Double pulse generator for discharge plasmas for particle accelerators

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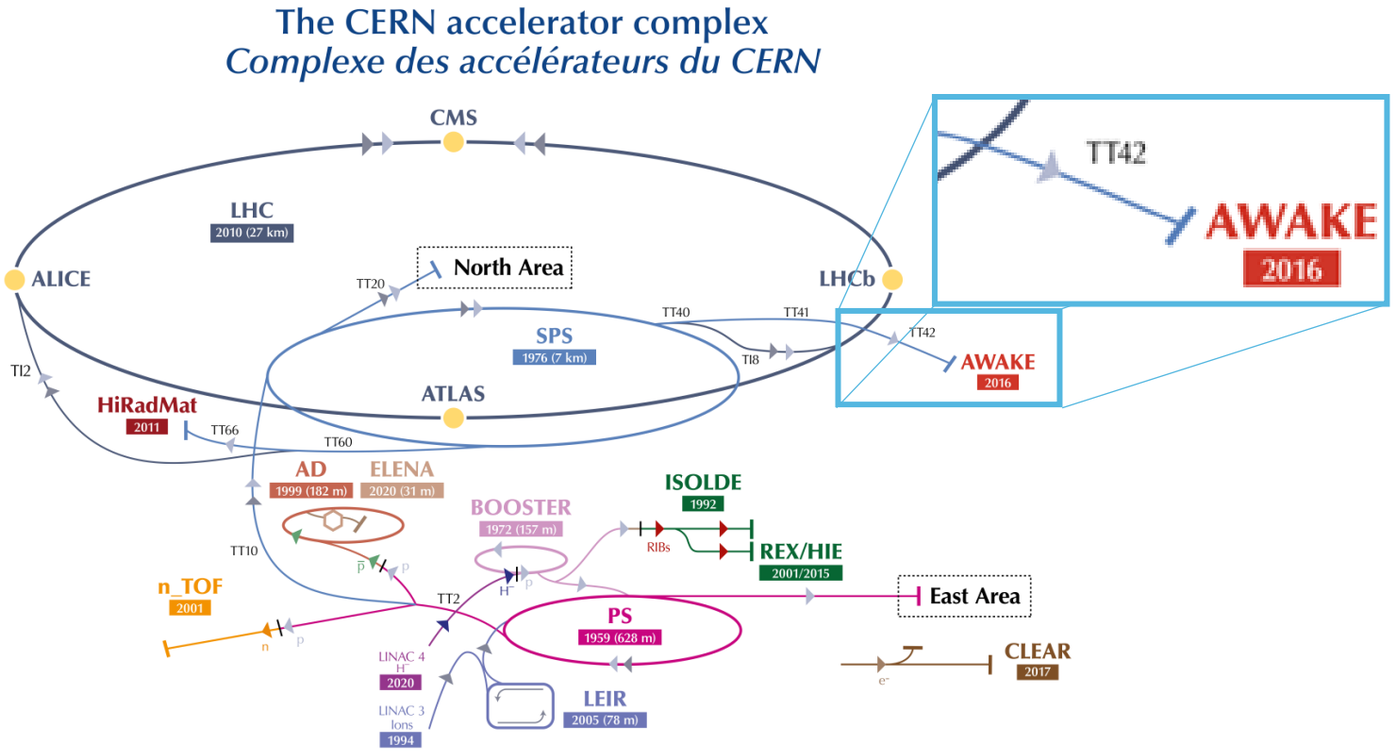
AWAKE Experiment - Motivation

TÉCNICO LISBOA

AWAKE

Advanced Proton Driven Plasma **Wake**field Acceleration Experiment

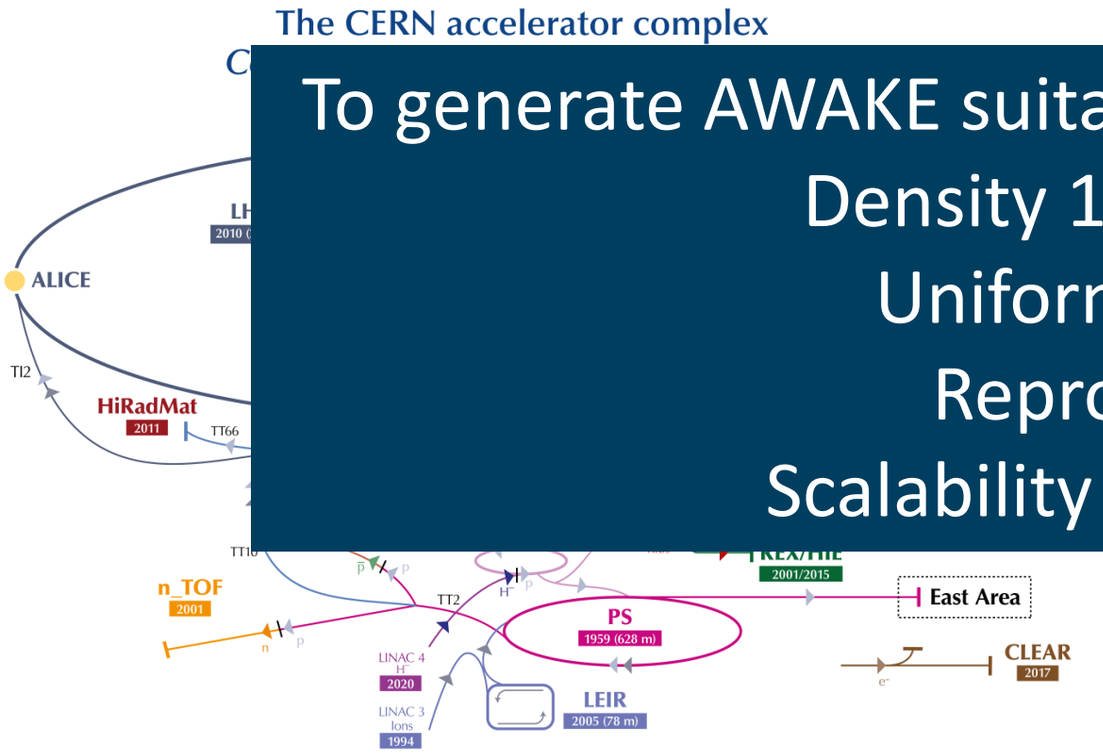


AWAKE Experiment - Motivation

TÉCNICO LISBOA

AWAKE

Advanced Proton Driven Plasma **Wake**field Acceleration Experiment



To generate AWAKE suitable plasmas for acceleration:

Density 1-10x10^{14} cm^{-3}

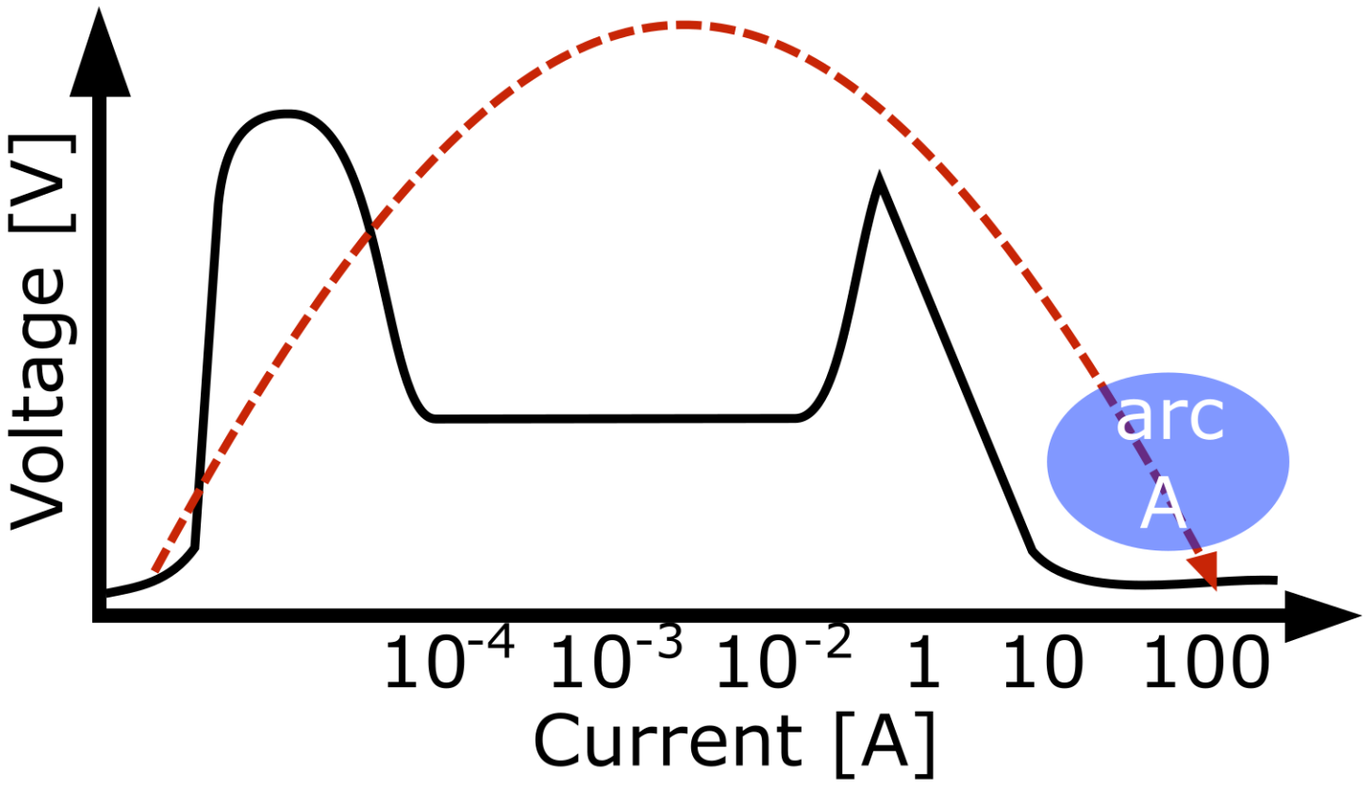
Uniformity < 0.2%

Reproducibility

Scalability (length > 10m)

*P Muggli et al., Plasma Phys. Control. Fusion, **60** (2018)

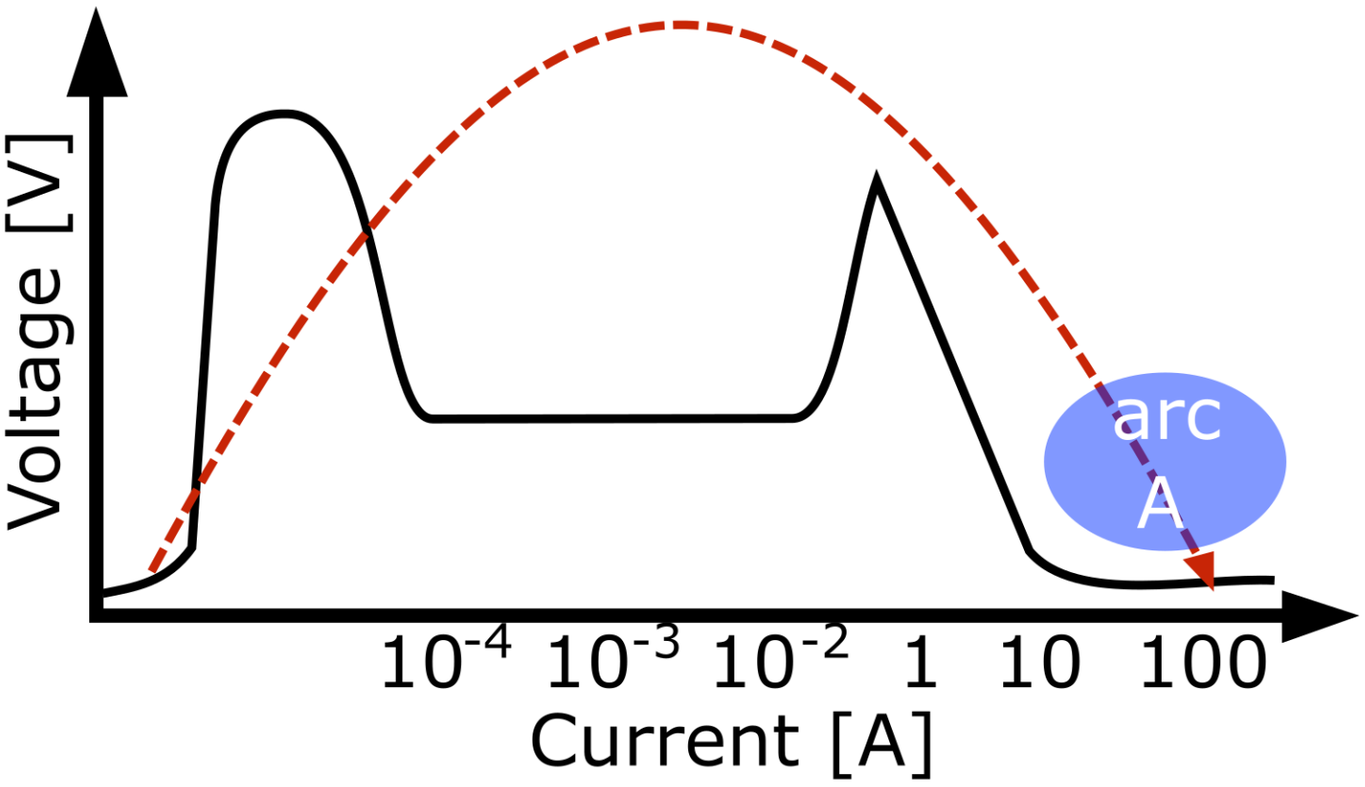
Discharge Plasma Source - Challenge



High uniformity requires high ionisation fraction:

Obtained with high current: 400-1200A

Discharge Plasma Source - Challenge



High uniformity requires high ionisation fraction:

Obtained with high current: 400-1200A

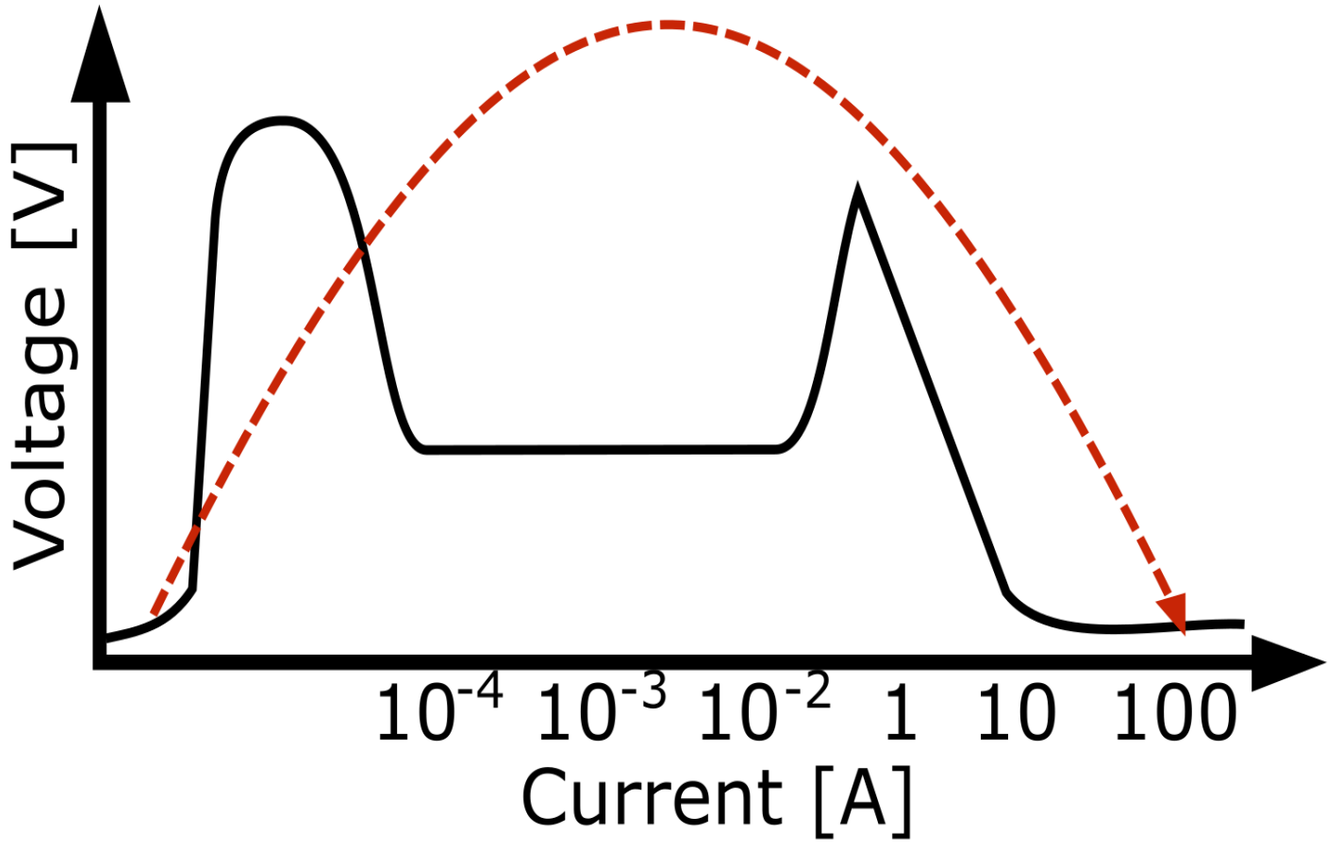
Reproducibility and Uniformity → Microsecond discharges

