AWAKE Discharge Plasma Source Overview

AWAKE meeting, 08 Dec. 2021

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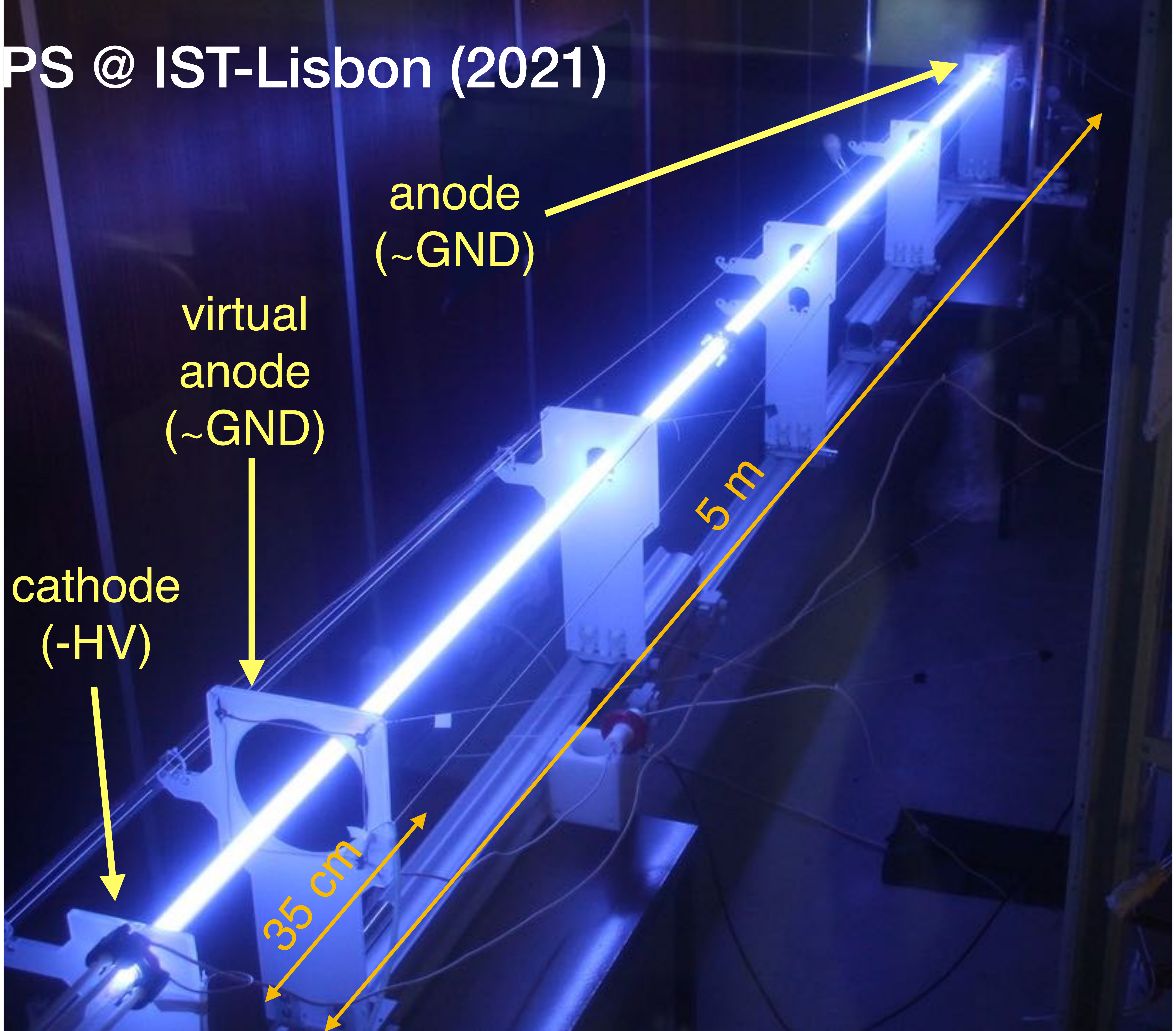
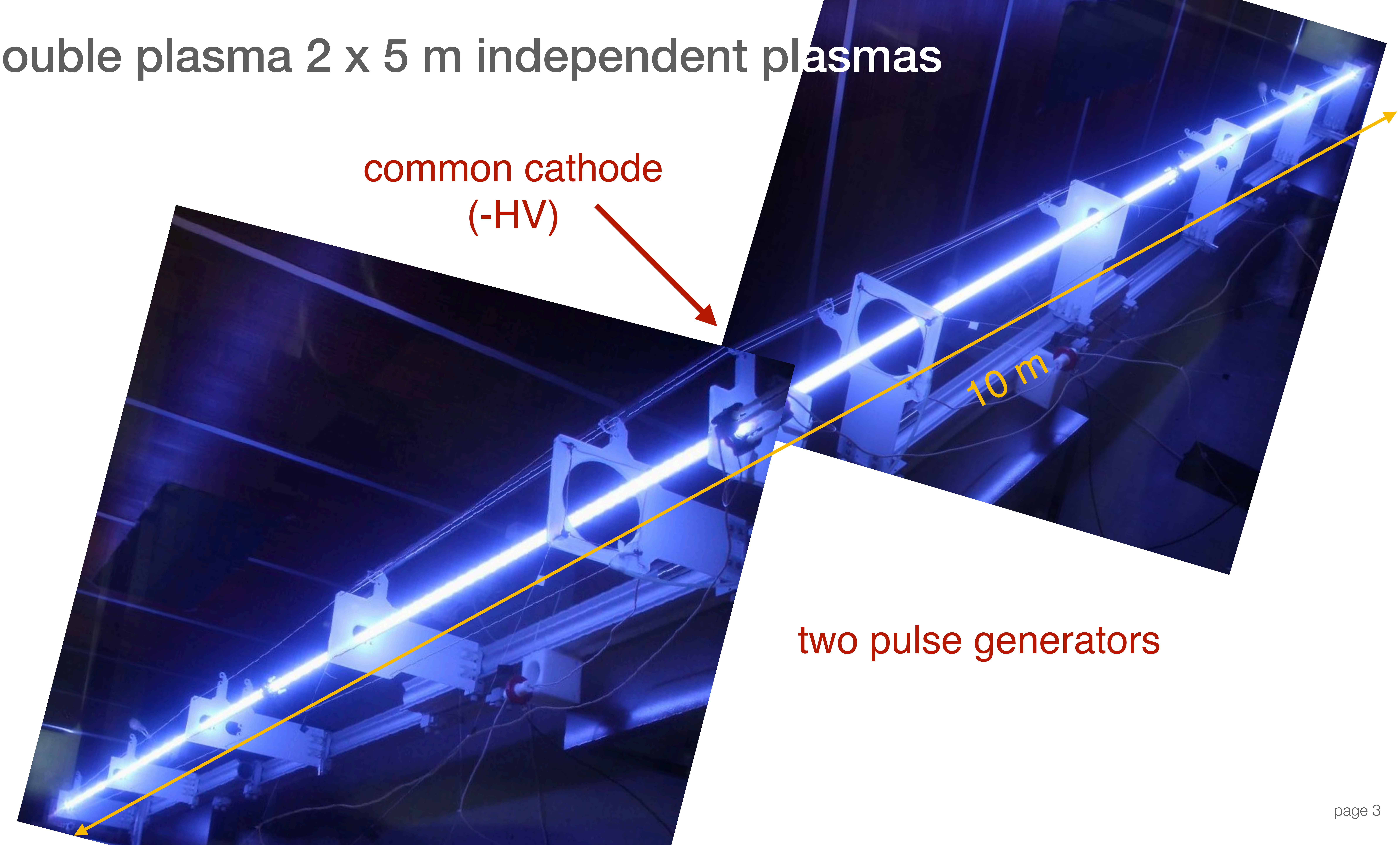
Jian Bin Ben Chen, Zulfikar Najmudin, IC

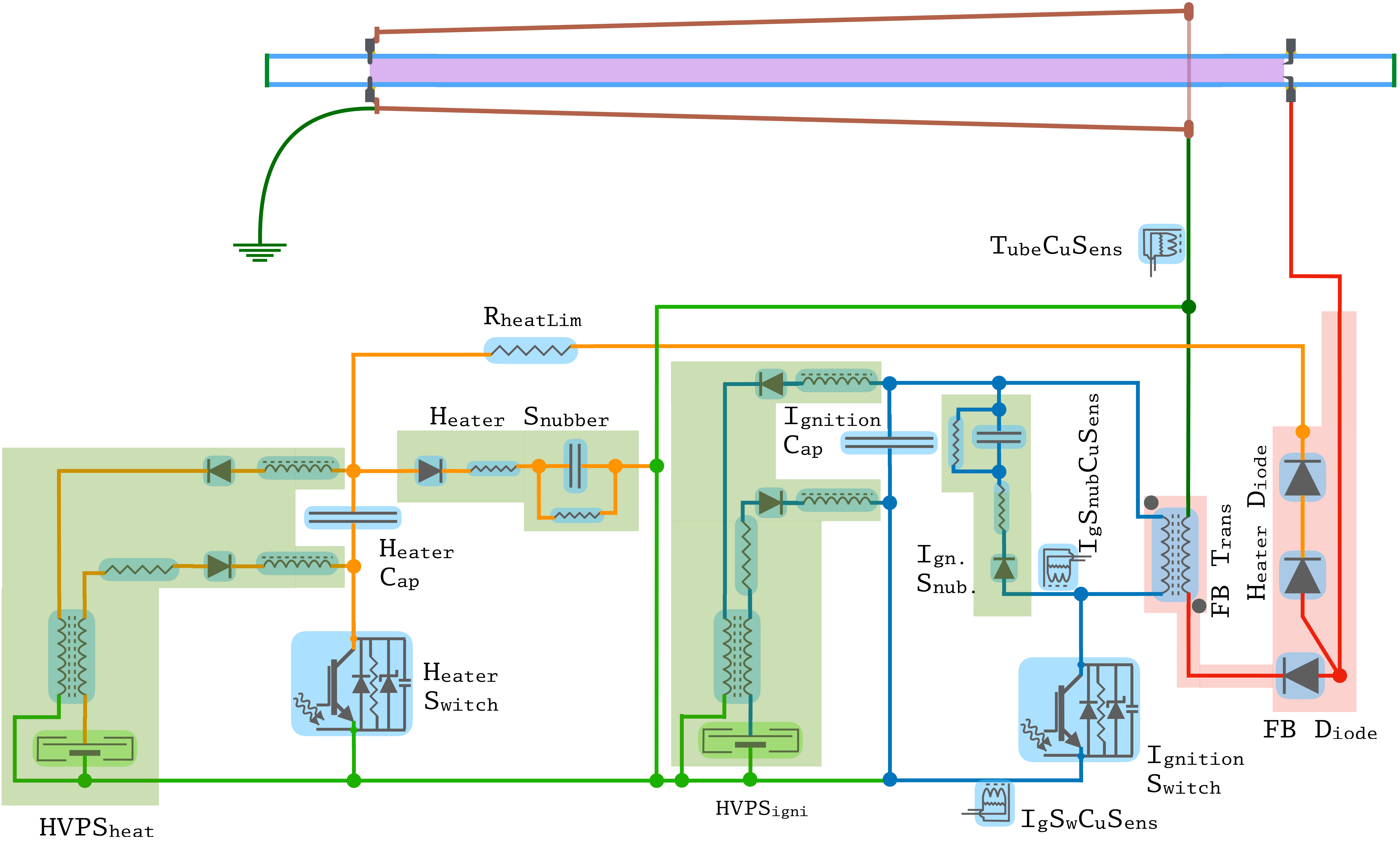
AWAKE DPS @ IST-Lisbon (2021)



Double plasma 2 x 5 m independent plasmas



Each plasma uses a ignition + heating circuit



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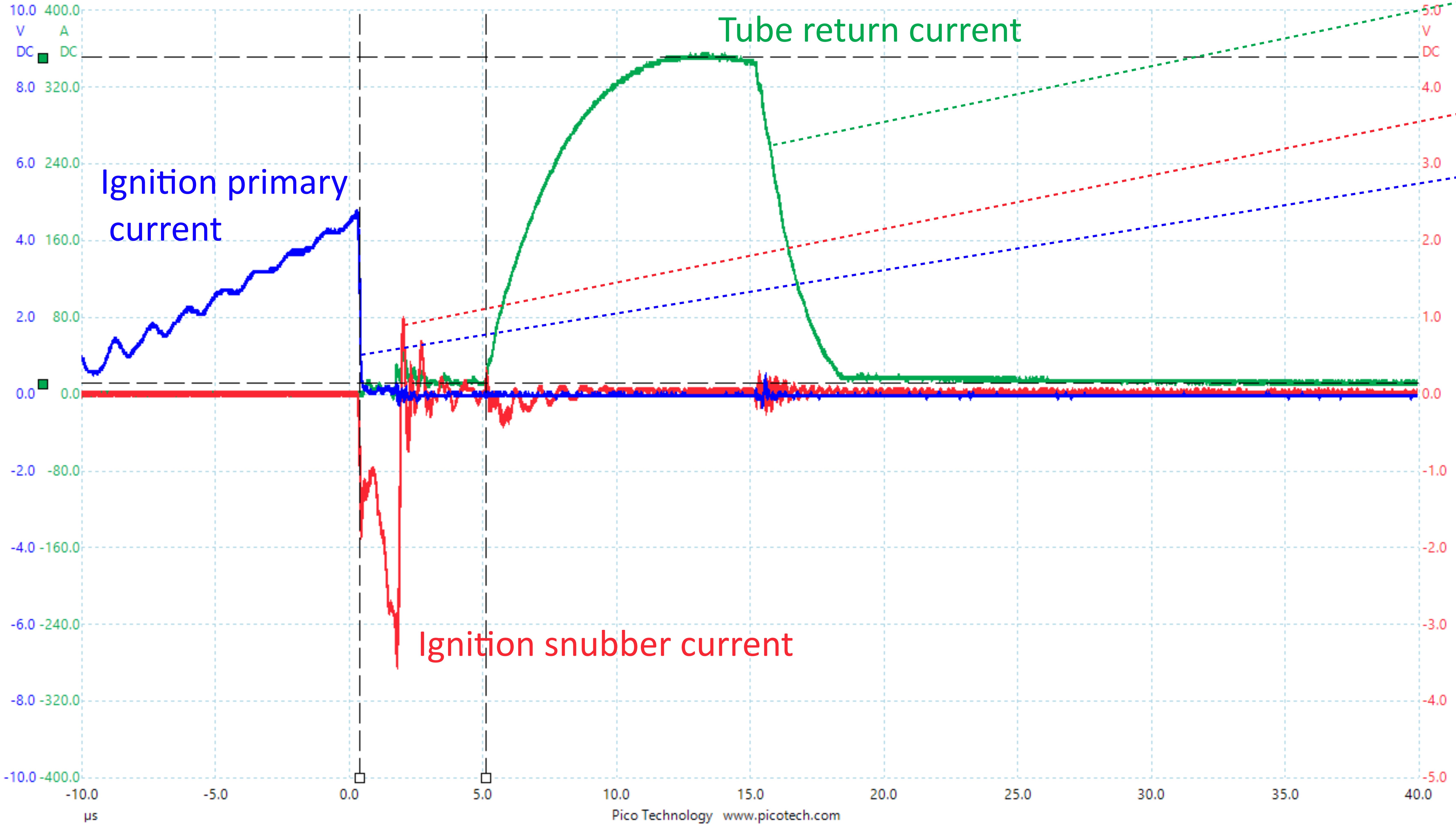
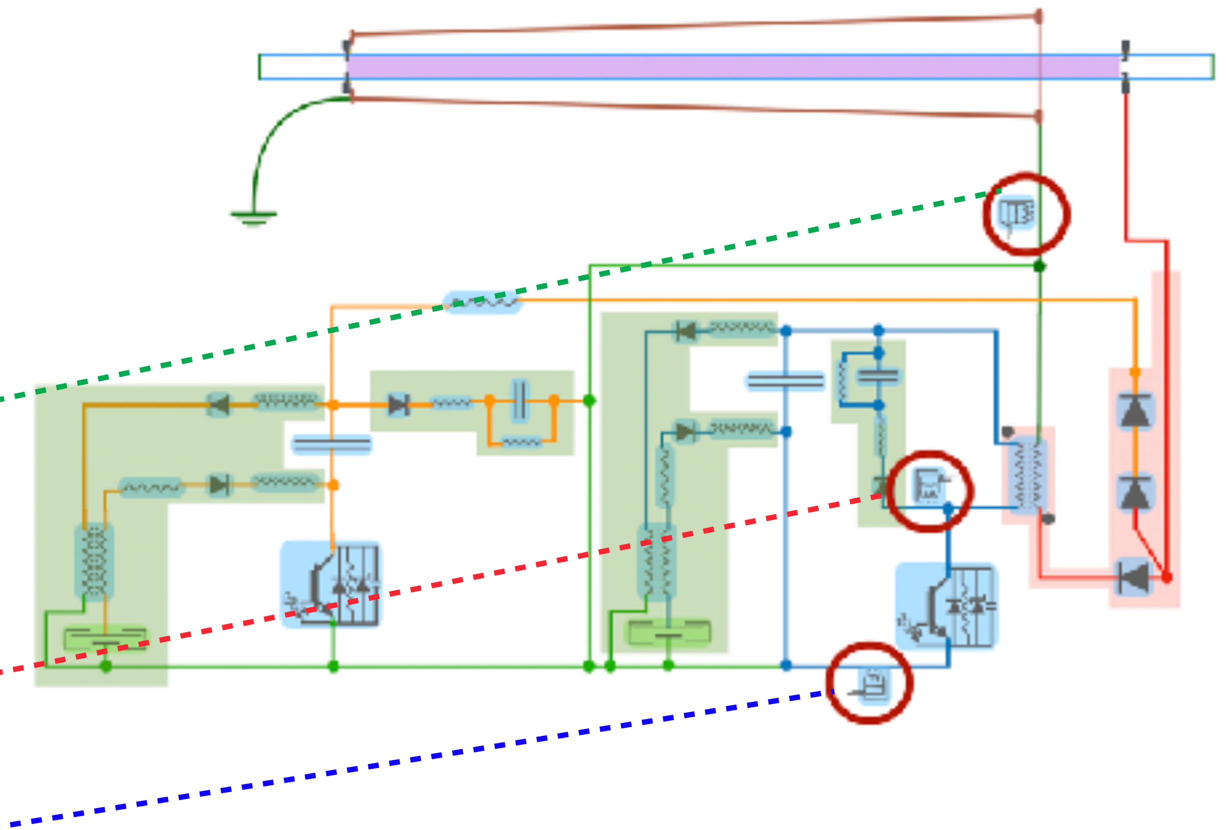




2021-09-02

Ignition
2.2 kV, 12 us
E_{cap} = 2.9 J
$I_{prim\ peak}$ = 70 A
L_{prim} = 377 uH
E_{prim} = 0.92 J

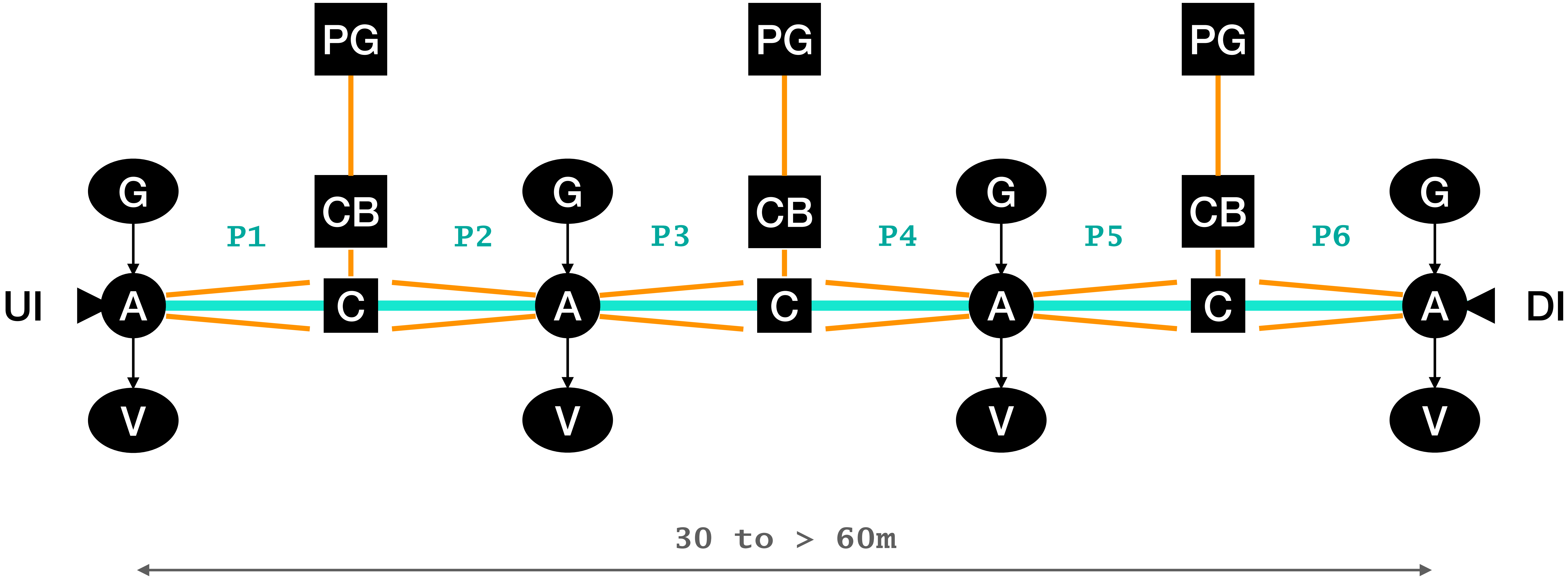
$I_{snub\ peak}$ ~ 45 A

$I_{sec\ peak}$ = 14.5 A (Arc)

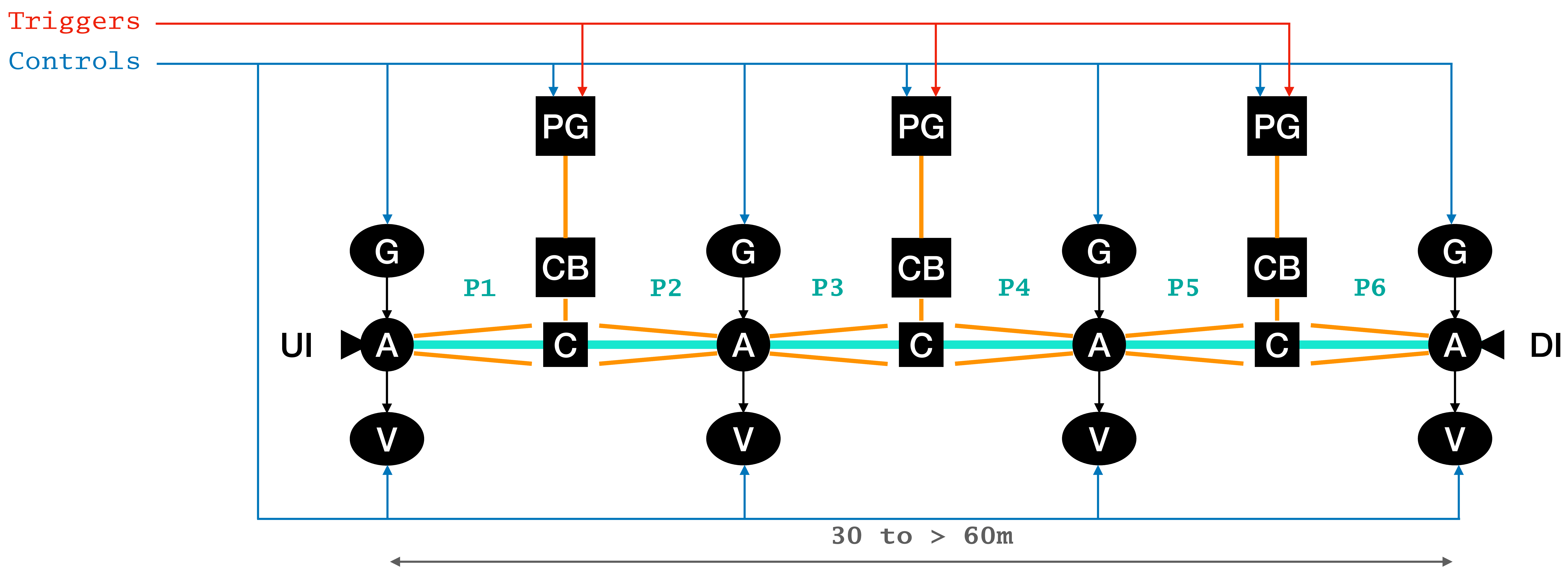
FB Ignition delay ~ 2 us
(12 m long cables, high tube inductance)

