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CBETA: Achievements, Challenges, and Plans

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for the CBETA Collaboration
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Outline

- Machine description
- Achievements
- Challenges
- Future possibilities

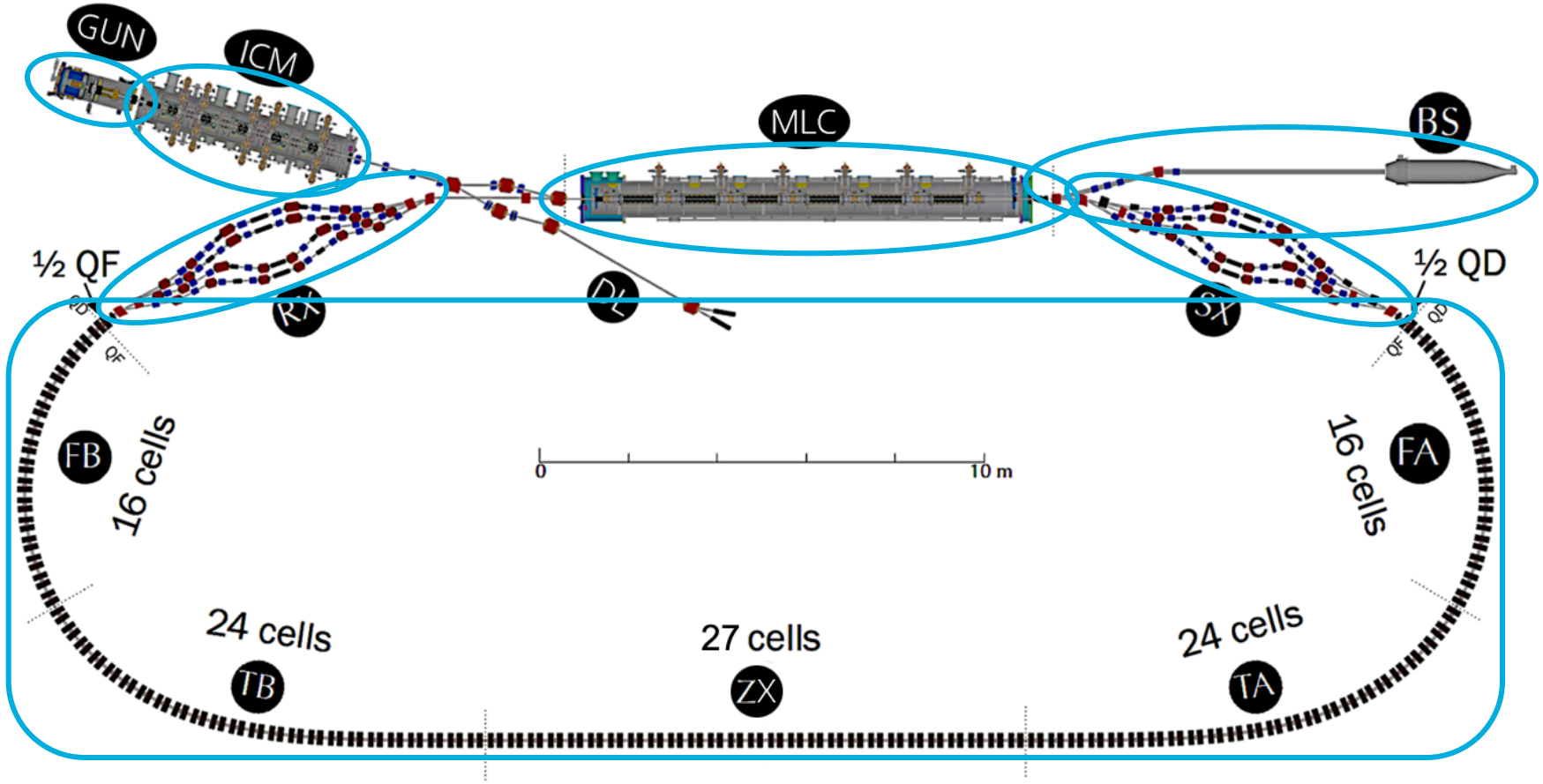
Machine Description

CBETA: Description

- 4-Pass ERL accelerating electrons to 150 MeV
  - Can be configured for any number of passes
- 1.3 GHz SRF injector, capable of 0.5 MW
- 6-cavity 1.3 GHz SRF linac, designed for ERL operations
- Fixed field alternating gradient (FFA) return arc
  - Single arc transmits energies from 42 to 150 MeV
  - Uses permanent magnets with windowframe correctors
- Splitter/recombiner lines between linac and return arc to control
  - Time of flight and R_{56}
  - Betatron matching

