Plasma accelerator: external injection

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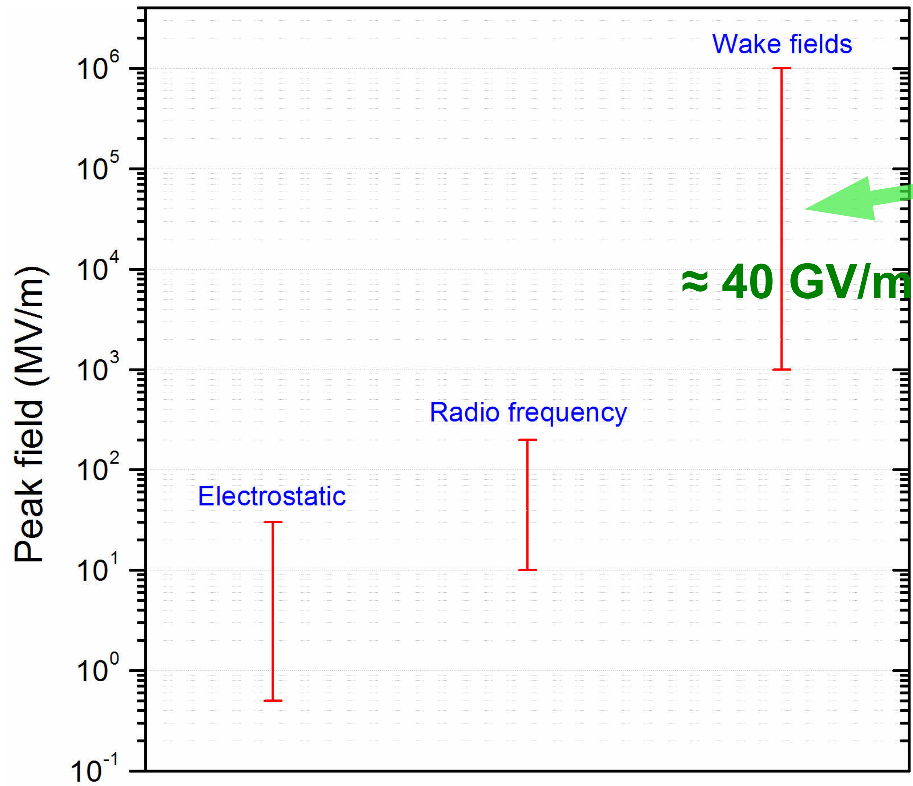
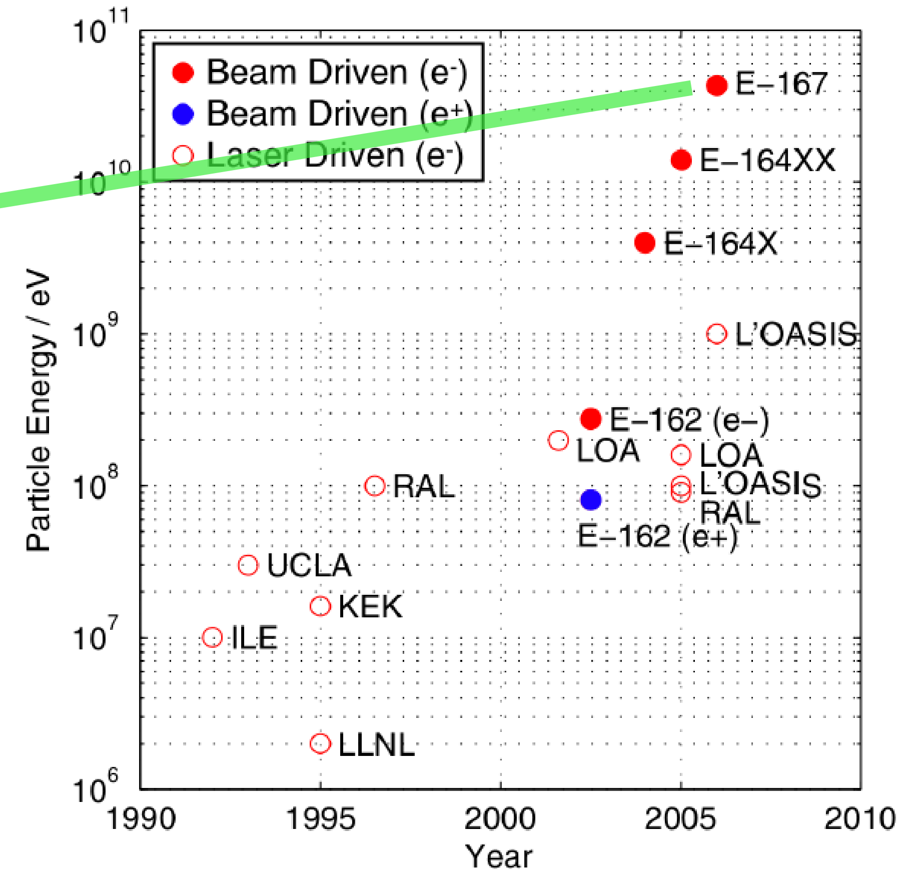
SPARC_LAB

Why advanced acceleration?

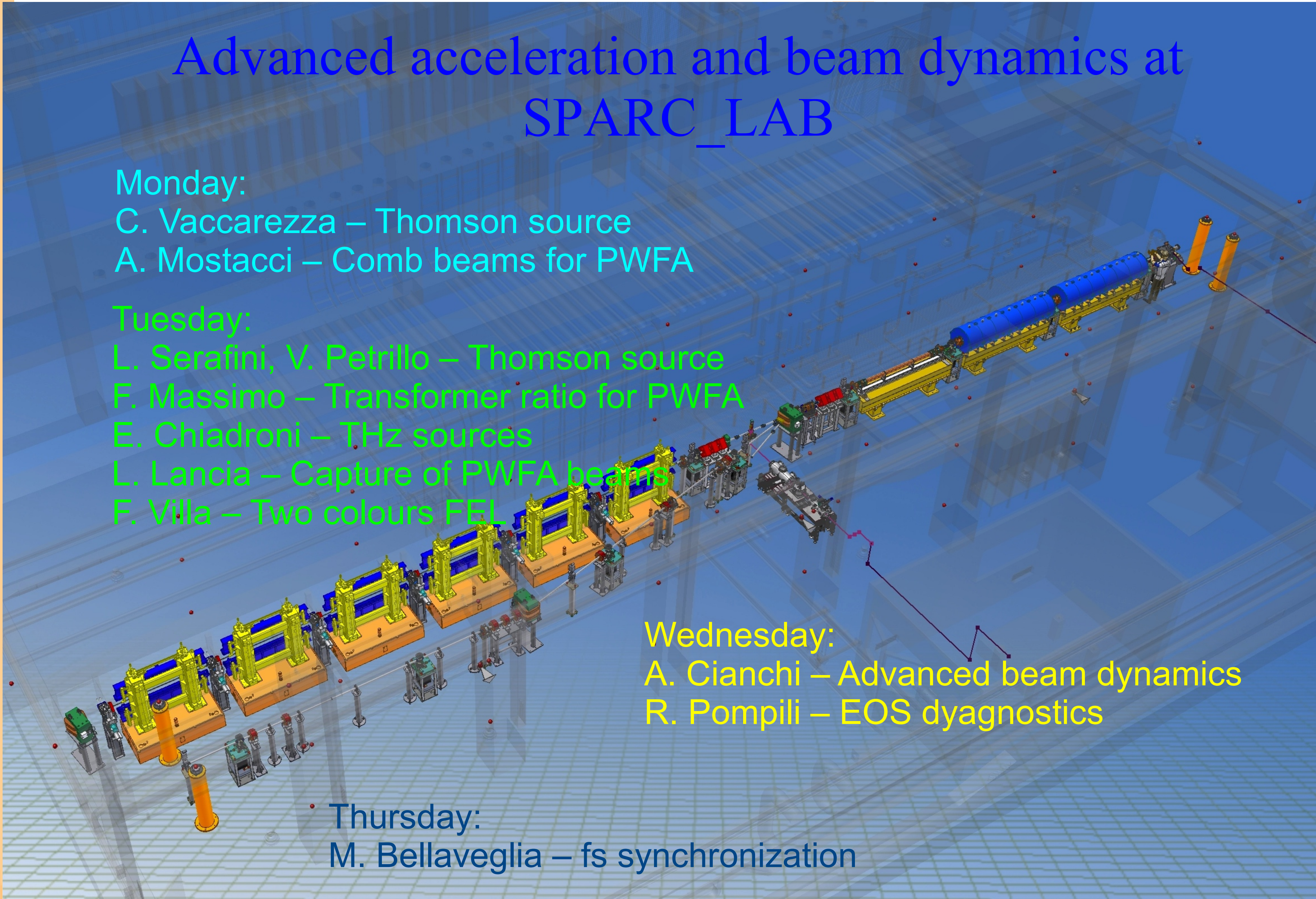
Acc. length for a 1 TeV machine: ≈ 10^5 m ≈ 10^4 m ≈ 10 m





