Plasma Source Performance and Two-Bunch PWFA Analysis

E300 Collaboration Meeting

FACET-II
Facility for Advanced Accelerator Experimental Tests

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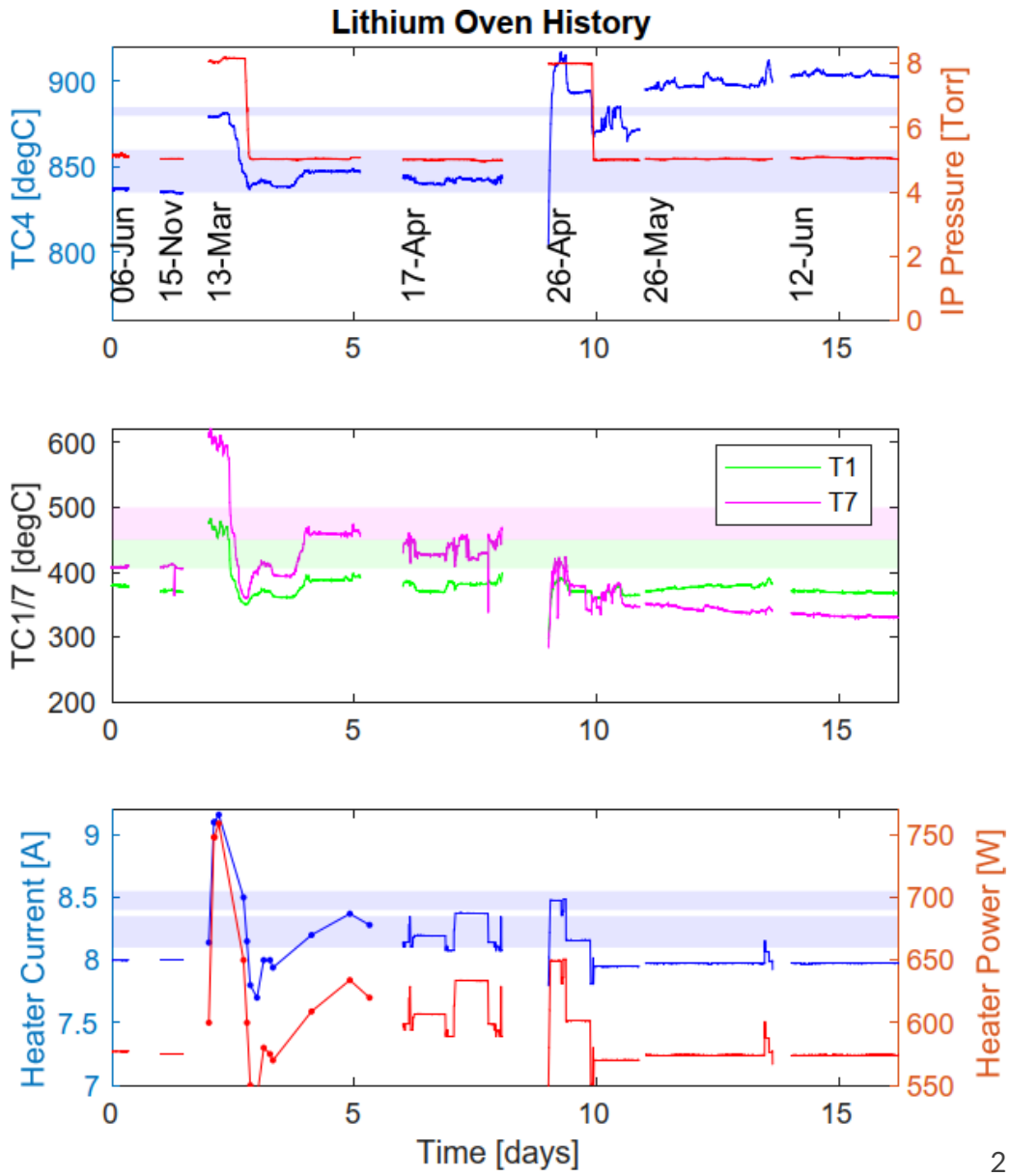
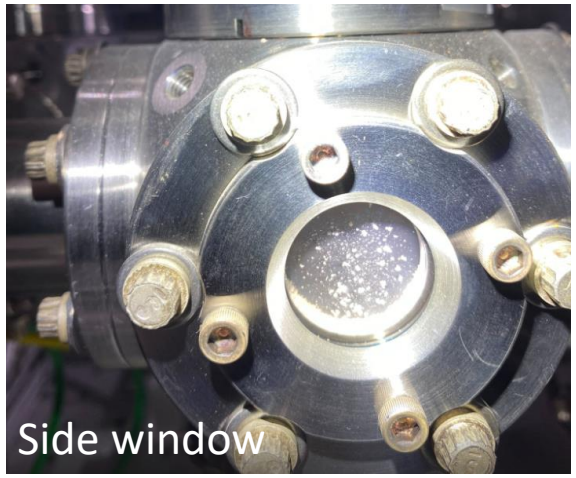
Lithium oven operation this run - Highlights

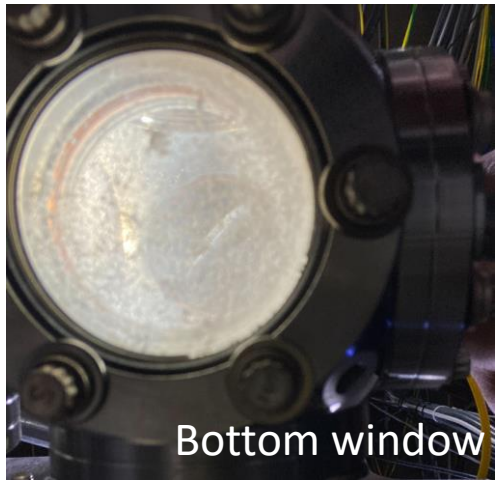
- >2 weeks cumulative oven time
- Highlights:
  1) Epics controls implanted for heater and static fill
     - Fully automated heat-up and shutdown
  2) Operated the oven in both 8 and 5 Torr modes
  3) No hard crashes by the DPS
     - But not a flawless performance either
     - Radiation levels become very high when focusing on accelerated charge
  4) Achieved greater than 50% drive-to-wake energy transfer
  5) Demonstrated witness bunch capture and acceleration

