Overview of the Beam Instrumentation and Commissioning Results from the BNL **L**ow **E**nergy **R**HIC **e**lectron **C**ooling (LEReC) Facility

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[MOBO01]

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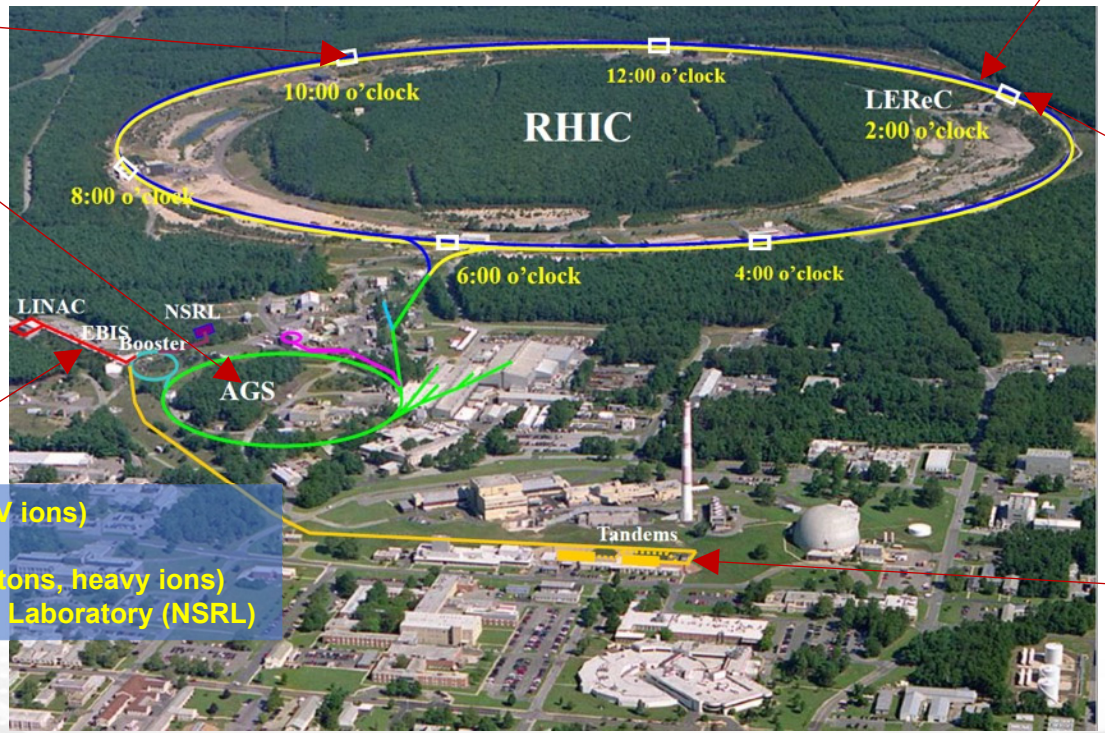
U.S. DEPARTMENT OF ENERGY

RHIC and associated Accelerators

Low Energy RHIC electron Cooling (LEReC,1.6 to 2.7 MeV electrons)

RHIC (3.85 to 255 GeV; protons, heavy ions)

Electron-Lens (5 KeV electrons)



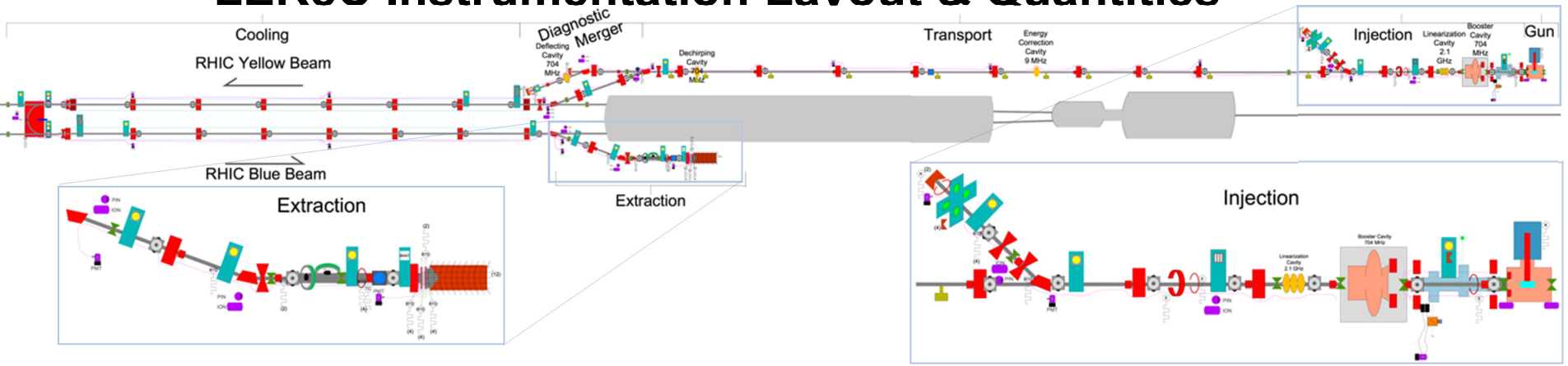
AGS (up to 28 GeV; protons, heavy ions)

Coherent electron Cooling (CeC,18 MeV electrons)

EBIS (range of 14 – 25 KeV ions)
Linac (200 MeV protons)
Booster (up to 3 GeV; protons, heavy ions)
NASA Space Radiation Laboratory (NSRL)

Tandem Van de Graaff (up to 28 MeV/AMU; protons, heavy ions)

LEReC Instrumentation Lavout & Quantities



- Gun X-Ray Detector (2)
- Gun Anode Bias & Current
- Ion Clearing Electrodes (2)
- Cathode Imaging & Laser Exit Instr.
- Gun Ripple – Capacitive Pick-up
- Charge & Current
  - FCTs (4), DCCT (1), ICT (1)
  - Faraday Cups (5)
  - Halo Monitors (4)

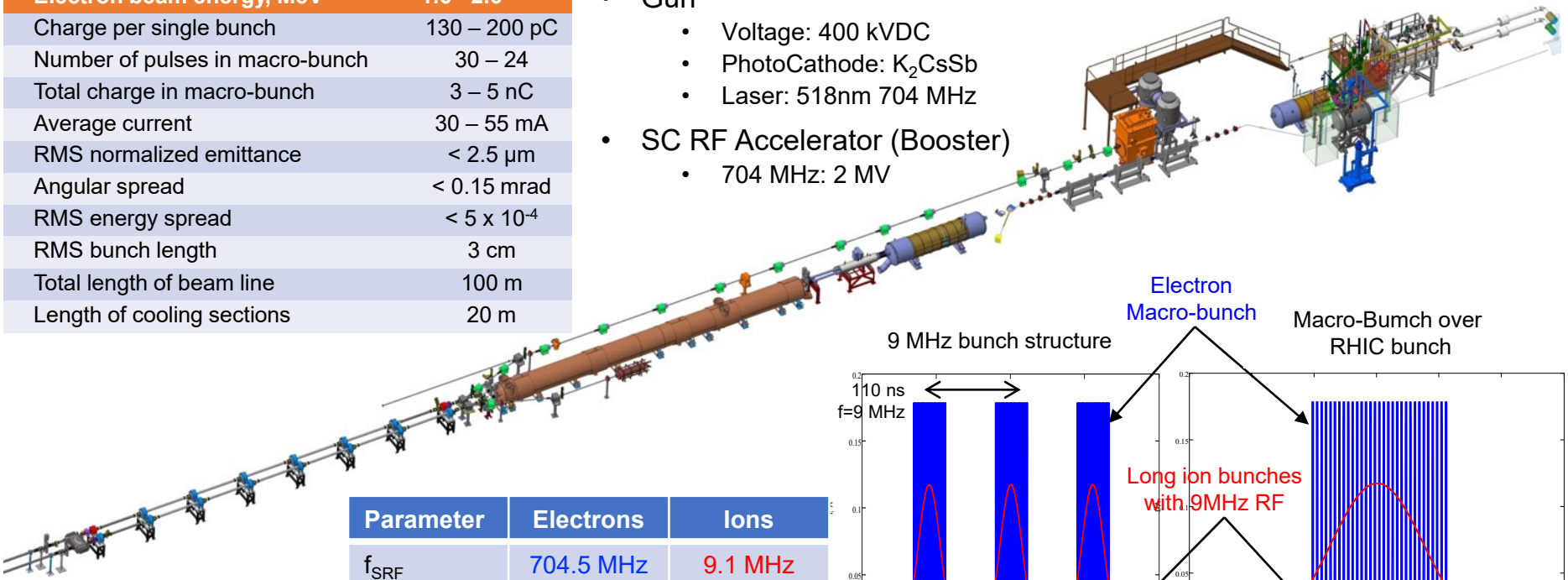
- Profile Monitors
  - Yag (15)
  - FWS (1) , BIF (2), BNNT (1)
- Defining Slits (3)
- Emittance Slit (3)
- Beam Position Mon (41)
- Beam Loss Monitor (16+8+8)
- Temperature Mon (44)

- Energy Measurement
  - NMR Magnetic Spectrometer (1)
  - Time of Flight (3)
- Recombination Mon (2 – RHIC: Blue & Yellow)
- Wall Current Monitor (2 – RHIC: Blue & Yellow)
- H-Jet Profile Monitor (1) – RHIC: Blue & Yellow)

LEReC Layout & Parameters

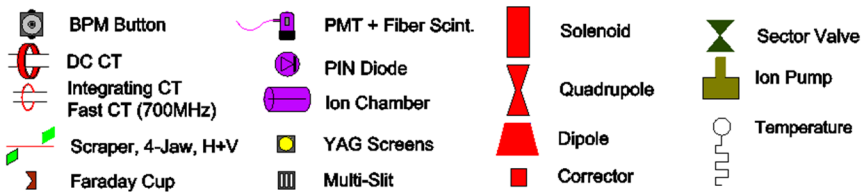
Electron beam energy, MeV	1.6 - 2.6
Charge per single bunch	130 – 200 pC
Number of pulses in macro-bunch	30 – 24
Total charge in macro-bunch	3 – 5 nC
Average current	30 – 55 mA
RMS normalized emittance	< 2.5 μm
Angular spread	< 0.15 mrad
RMS energy spread	< 5 x 10^{-4}
RMS bunch length	3 cm
Total length of beam line	100 m
Length of cooling sections	20 m

- Gun
  - Voltage: 400 kVDC
  - PhotoCathode: K_2CsSb
  - Laser: 518nm 704 MHz
- SC RF Accelerator (Booster)
  - 704 MHz: 2 MV



Parameter	Electrons	Ions
f_{SRF}	704.5 MHz	9.1 MHz
Q_e / N_{ion}	50 pC	$6x10^8$
I_{PK}	0.13 A	0.3 A
$Length_{FWHM}$	400 ps	3.2 m

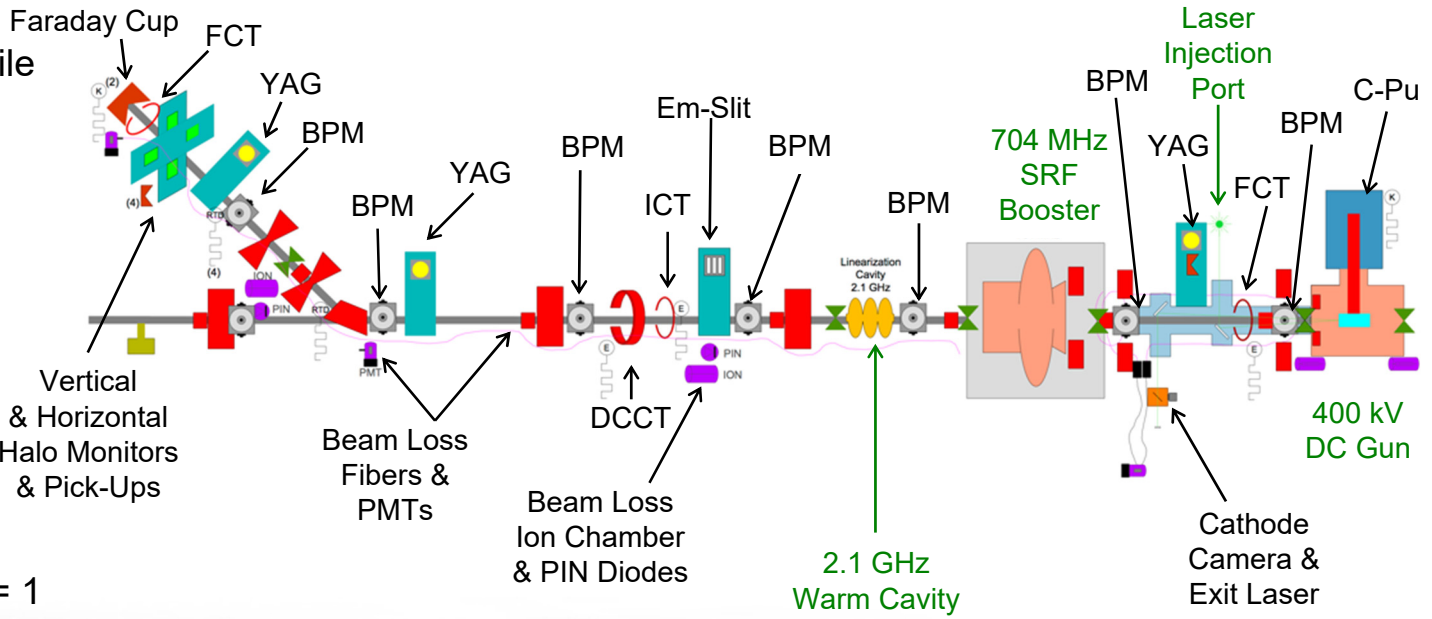
Injection Instrumentation



Injection

Cathode Imaging
- Exit Laser Power & Profile
- Anode Bias
- ICE
- Gun Ripple Mon.
  - Capacitive Pick-up(C-Pu)

