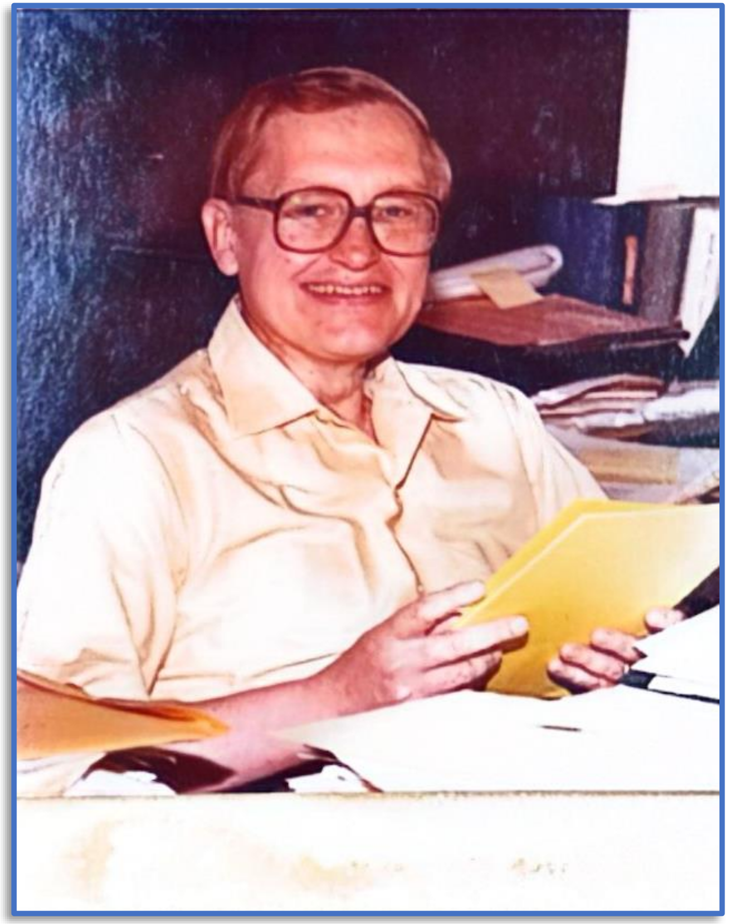
UCLA & THE BIRTH OF PLASMA ACCELERATORS

From Dawson's Idea to a Worldwide Field

Mark J. Hogan · xLight

Advanced Accelerator Concepts Workshop (AAC 2026) · UCLA

John Dawson: nurturing a field into being

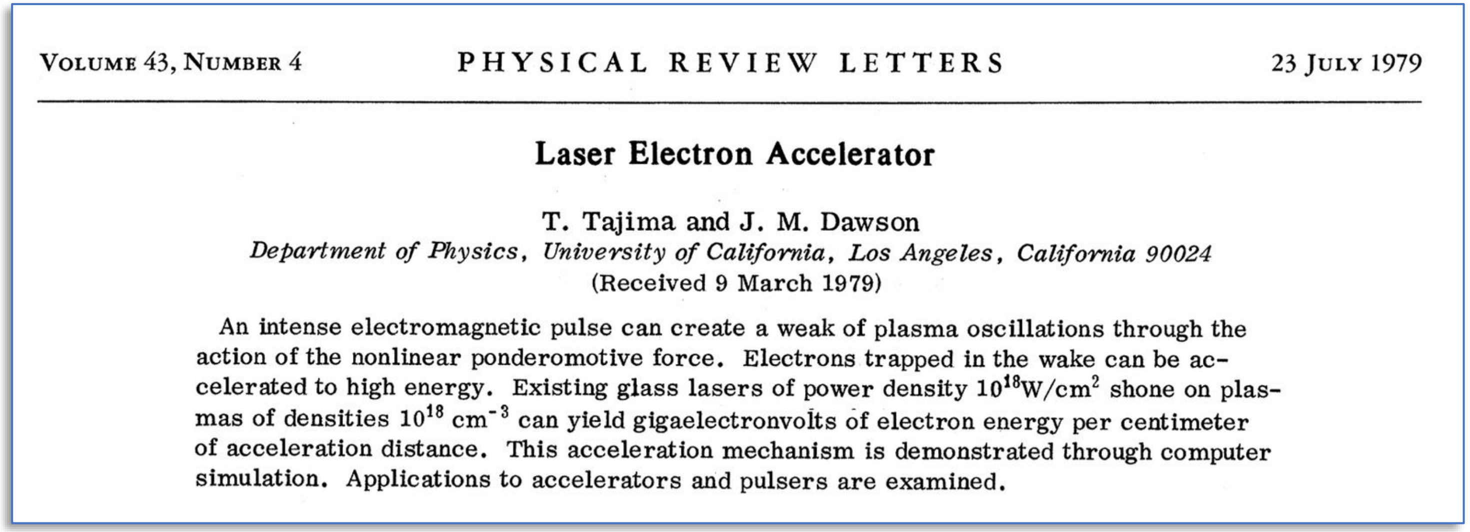


- Father of plasma particle-in-cell simulation, and — from his early Princeton fusion-lab years (Project Matterhorn) — author of the 1959 theory of nonlinear plasma oscillations that first derived the wave-breaking field limit, two decades before it would set the scale for plasma accelerators [Phys. Rev. 113, 383 (1959)]
- “Smarter than anybody you ever met” (Rosenzweig)
- A new idea almost every week; asked “why did you see that?” — never “why won't it work?” (Mori)
- Mentored by handing out real problems: Tom's very first — solar-wind ions V×B-surfing Earth's bow shock — became the “surfatron” paper (Katsouleas)
- Kept the SLAC beam parameters chalked on his board from the mid-80s until he passed — always looking for the next experiment (Mori)
- Any student could walk into his office and ask him anything (Joshi)

> *“This is the story of Science as a Living Thing… it must have the freedom to follow up interesting and unexpected results. This is what excites the good young researcher — and it is in their hands that our future rests.”*

— J. M. Dawson, Personal Recollections, AIP Conf. Proc. 569, p. 3 (2001)

1979: the Laser-Electron Accelerator



VOLUME 43, NUMBER 4 PHYSICAL REVIEW LETTERS 23 JULY 1979

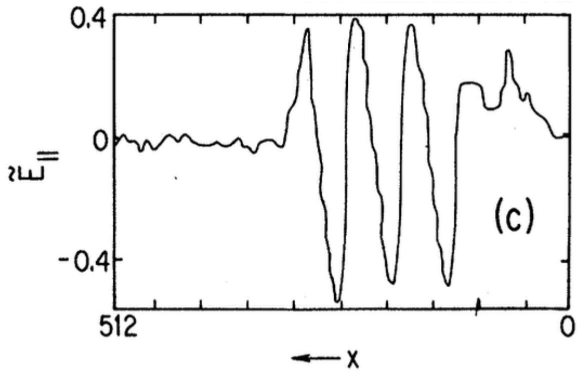
Laser Electron Accelerator

T. Tajima and J. M. Dawson

Department of Physics, University of California, Los Angeles, California 90024

(Received 9 March 1979)