From FACET CDR, 2009.

Peak field scales as square root of plasma density, i.e. plasma frequency.



Advanced acceleration and beam dynamics at SPARC_LAB

Monday:
C. Vaccarezza – Thomson source
A. Mostacci – Comb beams for PWFA

Tuesday:
L. Serafini, V. Petrillo – Thomson source
F. Massimo – Transformer ratio for PWFA
E. Chiadroni – THz sources
L. Lancia – Capture of PWFA beams
F. Villa – Two colours FEL

Wednesday:
A. Cianchi – Advanced beam dynamics
R. Pompili – EOS dyagnostics

Thursday:
M. Bellaveglia – fs synchronization

Advanced acceleration experiments can be ideally divided in 3 sub-categories:

Laser only

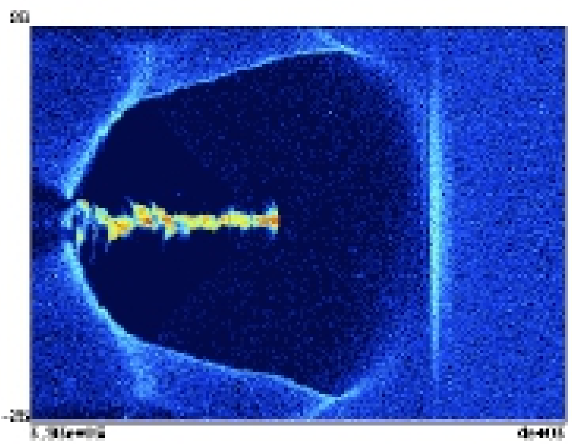
- Laser Wake Field Acceleration (LWFA) with self-injection
- Heavy particles acceleration (protons and light ions) by different physical mechanisms

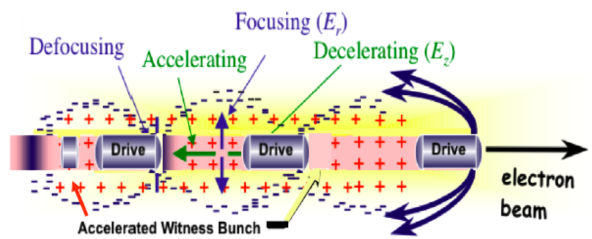
Electrons only

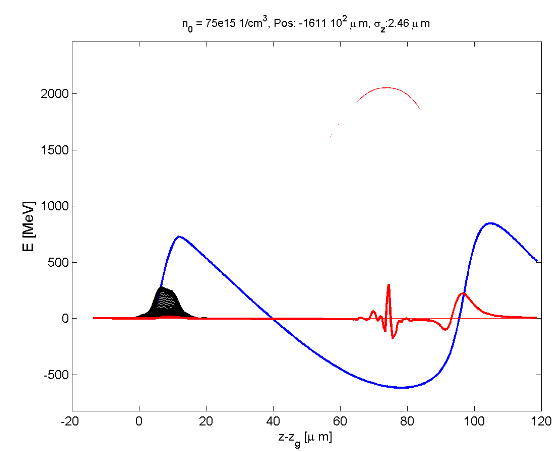
- Particle Wake Field Acceleration (PWFA)
- Dielectric Wake Field Acceleration (DWFA)

Laser + electrons

- LWFA with External Injection
- Inverse Free Electron Laser (IFEL)







Advanced acceleration experiments can be ideally divided in 3 sub-categories:

Laser only

Pros

- The "easiest" to implement (requires "only" to tune the laser and the target)

Cons

- Little to flimsy control over the whole process

Electrons only

Pros

- Easier implementation than laser+electrons (no need for indipendent synchro system and driver guiding)

Cons

- Produced e-beams quality and energy depends heavily on the ability to properly taylor the driver(s) and witness phase spaces

Laser + electrons

Pros

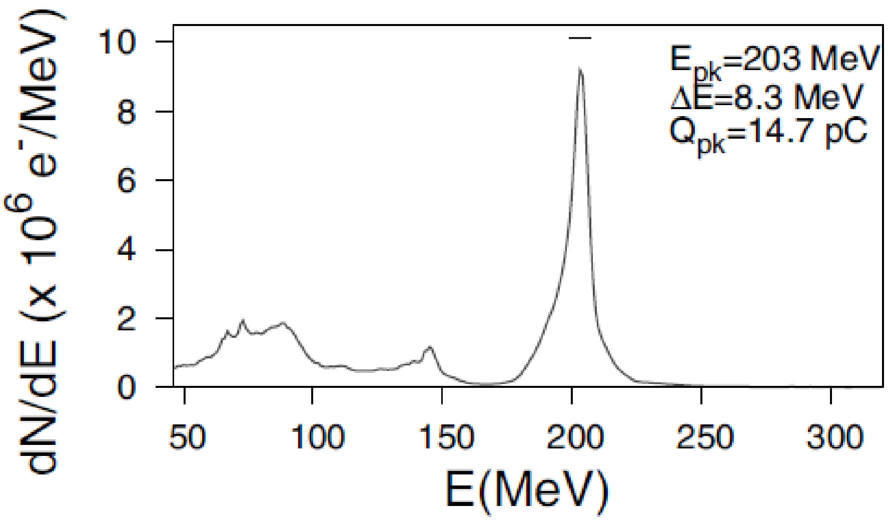
- In principle has the best potentialities in term of e-beam brightness and energy

