2020-10-28 FACET-II PAC

E-315:
Plasma Afterglow Attosecond Metrology

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Introduction

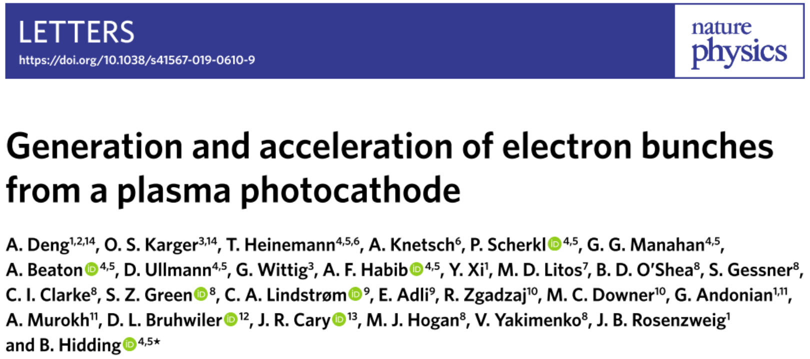
Plasma translates electron beam information to afterglow signal

- ❑ Scherkl et al., arxiv 1908.09263

- ❑ Sensitive response
- ❑ Non-destructive
- ❑ Versatile
- ❑ Intense/focused beams & in presence of plasma

Tip of the iceberg: injection enabled at FACET-I

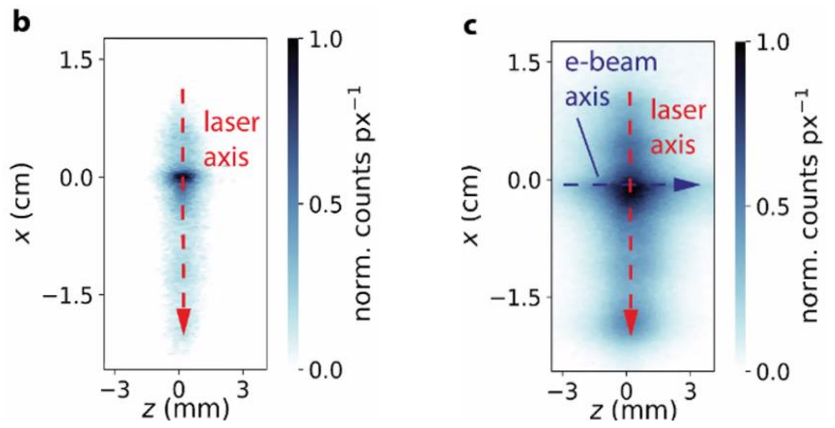
- ❑ Plasma Photocathode: Nat. Physics (2019)
- ❑ 1st demonstration of density downramp injection in PWFA
- ❑ Plasma Torch; Ullmann & Scherkl et al., arxiv 2007.12634

