External Injection experiment at the SPARC_LAB facility

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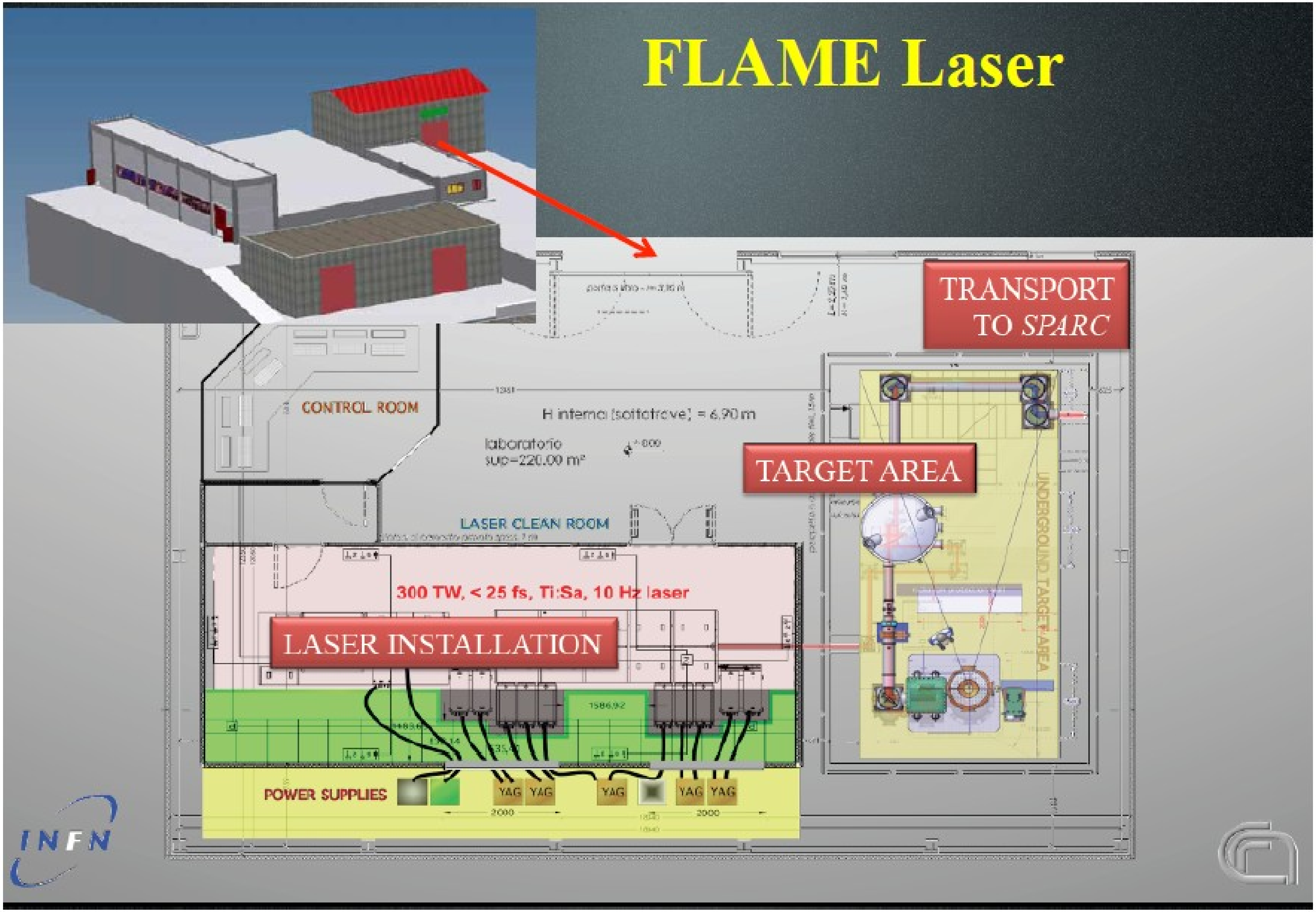
EXIN goals

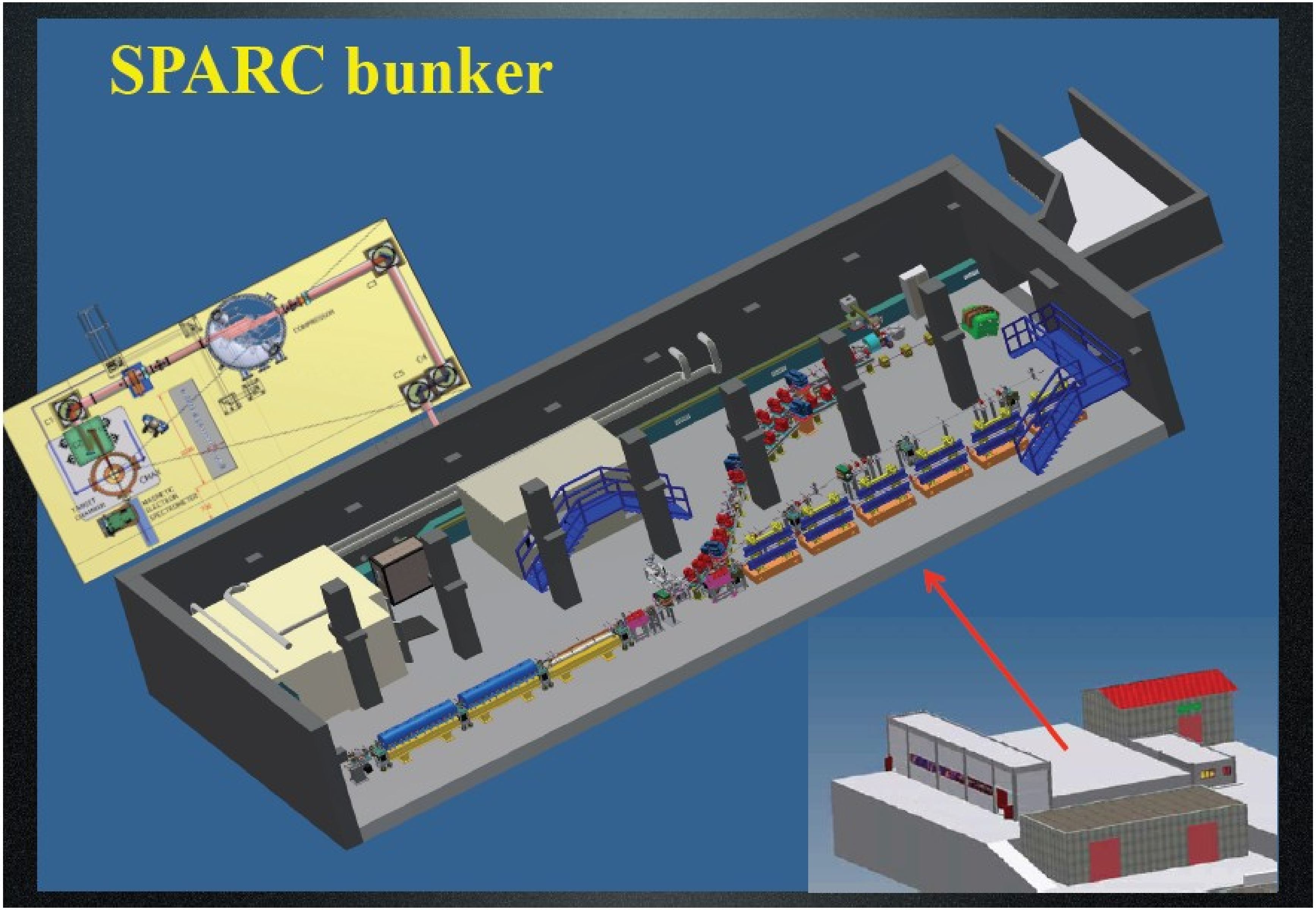
- Produce a high brilliance e-beam, peak or global.
- Stability.
- Reproducibility.
- Everything above in the easiest way (leading philosophy).

Highest energy record in LWFA is NOT a goal!

