Double pulse generator for AWAKE scalable discharge plasma source

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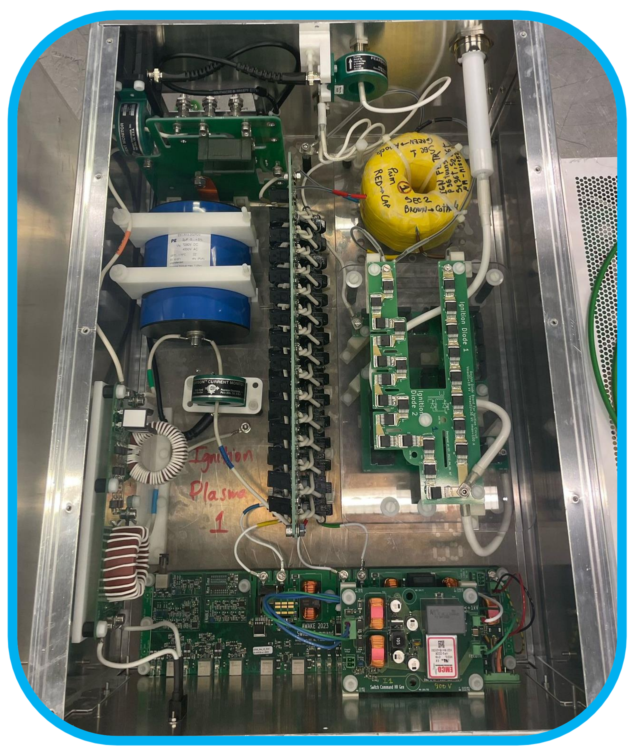
Motivation

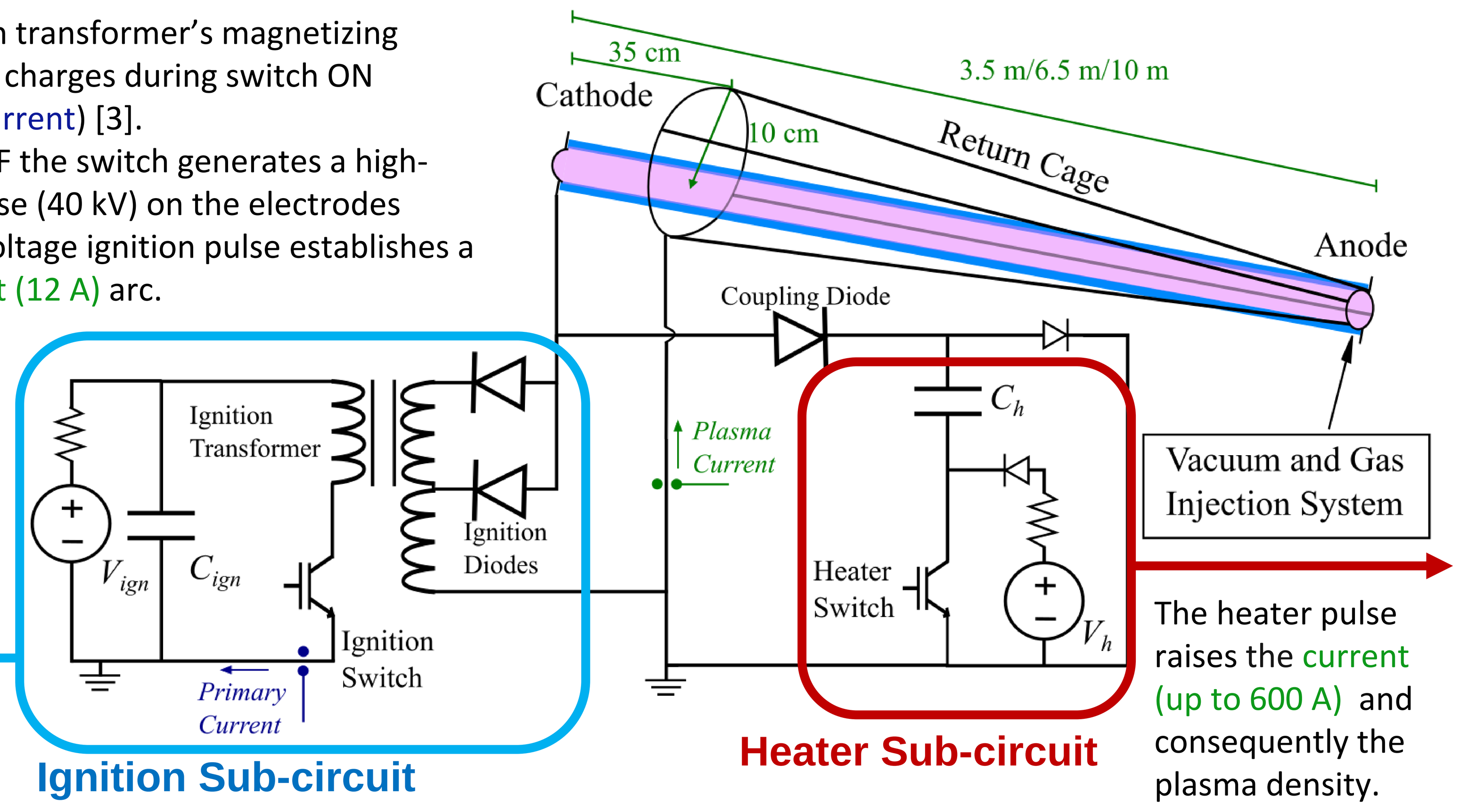
The length limitation in laser field ionisation from AWAKE's Rb cell led to the R&D of scalable plasma sources [1]. A discharge plasma source (DPS) is one alternative being investigated. To be suitable for AWAKE, it must deliver a high-current to reach the desired plasma densities [2] and demonstrate high stability and reproducibility in amplitude and time. Using two successive voltage pulses it is possible to obtain a highly reproducible plasma of up to 600 A and lasting tens of microseconds [3].