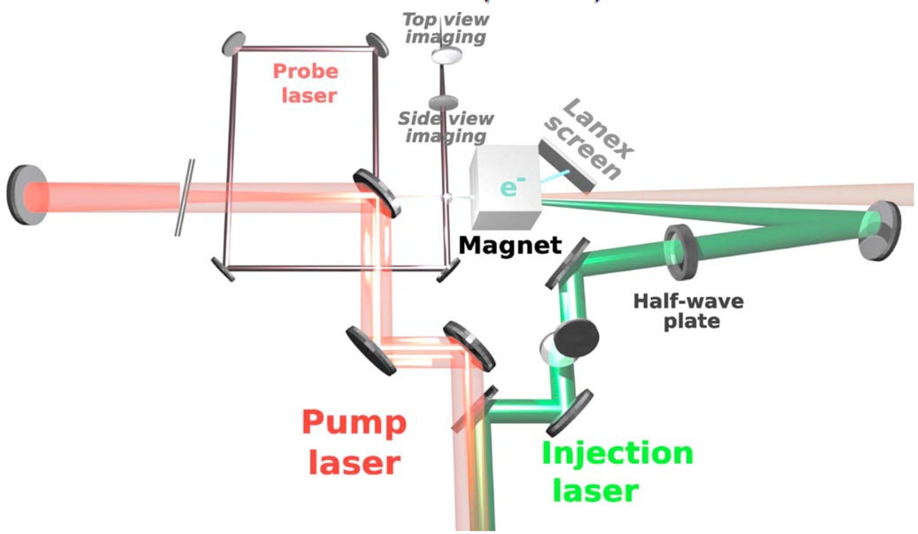
Cons

- The hardest to implement (laser guiding, sichronization issues, ...)

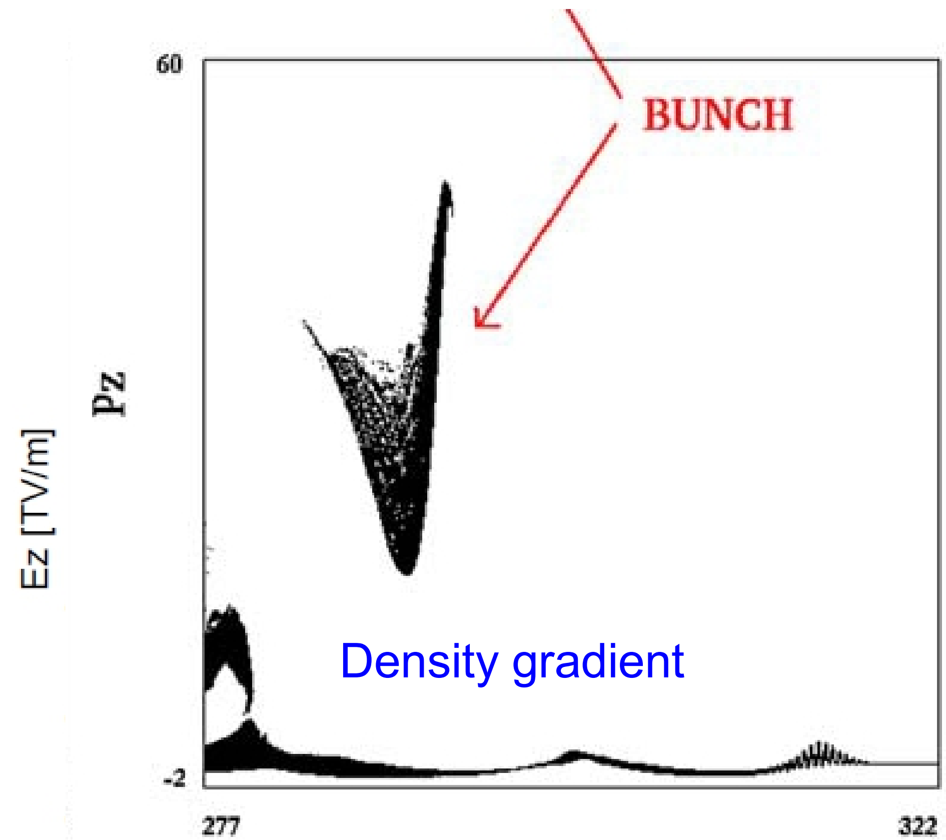
LWFA: self-injection

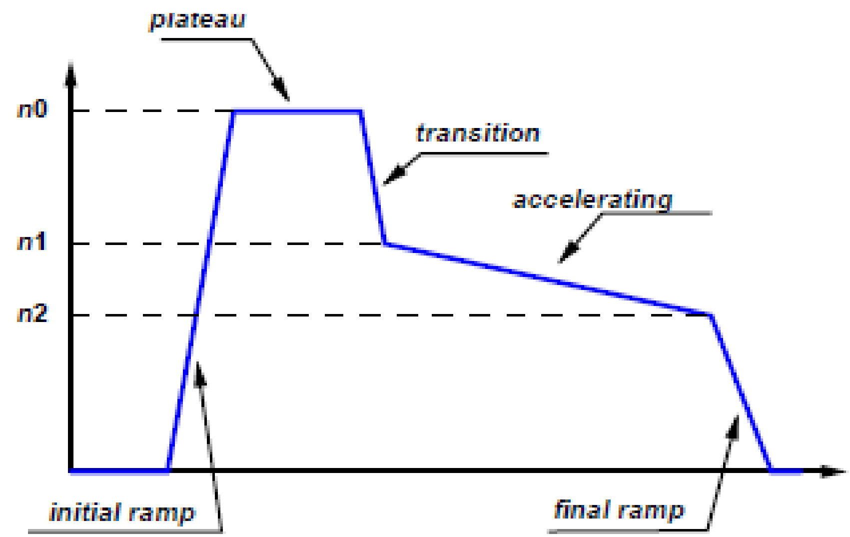
Colliding pulses





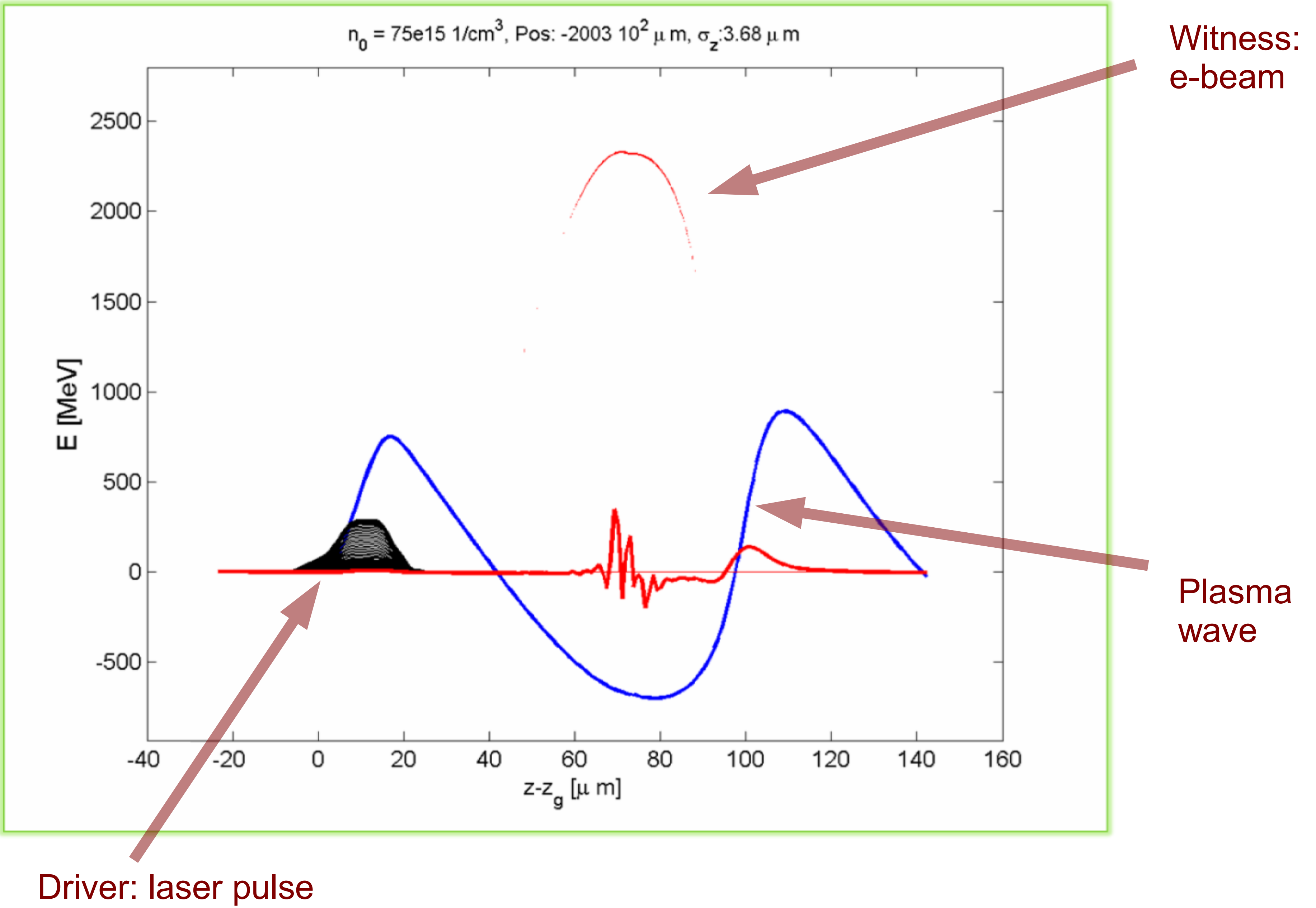
From: V. Malka et al., Phys. Plasmas **16**, 056703 (2009)



