Advanced Accelerator Concepts

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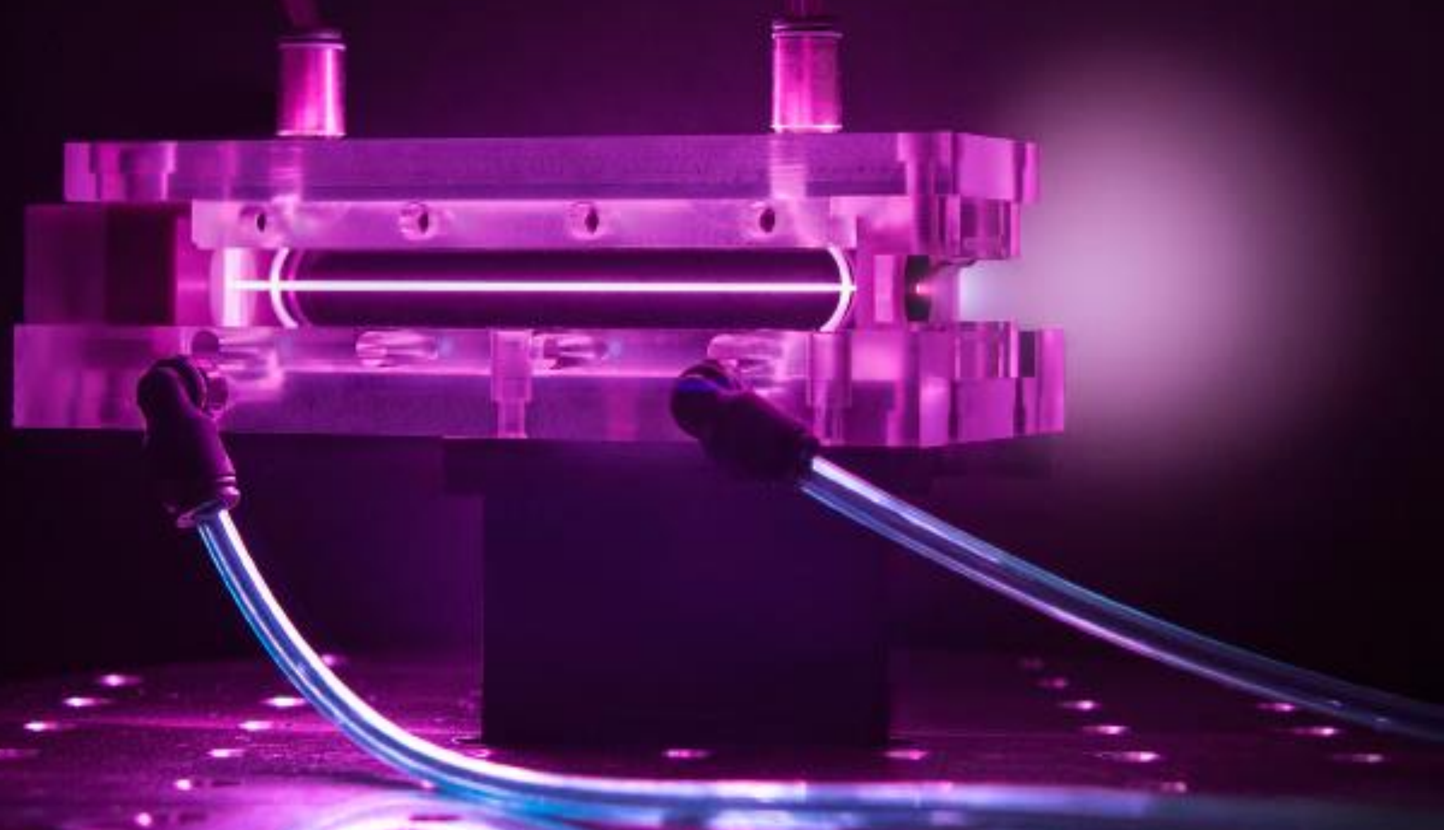
(special thanks to Massimo Ferrario)



The CERN Accelerator School

Constantia– 22 September 2018

Fermi’s Globatron: ~5000 TeV Proton beam

1954 the ultimate synchrotron

B_{max} 2 Tesla

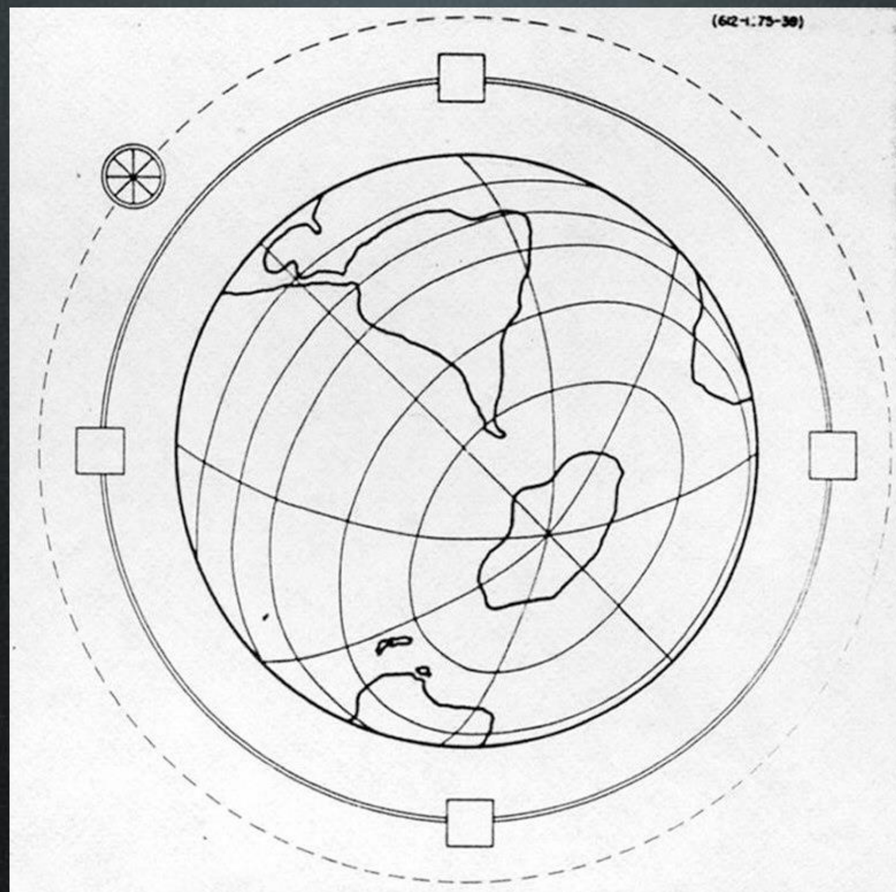
ρ 8000 km

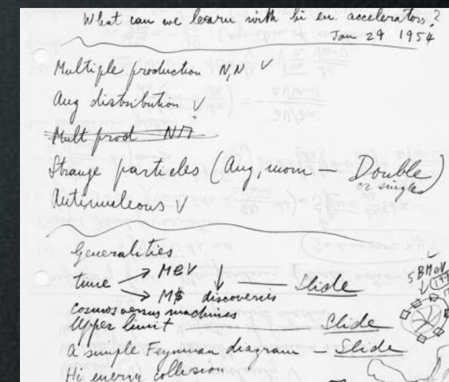
fixed target

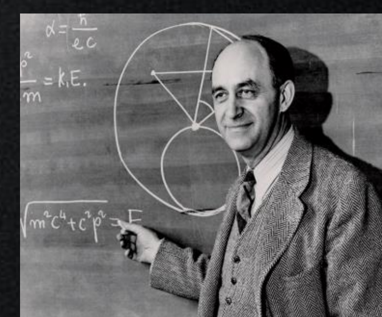
3 TeV cm

170 G$

1994

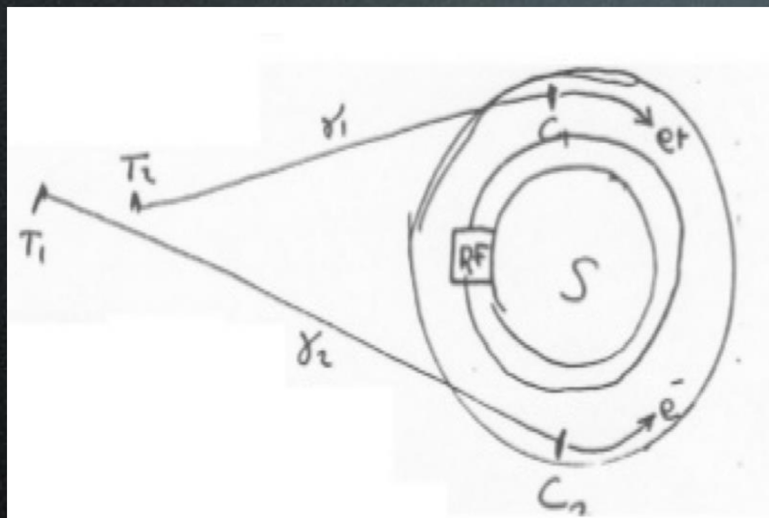


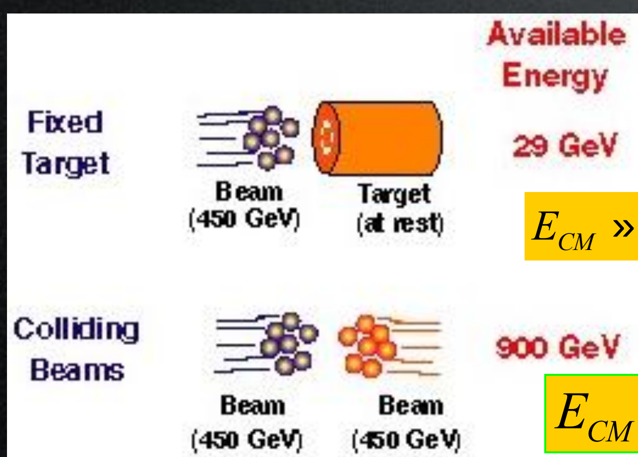




Touschek's Anello Di Accumulazione (ADA)

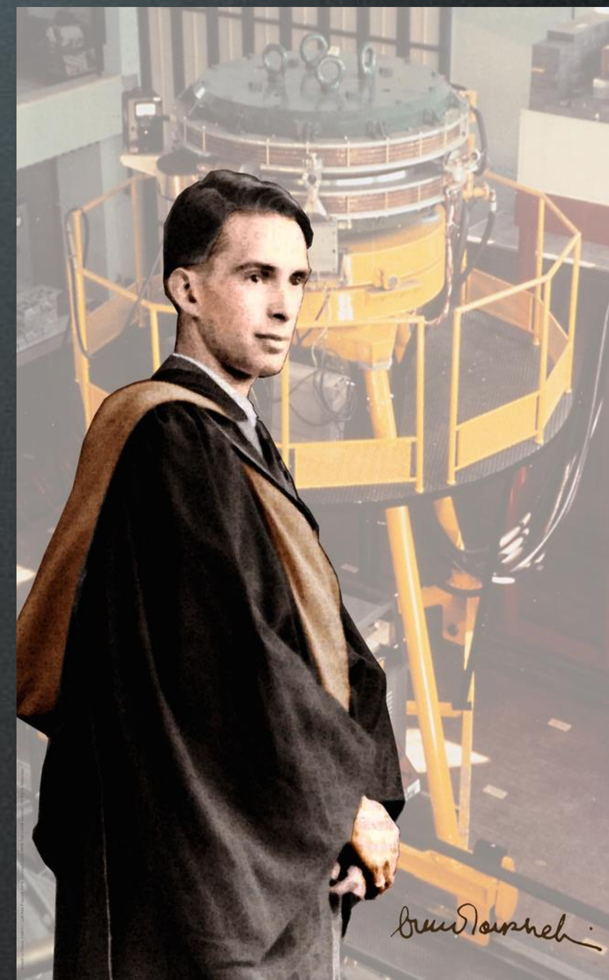
1961 the first e+e- Collider



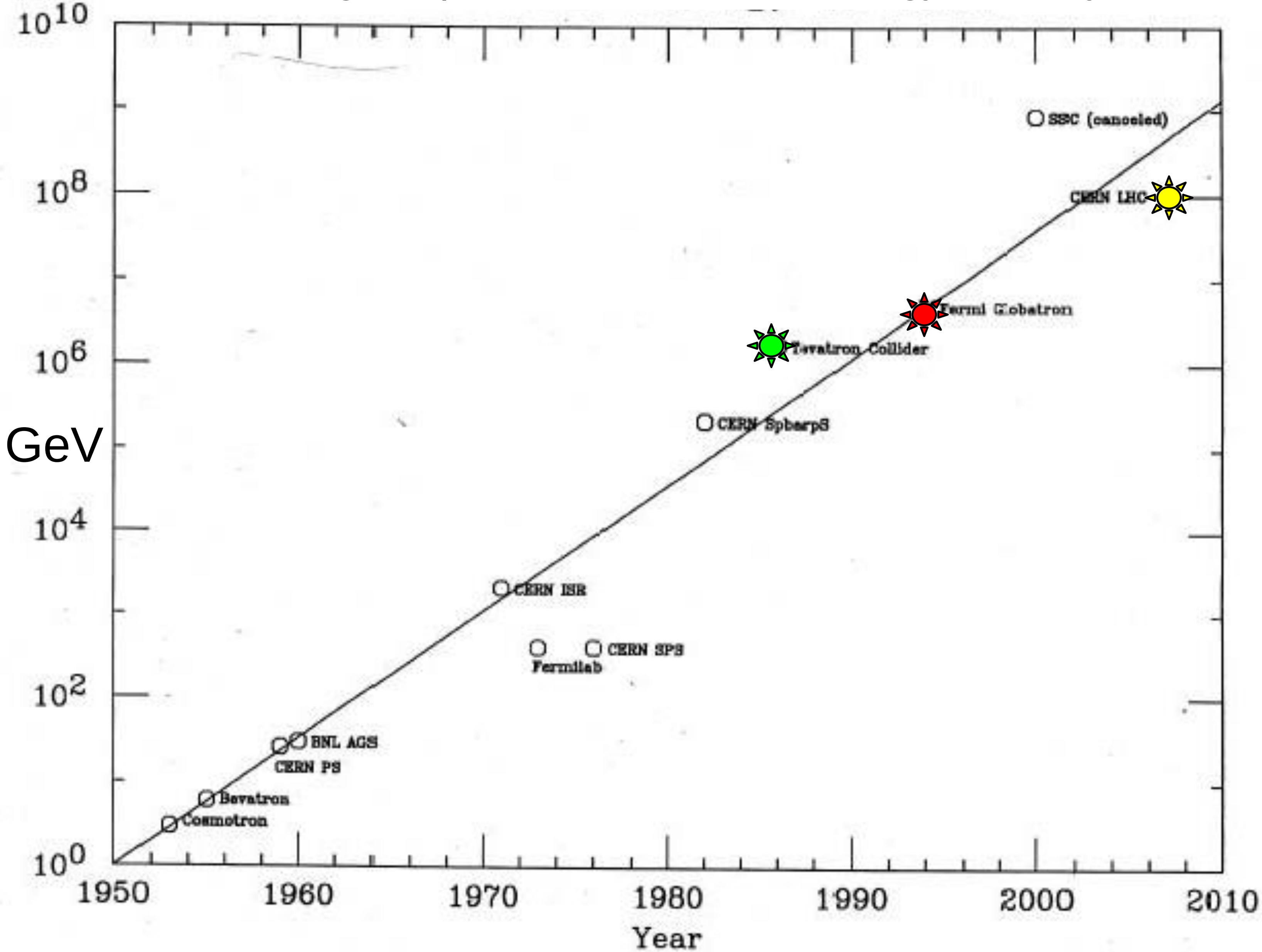


$E_{CM} \approx \sqrt{2E_1 m_2}$

$E_{CM} \approx 2E$



Fixed Target equivalent accelerator energy versus year



Hawking: the Solartron

Towards the Planck scale

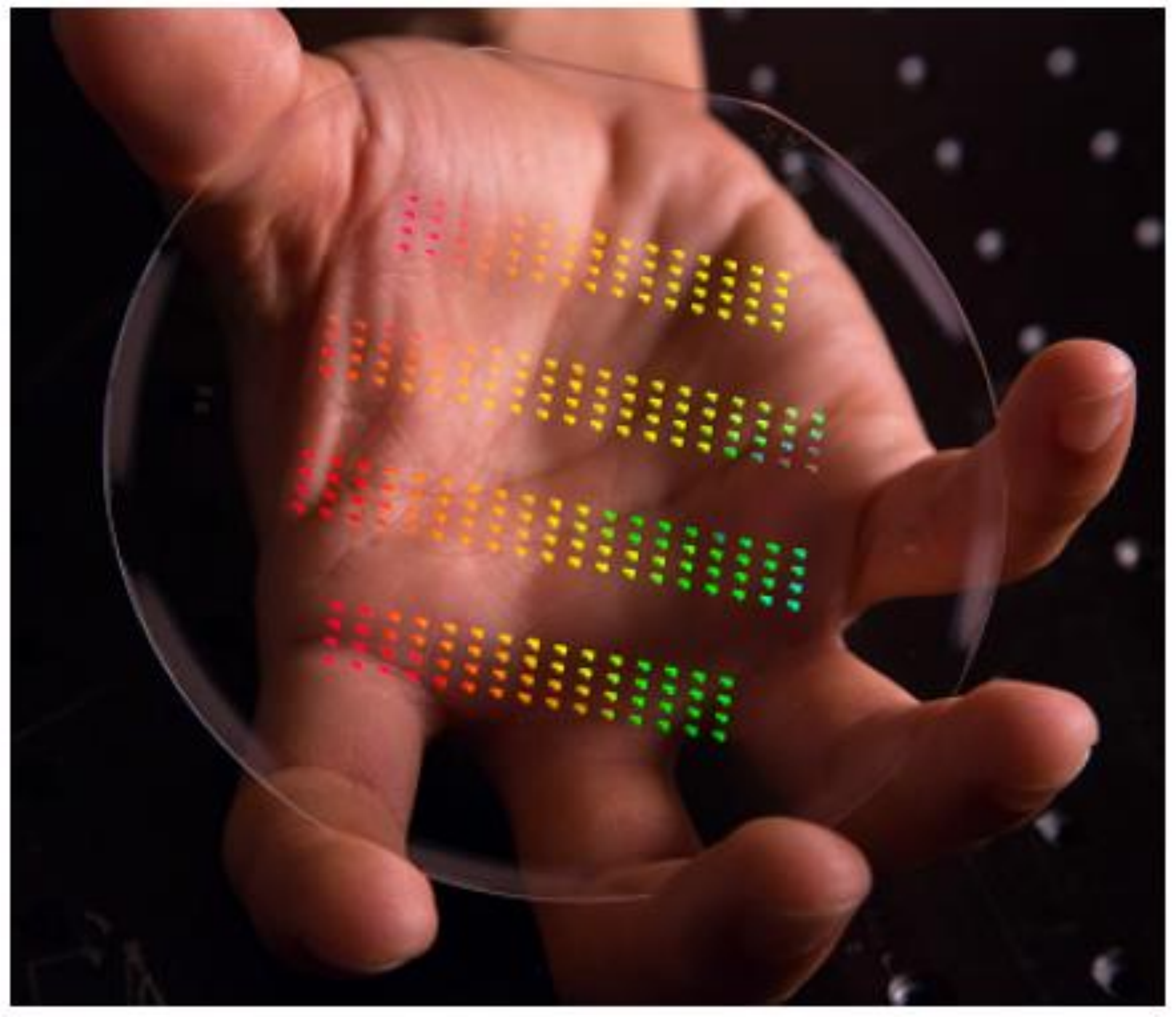
Without further novel technology, we will eventually need an accelerator as large as Hawking expected.

“The Universe in a Nutshell”, by Stephen William Hawking, Bantam, 2001

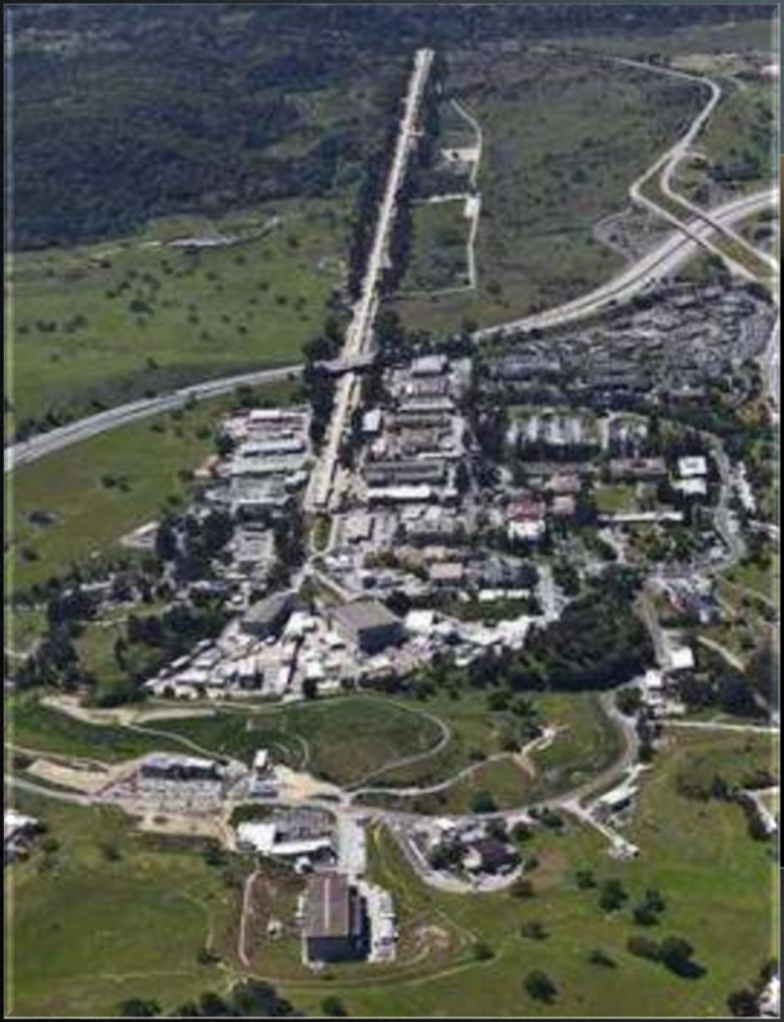
Big science machines …

LHC	HE-LHC	VHE-LHC	VHE-LHC
27 km, 8.33 T	27 km, **16 T**	80 km, **20 T**	100 km, **16 T**
14 TeV (c.o.m.)	33 TeV (c.o.m.)	100 TeV (c.o.m.)	100 TeV (c.o.m.)

… or accelerator on a Chip?



SLAC Now and Tomorrow?



Modern accelerators require high quality beams: ==> High Luminosity & High Brightness

==> High Energy & Low Energy Spread

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

- –N of particles per pulse => 10^9
- –High rep. rate f_r => bunch trains
- –Small spot size => low emittance

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

- –Short pulse (ps to fs)
- –Little spread in transverse momentum and angle => low emittance

HIGH GRADIENT AAC ROAD MAP

① Miniaturization of the accelerating structures (~resonant)

② Wake Field Acceleration (~transient)(LWFA, PWFA, DWFA)

- Power sources
- Accelerating structures
- High quality beams

The simplest solution: particle interacting with a plane wave in free space (e.g. laser)

Lawson-Woodward Theorem

(J.D. Lawson, IEEE Trans. Nucl. Sci. NS-26, 4217, 1979)

The net energy gain of a relativistic electron interacting with an electromagnetic field **in vacuum** is zero.

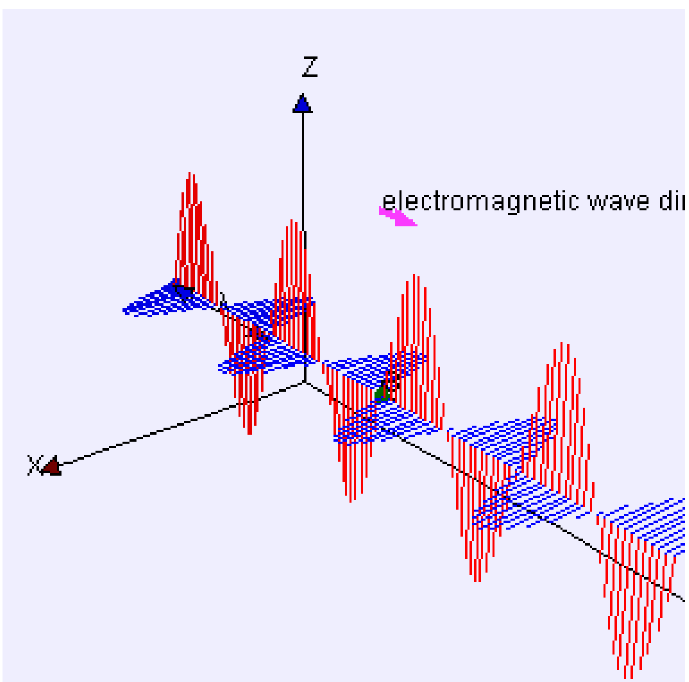
The theorem assumes that

(i) field is in vacuum with no walls or boundaries present,

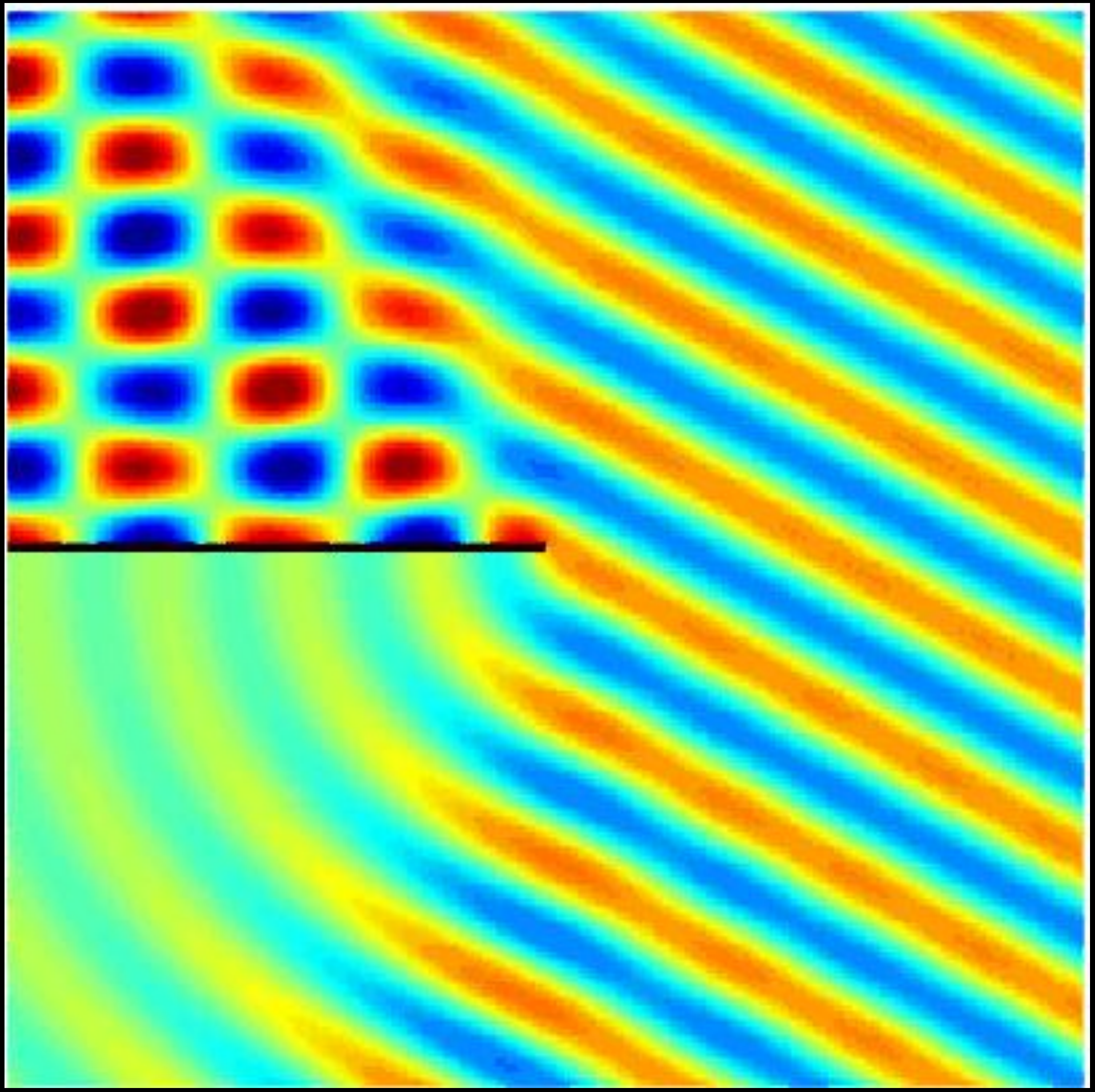
(ii) the electron is highly relativistic ($v \approx c$) along the acceleration path,

(iii) no static electric or magnetic fields are present,

(iv) the region of interaction is infinite,



$$F_{\perp} \cong \frac{eE_x}{2\gamma^2}\cos\left(\frac{\omega t}{2\gamma^2}\right)$$



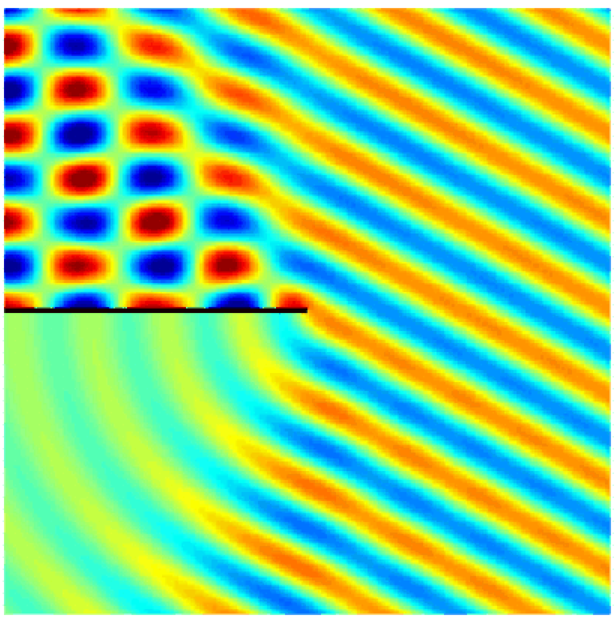
Taking into account the boundary conditions the accelerating component of the field becomes:

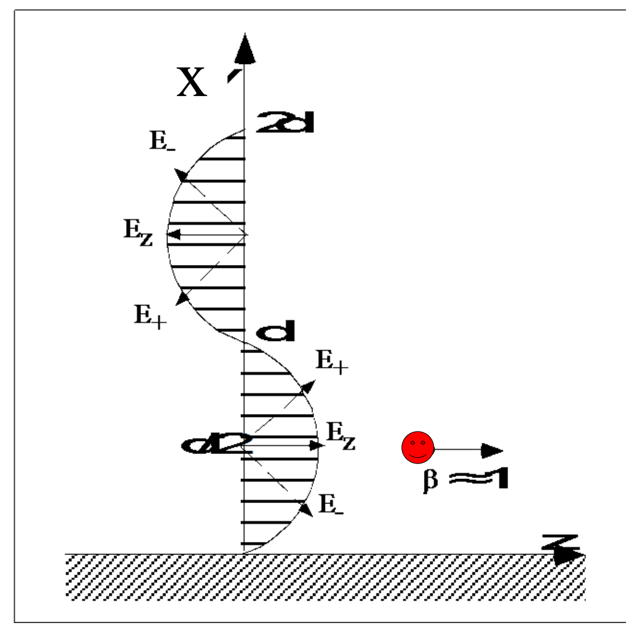
$$E_z(x,z,t) = (E_+ \sin\theta)e^{i\omega t - ik(z\cos\theta - x\sin\theta)} - (E_+ \sin\theta)e^{i\omega t - ik(z\cos\theta + x\sin\theta)}$$

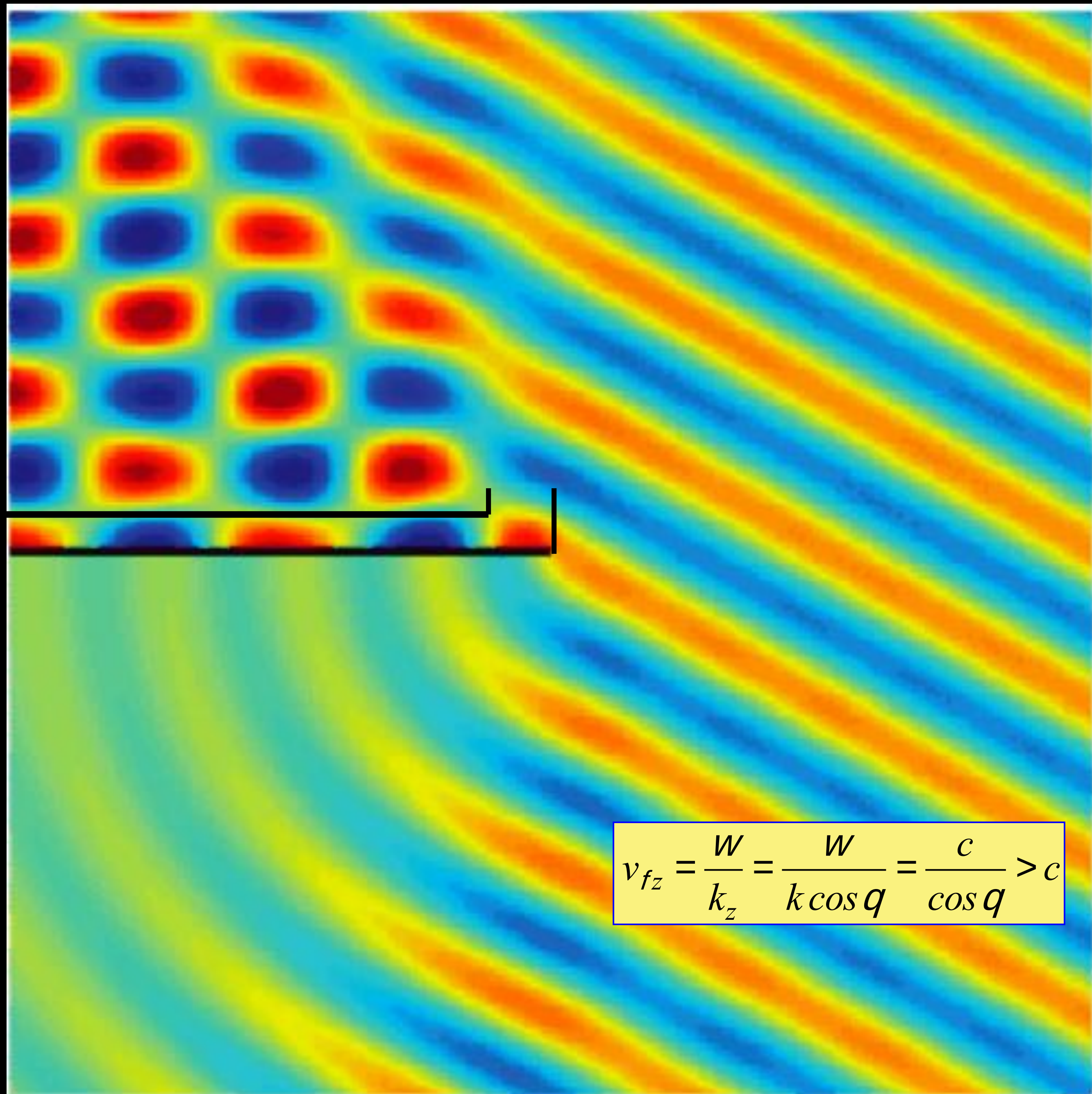
$$= 2iE_+ \sin\theta \sin(kx\sin\theta)e^{i\omega t - ikz\cos\theta}$$

z-TW pattern

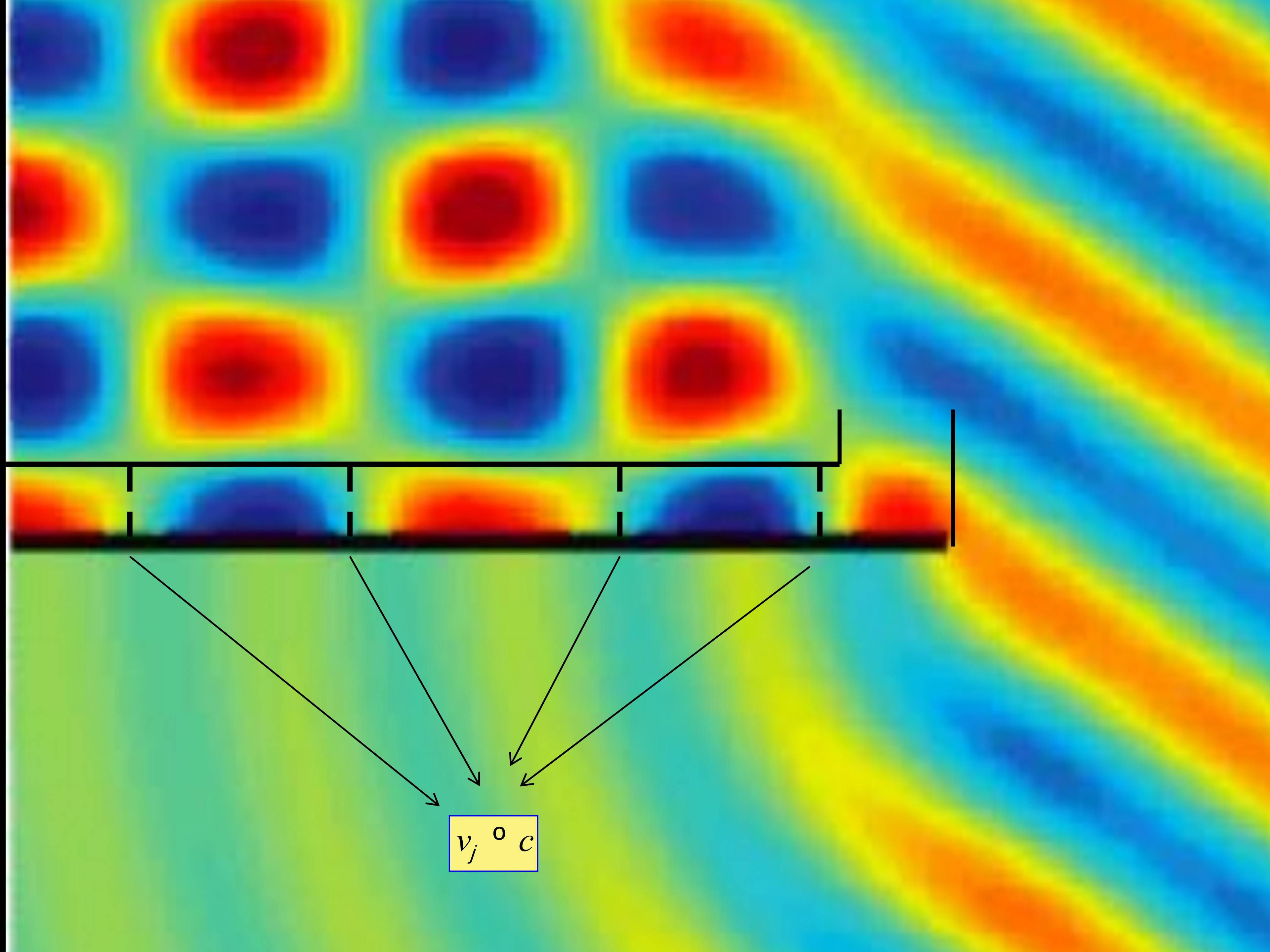
x-SW pattern





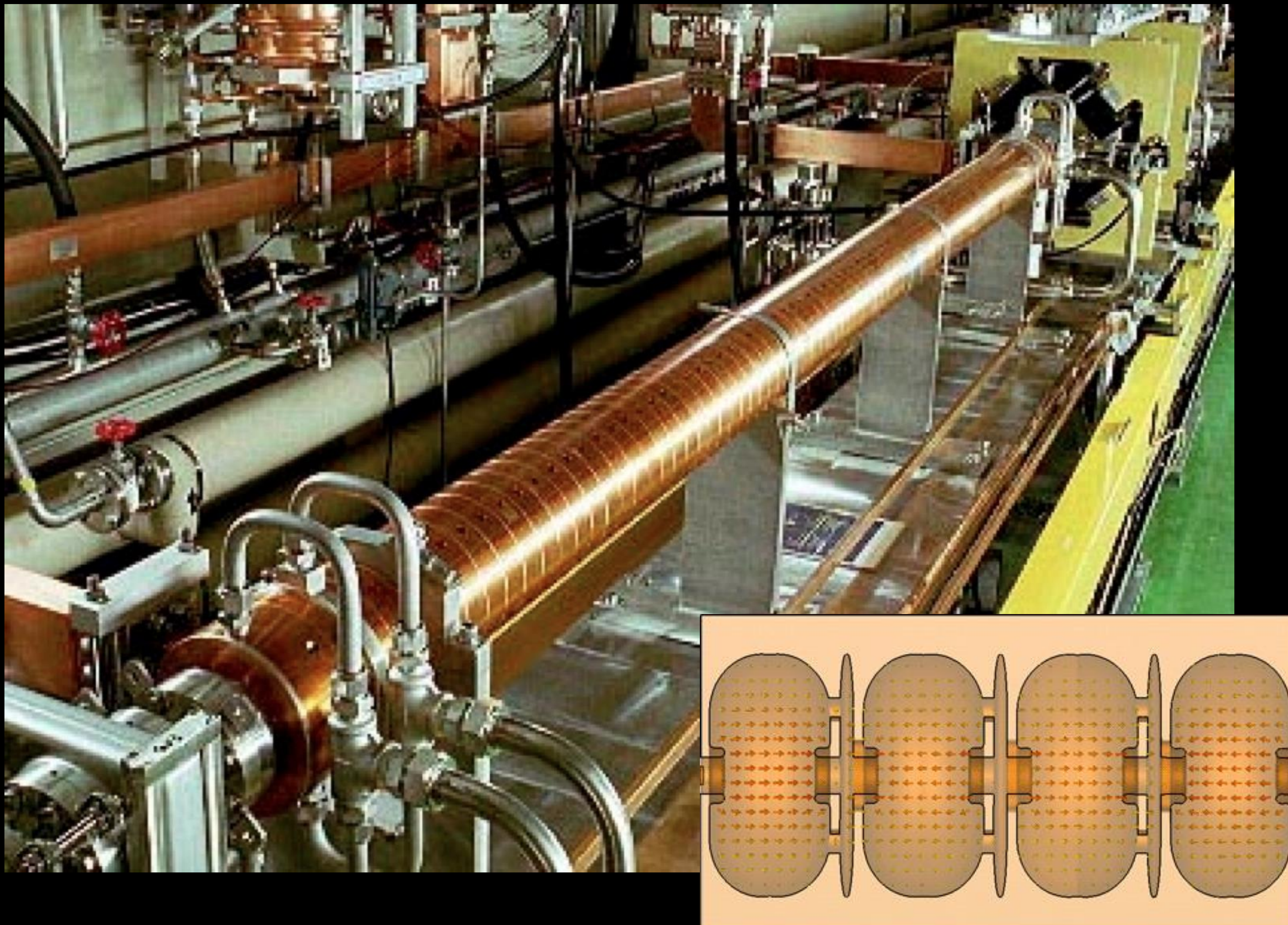


$$v_{fz} = \frac{\omega}{k_z} = \frac{\omega}{k\cos\theta} = \frac{c}{\cos\theta} > c$$

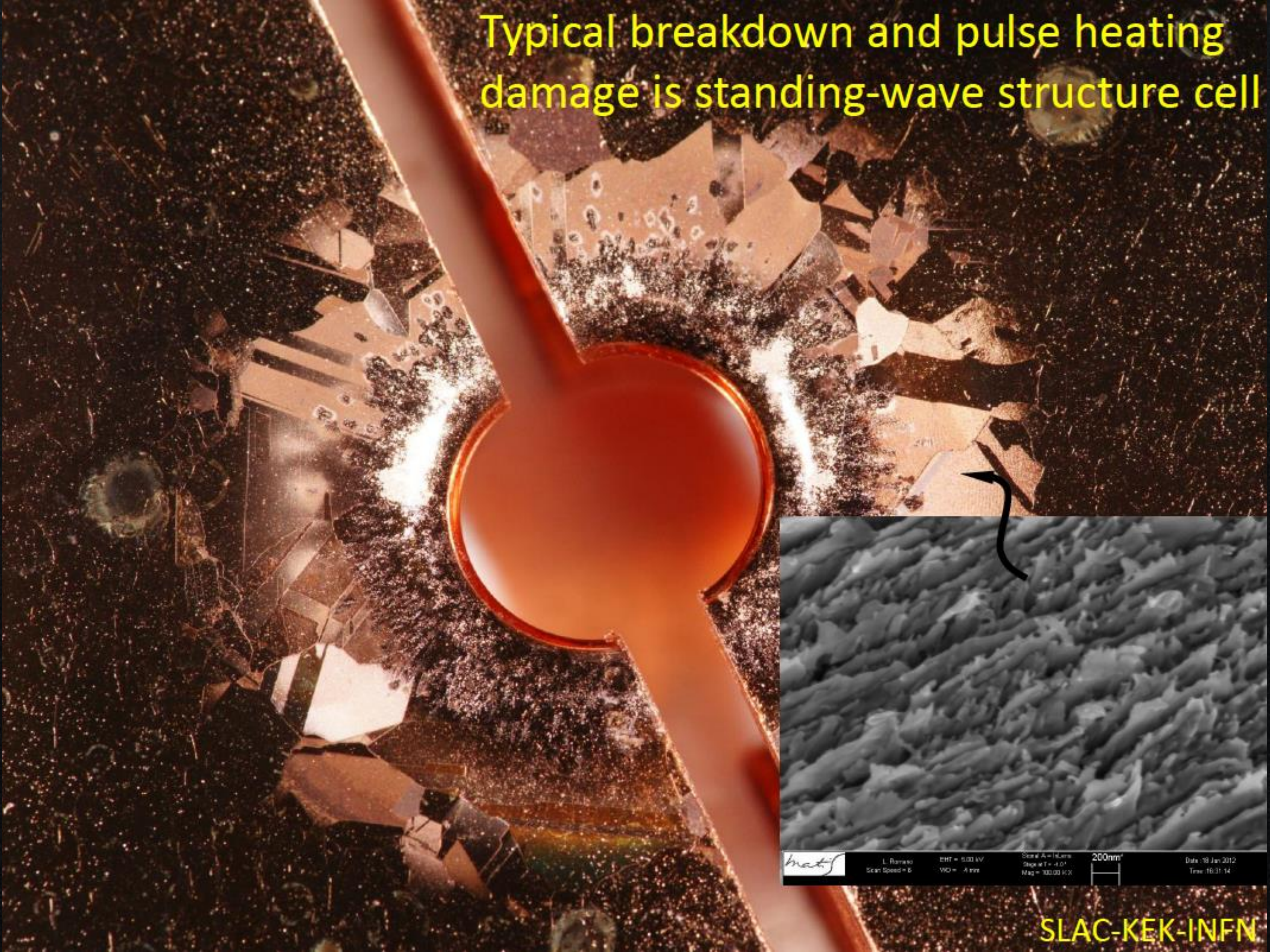


v_j o c

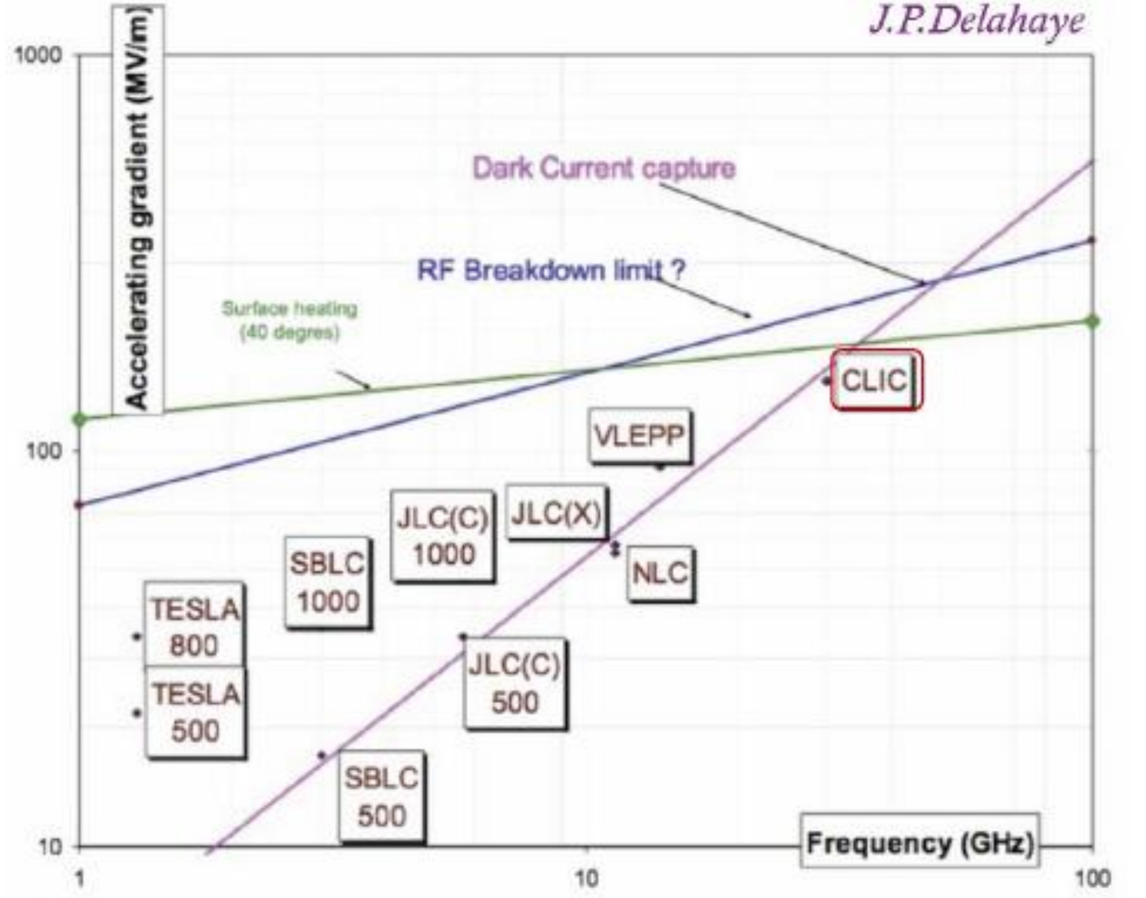
Conventional RF accelerating structures



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



SLAC-KEK-INFN



Breakdown limits metal:

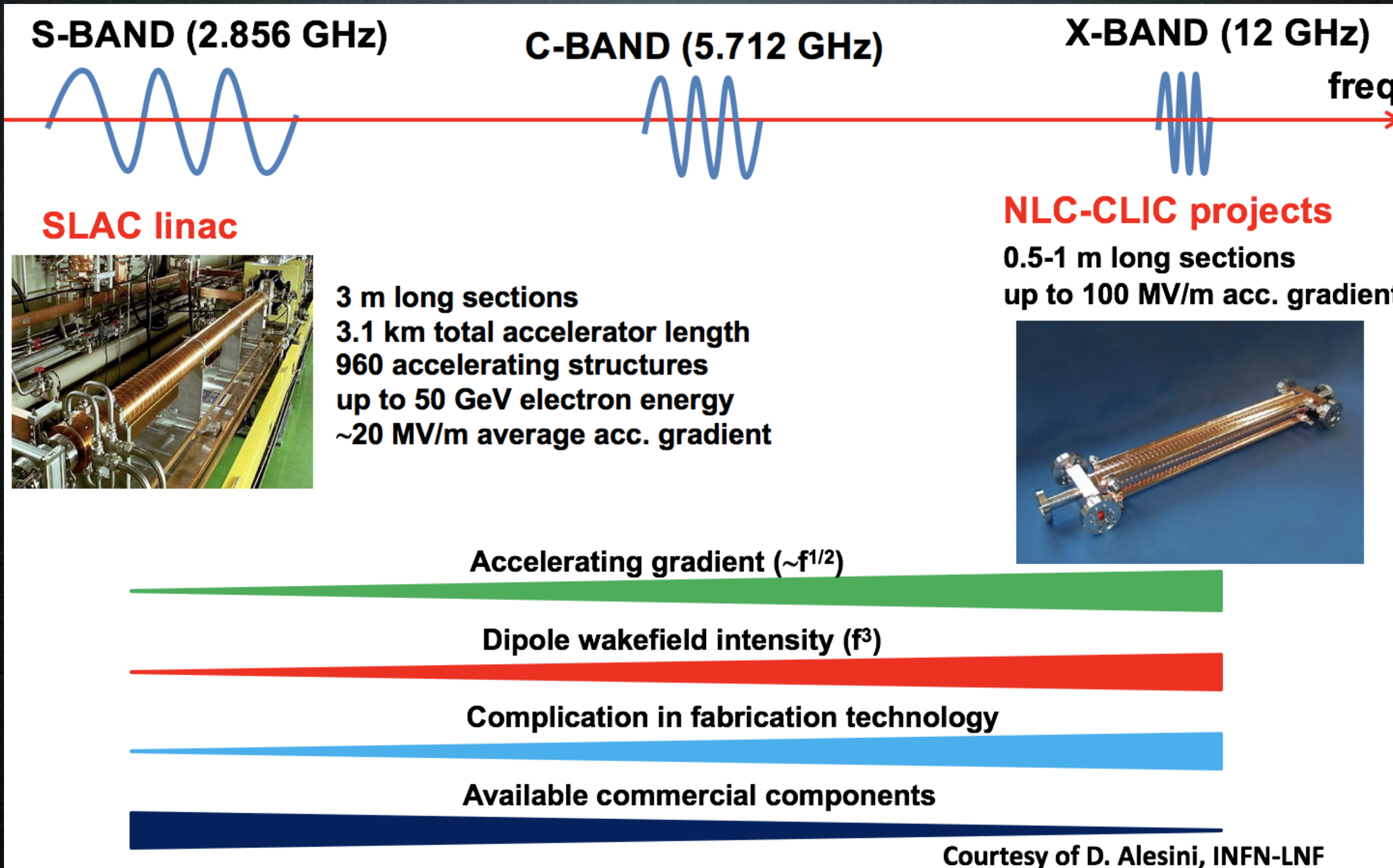
$$E_s = 220(f[\mathrm{GHz}])^{1/3}\ \mathrm{MV/m}$$

High field ->Short wavelength->ultra-short bunches-> low charge

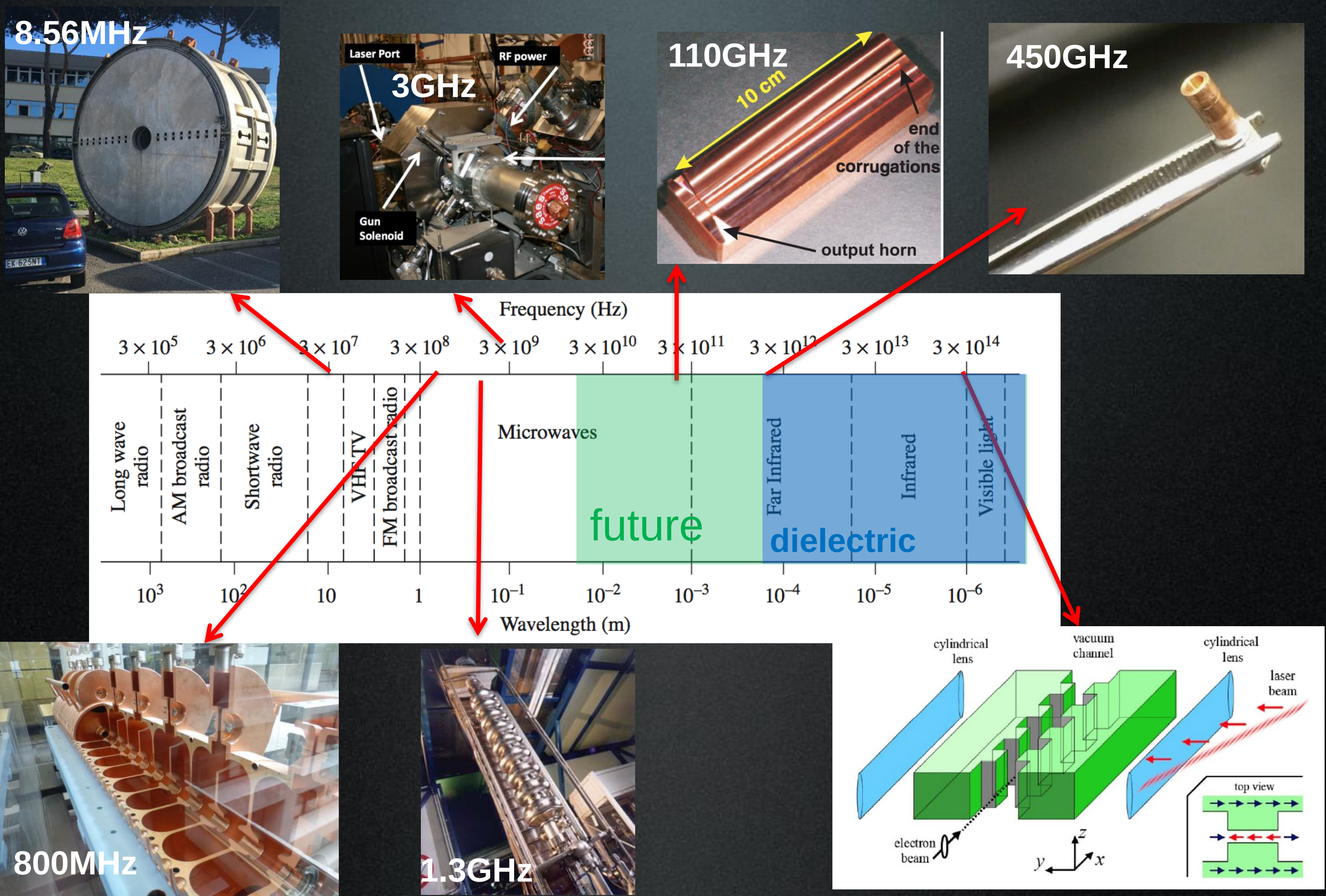
① Miniaturization of the accelerating structures (~resonant)

② Wake Field Acceleration (~transient)(LWFA, PWFA, DWFA)

Accelerating structures routinely used



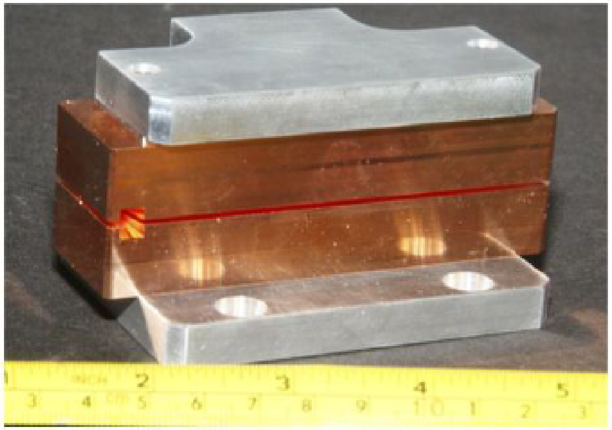
Accelerating structures and EM spectrum

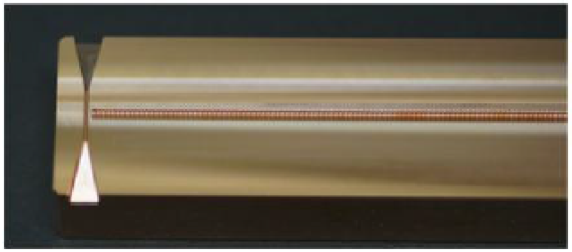


Future plans for the high gradient collaboration

- The collaboration during the next 5 will address 4 fundamental research efforts:
  - » Continue basic physics research, materials research frequency scaling and theory efforts.
  - » Put the foundations for advanced research on efficient RF sources.
  - » Explore the spectrum from 90 GHz to THz
    - Sources at MIT
    - Developments of suitable sources at 90 GHz
    - Developments of THz stand alone sources
    - Utilize the FACET at SLAC and AWA at ANL
    - Address the challenges of the Muon Accelerator Project (MAP)

