Acceleration of an external electron beam in a laser heated plasma cell

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Outline

- Motivation
- State of art
- Schematic of the accelerator
- Simulations
- Conclusion

Many thanks to Raphaël Roux for the preparation of this talk

HEP Collider requirements

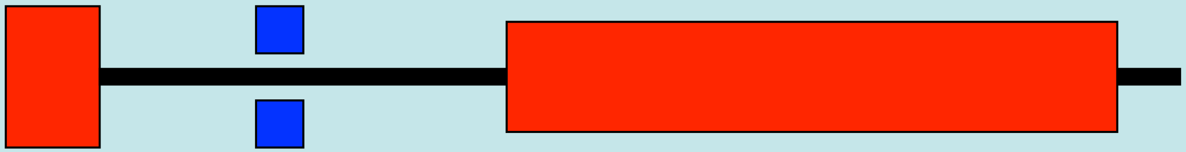
- HEP will most certainly need at some point a multiTeV collider
- Collider requirements:
  - Acceleration at reasonable cost and length
    - A few GV/m OK (eg 1000 1m cells with 5 GeV/m)
  - Very high luminosity
    - Small emittance
    - Very stable beams
    - High reliability
    - High repetition rate
  - Electrons AND positrons
  - Polarisation of 1 beam

Main milestone

- The main milestone is therefore acceleration in two successive plasma cells
- Experience is therefore needed on how to accelerate reliably an external electron beam in a plasma cell
  - Beam is external for all cells except may be the first one
  - Electron or positron
  - Polarised beam
- Extremely important therefore to test in a systematic way the acceleration of an external beam in a plasma cell

Motivation

1. Stable electron source for the laser-plasma accelerator



Injector=
RF Photo-injector

optics

Accelerating section=plasma cell (gas-jet, capillary)
in the **linear regime**, 150TW laser, ≈ 15 GV/m

Separate the functions

-source of electrons

-focusing

-acceleration

More knobs
de-correlation of problems

Higher control

Motivation

2. Study of the injection of electron bunch in the plasma cell

→ ***required whatever the source (RF or laser-plasma) in the concept of multi-stage accelerator***

List (non-exhaustive) of difficulties:

- focusing, bunch rms size < 50 μm
- alignment, ≈ 1 μm (derived from the first)
- bunch length ≈ λ_p → σ_z < 100 fs
- synchronisation at the fs level between the electron bunch and the laser used for the laser-plasma acceleration
- compatibility, mechanical integration of the plasma cell in a RF accelerator

State of art in Europe

1. **University of Strathclyde, Scottland, UK**

   RF photo-injector built by LAL *but big problems of modulator, no beam*
   Produced a 200 MeV electron bunch in the bubble regime

