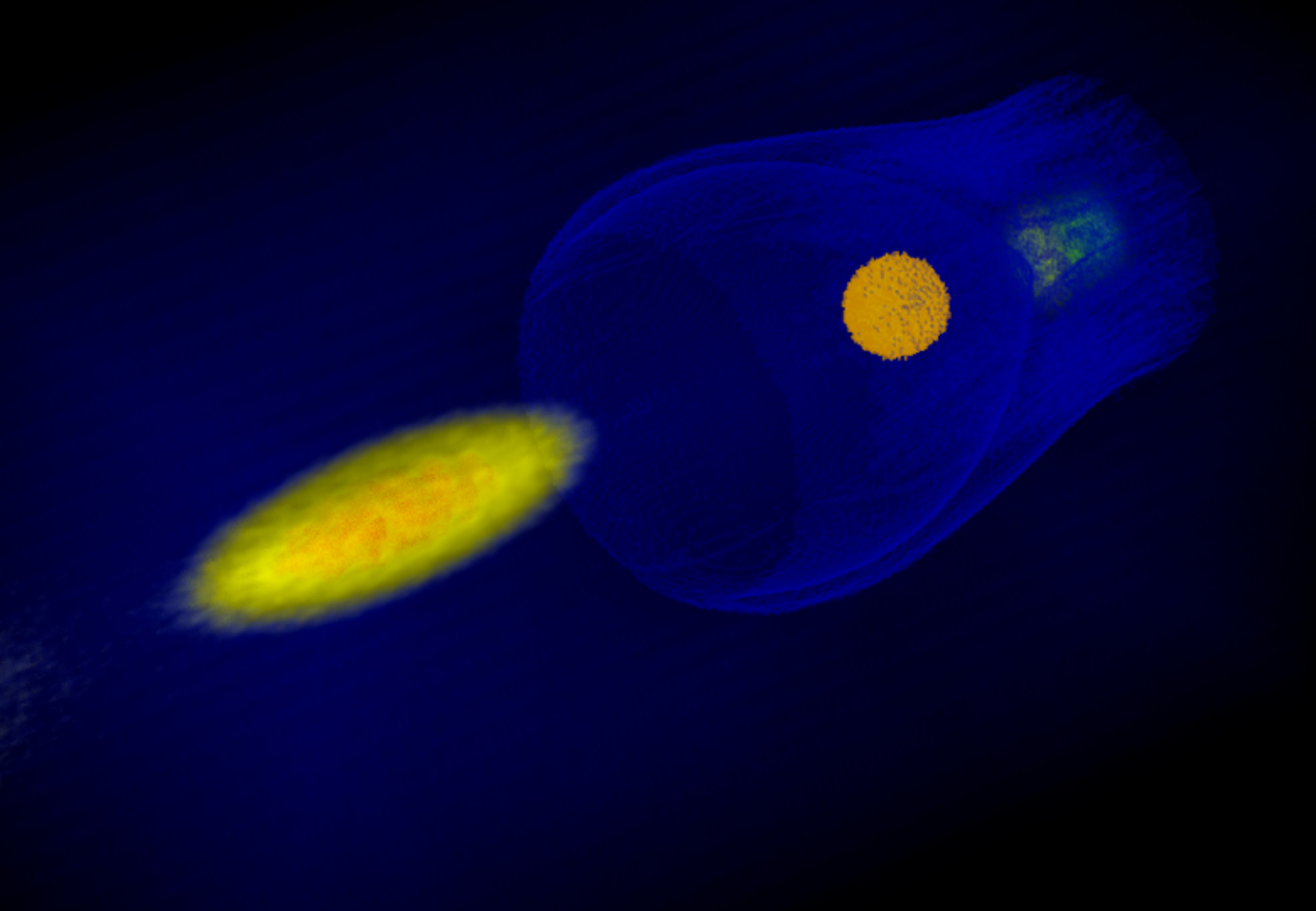


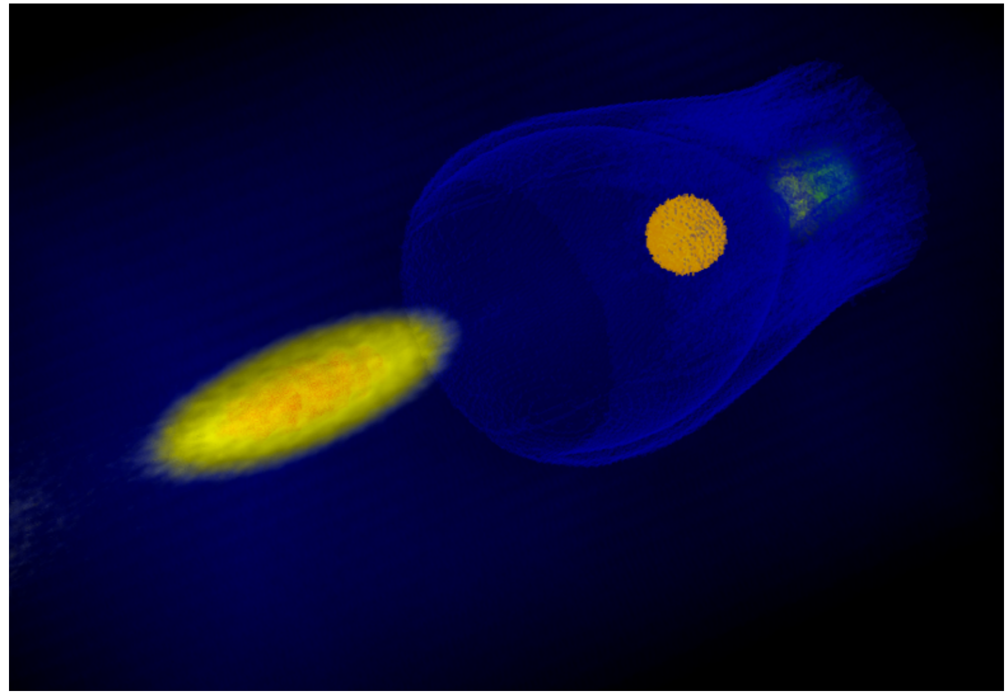
Plasma lenses

Alberto Marocchino

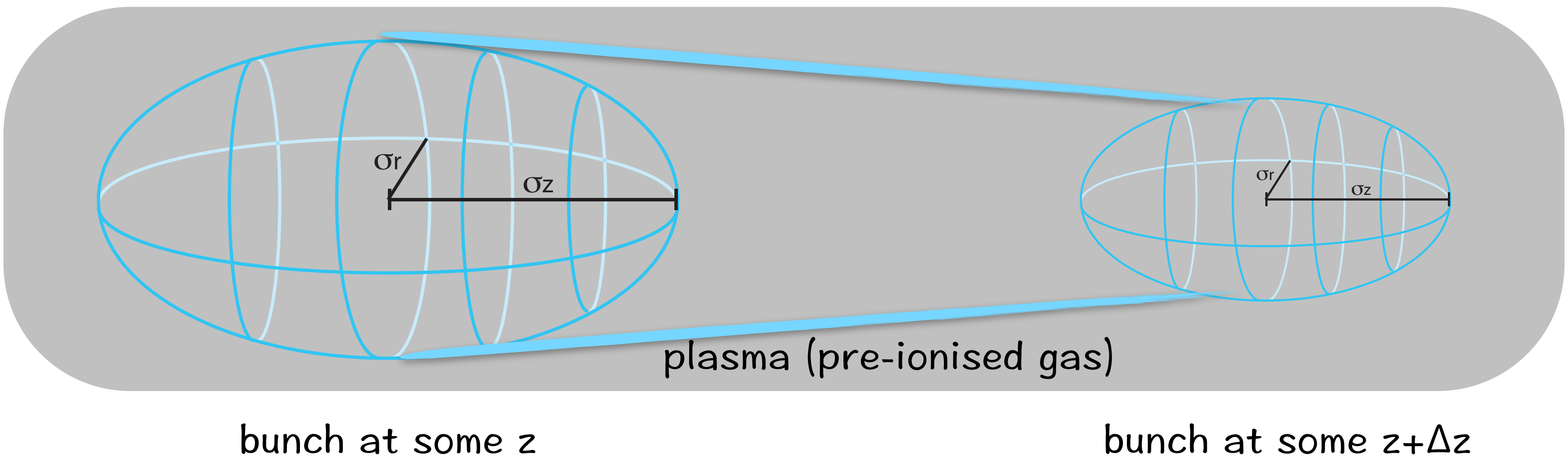
on behalf on the SPARC_Lab collaboration

layout

- What is plasma lens
- Why is it so important?
- Plasma lens brief historical review
- Overdense VS underdense lenses
- Plasma lens at SPARC_Lab
- Conclusions



what is a plasma lens?



- Transversely Smaller
- Trying to preserve:
  - emittance
  - energy spred

lattice: plasma-lens + FEL layout

I stage	II stage	final stage
plasma lens	bunch accelerating section	FEL

- Compress bunch
- accelerate bunch

FEL

lattice: plasma-lens + FEL layout

I stage

plasma lens

II stage

bunch accelerating section

final stage

FEL

- Compress bunch
- accelerate bunch

FEL

electrostatic-active-passive lenses

- **Electrostatic lenses**:
  - focusing is due to: Electrostatic fields in a quasi neutral plasma
  - Field are created by an electron beam travelling through a neutral gas
  - work mainly by: Halsted and Gabor
- **Active lenses**:
  - focusing is due to: ‘plasma discharge’ background electron motion
