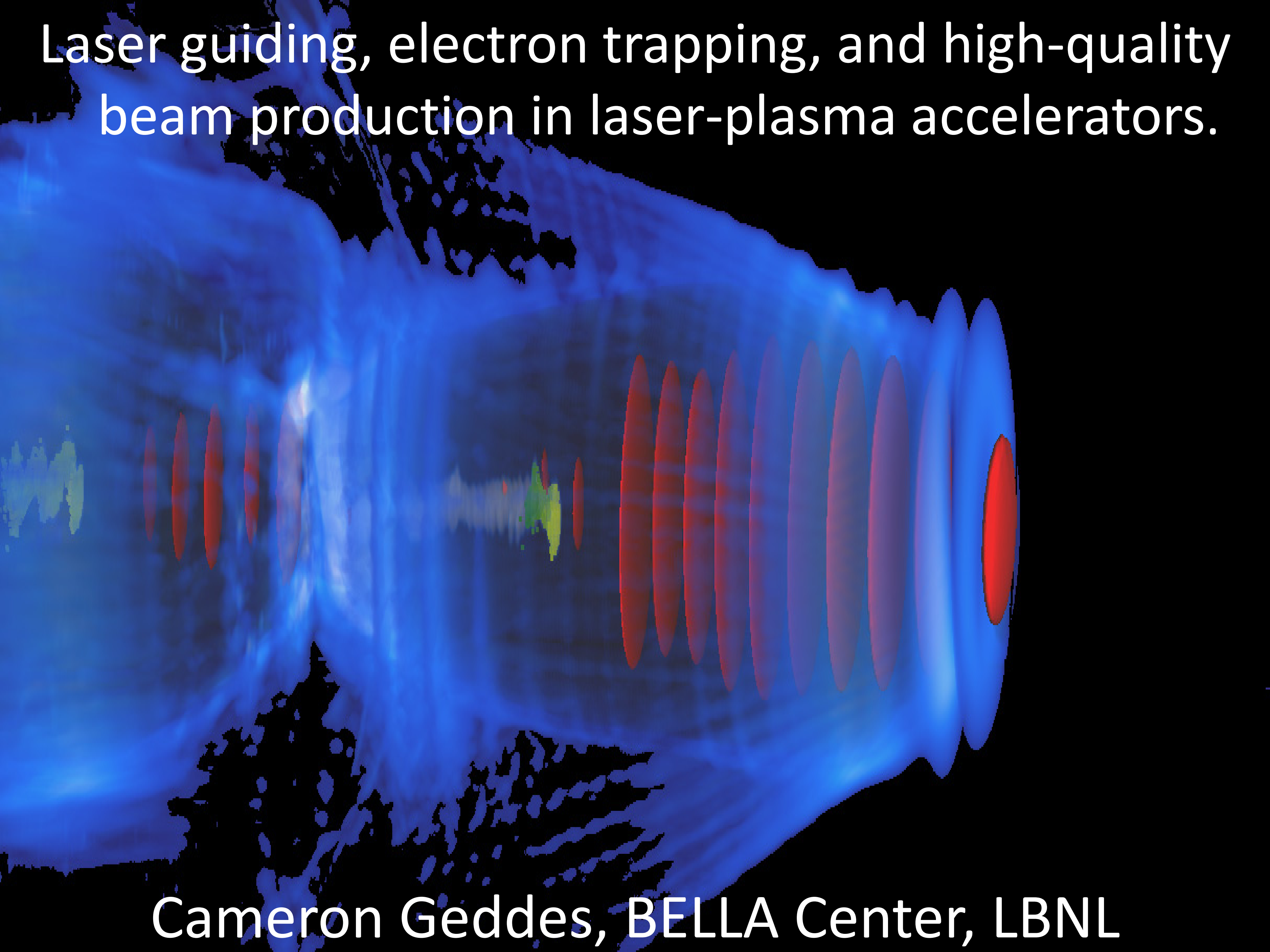
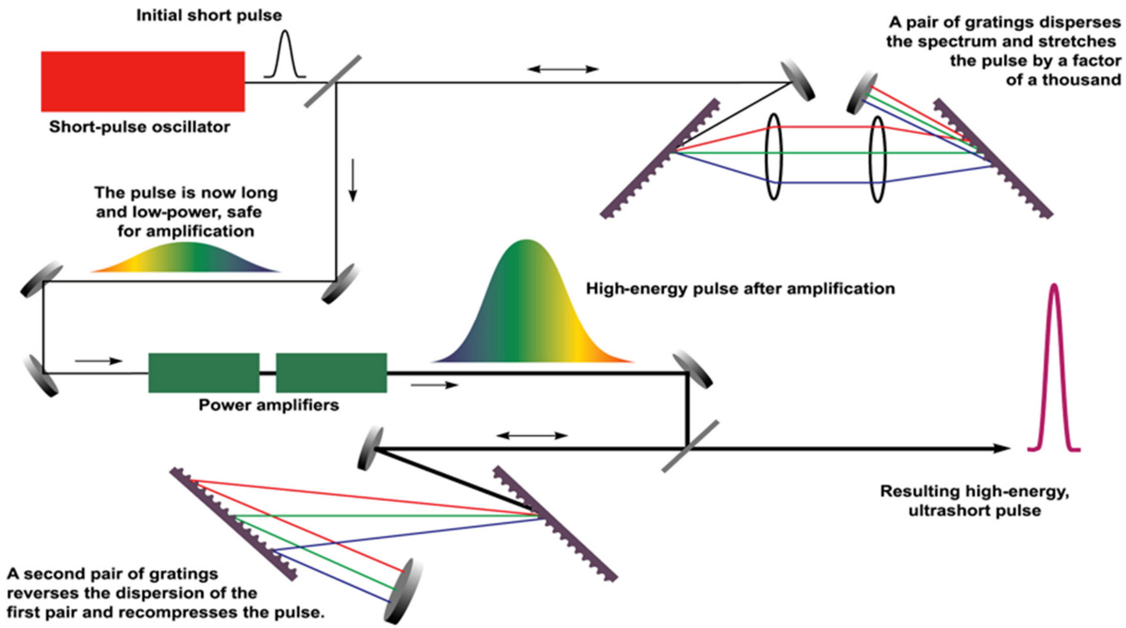
Laser guiding, electron trapping, and high-quality beam production in laser-plasma accelerators.



Cameron Geddes, BELLA Center, LBNL

LPA enabled by fs, TW lasers:
Chirped pulse amplification

1985 Concept



LPA a key scientific application

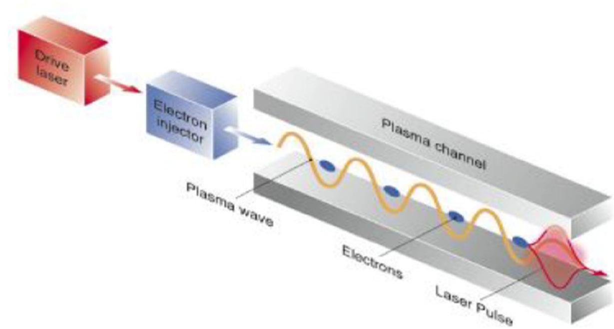


Figure 7. Schematic illustration of laser-plasma acceleration. An intense laser pulse drives a plasma wave (wake) in a plasma channel, which also guides the laser pulse and prevents diffraction. Plasma background electrons injected with the proper phase can be accelerated and focused by the wake. (Reproduced from W.P. Leemans (2010), White Paper of the ICFA-ICUIL Joint Task Force – High Power Laser Technology for Accelerators, http://icfa-bd.kek.jp/WhitePaper_final.pdf.)

At Lawrence Berkeley National Laboratory in California, a petawatt-class laser at the Berkeley Lab Laser Accelerator (BELLA) facility is used to accelerate electrons to 4.2 GeV over a distance of 9 cm [78]. This is an acceleration gradient of at least two orders of magnitude higher than what can be obtained with RF technology.