An intense electromagnetic pulse can create a weak of plasma oscillations through the action of the nonlinear ponderomotive force. Electrons trapped in the wake can be accelerated to high energy. Existing glass lasers of power density 10^{18}W/cm^2 shone on plasmas of densities 10^{18} cm^{-3} can yield gigaelectronvolts of electron energy per centimeter of acceleration distance. This acceleration mechanism is demonstrated through computer simulation. Applications to accelerators and pulsers are examined.



Phys. Rev. Lett. 43, 267 (1979)

Fig. 1c — the original simulation.
The laser-driven wake plasmon, with the longitudinal field $E_{||}$ reaching ~0.6 of the cold wave-breaking limit.

Why it mattered

- A relativistic plasma wave can hold GV/cm fields — thousands of times an RF cavity
- Electrons stay synchronous long enough to reach high energy
- The short, intense pulse it needed did not yet exist — so the beat-wave path came first
- Immediately caught the eye of high-energy physics: a route past the saturating RF energy-frontier curve

Two workshops that started a field

1982 Los Alamos

- DOE Workshop on Laser Acceleration of Particles (A. Sessler, scientific coordinator)
- The organizers invited Dawson; unable to attend, he suggested Chan Joshi go in his place
- Techniques sorted into four classes; the closing recommendations launched the DOE–HEP advanced-accelerator program

Proceedings: AIP Conf. Proc. 91 (ed. P. J. Channell, 1982)

1985 Malibu

- Second workshop — held at two beachfront houses UCLA had been given; Katsouleas, then a grad student, volunteered UCLA to host it
- The only one ever run over two full weeks — so many open questions it needed working groups
- Lawson's emittance objection raised here — and soon answered (Slide 8)

