



Diagnostic Measurements and Performance of the Cesiated H- Source at LANL

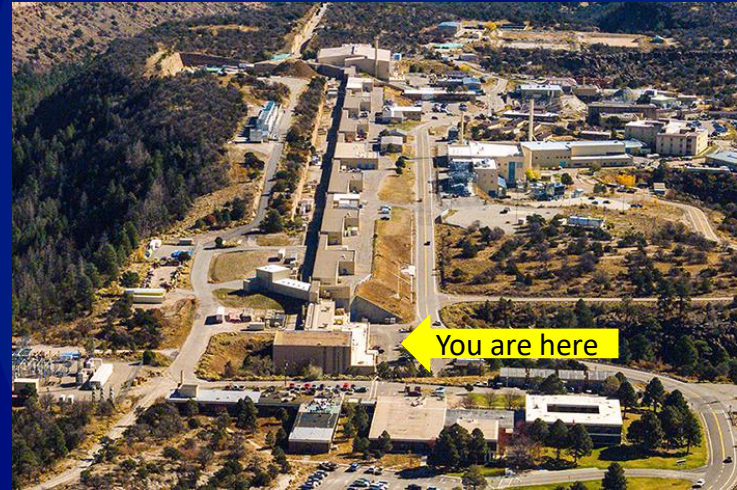
D. Kleinjan (speaker)

C. Rohde, G. Otero Munoz, A. Alexander,
G. Rouleau, J. Zhang, J. Quemuel, J.
Snyder

September 21, 2026

LA-UR-26-28289

Los Alamos Neutron Science Center



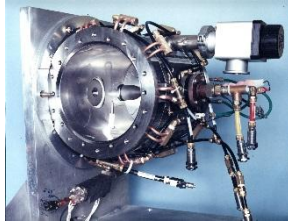
Outline

- Overview of LANSCE and its H- Ion Source
- Diagnostics
 - Review of Apparatus and summary of previous results
 - Plasma Diagnostics: OES of Balmer lines
 - Cs Diagnostics: First view of Cs density during operations
- Beam Stability: Prevent 80 kV pre-injector arc-downs
- Future Plans
 - <1 eV work function Perovskite research.
 - work function diagnostic development

The Los Alamos Neutron Science Center (LANSCE)

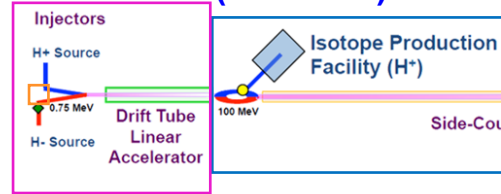


H⁺ Ion Source

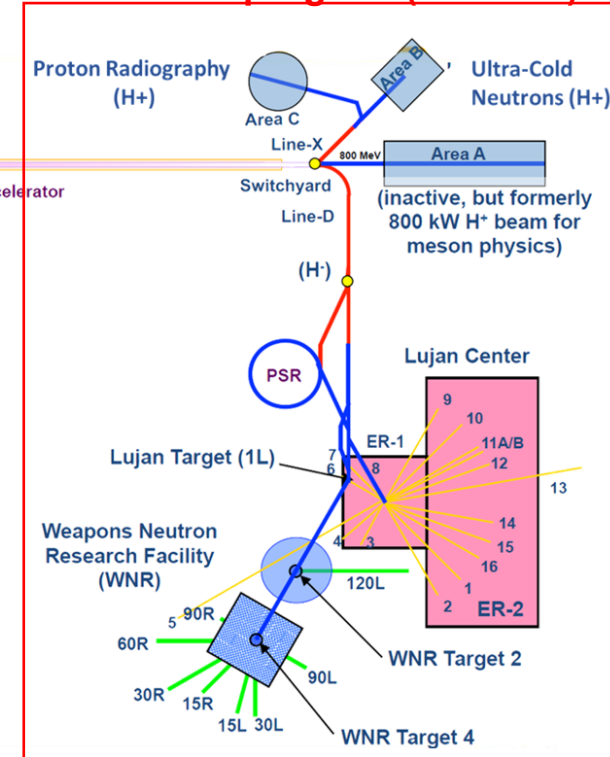


H⁻ ion source

H⁺ beam program (100 MeV)



H⁻ beam program (800 MeV)

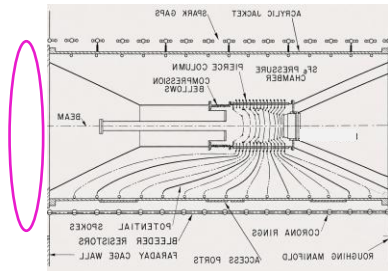


- LANSCE Dual H⁺ and H⁻ beam programs
- H⁺ beam one program: Isotope production Facility
- H⁻ beam multiple programs
 - Proton Radiography, Lujan Center WNR, Ultra-Cold Neutrons
- New downstream H⁻ emittance measurement
 - (152) C. Rohde “Integrating Laser Neutralizer Wire Scanner in the LANSCE H-LEBT”
- Future of LANSCE is LAMP. See also at NIBS’26:
 - (52) A. Alexander “The LAMP H⁻ ion sources: goals, status, and plans.”
 - (42) M. Howard “Status of the Internal RF Antenna Negative Ion Source for LAMP”

<https://lansce.lanl.gov>

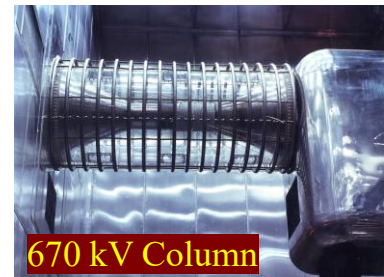
LANSC Front End Injection

670 kV column

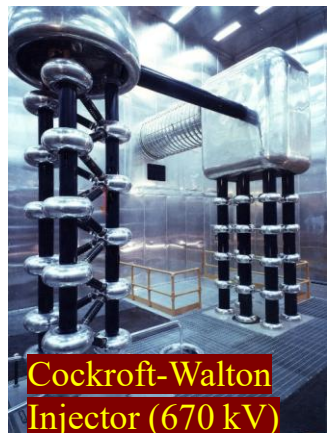


15 mA (H-)

670 kV acceleration



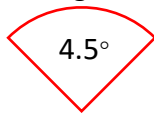
670 kV Column



Cockcroft-Walton
Injector (670 kV)

H- Current Emittance

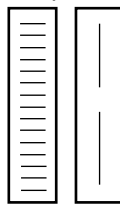
Bending
Magnet



Monitor

15+3 mA
(H⁻ + e)

Slit/Coll.

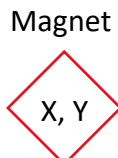


Beam

Deflector



Steering
Magnet

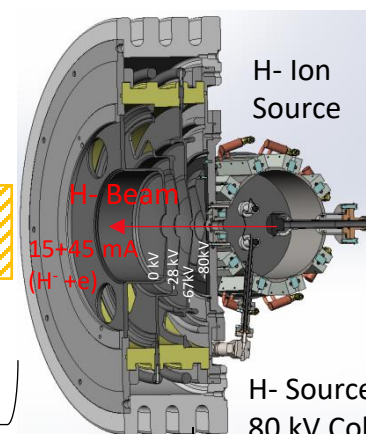


Solenoid 1



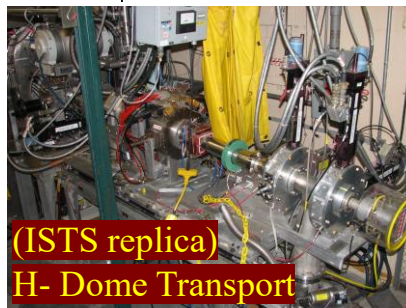
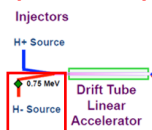
H- Dome Transport (select components, not to scale)

80 kV column

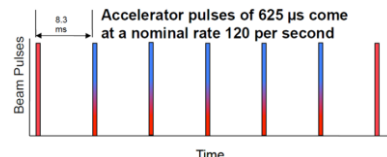


H- Source &
80 kV Column

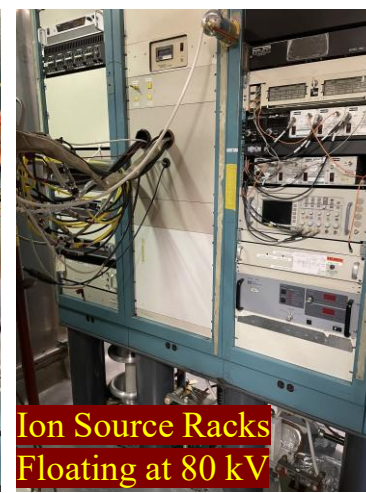
H- beam
injection
(750 keV)



(ISTS replica)
H- Dome Transport



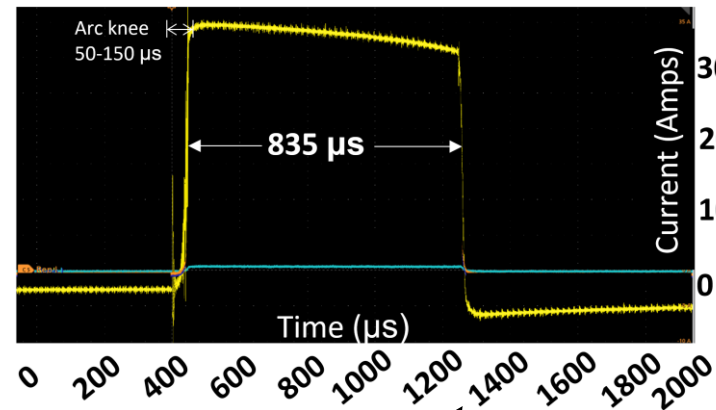
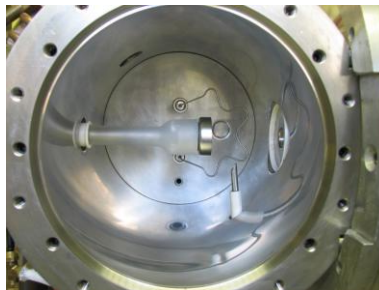
Ion Source &
80 kV extraction
column



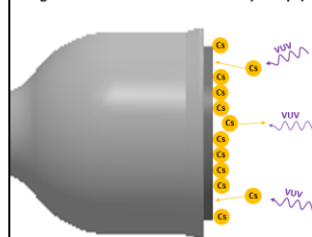
Ion Source Racks
Floating at 80 kV

The LANSCE H- Ion Source

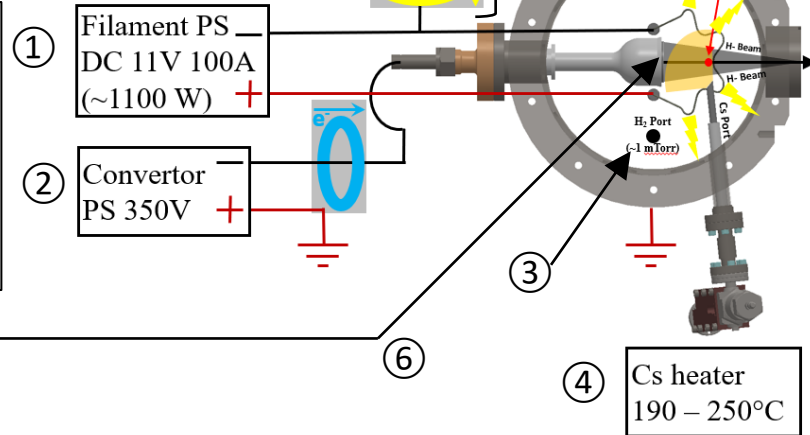
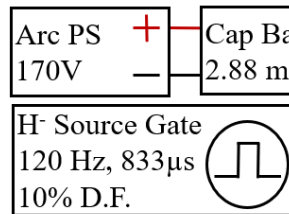
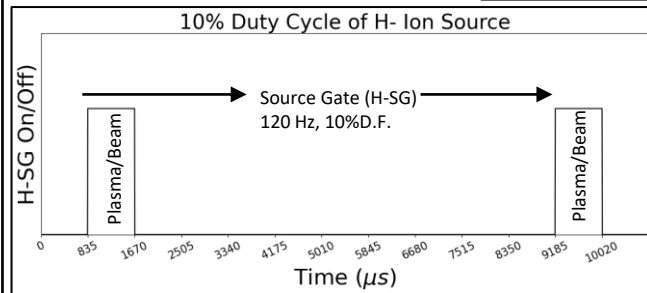
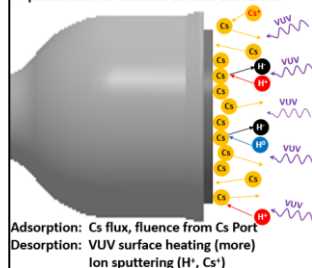
1. DC filament power, $P_{\text{Fil}} \sim 1000\text{W}$
2. DC Converter Voltage, $V_{\text{conv}} = -300\text{V}$
3. Continuous H_2 flow ($\sim 1\text{ mTorr}$)
4. Continuous Cs evaporation Controlled by T_{oven}
5. Filament arc-driven hydrogen plasma
6. H- production via Cesiumated surface conversion.
Adsorption/Desorption of Cs from converter.



