

35 years of CEBAF - Historic Review

Andrew Hutton
Jefferson Lab

SESAPS Meeting

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Thanks

- Much of this talk was taken from the excellent history of CEBAF by [Catherine Westfall](#), Professor Emerita, MSU
- I also used slides from talks by [Larry Cardman](#), Jefferson Lab (retired)
- My thanks to both of them; I would never have been able to prepare this talk without their input



References

- Catherine Westfall, “From Desire to Data: How JLab’s Experimental Program Evolved,” pt. 1, “From Vision to Dream Equipment, to the Mid-1980s,” *Physics in Perspective* 18, no. 3 (2016), 301–5
- Catherine Westfall, “From Desire to Data: How JLab’s Experimental Program Evolved,” pt. 2, “The Painstaking Transition to Concrete Plans, mid-1980s to 1990,” *Physics in Perspective* 20, no. 1 (2018), 43–123
- Catherine Westfall, “From Desire to Data: How JLab’s Experimental Program Evolved Part 3: From Experimental Plans to Concrete Reality, JLab Gears Up for Research, mid-1990 through 1997” *Physics in Perspective* 21, no.3 (2019) 108-159

Overview

- Why an Electron Accelerator?
- The dream of an electron-nuclear facility in the South-East
- Bait-and-switch – change to superconducting cavities
- The 4 GeV machine
- The 6 GeV machine, with hurricane
- The 12 GeV machine

The Larger Nuclear Physics Community Plans

- In 1977 the National Academy of Sciences/National Research Council Ad hoc Panel on the Future of Nuclear Science (the Friedlander Panel) had recommended:
 - The energy doubling of the MIT-Bates (1% duty factor) facility
 - The Construction of a new, high energy ($>1\text{GeV}$) CW electron facility
- This was followed (later in 1977) by a DOE/NSF Joint Study on the Role of Electron Accelerators in US Medium Energy Nuclear Science (the Livingston Panel) which further highlighted the value of a high-energy, CW electron accelerator

The Larger Nuclear Physics Community Plans

- In December 1979, the very first NSAC (then NUSAC) Long Range Plan included as its highest priority for major new construction a high energy (1-2 GeV) CW electron accelerator as a major new “national facility”
- The Barnes Subpanel of NSAC was created to evaluate the requirements in detail. In 1982 they concluded:
 - Investigations of complex nuclei with electron beams of 0.1-1.0 GeV, high duty factor and high intensity would have an important impact on our understanding of nuclear structure and dynamics*and*
 - An electron beam capable of reaching about 4 GeV with high intensity and duty factor would have substantial impact on the investigation of the transition between the nucleon-meson and quark-gluon descriptions of nuclear systems

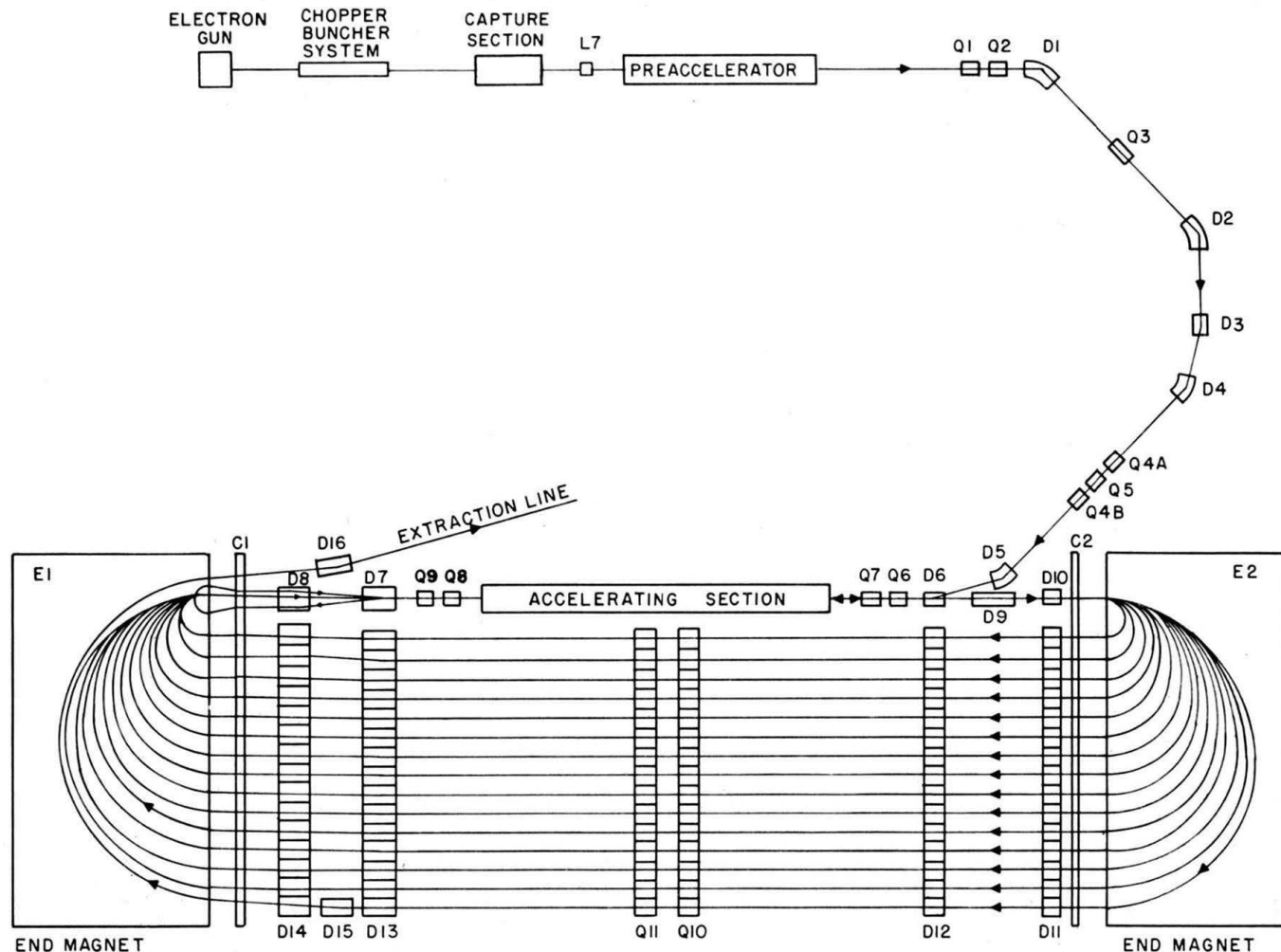
Battle lines are Drawn

- In December 1979, NSAC suggested the construction of an intermediate energy machine in 1981 and the construction in 1985 of an accelerator in the 1 to 2 GeV range, which would be a “national facility”
- Four groups wanted the machine
- The [National Bureau of Standards](#) (NBS), the [University of Illinois](#), [Argonne National Laboratory](#) (ANL), and [MIT-Bates](#) were established centers of electro-nuclear physics
- MIT-Bates, with the most powerful electro-nuclear physics accelerator in the U.S., was considered the frontrunner



