LEReC Instrumentation Gun Test Beam Line Summary

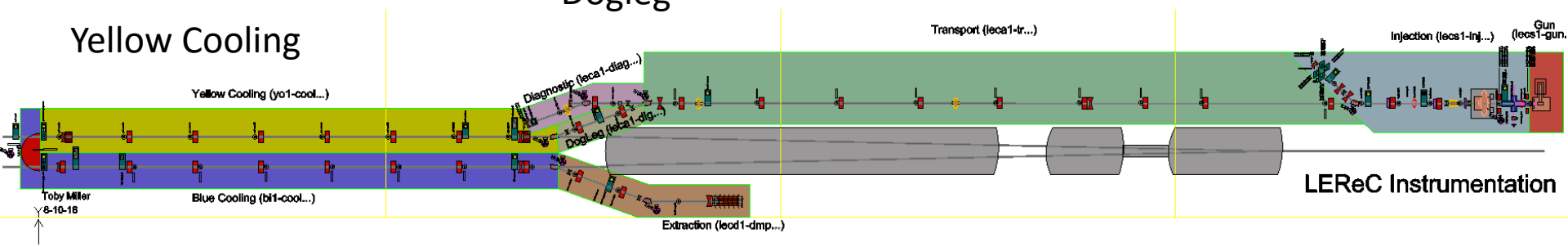
Toby Miller

8-18-16

Agenda

- Machine Sector Designations
- Emittance Multi-Slit Mask
  - Chamber impedance
- Cathode Imaging
  - Color camera development
  - Viewing via laser port limits color BW
- Postmortem data from BLMs and BPMs
  - Output from MPS required
  - Synchronizing using event link?
- NMR Probe & power supply
  - In-house PS development
  - Not for MPS
- Additional ICT
  - Available for Dump line (small aperture…)
- JLAB Collaboration
  - Agenda…
  - Date?

Machine Sector Designations



Yellow Cooling

Blue Cooling

Diagnostic

Dogleg

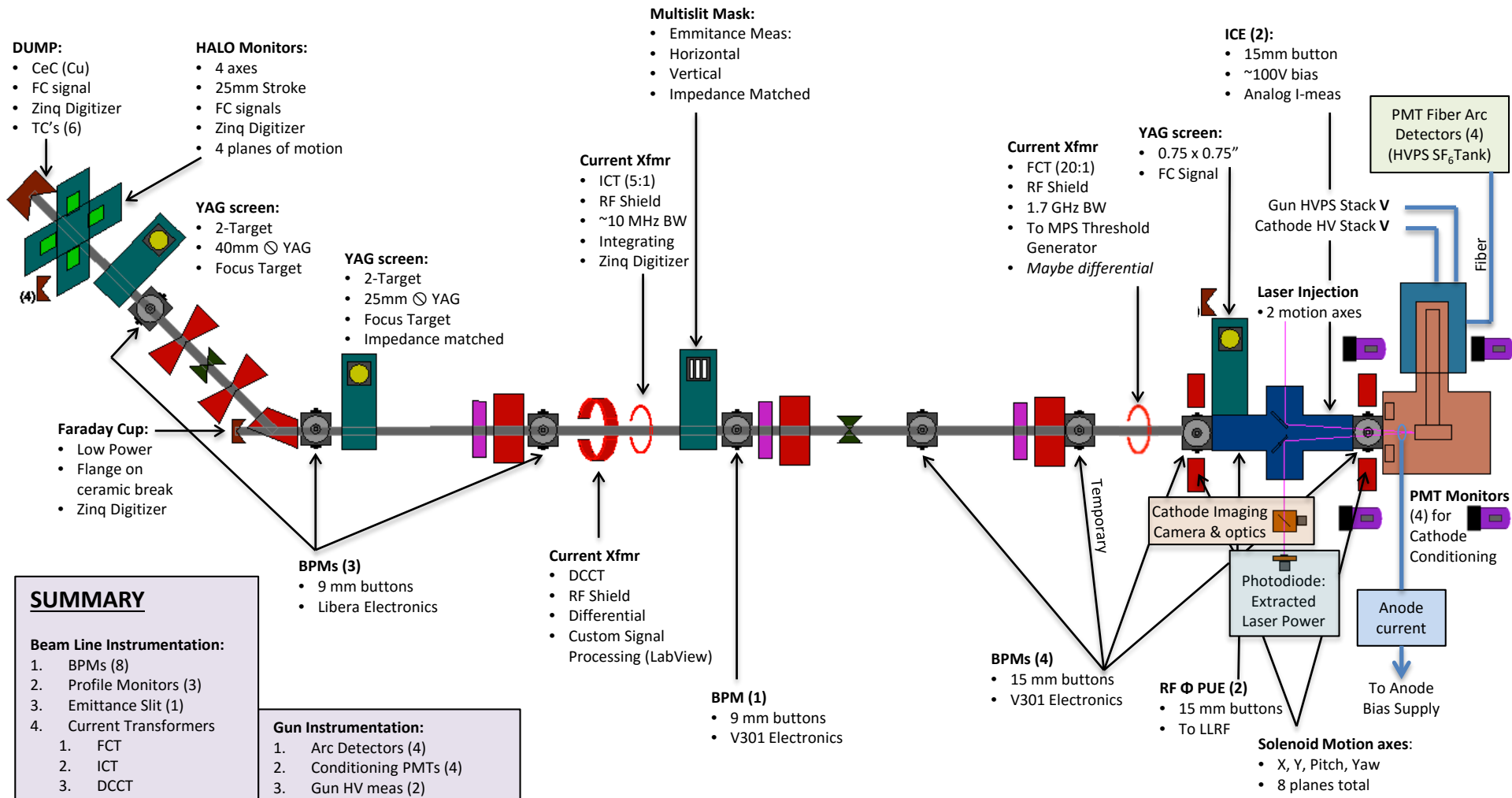
Extraction (Dump)

Transport

Injection

Gun

Gun Test Beam Line – 2016-17



SUMMARY

Beam Line Instrumentation:

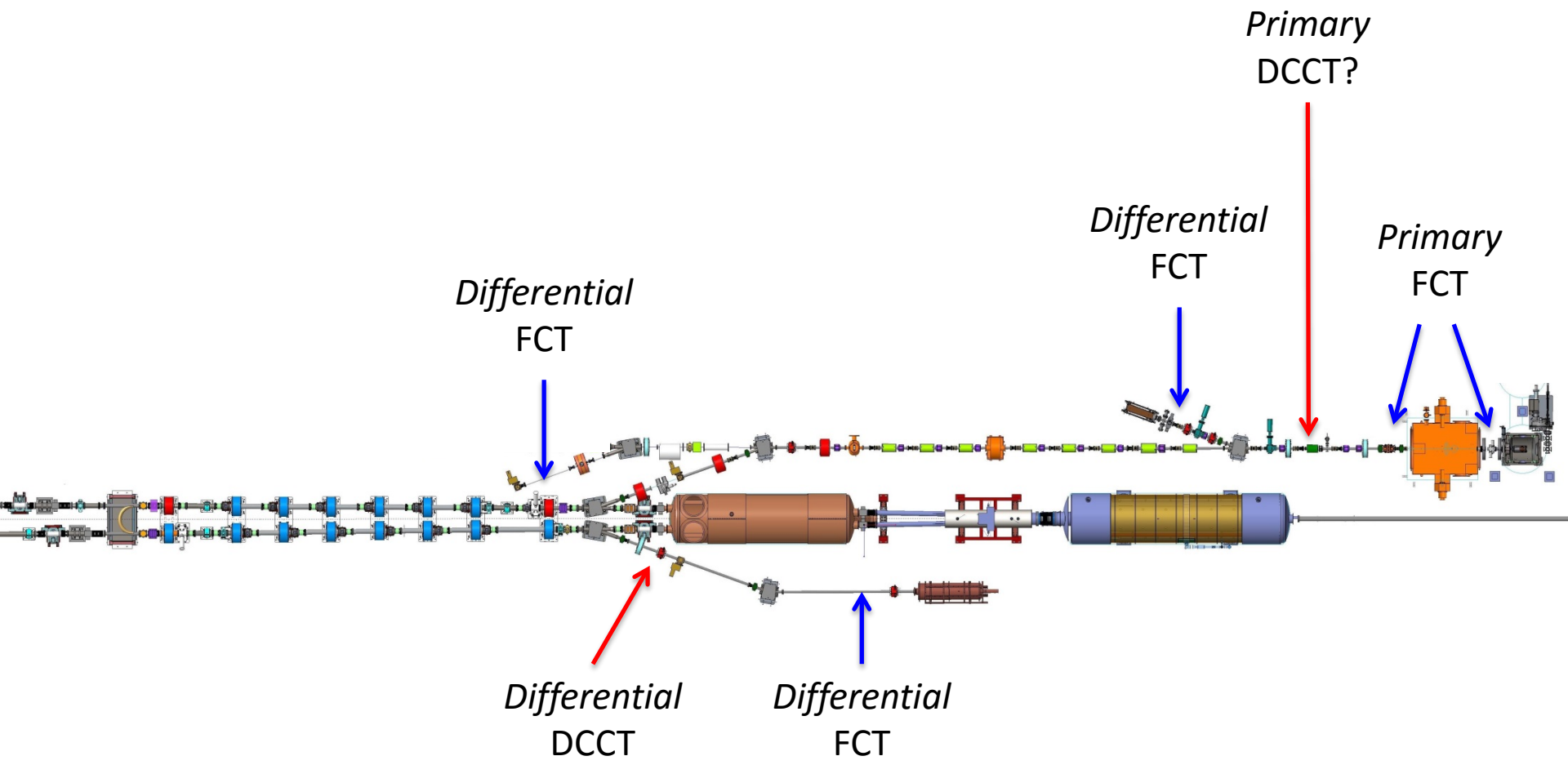
1. BPMs (8)
2. Profile Monitors (3)
3. Emittance Slit (1)
4. Current Transformers
   1. FCT
   2. ICT
   3. DCCT
5. Halo Monitors (4)
6. Faraday Cup Signals (7)
   1. PM
   2. Dump
   3. FC
   4. Halo (4)