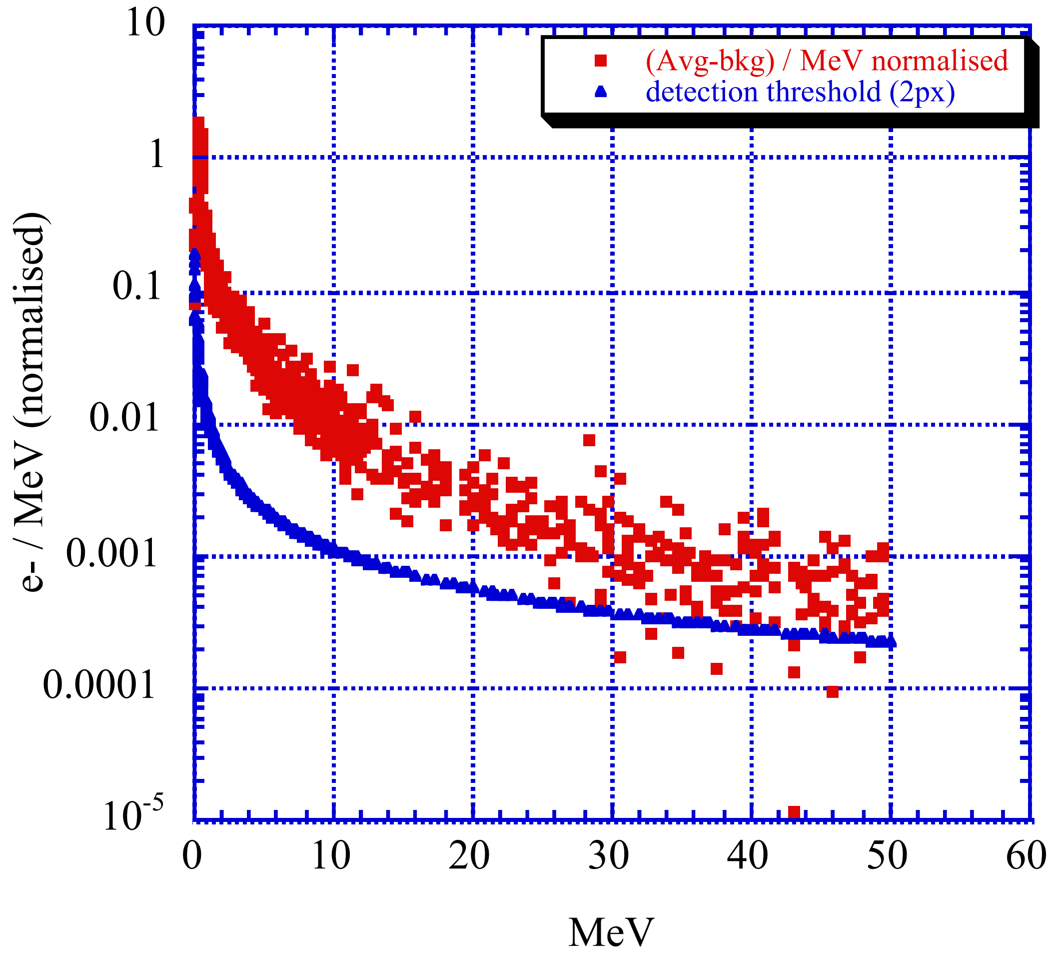
2000's Ti:Sa – 30 fs, TW then PW…

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

2018 Nobel Prize: Strickland and Mourou

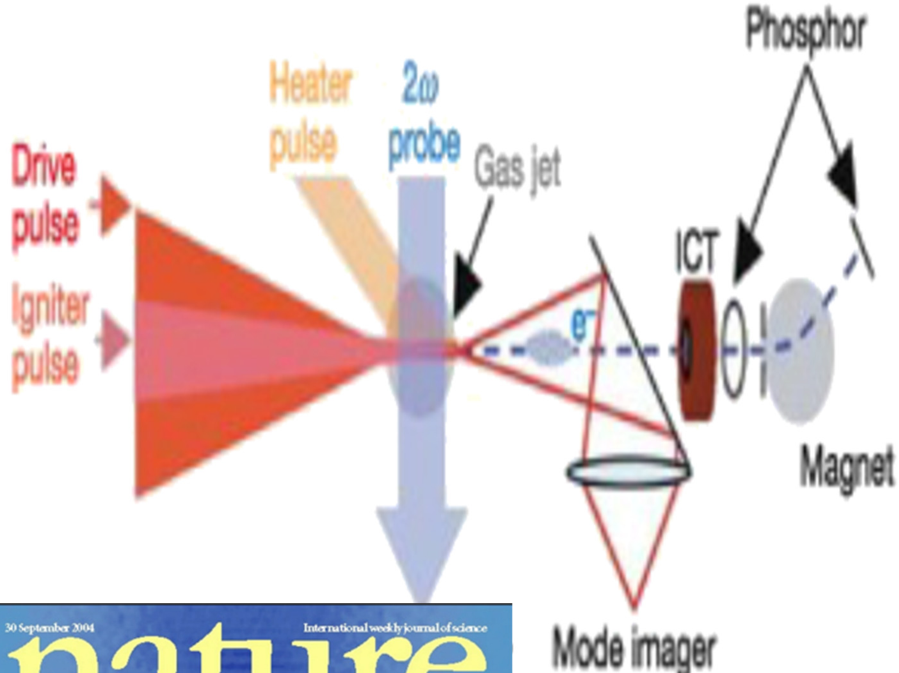
First results approached GeV/cm but:
broad energy spread

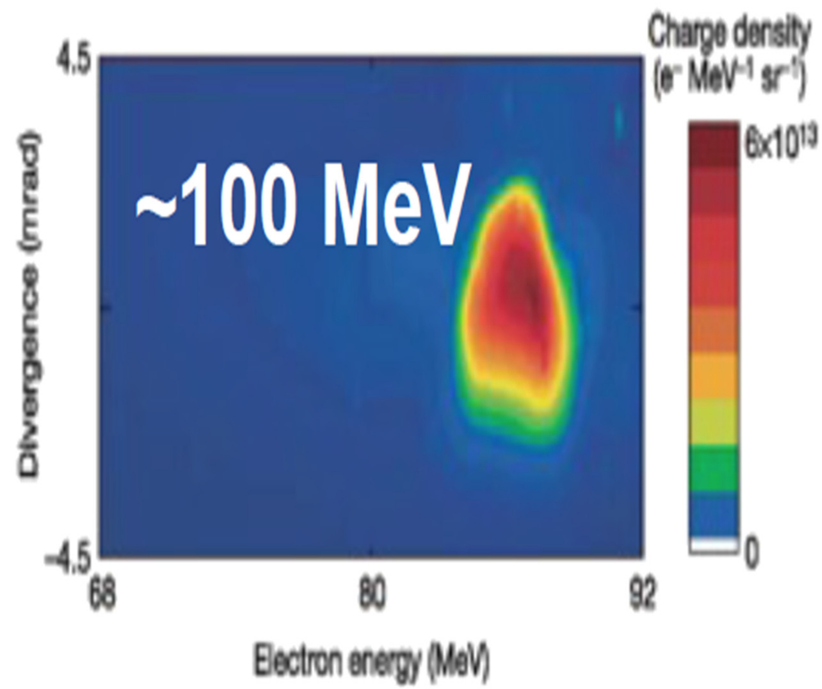
c. 2000 (LBNL and others)



