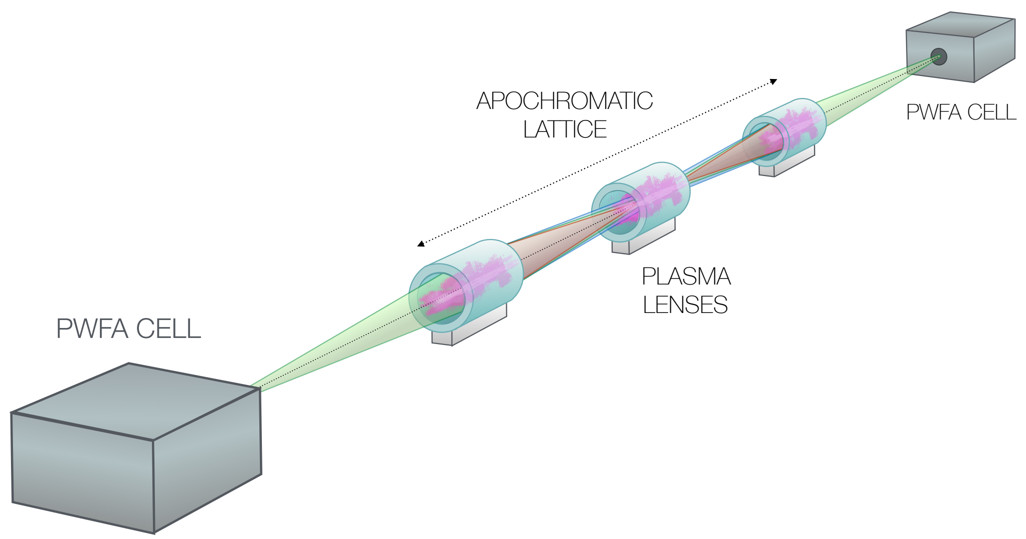

Emittance preserving plasma lens optics at CALIFES

CALIFES Workshop, CERN – October 12, 2016

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Supervisor: Erik Adli

Overview

- From the Department of Physics at the University of Oslo:
  - *Carl A. Lindstrøm (myself)*
  - *Erik Adli (my supervisor)*

- Based on work on: Emittance preserving staging optics for LWFA/PWFA.

- Problem: Chromatic errors dominate emittance growth during staging.
  Sextupole-based chromatic correction is not satisfactory.

- Solution: Apochromatic lattices using plasma lenses.
  (“Apochromatic” = Linear optics-based chromatic correction)

- We propose an experiment to test apochromatic plasma lens lattices in CALIFES.

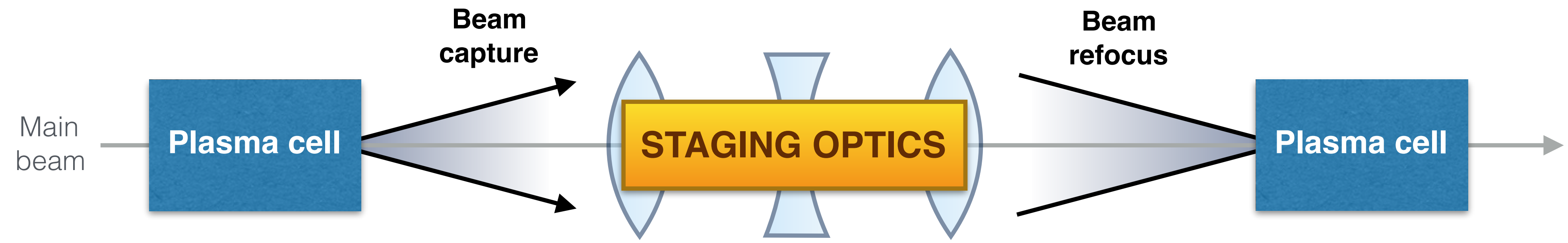
- An **initiative by University of Oslo**, in collaboration with DESY and University of Oxford, to test aspects of plasma lenses not yet tested: multi-lens dynamics.

- Bonus: Many synergies with other PWFA-experiments.

