E340 Control and observation of trajectory mixing and wakeless regime in plasma accelerators

Sebastien Corde, Visiting Scientist at SLAC and Professor at Ecole Polytechnique

25 July 2025

SLAC NATIONAL ACCELERATOR LABORATORY

ÉCOLE POLYTECHNIQUE

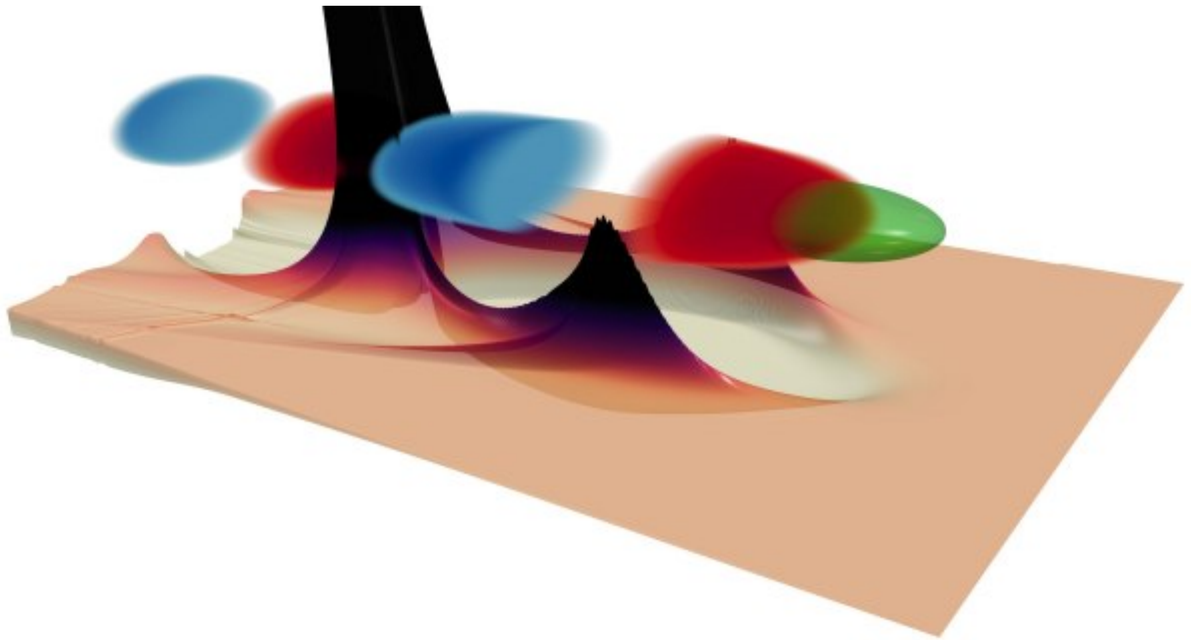
IP PARIS

Stanford University

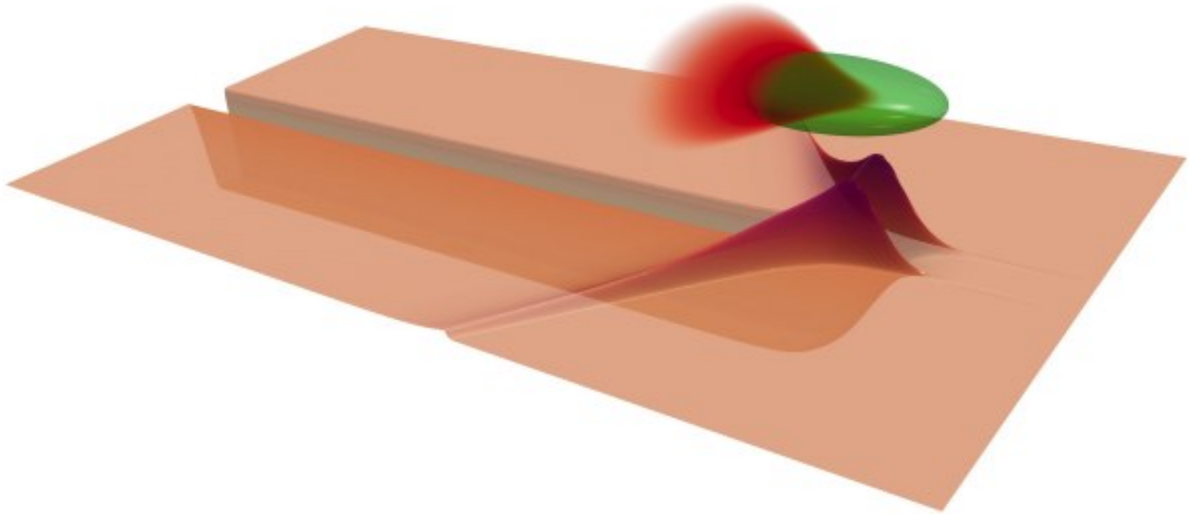
U.S. DEPARTMENT OF ENERGY

E340 the big picture

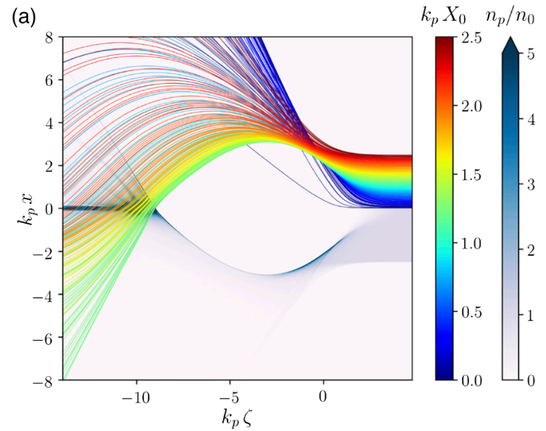
Plasma accelerator



Wakeless



Can we control? Can we observe? Positron regime (E333) at the transition?

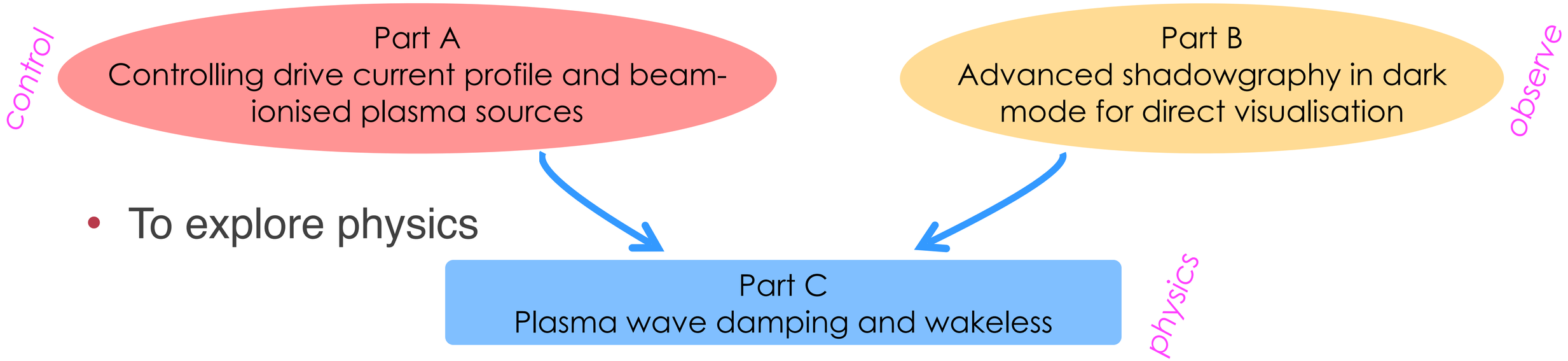


E340 high-level scientific goals

High level goal: control and observe trajectory mixing/plasma wave damping and transition from standard PWFA to wakeless.

How?

