Plasma accelerators for high energy physics

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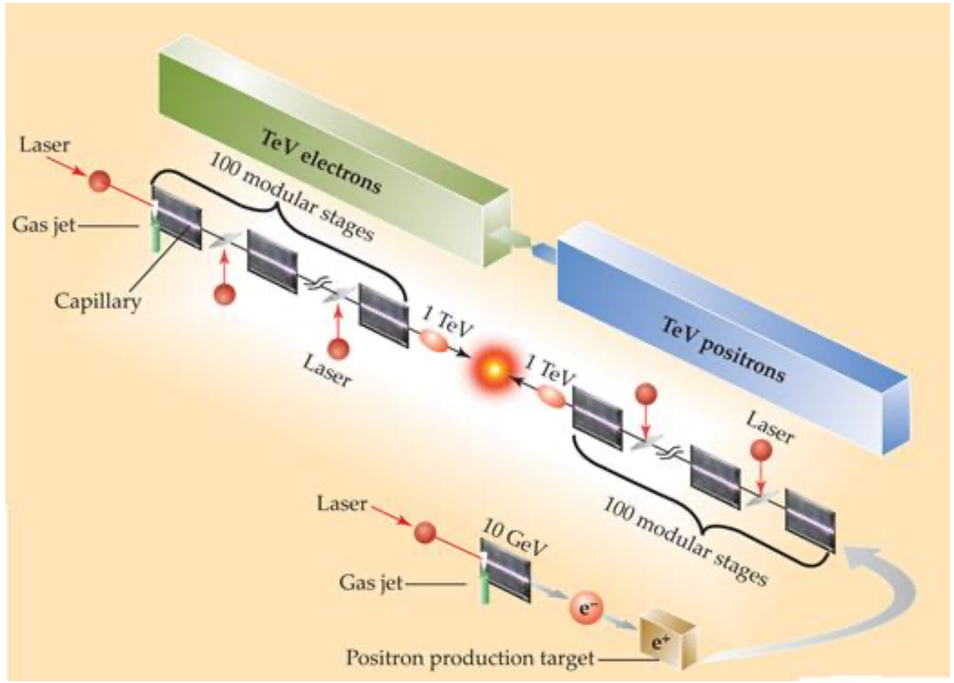
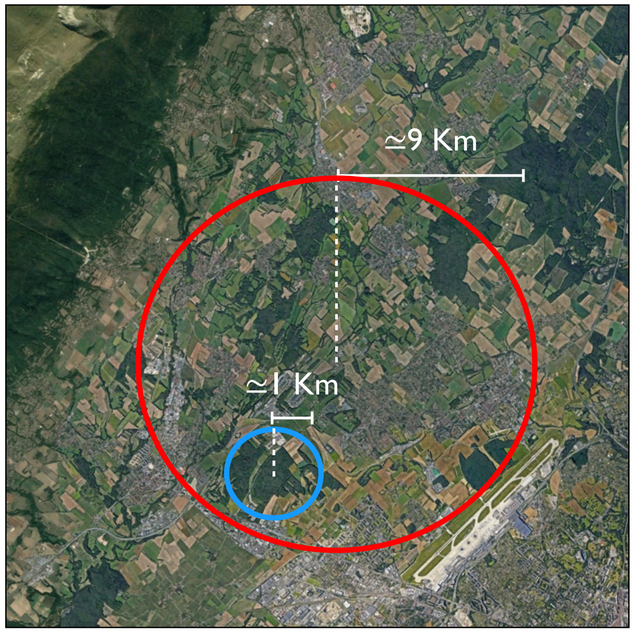


The need and the goal of plasma-based accelerators

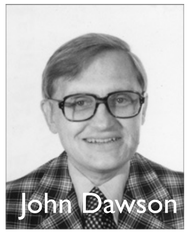
Need for transformational developments




Burton Richter

"Without some transformational developments to reduce the cost of the machines of the future, there is a danger that we will price ourselves out of the market."
Burton Richter, RAST pp. 1-8 (2005).