Possible with voltages over 100 kV

Discharge Plasma Source - Challenge

10 m x 25 mm tube:
I = **400 A**
V = **100 kV**
P = 400 A x 100 kV = **40 MW**

Prohibitive
… high voltage switching
… large capacitor bank
… low efficiency
… safety restrictions

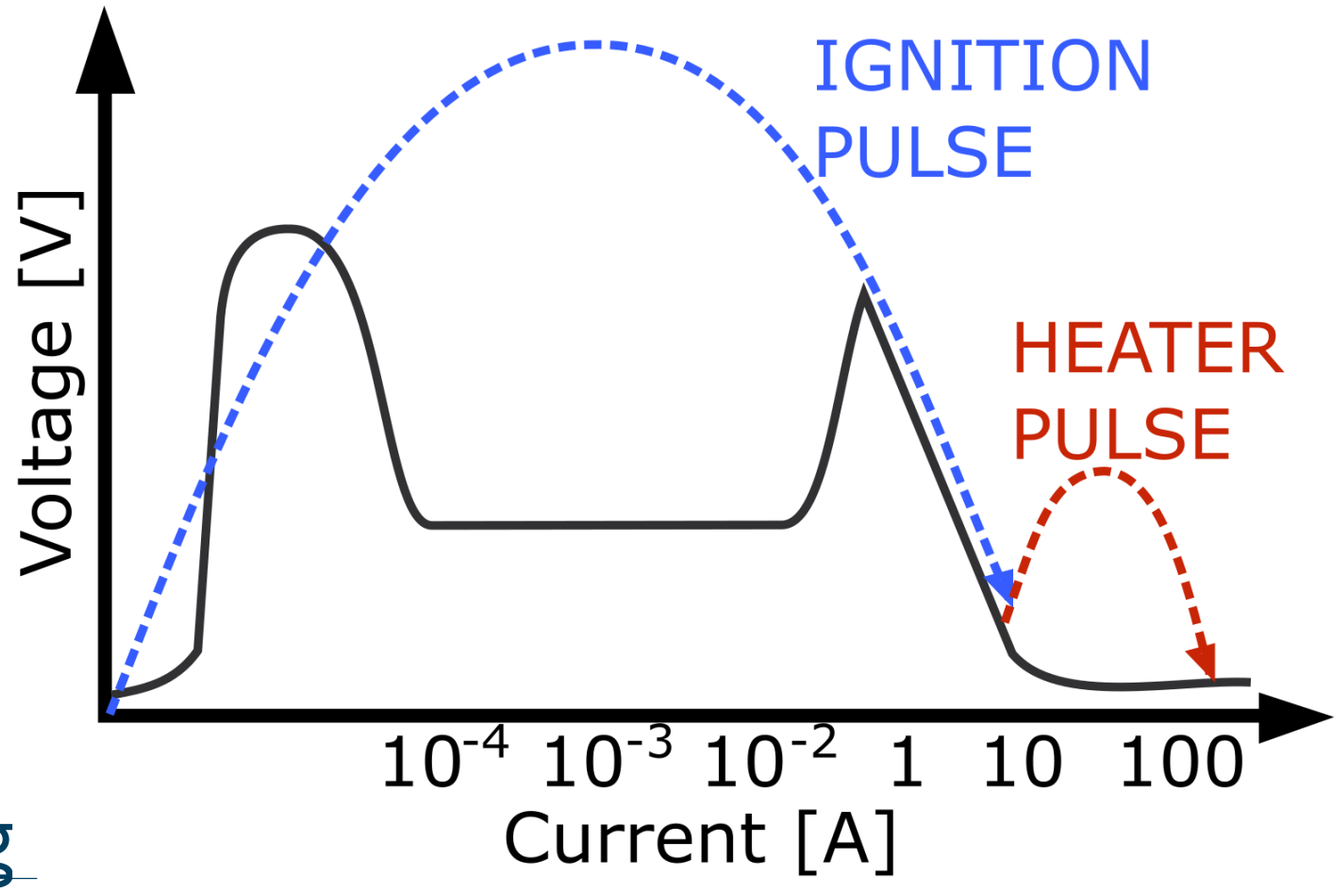


Double Pulse Solution

10 m x 25 mm tube:
I = **400 A**
V = **100 kV**
P = 400 A x 100 kV = **40 MW**

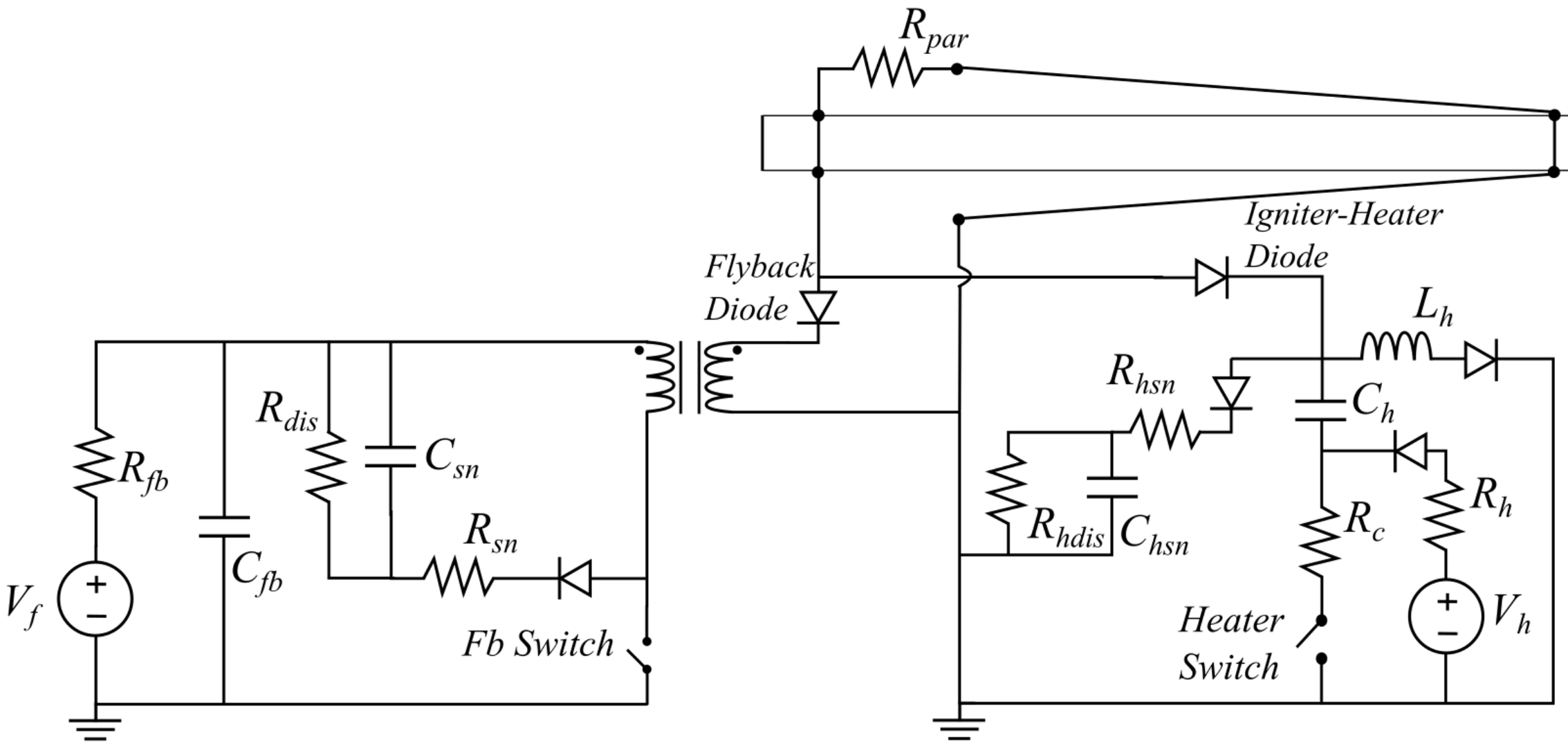
Prohibitive
… high voltage switching
… large capacitor bank
… low efficiency
… safety restrictions

possible solution
double pulse: **ignition + heating**

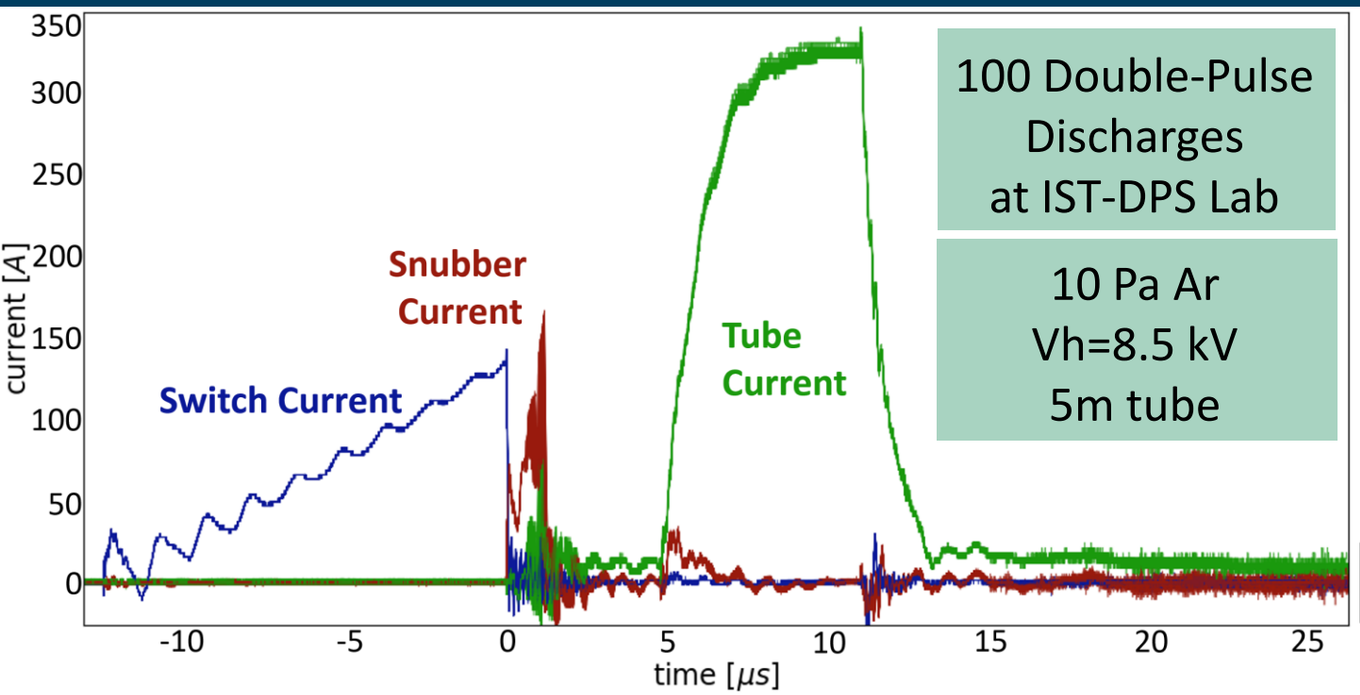


Double Pulse Generator - Circuit

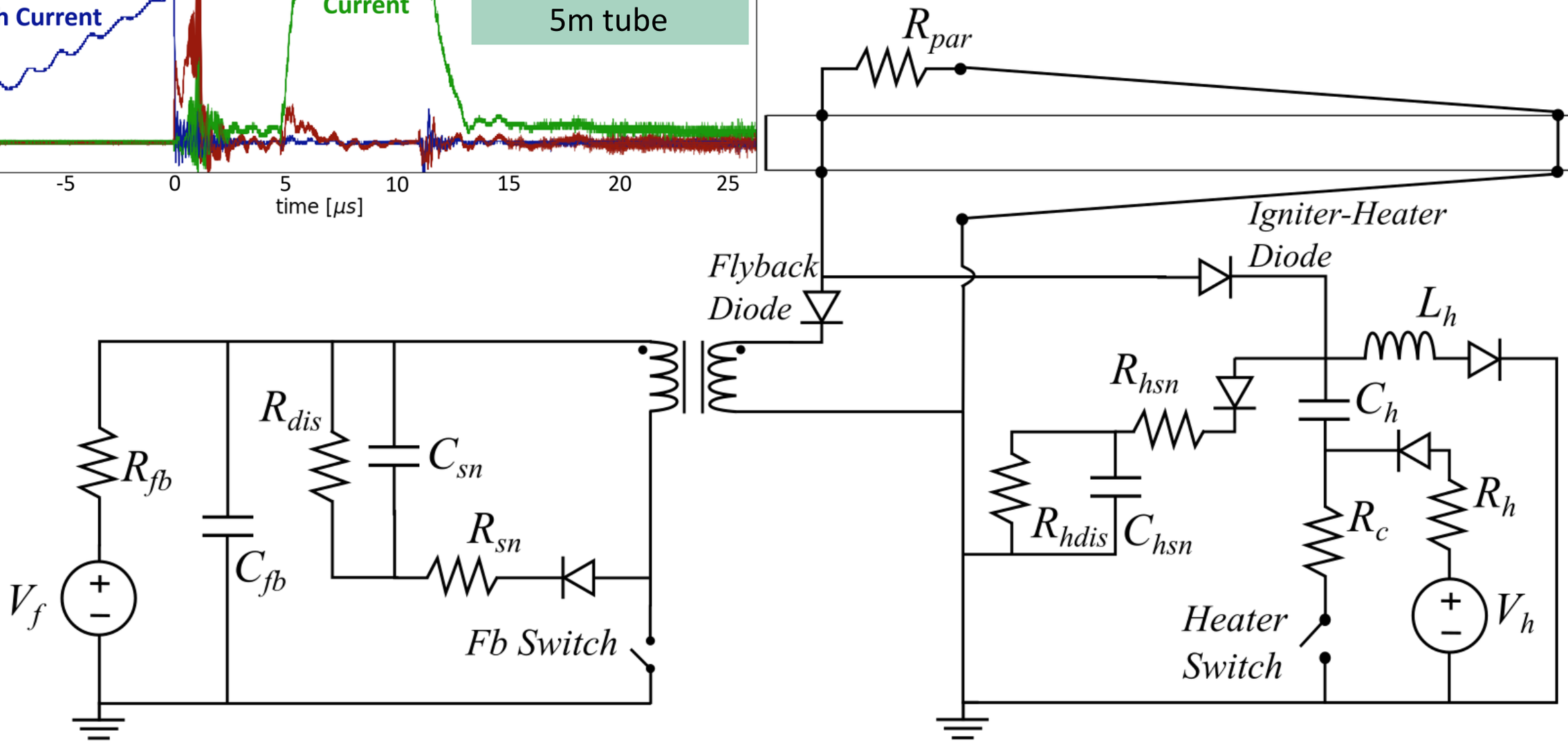
Double Pulse Generator circuit with ignition and heating sub-circuits



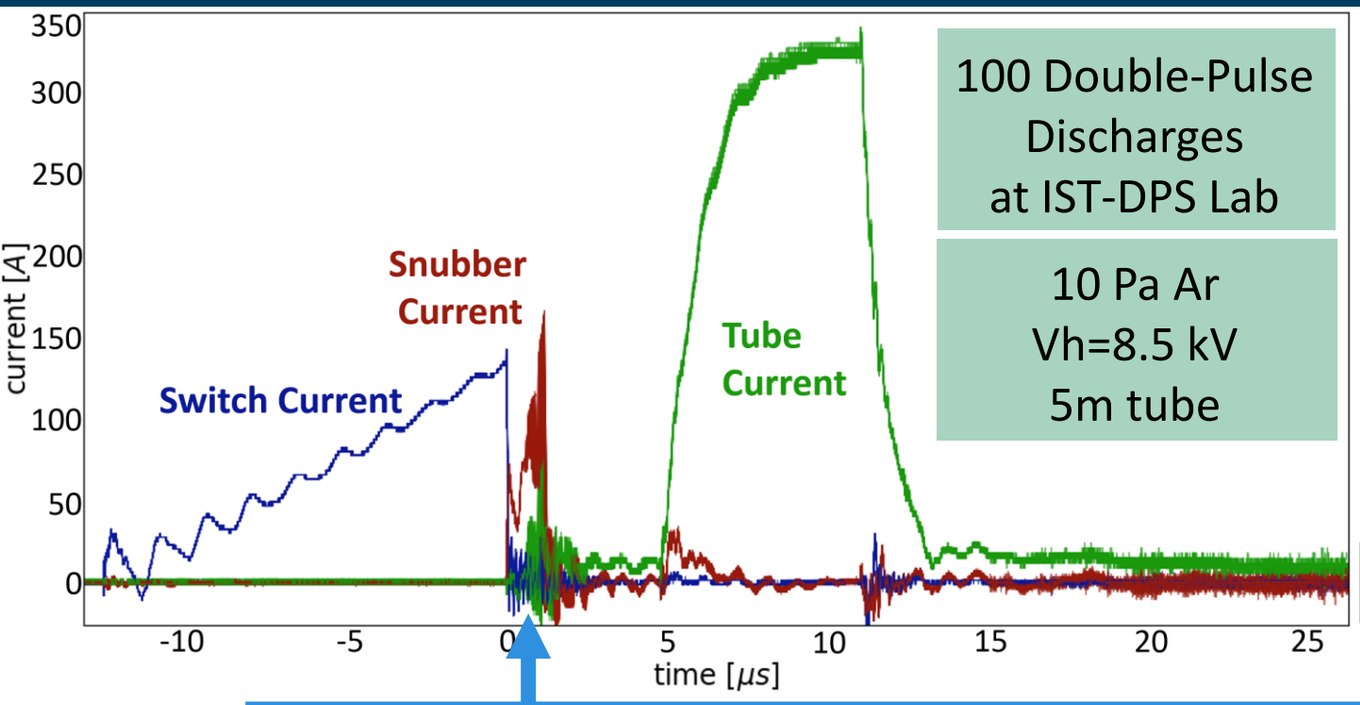
Double Pulse Generator - Circuit



Double Pulse Generator circuit with ignition and heating sub-circuits
Example of typical current waveforms measured