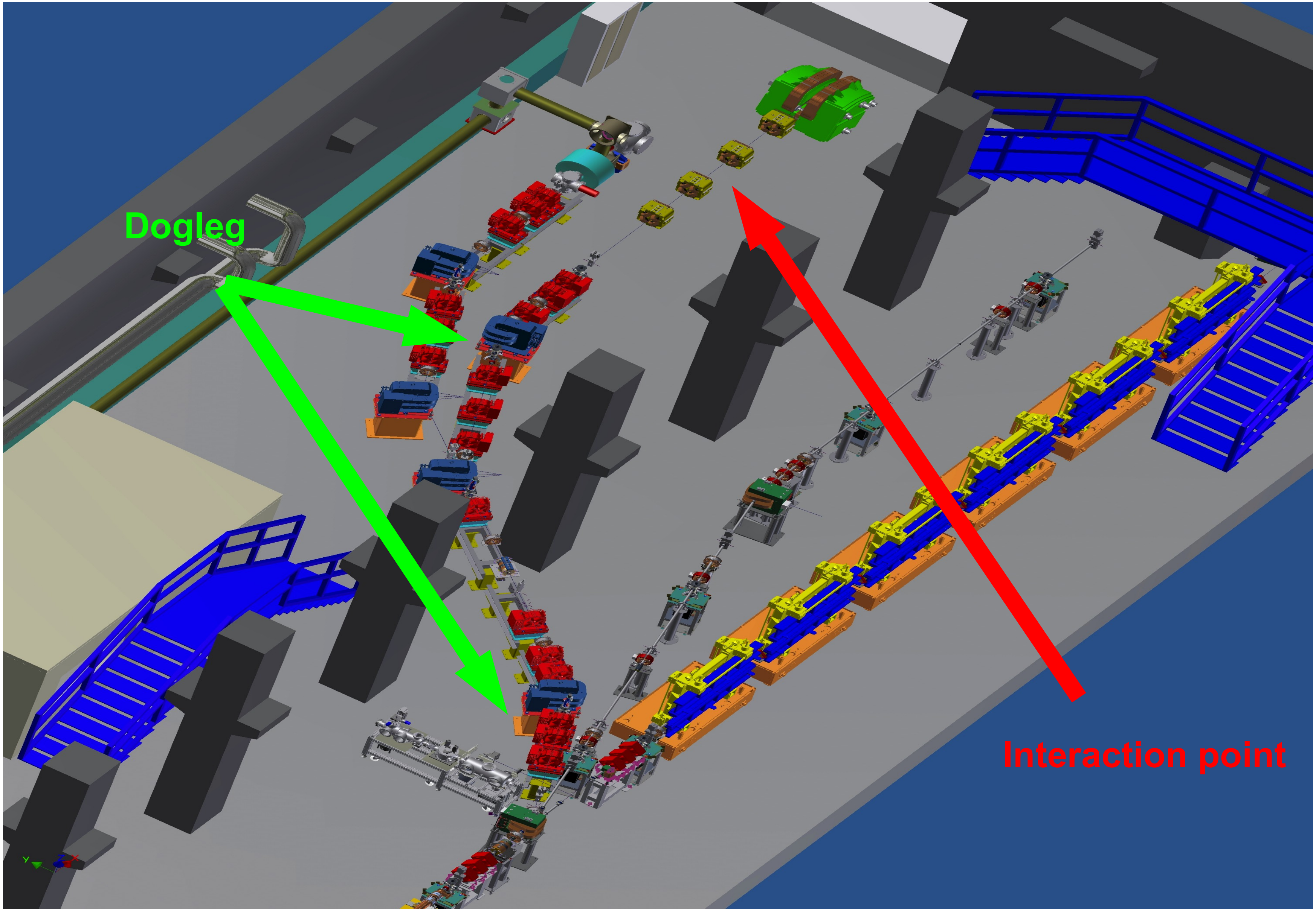
SPARC_LAB: the test facility



SPARC_LAB: the test facility



SPARC_LAB: the test facility



Choice of settings 1

Laser parameters:

E ≤ 3.5 J on target
T_{FWHM}: 20 – 40 fs
σ_{tr} ≥ 10 μm

e-beam parameters:

E = 70 - 150 MeV
L_{FWHM}: 7 – 40 fs
ε_{nt}: few μm (hopefully)
σ_{tr}: as per emittance
δγ/γ: not crtitical
Q: 5 – 30 pC

Beam line

VB and magnetic mixed compression

↓

Many possible plasma waves regimes: a_0 ≤ 4.8

Ionization energy is not a problem ~ 10 - 100 of μJ/cm

Matching to/from plasma needed

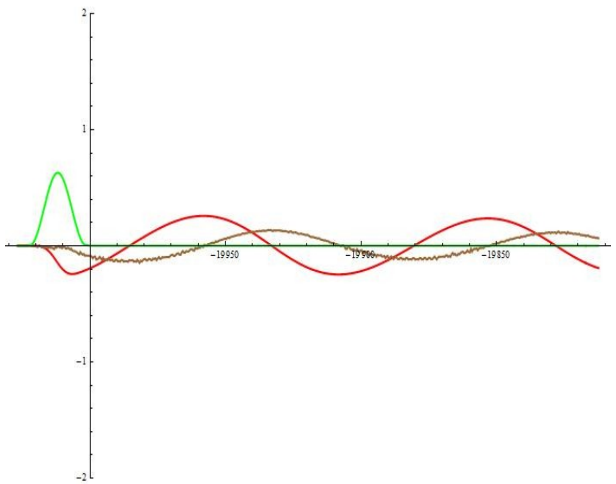
The shorter the better but high current means high loading

Many handles for delivering good quality – high current bunches

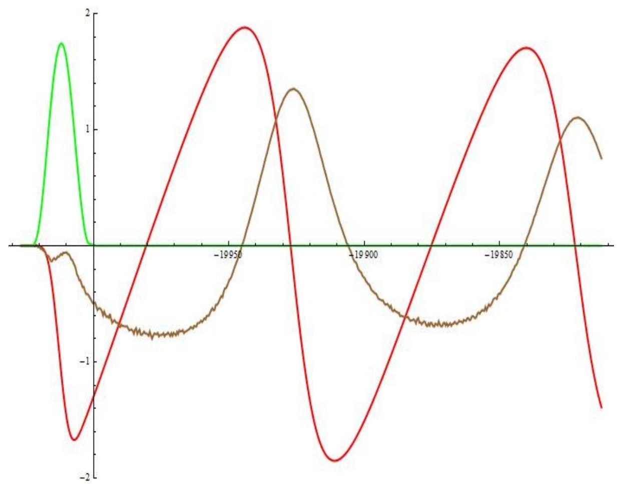
Choice of settings 2

Plasma wave regime

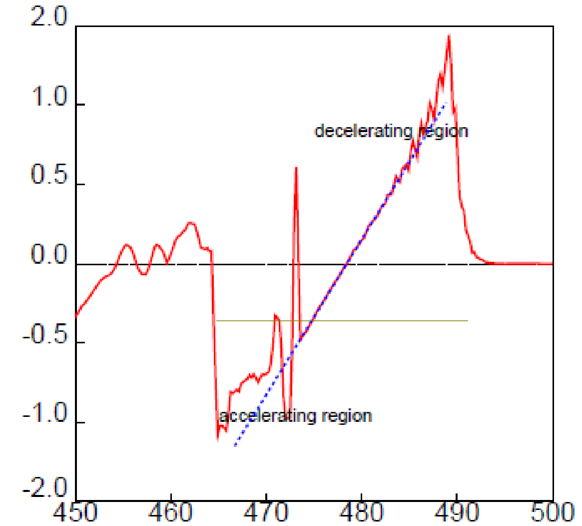
Linear



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 is significant but manageable with bunch charges up to few tens of pC.

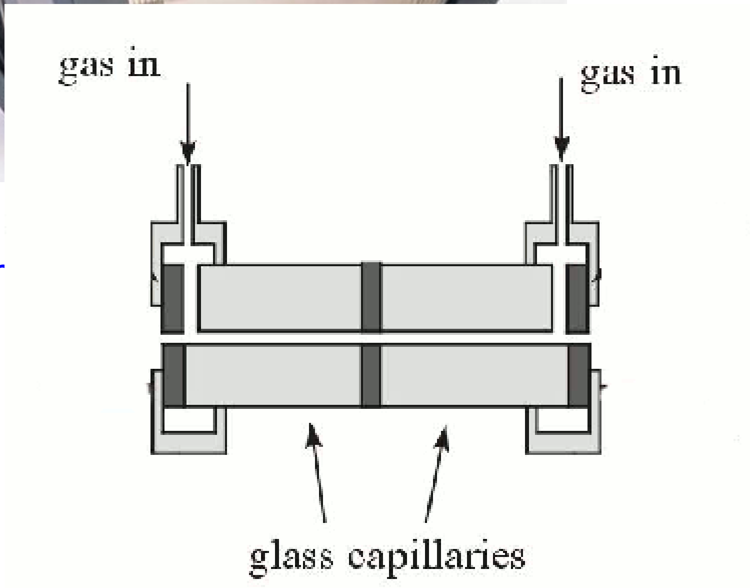
The hardest to implement and manage, due to high sensitivity to jitters.
Highest performances and beam loading is not a problem up to few hundreds of pC. Possible in future.

Choice of settings 3

To guide or not to guide

Gas cell: no guiding.

Easy,
length



Capillary waveguide: guiding by boundary conditions.

Laser guiding over a distance much longer than natural Rayleigh length

scharge capillaries: like a graded index optical fibre.

Excluded by the philosophy of the easiest way

Choice of settings 4

To guide or not to guide continued

A few data about monomode laser guiding in glass capillaries*:

The matching condition of the laser pulse to the capillary is:

$$w_0 = 0.645a$$

meaning that 98% of laser energy is coupled to the cap. The coupled mode is the EH_{11}, which is the closer to the TEM_{00}.

