Fast Scanning Diamond Detector
ASSRC Review

SBIR-DOE Project by Applied Diamond, Inc

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Introduction

- Description

  Fast scanning in-vacuum diamond multi-pixel strip detector for electron beam halo and profile measurements

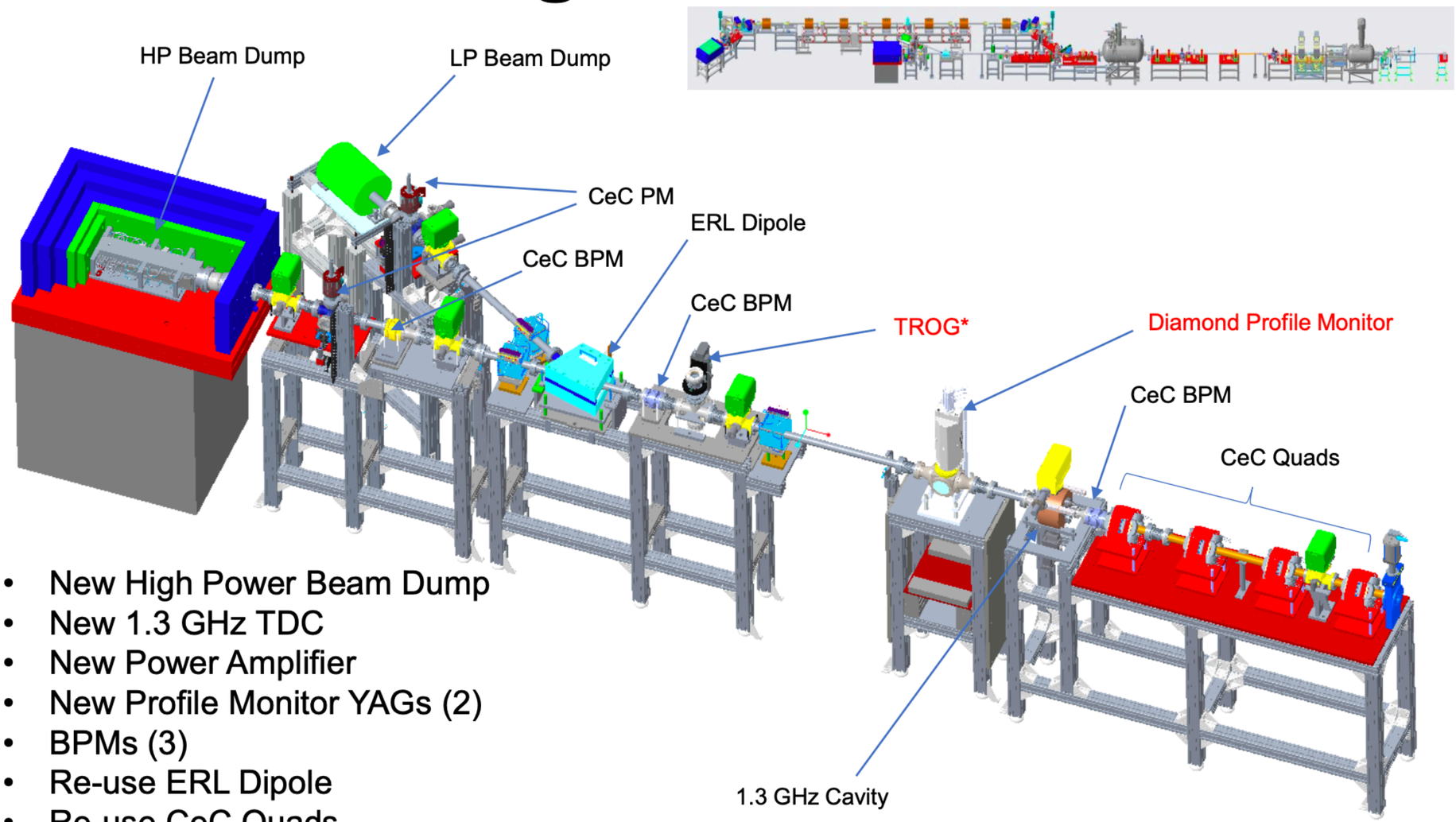
  This diamond detector will have
  - a fast time response
  - high radiation stability
  - operate at high temperatures

- Purpose – direct measurement of:
  - eBeam Halo
  - eBeam profile by fast scanning through the beam's core
  - eBeam temporal structure
- Schedule
  - Project started - February
  - ATF Testing – September
  - CeC installation – December

Review of Hazards
- To Personnel
  - Mechanical
  - Startle
  - High Voltage
  - Radiation
- To Equipment
  - Vibrational
  - Thermal outgassing
  - Debris from damage
  - Beam impedance
  - Radiation Damage

- Cliff presented the beam line layout
- Diamond detector is upstream of the TROG

2020 Diagnostics Beamline

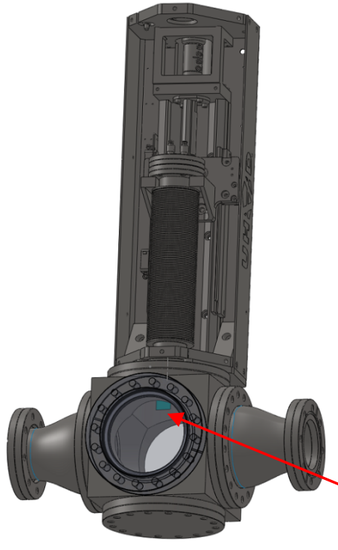


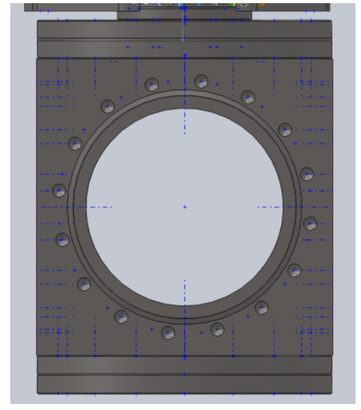
- New High Power Beam Dump
- New 1.3 GHz TDC
- New Power Amplifier
- New Profile Monitor YAGs (2)
- BPMs (3)
- Re-use ERL Dipole
- Re-use CeC Quads
- Re-use CeC LE Beam Dump
- New ICT

