PIP and the Booster Notch

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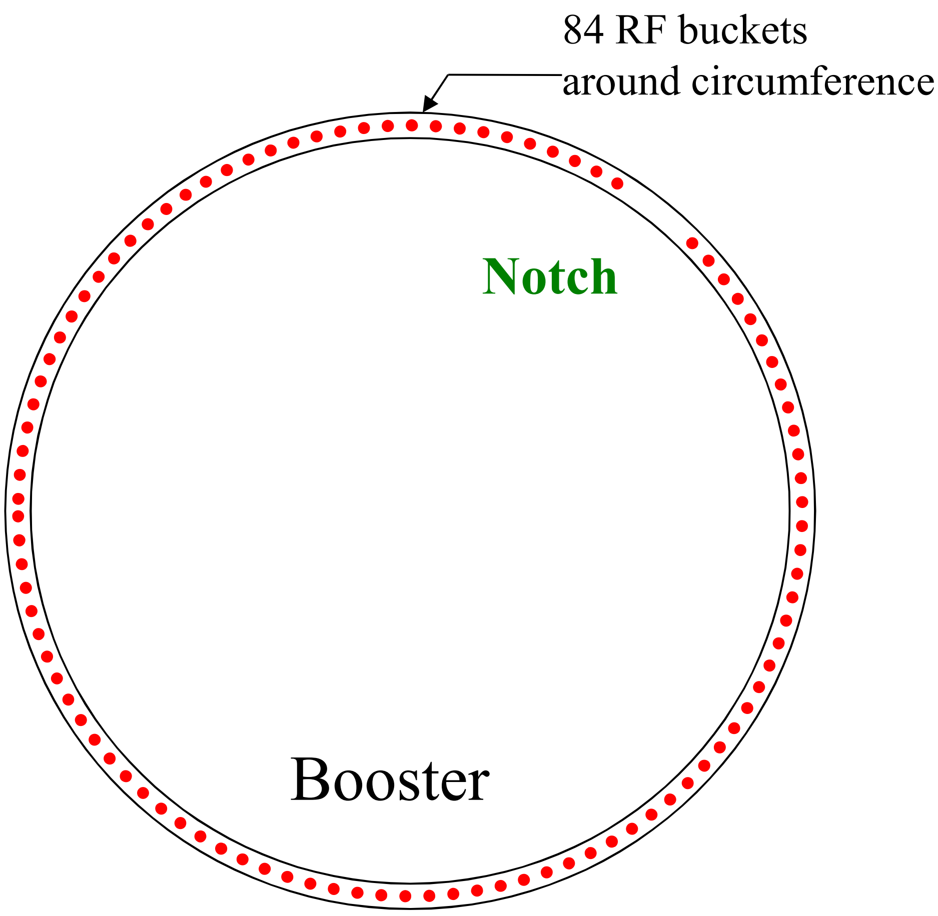
PIP Meeting