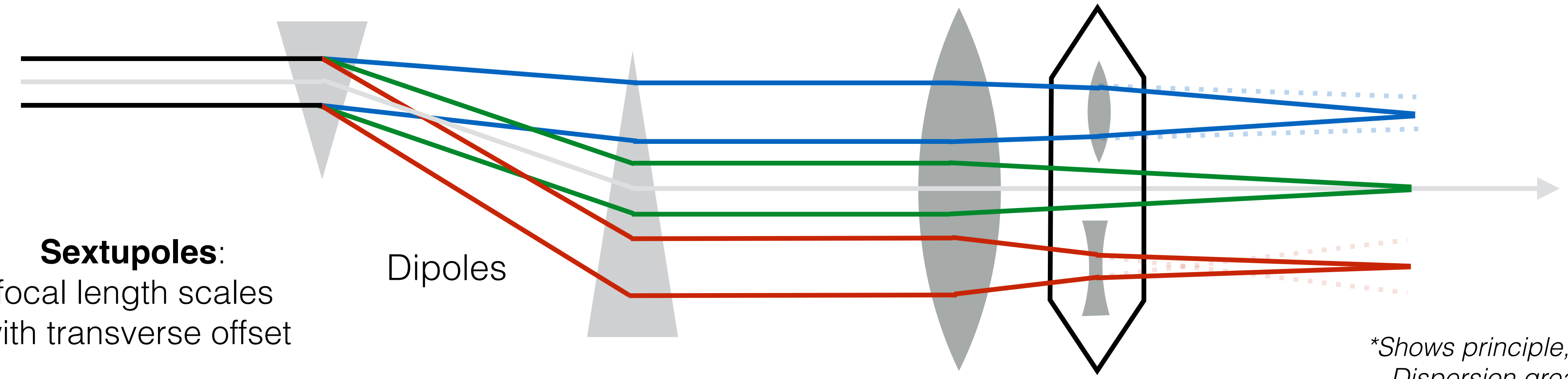
Staging in PWFA/LWFA (the problem)

- Plasma/laser wakefield accelerators require staging to reach high energies.

- High acceleration gradient → Strong focusing
  → Highly diverging beams
  → Chromatic focusing errors give significant emittance growth.

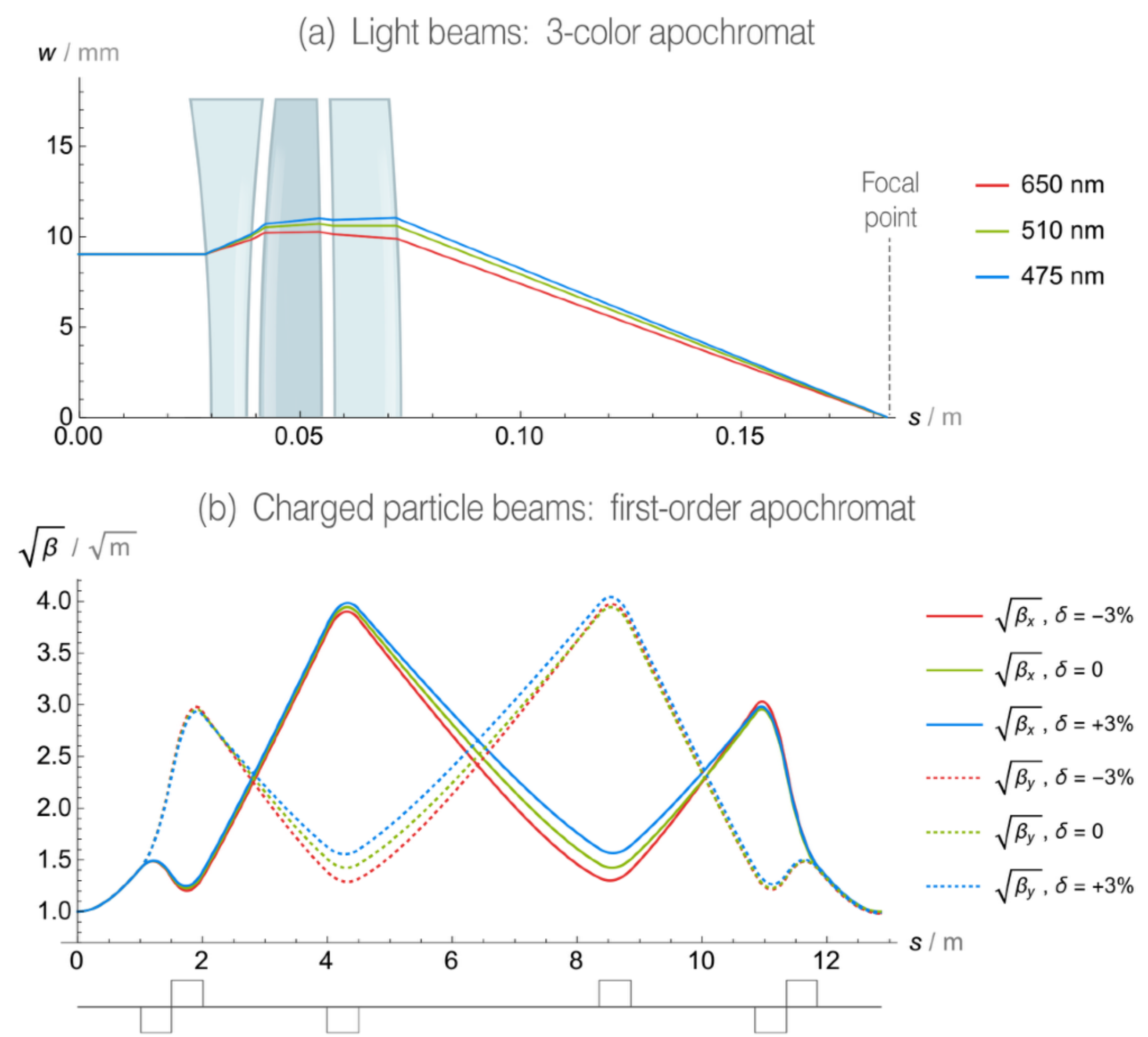


- Conventional chromatic correction uses **sextupoles in regions of large dispersion**: This introduces both **unwanted dispersion** as well as **synchrotron radiation from dipoles**.