Background Phase: H- Source Gate OFF (7497 μs)



Plasma Phase: H- Source Gate ON (833 μs)
H- production via cesiated surface conversion



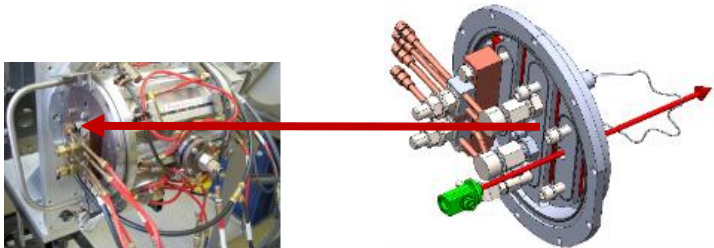
Optical Diagnostics on the LANSCE H- Ion Source

- Overview of our TLDS and OES diagnostics setup
- Quick review of data collected so far.
- 2026 Commissioning in LANSCE H- Ion Source Operations

Side plate modifications on LANSCE H- Ion Source

Minimal side plate modifications

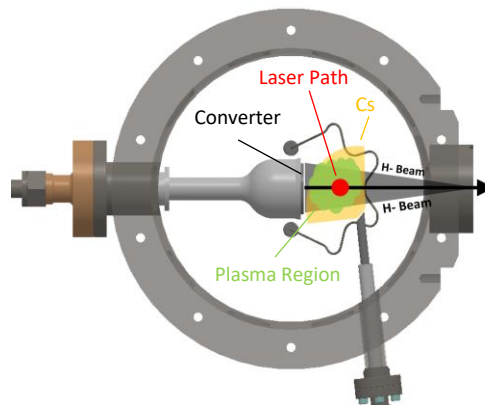
- matched optical inspection ports



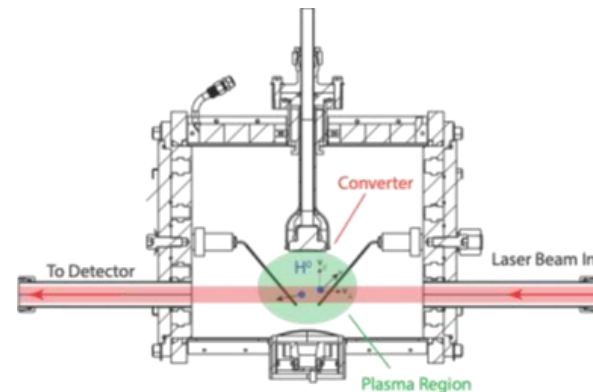
Probes the “heart” of source

- Diagnostic channels
 - Cesium Density, Temperature: 852.1 nm TLDS
 - Plasma Properties with OES: Balmer Lines H_α , H_β , H_γ
 - H_0 Temperature: 656 nm TLDS
 - H- Density: CRDS

Side View

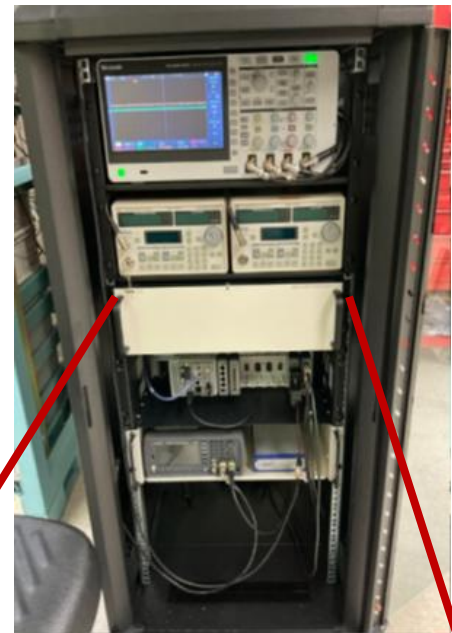
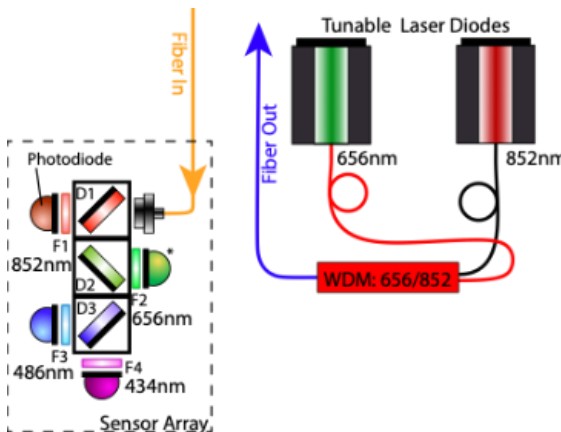
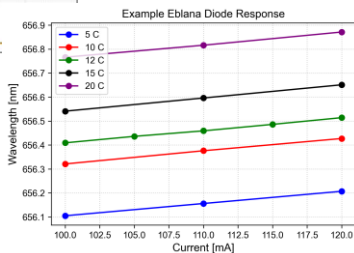
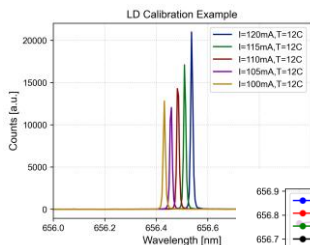


Top View



Dual Wavelength and OES Detector Design

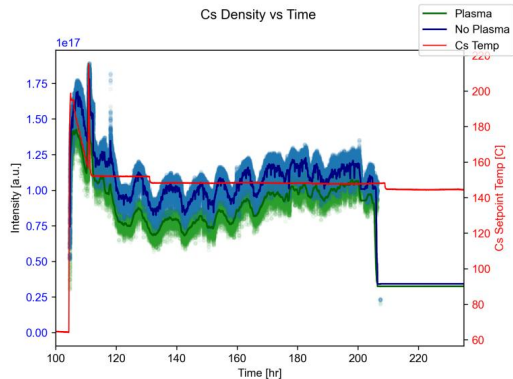
- Initial Source / Detector Setup
- 852 nm : stock item from Thorlabs
- 656 nm : custom DFB-like Laser Diode from Eblana Photonics
 - change emission wavelength based on operating temperature and drive current.
 - The output wavelength was calibrated using a high-resolution spectrometer.
- Peak detection used to estimate emission wavelength
- 20m single mode optical fiber delivery
- Custom-built fiber WDM (combiner)
- 400 micron-core MMF used for return



Results from 2024/2025 test runs

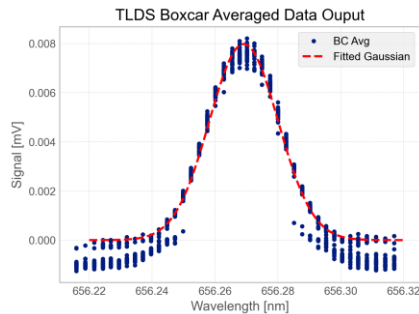
2025 Cs conditioning TLDS measurement

Cs Density vs Cs reservoir heating temperature

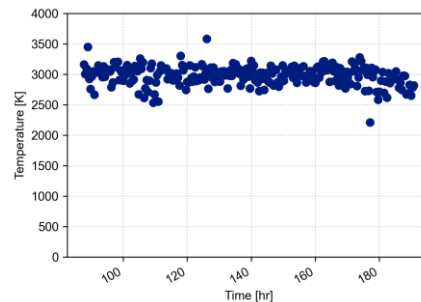


2025 H α TLDS measurement

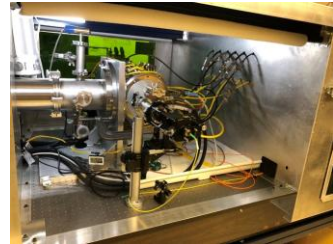
All collected TLDS scans overlaid



H0 Temperature calculated from every TLDS scan

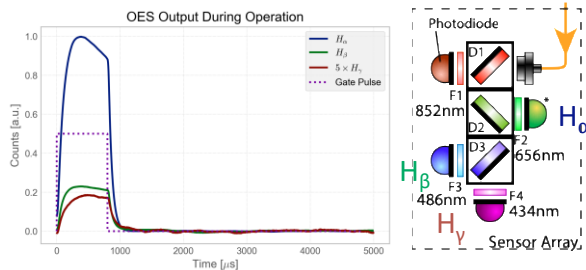


Laser Diagnostics Stand (LDS) with H- Ion Source and optical train



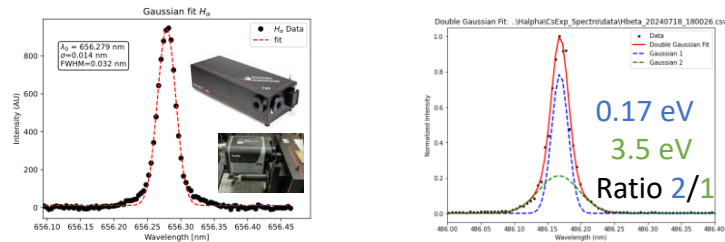
2025 Optical Emission Spectroscopy

Narrow Bandpass filters



2024 Optical Emission Spectroscopy

High Resolution Spectrometer, H α



C. Rohde et al., Proc. IPAC'24, Nashville, TN, May 2024, pp. 614-617

C. A. Rohde et al., J. Phys.: Conf. Ser. 3237 012027 2026 (Proc. ICIS'25)

David Kleinjan

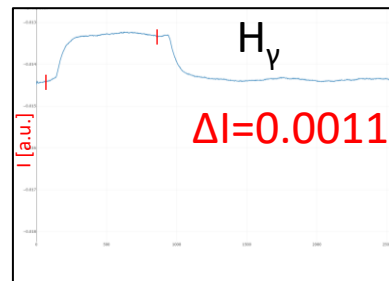
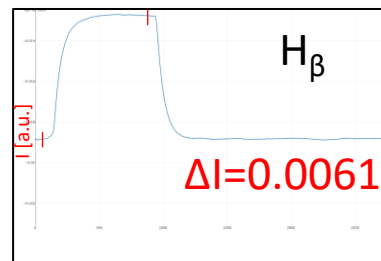
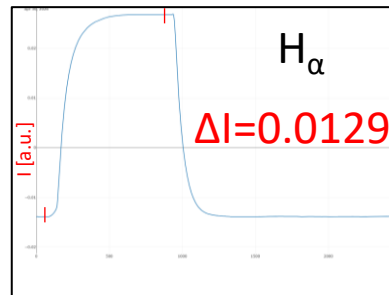
2026 runs on LANSCE Operational source

- Incorporated these measurements into real-time diagnostics for LANSCE production sources.
 - 852.1 nm (Cs) TLDS diagnostic
 - Parallel calibrated Cs cell (Vescent) for signal verification and QA.
 - OES capabilities remain active at 656.3 nm, 487 nm, and 437 nm.
 - No TLDS diagnostic available (yet) at 656.3 nm (H α).
- Source runs:
 - 2026/04/09 – 2026/05/18 (Fused silica windows)
 - 2026/06/16 – 2026/07/08 (Fused silica windows)
 - 2026/08/11 – 2026/09/04 (Dielectric AR coated windows)
- Overall issues
 - Cockcroft-Walton 670 kV column arc-downs trip off basement rack
 - Contaminated windows varied source-to-source.
 - Safety/Interlock commissioning.
 - Initial data collection anomalies.



