

E300 Update

E300 Collaboration Meeting

Doug Storey | AARD

4/30/2025



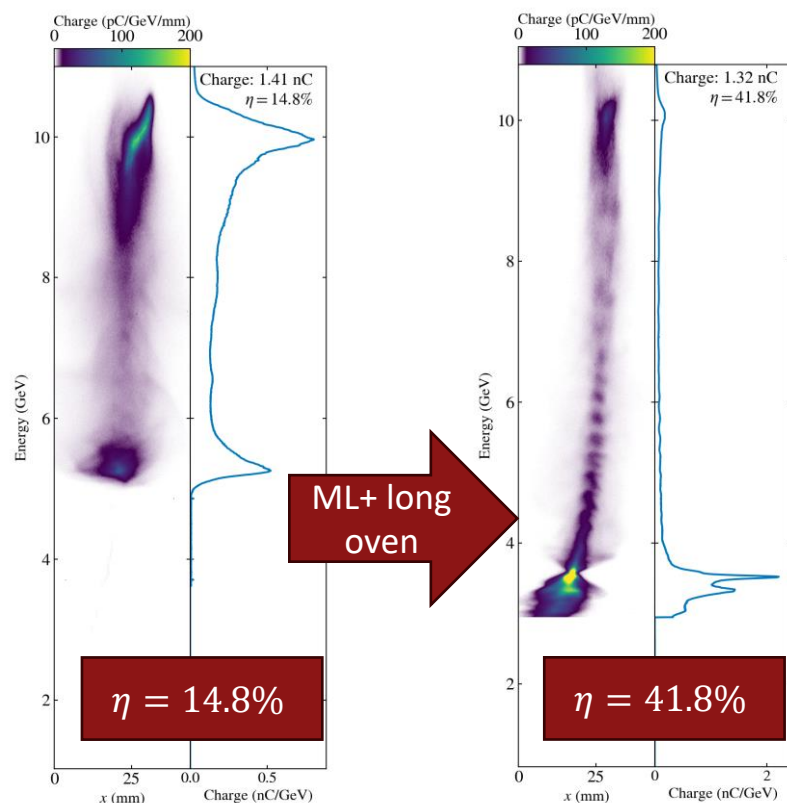
Facility for Advanced
Accelerator Experimental Tests



Reminder of main E300 results from FY2024

- Single bunch

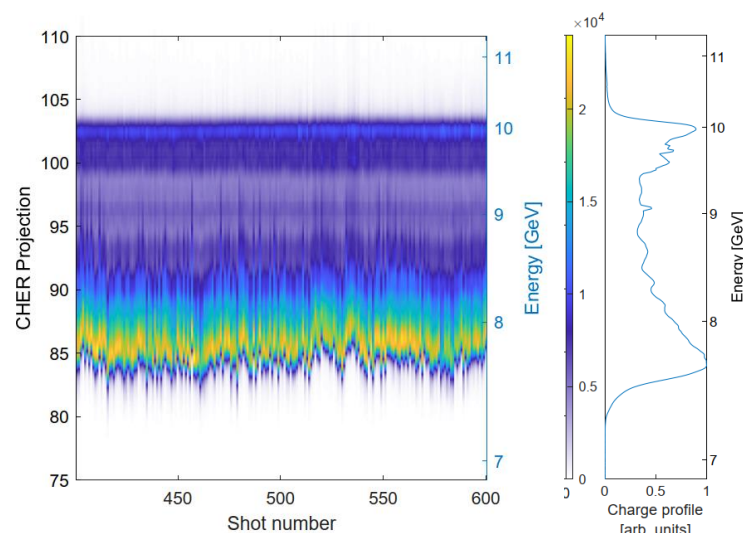
- Beam ionized
- Oven overheated
- Achieved very low non-participating charge



- Short oven (??) →

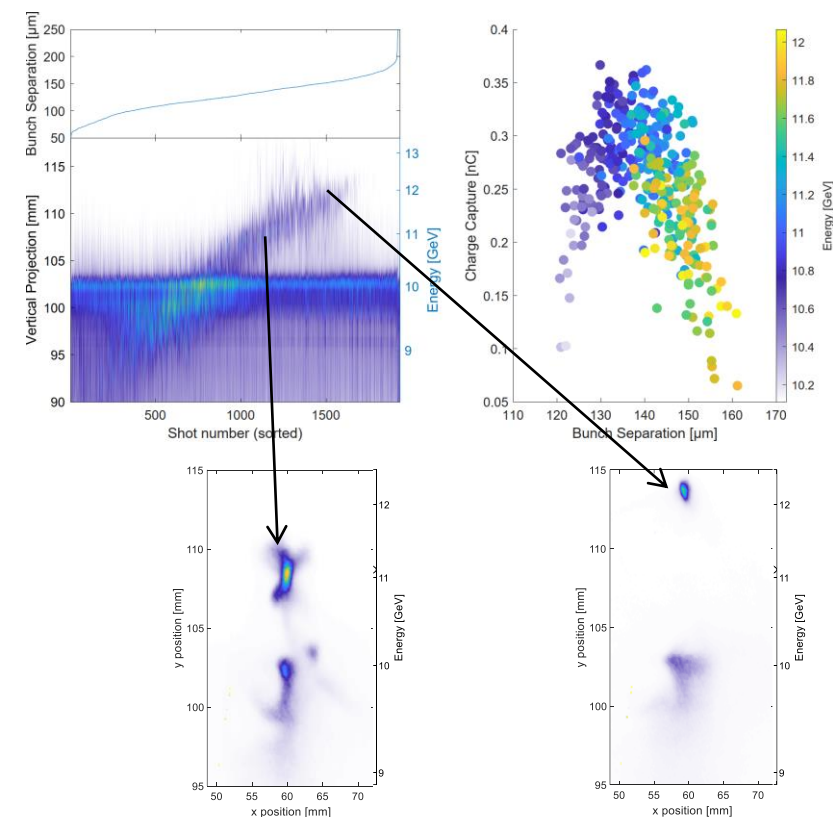
- Two bunch (but drive only)

- Max energy loss of ~2.5 GeV
- Up to 85% participating charge
- Maximum of ~13% drive-to-wake
- Quite stable deceleration



- Two bunch

- ~2 GeV max acceleration
- Up to ~0.35 nC accelerated (at 11 GeV)
- Energy spread ~1-4%, emittance ~200+ μm
- ~35% wake to witness energy transfer
- → ~4-5% total energy transfer



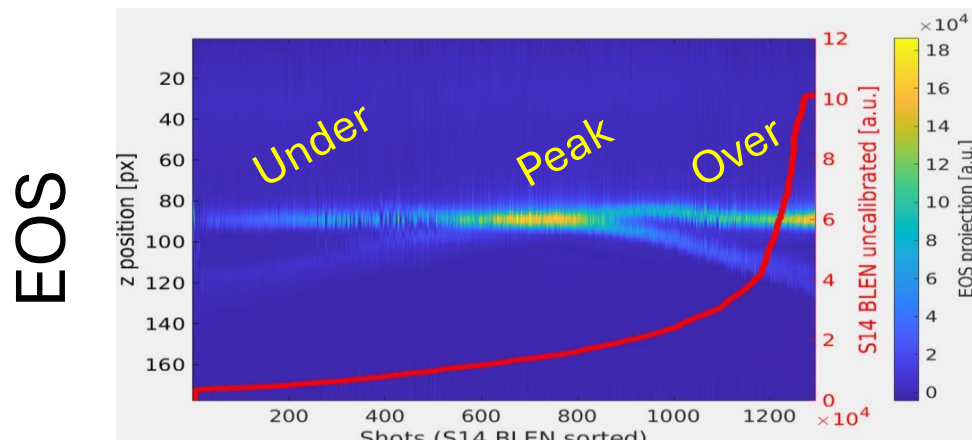
So – what have we done this year?