Interaction length & injection not controlled

Extending length – channel guiding: low energy spread

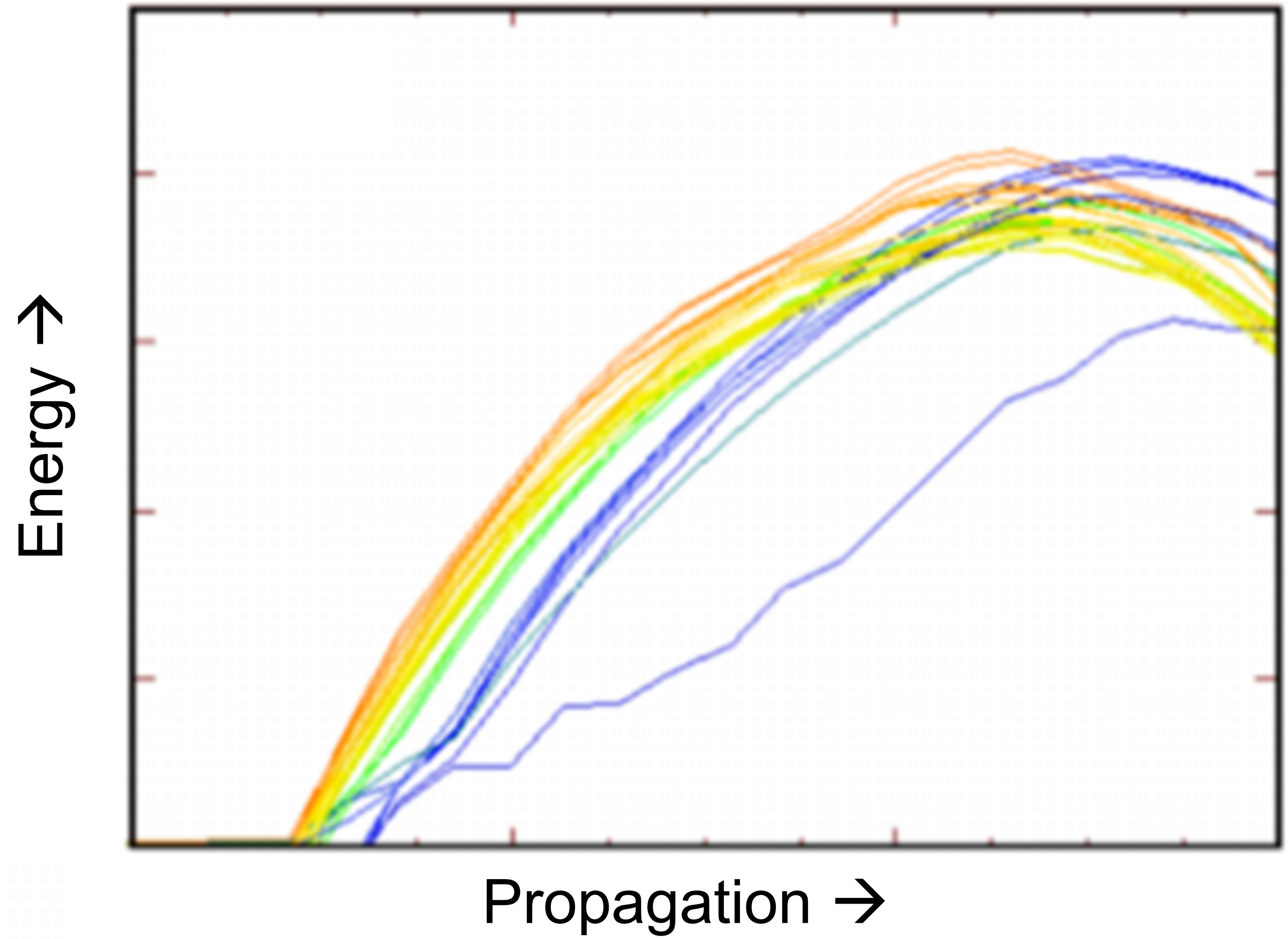




C.G.R. Geddes et al., Nature 431 p538 (2004)
S. Mangles et al., Nature 431 p535 (2004)
J. Faure et al., Nature 431 p541 (2004)

High quality beams:

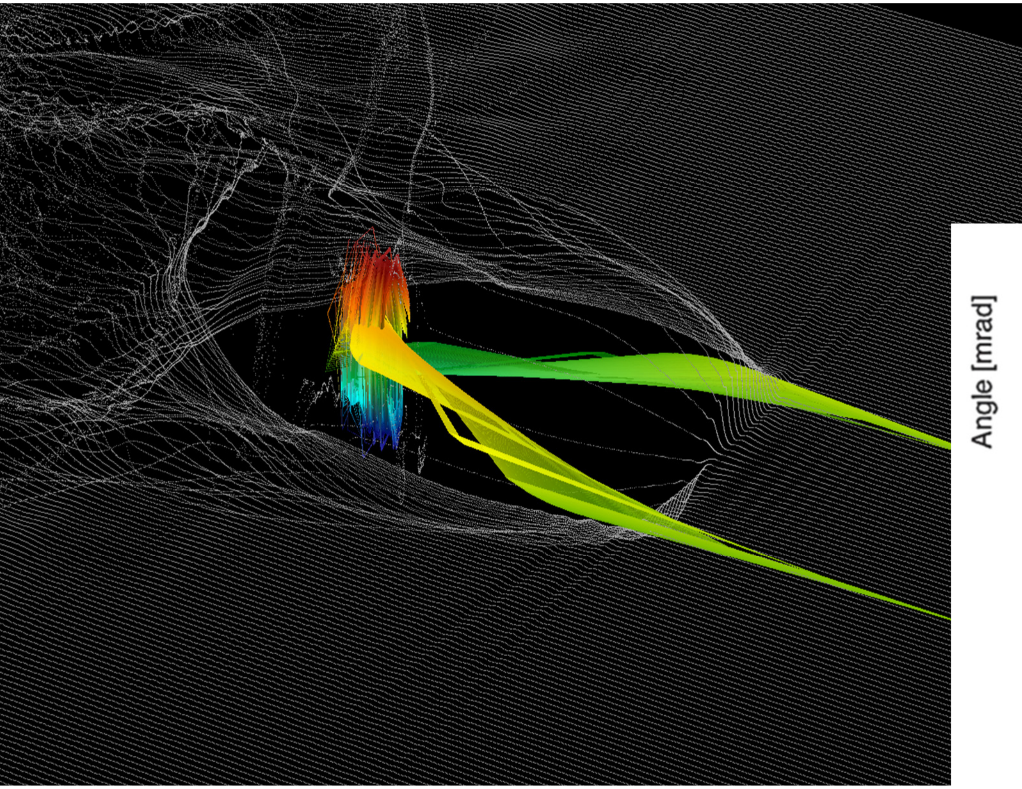
Trajectory crossing at dephasing

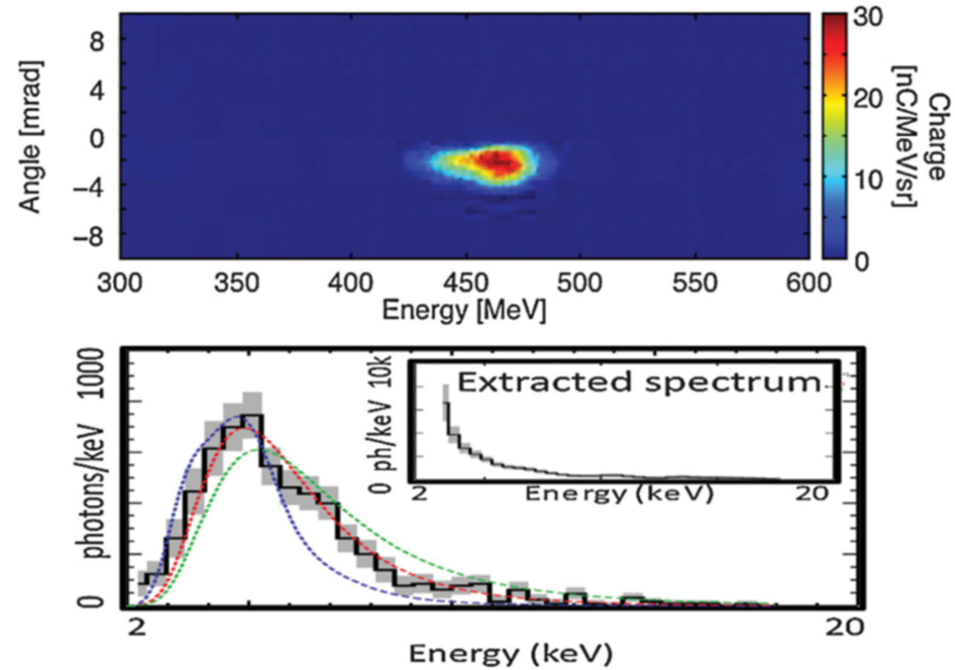


Trajectories indicate high quality accelerator structure

C.G.R. Geddes et al.,SciDAC Review 2009

Low emittance beams:
Trapping control, orbit selection & structure

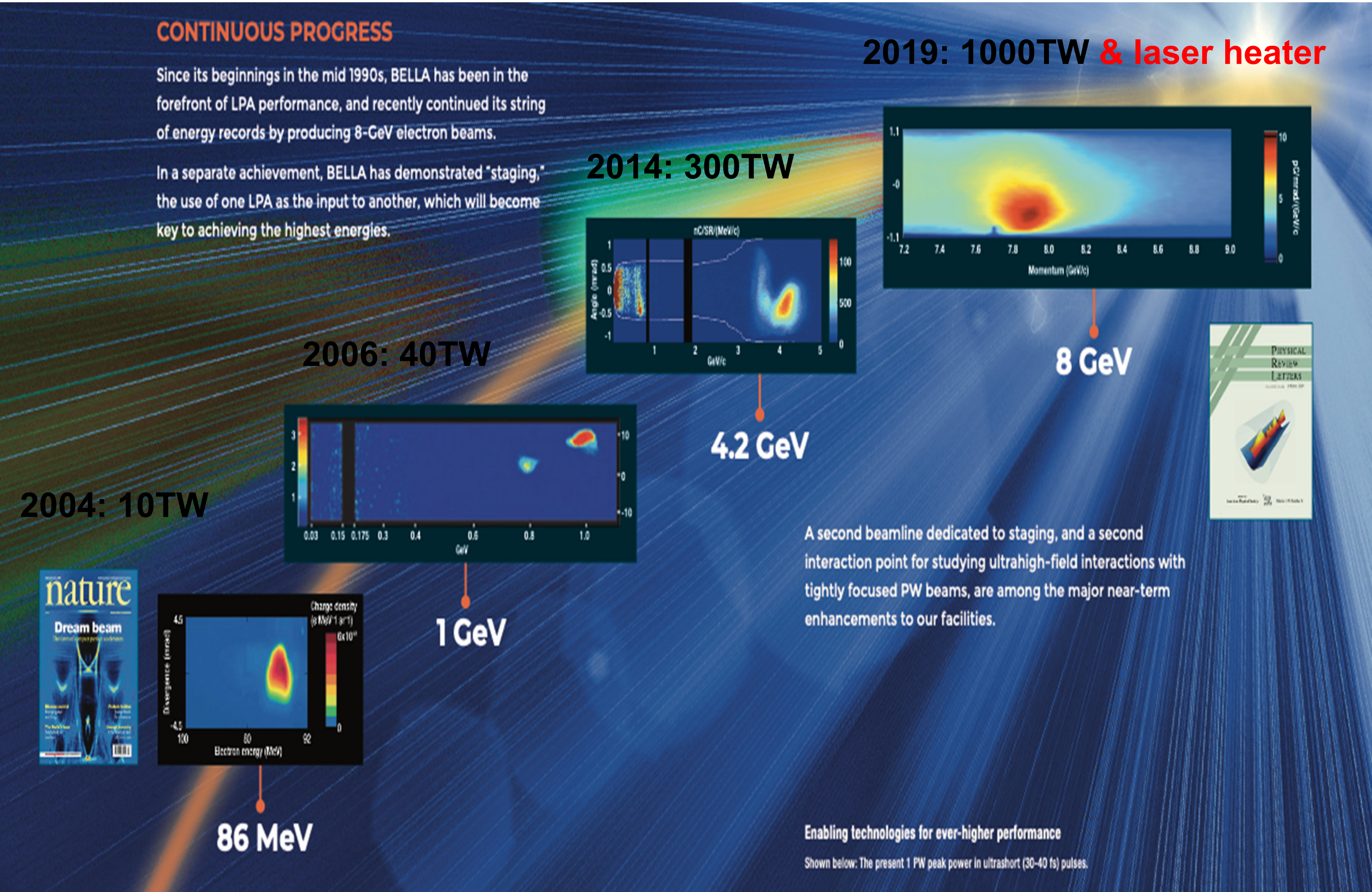




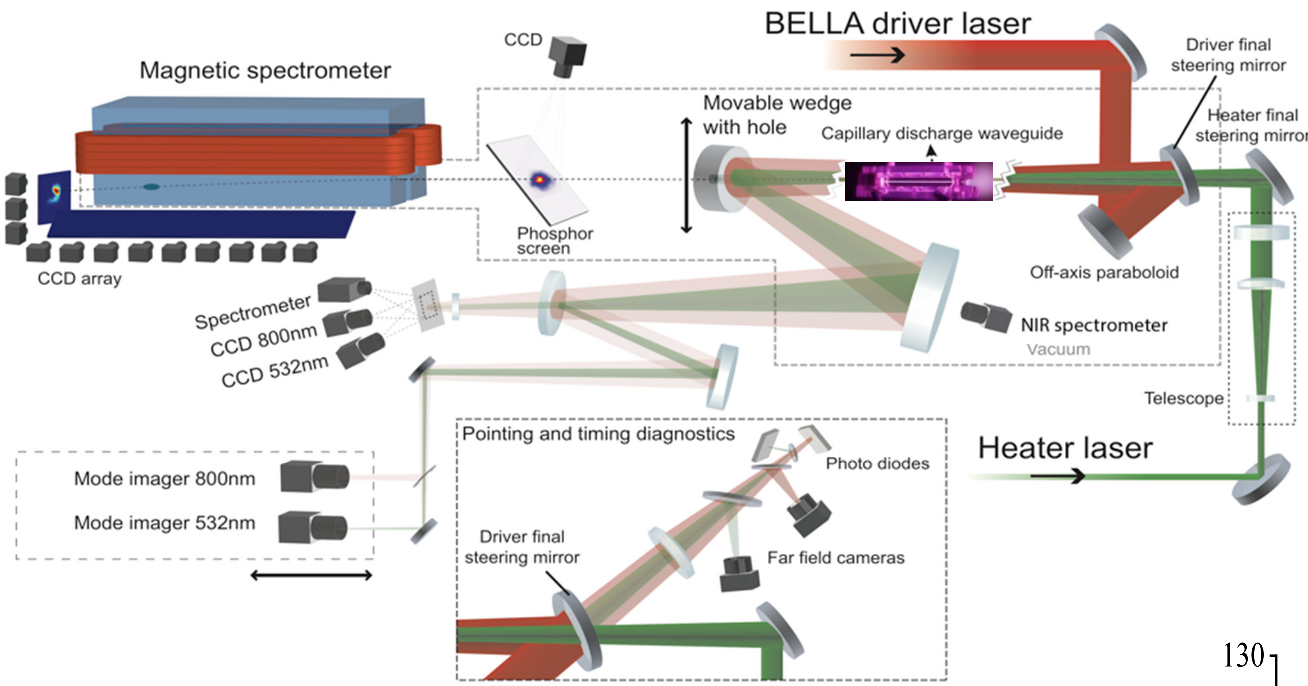
Low emittance, consistent with matching & preservation

Plateau et al., Phys Rev. Lett 2012
Geddes et al., Phys Rev. Lett 2009

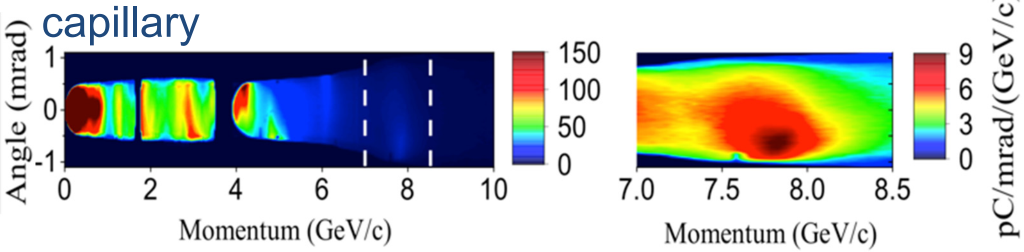
Channel guiding:
Predictable scaling to 8 GeV… and counting