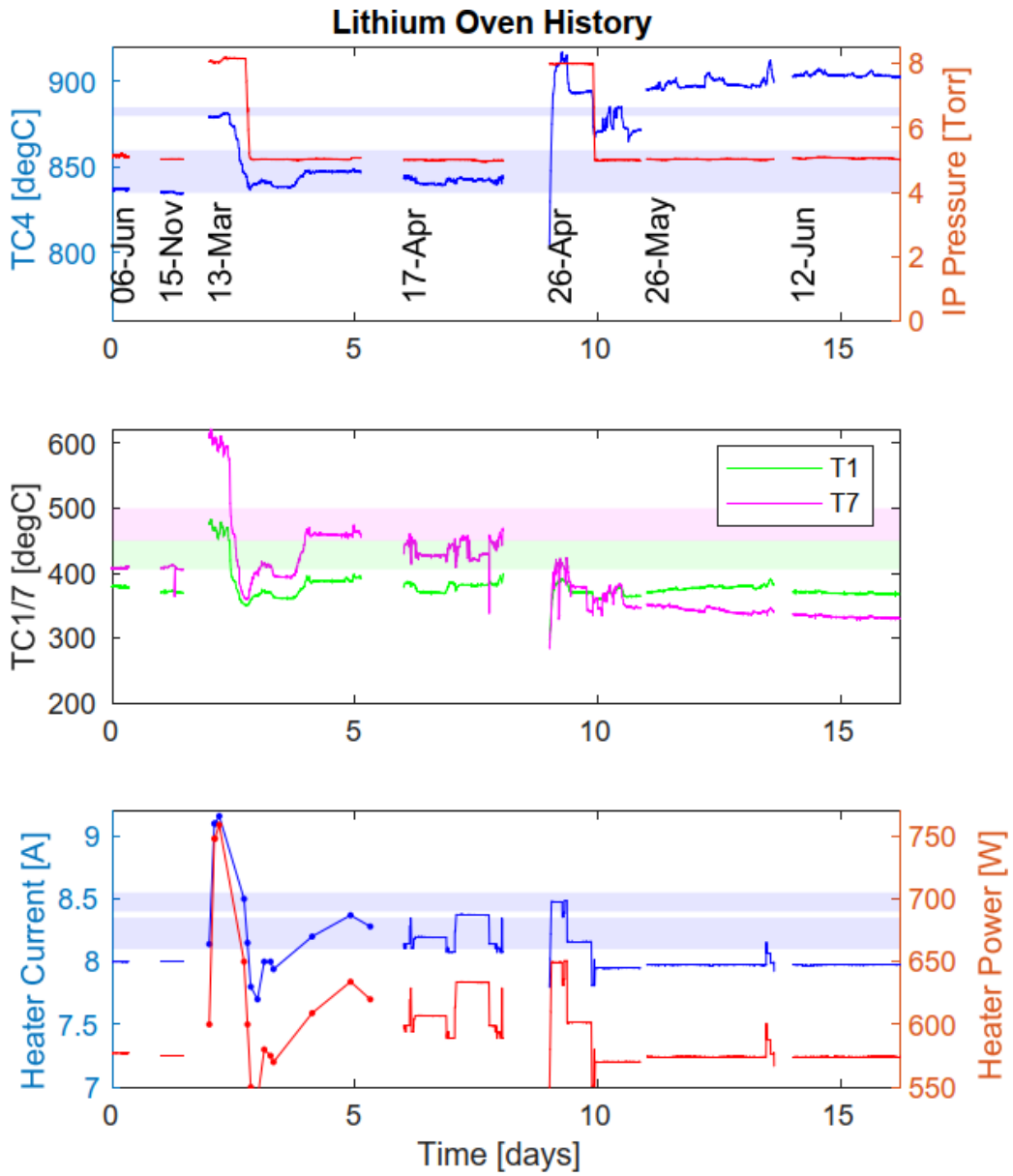


Lithium oven operation this run - Issues

1) Issue reaching nominal middle TC temperature at 8 Torr on Mar 13 run
2) Greater than 80W beam power deposited in the oven during Apr 17 run
3) Oven ran very hot on Apr 26 run
4) Reduced aperture stymied E324 progress on Apr 26 run
5) Lithium on IPOTR1P window found on May 7 PAMM
   - A lot of lithium in IPOTR1P cube, some specs in PB bellows
6) Severely degraded oven performance in May and June







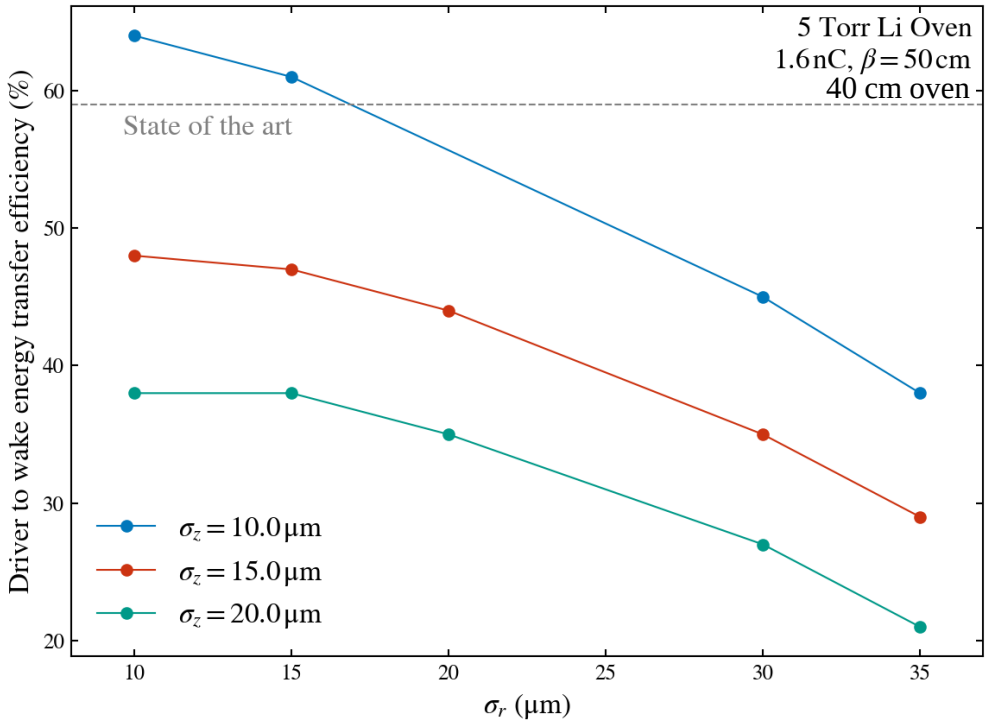
Next steps

- The lithium oven will continue to be very importance for progress in the next year
  - Low ionization threshold allows for greater tuning flexibility for the witness and spacing
  - Removes necessity for beam/plasma alignment

- But – there are issues:
  - Beam heating effects
  - Fixed oven length, ramps, and density**
  - Limited diagnostic feedback, other than the beam-pipe temperature

