La rivoluzione dell'accelerazione al plasma

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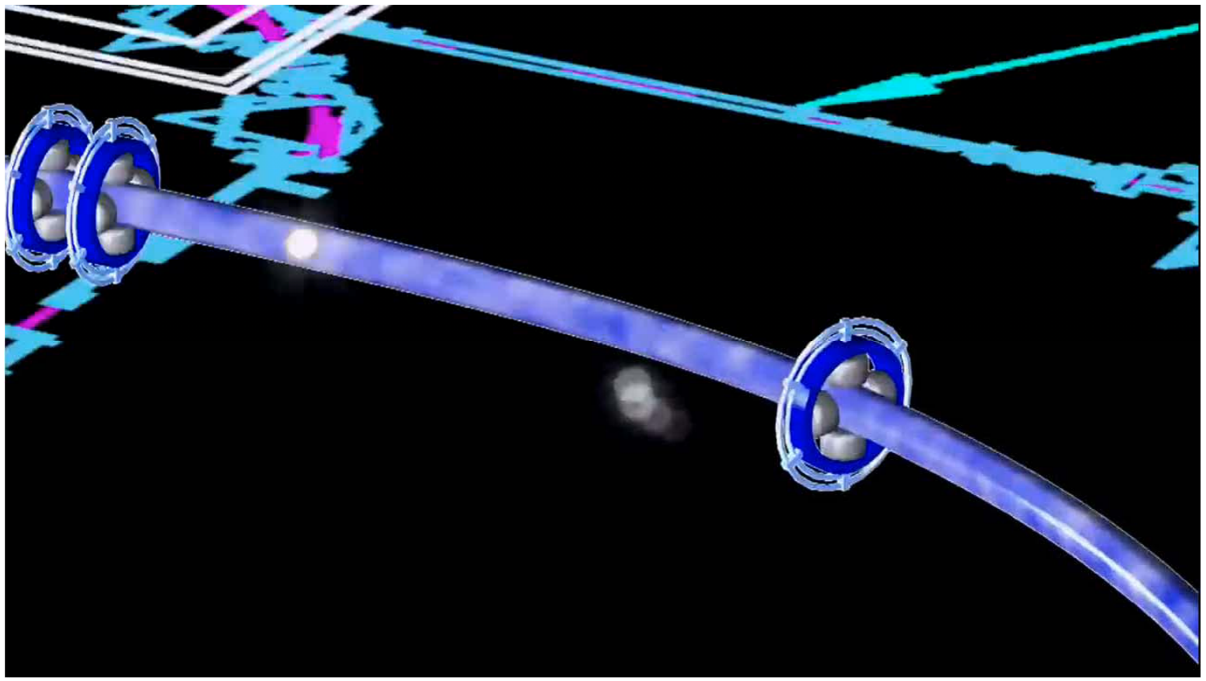
Big Accelerator

- State-of-the-art high-energy accelerators are too large and costly, and possibly they approach the end of the road