2. **University of Twente, Netherland**

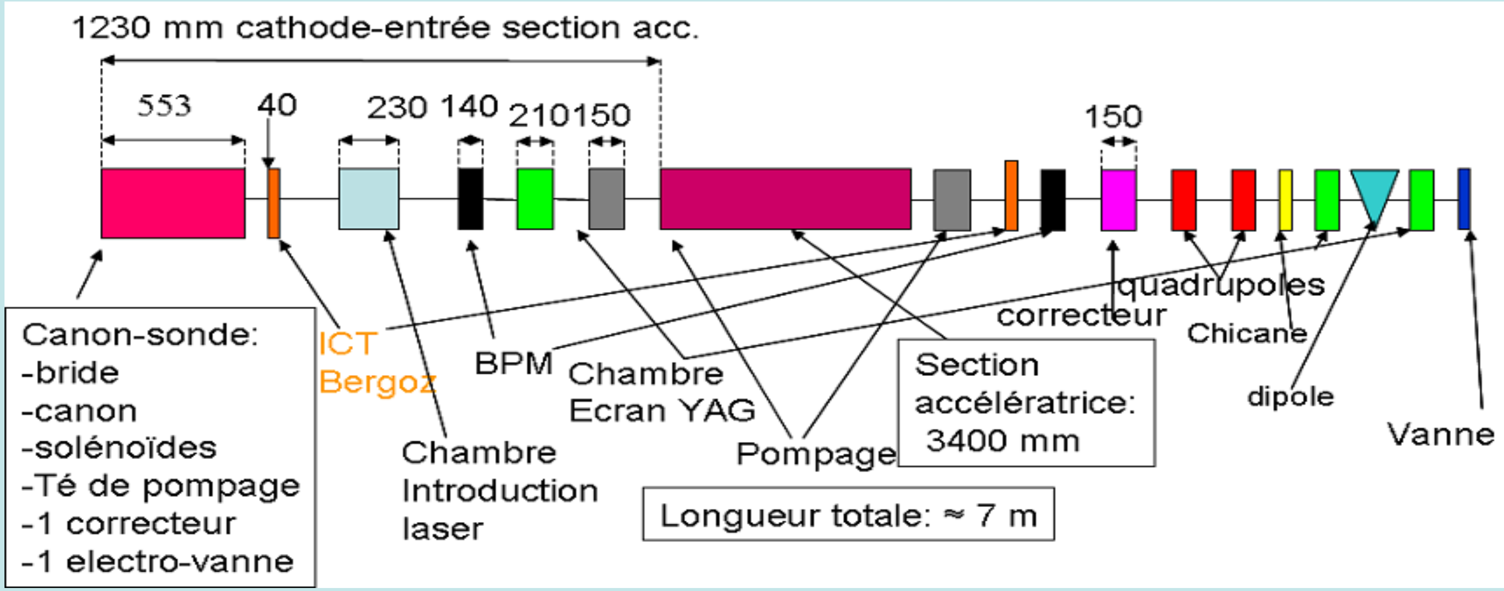
   RF photo-injector
   Produced 5 pC, 2.2 MeV, magnetic compression down to 1 ps
   Stopped now, transfer to another building, lack of budget

3. **University of Technology of Eindhoven, Netherland**

   Twin of the RF photo-injector of Strathclyde (also tested in PHIL, LAL)
   Produced 20 pC, 3 MeV (45 MV/m), bunch length not yet measured
   focused down to 50 μm, position stability < 6 μm, synchro. < 50 fs
   Stopped now, laser broken (pump), lack of manpower

4. **At LAL, 2nd try to get ANR funding for FEMTAC project**
   Involvement in the CILEX equipex

Schematic of the accelerator



2 options:

1. Linac: RF gun + acc. section, energy in the range of 50-70 MeV
   advantage: better geom. emittance (/10), no space charge, magnet. compression

