Optically Induced GeV Electrons beam :

The LOA Strategy

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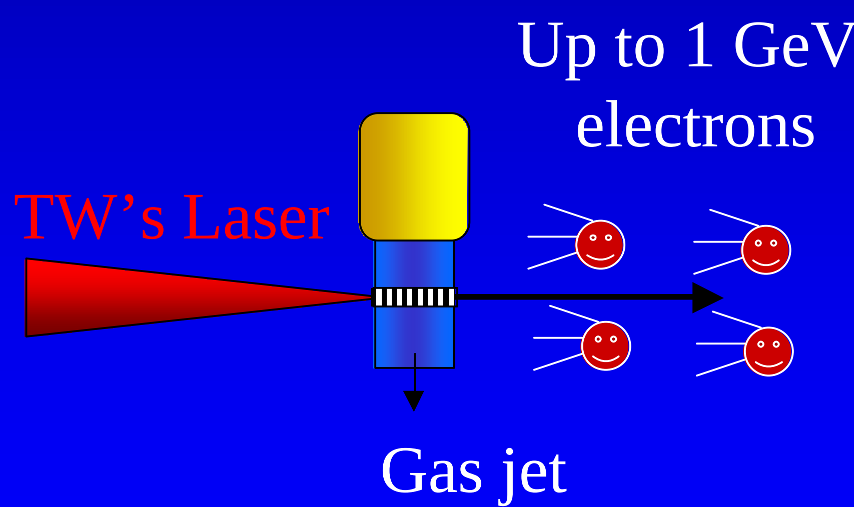

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Classical accelerator limitations

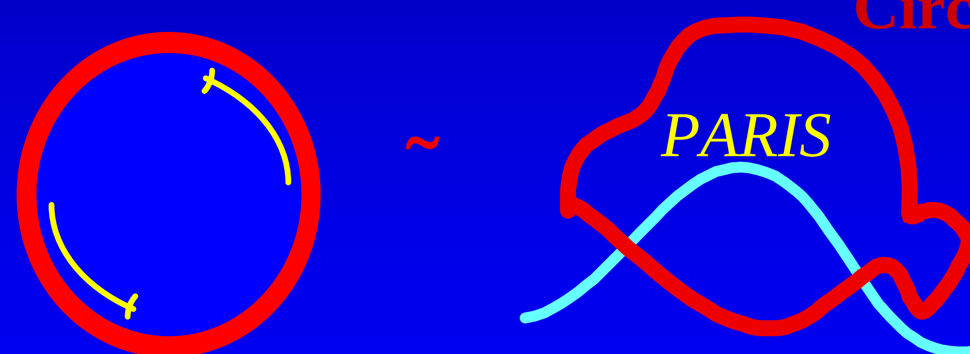
E-field $_{max}$ ~ few **10 MeV /meter** (Breakdown)

R>R$_{min}$ **Synchrotron radiation**

→ **Energy ↗ = Length ↗ = $$$ ↗**

Circle road

27 km

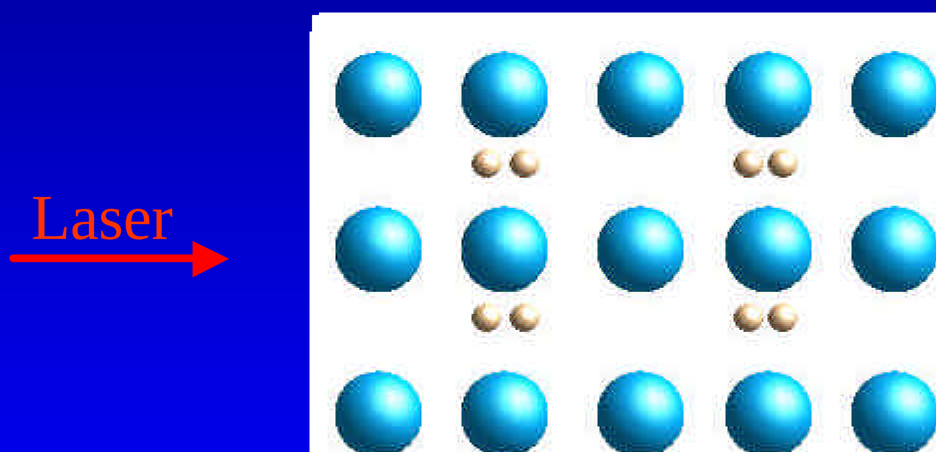


31 km

→ **new techniques**

Why use a Plasma ?

- Superconducting RF-Cavities : $E_z = 55$ MV/m
- Plasma is an Ionized Medium → High Electric Fields



$$E_z \sim \omega_p \sim \sqrt{n_e}$$

for 1 % Density Perturbation at 10^{17} cc^{-1} 0.3 GV/m
for 100 % Density Perturbation at 10^{19} cc^{-1} 300 GV/m

Tajima&Dawson, PRL79

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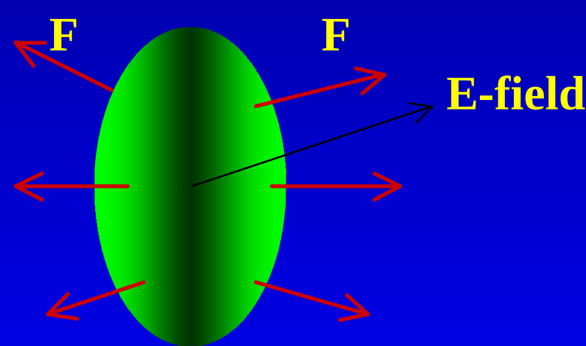
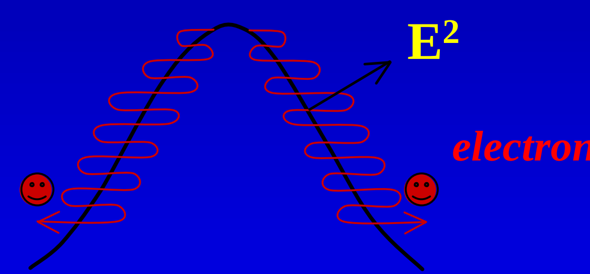
The ponderomotive force of the laser field can transform the transverse laser field into a charge separation and a propagating plasma wave

- An electromagnetic field acts as a pressure on charged particles :

  it expels the electrons from high-intensity zones





$$m\left[\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}\cdot\nabla)\mathbf{v}\right] = -e\,[\mathbf{E}(\mathbf{r}) + \mathbf{v}\times\mathbf{B}(\mathbf{r})] \Rightarrow \vec{F} \propto -\nabla E^2$$

- The heavier ions do not move

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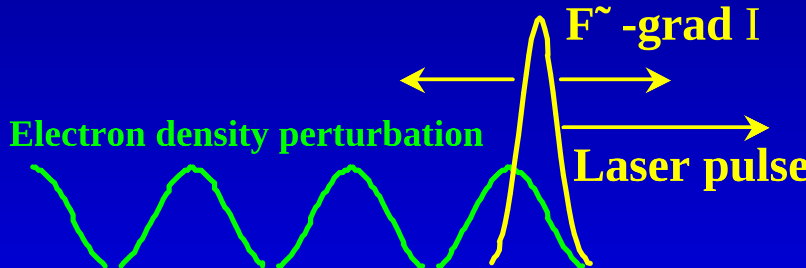
How to excite Relativistic Plasma waves?

(i) The laser wake field



Phase velocity $\mathbf{v}_{\phi_{epw}} = v_{g_{laser}}$

=> close to c

$$$$

$t_{laser} \sim T_p / 2$

=>Short laser pulse

$t_{laser} \sim$ 200 fs for $n_e = 10^{17} cm^{-3}$

Optical demonstration :

Hamster et al. PRL 93: THz measurements

Marques et al. PRL 96: Spectroscopy in the time domain

Siders et al. PRL 96 : Spectroscopy in the time domain

Electron gain demonstration :

Amiranoff et al. PRL 1998: E_{in}=3 MeV => E_{out}=4.6 MeV

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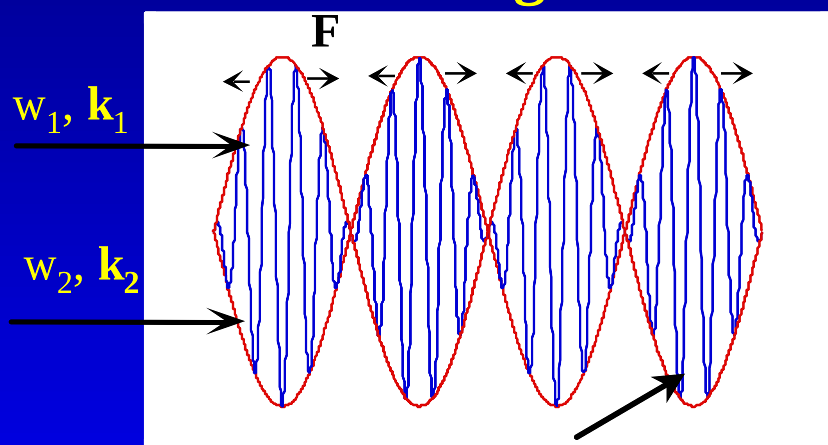
How to excite Relativistic Plasma waves?
(ii) The laser beat waves

F~ -grad I



Laser envelop modulation
Train of short resonant pulses

$$$$!