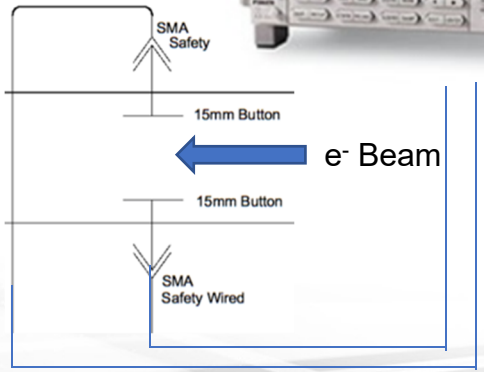
FCT = 2
ICT = 1
DCCT = 1
Faraday Cup = 2
BPM = 7
YAG = 3 Emittance Slit = 1
Halo Mon. Pairs = 2



Anode Bias & Ion Clearing

- Anode Bias
  - **needed** to keep gun from tripping at high current
  - Bias Voltage: Upgraded to 3kV
  - Series pA meter
  - No measured DC current thus far.
    - May need bias tee to monitor transient nature
- Ion Clearing
  - **needed** to keep gun from tripping at high current
  - 0 – 500V Bias across horizontal electrodes
    - 15 mm buttons in Gun-to-Booster chamber
  - Keithley 6487 Sourcing Picoamp current meter
    - No measured DC current thus far.
      - May need bias tee to monitor transient nature

Keithley 6487 Sourcing Picoammeter



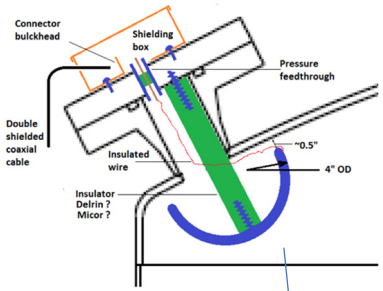
Ion Clearing

Gun HV Ripple Monitor

- Gun capacitance measured with special probe : 222 pF
- System scale factor:
  - Measured gap response
  - compared expected droop in gap on measured capacitance to measured C-Pu signal. => 1307x scale factor
- Measured ripple signals & scaled accordingly.
- ~1kV$_{P-P}$ ripple still below 500V$_{RMS}$ requirement

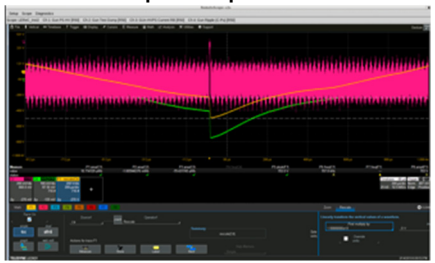
Gun HV Ripple Test Results

March 5, 2019			
Frequency of Ripple	4 mA CW	16 mA	21 mA CW
360 Hz	~ 525 V		~ 950 V
166 kHz	63 V		127 V
June 12, 2019			
360 Hz		980 V	
166 kHz		167 V	

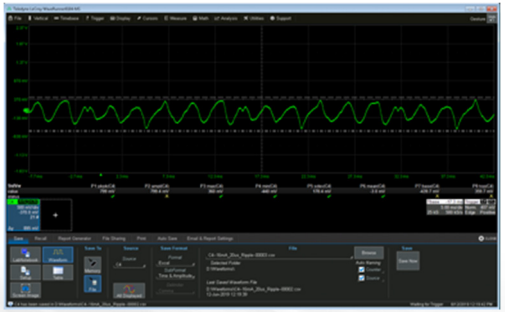


Capacitive Pick-Up

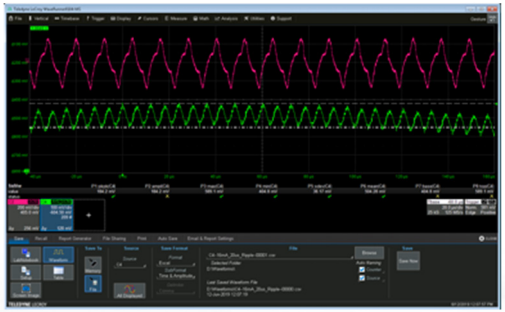
Gap Response Test



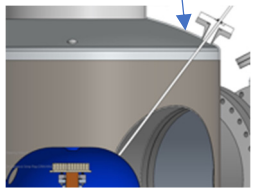
360 Hz ripple (averaging: 60)



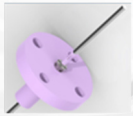
166 kHz ripple (averaging: 60)



Screen shots from eLog on June 12, 2019

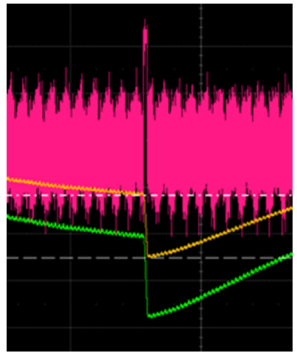


Special probe for capacitance measurement



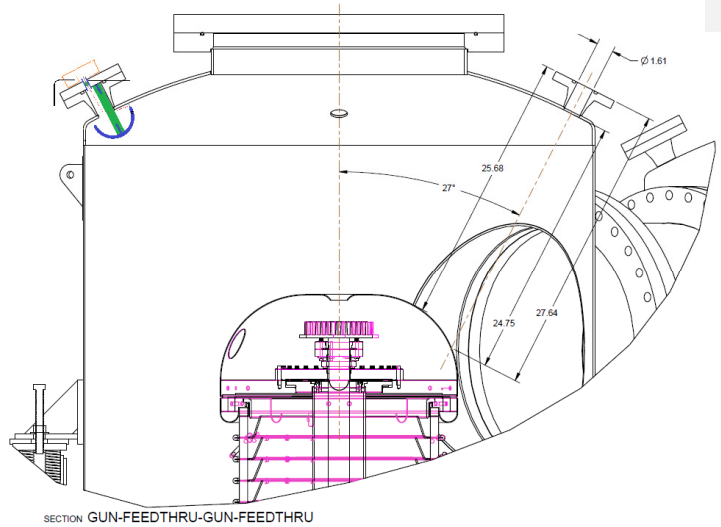
50 MB gap in 9.43mA 60s-averaged beam current

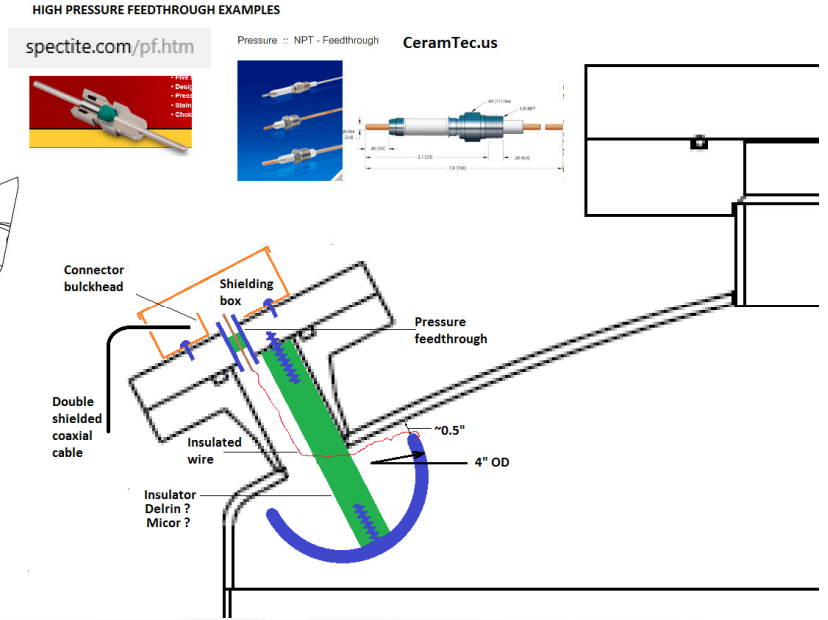
C-Pu voltage 173.3 mV



From eLog Feb. 14, 2019

Capacitive Pick-Up in Gun HV Tank





Cathode Imaging & Exit Laser Instr.

- Cathode Image
  - Navitar 12X zoom lens system
    - Images 25 mm cathode, 1 m away
  - Red illumination reduced DC emission
  - Used in automated QE mapping
  - Spotlight projection illumination to confine light through the tight aperture
  - reflector on gun laser table behind laser mirror
  - requires long exposure!

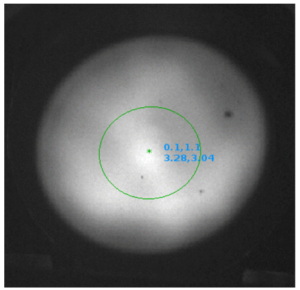
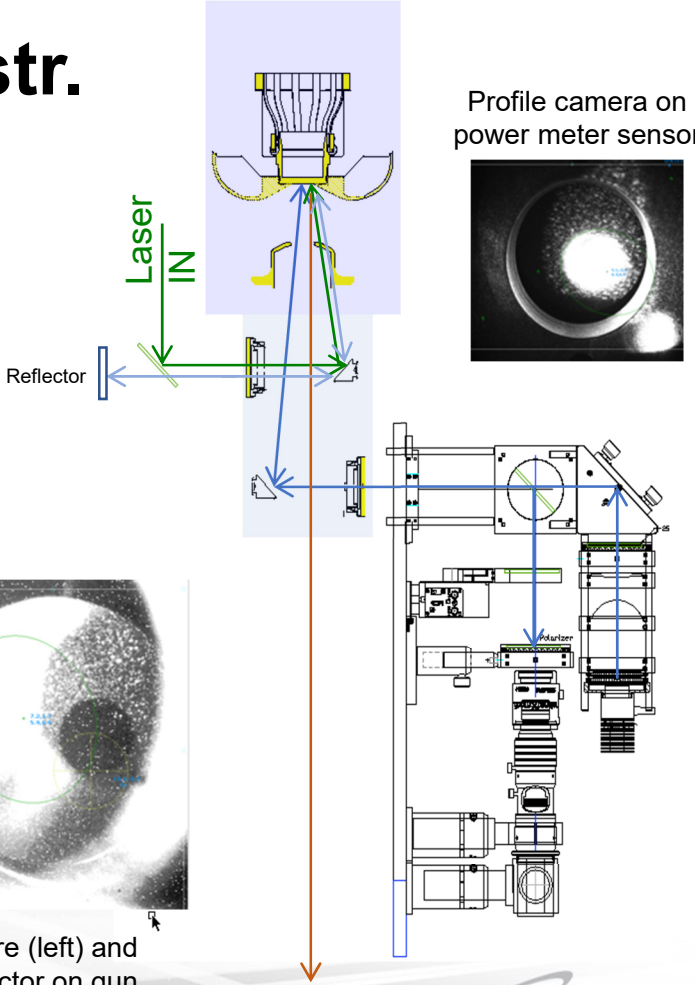
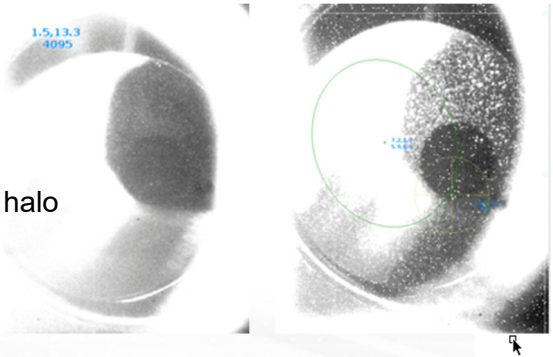


Image of QE map on profile monitor with LED illumination



Profile camera on power meter sensor

- Exit laser profile & power meter
  - Measure laser transport efficiency
  - Monitor profile for clipping
    - Stray light inside chamber contributes to beam halo

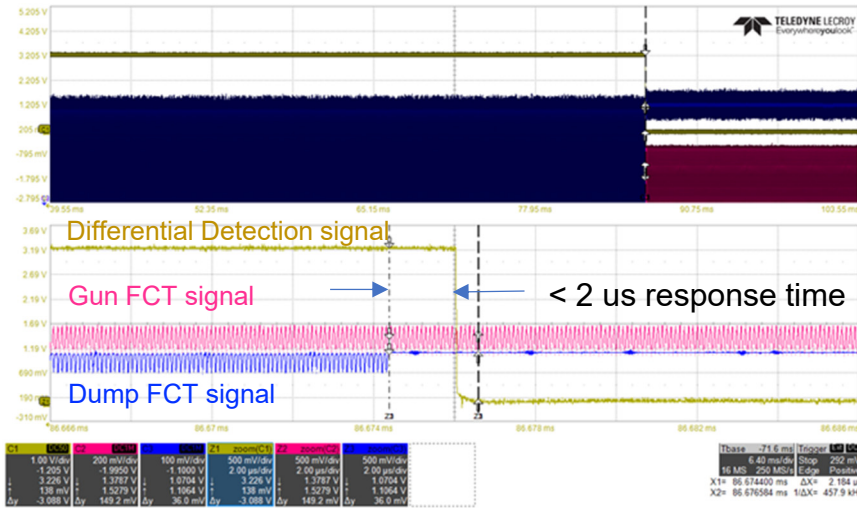


Cathode active area before (left) and after (right) installing reflector on gun table.