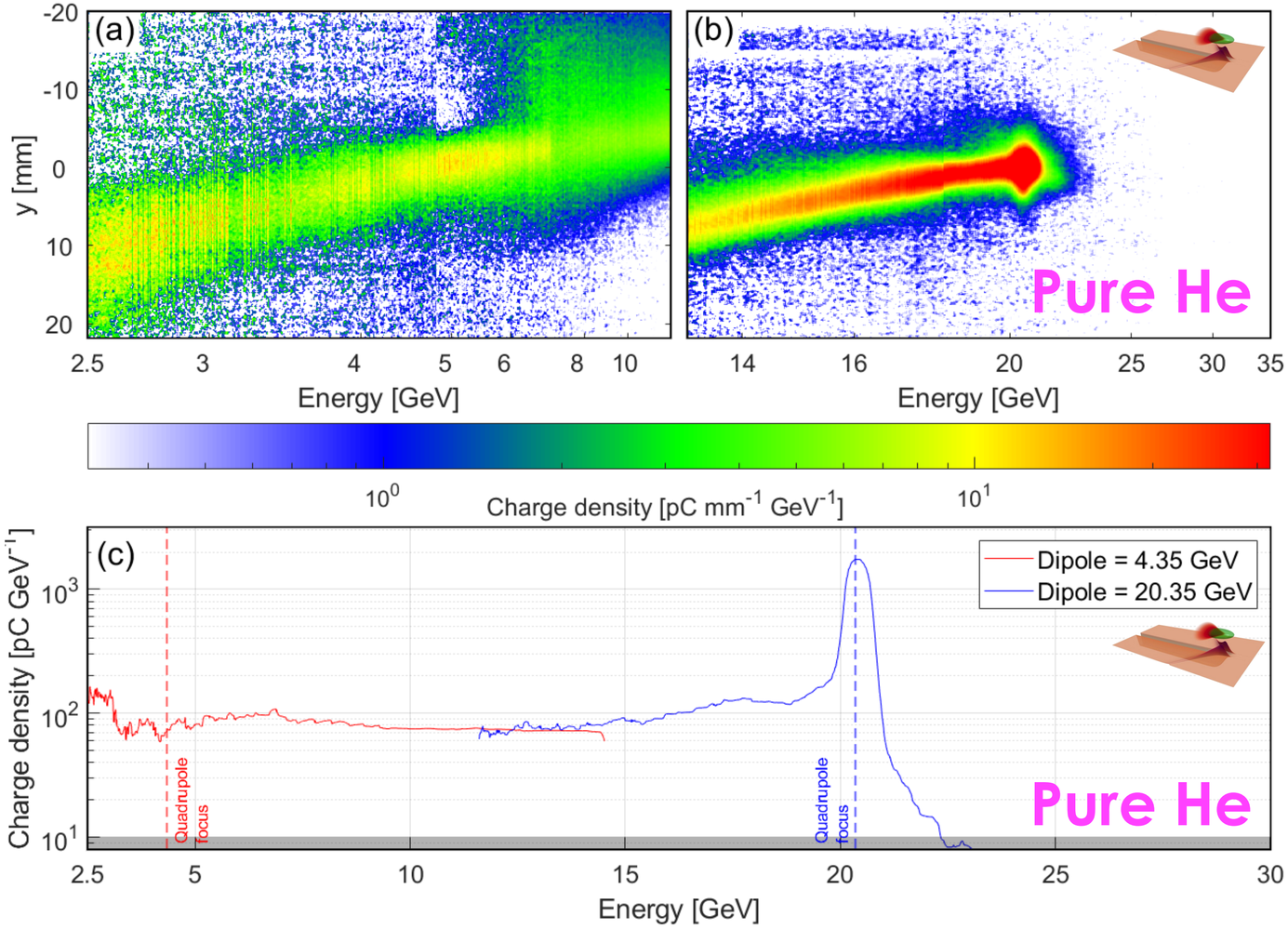
- Develop and use advanced tools

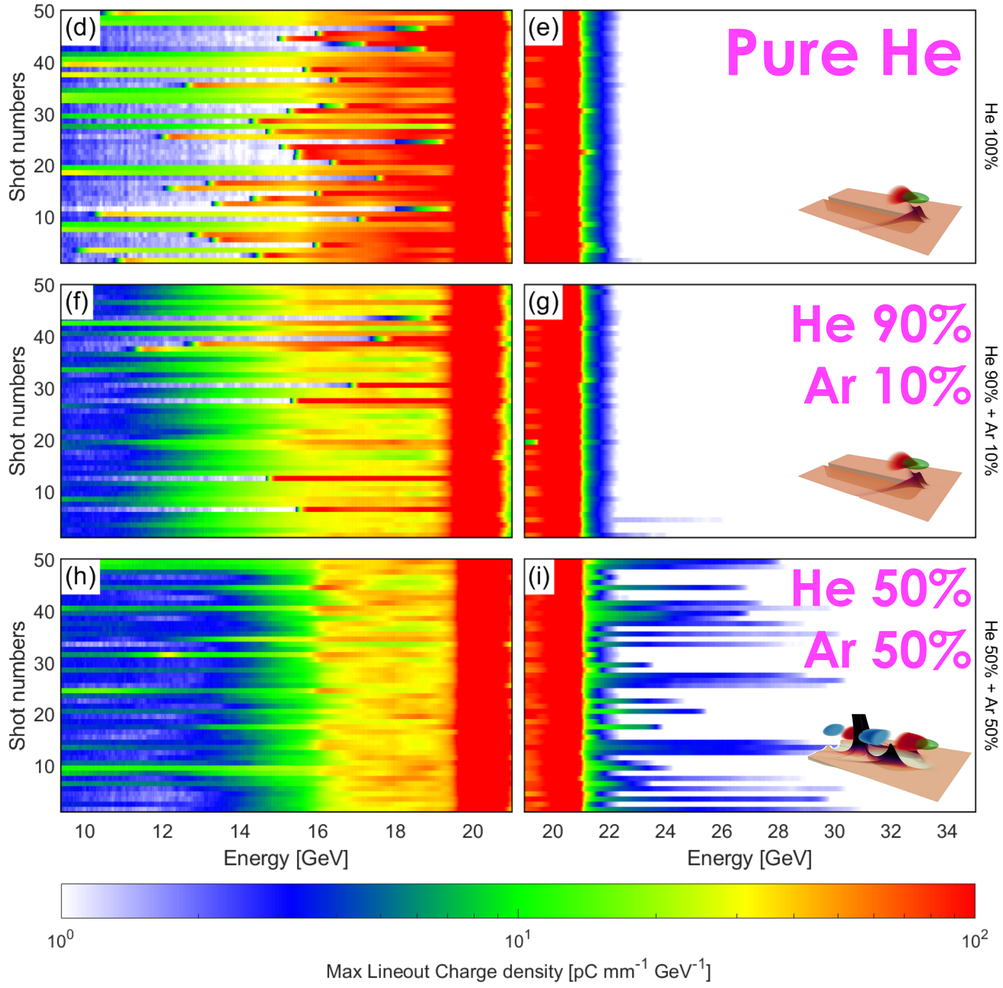


- To explore physics

E340 the data we have for short-term publication

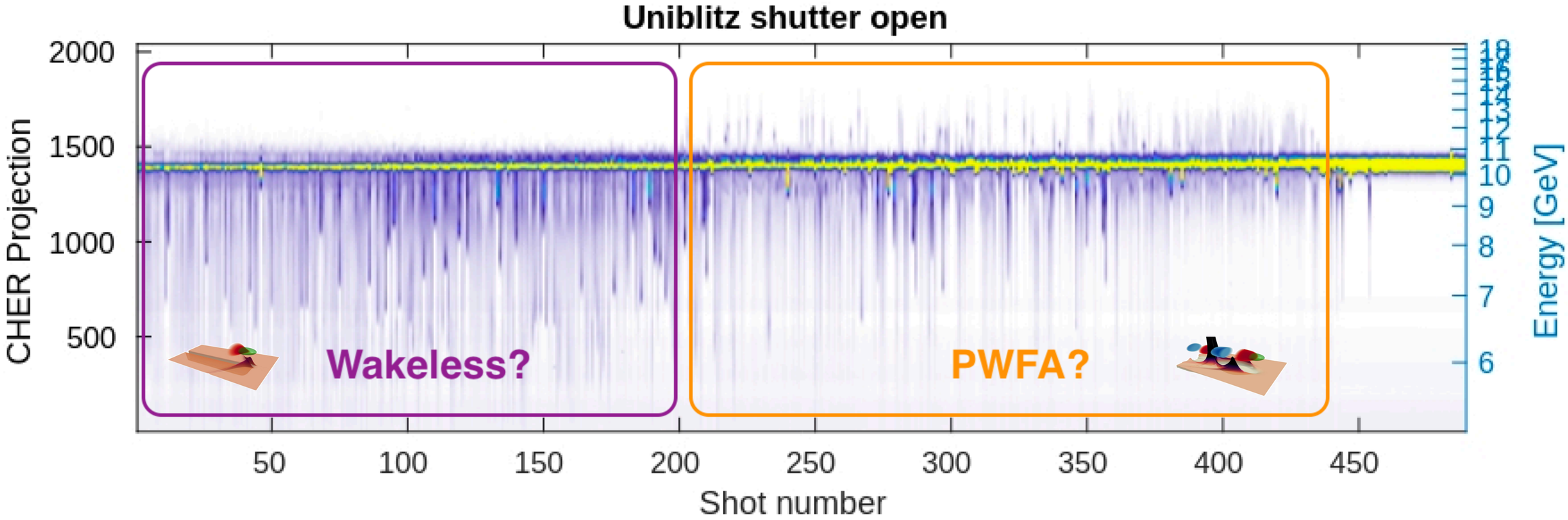
- Control of wakeless vs PWFA with gas ionization potential at FACET-I





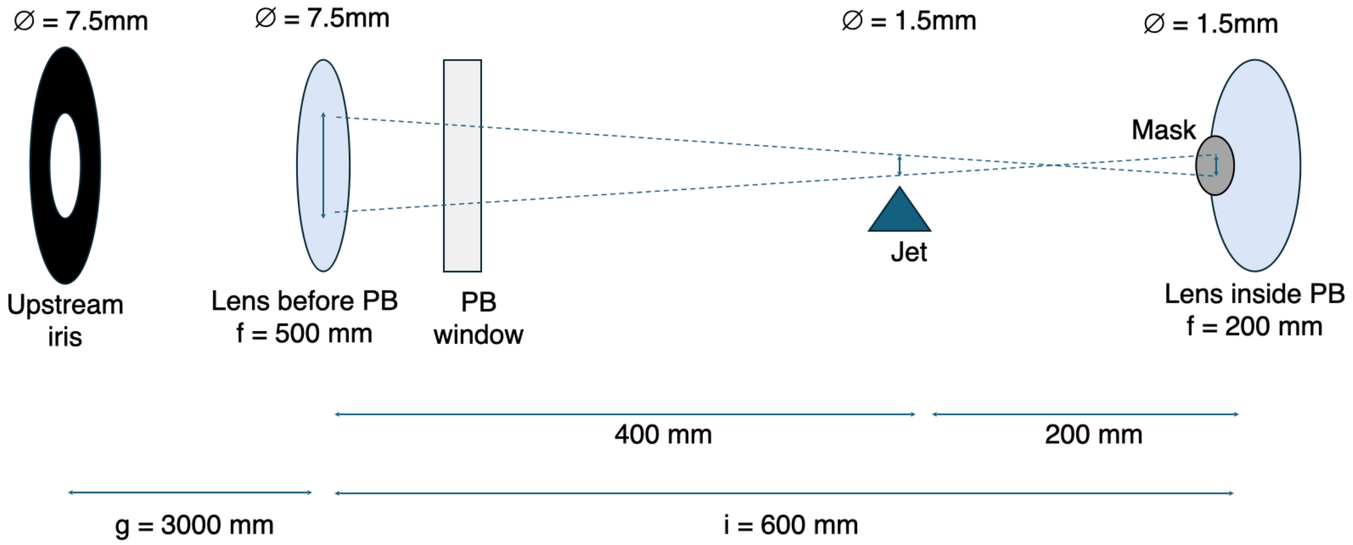
E340 the data we have for short-term publication

