Exploring Inside the LANSCE H- Ion Source with Laser Absorption Techniques

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Acknowledgements:

H- Ion source modelling team. I. Draganic, E. Henestroza, N. Yampolsky

Solidworks experts. B. Cantrell, J. Montross

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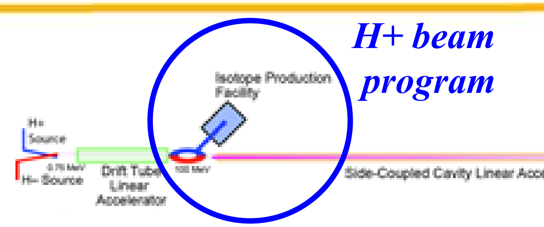
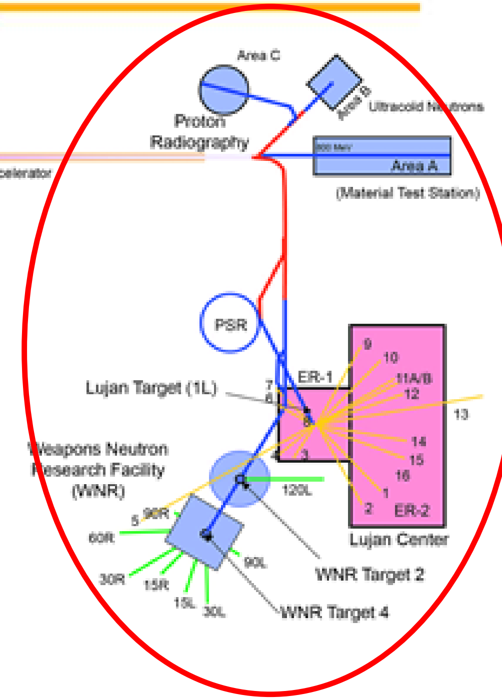
Research Goals

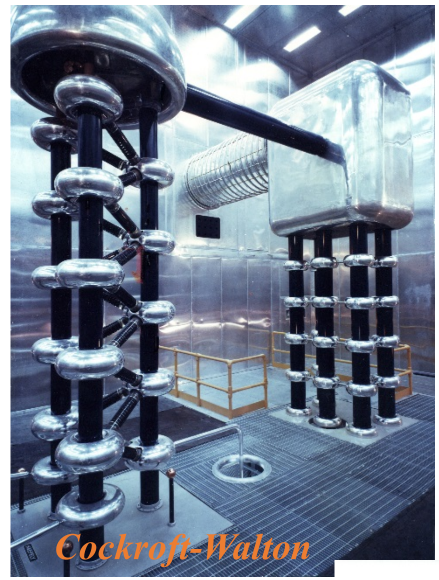
- New LANL funding early 2020 to establish two new diagnostic tools using Laser absorption spectroscopy to measure/quantify:
  - The density of Cs inside the H- ion source
  - The H- beam density inside the H- ion source
- Diagnostics already developed for fusion based H- Ion sources, like ITER
- Successful diagnostic will:
  - Immediate
    - Optimize present LANSCE H- ion source performance
    - Assist/validate LANSCE H- ion source models
  - Short term
    - Provide insight to changes in ion source design to make improvements
  - Long term
    - H- ion source data for the global community
    - Demonstrate its capability for accelerated based H- ion sources.

The Los Alamos Neutron Science Center (LANSCE)

- H+ and H- beams
  - Injection to 750kV using Cockroft-Walton (C-W) Generators
    - H- beam has 80kV pre-extraction inside its C-W dome
  - H+ beam: 100 MeV, Supports one program.
  - H- beam: 800 MeV, supports multiple programs
- H- beam parameters
  - 120 Hz, 10% D.F. (833μs pulse)
  - 14-16 mA of H- current
  - Ion Source recycle every 4-5 weeks.
- Focus today is on H- ion source.
  - What is the H- current density inside the ion source?
  - What is the Cs density inside the ion source?
  - **Laser Absorption techniques can answer these questions!**

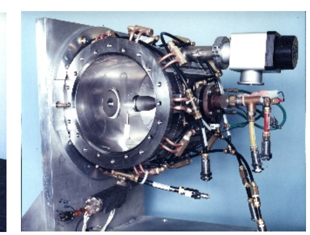



H- beam program



https://www.lansce.lanl.gov

H+ ion source



H- ion source

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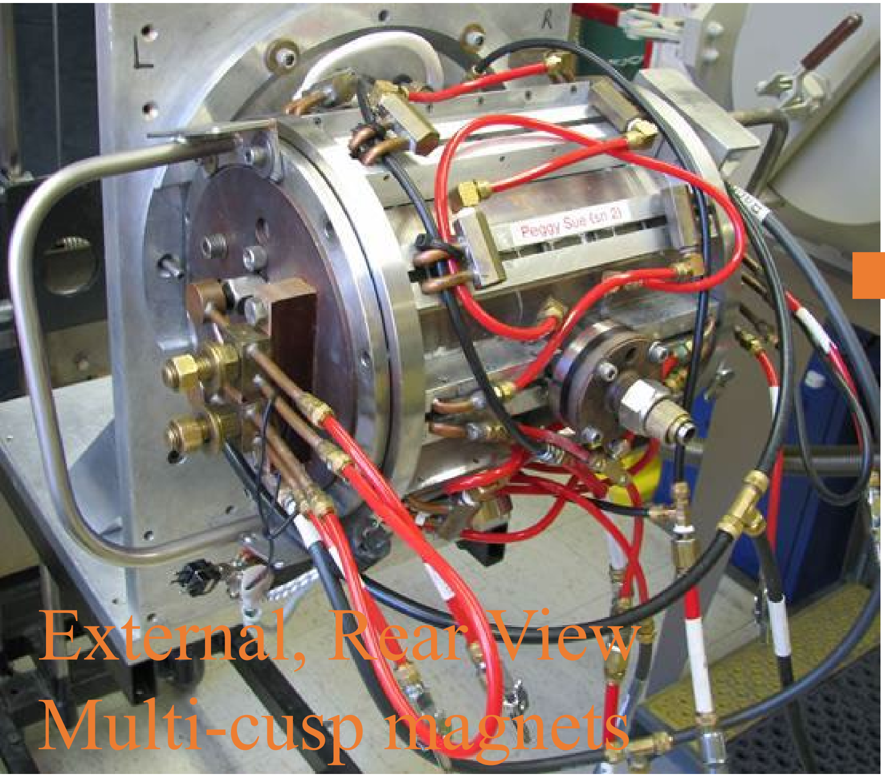
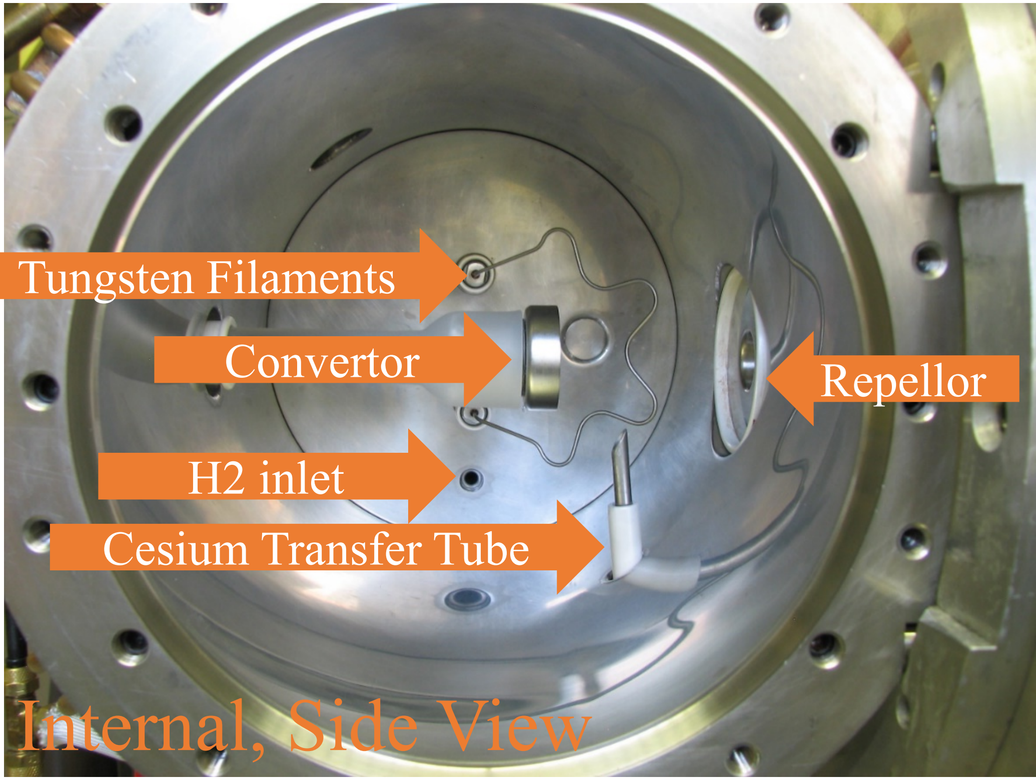
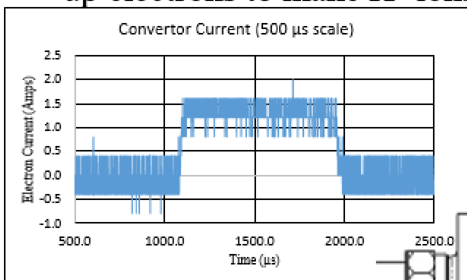
The LANSCE Multi-cusp Cesiated Surface-Conversion H- Source: Photos



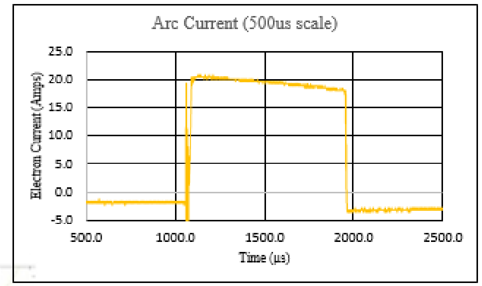


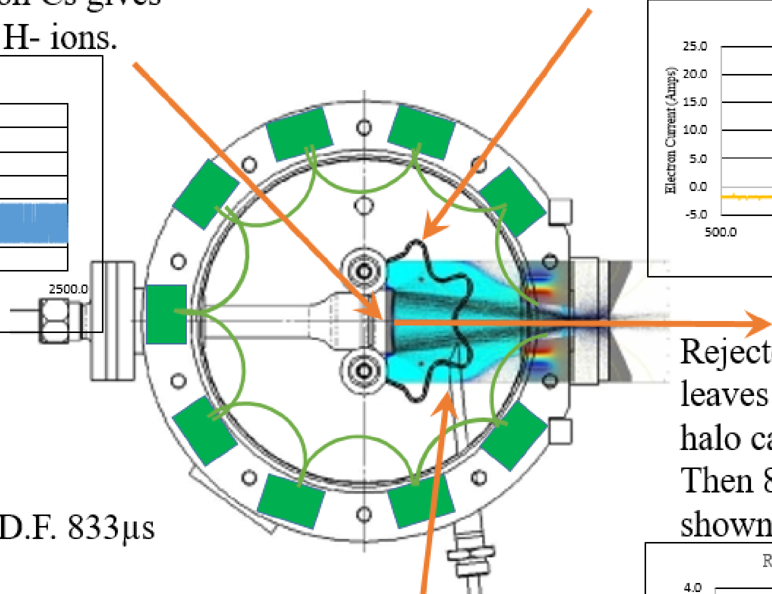
The LANSCE Multi-cusp Cesiated Surface-Conversion H- Source: Ideal Operation

3.) Convertor:
Negative potential bias attracts H+ ions low work function Cs gives up electrons to make H- ions.