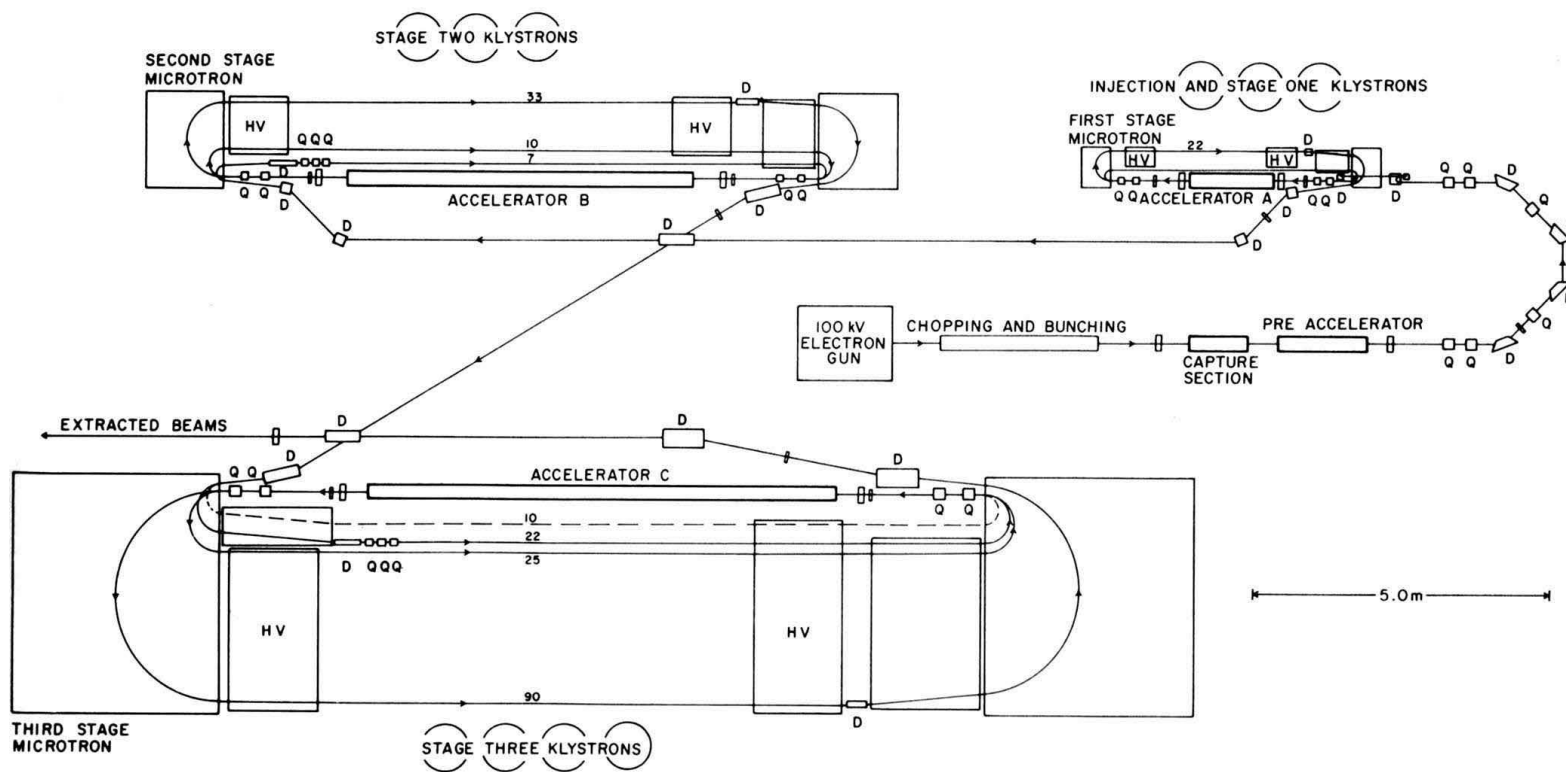
National Bureau of Standards Proposal

- 1 GeV Racetrack Microtron



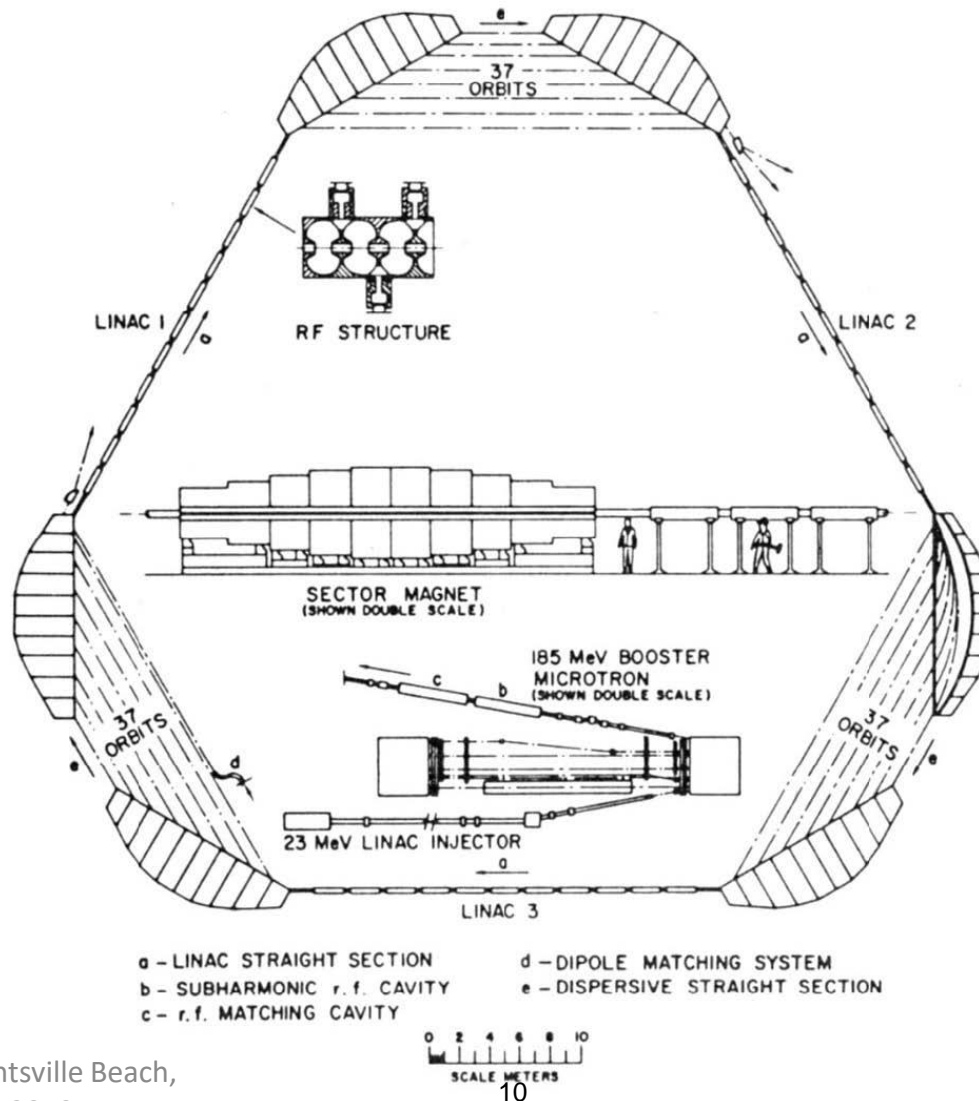
University of Illinois at Champaign-Urbana Proposal

- 0.75 GeV Cascade Microtron



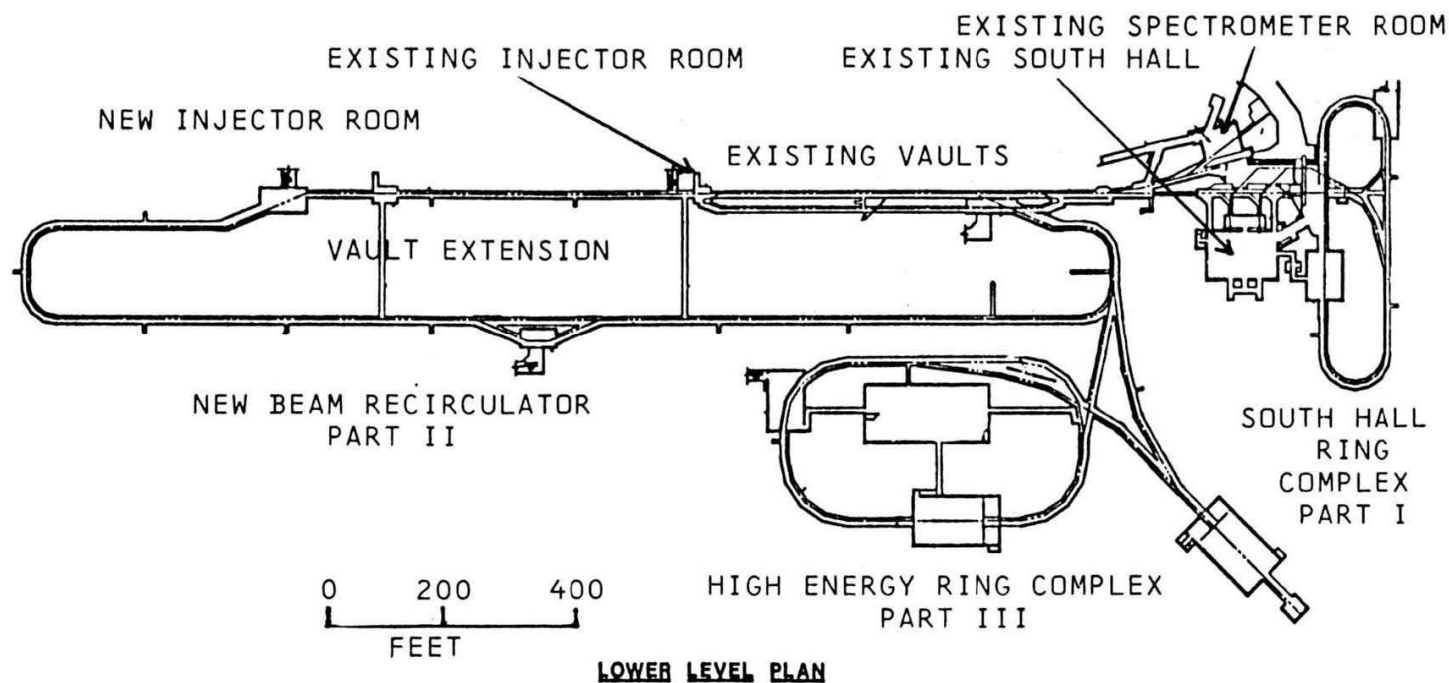
Argonne National Laboratory Proposal

- 4 GeV Electron Microtron



MIT-Bates Proposal

- Linac with stretcher ring to be built in stages
 - Part I – 1 GeV
 - Part 2 – 2 GeV
 - Part III – 4 GeV



The “Amateurs” Prepare a Coup

- James McCarthy of UVA formed a design group led by Blaine Norum and Richard York, neither of whom had accelerator experience, to compete with the established experts
- At the same time, Hans Von Baeyer (W&M) was looking for a use for the Space Radiation Effects Laboratory (SREL), the former NASA cyclotron facility at VARC in Newport News, Virginia
- Physicists from UVA and W&M came together under the “Four Musketeers” to design the “National Electron Accelerator Lab” at the NASA site
- By 1980, the South-Eastern Universities Research Association (SURA) was formed with 13 founding members



What Energy is Needed?