* TROG: Temporally Resolved Optical Gating, for an electro-optic longitudinal profile monitor system

Diamond Detector

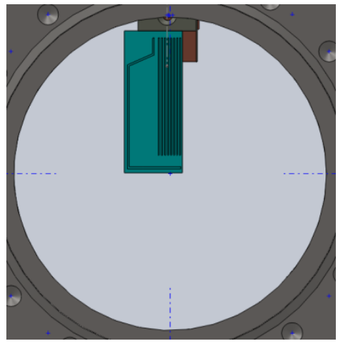
- Polycrystalline diamond plate: 46 x 19 x 0.1 mm
- Boron doped electrodes:
  - 1 x Horizontal pick-up
  - 8 x Vertical pick-ups
  - 9 x 50 Ω transmission lines
- Diamond brazed to WC interface attached to copper support rod
- Copper rod provides heat sink
- 50 Ω transmission lines on aluminum-nitride PCB to vacuum feedthrough
  - Not shown here
  - Dedicated R&D efforts planned for this
- 10 SMB coaxial feedthroughs provide 9 signals + 1 isolated ground
- Ultra-fast linear actuator, speed up to 1 m/s
- Detector insertion time into the beam core, about 20-50 ms.



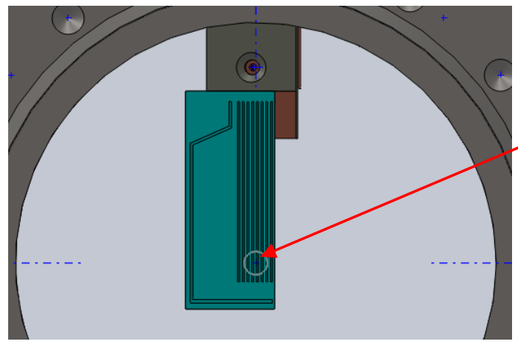


STROK= 0 mm
(fully retracted diamond)

- Thermal Outgassing Hazard
  - Materials are suitable for UHV & high temperature and include:
    - Diamond
    - Tungsten Carbide
    - Copper
    - Kapton
    - SS signal feedthroughs with alumina insulator



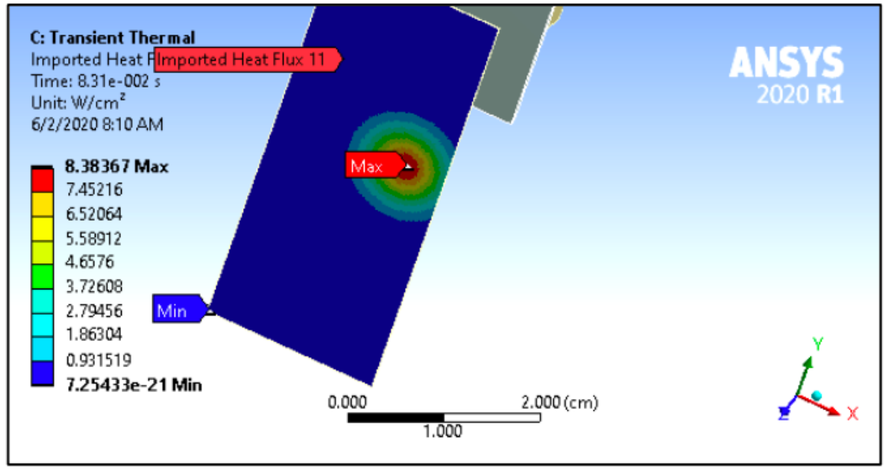
STROKE = 52mm
(diamond edge at the center)



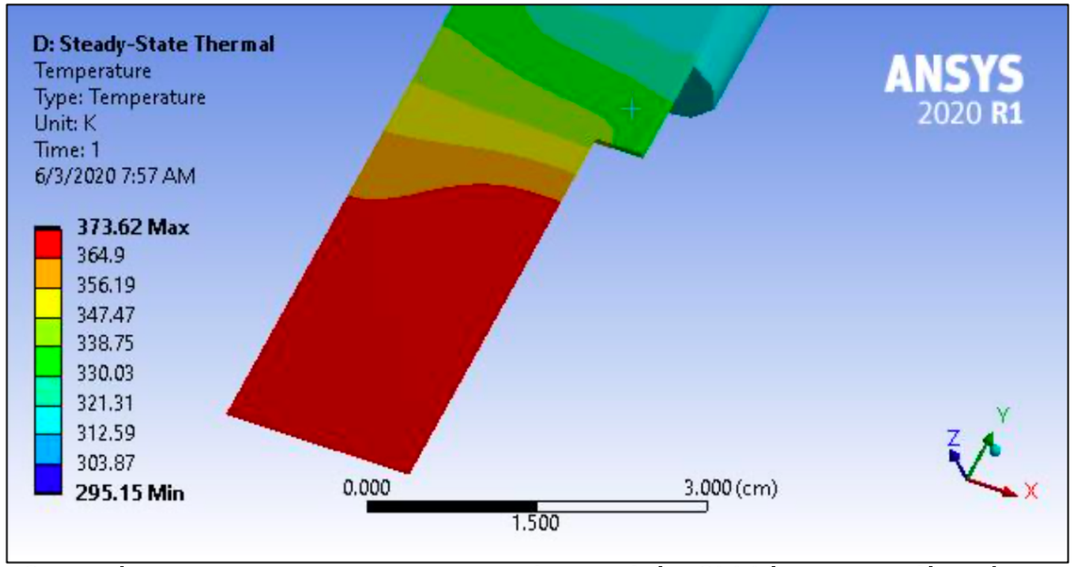
STROKE = 61mm
(fully inserted diamond, return point)

