Antiproton Source In Run 2

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DOE Review

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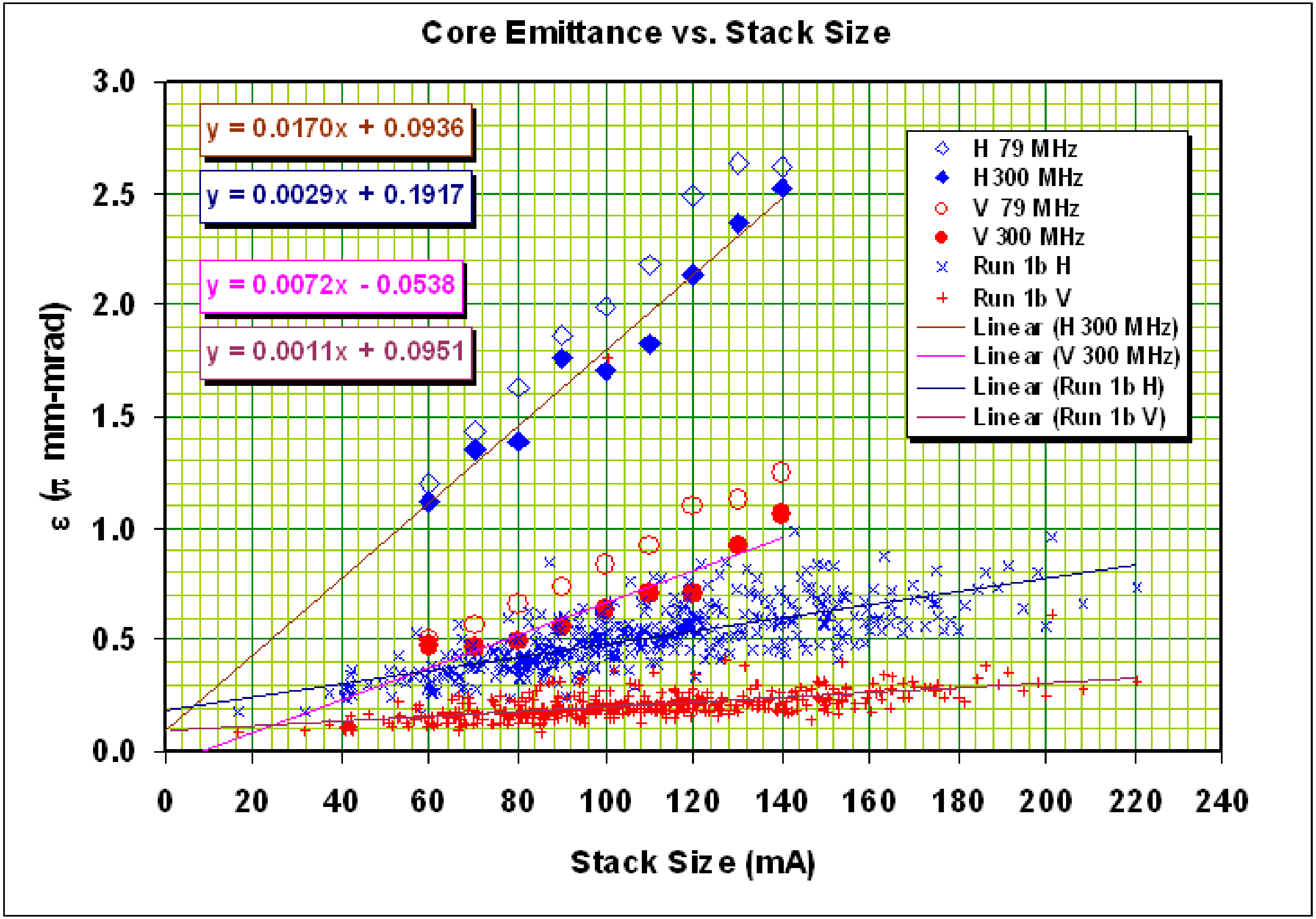
Overcoming IBS/Core Transverse Emittance

- Before July of 2002, the horizontal emittance of a typical 100 x 10^{10} antiproton stack was about a factor of two larger than the Run II handbook design value
  - At a stack of 100 x 10^{10} pbars the normalized horizontal transverse emittance was about 17 π-mm-mrad
  - The Run II handbook specifies 8 π-mm-mrad at 100 x 10^{10} pbars
- During the period of Nov. 2001 through July 2002, almost 100% of the manpower and machine study time of the Pbar Source department was devoted to trying to reduce the horizontal emittance
- We believe that the horizontal emittance growth was caused by
  - Intra-beam scattering (60%)
  - Trapped ions (40%)
- The intra-beam scattering (IBS) heating of the beam is worse now for Run II than it was in Run I because of the changes in beta functions that were the result of the Accumulator Lattice Upgrade

