Temperature diagnostics for high-repetition-rate plasma accelerator sources

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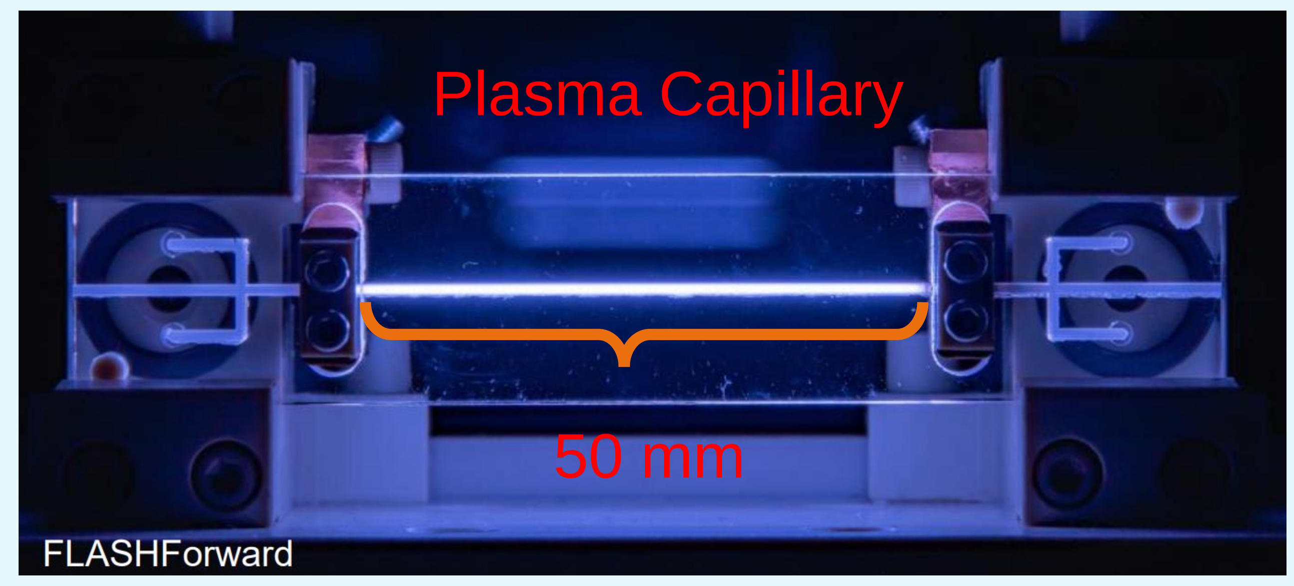
DESY. FLASHFORWARD

1. High-repetition-rate for PWFA

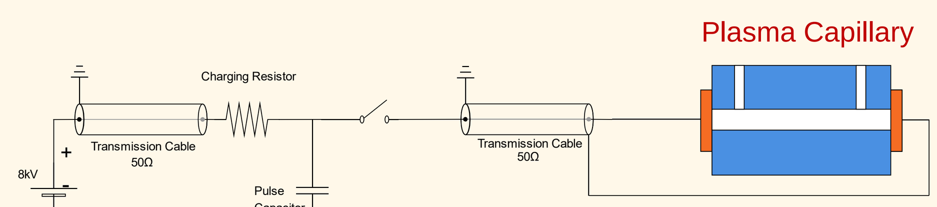
- Plasma-Wakefield accelerators (PWFA) promise to be a compact and cost-effective energy booster for electron linacs[1]: Gradients of 1-10 GeV/m.
- FLASHForward has demonstrated accelerated electron bunches can maintain charge, energy spread (0.1%) and emittance[2,3] (3μm) during plasma acceleration.
- A major challenge remains in achieving high-repetition-rate operation, as is common in radio-frequency accelerators.
- Most applications require ~ 10,000 acceleration events per second, to provide high luminosity for colliders or high average brightness for FELs (e.g. FLASH[4], XFEL, LCLS2, ILC[5], HALHF[6]).