Thermal Modeling

- Thermal simulations were made by Steve Bellavia using Creo 6 and brought into ANSYS 2020 R1 for both steady state and transient thermal analysis.
- CeC beam conditions were:
  - 1 nC pulses @ 78 kHz
  - 5 – 15 MeV
- Test configurations were:
  - Fixed
    - Normal
    - 45 degrees
  - Scanning
    - Normal
    - 45 degrees
- Final results showed
  - < 80C temperature rise under the worse conditions.
  - Scanning detector's temperature recovered in 5 – 10 seconds.
- Damage debris Hazard
  - Diamond shows negligible thermal shock due to low temperature rise



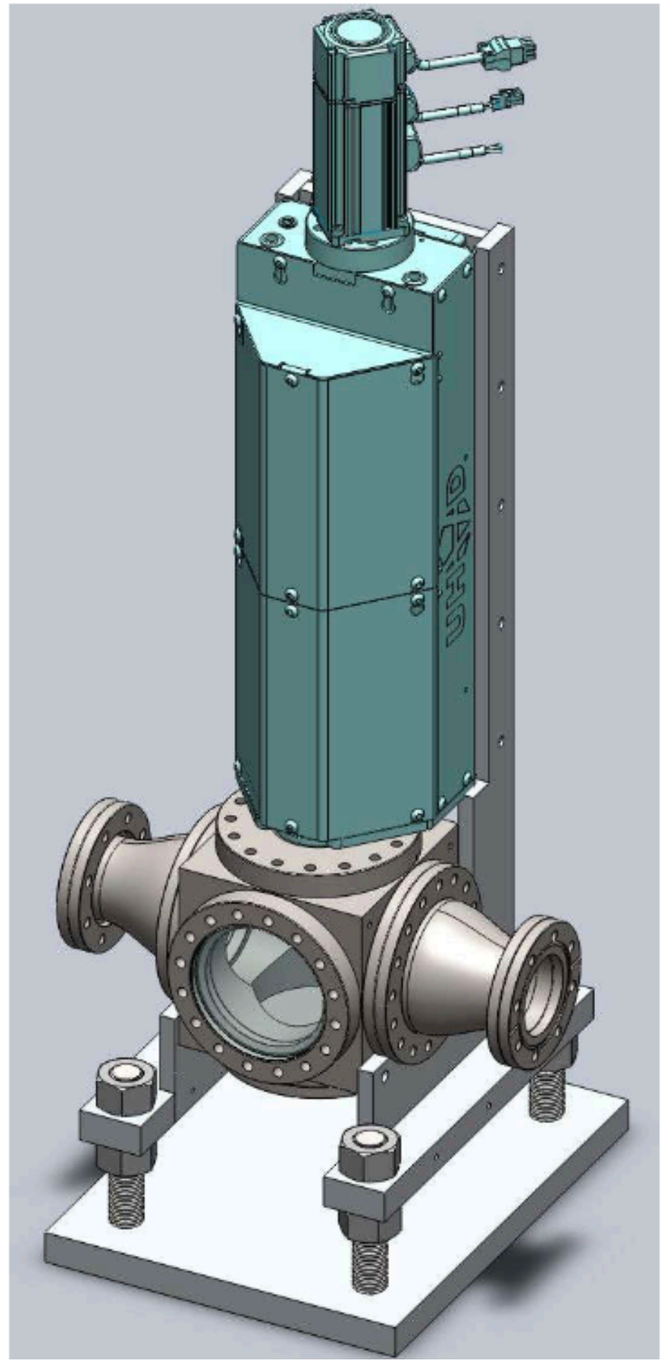
Gaussian beam spot, simulated interaction with diamond detector. Normal to beam shown.



Steady state temperature rise with CW beam, tilted orientation.

