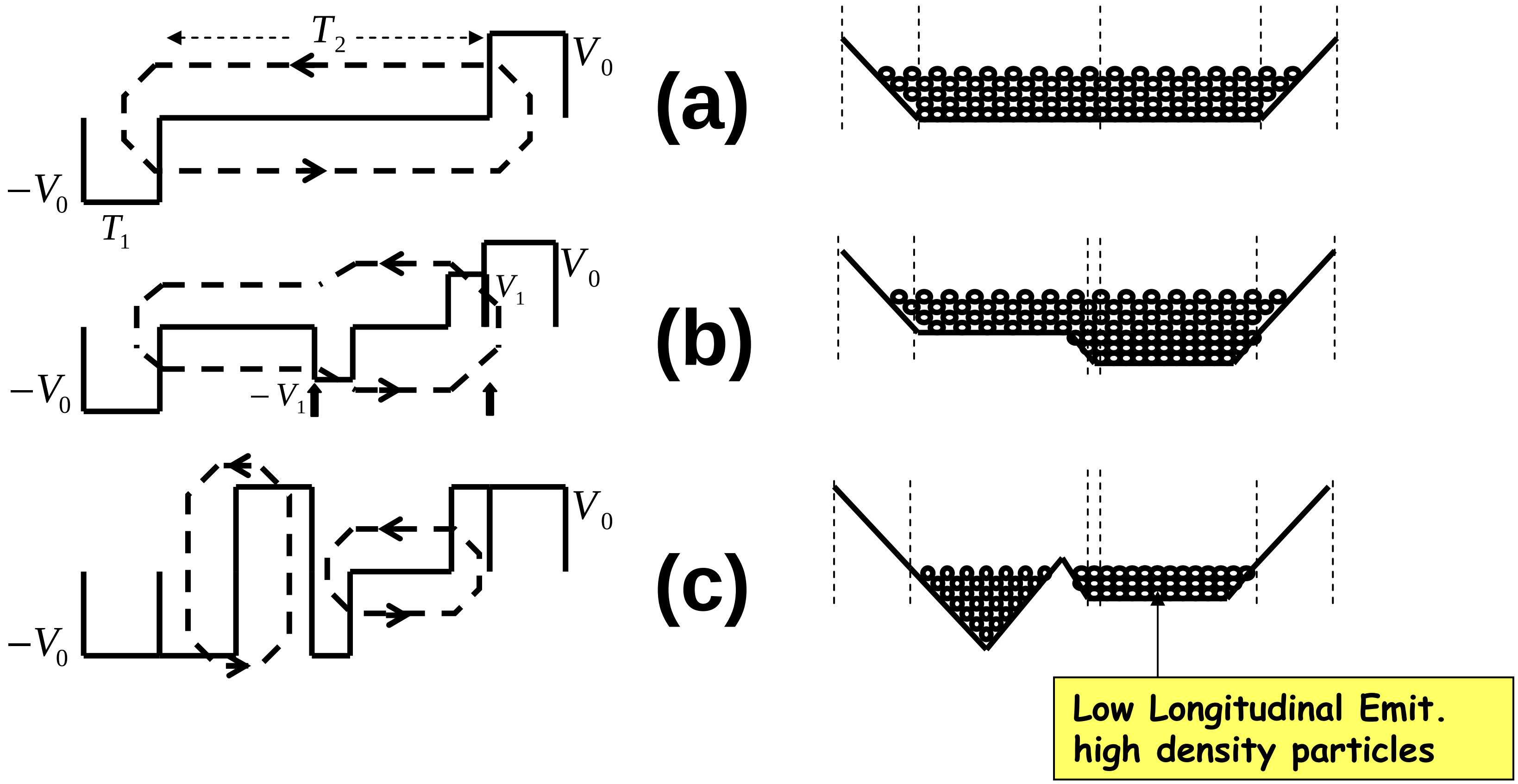


Is it possible to isolate the cold beam from the high momentum tail of a beam distribution without emittance growth and selectively use the cold beam and cool the leftover hot beam?

