# CEBAF Accelerator Update

Michael Tiefenback
CASA Accelerator Physics Experimental Liaison
March 07, 2018

With grateful thanks for input from
Roblin/Satogata/Benesch/Freyberger and many others

# Transformer Failure – CHL

- Spring 2018 run proceeding well up to March 05 2018
  - Both CHLs tripped off shortly after 13:30
  - Consequences and delay will be known shortly
  - Some number of days of limited maintenance/recovery
  - Possibly some time dedicated to improved setup tools
- Stay tuned for developments

# Linacs and Accelerator Systems

- Energy is 4% below 12 GeV nominal value
  - "Expect to hold at this energy" (A. Freyberger 3/28/17)
  - Still holding this energy (March 2018)
  - Working mitigations (such as C75 program)
- Trip rate "acceptable"
  - Marginal overhead;  trip rates can be low
- 750 MHz separators are operational (becoming reliable)
- We are learning the hardware boundaries
  - Some things have had to be fixed
  - Some are being worked around
- Development of  the accelerator continues
- Working at hardware limits eats "clock time" – a Bad Idea

# CEBAF 4-Hall Operation

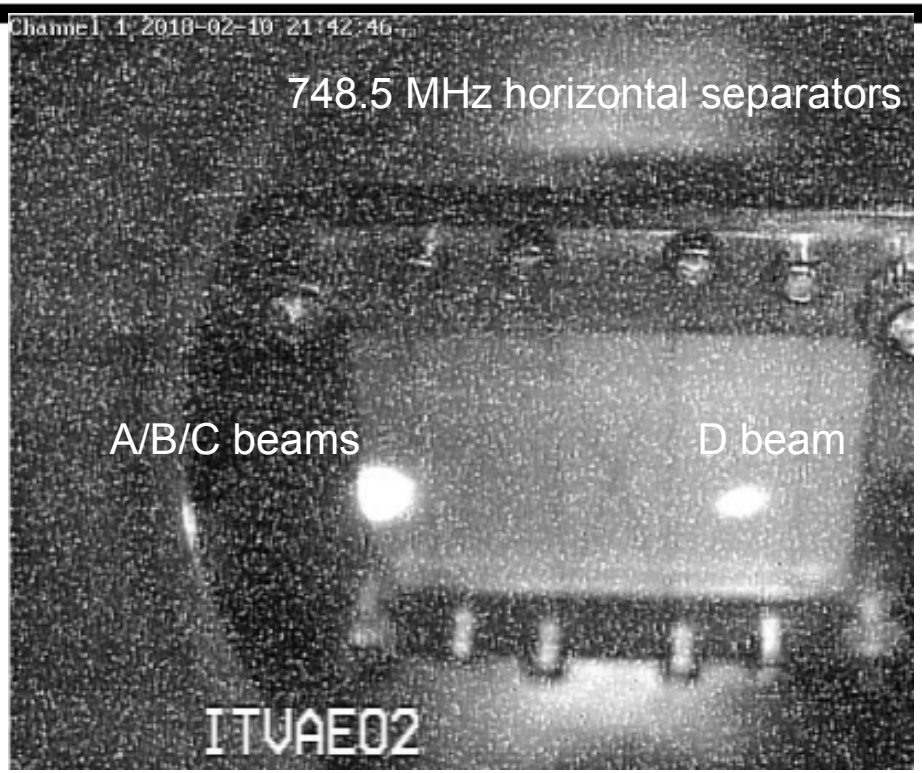
## Full 4 Hall Operations ("D+3") began Spring 2018 (table corrected from 2017 presentation)

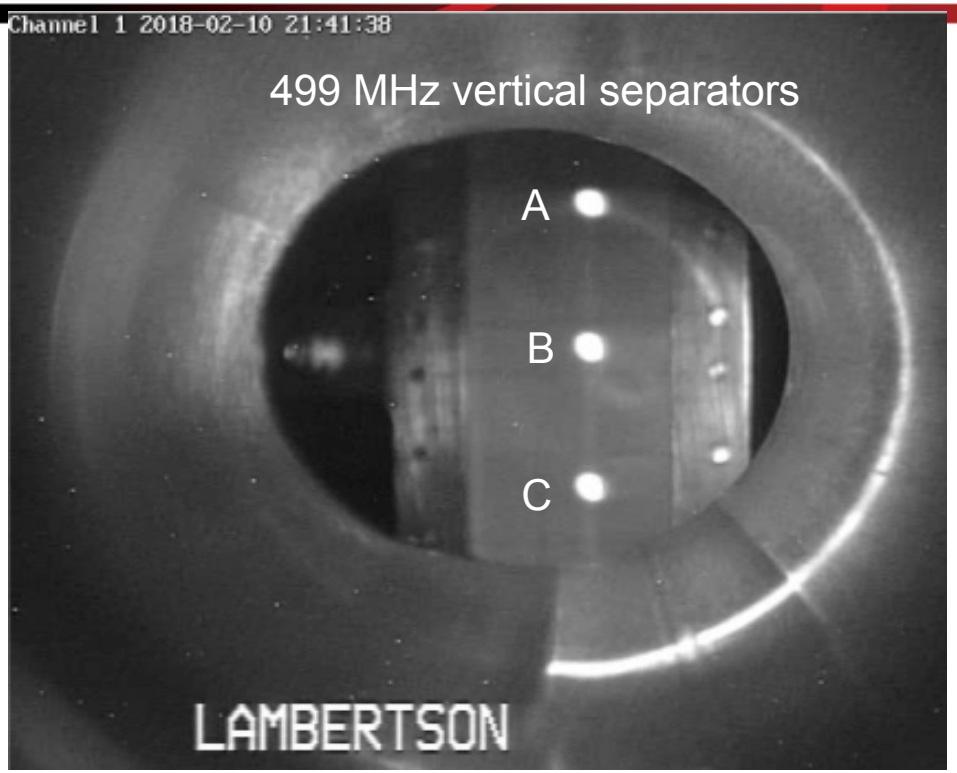
| Condition | (D+3) |
|---|---|
| • Maximum number of halls receiving beam | 4 halls |
| • ABC Beam @ 5th pass (Hall D on) | 249.5 MHz |
| • ABC Beam @ 5th pass (Hall D off – "_"+3) | 249.5/499 MHz (when D is DOWN) |
| • ABC Beam @ lower passes | **249.5 MHz default/499 MHz option** |