Overcoming IBS/Core Transverse Emittance



Overcoming IBS/Core Transverse Emittance

- A two-fold plan to reduce the transverse emittance was developed:
  - Better transverse stochastic cooling of the Accumulator core
    - The bandwidth was increased by a factor of 2
    - The center frequency of the band was increased by a factor of 1.5
  - Dual lattice operation mode of the Accumulator
    - Keep the "fast stacking" lattice (η=0.012) for pbar production
    - During shot setup, ramp the lattice with the beam at the core orbit to the "IBS" lattice (η=0.022)
      - The "shot" lattice will reduce the intra-beam scattering heating by a factor of 2.5
      - The "shot" lattice will increase the cooling rate by a factor of two increase in mixing due to the change in η

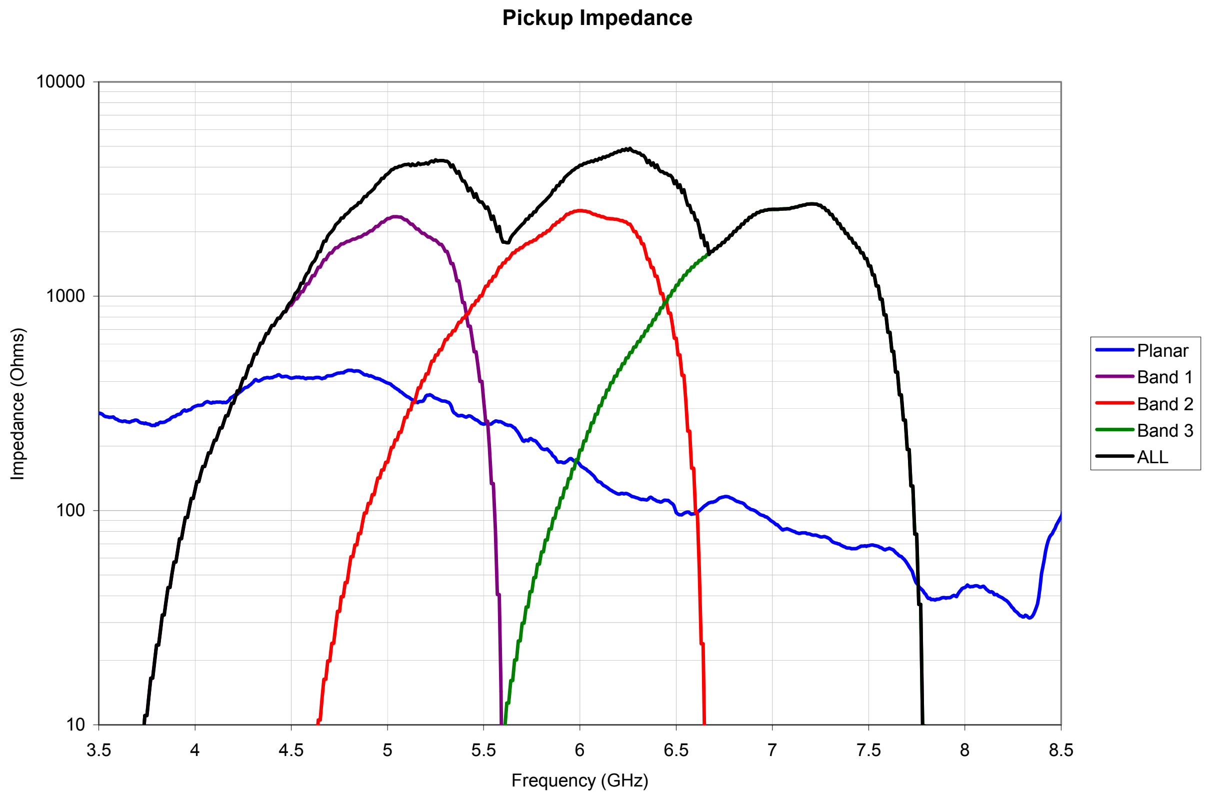
$$\frac{d\varepsilon}{dt} \approx -\frac{\varepsilon}{\tau_{cool}} + \frac{Heat}{\varepsilon^{3/2}}$$

$$\frac{\varepsilon_{old}}{\varepsilon_{new}} = \left(\frac{\tau_{cool_{old}}}{\tau_{cool_{new}}}\frac{Heat_{old}}{Heat_{new}}\right)^{2/5} = (2 \times 1.5 \times 2)^{2/5} \times \left(\frac{0.4+0.6}{0.4+\frac{0.6}{2.5}}\right)^{2/5} = 2.4$$

Annotations: Bandwidth (2); Center freq. (1.5); Better Mixing (2); Ions (0.4); IBS (0.6); Reduced IBS (2.5)