Physics of Longitudinal Momentum Mining in a Synchrotron

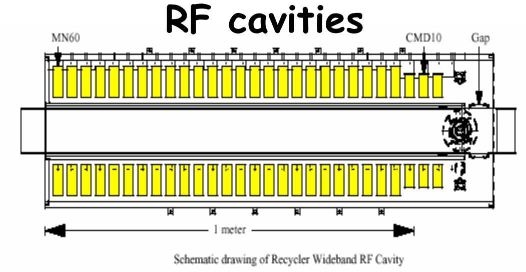
RF Voltage & Beam Boundary

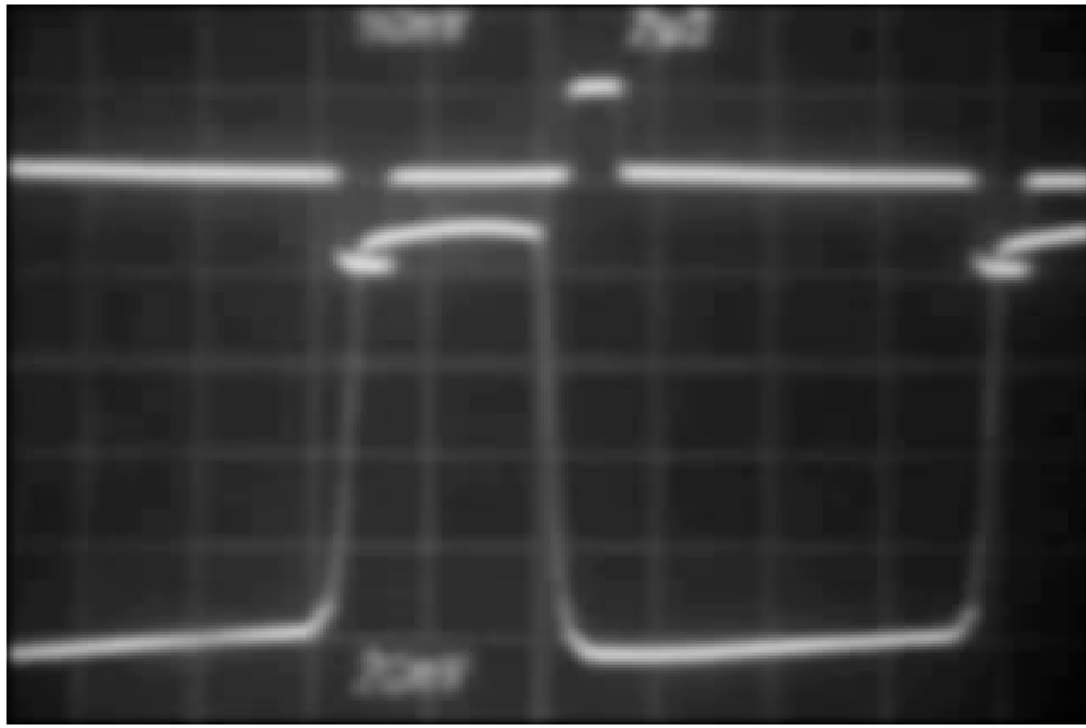
Potential $U = \int V(t)dt$ & Beam Particle



