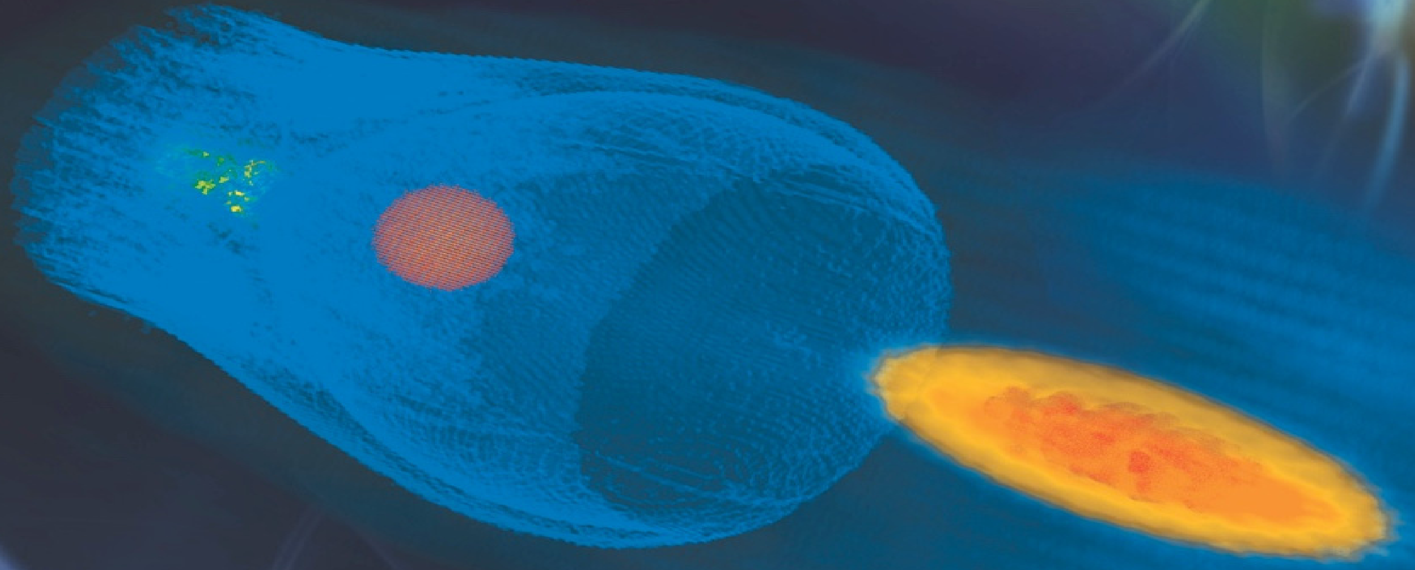
From Dreams to Reality

Prospects for Applying Advanced Accelerator Technologies to Next Generation Scientific User Facilities

Massimo.Ferrario@lnf.infn.it



EuPRAXIA

IPAC 2019, Melbourne (Australia), May 20, 2019

INFN
Istituto Nazionale di Fisica Nucleare

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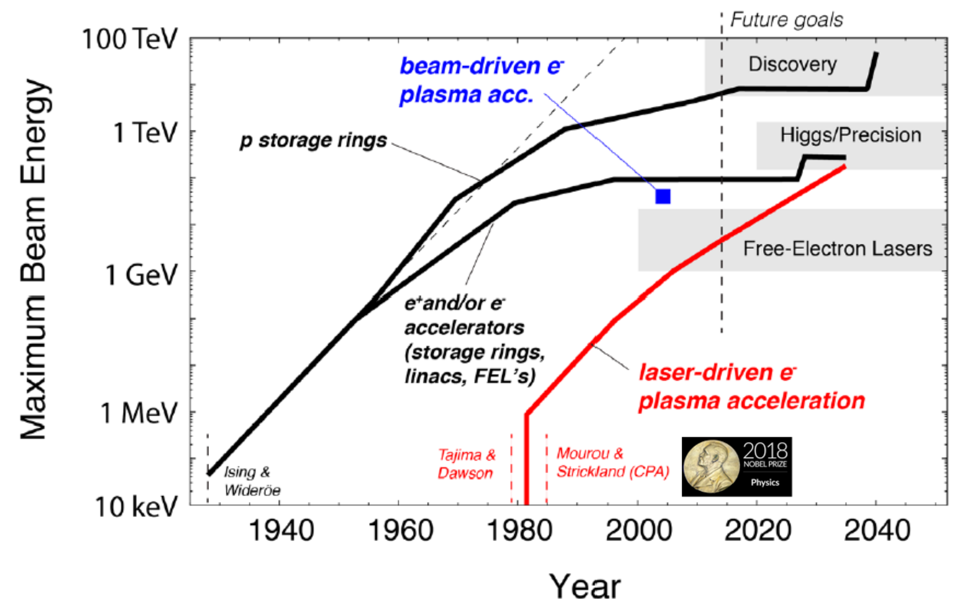

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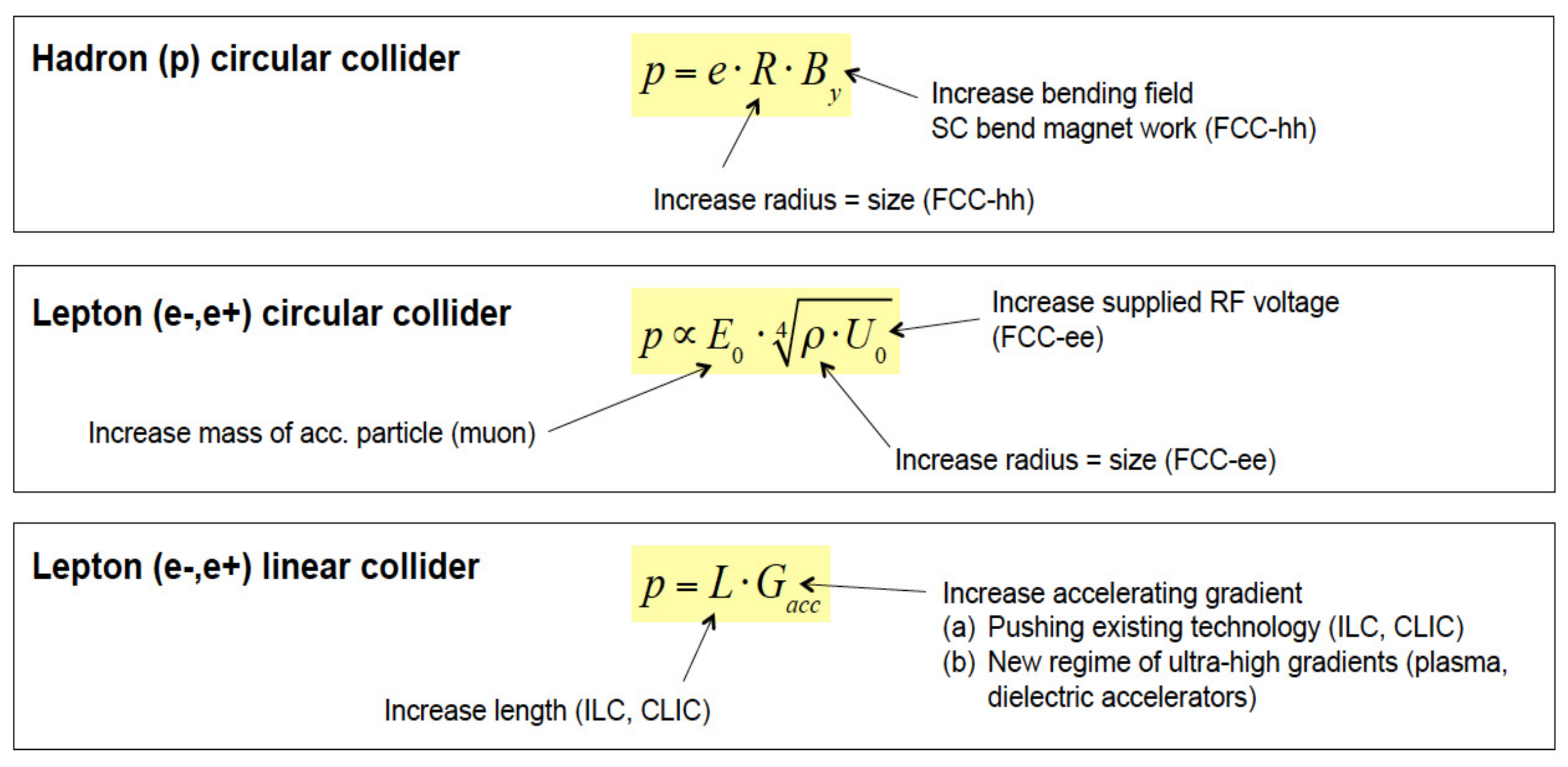
Options towards higher energies



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)

Lepton (e-,e+) linear collider

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

Increase accelerating gradient
(a) Pushing existing technology (ILC, CLIC)
(b) New regime of ultra-high gradients (plasma, dielectric accelerators)

Increase length (ILC, CLIC)

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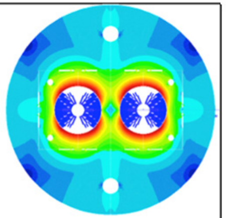

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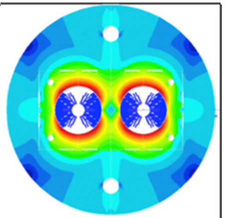

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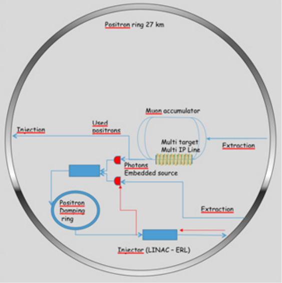

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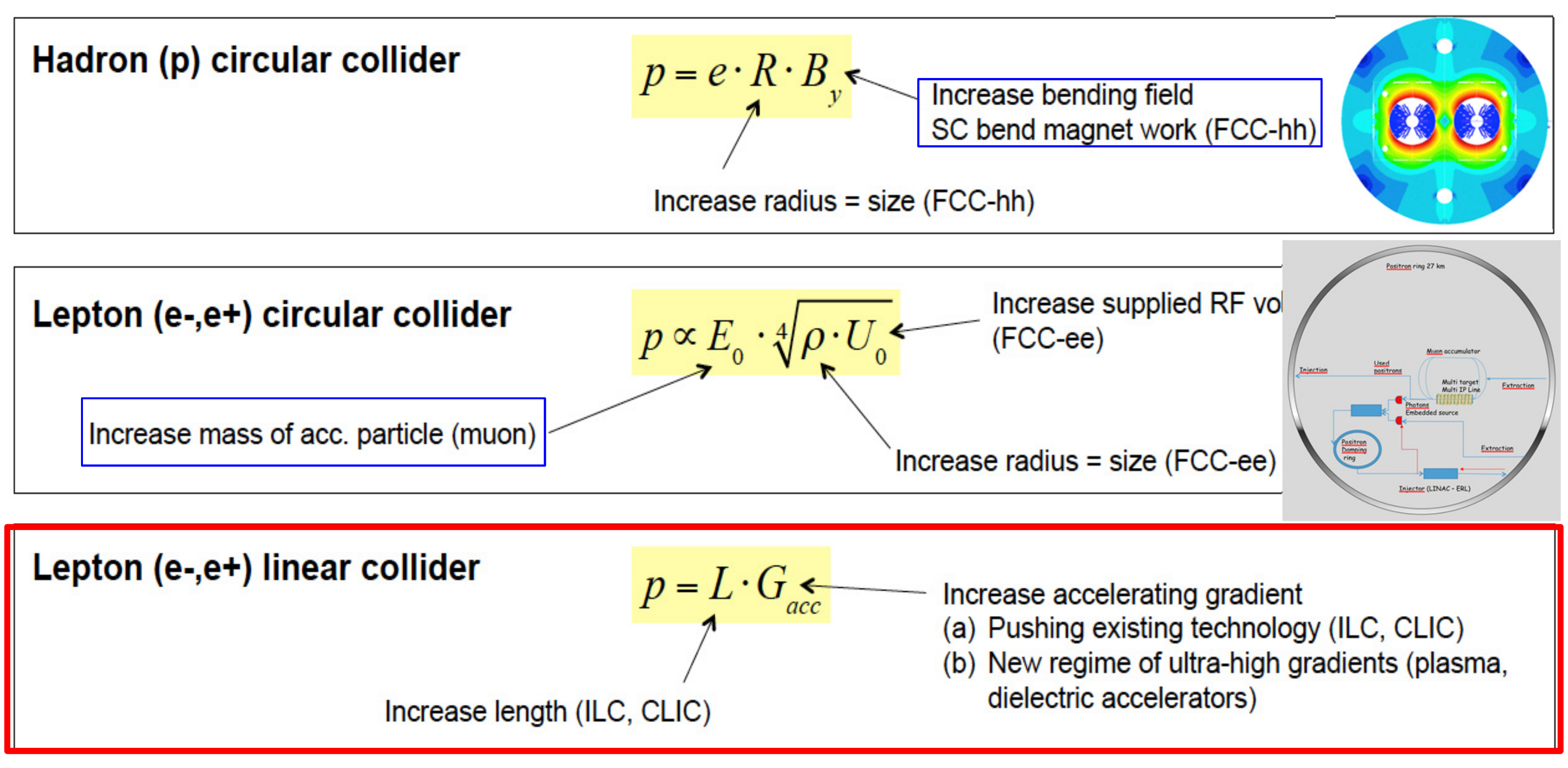

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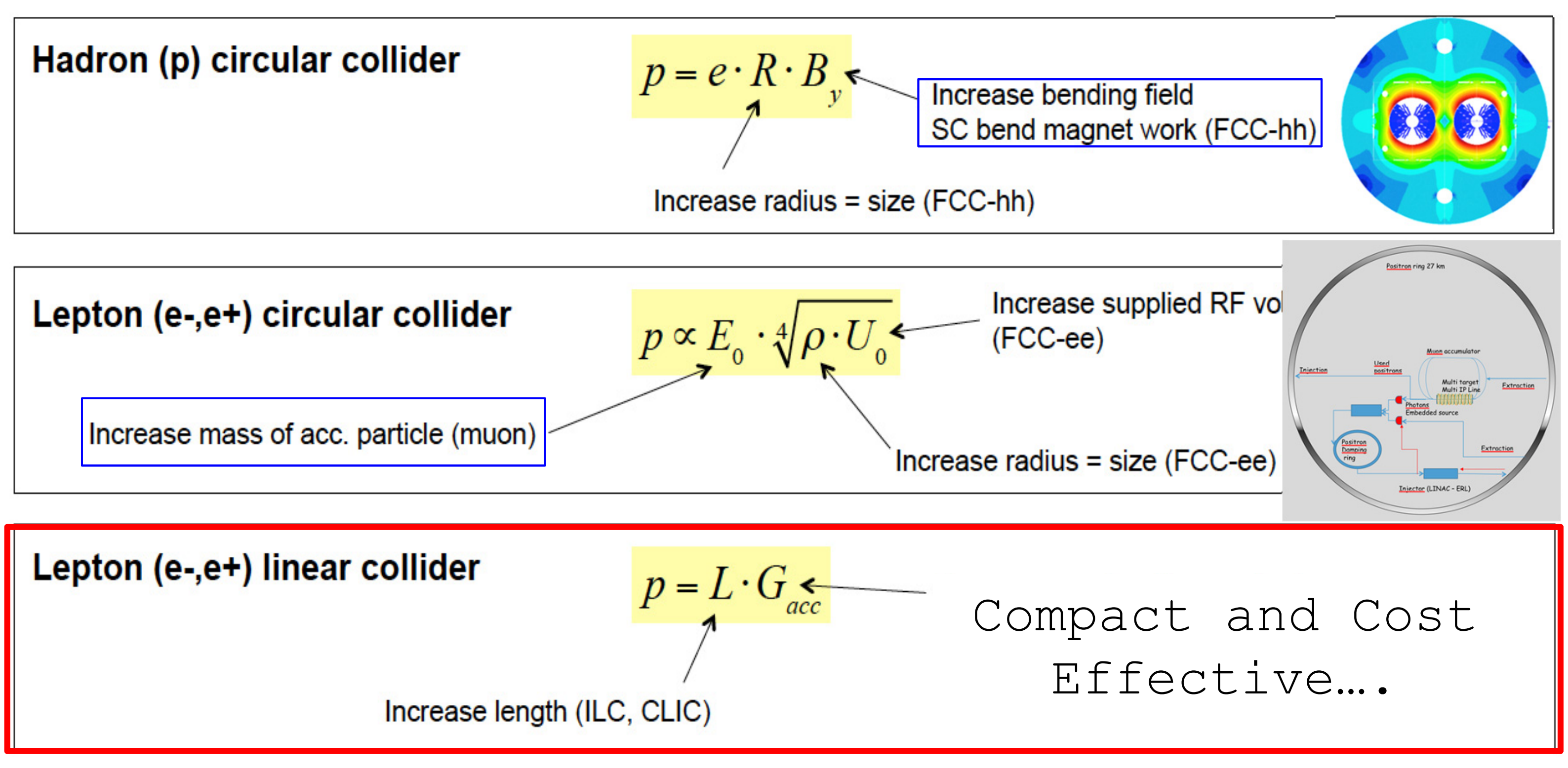