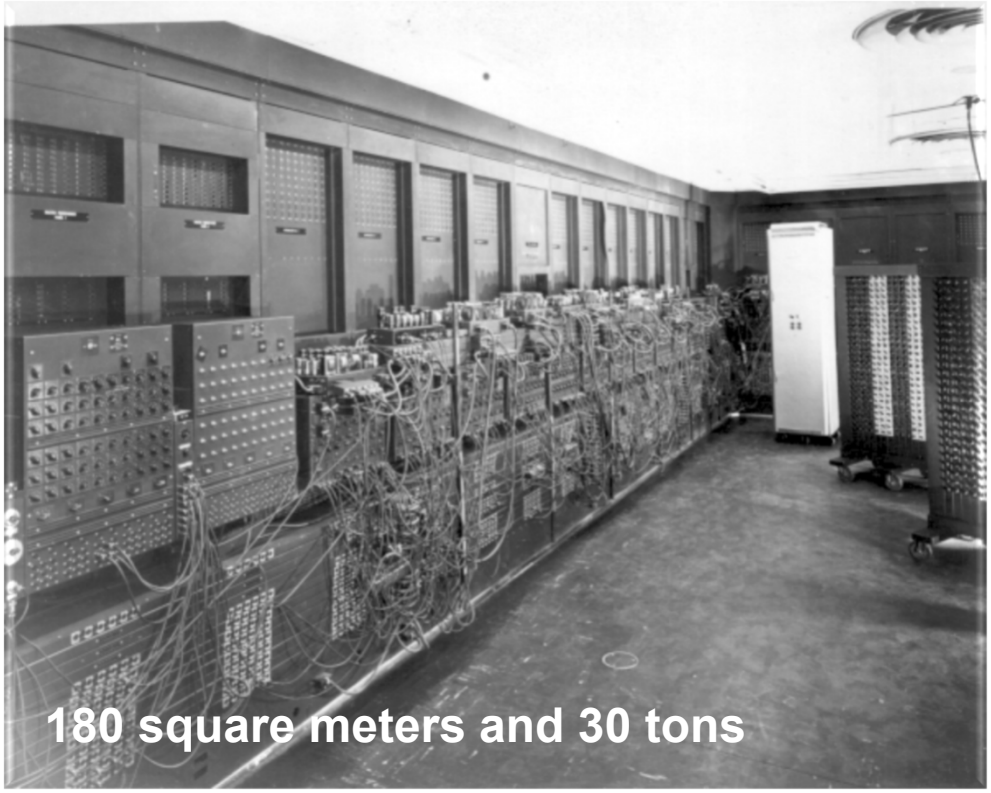


Particle accelerators in the world

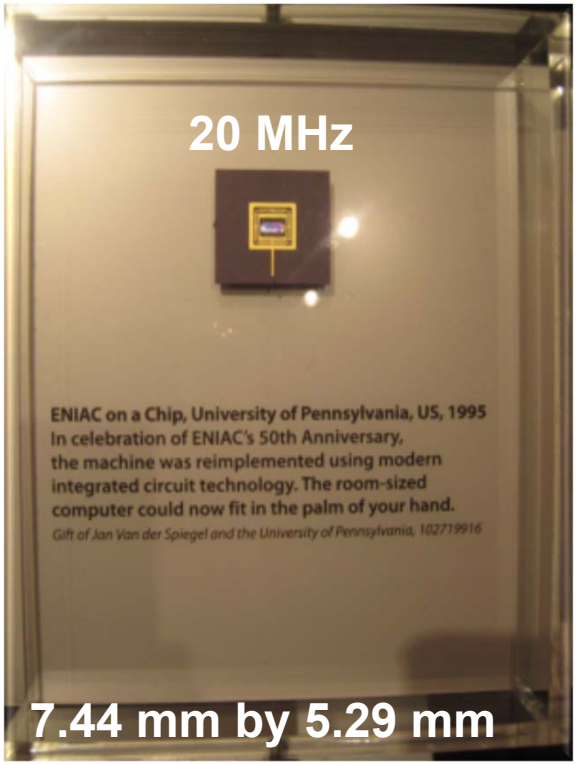
Accelerators		1994	2014
Industrial		>4500	27 000
	Electron accelerators >300 keV	1500	~5000
	Electron accelerators <300 keV	>1000	~8000
	Ion implanters and ion analysis	>2000	~12 000
	Neutron generators		~2000
Science		~1000	~1200
Medicine		~4200	~14 000
	Electron accelerators	~4000	~13 000
	Proton and ion accelerators	17	~59
	Production of radioisotopes	~200	~1100
TOTAL		**>9700**	**42 000**

Source: Chernyaev, A. P., and S. M. Varzar. "Particle accelerators in modern world." Physics of Atomic Nuclei 77.10 (2014): 1203-1215.