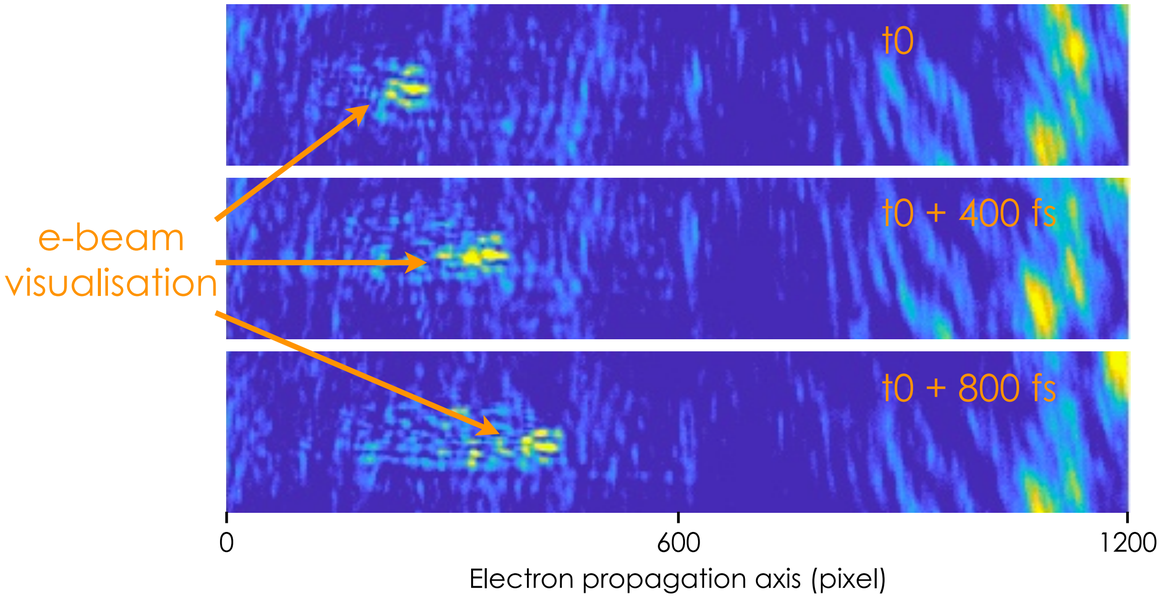
- Control of wakeless vs PWFA with beam compression at FACET-II



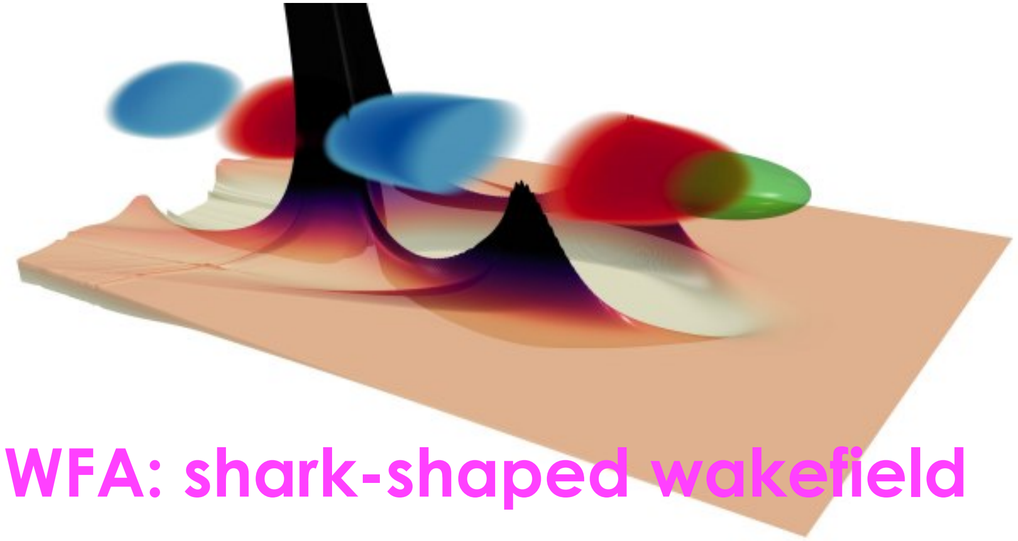
Sorted by increasing S14 BLEN

E340 Taking advantage of E305 Dark Shadow at low densities

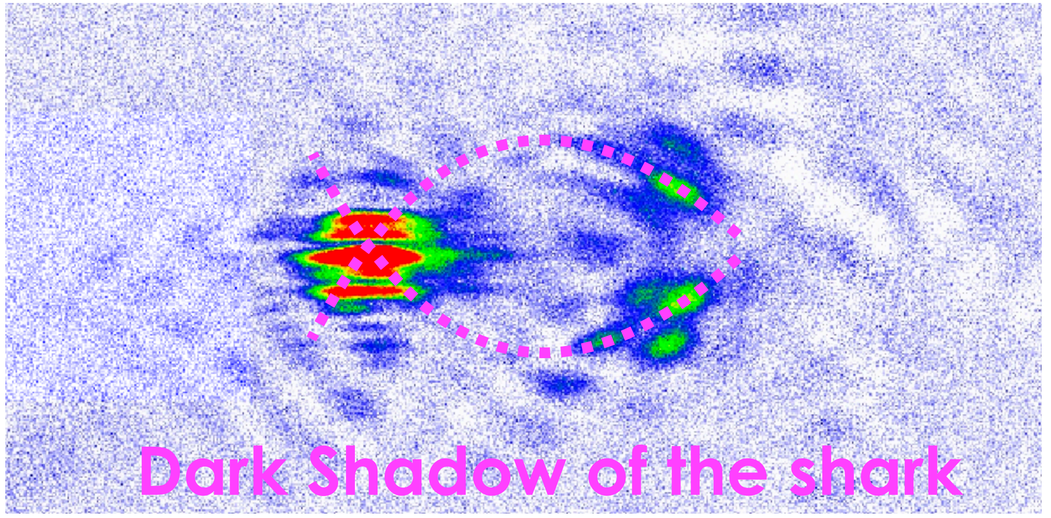




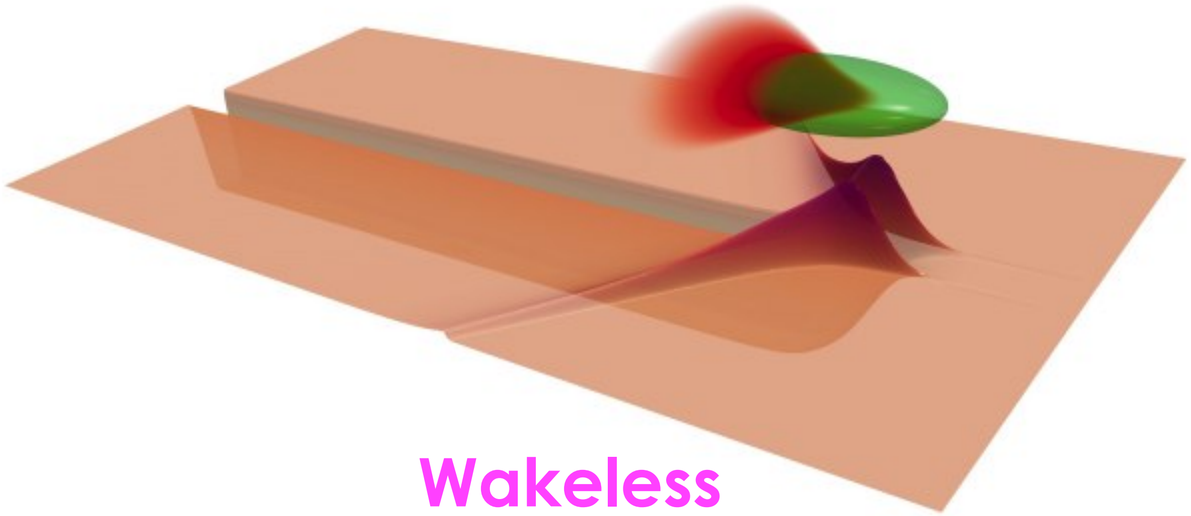
E340 the data we have for short-term publication



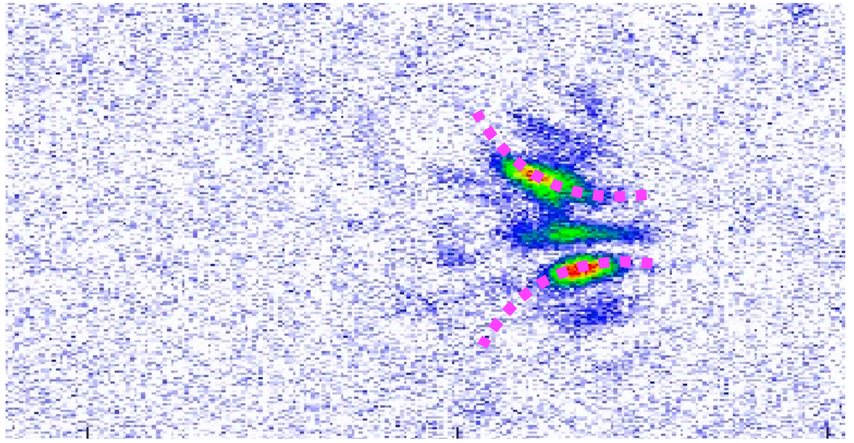
PWFA: shark-shaped wakefield



Dark Shadow of the shark



Wakeless



Dark Shadow of wakeless

E340 Beam conditions and control

Shift May 31, 2025:

- **Outstanding beam** (really strong and consistent interaction in He, wire sizes of 20 um x 24 um).

- **Laser heater rules**. When properly set up in its standard configuration (long pulse, low LH energy), was very effective to enhance He ionization and beam interaction.

