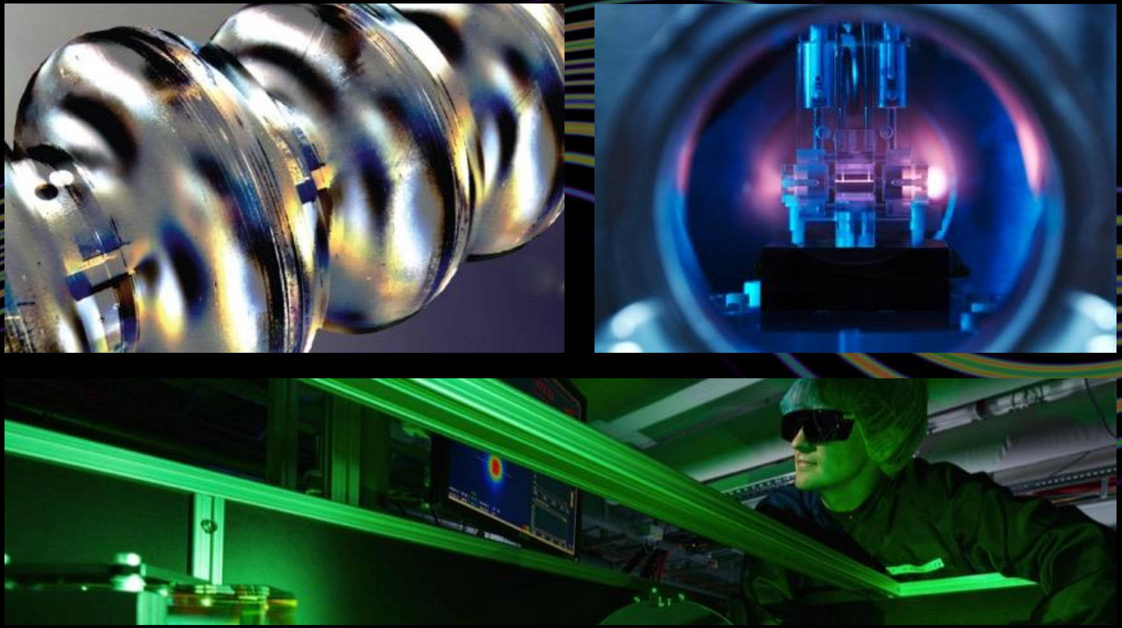
NOVEL HIGH GRADIENT ACCELERATORS: PLASMAS & BEYOND



Can we build smaller, less expensive accelerators?

6th Summer School on INtelligent signal processing for FrontIEr Research and Industry (INFIERI)

Seminar – Madrid, Spain

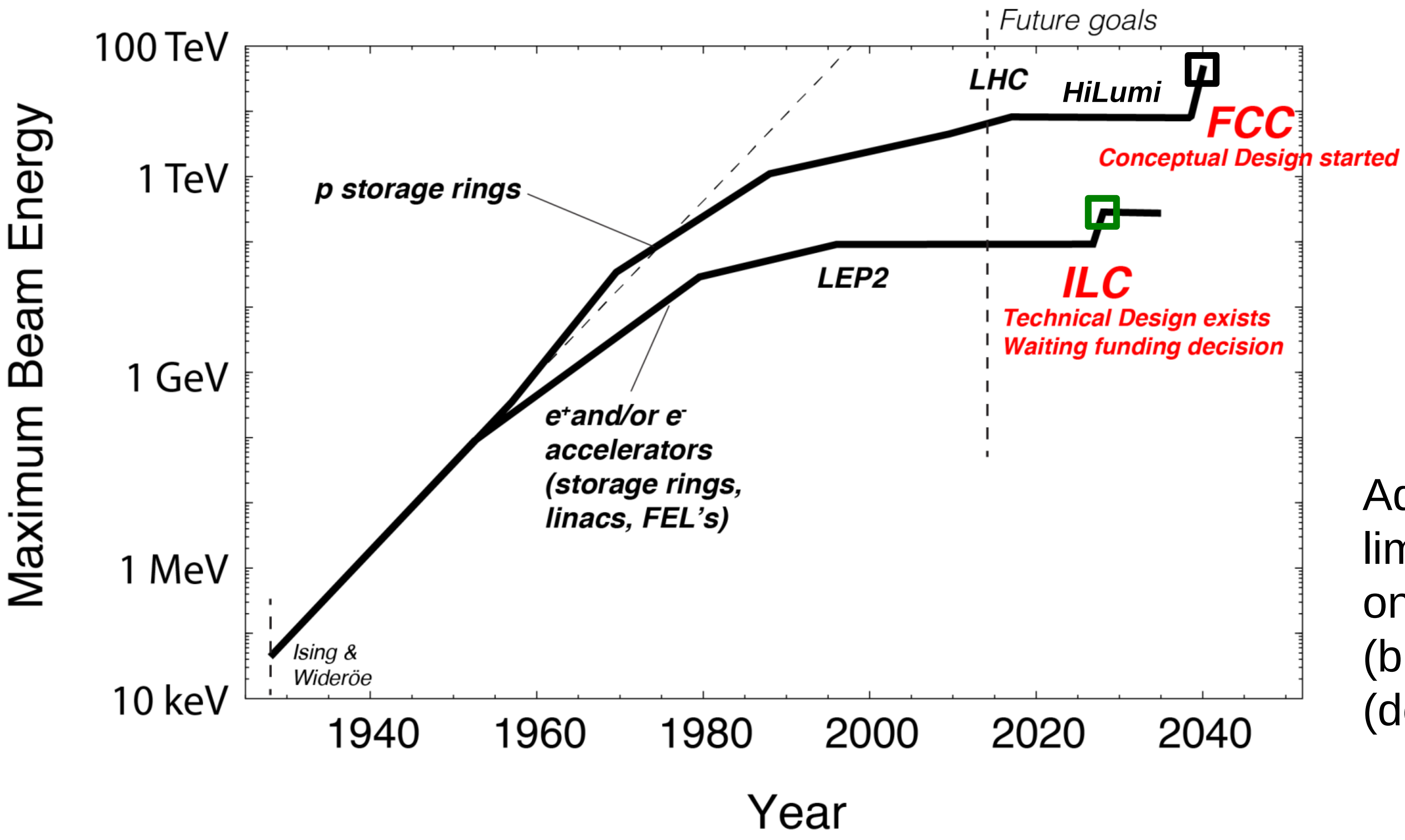
26 August 2021

Ralph W. Aßmann, DESY & INFN

Contents

Slow-down in Energy Increase of Frontier Accelerators

Livingston plot leveling off – here our version, giving beam energy versus time

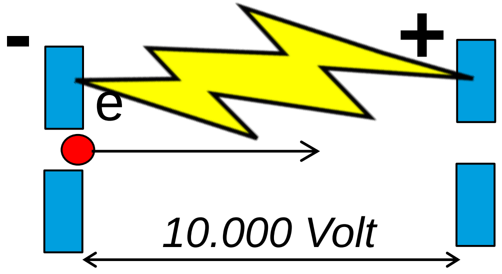


- ■ Hadron acc. project
- □ Hadron acc. proposal
- 🟩 Lepton acc. project
- □ Lepton acc. proposal

Advance of new colliders limited by practical constraints on required resources (budget, manpower) and size (does it fit on site?)

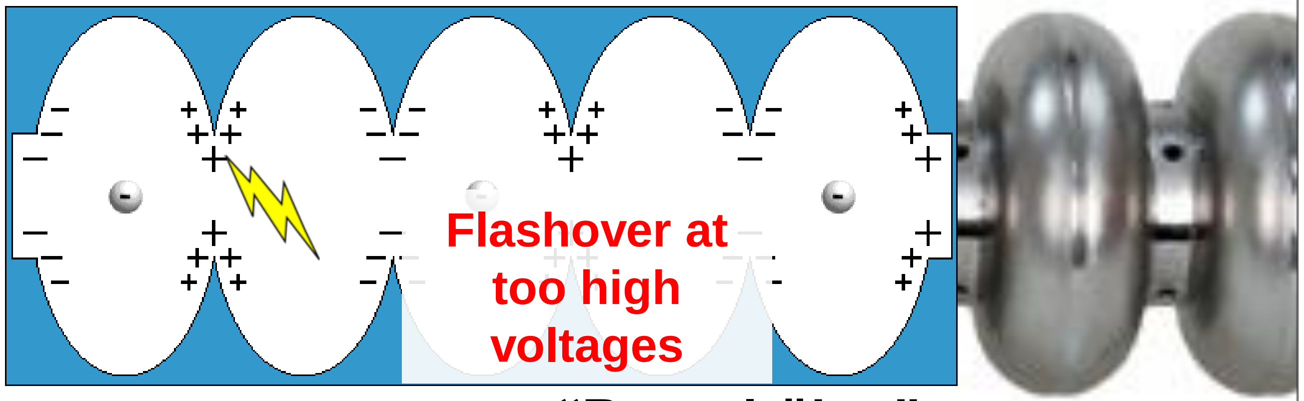
e- Acceleration: Principle and **Limit**

- Areas with positive and negative charge; free electrons in between.
- Free electron (e$^-$) is accelerated towards the positive charge (anode).



Flashover at too high voltages

- For 10.000 Volt the electron gains 10.000 electron-Volt („eV”).
- Higher energies with **alternating voltage („RF“)**:



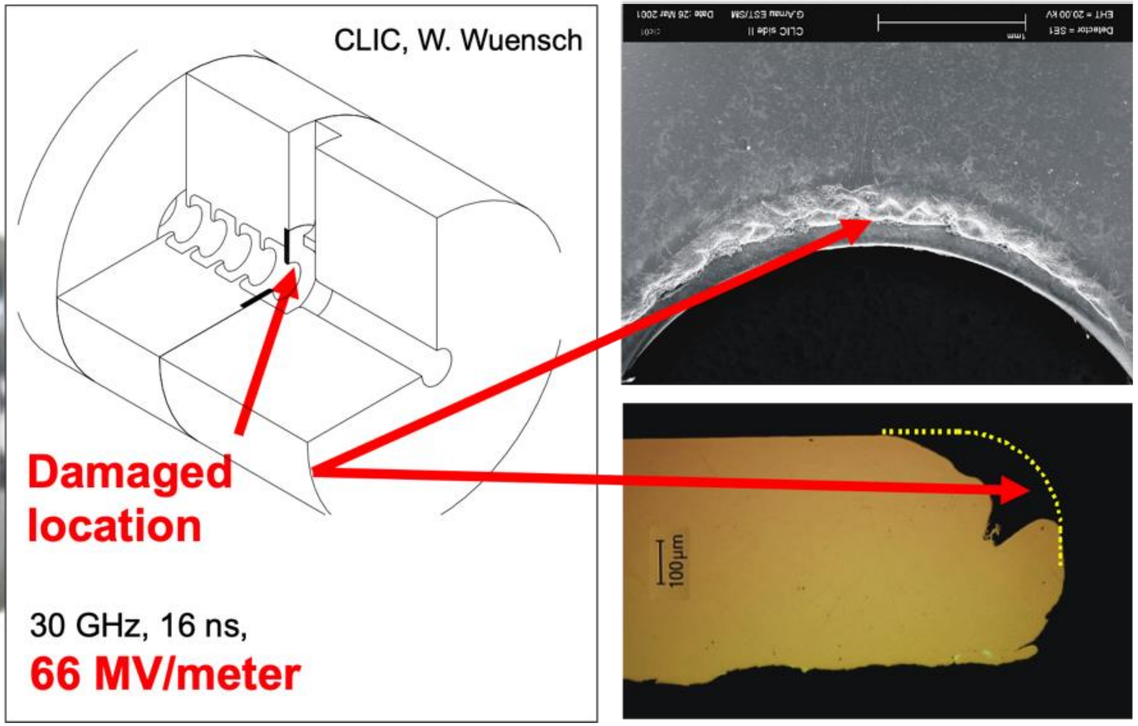
Sketch Padamse, Tigner

“Runzelröhre”

20.000.000 Volt per Meter

Can we increase the accelerating voltage? Higher energy accelerators in same size with same technology?

NO! metallic structures self destruct



Contents

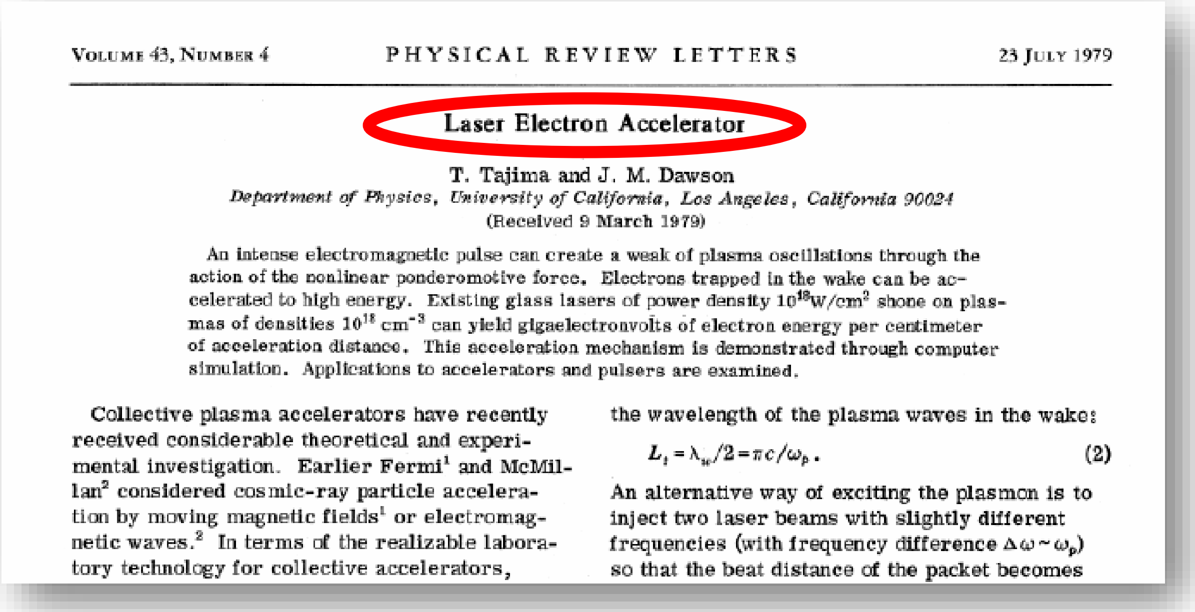
Towards Much Higher Accelerating Fields

In nature, theory and technology

R. Wideröe (in 1927 built first RF accelerator) in 1990:

“The **theoretical possibilities** with regard to accelerating particles by electromagnetic means (i.e. within the scope of the Maxwell equations which have been known since the 19th century), **are nowhere near being exhausted**, ...”

Schwinger limit: **1.3 x 10^9 GV/m**



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.

Collective plasma accelerators have recently received considerable theoretical and experimental investigation. Earlier Fermi[1] and McMillan[2] considered cosmic-ray particle acceleration by moving magnetic fields[1] or electromagnetic waves.[2] In terms of the realizable laboratory technology for collective accelerators,

the wavelength of the plasma waves in the wake:

$$L_t = \lambda_w/2 = \pi c/\omega_p . \qquad (2)$$

An alternative way of exciting the plasmon is to inject two laser beams with slightly different frequencies (with frequency difference $\Delta\omega \sim \omega_p$) so that the beat distance of the packet becomes

The Laser Promise: Transverse Electrical Field

We can produce every day very high transverse electrical fields

$$
\begin{aligned}
E_0 &= \sqrt{2 \cdot \frac{I_0}{c\,\epsilon_0}} \\
\epsilon_0 &= \text{Dielectric constant} \\
c &= \text{Light velocity}
\end{aligned}
$$

$$
\begin{aligned}
P &= 100\,\mathrm{TW} \\
r_0 &= 10\,\mu\mathrm{m} \\
I_0 &= 6.4 \cdot 10^{19}\,\mathrm{W/cm^2}
\end{aligned}
$$

$$E_0 = 22\,\mathrm{TV/m}$$

This is what we need!

Scientists wonder: Can we use the strong transverse electrical fields to accelerate our beam?

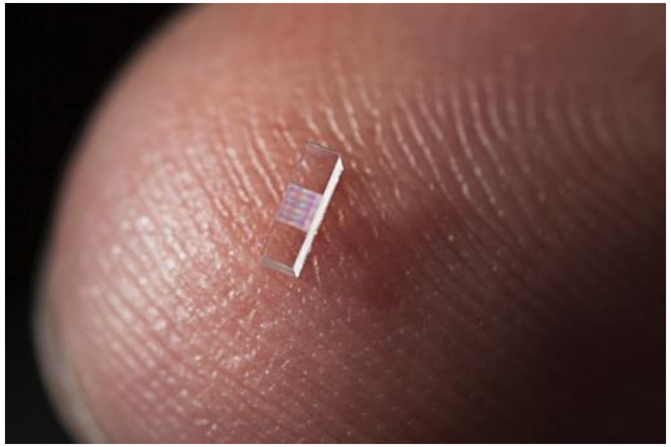
- Those high peak power lasers are commercially available from European industry.
- State of the art is at the several Peta-Watt level.
- Many facilities do exist, e.g. also in Spain.

High Gradient – High Frequency – Small Dimensions

Powering novel accelerators

High Gradients (1 – 100 GV/m) → **High Frequencies (> 100 GHz)** → **Small Dimensions (< 1 mm)**

- No **klystrons** for high frequencies!
- Use **particle bunches or laser pulses** as drivers.
- Material limitations solved through "new cavities": dielectric materials, plasma cavities, …
- **Two main directions**:



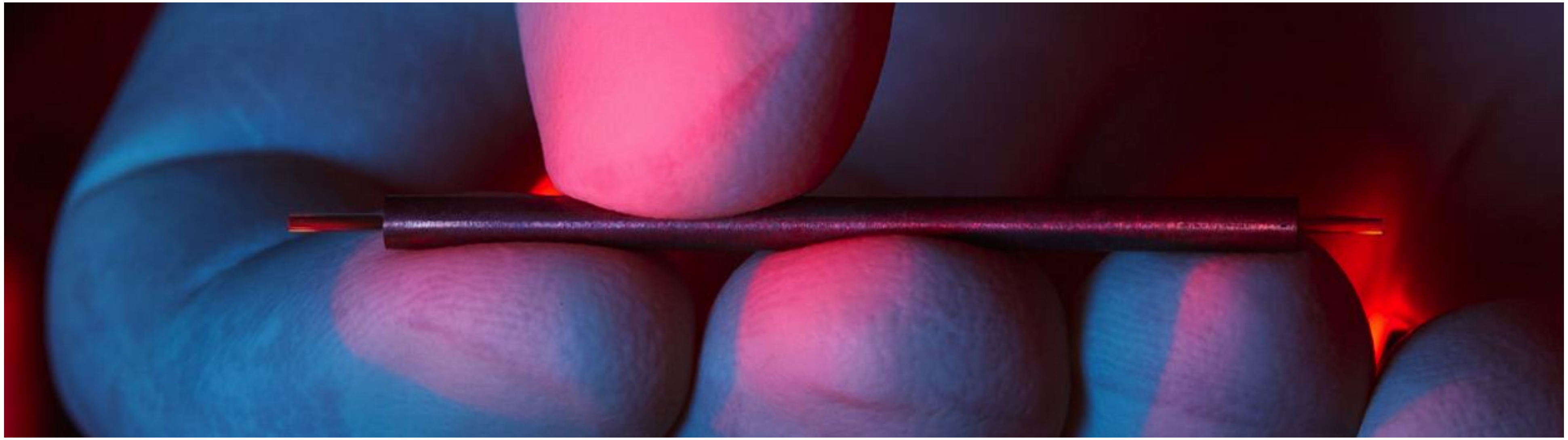
1 Microstructure Accelerator
Laser- or beam driven
Vacuum accelerators
Conventional field design

2 Plasma Accelerator
Laser- or beam driven
Dynamic Plasma Structure
Plasma field calculations

Laser-Driven Micro Structures (Vacuum) – 1

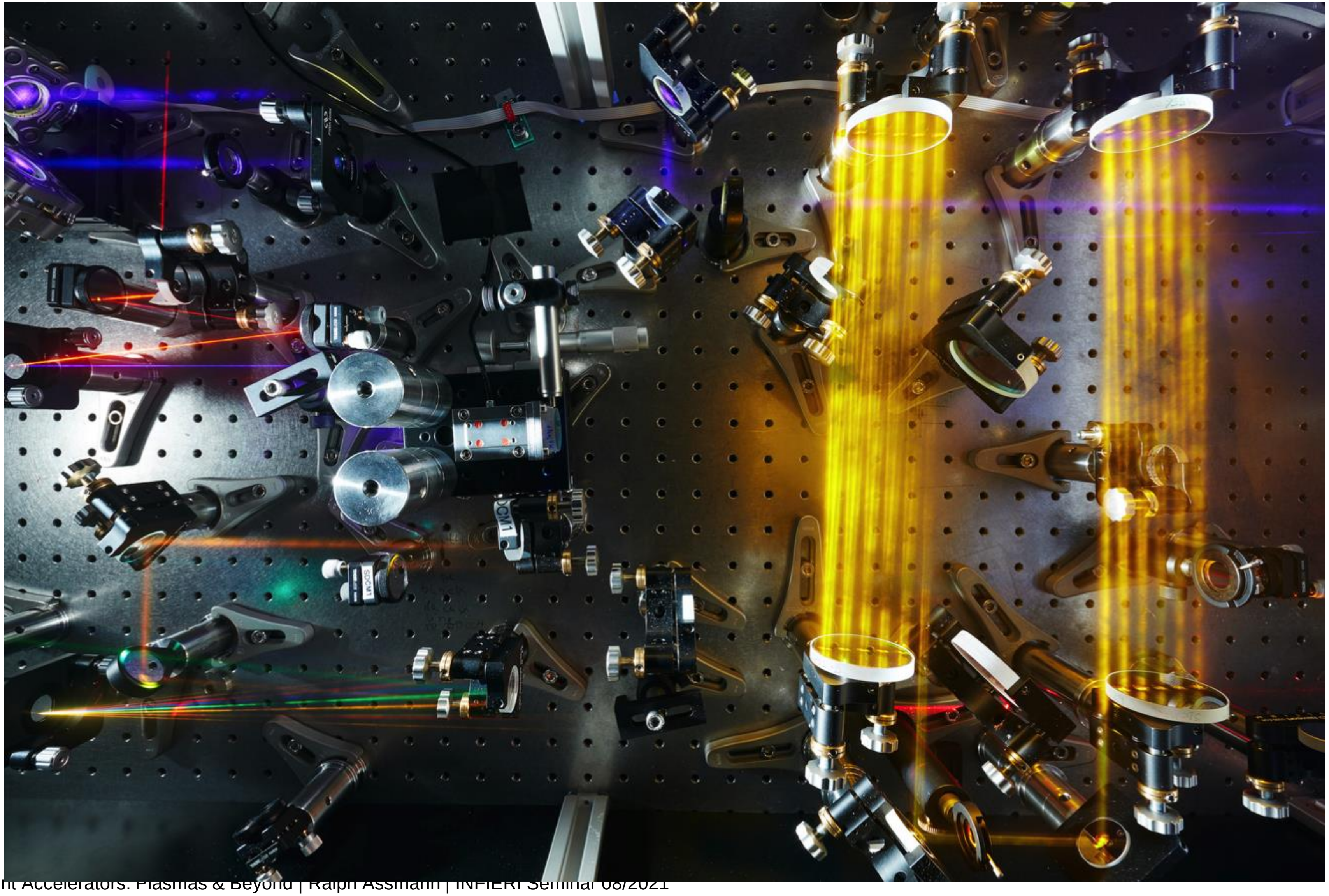
Vacuum dielectric accelerator

- 1 GeV/m possible but low absolute energies achieved so far
- **AXSIS project (ERC synergy grant)** at DESY/
  Uni Hamburg: THz laser-driven accelerator with
  atto-second science → *Kärtner/Fromme/Chapman/Assmann*



