Direct Current plasmas for long plasma accelerators

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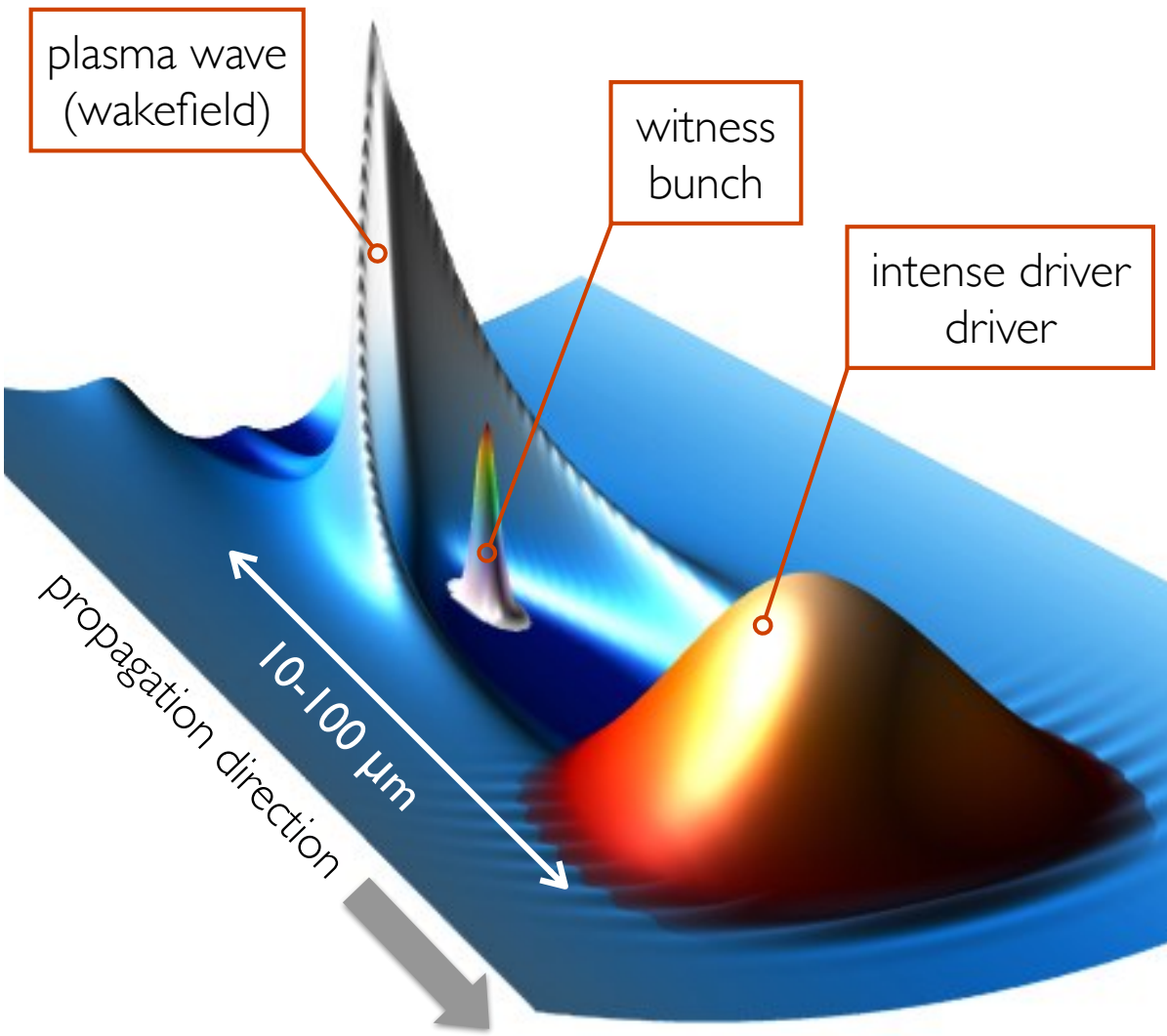
Plasma accelerator



simulation by Jorge Vieira, IST

2D representation of a wakefield plasma accelerator from an OSIRIS simulation
TED-X@CERN talk

- Plasma
  - density of electron "fluid": n_e [cm^{-3}]
  - electron waves: $\lambda_e = 3.3e4 / (n_e)^{1/2}$
  - w. break. lim. $E \approx 10\ (n_e/10^{16} cm^{-3})^{1/2}$ GV/m
- Driver
  - intense laser or particle beam (charged)
  - dimensions matching λ_e
- Witness
  - intense laser or particle beam (charged)
  - self injection or external injection
- Limits
  - dephasing
  - driver depletion

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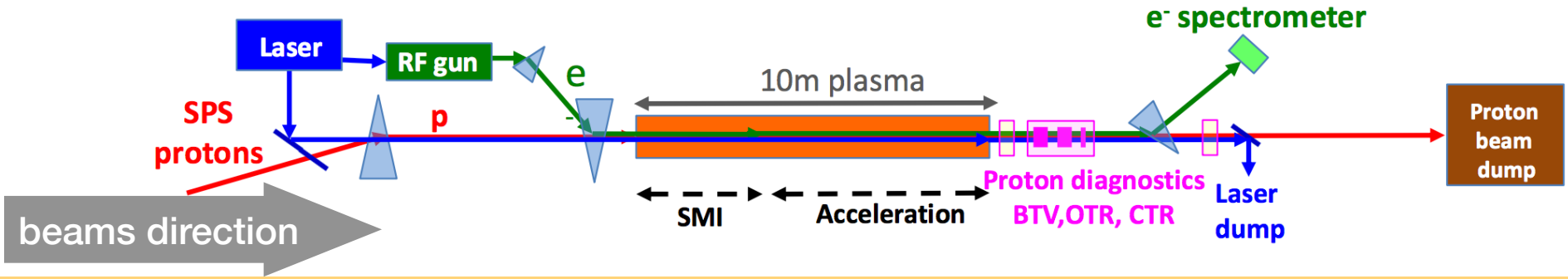
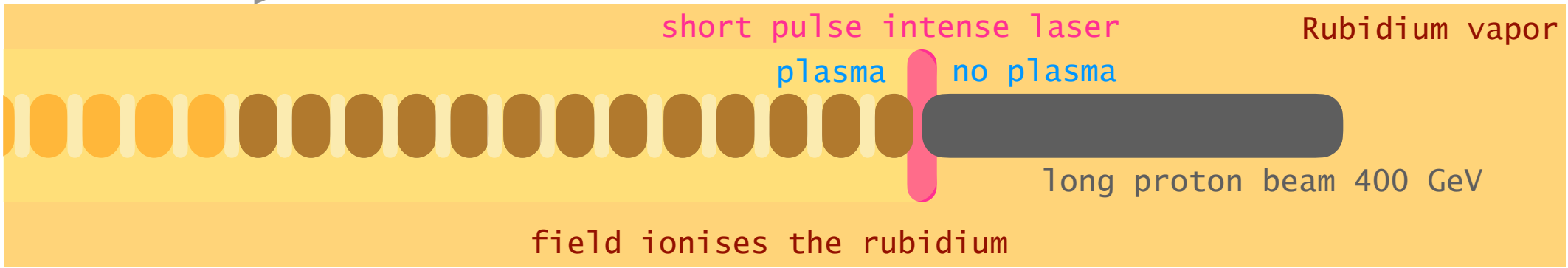
The AWAKE experiment MS1: p+ beam self-modulation*