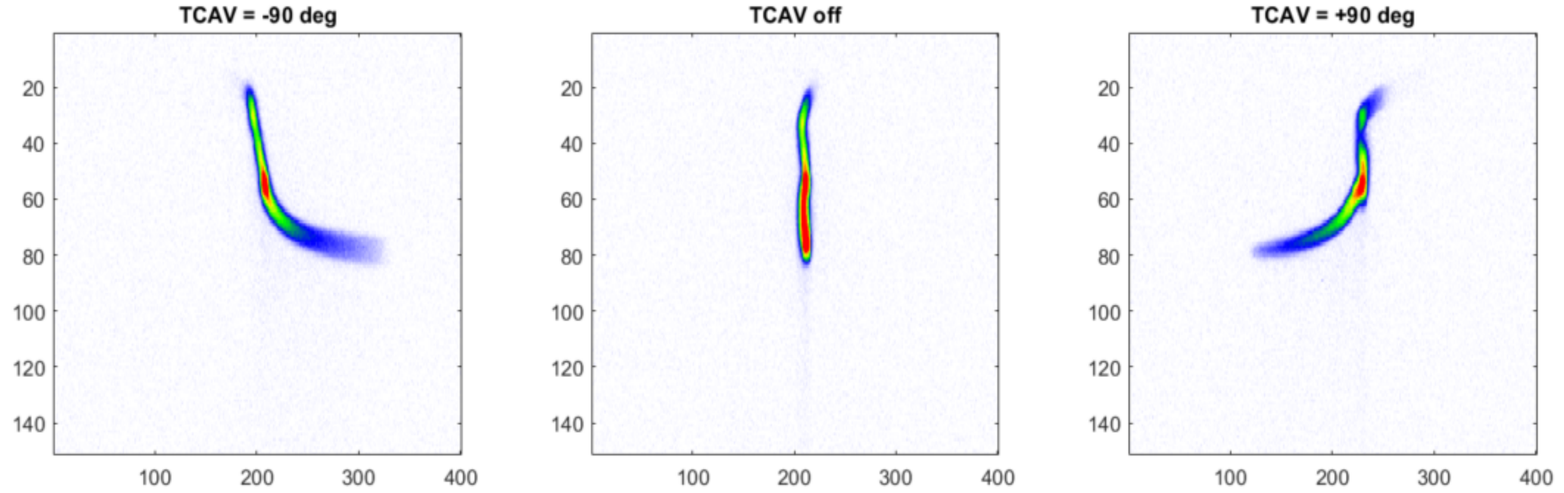
- Exploring the **L1/L2 phase parameter space: a game changer**. Could vary the nonlinearity and charge distribution of the LPS, thereby controlling the current profile, finding **two undercompressed working points for PWFA and wakeless respectively**.

E340 the data we have for short-term publication

TCAV:

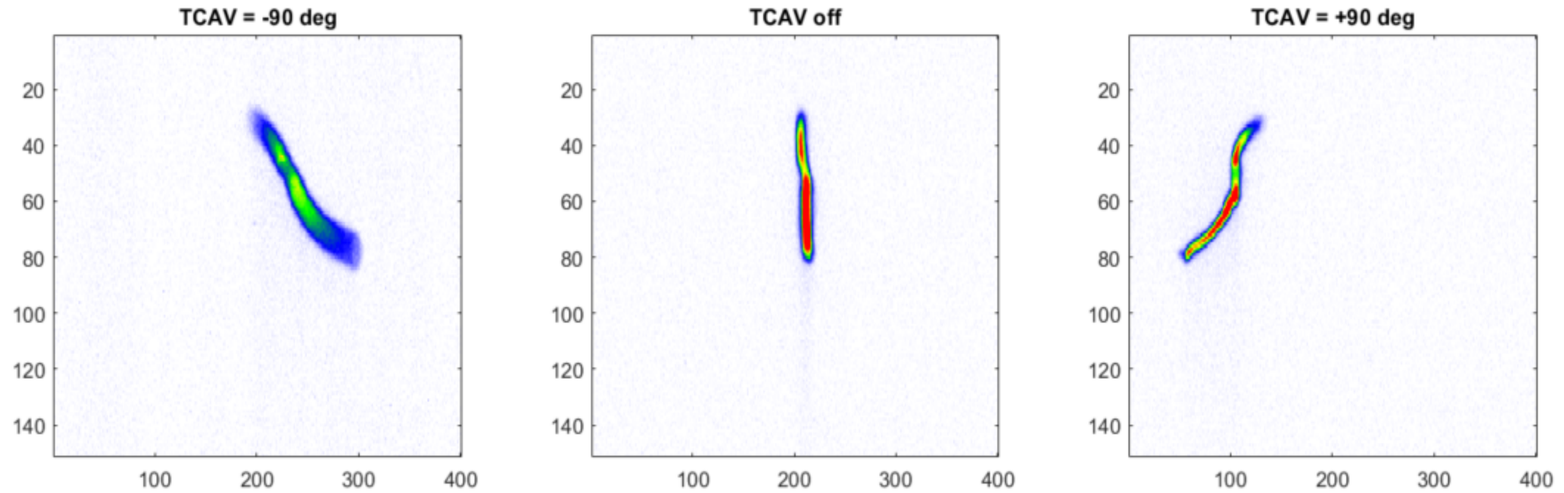
PWFA

S11 BLEN = 3-4k, S14 BLEN = 9.5k: less compressed/longer bunch length in L2 —> higher LPS nonlinearity, coma-shaped LPS with strong current peak at the front and long low-current tail



Wakeless

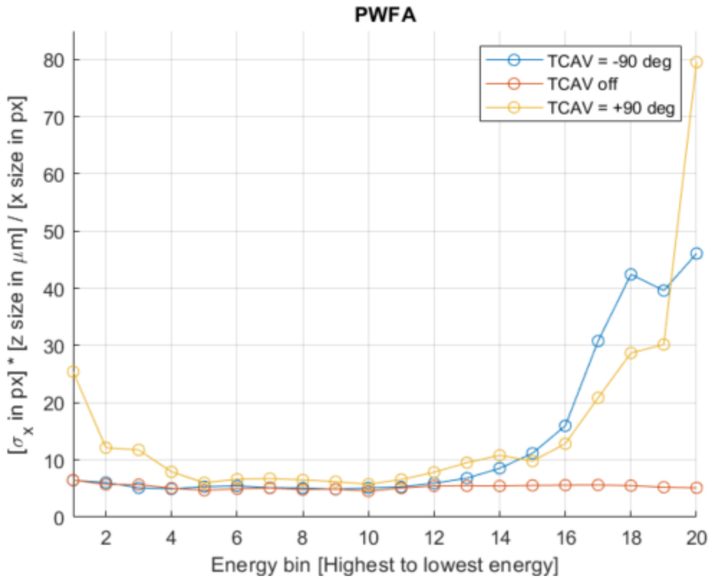
S11 BLEN = 9k, S14 BLEN = 13k: more compressed/shorter bunch length in L2 —> more linear and more uniform LPS, moderate current throughout the bunch



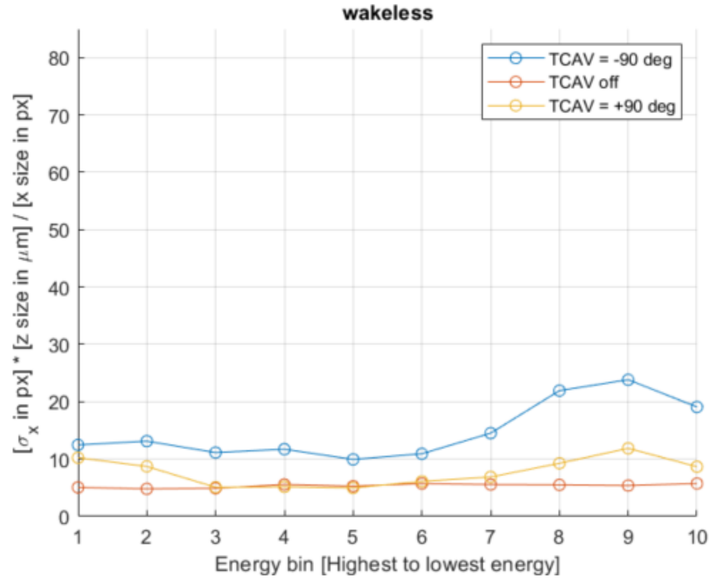
E340 the data we have for short-term publication

TCAV:

PWFA
S11 BLEN = 3-4k, S14 BLEN = 9.5k: less compressed/longer bunch length in L2
—> higher LPS nonlinearity, coma-shaped LPS with strong current peak at the front and long low-current tail

