Transport line for a multi-staged laser-plasma acceleration: DACTOMUS

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What is DACTOMUS?

- DACTOMUS: Diagnostic And Compact beam Transport fOr MUltiStages laser plasma accelerators
- Collaboration between:
  - LPGP (B. Cros, G. Maynard, F. Desforges, B. Paradkar)
  - LULI (J. R. Marquès)
  - LLR (A. Specka)
  - LAL (C. Bruni, N. Delerue, C. Rimbault, T. Vinatier)
  - CEA IRAMIS (S. Dobosz)
  - CEA IRFU (A. Chancé, O. Delferrière, J. Schwindling)

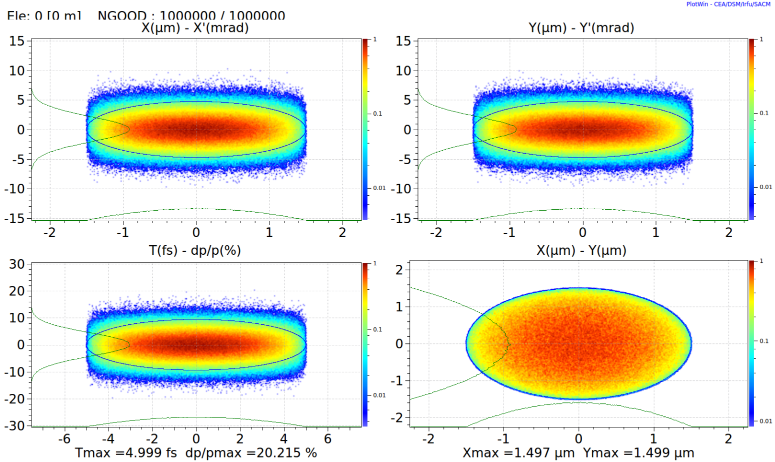
Aim of DACTOMUS

- The final goal is to inject and accelerate an electron beam by using the photo-ionizing trapping.
- An electron beam is extracted from a first plasma source, transported up to a capillary tube to be accelerated again.
- This transport line must keep the required properties (bunch length and size) to enable a proper re-acceleration.
- Some beam diagnostics are inserted to characterize the electron beam at the same time.
- The transport line will be built and tested on UHI100 at Saclay for middle 2014.

Initial beam

- The laser is UHI100:
  - Laser : $I_L = 4 \times 10^{18} W/\text{cm}^2$, $T(\text{FWHM}) = 40$ fs , waist $= 100\mu$m
  - Plasma density $= 10^{17}\text{cm}^{-3}$.
- The beam is assumed to have the following properties at the entrance of the transfer line:
  - The total charge is 10 pC;
  - The distribution is uniform in the space (x, y, z).
  - The beam is a sphere of diameter 3 μm;
  - The energy distribution is Gaussian and centered on 50 MeV. The full width at half-height (FWHM) is 10%.
  - The angular divergence distribution is Gaussian and centered on zero. The FWHM is 5 mrad.
  - There is no correlation between angle, position and energy.

Initial beam (2)



Constraints on the line

- The beam final size must be close to the initial size (3 μm) to inject in the capillary tube.
- The total length of the transport line must be about 1 meter (maximum: 1.20 m) to fit the experimental area.
- The beam line must be isochronous to avoid a bunch lengthening.
- Insertion locations must be foreseen to:
  - extract the laser;
  - insert screens for the transverse profile of the beam;
  - insert a dipole to measure the energy spectrum.
- Since the initial properties can vary from a shot to another shot, the final properties must not be sensitive to these variations.
- The beam line must be very energy accepting: about 10% around the reference energy (50 MeV).