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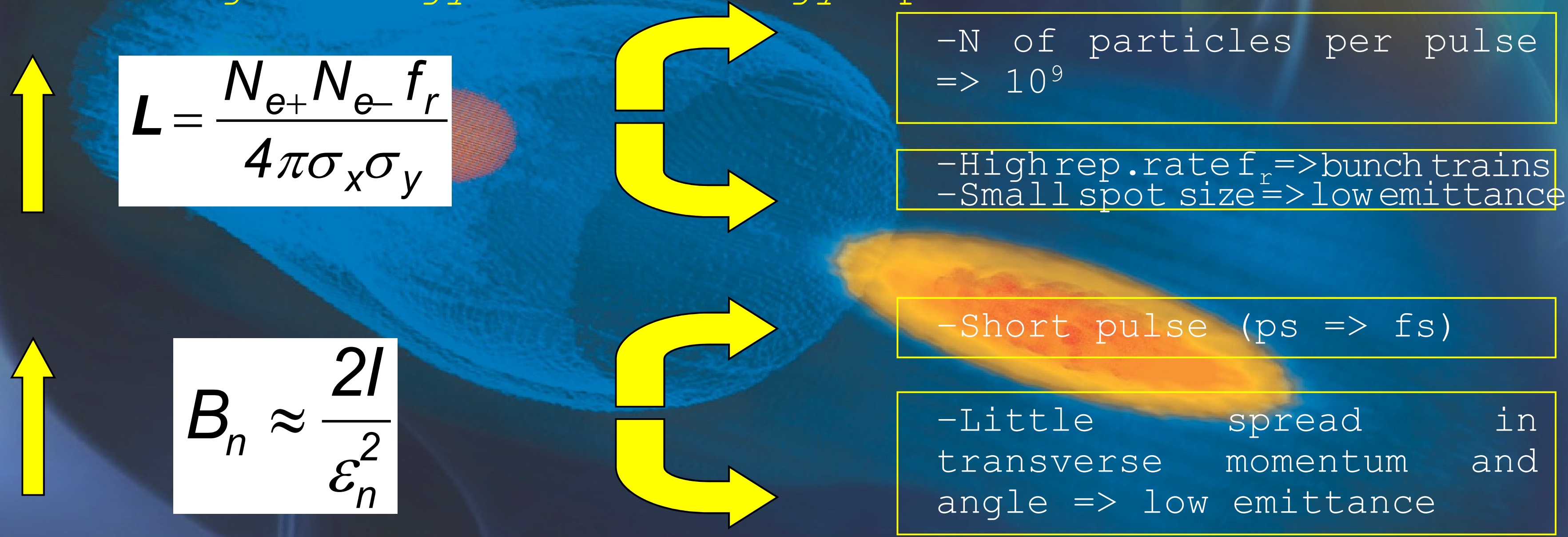
Compact and Cost Effective….

Beam Quality Requirements

Future accelerators will require also high quality beams :

==> High Luminosity & High Brightness,

==> High Energy & Low Energy Spread



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

-N of particles per pulse => 10^9

-High rep. rate f_r => bunch trains
-Small spot size => low emittance

$$B_n \approx \frac{2I}{\varepsilon_n^2}$$

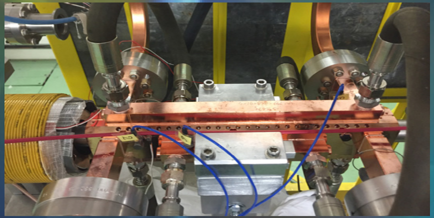
-Short pulse (ps => fs)

-Little spread in transverse momentum and angle => low emittance

High Gradient Options

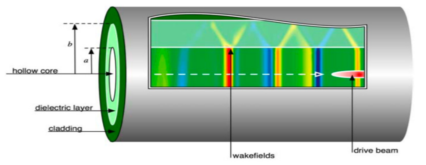
Metallic accelerating structures =>

100 MV/m < E_{acc}< 1 GV/m



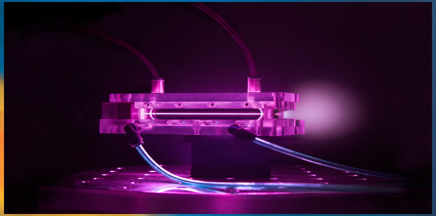
Dielectrict structures, laser or particle driven =>

E_{acc} < 10 GV/m



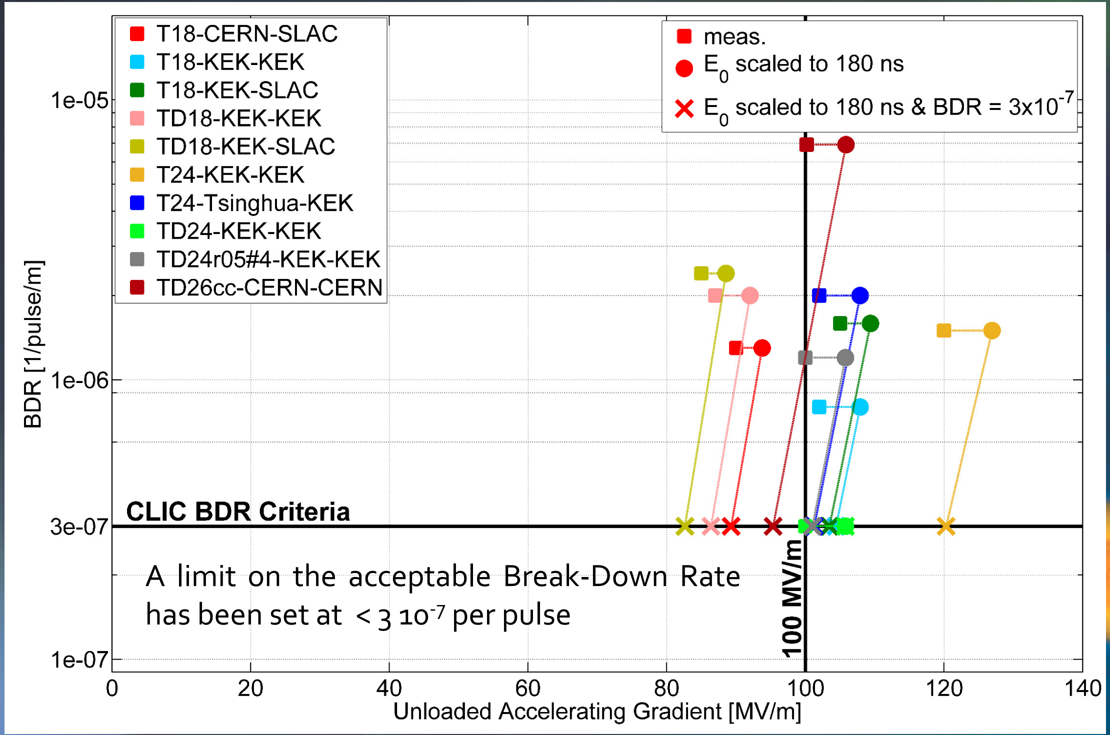
Plasma accelerator, laser or particle driven =>

E_{acc} < 100 GV/m

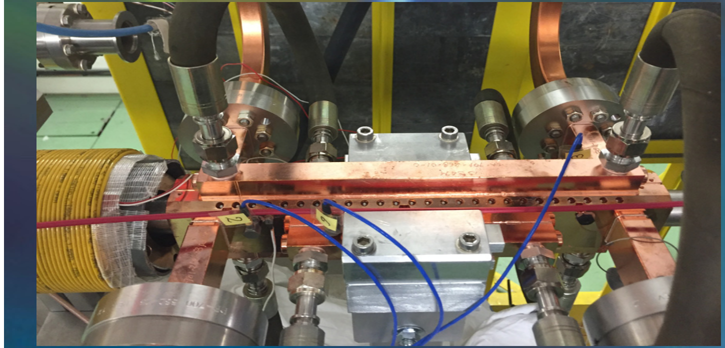


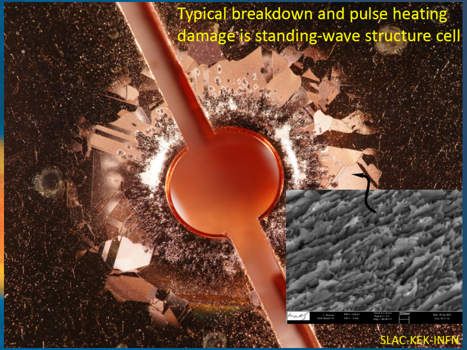
Related Issues: Power Sources and Efficiency, Stability, Reliability, Staging, Synchronization, Rep. Rate and short (fs) bunches with small (μm) spot to match high gradients

X-band RF structures – State of the Art



A limit on the acceptable Break-Down Rate has been set at $< 3\ 10^{-7}$ per pulse





Typical breakdown and pulse heating damage is standing-wave structure cell

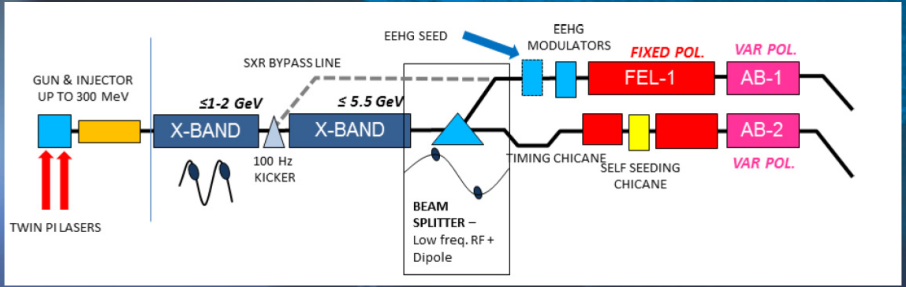
SLAC-KEK-INFN

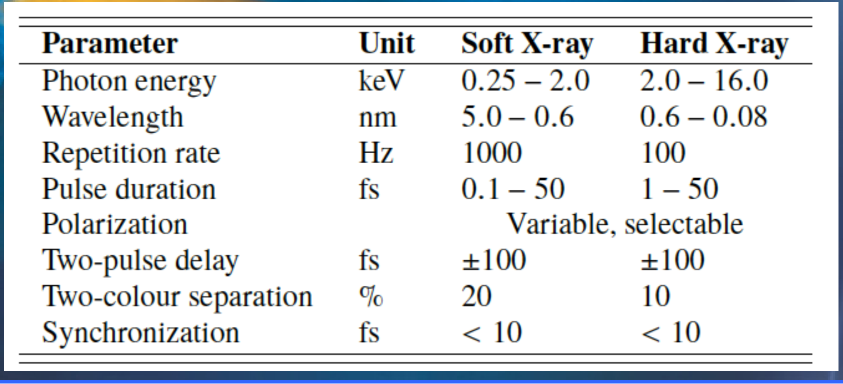
- Kilpatrick, W. D., Rev. Sci. Inst. 28, 824 (1957).
- *A. Grudiev et al, PRST-AB 12, 102001 (2009)*
- S. V. Dolgashev, et al. Appl. Phys. Lett. 97, 171501 2010.

XLS - Compact Light H2020-Design Study

Coord. By G. D’Auria (ST)

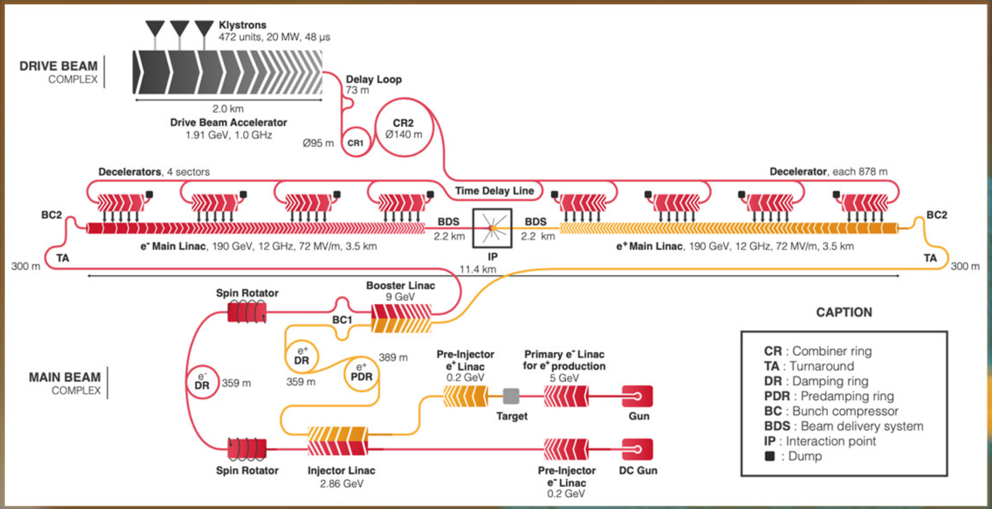
The key objective is to demonstrate through a Conceptual Design, the feasibility of a compact and cost effective FEL facility driven by X-band RF technology eventually up to kHz repetition rate.

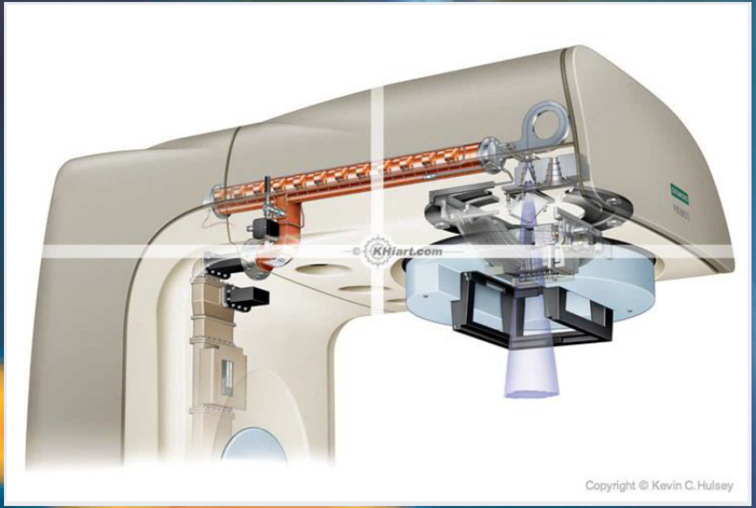




Parameter	Unit	Soft X-ray	Hard X-ray
Photon energy	keV	0.25 – 2.0	2.0 – 16.0
Wavelength	nm	5.0 – 0.6	0.6 – 0.08
Repetition rate	Hz	1000	100
Pulse duration	fs	0.1 – 50	1 – 50
Polarization		Variable, selectable	
Two-pulse delay	fs	±100	±100
Two-colour separation	%	20	10
Synchronization	fs	< 10	< 10

X-band from High Energy Physics to Industrial and Medical Applications





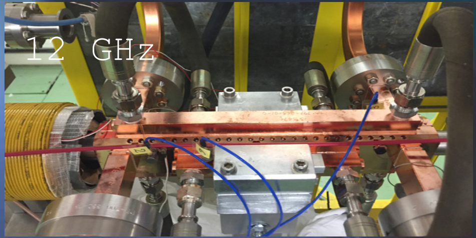
CLIC layout and power generation
Towards the TeV energy frontier