## 4 Hall Configurations tested:

- Hall D sharing chopper slit with Hall B (Early test; Limited D:B current ratio)
- Hall D sharing chopper slit with Hall A (22 µAmps to A, 0-150 nAmps to D)
- 748.5 MHz separators for 5th pass ABC / D separation
- Typically all halls will be at 249.5 MHz micro-pulse rate
- (NOTE: Other sub-harmonics are supported)

# All Halls on 5th Pass




- 748.5 MHz separator system working robustly
  - Note: viewer limited beam in above pictures
- Now targeting 4-hall, high current operations

# Source Operation – Continuing Progress

## Operations in 2016

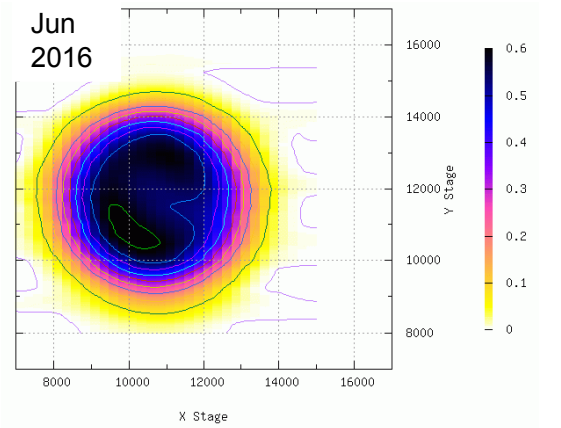
SSL GaAs/GaAsP SVT #5756-4 (Polarization ~ 87%)
No heat/activation over Summer 2016 / Winter 2017 SADS
Gun2 operating at -130 kV without any problems
Charge lifetime >100C with average current 70-80 μA

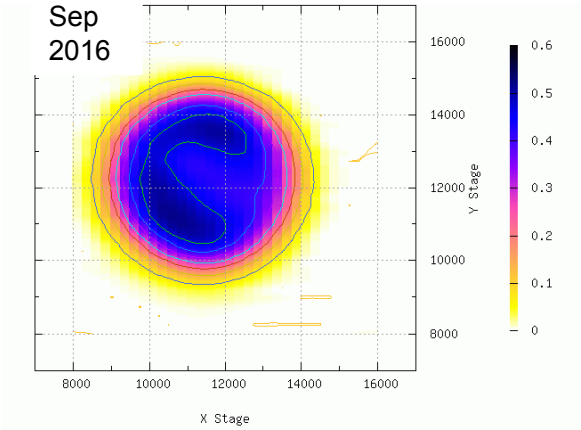
## Operations in 2017

Delivering up to 3 halls at a time (either 249.5 or 499 MHz)
Hall A (Physics), Hall B (KPP), Hall C (KPP), Hall D (Physics)

## Operations in 2018

Four (4) lasers operating simultaneously
Four (4) different experiments receiving beam
Maintaining ≥ 85% polarization