- Early 2 bunch (from the cathode) run in Nov '24
- Focus on machine development in Jan/Feb '25
- Notched two bunch (chirped single bunch)
 - E300 runs in March
 - E302 run
- Second 2 bunch from the cathode run just completed

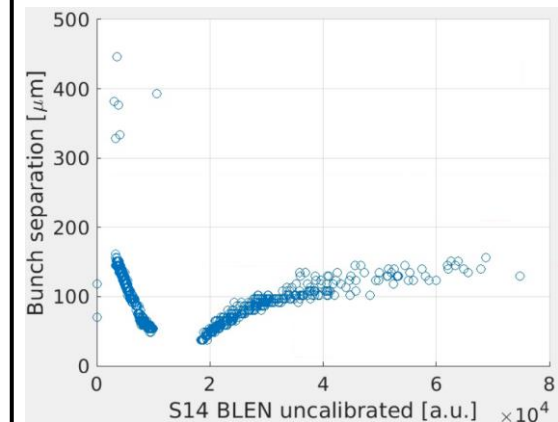
Creating two bunches with the notch

- Can vary bunch spacing, charge, current by varying notch and L2 phase
- Bunch characteristics correlate very well with S14 BLEN readback
- Charges
 - Drive: 600 - 750 pC
 - Witness: 200 - 300 pC
- Bunch separations 40-150 μm

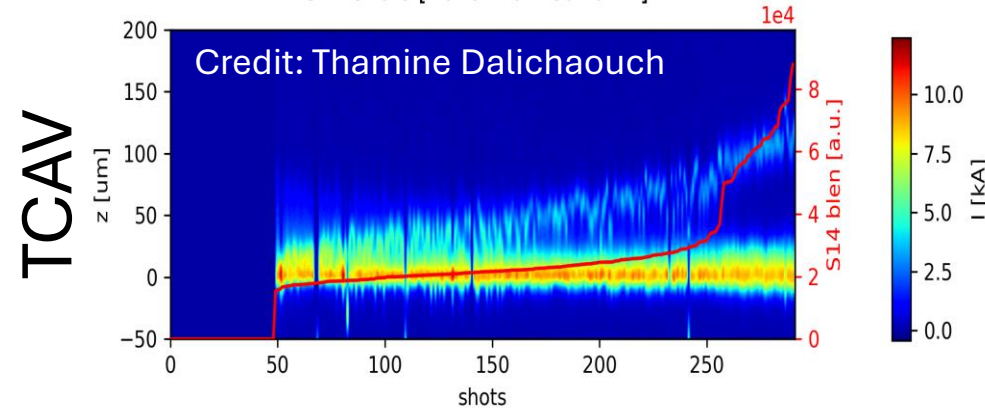
L2 phase scan
[energy feedback on, BLEN feedback off]



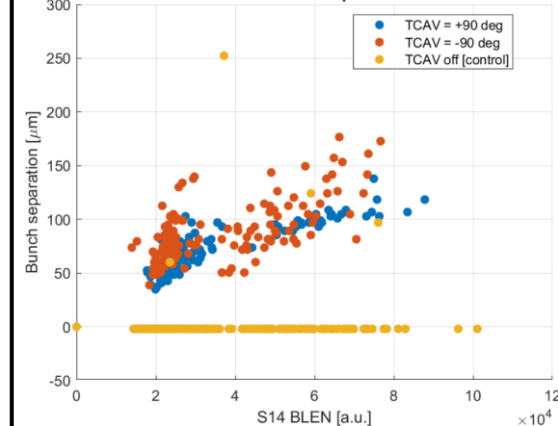
Bunch separation measurement



TCAV shots [Renormalized to kA]

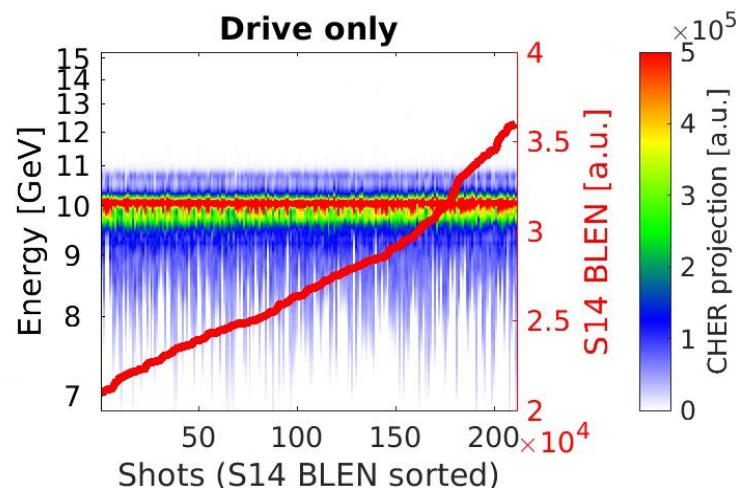
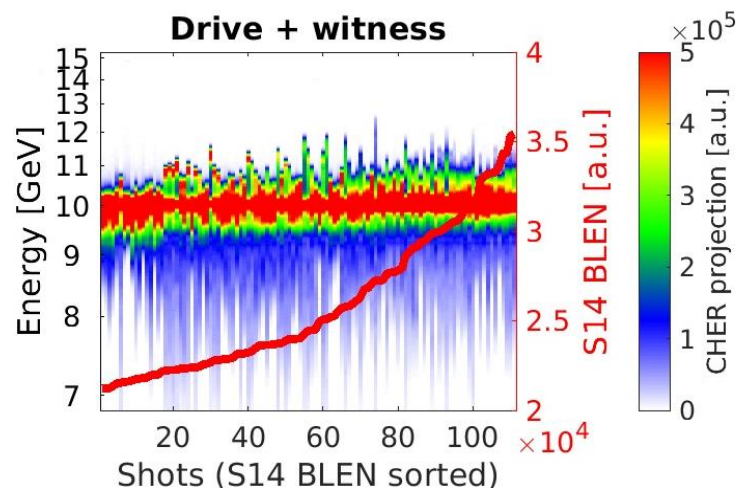
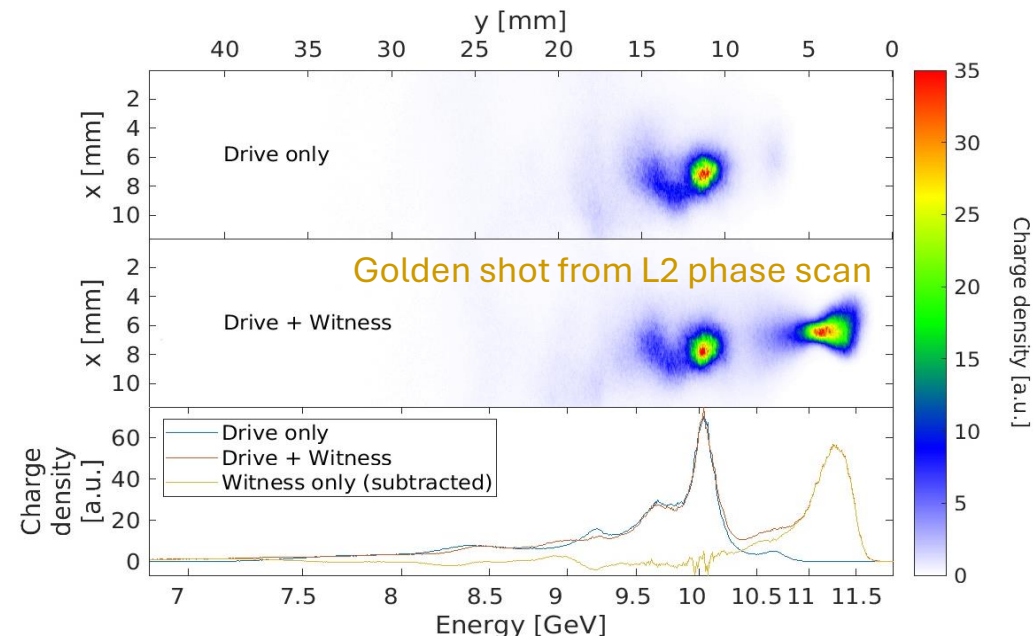


