LONGITUDINAL MOMENTUM MINING OF ANTIPROTONS AT THE FERMILAB RECYCLER

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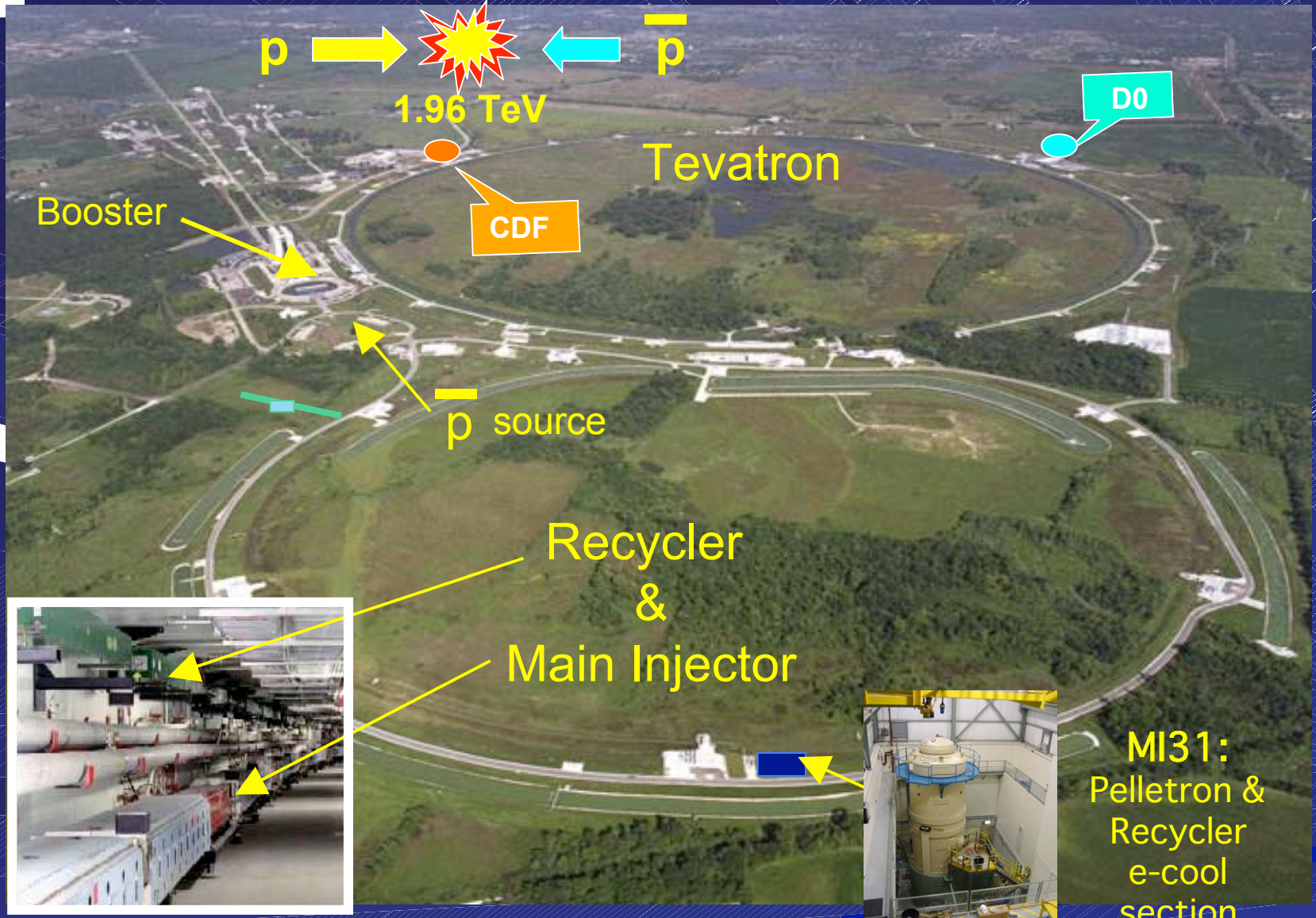
FERMILAB


p
p̄
1.96 TeV
D0
Tevatron
Booster
CDF
p̄ source
Recycler
&
Main Injector
MI31:
Pelletron &
Recycler
e-cool
section