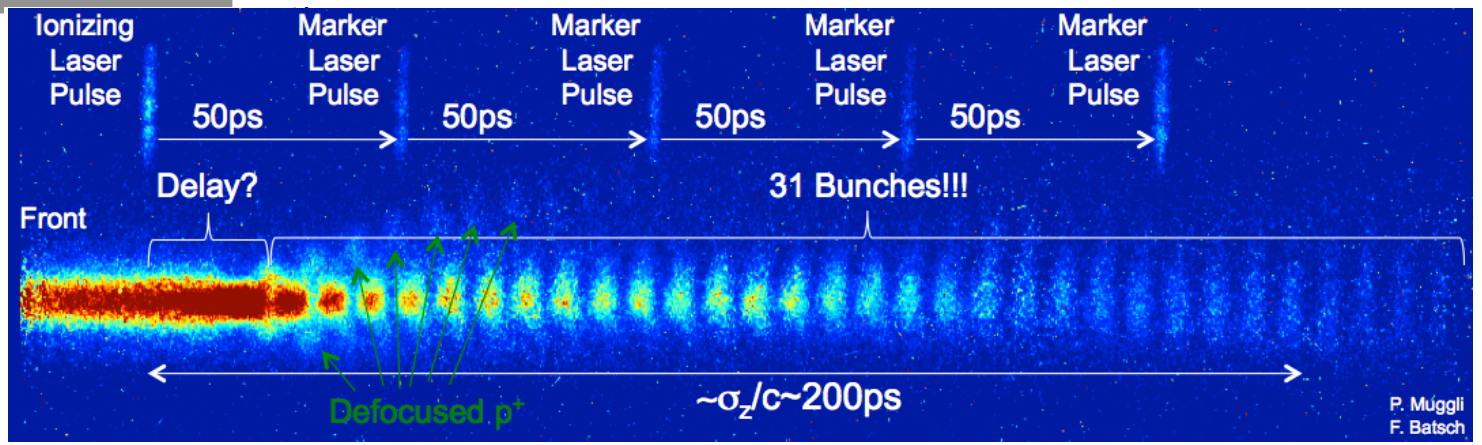




proton beam is self modulated by interacting with the plasma

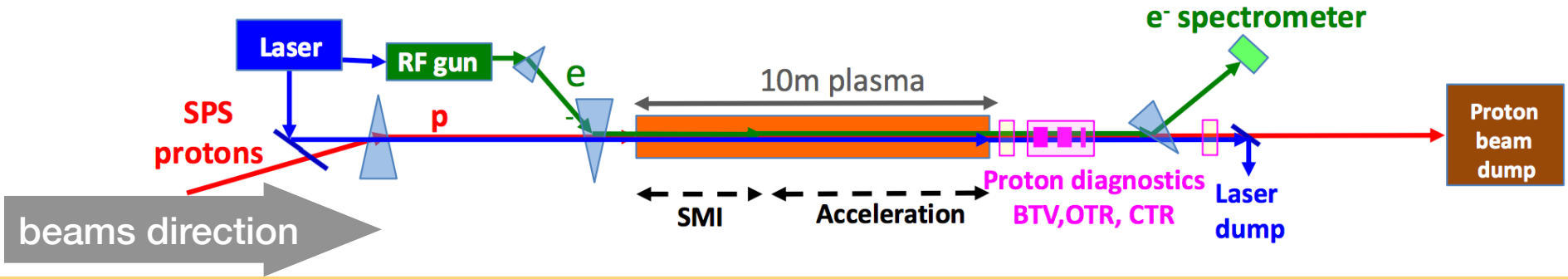
beams direction

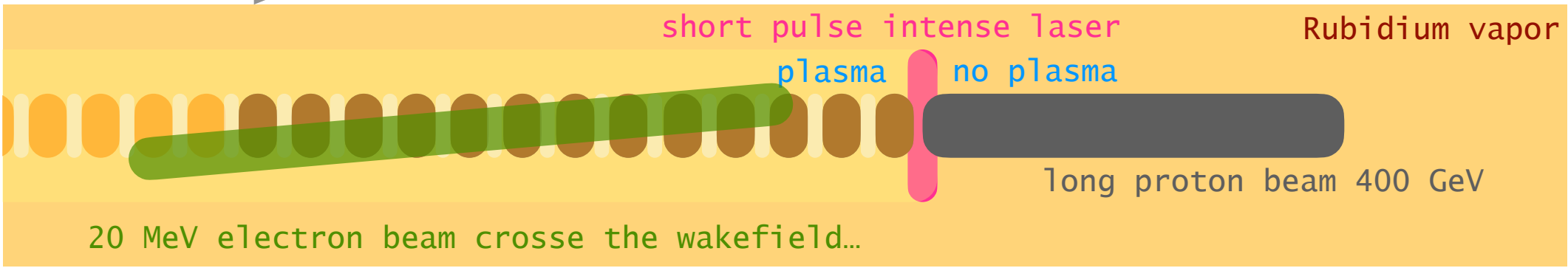
a plasma wave develops in the wake of the proton beamlets

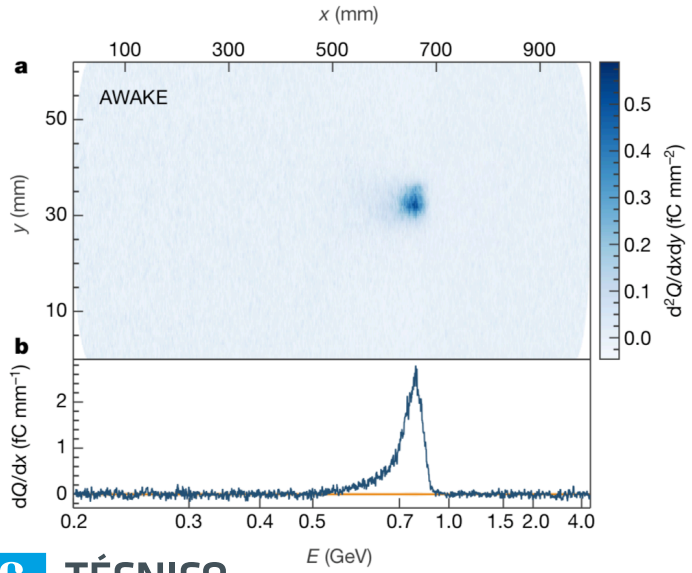


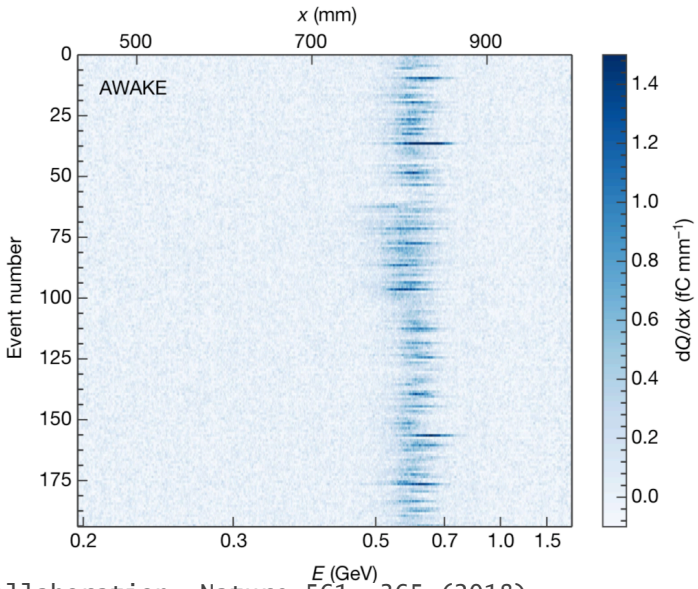
* AWAKE collaboration, Phys.Rev. Lett. 122, 054802 (2019)
M. Turner et al. Phys. Rev. Lett. 122, 054801 (2019)

The AWAKE experiment MS2: electron acceleration*









consistent 0.7 GeV gain

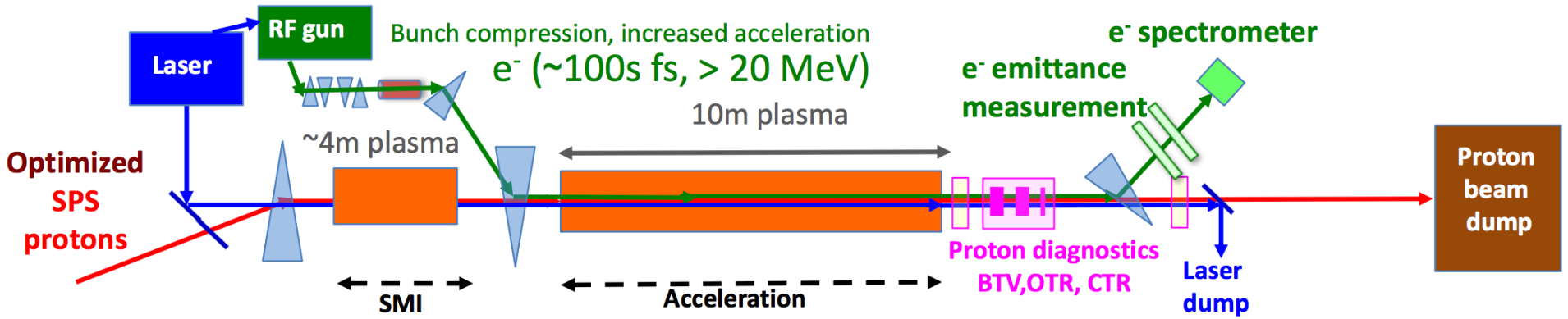
in ~ 8 m of plasma

* AWAKE collaboration, Nature 561, 365 (2018)

