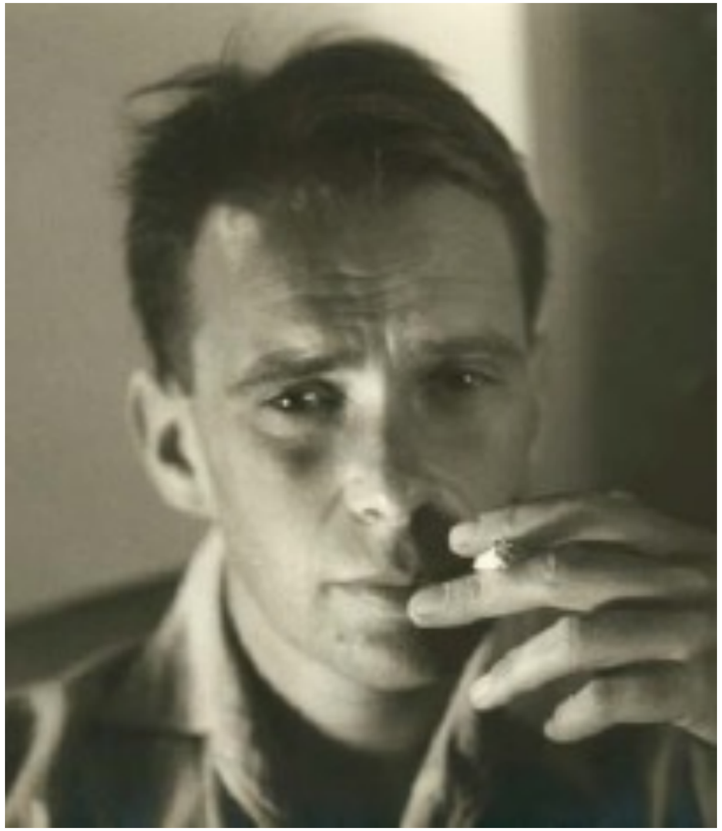
Bruno Touschek

ACCELERATOR GROUP
European Physical Society

- We recognize Bruno Touschek as **one of our historic leaders and pioneers in accelerator science**:
  - Outstanding scientist with ground-breaking achievements, e.g. father of the **e+e- collider**, concept (and name) of **luminosity**, **Touschek lifetime**, to name a few.
  - A dedicated teacher and professor at university.
- The EPS-AG decided, starting in 2017, to name one of its 3 prizes in memory of Bruno Touschek (awarded every 3 years):

Bruno Touschek Prize for a student registered for a PhD or diploma in accelerator physics or engineering or to a trainee accelerator physicist or engineer in the educational phase of their professional career, for the quality of work and promise for the future.



Bruno Touschek Prize

ACCELERATOR GROUP
European Physical Society

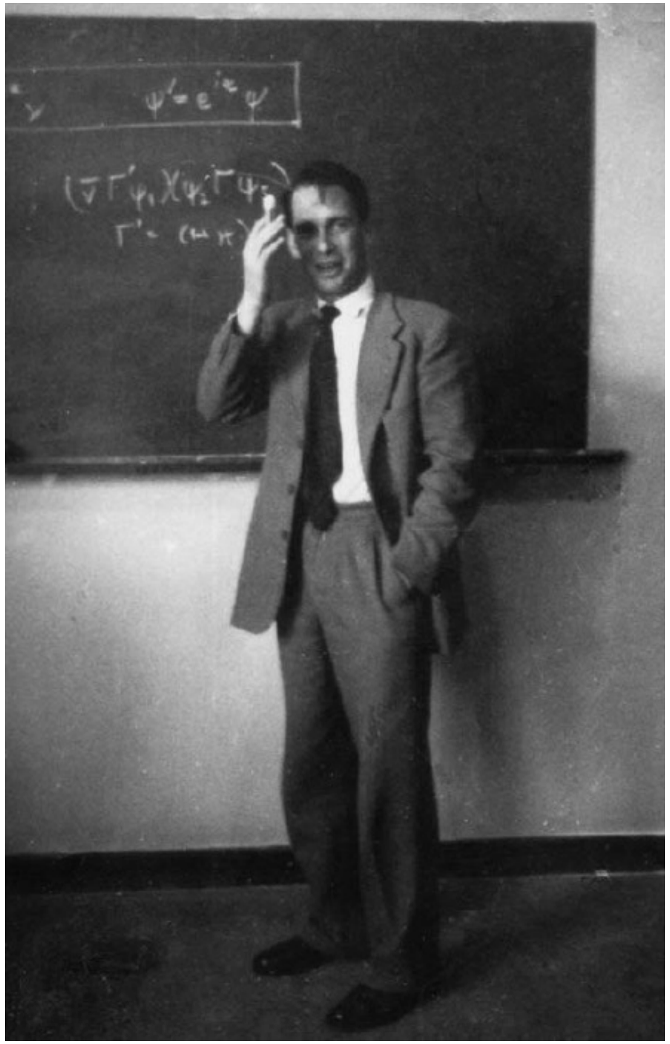
2017 – Fabrizio Giuseppe Bisesto, INFN/LNF, Frascati, Italy

For his contributions to the plasma related activities underway at **SPARC_LAB** exploiting the high-power laser FLAME. In particular, for his experimental work on the single shot diagnostics systems, including Electro Optical Sampling (EOS) for temporal measurement and Optical Transition Radiation (OTR) measurements for an innovative, one-shot emittance measurement.

2020 – Angel Ferran Pousa, DESY, Germany

For his contributions in the frame of the **EuPRAXIA** Project to the development of a novel concept for generating multi-GeV beams with low energy spread using plasma-based acceleration, providing a potential route towards ground-breaking applications such as compact short-wavelength free-electron lasers.

Bruno Touschek`s legacy lives on in his ideas, inventions, his dedication to physics and in our young scientists!



ACCELERATOR GROUP
European Physical Society

100th Birthday Bruno Touschek:

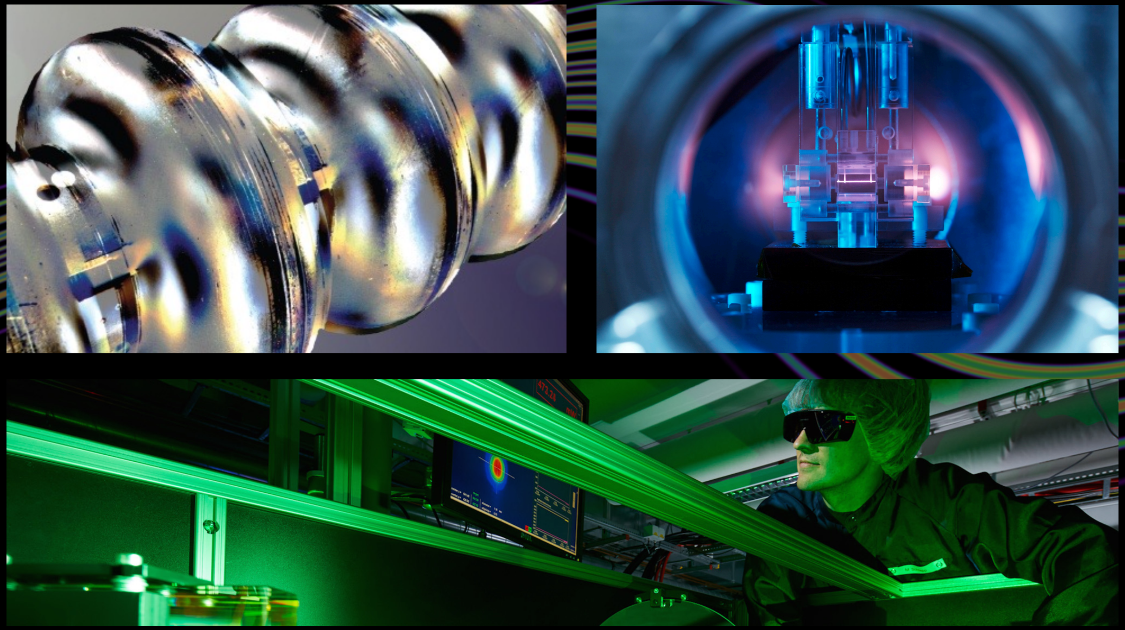
Strong appreciation and thank you from the EPS-AG!

MAGNETIC DISCUSSION

Bruno Touschek

High Gradient Acceleration

Towards a New Generation of Particle Accelerators



Bruno Touschek Memorial Symposium 2021

2-4 December 2021, Rome & Frascati, Italy

European Network for Novel Accelerators

EuroNNAc 3

supported by EU via ARIES

Ralph W. Aßmann
Leading Scientist Accelerator R&D, DESY
Senior Research Associate, LNF-INFN

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Thanks for input and material to:
Massimo Ferrario, Andrea Ghigo, Edda Gschwendtner, Barbara Marchetti, Frank Zimmermann, Brigitte Cros, Ulrich Dorda, Ulrich Schramm, Anthony Hartin, Patric Muggli, Allen Caldwell, Mark Hogan, C. Geddes

INFN
Istituto Nazionale di Fisica Nucleare

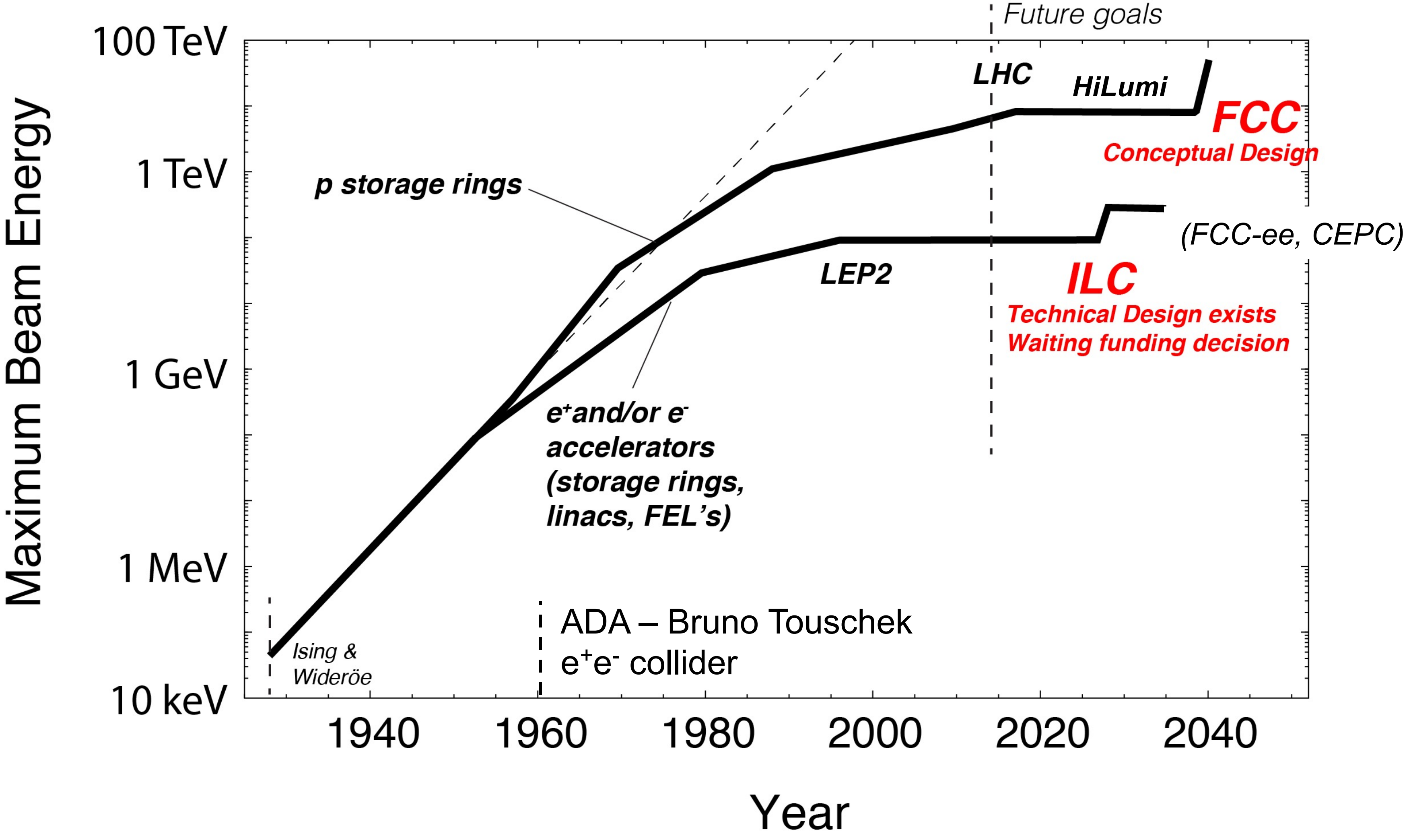
DESY

Livingston Plot: Progress at the Energy Frontier

Great success story: RF-based particle accelerators for discoveries and precision

Master-pieces of technology:

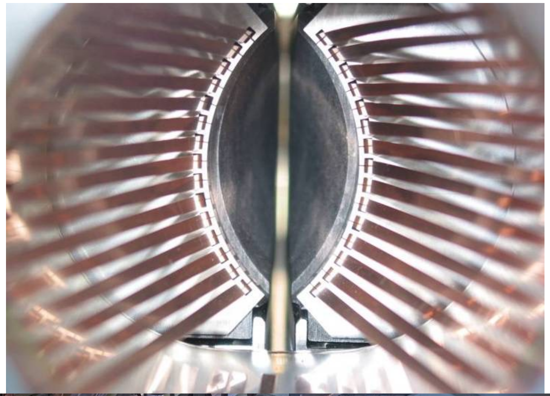
- LHC, LHC HiLumi
- SuperKEKb
- DAFNE
- LEP, LEP-2
- Tevatron
- HERA
- RHIC
- …

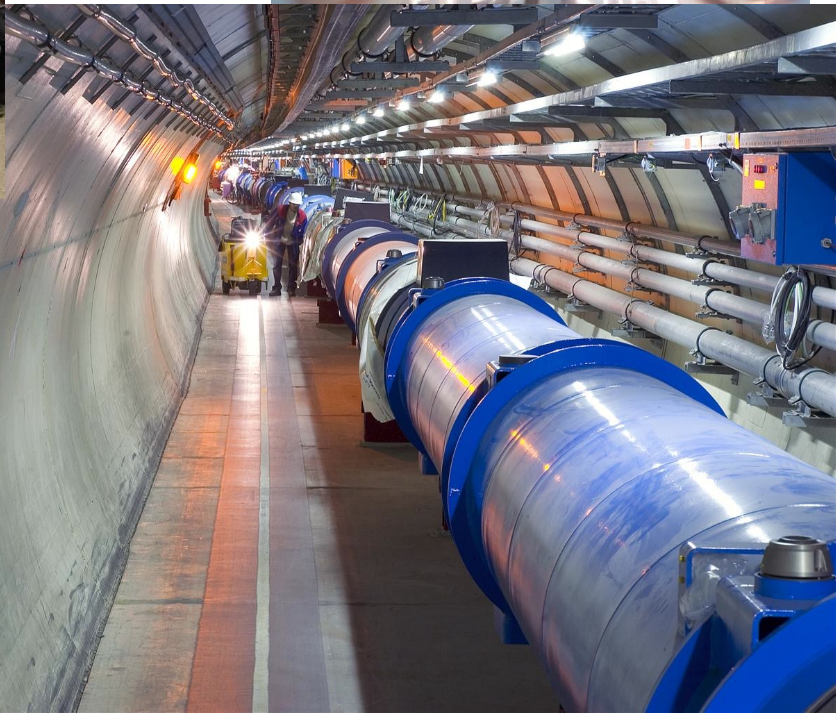


LHC as a Masterpiece of Accelerator Science

80 Years after the first RF accelerator in Aachen and 48 Years after Touschek`s e^+e^- Collider at Frascati

Higgs Sem. 4.7. 2012





First beam 10.9. 2008

Livingston Plot: Progress at the Energy Frontier

Great success story: RF-based particle accelerators for discoveries and precision

Master-pieces of technology:

- LHC, LHC HiLumi
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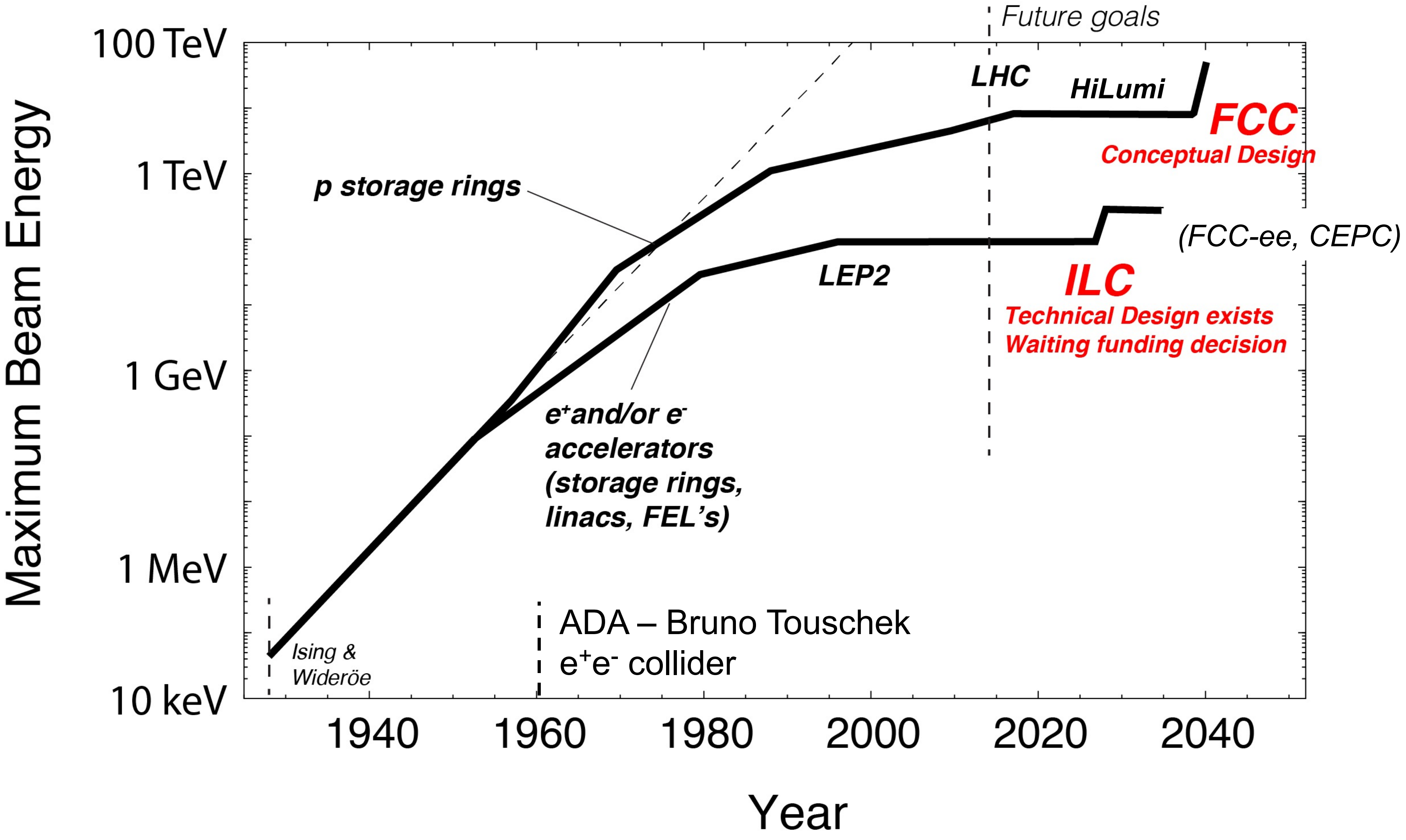
- …