Proceedings: AIP Conf. Proc. 130 (Malibu, 1985)

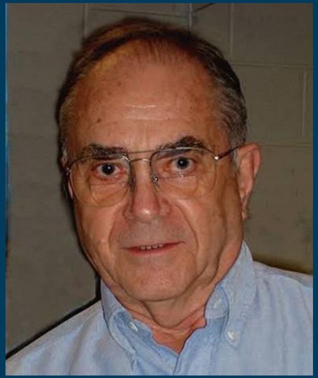
> *“This landmark workshop led to the formation of the advanced accelerator R&D program in the HEP office of the DOE that supports advanced accelerator research to this day.”*
>
> — C. Joshi, retrospective on the first Los Alamos workshop, AIP Conf. Proc. 1507, p. 61 (2012)

ONE IDEA, FOUR DECADES

A continuous community: the AAC workshops

1982 Los Alamos, NM	**1985** Malibu, CA	**1986** Madison, WI	**1989** Lake Arrowhead, CA	**1992** Port Jefferson, NY	**1994** Lake Geneva, WI	**1996** Lake Tahoe, CA
1998 Baltimore, MD	**2000** Santa Fe, NM	**2002** Oxnard, CA	**2004** Stony Brook, NY	**2006** Lake Geneva, WI	**2008** Santa Cruz, CA	**2010** Annapolis, MD
2012 Austin, TX	**2014** San Jose, CA	**2016** National Harbor, MD	**2018** Breckenridge, CO	**2022** Long Island, NY	**2024** Naperville, IL	**2026** UCLA — this workshop

Held every other year since 1982 (2020 cancelled, COVID). ***Gold-topped*** *= the two founding "Laser Acceleration of Particles" workshops and AAC 2026.*



The funding that made it possible

- David Sutter championed the Advanced Technology R&D Program of the Department of Energy's (DOE) Division of High Energy Physics — the dedicated funding line that has sustained advanced-accelerator research (today's General Accelerator R&D, GARD)
- The AAC workshop doubled as the PI meeting for these programs — keeping a dispersed community coherent
- The idea went global; the European EAAC now interleaves on the off years

Chan Joshi and the first plasma-accelerator group

The first group in the world formed exclusively to explore what role plasmas could play in future colliders and light sources.

- Read the Tajima–Dawson paper in 1979 at NRC Ottawa; recognized it as a “lifetime endeavor”
- Arrived at UCLA in 1980, age 24, as a Research Engineer — Frank Chen: “you can stay as long as you bring your own money”
- Dawson secured lab space from the Dean; Chan won the first multi-year DOE grant on beat-wave acceleration — turning a research engineer into a funded PI with a lab of his own
- Built the model the field would copy: experimentalists, theorists, and computational physicists under one roof
- Underappreciated engine-room: Chris Clayton, Ken Marsh, Sergei Tochitsky — the people who made the experiments actually run

The beat-wave experiment: fields you could believe

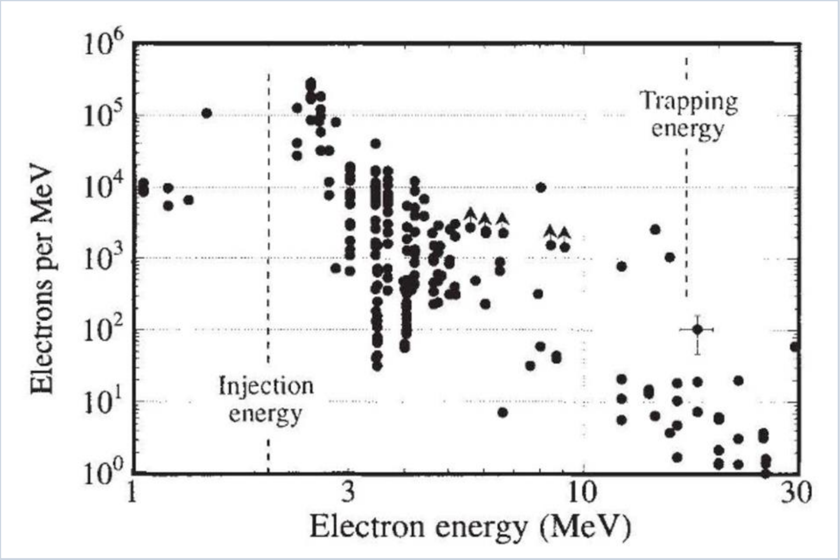


Fig. 1 from Everett et al., Nature 368, 527 (1994)