Pbar Momentum Mining in the Fermilab Recycler

Recycler Barrier RF cavities





RF Fanback signals

Wall Current Monitor Signals

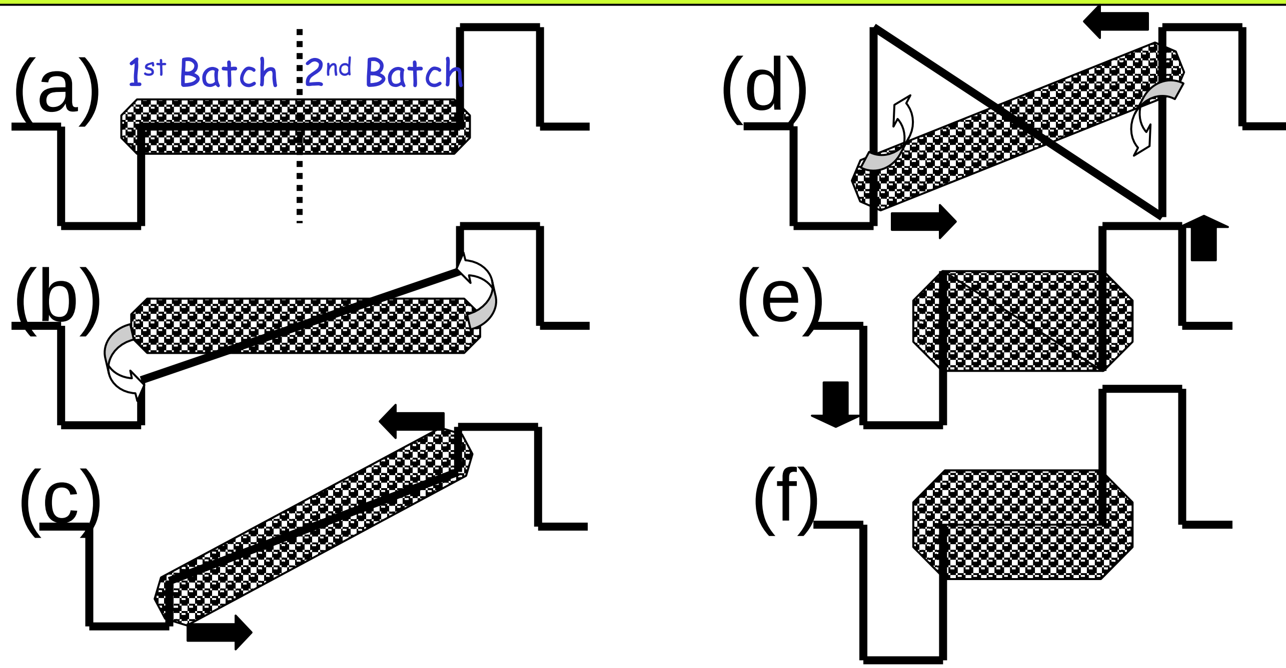
We have successfully implemented the longitudinal momentum mining in the Recycler to inject constant emittance, constant intensity pbars for Tevatron shots.

Production of Intense Proton Beam: Barrier Stacking

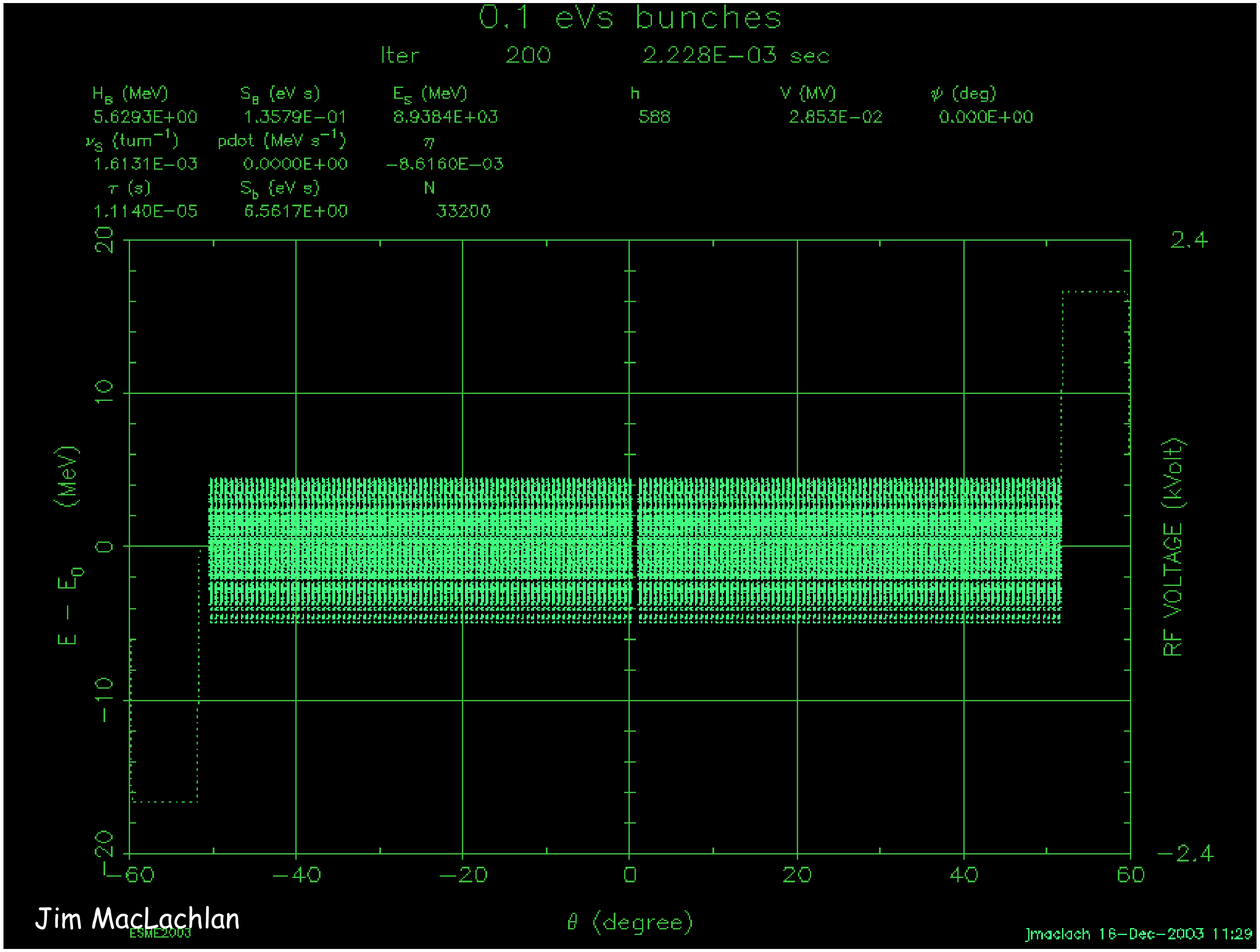
Beam for Antiproton production and Neutrino Experiments