Accumulator Core Cooling Upgrade

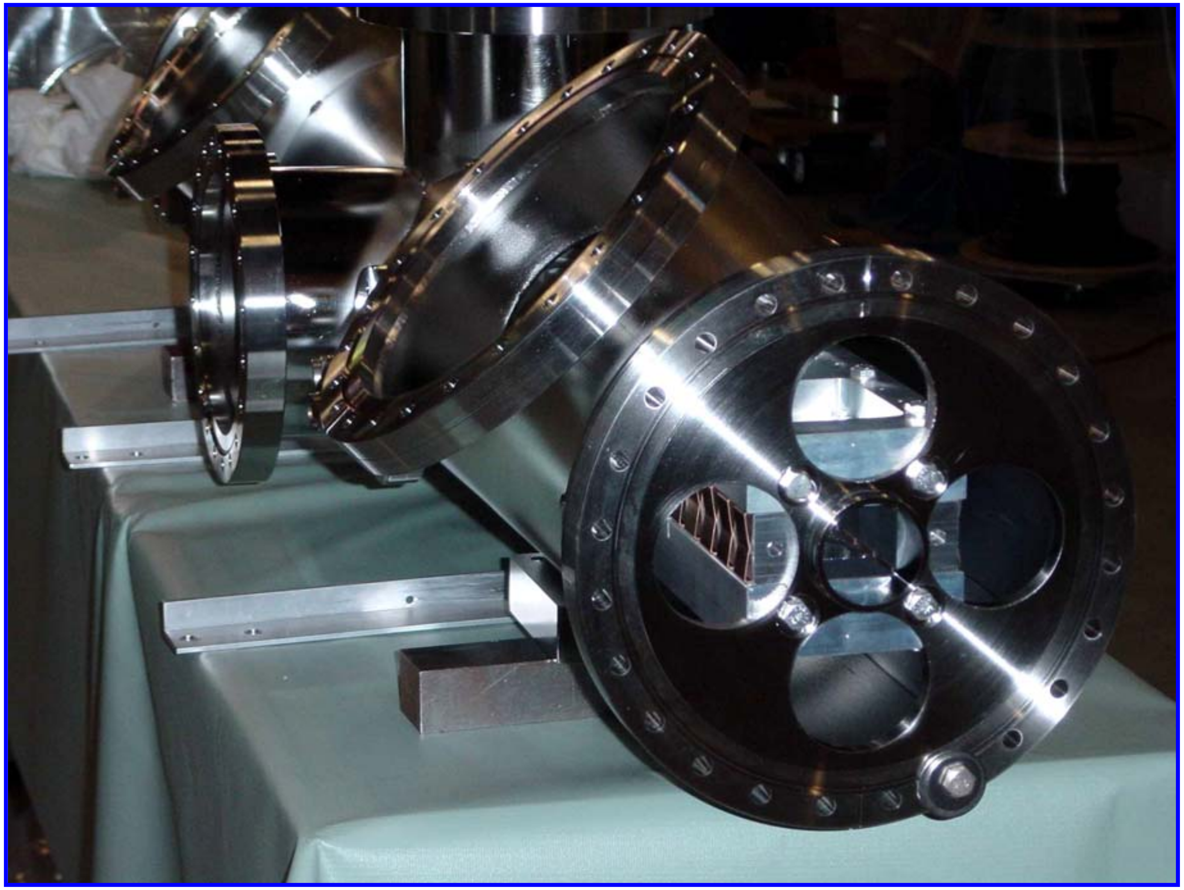
- Initial Run II system consisted of a 2-4 GHz band and a 4-6 GHz band
  - The 2-4 GHz band is ineffective because of the small value of η
  - The 4-6 GHz band suffers from poor signal to noise.
- Replaced both core bands with a 3 band Debuncher style system
  - Better sensitivity
  - More bandwidth (2x)
  - Better mixing factor (1.5x)



Accumulator Core Cooling Upgrade

- Project was started 30 October 2001 and completed 15 June 2002 (7.5 months)
  - 6 new cooling systems
  - 4 new ultra-high vacuum tanks
- The effective cooling rate of the new system is 1.4x faster than the combined rate of the old systems