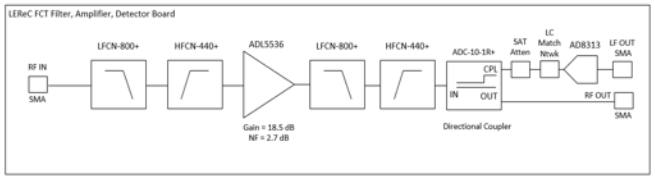
FCT

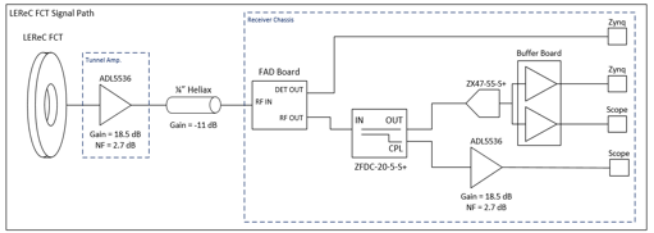
- FCT-CF6”3/4-96.0-40-UHV
  - In-flange type
  - Guarded ceramic option: 96mm ID
  - Custom 704 MHz narrow band option
- 704 MHz Narrow band filter, amplifier & detection
- Zynq FPGA signal processing
  - Beam current determined – 1 sec. sliding average
    - -> Current level sent to MPS
  - Current level is compared to beam destination in the machine
  - Trips if too much current goes to the wrong device
- Differential current protection (3 destinations)
  - < 2 us response time
  - Gun – Test Dump
  - Gun – RF Diag. Dump
  - Gun - Extraction

Courtesy Bergoz



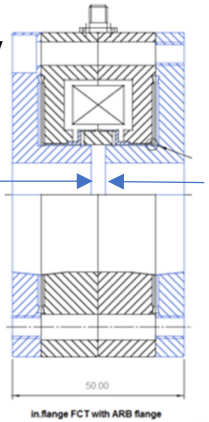
Filter, amplifier, detector converts the high-frequency signals into low-frequency signals that are converted to charge per bunch





Cut-Away of FCT

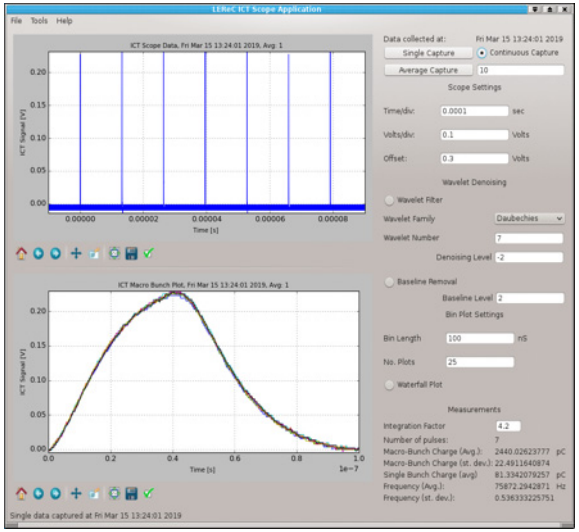
3mm gap shields ceramic



ICT & DCCT

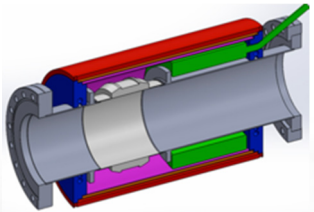
- ICT
  - Calibrated charge meas. in pulsed mode
  - BCM-IHR electronics: < 7 μs trains
  - New application uses DSO-X-3024 scope to process long trains & CW => calculates charge
  - ICT is used during as calibrated reference during pulsed mode
- DCCT
  - Bergoz NPCT & Electronics
  - Electronics put in a temperature controlled enclosure
  - used during as calibrated reference during CW mode 7 trains > 100 μs

Courtesy Bergoz



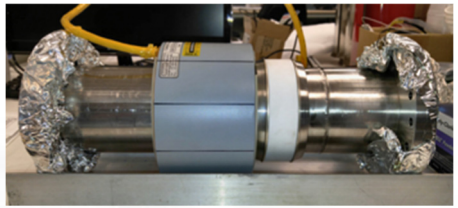
Scope application analyzes ICT signal and calculates charge for long trains & CW

Courtesy Bergoz



DCCT Assy. Cut-away

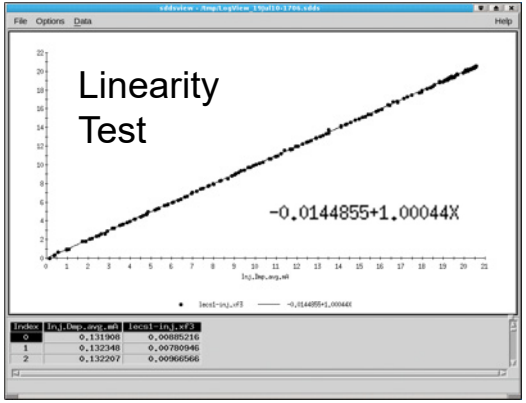
NPCT Sub Assembly

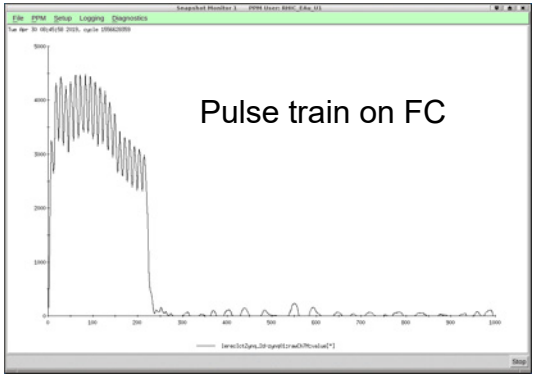


DCCT Assembly

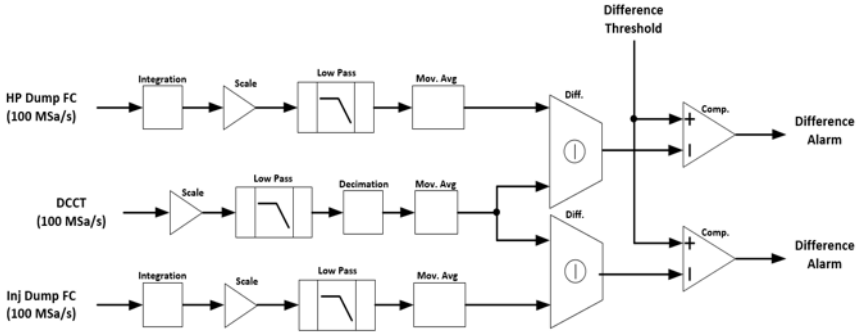
Faraday Cups & Halo Monitor

- Low voltage bias (series 48V Battery)
- Grounding resistor (1MΩ) & TVS surge suppressors at the electrode
- Signals processed by Zynq
  - charge is calculated – very linear
    - Isolated Gun Profile Monitor (1)
    - Gun Test Beam Dump (1)
    - Halo Monitor Jaws (4)
  - Differential Protection: DCCT – FC's (x3)



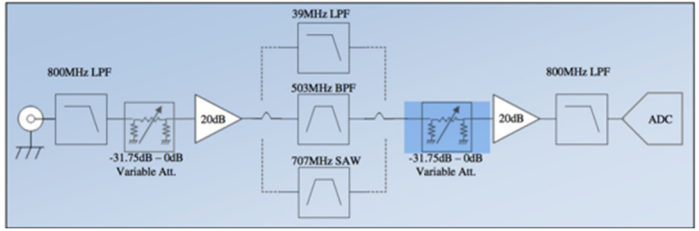


FC signals processed and compared to DCCT for differential protection of the beam line.

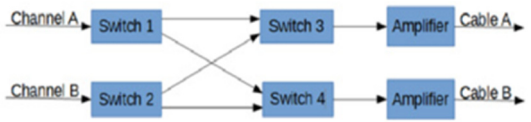


BPMs

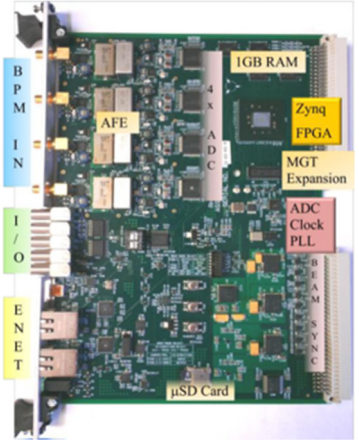
- BPM Electronics
  - BNL V301 VME Cards
  - Libera Brilliance Single Pass Units
- 9 mm & 15 mm buttons
  - Phase stabilized ¼” Heliax cables
  - Local amplifiers in tunnel
  - Includes cable commutating switches to average out cable mismatches
- Beam strikes to buttons damaged electronics.
  - Added PIN diode limiters ZFLM- 43-5W+
- Bias on buttons for Ion Clearing
  - Under investigation



BNL Designed V301 VME BPM card
Analog front end – Filter tailored for application



Cable commutation to average out imbalanced drifts in cable attenuation.



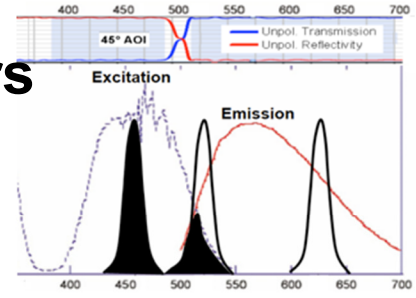
BNL Designed V301 VME BPM card (4-button)

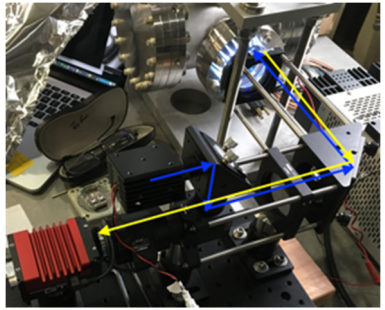
- VME Form Factor
- 4 x 400MSPS ADC’s
- FEC & FPGA on Zynq Chip
- 2 Ethernet Ports
  - Controls
  - Feedback

Libera Brilliance Single Pass BPM Unit (4-button)

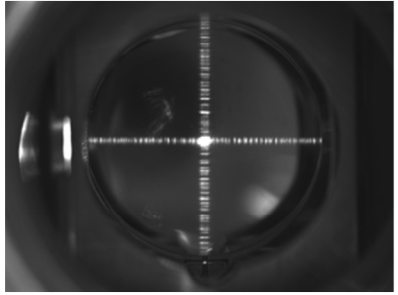
15 YAG Profile Monitors

- AVT GT1600 GigE camera
- P-iris lens driven by camera
  - Not auto-iris, remote iris control
  - failures (CeC nearby)
    - 3 iris control
    - 1 imaging
    - 1 complete
- Al coated, 100μm YAG (45mm aperture) with Cu mirror @ 45°
- Ferrite compensated low impedance design
- Normal & Fluorescent Illumination with RGB LED ring
  - Normal: Red + Green LEDs
  - Fluorescent: Blue LED (~450nm)
  - 500nm low pass filter in camera
- Project fluorescent cross on YAG
  - Inject 450nm laser with Diffractive Optical Element [8]
    - Dichroic beam splitter reflects Blue / Passes YAG emission

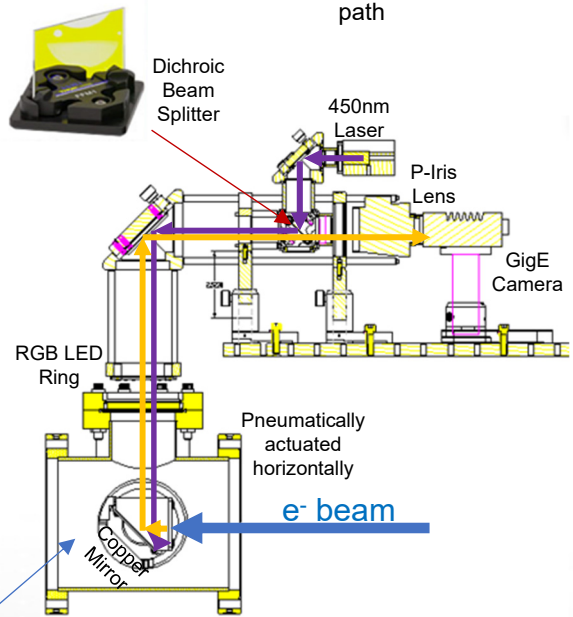


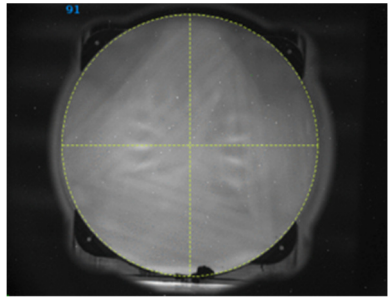


Illumination laser light path

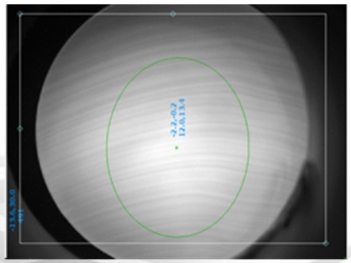


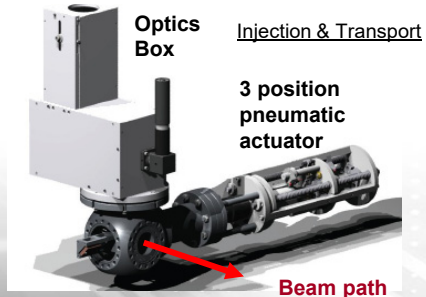
Blue laser through Diffractive Optical Element from Holoeye Photonics



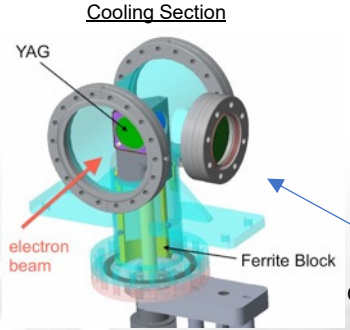


(Top & Bottom) 50mm YAG with Fluorescing under 450nm Blue illumination. Reference circle show above.





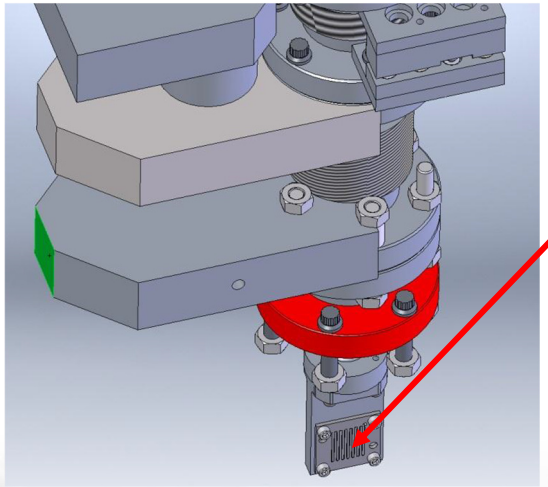
Courtesy Radiabeam

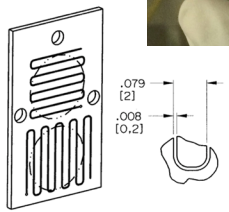


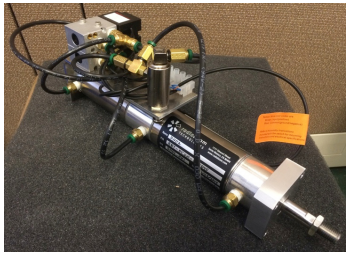
Chamber design in Cooling & Extraction Sections

Emittance Measurement: Multi-Slit Mask in Injection Section

- Low Power Operations Only
- Dual axis design for Horizontal & Vertical measurements.
- Positioned 2 m upstream of profile monitor
  - Tungsten Slit mask, optimized for beam parameters
    - Mask 1.5mm thick, 150um wide x 1.35mm spacing







Dual Station Actuator retrofitted for new dual axis mask.