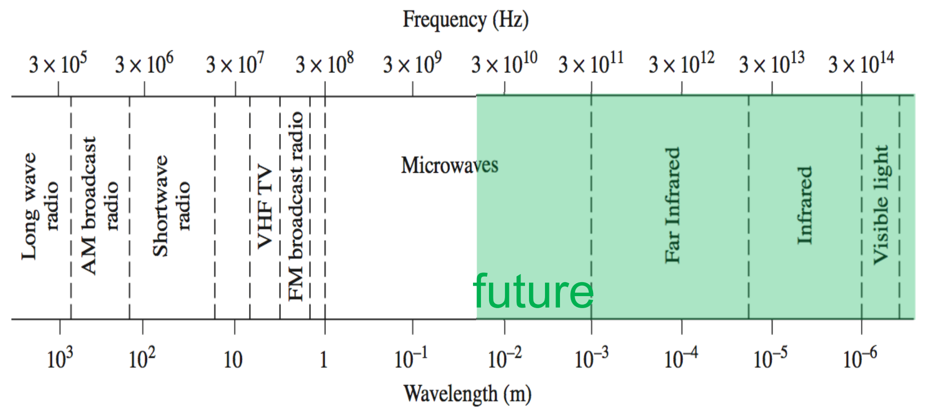
Radiology, Security, and X-ray analysis will benefit of cost and size reduction

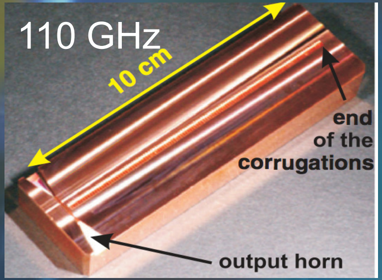
The E.M. Spectrum of Accelerating Structures

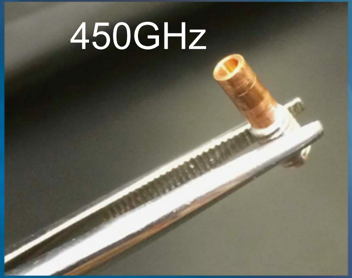
Max accelerating field: $\tau_{rf}^{-1/6}$

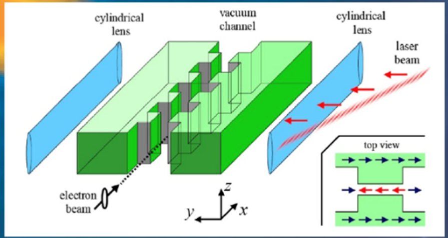
Lower stored energy: f^{-3}





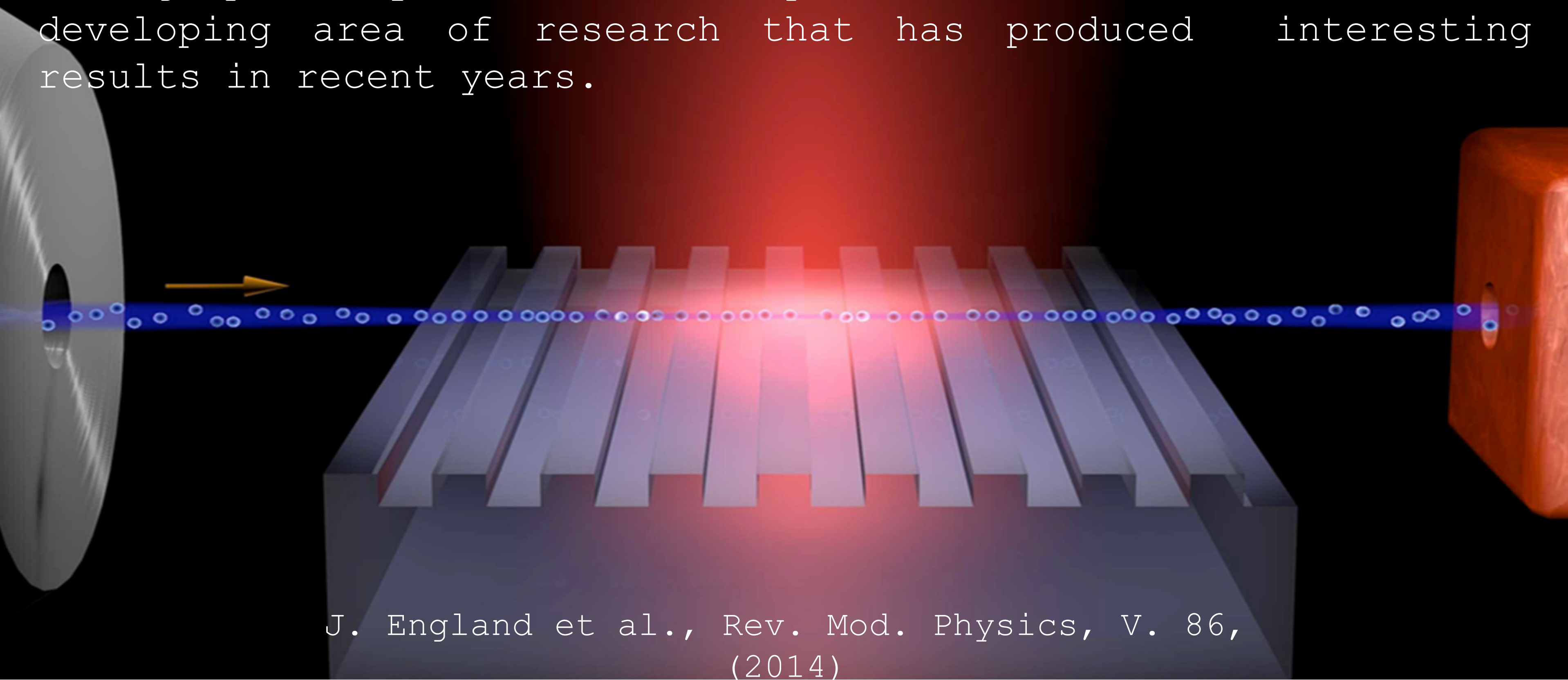






Dielectric Structures

The use of infrared lasers to power optical-scale lithographically fabricated particle accelerators is a developing area of research that has produced interesting results in recent years.



J. England et al., Rev. Mod. Physics, V. 86, (2014)

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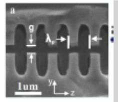
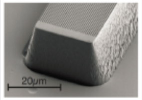
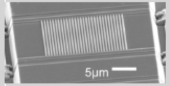
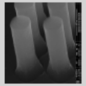
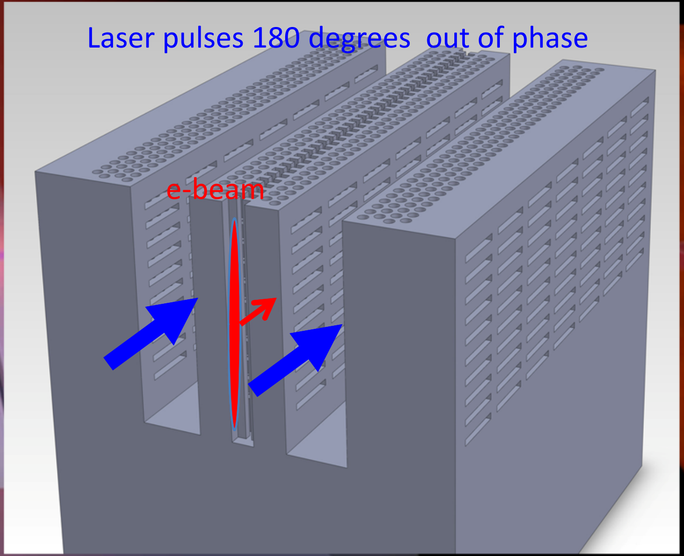
				
Electron Energy	8 MeV	30 keV	96.3 keV	86.5keV
Relativistic β	0.998	0.33	0.54	0.52
Laser Energy	150 uJ	160 nJ	5.2 nJ	3.0 nJ
Pulse Length	40 fs	110 fs	130 fs	130 fs
Interaction Length	~20 um	11 um	5.6 um	5.6 um
Peak Laser Field	8 GV/m	2.85 GV/m	1.65 GV/m	~1.1 GV/m
Max Energy Gain	**30 keV**	**0.275 keV**	**1.22 keV**	**2.05 keV**
Max Acc Gradient	**~1.5 GV/m***	**25 MeV/m**	**220 MeV/m**	**370 MeV/m**
G_{max}/E_p	~0.18	~0.01	~0.13	~0.4

Photonic band gap



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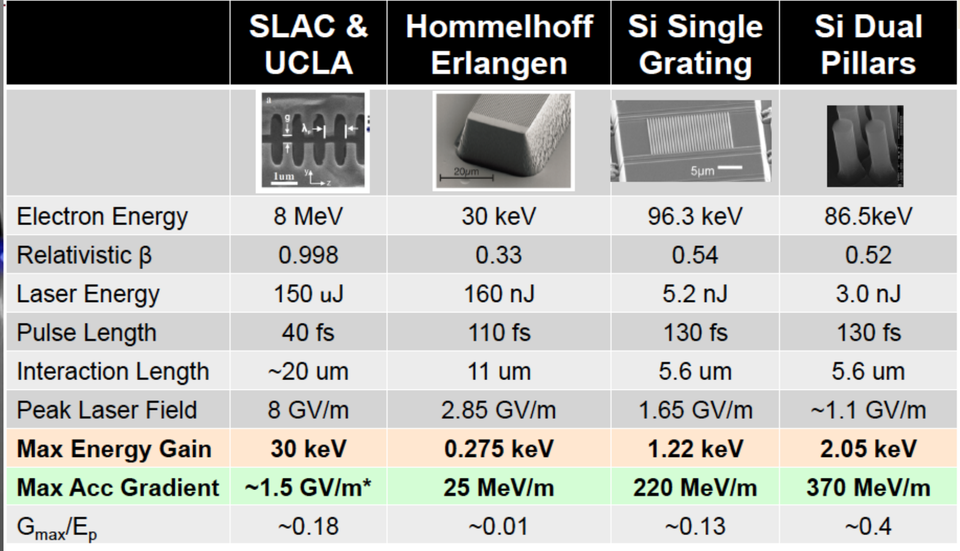

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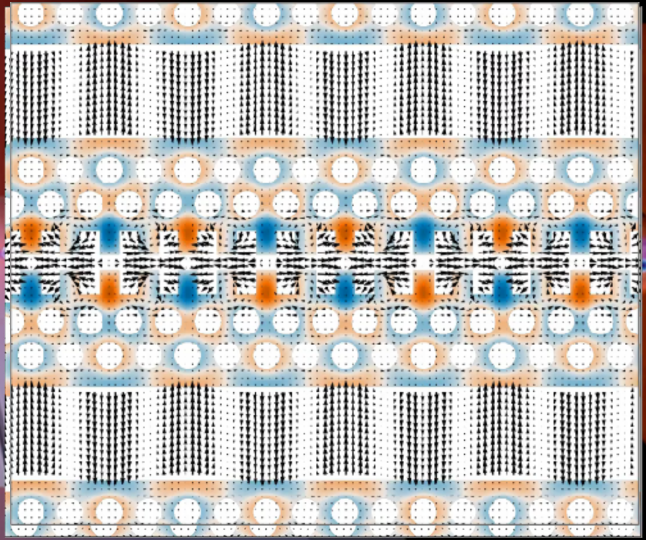

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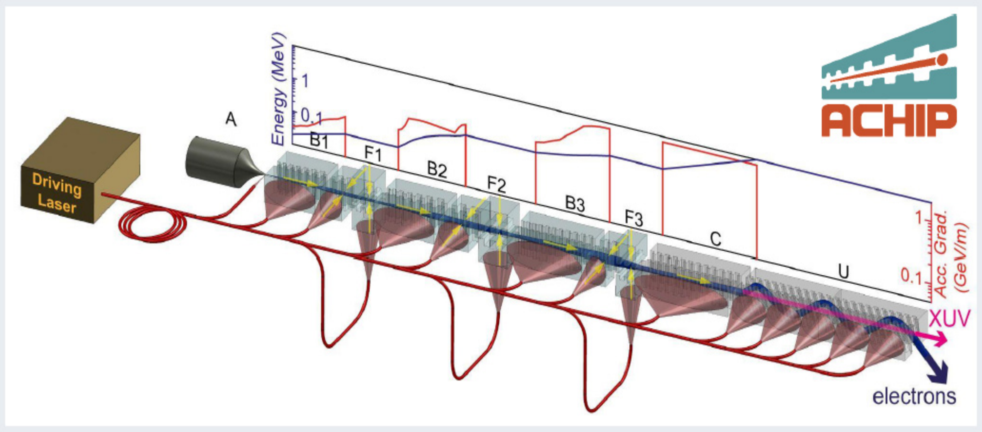
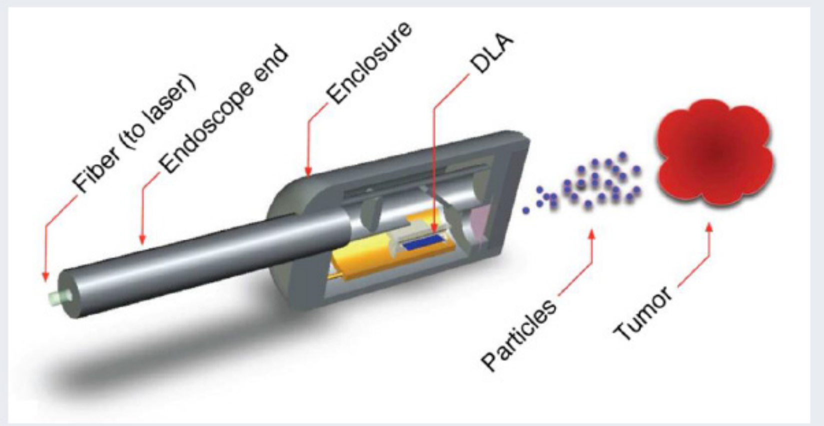
Dielectric Structures

A combination of DLA modules and optical undulator allows dreaming for a compact table top FEL



DLA module can be built onto the end of a fiber-optic catheter and attached to an endoscope, allowing to deliver controlled, high energy radiation directly to organs, tumors, or blood vessels within the body.

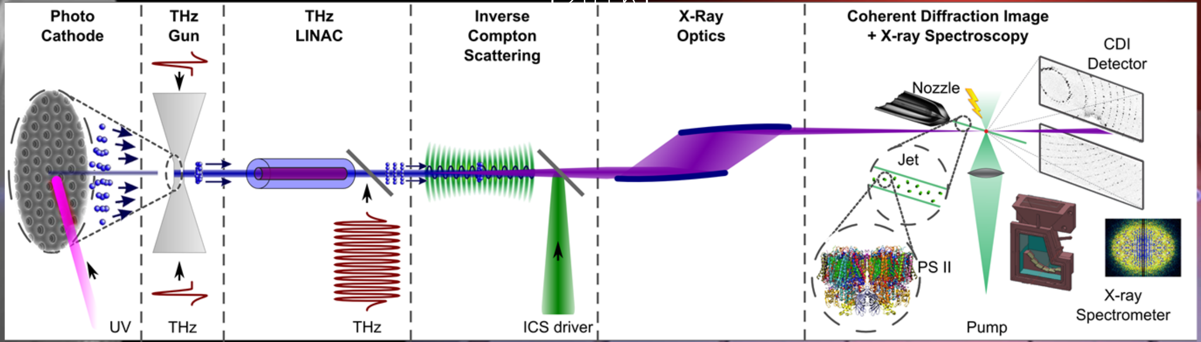


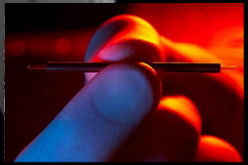
Electrons with 1-3MeV have a range of about a centimeter, allowing for irradiation volumes to be tightly controlled

Dielectric Structures

Attoseconds X-ray Science Imaging and

F.X. Kärtner et al., NIM A 829, 24 (2016)





All laser driven => intrinsic attosecond synchr.,
1 Joule, 1 kHz Cryogenic Yb:YAG Laser
Laser-based THz generation
THz Linac, Optical undulator