Introduction

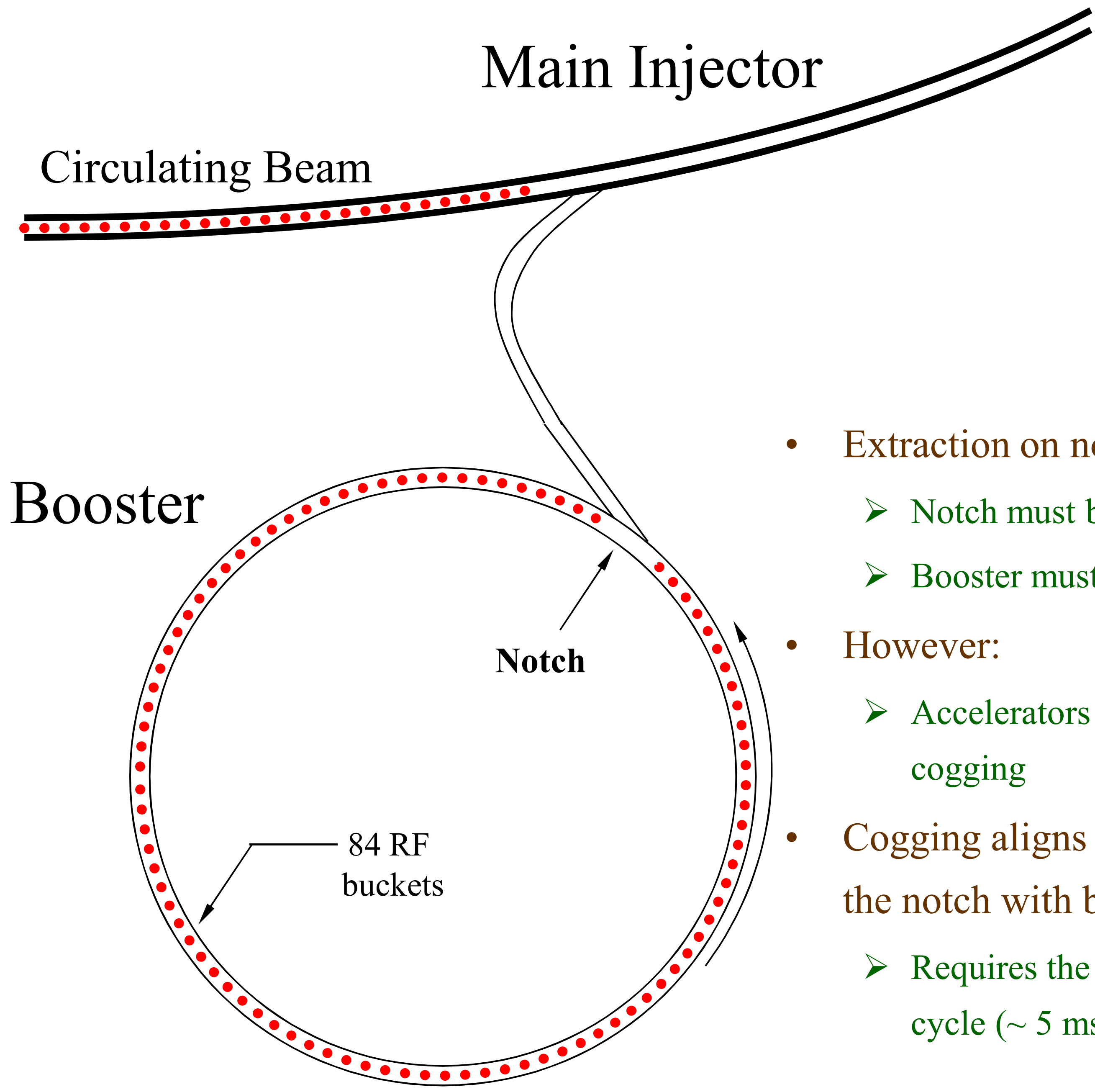
- Making the Booster notch causes losses
  - ➢ With improvements in cycle efficiency, now a significant fraction of Booster losses
  - ➢ Doubling the throughput requires ~ halving the losses
    - Notching losses need to be reduced or eliminated\
    - Can't be done by tuning
  - ➢ This is a significant piece of the path towards meeting the PIP goals
- 3-stage process to address notch losses:
  - ➢ Notcher relocation: partially control notch loss
  - ➢ Magnetic cogging: make notch at start of cycle
  - ➢ Linac notching: move notch out of the Booster

The Notch

- Extraction kicker has risetime of ~ 40 ns
  - Negligible space between buckets with bunch rotation
- Beam lost at 8 GeV during extraction
- Instead, beam is removed at 400 MeV
  - Reduces energy lost 20x
- Notcher is an extra extraction kicker magnet with short PFL at Long 5
  - An additional Nocker cleans up the notch