- Two-frequency laser beat wave drove a relativistic plasma wave at > 1 GeV/m — with modest ~5 GW lasers, no petawatt needed
- Debate over whether plasma waves could accelerate electrons was settled here, directly and repeatedly

Why Chan calls it "the most complete basic plasma-physics experiment ever done"

A remarkable string of firsts (all before 1995):

- First tunnel-ionized plasmas from both a pre-ionized discharge and a supersonic gas jet
- First relativistic plasma waves confirmed by collinear Thomson scattering (discrimination > 10^9), across the Compton-to-Raman regimes
- First energy exchange — acceleration and deceleration — with a continuously injected electron beam
- First MeV gains: a 2 MeV beam boosted to 26 MeV, later 50 MeV, in ~1 cm
- Relativistic physics with non-relativistic-intensity lasers ($a_0 \approx 0.1$–0.2); non-resonant acceleration shown possible

Complete, not just first: every plasma and laser parameter independently measured; the competing Brillouin and Raman/Compton instabilities quantified; full null tests to prove the accelerated electrons were real.

Key papers: Clayton et al., PRL 70, 37 (1993) · Everett et al., Nature 368, 527 (1994) · and companion PRLs / AAC proceedings

Tom Katsouleas: answering the emittance objection

Arrived at UCLA as a grad student (Southern California native); started with Burt Fried, then moved to Dawson. After his PhD, Chan kept him on as a postdoc.

The Malibu worry: for efficiency the beam seemed to need to fill the bubble — implying a large matched emittance, bad for HEP.

Beam Loading in Plasma Accelerators

Katsouleas, Wilks, Chen, Dawson & Su, ***Part. Accel. 22, 81 (1987)***

A beam much narrower than the plasma wavelength ($k_p\sigma_r \ll 1$) can still load the wake efficiently — because the wake's fields extend transversely out to a plasma skin depth c/ω_p.

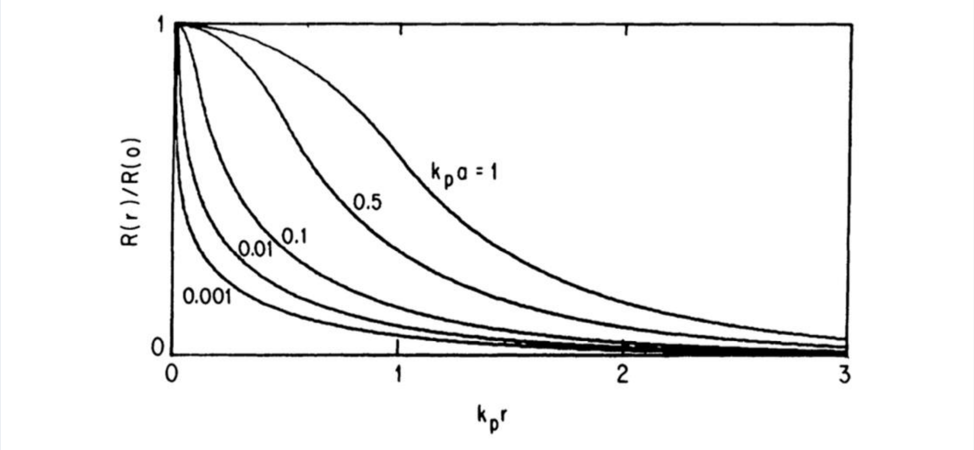


FIGURE 7 Radial profiles of longitudinal wake fields for uniform beams of various radii.

An important early advance

It addressed one of the field's first serious objections — showing emittance is decoupled from the wake size, so a **narrow, low-emittance beam and efficient energy extraction** can coexist. That result helped frame the next generation of PWFA experiments at SLAC.

“Although the beam radii differ by orders of magnitude, their radial wake profiles do not. Physically, this means that even very narrow beams can absorb plasma wave energy out to a skin depth c/w_p”

Warren Mori: no grand plan, no wrong turns

- Frank Chen steered him in: “we're working on this thing, laser acceleration”
- “I was not very good in the lab,” so Chen redirected him: “why don't you do simulations?” — placing him with Dawson, and with Chan Joshi
- The field was tiny and wide open: “there's no real competition... very few efforts at the labs.”
- UCLA's edge was “the brain power and the creativity of Dawson and Chan,” plus its own codes and heavy Los Alamos compute access
- Reproduced Tajima's 1D laser-wakefield PIC, then pushed to 2D — feeding the Nature 311, 525 (1984) paper and two PRLs, launching UCLA's simulation leadership

Had offers from Berkeley and UCLA; picked UCLA for a change of scene — “I had no idea that plasma physics was strong at UCLA.”