2. RF gun only, energy in the range of 5-7 MeV
   advantage: cheaper but only 0.5 M€ less/option 1

Integration of the plasma cell

Example of the AlphaX beamline

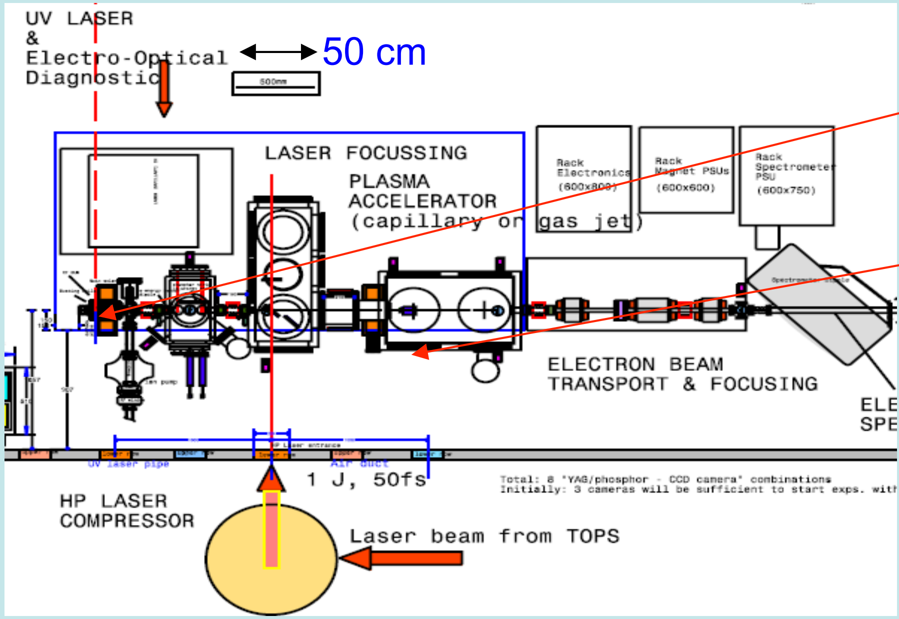
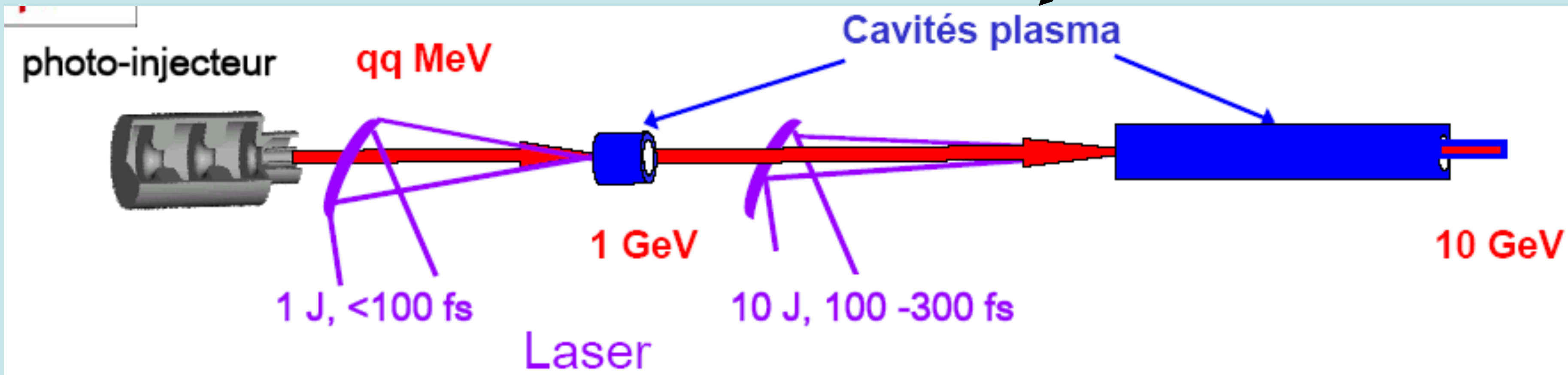


Photo-injector

Plasma cell

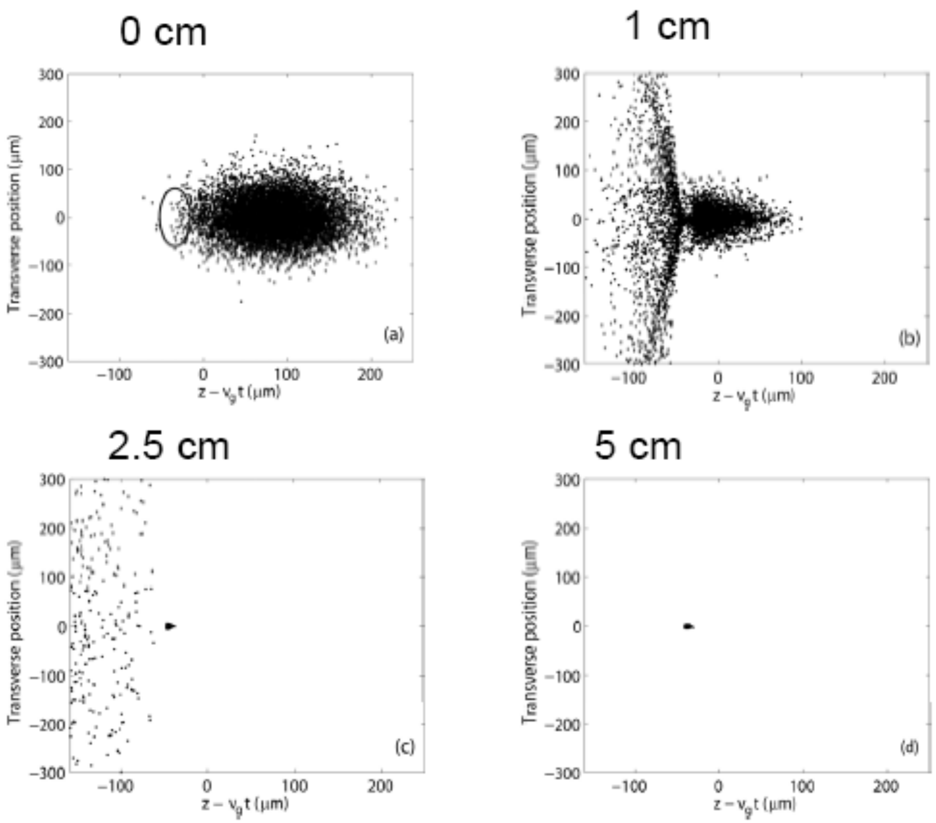
Schematic of multi-stages acc.