The AWAKE experiment Run 2 in preparation

Run 2 A (> 2021)
Acceleration of electron beams and quality preservation
Propagation of self-modulated beams in long plasmas

Run 2 B (>> 2021)
Acceleration in very long plasmas

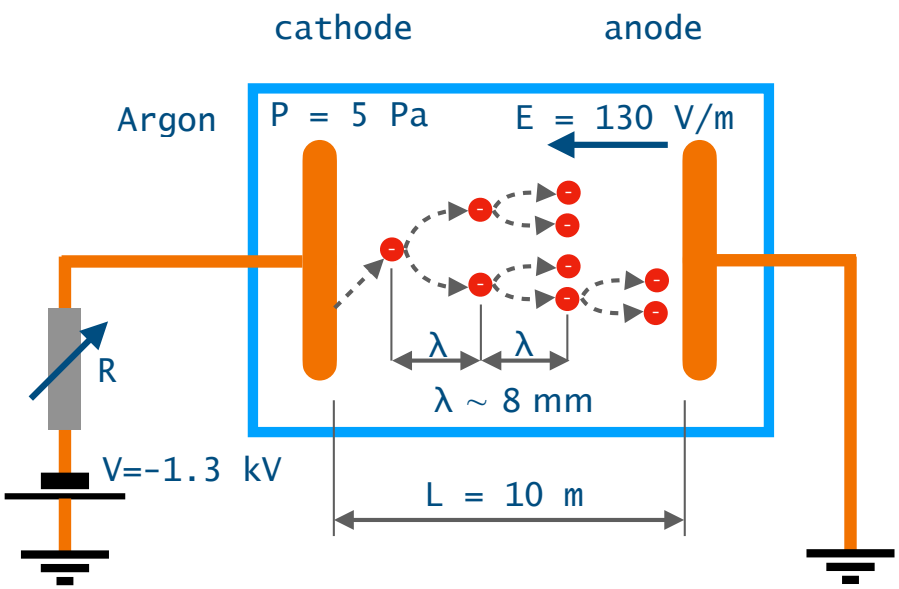


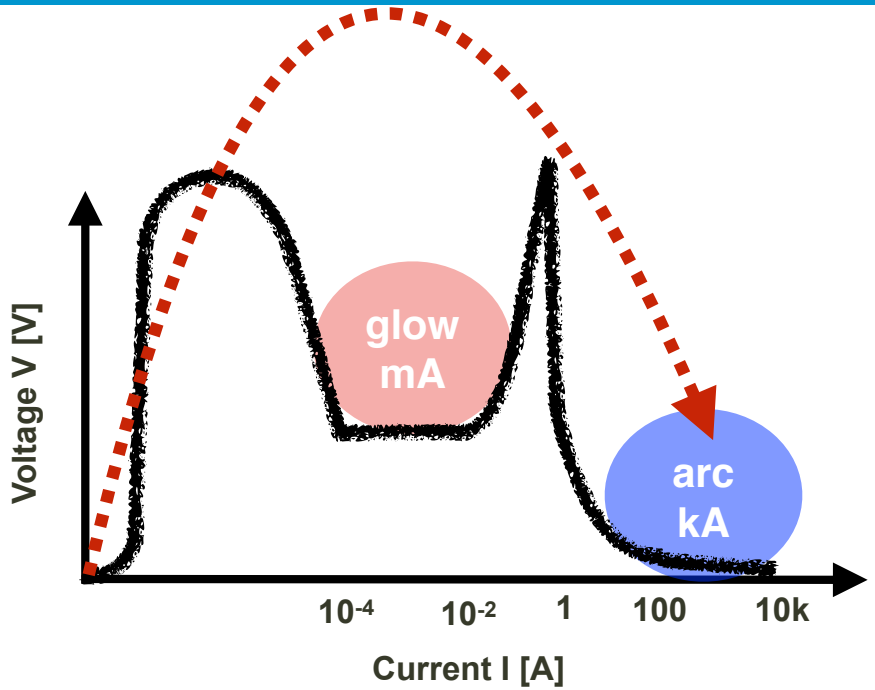
Project FCT : CERN/FIS-TEC/0017/2019

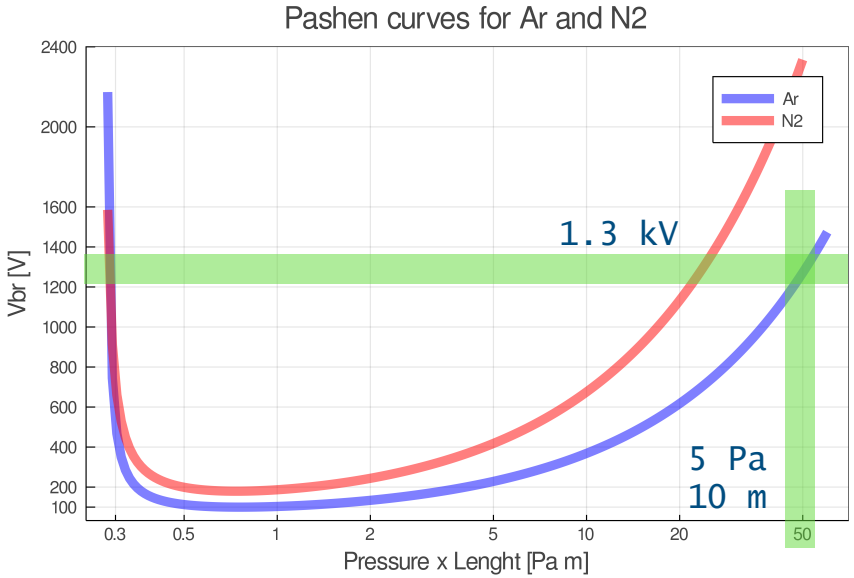
Task 3: Direct current discharge plasma source (in progress)

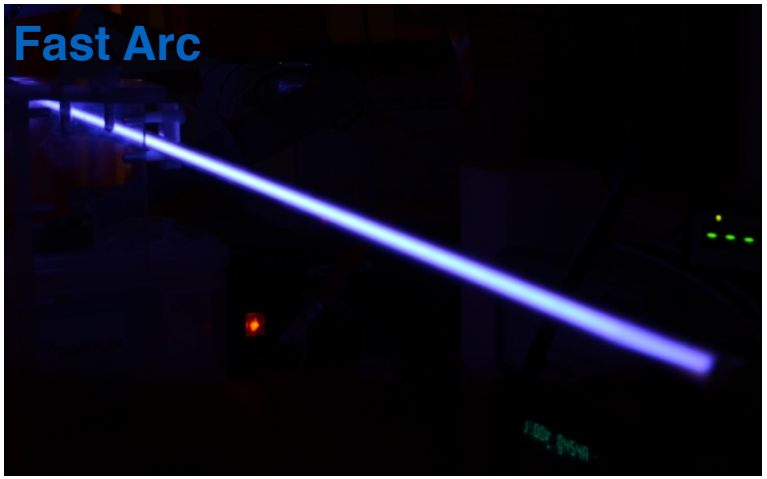
Objectives: long Ar / Xe plasmas (≥ 10 m) high density precision (~ 0.25 %)