ANALYSIS:
An algorithm was developed for analyzing the image from a multi-slit mask for emittance measurement.

Future plans are to automate the image analysis for on-line processing and data logging.

Intensity Distribution at mask

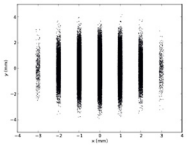
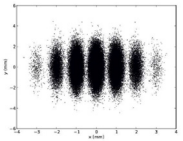
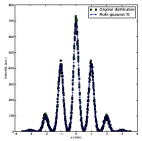
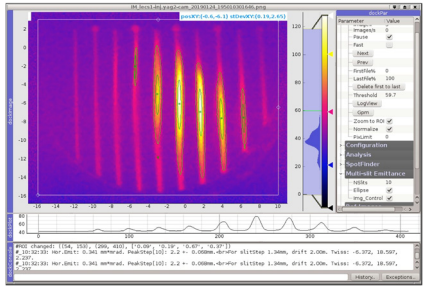


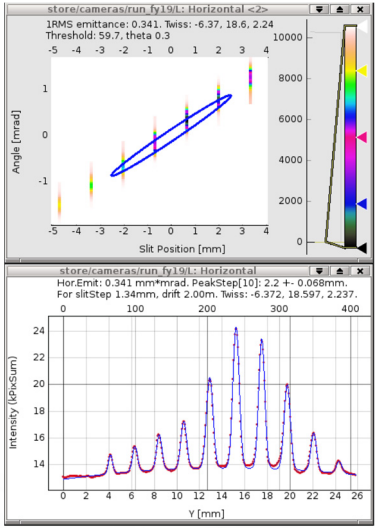
Image on profile monitor after drift distance





Images below from operations

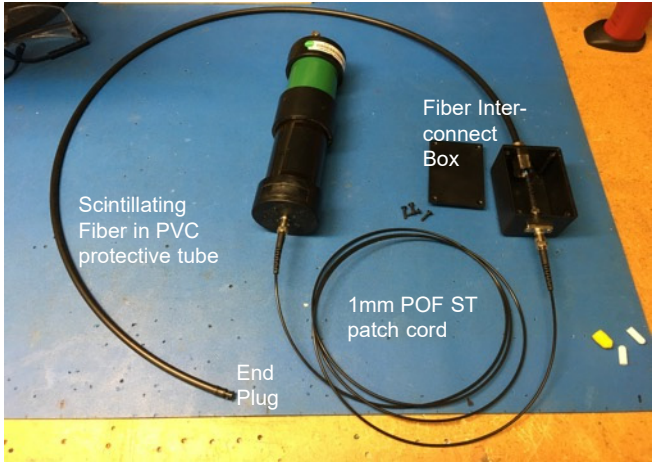




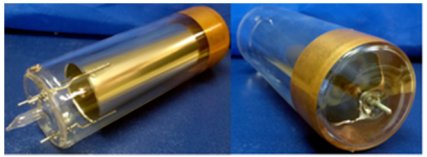
Beam Loss Detection

- PMT + Scintillating Fiber
  - 16 detectors
  - Trips MPS (Primary Protection)
  - Covers 100m of beam line
- Ion Chamber Detectors
  - 8 detectors
  - used for point source measurements
- PNI Diode Detectors
  - 8 detectors
  - used for point source measurements

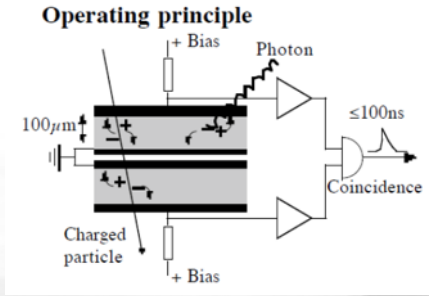
PMT with 3 fibers coupled



Ion Chamber Detector Assembly



Ion Chamber Detector Element

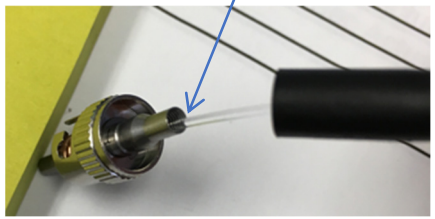


PIN Diode, dual incidence detector, by Bergoz Instr.

Fiber Loss Monitors (PMTs)

- ⦰1mm BC60FScintillating Plastic Optical Fiber (POF), from Saint Gobain has not outer jacket.
  - Black PVC tubing sheath and connectors designed
- Detector
  - Hamamatsu R11558 PMT
  - PVC enclosure
- Electronics
  - The new version of BLM electronics developed at JLAB for the 12GeV upgrade will be used for the PMT detectors.
  - We have three 8-ch modules for ERL.
  - Controls integration is underway.
- Performance
  - Used to protect LEReC for 2 years in pulsed mode
  - CW operation caused ~17% darkening of fibers
- New Fiber
  - ⦰1500 μm Armored Quartz fiber shall replace POF
  - Rad Hard materials
  - 85% as sensitive to 1.6MeV beam as Scintillating POF
    - Compensate with bias voltage

BC60F 1mm POF Fiber without jacket

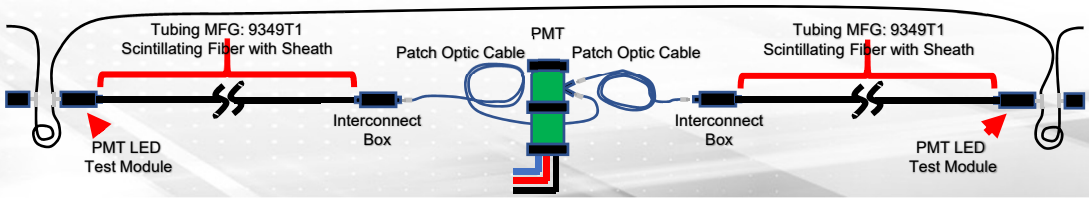


1500 μm Quartz fiber (in SMA bulkhead)

⦰1.5mm quartz

Stainless Steel Tubing

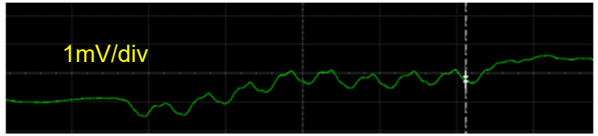
New Beam Loss Monitor for 12GeV Upgrade
J. Yan, K. Mahoney, ICALEPCS 2009



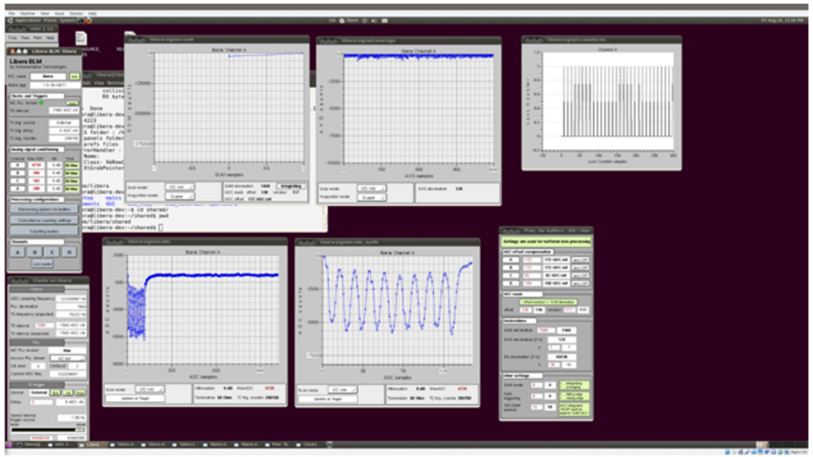
Other Beam Loss Monitors

- Diamond
  - Tested at end of transport w/ 9 MB's
  - Signal was too weak with 2.4nC/MB

Signal from in-air diamond detector

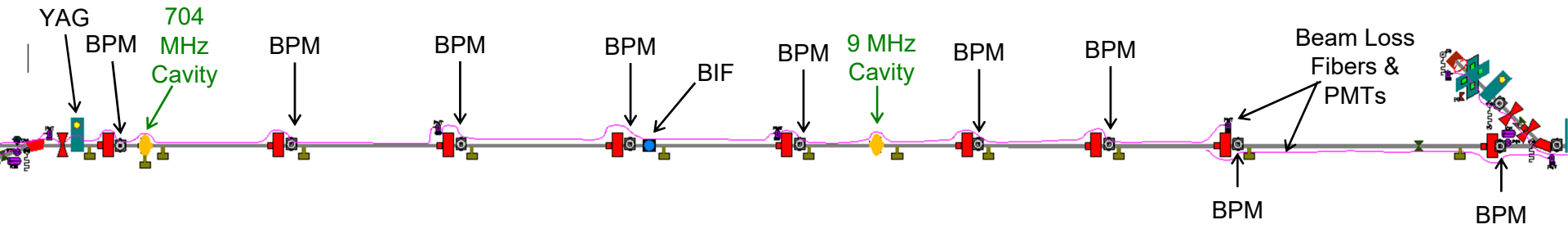


- Libera BLM Electronics
  - Tested with fiber PMTs
  - Successfully demonstrated RHIC synchronous masking for **sensitivity in abort gap only**
    - This method may be used in the future to mitigate gun trips during RHIC injection losses.



Libera BLM Module (4-ch)

Transport Section



Transport

BPM = 9

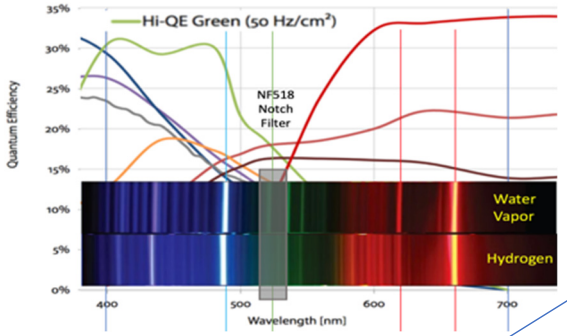
YAG = 1

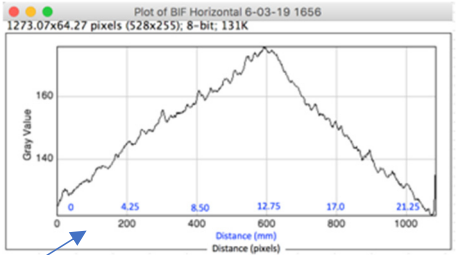
BIF = 1

BIF Monitor

Residual Gas

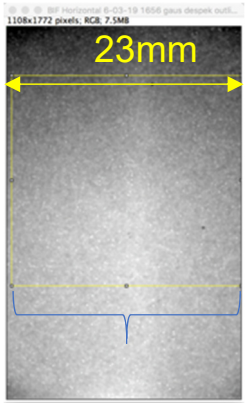
- **B**eam **I**nduced **F**luorescence
  - based on residual gas (H_2 & H_2O)
- Camera + Intensifier + Fast Lens
  - GT1930 (3.3e- noise), 40dB gain, 5.8um pixel, with f/0.95 lens
  - Photonis “Cricket”: 1xMCP, 30% QE cathode – Blue sensitivity, P43 phosphor
- Blackened Chamber
  - Acktar “Magic Black” - conductive coating
- Pressure
  - Pressure bump to 10^{-6} with filament
  - Very good conduction limiting
  - -> will test NEG for controlled outgassing
- Radiation Sensitivity
  - Images spoiled with radiation sensitivity
  - Need to add lead chicane in optics assy.

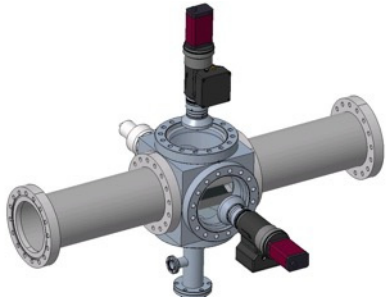


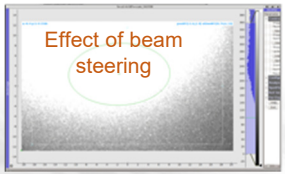


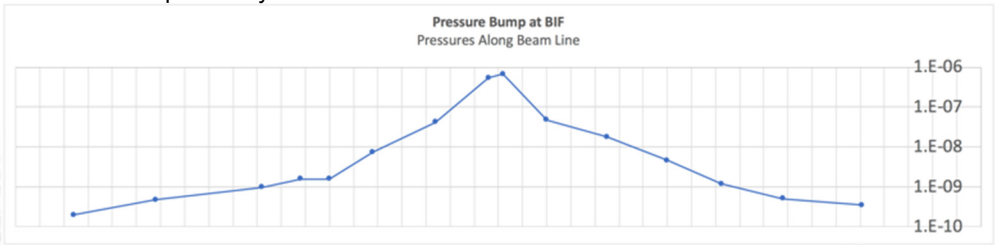
Profile of 1 good measurement with 17mA beam $1x10^{-7}$ pressure

