# Report on the list of actions for restarting the LINAC

## LINAC/FEL meeting #3

Bidault Niels
University of Hawaii at Manoa
Department of Physics and Astronomy

September 11th, 2024

# Progress towards restarting the linac

- HV Tests of the Thyratron
- Electron gun cathode reassembly
- Vacuum leaks in the RF gun sector
- Other projects

# HV Tests of the Thyratron

Data of April 2024 before opening the vault for leak chasing

| HV Conditioning | Day 1 | 04/23/2024 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Duration (min) | Voltage (kV) | Rep. Rate (Hz) | Perveance (uPerv) | Ion pump LabView (uA) | Ion pump Varian (uA) | Kly. fil. I (A) | Kly. fil. U (V) | Kly. fil. P (W) | Clam |
| 5 | 8.5 | 1 | | | | | | | |
| 5 | 16 | 1 | | | | | | | |
| 5 | 24 | 1 | 1.91 | 0.21 | 0.31 | | | | |
| 5 | 24 | 4 | 1.91 | 0.6 | 0.62 | | | | |
| 5 | 33 | 1 | 1.79 | 0.31 | 0.41 | 16 | 23.3 | 372.8 | |
| 10 | 33 | 4 | 1.81 | 0.84 | 0.95 | 16 | 23.4 | 374.4 | |
| 15 | 33 | 10 | 1.83 | 1.4 | 1.5 | 16 | 23.55 | 376.8 | |
| 5 | 35.35 | 1 | 1.78 | 0.32 | 0.45 | 16.05 | 23.3 | 374.0 | |
| 10 | 35.35 | 4 | 1.8 | 0.87 | 1 | 16.05 | 23.4 | 375.6 | |
| 15 | 35.35 | 10 | 1.81 | 1.5 | 1.7 | 16.05 | 23.45 | 376.4 | |
| 10 | 36.01 | 4 | 1.79 | 0.9 | 1 | 16.05 | 23.4 | 375.6 | |
| 10 | 36.47 | 4 | 1.78 | 0.89 | 1 | 16.05 | 23.35 | 374.8 | |

| HV Conditioning | Day 2 | 04/24/2024 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Duration (min) | Voltage (kV) | Rep. Rate (Hz) | Perveance (uPerv) | Ion pump LabView (uA) | Ion pump Varian (uA) | Kly. fil. I (A) | Kly. fil. U (V) | Kly. fil. P (W) | Clam |
| 5 | 8.5 | 1 | 2.18 | 0.1 | 0.15 | 15.7 | 23.4 | 367.4 | |
| 5 | 16 | 1 | 2.01 | 0.13 | 0.2 | 15.85 | 23.25 | 368.5 | |
| 5 | 24 | 1 | 1.91 | 0.18 | 0.27 | 15.9 | 23.25 | 369.7 | |
| 5 | 24 | 4 | 1.93 | 0.42 | 0.5 | 15.9 | 23.45 | 372.9 | |
| 5 | 33 | 1 | 1.8 | 0.26 | 0.36 | 16 | 23.3 | 372.8 | |
| 5 | 33 | 4 | 1.82 | 0.68 | 0.78 | 16 | 23.4 | 374.4 | |
| 10 | 33 | 10 | 1.82 | 1.2 | 1.7 | 15.95 | 23.5 | 374.8 | |
| 5 | 35.35 | 1 | 1.77 | 0.28 | 0.4 | 16 | 23.2 | 371.2 | |
| 5 | 35.35 | 4 | 1.79 | 0.72 | 0.8 | 16 | 23.3 | 372.8 | |
| 10 | 35.35 | 10 | 1.8 | 1.4 | 1.7 | 16 | 23.4 | 374.4 | |
| 10 | 36.01 | 4 | 1.79 | 0.8 | 0.85 | 16 | 23.3 | 372.8 | |
| 10 | 36.47 | 4 | 1.77 | 0.8 | 0.89 | 16 | 23.35 | 373.6 | |

## LabView Application:

- Perveance interlock threshold hardcoded and too high
- Corrections on the application are needed
- The control system generally works
- Add better visual information and logging of the data

## Thyratron and PFN commissioning:

- Need to repeat the procedure several days before expecting it to work
- Able to reach the last step of the procedure
- Better understanding of the interlocks and schematics

## To do:

- More commissioning test will give better indication of the long-term behaviour of the machine
- The stability of the output pulse needs to be better analysed
- Deploy a consolidated LabView

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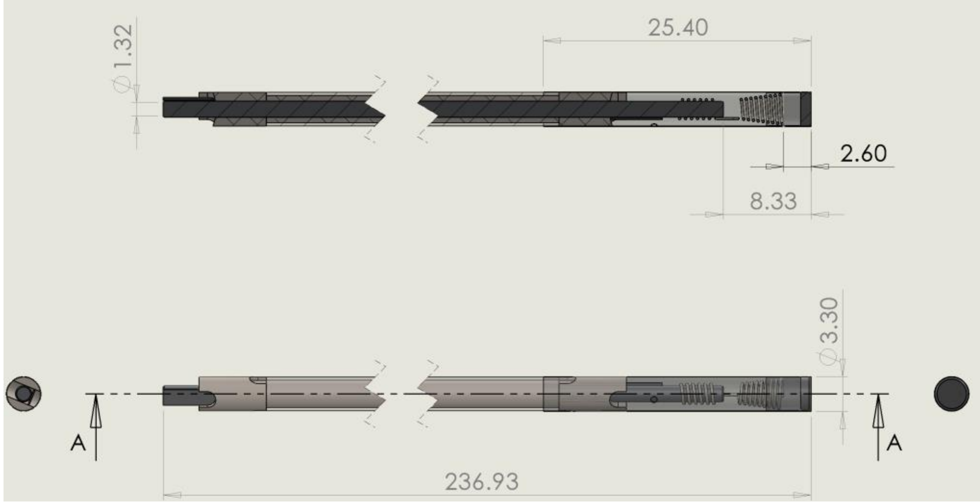
# Electron Gun Cathode Assembly