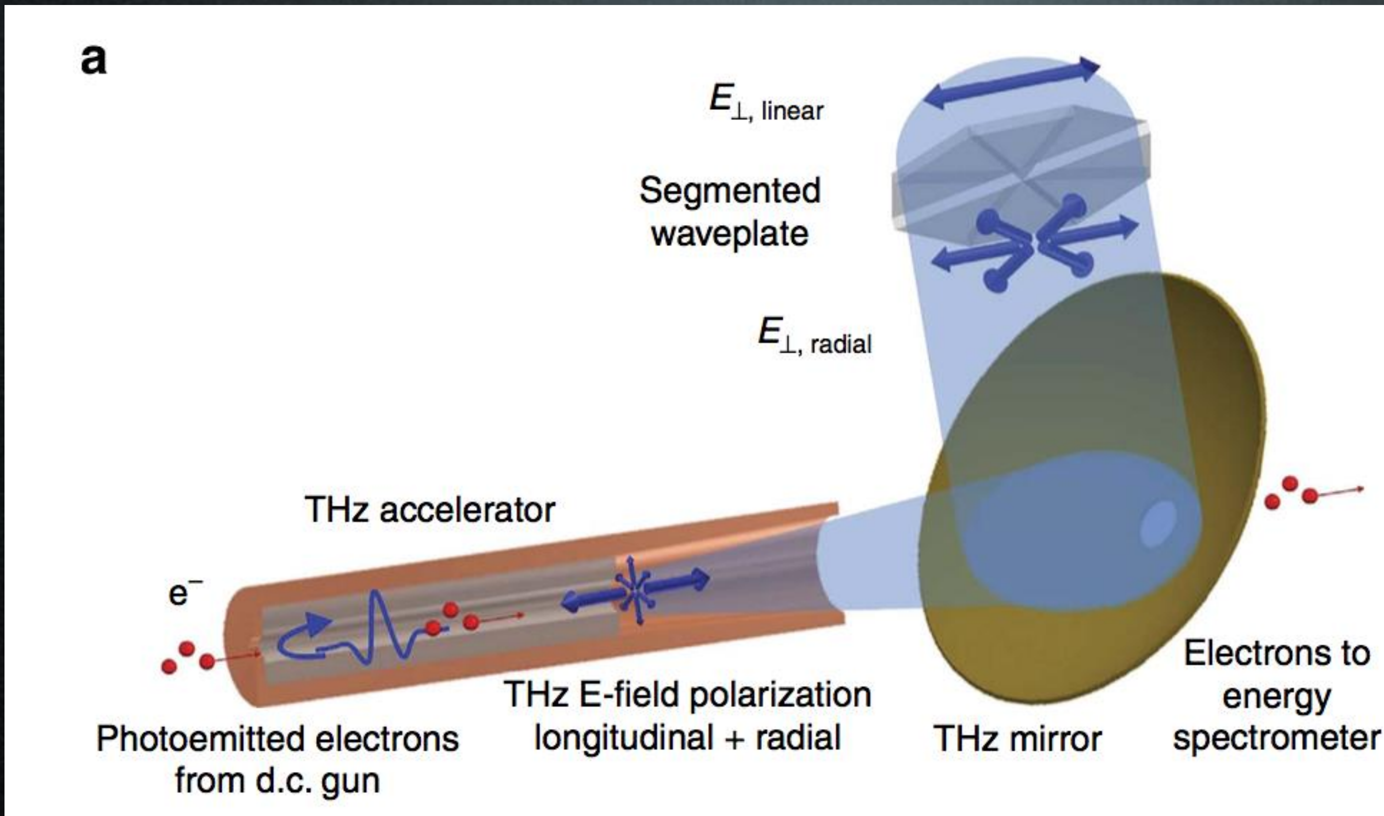
mm-Wave structure to be tested at FACET





SLAC NATIONAL ACCELERATOR LABORATORY

THz-driven linear acceleration



ARTICLE

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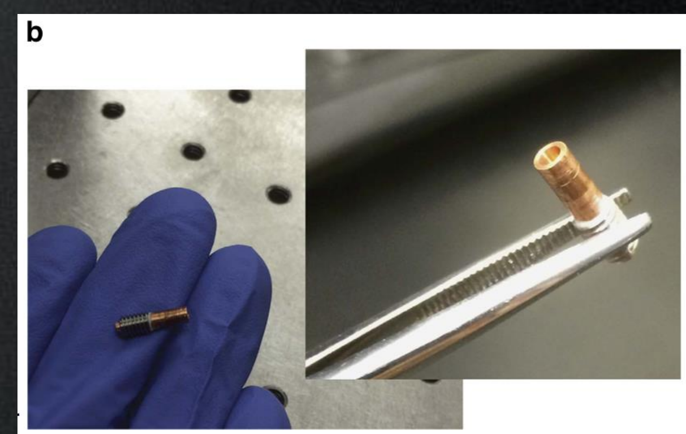
Terahertz-driven linear electron acceleration

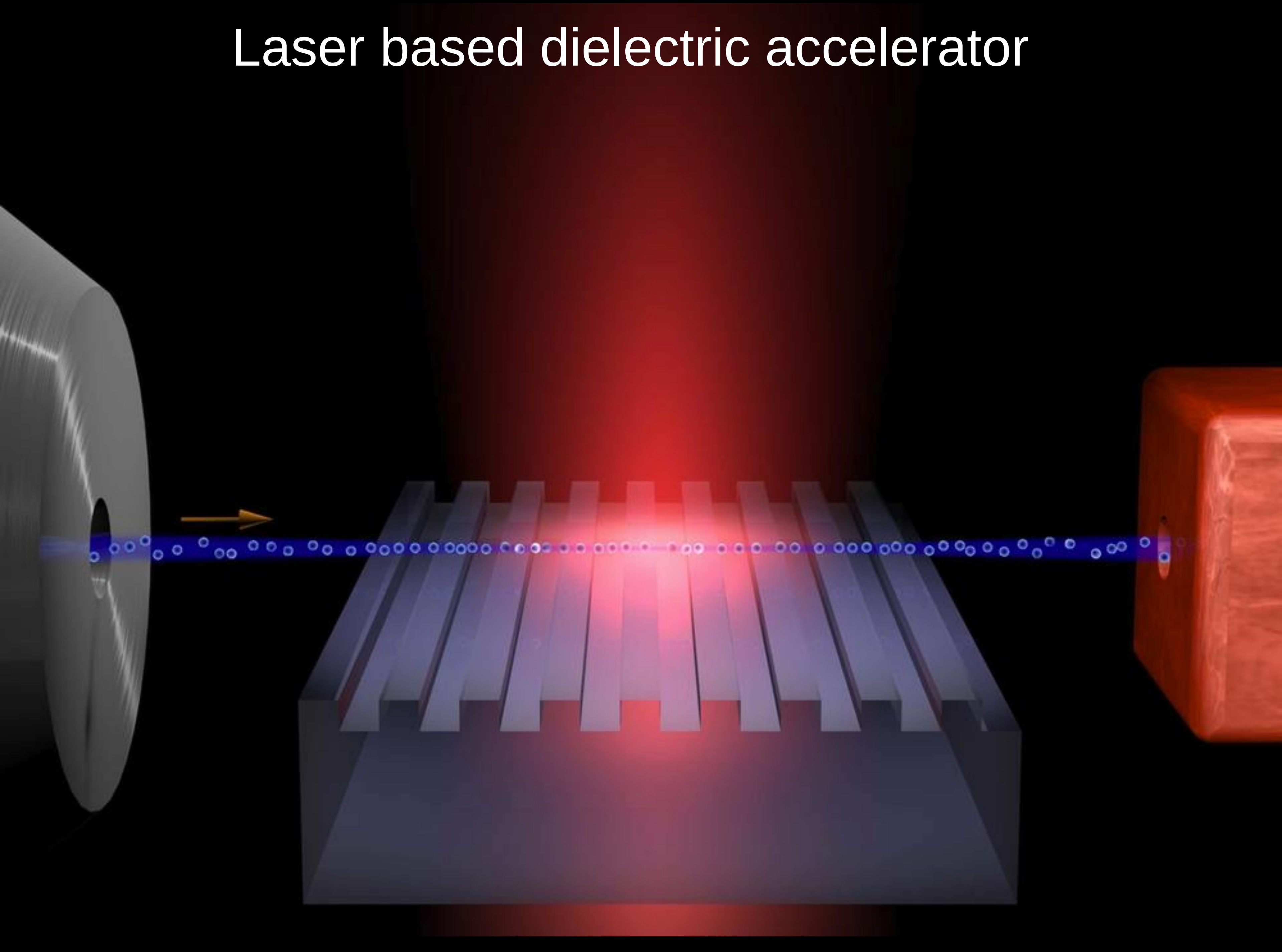
Emilio A. Nanni[1], Wenqian R. Huang[1], Kyung-Han Hong[1], Koustuban Ravi[1], Arya Fallahi[2,3], Gustavo Moriena[4], R.J. Dwayne Miller[3,4,5] & Franz X. Kärtner[1,2,3,6]



Direct Laser Acceleration

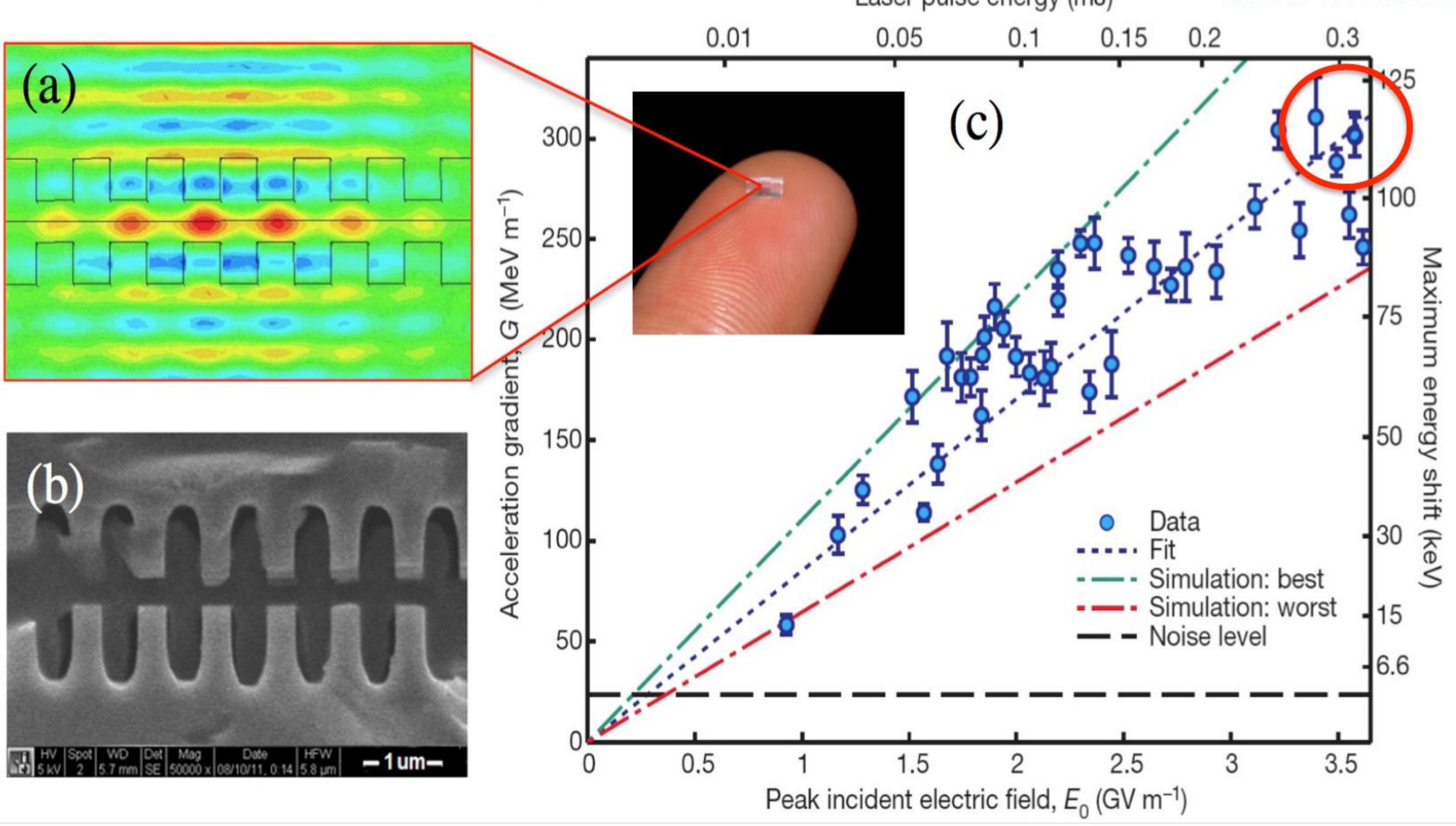
DLA

Laser based dielectric accelerator



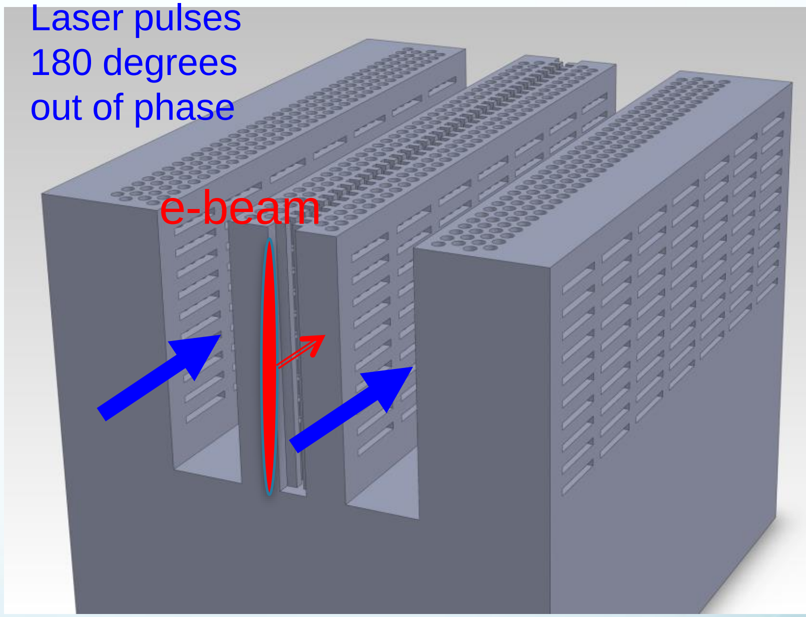
Nature **503**, 91-94 (2013).

300 MV/m



Dielectric Photonic Structure

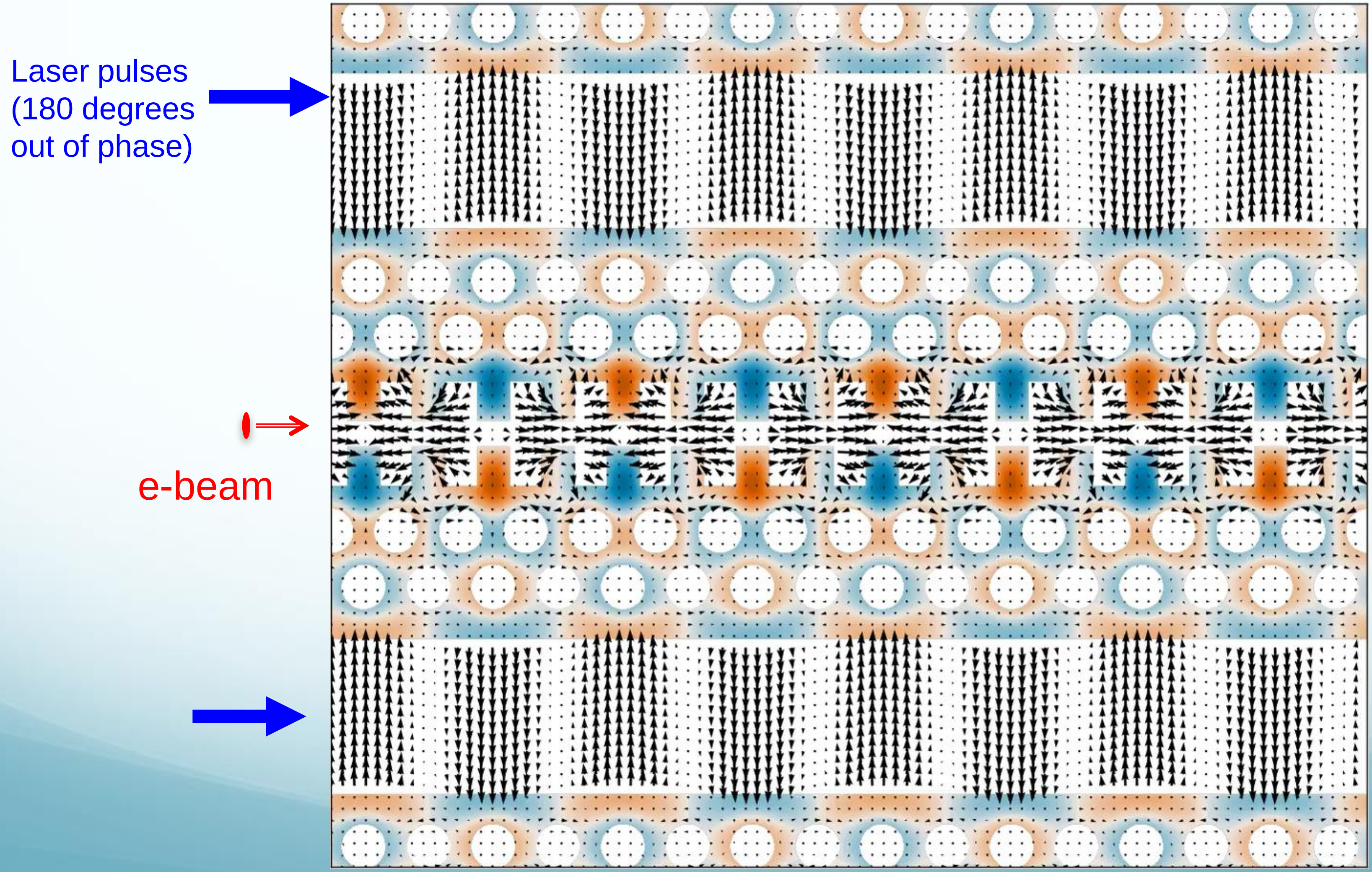
- Why photonic structures (periodic optical nanostructures) ?
  - Natural in dielectric
  - Advantages of burgeoning field
    - design possibilities
    - Fabrication
- Dynamics concerns
- External coupling schemes



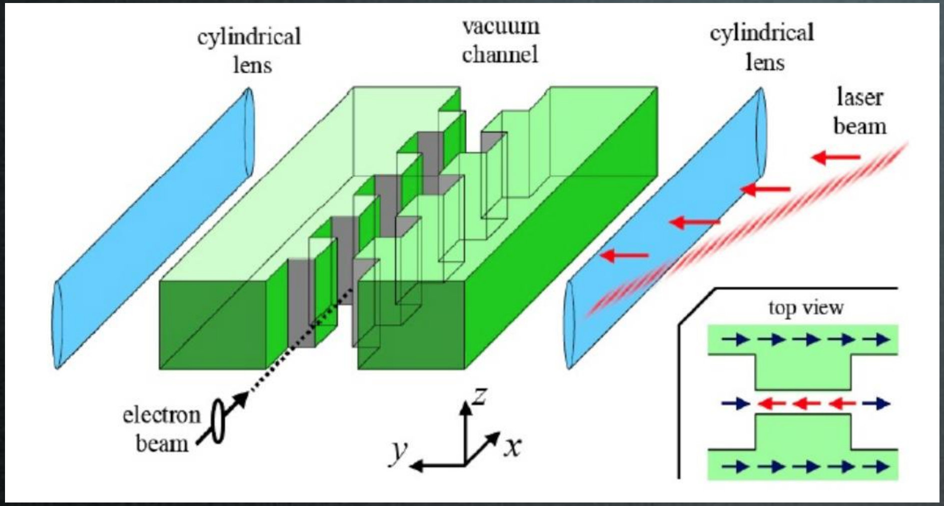
Schematic of GALAXIE monolithic photonic DLA

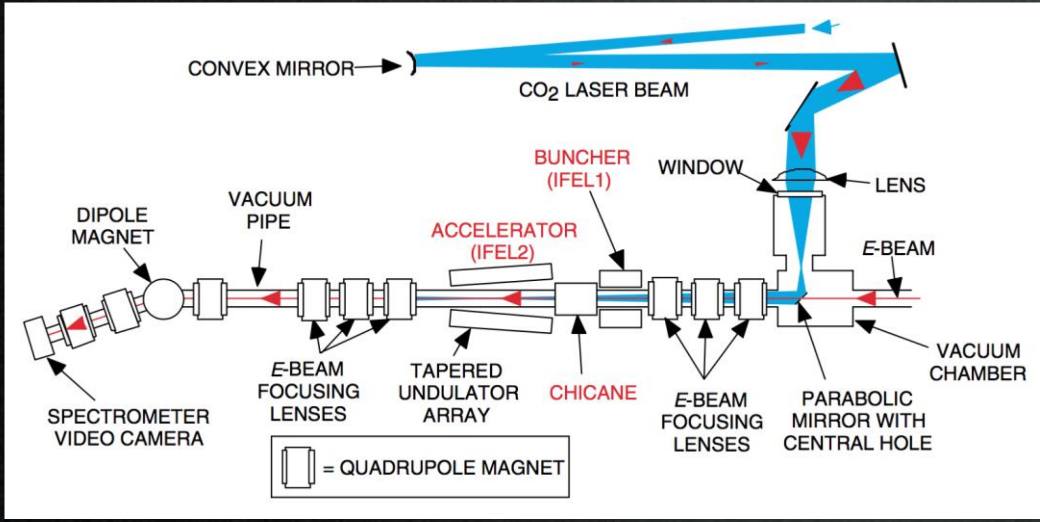
Laser-Structure Coupling: TW

GALAXIE Dual laser drive structure, large reservoir of power recycles



Limitations of Direct Laser Acceleration





Inverse Free Electron Laser

Low emittance

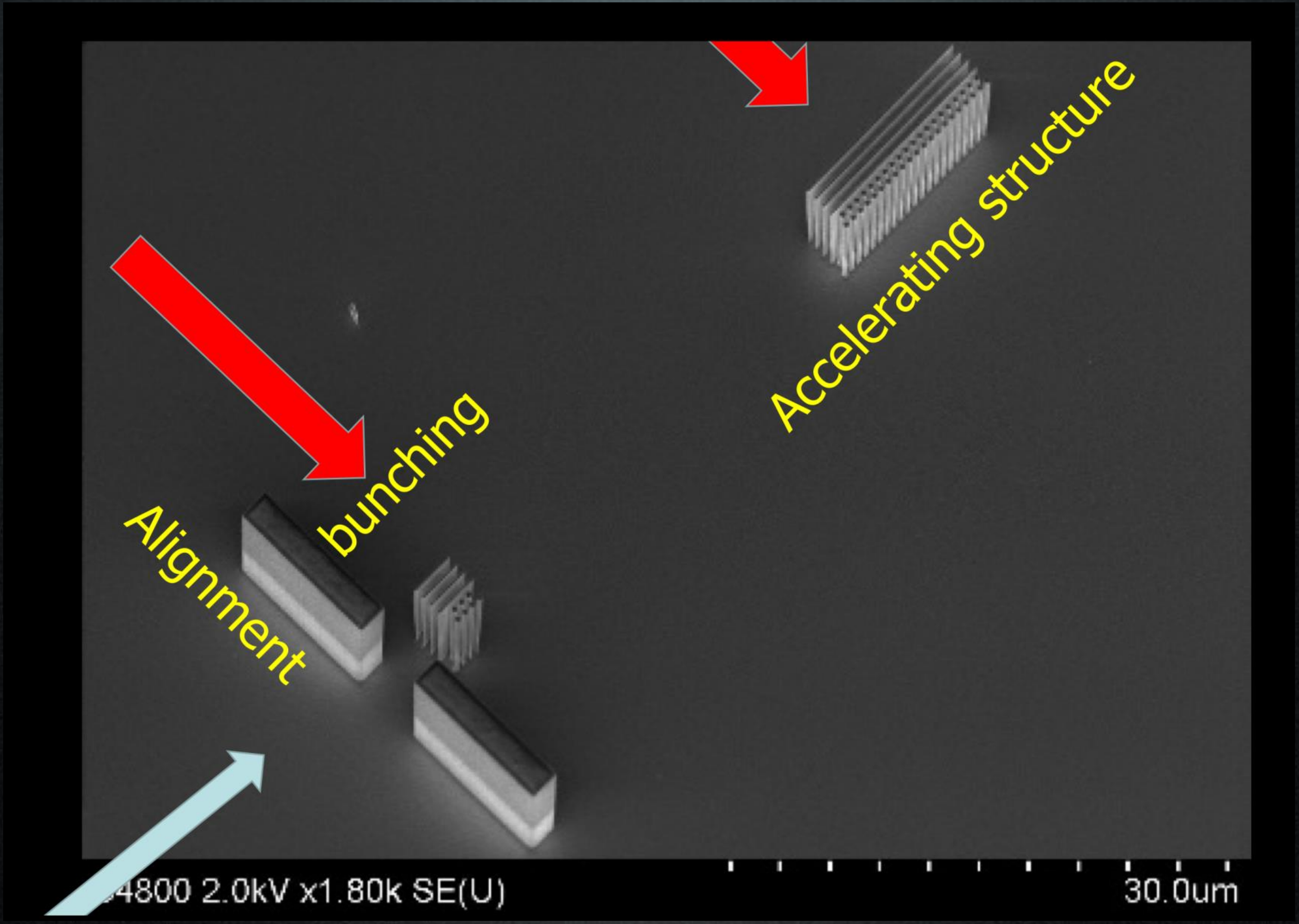
Low charge

Longitudinal dynamics

Timing issue

Alignment issues

Accelerator on chip option

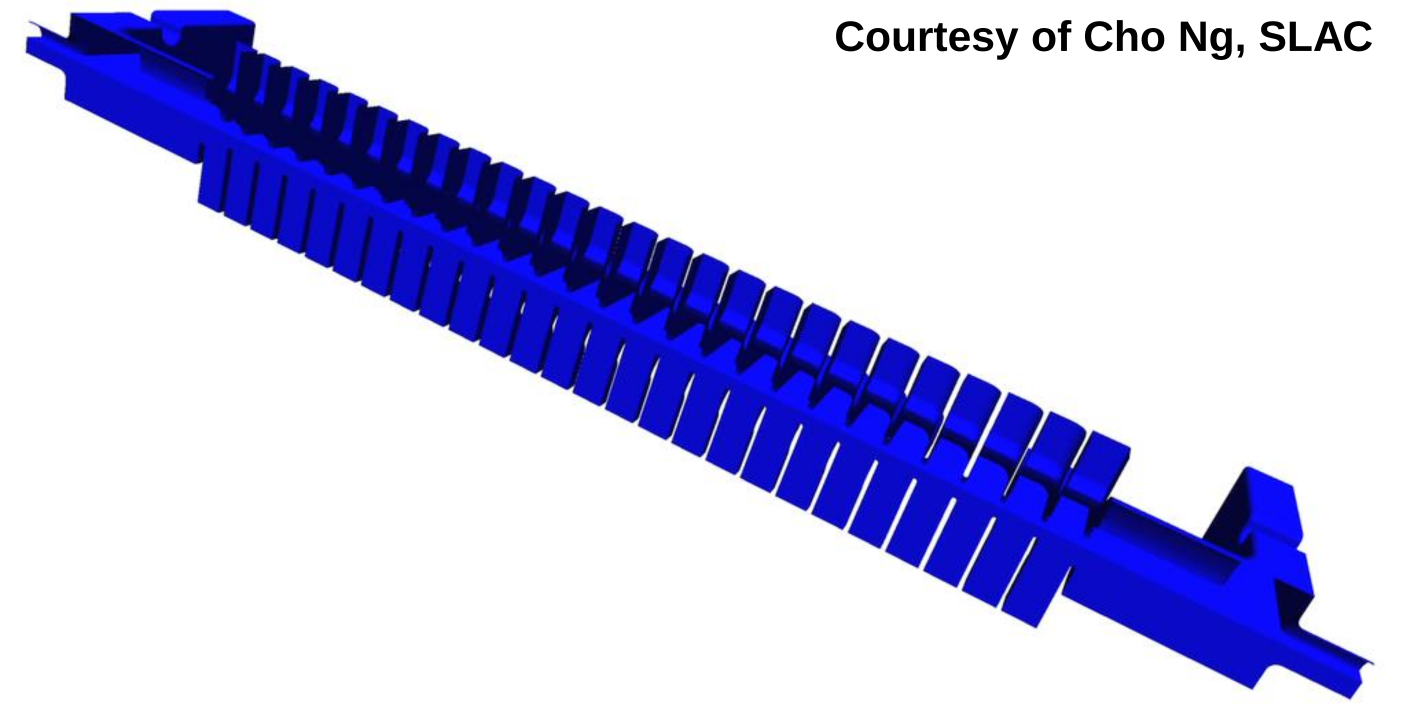


Rasmus Ischebeck for the ACHIP Collaboration, EAAC 2017

① Miniaturization of the accelerating structures (~resonant)

② Wake Field Acceleration (~transient)(LWFA, PWFA, DWFA)

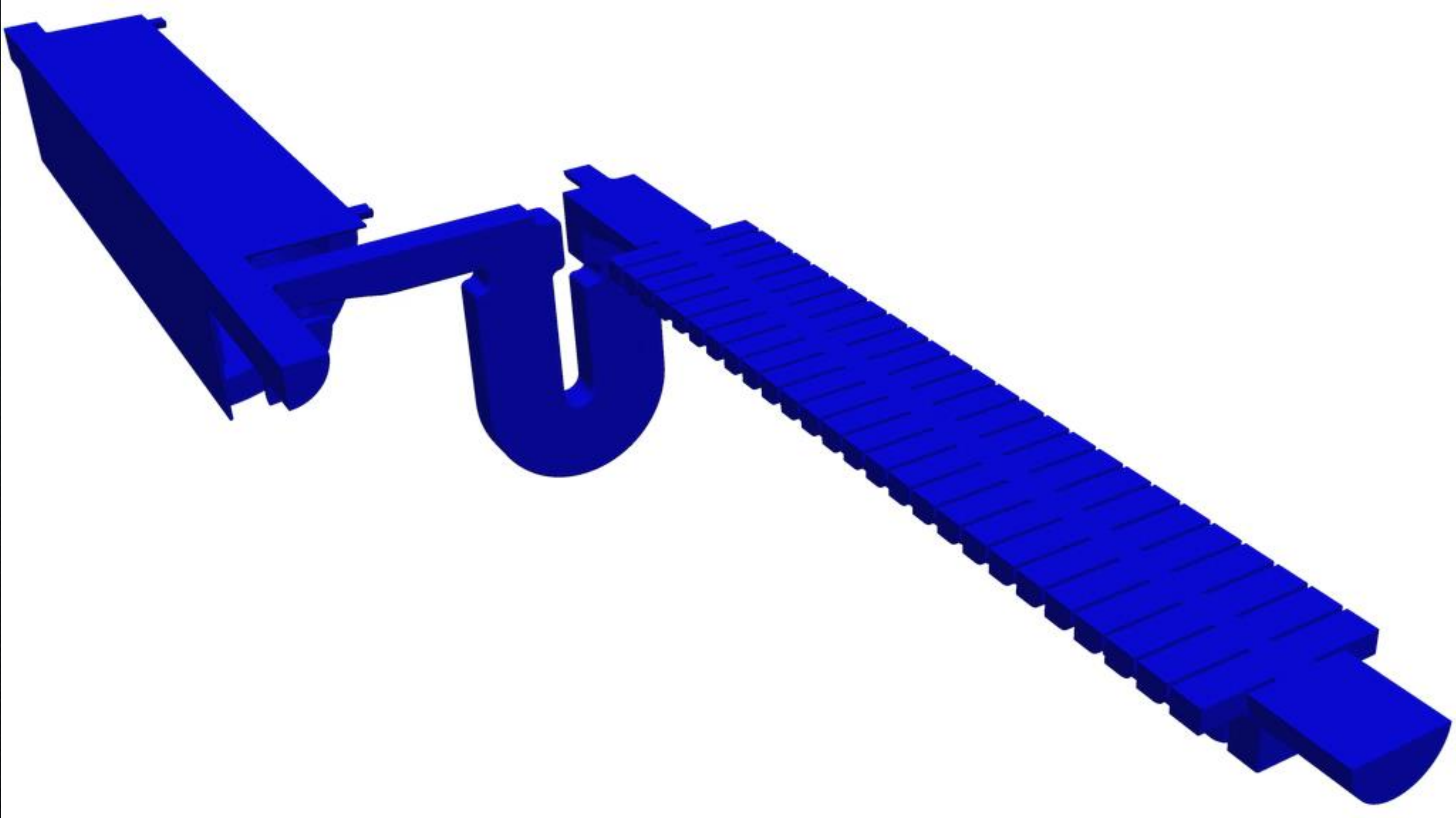
What about wakefields?