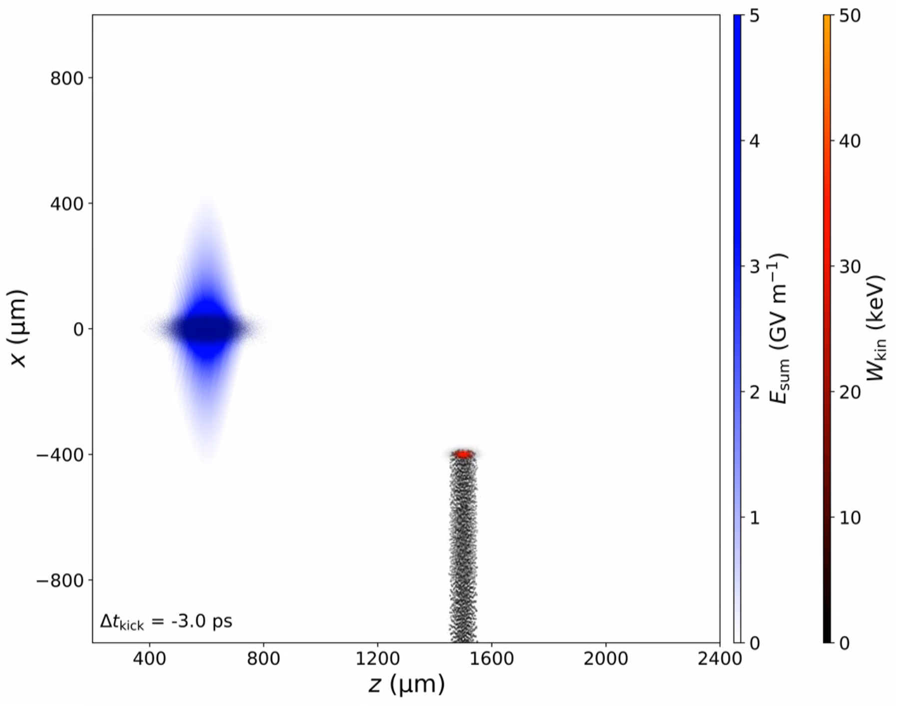

LETTERS
https://doi.org/10.1038/s41567-019-0610-9
nature physics

Generation and acceleration of electron bunches from a plasma photocathode

A. Deng[1,2,14], O. S. Karger[3,14], T. Heinemann[4,5,6], A. Knetsch[6], P. Scherkl[4,5], G. G. Manahan[4,5], A. Beaton[4,5], D. Ullmann[4,5], G. Wittig[3], A. F. Habib[4,5], Y. Xi[1], M. D. Litos[7], B. D. O'Shea[8], S. Gessner[8], C. I. Clarke[8], S. Z. Green[8], C. A. Lindstrøm[9], E. Adli[9], R. Zgadzaj[10], M. C. Downer[10], G. Andonian[1,11], A. Murokh[11], D. L. Bruhwiler[12], J. R. Cary[13], M. J. Hogan[8], V. Yakimenko[8], J. B. Rosenzweig[1] and B. Hidding[4,5*]

Laser-only plasma afterglow   Beam-enhanced afterglow





Experimental context & collaboration

Diagnostic vital for E-31x / plasma injectors

Further programs enabled by E-315 or having strong synergies:

- ❑ E-310 Trojan Horse-II
- ❑ E-311 Plasma Torch Optical Downramp Injection
- ❑ E-312 High Brightness Dragon Tail Injection
- ❑ E-313 Multibunch dechirper for ultrahigh B6D
- ❑ E-314 Exp. Investigations of Ion Collapse PWFA
- ❑ E-316 Icarus: Transient tunneling ionization
- ❑ E-330 Laserwire for Sector 20 IP
- ❑ E-306 Beam-driven Ion Channel Laser
- ❑ E-308 Extreme Focusing [...] Plasma Lens
- ❑ …

Beam – laser - plasma metrology crucial for almost all experiments

University of Strathclyde Glasgow
FACET-II Facility for Advanced Accelerator Experimental Tests
SLAC NATIONAL ACCELERATOR LABORATORY
U.S. DEPARTMENT OF ENERGY
UCLA
CU Boulder
DESY
TECH-X
radiasoft
radiabeam TECHNOLOGIES
QUEEN'S UNIVERSITY BELFAST

Science Goals

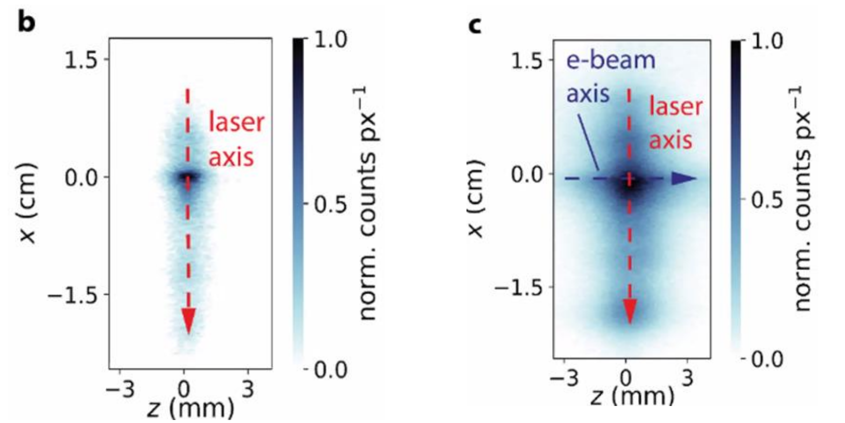
1. Quantification of beam-laser coincidence
   - ❑ Sub-10 fs, sub-5 µm accuracy
   - ❑ Directly at IP
   - ❑ Target time: 3 months

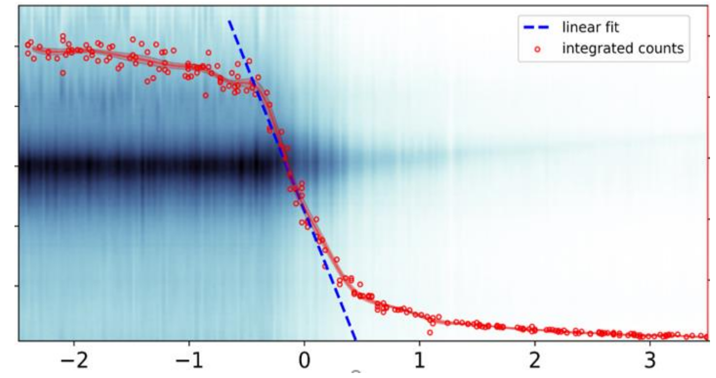
2. Extended diagnostic capabilities: beam metrology
   - ❑ Map beam duration/current
   - ❑ Exploit & cross-calibrate w/ other diagnostics & experiments
   - ❑ Target time: 6 months