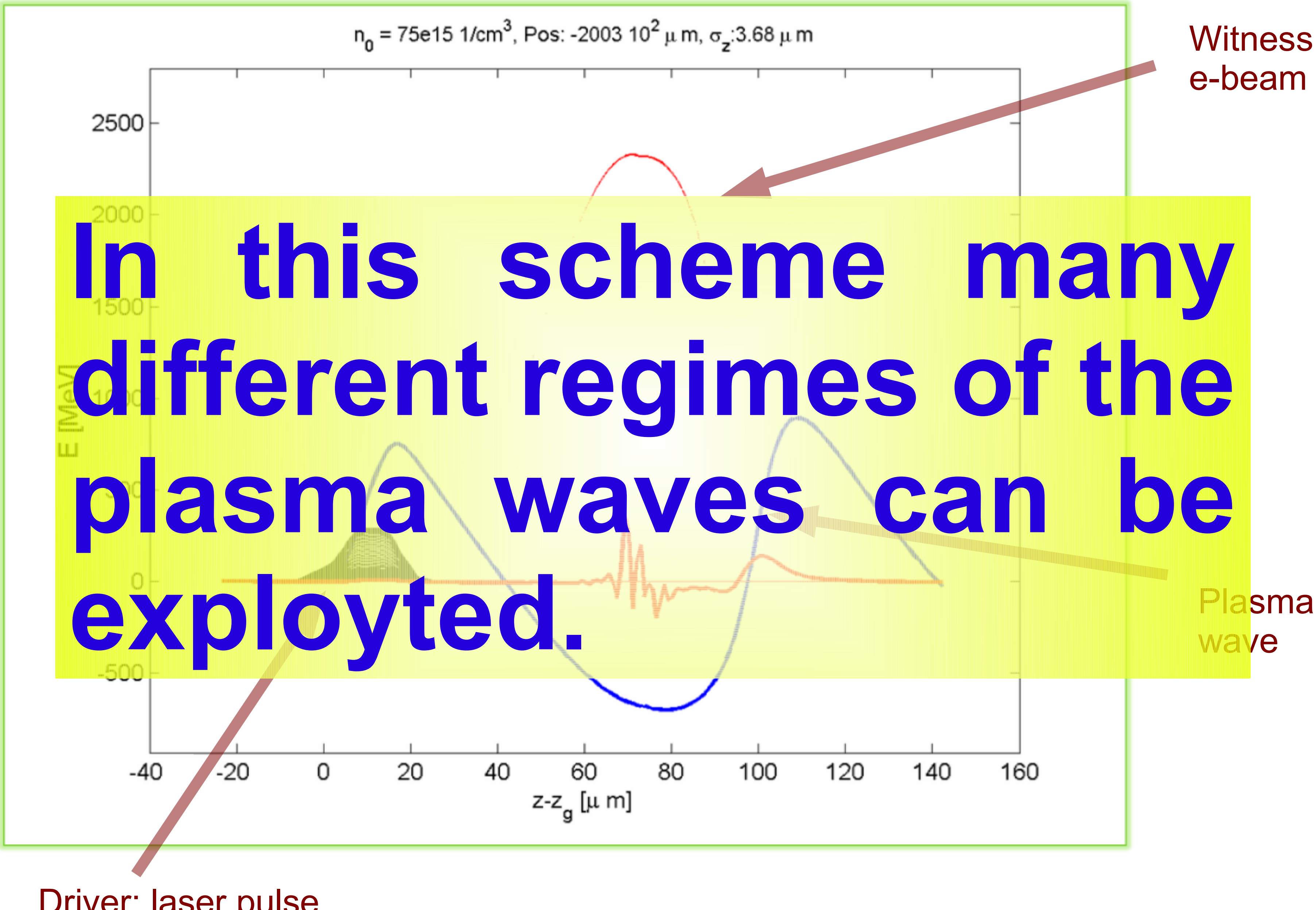


From: C. Benedetti et al., NIM A **608**, S94 (2009)

LWFA: external injection



LWFA: external injection



In this scheme many different regimes of the plasma waves can be exployted.

EXIN: goals

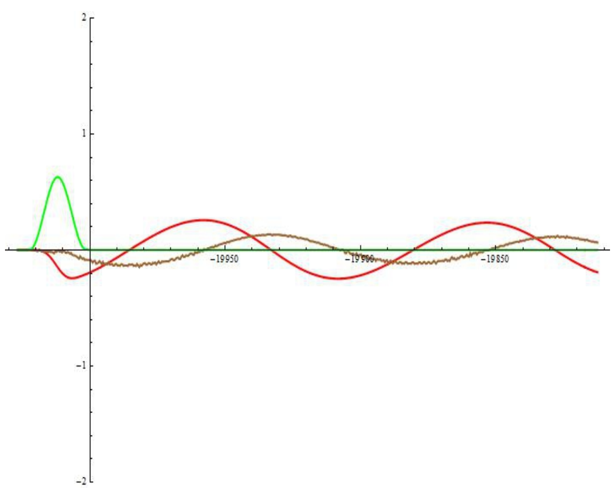
- Produce a high brilliance e-beam, peak or global.
- Stability.
- Reproducibility.
- Everything above in the easiest possible way.

Highest energy record in LWFA is NOT a goal!