Recycler History

- 1999 – Recycler Construction Completed
- Fall 2004 – Electron cooling installed in RR
- Jan 2005 – First mixed mode shots (ACC & RR)
  - Recycler becomes part of collider operations
- July 2005 – First observed electron cooling
- August 2005 – Electron cooling commissioned
- October 2005 – Recycler only shots
  - (L = 164e30 cm^{-2} s^{-1} on 10/31/05)

Recycler - 8GeV Pbar Storage Ring

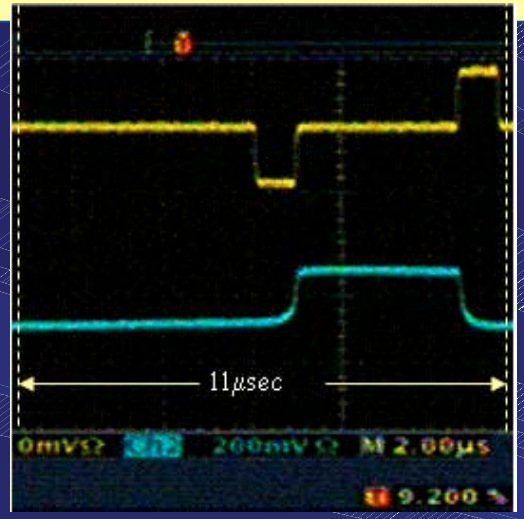
- Pbars produced in the Pbar Source, transferred to RR every few hours
- Pbar transverse and longitudinal emittances are cooled using stochastic and electron cooling systems in the Recycler
- Pbars are extracted from the Recycler for Tevatron shots using longitudinal momentum mining.← implemented Feb. 20, 2004
- HLRF system - 4 broadband cavities - 2kVp
- LLRF has 8 arbitrary waveform generators under DSP control

Phase-space distribution of pbars in the RR and Essence of Longitudinal Momentum Mining

