



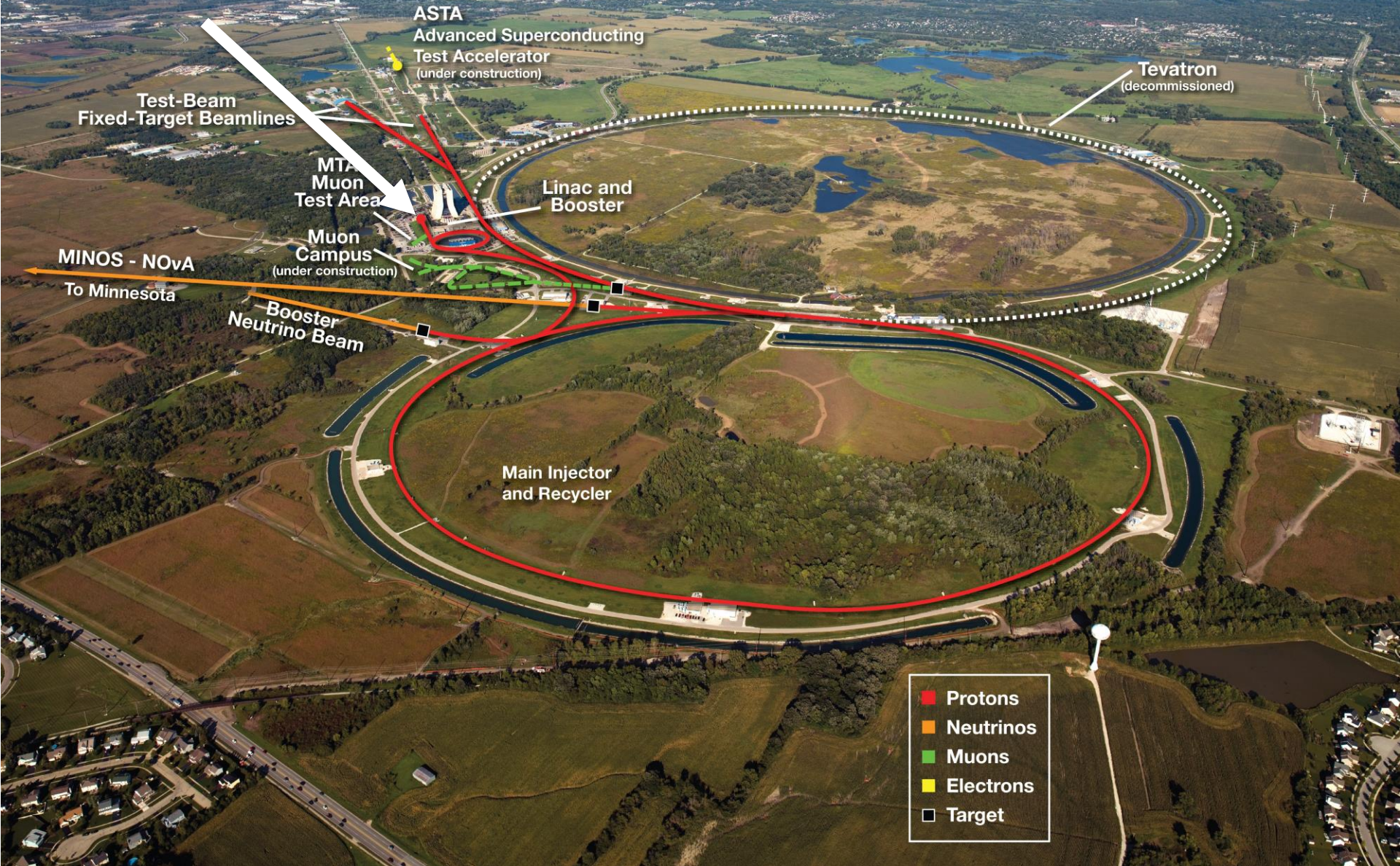
Implementation of Design Changes Towards a More Reliable, Hands-off Magnetron Ion Source

Alejandro Garcia Sosa

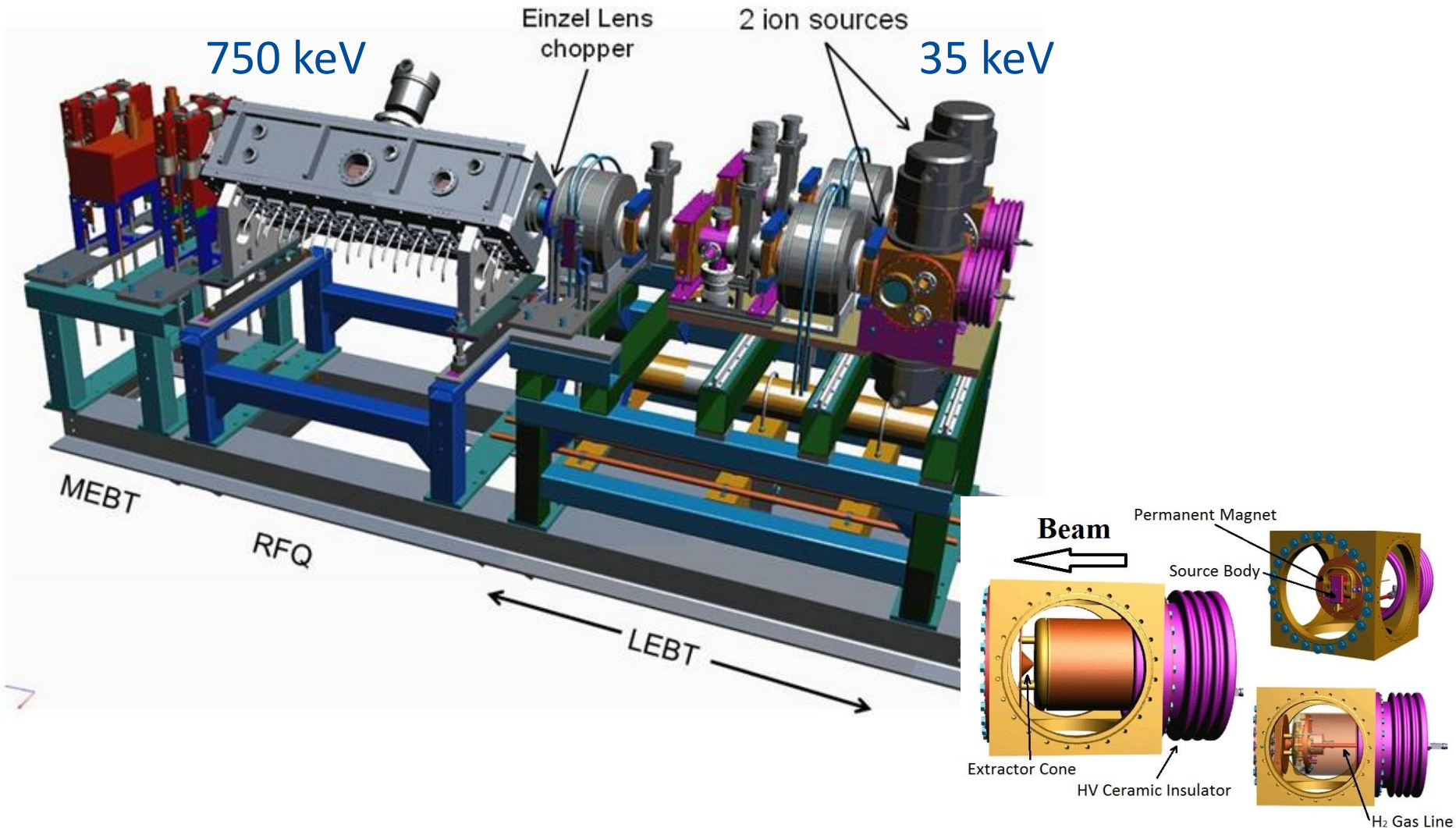
Outline

- Overview of FNAL's Magnetron Ion Sources
- Operational Magnetron Ion Sources
- Ion Source Pulse Timeline
- Offline Test Stand
- Developments
 - Cs Delivery System
 - Cs Oven Redesign
 - Piezoelectric Gas Valves
 - Solenoid Gas Valves
 - Voltage-regulated Arc Pulser
 - Current-regulated Arc Pulser
- Beam Noise Studies
 - $\text{H}_2 + \text{N}_2$ Gas Mixtures
 - Cathode Geometries
- Conclusions

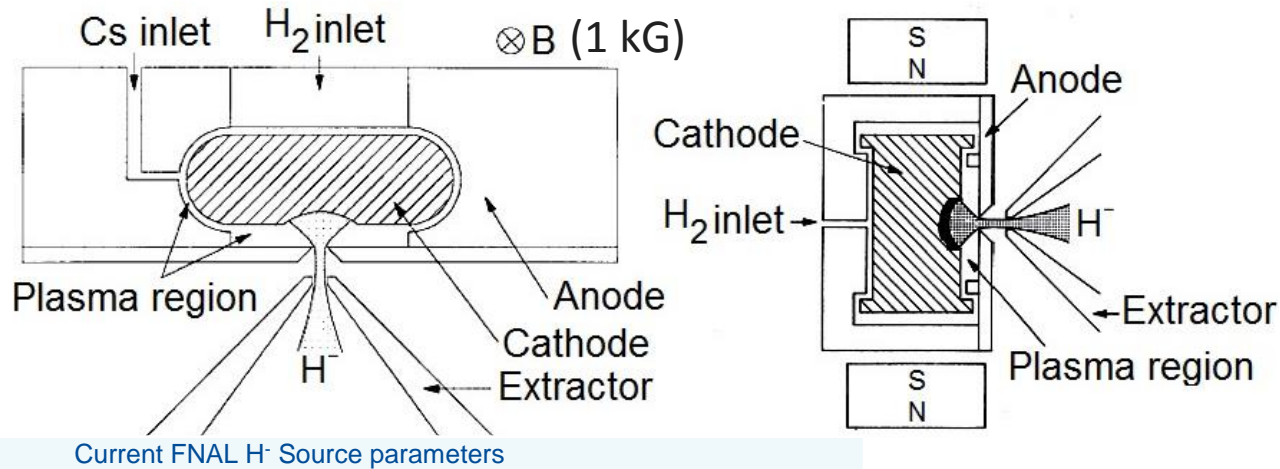
Pre-Acc Area



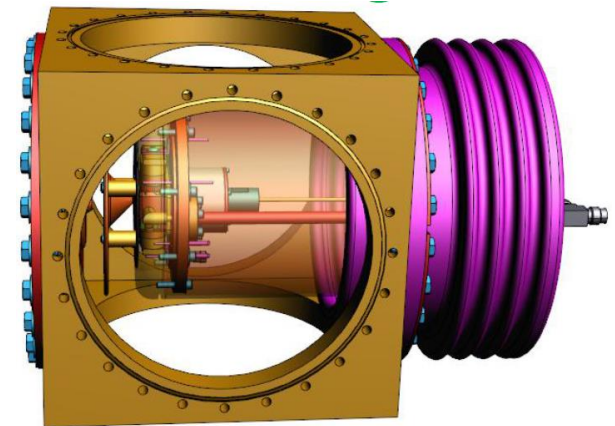
Overview of FNAL's Magnetron Ion Sources



