New Bunch Train Pattern for Tevatron

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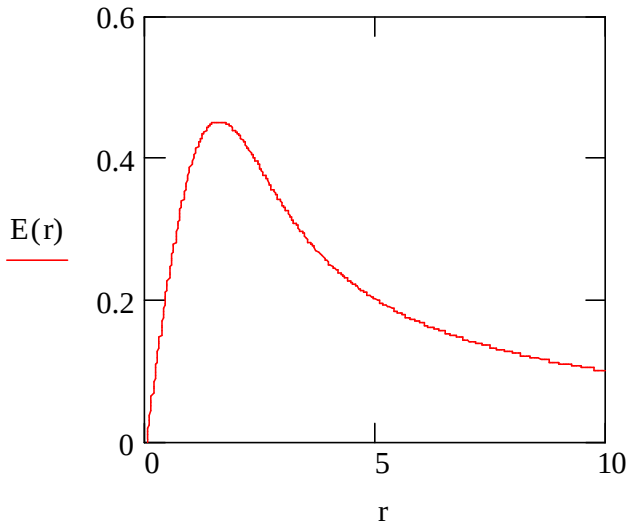
Talk outline

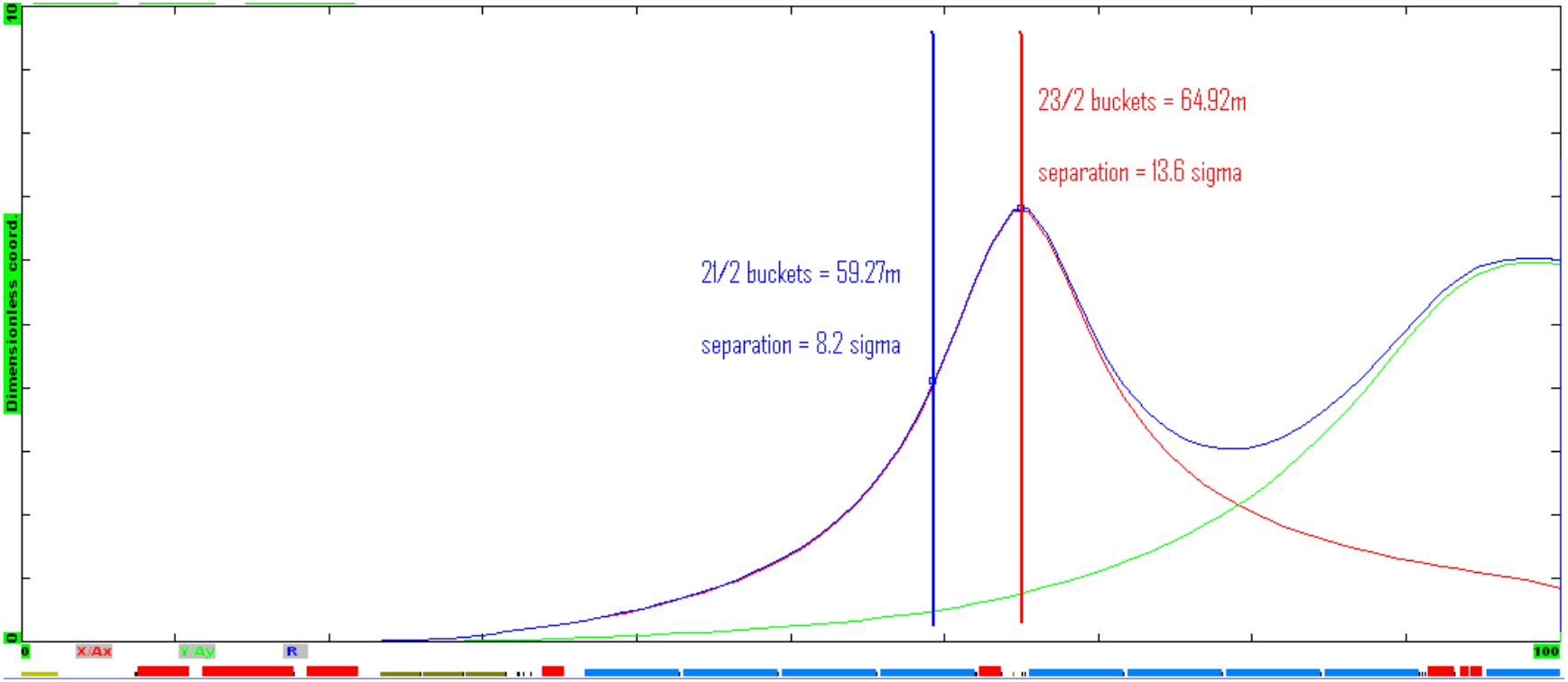
1. Introduction
2. Numerical simulations of the beam-beam effects
3. Experimental evidence
4. Operational issues
5. Conclusions

1. Introduction

- Tevatron performance is suffering from the beam-beam effects. They
  - Blow up the antiproton and proton beam size
  - Decrease the beam life time and increase losses
    - Increase background in the detectors
- Beam-beam is a multi-parameter phenomenon
  - Tunes, chromaticities, helices, phase advances between IPs Different for different bunches
- Much of the effect is attributed to the action of Long Range (Parasitic) collisions driving nonlinear betatron resonances.