Gun Instrumentation:

1. Arc Detectors (4)
2. Conditioning PMTs (4)
3. Gun HV meas (2)
4. Anode I meas
5. Ion Clearing I meas
6. Cathode Imaging
7. Solenoid Motion
8. Laser injection steering
9. Extracted Laser Power

BEAM LOSS MONITORS NOT SHOWN…

Current Transformers



FCT Details

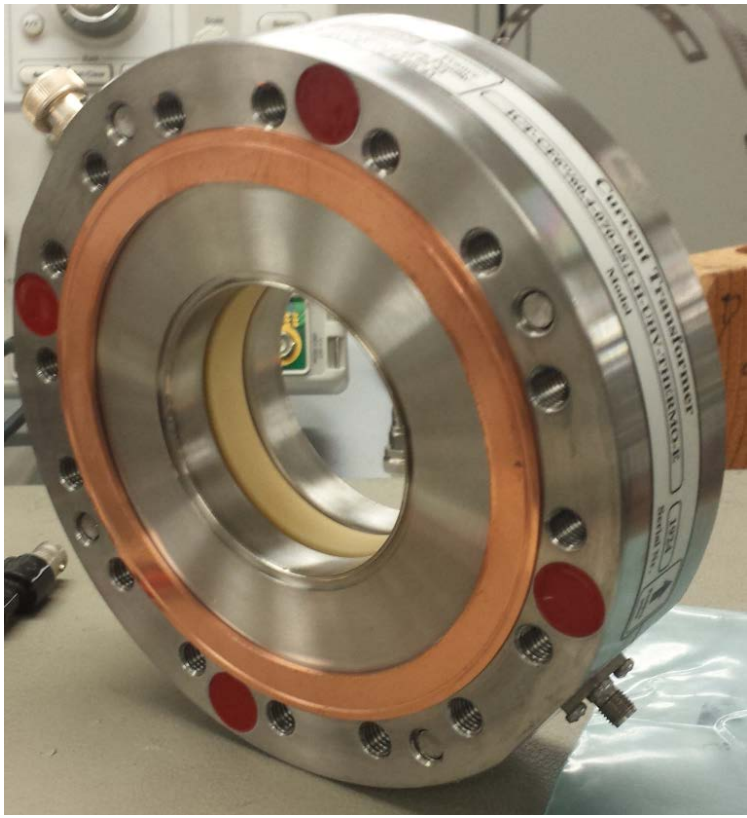
- **Fast Faraday Cup for MPS:**
  - 5.0 V/A Sensitivity (~4.0 V/A expected)
  - Tuned to 704MHz with Q=**5**
  - 6-3/4” CF flanges
  - ARB option: Slit shield
    - 3mm slit
- FCT’s
  - Dump:

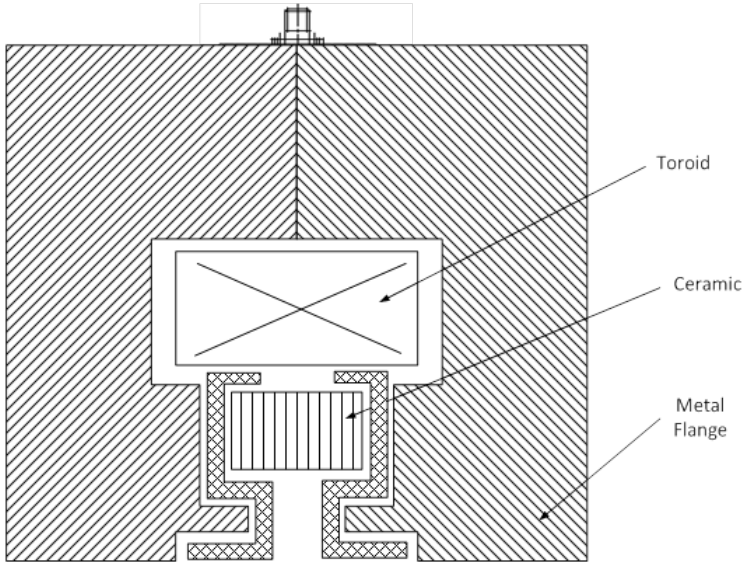
    FCT-CF6.75"-96.0-UHV-ARB#096

    (96mm aperture)
  - Injection:

    FCT-CF6.75"-96.0-UHV-ARB#060.4

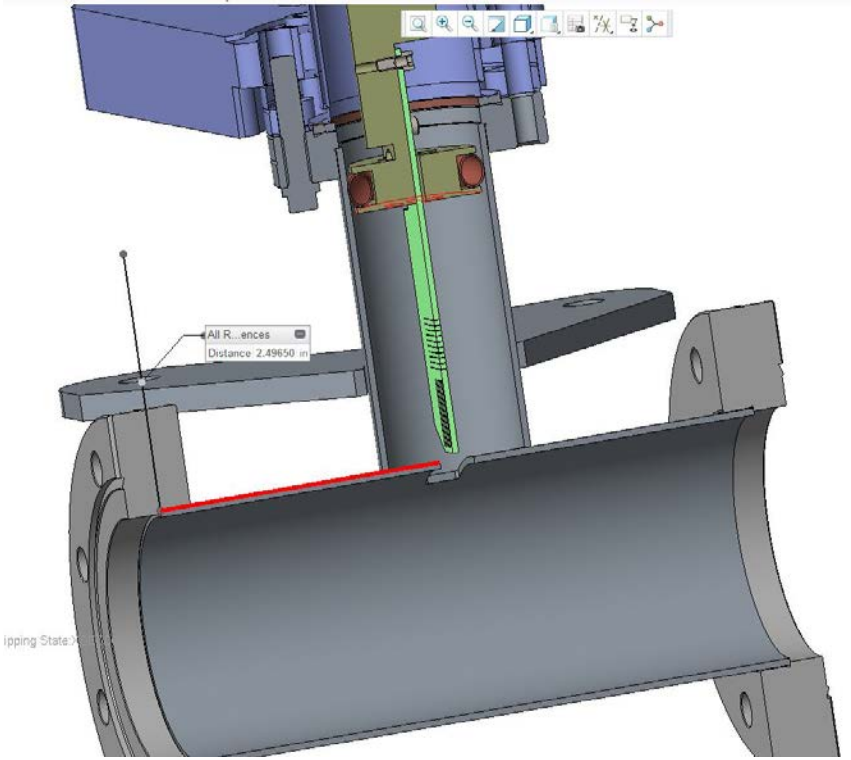
    (60.4mm aperture)