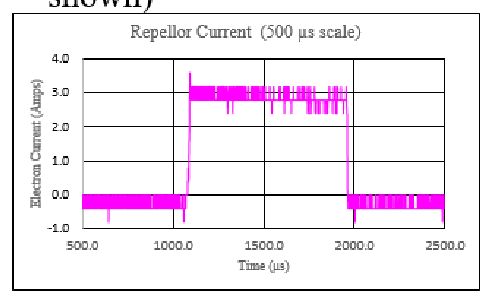


2.) Filaments:
Arc pulse ionizes H_2, creates plasma contained by multi-cusp field





4.) H- beam
Rejected from Convertor leaves Ion source. electron halo captured by Repeller. Then 80 kV Extraction (not shown)



Pulse information:
Timing: 120 Hz, 10% D.F. 833µs
Arc: 20-40 Amps
Convertor: 1-3 Amps
Repellor: 1-4 Amps

1.) Cesium:
Transfer tube deposits Cs continuously on convertor surface. Replaces Cs sputtered during beam pulse

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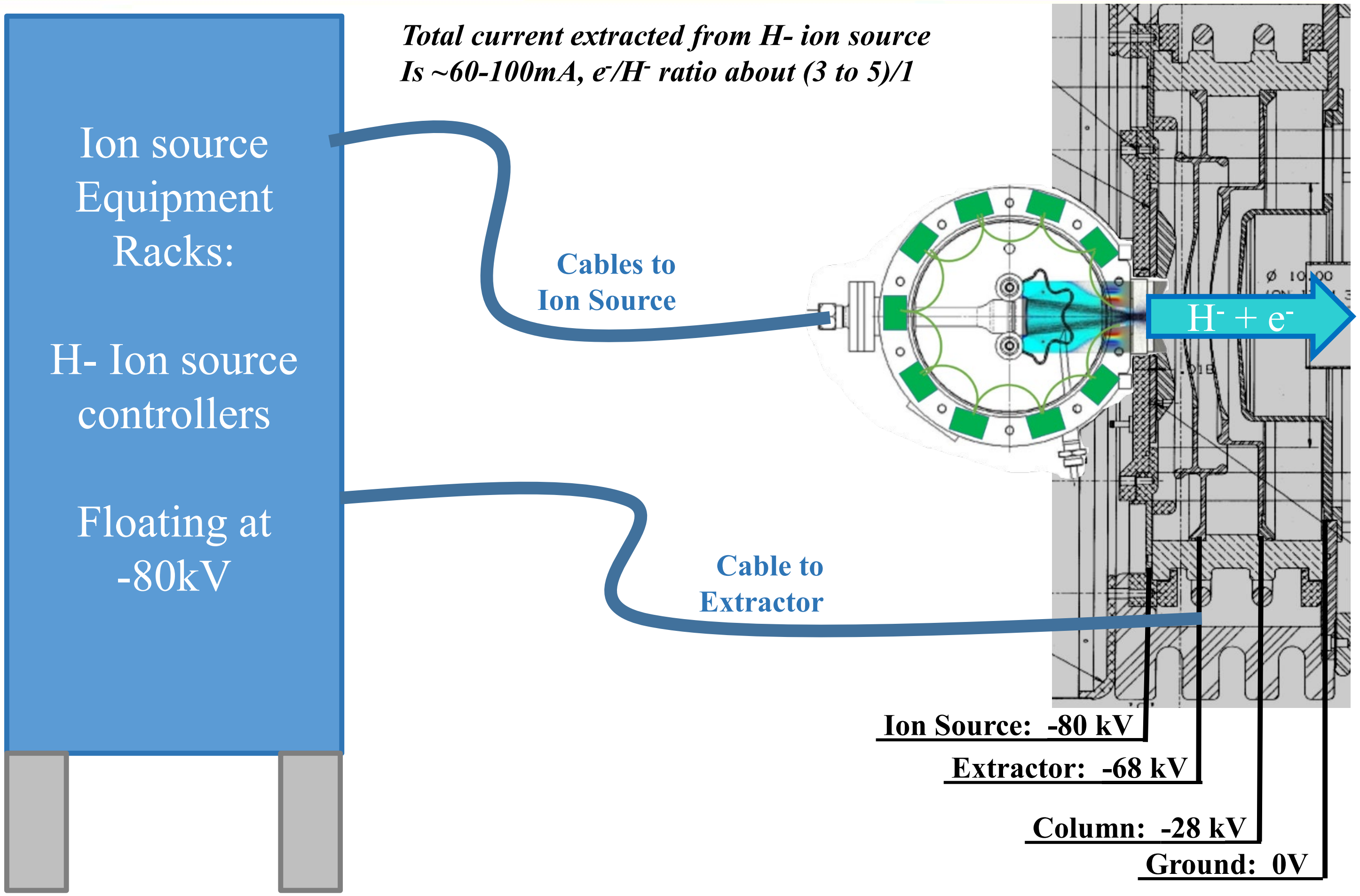
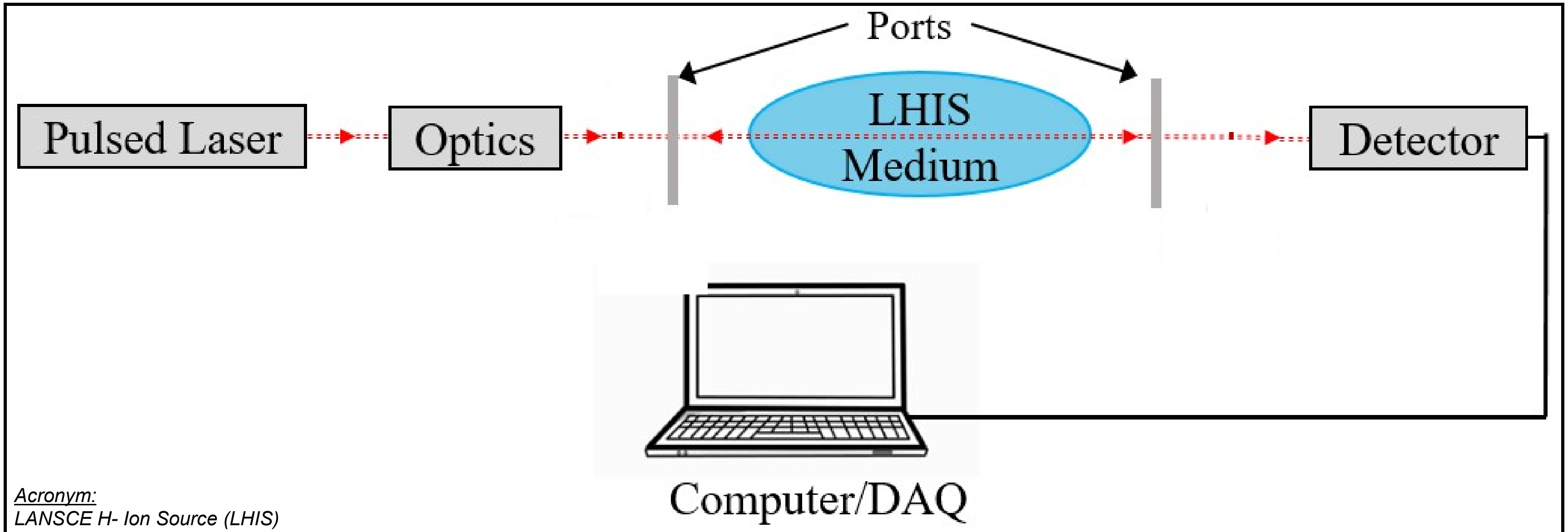
The LANSCE Multi-cusp Cesiated Surface-Conversion Source with initial 80 kV extraction



Simple optical setup diagram. Laser Absorption Techniques (LAT)



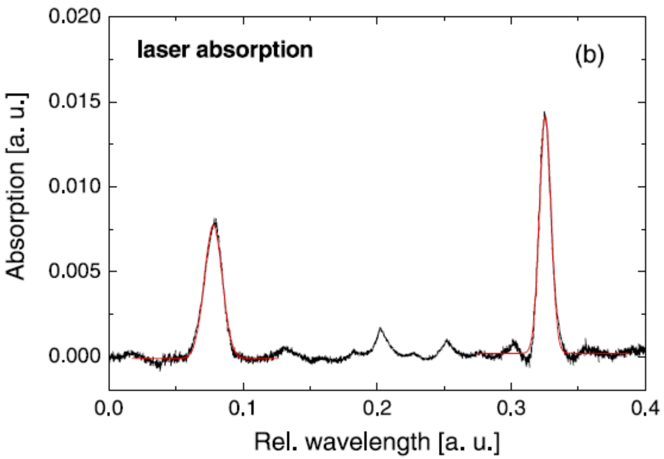
Acronym:
LANSCE H- Ion Source (LHIS)

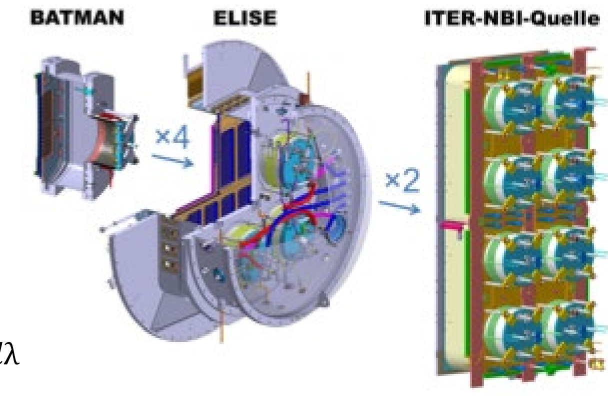
- *LAT* is a form of optical absorption spectroscopy.
  - high sensitivity and precision for a given atomic state
- Non-invasive, fast measurement that can directly monitor the cesium density inside in real time.
- Diagnose the real-time **Cesium** density inside source before, during, and after the beam pulse
  - will allow for the minimum-optimization of cesium
  - maximize H^- beam output while avoiding instabilities related to over-cesiation effects.