TCAV bunch separation



Notched two bunch PWFA in Hydrogen plasma

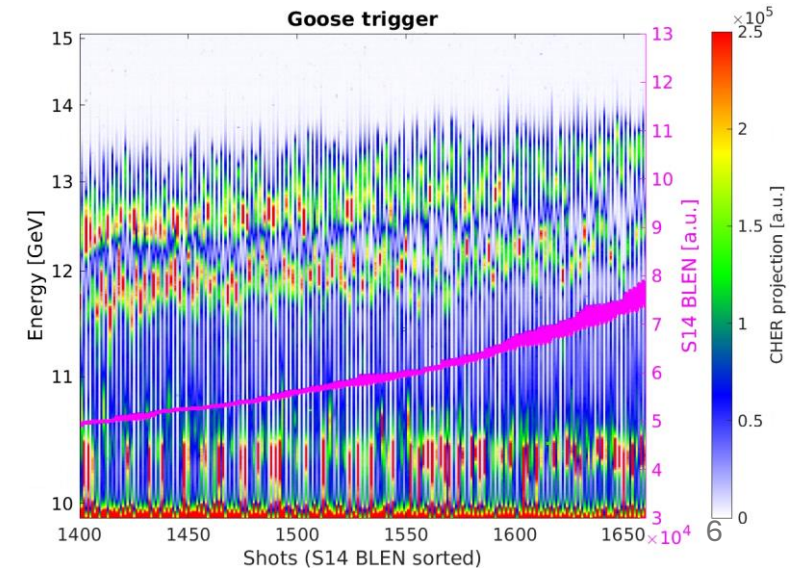
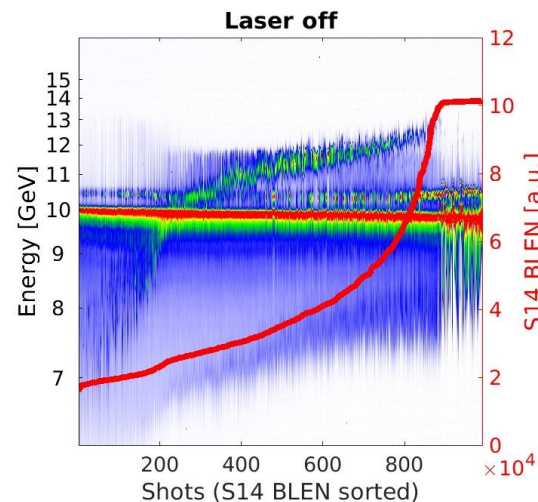
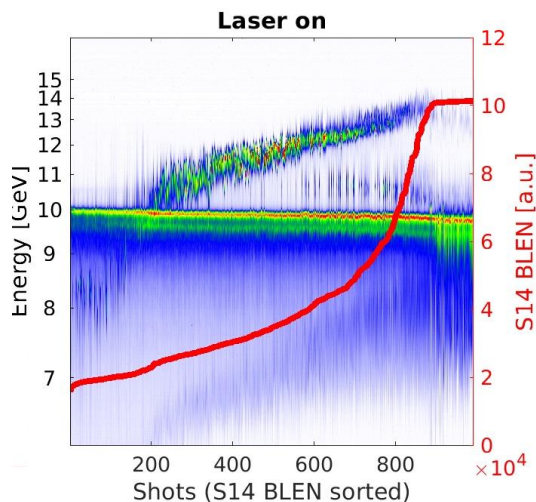
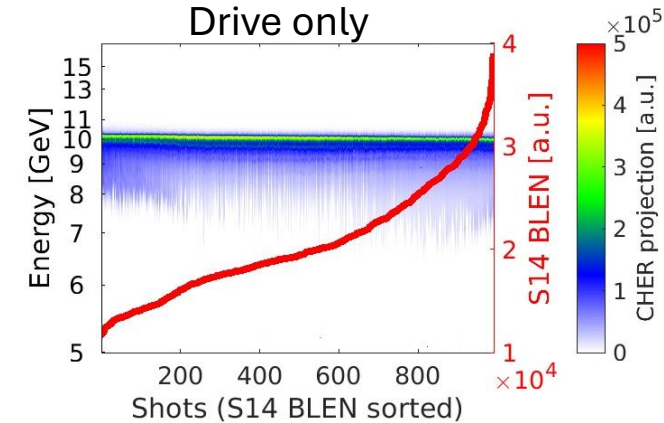
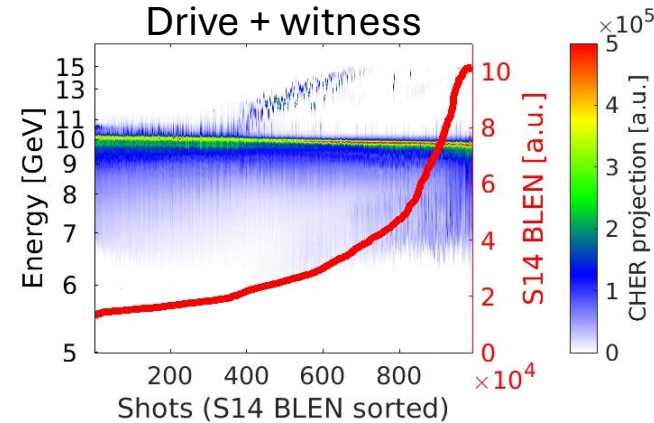
- Laser pre-ionized H2 plasma at $n_e = 5 \times 10^{16} \text{ cm}^{-3}$
- Trailing bunch accelerated to 11-12 GeV
 - Good charge capture (long ramps?)
 - Up to 85-90% charge capture on very select shots
 - Relatively large energy spread
- Difficulties:
 - Laser to e-beam alignment more sensitive
 - Less stable acceleration



- ~260 accelerated here out of ~294 incoming

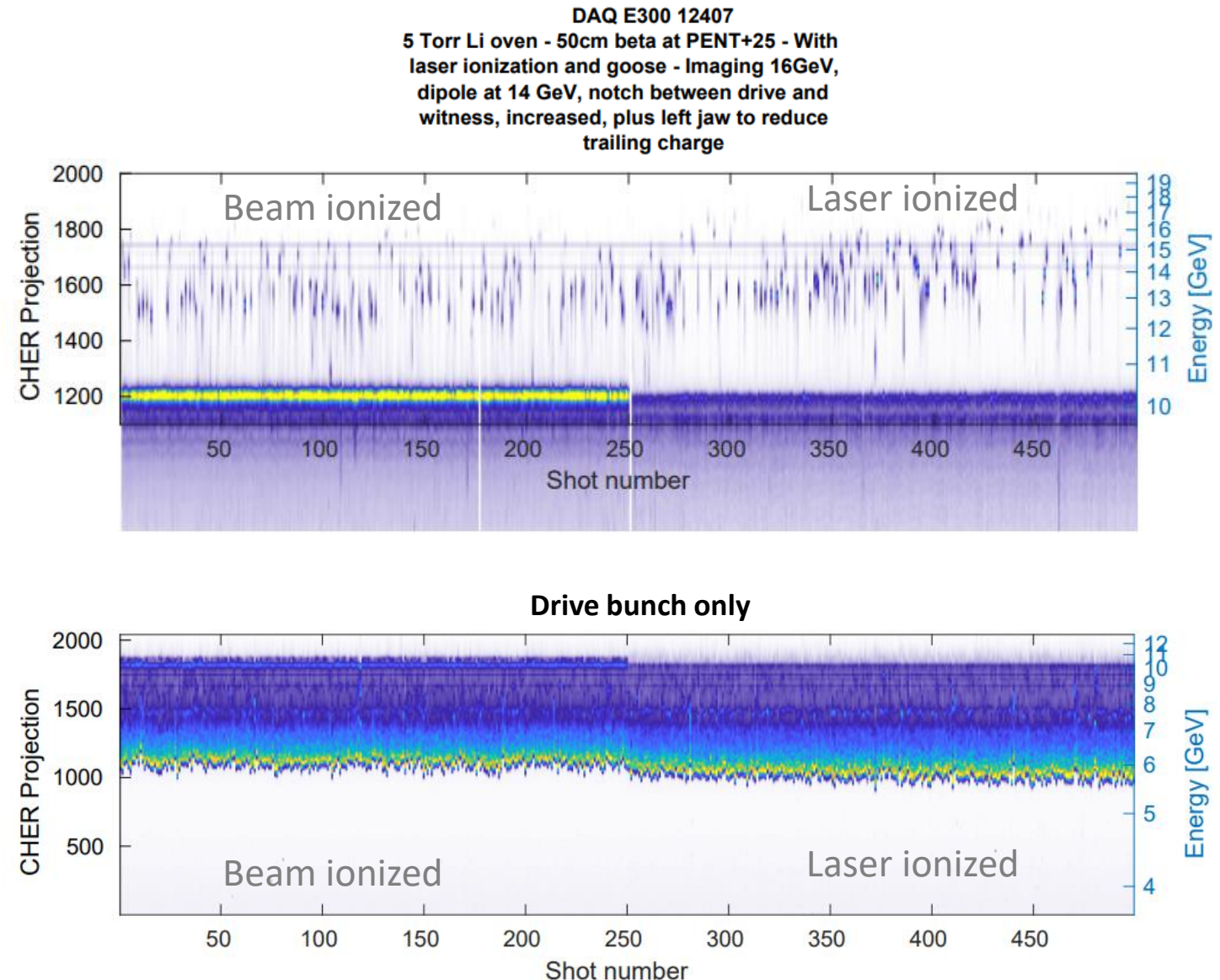
Notched two bunch PWFA in Lithium plasma

- Laser ionized Li plasma, $3.5 \times 10^{16} \text{ cm}^{-3}$
- Stronger/more stable acceleration
- Laser preionization gives $\sim 1 \text{ GeV}$ difference in energy gain and decreased “non-participating trailing charge”
 - 70-80% charge capture (in E302 shift)
 - Up to 7% total energy transfer
 - With laser off $\rightarrow$ drops to $\sim 50\%$ capture/5% efficiency