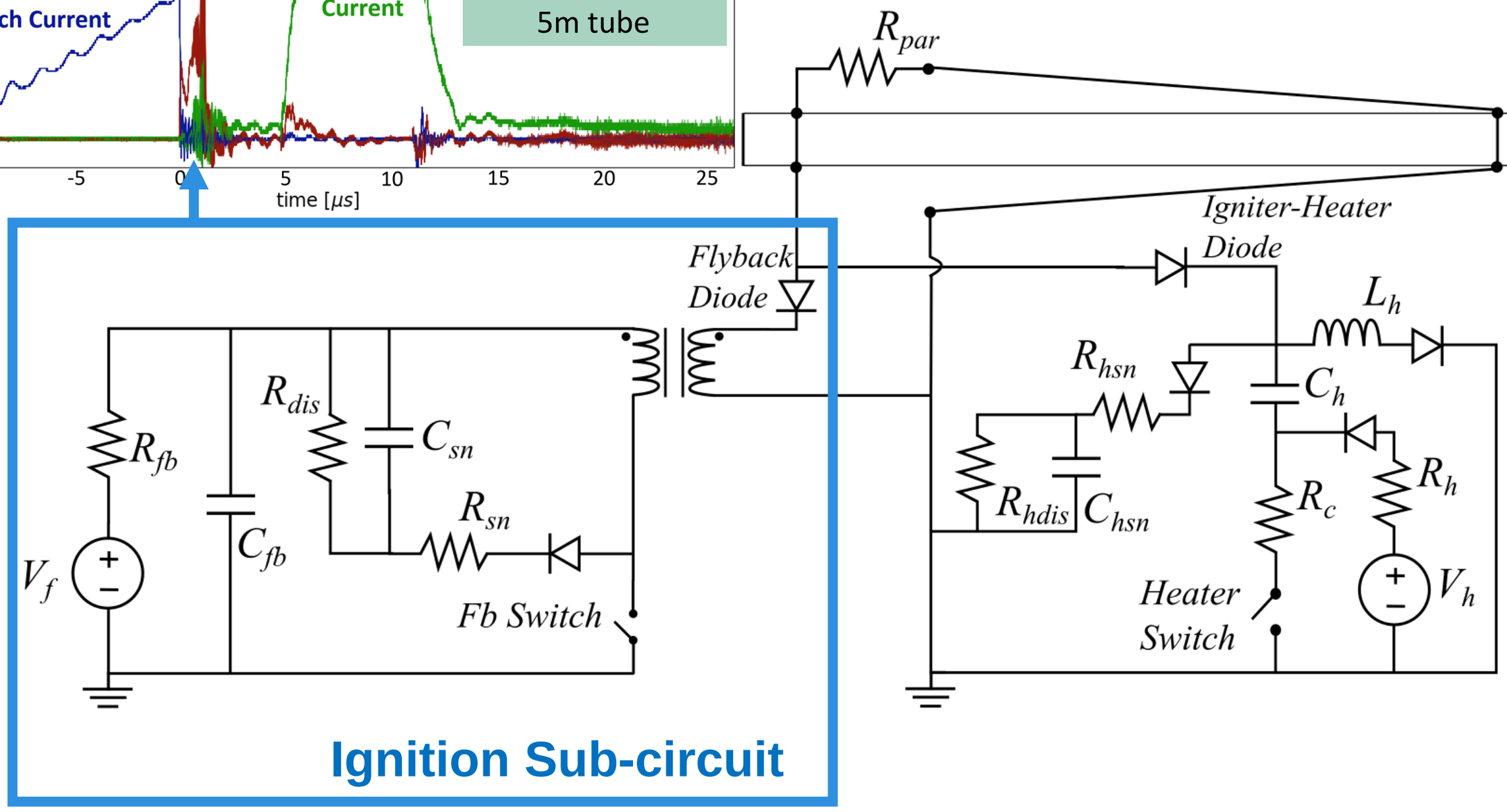


Double Pulse Generator - Circuit

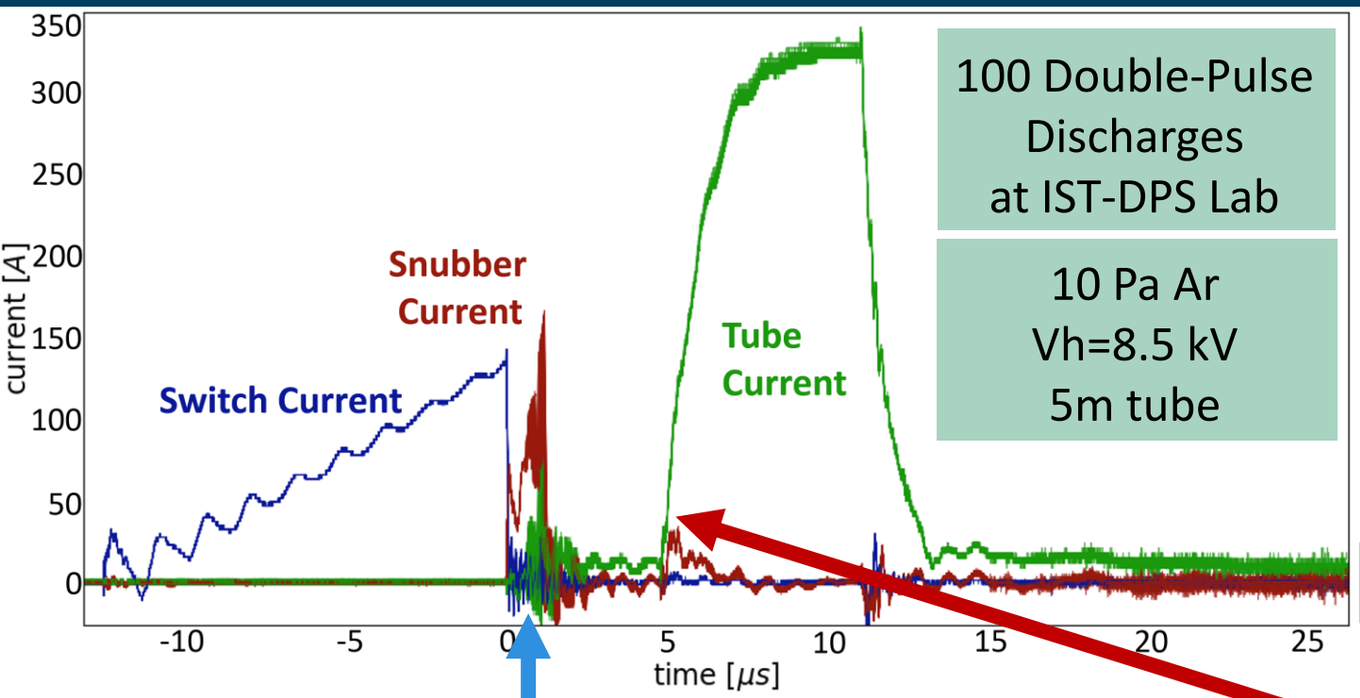


Double Pulse Generator circuit with **ignition** and heating sub-circuits

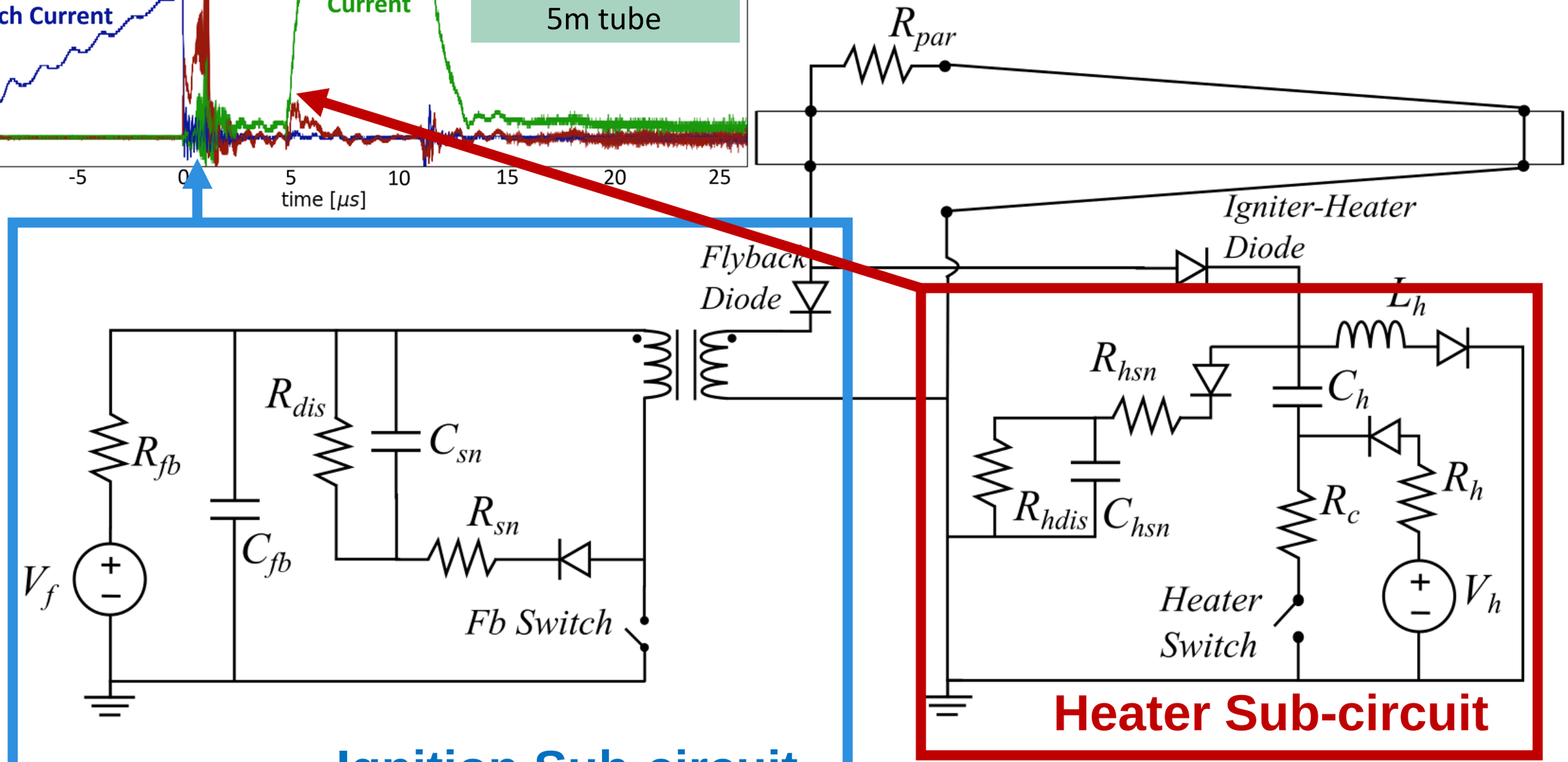
Ignition pulse sets the tube into a highly conductive arc



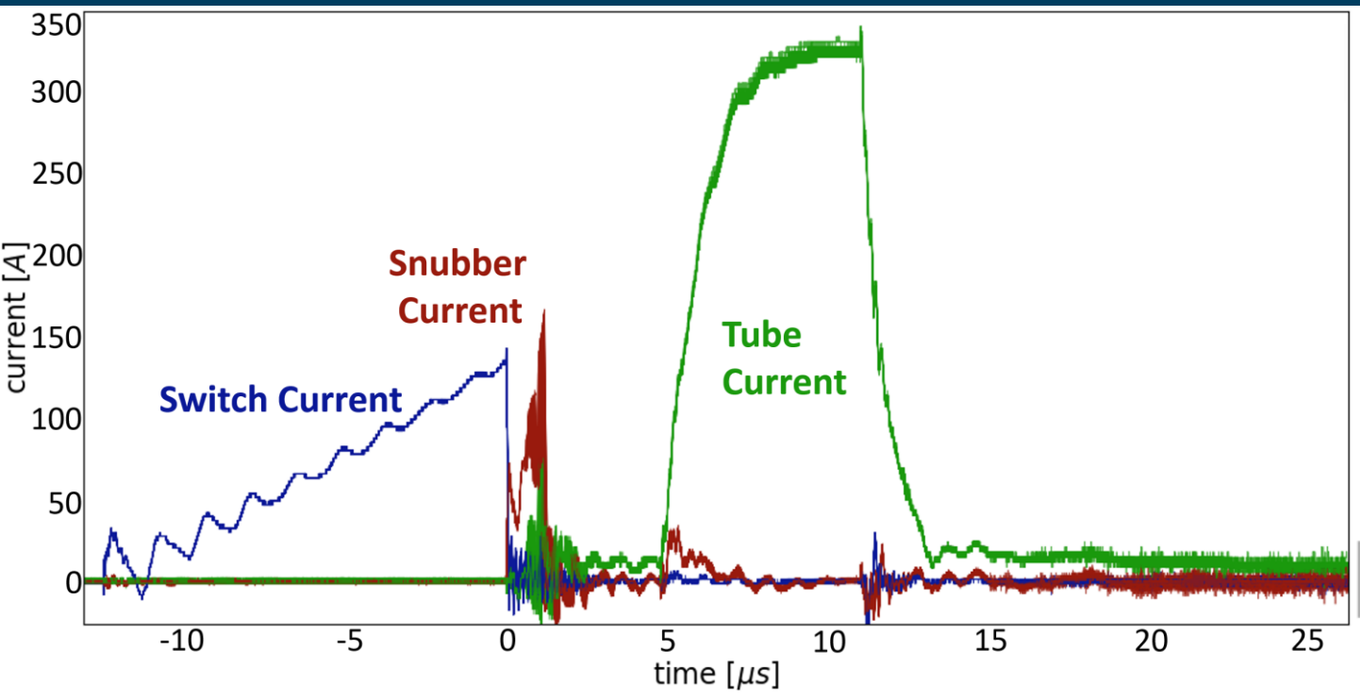
Double Pulse Generator - Circuit



Double Pulse Generator circuit with ignition and **heating** sub-circuits
Heating pulse raises the plasma density and ionisation fraction