Measurements of Cs in BATMAN for ITER (LAT)

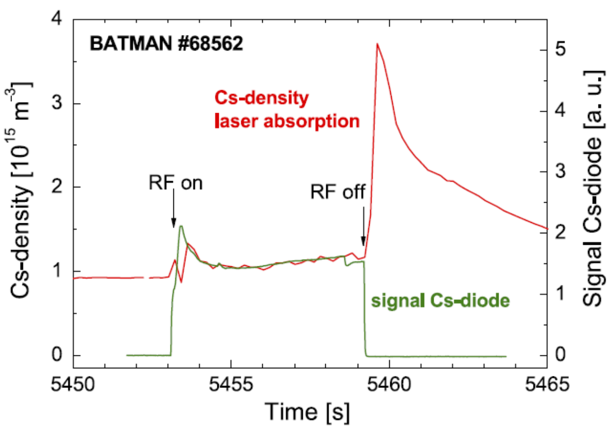
Jour. Phys. D: Appl Phys, vol. 44, no. 33502, 2011

https://www.ipp.mpg.de/3704093/nnbi



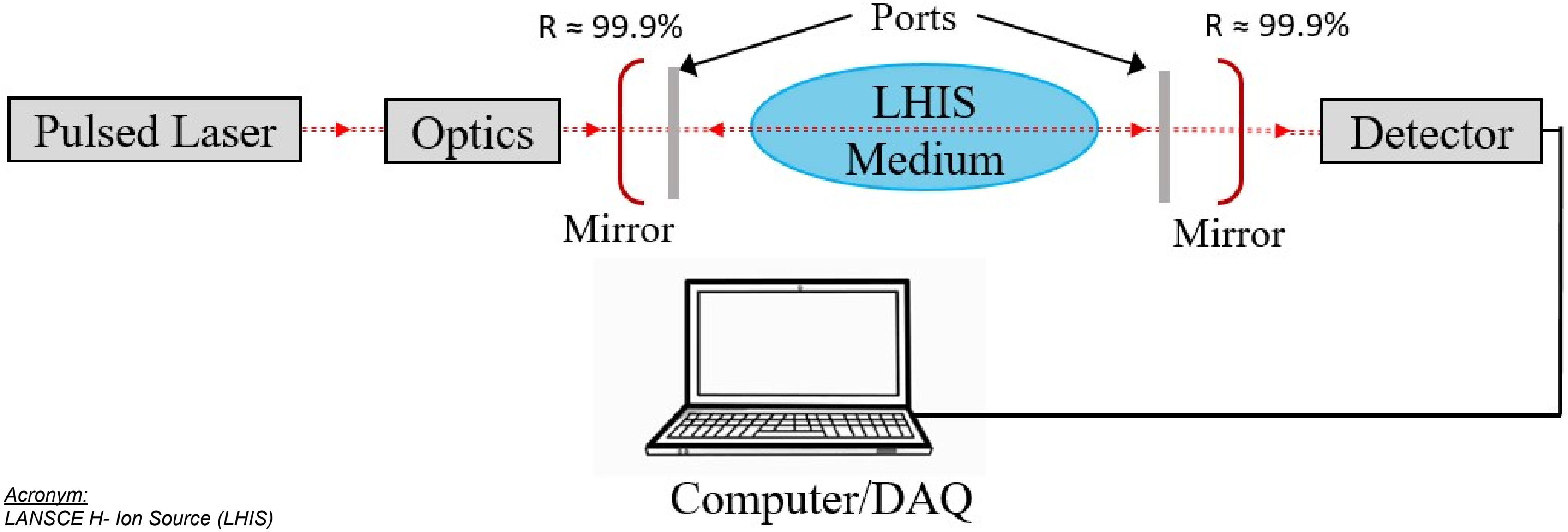


$$n_k = \frac{8\pi c}{\lambda_0^4}\frac{g_k}{g_i}\frac{1}{A_{ik}\,l}\int_{line}\ln\left(\frac{I(\lambda,0)}{I(\lambda,l)}\right)d\lambda$$



- D2 line of Cs (852.1 nm)
- *"during discharge the density of Cs atoms remains similar level as before which is quite surprising"*
- *"strong redistribution of Cs from the surfaces appears during the discharge"*
- *"…switched off the Cs density … recombination of Cs ions to neutrals.*
- Cs density, temperature increase correlated

Simple optical setup diagram. Cavity Ring Down Spectroscopy (CRDS)

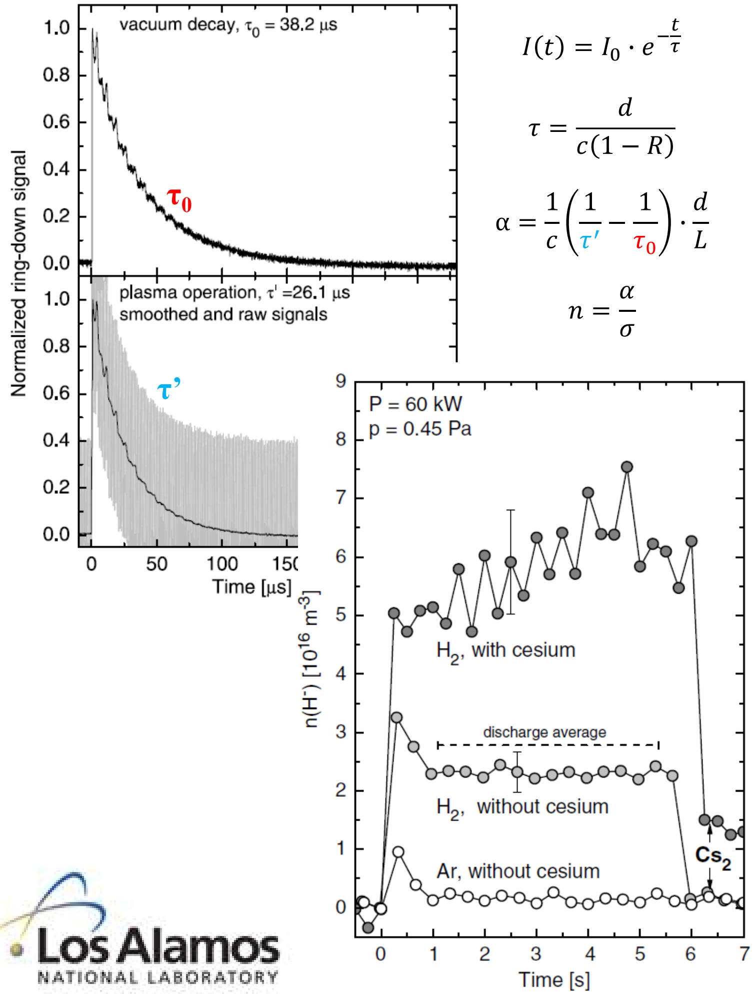


Acronym:
LANSCE H- Ion Source (LHIS)

- CRDS introduces highly reflective mirrors to the LAT setup.
  - Signal is an exponential decay curve related to the density, as well as the mirrors' reflectivity
- Non-invasive, fast measurement that can directly monitor the H- density inside source
  - Measure H- photo-detachment process. (>0.75 eV, $\sigma = 3.5x10^{-21}$ m^2)
  - Mirrors assist measuring small cross section.
  - Line-of-sight integrated measurements across several points inside the ion source
- Knowing the H- density profile inside ion source will
  - allow for capitalization of the LHIS performance,
  - fast-track innovative improvements to its research & development.

Measurements of H- in BATMAN for ITER (CRDS)

Plasma Sources Sci. Technol., vol. 18, no. 025004, 2009



$$I(t) = I_0 \cdot e^{-\frac{t}{\tau}}$$

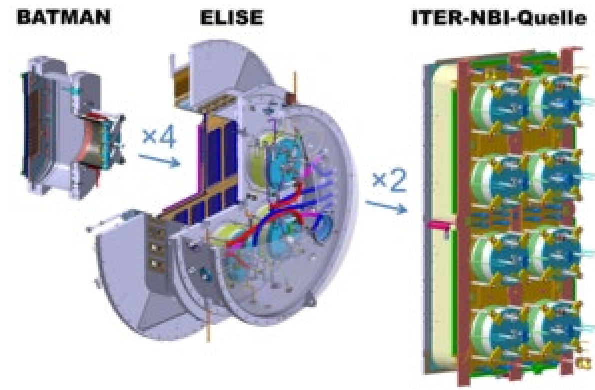
$$\tau = \frac{d}{c(1-R)}$$

$$\alpha = \frac{1}{c}\left(\frac{1}{\tau'} - \frac{1}{\tau_0}\right) \cdot \frac{d}{L}$$

$$n = \frac{\alpha}{\sigma}$$

τ: decay time
α: coeff. of absorption
σ: cross section
d: cavity length
L: plasma length

https://www.ipp.mpg.de/3704093/nnbi



- Nd-YAG laser (1024 nm)
  - measures H- detachment, avoids other processes (Cs, H_2, etc)
- Challenges:
  - Uncertainty in L
  - Mechanical vibrations

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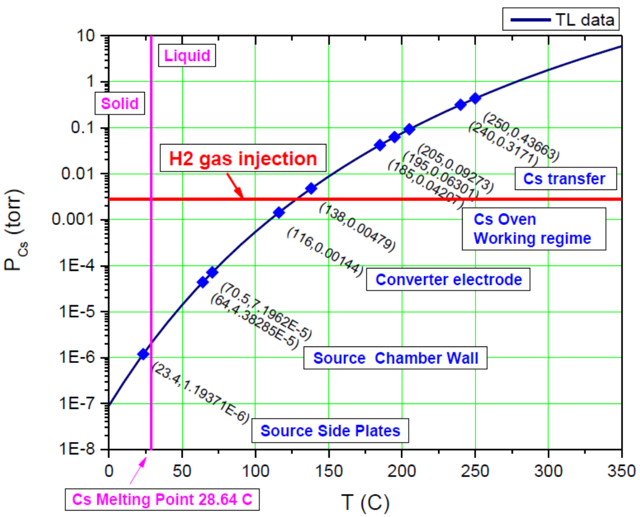
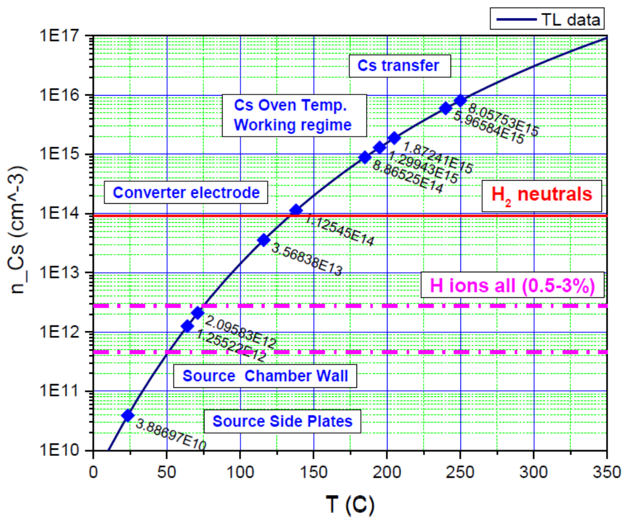
Comparison of ITER & LANSCE ion sources

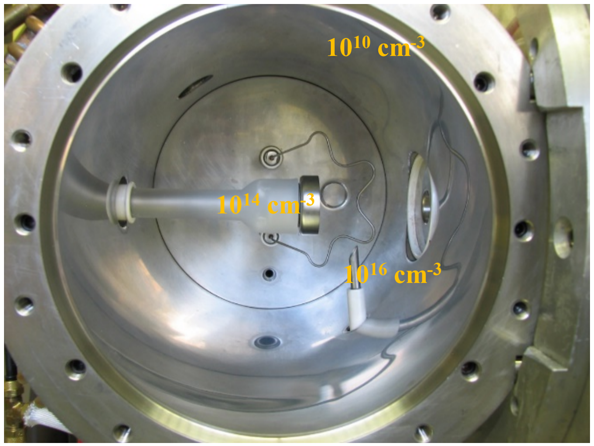
- Fusion source (ITER) vs Accelerator source (LANSCE)
- Seconds long pulse (ITER) vs ~1 ms pulse (LANSCE)
  - New challenge for Cs measurement
  - Similar challenge for H- measurement
- RF source (ITER) vs Filament driven source (LANSCE)
  - Windows contamination from Cs (ITER and LANSCE)
  - Additional contamination from W (LANSCE)

Model estimates for Cs Density measurement.