Cogging

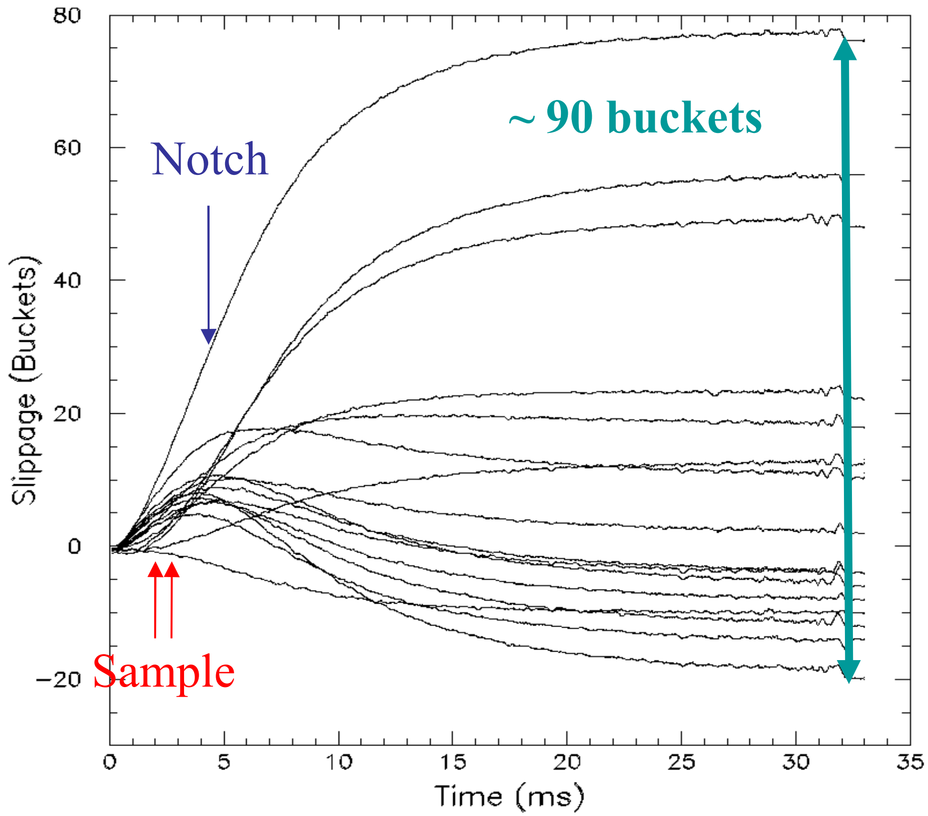


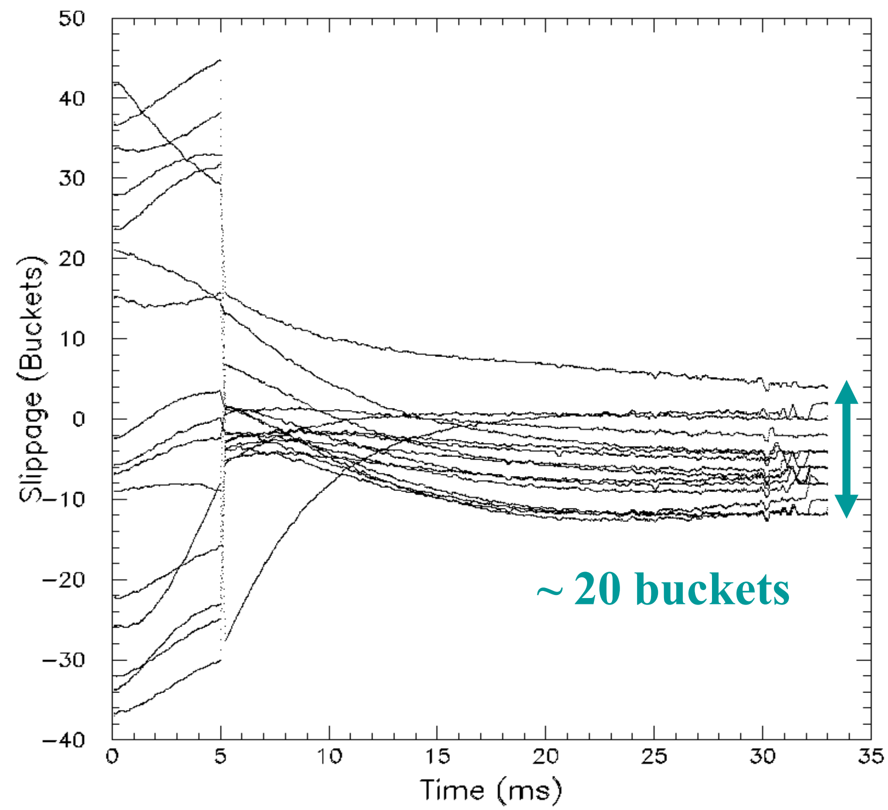
- Extraction on notch
  - Notch must be coincident with kicker pulse
  - Booster must be aligned with MI beam
- However:
  - Accelerators are only synchronized with cogging
- Cogging aligns the azimuthal position of the notch with beam in the MI
  - Requires the notch to be made later in the cycle (~ 5 ms)