  - for large aperture and large gradients
  - for electrons: conditions imply self focusing
- **Passive lenses**:
  - focusing is due to: pre-formed, current-free and neutral plasma
  - firstly studied by: Bennett, Katsouleas

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- high focusing gradients (much larger than conventional quadrupole)
- Sym focusing
- compact (~cm)

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- Sym focusing
- compact (~cm)

from the 80s to today

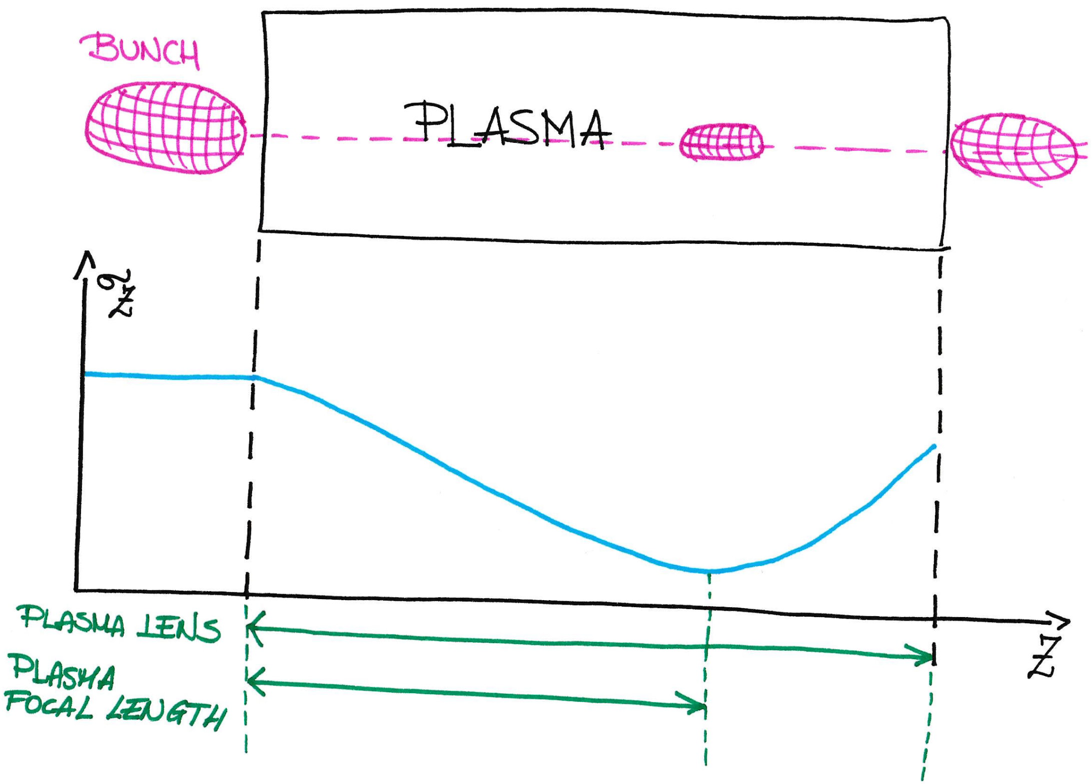
- First idea of passive lenses: *Bennett* while studying pinch
- First idea: plasma discharge as a focusing lens
  - T. Katsouleas '*Physical mechanism in the plasma wakefield accelerator*' Physical Review A (1986)
  - P. Chen 'A possible final focusing mechanism for linear colliders', Particle Accelerator (1987)
- Overdense lenses
  - R. Keinings '*Two dimensional dynamics of the plasma wakefield accelerator'* Physics of fluids (1987)
- Underdense lenses
  - J. J. Su 'Plasma lenses for focusing particle beams' Physical Review A (1990)