$w_1 - w_2 = w_p$

Linear growth : $d(t) = 1/4 a_1 a_2 w_p t$

=>Homogenous plasmas

Saturation : relativistic, ion motion

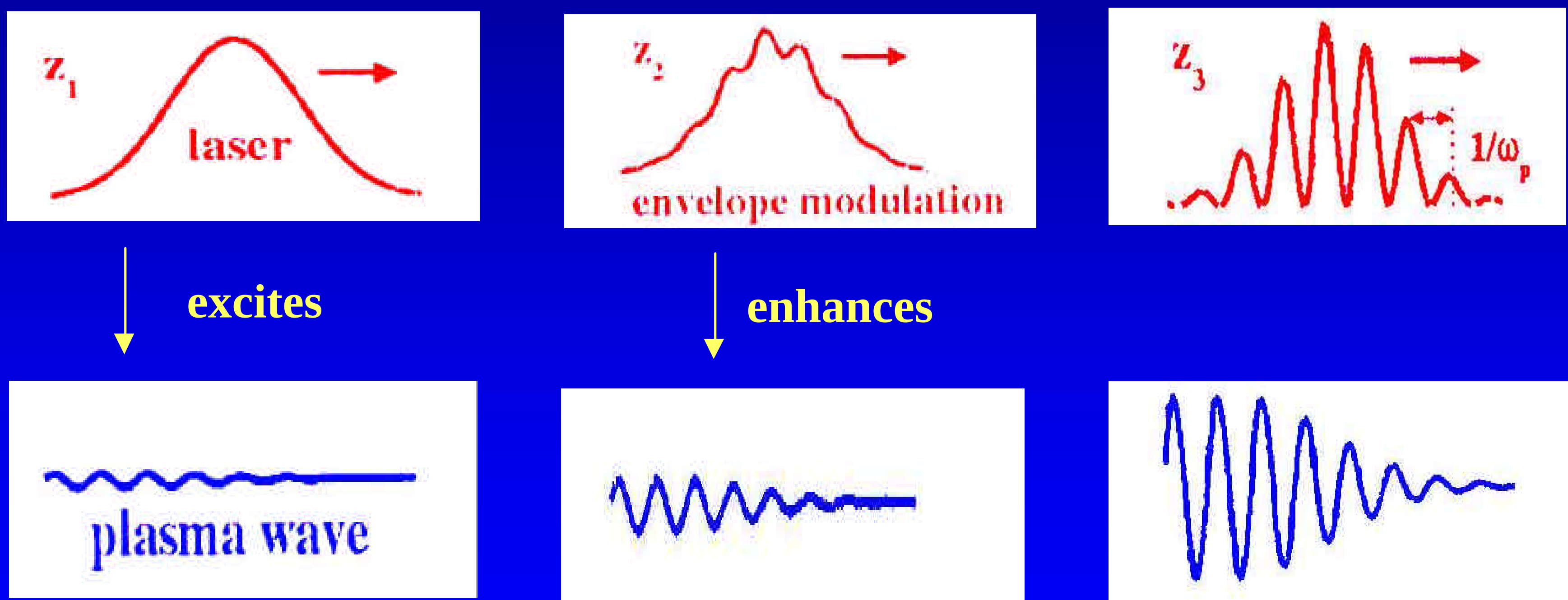
Optical demonstration by Thomson scattering :
Clayton et al. PRL 1985,Amiranoff et al. PRL 1992, Dangor et al. Phys. Scrypta 1990

Electron gain demonstration Few MeV's:
Kitagawa et al. PRL 1992,Clayton et al. PRL 1993,N. A. Ebrahim et al., J. Appl. Phys.1994, Amiranoff et al. PRL 1995

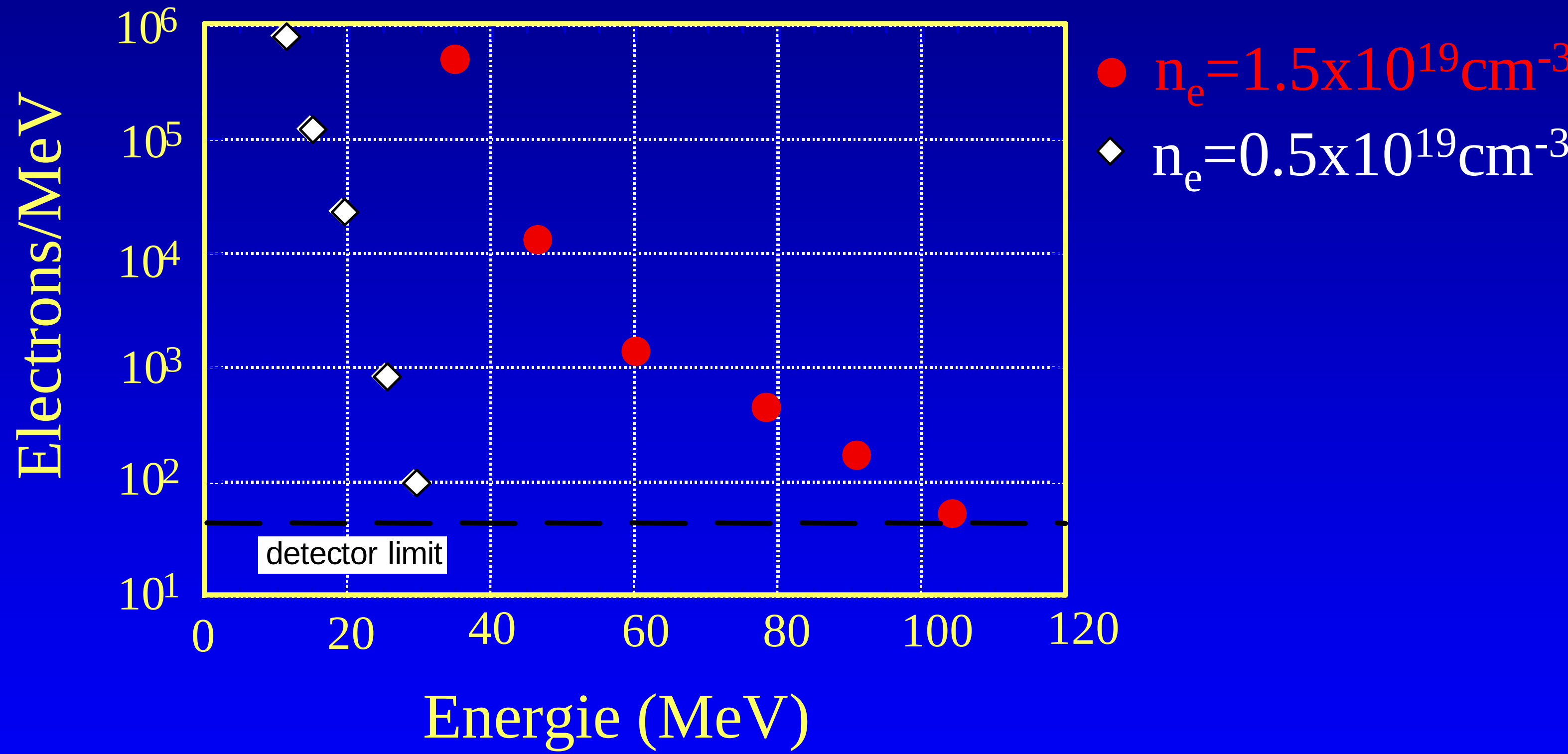
Chen, Introduction to plasma physics and controlled fusion, 2nd Edition, Vol.1, (1984

Longitudinal bunching : Self-modulated Laser Wakefield Scheme

$ct >> l_p$ *and* $P>P_c$



Relativistic wave breaking



Modena et al. Nature 377, (95)