ENIAC Then and now…

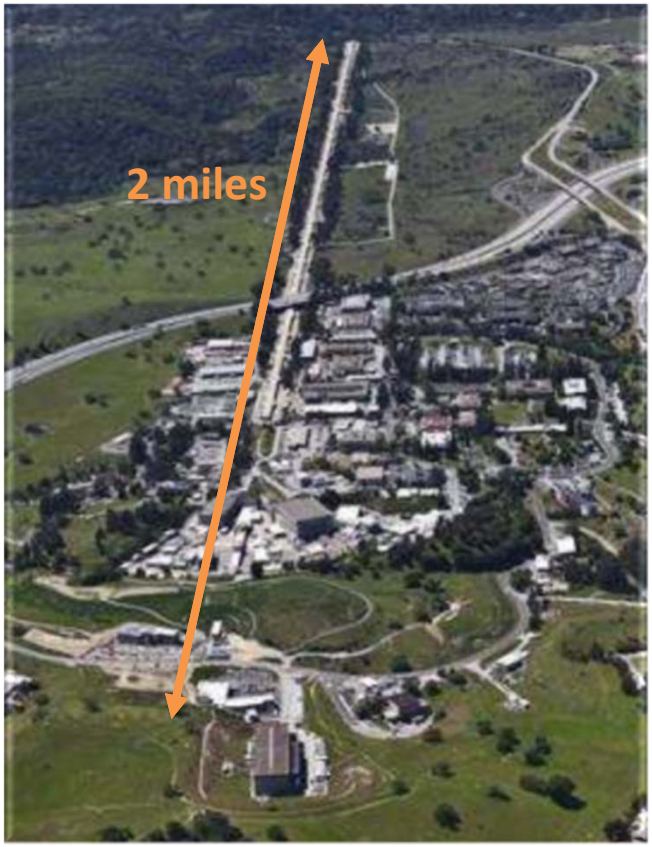


1946



1995

SLAC Now and Tomorrow

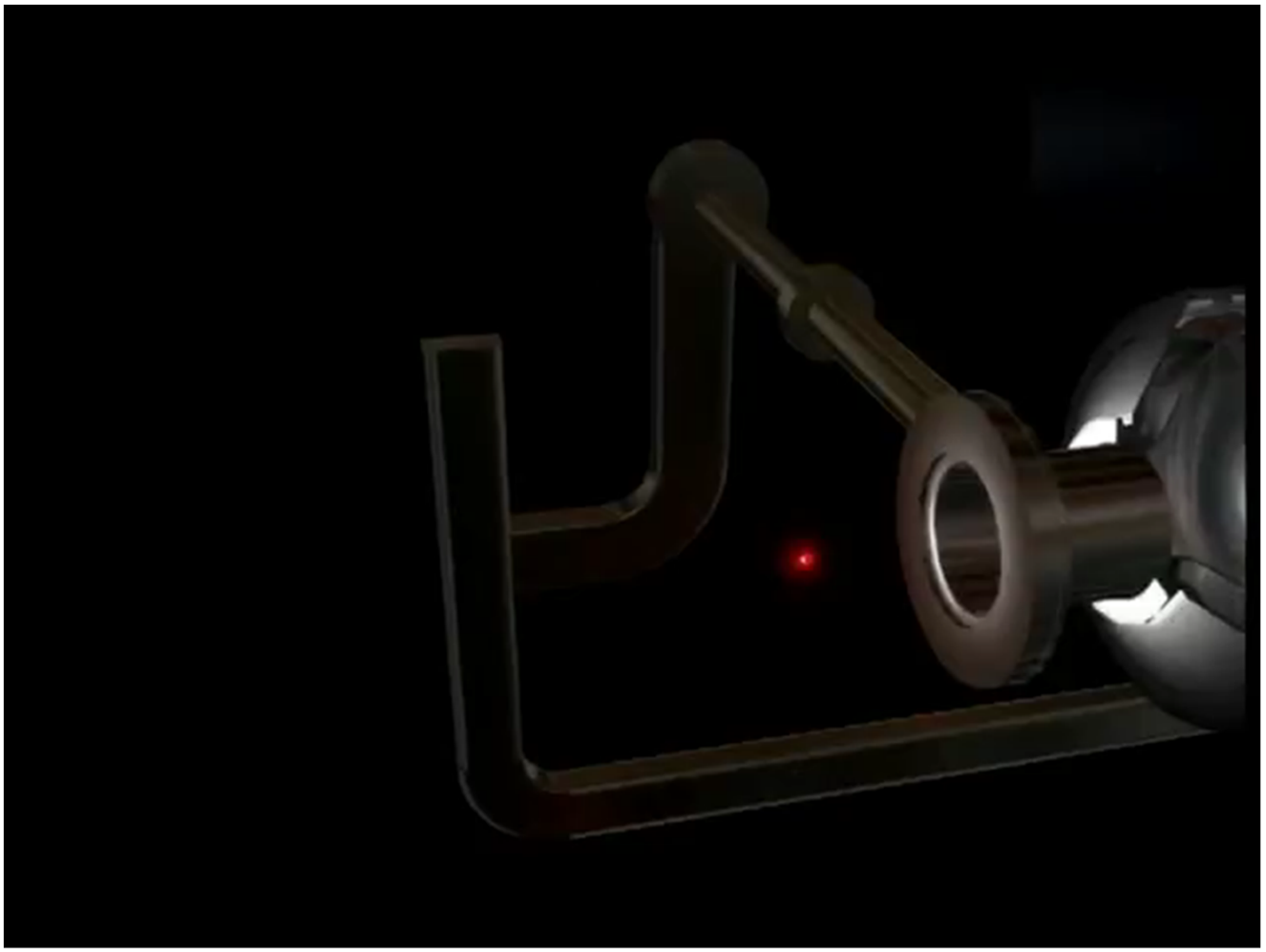


2018 **20??**

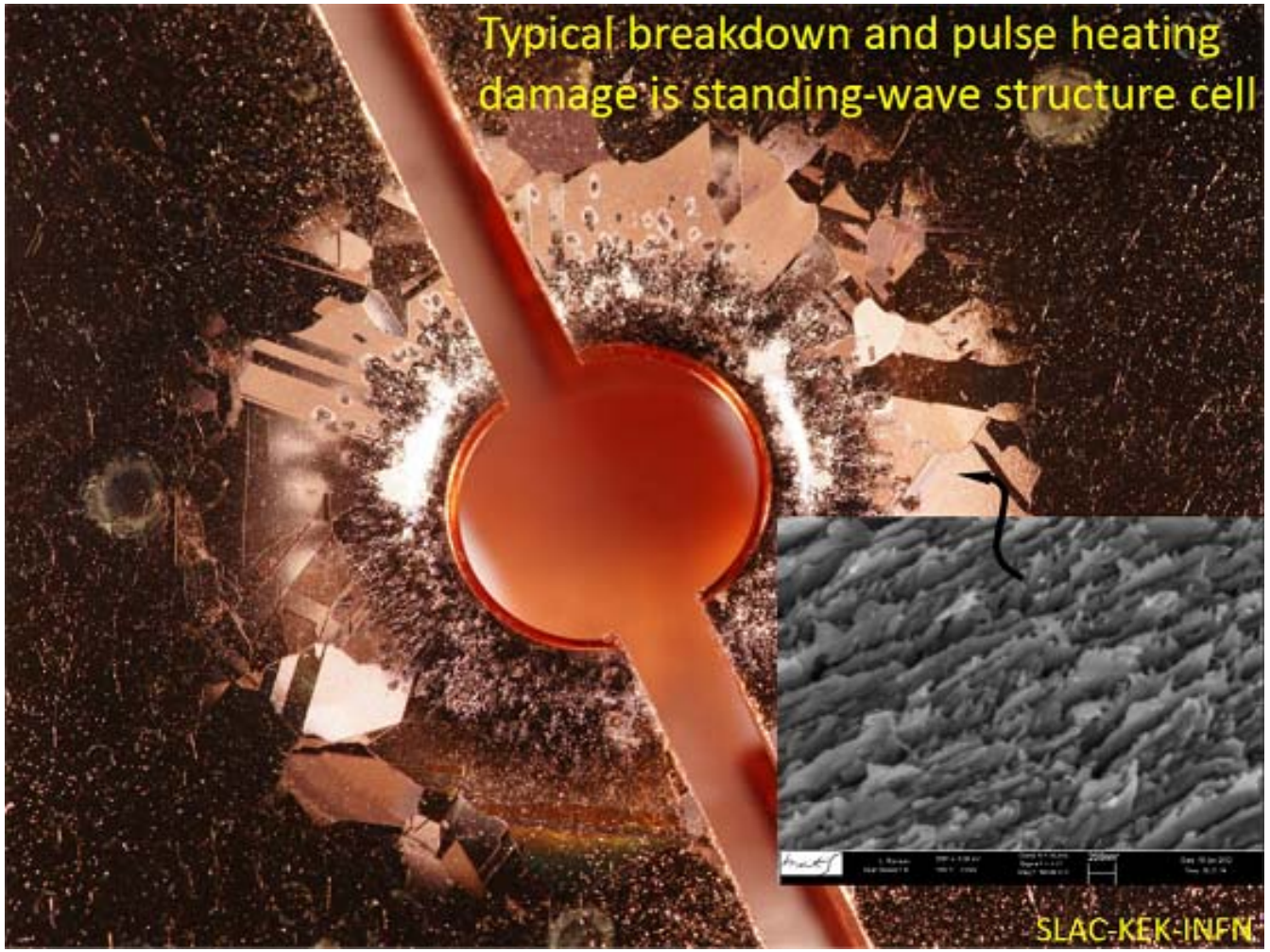
Accelerating gradient

- The reason why the cost has been scaling with the collider energy is that the accelerating gradients (i.e., the energy gained per unit length) have more or less remained constant over the **past few decades**, in the order of 20 – 50 MeV/m.
- Therefore, the only way to scale into higher energies is to simply make the accelerating portion longer, thus increasing the construction and maintenance costs at the same time

