ASTA Update

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Fermilab APT Seminar
14 January 2014

Talking Points

- Introduction/Overview
- Status of Major Subsystems
  - Laser
  - Photoinjector Gun
  - Capture Cavities
  - Cryomodules
  - Electron Production
  - Low Energy Beam line
- Next Steps
- Summary

the contents of this presentation reflects the work of many dedicated, highly motivated people at Fermilab and partner organizations

ASTA: What is it?

The ASTA program is based on the capability provided by an SRF linac (which provide electron beams from 50 MeV to nearly 1 GeV) and a small storage ring (with the ability to store either electrons or protons) to enable a broad range of beam-based experiments to study fundamental limitations to beam intensity and to develop transformative approaches to particle-beam generation, acceleration and manipulation which cannot be done elsewhere. It will also establish a unique resource for R&D towards Energy Frontier facilities and a test-bed for SRF accelerators and high brightness beam applications

ASTA Proposal

ASTA: What is it?

The ASTA facility at NML consists of the following:

- A 47 meter long, 4,500 ft^2 shielded accelerator enclosure housed inside the 12,000 ft^2 NML building.
- A 70 meter long, 8,000 ft^2 newly constructed tunnel enclosure to the North of the NML building.
- An 2,800 ft^2 support building
- A control room
- A radio-frequency photo-injector system, including drive laser system
- Operating high-power and low-level RF systems, RF distribution system and controls
- Refrigeration system capable of 120 W @ 2K

ASTA: Background and History

- In 2006, Fermilab was asked to lead the US ILC/SRF R&D Program
  - we felt that the most effective way to do that was to learn by doing
- Construction of ASTA and NML began in 2006 as part of ILC/SRF R&D and later American Recovery and Reinvestment Act (ARRA)
- The Facility was motivated by the goal of building, testing and operating a complete ILC RF unit to:
  - Develop industrial and laboratory capability for producing state-of-the-art SCL components, assemble into a fully functioning system (photo-injector, bunch compressor, three 1.3 GHz ILC CMs, beamlines to dumps)
  - To carry out full beam-based system tests with high-gradient cryomodules and demonstrate ILC beam quality

courtesy Stuart Henderson

- It was recognized early in the planning process that an electron beam meeting the ILC performance parameters was itself a valuable resource for the wider Advanced Accelerator R&D (AARD) community

ASTA: Background and History

courtesy Stuart Henderson

- In planning the construction of ASTA, we therefore wanted to ensure that the facility offered something of enduring value when it was completed.
  - Hence, the investment in establishing a flexible facility that would readily support an AARD user program on day one.
- For those reasons the Recovery Act (ARRA)-funded facility construction incorporated space for
  - additional ILC cryomodules to increase the beam energy to 1.5 GeV,
  - space for multiple high-energy beamlines,
  - space for a small circular ring for the exploration of advanced concepts,
  - capability of transporting laser light into and out of the accelerator enclosure,
- To date, an investment of $90M has been made, including $18M of ARRA funding, representing ~90% completion of the facility.

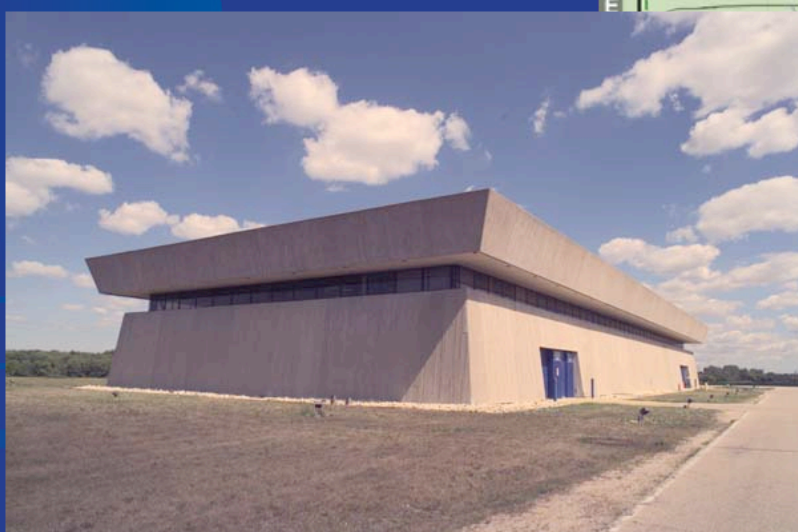
The Opportunity

courtesy Stuart Henderson

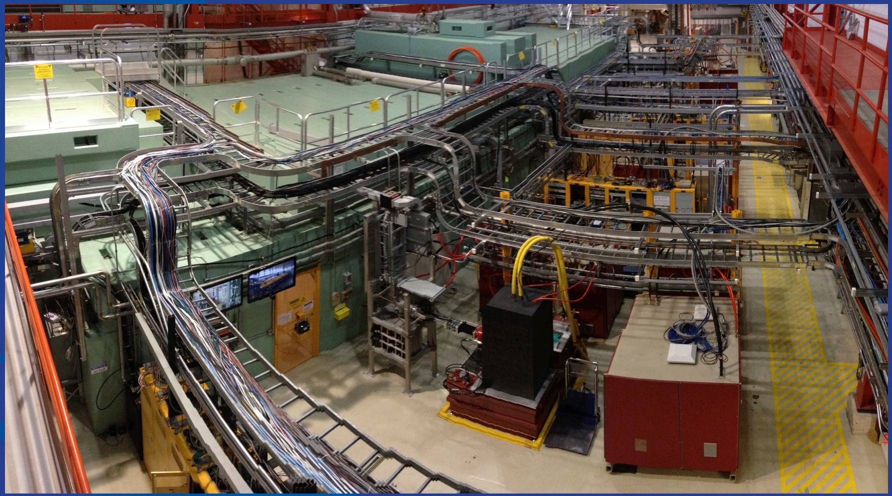
- OHEP has an opportunity now to establish a world-leading facility for Accelerator R&D that
  - Is based on state-of-the-art, modern SC technology
  - Sets the stage for future accelerators based on SRF
  - Supports an extremely broad accelerator R&D program ranging from HEP to photon sciences to applications
  - Serves critical needs in Intensity Frontier accelerator physics
  - Helps to fulfill OHEP's Stewardship role
  - Is cost-effective to complete and operate. There is no competition at this price
  - serves as a focal point for accelerator science education, not only for Fermilab, but for the nation.

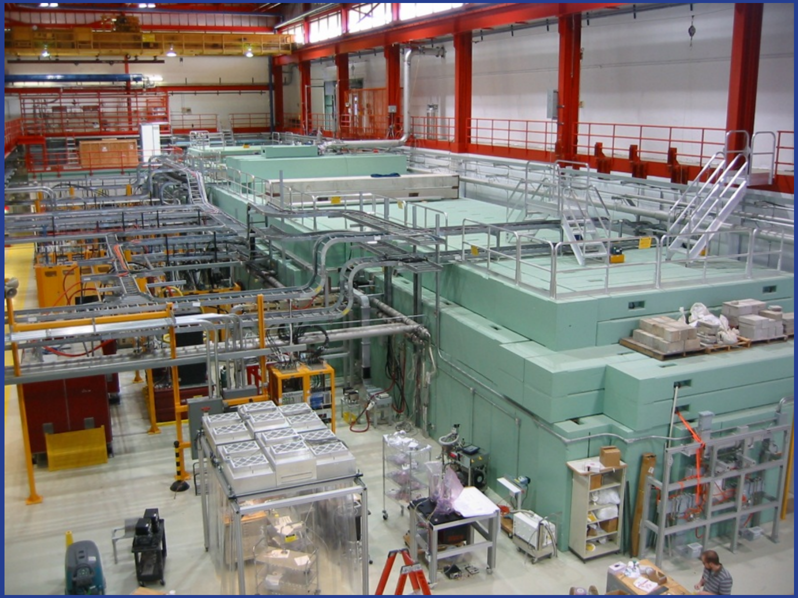
With most of the investment already made, ASTA is a huge opportunity that should not be missed!