The characteristic length L_d, for monomode guiding of EH_{11}, over which laser energy is reduced to 1/e the initial value, is the inverse modulus of

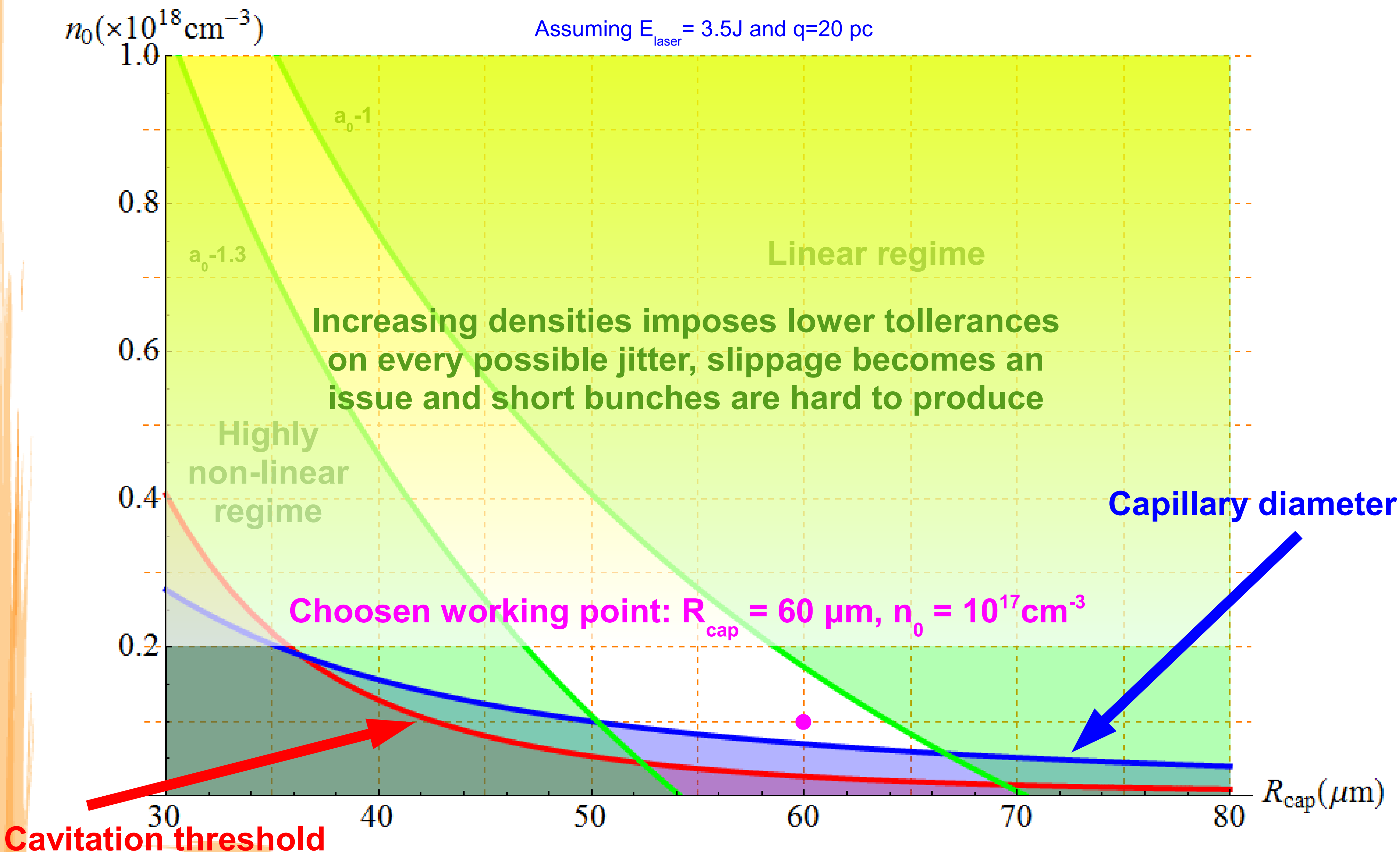
$$k_{zi} = -\frac{u_s^2}{2k_{z0}^2 a^3} \frac{1+\varepsilon_w}{\sqrt{\varepsilon_w - 1}}$$

where u_s=2.405, a=cap. radius and ε_w=2.25 for glass. For a=50 um L_d>1.5 m.

Damaging threshold of glass with grazing incidence > 10^{16} W/cm^2.

*B. Cross *et al.*, PRE 65, 026405 (2002).

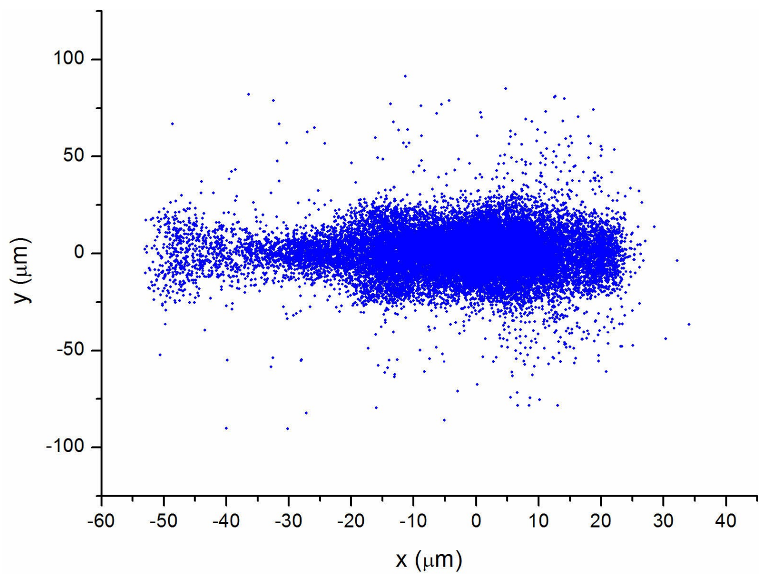
Choice of parameters: physical and practical constraints

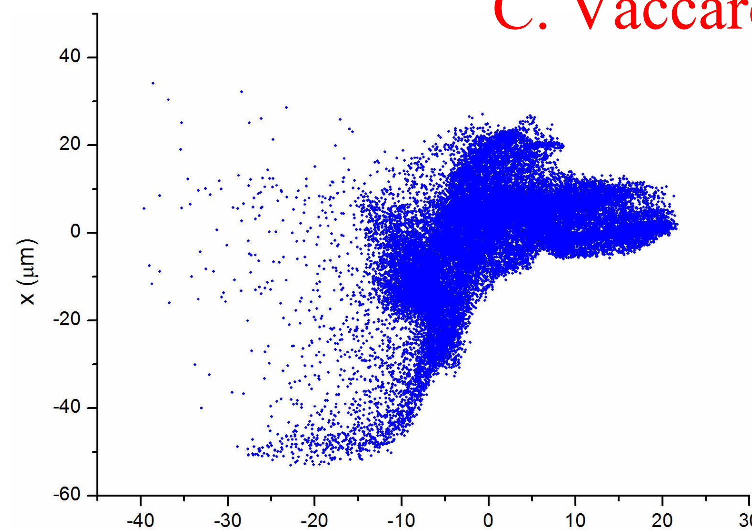


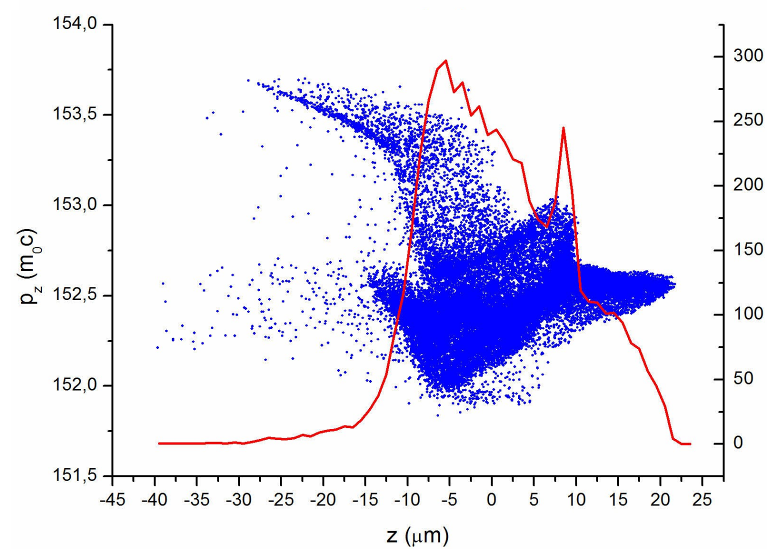
S2E simulation: beam production and transport

Production has been simulated using ASTRA together with the genetic optimizer GIOTTO up to injector's end. ELEGANT has been used for the transport inside the dogleg.

By A. Bacci
and
C. Vaccarezza







Final beam parameters: σx≈σy=12.7 μm, εx= 2.7 μm, εy= 0.4 μm, E= 78 MeV, δγ/γ= 0.2%.
Total compression: cf= 16 (8 by VB and 2 by dogleg).
Non particular optimization in dogleg.
X emittance overestimated!