THz Laser Lab (DESY, CFEL, University Hamburg)

Vacuum dielectric accelerator

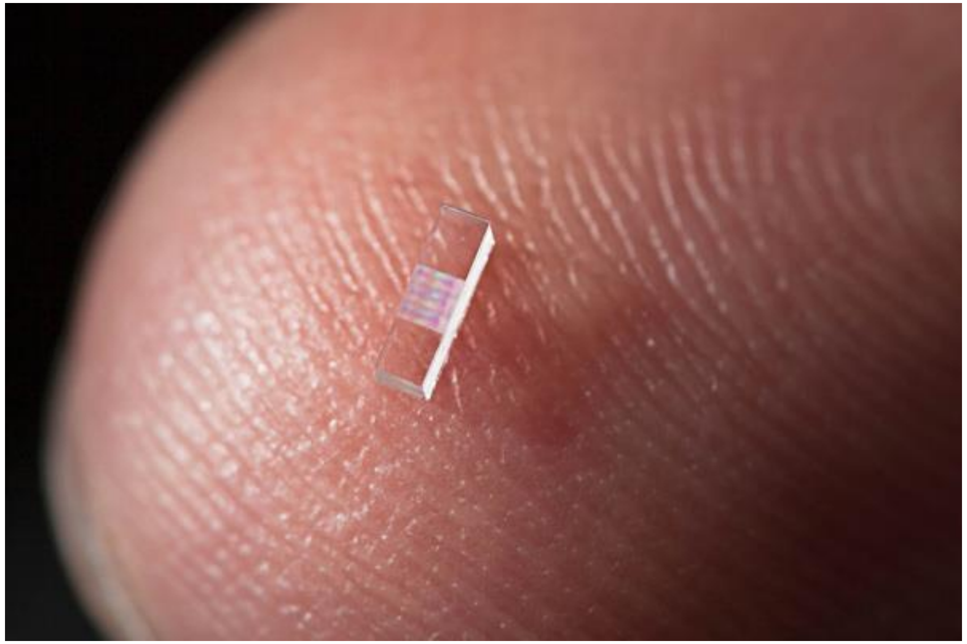


Laser-Driven Micro Structures (Vacuum) – 2

Vacuum dielectric accelerator

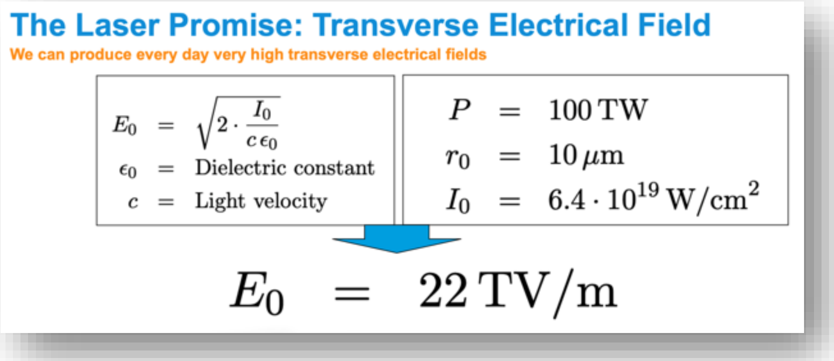
Accelerator on a Chip International Program

- **“Accelerator on a Chip”** grant from Moore foundation for work by/at Stanford, SLAC, University Erlangen, DESY, University Hamburg, PSI, EPFL, University Darmstadt, CST, UCLA
- Lasers drive **structures that are engraved on microchips** (e.g. Silicium)
- Major breakthroughs can be envisaged:
  - **Mass production**
  - **Implantable accelerators** for in-body irradiation of tumors
  - Accelerators for **outer space**



Laser Plasma Accelerator: Transverse to Longitudinal

Every accelerator is a transformator



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We can produce every day very high transverse electrical fields

$$E_0 = \sqrt{2 \cdot \frac{I_0}{c\,\epsilon_0}}$$

ϵ_0 = Dielectric constant

c = Light velocity

$P = 100\,\mathrm{TW}$

$r_0 = 10\,\mu\mathrm{m}$

$I_0 = 6.4 \cdot 10^{19}\,\mathrm{W/cm^2}$

$$E_0 = 22\,\mathrm{TV/m}$$

$$\boxed{\mathbf{F} = q\,(\mathbf{E} + \mathbf{v} \times \mathbf{B})}$$

q = Charge

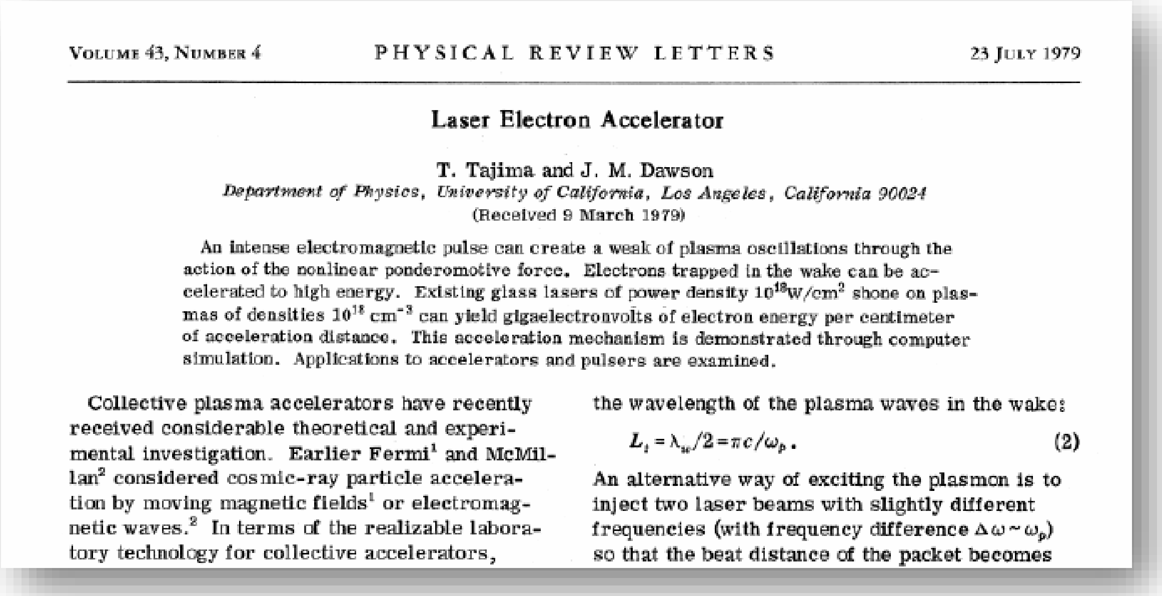
$\mathbf{v}$ = Velocity

Longitudinal electrical field to accelerate a particle

Transverse magnetic field to guide a particle

Idea in 1979:

Use a **plasma** to convert the transverse space charge force of a beam driver (or the electrical field of the laser) into a longitudinal electrical field in the plasma!



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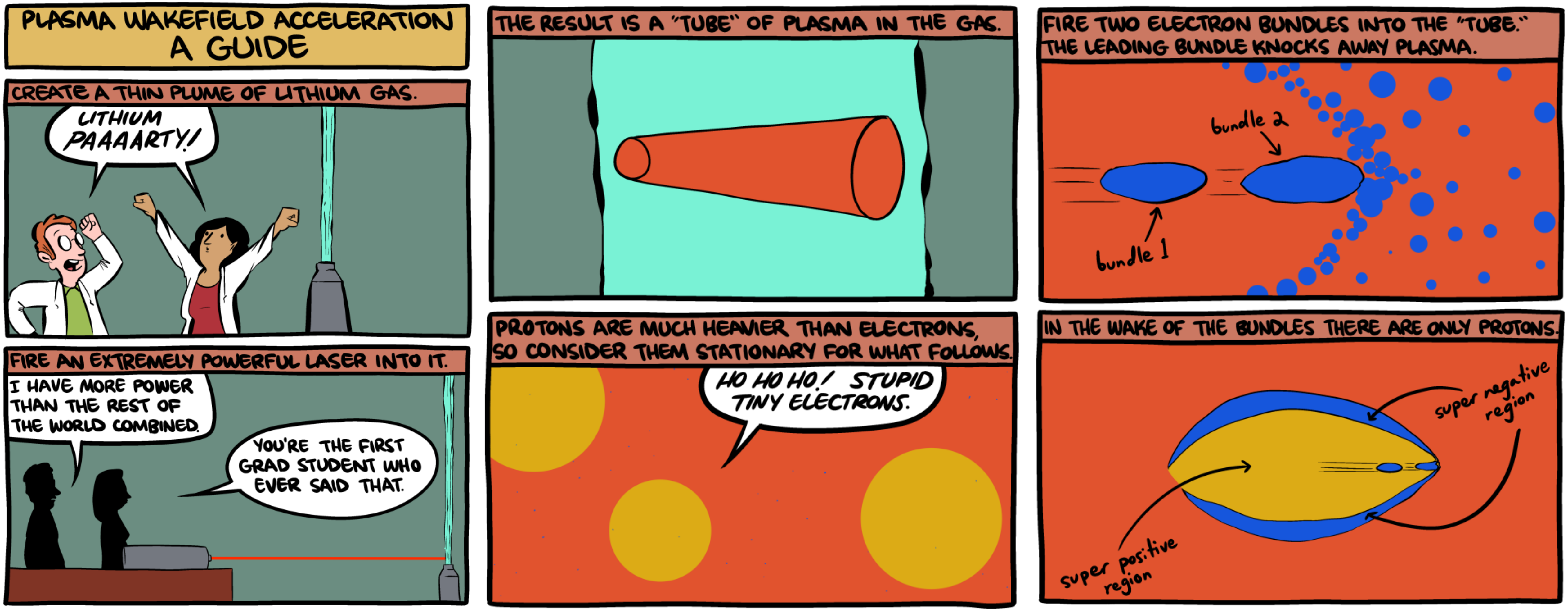
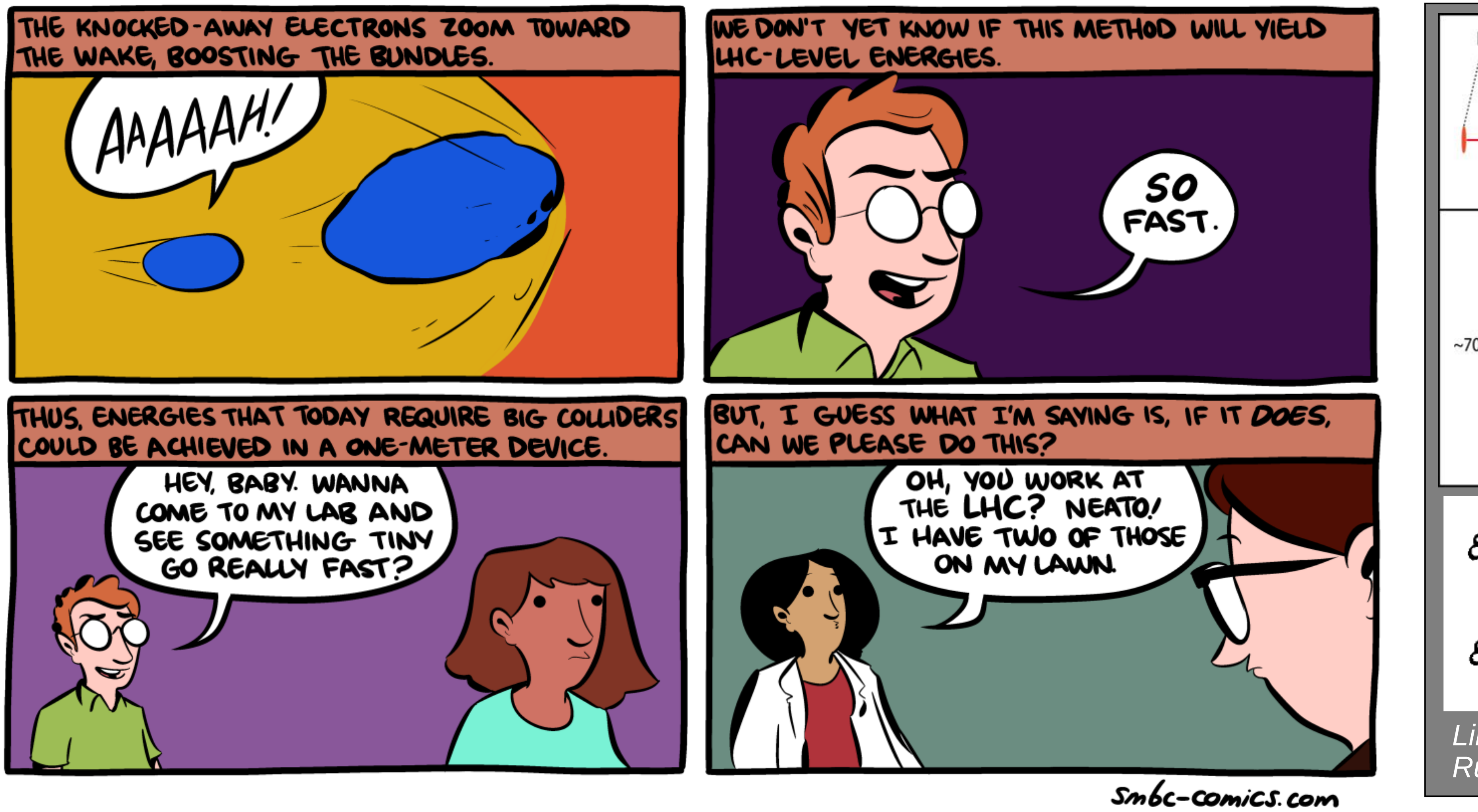
Plasma Acceleration Guide I

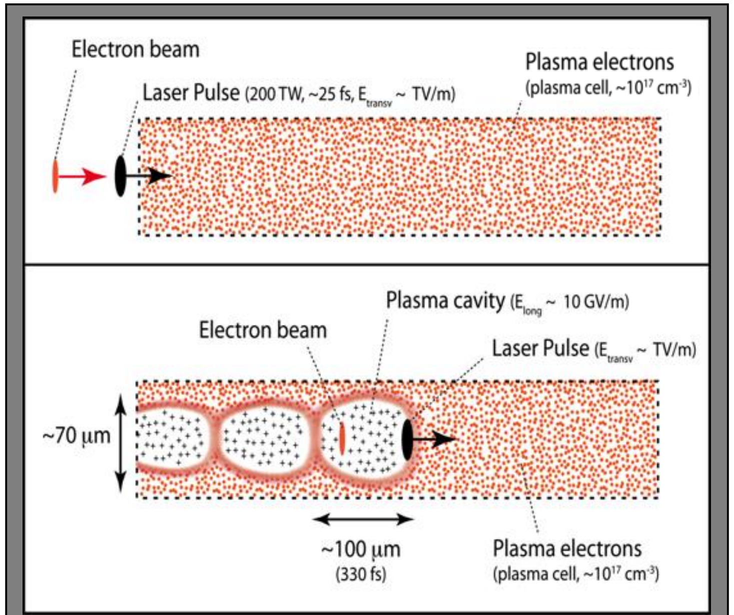
Comic courtesy Zach Weiner



Plasma Acceleration Guide II

Comic courtesy Zach Weiner





$$\mathcal{E}_z \simeq -A\left(1-\frac{r^2}{a^2}\right)\cos(k_p z-\omega_p t)$$

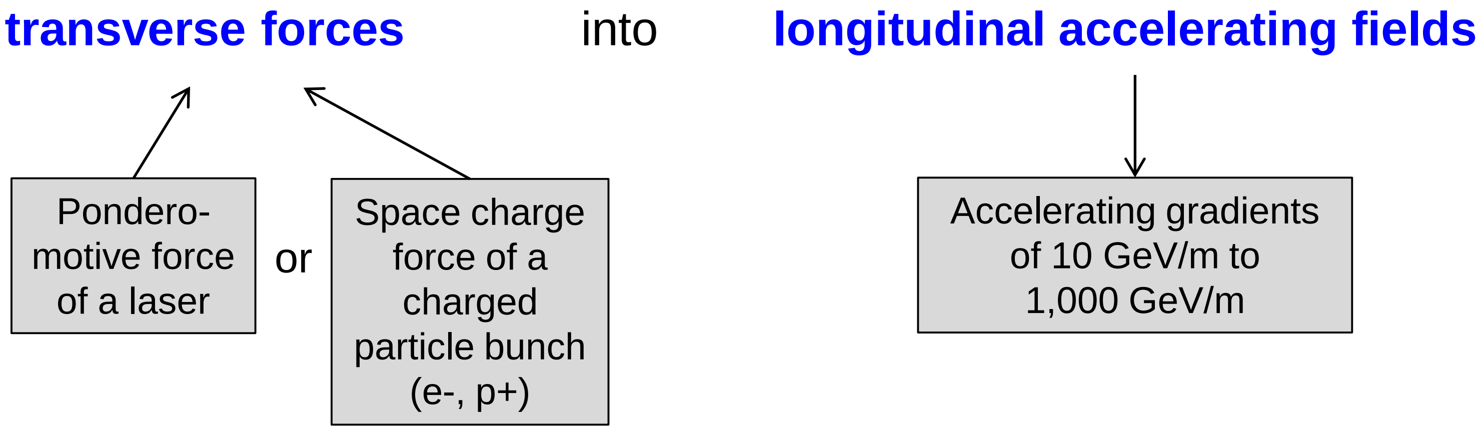
$$\mathcal{E}_r \simeq 2A\frac{r}{k_p a^2}\sin(k_p z-\omega_p t)$$

Linear Wakefield Theory (here from R. Ruth / P. Chen 1986)

Plasma Acceleration Guide III

Overcome high-field limitations of metallic walls with dynamic plasma structures (undestructible)

New idea in 1979 by Tajima and Dawson: Wakefields inside a homogenous plasma can convert



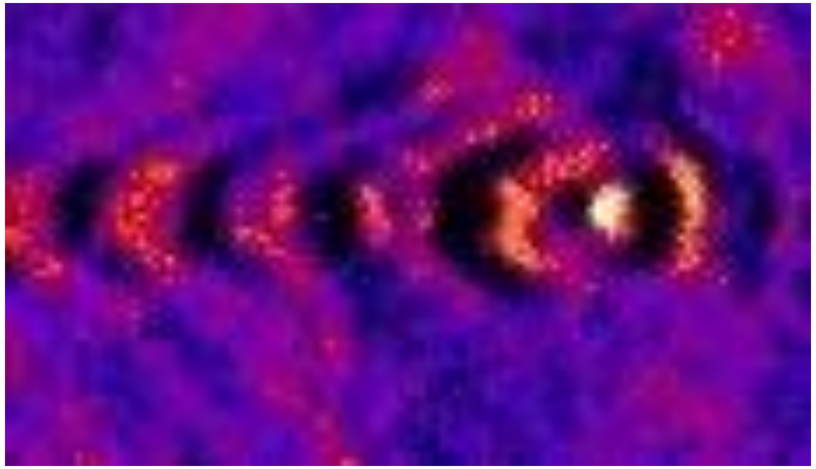
transverse forces into **longitudinal accelerating fields**

Pondero-motive force of a laser

or

Space charge force of a charged particle bunch (e-, p+)

Accelerating gradients of 10 GeV/m to 1,000 GeV/m



Courtesy M. Kaluza

Options for driving wakefields:

- **Lasers**: Industrially available, steep progress, path to low cost
  Limited energy per drive pulse (up to **50 J**)
- **Electron bunch**: Short bunches (need μm) available, need long RF accelerator
  More energy per drive pulse (up to **500 J**)
- **Proton bunch**: Only long (inefficient) bunches, need very long RF accelerator
  Maximum energy per drive pulse (up to **100,000 J**)

Side Remark Proton/Ion Beams

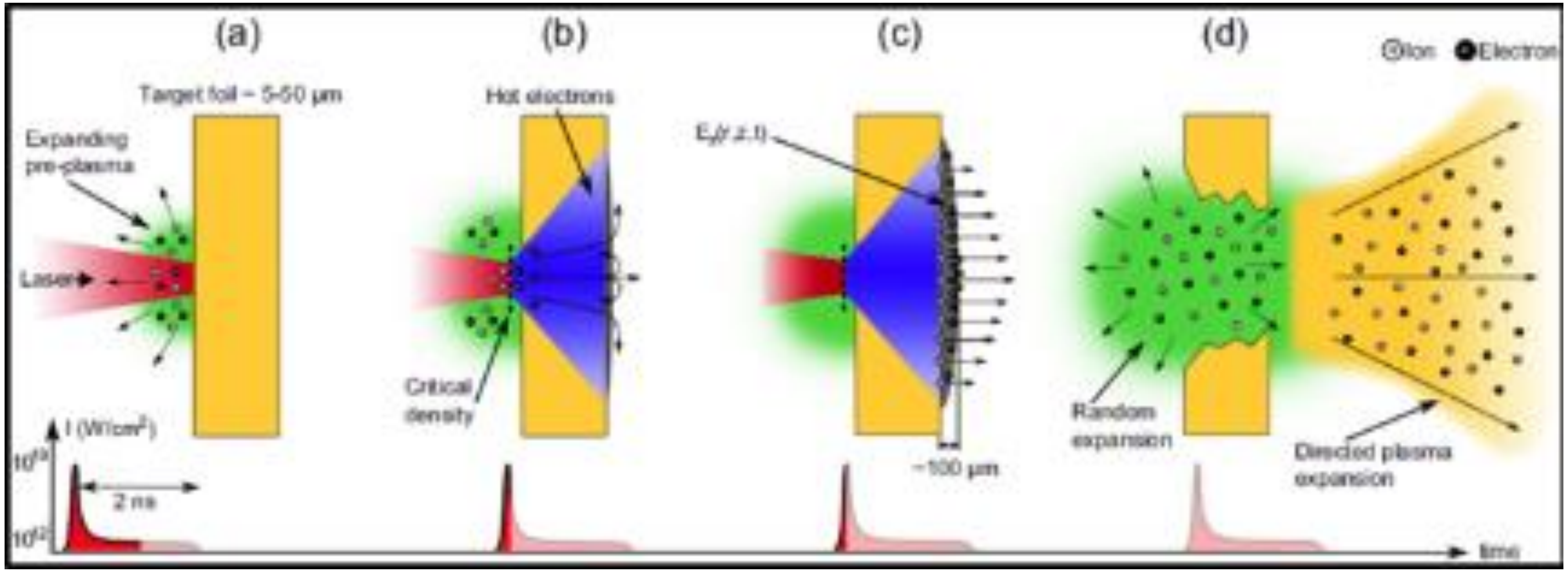
Plasmas can also be used to produce beams of proton or ion bunches

Lasers have **high peak power** (Peta-Watt) & **transverse electrical fields** (>Tera-eV/m).

1. ***Shoot in plasma***: *Used for electron beam generation and/or acceleration (see before).*
2. **Shoot on a solid target**: Create plasma → charge separation, acceleration of plasma ions.