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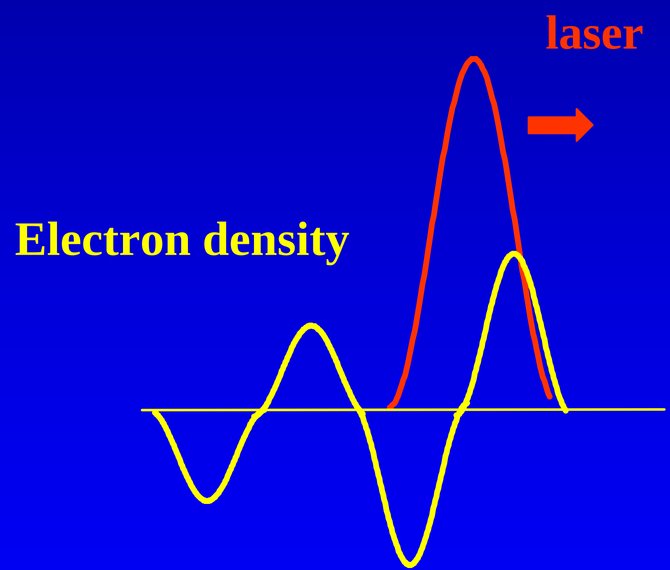
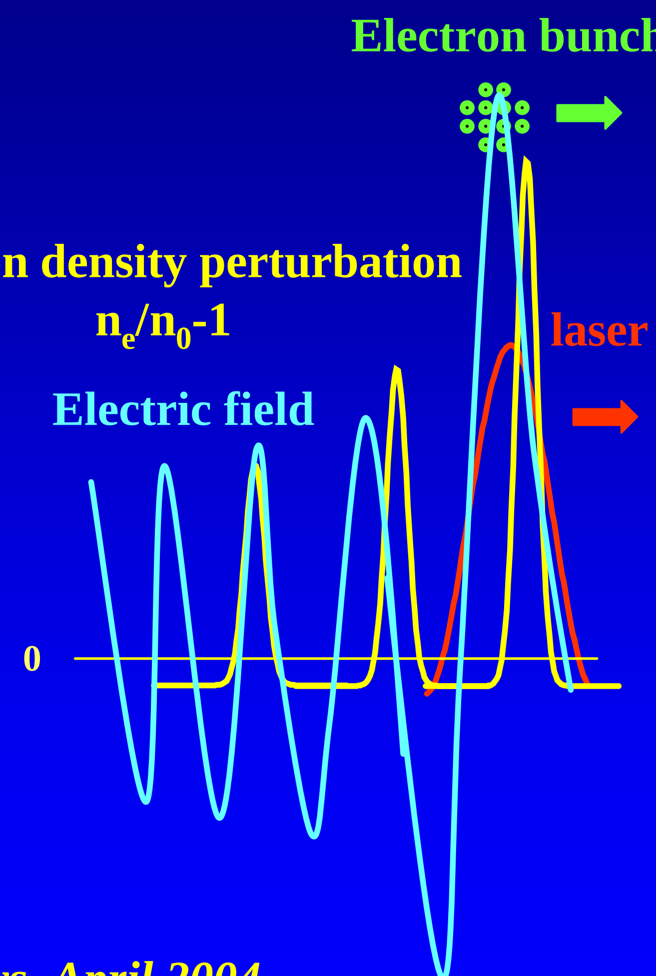
FLWF :

ct » l_p and $P>P_c$





Malka, V., Europhysics news, April 2004

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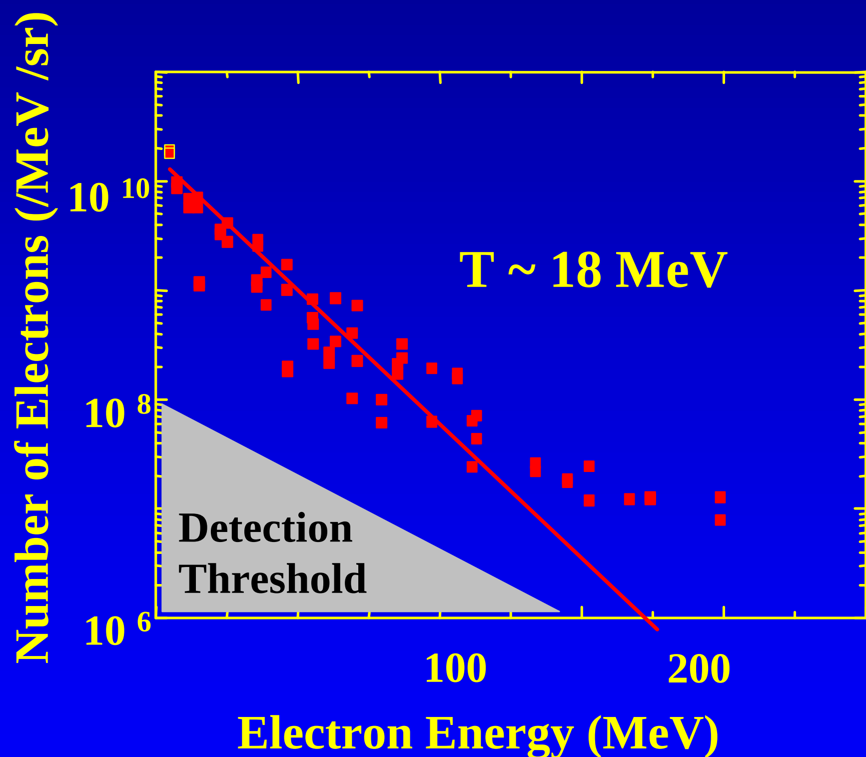
Electron Beam up to 200 MeV

Total Charge : 5 nC



Emittance - Definition and Meaning

- <u>Normalized RMS Emittance :</u>
  Volume of Electron Beam in 6-dimensional Phase Space

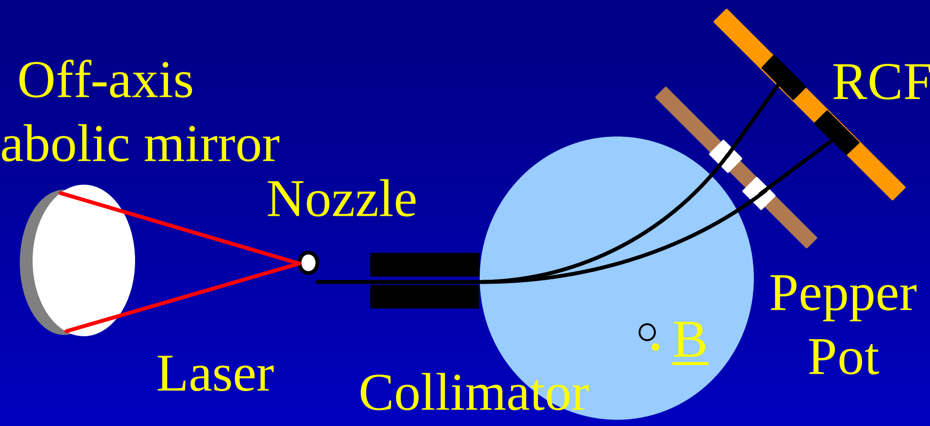
$$\varepsilon_x^n = \beta\gamma\sqrt{\langle x^2\rangle\langle (x')^2\rangle - \langle xx'\rangle^2}$$

- <u>Liouville's Theorem :</u>
  if isolated system classically specified by *f* generalized coordinates
  then the distribution of systems over states remains <u>unchanged</u> !

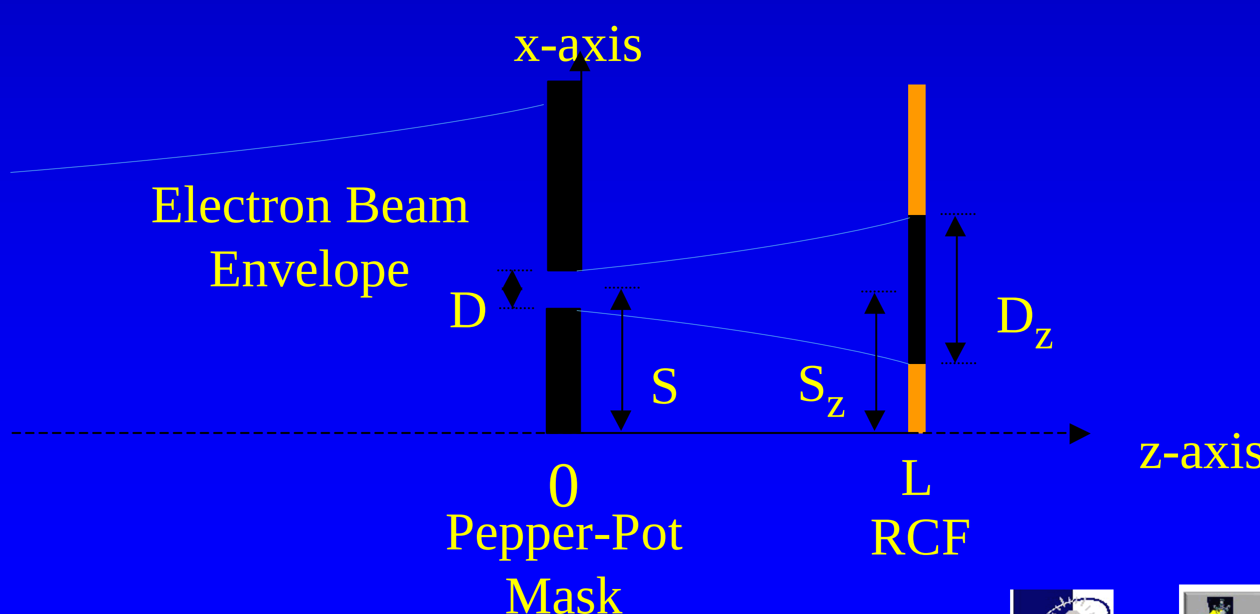
Important Value for any Electron Source

"Pepper Pot Technique"

