Topic around plasma acceleration

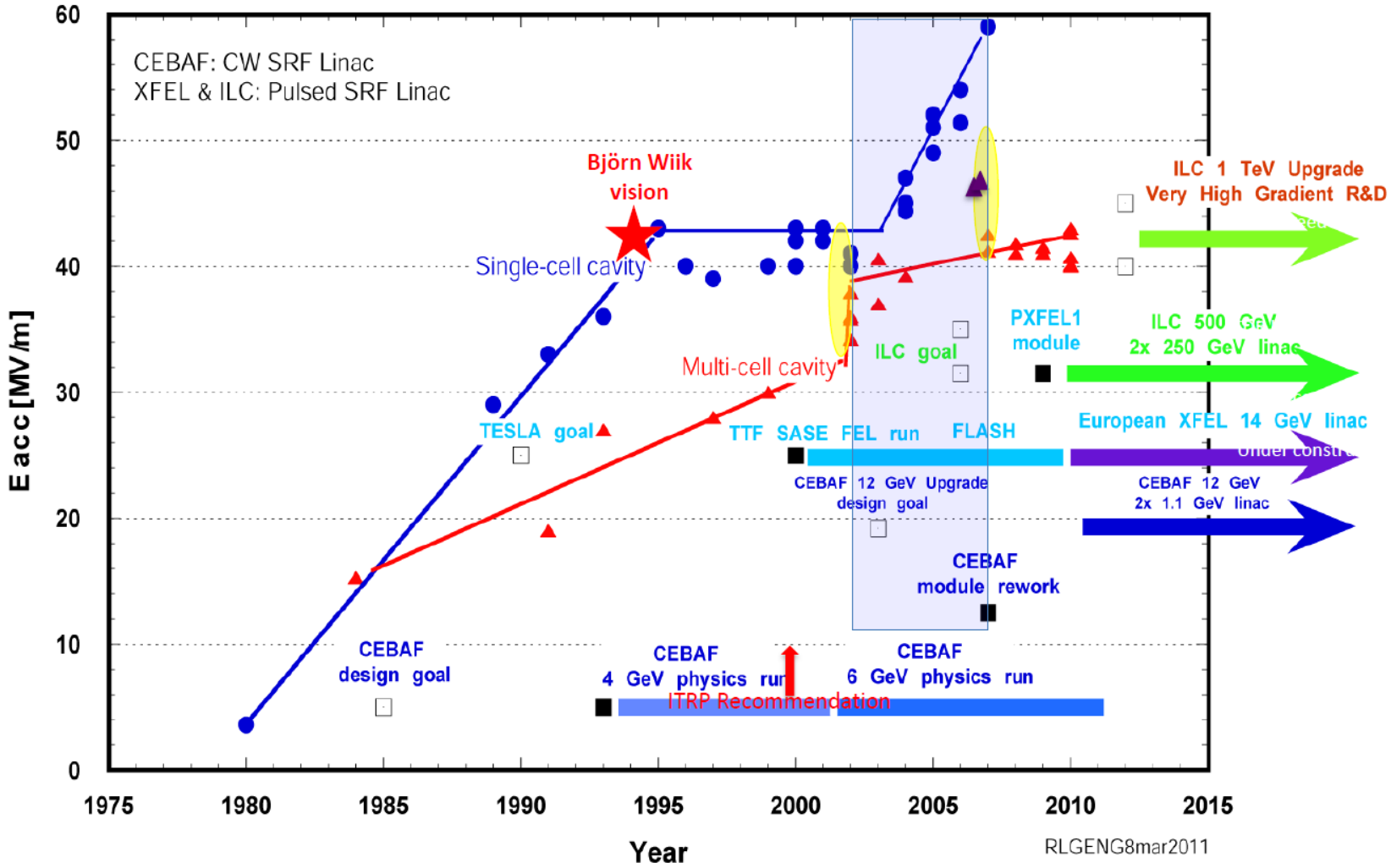
Main reference :
“Introduction to Plasma Accelerators: the Basics” , R. Bingham and R. Trines, arXiv:1705.10535v1
“Acceleration of electrons in the plasma wakefield of a proton bunch”, E. Adli, et al., Nature 561, 363-367(2018)

Gradient of RF cavity

ILC ~ 30 MeV/m

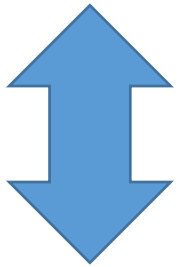
30 MeV/m x 11km
= 300 GeV

... Size is still big !