# High Power Operations

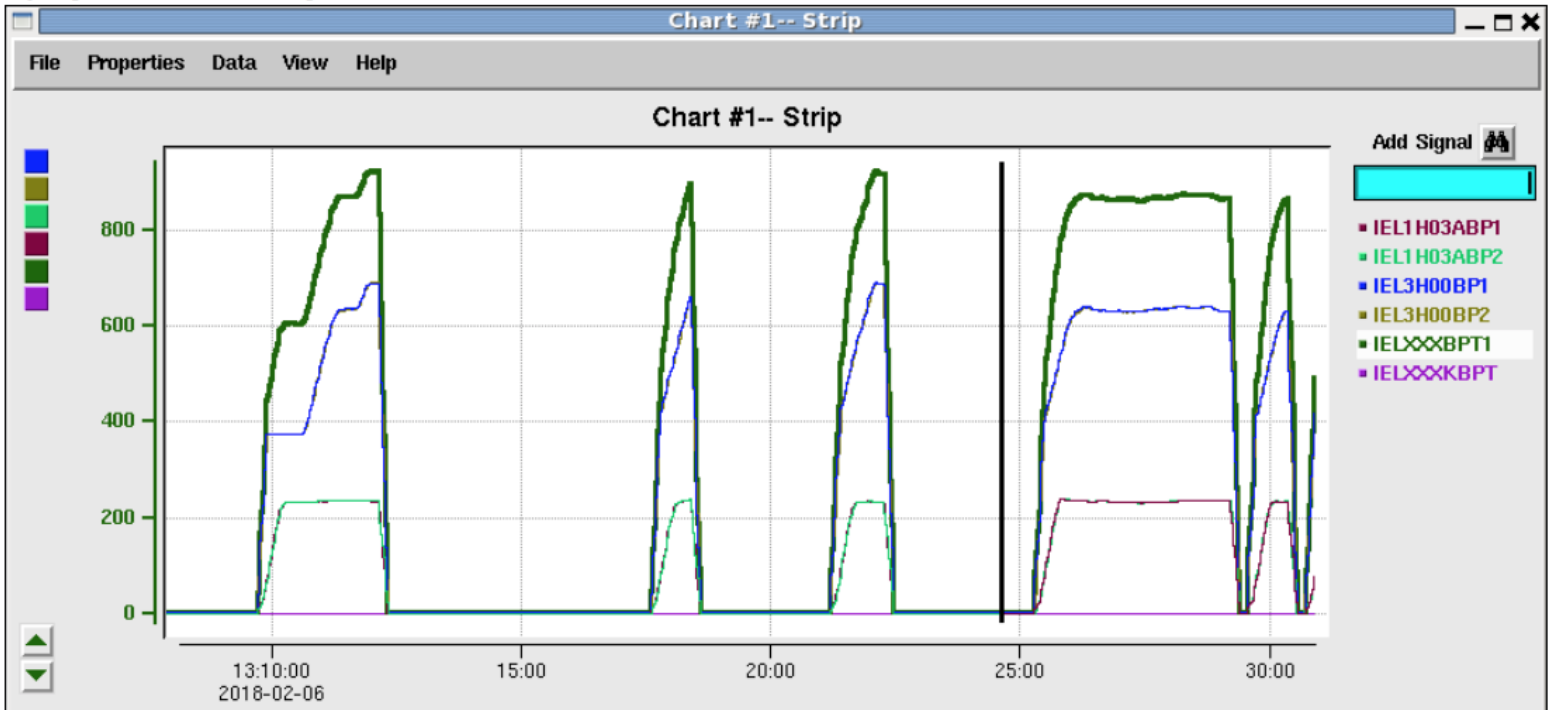
- Achieved 927 kW of total beam power Feb 6 2018
  - A new record for 12 GeV era with C100 cavities
  - Includes beam through 1L13 “hybrid” C75-like upgraded module

CEBAF achieves full power! 927kW of beam power, combined power of Hall-A (22.5 uA) and Hall-C (65 uA). This was held briefly until RF trips, mostly in the South Linac. RF was a bit of a challenge with Hall-C at 65 uA, and appears to be nominally ok at 60 uA (875 kW).

Note that sustained delivery above 900kW is not permitted due to the operational limit.

Elog 3528144

Fig. 1 [02/06/2018 13:30:55]



# 2018 RF Performance

- One pass energy gain remains at 2.1 GeV/pass
  - 100 MeV/pass lower than 12 GeV design (-5%)
  - Gradient margin is small and erodes between RF recovery periods
- Demonstrated beam delivery at administrative limit (900 kW)
  - 22 microAmperes to Hall A
  - 65 microAmperes to Hall C
- Now working to expand stability limits
  - Identify and correct limiting components (RF seems involved)
  - Improvements in coordination with improved beam optics

# Beam Parameters Effort

- Alex Bogacz is leading effort charged by Ops to deliver beam requirements tables for all halls
  - Similar to JC Denard table from 6 GeV era
  - All APELs soliciting input from halls
  - We are currently documenting existing 12 GeV capabilities
- Intent: Reference document for users for new proposals