**Possible defects:**

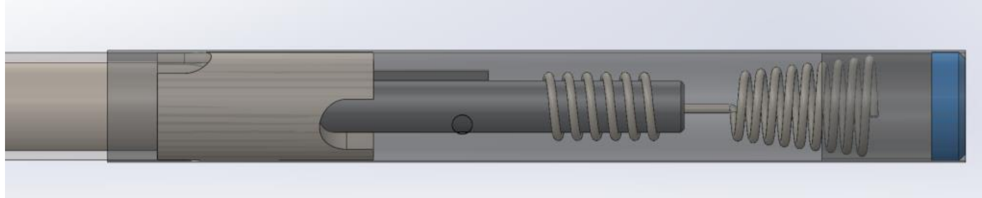
- Add more metrology to the procedure when the cathode is installed in the micrometre:
    - Measure the angle of the cathode surface (e.g. with a dial indicator)
    - Measure the angle of the cathode rod
- Not the “cleanest” assembly – cured during the baking out

**LaB6 button installed:**

- “Cathode #5” used and installed on 11/28/2011
- Last of the available cathodes with no scratch and good geometry.

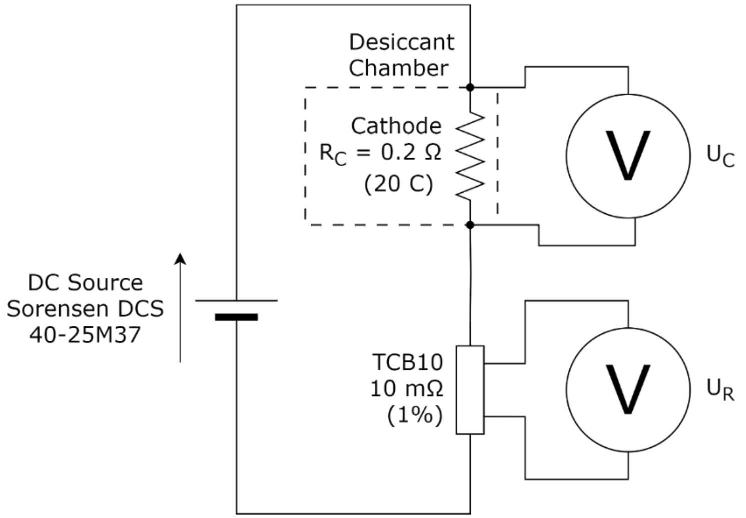



Height: 1.04 mm
OD: 3.21 mm
Bevel: 0.3 mm
(45 deg.)



# Cathode powering test and bake-out

Electrical components during the test:




- Measure $U_r$ and deduce the current I
- Measure $U_C$ and deduce the resistance $R_C$ (RIGOL DM858 for variations over time)
- Deduce Joule and radiation heating

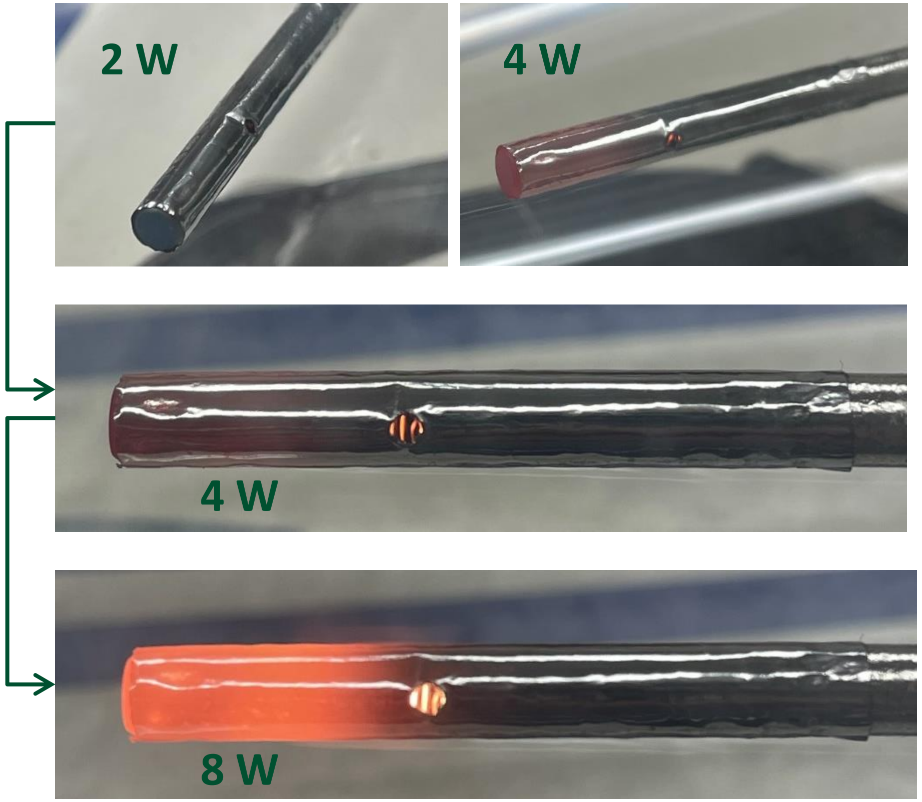
Bake-out:

$P_{start}$ = 1.10$^{-7}$ Torr
$P_{peak}$ = 5.10$^{-6}$ Torr
$P_{final}$ = 7.10$^{-8}$ Torr

$P_{start}$ = 7.10$^{-8}$ Torr
$P_{peak}$ = 3.10$^{-6}$ Torr
$P_{final}$ = 4.10$^{-8}$ Torr

Pump cart pressure
>?>
Real pressure

Aspects of the cathode during the powering steps:



# Temperature of the Tungsten heating coil

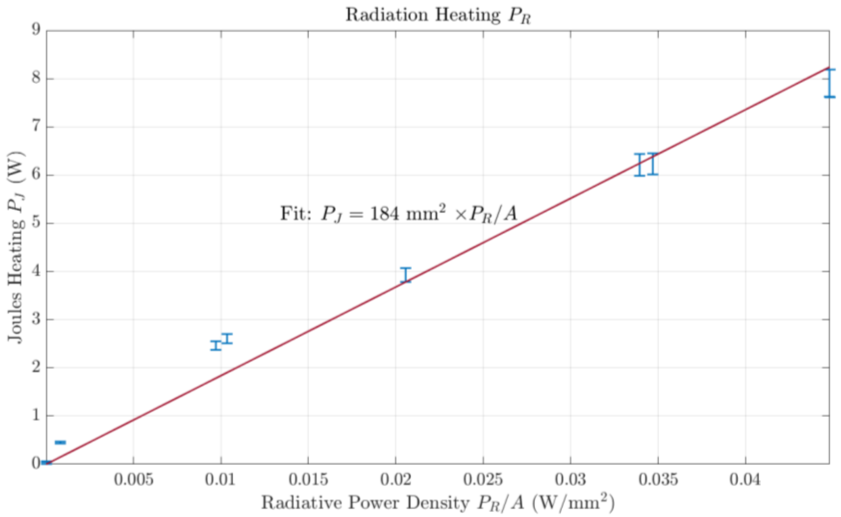
Properties of Tungsten available

- Thermal resistivity α as a function of the temperature

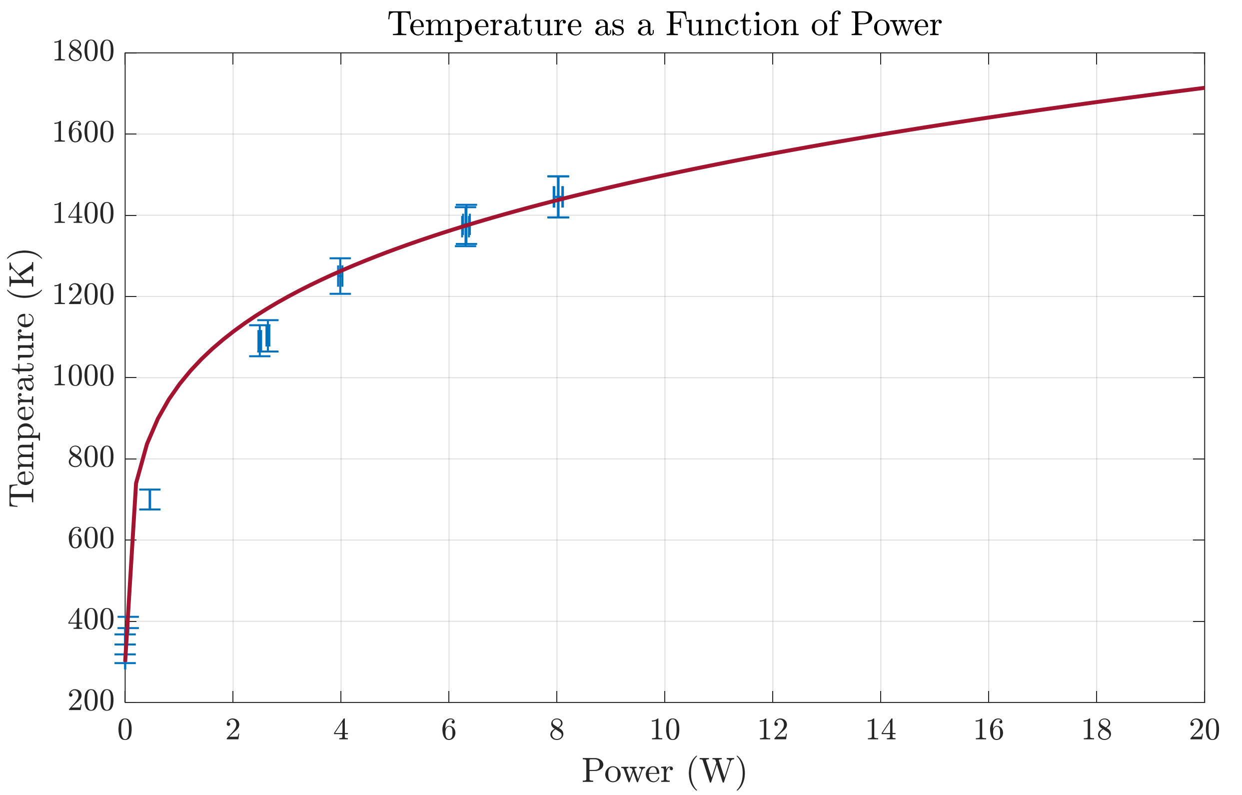
$$\frac{R}{R_0} - 1 = \alpha(T - T_0)$$

- Total emissivity ε as a function of the temperature

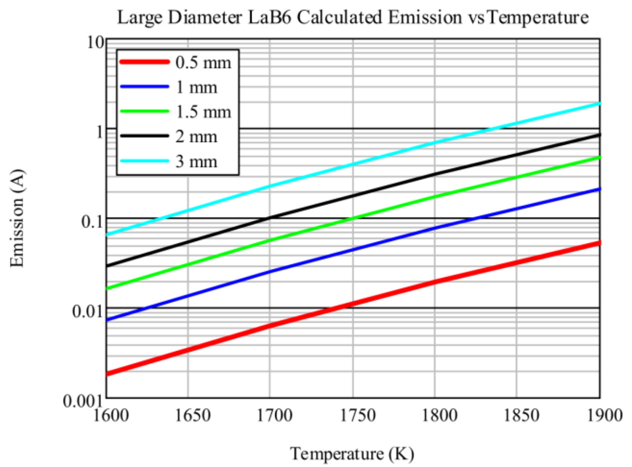
$$RI^2 = A\sigma\epsilon(T)(T^4 - T_0^4)$$



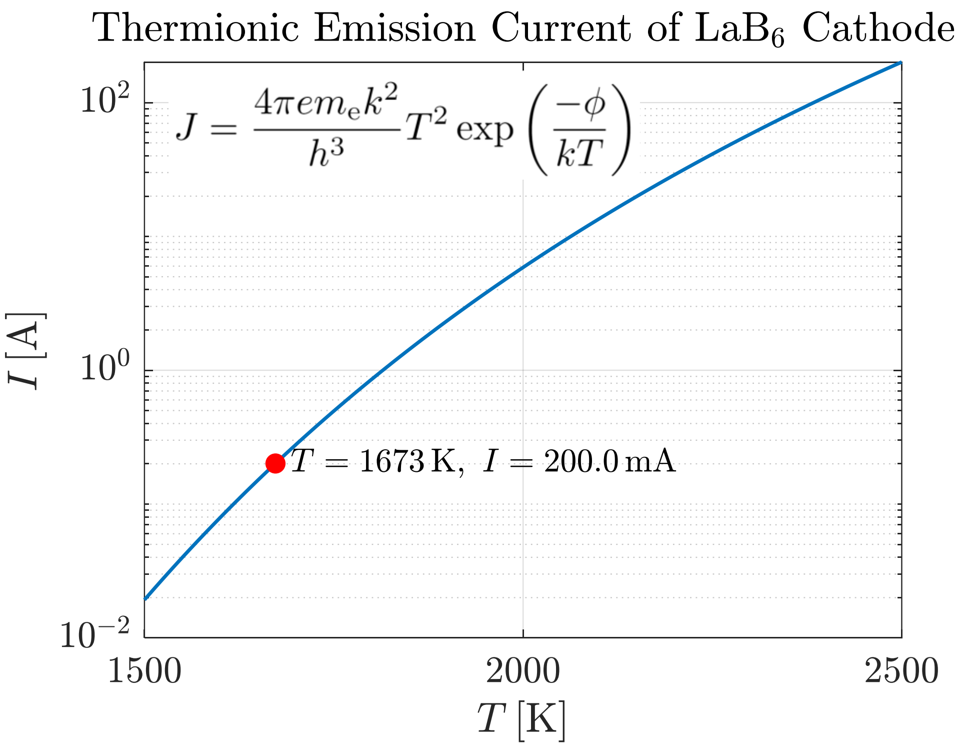

Fit used to extrapolate the temperature for higher power



# Thermionic Emission of the LaB6 buttons




Kimball Physics – Datasheet for LaB6 cathodes




Assumptions with Richardson Law:

- The effective work function for single-crystal LaB6 <100>, Φ = 2.66 eV.
- The effective flat surface of emission does not include the bevel.
- The emission from the cathode is not space-charge limited, otherwise must use a Child-Langmuir Law:

$$J = \frac{4\varepsilon_0}{9}\sqrt{\frac{2e}{m_e}}\frac{V^{3/2}}{d^2}$$

# Discussion over the following steps: Cathode

- Finalized the new procedure
- Continue characterizing the cathode and increase the maximum power up to 20 W
- Finish preparing a second cathode and review the procedure for installing it in the micrometer
- Infer on the heat transfer efficiency between the Tungsten coil and the LaB6 button using SolidWorks (?)
- Verify in advance the functioning of the Gun Toroid 1 and 2 (?)