E. Nanni et al., Nat. Comm. 6, 8486 (2015)

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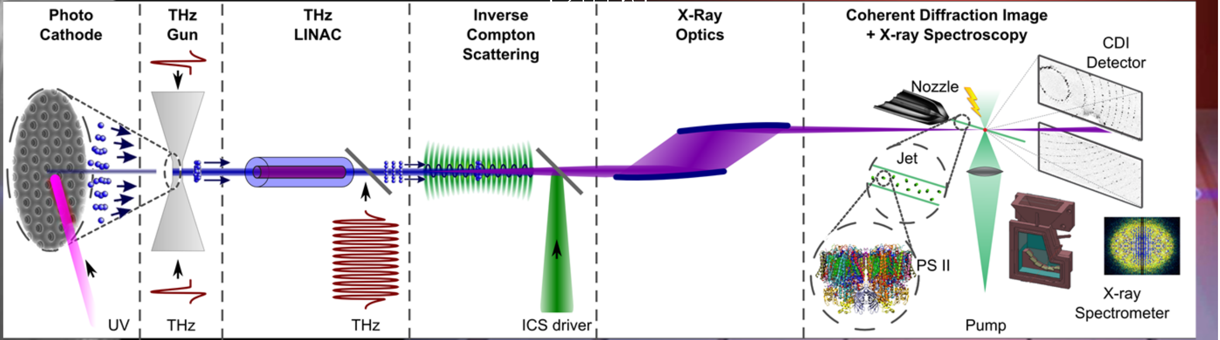

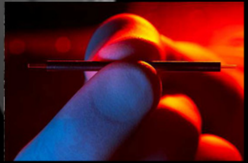

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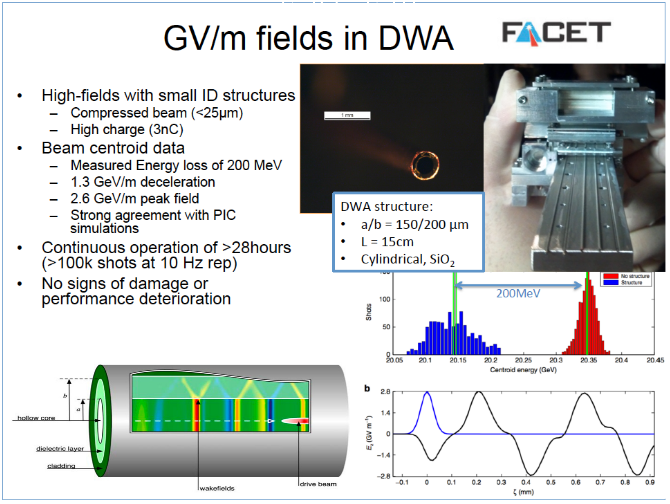
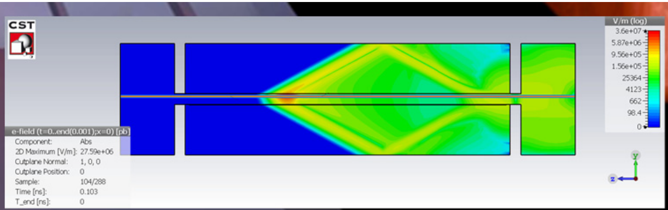
Beam Driven exp. at FACET



GV/m fields in DWA

- High-fields with small ID structures
  - Compressed beam (<25μm)
  - High charge (3nC)
- Beam centroid data
  - Measured Energy loss of 200 MeV
  - 1.3 GeV/m deceleration
  - 2.6 GeV/m peak field
  - Strong agreement with PIC simulations
- Continuous operation of >28hours (>100k shots at 10 Hz rep)
- No signs of damage or performance deterioration

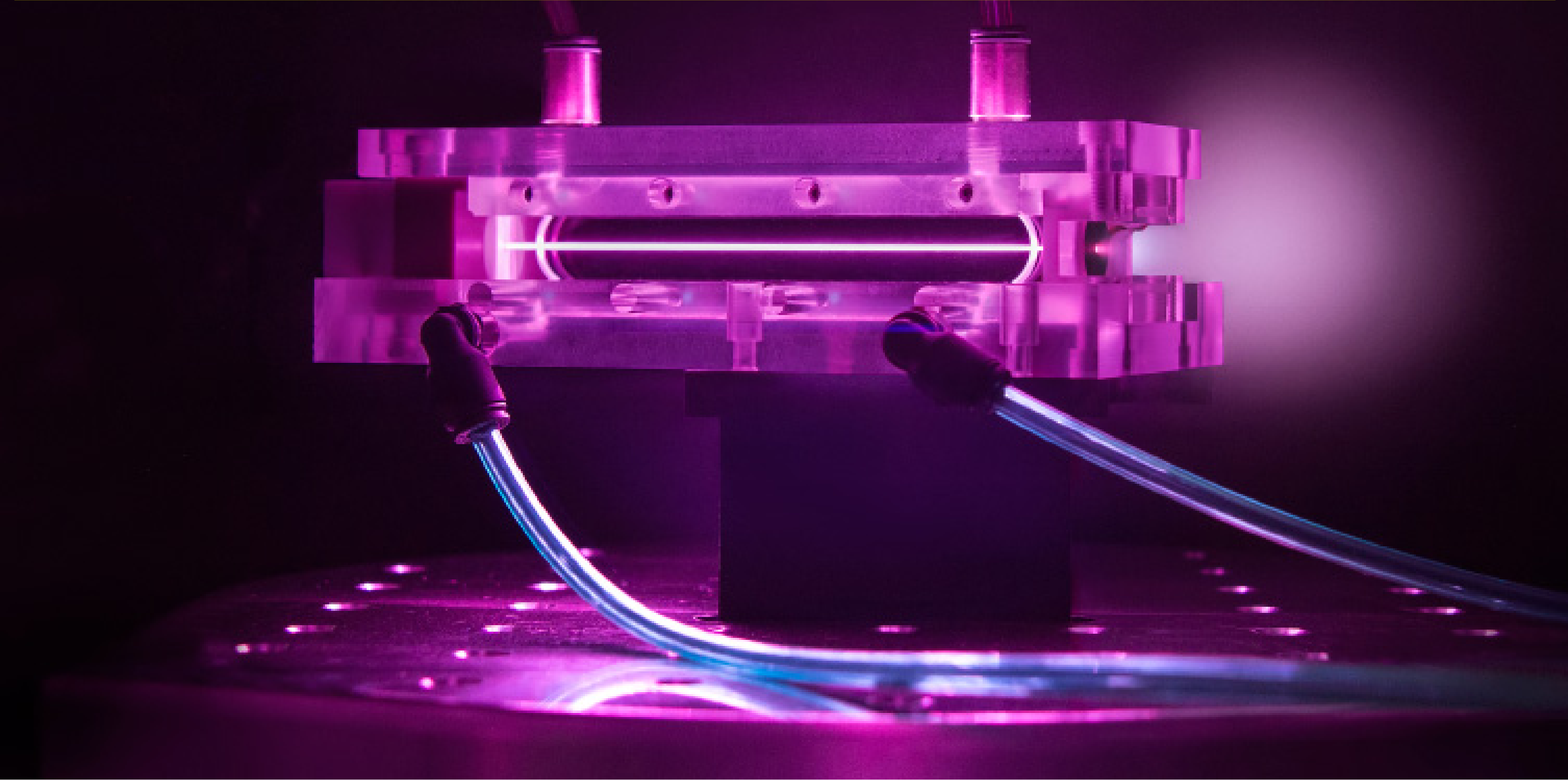
DWA structure:
- a/b = 150/200 μm
- L = 15cm
- Cylindrical, SiO_2



e-field (t=0..end(0.001);x=0) [pb]

Component:	Abs
2D Maximum [V/m]:	27.59e+06
Cutplane Normal:	1, 0, 0
Cutplane Position:	0
Sample:	104/288
Time [ns]:	0.103
T_end [ns]:	0

Principle of plasma acceleration



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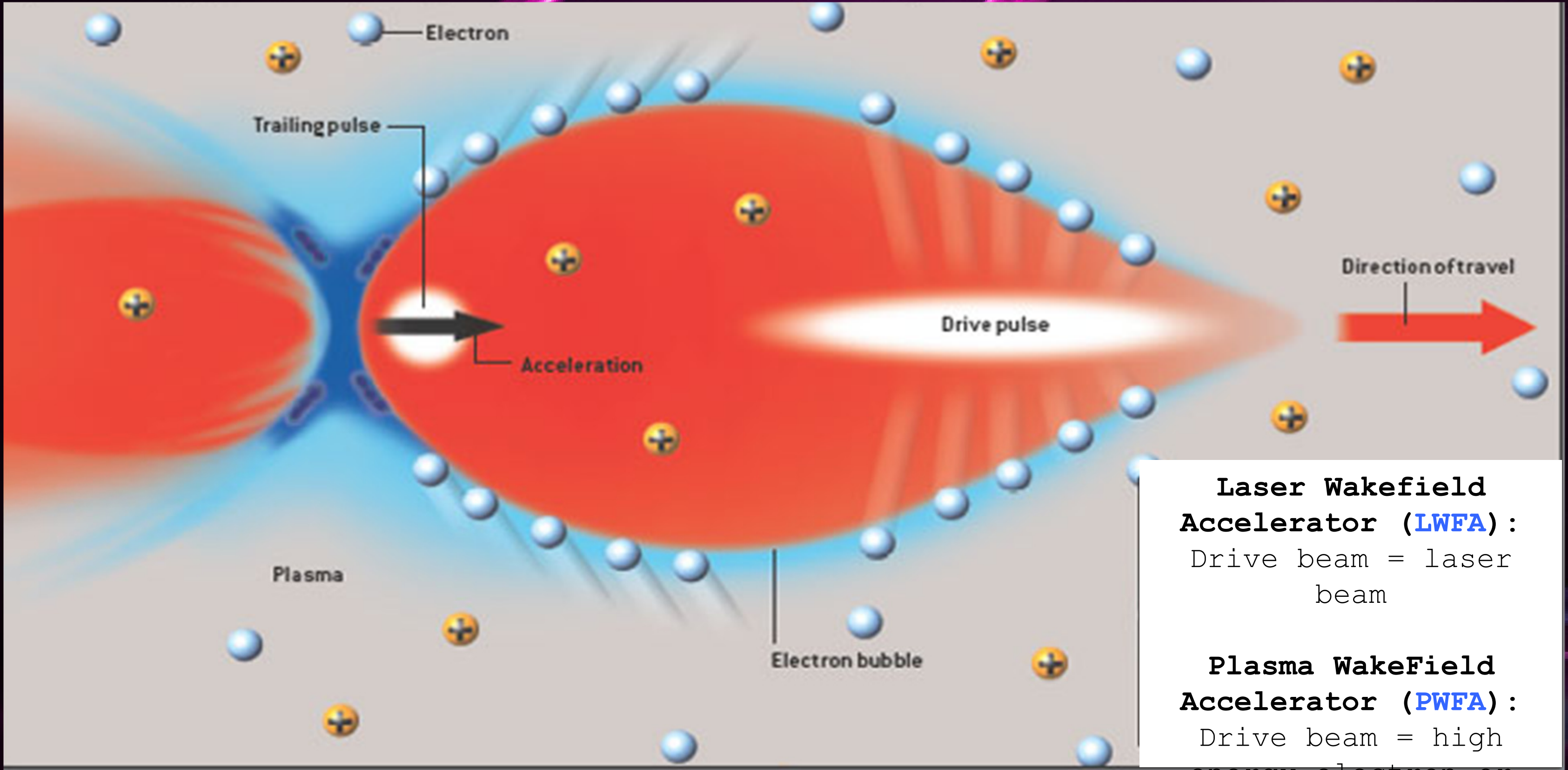
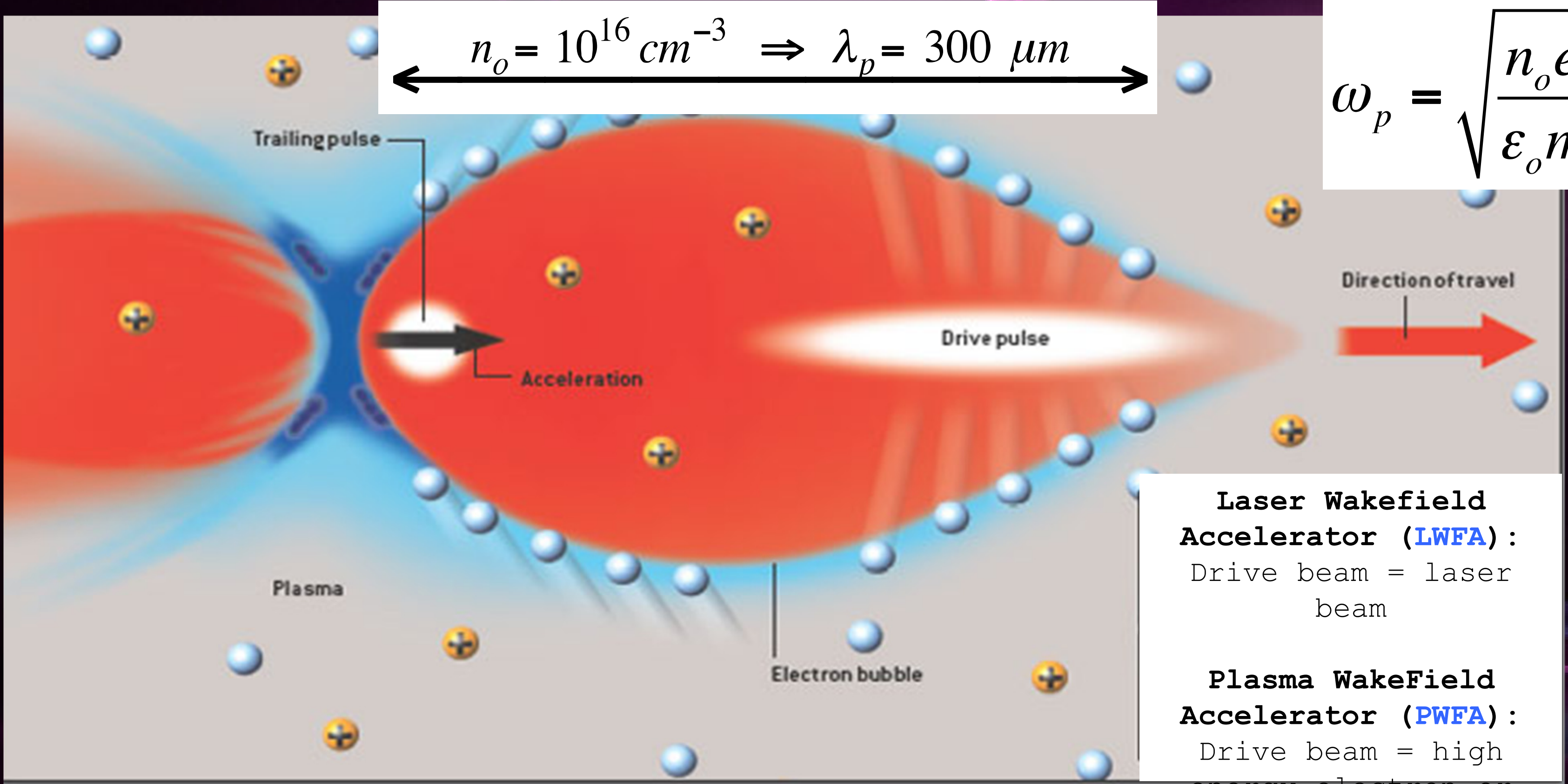


Laser Wakefield Accelerator (LWFA):
Drive beam = laser beam

Plasma WakeField Accelerator (PWFA):
Drive beam = high energy electron or proton beam