**BEAM REQUIREMENTS (10/31/01)**

| Parameter | Nominal Value and Range | stability (during 8 hours) (note 1) | helicity correlated unbalance averaged over 1 hour |
|---|---|---|---|
| rms spot size at the target | A: $\sigma_{x \text{ and } y}$ = 50 to 200μm; B: 50 < $\sigma_{x \text{ and } y}$ < 250 μm; C: $\sigma_{x \text{ and } y}$= 100 to 500μm A & C may request specific sizes (note 2) | A & C: 25% of requested value; B: any value within nominal range | A & C: 100% of nominal size; B: 60 μm |
| angular divergence at the target | $\sigma_{x'}$, $\sigma_{y'}$ < 100 μr | 50% of value | 100% of beam divergence tolerance |
| Beam position | any value requested by experiment within 3 mm of optics axis | drifts A: < 50% of spot size; B: < 120 μm; C: < 250 μm; transients A, B, C: < 1 mm | A & C < 10 μm; B < 60 μm |
| Beam direction | any value requested by experiment within 1 mr of optics axis to dump center | < 50 μr (1/2 beam divergence tolerance) | 100% of beam divergence tolerance |
| Energy (average) | multipass operation: 0.63 to 5.75 GeV; 1 pass 1 hall dedicated operation: 0.33 GeV to 0.63 GeV | A or C: ΔE/E < 1E-4 B: ΔE/E < 5E-4 and ΔE/E < 1E-3 over days for all | 100% of energy spread tolerance |
| Energy Spread (1σ) | A & C: $\sigma_E$/E < 5E-5 for E>1GeV B: $\sigma_E$/E < 4E-4 | A & C: $\sigma_E$/E < 5E-5 for E>1GeV B: $\sigma_E$/E < 4E-4 | X |
| **Parameter** | **Nominal Value and Range** | **stability (during 8 hours) (note 1)** | **helicity correlated unbalance averaged over 1 hour** |
| Background (Beam halo) close to the target | A, B, C: < 1 E-4 outside of a 5 mm radius **(notes 3 & 4)** | any value within the nominal range | 100% of nominal halo tolerance |
| CW average current (Note: 5 & 6) | 1 μA < A < 120 μA 1 nA < B < 1 μA 1 μA < C < 120 μA A+C < 180 μA ; A + C < 800 KW A or C < 180 μA (single hall) | within +/- 5% of nominal value (includes high frequency fluctuations) | A < 200 ppm; B & C< 1000 ppm 3 Halls: excursions of 5 second samples up to 5 times the nominal value are acceptable. |
| Polarization (current range to be determined between physics and Accelerator Divisions) | > 70% all halls with currents up to 100 μA in A or C | polarization > 70% | X |