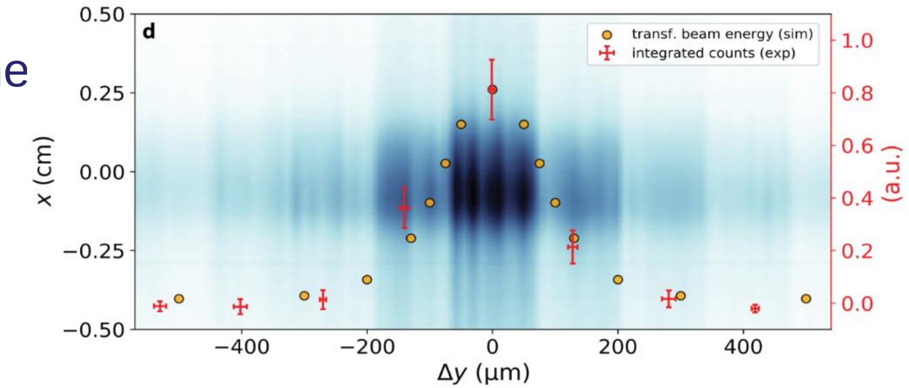
3. Establish & exploit plasma afterglow metrology along FACET-II lifetime
   - ❑ Facilitate E-310 & more
   - ❑ Target time: end of program

Laser-only plasma afterglow

Beam-enhanced afterglow





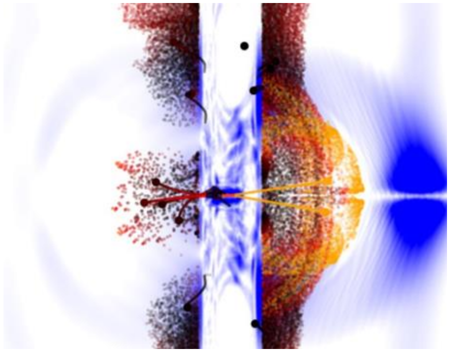


Experimental timeline

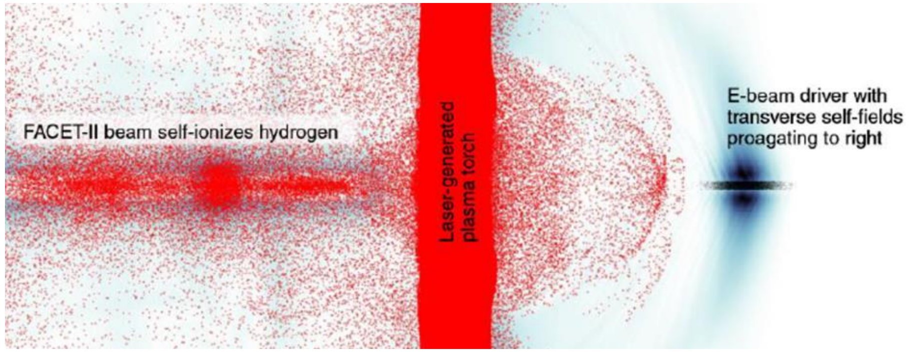
- ❑ Experimental design (90%): 10/2020
- ❑ Ready for experimental safety review: 10/2020

- ❑ Installation plan: ~mid 11/2020
- ❑ Ready for installation: 12/2020 – 01/2021

- ❑ Ready for commissioning & first science
  - ❑ Any available beam
  - ❑ Non-ionizing beam: regular mode



- ❑ Ionizing beam: explorative, stress test with extreme beams



- ❑ 2 phases of program:
  1. Laser-only, spatiotemporal measurements, extended diagnostic capabilities
     - ❑ Laser, gas (jet & flooded chamber), DAQ infrastructure, electron beam
     - ❑ ~3 - 6 months after first beam time