- In 1981, NSAC convened a Subcommittee on Electromagnetic Interactions to review “the current status and future direction” for electro-nuclear physics and assess “the need for facilities to pursue the highest priority” research
- The subcommittee’s report gave the “highest scientific priority” to a high duty factor accelerator “able to achieve an electron energy of about 4 GeV”
- MIT did not accept this decision
- “You can have a panel but not necessarily agree with everything the panel says. No one had convinced us. We still felt that anything much under 10 GeV provided about the same physics.”
 - They believed that ~10 GeV would be needed eventually, and 1 GeV, then 2 GeV was as good as 4 GeV in the meantime
 - BAD

Exit “The Bad”

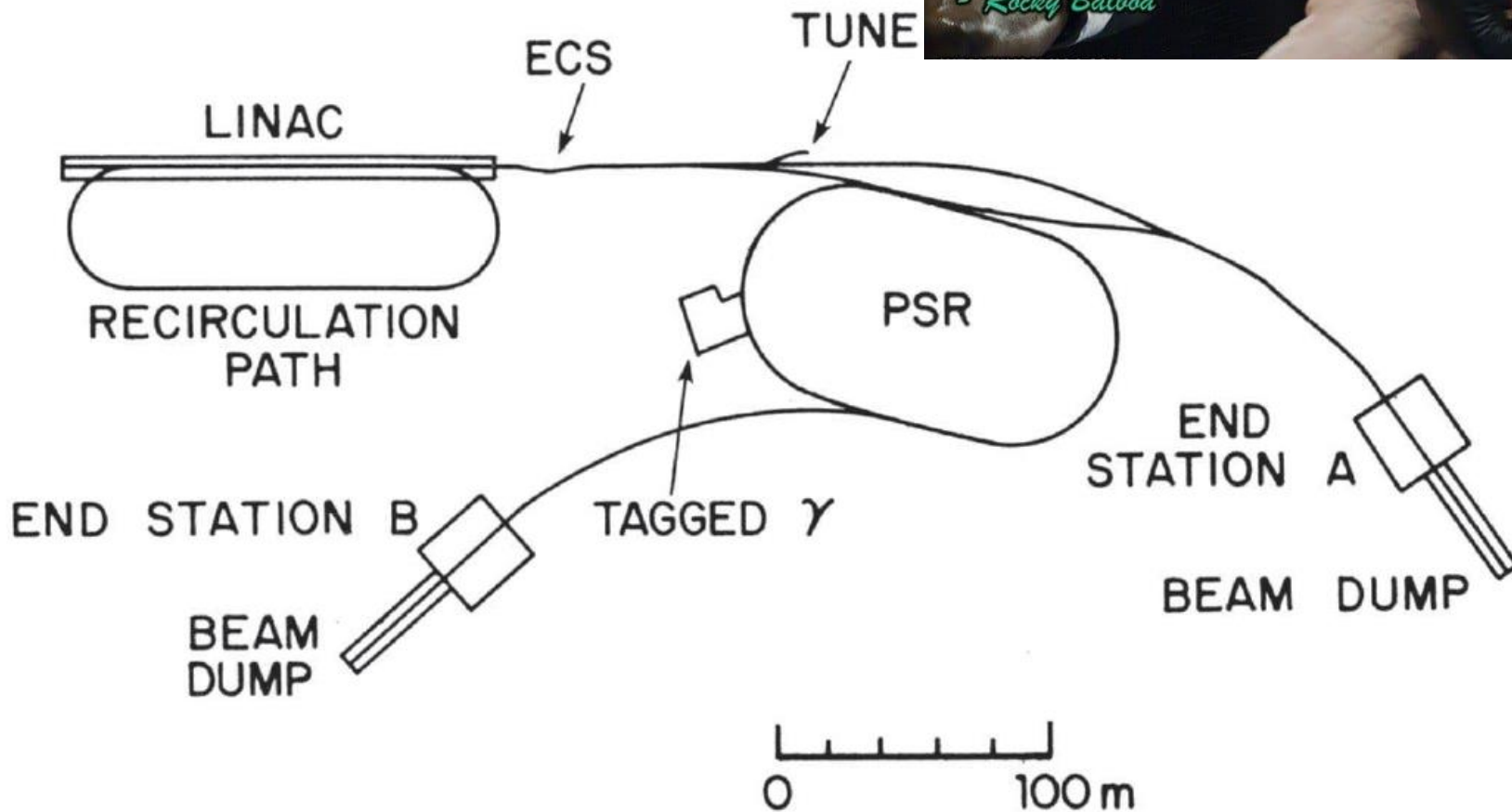
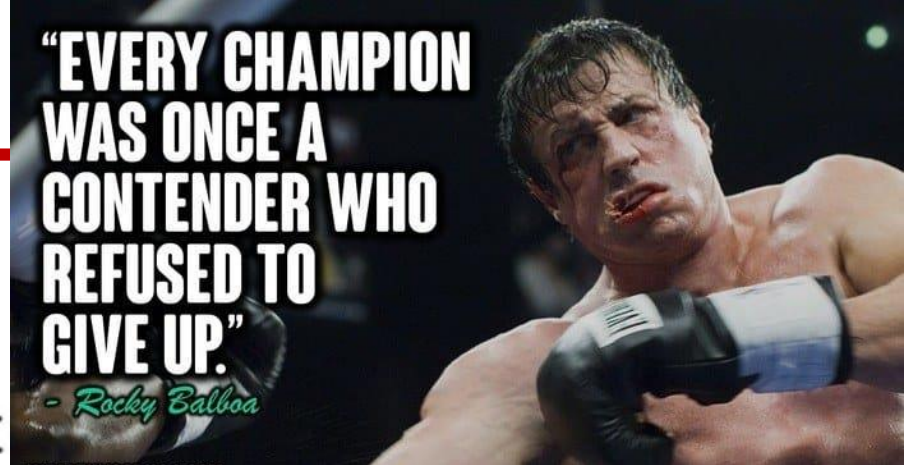
- MIT were disqualified because their design did not reach 4 GeV
 - This was a deliberate decision that backfired!
 - The designs from NBS and the University of Illinois were also rejected because they could not be scaled to 4 GeV
- Only ANL (microtron) and SURA (linac plus stretcher ring) presented 4 GeV proposals
- The panel admitted that both groups had feasible designs “and that either could very well form the basis for an extremely powerful national facility.”
- SURA’s design was selected
- Instead of focusing on ANL’s disadvantages, the report diplomatically stressed three advantages that clinched SURA’s victory
 - This led to the next shoot-out

Exit “The Ugly”

- Argonne director Walter Massey was incensed by the news that ANL had lost
 - He argued that the report did “not lead logically to the conclusion”
- Massey asked the Secretary of Energy to either choose the ANL proposal or allow the SURA design to be built at ANL
- Massey was supported by six midwestern governors, from Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin
 - UGLY
- Massey’s challenge and the fear of the resulting congressional response complicated DOE’s battle to obtain approval for the project from the Office of Management and Budget (OMB)
- DOE upheld the choice of SURA

SURA Wins the Battle

- In 1983, SURA's design was selected



“It Ain’t Over Till The Fat Lady Sings”

- Hermann Gruner was convinced to accept the job of full time Director
 - “They twisted my arm so hard I thought it would fall off”
- Hermann initiated a Technology Review under Christoph Leemann, to include SRF
- Hermann was concerned that MIT was correct that energies up to 10 GeV would be needed, and the linac and stretcher ring could not be upgraded sufficiently
- Hermann became convinced that a viable SRF accelerator could be built, and by early October 1985, he announced that CEBAF (the Continuous Electron Beam Accelerator Facility) would adopt a superconducting design
- This decision is the reason that CEBAF is still a forefront machine and Jefferson Lab still exists today

Hermann Grunder with IEEE Technology Prize



SRF Was a Gutsy Choice in 1985

- SRF Technology was first proposed by the Rutherford Lab in 1961*
- The first accelerator was built at HEPL (Stanford) in the 1960s and 70's
 - Could not achieve >2 MV/m because of multipacting, and the transverse Beam Break-Up (BBU) modes caused beam instabilities
- By 1981, work at Darmstadt/Wuppertal, Cornell, DESY, KEK, and CERN had made real progress
 - Helmut Piel used a temperature mapping technique to understand and solve the materials issues
- Multi-cell cavities had been installed and operated successfully in storage rings (notably in CESR at Cornell) demonstrating that the BBU modes had been tamed
- Industry was willing to bid on delivering cavities

* A. P. Banford and G. H. Stafford, The Feasibility of a Superconducting Proton Linear Accelerator, Plasma Physics, J. Nucl. Energy, Part C, 3, 287 (1961)