Progress in the energy frontier has slowed down



Slow Down of Progress – Rings

High magnetic fields – High synchrotron radiation losses – Large radius rings – Large size and cost

Hadron (p) circular collider

$$p = e \cdot R \cdot B_y$$

Increase bending field
SC bend magnet work (FCC-hh)

Increase radius = size (FCC-hh)

Lepton (e-,e+) circular collider

$$p \propto E_0 \cdot \sqrt[4]{\rho \cdot U_0}$$

Increase supplied RF voltage
(FCC-ee)

Increase mass of acc. particle (muon)

Increase radius = size (FCC-ee)

→ Accelerator R&D on stronger super-conducting magnets and muon colliders

→ For example, 16 Tesla magnet R&D work for future colliders (FCC, …)

→ Talks by Lucio Rossi and Daniel Schulte

Slow Down of Progress – Linear Accelerators

Limits in accelerating fields – Long accelerators – High size and cost

Lepton (e-,e+) linear collider

$$p = L \cdot G_{acc}$$

Increase length (ILC, CLIC)

Increase accelerating gradient

(a) Pushing existing technology (ILC, CLIC)

(b) New regime of ultra-high gradients (plasma, dielectric accelerators)

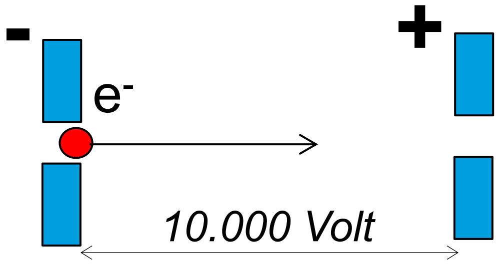
→ Accelerator R&D on linear colliders

→ Advancing accelerating fields into the domain of 80-200 MV/m

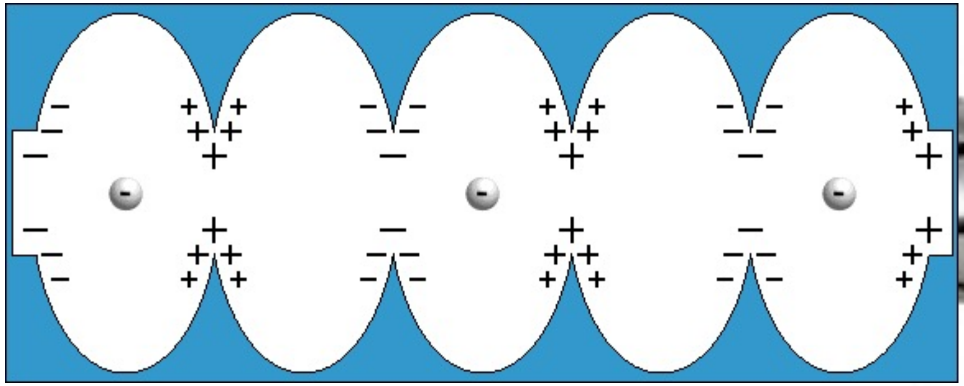
→ Talk on linear colliders by Steinar Stapnes

e- Acceleration: Principle

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



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



Sketch Padamse, Tigner

“Runzelröhre”

20 MV per Meter

Radio Frequency accelerators characterized by:

- **Longitudinal field component** for acceleration of charged particles:

  up to few 100 MV/m

- **Oscillation** frequency **f** of the field:

  MHz → GHz

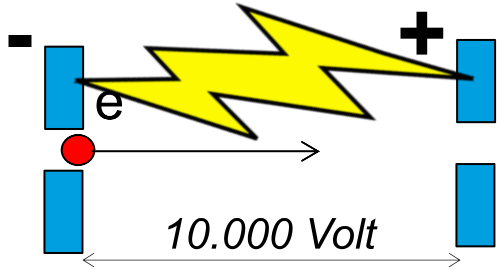
- **Synchronicity** with the charged particles. For fully relativistic particles:

  cavity size ~ 1/frequency

→ the 10 cm scale, Giga-Hz accelerator cavity with 10`s of Mega-Volt per meter acceleration

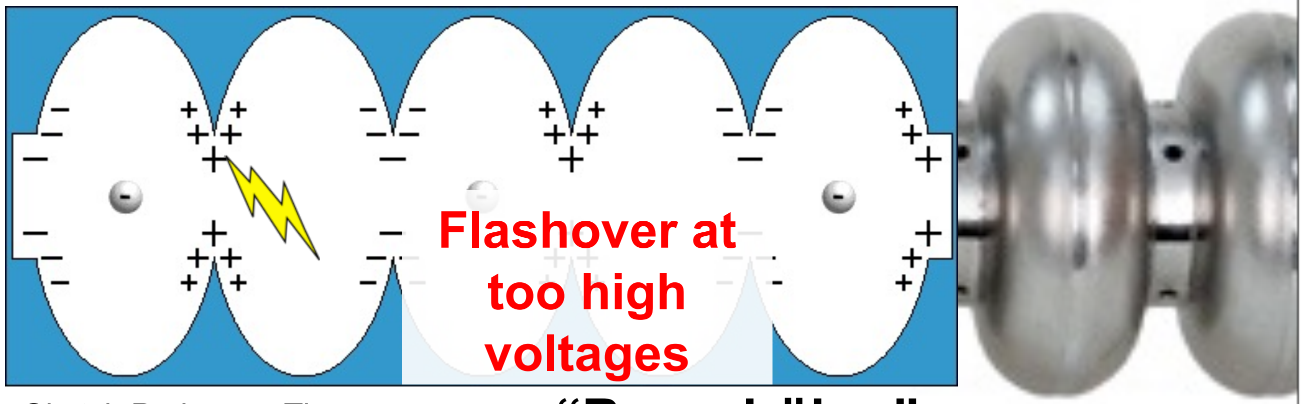
e- Acceleration: Principle **and Limit**

- 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“)**:



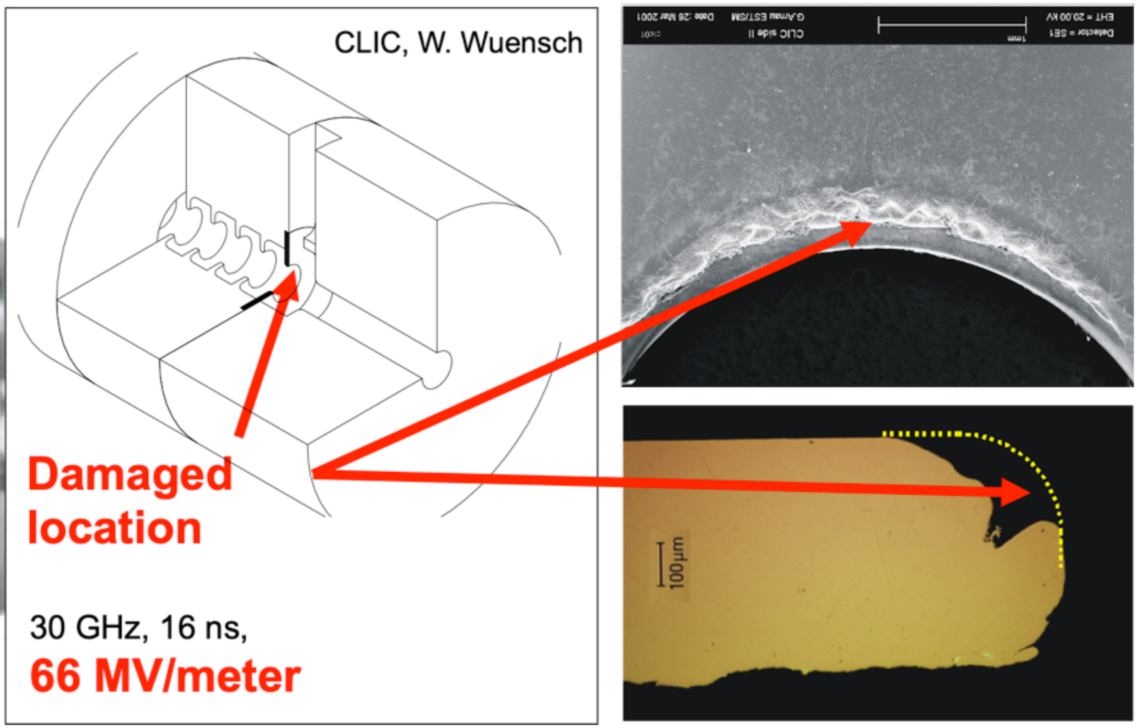
Sketch Padamse, Tigner

“Runzelröhre”

20 MV per Meter

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

NO! metallic structures self destruct



CLIC, W. Wuensch

30 GHz, 16 ns,
66 MV/meter

The Prospects of Much Higher Accelerating Fields

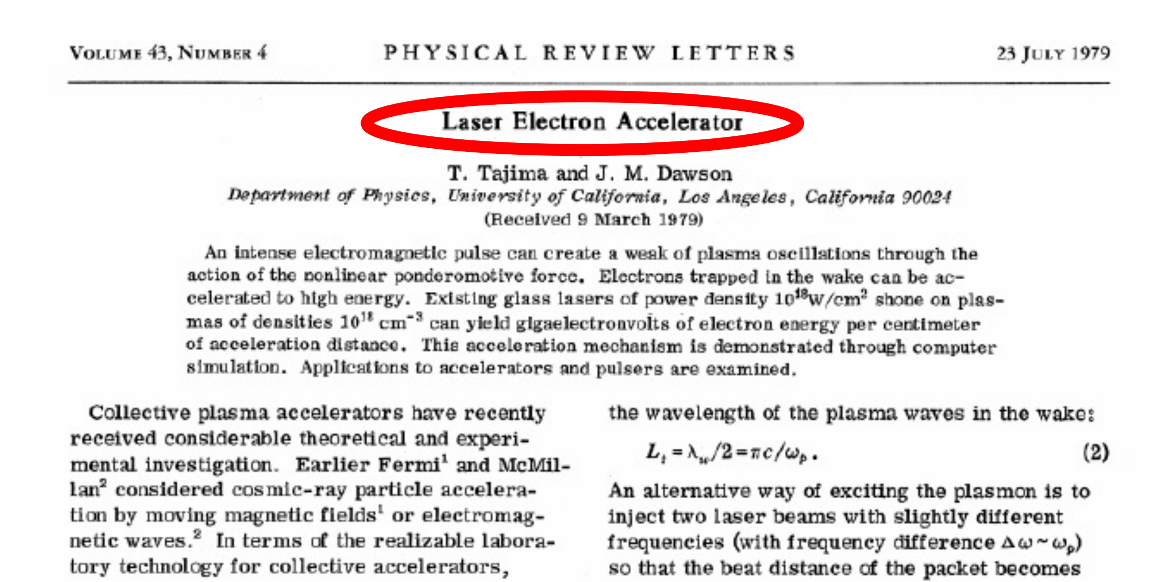
In nature, theory and technology

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: **1.3×10^9 GV/m**

1979: Path to **1×10^2 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,

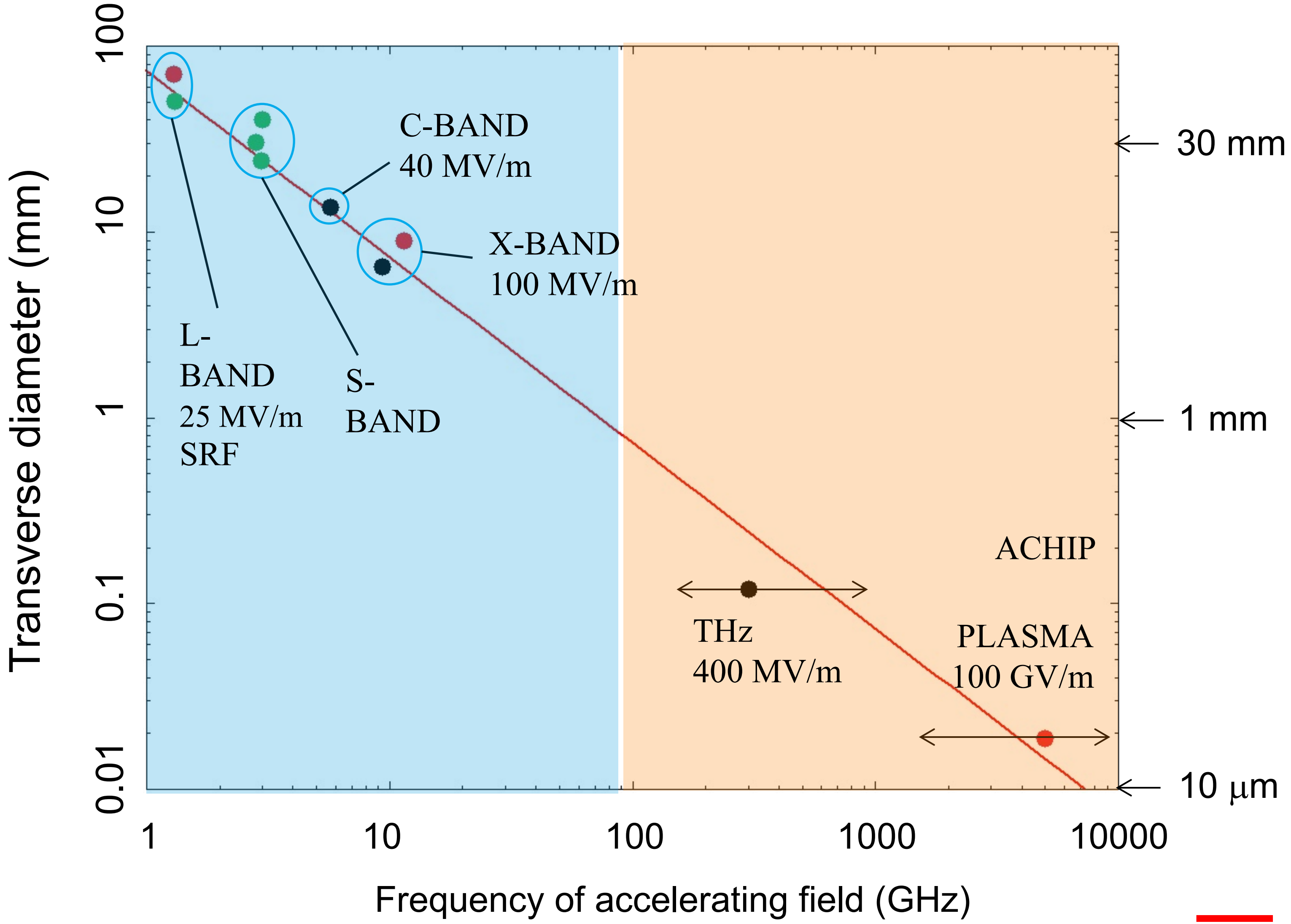
the wavelength of the plasma waves in the wake:

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

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

Accelerators: RF and Novel Regimes

High Gradients – High Frequencies – Small Dimensions



Fit based on the analytical law for the cavity diameter with the TM_{010} mode divided by π

Accelerators: RF and Novel Regimes

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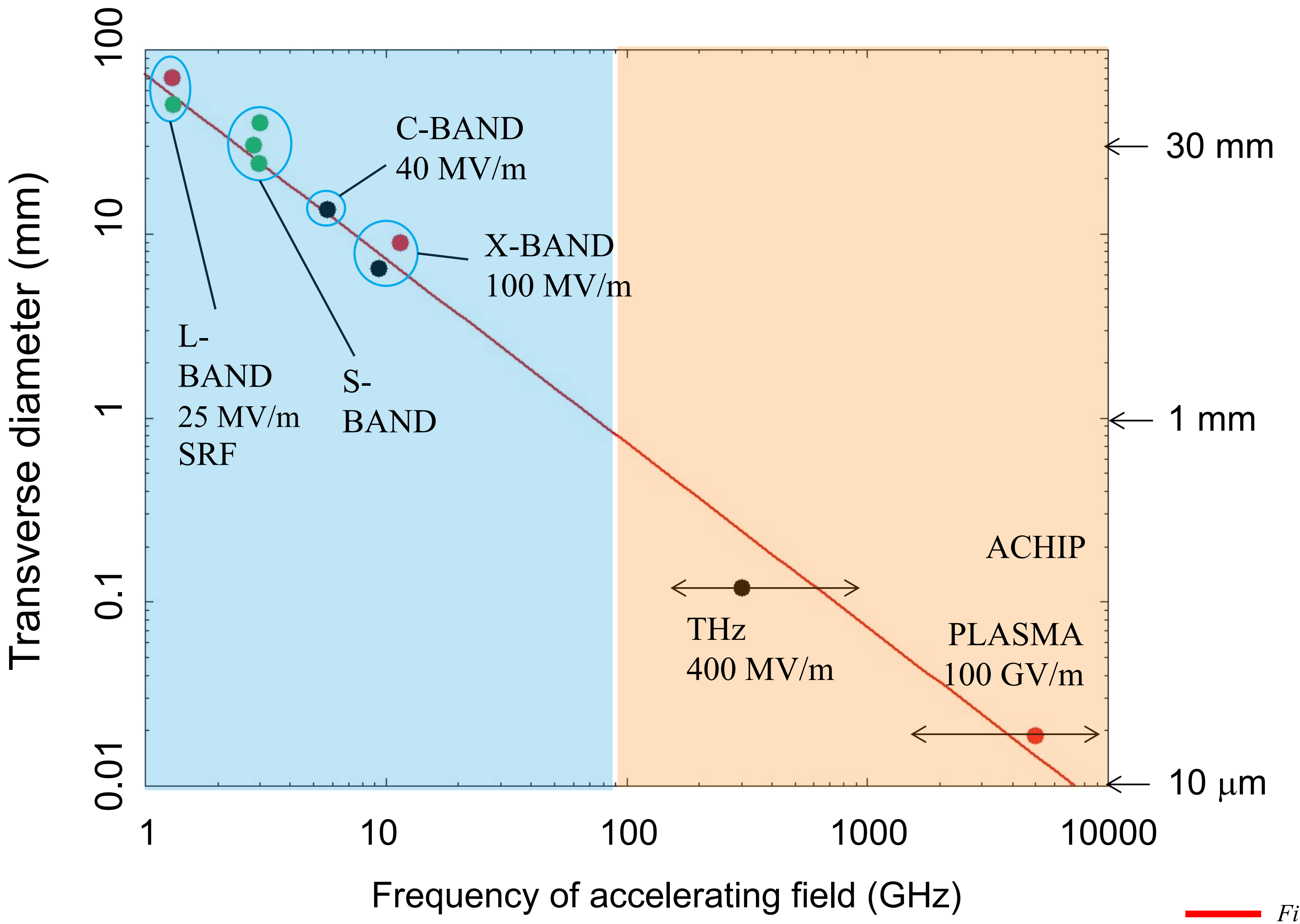


Metallic RF regime:

- **SRF**: High quality, high average power acceleration, long trains → CW
- **S/X band**: Generate high brightness beams for all purposes, ultra-fast science and diagnostics, injector for novel accelerators

Novel regime:

- Novel drivers, in particular **high tech lasers** for compact photon science and medical applications.
- **RF beam drivers** mainly for HEP or other high average power.
- **Compact** foot-print, low pulse charge, **high repetition rate**.
- **Challenges of micro and nano dimensions** – assess with modern tools (synergy with ultra-fast).

