Megahertz repetition rate discharge plasma cells for plasma-based particle accelerators

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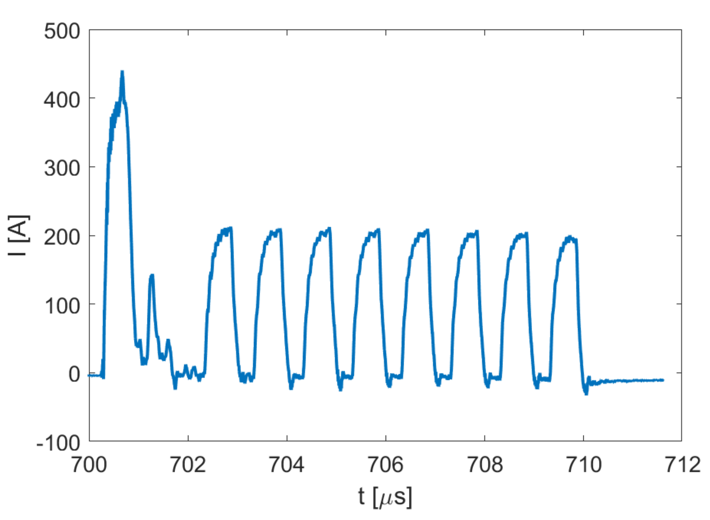
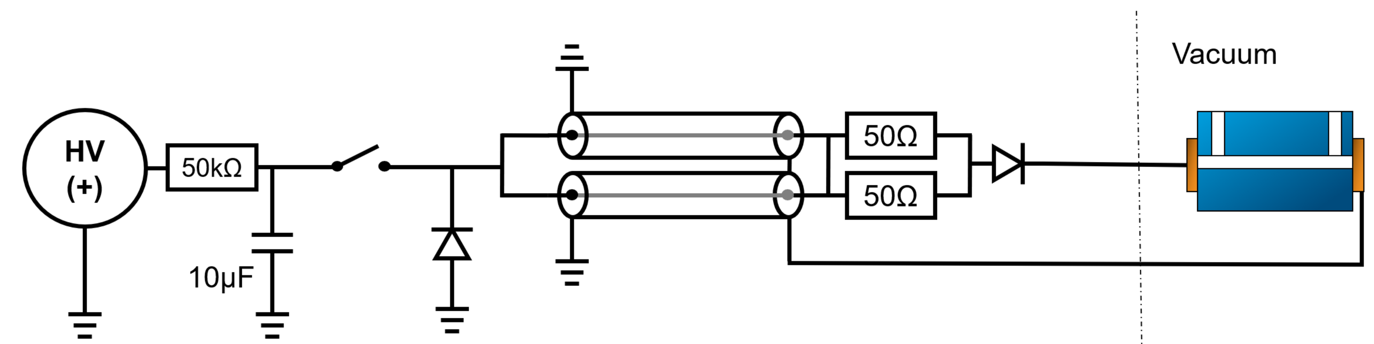
Abstract

Particle acceleration in wakefields excited in a plasma medium is one of the prime candidates to complement or even replace conventional radiofrequency accelerators in future accelerator facilities due to the far superior acceleration gradients achievable in plasma. In contrast to conventional acceleration techniques, which routinely supply experiments with up to 100's of thousands of bunches per second, allowing data taking in a short period of time, plasma accelerators at the moment usually operate at repetition rates of a few Hz. To enable high-gradient-acceleration at competitive repetition rates, the plasma acceleration medium has to be supplied with high reproducibility at similarly high repetition rates. Here, we report on the development of gas discharge plasma cells capable of producing plasma acceleration media with MHz repetition rate in bursts of tens of discharges.