Plasma acceleration I.

-- It is estimated that the conventional radio-frequency microware (RF) cavities can support the electric fields up to the 100 MV/m , but not higher than this order because of the electrical breakdown of the walls etc.



-- For more than 30 years, plasma-based particle accelerator driven by either lasers or particle beams have shown great promise, because of its large accelerating electric fields.

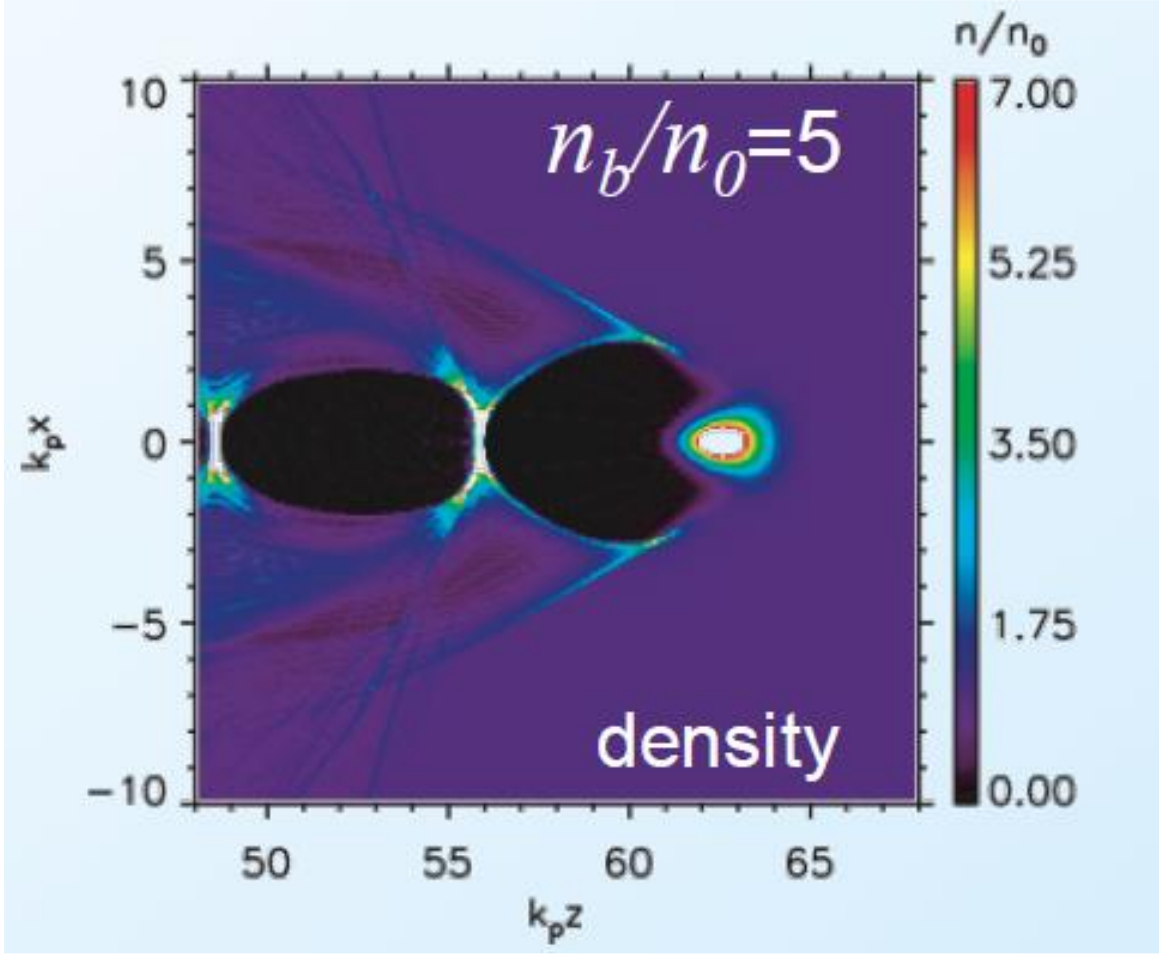
$E \propto \sqrt{n}$, n=electron plasma density. If $n=10^{18}$ cm^{-3}, $E=10^{9}$ V/cm