🟥 *Fit based on the analytical law for the cavity diameter with the TM_{010} mode divided by π*

High Gradient – High Frequency – Small Dimensions

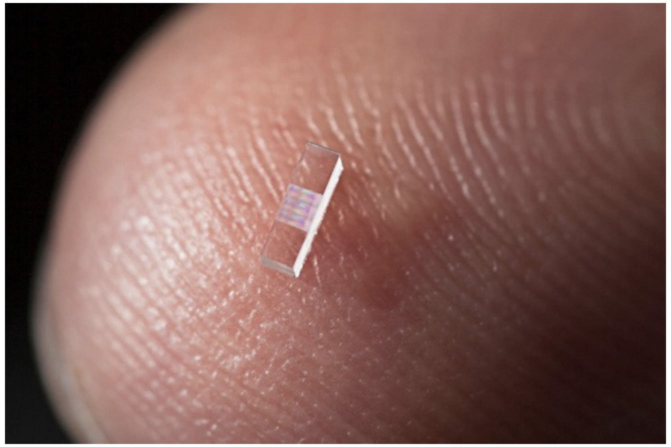
Powering novel accelerators

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

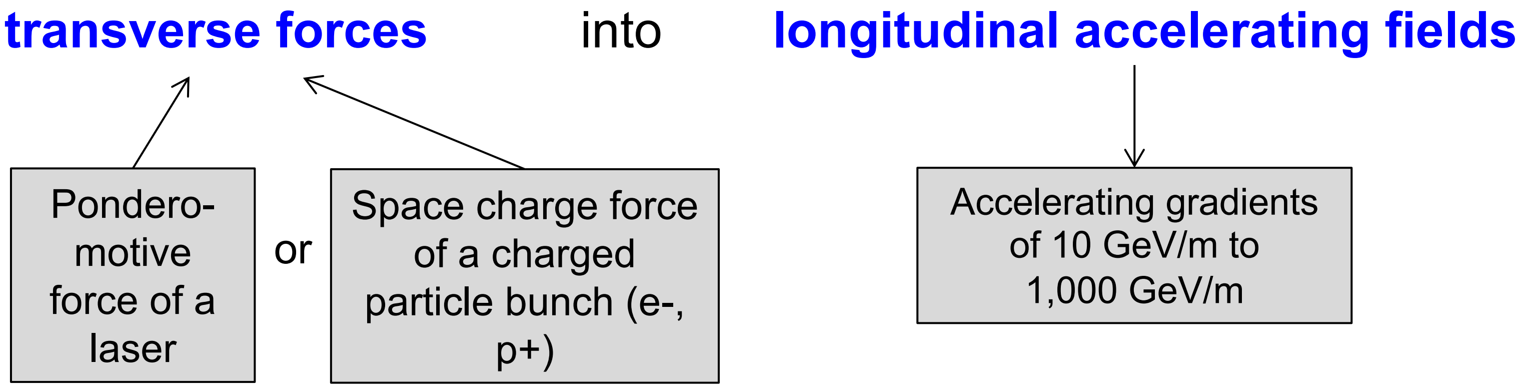
2 **Plasma Accelerator**
Laser- or beam driven
Dynamic Plasma Structure
Plasma field calculations



The Plasma Accelerator

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

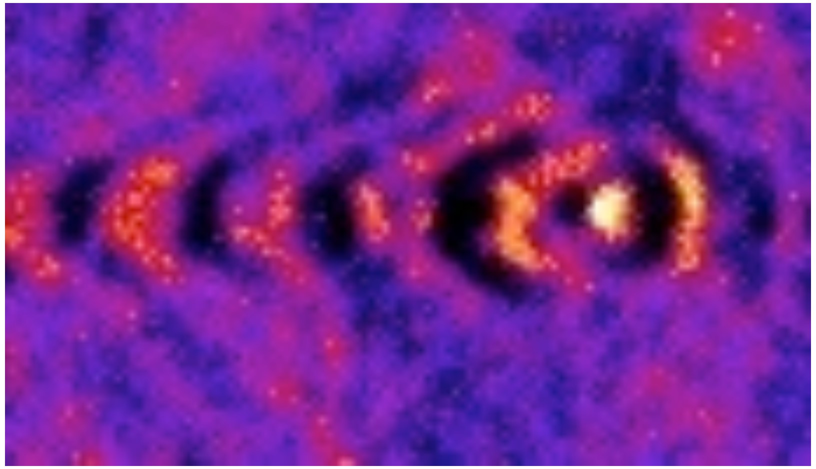
New idea in 1979 by Tajima and Dawson: Wakefields inside a homogenous plasma can convert



transverse forces into **longitudinal accelerating fields**

Pondero-motive force of a laser or Space charge force of a charged particle bunch (e-, p+)

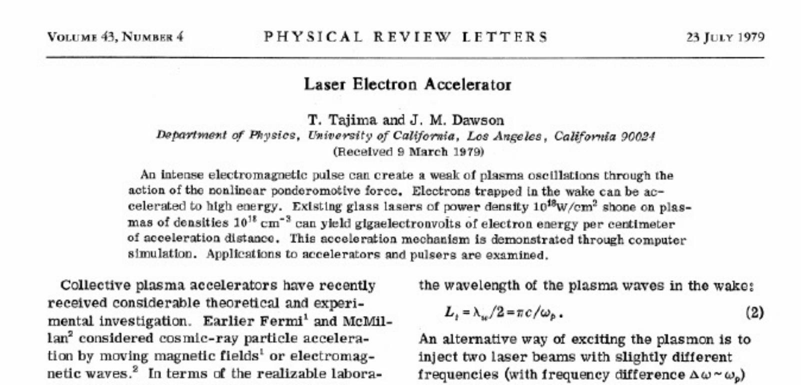
Accelerating gradients of 10 GeV/m to 1,000 GeV/m



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**)



VOLUME 43, NUMBER 4 PHYSICAL REVIEW LETTERS 23 JULY 1979

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

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)

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)

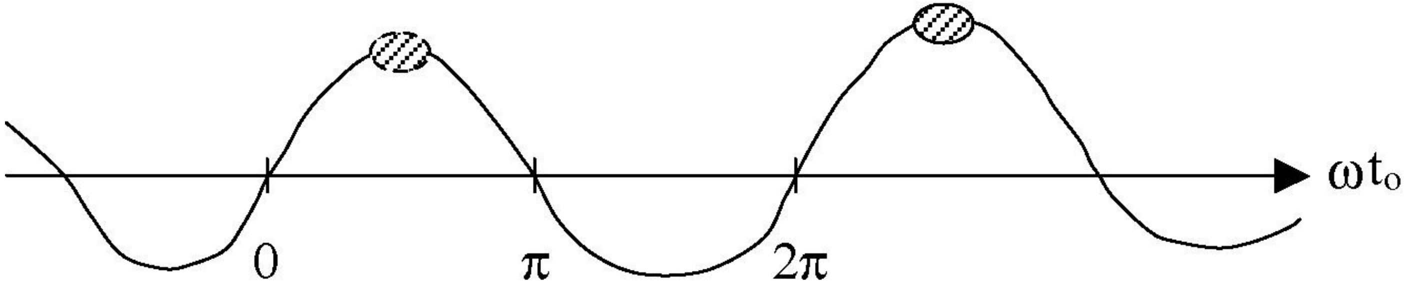
Two conditions for an accelerator:

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!

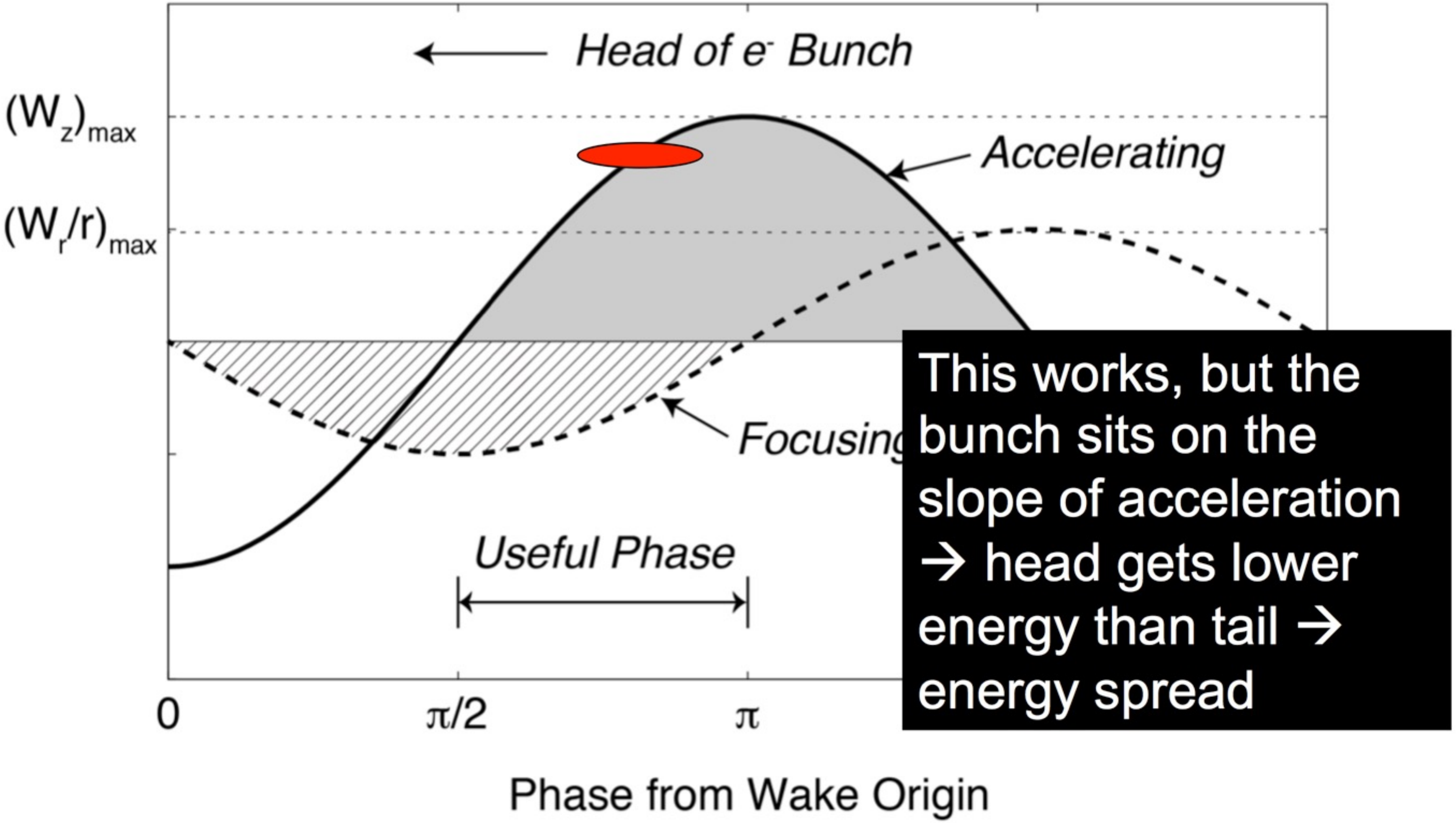
Reminder metallic RF accelerator structures:

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

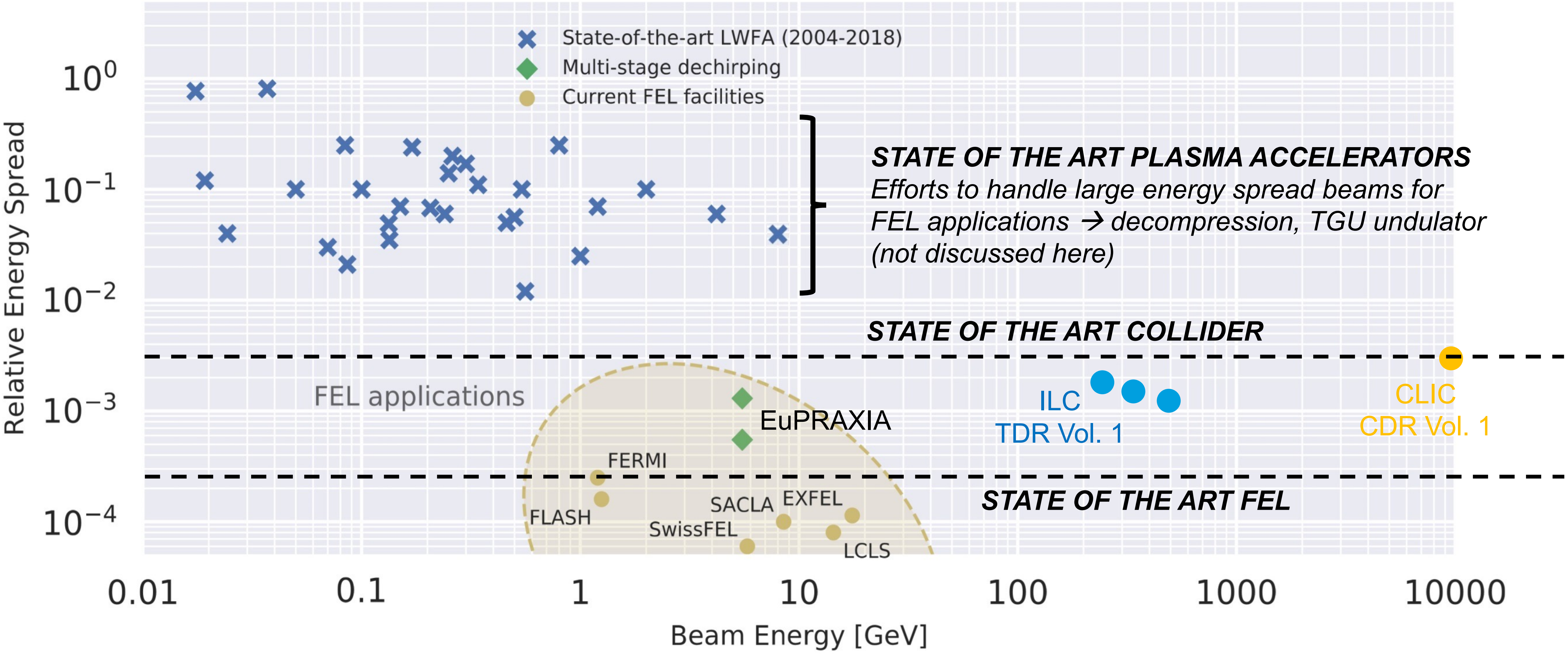
Finding the useful regime → Systematic problem of **large energy spread** is induced (not in RF accelerators)



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

Energy Spread Challenge

State of the art in plasma accelerators versus requirements



STATE OF THE ART PLASMA ACCELERATORS

Efforts to handle large energy spread beams for FEL applications → decompression, TGU undulator (not discussed here)