Overview of ASTA Facility



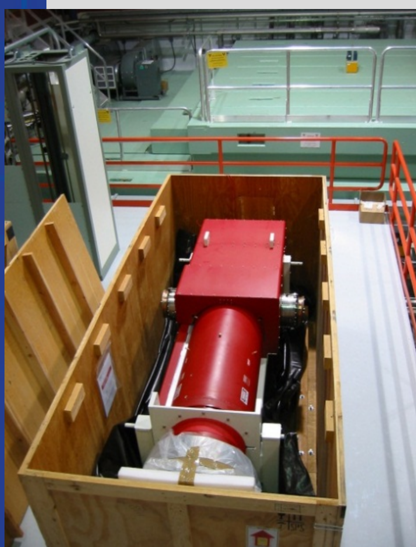
NML Facility



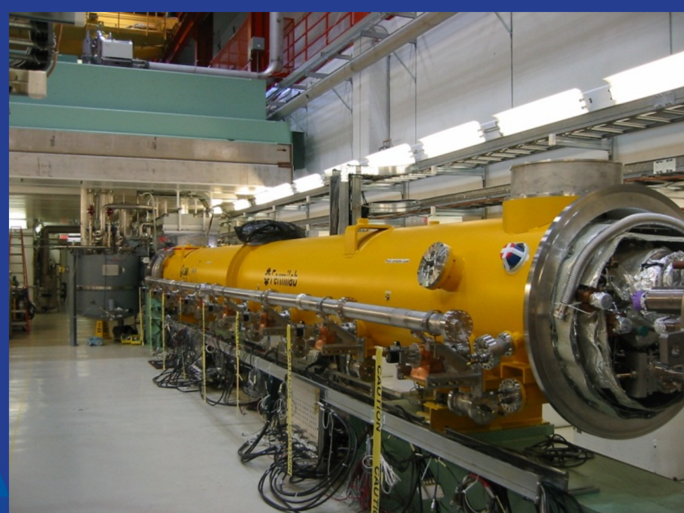


Substantial Investments ($90M) Have Been Made At ASTA

Magnets and Power Supplies: $4M



RF Power Systems: $8M



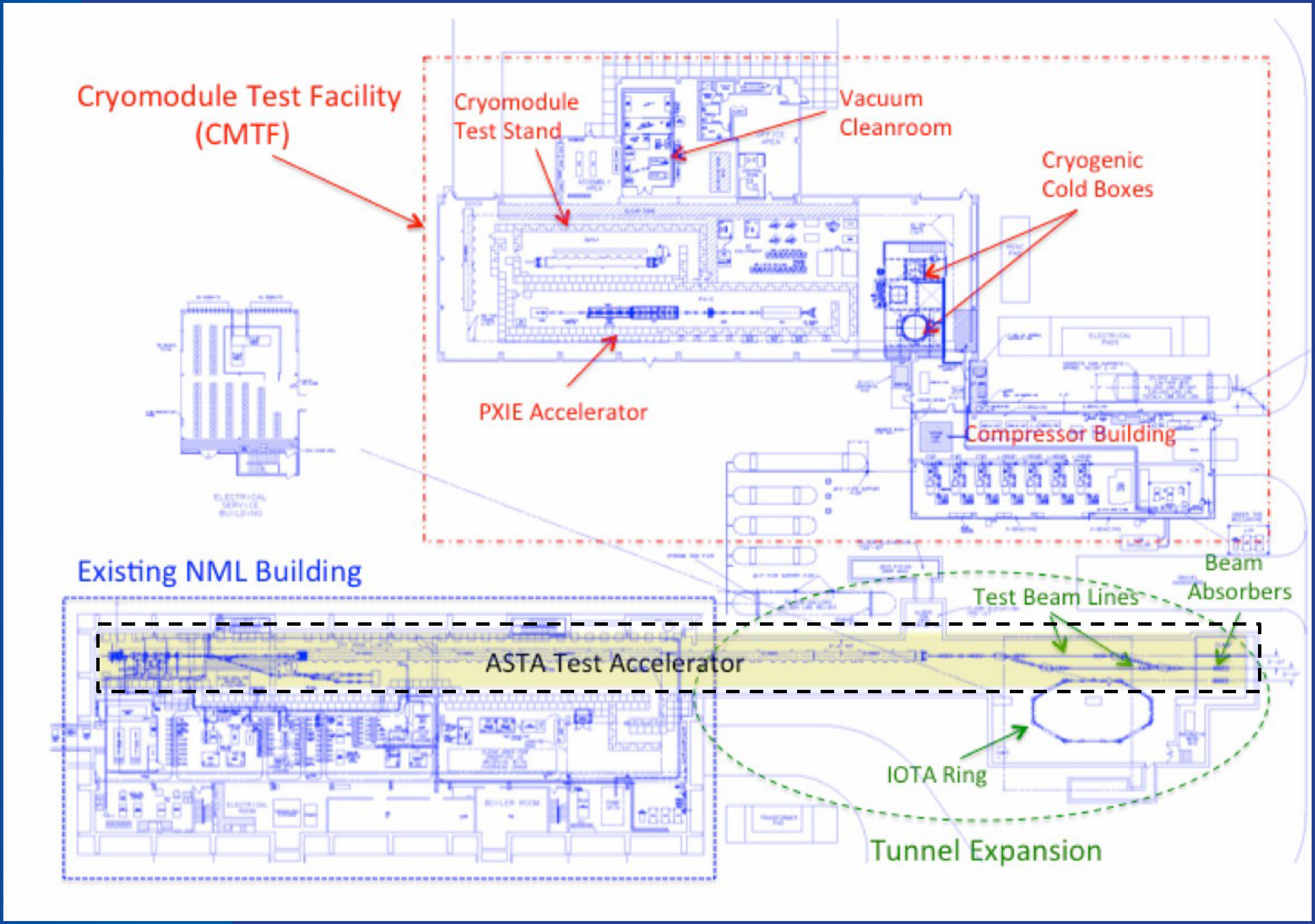
Cryomodules: $15M

ASTA Cost to-date

$4.9M	Tunnel Extension
$1.3M	Shield blocks
$8.0M	RF equipment
$1.7M	Cryo Equipment
$4.1M	Magnets, P.S.'s, vacuum equip
$2.0M	Beam absorbers, dumps, water systems
$4.4M	RF gun/injector
$1.3M	Laser system/lab
$2.6M	Controls, CR, offices
$5.4M	Electrical and Utility upgrades to facility
$1.0M	IOTA Equipment
$5.0M	Instrum. & vacuum
$48.3M	Labor (210 FTE's)
$90M	Total

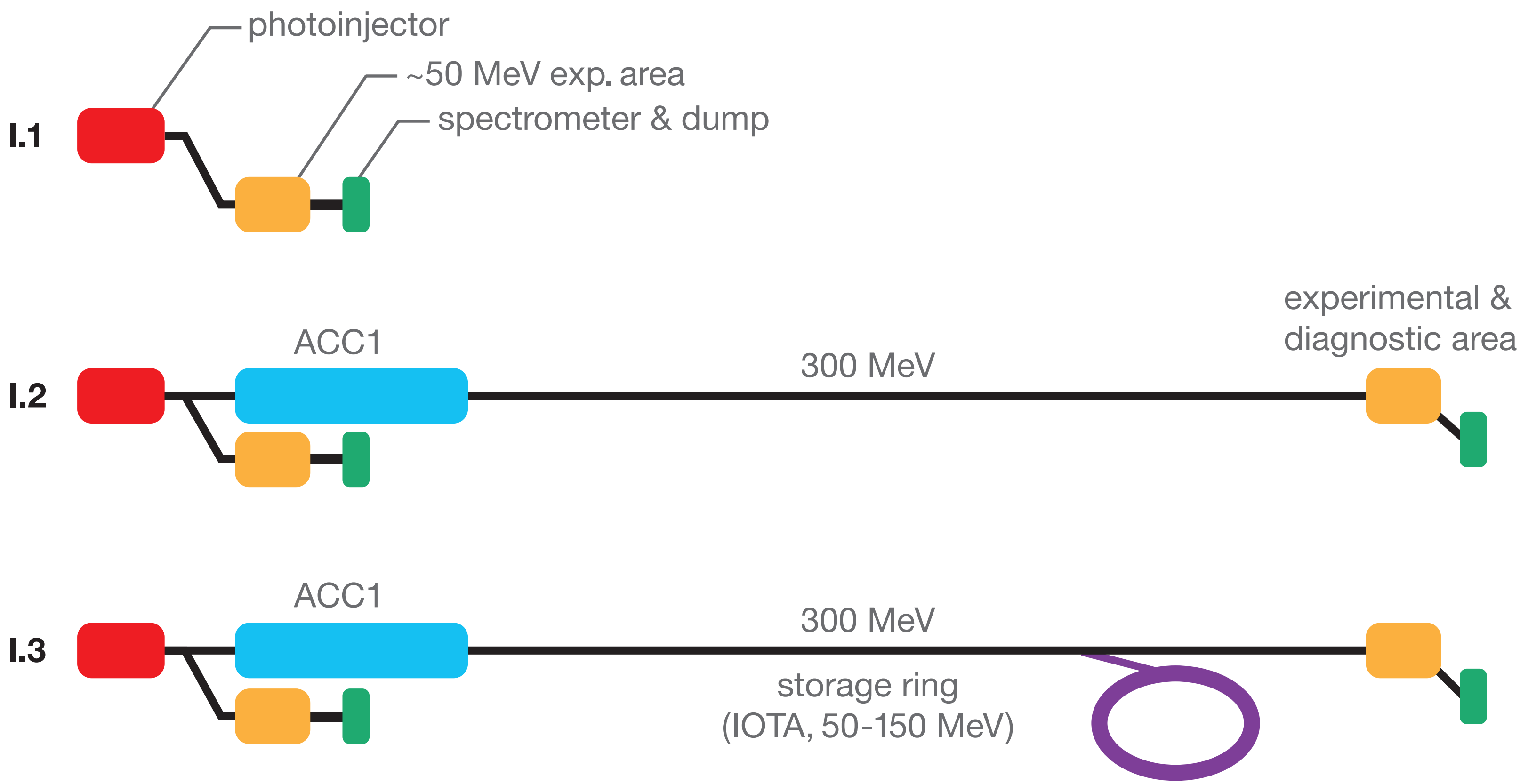
($18M ARRA funded)

Full ASTA Layout

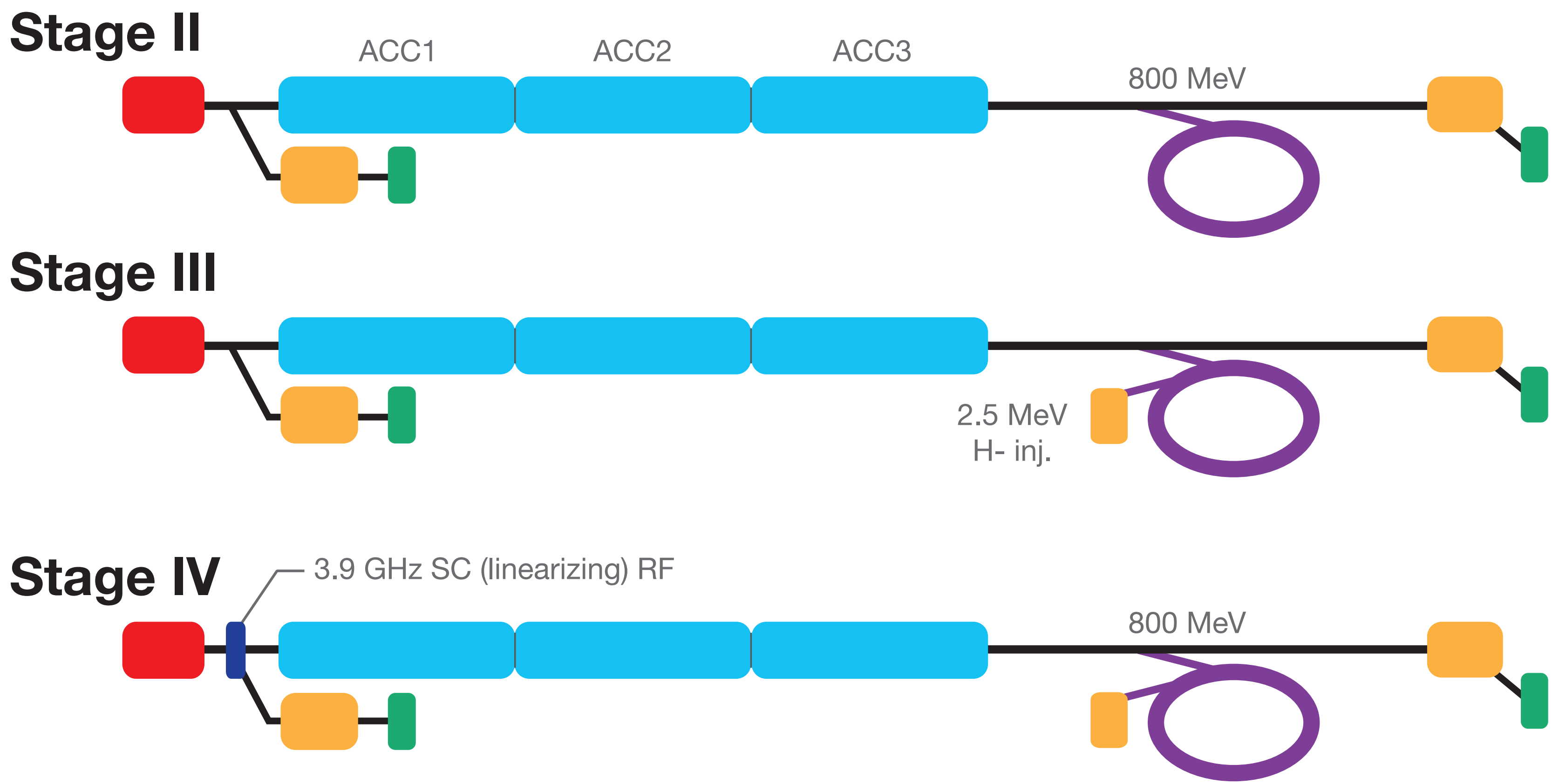


ASTA Buildout and Operation Occurs in Stages: Stage I

Stage I



ASTA Buildout and Operation Occurs in Stages: Stages II, III, IV



ASTA Parameters

Parameter	ILC RF unit test	Range	Comments
bunch charge	3.2 nC	10's of pC to >20 nC	minimum determined by diagnostic thresholds; maximum determined by cathode QE and laser power
bunch spacing	333 nsec	<10 nsec to 10 sec	lower laser power at minimum bunch spacing
bunch train length	1 msec	1 bunch to 1 msec	maximum limited by modulator and klystron power
bunch train repetition rate	5 Hz	0.1 Hz to 5 Hz	minimum may be determined by electron gun temperature regulation and other stability considerations
normalized transverse emittance	~25 mm-mrad	<1 mm-mrad to >100 mm-mrad	maximum limited by aperture and beam losses; without bunch compression emittance is ~4 mm-mrad at 3.2 nC
RMS bunch length	1 ps	~10's of fs to ~10's of ps	minimum obtained with Ti:Sa laser; maximum obtained with laser pulse stacking
peak bunch current	3 kA	> 10 kA (?)	3 kA based on CSRTrack simulations with low energy bunch compressor
injection energy	50 MeV	5 MeV to 50 MeV	may be difficult to transport 5 MeV beam to the dump; maximum determined by booster cavity gradients
high energy	820 MeV	50 MeV to 1500 MeV	radiation shielding issues limit the maximum; 1500 MeV with 6 cryomodules

ASTA is Unique Among Accelerator User Facilities in Six Principal Ways

1. **High repetition-rate:** ASTA accelerates 1 msec long bunch trains, with 3 MHz micro-pulse repetition rate, with up to 3000 bunches per train.

2. **High average power:** ASTA accelerates 1 msec long bunch trains at up to five pulses per second, providing the highest beam power and highest average brightness of any HEP accelerator test facility.

3. **High energy:** ASTA accelerates beam to ~1 GeV, which is important for a number of photon-science and FEL-related experiments.

