Positron Acceleration
using
Plasma-based accelerators

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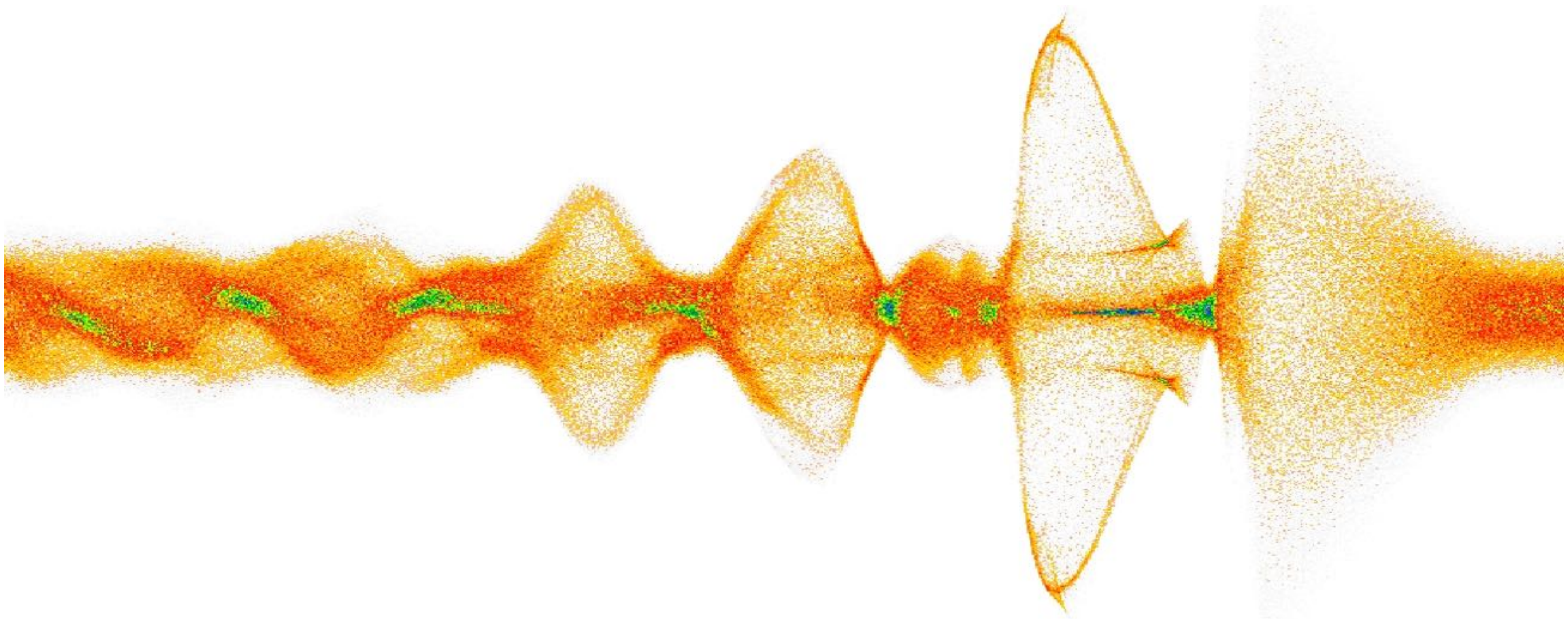

Outline

- Motivation – collider for Higgs factory and SUSY
- Positron acceleration – current challenges
- Homogeneous plasma – coherent structure
- Homogeneous plasma – focusing forces
- Hollowed-out laser modes - possibility
- Hollow channels / Ion-Wake channels - possibility
- Summary

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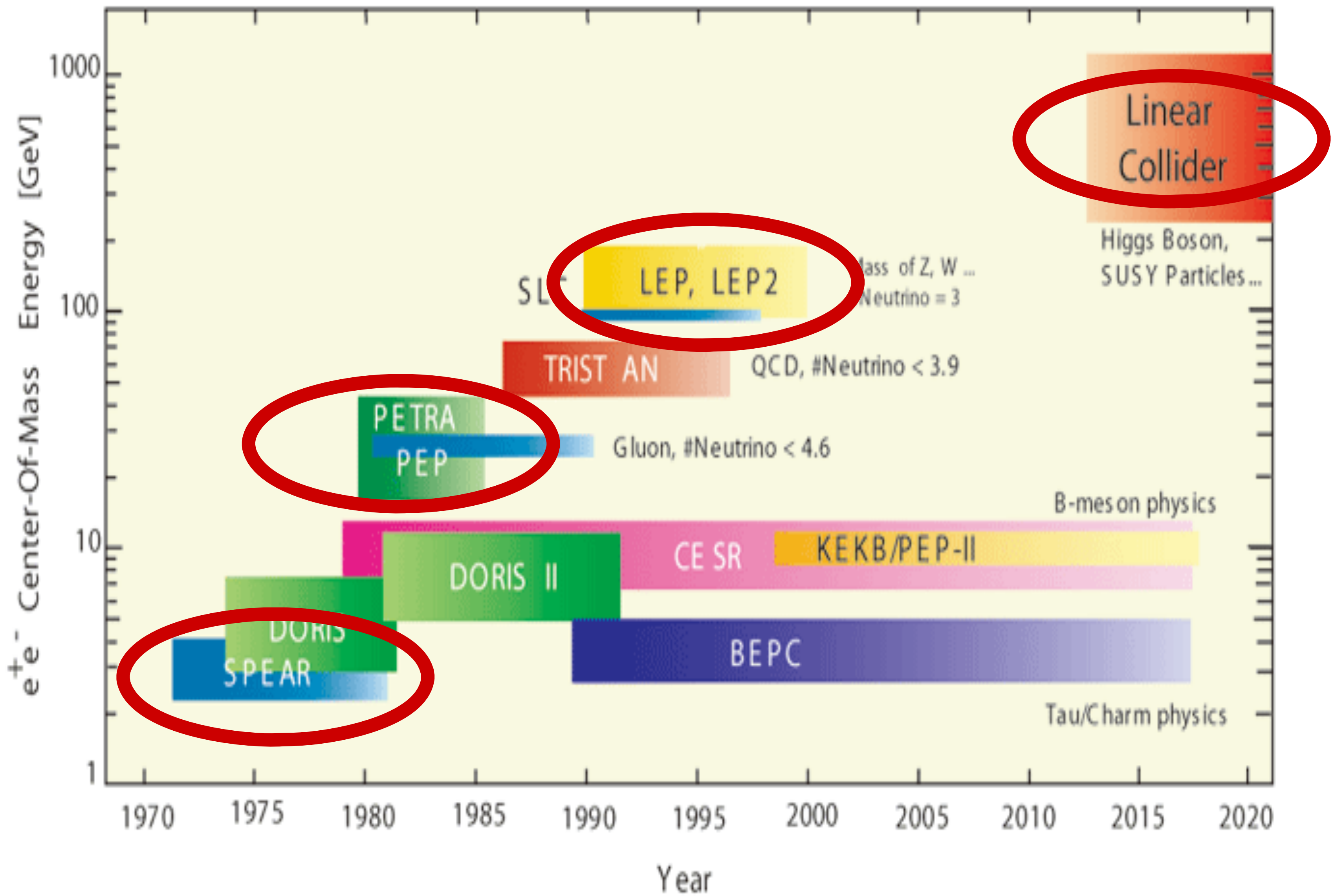
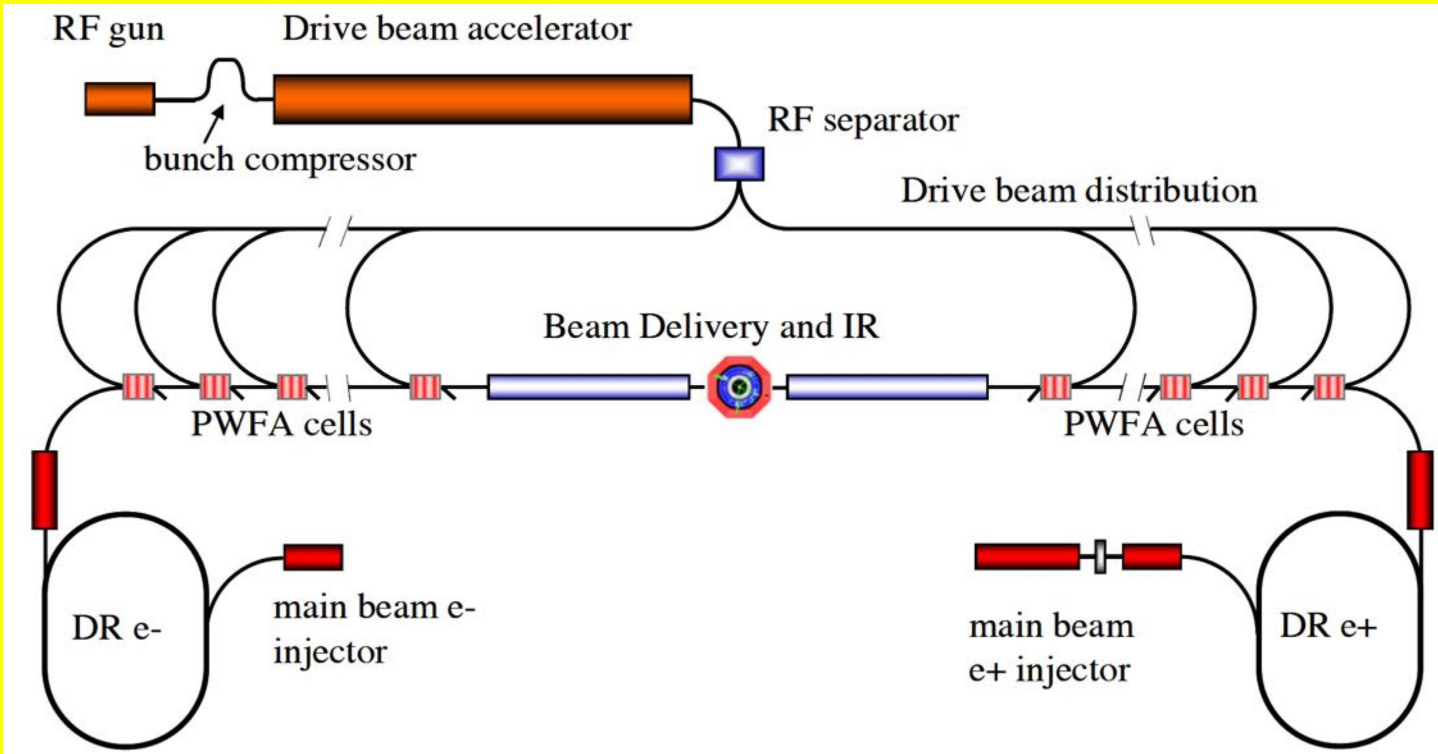
Motivation