- Alternative plasma sources (longer term):
  - E301 – Robert can discuss pros/cons
  - Capillary discharge - 195/500mm cells at FlashForward
  - Long gas jets
  - Long plasma tubes – 5 m plasma source for AWAKE

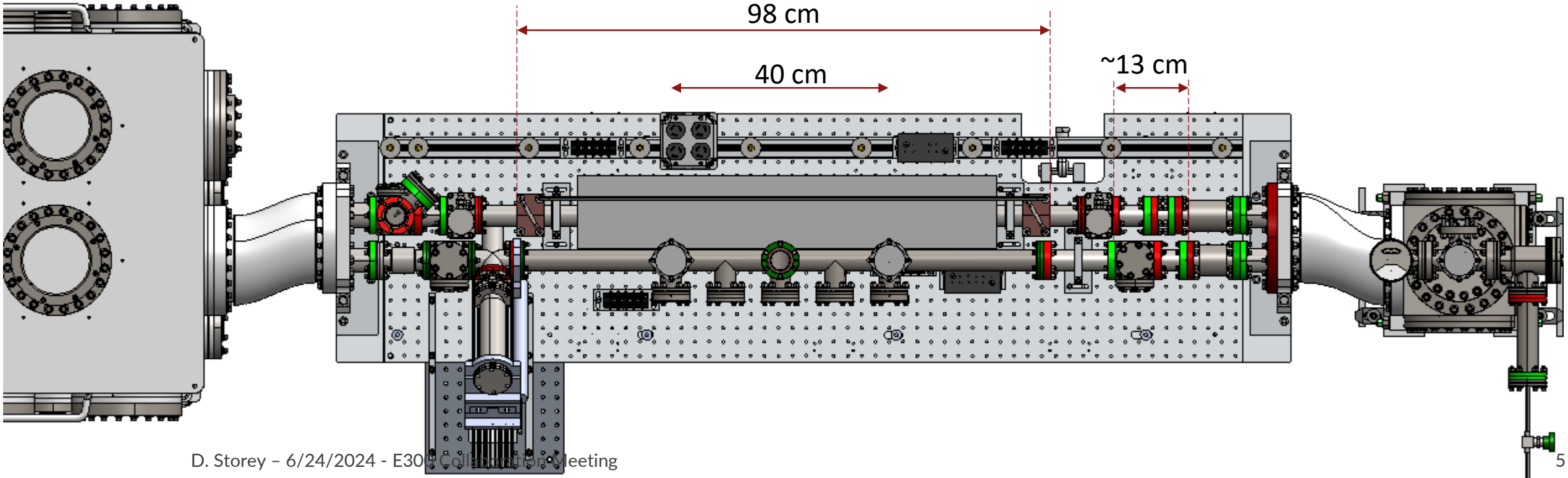
Drive-to-wake performance expectations



Simulation credit to Chaojie

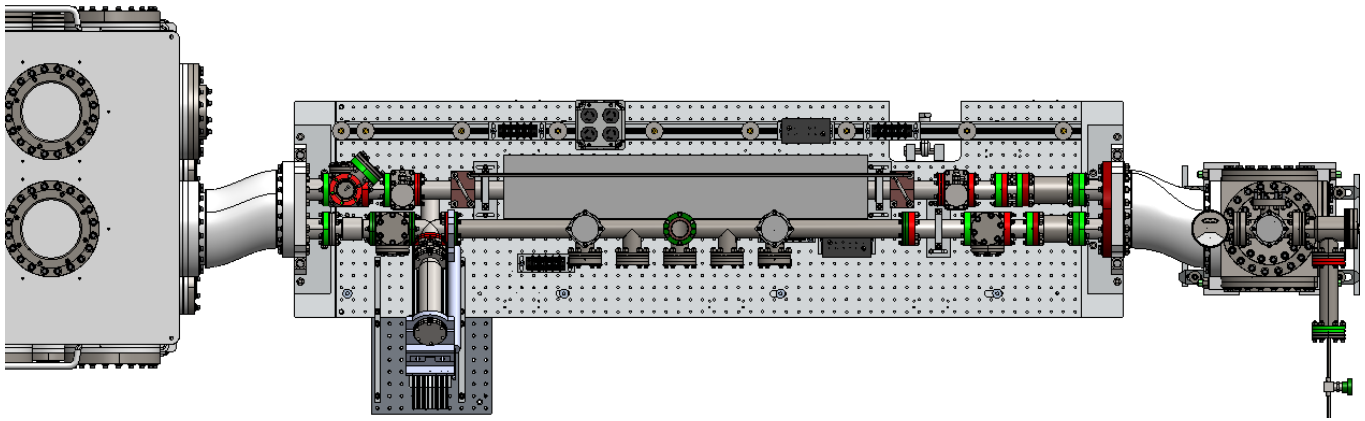
Plans for the 2025 run

- Oven replacement by this fall
  - Ideally with a longer one to aid pump depletion and energy transfer goals at 5 Torr
  - How much room can we gain in the current layout? 20cm?
  - Are there additional diagnostic capabilities that we can add?
- Regain ability to run beam at 10Hz with 1Hz delivery to the IP