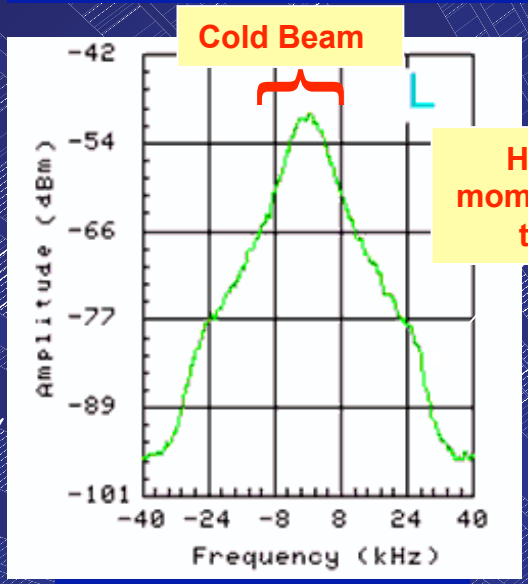
Barrier Bucket
& Beam In the bucket

Cavity Voltage

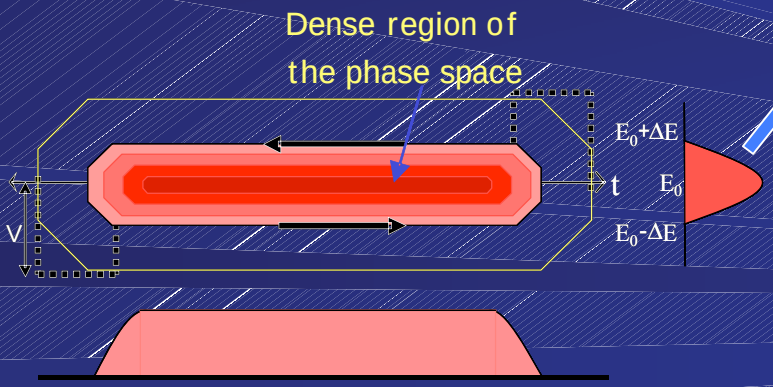
WCM data
of pbars



Frequency Spectrum



Pbars cooled using
Stochastic cooling



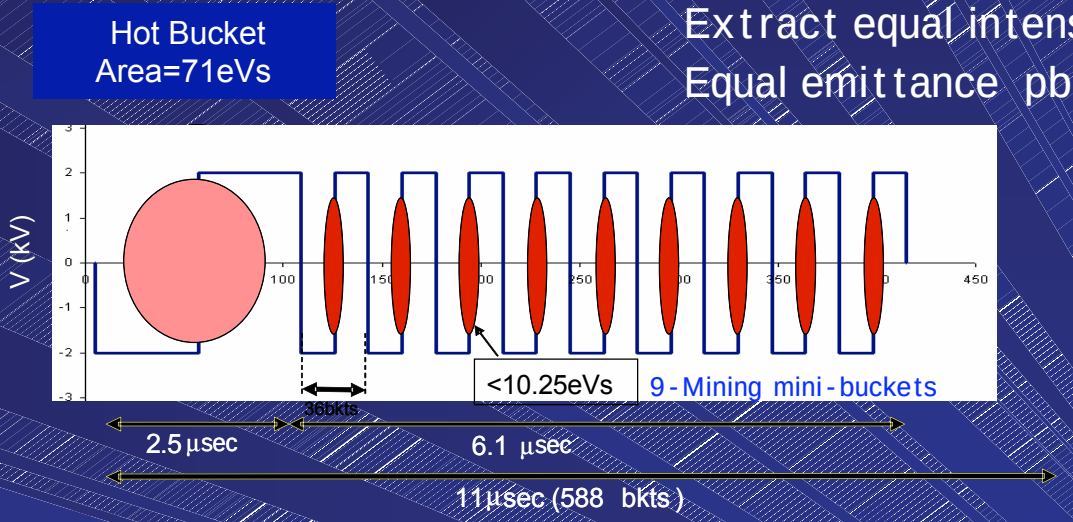
Wall Current Monitor (WCM) signal

Goal: Extract the dense region of the pbar distribution for Tevatron collider store and leave the rest back in the Recycler for the later transfers

Longitudinal Momentum Mining in the Recycler

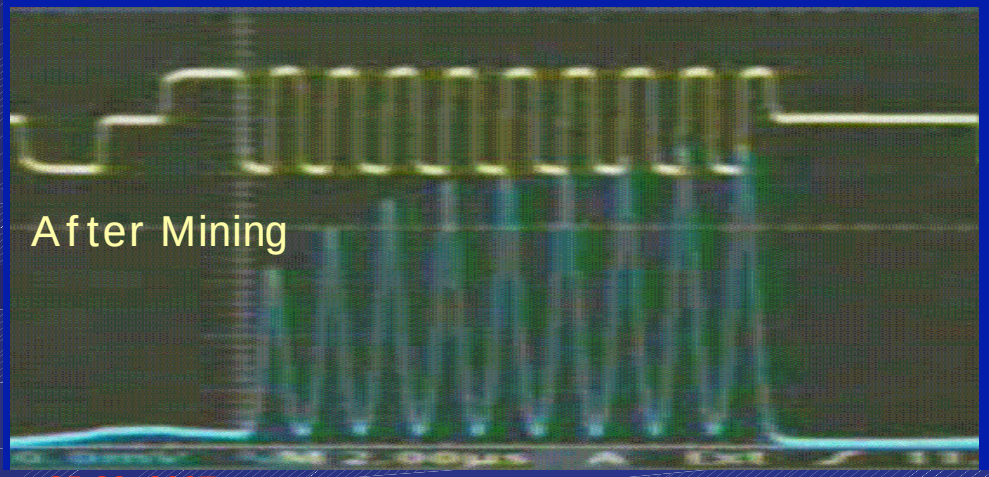
Goal:
Extract equal intensity
Equal emittance pbars