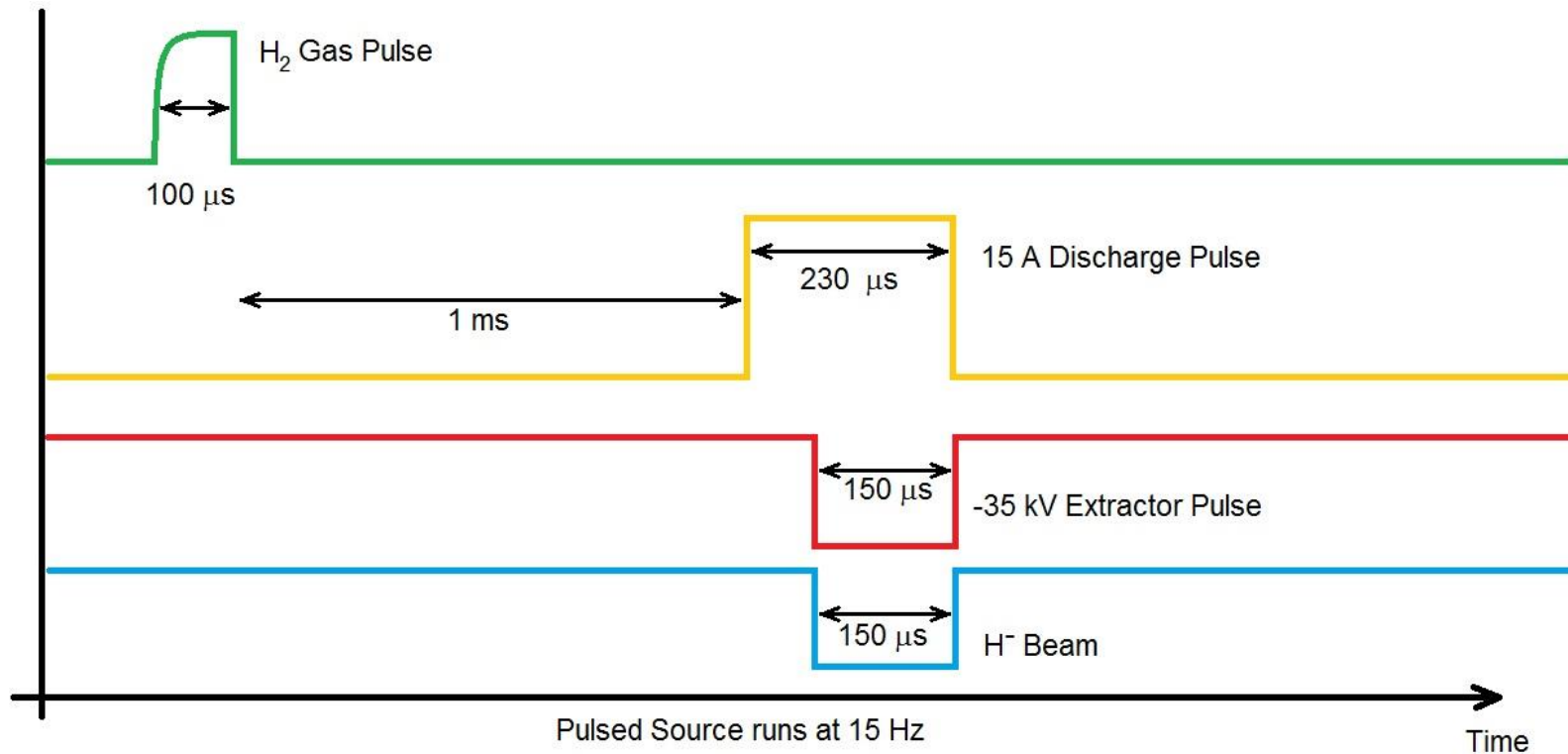
Operational Magnetron Ion Sources



Parameter	Value	Units
Arc Current	15	A
Arc Voltage	180	V
Extractor Voltage	35	kV
Beam Current	80	mA
Power Efficiency	30	mA/kW
Rep Rate	15	Hz
Arc Pulse Width	250	μs
Extracted Beam Pulse Width	80	μs
Duty Factor	0.375	%
Cathode Temperature	380	°C
Cs Boiler Temperature	100	°C
Emittance $\varepsilon_x/\varepsilon_y$ (norm., 95%)	0.17/0.28	π mm mrad
Extraction Gap	4.67	mm
Lifetime	9	months

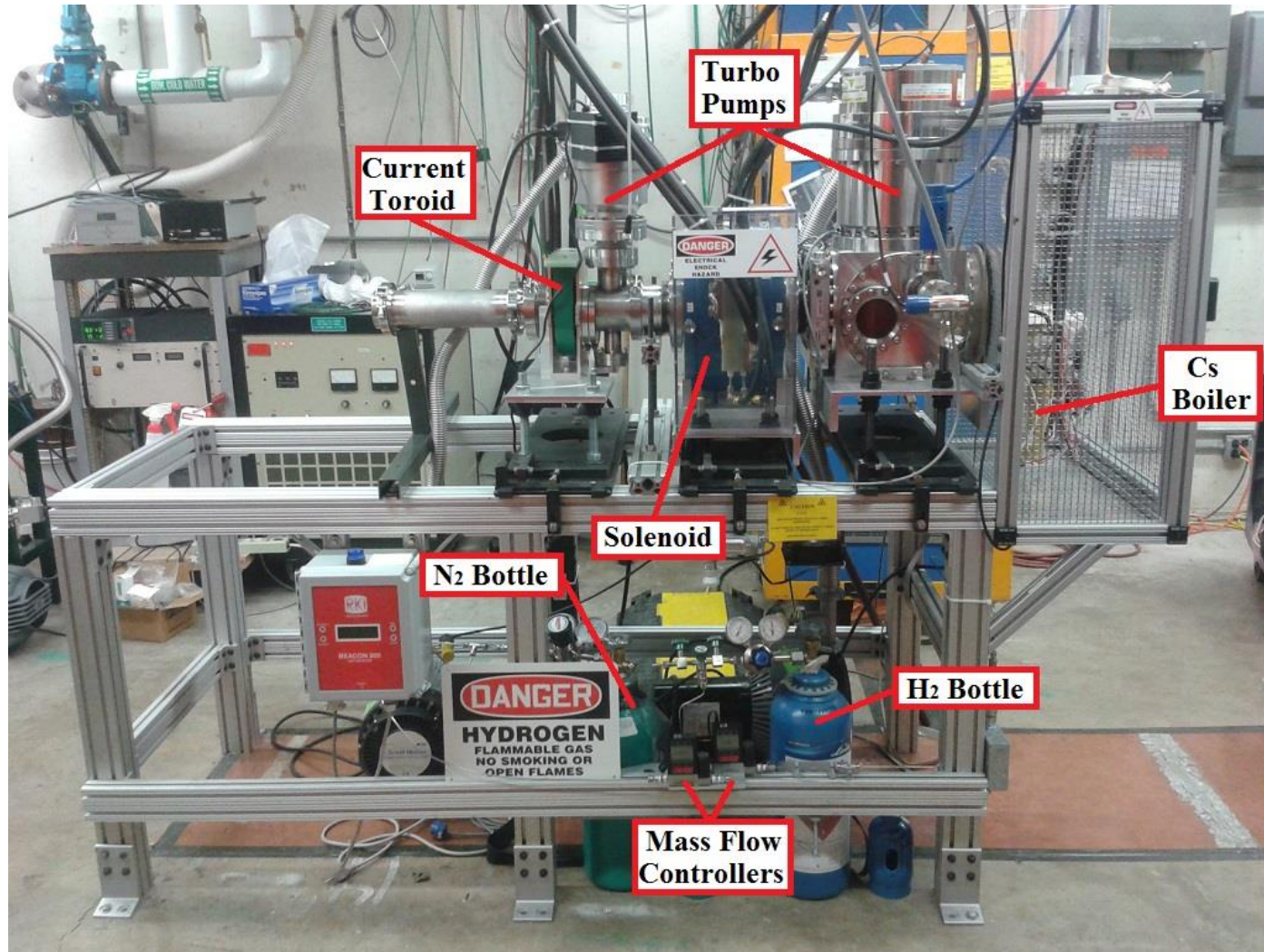


Ion Source Pulse Timeline



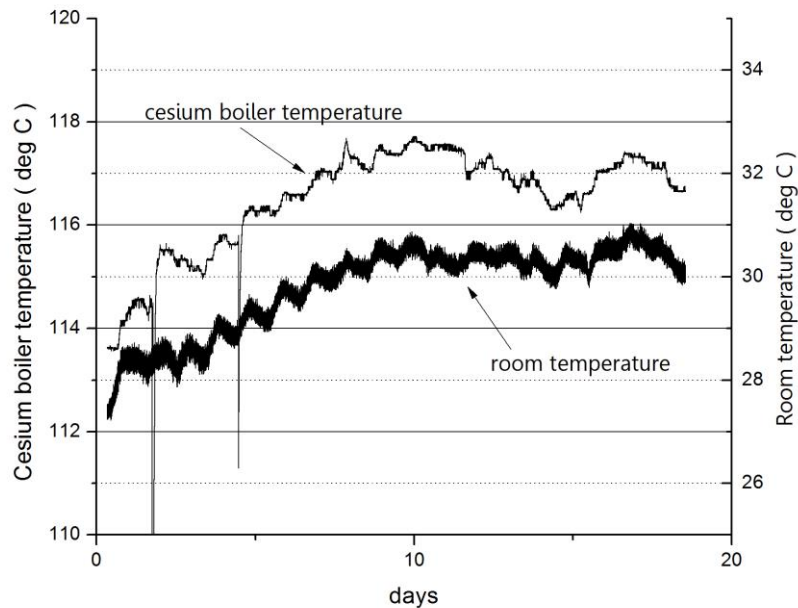
Offline Test Stand

- Commissioned in 2015
- Replica of the operational Ion Source & LEBT
- Emittance Scanner will be installed Soon