Plasma acceleration II.

・ Laser/beams injects into plasma region

・ Oscillation of plasma density (mainly electron density) is evoked. E-field as well.

・ The laser pulse length should be shorter than the plasma wavelength (if longer , the laser can not well penetrate the plasma) , which was achieved in late 1990s with the evolution of laser technique.



-- Plasma wakefield set up by charged particle beams propagating through the plasma is also shown and number of reviews on electron acceleration by laser-driven or beam driven plasma waves have been published.

-- Early experiments produced beams with large energy spread.

→ There is a breakthrough demonstrations by three-groups in 2004, producing mono-energetic electron beams with good emittance.

--Still the efforts are targeting on the improvement of beam quality, low energy spread, low emittance, beam focusing.

-- How effectively accelerate the positrons in the plasma ? is question for the electron-positron colliding system.

Very brief introduction of a paper on Nature

LETTER

OPEN

https://doi.org/10.1038/s41586-018-0485-4

Acceleration of electrons in the plasma wakefield of a proton bunch

E. Adli[1], A. Ahuja[2], O. Apsimon[3,4], R. Apsimon[4,5], A.-M. Bachmann[2,6,7], D. Barrientos[2], F. Batsch[2,6,7], J. Bauche[2], V. K. Berglyd Olsen[1], M. Bernardini[2], T. Bohl[2], C. Bracco[2], F. Braunmüller[6], G. Burt[4,5], B. Buttenschön[8], A. Caldwell[6], M. Cascella[9], J. Chappell[9], E. Chevallay[2], M. Chung[10], D. Cooke[9], H. Damerau[2], L. Deacon[9], L. H. Deubner[11], A. Dexter[4,5], S. Doebert[2], J. Farmer[12], V. N. Fedosseev[2], R. Fiorito[4,13], R. A. Fonseca[14], F. Friebel[2], L. Garolfi[2], S. Gessner[2], I. Gorgisyan[2], A. A. Gorn[15,16], E. Granados[2], O. Grulke[8,17], E. Gschwendtner[2], J. Hansen[2], A. Helm[18], J. R. Henderson[4,5], M. Hüther[6], M. Ibison[4,13], L. Jensen[2], S. Jolly[9], F. Keeble[9], S.-Y. Kim[10], F. Kraus[11], Y. Li[3,4], S. Liu[19], N. Lopes[18], K. V. Lotov[15,16], L. Maricalva Brun[2], M. Martyanov[6], S. Mazzoni[2], D. Medina Godoy[2], V. A. Minakov[15,16], J. Mitchell[4,5], J. C. Molendijk[2], J. T. Moody[6], M. Moreira[2,18], P. Muggli[2,6], E. Öz[6], C. Pasquino[2], A. Pardons[2], F. Peña Asmus[6,7], K. Pepitone[2], A. Perera[4,13], A. Petrenko[2,15], S. Pitman[4,5], A. Pukhov[12], S. Rey[2], K. Rieger[6], H. Ruhl[20], J. S. Schmidt[2], I. A. Shalimova[16,21], P. Sherwood[9], L. O. Silva[18], L. Soby[2], A. P. Sosedkin[15,16], R. Speroni[2], R. I. Spitsyn[15,16], P. V. Tuev[15,16], M. Turner[2], F. Velotti[2], L. Verra[2,22], V. A. Verzilov[19], J. Vieira[18], C. P. Welsch[4,13], B. Williamson[3,4], M. Wing[9]*, B. Woolley[2] & G. Xia[3,4]

The AWAKE (Advanced WAKEfield Experiment)

-- The Advanced WAKEfield Experiment (AWAKE) is an accelerator R'D project based at CERN.

