



# Bipolar Operation of CEBAF Magnets Considerations and Implications

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# Abstract

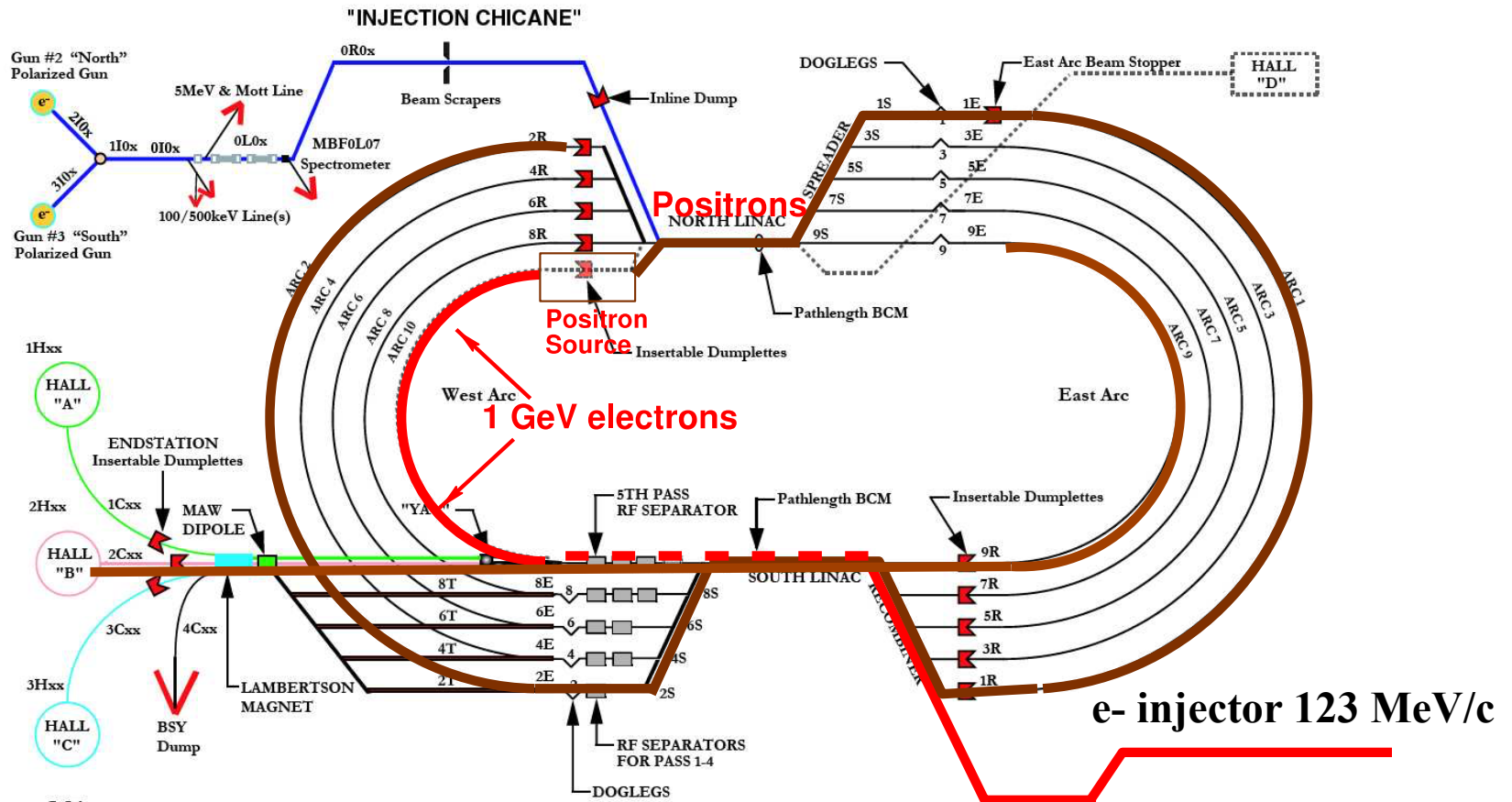
Operation of CEBAF with positrons using the standard electron beam direction (clockwise as viewed from above) requires inverting the polarity of the recirculation arc and Spreader/Recombiner dipoles. Retaining the focusing optics used for electrons requires inverting the quadrupole gradients. The hardware readily supports reversed polarity, and no observations are known to suggest any change of field vs. current calibration after restoring the (unipolar) dipoles to electron polarity.

Depending upon residual calibration errors and beam diagnostic capabilities, if it is necessary to make a demonstration with minimum investment, it may be useful to reverse the leads not only of the dipoles, but also of the quadrupoles. In dedicated positron operation with proper diagnostics, however, it is sufficient that the dipoles only be inverted. These and related operational issues will be discussed.