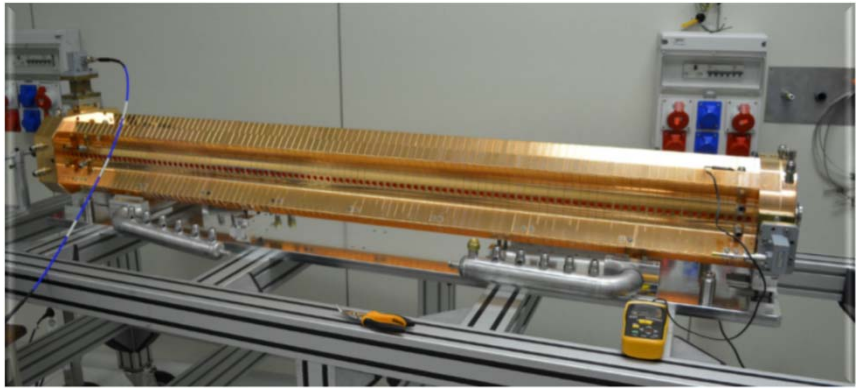
Acceleration

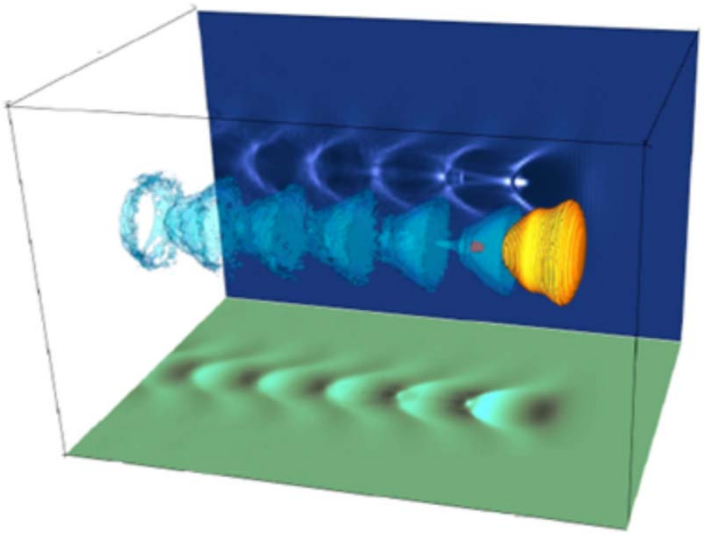


Breakdown


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

Scaling factor



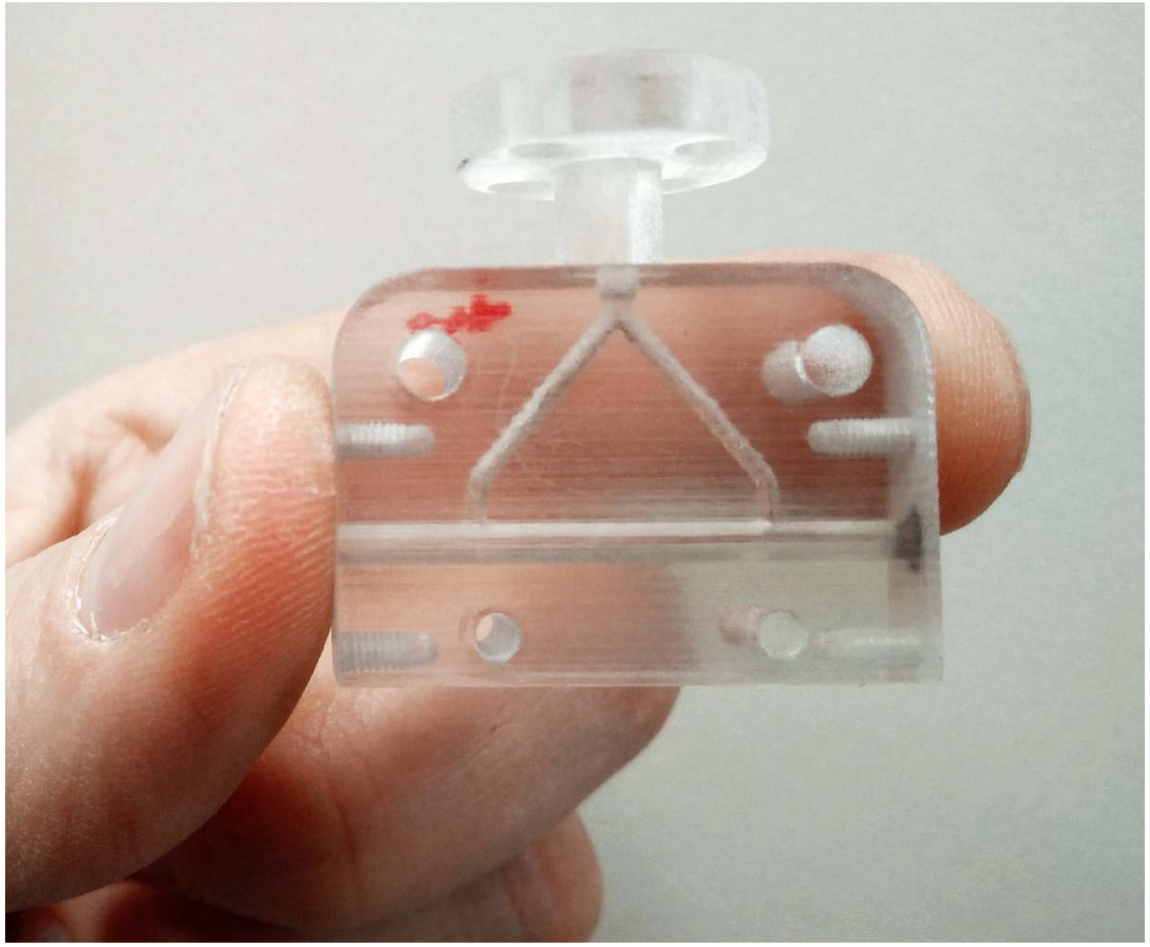


$4\pi p \sim 50$ MeV

R qc|#d#dfwru#5#ehwwhu#kdq#VODF/#3#
|hduv#diwhu$

$4\pi p\,p \sim 50$ MeV

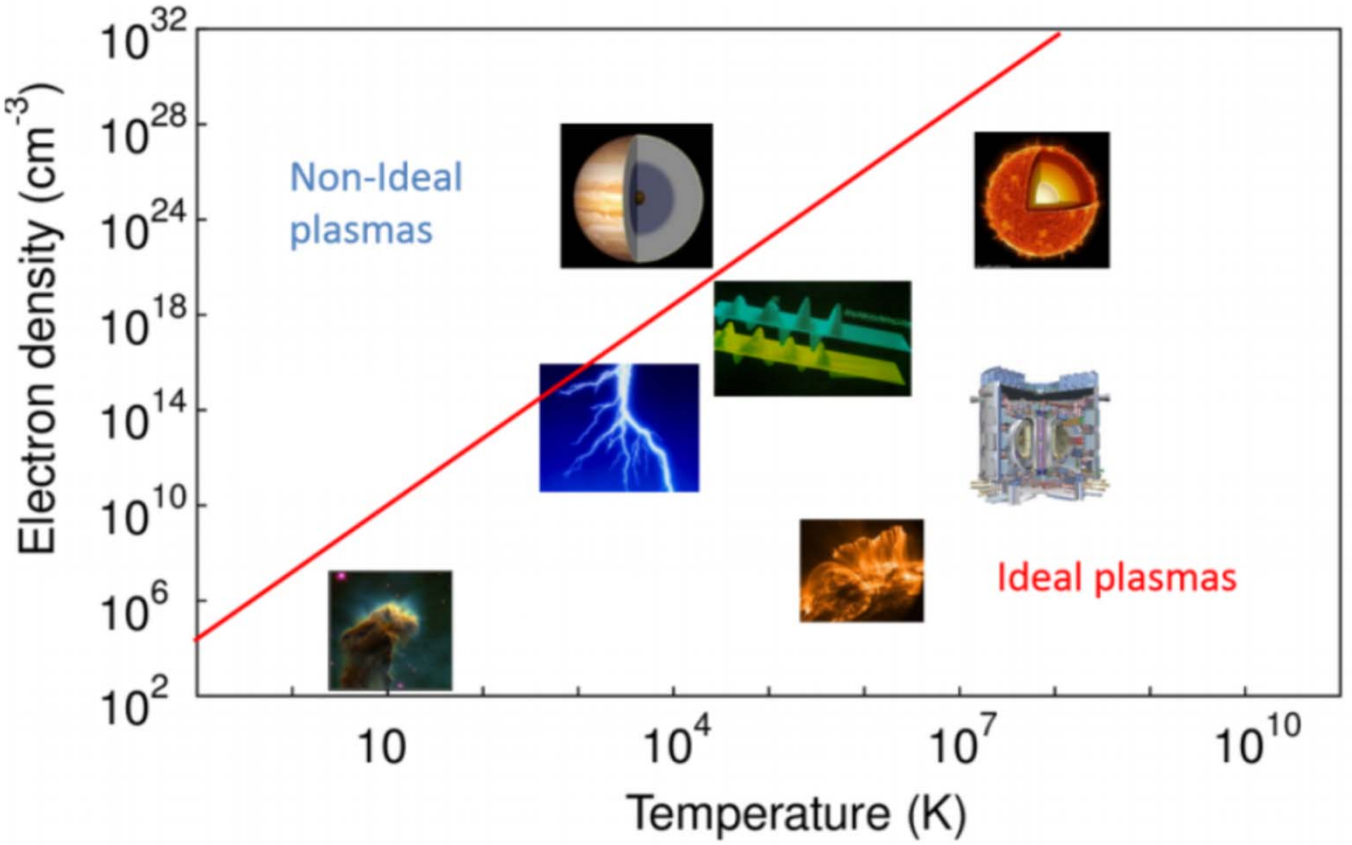
3 cm



What is plasma?

- Simple definition: a quasi-neutral gas of charged particles showing collective behavior
