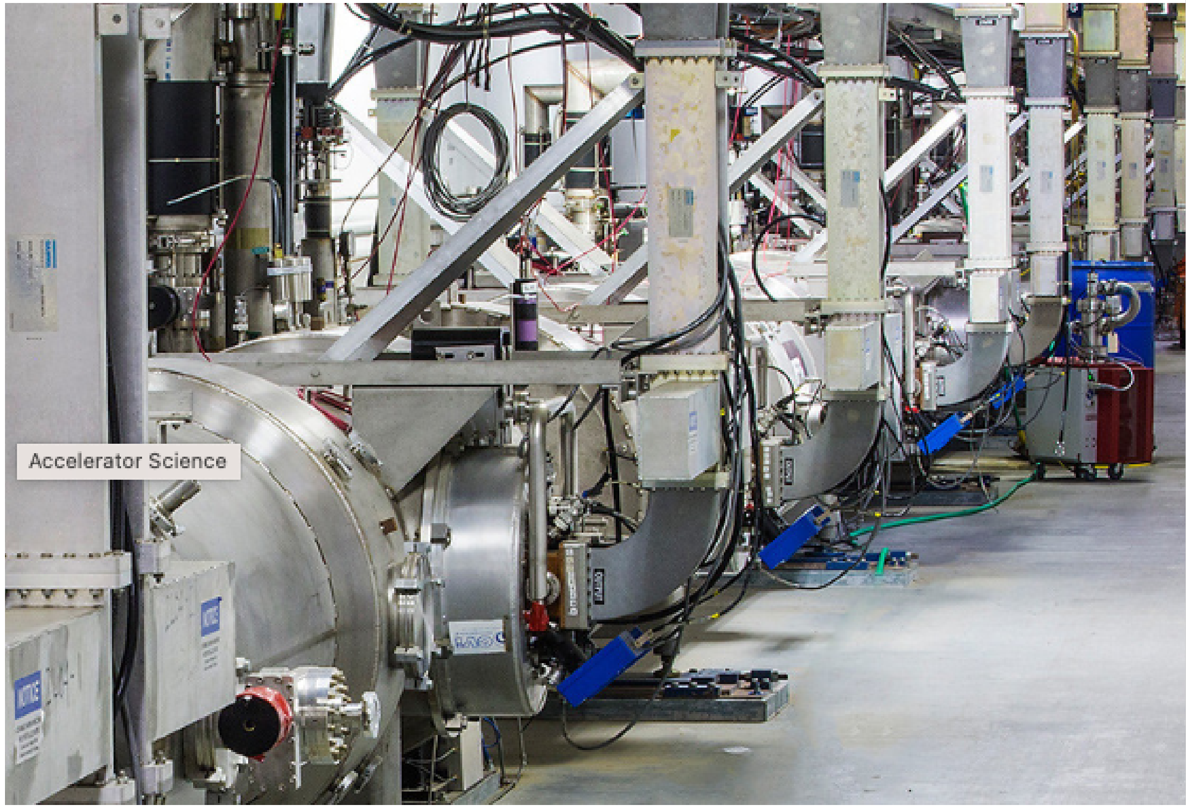
CEBAF Accelerator Status, November 12, 2024

Presented by Michael Tiefenback

Most materials gathered by Eduard Pozdeyev, plus material from other “involved parties”



CLAS Collaboration, Nov 12, 2024

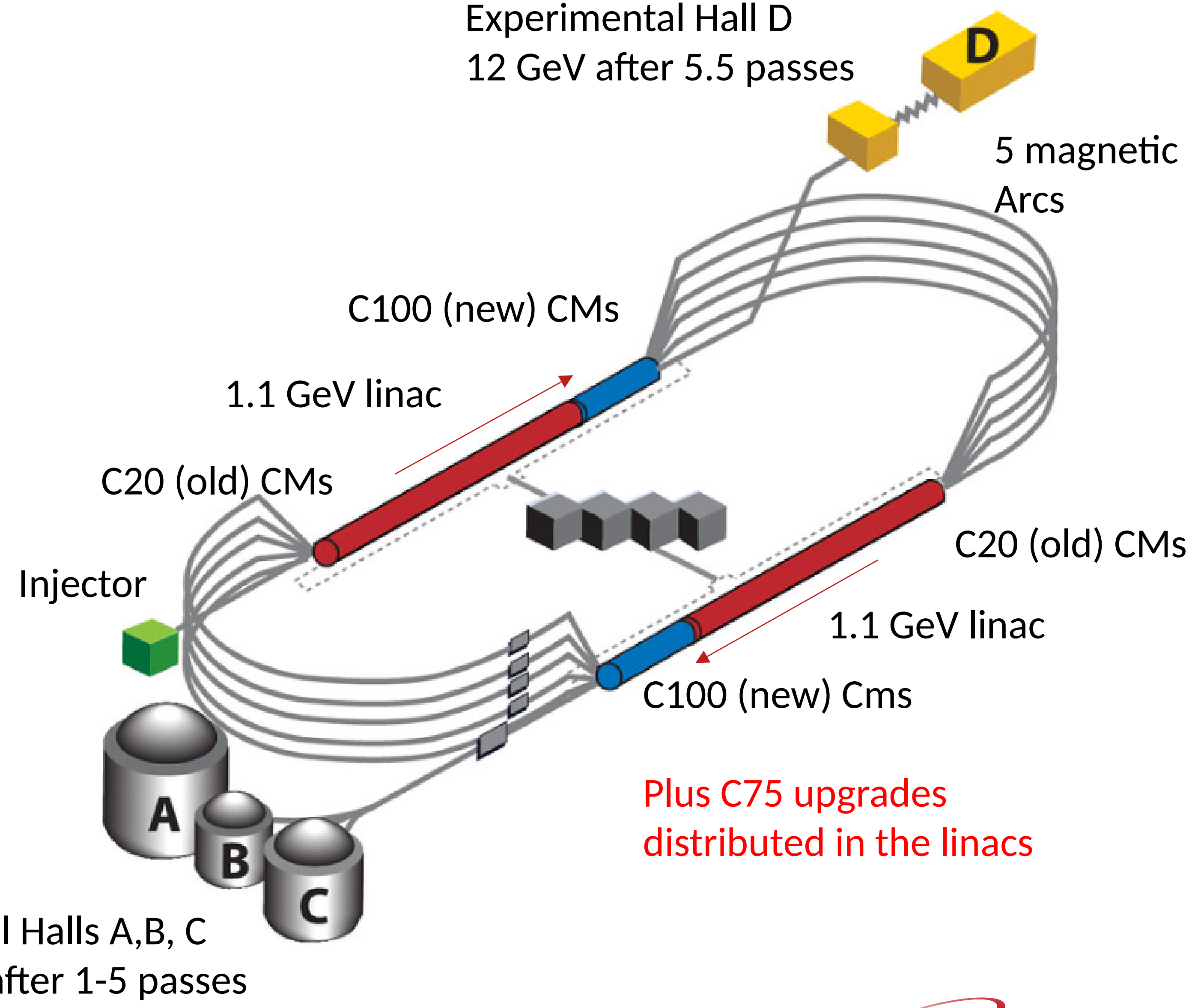
(Minor updates from June 2024)

Presentation Content

- Obligatory accelerator site schematic
- Mission; long-term plans and projects
  - Positrons mentioned, leading into e- energy straggler/degrader
- Accelerator Performance to date
- Upgrades – energy reach, 200 keV injector, target irradiation, etc
- Limitations and outlook
- Miscellaneous other upgrades and developments

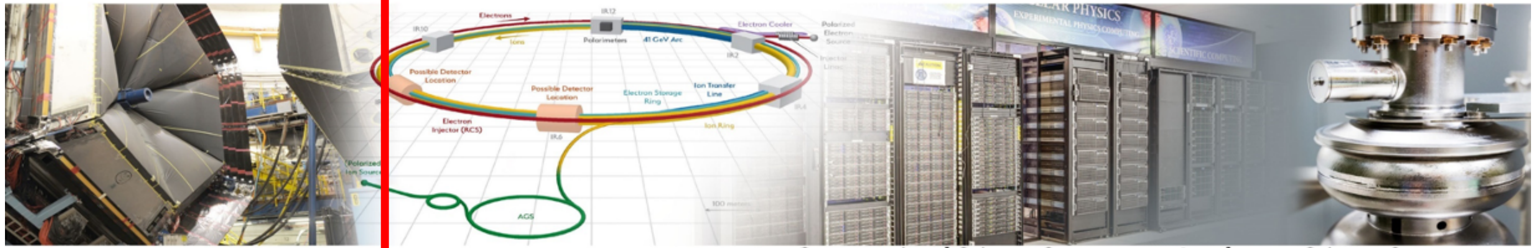
CEBAF Accelerator

- SRF, recirculating, 5.5 pass, 12 GeV Linac
- Beam power up to 900 kW
- Total recirculated beam current in each linac up to 450 uA
- CEBAF can provide beam up to 4 Halls simultaneously
- Beam can be extracted to a specific Hall at any selected pass
  - e.g., Hall A at pass 4, Hall B at pass 5, and Hall C at pass 3
  - (With usual constraints on concurrent operation...)