A DPS based on this principle was installed and tested in AWAKE. Thanks to the DPS large operation range, it was a unique opportunity to test three different plasma lengths (3.5 m, 6.5 m and 10 m), as well as three different gases (Ar, Xe and He). It was also possible to test a double plasma setting using the 3.5 m and 6.5 m plasma lengths, with shared cathodes and a current balancing system, paving the way to the scalability of the DPS.

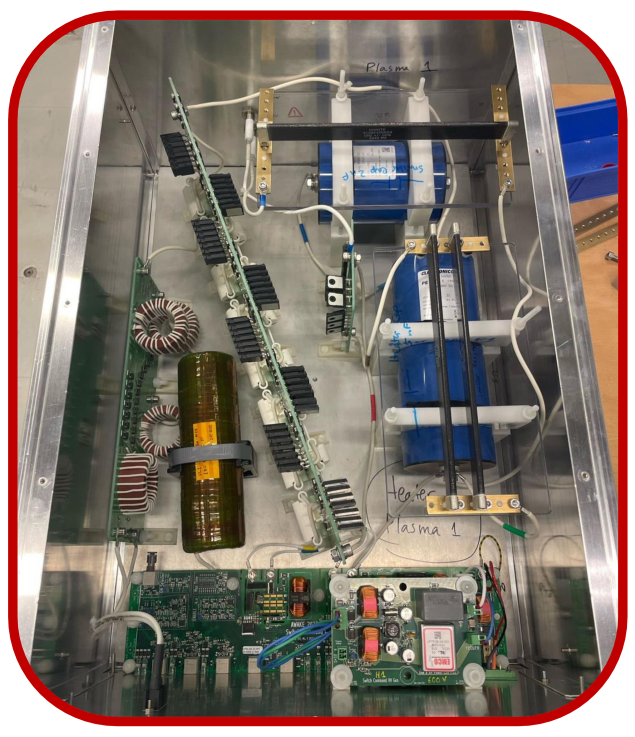
Double Pulse Generator Circuit Design



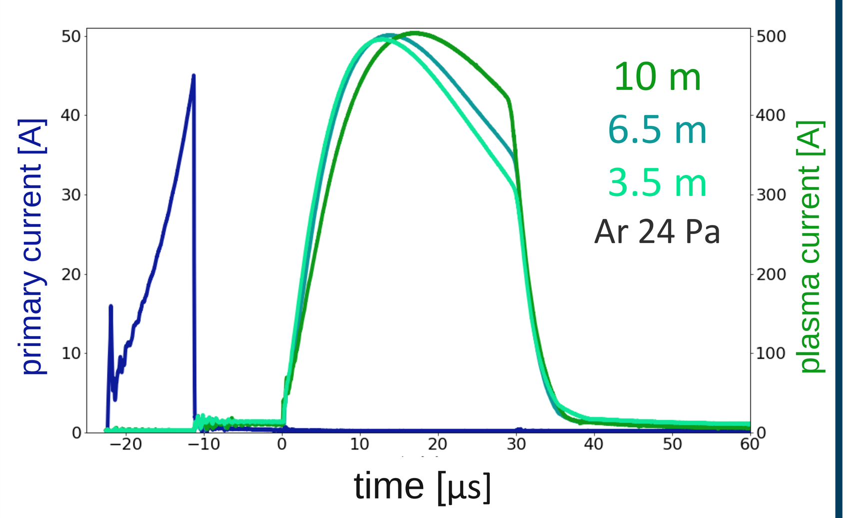
The ignition transformer's magnetizing inductance charges during switch ON (primary current) [3].
Turning OFF the switch generates a high-voltage pulse (40 kV) on the electrodes
The high-voltage ignition pulse establishes a low-current (12 A) arc.

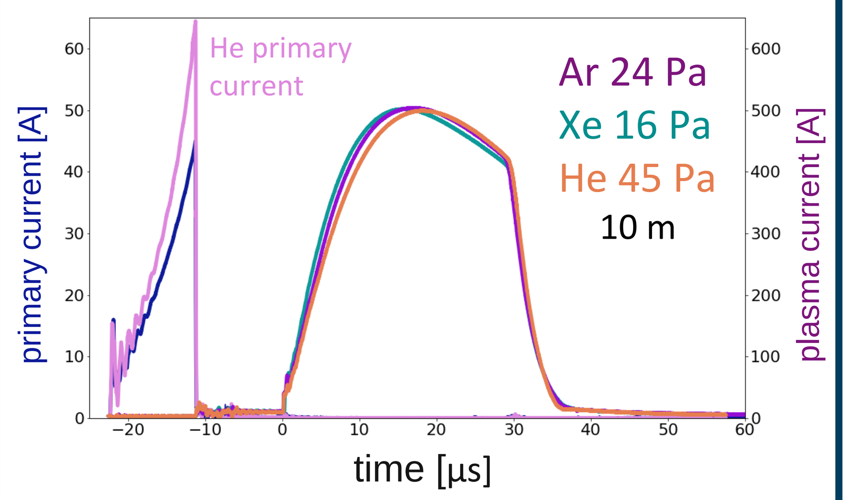


The heater pulse raises the current (up to 600 A) and consequently the plasma density.