I. Draganic, L. Rybarcyk. "Recent Results in Modeling of LANSCE H- Surface Converter Ion Source." In Proc. ICIS'17. Geneva

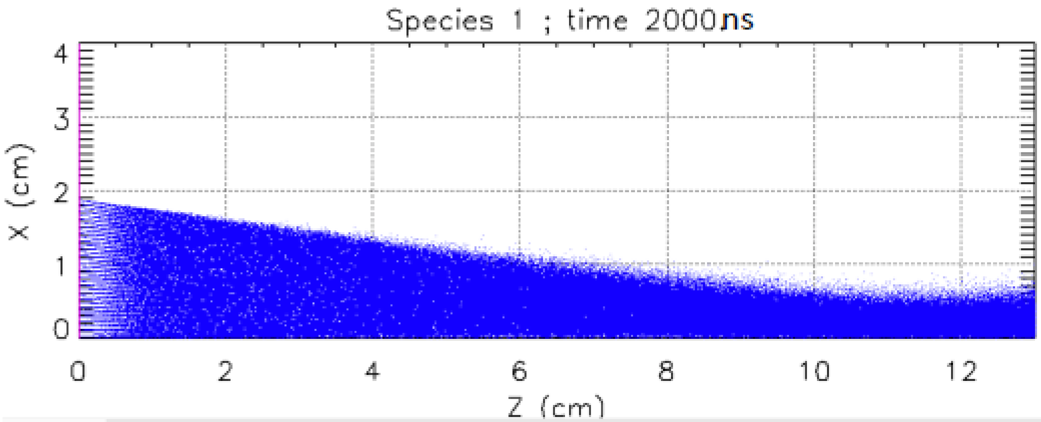


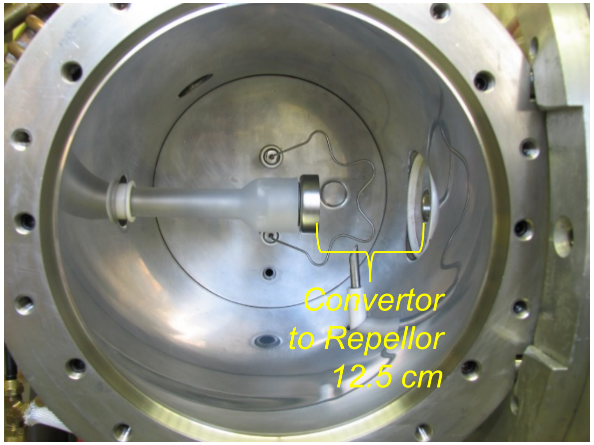




- Basic Cs Temperature/Vapor Pressure calculations
- 10^{10} cm^{-3} near the walls.
- 10^{14} cm^{-3} convertor face
- 10^{16} cm^{-3} at Cs transfer port
- *LAT will help study interplay between Cs transfer port, convertor electrode, wall coating.*

Model estimates for H- Density measurement.

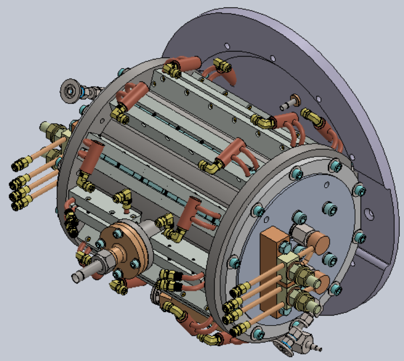




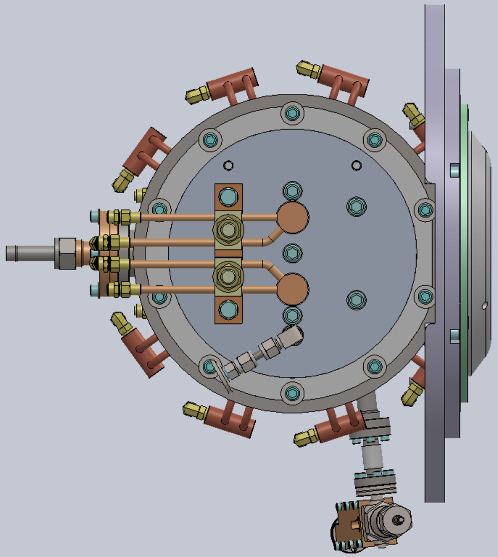
- See E. Henestroza et al. “Transport of a negative ion beam through a hydrogen plasma”
- Poster session P1, Abstract #57
- *“the beam is fully neutralized and the mean free path for extinction is ~20 cm producing a 50%drop in current for the 12.5 cm transport length”*

LANSCE H- Ion Source Side-plate modification.

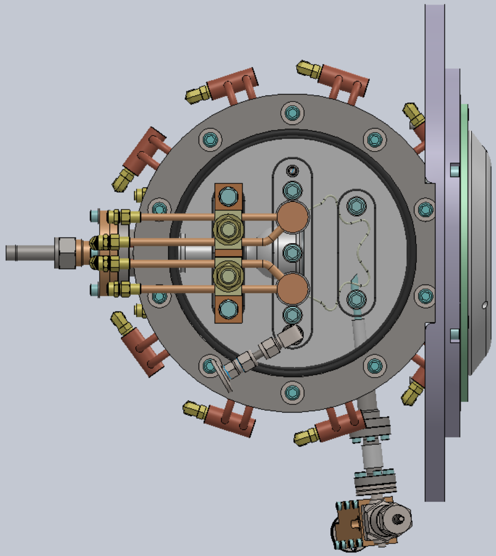
Isometric View



Side View



Transparent view

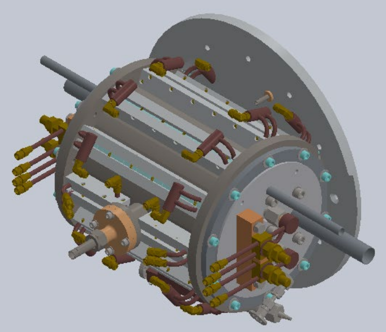


Solidworks Assembly File

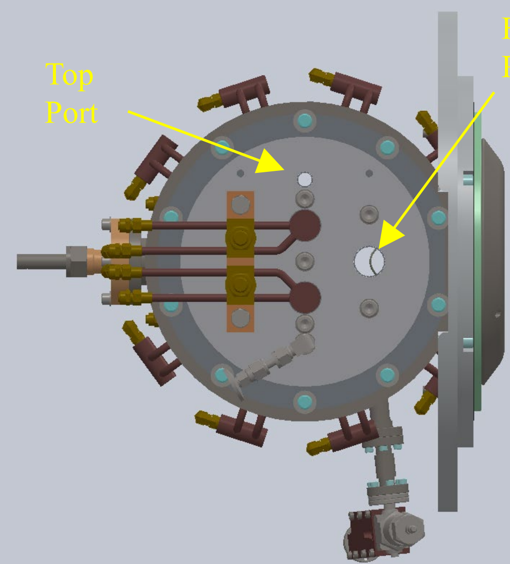
Challenge: Avoid water-cooling, magnets, o-rings for ports

LANSCE H- Ion Source Side-plate modification.