electron – positron collider



Motivation

Plasma-based Collider – beam-driven



arXiv.org > physics > arXiv:1308.1145

Physics > Accelerator Physics

A Beam Driven Plasma-Wakefield Linear Collider: From Higgs Factory to Multi-TeV

Erik Adli, Jean-Pierre Delahaye, Spencer J. Gessner, Mark J. Hogan, Tor Raubenheimer, Weiming An, Chan Joshi, Warren Mori

(Submitted on 6 Aug 2013 (v1), last revised 29 Sep 2013 (this version, v2))

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Motivation

Plasma-based Collider – laser-driven

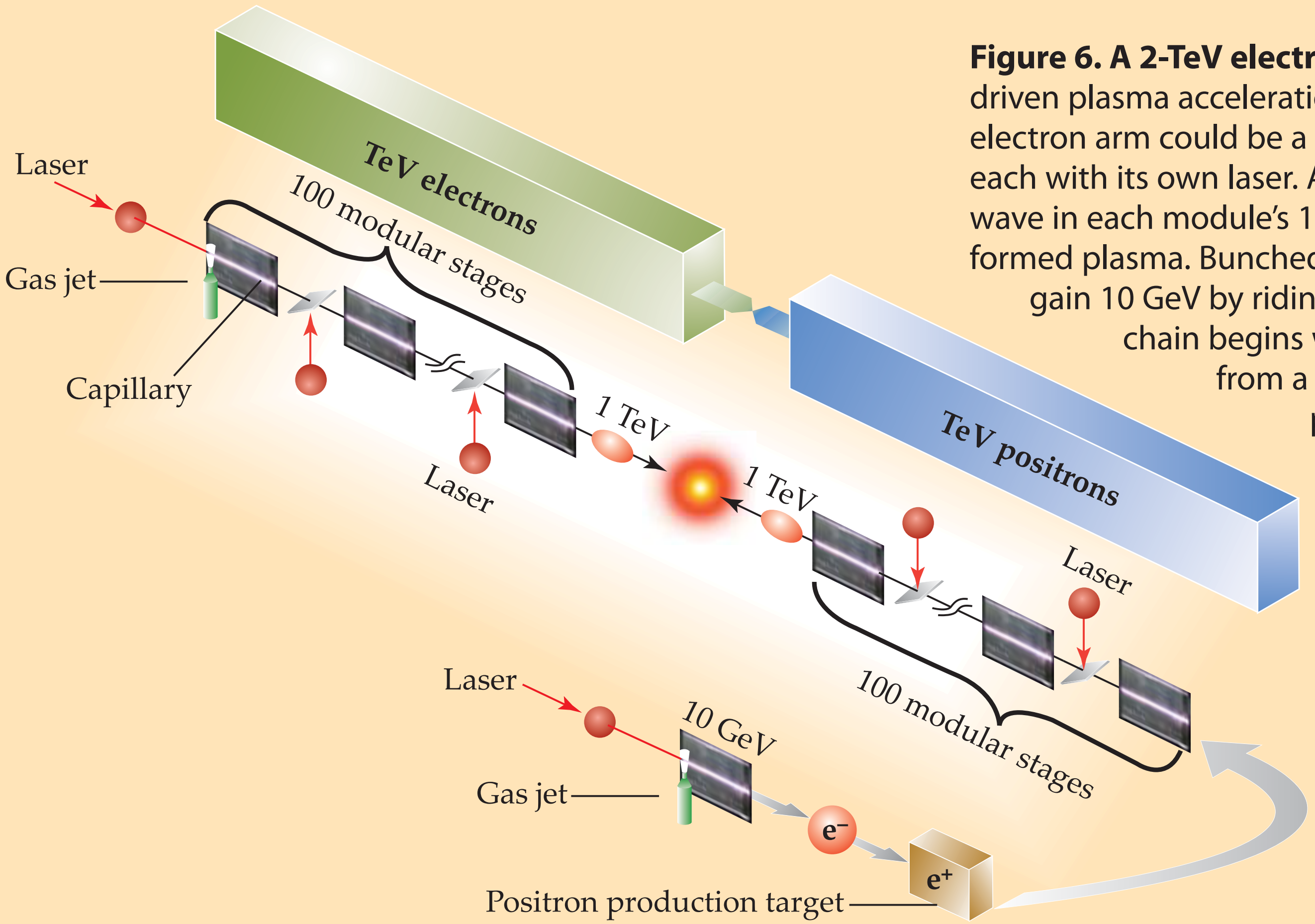

Figure 6. A 2-TeV electron–positron collider based on laser-driven plasma acceleration might be less than 1 km long. Its electron arm could be a string of 100 acceleration modules, each with its own laser. A 30-J laser pulse drives a plasma wave in each module's 1-m-long capillary channel of pre-formed plasma. Bunched electrons from the previous module gain 10 GeV by riding the wave through the channel. The chain begins with a bunch of electrons trapped from a gas jet just inside the first module's plasma channel. The collider's positron arm begins the same way, but the 10-GeV electrons emerging from its first module bombard a metal target to create positrons, which are then focused and injected into the arm's string of modules and accelerated just like the electrons.