  2. Continuous optimization towards stability, accuracy & injectors: until end of program

Experimental layout

Developed by A. Sutherland, R. Ariniello, H. Ekerfelt & many more

Shared setup
e.g. with E-308, E-316

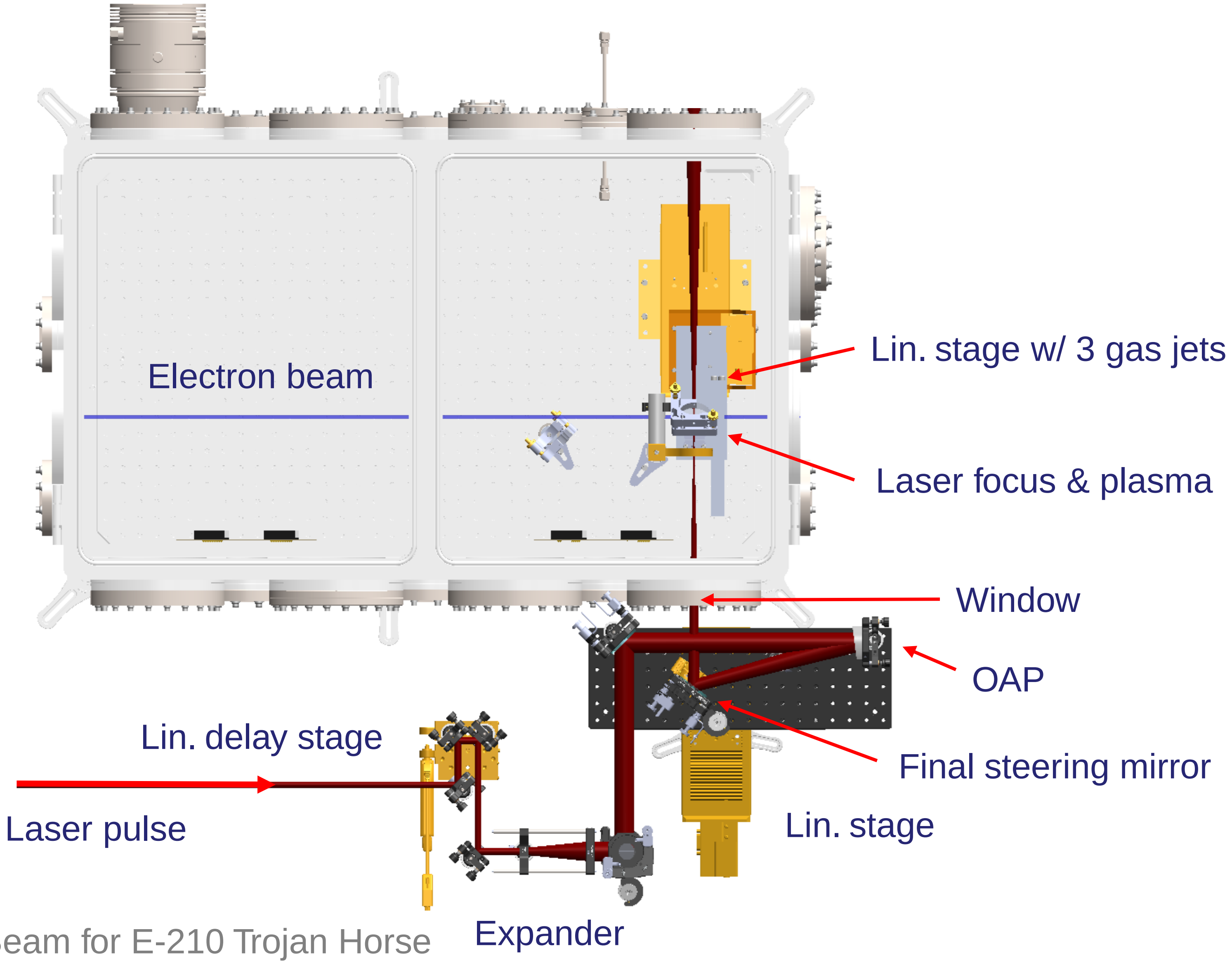
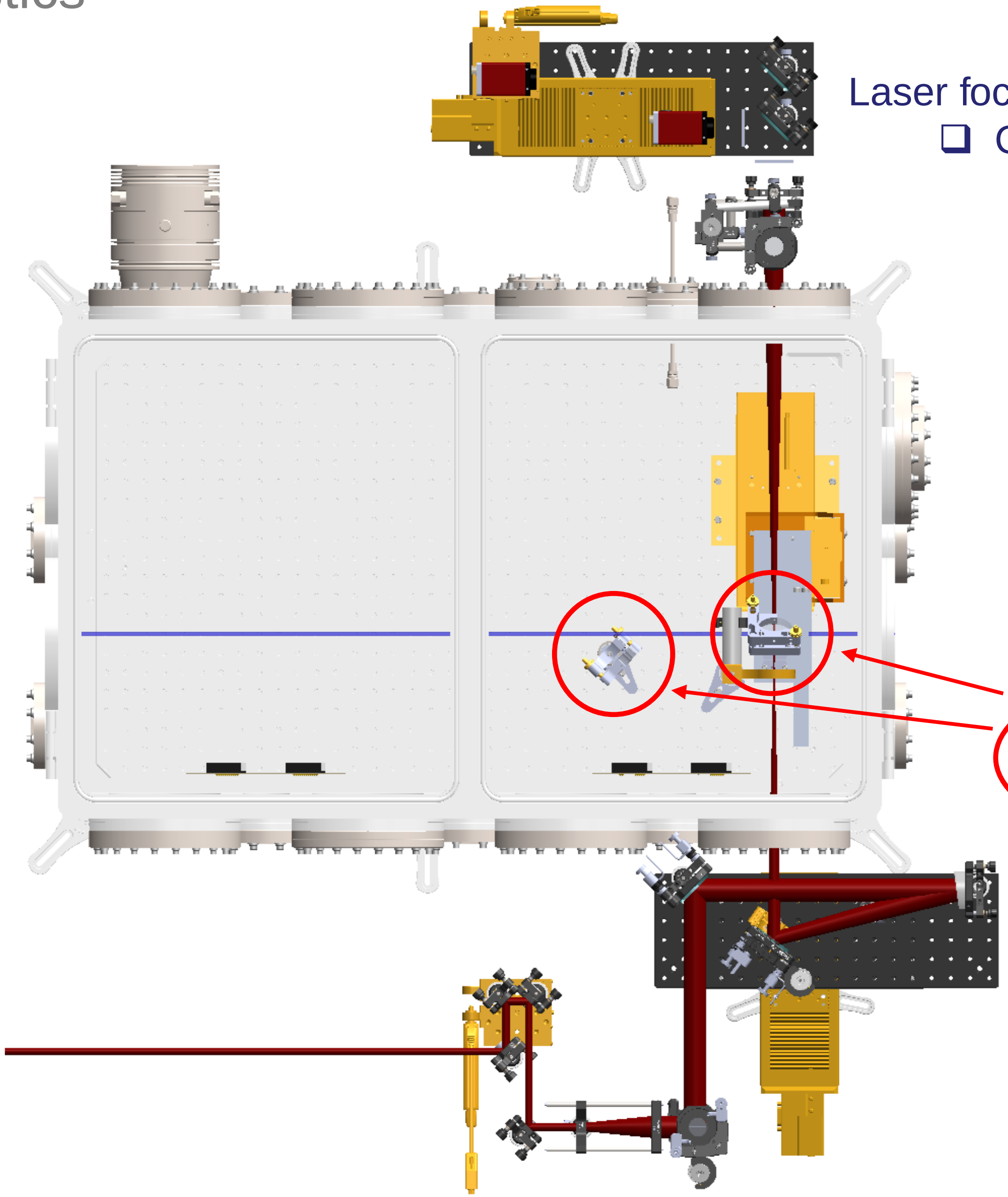