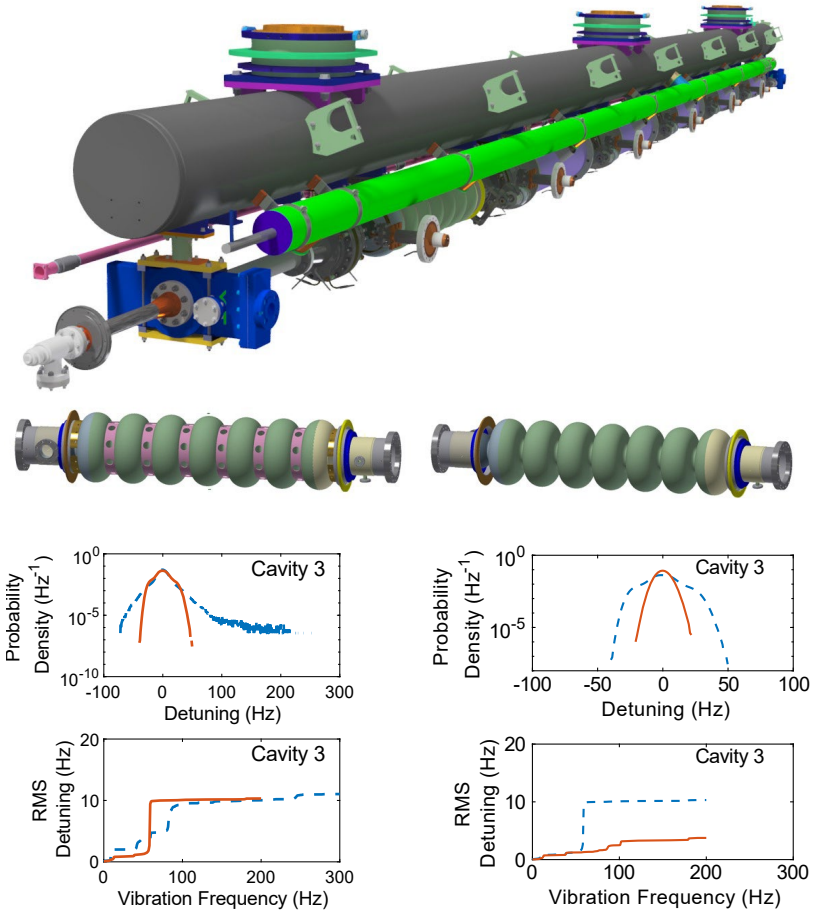
Machine Sections

- 350 keV electron gun
- Splitter and injection linac to 6 MeV
- Main linac, accelerating by 36 MeV
- Beam stop



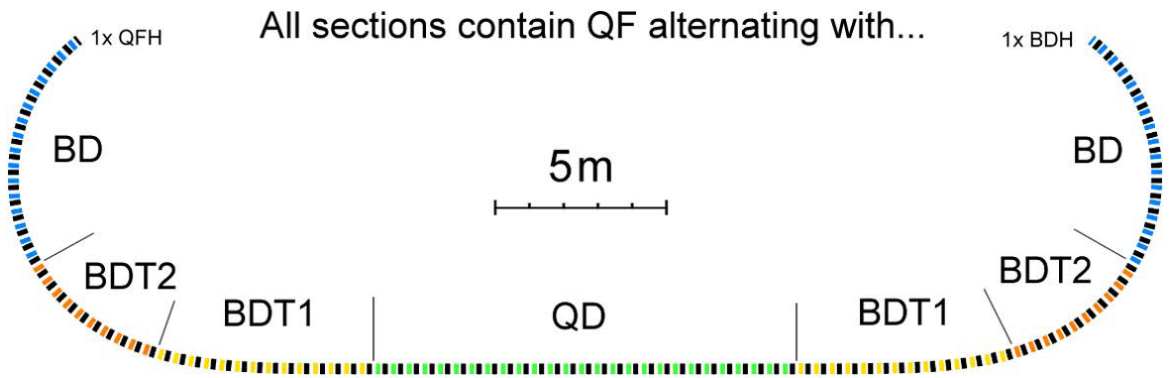
Main Linac

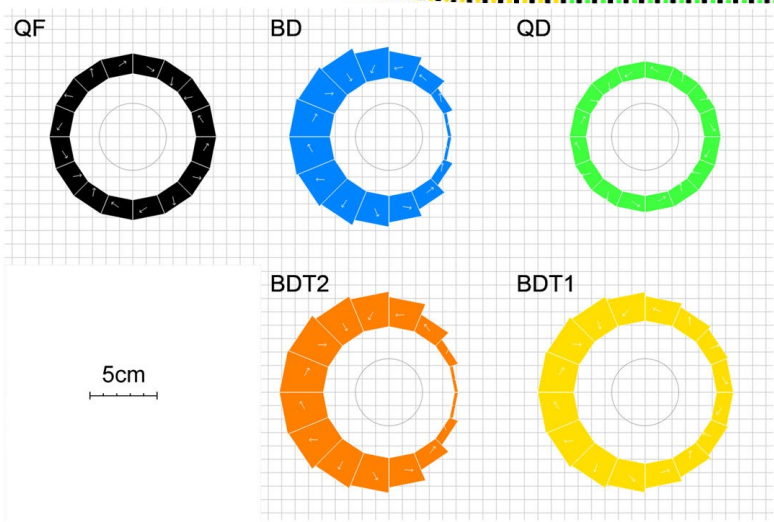
- Six 7-cell 1.3 GHz cavities
- Two cavity designs: with and without stiffener rings
- 5 kW or 10 kW power amplifiers
- Reduction of detuning
  - Mitigation of vibration sources
  - Active noise control