Laser-driven plasma-wave electron accelerators

Wim Leemans and Eric Esarey

Citation: Phys. Today **62**(3), 44 (2009); doi: 10.1063/1.3099645

View online: http://dx.doi.org/10.1063/1.3099645

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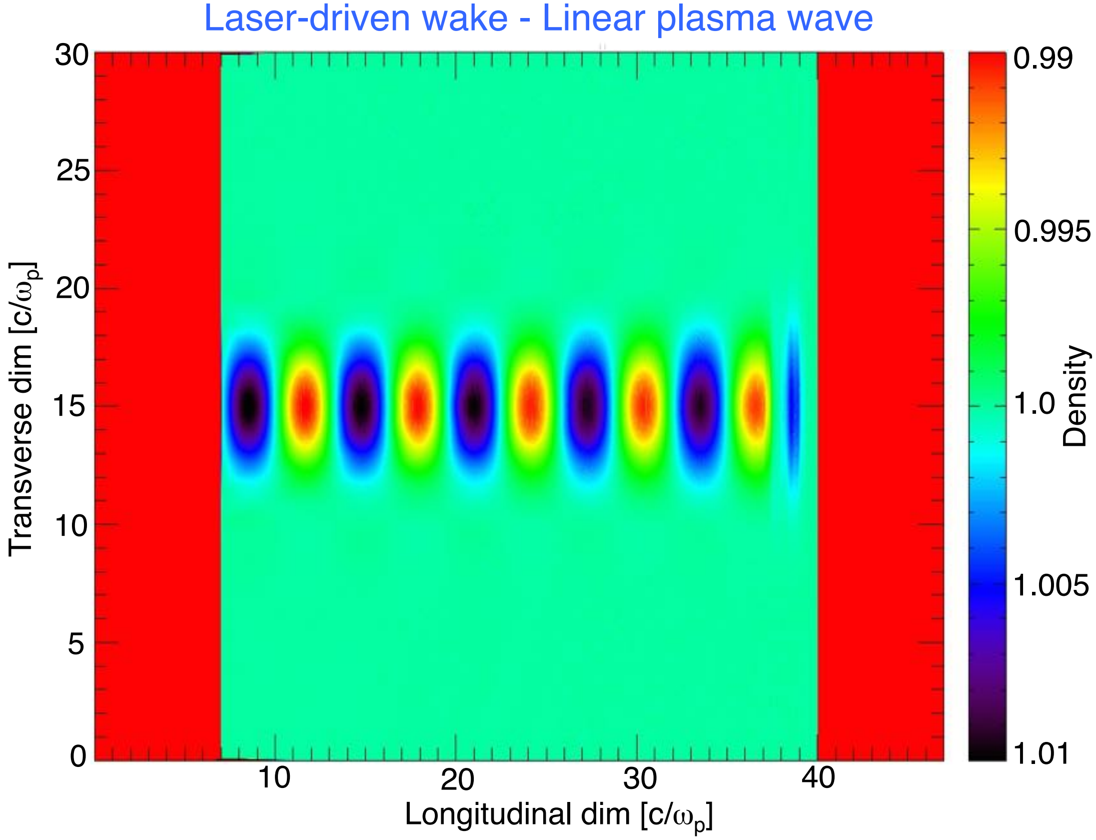
Challenges

positrons

- external injection – self-injection *not yet conceived*
- Plasma-wave phase-space volume – focusing & acc



evacuated regions

accelerating

defocusing

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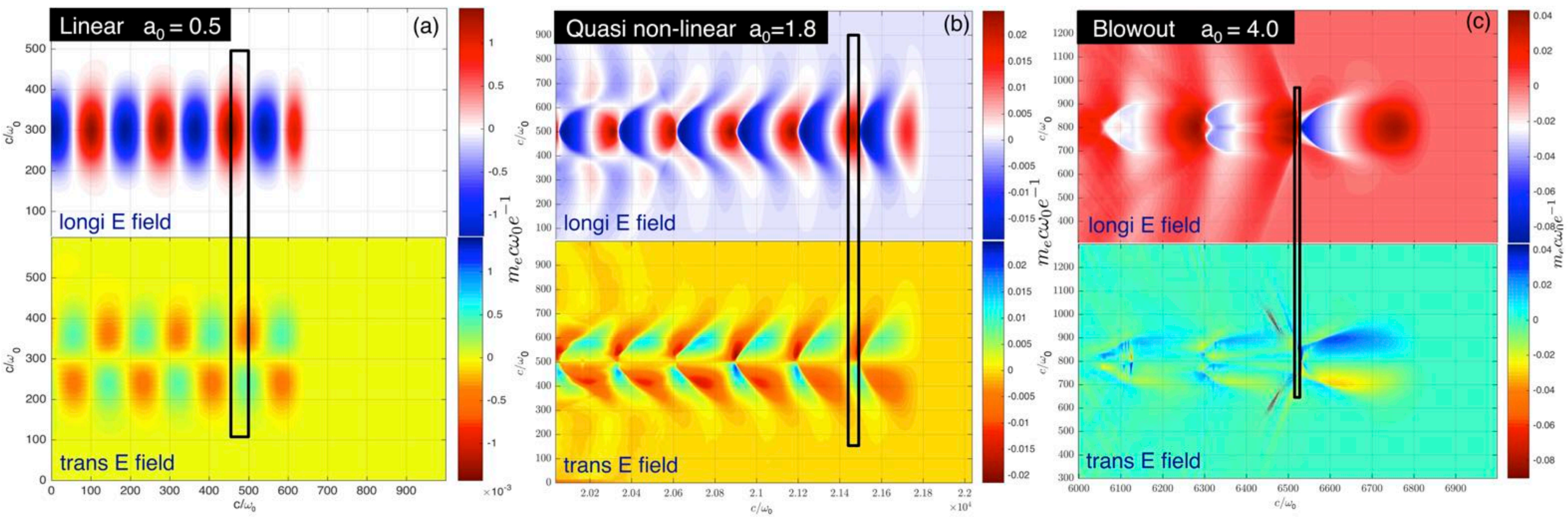
Challenges

positrons

- Laser self-guiding – typically non-linear regime
- Beam-driven waves – same problem



possible solutions

1. Hollow plasma channel
   - e^+ beam – no interaction with ions
   - shown the Crunch-in regime

2. Hollow-out laser modes – LG mode
   - drive excess electrons on-axis
   - PRL 112, 215001 (2014)

3. Leptonic beam – proposed
   - reduced space-charge beam
   - possible RAL / Gemini expt.

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Hollow-channel

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Hollow-channel

positron-beam driven

LETTER

doi:10.1038/nature14890

Multi-gigaelectronvolt acceleration of positrons in a self-loaded plasma wakefield