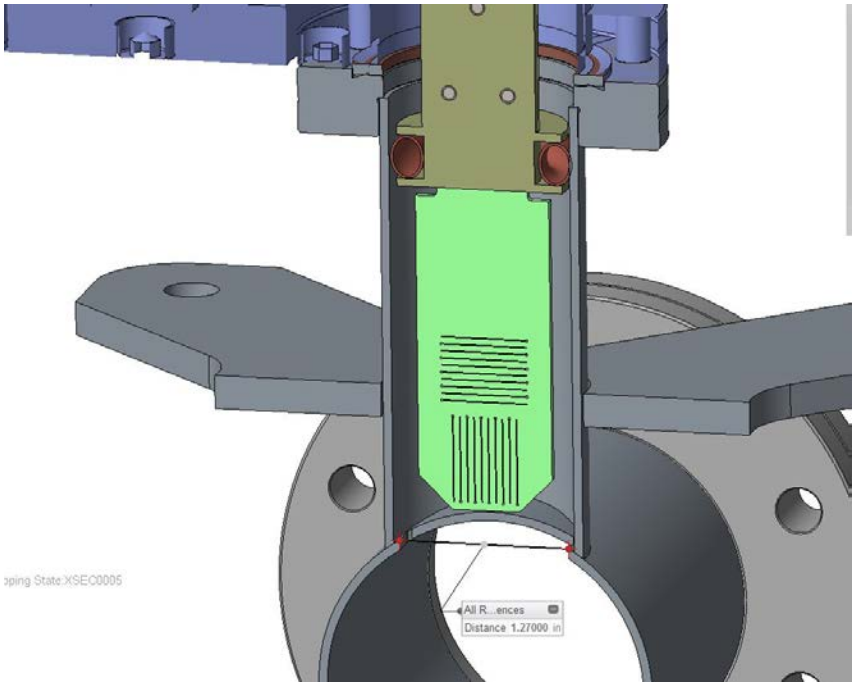




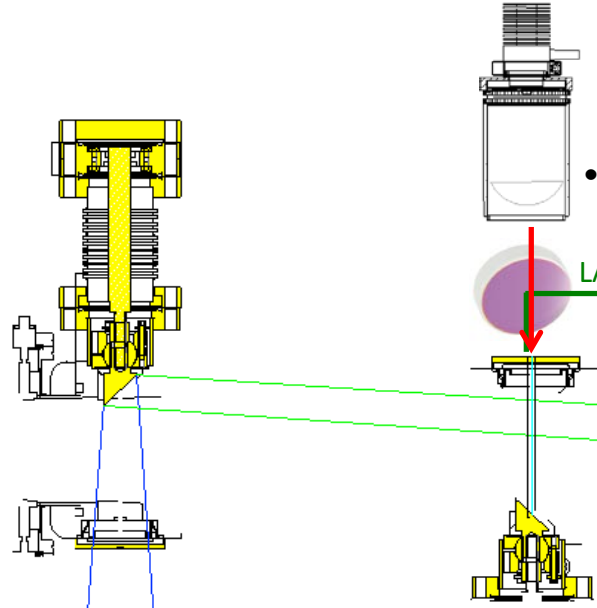
Emittance Multi-Slit Mask

- 3-position pneumatic acutator
- Dual H + V slits
  - 150 µm width
  - 1.35 mm spacing
- Low impedance chamber design
  - Single slit aperture
  - Simulation needed?



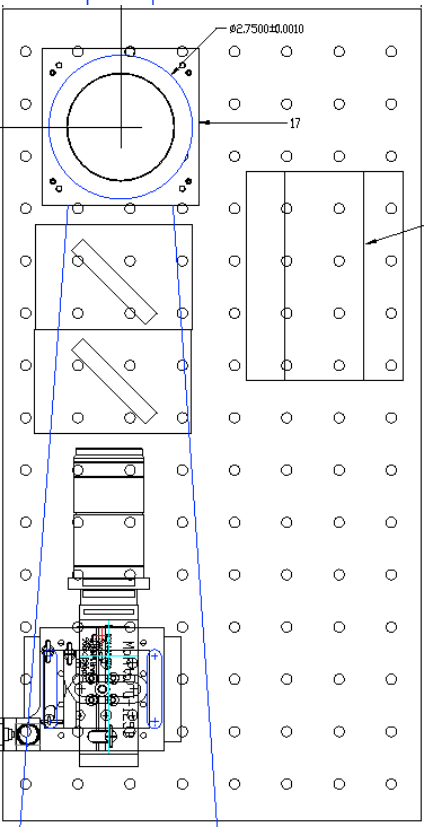


Cathode Imaging

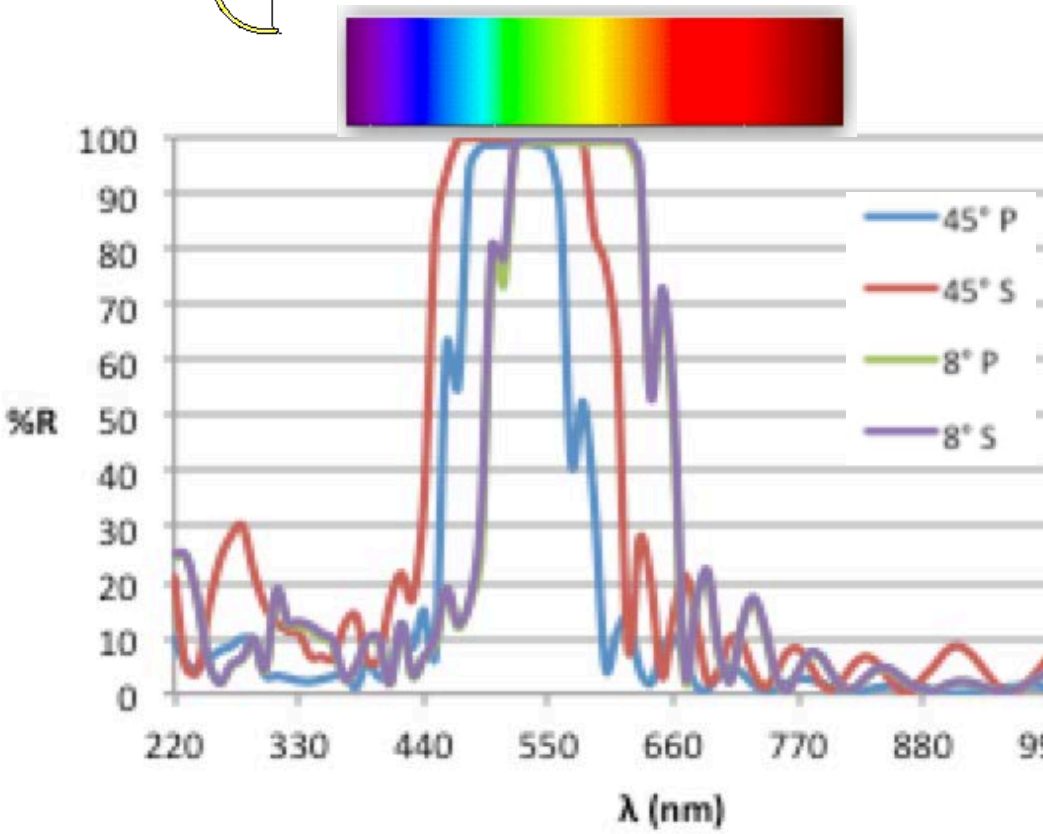


- Optics added to laser table.
  - Red LED spot light
  - Shine through laser mirror onto cathode.

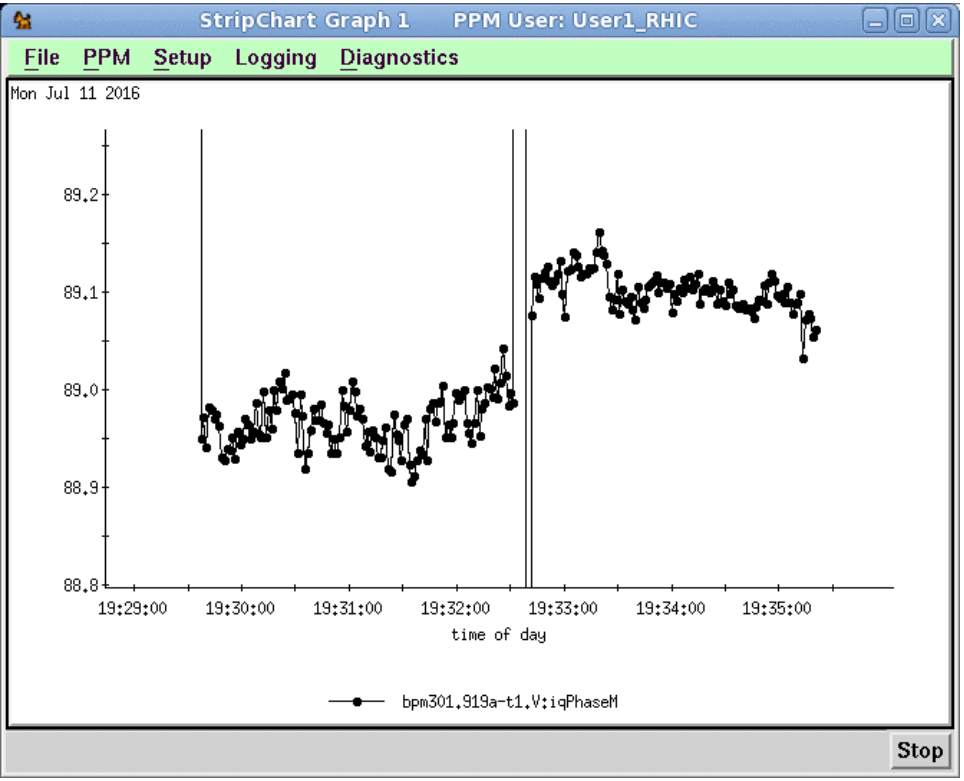
Dielectric Mirror,
524-532 nm, 0° to 45° AOI
ThorLabs NB1-K12