Accumulator Core Cooling Upgrade

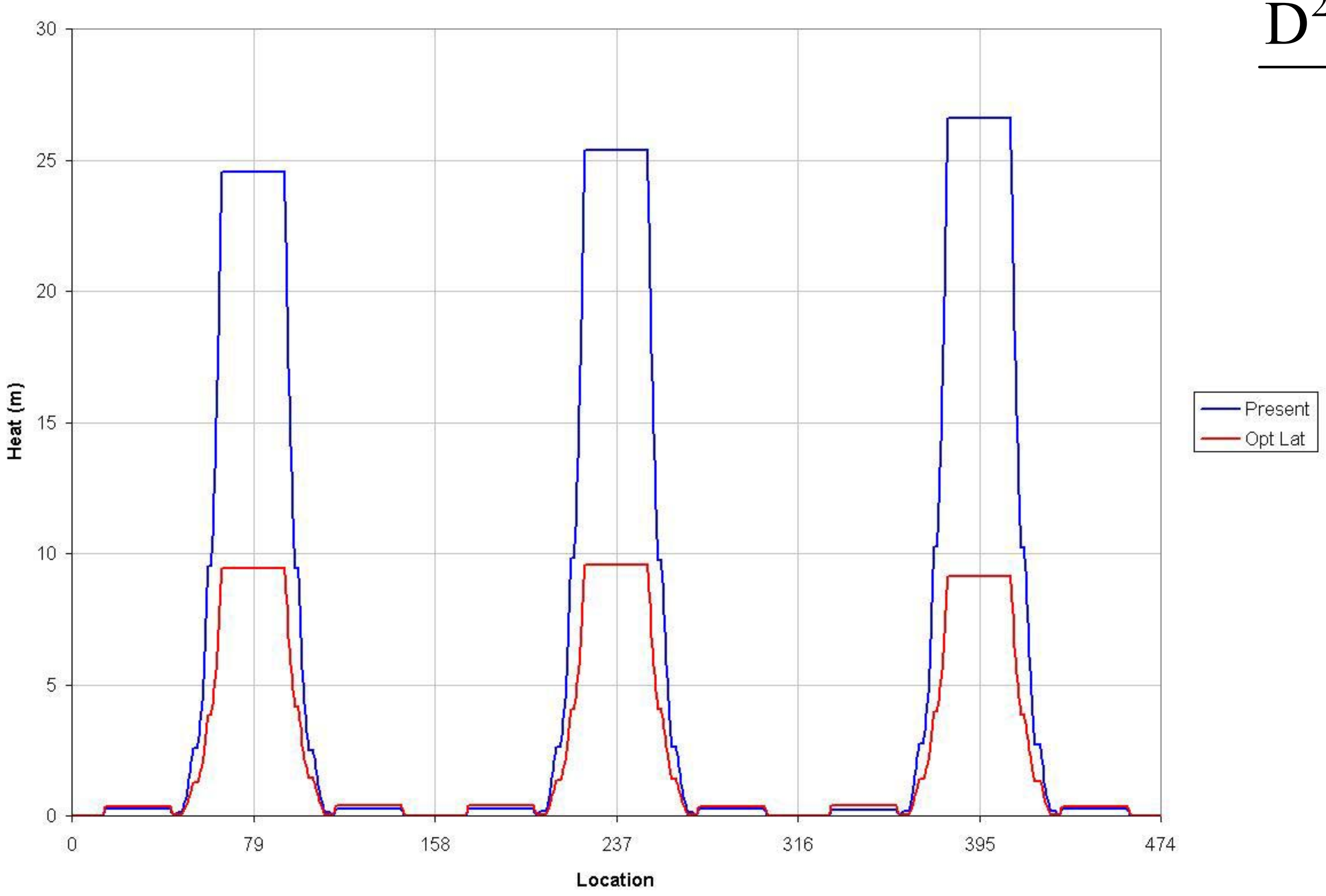


- With full system equalizers the new system will be 2.5x faster than the combined rate of the old systems
  - installed during recent shutdown
- With an 82 mA stack, we have a peak signal to noise ratio of 8 dB at 7.5 GHz for a 7π mm-mrad normalized emittance

Accumulator “Shot” Lattice

- An Accumulator lattice with a much smaller IBS heating term was designed
- The lattice was designed with the following constraints
  - No hardware changes to the present quadrupole configuration.
  - Same betatron tunes as the present Run II lattice
  - Zero dispersion in the odd straight sectors
  - High dispersion in the even straight sectors
  - Correct betatron cooling phase advances
  - Correct kicker phase advances
  - $\gamma_t < 5.5$ ($\eta < 0.022$)