Cs delivery system

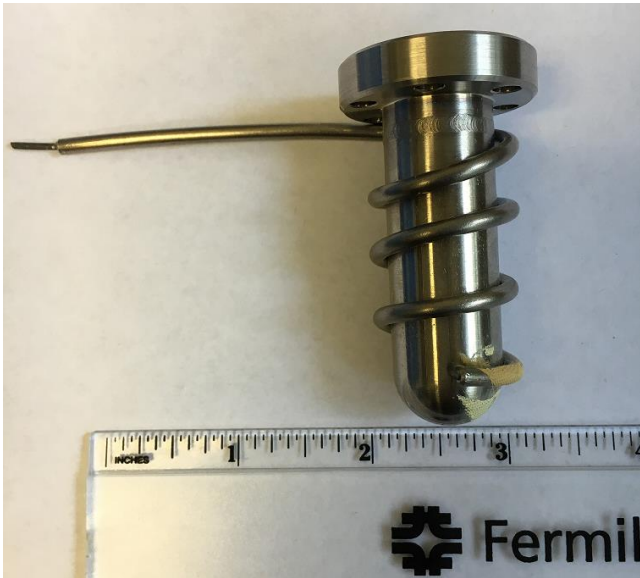
- We currently use 5 g Cs glass ampoules
- Cs is often trapped in the glass shards
- Cs oven followed room temperature due to thin insulation at $\sim 100^\circ\text{C}$



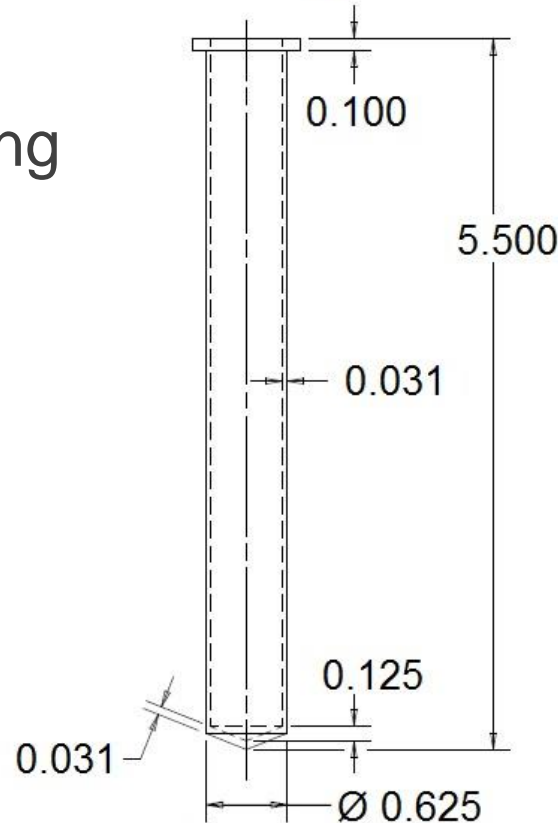
Old Cs oven (Copper)

Cs Oven Redesign

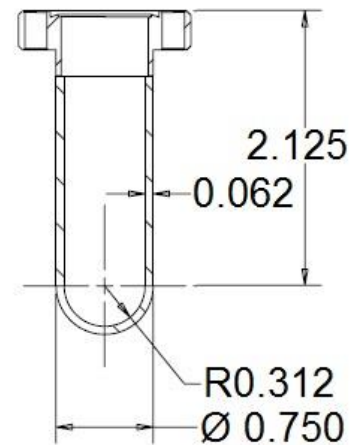
- More compact design
- Better temperature control
- Cs poured into oven allowing for safer handling and no trapped Cs



Existing Cs Boiler
Copper



New Cs Boiler
Stainless Steel



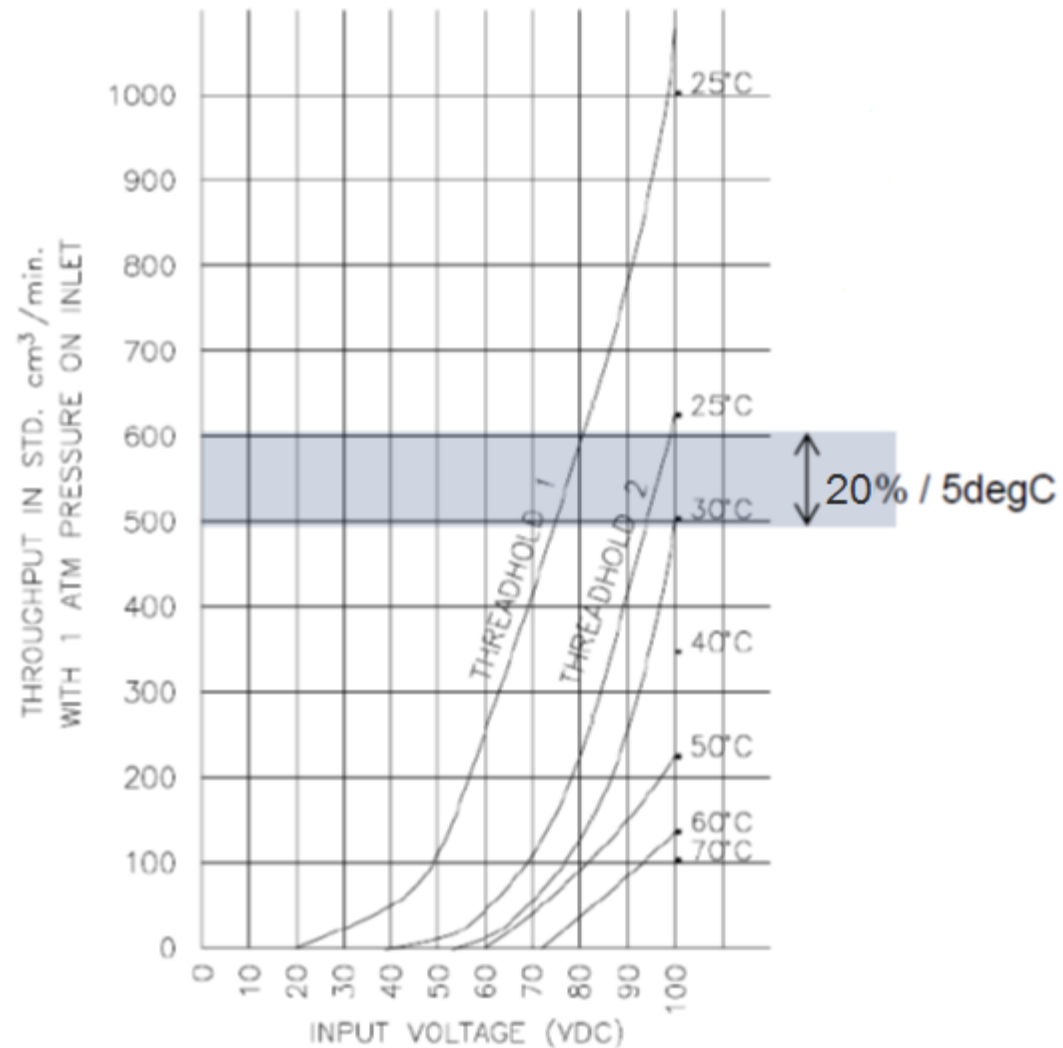
New Cs oven (304 Stainless)

Piezoelectric Gas Valves

- Veeco PV-10 piezoelectric valves
- Very sensitive to temperature changes
- Affects the arc current and vacuum pressure
- Calibration issues