Beam Separation in the Nearest Long Range Collision Point



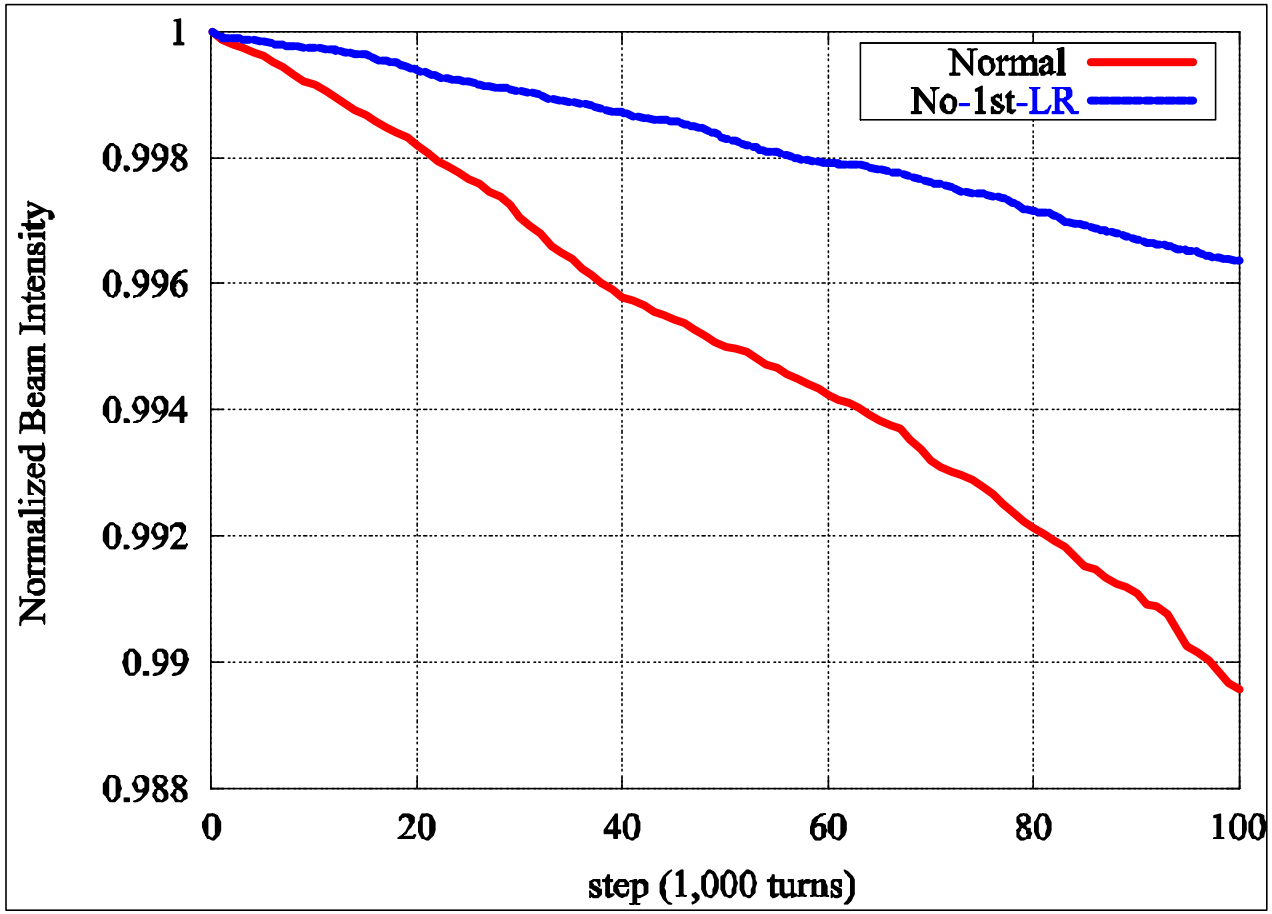
- Wwith 3 trains of 12 bunches the separation of beams in the nearest parasitic collision is 1.5 times smaller than the average, and these collisions dominate beam-beam effects.
- Increasing the bunch spacing increases the separation
  - 3x12 -> 3x11. The length of abort gap is conserved

Means to suppress beam-beam effects

- Tunes (every store)
- Reduced chromaticity (is being addressed presently)
  - Octupoles
- Phase advance correction between Main IPs (more simulations and studies are required)
- Helix size increase (upgrade project)
  - Little affect on nearest parasitic IP
- Changed beam separation
  - The only item which affects the detectors