S. Corde[1,2], E. Adli[1,3], J. M. Allen[1], W. An[4,5], C. I. Clarke[1], C. E. Clayton[4], J. P. Delahaye[1], J. Frederico[1], S. Gessner[1], S. Z. Green[1], M. J. Hogan[1], C. Joshi[4], N. Lipkowitz[1], M. Litos[1], W. Lu[6], K. A. Marsh[4], W. B. Mori[4,5], M. Schmeltz[1], N. Vafaei-Najafabadi[4], D. Walz[1], V. Yakimenko[1] & G. Yocky[1]

vents positron acceleration. To avoid this problem, the use of a hollow plasma channel to produce wakes without a focusing force[13–15], or the

electron-beam driven

VOLUME 81, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1998

High Beam Quality and Efficiency in Plasma-Based Accelerators

T. C. Chiou and T. Katsouleas

The focusing force is zero inside the channel for a very relativistic particle. The spikes at the channel walls are

Problem definition - II

laser-pulse driven

Laser wakefield acceleration and optical guiding in a hollow plasma channel

T. C. Chiou, T. Katsouleas, C. Decker, W. B. Mori, J. S. Wurtele, G. Shvets, and J. J. Su

Citation: Physics of Plasmas (1994-present) **2**, 310 (1995); doi: 10.1063/1.871107

channel. The electromagnetic fringe fields of the wake extend to the center of the channel, enabling focusing and acceleration of particles down the axis. This scheme differs

ated, so that the wake fields arise from surface currents at the channel edge rather than density bunching at the channel axis.

Control of focusing forces and emittances in plasma-based accelerators using near-hollow plasma channels PHYSICS OF PLASMAS **20**, 080701 (2013)

C. B. Schroeder, E. Esarey, C. Benedetti, and W. P. Leemans
Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA

The wake excited in such a channel will consists of an electromagnetic wake owing to surface currents driven in the channel walls and a wake owing to the background ions in the channel. In the limit $k_c^2 \ll k_w^2$, the accelerating field in

Linear regime - Hollow-channel

Laser-driven

$r_{ch} = 3\ c/\omega_{pe}$

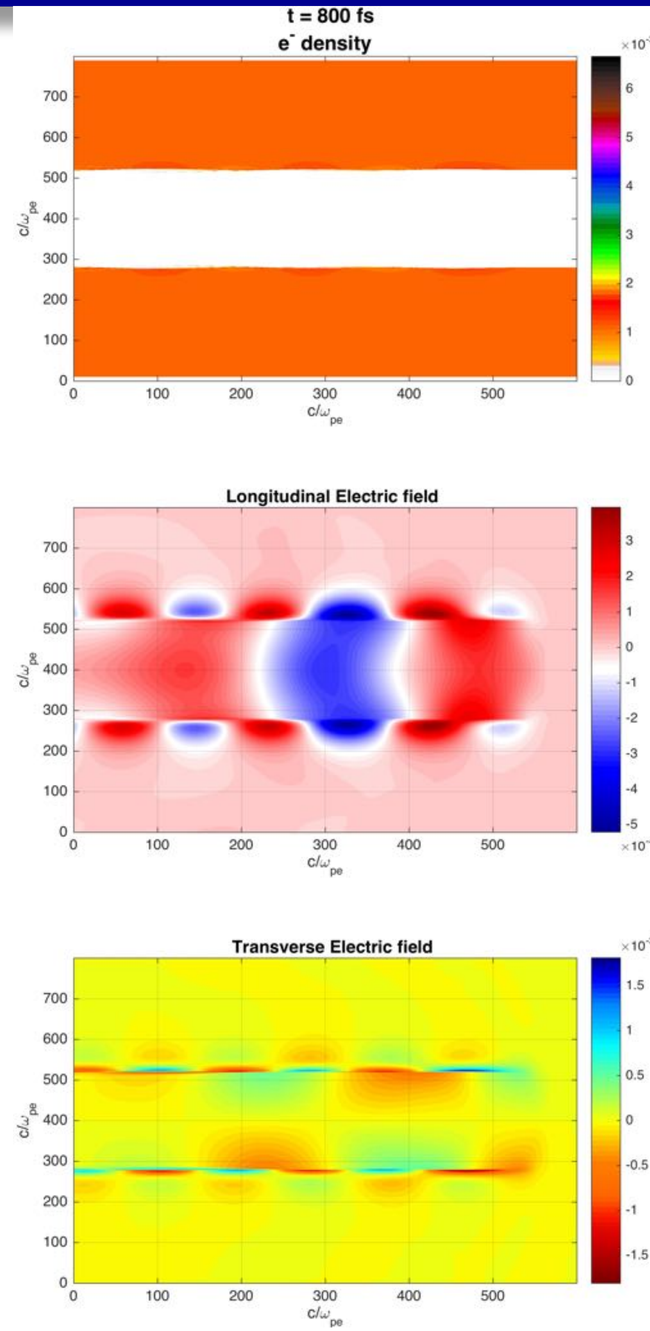
$a_0 = 4.0$
$w_0 = 2.5\ c/\omega_{pe}$

$\omega_0 / \omega_{pe} = 30$

source of the wakefields –

currents in the wall

EM acc. & focusing fields leak into the channel ~ $\mathbf{10^{-3}\ E_{WB}}$



CART
geometry

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e$^-$-beam Lin. regime - Hollow-channel