ASTA is Unique Among Accelerator User Facilities in Six Principal Ways

4. **Extremely stable beams:** ASTA, based on ILC technology, is capable of providing exceptional beam stability, feasibility of which was demonstrated at the FLASH facility at DESY

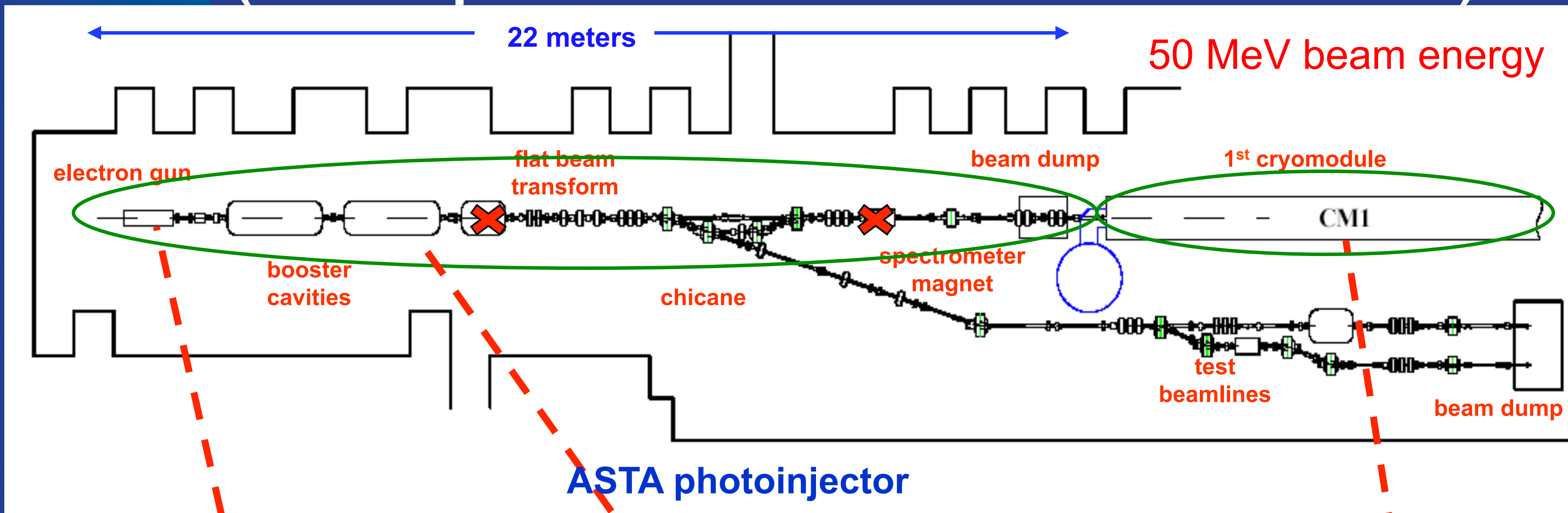
5. **Superconducting technology:** ASTA necessarily brings SRF and beams together. As nearly all future large scale accelerator facilities will rely on SRF technology, ASTA will be the only GeV-scale test facility which is capable of supporting R&D in prototypical conditions.

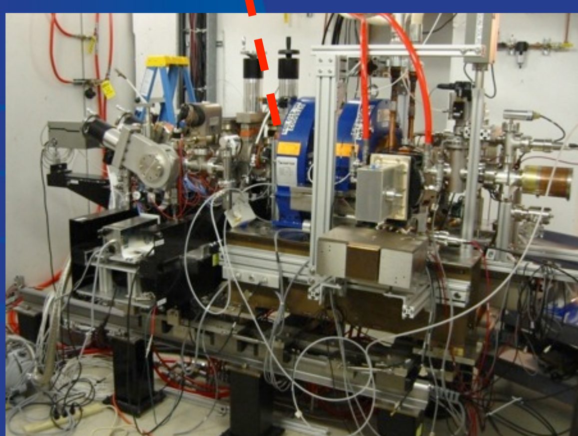
6. **Storage ring:** ASTA incorporates a small, very flexible storage ring, based on innovative optics, capable of supporting a broad range of ring-based advanced beam dynamics experiments.

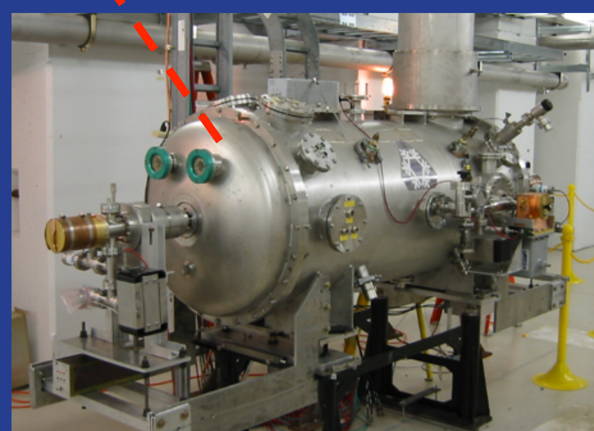
50 MeV Injector + 1 Cryomodule

- Goal: installation complete and beam commissioning started in 2014
  - RF gun + RF system and photocathode laser system
  - 2 SRF booster cavities (CC1 and CC2) + RF systems
  - 50 MeV Injector beam line elements and instrumentation to the low energy dump
  - Low energy beam dump
  - SRF cryomodule (CM2)
  - High energy beam line to dump
- Installation of 1st AARD experiment (high brightness X-ray channeling source)

Stage I.0: Expected Configuration in 2014 (Completed 50 MeV Beamline)

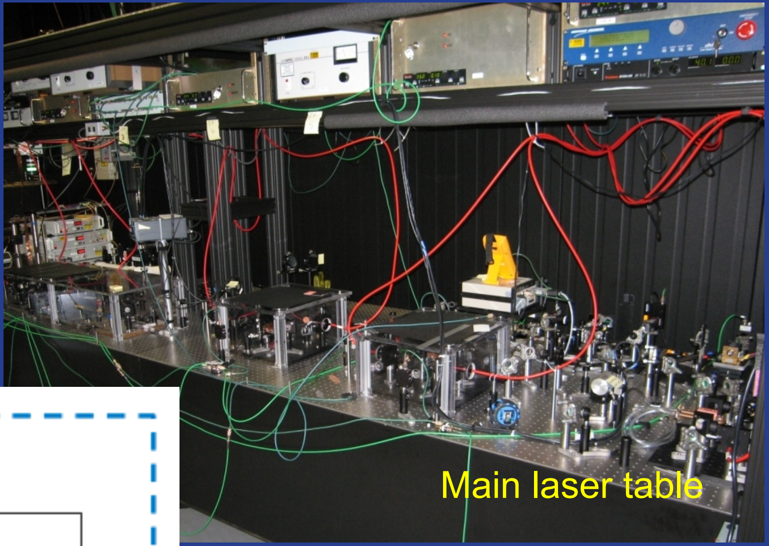


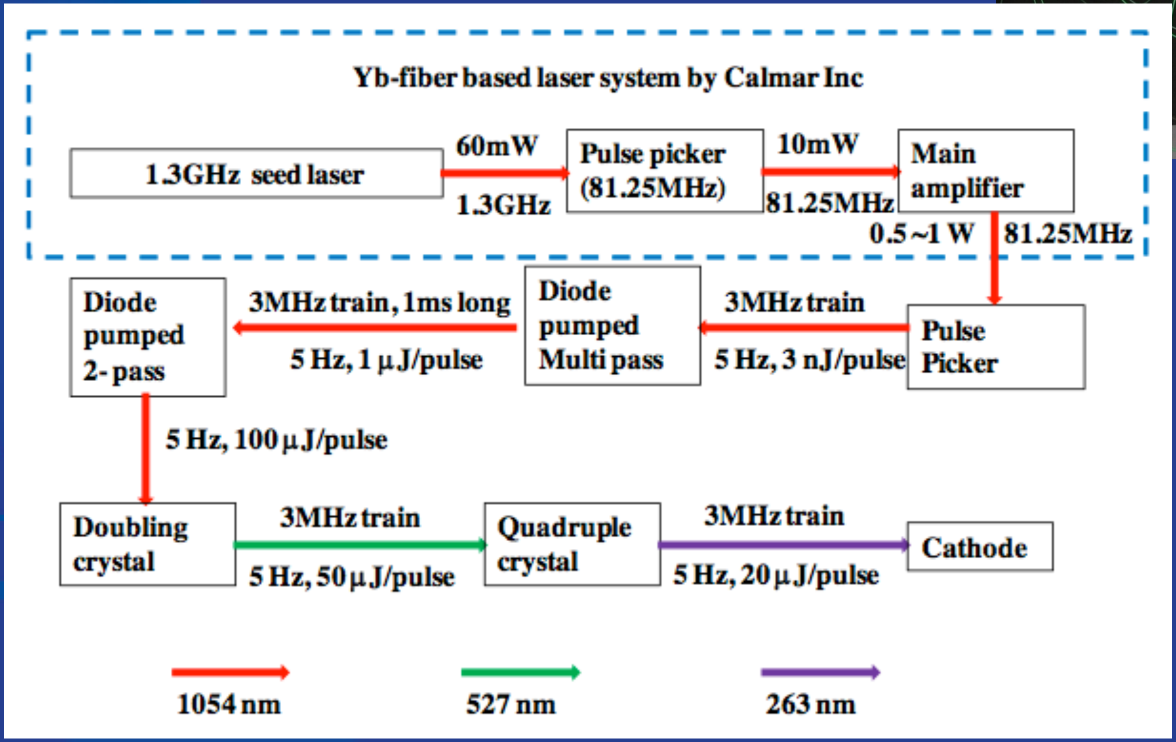




Photoinjector Laser

- Commercial 1054 nm Yb-fiber seed laser operating at 1.3 GHz; followed by 1 multipass, 3 single pass, and commercial amplifier, pulse-picked to 3 MHz, and frequency quadrupled to 263 nm UV
- Can now deliver 25 μJ, 300 μsec pulse train (UV): delivered charge - 37.5 nC

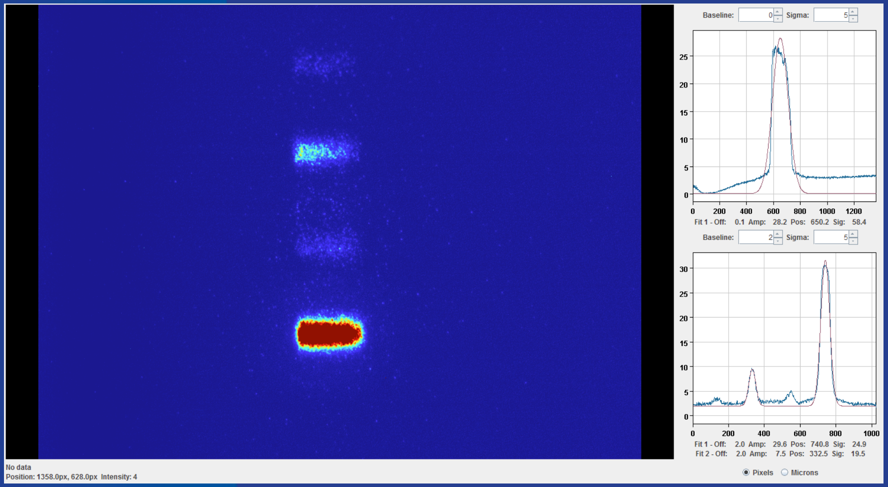




Photoinjector Laser

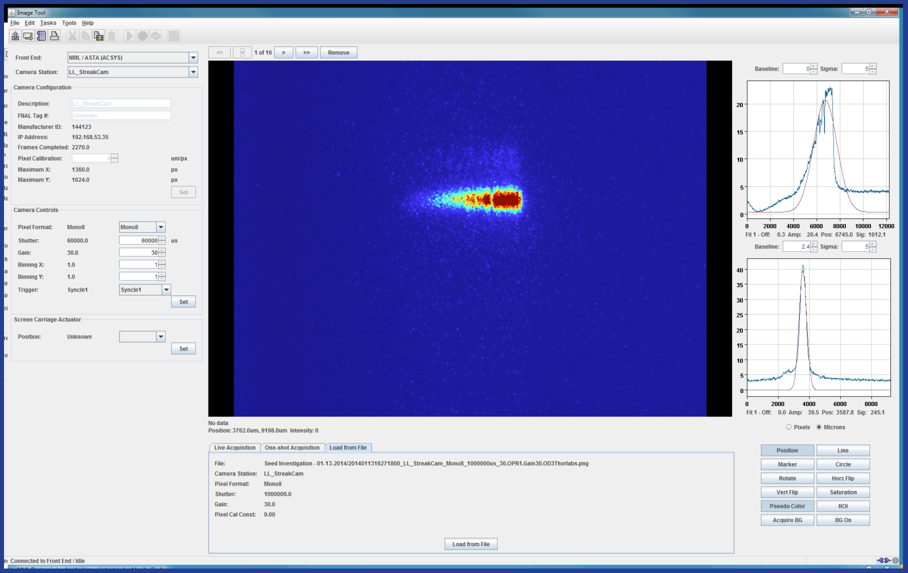
- Laser is up running with 3MHz pulse train and 5Hz repetition frequency
- User interface (ACNET Synoptic) is set up
- The longest flat pulse could be easily be up to 200~300μs.
- Some extensive tuning (few hours) would be needed for 500~600μs long pulse train with lower charge.
- A few issues are being actively addressed
  - Satellite structure in time domain when checked with the streak camera. Extensive studies are in progress to identify the cause.
  - Bunch length is 4.5ps rms instead of 3ps rms as designed. It has been verified that this can be solved by replacing the current Multi-pass structure with several single pass structures. This work is in progress.