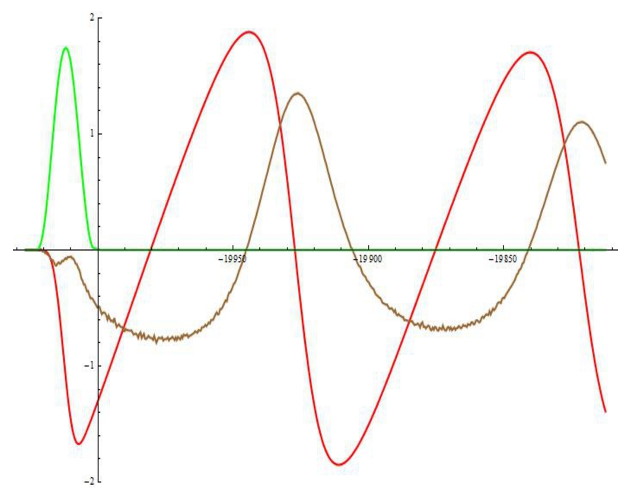
EXIN: choice of settings

Plasma wave regime

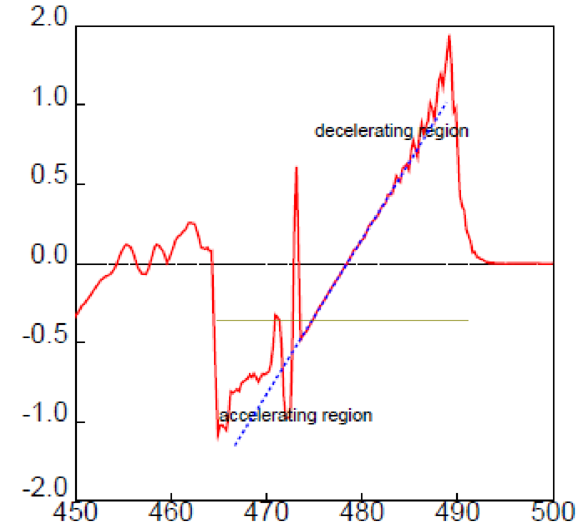
Linear



Quasi-linear



Bubble



Easier and more stable but beam loading can be very important (beam driver).
Would require the capability to manage bunches with a charge in the range from hundreds of fC to few pC.

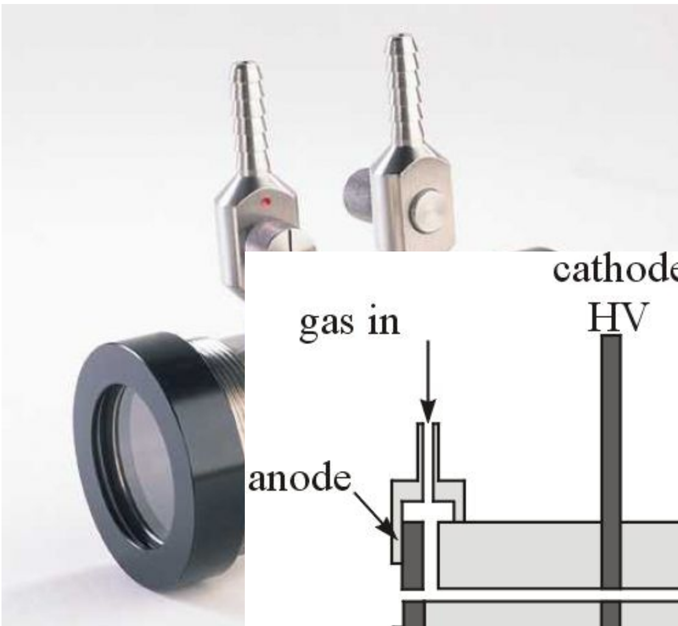
Fields are quite intense so performances can be very interesting.
Beam loading can be significant but manageable with bunch charges up to few tens of pC.

The hardest to implement and manage, due to high sensitivity to jitters.
Highest performances and beam loading is not a problem up to few hundreds of pC. Possible in future.

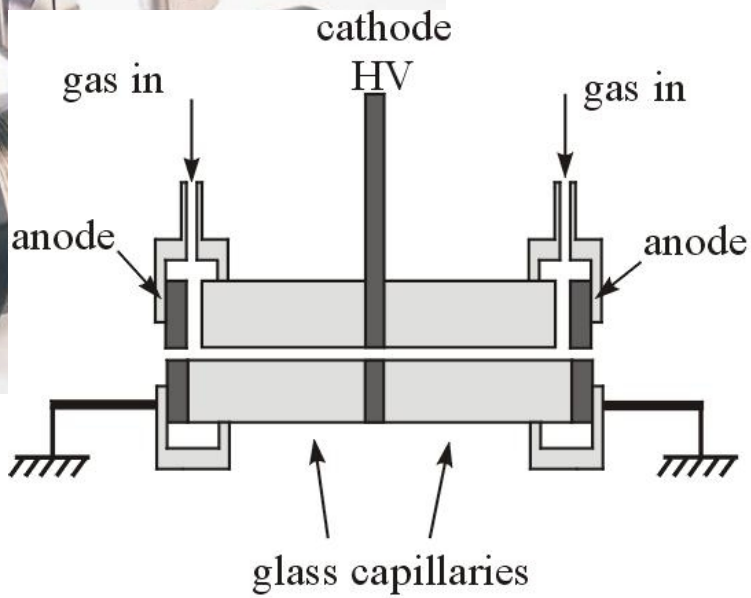
EXIN: choice of settings

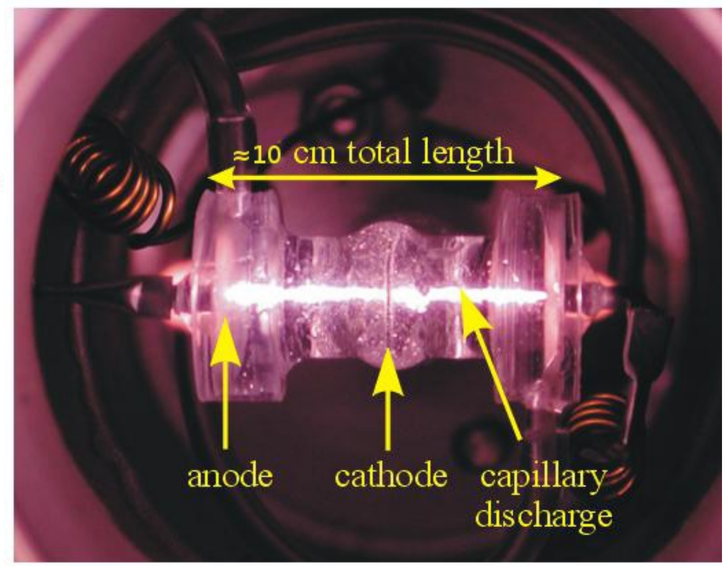
Laser guiding

Gas cell: no guiding.



Laser needs to be guided over a distance much larger than natural Rayleigh length





Capillary: guiding by boundary conditions.

$$n = n_0\left(1+\frac{\Delta n}{n_0}\frac{r^2}{w^2}\right); \qquad \frac{\Delta n}{n_0} = \frac{4}{(k_p w)^2}$$

Transverse plasma tapering: like a graded index optical fibre.