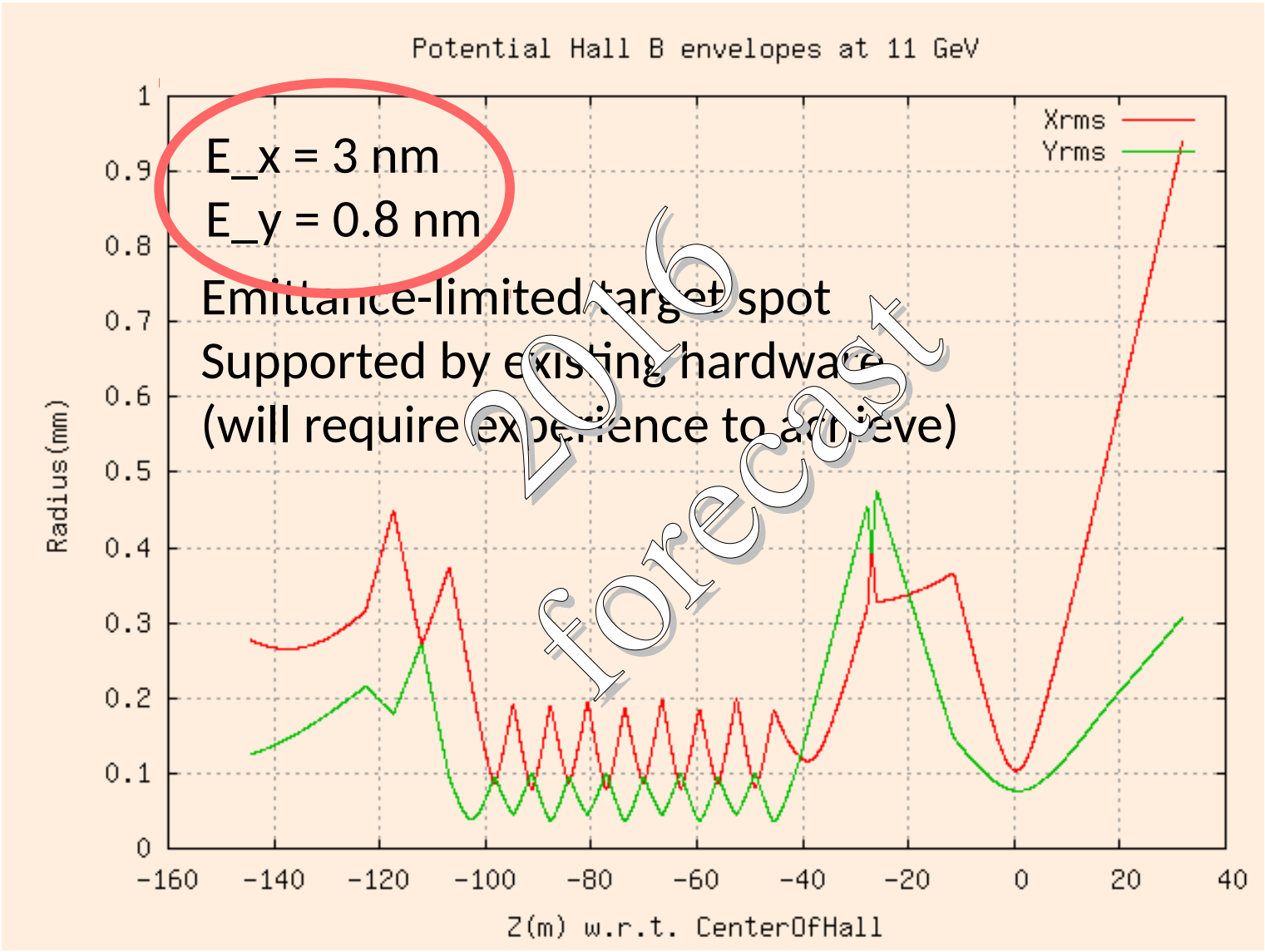
# 12 GeV Out-year Beam Requirements

| Hall | Emittance (nm-rad) | Energy Spread $\sigma$ (%) | Spot Size $\sigma$ ($\mu$m) | Halo |
|---|---|---|---|---|
| A | $\varepsilon_x < 10$<br>$\varepsilon_y < 5$ | <0.05<br>(12 GeV)<br><0.003<br>(2-4 GeV) | $\sigma_x < 400$<br>$\sigma_y < 200$<br>($\sigma_y < 100$)<br>(2-4 GeV) | $< 1 \times 10^{-4\dagger}$ |
| B | $\varepsilon_x < 10$<br>$\varepsilon_y < 10$ | <0.1 | $\sigma_x < 400$<br>$\sigma_y < 400$ | $< 2 \times 10^{-4\dagger}$ |
| C | $\varepsilon_x < 10$<br>$\varepsilon_y < 10$ | <0.05 | $\sigma_x < 500$<br>$\sigma_y < 500$ | $< 2 \times 10^{-4\dagger}$ |
| D | $\varepsilon_x < 50$<br>$\varepsilon_y < 10$ | <0.5 | At Radiator:<br>$\sigma_x < 1550$, $\sigma_y < 550$<br>At Collimator<br>$\sigma_x < 540$, $\sigma_y < 520$ | $< 1\%^{\ddagger}$ |

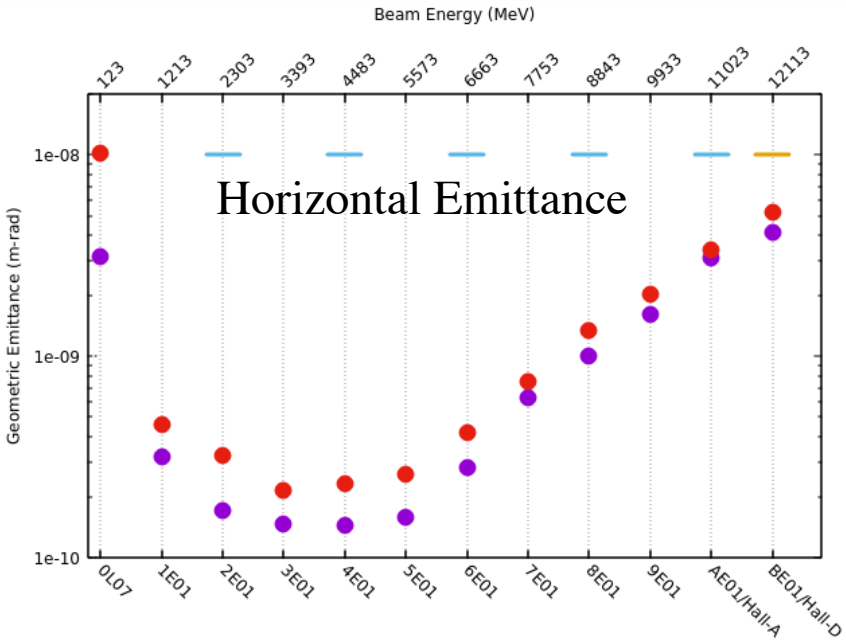
† Ratio of the integrated non-Gaussian tail to Gaussian core.

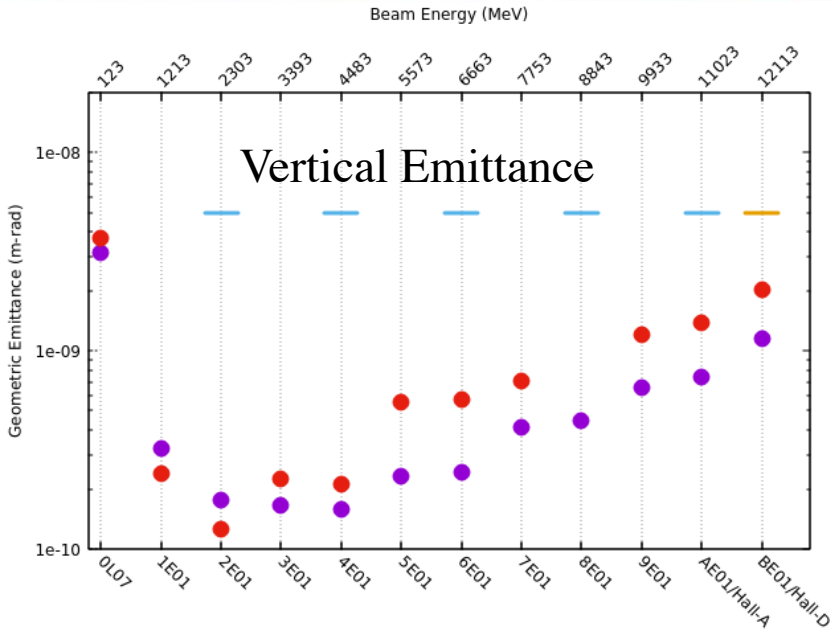
‡ Ratio of Halo background event rate to physics event rate.