Photoinjector Laser



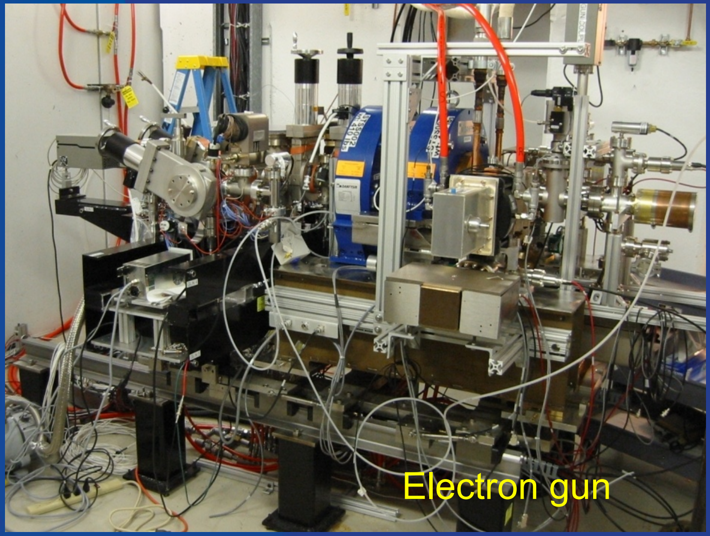
BAD!

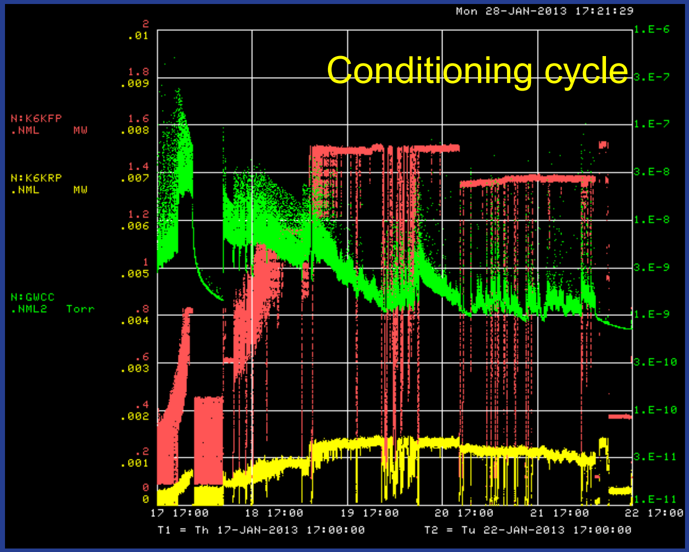
Better



Photoinjector Gun

- 1.5 cell copper L-band (1.3 GHz) photocathode gun (identical to FLASH design)
- Focusing Solenoids
- Water cooled
- Installation of cathode system, gun, and coupler was completed in Nov. 2012
- Conditioning started on Dec. 27, 2012.



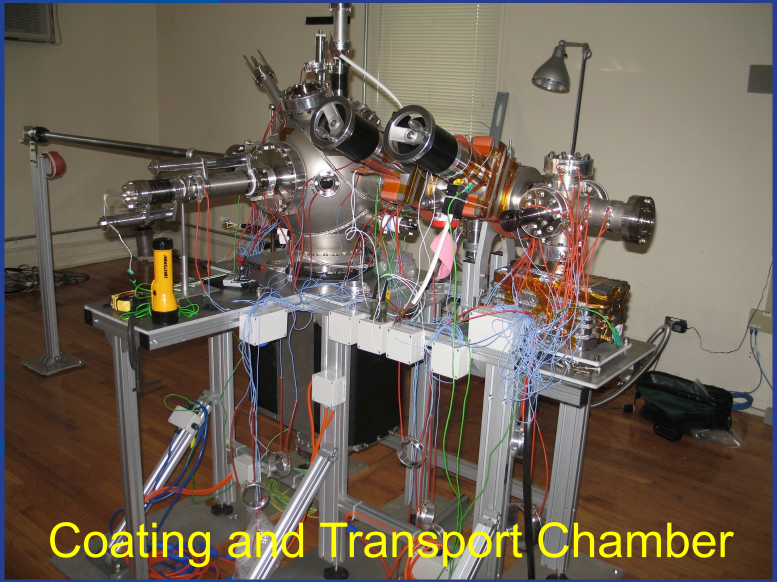


Photoinjector Gun

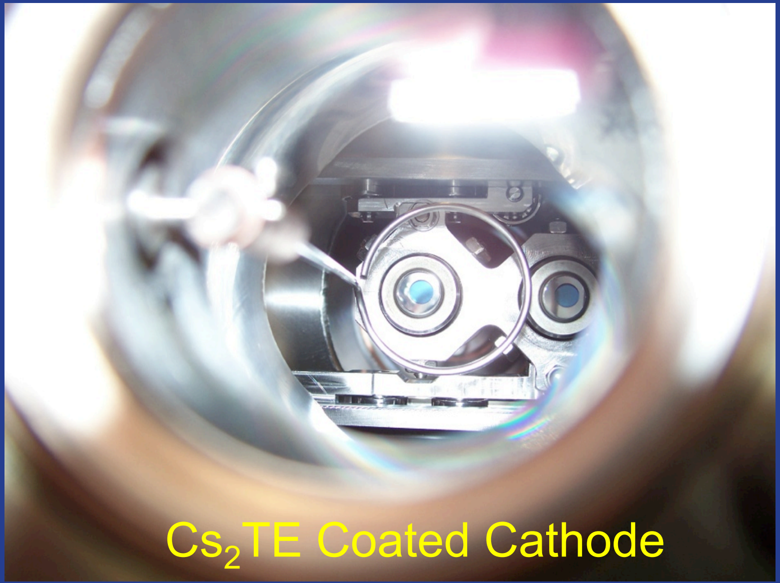
- Five RF Windows high power tested (conditioned) to 3.8 MW, 1 millisecond pulse width in 2011
- First stage Coupler/Gun Conditioning completed to 1.2 MW, 1 ms pulse width, 5 Hz repetition rate
- Second stage of conditioning in progress
  - Up to 2.55+ MW, 1 ms, 5 Hz
  - 2.55 MW, 700 μs, 1 Hz achieved to date
- Typically running at ~1.8 MW for electrons now
- Klystron upgraded to a 5 MW model in December
  - Gun-cavity is being conditioned up to ~ 4 MW / 1ms / 5Hz.

Photoinjector Cathodes

- Currently operating with an uncoated Molybdenum plug
- 3 Cs_2Te 'coated' cathodes in hand at NML
  - Quantum Efficiency ~2.9%
- Preparing to install
- Unique Coating/Preparation facility at Lab 7



Coating and Transport Chamber



Cs_2TE Coated Cathode

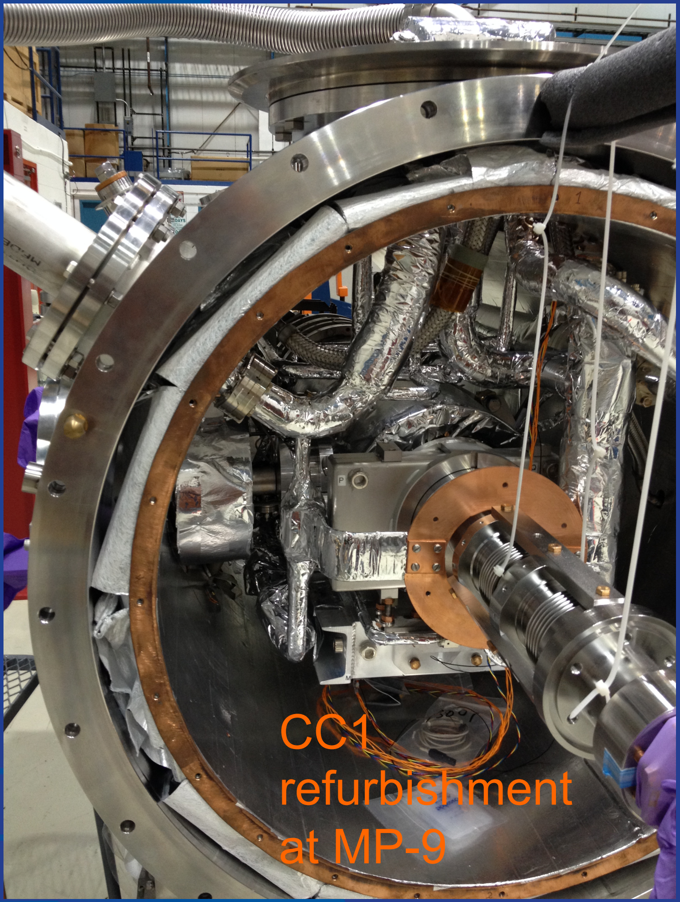
Capture Cavities

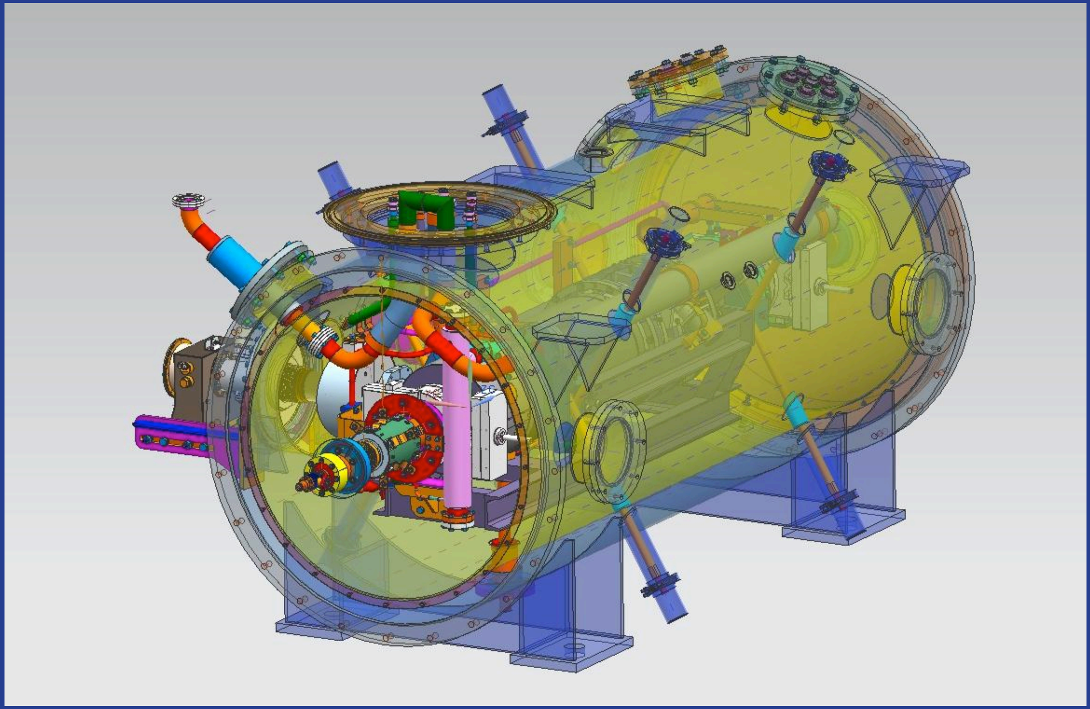
- Two 'Booster' 1.3 GHz cavities – single cavities each in their own cryomodule
  - Each cavity is powered by its own 300 KW RF system.
  - Capture Cavities needed because focusing strength of Cryomodule cavities is too strong for low energy electrons from Gun.