CEBAF Design Parameters

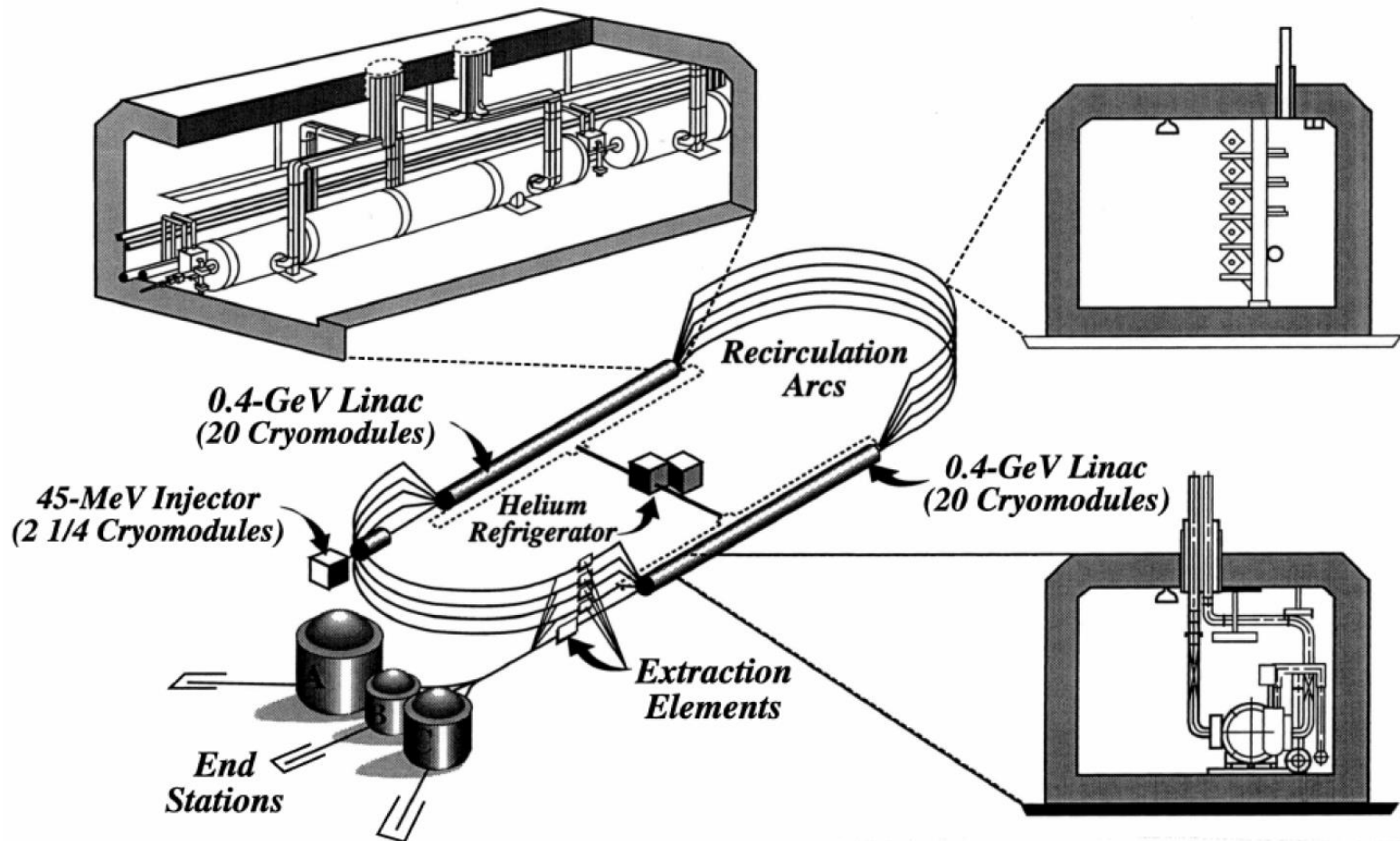
- Primary Beam: Electrons
- Beam Energy: 4 GeV (with upgrade path)
 - $10 > \lambda > 0.1$ fm
nucleon \rightarrow quark transition
baryon and meson excited states
- 100% Duty Factor (CW) Beam
 - coincidence experiments \Rightarrow excite system with a known (q, w) and observe its evolution
- Three Simultaneous Beams with Independently Variable Energy and Intensity
 - complementary, long experiments
- Polarization (beam and reaction products)
 - spin degrees of freedom
weak neutral currents

$\mathcal{L} > 10^6 \times \text{SLAC at the time of the original DIS experiments}$

CEBAF as Approved

MACHINE CONFIGURATION

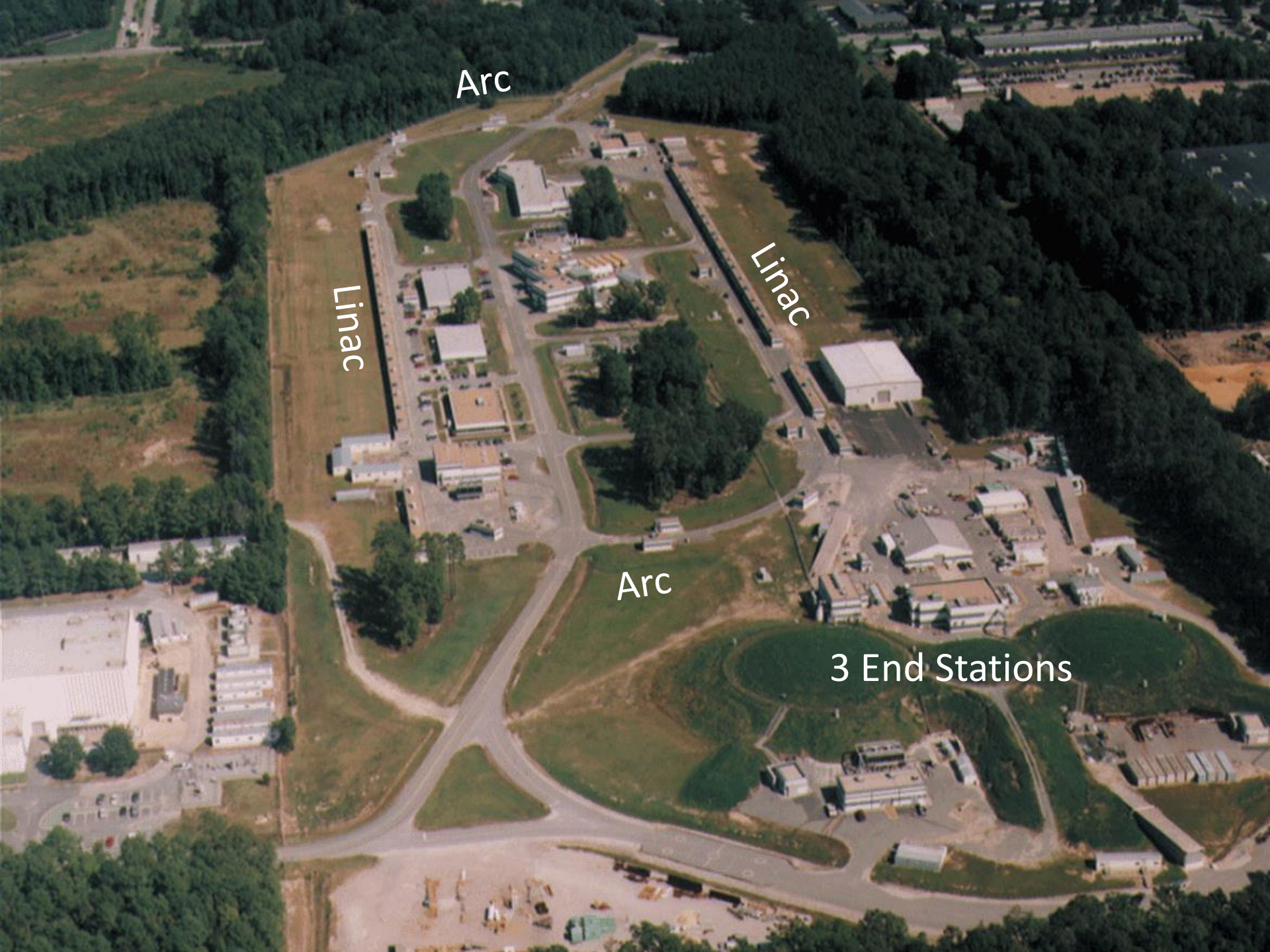
CEBAF



Construction

- Construction of CEBAF finally begun in February 1987, eight years after the first recommendation