2. Numerical simulations of the beam-beam effects

Influence of the First Long Range Collision



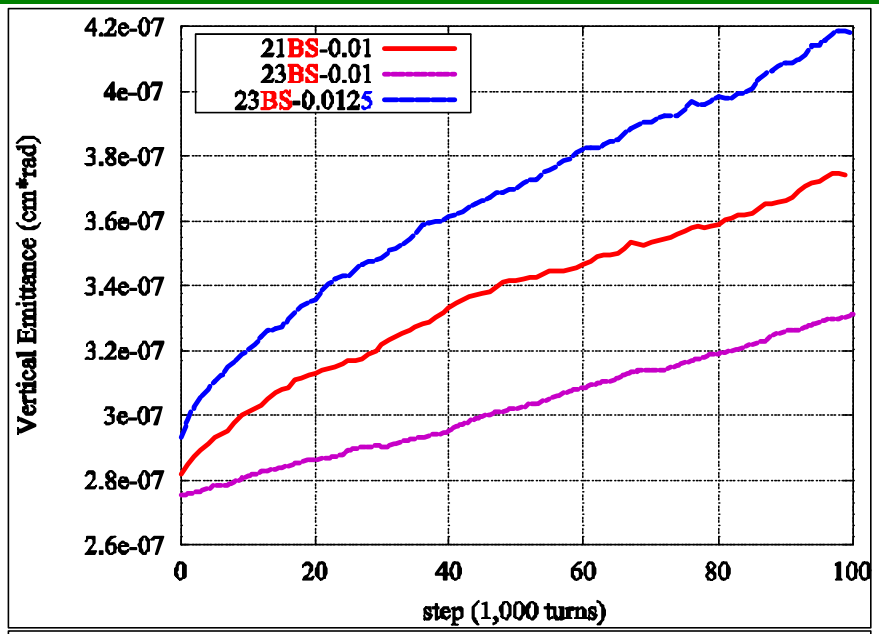
Red curve – present configuration,

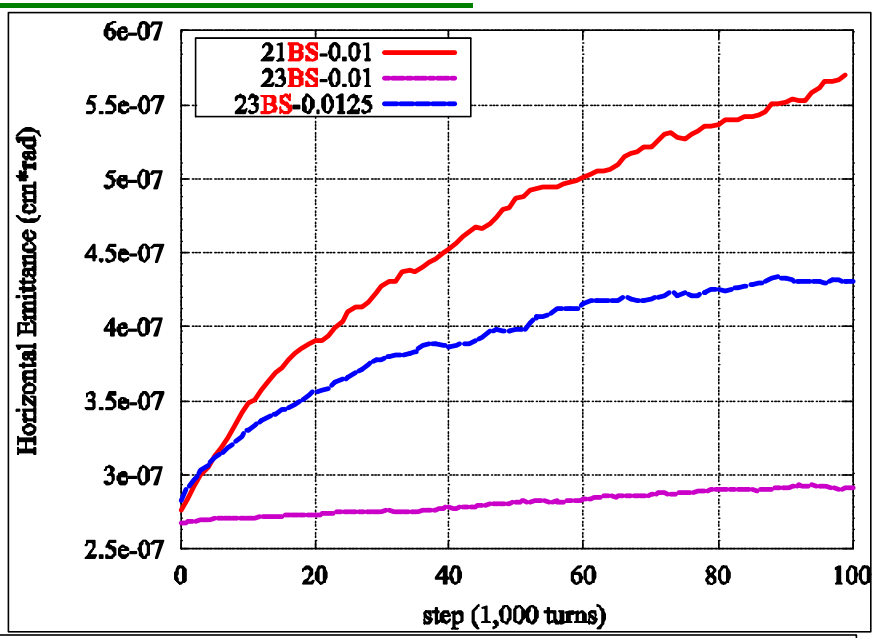
blue curve – the nearest (to the main IP's)

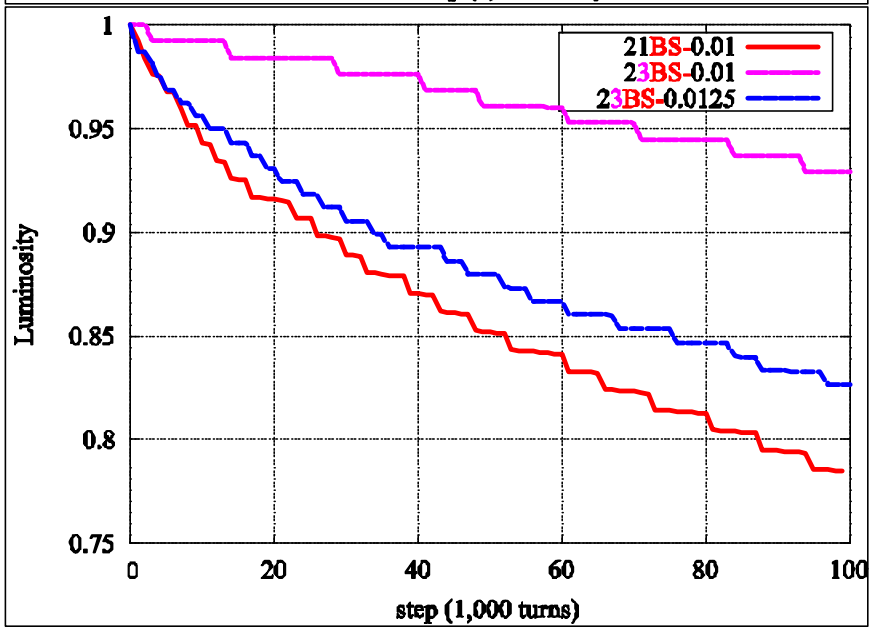
long range collision points are excluded and