Principle of plasma acceleration



$$\xleftrightarrow{\quad n_o = 10^{16}\,cm^{-3} \Rightarrow \lambda_p = 300\ \mu m \quad}$$

$$\omega_p = \sqrt{\frac{n_o e^2}{\varepsilon_o m_e}}$$

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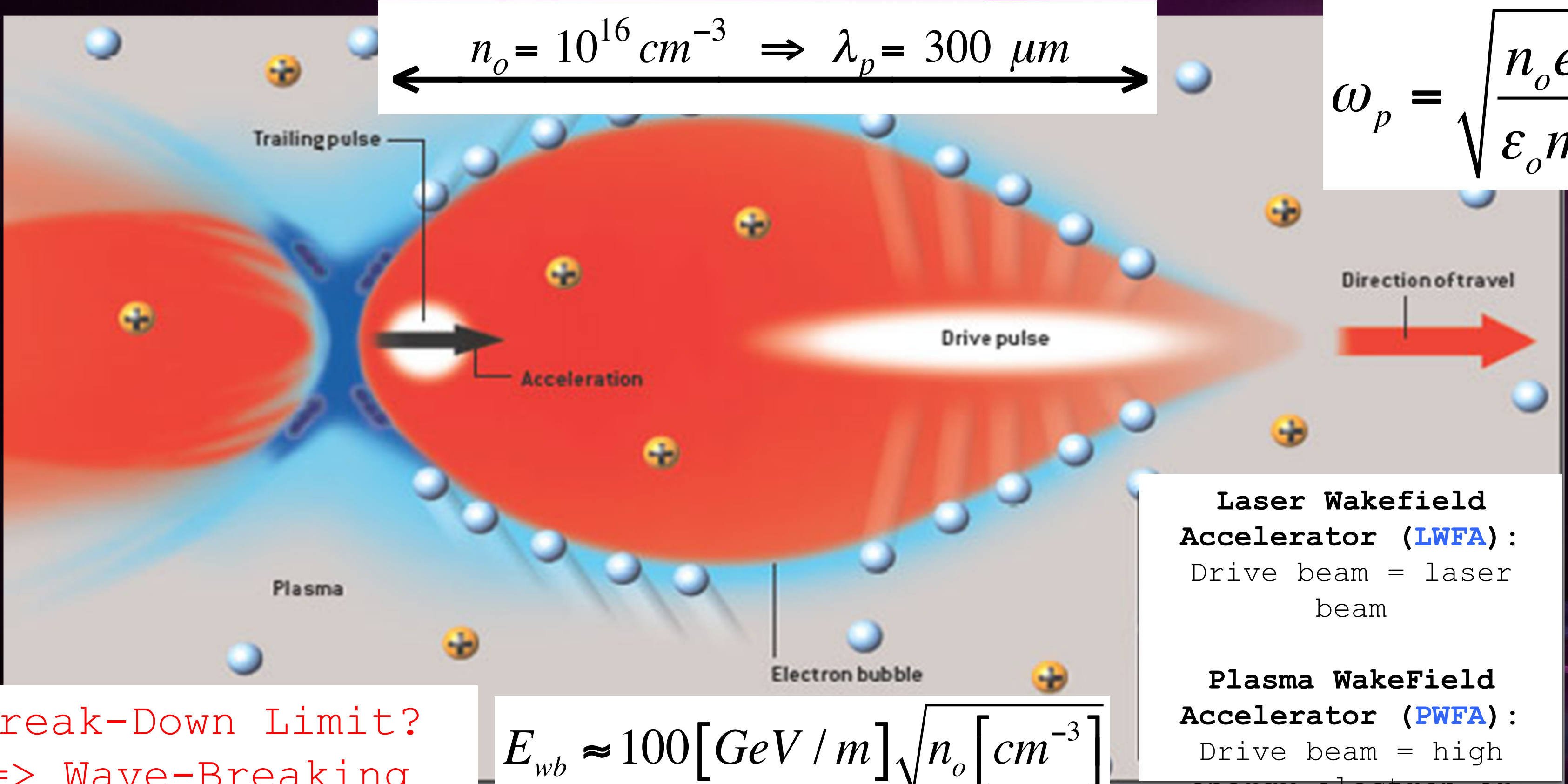

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Drive beam = laser beam

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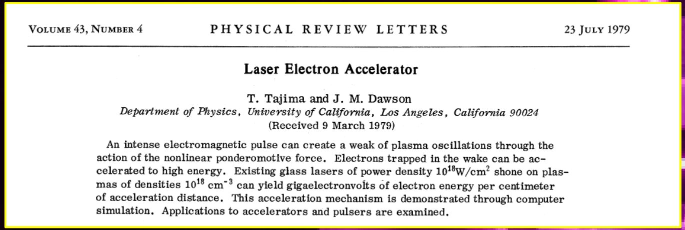
Break-Down Limit?
=> Wave-Breaking field:

$$E_{wb} \approx 100\left[GeV/m\right]\sqrt{n_o\left[cm^{-3}\right]}$$

Principle of plasma acceleration

Driven by Radiation Pressure



VOLUME 43, NUMBER 4 PHYSICAL REVIEW LETTERS 23 JULY 1979

Laser Electron Accelerator

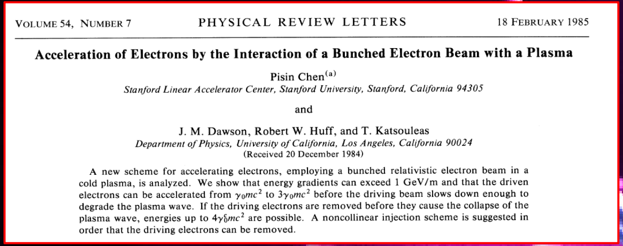
T. Tajima and J. M. Dawson
Department of Physics, University of California, Los Angeles, California 90024
(Received 9 March 1979)

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.

$$\left(\frac{\partial^2}{\partial t^2}+\omega_p^2\right)\frac{n}{n_o}=c^2\nabla^2\frac{a^2}{2}$$

$$a=\frac{eA}{mc^2}\propto\lambda J^{1/2}$$

Driven by Space Charge



VOLUME 54, NUMBER 7 PHYSICAL REVIEW LETTERS 18 FEBRUARY 1985

Acceleration of Electrons by the Interaction of a Bunched Electron Beam with a Plasma

Pisin Chen(a)
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

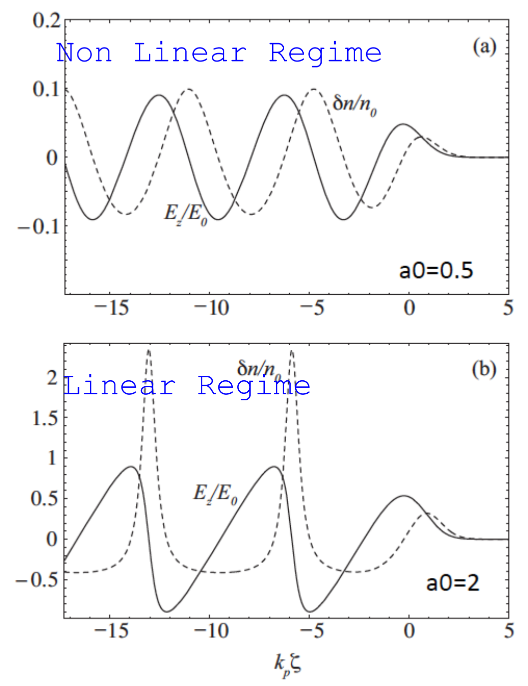
and

J. M. Dawson, Robert W. Huff, and T. Katsouleas
Department of Physics, University of California, Los Angeles, California 90024
(Received 20 December 1984)

A new scheme for accelerating electrons, employing a bunched relativistic electron beam in a cold plasma, is analyzed. We show that energy gradients can exceed 1 GeV/m and that the driven electrons can be accelerated from $\gamma_0 mc^2$ to $3\gamma_0 mc^2$ before the driving beam slows down enough to degrade the plasma wave. If the driving electrons are removed before they cause the collapse of the plasma wave, energies up to $4\gamma_0^2 mc^2$ are possible. A noncollinear injection scheme is suggested in order that the driving electrons can be removed.

$$\left(\frac{\partial^2}{\partial t^2}+\omega_p^2\right)\frac{n}{n_o}=-\omega_p^2\frac{n_{beam}}{n_o}$$

$$n_{beam}=\frac{N}{\sqrt{(2\pi)^3}\sigma_r^2\sigma_z}$$

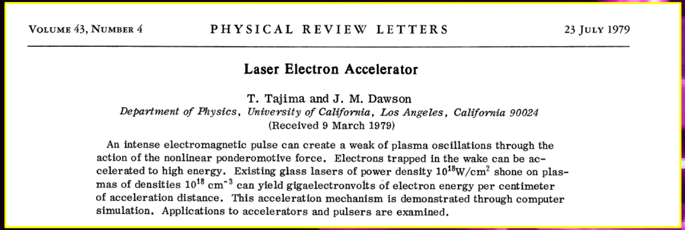


LWFA limitations: Diffraction, Dephasing, Depletion

PWFA limitations Head Erosion Hose

Principle of plasma acceleration

Driven by Radiation Pressure



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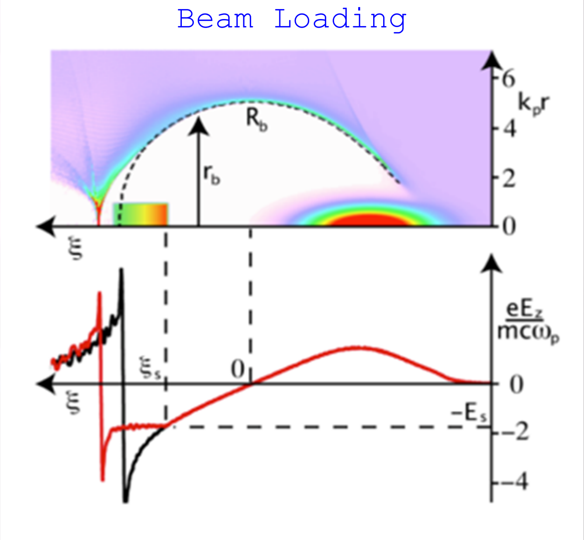
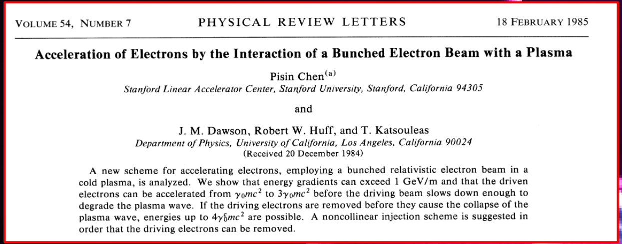


Driven by Space Charge



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LWFA limitations: Diffraction, Dephasing, Depletion

PWFA limitations: Head Erosion, Hose

World-wide effort

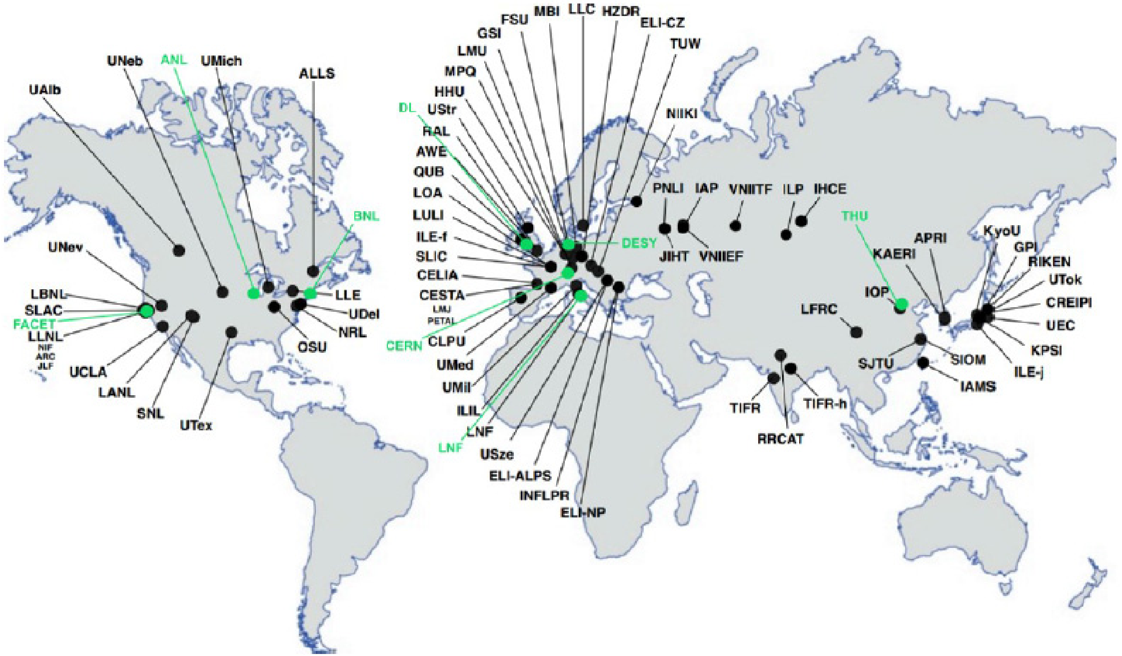


Figure 2: Non-exhaustive overview of laboratories working on (or with the capacity to work on) laser-driven (black) and particle beam-driven (green) plasma wakefield R&D. Based in part on the map of high-power laser laboratories produced by the International Committee on Ultra-high Intensity Lasers (ICUIL).[21]

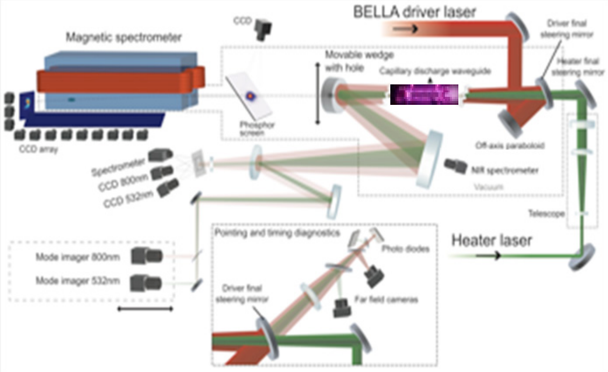
Courtesy B. Hiddings

BELLA, Berkeley Lab, US

Laser Driven Plasma Wakefield Acceleration Facility: Today: PW laser!

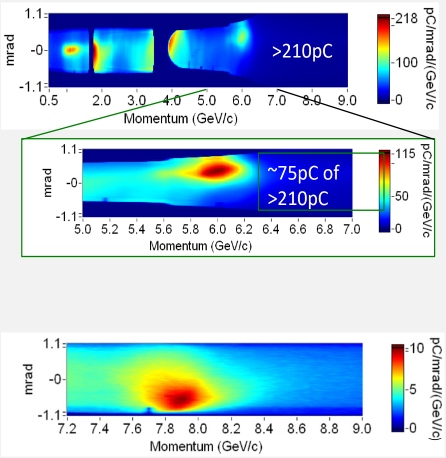
Petawatt laser guiding and electron beam **acceleration to 8 GeV** in a laser-heated capillary discharge waveguide

A.J.Gonsalves et al., Phys.Rev.Lett. ***122****, 084801 (2019)*



Laser heater added to capillary

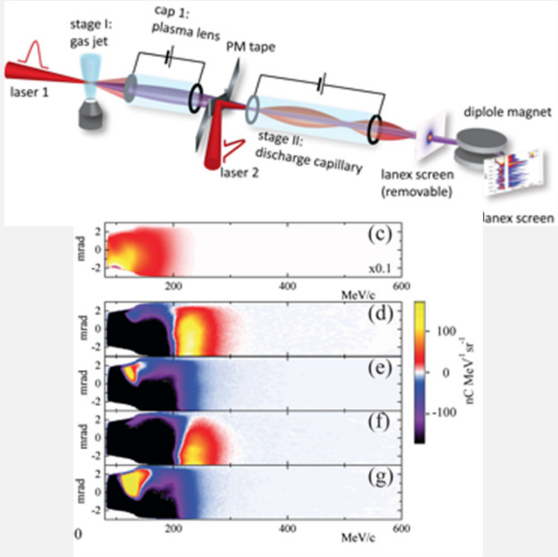
Electron spectra, up to 6- 8 GeV



→ path to 10 GeV with continued improvement of guiding in progress

Multistage coupling of independent laser-plasma accelerators

S. Steinke, Nature ***530****, 190 (2016)*



Staging demonstrated at 100MeVs level.