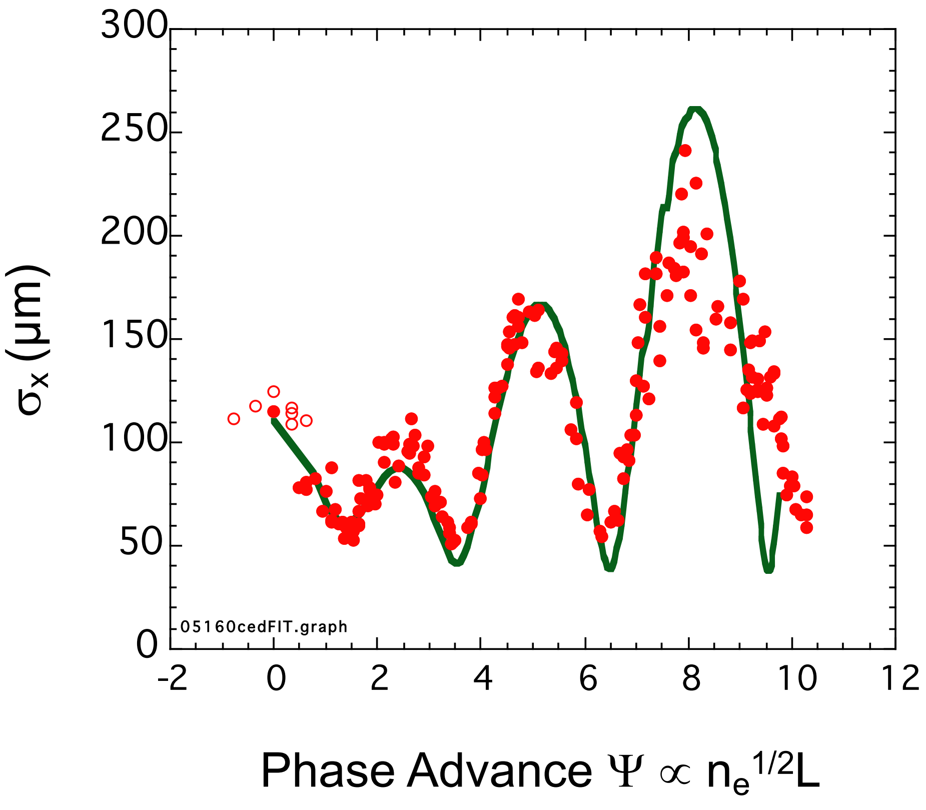
STATE OF THE ART COLLIDER

STATE OF THE ART FEL

Accelerator Builder's Challenge

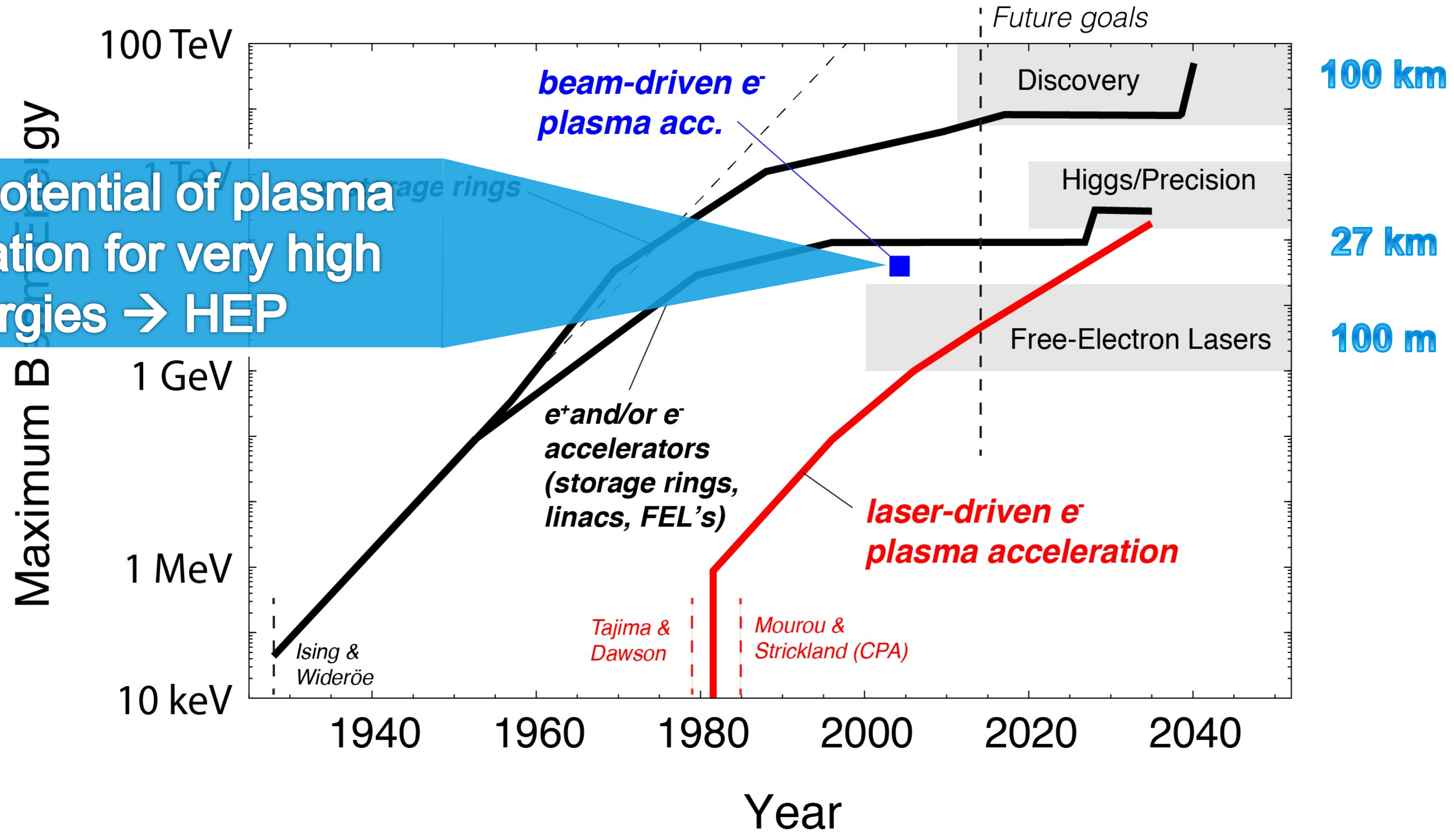
(simplified to typical values)

- 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 (ideas Simon van der Meer and others).
- Develop and demonstrate **user readiness of a 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

High Gradient Accelerators for Science

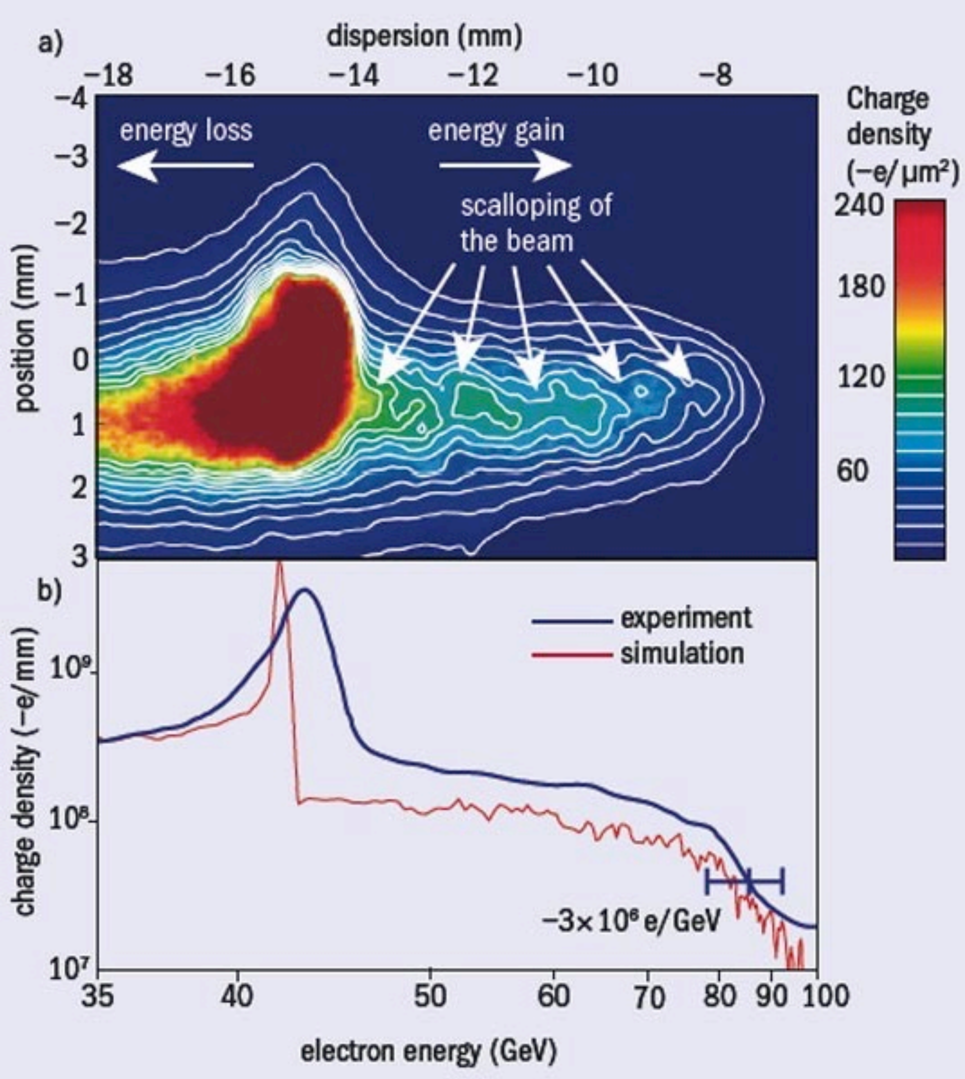


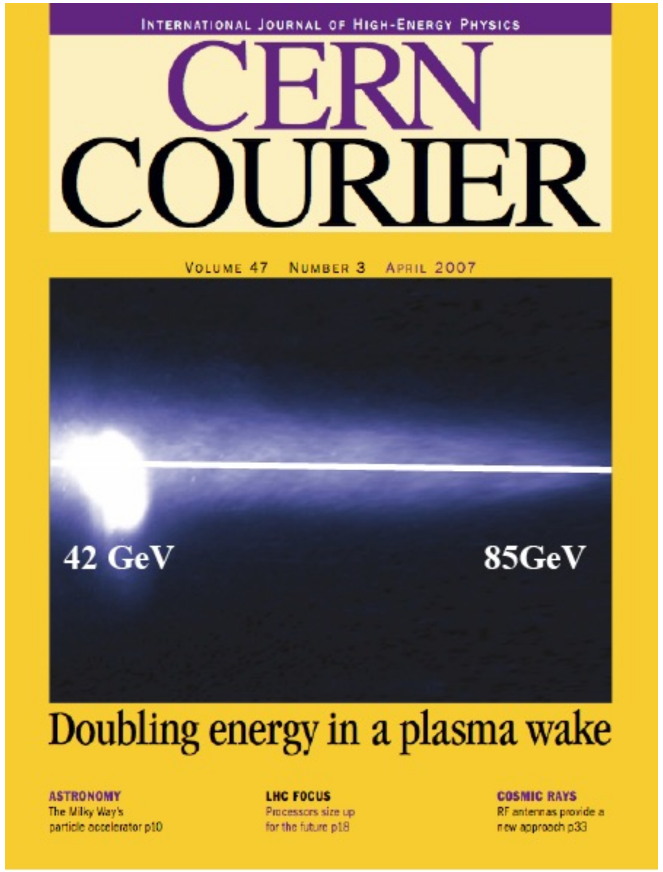
Shows potential of plasma acceleration for very high energies → HEP

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

42 GeV

85GeV

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

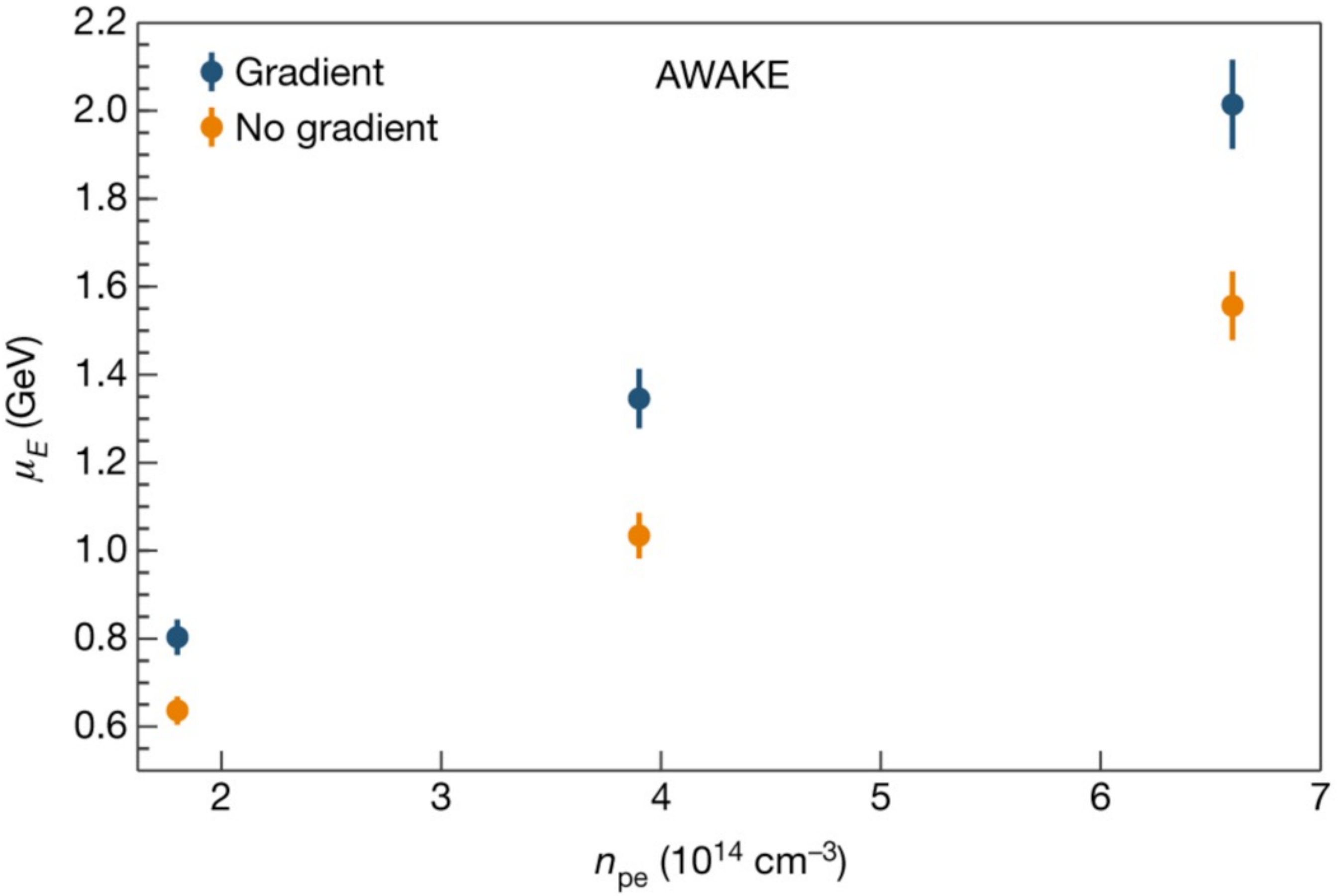
E167 collaboration
SLAC, UCLA, USC

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

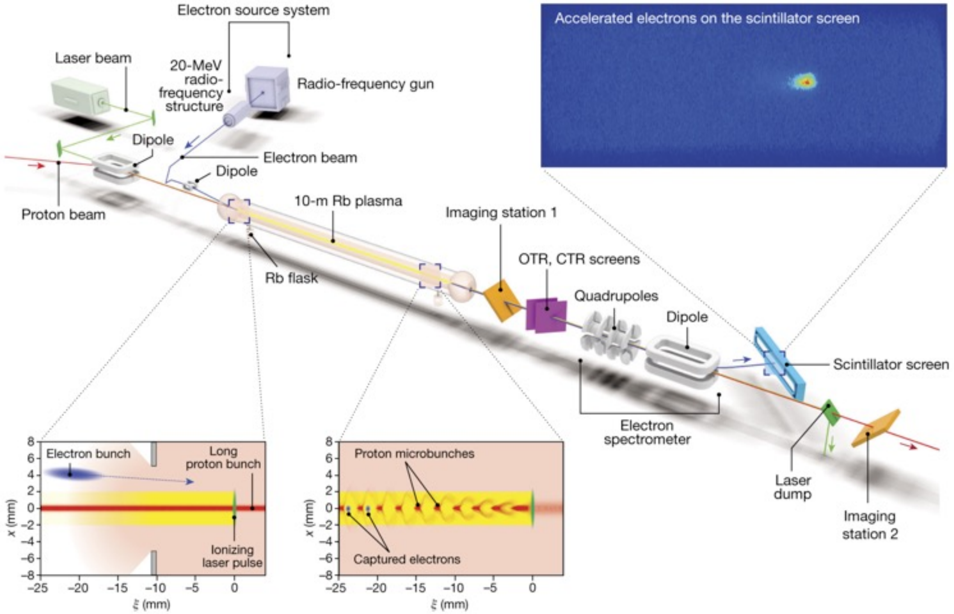
AWAKE at CERN: 2 GeV electron beam acceleration

p+ beam driver

Over a plasma cell length of 10 meters

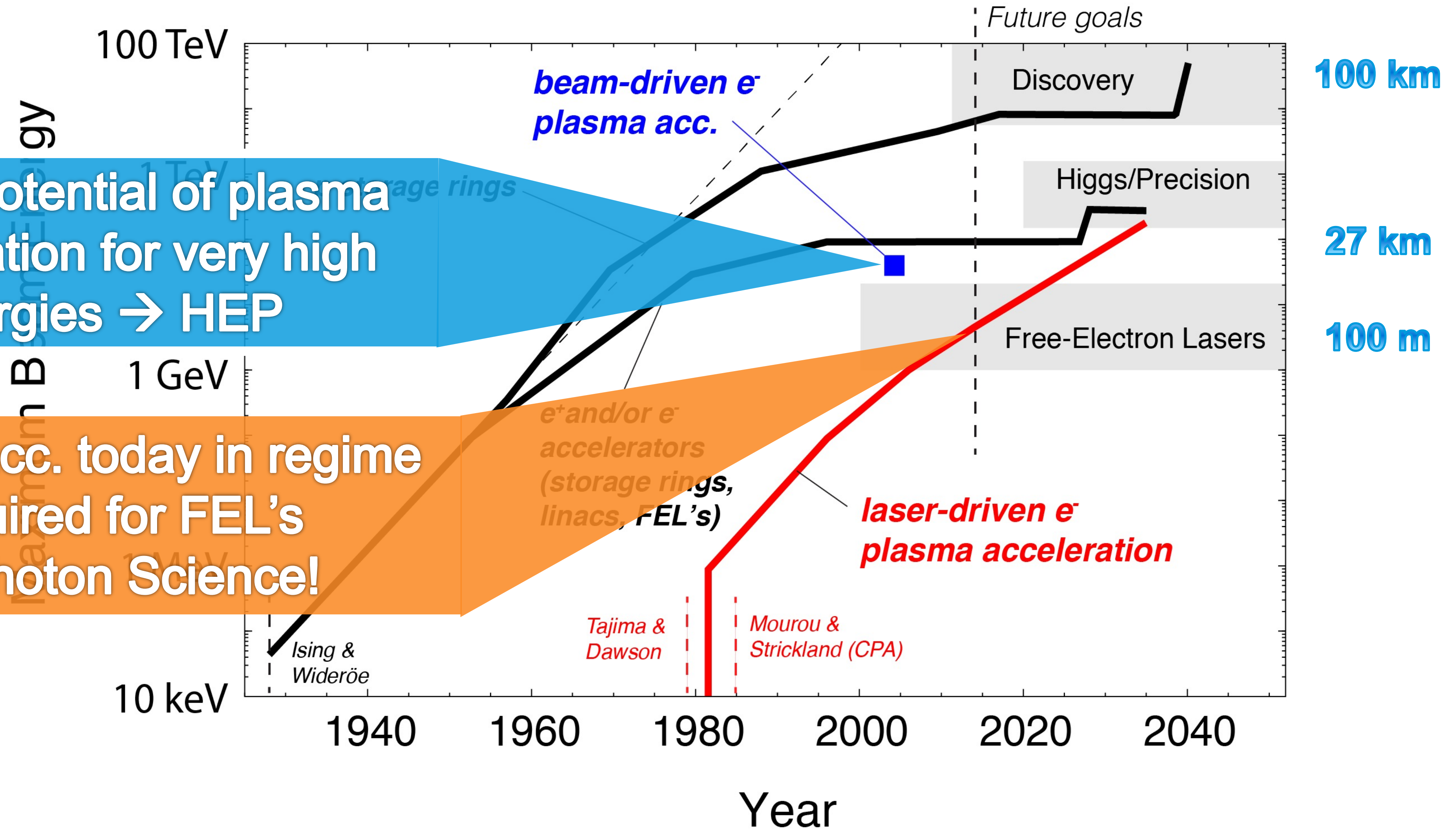


The error bars arise from the position–energy conversion. The gradients chosen are those that were observed to maximize the energy gain. Acceleration to 2.0 ± 0.1 GeV is achieved with a plasma density of 6.6×10^{14} cm^{-3} with a density difference of +2.2% ± 0.1% over 10 m.