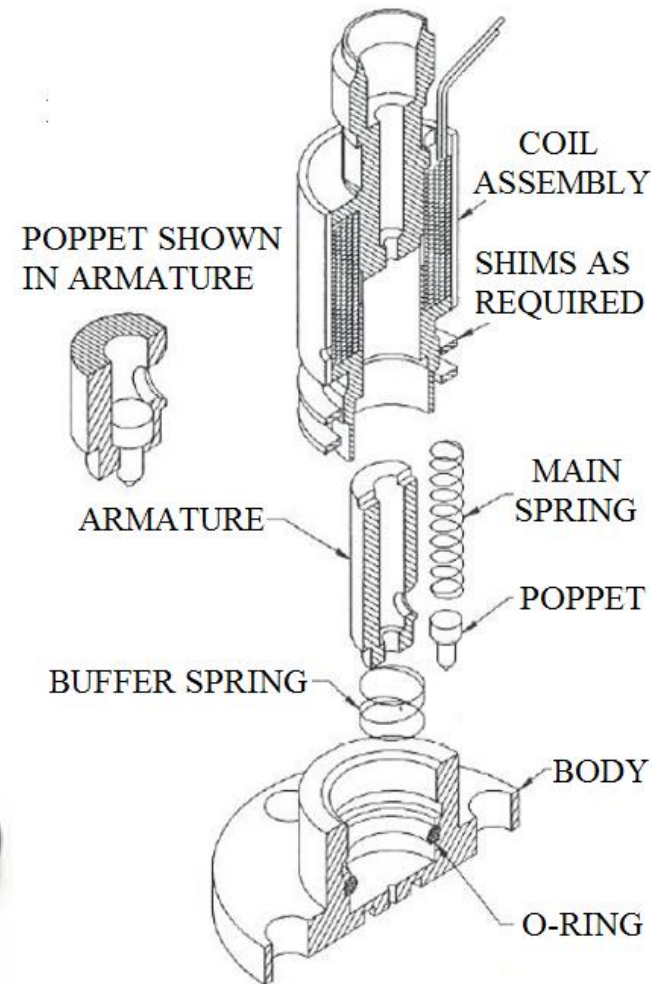


Veeco PV-10 data sheet



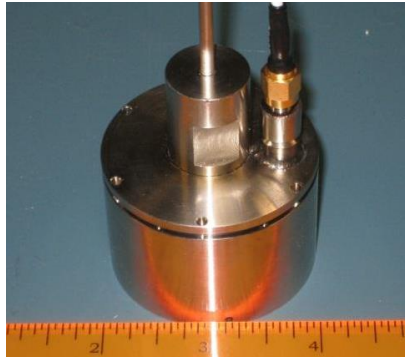
Solenoid Gas Valves

- Operating range: 4 to 105 °C
- No temperature dependence
- Min. Voltage (VDC): 28 V
- Resistance: 70 Ω
- Response time: 160 μs
- Pressures up to 85 atm
- Max. Rep. Rate: 120 Hz
- Vespel® poppet
- Leak Rate: $10^{-7} \text{ cm}^3 \text{ atm}^{-1} \text{ s}^{-1}$

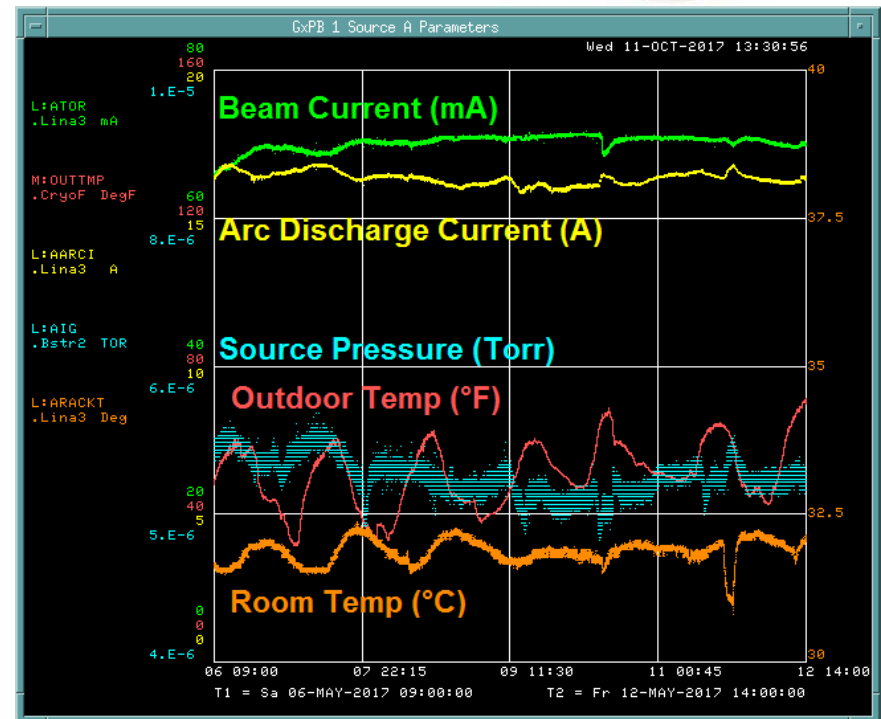
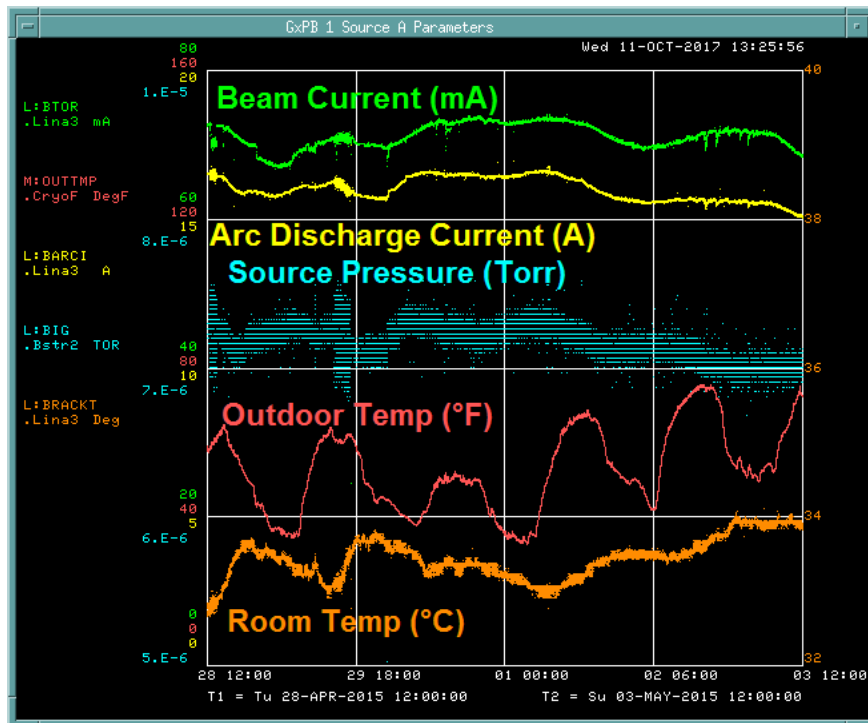


Comparison

Piezoelectric valves are very temperature dependent

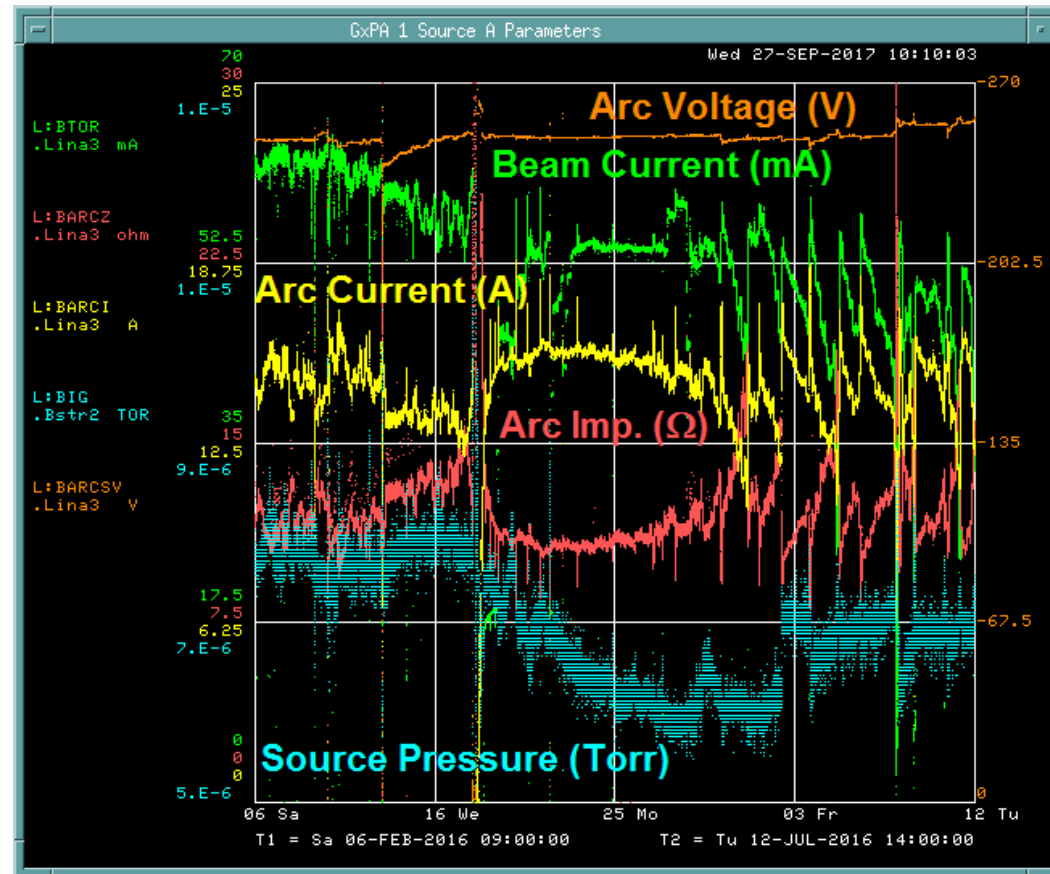
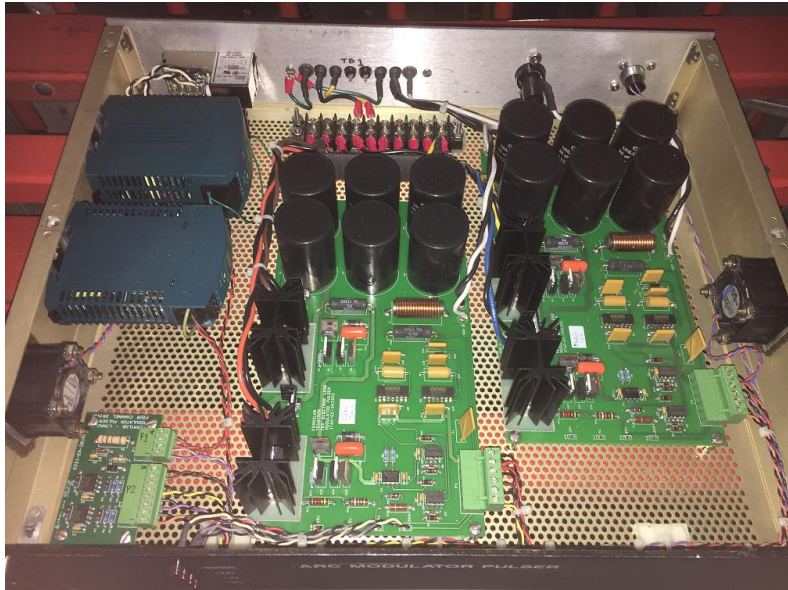