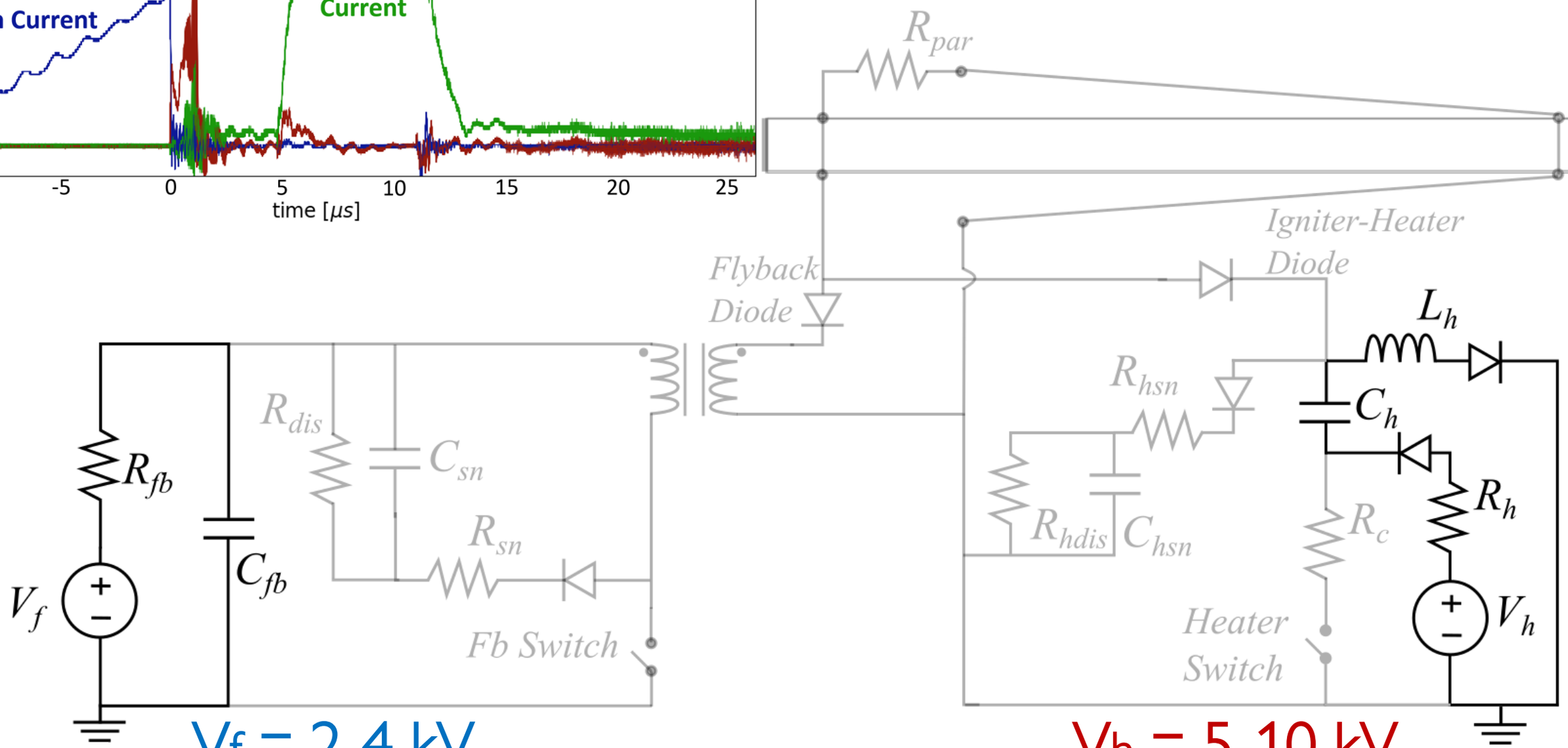


Double Pulse Generator - Operation



Mode 1

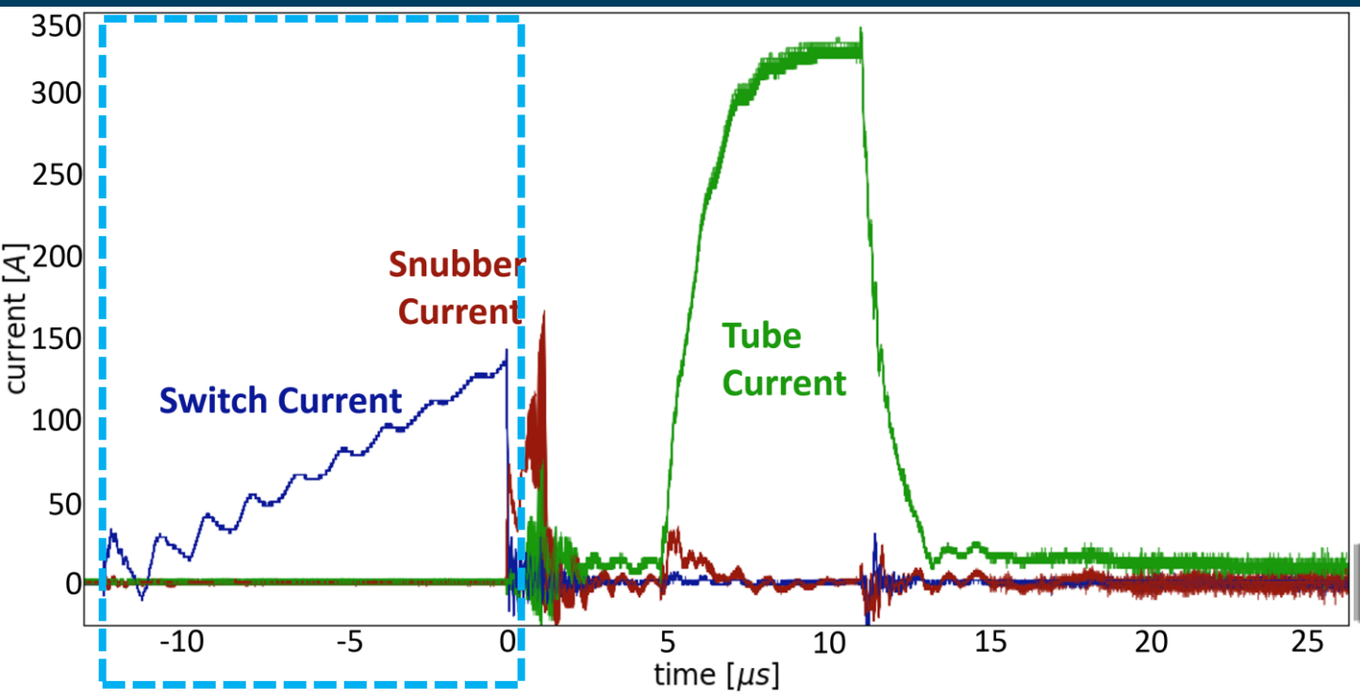
Capacitors charge to the input voltage



V_f = 2-4 kV
C_{fb} = 1 μF

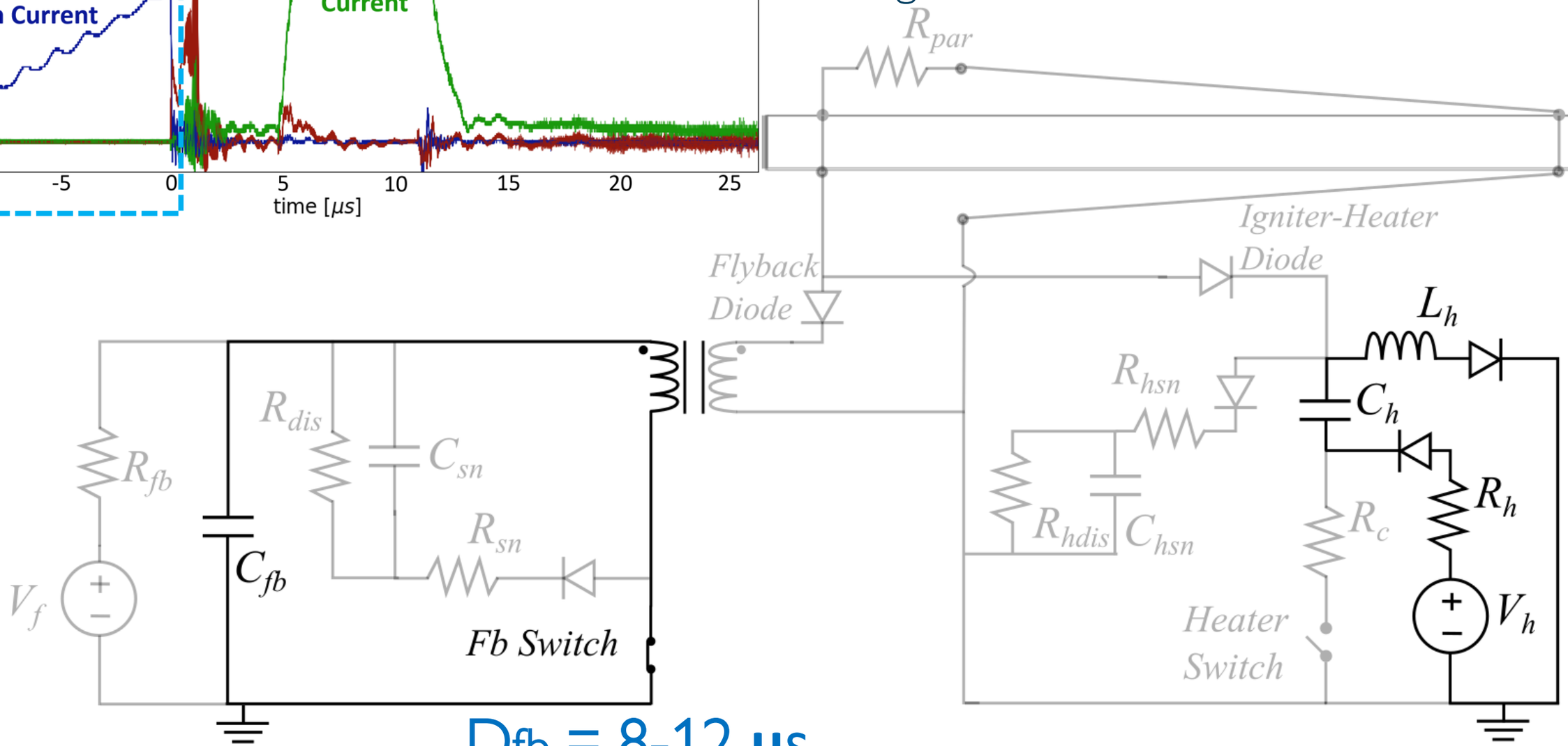
V_h = 5-10 kV
C_h = 1 μF

Double Pulse Generator - Operation



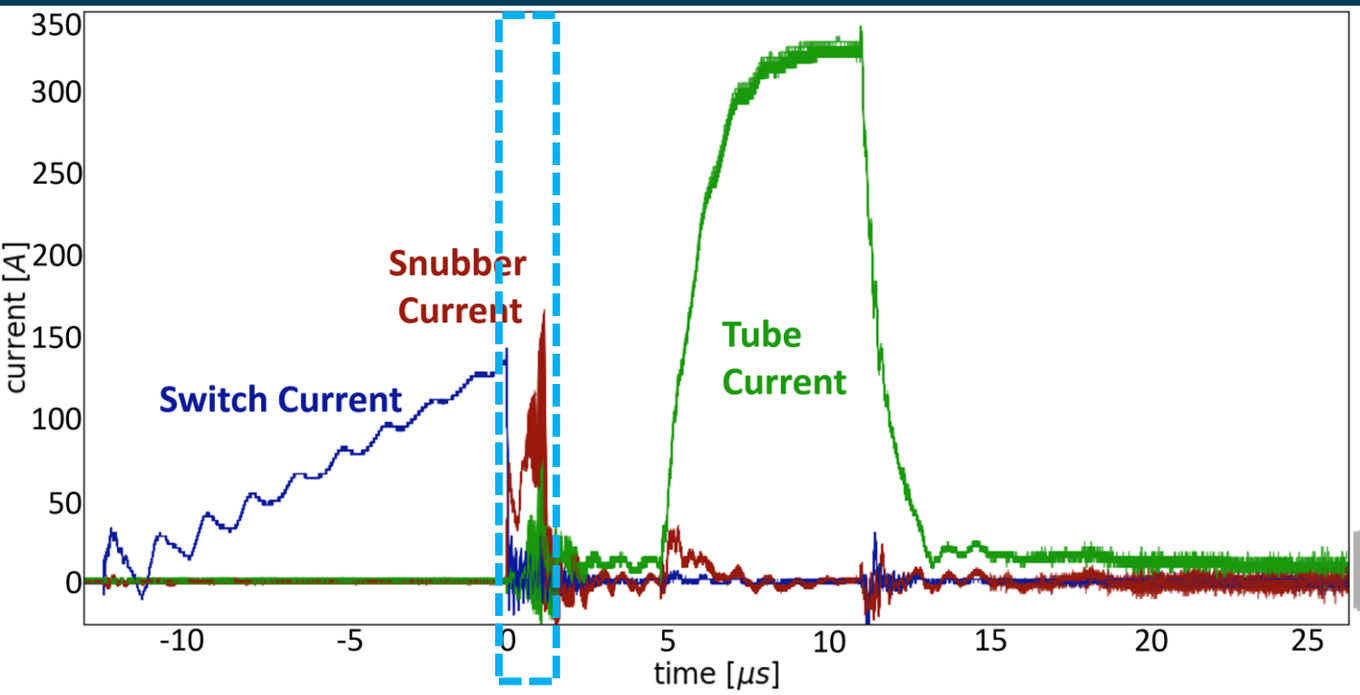
Mode 2

Transformer's magnetising inductance is charged



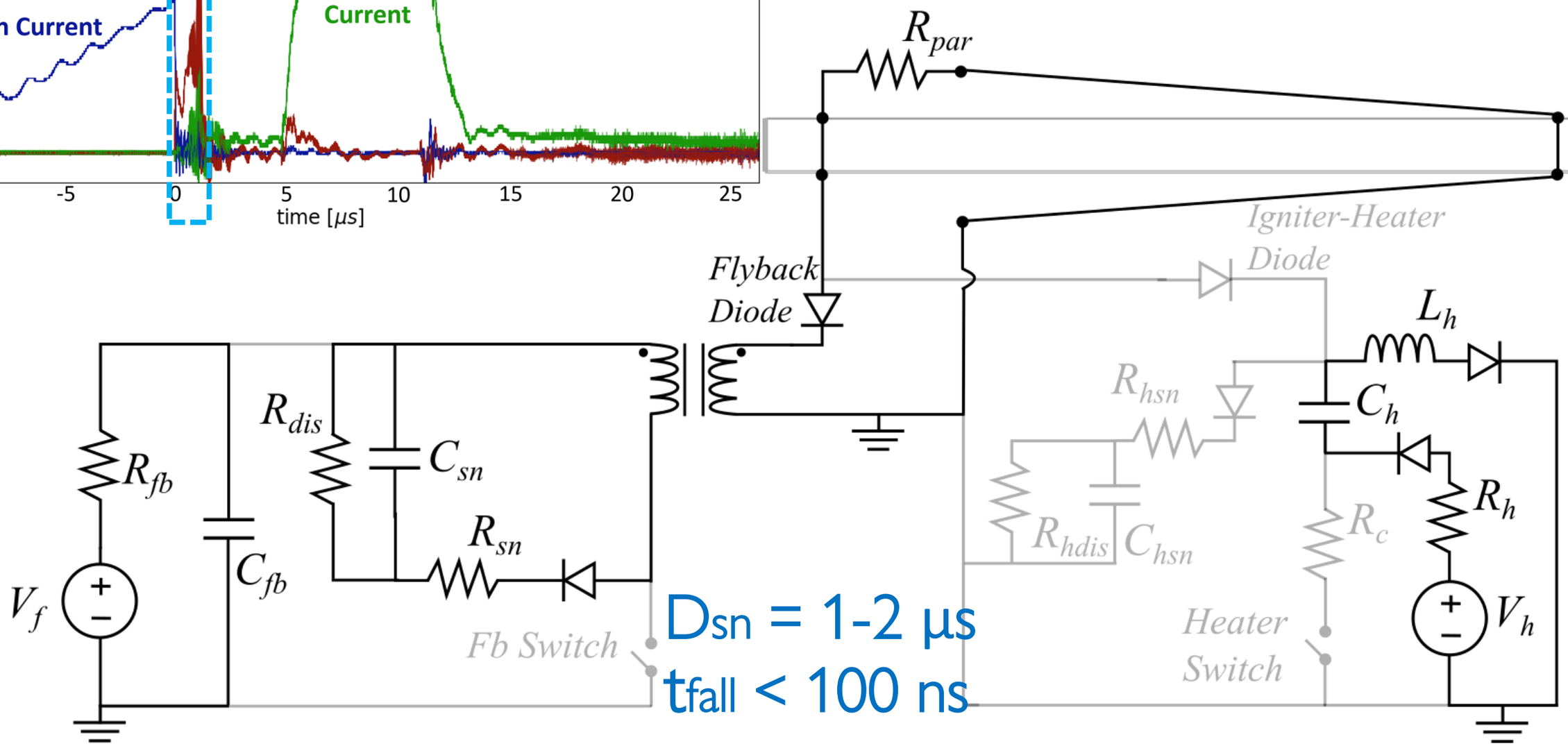
D_{fb} = 8-12 μs