Alignment with Lab's Mission and Long-Range Plan (LRP)

- **LRP Recommendation 1:** Capitalize on the extraordinary opportunities for scientific discovery made possible by the substantial and sustained investments. Continue effective operation of national user facilities, including CEBAF at TJNAF



Nuclear Physics at CEBAF

Vibrant 12 GeV research program, operating >30 weeks/yr, supporting > 1,800 users

MOLLER Project & SoLID proposal

Future opportunities in fixed-target, high-luminosity complementary to EIC

Theory and computation supporting NP goals

Electron-Ion Collider

Partnering with BNL in the management, design, and construction of the Electron-Ion Collider Project

Leadership in EIC scientific program

Computational Science & Technology

Vision for world-leading computational program

Developing concept of a High Performance Data Facility focused on the unique challenges and opportunities for data-intensive applications and near real-time computing needs

Computational Nuclear Physics

Accelerator Science & Technology

Accelerator component production for DOE/SC projects, including LCLS-II and LCLS-II-HE at SLAC, and SNS-PPU at ORNL

R&D in accelerators, detectors, isotopes

From S. Henderson's
all-hands presentation 07/2023

- Operate CEBAF for Nuclear Physics for >30 week/yr. for >1800 users
- Support 12 GeV experimental program (MOLLER, SoLID, K-Long) [and eventually e^+]

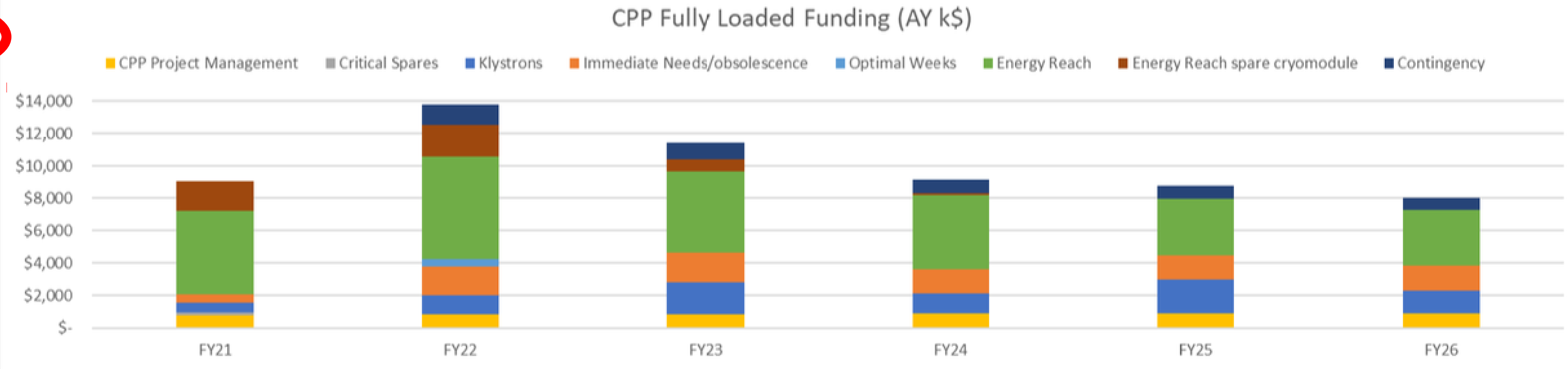
Jefferson Lab

CEBAF Performance Plan (CPP)

- Established in 2017 with goal of achieving 12 GeV in 5.5 passes with good reliability.
- Reliability Project, manager: Randy Michaud
  - Critical Spares
  - Klystrons
  - Obsolescence
  - Optimal Weeks Hardware
- Energy Reach Project, manager: Tony Reilly
  - C75 program
  - C100 refurbishment program
  - Plasma processing

ACCOMPLISHED! (Partially) and with favorable initial results

CPP funding vs FY. The total is $60.1M.



FY 2024 SAD Plasma Processing

			(1-hr run numbers)
	Plasma Gain:	Total (MV/m):	87
		Total (MeV)	60.9
	Per cavity:	(MV/m)	2.72
		(MeV)	1.90
Forecast: TN-23-013	Per cavity:	(MV/m)	1.3
		FE onset	2.4

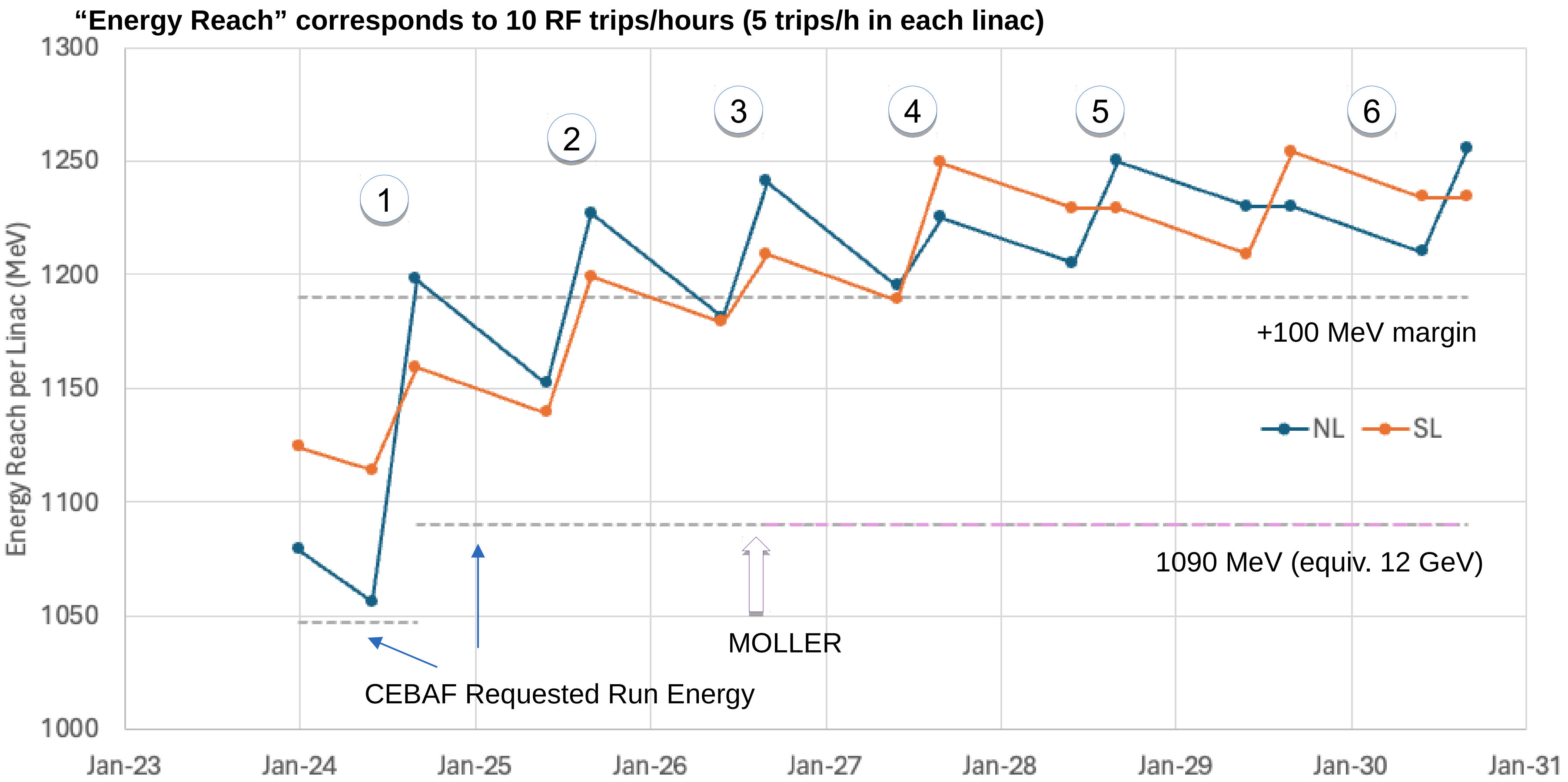
Zones processed 1L23/1L24/1L25/1L26, plus 2L26

Plasma-Processing Improvements (Tentative) --

Initial forecast: +1.3 MV/m per cavity (0.9 MeV)
Measured improvement: +2.72 MV/m per cavity (1.9 MeV)

To be verified in the coming weeks through longer periods of operation

CPP Energy Reach Project Is Critical For Success



1. C75-03, C75-04, C100R + 44 MeV Plasma Processing
2. C75-05, C75-06, C100R + 15 MeV PP SL
3. C75-07, C100R + 15 MeV PP NL
4. C75-08, C100R + 15 MeV PP SL
5. C75-09 (+ Booster)
6. Steady State: C100R + 15 MeV PP Each linac alternating years

Required CEBAF Energy Reach with margin can be nearly achieved in FY 26 and exceeded in FY27 with the proposed profile.