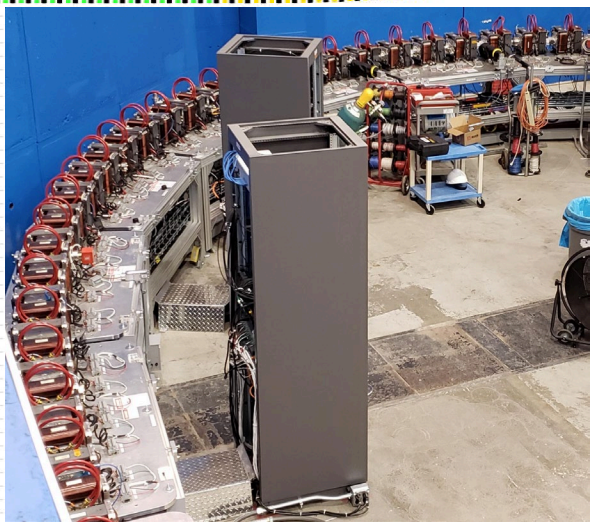


FFA Return Arc

- Alternating focusing quadrupoles and combined-function defocusing quadrupoles
- Halbach-style permanent magnets
- Four types of defocusing magnets depending on local radius of curvature
  - Shift magnets for fine control of dipole component