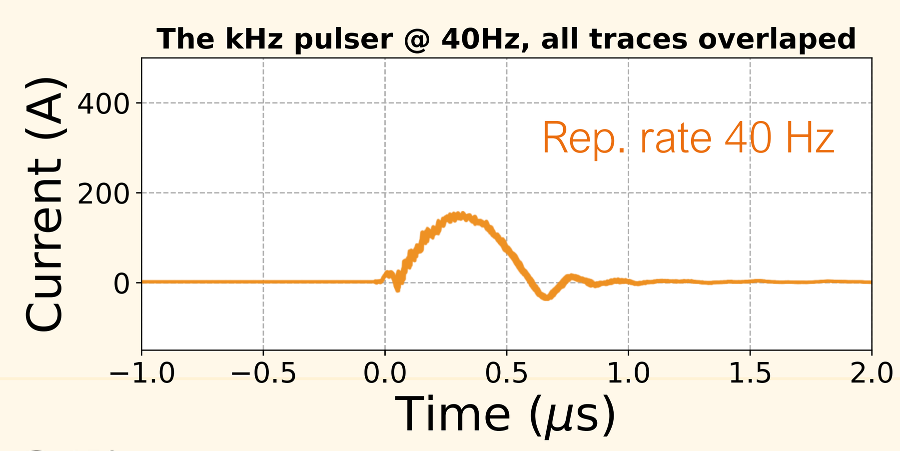
2. Plasma generated heat

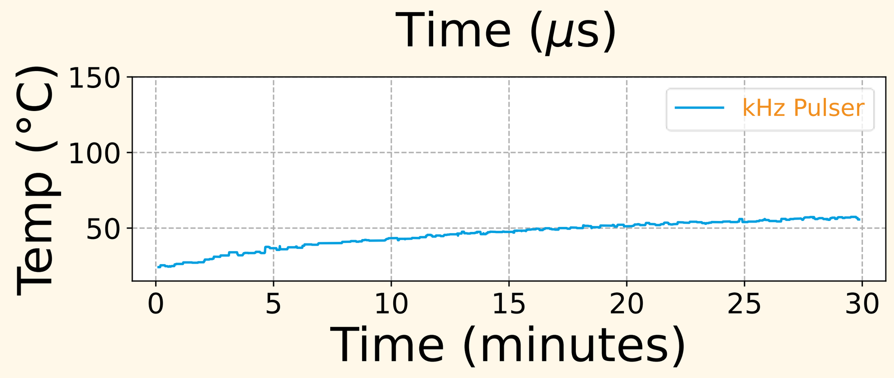
- Two challenges: **Plasma density stability; High heat loads[7]** into the capillary.
- Identical plasma acceleration events must take place at high frequencies over a long period of time. One of the important challenges is to deal with the high heat load placed on the plasma cell by the plasma formation process and the driving beam, which are similar in terms of power deposition at FLASHForward.
- New fast High Voltage pulser set up (kHz): Capacitor and semiconductor switch allows us to investigate much higher heat loads.