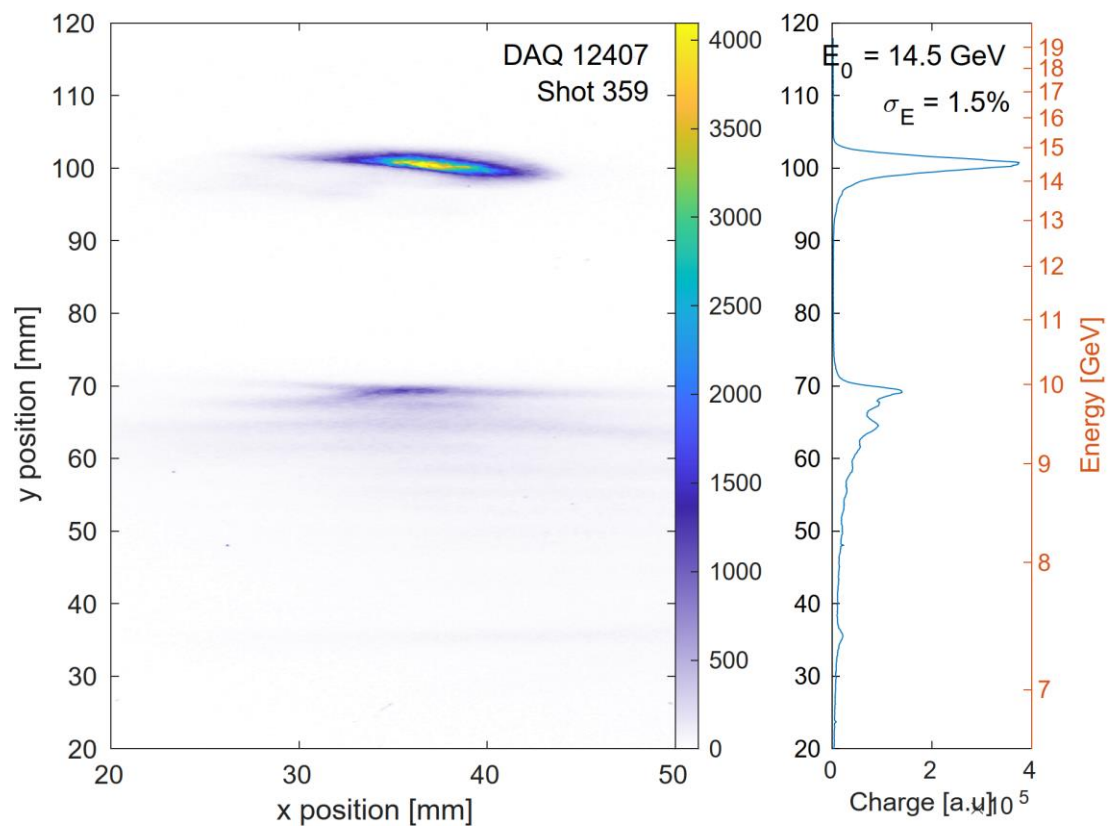
Two bunch results from this past week

- 2 bunches from the cathode
- Laser preionization, $4e16/cc$
- Some differences from prior runs:
 - New transverse tuning tools
 - New longitudinal feedbacks
 - Use of notch and jaw
- Deceleration by 2-3 J
 - Order 20-30%
- Acceleration of $\sim 100(s)$ pC to up to ~ 16 GeV

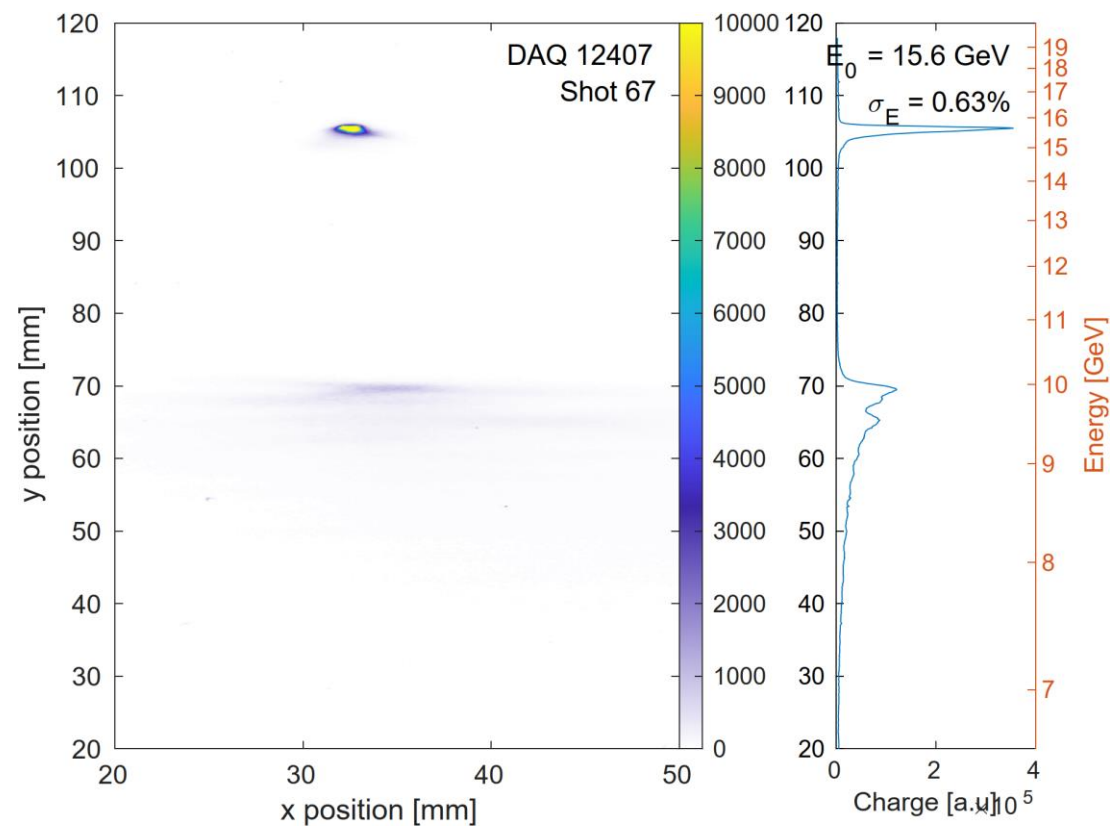


Interesting shots

- High charge capture:

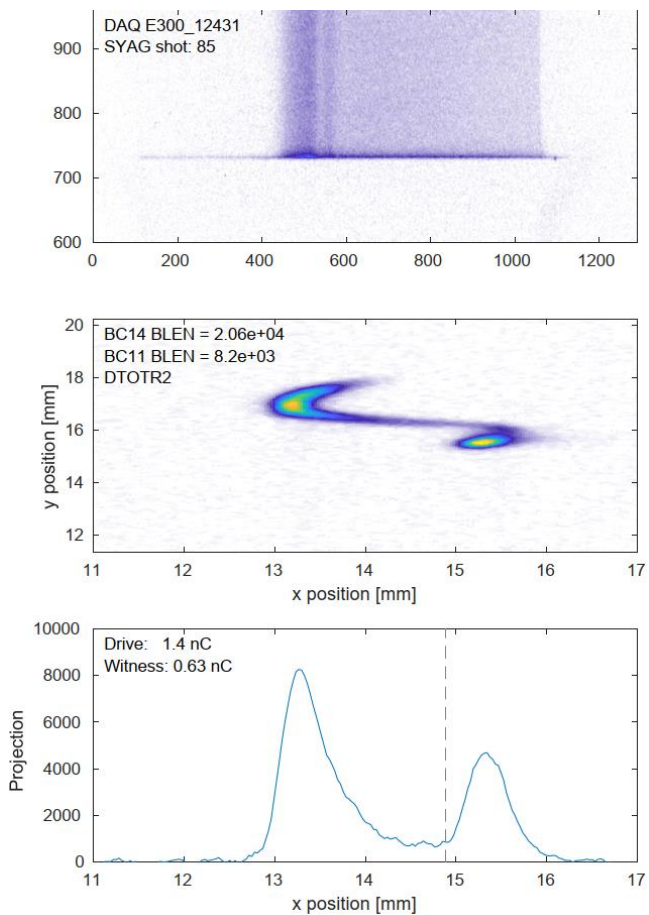


- High energy



Charge capture estimate – Very Preliminary!