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

High Gradient Accelerators for Science



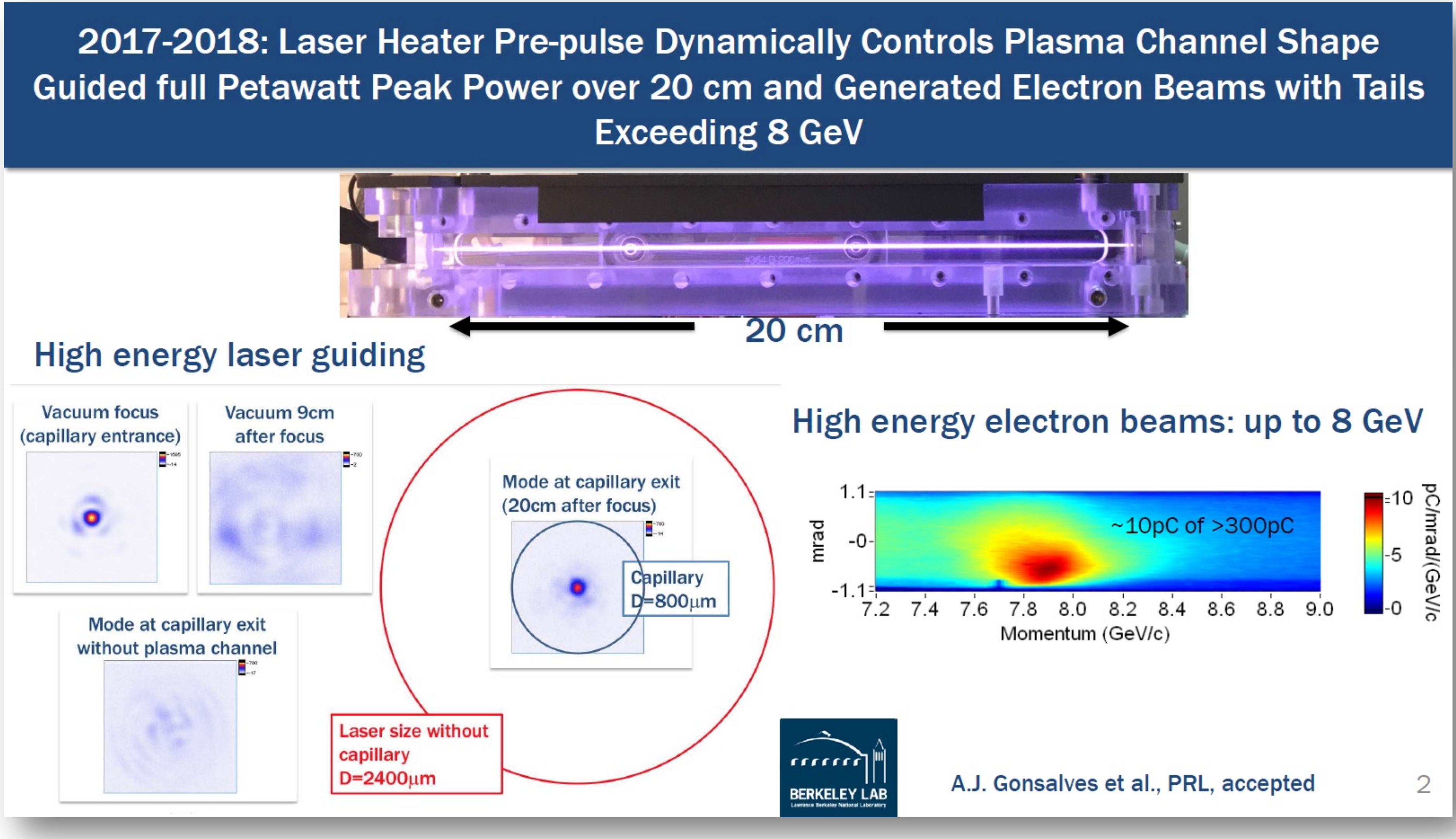
Shows potential of plasma acceleration for very high energies → HEP

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

LBNL: 8 GeV electron beams have been obtained

laser driver

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

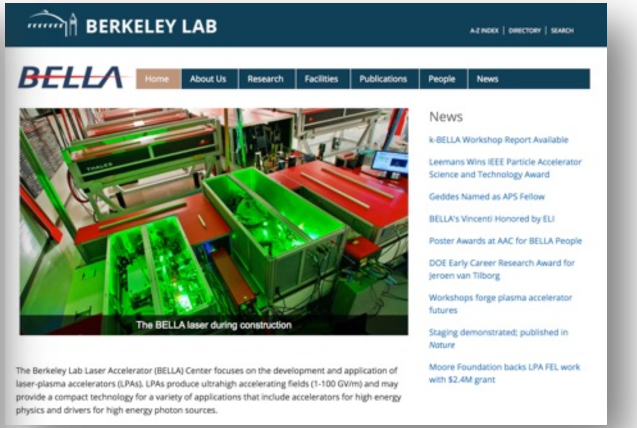


2017-2018: Laser Heater Pre-pulse Dynamically Controls Plasma Channel Shape Guided full Petawatt Peak Power over 20 cm and Generated Electron Beams with Tails Exceeding 8 GeV

High energy laser guiding

High energy electron beams: up to 8 GeV

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



News

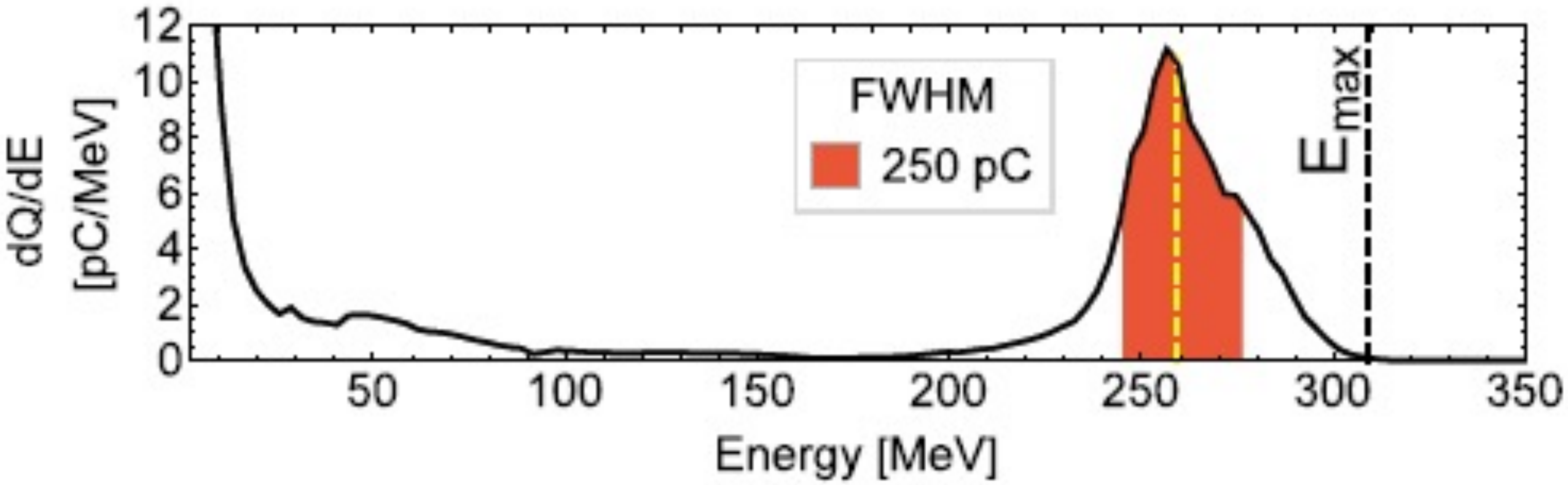
- k-BELLA Workshop Report Available
- Leemans Wins IEEE Particle Accelerator Science and Technology Award
- Geddes Named as APS Fellow
- BELLA's Vincenti Honored by ELI
- Poster Awards at AAC for BELLA People
- DOE Early Career Research Award for Jeroen van Tilborg
- Workshops forge plasma accelerator 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)

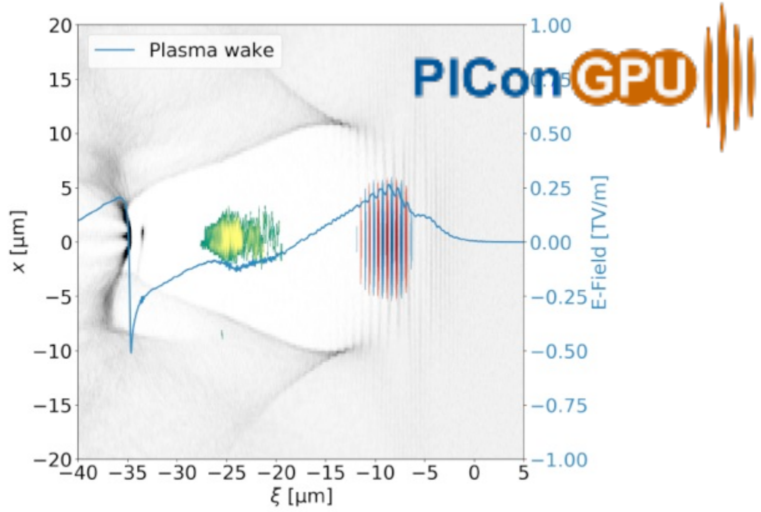
A.Irman, et al., PPCF 60, 044015 (2018)

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

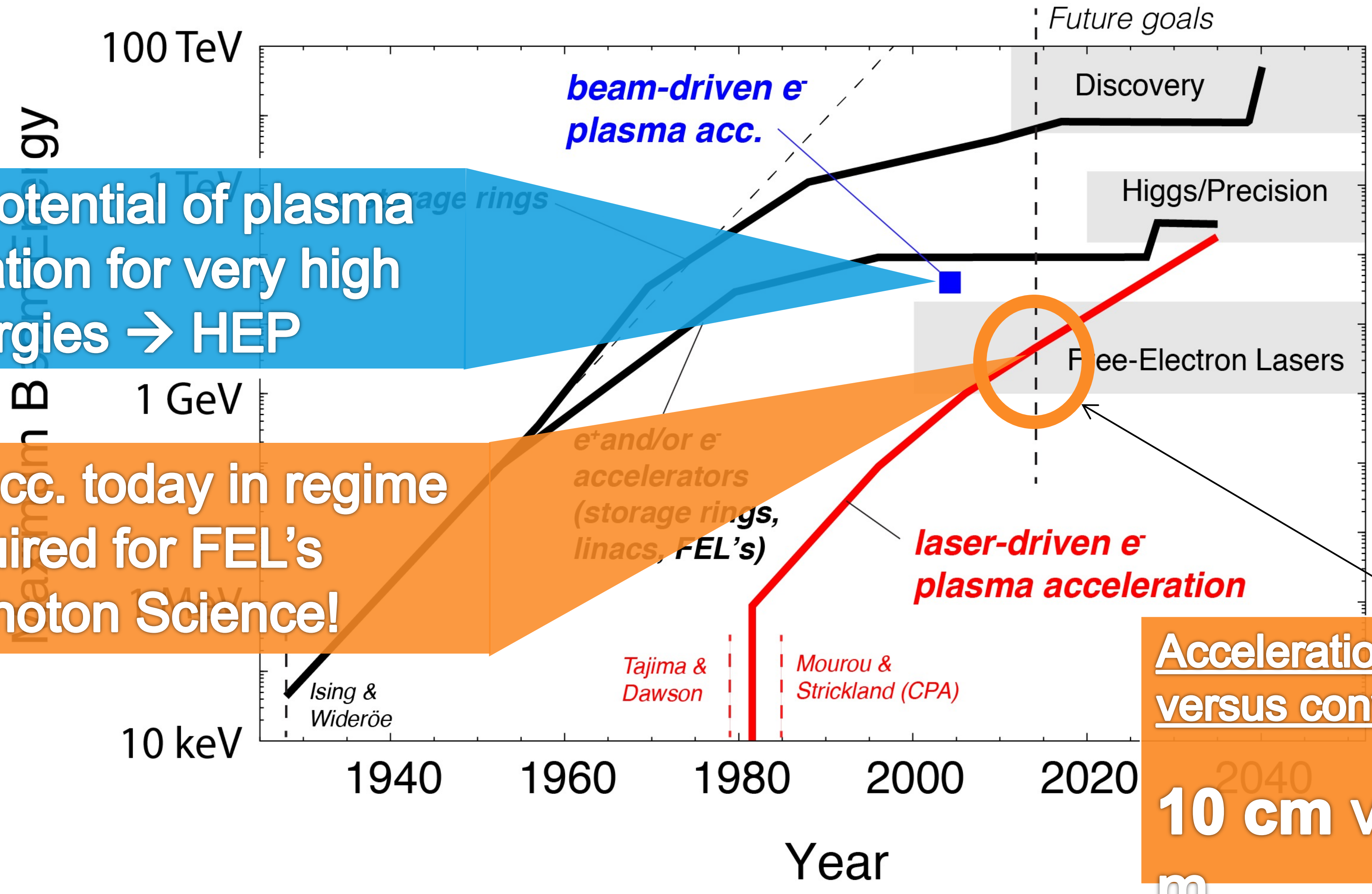
→ Higher charge electron applications (irradiation, collider, ...)

→ Driver for THz sources

→ Driver for beam driven wakefields



High Gradient Accelerators for Science



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):

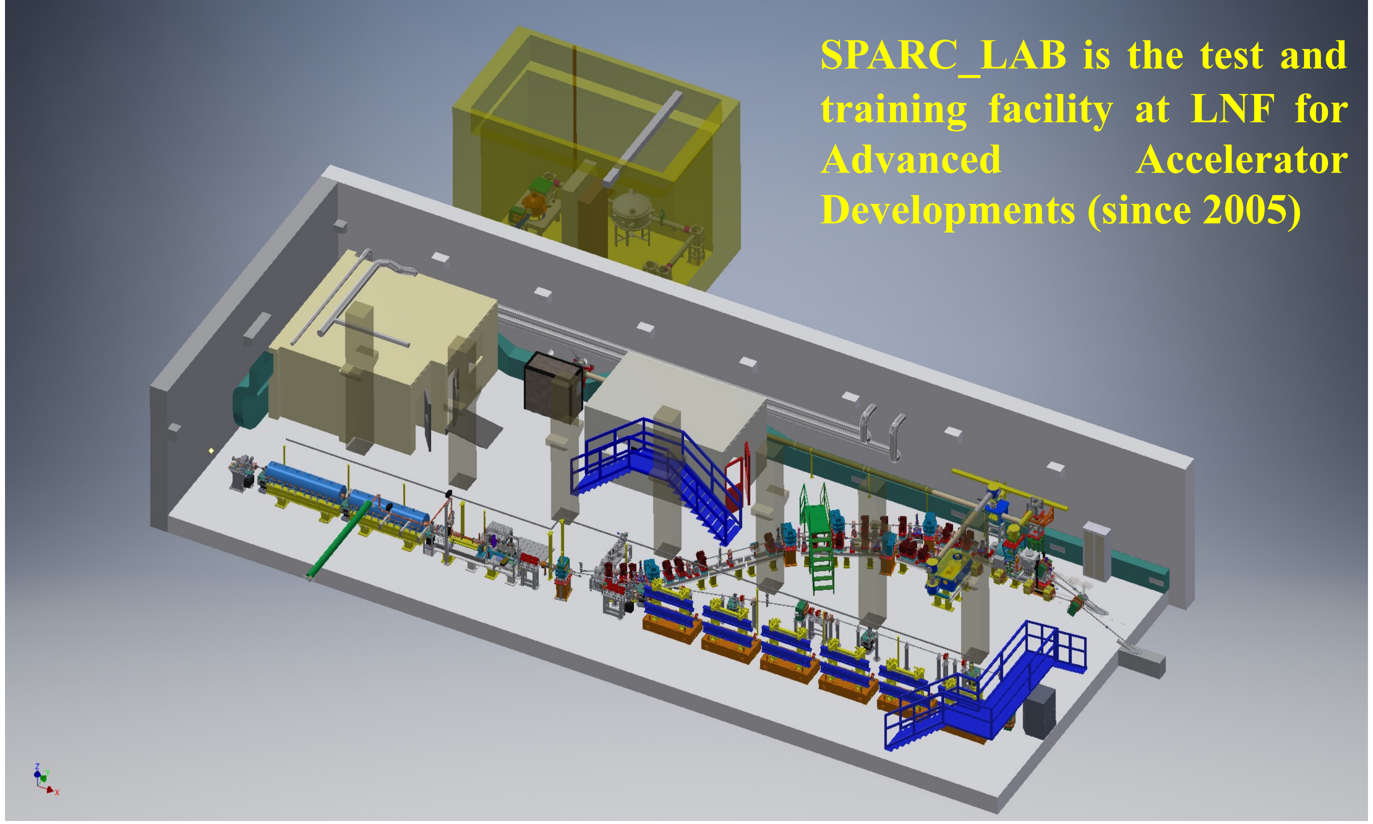
10 cm versus 100 m

Is it really useful beam?