from the 80s to today

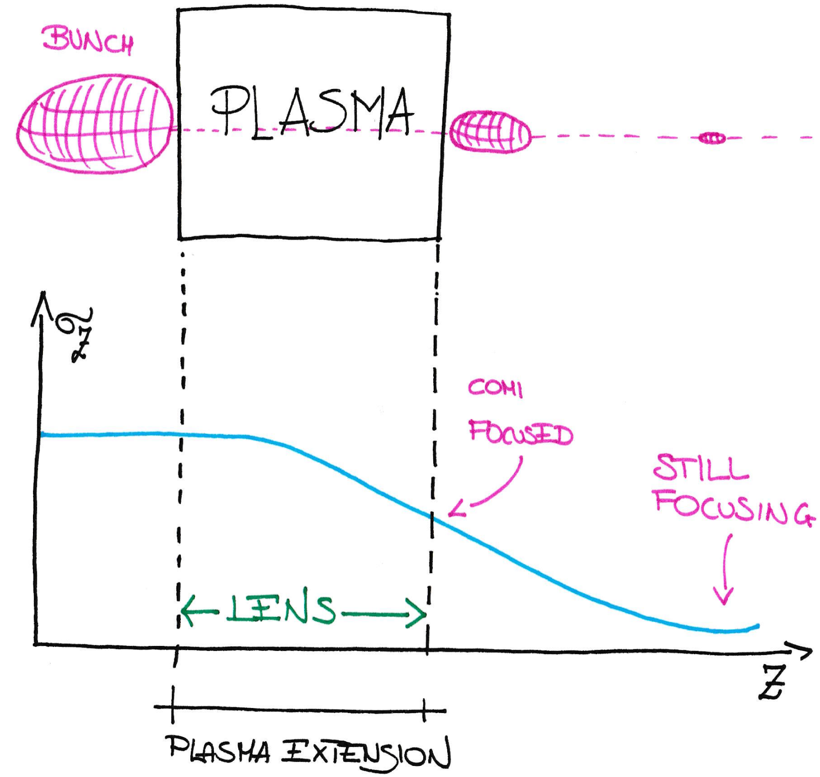
- First demonstration of passive lens (2.5 MeV bunch)
  - S. E. Graybill ‘Observation of magnetically elf-focusing electron streams’ Applied Physics Letter (1966)
- Plasma (thick) lens for ‘colliders’ (21 MeV, 5 nC)
  - J. B. Rosenzweig ‘Demonstration of electron beam self-focusing in plasma are fields’ Physics of Fluids (1990)
- Plasma thin lens (0.5 nC)
  - H. Nakanishi ‘Direct observation of plasma-lenseffect' PRL (1991)

thick-thin lenses

Thick

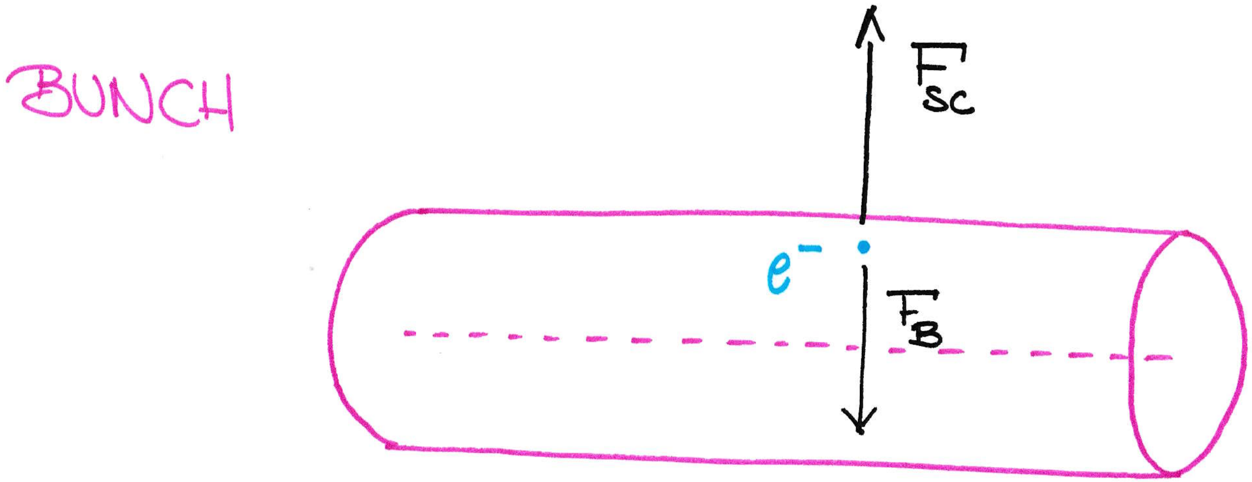


Thin



bunch in vacuum

Simplified-intuitive plasma lens treatment



from Gauss: $$\underline{F_{sc}} = 2\pi n_b e^2 r \, \hat{u}_r$$

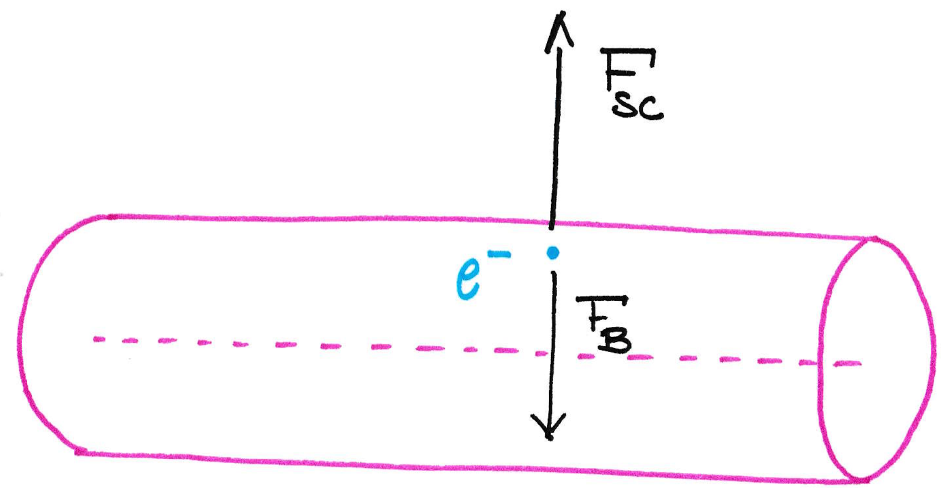
from Ampere: $$\underline{F_B} = -2\pi n_b e^2 \beta^2 r \, \hat{u}_r$$

$$\oplus \quad \underline{F_{tot}} = \frac{2\pi n_b e^2}{\gamma^2} r \, \hat{u}_r$$