Target Normal Sheath Acceleration (TNSA) method

Courtesy U. Schramm, HZDR

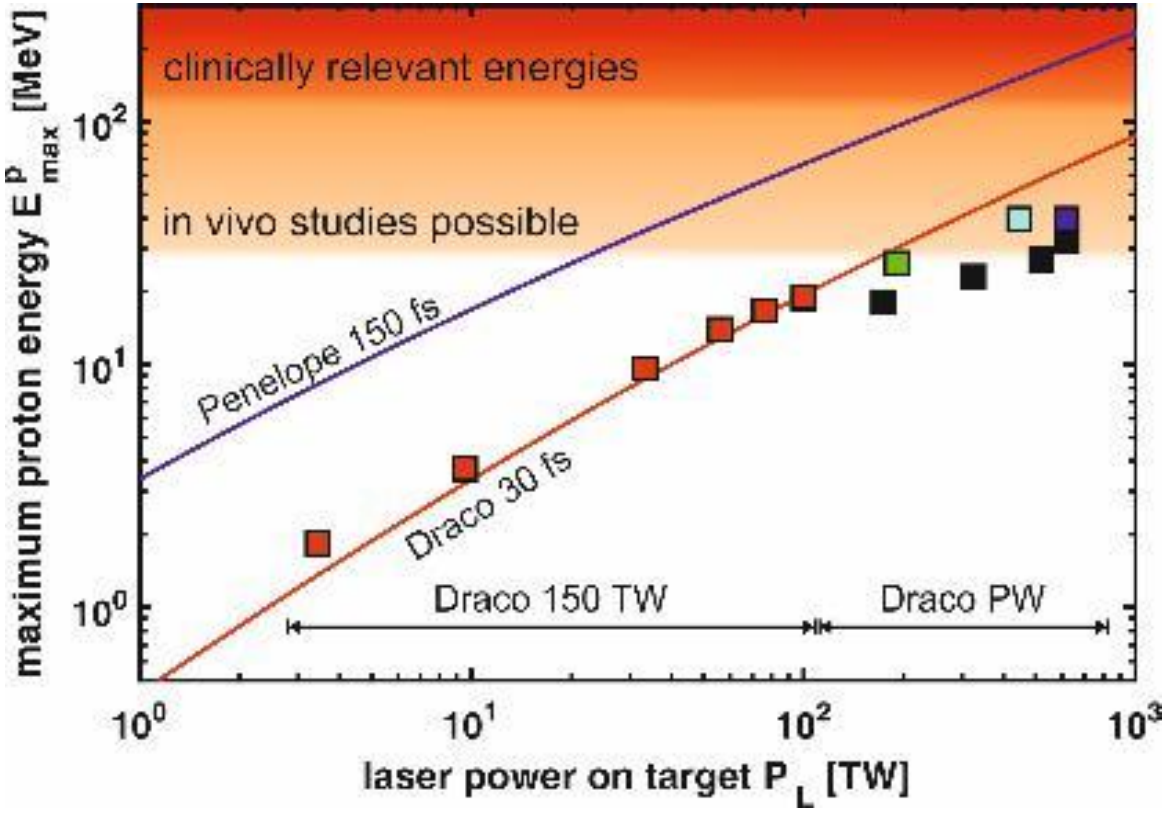


Side Remark Proton/Ion Beams

Plasmas can also be used to produce beams of proton or ion bunches

- Application driven - for the development of **compact proton and ion sources**
- Building on unique energy efficient **diode pumping technology** expected to support favorable proton energy scaling
- Science driven - for the **systematic optimization** of
  - driver laser technology
  - acceleration processes
  - energy scaling
  - average power

Courtesy U. Schramm, HZDR



Laser-Plasma Electron Accelerator: Photo

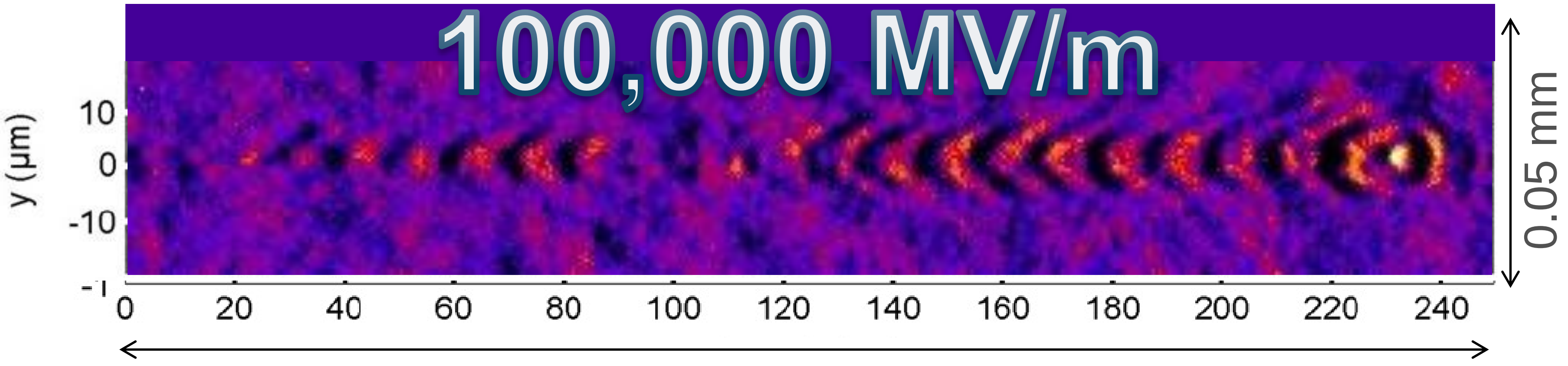
Small but can be photographed


APPLIED PHYSICS LETTERS **103**, 191118 (2013)

Few-cycle optical probe-pulse for investigation of relativistic laser-plasma interactions

M. B. Schwab,[1,a)] A. Sävert,[1] O. Jäckel,[1,2] J. Polz,[1] M. Schnell,[1] T. Rinck,[1] L. Veisz,[3] M. Möller,[1] P. Hansinger,[1] G. G. Paulus,[1,2] and M. C. Kaluza[1,2]
[1]*Insitut für Optik und Quantenelektronik, Max-Wien-Platz 1, 07743 Jena, Germany*
[2]*Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena, Germany*
[3]*Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany*

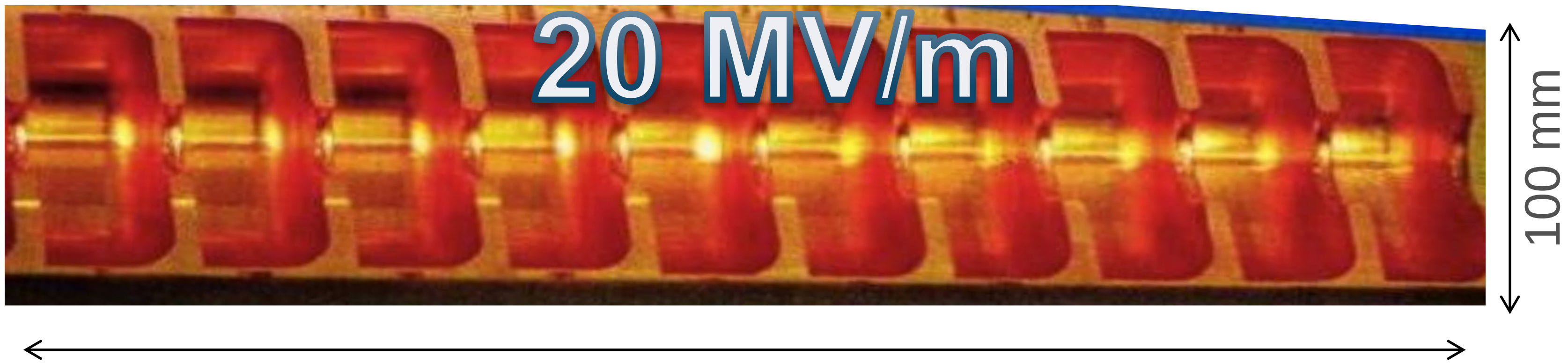
2013



0.25 mm

Metal (Copper)
S band
linac
structure

Microwaves for generation of RF waves

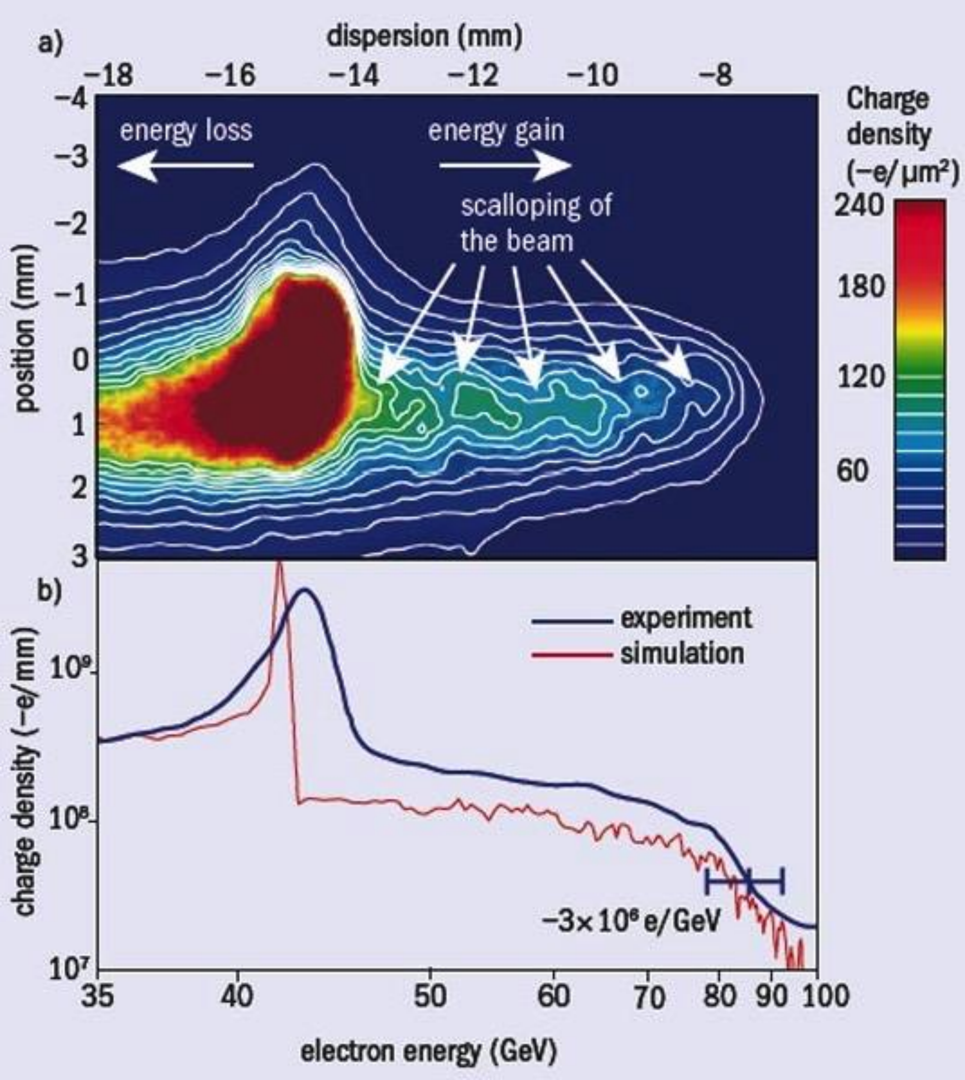


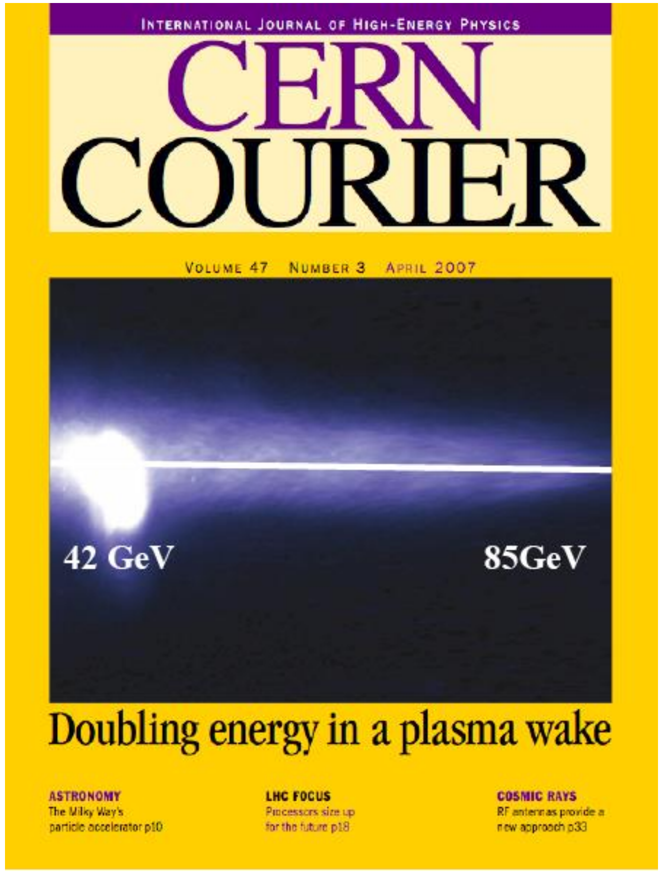
500 mm

SLAC: 42 GeV electron acceleration has been shown

e- beam driver

85 cm plasma driven by a 42 GeV electron beam, tail of bunch accelerated




INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERN COURIER

VOLUME 47 NUMBER 3 APRIL 2007

Doubling energy in a plasma wake

ASTRONOMY
The Milky Way's particle accelerator p10

LHC FOCUS
Processors size up for the future p18

COSMIC RAYS
RF antennas provide a new approach p33


Bob Siemann, SLAC

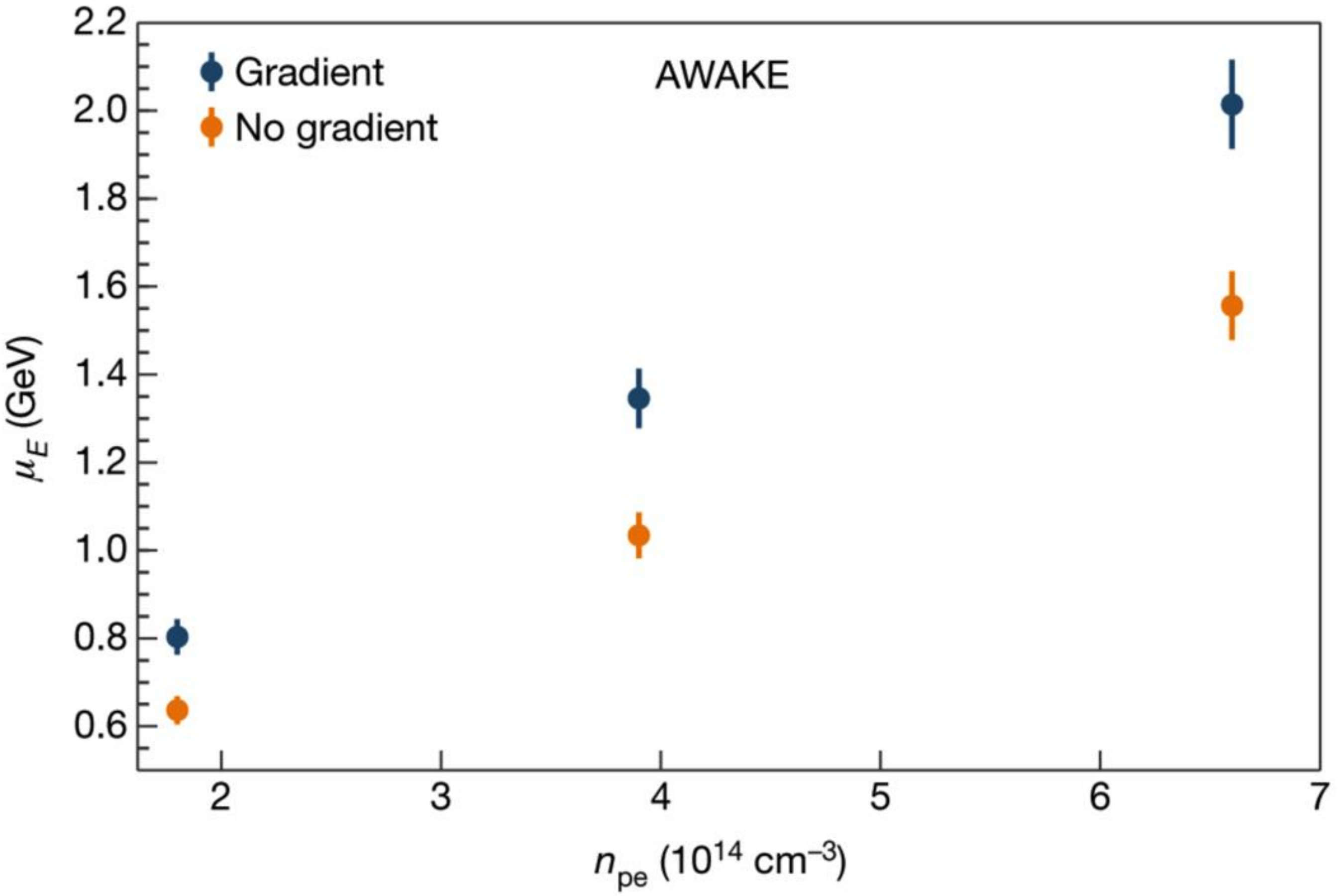
E167 collaboration
SLAC, UCLA, USC

I. Blumenfeld et al, Nature 445, p. 741 (2007)

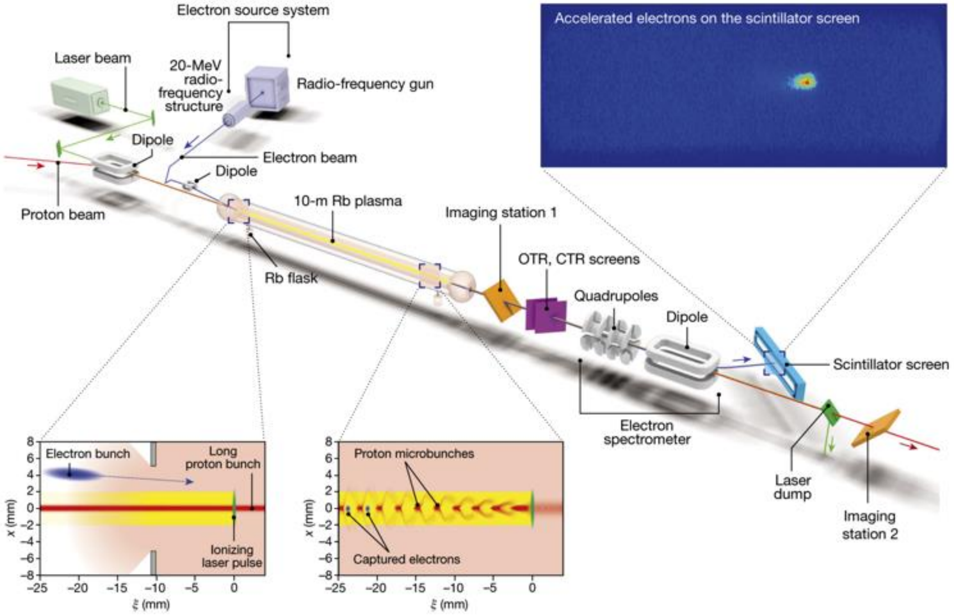
AWAKE at CERN: 2 GeV electron beam acceleration

p+ beam driver

Over a plasma cell length of 10 meters



The error bars arise from the position–energy conversion. The gradients chosen are those that were observed to maximize the energy gain. Acceleration to 2.0 ± 0.1 GeV is achieved with a plasma density of 6.6×10^{14} cm^{-3} with a density difference of +2.2% ± 0.1% over 10 m.

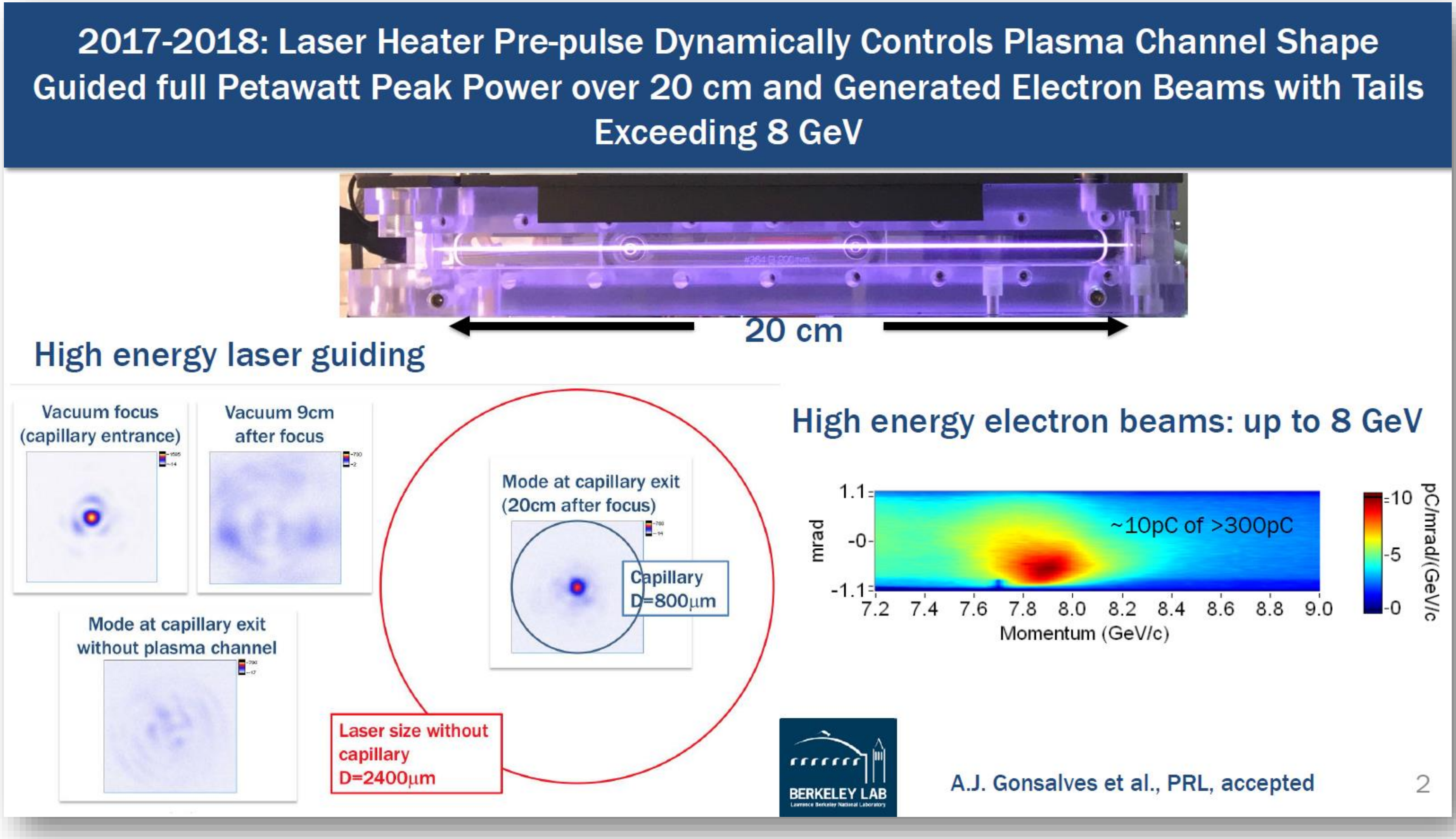


Adli, E., Ahuja, A., Apsimon, O. *et al.* Acceleration of electrons in the plasma wakefield of a proton bunch. *Nature* **561,** 363–367 (2018). https://doi.org/10.1038/s41586-018-0485-4

LBNL: 8 GeV electron beams have been obtained

From 20 cm plasma channel, wakefields driven by pulses from BELLA laser

laser driver



2017-2018: Laser Heater Pre-pulse Dynamically Controls Plasma Channel Shape Guided full Petawatt Peak Power over 20 cm and Generated Electron Beams with Tails Exceeding 8 GeV