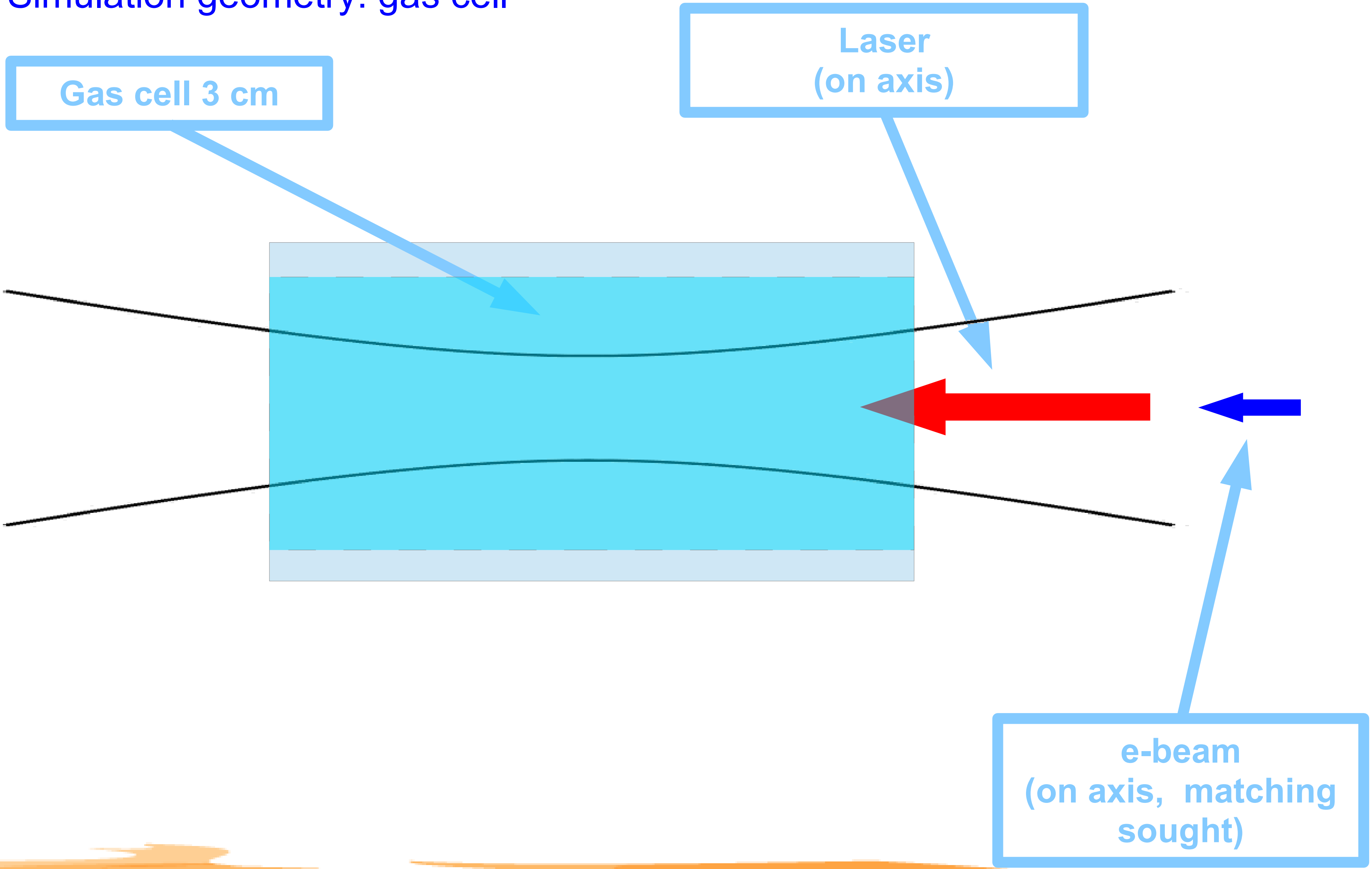
S2E simulation: plasma acceleration

Simulation tool: QFLUID2 by P. Tomassini

- 2D cylindrical.
- Fluid approximation for plasma.
- Supports mildly non-linear regimes.
- Laser evolution is self consistent and uses envelope approximation.
- Beam loading effects are included.

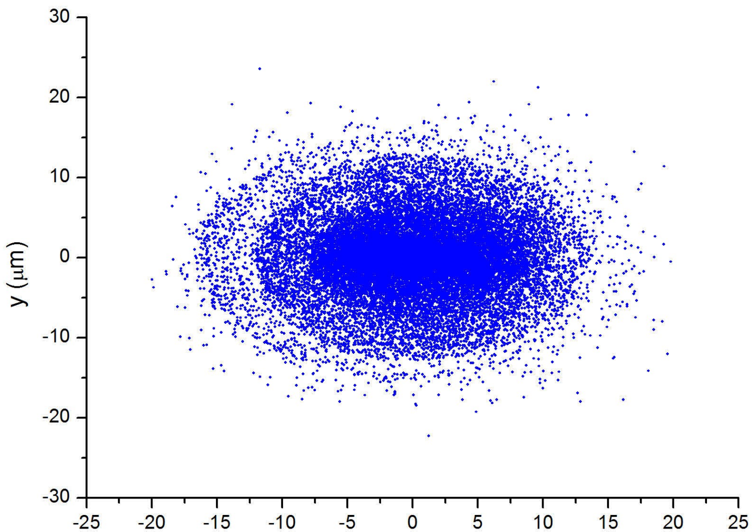
S2E simulation: plasma acceleration

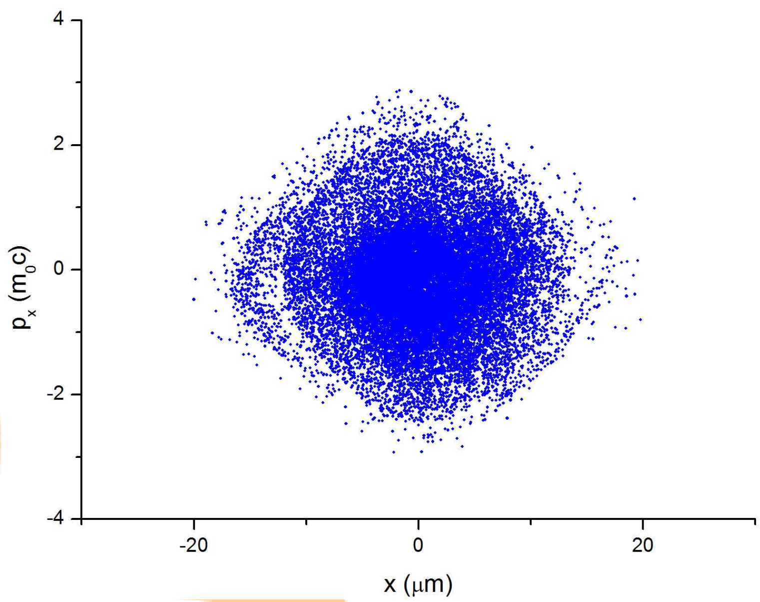
Simulation geometry: gas cell



S2E simulation: plasma acceleration

Sample beam: Δt = 157 fs, σ_x = 3.8 μm.