Apochromatic correction (the solution)

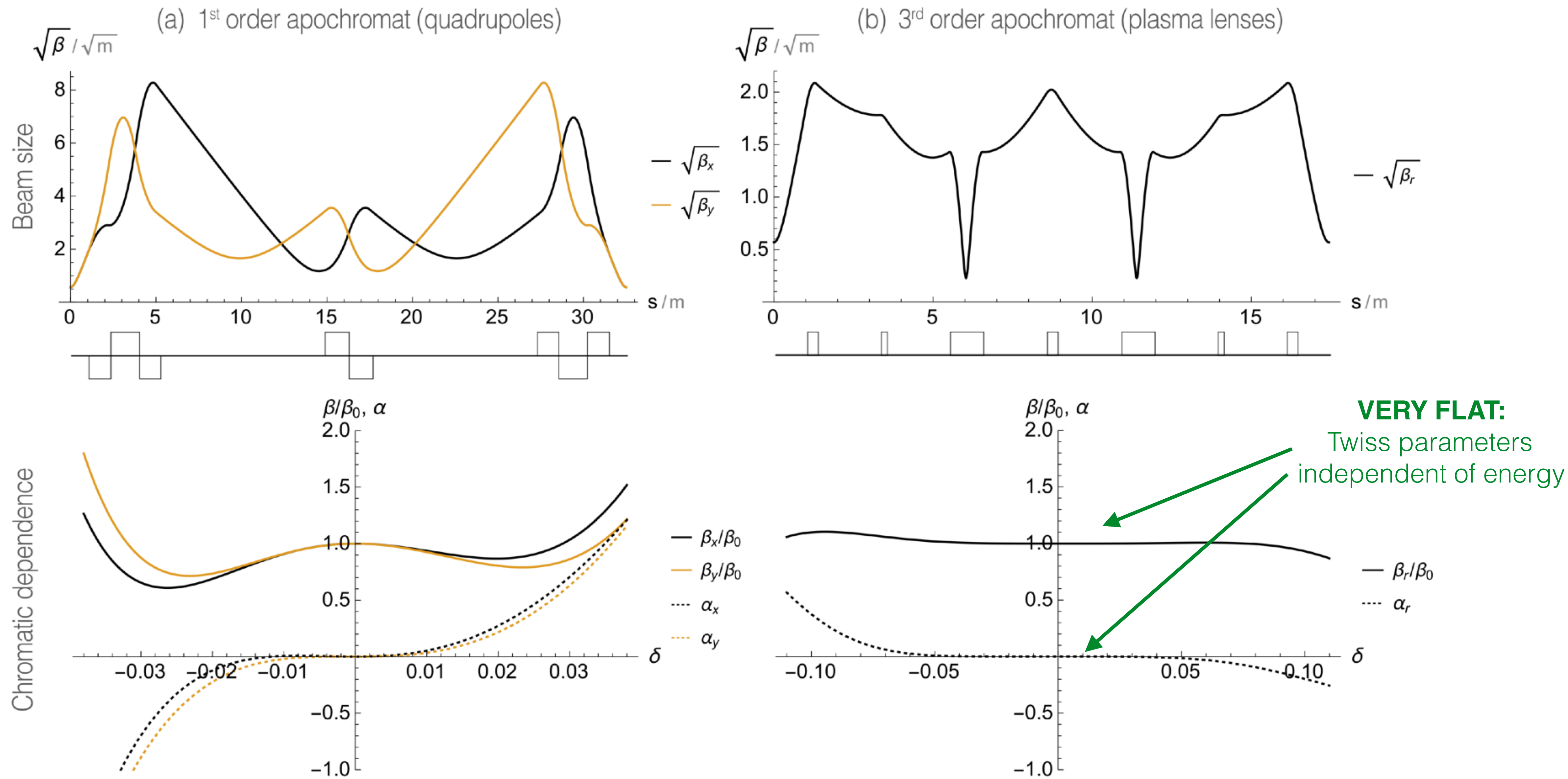
- Using **linear optics to correct chromatic focusing errors** at particular locations along the accelerator.
- Same method used in light optics (e.g. camera lenses).
- Relatively **new concept** in beam dynamics.
- We **recently published** the first peer-reviewed article on the topic in Physical Review Accelerators and Beams.