Capture Cavity 1

- Capture Cavity 1 was previously the A0 Photoinjector workhorse
  - (Significant) Upgrade in progress including new cavity
  - Dressed Cavity achieved ~29 MV/ m in January 2013 test at Fermilab's Horizontal Test Stand
  - 'Modern' cryomodule – upgrade is taking advantage of improvements in cryomodule design over the past 2+ decades
  - Installation expected in February 2014

Capture Cavity 1

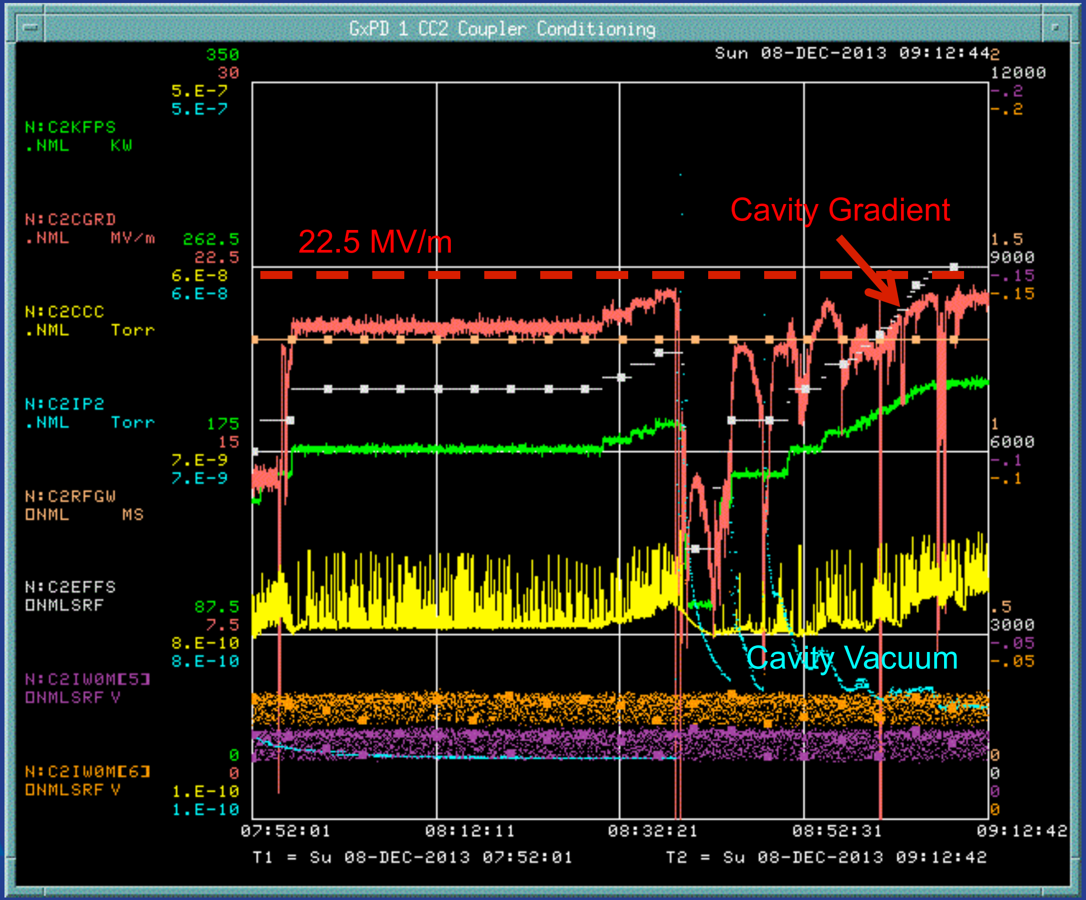




Capture Cavity 2

- Capture Cavity 2 - first SRF device delivered and operational at NML
  - 22 MV/m, 1 ms pulse, 5 Hz
  - LLRF & LFDC operational
- Re-commissioning began in late October
  - warm coupler conditioning
  - cool-down
  - on-resonance (cold) conditioning
  - performance evaluation
- 21.5 MV/m gradient demonstrated
  - limited by quench
  - some performance degradation since, investigating

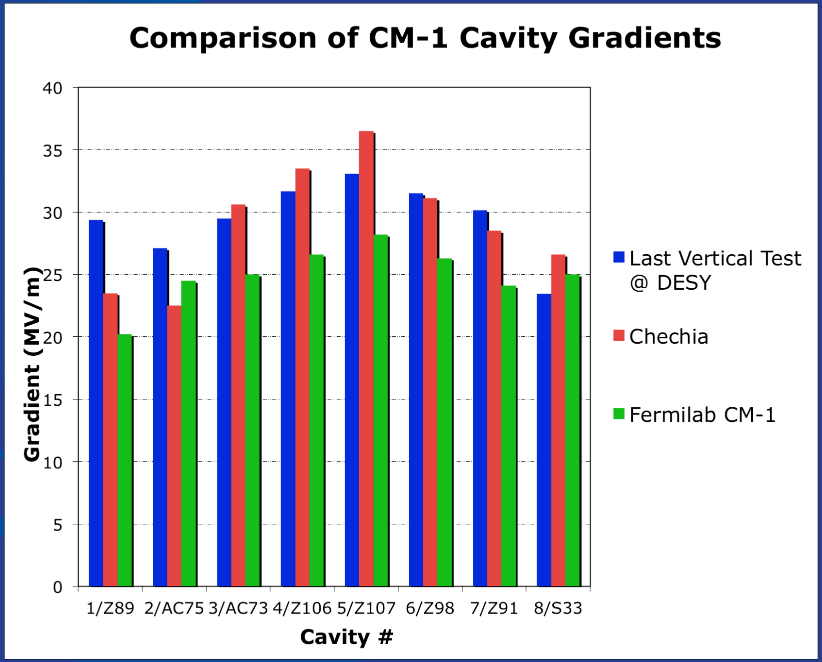
Capture Cavity 2



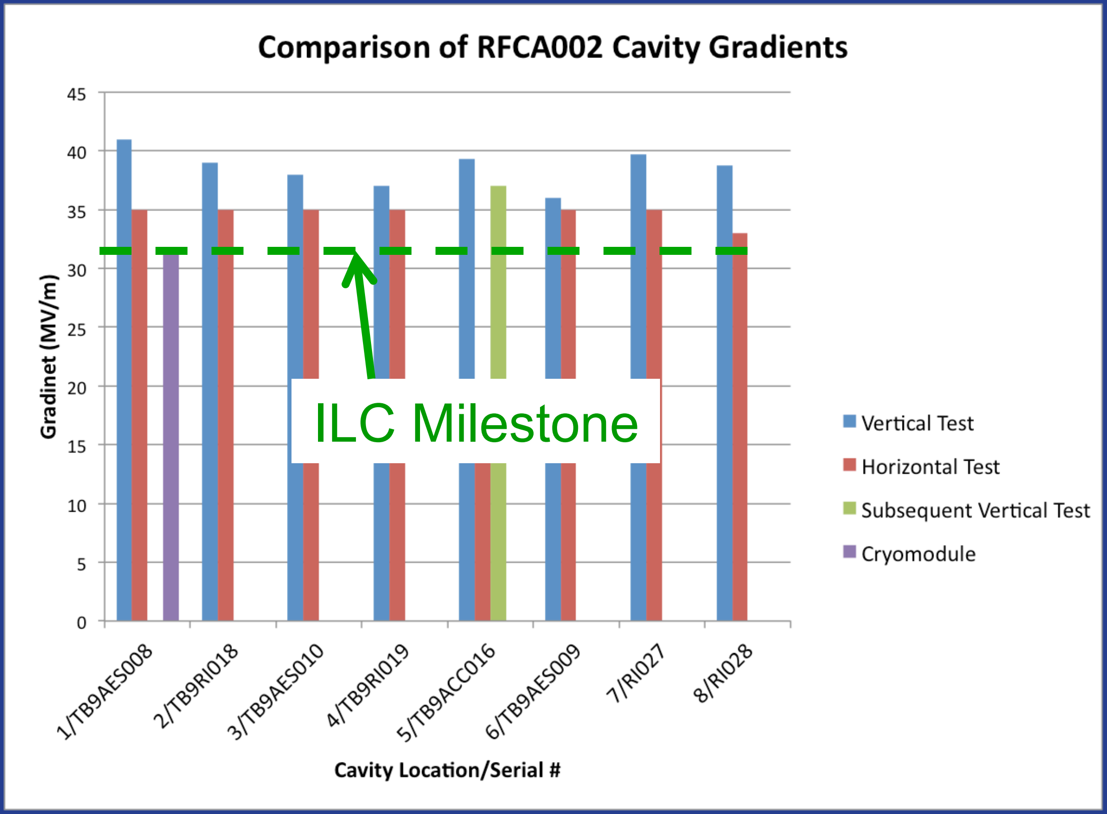
Capture Cavity 2

Cryomodules – CM1

- Installed, cooled to 2 Kelvin, commissioned and operated from October 2009 – April 2012
- Peak gradients from 20 – 28 MV/m
- Detailed LLRF & LFDC studies
- Valuable experience on many aspects of SRF operation