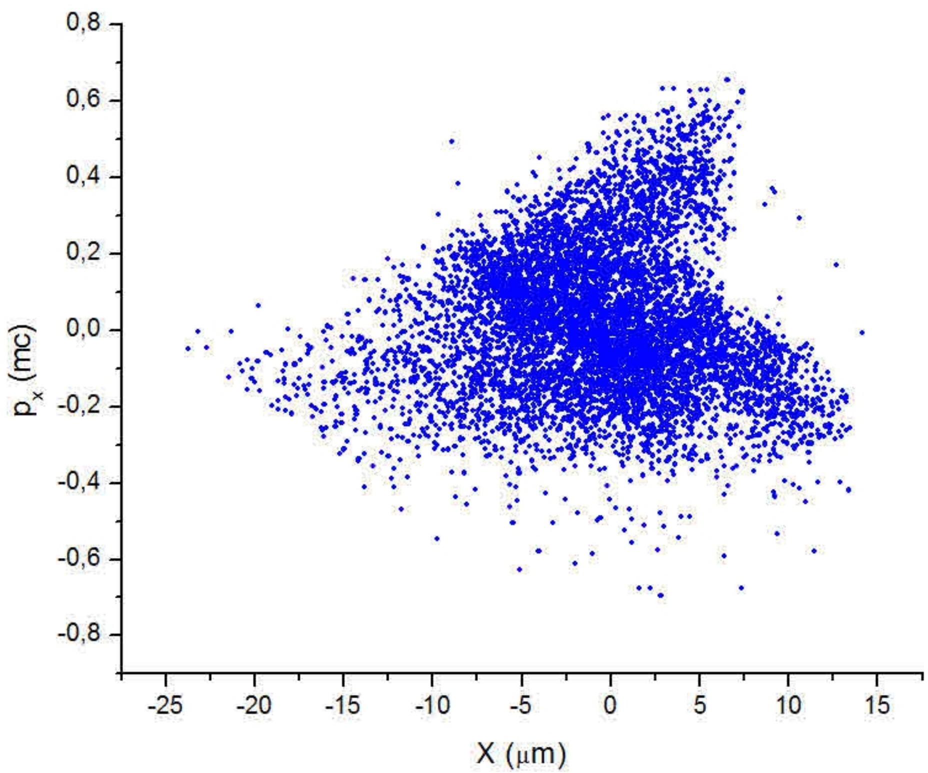
EXIN: simulations

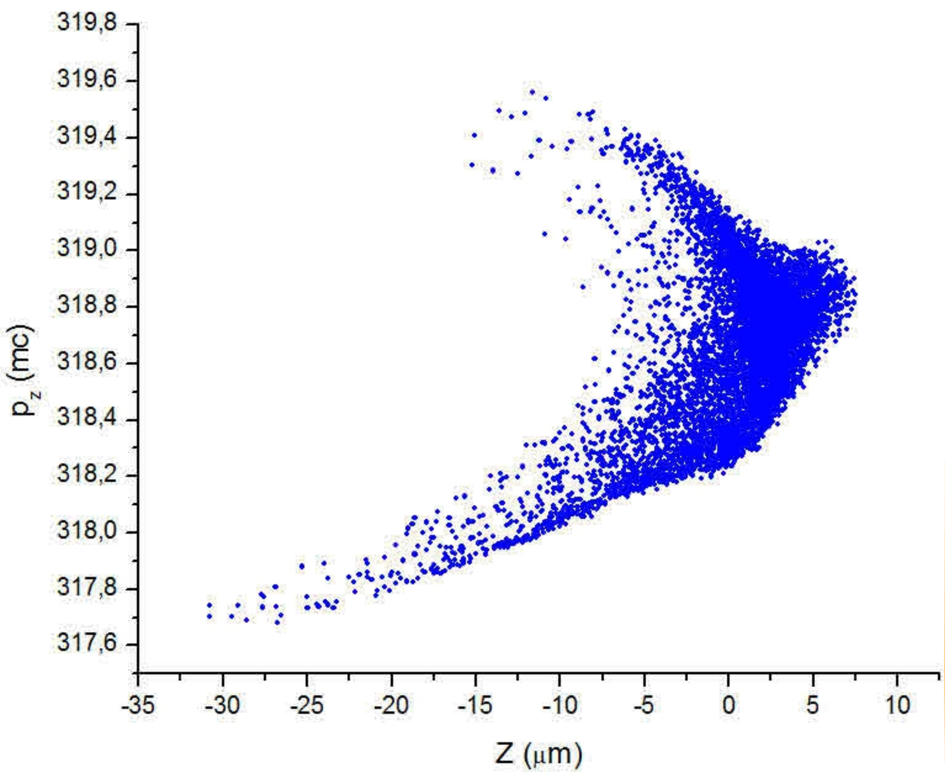
Laser parameters

- Energy: 6 J;
- Length: 35 fs (FWHM);
- W_0: 65 um;
- Rayleigh range: ~ 1.6 cm;
- Gaussian profiles;
- Guided by transverse plasma density tapering;
- Acceleration length: ~ 8 cm.

In - Beam parameters

- Charge: 5 pC
- σ_{tr}: ~ 4.5 um;
- σ_z: 4.5 um;
- ε_n: 0.8 mm – mrad;
- $\delta\gamma/\gamma$: 9 x 10^{-4};
- Energy: 159 MeV