Solenoid valves show no temperature dependence



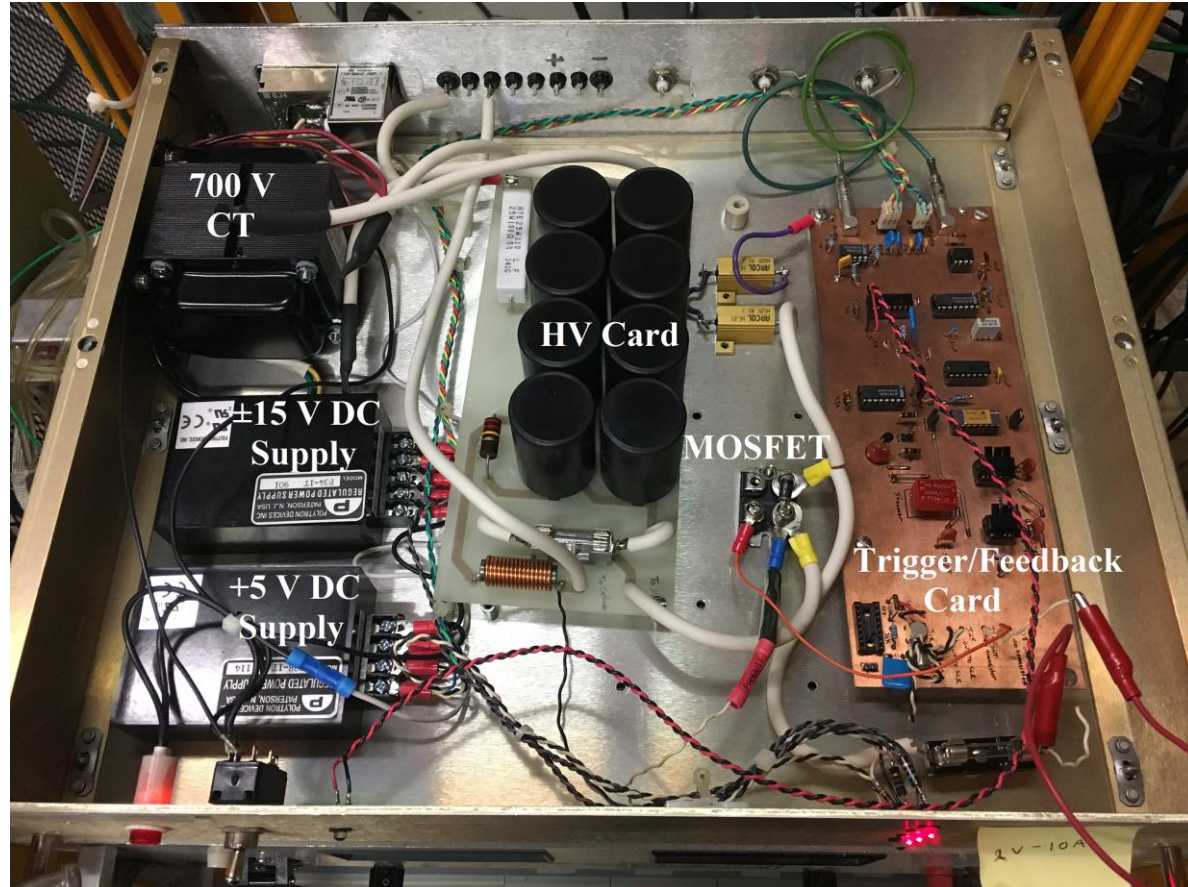
Voltage-regulated Arc Pulser

- Arc Current drifts over time
- Requires constant tuning changes when T, P change
- Difficult to achieve stable arc discharge and beam current long term



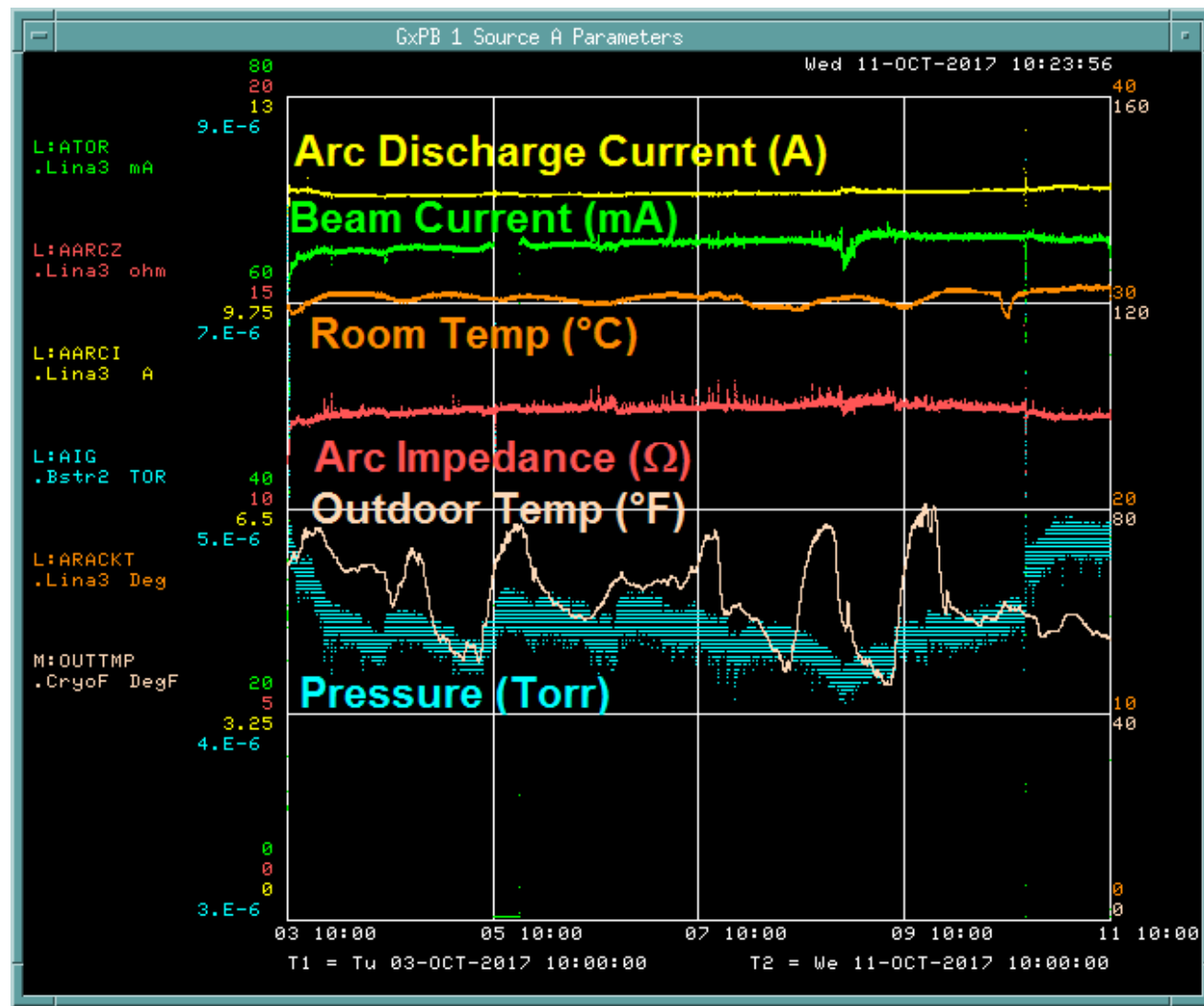
Current-regulated Arc Pulser

- High-voltage Card and Trigger/Feedback Loop Card
- Op-amp set up as a positive high-gain amplifier
- Power MOSFET acts as a gate for controlling the large current flowing out of the HV power supply