- Physics and first demo of long. momentum mining:
  C. M. Bhat, Phys. Lett. A 330 (2004) 481



RF Waveform

WCM



~300E10 pbar
21-38E10 pbars/mini-bunch
LE=6.0 eVs/mini-bunch
e_T= 5 pi-mm-mr

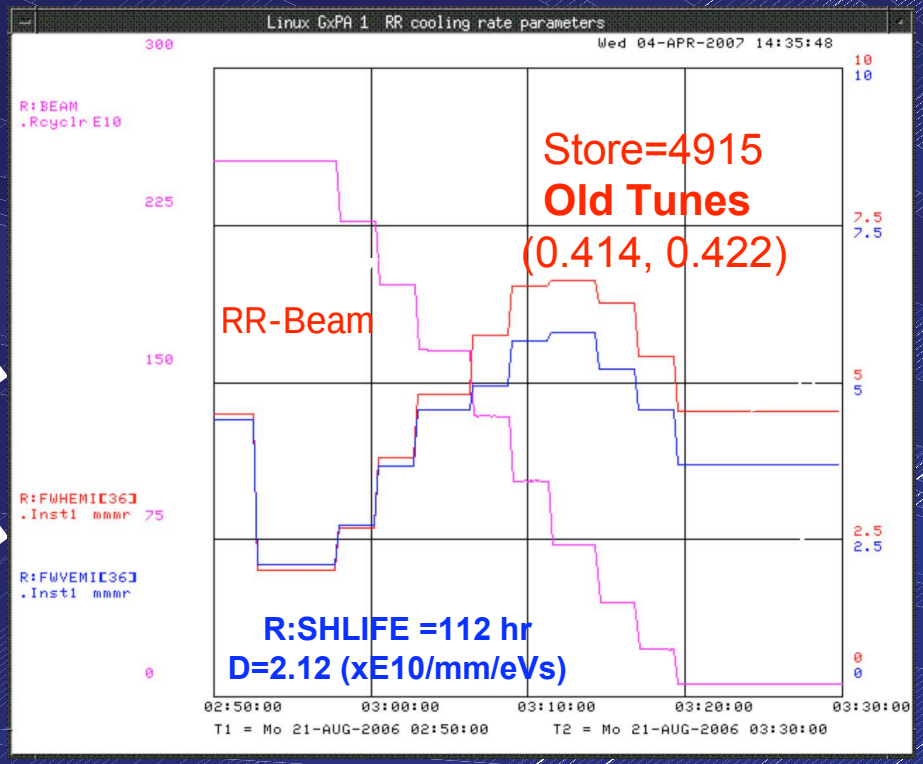
Issues and Solutions

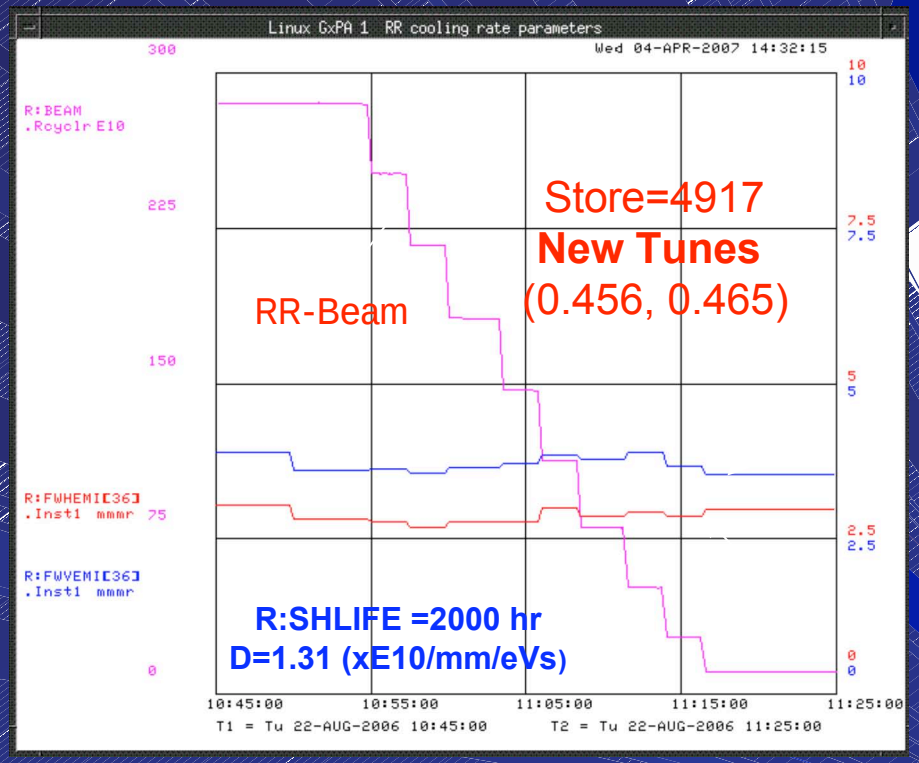
Goal -> Store 600E10 Pbars

- Poor Life-time and transverse emittance growth during mining
  - Cause: non-optimal transverse tunes
  - Solution: change transverse tunes to new values
- Large peak density at low emittances and higher intensities
  - Cause: hard (zero-length) mining barrier buckets
  - Solution: use soft (finite extent) mining barrier buckets
- Distortions of the Recycler HLRF voltage
  - Cause: non-linearities in cavity power amplifiers
  - Solution: Comb filter feedback around amplifiers
- About 20% longitudinal emittance growth during the formation of four 2.5 MHz bunches
  - Cause: non-adiabatic bunch expansion prior to 2.5 MHz bunch growth
  - Solution: adiabatic expansion by morphing to 2.5 MHz bunches
- Transverse instabilities at higher stash sizes and low emittances
  - Cause: resistive wall instability
  - Solution: transverse damper system

New tune operating points since Aug. 22, 2006

(A. Burov, et al. from a theoretical study)