C. A. Lindstrøm & E. Adli,
“Design of general apochromatic drift-quadrupole beam lines”,
Phys. Rev. Accel. Beams (19) 071002 (2016)

Apochromatic plasma lens optics (our focus)

Example: *100 GeV staging optics*



- **Plasma lenses are ideal** for apochromatic staging optics.
- Two reasons: **Radial symmetry** (halves d.o.f.) and **short focal length** (shorter L*)

Plasma lenses (what we will use)

- Our choice: **Gas-filled capillary discharge plasma lenses**
- High voltage (~10 kV) discharges result in radially uniform currents through the capillary, hence **a strong azimuthal magnetic field**.
- In discussion with **DESY** about supplying sapphire plasma lenses (endorsed by Jens Osterhoff)
- In discussion with **Uni. Oxford** on supplying high voltage sources (endorsed by Simon Hooker)

Radius: ~0.1→1 mm

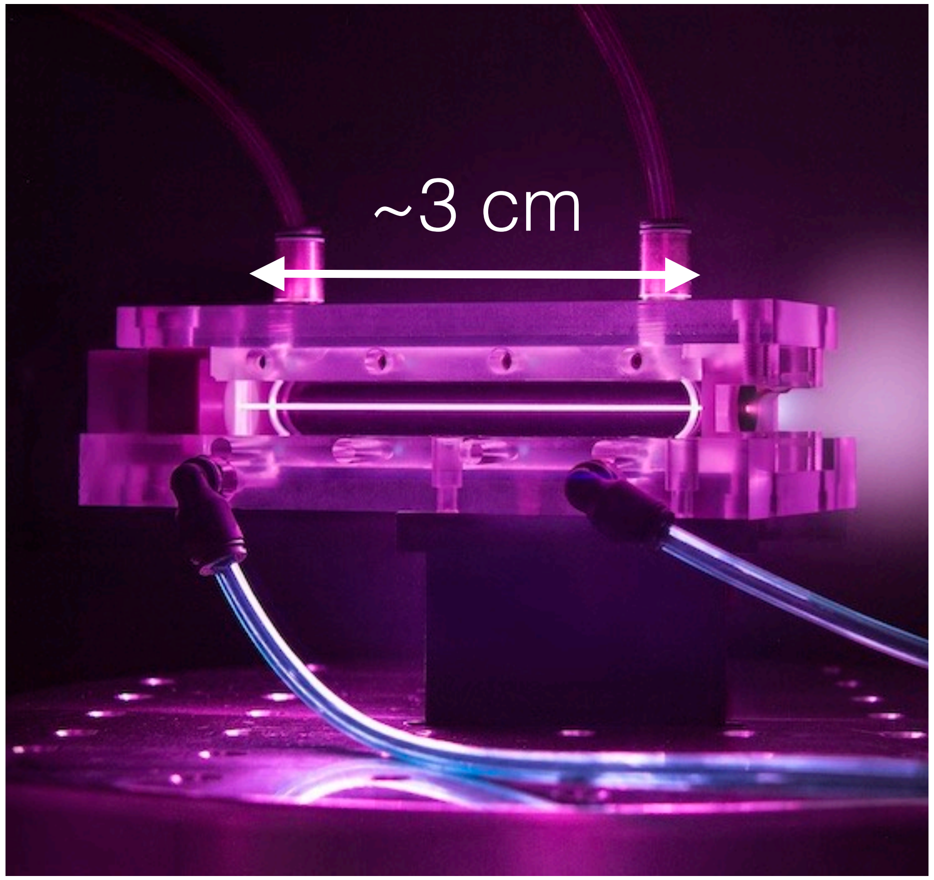
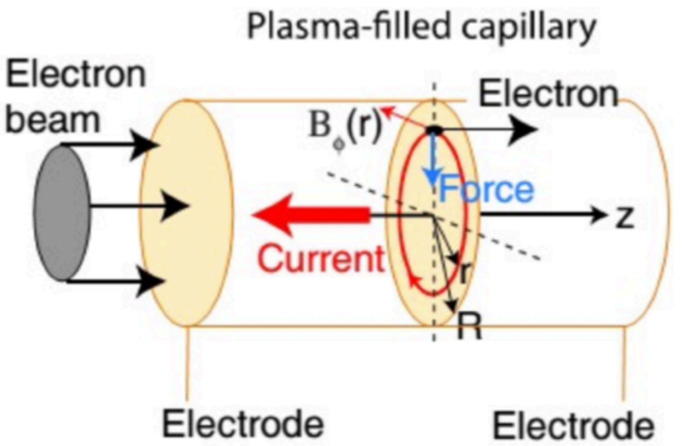
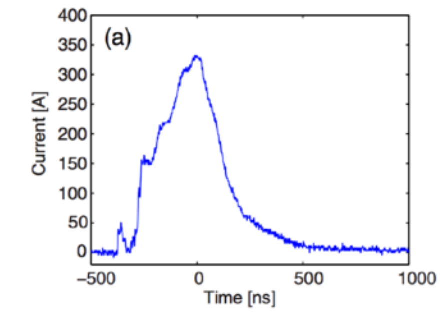


Image source: BELLA @ LBNL



Van Tilborg, J., et al. "Active plasma lensing for relativistic laser-plasma-accelerated electron beams." Physical review letters 115.18 (2015): 184802.