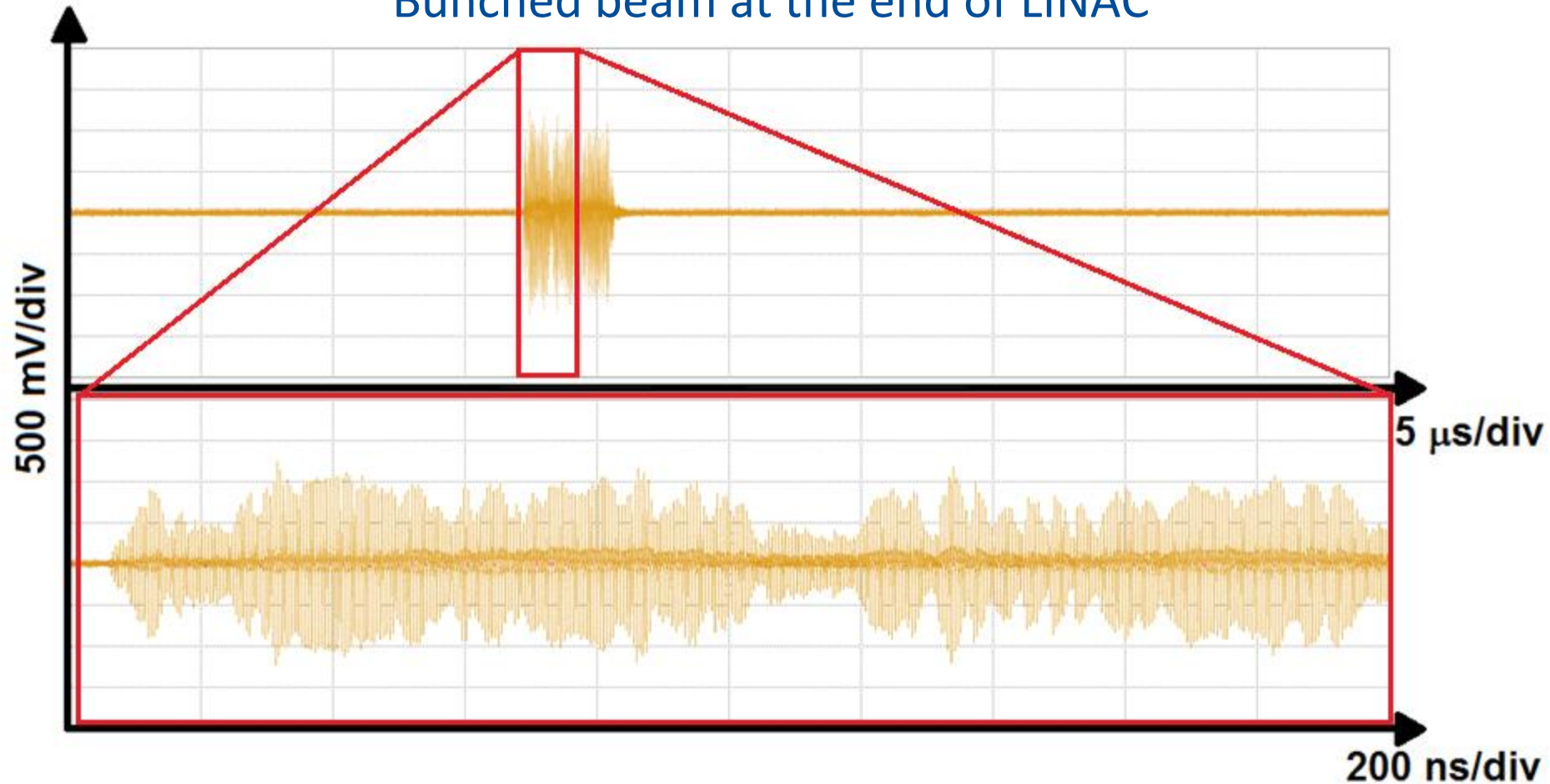
Current-regulated Arc Pulser

- 8 Days of beam run
- Pressure changes over time
- Arc Current is stable around 12 A
- Major Improvement towards more steady beam output for operations



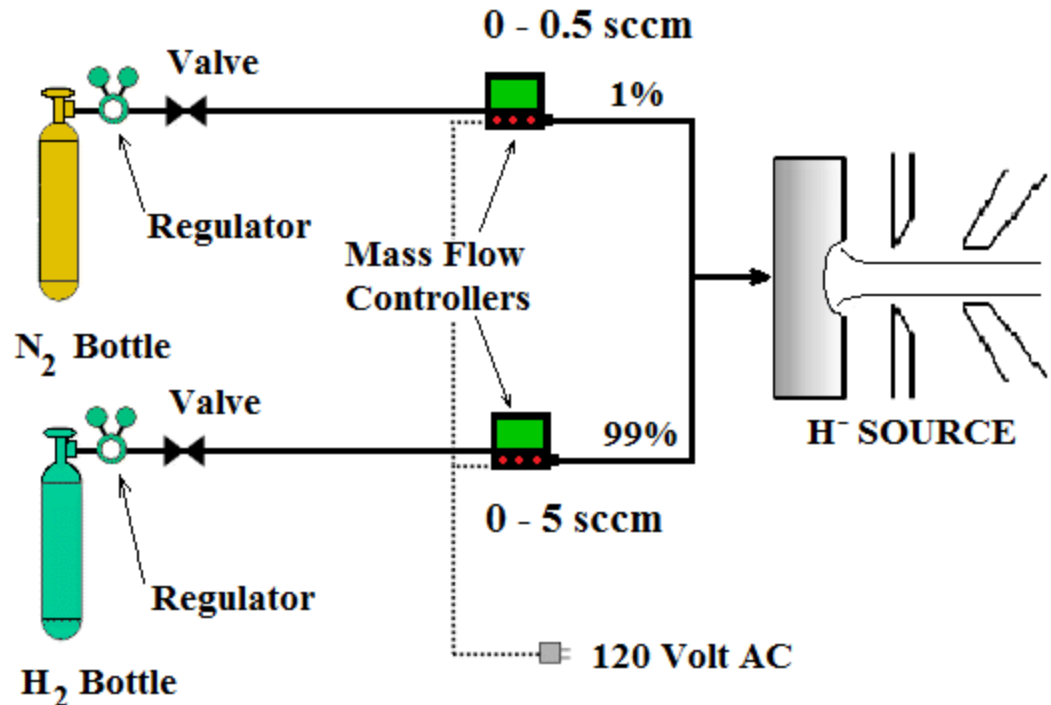
Beam Noise Studies

Bunched beam at the end of LINAC



H₂+N₂ Gas Mixtures

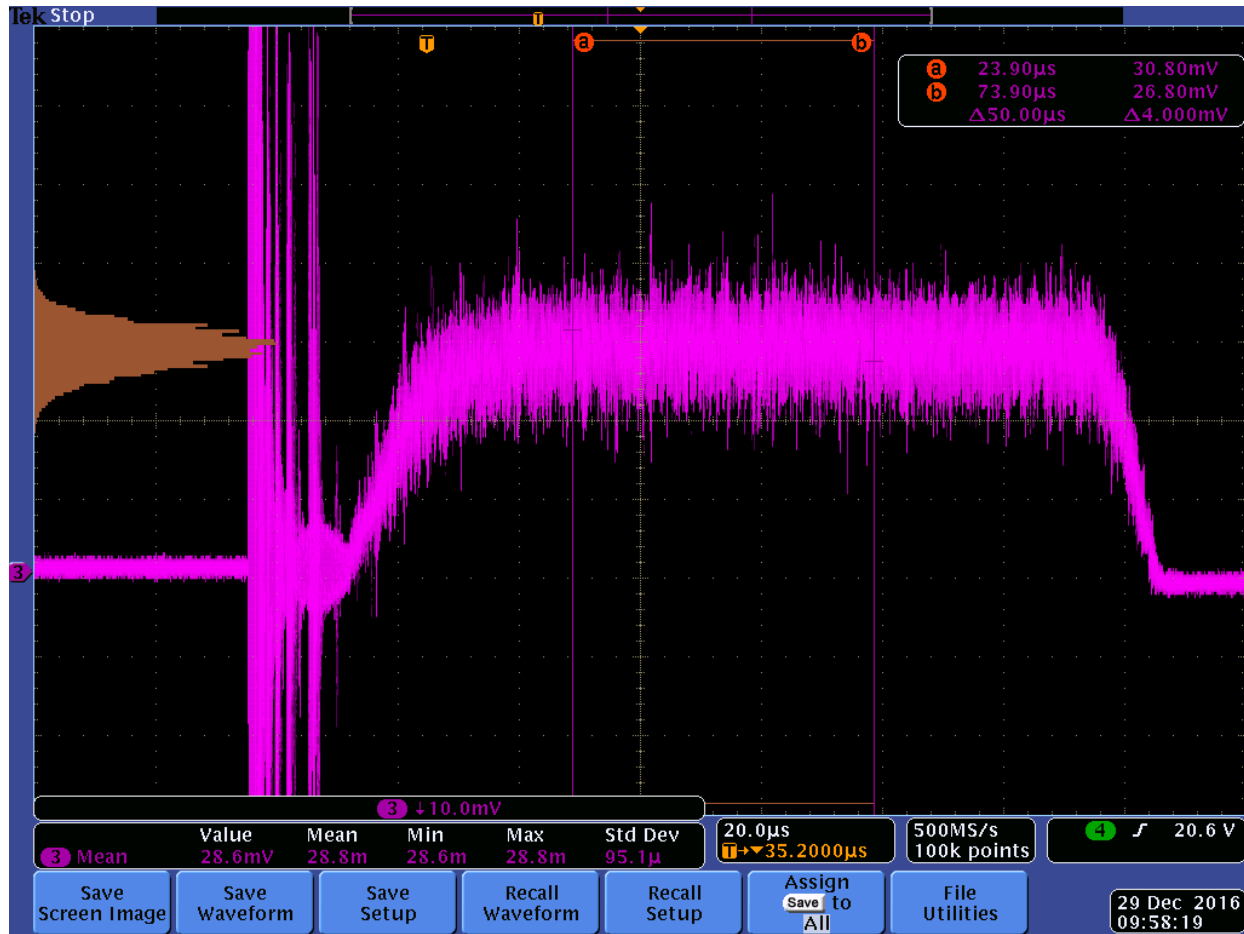
- Aim: Study effect on beam current noise
- Active mixing: gas mixture can be dynamically adjusted
- Mass Flow Controllers make use of pressure drop in a laminar flow (69 - 103 kPa)