Plasma discharges









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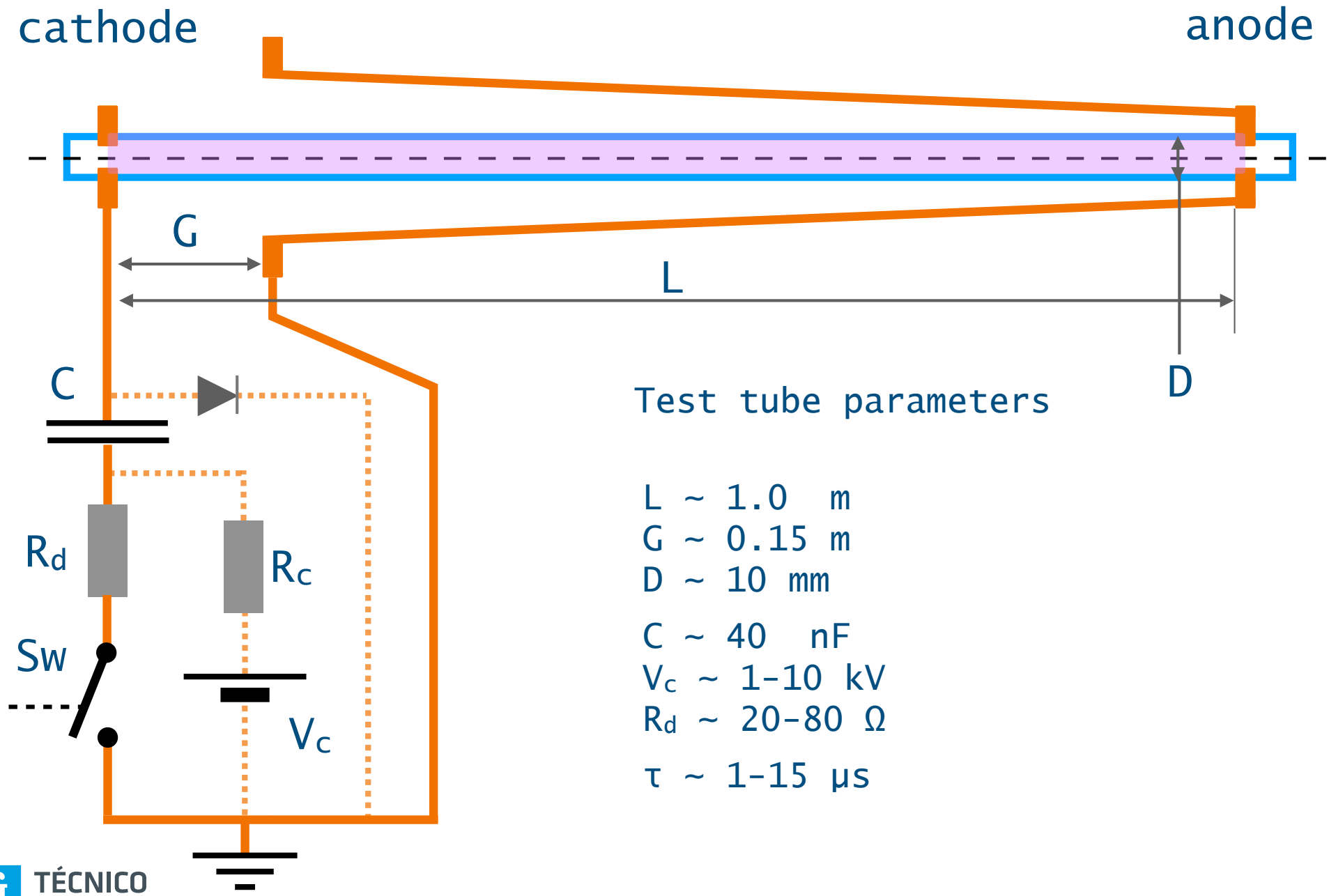
Accelerator tube geometry