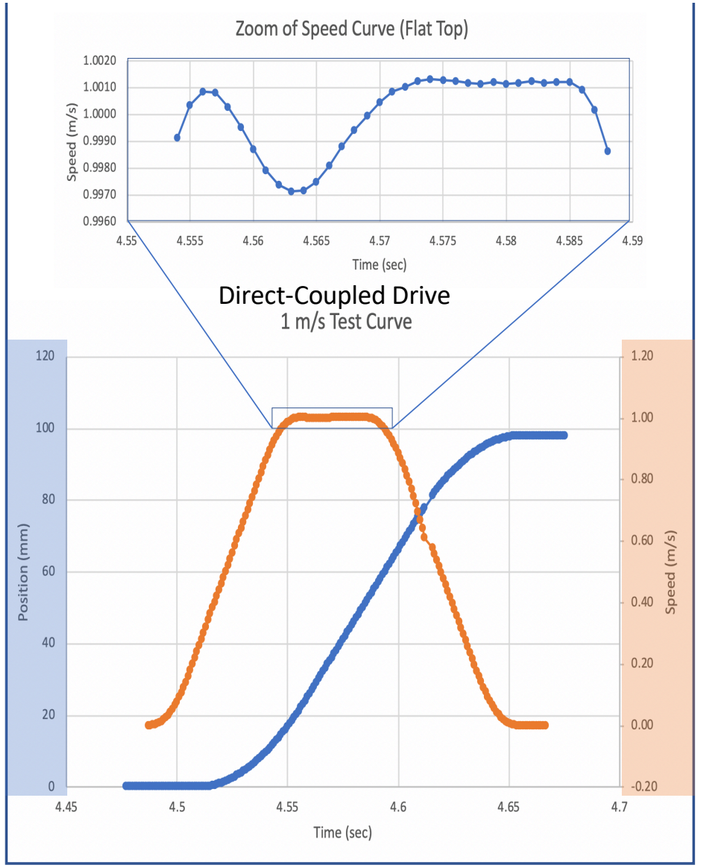
Vacuum Chamber

- 6-inch vacuum cube
  - 1 x 6” ITO coated Viewport
  - 2 x 6” to 4.5” conical reducers
  - 2 x 6” blank flanges
  - 1 x 6” to 2.75” Z/L reducer
- Actuator
  - High speed actuation up to 1m/s with 1.5kg load
  - 100 mm stroke
  - No port aligner for max rigidity
  - Custom feedthrough – 2.75”CF
    - ¾” Cu support rod
    - 10 x SMB signal coaxial feedthroughs
- Vibration
  - High speed actuation may cause significant vibration
  - Reinforced stand is required
- Support
  - Actuator support frame (extra sturdy for vibration damping)
  - Chamber cradle adapter
  - Threaded support post

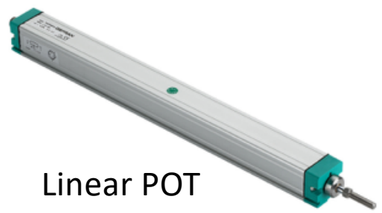


Fast Linear Actuator

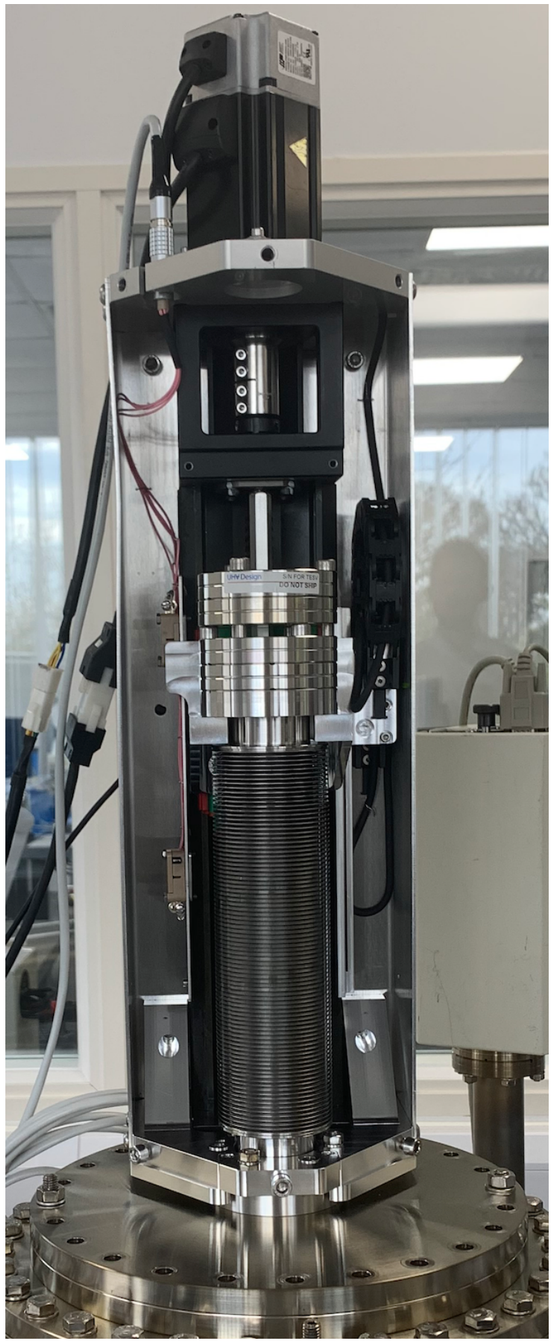
- Pinch Hazard:
  - All moving parts behind covers
- Startle Hazard:
  - Servo motor is very quite
- Applied Motion Servo drive
  - 3-phase 400W motor
  - Controller SV2A3-Q-AE
    - Tested with >100 m of cable with good results
  - Linear Position
    - Infinite resolution
    - Up to 60V operation (for better signal-to-noise)
    - Analog output digitized along with diamond detector signal by F460 local electrometer/digitizer
- Motion Profile to scan through beam
  - Move in at max acc. and move out max acc.



Motion profile for max speed 1 m/s & high acceleration.