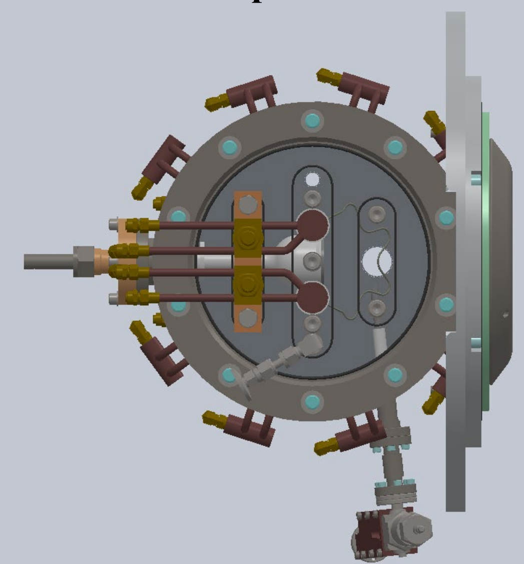
Isometric View



Side View



Transparent view

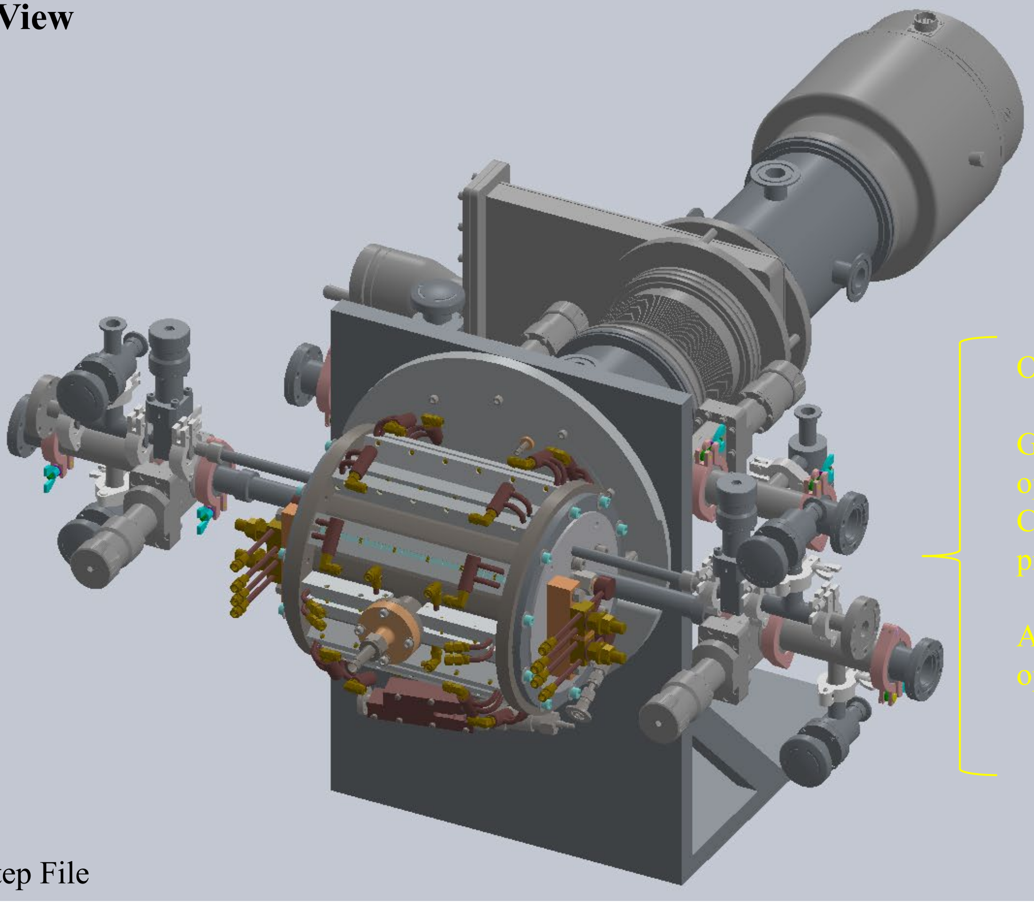


Solidworks Step File

Challenge: Avoid watercooling, magnets, o-rings for ports
Phase 1 side-plate design: Simply put ports where we can
Top port to see background Cs density.
Front port for H- beam, Cs transfer port measurement.
Mesuremtent Challenge: Measure both sides of W filaments

Simple Laboratory setup

Isometric View



Solidworks Step File

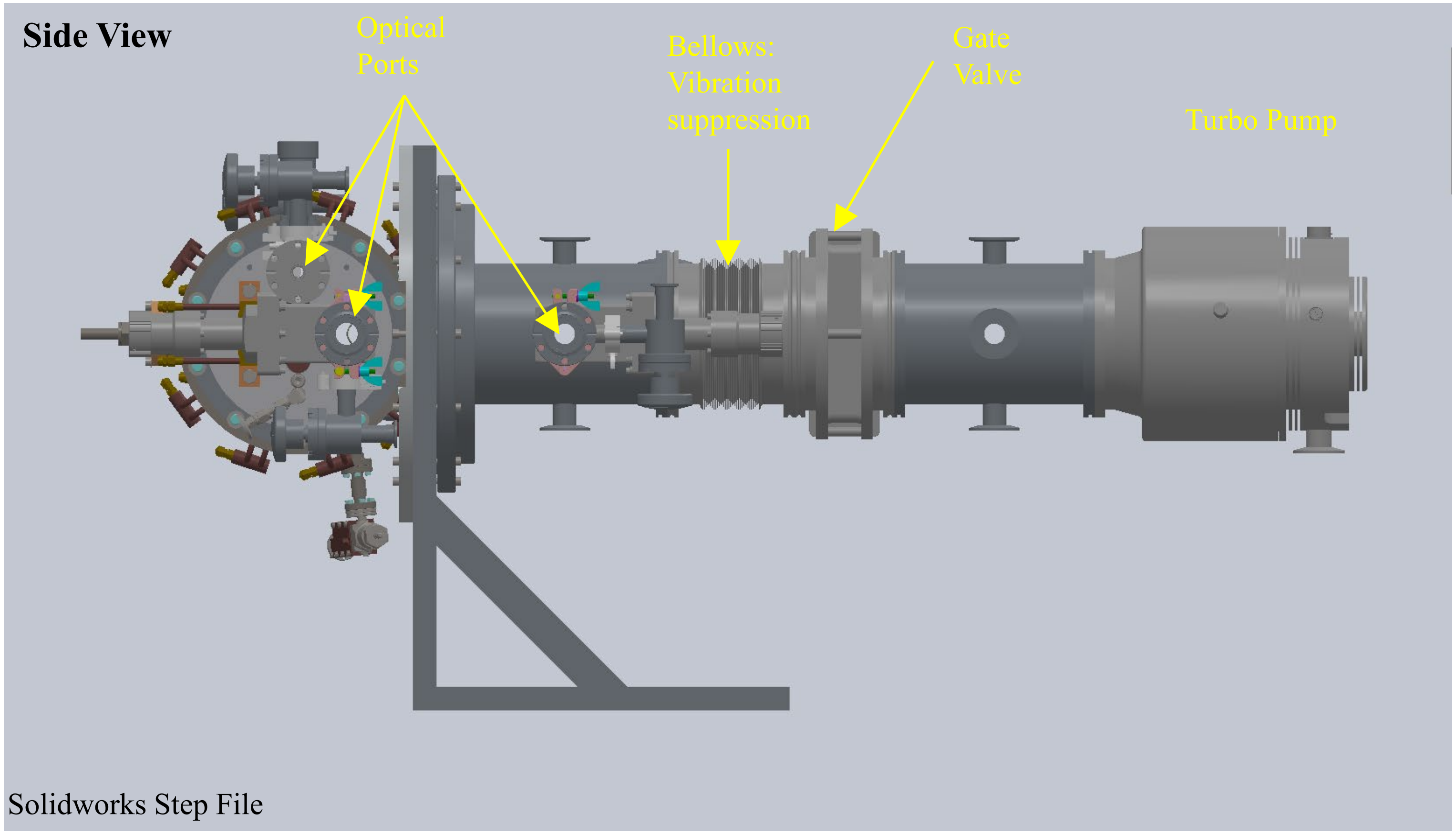
Challenge:
Optical port contamination

Optical ports setup:

Gate Valves to open/close optical path to block W, Cs deposits during preparation

Angle valves to rough out optical lines.

Simple Laboratory setup



Outlook

- Covid19 delayed many milestones
  - Collaborative trip between Max Planck IPP ITER group postponed indefinitely
  - Laser lab calibrations delayed.
- Outlook
  - Begin Cs laser calibrations next month.
  - Cs density measurement complete early 2021.
  - H- density measurement complete by mid/end 2021.

Video Release Information

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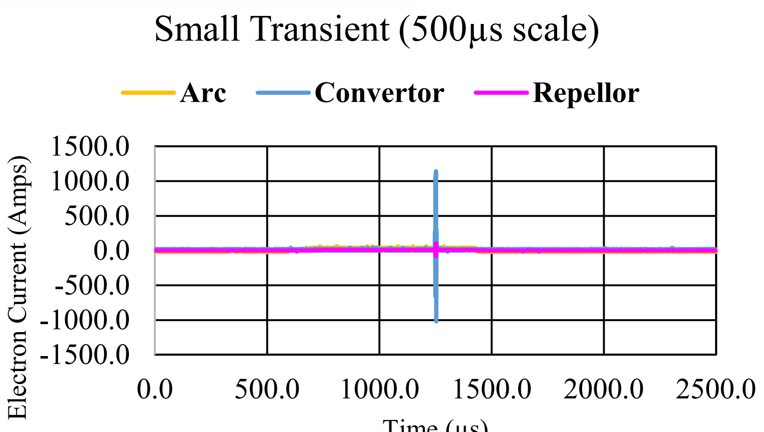
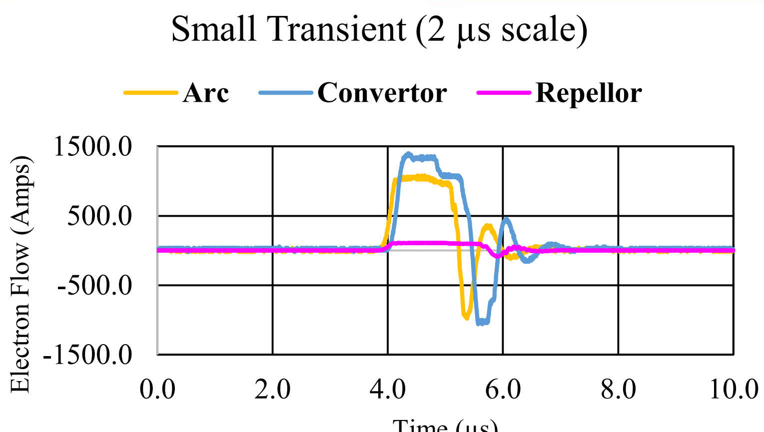
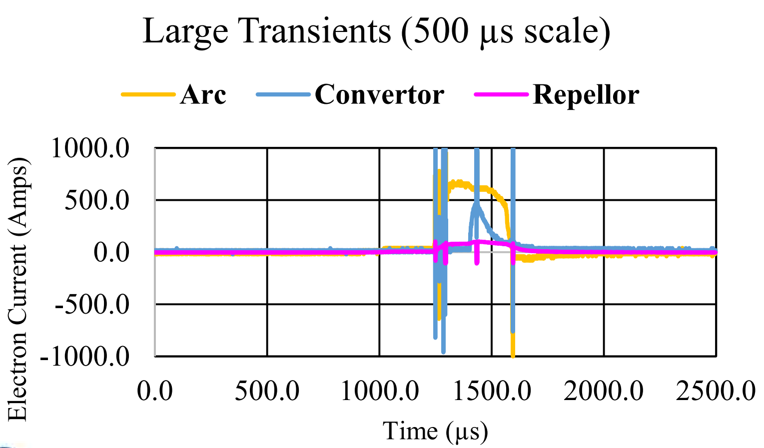
Backup

What are Arc Transients?