- Quasi-neutrality: number densities of electrons, n_e, and ions, n_i , with charge state Z are locally balanced
- Collective behavior: long range of Coulomb potential usually dominate over microscopic fluctuations

Plasma categories



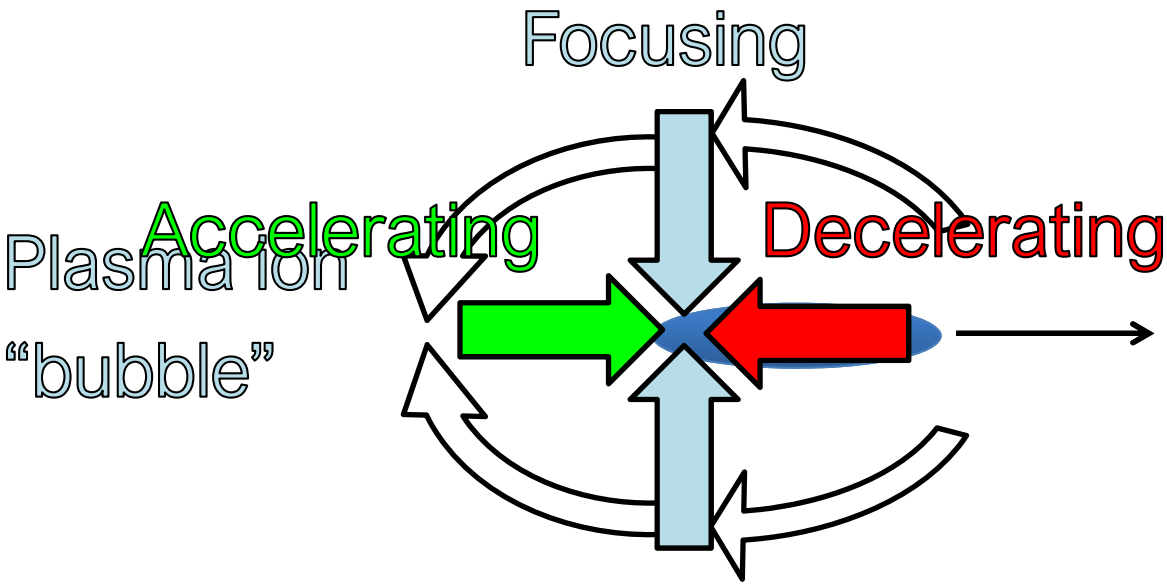
Two main categories

- LWFA (Laser Plasma Acceleration)
  - Based on the use of high power laser (>10^{18} W/cm^2)