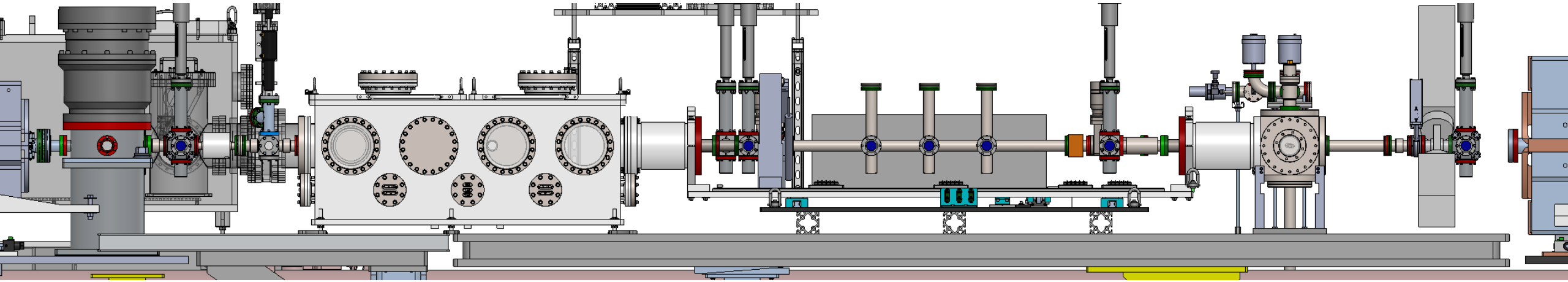


Larger layout – for discussion

Top view



Side view



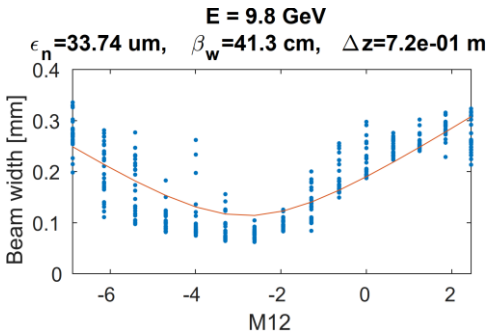
Two bunch studies

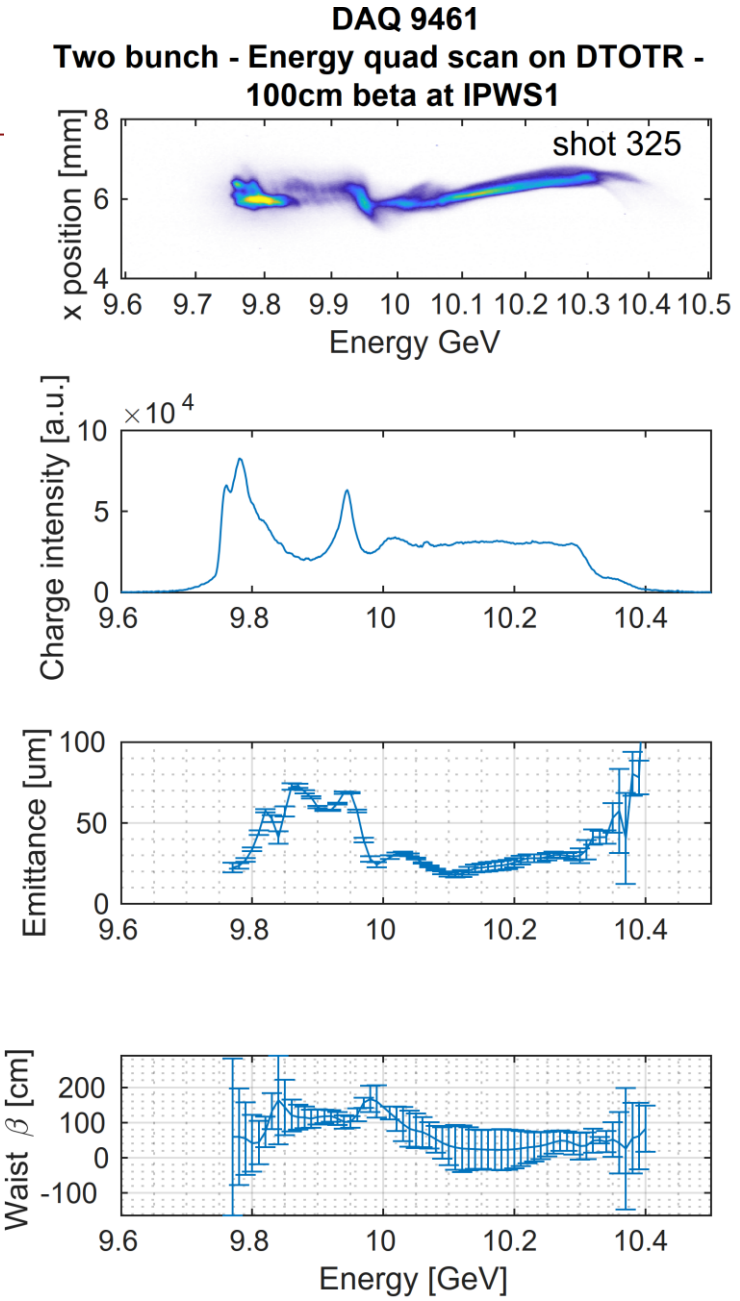
- We had 2 sessions with 2 bunch PWFA
  - May – 5 Torr Li oven
  - June – Started with Li oven, switched to beam ionized hydrogen plasma
- Nominal parameters in both runs:
  - 1.2/0.4 nC drive/witness charge
  - $\beta_{IP} = 50$ cm – at oven entrance OR IPWS1 in H2
  - Spectrometer imaging oven entrance +50cm, or DS Be window

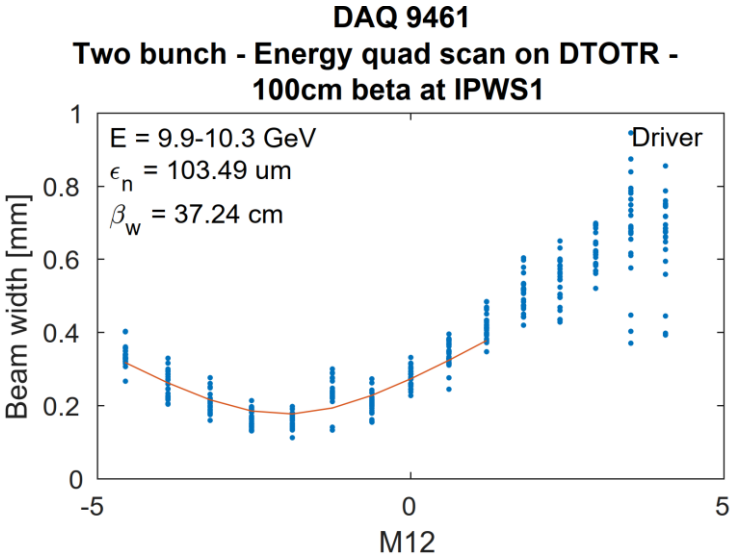
- Topics of discussion
  - Drive witness emittance measurements
  - Accelerated charge and max acceleration
  - Emittance measurements of the witness charge
  - PWFA in a long H2 plasma

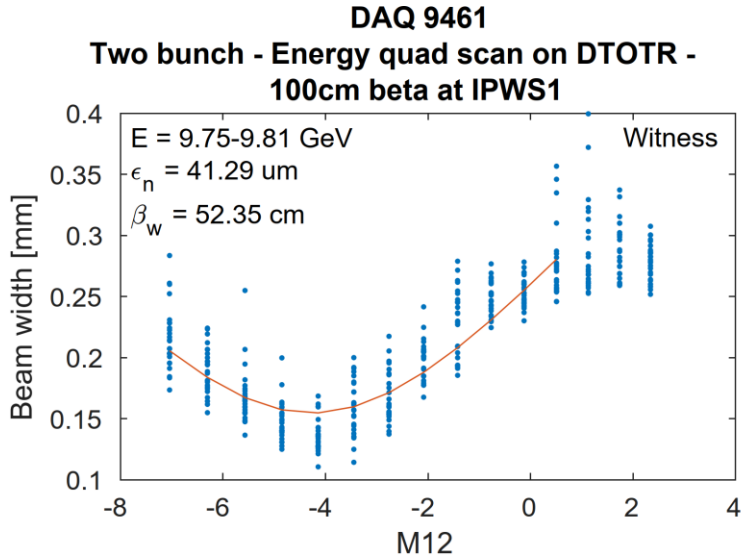
2 bunch emittance measurements

- Analysis needs some refinement:
  - Energy slice emittances and beta show strong correlations across the bunches
  - Projected emittances:
    - Suffers from non-canceled horizontal dispersion



