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Project X Cost Reduction Workshop
11-12 September 2013

Overview and Lessons Learned of the Jefferson Lab Cryomodule Production for the CEBAF 12 GeV Upgrade

Outline

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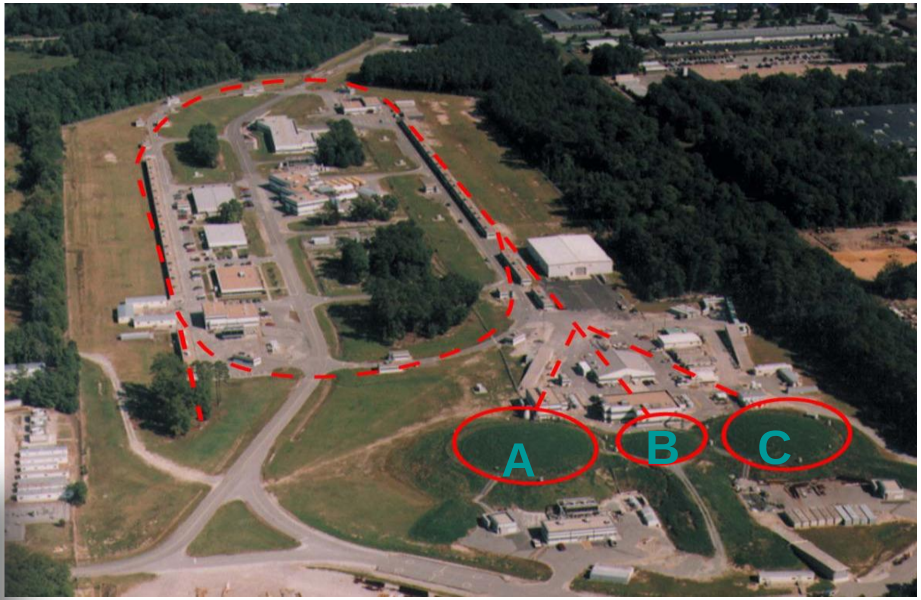
Introduction to Jefferson Lab

>1200 active member international user community engaged in exploring quark-gluon structure of matter