New kHz Pulser: up to 1 kHz, 8kV

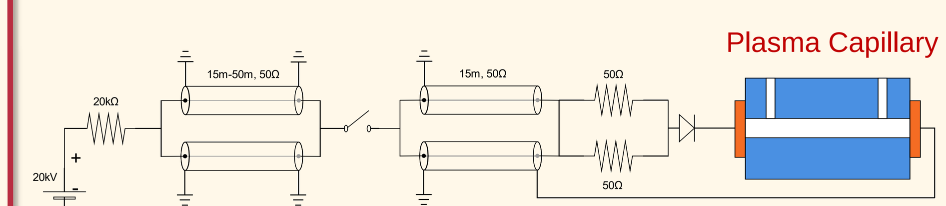


H2, 50mm cell, Flow rate: 150 mln/min, 5.8 kV

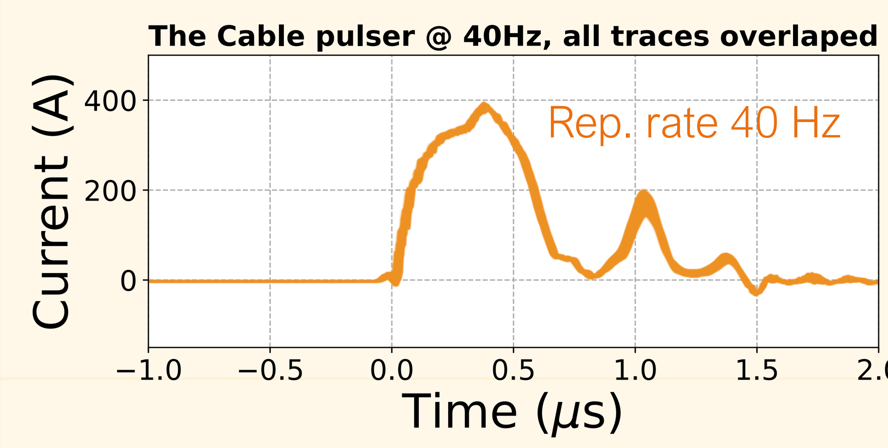


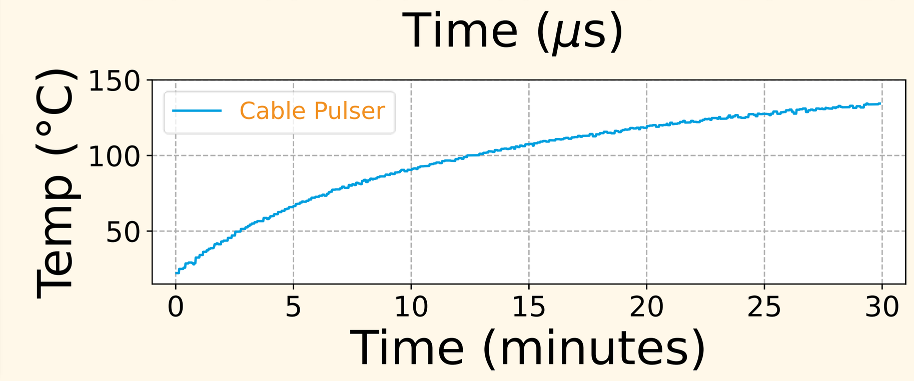


Old Cable Pulser: up to 40 Hz, 25kV



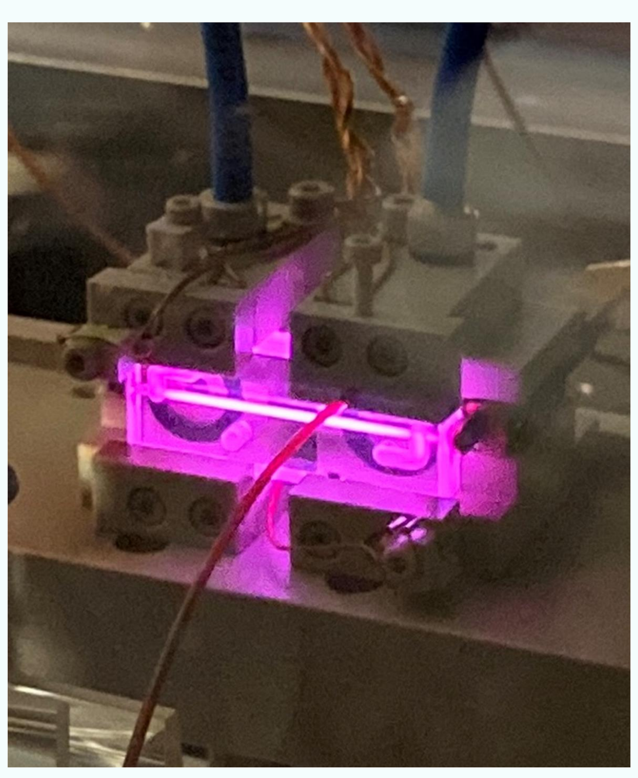
H2, 50mm cell, Flow rate: 100 mln/min, 20 kV





- Temperature increase is much lower with the kHz pulser (at 40 Hz) because of it's lower voltage and shorter pulse length due to fast semi-conductor switches.
- They both ionize the plasma and generate the required amount of density: ~10^{16} cm^{-3}
- kHz pulse jitter more stable (4.7 ns vs 7.8).