Heating
5.0 kV, 10 us, delay 5 us
$I_{tube\ peak}$ ~ 350 A
(high Ionisation fraction)

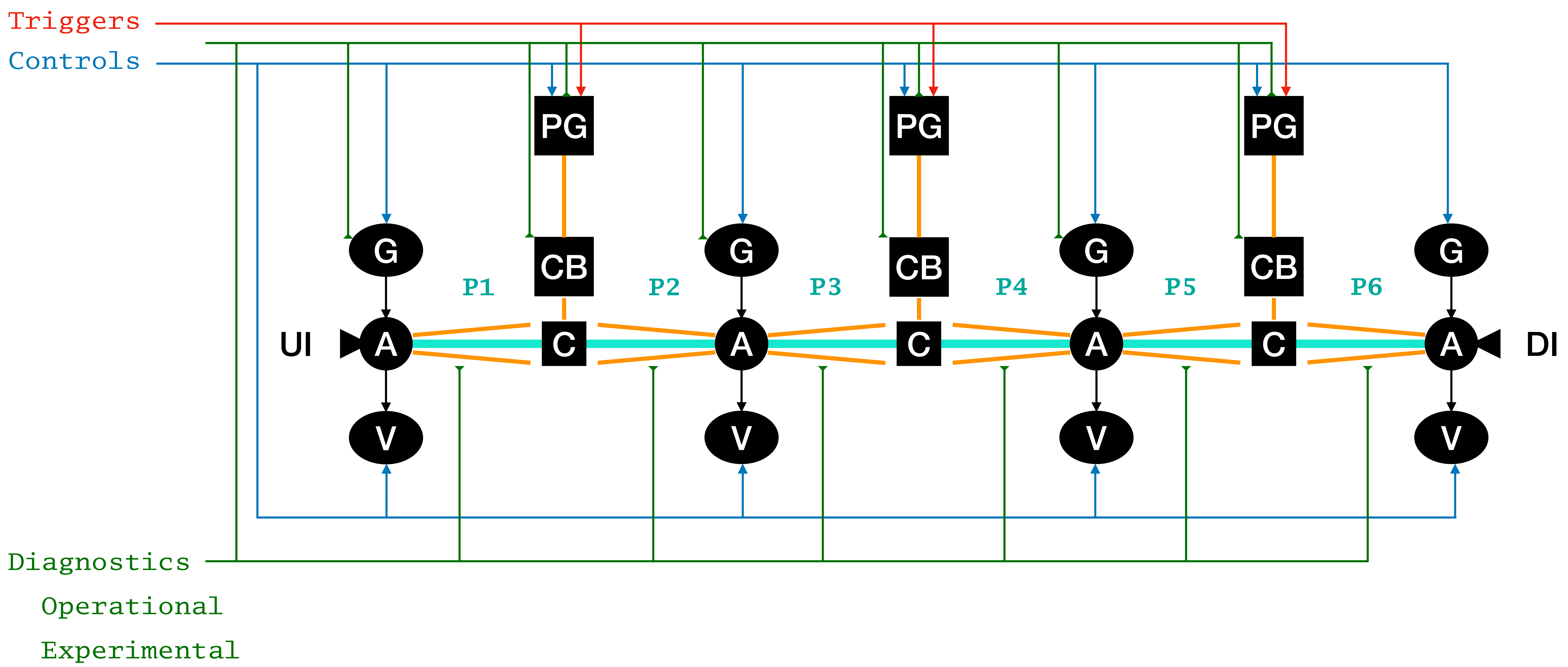
DPS length scalable long term solution scheme



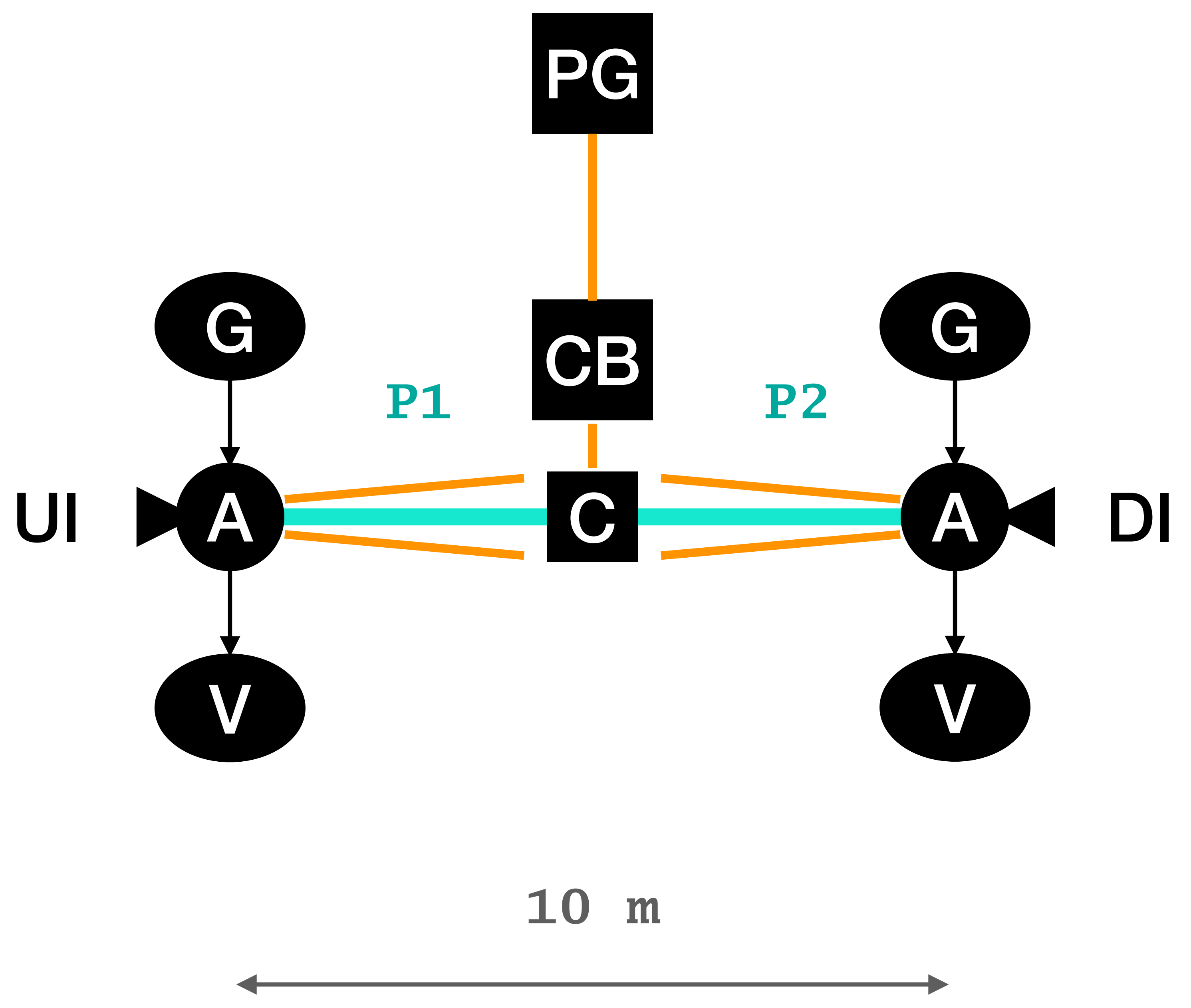
DPS length scalable long term solution scheme



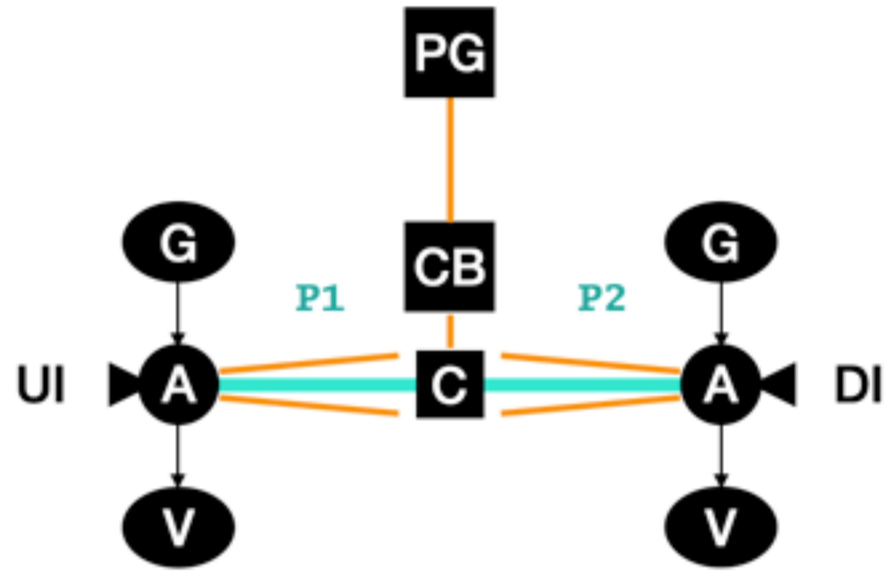
DPS length scalable long term solution scheme



DPS scheme for Jan 23 tunnel test



DPS electrical tech rational



Low jitter, fast arc, long tube, short gap, **plasma ignition**

\+

Low jitter, high reproducibility, 10 μs, 1.5 kA, **plasma heating** for Argon and Xenon

\+

Magnetic current balance enforcement for **symmetric tubes** & symmetric cathodes

Technical Solution:

Ignition by flyback pulse & heating by capacitive discharge

\+

Separation (high voltage - high current) by high-power diode (AKA heater diode)

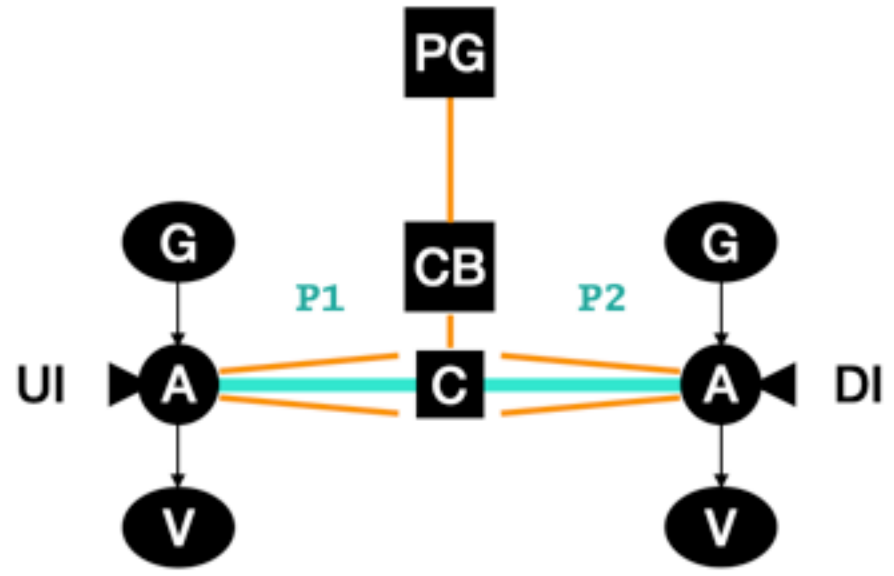
\+

Current balancing by (low parasitic) diff. mode chokes & 4 pin symmetric cathodes

Developed & Tested
@ IST 2020-2021

Partially implemented
@ CERN DPS Lab 2020-2021

DPS tube tech & phys rational



Low pressure, small & constant diameter, μs short pulse, high current **arc discharge**

+

Low average power, Low repetition rate, cold cathode, **uniform plasma density**

+

Symmetric tube & symmetric electrodes & symmetric ignition gap & symmetric tube E_field

Technical Solution:

Glass tube sections (25 mm diameter, KF 25 like) & “conical” **return cage**

+

Discrete, 4 pin, refractory, **common cathode** & single piece **annular anode**

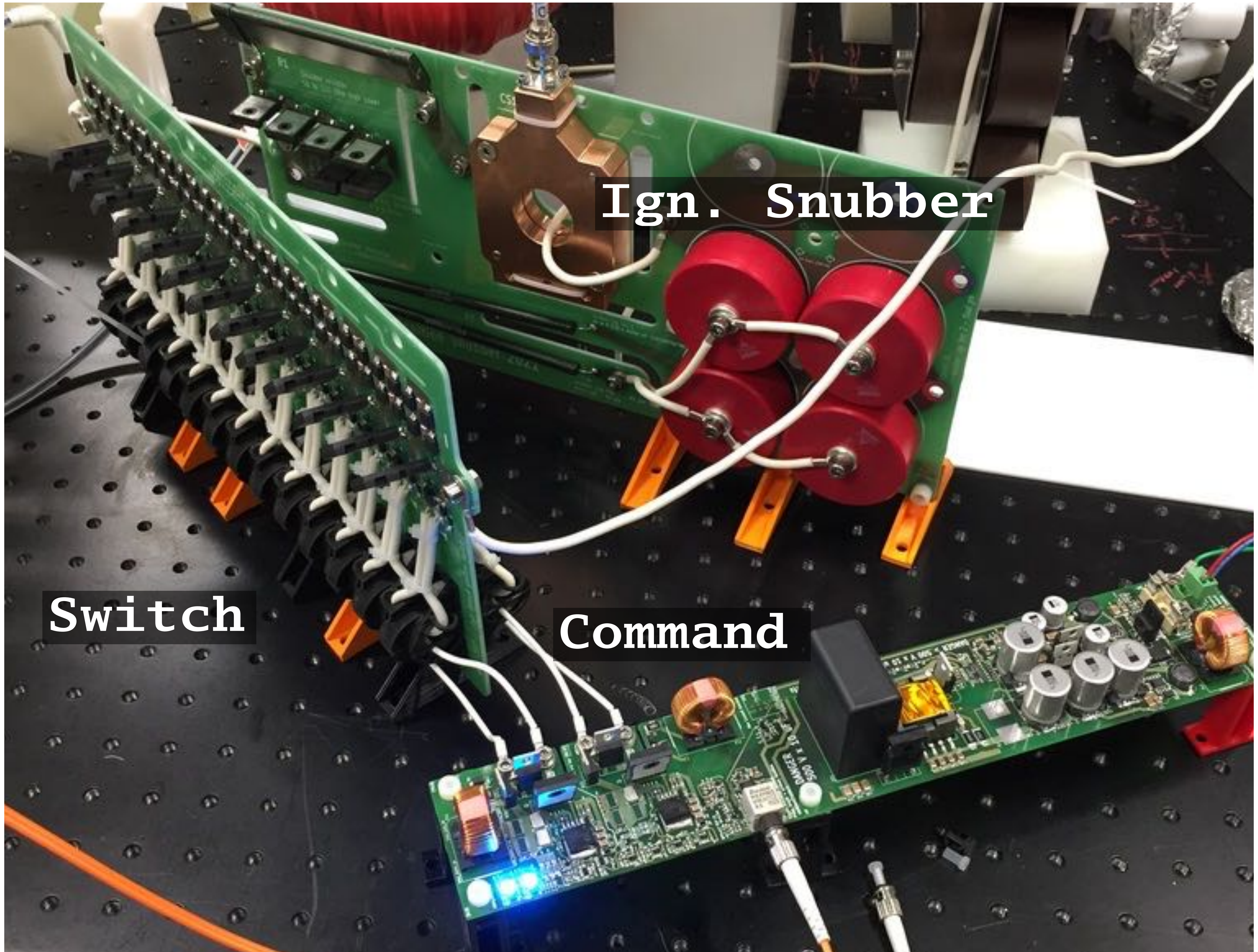
+

Viable phys and tech for Ar (Kr & Xe) (Ne & He ???)

Developed & Tested
@ IST 2020-2021
@ CERN DPS Lab 2020-2021

Recent milestones

>> switch topology for flyback pulse generation



Recent milestones

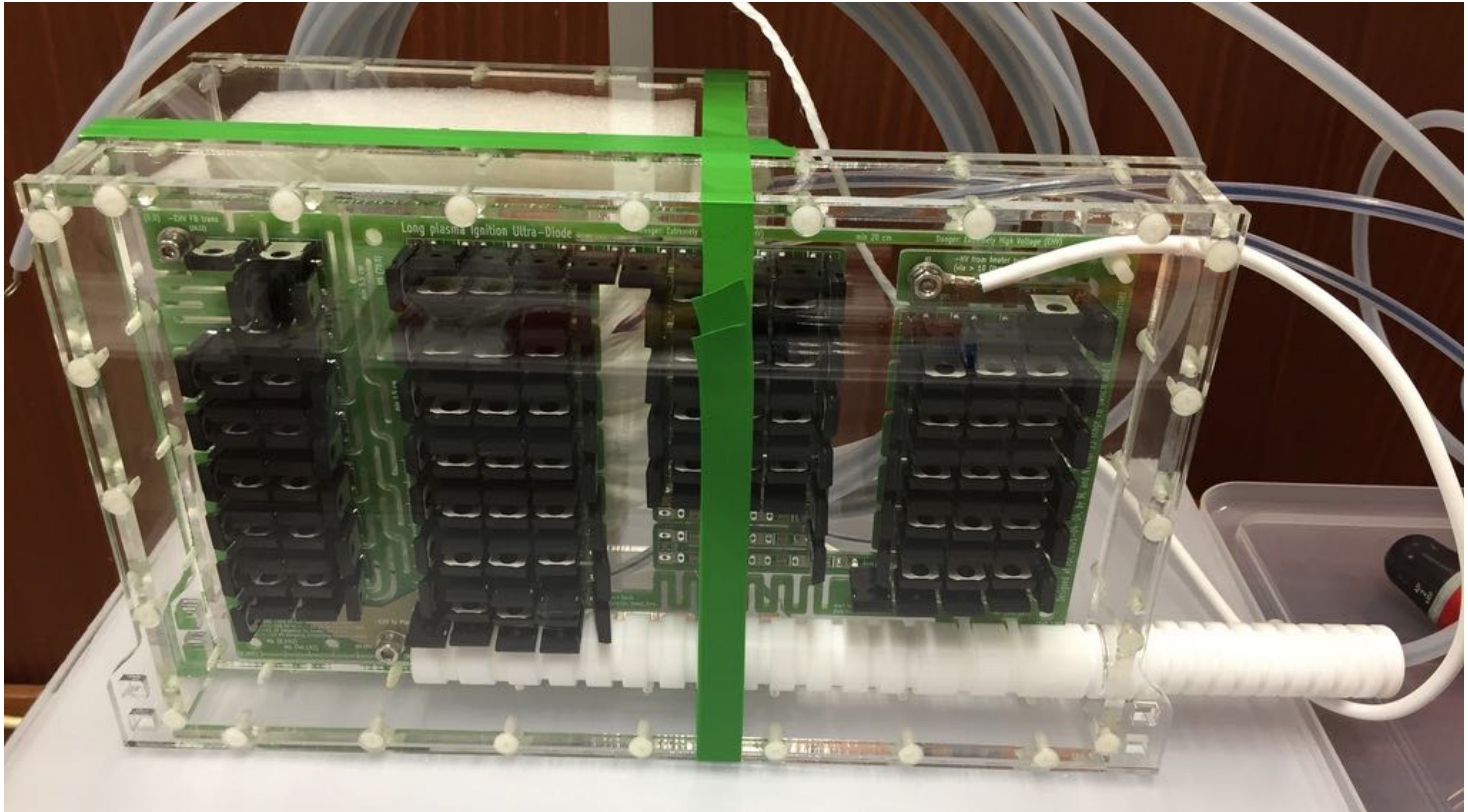
>> switch topology for high-current plasma heating

Recent milestones

>> high-power compact robust flyback transformer for up to 120 kV

Recent milestones

>> compact single-board FB diode + high power heater diode



Recent milestones

>> relatively compact ignition + heating system working at CERN DPS Lab

Recent milestones

>> relatively compact ignition + heating system working at CERN DPS Lab

Recent milestones

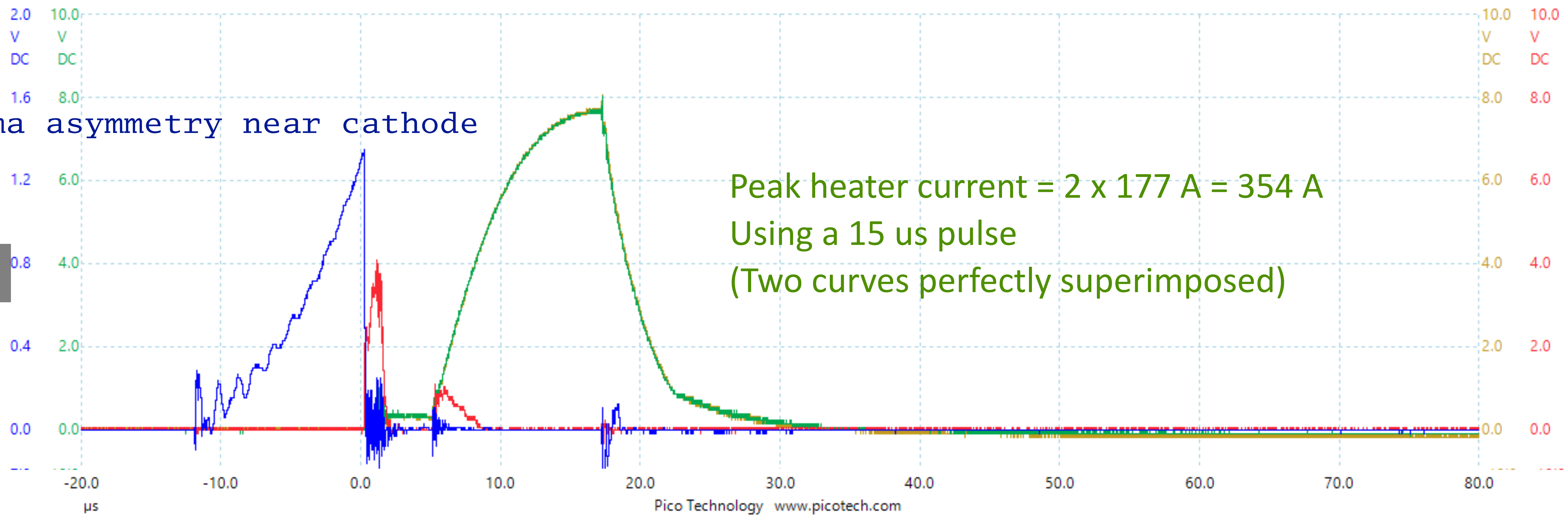
>> attenuation/correction of plasma asymmetry near cathode