e$^-$-beam -driven

$r_{ch} = 16\ c/\omega_{pe}$

$n_b = 1.5\ n_0$
$\sigma_z = 1.5\ c/\omega_{pe}$
$\sigma_r = 0.5\ c/\omega_{pe}$

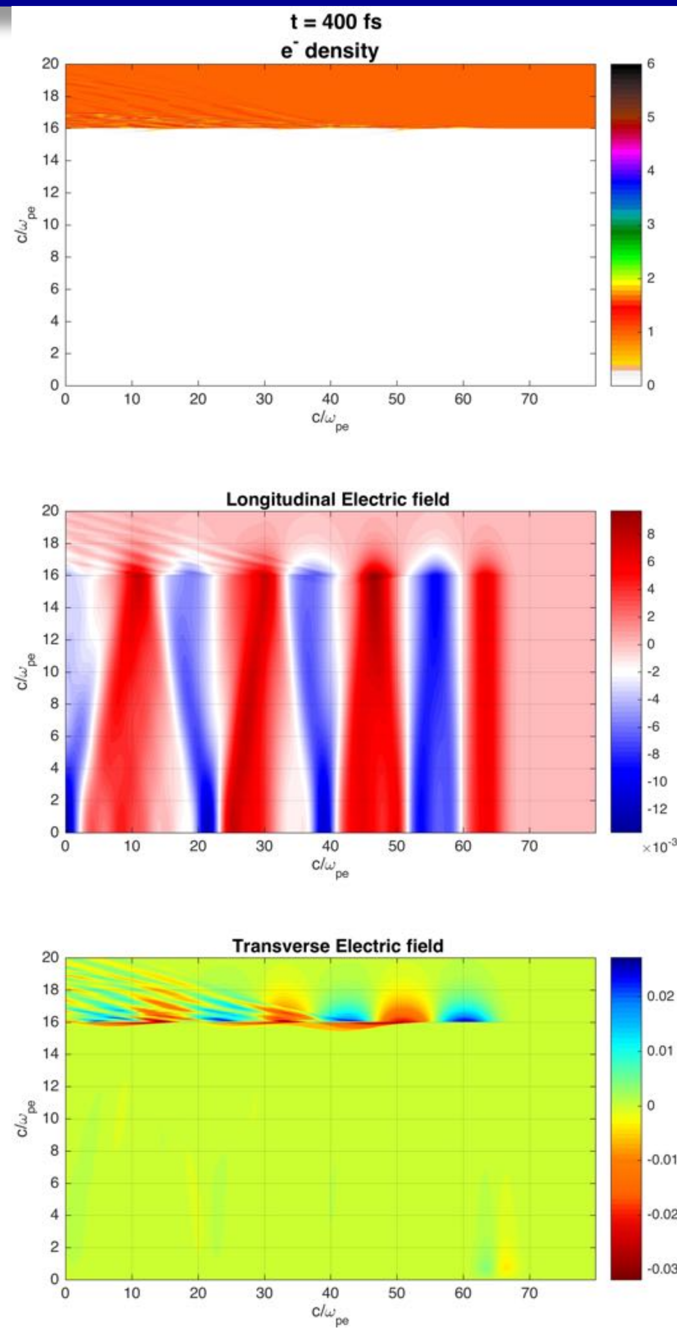
$\gamma_b = 1000$

NO focusing forces

currents in the wall

EM acc. fields leak into the channel

$10^{-3}\ E_{WB}$



CYL
geometry

e^{+}-beam Lin. regime - Hollow-channel

e^{+}-beam -driven

$r_{ch} = 16\ c/\omega_{pe}$

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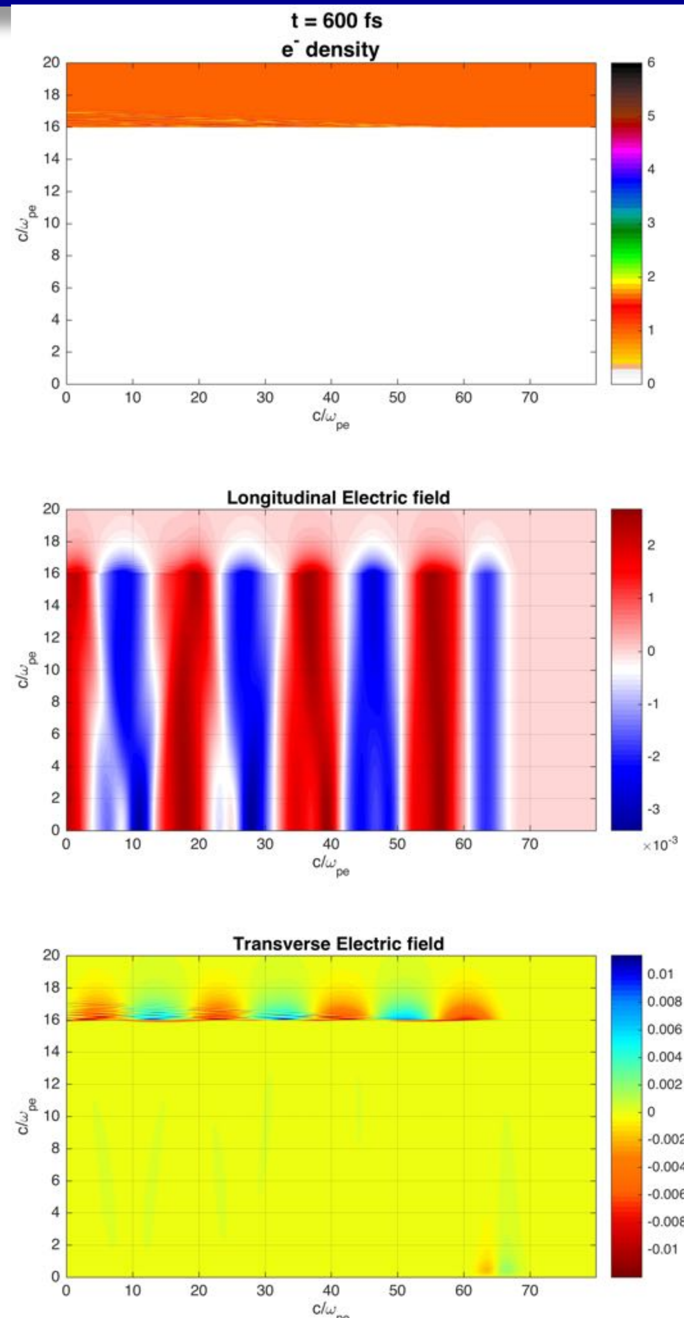
$\gamma_b = 1000$

NO focusing forces

currents in the wall

EM acc. fields leak into the channel

10^{-3} E_{WB}



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geometry

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What's the hypothesis we seek to prove ?

Non-linearly driven hollow-channel

accelerating & focusing forces → on-axis e-collapse

long. & tran. fields → **NOT** purely electromagnetic

also electrostatic

(due to on-axis e^- collapse from the channel edge)

electron-beam driven

VOLUME 82, NUMBER 6 PHYSICAL REVIEW LETTERS 8 FEBRUARY 1999

Multimode Analysis of the Hollow Plasma Channel Wakefield Accelerator

C. B. Schroeder,[1] D. H. Whittum,[2] and J. S. Wurtele[1,3]

the linear analysis to be valid, surface plasma density perturbations should be small compared to the channel radius. This implies that a particle drive beam must

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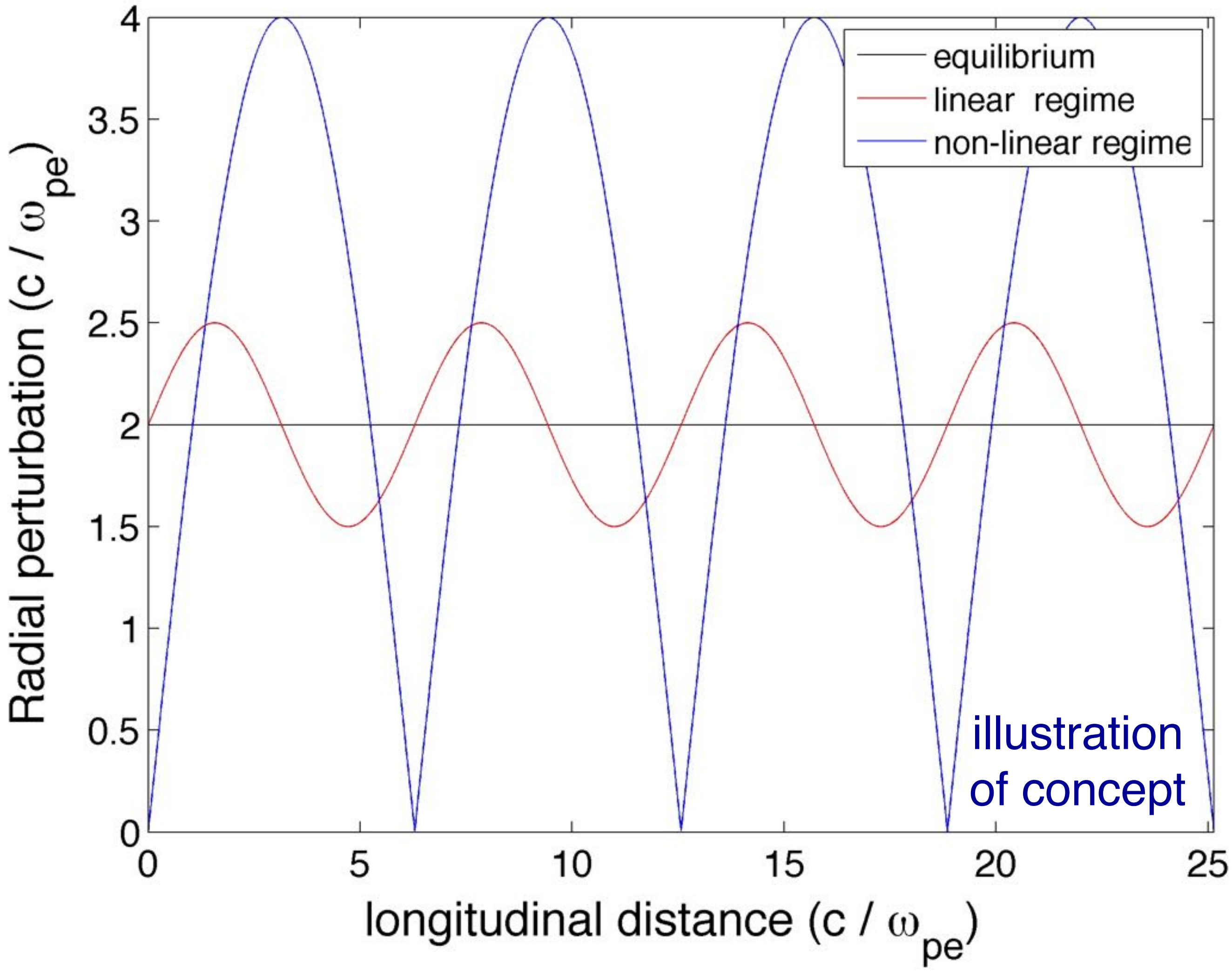
CRUNCH-IN REGIME