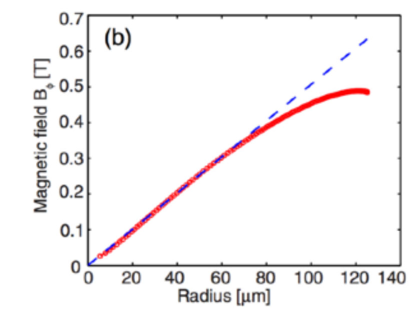
The CALIFES experiment (what we propose to do)



- The experiment will be approached in 2 parts:

Part 1: Characterizing a single lens (has been done before)

- Radial linearity (important for apochromaticity)
- Temporal profile
- Gas density/voltage dependence etc.



Part 2: Characterizing apochromatic lattices (has not been done before)

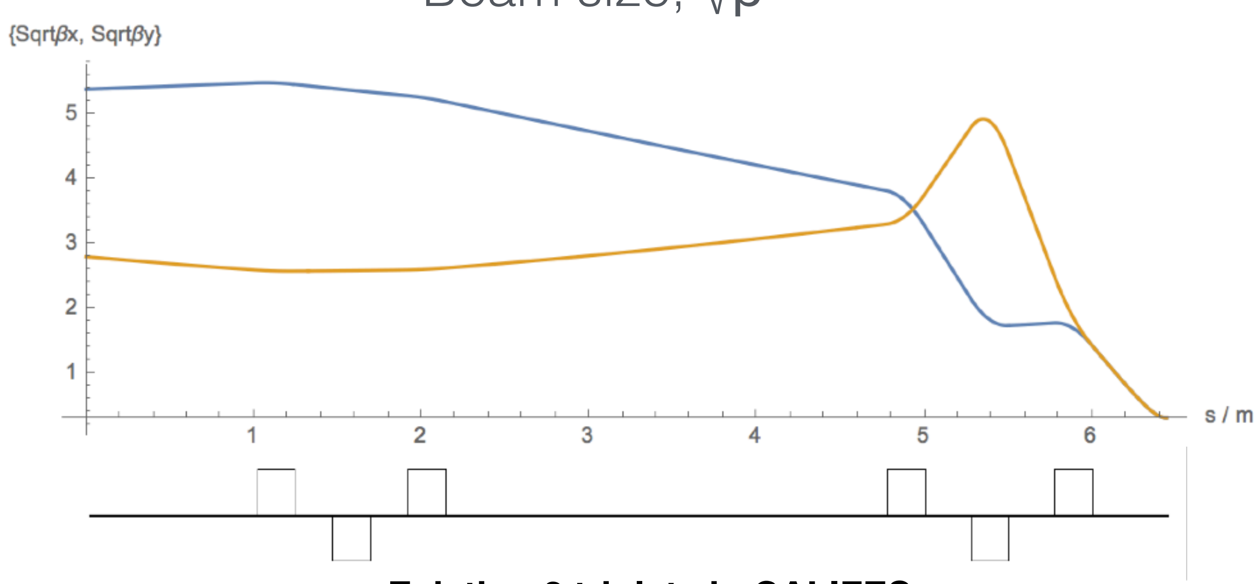
- Demonstrating plasma lens lattices
  - Multi-lens synchronization
  - Multi-lens alignment
- Comparing a single lens to an apochromat:
  Is the emittance growth lower for the apochromat?

- CALIFES is well suited for this experiment, **without major upgrades.**
  (Also no PWFA plasma source is necessary).

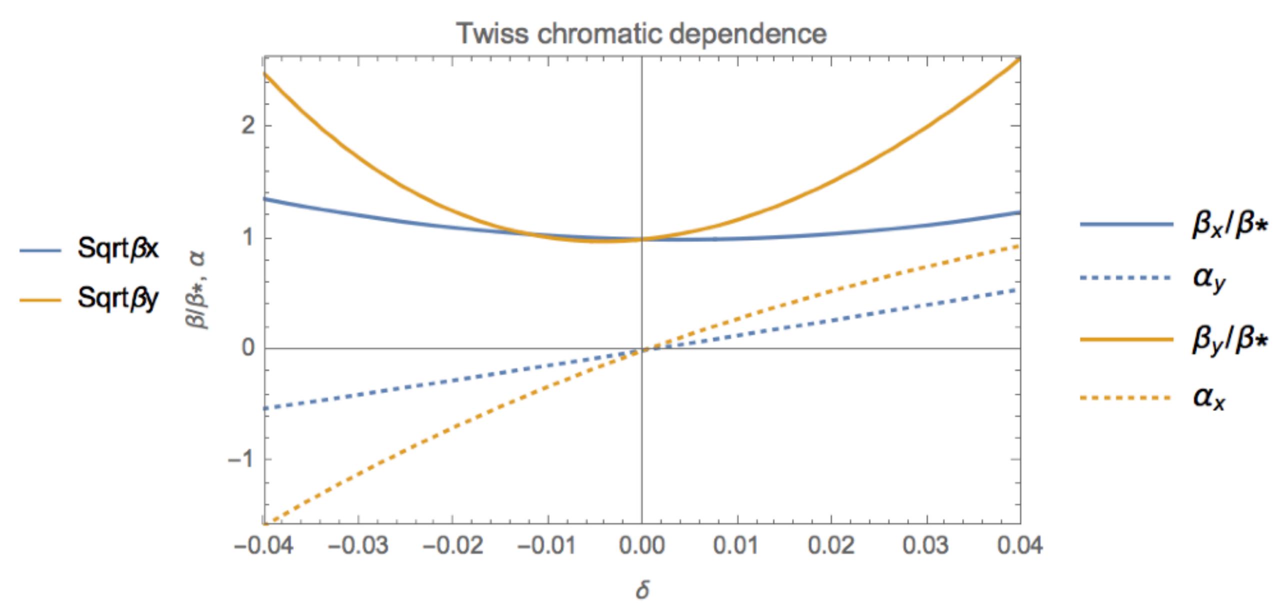
Optimizing the existing CALIFES 2-triplet optics (our optics setting)