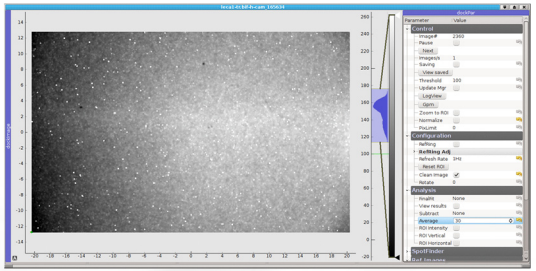
Region of analysis







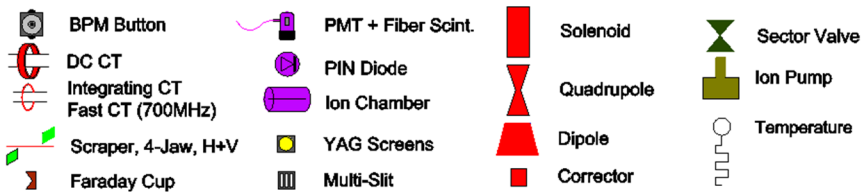




U.S. DEPARTMENT OF ENERGY

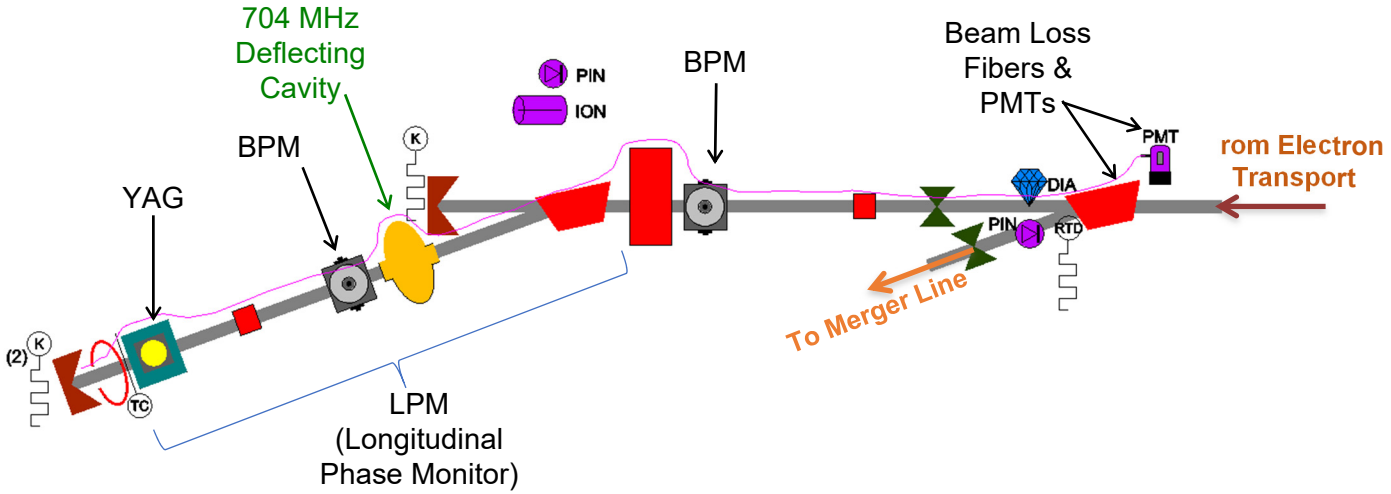
BROOKHAVEN NATIONAL LABORATORY

RF Diagnostic Beam Line

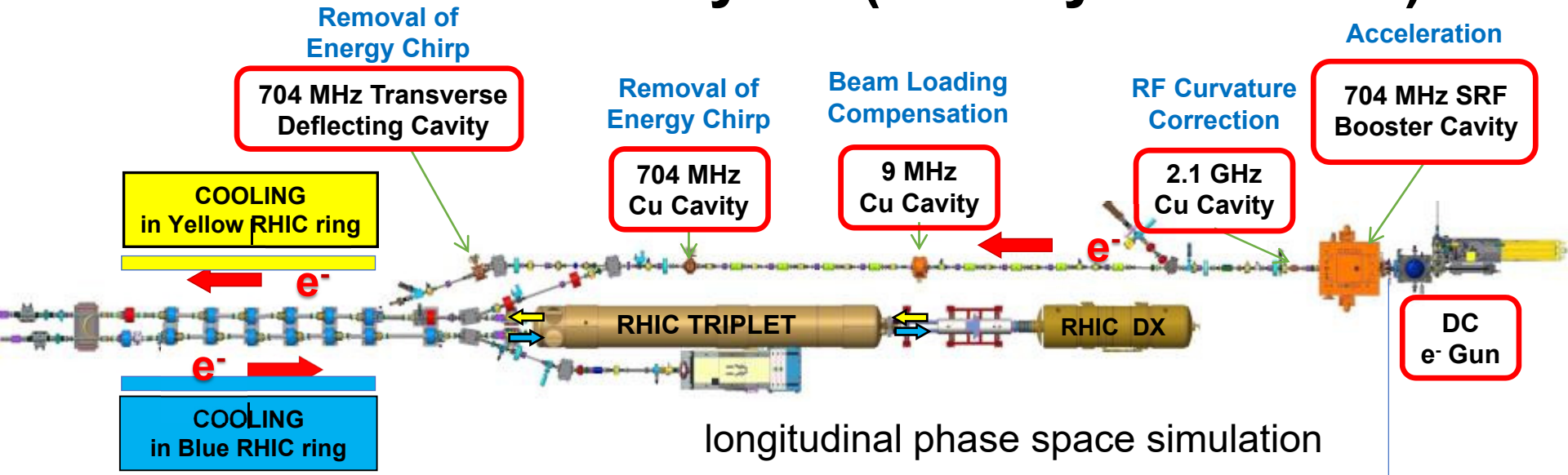


RF Diag.

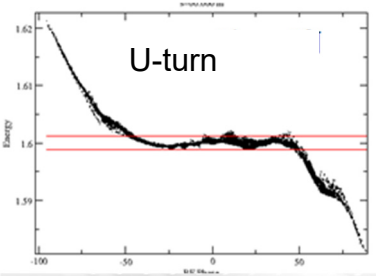
BPM = 2
YAG = 1
FCT = 1
FC = 2
LPM = 1

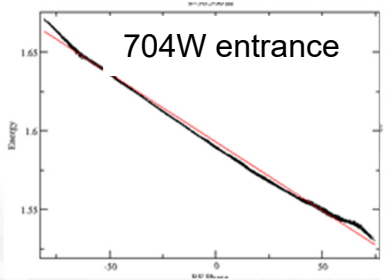


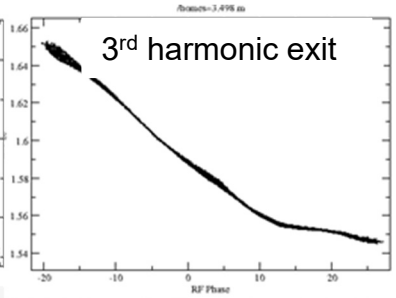
LEReC Accelerator Layout (RF "Gymnastics")

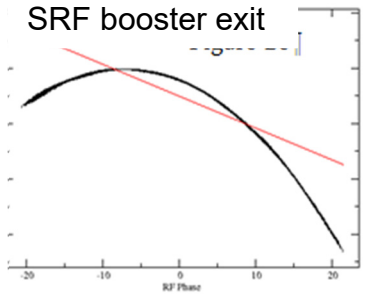


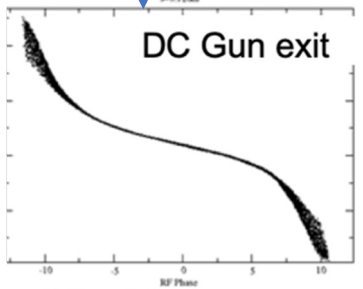
longitudinal phase space simulation







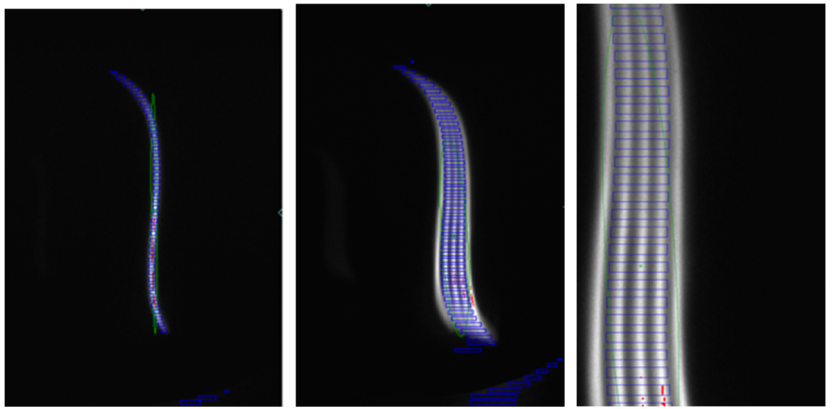




Beam direction

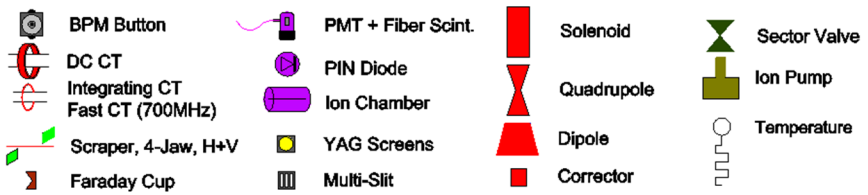
Longitudinal Phase Monitor (LPM)

- Required for cooling:
  - 2.5E-04 voltage
  - 0.25 degrees rms stability for the 704 MHz SRF cavity
- 704 MHz RF deflecting cavity chirps the beam to show the longitudinal energy spread vs bunch length on the profile monitor.
- The width of the beamlet is proportional to the longitudinal energy spread
- The separation between the MB's shows the beam loading effect on the RF cavities in pulsed mode.
  - ΔEnergy proportional to Charge
  - ΔEnergy = 2 keV for 3 nC
  - Compensate beam loading by tuning 9MHz cavity
    - reduces width of each MB image on the LPM.



Longitudinal Phase Monitor, left to right macrobunches (MB) with minimal energy spread: a) single MB, b) five MB's, c) zoom of five MB's.

Merger Section

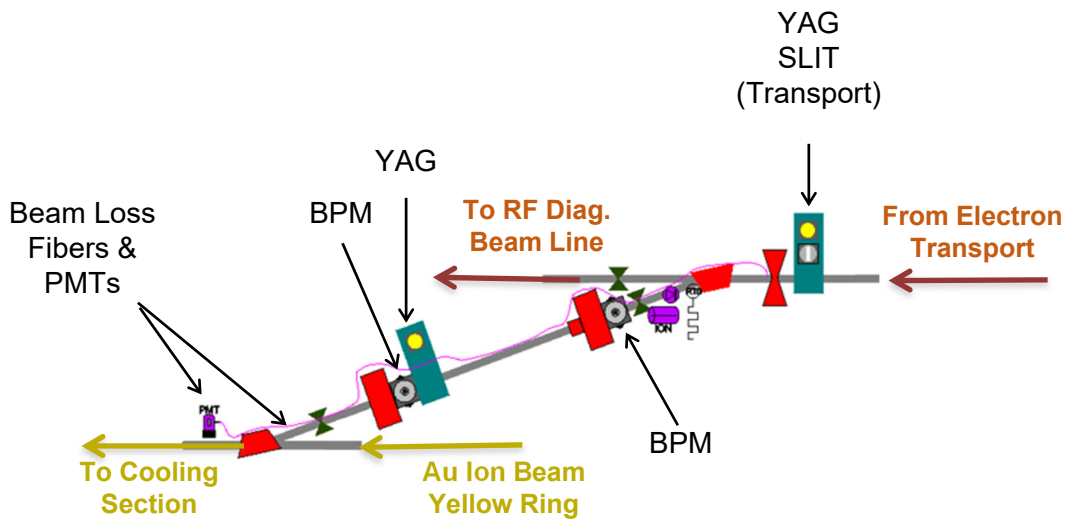


Merger

BPM = 2

YAG = 1

- Energy Spread meas.
  - Round beam on tr.YAG
  - Dispersion in dipole
  - ΔE/E proportional to θ_H/θ_V



Cooling Sections

RF Diag.

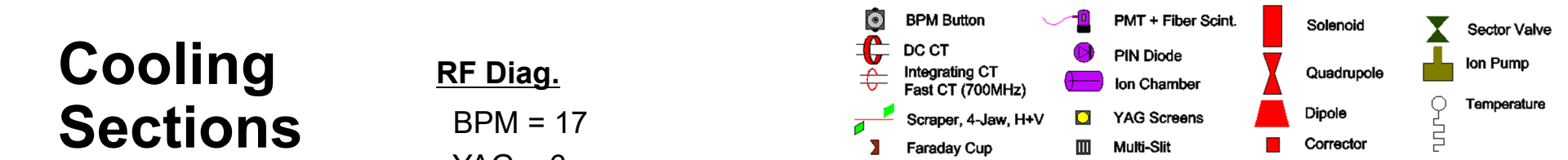
BPM = 17

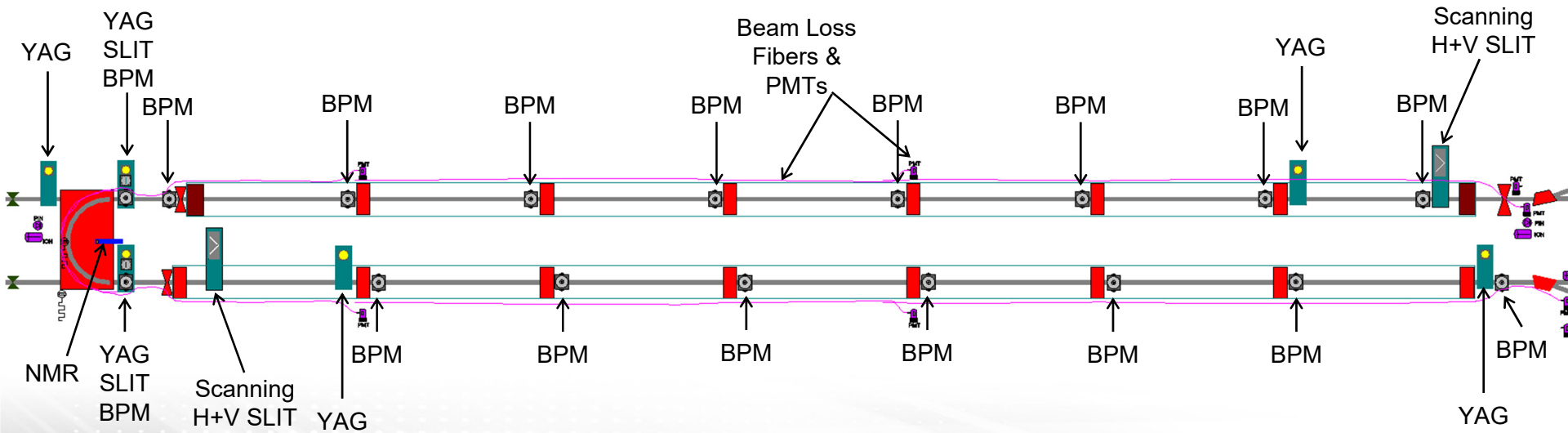
YAG = 6

SLIT = 2

Scanning SLIT – 2

NMR = 1



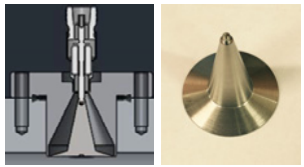


Dual Spectrum BPMs

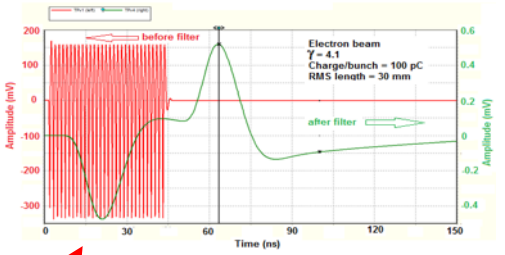
- Required for cooling:
  - < 50 μm relative to ions
  - < 100 μrad angular spread
- Two V301 cards per BPM station
  - one measuring electrons only
  - one measuring ions + electrons
    - 9 MHz MacroBunch appears as the ion bunch.
- Disagreement:
  - Change in beam charge causes 704 – 9 MHz disagreement gradually down cooling section
    - SEE GRAPHS ON NEXT SLIDE
    - Under Investigation

Conical BPM Button
A large diameter 30mm button for high bandwidth and improved matching.