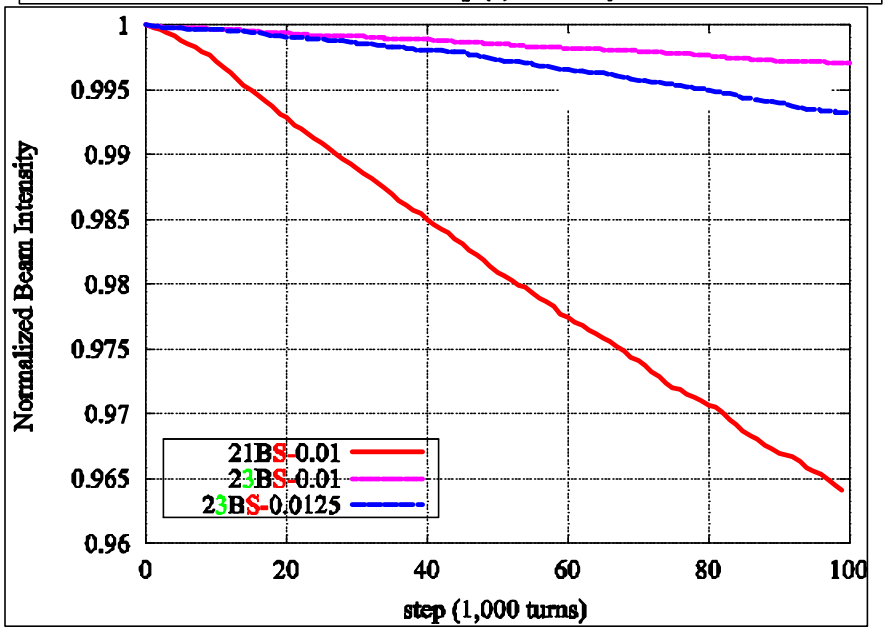
machine base tunes are corrected to achieve the same actual tune betatron tunes

