An Operational Diagnostic Complement for Positrons at CEBAF/JLab

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Operating CEBAF with Positron Beam(s)?

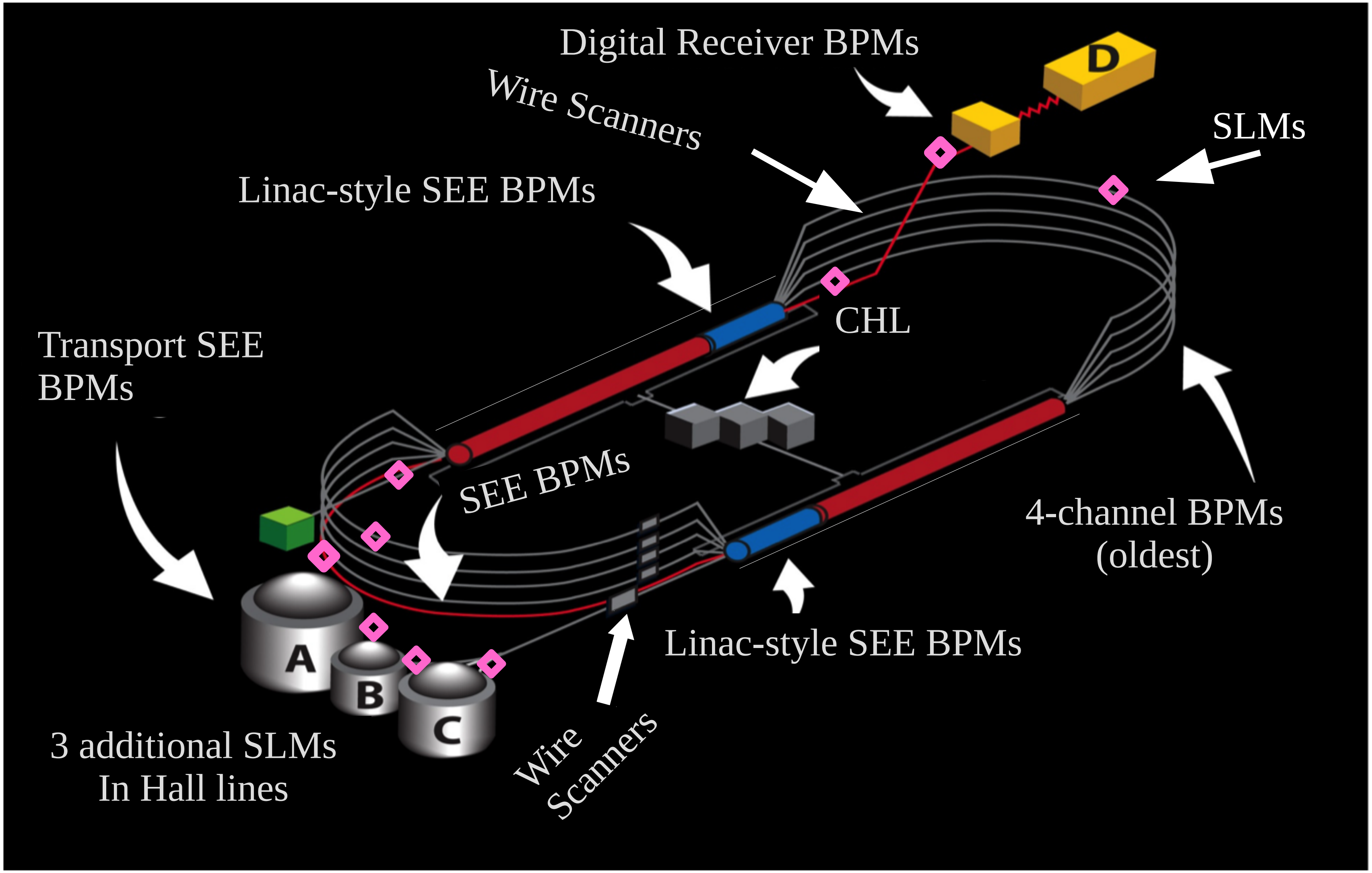
Abstract: The CEBAF accelerator has a demonstrated capacity for delivery of electron current to Hall B at the ~100 nA level, on par with the current anticipated for future positron beams. However, machine configuration requires macropulse current levels of a few micro-Amperes due to limited sensitivity of many installed diagnostics. Informed by this operational experience, we outline a set of diagnostic extensions leading to operationally reliable delivery at JLab of a low-current beam of positrons. Alternate diagnostic choices are listed, as well.