Before

Recent milestones

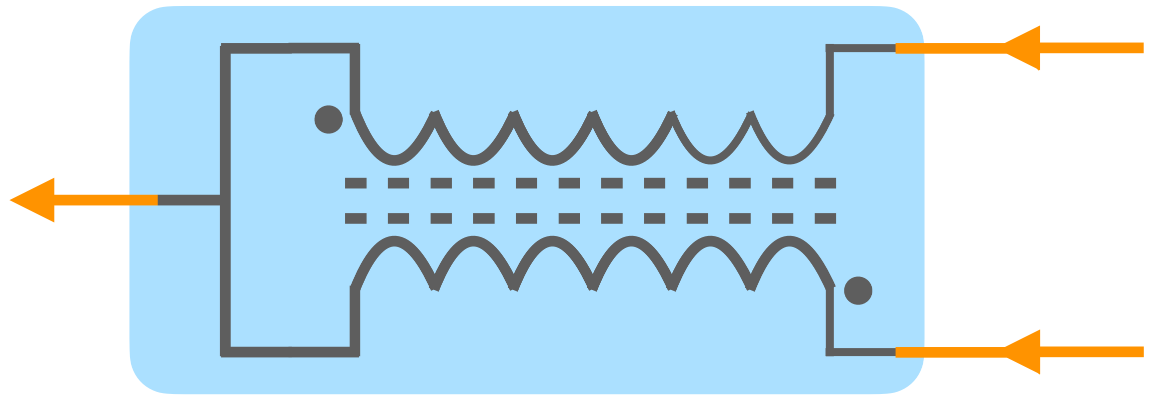
>> attenuation/correction of plasma asymmetry near cathode

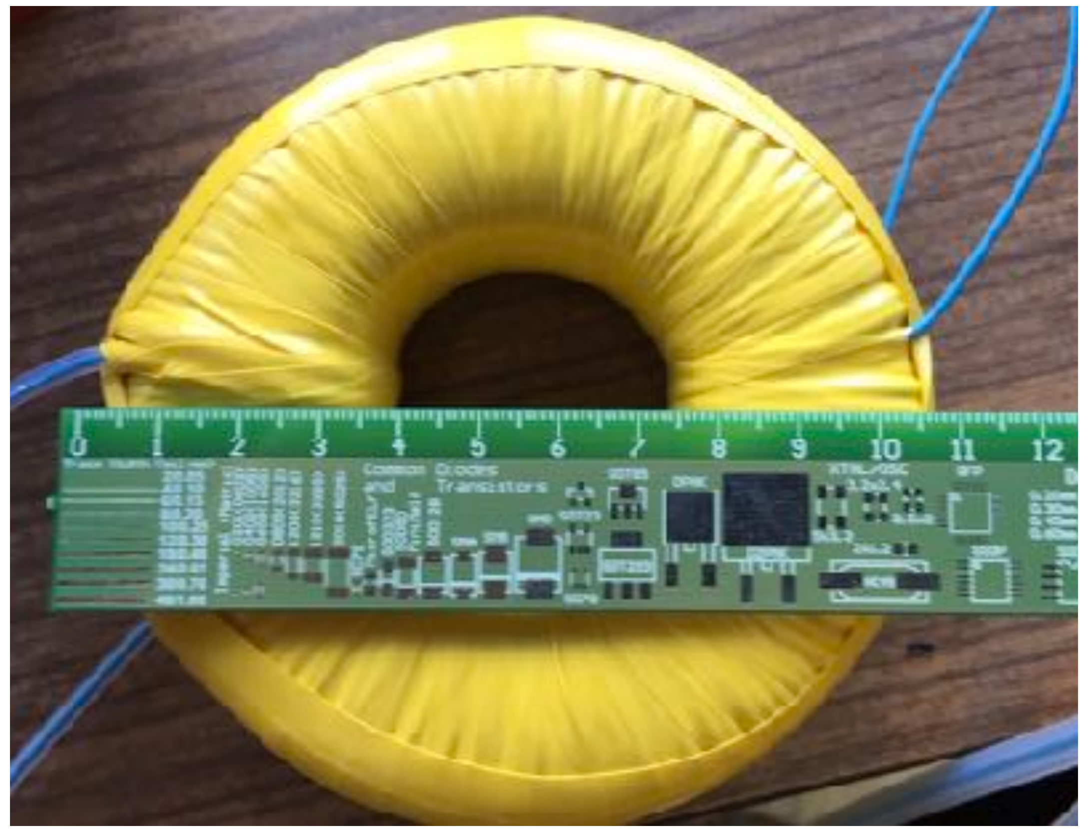
After



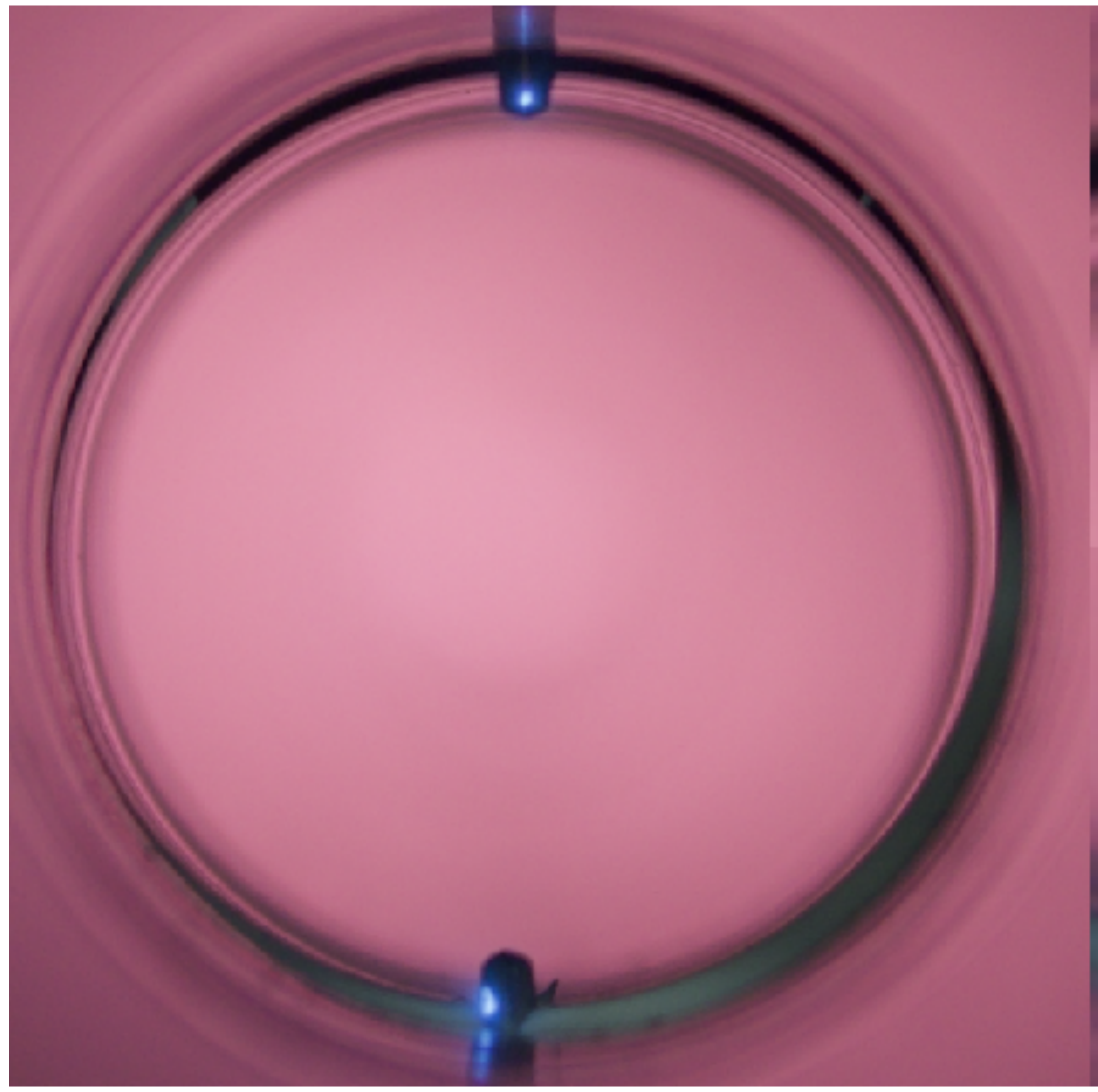
Peak heater current = 2 x 177 A = 354 A
Using a 15 us pulse
(Two curves perfectly superimposed)

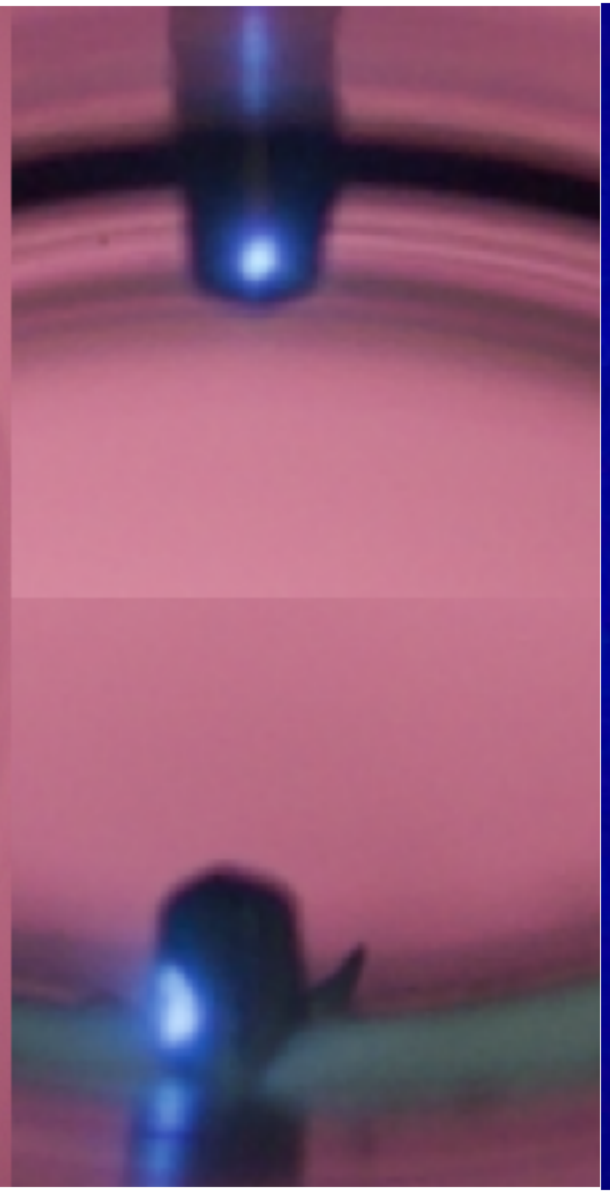
Differential Mode Choke (DMC)
Current divider

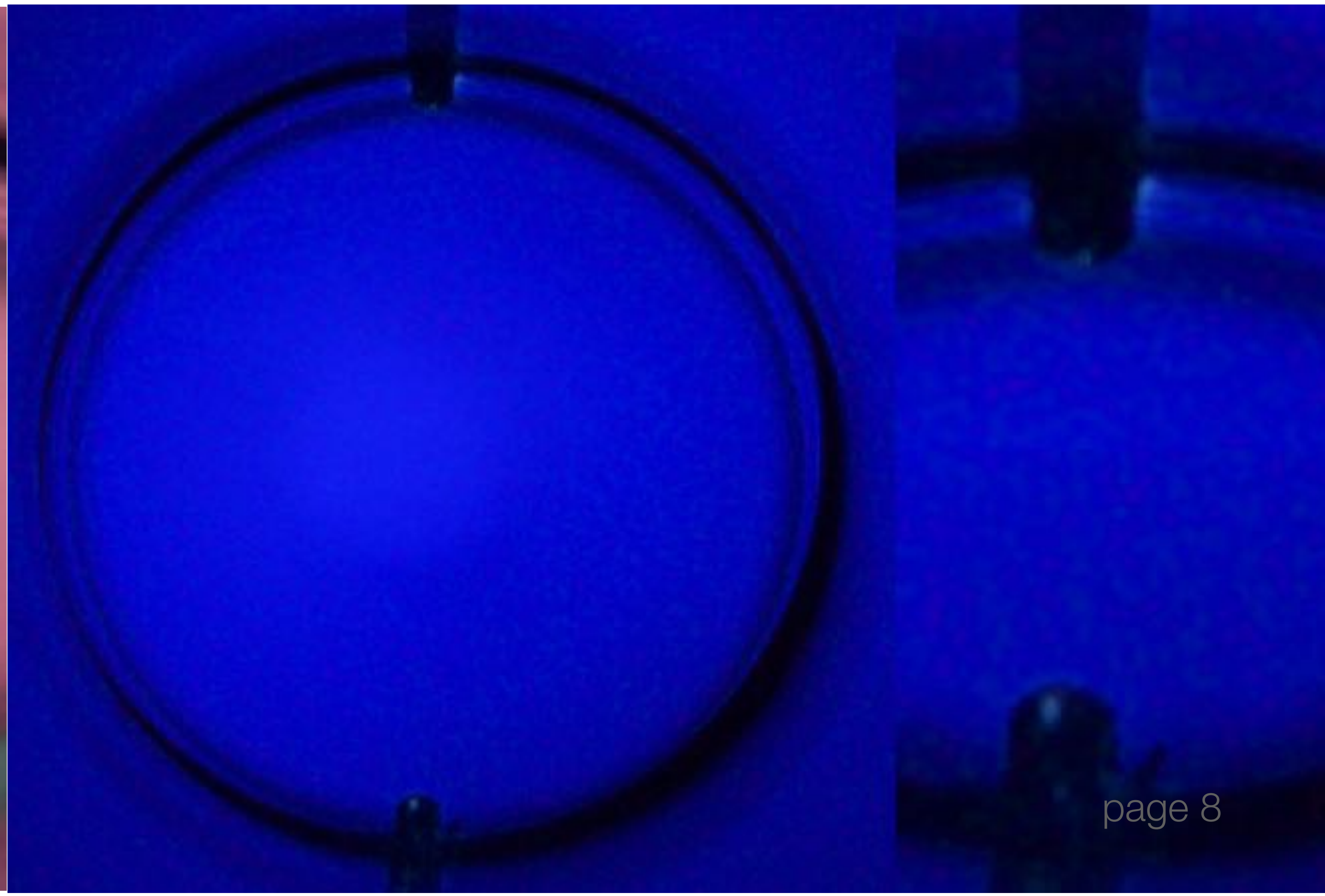




>> New cathode pins
With bent tips

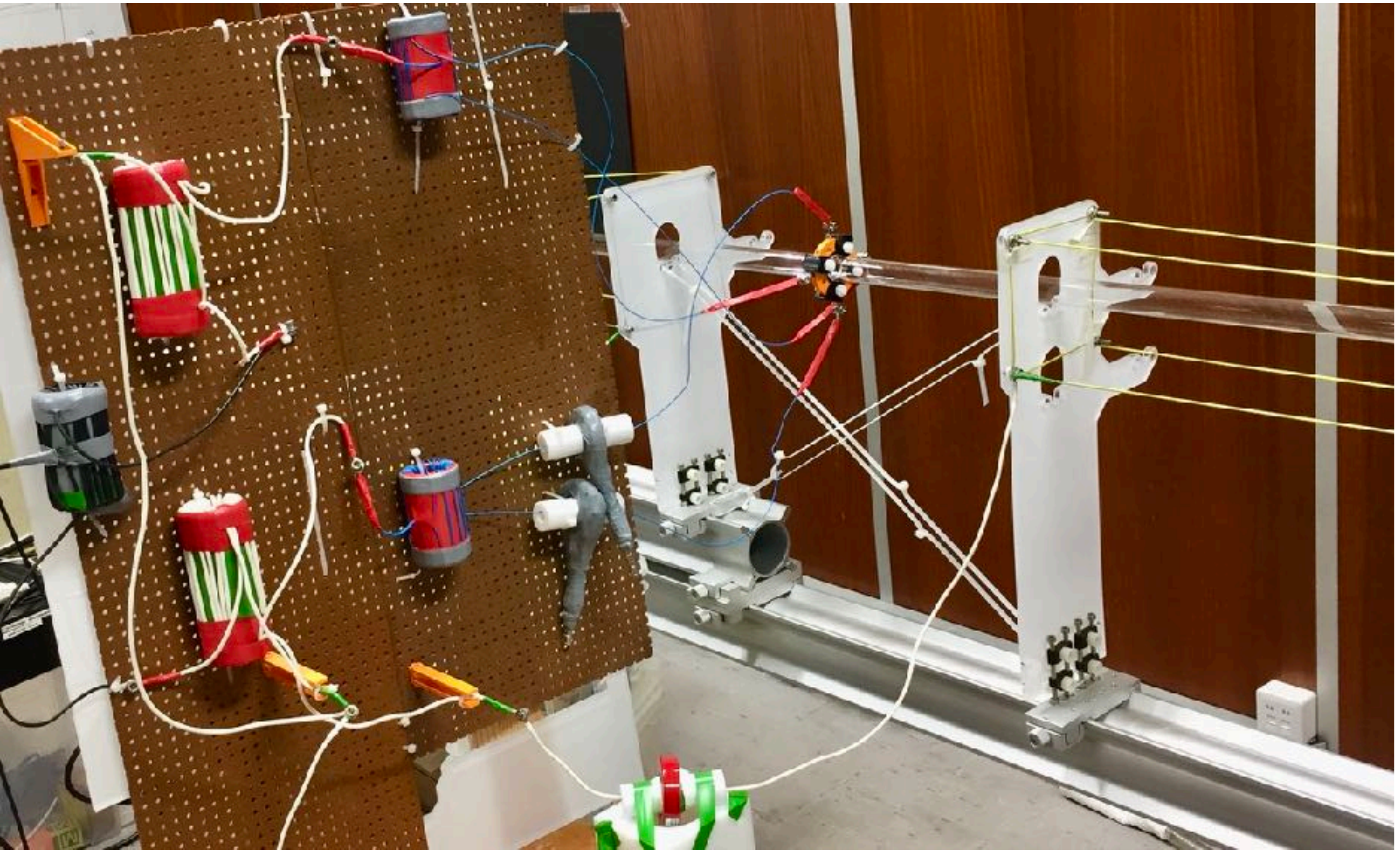


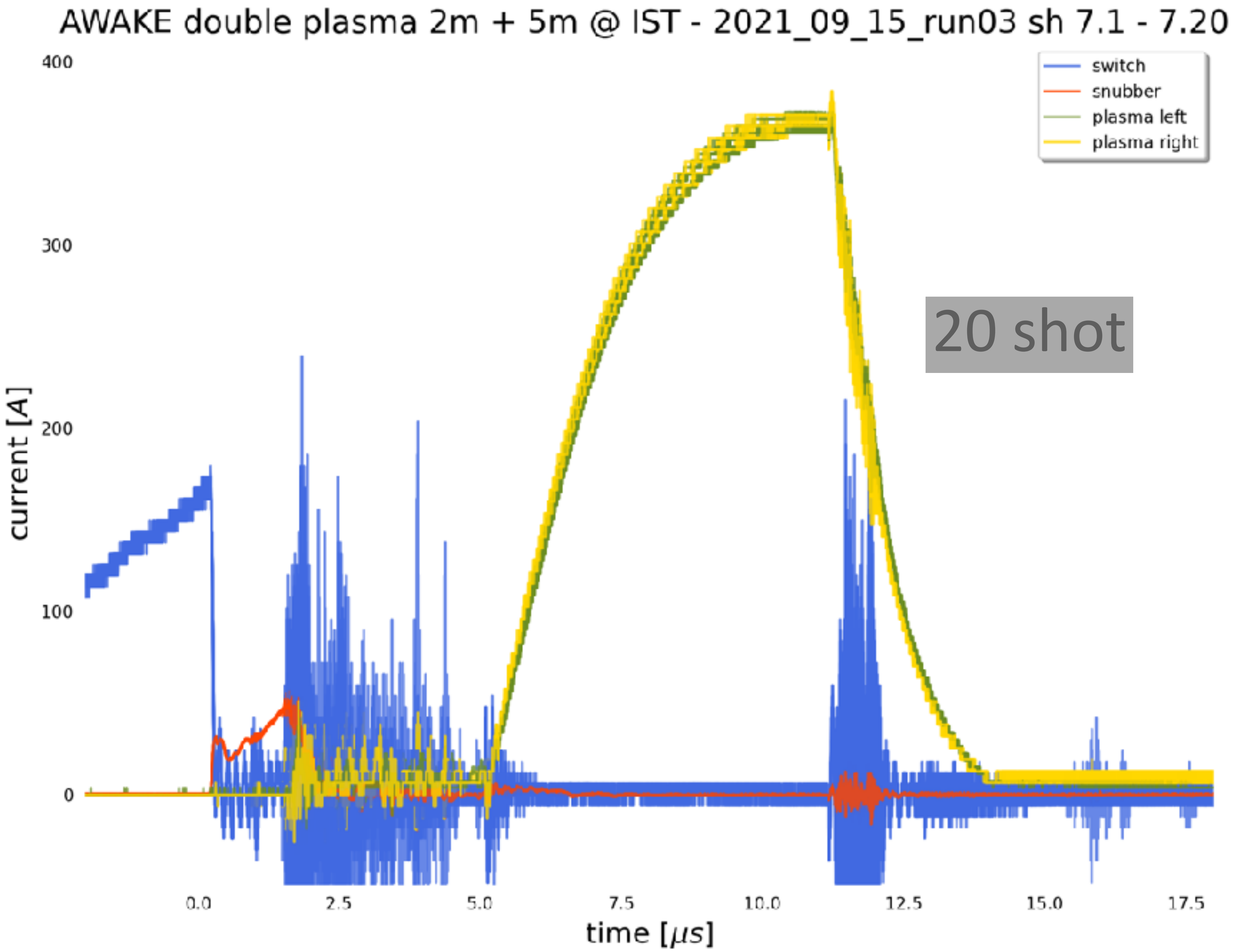




Recent milestones

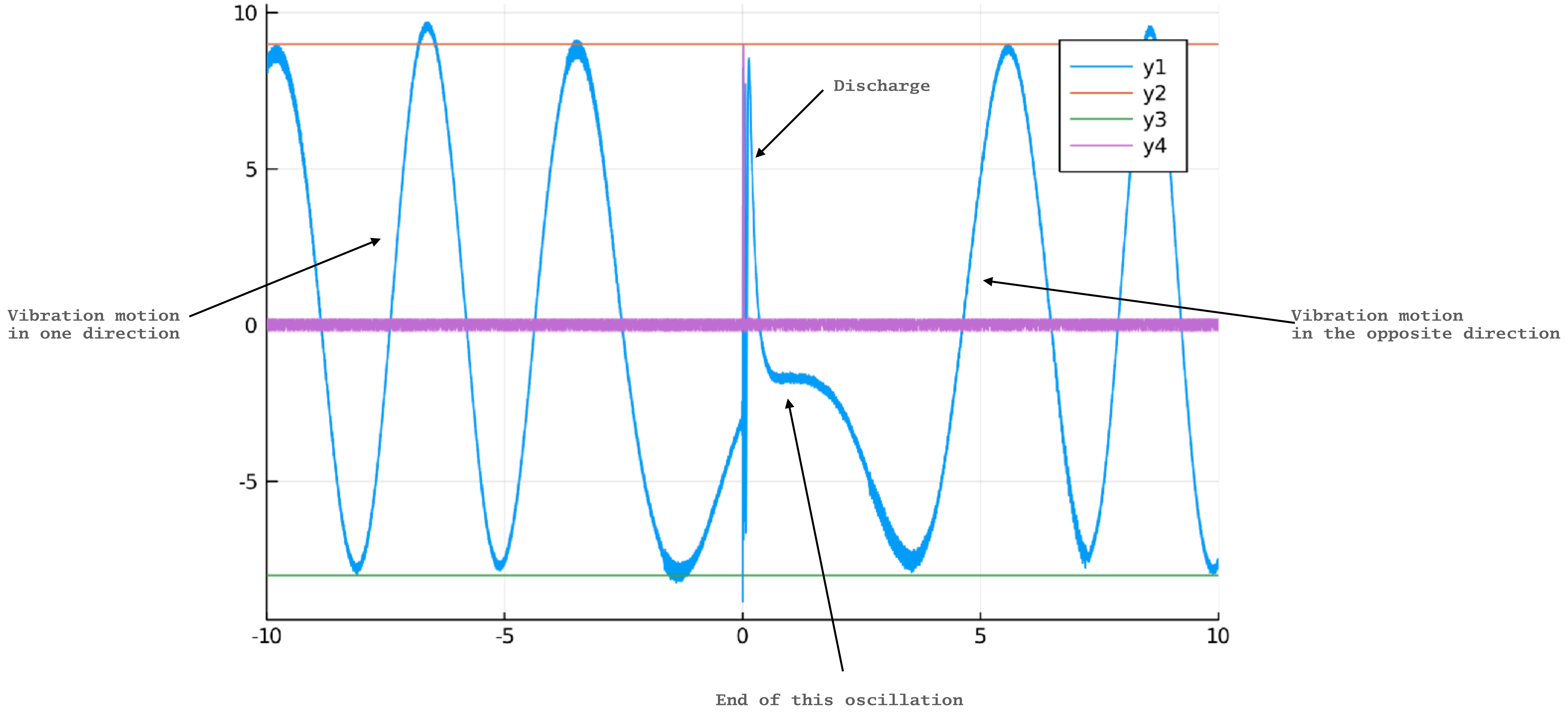
>> Full fast risetime CBM for 4 pin common cathode and **double plasma** in asymmetric tube (2m + 3m)