Experimental Set up



Method



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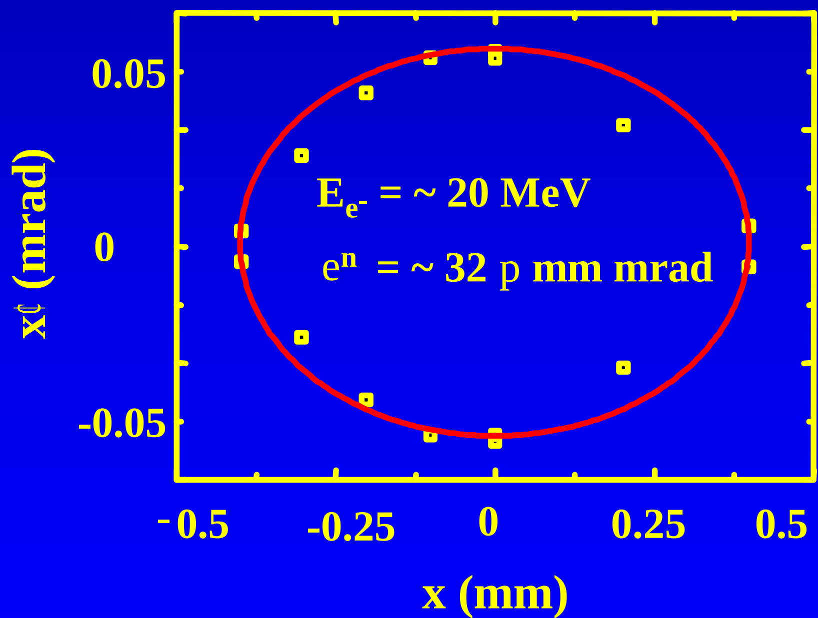
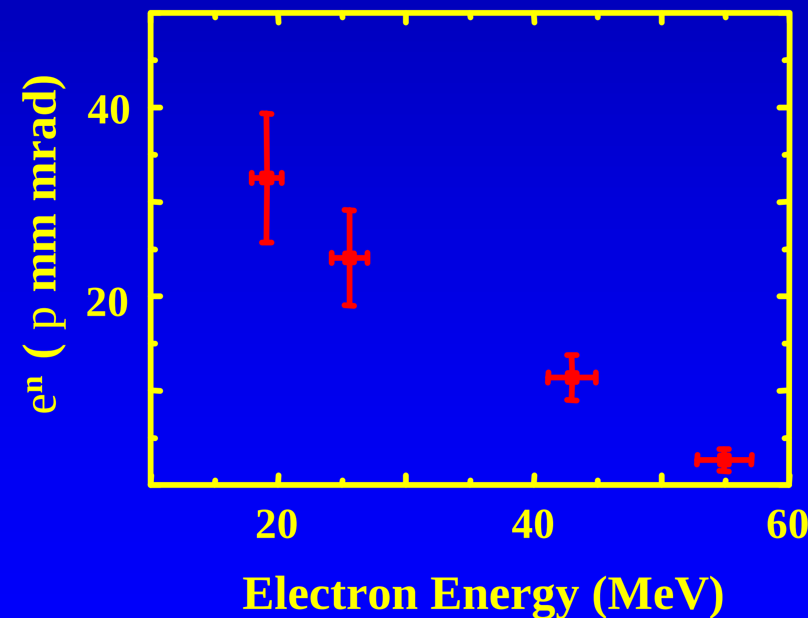
Low Normalized Emittance

Emittance is indeed comparable with todays Accelerators

→ E_{e^-} = ~ 55 MeV → ε^n = ~ 3 π mm mrad





Fritzler et al., PRL 04

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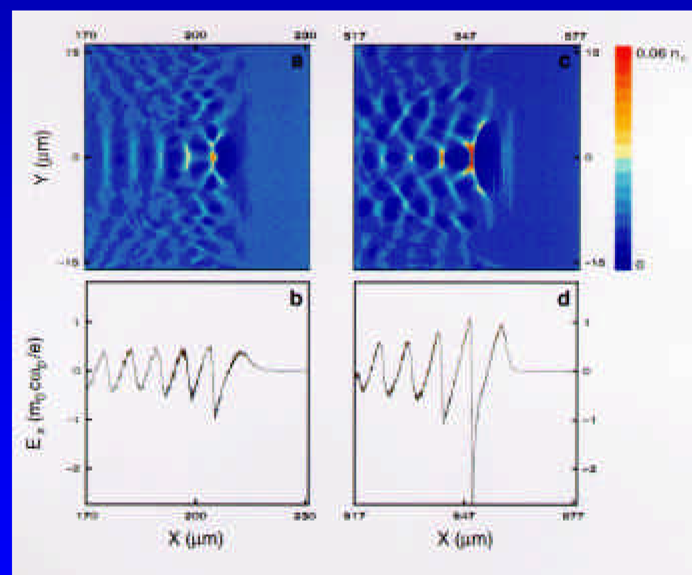
3-D Simulation : 1.4 TV/m

<u>Input values :</u>

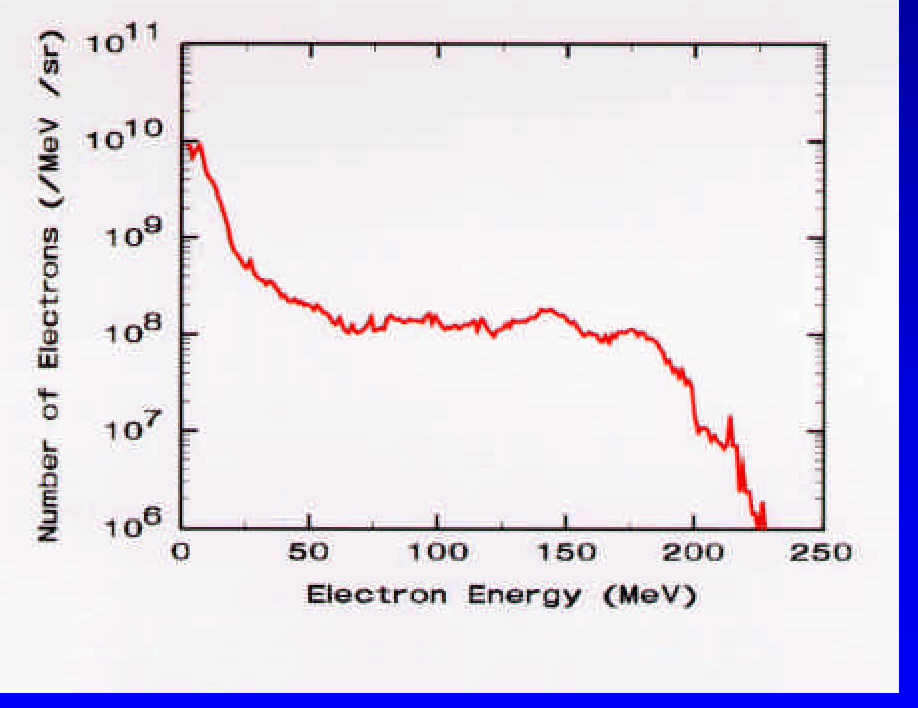
$n_e / n_c = 1\ \%$, $I = 3.5 \times 10^{18}$ W/cm^2, $w_0 = 18$ µm

Electron Acceleration up to 75 MeV after 440 µm



Electron spectra : very good agreement

With Experimental



V. Malka et al., Science 2002

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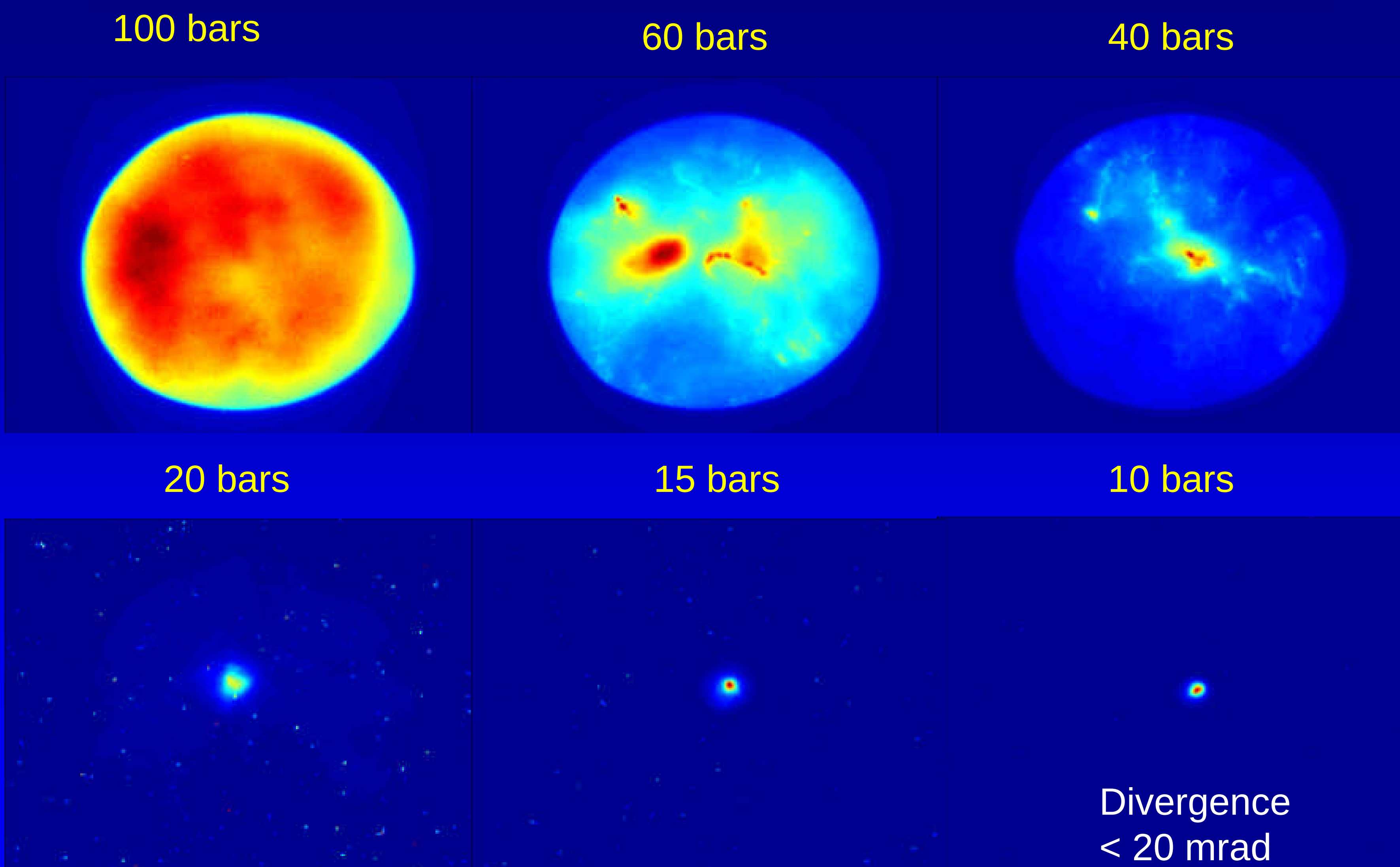
Recent results on e-beam quality improvements