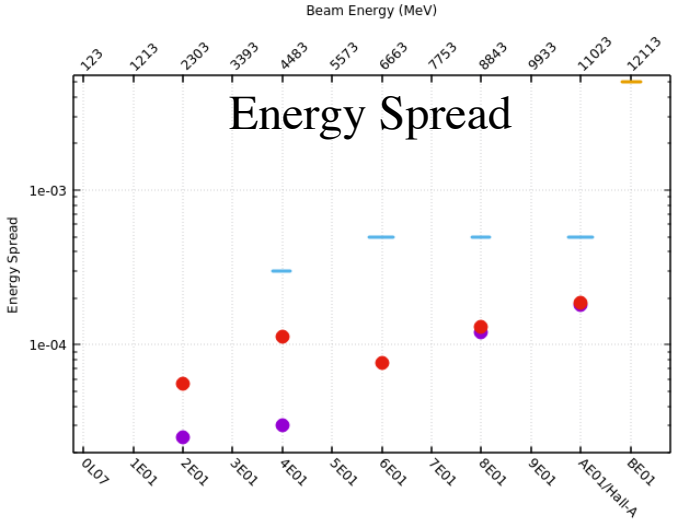
# Potential Hall B 11 GeV Beam Envelope

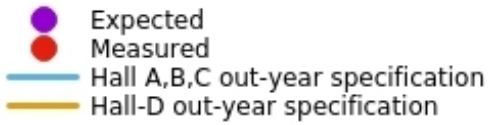


# Beam Parameters at 12 GeV (2.2 GeV/pass)




- Beam parameters at 12 GeV meet **out-year** specification.
- Growth in emittance/energy spread due to synchrotron radiation effects agrees well with expectations.

# Commissioning Request from HallB

| Parameter | Requirement | Unit |
|---|---|---|
| Energy (GeV) | 10.6, 6.4 & 2.2 | The 2.2 GeV, 1-pass, may not be needed if required measurements can be performed at 6.4 GeV |
| δp/p | $< 10^{-4}$ | Not possible at all energies, marginally feasible 4$^{th}$ pass |
| Current (nA) | 1 to 160 | The production running will be at ~ 75 nA |
| Current stability | <5% | for > 5 nA |
| σxy (μm) | < 300 | As measured by 2H01A harp Not presently allowed to be "required;" but is achievable |
| Position stability (μm) | < 100 | On 2H01 and 2H00 (> 30nA) BPMs with feedback |
| Divergence (μrad) | < 100 | Collective or microscopic? Any rasterization involved? |
| Beam Halo (> ±5σ) | $< 10^{-5}$ | As measured by 2H01A harp |
| Charge asymmetry | < 0.1% | Measured with SLM and halo rates, and controlled by hall |
| 60Hz harmonics | < 10% | of the total power, measured with SLM and halo rates |

# Input for Revised Beam Property Table

- Is it helpful to CLAS12 users to specify an energy-dependent beam radius? Or is a single value such as 300 microns adequate?
  - Reasonably easily achievable values range from ~80 microns in x and y below 6 GeV to 150-200 microns at 11 GeV
- What resolution is useful to you?
  - Asking for what you don't need wastes clock time
  - I would plot radius vs. energy and treat 6 GeV at 3-pass as not much different from 6 GeV at 5-pass (which won't occur often).
  - For experimental planning, ask about parameters you need that are somehow harder than table values
- Please let me know what is useful to you.

# Unscheduled Tuning: What? Why?

- Something goes wrong during beam delivery
- No system shows a fault
- Beam doesn't go where/how intended
  - Vacuum
  - Focusing/Bending/Steering magnets
  - Linac accelerating RF
  - Injector bunch formation RF
  - Cathode drive laser
  - Unrecognized drifts in other systems
- Beam-based diagnosis: time-consuming, inefficient
- Robust Q/A can help prevent lost time
  - Let's do that.

# DC Systems: Better Calibration

- Calibration of voltage read-backs
  - Voltage historically secondary to current
  - Accurate resistance measurement
  - Flags installation error and in-service faults
- Better system monitoring → early error detection
- Follow-on to previous system improvements
- Systematic measurement of magnet resistances
  - Noise alarm (flicker in readback)
  - Voltage tracking after establishing set point
  - Targeted at detection of in-situ degradation

# What Else Can Go Wrong?

- "Trim" magnet racks – mis-placed P/S cards
  - Yesterday a power supply card was found in an "empty" slot (very unusual)
  - An "unpowered" steering corrector was active
  - Adjacent correctors had been set to compensate
  - Invisible to the control system
  - Diligent hands-on examination uncovered it
- Degraded labeling contributes to wiring errors
  - Beam-based discovery is expensive
  - In situ inductance measurements can find most faults
  - Several miswired quads have been identified/fixed
  - Optics tools are being reworked to target point faults