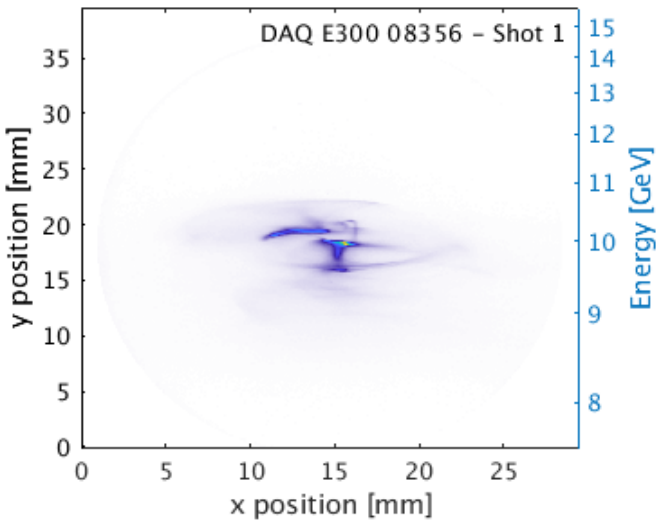




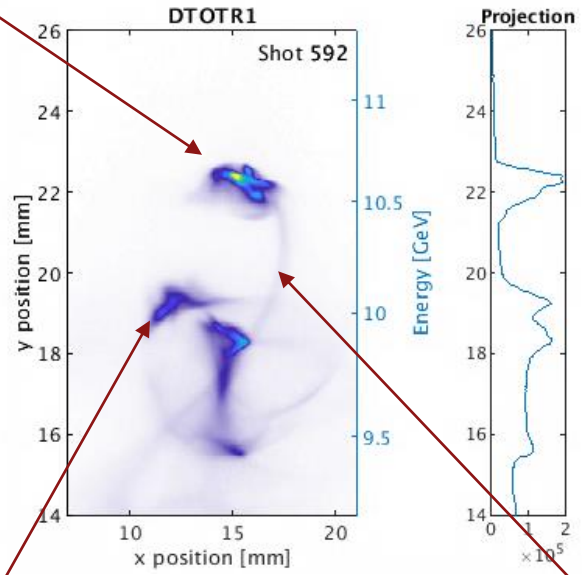


Accelerated charge

- We have good correlation between bunch spacing and accelerated charge in the lithium oven
  - Alex showed ~250pC captured charge at the optimal bunch spacing

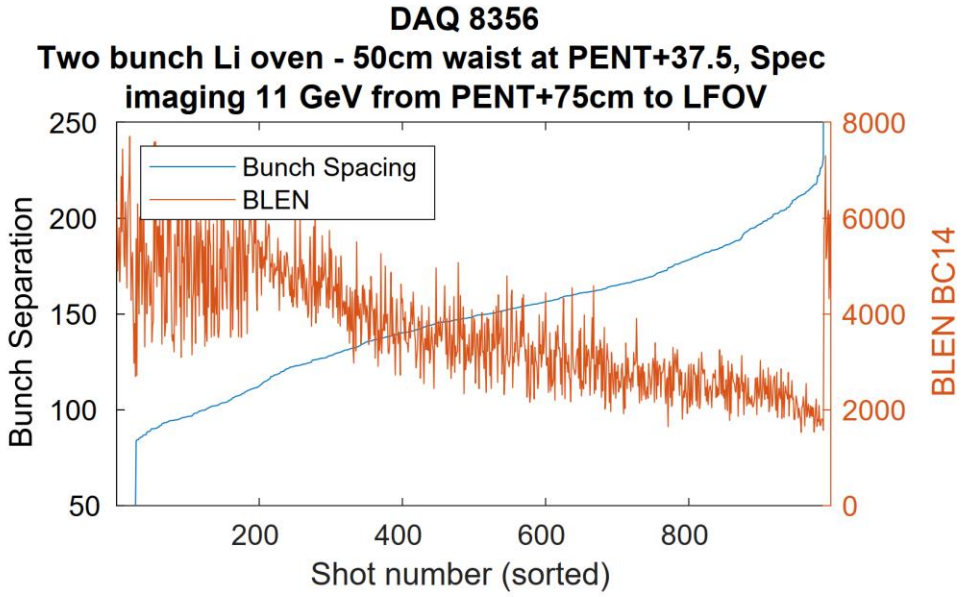


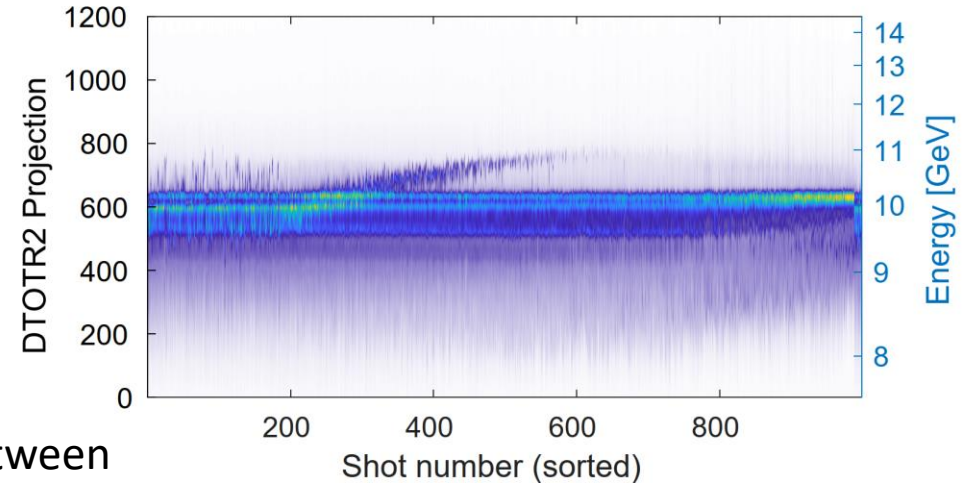
~250pC witness (~60%)