Recent milestones

>> Direct measurement of full range of AWAKE target densities by interferometry (**preliminary** & ongoing)



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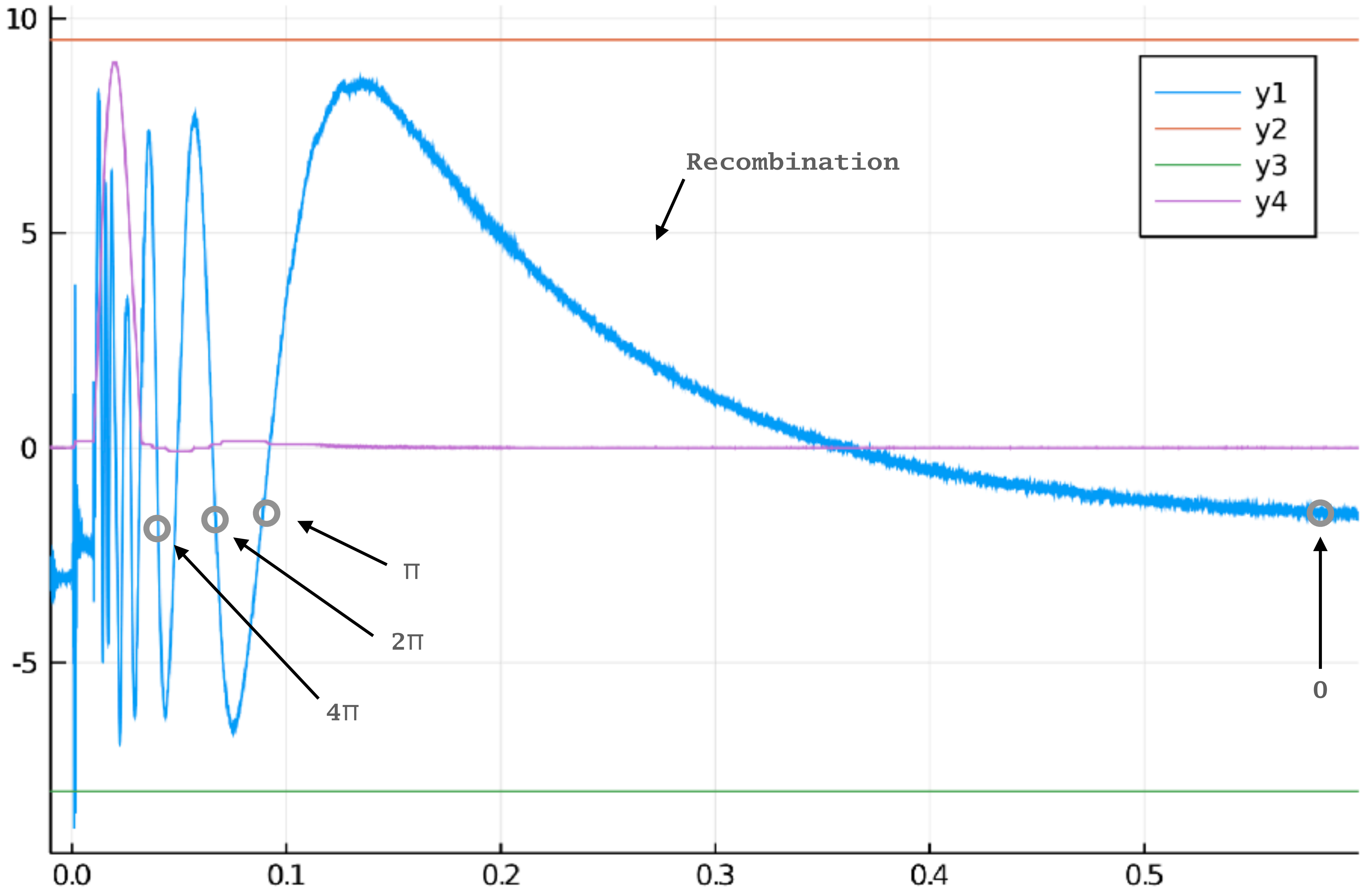
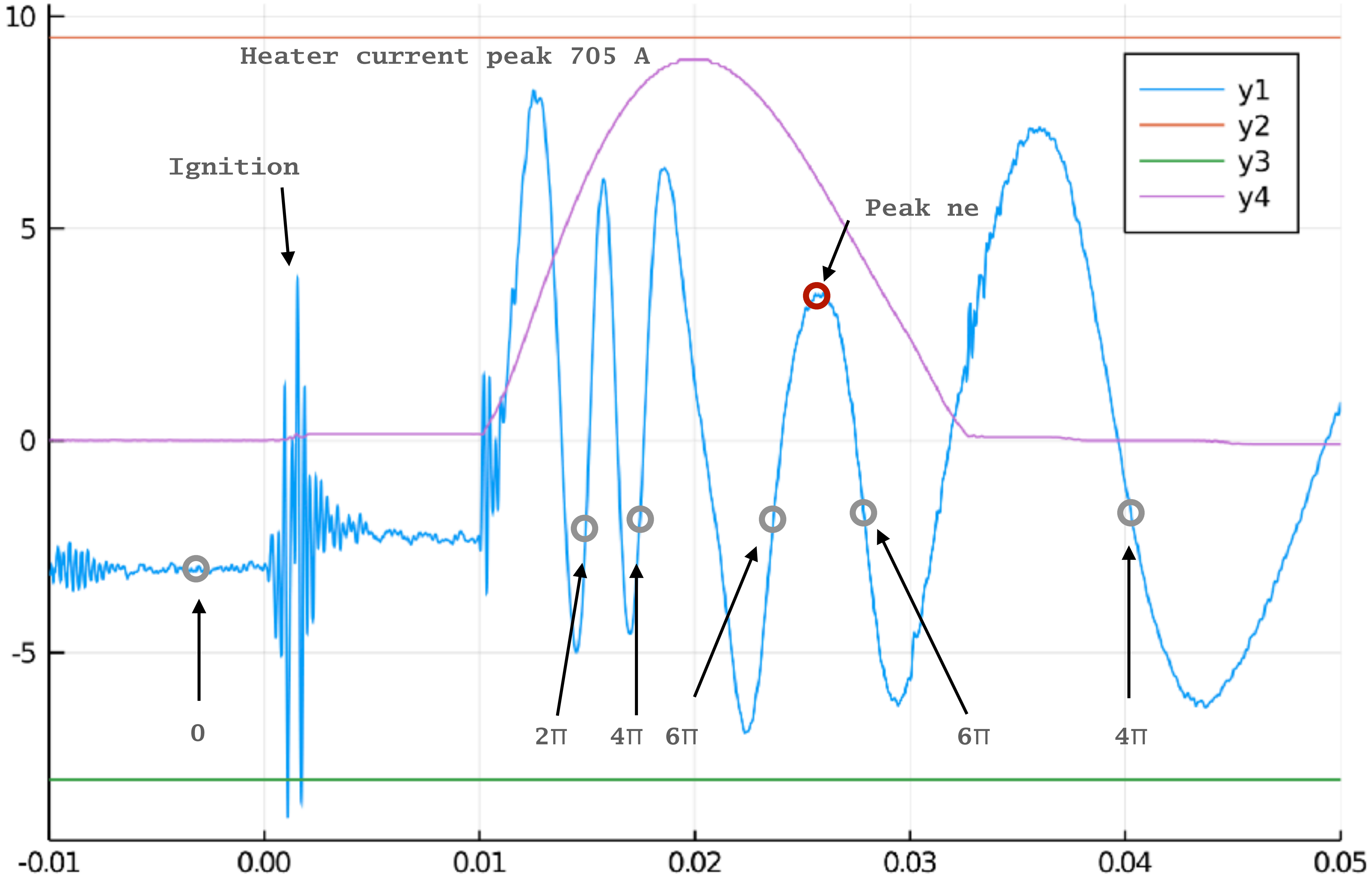




Time is in milliseconds

Current is in A/80

Peak ne ~ 3.1 fringes

~ 3.1 x 3.3e14 cm^{-3}

n_e (peak) = 10.2 e14 cm-3

Error ~ 0.25 fringes

~ 0.8 e14 cm^{-3}, 8%

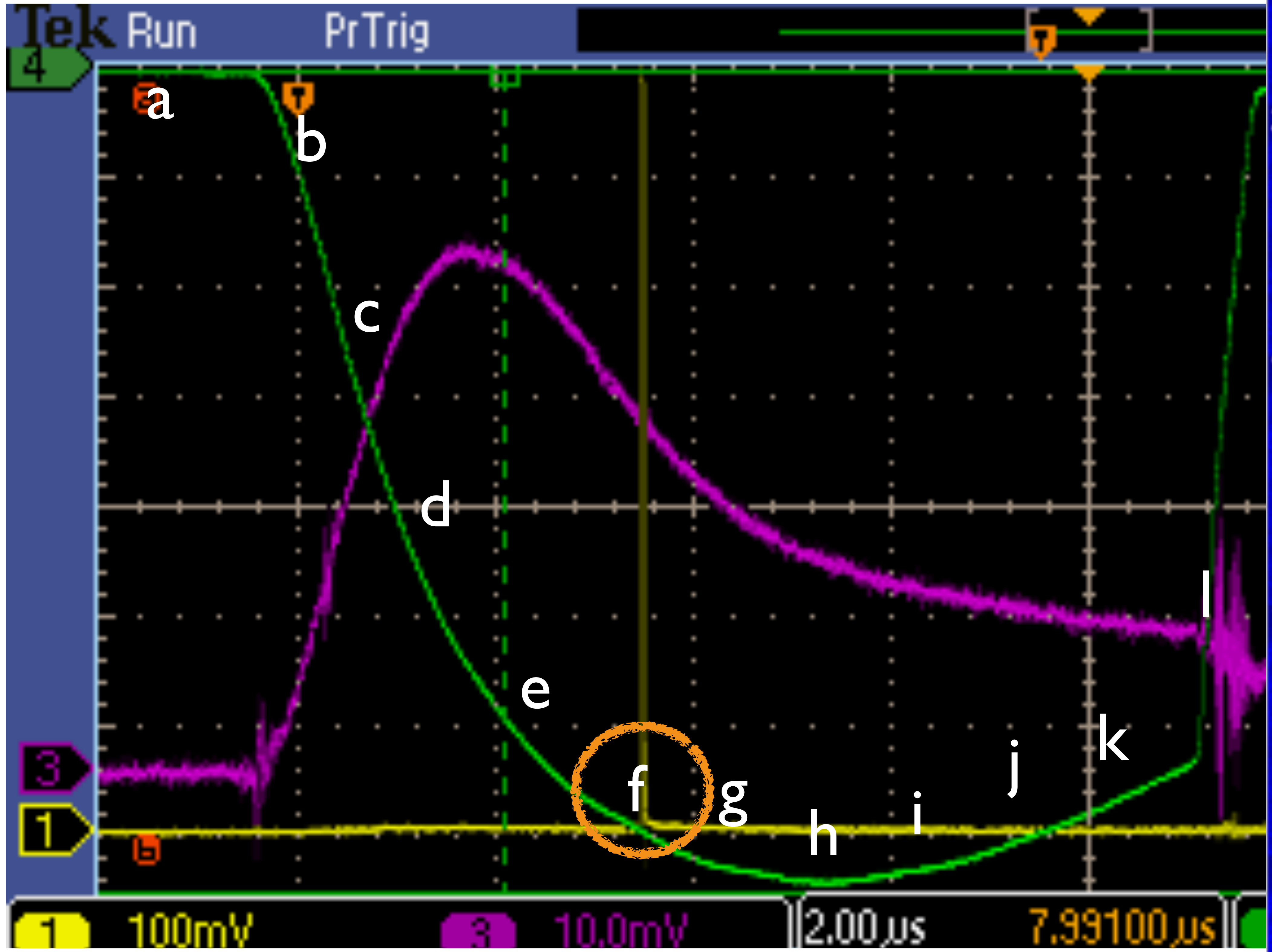
Argon P = 15 Pa

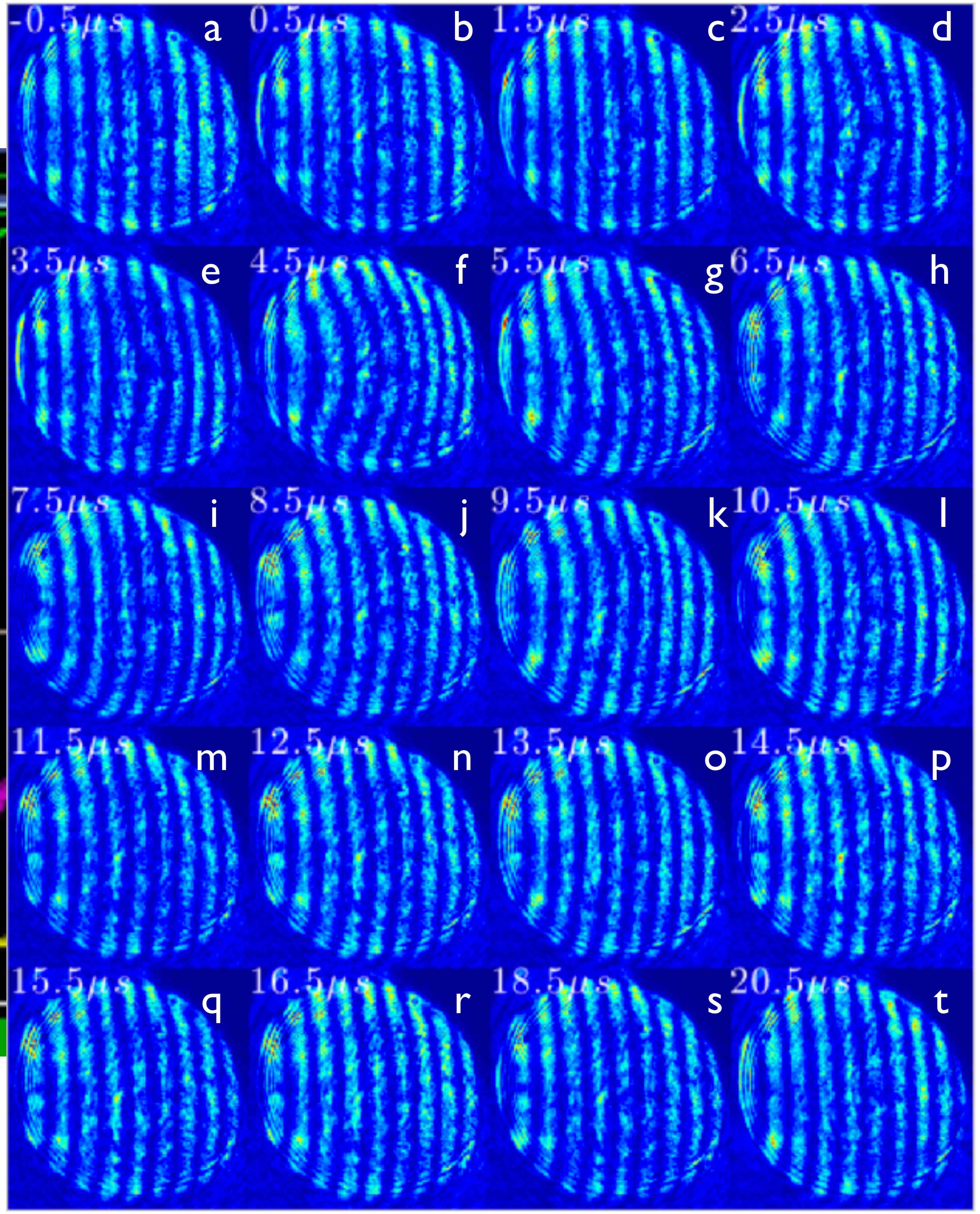
n_0 = 3.7 e15 cm^{-3}

n_e/n_0 = 27.5 %

~~Recent~~ old milestones

>> qualitative plasma uniformity assessment by space resolved axial interferometry (@ IC)





Maximum radial Δne @ position (f)

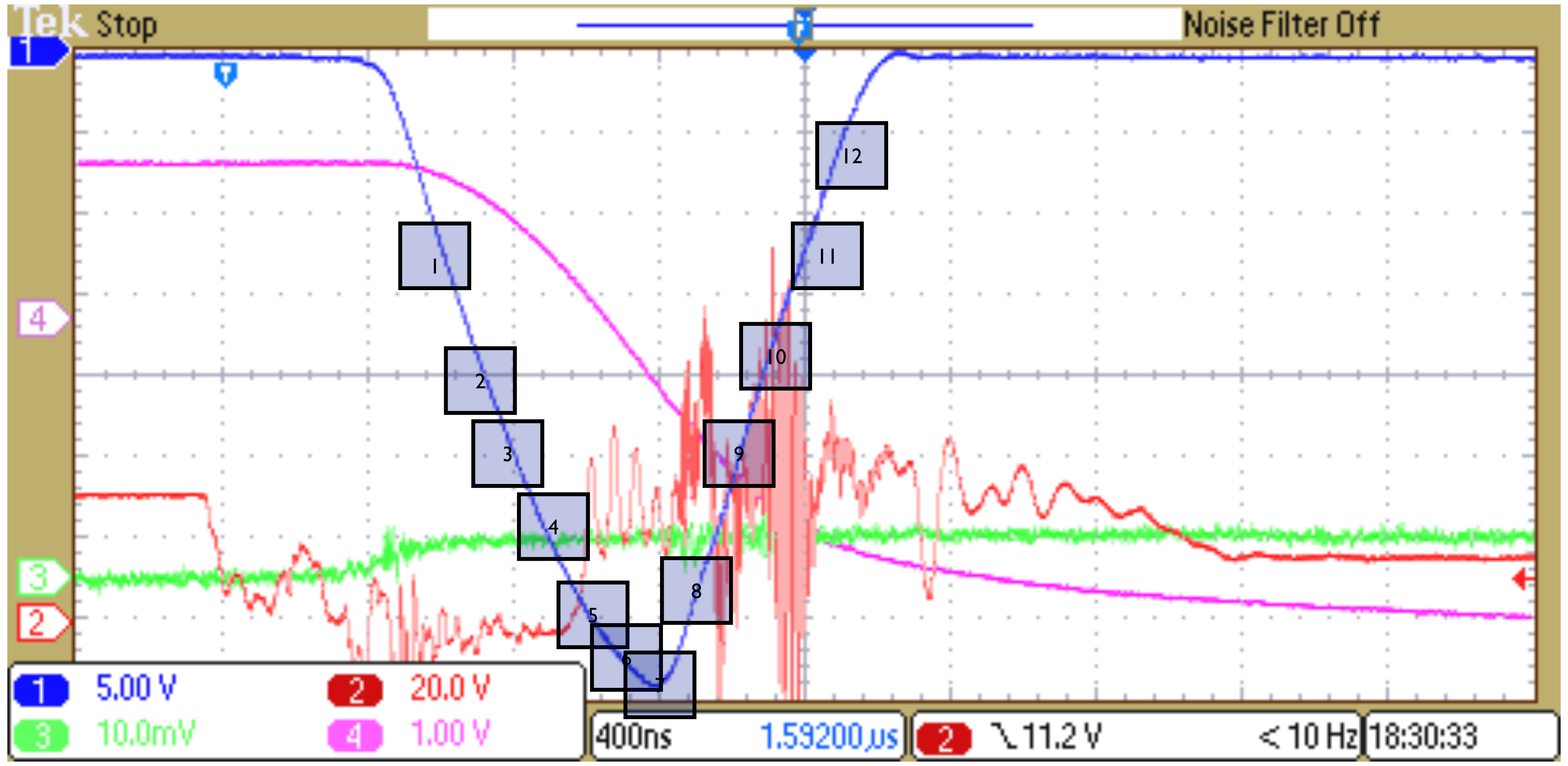
Δn_e (f) ~ 1/2 n_0

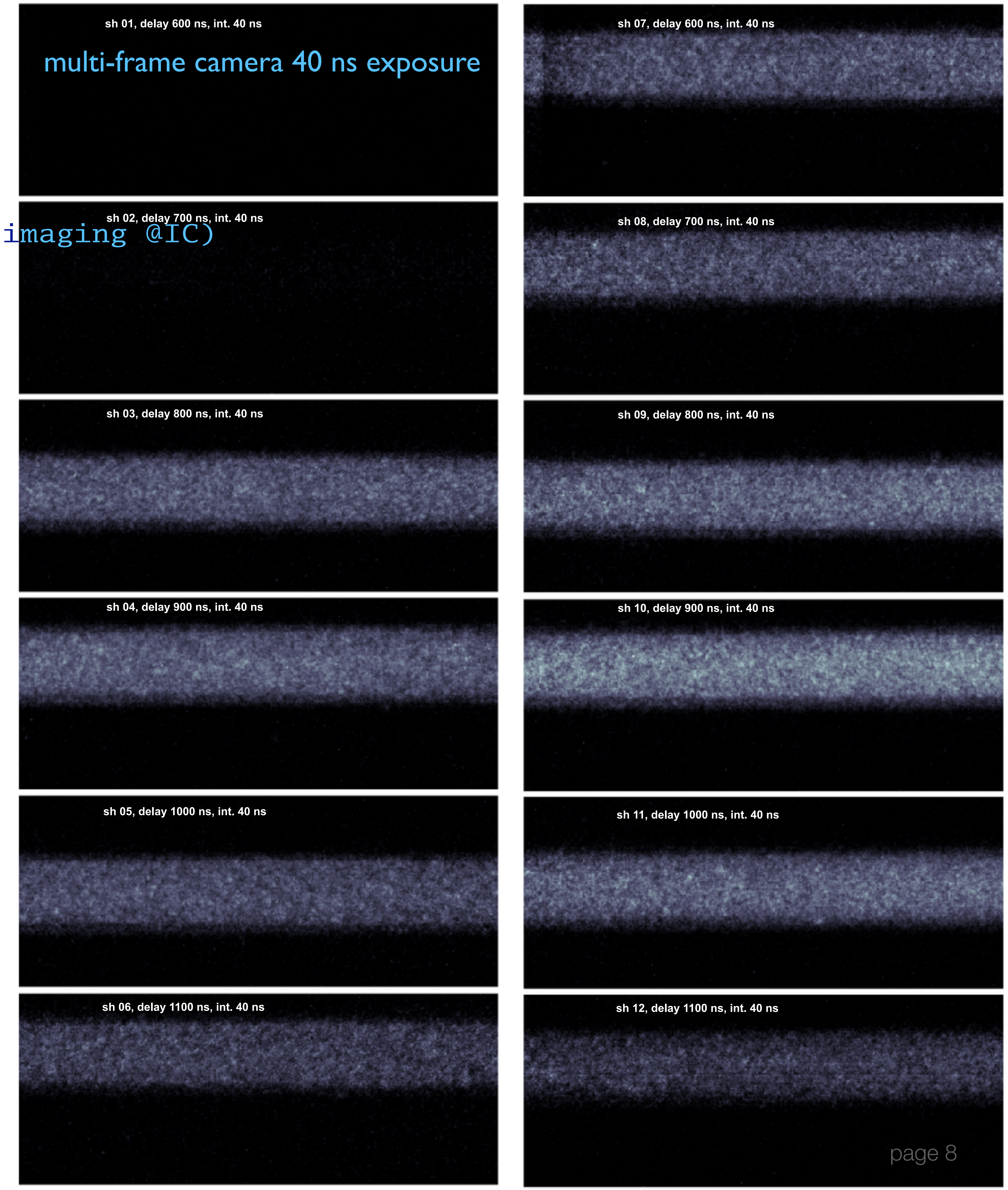
n_e flatens after (f)