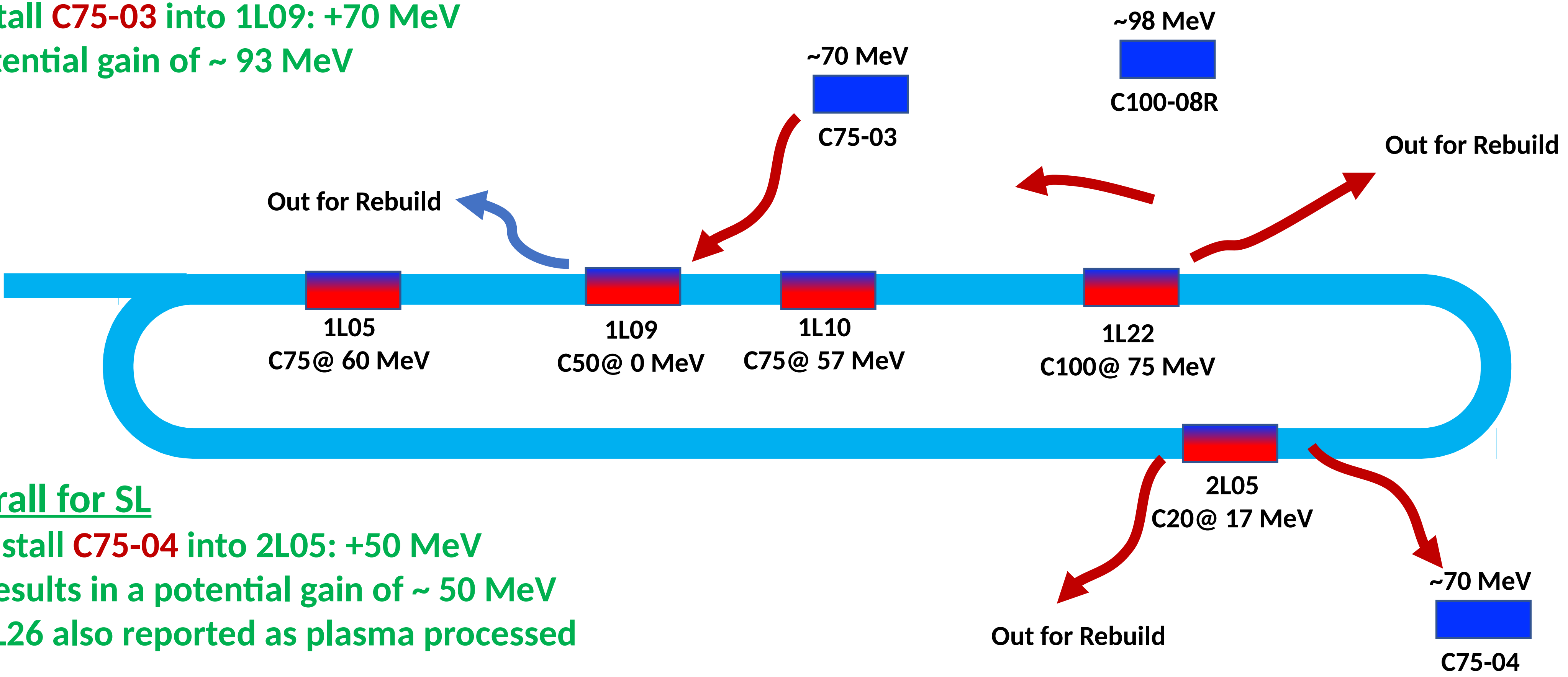
FY 2024 SAD Cryo Module Dance

Plasma Processing Plans

- Process C100s in NL (1L23-1L26 reported)
- Process 1L05 and 1L10 (C75s) in NL (not reported)

Overall for NL

- Install **C100-08R** into 1L22: +23 MeV
- Install **C75-03** into 1L09: +70 MeV
- Potential gain of ~ 93 MeV



Overall for SL

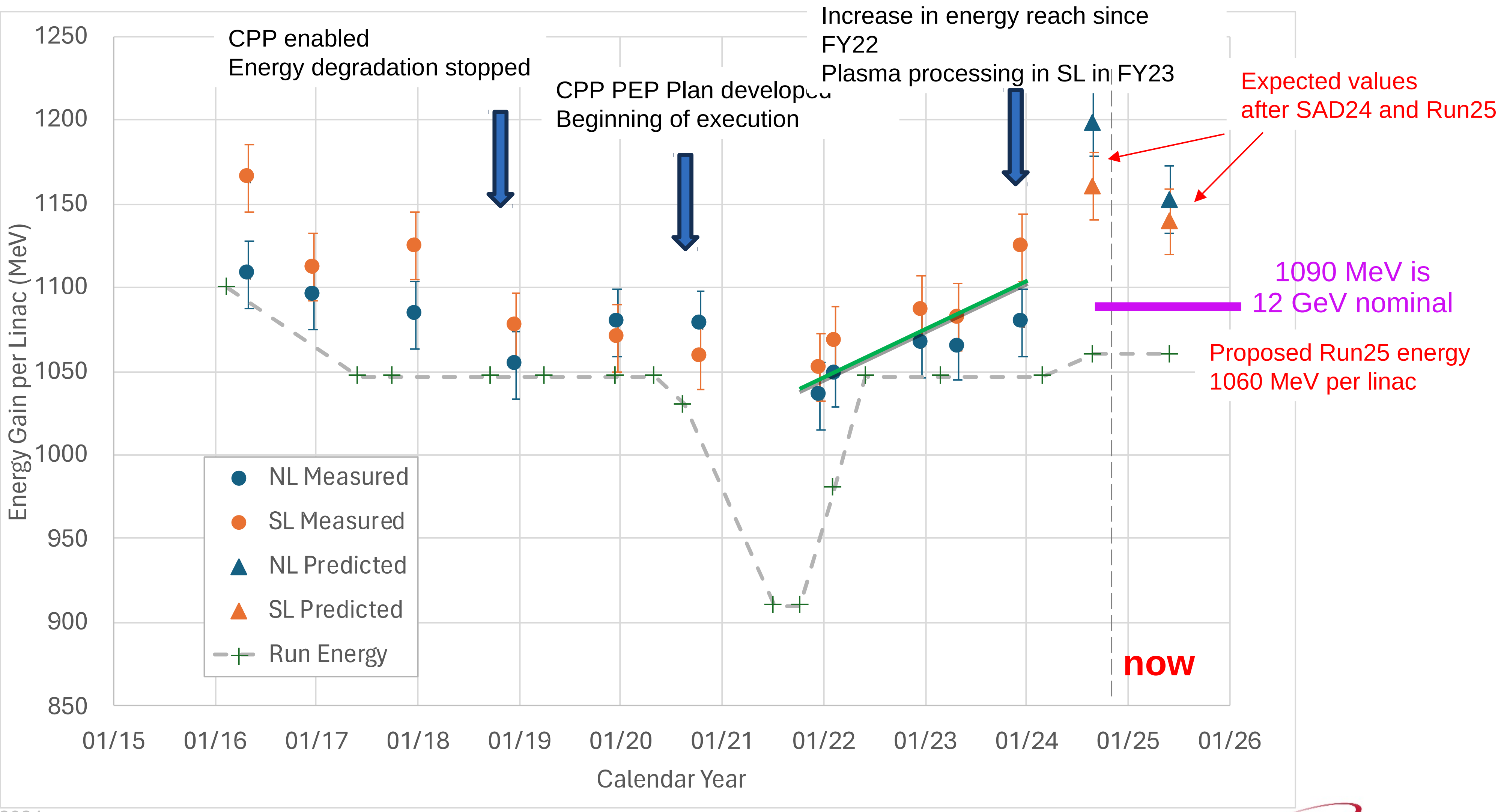
- Install **C75-04** into 2L05: +50 MeV
- Results in a potential gain of ~ 50 MeV
- 2L26 also reported as plasma processed

Note: Cryomodule MeV recorded from 12/18/23 data

Taken from Tony Reilly's JLAAC Talk

CEBAF Energy Reach Evolution and Next Year Projection

- CPP stopped and turned around energy degradation and reliability decrease

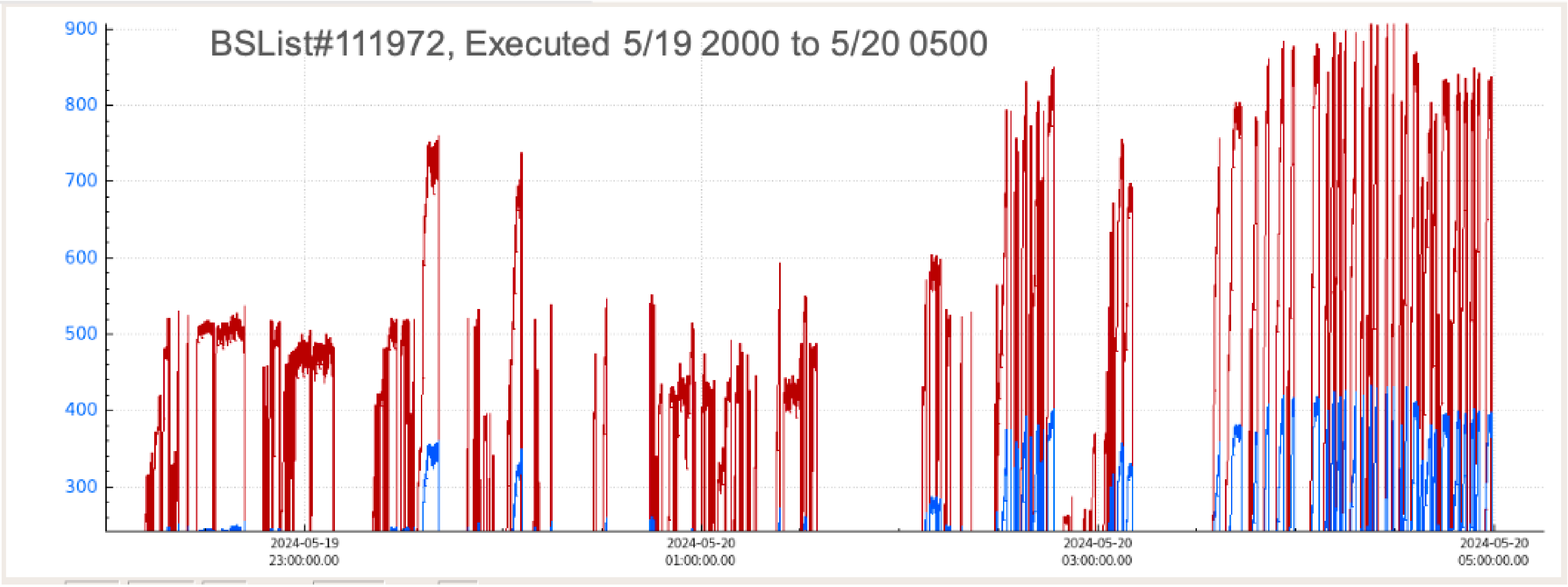


Energy reach corresponds to 10 RF trips/h for zero beam current.