Recent ground-breaking results in Frascati:

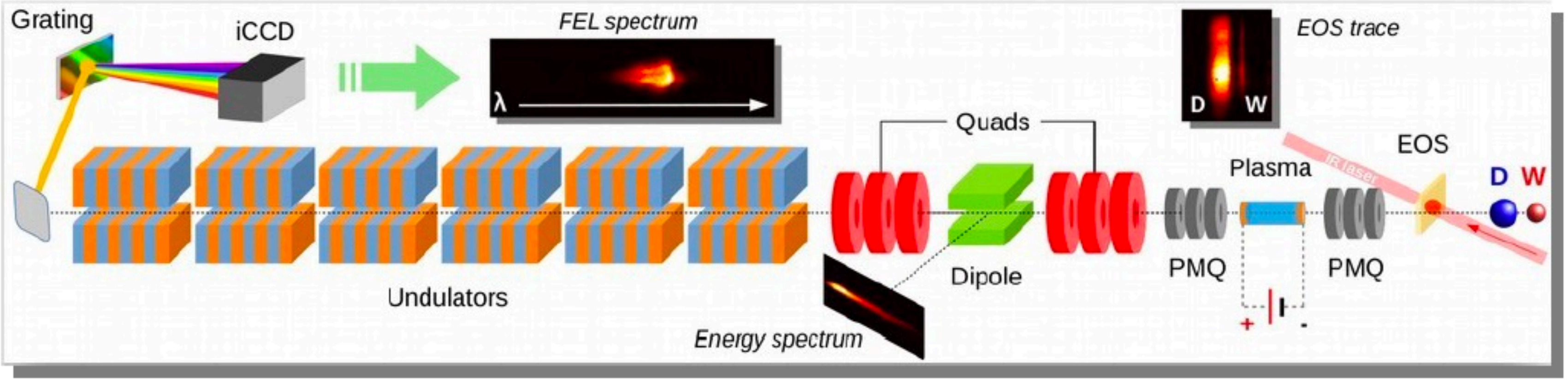
First FEL lasing from a beam-driven plasma accelerator

(in publication)



SPARC_LAB is the test and training facility at LNF for Advanced Accelerator Developments (since 2005)

Experimental layout:



Courtesy M. Ferrario et al

Assisted Beam Loading Energy Spread Compensation

Recent ground-breaking results in Frascati:

First FEL lasing from a beam-driven plasma accelerator

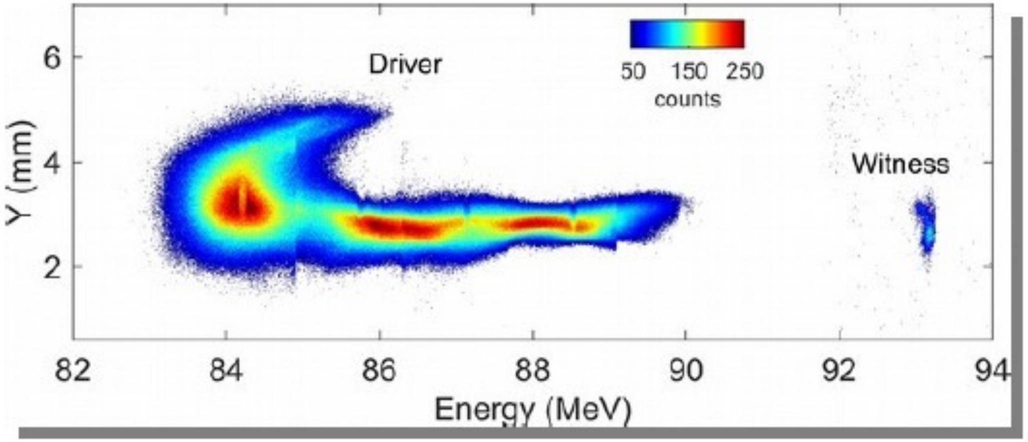
(in publication)

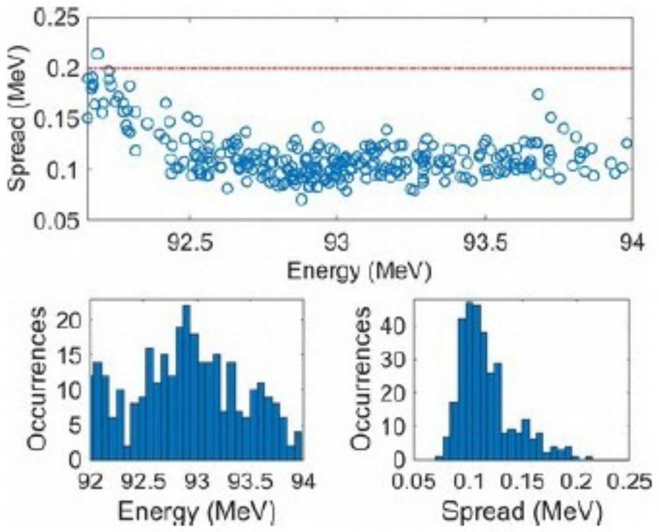
Achieved 4 MeV acceleration in 3 cm plasma with 200 pC driver

- *~133 MV/m accelerating gradient*
- *$2x10^{15}$ cm^{-3} plasma density*

demonstration of energy spread compensation during acceleration

- *Energy spread reduced from 0.2% to 0.12%*
- *99.5% energy stability*





Pompili, R., et al. "Energy spread minimization in a beam-driven plasma wakefield accelerator." Nature Physics (2020): 1-5.

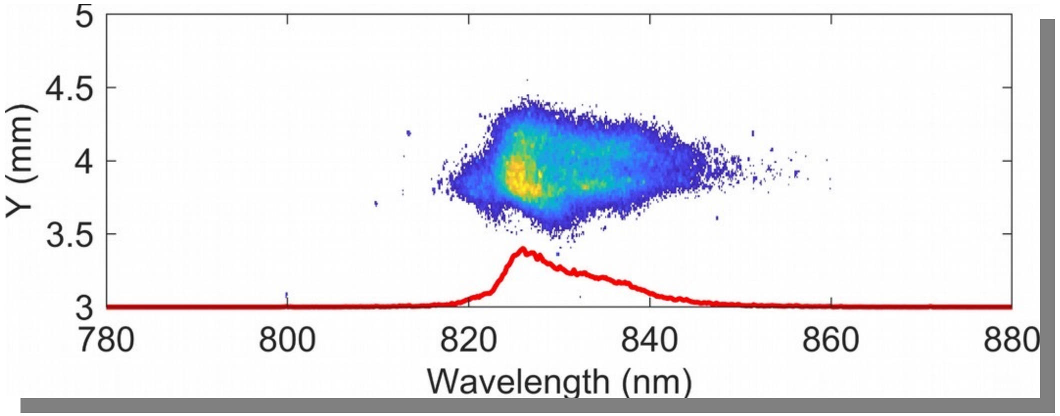
Courtesy M. Ferrario et al

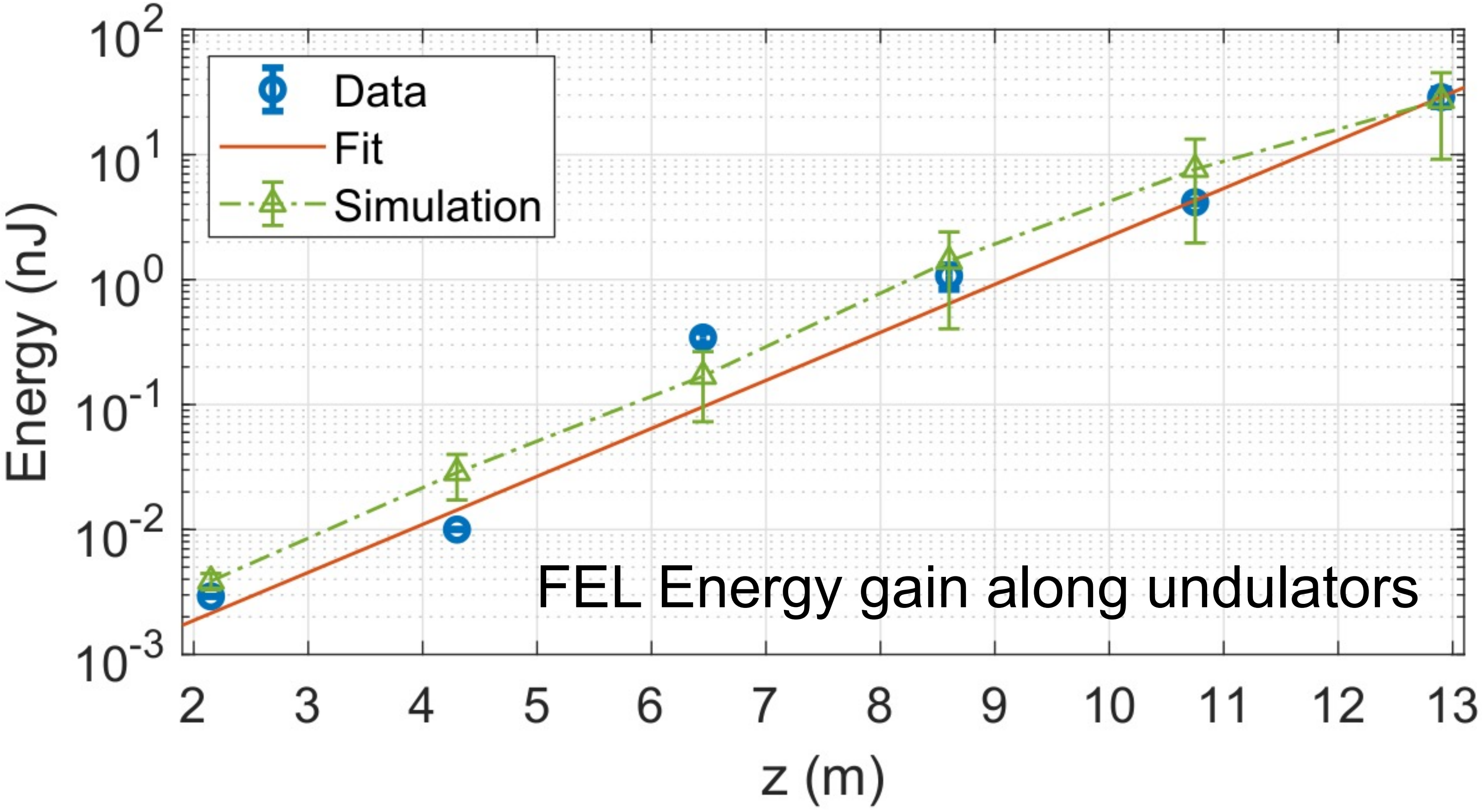
Recent ground-breaking results in Frascati:

First FEL lasing from a beam-driven plasma accelerator

(in publication)

Single Spike SASE spectrum





FEL Energy gain along undulators

Courtesy M. Ferrario et al

W. T. Wang, K. Feng, *et al.*, *Nature*, **595**, 561 (2021).

Article | Published: 21 July 2021

Free-electron lasing at 27 nanometres based on a laser wakefield accelerator

Wentao Wang, Ke Feng, Lintong Ke, Changhai Yu, Yi Xu, Rong Qi, Yu Chen, Zhiyong Qin, Zhijun Zhang, Ming Fang, Jiaqi Liu, Kangnan Jiang, Hao Wang, Cheng Wang, Xiaojun Yang, Fenxiang Wu, Yuxin Leng, Jiansheng Liu, Ruxin Li & Zhizhan Xu

Nature **595**, 516–520 (2021) | Cite this article

Recent ground-breaking result in China

500 MeV electron beam from a laser wakefield accelerator

FEL lasing **amplification of 100** reached at 27 nm wavelength (average radiation energy 70 nJ, peak up to 150 nJ)

Is it really useful beam?

It can drive an FEL lasing process – sufficient coherency!

Great News End of June

Building the first plasma accelerator facility

ESFRI announces new RIs for R

30.06.2021

PRESS RELEA

ESFRI annou
included in it

€4.1 billion ir
European cha

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

The new ESFRI Projects are:

- **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.

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

Recognized by European Physical Society

Special Topics

EuPRAXIA Conceptual Design Report

Ralph Assmann and Maria Weikum (Eds.)

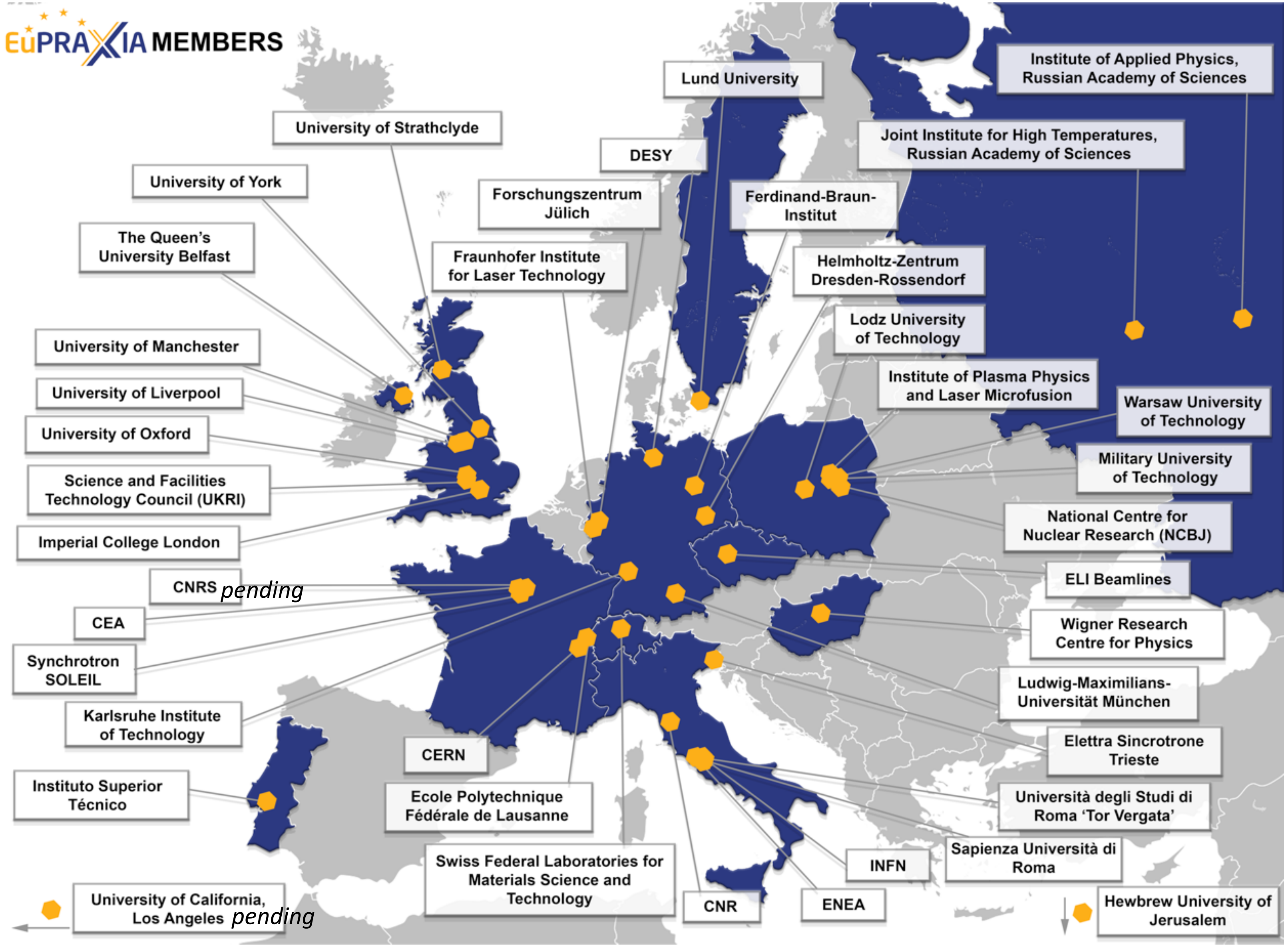
edp sciences Springer

653 page CDR, 240 scientists contributed

The Consortium Members for the Next Phase

(from 16 to 40)

Horizon 2020

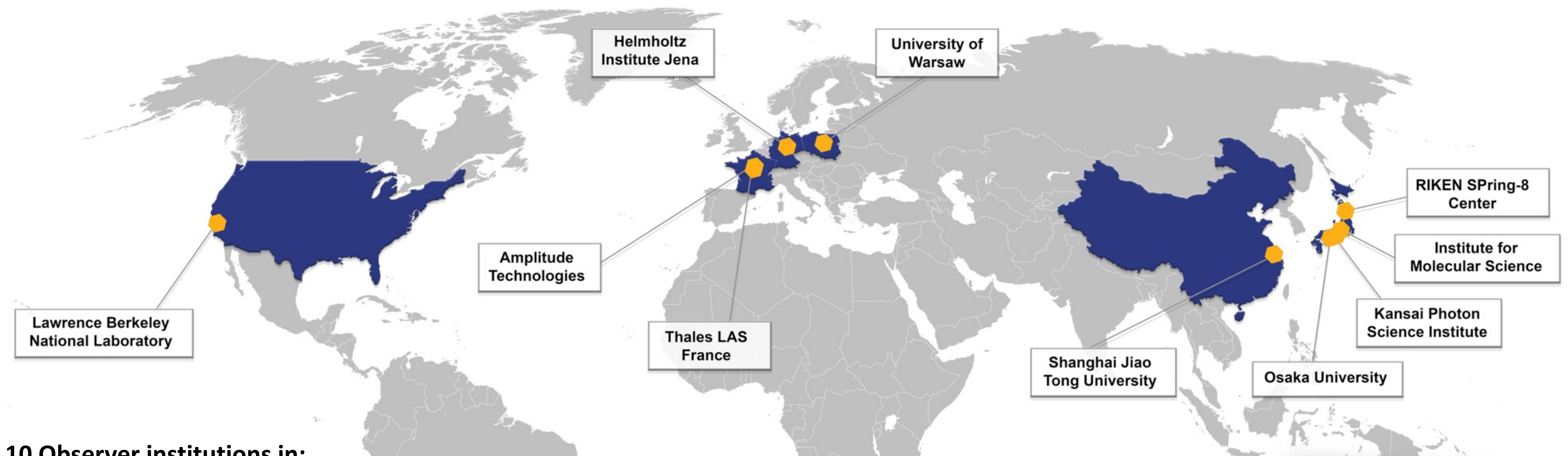


40 Member institutions in:

- **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)



10 Observer institutions in:

- **France** (Amplitude Technologies, Thales LAS France SAS)
- **Germany** (Helmholtz-Institut Jena)
- **Poland** (University of Warsaw)
- **United States** (LBNL)

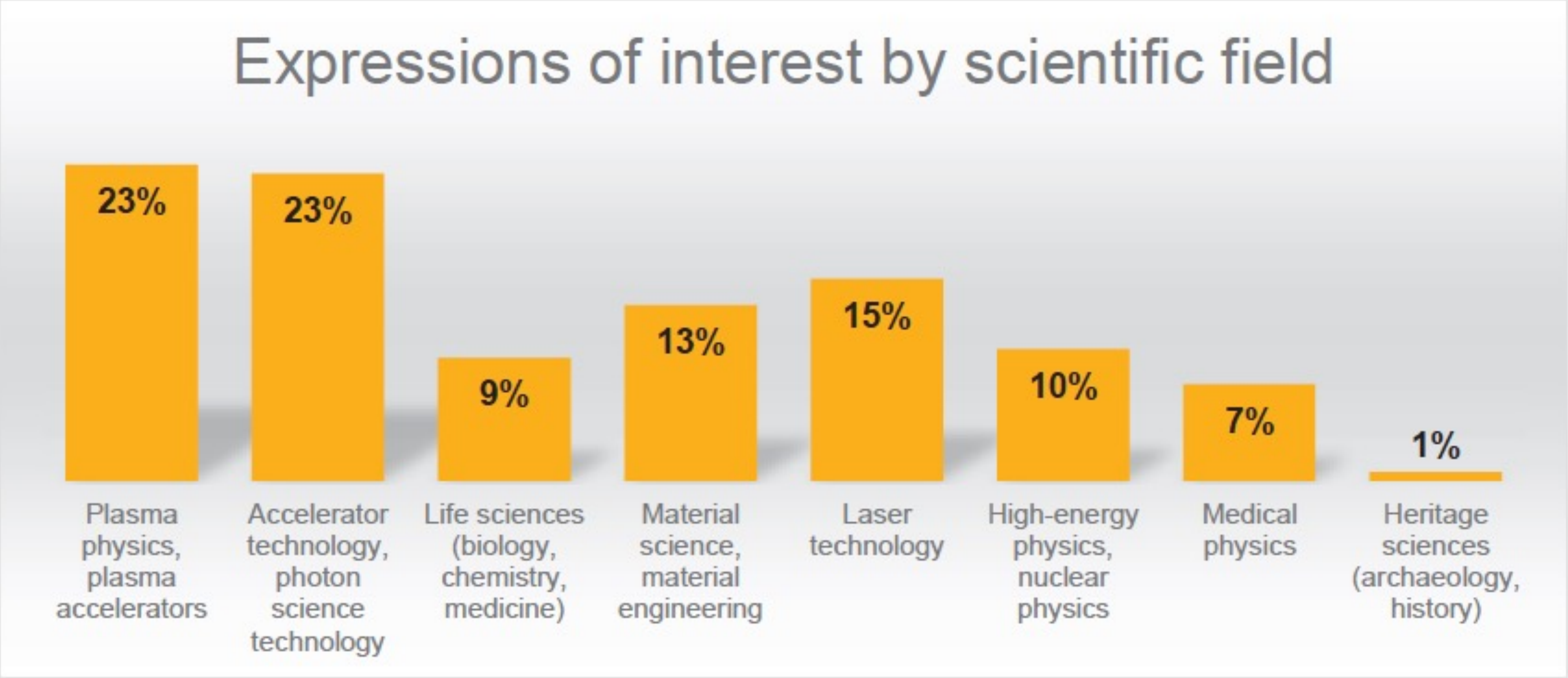
- **China** (Shanghai Jiao Tong University)
- **Japan** (Institute for Molecular Science, Osaka University, Kansai Photon Science Institute, RIKEN SPring-8 Center)