Predictive Notching

- Delay creation of the notch 5 ms for cogging
  - Use information from that initial period
  - Make notch anticipating further slippage
- Reduces bucket range by a factor of 5
  - Feedback takes care of the rest

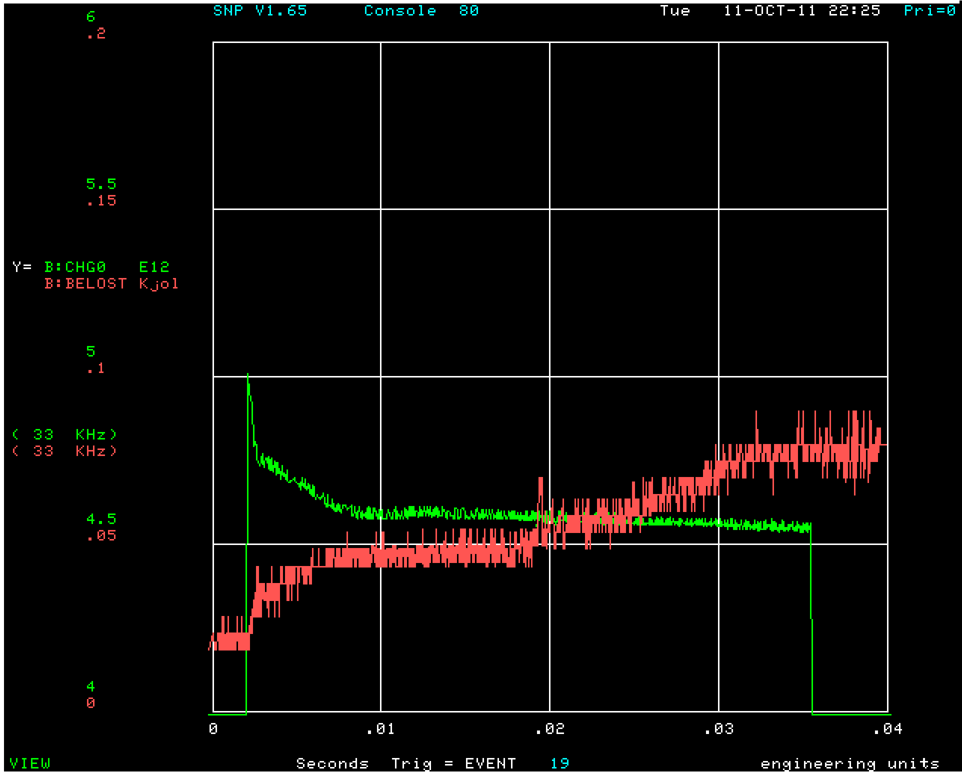
w/o correction and w/ correction





Losses

- About 3 % of the beam is notched out
  - ➢ 2.x buckets ~ 0.2e12
  - ➢ ~ 20 J / notch -> @ 15 Hz 300 W
  - ➢ About 30 % of the total power lost in the Booster