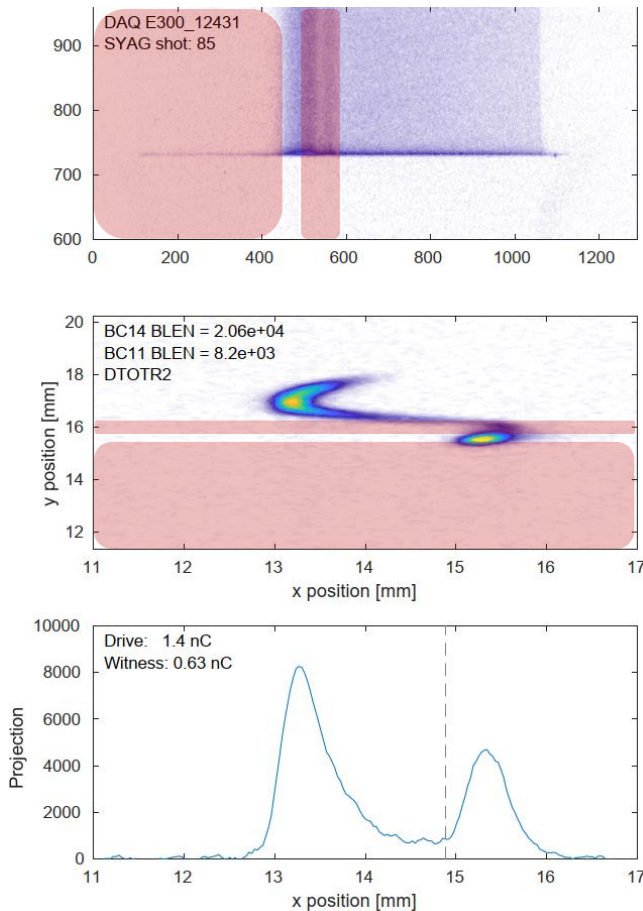
No collimation



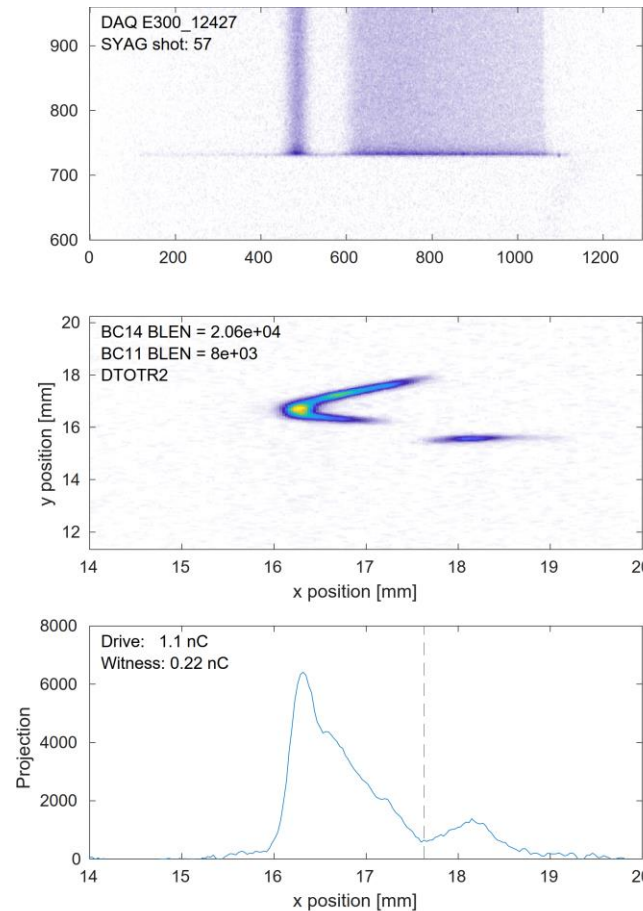
Note – TCAV profiles require further processing before representative of LPS

Charge capture estimate – Very Preliminary!

No collimation



Jaw and Notch

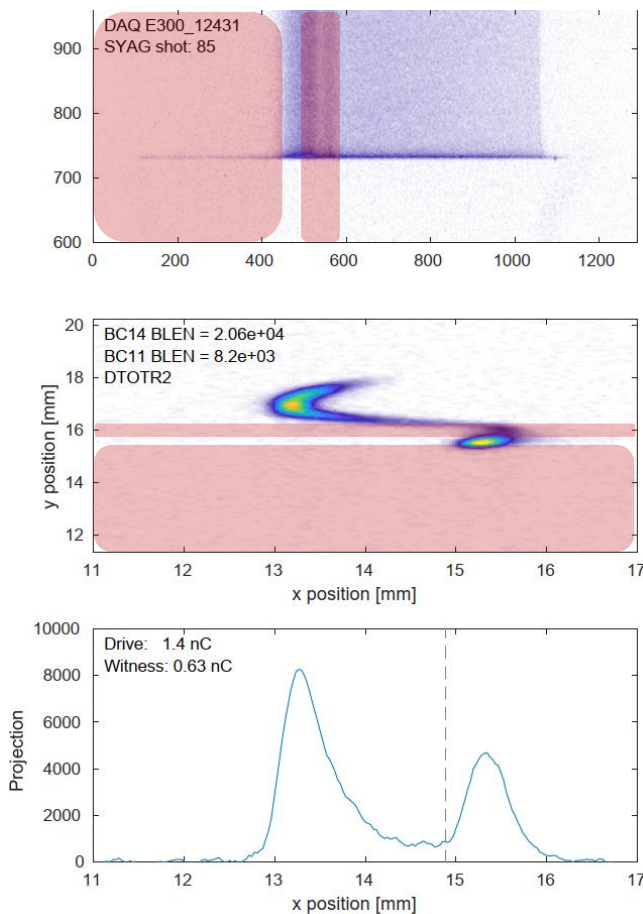


- Incoming witness charge can be tricky to estimate
- Initial estimates from DTOTR give 200-300 pC trailing charge

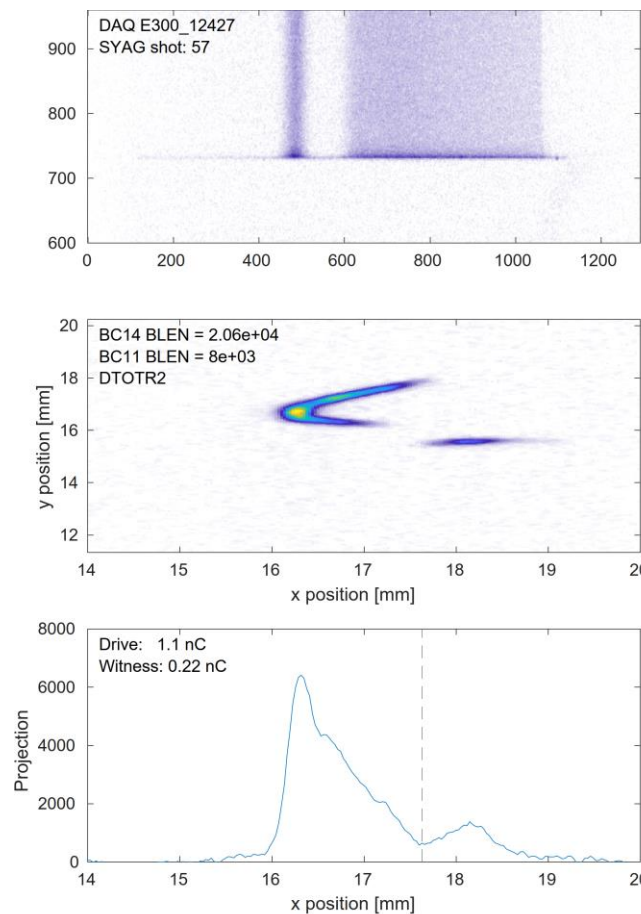
Note – TCAV profiles require further processing before representative of LPS

Charge capture estimate – Very Preliminary!