Figure: courtesy of Henrik Ekerfelt

Picnic basket produced by RadiaBeam for E-210 Trojan Horse

Observables and diagnostics

Developed by A. Sutherland, R. Ariniello, H. Ekerfelt & many more



Laser focus, pointing and energy stability
- CCD imaging interaction region

Beam spectrum & divergence
- Electron spectrometer

Composite measurements via EOS/EOS-BPM
- Time stamps
- Beam position

Afterglow signal
- 2 CCD w/ filters

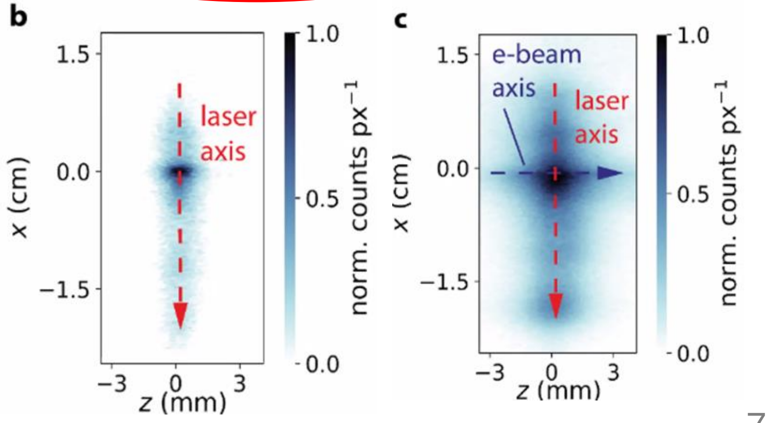
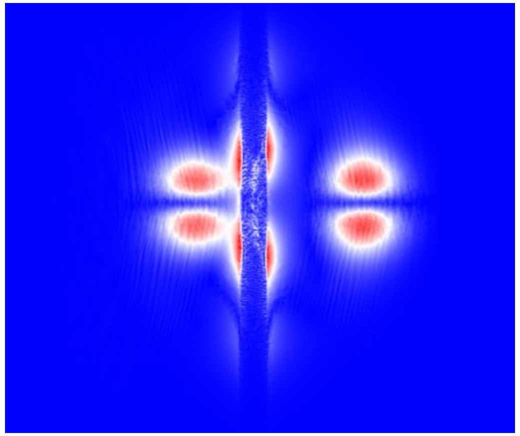