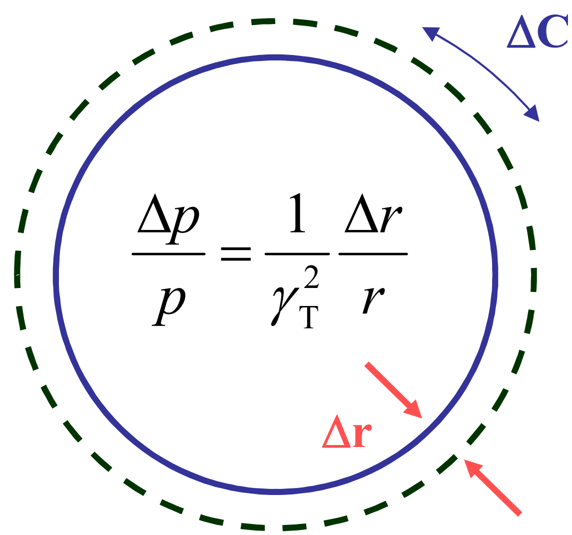


1st Step: Notcher Relocation

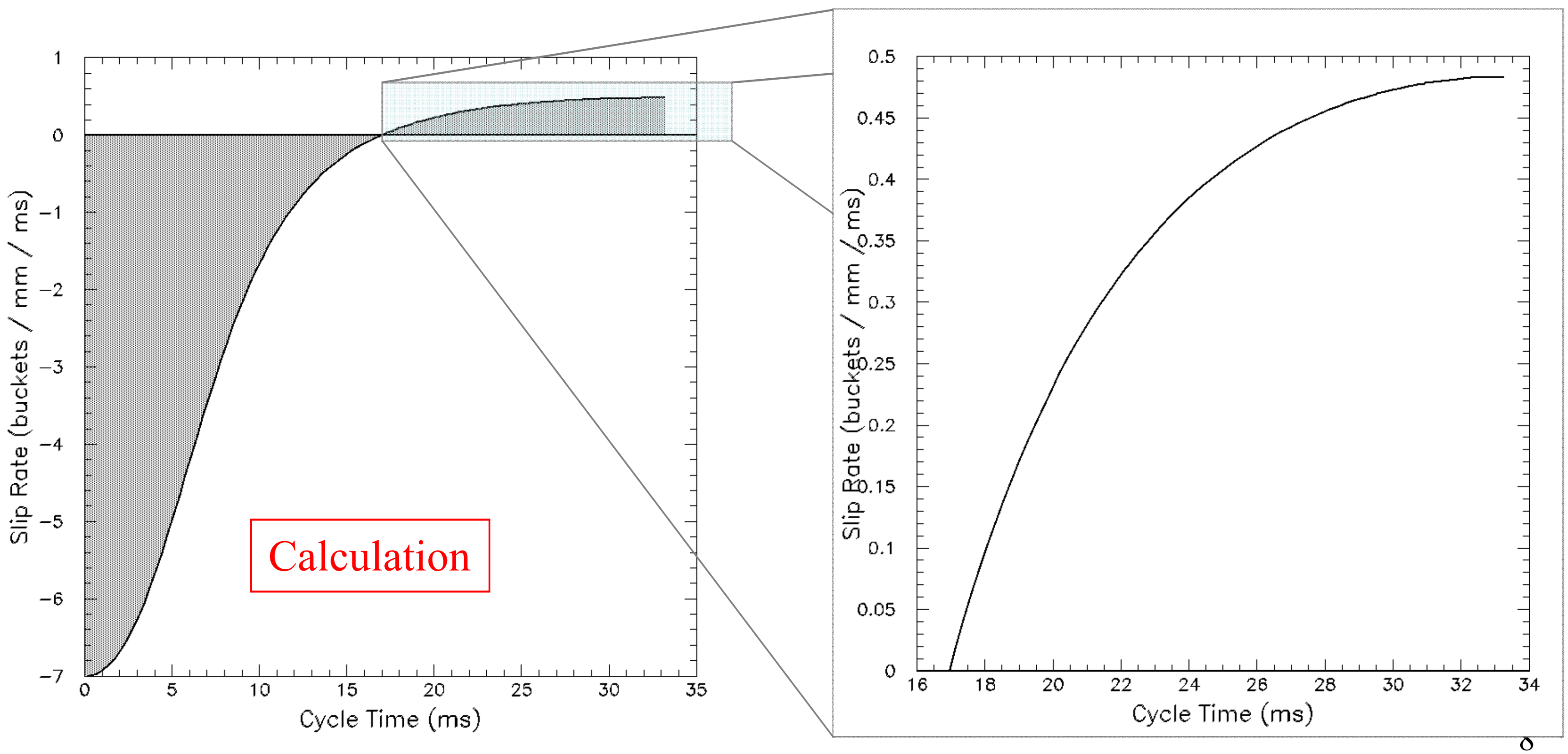
- In present location, the notcher fires the beam into a gradient magnet
  - Mostly inescapable result of Booster lattice
  - Few gradient magnets are heating up, damage possible
- Scheme to relocate notcher to long 13
  - Presentation by V. Sidorov two weeks ago
    - Also work by Drohzdin, Lebedev, Tropin – talks in future
  - Notched beam will be mostly collimated there
    - However, the loss will still be in the Booster, and not totally contained
- This will protect our magnets and be important in future schemes as well

