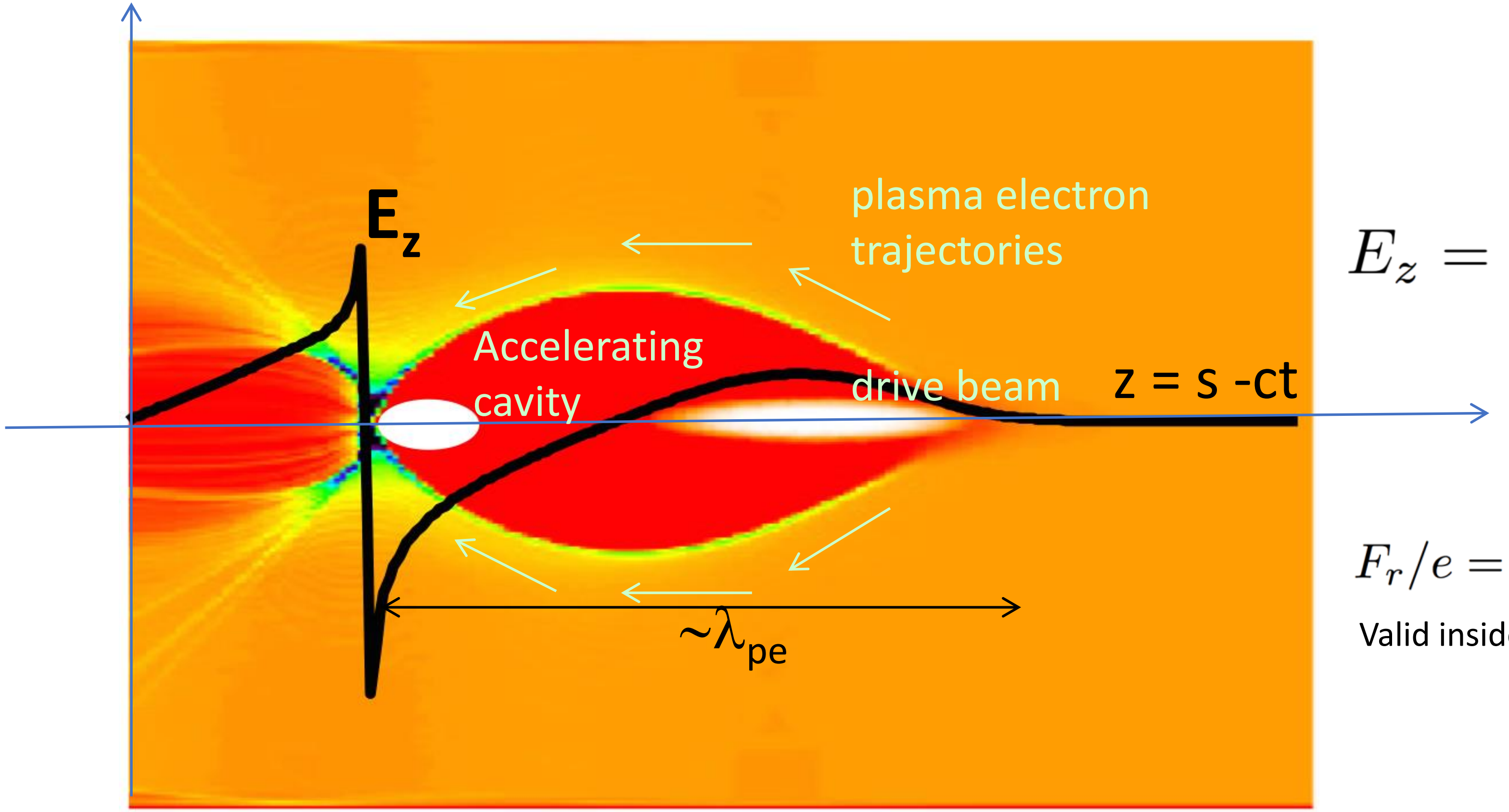
Plasma colliders: e- linacs

Erik Adli, Carl A. Lindstrøm, Gevy Cao, Ole Gunnar Finnerud, Daniel Kalvik
Department of Physics, University of Oslo, Norway
Erik.Adli@fys.uio.no

ALEGRO 2023, DESY, Germany, March 23, 2023

Status: electron acceleration

- The e^- blow-out regime: **high-gradient**, **high-efficiency**, **low emittance growth, low e energy spread** have been shown on paper, and demonstrated to increasingly good level in experiment.



$$E_z = \frac{1}{c\epsilon_0}\int_r^\infty dr\, j_r$$

$$F_r/e = E_r - cB_\phi = \frac{en_0}{2\varepsilon_0} r$$

Valid inside a fully blown-out bubble.