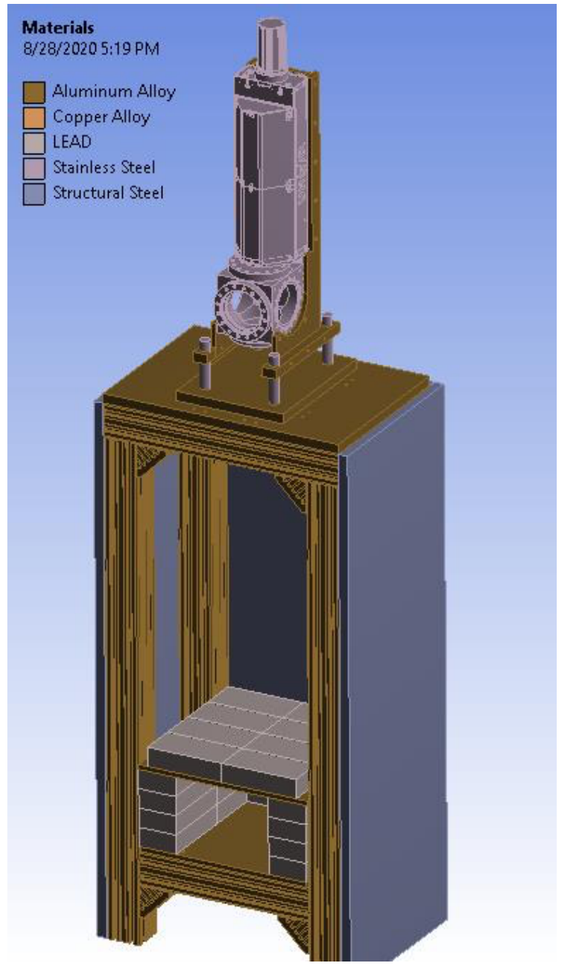


Linear POT



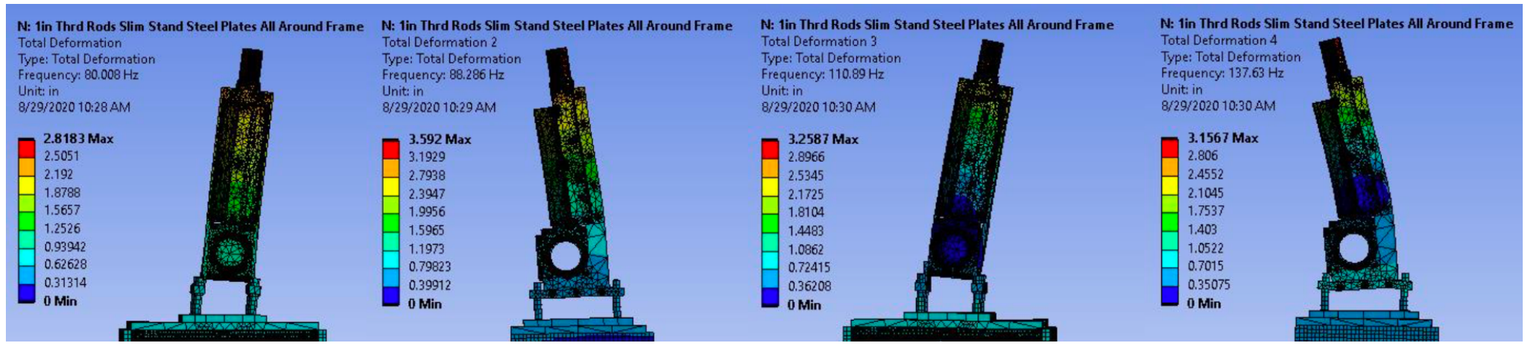
Vibration Modal Analysis

- Inertial forces from 3kg @ 2 g acceleration.
- Modal analysis ran by Cliff Brutus with the goal of reducing the mechanical resonances to below 100 Hz.
- Many mechanical configurations were tried.
- Most cost-effective approach was Aluminum Rexroth stand reinforced by steel plates with a minimum f = 80 Hz.
- Vibrational Hazard
  - This design limits vibrational “noise” from affecting nearby devices (such as the TROG).

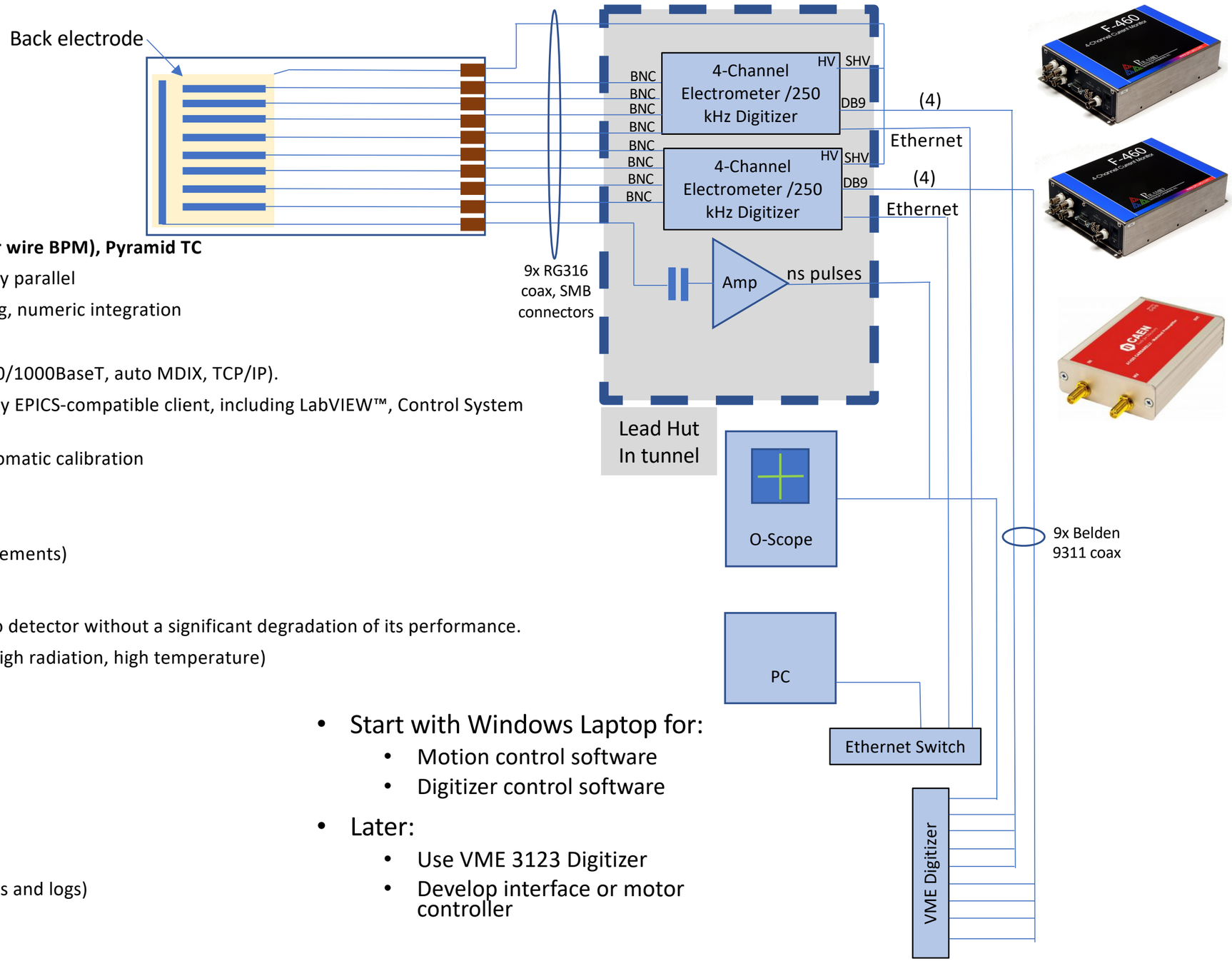


Rexroth stand with steel plates for reinforcement

Exaggerated deformations showing vibrational modes and resonant frequencies.