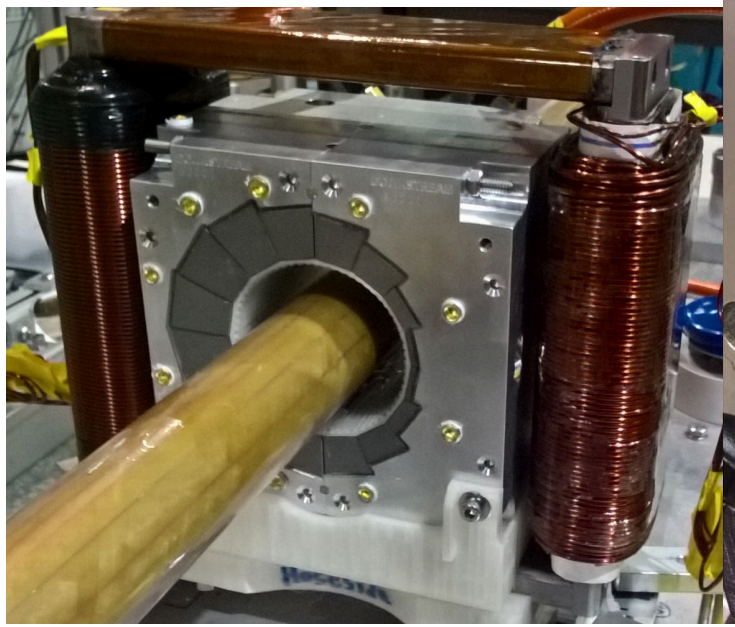


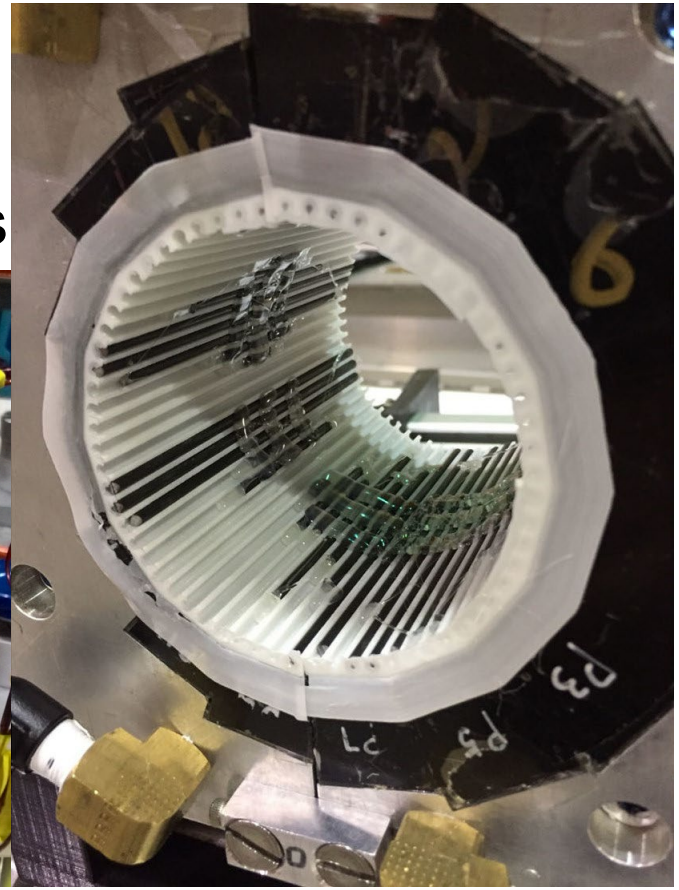




FFA Return Arc: Magnets

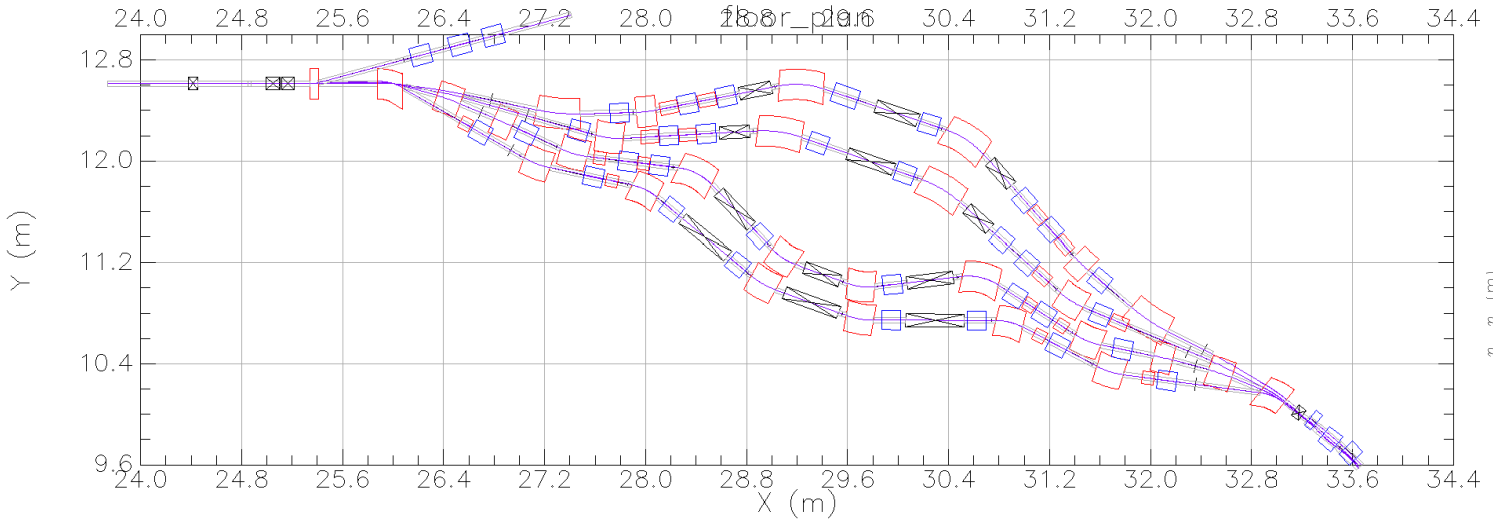
- Magnets individually measured and corrected
  - Measure magnet field
  - Insert iron wires near inside aperture to correct fields
  - Repeat if needed
- Field errors corrected to about 2 units

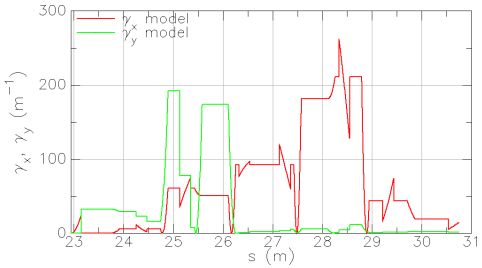


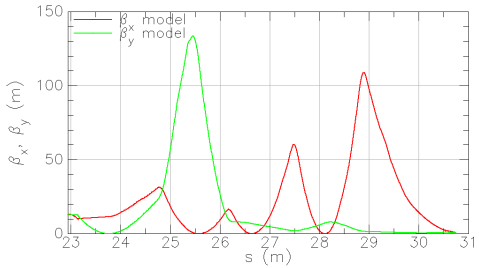


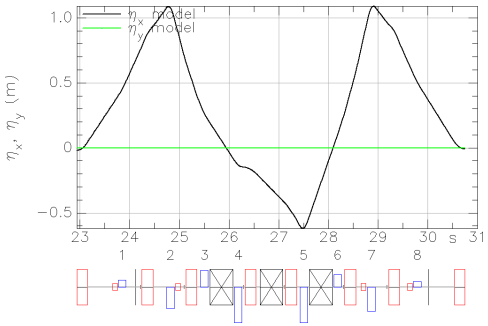
Splitter/Recombiner Lines

- Individual electromagnet lines needed to
  - Match beta functions from linac to FFA arc
  - Control time of flight and R_{56}
- Sliding joints (bellows) to adjust time of flight