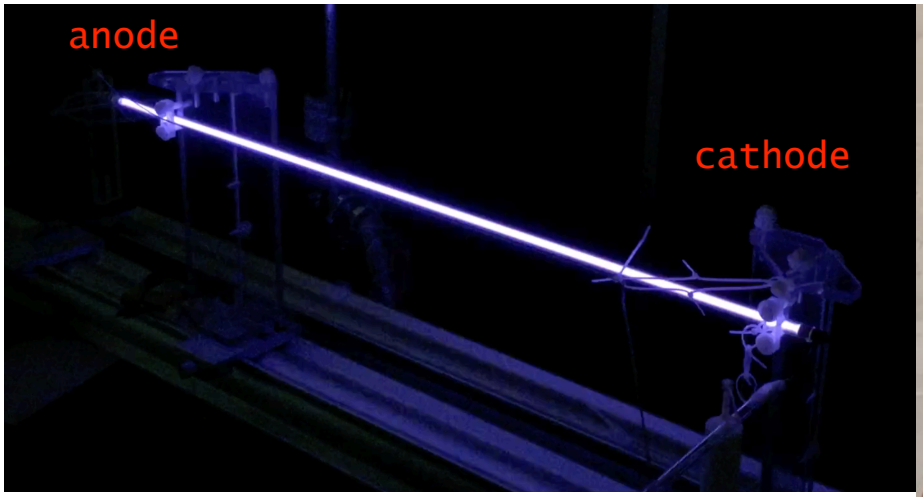
Test tube parameters

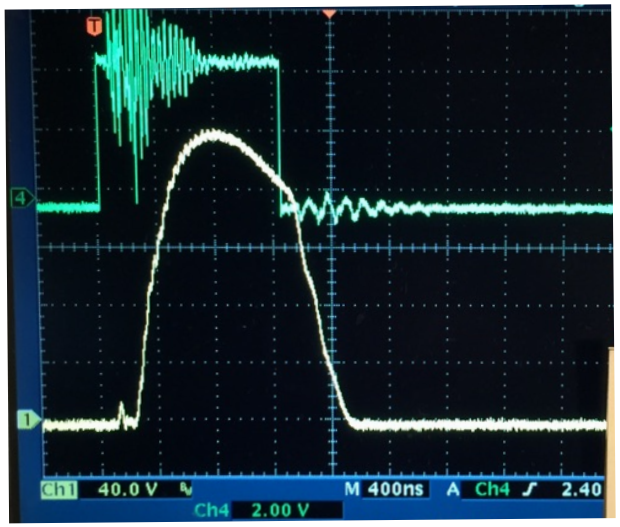
L ~ 1.0 m
G ~ 0.15 m
D ~ 10 mm

C ~ 40 nF
V_c ~ 1-10 kV
R_d ~ 20-80 Ω

τ ~ 1-15 μs

Test of an heater switch



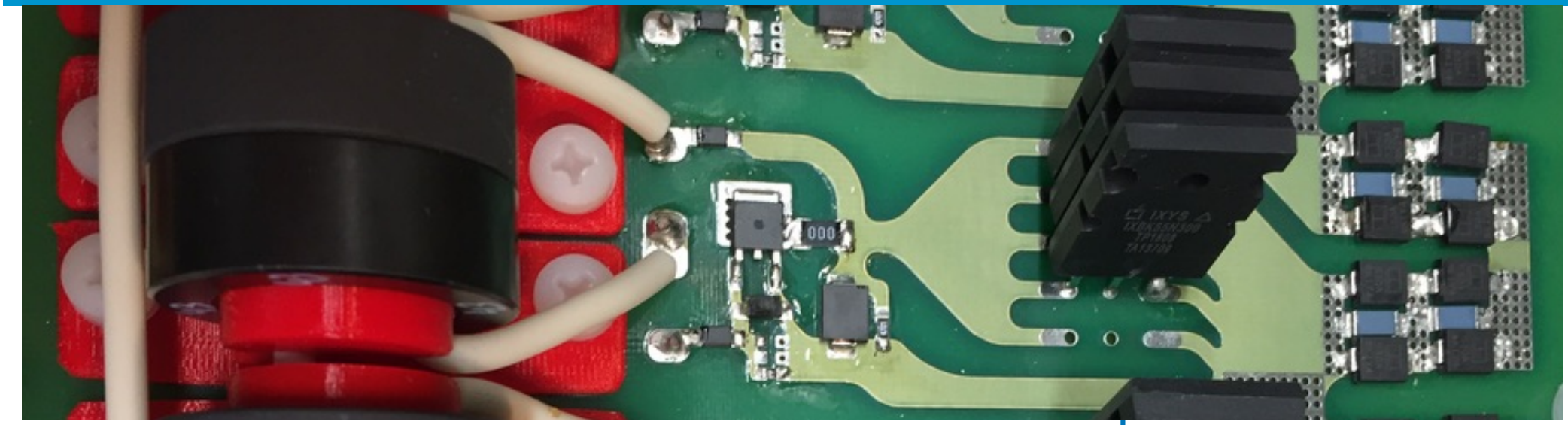


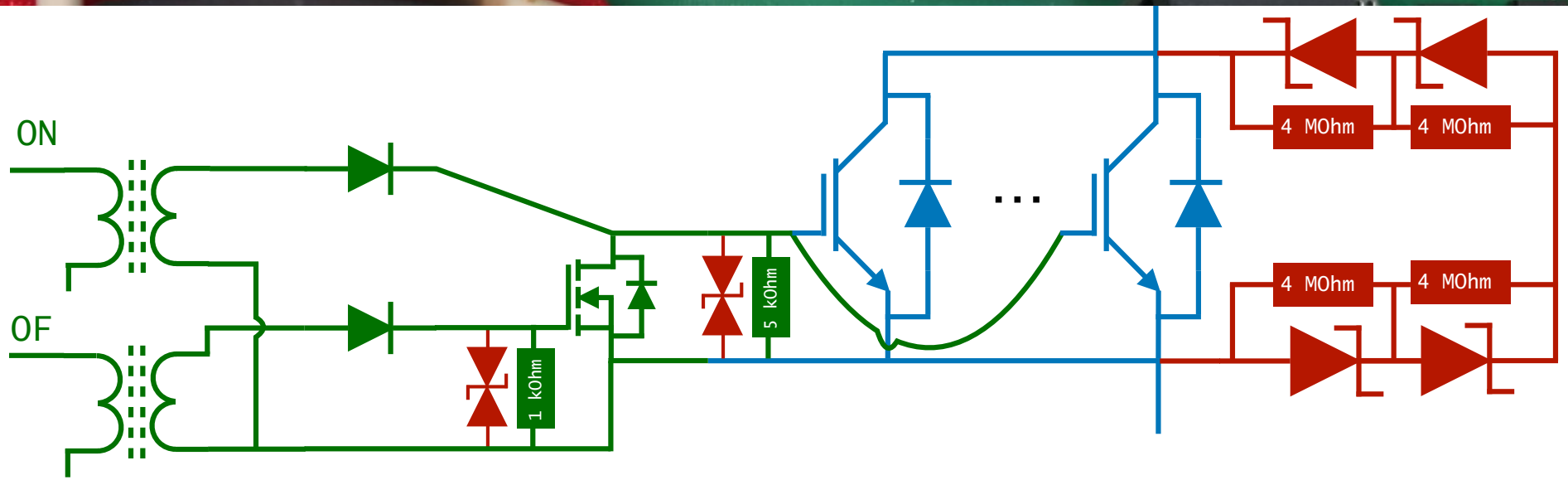
τ = 1.0 µs
V_c = 10 kV
I_{peak} = 200 A

T_R ~ 200 ns
T_F ~ 400 ns

P ~ 10 Pa
(Argon + Air)