Non-participating drive charge

Charge between drive/witness

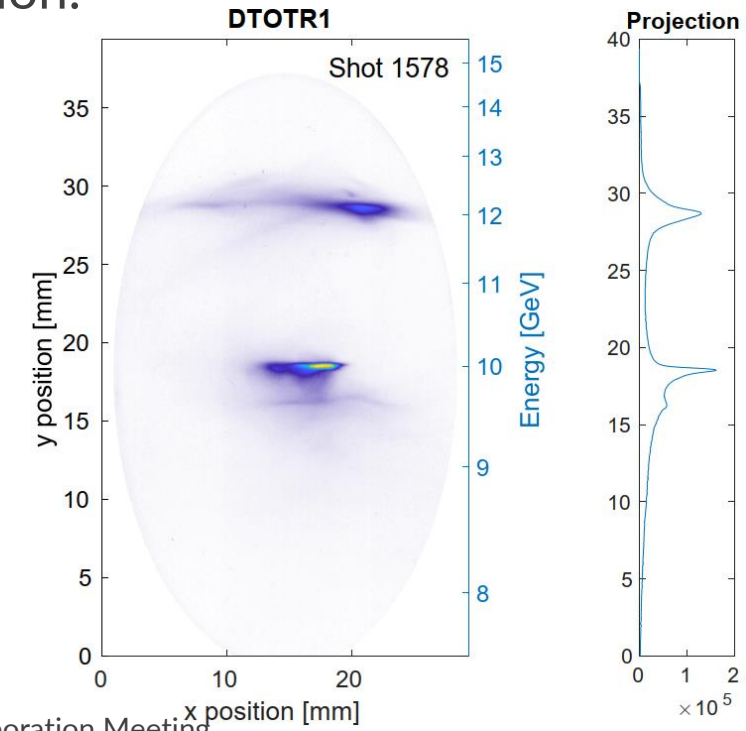


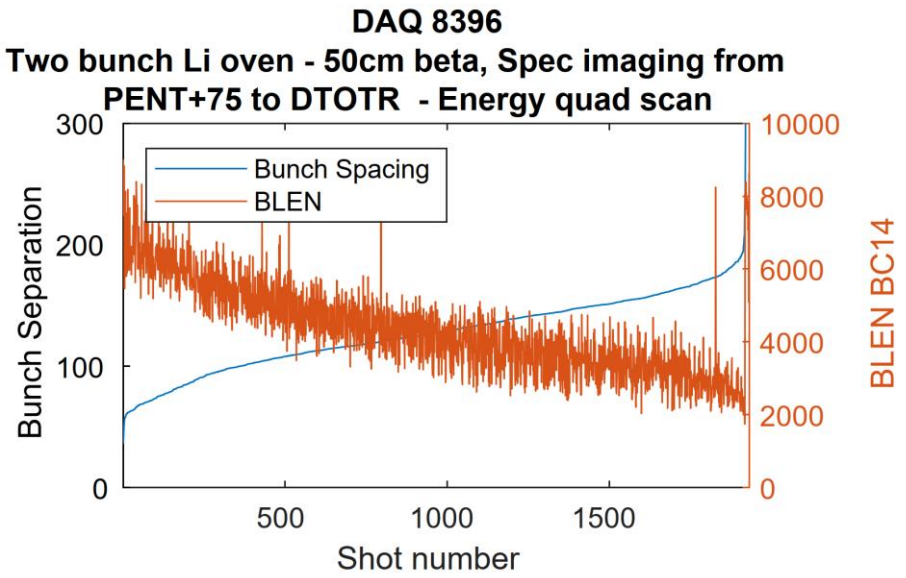


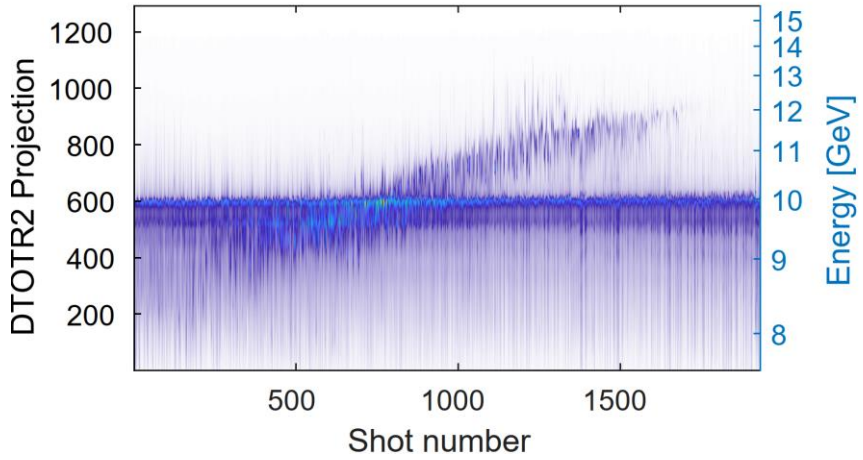
Max acceleration in the lithium oven

- Acceleration up to at least 12 GeV observed after manual optimization of sextupoles
  - Minimize non-participating charge, maximize energy gain
- Max acceleration also correlated with the maximum drive-to-wake energy transfer

- Shot with ~peak acceleration:
  - Bunch separation = 142 um
  - Charge ~250 pC
  - Energy spread ~ 0.6 GeV (FWMH)
  - Large transverse kick!
  - Bunch is getting closer to the back of the bubble here