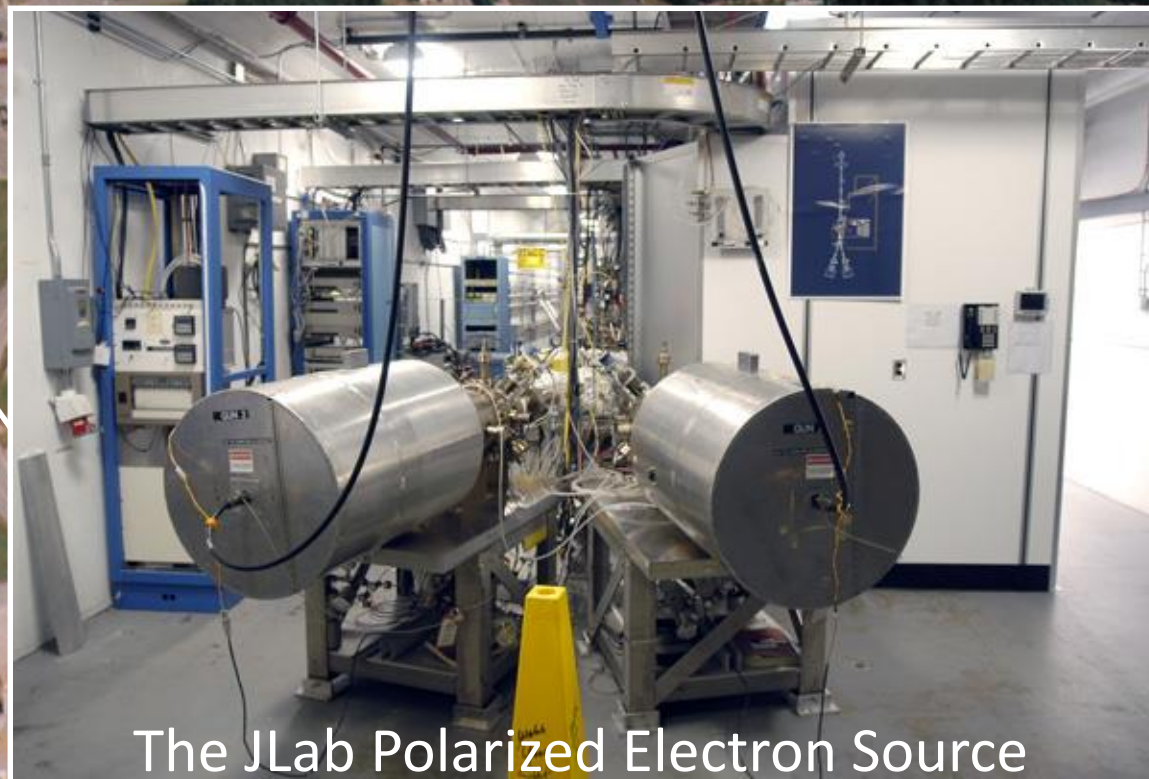
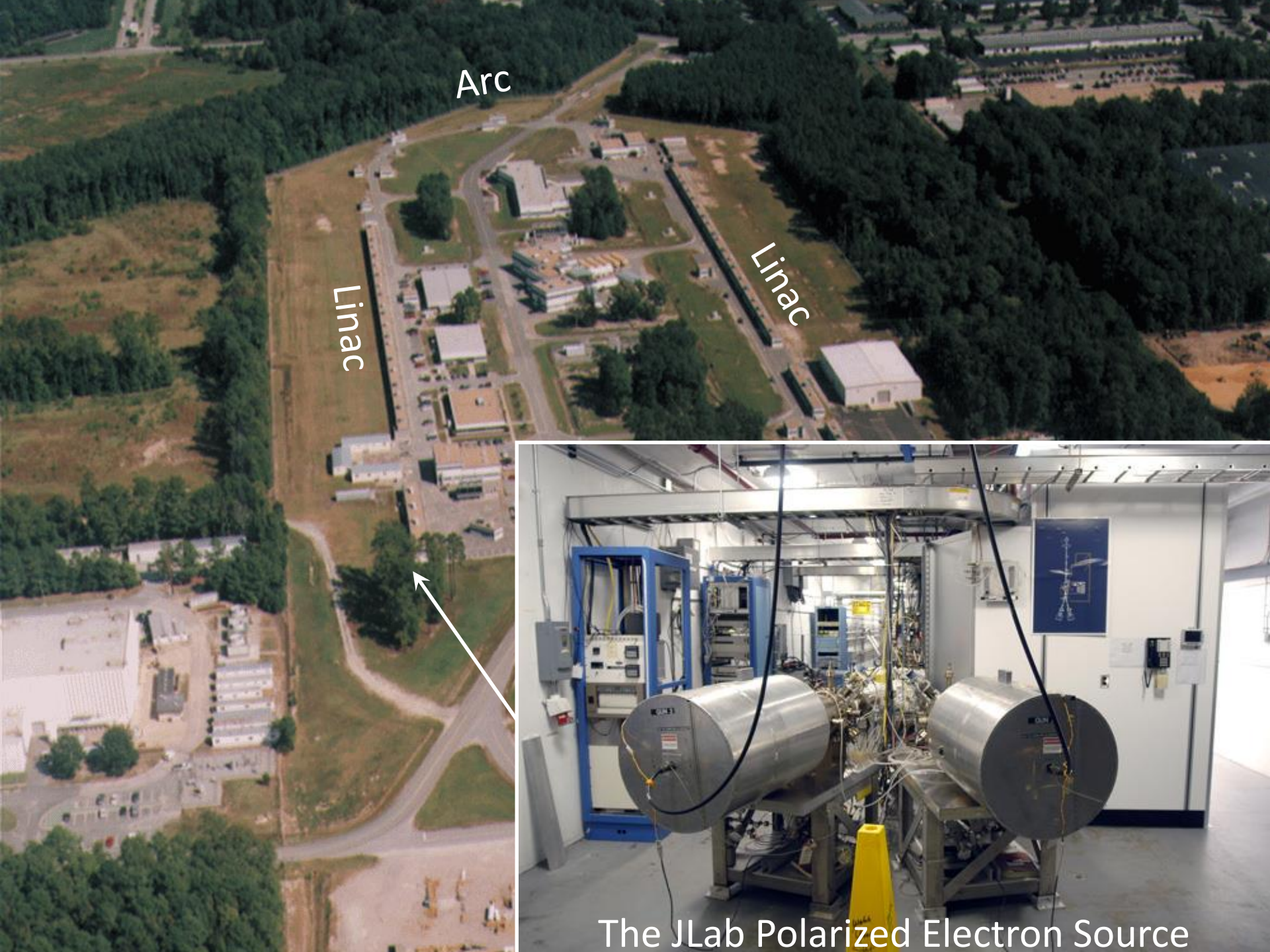
Arc