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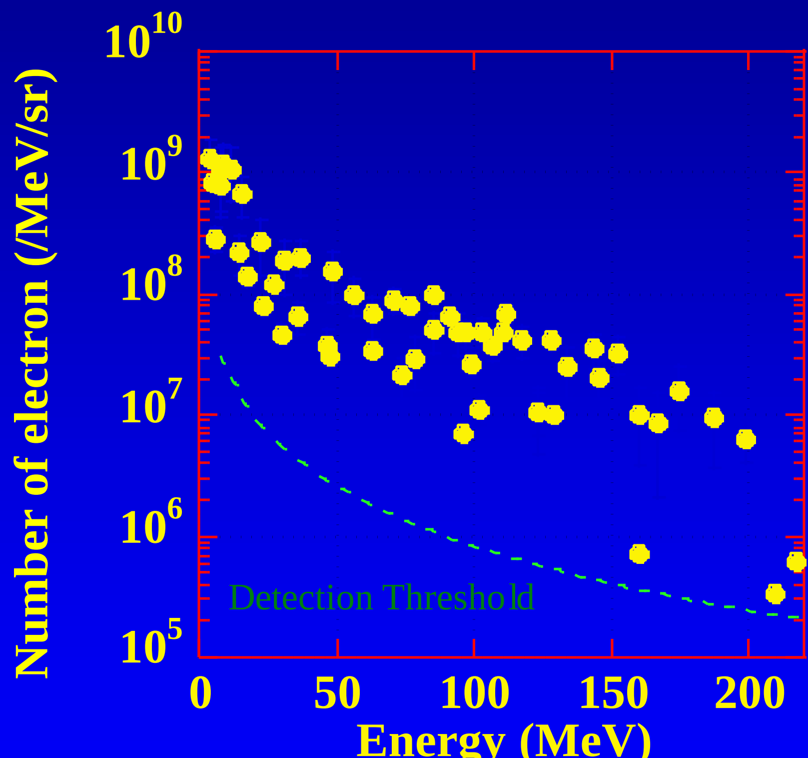
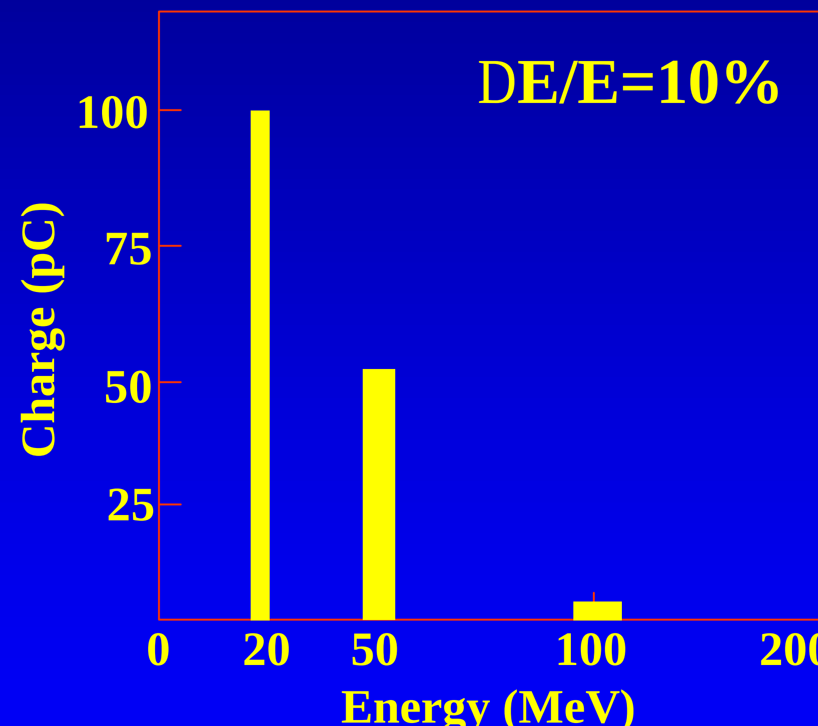
Recent results and beam charge estimation





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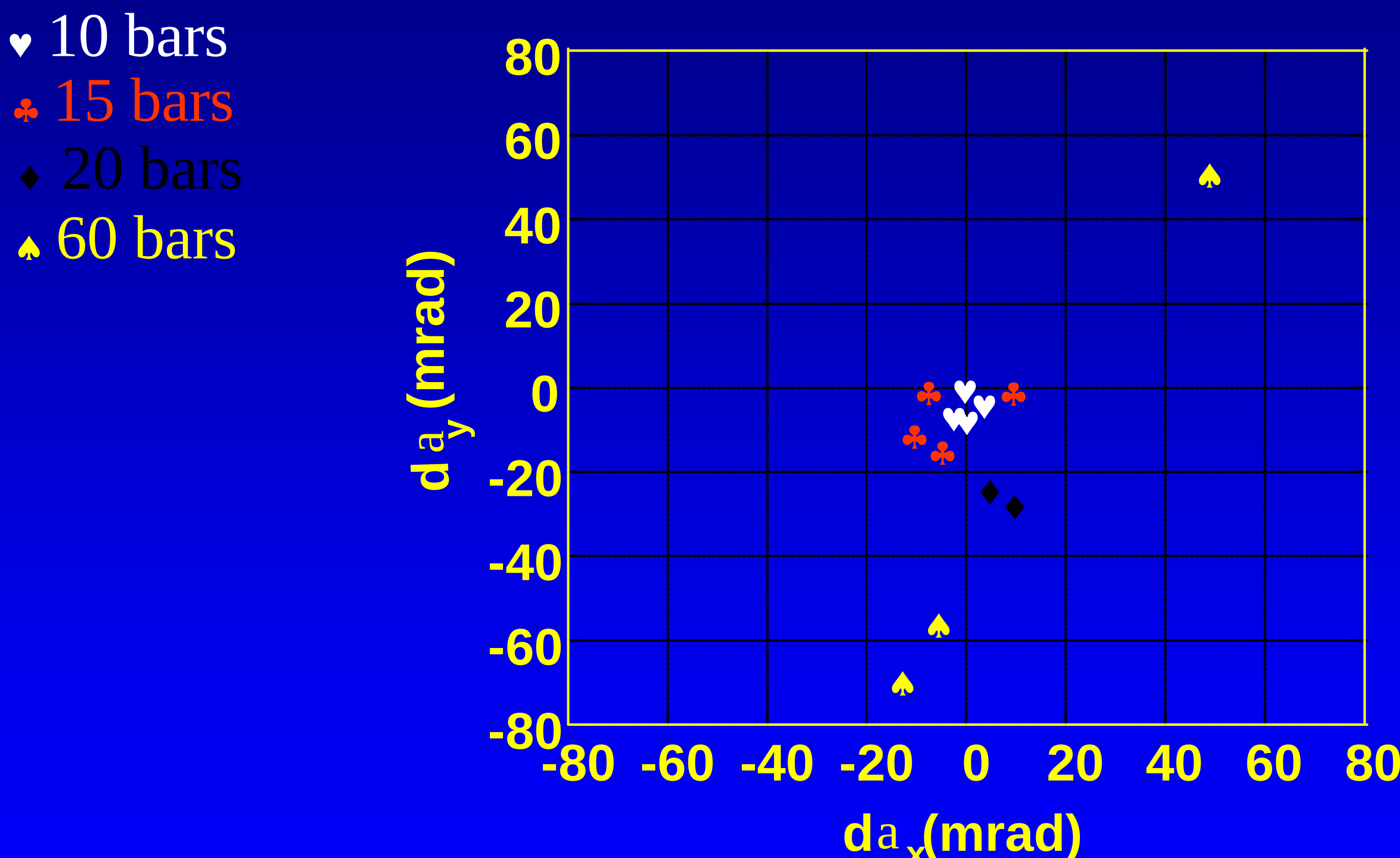
e-beam stability improvements