- The **experiment investigates capture of highly diverging beams**, with minimal emittance growth.
- Small beta-functions are therefore necessary (β << length of drift space)
- Plasma accelerators are x/y symmetric, we therefore need a symmetric waist ($\beta_x = \beta_y$)
- **We have studied the 2-triplet optics in CALIFES and found a working <u>small-β</u> setup**: $\beta_x = \beta_y$ = 10 cm at the waist → initial beam is well behaved (gun emittance ~preserved)

Beam size, √β



Existing 2 triplets in CALIFES

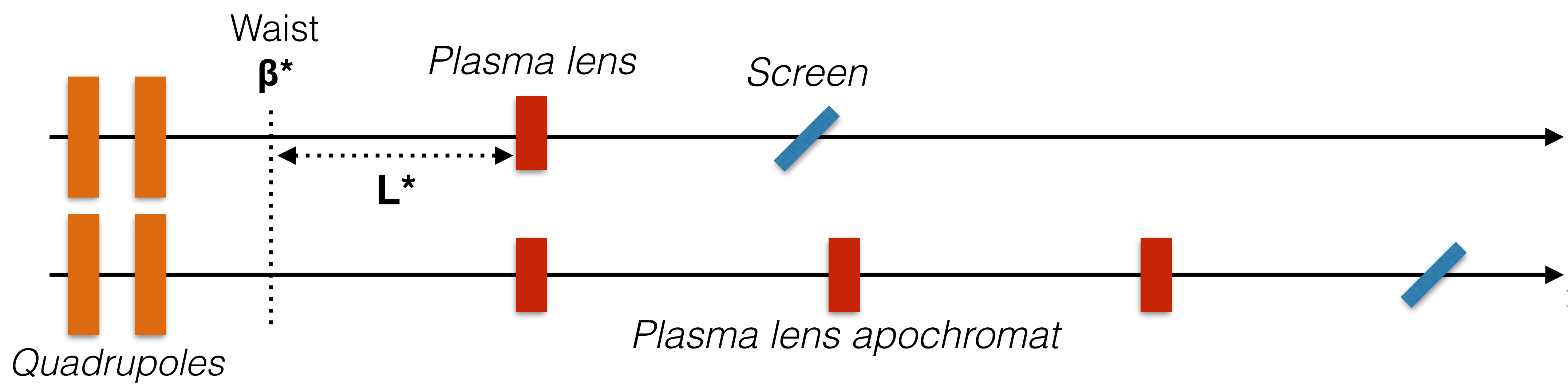


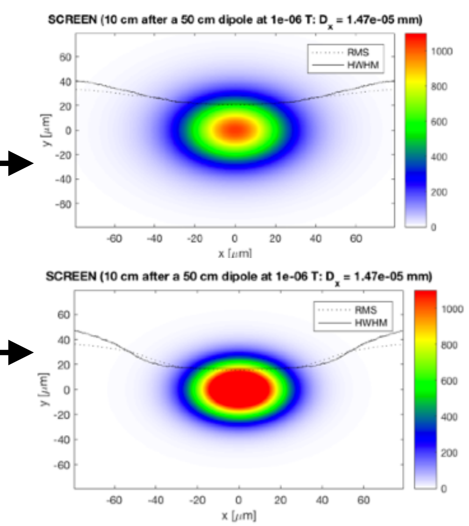
Measuring emittance growth (to disperse or not to disperse?)