1) Flip-flop (W. Foster, C. Bhat, J. MacLachlan et al, TUPLT149)

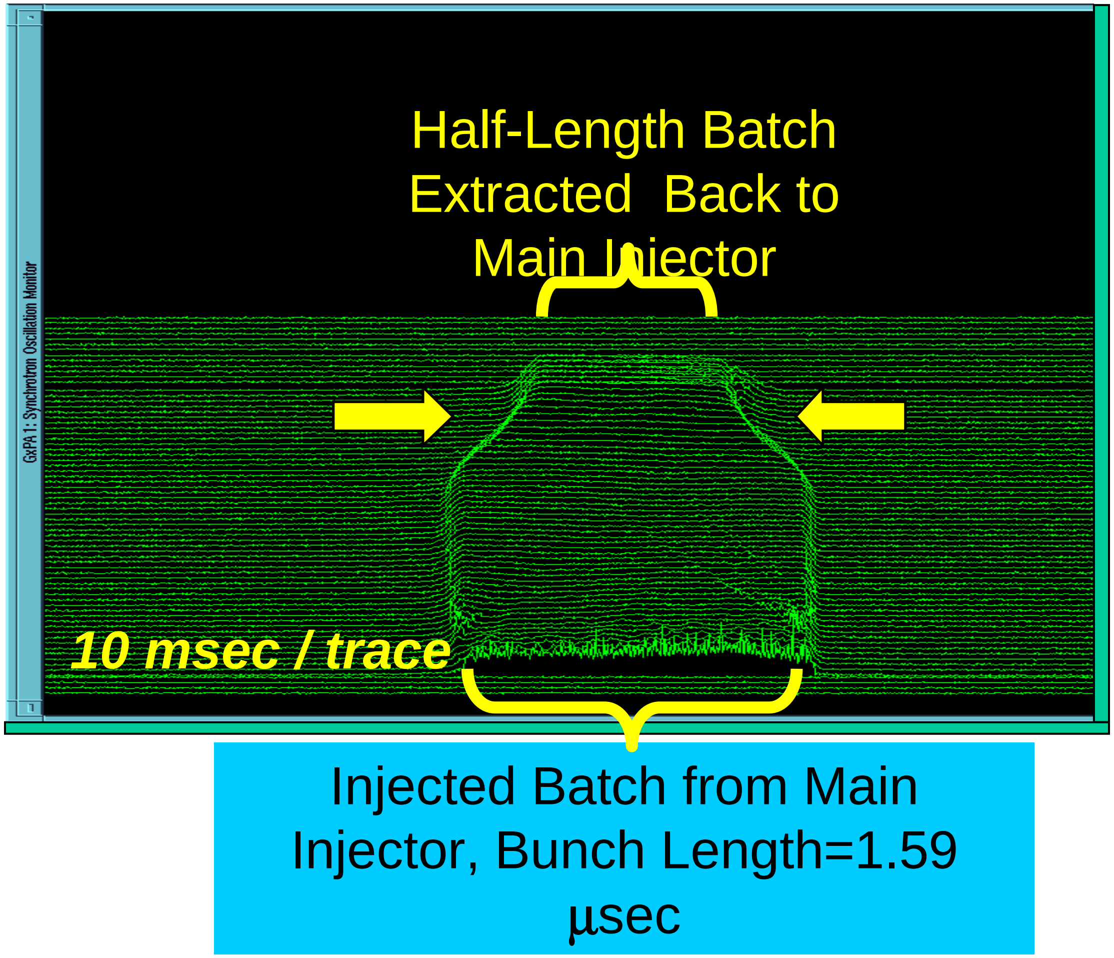
Concept: Fast rotation of a bunch about rf stable and unstable points.