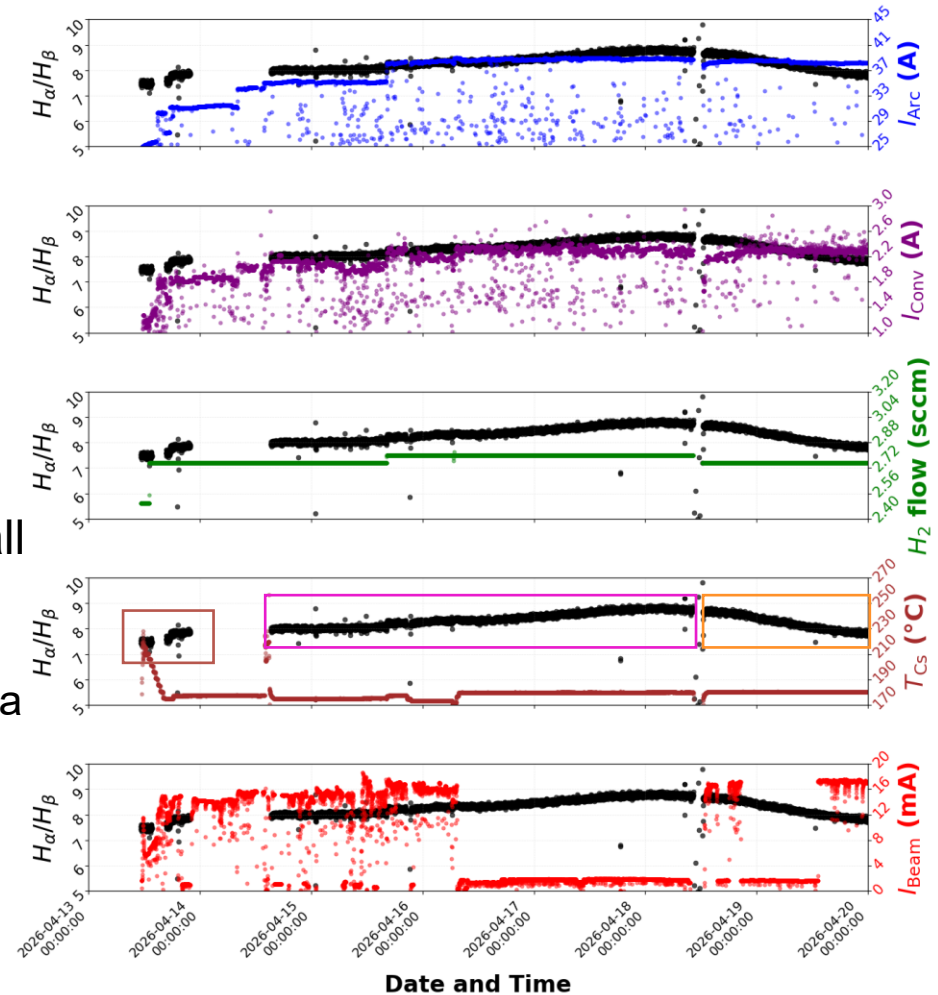
Balmer Line Plasma Diagnostics

- H_α/H_β for April and June runs
 - Reflects H- density
- H_β/H_γ for April run
 - Reflects n_e , T_e
 - Data limited, as channel was intermittently taken for Cs Vescent
- Assumptions:
 - Transmission factor same for all three
 - Window contamination effects all signals equally
 - Collision-Radiative Model Regime
- Relied on following paper for most interpretations
 - U. Fantz & D. Wunderlich 2006 New J. Phys 8 301



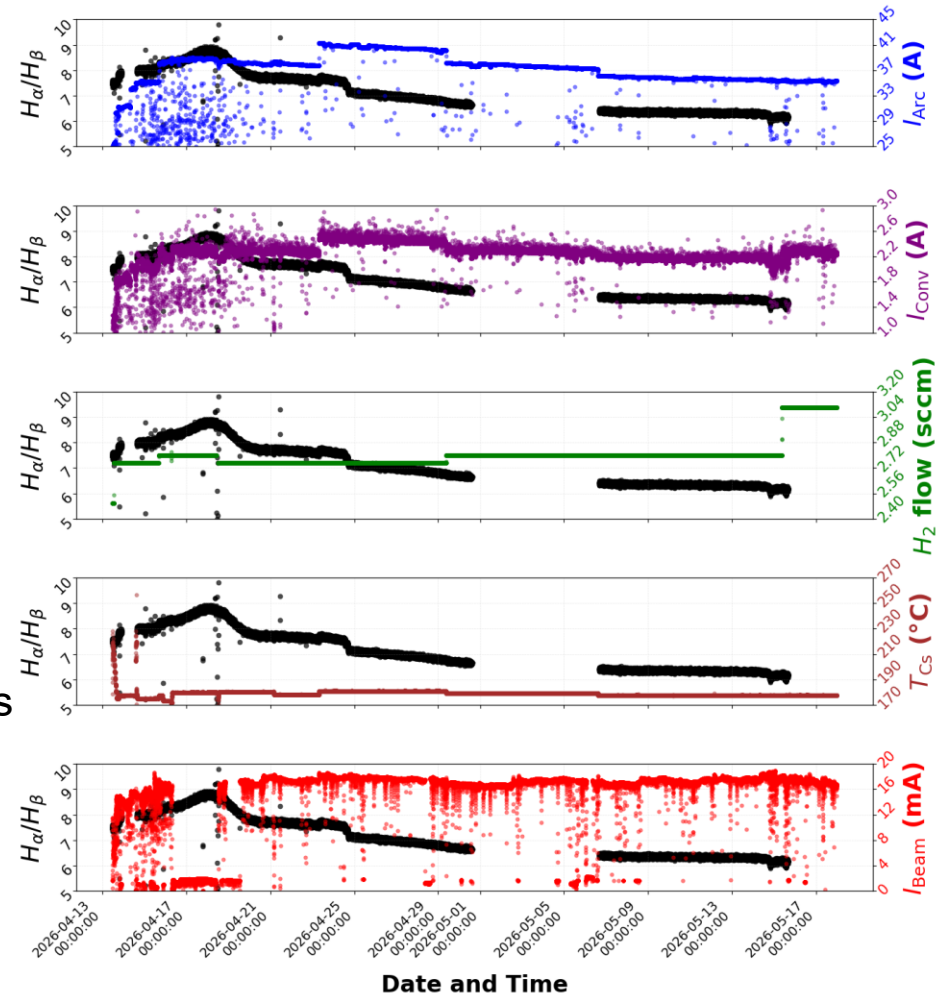
April Run, H_{α}/H_{β}

- Reflects changes in H- density
- Initial increase due to **Cs conditioning**
- **Consistent increase** over 1st few days after Cs conditioning
 - Independent of source parameters?
 - Ion Source Cs-wall equilibrium
- Pre/Post Cs conditioning effect is small
 - H- Ions created at 300 eV.
 - Small fraction of H- ions created at converter are <5 eV or slowed by plasma to <5 eV
- **Decrease** begins later days into source operational lifetime



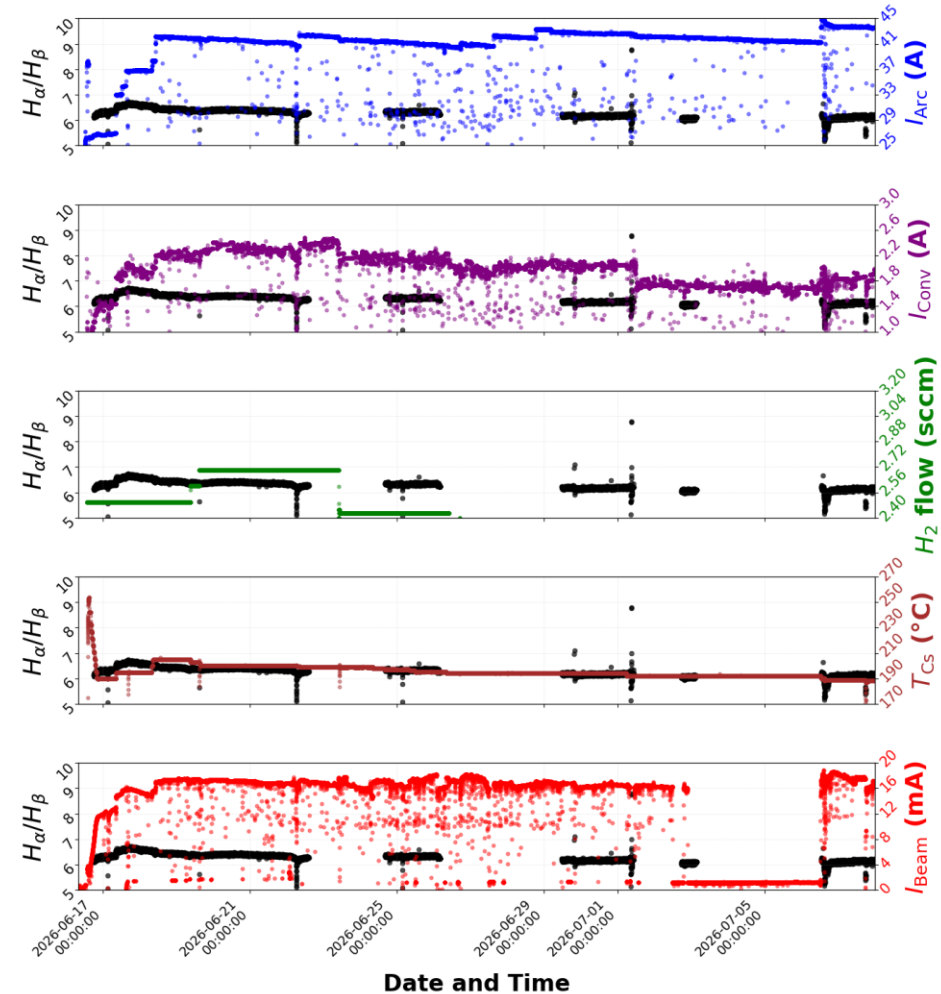
April Run, H_{α}/H_{β}

- **Decrease** begins later days into source operational lifetime
- Due to slow degradation in source?
 - Work function degradation due to surface impurities?
 - Slow over-cesiation of walls?
- Systematic window contamination effects?
- Operational Experience
 - Sources often give best beam 4-6 days into operational lifetime
 - Slow H- beam degradation afterwards
 - Beam peak maintained by continual optimization of I_{Arc} , H_2 flow, T_{Cs}



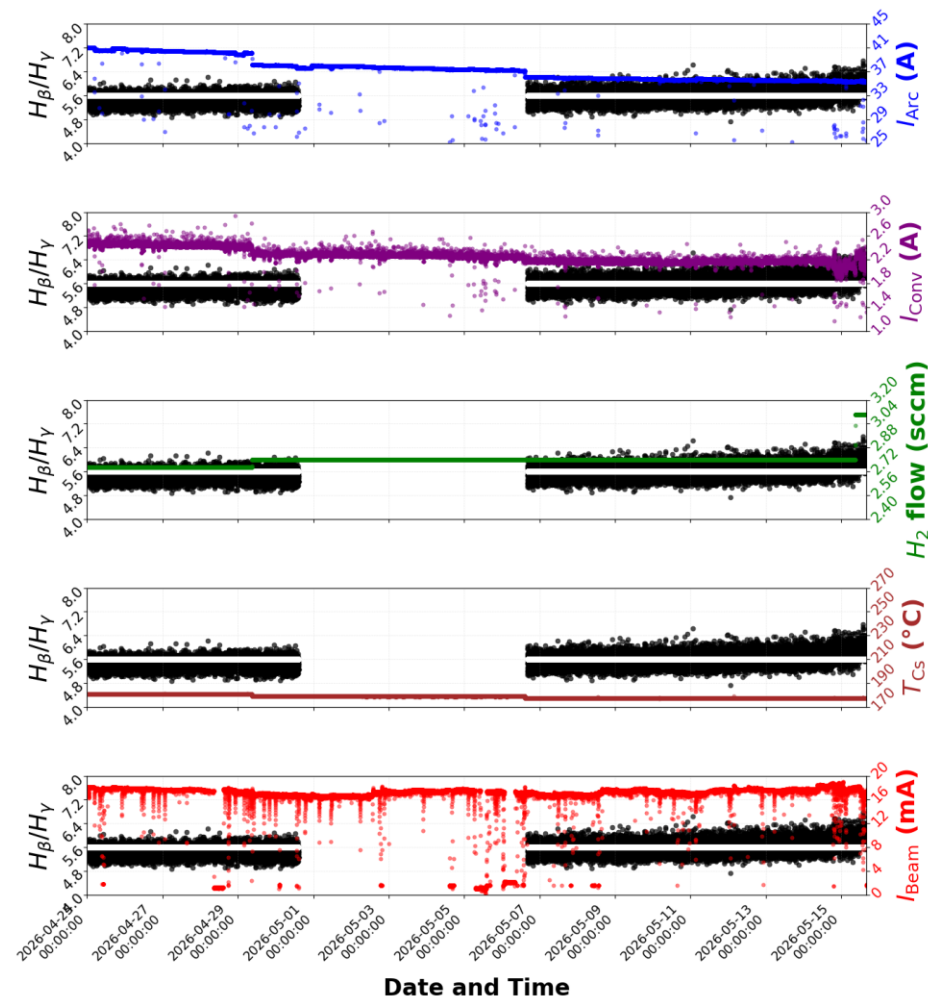
Jun Run, H_{α}/H_{β}

- Similar peak seen, but a few days sooner.
- **April $H_{\alpha}/H_{\beta} \sim 8-9$ peak**
- **June $H_{\alpha}/H_{\beta} \sim 6-7$ peak**
- Will continue to observe in the future.