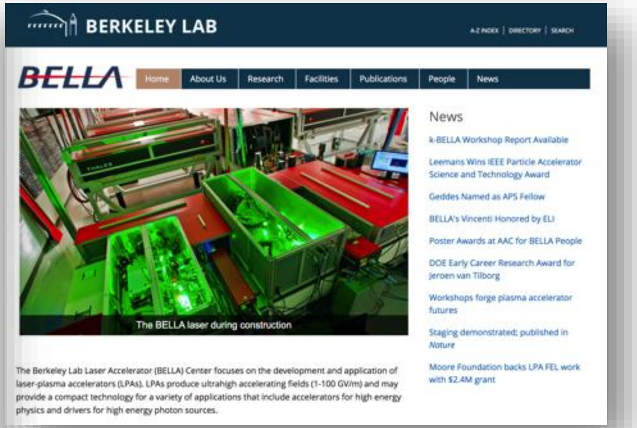
High energy laser guiding

High energy electron beams: up to 8 GeV

BERKELEY LAB

A.J. Gonsalves et al., PRL, accepted

2



BERKELEY LAB

The BELLA laser during construction

News

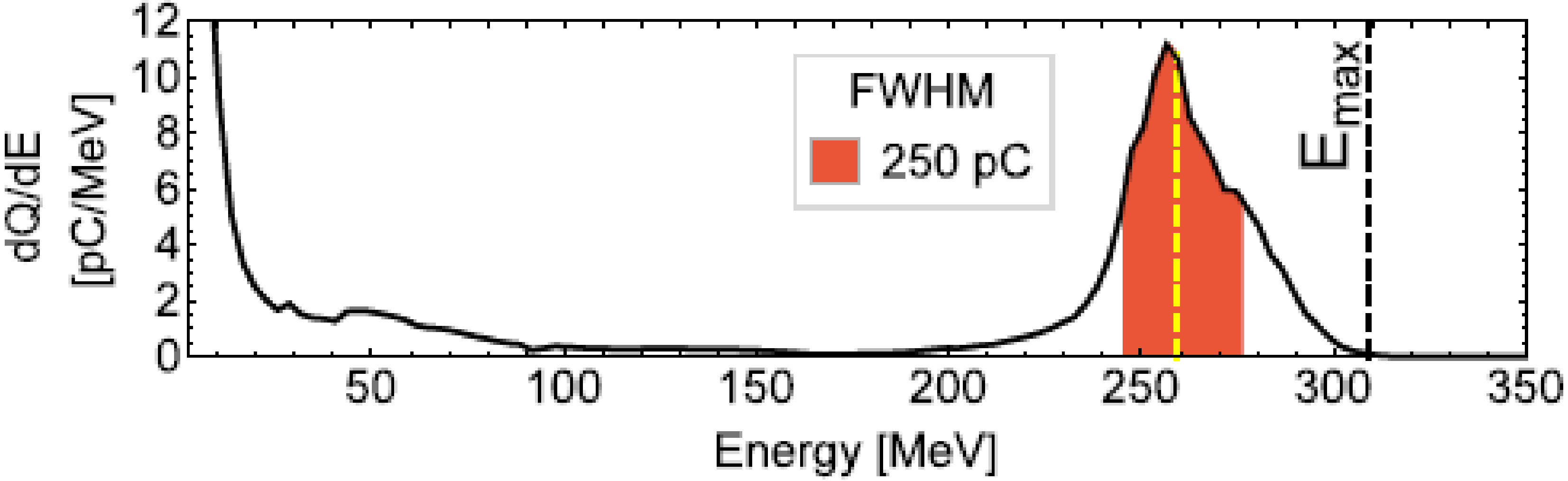
- k-BELLA Workshop Report Available
- Leemans Wins IEEE Particle Accelerator Science and Technology Award
- Geddes Named as APS Fellow
- BELLA's Vincenti Honored by ELI
- Poster Awards at AAC for BELLA People
- DOE Early Career Research Award for Jeroen van Tilborg
- Workshops forge plasma accelerator futures
- Staging demonstrated; published in *Nature*
- Moore Foundation backs LPA FEL work with $2.4M grant

The Berkeley Lab Laser Accelerator (BELLA) Center focuses on the development and application of laser-plasma accelerators (LPAs). LPAs produce ultrahigh accelerating fields (1-100 GV/m) and may provide a compact technology for a variety of applications that include accelerators for high energy physics and drivers for high energy photon sources.

HZDR Dresden: Electron beam 500 pC charge, > 10 kA

laser driver

Applying Novel Solutions for Pushing the Charge



J. Couperus, et al., Nat. Commun. 8, 487 (2017)

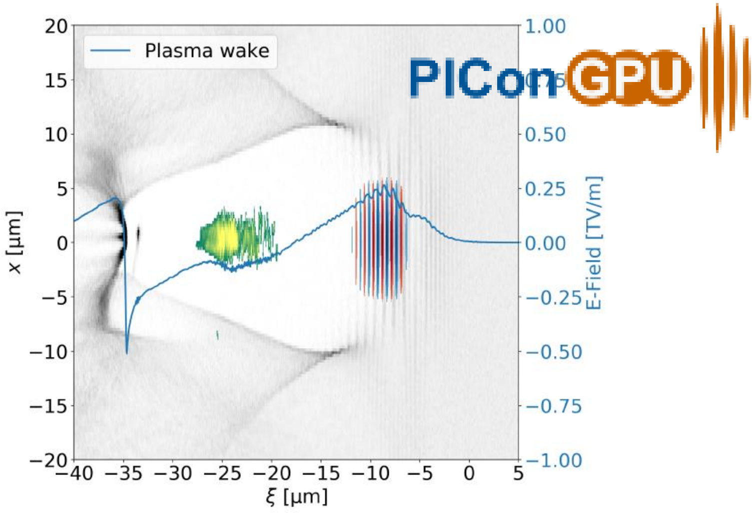
A.Irman, et al., PPCF 60, 044015 (2018)

World record peak current (~20 kA). Opens exciting new applications:

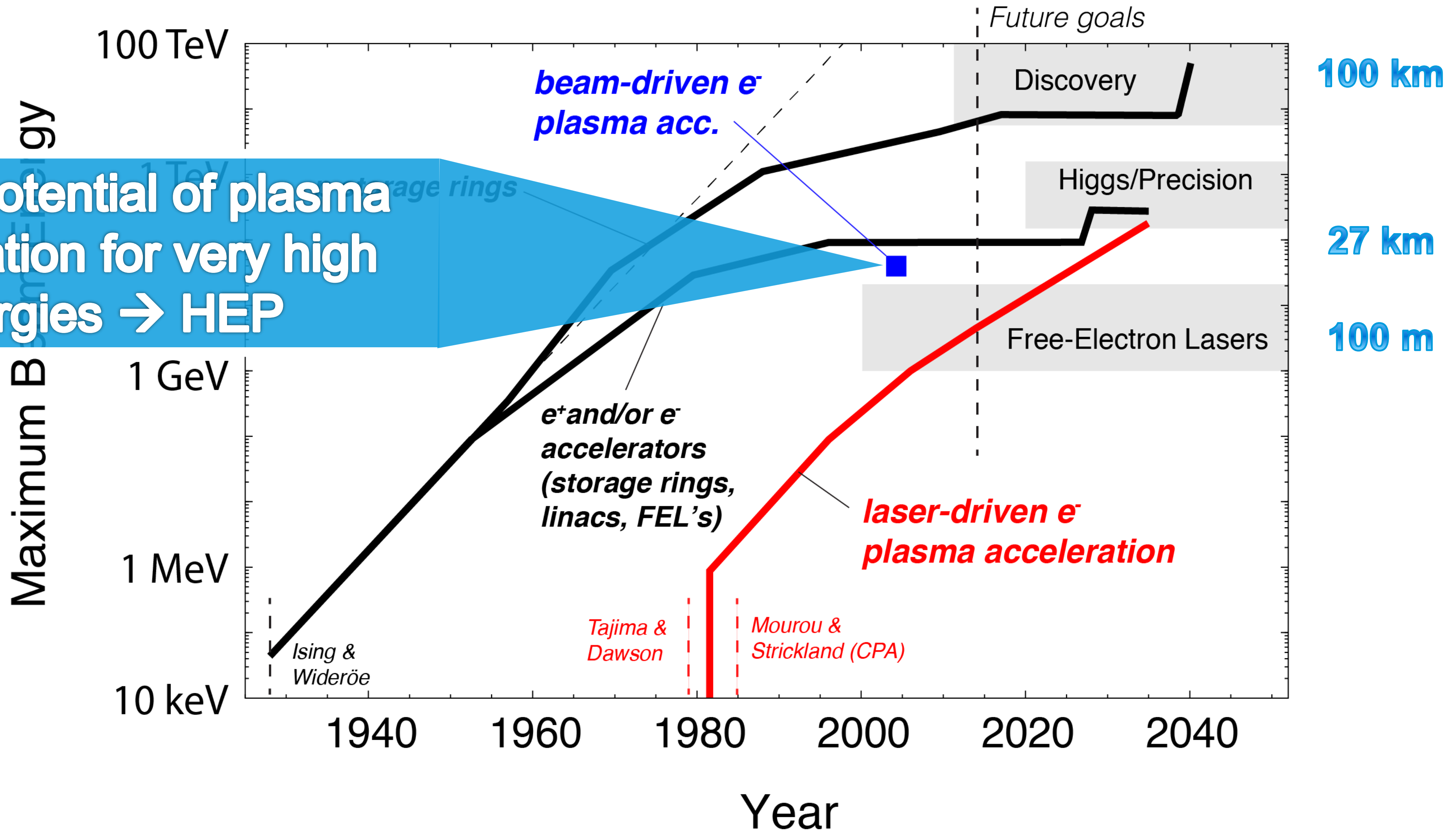
→ Higher charge electron applications (irradiation, collider, ...)

→ Driver for THz sources

→ Driver for beam driven wakefields

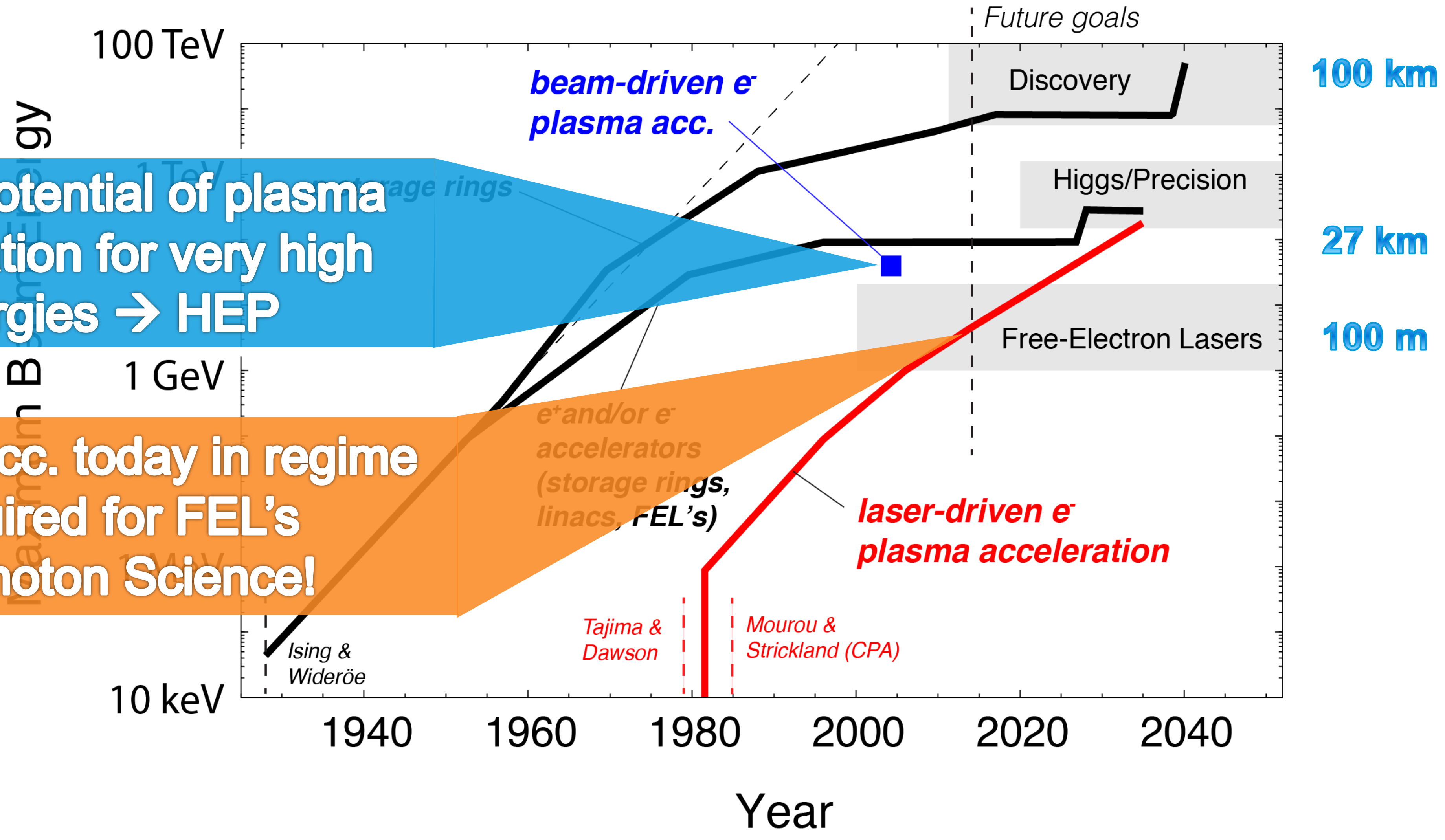


Compact Accelerators for HEP?



Shows potential of plasma acceleration for very high energies → HEP

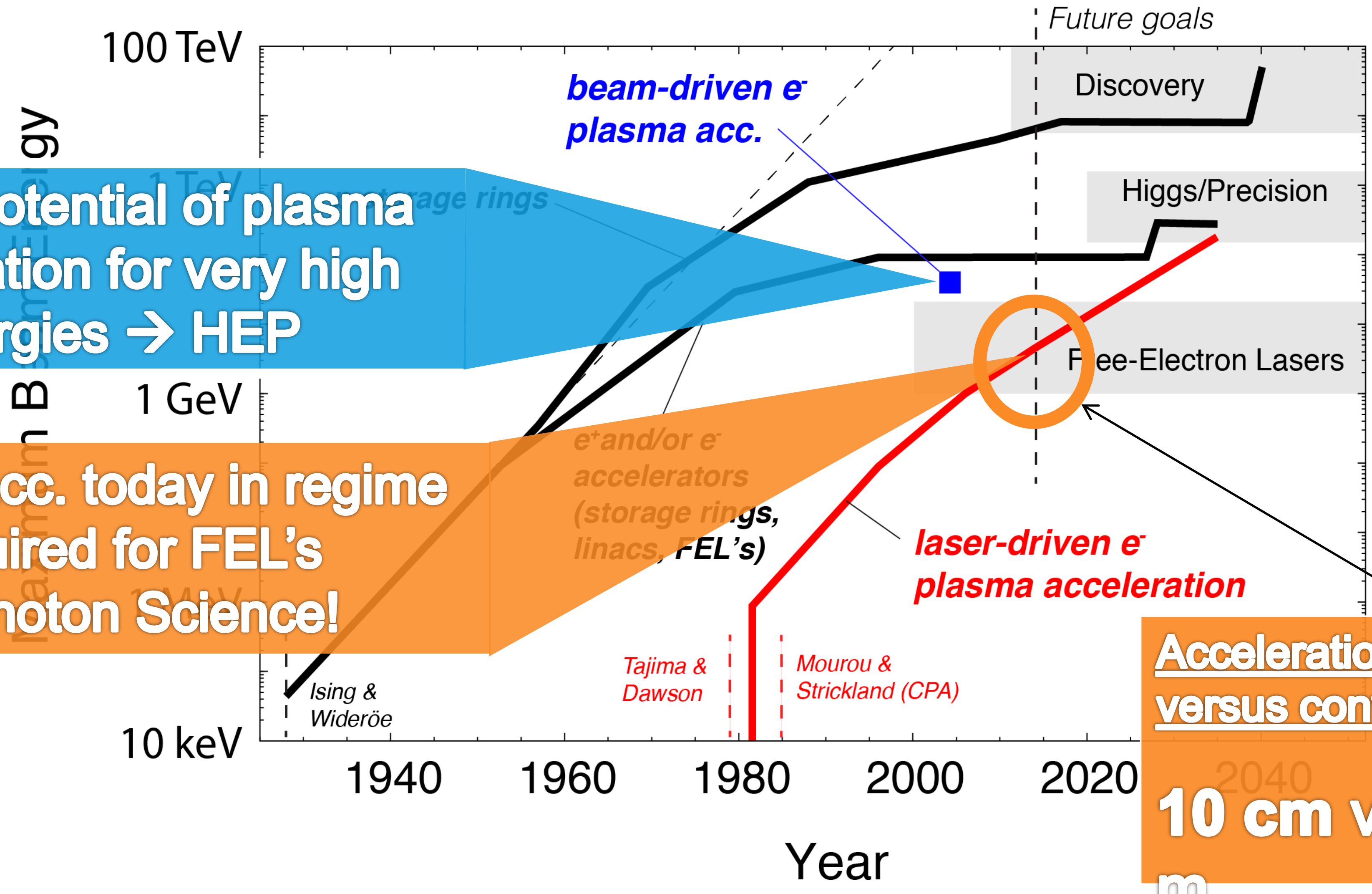
Compact Accelerators for HEP?



Shows potential of plasma acceleration for very high energies → HEP

Plasma acc. today in regime required for FEL's → Photon Science!

Compact Accelerators for HEP?



100 km

27 km

100 m → 9 cm

Shows potential of plasma acceleration for very high energies → HEP

Plasma acc. today in regime required for FEL's → Photon Science!

Acceleration length (new versus conventional):

10 cm versus 100 m

The Plasma Accelerator: The Next Step?

DER SPIEGEL

DER SPIEGEL 11/2015

Im Bann von Waxahachie

Physik Forscher bauen immer gewaltigere Teilchenbeschleuniger, um die Geheimnisse des Universums zu enträtseln. Geht es auch eine Nummer kleiner?

Unter den Feldern von Texas erstreckt sich ein verlassener Tunnel, knapp 23 Kilometer lang. Die Zugänge sind verschüttet, in der Röhre sammelt sich Wasser.

Die Ruine nahe dem Städtchen Waxahachie steht für das Trauma der Teilchenphysik: Hier baute die stolze Zunft einst

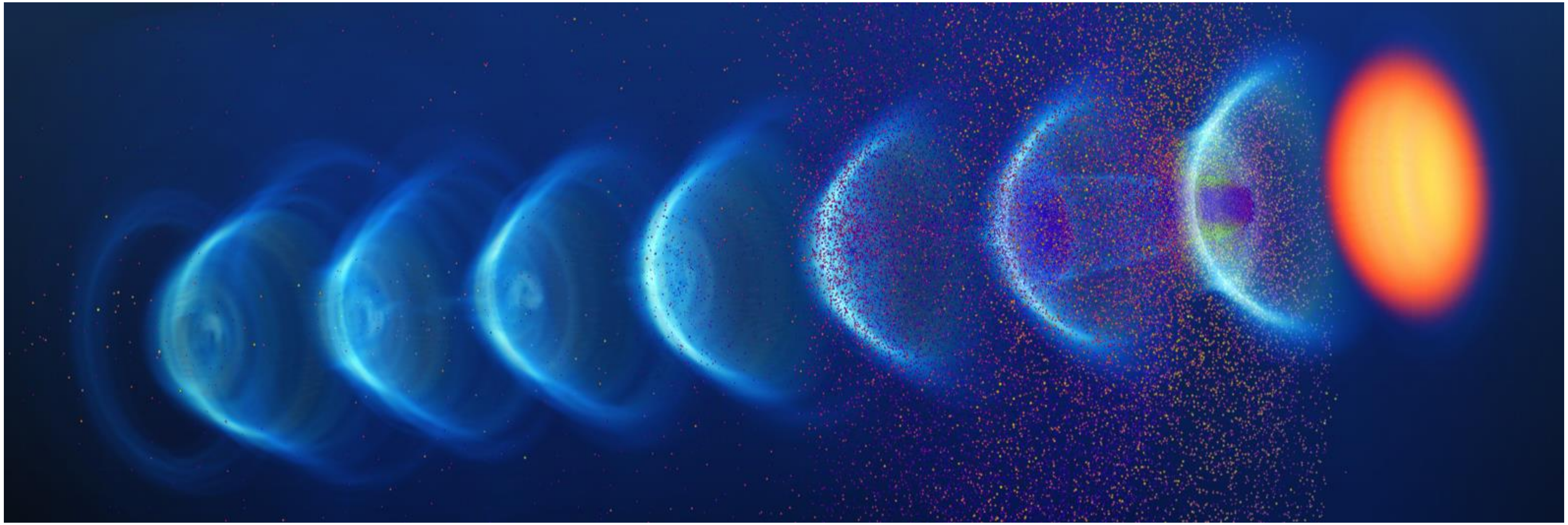


Illustration from PhD A. Ferran Pousa

DIE WELT

SAMSTAG, 28. MÄRZ 2015

Bremse für Superbeschleuniger

Größer, schneller, teurer geht's nicht mehr. Bis zu sechs Milliarden Dollar kosten die Teilchenschleudern in Genf oder anderswo. Materieforscher müssen sich etwas einfallen lassen

A 1 TeV collider in 10-100 meters?

Not so easy...

Physics – Linear Wakefields (R. Ruth / P. Chen 1986)

The formulae behind it all

$$\mathcal{E}_z \simeq -A\left(1-\frac{r^2}{a^2}\right)\cos(k_p z-\omega_p t)$$

$$r \ll a$$

$$\mathcal{E}_r \simeq 2A\frac{r}{k_p a^2}\sin(k_p z-\omega_p t)$$

$$A = \begin{cases} \dfrac{\omega_p \tau k_p e E_0^2}{8\omega^2 m} & PBWA \\[2ex] \dfrac{8eN}{a^2} & PWFA \end{cases}$$

ε = electrical field
z = long. coord.
r = radial coord.
a = driver radius
ω_p = plasma frequency
k_p = plasma wave number
t = time variable
e = electron charge

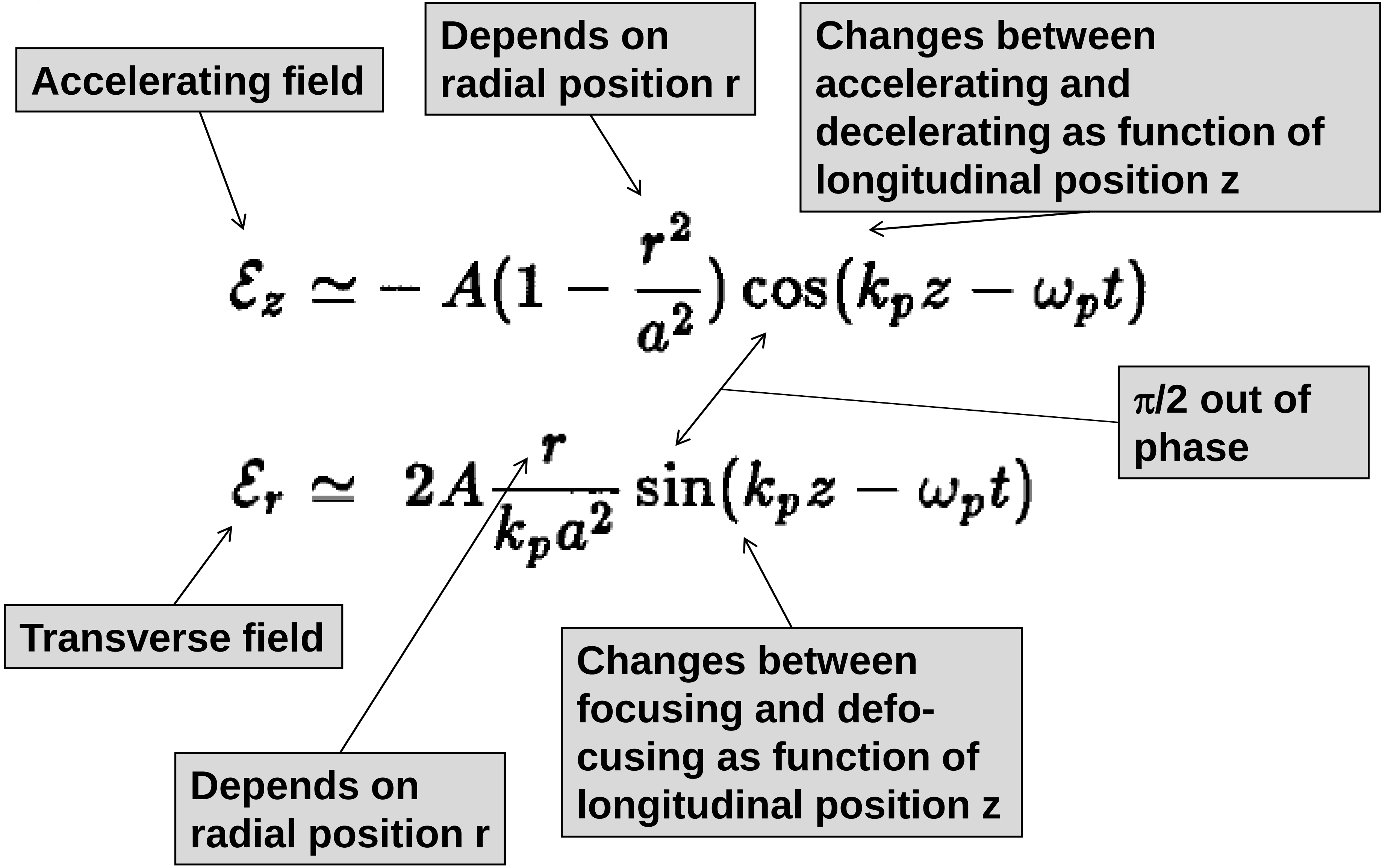
N = number e- drive bunch

ω = laser frequency
τ = laser pulse length
E_0 = laser electrical field
m = mass of electron

Can be analytically solved and treated. Here comparison beam-driven (PWFA) and laser-driven (beat wave = PBWA).