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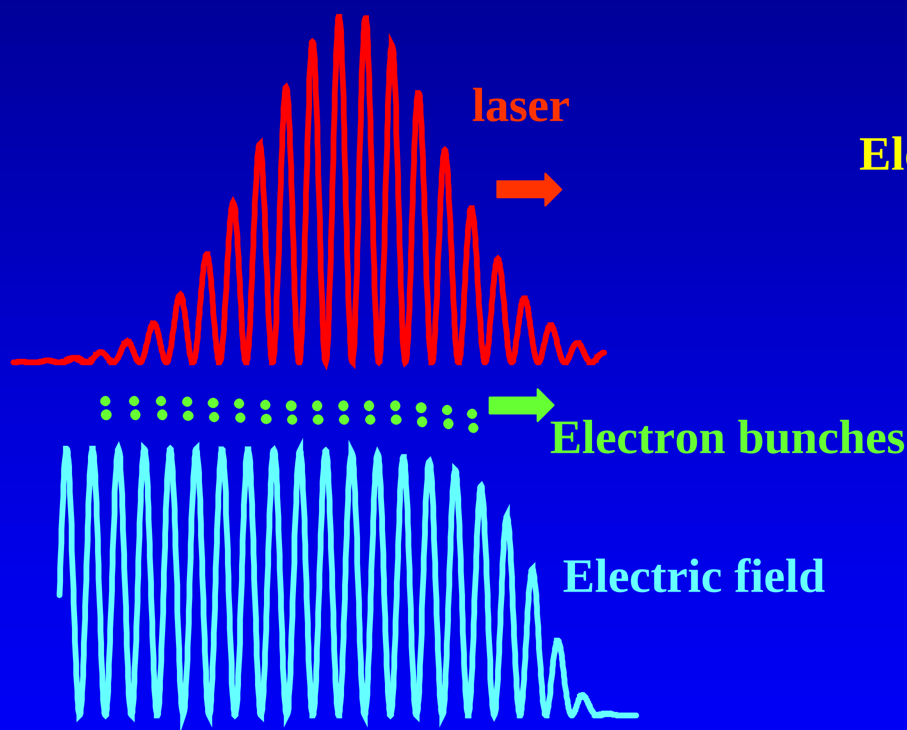
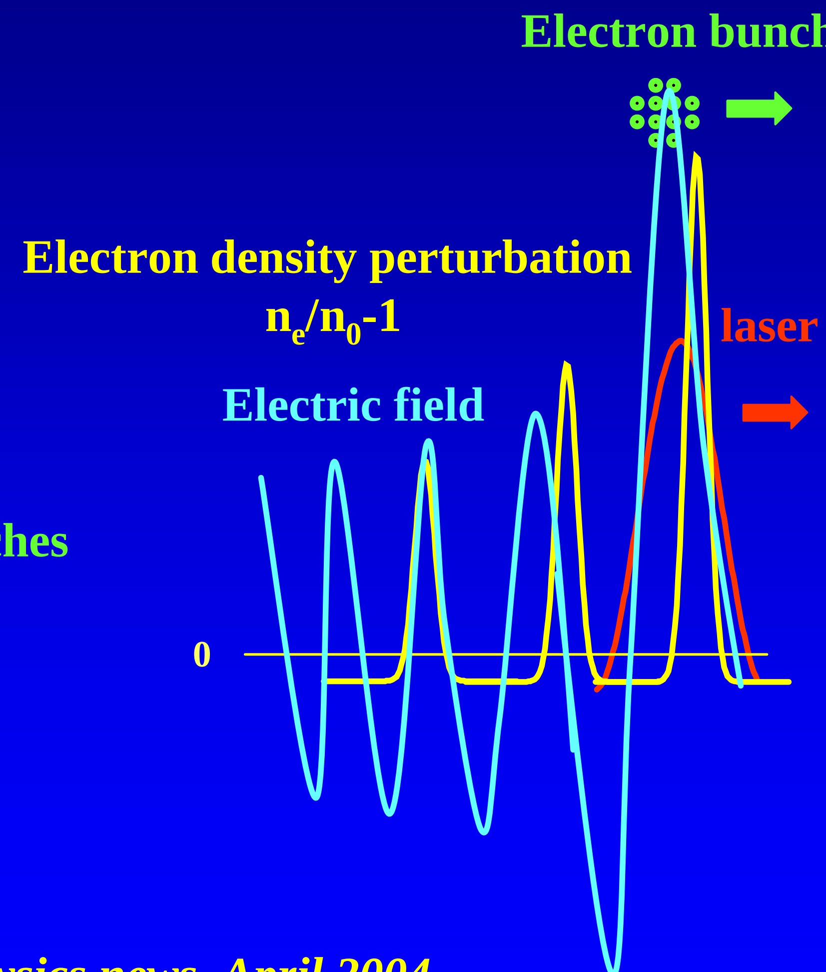
SMLWF : Linear regime / FLWF : Non linear regime

SMLWF : Multiple e^- bunches / FLWF Single e^- bunch





Malka, V., Europhysics news, April 2004

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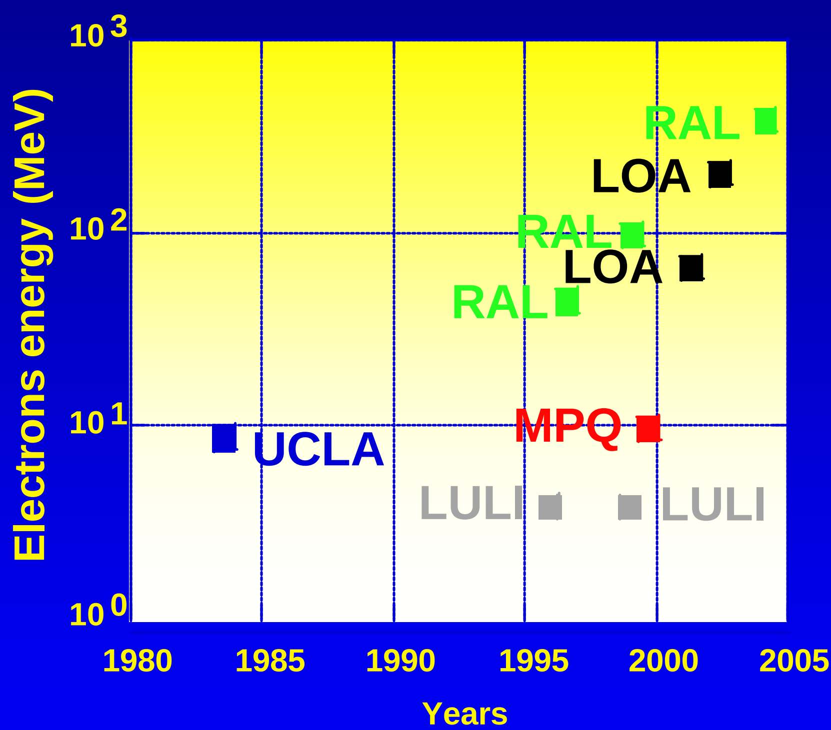
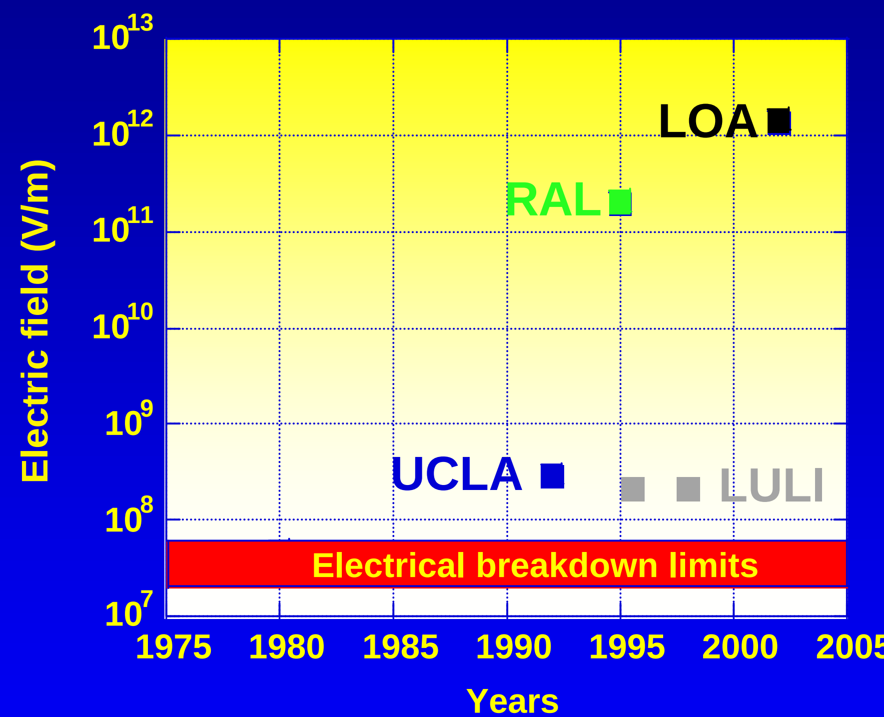
Laser plasma accelerator progress