The one that got away: “Dawson came to me — I have this idea of using the SLAC beam,” and the sim showed “the energy just doubled.” But “I said, John, I want to graduate” — so “he gave it to Pisin Chen”

Simulation and theory — from 1990 to today

SIMULATION

OSIRIS — fully 3D PIC with ever-growing physics packages; a long-running UCLA co-development with the IST Lisbon group (Silva, Fonseca), who trained in the Mori/Dawson orbit

QuickPIC — quasi-static approximation; hugely efficient at large γ, essential for modeling SLAC beams from 10–80 GeV (Huang et al.)

QPAD — quasi-static with azimuthal-mode decomposition for rapid parameter-space exploration (F. Li et al.)

THEORY

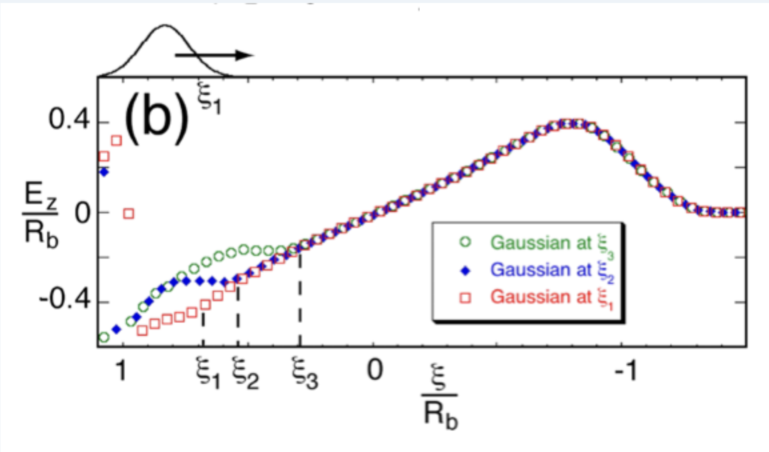


Fig 2b from M. Tzoufras et al.

- Wei Lu's nonlinear theory for the 3D blowout regime gave the field its first analytic handle for design (W. Lu et al., DOI: 10.1103/PhysRevLett.96.165002
- Michail Tzoufras beam loading in the nonlinear regime — how to flatten the wake for low energy spread at high efficiency (M. Tzoufras et al.DOI: 10.1103/PhysRevLett.101.145002)

FOUR DECADES OF FIRSTS

One team, many facilities, sustained impact

The team of experimentalists, theorists and computationalists Chan Joshi assembled at UCLA has stayed at the forefront for four decades by collaborating at whichever facility could push the physics furthest — from campus labs to the world's leading beam and laser centers.

Mars (UCLA)	Saturnus (UCLA)	Neptune (UCLA)	RAL (UK)	SLAC	LLNL
big CO_2 laser	photoinjector	the two combined	SMLWFA → 100+ MeV	multi-GeV e^- & e^+	Callisto ~200 TW laser

- First relativistic plasma wave & >1 GeV/m beat-wave gradients
- Li plasma-oven source: reproducible, >10^6-shot lifetime
- Energy doubling of 42 GeV SLAC electrons in <1 m
- Positron acceleration & a new nonlinear-wake mechanism
- Forward Raman scattering — later renamed SMLWFA
- First GeV-scale PWFA; energy gain scales with plasma length
- Ionization injection; betatron radiation; field-ionized plasmas
- High-efficiency two-bunch acceleration; ~1% energy spread

50+ high-impact papers over four decades — Nature, Science, PRL, Nature Photonics, Scientific American

Jamie Rosenzweig: beam-driven wakes & colliders

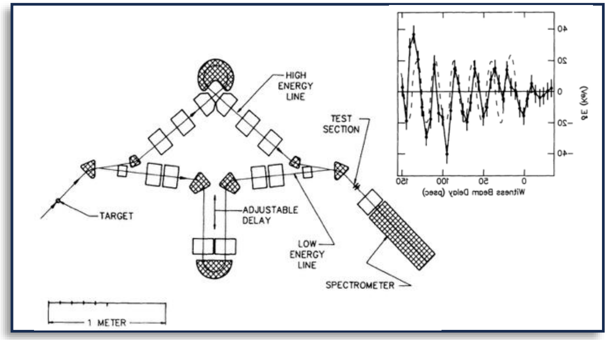
PhD (Wisconsin) and proof-of-principle work at Argonne; came to UCLA Physics faculty in 1991 from a Fermilab Wilson Fellowship (superconducting-RF collider work), recruited by Pellegrini and Peccei.