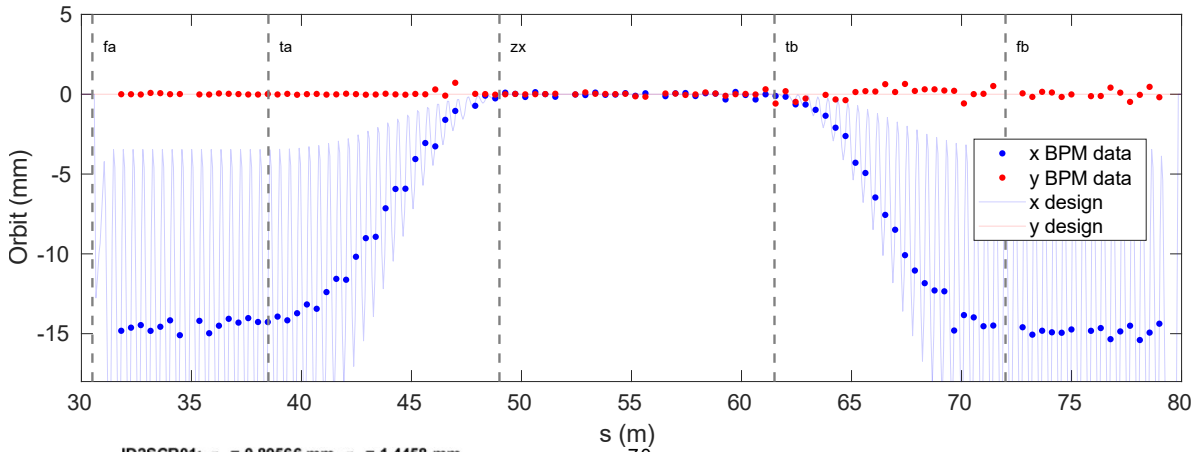


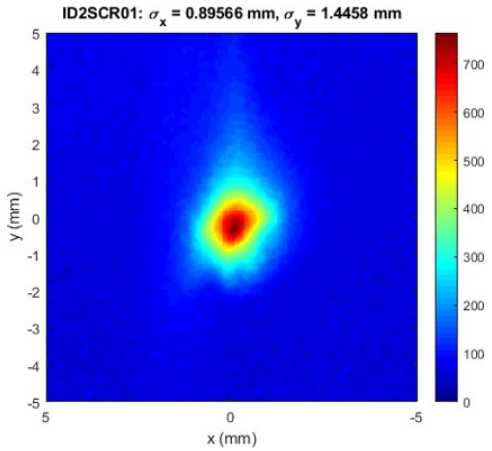


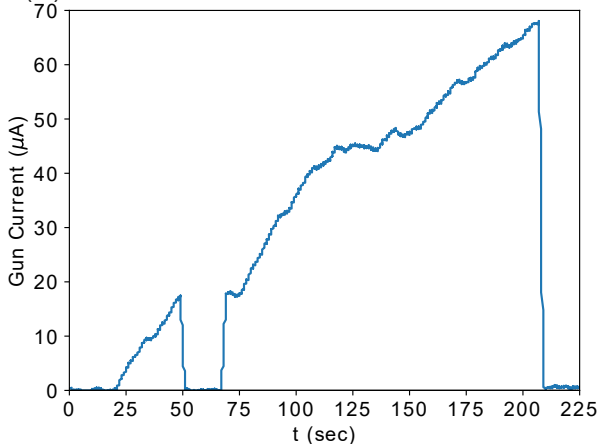
CBETA: Achievements

1-Pass: Measurement of Energy Recovery

- Beam injected at 6 MeV, accelerated to 42 MeV, decelerated to 6 MeV
- Reached nearly 70 μA current
  - Likely could have reached 1 mA, but fast shutdown system was not operational and beam dump entrance was not fully shielded