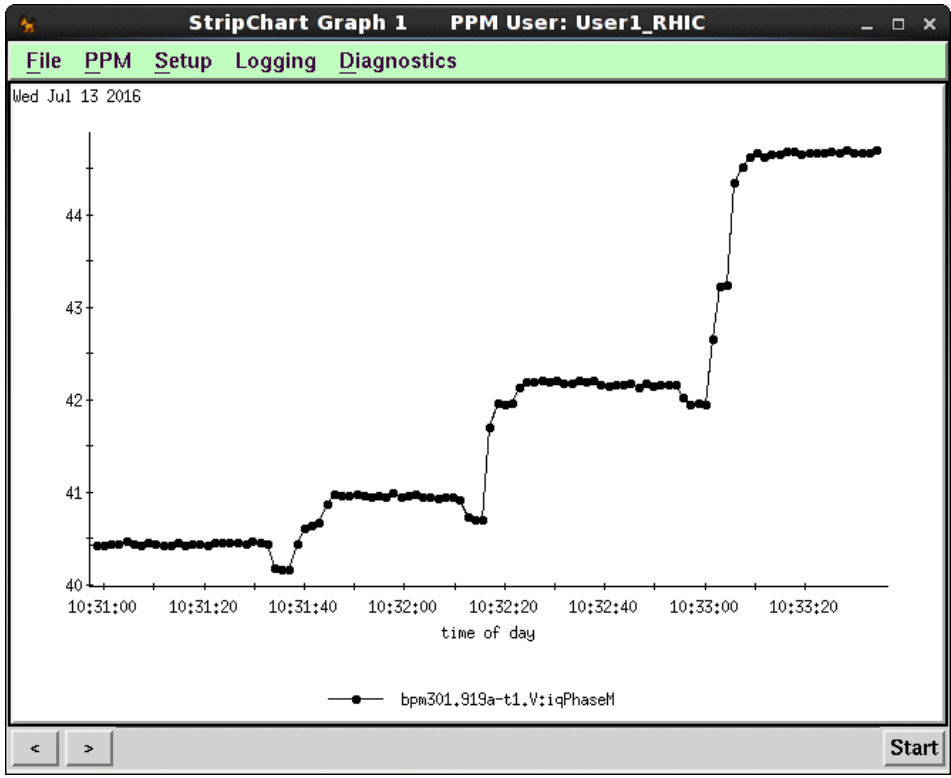


- Optics on laser outlet port.
  - Turning mirror
  - Power Meter
  - Dielectric mirror(s)
  - Camera



BPM Measurements

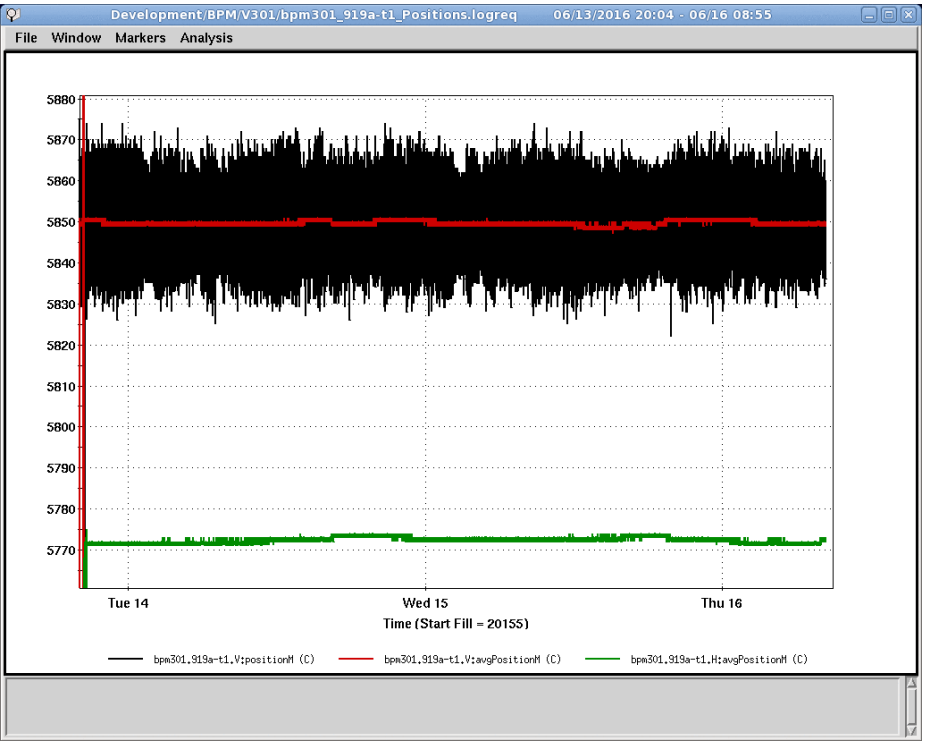


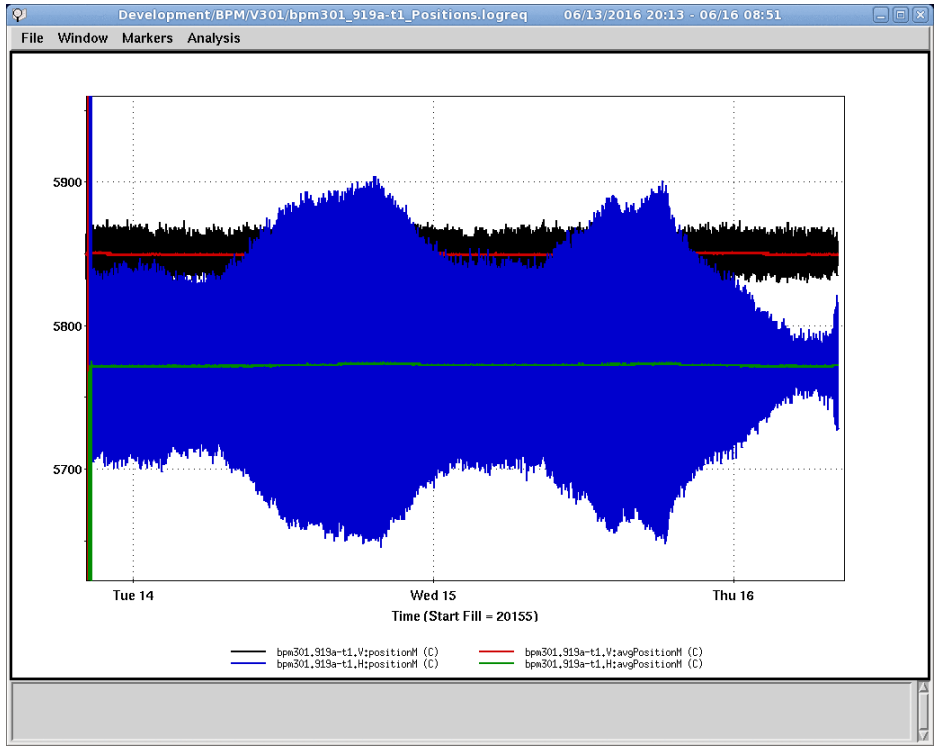


The average phase variations between two channels on a V301 with simulated beam signals appears to be on the order of 0.1 degree at 700MHz CW input. The step change at 19:32 reflects adjusting some of the VCO parameters (Icp), which seems to reduce the noise somewhat. This gives a rough idea of where the phase measurement noise floor will be.

Courtesy of Rob Hulsart

BPM Measurements

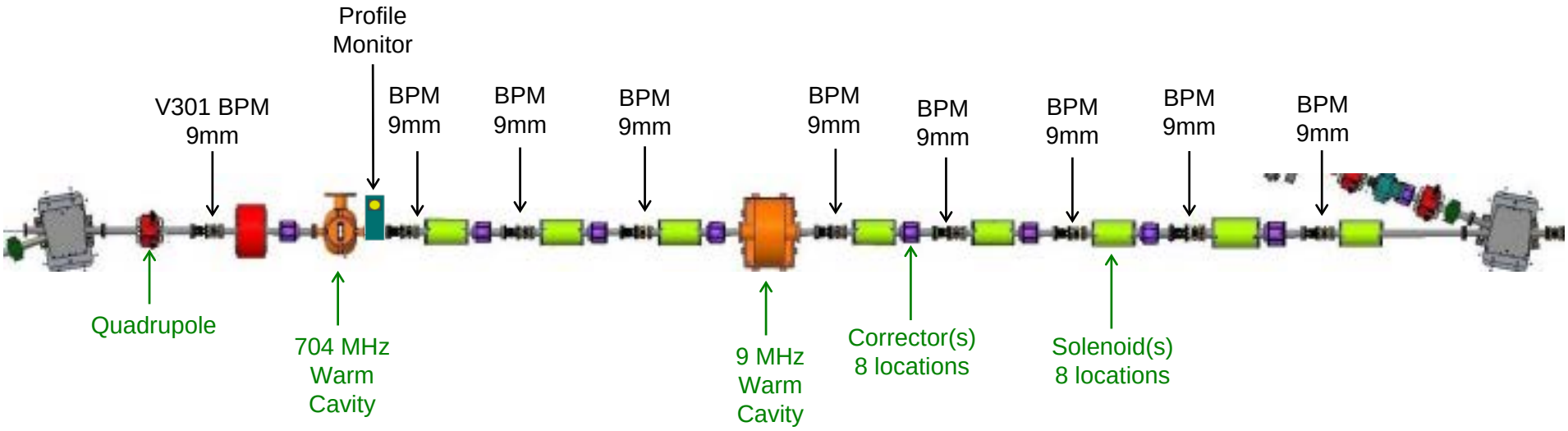




These pictures speak volumes for using the switch in fast-switching mode for position stability. Over more than 48 hours the average position varies by only a few microns. The V channels are measuring the 9MHz component of the macro-bunch of electrons, that shows little temperature dependence. The H channels use the 704MHz SAW filter and show a large variation. Following the upper or lower edge of the envelope shows what the position would have been doing with the cables in a fixed position. The average however is highly stable. The V301 is open to room air, but the switch board and splitter are in the TEC chamber.