$$r_{e-ring}(driven) - r_{ch} = \delta r_{e-ring} \simeq r_{ch}$$



e^+-beam driven Hollow-channel

Coherent **on-axis** compression of e^- rings – **Crunch-in**

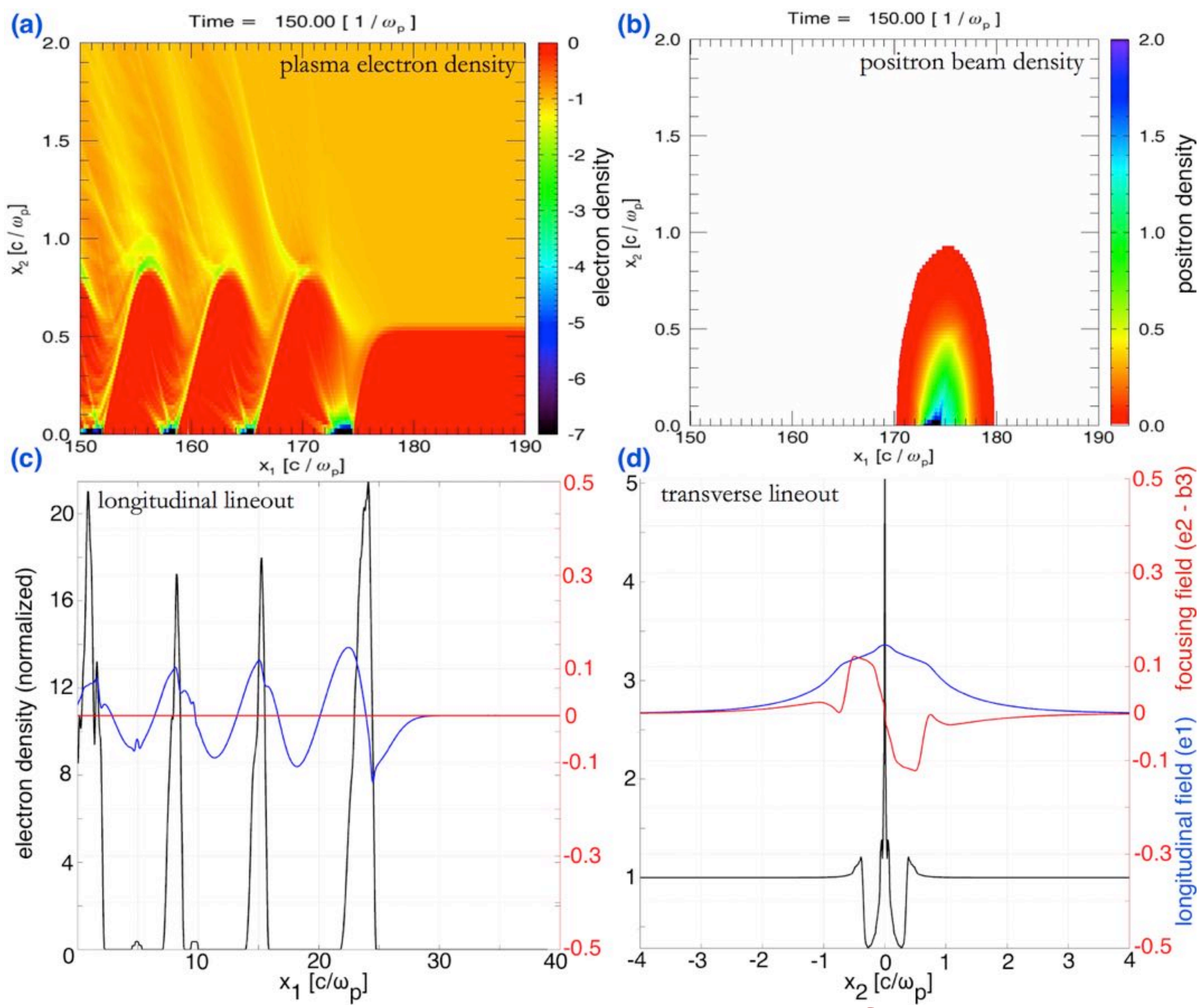
$r_{ch} = 0.6\ c/\omega_{pe}$

$n_b = 1.3\ n_0$
$\sigma_z = 1.5\ c/\omega_{pe}$
$\sigma_r = 0.3\ c/\omega_{pe}$

$\gamma_b = 10000$

on-axis dynamics

electron density
transverse field
longitudinal field



CYL geometry

Matching collapse-time to channel radius

e$^-$ ring collapse $$\frac{d^2}{d\,\xi^2} r \propto -\frac{1}{r} n_{bp}(\xi) r_{bp}^2(\xi)$$

non-linear / inhomogeneous PDE $$r'' = f(r, r', \xi)$$

PDE solution $$r_{ch}\sqrt{\pi}\,\mathrm{erf}\left(\sqrt{\ln(r_{ch}/r)}\right) = -\sqrt{2C}\,\xi$$

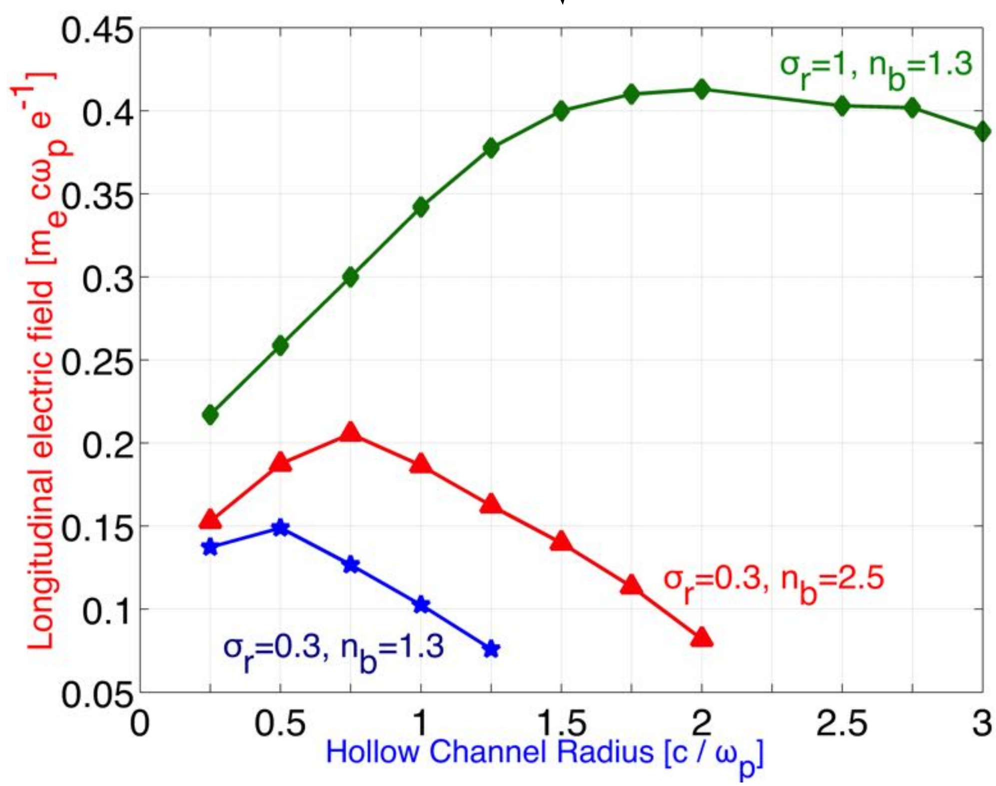
e$^-$ collapse time driven by e$^+$ - beam $$\tau_c = \sqrt{\pi}\frac{r_{ch}}{\omega_{pe}\sqrt{n_{bp}/n_0}\, r_{pb}}$$