> *"I fully intended to bail on plasma wakefields forever... As soon as you accept that it's a nonlinear problem, the world becomes beautiful."*

Proof of principle at Argonne

J. Rosenzweig et al., PRL 61, 98 (1988)

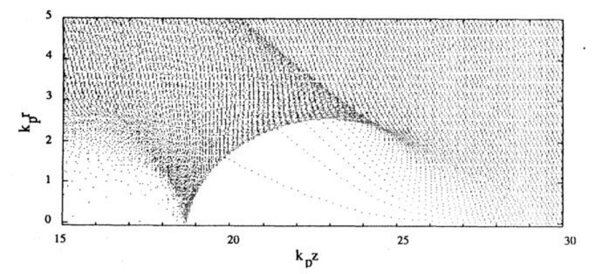
First experimental observation of plasma wakefield acceleration, mapping the wake with a witness beam.



The blowout regime

Rosenzweig, Breizman, Katsouleas & Su, Phys. Rev. A 44, R6189 (1991)

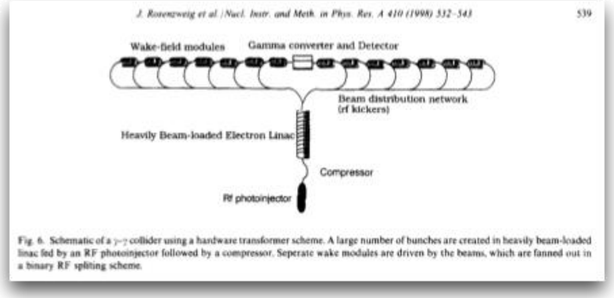
High beam density locally evacuates the plasma electrons — the "bubble" that made nonlinear PWFA viable.



Thinking colliders early

J. Rosenzweig et al., Nucl. Instrum. Methods A 410, 532 (1998)

Laid out plasma accelerators for collider applications — and their many hard challenges — from the start.



Claudio Pellegrini and the birth of PBPL (~1990)

Chan Joshi, EE

Jamie Rosenzweig, Physics

Claudio Pellegrini, Physics

Three new faculty came together to create a small accelerator laboratory focused on photoinjectors and FELs — that would be built and operated by students.