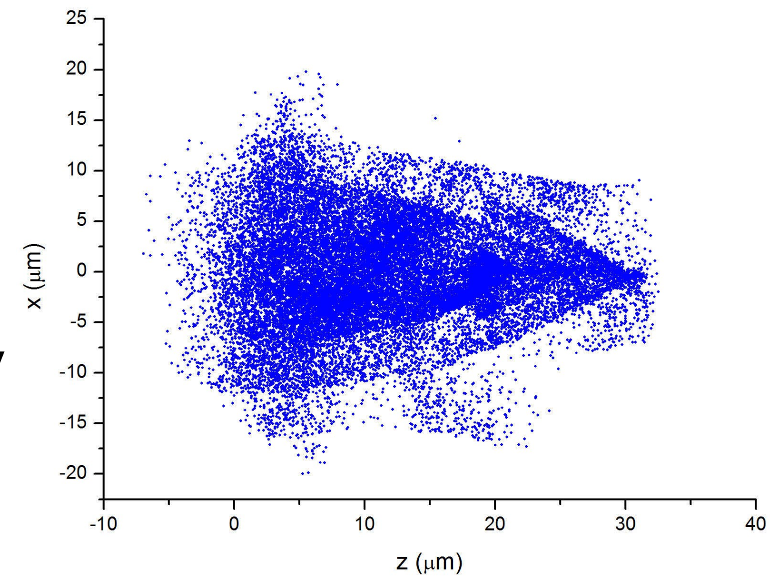
σ_x = 5.4 μm

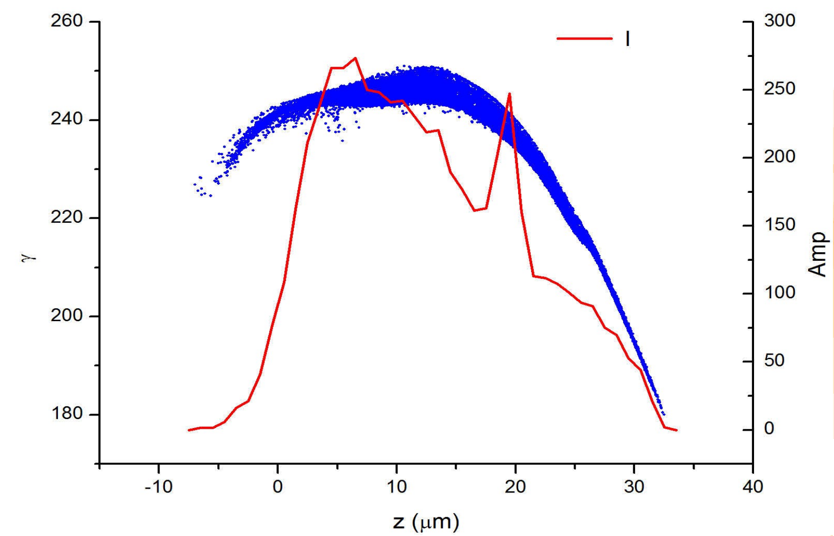
E = 120 MeV

Charge loss = 8%

ε_{nx} = 4.5 μm

$\Delta\gamma/\gamma$= 4.5 %





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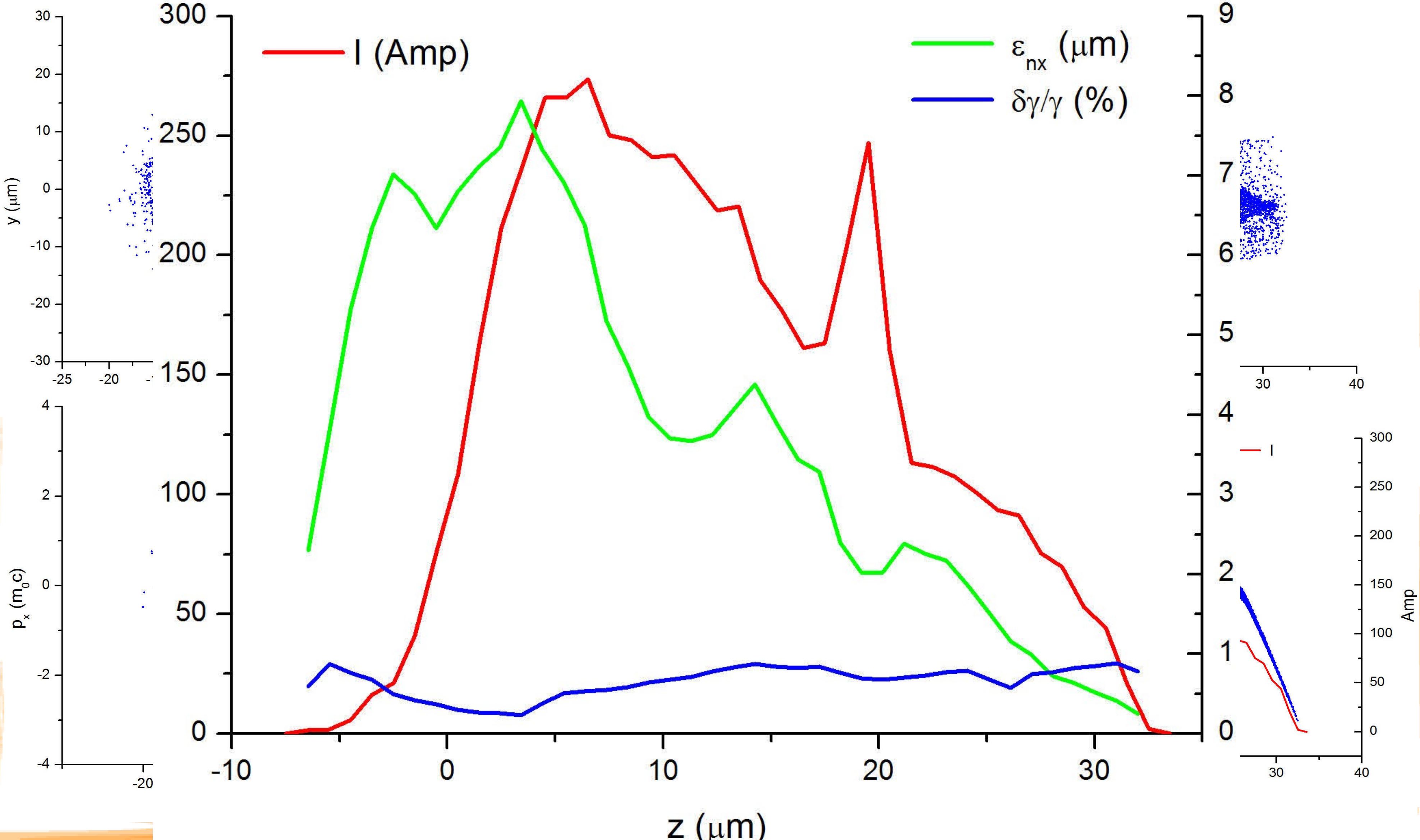
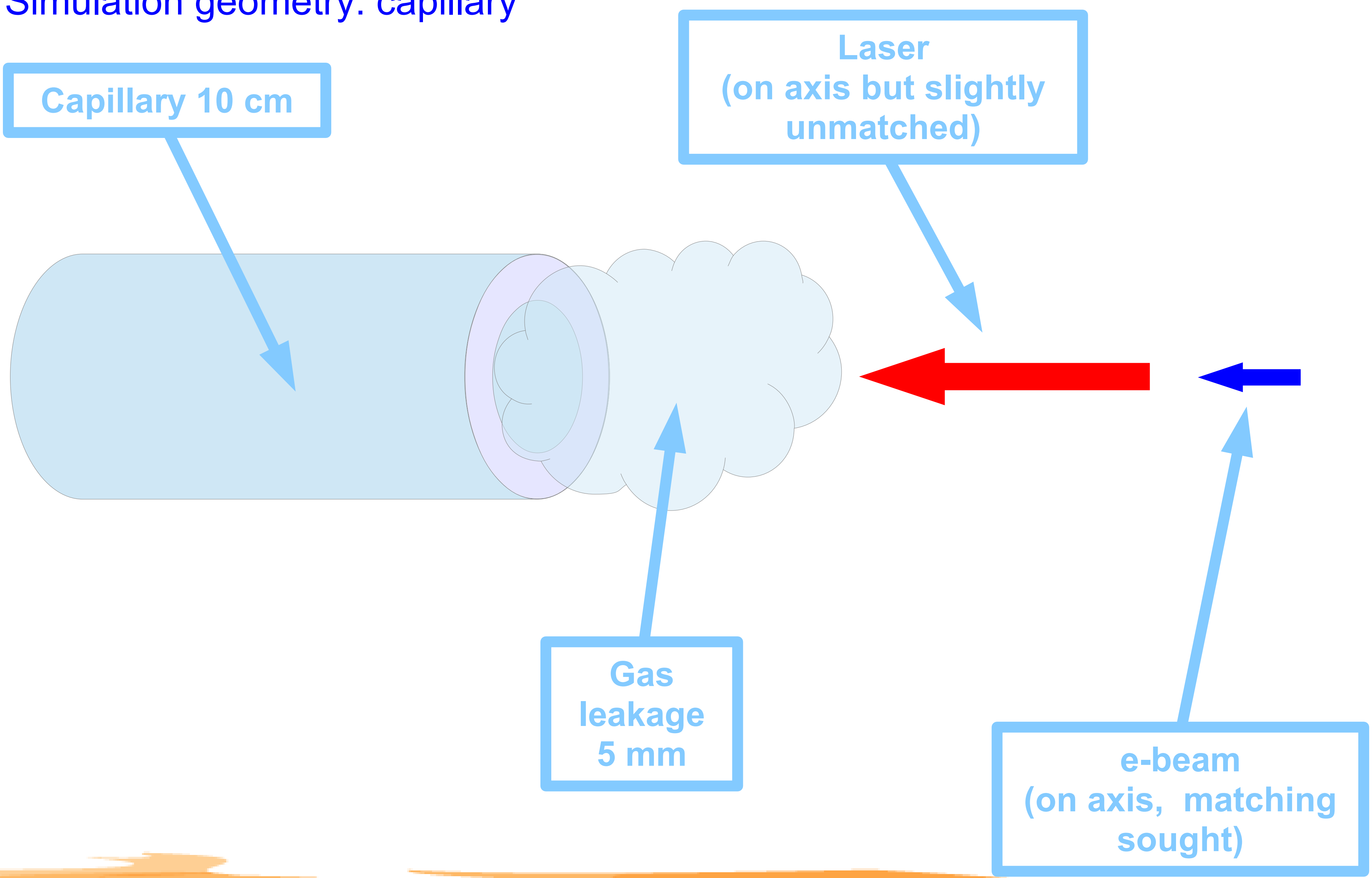