RF Cogging

- Present cogging system uses RF to force slippage in the beam
- Induced slippage scales with radial offset
  - Rates of ~ 1 kHz/mm
- Not enough to cog unless we make the notch 5 ms into the cycle
- Earlier notches, or linac notches are not compatible with the present cogging system



$$\frac{\Delta p}{p} = \frac{1}{\gamma_T^2} \frac{\Delta r}{r}$$



2^{nd} Step: Magnetic Cogging

- New Booster correctors allow the possibility of cogging magnetically
  - New correctors are substantially stronger and faster than previous ones
- Magnetic cogging works by using feedback to change the horizontal dipoles in all (or a large fraction) of the correctors
  - The orbit remains constant, in contrast to RF cogging
    - The momentum of the central orbit changes
    - Aperture is not an issue, only corrector strength
  - Much stronger at the start of the cycle
    - Can deal with the notch in an arbitrary location
    - May still need RF cogging late in the cycle – a hybrid system
- This will immediately allow notching earlier in the cycle, reducing power loss
  - Also a prerequisite for any linac notching to work
- Kiyomi Seiya is working on this – presentation in future

3rd Step: Linac Notching

- Making the notch in the Linac
  - Similar concept as Booster, but the notch has to be made for every turn added to the Booster
    - Typically would be 10-12 65 ns notches spaced 2.2 us apart
- Moves the loss entirely out of the Booster
- Requires timing and probably needs to be integrated into the cogging module
  - Even thought the notch will pre-exist the beam in the Booster, cogging will need to know where it is, and can possibly have a preferred position
- Some spreading of the beam will occur before capture in the Booster, but this will be a small amount
  - Notcher/nocker can still fire to clean up notch, but cause many fewer losses in the Booster

Several Options for Linac Notching

- Electrostatic notching
  - ➢ Pulser in the pre-acc (LEBT, maybe MEBT)
    - Tested by Doug Moehs several years ago
    - Had issues with long tail
      - Not clear if it was neutralization, poor matching, or RF loading in the Linac
  - ➢ Deflector Kicker
    - Probably can't charge up for multiple notches – would need a deflector for each notch
- Magnetic notching
  - ➢ Kicker in the linac (higher-energy)
    - Can't charge up the PFN fast enough between notch pulses
- Laser notching
  - ➢ Use laser to remove electrons from the beam
    - Convert H^- to H^0
  - ➢ Separate with magnets and direct H^0 into a dump
    - At low energy this might not even be necessary
  - ➢ Dave Johnson has been investigating this
    - Based on experience with laser profile monitor
    - Initial thoughts look reasonable, Dave will present in future

An Example System

- Linac beam is notched out by pulsed laser in the 400 MeV line
  - 12 successive notches of 65 ns, separated by 2.2 us
  - Remove > 90% of the beam in the notch
  - Notched beam directed into dump at floor
- Notched pulses are injected on top of eachother into the Booster and capture by the RF
- Notcher and nocker fire, cleaning out the notch entirely
  - Notched beam lost in collimator at Long 13, and it is only 10 % of what we had before
- Cogging system takes over the synchronization using initially the corrector magnets, and finally the RF position feedback

This scheme reduces losses in the Booster by ~ 30%

Summary

- With the present notching scheme, at 15 Hz we would be putting 300 W of losses into the Booster from the notch alone
  - ➢ This loss would be localized in a few gradient magnets
- We have a 3-stage approach to eliminating the losses from the notch
  1. Modify the notcher arrangement in the Booster
     - Long shutdown
  2. Cog with the corrector magnets
     - Under study now
  3. Make the notch in the Linac
     - Still looking at options

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