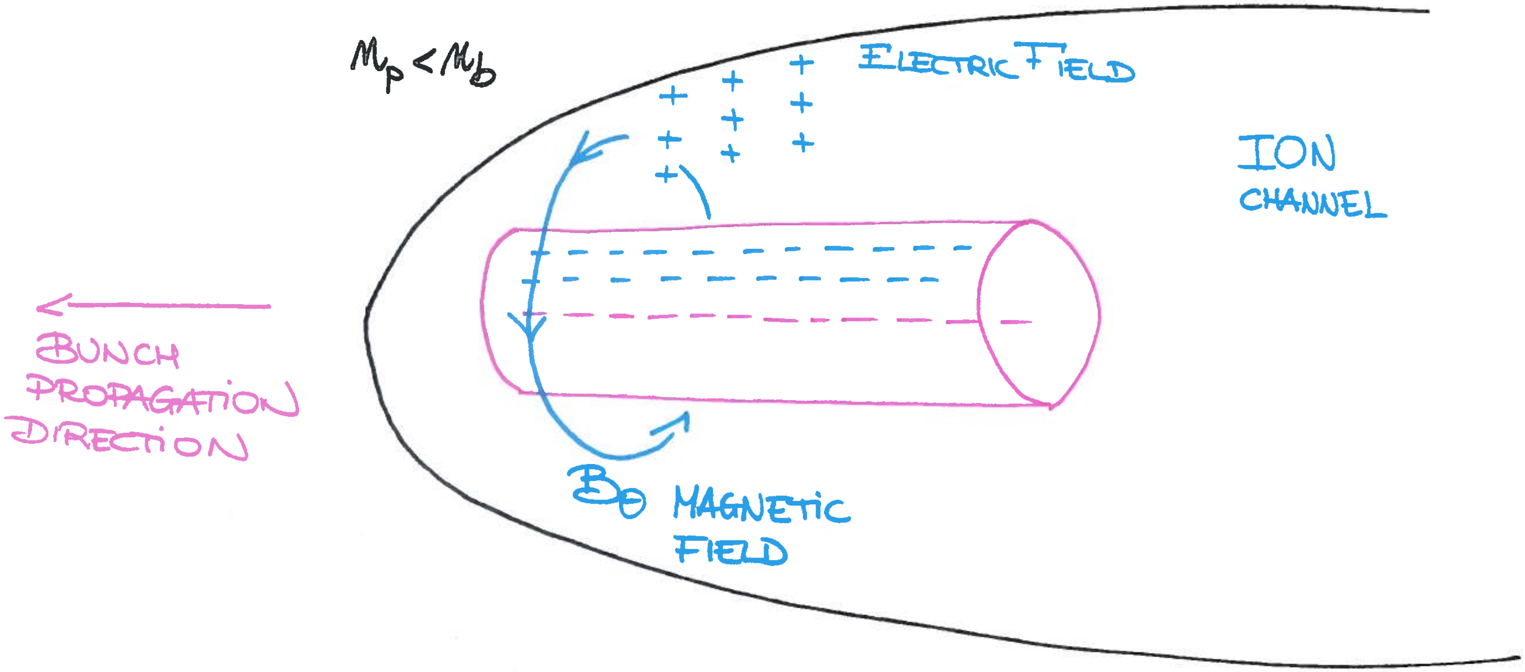
bunch in vacuum assumptions

Some assumptions have been made:

- no temperature (cold)
- beam velocity is c



passive lenses

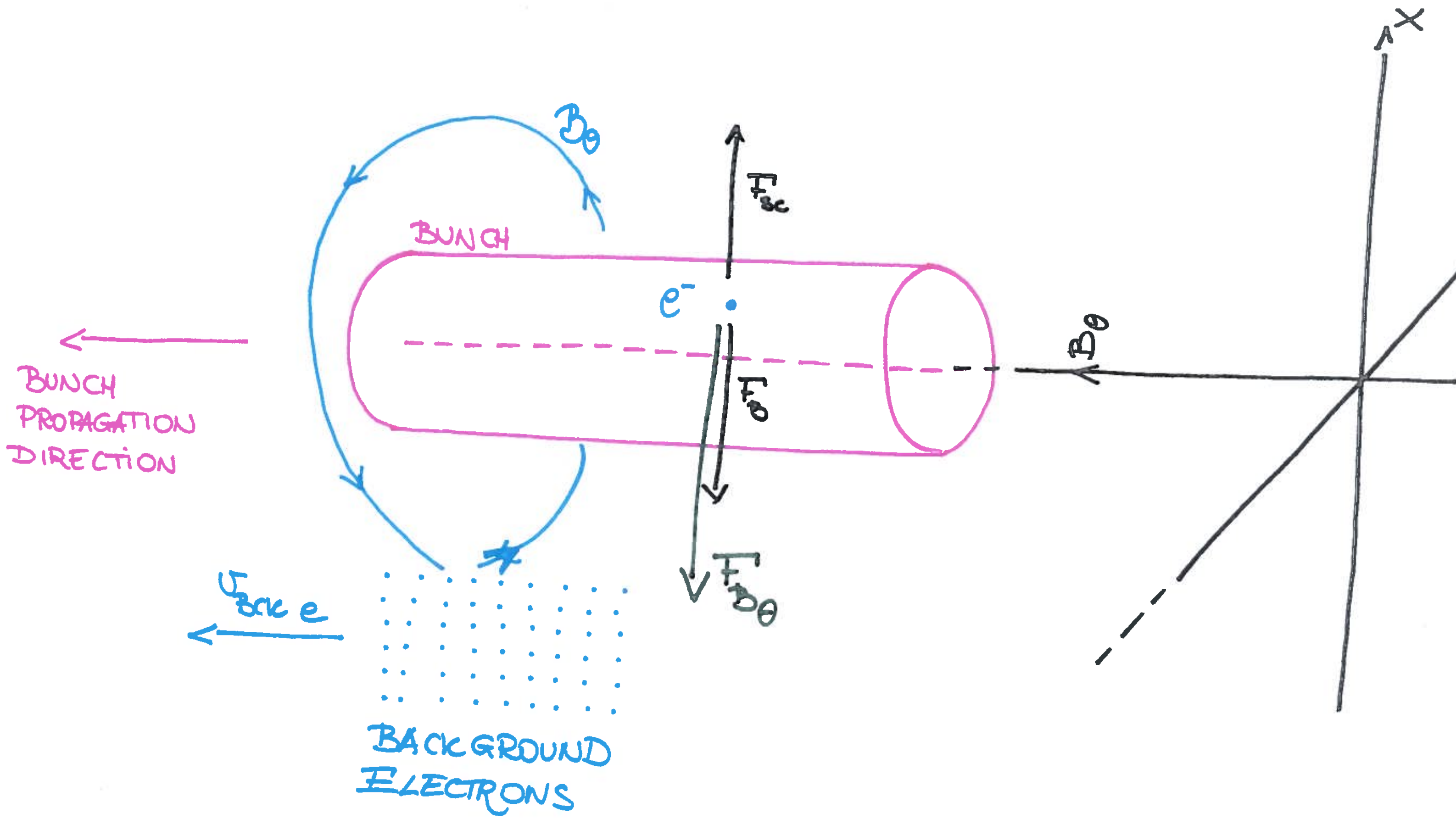


$$F_{Bck} = -2\pi n_p e^2 r \, \hat{u}_r$$

focal length : $f = \dfrac{2\gamma c^2}{L\,\omega_p^2}$

$$= 5.6 \cdot 10^{11} \frac{\gamma}{L \; n_p}$$

active lenses



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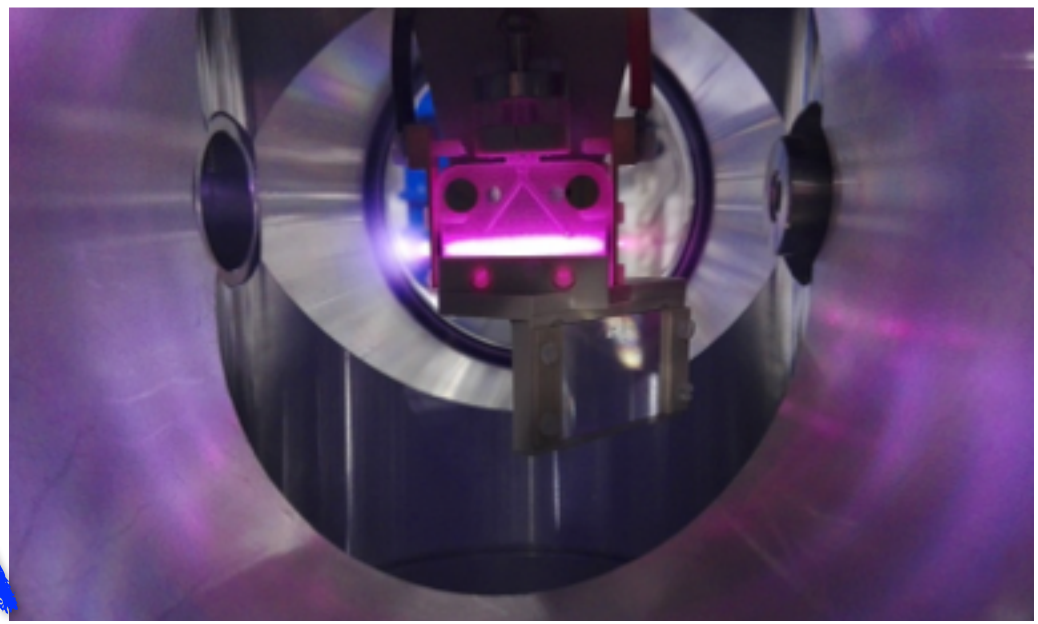
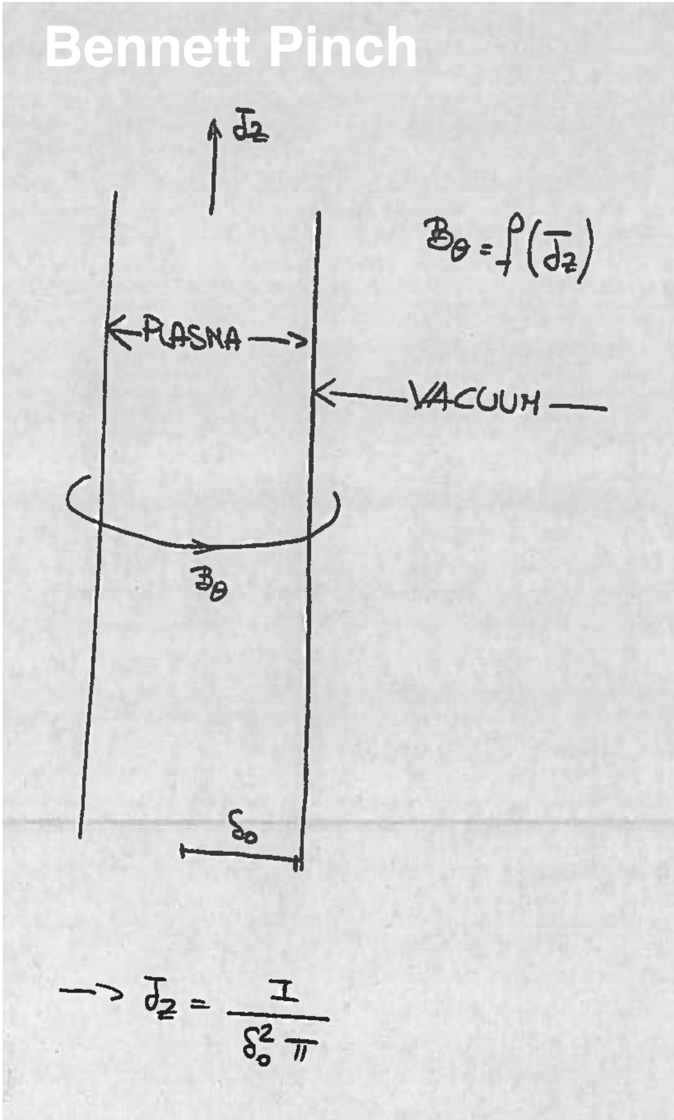


$n_p \sim 10^{16}, 10^{17}$

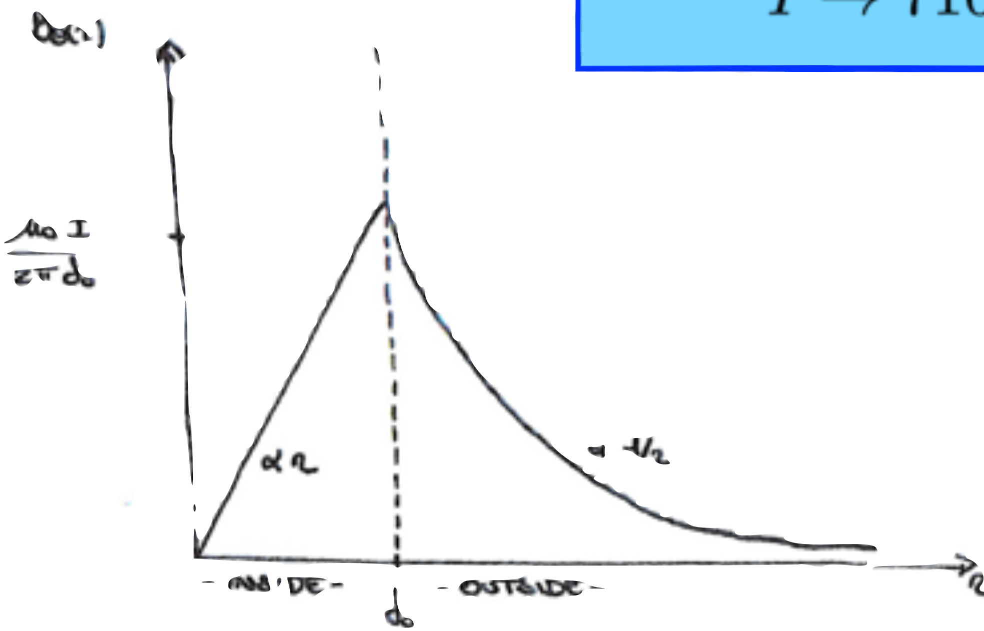
Far away from Bennett threshold



Bennett Condition:

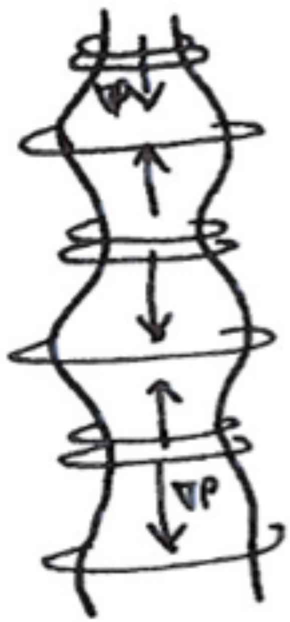
$$N k_b T = \frac{\mu_0 I^2}{8\pi}$$

$$n_p = 10^{17}\mathrm{cm}^{-3}$$
$$T_e = 2\mathrm{KeV}$$
$$R = 500\mu m$$
$$I \rightarrow 710A$$