FACET, SLAC, US

Premier R&D facility for PWFA: Only facility capable of e$^+$ acceleration

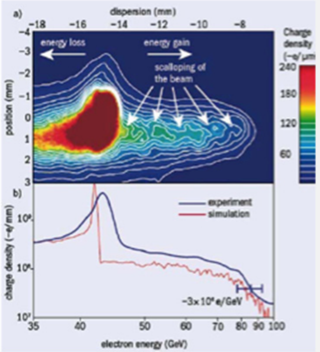
- **Timeline:**
  - Commissioning (2011)
  - Experimental program (2012-2016)
- **Key PWFA Milestones:**
  - ✓ Mono-energetic e$^-$ acceleration
  - ✓ High efficiency e$^-$ acceleration
  - ✓ First high-gradient e$^+$ PWFA
  - ✓ Demonstrate required emittance, energy spread

- Facility hosted more than 200 users, 25 experiments
- One high profile result a year
- Priorities balanced between focused plasma wakefield acceleration research and diverse user programs with ultra-high fields
- Unique opportunity to develop future leaders

Energy doubling of 42 GeV electrons in a metre-scale plasma wakefield accelerator

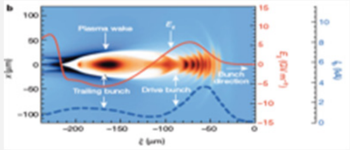
*I. Blumenfeld et al, Nature 455, p 741 (**2007**)*

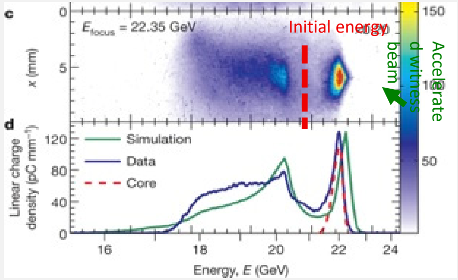
→ **gradient of 52 GV/m**



High-Efficiency acceleration of an electron beam in a plasmas wakefield accelerator, 2014

*M. Litos et al., doi, Nature, 6 Nov **2014**, 10.1038/nature 13882*





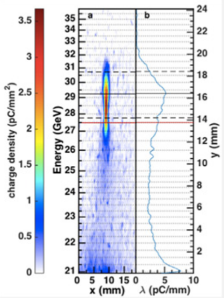
Initial energy

Accelerated witness beam

70 pC of charge accelerated, 2 GeV energy gain, 5 GeV/m gradient ➔ **Up to 30% transfer efficiency, ~2% energy spread**

9 GeV energy gain in a beam-driven plasma wakefield accelerator

*M Litos et al **2016** Plasma Phys. Control. Fusion 58 034017*



Positron Acceleration, FACET

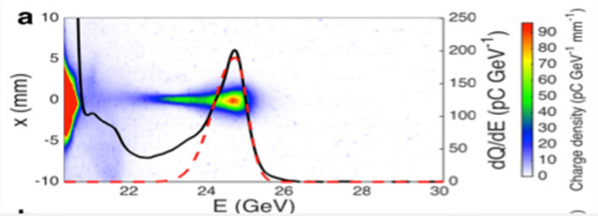
Positrons for high energy linear colliders: **high energy, high charge, low emittance**.

First demonstration of positron acceleration in plasma (FFTB)

*B.E. Blue et al., Phys. Rev. Lett. 90, 214801 (**2003**)*
M. J. Hogan et. al. Phys. Rev. Lett. 90 205002 (2003).

Energy gain of 5 GeV. Energy spread can be as low as 1.8% (r.m.s.).

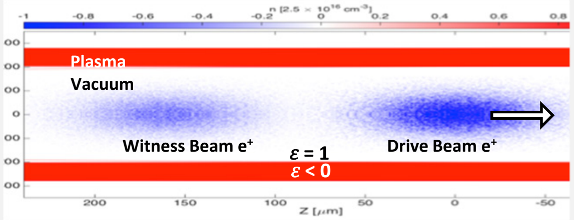
*S. Corde et al., Nature **524**, 442 (2015)*



High-density, compressed positron beam for non-linear PWFA experiments. Energy transfer from the front to the back part of the bunch.

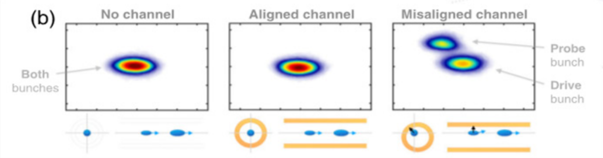
Two-bunch positron beam: First demonstration of controlled beam in positron-driven wake
S. Doche *et al.*, Nat. Sci. Rep. 7, 14180 (2017)

Hollow plasma channel: positron propagation, wake excitation, acceleration in 30 cm channel.
S. Gessner et. al. Nat. Comm. 7, 11785 (2016)



Measurement of **transverse wakefields in a hollow plasma** channel due to off-axis drive bunch propagation.

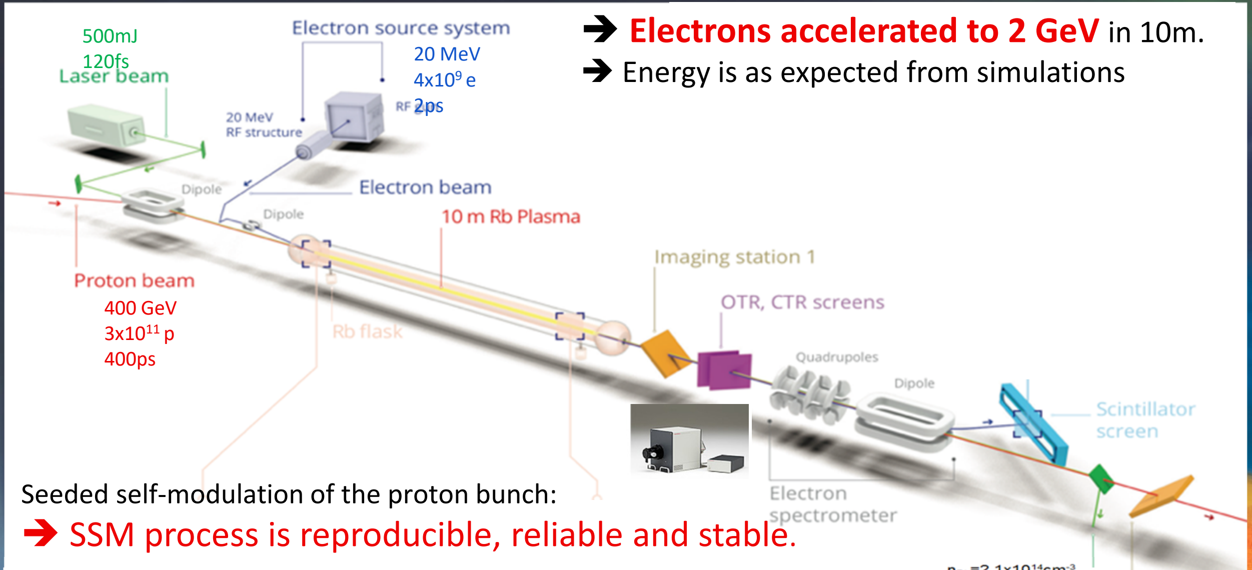
*C. A. Lindstrøm et. al. Phys. Rev. Lett. 120 124802 (**2018**).*



➔ Emittance blow-up is an issue! → Use hollow-channel, so no plasma on-axis, no complicated forces from plasma electrons streaming through the plasma → but then strong transverse wakefields when beams are misaligned.

AWAKE, CERN

AWAKE has demonstrated during Run 1 (2016-2018) that the seeded self-modulation is a reliable and robust process and that electrons can be accelerated with high gradients.

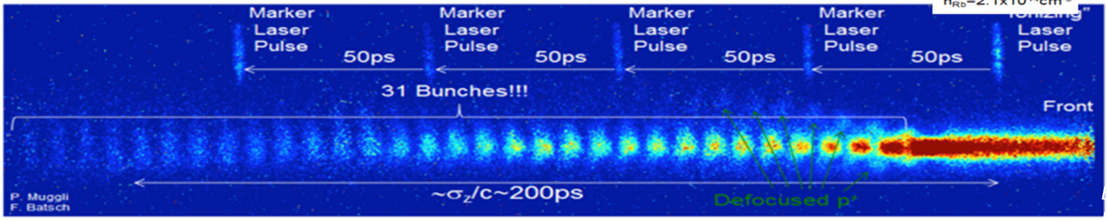


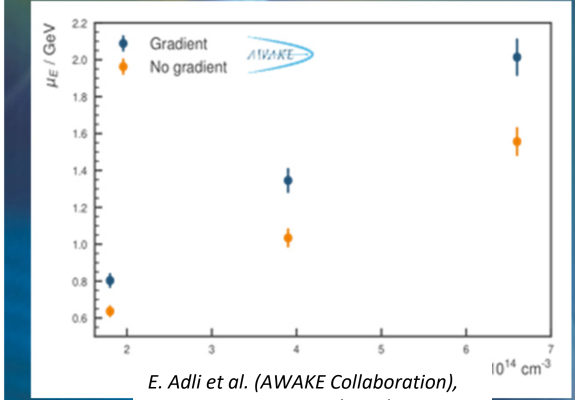
➔ **Electrons accelerated to 2 GeV** in 10m.

➔ Energy is as expected from simulations

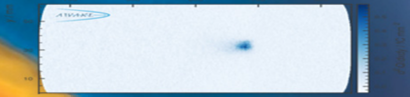
Seeded self-modulation of the proton bunch:

➔ SSM process is reproducible, reliable and stable.





E. Adli et al. (AWAKE Collaboration), ***Nature 561****, 363–367 (2018)*

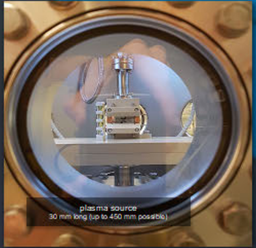


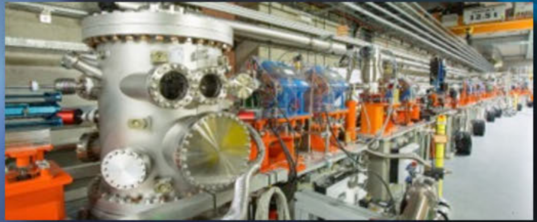
E. Adli et al. (AWAKE Collaboration), ***Phys. Rev. Lett. 122, 054802 (2019).***

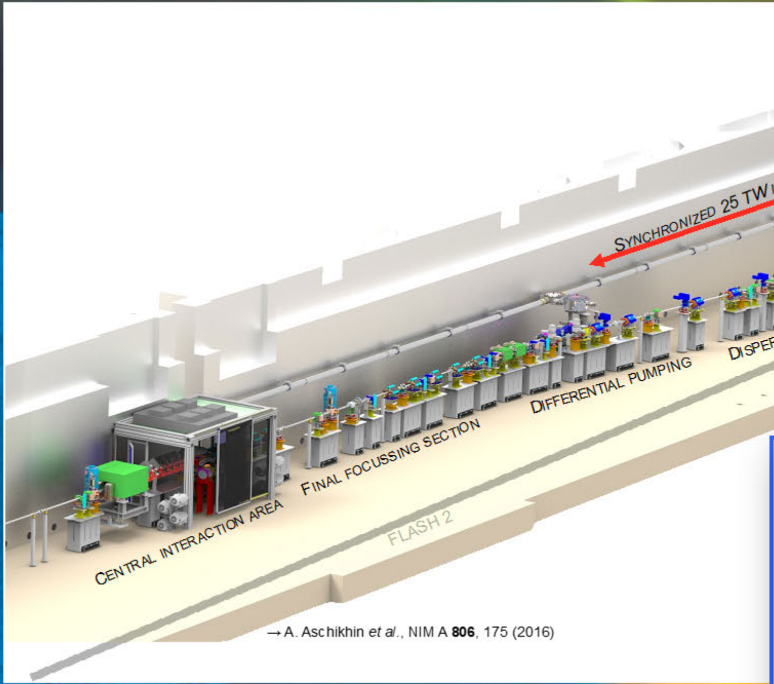
M. Turner et al. (AWAKE Collaboration) ***PRL, 122, 054801 (2019).***

FLASHForward>>, DESY

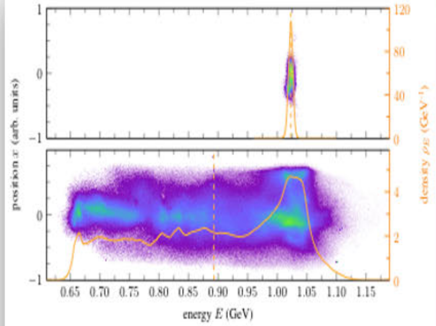
→ unique FLASH facility features for PWFA
- FEL-quality drive and witness beams
- up to 1 MHz repetition rate
- 3rd harmonic cavity for phase-space linearization → tailoring of beam current profile
- differentially pumped, windowless plasma sources
- *2019*: X-band deflector of 1 fs resolution post-plasma (collaboration with FALSH 2, SINBAD, CERN & PSI)
- *Future:* up to 800 bunches (~MHz spacing) at 10 Hz macro-pulse rate, few 10 kW average power.


plasma source
30 mm long (up to 450 mm possible)





→ A. Aschikhin *et al.*, NIM A **806**, 175 (2016)



- → (12.3 ± 1.7) GV/m wakefield generated in 30 mm plasma cell
- → 12.7% total energy loss to plasma wakefield

SPARCLAB, Frascati, Italy

SPARC_LAB is the test and training facility for EuPRAXIA@SPARC_LAB

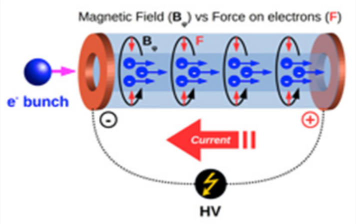
M. Ferrario et al., SPARC_LAB present and future, NIM B 309, (2013)

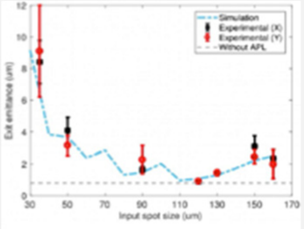
➔ Main challenges addressed in this facility: beam quality, beam transport

- 150 MeV drive/witness beam
- FEL experiments
- Resonant PWFA
- LWFA with 200 TW laser

Plasma Lens Experiments:

Acceleration of high brightness beams and transport to the final application, while preserving the high quality of the 6D phase space



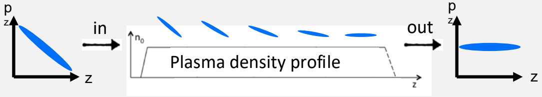


R. Pompili et al., PRL 121 (2018), 174801

BELLA, LBNL: *J. van Tilborg et al., PRL 115 (2015), 184802*
CLEAR, CERN: *C.A. Lindstrom et al., PRL 121 (2018), 194801*

Plasma dechirper:

Longitudinal phase-space manipulation with the wakefield induced in plasma by the beam itself.

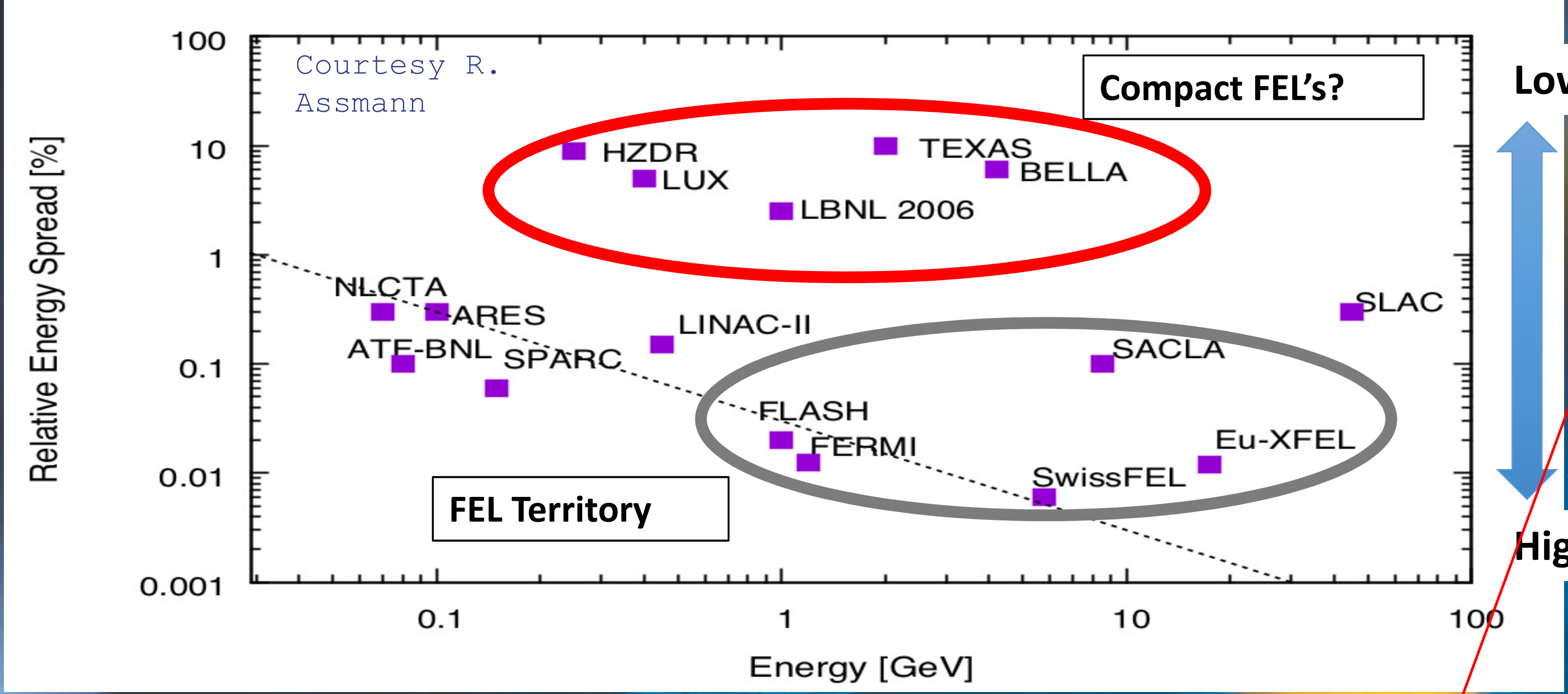


From 0.6% to 0.1% energy spread

V. Shpakov et al., PRL 122 (2019), 114801

FLASHForward, DESY: *R. D'Arcy et al., PRL 122 (2019), 034801*

“Wake-up-call” to reality



Lower quality

Higher quality

$$\frac{\sigma_\gamma}{\gamma} = \frac{\sqrt{3}}{2} k_p^2 \sigma_z^2$$

$$\sin\varphi_w \propto \frac{q_w}{Q_d}$$

$$\varepsilon_{n,rms} = \sqrt{\left\langle\gamma^2\right\rangle\left(\sigma_\gamma^2\sigma_x^2\sigma_{x'}^2 + \varepsilon_{rms}^2\right)}$$