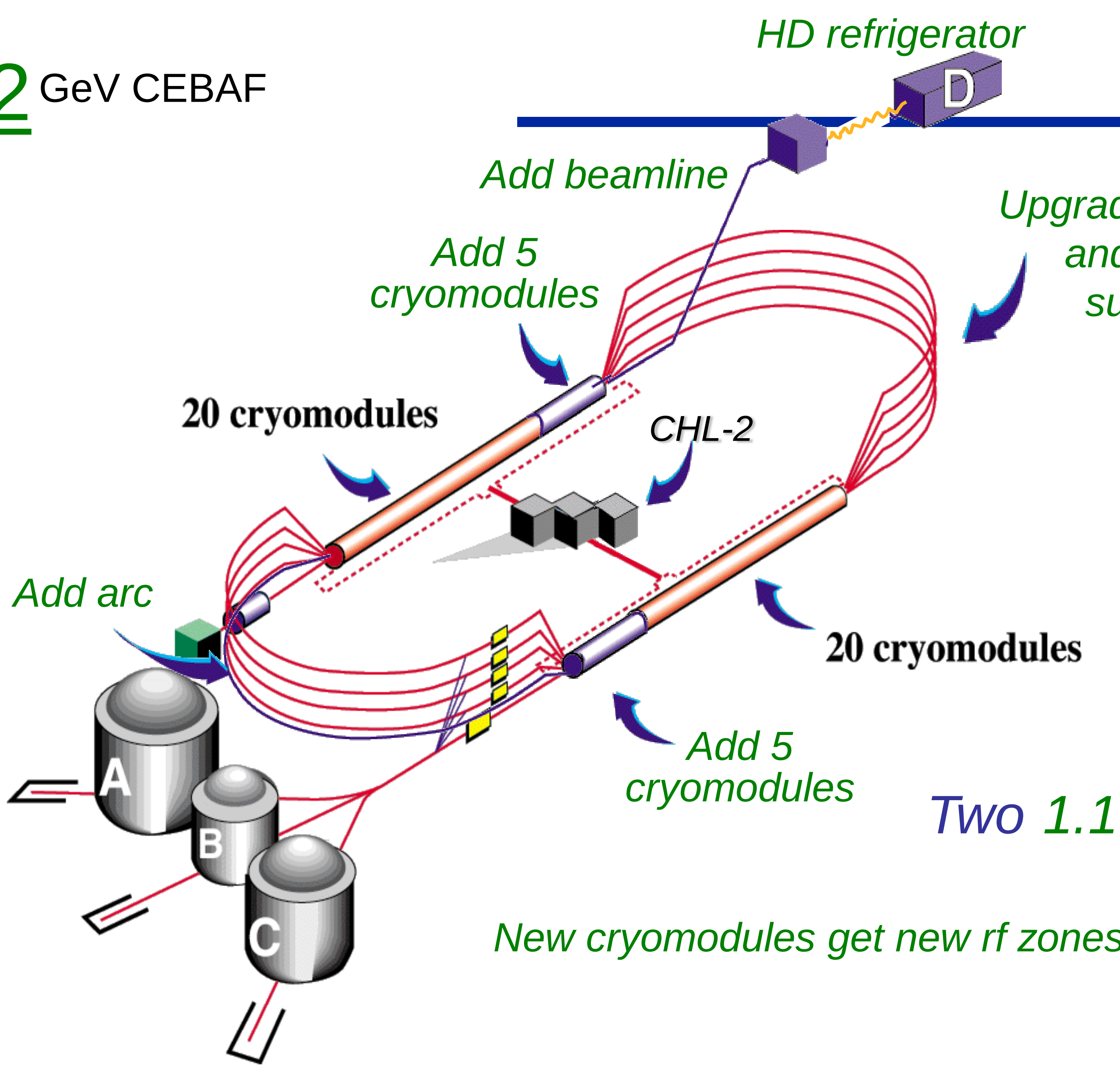
Superconducting electron accelerator provides 100% duty factor beams of unprecedented quality, with high polarization at energies up to 6 GeV



Newport News, VA

Test Lab (SRF) Renovation and Technology & Engineering Development Facility Complete