# Progress towards restarting the linac

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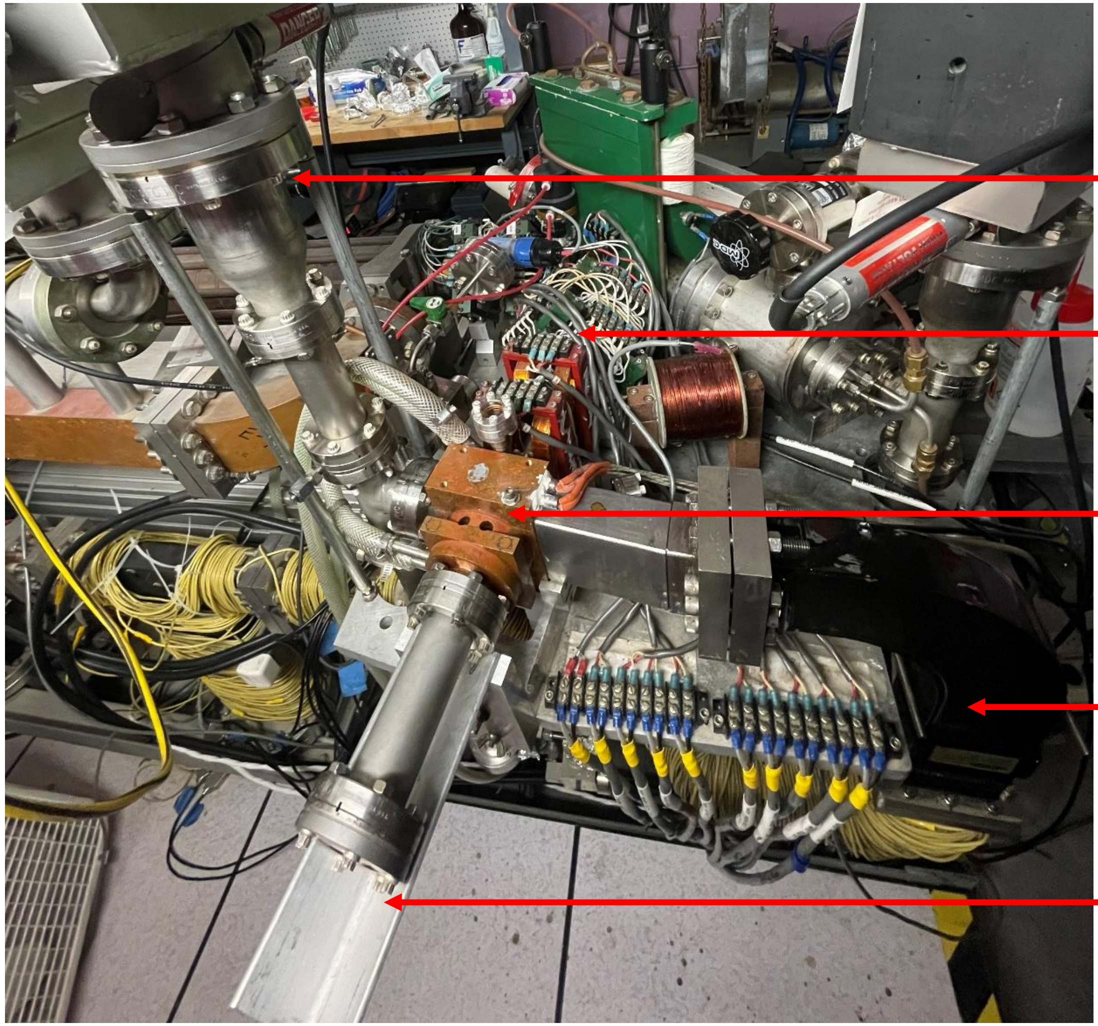
- Vacuum leaks in the RF gun sector
- Other projects

# Vacuum Leaks in the RF Gun Sector



4$^{th}$ step, leak on the vacuum column:
Ion Pumps = 2.5 mA -> 5 mA

3$^{rd}$ step, leak near Gun Toroid1:
Ion Pumps = 2.5 mA -> 3 mA

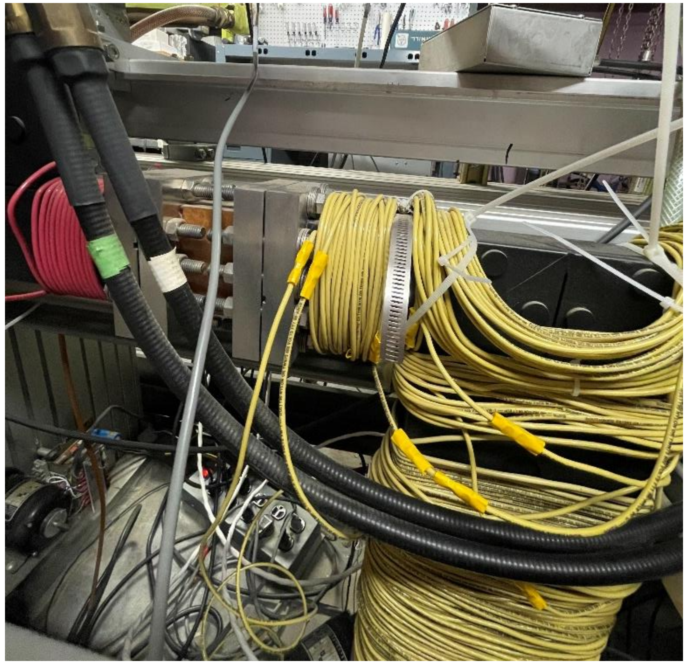
2$^{nd}$ step, bake-out:
Ion Pumps = 150 uA -> 2.2 mA