Courtesy of Rob Hulsart

Scope: Transport



e-Beam Transport

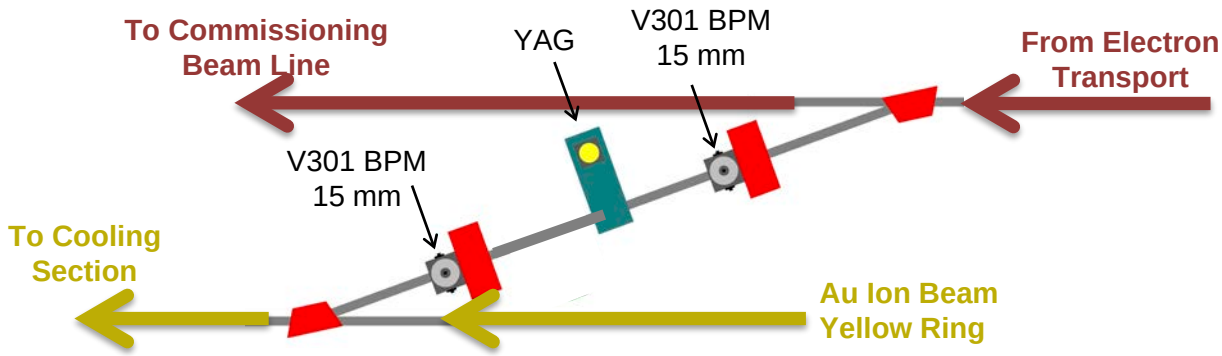
BPM = 9 (9mm)
YAG = 1

1 x V301 module
8 x Libera Single Pass Units

Axes of Motion = 2 (1 / RF cavity)

Ref drawing No. 3015M0134 "LEReC Transport, Merger & Extraction"

Merger Beam Line



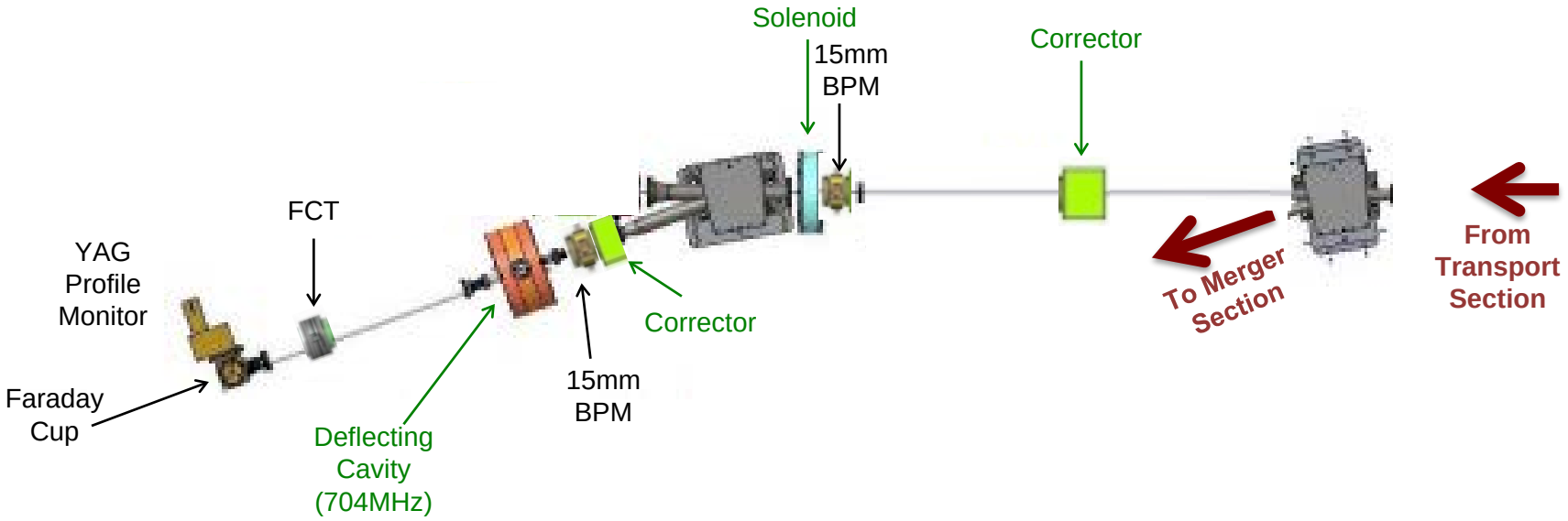
e-Beam Transport

BPM = 2 (9mm) 2 x V301 modules

YAG = 1

Ref drawing No. 3015M0134 "LEReC Transport, Merger & Extraction"

Commissioning Beam Line - Final



Instrument Count

YAG = 1

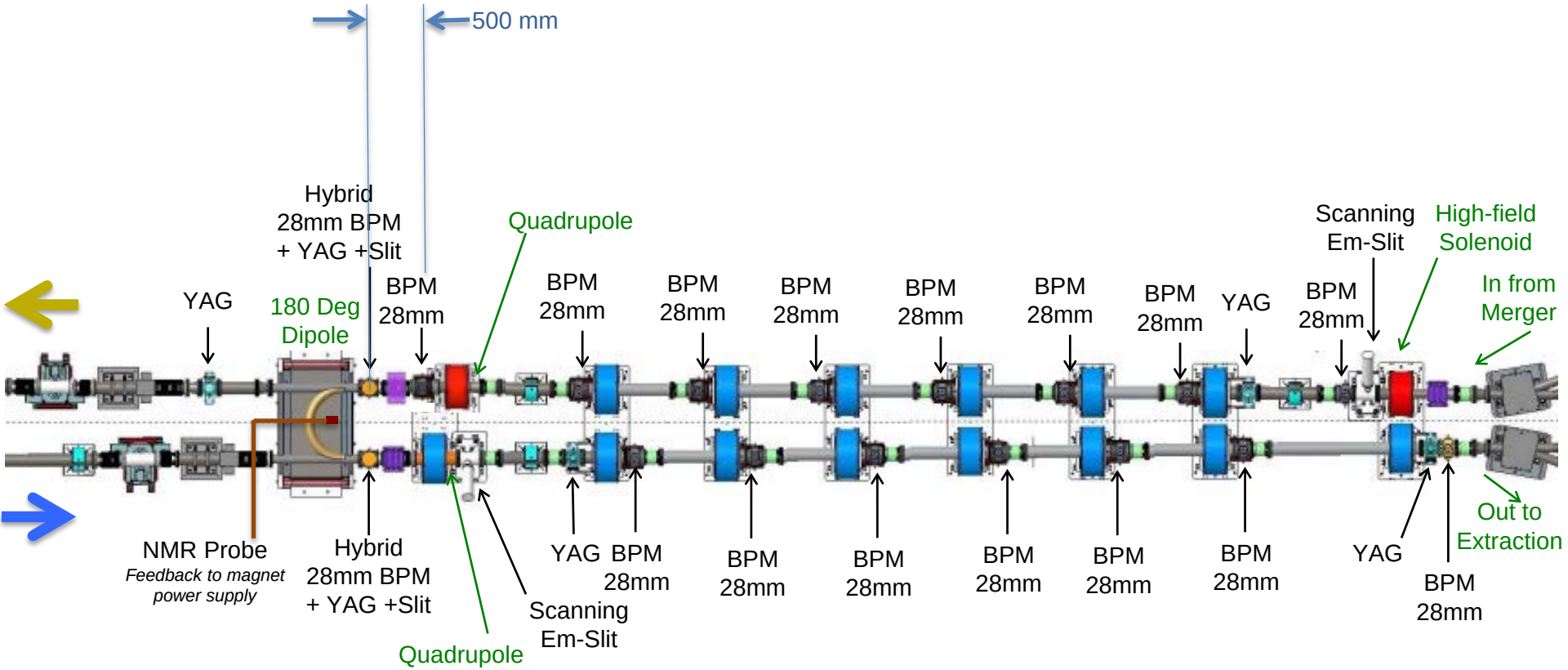
Faraday Cup = 1

BPM = 2 (+1 in transport) 2 x Libera Single Pass Units

Correctors = 2 (+1 in transport)

Ref drawing No. 3015M0137 "LEReC Diagnostic Beam Line"

Scope: Cooling Sections



Cooling Sections

BPM = 17 (28mm; 15 dual plane chambers) *Purchased 18, 14 installed as of 3-17-16*