12 GeV CEBAF



Two 1.1 GeV linacs

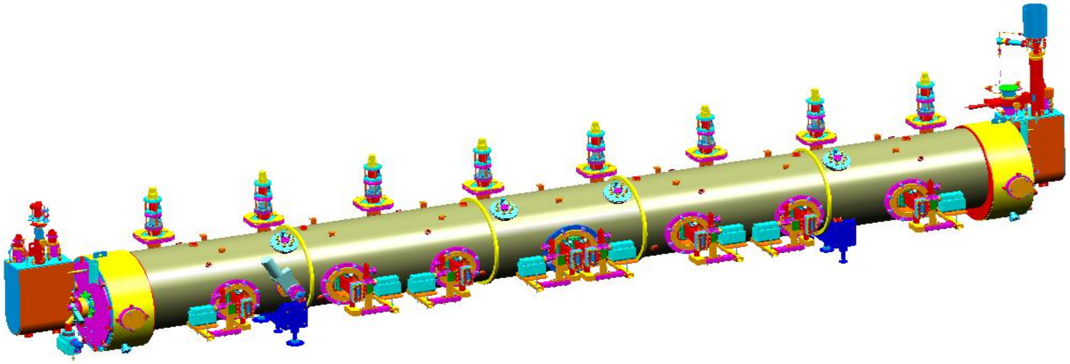
New cryomodules get new rf zones

SCOPE OF 12 GeV UPGRADE

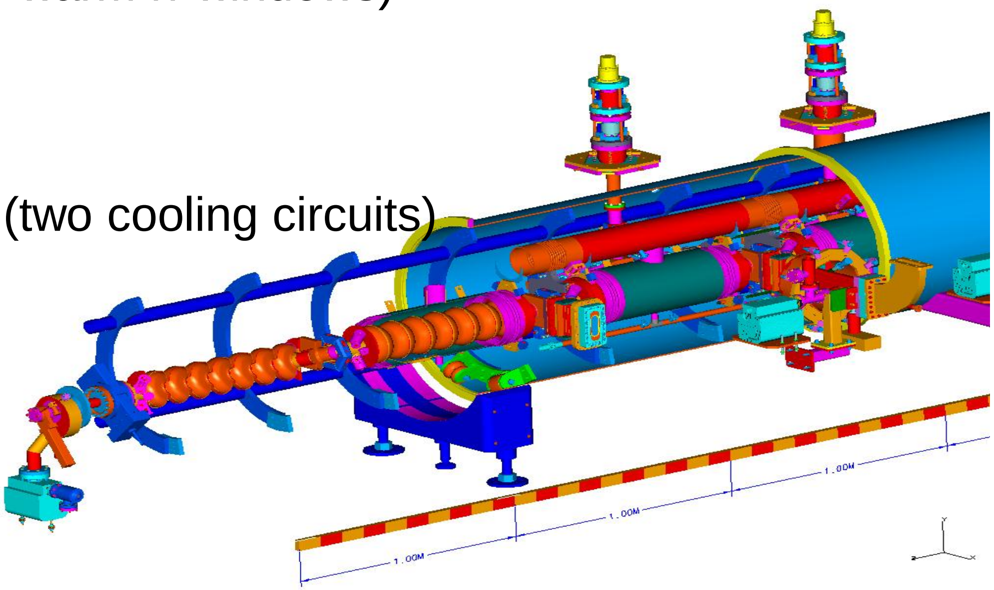
Parameter	Present JLab	Upgraded JLab
Number of Halls	3	4
Number of passes Halls A/B/C	5 (for max energy)	5 (for max energy)
Max Energy to Halls A/B/C	up to ~6 GeV	up to ~11 GeV
Number of passes to Hall D	New Hall	5.5
Energy to Hall D	New Hall	12 GeV
Current – Hall A & C	max ~180 μA combined	max ~85 μA combined (higher at lower energy)
Current – Hall B & D	(B) Up to 5 μA max	(B, D) Up to ~5 μA max each
Central Helium Liquefier (CHL)	4.5 kW	9 kW
# of cryomodules in LINACS	40	50
Accelerator energy per pass	1.2 GeV	2.2 GeV

Routinely provide beam polarization of ~85% now, same in 12 GeV era

C100 Cryomodule Design



- Eight-seven cell SRF cavities (2K - nominal operating temp)
- Eight individual helium vessels (stainless steel)
- Waveguide power couplers (double warm rf-windows)
- Cavity tuners
  - Cold scissor jack
  - Warm drive components
- Supply/Return cryogenic end-caps (two cooling circuits)
  - 2K primary & 50K shield



Cryomodule Scope & Key Technical Parameters

- **Scope: Develop, Design, Fabricate, Install and Check-out 10 Cryomodules (5 new cryomodules per linac)**

(Note: The following parameters are for each Cryomodule)