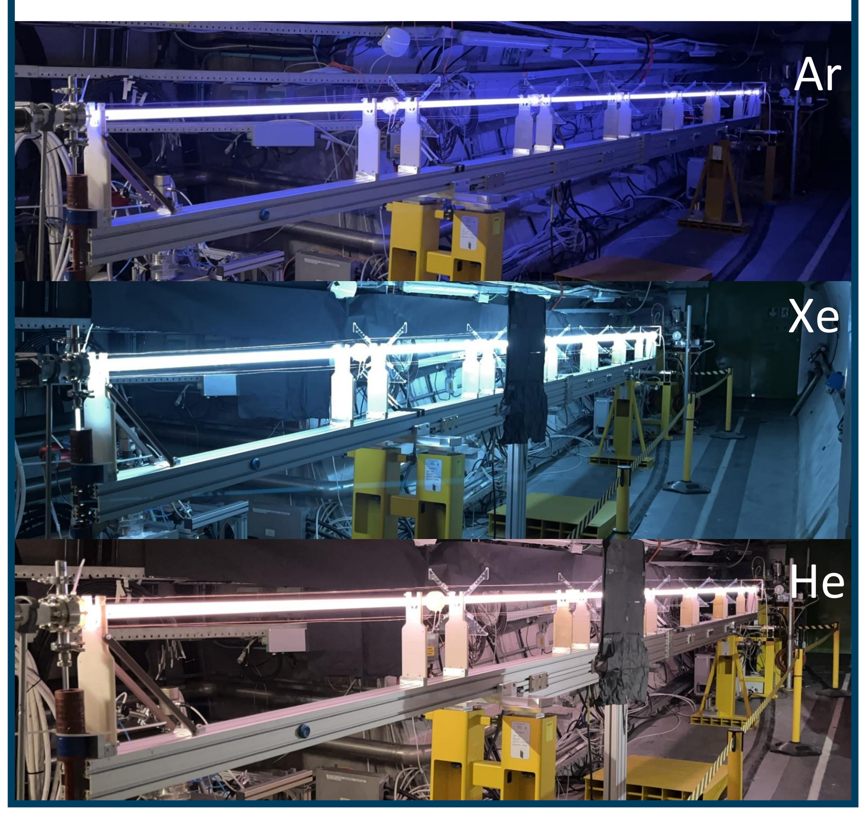


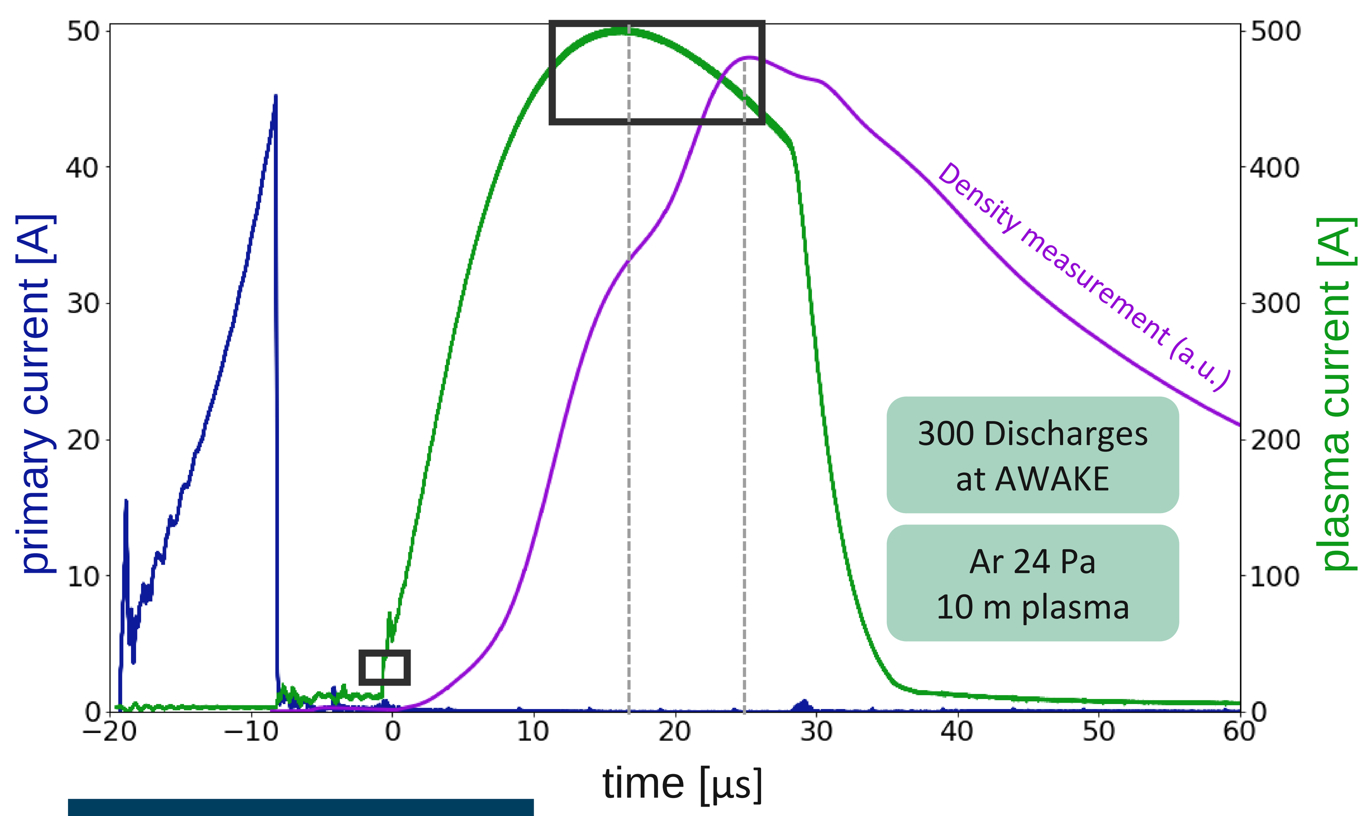
Operation range



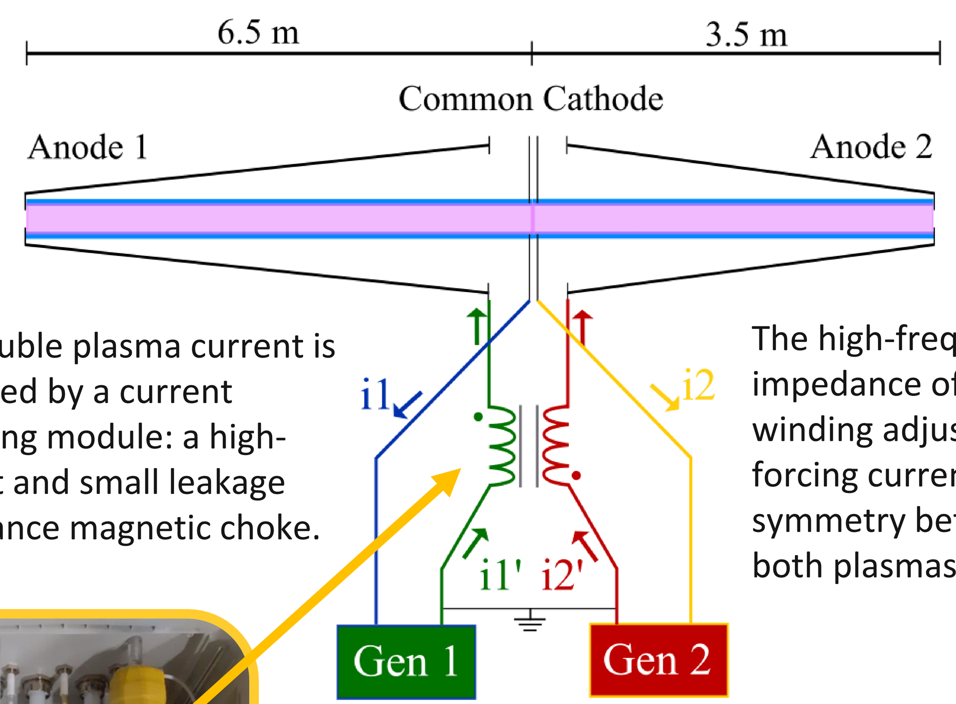


The DPS reaches the target currents in all three lengths and gases.
Plasma length affects the load impedance, thus causing differences in the pulse shape.
Gas affects mostly the ignition voltage required, thus requiring higher primary current for He.