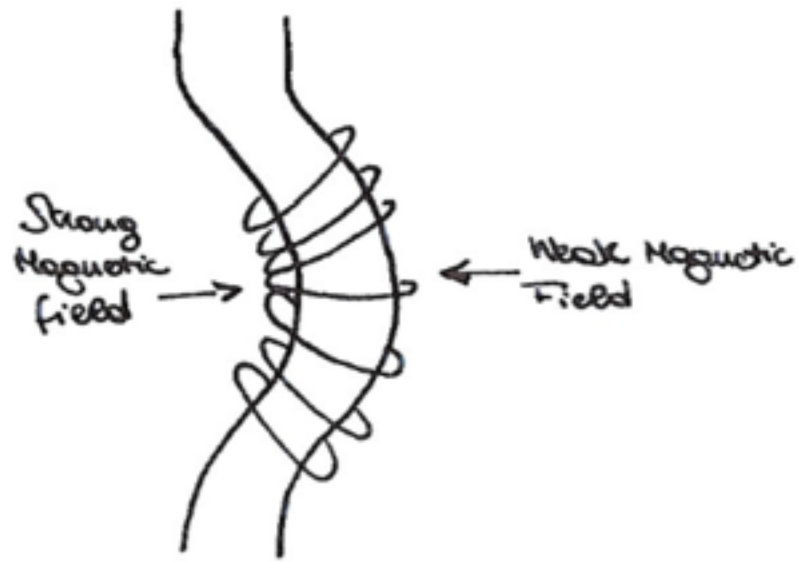


Far away from Bennett threshold

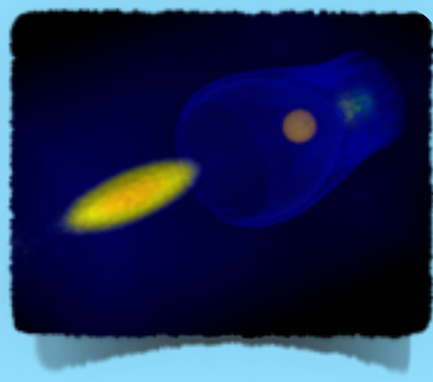
Sausage instability



Kink instability

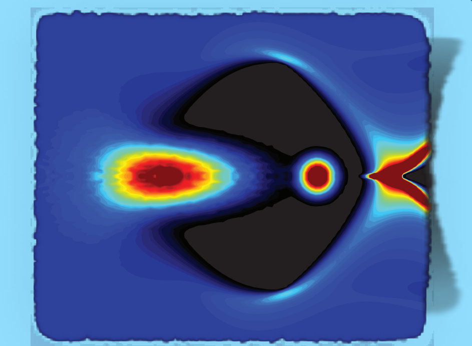


the toolbox



ALaDyn

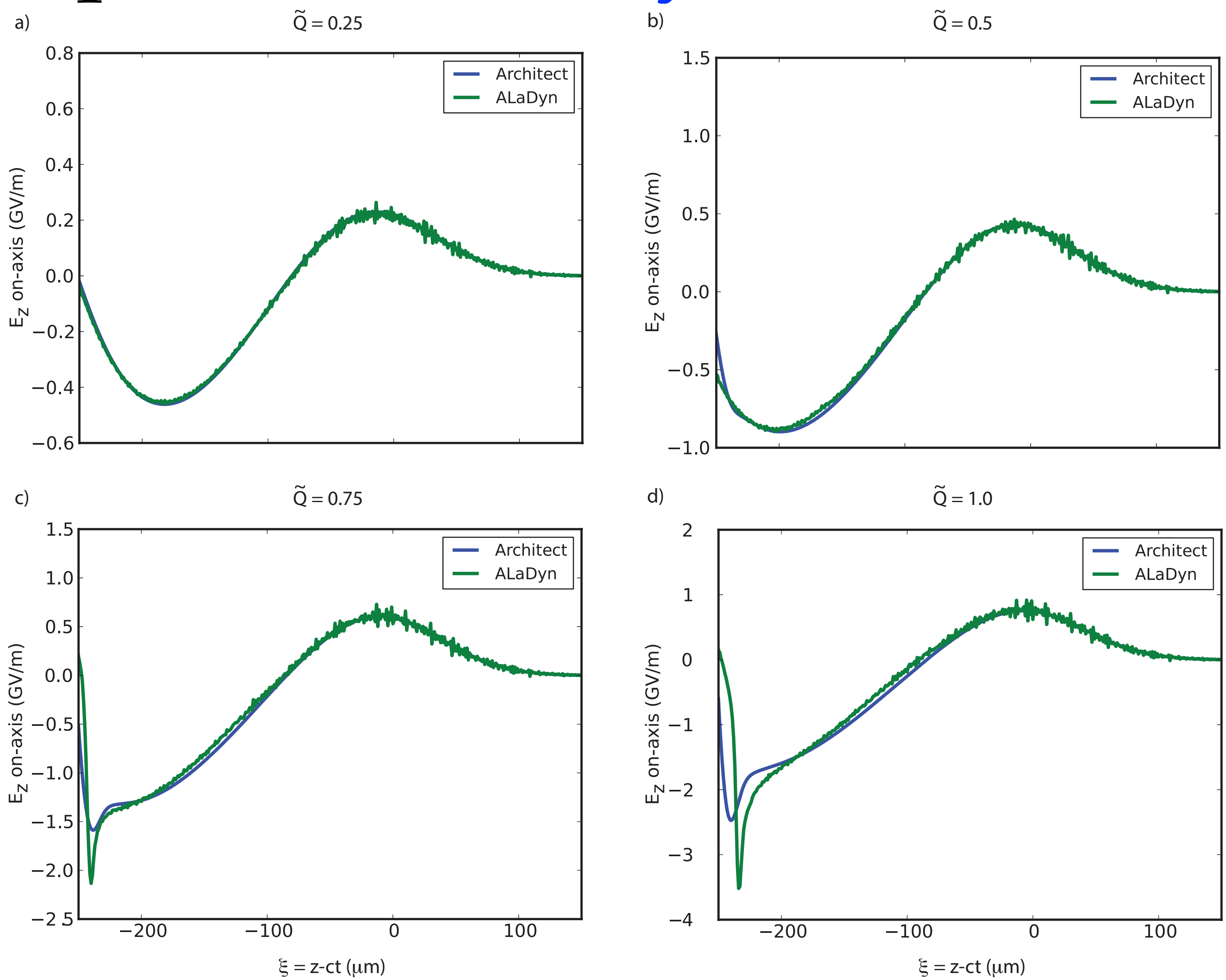
PIC code



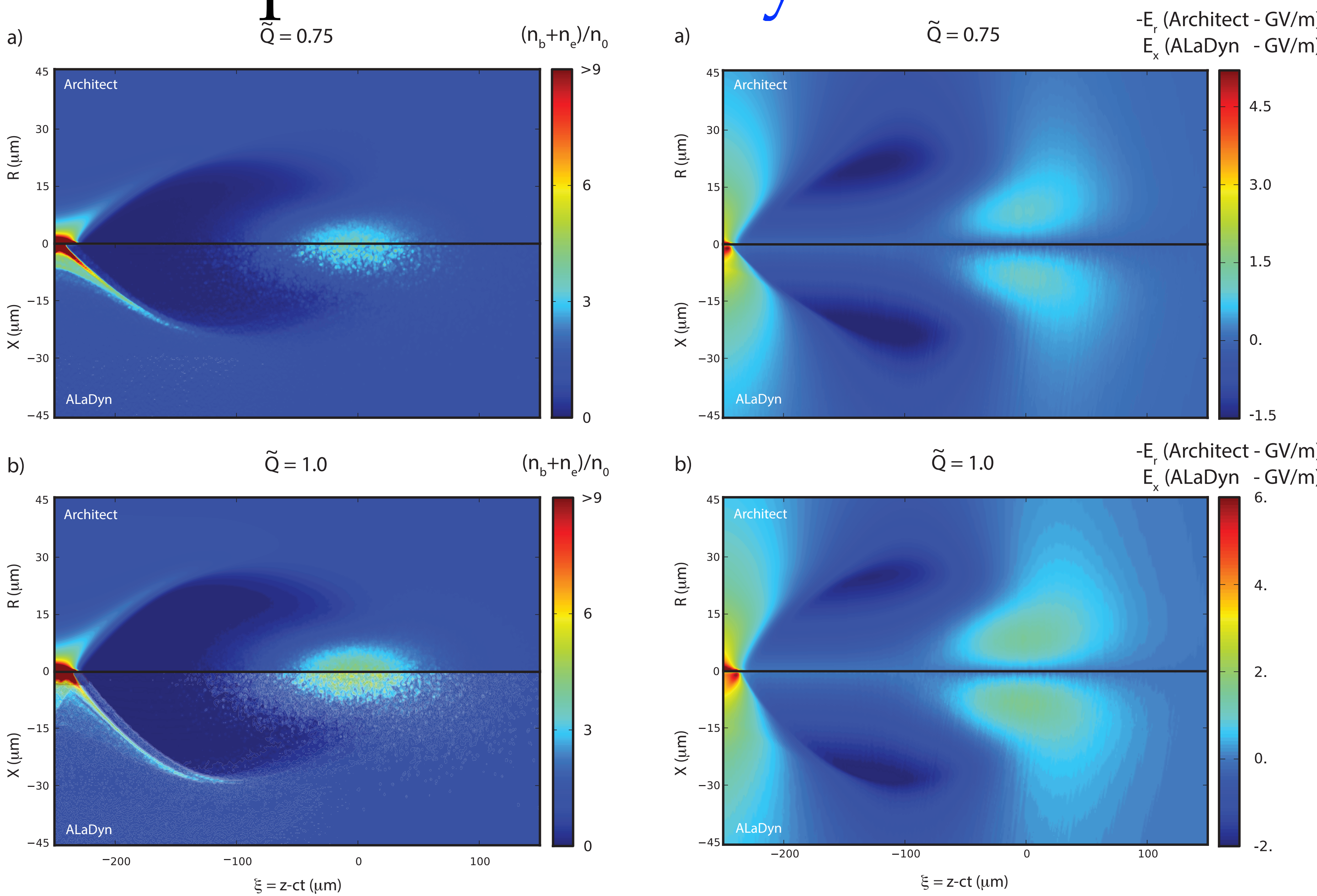
Architect

hybrid code
for PWFA

comparison ALaDyn Architect (Ez)