Heater circuit stage





synchronous command
of all stages

1-5 IGBT's
0.6 - 3 kA

Over voltage prot.
1.8 kV/stage

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Scaling for long tubes

tentative 5 m x 25 mm test tube…

I = 1000 A x 5 cm2 / 4 us = 1250 A

V = 120 kV

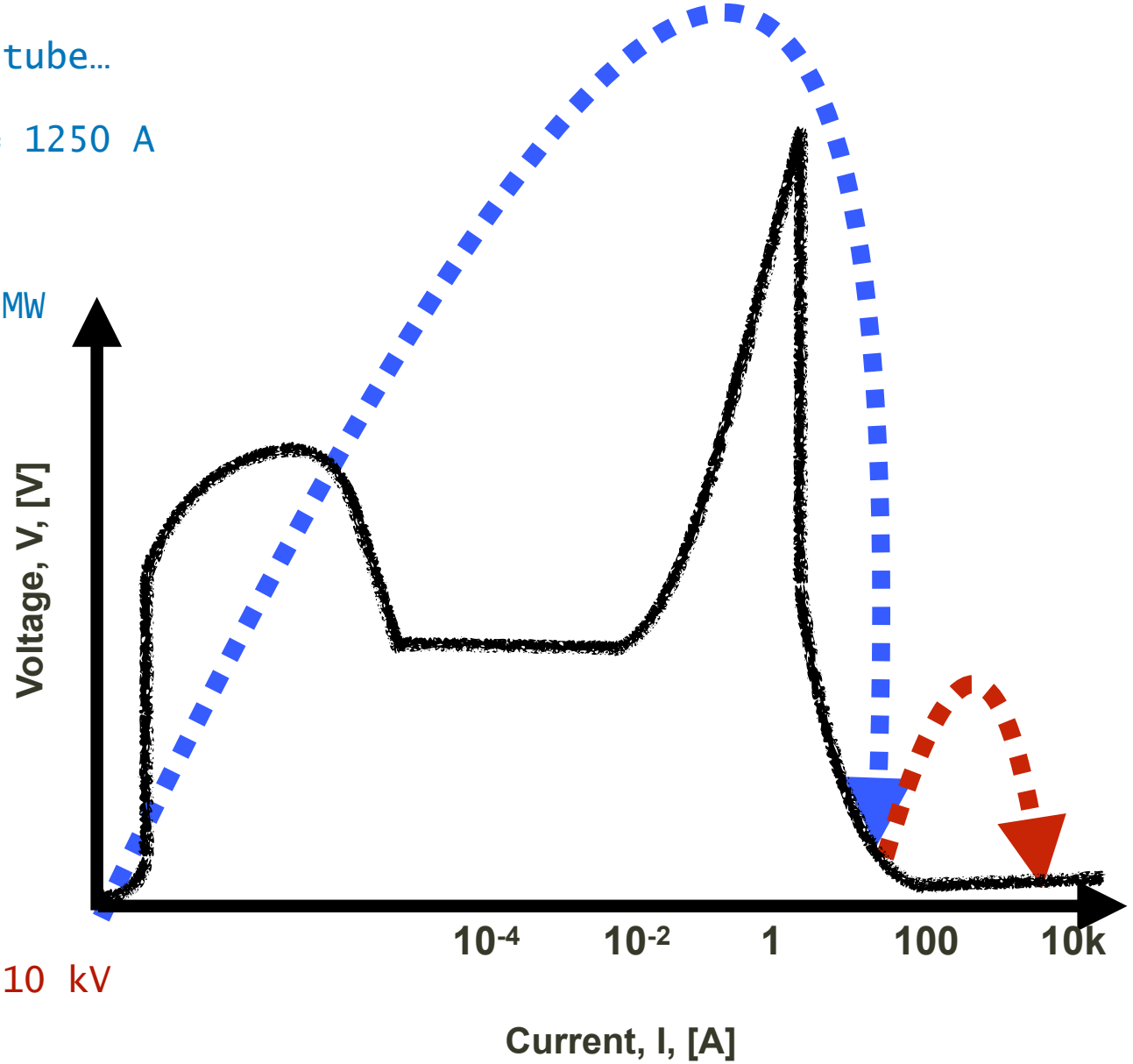
P = 1.25 kA x 120 kV = 150 MW

prohibitive…
… power switching
… capacitor bank
… low efficiency
… safety

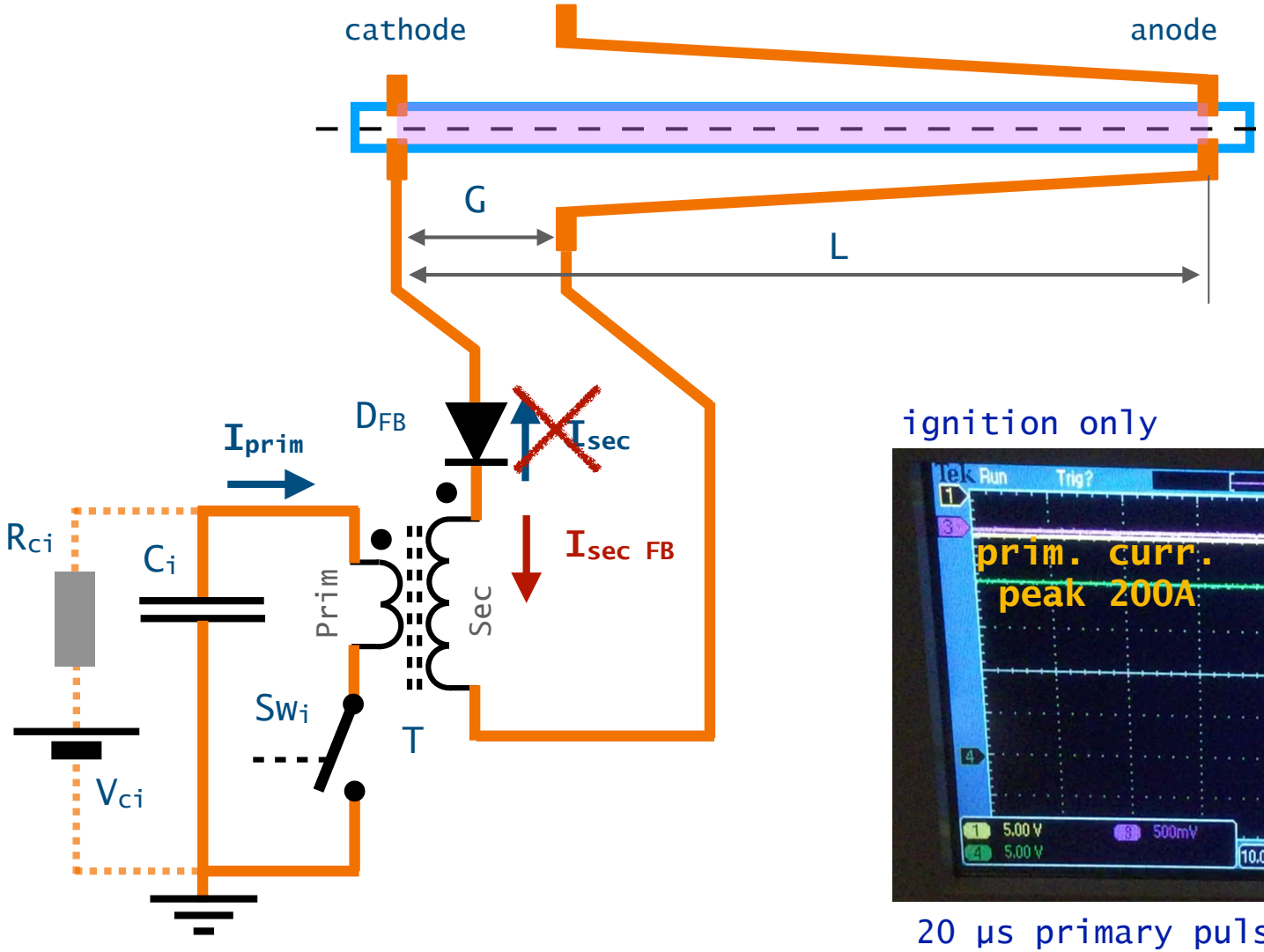
possible solution…

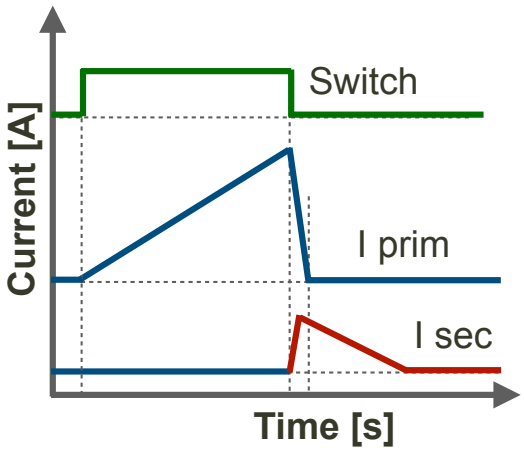
…ignition + heating

P = 20 A x 120 kV + 1250 x 10 kV
= 2.4 kW + 12.5 kW

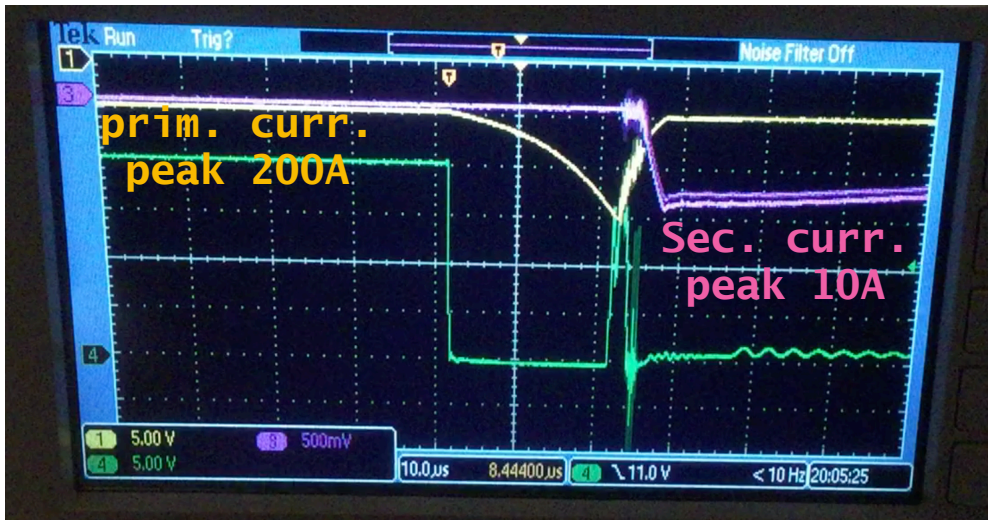


Ignition flyback circuit

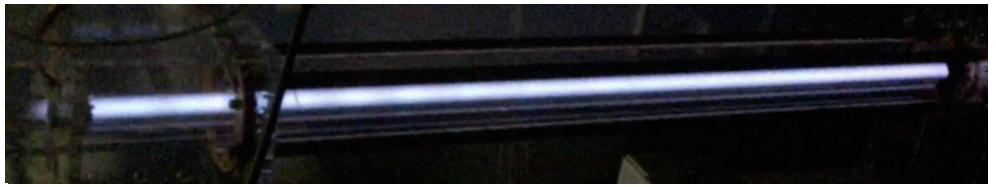




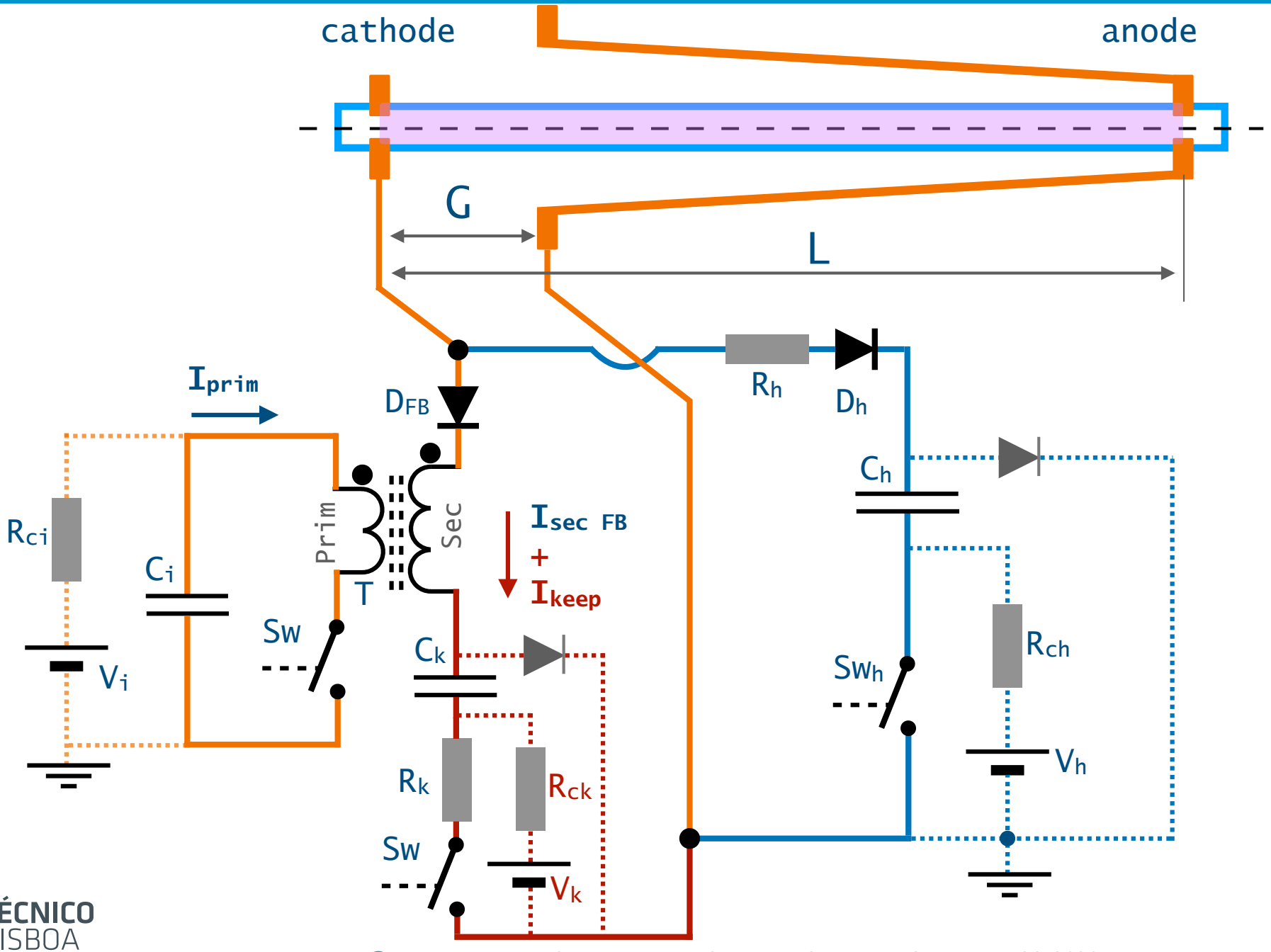
ignition only



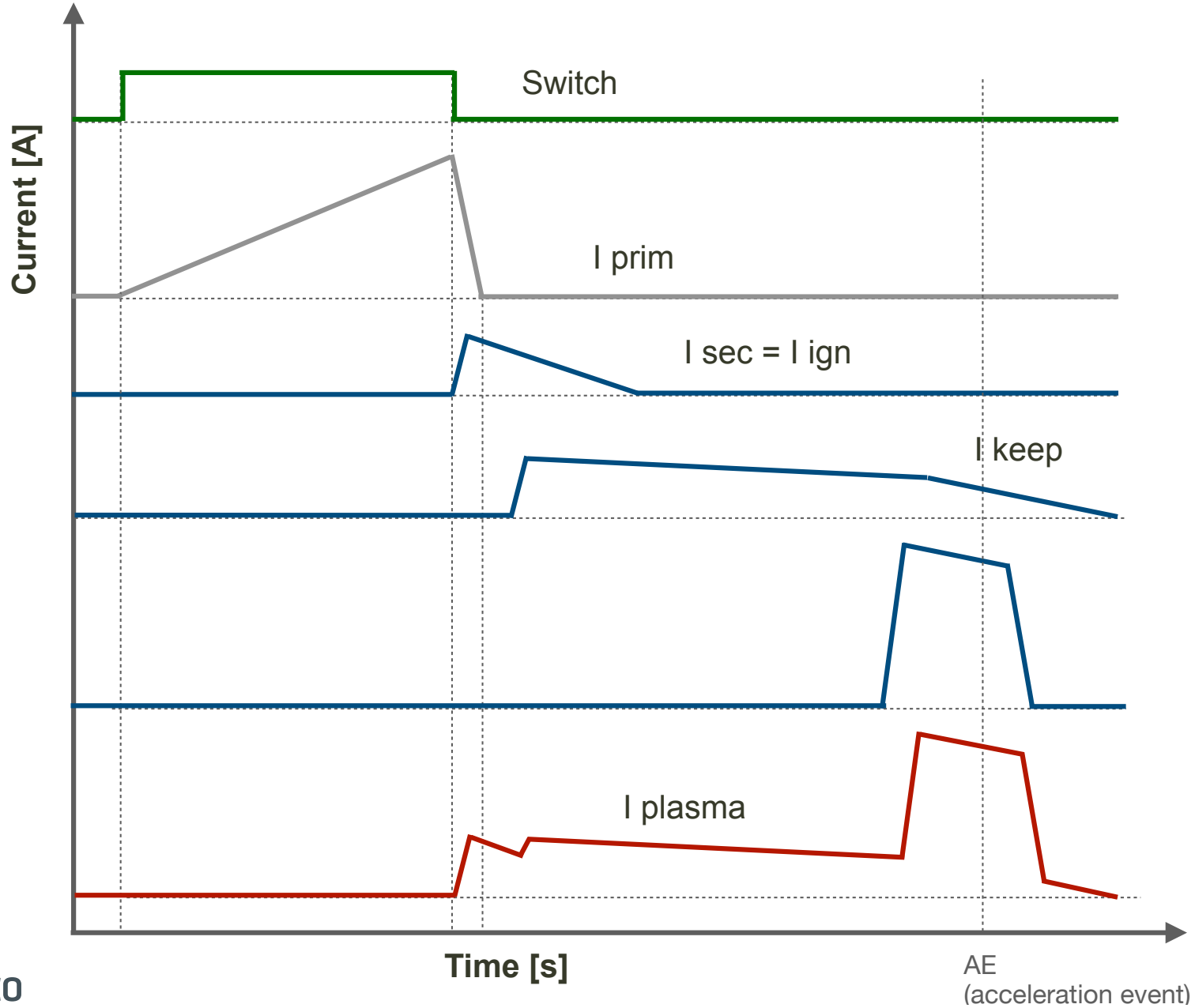
20 µs primary pulse



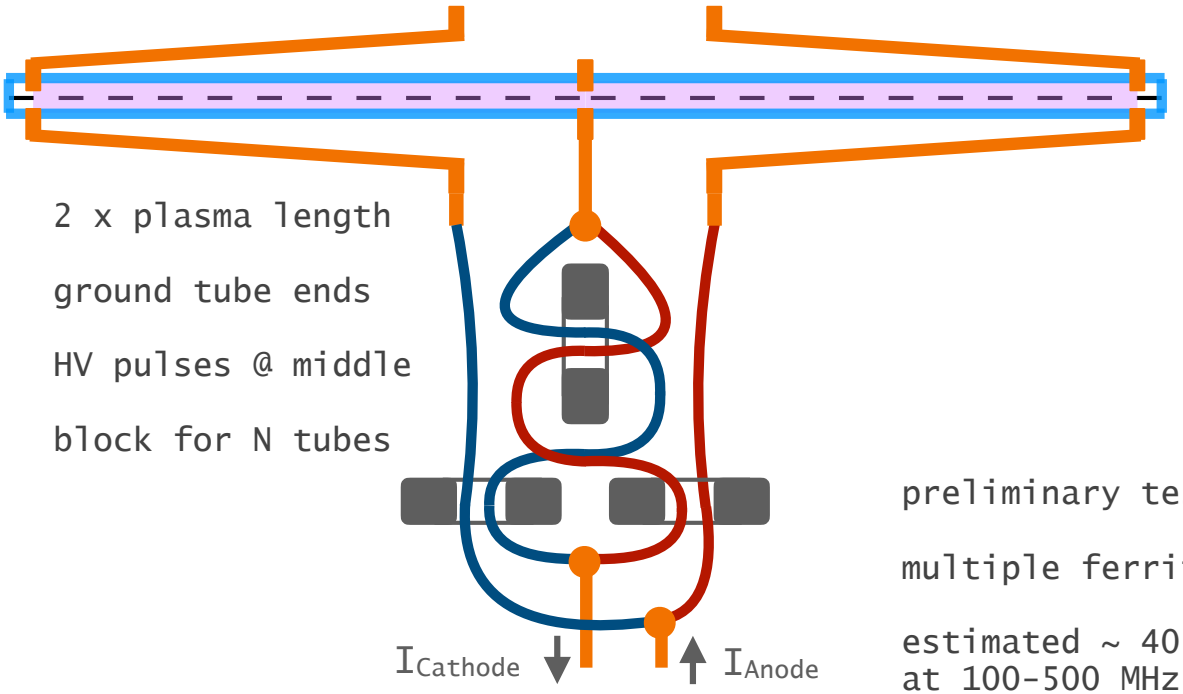
Ignition + keep + heater circuit



Ignition + keep + heater circuit



Common cathode tube geometry

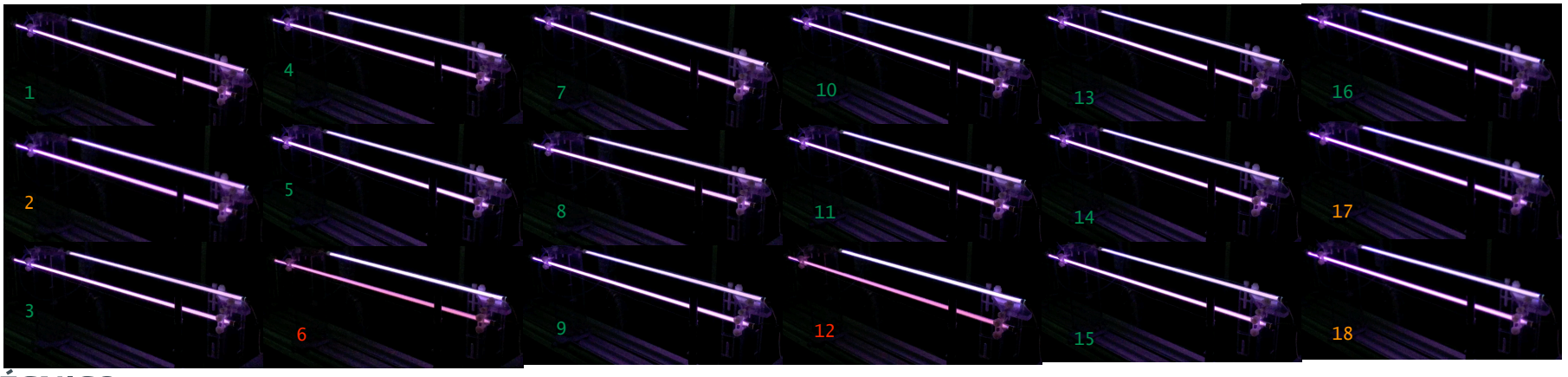