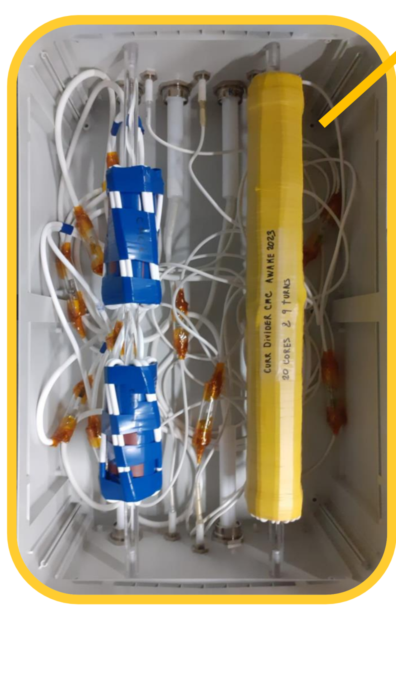


Double plasma

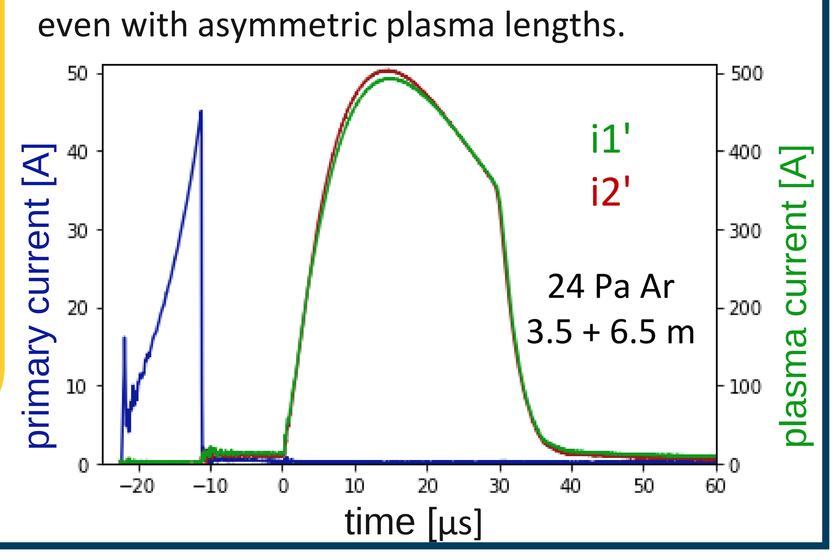


The double plasma current is equalized by a current balancing module: a high-current and small leakage inductance magnetic choke.

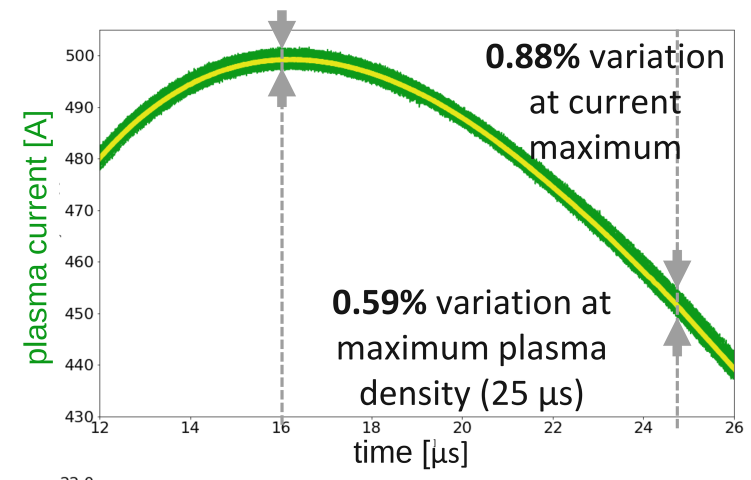
The high-frequency impedance of each winding adjusts, forcing current symmetry between both plasmas.

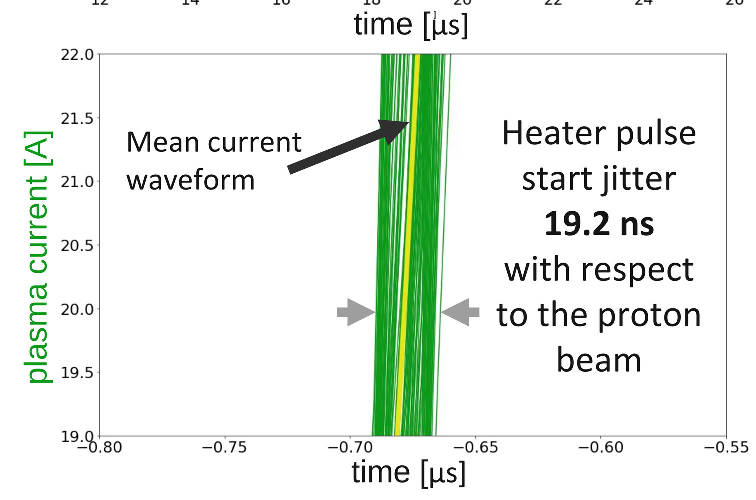


Tested in AWAKE delivering symmetric currents, even with asymmetric plasma lengths.



Reproducibility





Current variation of <1% as well as a pulse jitter of 19.2 ns, demonstrating good electrical reproducibility over 300 discharges.

Conclusion

The Discharge Plasma Source delivered over 21000 plasma discharges for AWAKE

- The double pulse generator can accommodate a variety of plasma loads, which allows a large spectrum of operation;
- The double pulse concept generates plasma with high current reproducibility, with a variation of below 1% and a jitter of around 20 ns;
- Scalability is potentially achievable by introducing current balancing modules.

[1] E. Gschwendtner et al. (AWAKE Collaboration), Symmetry 14 (8) (2022)
[2] P Muggli et al. (AWAKE Collaboration), Plasma Phys. Control. Fusion, 60 (2018)
[3] N. Torrado et al., submitted for publication (2023)

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