Figure: courtesy of Henrik Ekerfelt

Picnic basket produced by RadiaBeam for E-210 Trojan Horse

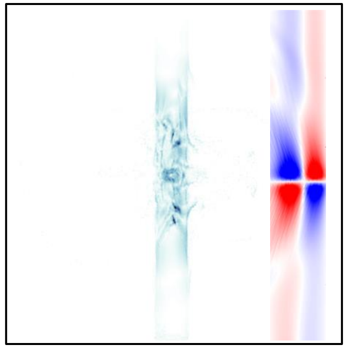
Potential future evolution beyond PAC

- 2-bunch measurements
  - Linac- and plasma-based scenarios
    - Quantify individual contributions
    - Diagnose only second beam

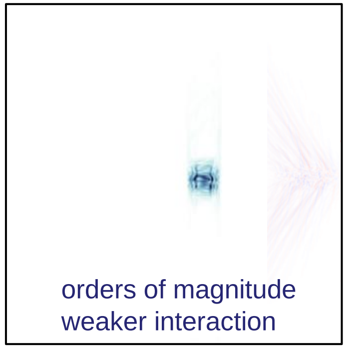


- Application to positrons
  - Demonstrate applicability
  - Space charge neutralization w/ electron beams

e^- - e^+ separated



e^- - e^+ overlapped



- Characterize compact/low-emittance beams (linac and plasma-based)
  - Test limits

- Multiple implementation
  - Explore single-shot capabilities
  - Emittance measurement

Desired facility upgrades

- Upgraded remote access to experiment
  - More camera & motor controller/driver
  - More afterglow diagnostics
  - → Reduced # of tunnel accesses

- High stability of laser system
  - Shot-to-shot pointing stability
  - Energy stability
  - Aligns well with “constant vigilance” strategy

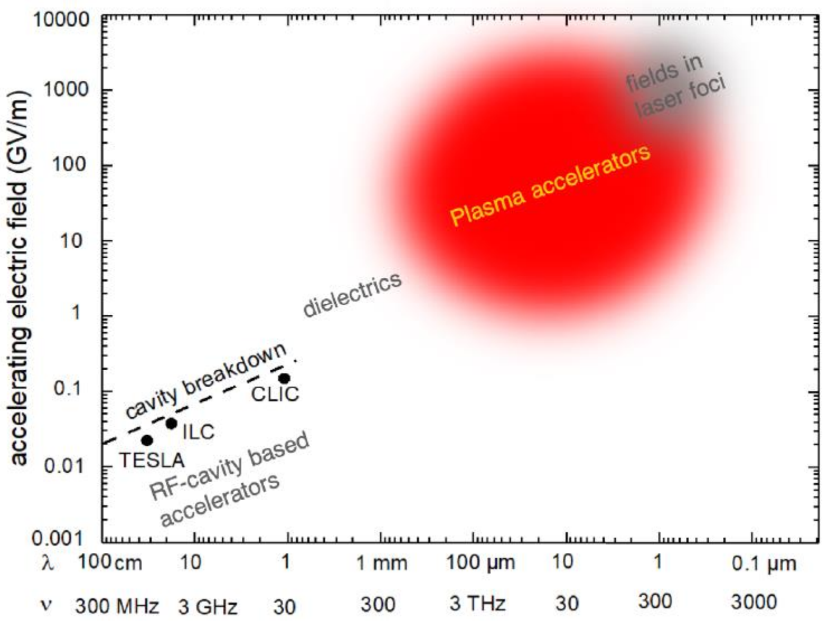
- Laser polarization control
  - Circular polarization modulates signal → laser beam metrology
  - Aligns well with E-310 goal of spin-polarized electrons

- Probe line OAP in vacuum
  - Avoid focusing through window
  - Allows for higher laser intensities

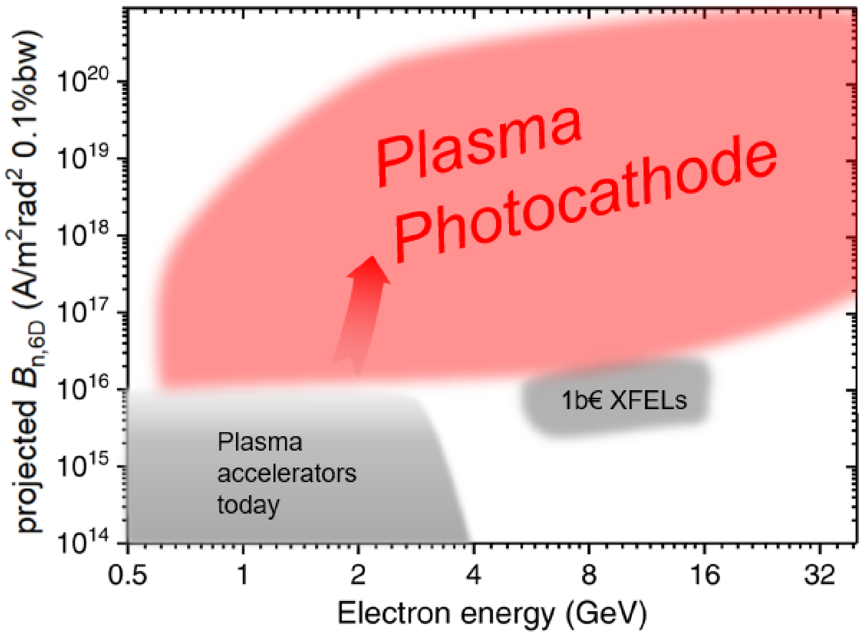
- Beam for Trojan Horse-II
  - Systematic afterglow metrology for Trojan Horse-II exp. family