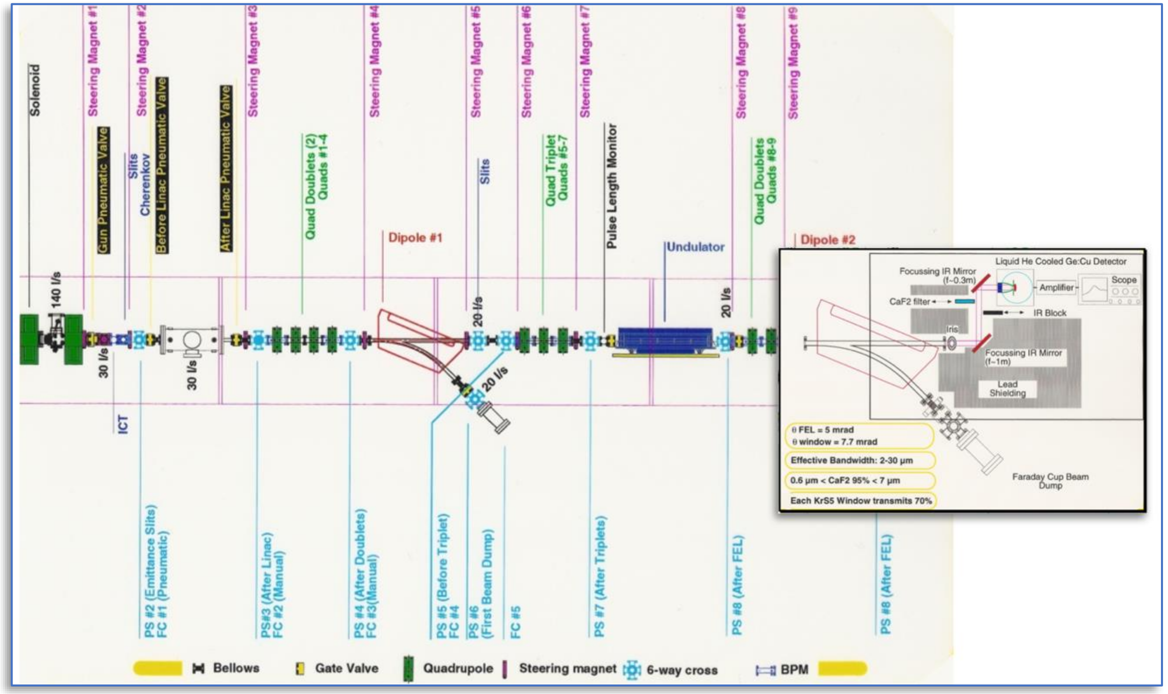
PBPL, Knudsen Hall sub-basement B-105

- Pellegrini arrived from BNL in 1989, bringing the SASE high-gain FEL idea (Bonifacio–Pellegrini–Narducci, 1984)
- UCLA became the rare place with no divide between advanced and conventional accelerators — plasmas, lasers, RF and undulators as one field
- Photoinjector physics here seeded plasma-lens work and the earliest SASE-FEL experiments
- Timeline: Saturnus → Neptune → Pegasus — one lab lineage across three decades

"Students here grew up seeing plasma, lasers, undulators and RF beam physics as aspects of one field — that's rare, and it's why they've succeeded everywhere." — P. Musumeci

BUILT BY STUDENTS

Saturnus: a student-built accelerator, and the first SASE steps



> *"The lab had all kinds of amazing new hardware — laser, klystron, modulator, injector, cameras, optics, power supplies, scopes, computers, network analyzers. I felt like a kid who'd walked into a candy store — and it was all being put together by fellow graduate students."*
>
> — M. Hogan, recalling arriving at PBPL as a graduate student

- 1996–98: completed beamline demonstrates the SASE principle — gain above spontaneous (PRL 80, 289, 1998)
- 1998: higher-energy, higher-brightness beam + longer undulator (UCLA–LANL–Kurchatov–SSRL) reaches 10^5 gain with SASE fluctuation statistics (PRL 81, 4867)
- Then VISA at BNL: saturation and harmonics
- Sutter's AAC program helped fund the lab — so the AAC can claim a share of the first university SASE result

A NUCLEUS FOR THE COMMUNITY

PBPL: training ground and idea factory

1

High transformer ratio

Shaped drive bunches pushing energy-transfer efficiency in structure wakefields.

PRL 124, 044802 (2020)

2

Dielectric wakefield acceleration

Structure-based wakes carried to SLAC — Jamie's parallel to the plasma track.

Nat. Commun. 12763 (2016); PRL 123, 134801 & 124, 104801

3

Ion motion

New theory of how heavy ions move in intense wakes, limiting achievable emittance.

PRL 95, 195002 (2005)

4

Trojan Horse injection

Plasma-photocathode concept for ultra-low-emittance bunches — developed while B. Hidding visited UCLA Physics & Astronomy.

PRL 108, 035001 (2012)

A UCLA engine for the field: a vibrant community of young people, PBPL trains new students alongside seasoned students and postdocs, then sends them out to the national labs and facilities worldwide to test new AAC ideas at scale.

Pietro Musumeci: Saturnus transformed to the Pegasus Lab

Came to UCLA from Italy as an undergraduate (1996), drawn by Pellegrini; PhD in Neptune with Chan, Jamie and Claudio; returned as faculty in 2007 — a product of PBPL now leading it.

From Neptune to Pegasus: he carried skills learned at Neptune into a lab of his own — Pegasus, now among the world's brightest low-energy electron sources.

- ### Inverse-FEL acceleration at Neptune

  As a young researcher: >20 MeV energy gain in a tapered, diffraction-dominated IFEL driven by the Neptune CO_2 laser — precision laser acceleration.

  Musumeci et al., PRL 94, 154801 (2005)

- ### New regimes for photoinjectors

  At Pegasus: the space-charge "blow-out" regime producing uniformly filled ellipsoidal bunches with linear self-fields — a new mode of photoinjector operation.

  Musumeci, Moody, England, Rosenzweig & Tran, PRL 100, 244801 (2008)

- ### High-brightness electron beams

  Generation and direct measurement of few-MeV beams with < 20 nm emittance and sub-10 fs bunch length — among the brightest anywhere.