preliminary test

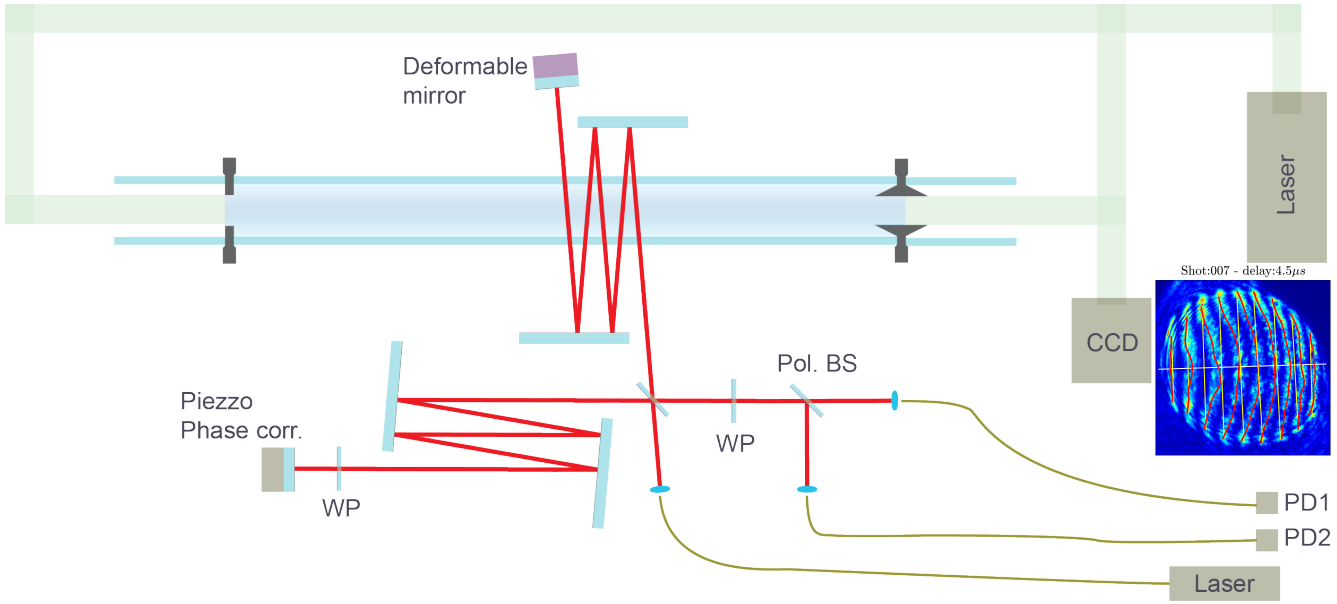
multiple ferrites

estimated ~ 40 Ω resistance at 100-500 MHz

e.g $\Delta i = 1$ A → $\Delta V = 40$ V



Plasma density interferometry diagnostic



- Axial interferometry
  - transverse density uniformity
  - pulsed laser - space resolved
  - slow response - characterisation

+

- New Transverse interferometry
  - integrated transverse
  - CW laser - time resolved
  - multipass & quadrature - precision
  - fast response - real-time control
  - slides along plasma

- New interferometry to be developed at IST under this project
  - igniter + heater scheme, double plasma, >10 m, real time density control
- High precision density characterisation of plasma source @ CERN
  - combines high-precision plasma tube (CERN & IST) + Ignition+heating circuit + Axial interf. (Imperial)
- Real-time plasma density control information for high precision density
  - combines transverse interferometry with advanced heating circuit