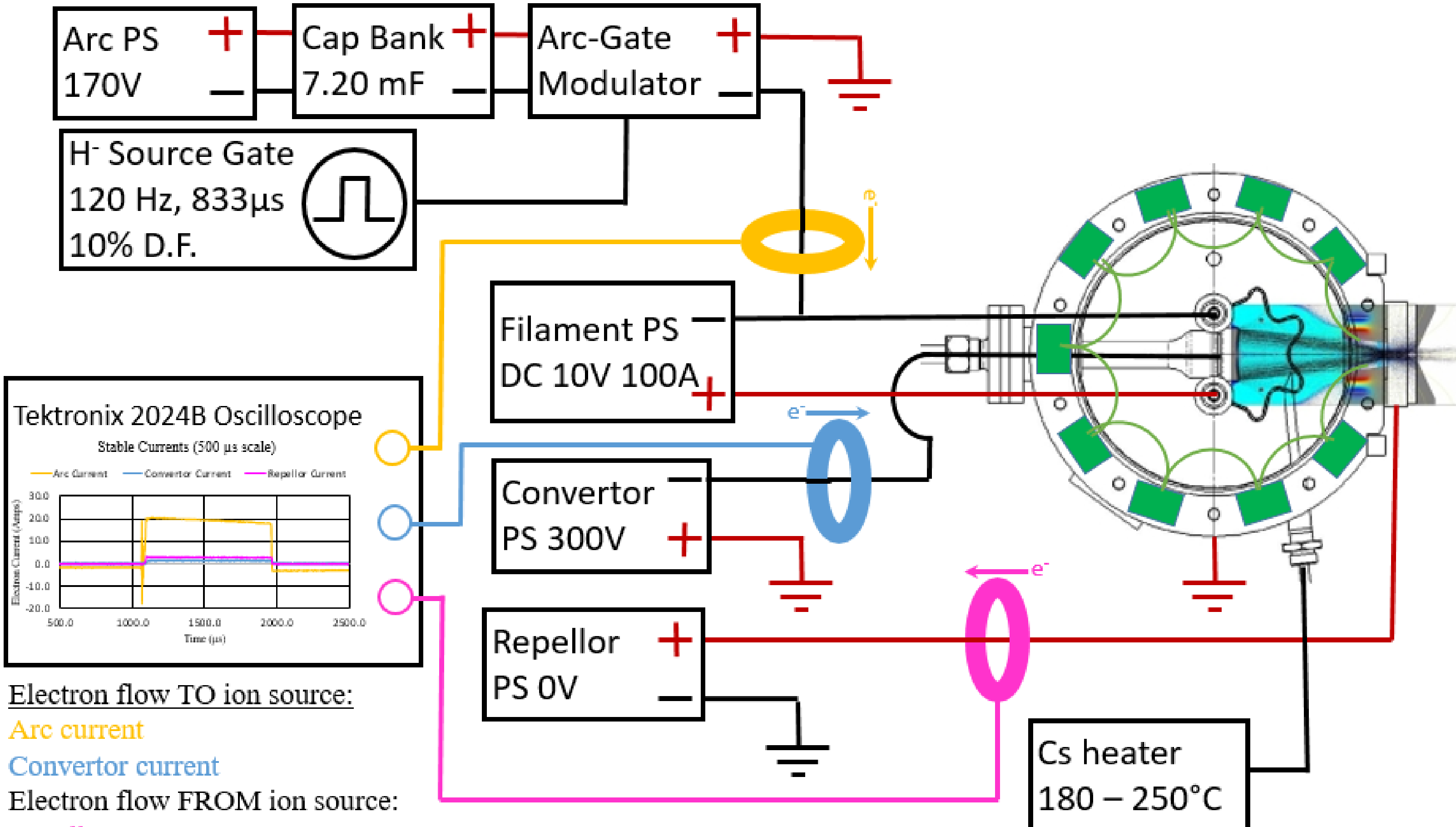






- High Current transients in the ion source Arc current observed during LANSCE Operations.
  - Trigger scope just above nominal Arc current
- Small Transients (10-20/hr)
  - a few µs, ~10^3 Amps
  - Saturates fiber-optic bandwidth
  - **Don't effect beam stability (usually)**
- Large Transients (0-4/hr)
  - Hundreds of µs, ~10^2 Amps
  - Effect beam output
  - **Effect beam stability, 80kV extraction arc down!**

H- Ion source controls



Electron flow TO ion source:
Arc current
Convertor current
Electron flow FROM ion source:
Repellor current

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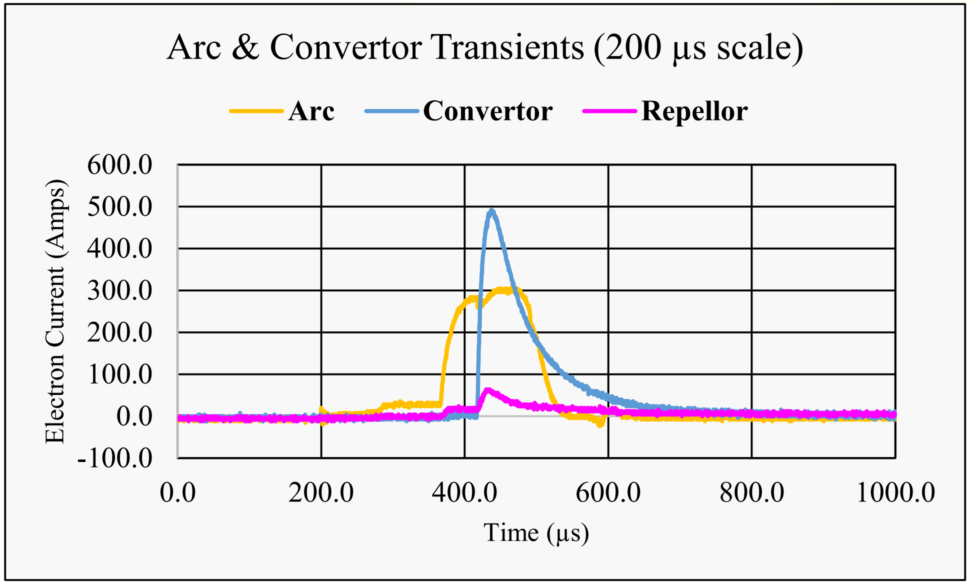
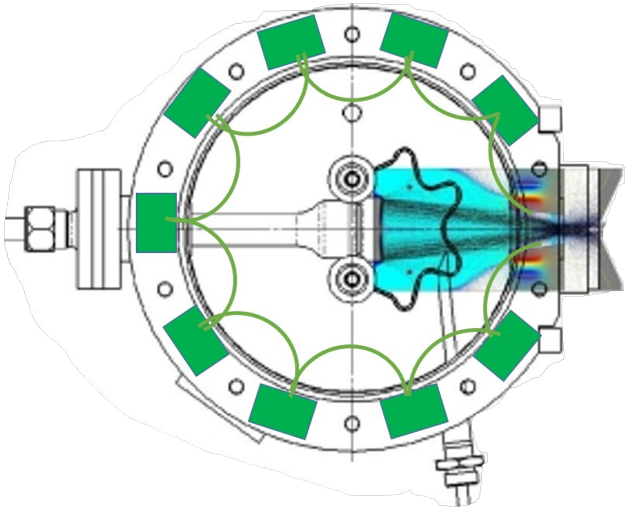
ISTS Observations. Transients Rates: Cesium

- No Cesium No Arc Transients
  - Ran for a few days before opening Cs Oven
- **Immediately into Transferring Cesium, we got Transients!**
  - In General, Higher Cesium Temperature lead to more Transients
- Other tests (with Cesium)
  - Convertor Voltage adjustments had minimal effects.
  - Water Chiller temperature had minimal effect.
- Other Observations
  - Linear rate: Single transients are random, but were linear averaged over a day.
  - Cold starting the source leads to many in a row. dI/dt effects?
  - Events always occurred during H- source timing gate pulse, i.e. with plasma in source.

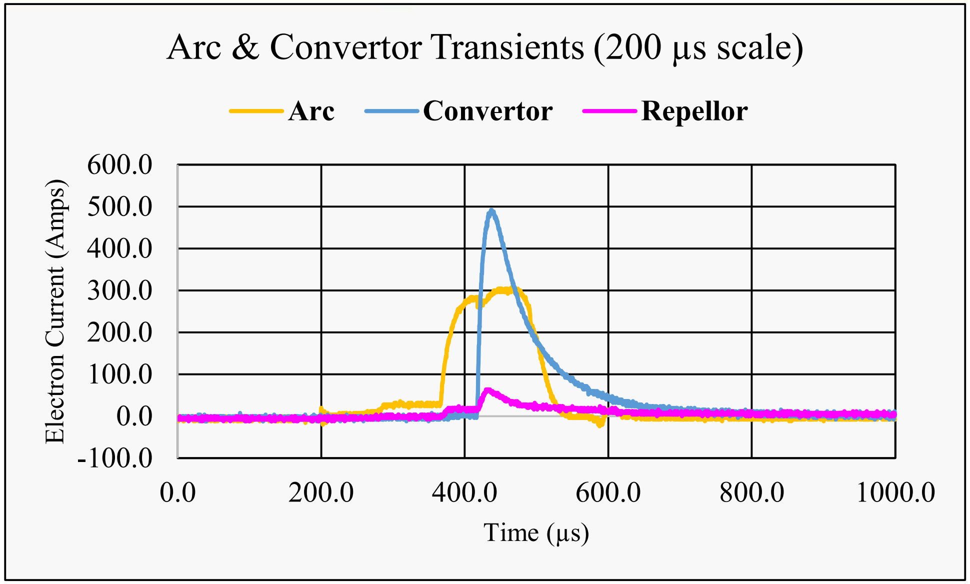
ISTS Observations. Large Transients Observed

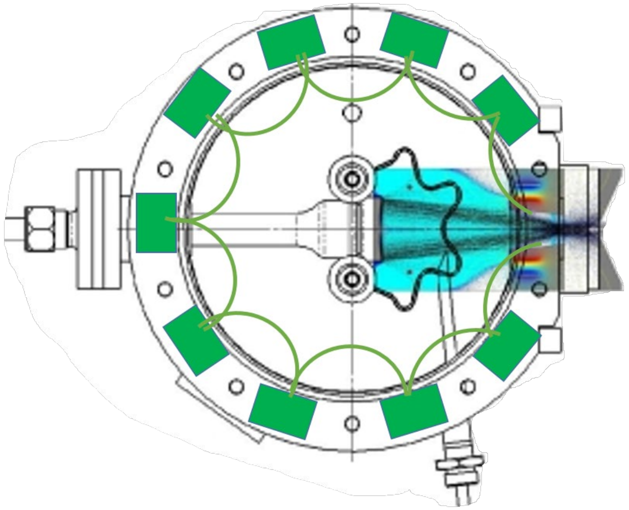




- Most transients observed were of the large transient types, i.e. a ***surge***
  - Small, µs transients were not seen. (80kV related?)
- Large surges seen on Arc also realized on Convertor
- Arc & Convertor Transients can occur together, or separate. Arc surge usually lead convertor spikes, but not always.
  - Both:ArcOnly:ConvOnly ratio is about 3:2:1
- ***Essentially, Arc and Capacitor circuits are shorted inside the source.***