(Particle Driven) Wakefield Acceleration paradigm

the EM fields of the accelerating wave are created **inside of the structure** itself by an **intense,** relativistic particle beam. This **drive beam** may be of lower quality and energy than a trailing, accelerating beam. Further, the drive beam may be **specially shaped** (in, e.g. a rising triangular current profile) to give much larger acceleration in the trailing beam than **deceleration in the driver**.

Wakefield feeding RF structures

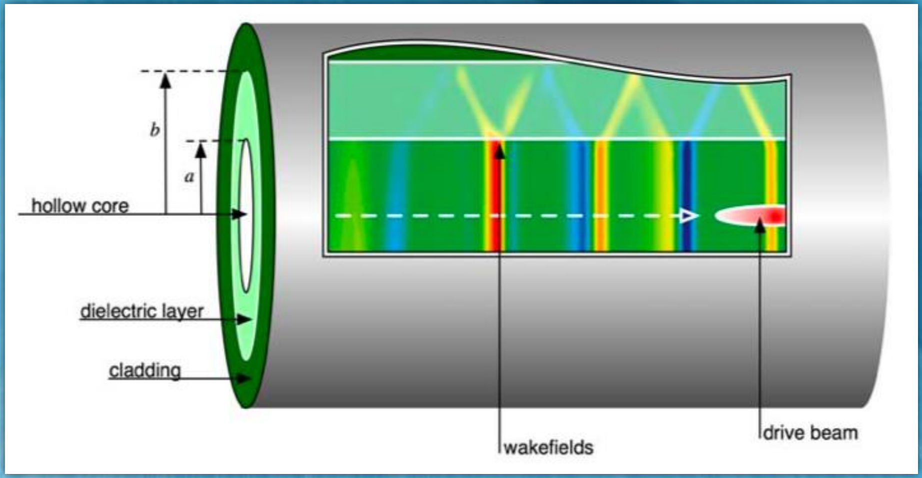


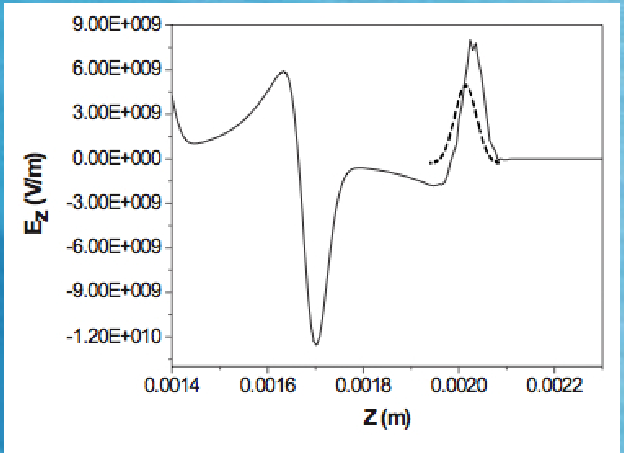
Courtesy of Cho Ng, SLAC

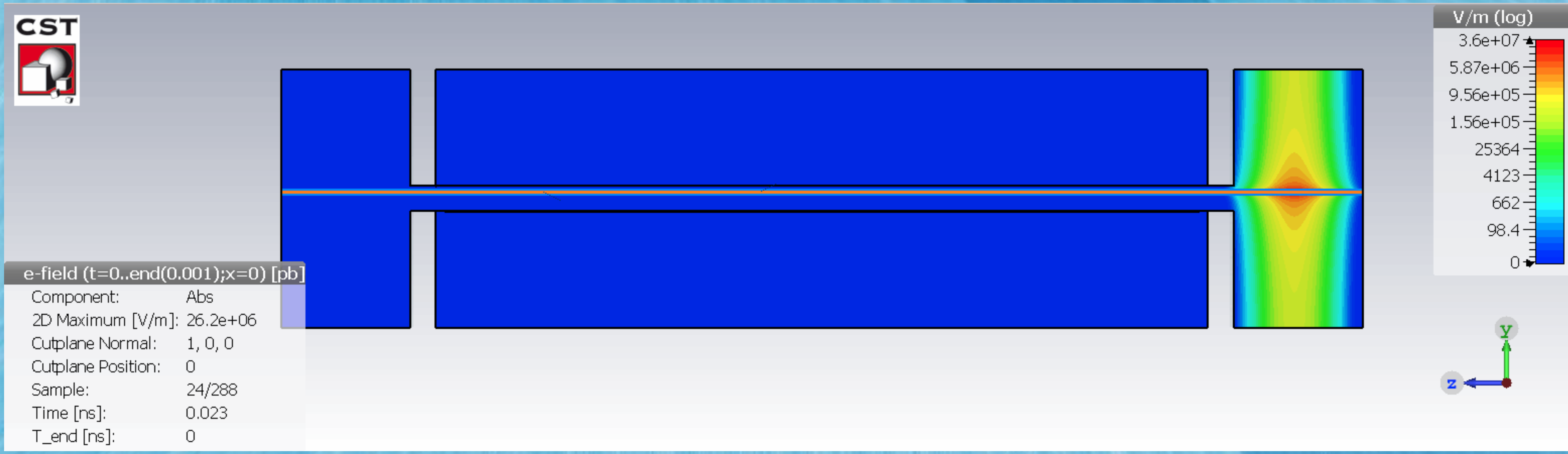
Dielectric Wakefield Acceleration

DWA

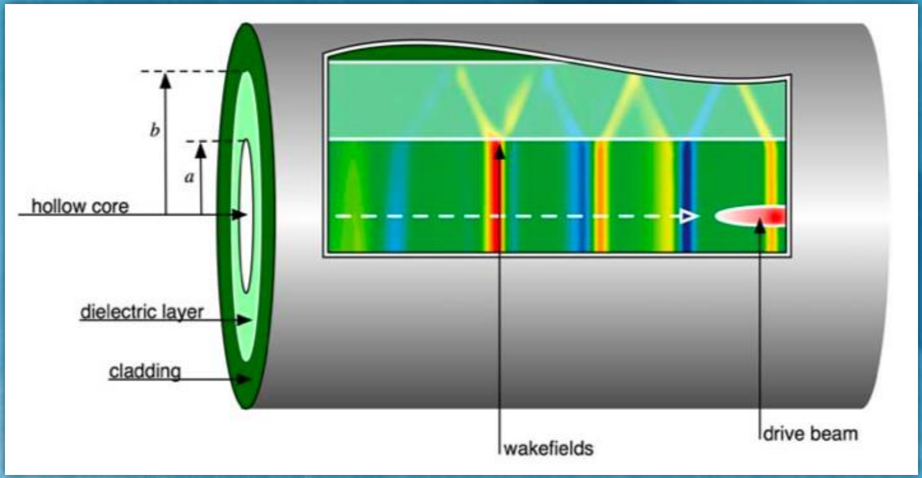
Dielectric Wakefield Accelerator

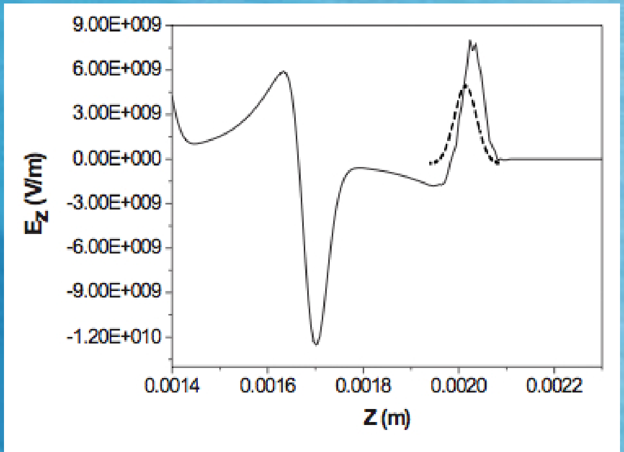


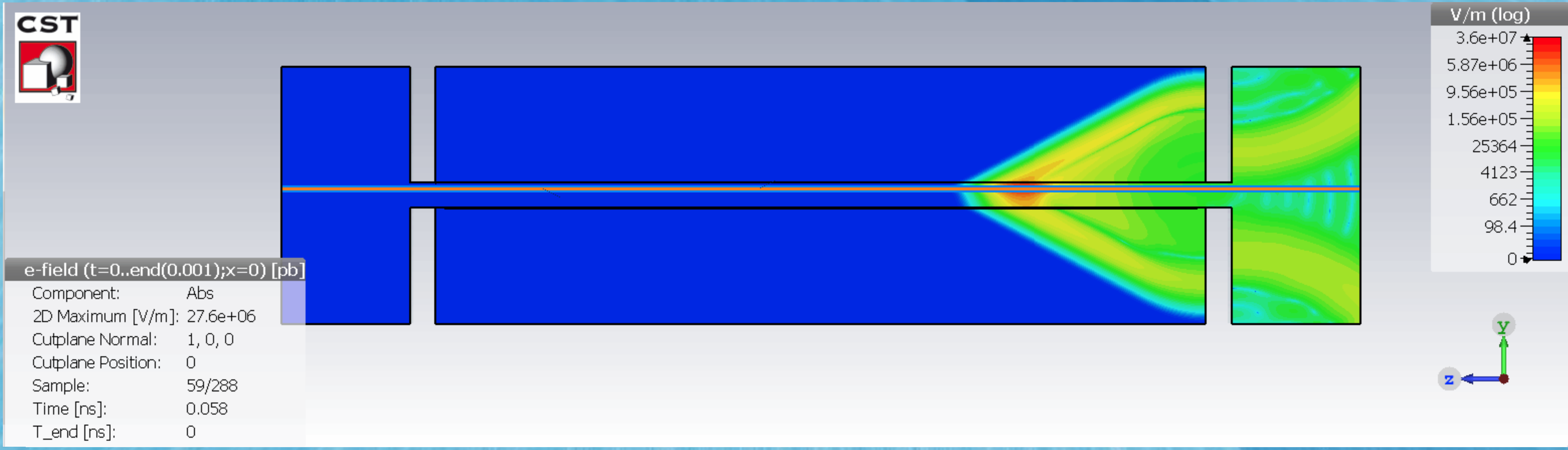




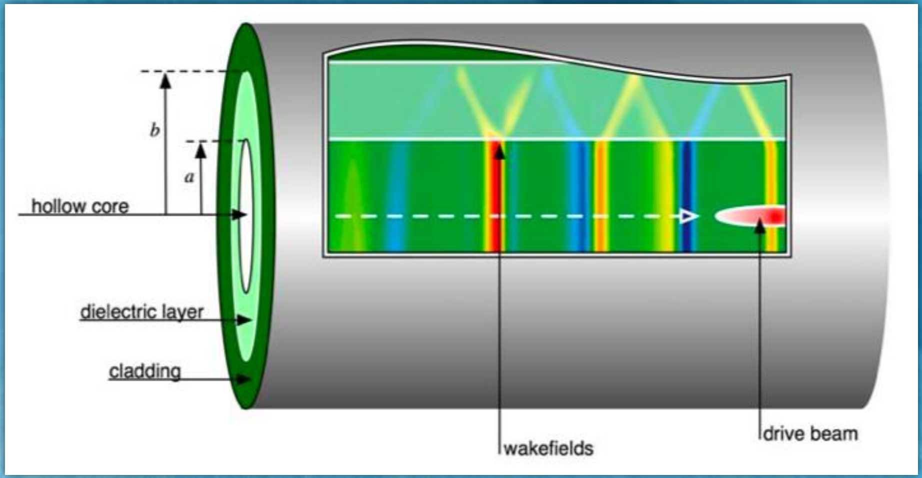
Dielectric Wakefield Accelerator

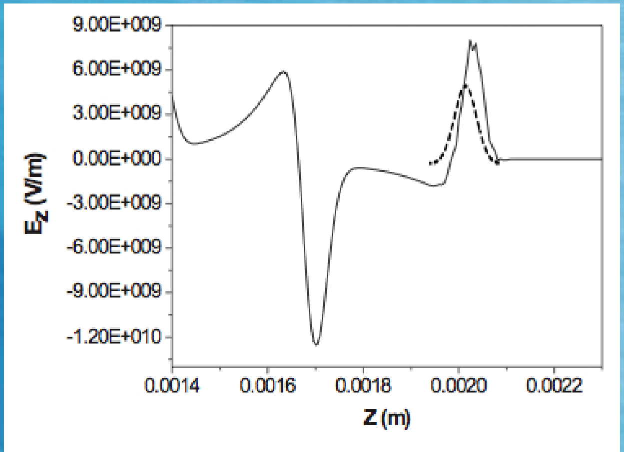


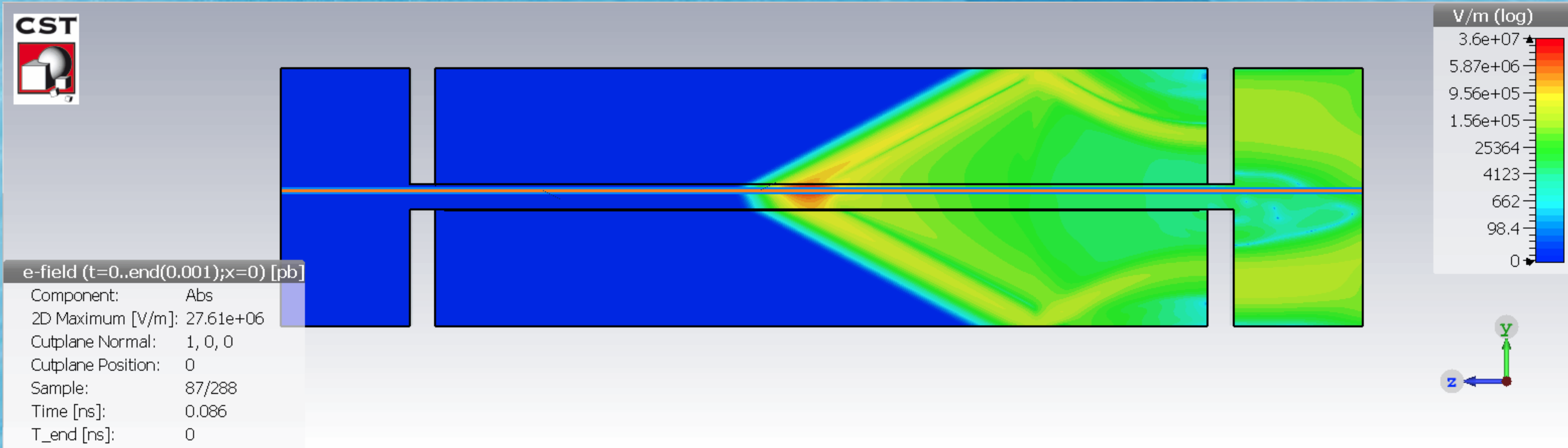




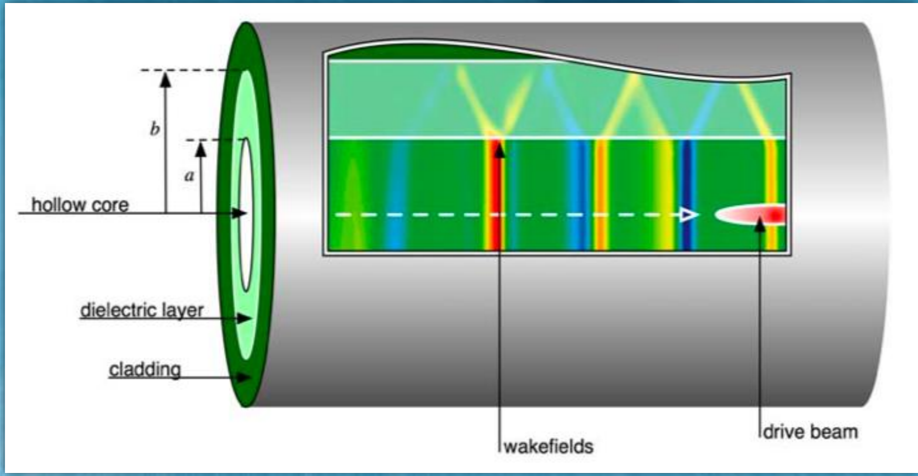
Dielectric Wakefield Accelerator

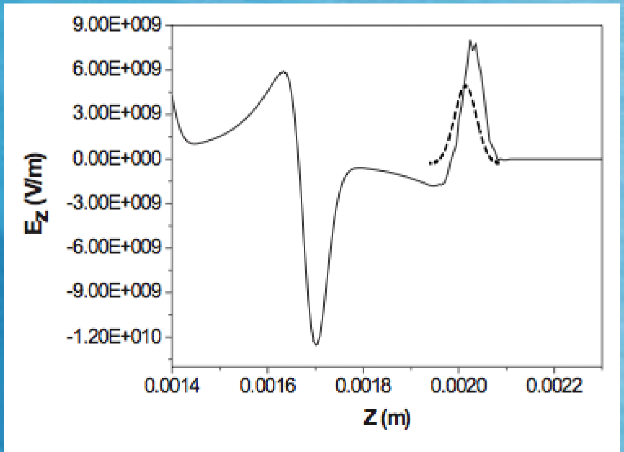


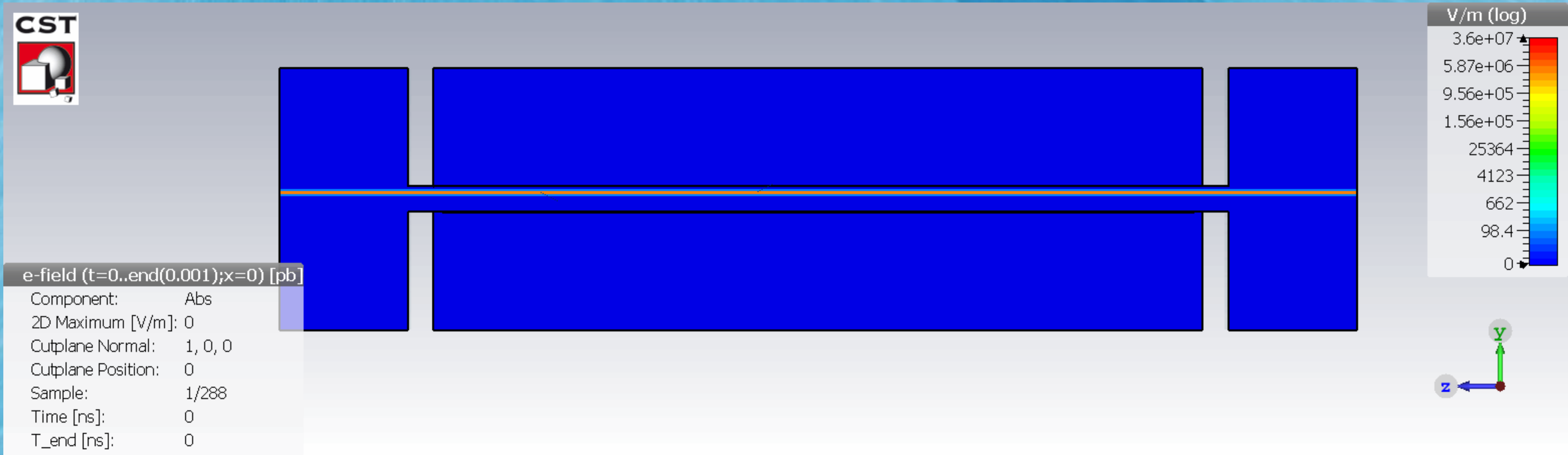




Dielectric Wakefield Accelerator



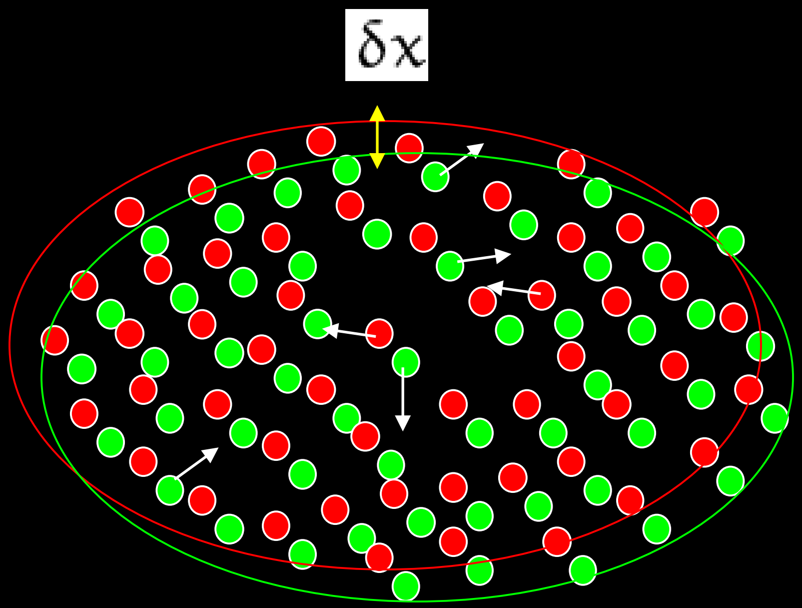




Plasma Acceleration

Surface charge density

$$\sigma = e\,n\,\delta x$$



Surface electric field

$$E_x = -\sigma/\epsilon_0 = -e\,n\,\delta x/\epsilon_0$$

Restoring force

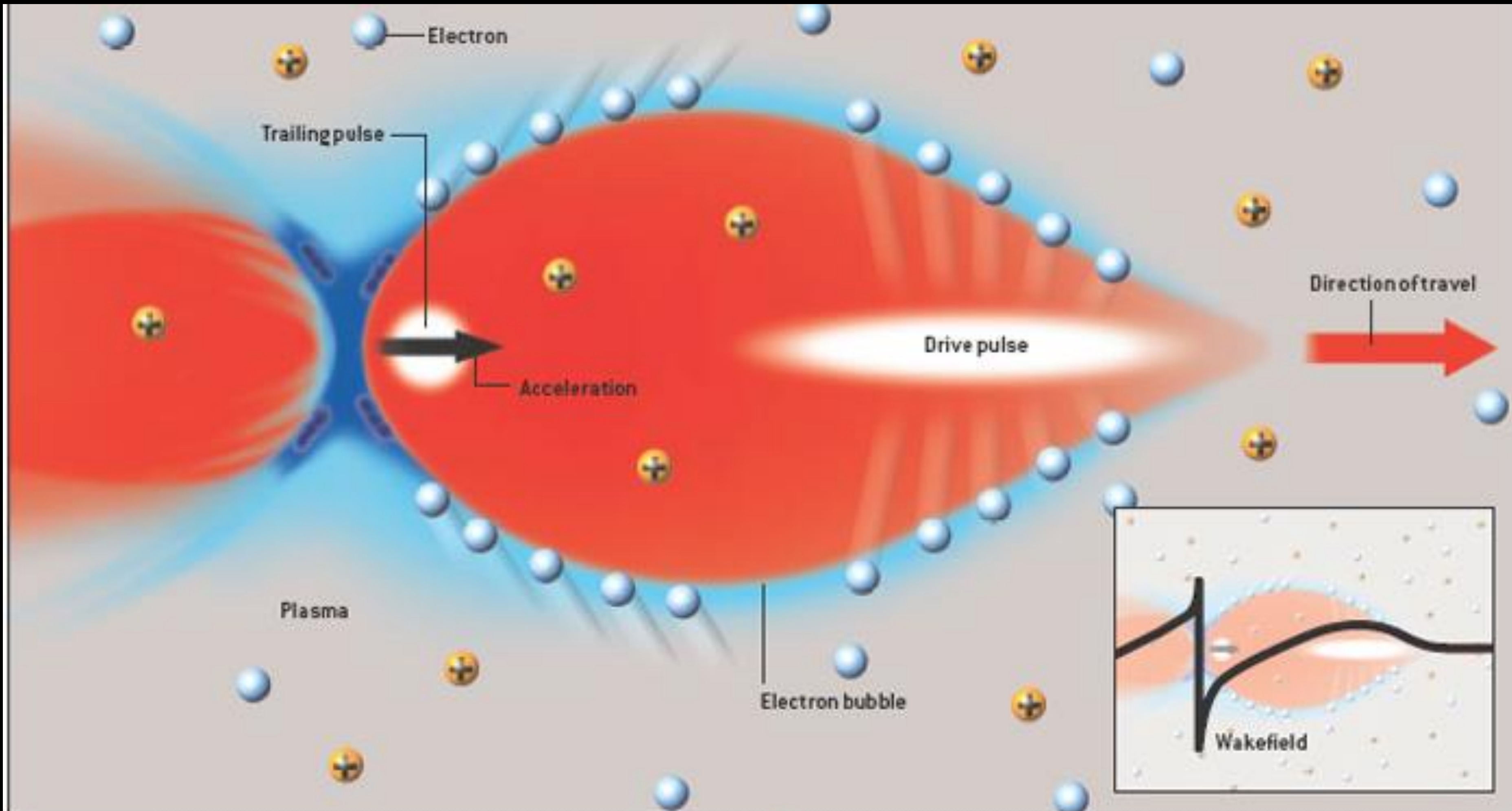
$$m\,\frac{d^2\delta x}{dt^2} = e\,E_x = -m\,\omega_p^{\,2}\,\delta x$$

Plasma frequency

$$\omega_p^{\,2} = \frac{n\,e^2}{\epsilon_0\,m}$$

Plasma oscillations

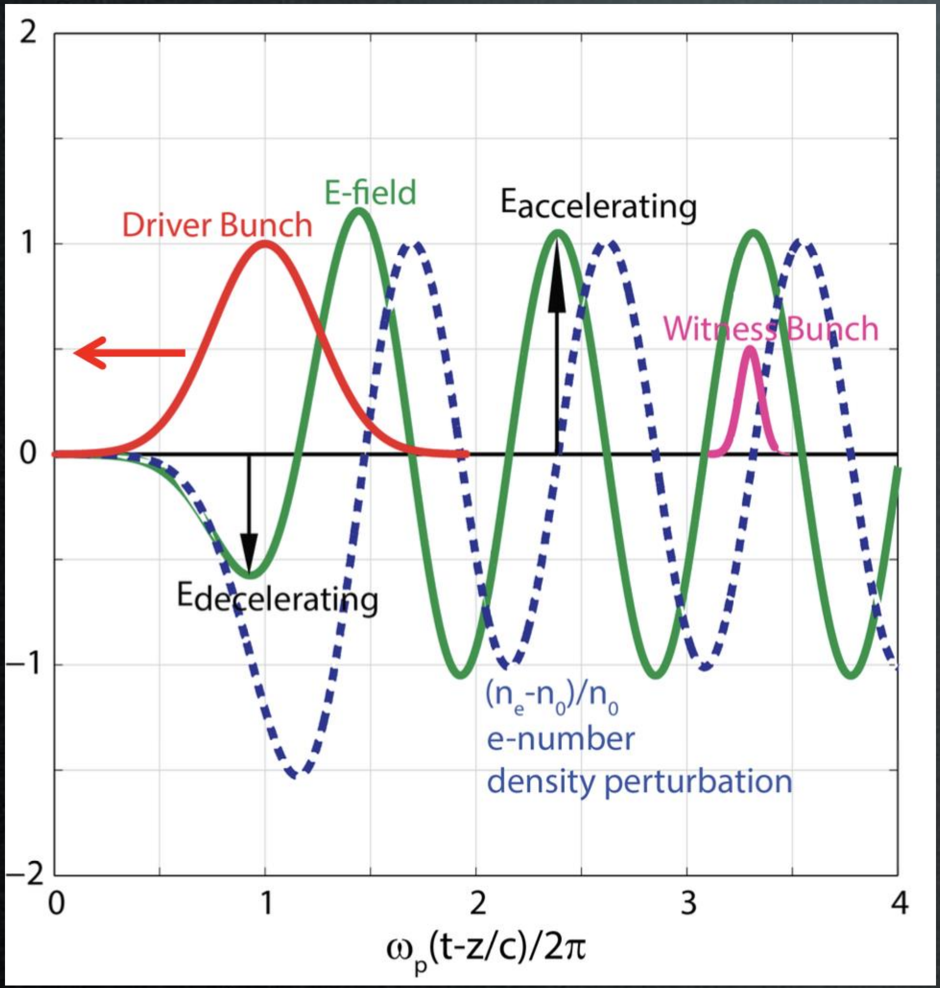
$$\delta x = (\delta x)_0\,\cos\,(\omega_p\,t)$$



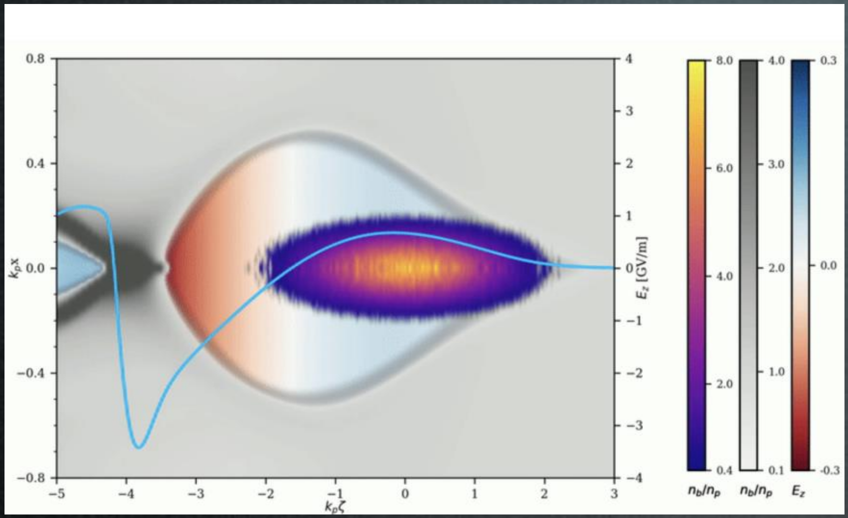
Breakdown limit?