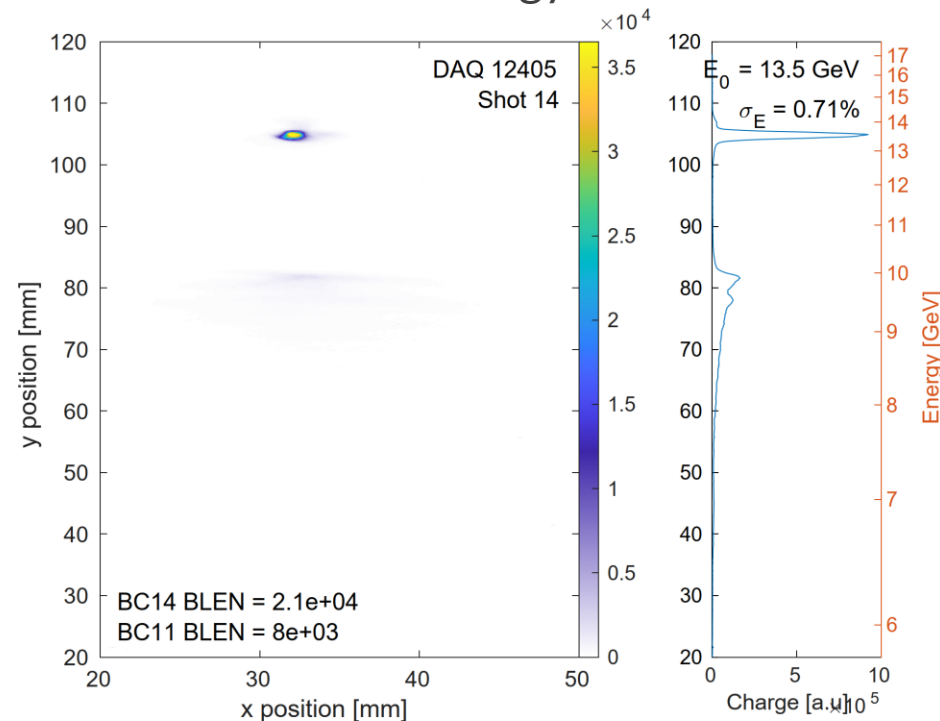
No collimation



Jaw and Notch

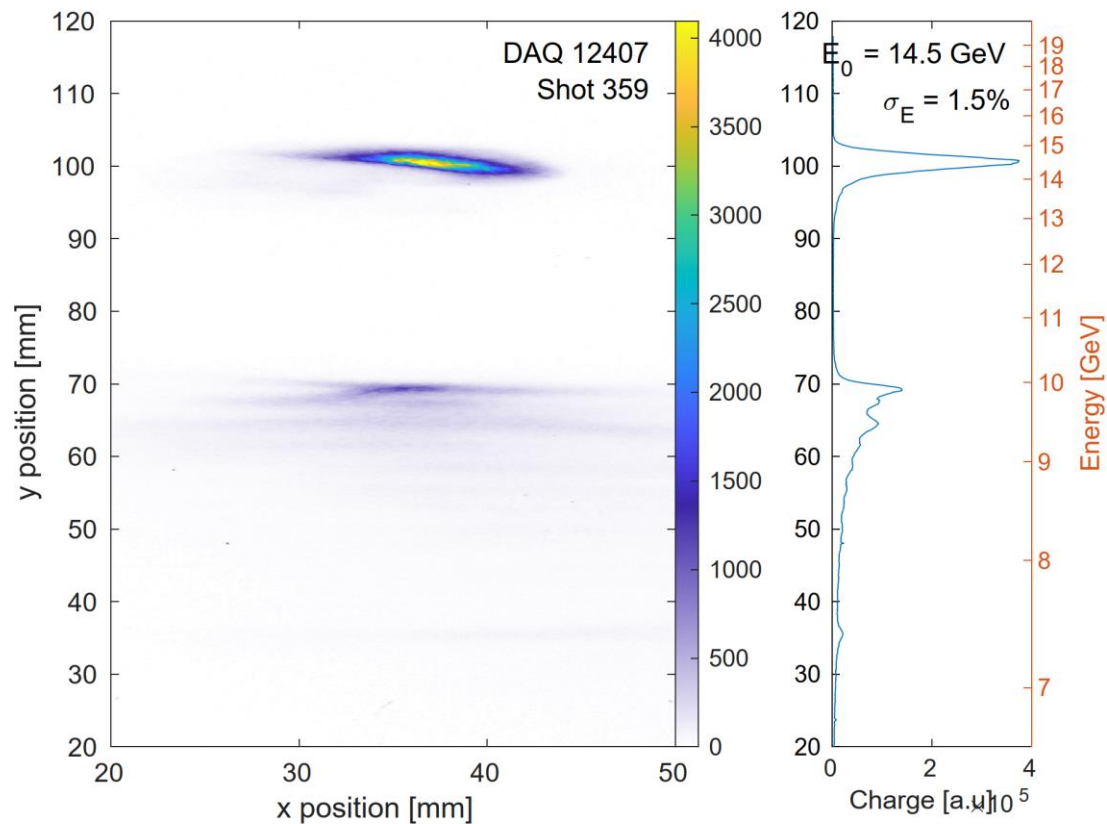


- Incoming witness charge can be tricky to estimate
- Initial estimates from DTOTR give $\sim 200 \pm 100$ pC trailing charge
 - ~ 150 pC charge capture here
 - Order 5% total energy transfer



Note – TCAV profiles require further processing before representative of LPS

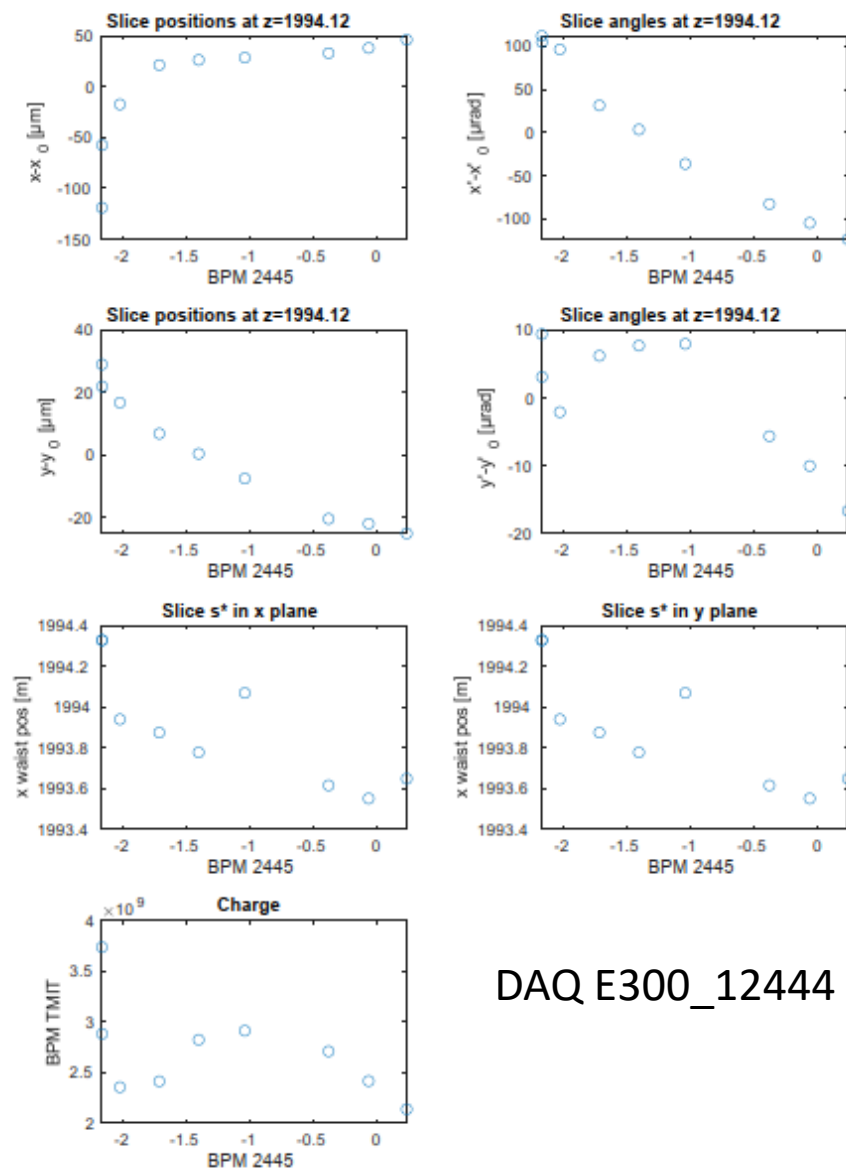
Divergence estimate – Very Preliminary!



- Imaging 16 GeV from plasma exit to CHER
- At 14 GeV
 - M11 = 6.5
 - ~ 10 's μm spot size $\rightarrow \ll 1\text{mm}$ at CHER
 - M12 = 6.8
 - 1cm at CHER $\rightarrow \sim \text{mrad}$ -level divergence
 - Possible charge loss in transport

How do we build on this?

- Improved transverse tuning
 - Remove dispersion and dispersion prime to minimize offsets in position and angle
 - Ensure x and y waists are at the same plane
- Reduce beta function to better match into the plasma and reduce the divergence coming out
- Clean up the longitudinal phase space
- Collect more data:
 - Charge capture and acceleration data → energy transfer goal
 - Emittance/divergence data → show progress towards emittance matching
 - Betatron radiation data → as a metric for matching



DAQ E300_12444

How do we build on this?

- Improved transverse tuning
 - Remove dispersion and dispersion prime to minimize offsets in position and angle
 - Ensure x and y waists are at the same plane
- Reduce beta function to better match into the plasma and reduce the divergence coming out
- Clean up the longitudinal phase space
- Collect more data:
 - Charge capture and acceleration data → energy transfer goal
 - Emittance/divergence data → show progress towards emittance matching
 - Betatron radiation data → as a metric for matching

```
04/28/2025 23:58 Doug

Drive

Transverse positions at z = 1994.12 m:
[x, y] = [0.031, 0.056] mm
[sigx, sigy] = [0.007, 0.005] mm

Minimum spot size at z = 1993.61 in x, 1993.97 in y, m:
Min [sigx, sigy] = [0.006, 0.004] mm

[x' y'] =
xpmeanq: -0.1193
ypmeanq: -0.0733

Witness

Transverse positions at z = 1994.12 m:
[x, y] = [-0.024, 0.075] mm
[sigx, sigy] = [0.012, 0.013] mm

Minimum spot size at z = 1994.23 in x, 1993.55 in y, m:
Min [sigx, sigy] = [0.012, 0.009] mm

[x' y'] =
xpmeanq: -0.0413
ypmeanq: -0.0854
```

Goals summarized from Brendan

Current long-term strategy

Parameter	Units	2016 AAC	FACET-II results 2024	FY25	FY26	FY27
Emittance (post plasma)	μm	10	>200*	>200 yep	20	10
Energy Spread	%	<5	4	<5 <1%	<5	<5
Energy Gain	GeV	10	1.5	3 >5 GeV	4.5	9
Total Efficiency	%	>10	4	10 5% for sure Maybe up to ~8%	15	15
Gradient	GV/m	>1	2.5	5 Easy	5	5
Charge	pC	~100	~100	>100 Easy	>100	>100
Plasma Source			40 cm Li Oven	40 cm Yep	60 cm	New Source

What can/should we do with the remaining time?