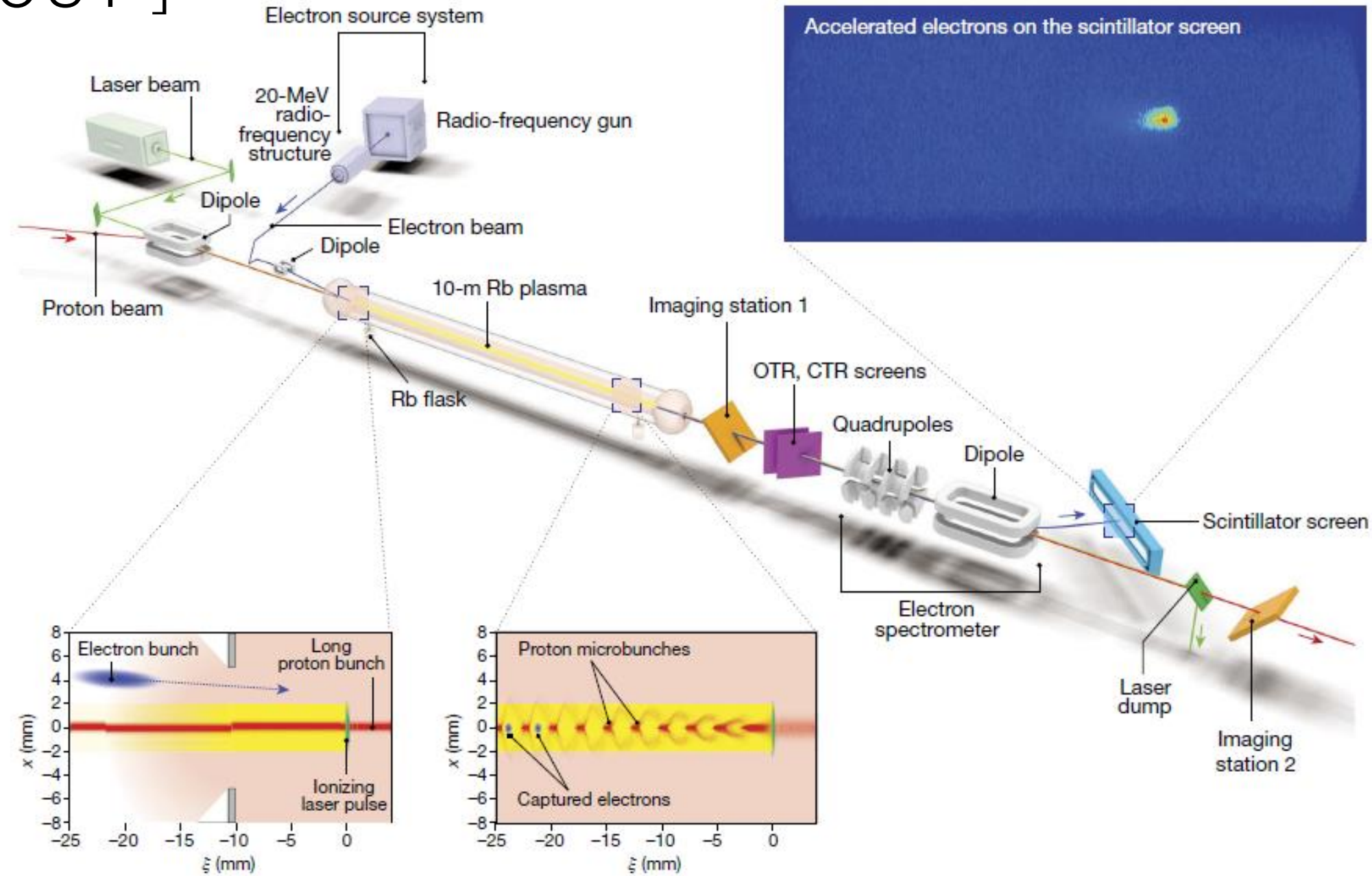
-- Investigating the use of plasma wakefields driven by a proton bunch to accelerate charged particles.