No sign of uniformity in axial integrated interferometry

~~Recent~~ Old milestones

>> qualitative plasma uniformity assessment by fast gated imaging @IC)



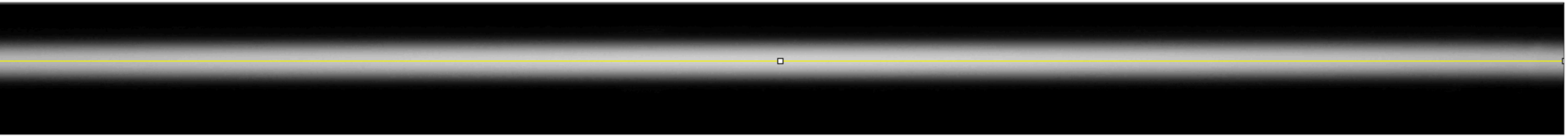


- High-speed imaging sugests the formation of an uniform plasma...
- ... with a high ionization level of 0.5 µs
- Uniform plasmas where observed for pressures in the range 0.05 - 20.0 mbar...
- ... and for lengths from 0.5 m to 1.5 m

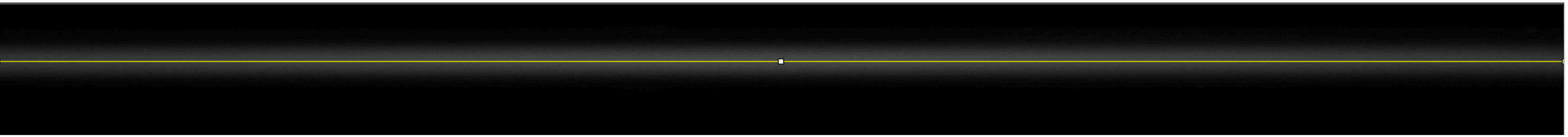
- Parameters: Current 300-400 A
- Pressure: 20 mbar
- Tube diameter: 10 mm
- Tube length: 0.5 m

Recent milestones

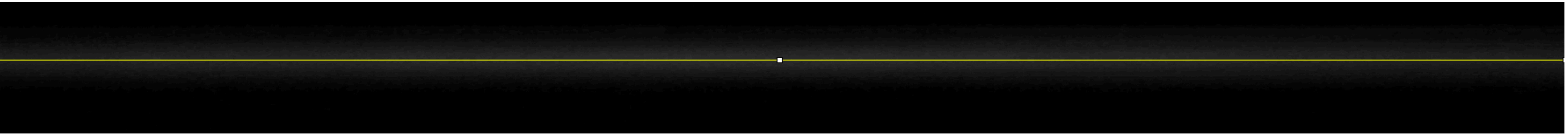
>> qualitative plasma uniformity assessment by side integrated imaging (1.2 m of plasma, IST)



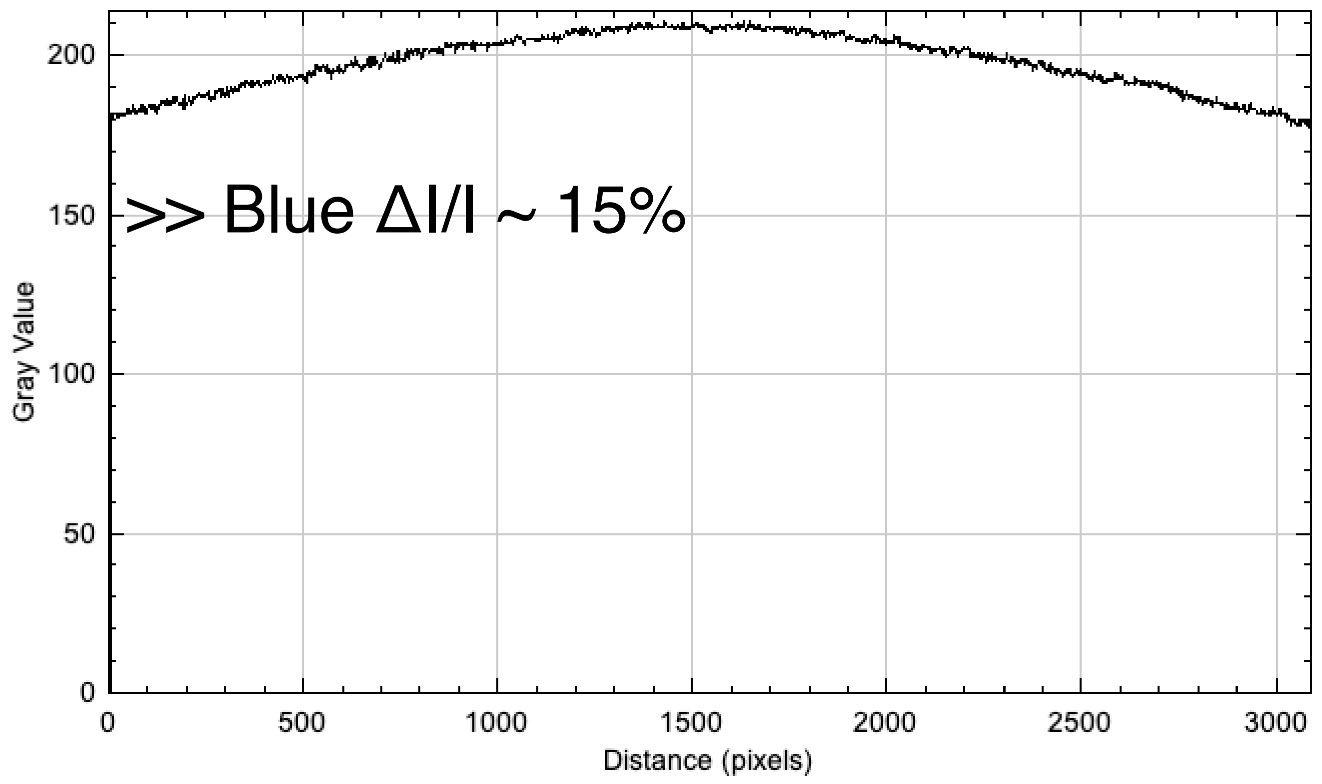
>> Blue

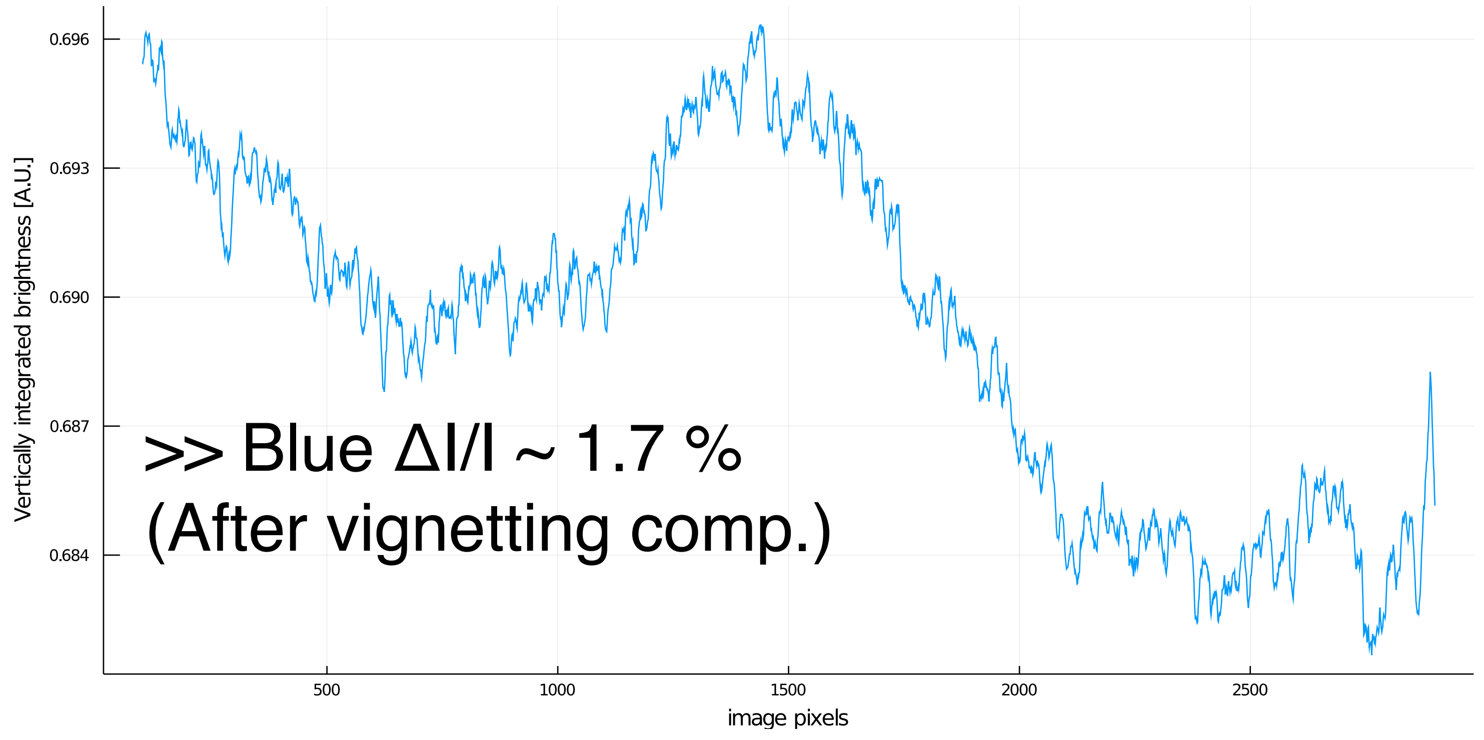


>> Green



>> Red





Imaging with DSLR camera

Over black paper

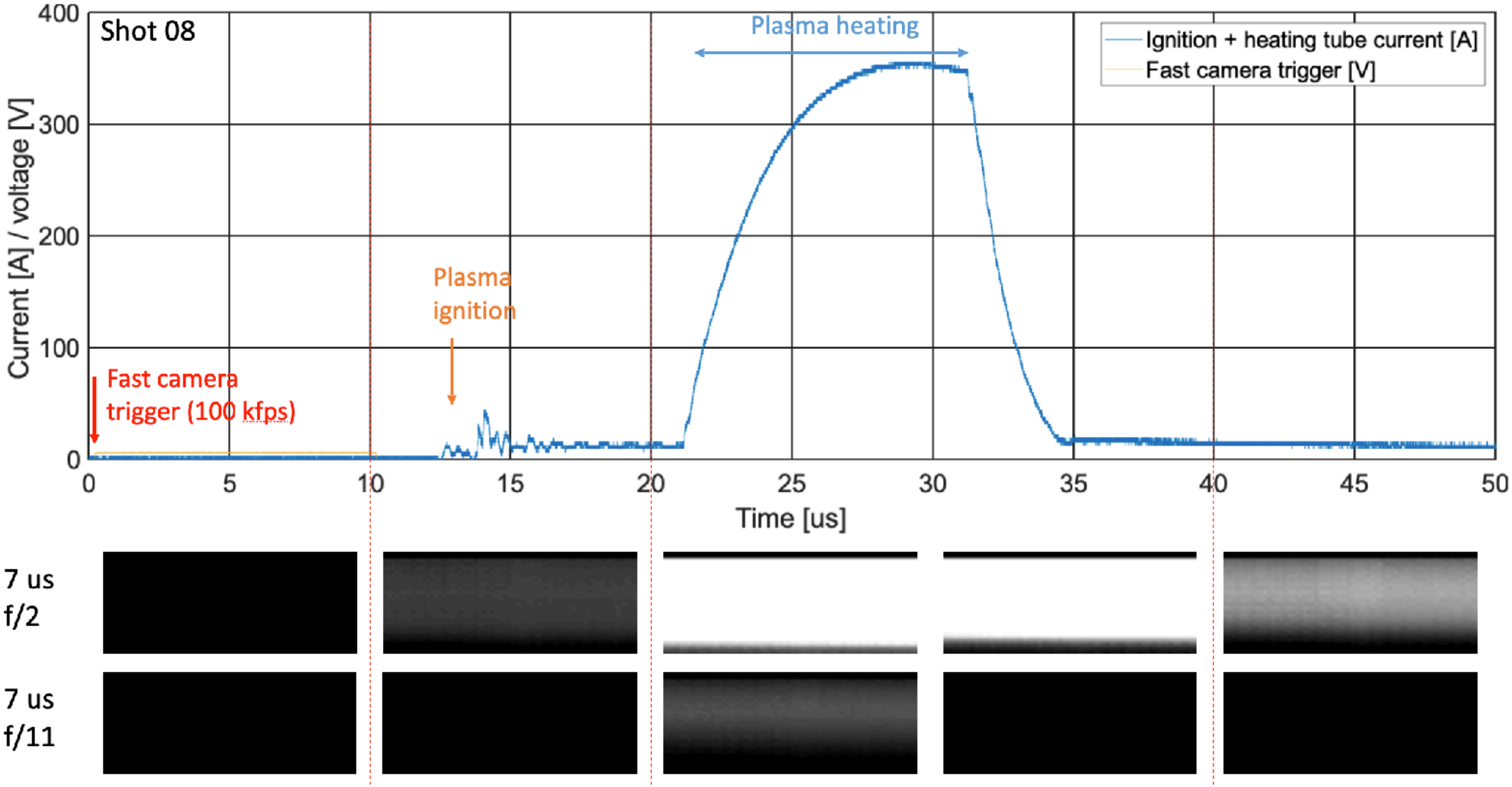
1.2 m section
> contains glass joint
> glass is not uniform
> ends have reflective surfaces

Vignetting compensation
> Best Cos^4 curve

>> ΔI/I < 1.7%

Recent milestones

>> qualitative plasma uniformity assessment by side gated imaging (CERN DPS Lab)

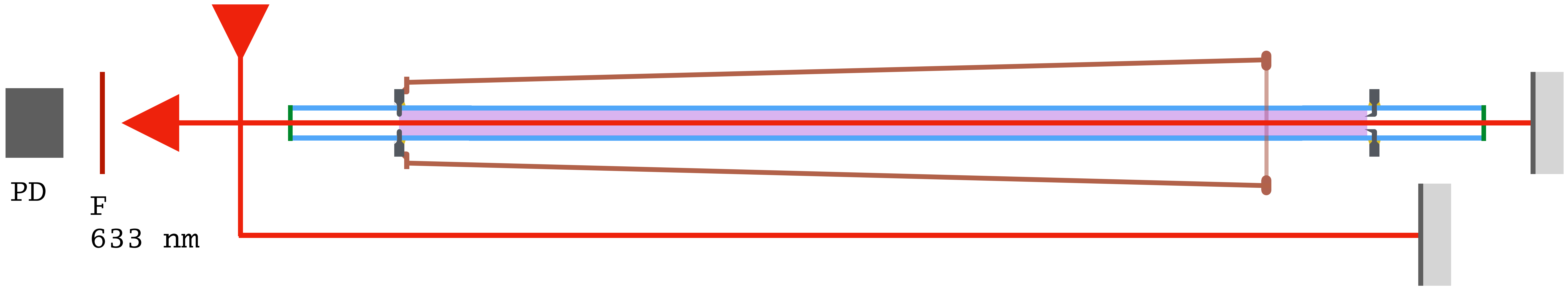


Recent milestones

>> CERN electrical safety approval …

Relevant diagnostics in use or under development

>> Time resolved axial interferometry



Essential diagnostic to balance > 1 plasma

Used at **IST** with He:Ne laser with ~ 5 % precision so far

Plan to improve SRN and reach ~ 2 %

Plan to implement quadrature measurement to reach < 1 %

@ CERN

Plant to use 1.5 µm laser and reach ~ 1 %

Eventually implement quadrature measurement to reach < 1%

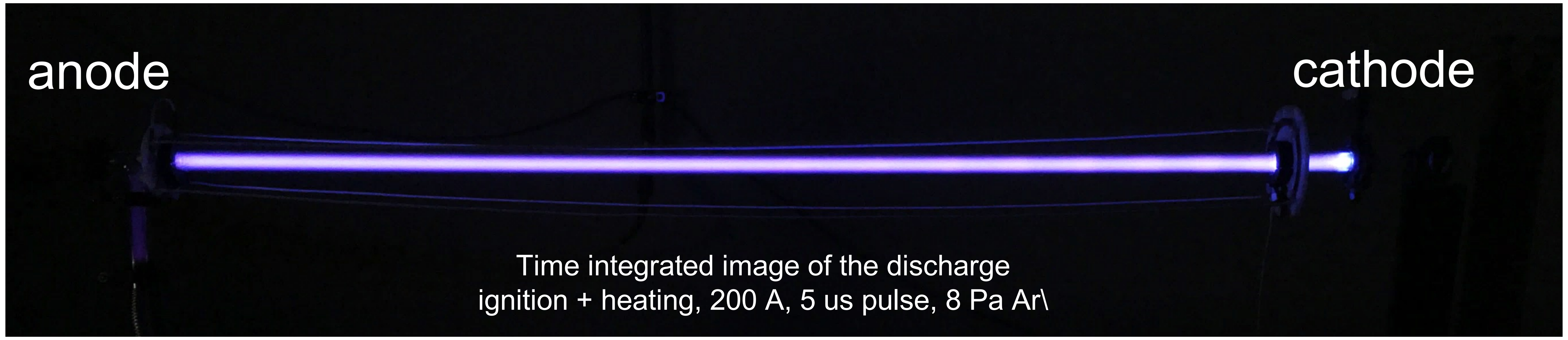
Eventually find a way to use it in tunnel … … …

Plasma Diagnostics

Optical Emission Spectroscopy (OES)

→ **light emitted by the plasma**
→ assess plasma composition
→(potentially) plasma density

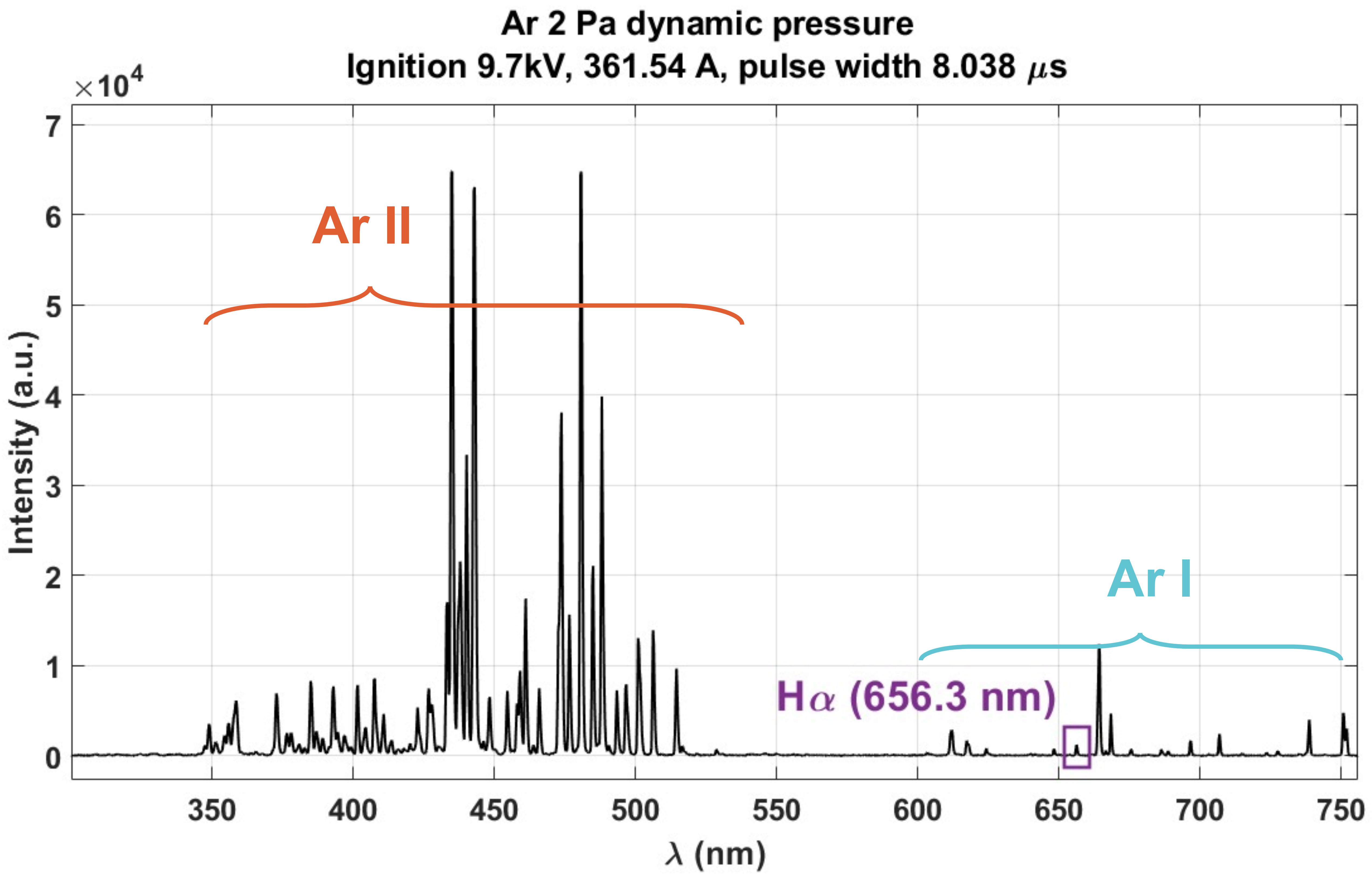
→ **Diagnostic of choice:** easiness of implementation and non-invasiveness



Time integrated image of the discharge
ignition + heating, 200 A, 5 us pulse, 8 Pa Ar\

$$\varepsilon_{\mathrm{pk}} = n_0 n_{\mathrm{e}} X_{\mathrm{pk,eff}}(T_{\mathrm{e}}, n_{\mathrm{e}}, \ldots),$$