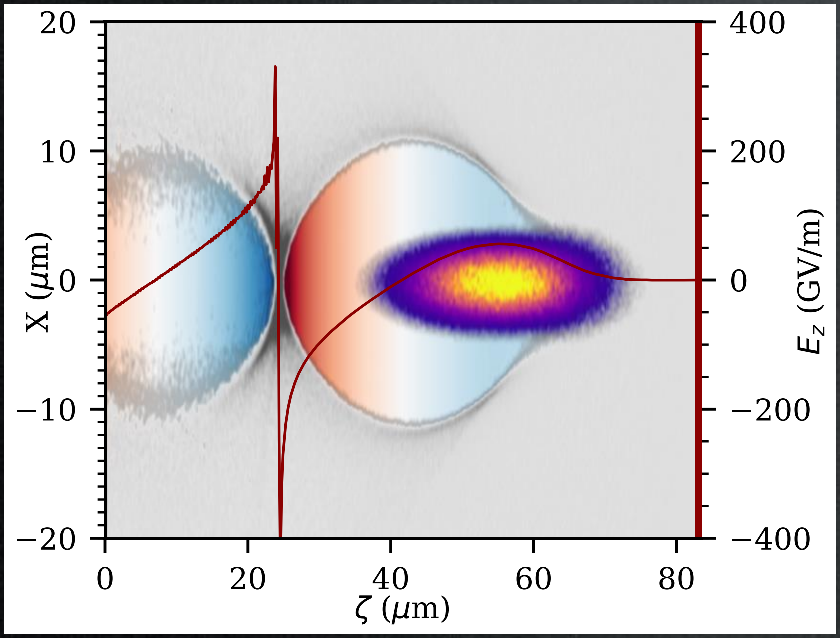
$$E_0 = \frac{m_e c \omega_p}{e} \approx 100[\frac{GeV}{m}] \cdot \sqrt{n_0[10^{18} cm^{-3}]}$$

From linear regime ...

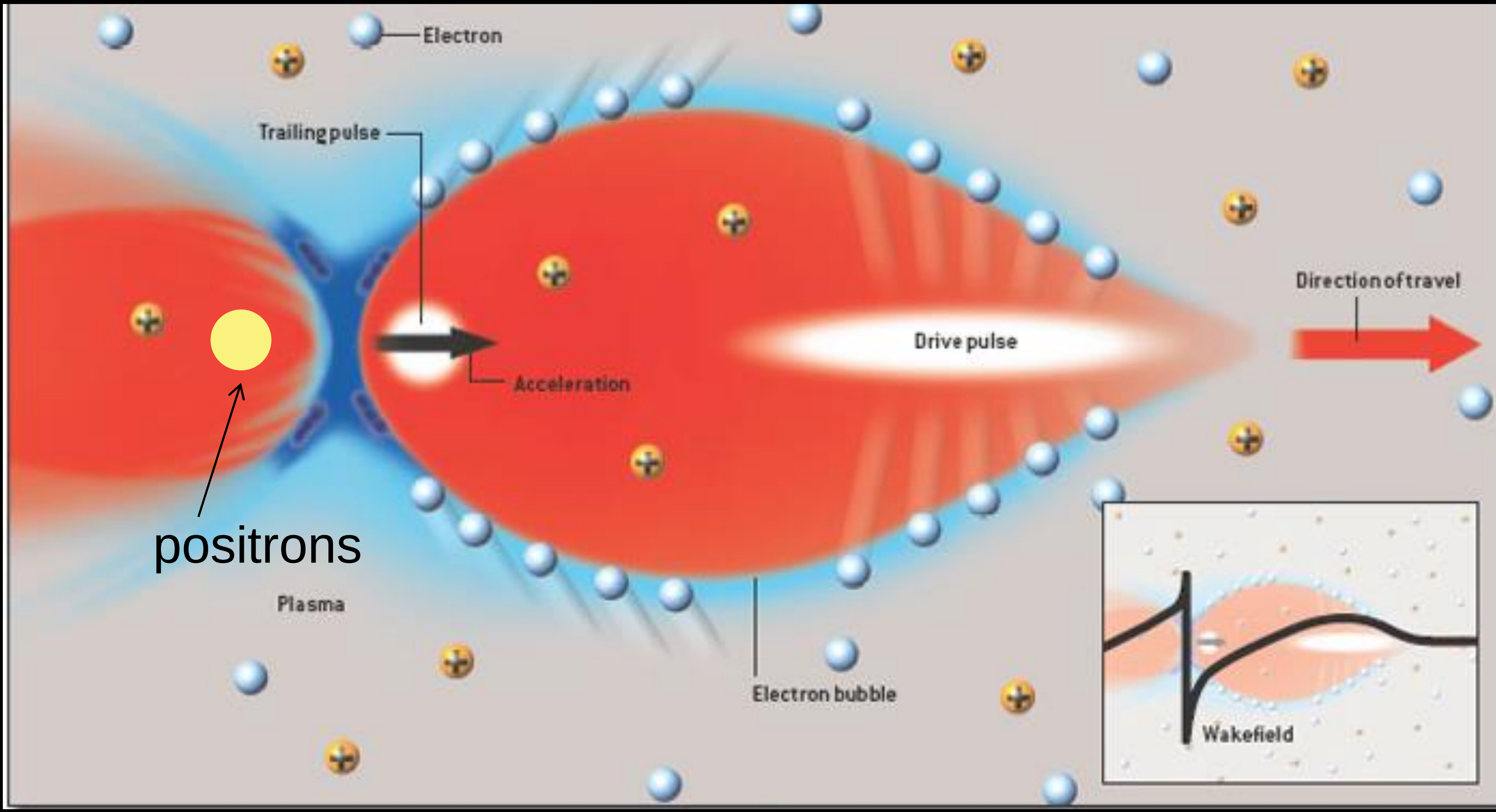


... to quasi linear and non linear regime



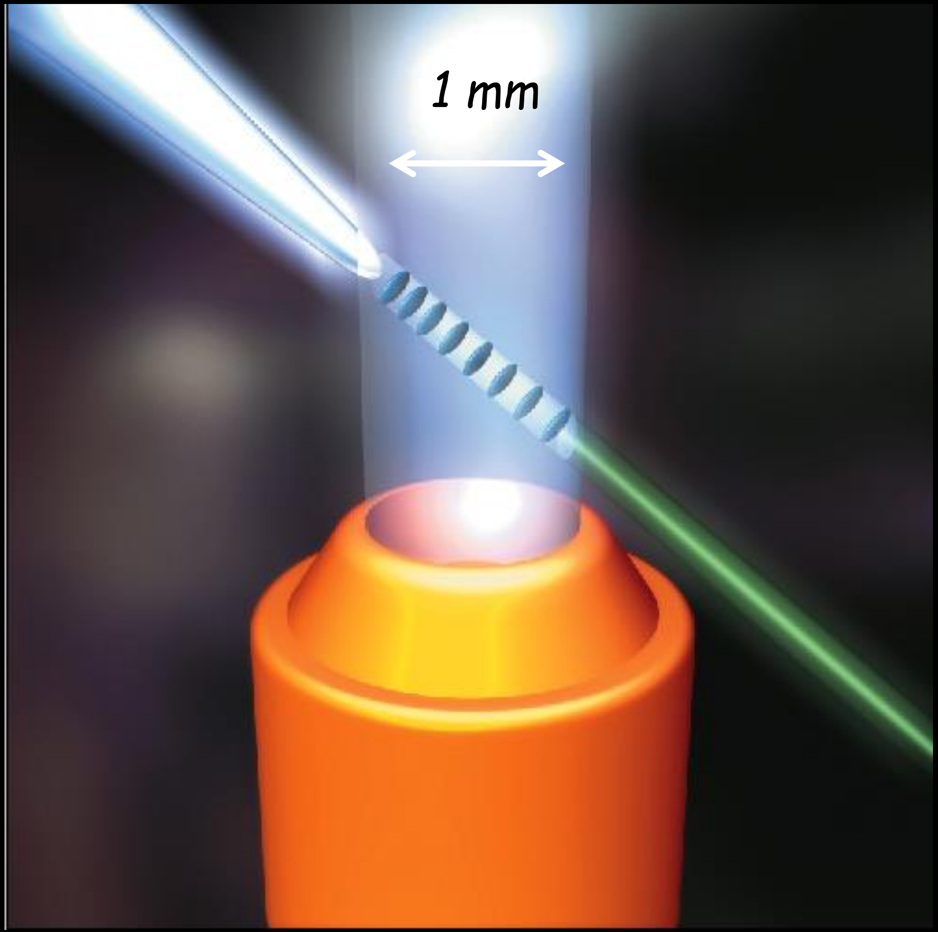


What about externally injected electrons or positrons?



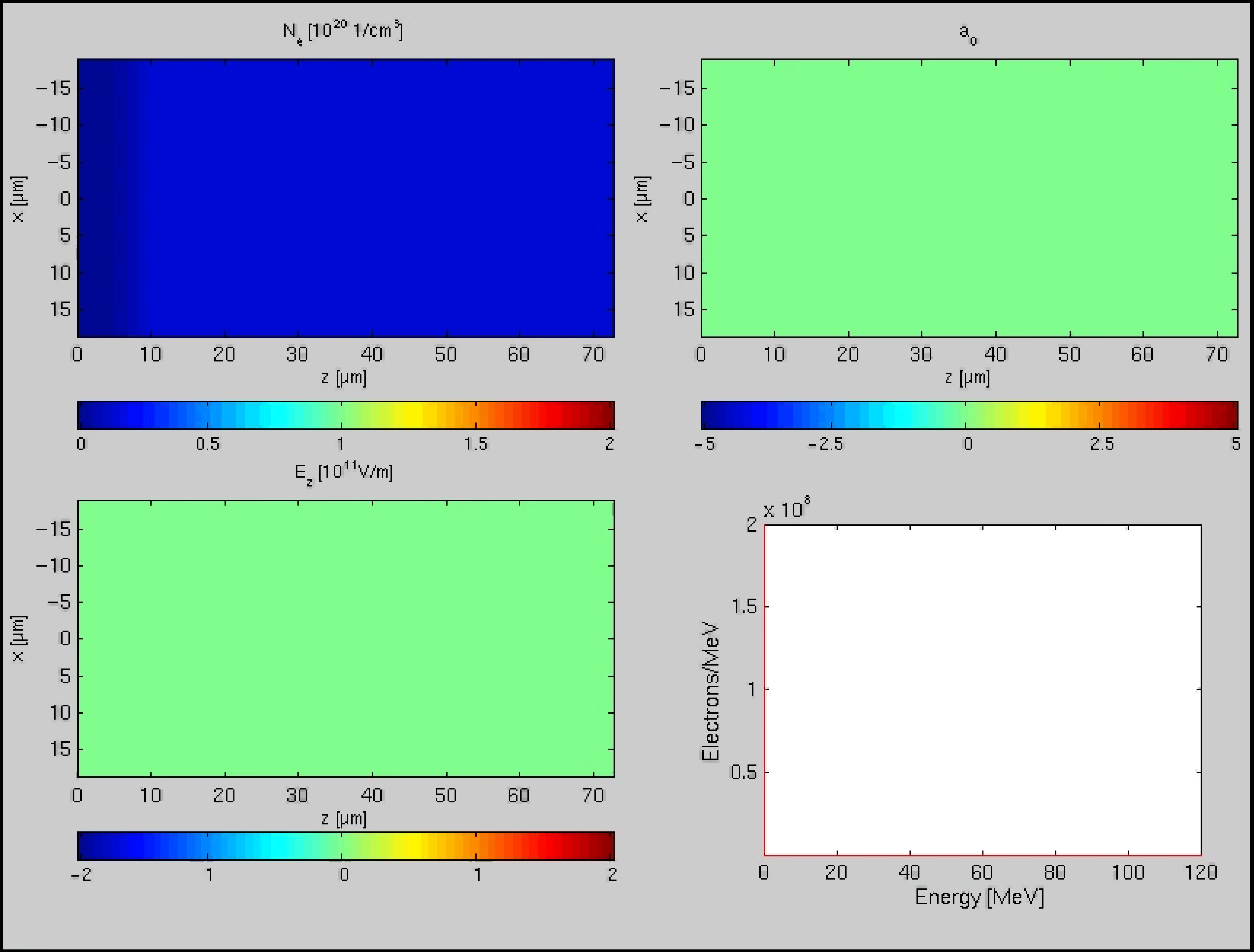
Wake Field Acceleration 1
Laser Driven
LWFA

Direct production of e-beam

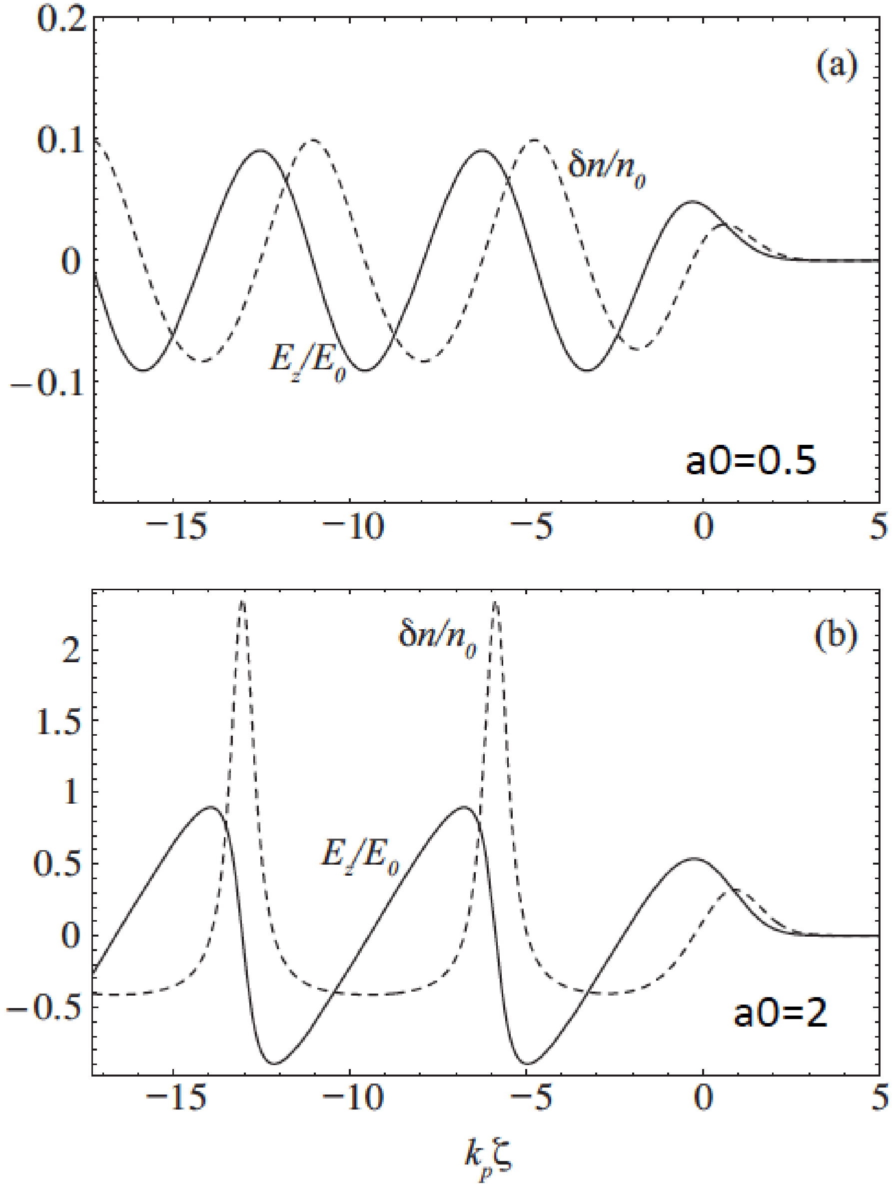


Electron beam

Diffraction - Self injection - Dephasing – Depletion



Regimes: Linear & Non-Linear



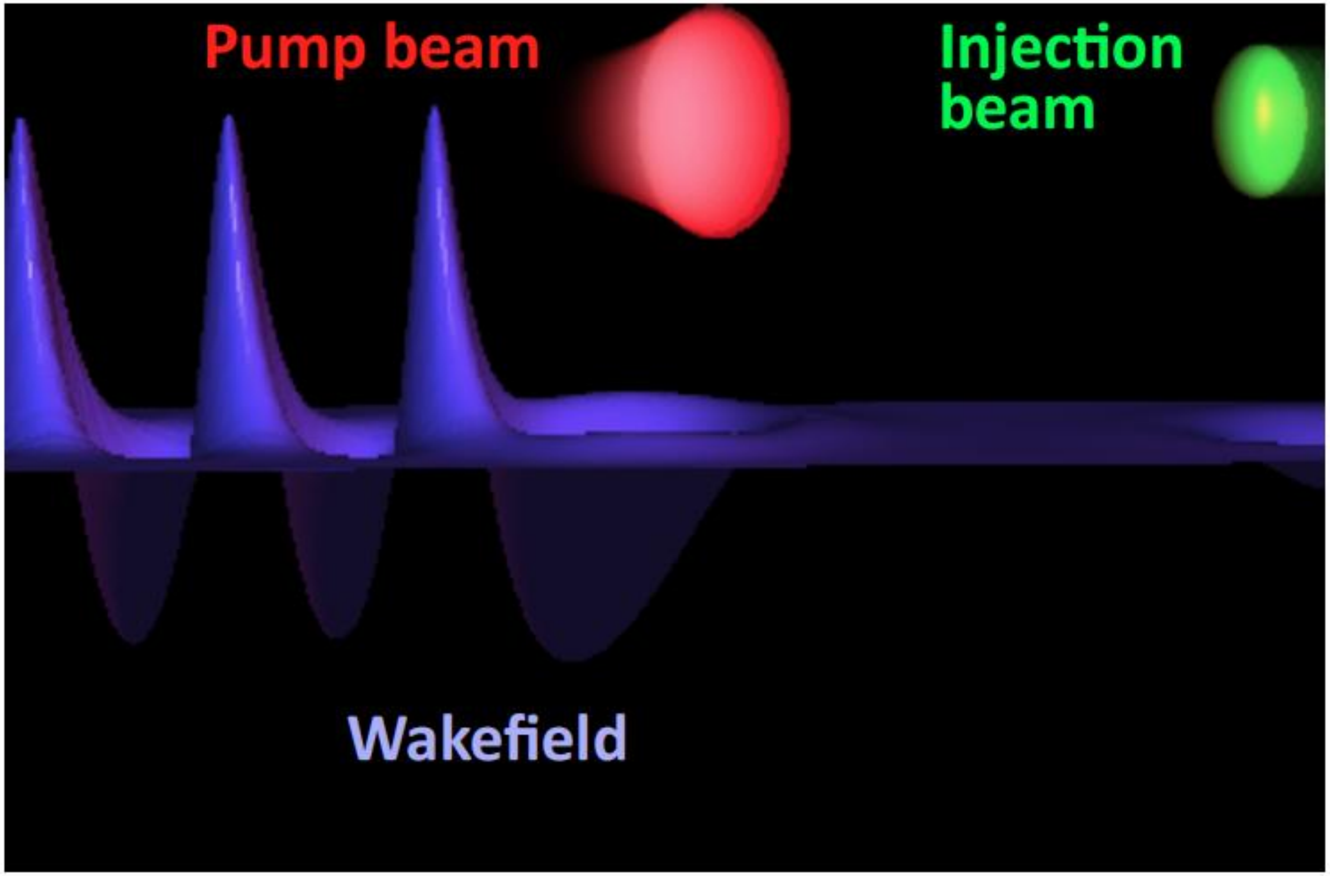
Linear

FIG. 8. Time-averaged density variation $\delta n/n_0$ (dashed curve) and axial electric field E_z/E_0 (solid curve) in an LWFA driven by a Gaussian laser pulse (pulse is moving to the right, centered at $k_p\zeta=0$ with rms intensity length $L_{\rm rms}=k_p^{-1}$) for (a) $a_0=0.5$ and (b) $a_0=2.0$.

Non-Linear

Colliding Laser Pulses Scheme

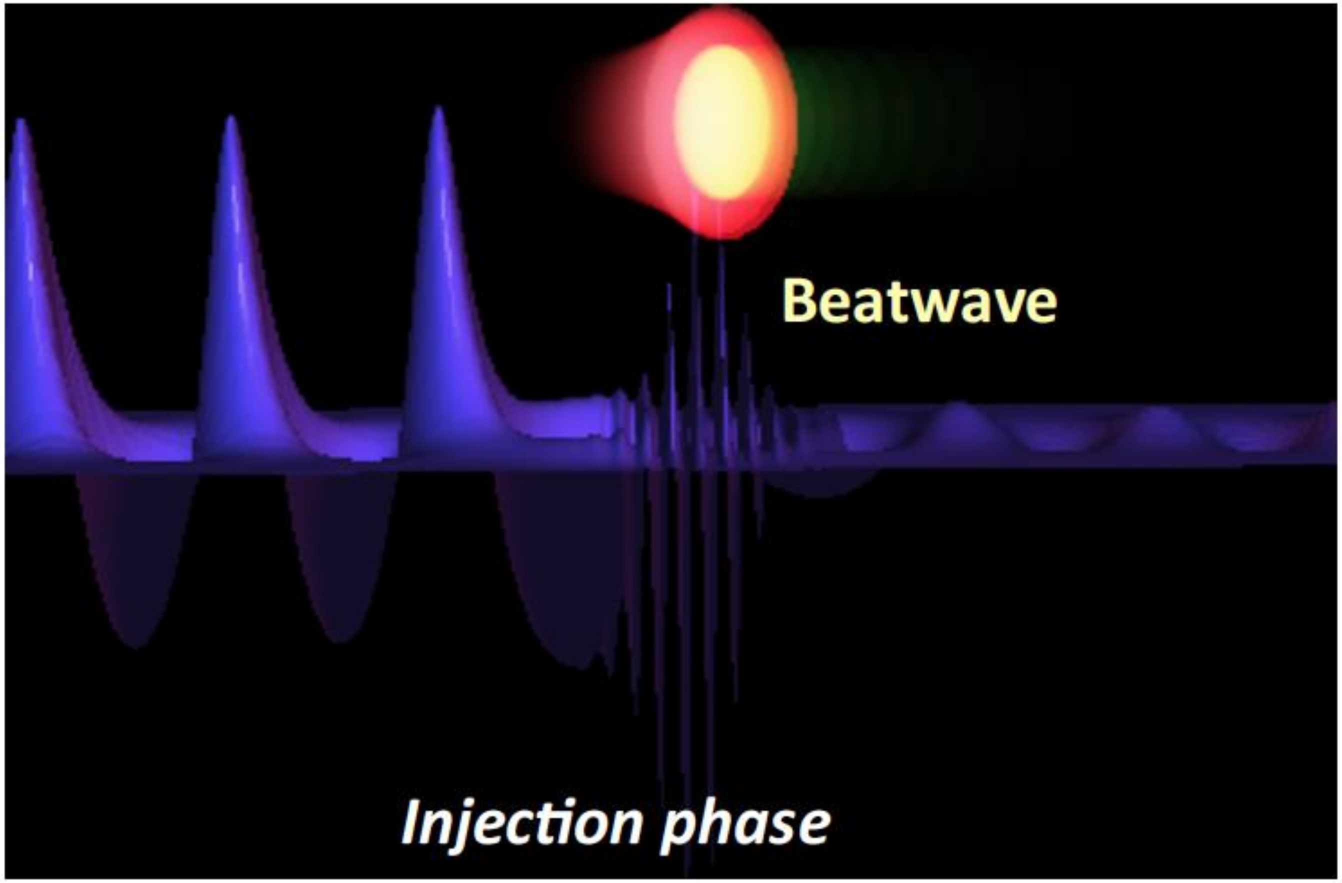
The first laser creates the accelerating structure, a second laser beam is used to heat electrons



Theory : E. Esarey *et al.*, PRL **79**, 2682 (1997), H. Kotaki *et al.*, PoP **11** (2004)
Experiments : J. Faure *et al.*, Nature **444**, 737 (2006)

Colliding Laser Pulses Scheme

The first laser creates the accelerating structure, a second laser beam is used to heat electrons



Theory : E. Esarey *et al.*, PRL **79**, 2682 (1997), H. Kotaki *et al.*, PoP **11** (2004)
Experiments : J. Faure *et al.*, Nature **444**, 737 (2006)

Colliding Laser Pulses Scheme

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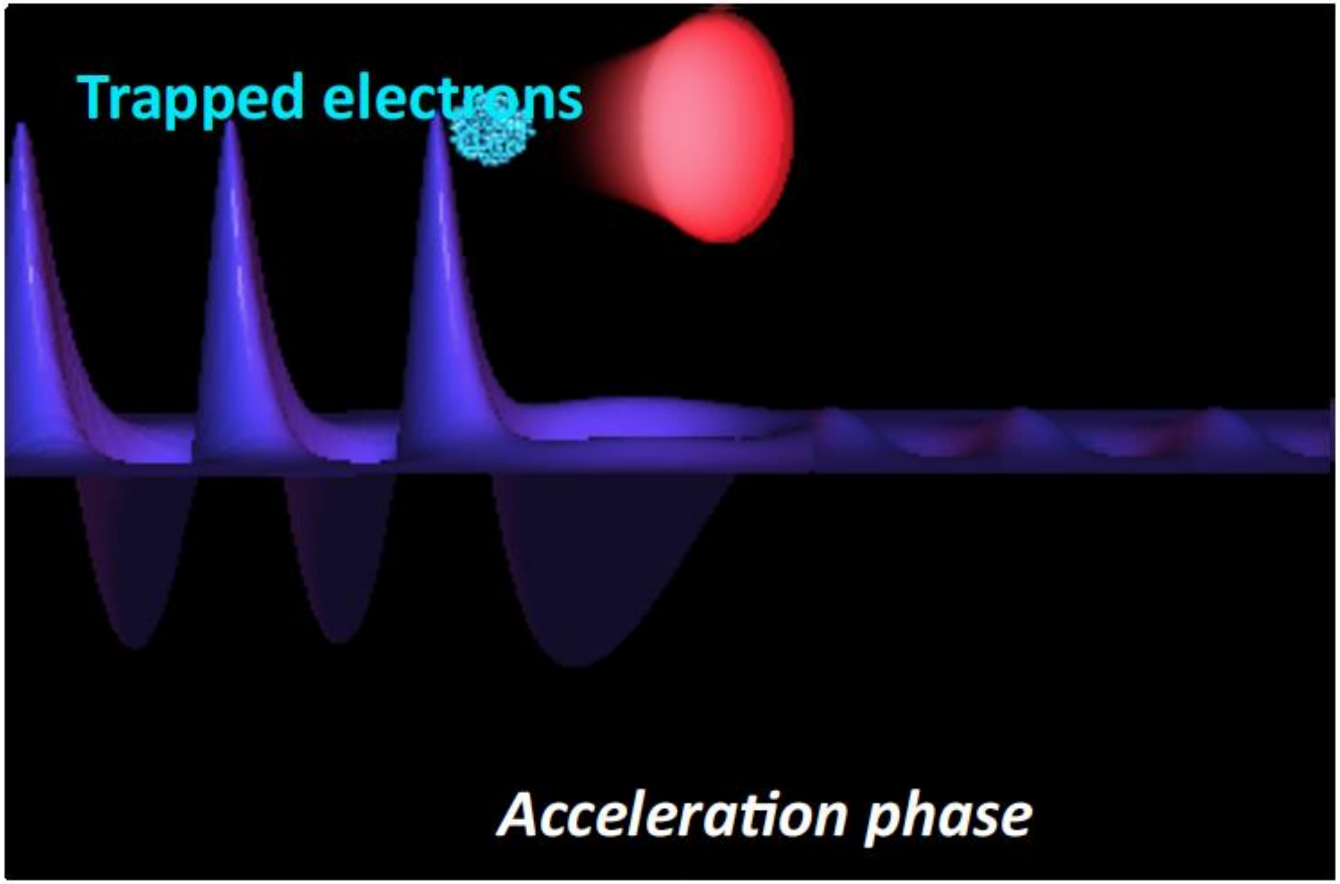
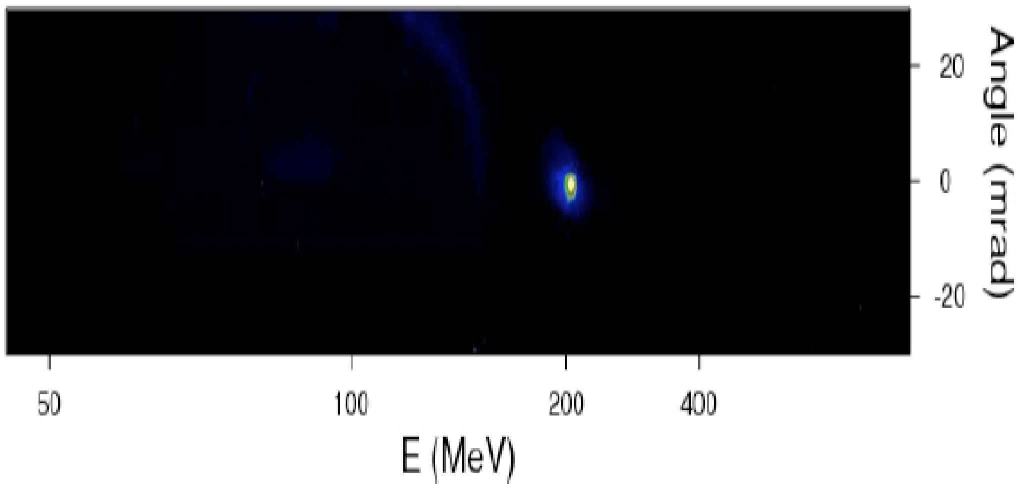
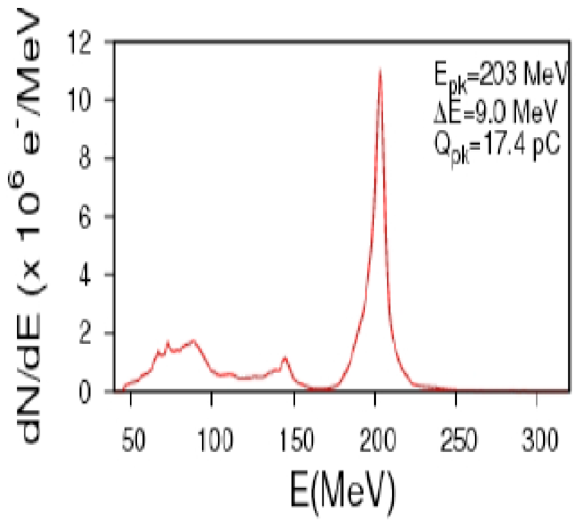