Accumulator "Shot" Lattice



$$\frac{D^2 + (\beta D' + \alpha D)^2}{\beta}$$

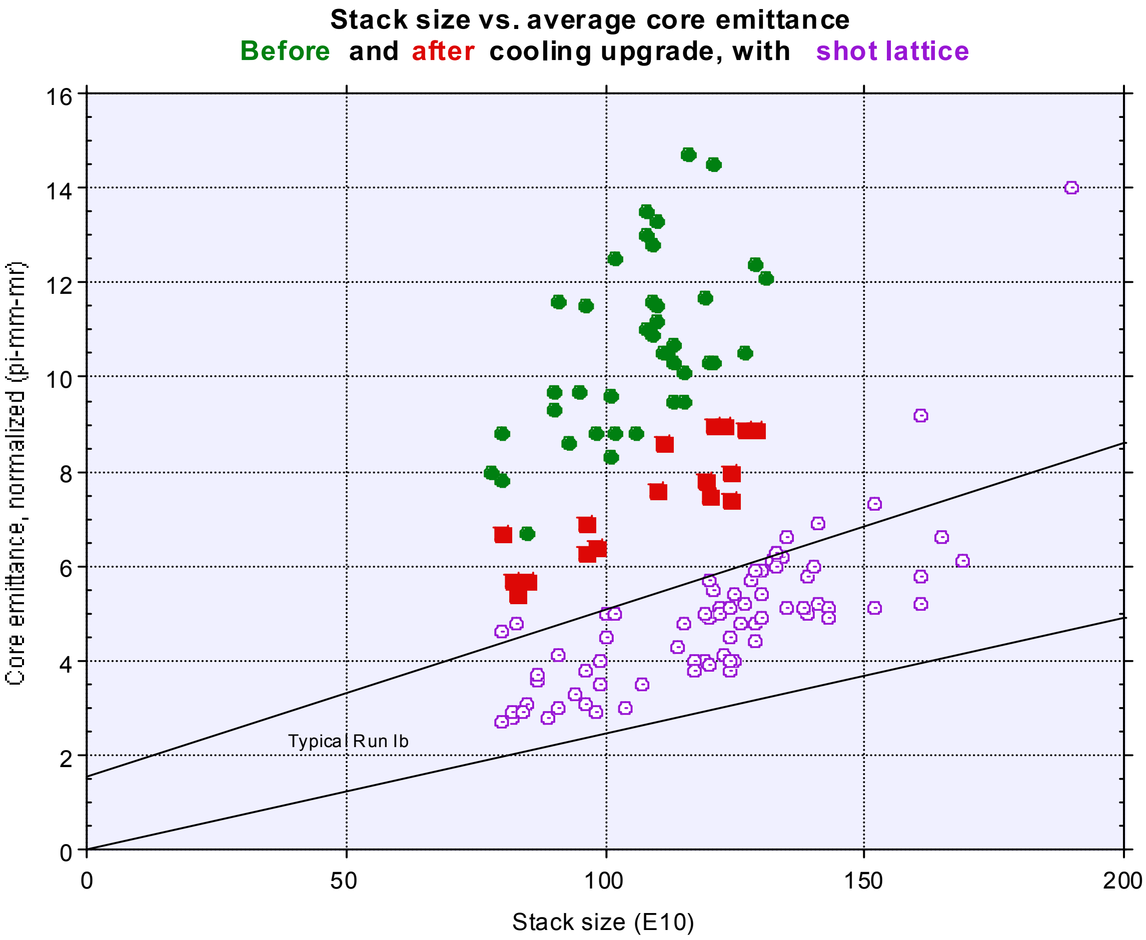
Accumulator “Shot” Lattice

- Ramp Development began 9 April 2002 and dual lattice mode became operational July 2002
  - Ramps are 100% efficient
  - Tunes are controlled to within 0.0005
  - Orbits are controlled to within +/- 1mm
  - Ramping from the Stacking Lattice to the Shot Lattice adds about 15 minutes to shot setup
    - mainly due to cooling core to within grasp of 4-8 GHz Momentum system.

Accumulator "Shot" Lattice

- Final step was to build ramps to move remaining Pbars back to Stacking lattice
  - Initially sent remaining stack (typically <20 mA) to Recycler or dumped it
  - Restored orbit correctors, cooling, cycled buses on stacking lattice
  - Resume stacking
  - Ramps built and tested to mimic effects of hysteresis between two lattices
  - Process automated and put into routine operation in early December 2002
  - 100% efficient
  - Luminosity enhancement
    - faster than cycling buses
    - Stack preserved