M. Migliorati et al, Physical Review Special Topics,Accelerators and Beams 16, 011302 (2013)
K. Floettmann, PRSTAB,6, 034202 (2003)

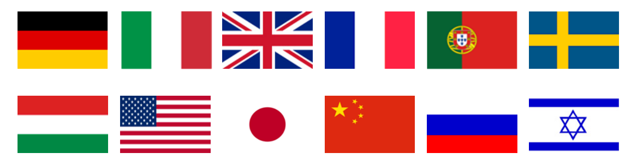
EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA

EuPRAXIA Design Study started on November 2015

Approved as HORIZON 2020 INFRADEV, 4 years, 3 M€

Coordinator: Ralph Assmann (DESY)



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

http://eupraxia-project.eu

EUROPEAN
PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN

Consortium

Horizon 2020

16 Participants

25 Associated Partners

(as of December 2018)

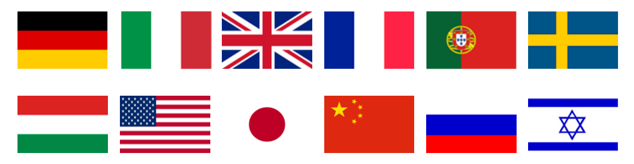
Participating Institutions

Horizon 2020

ASSOCIATED PARTNERS

December 2018

- ① Shanghai Jiao Tong University, China
- ② Tsinghua University Beijing, China
- ③ ELI – Extreme Light Infrastructure – Beamlines, International
- ④ PhLAM – Laboratoire de Physique des Lasers Atomes et Molécules, Université de Lille 1, France
- ⑤ Helmholtz-Institut Jena, Germany
- ⑥ Helmholtz-Zentrum Dresden-Rossendorf, Germany
- ⑦ Ludwig-Maximilians-Universität München, Germany
- ⑧ Wigner Fizikai Kutatóközpont, Hungary
- ⑨ CERN – European Organization for Nuclear Research, International
- ⑩ Kansai Photon Science Institute/Japan Atomic Energy Agency, Japan
- ⑪ Osaka University, Japan
- ⑫ RIKEN SPring-8 Center, Japan
- ⑬ Lunds Universitet, Sweden
- ⑭ CASE – Center for Accelerator Science and Education at Stony Brook University and Brookhaven National Laboratory, USA
- ⑮ LBNL – Lawrence Berkeley National Laboratory, USA
- ⑯ UCLA – University of California Los Angeles, USA
- ⑰ KIT – Karlsruher Institut für Technologie, Germany
- ⑱ Forschungszentrum Jülich, Germany
- ⑲ Hebrew University of Jerusalem, Israel
- ⑳ Institute of Applied Physics of the Russian Academy of Sciences, Russia
- ㉑ Joint Institute for High Temperatures of the Russian Academy of Sciences, Russia
- ㉒ Università degli Studi di Roma "Tor Vergata", Italy
- ㉓ Queen's University Belfast, UK
- ㉔ Ferdinand-Braun-Institut, Germany
- 2 University of York, UK



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http://eupraxia-project.eu

PRESENT PLASMA E- ACCELERATION EXPERIMENTS

Demonstrating **100 GV/m** routinely

Demonstrating many **GeV** electron beams

Demonstrating basic **quality**

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, ...

PLASMA ACCELERATOR PRODUCTION FACILITIES

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

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

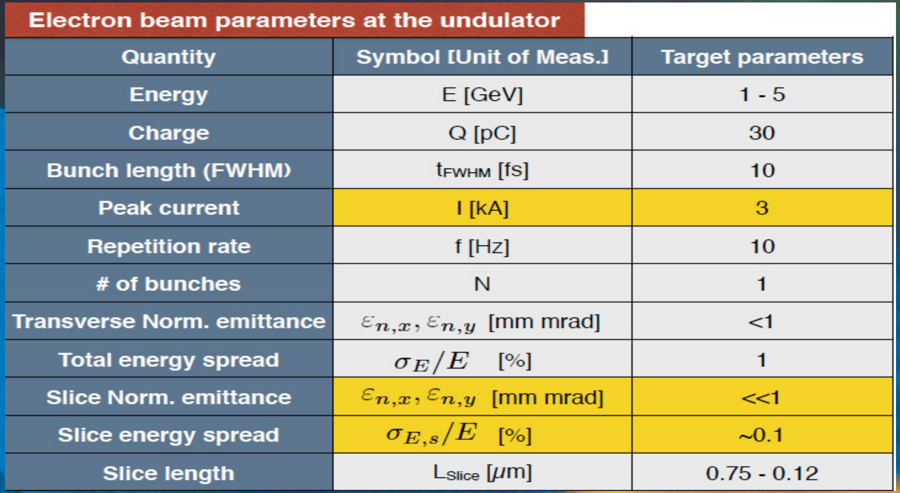
Medical, industrial applications soon

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

http://eupraxia-project.eu

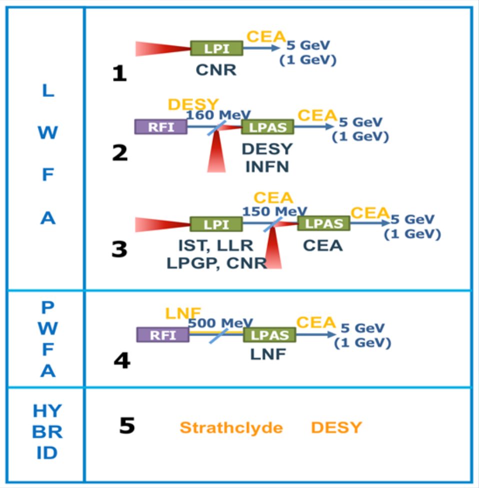
EuPRAXIA scientific goals
Compact Free Electron Laser et al.

- **Single and multi-stage** acceleration of electrons to **1 – 5 GeV,** transverse emittance of **1 mm-mrad**, energy spread between **% to 10^{-3}**
- **Highly compact** machine layout (factor 3 gain in floor space, up to factor 10)
- **PW pulsed lasers** developed together with industry and laser institutes. → Operation with high stability at **20 – 100Hz**.
- **Compact beam driver** based on X-band RF technology from CERN.
- **Versatile user area**



Electron beam parameters at the undulator

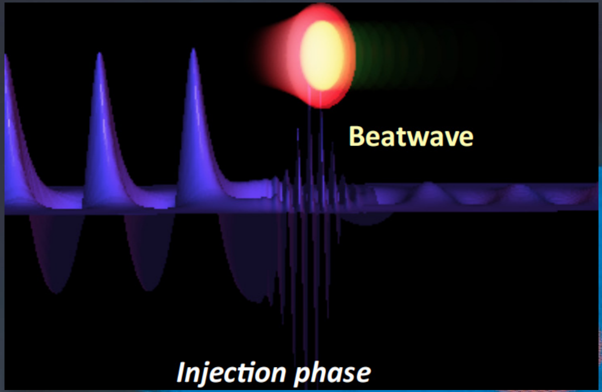
Quantity	Symbol [Unit of Meas.]	Target parameters
Energy	E [GeV]	1 - 5
Charge	Q [pC]	30
Bunch length (FWHM)	t_{FWHM} [fs]	10
Peak current	I [kA]	3
Repetition rate	f [Hz]	10
# of bunches	N	1
Transverse Norm. emittance	$\varepsilon_{n,x}, \varepsilon_{n,y}$ [mm mrad]	<1
Total energy spread	σ_E / E [%]	1
Slice Norm. emittance	$\varepsilon_{n,x}, \varepsilon_{n,y}$ [mm mrad]	<<1
Slice energy spread	$\sigma_{E,s} / E$ [%]	~0.1
Slice length	L_{Slice} [μm]	0.75 - 0.12



Other Related Talks at IPAC2019:

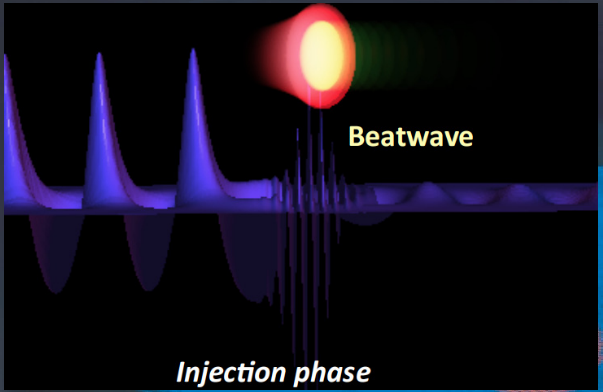
- Control of Laser Plasma Accelerated Electrons: A Route for Compact FELs – *Marie-Emmanuelle Couprie (SOLEIL)*
- Lasers for Novel Accelerators – *Leonida Gizzi (INO-CNR)*

Advanced methods to control beam quality

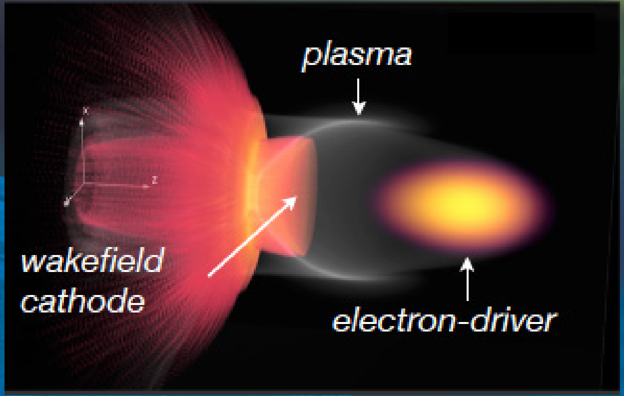


Colliding laser pulses: use the beating of 2 laser pulses to control the localized electron injection above wave-breaking threshold
J. Faure et al., Nature 444, 737 (2006)

Advanced methods to control beam quality

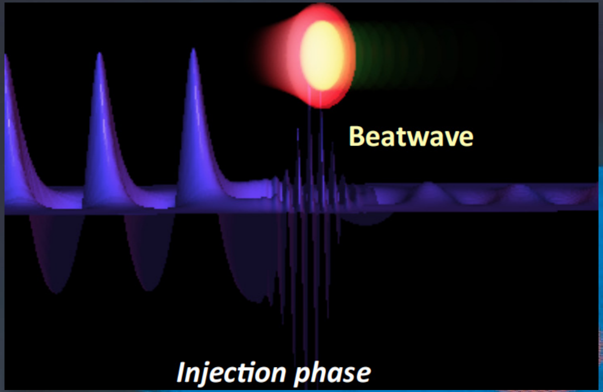


Colliding laser pulses: use the beating of 2 laser pulses to control the localized electron injection above wave-breaking threshold
J. Faure et al., Nature 444, 737 (2006)



Wake Field Induced Ionization: This mechanism exploits the electric wakefields to ionize electrons from a dopant gas and trap them in a well-defined region of the accelerating and focusing wake phase, Martinez de la Ossa *et al.*, Phys. Rev. Lett. **111**, 245003 (2013)

Advanced methods to control beam quality



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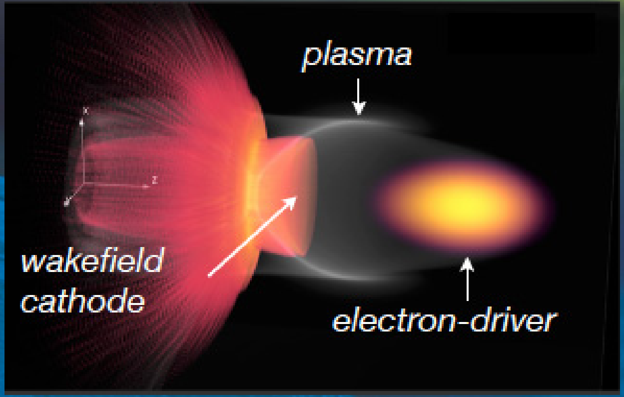

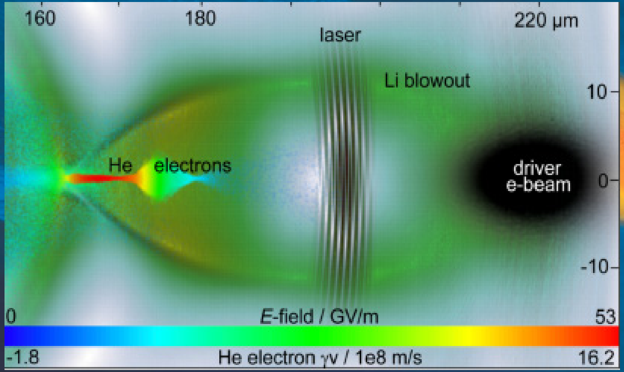

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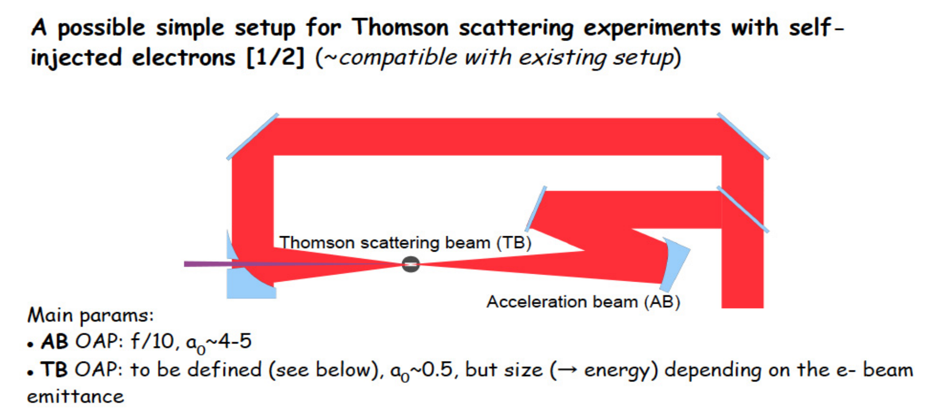
Trojan Horse methodes: laser-controlled release of electrons directly into a particle-beam-driven plasma blowout.
B. Hidding et al., Rev. Lett. 108, 035001 (2012).

