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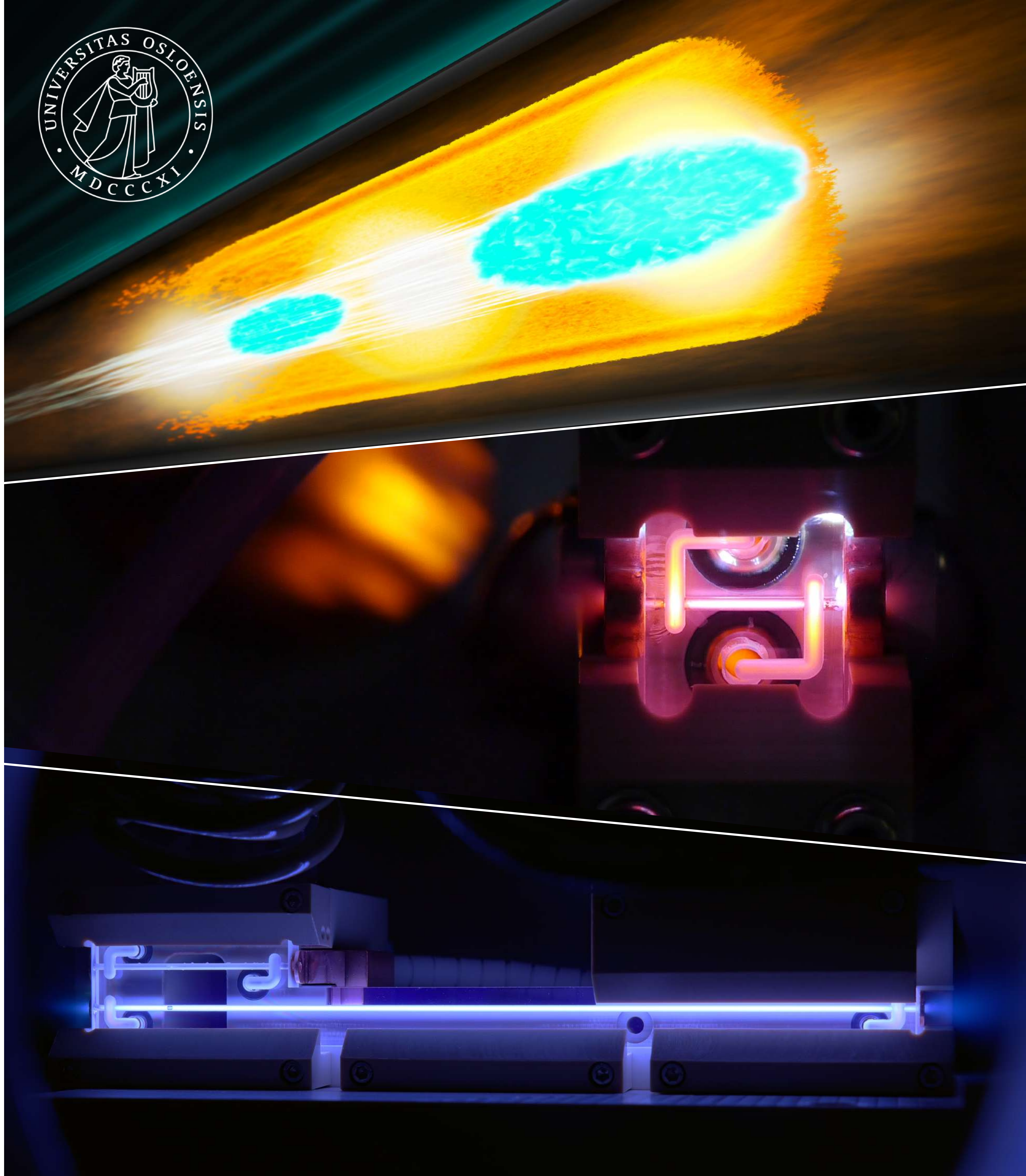

PWFA updates for HALHF

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HALHF — a high-risk/high-reward endeavour

- HALHF is high-risk/high-reward:
  - Can greatly reduce the collider cost and footprint
  - But the PWFA linac (the "innovative" part) is associated with large uncertainty
- Originally mainly meant as a push toward **concretising** a plasma-based collider by taking into account all that is currently known (on a macro level).
  - Main improvement: "solving" the positron problem (by avoiding it).
- This is what's needed to motivate detailed self-consistent simulations (which are computationally and time intensive).

Iteration is key

- Had a chicken-and-egg problem: cannot (get resources to) study something in detail if there is no credible design, which needs detailed study. 
- HALHF is a “shell” around the PWFA arm:
  - Informs general direction of parameter choices
    (e.g. need high charge, high energy efficiency etc.)
- Updated iterations to the overall design will be required if…
  - …the PWFA is not self-consistent.
  - …the PWFA is not consistent with what can be delivered by subsystems.
- It doesn’t matter if it “blows up” a few times on the way
  - Just an efficient design process.

We are already learning a lot — main PWFA updates

> *Main challenges identified:*

> **Plasma-cell cooling** (heat management will be challenging)

> **Transverse instabilities** (too large of an emittance growth)

> **Beam ionization** (the beam density and hence peak E-field is too high)

> **Ion motion** (a new effect discovered by S. Diederichs and M. Thévenet)

Conclusion #1: We should lower the plasma density

- ***Bad part:* Lower density reduces the acceleration gradient**
  - Turns out gradient is not so crucial
    (a major lesson learnt from HALHF, though this will be less true at multi-TeV).
  - At ~1 GV/m (6.4x lower), the PWFA arm is ~850 m long (double length).
- ***Good part:* everything else is easier**
  - The cell cooling requirements go down (scales as E_z)
  - Transverse instabilities are reduced (scales as $R_b^4 \sim E_z^2$, though complex)
  - Beam ionization can be avoided (beam density goes down), also with heavier gases like xenon (needed for reduced ion motion)
  - Matching (beta functions are larger), alignment and synchronization
  - Bunches are longer, currents are lower (less compression/stretching required)
- **Synergy**: Long plasma cells required—starting to look a lot like AWAKE plasma cells

Conclusion #2: Flat beams are going to be challenging

- However, lower density does not (to first order) reduce the effect of ion motion (beyond being able to operate very heavy gases like Xe).
- New problem discovered by **Severin Diederichs and Maxence Thévenet** using very long PIC simulations (HiPACE++):
  - Simulations that were motivated by the HALHF design (exactly what we wanted, and a direct outcome of "concretisation")
  - Their finding: **flat beams going to be very challenging to maintain, at least in our existing HALHF parameter set**
  - Very fresh/preliminary result—they are currently preparing a manuscript (online soon).
- Implication for HALHF: **need to rethinking the parameter set to avoid this issue**.
  - Have some new ideas that we are exploring (which are promising, but a bit to early to tell).
  - Not sure yet in what way it will affect the surrounding subsystems (*a priori* not a lot).

Summary

- The "concretisation" approach has already lead to new results

- Iteration is key, and we are working on a new iteration:
  - Lower density makes everything simpler
  - Flat beams will be challenging

- In short: there is forward momentum, but with some added friction