Overcoming IBS/Core Transverse Emittance



Stacking Improvements

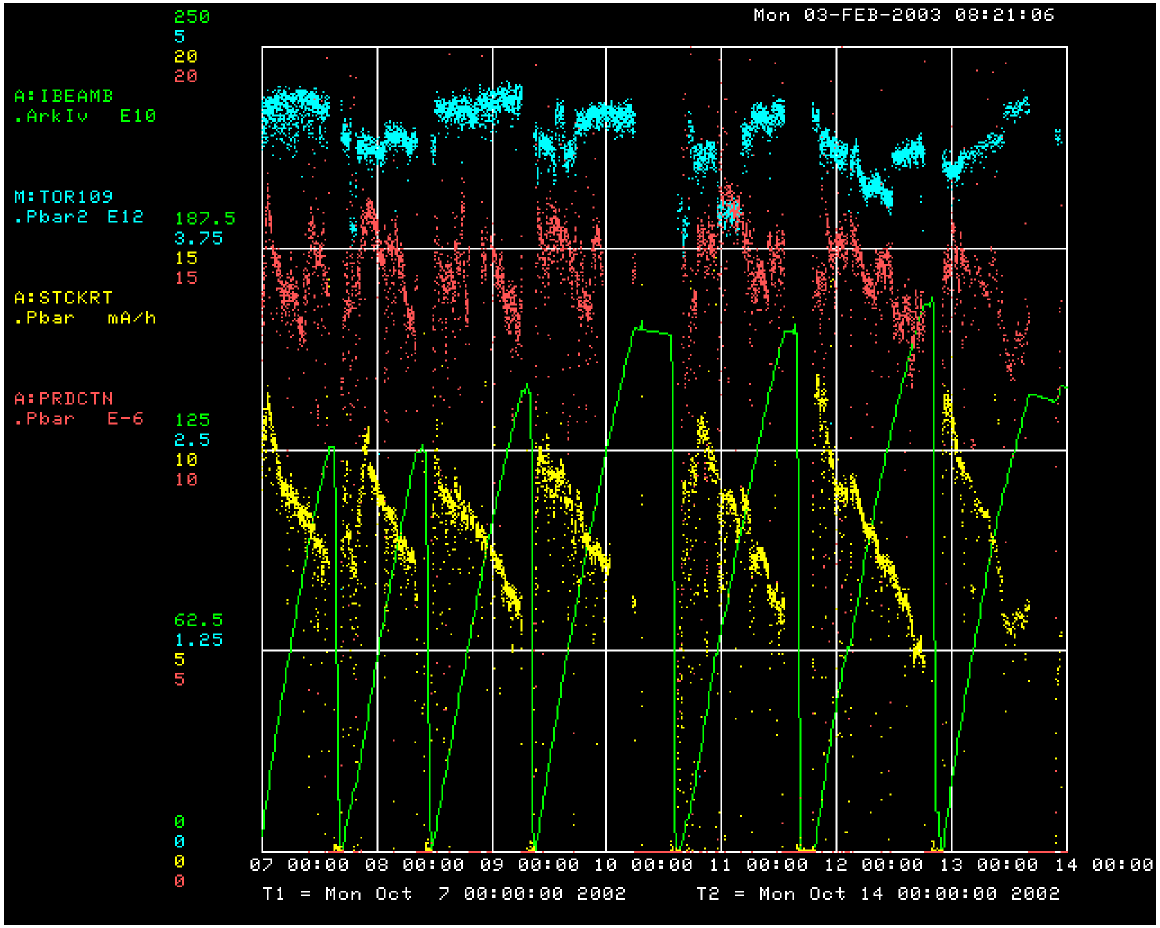
- Peak stacking rate of 13 x 10^{10} pbars per hour achieved
  - 9 November 2002
  - compared to 11 x 10^{10} in April
- Peak stack size of 225 x 10^{10} achieved
  - early December
  - previous best of 221 in 1995
- Peak weekly average 8.5 x 10^{10} /hour

Stacking

- With antiproton source emittances under control, the focus of the Antiproton Source Department has shifted to increasing the stacking rate
- We have achieved
  - an initial stacking rate of 13 x 10^{10} /hr
  - An average a production efficiency greater than 15×10^{-6} pbars/proton
  - An initial production interval of 2.2 seconds, 2.0 has been tried
  - A stack of 160 x 10^{10} in a 20 hr period
- Our immediate goal is to achieve the initial Run II design goal of 18.5×10^{10} pbars/hour with no stack
  - Production efficiency = 16×10^{-6} pbars/proton on target
  - Initial production interval of 1.5 seconds
  - Be able to stack to a 200 x 10^{10} stack in a 20 hr period.
    - Stack at 16 x 10^{10} /hr for a stack size of 50 mA
    - Stack at 13 x 10^{10} /hr for a stack size of 100 mA
    - Stack at 9 x 10^{10} /hr for a stack size of 150 mA
  - Be able to shoot from a 200 x 10^{10} stack with emittances below 10π mm-mrad (normalized)

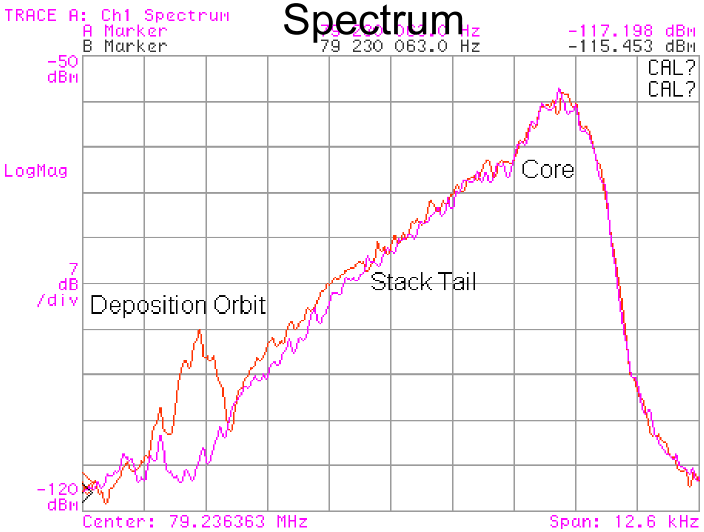
Stacking

- Stacking goals are achievable if we can reduce the initial production cycle time from the present 2.2 seconds to the design 1.5 seconds