- CEBAF operational setup sequence, diagnostics
- Highlight e- experience at low current (most diagnostics inoperative)
- Compare e- beam properties to what may be available with e+
  - See Yves Roblin on e+ production
- Could some proof of principle demonstration be useful?
- What will change with low current operation? Why and how?
- Critical (and less so) diagnostic extensions
- Which operational differences are unavoidable, significant?

CEBAF Setup Overview

- Injector (worthy of a tale on its own)
- Configure baseline optics in recirculation arcs, spreaders, recombiners
- Linac configuration (RF and magnets matched to acceleration profile)
- For each half-circuit of machine, do:
  - Thread beam through Linac
  - Adjust trajectory into Spreader
  - Steer beam around Arc into tune-up dump
  - If beyond 3rd linac (providing closure) adjust prior Arc path length
  - Measure envelope functions and re-tune as appropriate
- Repeat through extraction to experimental hall
- Measure and refine polarization as appropriate (injector Wien filter)
- Measure and refine beam envelope on target
- [Adjust operational parameters to satisfy user requirements]

Selected Diagnostics in the Accelerator



Viewers are distributed through the machine, plus Synchrotron Light Monitors (◇)

CEBAF Diagnostic System Sensitivities

- viewers
  - Working average current range for viewers 1 – 100 nA
  - Multiple materials, with OTR viewers needing tens of nA
  - BN nanotube material being investigated
- "BPMs" of various amplification schemes
  - (Older) 4-channel BPMs require ~2 uA beam current (most limited)
  - SEE BPMs can operate at ~200 nA CW (Hall B)
  - Digital Receiver BPMs operate starting at ~ 30 nA CW
  - Dedicated cavity coupled BPMs respond to 1 nA CW
- SLMs
  - Useful images and current monitoring at < 1 nA average
  - Potentially applicable to optical BPMs (not yet fielded at CEBAF)
- Wire scanners ("harps") requiring from ~ nA CW to ~5 uA macropulse
- Cavities: current resolution < 1 uA, fine-grained phase detection

Diagnostic Applications I

- Injected bunch length and energy spread (CEBAF e- operation)
  - Injector dump harp prior to final chicane magnetic compression
  - Arc1 SLM for compressed bunch (momentum spread vs. phase)
- Beam trajectory – BPMs
- Beam momentum
  - BPMs in dispersive regions
  - SLMs for relative momentum measurement (extensible)
- Momentum spread
  - SLMs in dispersive regions (direct)
  - Dedicated RF phase modulation system ("MOMod"/indirect)
- Path Length (time of flight)
  - dedicated RF phase based system (direct)
  - Maximize acceleration vs. path length chicane setting (slow)

Diagnostic Applications II

- Beam envelope
  - Transfer function measurements with BPMs (indirect)
  - Wire scanner profiles
  - Beam viewers (various materials, variable resolution)
  - SLMs
- Beam loss
  - Beam current cavities (arguably microAmpere resolution/drift)
  - PMT-based Beam Loss Monitors (critical areas like septa)
  - User background can signal beam scraping (low-current ops)
- Polarization (user-space, almost transparent to other operations)
  - Moller and Compton polarimeters
  - Mott polarimeter (injector)