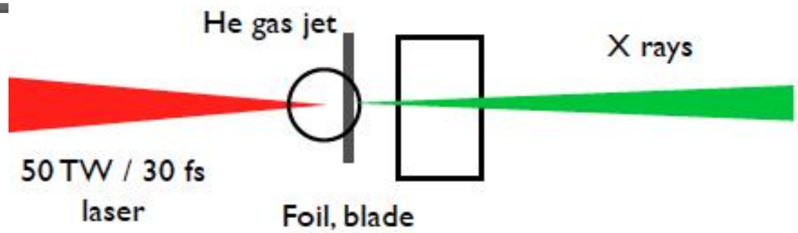
Theory : E. Esarey *et al.*, PRL **79**, 2682 (1997), H. Kotaki *et al.*, PoP **11** (2004)
Experiments : J. Faure *et al.*, Nature **444**, 737 (2006)

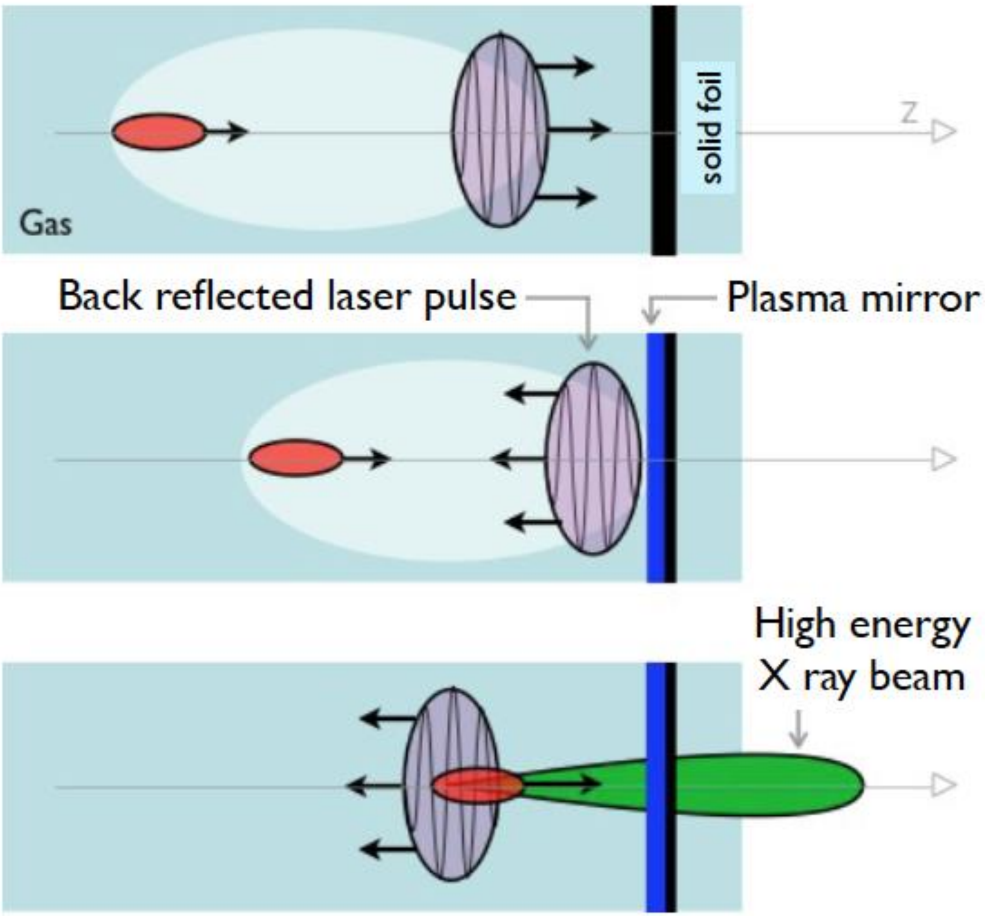
Stable Laser Plasma Accelerators





Inverse Compton Scattering : New scheme





A single laser pulse

A plasma mirror reflects the laser beam

The back reflected laser collides with the accelerated electrons

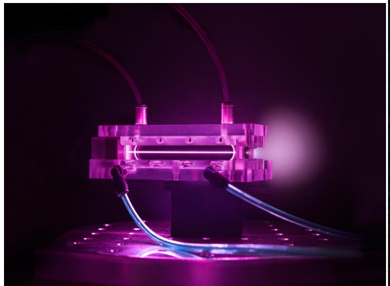
No alignment : the laser and the electron beams naturally overlap

Save the laser energy !

BELLA: BErkeley Lab Laser Accelerator

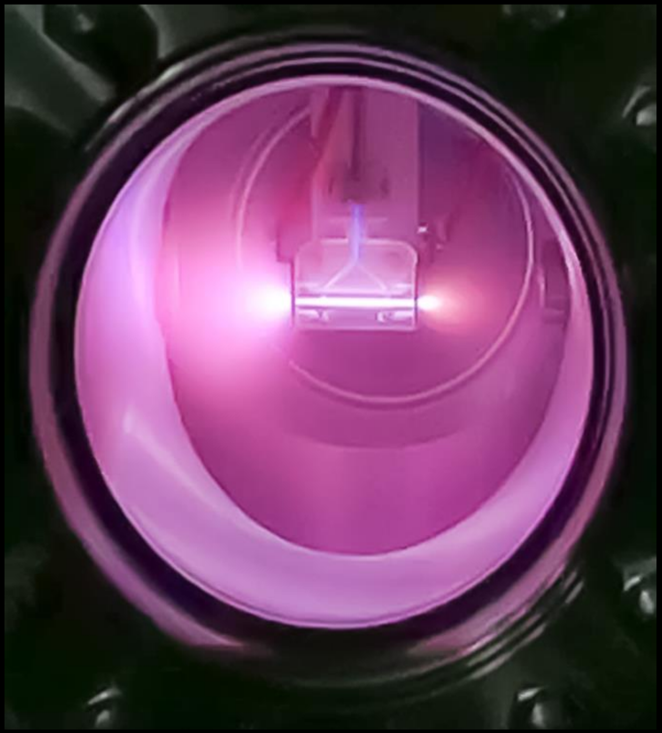
BELLA Facility: state-of-the-art 1.3 PW-laser for laser accelerator science: >42 J in <40 fs (> 1PW) at 1 Hz laser and supporting infrastructure at LBNL

Critical HEP experiments:
- 10 GeV electron beam from <1 m LPA
- Staging LPAs
- Positron acceleration

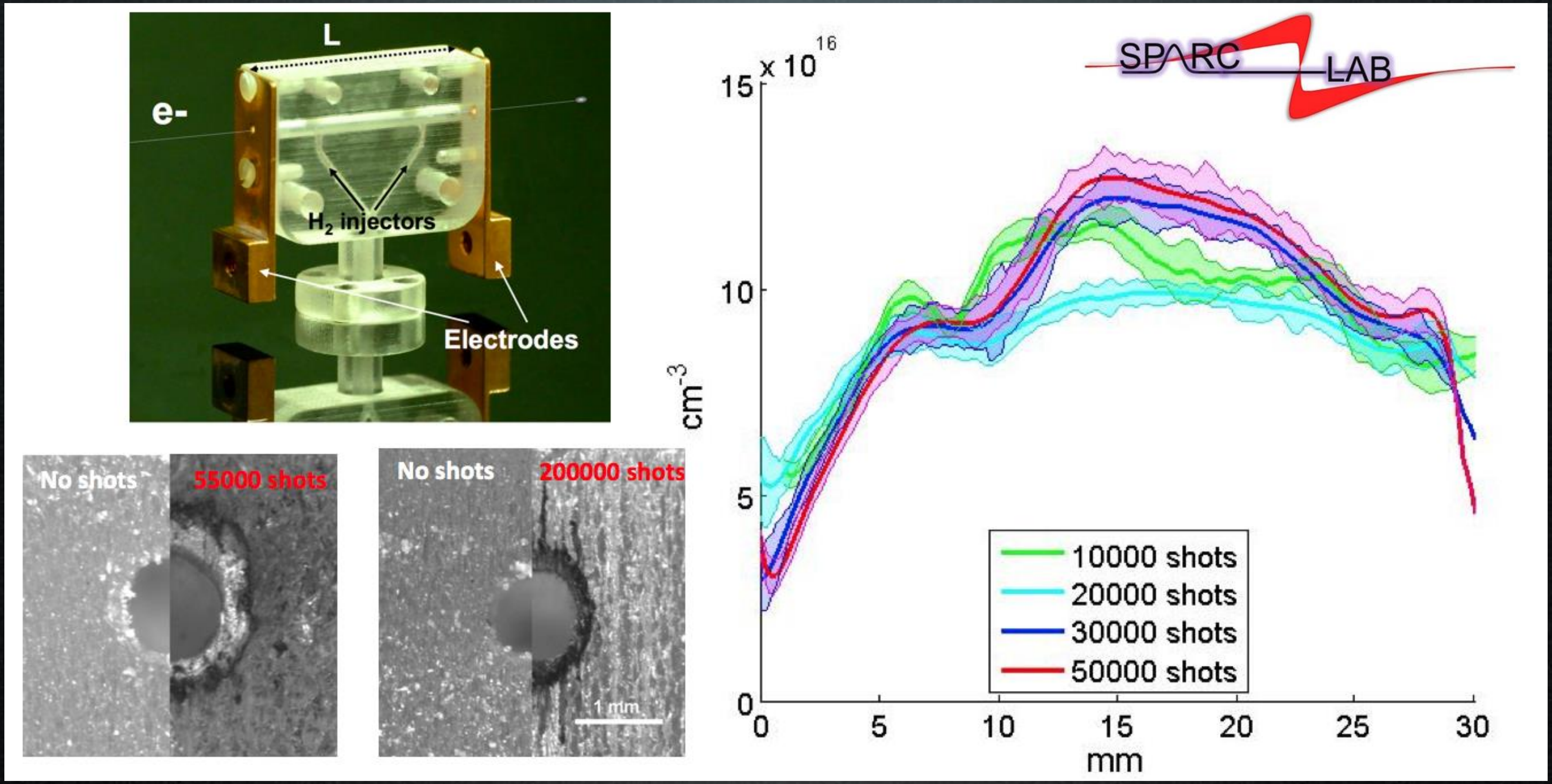


BELLA

Capillary Discharge

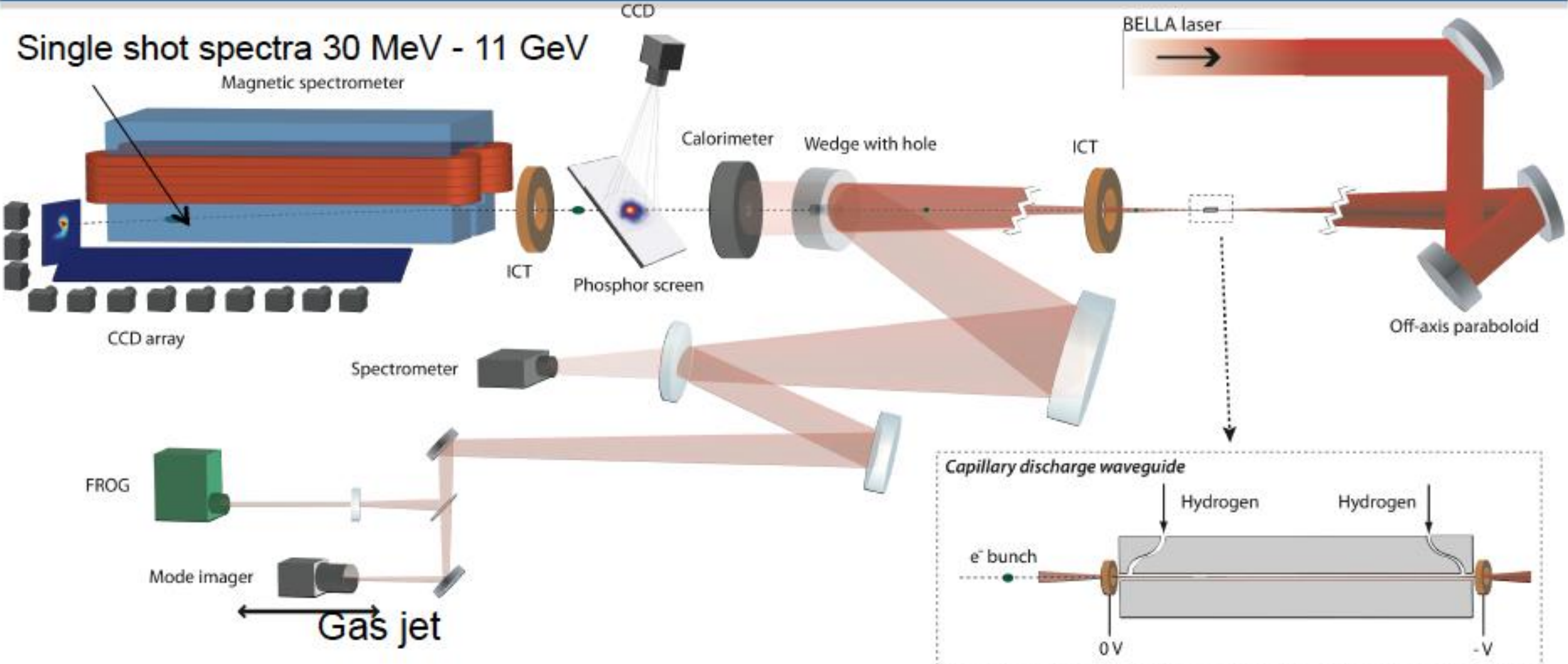


Capillary in the beam line

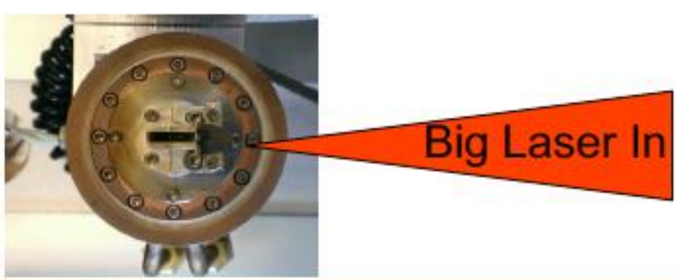


Experiments at LBNL use the BELLA laser focused by a 14 m focal length off-axis paraboloid onto gas jet or capillary discharge targets

Single shot spectra 30 MeV - 11 GeV



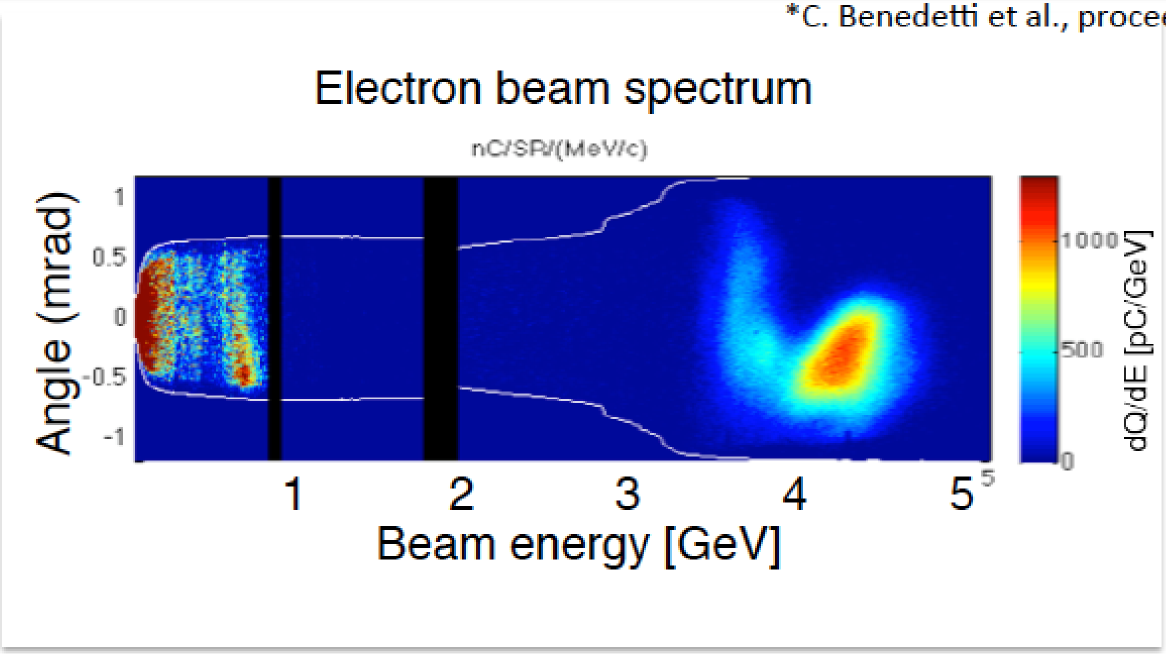
Gas jet

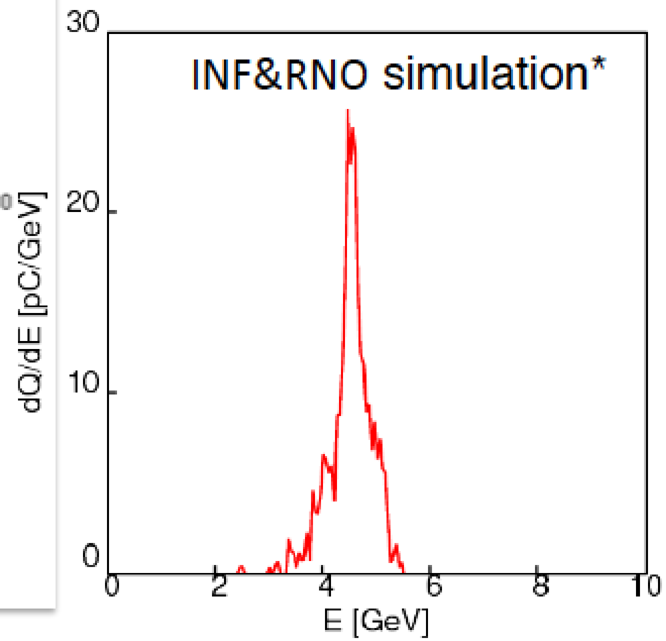


Capillary discharge

4.25 GeV beams have been obtained from 9 cm plasma channel powered by 310 TW laser pulses (15 J)

*C. Benedetti et al., proceedings of AAC2010, proceedings of ICAP2012





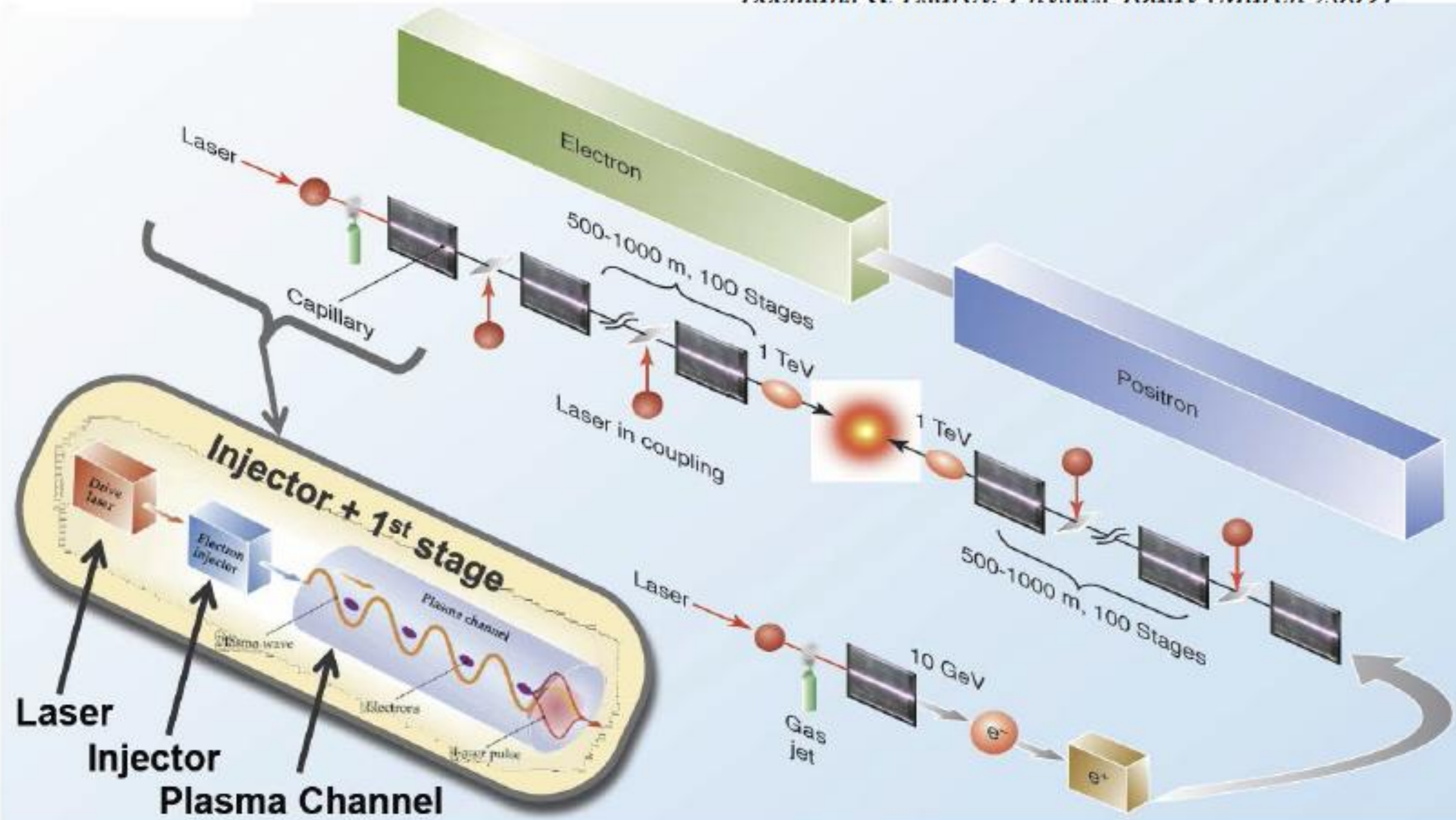
- **Laser** (E=15 J):
  - Measured) longitudinal profile (T_0= 40 fs)
  - Measured far field mode (w_0=53 µm)
- **Plasma:** parabolic plasma channel (length 9 cm, n_0~6-7x10^{17} cm^{-3})

	Exp.	Sim.
Energy	4.25 GeV	4.5 GeV
ΔE/E	5%	3.2%
Charge	~20 pC	23 pC
Divergence	0.3 mrad	0.6 mrad

W.P. Leemans et al.,PRL 2014

Laser-Plasma-Accelerator LC

Leemans & Esarey, Physics Today (March 2009)



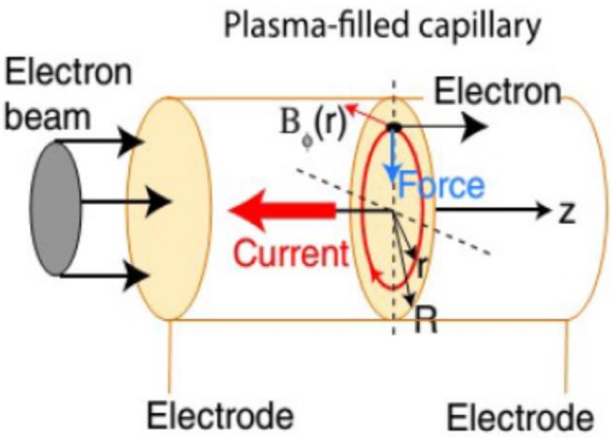
Active Plasma lens

The use plasma wakefields for creating lenses with extreme focusing strength was proposed for a linear collider final focus (**5 orders stronger** than conventional magnets).

- Focusing field produced by electric discharge in a plasma-filled capillary
  - *Focusing field produced, according to Ampere's law, by the discharge current*

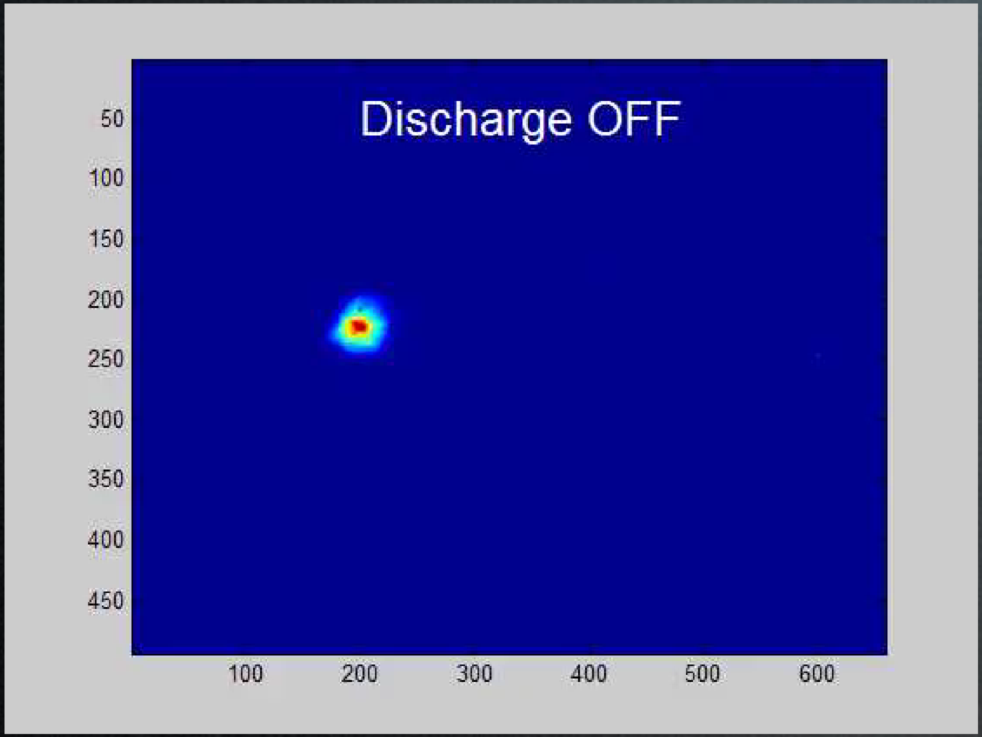
$$B_\phi(r) = \frac{1}{2}\int_0^r \mu_0 J(r')\,dr'$$

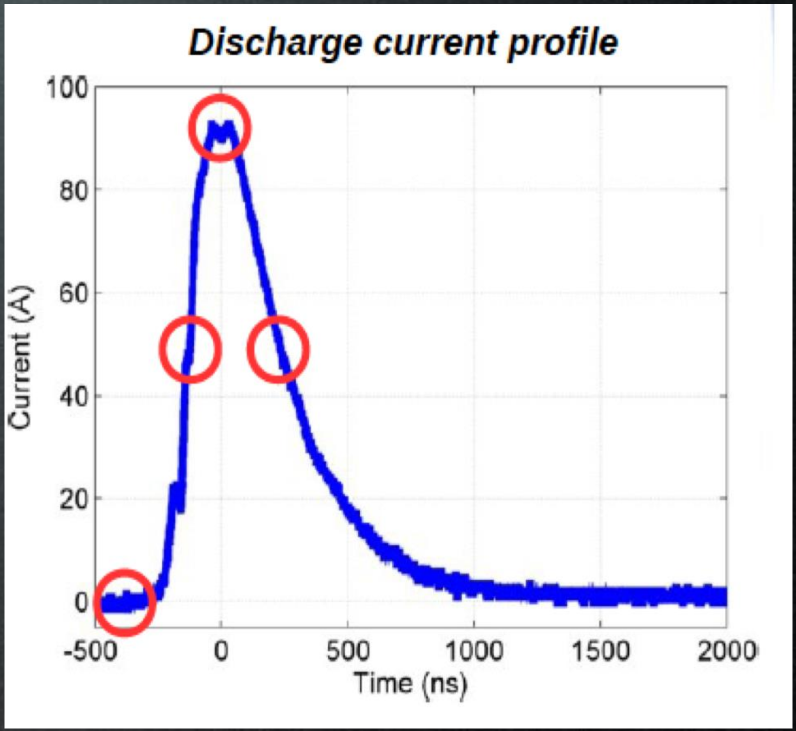
- ✔ Radial focusing
  - *X/Y planes are not dependent as in quads*
- ✔ Weak chromaticity
  - *Focusing force scales linearly with energy*
- ✔ Compactness
  - *Higher integrated field than quad triplets*
- ✔ Independent from beam distribution
  - *Not sensitive to longitudinal/transverse charge profile as in passive plasma lenses*



Van Tilborg, J., et al. "Active plasma lensing for relativistic laser-plasma-accelerated electron beams." Physical review letters 115.18 (2015): 184802.