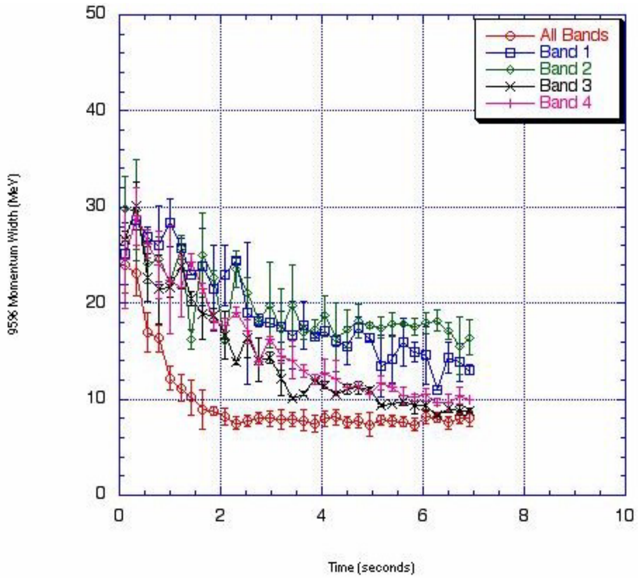


Why is the Cycle Time so Slow?

Accumulator Longitudinal Spectrum



Debuncher Momentum Spread vs. Cycle Time



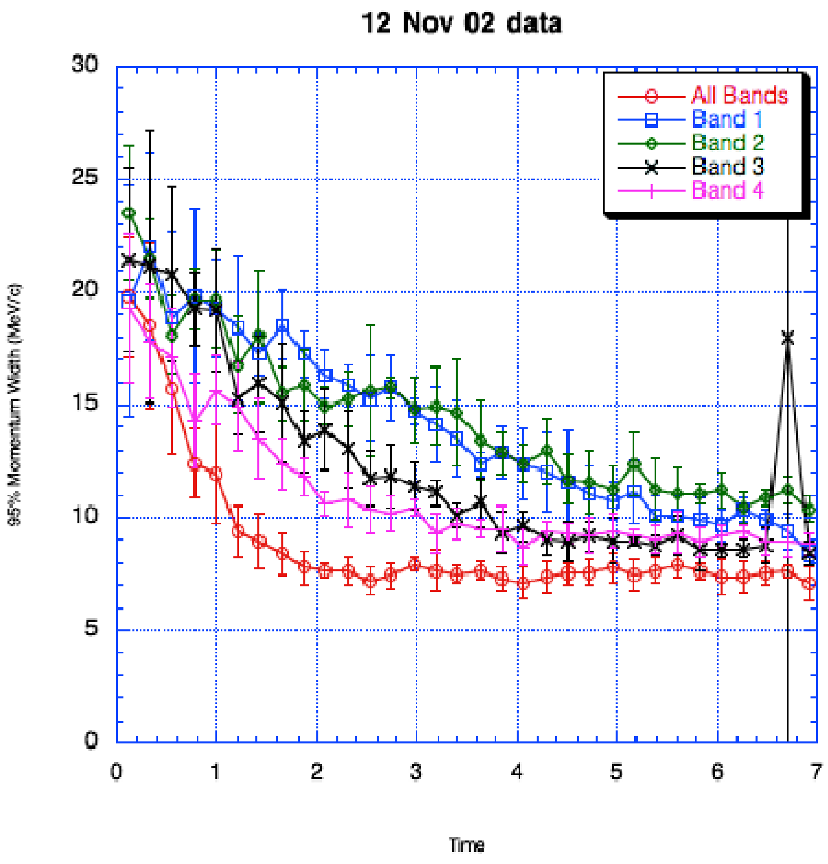
- Beam must be cleared off the Stack tail deposition orbit before next beam pulse
  - The more gain the Stack tail has, the faster the pulse will move
  - The Stack tail gain is limited by system instabilities between the core beam and the injected beam
- For a given Stack tail gain, the larger the momentum spread of the injected pulse, the longer it takes to clear the pulse from the Stack tail Deposition orbit
  - The momentum spread coming from the Debuncher is too large

Stacking Projects

- Debuncher Momentum Cooling Improvements
  - Smaller momentum spread delivered to Accumulator, which would permit faster cycle time. Faster cycle time would increase stacking rate at low and high stacks
- Transverse Debuncher Notch Filters for Bands 1 & 2
  - Removal of longitudinal lines would permit for larger transverse cooling gain which would permit faster stacking cycle times.
- Commission Core Momentum-Stacktail Compensation Legs
  - Keep the stacktail stable at high stacks. Stacktail gain could be increased. Faster stacking at large stacks would result.
- Implement Core Momentum "Spreading" during stacking
  - Keep the stacktail stable at high stacks. Stacktail gain could be increased. Faster stacking at large stacks would result.
- Stacktail Notch Filter Upgrade
  - Increasing bandwidth of the stacktail will permit faster stacking rates
- Develop Improved Transverse Compensation of the Stacktail
  - Reduce heating of the transverse heating of the core via the stacktail which would permit a faster rep rate at large stacks.
- AP1 Bunch by Bunch length monitor
  - Measure effective longitudinal emittance provided by MI so we can identify sources of emittance growth in MI. Reduce bunch length on target will permit for a faster stacking cycle time.