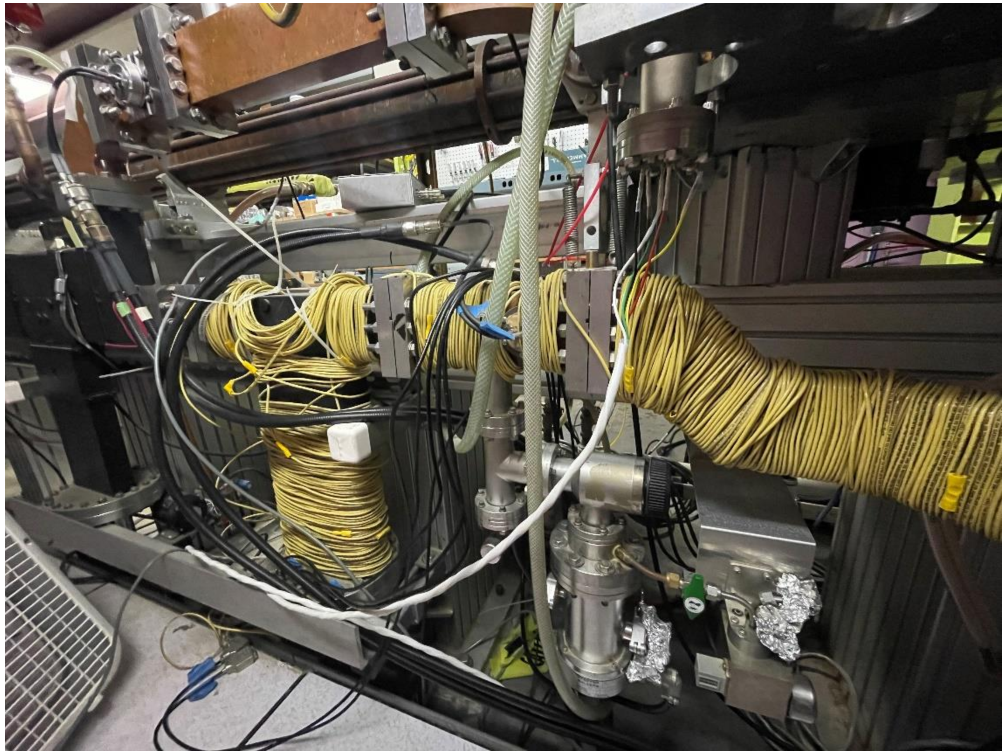
Leak detected on the Waveguide

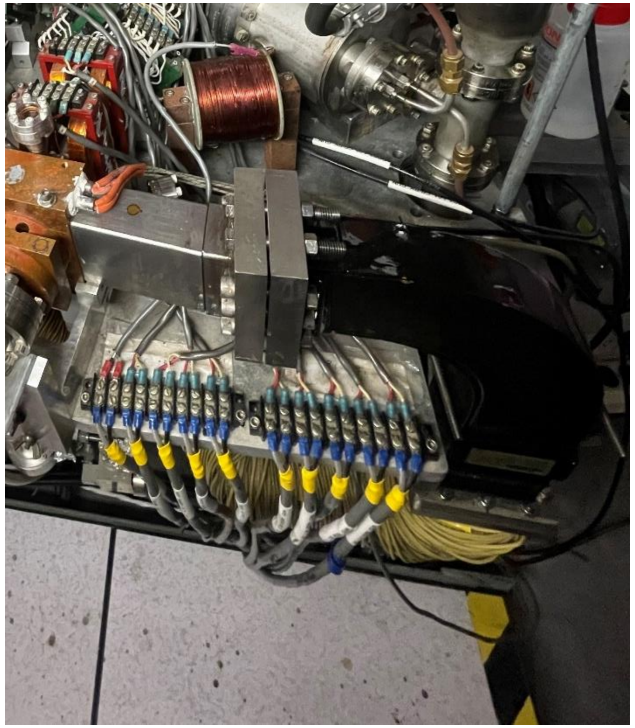
1$^{st}$ step, cathode removal:
Ion Pumps = 120 uA -> 130 uA

# Discussion over the following steps: Vacuum Leaks

- Remove H-bend Waveguide to repair or replace.
- Install RF windows and SF6 gas injection system if compatible with the phase shifter.