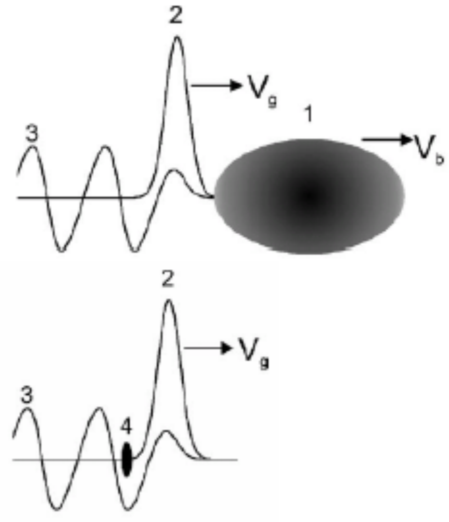
Simulation of the laser-plasma acceleration

Thanks to B. Cros

Simulation of the capture and the acceleration by the plasma wave
Injection in front of the wave according to the Kachatryan scheme



NIM A 566 p.244 (2006)



Scénario montrant le piégeage, la compression et l'accélération du paquet d'électrons dans l'onde à différentes positions dans le plasma (0 à 5 cm) - (U. Twente)

Simulations

●At LAL, a small team: C. Bruni and R. Roux, RF and electron dynamics simulations
Since January 2011, N. Delerue, expert in electron beam diagnostics

Is it possible to have fs bunches while being at low energy (≈5 MeV)?

The principle is simple: use Ti:Sapph laser to produce 100 fs electron bunch in the RF photo-injector

→ But simulations of electron beam dynamics must be carried out to validate it

●Well-known accelerator codes used: PARMELA, ASTRA
-space charge included
-different shapes of the laser are possible

Simulations

First stage: check the validity of the code PARMELA

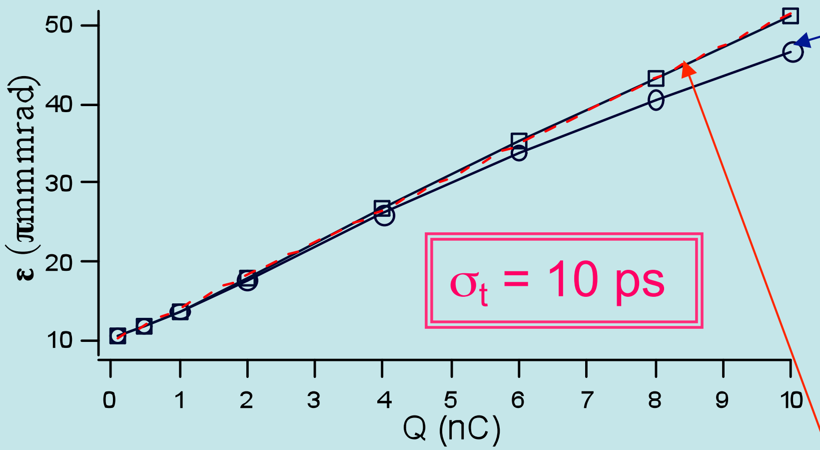
Up to now, codes are used for ps electron beam