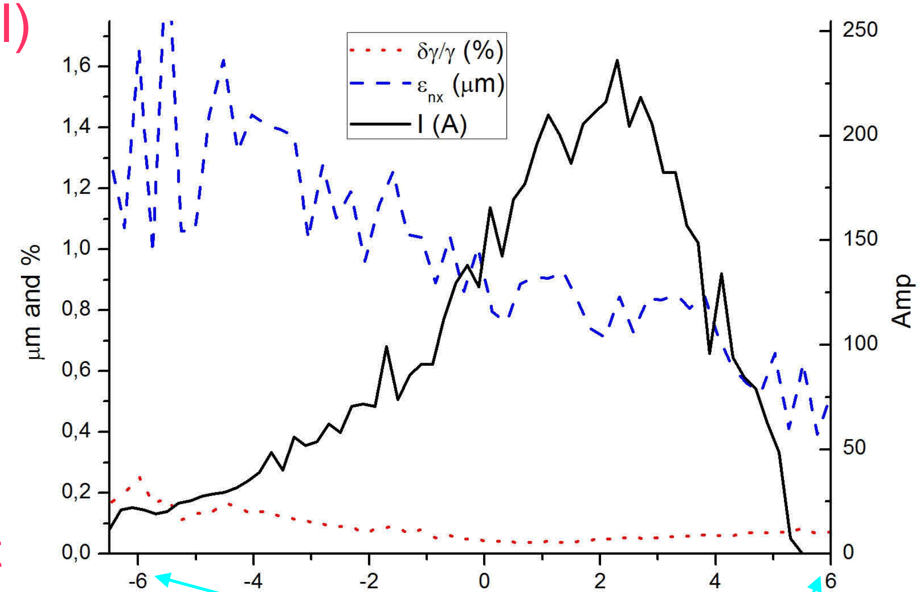
EXIN: simulations

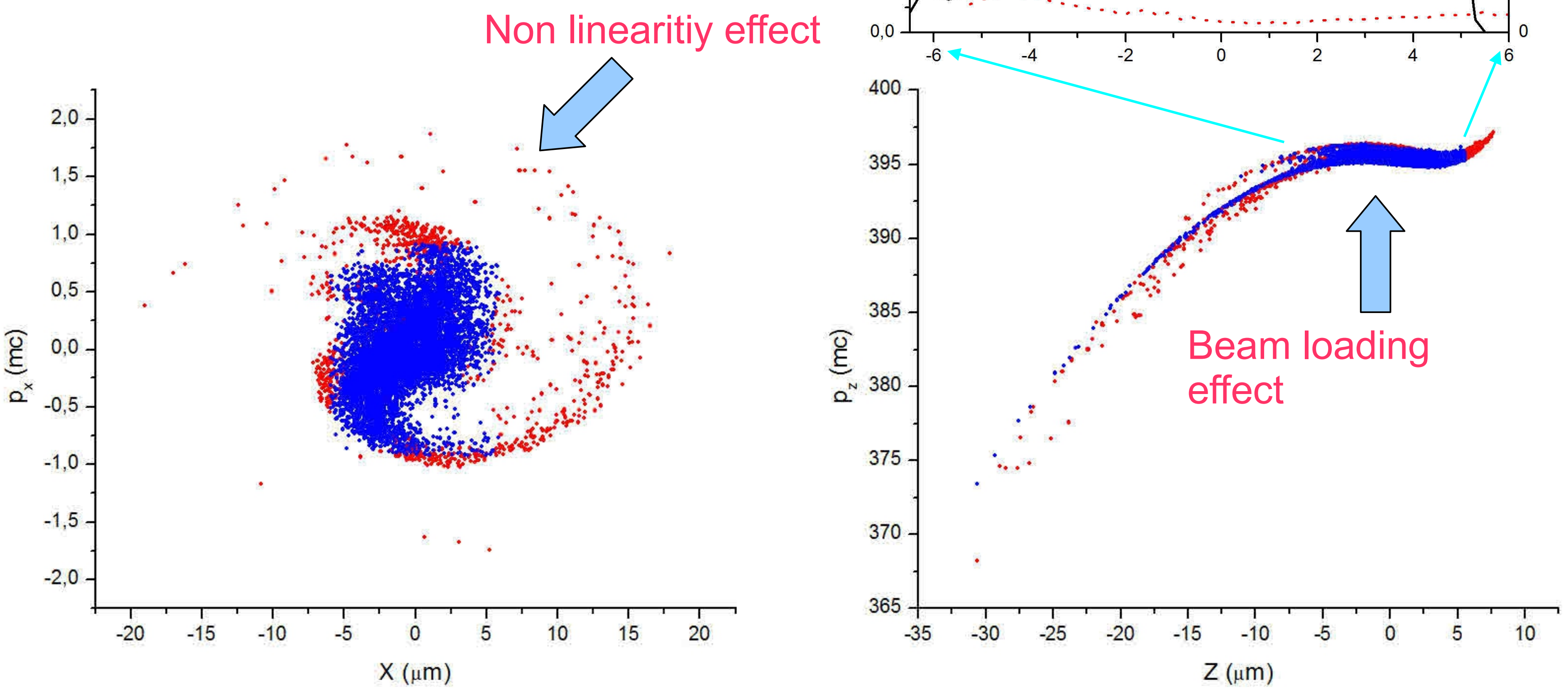
Setting 1: n_0=0.8 x 10^{16} cm^{-3} (educational)

Out - Beam parameters

(not including red particles: 15% charge cut)

- σ_{tr}: ~ 2.5 um;
- σ_z: 3.6 um;
- ε_n: 0.9 mm – mrad;
- $\delta\gamma/\gamma$: 3 x 10^{-3};
- Energy: 198 MeV