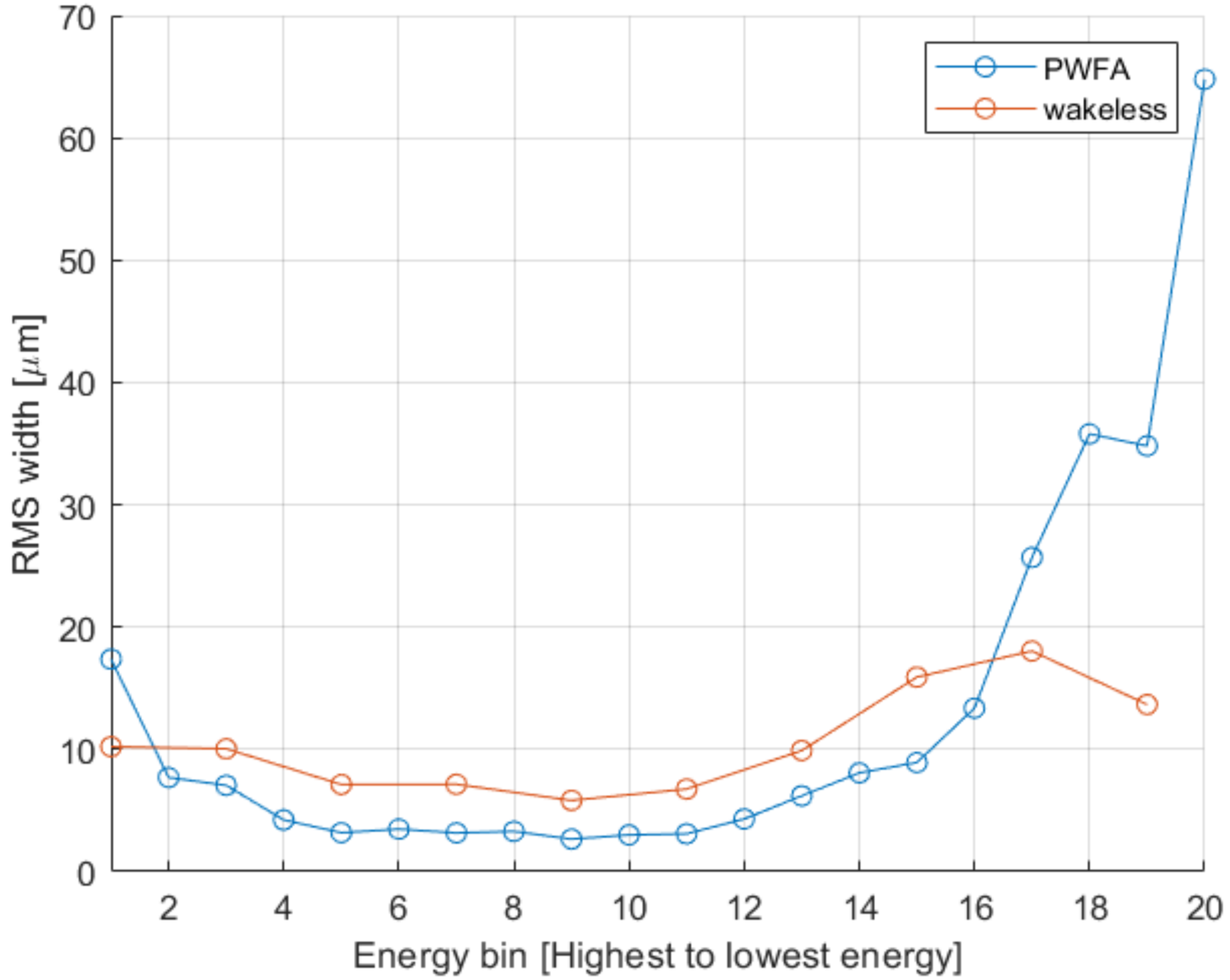


Wakeless
S11 BLEN = 9k, S14 BLEN = 13k: more compressed/shorter bunch length in L2
—> more linear and more uniform LPS, moderate current throughout the bunch



E340 the data we have for short-term publication

TCAV:

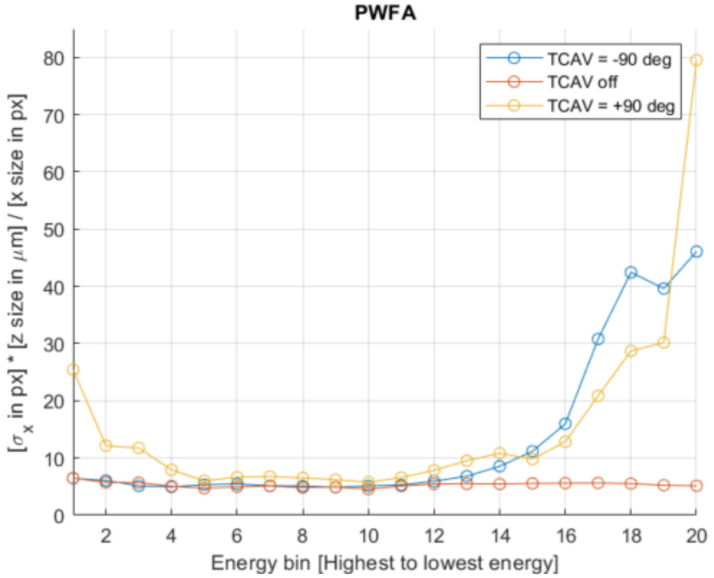


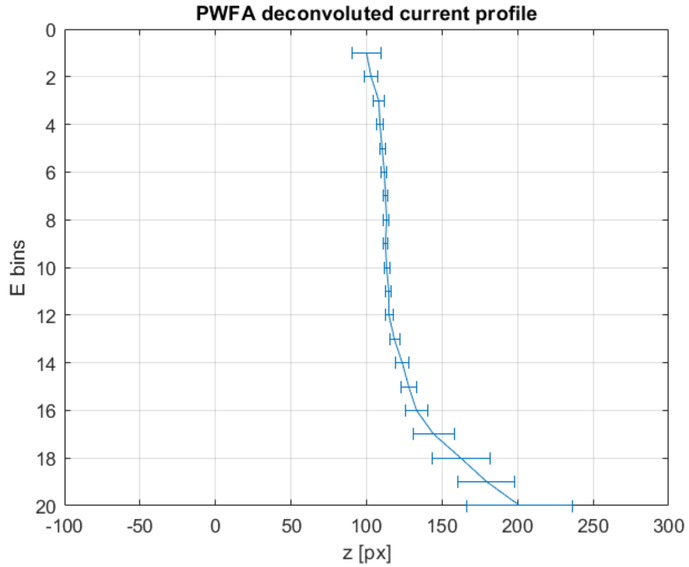
E340 the data we have for short-term publication

TCAV:

PWFA

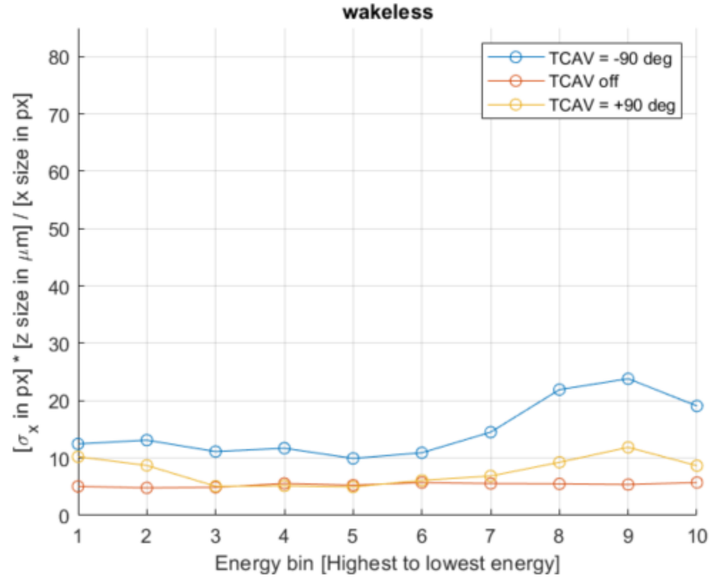
S11 BLEN = 3-4k, S14 BLEN = 9.5k: less compressed/longer bunch length in L2 —> higher LPS nonlinearity, coma-shaped LPS with strong current peak at the front and long low-current tail

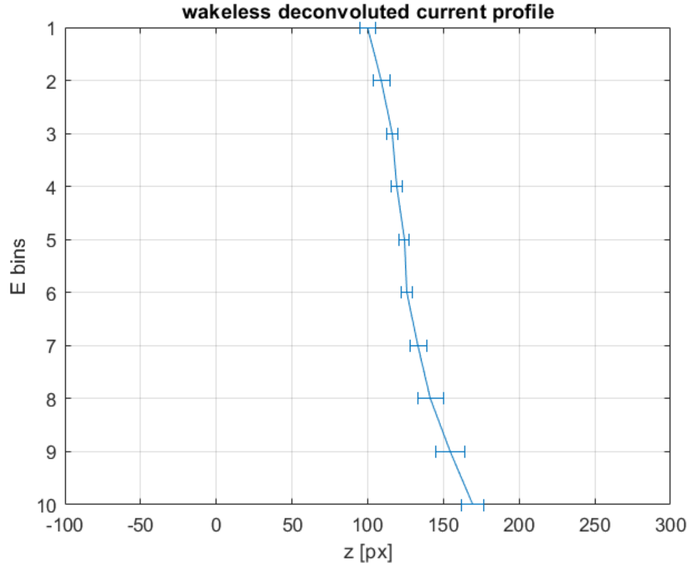




Wakeless

S11 BLEN = 9k, S14 BLEN = 13k: more compressed/shorter bunch length in L2 —> more linear and more uniform LPS, moderate current throughout the bunch



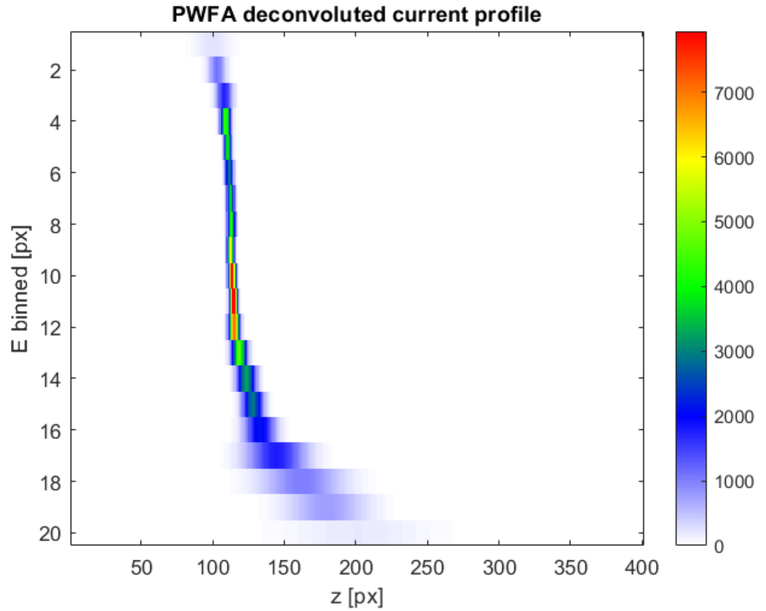


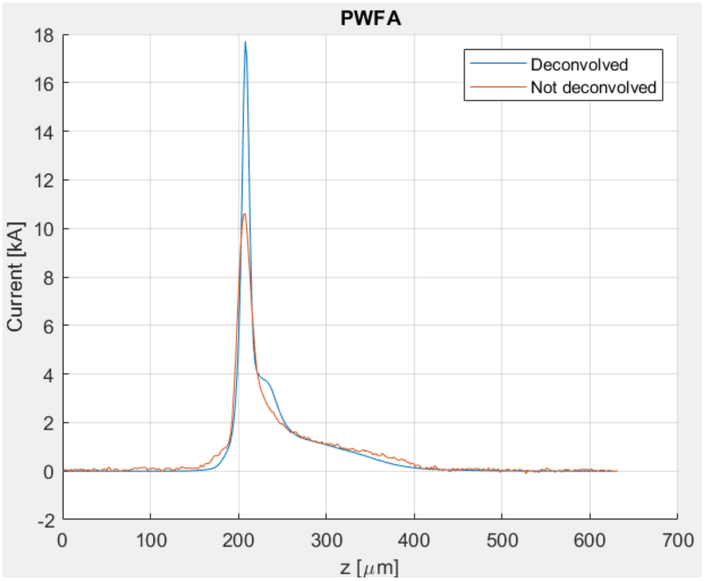
E340 the data we have for short-term publication