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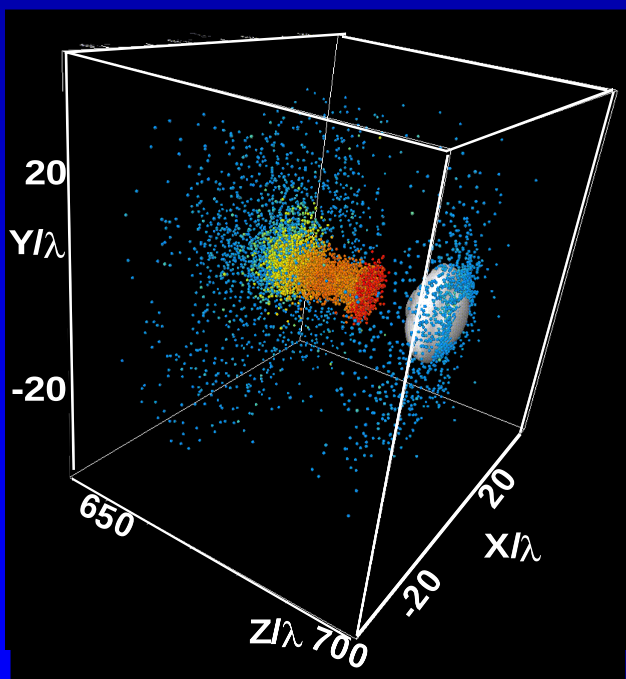
One stage LPA

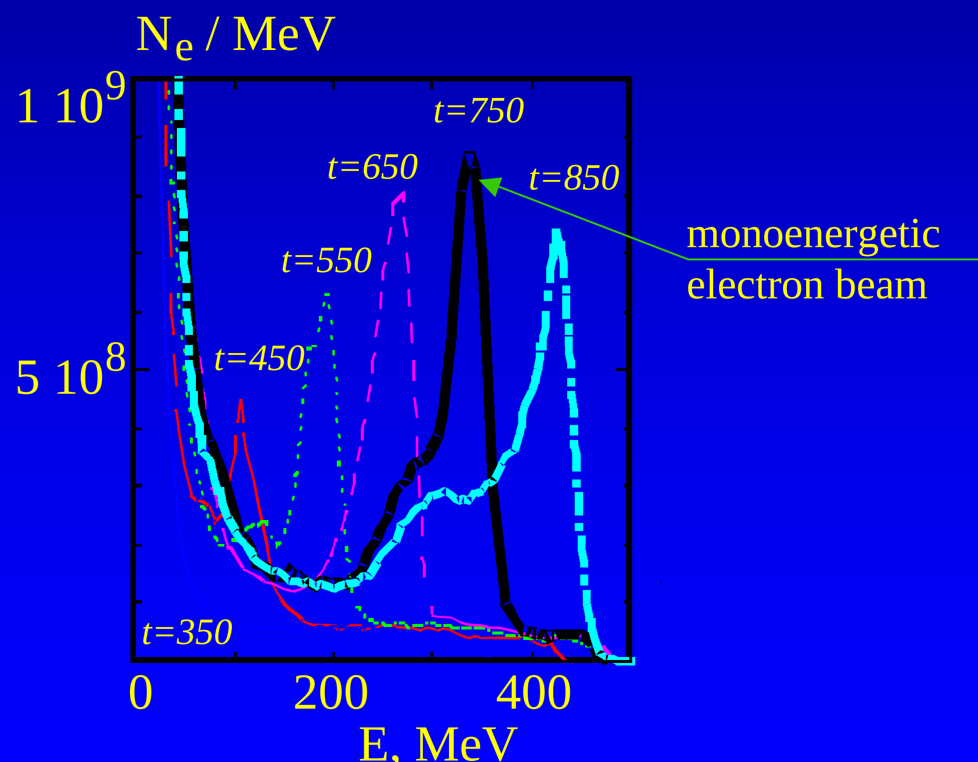
Quasi-Monoenergetic Electron Beams In homogenous plasma

VLPL

A.Pukhov & J.Meyer-ter-Vehn, Appl. Phys. B, 74, p.355 (2002)



Time evolution of electron spectrum



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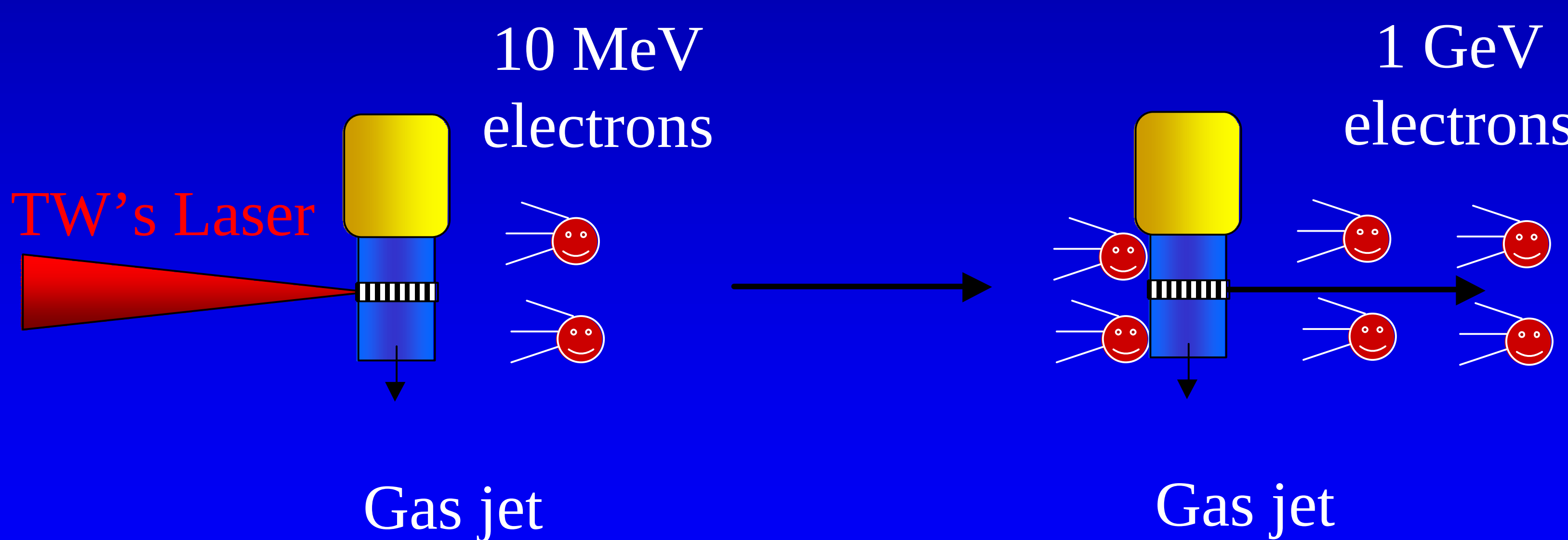
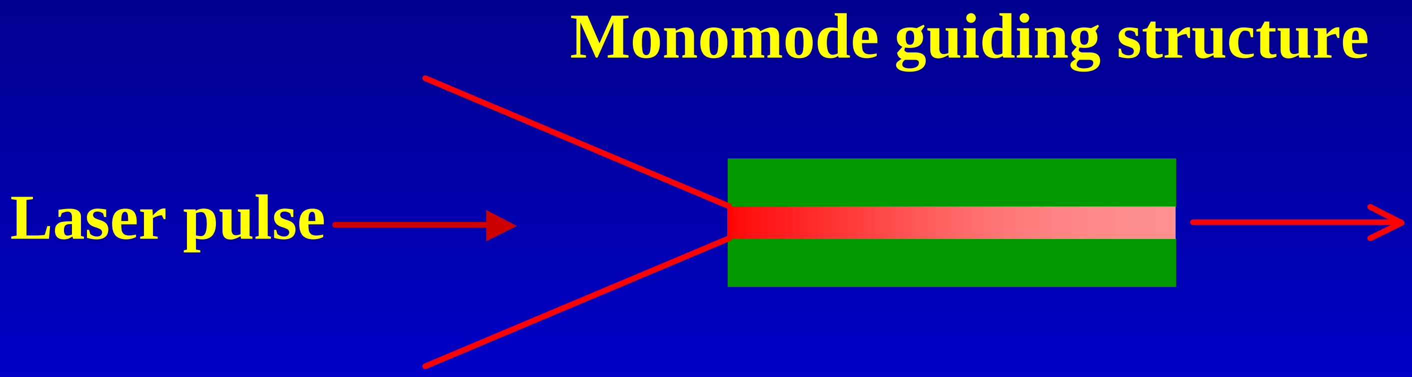
Acceleration of injected electrons beam