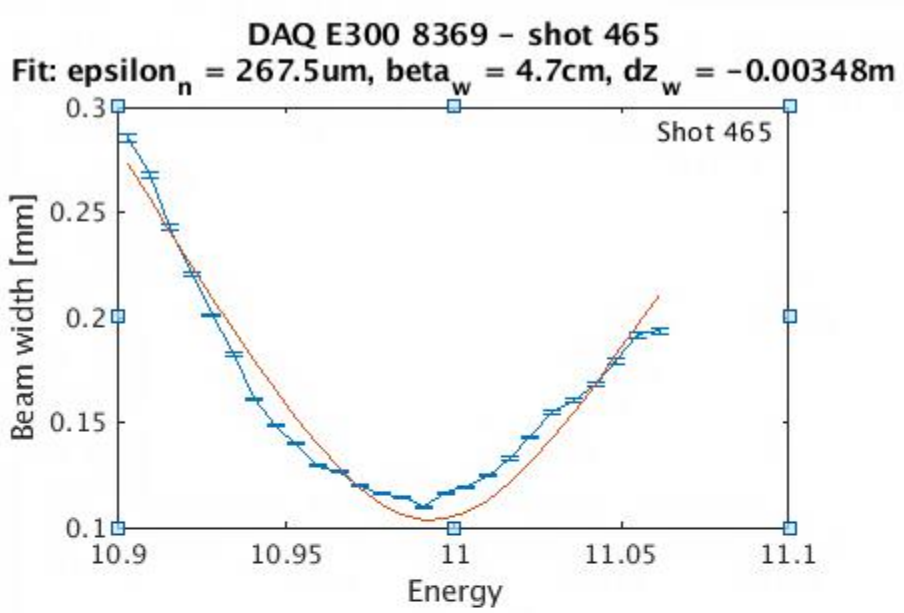


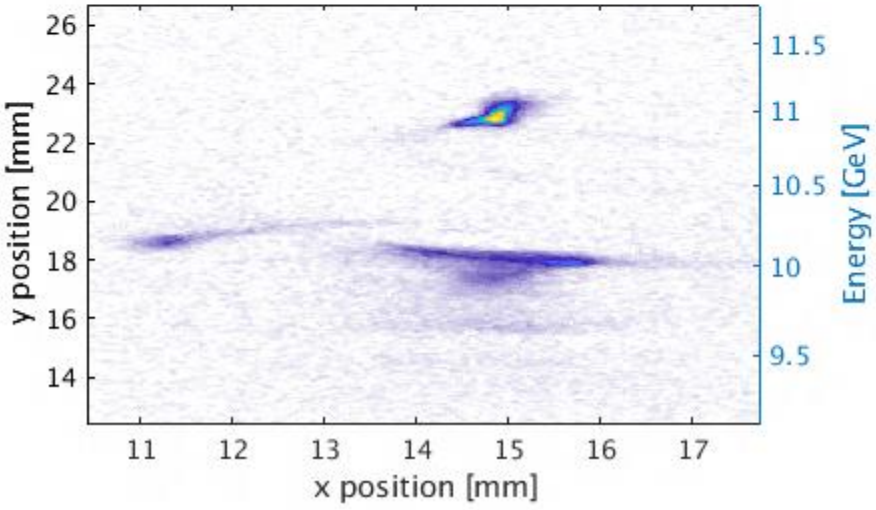


Witness emittance measurements

- Single shot emittance measurements:
  - ~90 pC charge in this shot
  - Bunch separation = 140 um
  - Vacuum waist is roughly at the plasma exit location

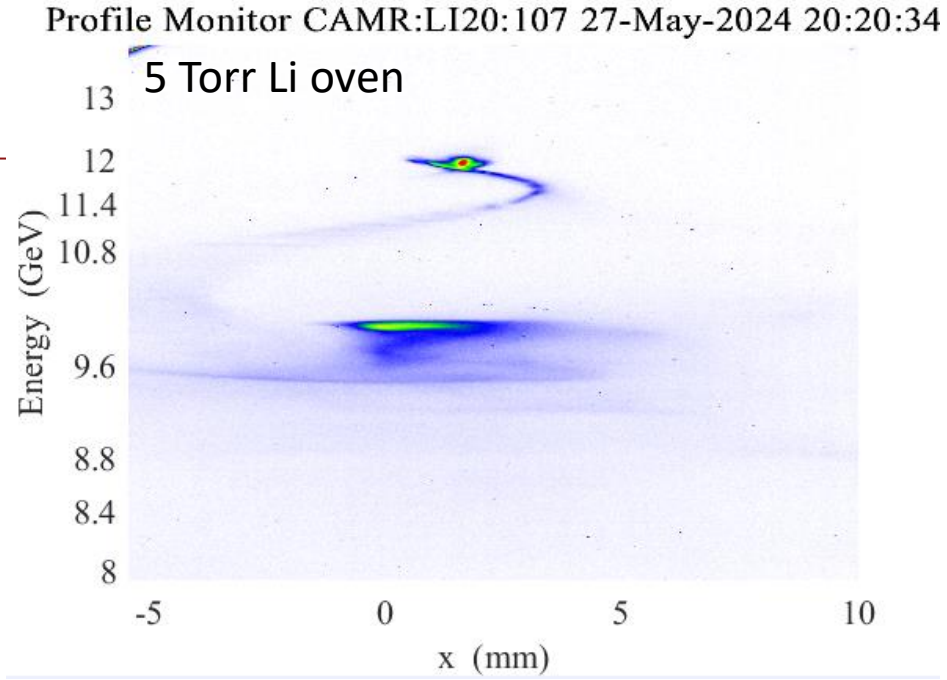
- Further analysis:
  - Careful energy calibration for more accurate locating of the plasma exit
  - Analysis with higher resolution DTOTR1
  - Analyze correlation between emittance and bunch separation and other scalars