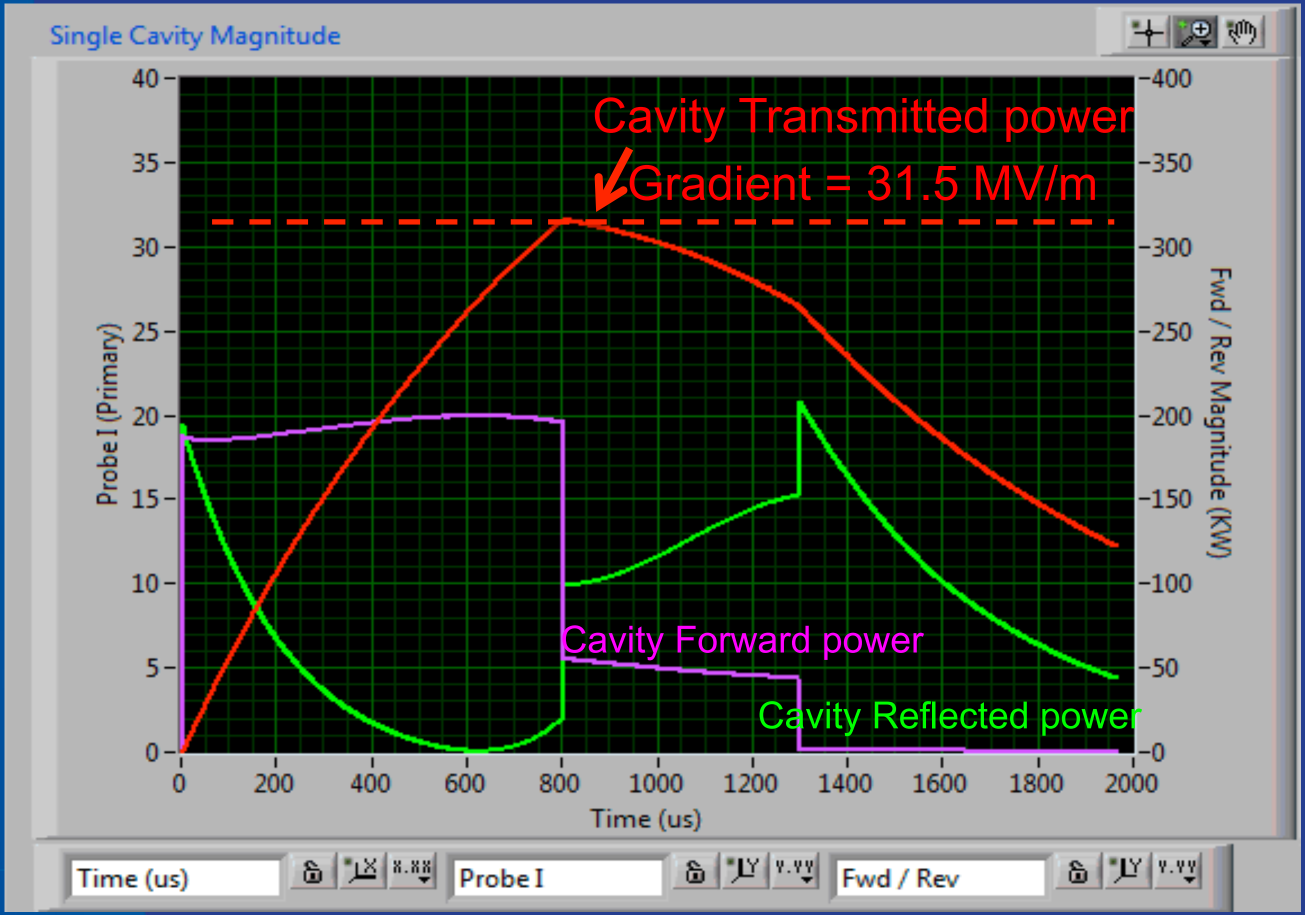
Cryomodules – CM2



Cryomodules – CM2

- Cryomodule installed in NML/ASTA – April 2013,
- Warm coupler conditioning (one cavity at a time) – 9 May to 18 June 2013
- All piping work completed including Leak checks and Pressure tests – October 2013
- Cooldown – 23 October to 11 November 2013
- Begin cold operation, Cavity 1 only – 13 November 2013
  - Test plan includes individual cavity characterization followed by full module powering
- On-resonance conditioning – 6 to 20 December 2013
- Achieve 31.5 MV/m (Administrative limit) – 20 December 2013
- Commission Lorentz Force Detuning Compensation
  - this morning

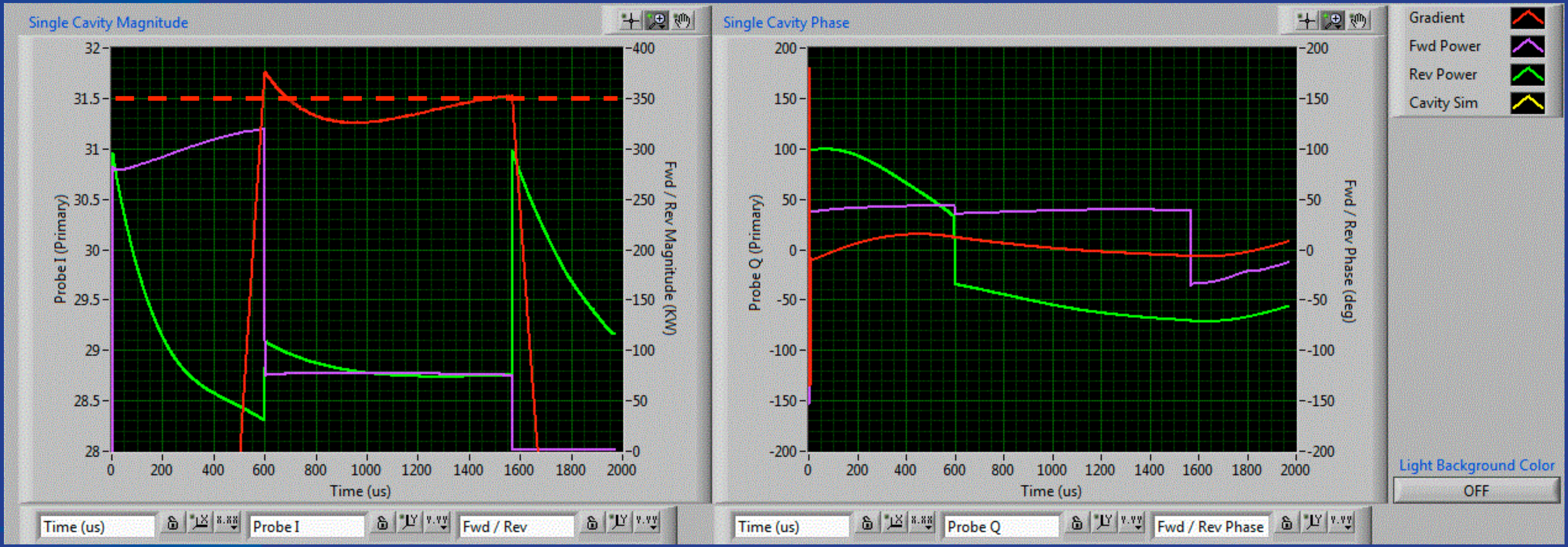
Cryomodules – CM2



20 December 2013: CM-2 Cavity 1 achieves 31.5 MV/m (Administrative limit)

1 Hz, 1.3 ms pulse width

Cryomodules – CM2

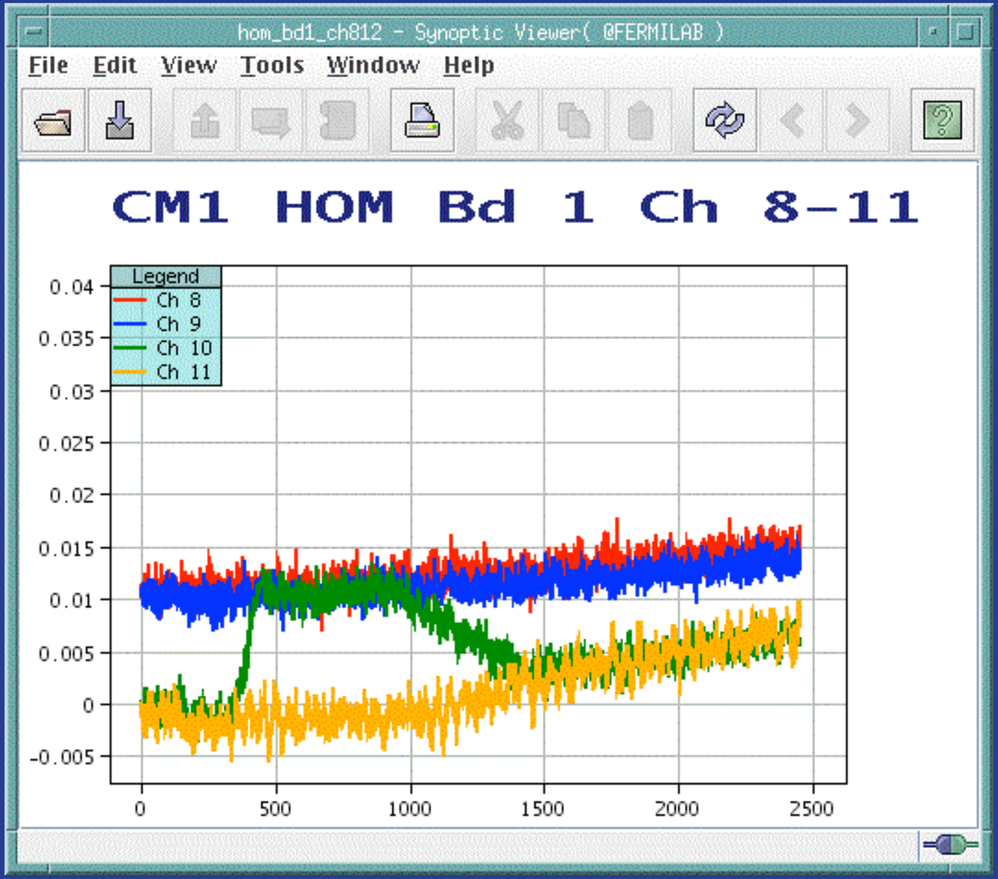


14 January 2014:

CM-2 Cavity 1 achieves 31.5 MV/m (Administrative limit)

1 Hz, 1.3 ms pulse width, LFDC Active

Cryomodules – CM2



14 January 2014:

Dark Current Observed at upstream end of CM2: ~ 1 nA.

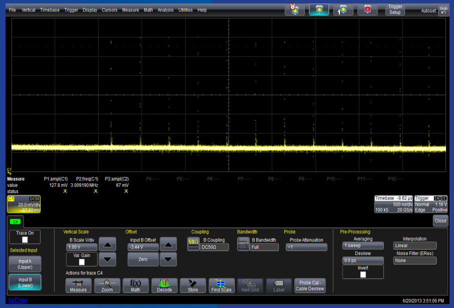
CM2 Next Steps

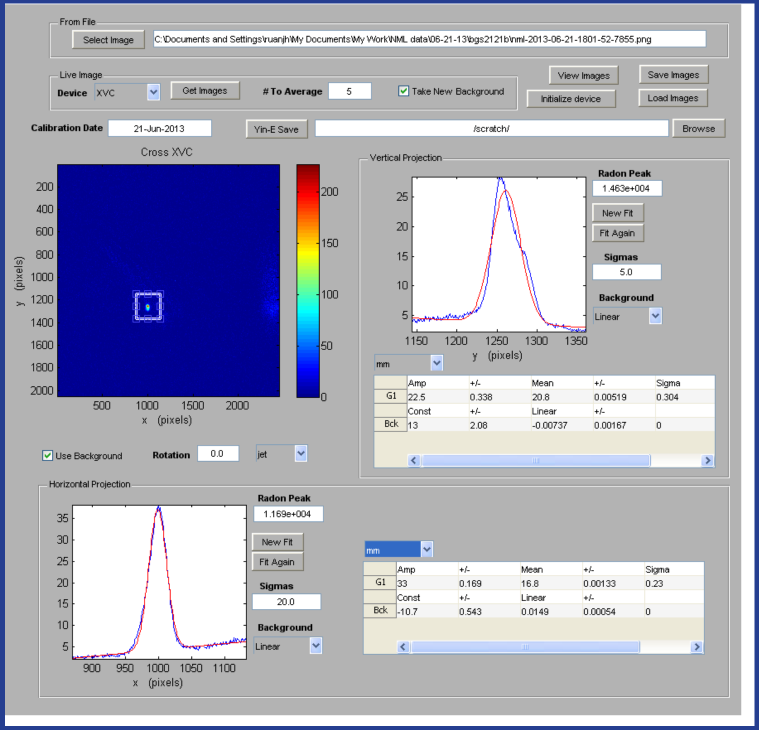
- Finish Up Cavity 1
  - Further LLRF work
  - Dynamic Heat Load measurements
- Switch to Cavity 2 (late this week?)
- Repeat sequence for Cavities 2-8
  - complete ~mid-March
- Power and characterize entire Cryomodule
- Wait for beam….