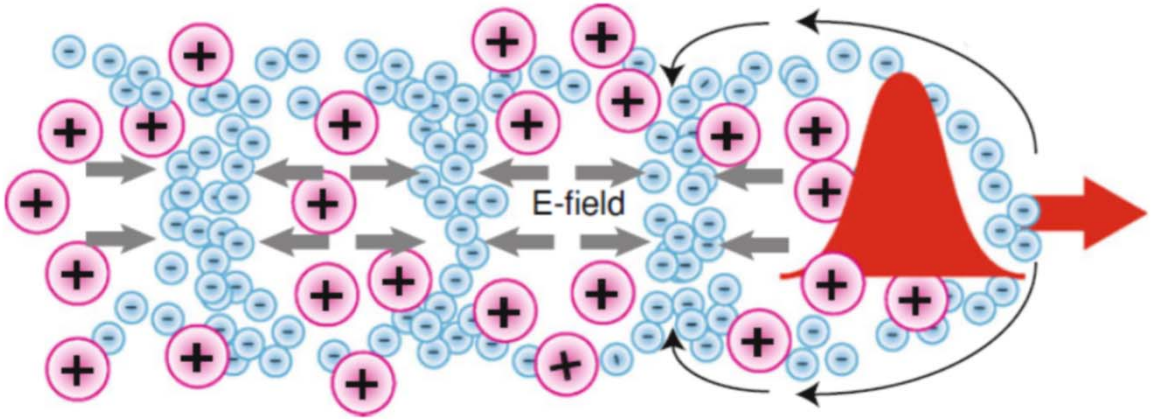
- PWFA (Plasma Wakefield Acceleration)
  - Based on the use of high brightness bunches

What is a Plasma Wakefield Accelerator?

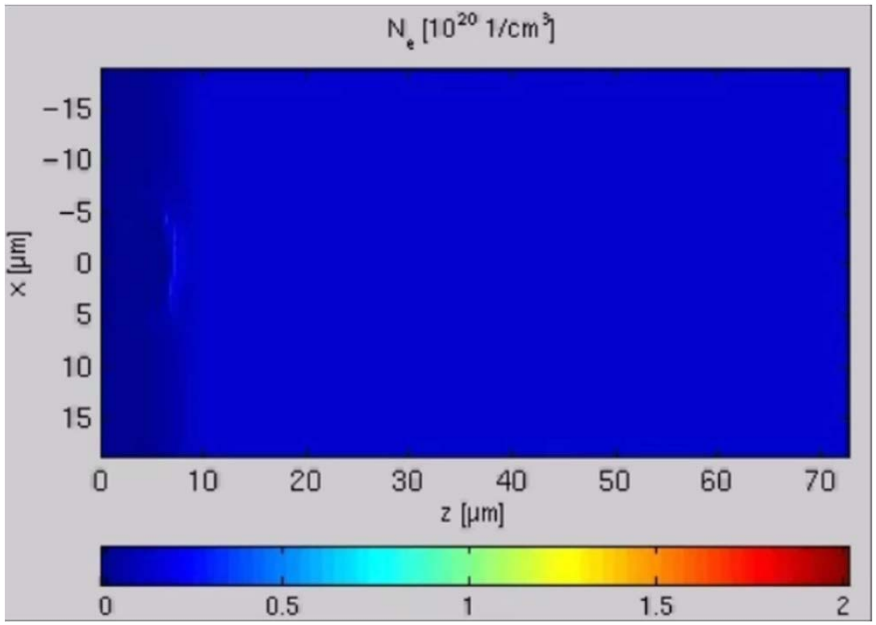
Ydfxxp



Plasma wake



LWFA
Laser
Plasma
Acceleration



Just an estimation

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0} = \frac{e\,(n_i - n_e)}{\varepsilon_0}$$

n_i=ion density
n_e= electron density
n_0= plasma density

$$\omega_p = \sqrt{\frac{e^2 n_0}{\varepsilon_0 m_e}}$$

Plasma frequency

$$E = E_0 \exp(ik_p z)$$

$$\frac{\omega_p}{c} E_0 = \frac{e}{\varepsilon_0} n_0$$

Electric field strength

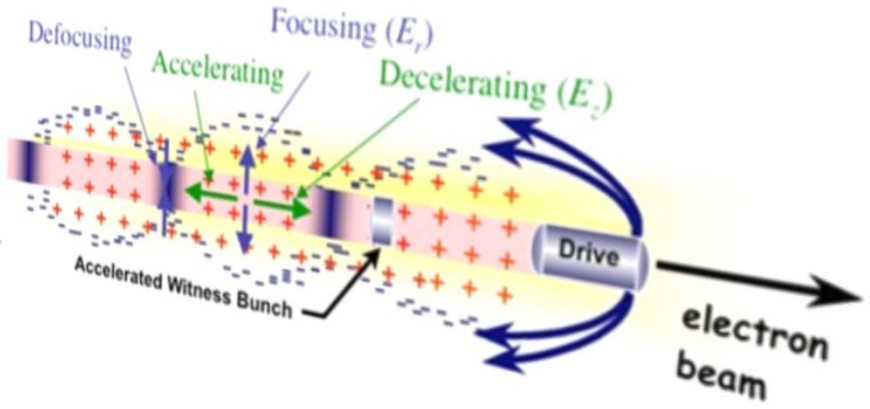
$$E \approx (96\ \mathrm{V/m}) \sqrt{n_e[\mathrm{cm}^{-3}]}$$

e.g. E ≈ 100 GV/m (for $n_e \approx 10^{18}$ cm^{-3})

The reasons of high gradient

- The collective effect of the plasma electrons; inside a plasma its billions of freed electrons can be manipulated together and forced to act coherently.
- It is merely an energy transformer.
- It does not provide energy; it may only transfer the energy of an existing beam to a trailing beam.