# Summary

- **12 GeV Experimental program under way**
- **12 GeV beam milestones:**
  - Simultaneous 4-hall operation
  - Attainment of 900 kW beam power administrative limit
- Accelerator Operations continues to dial in 12 GeV performance
  - Combined effort with CASA, SRF, Engineering, Facilities
- CASA improving optics analysis, setup procedures, diagnostic tools
  - Fielding more effective beam-based optics characterization
  - Coordinating with DC Power to identify and correct magnet errors
- Availability Challenges Remain
  - New systems issues:  Box supplies, magnet buses
  - End-of-life issues: SRF Window failures, SC1 2K cold-box
  - Performance Plan being initiated
    - Critical spares shortages being addressed by procurements
    - End-of-life/obsolescence to be addressed by replacement
    - Initiating "C75" program to restore acceleration margin
    - Cavity reconditioning *in situ* to reduce field emission

# Supplemental Slides

Examples of rayTrace diagnostics for visualizing the beam and comparing against models

# Example: MQA2R09 wiring error

- Resistance (barely) within range
- Use rayTrace differential orbit data to diagnose
- Identified long-standing 15% focusing strength error

Fig. 1 [04/21/2017 16:21:56]

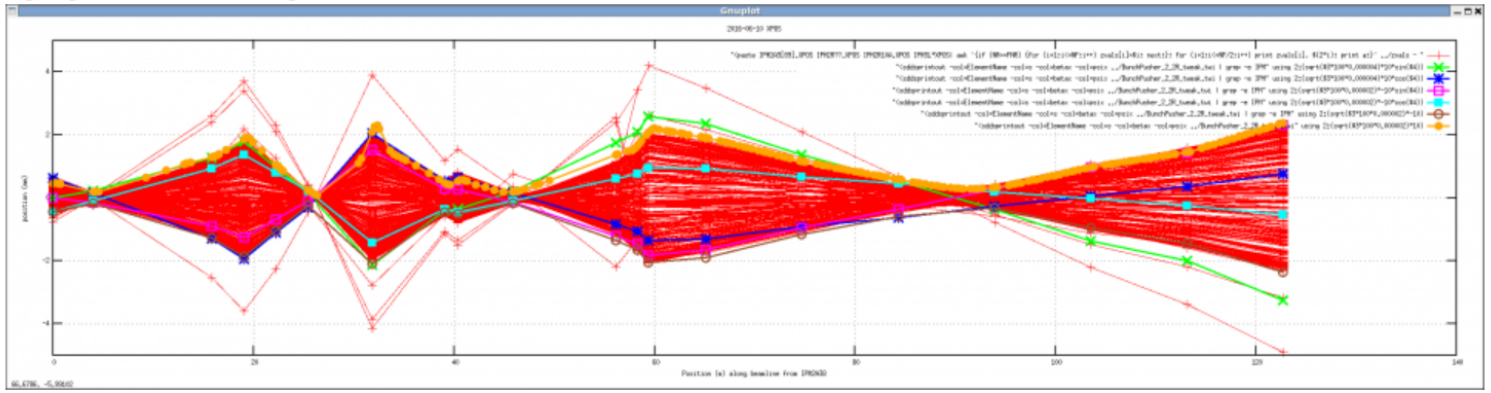
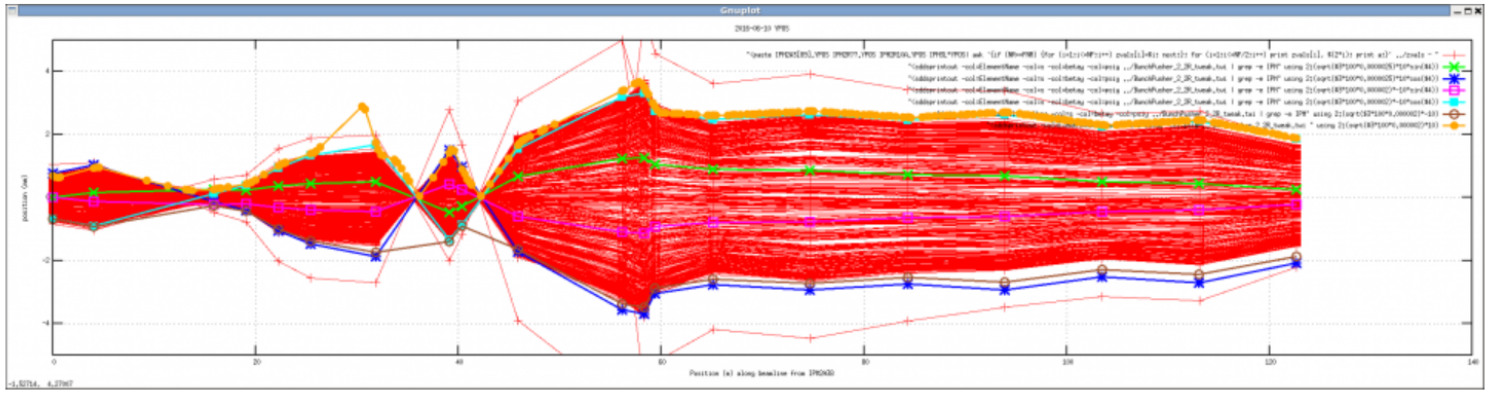