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# Beam Transport Lattice

Beamline elements distances from previous reviews

| Nomenclature | z start (m) | z mid (m) | z end (m) | z logbook UH (m) | Element name | Channel # | Label | Difference | Sector | Element |
|---|---|---|---|---|---|---|---|---|---|---|
| start | | | 0 | 0 | LINAC | | | 0.000 | LIN | |
| LIN.QPF.004 | 0.359 | 0.403 | 0.448 | 0.394 | Quad | 20 | | -0.010 | LIN | QPF |
| | | | | | Beam position monitor | | | | LIN | BPM |
| LIN.QPD.007 | 0.645 | 0.689 | 0.733 | 0.699 | Quad | 21 | LQ2 | 0.010 | LIN | QPD |
| LIN.STV.008 | | | | 0.838 | V. Corrector | 22 | VC1 | | LIN | STV |
| LIN.SPC.011 | | | | 1.105 | Spectrometer | 23 | LSP | | LIN | SPC |
| | | | | | Energy measurement | | | | | |
| LIN.STV.015 | | | | 1.461 | V. Corrector | 24 | VC2 | | LIN | STV |
| DC1.OTR.016 | 1.633 | 1.633 | 1.633 | | OTR Screen | | OS1 | | DC1 | OTR |
| DC1.SB1.018 | 1.708 | 1.752 | 1.797 | 1.753 | Split Bend 1 start | 26 | SB1a | 0.000 | DC1 | SB1 |
| DC1.QPC.021 | 2.033 | 2.077 | 2.122 | 2.070 | Chromacity quad | 28 | SB1Q | -0.007 | DC1 | QPC |
| DC1.SB1.024 | 2.358 | 2.403 | 2.447 | 2.400 | Split Bend 1 end | 26 | SB1b | -0.002 | DC1 | SB1 |
| | | | | | Beam position monitor | | BPM1 | | DC1 | BPM |
| DC2.QPF.028 | 2.735 | 2.780 | 2.824 | 2.769 | Quad | 29 | F1QA | -0.011 | DC2 | QPF |
| DC2.QPD.029 | 2.867 | 2.912 | 2.956 | 2.896 | Quad | 30 | F1QB | -0.016 | DC2 | QPD |
| DC2.QPF.030 | 3.000 | 3.044 | 3.088 | 3.023 | Quad | 31 | F1QC | -0.021 | DC2 | QPF |
| DC2.OTR.032 | 3.219 | 3.219 | 3.219 | | OTR Screen | | OS2 | | DC2 | OTR |
| DC2.SB2.033 | 3.298 | 3.318 | 3.339 | 3.302 | Split Bend 2 start | 32 | SB2a | -0.016 | DC2 | SB2 |
| DC2.QPC.036 | 3.554 | 3.599 | 3.643 | 3.594 | Chromacity quad | 34 | SB2Q | -0.005 | DC2 | QPC |
| DC2.SB2.039 | 3.859 | 3.880 | 3.900 | 3.861 | Split Bend 2 end | 32 | SB2b | -0.019 | DC2 | SB2 |
| DC2.STV.041 | | | | 4.102 | V. Corrector | 35 | VC3 | | DC2 | STV |
| DC2.STH.041 | | | | 4.102 | H. Corrector | 36 | HC1 | | DC2 | STH |
| DC2.QPF.042 | 4.152 | 4.196 | 4.241 | 4.204 | Quad | 37 | F2QA | 0.007 | DC2 | QPF |
| DC2.QPD.043 | 4.292 | 4.336 | 4.380 | 4.331 | Quad | 38 | F2QB | -0.005 | DC2 | QPD |
| DC2.QPF.045 | 4.431 | 4.476 | 4.520 | 4.483 | Quad | 39 | F2QC | 0.007 | DC2 | QPF |
| | | | | | Beam position monitor | | BPM2 | | DC2 | BPM |
| DC3.QPF.050 | 4.935 | 4.980 | 5.024 | 4.978 | Quad | 40 | F2QD | -0.001 | DC3 | QPF |
| DC3.QPD.051 | 5.075 | 5.119 | 5.164 | 5.131 | Quad | 41 | F2QE | 0.012 | DC3 | QPD |
| DC3.QPF.053 | 5.215 | 5.259 | 5.303 | 5.271 | Quad | 42 | F2QF | 0.012 | DC3 | QPF |
| DC3.OTR.055 | 5.498 | 5.498 | 5.498 | | OTR Screen | | OS3 | | DC3 | OTR |
| DC3.SB3.056 | 5.574 | 5.595 | 5.615 | 5.613 | Split Bend 3 start | 45 | SB3a | 0.019 | DC3 | SB3 |
| | | | | | H. Coil? | | | | | |
| DC3.QPC.059 | 5.831 | 5.875 | 5.920 | 5.867 | Chromacity quad | 47 | SB3Q | -0.008 | DC3 | QPC |
| | | | | | H. Coil? | | | | | |
| DC3.SB3.062 | 6.136 | 6.156 | 6.176 | 6.147 | Split Bend 3 end | 45 | SB3b | -0.009 | DC3 | SB3 |
| DC3.STV.065 | | | | 6.464 | V. Corrector | 43 | VC4 | | DC3 | STV |
| DC3.STH.065 | | | | 6.464 | H. Corrector | 44 | HC2 | | DC3 | STH |
| DC3.QPF.064 | 6.369 | 6.414 | 6.458 | 6.566 | Quad | 48 | F3QA | 0.152 | DC3 | QPF |
| DC3.QPD.066 | 6.558 | 6.602 | 6.647 | 6.680 | Quad | 49 | F3QB | 0.078 | DC3 | QPD |
| | | | | | Beam position monitor | | BPM3 | | IPC | BPM |
| | | | | | Interaction point chamber start | | IPa | | IPC | |
| IPC.XRS.071 | 7.110 | 7.110 | 7.110 | | X-ray screen (IP) | | IPXS | | IPC | XRS |
| | | | | | OTR Screen | | IPOS | | IPC | OTR |
| | | | | | Scanning wire | | IPSW | | IPC | BSW |
| | | | | | Interaction point chamber end | | IPb | | IPC | |
| DC4.STV.074 | | | | 7.353 | V. Corrector | 51 | VC5 | | DC4 | STV |
| DC4.QPF.074 | 7.326 | 7.370 | 7.415 | 7.442 | Quad | 50 | F3QC | 0.072 | DC4 | QPF |
| DC4.QPD.075 | 7.470 | 7.514 | 7.559 | 7.569 | Quad | 59 | F3QD | 0.055 | DC4 | QPD |
| DC4.OTR.078 | 7.773 | 7.773 | 7.773 | | OTR Screen | | OS4 | | DC4 | OTR |
| DC4.SB4.079 | 7.851 | 7.871 | 7.892 | 7.849 | Split Bend 4 start | 52 | SB4a | -0.023 | DC4 | SB4 |

## Other documents and information:

- Some geometrical information on the magnets
- Calibration values for the spectrometer and alpha-magnets
- DC channel list
- Database restored with magnets values, 2009
- A few beam profiles from 2009
- A few simulation results