Maximum beam energy Is lower for a high beam current because of insufficient RF power.

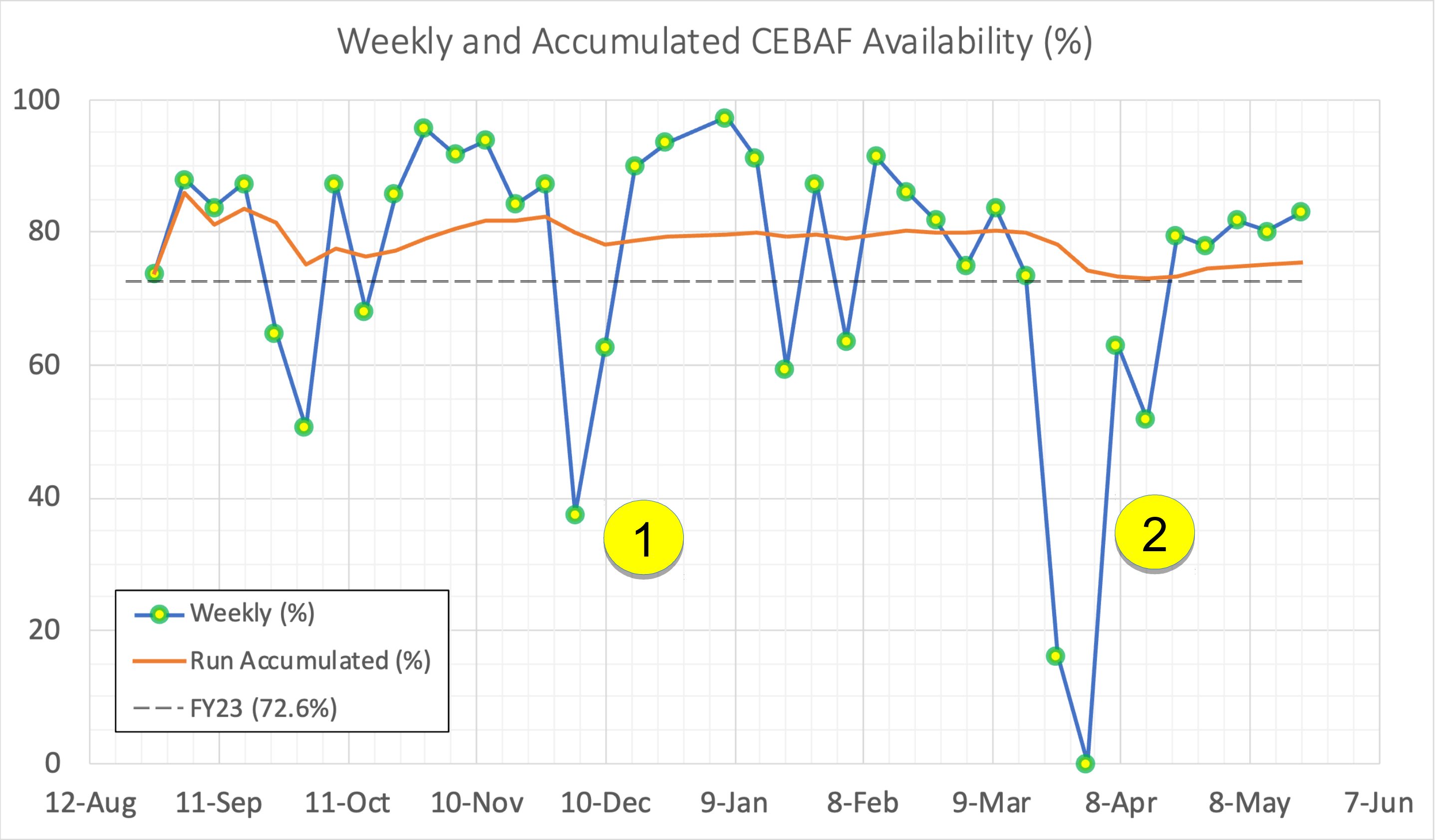
High Power Beam Test, 5/20/2024

- 85 uA beam current to Hall C @ 5 pass => 900 kW
- 860 kW for 2 min (1L22 RF trip), 800 kW for 3 min (1L23 RF trip)
- Maximum beam power was limited by available RF power
- We need a few days of sustained effort to push power beyond this level after SAD



Weekly CEBAF Reliability Last Run (08/26/2023 – 05/20/2024)

- Two significant downtime events that impacted reliability
  - Gun field emission, Nov/Dec 2023, and
  - Gun laser shutter failure, Mar/Apr 2024



1 Gun field emission required reducing gun HV and injector energy.
Root cause:
Design and test processes for the new gun did not follow best engineering practices.

2 Gun laser shutter was not in the right position after maintenance and failed to stop the laser beam, causing beam strike event.
Root causes:
1) Inadequate configuration control
2) Gun laser system can fail and send full beam for tens of milliseconds without ability to stop it.

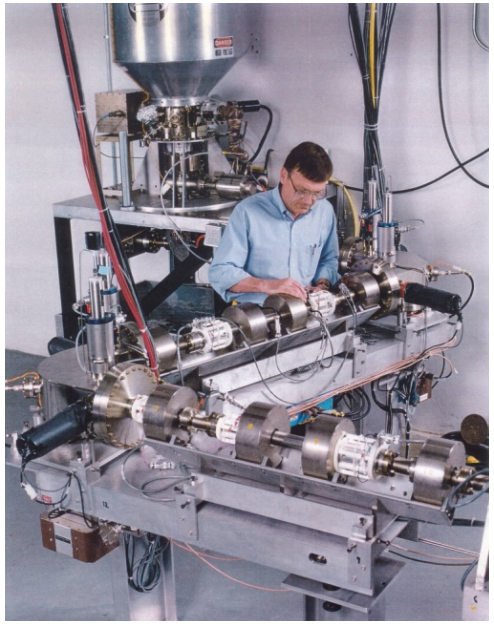
Accelerator Performance Limitations

- SRF
  - C100 cavity gradient degradation due to field emission and linac contamination
  - Loss of cryomodules and cavities to vacuum leaks and other events
  - Cavity faults caused by microphonics and other effects.
- RF
  - Performance of C100 RF stations lags relatively to the requirement
  - Loss of RF stations during run
  - C20, C50, C75 Klystron degradation needs attention
- Outdated accelerator systems limit understanding of the machine, post- mortem capabilities, and application of improved techniques such as AI/ML
  - LLRF, earlier, analog versions are still prevalent at CEBAF
  - BPMs and BLMs, slow DAQ (most), no buffering for postmortem processing
  - (No) Global timing system to synchronize CEBAF systems
  - Mitigation: AIP projects