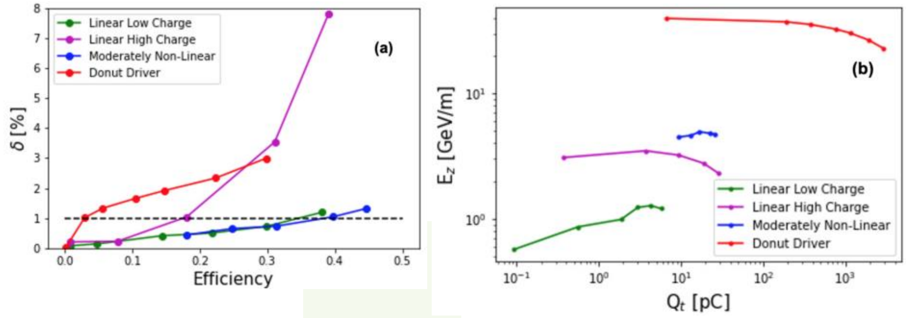
$$\frac{\partial}{\partial r} F_z = 0 \qquad \frac{\partial}{\partial r} F_r = const.$$

$$\frac{\partial}{\partial z} F_z = 0 \text{ (loaded)} \qquad \frac{\partial}{\partial z} F_r = 0$$

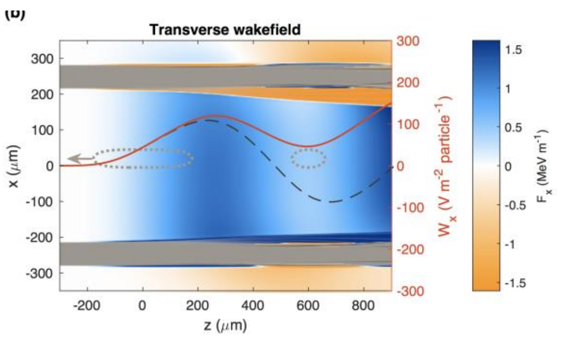
- Experimental results are consistent with theory/numerical simulations -> **possible to work with simplified models, with a good level of confidence**

Status: positron acceleration

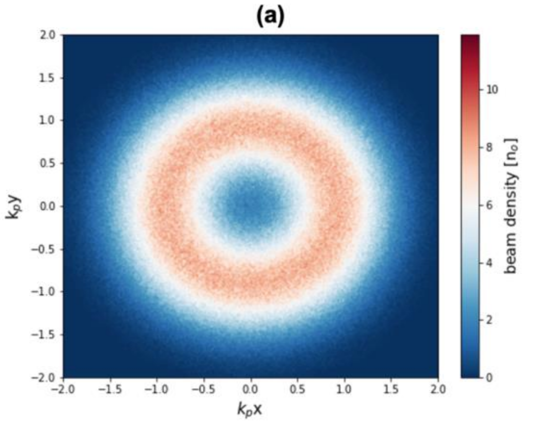
See also Severin's talk



J. Vieira et al, Phys. Rev. Lett. 112, 215001 (2014).
C. S. Hue,1, G. J. Cao et al., Phys. Rev. res. 3, 043063 (2021)



S. Gessner et al., to be submitted



] J. Vieira et al, Phys. Rev. Lett. 112, 215001 (2014)
C. S. Hue,1, G. J. Cao et al., Phys. Rev. res. 3, 043063 (2021)

Quasi-linear plasma wakefield

How to accelerate low emittance beams with high efficiency?

Multi-pulse, energy recovery.

Hollow plasma channels

How to mitigate transverse instabilities?

Position trailing bunch at zero-crossing of transverse wakefield, look for damping mechanisms, flat channels.