Double Pulse Generator - Operation



Mode 3

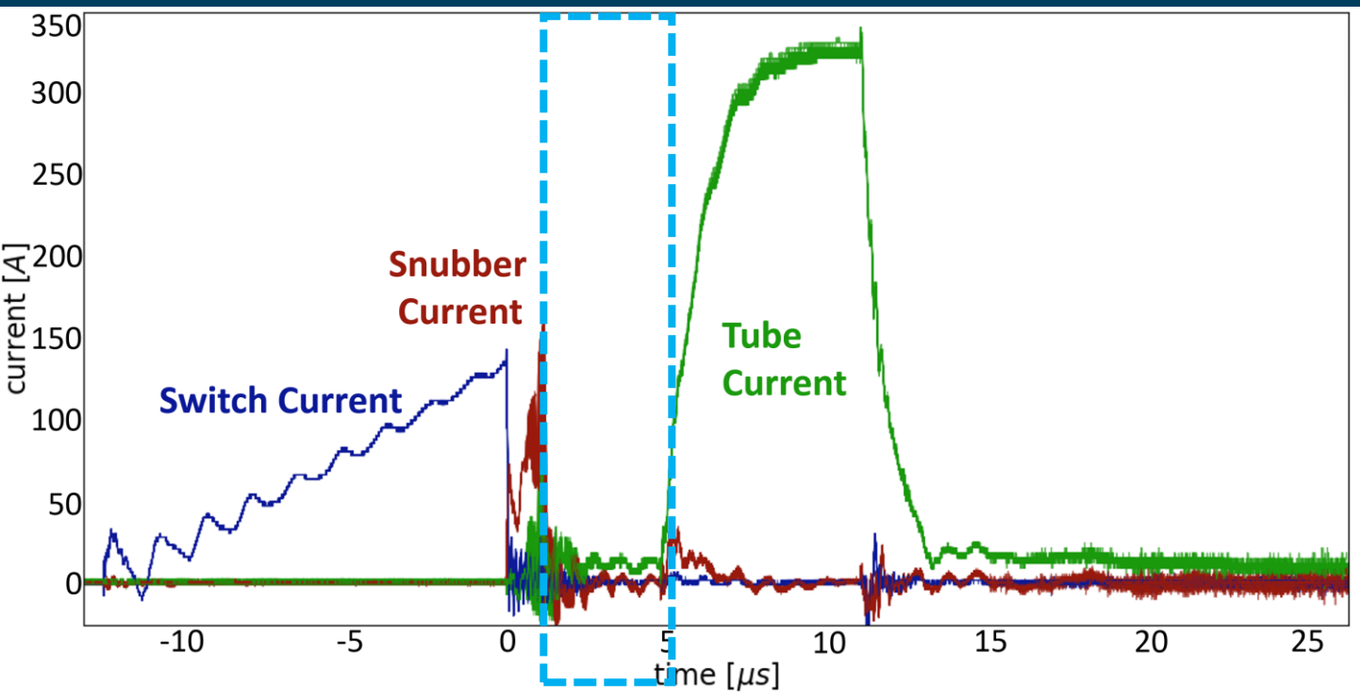
Snubber and Flyback diodes activate



D_{sn} = 1-2 µs

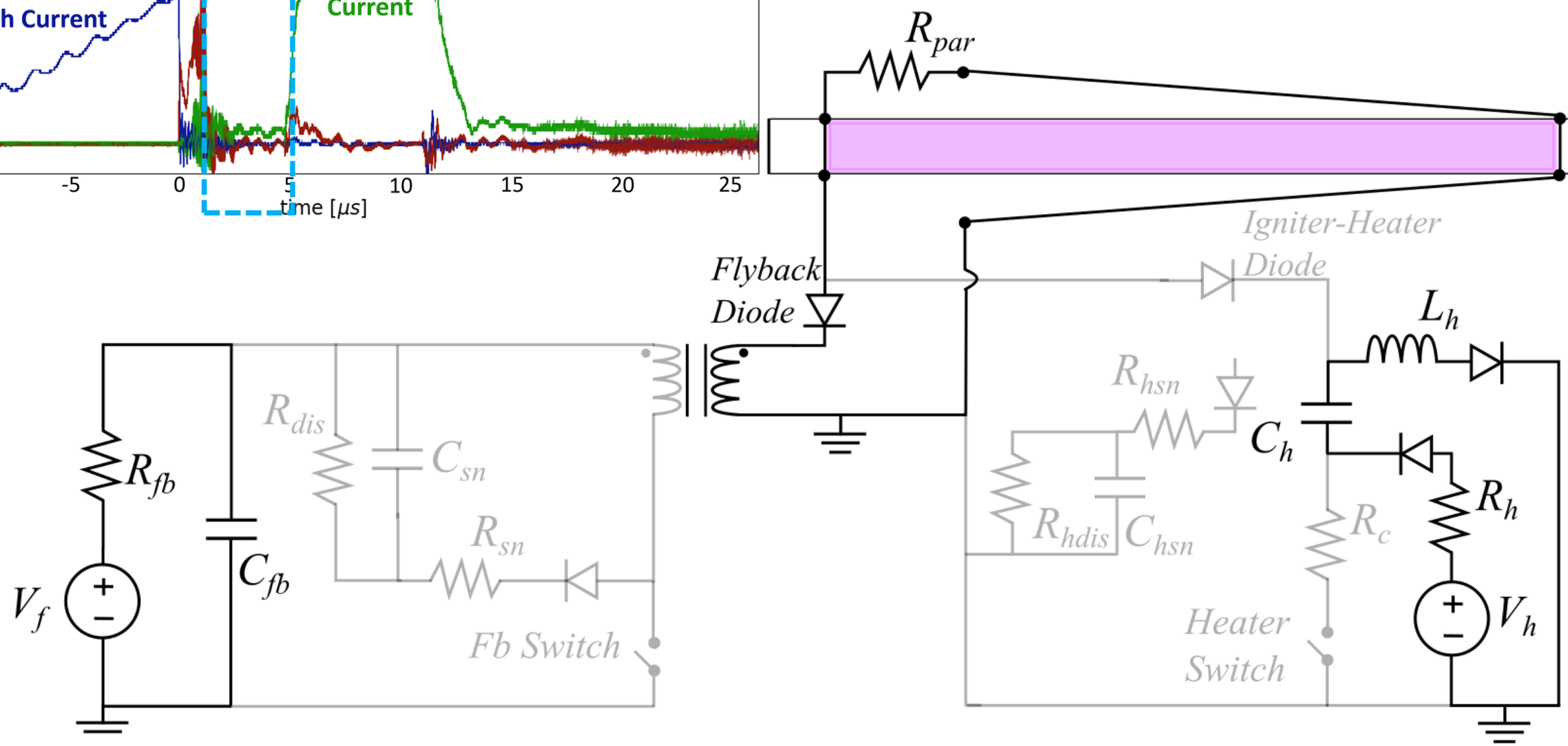
t_{fall} < 100 ns

Double Pulse Generator - Operation

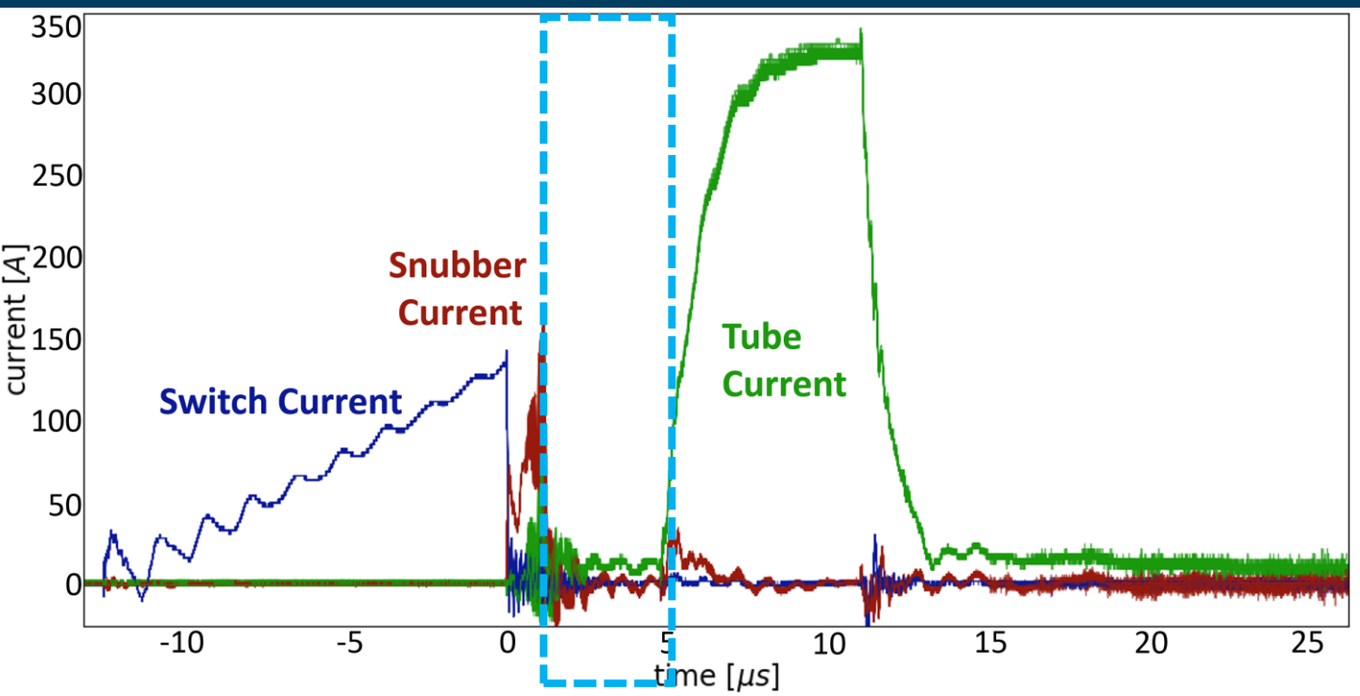


Mode 4

Plasma ignition. Tube is now conductive

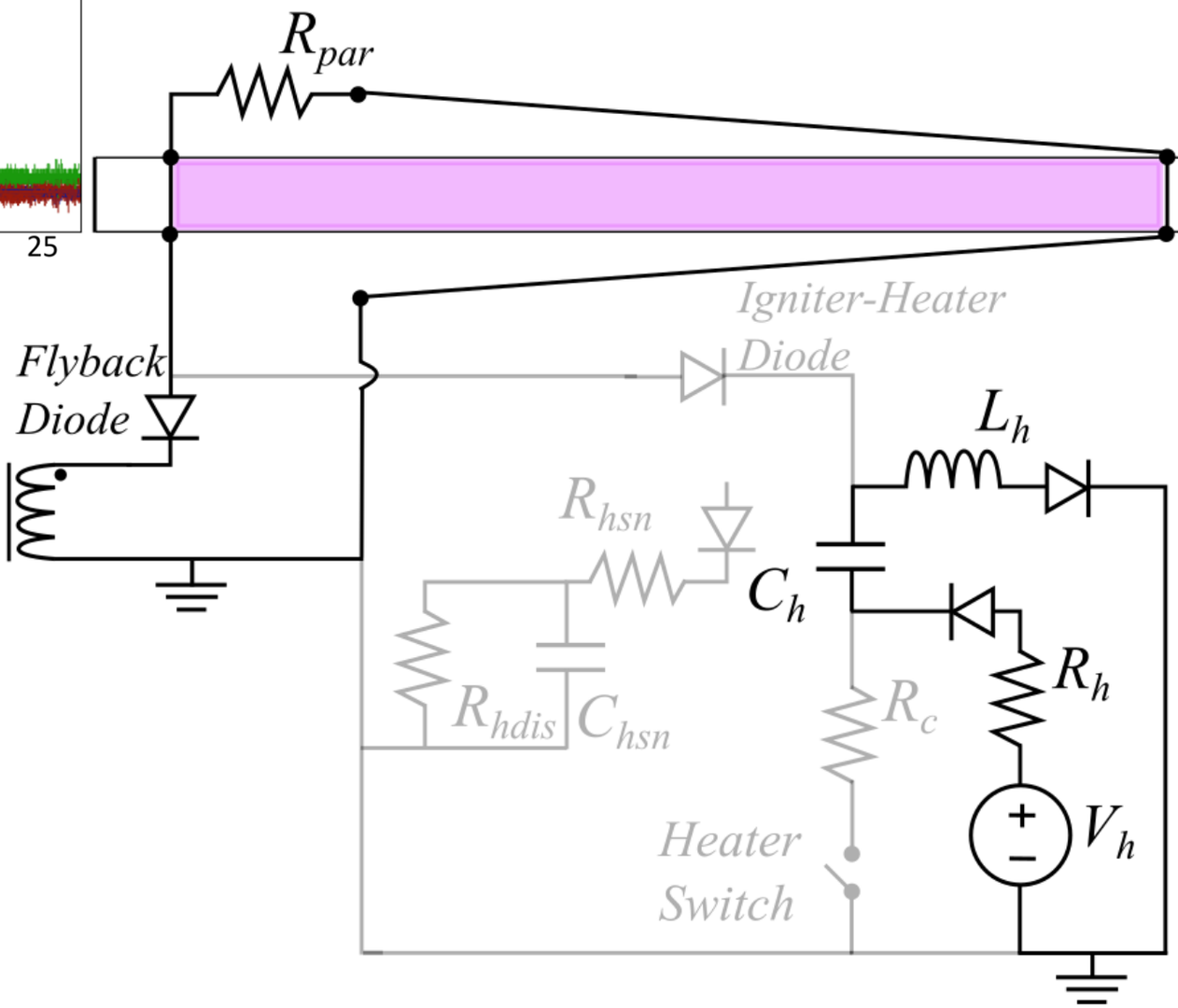


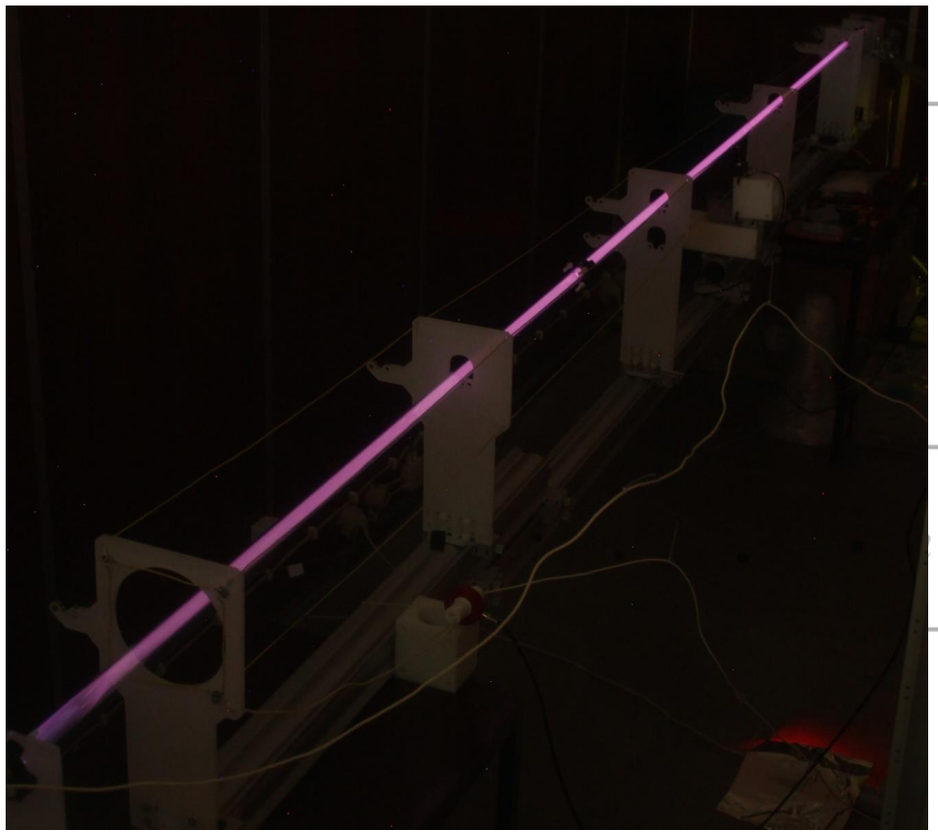
Double Pulse Generator - Operation



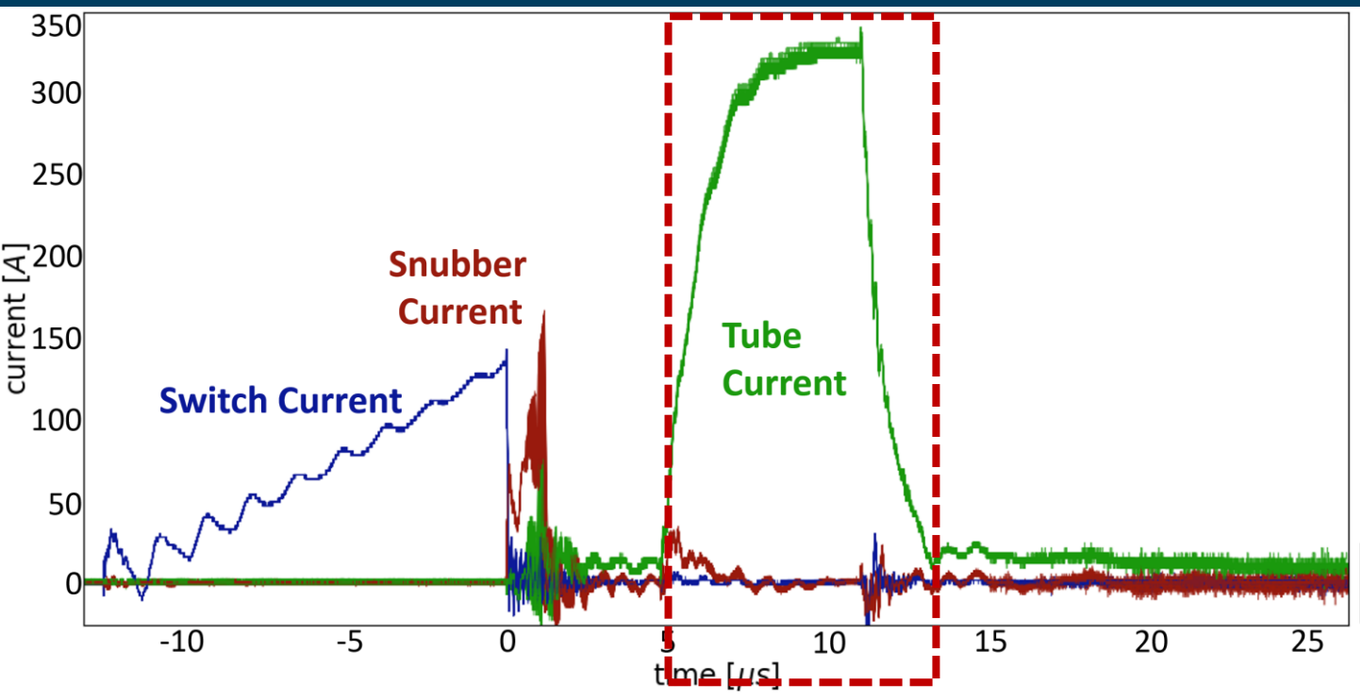