Consortium Agreement
between research institutions and organisations

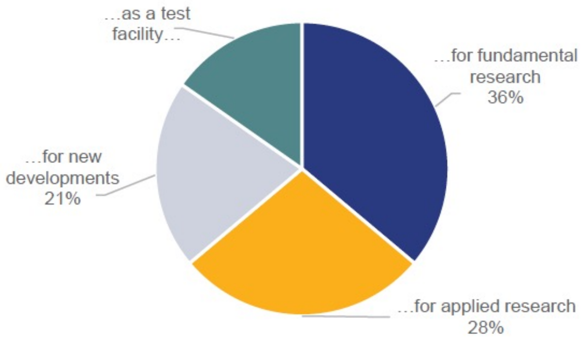
EuPRAXIA Deliverables and User Interests

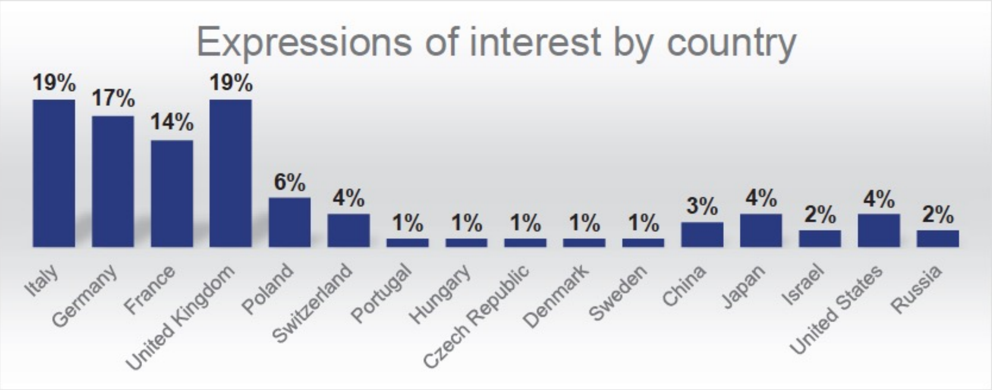
EuPRAXIA is designed to deliver at 10-100 Hz ultra-short pulses of

- 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})



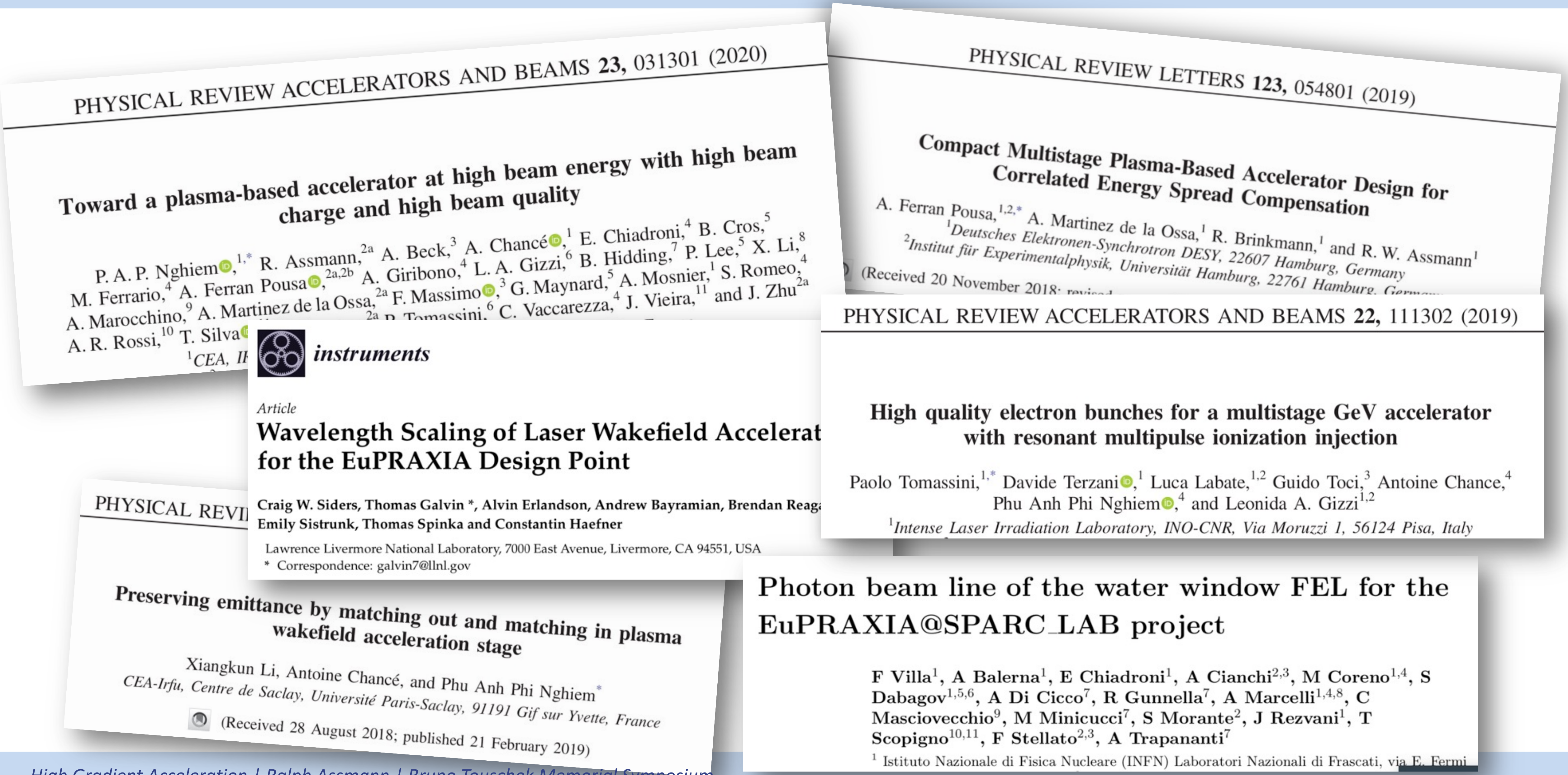
Expressions of interest from **95 research groups** representing several thousand scientists in total.





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

Examples of EuPRAXIA Ideas and Innovation



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 … P. Tomassini,[6] C. Vaccarezza,[4] J. Vieira,[11] and J. Zhu[2a]

[1]*CEA, IF*

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 Reaga 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

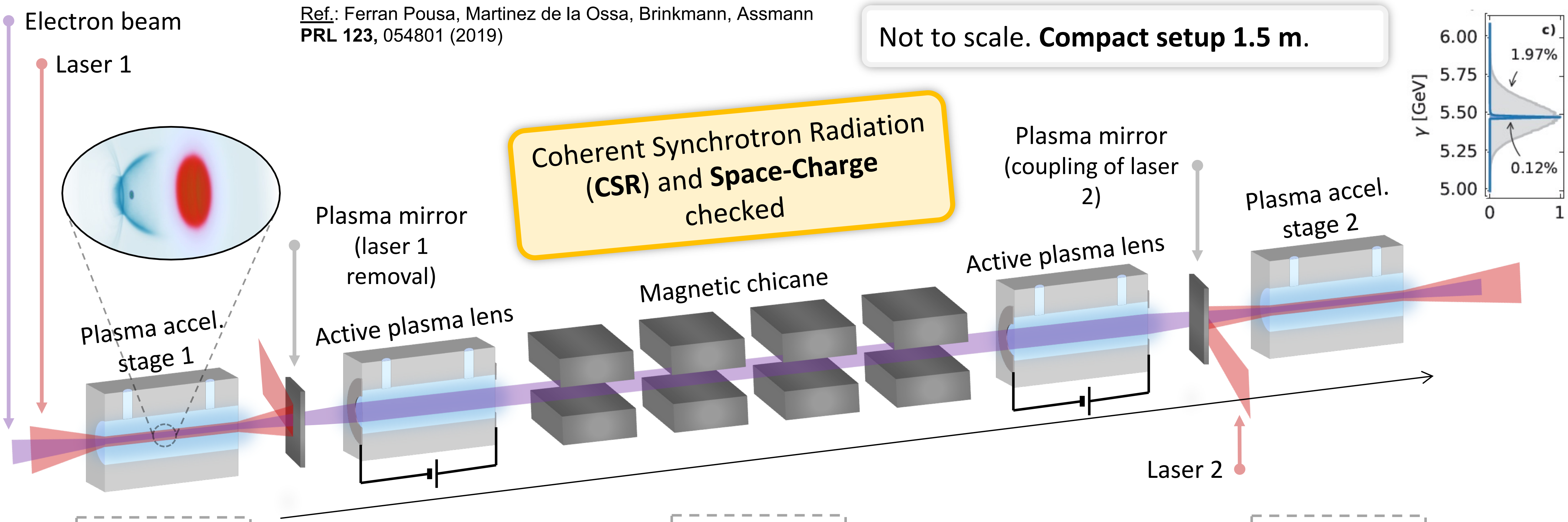
(Received 28 August 2018; published 21 February 2019)

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

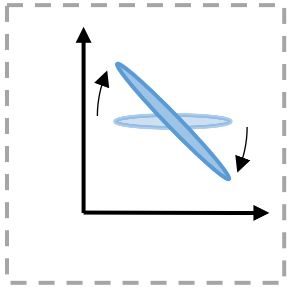
Solving Energy Spread (Touschek Prize 2020)



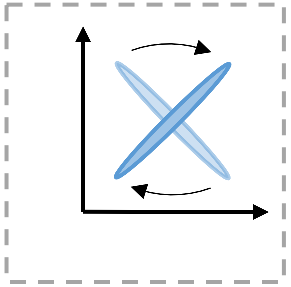
<u>Ref.</u>: Ferran Pousa, Martinez de la Ossa, Brinkmann, Assmann
PRL 123, 054801 (2019)

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

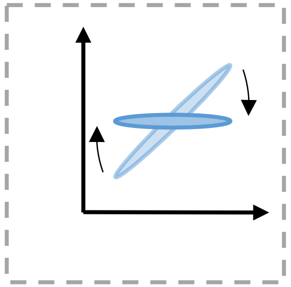
Coherent Synchrotron Radiation (**CSR**) and **Space-Charge** checked



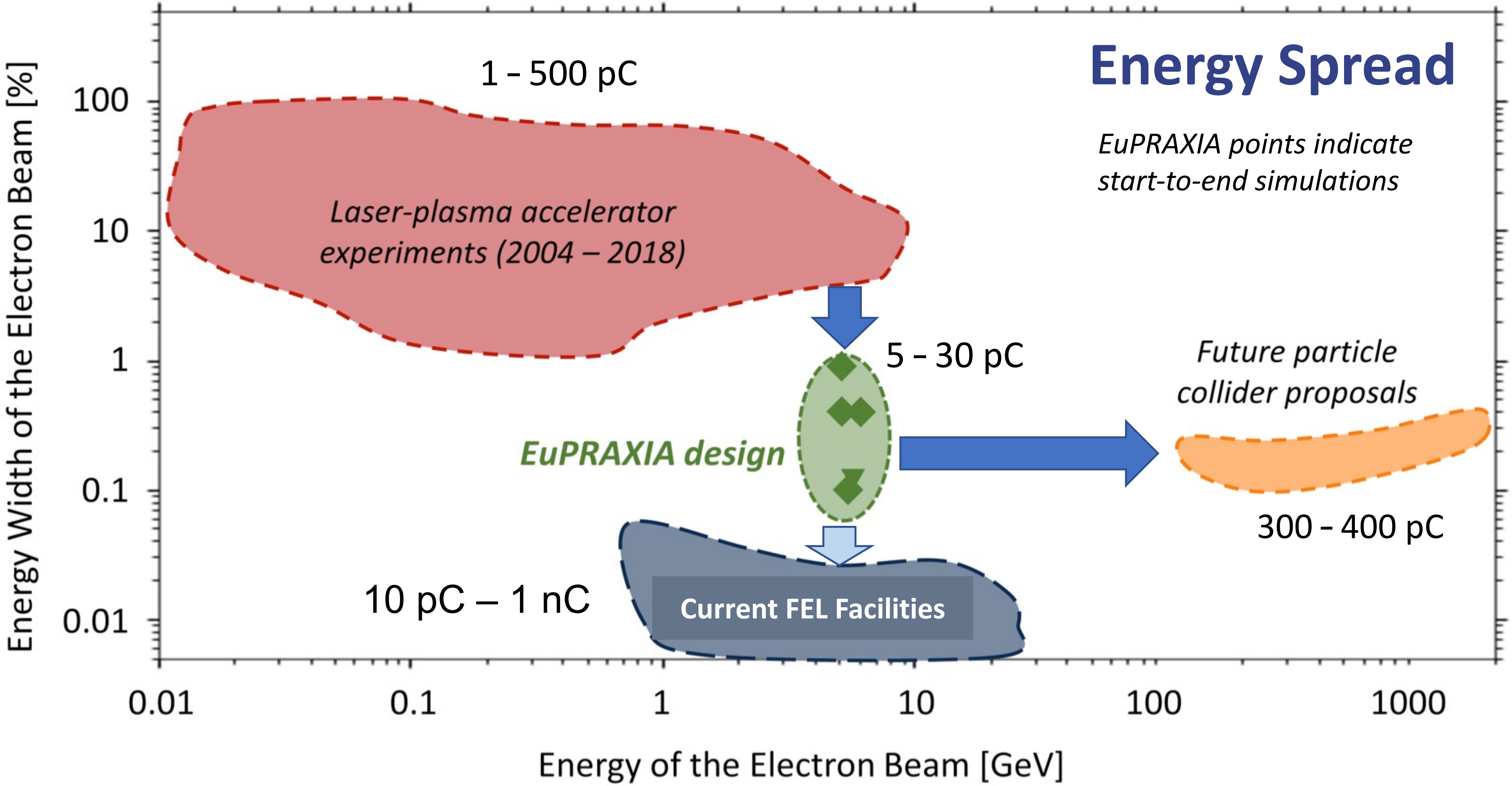
Accelerating in a plasma stage and...



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

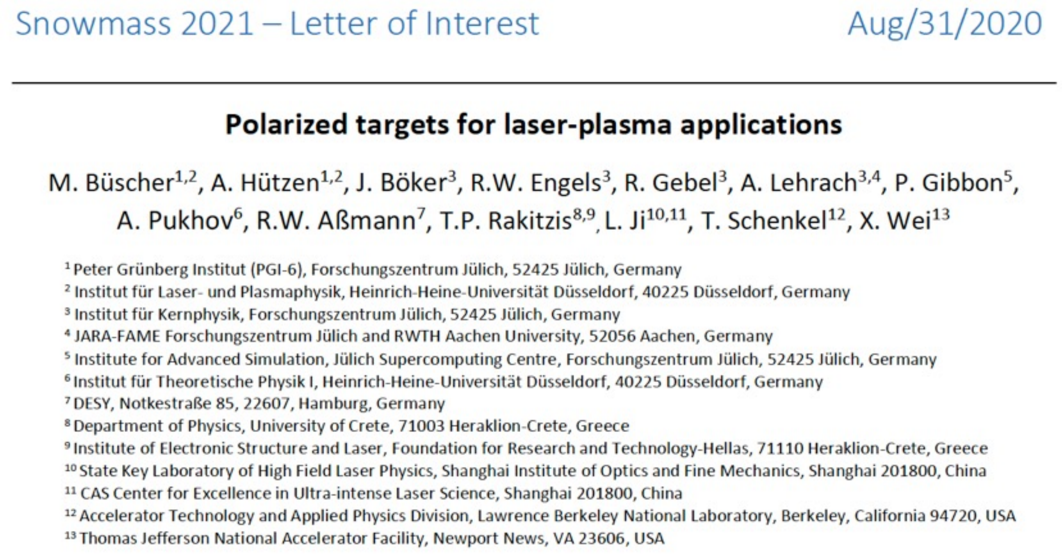


Solving Energy Spread



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, ...