YAG = 6

Scanning Em-Slit = 2

Energy Spread Slit = 1

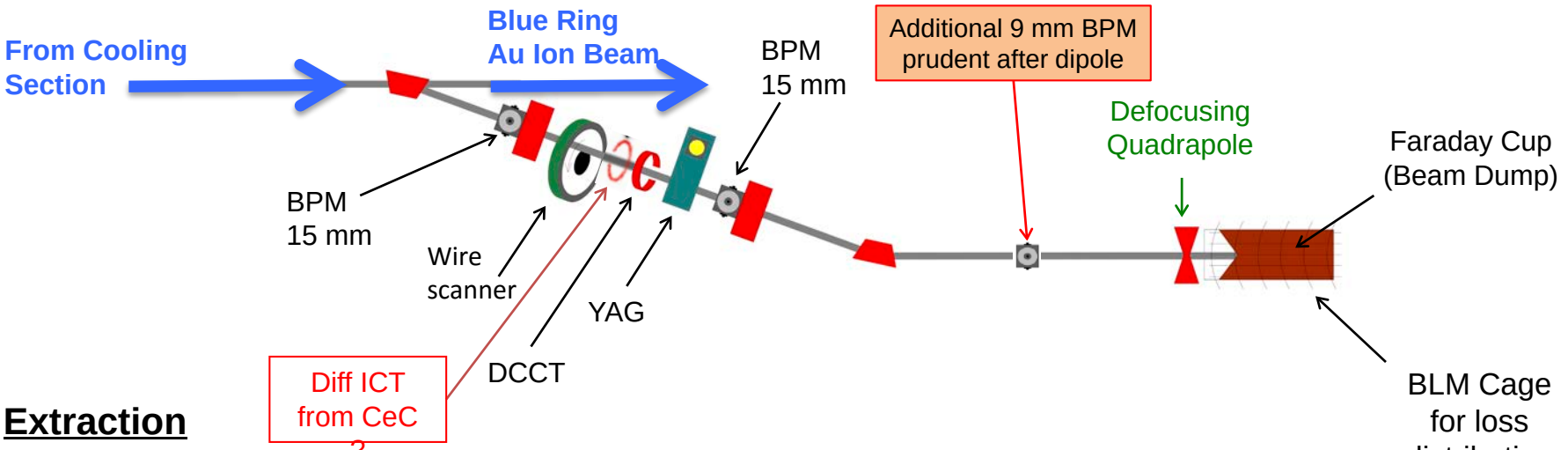
Axes of Motion = 2 (for scanning Em-Slits)

NMR Probe = 1

17 x V301 modules for electrons
17 x v301 modules for ions
34 x V301 modules in total

Ref drawing No. 3015M0133 "LEReC Cooling"

Scope: Extraction



Extraction

- BPM = 3 (9mm; incl. new one after dipole)
- YAG = 1
- DCCT = 1
- Faraday Cup = 1
- Wire scanner = 1

3 x Libera Single Pass Units

Dump beam line design not yet finalized

Ref drawing No. 3015M0134 "LEReC Transport, Merger & Extraction"

16 Loss Monitors Locations

- One set of BLMs at 8 locations:
  - Near 7 bending magnets
  - the entrance to the SRF Booster.
  - Each location: PMT, Ion Chamber, PIN Diode
- Spread remaining 8 PMTs in between these specified locations
- Single side or on both sides?
  - For the 1.5 MeV cases the 90 degree to 0 degree ratios are roughly ~42% and `16% respectively.
  - A guestimate for us is ~~30%. But that doesn't really matter very much because our long detectors will cover wide angular ranges for any impact point.
  - While it doesn't matter much on which side the detector is located, putting it on the top or bottom would provide equal detection efficiencies for left and right impacts.

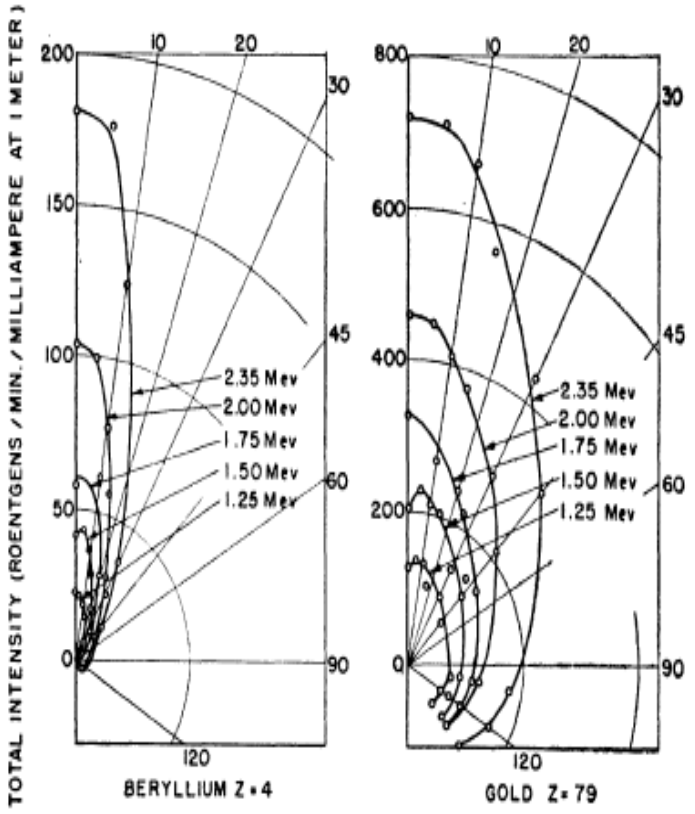


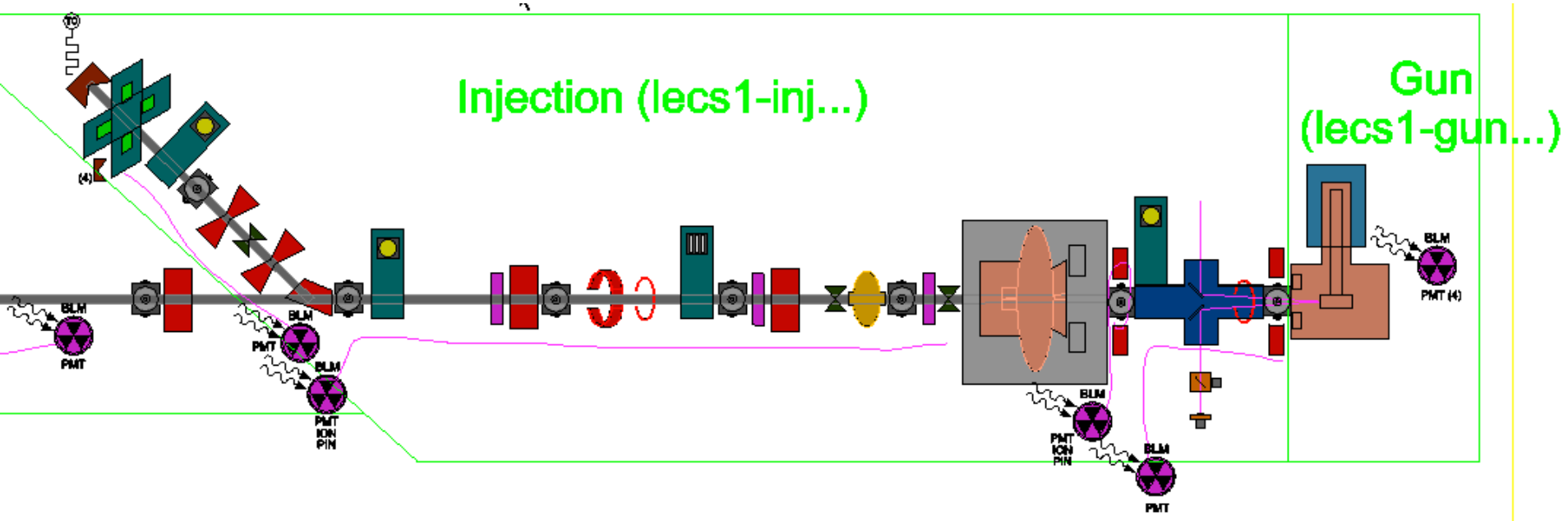
FIG. 27. Angular dependence of the thick-target bremsstrahlung intensity integrated over photon energy for 1.25- to 2.35-Mev electrons. These results were obtained by Buechner, Van de Graaff, Burrill, and Sperduto[43] and include corrections for the target.

Courtesy of P. Thieberger

PMT BLM Specs

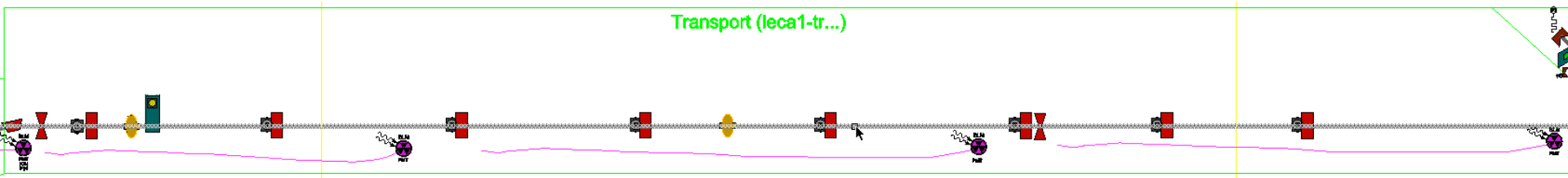
- PRIMARY Machine Protection Input
- Goal of 10µs response time
- Logged data /1s for Integrated & Sum signals
- 650ms post mortem data saved on Beam Loss
  - (upgradeable to 10 sec)
- Correlation with other systems?
  - What timing is necessary for correlation
  - BPMs?
    - Should BPMs save post mortem data on Beam Loss?