Linac

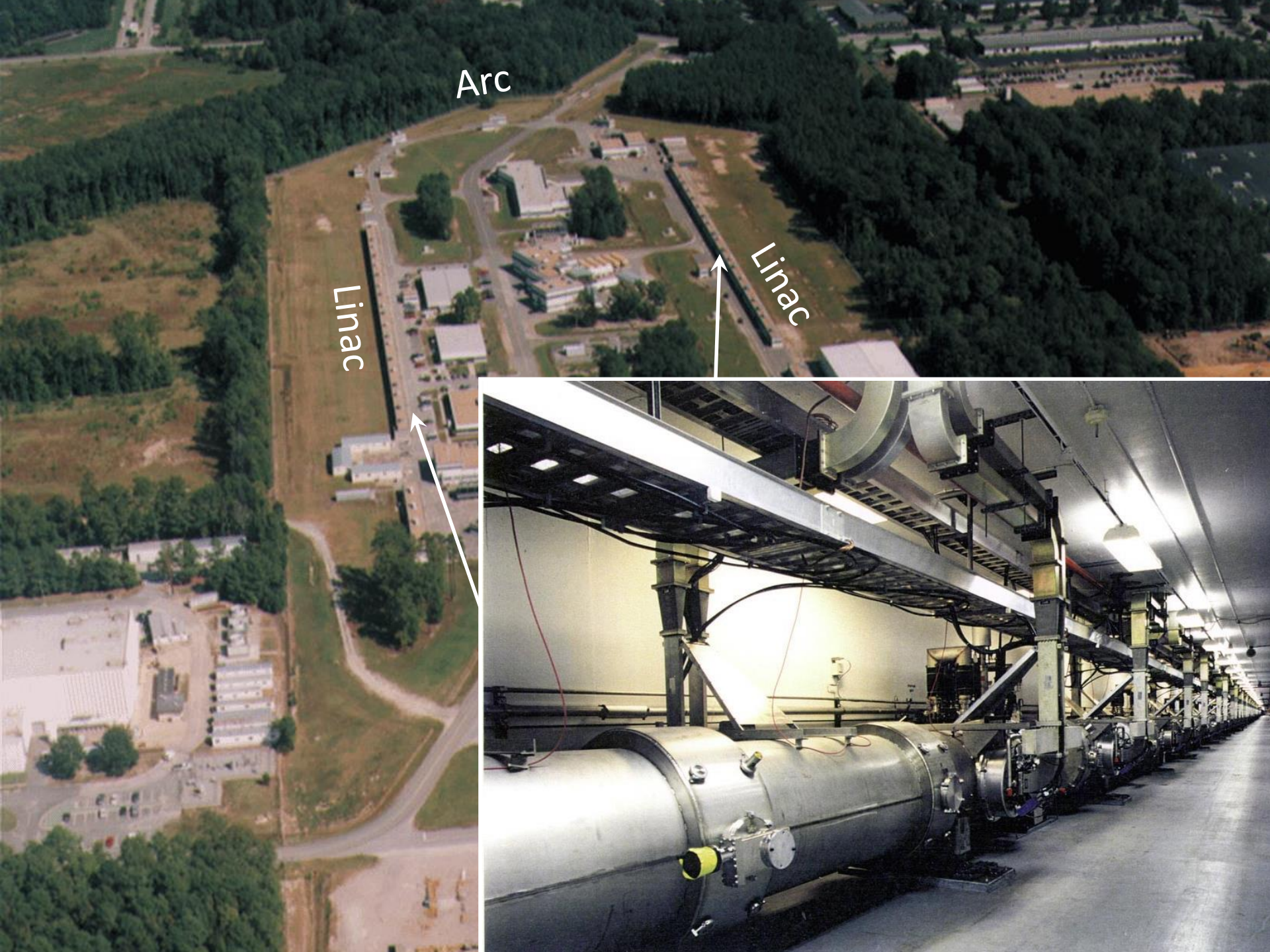
Linac

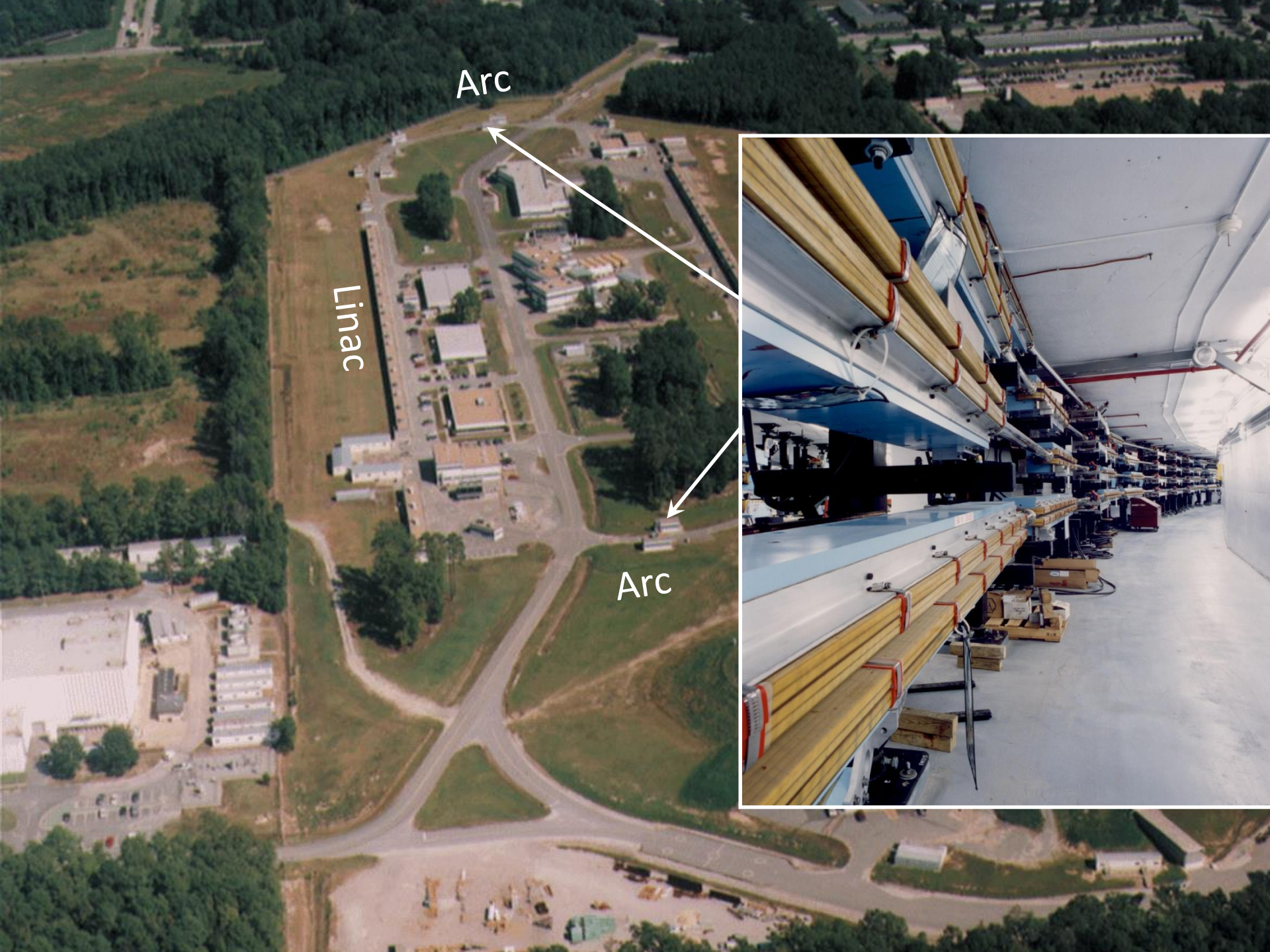
Arc

3 End Stations



The JLab Polarized Electron Source





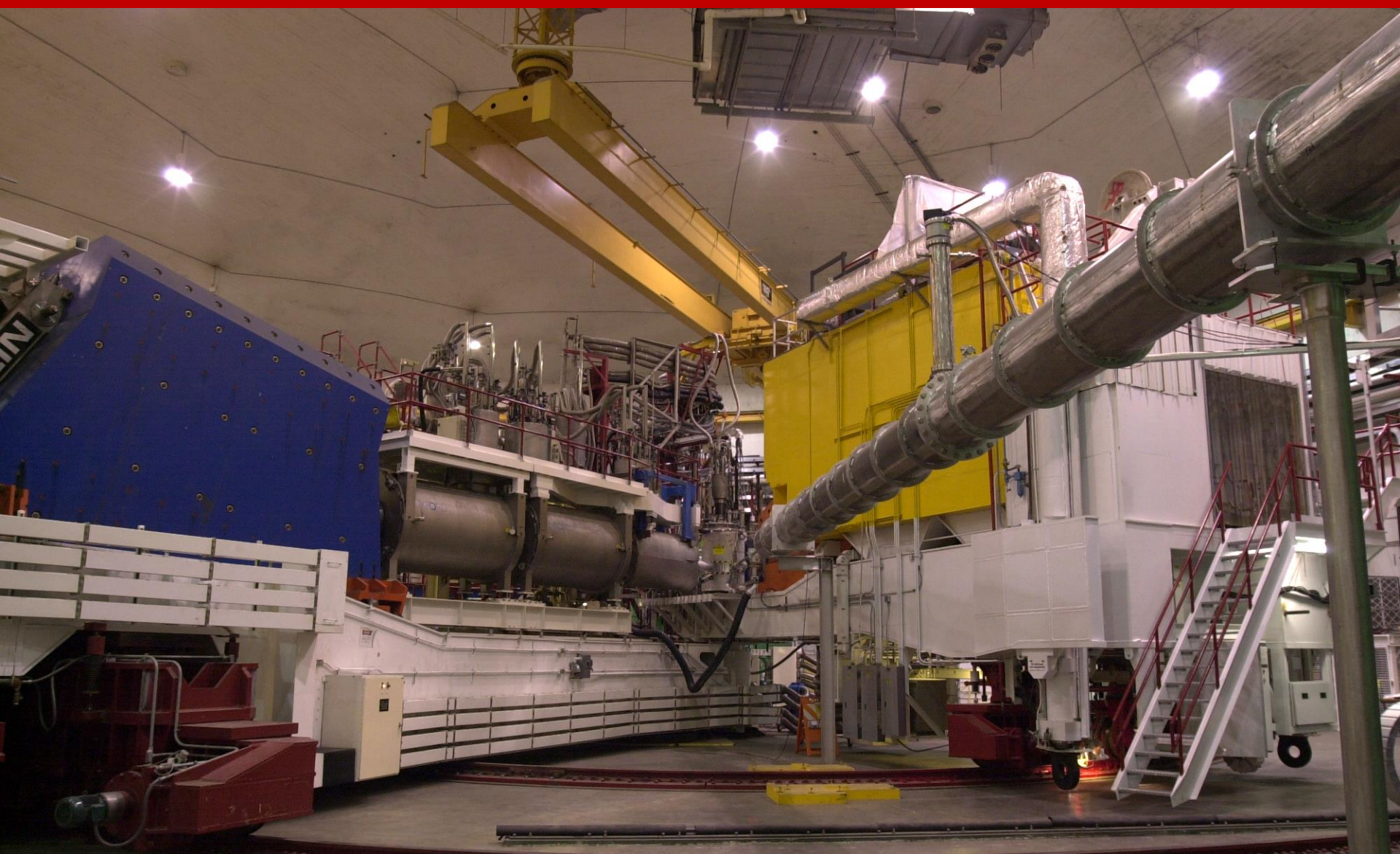
Never Enough Money

- Nuclear physics in 1985 was “small science”
- CEBAF required major investment of money, scientists & engineers
- The accelerator had to be built, so the experiments were at risk for cost cutting
- Experimental groups were encouraged to participate in producing the equipment
 - Should they earn precedence for the experimental program?
 - Or would this allow “second rate” experimenters to “buy” entry into the program to the detriment of “better” researchers?
- Hermann pushed hard for approval of all three Halls and started the civil engineering
 - This allowed all three halls to be fully equipped after some delay