Apr Run, H_{β}/H_{γ}

- Reflects n_e , T_e
- Last two weeks: Very slow increase over time
 - White line comparison
- Only goes up with H_2 flow at the end.
 - I_{Conv} , I_{Beam} anomaly
 - H_2 increased

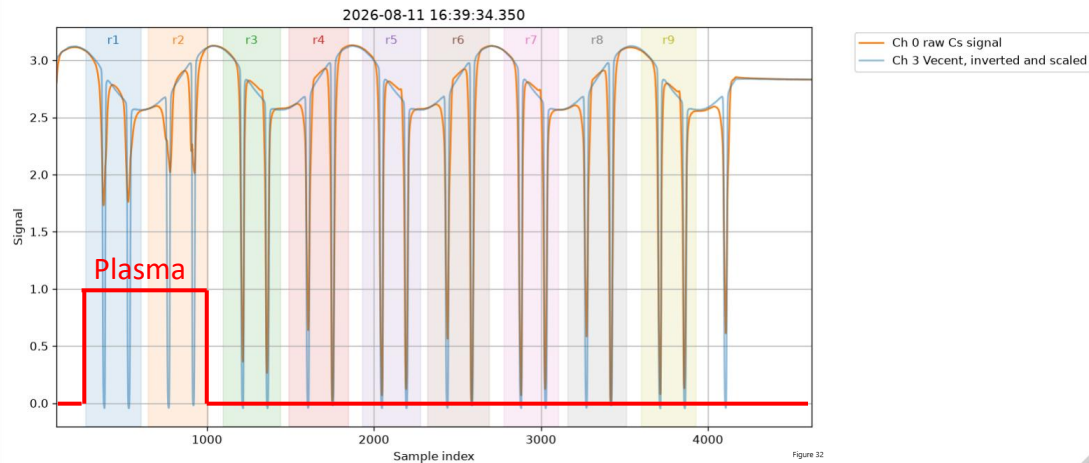


Cs Density

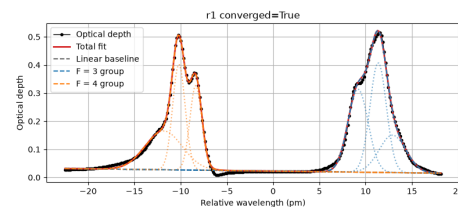
- April Data
 - Just getting going, line saturation issues
- June Data
 - Anomalies line shapes, line saturation issues
- August Data
 - High quality data
 - Changed laser beam size (bigger -> smaller, 8 -> 1.5 mm)
- Cs laser passed through Ion Source, but also Vescent calibrated cell as a reference.

August TDLs data

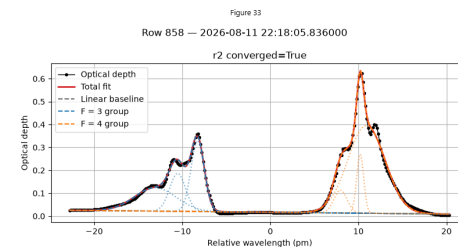
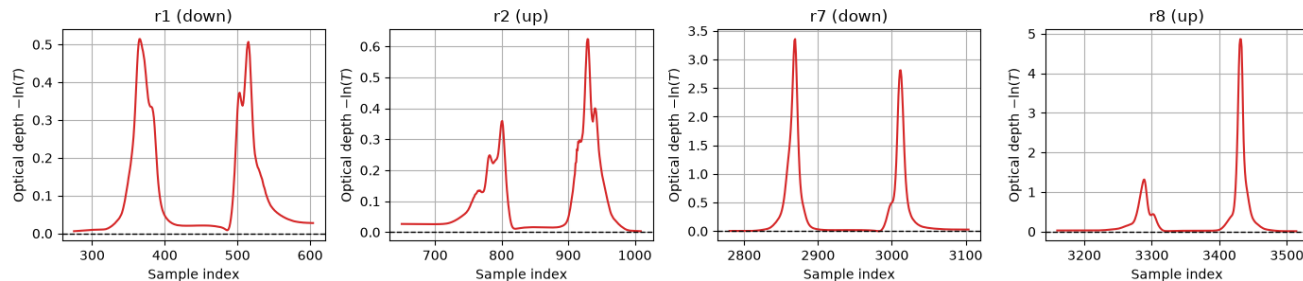
- Good signals with very little line saturation
- In plasma, r1, r2 peaks “hot” enough to see:
 - 3-peak nuclear hyperfine splitting?
 - Zeeman effect from wall magnets?



Row 858 — 2026-08-11 22:18:05.836000

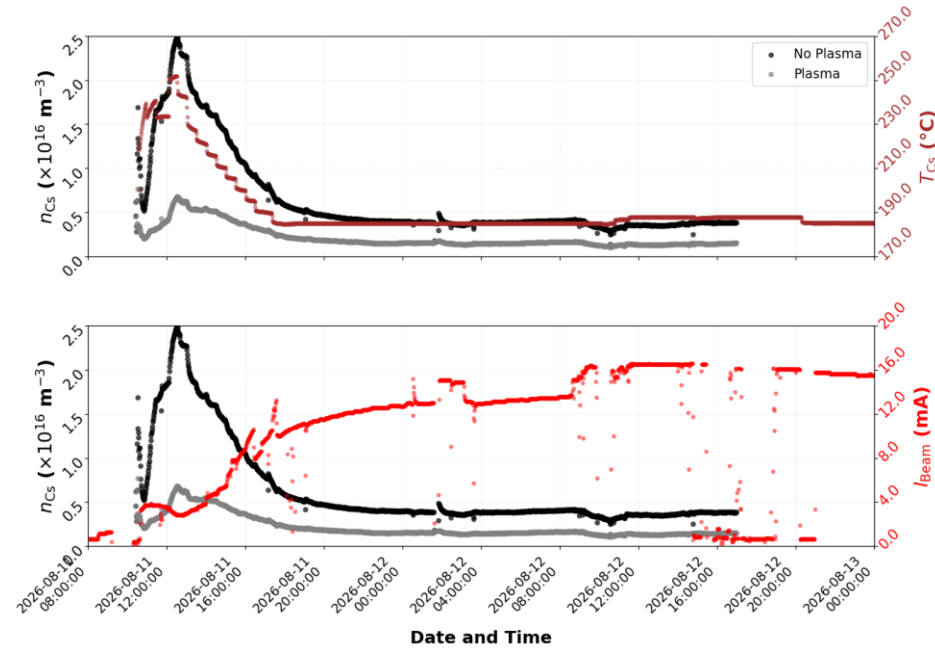


Optical depth by scan region — 2026-08-11 22:18:05.836000



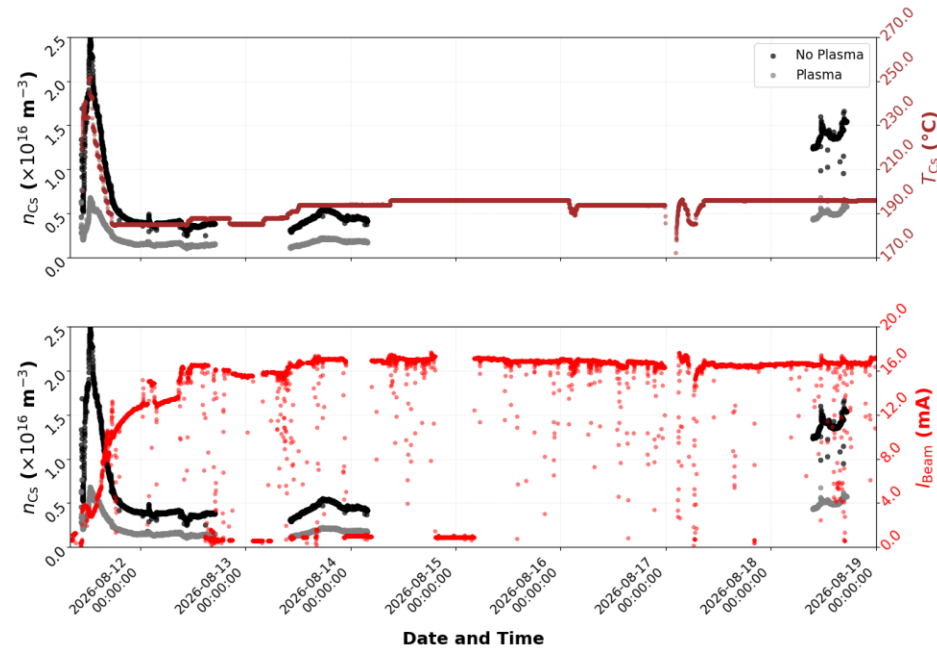
Cs Density

- Numerical Integration (Simpson's rule)
- Cs density in plasma lower due to ionization
- n_{Cs} vs T_{Cs} (Oven)
 - during conditioning
 - $n_{Cs} \sim 2.5 \times 10^{16}$ @ $T_{Cs} = 250^\circ\text{C}$
 - $n_{Cs} \sim 0.5 \times 10^{16}$ @ $T_{Cs} = 190^\circ\text{C}$
 - 5/1 difference
 - Vapor pressure curve is
 - $n_{Cs} \sim 9.79 \times 10^{21}$ @ $T_{Cs} = 250^\circ\text{C}$
 - $n_{Cs} \sim 1.25 \times 10^{21}$ @ $T_{Cs} = 190^\circ\text{C}$
 - 9/1 difference, 6 Ord.Mag.
- Impurities in source lower magnitude.
- Unequal heating along Cs Reservoir/Tube lead to scale breaking from vapor pressure curve
 - Cold sinks will affect final Cs density



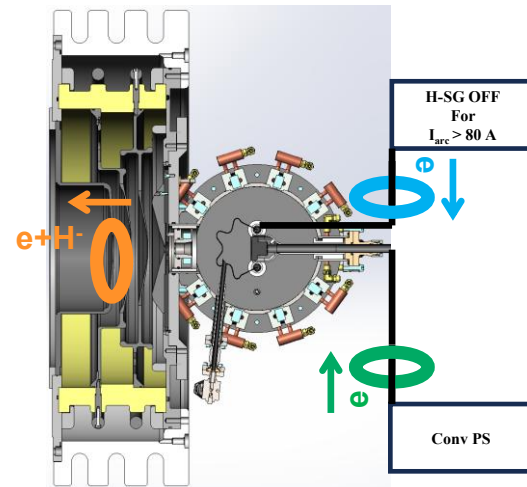
Cs Density

- Density high later in run
 - Gaps due to CW trip...
 - Due to window contamination, or increased wall coating?
- Will continue to investigate

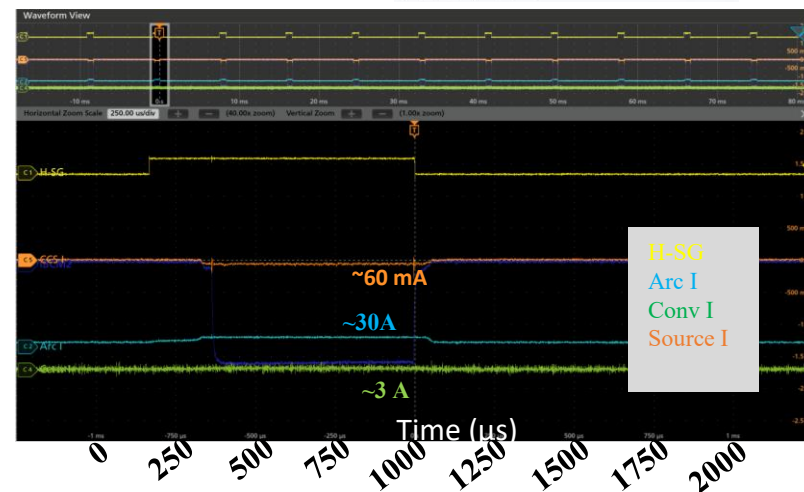


The H- Ion Source. Beam Stability

- Nominal source operation
 - $I_{\text{Arc}} = 3 \text{ A}$, $I_{\text{Conv}} = 3 \text{ A}$, $I_{\text{Src}} = 80 \text{ mA}$

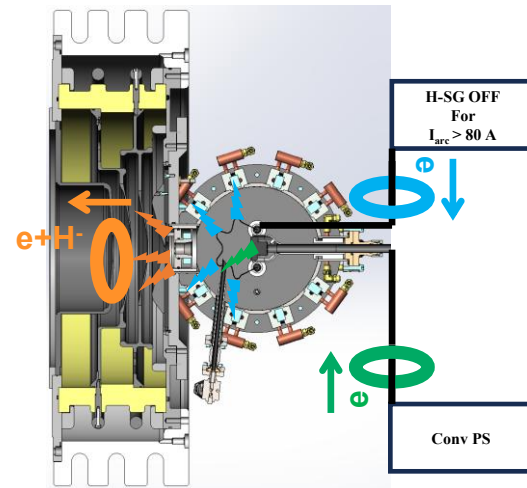


Nominal currents

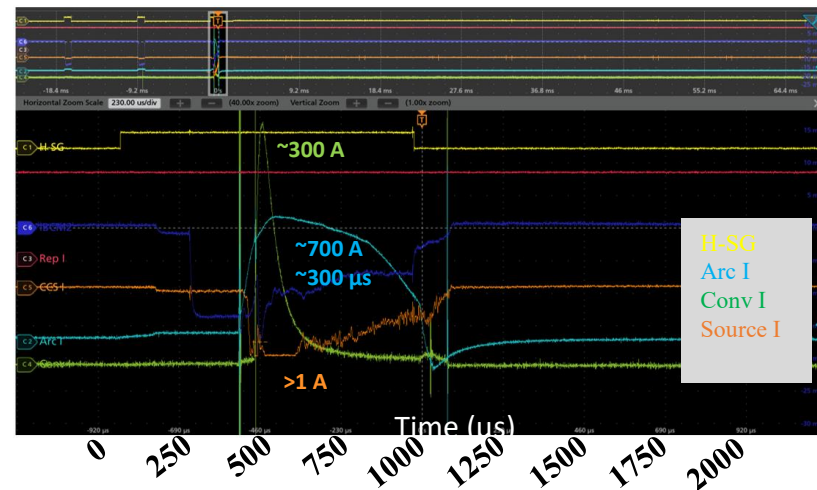


The H- Ion Source. Beam Stability

- Nominal source operation
 - $I_{\text{Arc}} = 3 \text{ A}$, $I_{\text{Conv}} = 3 \text{ A}$, $I_{\text{Src}} = 80 \text{ mA}$
- Cs instabilities leads to **arc/converter** transients
 - $I_{\text{Arc}} = 700 \text{ A}$, $I_{\text{Conv}} = 300 \text{ A}$, $I_{\text{Src}} > 1 \text{ A}$
 - Correlate with **vast majority** of 80 kV arcdowns.