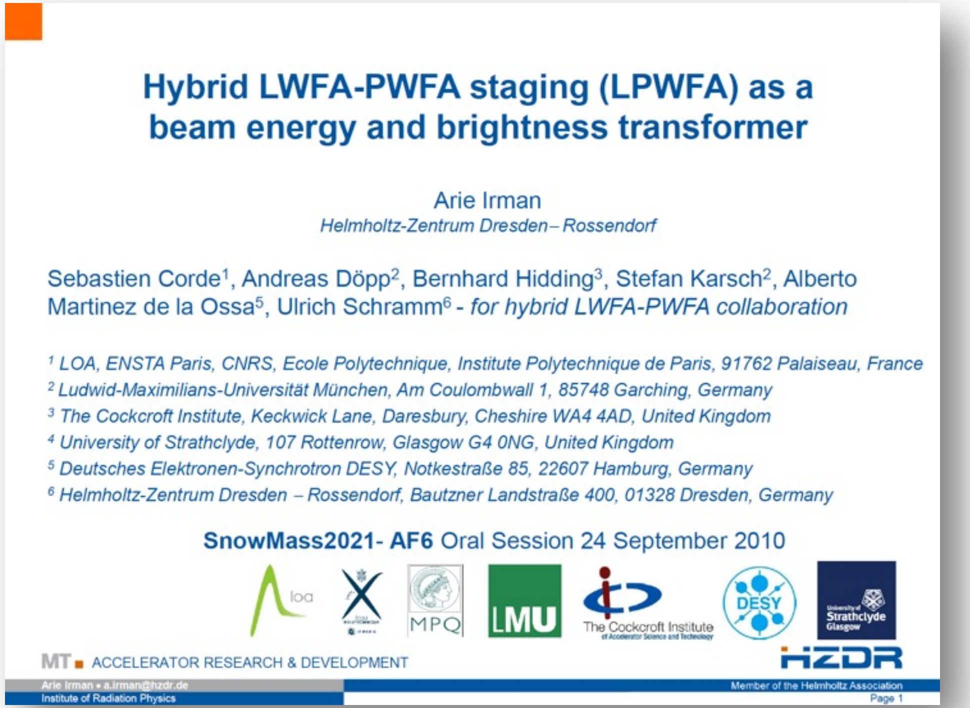
Snowmass 2021 – Letter of Interest Aug/31/2020

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]

[1] Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich, 52425 Jülich, Germany
[2] Institut für Laser- und Plasmaphysik, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany
[3] Institut für Kernphysik, Forschungszentrum Jülich, 52425 Jülich, Germany
[4] JARA-FAME Forschungszentrum Jülich and RWTH Aachen University, 52056 Aachen, Germany
[5] Institute for Advanced Simulation, Jülich Supercomputing Centre, Forschungszentrum Jülich, 52425 Jülich, Germany
[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
[3] The Cockcroft Institute, Keckwick Lane, Daresbury, Cheshire WA4 4AD, United Kingdom
[4] University of Strathclyde, 107 Rottenrow, Glasgow G4 0NG, United Kingdom
[5] Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany
[6] Helmholtz-Zentrum Dresden – Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany

SnowMass2021- AF6 Oral Session 24 September 2010

MT ACCELERATOR RESEARCH & DEVELOPMENT

Arie Irman • a.irman@hzdr.de
Institute of Radiation Physics
Member of the Helmholtz Association
Page 1

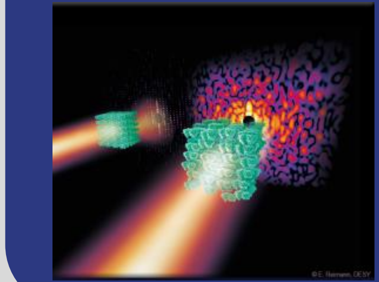
Distributed Research Infrastructure – 1^{st} Users 2028

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*


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

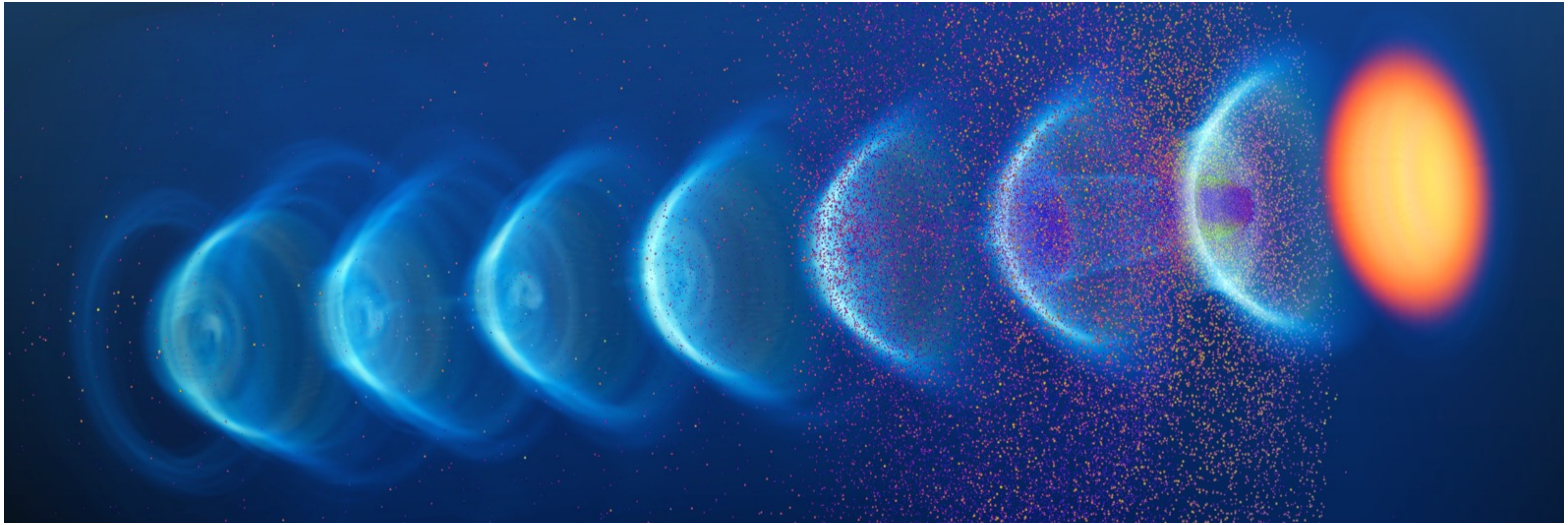
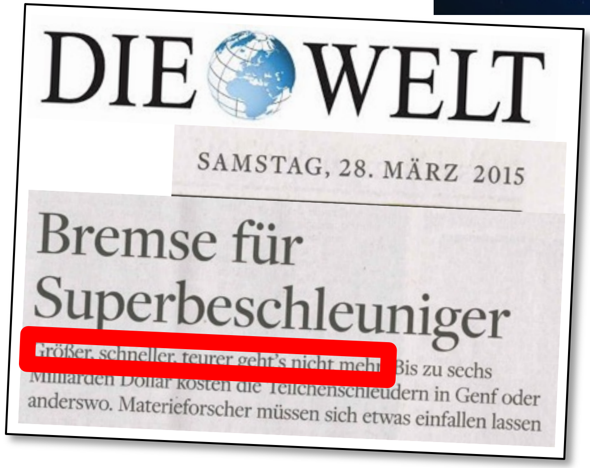


Illustration from PhD A. Ferran Pousa


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?

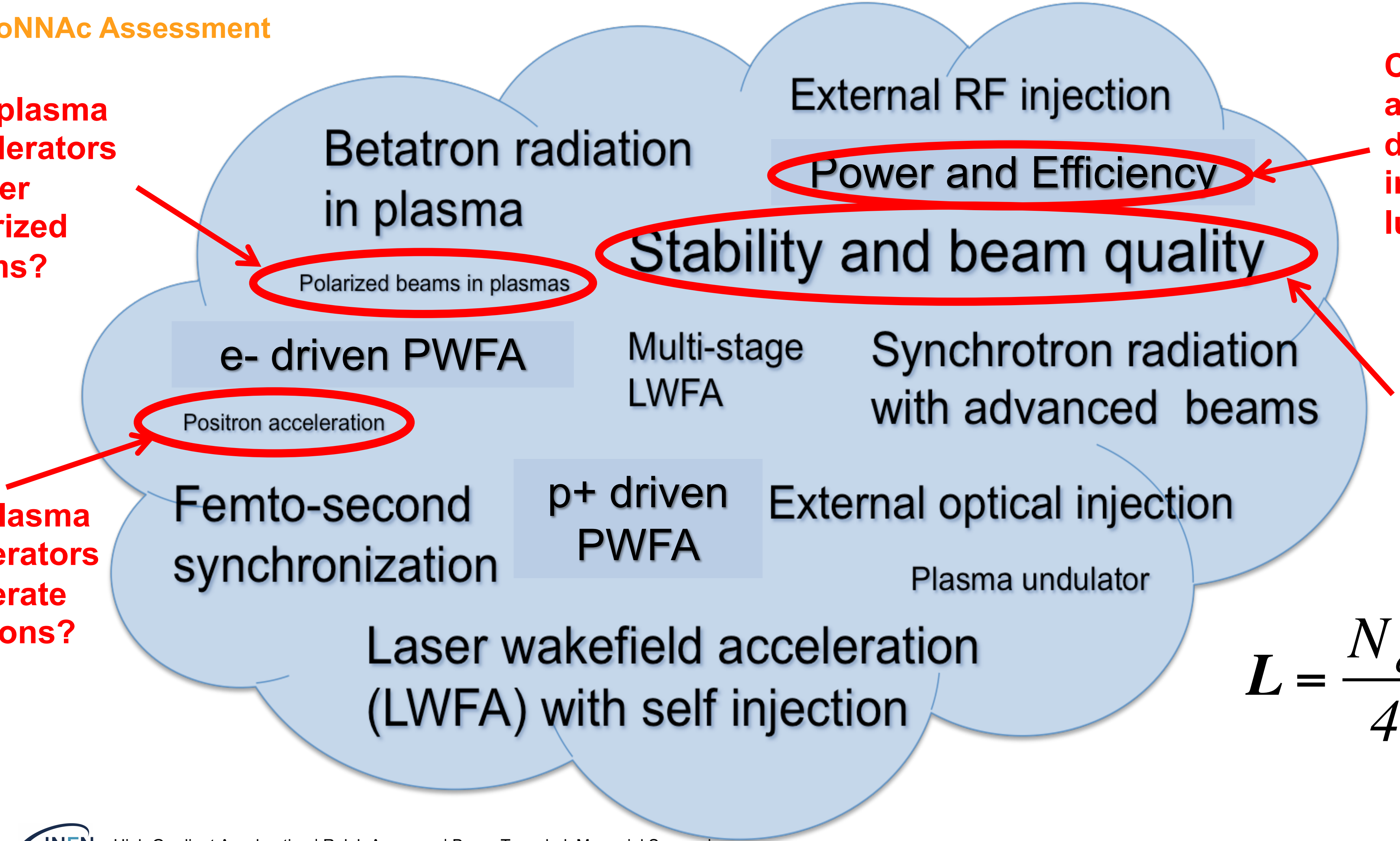
Not so easy...

R&D Paths Plasma Accelerators

EuroNNAc Assessment

Can plasma accelerators deliver polarized beams?

Can plasma accelerators accelerate positrons?



Betatron radiation in plasma

External RF injection

Power and Efficiency

Stability and beam quality

Polarized beams in plasmas

e- driven PWFA

Multi-stage LWFA

Synchrotron radiation with advanced beams

Positron acceleration

Femto-second synchronization

p+ driven PWFA

External optical injection

Plasma undulator

Laser wakefield acceleration (LWFA) with self injection

Can plasma accelerators deliver integrated luminosity?

Can plasma accelerators deliver peak luminosity?

$$L = \frac{N_{e+}N_{e-}f_r}{4\pi\sigma_x\sigma_y}$$

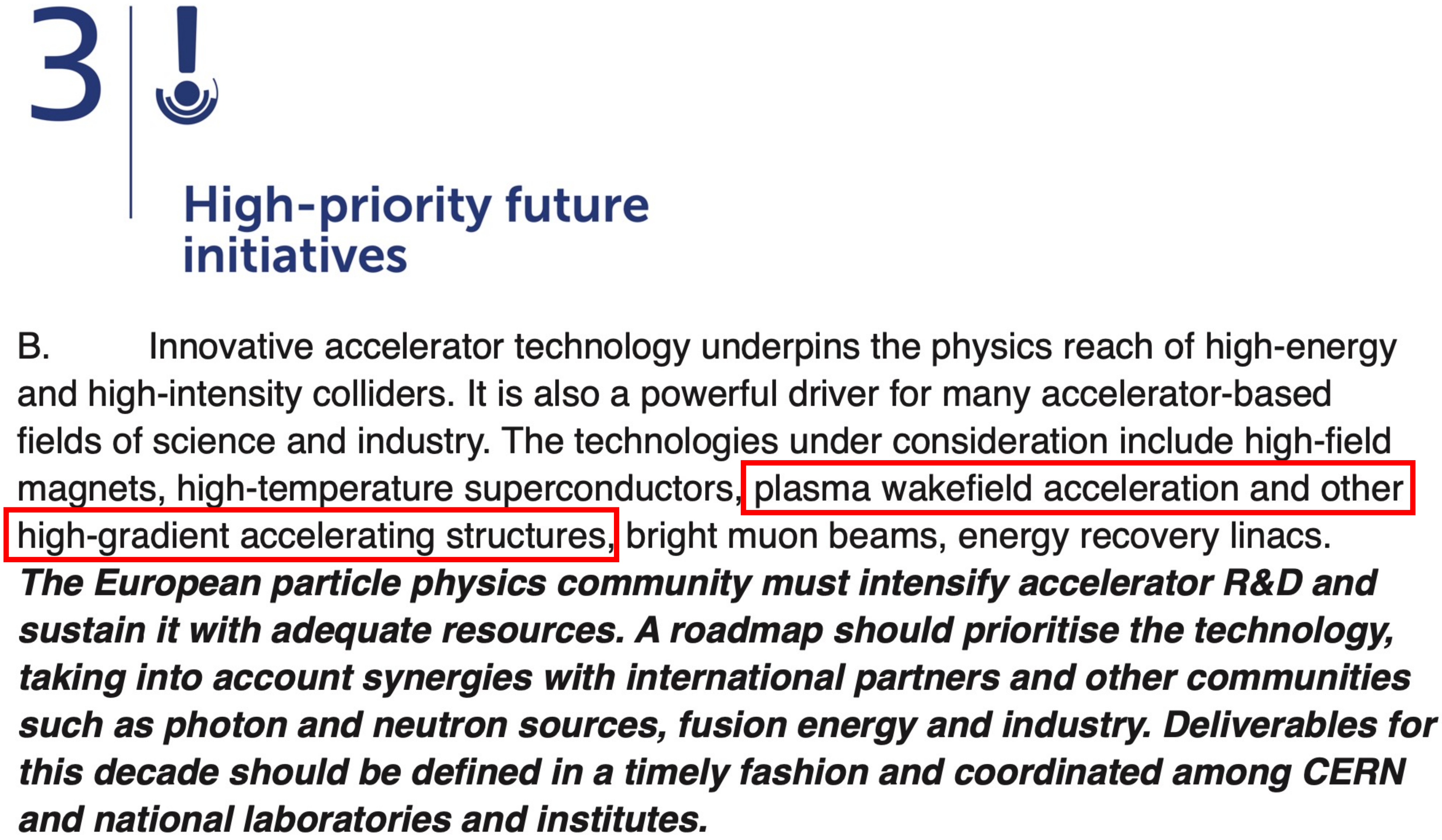
2020 UPDATE OF THE EUROPEAN STRATEGY
FOR PARTICLE PHYSICS

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.***

Ongoing: European Strategy Expert Panel

Defining a European Particle Physics Roadmap for High-Gradient Novel Accelerators

Expert Panel – Panel chairs:
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)

Final report with the CERN council

CERN Yellow Reports: Monographs, CERN-2021-XXX

4 High-gradient Plasma and Laser Accelerators

Editors: R. Assmann^{a,b}*, E. Gschwendtner*^{c}*, R. Ischebeck*^{d}

Panel members: R. Assmann^{a,b,*} *(Chair), E. Gschwendtner*^{c} *(Co-Chair), K. Cassou*^{e}*, S. Corde*^{f}*, L. Corner*^{g}*, B. Cros*^{h}*, M. Ferrario*^{b}*, S. Hooker*^{i}*, R. Ischebeck*^{d}*, A. Latina*^{c}*, O. Lundh*^{j}*, P. Muggli*^{k}*, P. Nghiem*^{l}*, J. Osterhoff*^{a}*, T. Raubenheimer*^{m}*, A. Specka*^{n}*, J. Vieira*^{o}*, M. Wing*^{p}

Associated members: C. Geddes^{q}*, M. Hogan*^{m}*, W. Lu*^{r}*, P. Musumeci*^{s}

[a]DESY, Hamburg, Germany
[b]LNF/INFN, Frascati, Italy
[c]CERN, Geneva, Switzerland
[d]PSI, Villigen, Switzerland
[e]IJCLab, Orsay, France
[f]IP Paris, Palaiseau, France
[g]Liverpool University, UK
[h]LPGP-CNRS-Université Paris Saclay, Orsay, France
[i]Oxford University, UK
[j]Lund University, Sweden
[k]MPI Physics, Munich, Germany
[l]CEA, Saclay, France
[m]SLAC and Stanford University, California, USA
[n]LLR, Palaiseau, France
[o]IST, Lisbon, Portugal
[p]UCL, London, United Kingdom
[q]LBNL, Berkeley, California, USA
[r]Tsinghua University, Beijing, China
[s]UCLA, Los Angeles, California, USA

4.1 Executive Summary

Novel accelerators have demonstrated acceleration of electrons and positrons with very high accelerating gradients of 1 to >100 GeV/m. This is about 10 to 1000 times higher than achieved in RF accelerators, and as such they have the potential to overcome their limitations. They have produced multi-GeV bunches with single parameters approaching those suitable for a linear collider. A significant reduction in size and, perhaps, cost of future accelerators can therefore in principle be envisaged.

Based on the various R&D achievements, the field has reached the stage of setting up first user facilities for photon and material science in the European research landscape. The many national and regional activities will continue through the end of the 2020s with a strong R&D and construction program, aiming at low energy research infrastructures, for example to drive a free electron laser (FEL) or ultrafast electron diffraction (UED). Various important milestones have been and will be achieved in internationally leading programs at CERN, CLARA, CNRS, DESY, various centres and institutes in

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[*] ralph.assmann@desy.de

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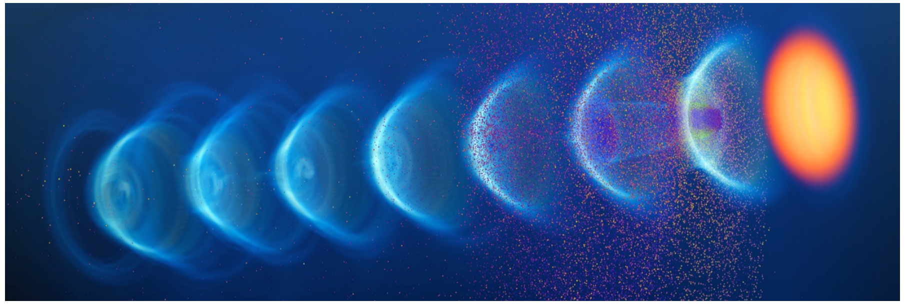
83

Conclusion

Advanced Accelerator Physics

- **Particle accelerators** have been used extensively by physics for amazing discoveries and insights into the laws of our universe.
- We are **still developing the metallic RF technology, super-conducting magnets and many other technologies further**, opening new possibilities for colliders.
- **Plasma accelerators** open the horizon to transformative steps with several orders of magnitude to be gained.
- **EuPRAXIA project** for plasma FEL etc as realistic stepping stone to particle physics machines. Selected for ESFRI roadmap update.
- Encouraging R&D, new ideas and use of unique test facilities will bring **significant progress in very high gradient approaches**.
- Present roadmaps indicate that we will need a clear, stable strategy and long-term R&D investments before the **new concepts will eventually materialize as particle physics colliders** (2050`s?).
- RF accelerators took 80 years (and Bruno Touschek`s ideas and inventions) to arrive at the LHC masterpiece!



2020 UPDATE OF THE EUROPEAN STRATEGY FOR PARTICLE PHYSICS

by the European Strategy Group

European Strategy Update

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

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Special Topics

EuPRAXIA Conceptual Design Report

Ralph Assmann and Maria Weikum (Eds.)

edp sciences Springer

Thank you for your attention