# Magnets. Polarity. It should be simple...

- Machine layout and apertures
- Magnet system parameters
- Protections
- Calibrations
- Previous calibration anomalies
- Magnet inversion: no obvious problems
- Overall outlook good (but nothing is ever quite “simple”)

# Machine Layout for 1GeV option



Courtesy Yves Roblin

# Constraining Apertures in CEBAF

- Each linac is bounded by differential pump stations
  - 1 cm aperture diameter
- Spreader/Recombiner septum magnets
  - Beams separate to straddle a current-carrying wall
- RF separator cavities near 2/4/6/8/A Extraction regions
  - Another small aperture
- Separators followed by small-aperture septum magnets

The lens lattice “encourages” the beam to stay near the focusing axis

There are errors and steering kicks distributed along the beam path

No symmetries are guaranteed

Operators steer the beam to near-axis

# Electrons $\longleftrightarrow$ Positrons

- Sign change of the beam particle changes the sign of force
- **Bending magnets must invert field** to preserve the particle path
- Linac FODO optics (alternating gradient) appears indifferent to polarity
  - Dispersion telescopes in the S/R areas set the polarity
  - Arc optics also has preferred polarity
  - So the **linac inverts polarity**, too, to preserve envelope match
- All of the quadrupoles invert field with the particle charge, so the forces on the beam remains the same, misalignment effects included
- **Geomagnetic field does not transform**, so its force inverts
- Correctors not inverted, so their force is inverted
- The quad kicks no longer balance the geomagnetic field and correctors
  - Should be able to “see” to steer through the linacs
  - Polarity change is just a start, not “the whole thing”

# Magnet System Components

- Main dipole strings
  - Recirculation arcs – strings of 16 or 32 series-connected dipoles
  - Series-connected spreader/recombiner magnets
  - Common power supply for the string (“box supply”)
  - Arc magnets are closely matched in strength
  - S/R magnets are by design a bit “too strong” relative to arcs
    - Strength adjusted using electronic load to bypass current
    - “Shunts” as termed at Jefferson Lab weaken the dipole, driven by the voltage drop across the magnet
    - Uni-polar systems
    - Dipole voltage inversion → reverse leads on shunts ←
  - Similar networks for other composite magnet groups
  - Formerly (6 GeV) installed a few supplementary power supplies
    - “Shunt adders” to boost rather than weaken a dipole
    - None presently needed

# Magnet System Components

- “Trim magnet” system
  - Similar topology to “shunts” but leakage current powers magnet
  - Dual power supply rack-connected to separate +/- “bulk supplies”
  - Circuitry for selected polarity to drive load meters desired current to output contact, returns to ground
  - Each side as independent zero offset, gain; as a unit is bipolar
  - +/- 10 A, +/- 30 V as resistance allows
- “Super trim” system
  - Independent bipolar power supply
  - Higher current/voltage rating than “trim”
- Exact inversion is only guaranteed when leads are swapped
  - Otherwise, zero offsets and differential gains enter



# More Magnet System Details

- Field integral vs. current is measured on magnet test stand
  - Test stand hysteresis not precise duplicate of ops protocol
  - Slight variations as a result
  - Many magnets have population-averaged  $\int(B \cdot dL)$  vs.  $I$  maps
- Hysteresis Protocols
  - Dipole magnets run on minimum current (typically  $\sim 0$ , unipolar) to maximum current, stopping on the way at the desired set point.
  - Allows shunt controls a gradual turn-on during dipole power ramp
  - “Trim” and “super-trim” systems are bipolar and use the portion of the hysteresis curve from algebraic positive to algebraic negative.
  - For (+) field, the remanent field augments the coil
  - For (-) field the remanent field opposes the coil
  - Any sag in remanent magnetization creates systematic shifts
- All contribute to the need to fine-tune each accelerator setup

# Magnet Fault Detection, Self-Protection

- Alarms are provided for current mismatch
  - Additional alarms are provided to detect long-term drifts/noise
- Overcurrent and ground fault detections are in place
  - Self-protection for both magnets and power supplies
  - Recent ZA damage incident due to fault detection failure
- Water flow and over-temperature shutoffs are part of each “box supply” network
- These hardware protections are polarity independent

# Summary

- No “damage” to B.dL vs I relationships has been observed in CEBAF systems, so no hazard is presented from polarity inversion/reversion
- For positron reconfiguration of CEBAF
  - Dipole and “shunt” polarity inversion appears straightforward
  - Machine protection issues appear to be in hand
  - Bipolar systems may need no attention if all beam tune-up diagnostics are available
- It is possible to run CEBAF “blind” for hours-long periods with beam to Hall B below current levels for which accelerator instrumentation is active
- Any attempt to use CEBAF as a positron accelerator must involve diagnostic upgrades in order to accomplish setup and track known variations experienced in electron operation