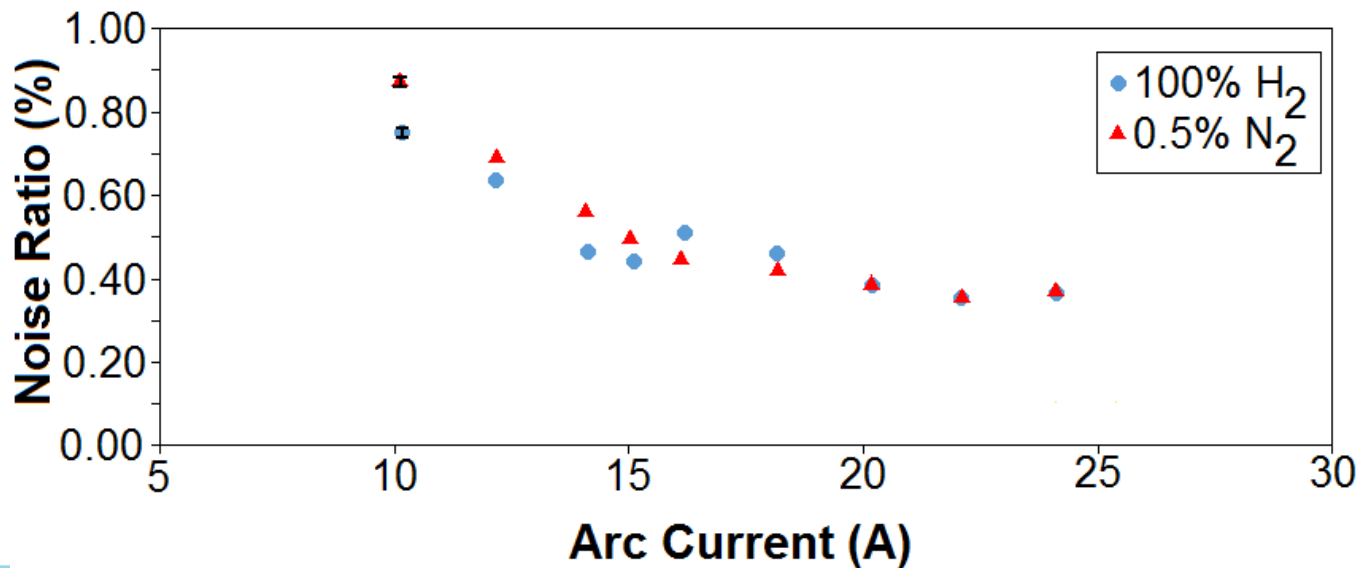
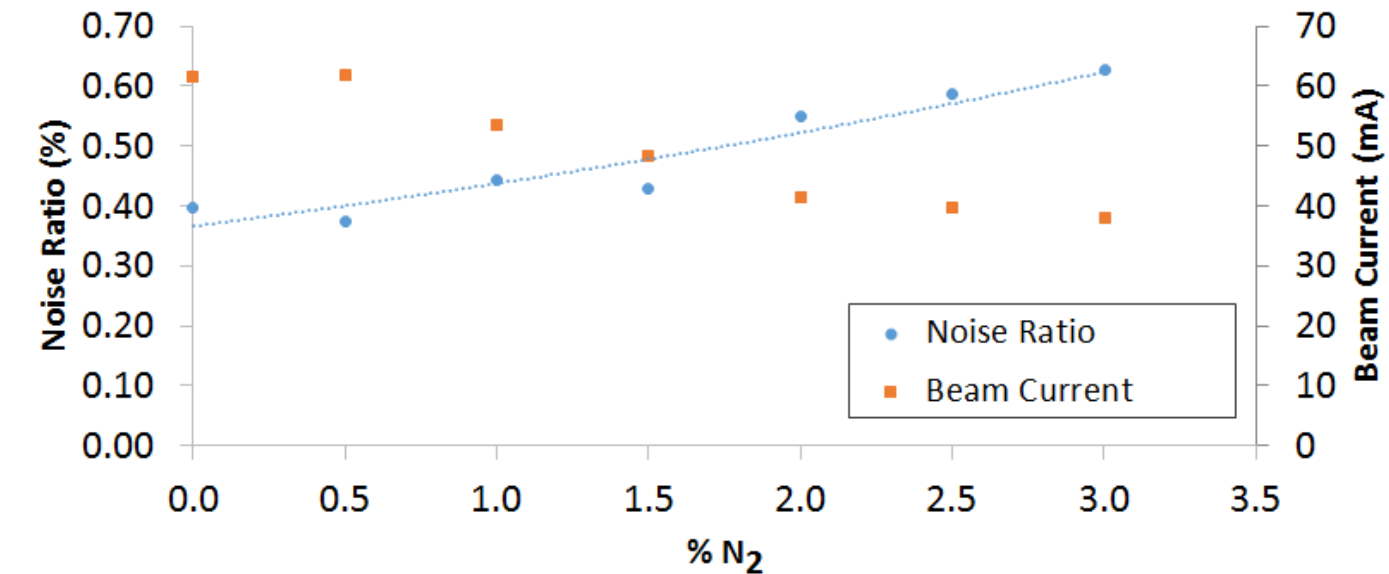
Chaco, E., Moehs, D., & Schmidt, C. W. The Effects of Nitrogen Gas on the Production of Negative Hydrogen Ions. *Fermilab SIST Program*.

H₂+N₂ Gas Mixtures

$$\text{Noise Ratio} = \sigma / I_{\text{beam}} \times 100$$



H₂+N₂ Gas Mixtures

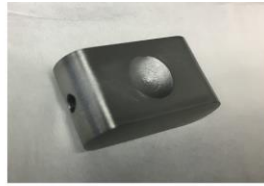


Cathode Geometries

Dimpled Cathode



a)



b)

Hollow Cathode (V. Dudnikov)

Thin Cathode

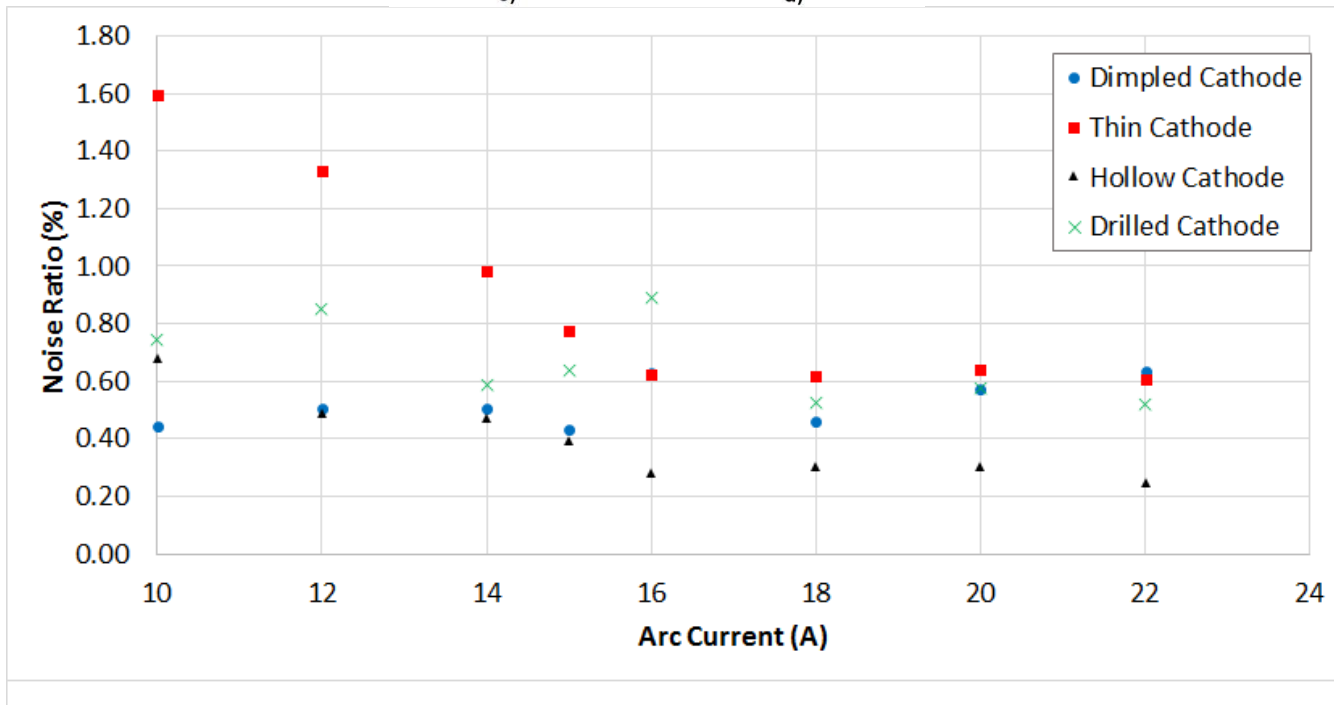


c)

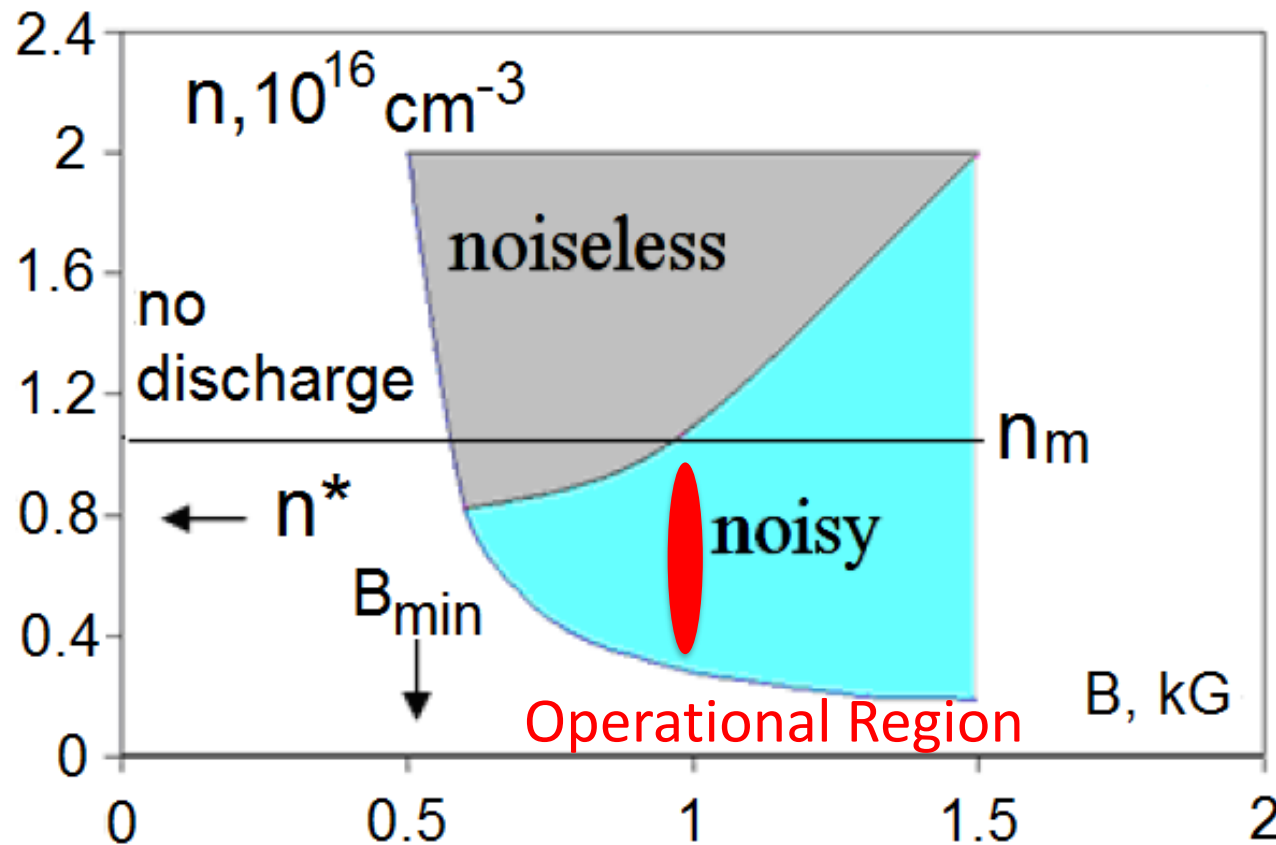


d)

Drilled Cathode



Operational Magnetron Sources are Noisy



V. Dudnikov, "Method and apparatus for surface plasma source (SPS) with anode layer plasma accelerator." U.S. Patent WO2013096519 A1, issued June 27, 2013.