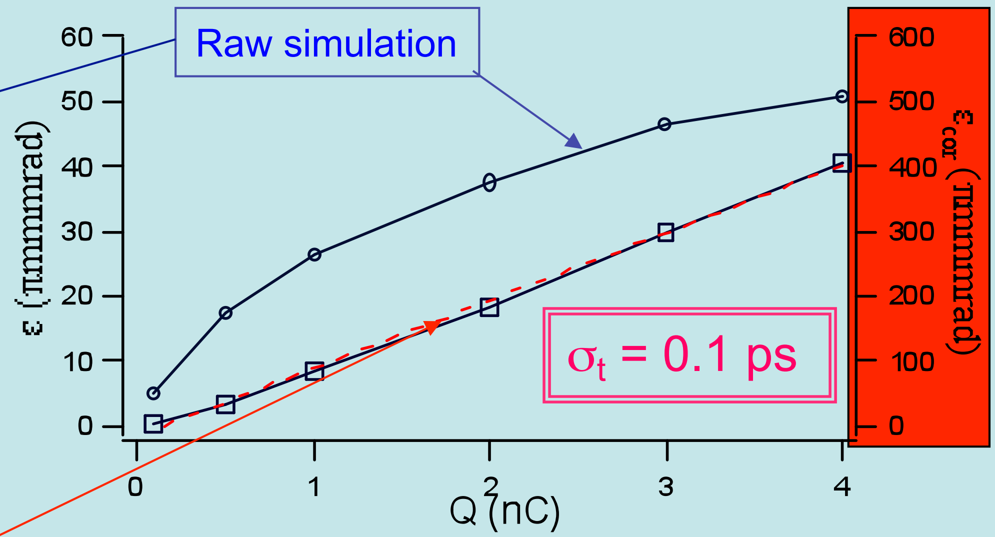
Usually a good test is to confront simu. to measurement: impossible…

One is left with a test of the consistency with physics: scaling of the emittance

Space charge induces
Emittance growth

$$F_{\text{space charge}}\ \alpha\ \frac{Q}{\sigma_r \sigma_z} \quad \Rightarrow \varepsilon\ \ \alpha\ \ Q$$

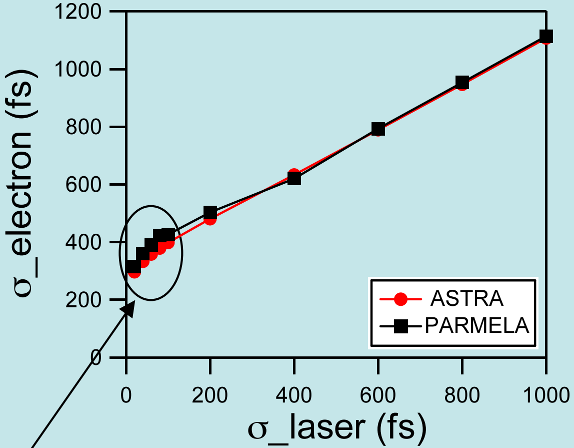




After correction of bunch lengthening, $\varepsilon\ \alpha\ Q$ => PARMELA is OK for fs bunches