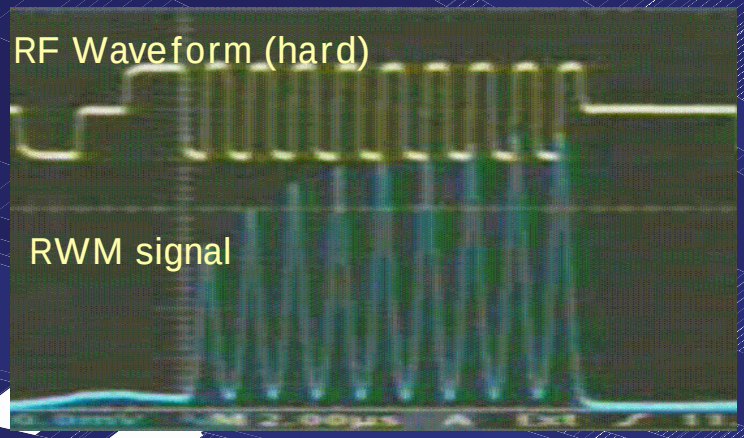


Average Trans. Emit. Variation > 200% and an RMS spread of 30%

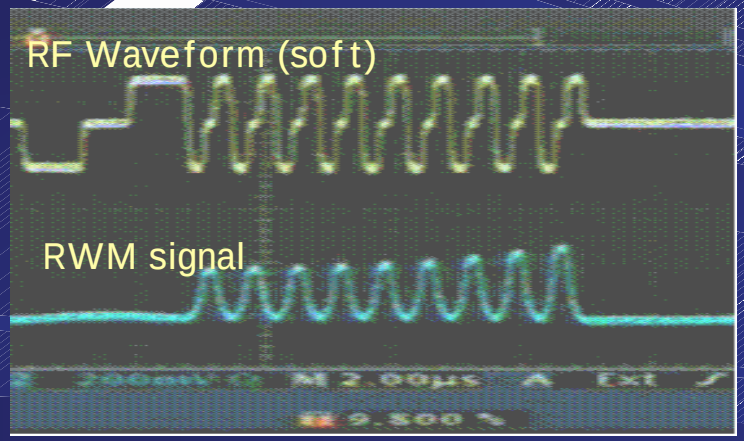
Average Trans. Emit. Variation ~ 30% and an RMS spread <10%

Result: Nearly constant transverse emittance pbars to the Tevatron

Hard Mining Barriers vs. Soft Mining Barriers



Peak density is too high. Consequently the beam becomes more unstable at higher intensities



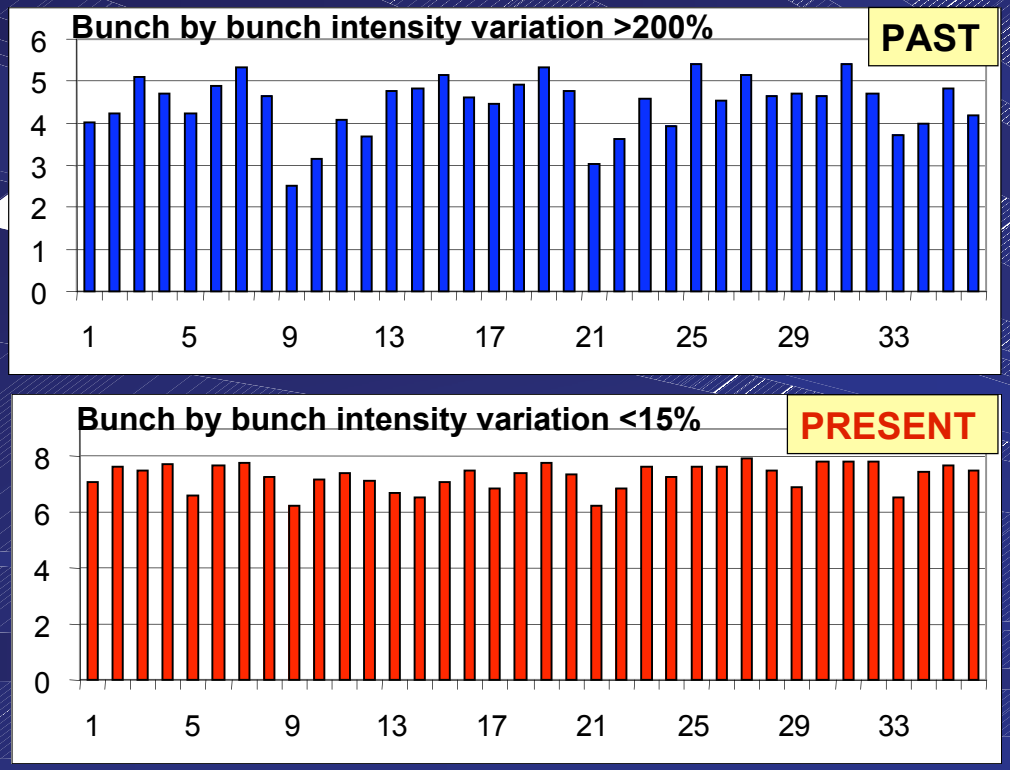
Peak density is reduced by a factor of two. Can store more beam in the same bunch

Still, 40-50% bunch-to-bunch intensity variation for the Tevatron.