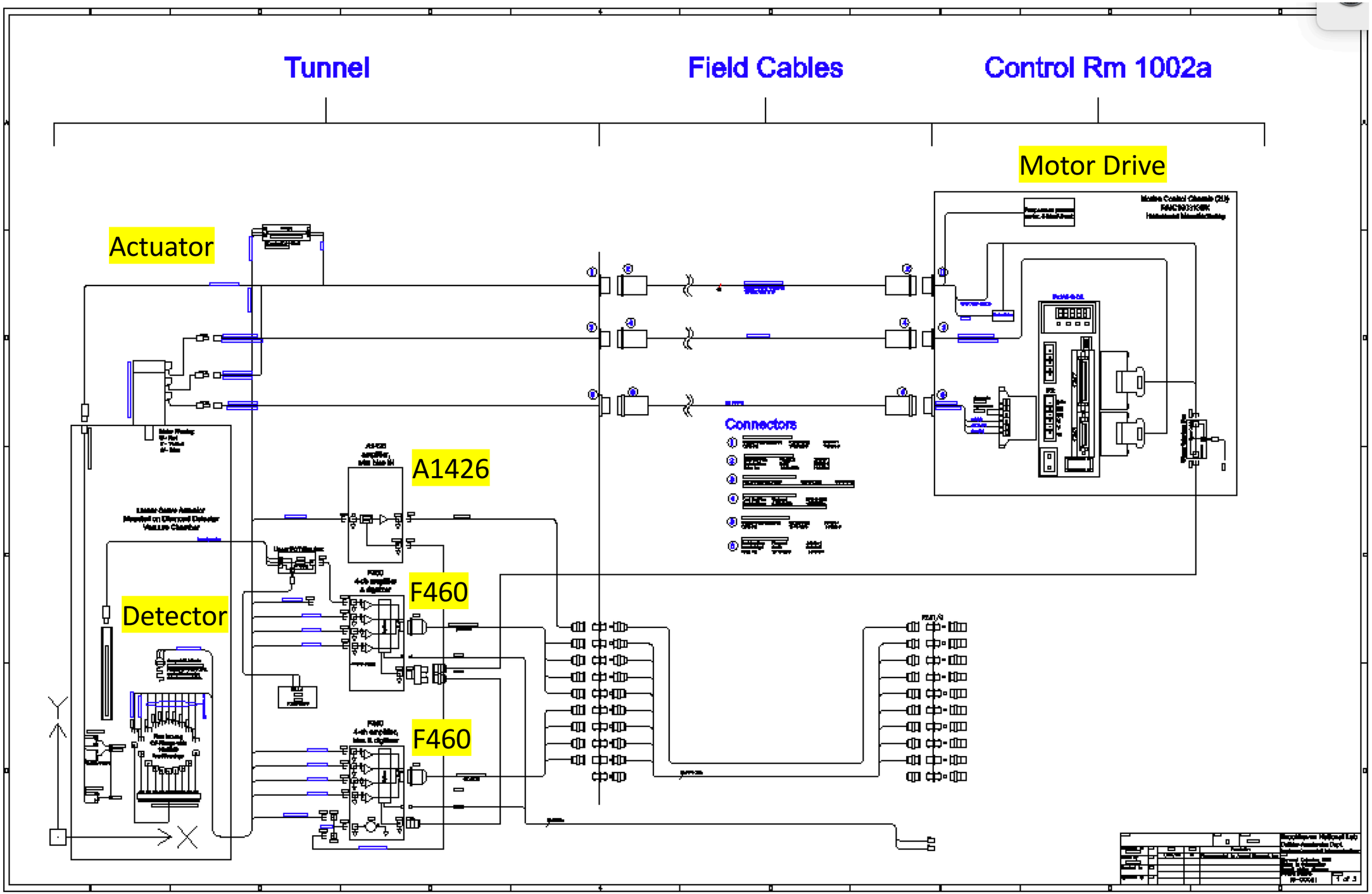
Electronics



- **8 channel (2 x 4ch) F460 fast electrometers (designed for wire BPM), Pyramid TC**
  - Dynamic range 0.1 nA to 1mA, 16 bit 250 kHz, fully parallel
  - Integrated digitization and filtering, bulk averaging, numeric integration
  - On-board data buffer (up to 50000 samples)
  - Fiber-optic, RS-232 / RS-485 and Ethernet (10/100/1000BaseT, auto MDIX, TCP/IP).
  - IG2 EPICS interface service allows control from any EPICS-compatible client, including LabVIEW™, Control System Studio, Matlab™, C#, C++, Python.
  - Two internal precision calibration sources for automatic calibration
  - Independent channel gain control
  - External trigger capability
  - Servo controller option (based on current measurements)
- **Broadband Preamplifier CAEN A1426**
  - Fast and low noise. Allows a long 50 ohm cable to detector without a significant degradation of its performance.
  - Designed for detectors in hostile environments (high radiation, high temperature)
  - Sensitivity up to 5 mV/fC
  - Input pulse width 100 ps to 8 ns
  - AC Input, 50 Ω.
  - Detector HV 1000 V
- **Remote Signal Analysis**
  - Oscilloscope, ns pulses
  - PTCDiagnosticG2 software for F460 (displays, plots and logs)
  - Actuator control software