Plasmas provide more compact and affordable accelerators


John Dawson


Toshi Tajima

VOLUME 43, NUMBER 4 PHYSICAL REVIEW LETTERS 23 JULY 1979

Laser Electron Accelerator

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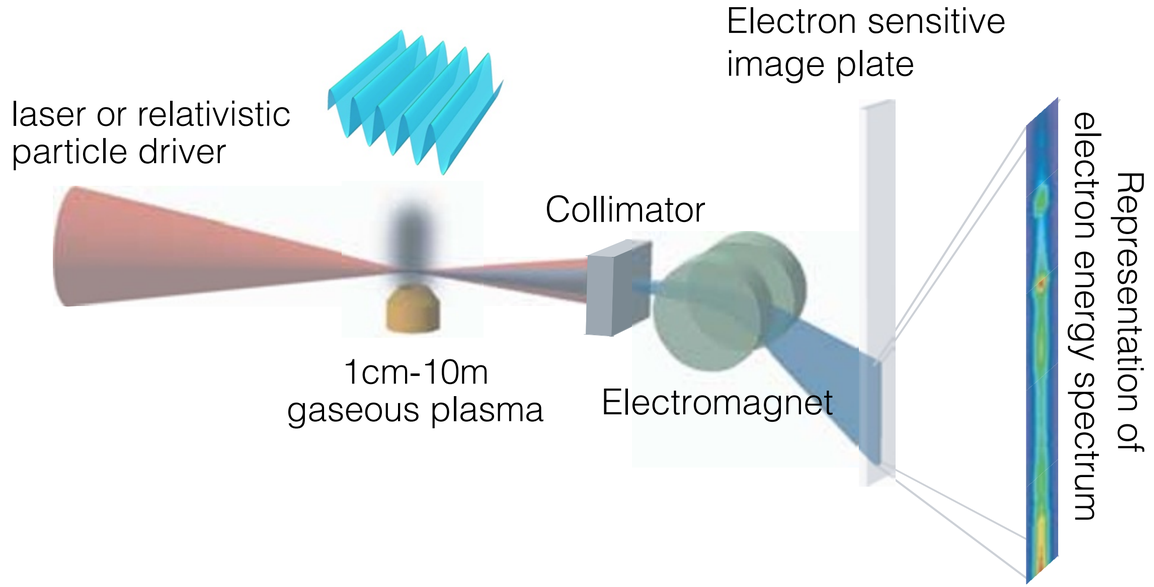
(Received 9 March 1979)

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.



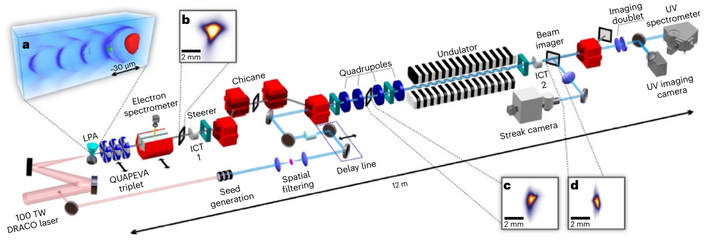
Electron (and positron) acceleration

$E_{\text{accel}} \simeq \mathbf{1 - 100\ GV/m}$

There were significant achievements in the last 5 years

Plasma injectors: FEL lasing

Laser driven and beam driven



Up to 500 MeV electron bunches

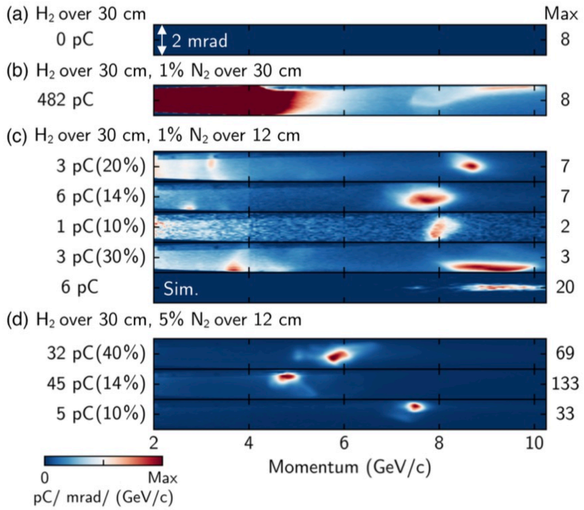
Charge <100 pC

Sub-percent relative energy spreads, sub-mm-mrad emittance

M. Fuchs et al. Nature Physics 5 826 (2009)
W. Wang et al. Nature 595 516 (2021)
R. Pompili et al. Nature 605 659 (2022)
M. Labat et al. Nature Photonics 17 150 (2023)

10 GeV e- acceleration stage

Laser driven



Up to 9 GeV electron bunches

30 GeV/m

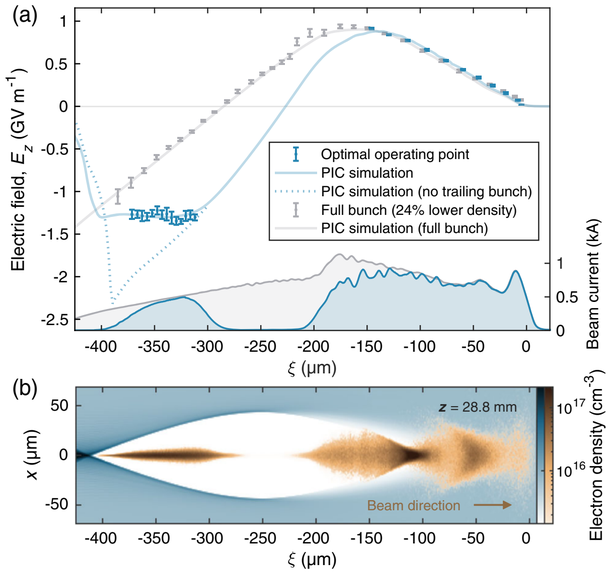
3% relative energy spread, sub-mrad divergence