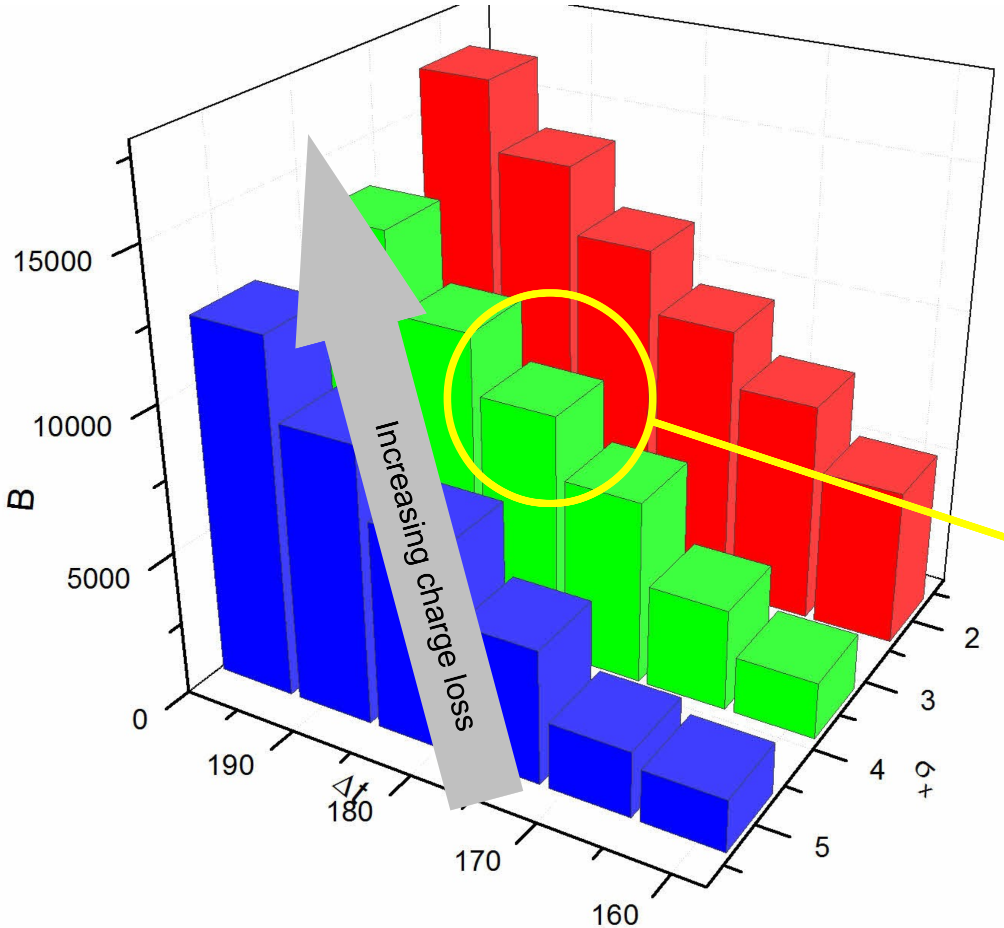
S2E simulation: plasma acceleration

Simulation geometry: capillary



S2E simulation: plasma acceleration

Parameters scan results



Δt: injection phase
σ_x: bunch envelope

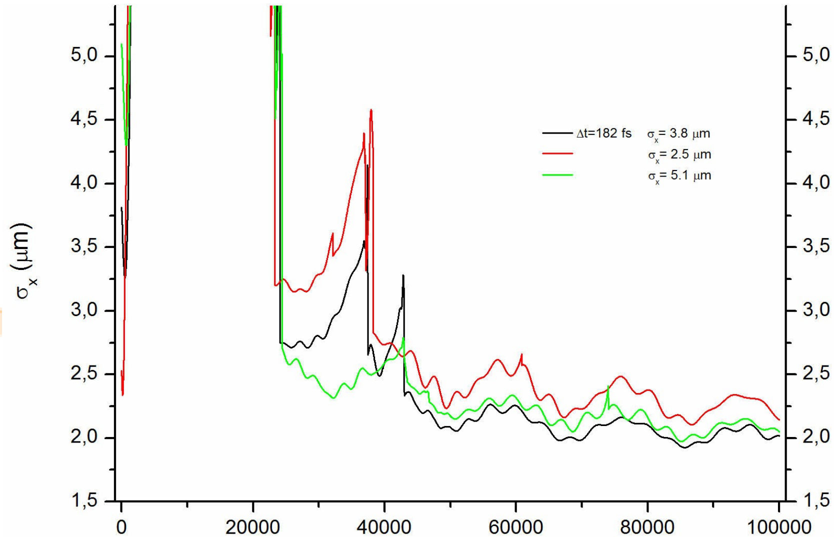
Charge loss from 10% to 65%

Selected reference beam:
Δt = 182 fs
σ_x = 3.8 μm

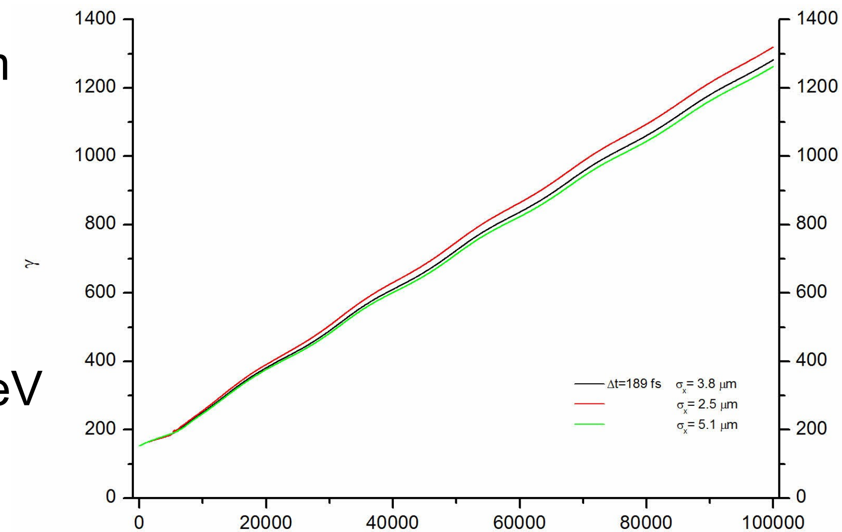
Figure of merit:
$\mathbf{B}=q_s/(\varepsilon_{nx}^2\ \sigma_t\ \delta\gamma/\gamma \times 1000)$