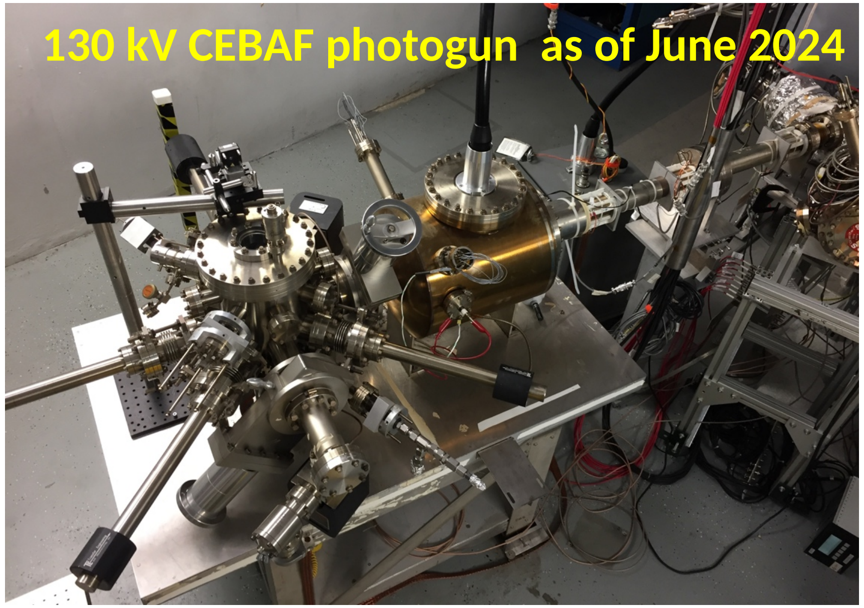
Challenges And Risks

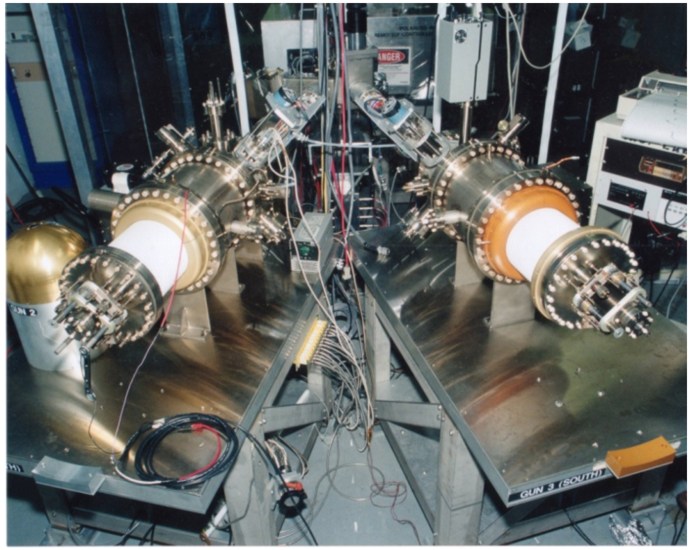
- Impact of delayed and reduced budget in FY24
  - Unable to procure and install all-metal gate valves this SAD due to late arrival of funding and procurement freeze. This delays effort to mitigate gradient degradation in CEBAF by a year.
  - Delay in refurbishment of klystrons (CPP). Risk of losing potential vendor for klystron refurbishment.
  - 50% reduction in funding of the CPP Obsolescence program. Risk of catastrophic failures increases.
- Safety issues have negative impact on operations
  - Take focus and effort away from operations and reliability
  - Make SAD and maintenance work planning and execution difficult
  - However, we have restored LOTO capacity
- Risk: lagging CPP funding
  - Insufficient funds for CPP can further affect our ability to address energy reach and reliability gaps
- Risk: Insufficient funding of AIPs
  - Upgrade of LLRF, BPM, BLM, Timing System can be significantly delayed limiting our ability to improve CEBAF performance

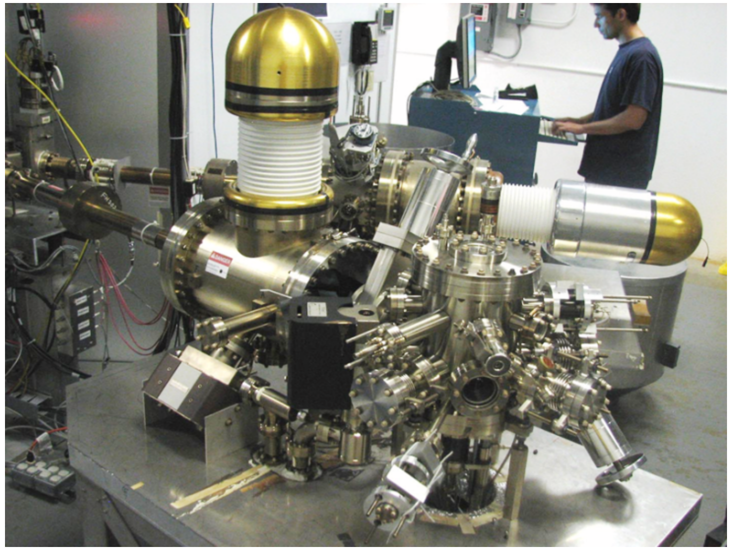
About every 5 years we have a major polarized source advancement