21 Bucket Spacing Pattern vs. 23 BS for bunch 5



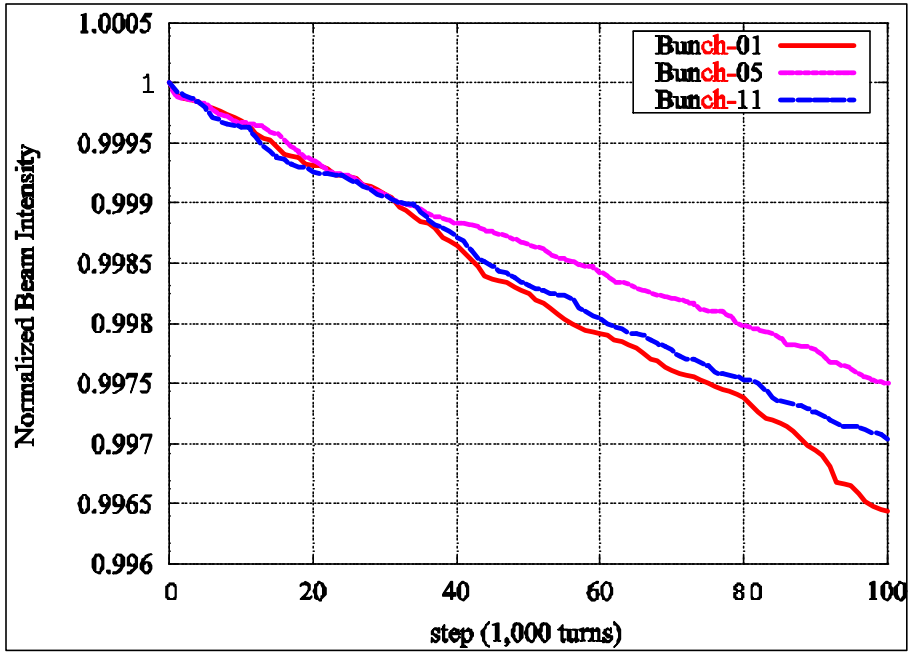


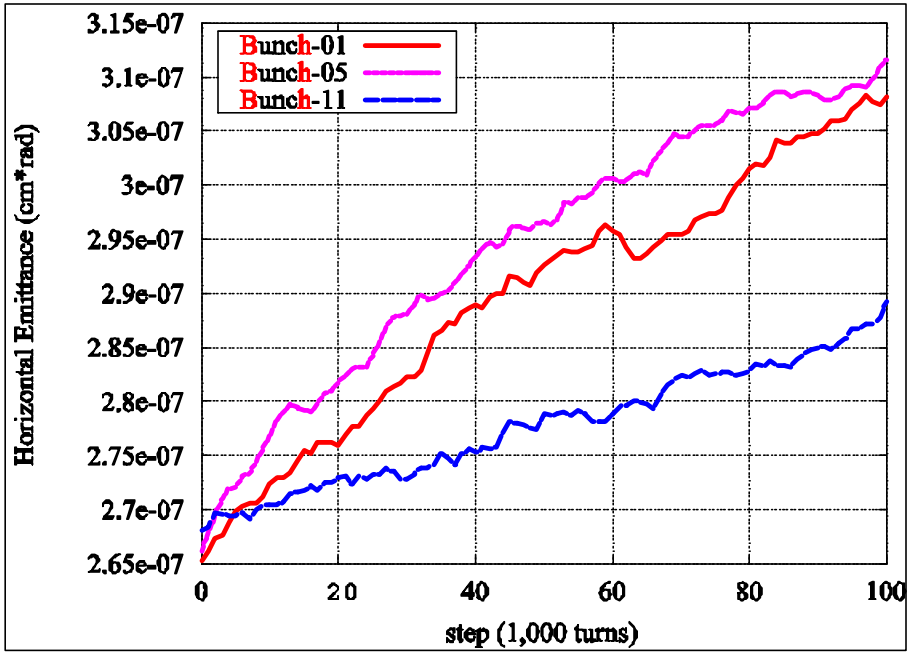




Curve labels mark Pattern and Beam-Beam Parameter

Behavior of Different Bunches in the Train

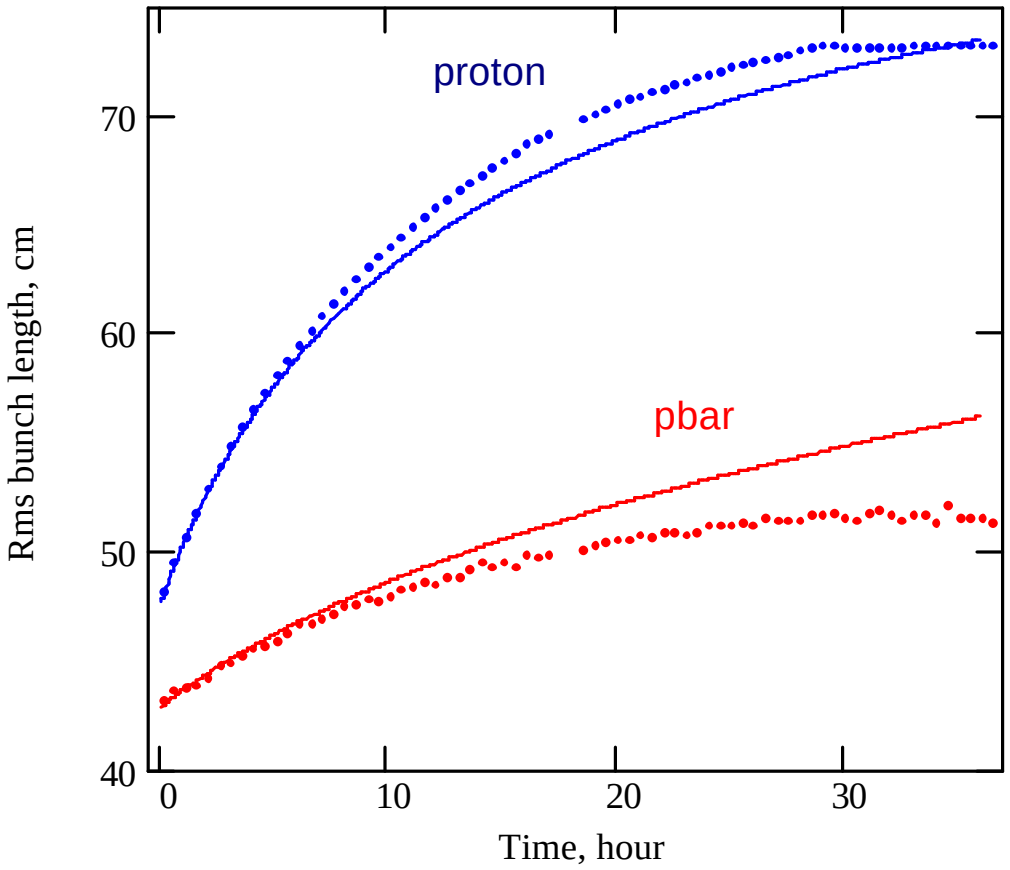




- Simulations verify predictions of analytical theory:
  - the long range interactions are important
  - The nearest collision points make the main contribution.
- Changing bunch train scheme in the Tevatron from 12x3 to 11x3 one can increase the beam separation in these points.
- Simulation predicts at least 20% increase in the maximum attainable beam-beam parameter for antiprotons

3. Experimental evidence

- Pbar bunch lengthening is strongly suppressed
- Intensity decays faster due to beam-beam effects
- These problems will be significantly worse with increased pbar intensity!!!