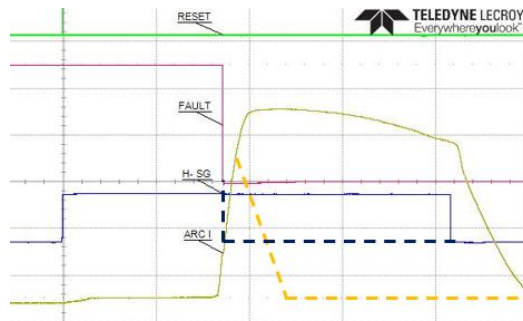


Transient currents

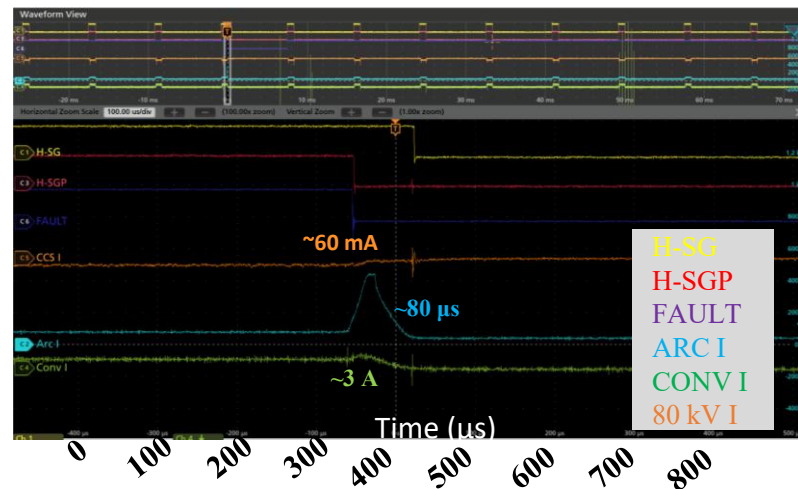
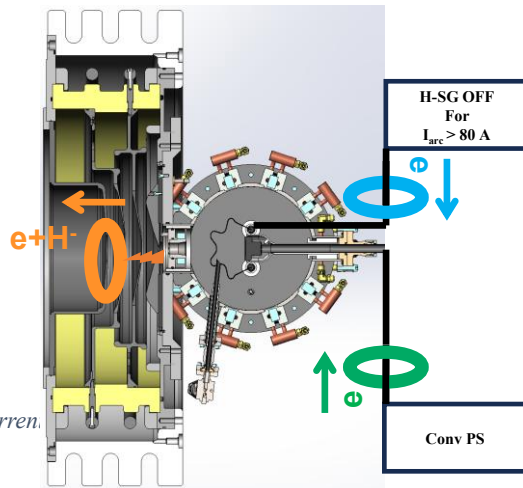


The H- Ion Source. Beam Stability

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- Cs instabilities leads to **arc/converter** transients
 - $I_{\text{Arc}} = 700 \text{ A}$, $I_{\text{Conv}} = 300 \text{ A}$, $I_{\text{Src}} > 1 \text{ A}$
 - Correlate with **vast majority** of 80 kV arcdowns.
- Protection mechanism(s)
 - (6/2024) Source gate (H-SG) shut off on discharge over-current

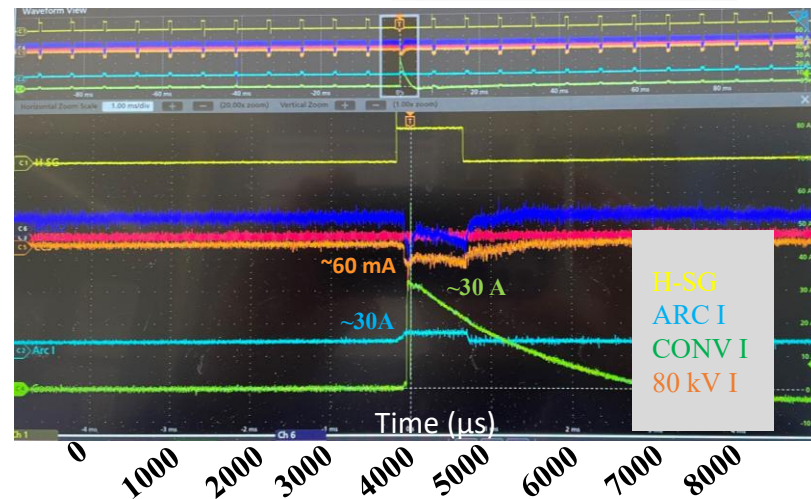
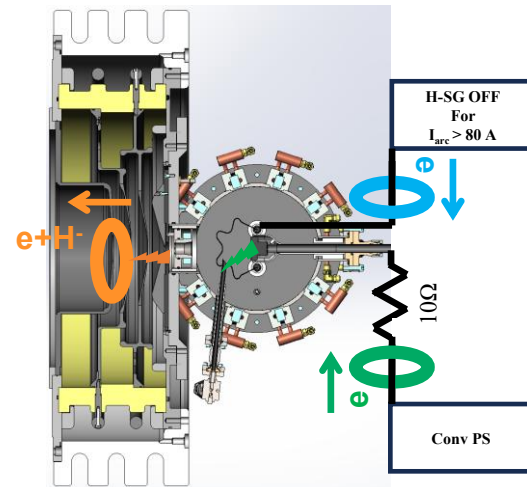


Side-by-side of before/after implementation of over-current limit channel



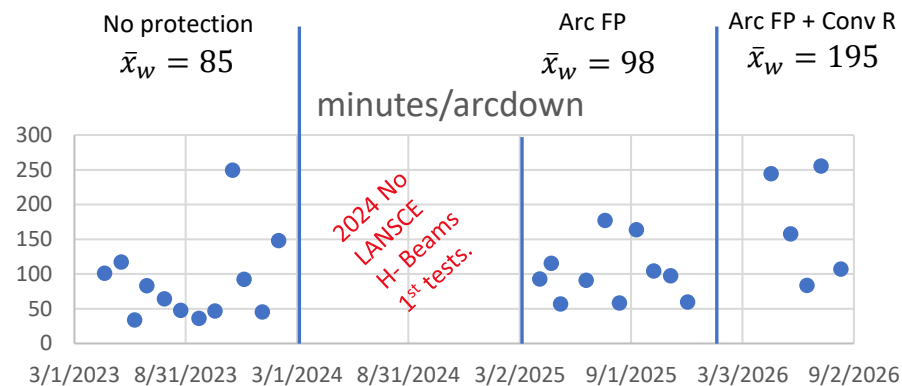
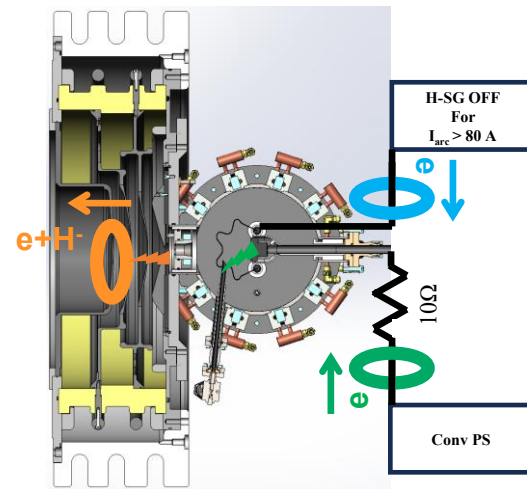
The H- Ion Source. Beam Stability

- Nominal source operation
 - $I_{\text{Arc}} = 3 \text{ A}$, $I_{\text{Conv}} = 3 \text{ A}$, $I_{\text{Src}} = 80 \text{ mA}$
- Cs instabilities leads to **arc/converter** transients
 - $I_{\text{Arc}} = 700 \text{ A}$, $I_{\text{Conv}} = 300 \text{ A}$, $I_{\text{Src}} > 1 \text{ A}$
 - Correlate with **vast majority** of 80 kV arcdowns.
- Protection mechanism(s)
 - (6/2024) Source gate (H-SG) shut off on discharge over-current
 - (4/2026) 10Ω current limiting resistor in series w/ converter. Been very successful for stability.



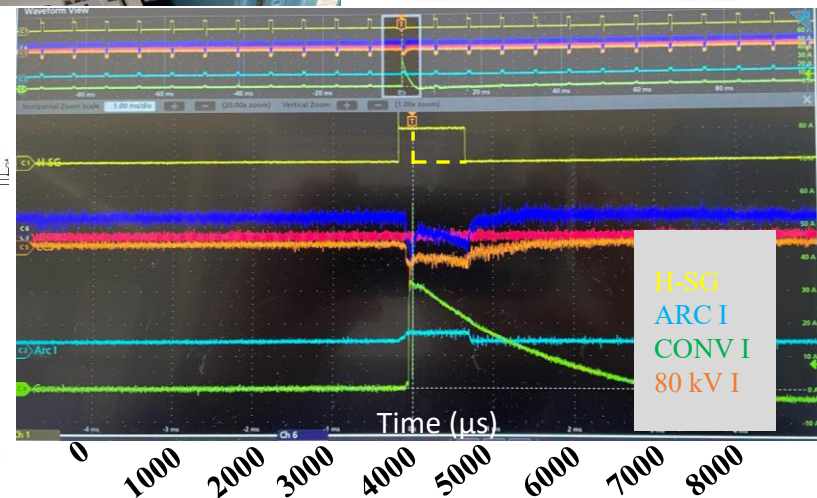
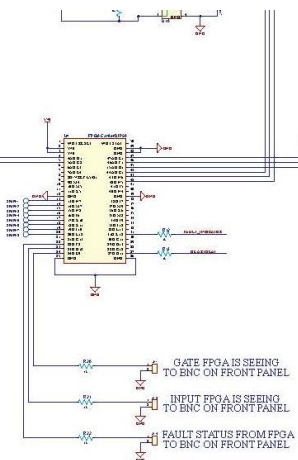
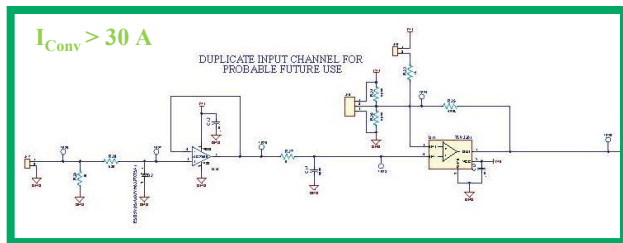
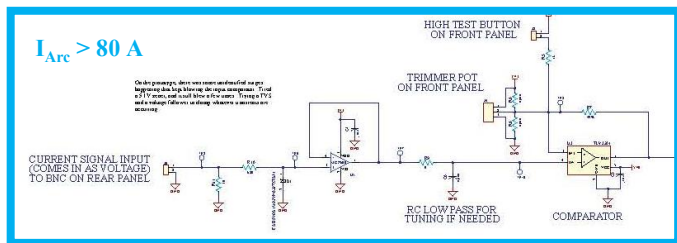
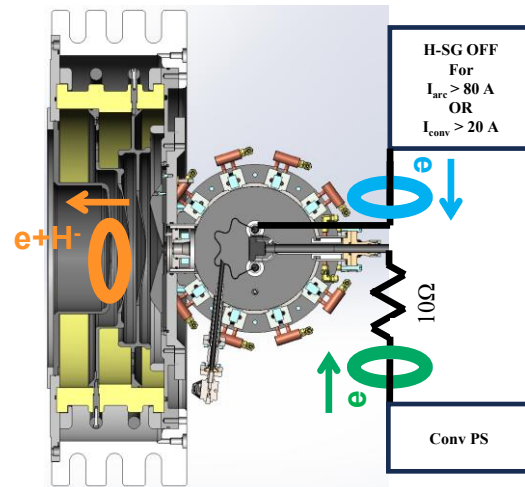
The H- Ion Source. Beam Stability

- Nominal source operation
 - $I_{\text{Arc}} = 3 \text{ A}$, $I_{\text{Conv}} = 3 \text{ A}$, $I_{\text{Src}} = 80 \text{ mA}$
- Cs instabilities leads to **arc/converter** transients
 - $I_{\text{Arc}} = 700 \text{ A}$, $I_{\text{Conv}} = 300 \text{ A}$, $I_{\text{Src}} > 1 \text{ A}$
 - Correlate with **vast majority** of 80 kV arcdowns.
- Protection mechanism(s)
 - (6/2024) Source gate (H-SG) shut off on discharge over-current
 - (4/2026) 10Ω current limiting resistor in series w/ converter. Been very successful for stability.
 - Stepwise improvement as protection is added



FP Chassis in ICR. Will be modified soon: 10/8/2026 source recycle

- Replace FPGA board in existing chassis
- New Board adds converter overcurrent (25 A) protection
- A little more protection...