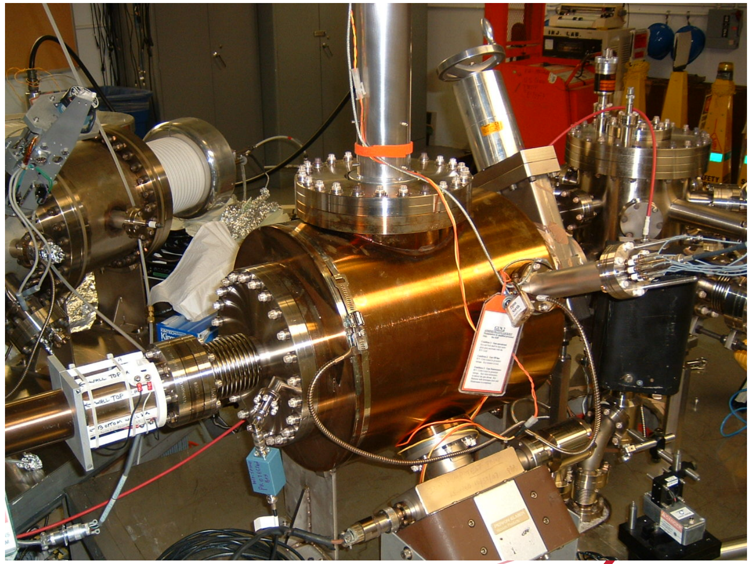


An endless (?) quest for perfection



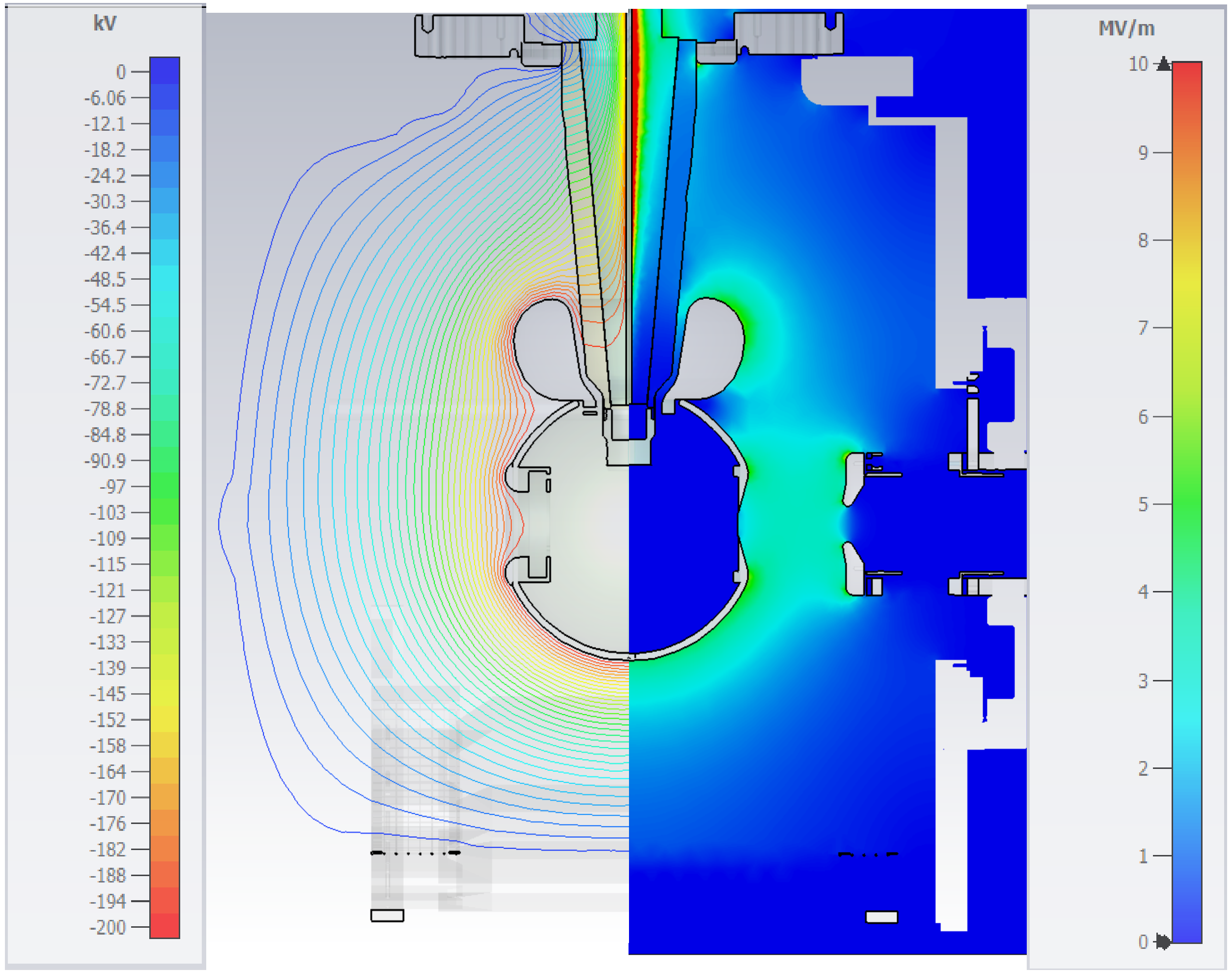






The CEBAF design allows for a photocathode preparation chamber behind the gun

New photogun electrostatic fields at 200 kV

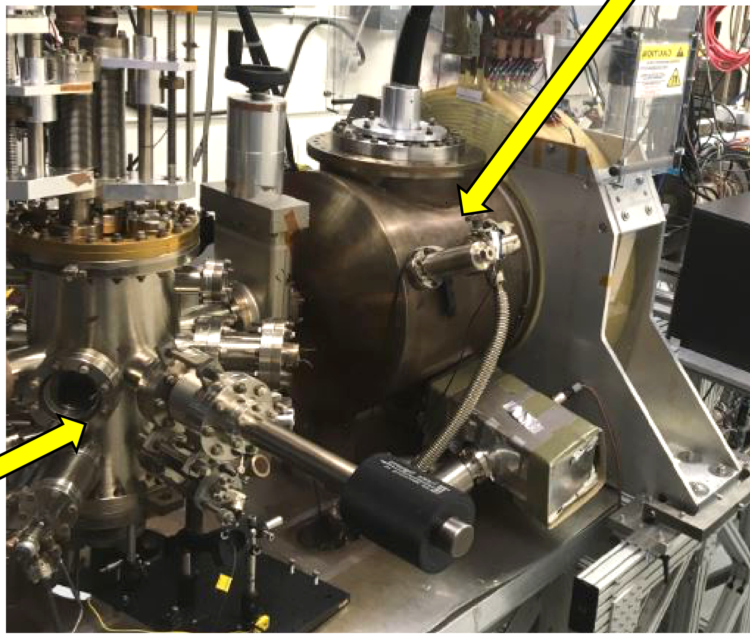


Alumina insulator

Triple-junction shielding electrode

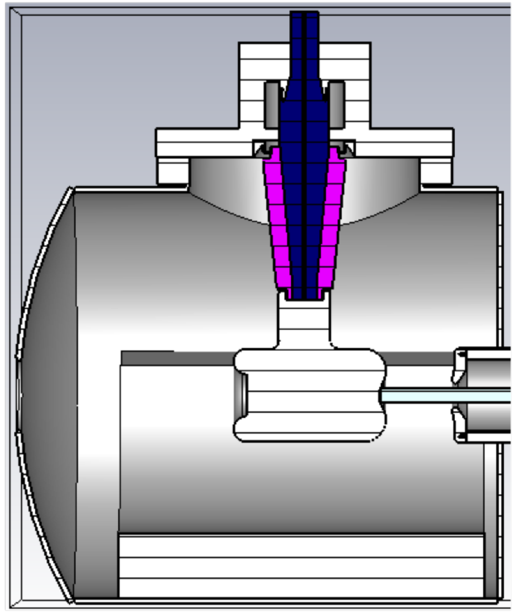
Photocathode

Gun HV chamber

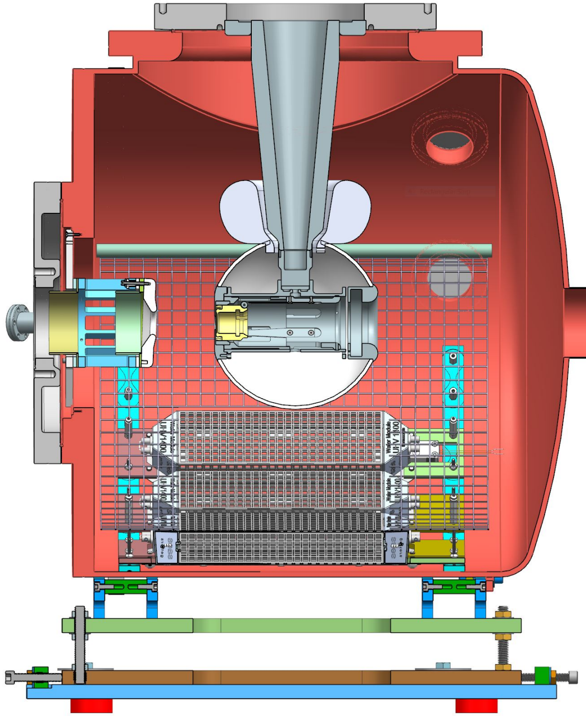


Photocathode Prep chamber

New, larger photogun installed for operation up to 200 kV

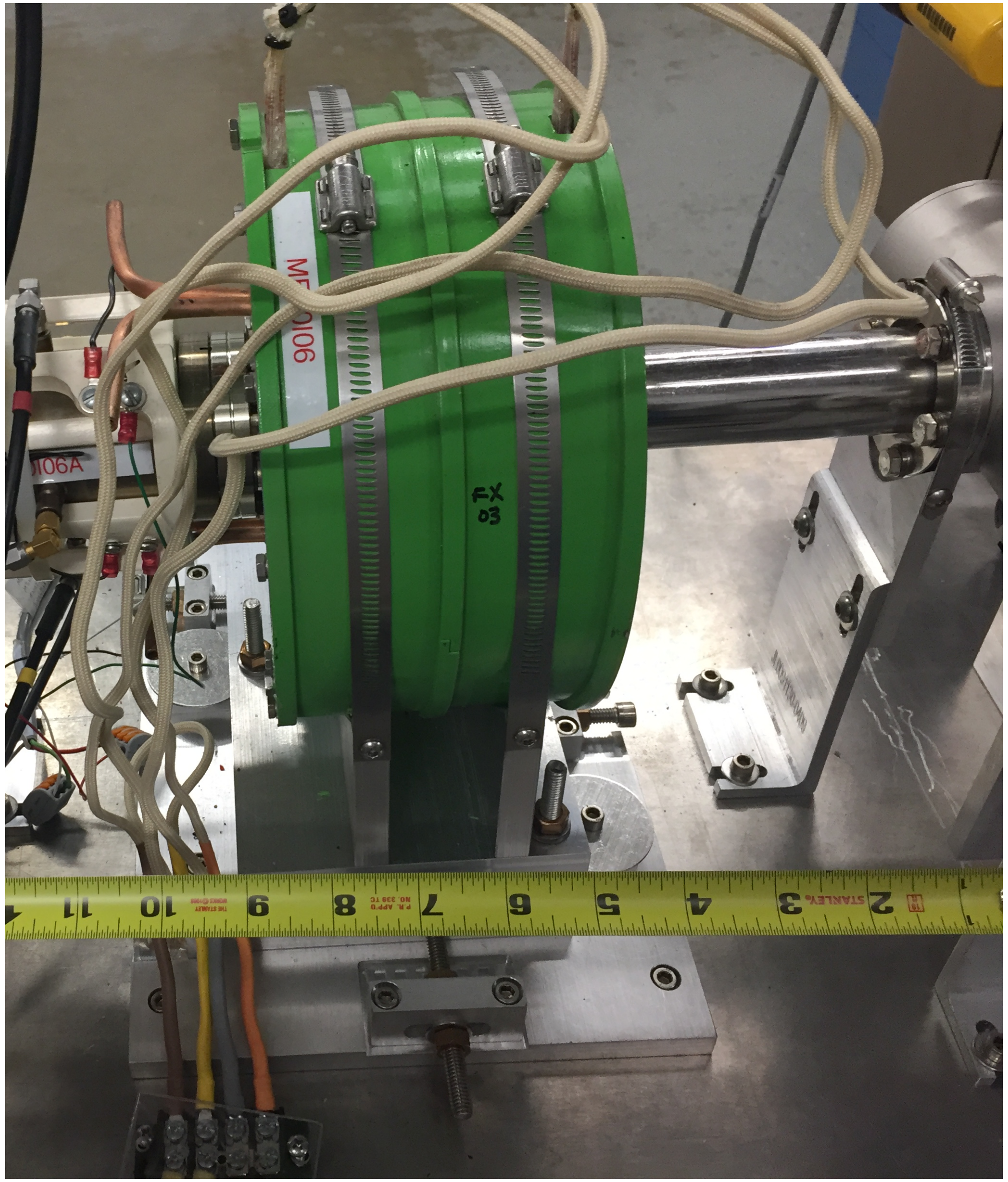


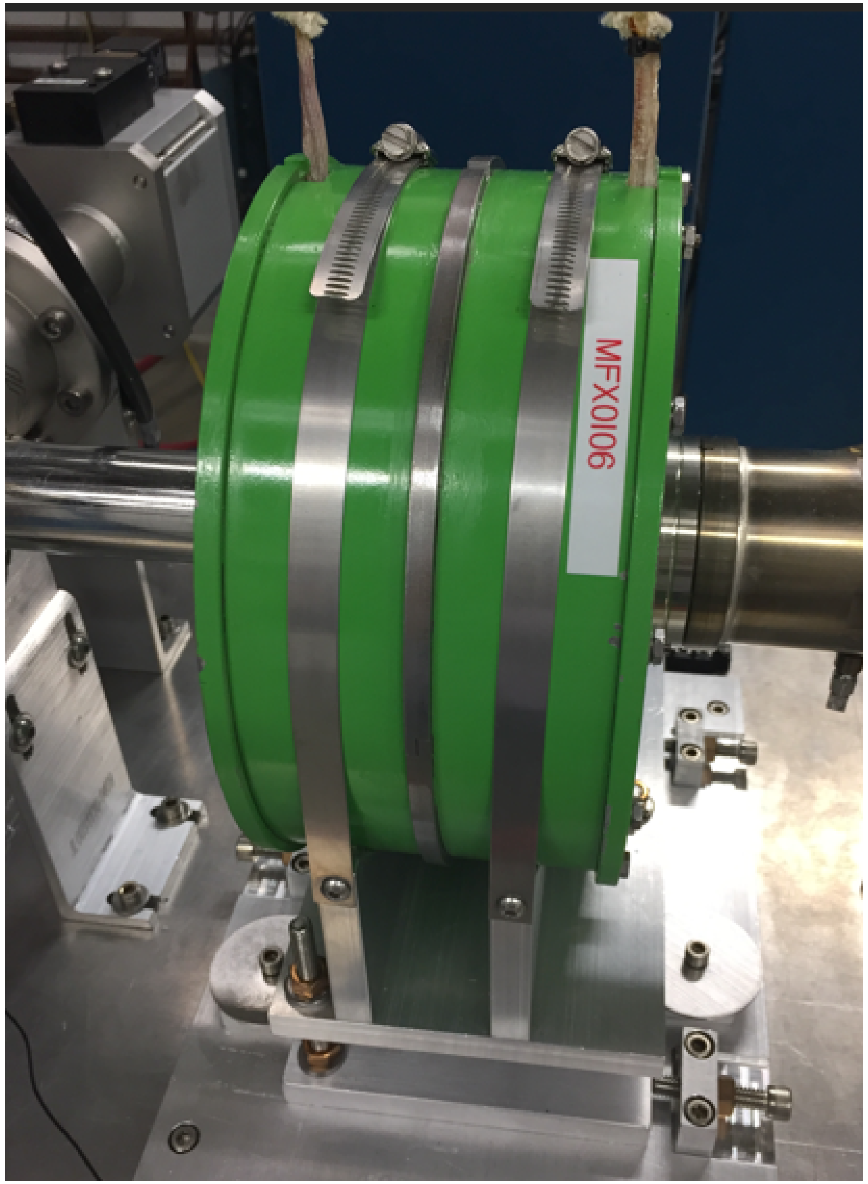
Present CEBAF 130 kV
photogun



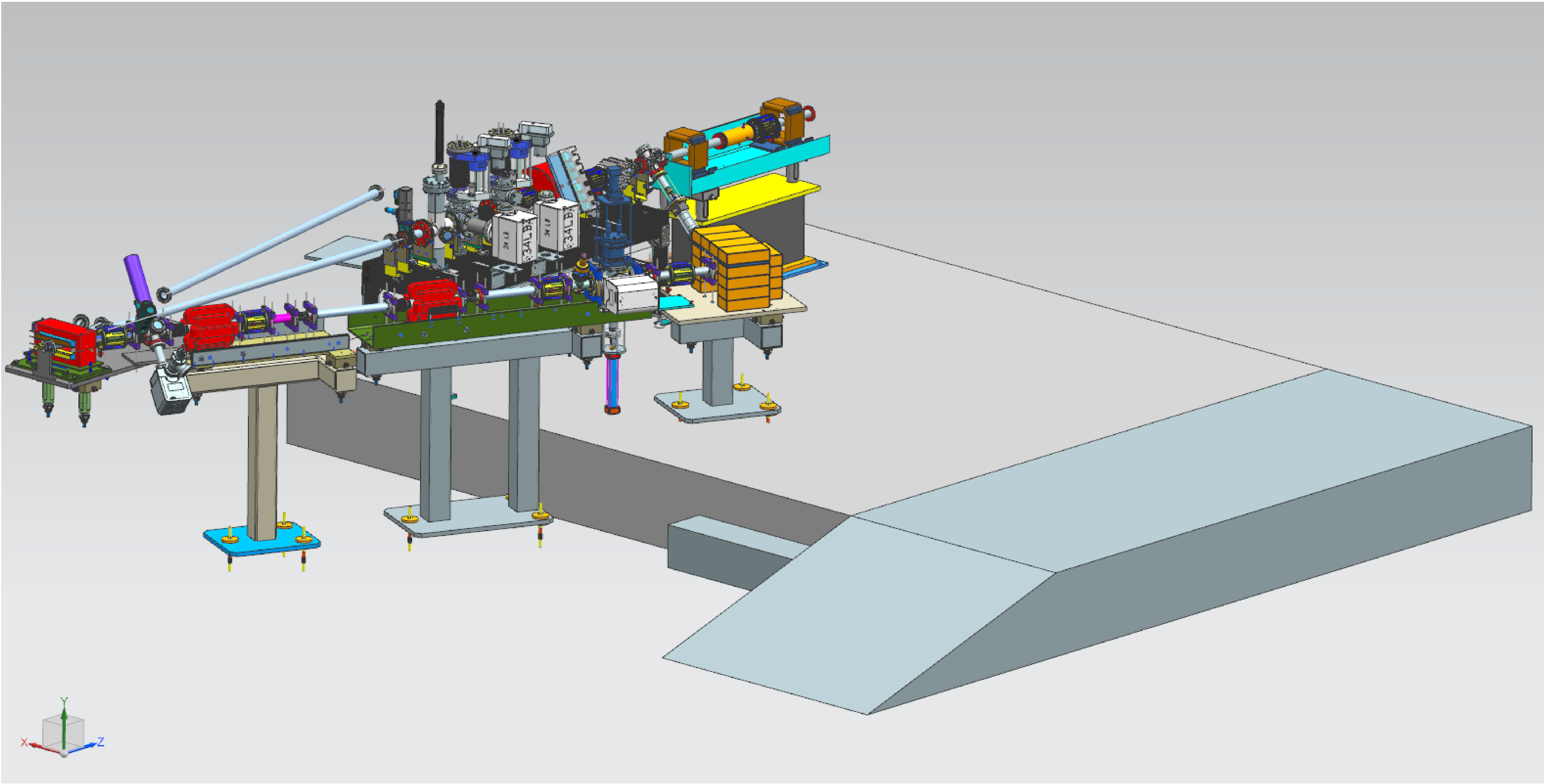
New CEBAF 200 kV photogun

Upgraded Injector Solenoids – as-built error corrected





Injector Polarized Solid Target irradiation station installation



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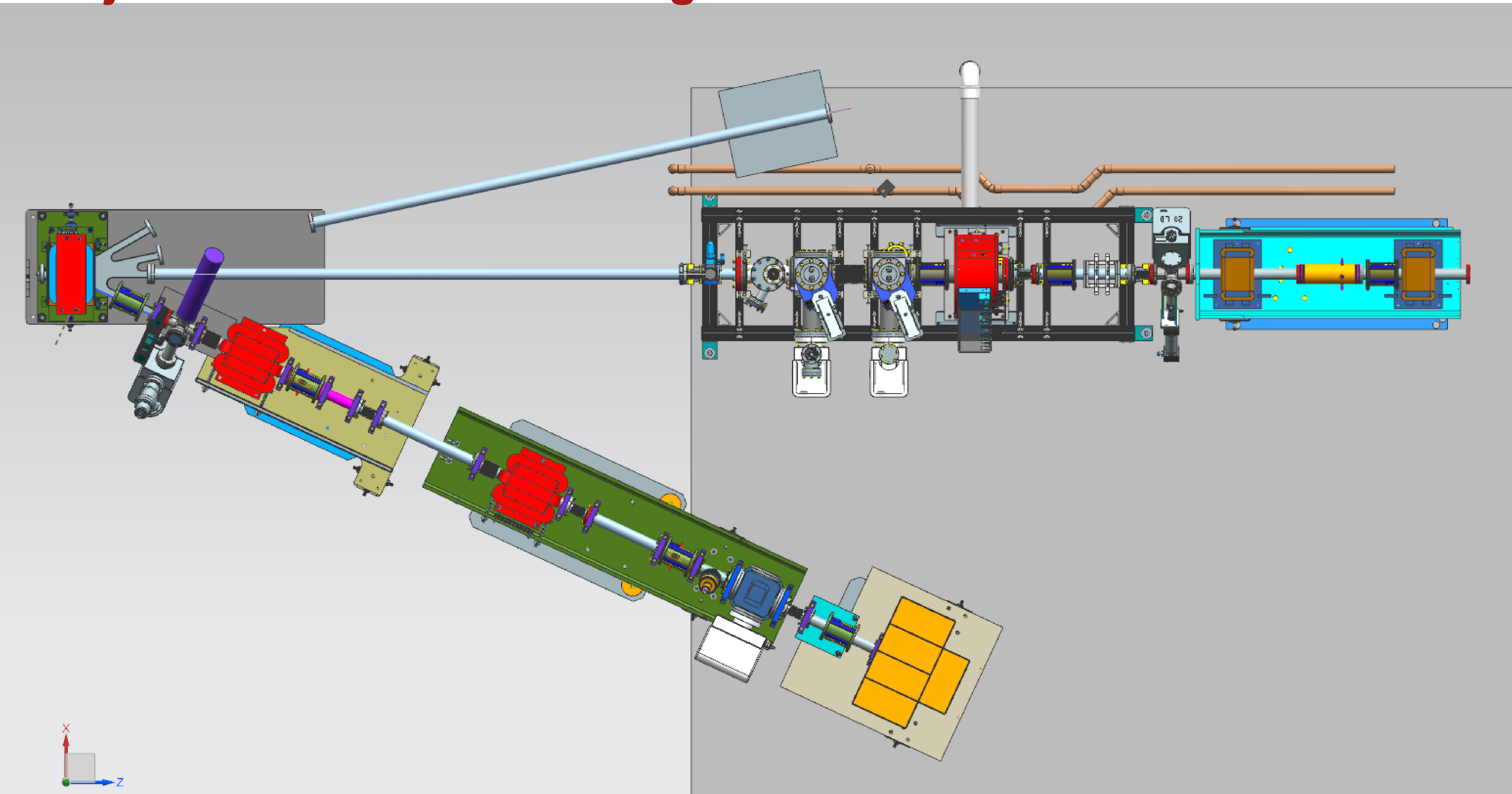
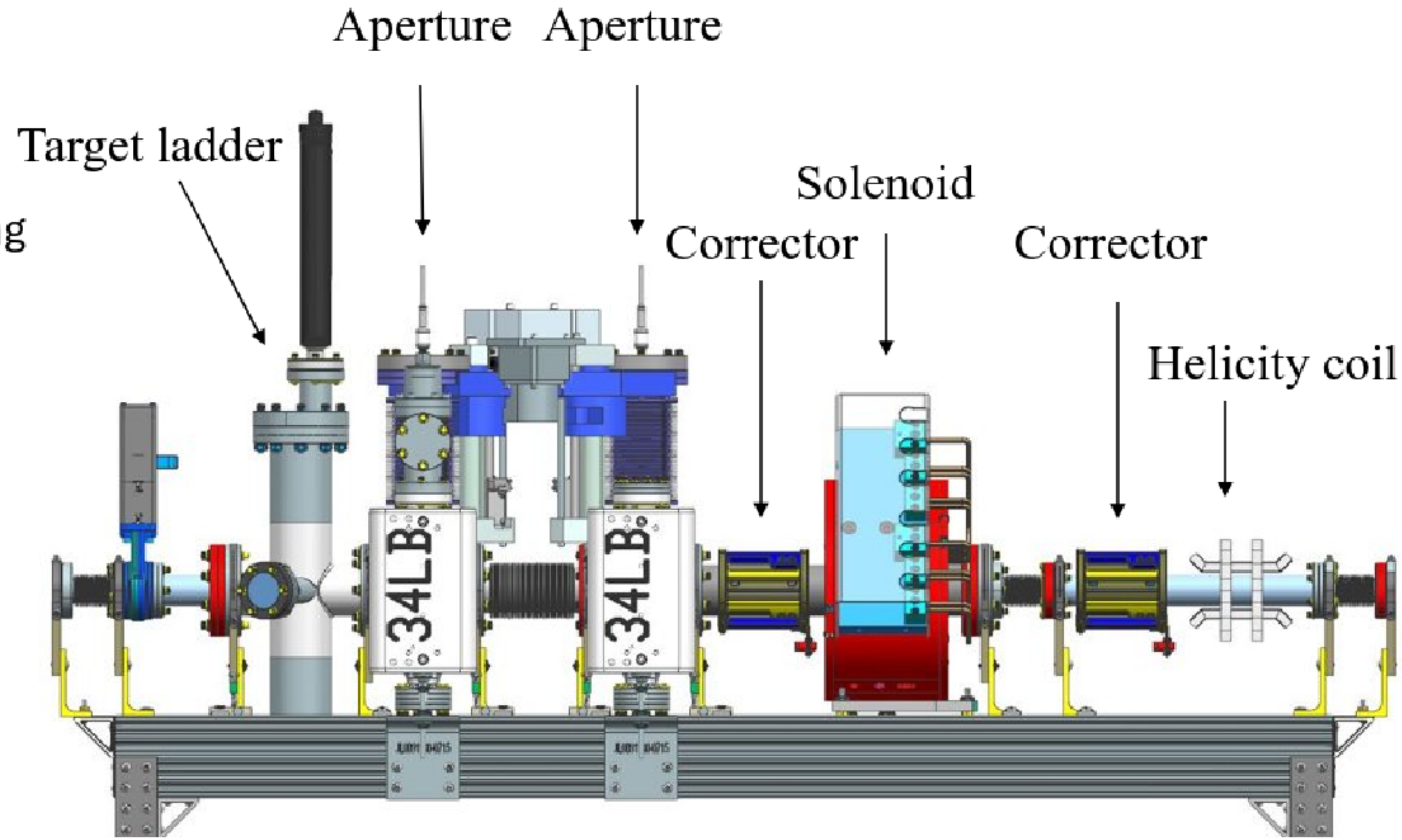


LDRD: Degraded electron beam transport in CEBAF

- Positron source at CEBAF will have higher emittance
- “Degrader” to increase emittance of CEBAF electron beam to match positron beam
  - carbon target, 2 apertures
- Installed between injector booster and first cryomodule
- Tune mode beam to 123MeV dump, NL during beam studies

As of Nov 11, 2024,

Undergoing Hot Check-Out



LDRD contact: Amy Sy

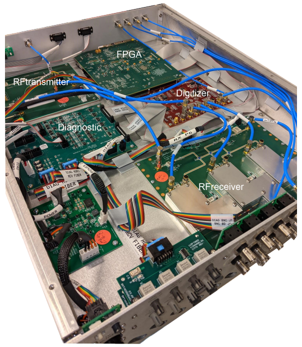
Jefferson Lab

LLRF, BPM, BLM, and Timing System Upgrades….

- LLRF Upgrade
  - Provides advanced functionality for field control and diagnostics capabilities.
  - Upgrade in progress. Installation to proceed until 2027.