BLMs in Injection

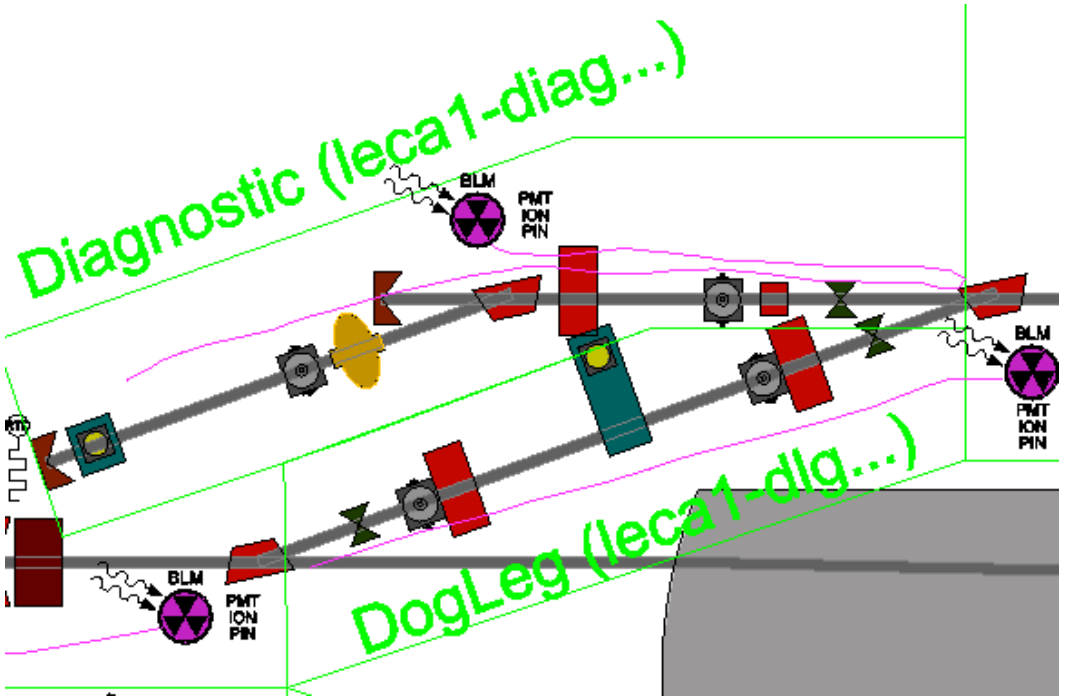


- 2 Groups of:
  - PMT
  - Ion Chamber
  - PIN Diode
- 2 Long Fiber PMTs (*only*)
- 4 PMTs for HV conditioning

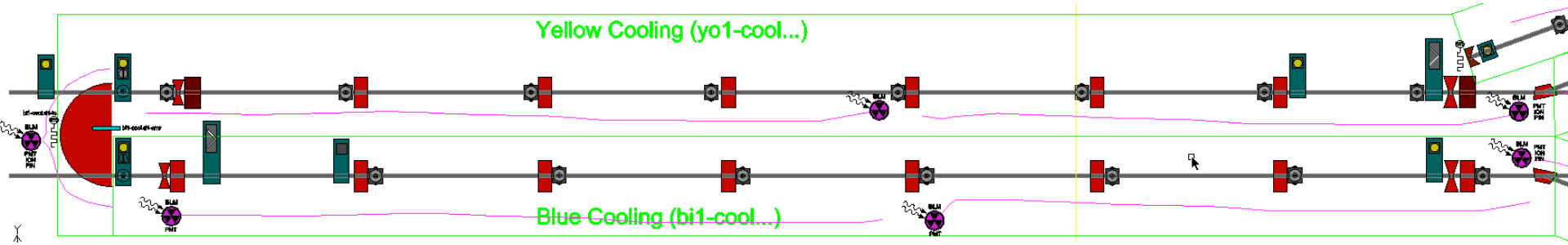
BLMs in Transport, Merger & RF Diag.

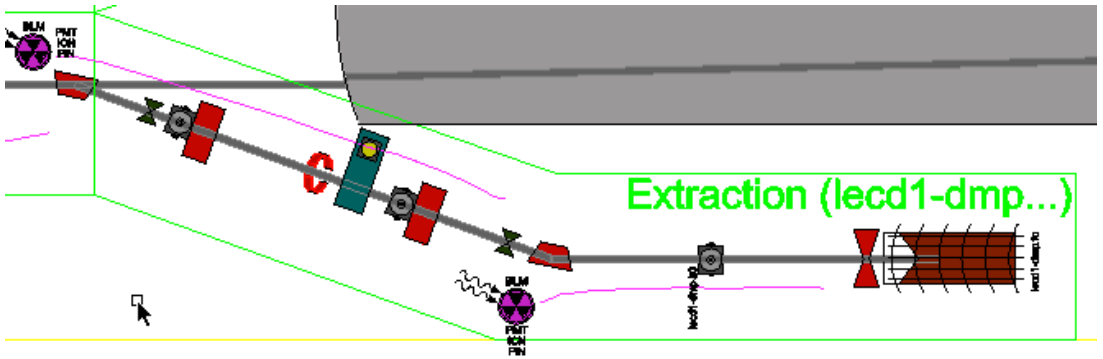


- 2 Groups of:
  - PMT
  - Ion Chamber
  - PIN Diode
- 3 Long Fiber PMTs (*only*)



BLMs in Cooling & Dump





- 4 Groups of:
  - PMT
  - Ion Chamber
  - PIN Diode
- 3 Long Fiber PMTs (*only*)

Instrumentation Details

- **Gun Current Monitor**
  - Stand alone digitizer monitoring a shunt resistor on top of the gun HVPS inside the SF6 tank.
  - This will be used during processing only
    - Q/ Will the shunt resistor might be removed afterwards?
  - Uses a power over fiber link to remotely power the unit.
    - Waiting on comments from Laser Safety Officer on use of the device… specs sent by email on 4/22/16.
  - Mike Costanzo is leading the entire implementation of this device.
- **PMT Arc Detectors**
  - PMTs installed in the SF6 tank by Cornell were used to detect arcs during HVPS conditioning and operation
  - We plan to move them outside of the SF6 and relay their sensitivity with fibers into the SF6. Fiber feedthroughs will be used instead of trying to find SHV feedthroughs.
  - ACTION: We still need to identify a proper light collecting end for the fibers. The plan is to check how the RF arc detectors work.
- **Gun HVPS SF6 Tank Fiber Temperature Sensors**
  - Suggested to have Cornell install these – prudent for LEReC's operational status
  - Need confirmation from Joe T/ Cornell of the status
  - Q/ what type of controls interface required?
- **Gun HVPS Differential Water Flow**
  - Required to guard against a water leak in the SF6 tank!
  - Specs to be given to the water group….
- **HVPS Stack Voltage**
  - Voltage divider signal to O-scope
  - Q/ Should we log continuously?
  - With what resolution?
- **Cathode HV Stack Voltage**
  - Voltage divider signal to O-scope
  - Q/ Should we log continuously?
  - With what resolution?

Instrumentation Details

- **Anode bias & current**
  - Keithley 6514 Electrometer with bias supply “on top”
  - bias Tee for monitoring fast transients on O-scope
  - 10’s of pA (+) for ion current during operation
  - 10’s of nA (-) for emission during conditioning
  - Q/ Type of low loss cable… maybe Heliax… something else?
  - Don searching for suitable power supply (likely a Spellman)
- **Cathode Imaging**
  - Camera on laser extraction port
  - Need to separate specular reflected beam from image of diffuse reflection of beam off the cathode. No perfect solution yet…
    - Laser mirror too small for off-axis imaging….
  - Projected illumination through dichroic mirror on incoming optics table
    - Need to coordinate with Zhi
  - Photodiode to measure extracted laser power
  - Fast gated color camera
    - Imperex B1610
    - Low trigger jitter, 5usec min shutter
  - Plan to borrorow spare laser mirror and polished blank cathode puck for optics mock-up
    - Need to confirm availability of blank puck
- **Laser controls & Instrumentation**
  - Q/ how many cameras?
  - Q/ how many servo devices?
  - Q/ how many photodiodes or other detctors?
  - Laser average power electronics for MPS
    - LPF + Integrator
    - *Alternative fast pulse counter*
    - Matt P. working on electronics design

Instrumentation Details

- **Gun Profile Monitor**
  - B 1610 fast gated monochrome camera
  - 0.75x.075” YAG crystal
  - Faraday Cup Signal from SS mirror
    - Zinq digitizer
- **Motion (14 planes)**
  - Solenoids motion – 2 x 4 planes
    - X. Y, Pitch, Yaw
    - Resolvers?
    - Need Status…
  - Booster Cavity – single plane
  - 2.1 GHz Cavity – single plane
  - Halo Monitors 4 x single planes
- **Laser Mirror Motion**
  - X, Y
  - Q/ has controller & actuator been chosen?
- **Ion Clearing Electrodes (2)**
  - 100V – $1kV_{max}$ Negative DC power supply (~100uA)
  - need to monitor analog voltage & current
  - bias Tee for monitoring fast transients on O-scope
- **RF Phase PUE (2)**
  - 15mm buttons with 2 Heliax cables to LLRF

Instrumentation Details

- **BPMs**
  - 8 BPMs total
  - Two button sizes (9 & 15mm) and two electronics types

BPM #	Button	Electronics	
1	15 mm	V301	
2	15 mm	V301	
3	15 mm	V301	*Temporary*
4	15 mm	V301	
5	9 mm	V301	
6	9 mm	Libera	
7	9 mm	Libera	
8	9 mm	Libera	

  - Need phase measurement for Time of Flight energy measurement
  - Plan to test in-tunnel amplifiers with cable switches
  - All electronics, buttons & chambers are on order