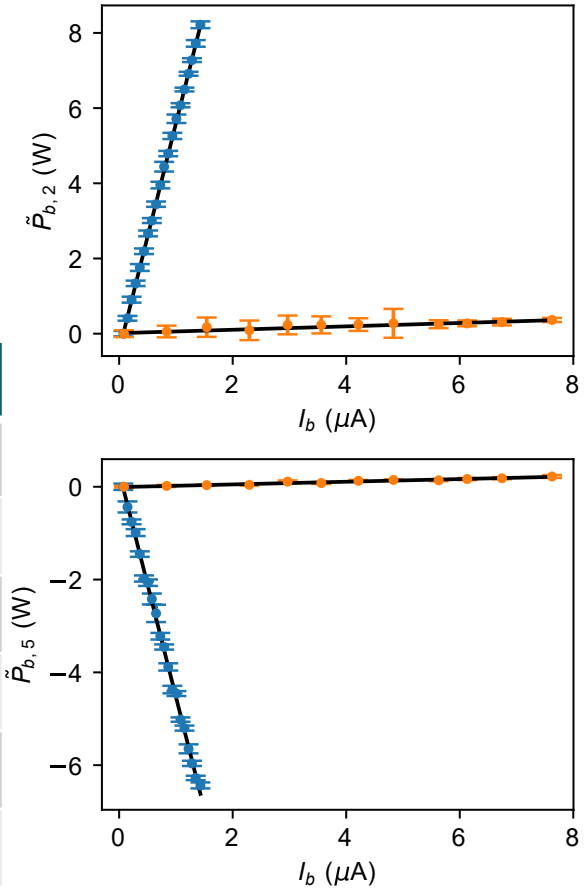




1-Pass: Measurement of Energy Recovery

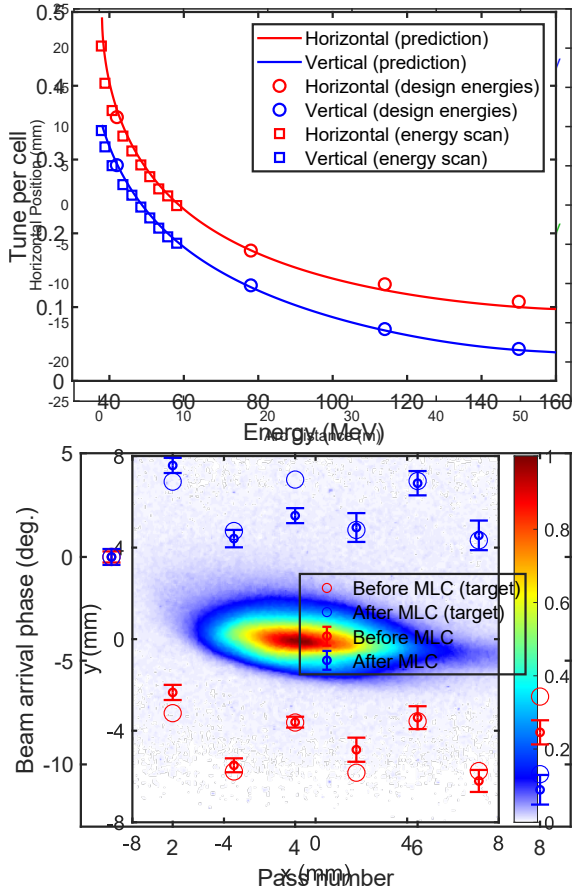
- Measured energy balance at each cavity
- First, for calibration: beam through linac to dump, 3 cavities accelerating, 3 decelerating
- Then 1 turn ERL mode
- Efficiencies measured, accounting for beam loss
- Note trend: machine not tuned for perfect balance at each cavity due to RF stability issues

Cavity	Efficiency (%)
1	99.99 ± 0.42
2	99.91 ± 0.19
3	99.86 ± 0.12
4	99.81 ± 0.15
5	100.04 ± 0.11
6	100.48 ± 0.23



4-Pass ERL Operation

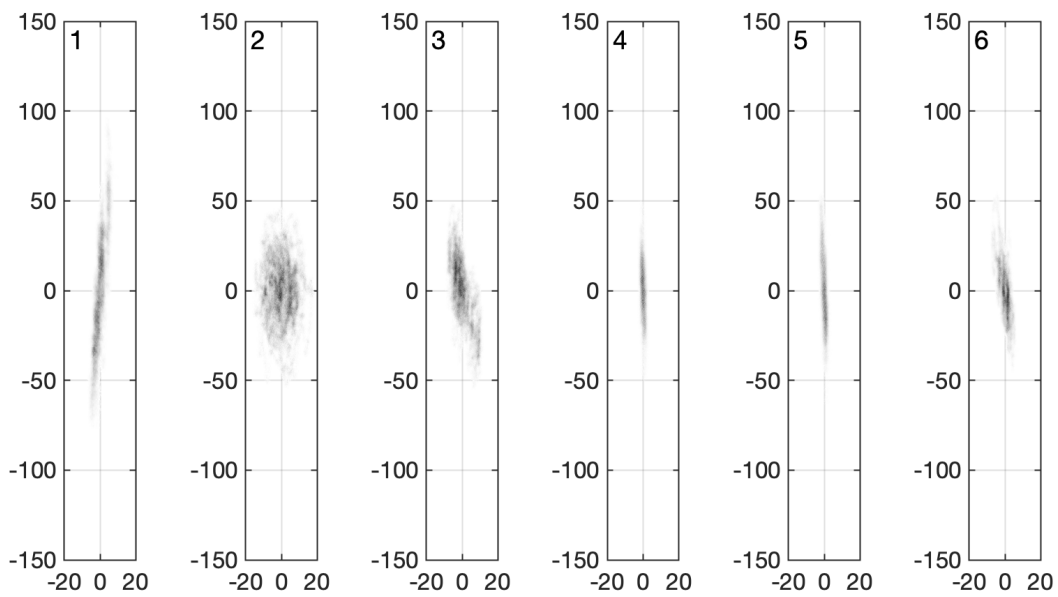
- 4 accelerating, 4 decelerating passes
- Simultaneous correction of all orbits in the common return arc
- Low current (5 pC/1 nA) operation
- Good agreement between model and measurements
  - FFA return arc tunes over the entire energy range
  - Linac phases