1) ***1 laser beam produces e-beam***

1) ***1 laser excites plasma wave to boost the e-beam***



Different laser-guiding structures are tested

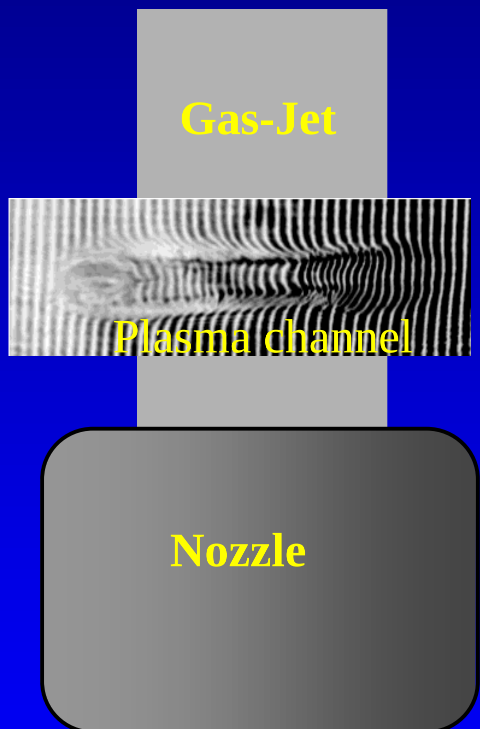


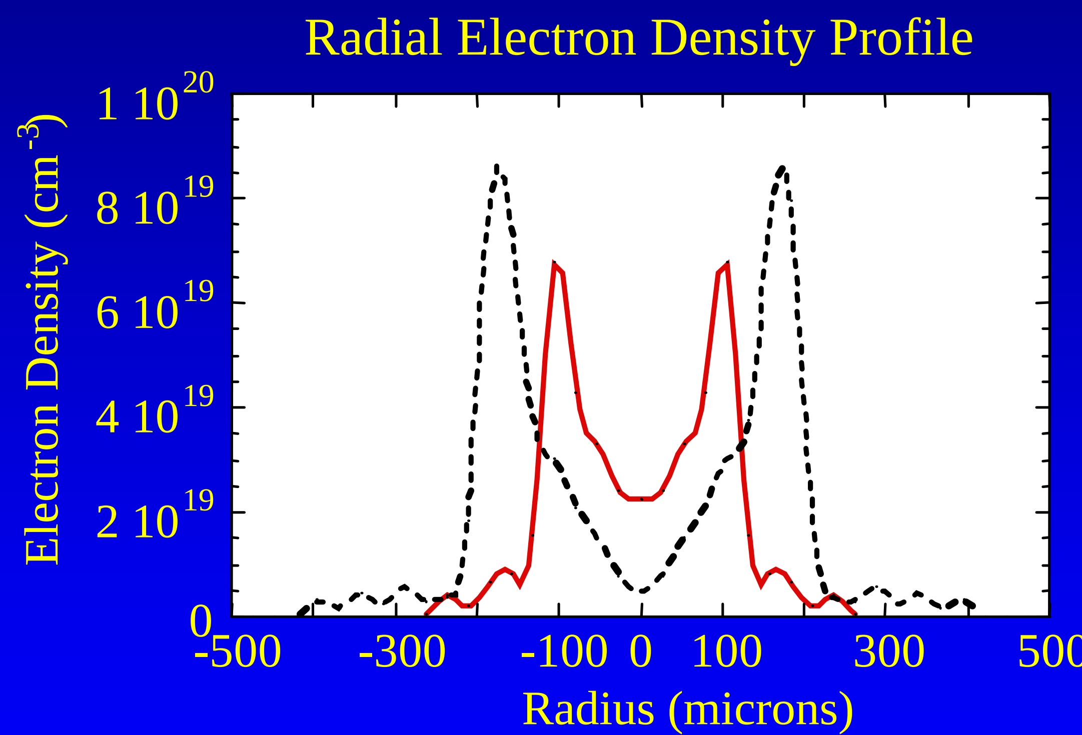
Capillary tubes (Orsay, Fr.) : high contrast, good spatial quality, Repetition, ionization…

Capillary discharges (Lisboa P., Oxford G.B., Jerusalem Is.) : ionization free, density profil is controlled.

Plasma channels produced by lasers : Berkeley US, Palaiseau Fr., Austin US, Maryland US.

Laser induced plasmas channel





V.Malka et al., PRL, 79, 16 (1997)

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Some Applications ...

X-rays:diffraction
γ-rays:radiography

Medicine
Radiotherapy
Proton-therapy
PET

Electrons and Protons generated by Laser-Plasma Interactions

Accelerator Physics
Injector

Chemistry
Radiolysis

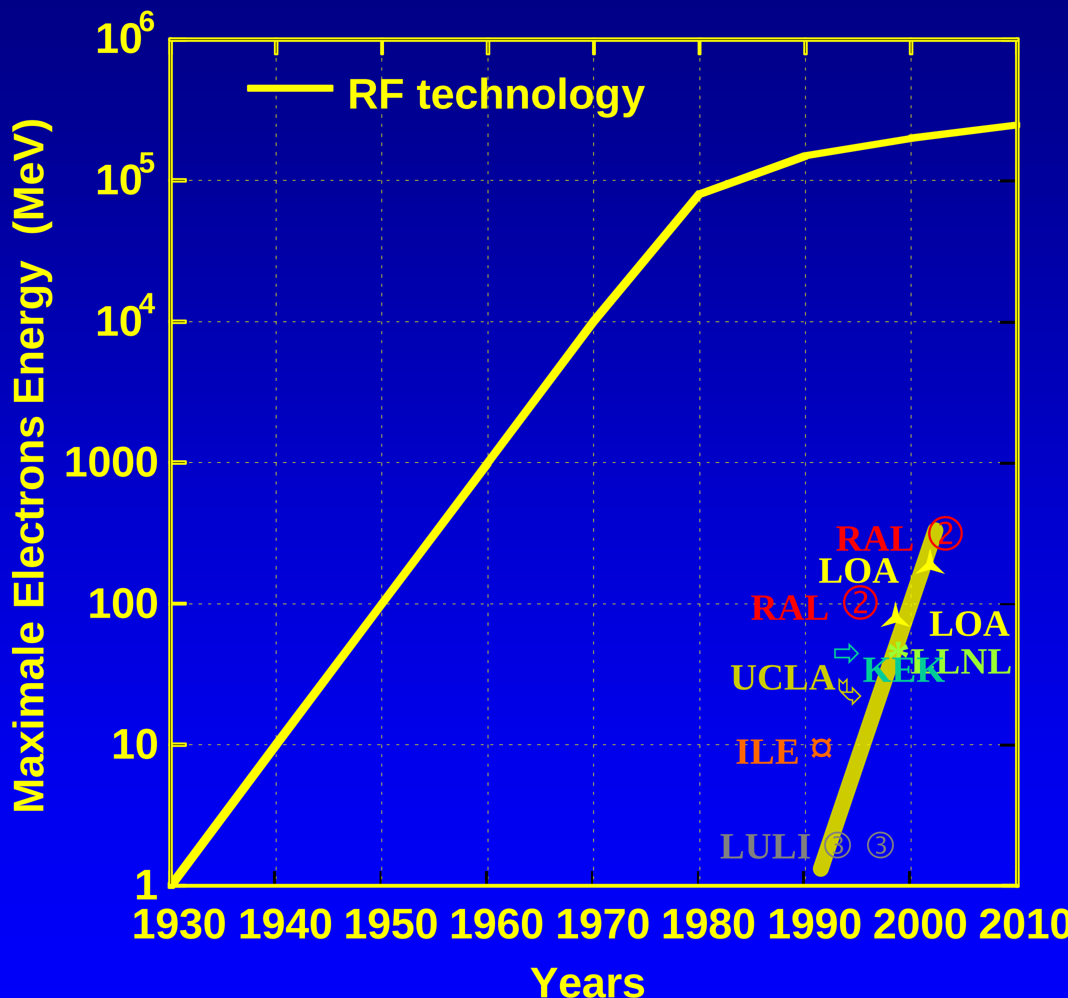
Conclusion and future of laser particle acceleration

- Laser particle acceleration has been demonstrated
  - Energy gains of 1 MeV to 200 MeV
  - E-fields of 1 GV/m to 1000 GV/m
  - GeV energy gains are expected
  - Good quality
- Electron sources up to ~ 1 GeV (nC, <1 ps)
- Electron beam duration has to be measured
- Very high energy gains mainly rely on guiding
  - Different schemes are being tested

Laser particle acceleration could help in reducing the size of accelerators

- The E-field in present day accelerators is limited to < 100 MV/m
- The interaction between high-intensity lasers and plasmas can generate **GV/m** to **>1000 GV/m** E-fields
- This could lead to future **“compact” accelerators** and/or **particle sources**
- This topic has also interesting connections with high-intensity laser-plasma interaction physics (fundamental plasma physics, laser fusion program)
- It has initiated a number of multidisciplinary collaborations between laser, plasma, accelerator and particle physicists
- These new sources will open new field of research in different domains
- They will serve science and society

Relevance of laser plasma approach for high energy physics > TeV



Define in collaboration with high energy physicists the requierement for their experiments (particles, charge, stability current, luminance,reproducibility).

Define schemes, cost and compare to conventional approach (present and expected)

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