Nonlinear plasma wakefield

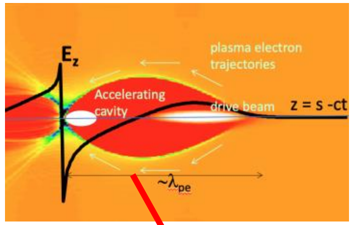
How to preserve emittance?

Doughnut-shaped wakes, weird trailing bunch shaping, single-stage accelerator, betatron cooling.

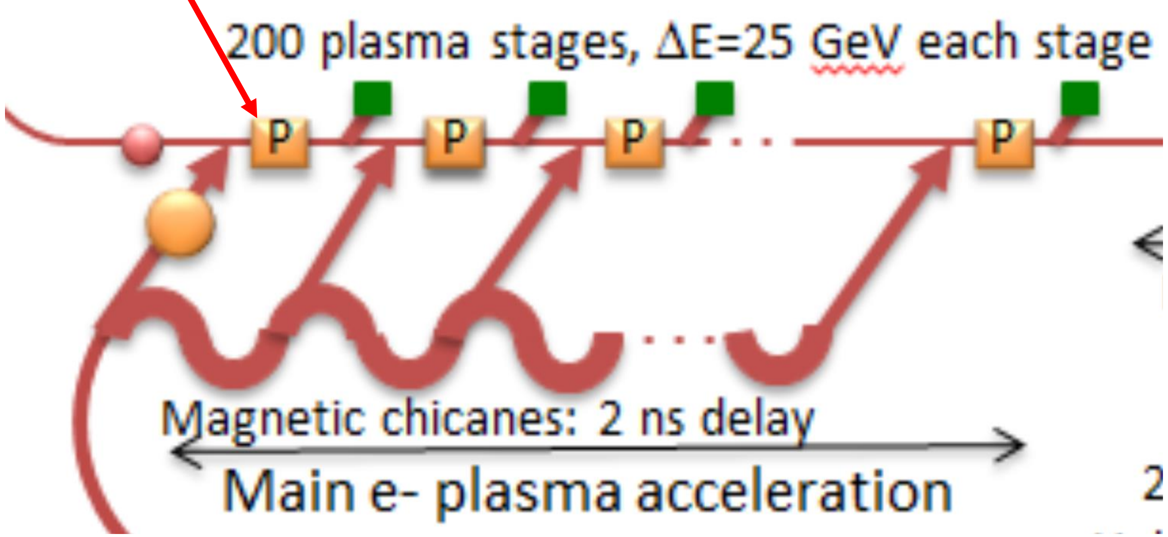
- **Good progress in e^+, but no clear path to achieving same beam quality/efficiency as e^- blow out regime**
- Fewer experimental results, less good match/theory -> **harder to rely on simplified models**

e- arm: better performance, better suited for modelling

The e- linac arm



Single stage physics



Drive beam generation and distribution

Example of interstaging ideas :

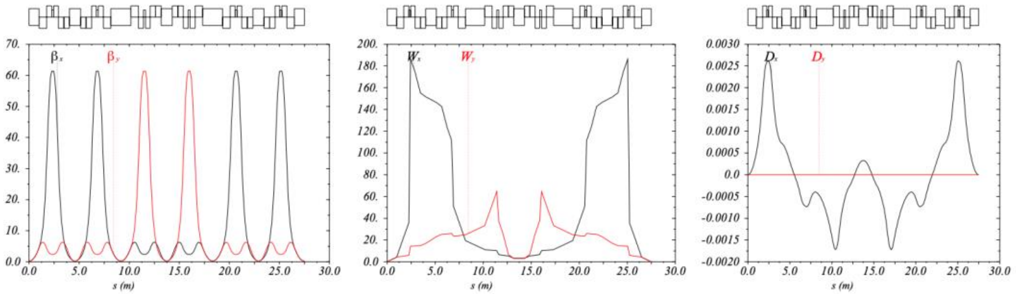
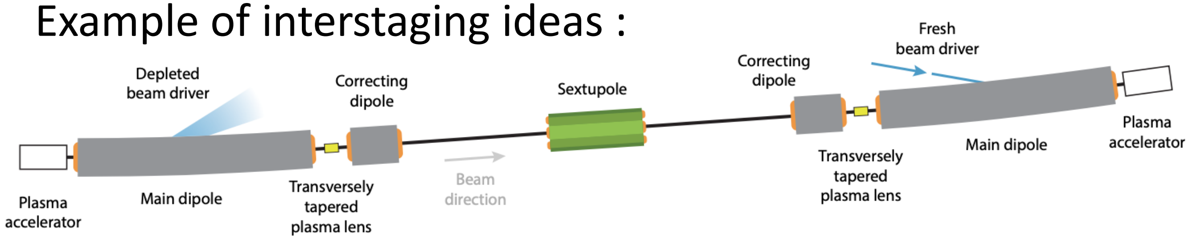