CBETA: Challenges

RF Stability

- High phase and voltage fluctuations
  - Improved as we got better control of noise
  - Sometimes prevented reaching desired voltage, operating off-crest
- Long term drift i
  - Two different v
  - Attempted to c



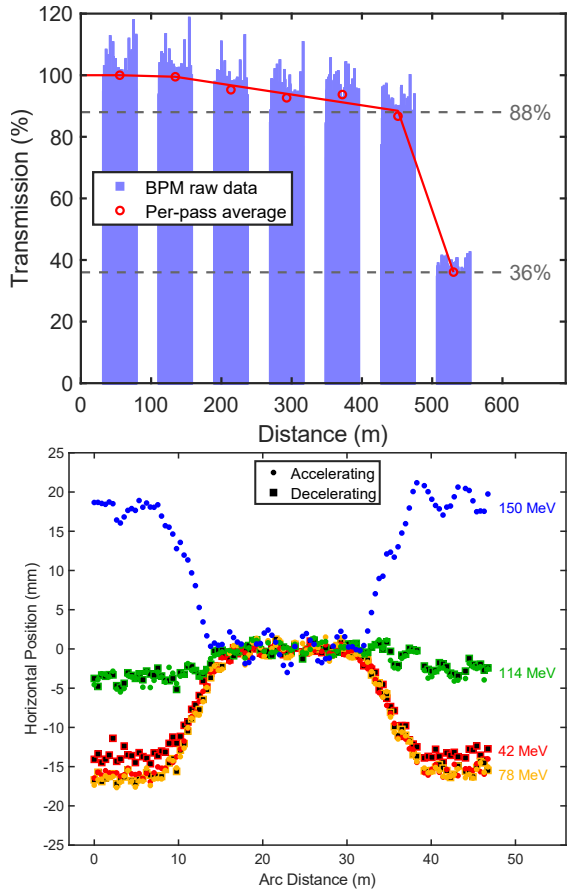
Cavity	σ_V/V	σ_φ (deg.)
1	3.9×10^{-4}	0.26
2	10×10^{-4}	0.16
3	8.0×10^{-4}	0.18
4	1.7×10^{-4}	0.15
5	1.8×10^{-4}	0.17
6	4.5×10^{-4}	0.15

Splitter Lines

- Splitter lines very close to each other
- Fields controlling one line impact the adjacent line(s), making correction and matching challenging
- Made first attempts at knobs controlling a group of magnets simultaneously
- In addition, see hysteresis effects
- Unable to steer beam through quadrupole centers
- Binding in sliding joints

4-Pass Losses

- Significant beam loss between last two return passes in the 78 MeV recombiner line
- Slower losses before that