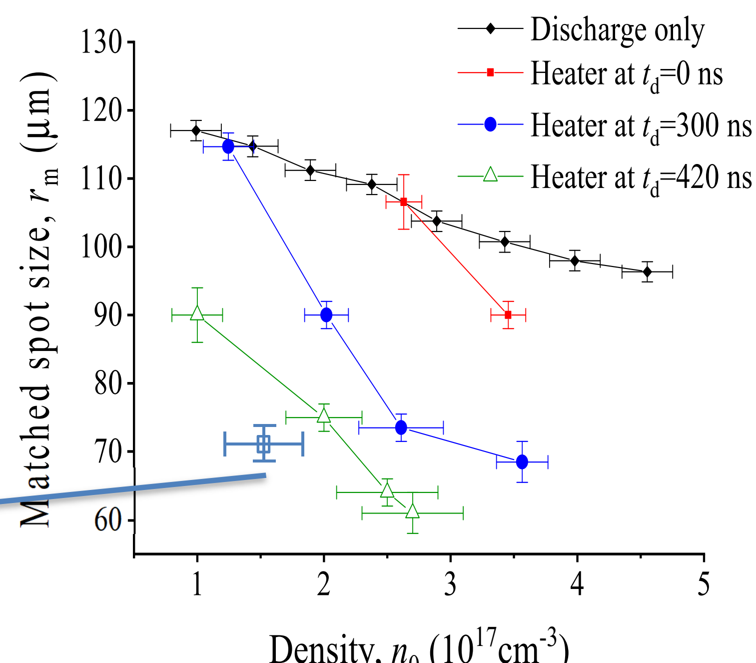


Energy scaling supported by new guides



BELLA @ 0.85PW with laser-heated capillary



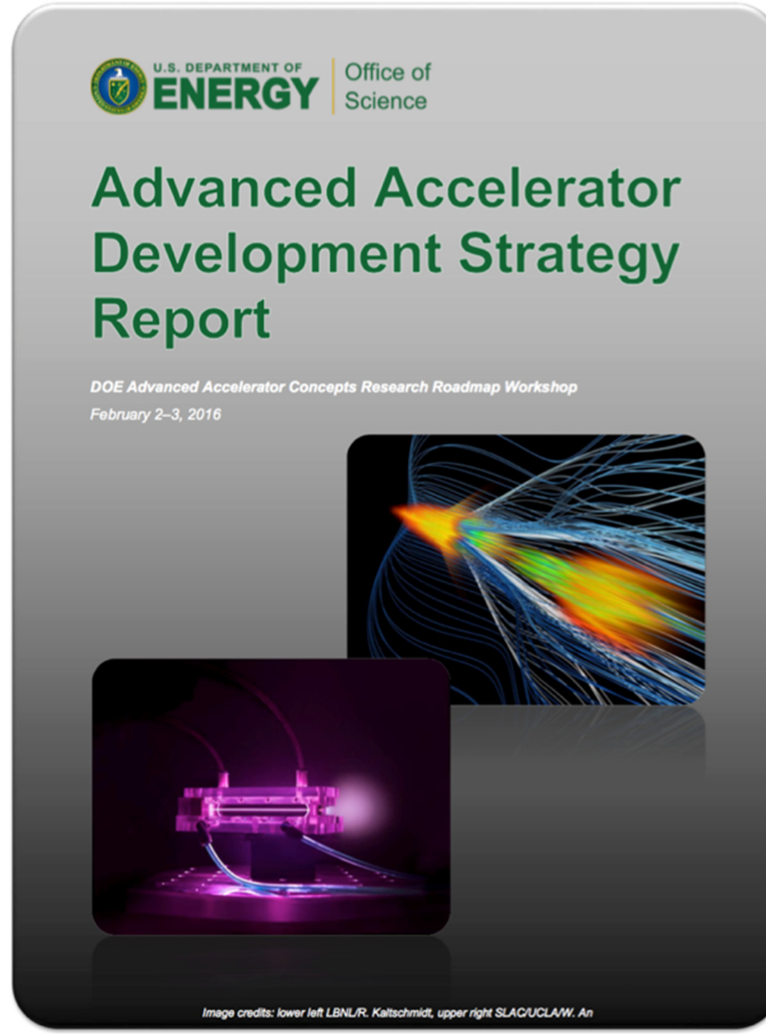


New since paper

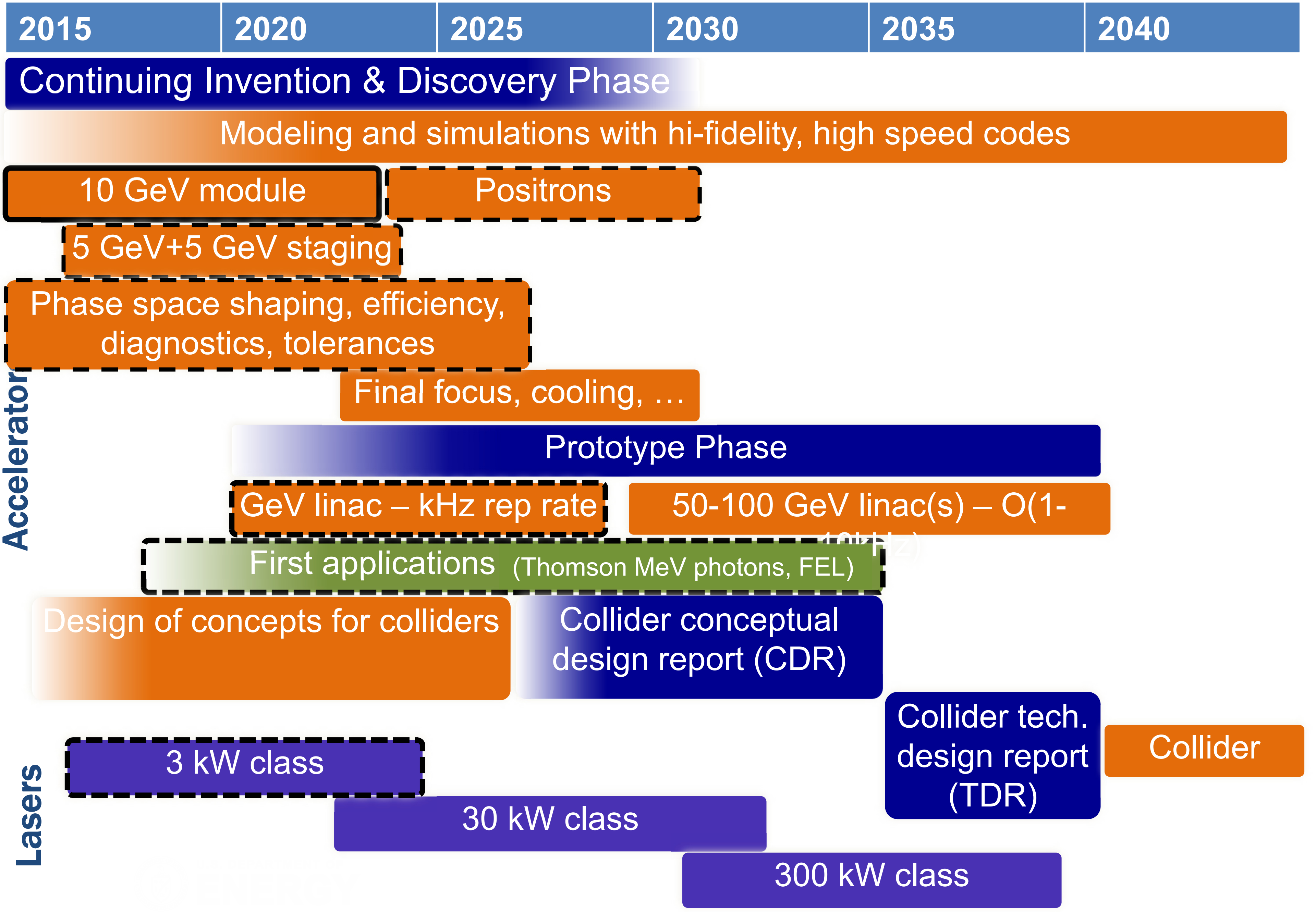
Gonsalves et al., Phys Rev. Lett 2019

Important firsts demonstrated:
Far from optimum, much exciting work to do

Currently	Developing
E: Stable few %	<1%
ΔE: Stable at 10%	<1%
Diverg: ~ mrad	< 0.1mrad
Point: ~ mrad	< 0.1 mrad
Emittance: 0.1 μm	0.01 μm
Charge: ~10 pC	~100pC
Efficiency: few %	~30%
Rate: Hz	≥ kHz
e- only	e-, e+