- $\varepsilon_{\mathrm{pk}}$ → Calibrated line emission
- $n_0 n_{\mathrm{e}}$ → Population of states
- $X_{\mathrm{pk,eff}}$ → Effective emission Rate coeff

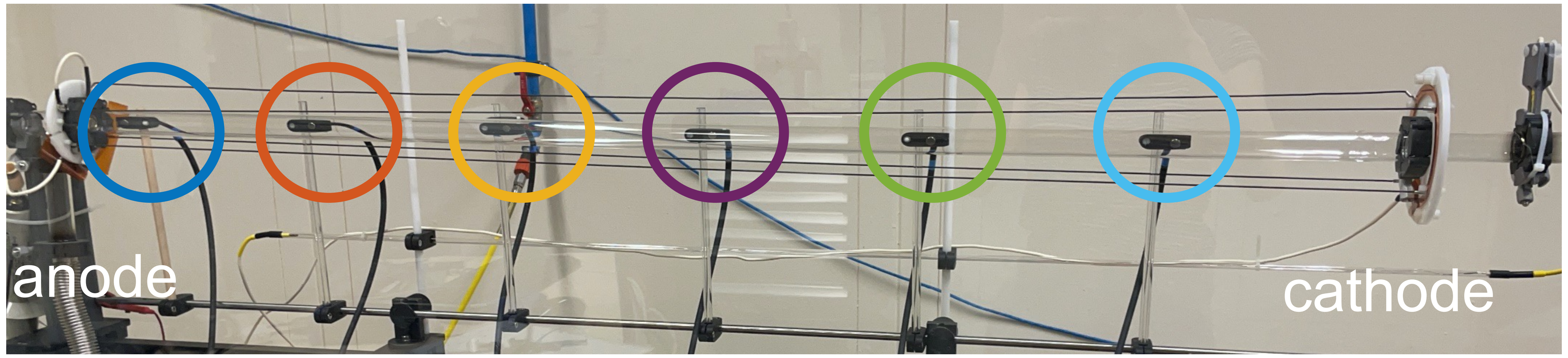


Optical emission spectroscopy

→ **Existing spectrometer (imaging CCD, 3 gratings: w/1200 g/mm grating spectral range 150 to 1500 nm, resolution of 0.05 nm**)

→ 6 fibers collecting light simultaneously at 6 locations
→ **Spatial resolution**

→ Test **uniformity** and different behaviour of plasma species



DPS in the AWAKE experiment by Jan 2023…

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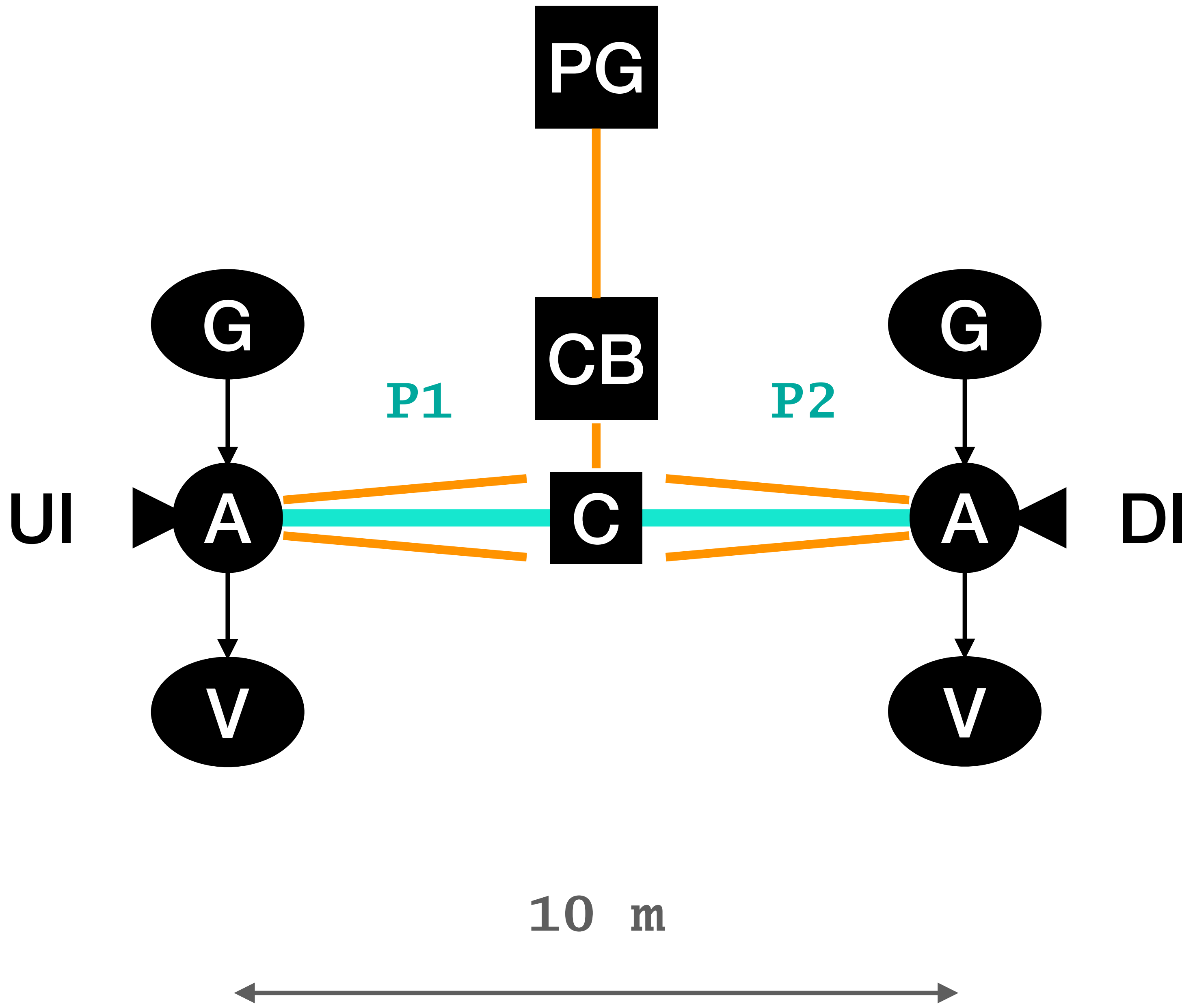


Step 1:

> secure key components
> gather integration information

Step 2:

> design, produce and test new PG & new CBM
> design and produce new tube

Step 3:

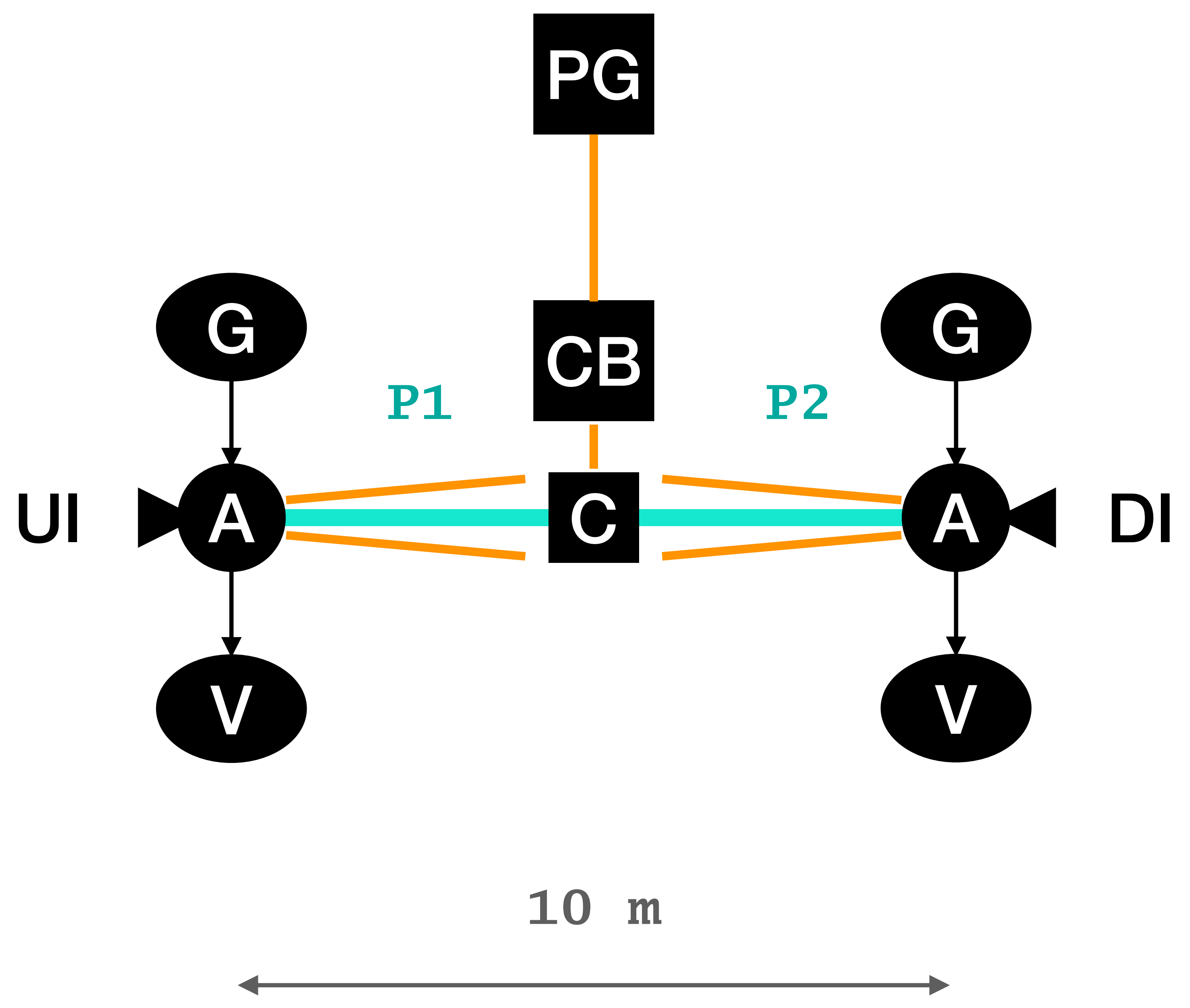
> install and test 10 m double plasma @ cern

Step 4:

> Add new gas & vacuum modules for remote operation
> upgrade PG for remote operation
> test full DPS as it was in tunnel (except non-flat floor and beam alignment)

Step 5:
> move modules to tunnel
> install new mounts in tunnel
> alight mounts using fiducial parts
> “drop” tube modules + diagnostics
> connect PG + CB + G + V
> connect triggers and control

DPS in the AWAKE experiment by Jan 2023...



Step 1: (Dec 21 / Jan 22)

> secure key components
> gather integration information

Step 2: (Jan 22 / Apr 22)

> design, produce and test new PG & new CBM
> design and produce new tube

Step 3: (Mar 22 / July 22)

> install and test 10 m double plasma @ cern

Step 4: (Apr 22 / Nov 22)

> Add new gas & vacuum modules for remote operation
> upgrade PG for remote operation
> test full DPS in tunnel config. (except non-horizontal floor & beam alignment)

Step 5: (Dec 22 / ??? 23)
> move modules to tunnel
> install new mounts in tunnel
> alight mounts using fiducial parts
> “drop” tube modules + diagnostics
> connect PG + CB + G + V
> connect triggers and control

Project breakdown

			2021	2022												2023		
A	Electrical	Who	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1	Secure key electrical components	D																
2	Design main pulsed power modules	D																
3	Design Box, cap banks, power	D																
4	Validate design for fire safety (others?)	D, C																
5	Produce boards	D																
6	SMD board population @ CERN	D																
7	Board finishing ant testing @ IST	D																
8	Box, internal parts, production	D																
9	CBM production	D																
10	Manual box operating @IST (2+3m plasma)	D																
11	Manual box operating @CERN (2x5m plasma)	D																
12	Remote module solution design	D, C																
13	Remote module solution production	D																
14	Remote solution testing @IST (Remote Box)	D																
15	Remote box operating @CERN	D																
16	Manual Box becomes Remote box 2	D																
B	Mechanical		12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1	Detailed tube-beam alignment plan	D, C, A																
	Detailed vacuum and gas injection plan	D, C, A																
	Decision on axial interferometry inclusion	D, A																
	Tentative final design of full tube	D, C, A																
	Tentative final decision on glass components	D, C, A																
	Secure key mechanical components inc. glass	D																
	Purchase tube mech components and modules	D																
	Produce tube mech custom parts	D																
	Manual vacuum and gas modules ready @ CERN	D																
	Interface components & modules ready @ CERN	D																
	Surface HV protection ready @ CERN	D																
	Surface CBM mount ready @ CERN	D																
	Surface tube mounts ready @ CERN	D																
	Remote final gas modules ready @ CRERN	D																
	Remote final vacuum modules ready @ CERN	D																
	Tunnel HV protection (if needed) ready @ CERN	D																
	Tunnel CBM mount ready @ CERN	D																
	Tunnel tube mounts ready @ CERN	D																
C	Experiment		12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1	Surface test Place for 10 m DPS ready at cern	D, C																
2	Manual Tube Ready @ CERN	D																
3	Manual DPS box 1 ready @ CERN	D																
4	Manual DPS offine test 1 @ cern surf	D, A																
5	Changes/improvements	D																
6	Manual DPS offine test 2 @ cern surf	D, A																
7	Install and test remote operation	D, C																
8	Change/improve remote	D, C																
9	Full DPS offine test 1 @ cern surf	D, C, A																
10	Final changes/improvements	D, C																
11	Full DPS offine test 2 @ cern surf	D, C, A																
12	Components/modules packaging	D																
13	Components/modules transport	D, C																
14	Experiment installation @tunnel	D, C, A																
15	Experiment tests @tunnel	D, C, A																
16	Experiment operation @tunnel	D, C, A																
17	Experiment dismantling & removal	D, C, A																
			12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3

Project breakdown-A Electrical

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14	Remote solution testing @IST (Remote Box)	D																
15	Remote box operating @CERN	D																
16	Manual Box becomes Remote box 2	D																

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	Tentative final decision on glass components	D, C, A																
	Secure key mechanical components inc. glass	D																
	Purchase tube mech components and modules	D																
	Produce tube mech custom parts	D																
	Manual vacuum and gas modules ready @ CERN	D																
	Interface components & modules ready @ CERN	D																
	Surface HV protection ready @ CERN	D																
	Surface CBM mount ready @ CERN	D																
	Surface tube mounts ready @ CERN	D																
	Remote final gas modules ready @ CRERN	D																
	Remote final vacuum modules ready @ CERN	D																
	Tunnel HV protection (if needed) ready @ CERN	D																
	Tunnel CBM mount ready @ CERN	D																
	Tunnel tube mounts ready @ CERN	D																
C	Experiment		12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1	Surface test Place for 10 m DPS ready at cern	D, C																
2	Manual Tube Ready @ CERN	D																
3	Manual DPS box 1 ready @ CERN	D																
4	Manual DPS offine test 1 @ cern surf	D, A																
5	Changes/improvements	D																
6	Manual DPS offine test 2 @ cern surf	D, A																
7	Install and test remote operation	D, C																
8	Change/improve remote	D, C																
9	Full DPS offine test 1 @ cern surf	D, C, A																
10	Final changes/improvements	D, C																
11	Full DPS offine test 2 @ cern surf	D, C, A																
12	Components/modules packaging	D																
13	Components/modules transport	D, C																
14	Experiment installation @tunnel	D, C, A																
15	Experiment tests @tunnel	D, C, A																
16	Experiment operation @tunnel	D, C, A																
17	Experiment dismantling & removal	D, C, A																
			12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3

Project breakdown-B Mechanical

			2021	2022												2023		
B	Mechanical		12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1	Detailed tube-beam alignment plan	D, C, A																
	Detailed vacuum and gas injection plan	D, C, A																
	Decision on axial interferometry inclusion	D, A																
	Tentative final design of full tube	D, C, A																
	Tentative final decision on glass components	D, C, A																
	Secure key mechanical components inc. glass	D																
	Purchase tube mech components and modules	D																
	Produce tube mech custom parts	D																
	Manual vacuum and gas modules ready @ CERN	D																
	Interface components & modules ready @ CERN	D																
	Surface HV protection ready @ CERN	D																
	Surface CBM mount ready @ CERN	D																
	Surface tube mounts ready @ CERN	D																
	Remote final gas modules ready @ CRERN	D																
	Remote final vacuum modules ready @ CERN	D																
	Tunnel HV protection (if needed) ready @ CERN	D																
	Tunnel CBM mount ready @ CERN	D																
	Tunnel tube mounts ready @ CERN	D																

Project breakdown

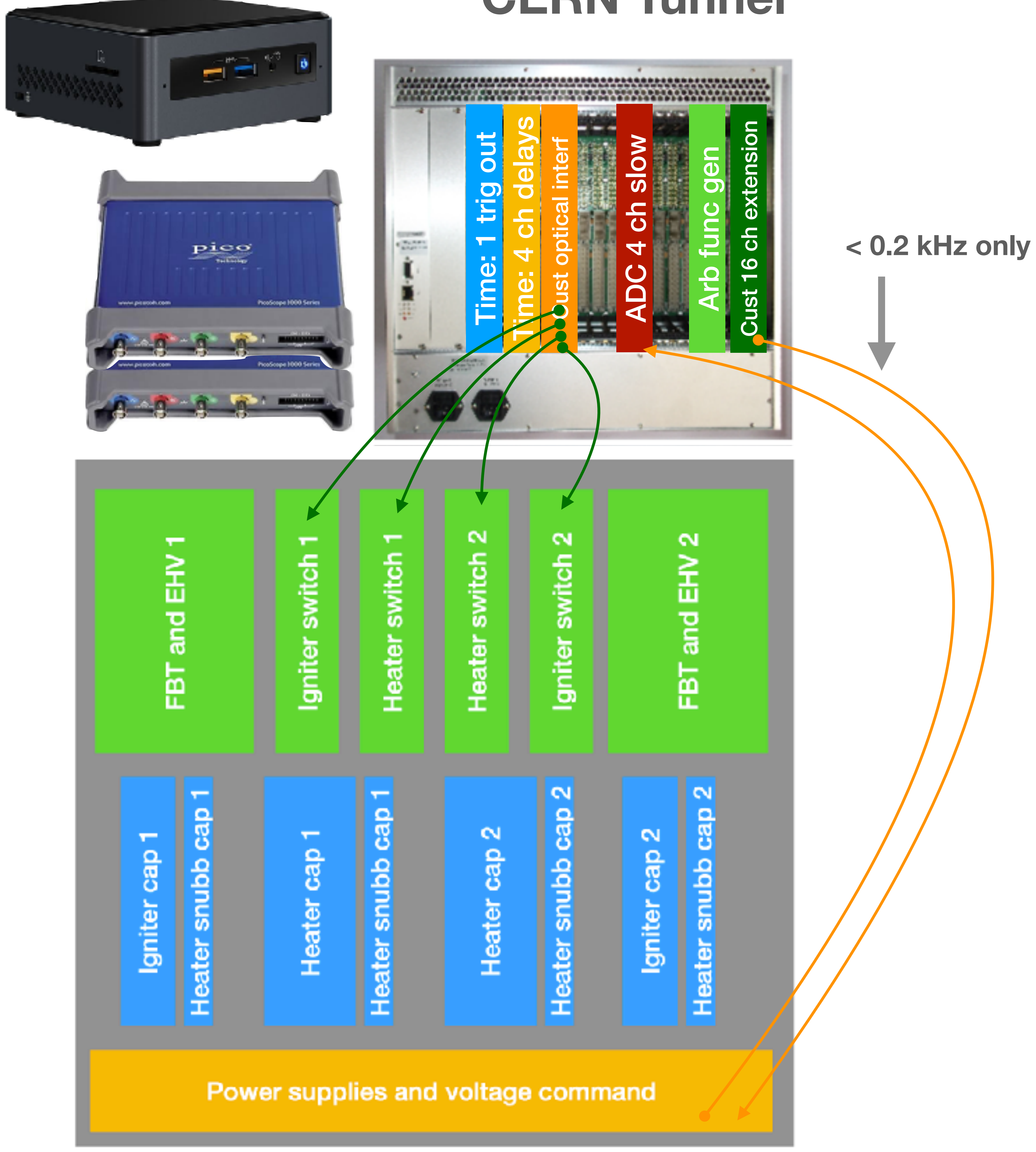
			2021	2022												2023		
A	Electrical	Who	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1	Secure key electrical components	D																
2	Design main pulsed power modules	D																
3	Design Box, cap banks, power	D																
4	Validate design for fire safety (others?)	D, C																
5	Produce boards	D																
6	SMD board population @ CERN	D																
7	Board finishing ant testing @ IST	D																
8	Box, internal parts, production	D																
9	CBM production	D																
10	Manual box operating @IST (2+3m plasma)	D																
11	Manual box operating @CERN (2x5m plasma)	D																
12	Remote module solution design	D, C																
13	Remote module solution production	D																
14	Remote solution testing @IST (Remote Box)	D																
15	Remote box operating @CERN	D																
16	Manual Box becomes Remote box 2	D																
B	Mechanical		12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1	Detailed tube-beam alignment plan	D, C, A																
	Detailed vacuum and gas injection plan	D, C, A																
	Decision on axial interferometry inclusion	D, A																
	Tentative final design of full tube	D, C, A																
	Tentative final decision on glass components	D, C, A																
	Secure key mechanical components inc. glass	D																
	Purchase tube mech components and modules	D																
	Produce tube mech custom parts	D																
	Manual vacuum and gas modules ready @ CERN	D																
	Interface components & modules ready @ CERN	D																
	Surface HV protection ready @ CERN	D																
	Surface CBM mount ready @ CERN	D																
	Surface tube mounts ready @ CERN	D																
	Remote final gas modules ready @ CRERN	D																
	Remote final vacuum modules ready @ CERN	D																
	Tunnel HV protection (if needed) ready @ CERN	D																
	Tunnel CBM mount ready @ CERN	D																
	Tunnel tube mounts ready @ CERN	D																
C	Experiment		12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1	Surface test Place for 10 m DPS ready at cern	D, C																
2	Manual Tube Ready @ CERN	D																
3	Manual DPS box 1 ready @ CERN	D																
4	Manual DPS offine test 1 @ cern surf	D, A																
5	Changes/improvements	D																
6	Manual DPS offine test 2 @ cern surf	D, A																
7	Install and test remote operation	D, C																
8	Change/improve remote	D, C																
9	Full DPS offine test 1 @ cern surf	D, C, A																
10	Final changes/improvements	D, C																
11	Full DPS offine test 2 @ cern surf	D, C, A																
12	Components/modules packaging	D																
13	Components/modules transport	D, C																
14	Experiment installation @tunnel	D, C, A																
15	Experiment tests @tunnel	D, C, A																
16	Experiment operation @tunnel	D, C, A																
17	Experiment dismantling & removal	D, C, A																
			12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3