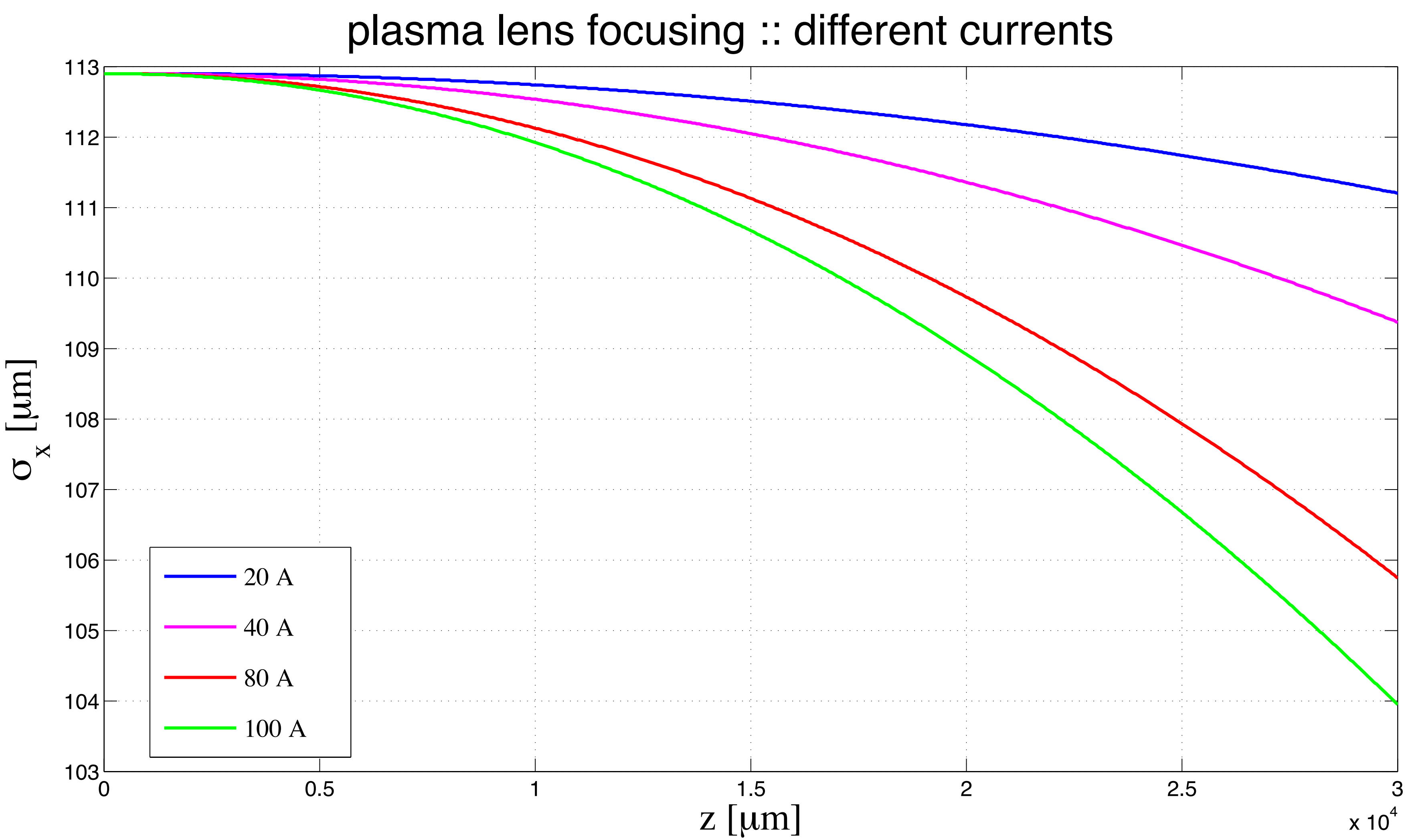
comparison ALaDyn Architect



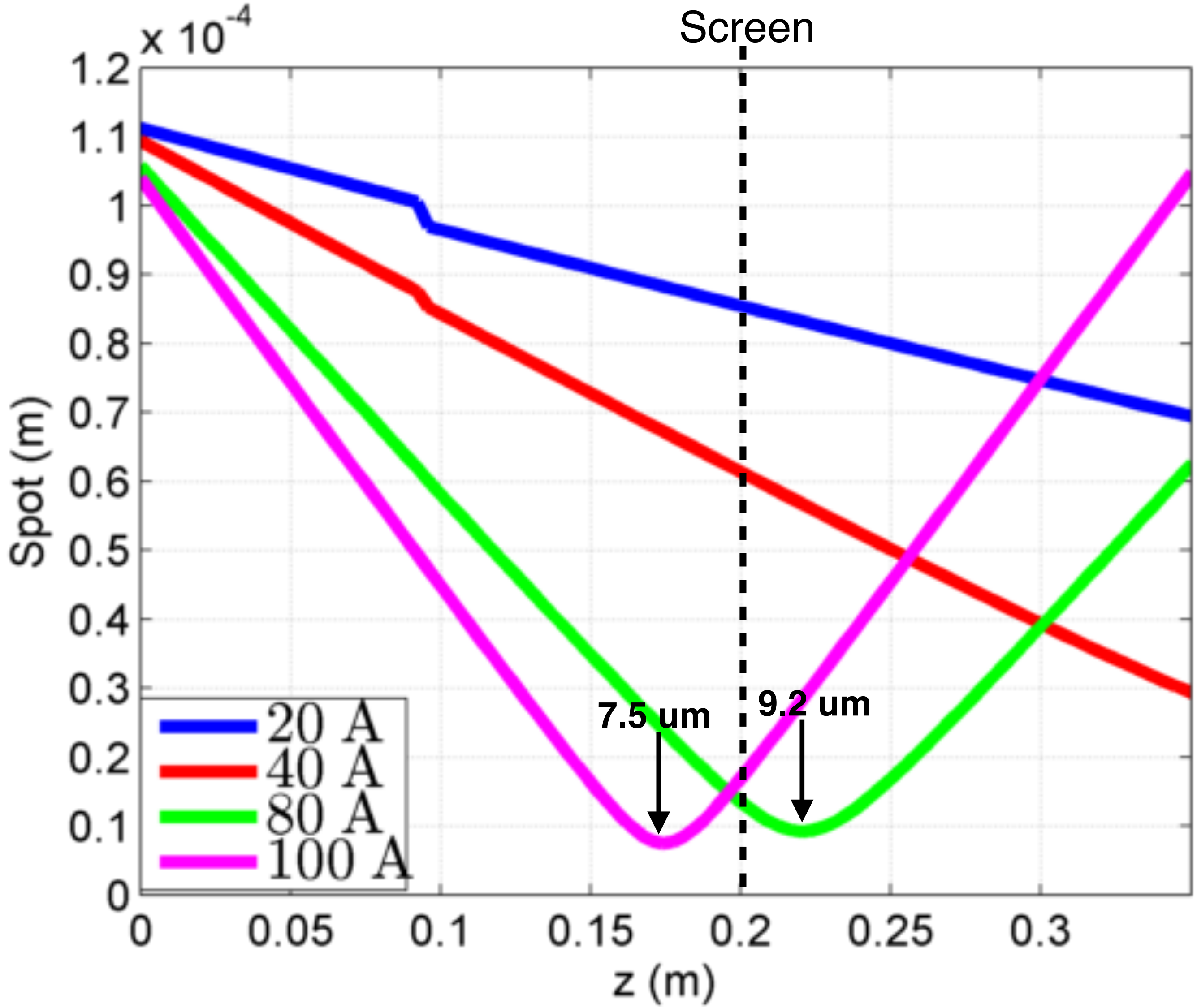
on crest beam

Charge:	50 pC
Length:	224 um (750 fs)
Emittance:	1.1 um (1 um @ cathode)
Energy:	127 MeV (60MW power on K2 line)
Energy spread:	12 keV
Spot:	113 um
Twiss α:	-0.11
Twiss β:	2.86 m

on crest beam



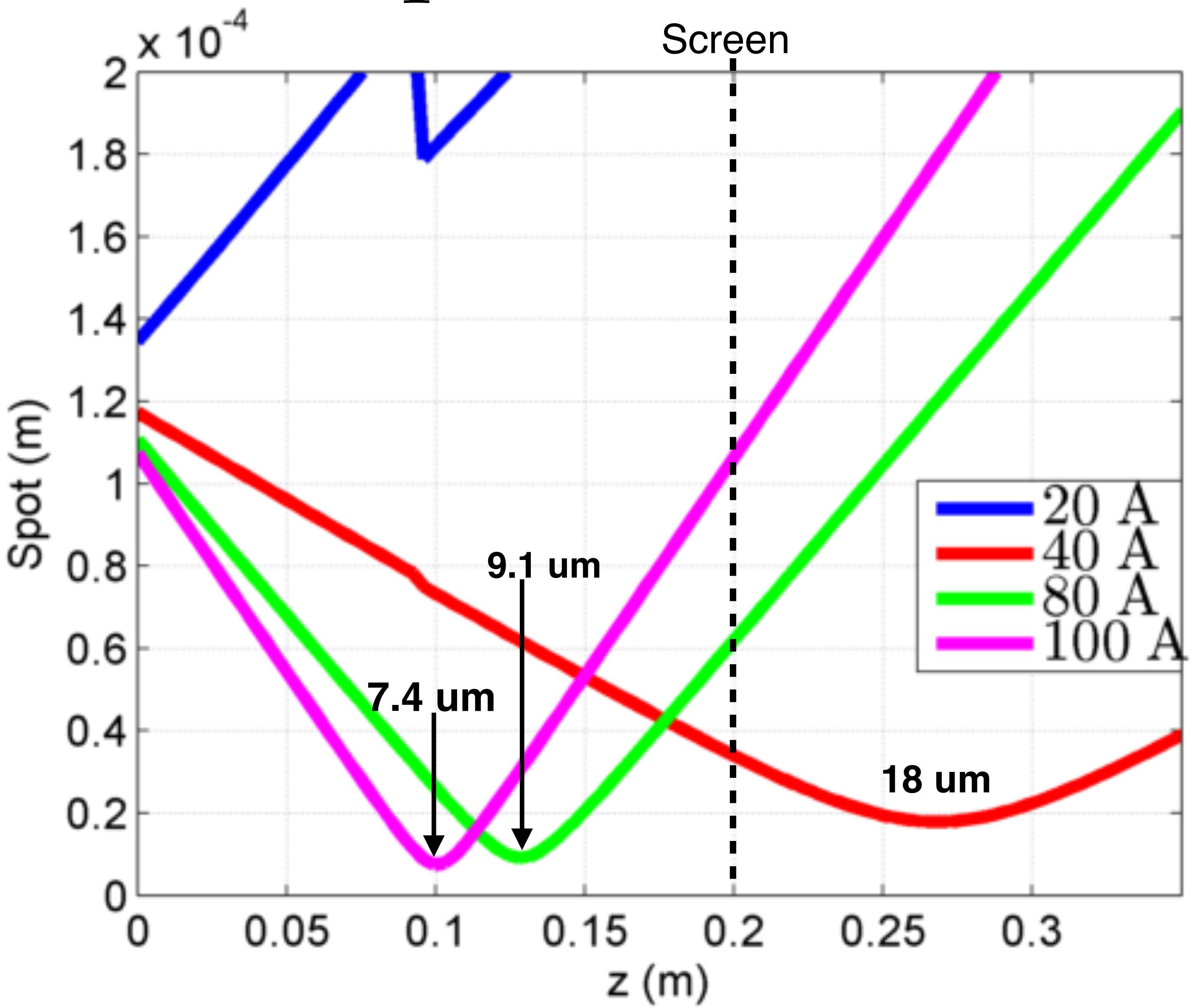
on crest beam



compressed beam

Charge:	50 pC
Length:	18 um (60 fs)
Emittance:	1.15 um (1 um @ cathode)
Energy:	77 MeV (60MW power on K2 line)
Energy spread:	280 keV
Spot:	123 um
Twiss α:	-0.32
Twiss β:	1.98 m

compressed beam



Conclusions

- *A brief overview of lenses*
  - different types
  - the working mechanism

- *Plasma Lenses at LNF*
  - active plasma lenses
  - identify an effective mechanism for PWFA pre-focusing