- **Single plasma lens** vs. **Three-lens apochromat:** using *identical β* and L**

Option 1: **No dispersion** (less complicated)

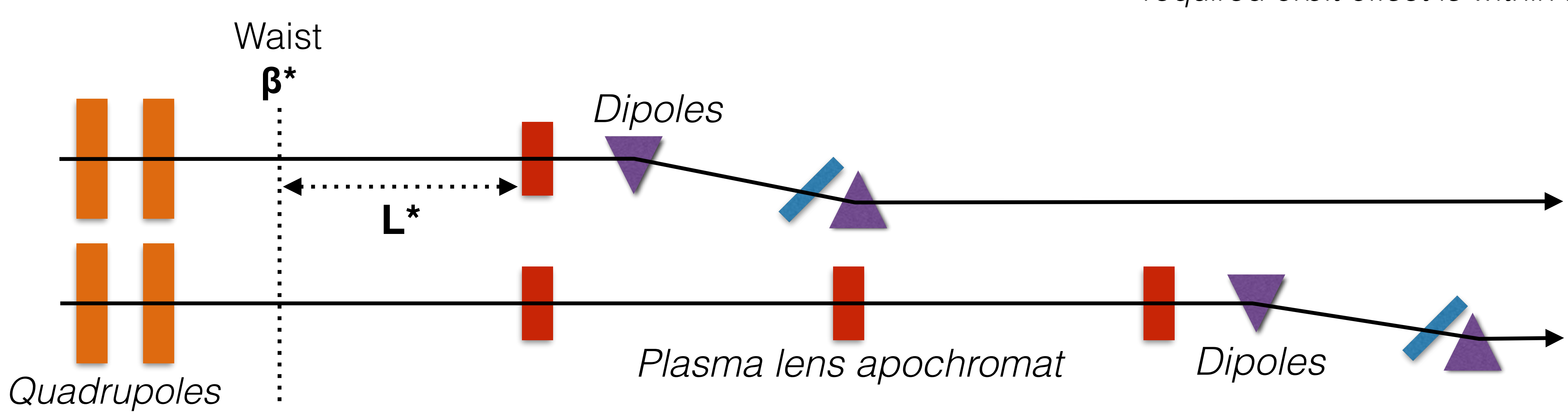
Simulated screen image:

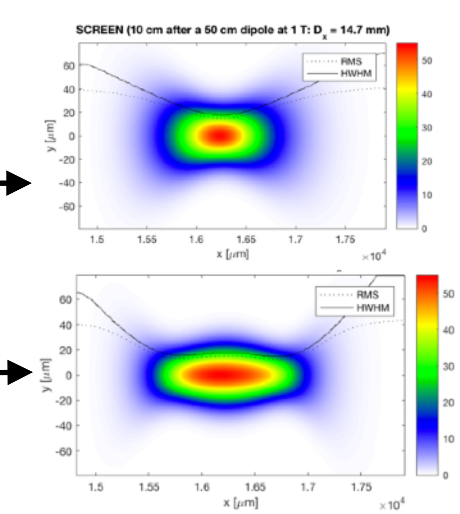




Option 2: **With dispersion*** (better resolution)

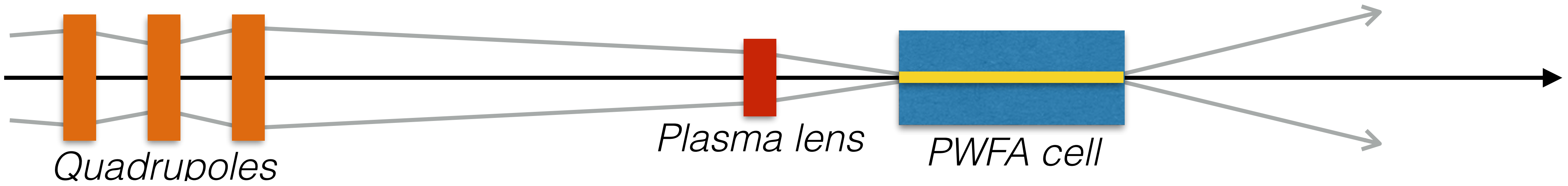
** required orbit offset is within limits of apertures*



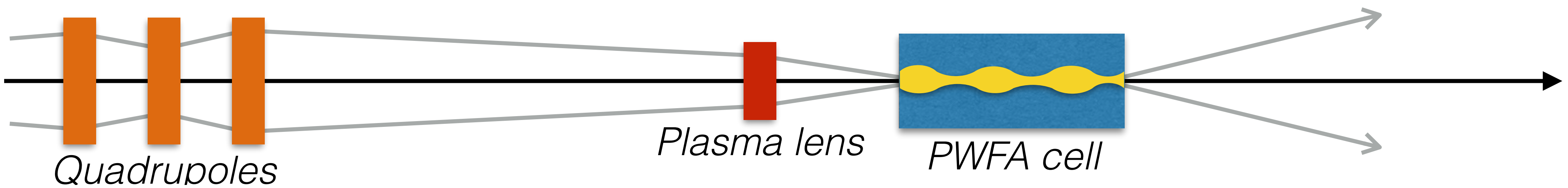


Potential side/extension experiments (medium/long term perspectives)