An example of active Plasma lens



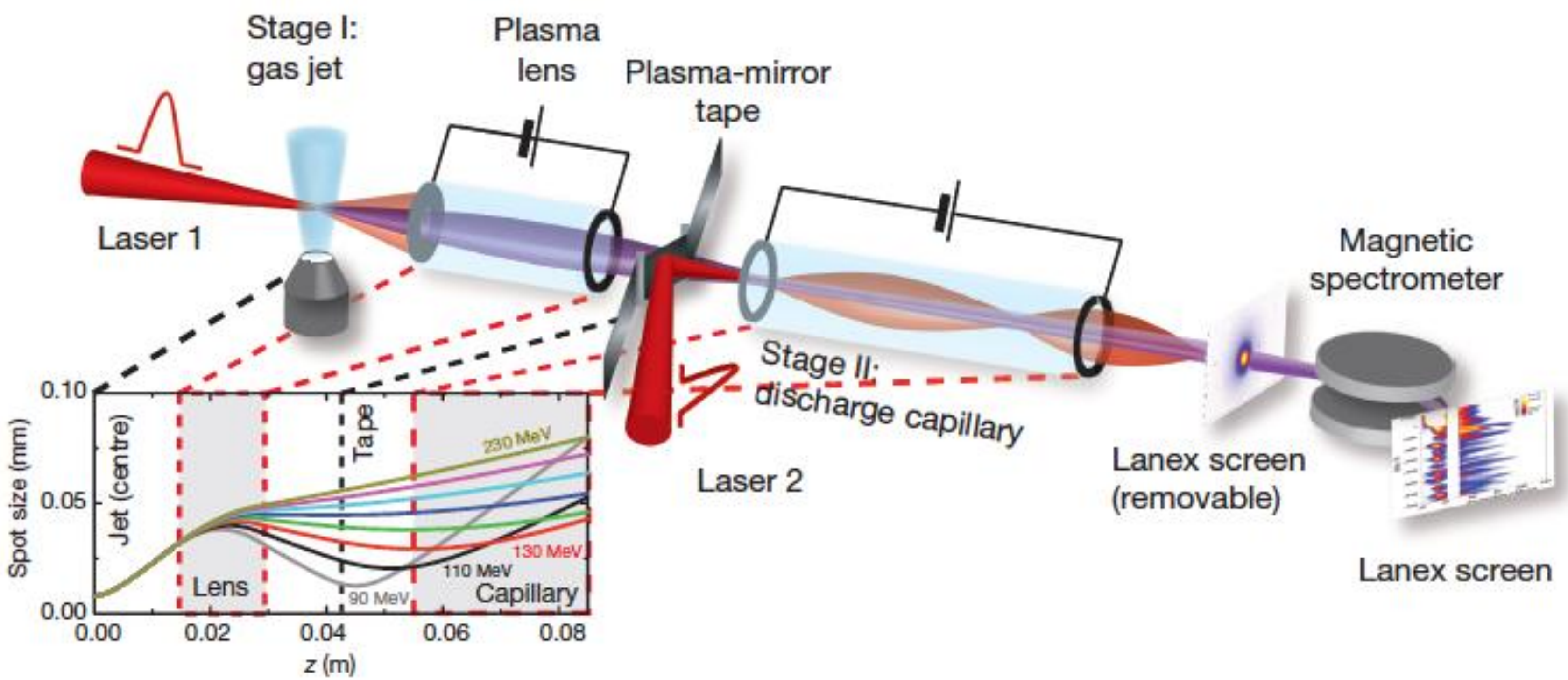


LETTER

doi:10.1038/nature16525

Multistage coupling of independent laser–plasma accelerators

S. Steinke[1], J. van Tilborg[1], C. Benedetti[1], C. G. R. Geddes[1], C. B. Schroeder[1], J. Daniels[1,3], K. K. Swanson[1,2], A. J. Gonsalves[1], K. Nakamura[1], N. H. Matlis[1], B. H. Shaw[1,2], E. Esarey[1] & W. P. Leemans[1,2]



Parameter Set for LPWA LC

Case: CoM Energy (Plasma density)	1 TeV (10^{17} cm^{-3})	1 TeV (2×10^{15} cm^{-3})	10 TeV (10^{17} cm^{-3})	10 TeV (2×10^{15} cm^{-3})
Energy per beam (TeV)	0.5	0.5	5	5
Luminosity (10^{34} cm^{-2}s^{-1})	2	2	200	200
Electrons per bunch ($\times10^{10}$)	0.4	2.8	0.4	2.8
Bunch repetition rate (kHz)	15	0.3	15	0.3
Horizontal emittance $\gamma\varepsilon_x$ (nm-rad)	100	100	50	50
Vertical emittance $\gamma\varepsilon_y$ (nm-rad)	100	100	50	50
β^* (mm)	1	1	0.2	0.2
Horizontal beam size at IP σ^*_x (nm)	10	10	1	1
Vertical beam size at IP σ^*_y (nm)	10	10	1	1
Disruption parameter	0.12	5.6	1.2	56
Bunch length σ_z (μm)	1	7	1	7
Beamstrahlung parameter Υ	180	180	18,000	18,000
Beamstrahlung photons per e, n_γ	1.4	10	3.2	22
Beamstrahlung energy loss δ_E (%)	42	100	95	100
Accelerating gradient (GV/m)	10	1.4	10	1.4
Average beam power (MW)	5	0.7	50	7
Wall plug to beam efficiency (%)	6	6	10	10
One linac length (km)	0.1	0.5	1.0	5

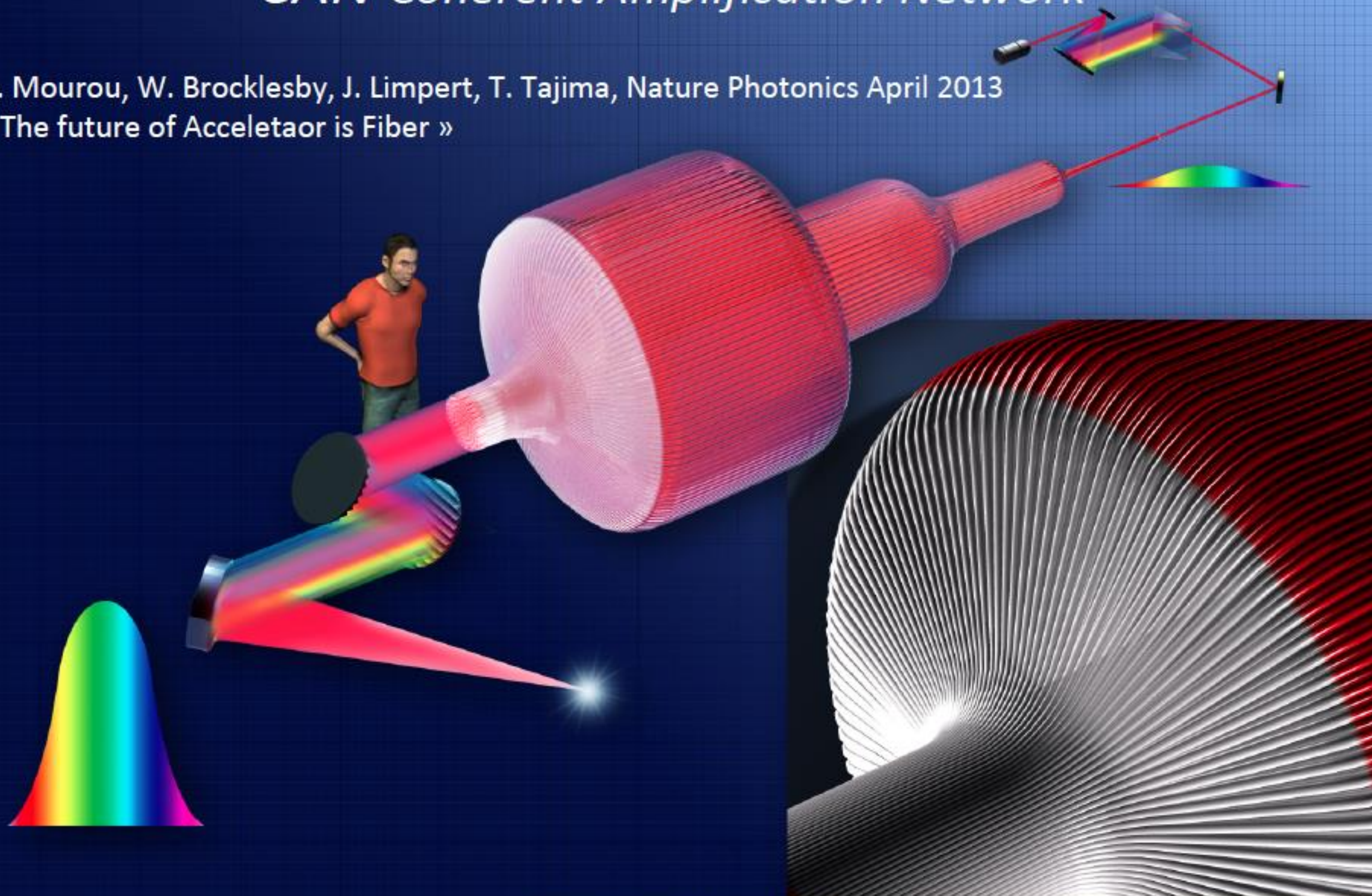
×2+FF

ICAN (European Project)

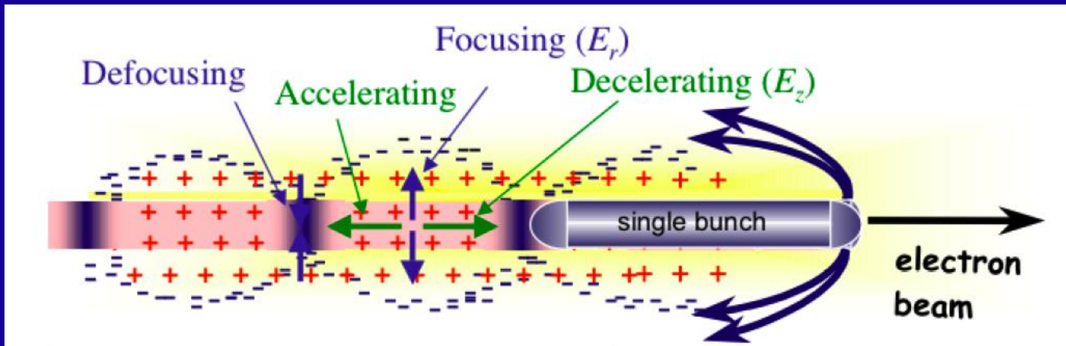
CAN Coherent Amplification Network

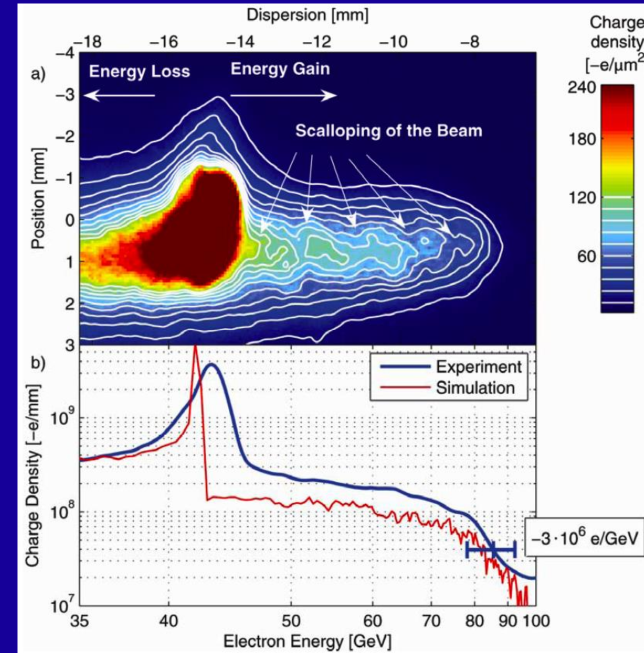
G. Mourou, W. Brocklesby, J. Limpert, T. Tajima, Nature Photonics April 2013

« The future of Acceletaor is Fiber »

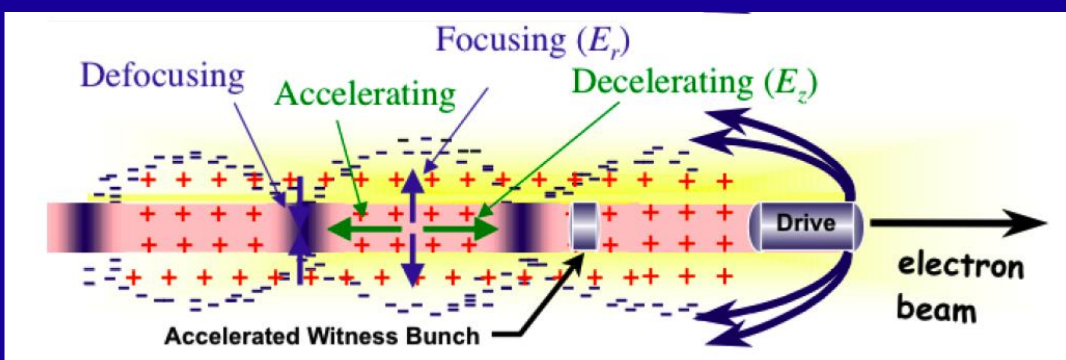


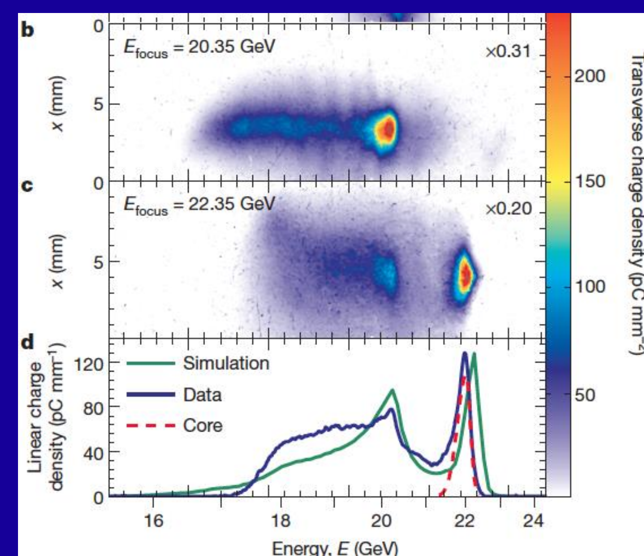
Wake Field Acceleration 2
Beam Driven
PWFA





Blumenfeld, I. et al. *Energy doubling of 42 GeV electrons in a metre-scale plasma wakefield accelerator*. **Nature** 445, 741–744 (2007).



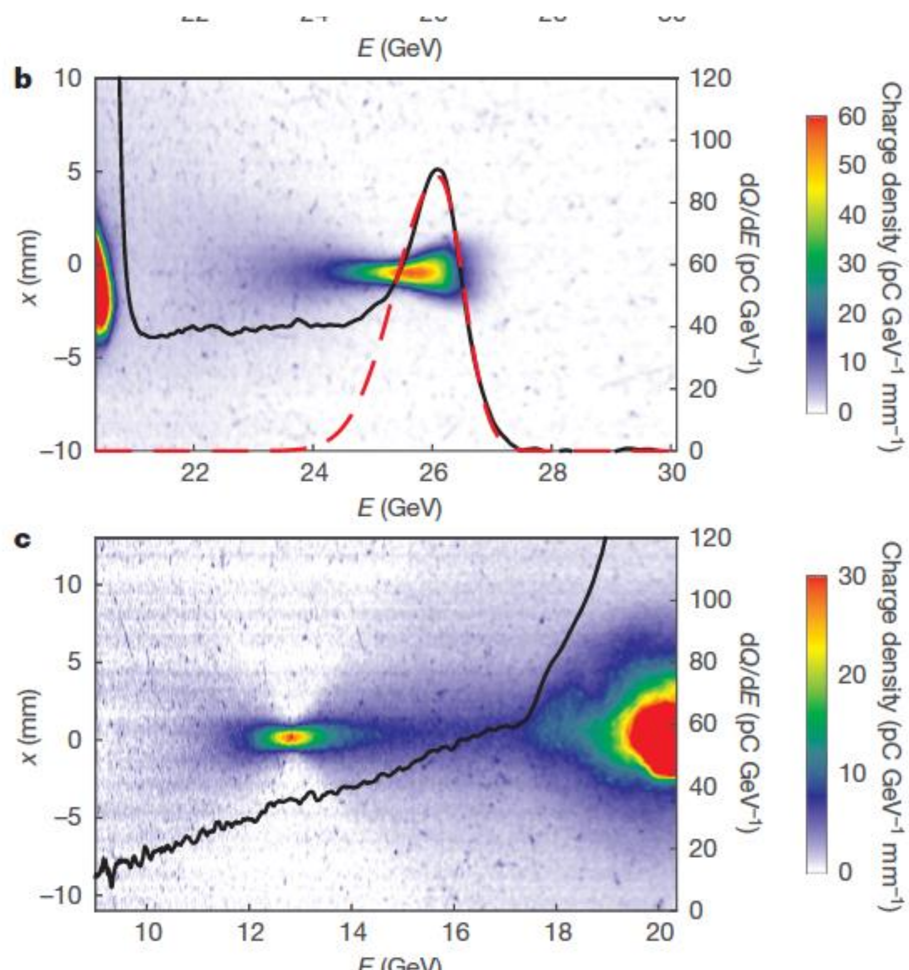


Litos, M. et al. *High-efficiency acceleration of an electron beam in a plasma wakefield accelerator*. **Nature** 515, 92–95 (2014).

doi:10.1038/nature14890

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

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



CONCEPTUAL DESIGN OF THE DRIVE BEAM FOR A PWFA-LC*

S. Pei#, M. J. Hogan, T. O. Raubenheimer, A. Seryi, SLAC, CA 94025, U.S.A.
H. H. Braun, R. Corsini, J. P. Delahaye, CERN, Geneva

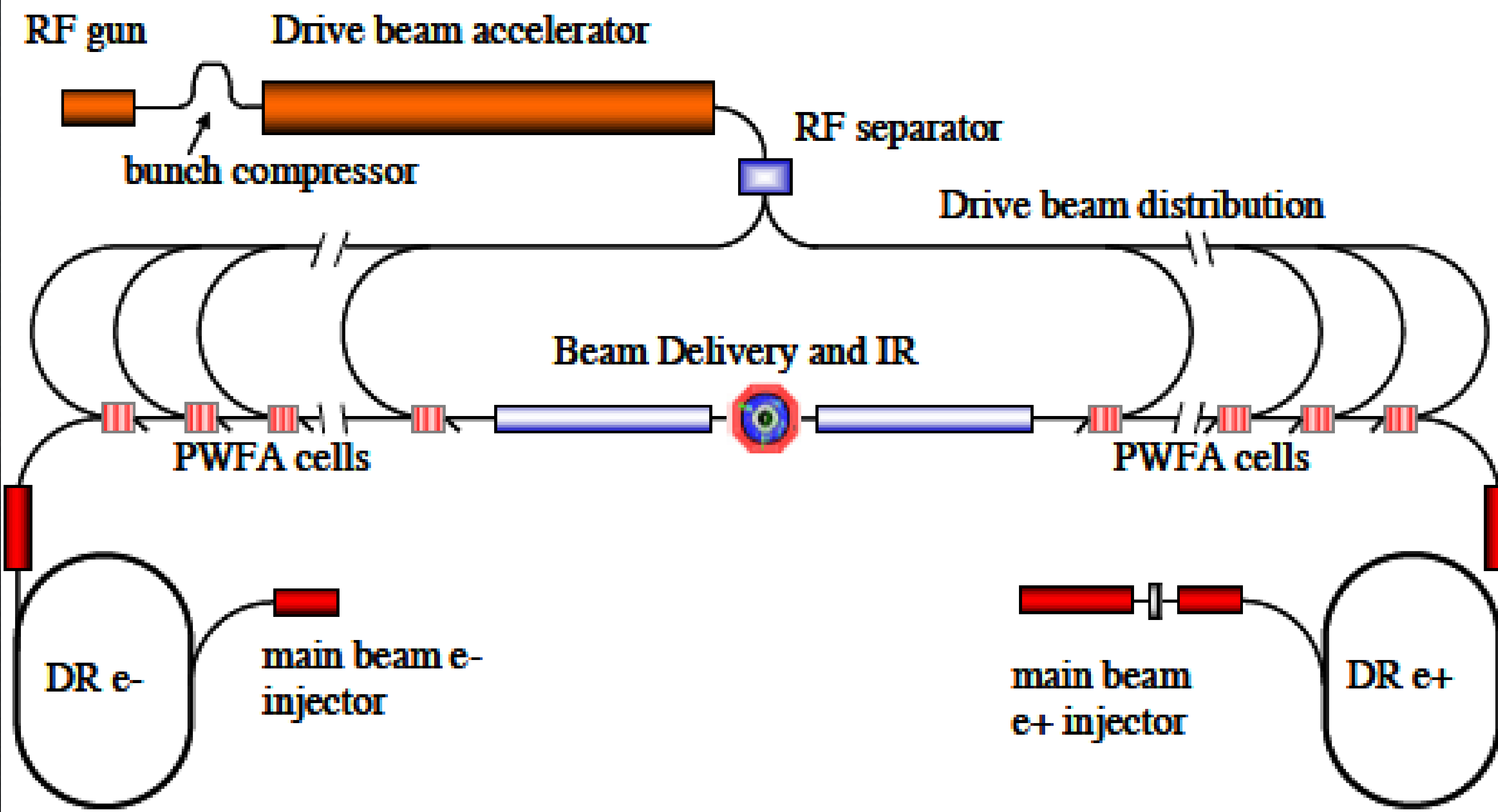


Fig. 1: Concept for a multi-stage PWFA Linear Collider.

Table 1: Key Parameters of the Conceptual Multi-Stage PWFA-based Linear Collider

Main beam: bunch population, bunches per train, rate	1×10^{10}, 125, 100 Hz
Total power of two main beams	20 MW
Drive beam: energy, peak current and active pulse length	25 GeV, 2.3 A, 10 μs
Average power of the drive beam	58 MW
Plasma density, accelerating gradient and plasma cell length	1×10^{17} cm^{-3}, 25 GV/m, 1 m
Power transfer efficiency drive beam=>plasma =>main beam	35%
Efficiency: Wall plug=>RF=>drive beam	50% × 90% = 45%
Overall efficiency and wall plug power for acceleration	15.7%, 127 MW
Site power estimate (with 40MW for other subsystems)	170 MW
Main beam emittances, x, y	2, 0.05 mm-mrad
Main beam sizes at Interaction Point, x, y, z	0.14, 0.0032, 10 μm
Luminosity	3.5×10^{34} cm^{-2}s^{-1}
Luminosity in 1% of energy	1.3×10^{34} cm^{-2}s^{-1}

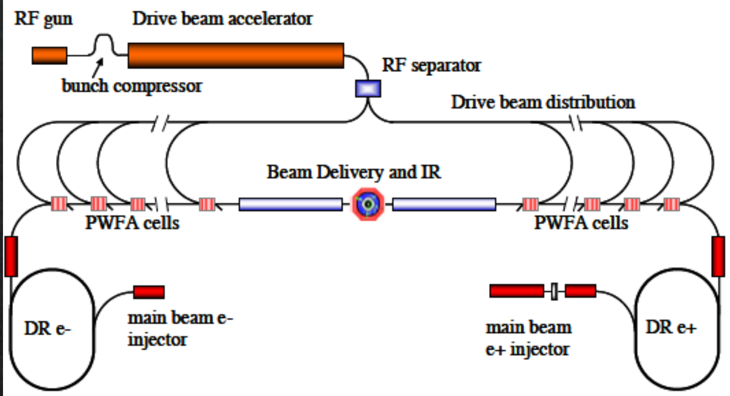


Fig. 1: Concept for a multi-stage PWFA Linear Collider.

ILC – International Linear Collider

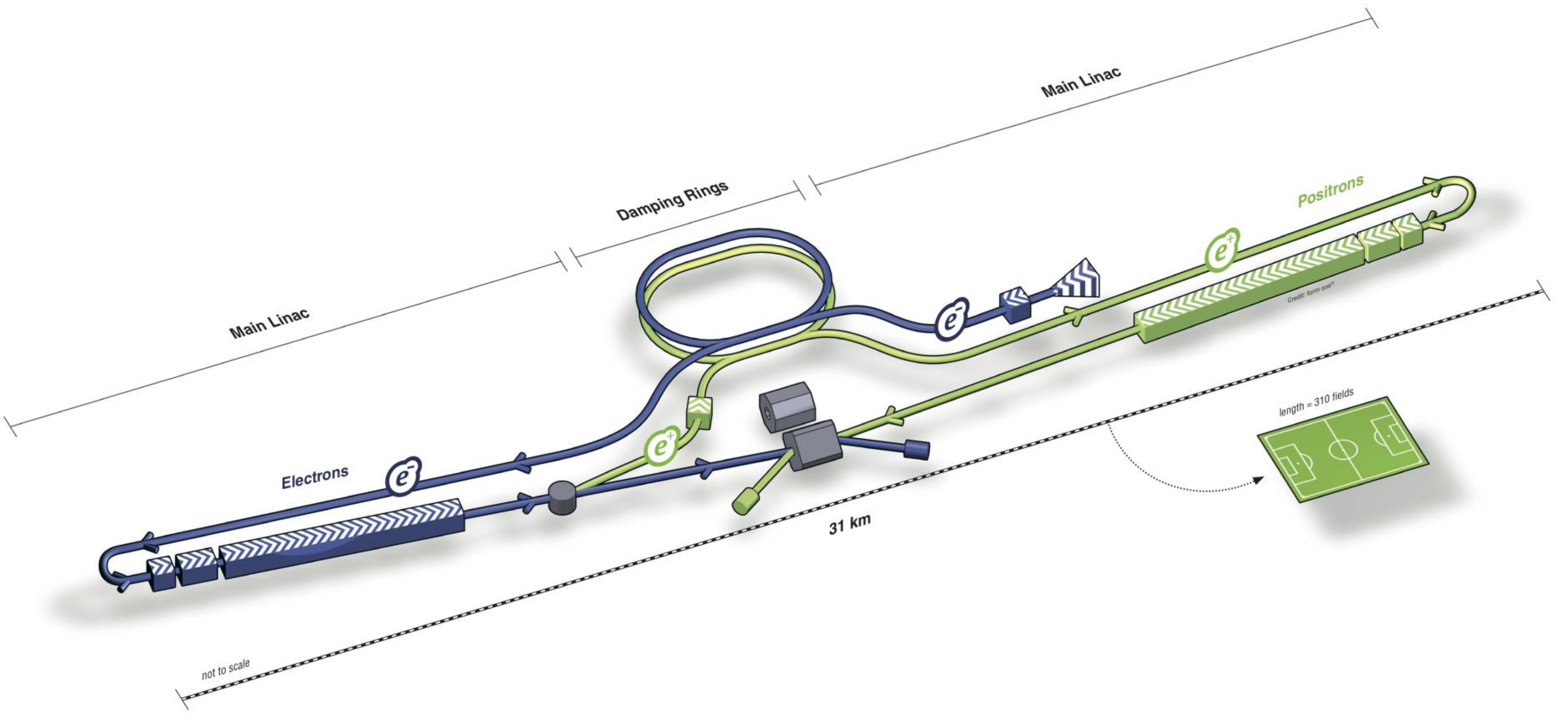


Table 2: ILC energy upgrade by PWFA after-burner

Parameter	Unit	ILC	ILC	ILC + PWFA
Energy (cm)	GeV	500	1000	PFWA = 500 to 1000
Luminosity (per IP)	$10^{34}cm^{-2}s^{-1}$	1.5	4.9	2.6
Peak (1%)Lum(/IP)	$10^{34}cm^{-2}s^{-1}$	0.88	2.2	1.3
# IP	-	1	1	1
Length	km	30	52	30
Power (wall plug)	MW	128	300	175
Lin. Acc. grad.(p/eff)	MV/m	31.5/25	36/30	7600/1000
# particles/bunch	10^{10}	2	1.74	0.66
# bunches/pulse	-	1312	2450	2450
Bunch interval	ns	554	366	366
Pulse repetition rate	Hz	5	4	15
Beam power/beam	MW	5.2	13.8	13.8
Norm Emitt (X/Y)	$10^{-6}/10^{-9}$radm	10/35	10/30	10/30
Sx, Sy, Sz at IP	nm,nm,μm	474/5.9/300	335/2.7/225	286/2.7/20
Crossing angle	mrad	14	14	14
Av # photons	-	1.70	2.0	0.7
δb beam-beam	%	3.89	9.1	9.3
Upsilon	-	0.03	0.09	0.52

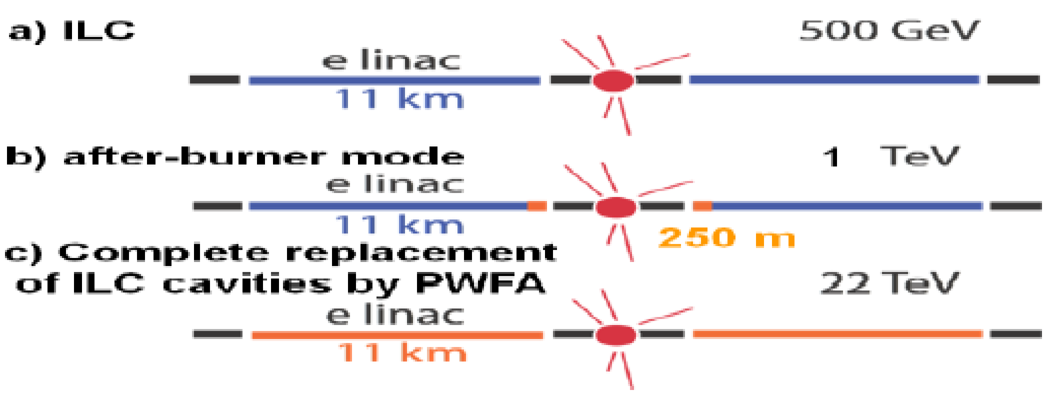


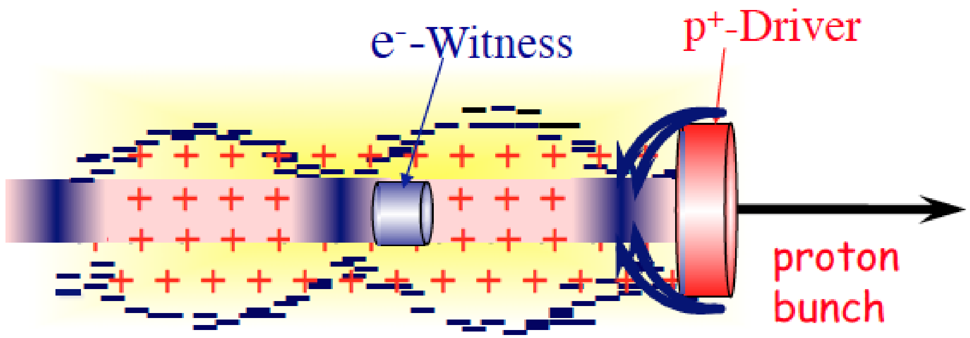
Figure 3: ILC energy upgrade by PWFA technology in the 500 GeV ILC tunnel (a), in after-burner mode (b), in the extreme case of PWFA technology use only (c).