Preliminary remarks

- The chosen solution is a symmetric beam line.
- The used coordinates are $(x, x', y, y', -ct, \delta)$.
- The simplest beam line is a triplet of quadrupoles.
- The constraints on the beam transfer are then:

$$|R_{11}| \approx |R_{33}| \approx 1$$
$$|R_{22}| \approx |R_{44}| \approx 1$$
$$R_{12} = R_{34} = 0$$

- A more complicated beam line is an achromatic line in which sextupoles are inserted. The added constraints are:

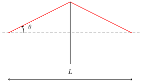
$$R_{16} = R_{56} = 0$$
$$T_{126} = T_{346} = T_{166} = 0$$

Constraints on the bunch length

- The bunch length must be less than the plama period
  $\Rightarrow$ a few tens of fs.
- There are 3 main lengthening sources for a L-long beam line. We assume $L \approx 1$ m, an angular divergence of $\theta = 5$ mrad and an energy spread of 10%.
  - Velocity dispersion of the beam.

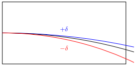
$$dT = -\frac{L}{\beta^3\gamma^2 c}\frac{d\gamma}{\gamma} \approx 35 \text{ fs}$$

  - Path length difference due to the angular divergence.



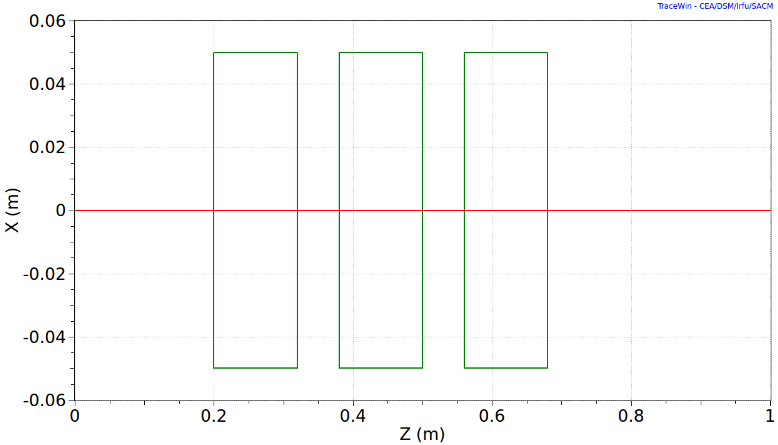
$$dT = \frac{L}{\beta c}\left(\frac{1}{\cos\theta} - 1\right) \approx 42 \text{ fs}$$

  - Path length difference due to the energy (true if dipoles are used in the beam line).



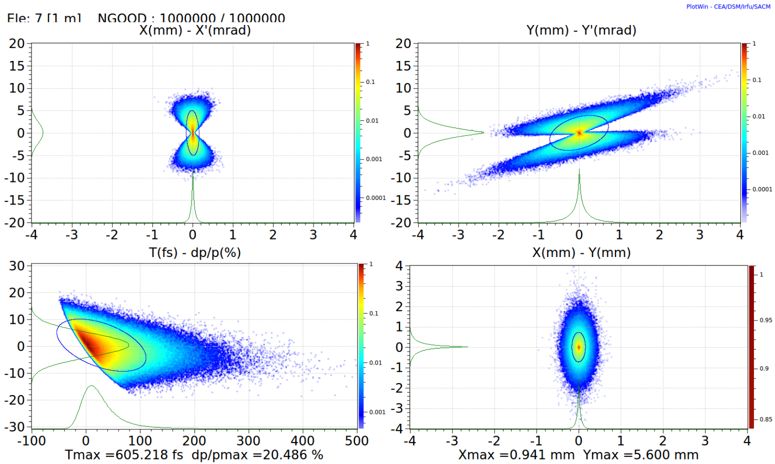
    - The 1st order is corrected ($R_{56} = 0$).
    - The bunch lengthening is then quadratic with energy.