Future

- Exploratory research of low work function Perovskites
- Work function plans

Future: LANL Exploratory Research Grant 2027-2029

“Breaking the 1 eV Barrier: Perovskite Oxides as Cesium-Free H⁻ Emitters”

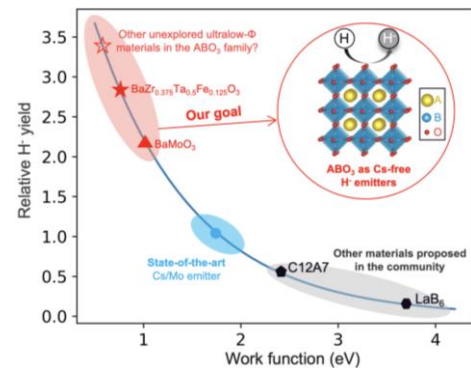


Figure 2. Predicted H⁻ yield relative to Cs/Mo emitter. The inset shows the structure of ABO₃.

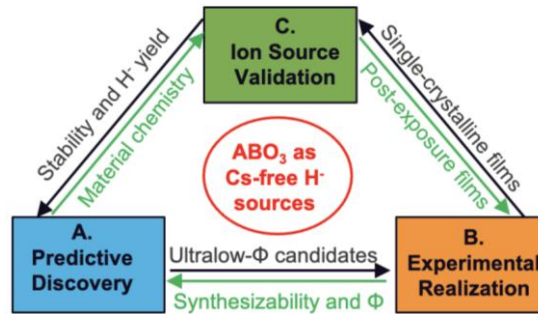
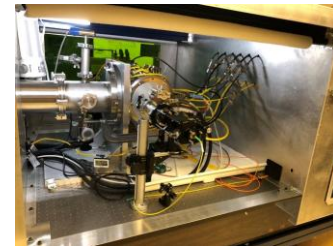


Figure 7. Integrated workflow and feedback between tasks.

Challenges

- A.) Many ABO₃ Candidates
- B.) Achieving single-crystalline structure
- C.) Thermal stress, Electron D.o.S

C.) Kleinjan *et al.*
Accelerator Div.



H- Laser Diagnostic Stand

B.) Chen *et al.*
Materials Div.

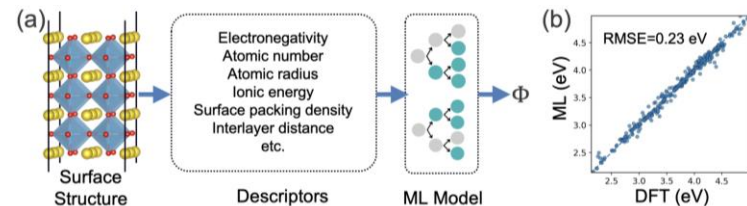


Figure 4. ML prediction of Φ .

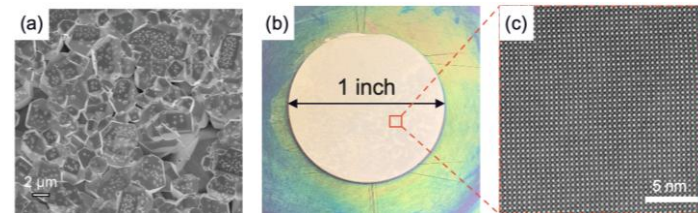
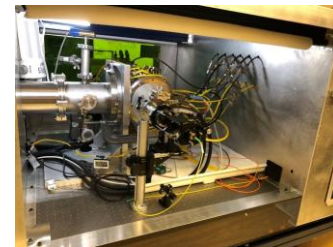
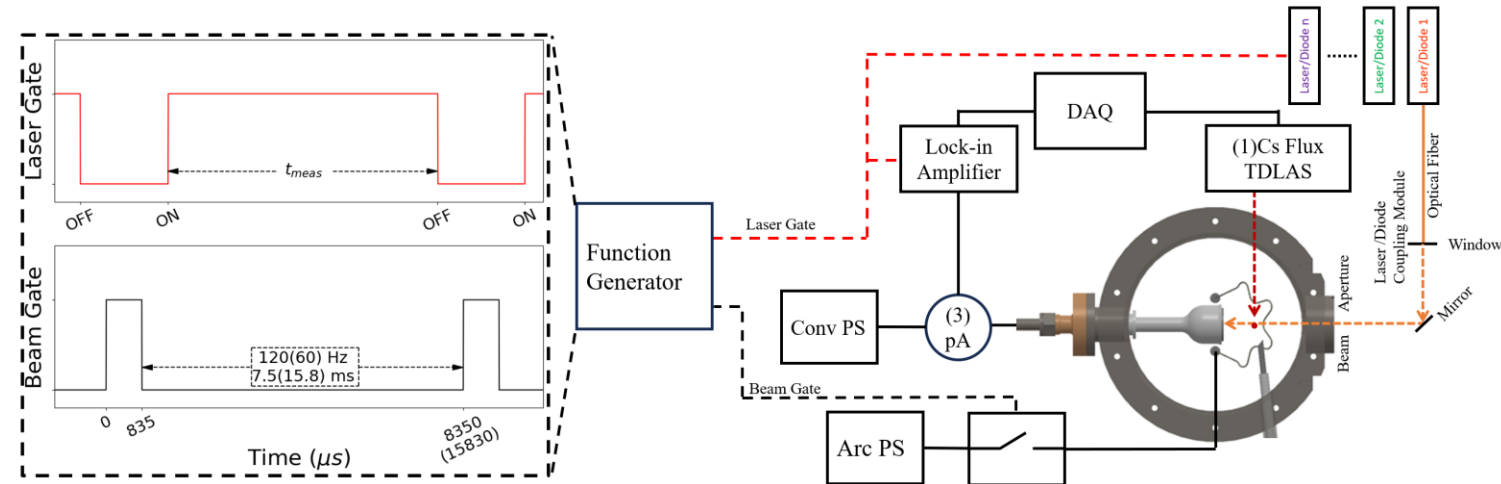


Figure 3. (a) Polycrystalline ABO₃ samples reported in literature,^[26] (b) photograph and (c) TEM image of single-crystalline ABO₃ films synthesized at LANL.

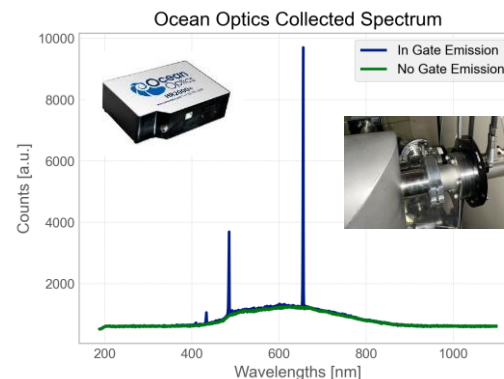
Future: work function measurements on H- Ion Source



H- Laser Diagnostic Stand

- Technical Challenges:

- Lamp vs LEDs vs Lasers
- Measurement states
 - Cold Vacuum
 - Sufficient for Perovskite Oxides, but not for existing Cs/Mo.
 - In between beam pulses
 - Enough power in LED/Laser to take ~7 ms measurement?
 - Large Tungsten background



Conclusions

- Diagnostic commissioning on LANSCE H- Ion source
 - So Far
 - Cs density/Temp w/ TDLS: becoming established
 - OES Balmer lines, particularly H_{α}/H_{β} may give early qualitative diagnosis of H- Source Quality.
 - To Do
 - High Voltage 670 kV arcdowns of Cockcroft Walton trips off diagnostic equipment.
- Beam stability is enhanced by mitigating 80 kV arc downs with FPGA fast-protect logic, and current limiting, high-power resistor.
- Future research
 - H- Ion Source to become a testbed for exploring <1 eV Perovskite Oxides
 - Work function measurements on H- Ion Source

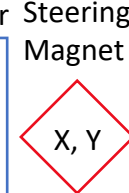
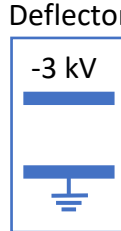
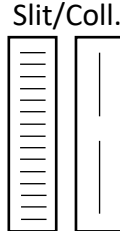
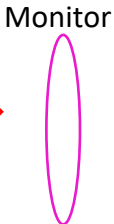
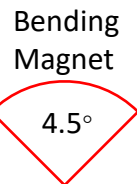
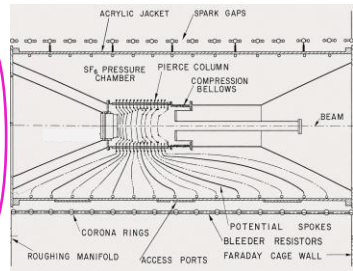
Acknowledgements

- Future Perovskite Research
 - Gaoxue Wang, LANL T-Division (Theory)
 - Aiping Chen, LANL MPA-Division (Material Physics & Applications)
- IPP Garching Group
 - U. Fantz, D. Wunderlich, C. Wimmer *et al.*
 - Many papers related to Cesium density, Plasma diagnostics.
- Rob Welton, ORNL

backup

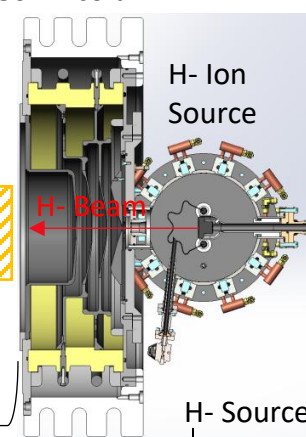
LANSC Front End Injection

670 kV column (backwards)

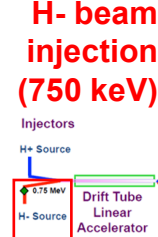


H- Dome Transport (select components, not to scale)

80 kV column



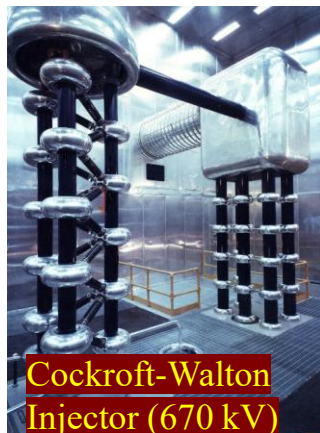
H- Source & 80 kV Column



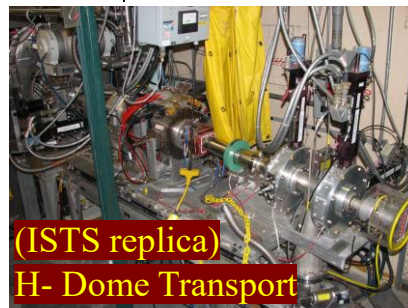
670 kV acceleration



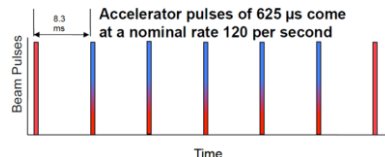
670 kV Column



Cockcroft-Walton
Injector (670 kV)