Low-current CEBAF Operations

- Hall B operations have requested very low current
  - 200 pA or less for HDIce testing
  - ~ 300 nA for HPS
  - Operation is common with ~ 5 – 50 nA
- Hall B preliminary operation at tens to hundreds of nA
- Preliminary setup for these operations used microAmpere macropulse current to make beam visible to all diagnostics
- Once set up and configured for monitoring by low-current capable devices, the current was set to experimental requirements
- Operators relied on manual control using SLMs in 1A/2A
  - Manual “energy lock” and tracking linac phases
- On a time scale of hours, return to microAmpere current was required to make visible and compensate for trajectory drift
  - Associated polarity changes appear infeasible during e+ operation

Transverse Emittance* and Energy Spread†

Area	δp/p [x10^{-3}]	ε_x [nm]	ε_y [nm]
Chicane	0.5	4.00	4.00
Arc 1	0.05	0.41	0.41
Arc 2	0.03	0.26	0.23
Arc 3	0.035	0.22	0.21
Arc 4	0.044	0.21	0.24
Arc 5	0.060	0.33	0.25
Arc 6	0.090	0.58	0.31
Arc 7	0.104	0.79	0.44
Arc 8	0.133	1.21	0.57
Arc 9	0.167	2.09	0.64
Arc 10	0.194	2.97	0.95
Hall D	0.18	2.70	1.03

12GeV config

Damping

e- beam is dominated by synch. rad at 12GeV

Sync. Rad.

* Emittances are geometric
† Quantities are rms

Transverse Emittance* and Energy Spread†

Area	δp/p [x10^{-3}]	ε_x [nm]	ε_y [nm]
Chicane	10	500	500
Arc 1	1	50	50
Arc 2	0.53	26.8	26.6
Arc 3	0.36	19	18.6
Arc 4	0.27	14.5	13.8
Arc 5	0.22	12	11.2
Arc 6	0.19	10	9.5
Arc 7	0.17	8.9	8.35
Arc 8	0.16	8.36	7.38
Arc 9	0.16	8.4	6.8
MYAAT01	0.18	9.13	6.19

Positrons

Damping

Sync. Rad.

* Emittances are geometric

† Quantities are rms

Courtesy Yves Roblin

Beam-related Machine Protection

- Operation at visible e+ levels requires high average current e- beam
- New beam current monitors required at e- injection and e+ target
  - Additional monitoring points to verify near lossless transport
  - e+ conversion target rad shielding against hardware damage
  - May be needed to prevent camera damage in SLMs, viewers
- Diagnostics for e+ beam tightly constrained where coincident with e-
  - Possibly relevant only to South Linac
- Viewer system (dominantly Chromox) tightly interlocked to gun mode
  - Prevents insertion and destruction of viewers with CW beam
  - YAG viewers insertable in regions with low average current limit
  - OTR viewers are unlimited for insertion
- Viewer system interlock (control architecture?) must be altered to allow use with low-current CW e+ beam in main accelerator
  - Separation of e+ beam viewer control from e- control?

Beam-related Procedural Issues

- Tune-up dumps in all arcs are interlocked against CW beam
  - Over-ride provided, but must not desensitize Ops crews
- e+ beam large emittance, momentum spread may result in scattered "hot spots" in accelerator – radiation control management issue
  - See Yves Roblin's talk for emittance and momentum spread estimates and limits
  - One can expect that the boundaries will be approached sometime for users wanting maximum e+ current, whatever activation limit is adopted

Parameters To Be Monitored

- Beam current – stable at requested value
- Beam transmission to user (must be monitored and kept near unity)
  - Beam trajectory and envelope must be “adequately stable”
  - Sparse sampling provides notice of change, prompting a response
- Beam energy
  - Stable linac energy gain (Arc 1A/2A “energy lock” feedback)
  - RF phase must be stable (machine “path length” stable)
    - Non-isochronous transport? (may be more stringent)
  - Beam energy in all arcs presently requires BPM readbacks
  - May be able to substitute SLMs if adequate in number
- Momentum spread
  - Presently monitored via SLMs in Halls A/C
  - Sometimes signaled by increased background, beam scraping, or extended wire scanner profiles (through residual dispersion)

Can a Low-Effort Demonstraton Be Useful?