Ecosystem of mutually reinforcing plasma-based approaches

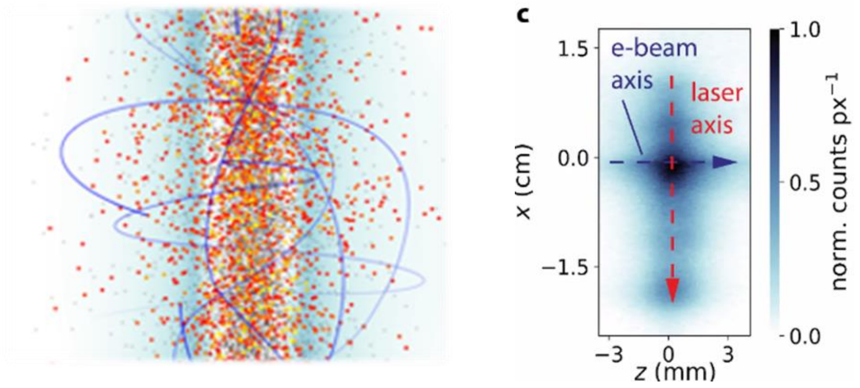
Plasma acceleration: 1000× stronger



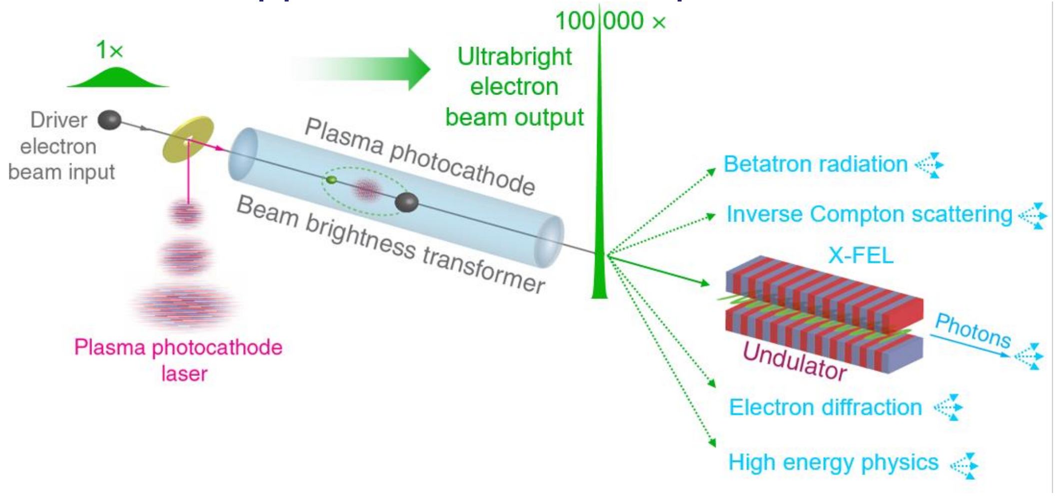
Plasma photocathode: 10000× brighter?



Plasma metrology: ?× more sensitive?