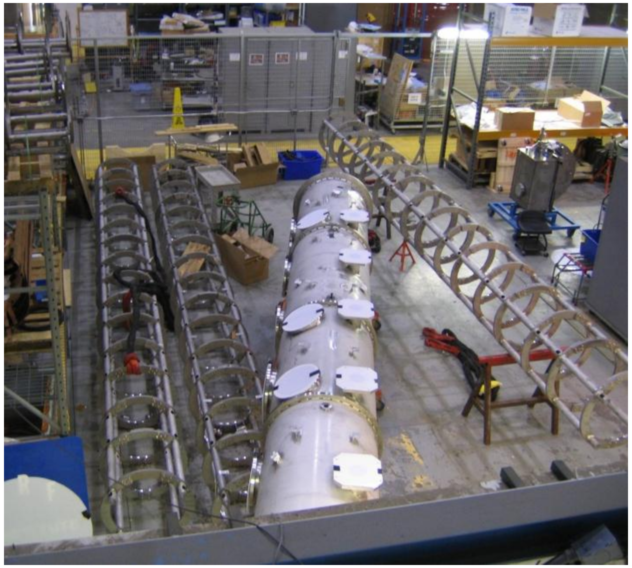
Voltage (Includes 10% reserve):	**$\geq$ 108 MV (ensemble average in each linac)**
Heat budget: (Interface with Cryogenics)	
– 2 K	$\leq$ 300 W
– 50 K	$\leq$ 300 W
Slot Length:	**9.8 m**
Tuner resolution:	**$\leq$ 2 Hz**
Fundamental Power Coupler (FPC):	**7.5/13 kW (Avg/Pk)**
Higher Order Mode (HOM) damping:	
– Transverse (R/Q)Qk	$< 2.4 \times 10^{10}\ \Omega/m$
– Longitudinal (R/Q)Q	$< 6.5 \times 10^{11}\ \Omega$
Cryomodule Length (Physical)	**~8.5m**

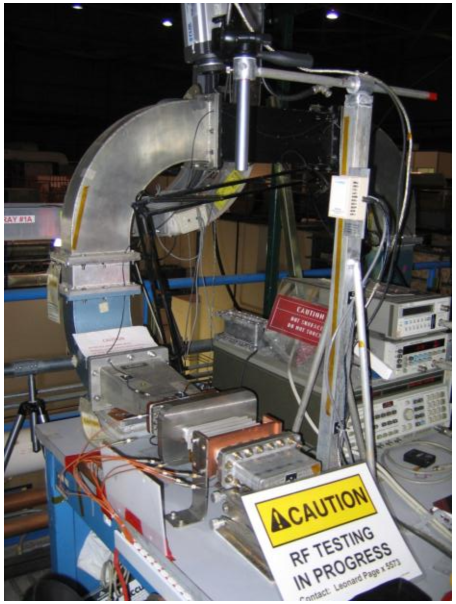
Procurement - Planning

- **Industry to produce components (build to print)**
  - Develop advanced procurement plan
  - Specifications, drawings, acceptance criteria, schedule
  - Bid/Award process
    - Stock components
    - Low price technically acceptable
    - Best Value (consideration for experience)
  - Acceptance criterion
  - Delivery schedule
  - Production Schedule

Procurement - Execution

- **Acceptance Criterion**
  - Must be detailed & defined prior to award
  - Visits to vendor during production critical
  - First article (FA) delivery schedule (very beneficial)
- **Release for use in production**



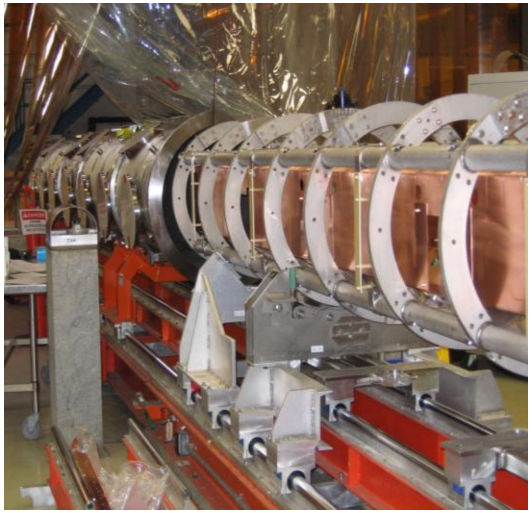


Procurement – Lessons Learned

- **Quality Assurance**
  - **Get early start on ‘non-standard’ components**
    - **Specifications & acceptance criteria must be well documented**
      - **Acceptance travelers, staff training, feedback to vendor**
    - **Issues with vendor performance must be communicated promptly**
  - **Management of resources is critical**
    - **Resources must be in place prior to delivery of FA**
    - **Staffing: Availability, allocation, training, skill sets, etc.**
    - **Facilities: Process control, priority access, maintenance**
  - **Documentation**
    - **All procedures must be vetted prior to release**
    - **Establish robust QC; traveler system - (receiving inspections, process control, testing results, database management)**