Applications of plasma accelerators

- Free Electron Lasers
- Synchrotron sources
- Compton sources
- High Field Physics
- Positron Sources
- High Energy Physics

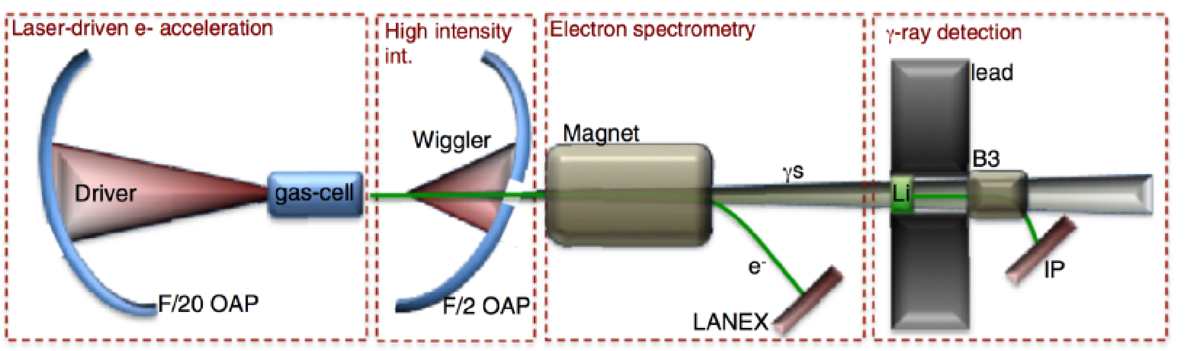


A possible simple setup for Thomson scattering experiments with self-injected electrons [1/2] (~*compatible with existing setup*)

Main params:

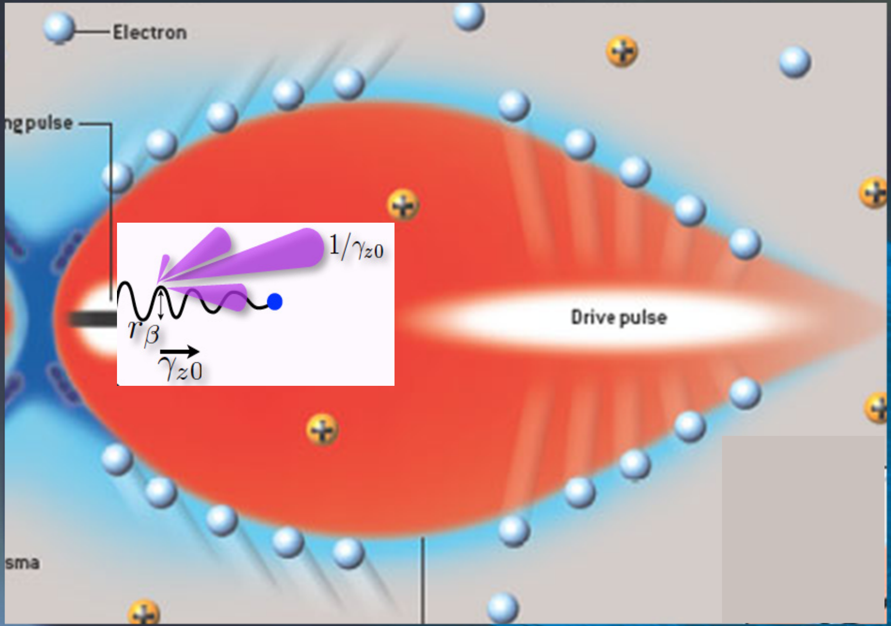
- **AB** OAP: f/10, a_0~4-5
- **TB** OAP: to be defined (see below), a_0~0.5, but size (→ energy) depending on the e- beam emittance

Sarri, G. et al, Nat. Commun. 6, 6747 (2015).

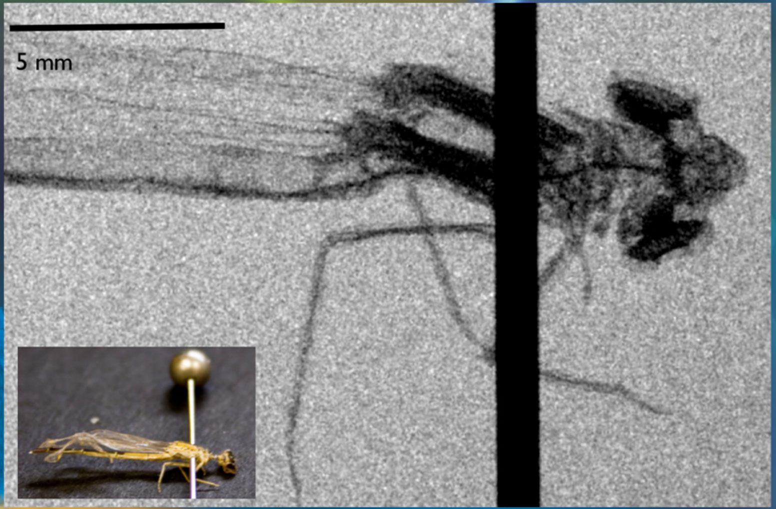


$$E_s = 4\gamma^2 \hbar\omega$$

Betatron Radiation Source



E Esarey PRE 65, 056505 (2002)
Kneip, Appl. Phys. Lett. 99, (2011).



Photon energy > 25 keV, investigating dense material, biological materials

Small source size (~ μm), intrinsically high resolution, exhibits spatial resolution

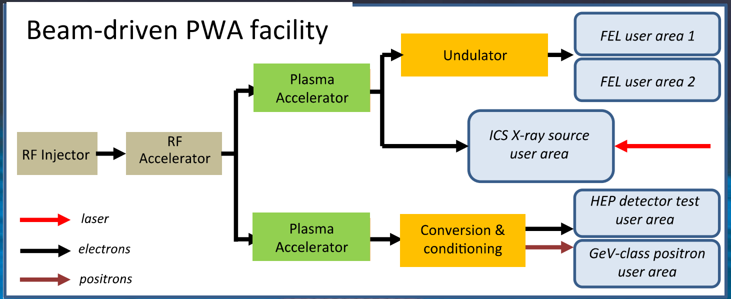
Small divergence (~ 10 mRad)

Short pulse (~10s fs), suitable for ultrafast dynamics

Bright (>109 photons per shot), suitable for single shot imaging

EuPRAXIA future

Two facilities will be proposed as the required intermediate step between proof of principle and user facility!



Beam-driven PWA facility

RF Injector

RF Accelerator

Plasma Accelerator

Undulator

FEL user area 1

FEL user area 2

ICS X-ray source user area

Plasma Accelerator

Conversion & conditioning

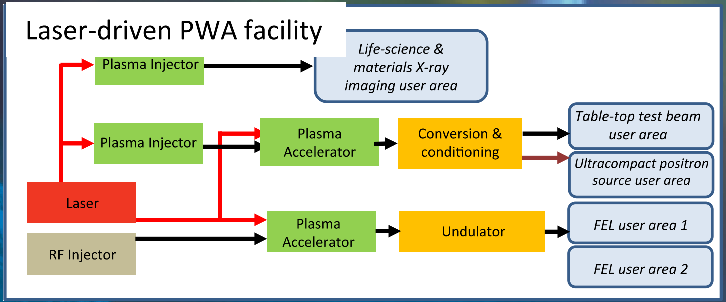
HEP detector test user area

GeV-class positron user area

laser

electrons

positrons



Laser-driven PWA facility

Plasma Injector

Life-science & materials X-ray imaging user area

Plasma Injector

Plasma Accelerator

Conversion & conditioning

Table-top test beam user area

Ultracompact positron source user area

Laser

RF Injector

Plasma Accelerator

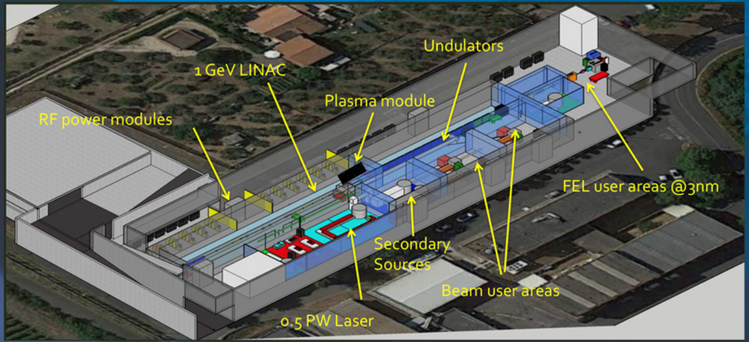
Undulator

FEL user area 1

FEL user area 2

EuPRAXIA@SPARC_LAB

EuPRAXIA@SINBAD

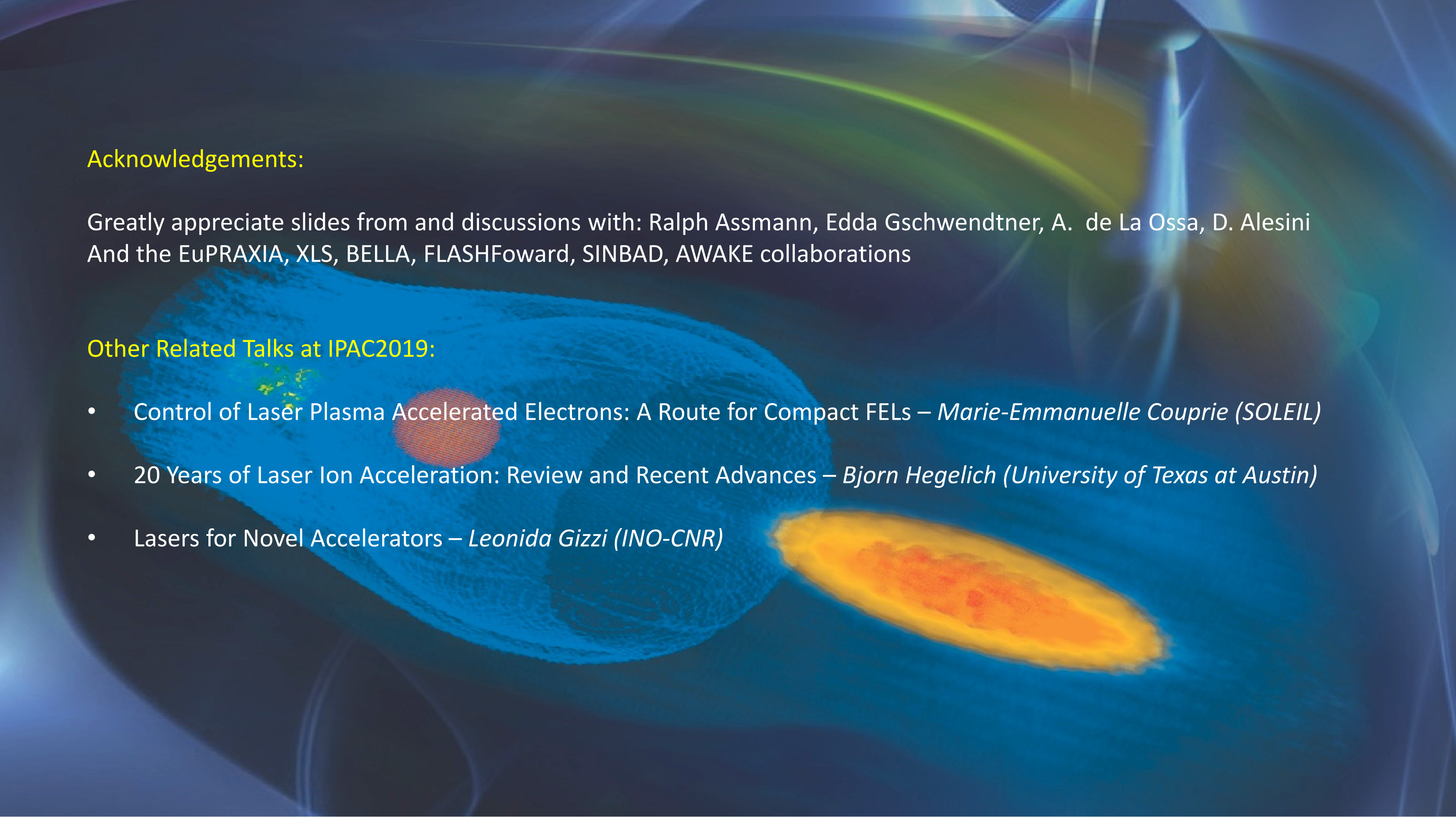


Conclusions

- Accelerator-based High Energy Physics will at some point become practically limited by the size and cost of the proposed e^+e^- colliders for the energy frontier.
- **Novel Acceleration Techniques and Plasma-based, high gradient accelerators open the realistic vision of very compact accelerators for scientific, commercial and medical applications.**

- The R&D now concentrates on **beam quality, stability, staging and continuous operation**. These are necessary steps towards various technological applications.
- The progress in advanced accelerators benefits from strong synergy with general advances in technology, for example in the laser and/or high gradient RF structures industry.

- **A major milestone is an operational, 1 GeV compact accelerator. Challenges in repetition rate and stability must be addressed. This unit could become a stage in a high-energy accelerator..**
- **➔ PILOT USER FACILITIES Needed**



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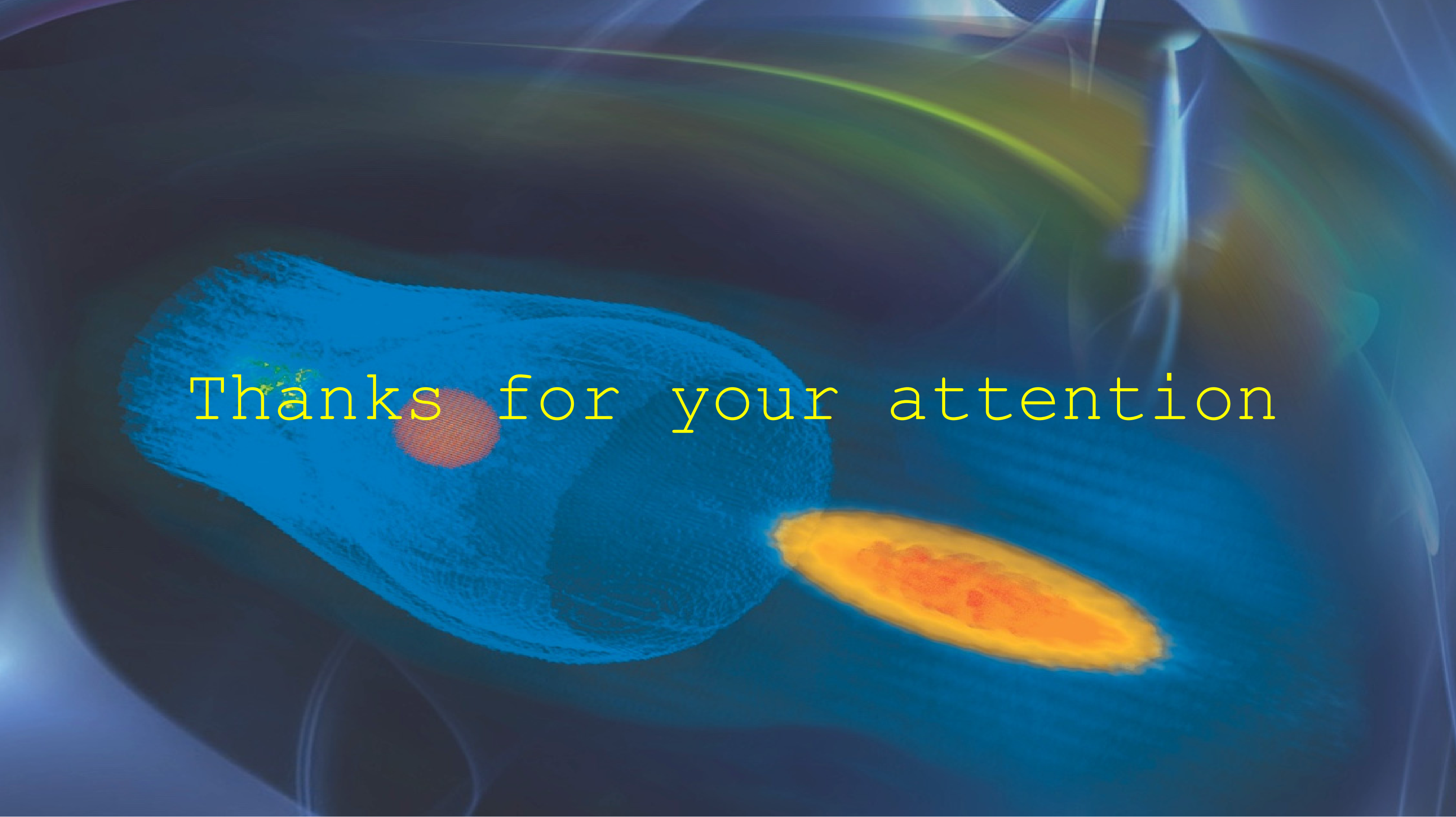
Other Related Talks at IPAC2019:

- Control of Laser Plasma Accelerated Electrons: A Route for Compact FELs – *Marie-Emmanuelle Couprie (SOLEIL)*
- 20 Years of Laser Ion Acceleration: Review and Recent Advances – *Bjorn Hegelich (University of Texas at Austin)*
- Lasers for Novel Accelerators – *Leonida Gizzi (INO-CNR)*



Thanks for your attention