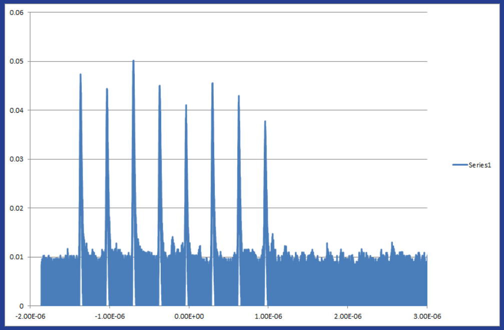
Electrons

- Photoelectrons first produced at ASTA on 20 June 2013
  - Molybdenum (uncoated) cathode
  - Visible on Loss Monitor, Faraday cup, and Wall Current Monitor
- 'Routine' Electron operation
  - 80 μs pulse, 1.8 MW peak power typical
  - Calibrate FC, WCM, look for BPM signals
  - RF Phase scans to optimize electron output
  - Low Level RF operated in closed loop
  - Extend pulse length/laser for more bunches
  - Exercising trim dipoles – verify beam movement, perform energy measurements

First Electrons







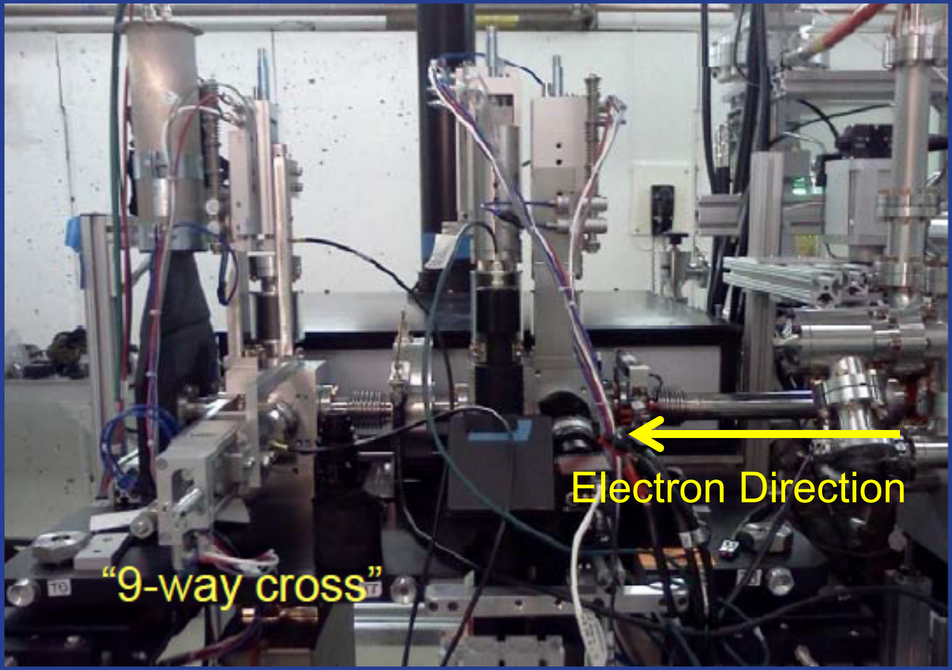
Electronic Logbook entry from first electron production:

5280, Mike Church (church), Thu, 06/20/2013 17:53:24 Gun/Commissioning

Summary of this afternoon's activities: We successfully produced our 1st photelectron beam from the gun into a Faraday cup. 8-15 pulses at 1 Hz rep rate. Conditions were approximately as listed in entry Entry #5273. Signal was observed on the resistive wall monitor, loss monitor, and YAG screen as shown in the last 3 entries. Hooray!

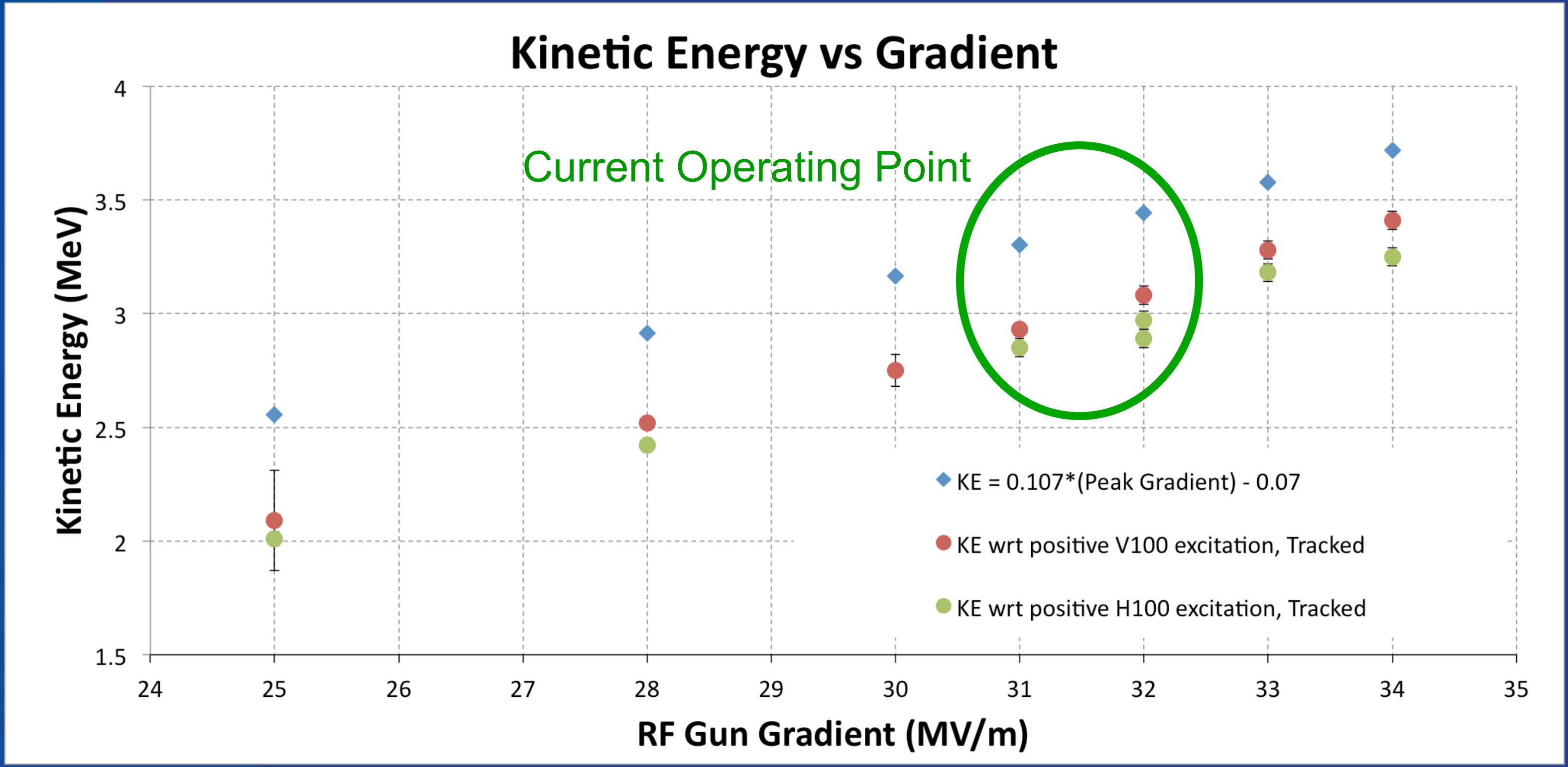
Electrons – 9-way Cross

- Instrumentation platform directly downstream of the gun containing
  - Laser optics
  - Laser Injection Mirror
  - YAG profile monitor
  - Cathode viewing mirror
  - Dark current collimator
  - Faraday cup
  - Wall Current monitor
  - 2 BPM's
  - 2 Corrector magnets
  - Vacuum pumping



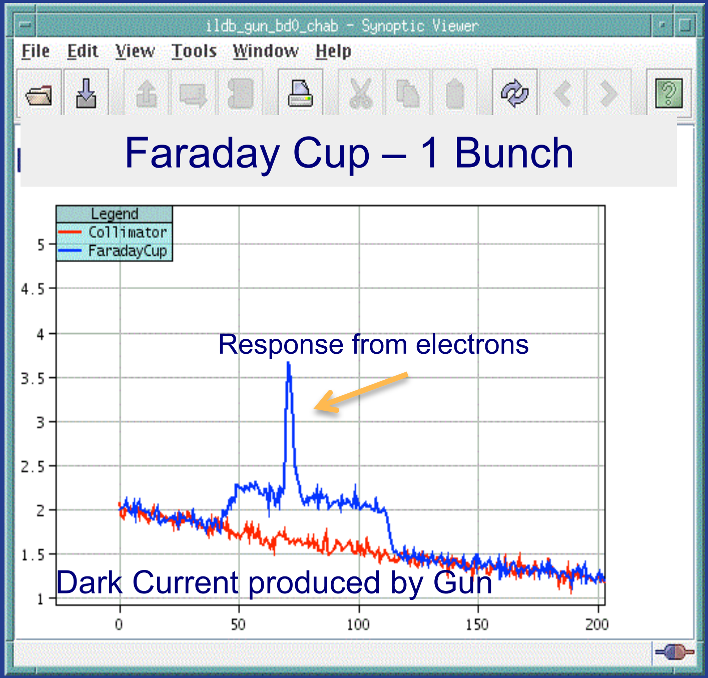
Electrons – Energy Measurement

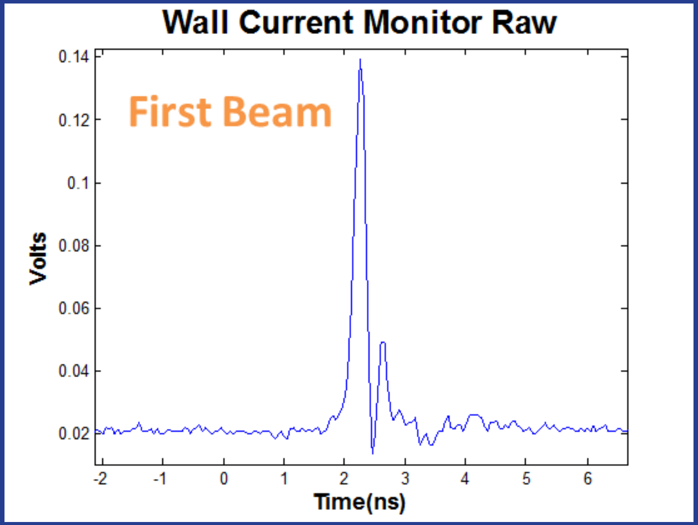
- Estimating Electron Kinetic energy by means of dipole scans
- Next step to scan solenoids



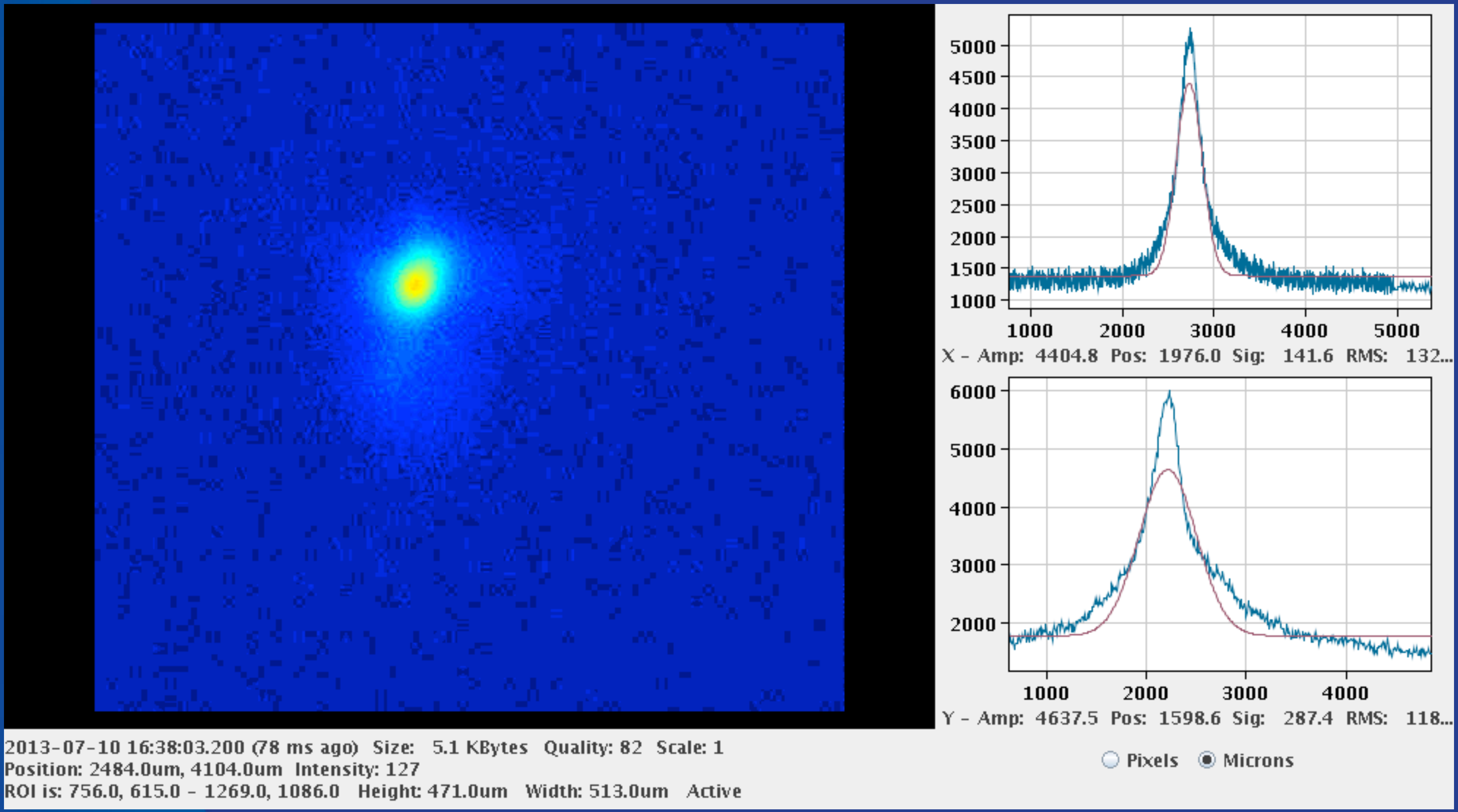
Instrumentation

- Faraday Cup measures total current on each pulse
  - Nominal Bunch Charge measured to be 0.5 picoCoulomb
- Wall Current Monitor is a complementary, non-invasive monitor
  - Verified charge produced with Faraday Cup