(ISTS replica)
H- Dome Transport



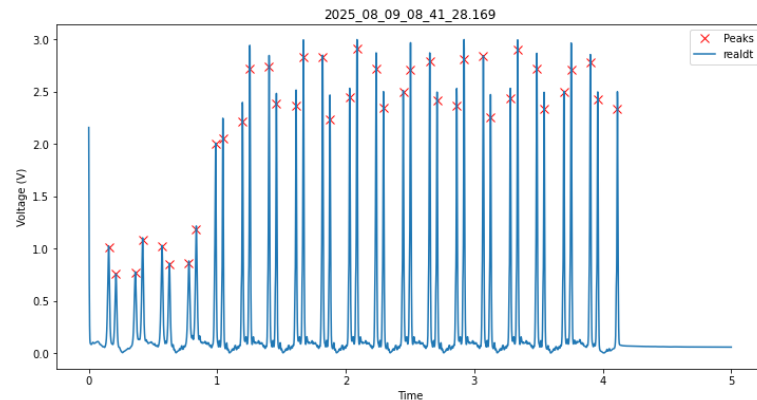
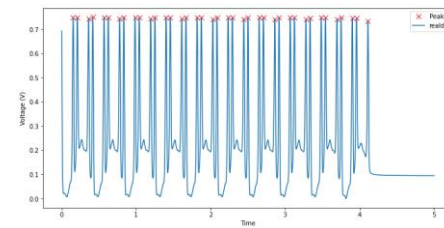
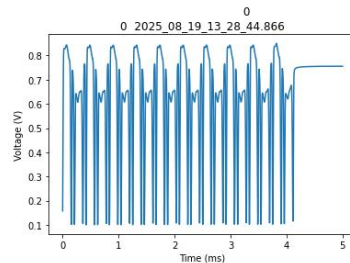
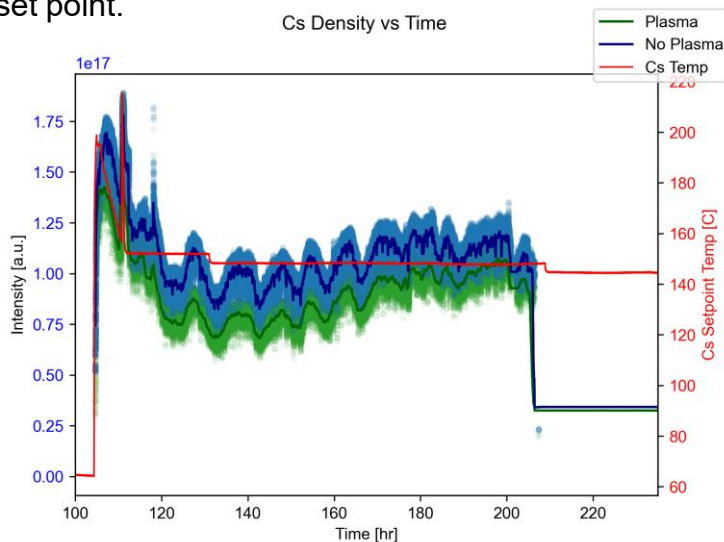
Ion Source &
80 kV extraction
column



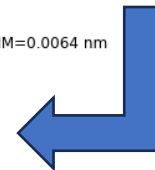
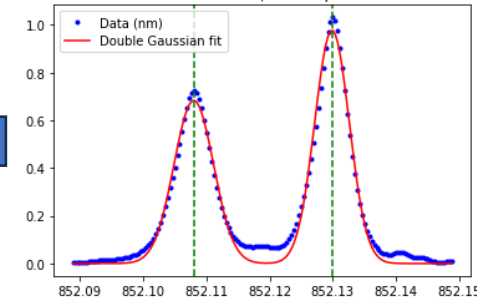
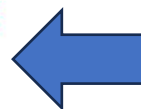
Ion Source Racks
Floating at 80 kV

Cesium TLDS Collection

- Cs TLDS signals are based on measuring the absorption of the Cs ground state ($6^2S_{1/2} \rightarrow 6^2P_{3/2}$) transition.
 - Ground state absorption measurement results in a strong, self calibrating signal.
- Cs conditioning
 - Three weeks Cs operation.
 - TLDS Cs density measurement overlaid on Cs oven temperature set point.

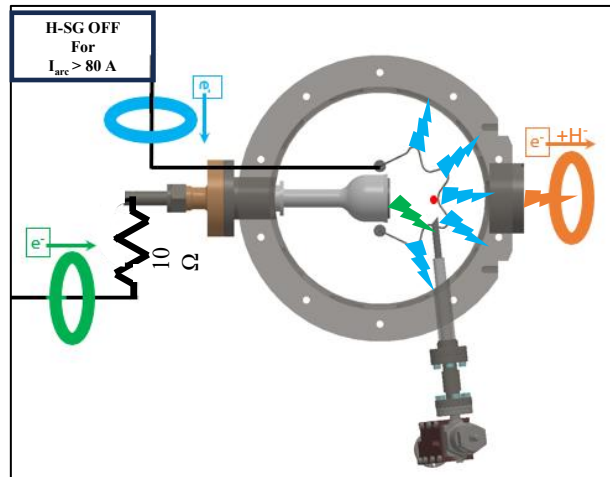


Peak2: $\mu=852.1080$ nm, FWHM=0.0074 nm | Peak3: $\mu=852.1299$ nm, FWHM=0.0064 nm

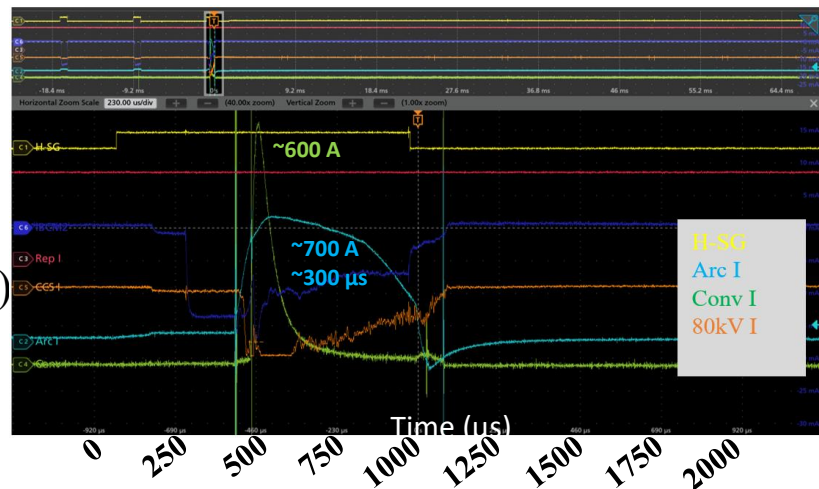


The H- Ion Source. Beam Stability

- Cs instabilities leads to **arc/converter** transients
- Correlate with **vast majority** of 80 kV arcdowns
 - Interrupted beam for ~ 10 secs
 - 1/hr 0.4% downtime, 2/hr 0.8%, 5/hr 2%, 10/hr 4%
 - Ion source trips off (minutes)
 - Equipment breaks (hours/days)
- How do we stop them?**
 - 10 Ω resistor on converter. Current limit PS.
 - Arc overcurrent (~ 80 A) inhibit to H-SG
- Both installed for tests Feb/26/24 – Mar/7/24
 - Resister first, Feb/26 – Mar/5 (0.46 arcs/hr)
 - Then add Arc o.c. Mar/5 – Mar/7 (0.29 arcs/hr)
 - Removed both Mar/7 – Mar/9 (1.11 arcs/hr)
- Results very promising**

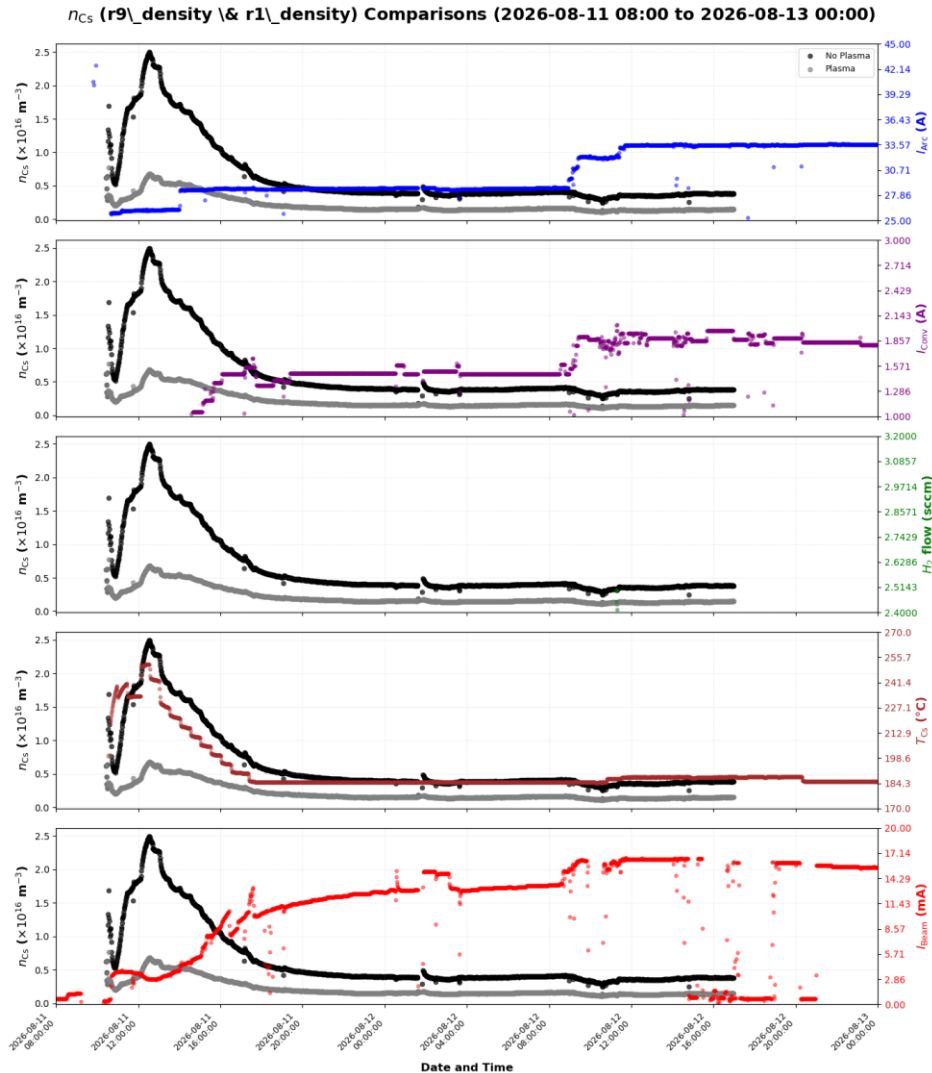


Transient currents



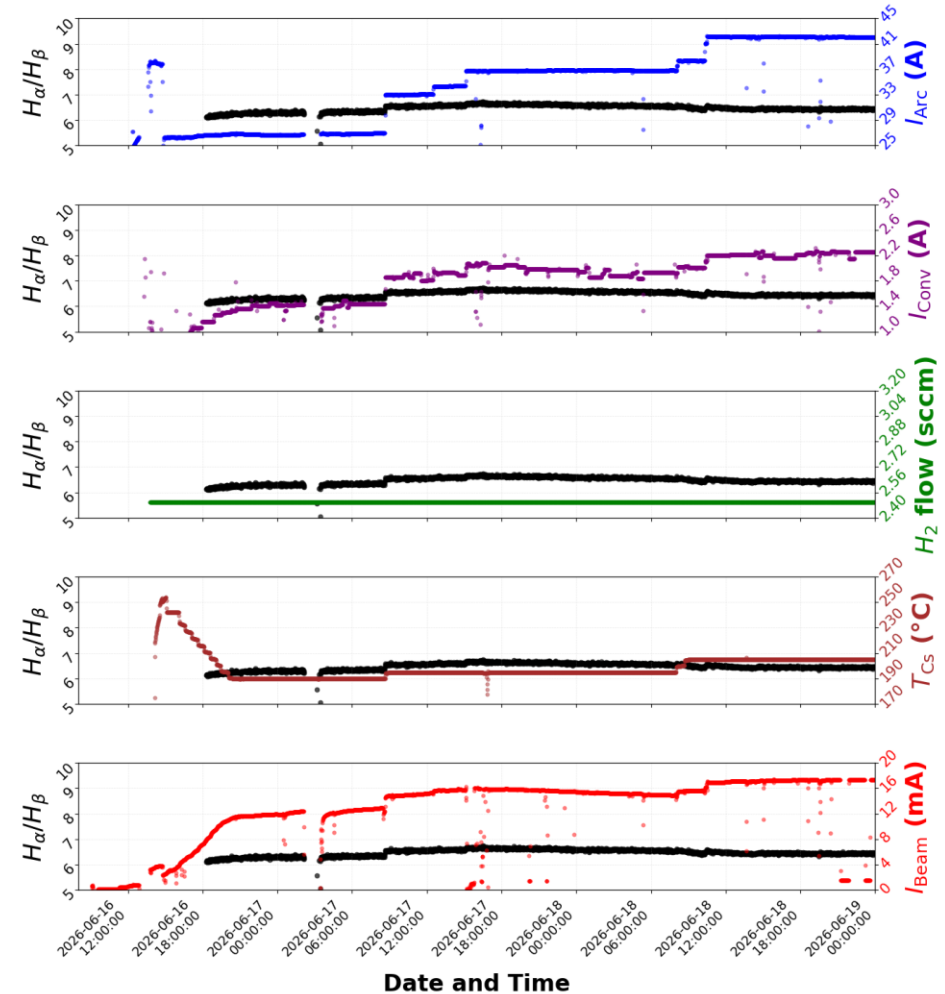
Cs Density

- Numerical Integration
- Cs density in plasma lower due to ionization
- n_{Cs} vs T_{Cs} (Oven)
 - during conditioning
 - $n_{Cs} \sim 2.5e16$ @ $T_{Cs} = 190^\circ C$
 - $n_{Cs} \sim 0.5e16$ @ $T_{Cs} = 190^\circ C$
 - 5/1 difference
 - Vapor pressure curve is
 - $n_{Cs} \sim 9.79e+21$ @ $T_{Cs} = 250^\circ C$
 - $n_{Cs} \sim 1.25e+21$ @ $T_{Cs} = 190^\circ C$
 - 9/1 difference, 6 Ord.Mag.
- Impurities in source lower magnitude
- Unequal heating along Cs Reservoir/Tube lead to scale breaking



Jun Run, H_{α}/H_{β}

- Reflects H- density
- Got diagnostic started partially into Cs conditioning
- Increases due to
 - Increased $I_{\text{Arc}/H_2} \rightarrow I_{\text{Conv}} \rightarrow I_{\text{beam}}$



Cs Atomic Temperature

- Triple Gaussian Behavior?
- Especially in Plasma Peaks
- Investigation ongoing
- Early Run

Fitting function:

$$\tau(u) = b + mu + \sum_{k=1}^6 a_k \exp \left[-\frac{(u - \mu_k)^2}{2\sigma_k^2} \right]$$

which is 6 gaussians and a line, where a_k is amplitude, μ_k is centroid (x), and σ_k is width. Total of $3 \times 6 + 2$ parameters, a lot!