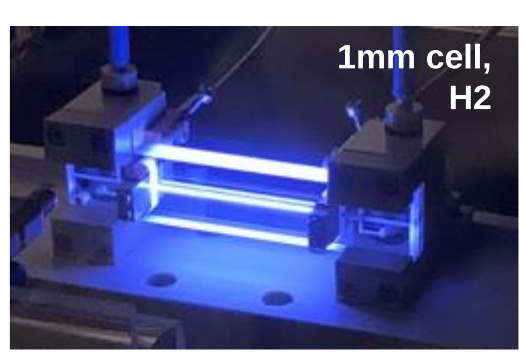
MHz burst HV modulators

- Beam-driven plasma-wakefield acceleration @DESY performed at FLASH FEL linac
  → MHz burst electron beam
- High rep. rates next major step for plasma acceleration
- Pulse modulators required for MHz plasma production
- Two MHz burst modulators operational
- SiC MOsFET switching unit
- Main parameters
  - Voltage 1 – 8kV
  - Peak current 40 – 350A
  - Pulse length 150 – 5000ns
  - Burst rep. rate 1 – ~100Hz
  - Pulse rep. rate ≤ 1.5MHz
  - Burst length 1 – 200

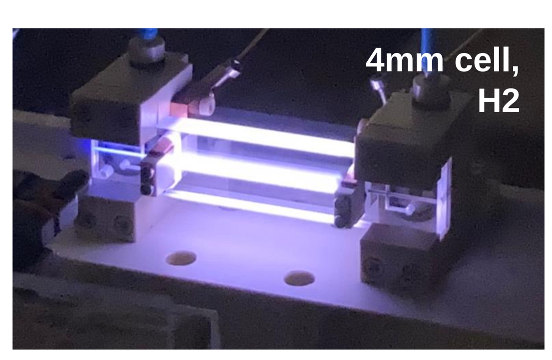




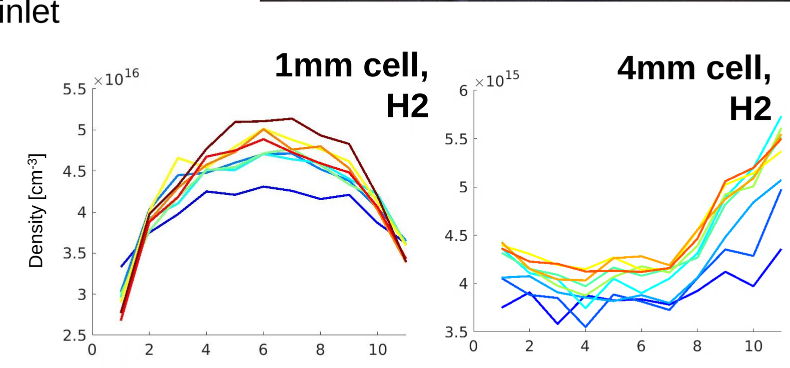
Different cell geometries



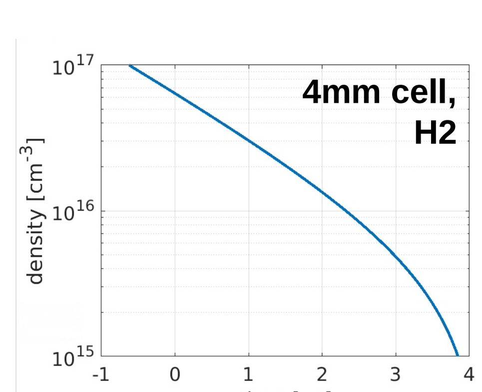
- Original/standard FLASHForward cell geometries not suitable for MHz operation
  - Gas outflow significant → required density not reachable after few pulses
  - Longitudinal plasma density profile changing significantly



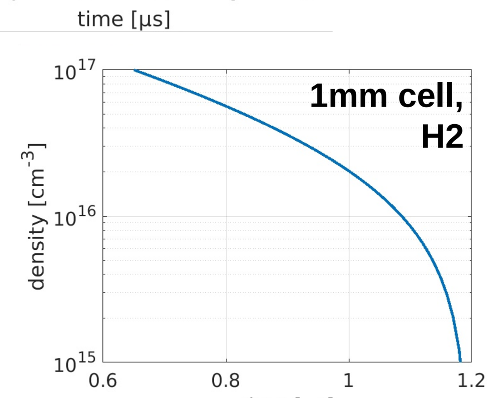
- New cell designs developed
  - Gas inlets outside of electrodes
  - → homogeneous discharge channel
  - Variable discharge diameters with same inlet geometry
  - Electrodes gas-sealed & removable
- Various cells produced & tested
  - 1mm constant capillary diameter
  - ≤4mm discharge channel & 1mm exit
  - Shaped exit geometries, etc.