Figure 2.8: Example of staging optics using sextupoles, calculated using MADX [222]. The beta functions (left), chromatic amplitude (middle) and dispersions (right) are all simultaneously matched or canceled (to first order), but the system is long and complex—not ideal for compact staging.

Example of interstaging ideas :

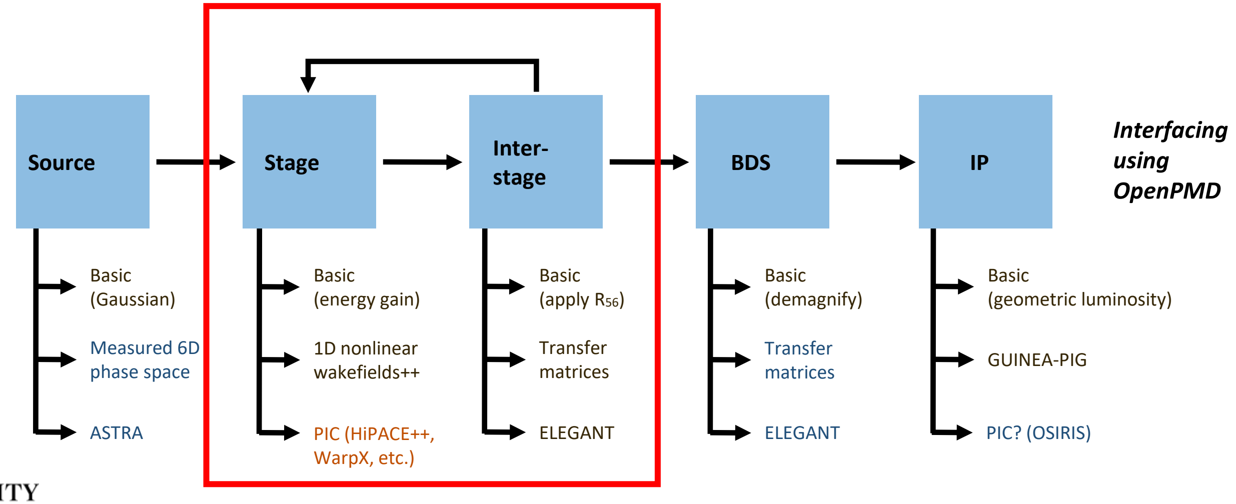


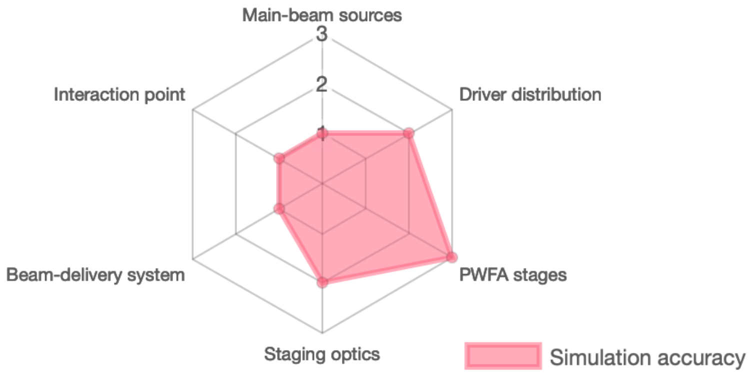
To estimate the performance of the e- linac arm :

- single stage model
- interstage model
- full length to correctly estimate longitudinal and transverse stability (BBU, static imperfections, jitter)
- all known physics like ISR, CSR, scattering, betatron radiation should be included (at the appropriate level of modelling)
- technical constraints on plasma sources, DB generation etc. taken into account (e.g. from high-rep rate experiments)