S2E simulation: plasma acceleration

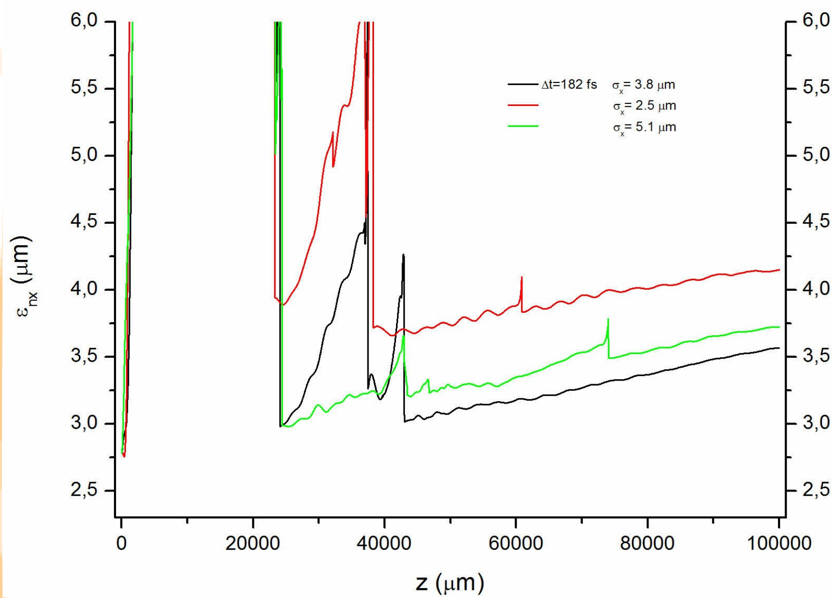
Best beam transport and parameters



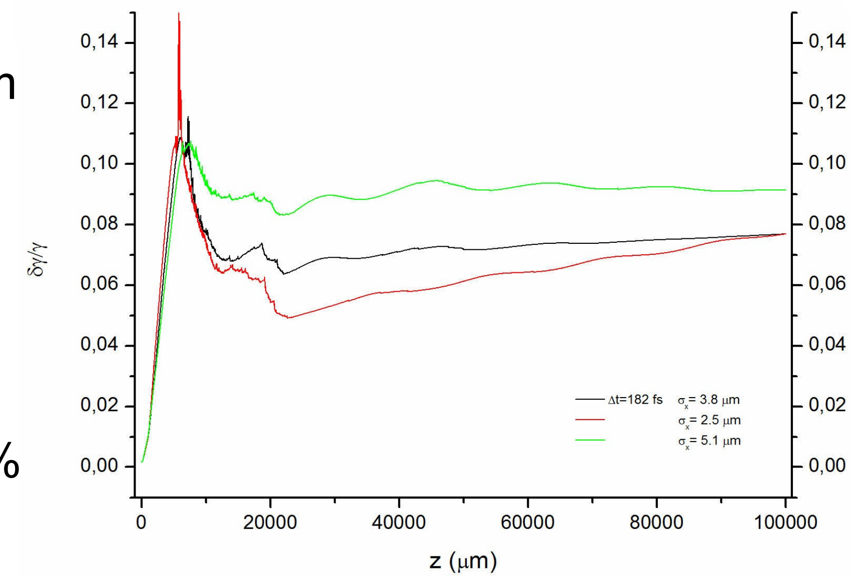
σ_x = 2.0 μm



E = 630 MeV



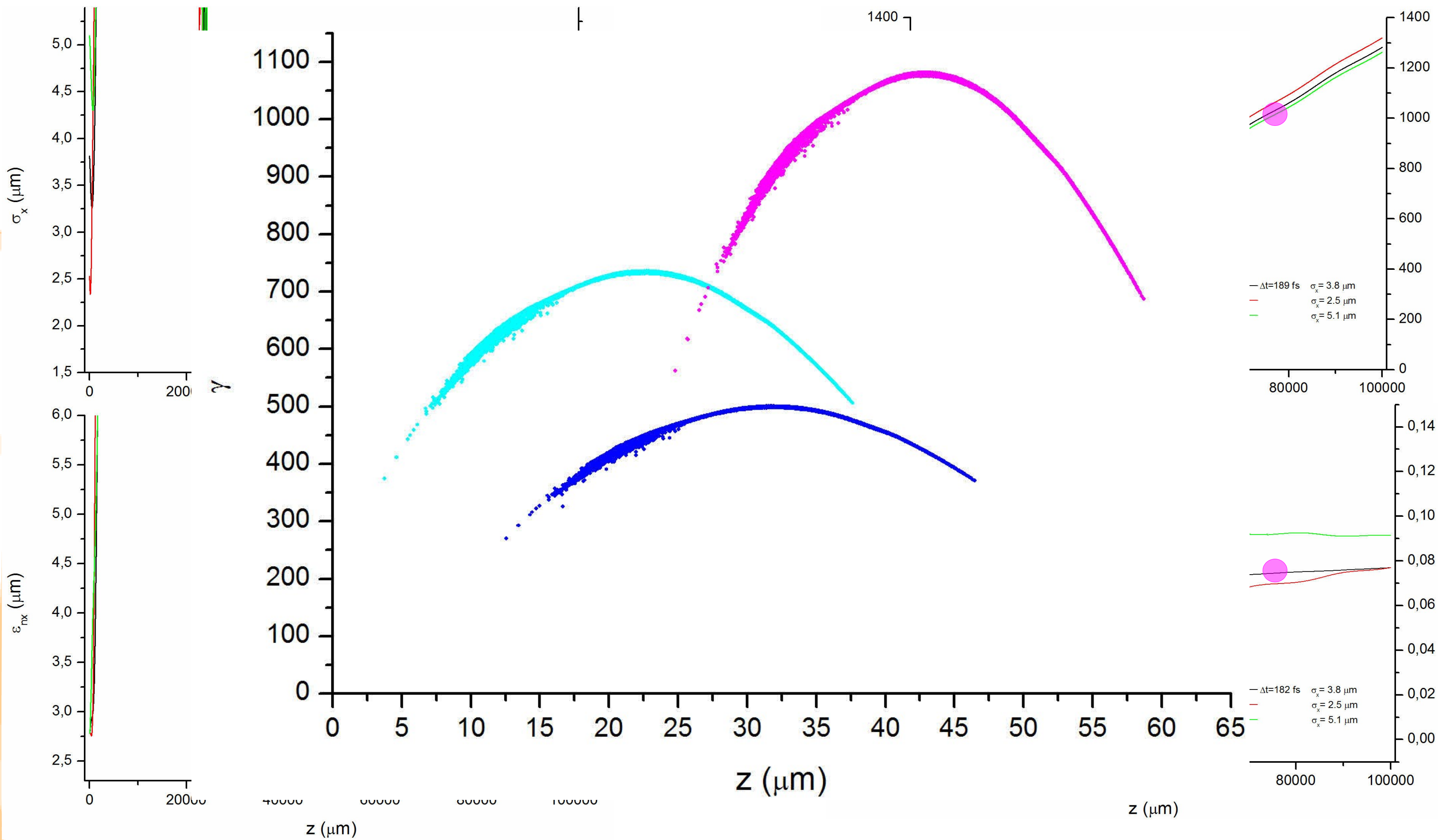
ε_{nx} = 3.5 μm



Δγ/γ= 7.7 %

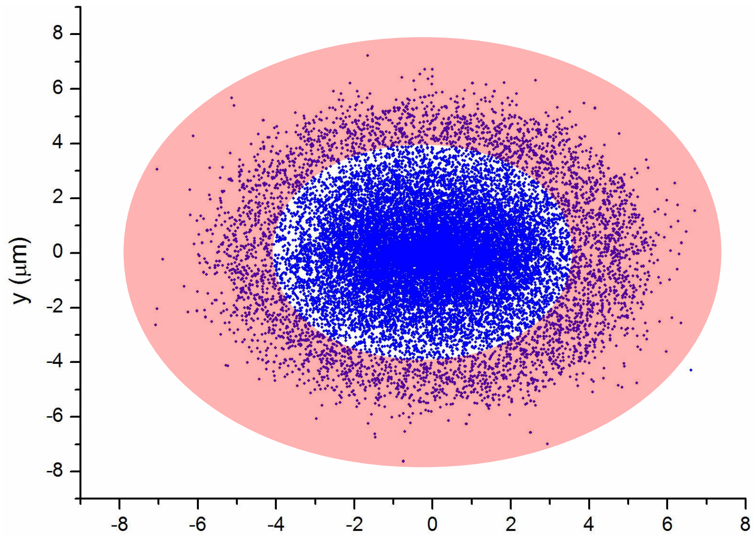
S2E simulation: plasma acceleration

Best beam transport and parameters



S2E simulation: plasma acceleration

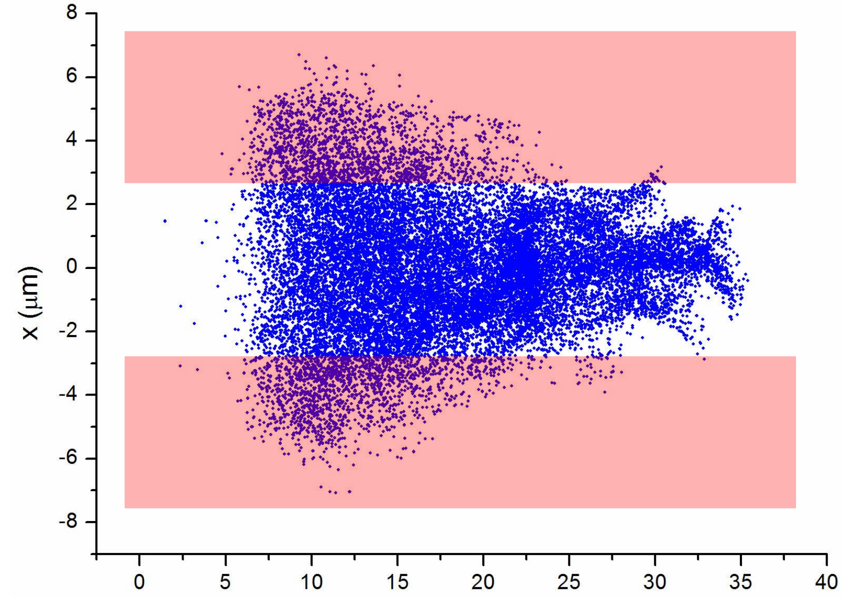
Best beam

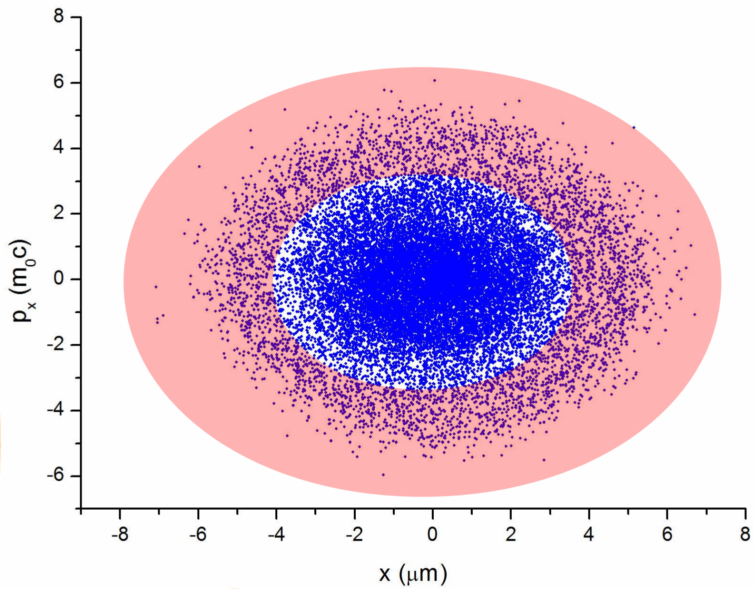


σ_x = 2.0 μm

Emittance dilution due to transverse field dependence on *z*

E = 630 MeV





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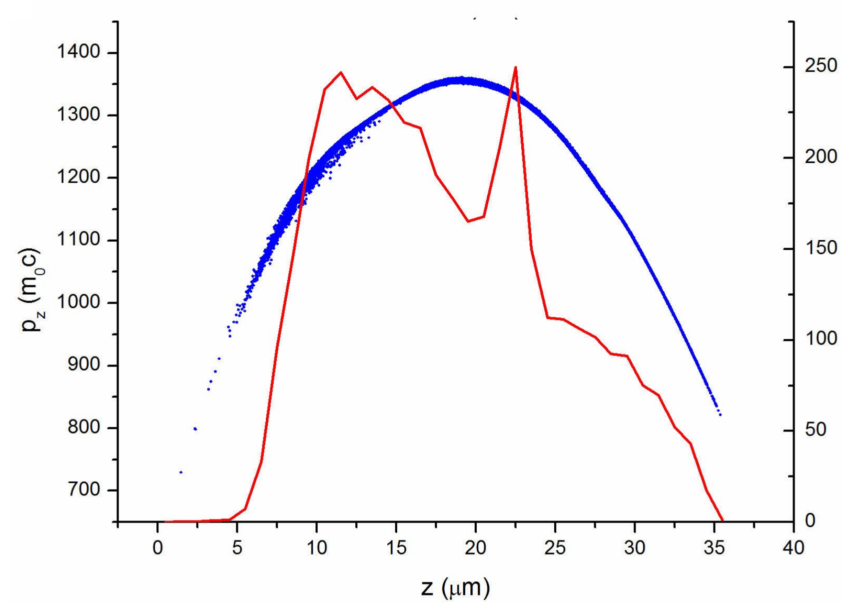