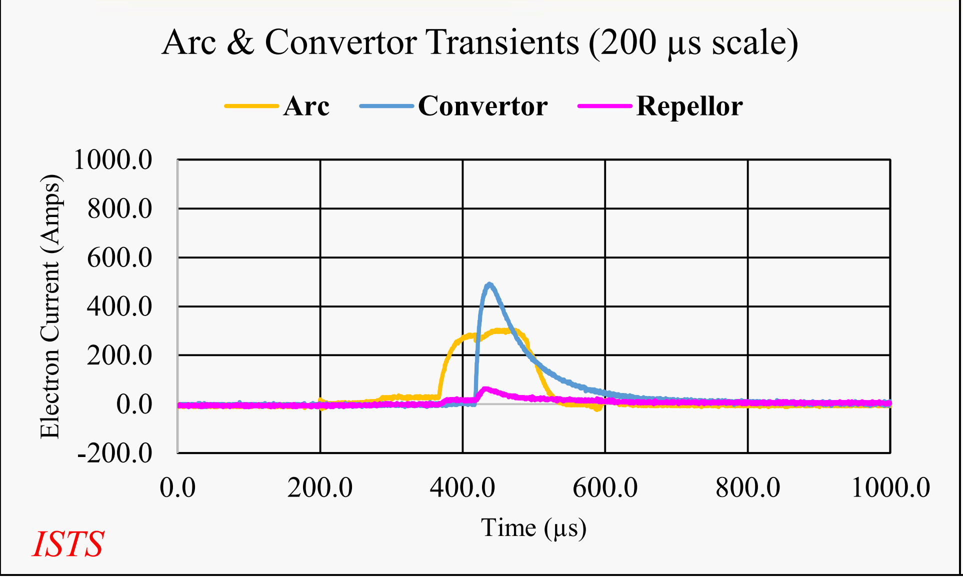
ISTS Observations. Large Transients Observed

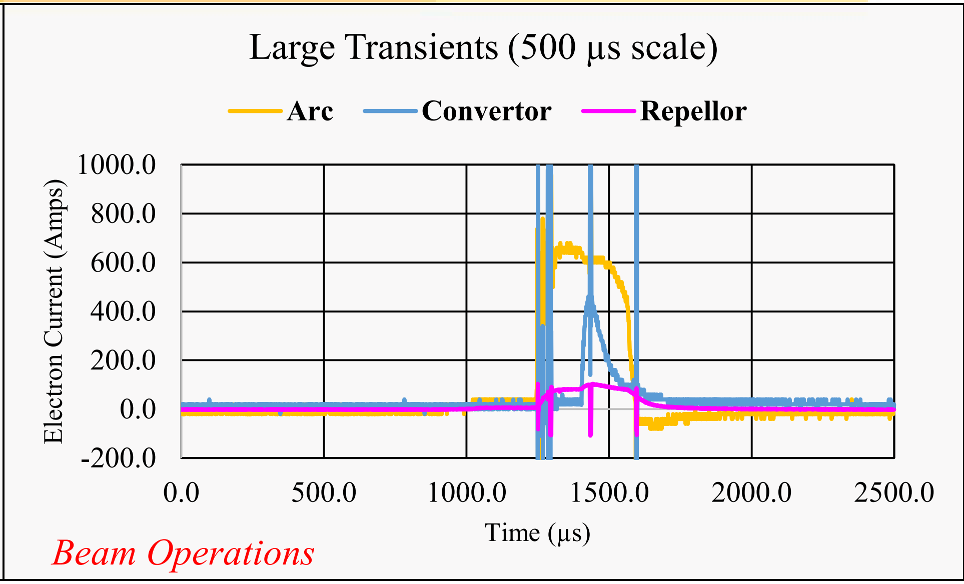




- Arc surges sustained by capacitor bank.
- Convertor surges drop off immediately—no capacitor bank on convertor PS.
- Repeller reacts to Arc and Convertor surge,
  - Response like a "solid angle"

Large Transients: ISTS Observation vs LANSCE Production

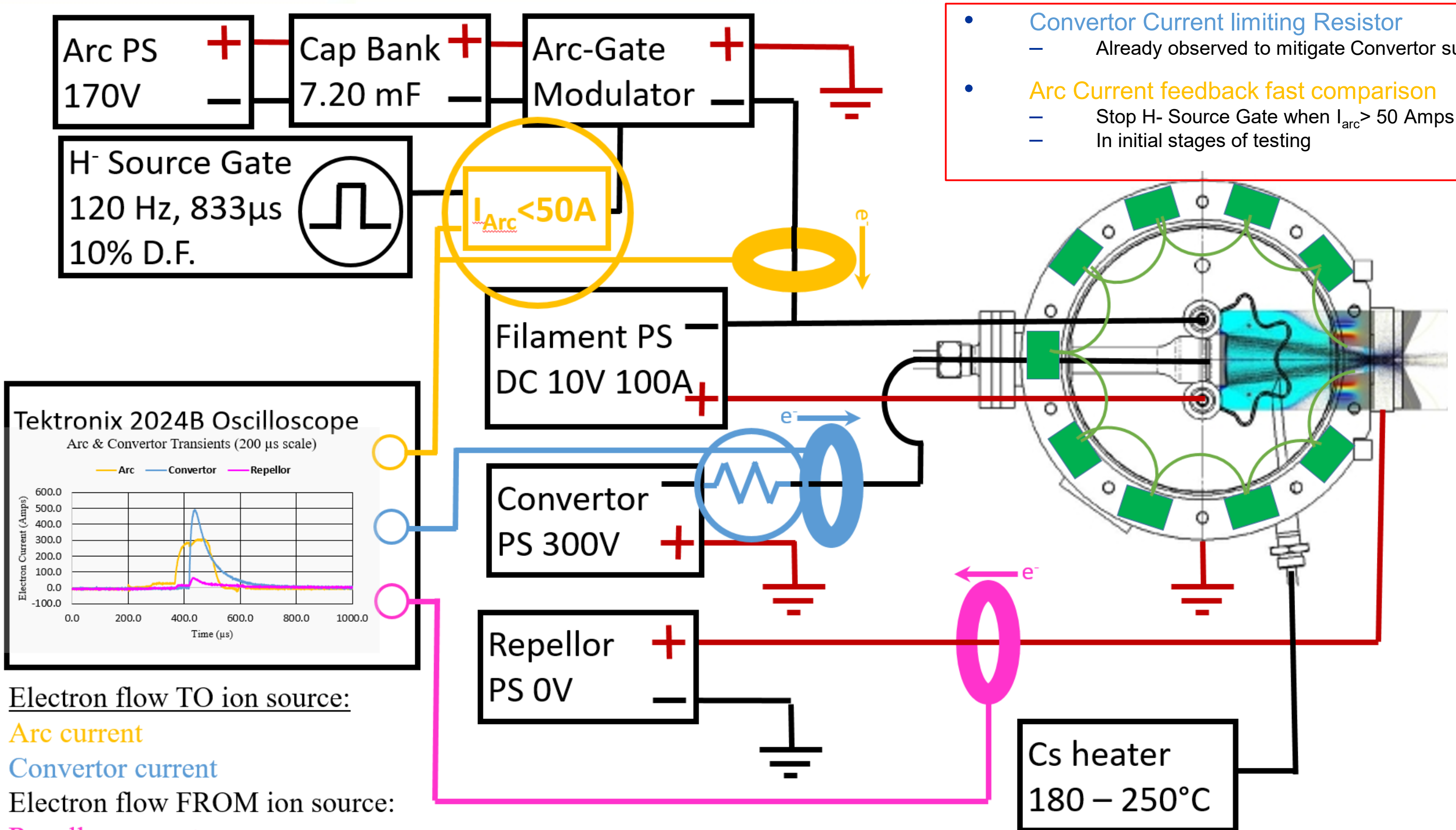




- Arc surges: 300 Amp vs 600 Amps
  - Different Cap bank values, different arc modulators leads to different input impedance.
- Convertor surges: Comparable
- Repeller response: Comparable

Mitigation of Surges

- Convertor Current limiting Resistor
  - Already observed to mitigate Convertor surges
- Arc Current feedback fast comparison
  - Stop H- Source Gate when I_{arc}> 50 Amps
  - In initial stages of testing



Electron flow TO ion source:

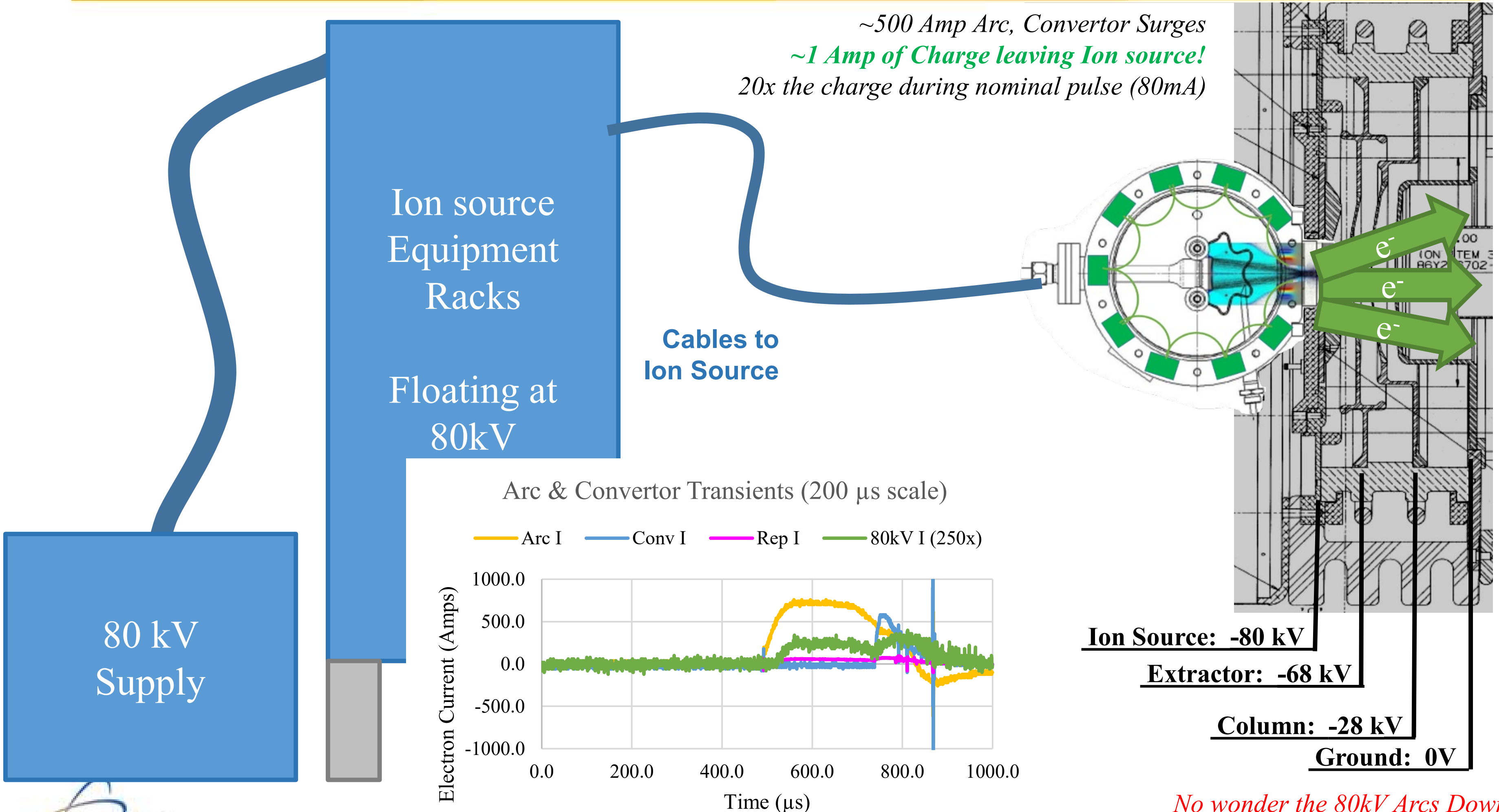
Arc current

Convertor current

Electron flow FROM ion source:

Repellor current

Large Transient observed with 80kV (June 2019)

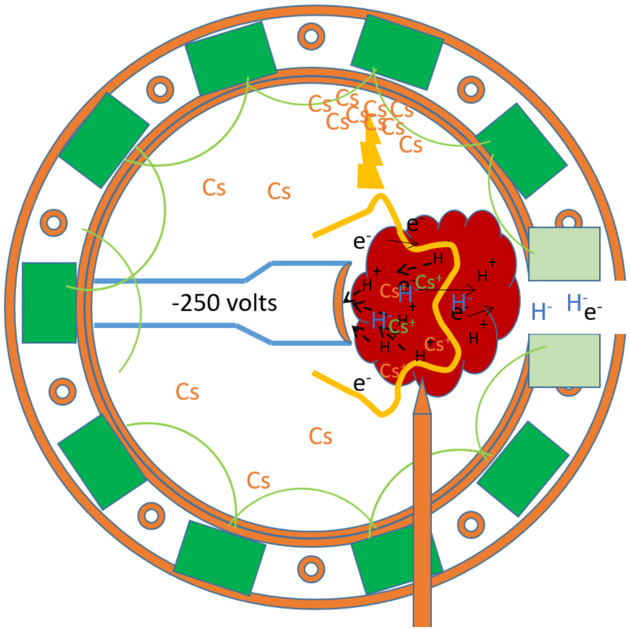


Mitigating is one thing, but what is the cause

The main culprit is Cesium!

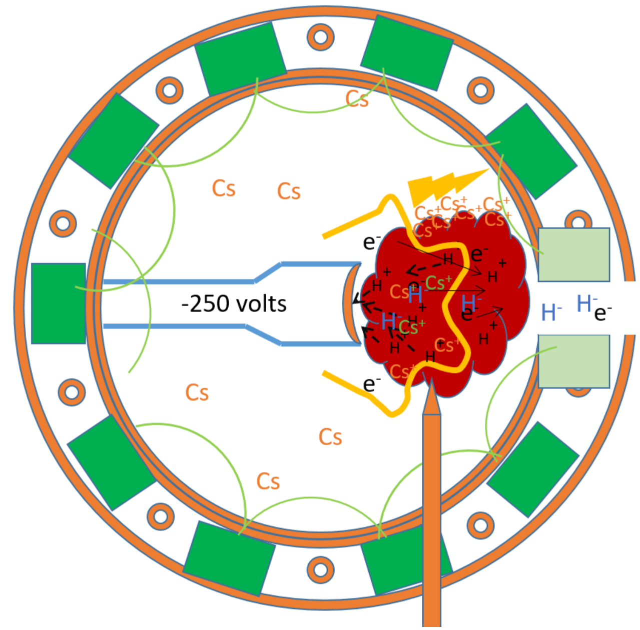
Cartoon of Cold Cs Deposit

Does a cold deposit of Cs short out the Arc and/or convertor?

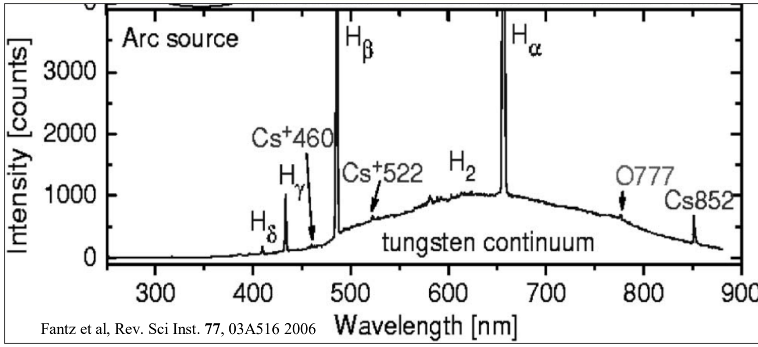


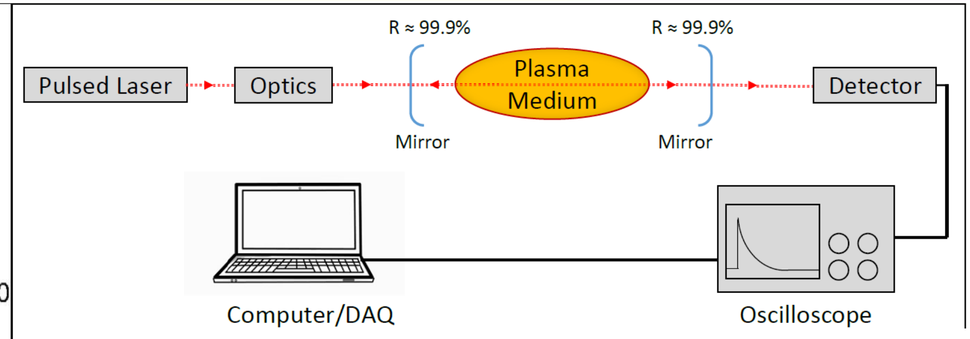
Cartoon of Non-neutral Plasma

Does excess Cs^+ in the plasma short out the Arc and/or convertor?



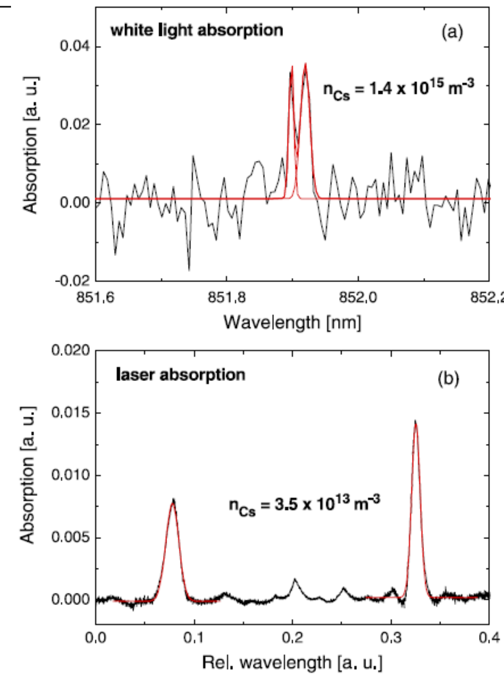
Need Laser Absorption Spectroscopy Plasma Diagnostics to identify true cause.





Fantz et al, Rev. Sci Inst. **77**, 03A516 2006

- Laser tuned to Cs emission (852.1 nm) can quantify Cs in ion source.
  - Fast quantitation: Individual Pulse Cs densities.
  - Disentangle cold cesium effects from cesiated plasma effects
- Currently seeking funding



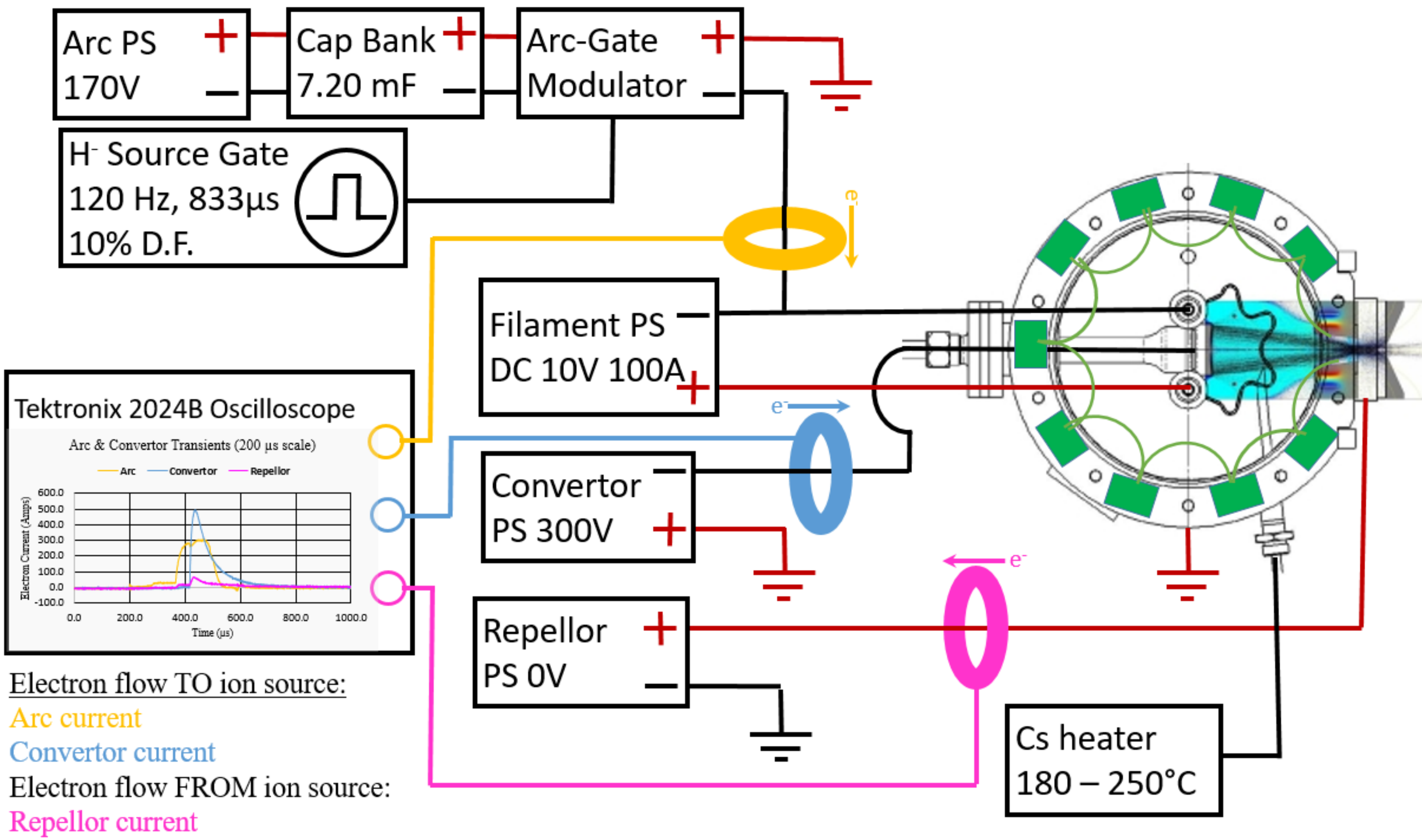
U. Fantz, C. Wimmer J. Phys. D **44** (2011) 335202

Conclusions

- Successful diagnosis of Large Transients in ion source
- Mitigation controls are currently being studied
- Seeking proposal funding for Plasma Diagnostics using Laser Absorption Techniques.

Backup

Experimental Setup: Measured Surge



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Both:Arc Only:Conv Only