-- AWAKE uses proton beam from the Super Proton Synchrotron (SPS). These protons are injected into a 10m plasma cell to initiate strong wakefield.

-- The first proton beams were sent at the end of 2016.

From their homepage **https://home.cern/about/experiments/awake**

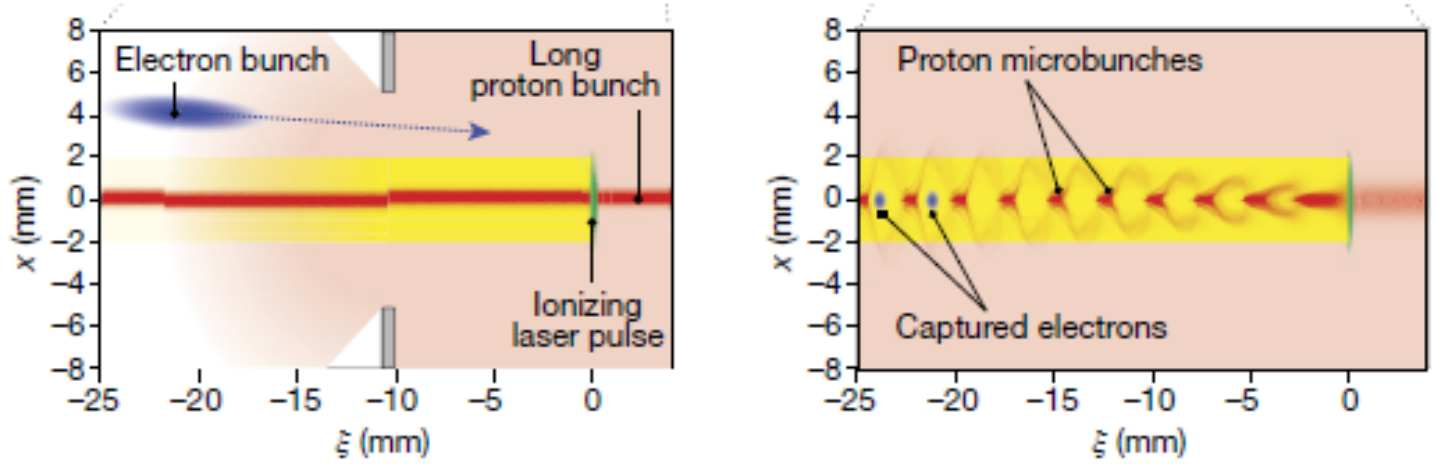
[LAYOUT]


Electron source system
Laser beam
20-MeV radio-frequency structure
Radio-frequency gun
Dipole
Electron beam
Dipole
Proton beam
10-m Rb plasma
Rb flask
Imaging station 1
OTR, CTR screens
Quadrupoles
Dipole
Scintillator screen
Electron spectrometer
Laser dump
Imaging station 2
Accelerated electrons on the scintillator screen
Electron bunch
Long proton bunch
Ionizing laser pulse
x (mm)
ξ (mm)
Proton microbunches
Captured electrons
x (mm)
ξ (mm)

Steps toward the electron acceleration

1. Proton bunch (400GeV) from SPS with the bunch length of 6-8 cm is guided to the rubidium vapour source.

2. Laser pulse (120 fs) ionizes the rubidium , and then proton bunch modulate into microbunches.



3. Electrons (already accelerated to 18MeV) are injected to the cell 200 ps delay with respect to the laser.

Conclusion of this paper

・ Proton-driven plasma wakefield acceleration is demonstrated.

・ The electron bunch is captured within the proton micro-bunch, and accelerated to 2 GeV with the plasma density of 6.6×10^{14} cm^{-3}. The energy spread is 10%.