Agile development of plasma-based linacs/colliders

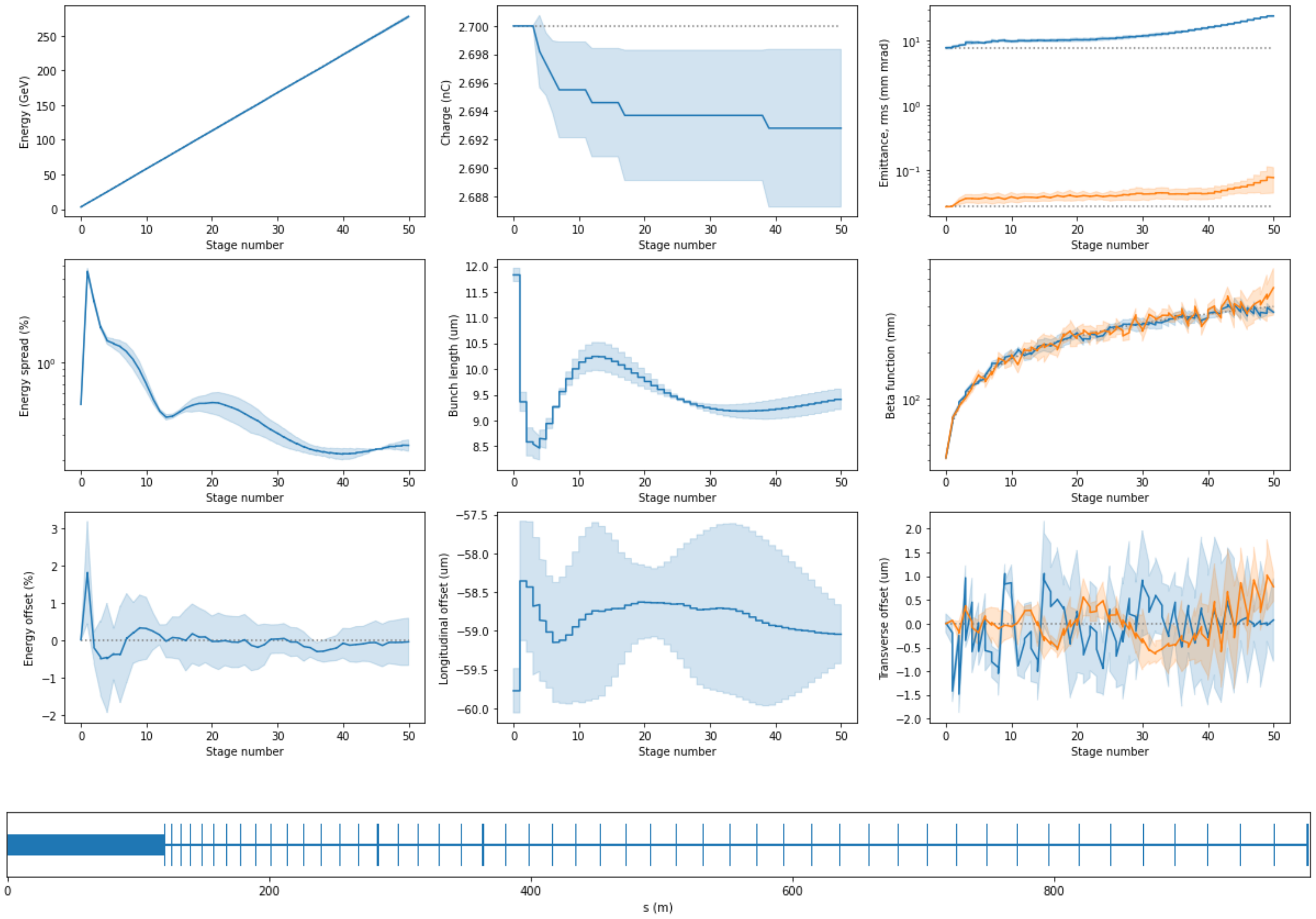
- When the machine concept is not yet clear, **agile development is most appropriate:**
  - *Start **broad and inaccurate**—learn by failure and quick iteration*
  - ***Gradually introduce accuracy**—don't spend time/resources until basics are settled*
- Need <u>a conglomerate of different codes</u> at varying levels of speed and accuracy.
- We are currently developing a local UiO **plug-and-play framework for start-to-end simulations**:
  - *Actively **selecting the accuracy**/code based on requirements for the effect studied.*
  - *Using accurate codes to quickly develop and **benchmark** (faster) **reduced models**.*