Comb Filter Feedback around RF Power Amplifiers and Cavities (adaptive feed -forward)

Small voltages between barriers integrate to large distortions of the potential well

The feedback system corrects For non-linear effects in the power amplifier and the low frequency response of the cavities

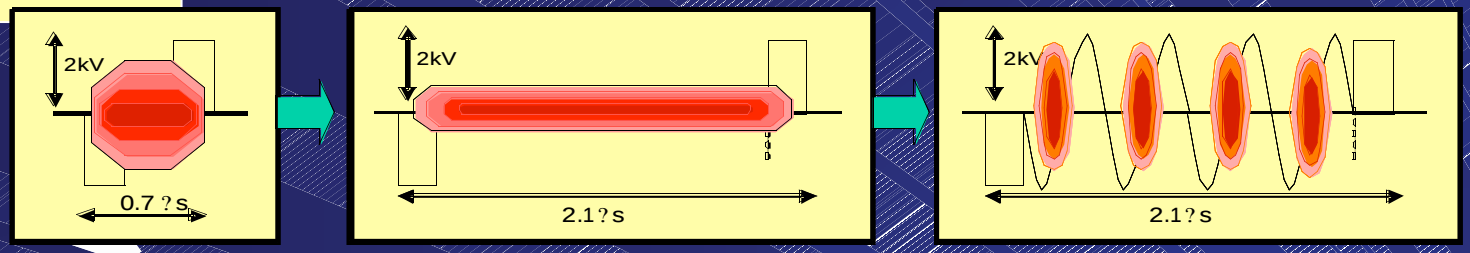


Without improvements:
Intensity variation >200%

With Improvements:
Intensity variation <15%

2.5 MHz pbar bunches by Morphing (frequency chirp)

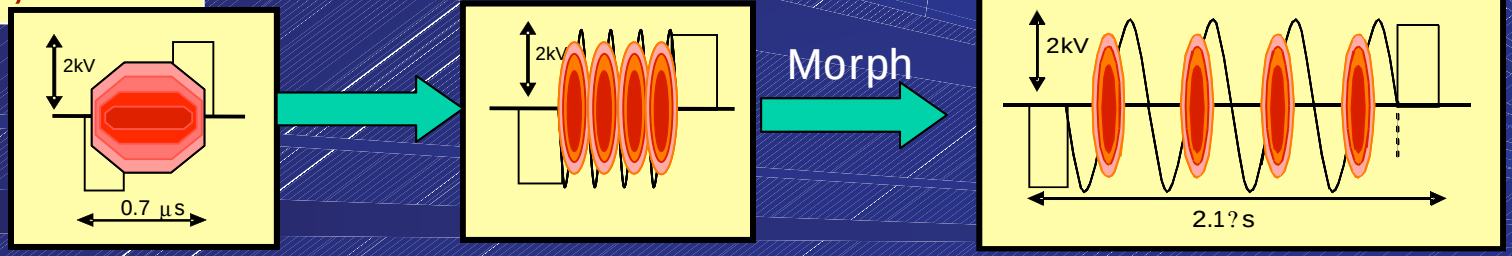
Before March 20, 2007



Mini-bunch after mining — Stretch — 2.5 MHz Bunches