Project breakdown-C Experiment

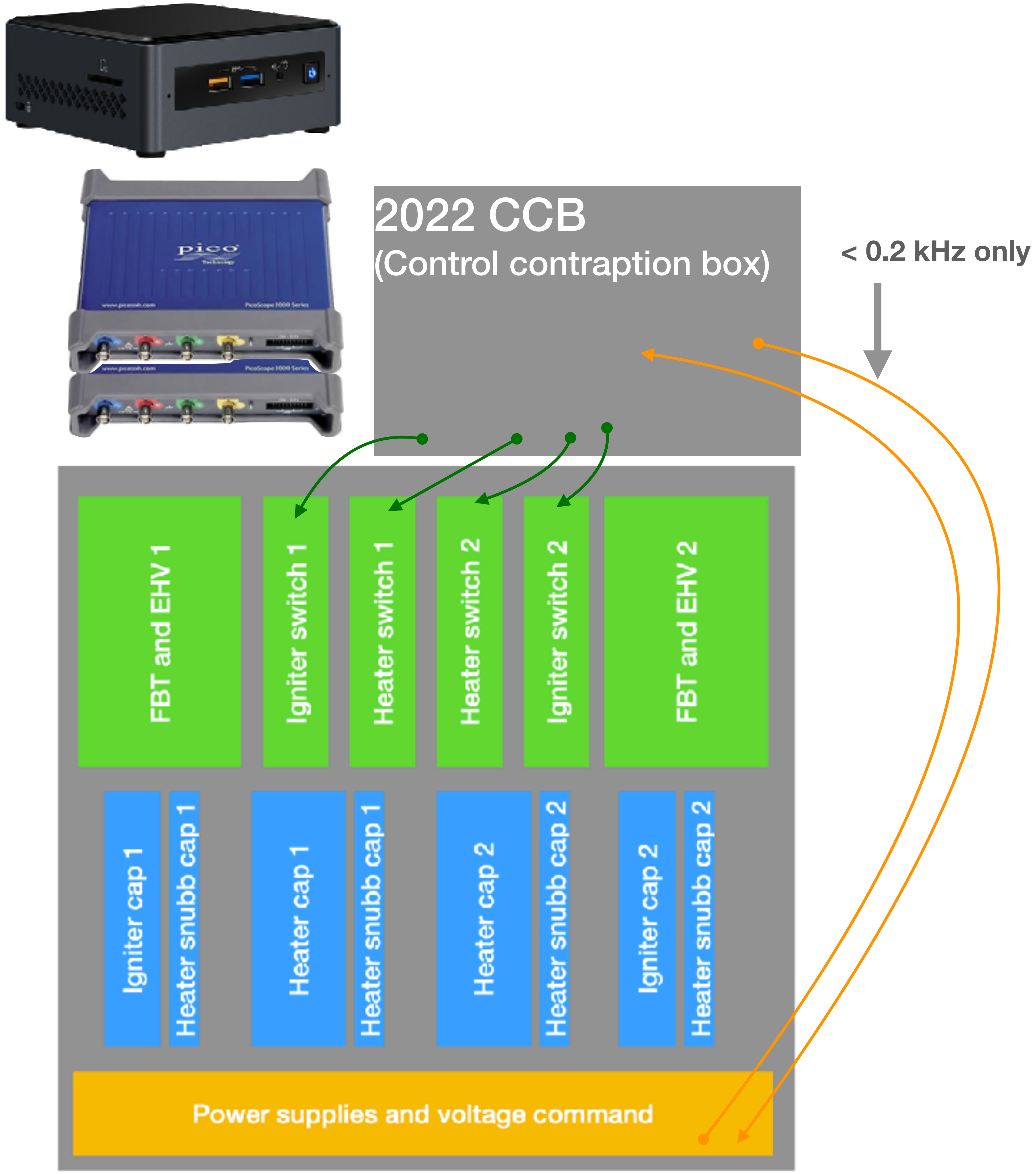
			2021	2022												2023		
C	Experiment		12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1	Surf. test Place for 10 m DPS ready @ cern	D, C																
2	Manual Tube Ready @ CERN	D																
3	Manual DPS box 1 ready @ CERN	D																
4	Manual DPS offine test 1 @ cern surf	D, A																
5	Changes/improvements	D																
6	Manual DPS offine test 2 @ cern surf	D, A																
7	Install and test remote operation	D, C																
8	Change/improve remote	D, C																
9	Full DPS offine test 1 @ cern surf	D, C, A																
10	Final changes/improvements	D, C																
11	Full DPS offine test 2 @ cern surf	D, C, A																
12	Components/modules packaging	D																
13	Components/modules transport	D, C																
14	Experiment installation @tunnel	D, C, A																
15	Experiment tests @tunnel	D, C, A																
16	Experiment operation @tunnel	D, C, A																
17	Experiment dismantling & removal	D, C, A																
			12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3

Baseline solution: Box + VME crate + computer + 2 picoscopes

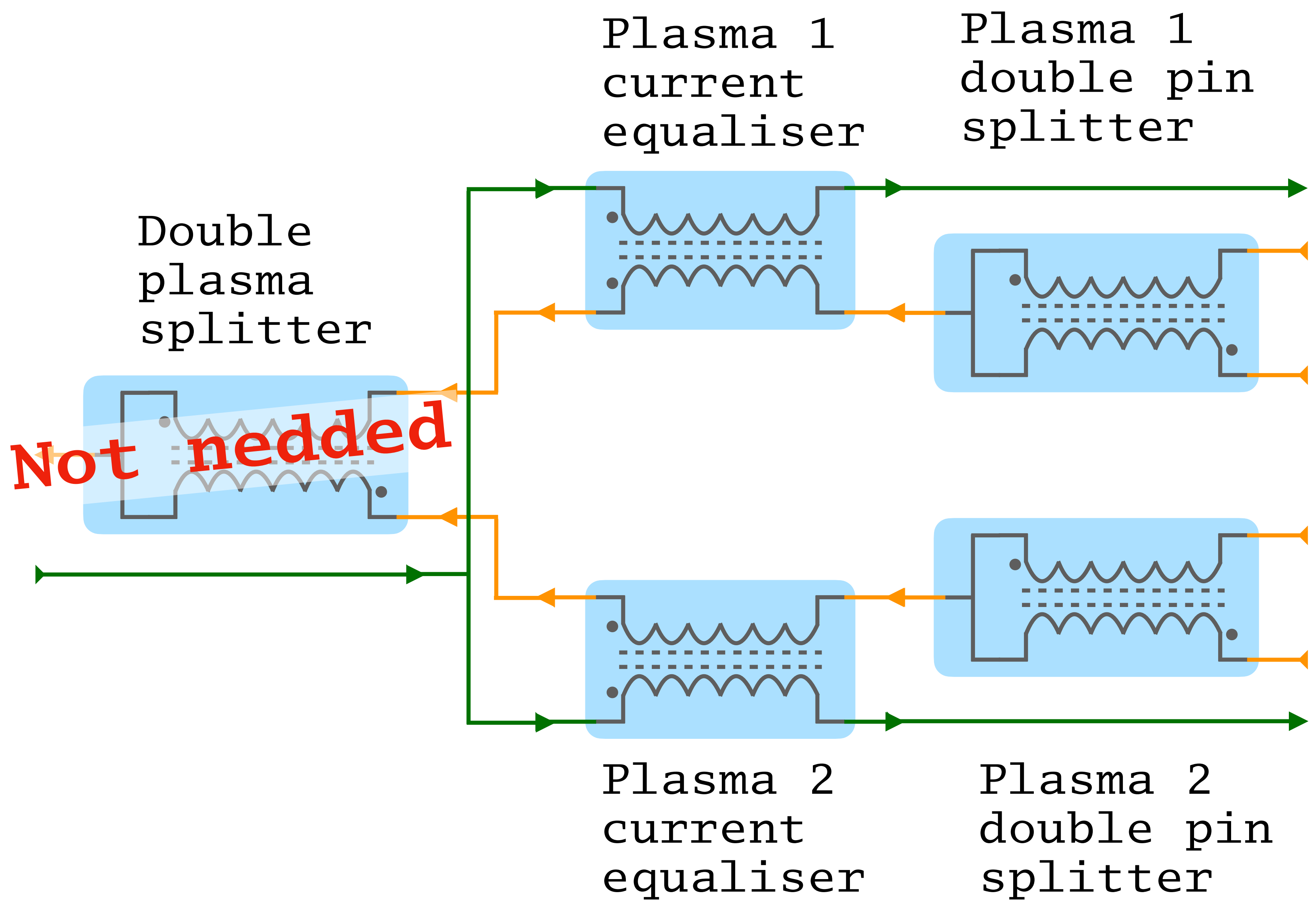
CERN LAB
CERN Tunnel

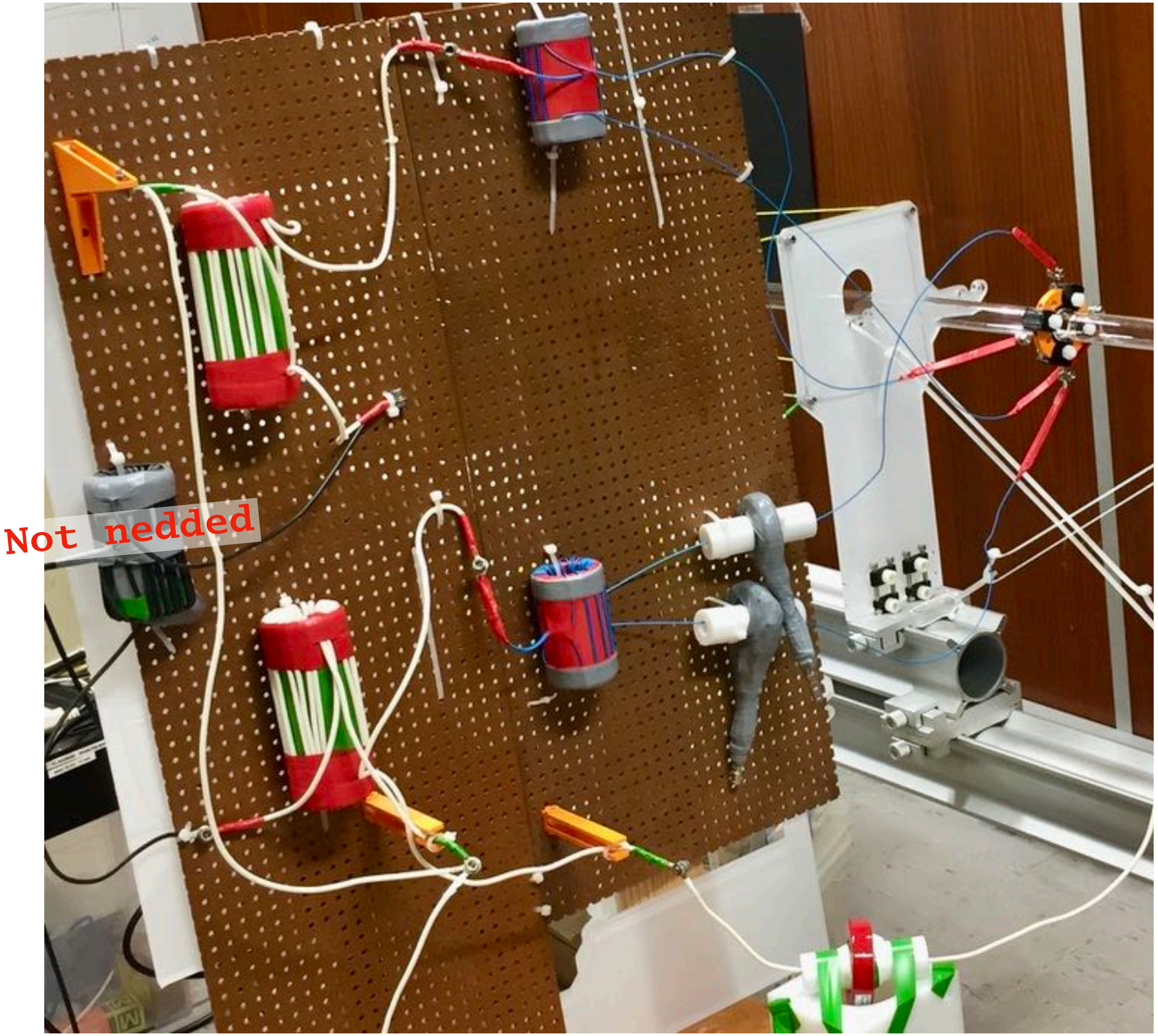


CERN LAB
IST LAB



Baseline solution: CBM





>> CBM for a double plasma with a common 4 pin cathode

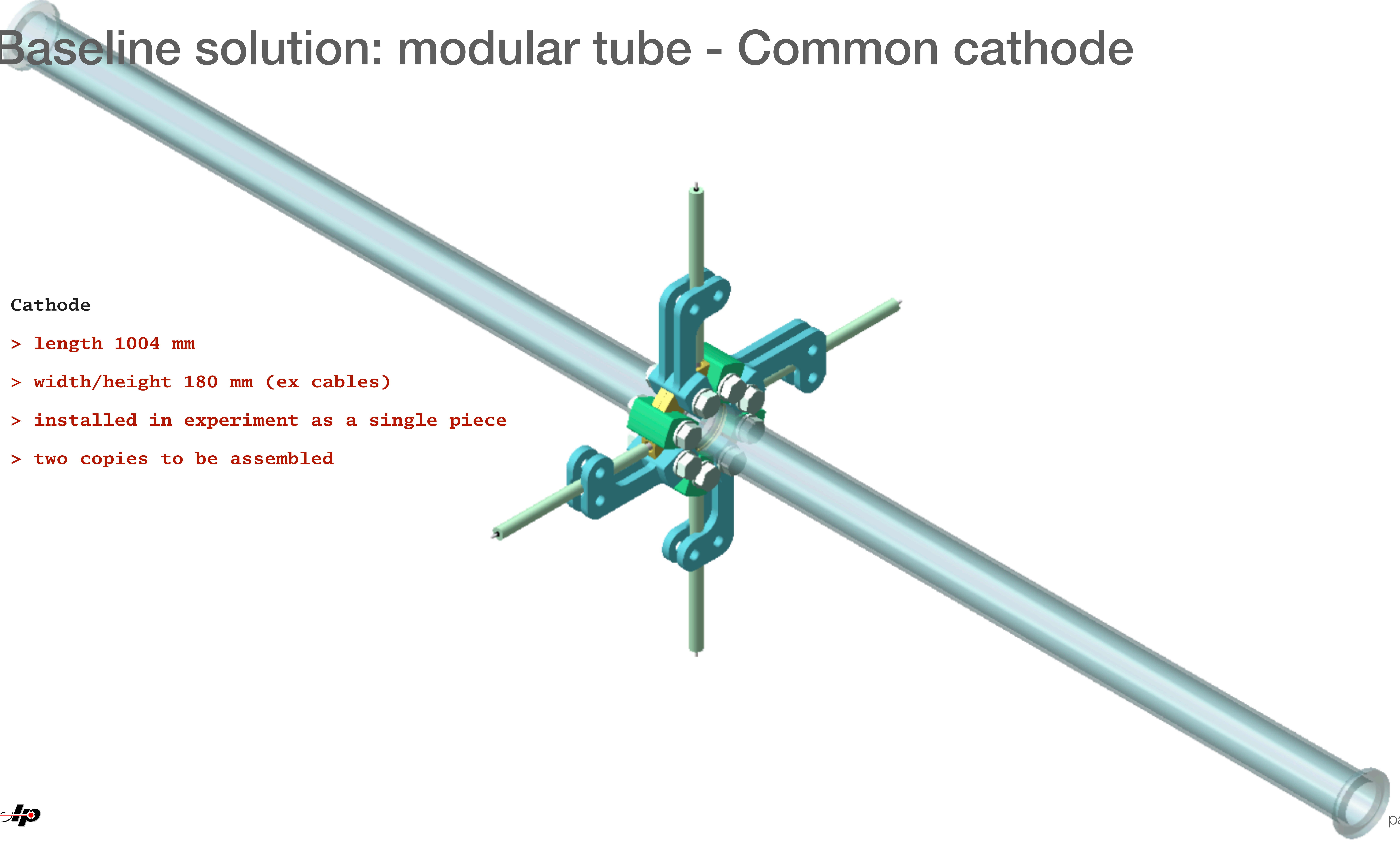
>> two end anodes

>> uses a double pulse generator

>> uses microcrystalline tape cores

>> very low parasitic inductance

Baseline solution: modular tube - Common cathode



Cathode

> length 1004 mm

> width/height 180 mm (ex cables)

> installed in experiment as a single piece

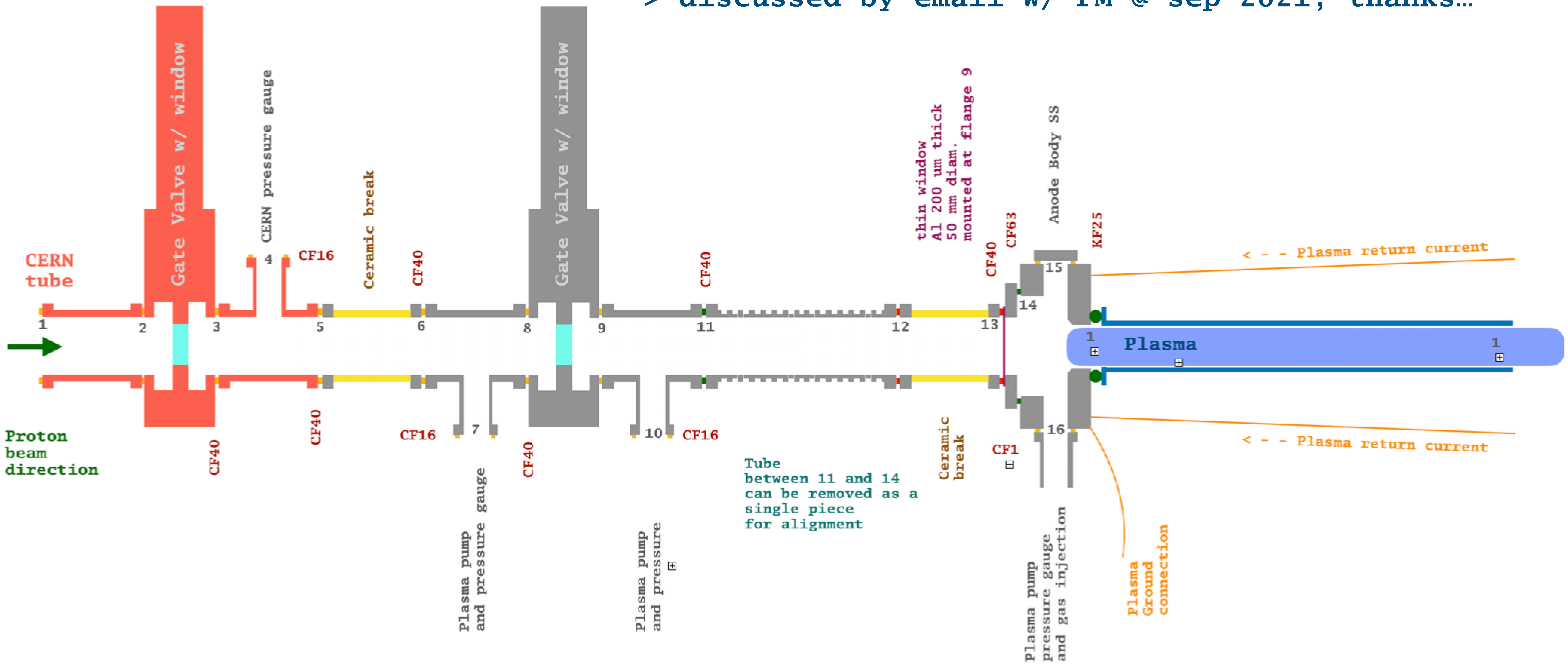
> two copies to be assembled

Baseline solution: modular tube - Anodes & Interfaces

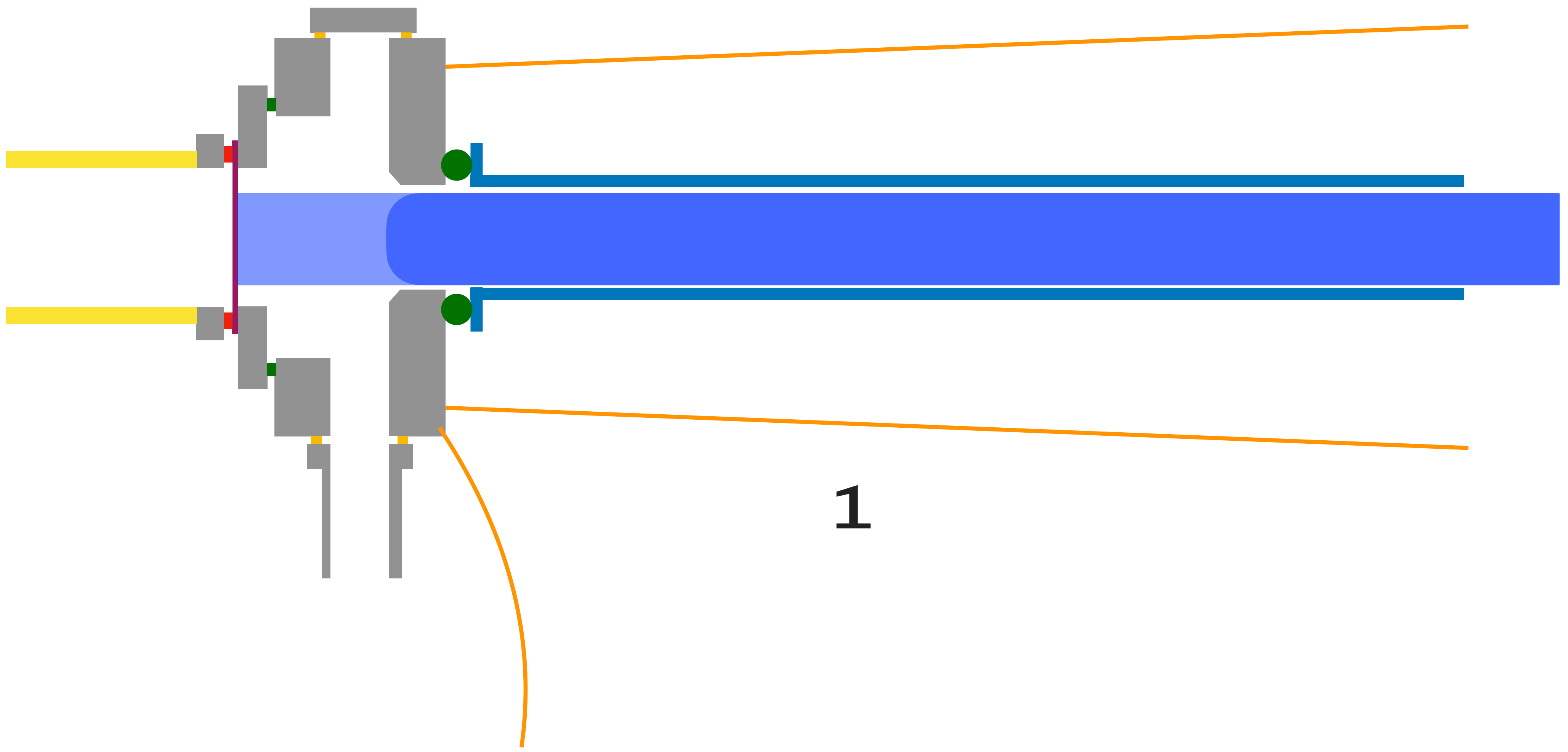
> this is new
> previously the anode is a metal pipe attached to the glass tube
> no interface with am evacuated pipe was tested before