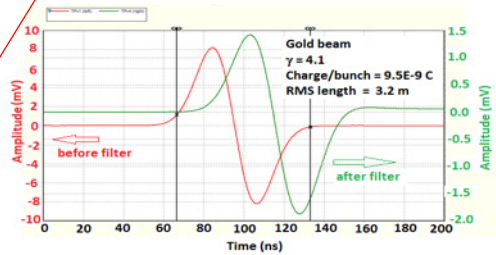
BPM housing from MPF.



- Large Conical Buttons
  - 30 mm diameter buttons
  - N-Type feedthrough
  - MPF PN Q7031-1



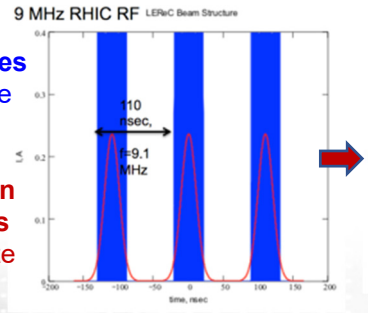
SPICE simulation using the Particle Studio simulated electron and gold signals as inputs to the standard RHIC ion BPM low pass filters



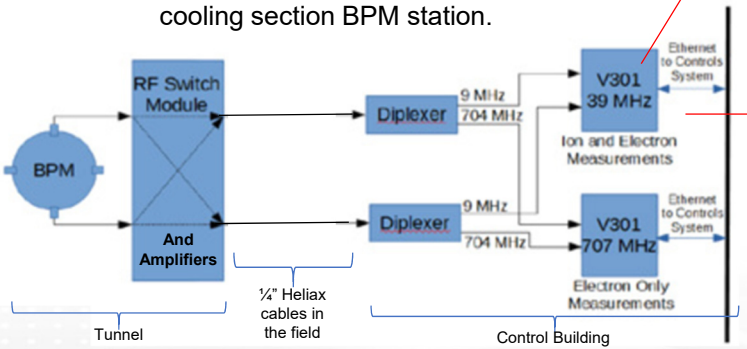
Ion beam bunches @ 9MHz rep rate

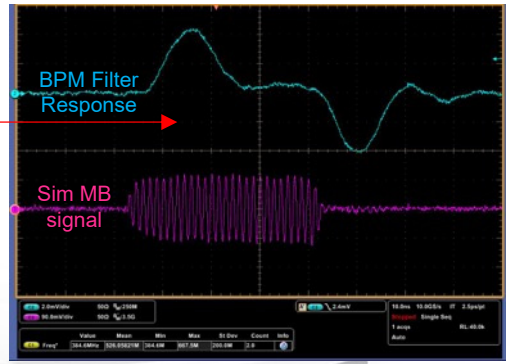
overlapped by

700MHz **electron macro-bunches** @ 9MHz rep rate



BPM overall configuration – 2 x V301 for each cooling section BPM station.

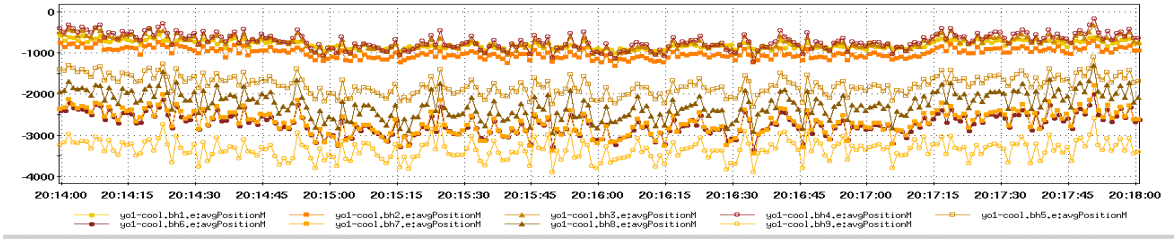




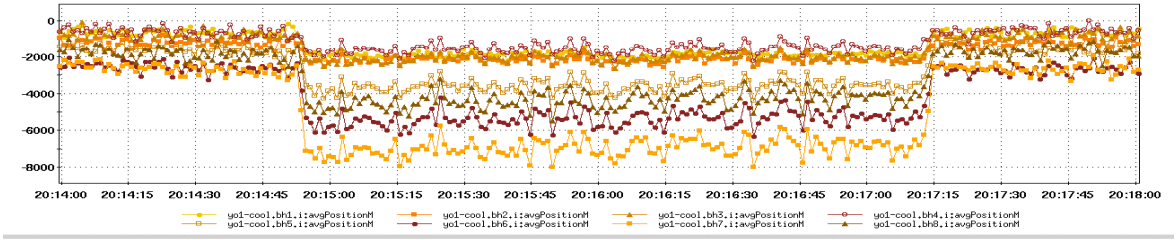
BPM 704MHz vs 9MHz Issue

40pC -80pC -40pC

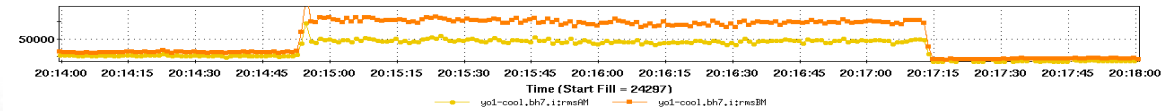
704M Hz



9MHz



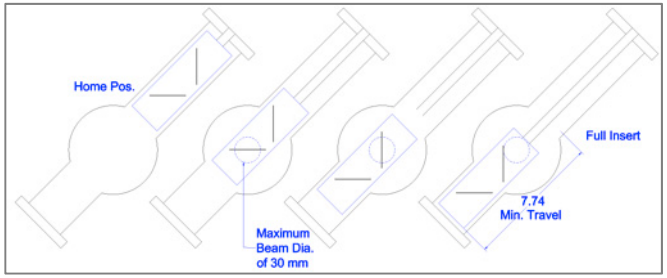
Signal RMS

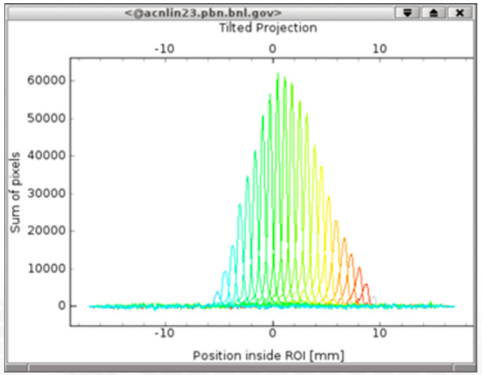


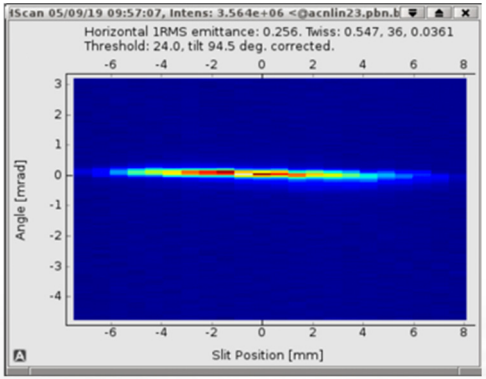
BPM slides courtesy of R. Hulsart

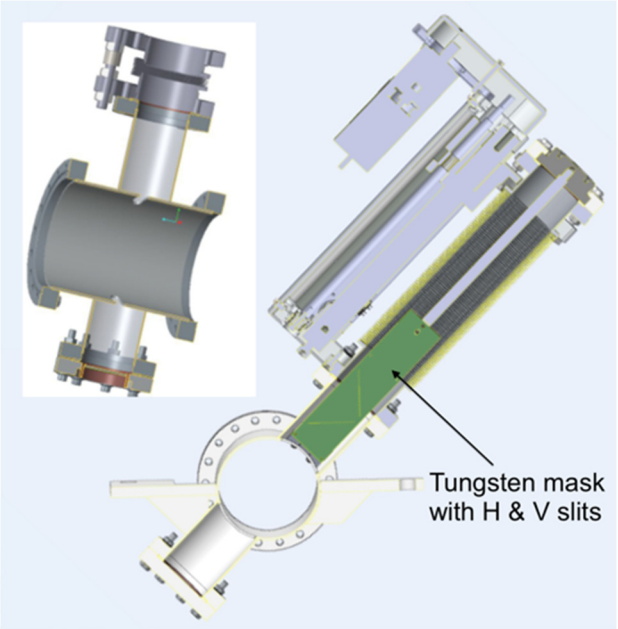
Emittance Scan (2 stations)

- Geometric emittance measured down to 0.25 μm as well.
- The tungsten mask H+V slits scans at a 45° angle at 1 mm/s while the camera captures images at 1 Hz.



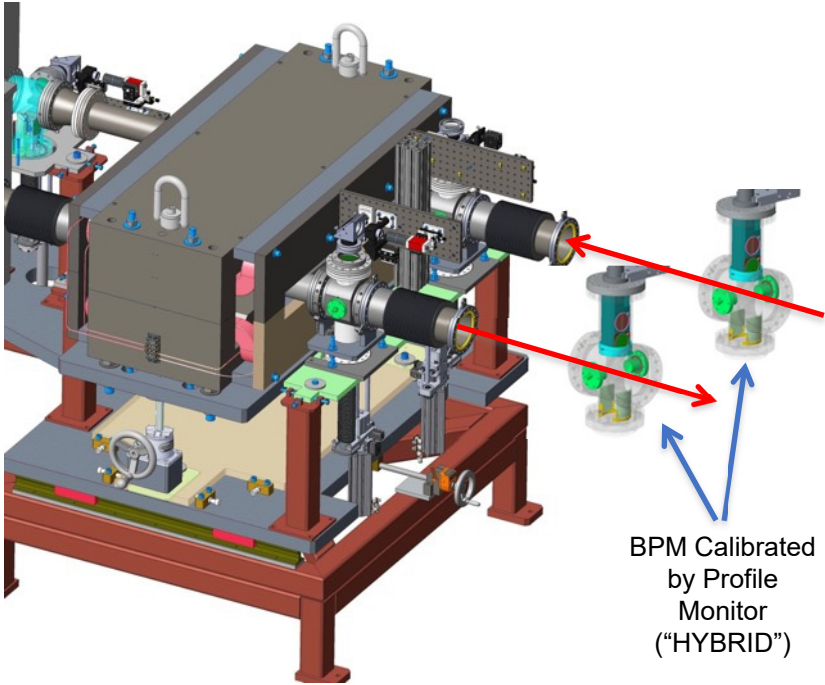






Energy Spectrometer

- Low Field NMR Gaussmeter (CAYLAR)
  - Dipole at 180 gauss (NMR range: 150 – 560 gauss)
  - <20 milligauss noise
  - < 3 milligauss deviation in 8 hrs
- Magnetic Spectrometer
  - 2 Horizontal BPMs measure position in/out dipole
  - Dispersion converts Δenergy to Δ Pos_{Horiz}
  - Final error of spectrometer readings of 6 keV.
  - Accuracy of 3.75e-3 was achieved for energy measurements
- Fast Energy Feedback Serial Link to RF System for 180deg. Spectrometer BPMs

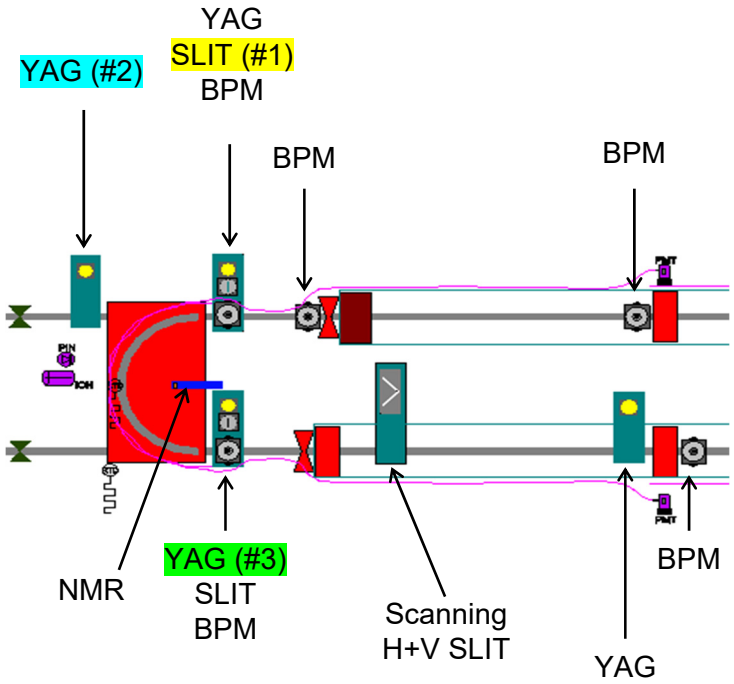


Δ H-Pos_{BPM} = ΔEnergy

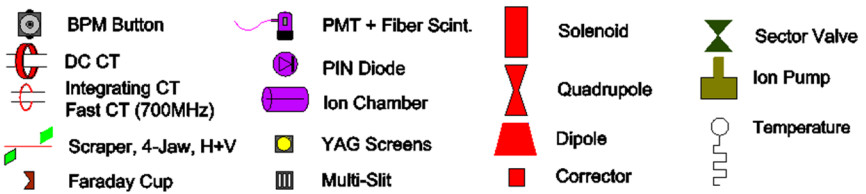
BPM Calibrated by Integral Profile Monitor ("HYBRID")