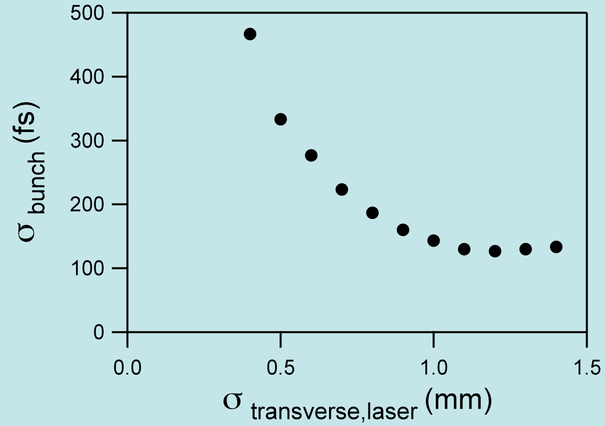
Simulations

σ_r laser = 0.5 mm



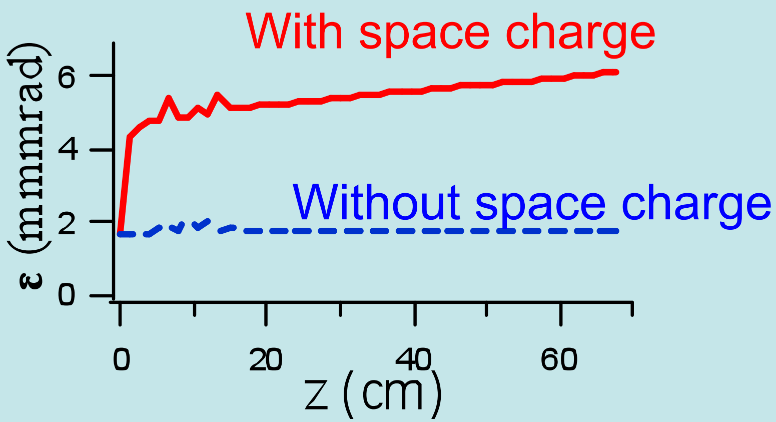
σ_t (laser) < 100 fs, huge space charge

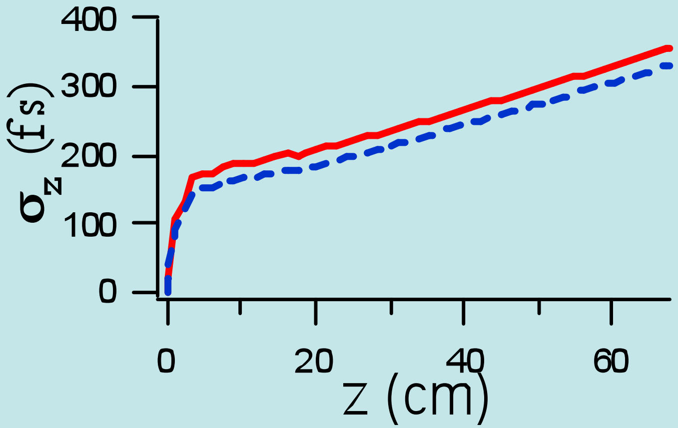
σ_t (bunch) ≈ 300 fs



lower σ_t but ε ↗

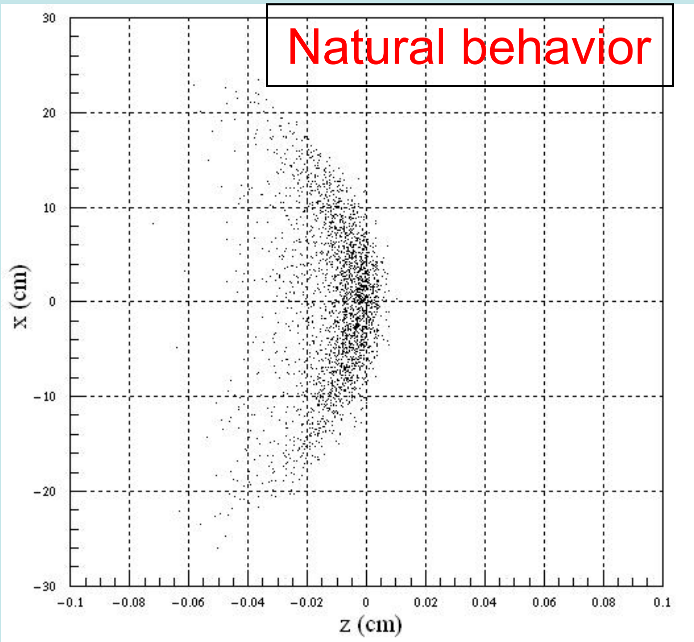
And geometrical effect ↗

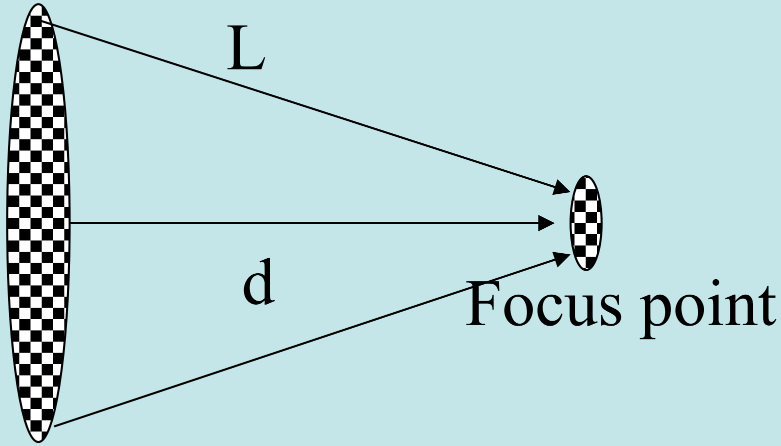




For laser with σ_t = 100 fs and σ_r = 1.4 mm

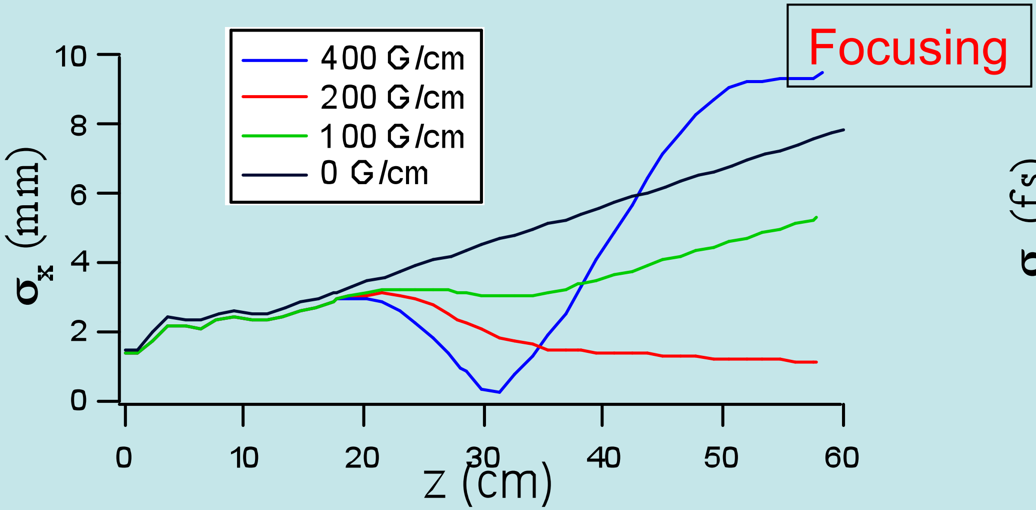
Simulations

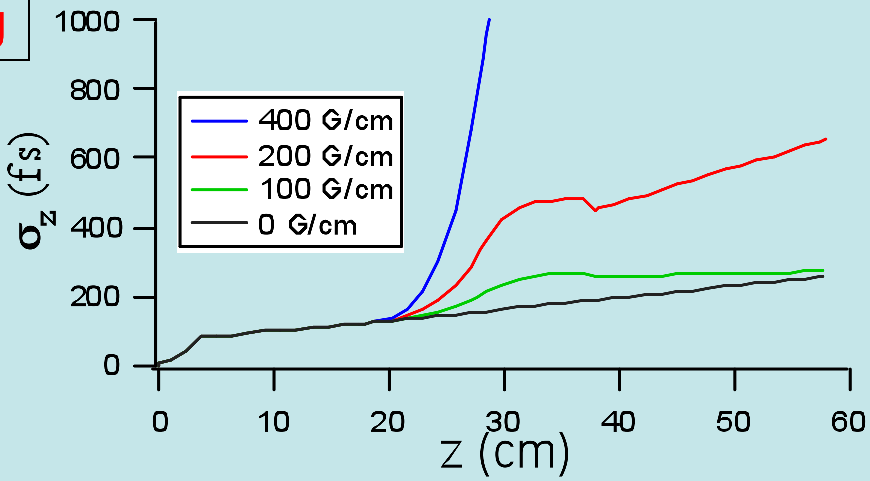




L > d

=> Bunch lengthening too





Conclusion

• fs electron bunch in RF acc. quite challenging

➡ Trade-off between space charge and geometrical effect

Preliminary results, should be achievable:

- $Q = 100$ pC
- $\sigma_z = 150$ fs
- $\varepsilon = 2.5\ \pi$mmmrad

Requirements:

- Eacc ↗↗ near 100 MV/m *(got 92 MV/m on PHIL)*
- Square distribution of laser to reduce space charge
- Curved photo-cathode to compensate geometrical effect

Conclusion

- We want to build a high performance photo-injector to investigate in a systematic manner the accleration of an external beam in a laser-heated plasma cell
- Main milestone : multicell acceleration
- Longer term goals : positron acceleration, polarised beam acceleration