Conclusions

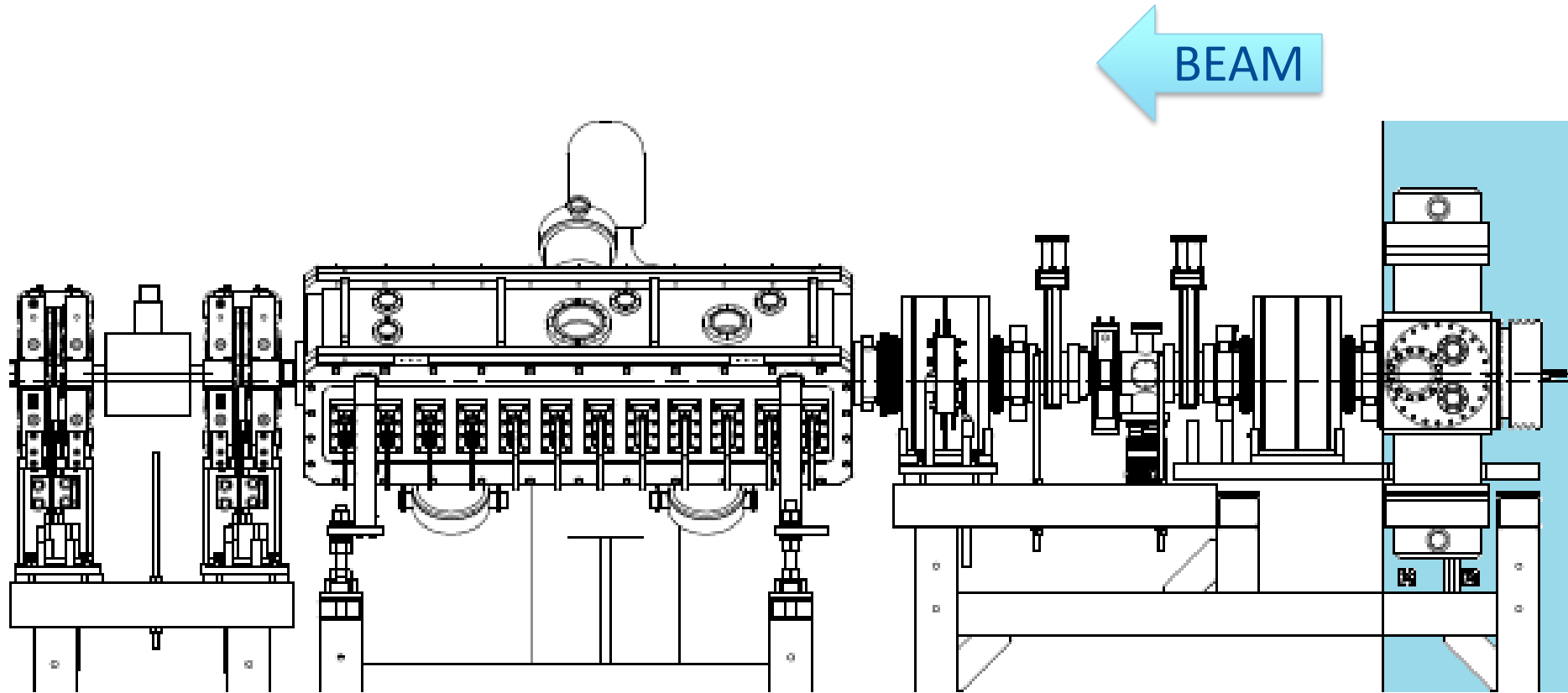
- New Cs oven is safer and better for temperature control
- Solenoid gas valve no temperature dependence, stable beam output
- N₂ gas has little effect in H⁻ current noise in conditions studied
- Noise ratio is <2% for all cathode types
- Magnetron Ion Source cannot operate in noiseless region in our operation conditions (P, I, B)
- New Current-regulated Arc Pulser, very reliable, stable arc current.

Thank you!

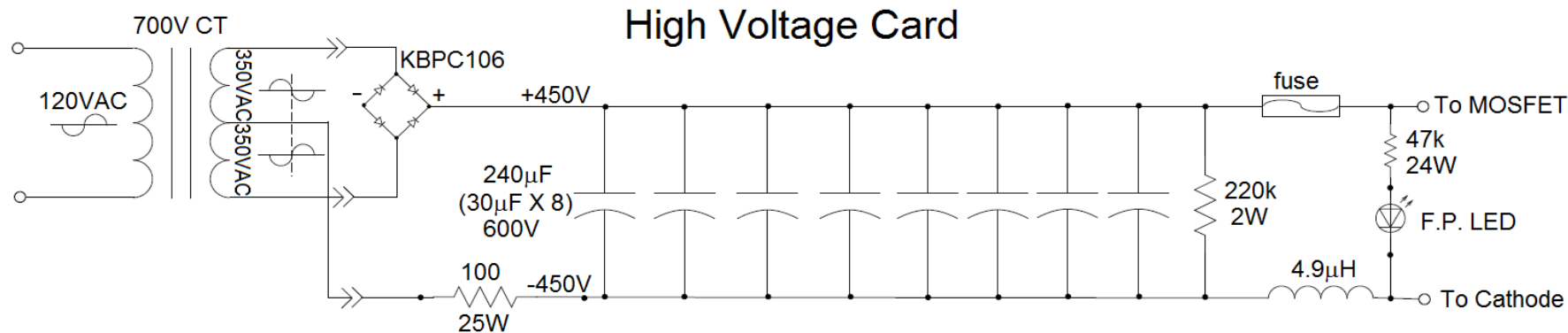
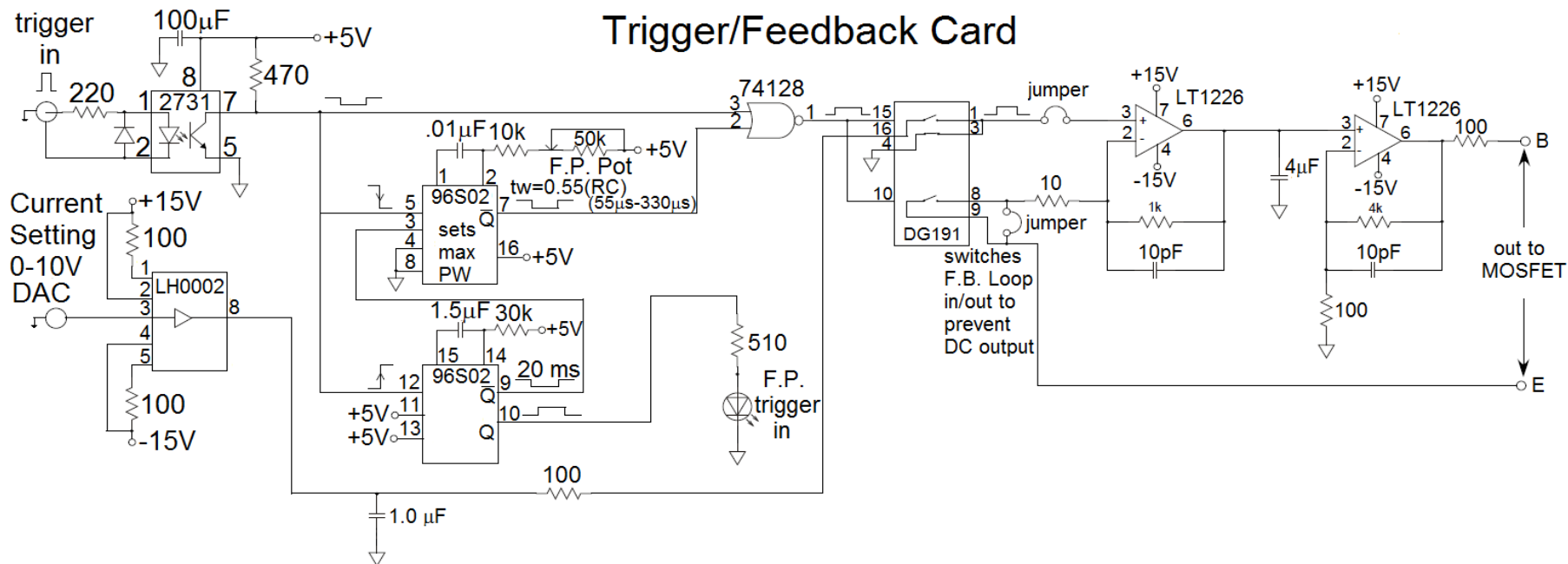
Merci!

Backup Slides

RFQ Injection Line



Current-regulated Arc Pulser Schematic



note: no ground plane