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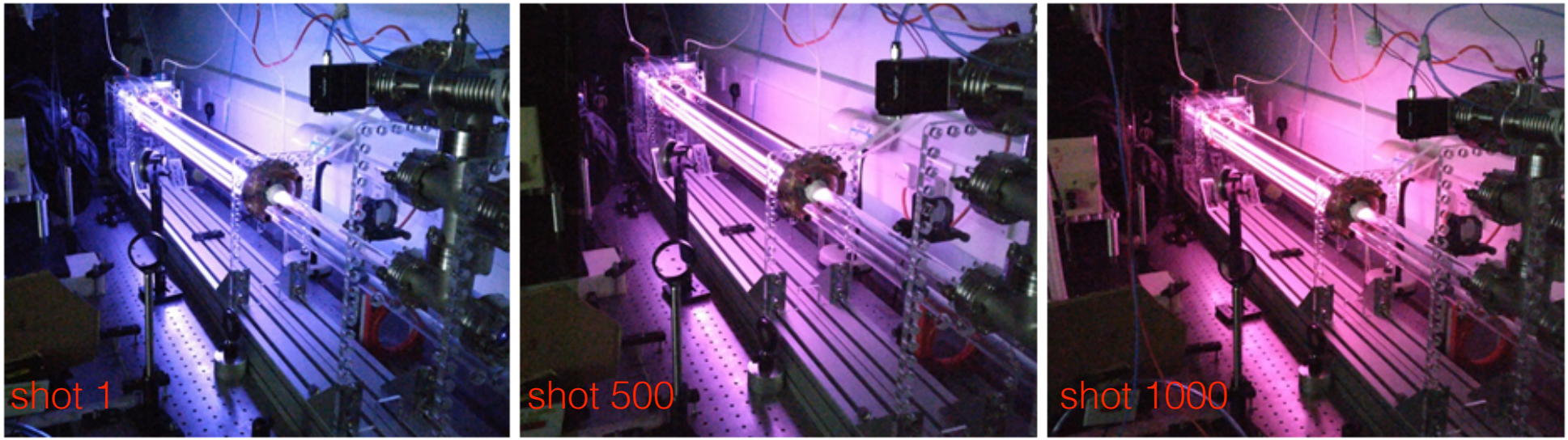
Hydrogen contamination



Plasma spectrometric measurements show release of H2 in the plasma

Detected in first high-stability tube at IC (2017-2018)

Likely cause is release from glass walls after plasma ion bombardment

Problem under study by CERN plasma group

Possible solutions…

- … high temperature (400 ºC) degassing of glass tubes
- … tubes made of quartz and degassed at high temperature (900 ºC)
- … change gas from Argon to Xenon (w/ lower ionisation potential than hydrogen)

Summary

Project in progress aiming delivery of prototype plasma sources for AWAKE run II

Plasmas tubes with up to 3 m long tested

Aiming to develop 10 - 20 m long plasma

Aiming to double the length with common cathode geometry

Ignition + keep + heater circuit in development

Interferometry diagnostics in development (collab. IC)

Tubes for high-purity gas and high stability in development (collab. CERN)