Triplet solution



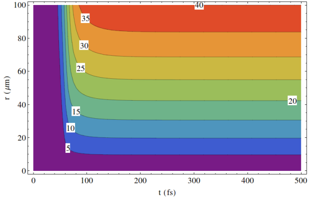
Total length: 1 m

Final distribution Triplet

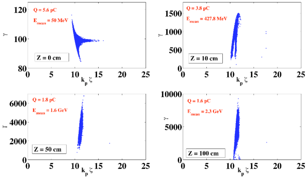


Beam profile Triplet

Integrated distribution at the end of the beam line



Acceleration in the capillary tube

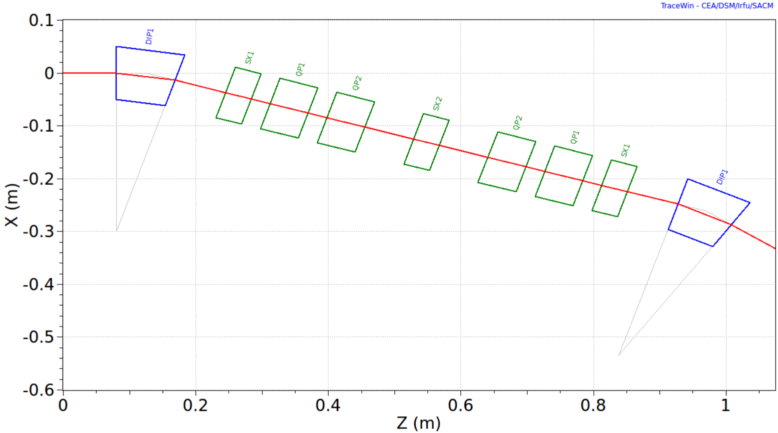


Courtesy: B. S. Paradkar

see Paradkar's presentation on 5th June

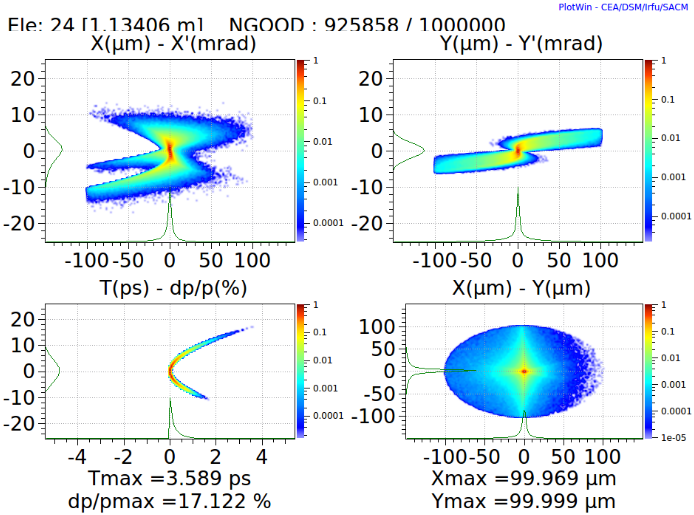
- The final bunch length is about 60 fs.
- The main drawback is the large beam size due to the chromatic aberrations.
- Only 10% of the beam are in a radius of less than 20μm.

Achromatic line



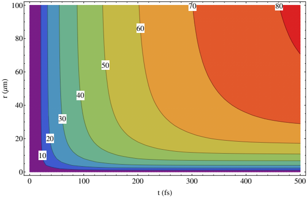
Total length: 1.13 m.

Final distribution Achromatic line

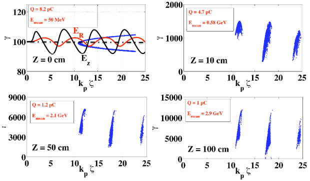


Beam profile Achromatic line

Integrated distribution at the end of the beam line



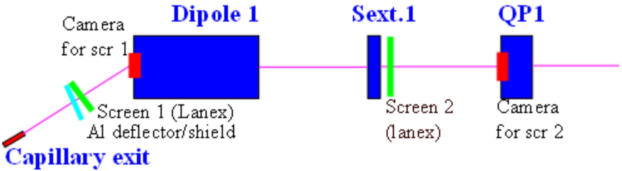
Acceleration in the capillary tube



Courtesy: B. S. Paradkar

- The final bunch size is a few 10 μm.
- The final bunch length is several 100 fs.
- The main drawback is the bunch lengthening due to the dipoles.