・ “This technique has the potential to accelerate electrons to the teraelectronvolt scale in a single accelerating stage. “

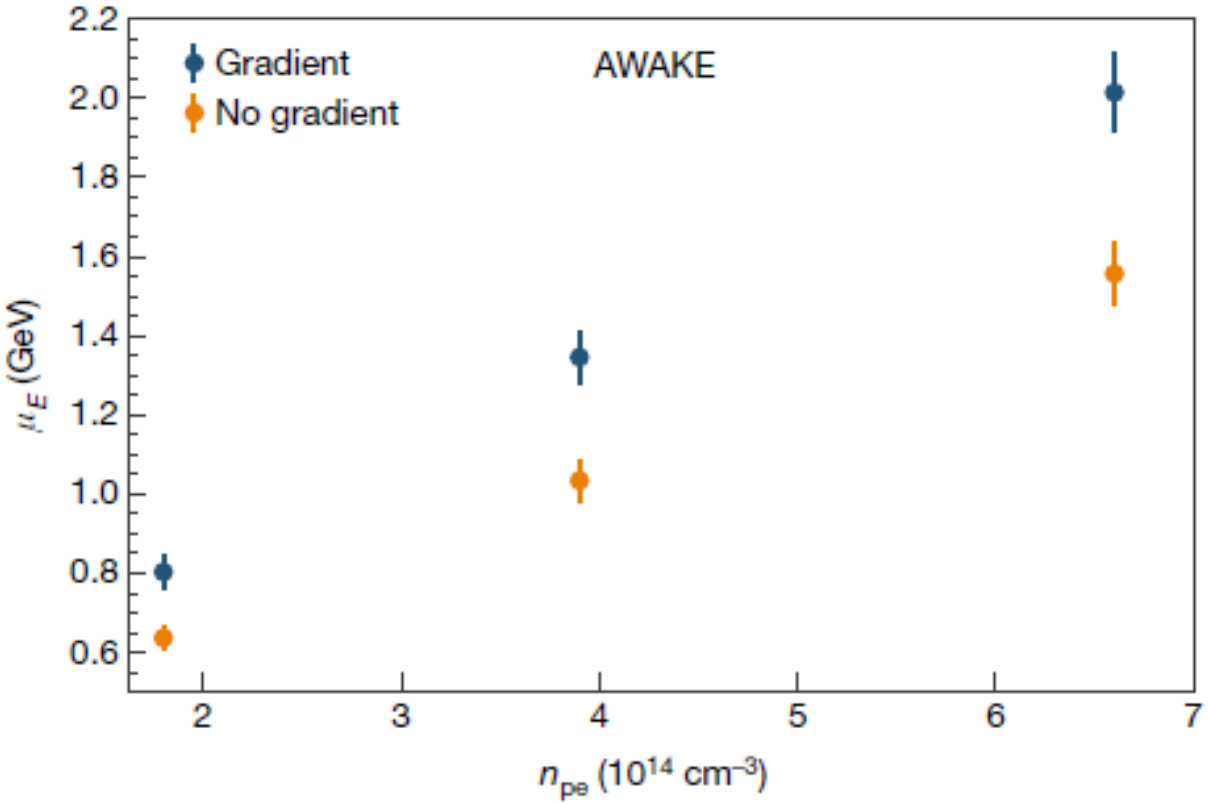


Fig. 4 | Measurement of the highest peak energies μ_E achieved at different plasma densities n_{pe}, with and without a gradient in the plasma density. The error bars arise from the position–energy conversion. The gradients chosen are those that were observed to maximize the energy gain. Acceleration to 2.0 ± 0.1 GeV is achieved with a plasma density of 6.6×10^{14} cm^{-3} with a density difference of $+2.2\% \pm 0.1\%$ over 10 m.

Comment

・ Small size (“table-top”) accelerator can be used for biology, medicine, industry etc.

・ For high energy usage, the energy transfer , proton<--->electron, has certain meaning as well as its size.

・ There are many reports from universities in China for this field. (though I can not check them this time)