Start-to-end simulation of a plasma linac (preliminary example)

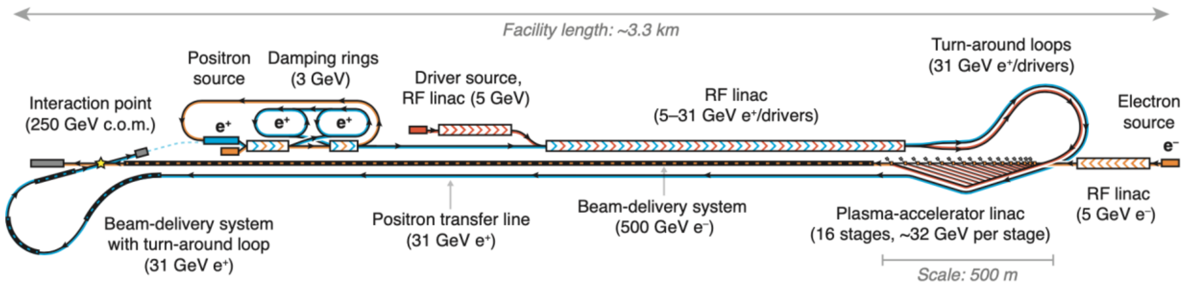
- Example:
  - 50-stage plasma linac (280 GeV)
    - 5.5 GeV per stage
  - ELEGANT for interstage
    - Nonlinear plasma lenses
    - CSR/ISR included
  - Nonlinear 1D wake model
  - Multiple samples with jitter:
    - 3 fs rms driver synch.
    - 50 nm rms alignment
    - 1% rms plasma density

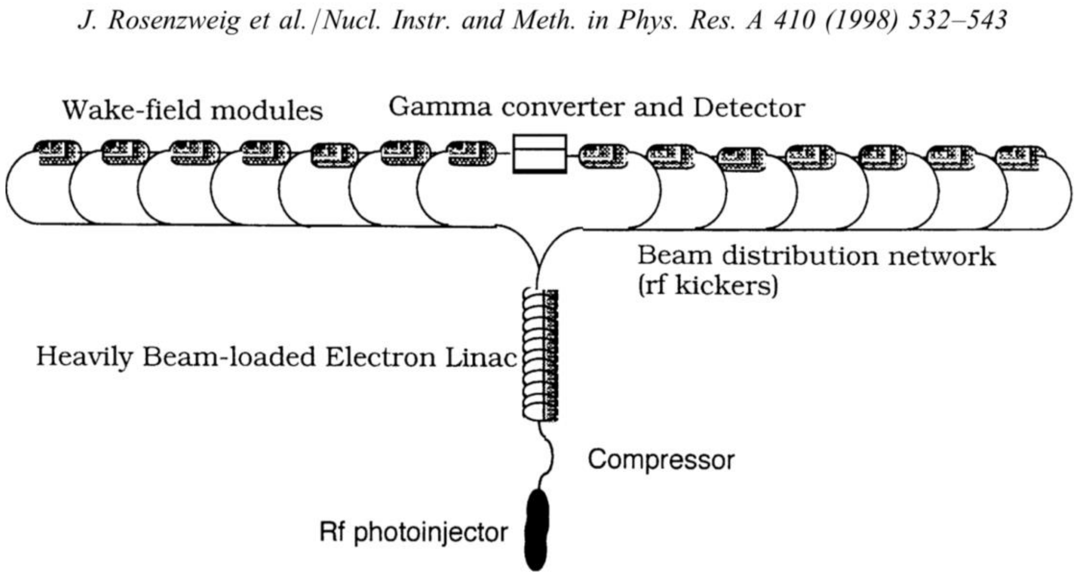


Main question:
performance of **plasma e- linac vs RF e- linac?**

How much more compact? More or less efficienct? How much less costly?
Are the improvements sufficient to stir more interest from the HEP community?