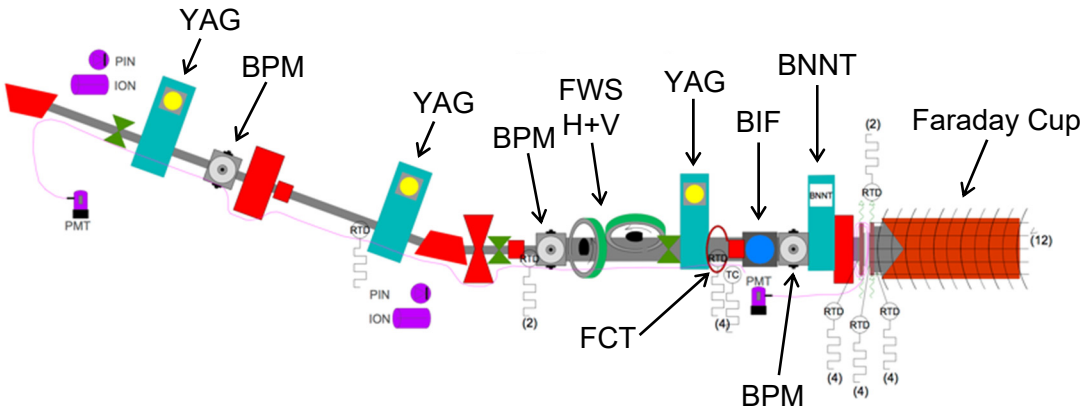
Energy Spread

- Scanning SLIT Emittance meas.
- Energy Spread meas. Scheme An energy spread measurement is required with a resolution of better than 10% of the maximum $\Delta p/p$ of 5×10^{-4}.
  1) Insert slit #1 ,turn off 180° Dipole, energize high field solenoid
  2) Take Profile on YAG #2
  3) Energize 180° Dipole & take image on YAG #3
  4) Compare images from #2 - #3 in horizontal



Extraction Line





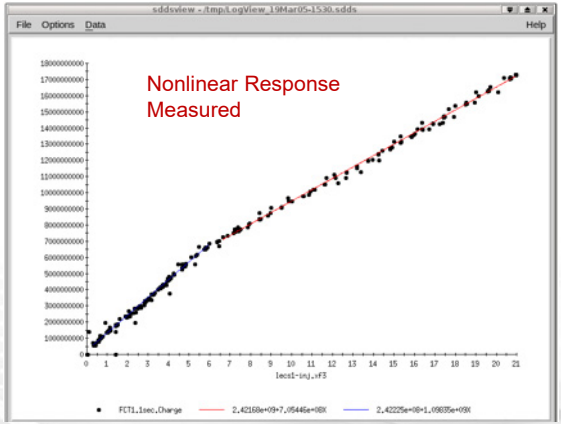
Extraction

BPM = 3
YAG = 3
FWS = 1
BIF = 1
BNNT = 1
FC = 1
FCT = 1

FCT

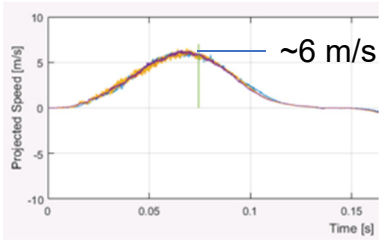
- Sensitive to bunch length
  - Longer bunch length in extraction
  - => lower current reported
- Nonlinearity In detector electronics
  - Nonlinear scale factor will be added to Zynq code

FCT Signals on Scope



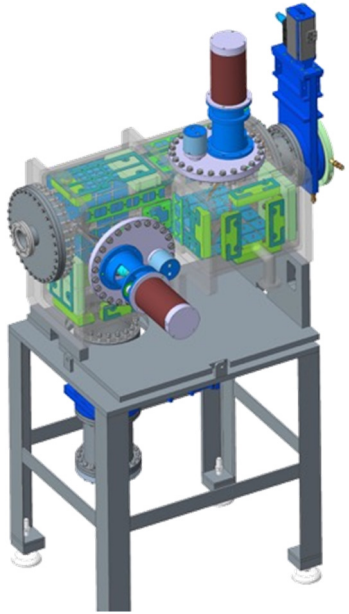
Fast Wire Scanner

- Two systems prepared
  - 1002D
    - electronics installed and tested
    - Chamber + 2 scanners: **Ready to Install**
  - Test bench in 924
    - Fully operational (dismantled)
    - Electronics, Chamber & 2 scanners (testing & spares)
- Experience gained:
  - Redesigned fork tips for lower impedance
  - Troubleshooting effects of cable breakage on motion control
  - Failure and repair of motor-drive power amplifier
  - GUI development for expert interface
  - Tested Scintillator PMT detector with beam – yielded design location and shielding design
  - Plan to use 50 μm gold plated tungsten wire with 300 μm copper plated ends for connection.
- What's left to do (if ever revived)
  - Commission wire breakage detection feature built in to VME controller

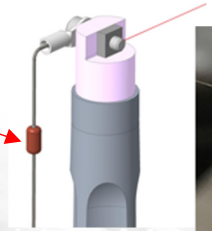


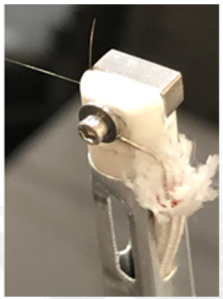
Tangential Speed


New Ferrites added to reduce the induced field that can melt the 50 μm wire



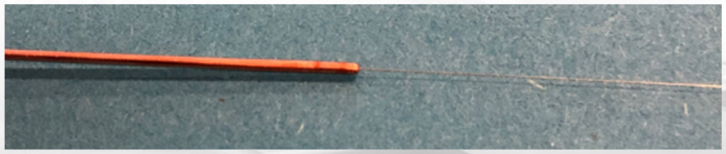
Glass encapsulated 1M resistor on one fork limits wire heating

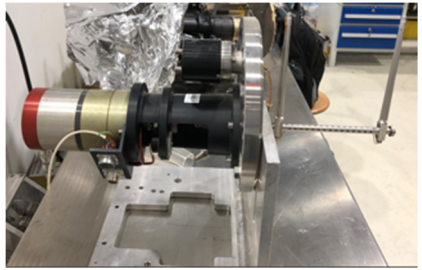




300 μm copper plated both ends

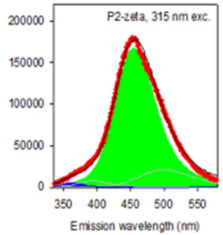
50 μm gold plated tungsten wire



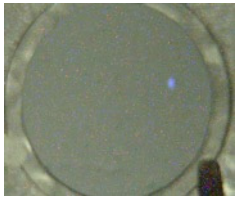

Wire scanner motor & wire forks

BNNT Screen Profile Monitor

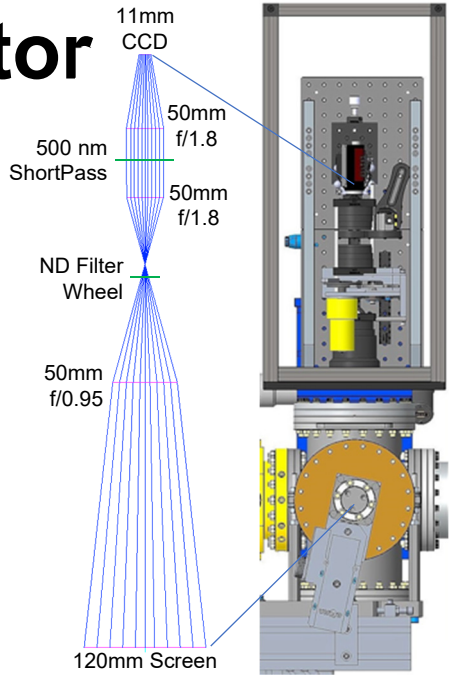
- Beam is
  - ~⦰70mm$_{FW}$
  - 38 mA @ 1.6 MeV => ~ 100W in screen => 780ºC “red hot”
- BNNT screen (120 mm square)
  - 45º angle – Active area on beam axis is 120 mm x 86 mm
  - BNNT paper shall be 140mm x 140mm overall to be clamped by Invar U-shaped open-ended frame
- Optics
  - GT1930 camera w/ Navitar DO5095 f/0.95 lens – close to viewport (9” WD only)
  - Scheimpflug angled CCD for 45º screen
  - 500nm shortpass filter to image ~450nm emission and block thermal emission
  - ND filter wheel to study thermal emission



BNNT predicted emission spectrum

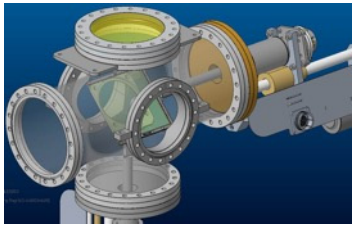


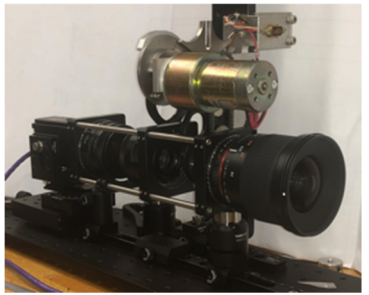
Test at JLAB, 10 Gev electron beam at 11 nA. *(courtesy of Kevin Jordan)*

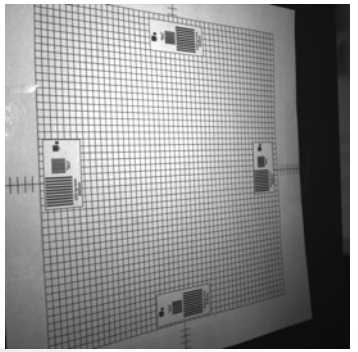


Optical schematic

Side view of chamber & optics assy

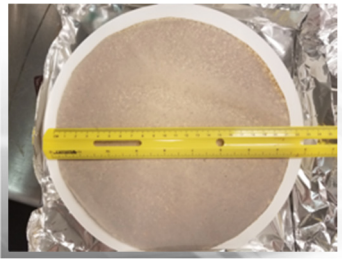




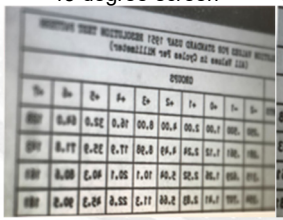


Equivalent BNNT screen size

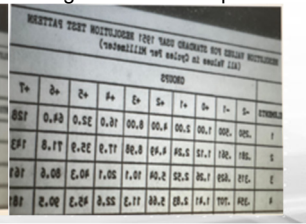
large 50um BNNT paper (⦰215mm)



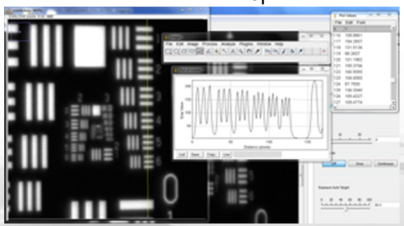
Limited depth of field with 45 degree screen



Scheimpflug tilted CCD for 45 degree tilted focus plane



Resolution of 176µm

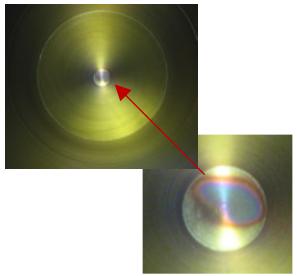


BROOKHAVEN NATIONAL LABORATORY

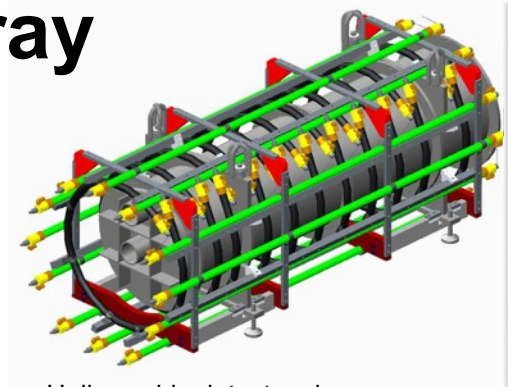
Dump Radiation Monitor Array Beam Distribution

- 23 channels Argon filled 7/8” Heliax cable as ionization chambers
  - 12 radial detectors
  - 11 axial detectors
- 12 ion chamber “pinhole” detectors outside of shielding

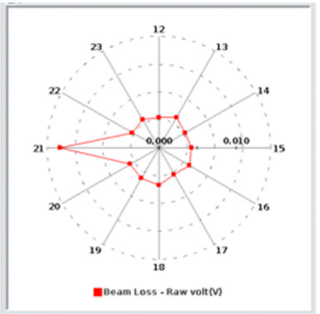
Near miss of focused beam in dump

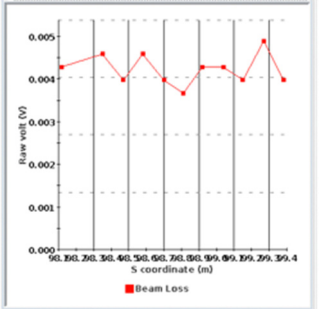


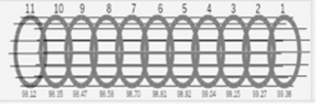
Discoloration from hitting with focused beam.