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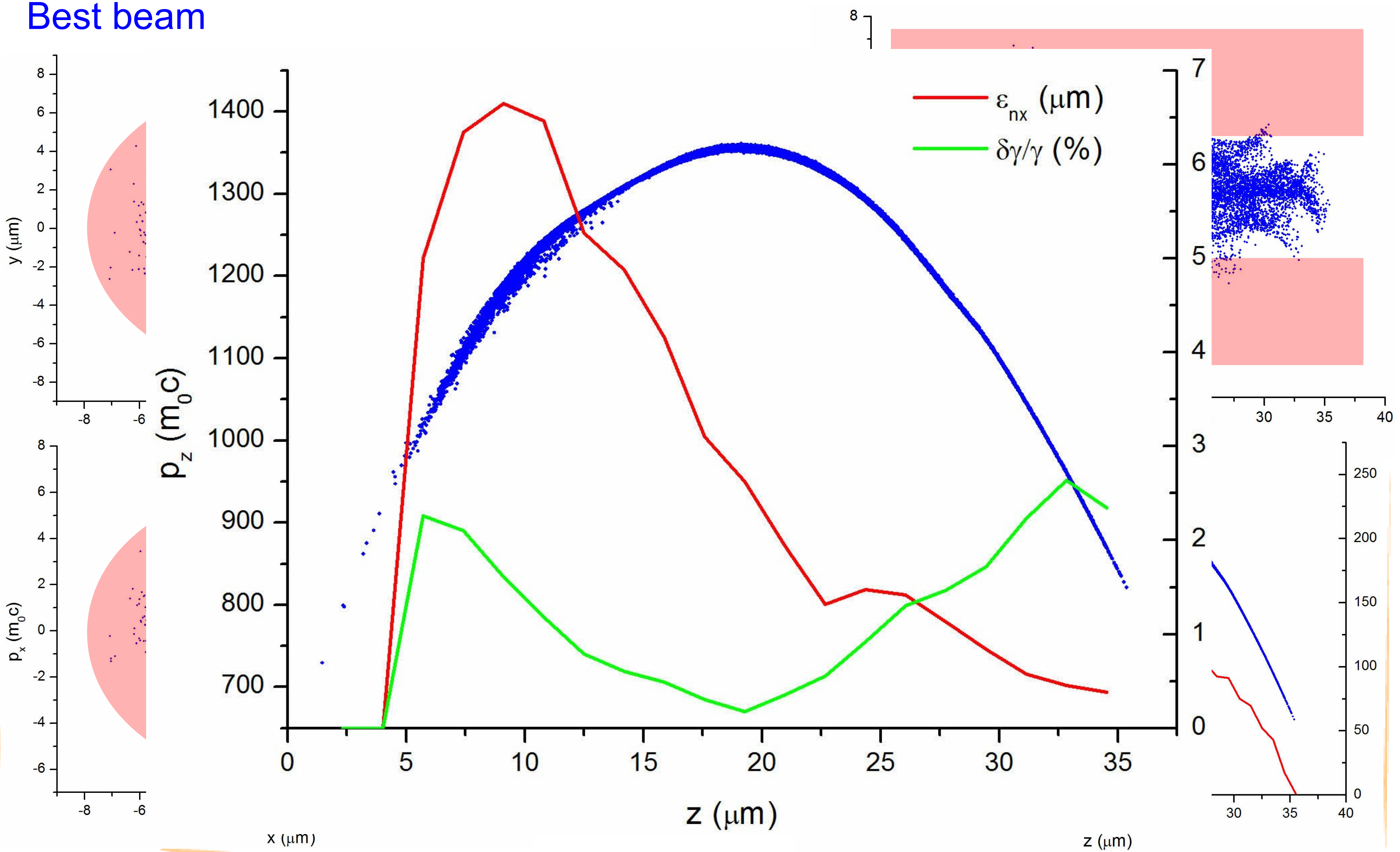
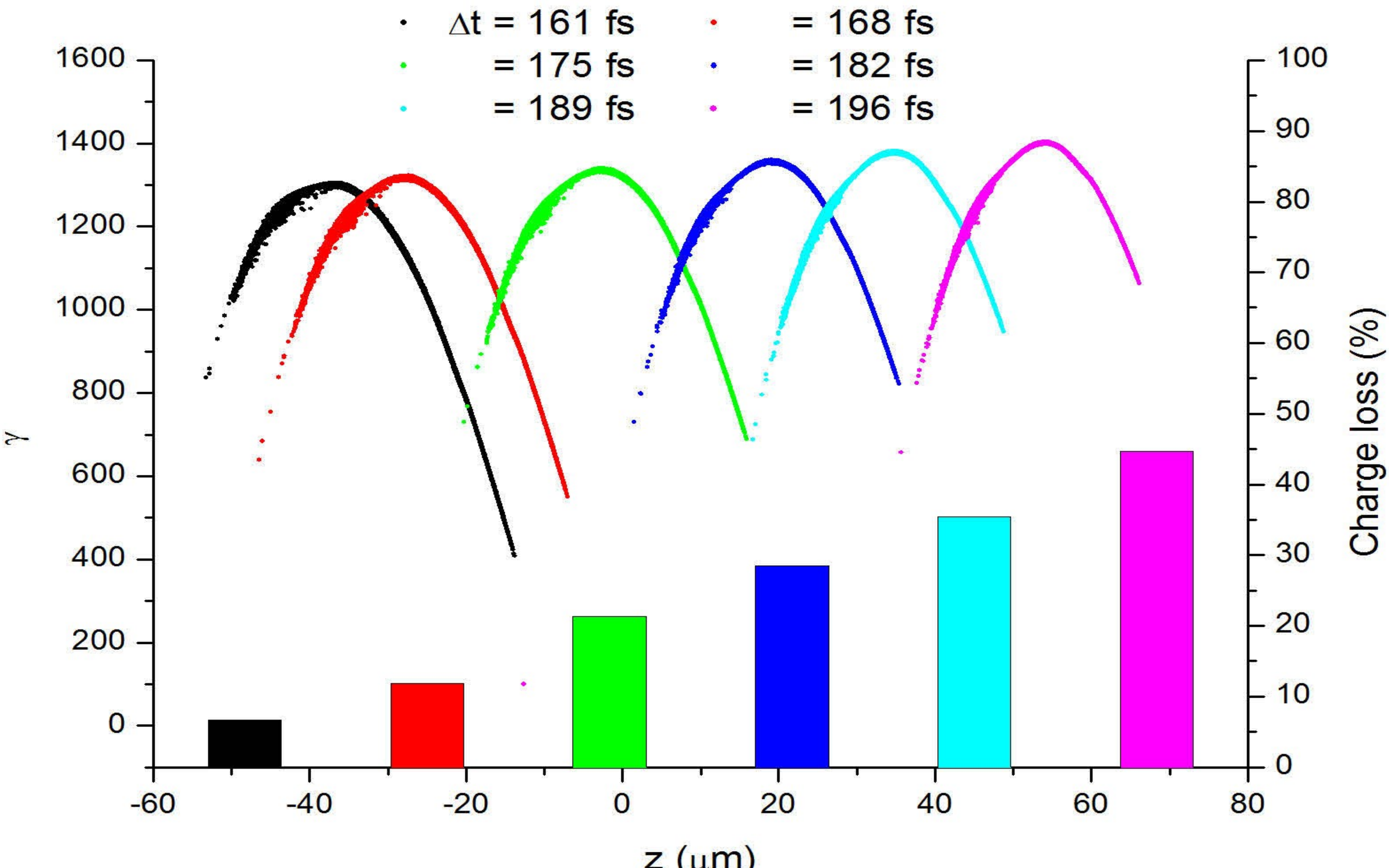
Best beam



S2E simulation: plasma acceleration



Conclusions

- Simulations for the external injection experiment at SPARC_LAB are ongoing and yield promising results
- Further optimizations of whole S2E simulations is needed
- Interaction chamber design is ongoing
- First experimental results are scheduled for mid 2015

Thanks for your attention