- Significant influence of cell geometry found
  - Gas expulsion largely mitigated by large discharge/exit diameter ratio
  - Recombination time strongly depending on discharge channel diameter
    → heat transfer through walls determines recombination



- Various exit geometries under investigation
- All cells having 50mm discharge length so far
  → transfer of results to meter-scale cells planned



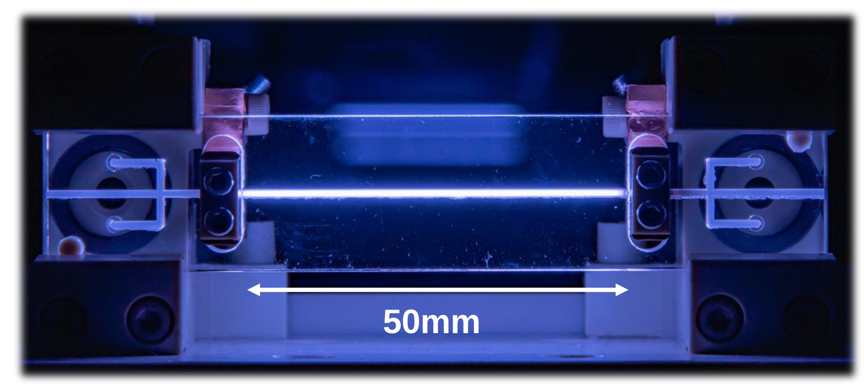
Long story short

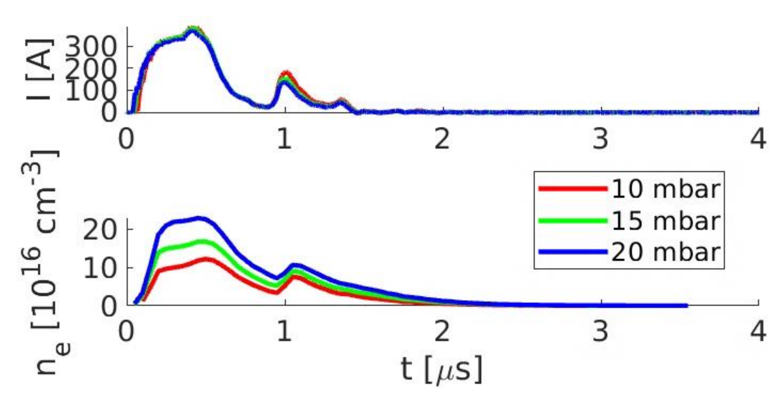
- Discharge plasmas which supply plasma acceleration media thus far limited to 10's of Hz (<kHz)
  → development of high rep. rate cells ongoing at DESY
- Plasma medium production increased to MHz rep. rate in bursts of <50 pulses
- Achieved densities & density profiles compatible with PWFA
- Developed cells will be employed for MHz PWFA at FLASHForward

Gas discharge plasma cells for accelerator applications

Why use discharge plasma cells?

- Plasma-wakefield accelerators require stable & tunable plasma sources
- Discharge plasmas are a compact & reliable option
- FLASHForward successfully using discharges
- High repetition rate drive electronics readily available