Hall C

- The experimental equipment in Hall C was fully funded by the CEBAF Project
 - The only Hall for which this was true
- Because of this, Hall C was to be the first to take beam and the decision was made that the Hall would be where new experimental equipment would be deployed in later years
- The scientists under Roger Carlini were able to push the performance of the initial spectrometers
 - The high momentum spectrometer (HMS) was boosted to allow for detection up to 7.5 GeV/c
 - The short-orbit spectrometer (SOS) could be used in a variety of flexible arrangements along with ancillary equipment to take measurements at moderate resolution and high momentum

Hall C Spectrometers



Hall A

- Initially, Hall A would contain one horizontal spectrometer capable of measuring to 4 GeV/c, and a second measuring to 1.2 GeV/c)
- It was pointed out that the spectrometers would be more effective if they bent vertically
- A cost reduction proposal led to two identical, high-momentum spectrometers
 - “If you were going to build one, it would be smart—in terms of cost-effectiveness, in terms of versatility, and reliability—to build two identical spectrometers”
- Only one spectrometer was included in the laboratory’s construction funding with the other funded through supplementary ACE funding
- Eventually, both were built, albeit with some delay

Hall A Spectrometer

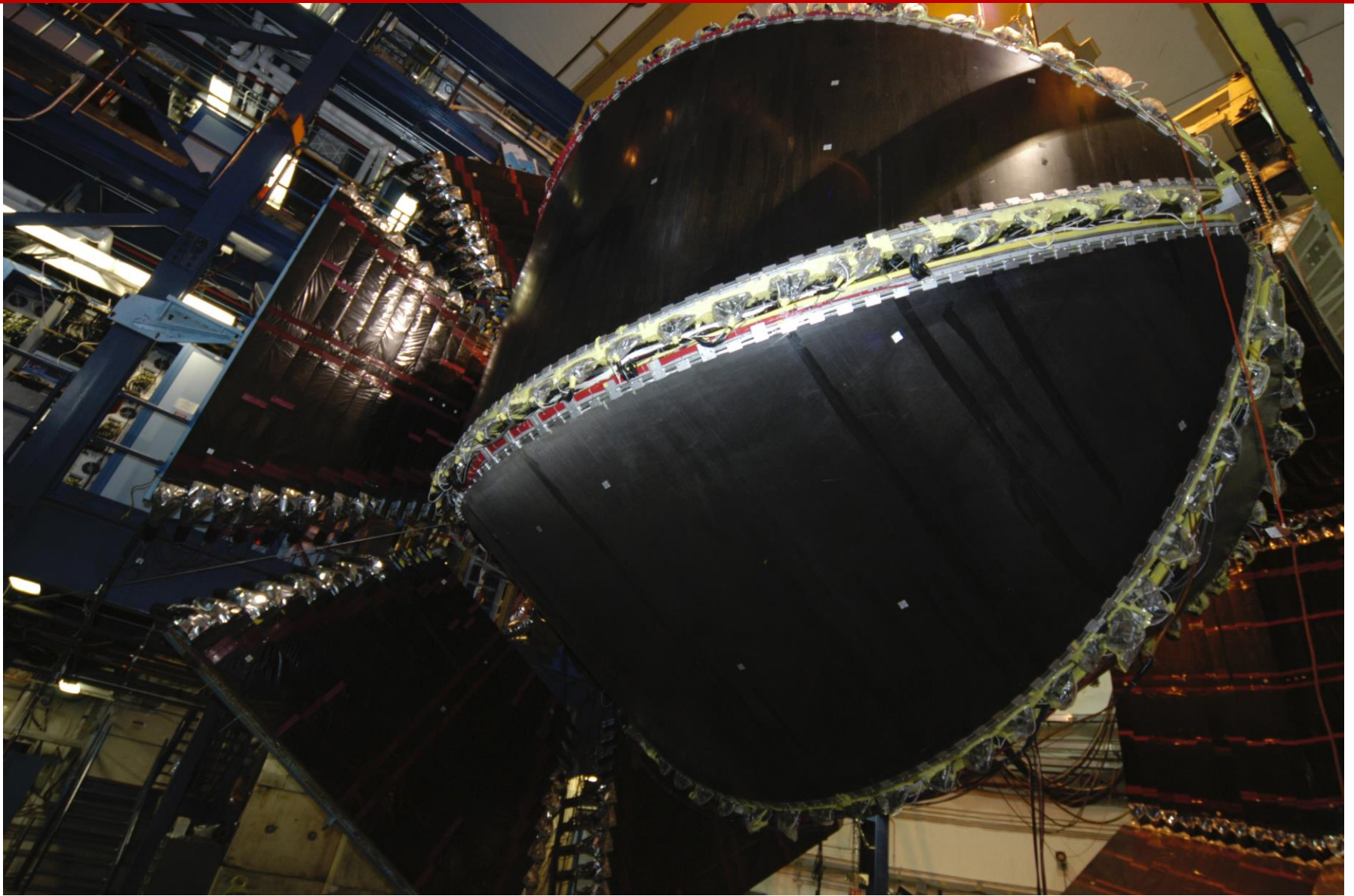


Hall B

- Bernard Mecking and Volker Burkhardt were convinced that a toroidal magnet would be needed in Hall B
- Everyone outside the lab was concerned, as such a magnet had never been built
 - Why not just build a solenoid magnet?
- They persisted and convinced everyone that the toroidal magnet was the right choice
- They improved the design to provide a field-free region for a polarized source
- They got a convincing quote from Oxford Instruments, who delivered on time & on budget



Hall B Torus Magnet with Inner Detectors



Additional Accelerator Requirements

- Experiments to extend measurements of parity-violating electron scattering to measure the weak neutral currents of the nucleon were requested
- These measurements require beams of **polarized** electrons where first the electron spin is aligned parallel to the beam direction and then reversed so the electron spin is antiparallel to the beam
- It is essential that all properties of the beam except the spin direction be identical for the two cases so that the experiment can measure precisely the small effects associated with the polarization direction reversal
- The SRF accelerator promised to provide the necessary stability, but such measurements also required a well-designed, technologically tricky polarized electron source that was not a part of the initial experimental equipment budget
- Polarized gun development was approved, but delayed

Commissioning the Accelerator

- In 1992, the CEBAF accelerator civil engineering was ending
- Needed a “knight in shining armor” to commission the accelerator and set up beam operations



Commissioning the Accelerator

- In 1992, the CEBAF accelerator civil engineering was ending
- Needed a “knight in shining armor” to commission the accelerator and set up beam operations
- They got me instead



Commissioning in Parallel with Experiments

- Commissioning started in the Injector with a wall in the middle of the North Linac as cryomodule installation was still ongoing downstream
- First single-pass beam to the Hall C target was in July 1994
 - This was followed by a period of experimentation while the accelerator experts prepared the next phase

We are here today to celebrate 35 years of CEBAF physics

- In 1995, CEBAF reached the design energy of 4 GeV in May and by November, reached the full design goal with a stable, five-pass 100 kW continuous 4 GeV beam delivered to Hall C
- It took Hall A and Hall B until 1997 to be ready for beam
- Finally, in June 1998, all three Halls received simultaneous beam for experiments
 - The 4 GeV CEBAF experimental program was fully launched!

The Push for Higher Energy

- The CEBAF superconducting cavities were functioning perfectly
 - It was decided to push the energy to 6 GeV
 - This was accomplished in August, 2000
- The experimental program was ready and was booming
- When