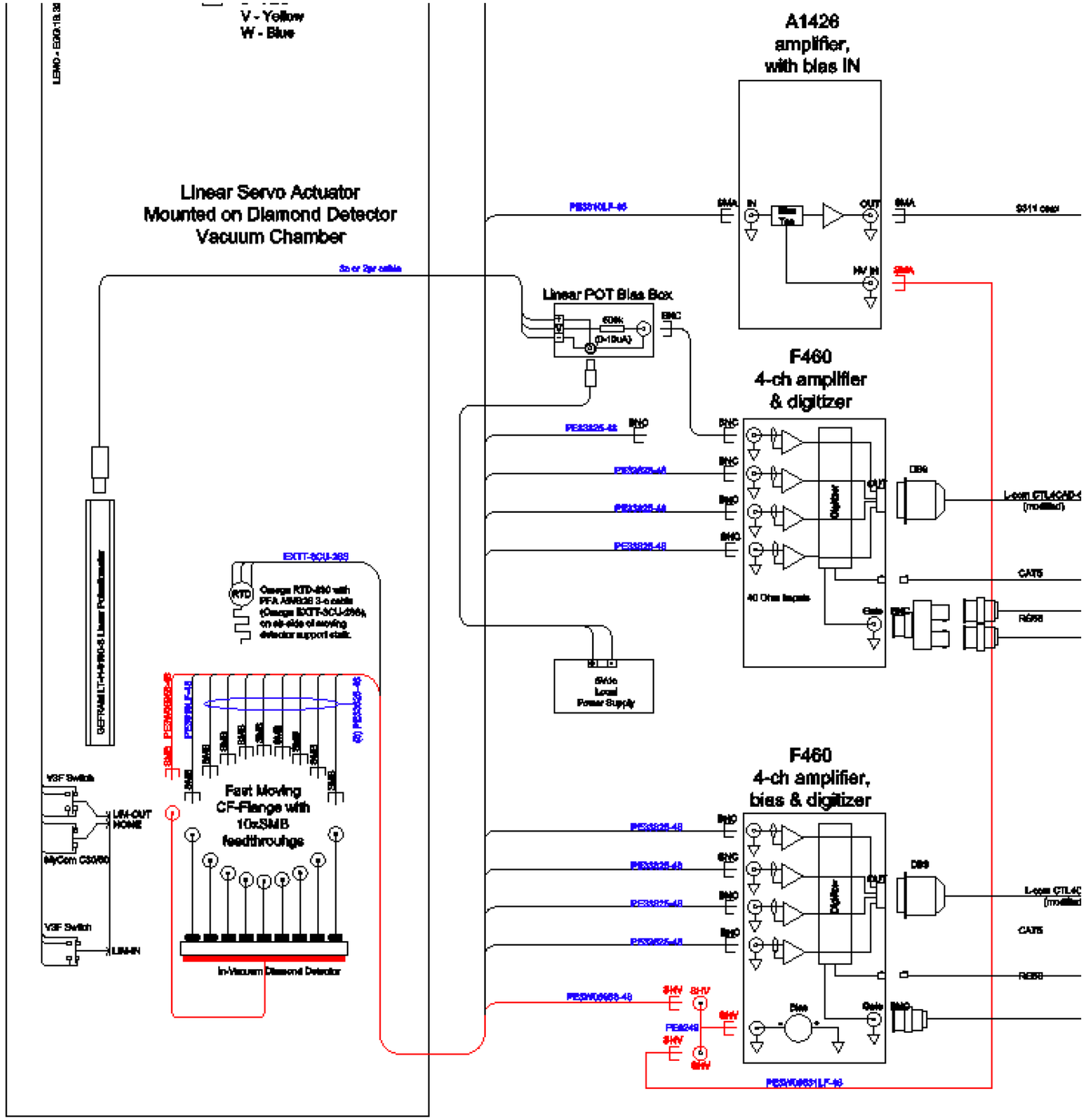
- Start with Windows Laptop for:
  - Motion control software
  - Digitizer control software
- Later:
  - Use VME 3123 Digitizer
  - Develop interface or motor controller

Wiring


Tunnel
Field Cables
Control Rm 1002a
Motor Drive
Actuator
A1426
F460
Detector
F460
Connectors

F460 provides Bias

- Bias voltage up to 500V
- High Voltage Hazard
  - SHV connector output
  - At-risk connectors need heat-shrink & HV label:
    - SMB connector on detector
    - SMA connector on amplifier
- System will first be used without bias connected.
  - Tests at the ATF will show if it is necessary.