PWFA



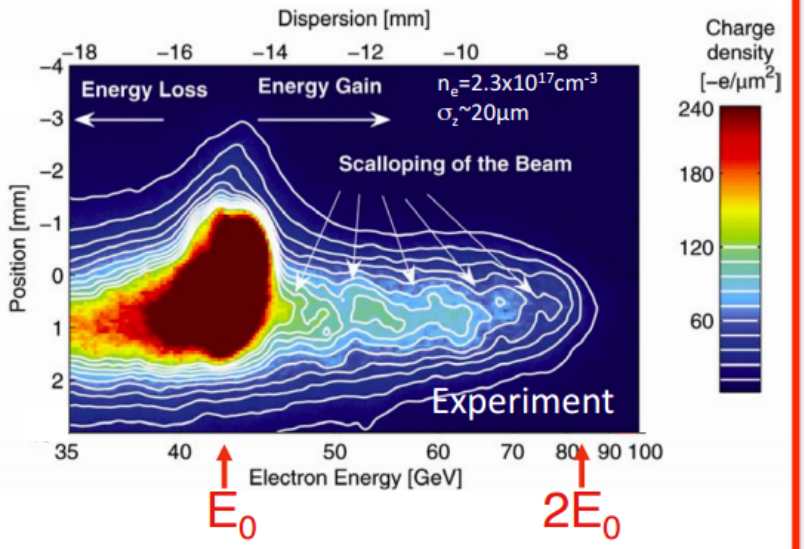
PWFA
Plasma
Wakefield
Acceleration

Energy exchange between drivers and witness inside a capillary

First proof of principle

"quantity"

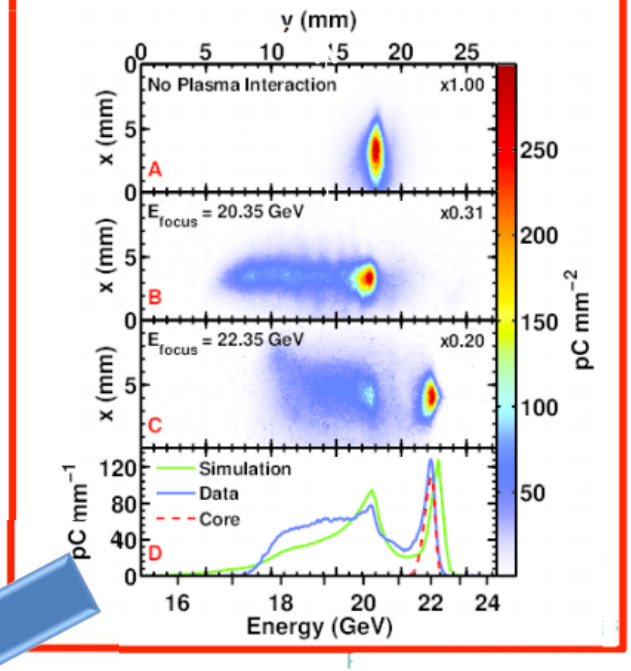
Blumenfeld, Nature 445, 741 (2007)



42 => 84GeV in 85cm! 50GeV/m

"quality"

Litos, Nature 515, 92 (2014)



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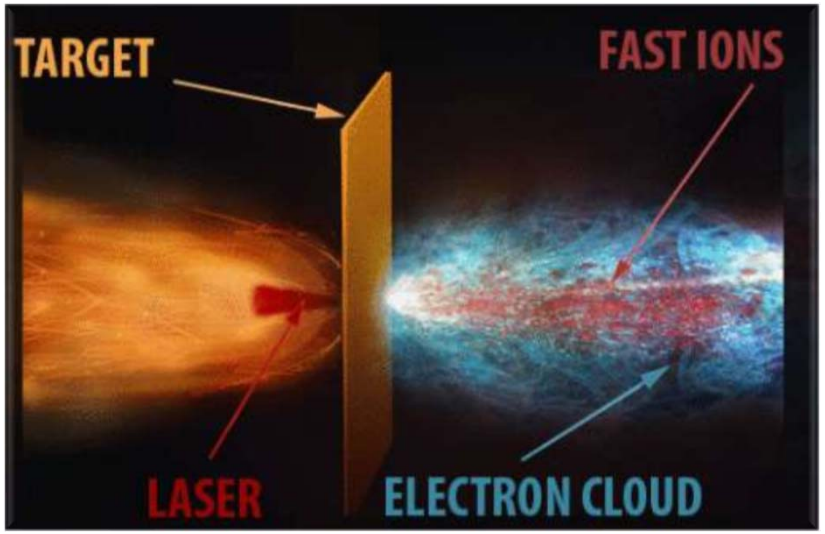
Hiilflqf|#53(