Instrumentation Details

- **FCT**
  - 1.7GHz BW, 20:1 ratio
  - study to determine in-flange version ($$$) or we build our own clamshell + ceramic break
  - Karim Hamdi, Matt Paniccia
  - For use with MPS for Beam Mode / Machine Mode Protection Scheme
  - Buffer needed for parallel signal on scope
  - Do we need pulse mode differential current protection?
    - Would need 2 or 3 more FCTs – one at each dump…
- **ICT**
  - 5:1 ratio, from ERL
  - used with Zinq digitizer
  - Buffer needed for parallel signal on scope
  - no longer limited to 7us
  - BW limited to ~10MHz (macrobunch mode only)
  - Shield designed – needs fabrication
- **DCCT**
  - Two from ERL
  - 100 kHz BW
  - 1 – 5 uA sensitivity with 1 second averaging
  - Needs continued development of electronics for diff. mode
  - Buffer needed for parallel signal on scope

Instrumentation Details

- **Emittance Slit**
  - Design not begun yet – beginning mid July (Gary W., Dan Weiss)
  - Dual plane Multi Slit mask (H + V)
  - 3 position pneumatic cylinder needed
  - Impedance matched chamber
- **ERL style Profile Monitor**
  - PM in transport
    - Increased YAG to 25mm aperture
    - Impedance matched chamber modifications
    - New parts fab in July – assembly in August
  - PM in Diag. Dump
    - 40mm YAG aperture
    - not impedance matched
    - assembly & survey underway
- **Faraday Cups (3)**
  - Gun PM, Diag. Dump, Transport Flange
  - Processed by Zinq digitizer
  - No bias *but* bias cables being pulled
  - Buffer needed for parallel signal on scope
- **Temperature Monitoring**
  - Diag. Dump (2)
  - Upstream beam pipe (4)

Notes from this meeting (8/18/16)

- Synchronization of post mortem data from BLMs and BPMs was suggested to be made via the event link. Due to a shortage of to 1004B, it was suggested to use the local event like in 1002A for this.
- The necessity for cathode imaging in color was questioned as the level of effort for controls integration is significant.
  - Damage to the cathode surface will alter its color and reflective properties. Imaging this can provide useful information pertaining to the cathode's failure mode.
  - So far, only viewing & saving of the color images is expected.
  - Full color imaging of the LEReC cathode is compromised by the need to image through laser mirrors in order to share the laser IN/OUT ports. This limits the imaging to the reds and blues only!
  - A dedicated viewport and fixed mirror would be required for full color imaging of the cathode.
- BPM post mortem data will only be available from V301's. This may require redistributing the Libera units to have a more distributed post mortem data. Currently, 8 of the 9 transport line BPMs are covered by Libera units.
- High Power Dump line optics are under development.
  - A suitable minimum beam size will be possible to squeeze through the limited aperture of 1.8" through the DCCT (& possible 2nd ICT). The FCT will have a standard 2.37" aperture.
  - It was proposed to move the transformers to the straight just after the last dipole. The profile monitor has a larger aperture and can sit downstream of the transformers.
  - Space should be left in the dogleg for the eventual beam scanning online profile monitor or a much more compact wire scanner.
- PMT BLMs shall use scintillating fibers for increased range & sensitivity
  - Need to review rad-hardness of the plastic fibers
  - Choose fiber diameter: large for sensitivity but small for flexibility… need to find a compromise.

Notes from previous (8-4-16) Meeting

- FCT's
  - Several tuning options were proposed by Bergoz for the narrow BW FCTs.
  - We decided that a larger BW with lower Q, here 637 - 774 MHz was the optimal case for our application.
    - Decided to take Q=5
  - Can this still be usefull with a large factor down in bunch charge? This depends on signal to noise ratio...
    - We can add a bandpass filter in the electroncis
    - May use local amplifiers if noise issue is too great.
  - Although the FCT will not resolve individual bunches, it's high frequency response is necessary to respond to 704MHz CW where the ICT cannot.
  - The new –ARB option on the FCT provided for a narrow 1mm gap in metal under the ceramic break.
    - This alleviates the need for a shield and a coating on the ceramic.
    - This does require a larger FCT to accommodate the metal beneath the ceramic
    - and increases the FCT's length form 40mm to 50mm.
    - The requires ~$6K adder to the price but allows for precalibration and frequency response testing at the factory.
    - All agreed to include this option on all 4 FCTs
- BPM Phase Measurements
  - Recent testing shows that average phase variations between two channels on a V301 with simulated beam signals appears to be on the order of 0.1 degree at 700MHz CW input (averaging over 1 minute).
  - Plan to use 100MHz RF clock to all modules
  - One 1/4 degree resolution is required for energy measureemnts
- BPM cable switches
  - effect of switching cables every other turn @ 39kHz shows sensitivity sun day and night @ 5 microns over several days with testing over 200ft heliax cable
  - need AC power in the tunnel for all switch boxes…
  - processing every other turn (39kHz) instead of 87kHz to ignore 5us switch transient settling times.
  - Could switch at lower frequency. Only 10Hz is required to counteract temperature changes.
  - Goal is to provide 1 turn response for the MPS.

Notes from this meeting (6/17/16)

- The status of beam line devices are as follows. The only critical item not yet started is the emittance slit.
  - BPMs – Buttons, chambers, electronics on order
  - Gun Profile Monitor – (Sumanta/J. Halinski) drawings near completion
  - FCT(s) – (K. Hamdi/M. Paniccia) order being prepared
  - ICT – (K. Hamdi/ M. Paniccia) shield drawings ready to be fabricated
  - DCCT – (K. Hamdi/L.Desnato) shields installed
  - Emittance Slit – designer (G. Whitbeck) assigned but not started yet…
  - Transport Profile Monitor – (G. Whitbeck/ D. Weiss) drawings nearly ready for fab, mod's underway
  - Dump Profile Monitor – (G. Whitbeck/ D. Weiss) assembled and in survey
  - Halo Monitors – (J. Corbin/J. Fite) new chamber being designed
- A single FCT is now planned to go where the Booster Cavity will be. This will provide the MPS with the beam power for it to determine if the beam power is allowed in the current machine configuration.
  - A shield for the ceramic still needs to be designed.
  - The FCT aperture should be large enough to accommodate the shield without decreasing the beam pipe aperture.
  - We are waiting on input from Bergoz on whether differing FCT ID's will affect the matching of FCT's. The high power beam dump line will likely have larger ID than the injection transport line.
  - Differential current measurements were discussed. The two DCCT's from ERL require significant averaging time to arrive at a high resolution. The newly announced 3us MPS response requirement suggests the use of multiple FCTs for differential current measurement.
  - A second FCT is being considered in the Gun diagnostic bump line to help develop the differential signal processing for the full LEReC where the FCT would be moved to the high power dump beam line after the cooling section.
  - Moreover, the RF diagnostic beam line may also need to be fitted with a 3rd FCT in a differential arrangement for use when the beam is steered to that line's beam dump.
- The gun current measurement circuit installed inside the SF6 tank (laser powered over fiber) is used for gun conditioning with a high value shunt resistor for sensitivity.
  - This will not be used for operational gun current measurement. To do so, a smaller shunt resistor would have to be installed instead of the shorting bar that usually replaces the resistor. Alexei & Joe have expressed concern with adding an operational shunt resistor. Thus the only gun current will be the power supply current read back.
  - This should be discussed further. Although an arc would cause an overvoltage in the measurement electronics, an over-voltage suppressor would protect it.
- So far the two HV stack voltage dividers (one in the gun HVPS and the other in the cathode tank) were planned to be monitored by the O-scope directly.
  - We need to decide if dedicated voltmeter instruments need to be purchased to monitor these voltages where a wide selection of gains could be used.
  - Although the operational value is not expected to change, we need a high resolution measurement at a constant value.
- Cornell uses a beam stabilization system for the laser. Is Zhi planning to install the same system in the laser & tunnel?
- The Zynq digitizer platform needs to be reviewed to ensure that it can handle digitizing multiple channels with sufficient memory
  - 8 channels are needed for the Gun test for these signlas: ICT, PM FCT, 4 Halo Mon FCT's, 2 dump FC's
  - Up to 6 channels will need to be viewed at the same time (4 halo's, ICT & dump FC)
- The 4 Halo Monitors upstream of the Gun Diagnostic Dump will have FC signals viewable on the O-Scope.
  - Should we outfit these with fast comparators to trip the MPS?
  - The question was asked "Why were these not used in the transport to measure beam halo?" This may have been a preference of Dmitry. Perhaps he can comment here…
- There was a concern of secondary electrons emitted by the Gun Profile Monitor (when inserted) sending electrons back to the gun.
  - It was pointed out that the Anode would likely collect these reflected electrons.
  - ANYONE PLEASE COMMENT HERE…
- ON the question of biasing Faraday Cups (FC):
  - Bias cables will be run into the tunnel; however, we did not bias the ERL FC's as it was desired to make DC measurements of the dark current. Biasing requires capacitively coupling the FC signal.
  - We will proceed with unbiased FC's until a need for biasing is shown; where we will have to trade the dark current measurement for biasing.
  - Amplifiers are planned for the FC signals for increased sensitivity.
  - Selectable termination resistors is also a possibility... TBD
  - All FC signals should be logged.