Video from ESME Simulations



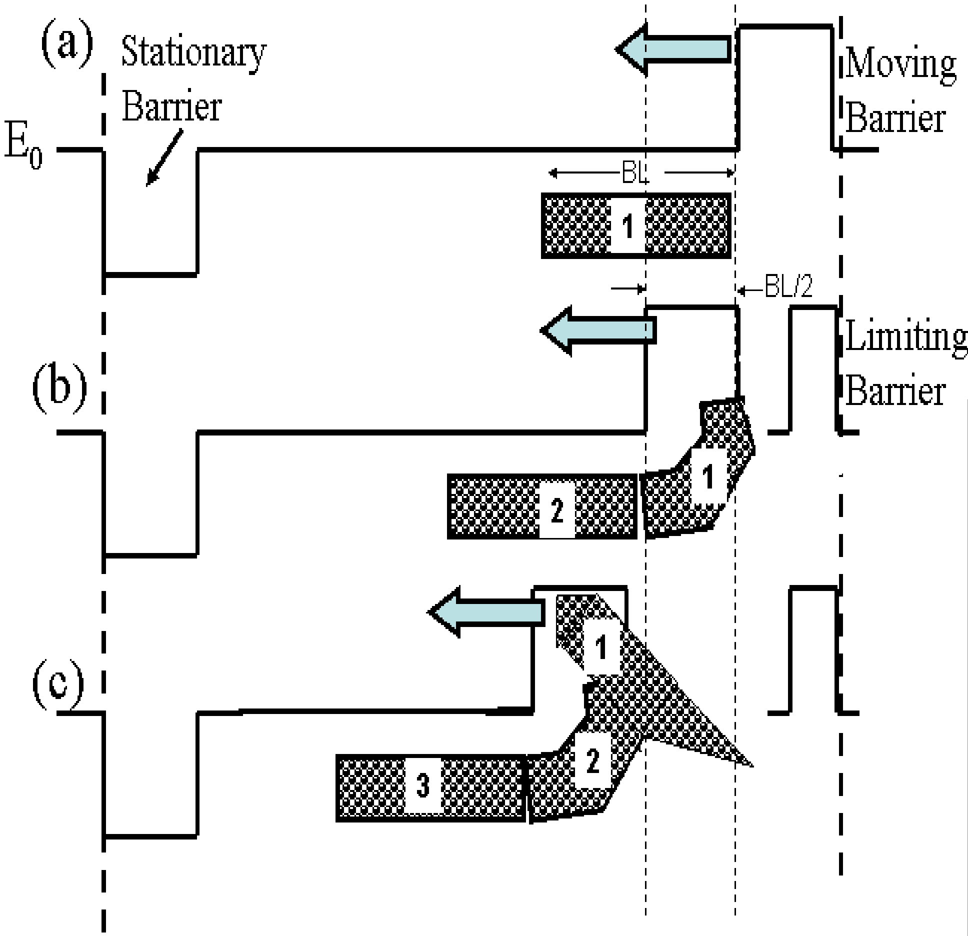
Beam Experiment in the Recycler



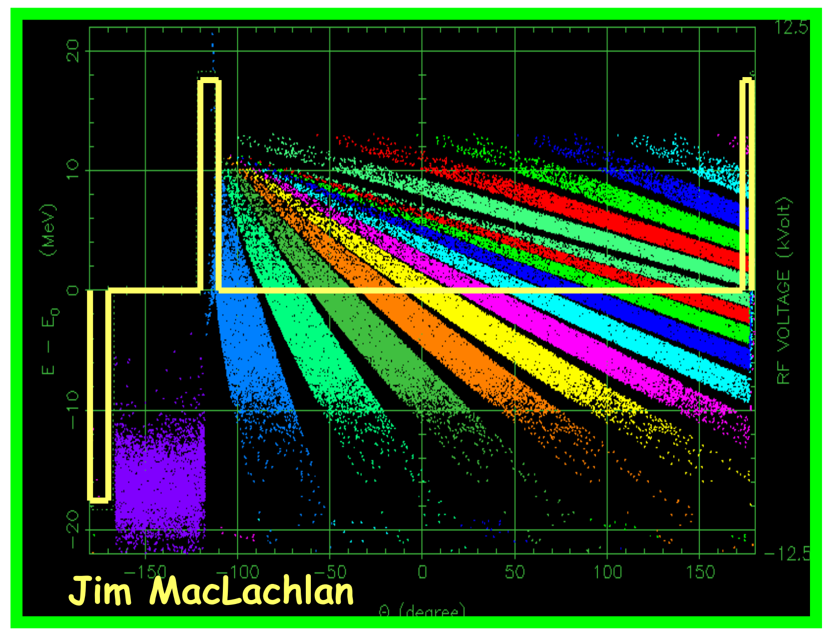
Experiment at the Fermilab Main Injector is in Progress

In the case of Fermilab Main Injector, typically one can inject up to 6 similar batches and accelerate to 120 or 150 GeV. If we use this scheme, then one can accelerate > 6 batches. The Maximum amount of compression depends upon the momentum acceptance of the machine. We believe that one can increase MI 120 GeV intensity by a factor of 1.5.

2) Momentum Stacking (J. Griffin)



Concept: Inject batches of beam particles with slightly below synchronous energy between a stationary and a moving barrier pulse. Confine the beam batches in a limiting barrier. And so on.



Applications of Barrier RF Systems

- **Longitudinal Momentum Mining**
- New Schemes to **produce intense beam** in accelerators
  Barrier Stacking
  - Flip-flop method (W. Foster, C. Bhat, et. al.)
  - Momentum Stacking (J. Griffin, et. al.,)
  - *Adiabatic barrier compression (D. Wildman, C. Bhat and W. Chou et. al.,)*
- Merge **hot** and **cold** beam by momentum matching
- Gap Preservation in a coasting beam (Debuncher, Recycler Ring)
- Ion-clearing gap – beam stability (Accumulator and Recycler Ring)
- Broad-band cavities as Dampers (MI, Tevatron, Recycler, Antiproton Source - W. Foster)

Barrier RF Systems Around the World

- Ø **CERN** SPS traveling wave structures were used to create barrier buckets–T. Bohl et al., SL Note 2000-32-HRF

- Ø Super-bunch Hadron Collider – Ken Takayama's Group at **KEK** (PRL Vol 88, 144801 (2002), PRST Vol 7, 014201 (2004))

- Ø A Barrier Bucket Experiment for accumulating De-bunched Beam in the **AGS** – M. Blaskiewicz *et., al.,* Proc. of PAC99, New York, page 2280 and 857.

Summary

- We have used barrier RF systems for a number of applications at Fermilab.

- Most importantly, we have recently developed a new scheme called longitudinal momentum mining for selectively isolating low longitudinal emittance anti-protons using barrier rf system and is routinely used in the Recycler for Tevatron shots.

- Barrier RF systems can be of great use to produce intense neutrino beam at hadron facilities.

- There are probably a number of unexplored applications of barrier RF systems at storage rings and circular accelerators.