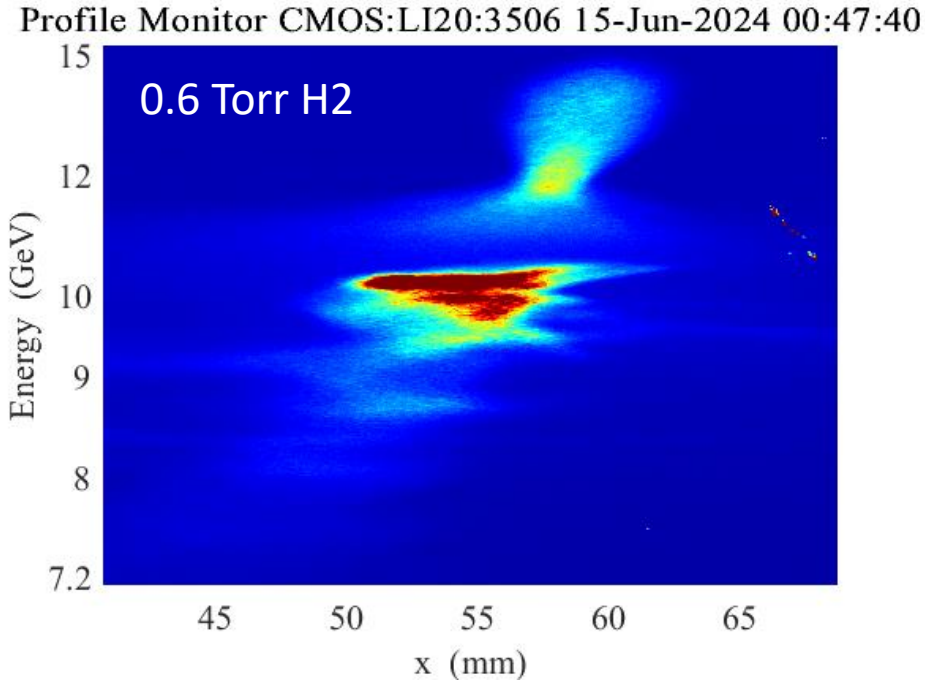




Two bunch PWFA in Hydrogen

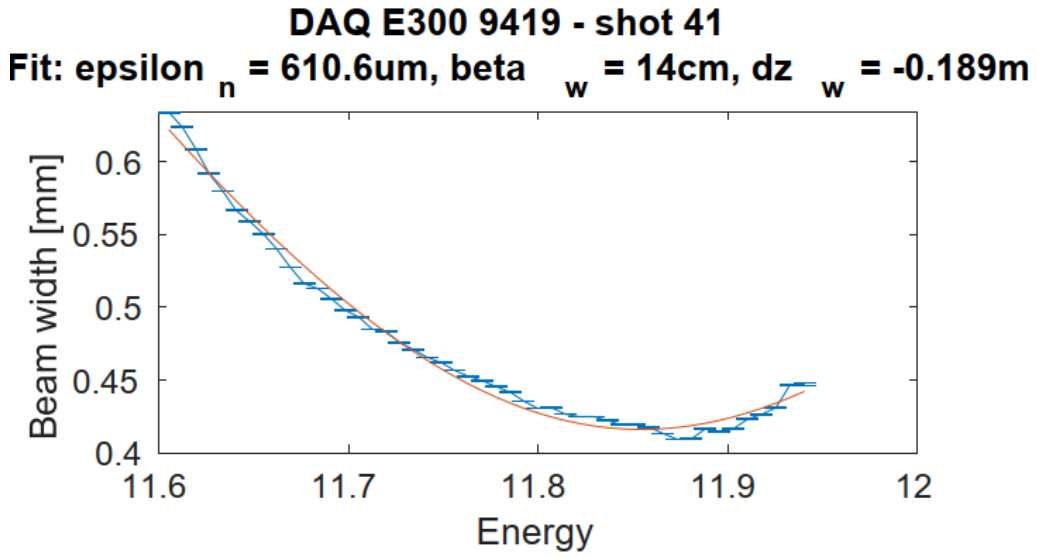
- Last resort after the oven failed
- Beam ionized hydrogen plasma
  - Energy loss down to <1 GeV
  - Plasma length >2m
    - Witness transported to the downstream Be window
  - Primarily worked at ~0.6 Torr, for a nominal bunch separation closer to ~200 um
- Witness acceleration:
  - Charge accelerated up to ~15 GeV
  - The transverse profile is very different than with the lithium oven
- Further analysis:
  - Confirm for certain that this is trapped witness charge

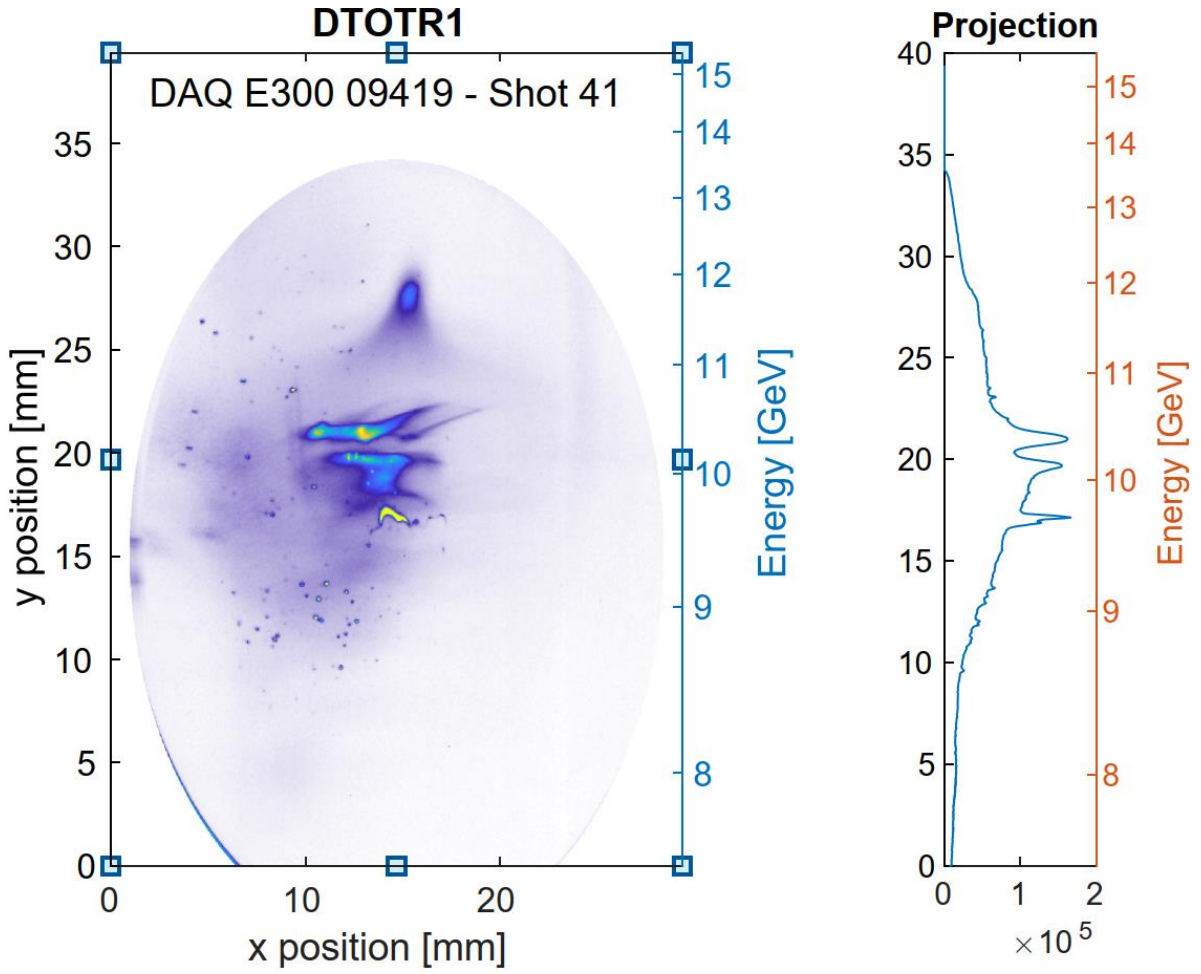




Preliminary charge and emittance analysis

- Shot with acceleration to 12 GeV:
  - ~140 pC charge
  - Bunch separation TBD
  - Emittance is rather large
  - Witness charge transported all the way to the DS Be window





DTOTR YAG screen became severely damaged in the final days

Things we need to improve on for the next time around

- DPS improvements
  - We need to find new “dumb” roughing pumps
- New lithium oven
  - Longer oven?
  - Scav-line beam dump + kicker for 1 Hz delivery to the IP
- Improved longitudinal feedbacks
  - Jitter may be ok, but we need better control of drifts to maintain our bunch spacing AND bunch lengths
- We need better diagnostics
  - More resolution from the XTCAV, S15 XTCAV, EOS-BPM
- Better control over dispersion, i.e. transverse tilts and alignment
  - Both by manual tuning using traditional diagnostics,
  - Or – through machine learning tools
  - Demonstrate >80% drive-to-wake energy transfer

Additional data acquired:

- H2 pressure scans
- Further analysis:
  - Determine optimal bunch spacing at each pressure