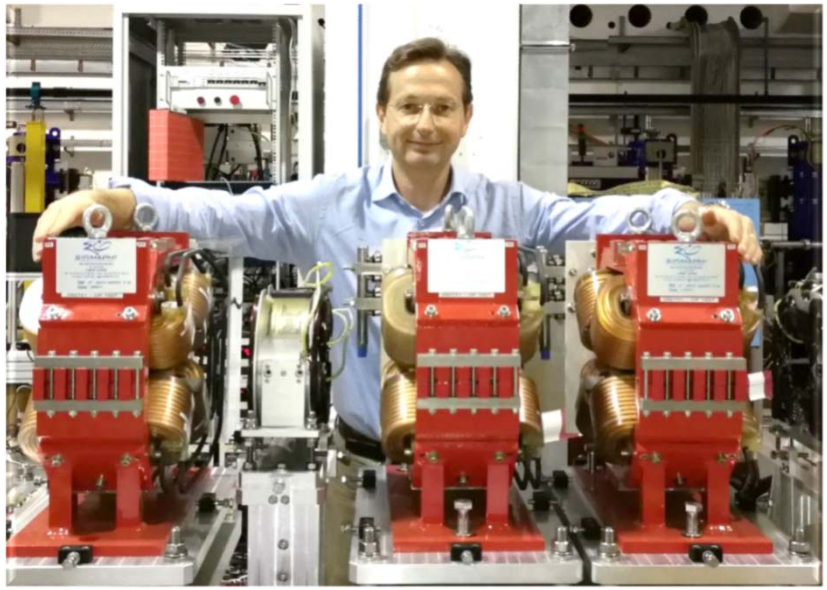
Target Normal Sheath Acceleration

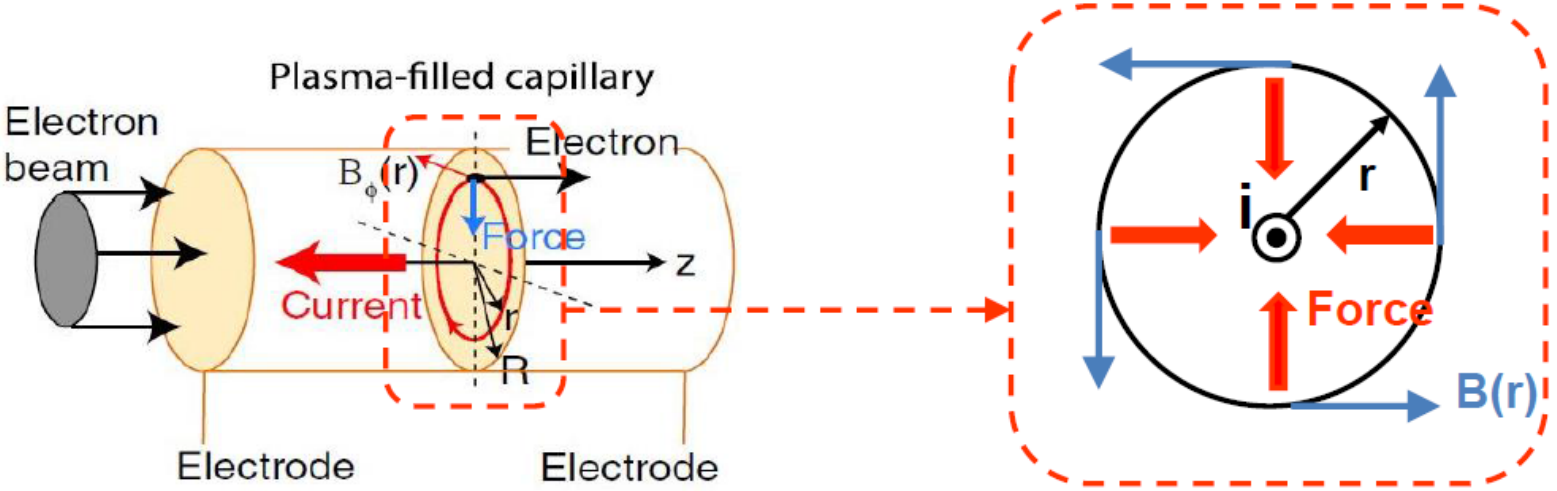
- Proton and ions are too slow to catch the wave: only indirect acceleration via electrons

- Laser (10^{19} W/cm^2) creates a blow off plasma on front surface
- Hot electrons create electric field by space charge
- It accelerates protons

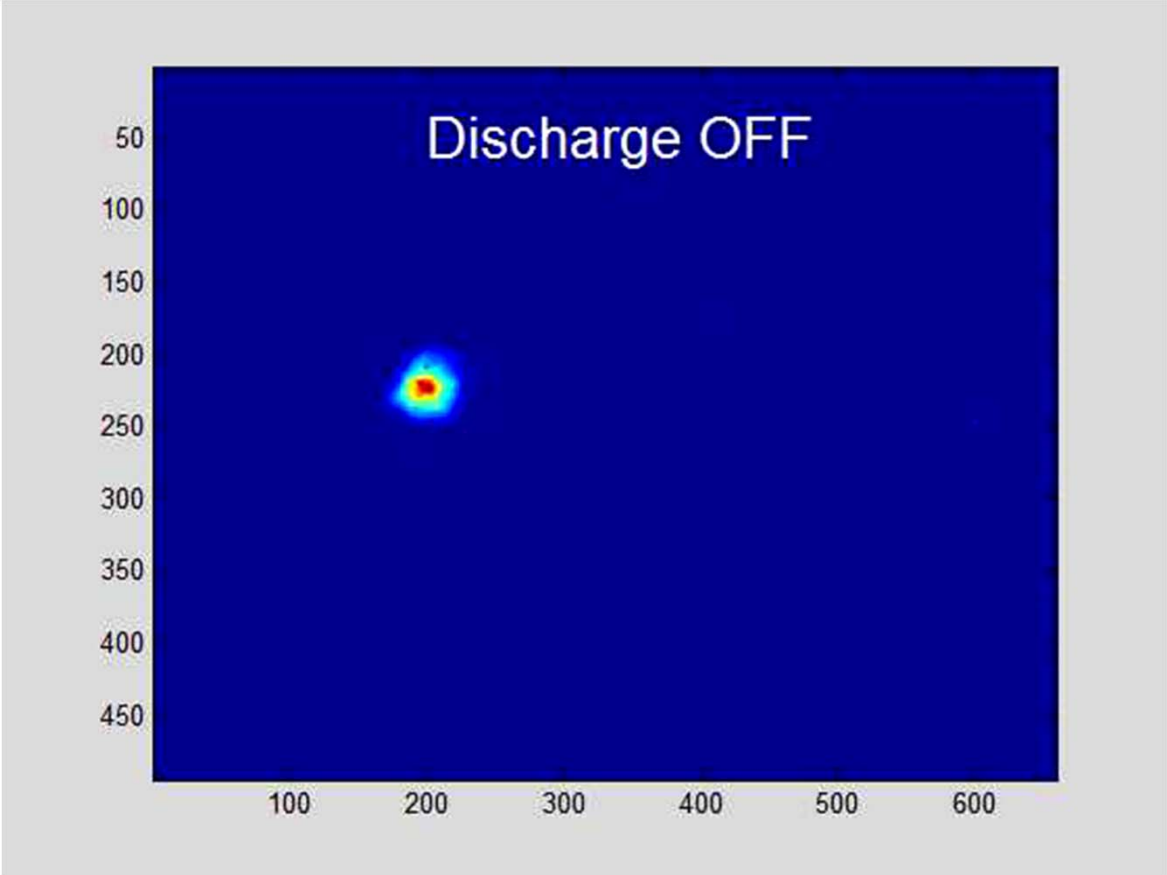


Plasma Lens




Plasma-filled capillary
Electron beam
Electron
$B_\phi(r)$
Force
z
Current
r
R
Electrode
Electrode
i
r
Force
B(r)

Active plasma lens



Conclusions

- New and revolutionary techniques based on plasma are developing for particle acceleration, transport and even damping
- New accelerators will be available for industrial applications
- Light sources and medical applications will follow
- For HEP table-top machine maybe a longer time will be needed

Citation

«Non è importante avere capito tutto, ma è fondamentale comprendere che c'è qualcosa che vale la pena di capire»

Giorgio Salvini
(1920-2015)