  Maxson, Cesar, Calmasini, Ody, Musumeci & Alesini, PRL 118, 154802 (2017)

A key pipeline of students today — and the organizer of AAC 2026.

THE LEGACY

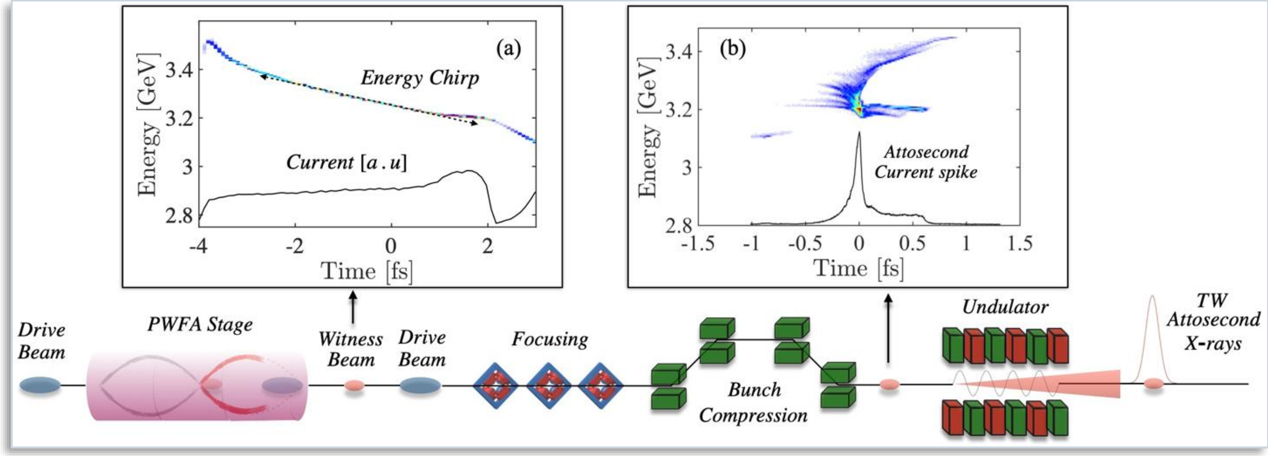
The people are the product *— a workforce developed at UCLA that now helps lead beam and light-source facilities worldwide, and arguably UCLA's greatest contribution to the field.*

Well over 100 students and postdocs — five generations, one lineage

"… and it is in their hands that our future rests." — J. M. Dawson

Carrying the dream forward: extreme beams → light sources

The dream that runs from Dawson's 1979 title to today: turn these extreme beams into **compact, user-serving light sources that enhance — not replace — the SASE XFELs like LCLS.**



C. Emma et al., APL Photonics 6, 076107 (2021)

PAX — Plasma-driven Attosecond X-rays — as the example:

- Connects three UCLA threads at once — extreme beams, plasma acceleration, and FELs
- Turns the plasma's large energy chirp from a bug into a feature: attosecond X-rays from pre-bunched beams
- Bridges generations — Chan's UCLA PWFA team with SLAC groups led by former Bruins Claudio Emma and Agostino Marinelli
- Aims to complement conventional SASE FELs, not compete with them; E-304 demonstrated the brightness booster, E-338 (PAX) is installing hardware at FACET-II now

Chaojie Zhang (Chan Joshi postdoc)

Claudio Emma (PhD with Claudio Pellegrini)

Agostino Marinelli (PhD with Jamie Rosenzweig)

Honest note: HEP is shifting focus towards the near term and away from long-horizon AAC — but BES may be stepping in, and solutions less dependent on collider funding are emerging.

The next generation is building on the UCLA legacy with bold new ideas

FOR STUDENTS STARTING TODAY

What the mentors would tell you

Chan

Go where the facilities are state of the art. At the PhD level your advisor matters most — after that, access to the best hardware.

Tom

The best training ground in physics — mechanics, E&M, plasma, beam physics, computation, AI. Be ready to move as funding shifts abroad.

Warren

Even if AAC doesn't pan out, every skill transfers to conventional accelerators. You can't lose.

Jamie

The field is in its strongest position yet — the science has matured, and the practical uses are finally clear. There's never been a better time to start.

Pietro

The best sub-field to be in within accelerator and beam physics — a field with a special place in physics for its unique mix of science and technology.

The through-line from Dawson's idea to real machines is finally visible — and the best of it is still ahead, yours to build.

Thank you — and happy 40 years to a field that UCLA Bruins helped invent and are still carrying forward.