Mode 4

Plasma ignition. Tube is now conductive



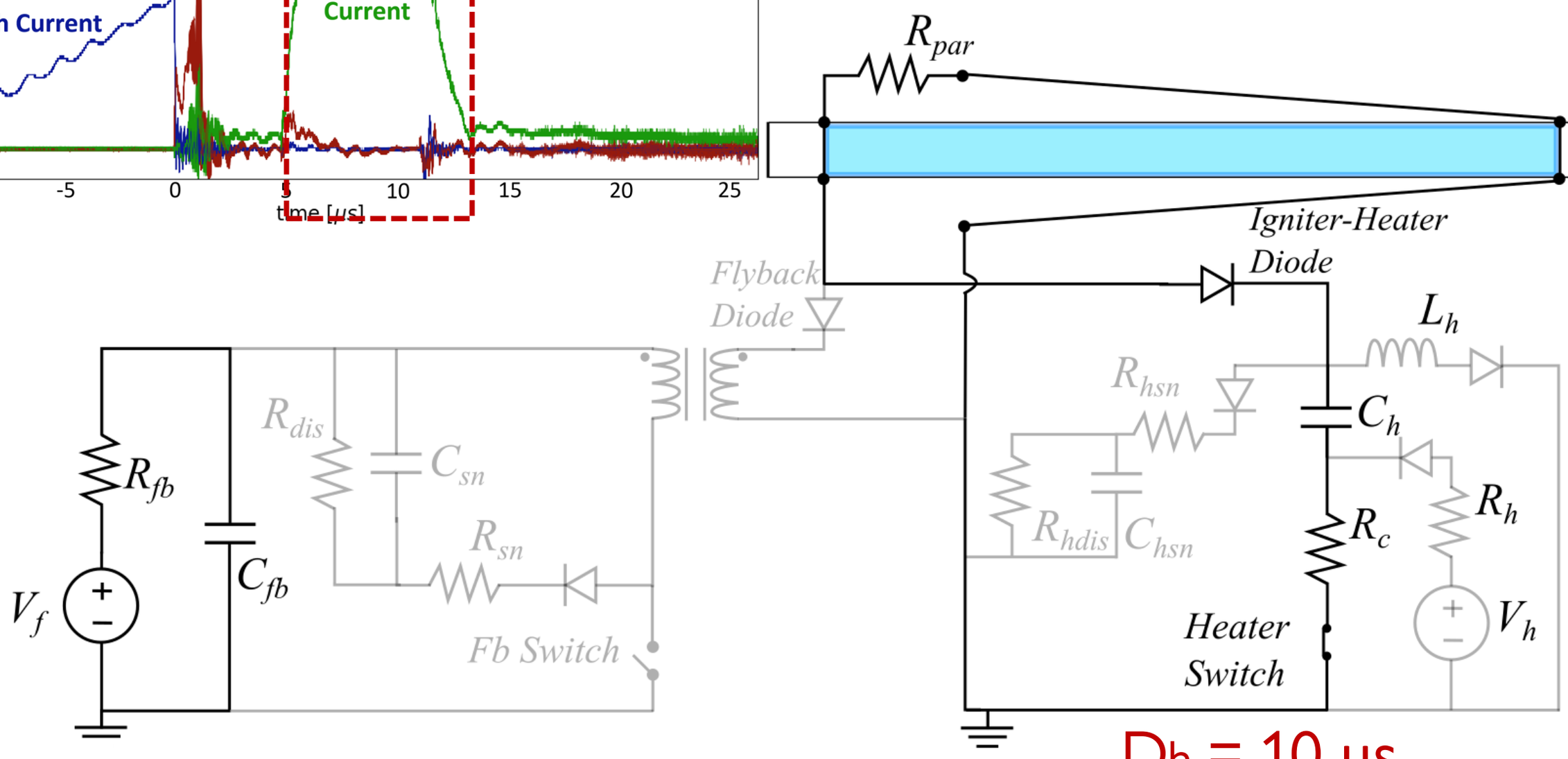


Double Pulse Generator - Operation



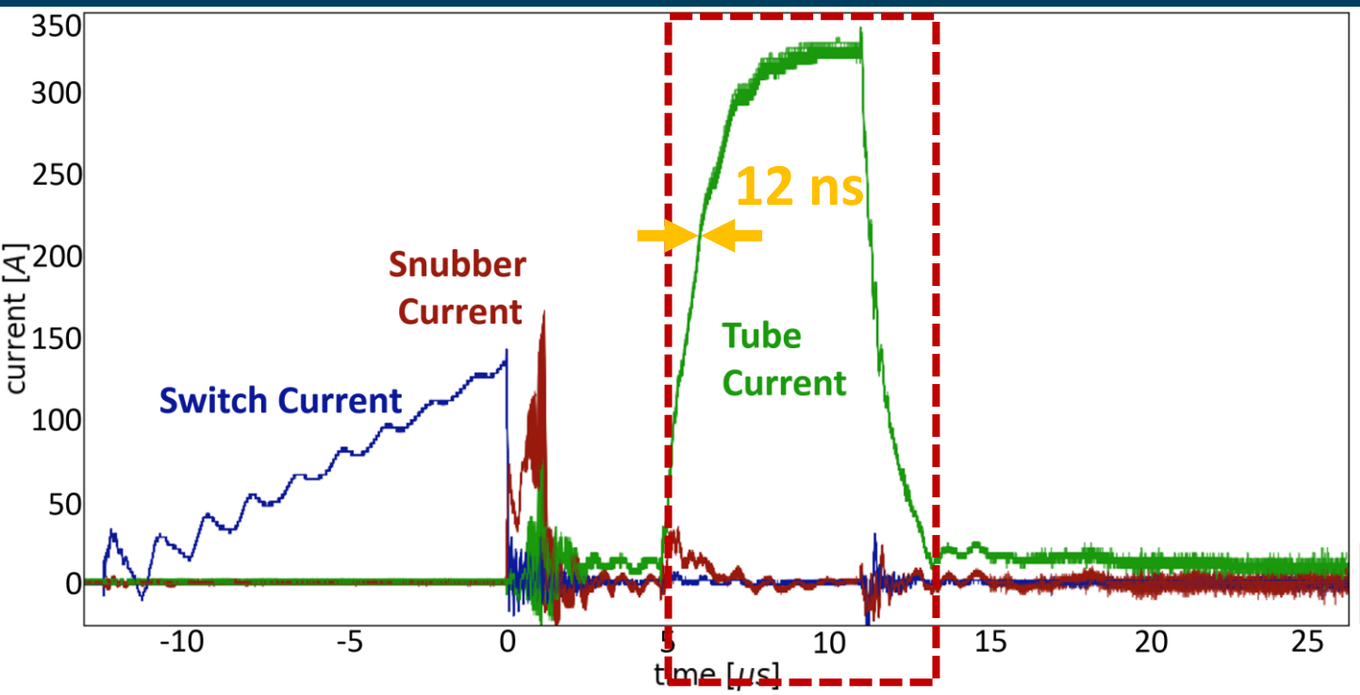
Mode 5

Heating stage. High-density plasma



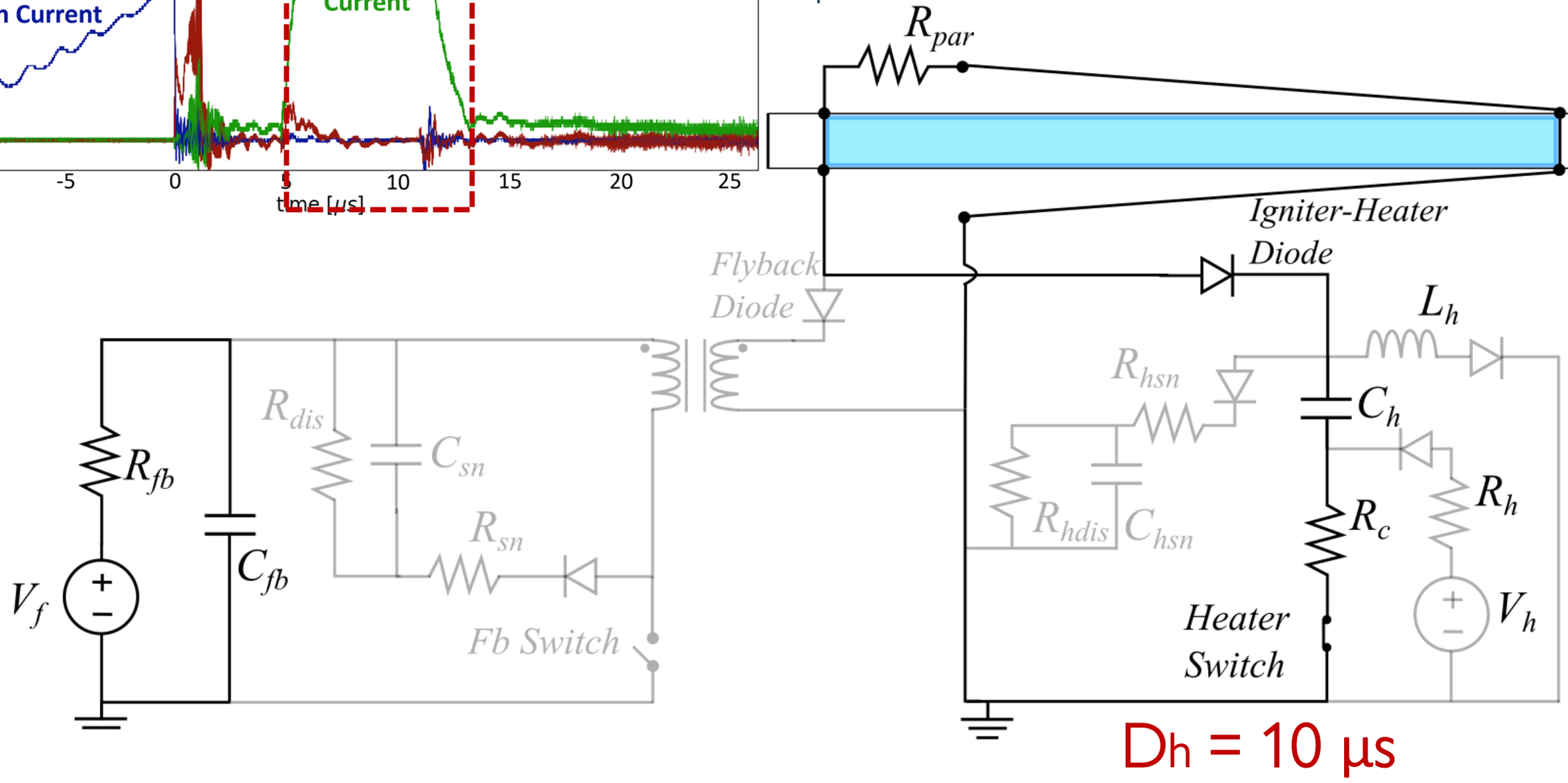
D_h = 10 µs

Double Pulse Generator - Operation



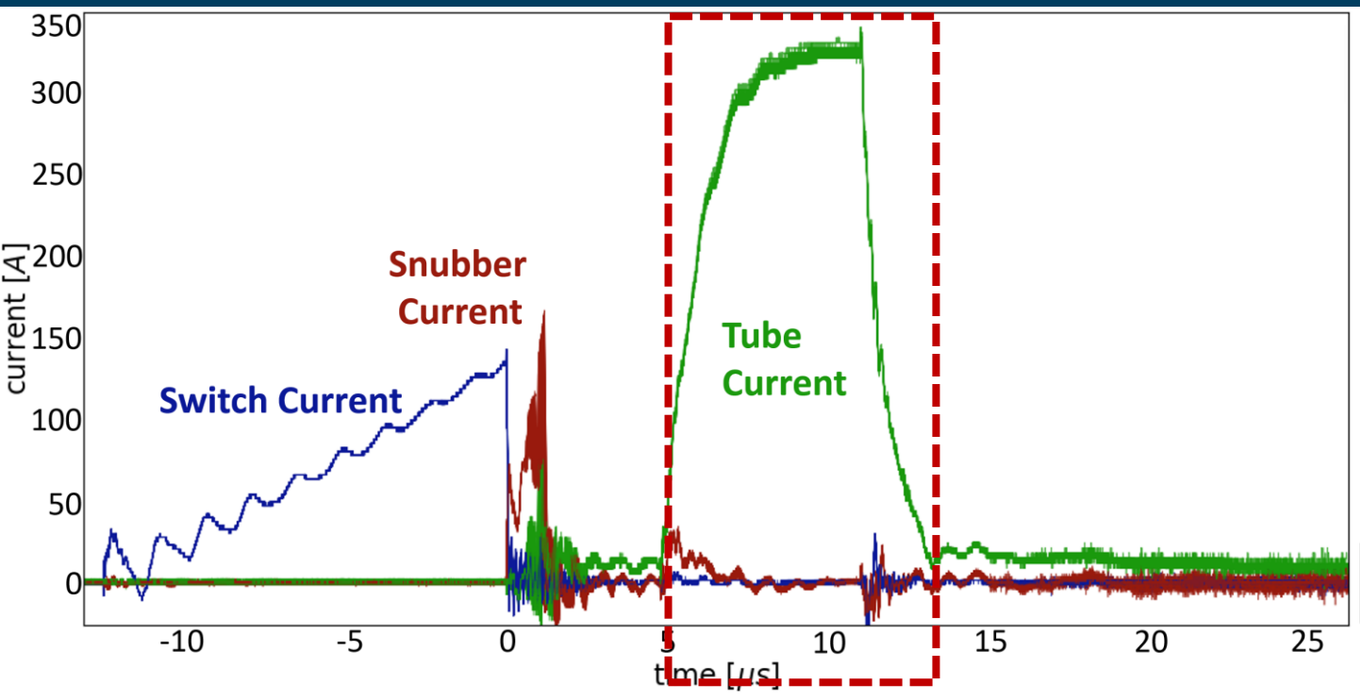
Mode 5

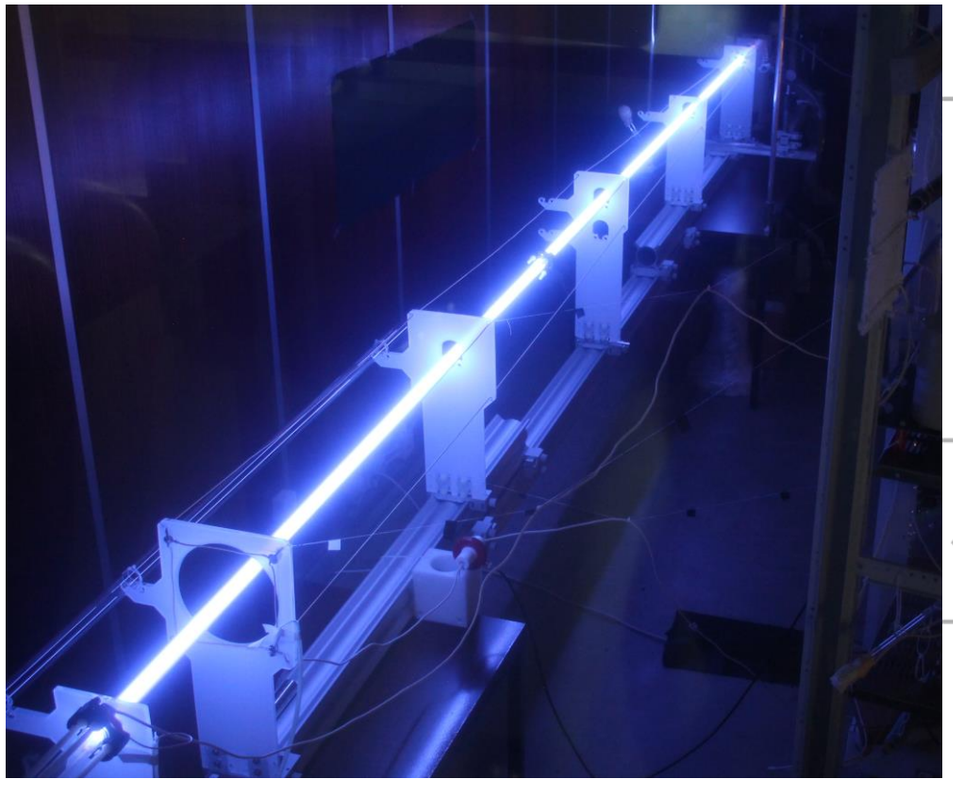
Heating stage. High-density **low jitter** plasma