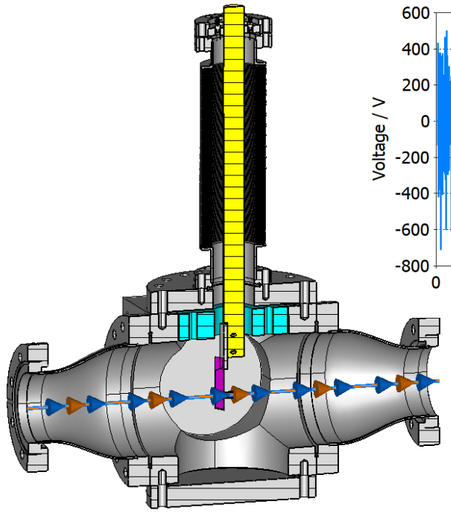


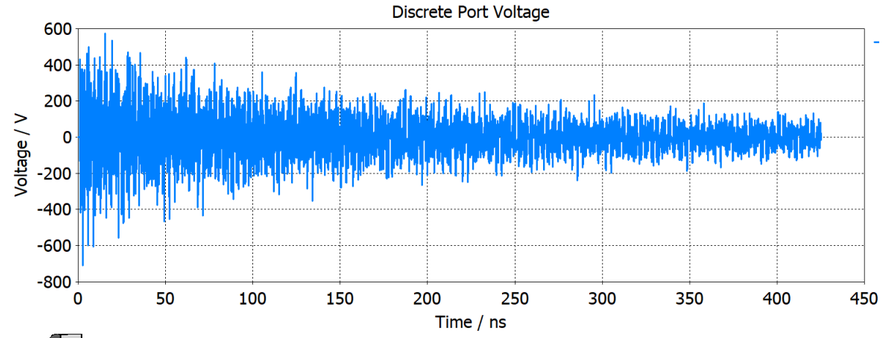
Radiation Generation

- Diamond had direct interaction with electron beam
- Interaction calculations made by Peter T. for thermal load estimate
  - Need to apply to radiation generation estimate
- Radiation Hazard:
  - Hazard to Personnel
    - Tunnel is closed when device interacts with beam
  - Hazard to Equipment
    - Frequency of operation can be limited to as a function of integrated dose generated
    - There will be one dedicated PMT

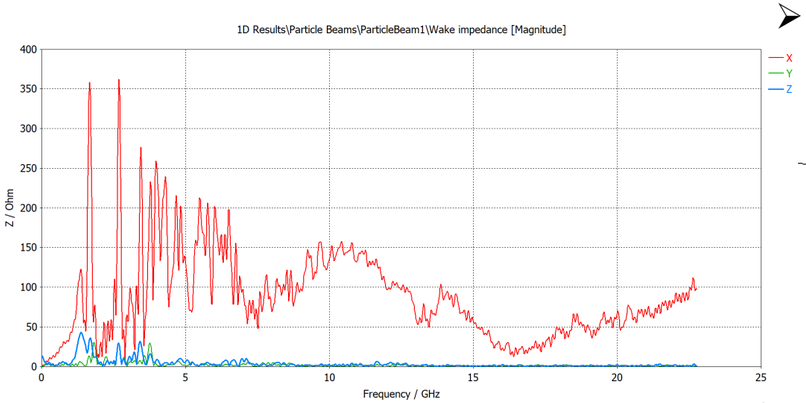
Electrical response and Wakefield Impedance Simulations

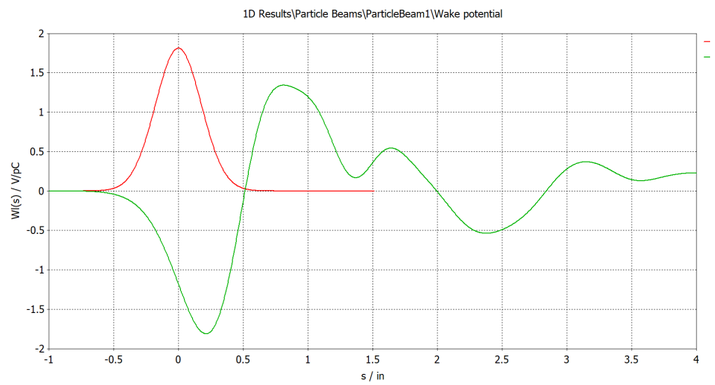
- Configuration:
  - Detector is held by a long copper stalk through a bellows, making a coaxial oscillating structure.
  - Chamber expands abruptly from a small beam pipe.
- Electrical response to a beam pulse was simulated in Particle Studio by Peter T.
  - With a bunch frequency of 78 kHz, there is enough time for the induced oscillations to decay before the next bunch arrives, even without any ferrite.
- Wakefield impedance to the beam was simulated by Peter T.
  - The wake effects are not significant given the relatively large amount of time between 78kHz bunches.
- Beam Impedance Hazard
  - The wake effects will probably have no significant impact on the bunch given the single pass operation of the CeC diagnostic line.



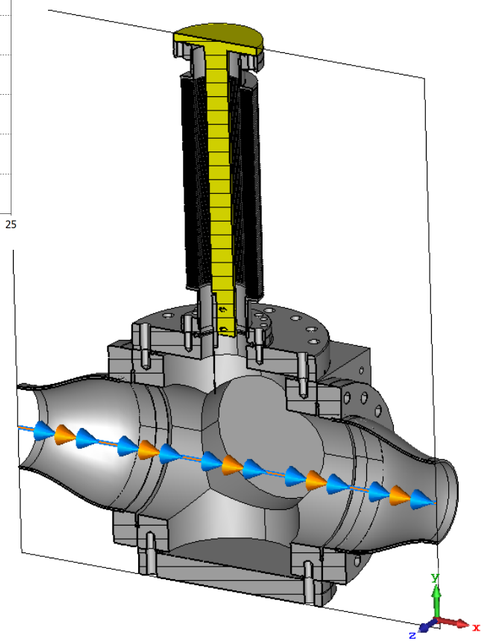


- Detector voltage with respect to ground for 5nC, 100ps FWHM bunches.
- With 1.5 nC instead of 5, the amplitudes will be correspondingly smaller.





➢ Simulated wake effects of chamber with with retracted detector.



Conclusion

Summary of Hazards

- <u>To Personnel</u>
  - Mechanical - All moving parts are behind covers
  - Startle - Servo motor is very quite
  - High Voltage:
    - SHV connector output from source
    - SMB & SMA connectors need heat-shrink & HV label
  - Radiation - Tunnel is closed when device interacts with beam

- <u>To Equipment</u>
  - Vibrational – A reinforced support design limits vibrational “noise” from affecting nearby devices.
  - Thermal outgassing - Materials are suitable for UHV & high temperature
  - Debris from damage - Diamond shows negligible thermal shock due to low temperature rise
  - Beam impedance - significant impact with the long 12.8 µs space between bunches
  - Radiation Damage - Frequency of operation can be limited to as a function of integrated dose generated