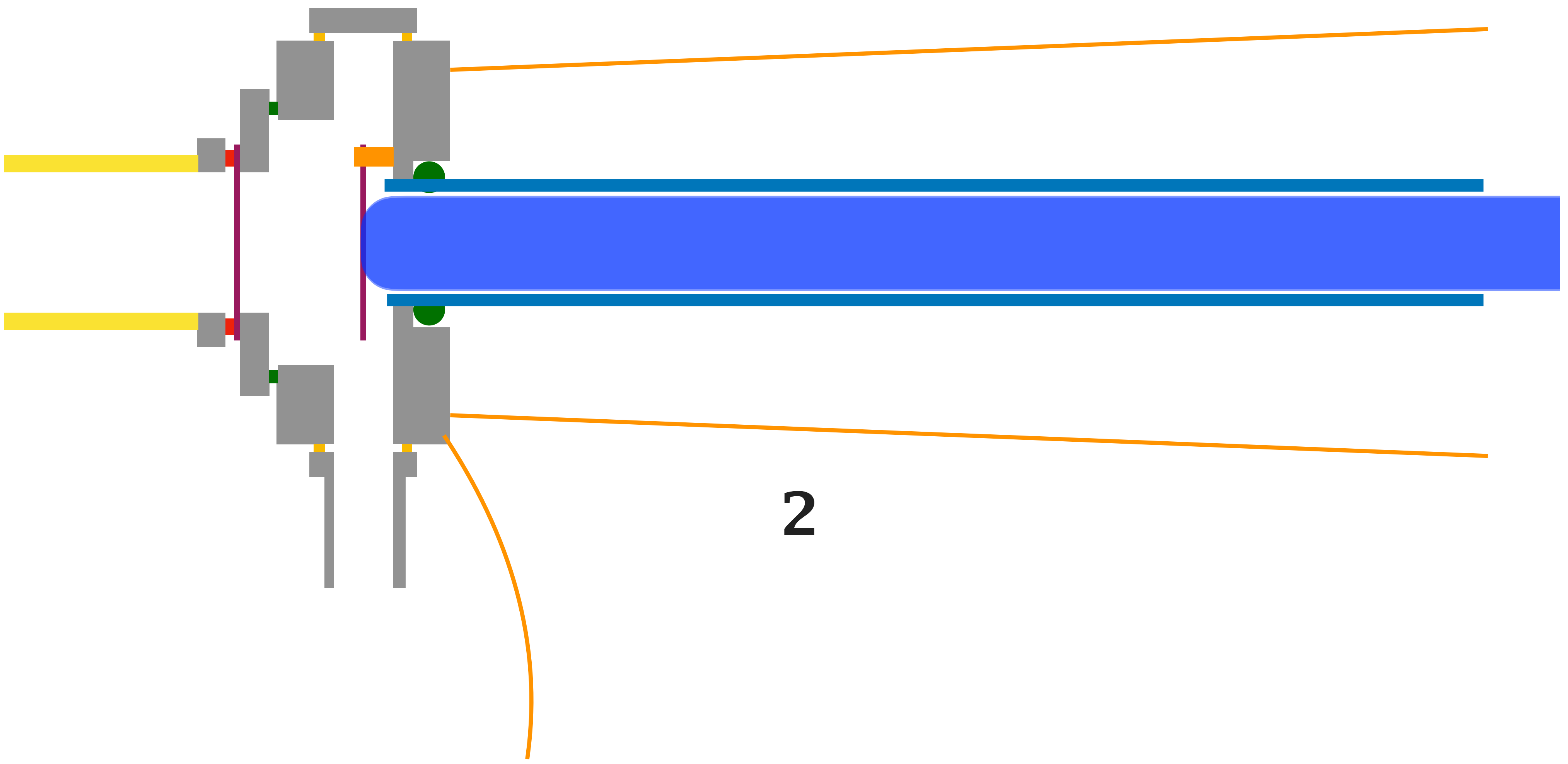
Tentative scheme for the DPS upstream interface V02
(NL reviewed at 2021- 10 - 20)

> discussed by email w/ PM @ sep 2021, thanks…



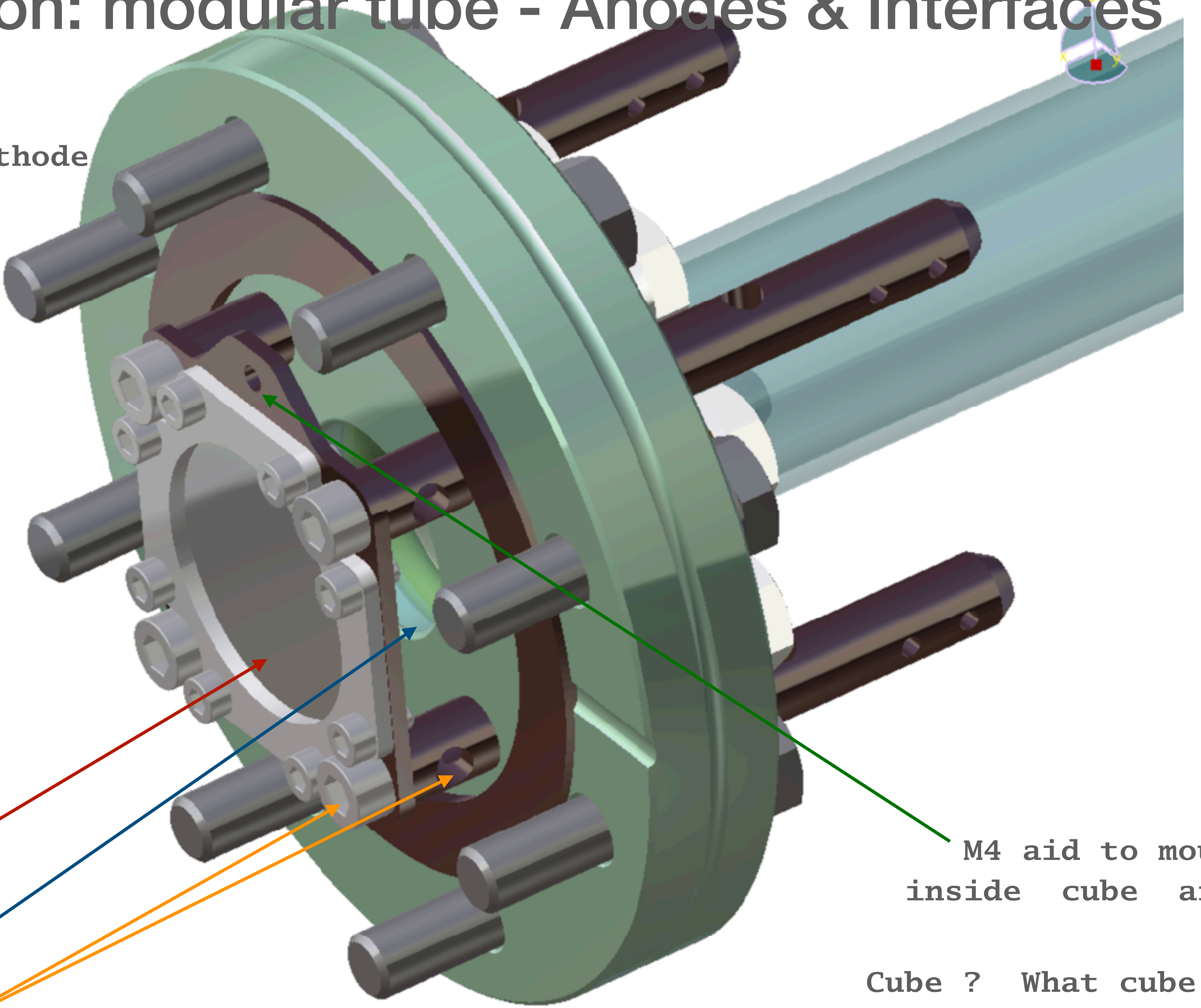
Baseline solution: modular tube - Anodes & Interfaces





- conductance is required between tube and vacuum/gas system
- foil is required to separate 1-10 Pa argon/xenon in tube and vacuum in pipe
- glass tube should end when it meets the metal
- plasma should have well defined density (avoid ambiguous extremities)
- two (four) foils are acceptable for this experiment (plasma foil can be very thin Al)
- vacuum separation foil is 100 um Al

Baseline solution: modular tube - Anodes & Interfaces



> flange contains the cathode

> tube “sits” here

> CF 40 too small

> CF 63 is good

> dielectric clamp
Compress o-ring to seal

> 4 copper pins for
symmetric return cage

> discharge end mounted
inside …

> very thin Al foil

> conductance to tube

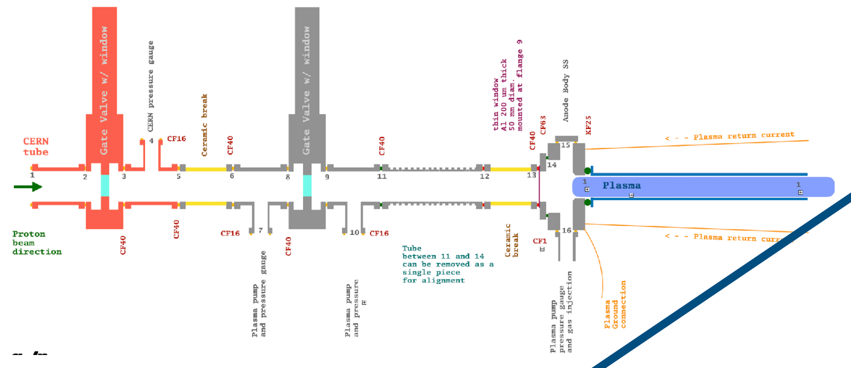
> all vented

M4 aid to mount the foil <
inside cube after alignment

Cube ? What cube ? …

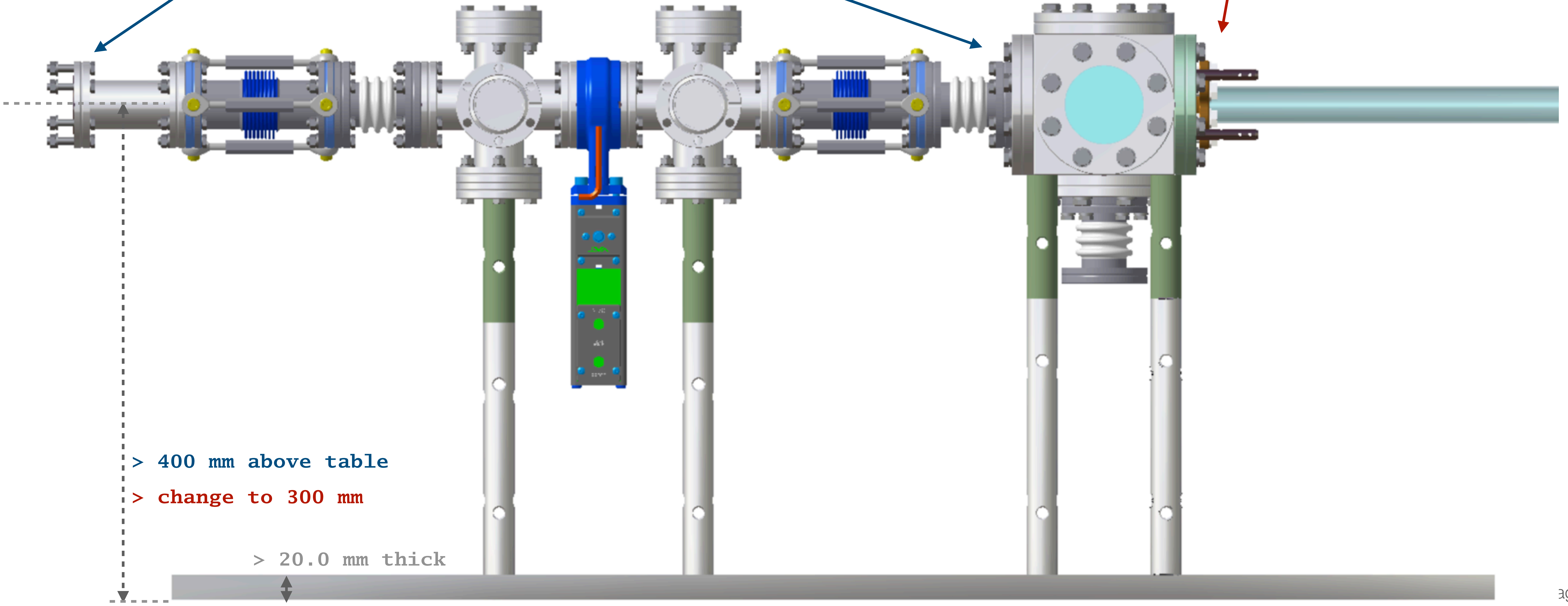
Baseline solution: modular tube - Anodes & Interfaces

… interpretation of



> pipe keeps CF 40 as before

> tube is KF 25 from here



> 400 mm above table

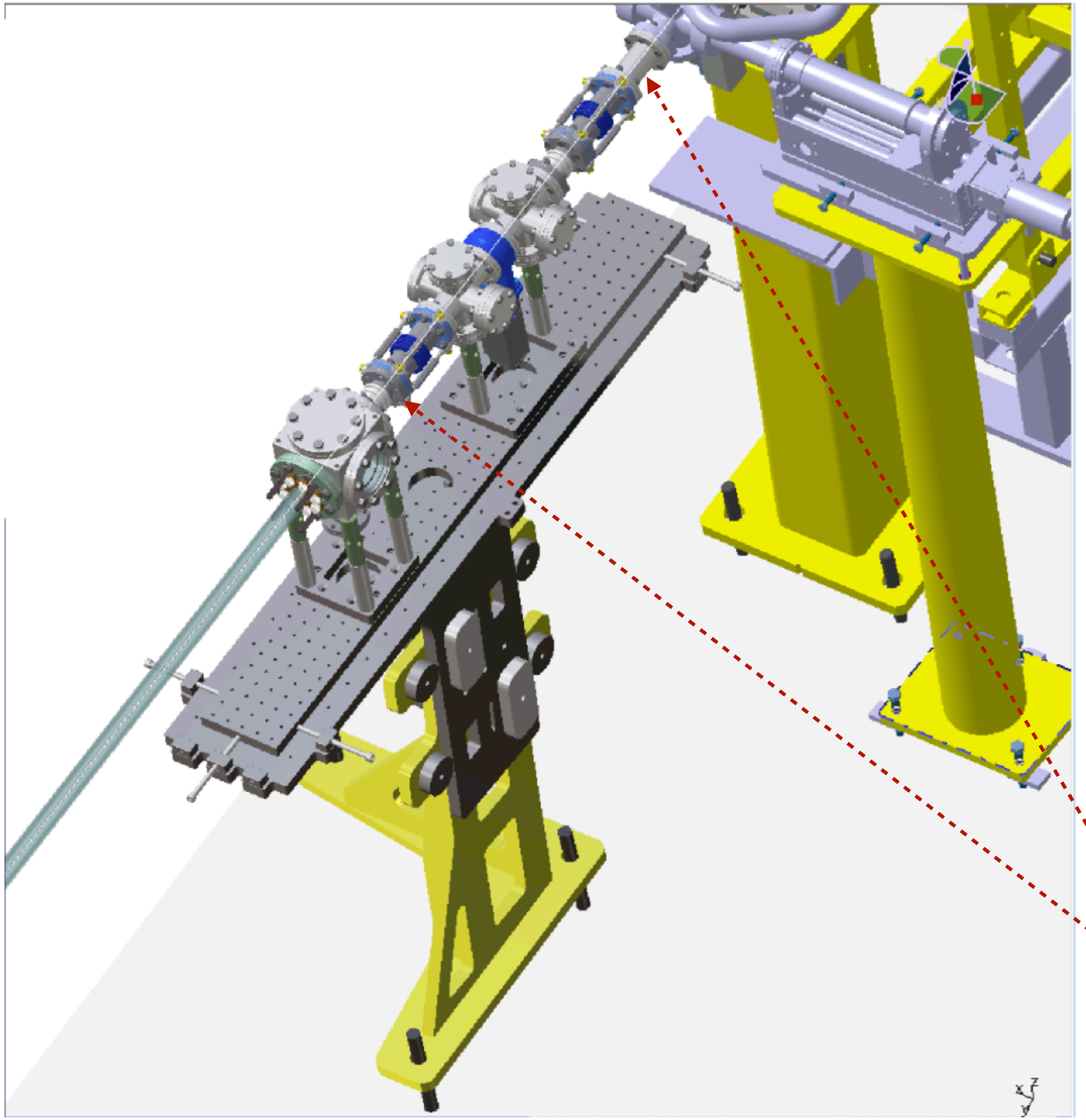
> change to 300 mm

> 20.0 mm thick

Baseline solution: modular tube - Anodes & Interfaces

> install alignment targets…
> … at central column of hole pattern
> alignment = laser centred with apertures

Baseline solution: modular tube - Anodes & Interfaces



> drill 3 anchor holes at correct positions (D=22mm)
(2 mm error ideal, 6 mm error tolerable)

> install M20 anchor screws, fix them, instal the base support nuts and washers… (screws perpendicular to floor and 165 mm out of the floor)

> install the steel base, align it until the base is 90 mm above floor and the vertical pice is vertical from both sides (precision spirit level), ideally the vertical surface visible is coincident with the beam…, have it vertical is more important, fix the steel base with appropriate nuts and washers (steel base weight 48 kg, heaviest part)

> install the main vertical piece of the mount…
Fix it with the fixed position screws (safer)

> install the vertical adjustment pieces screws and locking nuts

> mount the vertical motion guides and the clamps for angular correction (that substitute the strict vertical screws)

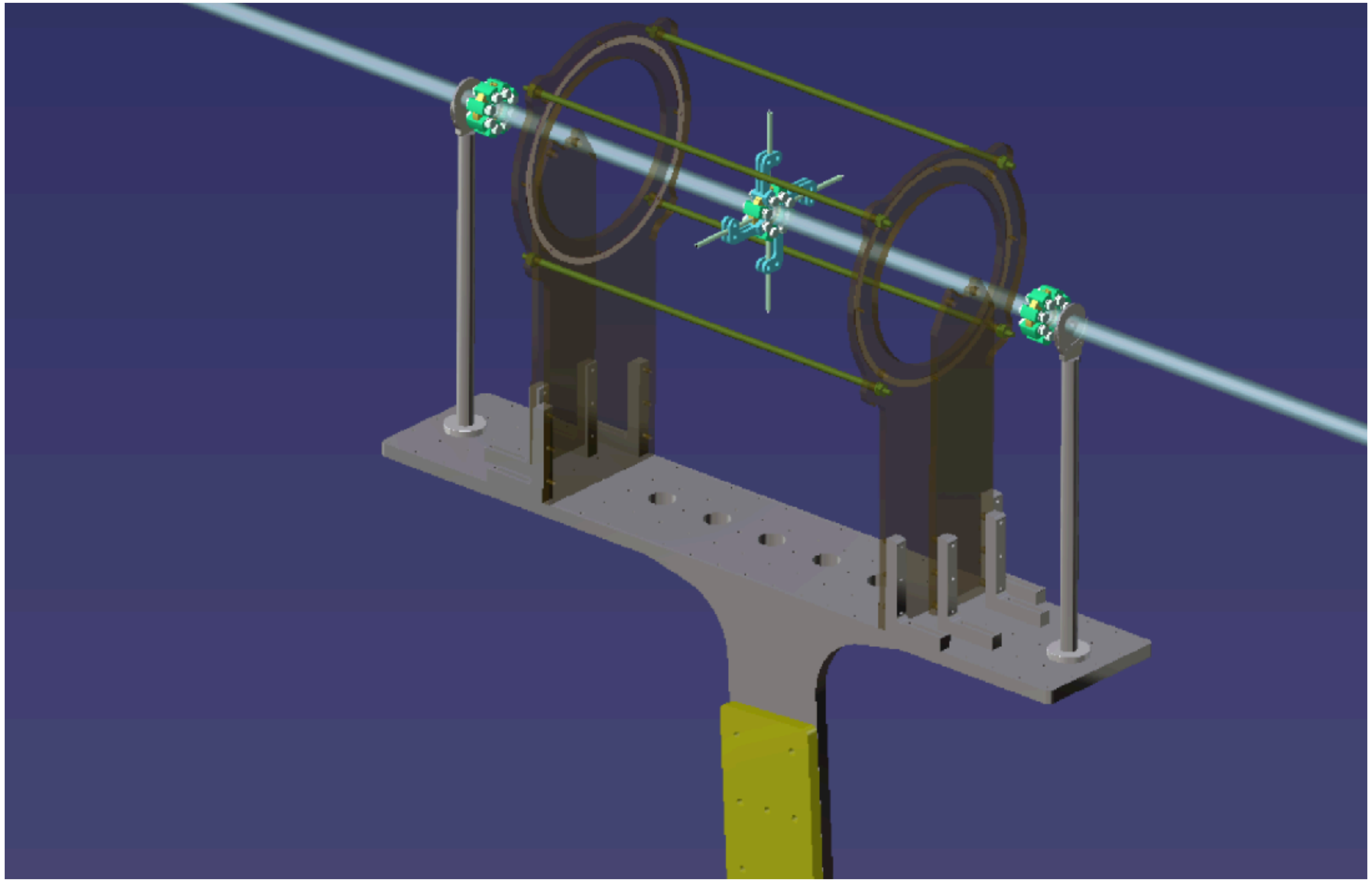
> mount the horizontal table, the top breadboard, the alignment tools and start the laser… using the adjustment screws of the table adjust position of breadboard in X1,Y1, using the central vertical adjustment screws correct the height by releasing the vertical pieces fixing screws (need to remove the fixed height screws and use only the variable height screws… if a correction of in pitch angle is needed then use the angular correction screws to do it but first you need to change the fixing screws to the variable angle screws and reales the vertical reference clamps

> Remove the alignment tools and install the cube and the valve modules

> after installing the middle table, the downstream table, and the intermediate aluminium profiles and intermediate dielectric tube mounts… install the anode flange + anode + clamps and anode tube…

> when ready to close, install the isolation foil unit and the extreme custom length intermediate piece

Baseline solution: cathode mount



Baseline solution: installation week (feasibility test procedure)

Monday
> clear the space
> drill 3 x 3 holes in the floor
> clean and bring the materials close
> verify alignment laser beam
> install and align 3 bases of the mounts + install the mounts + align the bases

> install Pulsed Generator (PG) in place
> install cables + instal CBM + connect PG to CBM

Tuesday
> install and align the interface modules + cathode module
> connect cathode to CBM
> connect gas and vacuum
> close the tube (may require fast machining and vacuum cleaning of a vacuum pipe piece to length)
> pump the tube and interface

Wednesday
> finish the return cage and complete electrical connections
> test gas injection and pressure control
> make test discharges

Thursday
> solve issues
> test remote operation
> test the plasma operation

Friday
> solve issues
> test the plasma operation

How to do from here ?

How to do from here ?

DSP team (CA, NT, AS, NL, +++) (HR + FR? + knowledge + motivation) -> DPS (2 x 5 m) @ **surface**

For DPS (2 x 5 m) @ **AWAKE** … … … help is needed

At least

Priority
> discuss electrical materials (acceptable insulation and structural materials)
> detailed aligned procedure (ideally “drop and forget”)
> detailed tentative installation procedure

Next
> two controlled vacuum points for tube and gas system
> the integrated gas system operation
> location of pulsed power unit and HV cable path
> electrical safety plan for tunnel installation

After
> Triggering at tunnel
> Control at tunnel
> interface with AWAKE experiment

Last but not least
> detailed experiment plan

How to do from here ?

DSP team +++ (CA, NT, AS, NL, +++) (HR + FR? + knowledge + motivation) -> DPS (2 x 5 m) @ **surface**

For DPS (2 x 5 m) @ **AWAKE** … … … help is needed

At least

Priority (Dec 22 - Jan 23)
> discuss electrical materials (acceptable insulation and structural materials)
> detailed aligned procedure (ideally “drop and forget”)
> detailed tentative installation procedure

Next (Jan 23 - Mar 23)
> two controlled vacuum points for tube and gas system
> the integrated gas system operation
> location of pulsed power unit and HV cable path
> electrical safety plan for tunnel installation

After (Jan 23 - May 23)
> Triggering at tunnel
> Control at tunnel
> interface with AWAKE experiment

Last but not least (Jan 23 - Dec 23)
> experiment plan

Thank you

Questions & Answers…