D_h = 10 µs

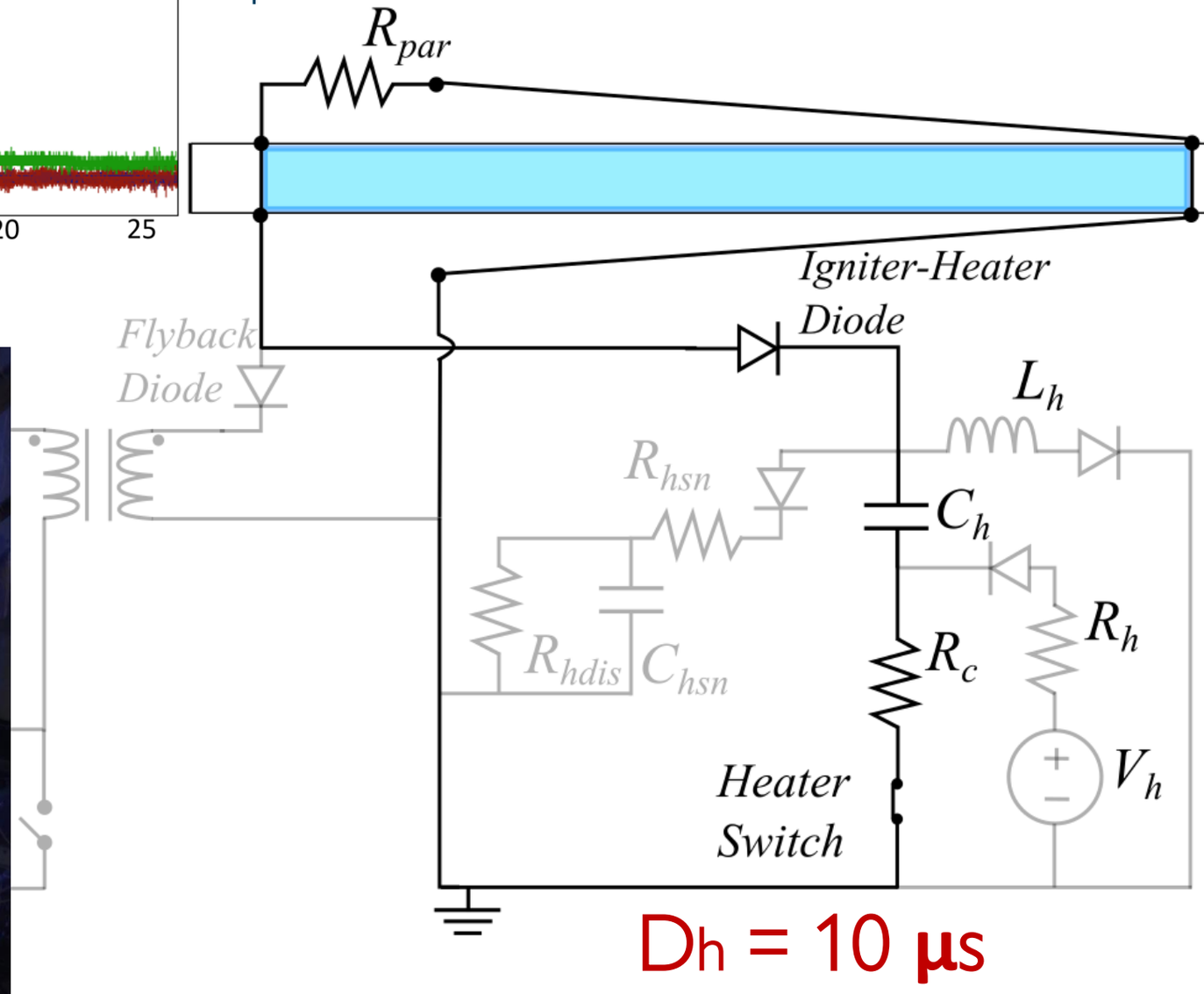
Double Pulse Generator - Operation





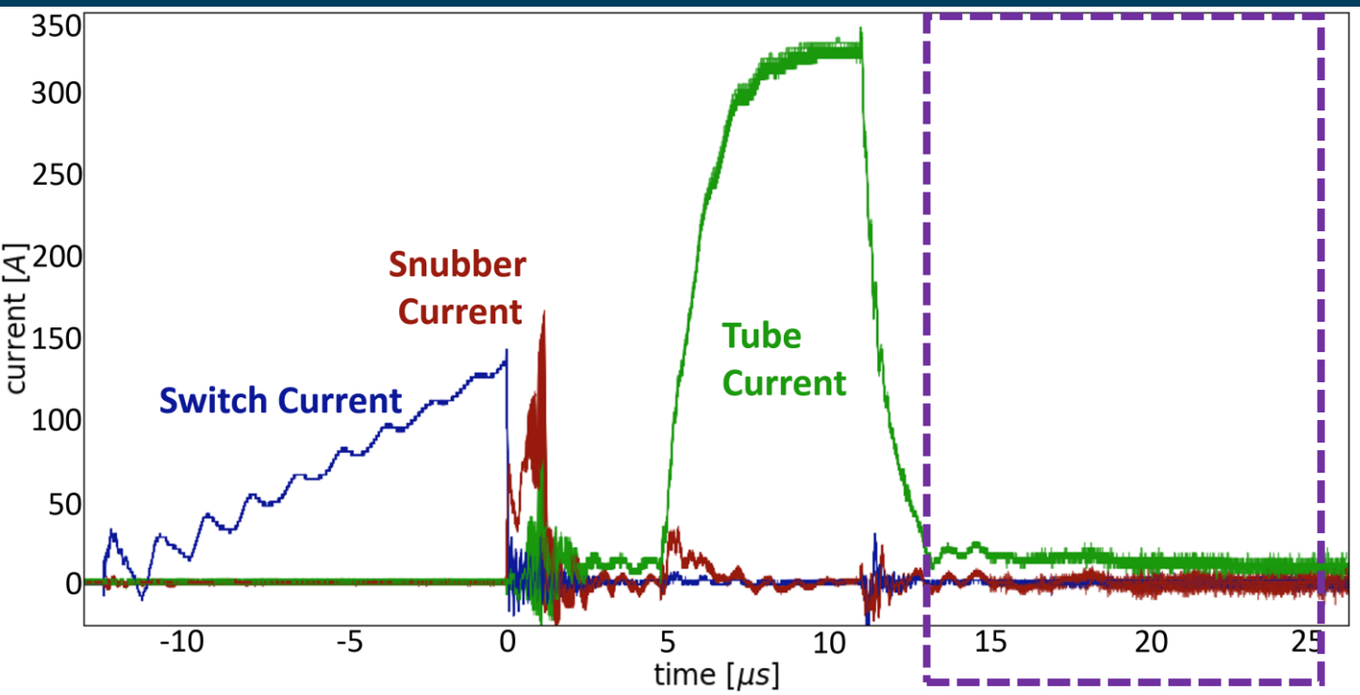
Mode 5

Heating stage. High-density low jitter plasma



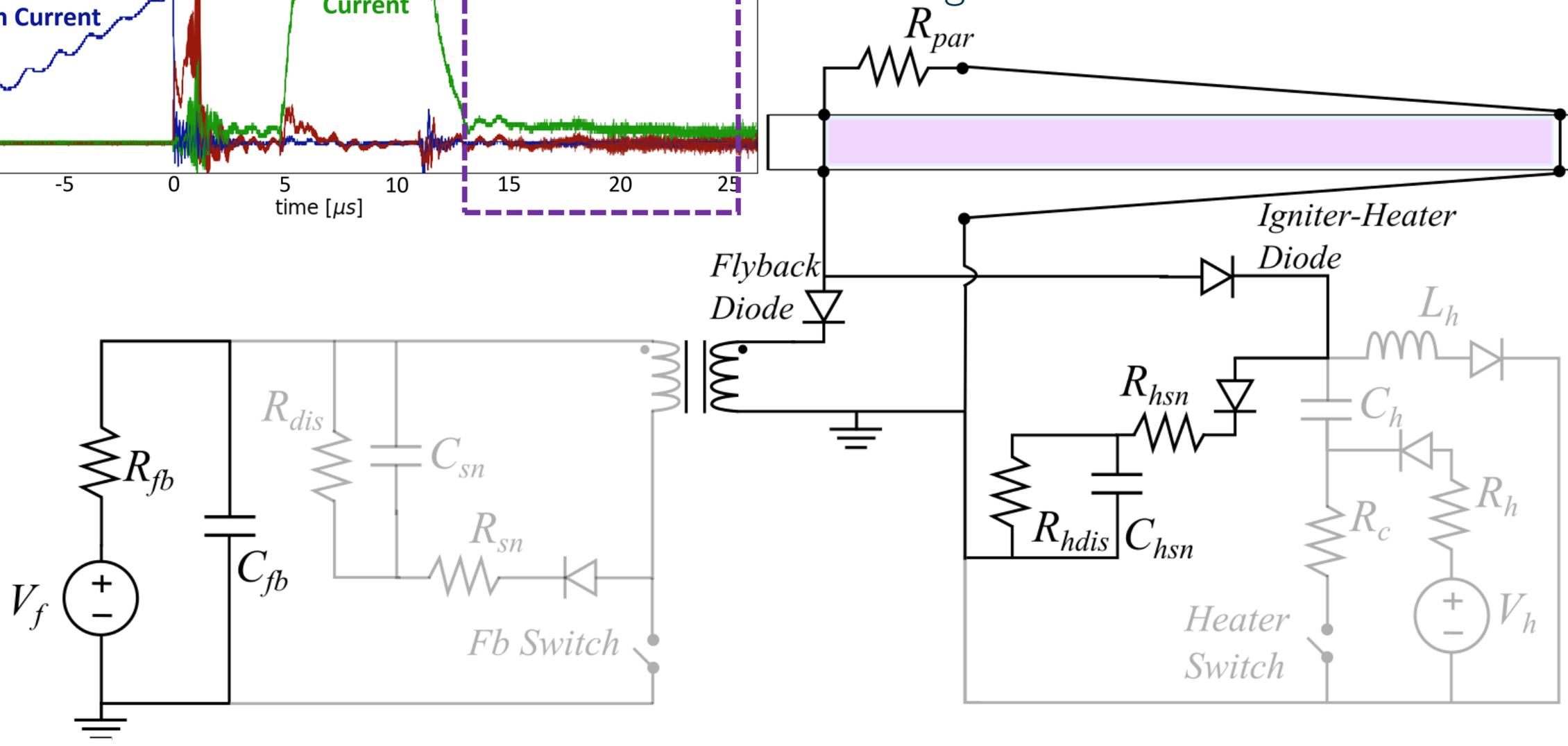
D_h = 10 µs

Double Pulse Generator - Operation

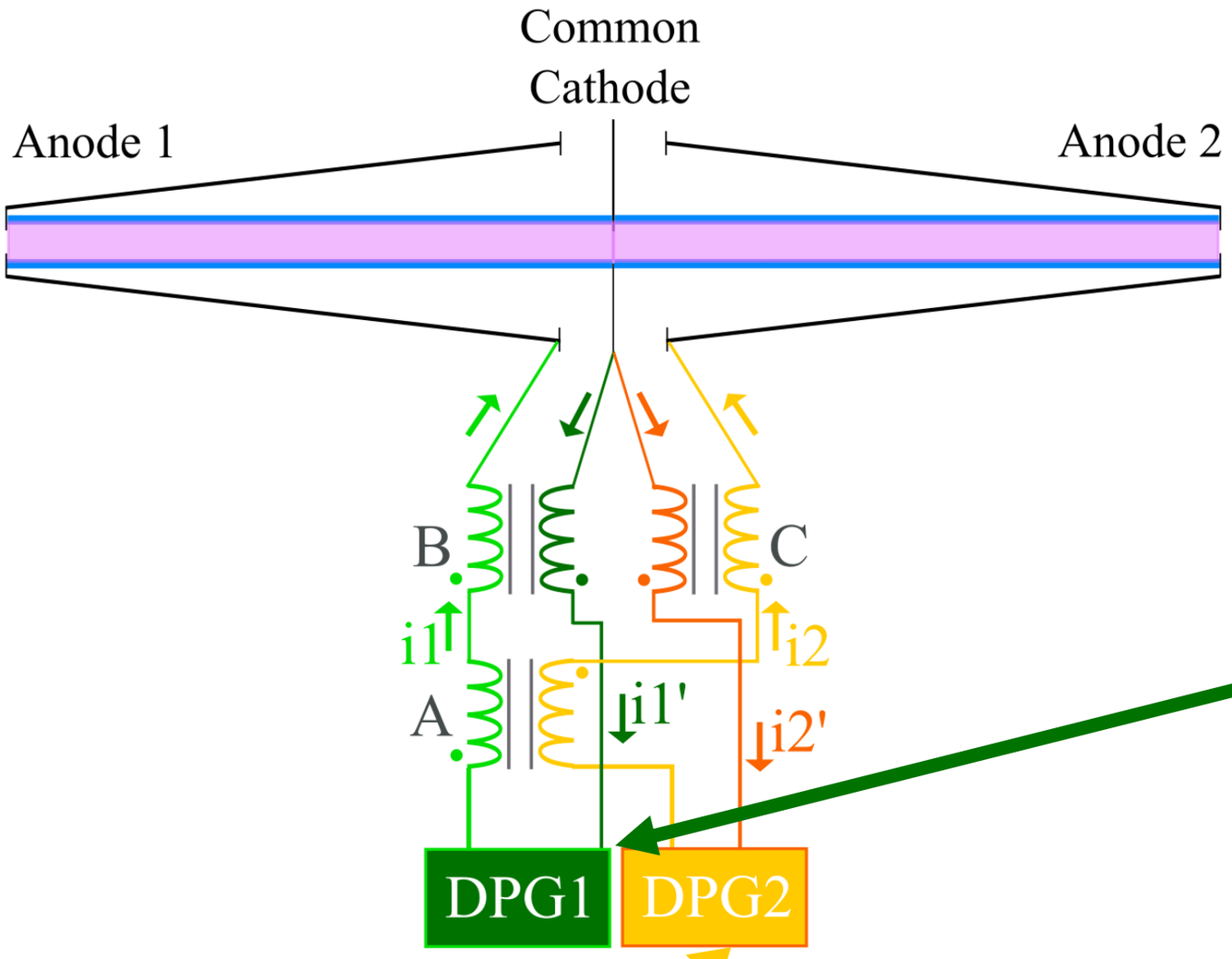


Mode 6

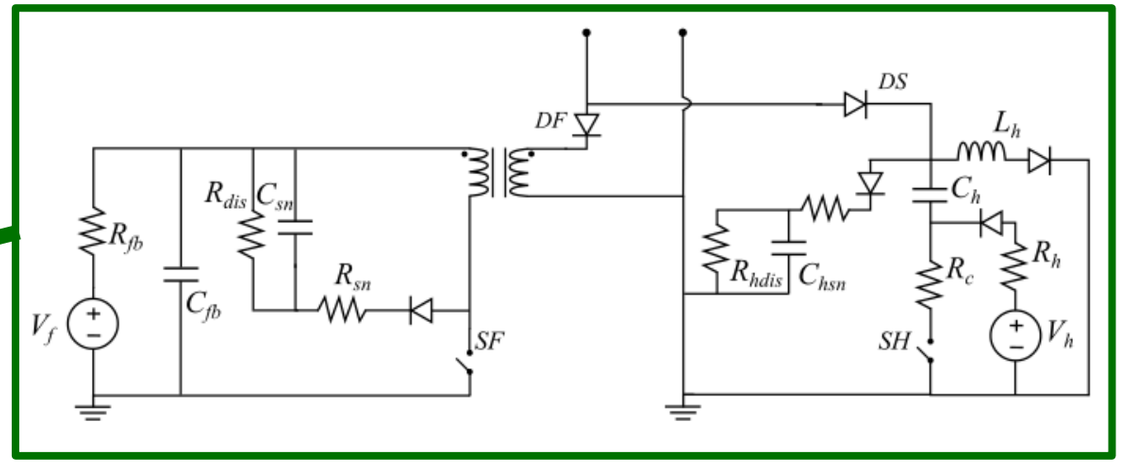
Transformer's remaining energy is discharged

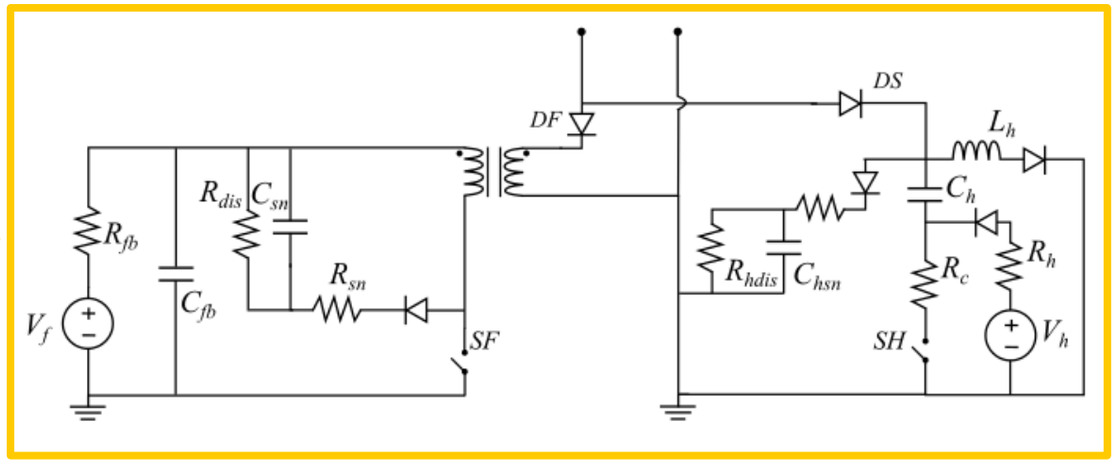


Discharge Plasma Source Scalability



Plasma source modules can be connected through common electrodes.