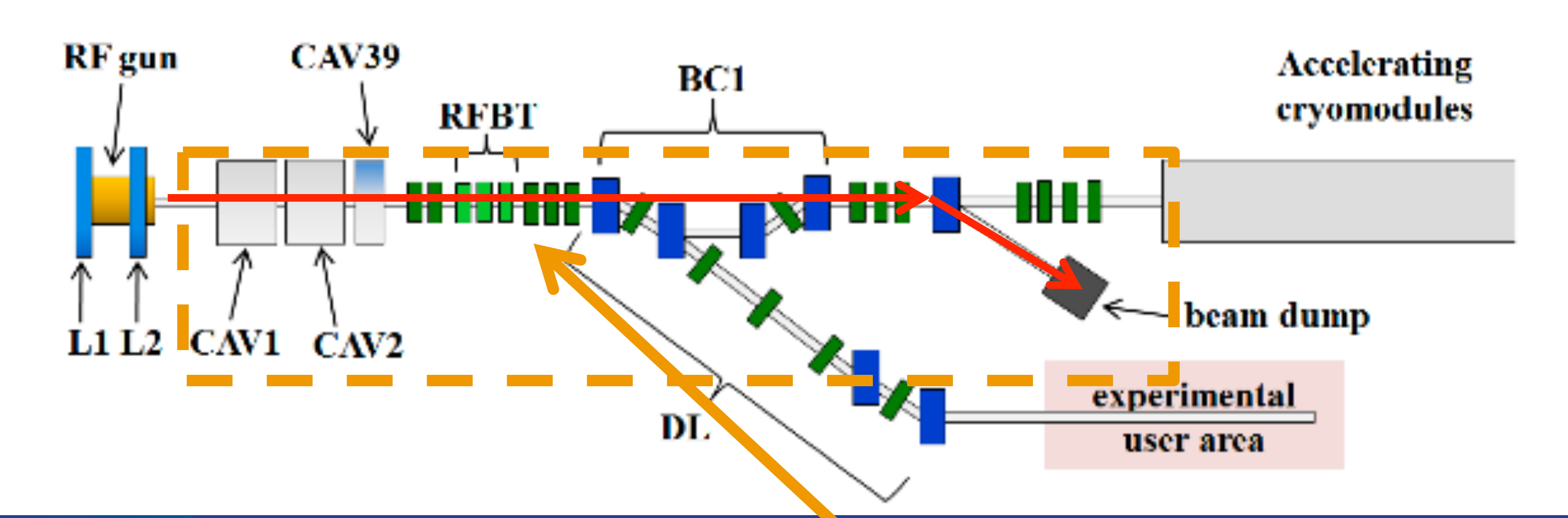


Instrumentation (2)

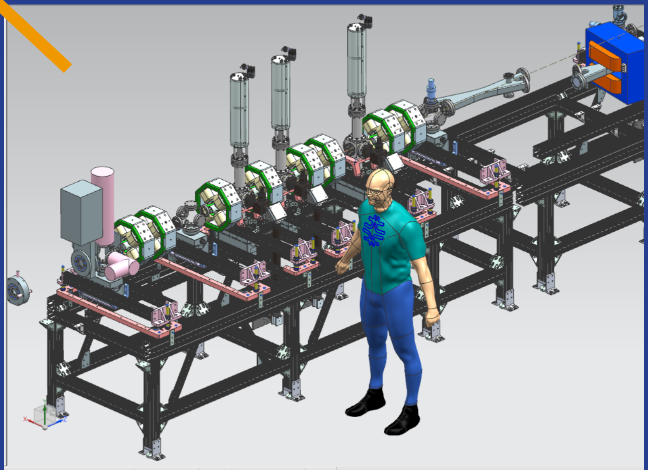


9-way Cross YAG Screen – 5 Bunches

50 MeV Beam line

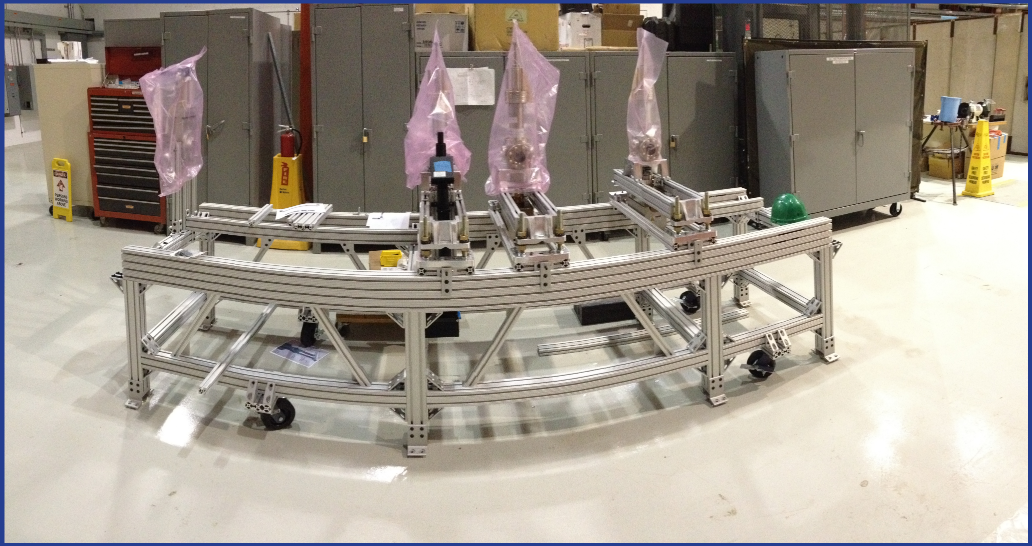


- Current emphasis on installing 50 MeV line (gun to Cryomodule)
- Components installed on girders as much as practical
- Girder alignment, interfaces, vacuum work in situ



50 MeV Beam line

- Girder #1 being assembled
- Girders #2 & #3 ordered
- Most parts in hand and certified
- Installation expected to be finished in March
- Much of the effort is clean room work



Accomplishments in 2013

- Laser installed & Commissioned - UV to ASTA cave
- CM2 installed and warm conditioning completed
- CM2 cooled down and commissioning begun
  - ILC gradient achieved
- Gun installed and 2nd phase of conditioning complete
  - 5 MW klystron installed and operational
  - 3rd (& final) phase of conditioning in progress

Accomplishments in 2013 (2)

- 9-way diagnostic cross installed and operational
- Electrons
  - Beam sensed on Faraday cup, Loss Monitor, Wall Current Monitor, and BPM
  - Instrumentation commissioning & calibration
- 50 MeV Beam line work begun
- Low energy beam dump in place

Planned Activities in FY14

- Complete RF Gun conditioning – 45 MV/m
- Install ‘coated’ cathode – generate a real beam
- Bring CM2 into operation
- Complete upgrade and install CC1
- Complete installation & begin commissioning 50 MeV Injector to low energy dump (Stage I.0)
  - initially ~20 MeV operation
- Begin installation of high energy beam line to dump (Stage I.2) including tunnel extension

Etc.

- ASTA Website
  - http://asta.fnal.gov/
- ASTA Newsletter
  - http://asta.fnal.gov/newsletter/archive/ASTA_News_Dec2013-3.pdf

The ASTA Community is Ready to Go!

First ASTA User's meeting and first ASTA Advisory Committee meeting held July 2013

- 84 participants presenting 30 proposals

Summary

- Major components of ASTA Stage I.0 nearly in place
- Commissioning is in progress on many fronts
- Collaborations and interactions with young scientists and other have already begun
- 2014 promises to be busy and exciting

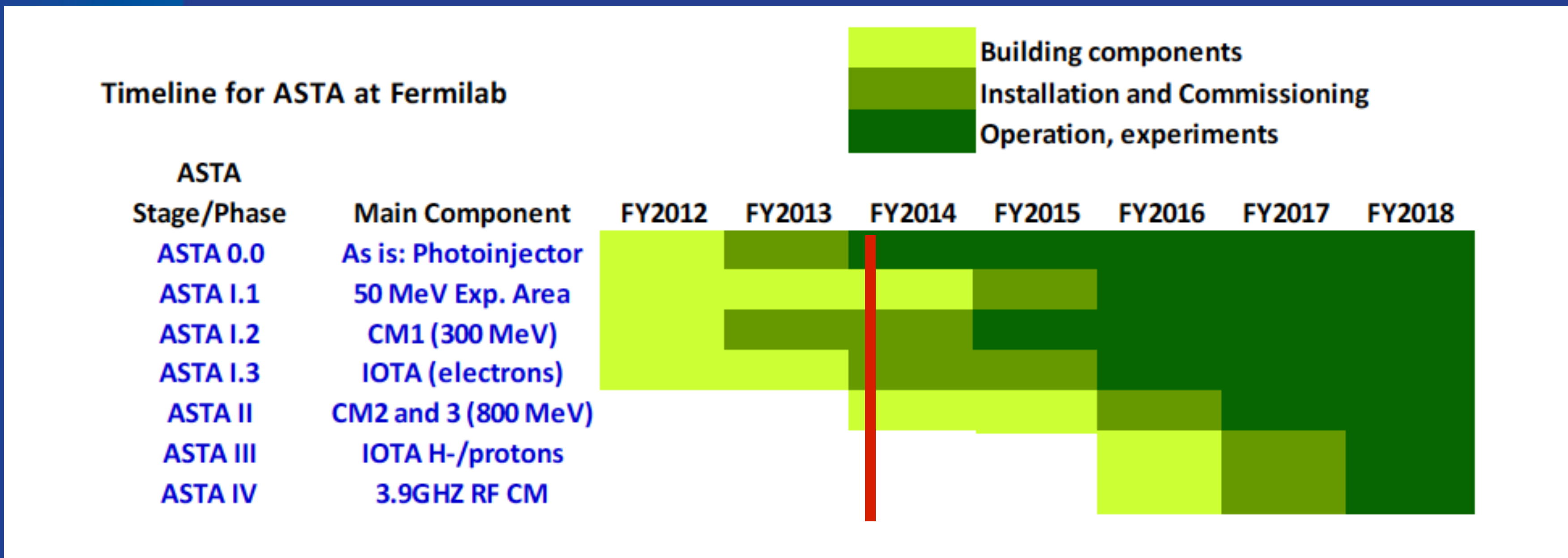
Thank you for your attention

Questions?

Ancillary Systems

- Gun, CC2, Cryomodule RF systems in place and operational
  - some upgrades, improvements planned including Gun Klystron replaced with 5 MW model (in hand), 10 MW multi-beam klystron for CM’s (installation beginning)
- CC1 RF installation in progress
- Protection systems, Vacuum, water, Controls verified functional in early stages
- Some life testing carried out as part of commissioning systems

Timeline



Timeline for ASTA at Fermilab
Building components
Installation and Commissioning
Operation, experiments
ASTA Stage/Phase
Main Component
FY2012
FY2013
FY2014
FY2015
FY2016
FY2017
FY2018
ASTA 0.0
As is: Photoinjector
ASTA I.1
50 MeV Exp. Area
ASTA I.2
CM1 (300 MeV)
ASTA I.3
IOTA (electrons)
ASTA II
CM2 and 3 (800 MeV)
ASTA III
IOTA H-/protons
ASTA IV
3.9GHZ RF CM