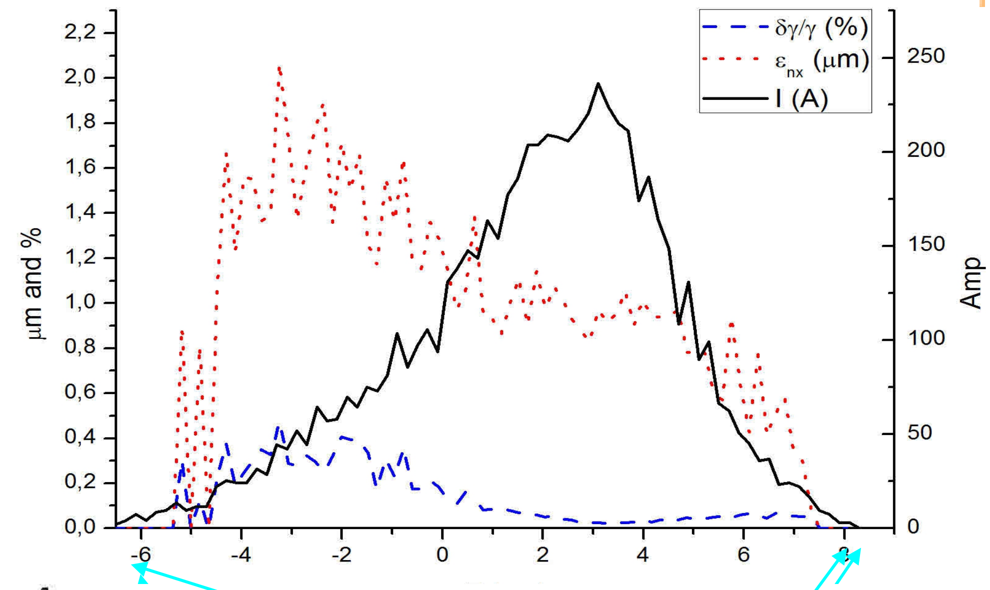
EXIN: simulations

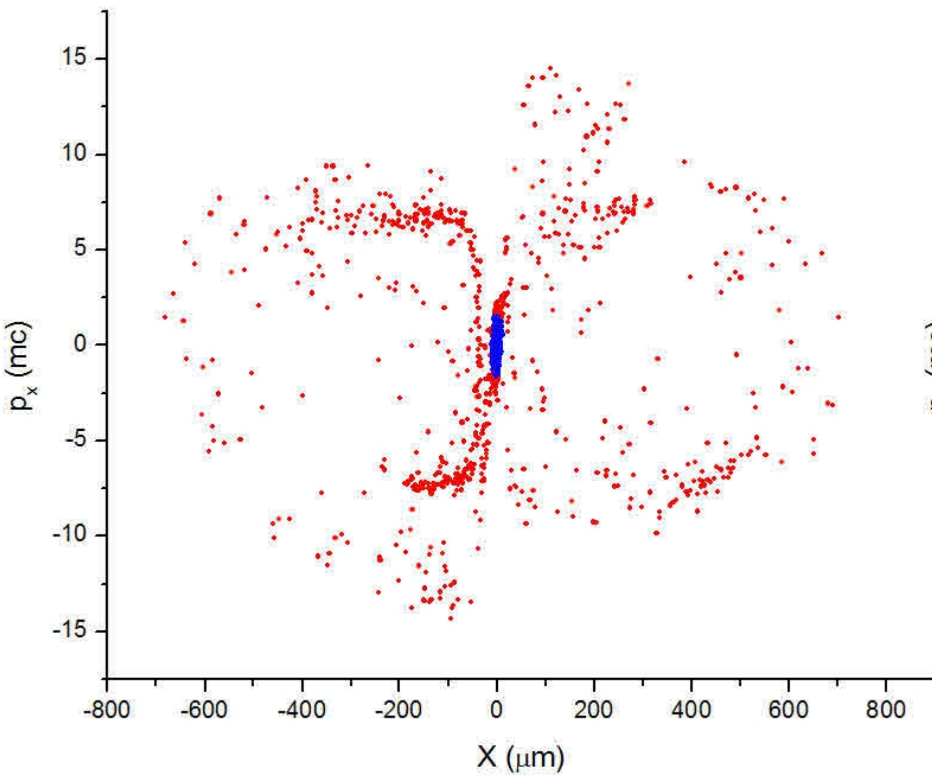
Setting 2: n_0=1.0 x 10^{17} cm^{-3}

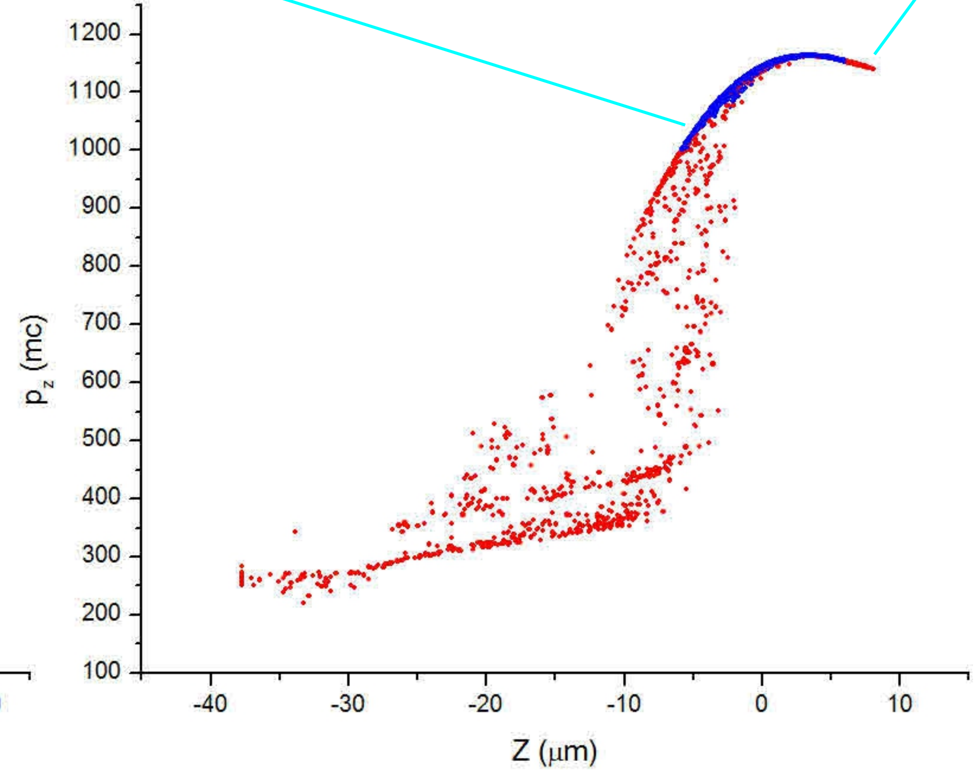
Out - Beam parameters

(not including red particles: 15% charge cut)

- σ_{tr}: ~ 2.3 um;
- σ_z: 1.7 um;
- ε_n: 0.9 mm – mrad;
- $\delta\gamma/\gamma$: 2.3 x 10^{-2} (no significant beam loading);
- Energy: 570 MeV





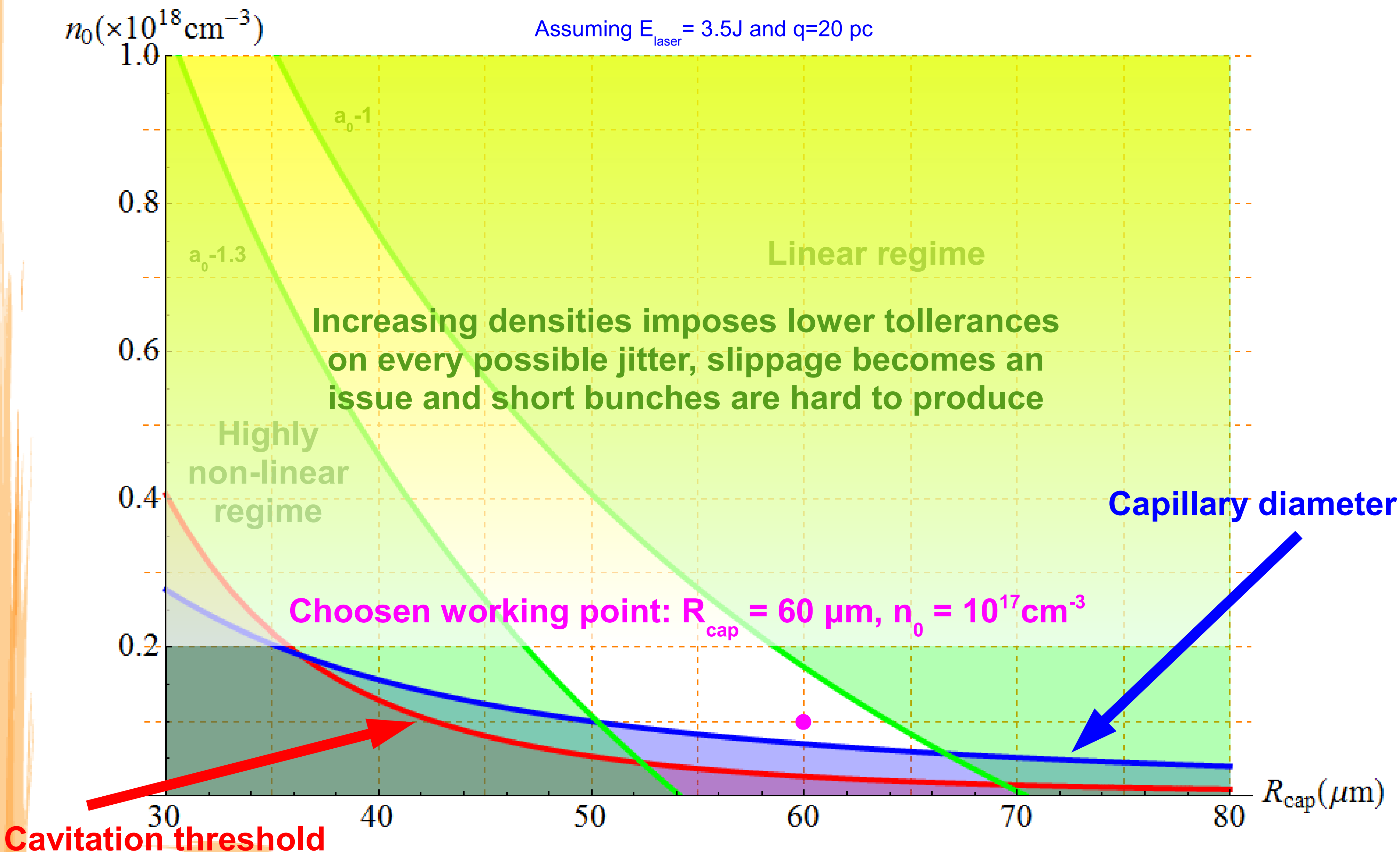


Conclusions

- External injection appears as a very promising scheme to exploit plasma acceleration for high brightness electron beam.
- Technical issues are challenging but we are doing our best to overcome them.
- Exin beam line is under construction stage at LNF – INFN.
- First accelerations are expected for mid to late 2015.

Backup slides

Choice of parameters: physical and practical constraints



EXIN: simulations

Setting 2: $n_0 = 1.0 \times 10^{17}$ cm^{-3}

Out - Beam parameters

(not including red particles: 15% charge cut)

- σ_{tr}: ~ 2.3 um;
- σ_z: 1.7 um;
- ε_n: 0.9 mm – mrad;
- $\delta\gamma/\gamma$: 2.3 x 10^{-2} (no significant beam loading);
- Energy: 570 MeV