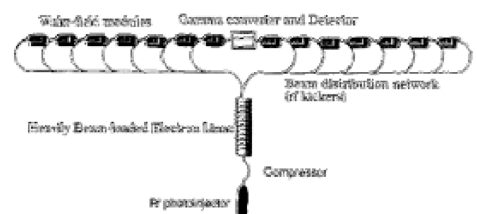
MAX-PLANCK-GESELLSCHAFT

AWAKE

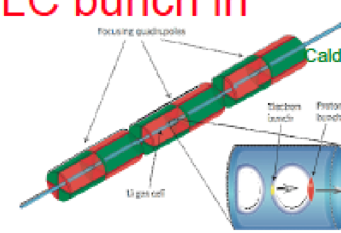
Proton-driven Plasma Wakefield Acceleration Collaboration: Accelerating e^- on the wake of a p^+ bunch

WHY p⁺-DRIVEN PWFA?





- ✧ILC, 0.5TeV bunch with $2\times10^{10}e^-$ ~1.6kJ
- ✧SLAC, 20GeV bunch with $2\times10^{10}e^-$ ~60J
- ✧SLAC-like driver for staging (FACET= 1 stage, collider 10^+ stages)
- ✧SPS, 400GeV bunch with $10^{11}p^+$ ~6.4kJ
  LHC, 7TeV bunch with $10^{11}p^+$ ~112kJ
- ✧A single SPS or LHC bunch could produce an ILC bunch in a <u>single</u> PWFA stage!
- ✧Large <u>average</u> gradient! (≥1GeV/m, 100's m)



Caldwell, Nat. Phys. 5, 363, (2009)

P. Muggli, 06/04/2013, EAAC 2103

Discharge configuration II

preliminary tests with the AWAKE 3 meter test tube at IC - 2016

very promising results

… reliable, low jitter plasma formation

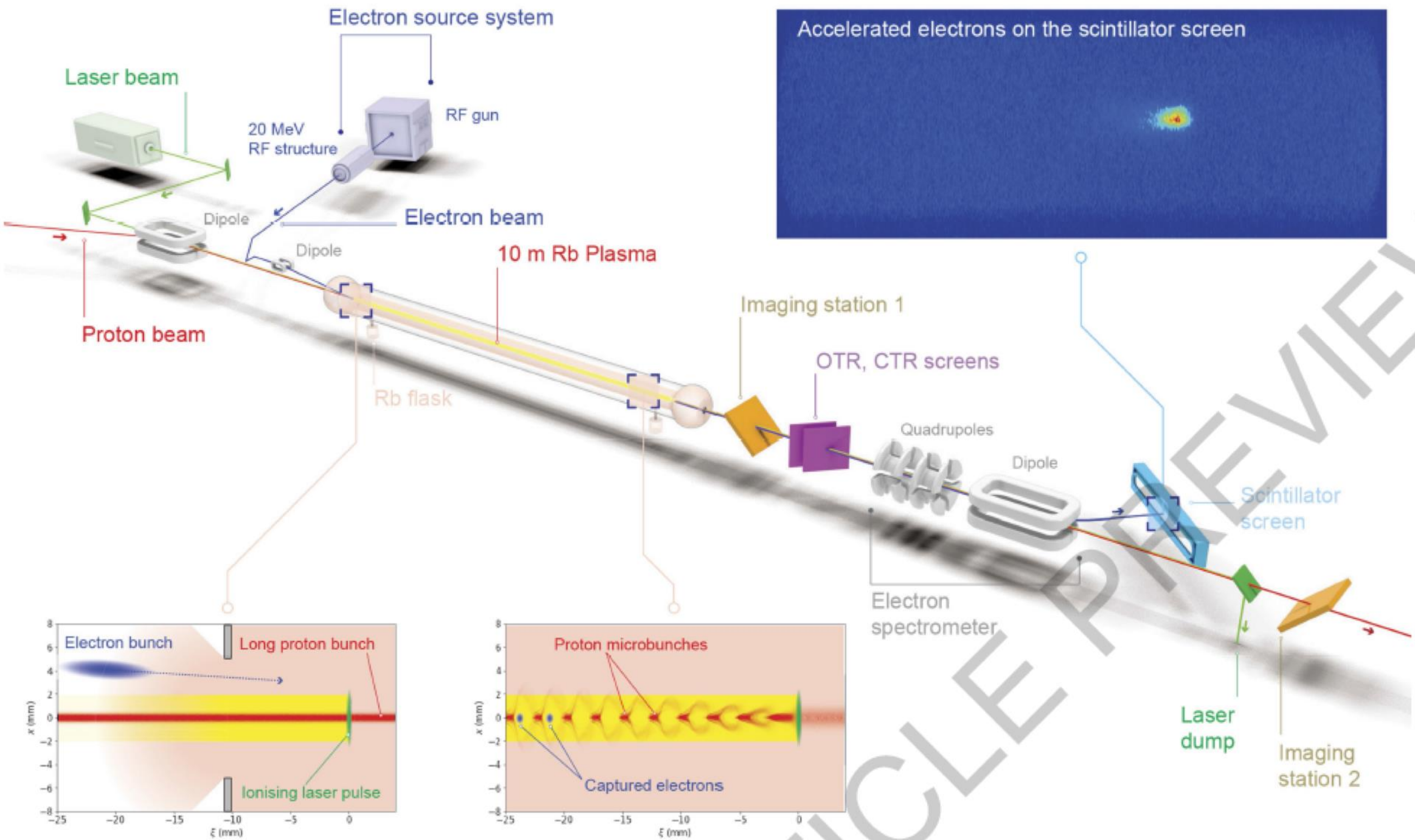
scalability of electric circuit for plasmas > 10 m seem achievable…

nature Accelerated Article Preview

LETTER
doi:10.1038/s41586-018-0485-4

Acceleration of electrons in the plasma wakefield of a proton bunch

E. Adli, A. Ahuja, O. Apsimon, R. Apsimon, A.-M. Bachmann, D. Barrientos, F. Batsch, J. Bauche, V.K.Berglyd Olsen,



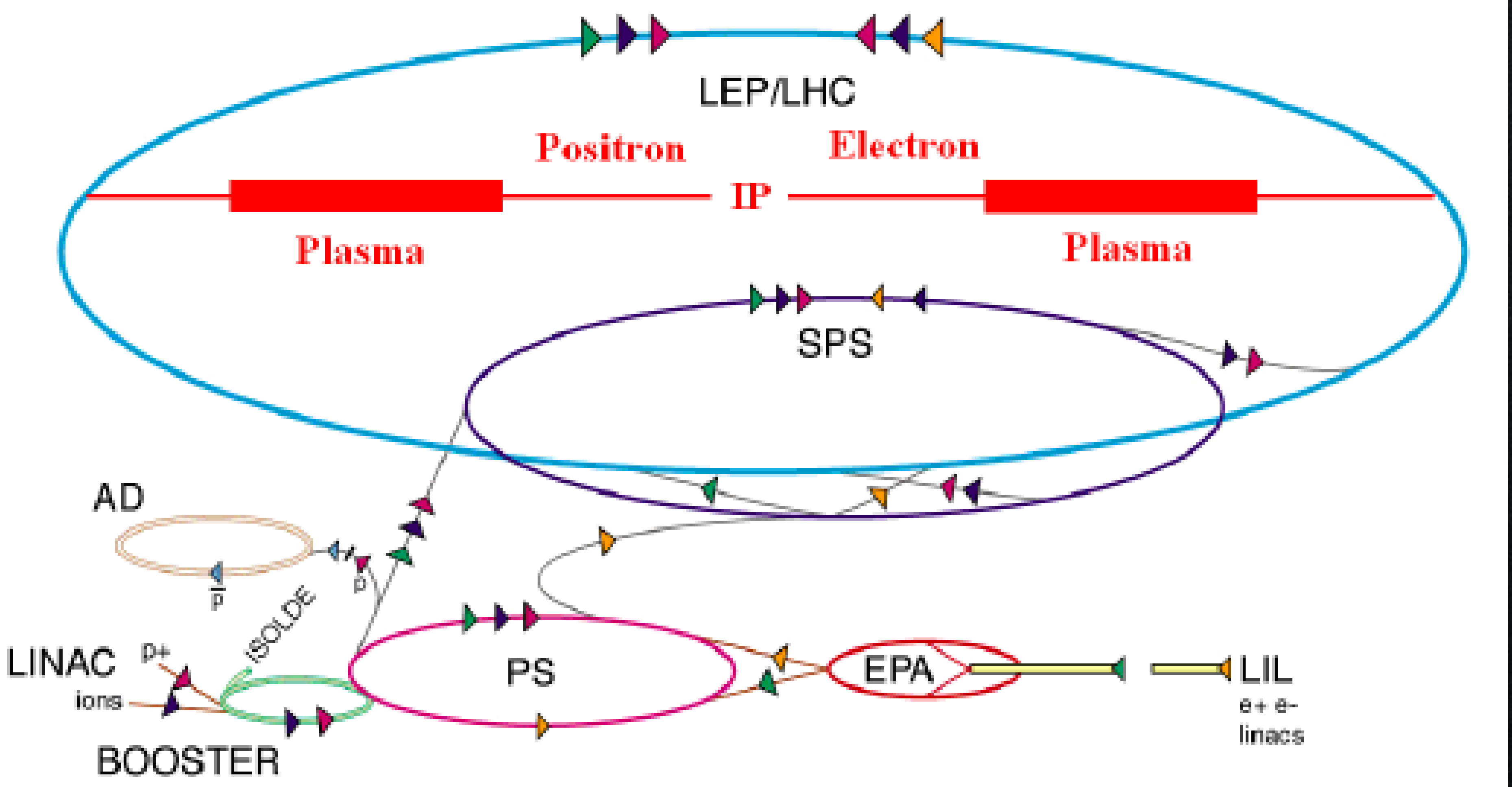


Figure 1: Schematic layout of a 2 TeV CoM electron-positron linear collider based on a modulated proton-driven plasma wakefield acceleration.

Protons and Ions

Protons and ions are too slow to catch the wave - only indirect acceleration via electrons

Laser Driven Acceleration of Protons

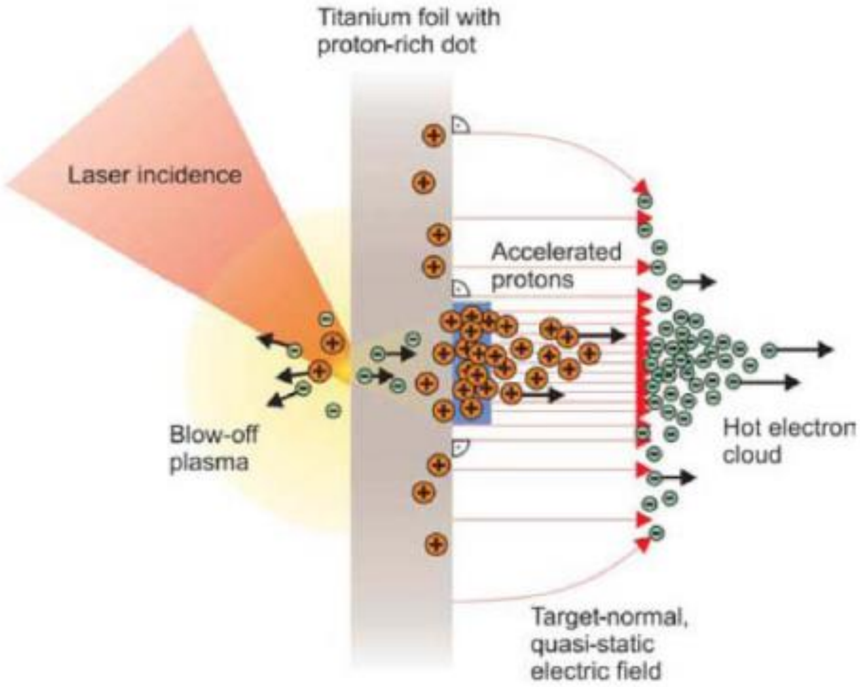
- Direct acceleration in laser field > 10^{25} W/cm² far beyond current lasers
- Plasma wakefield phase velocity too fast for protons & ions
- → only indirect ways

Need typically:
50 J 500 fs → 100 TW
30 μm radius → 10^{19} W/cm²

Target Normal Sheath Acceleration

"best understood" candidate:

- laser creates blow-off plasma on front surface
- backside expansion accelerated electrons ionize hydrogen
- hot electrons create electric field (by space charge)
- causes acceleration of protons (electrons slowing down – end of acceleration)
- neutralized bunch of comoving p and e generated



3 Steps towards a reliable PWA

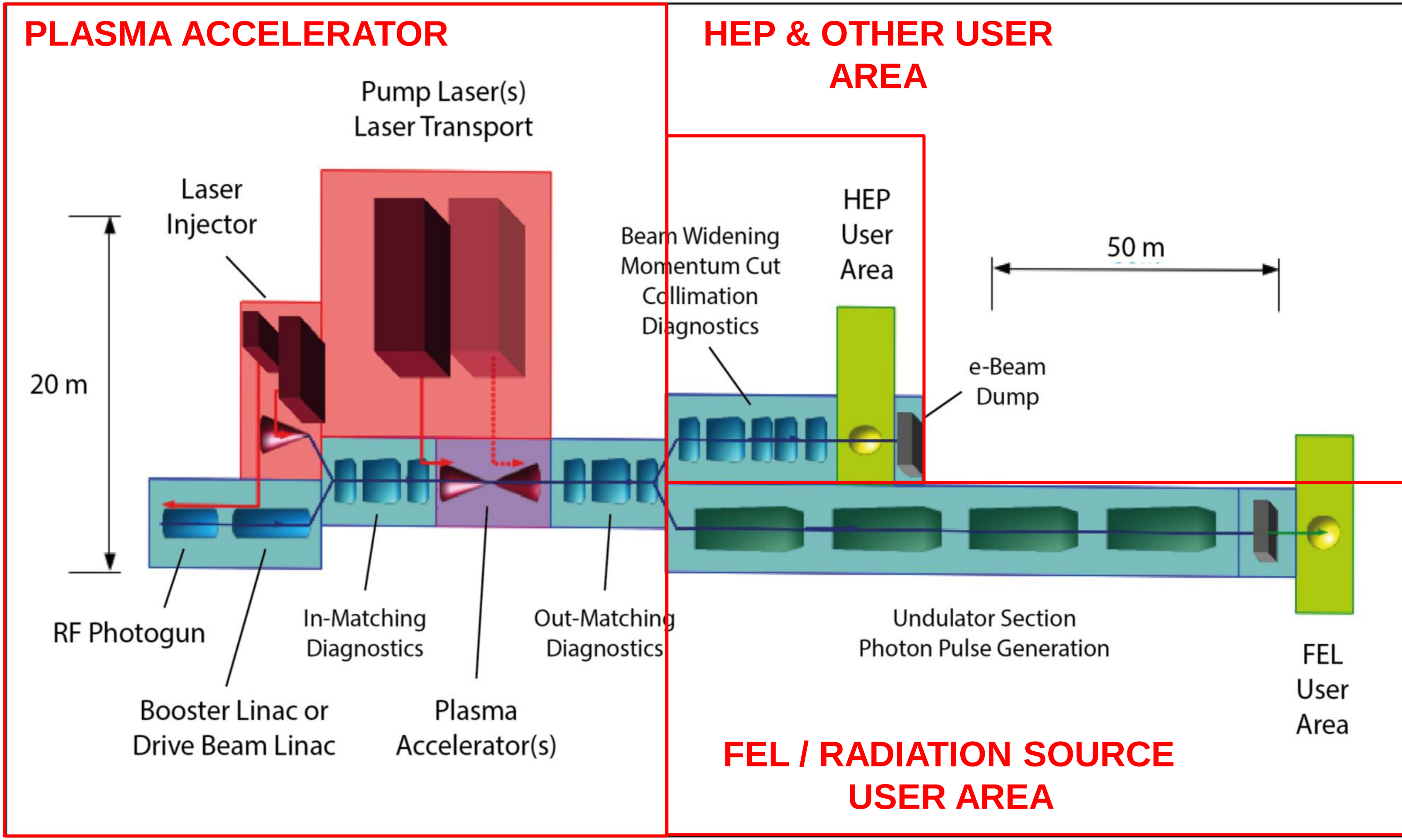
① High Gradient – Low e- Beam Quality

② High e+e- Beam Quality – Low Gradient

③ High e+e- Beam Quality - High Gradient

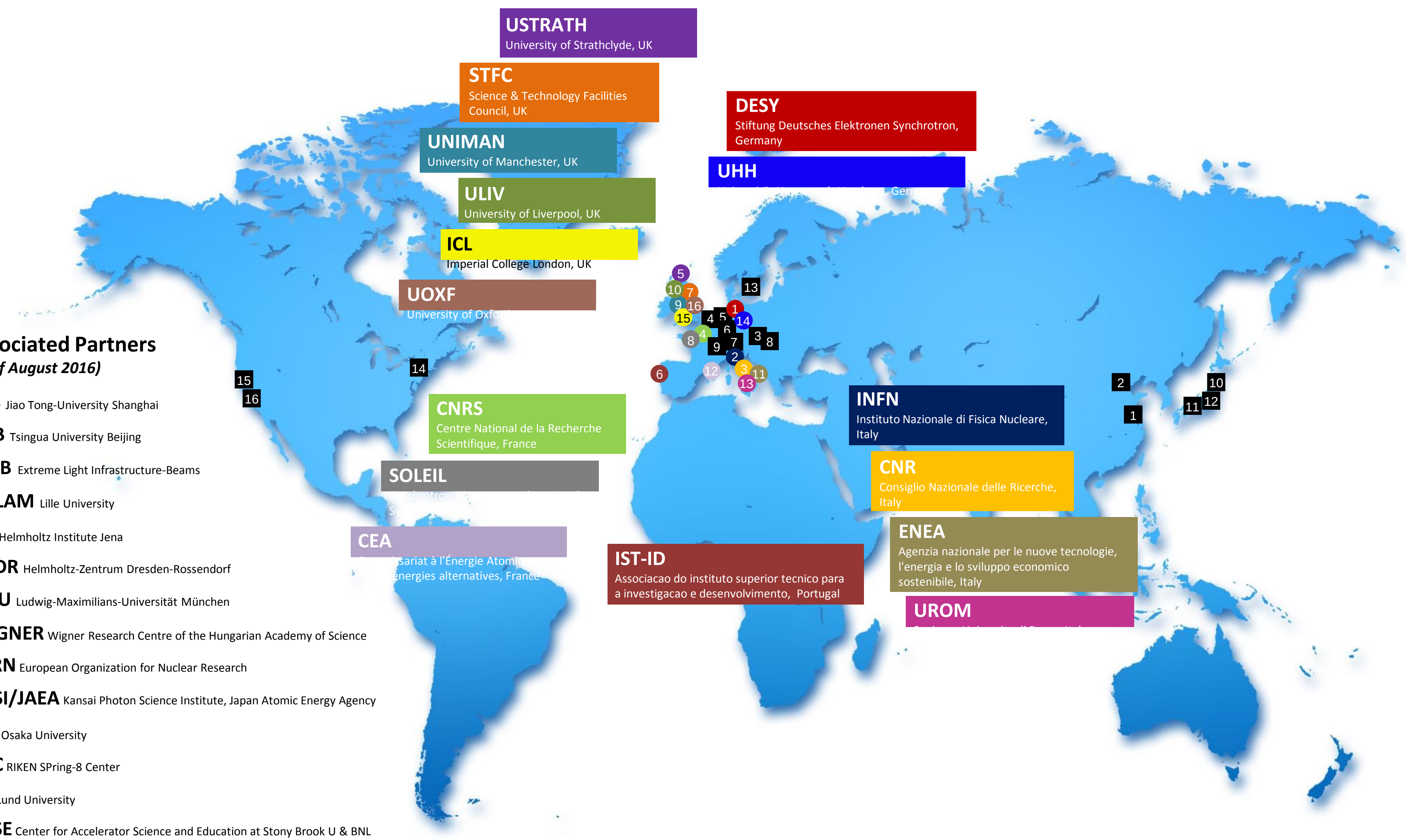
EUROPEAN PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN APPLICATIONS

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


PLASMA ACCELERATOR
HEP & OTHER USER AREA
Pump Laser(s)
Laser Transport
Laser Injector
20 m
Beam Widening
Momentum Cut
Collimation
Diagnostics
HEP User Area
50 m
e-Beam Dump
RF Photogun
In-Matching Diagnostics
Out-Matching Diagnostics
Undulator Section
Photon Pulse Generation
FEL User Area
Booster Linac or Drive Beam Linac
Plasma Accelerator(s)
FEL / RADIATION SOURCE USER AREA

EuPRAXIA Participating Institutions

Horizon 2020



Associated Partners

(as of August 2016)

1 **JUS** Jiao Tong-University Shanghai

2 **TUB** Tsingua University Beijing

3 **ELI-B** Extreme Light Infrastructure-Beams

4 **PHLAM** Lille University

5 **HIJ** Helmholtz Institute Jena

6 **HZDR** Helmholtz-Zentrum Dresden-Rossendorf

7 **LMU** Ludwig-Maximilians-Universität München

8 **WIGNER** Wigner Research Centre of the Hungarian Academy of Science

9 **CERN** European Organization for Nuclear Research

10 **KPSI/JAEA** Kansai Photon Science Institute, Japan Atomic Energy Agency

11 **OU** Osaka University

12 **RSC** RIKEN SPring-8 Center

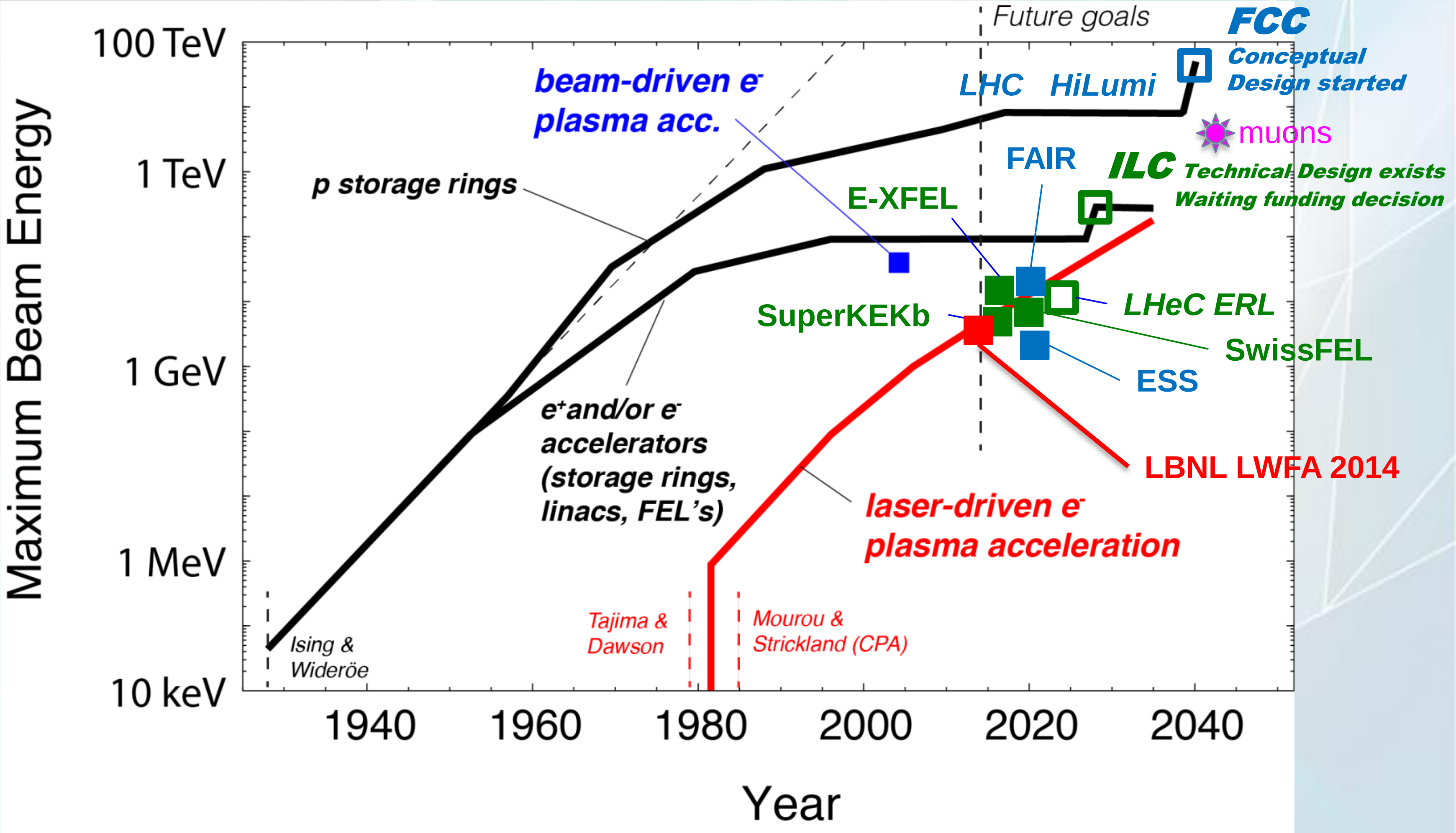
13 **LU** Lund University

14 **CASE** Center for Accelerator Science and Education at Stony Brook U & BNL

15 **LBNL** Lawrence Berkeley National Laboratory

16 **UCLA** University of California, Los Angeles

Future of Accelerators



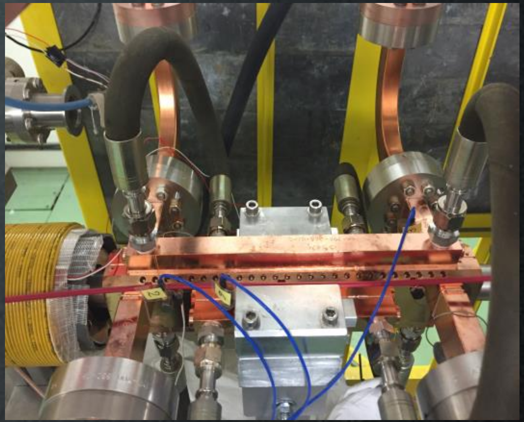
- Hadron acc. project
- Lepton acc. project
- Hadron acc. proposal
- Lepton acc. proposal

R. Assmann, EAAC 2015, 9/2015

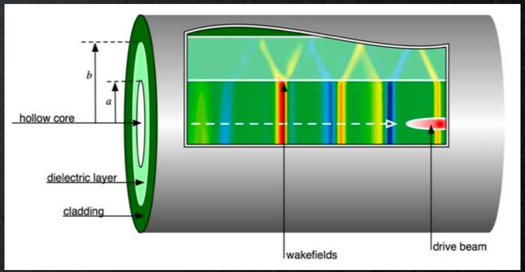
Conclusions (I)

There are several options for high gradient structures:

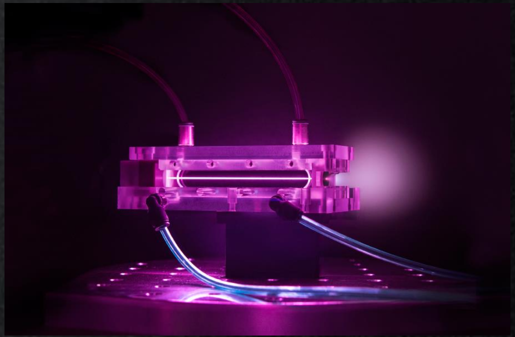
- RF accelerating structures, from X-band to K-band => 100 MV/m < E_{acc} < 1 GV/m



- Dielectric structures, laser or particle driven => 1 GV/m < E_{acc} < 5 GV/m



- Plasma accelerator, laser or particle driven => 1 GV/m < E_{acc} < 100 GV/m



Conclusions (II)

The R&D now concentrates on **beam quality**, **stability**, **staging** and **continuous operation**.

The R&D is pursued in a modern way

- **Collaborative effort** (networking, both in Europe and US)
- Building a **demonstrator facility**
- Strong use of **simulation** (start-to-end, multidisciplinary)

Compact machine to spread the use of particle accelerators

Application driven accelerators (HEP, radiation sources, material science, radio-biology, …)

Accelerator physics is opening to different fields (laser science, plasma physics, computer science, advanced technology…) …**very interesting!**

CAS on High Gradient Wakefield Accelerator


Thank you