Production – Facilities & Planning

- **Pre-production**
  - **Inventory management**
    - **Logistics:**
      - **Space, access, equipment, staffing**
  - **Scheduled mockup activities**
    - **Exercise tooling (ensure fit & function)**
    - **Work through assembly procedures**
    - **Identify/resolve any interference issues**
    - **Opportunity to vet assembly travelers**



Production – Execution

- **Production**
  - Cavity qualification
    - Cavities qualified in VTA
  - Cavity string assembly
    - Assembly in cleanroom
  - Cold mass assembly
    - Mag shielding, Headers, tuners, instrumentation, MLI
  - Space frame assembly
    - Alignment, Thermal & Mag shielding, MLI

Production – Acceptance Testing

- **Production**
  - **Final assembly**
    - **Complete warm checkout of all subsystems.**
  - **Acceptance testing**
    - **Completed cryomodule cooled down to 2K**
      - **Instrumentation checkout**
    - **Low power measurements**
      - **Tuner operation, cavity frequencies, HOM damping, heater control**
    - **High power measurements**
      - **Emax, Qo, Heat loads, Lorentz**

Production – Lessons Learned

- **Production Issues**
  - **Carbon steel in He vessel**
    - **Spuncast head manufacturer added carbon steel to process**
      - **Manufacturer contacted; new (C-free) process implemented**
      - **Replacement heads manufactured from bulk 316 SS**
  - **Cryogenic electrical feed-through(F-T’s) leaks**
    - **Failed after QA acceptance testing**
      - **Replaced: Based on previous experience, F-T’s located behind access panels.**
  - **Microphonic response higher than planned**
    - **Cold tuner modified to add stiffness to system.**
  - **Individual cavity heater control needed for operations**
    - **LLrf controls modified to accommodate**
      - **Based on previous experience, individual heaters installed**

Installation / Checkout & Commissioning - Planning

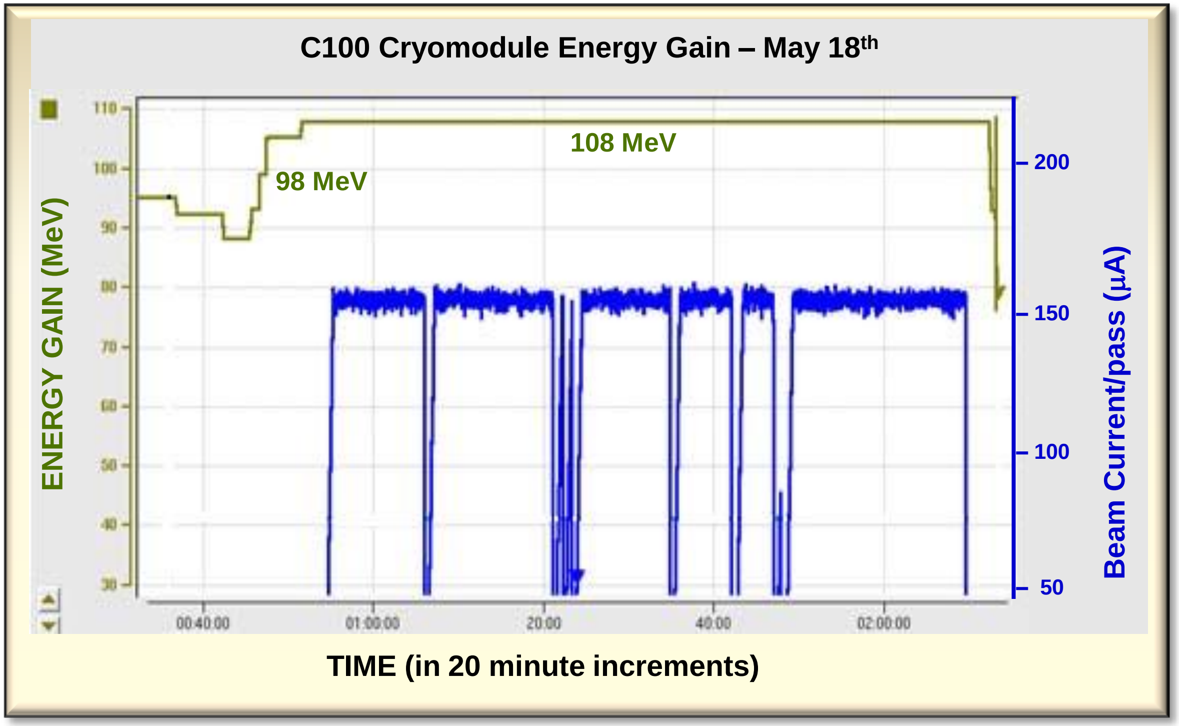
- **Coordination with other 12 GeV upgrade activities**
  - **Civil, beam transport, cryogenics, high power-rf, instrumentation, controls & safety**
    - **Integrate detailed schedule of activities including resources and interdependencies**
- **Goal – Install two cryomodules into CEBAF ahead of baseline schedule**
  - **Opportunity to operate cryomodules with beam and demonstrate performance goals.**
    - **Close coordination with physics program to integrate new digital llrf control system designed for C100 cryomodules.**