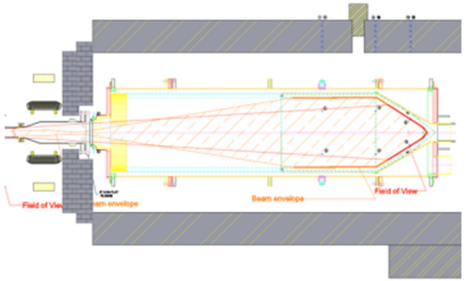
Heliax cable detectors in array around beam dump (above)





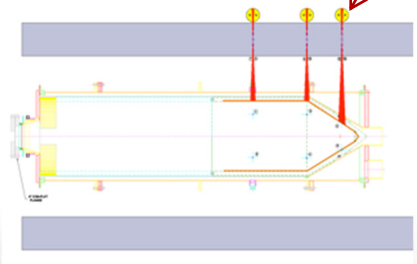


Radial & Axial Plots

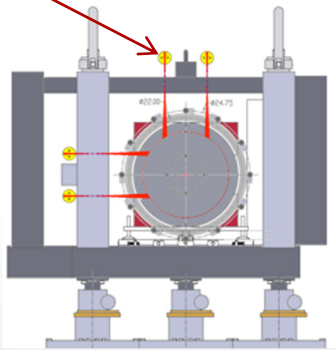


Beam distribution envelope, spread by solenoid

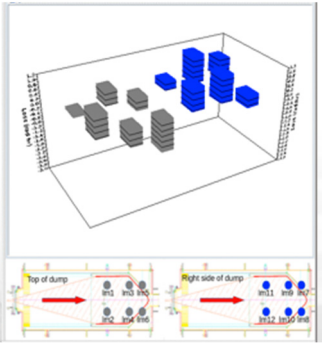
Ion Chamber BLMs



Side view of detection areas



End view of detection areas



”Pinhole” detectors on top & side of shielding.

U.S. DEPARTMENT OF ENERGY

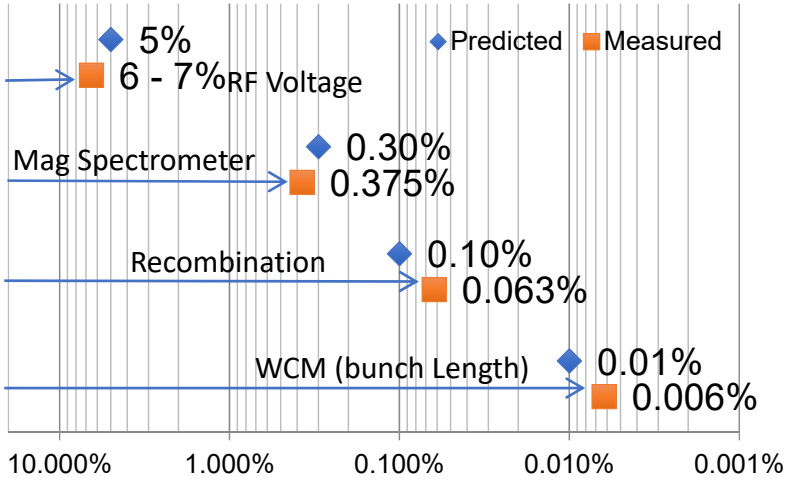
BROOKHAVEN NATIONAL LABORATORY

Roadmap to Cooling

4 steps to 10^{-4} energy matching

1. RF voltage was set to 100 kV (6 – 7%) known accuracy.
2. RF Voltage was adjusted by energy measured by the magnetic spectrometer to within 6 kV (0.3%).
3. RF phase was adjusted in steps of 1 kV (0.063%) of accelerating voltage to maximize recombination rate.
4. RF phase was adjusted in steps of 100 V (0.006%) of accelerating voltage to:
   a) minimize **ion bunch length**, measured by the RHIC wall current monitor (WCM).
   b) Minimize the **average bunch width** using the RHIC H-JET profile monitor.

Energy Matching for Cooling

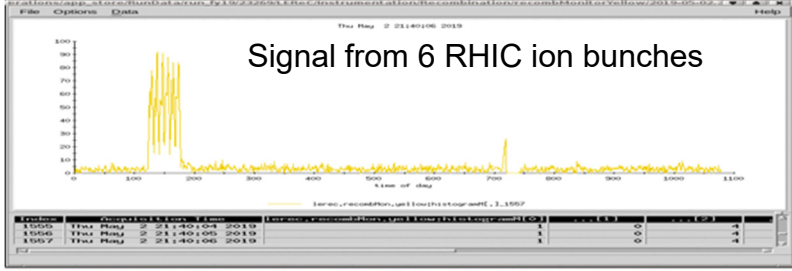


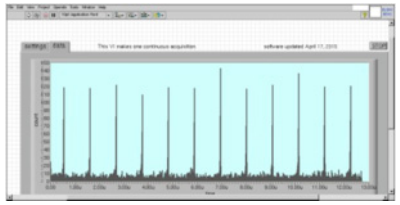
Key Instruments:

- Mag. Spectrometer
- Recombination Mon.
- Wall Current Mon.
- H-JET bunch width mon.

Recombination Monitor

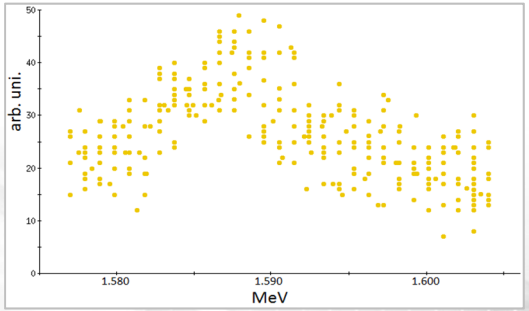
- Scaler counter of recombination events
  - The recombination monitor was used to match IONs and Electrons energy with accuracy of ~1 keV (6.25E-4).
  - Also, it gave confirmation of 180-degree magnet absolute energy measurements system calibration.
- Time Digitizers (Agilent 53230A) set up for bunch by bunch recombination monitoring.
  - Independent Blue & Yellow Systems
  - Recombination of one bunch next to a non-overlapped bunch was not observed.
    - Frequent changes to tunes & beta function caused the loss of the dispersion bump lattice required to detect recombined ions.



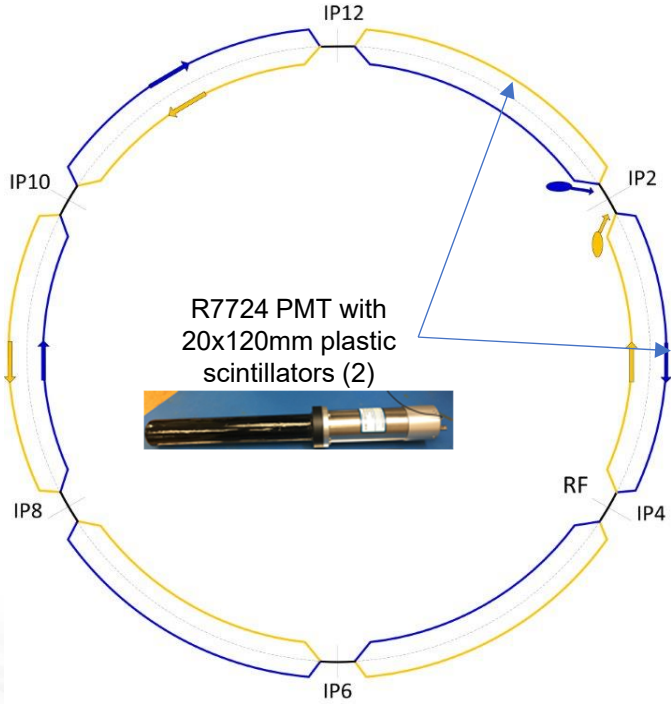


Timing bins show RHIC bunches (only 12 filled in ring)

Agilent 53230A Time Digitizer sync'd to RHIC Rev

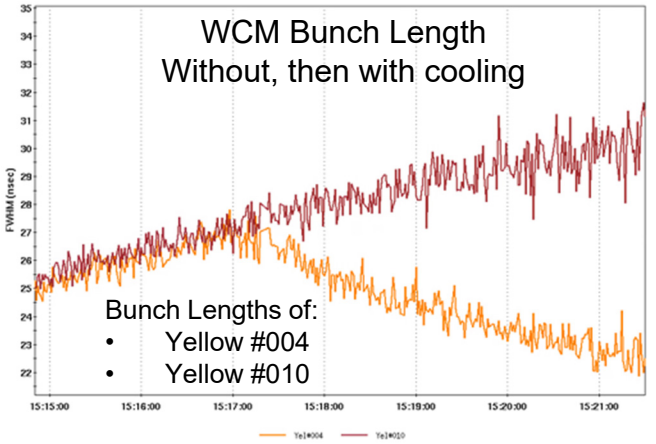


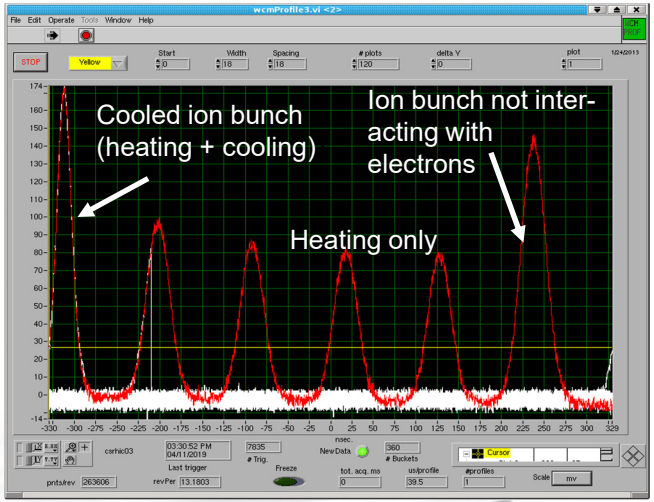
Recombination rate during the energy scan. PSD readings are given on y-axis and spectrometer readings on x-axis.



Wal Current Monitor (WCM) – Bunch Length

- Used to measure individual bunch length for measuring cooling efficiency.
- Work Planned
  - New 2.5GHz scopes on order will provide:
    - Increased resolution
    - Lower noise
    - For better measurements

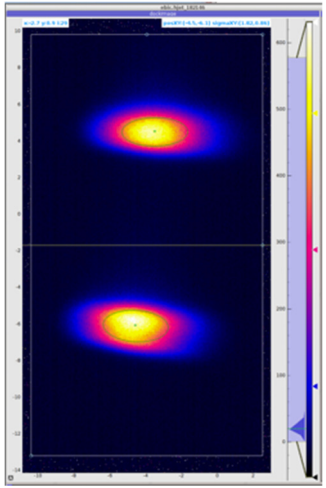




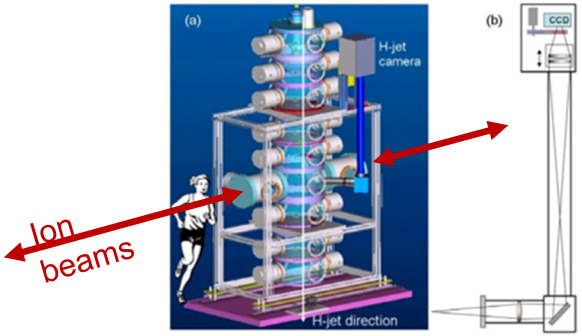
Resistive WCM on ceramic break

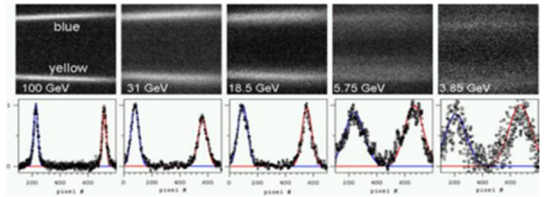
H-Jet
Bunch Width

- Camera improvement (G145 -> GT1930):
  - temporal dark noise reduced form 11.5e to 3.3e
  - Size increased from 2/3” to 1/1.2”
  - rotated 90 degree to eliminate row noise in vertical direction
- Added de-speckling to analysis.
- Achieved advantage:
  - overall sensitivity improvement ~3 times.
  - reliable beam size measurement for low intensity beam:
    - 6+ bunches with exposure 1s.
    - 1 bunch with exposure 10s.
- Beam size measurement dependencies found:
  - Varies with energy
  - Varies with bunching length
- Work Planned:
  - Study dependencies
  - Develop compensation factors

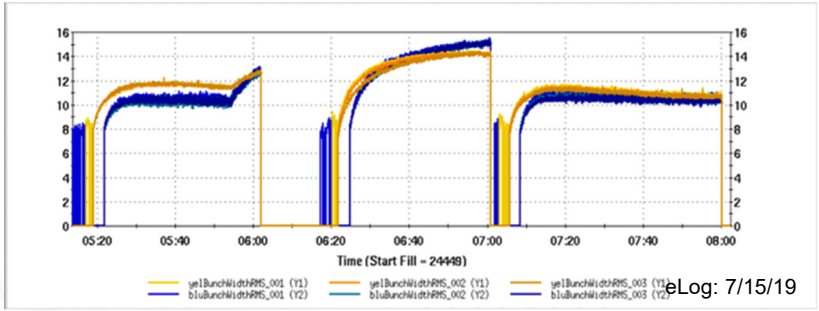


100 GeV Bem
10^{10} ions





RHIC ion beam Vertical profiles at varying energies.
All images are captured with 1 minute exposure



eLog: 7/15/19

Good cooling of full 111x111 stores to finish commissioning at 2MeV electron energy, with 3D cooling: 1) cooling ON, then OFF; 2) no cooling; 3) cooling ON.

Acknowledgements

- Thank you for the contributions of
  - R. Jones, F. Roncarlo, J. Emery, and R. Veness with **CERN** for their contributions and support of the SPS wire scanner system,
  - Kevin Jordan and Roy Whitney with **JLAB** and **BNNT, LLC** for their work to customize the BNNT screen,
  - Cyrille Thomas with the **ESS** for help with the calculations for the BIF project,
  - Cedric Germain with **Caylar** for support of the NMR Gaussmeter,
  - M. Cargnelutti with **Instrumentation Technologies** for the loan of the Libera BLM electronics.
- Special thanks also go to
  - members of the Accelerator Components & Instrumentation Group, especially A. Curcio, and D. Lehn,
  - members of the design room, especially K. Hamdi and M. Grau.