- Minimum supplement for a demonstration may be possible, but will not provide a robust e+ program
- Unless some compressed e+ macropulse beam structure is available, all diagnostics should ultimately be refitted for low current
- A "shoestring budget" demonstration effort might be imagined:
  - Tune optics and aperture for a specific e- beam energy
  - Use a careful absolute trajectory analysis to identify geomagnetic and other interferences, trying to avoid upgrading all BPMs
  - Invert all dipoles and quadrupole leads (to avoid some systematic power supply offset issues)
  - Use sparse steering input from viewers, SLMs, and steering around beam loss indications to coarsely center beam in the acceptance
  - Minimally extend wire scanner data acquisition or supplementary SLMs to verify envelope behavior
- Fitful, unsatisfying operation; high effort if polarity inversion frequent

Metrological Scenario

- Consider the case with e+ beam peak current limited to < 100 nA
- Reliable steering of e+ beam (large emittance, beam size) is required
  - Tuning processes in CEBAF start with beam steering
  - Differential pumping apertures and septa limit beam aperture
- Current for e+ is too low for existing path length diagnostics
- Optical BPMs are possible resolution for some needs
- Arc SLMs at low dispersion may provide efficient envelope tuning

Instrumentation Upgrades Indicated

- Steering: upgrade most BPMs to e+ sensitivity
  - Experience with e- should allow reduction of BPM count by determining magnet properties and linac alignment)
- Envelope tuning needs:
  - Wire scanner sensitivity upgrade (scaler system like Hall B?) *or* supply SLM at path length chicane to image beam at <n>E01 *or* supply multiple SLMs per arc for optically based envelope tuning
  - SLMs would provide CW monitoring as a benefit
- Upgrade path length system or plan for invasive tuning
  - Cavity-based process as now in use might use 20% duty factor, ~4.4 microsecond pulse with lock-in ampifiers to gain sensitivity
- Arcs 1A/2A return to low-dispersion configuration, SLM or BPM data acquisition at dispersion peaks supporting crest phase (as MOMod)
- Lock-in techniques applied to high arc BPMs/SLMs at dispersive points desirable for non-invasive CW path monitor

How to Prepare for Upgrade Selection?

- Ongoing model development in CEBAF allows for tests of partial BPM complement upgrade
  - All BPMs are available for e- use, but not all need be used for e+
  - Significant cost savings may be possible
- Optical instrumentation can be developed and fielded for prospective improved efficiency – good for both e- and e+ operation
- Instrumentation can be developed and tested with low e- current
  - SLMs, potentially optical BPMs
  - Path length cavity operational tests
- Digital Receiver BPM signal processing can be tested
  - In situ in CEBAF with old BPM cans for sensitivity
  - Test 249.5 MHz harmonics other than 1497 MHz for lower background, e.g., 1 GHz

Differences With e+ Operation

- Should be little significant change
  - Beam is in the tunnel and still visible only via instrumentation
- Electron operation involves more hazard of machine damage
  - Extended operation with e+ may allow actions unwise with e-, such as relaxed vigilance in viewer handling
- Viewer based information may become more important
  - BPMs near existing viewers may be less likely for upgrade
- Misalignment of S/R with linac axis may be more important
  - Larger beam sizes interacting with, e.g., D.P. aperture limits
- Diagnostic design should not choke control room information flow
  - Perception of “flying blind” can lead to inefficient operation

Hardware Summary

- BPMS should be upgraded in sensitivity except for those whose purpose is known from analysis of e- operation to be unnecessary
- Wire scanner sensitivity should be upgraded to support envelope tuning unless SLMs are substituted
  - SLM developments in CEBAF may show which path is preferred
- Certain hardware protections will be seriously relaxed in e+ operation
  - Dumplet and viewer constraints
  - May drive changes to ioc control distribution
- Path length and RF to beam relative phase monitors are essential to upgrade
- Diagnostics for e- path (potentially from new SL injector through Arc 10 to conversion target near NL) are not included in this discussion
  - Should be similar to existing CEBAF injector

Back-up Slides