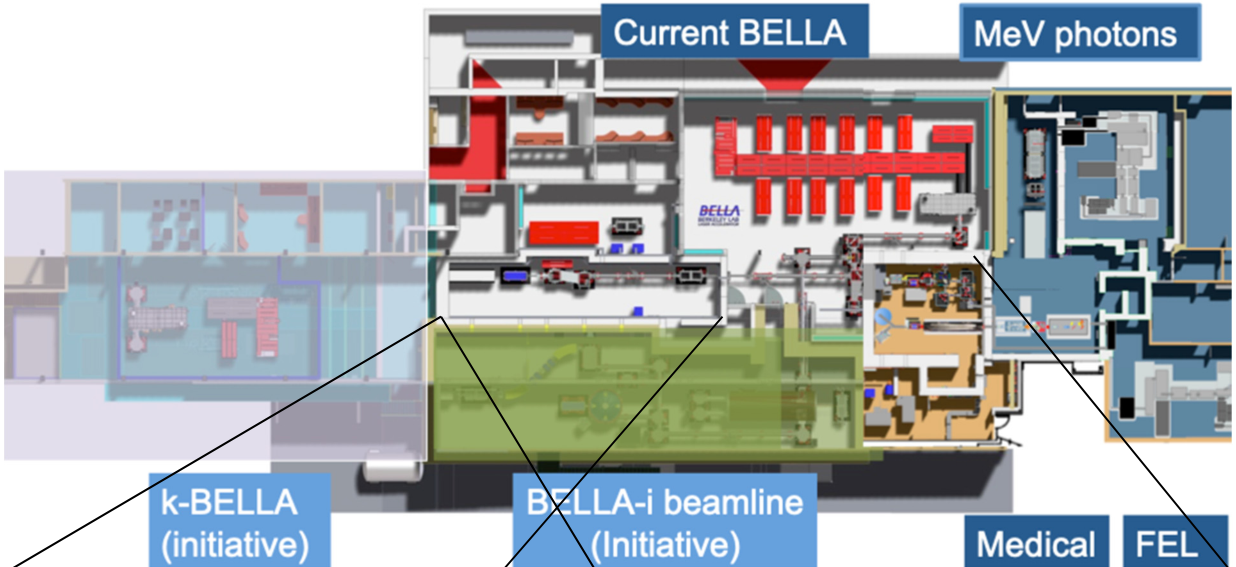
Path forward for Laser Plasma Accelerators



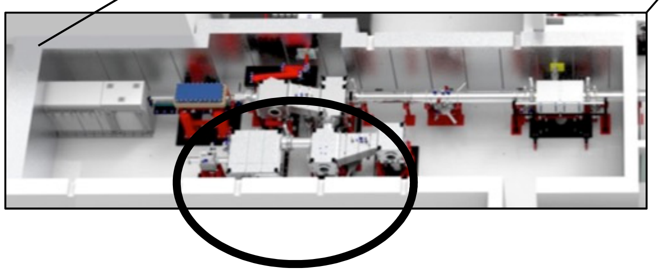
New facilities open multi-GeV staging, high field physics

Sc. HEP

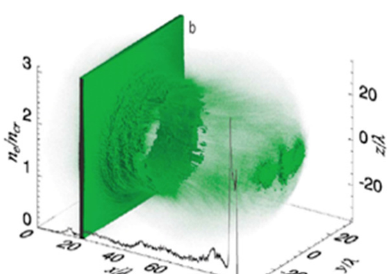
NNSA DNN R&D



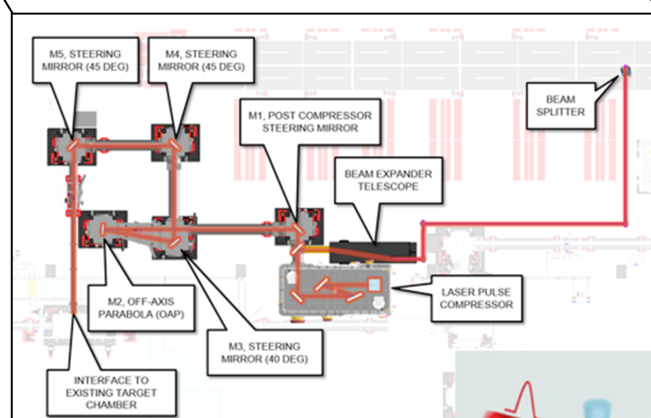
Moore, Sc. BES



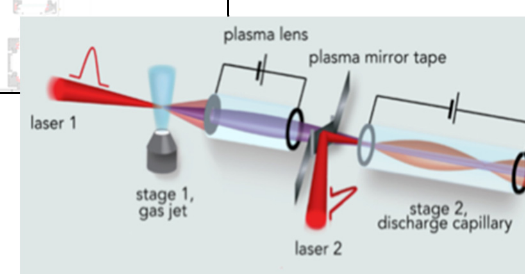
IP2 - Sc. FES
ion acceleration
basic plasma
LaserNetUS



Esirkepov, et al.,
*PRL **92,** 175003 (2004)*

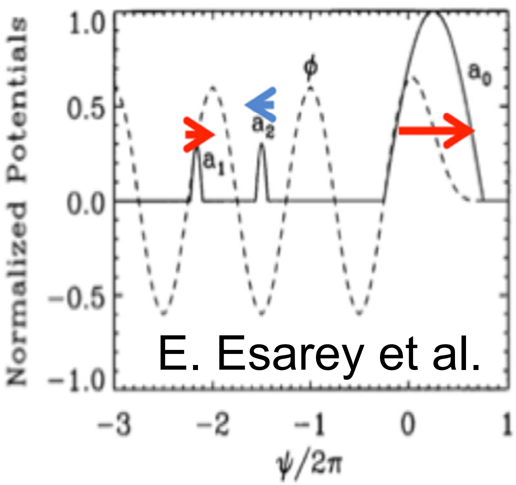


2[nd] Beamline
Sc. HEP
Staging
Positrons
Injection

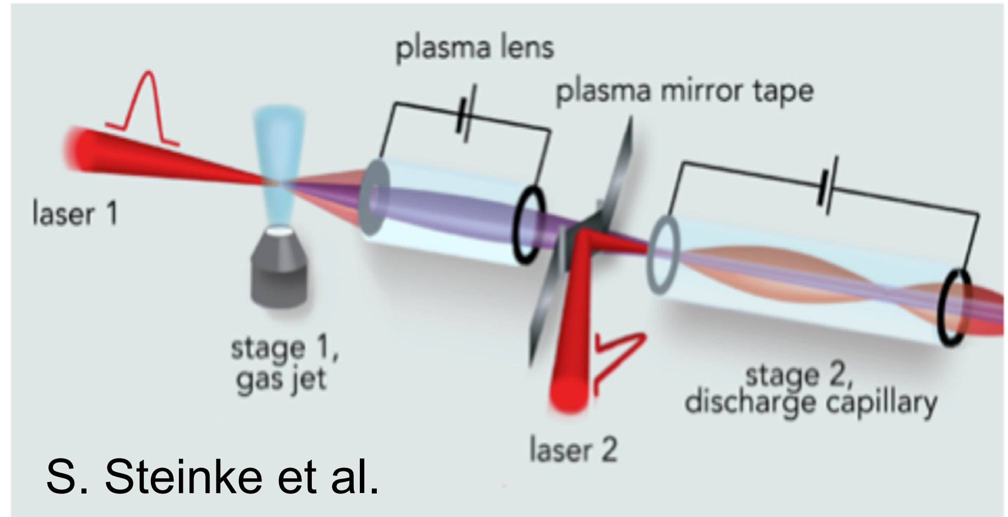


Challenge: generate/manipulate ultra-bright beams– Precision laser and plasma control/shaping