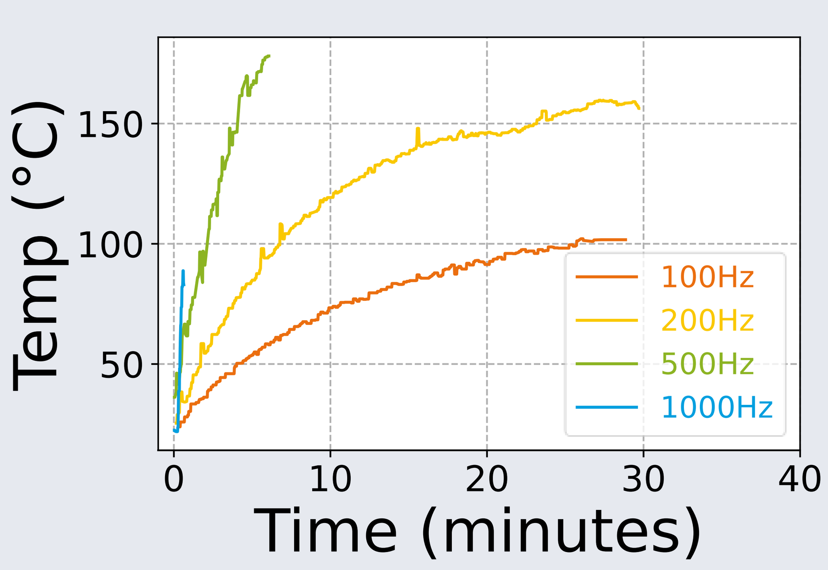
3. Measurements



- **Main Temperature Diagnostic:**
  - Fiber optic with Gallium Arsenide (GaAs) semiconductor crystal: Temperature dependence of the bandgap of GaAs.

4. Scaling

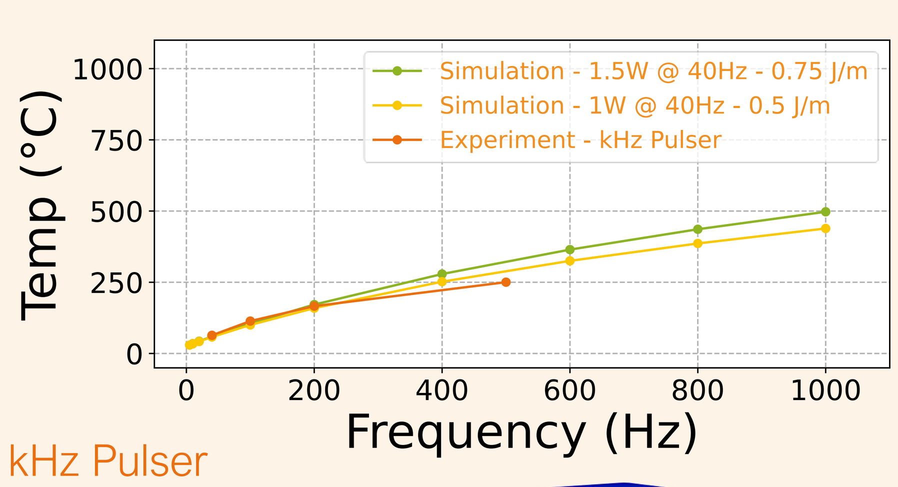
- kHz pulses:
  - Temperatures start rising very quickly!