Installation / Checkout & Commissioning - Execution


- **Following acceptance testing**
  - **Cryomodule transported from Test Lab to CEBAF tunnel**
  - **Installation into designated zone**
    - **Complete integration with all other accelerator systems**
      - **Beamline, cryogenics, high-power-rf & control systems**

Full Performance of C100 & RF Demonstrated

Cryomodule voltage



Beam Current 465 μA

Installation / Checkout & Commissioning - Performance

- **Design goals**
  - **98MV average/CM**
    - **Required for 12 GeV operations**
  - **108MV/CM design goal**
    - **Provide operational margin**

Tunnel Performance (MV)	
C100-01	104
C100-02	110
C100-03	118
C100-04	105
C100-05	109
C100-06	108
C100-07	108
C100-08	In progress
C100-09	114
C100-10	In progress

Installation / Checkout & Commissioning – Lessons Learned

- **Baseline design performance goal achieved**
- **Design goal of 10% margin not achieved on all cryomodules**
  - **These activities are still in progress**
    - **Preliminary lessons learned**
      - **Prototyping systems ahead of production will reduce project cost risk**
      - **Improvements made to process/configuration control**
      - **Upgrades to testing hardware & software beneficial**
      - **Review field emission & process control**

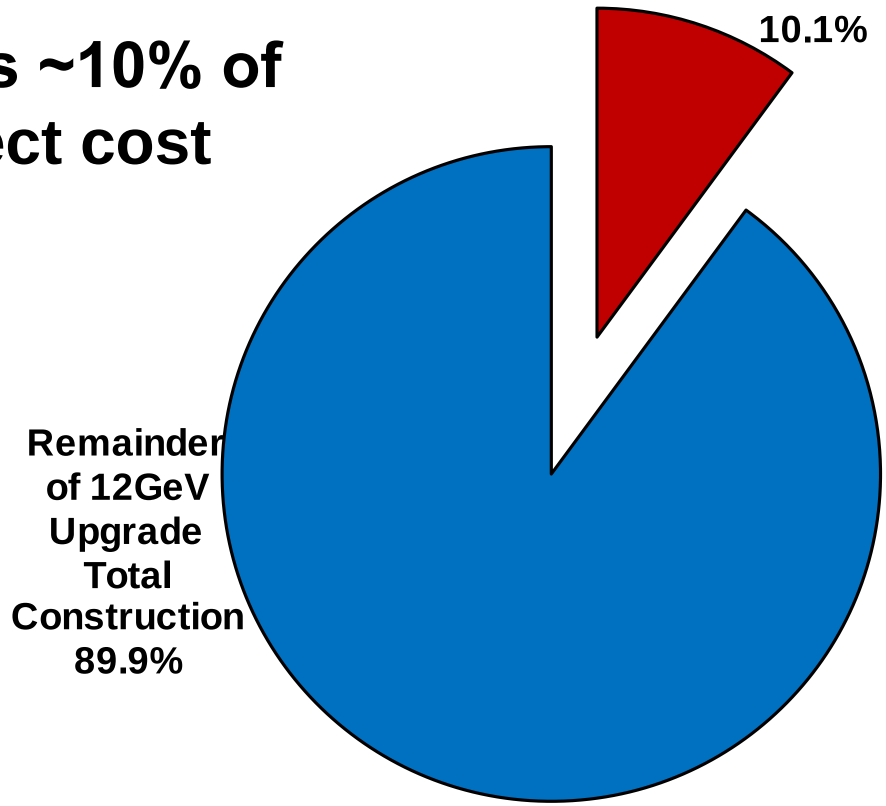
Cost & Schedule – Planning

Basis of Estimate (BOE) Categories	
Quotes from vendors	Risk factor
Catalog prices	Risk factor
Estimates from vendors/consultants	Risk factor
Previous JLab experience	Risk factor
Information from other labs, universities, etc.	Risk factor
Engineering judgment	Risk factor

- **Basis of Estimate**
  - **JLab was able to benefit from previous experience**
    - **Infrastructure and staffing in place**
    - **20+ years design, production and operational experience**

Cost & Schedule – Monitoring & Control

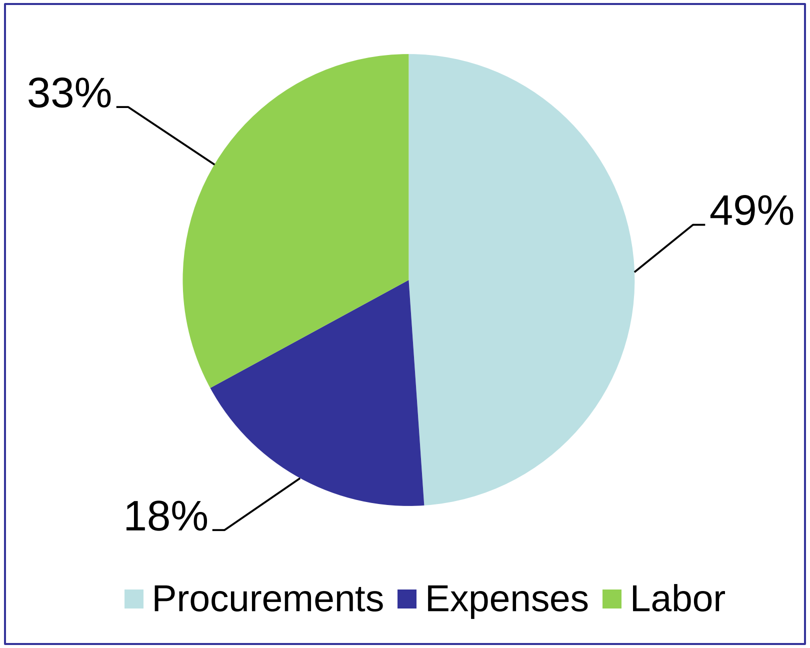
- **C100 CM's ~10% of total project cost**