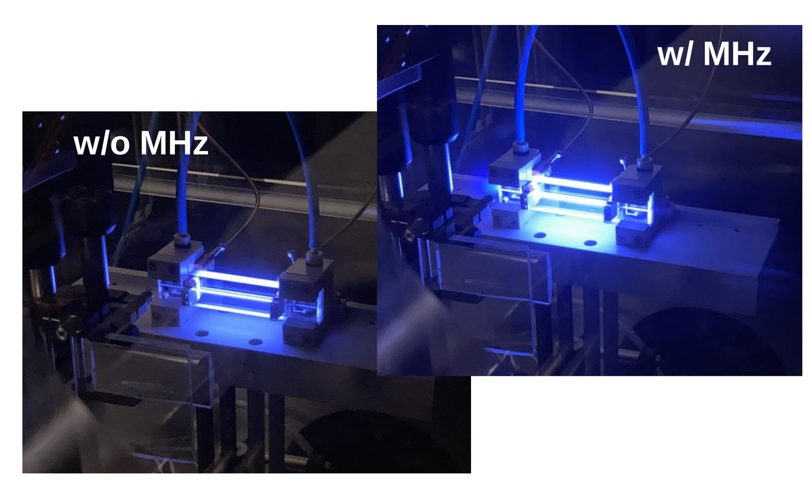


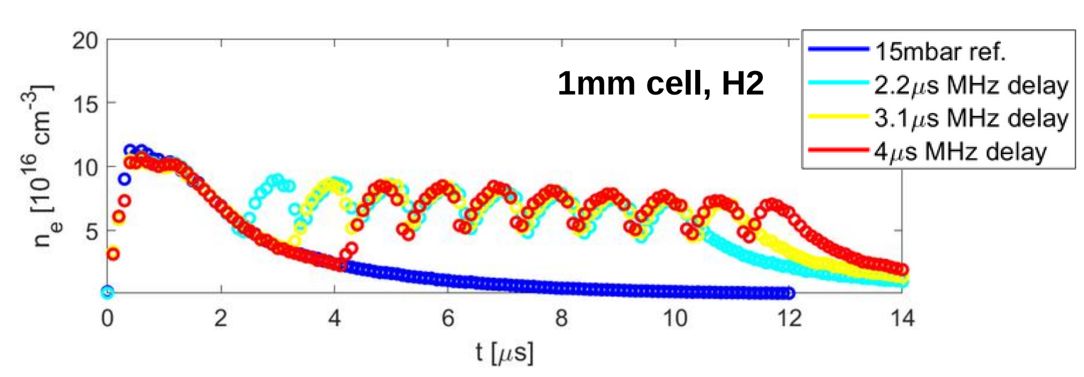
How does it work?

- Pulsed, high voltage is applied between 2 electrodes
- A plasma is formed by avalanche breakdown
- An arc is formed if sufficient current is supplied
- Current pulse duration, current density, and gas species/pressure determine plasma electron density
- Density decays ~exponentially due to recombination & gas expulsion from discharge volume