1-45 pC charges

A. Picksley et al. 133, 25500 PRL (2024)

High efficiency e- acceleration

Beam driven



40% energy conversion efficiency

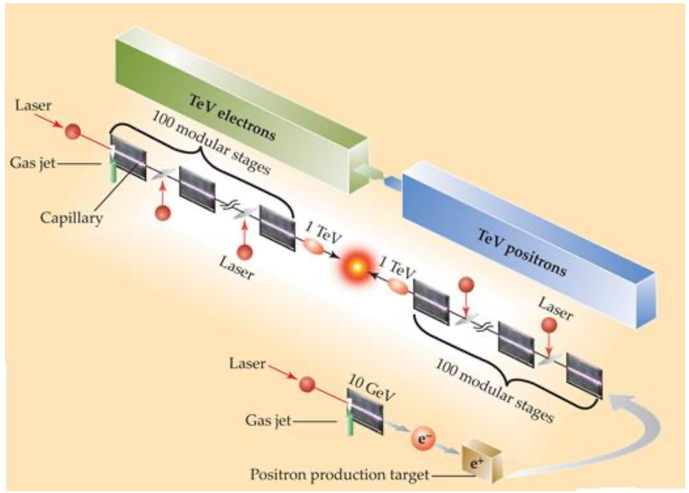
Limited energy gain (0.1-100 GeV)

C. A. Lindstrøm et al, Phys. Rev. Lett. 126, 014801 (2021)
M. Litos et al. Nature 515, 92–95 (2014)

A design study is crucial for further advance in the area of HEP

TÉCNICO LISBOA

Plasma-based linear collider concept



Parameter	Units	Needed	Achieved
Bunch charge	pC	833	10-100
Energy spread	%	0.35	<1
Normalised emittance H/V	μm/nm	0.890/19	1/1000
Emittance growth budget H/V	μm/nm	0.01/1	1/1000
Effective rep rate	KHz	10-100	10^{-3}-10^{-2}
Effective wall-plug efficiency	%	11.4	10%

Global design study efforts for plasma accelerator colliders

>10 TeV machine for new physics (US)

TeV collider for Higgs precision studies (EU)

There are many international plasma accelerator projects on-going

EuPRAXIA (light source)

AWAKE (N. Lopes Talk),

Injectors for Circular Electron Positron Collider (China)

HALHF, ALiVE, …

Plasma-based collider design is a community goal

Advanced LinEar collider study GROup (ALEGRO) lead by Patric Muggli (CERN, MPP) and Brigitte Cros (LPGP, France).

2024 workshop edition held at IST

Objective

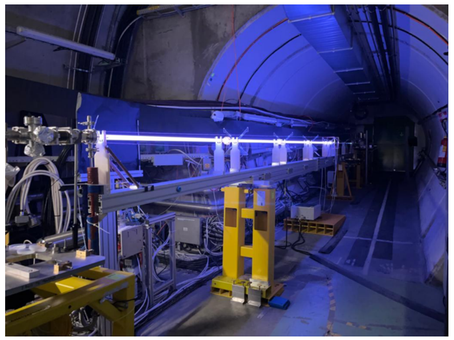
Demonstrate, through **theory** and **computer simulations**, that (laser-driven) plasma-based accelerators can accelerate electrons (positrons) bunches meeting the requirements for HEP in terms of phase-space quality, efficiency, and luminosity.

Design study needs to be endowed and supported by the global HEP community.

Portuguese plasmas for high energy physics

GoLP is extremely active in plasma-based accelerators and in accelerators for astrophysics

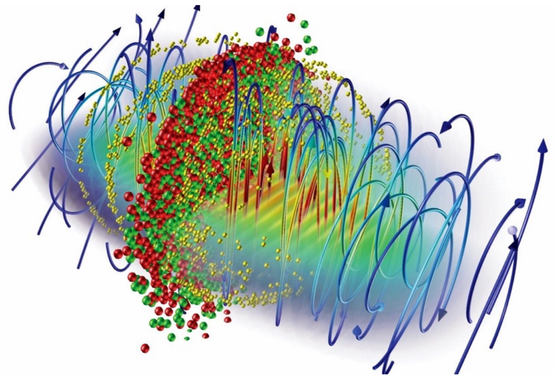
Plasma sources



>10 meter long plasma sources ready for **multi-10 GeV energy gain**

Successfully used in AWAKE and foreseen use in ALiVE

Plasma simulations



Beam-beam physics and physics at interaction point

One-to-one computer models of plasma accelerators

Large scale simulations and access to **TIER-0 supercomputers**

Laboratory astrophysics

Experimental model of **astrophysical jets**

HiRadMat fireball experiments

CERN provides beams with **relevant parameters for plasma astrophysics**