Physics – Linear Wakefields (R. Ruth / P. Chen 1986)

The formulae behind it all



Accelerating field

Depends on radial position r

Changes between accelerating and decelerating as function of longitudinal position z

$$\mathcal{E}_z \simeq -A\left(1-\frac{r^2}{a^2}\right)\cos(k_p z-\omega_p t)$$

π/2 out of phase

$$\mathcal{E}_r \simeq 2A\frac{r}{k_p a^2}\sin(k_p z-\omega_p t)$$

Transverse field

Depends on radial position r

Changes between focusing and defocusing as function of longitudinal position z

The Useful Regime of Plasma Accelerators

Where do we put the electron bunch inside the wave (or the surfer on the wave)

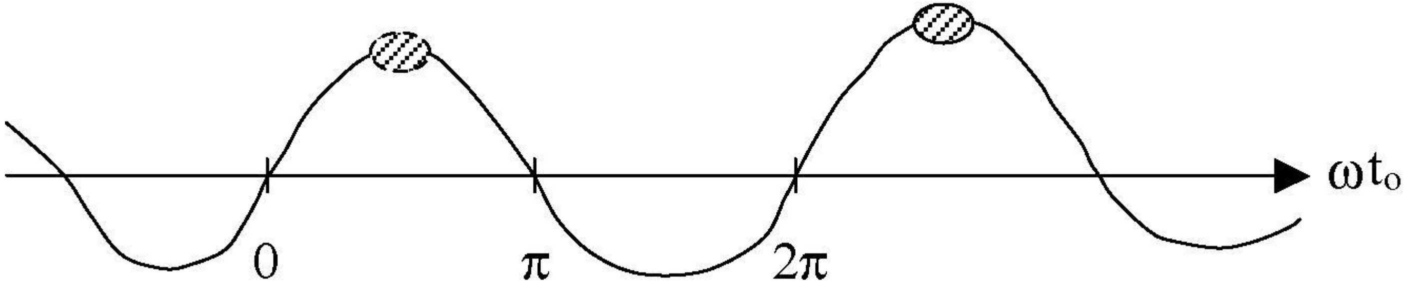
Two conditions for an accelerator:

1. **Accelerated bunch must be in accelerating regime.**
2. **Accelerated bunch must be in focusing regime.**

These two conditions define a useful range of acceleration!

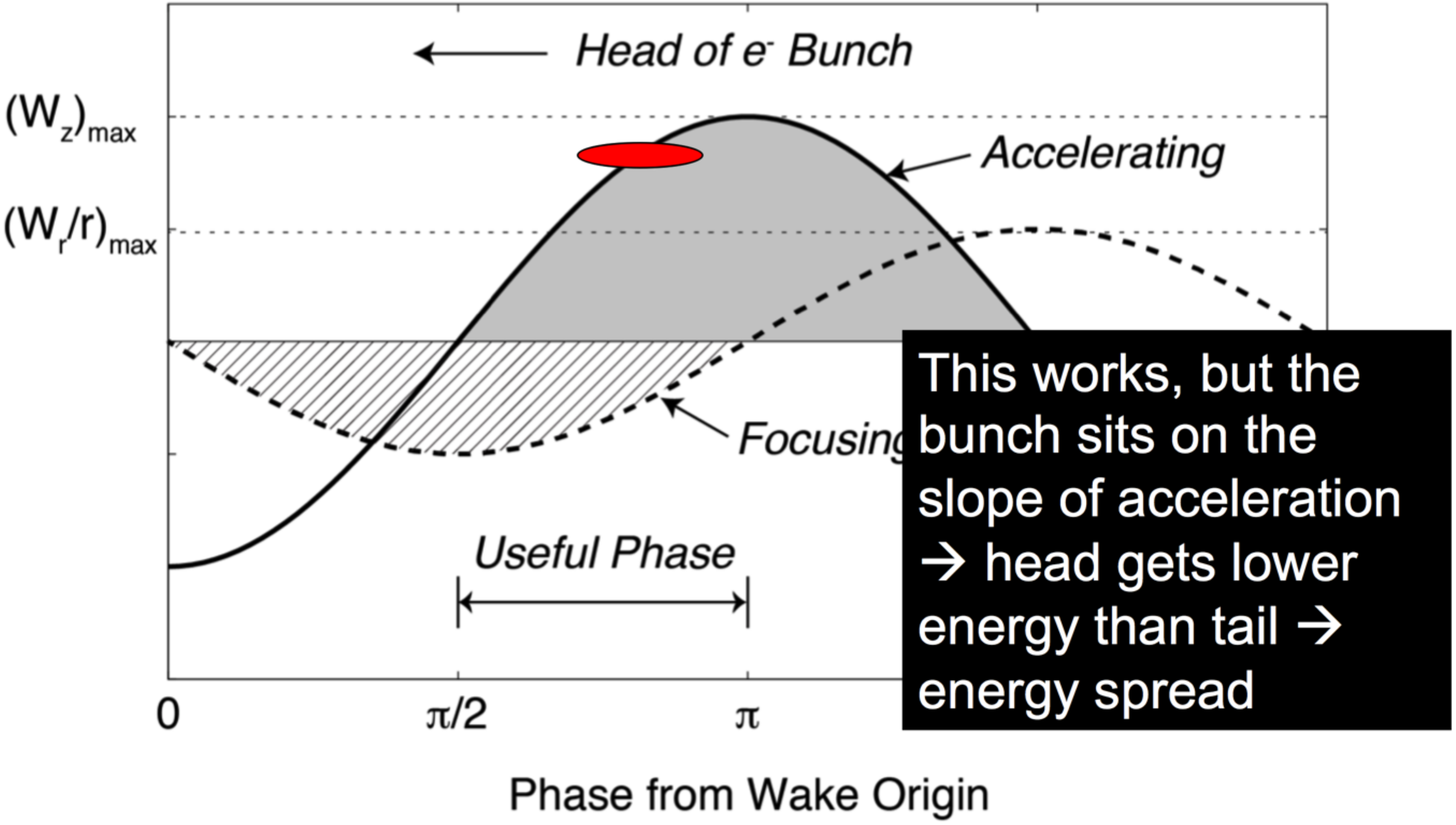
Reminder metallic RF accelerator structures:

no net transverse fields for beam particles → full accelerating range is available for beam → usually place the beam on the crest of the accelerating voltage



Plasma Accelerator Phasing

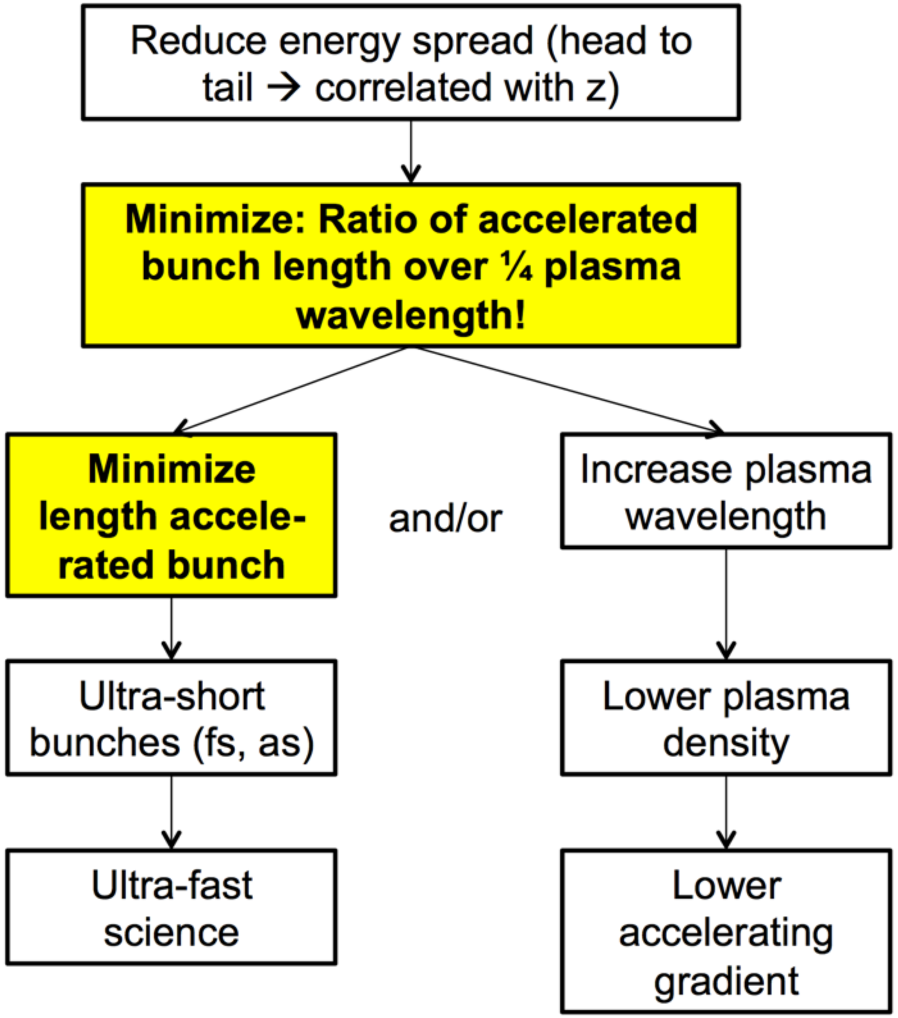
Finding the useful regime → Systematic problem of large energy spread is induced (not in RF accelerators)



This works, but the bunch sits on the slope of acceleration → head gets lower energy than tail → energy spread

Optimization: Minimal Energy Spread

Avoid creation of too much energy spread (cannot be avoided by principle explained before)



Reduce energy spread (head to tail → correlated with z)

Minimize: Ratio of accelerated bunch length over ¼ plasma wavelength!

Minimize length accelerated bunch

and/or

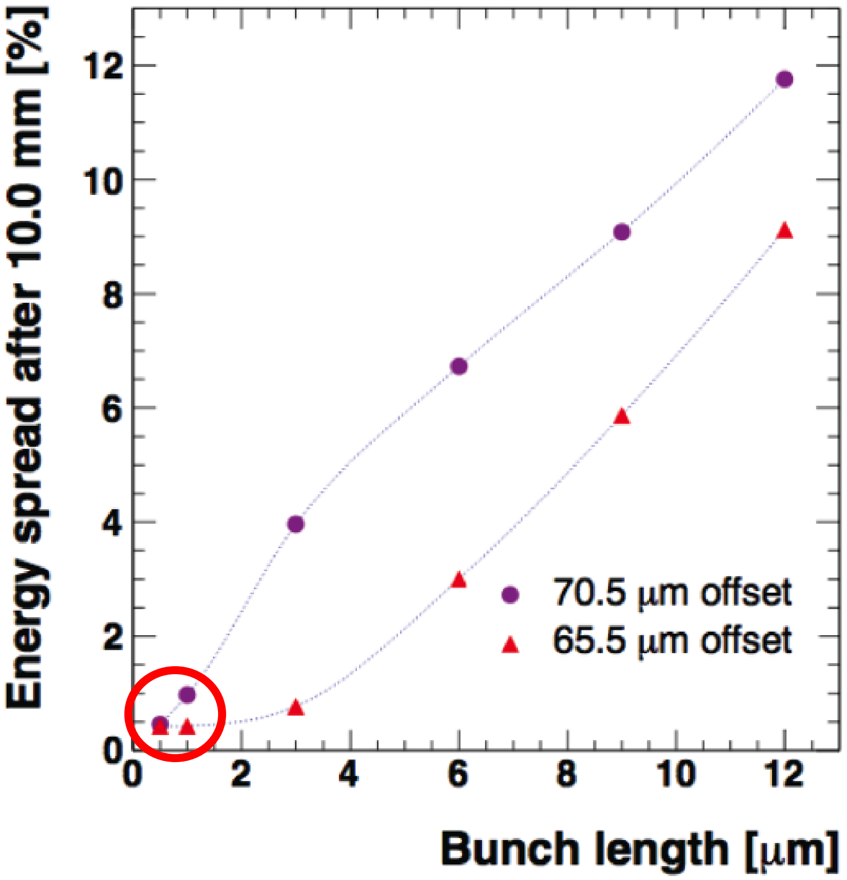
Increase plasma wavelength

Ultra-short bunches (fs, as)

Ultra-fast science

Lower plasma density

Lower accelerating gradient

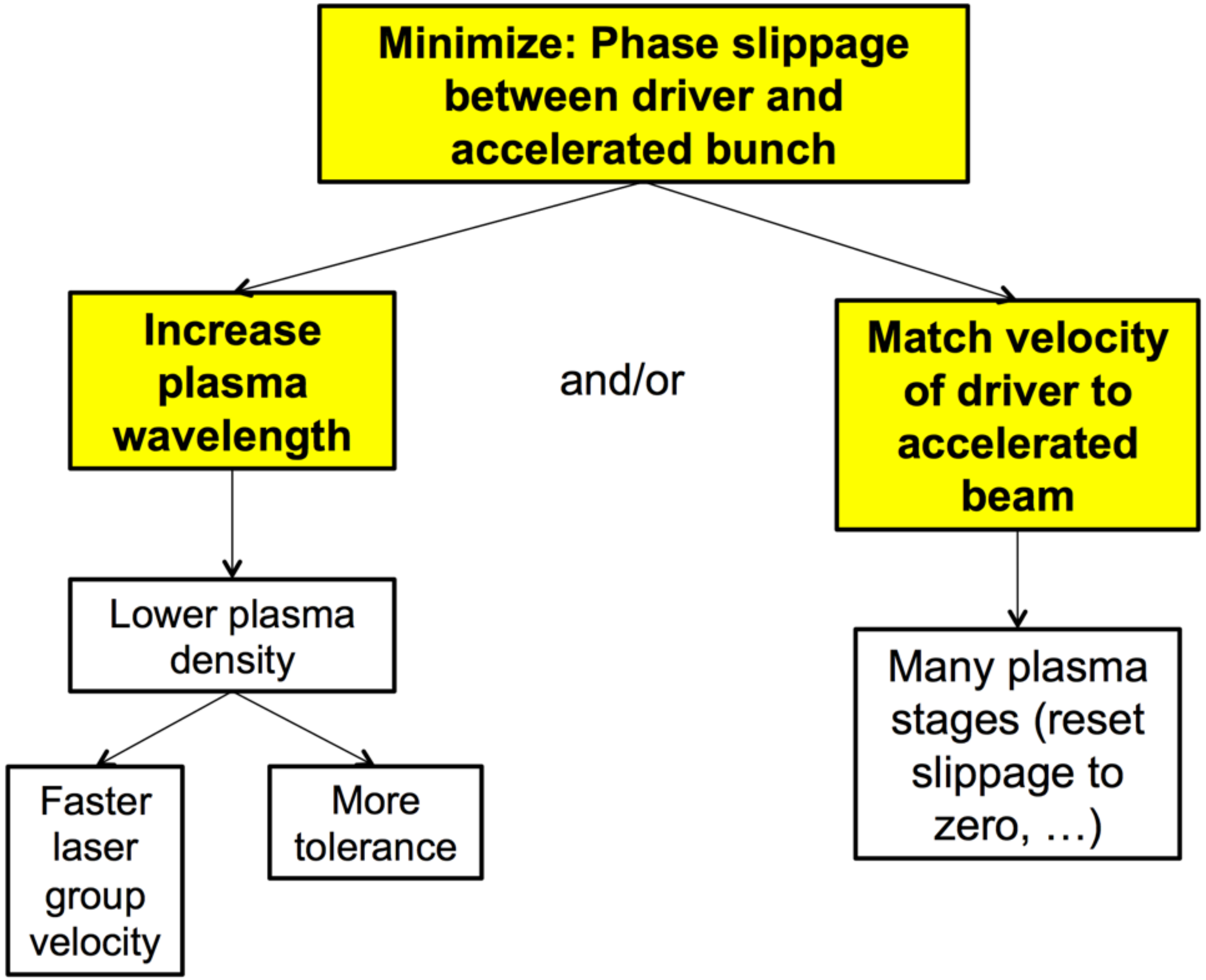


R. Assmann
J. Grebenyuk
IPAC 2014

1 fs = 0.3 μm when travelling with light velocity c

Optimization: Phase Slippage

Maximize distances over which we can accelerate



Minimize: Phase slippage between driver and accelerated bunch

Increase plasma wavelength

and/or

Match velocity of driver to accelerated beam

Lower plasma density

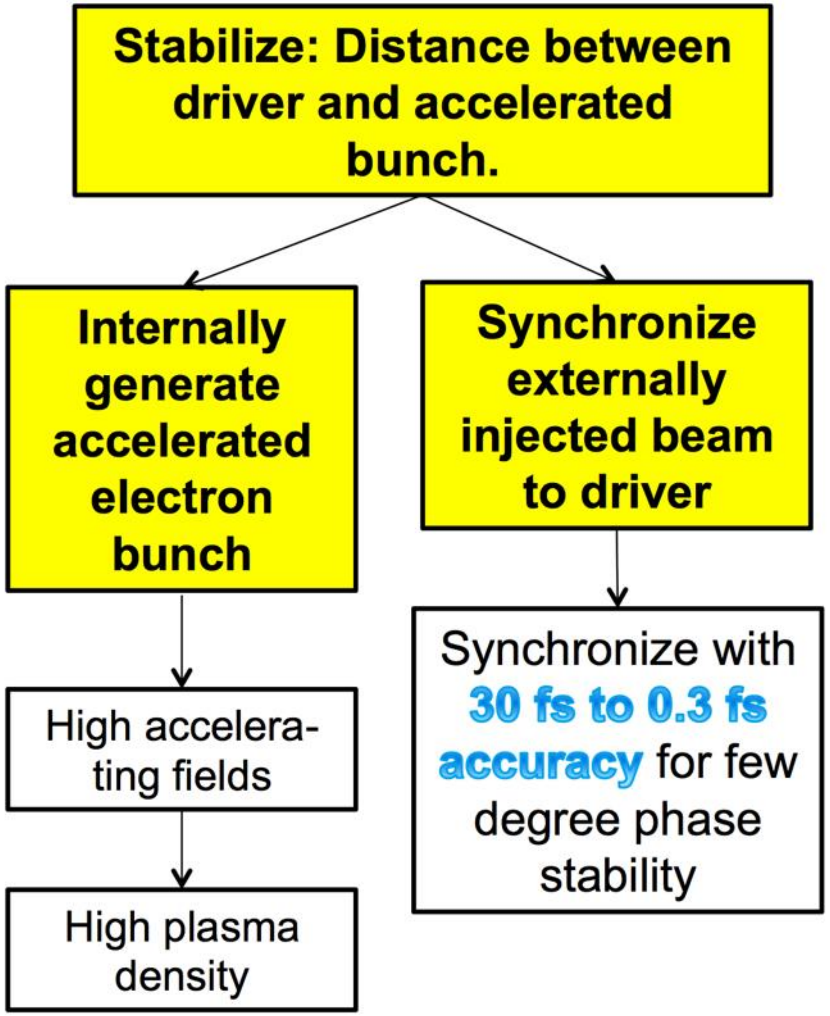
Faster laser group velocity

More tolerance

Many plasma stages (reset slippage to zero, …)

Stability/Reproducibility

Hit the same phase every time



Stabilize: Distance between driver and accelerated bunch.