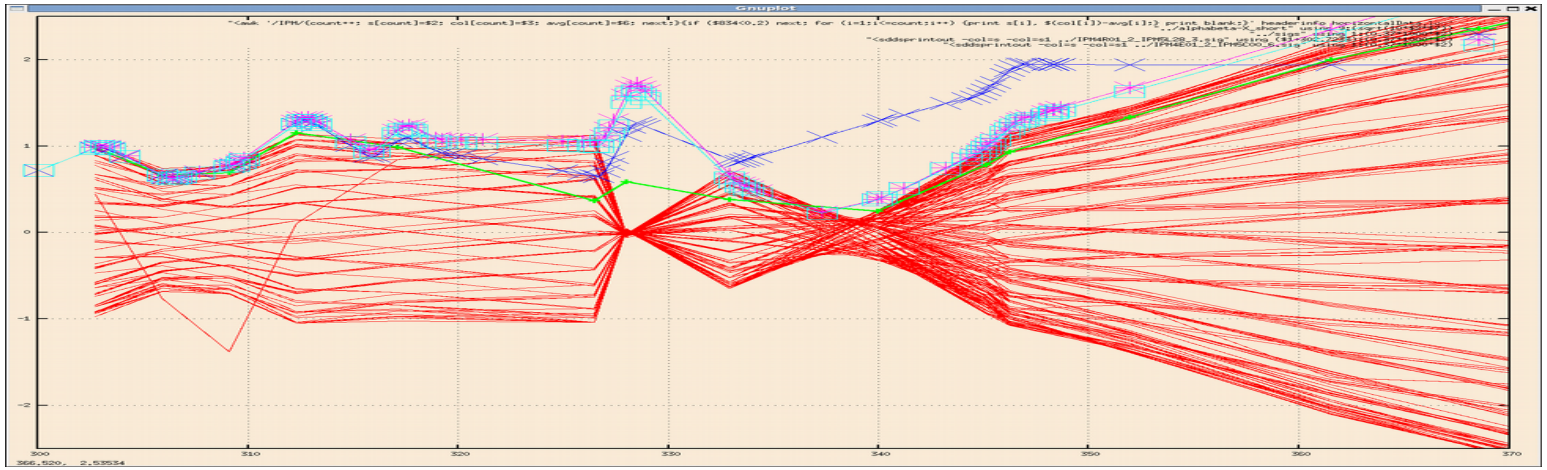
Fig. 2 [04/21/2017 16:22:02]



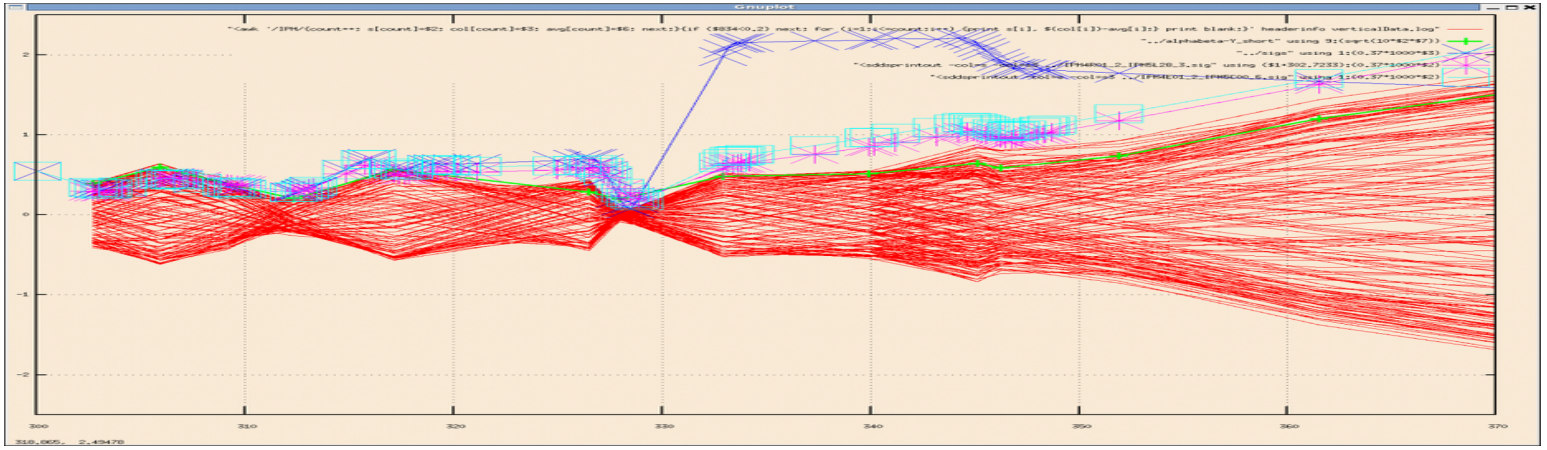
# Example: MQK4R08 wiring error

- Use rayTrace differential orbit data to diagnose
- Identified focusing strength error

Horizontal



Vertical



# Confirmed quadrupole wiring faults

- MQABT03 (Hall D line)
- MQA2R09 (West Recombiner at 2nd pass NL injection)
- MQK4R08
- MQA3S03
- MQA2T07
- MQK7R08A

# Reported Resistance of QA/QK Quads