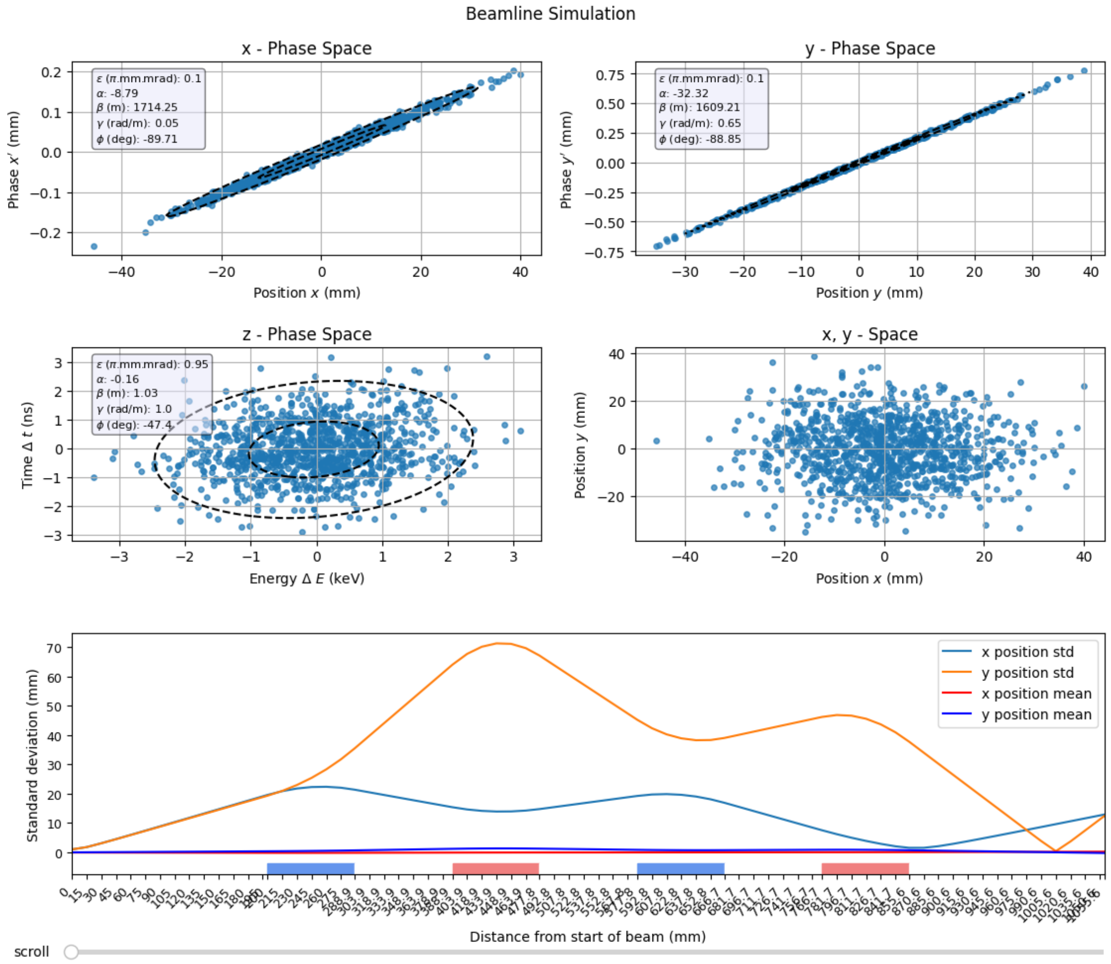
## To do:

- Characterize quadrupole and dipole fringe fields
- Implement a new transport code

| | |
|---|---|
| Quadrupole length (m): | 0.0889 |
| Quadrupole aperture (m): | 0.027 |
| SB dipole aperture (m): | 0.014478 |
| Mkiii dipole aperture (m): | 0.0127 |
| Undulator half length (m): | 0.5405 |
| Undulator K_hat_squared: | 1 |
| Kinetic energy (MeV/c^2): | 37.8 |

# Beam Transport Simulation

Framework for linac beam dynamics simulations developed by Christian Komo in Python ([GitHub link](#))




Modular upper layer of the simulation, which can use:

- Arbitrary beam distribution
- Simple beam matrix model
- Complex simulations using **MadX**, COSY Infinity or other codes
- Can provide optimization algorithm
- C. Komo to present the project in the future

Discussion about simulation codes and software licenses (CST?)

# New and Refurbished Equipment

Safety:

- Personal dosimeters: Add Amir and Harsh?
- Radiation Monitors
- To do: Chemicals cabinet, general safety procedures and trainings to follow

Vacuum systems:

- Two Varian RVA-30-TR/O ion pumps, various gaskets, windows and a lot of VacSeal
- To do: Turbo pumps – RGA – $SF_6$ injection system

RF System:

- 500 W Amplifier to drive the klystron from Microwave Amps Ltd
- To do: Control systems for the 500 W amplifier
- RF windows on the waveguide/phase shifter for the electron gun

Instruments:

- Workstation in the control room
- RIGOL and Fluke multimeters for data loging (C. Komo application), clamp meter
- Spot welder, ion gauge dual controller SRS IGC 100

# Thank you for your attention

Conclusion:

- Main bottleneck before the restart is the vacuum leak in the RF gun sector
- The new cathode is promising
- HV commissioning test for the Thyratron achieved and the control system is working
- The low RF power tests were promising
- Procedures, lab safety measures and equipment purchase

Progress needed:

- H-bend waveguide replacement and solve the vacuum leaks in RF gun sector
- Drive RF amplifier for the Klystron and coupling value between LFP and GFP
- Testing of beamline elements (magnet powering, HV switch,…)
- Beam dynamics simulation including more realistic models of the magnets