matching collapse time to "crunch-in" wavelength

$$\tau_c \simeq \mathcal{D}\lambda_{Np}/c$$

$$\text{duty-cycle } \mathcal{D} = \frac{\tau_{back}}{\tau_{back}+\tau_{cav}}$$

$$r_{ch}^{opt} \simeq 2\sqrt{\pi}\mathcal{D}\frac{\lambda_{Np}}{\lambda_{pe}}\frac{\omega_{pb}}{\omega_{pe}} r_{pb}$$



electron-beam driven “Crunch-in”

matched

$r_{ch} = 1\ c/\omega_{pe}$

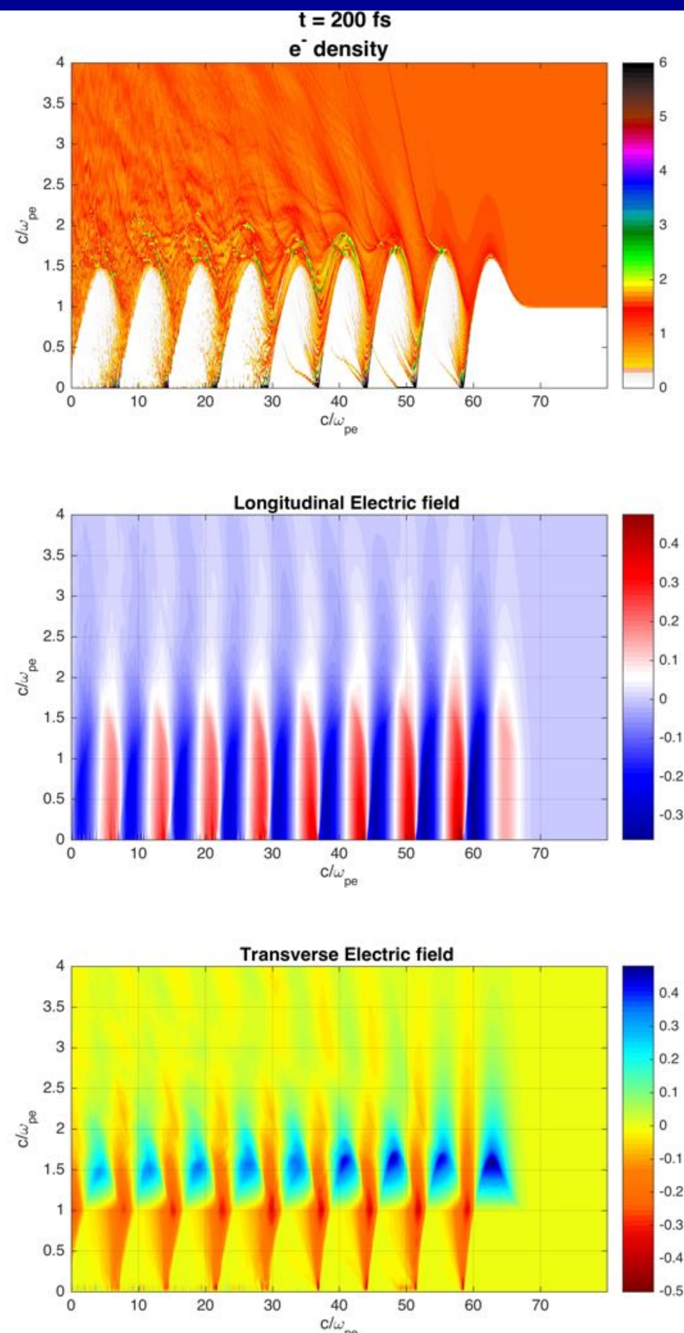
$n_b = 1.5\ n_0$
$\sigma_z = 1.5\ c/\omega_{pe}$
$\sigma_r = 0.5\ c/\omega_{pe}$

$\gamma_b = 1000$

coherent radial oscillations
e^- collapse to the channel axis

Coherent acc. fields **~ 0.4 E_{WB}**

Focusing fields for positrons
Collocated with acc. fields
~ 0.4 E_{WB}



CYL
geometry

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laser-beam driven Hollow-channel