Internally generate accelerated electron bunch

Synchronize externally injected beam to driver

High accelerating fields

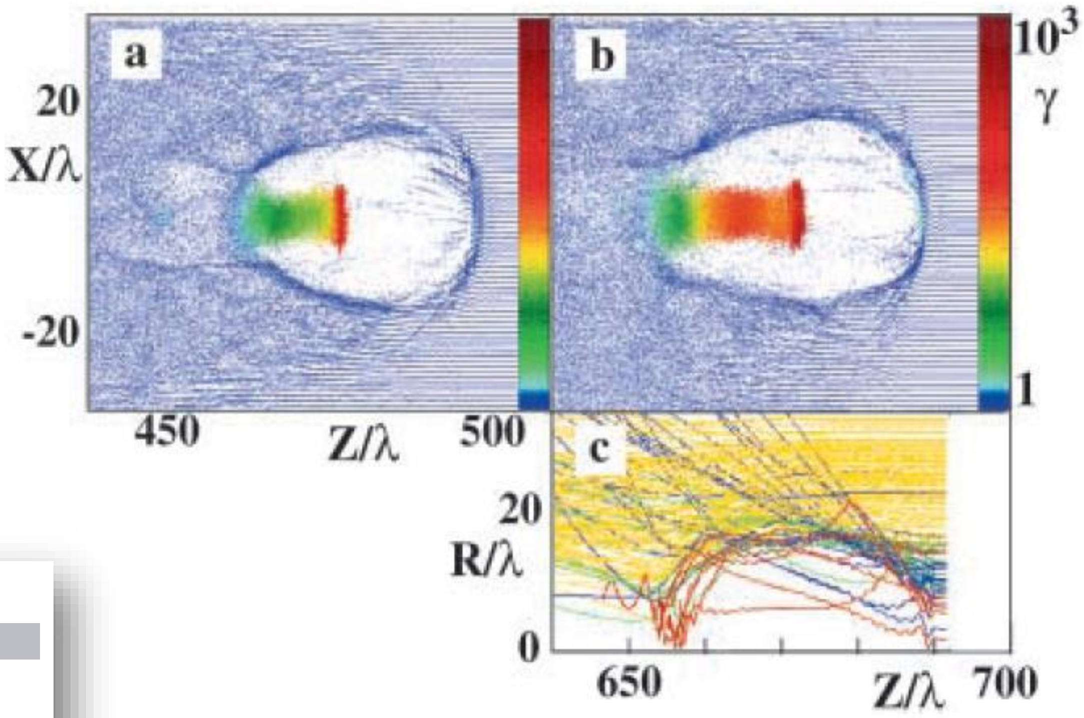
High plasma density

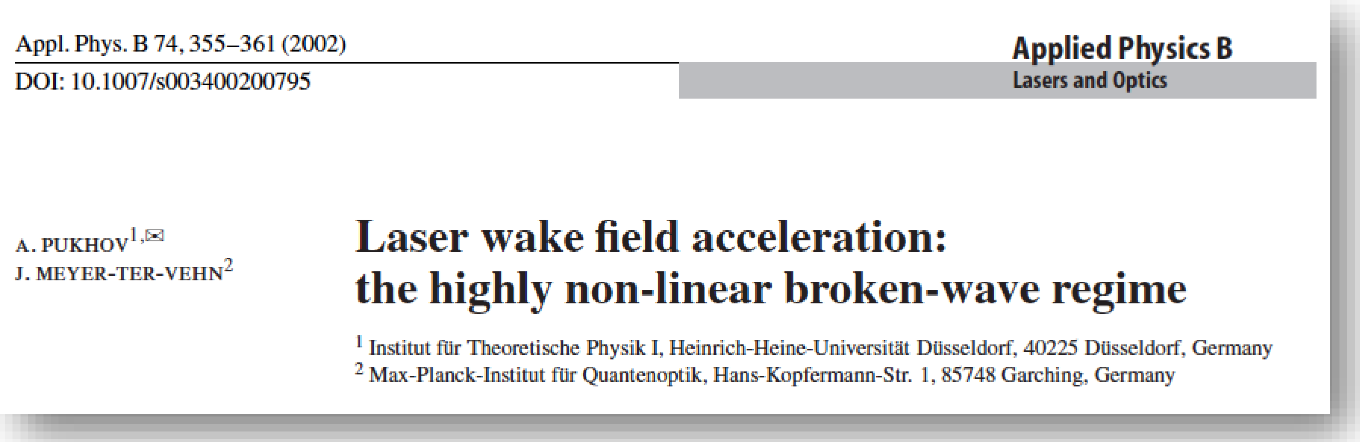
Synchronize with **30 fs to 0.3 fs accuracy** for few degree phase stability

Warning: Non-Linearities are Important

Linear regime nice to get an understanding – Quasi-linear and non-linear regimes most often used

- Plasma wakefield acceleration is most often operated in the so-called **non-linear regime**.
- No time to discuss here – would require more time.
- Accelerating field approaches triangular shape and focusing field is constant with radius → easier regime in many aspects.
- Electron trapping (beam forming) occurs here.





Appl. Phys. B 74, 355–361 (2002)
DOI: 10.1007/s003400200795

Applied Physics B
Lasers and Optics

A. PUKHOV[1,✉]
J. MEYER-TER-VEHN[2]

Laser wake field acceleration: the highly non-linear broken-wave regime

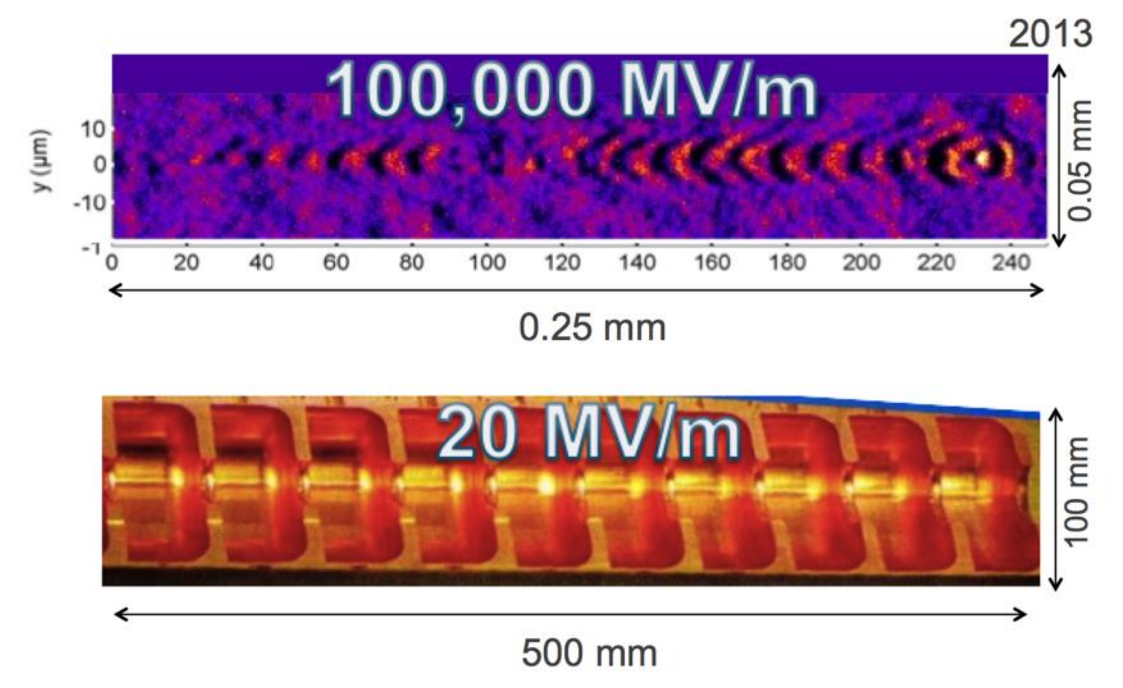
[1] Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany
[2] Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Paper by Pukhov and Meyer-Ter-Vehn one of most cited papers in accelerators: refused at higher impact journals as irrelevant ("would never work")

Plasma opens new reach but also difficulties…

Comparing plama to conventional accelerators

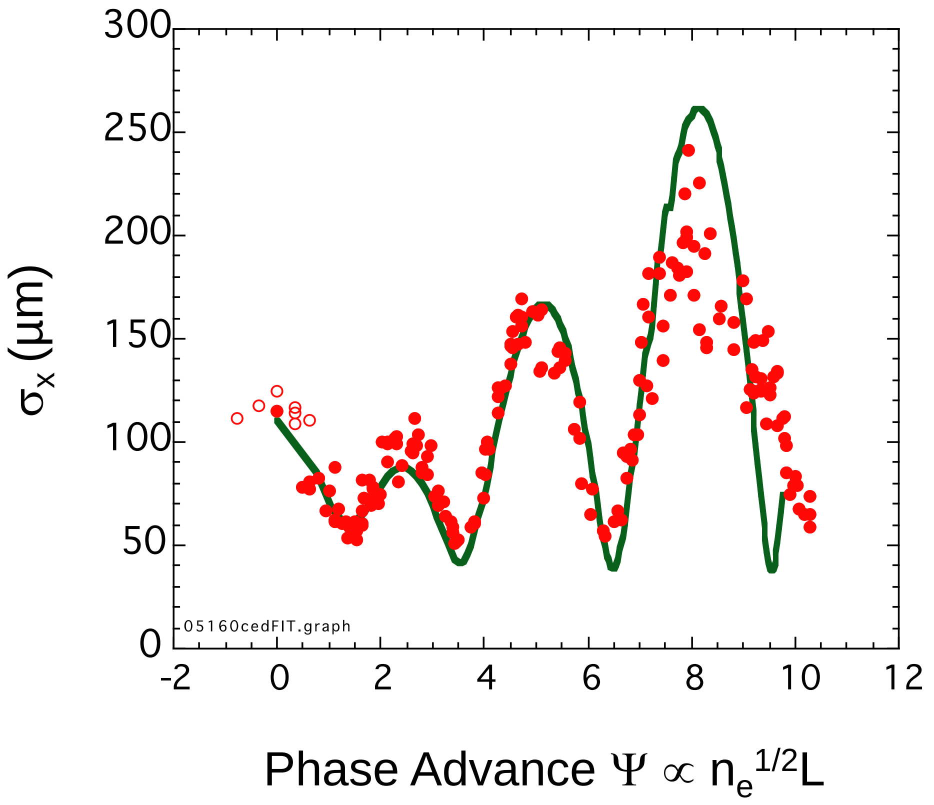
- **Conventional acceleration structures:**
  - Optimized to provide longitudinal acceleration and **no transverse forces** on the beam.
  - Only due to imperfections, transverse forces can be induced → correction of trajectory, wakefields, dispersion with well established methods.
- **Plasma acceleration:**
  - Ultra-strong longitudinal fields → high accelerating gradient.
  - **Ultra-strong transverse fields** → transverse forces cannot be avoided and must be controlled.



Accelerator Builder's Challenge

(simplified to typical values)

- Match into/out of plasma with **beam size ≈1 μm** (about 1 mm beta function). Adiabatic matching (Whittum, 1989).
- Control **offsets** between the wakefield driver (laser or beam) and the accelerated electron bunch at **1 μm level**.
- Use **short bunches (few fs)** to minimize energy spread.
- Achieve **synchronization stability of few fs** from injected electron bunch to wakefield (energy stability and spread).
- Control the **charge and beam loading** to compensate energy spread (idea Simon van der Meer).
- Develop and demonstrate **user readiness of a 5 GeV plasma accelerated beam**.



PRL 2002, C. E. Clayton, B. E. Blue, E. S. Dodd, C. Joshi, K. A. Marsh, W. B. Mori, and S. Wang, P. Catravas, S. Chattopadhyay, E. Esarey, and W. P. Leemans, R. Assmann, F. J. Decker, M. J. Hogan, R. Iverson, P. Raimondi, R. H. Siemann, and D. Walz, T. Katsouleas, S. Lee, and P. Muggli

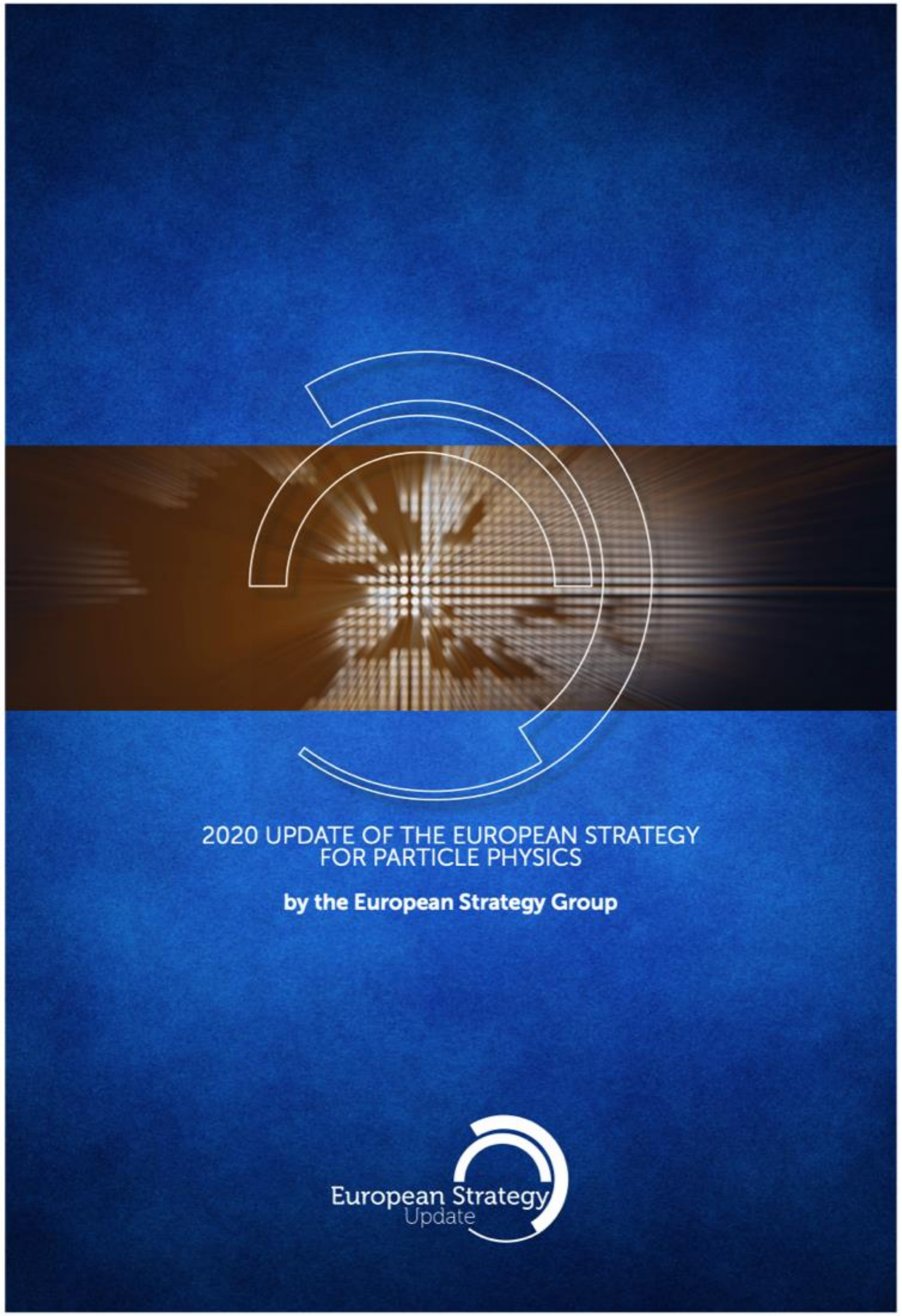
Contents

1. Introduction

2. Ultra-High Gradient Accelerators

3. **Outlook for Europe**

4. Conclusion

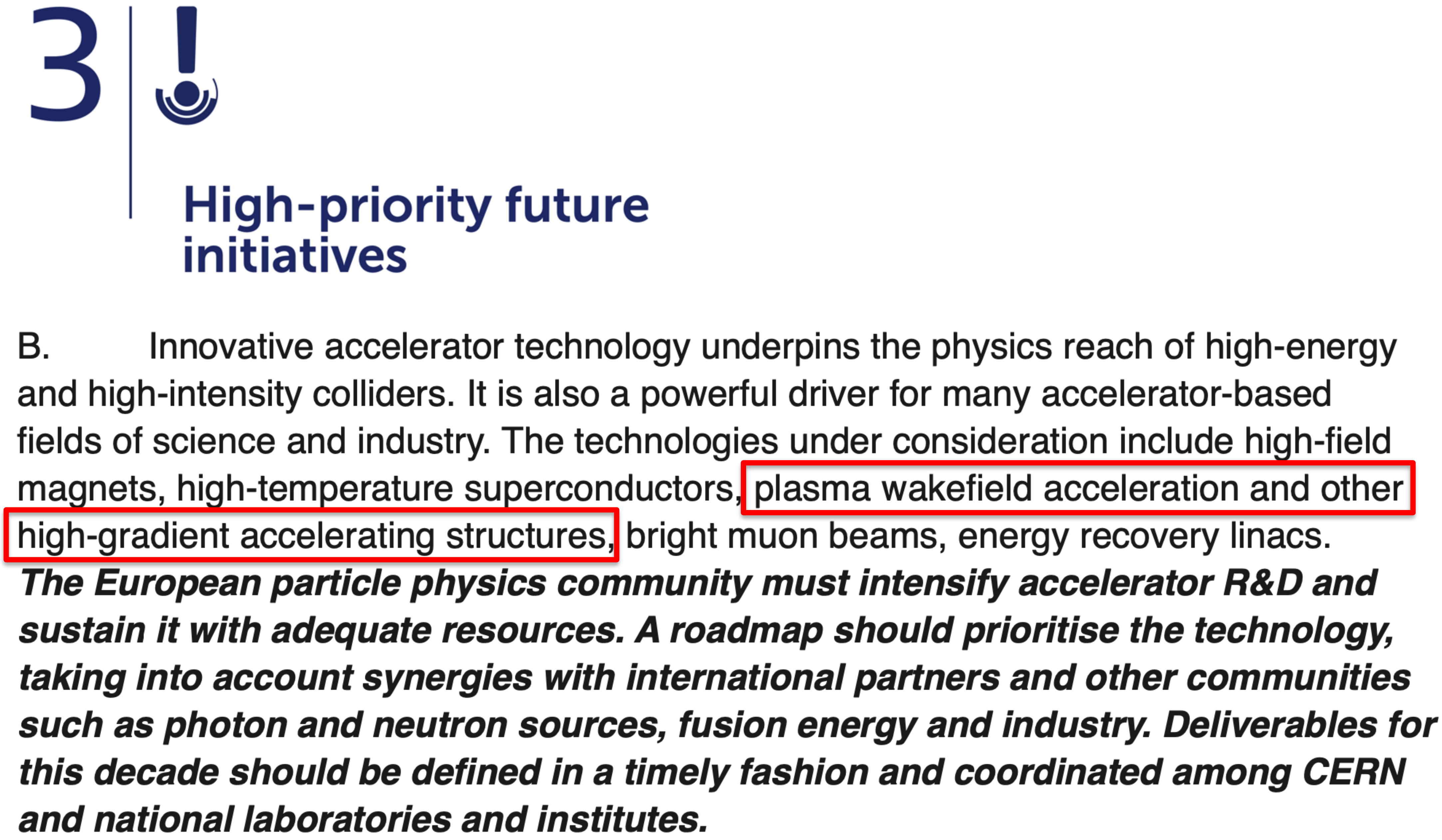

2020 UPDATE OF THE EUROPEAN STRATEGY FOR PARTICLE PHYSICS

by the European Strategy Group

European Strategy Update

European Strategy for Particle Physics

- The European Strategy for Particle Physics is updated every 5 years in a procedure based on wide community input.
- Many of us provided input to this process:
  - Written statements from European Network for Novel Accelerators (EuroNNAc), AWAKE, ALEGRO and EuPRAXIA.
  - Several talks at meetings.
- Strategy defines future directions and priorities for particle physics in Europe and for CERN. Last update: 2020.
- Outcome a great success for advanced accelerators:
  - Importance of accelerator R&D in general.
  - Explicit mentioning of plasma and laser high gradient acceleration.
  - Request for accelerator R&D roadmap, adequate resources, priorities, deliverables for next decade, synergy with other science fields, …



3

High-priority future initiatives

B. Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs. ***The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.***

Expert Panel HGPL "High Gradient Acceleration (Plasma/Laser)"

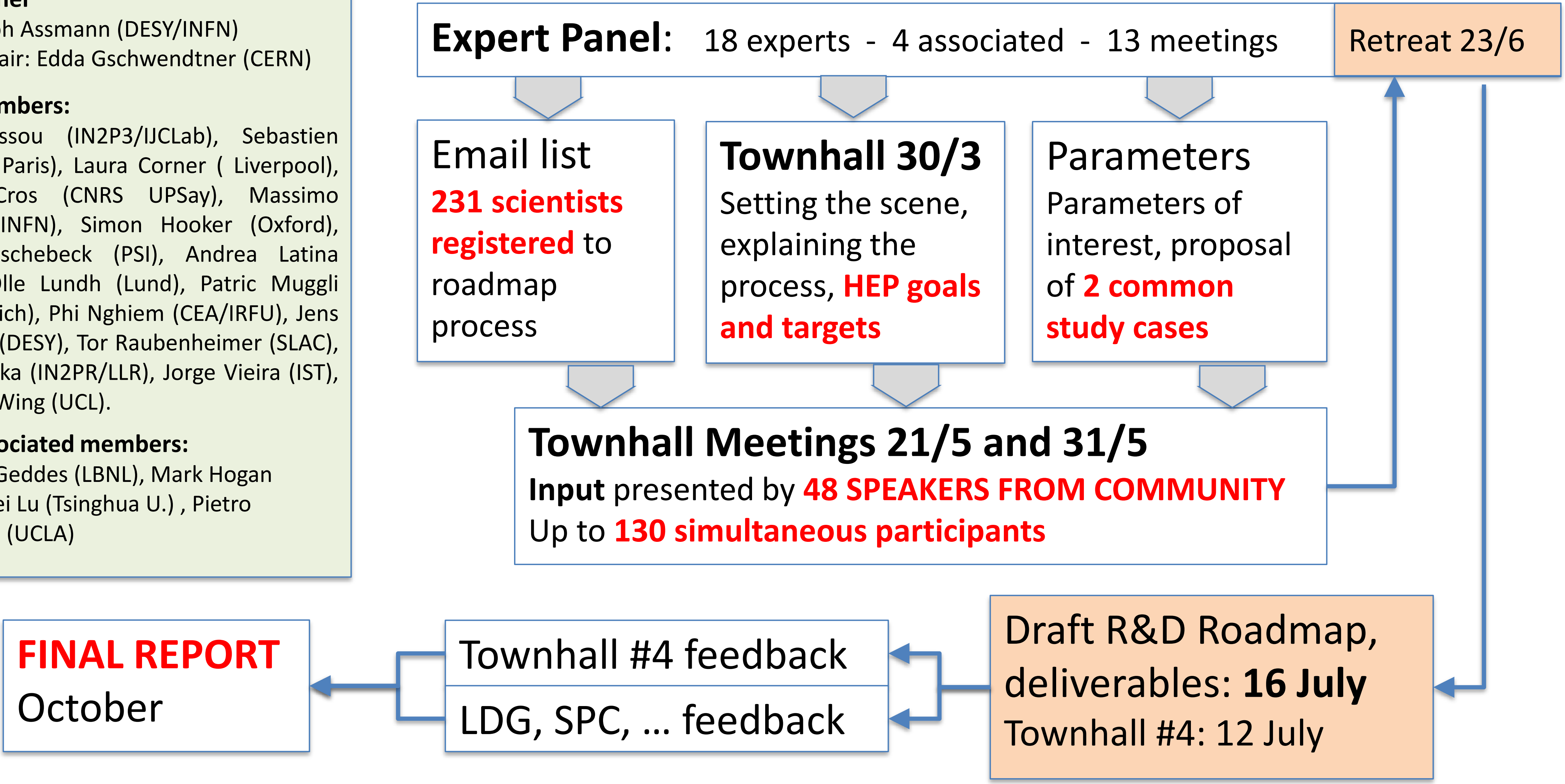
Expert Panel
Chair: Ralph Assmann (DESY/INFN)
Deputy Chair: Edda Gschwendtner (CERN)

Panel members:
Kevin Cassou (IN2P3/IJCLab), Sebastien Corde (IP Paris), Laura Corner (Liverpool), Brigitte Cros (CNRS UPSay), Massimo Ferarrio (INFN), Simon Hooker (Oxford), Rasmus Ischebeck (PSI), Andrea Latina (CERN), Olle Lundh (Lund), Patric Muggli (MPI Munich), Phi Nghiem (CEA/IRFU), Jens Osterhoff (DESY), Tor Raubenheimer (SLAC), Arnd Specka (IN2PR/LLR), Jorge Vieira (IST), Matthew Wing (UCL).