4. Operational issues

RF in MI

- Operational issues (kickers) Both Accumulator and MI do not support multi-bunch operation with 23 bucket separation:
  - MI: 588 buckets of 53.1 MHz RF = 3*4*7*7
    Possible separations: 3,4,12,21,28,49,147…
  - Bunches separated by 23 buckets cannot be accelerated in MI
  - Although we could accelerate bunches with 53.1 MHz RF and 23 bucket separation we cannot coalesce them in MI
- That sets that only one pbar bunch can be accelerated in MI
  - Accumulator cannot be used to prepare a single bunch
  - There is no severe limitations on Recycler to make possible a single bunch transfers to MI
- 33 bucket scenario implies that electron cooling is fully operational and the entire shot goes from Recycler

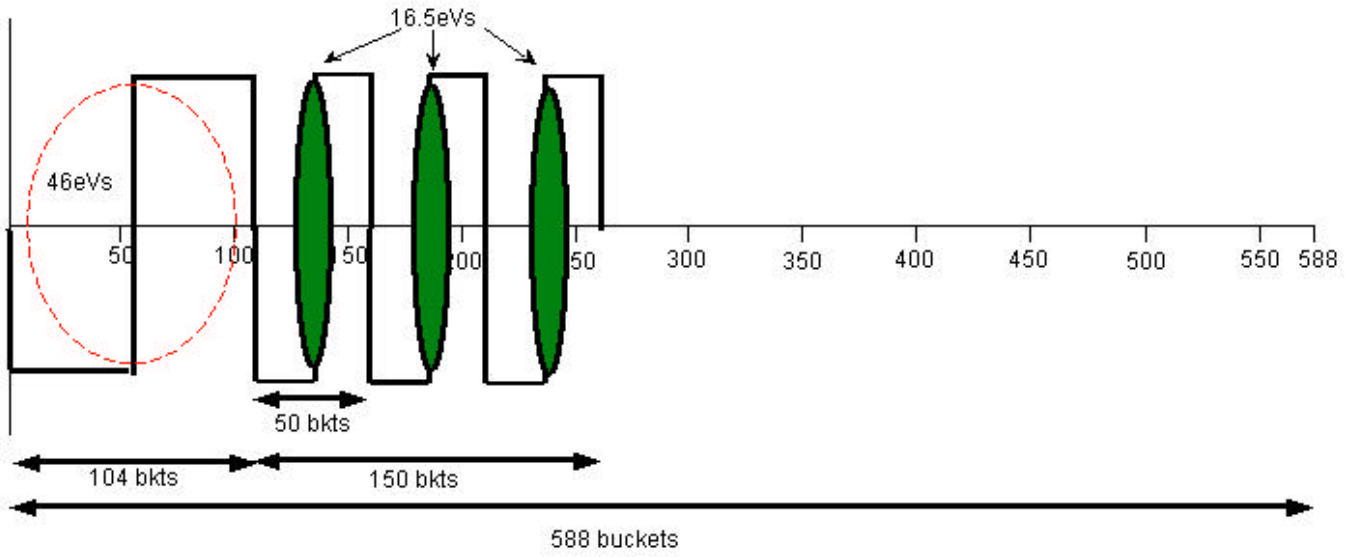
Kickers in MI and Tevatron

- Abort Gap in Tevatron is one bucket longer
  - Present (1113-21*11*3)/3=140 buckets
  - Future (1113-23*10*3)/3=141 buckets
- No affect in the abort scheme
- We already inject proton bunches one-by-one
- Only timing/cogging will need to be adjusted
- There is no problem to use present pbar kickers to inject pbars from MI to Tevatron
  - Similar to present operation pbar bunches are injected in the proton abort gap at the leading side of kicker pulse one-by-one from bunch 1 to bunch 11

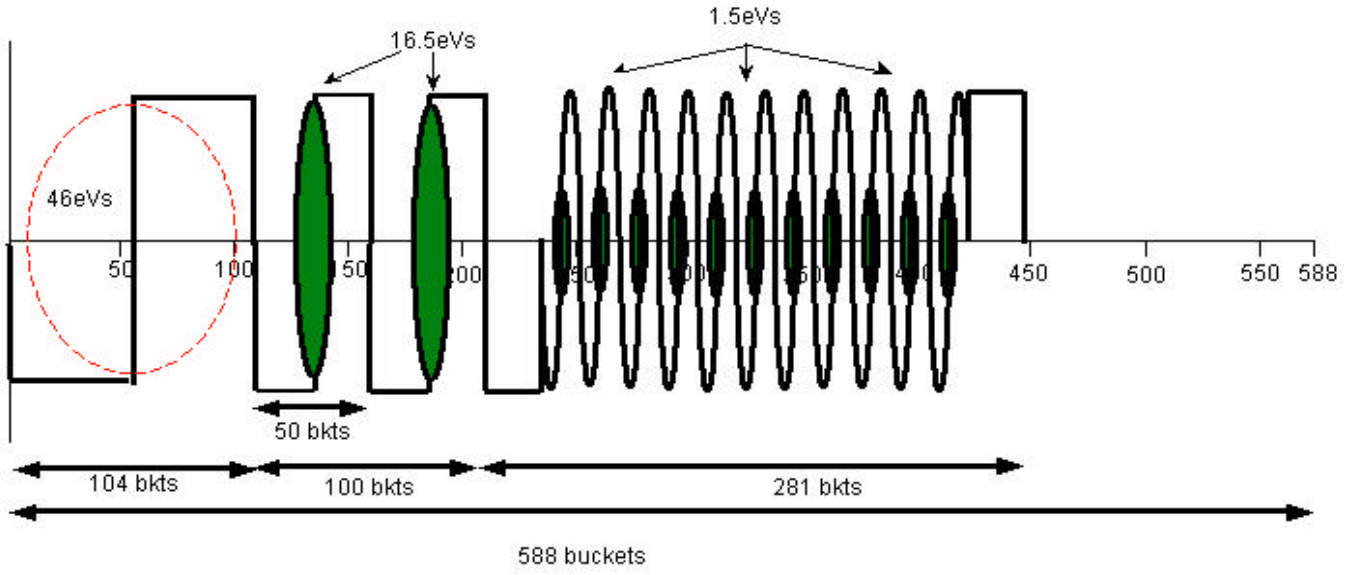
Recycler Issues with the 33 by 33 Collider Mode of Operations