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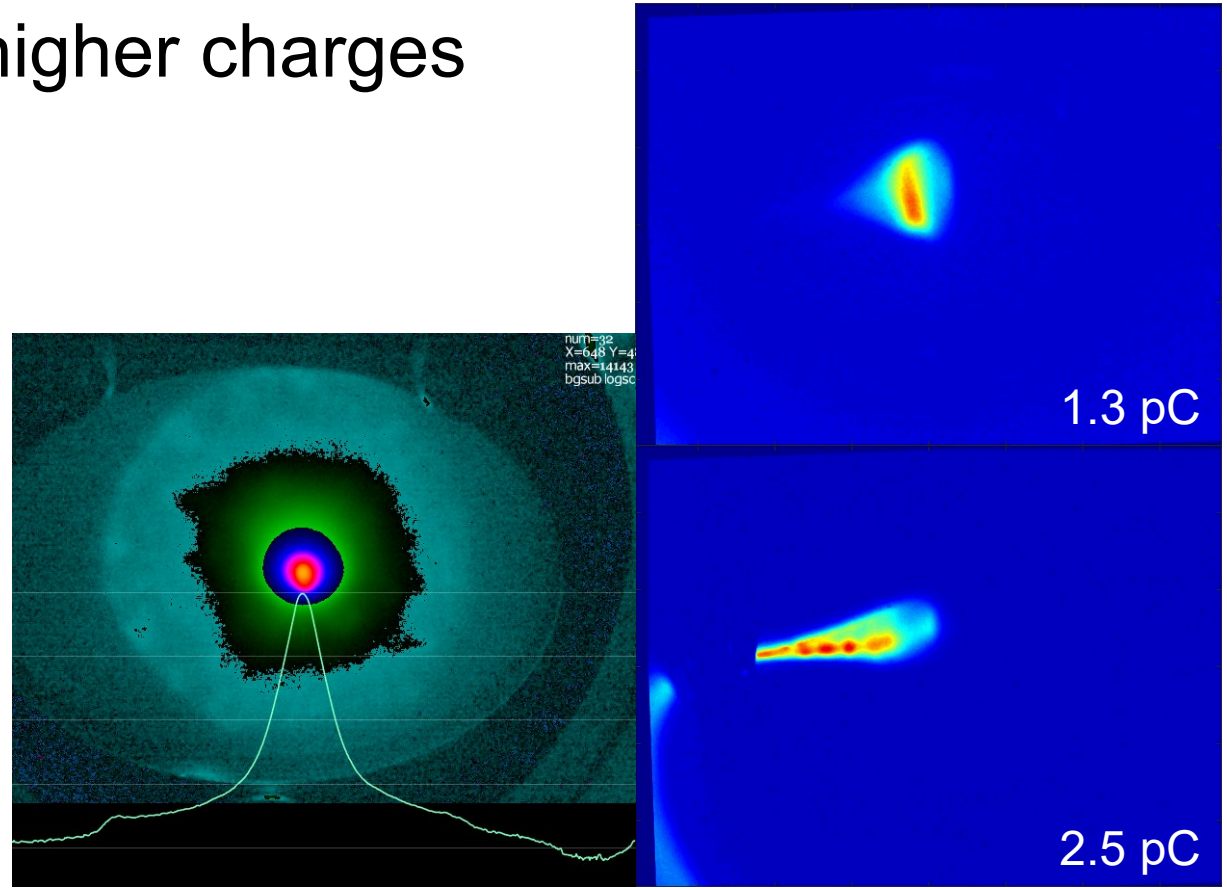
Microbunching and Halo

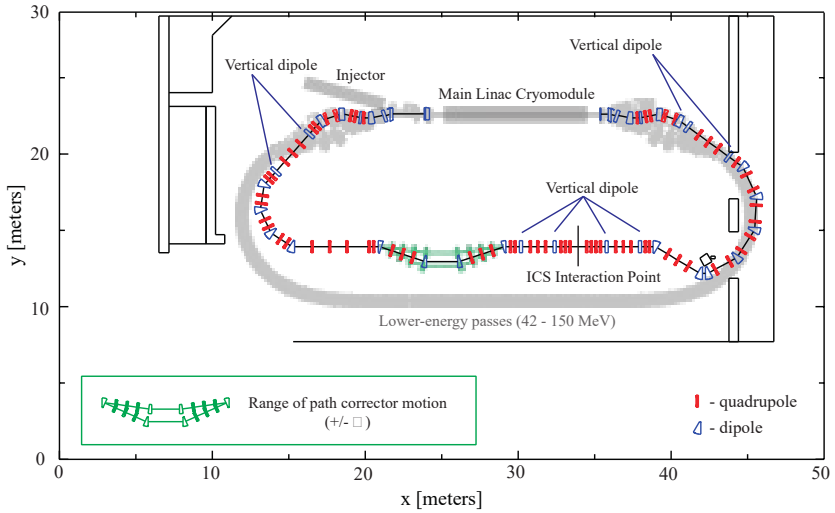
- Evidence of microbunching at higher charges
  - Pictures at entrance to S2
- Halo observed in injector
  - Likely from photocathode
  - Selectively activated photocathode has been used in the past



CBETA: Future Possibilities

Future Possibilities

- CBETA still intact, could operate with required funding
- Bypass line for inverse Compton scattering source designed
- One pass high-current operation for ERL studies for EIC (electron cooling)
- CEBAF 22 GeV upgrade similar to CBETA
  - Two FFA return loops, 10–22 GeV
  - Splitter lines for 6 passes
  - *Not* ERL
  - Studies of CBETA issues would be beneficial



Conclusion

Conclusions

- We successfully built and commissioned CBETA
  - 1-Pass ERL mode
  - 4-Pass ERL mode at low current
- Many issues have not yet been fully addressed and would benefit from future machine studies
- CBETA could restart operations given sufficient funding, and there are many studies of interest that could be done