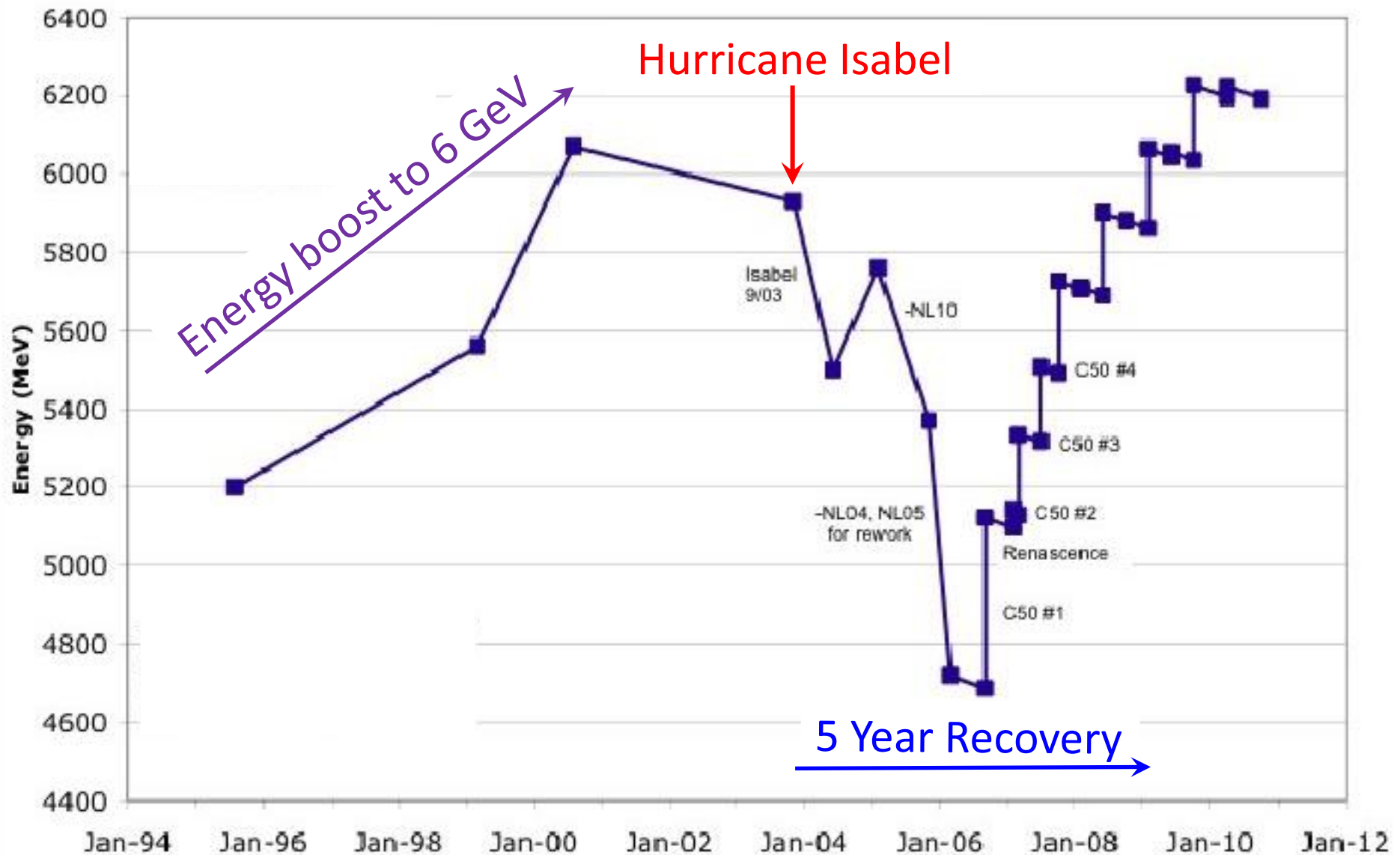
Hurricane Isabel Came to Visit



Damage from Isabel

- CEBAF lost electrical power for four days
- The Central Helium Liquefier (CHL) went down and stayed down
 - No cooling for the cryomodules
- The vacuum pumps that assured insulation also went down
 - The cryomodules warmed up in an uncontrolled way
- The eight cavities in a cryomodule are connected using indium seals
 - The uncontrolled warm-up stressed the seals
 - Some lost vacuum integrity
- Two cryomodules were damaged by the uncontrolled warm-up
 - Affected early production cryomodules
- Result – CEBAF energy reach was curtailed for years
 - We are still suffering the consequences today

Energy Reach of CEBAF – Impact of Isabel



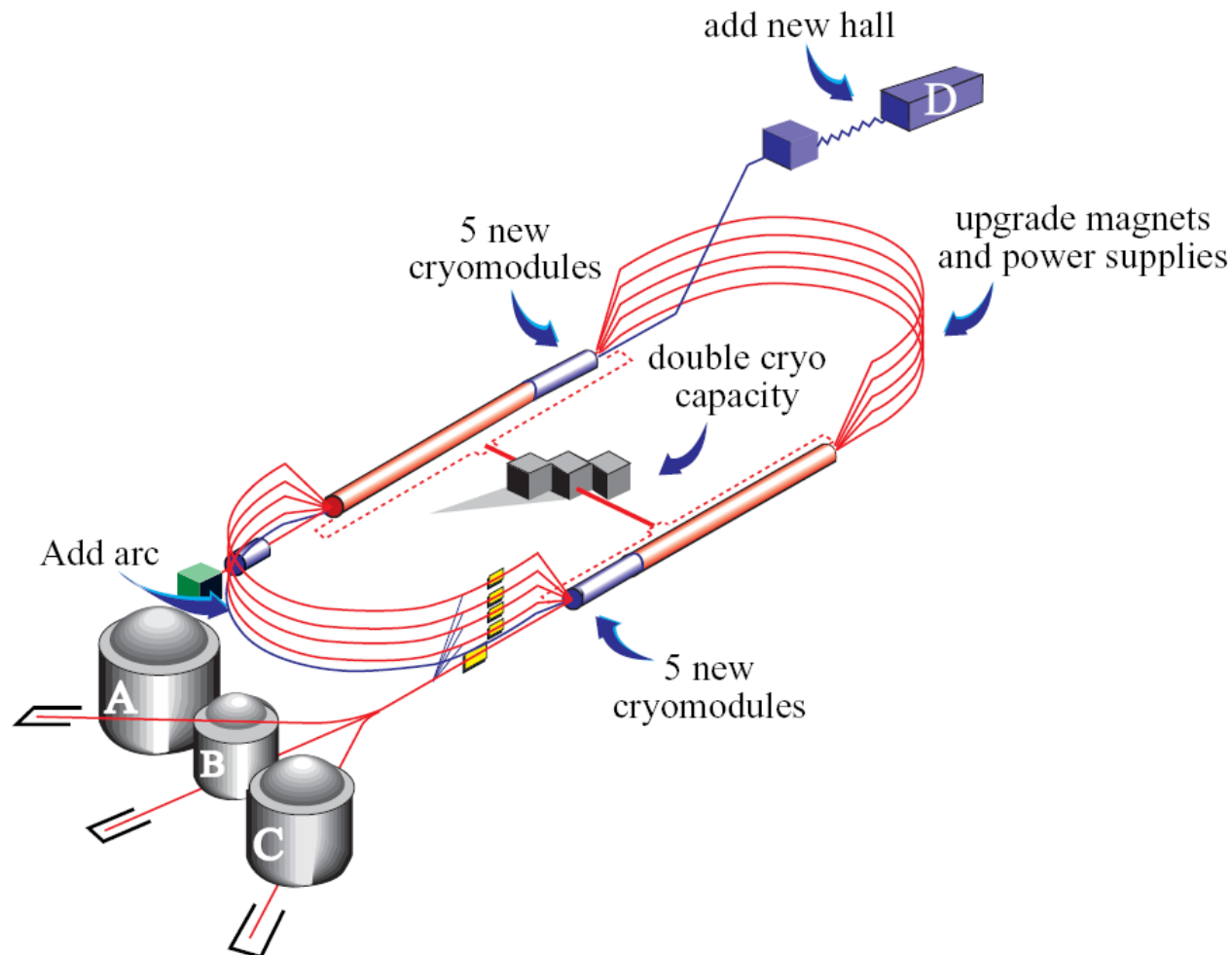
12 GeV Project

- In 2003, DOE's 20-year facility plan names Jefferson Lab's 12 GeV Upgrade one of the 12 near-term priorities
- In 2007, 12 GeV Upgrade Project receives Critical Decision-2 approval from the Department of Energy
- In 2012, CEBAF ceases 6 GeV operations for 12 GeV Upgrade installation on May 18
 - 178 experiments were completed with the original CEBAF
- The End – or was it?



The 12 GeV Project

- The project included doubling the CEBAF energy and adding an additional experimental Hall



How Come it was Possible?

- The SRF original specification was for 5 MV/m
 - Each cavity was 0.5 m long with 8 cavities per cryomodule
 - Original cryomodule energy gain = 20 MV
- There were 40 cryomodules with 5 recirculations
- Original energy = $20 \text{ MV} \times 40 \times 5 = 4 \text{ GeV} + \text{Injector}$
- The average cryomodule energy gain had been pushed to 7.5 MV/m
- Improved energy = $6 \text{ GeV} + \text{Injector}$

- There were 10 empty slots for cryomodules
- Doubling the energy required 100 MV/cryomodule
- This was achieved – a tribute to SRF improvements in thirty years

Problems

- The original cryomodules continue to degrade following Isabel
- When the gradient is high in the cavities, field emission can occur, specifically if the inner surfaces get “dirty”
 - This can create high radiation levels around the cryomodules which degrades the Viton vacuum seals
 - Degradation of the Viton seals allows air (and “dirt”) into the cavities
 - Increases the field emission
- At this time, 12 GeV is no longer attainable
 - There is an active program to refurbish the original and the new cryomodules to reduce field emission

More CEBAF Talks in this Session

- Highlights of the CEBAF 6 GeV Physics Program

Gordon Cates

- The 12 GeV Science at the upgraded Jefferson Lab: the new and upcoming results

Dipangkar Dutta

- Jefferson Lab's Pursuit of Nuclear Femtography – from 12 GeV to JLEIC

Rolf Ent

Thank You