Answer depends strongly on which machine the e- linac is part of - assymetric Higgs-Factory, Multi-TeV gg ... ?

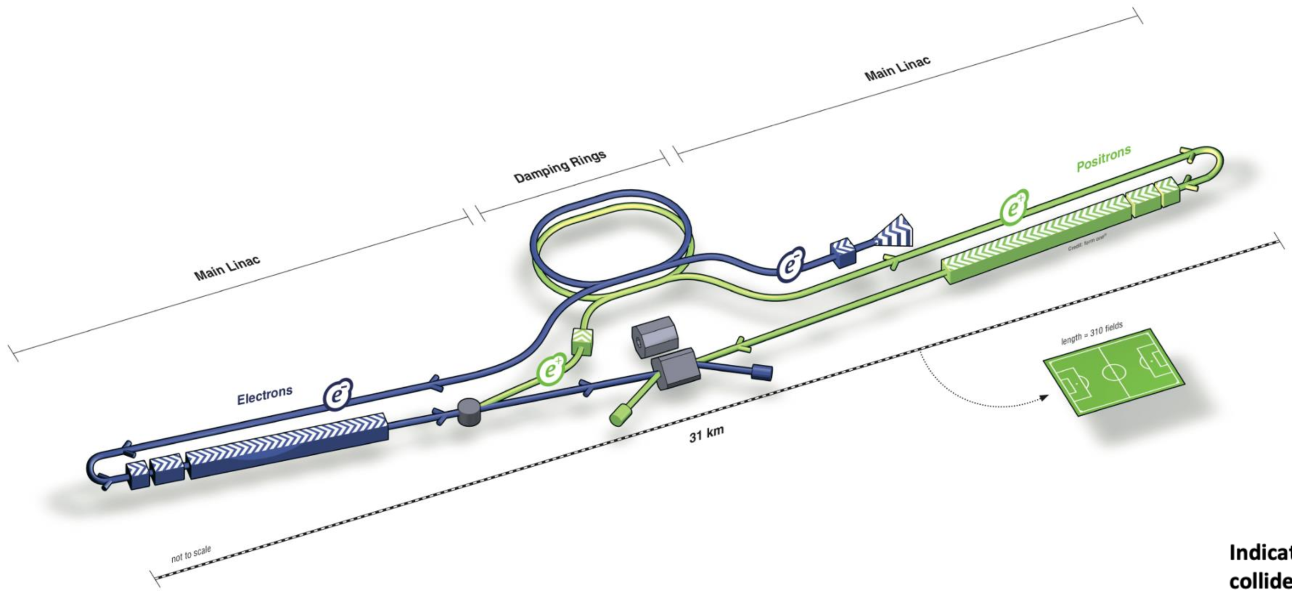


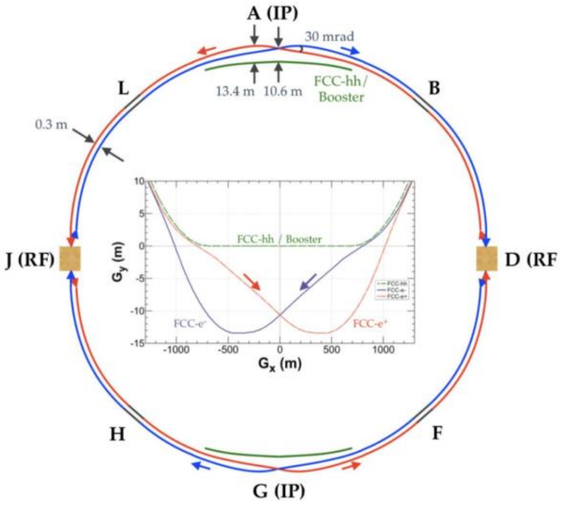


At Oslo we work mainly on modelling and simulation of the **beam-driven e- linac.** We need to do the work in a context of a machine, and will also be involved in **looking at different concepts.**

An better understanding of the linac is a pre-requisite for estimating overall parameters for the machine, or talking about a pre-CDR for the overall machine.

HEP community wish: $e^- e^+$ Higgs factory as the next machine





Schematic of the FCC-ee collider with the details of the crossing schemes at the interaction points.