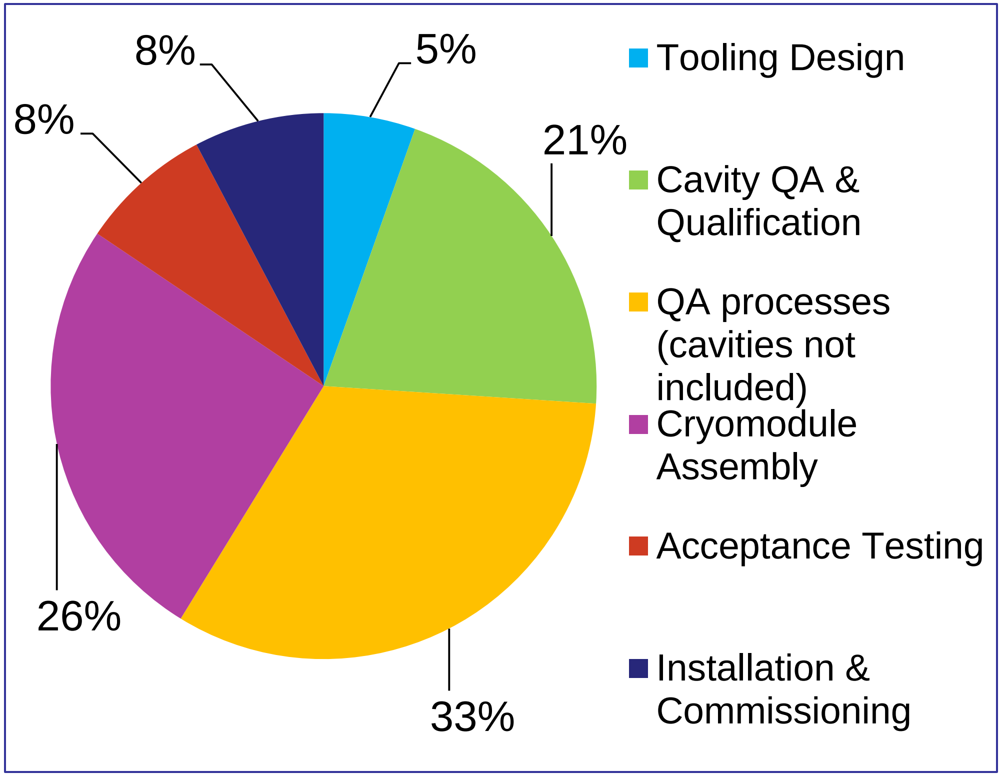
- **EVMS**
  - Formal EVMS implemented for 12 GeV project in accordance with DOE Order 413.3B

Cost & Schedule – Monitoring & Control

Total C100 Cost Breakdown



Labor Breakdown by Process



- **EVMS data**
  - **Procurements were the dominate cost for the C100 CM's**
  - **Labor costs dominated by QA, cavity processing & cryomodule assembly**

Cost & Schedule – Monitoring & Control

- **EVMS – 'Touch labor'**
  - Quality Control
    - Component receiving inspections
      - Several hundred individual component inspections
    - Documentation (travelers, database management, etc.)
    - Inventory control
      - 1000's of parts inventoried, tracked & released for production
  - Cavity QA & qualification
    - Cavity receiving inspection, chemical cleaning, testing and assembly
  - Cryomodule assembly
    - Cold mass, space frame & final assembly

Cost & Schedule – Lessons Learned

- **Cost**
  - **Procurement**
    - Work with vendors to identify cost drivers and minimize NRE & schedule delays
    - Take advantage of quantity discounts were possible
    - Minimize custom components/maximize common parts
  - **Labor**
    - QA: Develop capable vendors prior to request for quotes
    - Processing & Assembly:
      - Automate processes and redundancy
      - Minimize touch labor
- **Schedule**
  - **Good communication critical**
    - With vendors, safety, facility and technical and PM staff

Summary

- **Planning**
  - **Prototyping**
    - **Develop/finalize component specifications & acceptance criteria**
    - **Identify/resolve any potential performance issues**
    - **Thoroughly vet processes, procedures, tooling and staffing needs**
    - **Develop sound basis for full production planning**
- **Execution, Monitoring and Controlling**
  - **Utilize formal EVMS**
    - **Establish baseline, monitor progress & promptly identify cost issues**
  - **Work the plan**
    - **Communicate progress to all stakeholders on a regular basis**