- Being able to mine out 33 transfer would be very similar to what is currently being done. But, there are some issues that would need to be addressed;
  - Tighter requirements on longitudinal emittance
    - Cooling equilibrium point would be reduced by about 10% from 54 eV-s to 49.5 eV-s to maintain the same 1.5 eV-s
  - RR Pbar extraction kicker
    - Raise time is currently 300 ns is desired to be shortened
      - Affect how fast bunches can be extracted
    - Quality of flat time level
    - Kicker timing adjustment/stability
  - LLRF
    - Morphing of 2.5 MHz waveform

- The mining process would be the need to be modified slightly.
  - The initial starting point would be the same; Cold beam stored in two standard square barrier buckets (48 buckets wide)
  - The mining process changes slight from mining 54 eVs to be able to 49.5 eV s. Instead of growing 9 6 eV s buckets we would grown 3 16.5 eV s buckets
  - Once the 3 16.5 eV s buckets have been mined there are two methods of extracting them. Once a quick rapid fire technique the second is a slower pulse-by-pulse extraction. The time difference for these extraction will be driven by these two modes.
  - Rapid mode: to extract all 33 bunches in the rapid mode will take about 20 mins.
  - Slower mode : to extract all 33 bunches in the rapid mode will take about 45 mins.

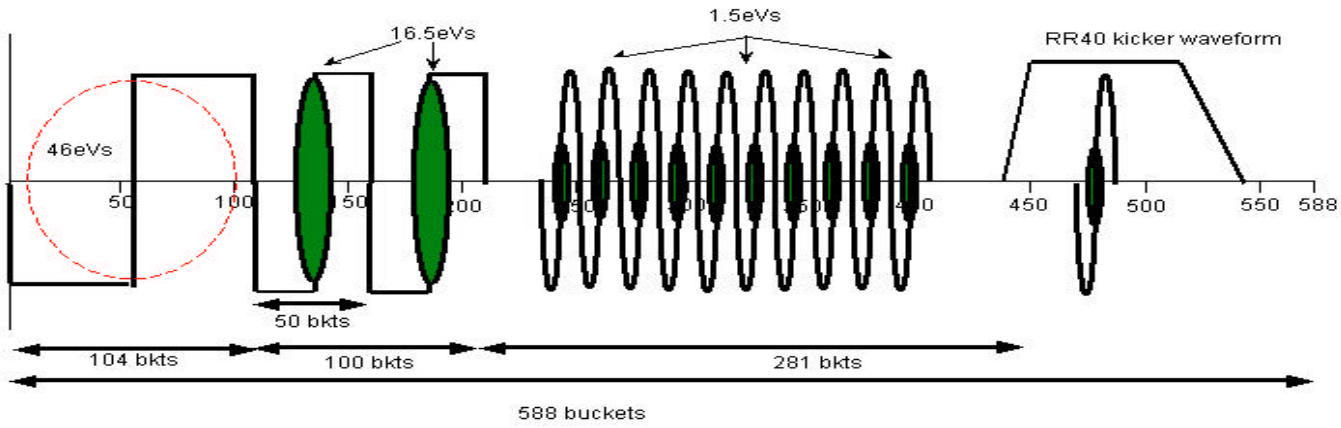


Instead of growing 9 6 eV s buckets we would grown 3 16.5 eV s buckets.