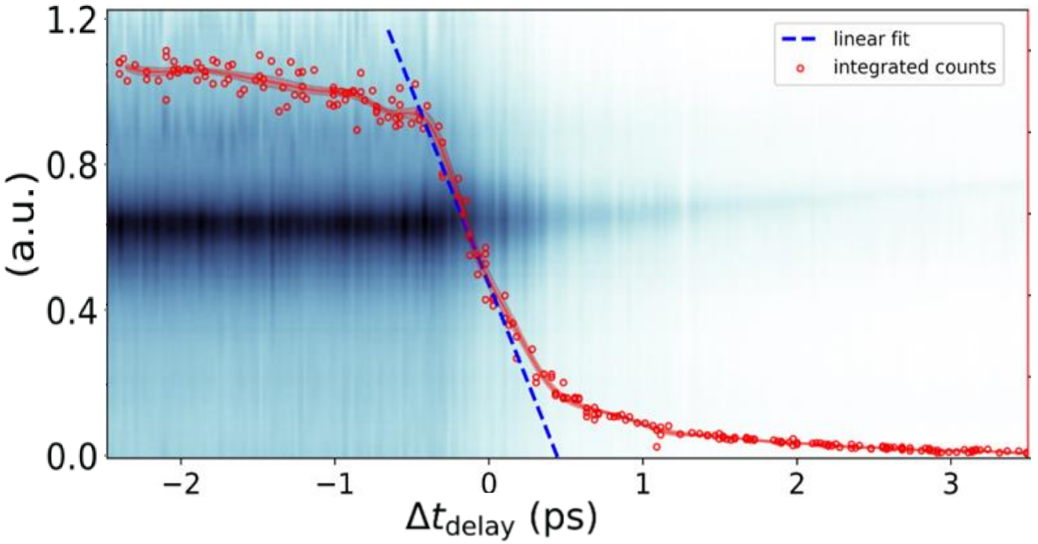


Plasma applications: ?× more performance?

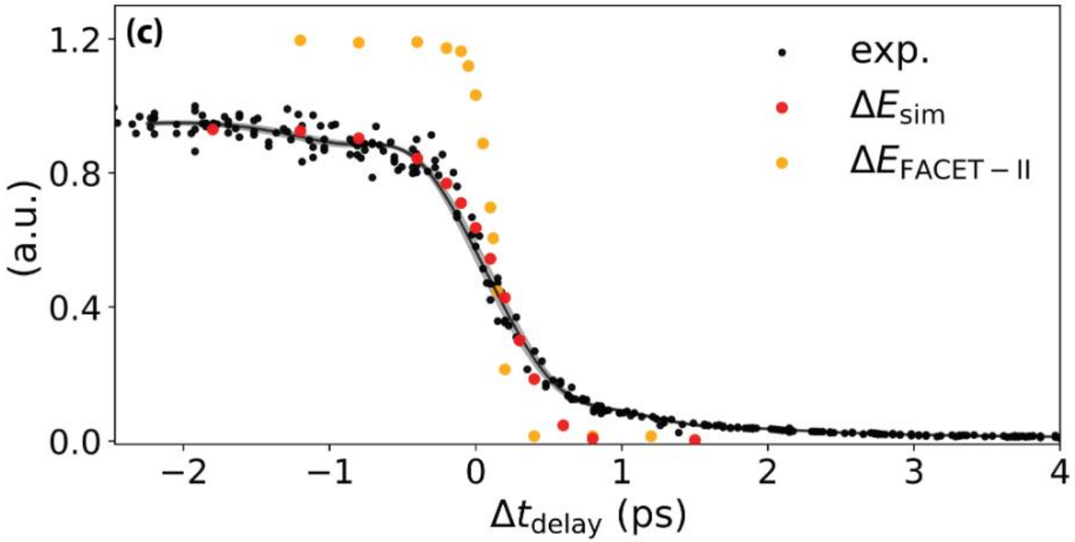


Backup: FACET vs FACET-II

Raw experimental data



PIC comparison

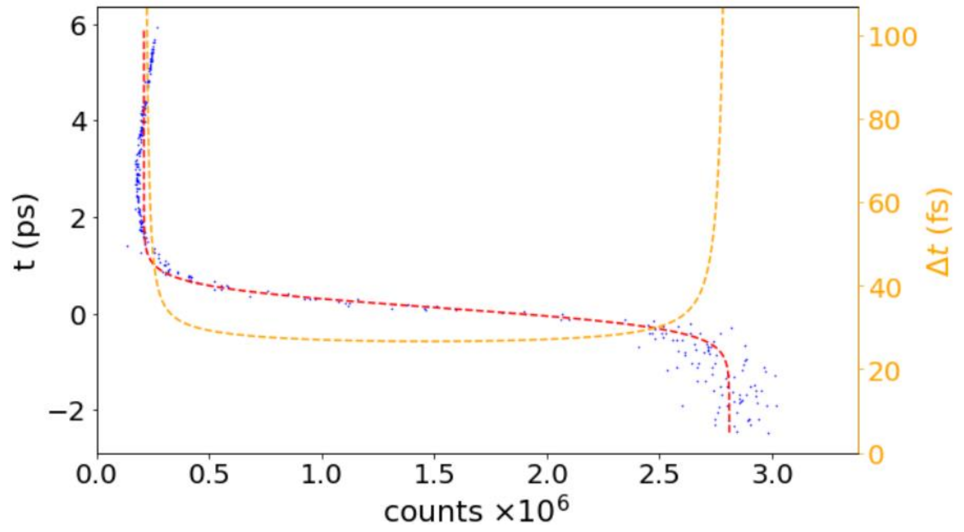


- ❑ Gradient determines accuracy
- ❑ Expt & PIC agree
- ❑ FACET-II beams promise much steeper gradient

Scherkl et al., arxiv 1908.09263

Backup accuracy FACET-I

- TOA accuracy as function of afterglow signal



FACET-I experiment
6% RMS shot-to-shot error
+ EOS error (25 fs)

Modelled signal & error