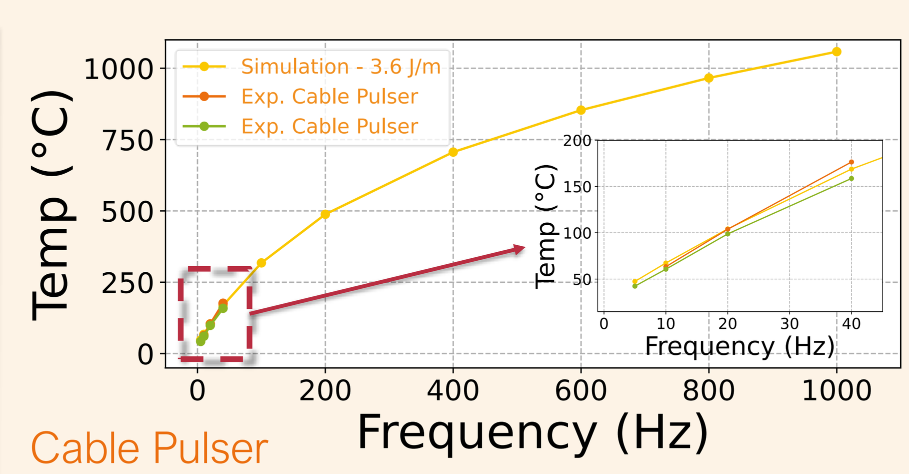
- We need capillaries able to sustain average power depositions of 1-10 kHz.
  - Scaling the temp. measurements allows us to think on how to designs cooler cells for higher rep. rates.

5. Simulations

- How much energy is deposited by each pulse[8]:
  - Cable Pulser: 3.6 J/m
  - Power deposition for kHz pulser is estimated from matching simulations to be around 0.5 to 0.75 J/m

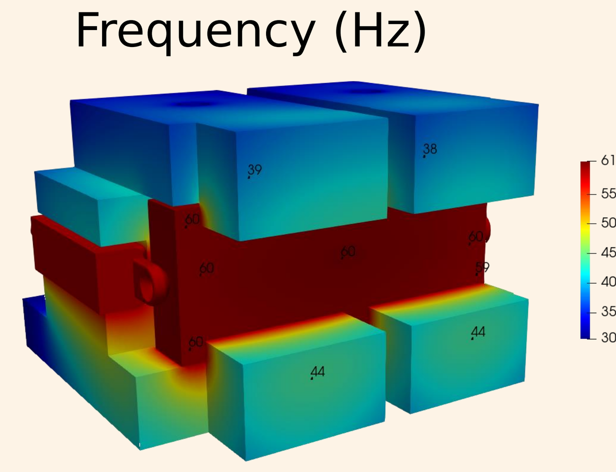


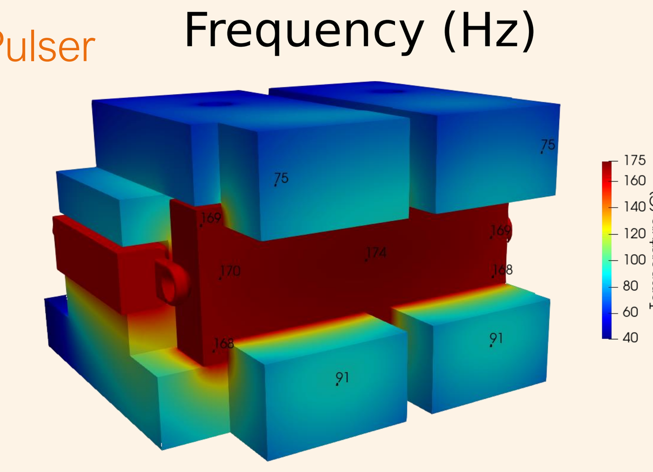
kHz Pulser



Cable Pulser

- ANSYS simulations agree with experiments.





5. Outlook

- It is possible to improve the efficiency of plasma generation to go to higher repetition rates by using shorter, lower voltage pulsers.
- Temperature measurements help us prepare on what to expect at higher rep rates.
- Next steps:
  - More temperature measurements: Scaling, increase of repetition rates.
  - Can design effective cooling solutions.

References:
[1] P. Chen et al., Phys. Rev. Lett. 54, 693 (1985)
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