Minimum time for PWFA – 7 days

- Notched 2 bunch: **2 total** (with oven)
 - E300 one day, mapping wakefields scan 2nd day
 - Milestones we think we can achieve:
 - Charge capture, Wakefield mapping, improved total efficiency, E338 chirped
- Two bunches from cathode: **5 days total**
 - 2 days setup, 4 shift min. with oven starting day 2
 - Milestones:
 - Charge capture, total efficiency, progress on transverse (waist control, beta function, minimizing outcoming emittance and divergence)

More PWFA time – up to 12 days total:

- Notch
 - 2 more shifts dedicated to transverse optimization
 - 1 final shift in H2 to match trailing at 15 cm beta
- Two bunches from cathode
 - 1-2 additional tuning days incl. tool development/low beta function

What can/should we do with the remaining time?

Minimum time for PWFA – 7 days

- Notched 2 bunch: **2 total** (with oven)
 - E300 one day, mapping wakefields scan 2nd day
 - Milestones we think we can achieve:
 - Charge capture, Wakefield mapping, improved total efficiency, E338 chirped
- Two bunches from cathode: **5 days total**
 - 2 days setup, 4 shift min. with oven starting day 2
 - Milestones:
 - Charge capture, total efficiency, progress on transverse (waist control, beta function, minimizing outcoming emittance and divergence)

More PWFA time – up to 12 days total:

- Notch
 - 2 more shifts dedicated to transverse optimization
 - 1 final shift in H2 to match trailing at 15 cm beta
- Two bunches from cathode
 - 1-2 additional tuning days incl. tool development/low beta function

What do we need to get done to achieve this:

1. Jaw/collimator scan tools – (1/2 shift)
2. Transverse tuning tools
 - In a state that they can be used during day-shift tuning
 - Need better control/understanding of sextupole tuning
3. Low beta function
 - Repeat jitter and optimize X and Y waist
 - Measure trailing spot size with DTOTR1 quad scan? Quantify if lower beta results in smaller trailing spot size (ignoring driver)
 - Waist scan and emittance/divergence/gamma measurements

Extra Slides

To do for the next shift (Copied from shift report)

- Get back witness acceleration
- Tune transverse and reduce beta functions to better match into plasma and reduce the divergence coming out.
- This will require even stricter requirements on transverse and waist positions of the witness.
- Some prep before the next shift.
 - Get a better handle on transverse tuning.
 - One option is an automated script that tunes the sextupoles by inserting various combinations of collimators to block either the drive or witness, and minimise dispersion AND dispersion prime. I think that this would be the most efficient and direct tuning method.
 - We want to be able to set the L2 feedback to regulate on the bunch length. This requires some slight modification to the feedbacks to allow us to change the PV it regulates on (or some other hack).

Notch or not?

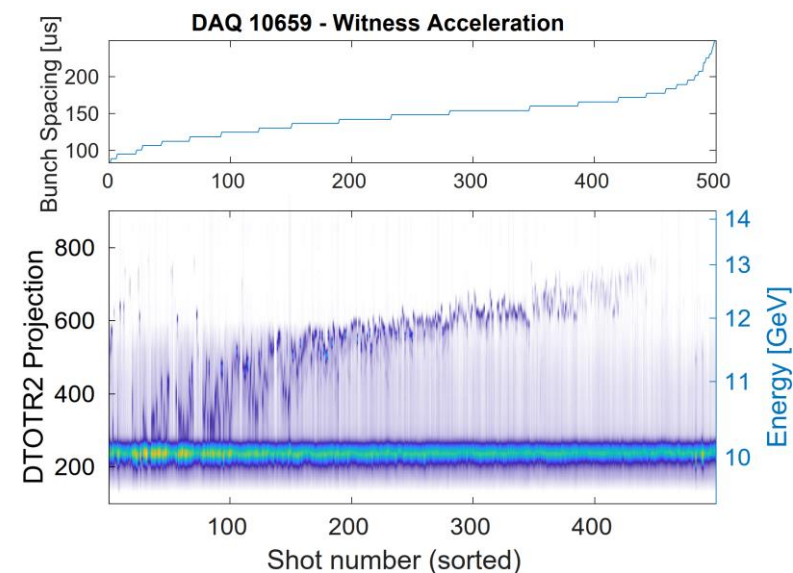
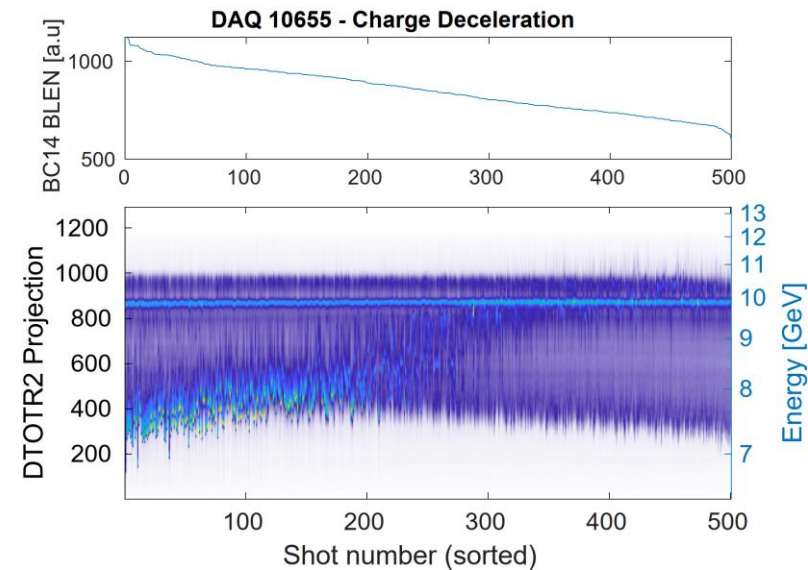
- Goals that we want to do with the 2 bunch from cathode, and some challenges:
 - We think we can achieve lower energy spread in this config, but the transverse tuning is harder. So getting 100% charge capture might be harder. We might have an easier time getting to higher transfer efficiency due to higher witness charge (?). Easier to drive a strong wake.
- From the notched 2 bunches:
 - Mapping the wakefield strength as a function of long. position.
 - This would be nicer to do in this case because we can use the collimators to scan the "witness" without affecting the drive (bubble stays constant)
 - The transverse tuning seems much easier. It has been easier to get into a good starting point with single bunch than with 2 bunches.

Machine development work

- Much improved longitudinal feedbacks
 - Machine can hold a much more stable longitudinal and energy setpoint than prior runs
- BBA and FFS quad alignment
- Started using laser preionization in the Li oven
 - Works better than we feared – makes a very wide plasma, relatively quick to align
- Tools – to be discussed in more detail later
 - Spectrometer quad analysis – emittance + x orbit in the IP
 - Collimator + BPM tools for dispersion and dispersion'
 - Jitter tool – x and y waist positions at the IP
 - EOS BPM