Panel associated members:
Cameron Geddes (LBNL), Mark Hogan (SLAC), Wei Lu (Tsinghua U.) , Pietro Musumeci (UCLA)

Input M. Lamont,
L. Rivkin, C. Biscari

OPEN CONSULTATION PROCESS – WORK FLOW



Expert Panel: 18 experts - 4 associated - 13 meetings

Retreat 23/6

Email list
231 scientists registered to roadmap process

Townhall 30/3
Setting the scene, explaining the process, **HEP goals and targets**

Parameters
Parameters of interest, proposal of **2 common study cases**

Townhall Meetings 21/5 and 31/5
Input presented by **48 SPEAKERS FROM COMMUNITY**
Up to **130 simultaneous participants**

Draft R&D Roadmap, deliverables: **16 July**
Townhall #4: 12 July

Townhall #4 feedback

LDG, SPC, … feedback

FINAL REPORT
October

Expert Panel HGPL “High Gradient Acceleration (Plasma/Laser)”

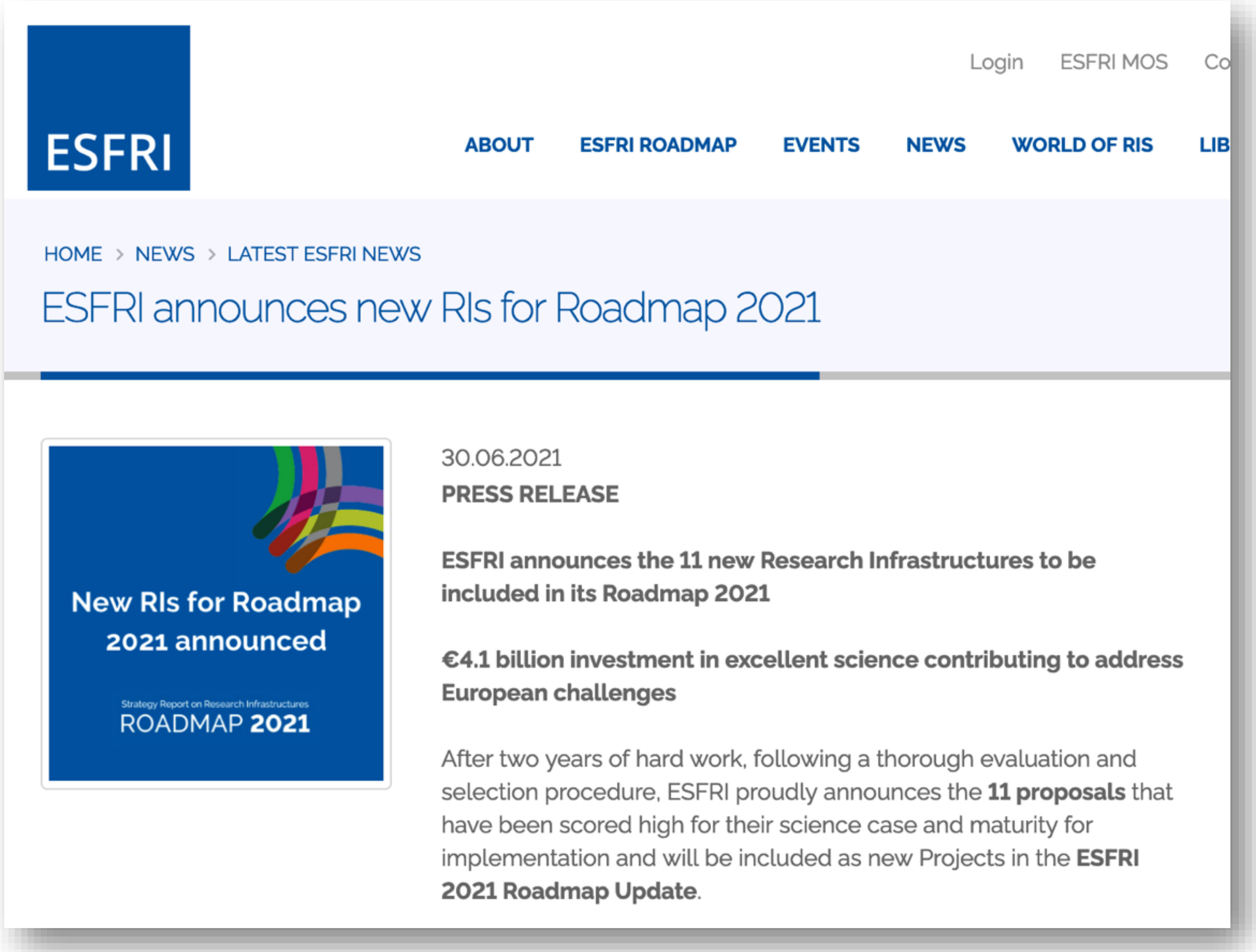
Scope:

- Accelerator R&D Roadmap for **plasma and laser accelerators** (includes beam-driven options and **dielectric** structures).
- Roadmap to support esta-blishing compact, high gradient accelerator techno-logy (> 1 GV/m) as a **viable option for HEP**.
- Enable **intermediate HEP experiments** and on the longer-term a **compact, cost-effective plasma linear collider** design.

→ Expert panel is working on a final report for end of October. Too early to report any conclusions today!

Great News End of June

Building the first plasma accelerator facility



ESFRI announces new RIs for Roadmap 2021

30.06.2021

PRESS RELEASE

ESFRI announces the 11 new Research Infrastructures to be included in its Roadmap 2021

€4.1 billion investment in excellent science contributing to address European challenges

After two years of hard work, following a thorough evaluation and selection procedure, ESFRI proudly announces the **11 proposals** that have been scored high for their science case and maturity for implementation and will be included as new Projects in the **ESFRI 2021 Roadmap Update**.

About the ESFRI Roadmap

ESFRI has established a European Roadmap for Research Infrastructures (new and major upgrades, pan-European interest) for the next 10-20 years, stimulates the implementation of these facilities, and updates the roadmap as needed. The ESFRI Roadmap arguably contains the best European science facilities based on a thorough evaluation and selection procedure. It combines ESFRI Projects, which are new Research Infrastructures in progress towards implementation, and ESFRI Landmarks successfully implemented Research Infrastructures enabling excellent science.

Great News End of June

Building the first plasma accelerator facility

ESFRI

ABOUT ESFRI ROADMAP EVENT

HOME > NEWS > LATEST ESFRI NEWS

ESFRI announces new RIs for Roadmap 2021

New RIs for Roadmap 2021 announced

Strategy Report on Research Infrastructures

ROADMAP 2021

30.06.2021

PRESS RELEASE

ESFRI announces the 11 new Researc
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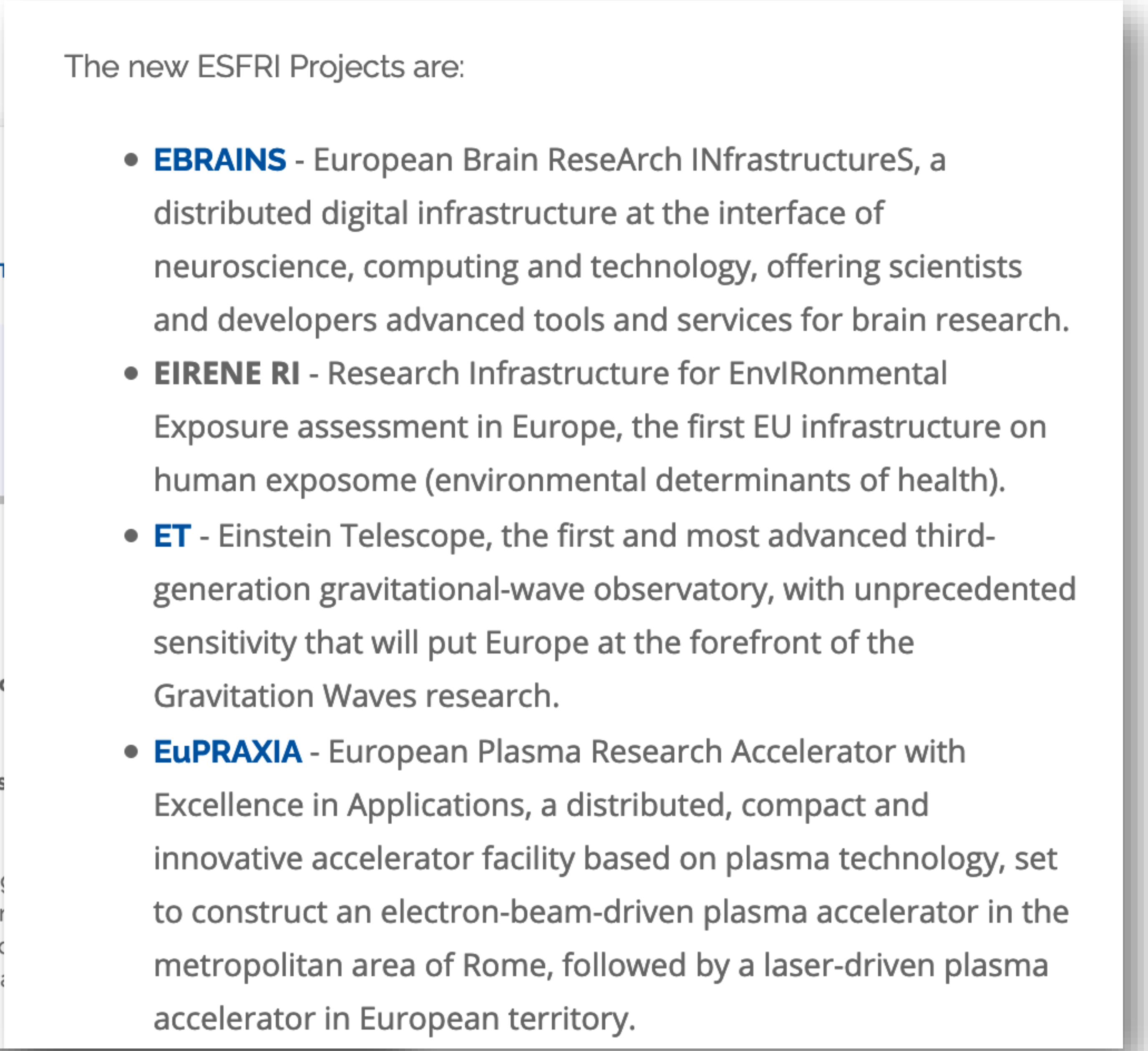
European challenges

After two years of hard work, following
selection procedure, ESFRI proudly a
have been scored high for their scienc
implementation and will be included
2021 Roadmap Update.



The new ESFRI Projects are:

- **EBRAINS** - European Brain ReseArch INfrastructureS, a distributed digital infrastructure at the interface of neuroscience, computing and technology, offering scientists and developers advanced tools and services for brain research.
- **EIRENE RI** - Research Infrastructure for EnvIRonmental Exposure assessment in Europe, the first EU infrastructure on human exposome (environmental determinants of health).
- **ET** - Einstein Telescope, the first and most advanced third-generation gravitational-wave observatory, with unprecedented sensitivity that will put Europe at the forefront of the Gravitation Waves research.
- **EuPRAXIA** - European Plasma Research Accelerator with Excellence in Applications, a distributed, compact and innovative accelerator facility based on plasma technology, set to construct an electron-beam-driven plasma accelerator in the metropolitan area of Rome, followed by a laser-driven plasma accelerator in European territory.

Great News End of June

Building the first plasma accelerator facility

The new ESFRI Projects are:

ESFRI

ABOUT

HOME > NEWS > LATEST ESFRI NEWS

ESFRI announces new RIs for R

New RIs for Roadmap 2021 announced

Strategy Report on Research Infrastructures

ROADMAP 2021

30.06.2021

PRESS RELEA

ESFRI annou
included in it

€4.1 billion in
European ch

After two yea
selection pro
have been sc
implementati
2021 Roadmap Update.

- **EuPRAXIA** - European Plasma Research Accelerator with Excellence in Applications, a distributed, compact and innovative accelerator facility based on plasma technology, set to construct an electron-beam-driven plasma accelerator in the metropolitan area of Rome, followed by a laser-driven plasma accelerator in European territory.

generation gravitational-wave observatory, with unprecedented

- There is a **new level of ambition** to develop globally unique, complex facilities for frontier science: Einstein Telescope – highest value project ever on the Roadmap - EUR 1.900 million, and EuPRAXIA – innovative accelerator based on plasma technology - EUR 569 million.

accelerator in European territory.

EuPRAXIA: A European Strategy for Accelerator Innovation

Do the required intermediate step between proof of principle and production facility – make one acc. unit!

PRESENT EXPERIMENTS

Demonstrating
100 GV/m routinely

Demonstrating **GeV** electron beams

Demonstrating basic **quality**

EuPRAXIA INFRASTRUCTURE

Engineering a high quality, compact plasma accelerator

5 GeV electron beam for the 2020's

Demonstrating user readiness

Pilot users from FEL, HEP, medicine, ...

PRODUCTION FACILITIES

Plasma-based **linear collider** in 2040's

Plasma-based **FEL** in 2030's

Medical, industrial applications soon

The EuPRAXIA Project

http://www.eupraxia-project.eu/

Horizon 2020

- First ever international design of a **plasma accelerator facility**.
- Challenges addressed by EuPRAXIA since 2015:
  - How **can plasma accelerators produce usable electron beams**?
  - **For what can we use those beams** while we increase the beam energy towards HEP and collider usages?
- **CDR for a distributed research infrastructure** funded by EU Horizon2020 program. Completed by 16+25 institutes.
- **Next phase consortium** with 40 partners, 10 observers.
- **Applied to ESFRI roadmap update 2021** with government support in Sep 2020.
- **Successful** and and placed on ESFRI roadma.

The European Physical Journal volume 229 · number 24 · December 2020

EPJ ST

EPS Recognized by European Physical Society

Special Topics

EuPRAXIA Conceptual Design Report

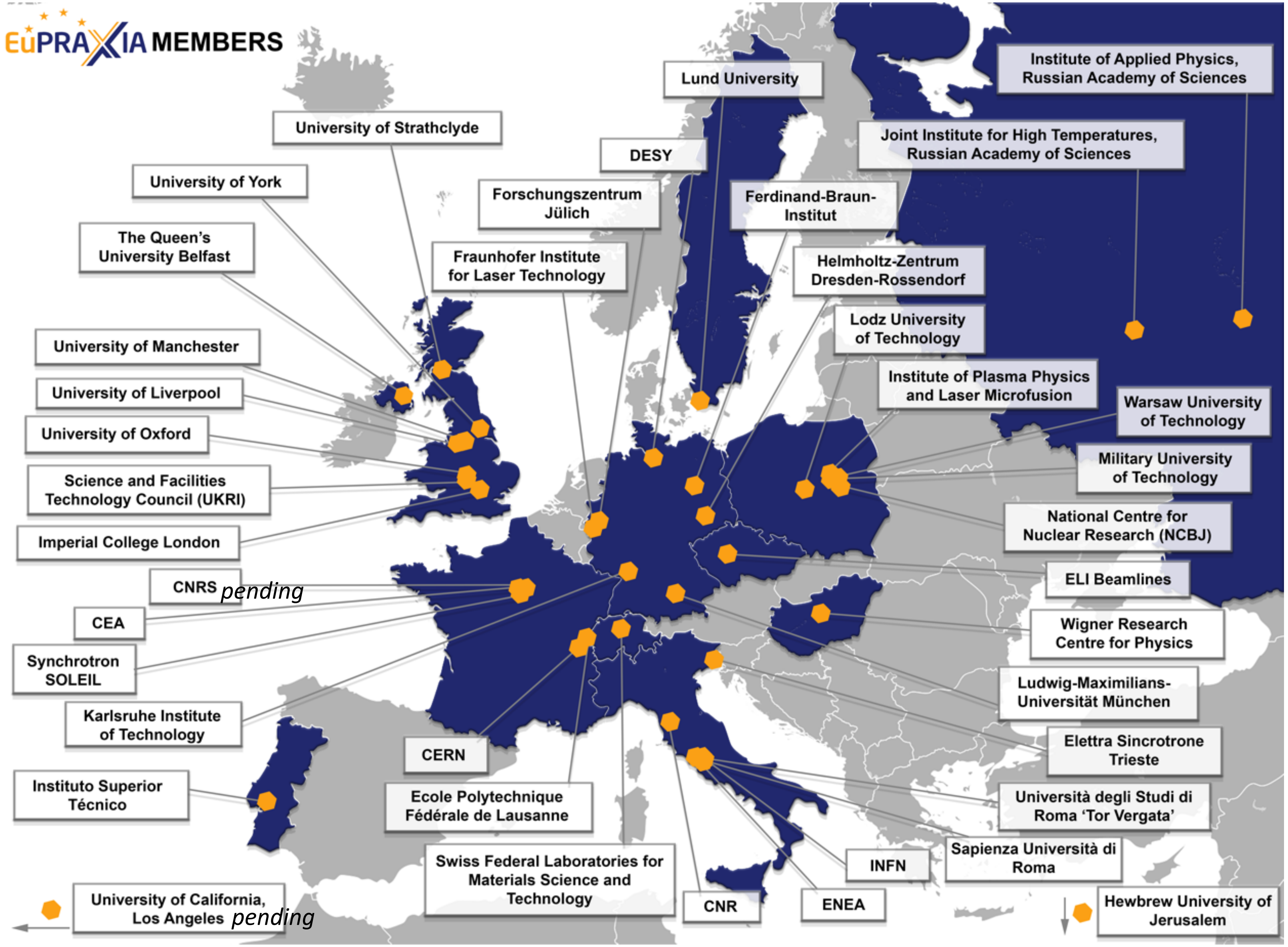
Ralph Assmann and Maria Weikum (Eds.)

edp sciences Springer

653 page CDR, 240 scientists contributed

The Consortium Members for the Next Phase

(from 16 to 40)



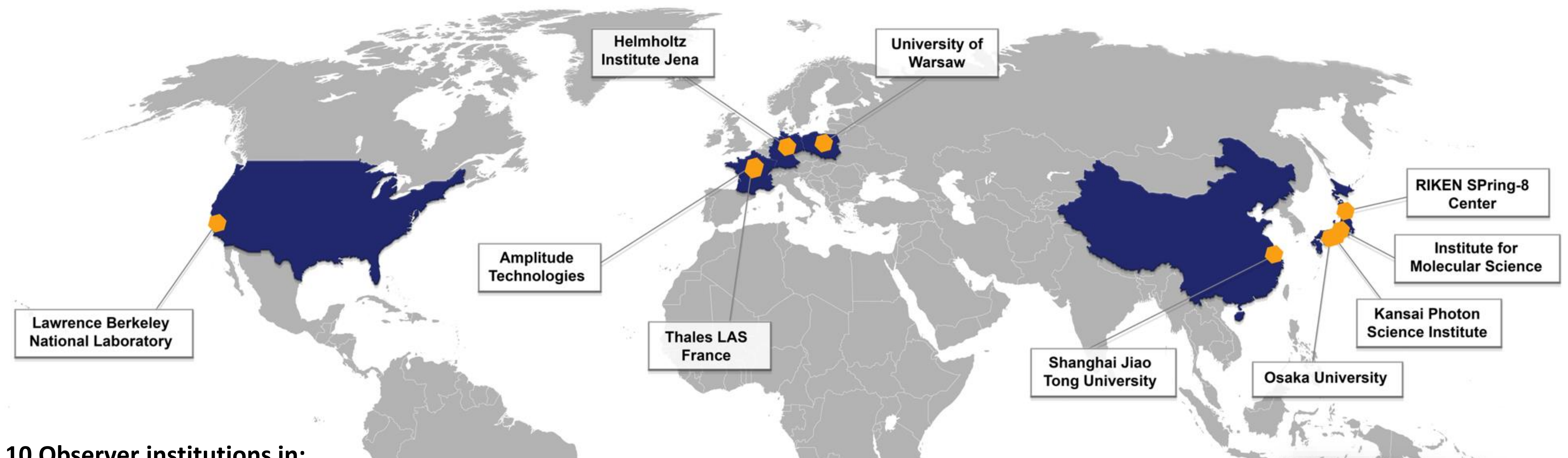
40 Member institutions in:

- **Italy** (INFN, CNR, Elettra, ENEA, Sapienza Università di Roma, Università degli Studi di Roma "Tor Vergata")
- **France** (CEA, SOLEIL, CNRS)
- **Switzerland** (EMPA, Ecole Polytechnique Fédérale de Lausanne)
- **Germany** (DESY, Ferdinand-Braun-Institut, Fraunhofer Institute for Laser Technology, Forschungszentrum Jülich, HZDR, KIT, LMU München)
- **United Kingdom** (Imperial College London, Queen's University of Belfast, STFC, University of Liverpool, University of Manchester, University of Oxford, University of Strathclyde, University of York)
- **Poland** (Institute of Plasma Physics and Laser Microfusion, Lodz University of Technology, Military University of Technology, NCBJ, Warsaw University of Technology)
- **Portugal** (IST)
- **Hungary** (Wigner Research Centre for Physics)
- **Sweden** (Lund University)
- **Israel** (Hebrew University of Jerusalem)
- **Russia** (Institute of Applied Physics, Joint Institute for High Temperatures)
- ***United States*** (UCLA)
- **CERN**
- **ELI Beamlines**

The Consortium Observers for the Next Phase

(from 25 to 10, Consortium Agreement signed)

Horizon 2020



10 Observer institutions in:

- **France** (Amplitude Technologies, Thales LAS France SAS)
- **Germany** (Helmholtz-Institut Jena)
- **Poland** (University of Warsaw)
- **United States** (LBNL)
- **China** (Shanghai Jiao Tong University)
- **Japan** (Institute for Molecular Science, Osaka University, Kansai Photon Science Institute, RIKEN SPring-8 Center)

EuPRAXIA OBSERVERS


Consortium Agreement

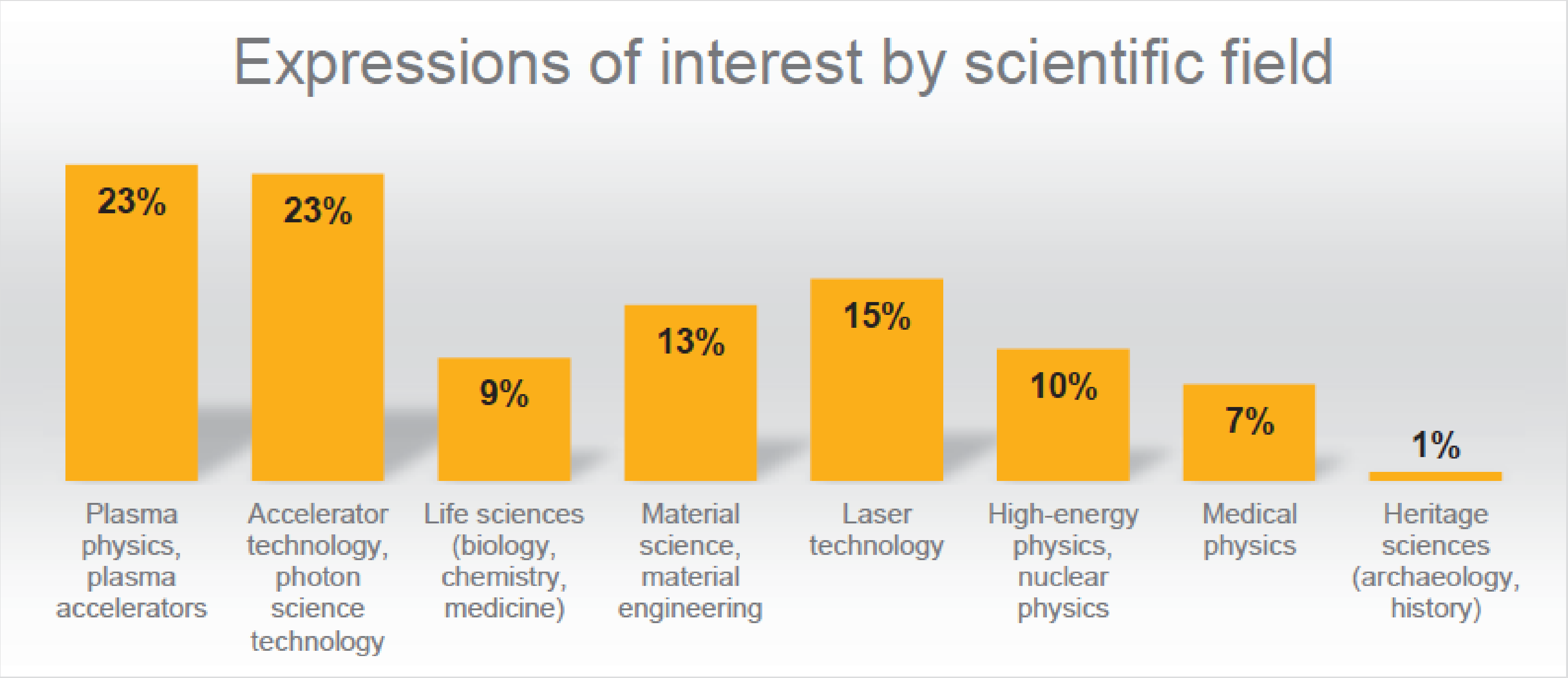
between research institutions and organisations

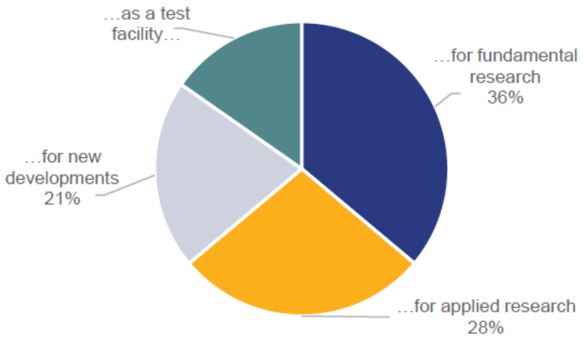
EuPRAXIA Deliverables and User Interests

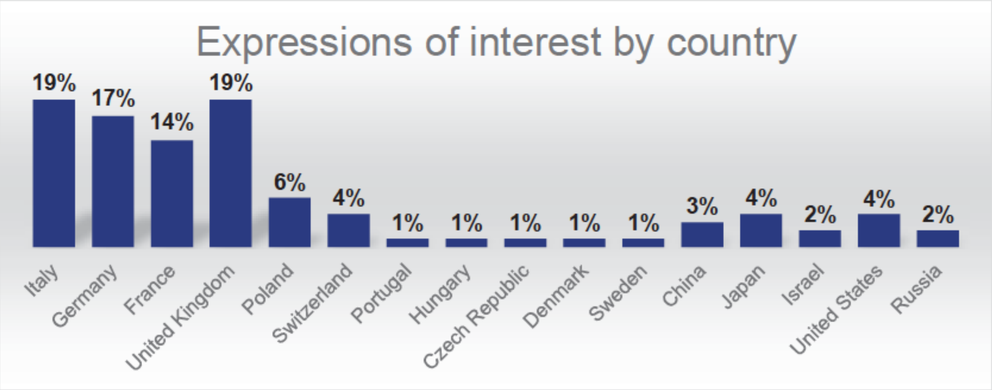
EuPRAXIA is designed to deliver at 10-100 Hz ultra-short pulses of

- Electrons (0.1-5 GeV, 30 pC)
- Positrons (0.5-10 MeV, 10^6)
- Positrons (GeV source)
- Lasers (100 J, 50 fs, 10-100 Hz)
- Betatron X rays (5-18 keV, 10^{10})
- FEL light (0.2-36 nm, 10^9-10^{13})

Expressions of interest from **95 research groups** representing several thousand scientists in total.


