IPAC21

HZB Helmholtz Zentrum Berlin

bERLinPro Helmholtz-Zentrum Berlin

High power coupler conditioning for bERLinPro Energy Recovery Linac Injector

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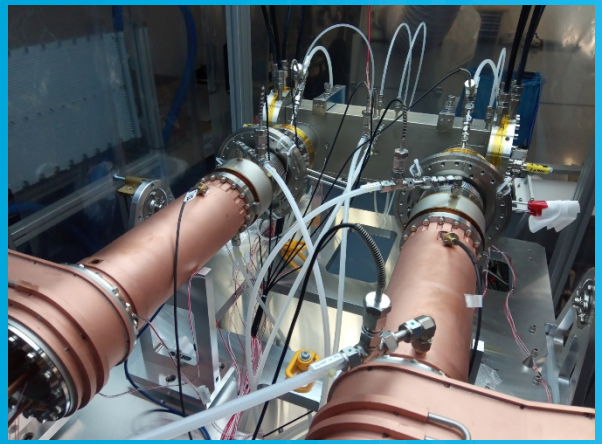
Bom dia, boa tarde, boa noite!



Session:MOPAB347

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Driver for Coupler Studies: bERLinPro ERL

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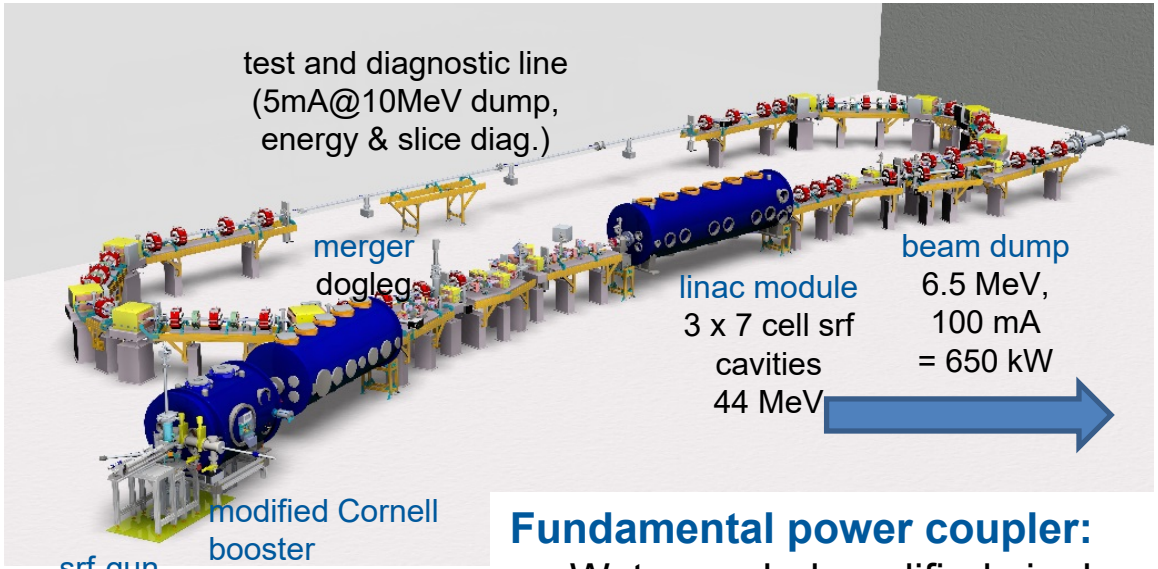
Main goal: **100 mA** ERL with **1µrad** normalized emittance and **2 ps** bunch length beam at **50 MeV**



Booster:

- Deliver power to the beam (450 kW)
- Preserve emittance
- Allow long. phase space manipulation

Fundamental power coupler:

