Milestone
• Lasing with 800 bunches, >10 µJ/pulse

Macropulse Views
• Charge, compression, orbit, ...
• Spectra of oscillations

Problems & Improvements
• Gun water regulation
• Beam loading compensation & adaptive feedforward
• ACC1 phase feedback
The Way to the Milestone

- Startup: Lasing with few bunches, 10–20 µJ, 690 MeV
- Increased RF pulse lengths to ~850 µs
  - ACC2-6: no problem
  - ACC1: unstable at 122 MeV energy gain, gradient reduced by 5–10 %
  - Gun: sparks with long pulses, re-conditioning needed
- Optics: design op2-v4 matched in UBC2, but energy after ACC1 changing frequently

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The Way to the Milestone

• LLRF problems solved:
  – No feedback on the gun because $P_{fwd}$ setpoint above soft limit
  – No adaptive feedforward on ACC2–6 because state machines not working

• Limited by beam losses in undulator 1
  – Much manual tuning required
The Milestone

- Milestone: Lasing with 800 bunches, >10 µJ/pulse achieved

...without destroying the machine

800 bunches at 685 MeV
electron beam: 2.7 kW
photon beam: 56 mW

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Macropulse Views
First ~20 bunches

Mean pyro signal per bunch at pyro 9DBC2.1

Mean signal: 
\((-0.21068 \pm 0.01157\) a.u.
Relative stability: 
\(\pm 5.49\%\)

Mean pyro signal per bunch at pyro 4DBC3 (4DBC3.3)

Mean signal: 
\((-0.17792 \pm 0.00818\) a.u.
Relative stability: 
\(\pm 4.60\%\)

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Pyro ECOL / Charge 3GUN

Mean pyro signal per bunch at pyro D7ECOL (4DBC3.1)

Mean charge per bunch at toroid 3GUN

beating frequencies: ~70 kHz

injector laser: not able to adjust pump power/timing for flat charge profile

mean signal: 
\((-0.09651 \pm 0.00436)\) a.u.
relative stability: 
\(\pm 4.52\%\)

mean charge: 
\((0.663 \pm 0.014)\) nC
relative stability: 
\(\pm 2.07\%\)

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Charge Oscillations

Spectrum: toroid 3GUN

- 66.3 kHz
- 72.5 kHz

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BPM 1GUN

Mean bunch position at BPM 1GUN (x)

mean position: 
(-0.76806 ± 0.01917) mm
relative stability:
± 2.50%

oscillation: ~8 kHz

Mean bunch position at BPM 1GUN (y)

mean position: 
(0.37889 ± 0.03986) mm
relative stability:
± 10.52%

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BPM 2UBC2

Mean bunch position at BPM 2UBC2 (x)

mean position: (0.05522 ± 0.01625) mm
relative stability: ± 29.42%

Mean bunch position at BPM 2UBC2 (y)

mean position: (-0.70717 ± 0.01938) mm
relative stability: ± 2.74%

2007-10-21T191809.mat
Mean bunch position at BPM 1DBC2 (x)

- Mean position: (2.70061 ± 0.01170) mm
- Relative stability: ± 0.43%

Mean bunch position at BPM 1DBC2 (y)

- Mean position: (−0.12207 ± 0.00746) mm
- Relative stability: ± 6.11%

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fast oscillation: 250 kHz

mean position: 
\(-2.13314 \pm 0.03338\) mm
relative stability: 
\(\pm 1.56\%\)

mean position: 
\(-0.62388 \pm 0.01238\) mm
relative stability: 
\(\pm 1.99\%\)
Orbit Oscillations

Spectrum: BPM 1DBC3 (x)

250 kHz  Should be improved by ripple table!
250 kHz oscillation
peak-to-peak:
~ 90 µm

mean position:
(-0.55514 ± 0.02637) mm
relative stability:
± 4.75%

mean position:
(0.19758 ± 0.01027) mm
relative stability:
± 5.20%

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bunch energy (MeV/particle)

>2 MeV (~ 0.3 %)
Problems & Improvements
At 850 µs gun flat top, the temperature is not stabilized anymore.

reflected power interlock  reflected power interlock

no operator action  manual tuning

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At 850 µs gun flat top, the temperature is not stabilized anymore.
Beam Loading Compensation

ACC1 toroid-based beam loading compensation

+ immediately adapts to number of bunches
- have to tune amplitude, phase, start time
- does not get the vector sum right
Adaptive Feedforward

Adaptation of feedforward tables by state machine (A. Brandt)

- slow (30–60 seconds to adapt to changed number of bunches)
+ almost foolproof (no tuning of parameters required)
+ flat vector sum except high frequency disturbances

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ACC1 Phase Feedback

- regulates ACC1 phase based on pyro signal of
  - single bunch, or
  - average of all bunches

Solution:
feedback on each single bunch

(manipulation of feedforward and setpoint tables)

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Pyrodetector Baseline Shift

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Conclusion
Conclusion

We reached that milestone, but...

We cannot provide 800 bunches during user run.
- Gun temperature regulation unstable at full RF pulse length
- Gun: reflected power interlocks

We need too long to switch to long pulses.
- Bad gun conditioning (sparks)
- Too high module gradients, especially in ACC1 (quenches+instabilities)
- Typically operating with high losses

Do conditioning in advance.
Why not run modules at full pulse length all the time?
Keep losses low even in short pulse mode.
Inhomogeneous lasing

- Mainly caused upstream BC2: energy/phase of laser, gun, ACC1
- 250 kHz ripple from ACC2–6
  - Reliable adaptive feedforward for all modules + gun
  - Ripple correction table for ACC2–6
  - ACC1 phase feedback for single bunches
  - Fast orbit feedback