TCAV:

PWFA

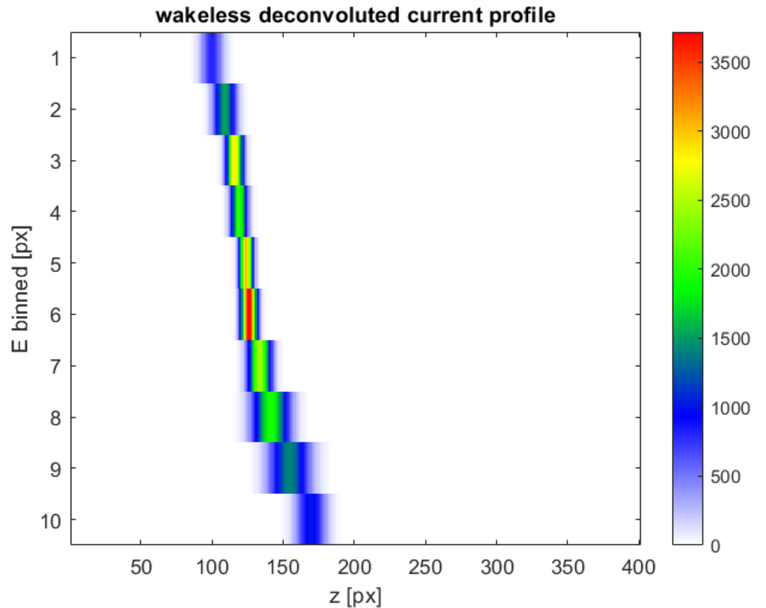
S11 BLEN = 3-4k, S14 BLEN = 9.5k: less compressed/longer bunch length in L2 —> higher LPS nonlinearity, coma-shaped LPS with strong current peak at the front and long low-current tail

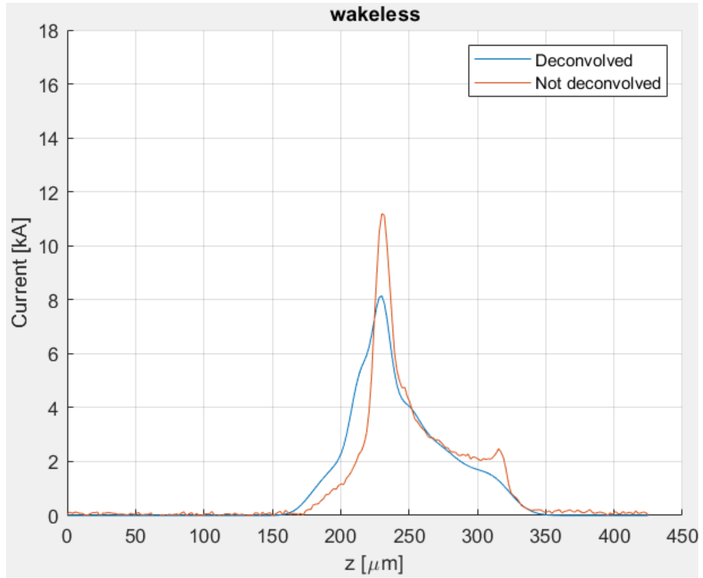




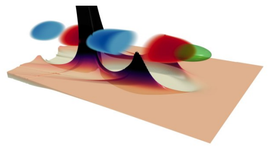
Wakeless

S11 BLEN = 9k, S14 BLEN = 13k: more compressed/shorter bunch length in L2 —> more linear and more uniform LPS, moderate current throughout the bunch





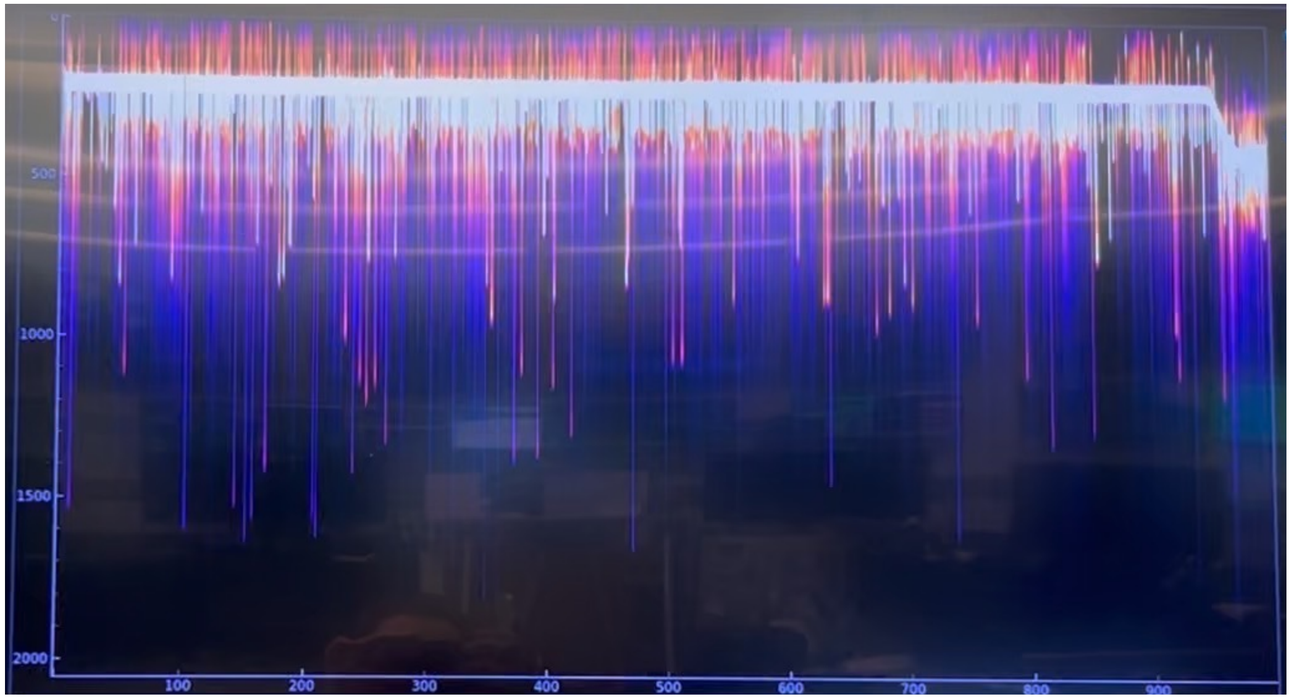
E340 the data we have for short-term publication



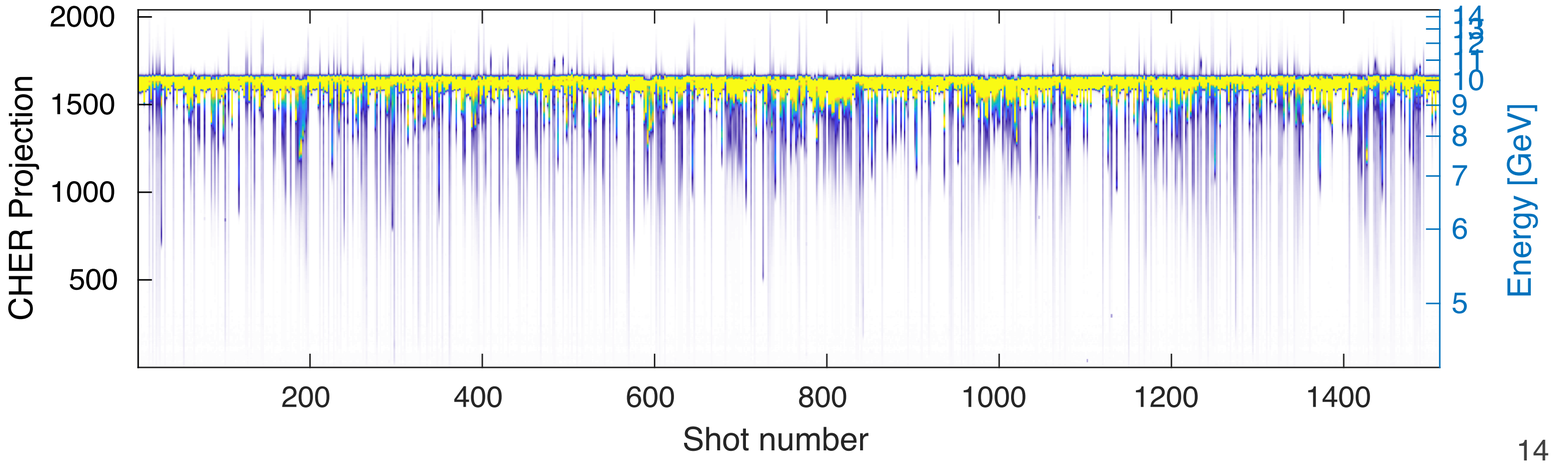
PWFA working point

S11 BLEN = 4000, S14 BLEN = 9500

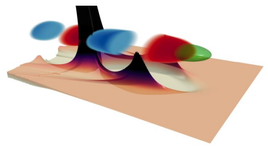
Can observe **VERY consistent acceleration** in beam-ionized He —> PWFA



THEN we DAQ, and it isn't as consistent anymore :(. Dataset 13750.