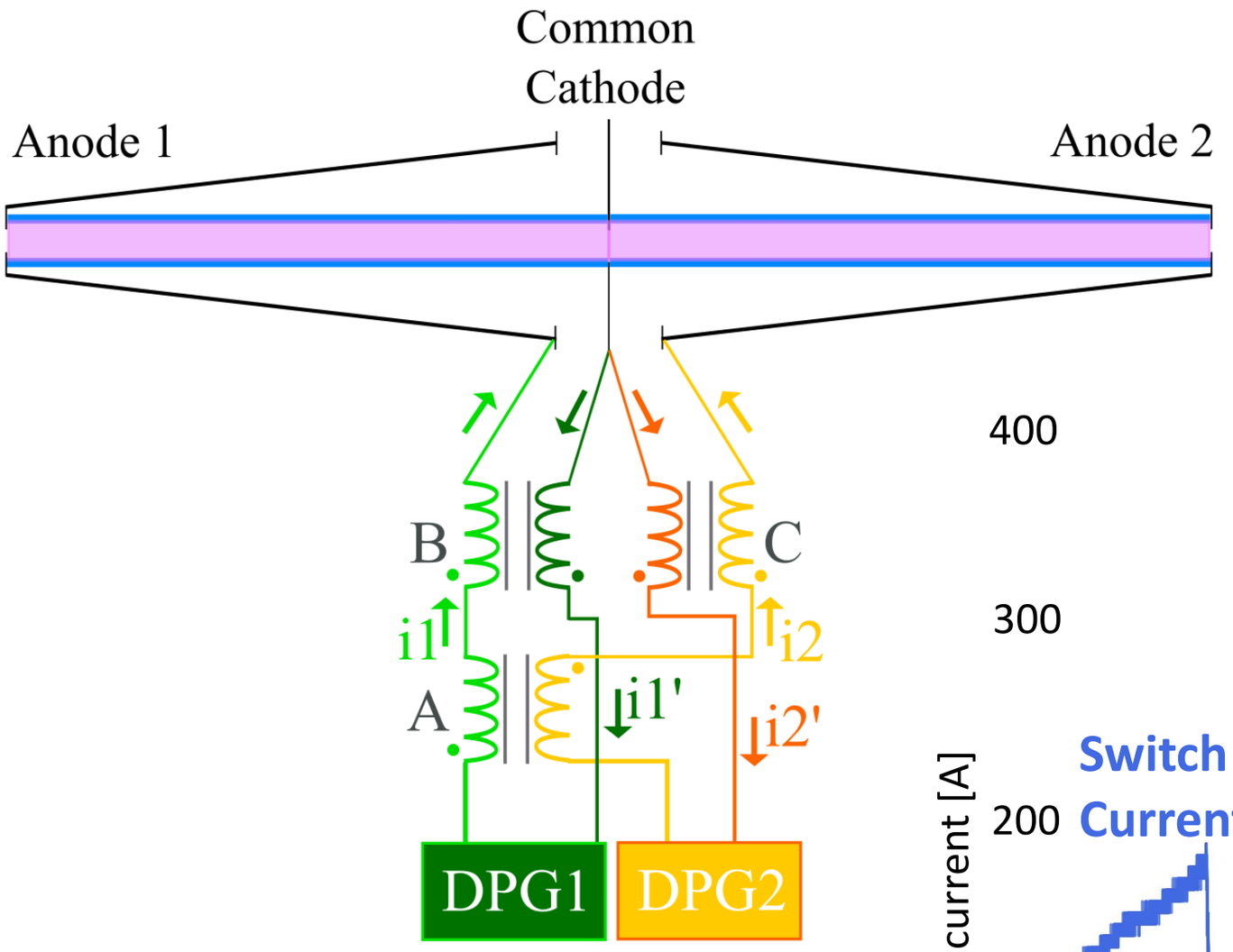


A: Balance the current from both generators

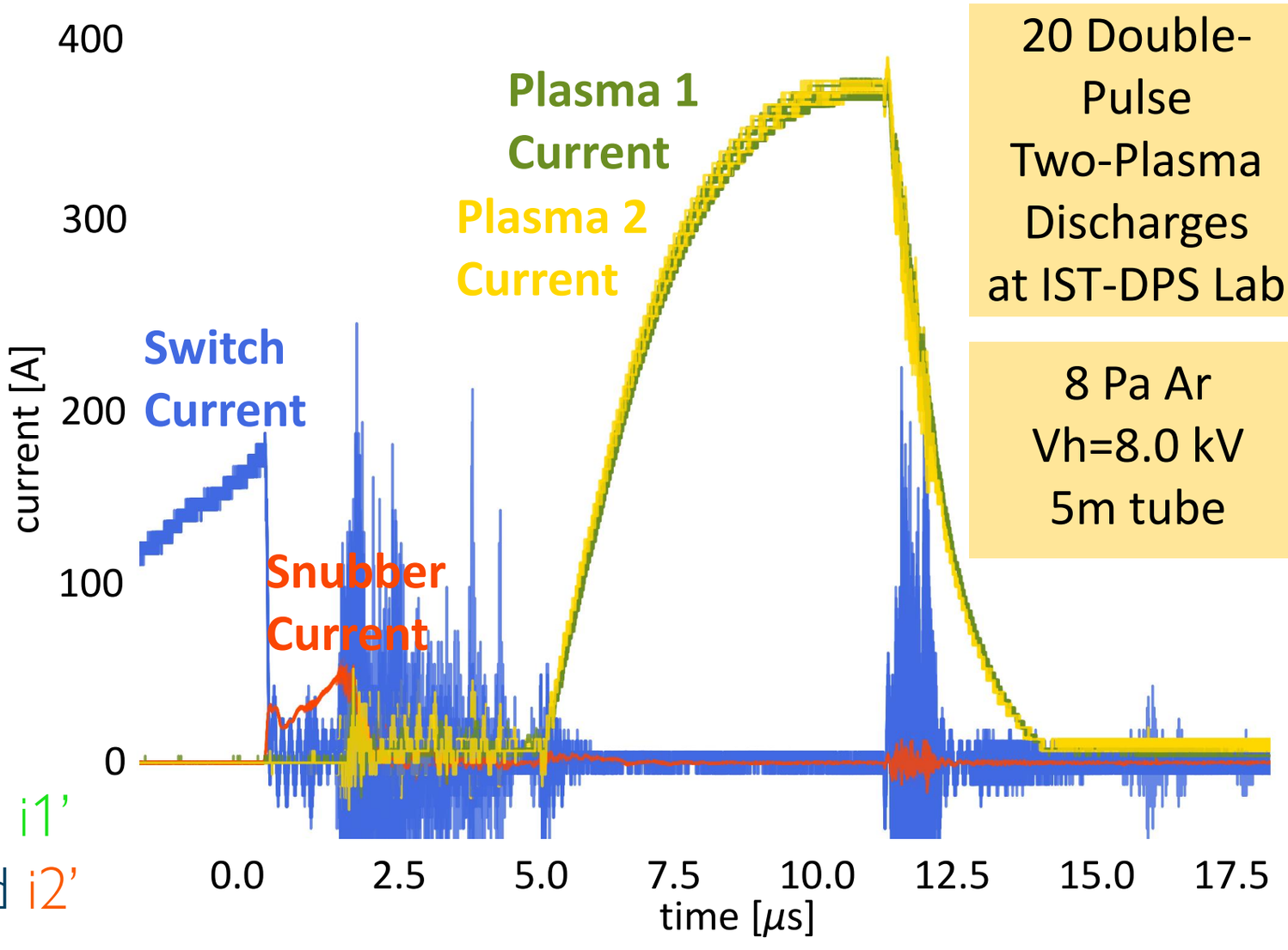
B: Forces symmetry between i1 and i1'

C: Forces symmetry between i2 and i2'

Discharge Plasma Source Scalability



Plasma source modules can be connected through common electrodes.



20 Double-Pulse Two-Plasma Discharges at IST-DPS Lab

8 Pa Ar
Vh=8.0 kV
5m tube

A: Balance the current from both generators
B: Forces symmetry between i1 and i1'
C: Forces symmetry between i2 and i2'

Conclusion

AWAKE Requirements

Double Pulse Solution

Double Pulse Generator Operation

Scalable Plasma Source

Conclusion

AWAKE Requirements

Density, uniformity, reproducibility and scalability

Double Pulse Solution

Double Pulse Generator Operation

Scalable Plasma Source

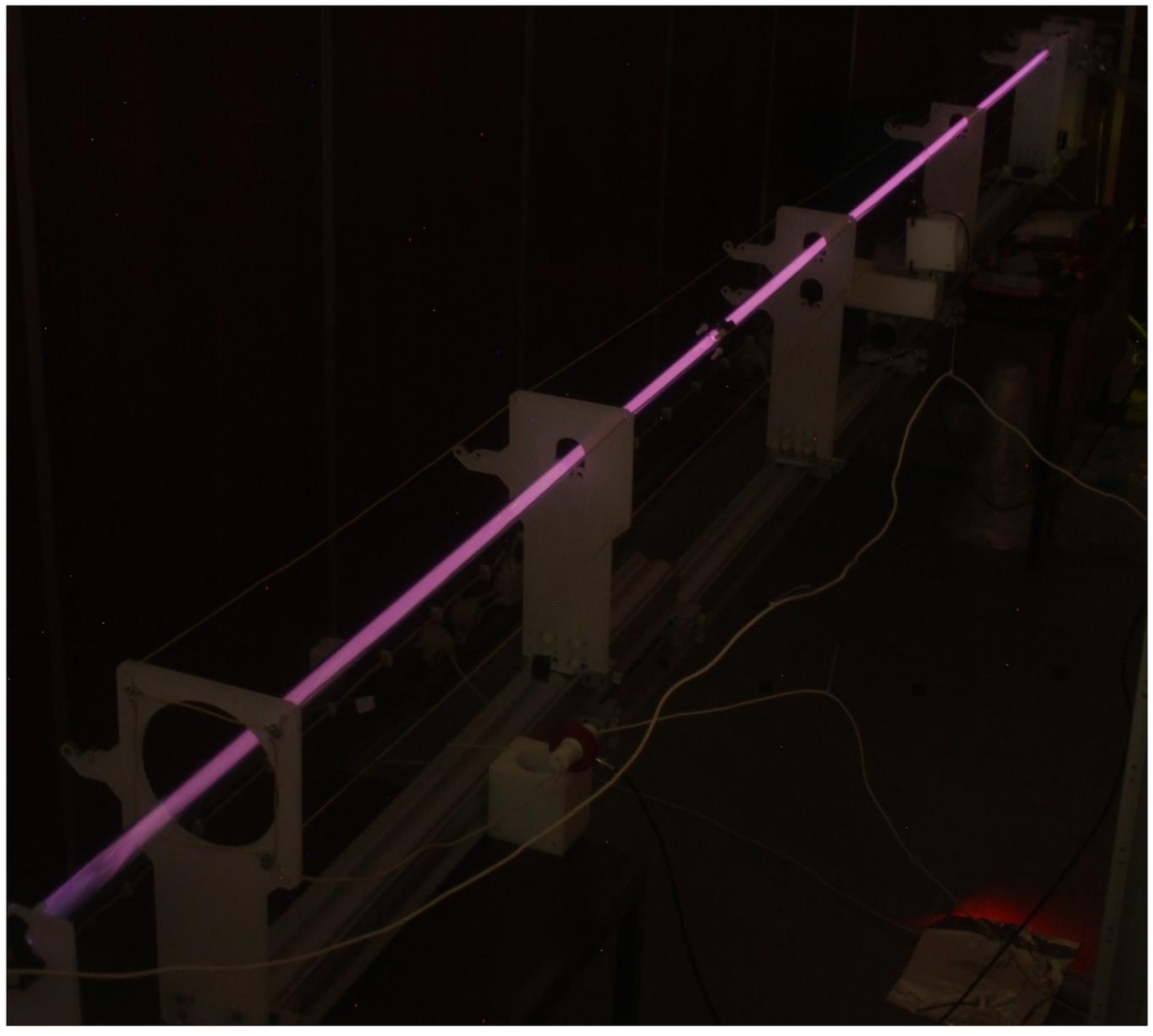
Conclusion

AWAKE Requirements

Double Pulse Solution
Efficient and safe

Double Pulse Generator Operation

Scalable Plasma Source



Conclusion

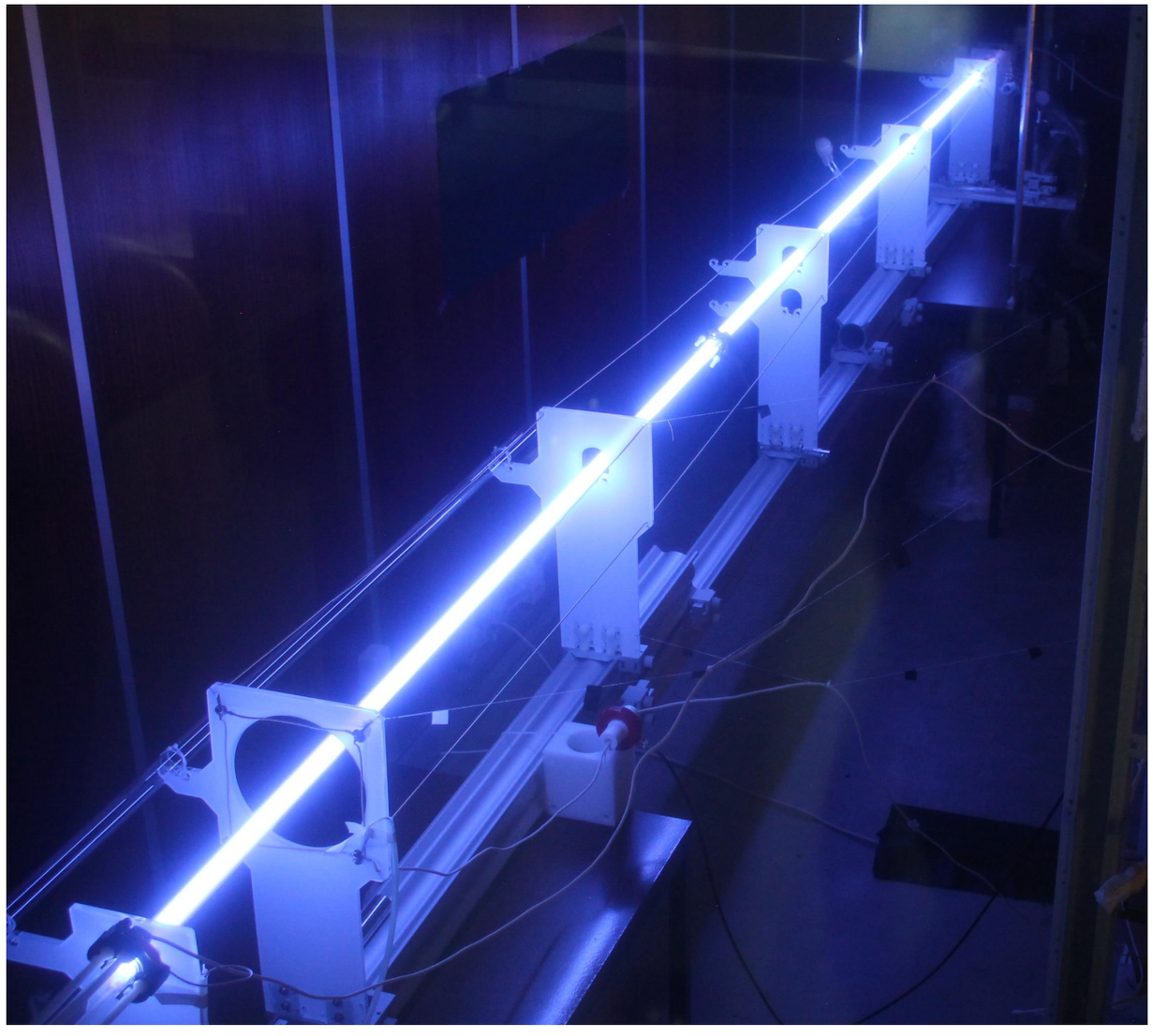
AWAKE Requirements

Double Pulse Solution

Double Pulse Generator Operation

Inductive and capacitive discharges

Scalable Plasma Source



Conclusion

AWAKE Requirements

Double Pulse Solution

Double Pulse Generator Operation

Scalable Plasma Source

Enabled by the magnetic circuit