Expressions of interest by scientific field

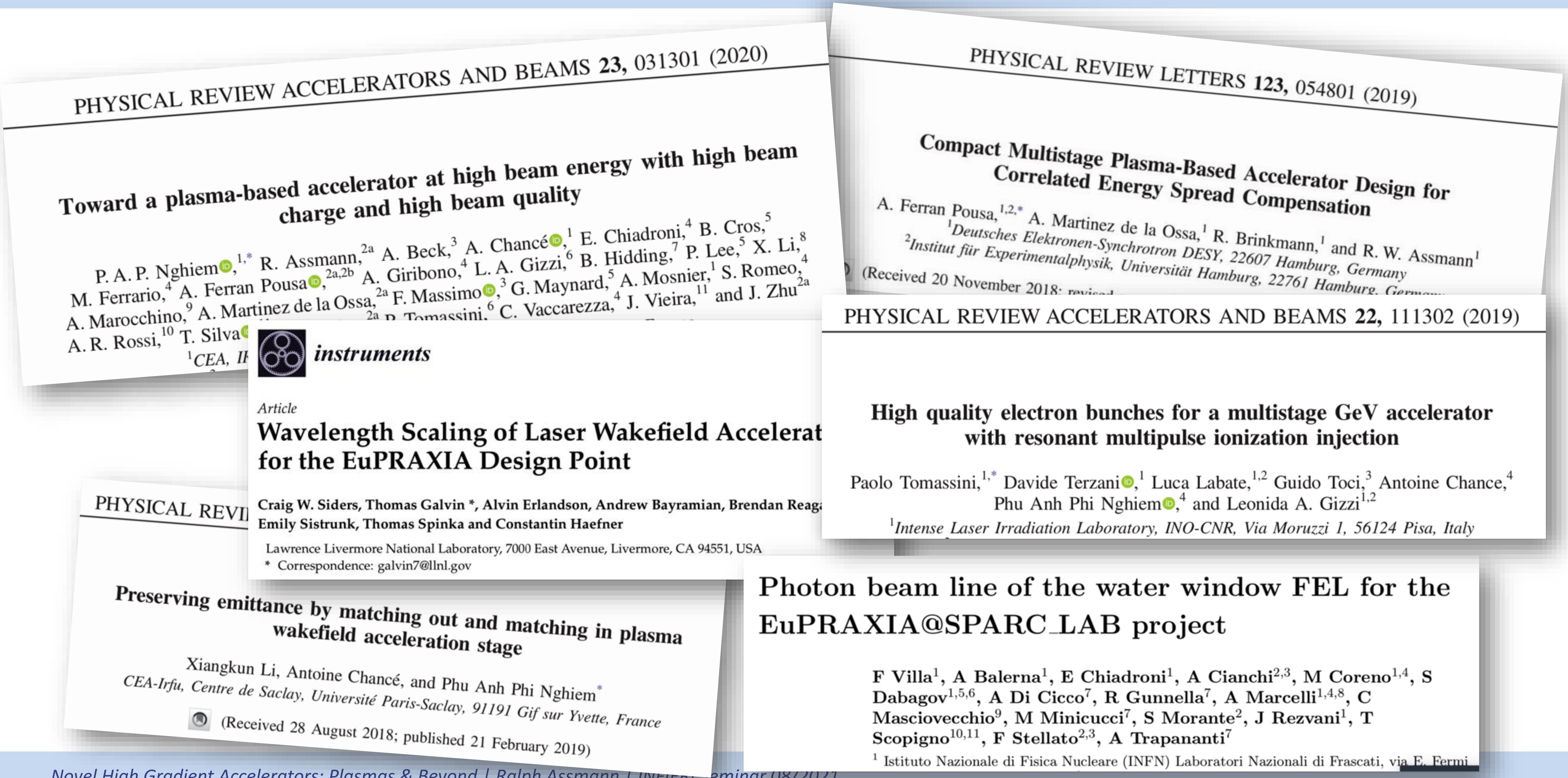



Expressions of interest by country

IMPORTANT: EuPRAXIA design includes RF injectors, transfer lines, undulator lines, shielding, ...

Examples of EuPRAXIA Ideas and Innovation

Horizon 2020



PHYSICAL REVIEW ACCELERATORS AND BEAMS **23,** 031301 (2020)

Toward a plasma-based accelerator at high beam energy with high beam charge and high beam quality

P. A. P. Nghiem,[1,*] R. Assmann,[2a] A. Beck,[3] A. Chancé,[1] E. Chiadroni,[4] B. Cros,[5]
M. Ferrario,[4] A. Ferran Pousa,[2a,2b] A. Giribono,[4] L. A. Gizzi,[6] B. Hidding,[7] P. Lee,[5] X. Li,[8]
A. Marocchino,[9] A. Martinez de la Ossa,[2a] F. Massimo,[3] G. Maynard,[5] A. Mosnier,[1] S. Romeo,[4]
A. R. Rossi,[10] T. Silva [2a] P. Tomassini,[6] C. Vaccarezza,[4] J. Vieira,[11] and J. Zhu[2a]
[1]*CEA, IR*

PHYSICAL REVIEW LETTERS **123,** 054801 (2019)

Compact Multistage Plasma-Based Accelerator Design for Correlated Energy Spread Compensation

A. Ferran Pousa,[1,2,*] A. Martinez de la Ossa,[1] R. Brinkmann,[1] and R. W. Assmann[1]
[1]*Deutsches Elektronen-Synchrotron DESY, 22607 Hamburg, Germany*
[2]*Institut für Experimentalphysik, Universität Hamburg, 22761 Hamburg, Germ*

(Received 20 November 2018;

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instruments

Article

Wavelength Scaling of Laser Wakefield Accelerat for the EuPRAXIA Design Point

Craig W. Siders, Thomas Galvin *, Alvin Erlandson, Andrew Bayramian, Brendan Reag
Emily Sistrunk, Thomas Spinka and Constantin Haefner

Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94551, USA
* Correspondence: galvin7@llnl.gov

PHYSICAL REVIEW ACCELERATORS AND BEAMS **22,** 111302 (2019)

High quality electron bunches for a multistage GeV accelerator with resonant multipulse ionization injection

Paolo Tomassini,[1,*] Davide Terzani,[1] Luca Labate,[1,2] Guido Toci,[3] Antoine Chance,[4]
Phu Anh Phi Nghiem,[4] and Leonida A. Gizzi[1,2]
[1]*Intense Laser Irradiation Laboratory, INO-CNR, Via Moruzzi 1, 56124 Pisa, Italy*

PHYSICAL REVI

Preserving emittance by matching out and matching in plasma wakefield acceleration stage

Xiangkun Li, Antoine Chancé, and Phu Anh Phi Nghiem*
CEA-Irfu, Centre de Saclay, Université Paris-Saclay, 91191 Gif sur Yvette, France

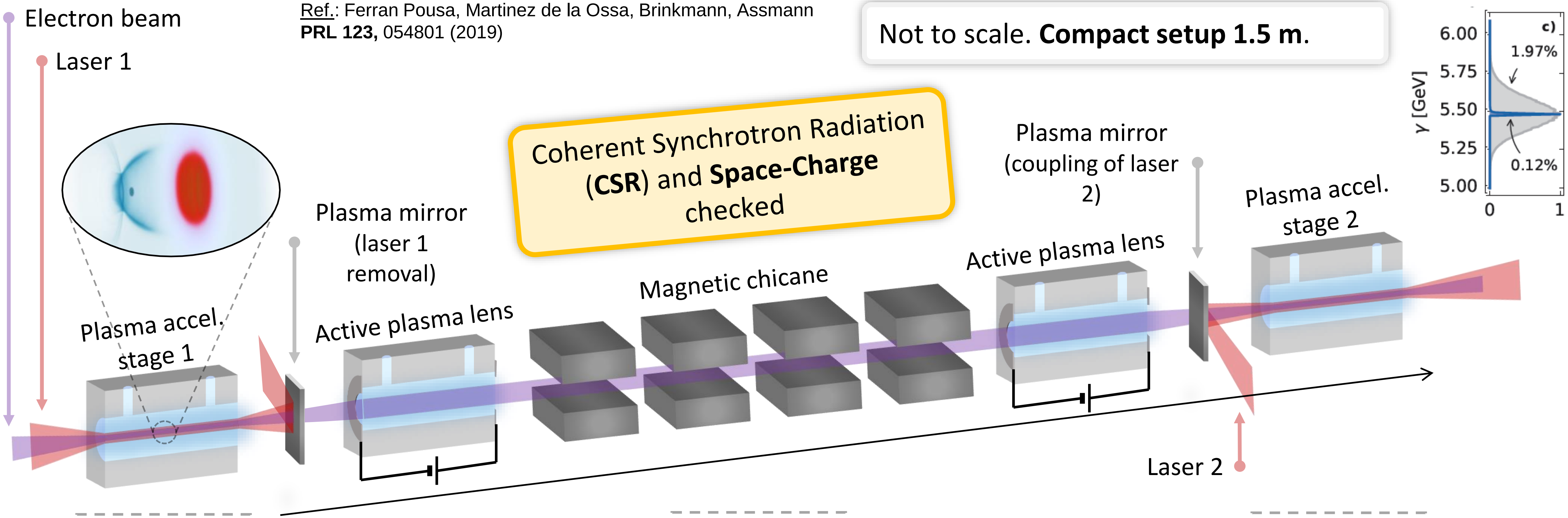
(Received 28 August 2018; published 21 February 2019)

Photon beam line of the water window FEL for the EuPRAXIA@SPARC_LAB project

F Villa[1], A Balerna[1], E Chiadroni[1], A Cianchi[2,3], M Coreno[1,4], S Dabagov[1,5,6], A Di Cicco[7], R Gunnella[7], A Marcelli[1,4,8], C Masciovecchio[9], M Minicucci[7], S Morante[2], J Rezvani[1], T Scopigno[10,11], F Stellato[2,3], A Trapananti[7]

[1] Istituto Nazionale di Fisica Nucleare (INFN) Laboratori Nazionali di Frascati, via E. Fermi

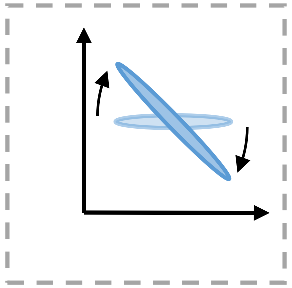
Solving Energy Spread



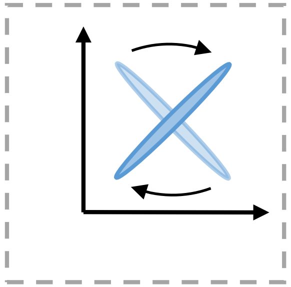
Ref.: Ferran Pousa, Martinez de la Ossa, Brinkmann, Assmann
PRL 123, 054801 (2019)

Not to scale. **Compact setup 1.5 m.**

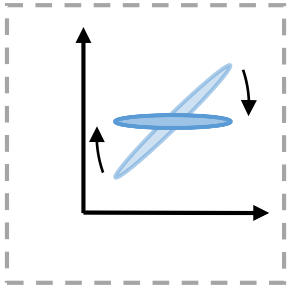
Coherent Synchrotron Radiation (**CSR**) and **Space-Charge** checked



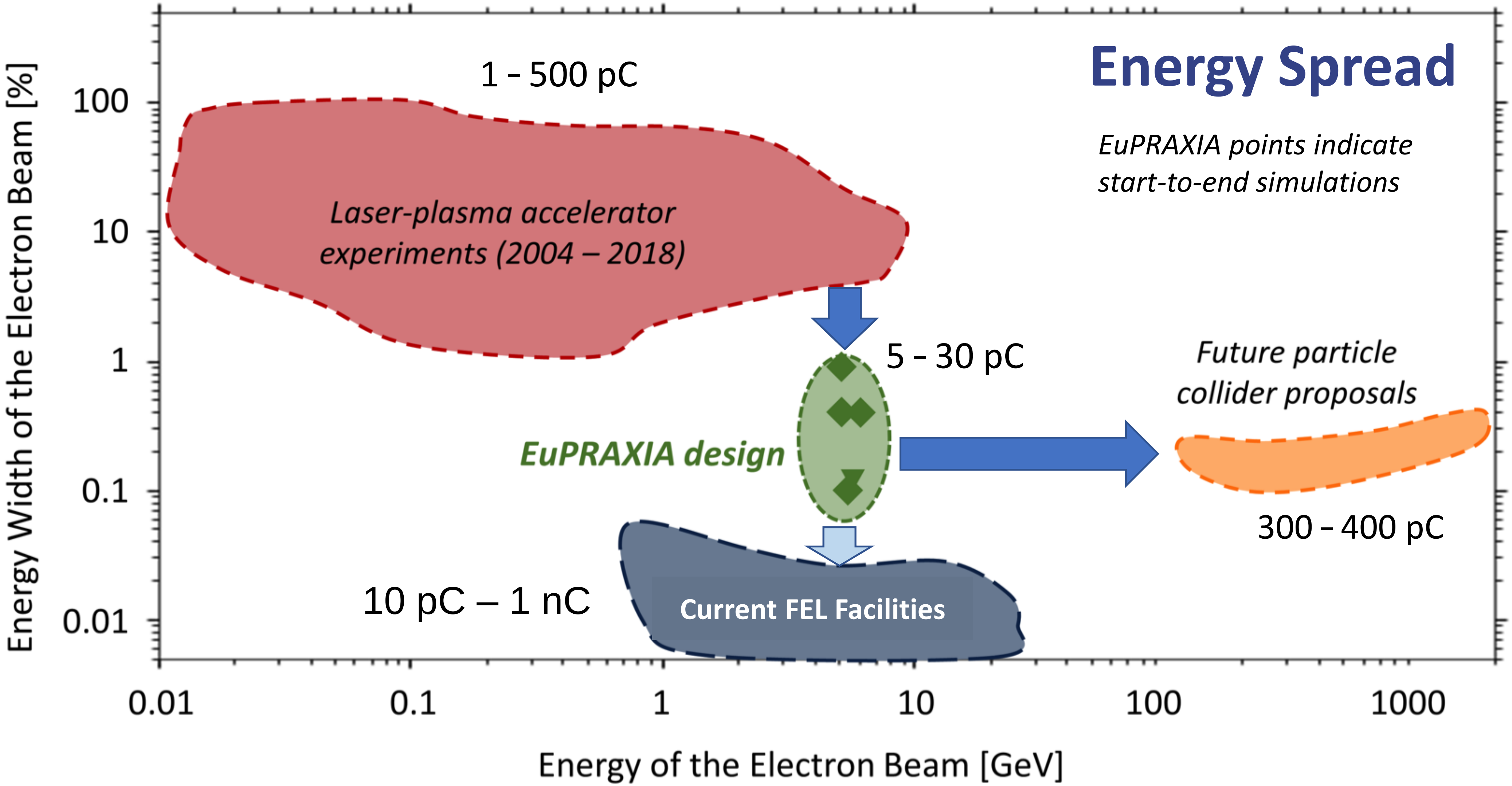
Accelerating in a plasma stage and...



... flipping phase space in the middle before second plasma stage



Solving Energy Spread



Spin Polarization | Hybrid Plasma Accelerators

- e+e- colliders and physics reach enhanced by spin polarized beams
- International Partners: Germany, Greece, China, and USA → facilities involved at FZJ, Shanghai, ...

Snowmass 2021 – Letter of Interest Aug/31/2020

Polarized targets for laser-plasma applications

M. Büscher[1,2], A. Hützen[1,2], J. Böker[3], R.W. Engels[3], R. Gebel[3], A. Lehrach[3,4], P. Gibbon[5], A. Pukhov[6], R.W. Aßmann[7], T.P. Rakitzis[8,9], L. Ji[10,11], T. Schenkel[12], X. Wei[13]

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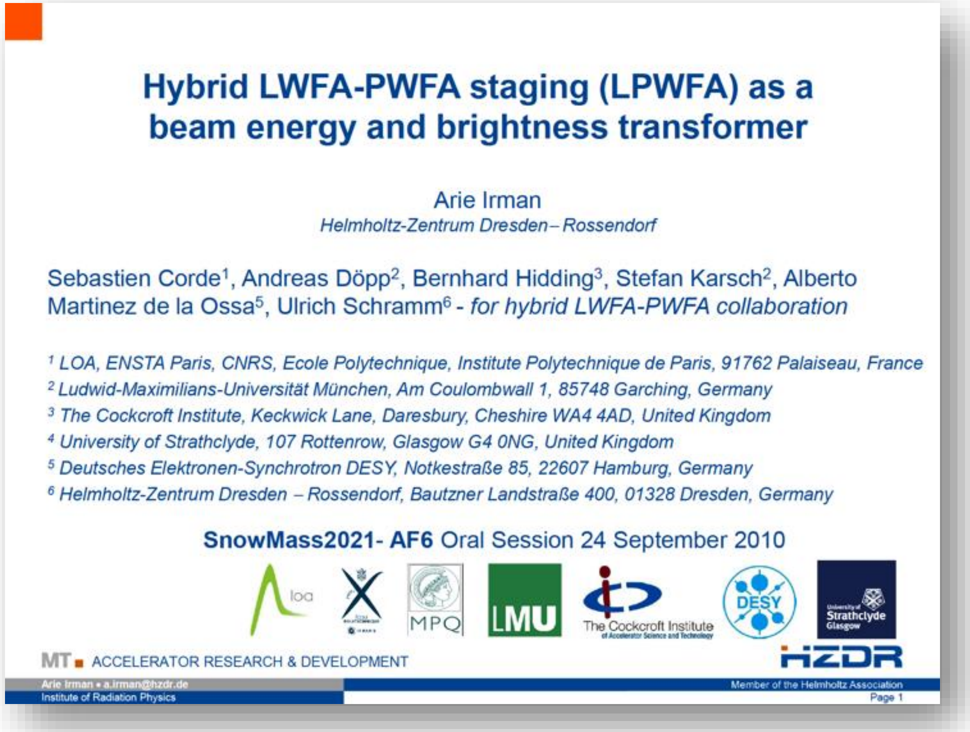
[6] Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany
[7] DESY, Notkestraße 85, 22607, Hamburg, Germany
[8] Department of Physics, University of Crete, 71003 Heraklion-Crete, Greece
[9] Institute of Electronic Structure and Laser, Foundation for Research and Technology-Hellas, 71110 Heraklion-Crete, Greece
[10] State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Shanghai 201800, China
[11] CAS Center for Excellence in Ultra-intense Laser Science, Shanghai 201800, China
[12] Accelerator Technology and Applied Physics Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
[13] Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

- Use a laser-generated electron beam for driving plasma wakefields in a second stage → HQ electron beam from ultra-compact setup
- Several facilities involved at HZDR, Strathclyde, ...



Hybrid LWFA-PWFA staging (LPWFA) as a beam energy and brightness transformer

Arie Irman
Helmholtz-Zentrum Dresden – Rossendorf

Sebastien Corde[1], Andreas Döpp[2], Bernhard Hidding[3], Stefan Karsch[2], Alberto Martinez de la Ossa[5], Ulrich Schramm[6] - *for hybrid LWFA-PWFA collaboration*

[1] LOA, ENSTA Paris, CNRS, Ecole Polytechnique, Institute Polytechnique de Paris, 91762 Palaiseau, France
[2] Ludwig-Maximilians-Universität München, Am Coulombwall 1, 85748 Garching, Germany
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[5] Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany
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SnowMass2021- AF6 Oral Session 24 September 2010

MT ACCELERATOR RESEARCH & DEVELOPMENT

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EuPRAXIA

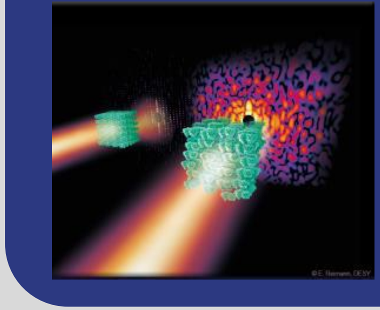
Distributed Research Infrastructure – 1st Users 2028

Horizon 2020

Construction Site Frascati

Local Project Team

Beam-driven plasma accelerator
Delivers FEL light, X rays, electrons, positrons
Life sciences, particle physics, medicine, materials



Location: metropolitan area Rome, Italy

Construction Site

(tbd in 2023)

Local Project Team

Laser-driven plasma accelerator
Delivers FEL light, X rays, electrons, positrons
Life sciences, medicine, materials

Four candidate sites described in conceptual design report

Excellence Centres

Local Project Teams

- *Plasma Simulations & Theory*
- *Laser-Plasma Acceleration & FEL Developments*
- *Plasma Acceleration & High-Rep-Rate Developments*
- *Advanced Application Beamlines*
- *Technology Incubator to Laser Science Users*

Technical design tests, prototyping, production

- *EuPRAXIA user e-needs infrastructure*

Conclusions

Long-term future

- The **long-term future is bright**: there will be plenty of opportunities as technology advances!
- **Plasma colliders** are another possible game changer. Energy very promising but beam quality insufficient:
  - There are **now near future science applications outside HEP, e.g. FEL**. This can be the stepstone towards a plasma linear collider.
  - Major projects going on, all including HEP aspects. Please follow up.
- A long-term future with novel colliders does not come by itself: **We (you) must work towards this goal and support it as required, continuing long tradition**.

Thank you for your attention...