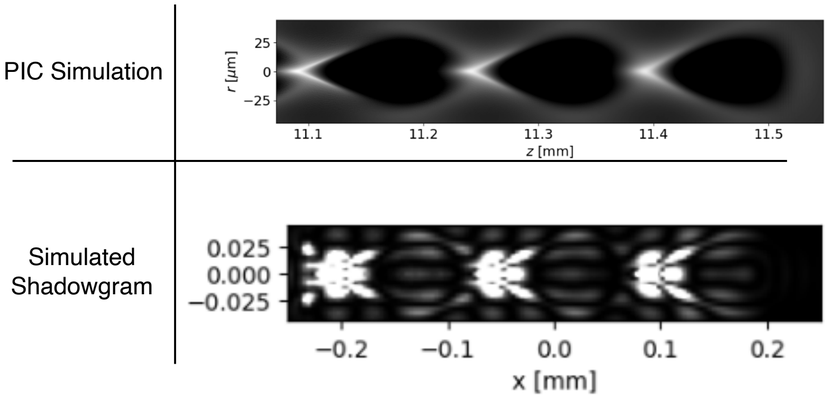
E340 the data we have for short-term publication

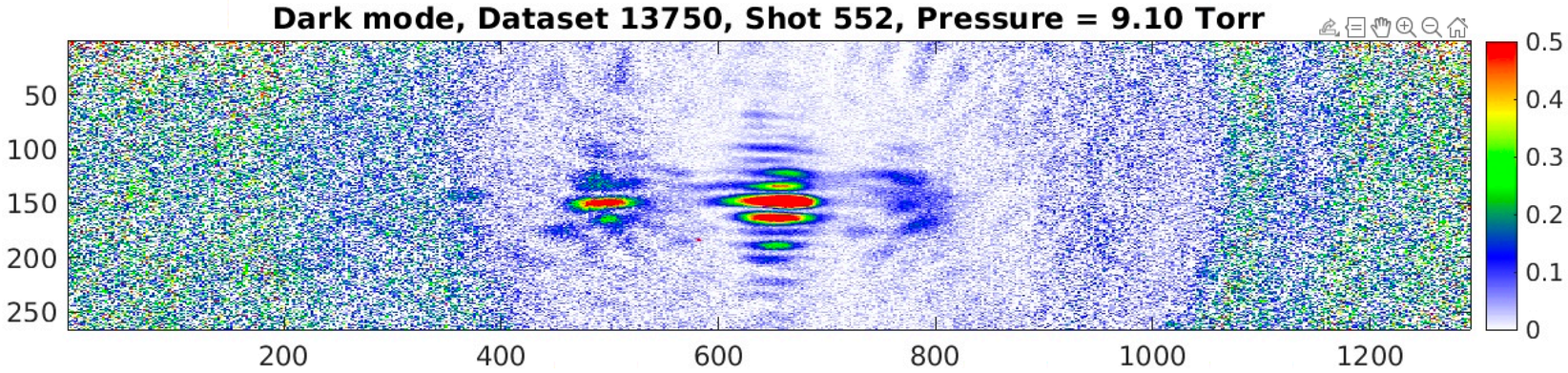


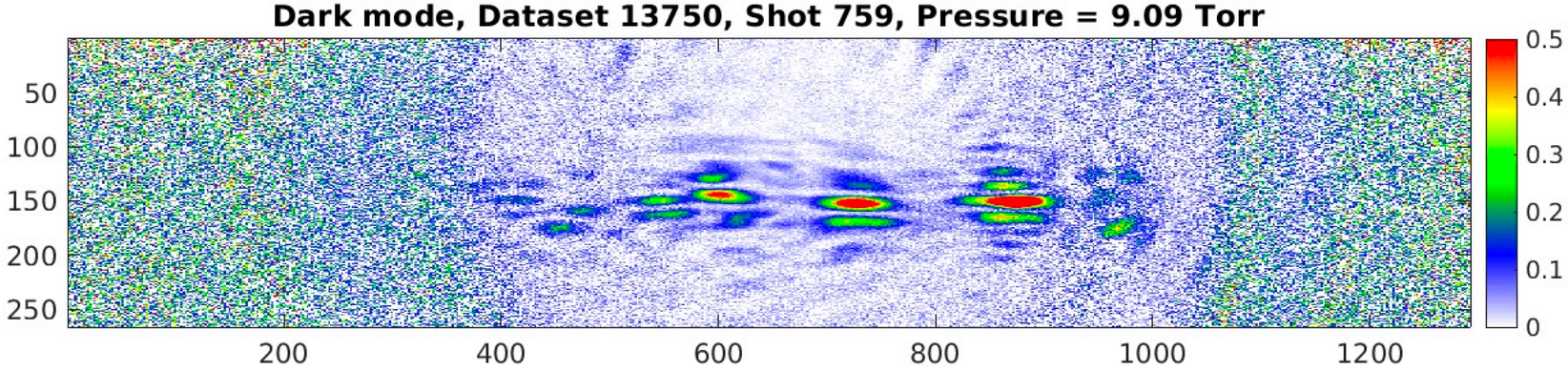
PWFA

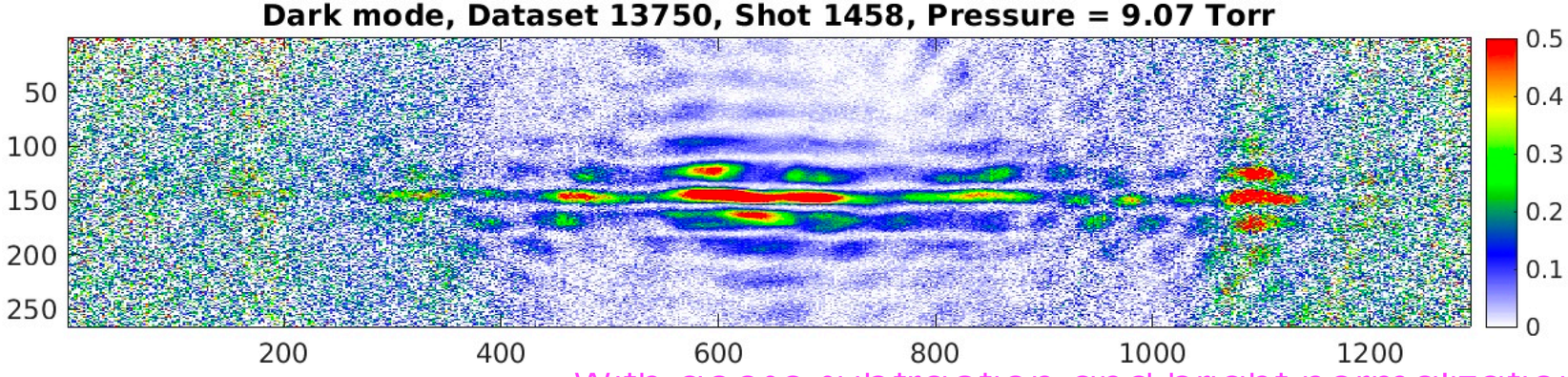
PWFA —> much stronger Dark Shadow signal

PWFA —> strong signal also present at long delays





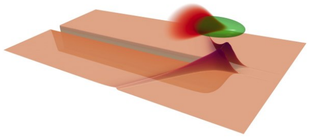




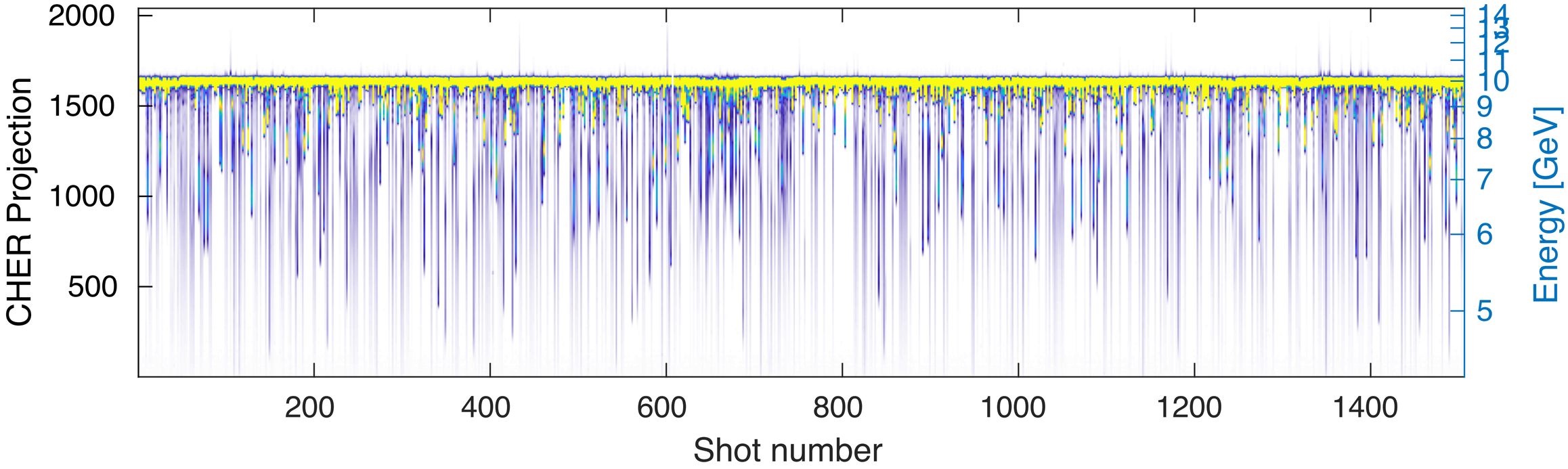
With goose subtraction and bright normalization