Plasma

Row 858 — 2026-08-11 22:18:05.836000

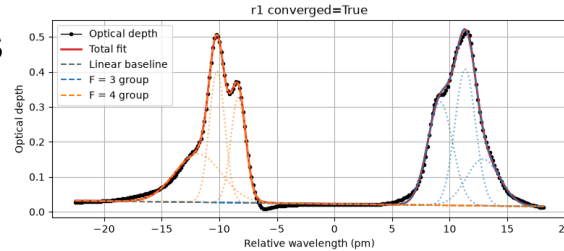
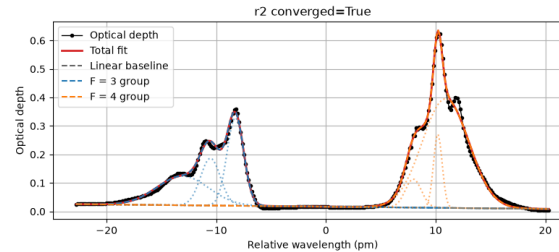


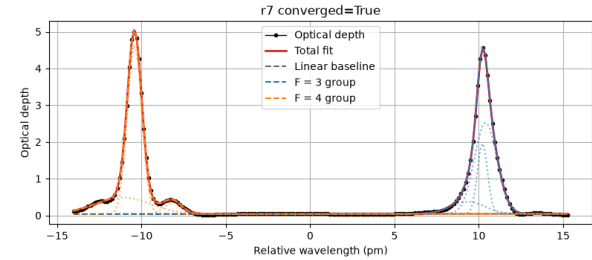
Figure 33

Row 858 — 2026-08-11 22:18:05.836000



No Plasma

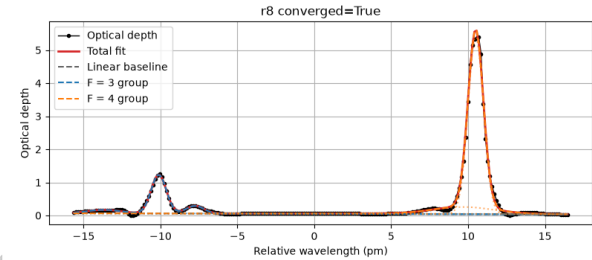
Row 858 — 2026-08-21 11:31:48.734000



(x, y) = (-14.29, 2.32)

Figure 10

Row 858 — 2026-08-21 11:31:48.734000



Cs Atomic Temperature

Fitting function:

$$\tau(u) = b + mu + \sum_{k=1}^6 a_k \exp \left[-\frac{(u - \mu_k)^2}{2\sigma_k^2} \right]$$

which is 6 gaussians and a line, where a_k is amplitude, μ_k is centroid (x), and σ_k is width. Total of $3 \times 6 + 2$ parameters, a lot!

- Triple Gaussian Behavior?
- Especially in Plasma Peaks
- Investigation ongoing
- Mid Run

Plasma

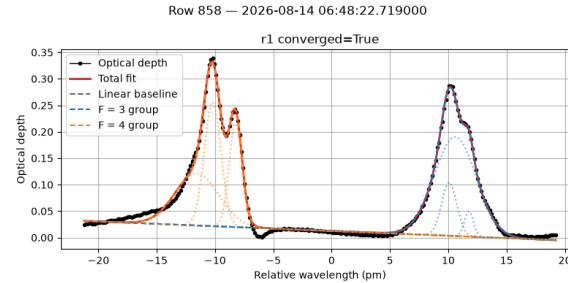
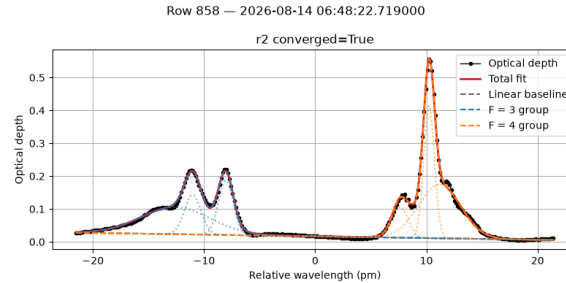


Figure 8



No Plasma

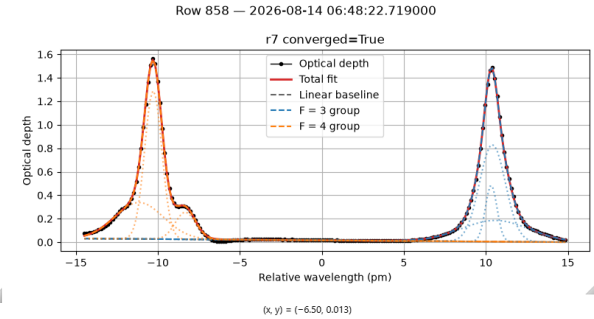
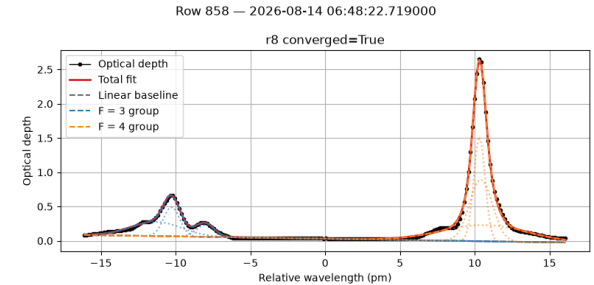


Figure 10



Fitting function:

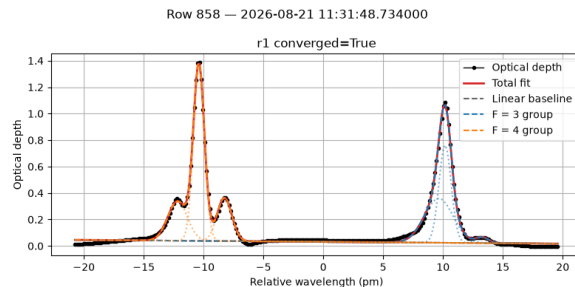
$$\tau(u) = b + mu + \sum_{k=1}^6 a_k \exp \left[-\frac{(u - \mu_k)^2}{2\sigma_k^2} \right]$$

which is 6 gaussians and a line, where a_k is amplitude, μ_k is centroid (x), and σ_k is width. Total of $3 \times 6 + 2$ parameters, a lot!

Cs Atomic Temperature

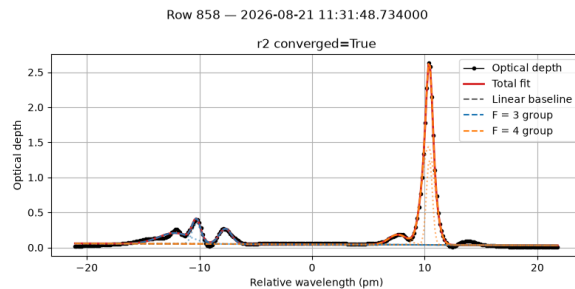
- Triple Gaussian Behavior?
- Especially in Plasma Peaks
- Investigation ongoing
- End Run

Plasma



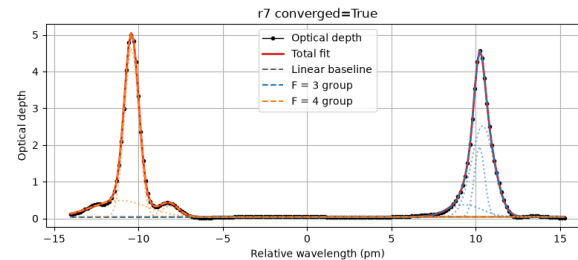
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Figure 8



No Plasma

Row 858 — 2026-08-21 11:31:48.734000



(x, y) = (-14.29, 2.32)

Figure 10

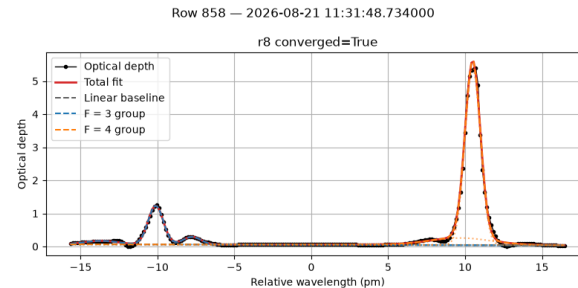
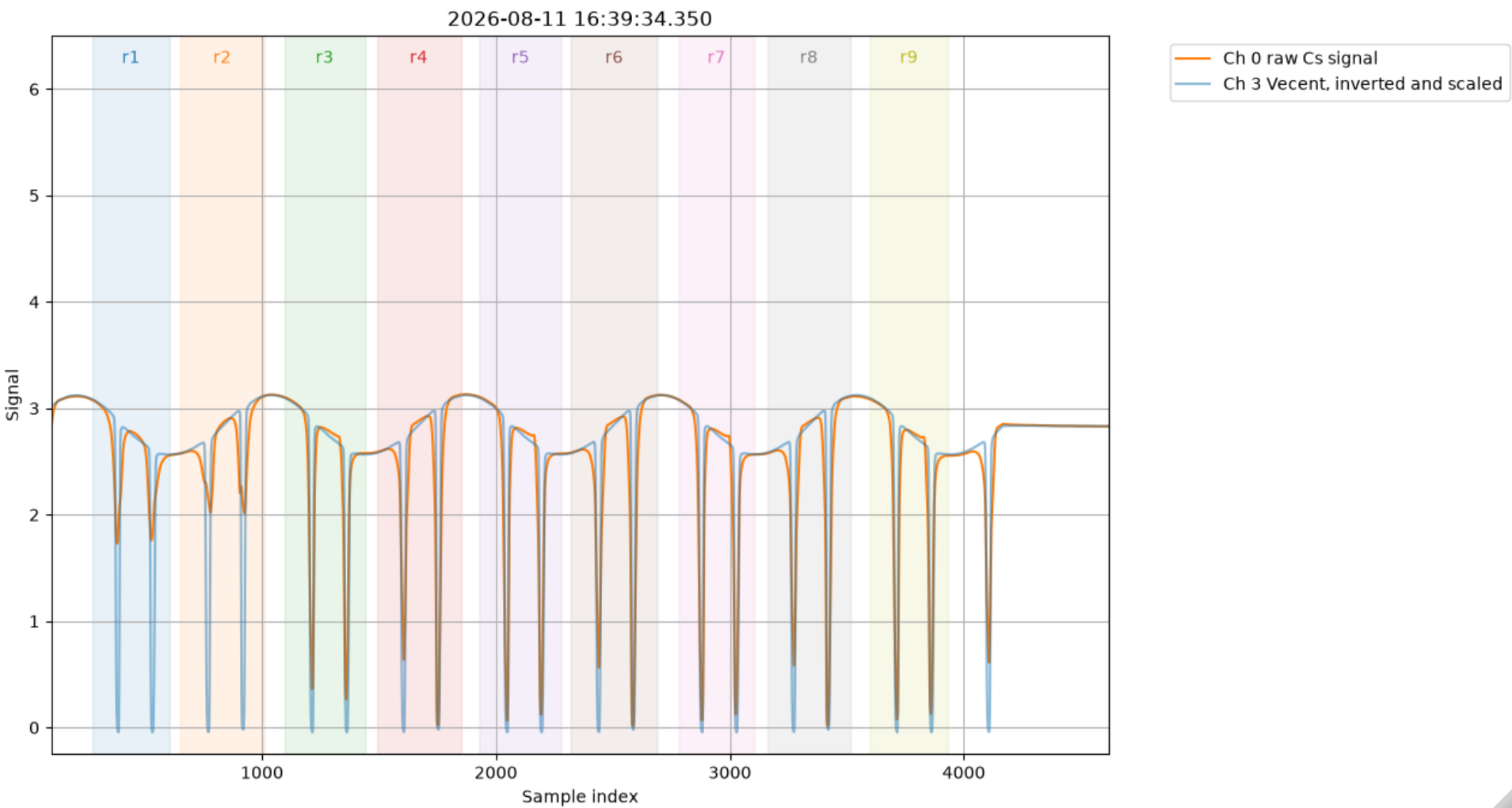


Figure 4



Cs Density Beginning, Middle, End