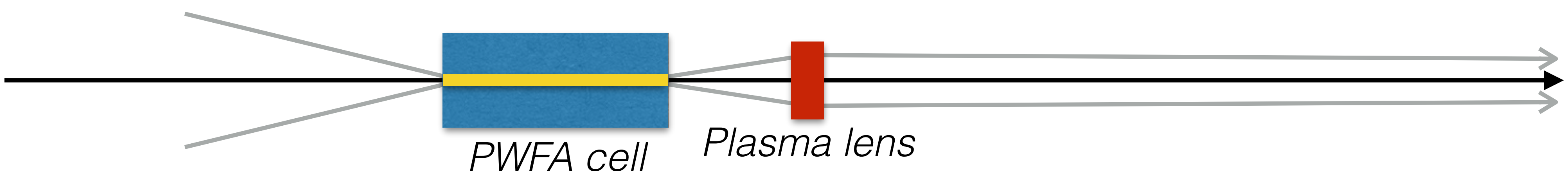
- **Plasma lens-assisted PWFA injection** (additional transverse compression)



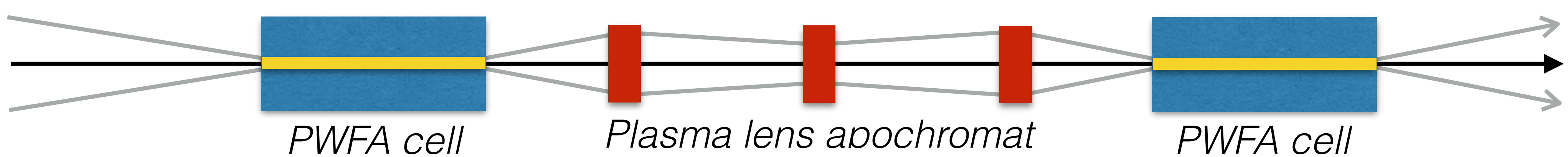
- **Beta matched PWFA injection** (study emittance growth when mismatched)



- **PWFA output capture**

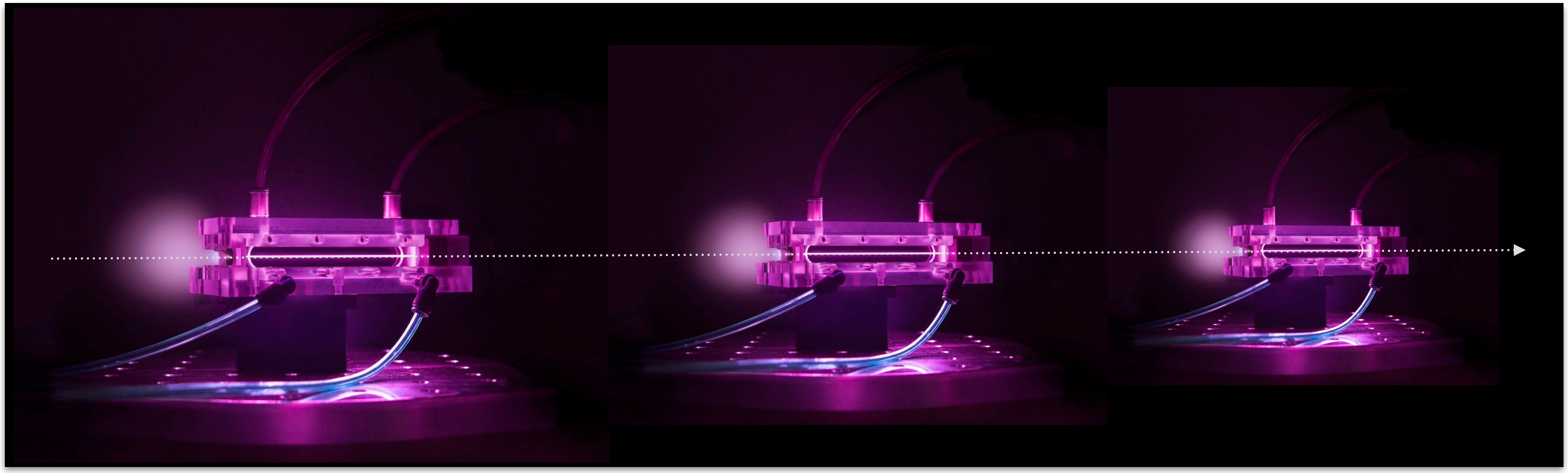


- **(Staging between two PWFA cells) =** ultimate long term goal



Final remarks

- **Plasma lenses** are a popular, but unsaturated field: **There is much left to do**!
- We believe **plasma lens optics** is the **natural next step**
- This experiment is **HIGH IMPACT** for **LOW COST**
- **Funding is available for start in 2017: we are ready to go!**
  (Oslo is seeking funding for further experiments, from 2018: EU and national funding)



Backup slides

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Example shown on SLIDE 9

- Beam parameters:
  L* = 1 m,
  β* = 5 cm,
  σ_E = 3%

- Lattice solutions:
  - Single lens: 2 m long
  - Apochromat: 8 m long

  (can be reduced at cost to emittance preservation)

- Dipole required: 50 cm, 1 T

- This is just an example setup, not the final solution.

Single lens | Apochromat