E340 the data we have for short-term publication

Waterfall of electron spectra for the wakeless dataset 13751



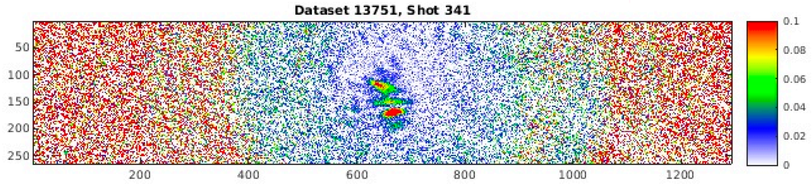
Wakeless

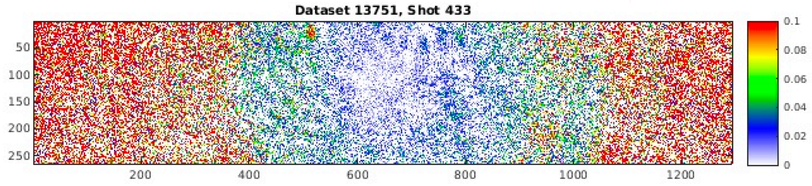


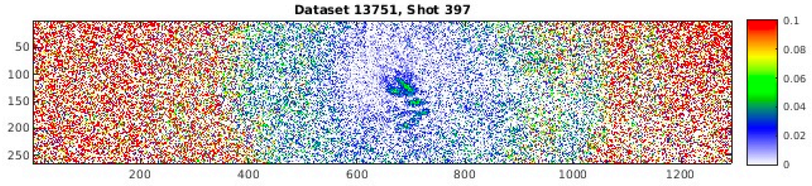
Mostly NO ACCELERATION, as expected from wakeless regime

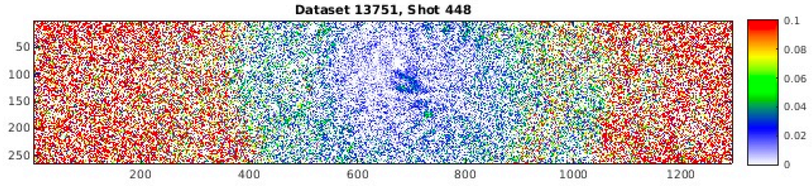
E340 the data we have for short-term publication

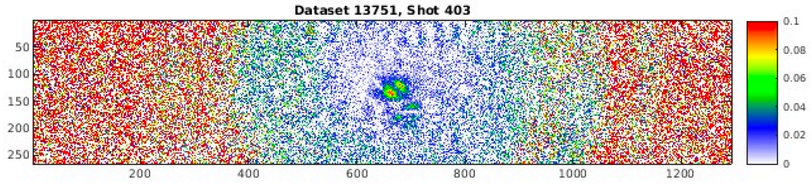
Series of wakeless shots

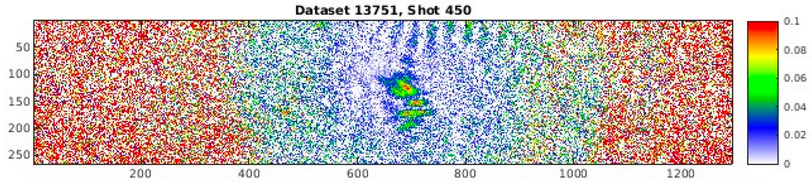


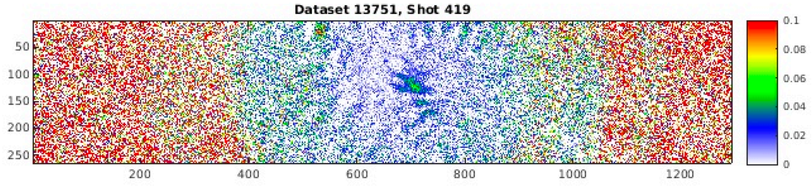


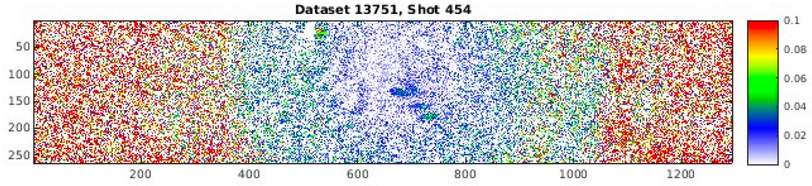


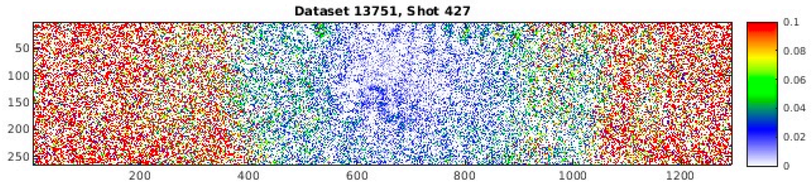


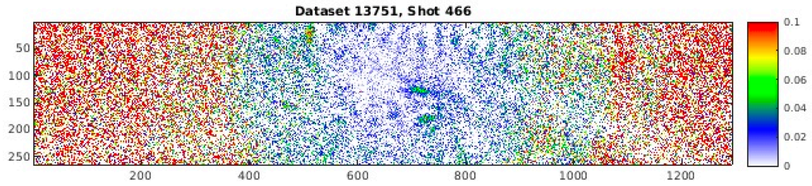


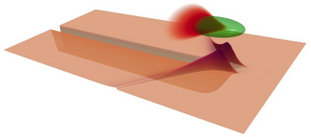












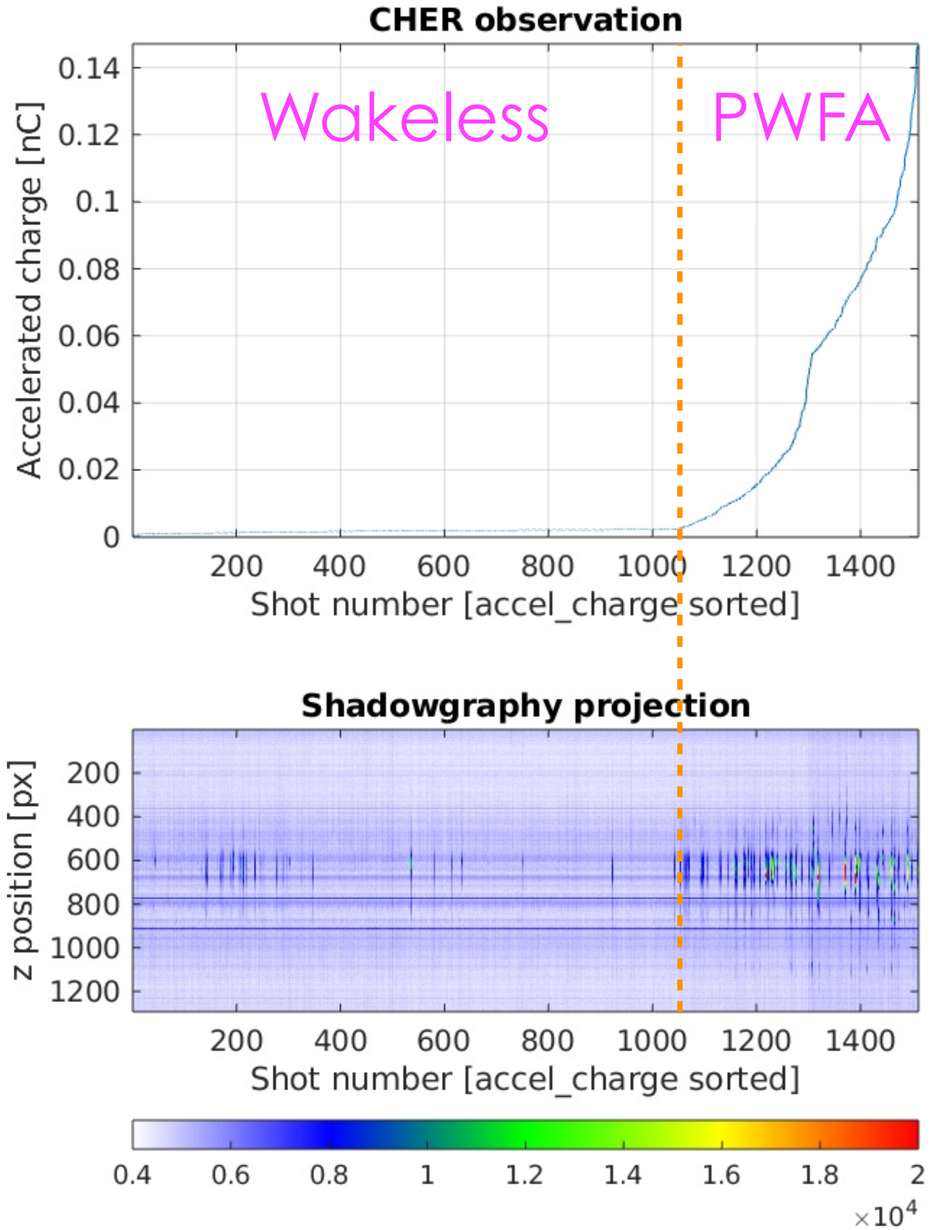
Wakeless

No acceleration on CHER for these shots (<15 pC)

With goose subtraction and bright normalization

E340 the data we have for short-term publication

“PWFA” dataset 13750.



(Disclaimer: half the shots are goose)

E332 What's next/key improvements

- Finish/submit publication, time frame of few months.
- Continue E340 research program:
  - first key milestone essentially reached (control and observe strong NFCTR focusing)
  - improved control, use of laser heater for the PWFA-wakeless transition
  - advanced measurements with notch and CSR
  - more stable conditions? Compatibility with laser ionization?
  - focus on the transition: trajectory mixing, plasma wave damping, extended blowout for e+ acceleration

E332 What's next/key improvements

- Synergy with laser-ionized experiments:
  - E333 for e+ regime
  - E306 for wakeless
  - Long laser-ionized plasma starting before FILG, new axilens?
- Key improvements:
  - Move EOS camera Z position away from FILG, to have it available for gas experiments at FILG with strong interaction. Need EOS-time-synchronisation Dark Shadow for precise timing scan.
  - New probe layout with DM, spatial filter on the ionizer/shadow breadboard
  - Compatibility between ionizer and shadowgraphy, or easy switch during PAMM.
    We showed it is possible at the end of May with the alternative main laser setup.
  - Mid-term: consider having an additional high-quality probe picked up from the main laser

Thank you for
your attention