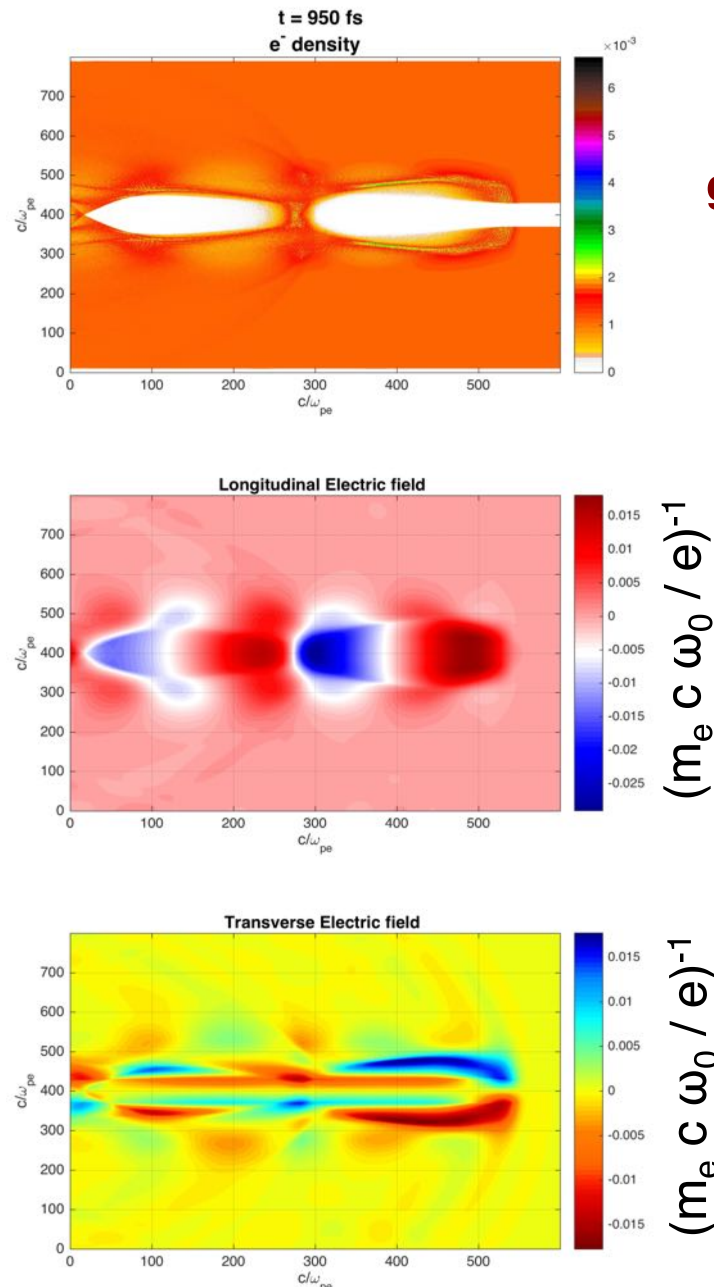
$r_{ch} = 1\ c/\omega_{pe}$

$a_0 = 4.0$
$w_0 = 2.5\ c/\omega_{pe}$

$\omega_0 / \omega_{pe} = 30$

Strong coherent acc. / foc. fields
~ 0.4 E_{WB}

Focusing fields for positrons
Collocated with acc. fields

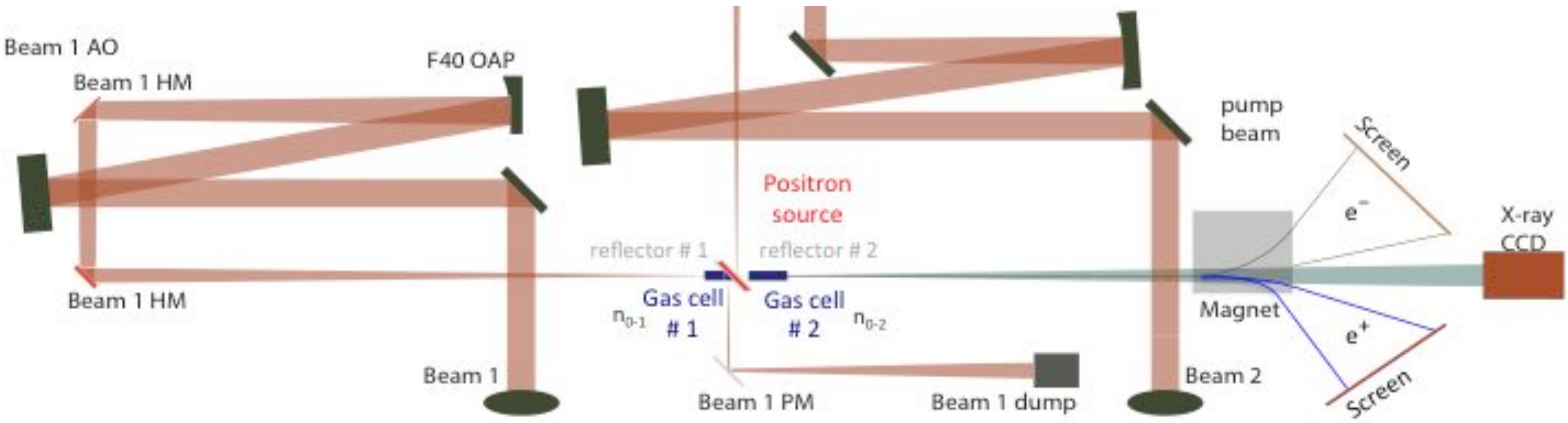


CART
geometry

Leptonic beam

Leptonic beam - motivation

Can having a nearly neutral mix of electron and positron particles in the beam allow sustained acceleration of the positron beam ?



ARTICLE

Received 4 Apr 2014 | Accepted 24 Feb 2015 | Published 23 Apr 2015 DOI: 10.1038/ncomms7747 OPEN

Generation of neutral and high-density electron-positron pair plasmas in the laboratory

G. Sarri[1], K. Poder[2], J.M. Cole[2], W. Schumaker[3,†], A. Di Piazza[4], B. Reville[1], T. Dzelzainis[1], D. Doria[1], L.A. Gizzi[5,6],

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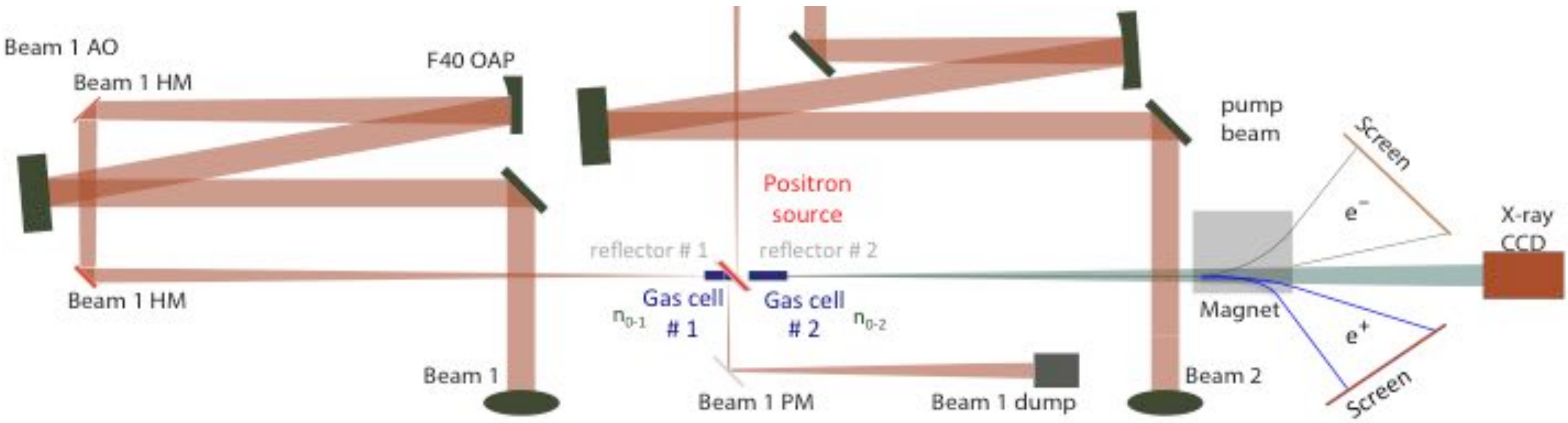

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Leptonic beam - experiment

Central Laser Facility
Application For Experimental Time on
High Power Lasers

Application Number
17110007

Principal investigator(*)	Dr A Sahai, Imperial College London, United Kingdom
Co-investigator	Dr G Sarri, Queen's University of Belfast, United Kingdom
Co-investigator	Dr S Mangles, Imperial College London, United Kingdom
Co-investigator	Professor Z Najmudin, Imperial College London, United Kingdom
Co-investigator	Professor M Zepf, Queen's University of Belfast, United Kingdom
Co-investigator	Dr N Lopes, Imperial College London, United Kingdom
Co-investigator	Professor A Thomas, Lancaster University, UNITED KINGDOM

Experiment Title	Laser-driven Plasma Acceleration of Positrons	
Facility / Area	Gemini	**Weeks Requested:** 3
Precluded Dates	-	
Access Route	Direct Access - New	**Previous Application Number:** -
Science Areas	Physics	
Grant Title	John Adams Institute for Accelerator Science	

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Summary

- Positron acceleration – active area of research
- Hollow-channel – work on-going on generating the channel
- Hollowed-out laser mode – work on-going on generation of high-intensity LG mode
- Leptonic beam – work on-going on staging setup and simulations
- Several existing facilities (RAL Gemini) and planned facilities (FACET-II / FLASH forward)