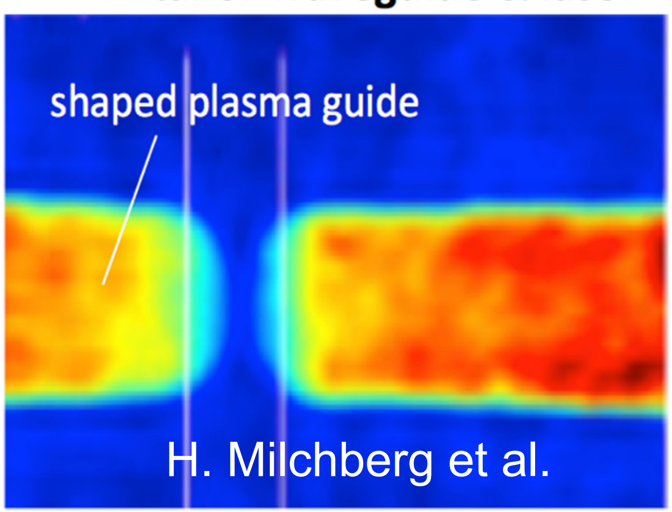
Injection: brighter 6D, shaped bunches



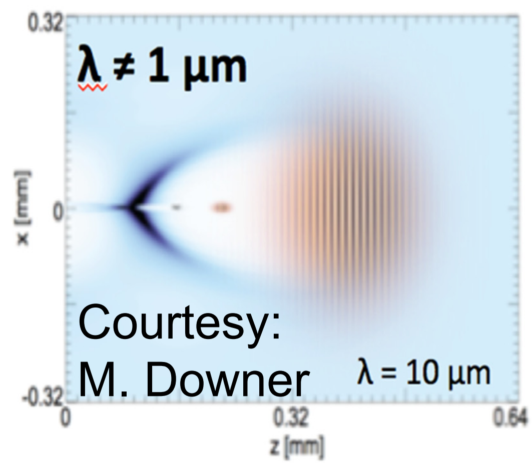
Acceleration: preserve emittance, stage efficiently

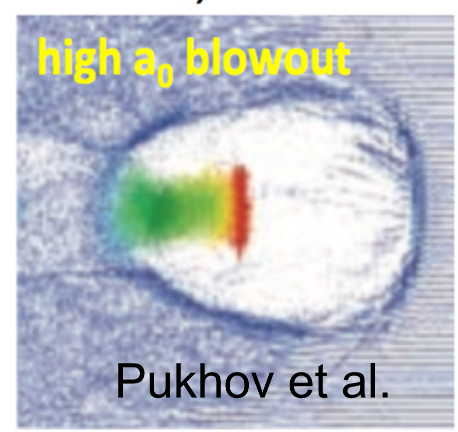


Guiding: reach depletion limit, tailor waveguide & laser



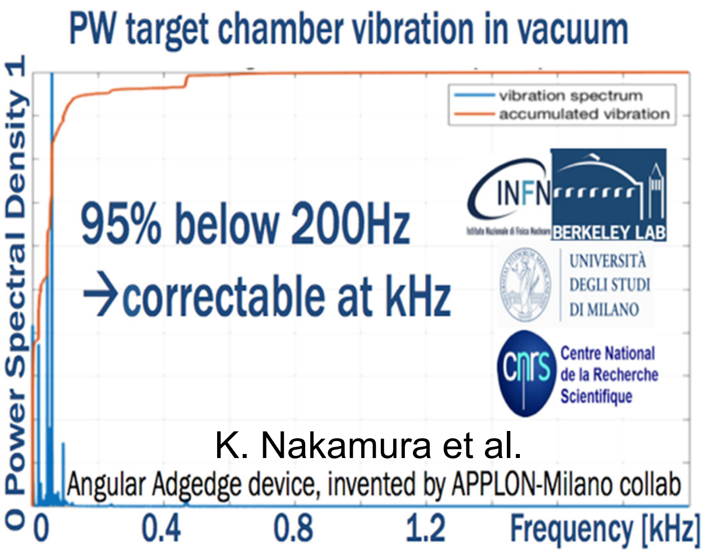
Optimization: scaling with λ, a_0, etc.





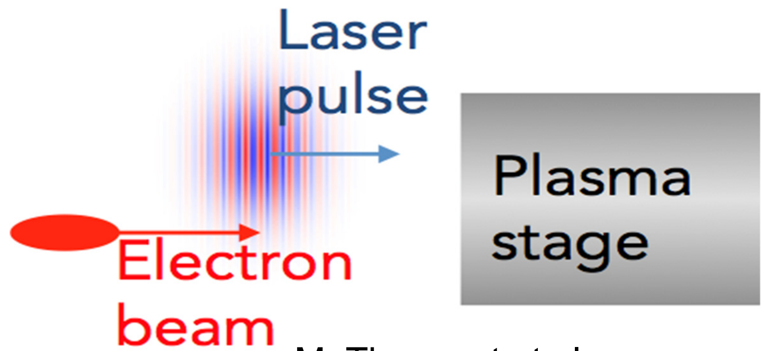
Near future– kHz active feedback:
Precision control to realize LPA potential

Correction
at kHz >10 fold



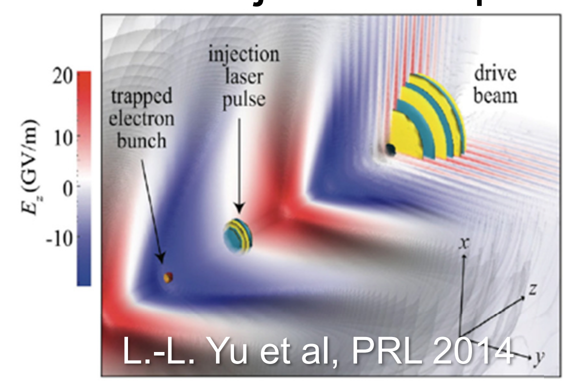
BELLA mJ kHz: 10x reduced pointing fluctuation
Other groups: CEP, spectral phase…

Staging: < μm



M. Thevenet et al

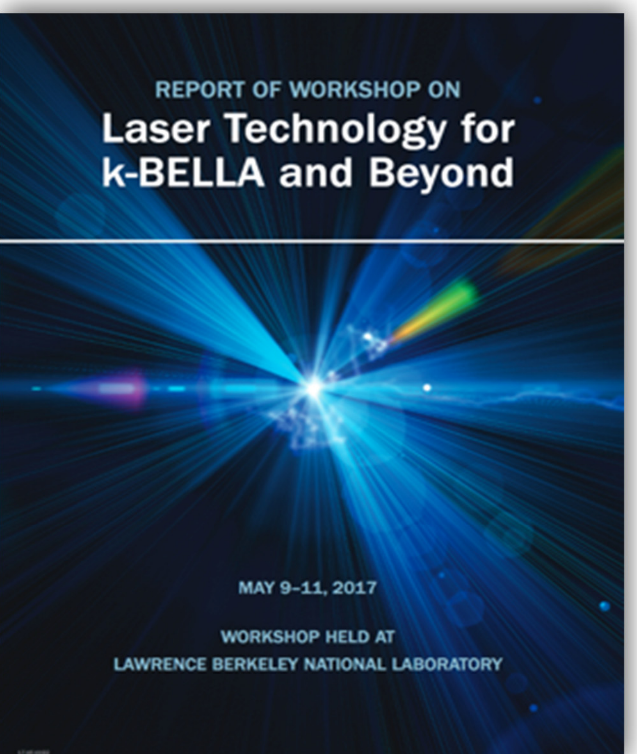
Low-ε injectors:< μm



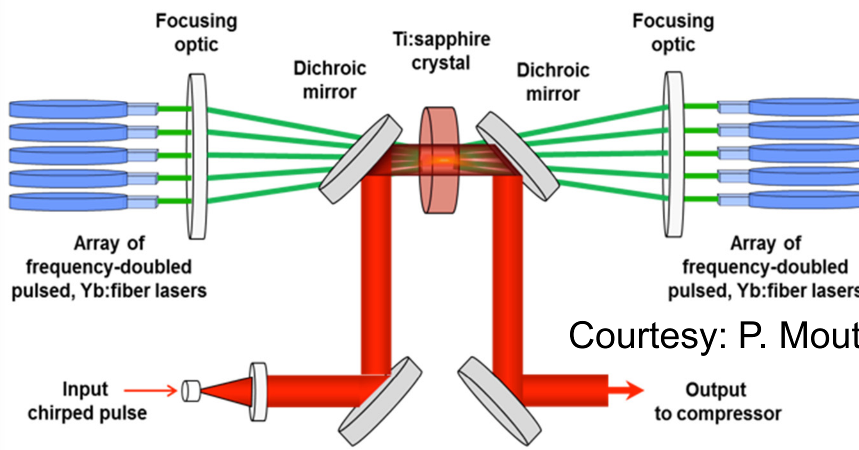
kHz correction demonstrated at mJ energy:

pointing…. pulse-shape, focal spot, wave front

Precision kHz control:
Precision & stability to realize LPA potential

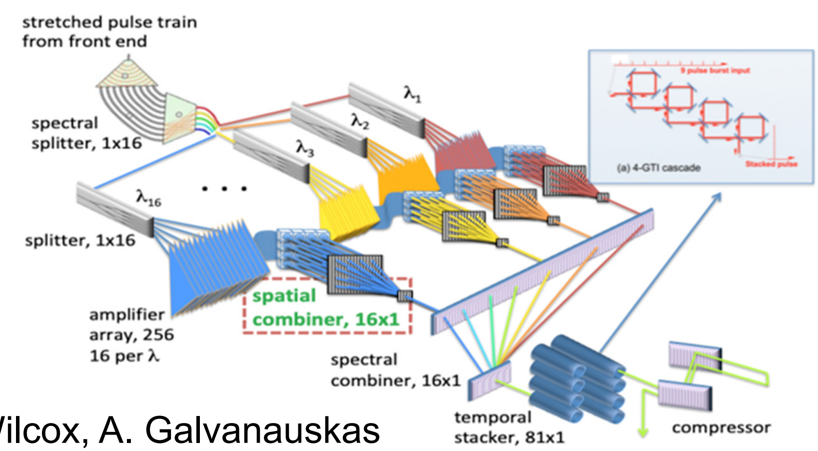


Diode pumps now possible – opens frontier



Courtesy: P. Mouton

Efficient fibers & media – efficient path



Courtesy: R. Wilcox, A. Galvanauskas

kHz-Joule class enables precision LPA at GeV-class

With thanks to colleagues at LBNL

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Interim Division Director, ATAP

Carl Schroeder
Deputy Center Director, Theory

Eric Esarey
BELLA Center Director

Cameron Geddes
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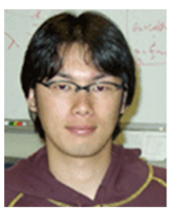
Staff


Csaba Toth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Tony Gonsalves


Jeroen van Tilborg


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Hai-En Tsai
Tong Zhou

Doctoral Students

Blagoje Djordjevic,
Fumika Isono
Kelly Swanson
Liona Fan-Chiang
Chris Pieronek

Also: Accelerator Modeling (AMP) and Controls & Instrumentation (BACI) programs

With thanks to the plasma accelerator community

Advanced Accelerator Concepts Workshop

- 37 presentations and 21 posters

Summary of Working Group 1: Laser-Plasma Wakefield Acceleration

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***Abstract*—Advances in and the physics of the acceleration of electrons and positrons using underdense plasma structures driven by lasers were the topics of presentations and discussions in Working Group 1. Such accelerators have demonstrated gradients several orders beyond conventional machines, with quasi-monoenergetic beams at MeV-GeV energies, making them attractive candidates for next generation accelerators and photon sources. The status, future direction, and research outlook are summarized and references given to group presentations.**

***Keywords*—laser-plasma accelerators, laser wakefield acceleration, positron acceleration, staging, injection, laser guiding**

I. Introduction

Working Group 1 (WG1) focused on the acceleration of electrons and positrons using laser-plasma wakefield accelerators (LPAs). Workshop discussions included advances in control over injection and laser guiding to further improve beam quality and stability; techniques for accelerator efficiency, beam quality preservation and staging; detailed diagnostics; radiation generation as a photon source and diagnostic; and beam manipulation. Paths from current results towards achieving parameters required for applications, particularly high energy physics (HEP) colliders at the TeV scale and compact photon sources (such as MeV Thomson sources and free electron lasers) were discussed.

The working group hosted eight oral sessions with 37 presentations and 21 posters. The roles of both plasma wakefield acceleration driven by lasers and of direct laser acceleration were discussed. The working group, including three joint sessions, was organized around six themes:

- Controlled particle injection into the wake for beams that are stable and of higher quality and charge.
- Diagnostic techniques including radiation sources as well as accelerator controls to improve operability.
- Acceleration with preservation of beam quality (special focus on hosing) and efficient transfer of laser energy to realize performance goals.
- Staging multiple plasma elements, including beam manipulation, for high beam energies in colliders and beam disposal (deceleration) in photon sources.
- Guiding of the drive laser pulses to extend the laser-plasma interaction/acceleration length.
- Novel regimes in driver duration, driver wavelength, or plasma density that open new capabilities.

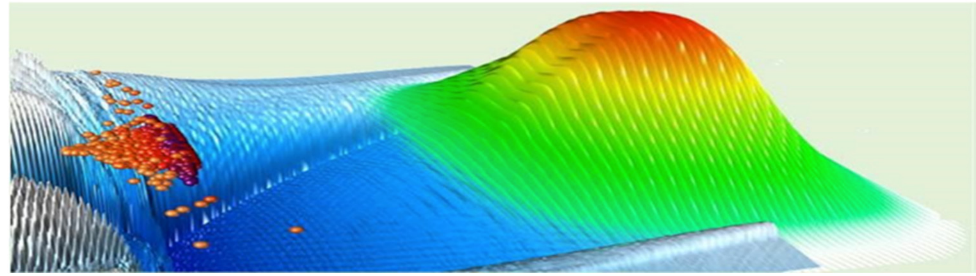
This summary paper presents highlights from each of the themes on progress in laser-plasma acceleration physics and towards meeting the needs of applications. Detailed results and references may be found in the respective papers in these proceedings. Presented results build on past work in these and related techniques, as reviewed in [1-3].

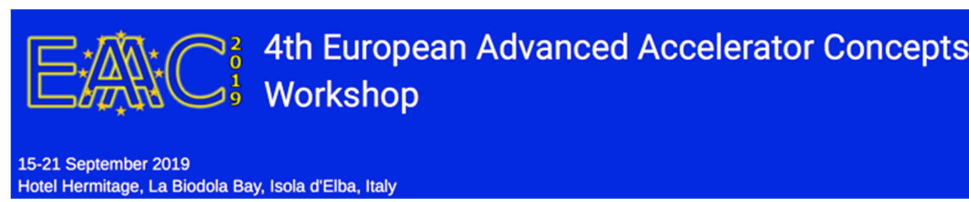
II. Controlled Particle Injection

Injection control is the first key element to obtaining high quality beams. Injection of the appropriate charge and longitudinal bunch shape is required such that acceleration (including beam loading and dephasing) will produce narrow energy spread and high flux. Transverse emittance should also be minimized for focusability of the beam and photon source performance. Progress was presented on ionization, multi-pulse, and external injection techniques. Posters and presentations in Working Group 7 (Radiation Generation and Advanced Concepts) and Working Group 4 (Beam-Driven Acceleration) additionally addressed plasma density transition or 'downramp' injection and 'self' injection. While self-trapping, which occurs when the wake reaches an amplitude sufficient to trap electrons from the plasma through which it propagates, is simple, it offers very limited control. Separate control over electron injection into a wake driven to an amplitude below the self-trapping threshold is hence important so that injection and wake can be tuned independently. Progress was made on several such techniques.

Ionization can be used to control injection into the wake if a gas or gas mixture is used which has ionization states near the peak intensity of the wake drive laser. The leading edge of the driver at low intensity ionizes the bulk states producing a plasma in which the wake is driven. The last state(s) are ionized near the peak of the laser pulse, injecting electrons at near-zero velocity, which are therefore trapped by the wake where the bulk plasma is not. For high-quality beams, injection must be localized and residual ionization momentum

2017 Laser Plasma Accelerator Workshop





Thank you