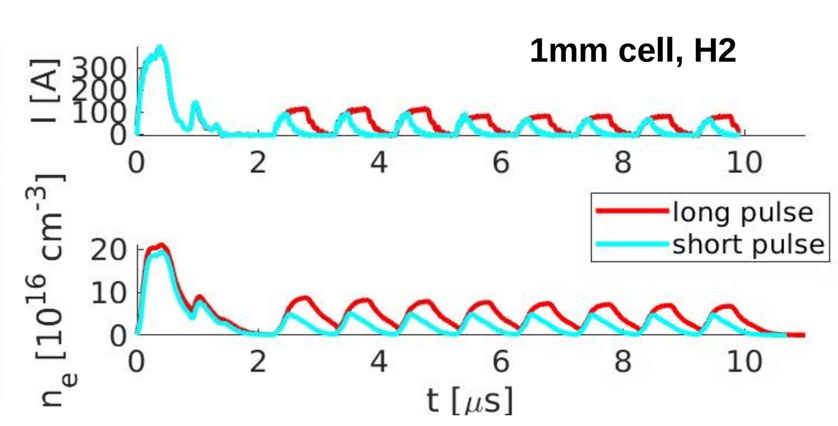
MHz discharge operation

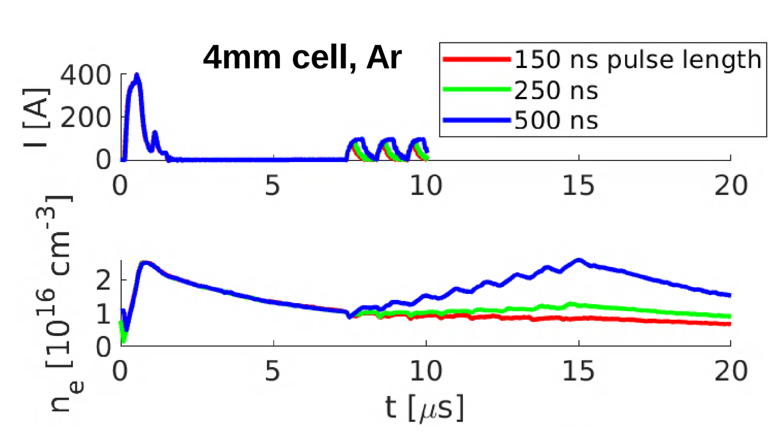
- Ignition pulse (U = ~7-27kV) produces plasma
- Consecutive MHz pulses re-ionise plasma to desired density
- Density measured by optical emission spectroscopy (line broadening)

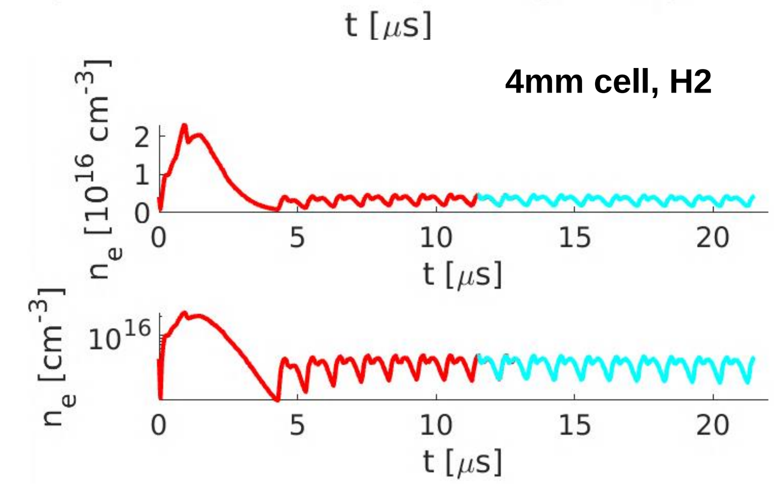


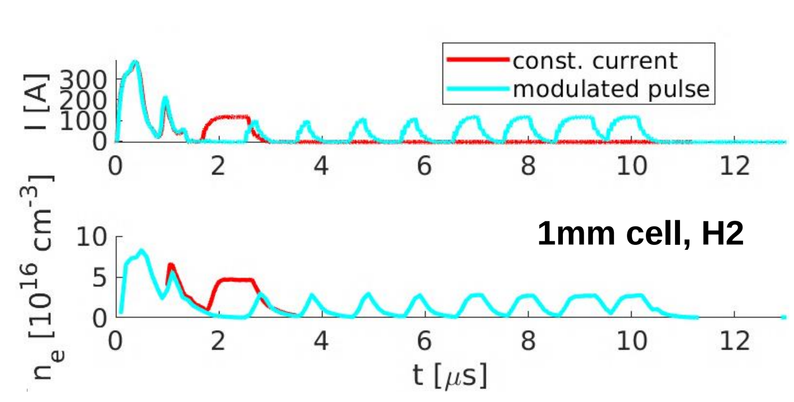


- Various parameter studies performed
  - Gas species
  - Gas pressure
  - Pulse repetition rate
  - Pulse length
  - Different target densities









- Mitigation of peak density decay
  - Decay of ~30% over 8 pulses
  - Applying progressively longer current pulses
    → reduction to 7% density decay
  - Linear increase, optimisation possible

Outlook

- MHz supply of plasma acceleration media successfully demonstrated
- Developing detailed understanding of parameter influence (gas, pressure, discharge diameter, current density, etc.)
- 50mm long plasma cells in use for MHz PWFA experiments
- Planning transfer of concepts to ~500mm long plasmas

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

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