→ 20-30% longitudinal emittance growth; takes ~75 sec

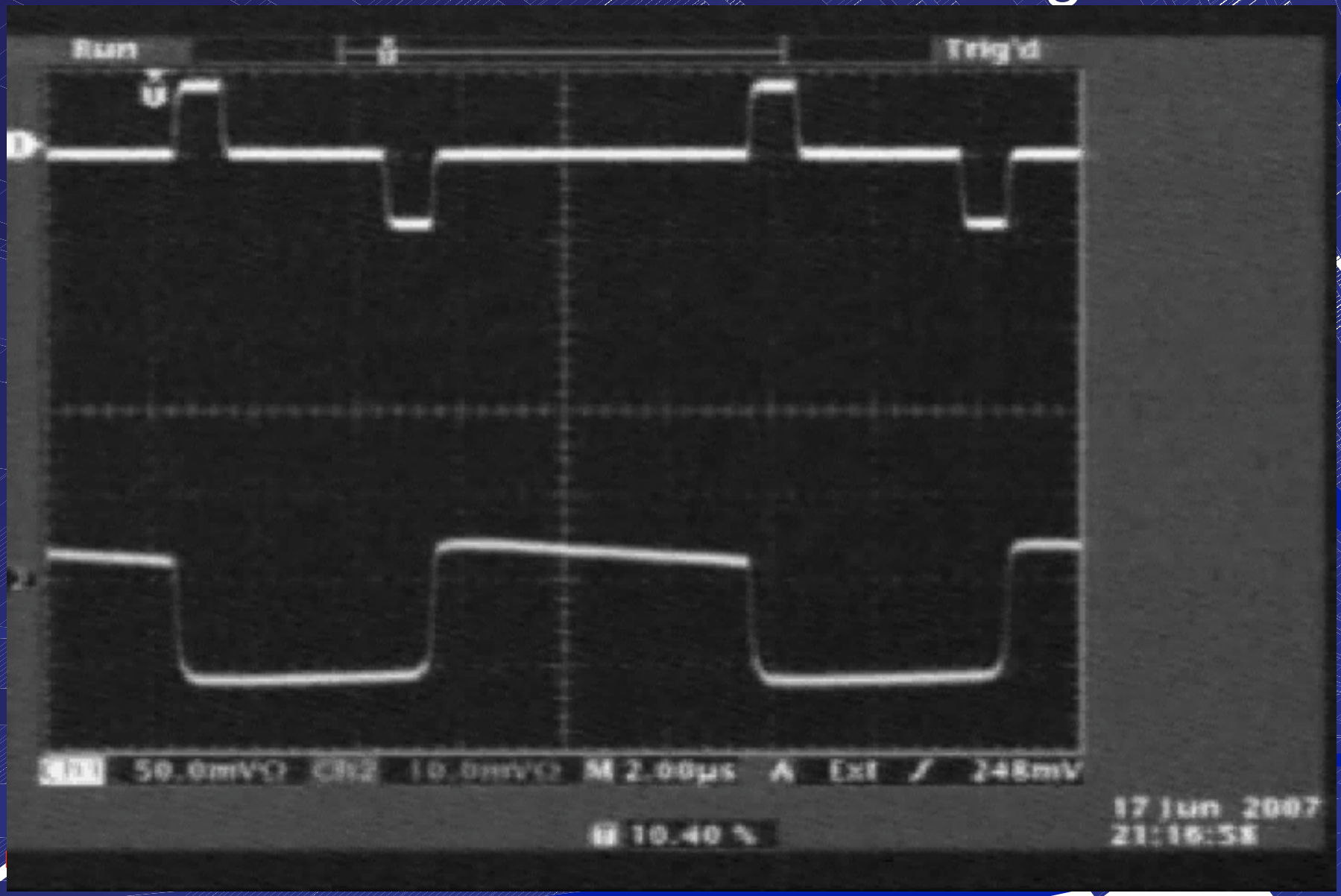
Since March 21, 2007



Mini-bunch after mining — Capture in 7.5 MHz — 2.5 MHz Bunches

→ <10% longitudinal emittance growth and takes ~60 sec

Present Momentum Mining



Accomplishments

- Peak density is reduced by ~35%.
  - **So, in future we can increase the bunch intensity**
- Lower LE (<10% growth) pbar bunches to the Tevatron
- The bunch by bunch transverse emittance variation is reduced from 200% to 30%
- Provide nearly equal intensity pbars bunches to Tevatron