- Next Generation BPMs
  - Addresses obsolescence. Provides new functionality: high bandwidth DAQ, buffering, interface to global timing system, suitable for capturing fast transients.
  - Porotype construction in progress. Plan to install by 2028.
- BLM System Upgrade
  - Provides new functionality (faster DAQ, buffering, interface to timing system). Total loss monitors can extend area coverage.
- Global Timing System
  - Synchronizes instrumentation and allows correlating their response to beam events

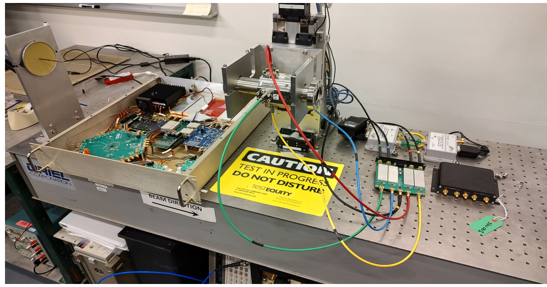
- These systems will benefit CEBAF the most if they are treated as parts of an integrated system, complementing each other.
- Advanced functionality and global timing will provide insight into machine behavior and allow us to use modern tools such as ML/AI.

N. Rider

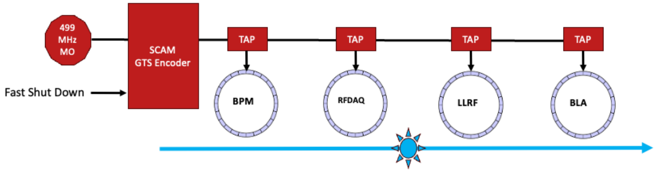


LLRF v3

New gen. BPM prototype



Global timing system concept



Jefferson Lab

Helium Vapor Return mass flowmeter installation

- Hot-wire anemometer (Superconducting probe loop, Hyperboloid LLC)
- Competes 3K vapor refrigeration against supplemental heater
  - Static conduction/natural convection/forced convection
- Track and measure heat to maintain partially normal-conducting probe
- Includes a diode thermometer to measure vapor temperature
- Fast (time scale of minutes) measurement of RF cavity dissipation (Q_0)

Helium Vapor Return flowmeter –
Keep an eye on Q_0, Avoid insulating vacuum surprises

Development, Commissioning, and Measurement of SRF Cavity Heat-loads and Quality Factors with a Conduction-Cooled Helium Flow meter