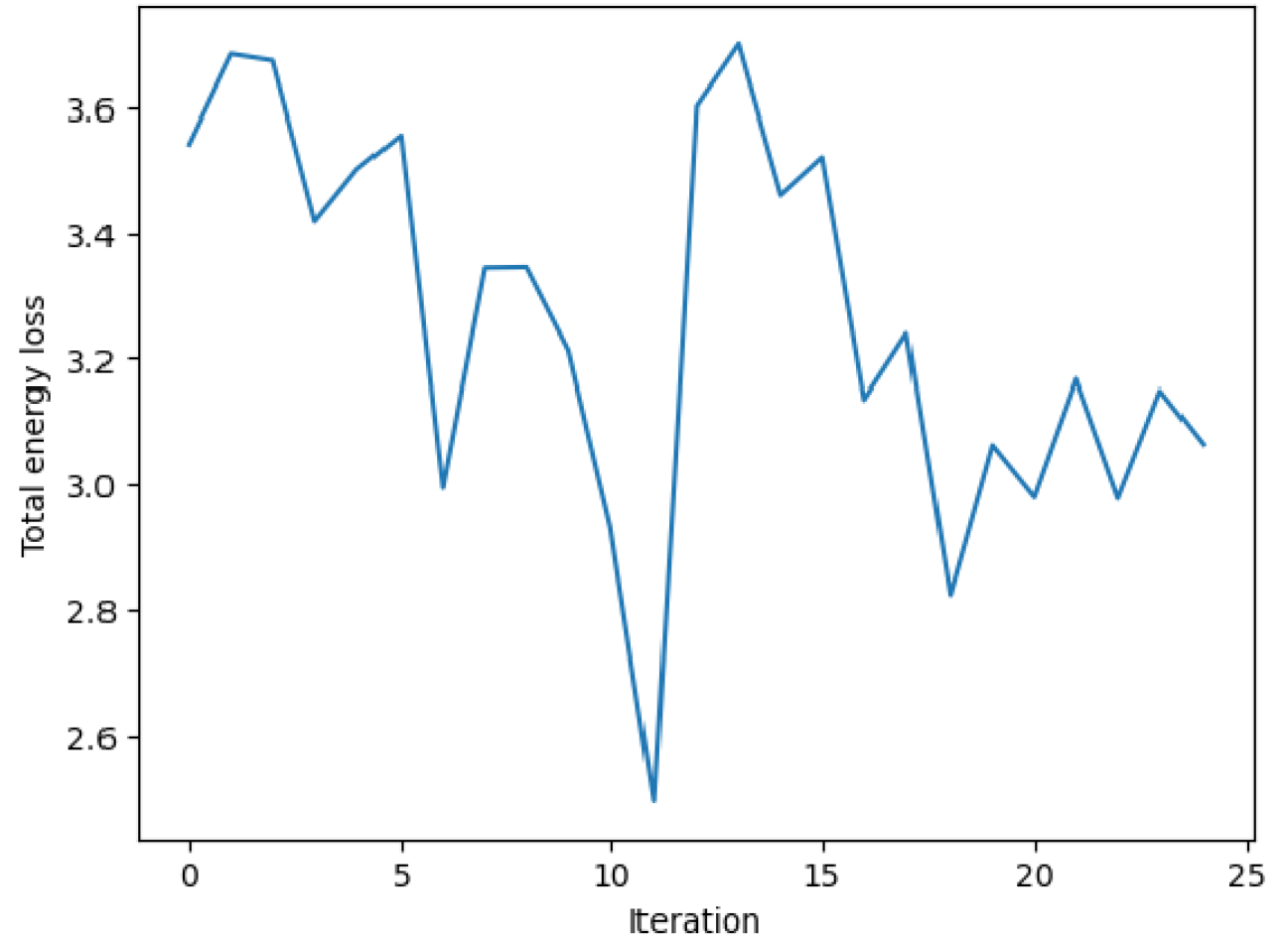
Nov 2024 – First two bunch run

- Feedbacks (old feedbacks) relatively unstable
- Slight improvement over May results
 - Drive only energy transfer to plasma wake up to 15-20%
 - Achieved charge acceleration up to 12-13 GeV
 - Consistent with slightly longer oven
- Order ~50% witness charge capture
 - Worse than May '24
- Identified next steps to improve performance:
 - Improve stability of two-bunch delivery to the IP
 - Further longitudinal tuning to increase drive-to-wake energy transfer while maintaining bunch separation
 - Improved transverse control via dispersion control and sextupole tuning



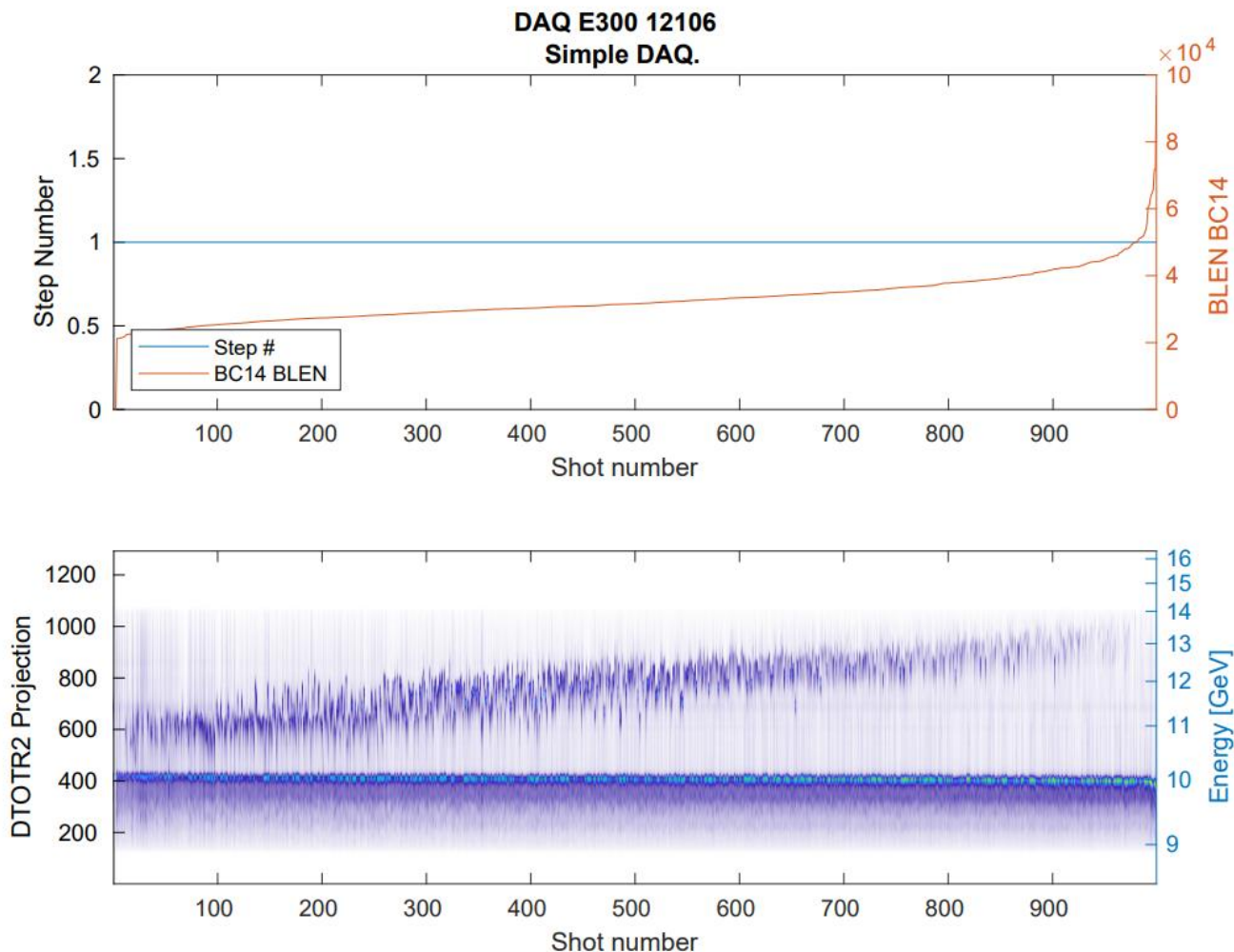
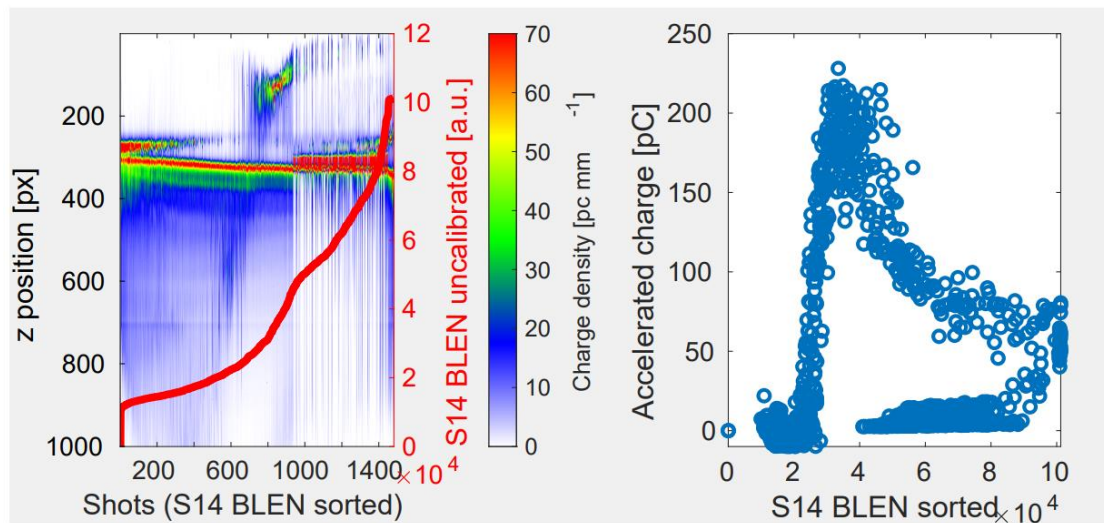
Single bunch, maximizing drive to wake energy transfer w. ML

- Developed new ML/xopt optimization scripts that acquire BSA data
 - Can tune on only shots within a defined BLEN trange
- Results – not so conclusive
 - Started with around 3.5 J energy transfer from hand tuning
 - Max of ~3.7J out of 16J (23%)
 - Did not do too much better with ML tuning
 - Might need to tune the search parameters – seemed like it was searching over a very small region
 - Issue with sextupole repeatability caused some issues at the end



E302 acceleration results

- Notched two bunch
 - Stable acceleration
 - Lots of instability
 - Ole and Eric seemed happy
- Charge capture efficiency
 - Sheldon developing new live/DAQ tools
 - Sheldon to comment



New live spectrometer tool - Sheldon