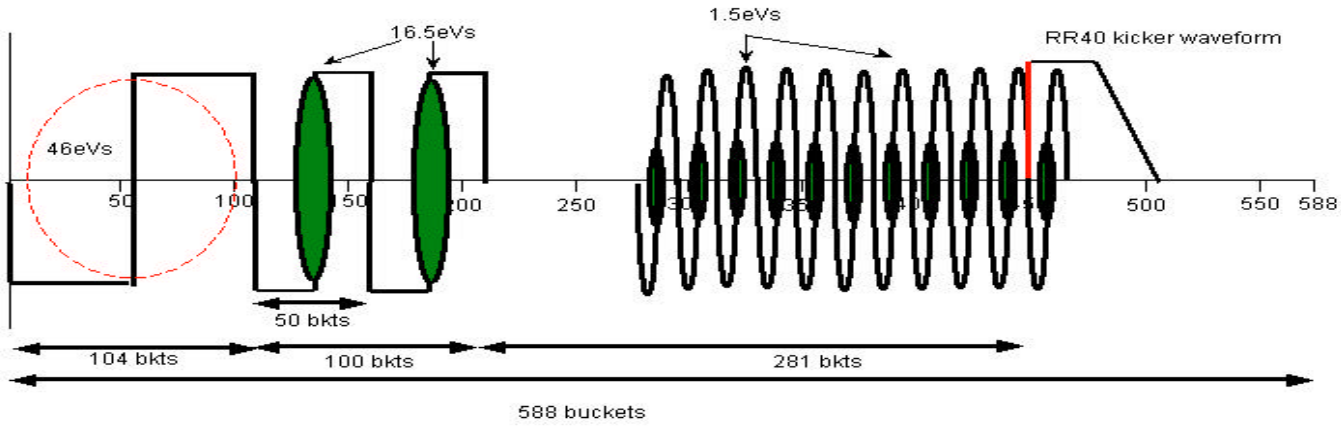


Each bucket is then stretched out and 11 1.5 eV s 2.5 MHz bunches are created.

Extraction

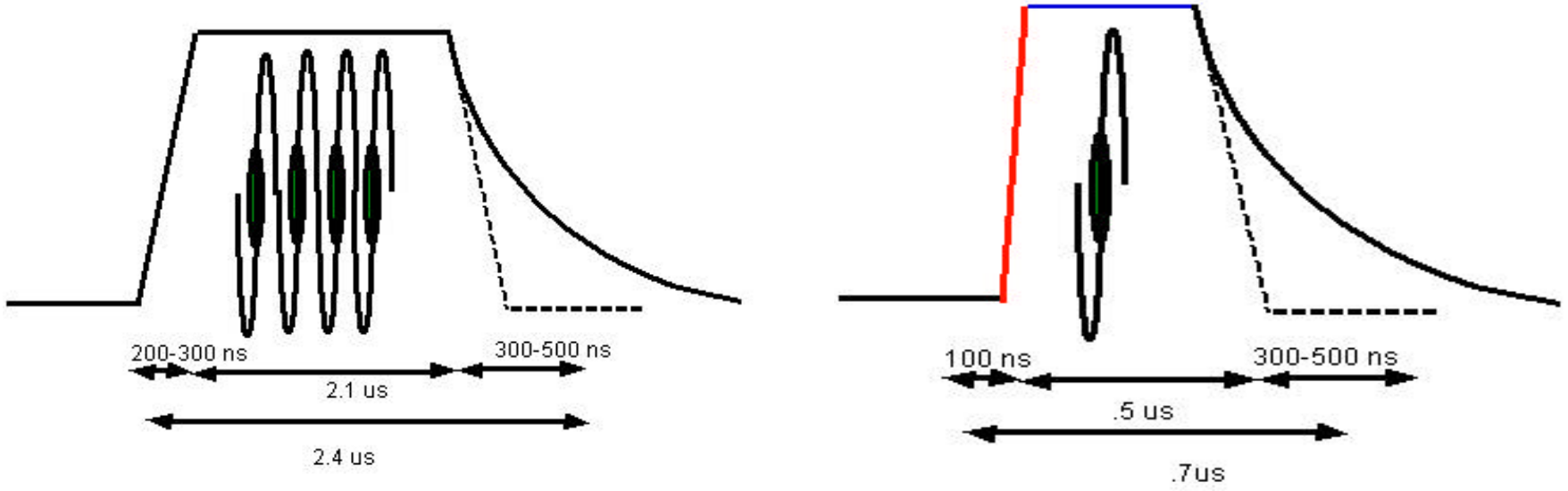


Slow mode requires no changes to the current kicker wave form. Current estimate is that we can transfer one bunch about every 45 secs to a 1 minute.



Rapid mode would require some major changes to the extraction kicker. On the order of 1 transfer every 15 secs.

Recycler extraction kicker



- The left hand image is an approximation of the kicker waveform as it currently being used today.
- To speed up the process we need to make changes to the kicker power supply and magnet, the (red trace) rise time needs to be fast enough to slip between two 2.5 Mhz RF cycles, (blue trace)
  - adjustment to the PFN (pulse forming network) may or may not be needed it depends on the power supply response (all times shown above are approximations)

Conclusions

- 33 bunch scenario requires fully operational electron cooling in Recycler
  - Initially, no other hardware changes are necessary
    - Recycler kicker replacement would make pbar transfers faster
  - After everything is tuned 36->33 change and vice versa do not require additional time for shot setup
- At zero-th order luminosity stays the same
  - Number of protons per bunch stays the same
  - Total number of pbars is fixed $\Rightarrow$ Number of pbars per bunch grows by 9% due to smaller number of bunches
- 33 bunch scenario strongly alleviates Beam-beam effects
  - Peak luminosity is expected to grow by ~20% due to larger number of protons per bunch (Np=2.5E11 -> 3.0E11)
    - Improvements of proton source are required
- IBS in pbar will be stronger

  => Luminosity integral will be dropped ~1%

- Luminosity integral for 24 hour store will grow by ~13%
- Affect on the experiments needs to be understood
  - 9%=(12/11-1) larger number of interactions per crossing
  - How transition from 395 ns to 433 ns