We present a cryogenic flow meter, acting as a power meter to measure real-time helium vapor mass flow in the return U-tube of a superconducting cryomodule. The meter employs a superconducting niobium-titanium sensor element (Tc=9.2K) adjacent to a resistive heater. Cooling from ~3K helium vapor competes with resistive heat, stabilizing the sensor in a fractionally normal-conducting state. This dynamic balance enables the meter to function as a hot-wire anemometer with a sensitivity of 0.05 g/s (equivalent to 1 Watt of cavity dissipation).

Matching RF-induced vapor flow with calibrated cryomodule heater output offers a rapid and reliable method for assessing cavity performance vs. accelerating gradient, expediting commissioning processes. It also enables effective Q_0 tracking over time, optimizing SRF systems' efficiency, guiding cryogenic heat load management, and enhancing the correlation of eventual cavity performance degradation with possible environmental or hardware-related influences

Path Forward – Basically "Make It Better"

- Continue critical CPP effort to close energy and reliability performance gaps
- Reestablish CEBAF SRF cleanness effort, implement it as part of CPP, and include plasma processing into operations
- Review and improve CEBAF RF performance
- Improve beam transport and tuning procedures and ensure continuity of experience with machine tuning within AD
- Focus on improving reliability, restore reliability team, and continue effort to turn maintenance from reactive to proactive
- Upgrade CEBAF accelerator system through AIPs and expedite upgrades if possible
- Develop Accelerator Management Plan that will summarize CEBAF path forward for next five years (by end of CY24)