Energy spectrometer

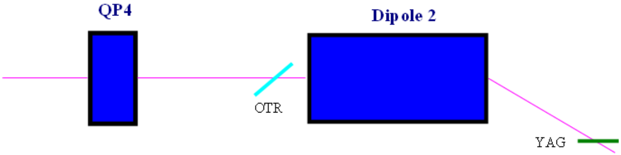


Courtesy: N. Delerue

- The first dipole is used as an energy spectrometer.
- A large screen (lanex) is put before the first quadrupole and looked at with a camera.
- The beam position must be known before the dipole

$\Rightarrow$ Another lanex is put before the dipole.

Beam profile



Courtesy: N. Delerue

- The aim is to measure the final beam size.
- A YAG is put at the end of the transfer line.
- The energy dispersion can be measured with an OTR before the last dipole.

Permanent magnets vs Electromagnets

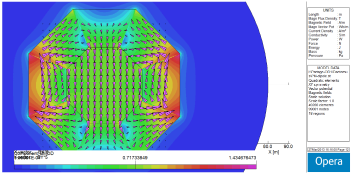
Permanent magnets	Electro-magnets
☺ Compactness	☺ Variable fields: more flexible
☺ No power supply	☹ Needed power supply
☺ No cooling	☹ Bigger
☺ Possibility of very small inner radius	☹ Inner radius larger
☹ Fixed field	☹ Needed cooling
	☹ Needed beam pipe (vacuum)

$\Rightarrow$ We have chosen to use permanent magnets.

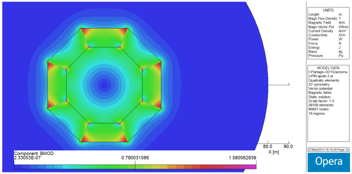
A Halbach structure has been studied.

Permanent magnets

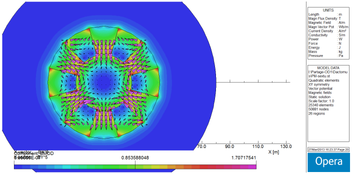
Dipole



Quadrupole



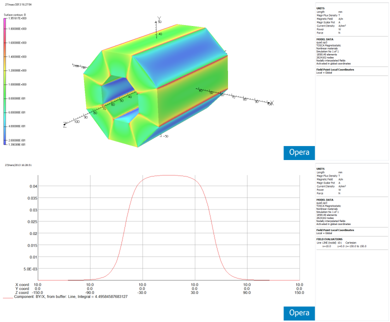
Sextupole



Courtesy: O. Delferrière

- Inner radius: 20 mm.
- Dipole field: 0.7 T (we need 0.56 T)
- Sextupole gradient: 1600 T/m^2 (we need 690 T/m^2)
- We have margin! The magnets are doable.

Fringe field



- Gradient integrate at 10 mm: 4.49 T
- The needed integrate is 1.7 T.
- The main problem is the fringe field (the quadrupoles are short compared to their aperture).
- Until now, the line parameters were chosen with the hard edge approximation.
- That is a rough approximation to have the order of magnitude of the needed fields.
- Tracking studies with realistic field maps must be performed.

Conclusion

- Two transfer line proposals were made.
- The first one (very simple) keeps the required bunch length but the beam size is too large (chromatic aberrations).
- The second one (more complicated) gives the required beam size. The price is a longer beam.
- Some studies must be done to have the best compromise.
- First magnet designs were made. The required fields are doable with permanent magnets.
- Tracking studies with realistic maps must be done to study the impact of the fringe field.
- Misalignment and field tolerances must be looked at.
- A more precise diagnostic study will be done.