Debuncher Cooling

- Debuncher Momentum width reaches an asymptotic limit; it should not
- Better control (<1 ps) between center frequencies of individual bands will help
  - upgraded control installed this shutdown
- Reduce notch filter dispersion of each band
  - new equalizer design in progress



Accumulator Cooling

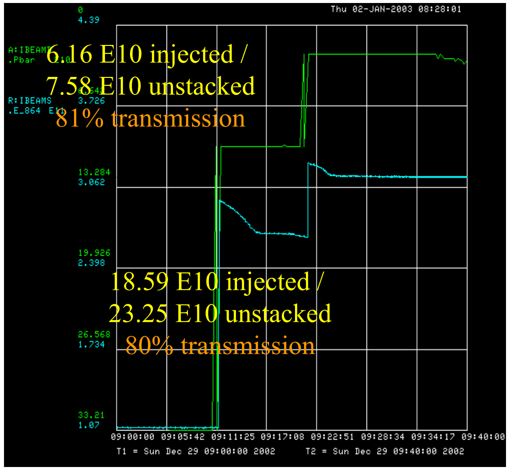
- Stack Tail Compensation attempted
  - Core feedback on the Stack Tail was reduced at Stack Tail frequencies as expected
  - But, too much gain at the core made the core unstable
  - <u>a bust</u>
- Next step
  - commission higher flux core momentum system used during stacking
  - run 2-4 GHz and 4-8 GHz systems simultaneously
- Don't go to big stacks….

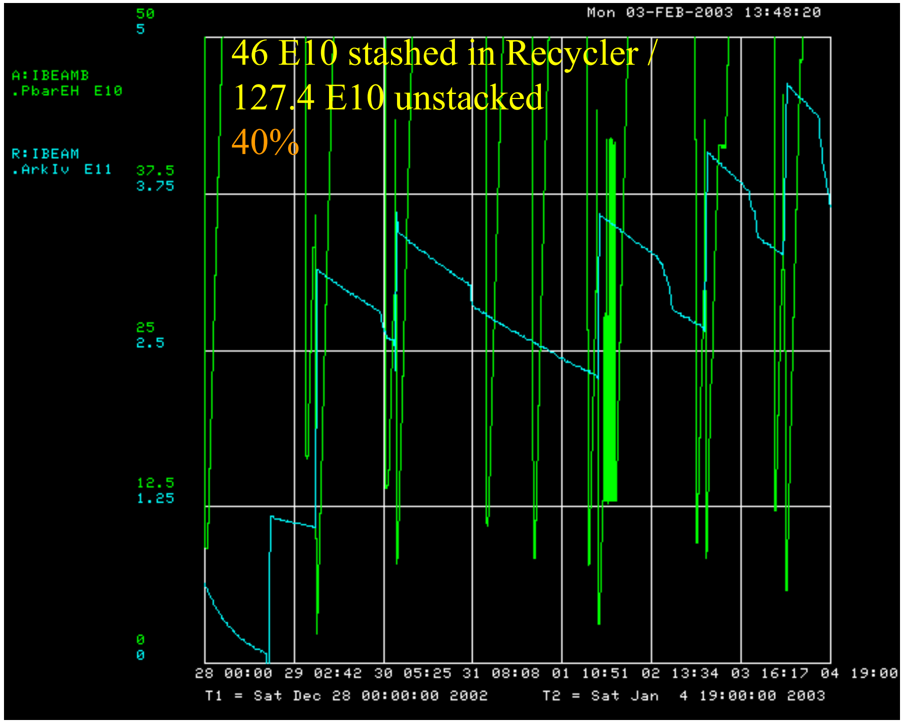
Transfers to Recycler

- Support Recycler transfers under different conditions
  - Shoot 'off of top'
  - 'Leftovers' after Tevatron is loaded
  - Dedicated stacks & transfers
- Since December 16 using dedicated stacks (20 - 40 mA) for Recycler commissioning
  - rapid turnaround: 1-hour stacking to stacking time, aiming for 30 minutes
  - stay on Stacking lattice
  - do not worry greatly about beam line tune up
  - do not wait for core to completely cool, but asymptotic limit is reached anyway
  - amount to unstack determined by longitudinal emittance instead of intensity
  - typically empty the stack in one or two transfers
  - procedures applicable to faster Shot Set-Up times

Transfers to Recycler

- Single transfers as good as 80% Accumulator to Recycler
- Short-term ‘stashing’ efficiency ~67%
- Longer-term performance requires work





Summary

- Emittance Control projects perform as hoped for and have lived up to their expectations
- Stacking and general Pbar performance continues to improve
  - Stacking rate within 70% of Run II design
- Pbar transfers are mature and the process is flexible
- Stacking with fast repetition rate to achieve design rate is a priority
  - limitations in Debuncher and Stack Tail cooling