- Water cooled modified single-window KEK C-ERL design
- New antenna tip:
  Improved coupling, lower kicks + lower emittance dilution

bERLinPro 1.3 GHz Booster Coupler

A. Neumann, 14.05.2021, MOPAB347

Booster Module Operation at bERLinPro 1st stage: 6 mA Gun

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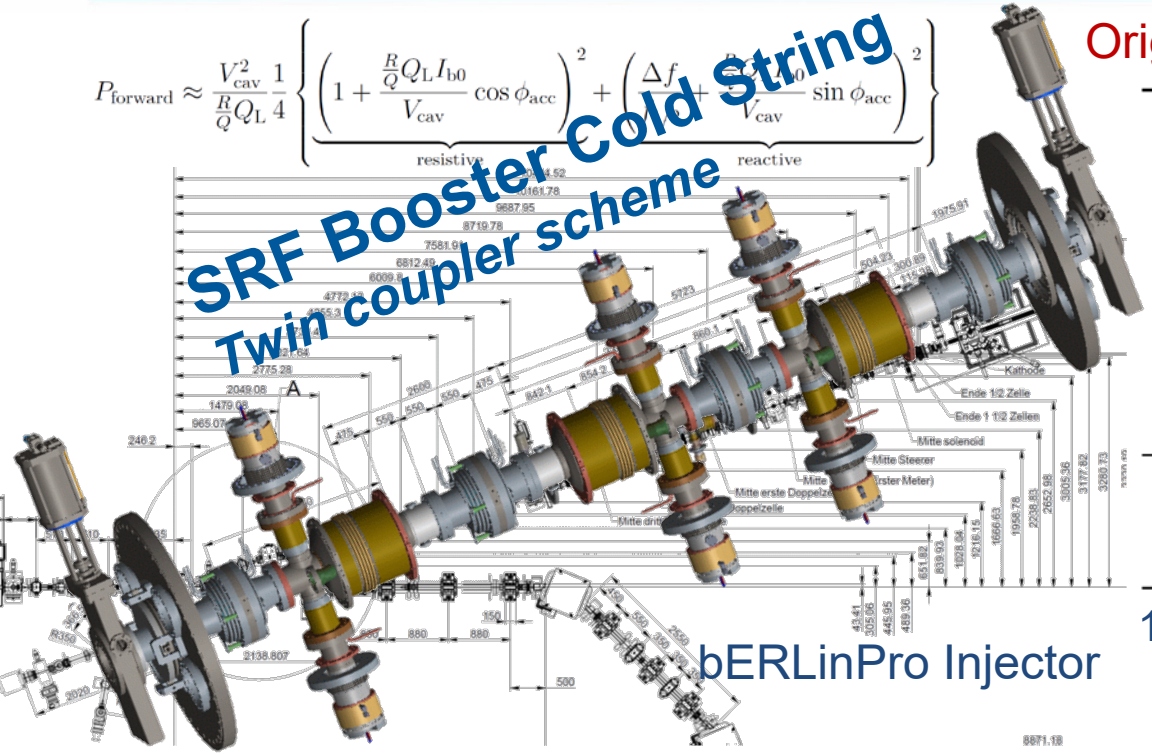
$$P_{\text{forward}} \approx \frac{V_{\text{cav}}^2}{\frac{R}{Q}Q_{\text{L}}}\frac{1}{4}\left\{\underbrace{\left(1+\frac{\frac{R}{Q}Q_{\text{L}}I_{\text{b0}}}{V_{\text{cav}}}\cos\phi_{\text{acc}}\right)^2}_{\text{resistive}}+\underbrace{\left(\frac{\Delta f}{f_{\text{RF}}}+\frac{\frac{R}{Q}Q_{\text{L}}I_{\text{b0}}}{V_{\text{cav}}}\sin\phi_{\text{acc}}\right)^2}_{\text{reactive}}\right\}$$

SRF Booster Cold String
Twin coupler scheme



bERLinPro Injector

Original cavity parameter: I_b=100 mA

Number of cells	2
$R/Q_{\parallel}$	219 Ω
f_{RF}	1.3 GHz
$E_{\text{peak}}/E_{\text{acc}}$	2.0
$B_{\text{peak}}/E_{\text{acc}}$	4.4 mT/MVm^{-1}
Q_{ext} TE$_{111}$ dipole	130, 370
Q_{ext} TM$_{110}$ dipole	170, 7300
Q_{L} at 3mm penetration depth	$1.05 \cdot 10^5$
P_{forward}	3.4, 220 kW
V_{acc}	0.56, 2.1 MV
E_0	4.833, 19, 19 MV/m
Φ_{acc}	-90, 0, 0 deg

1st cavity zero-crossing, 2nd-3rd: on-crest

Current reduction from 100 to 6 mA → FPC retracted by 20 mm to Q_L=1.74·10^6
→ Forward power per coupler: 7 kW in TW and 1.7 kW SW (original 120 kW TW and 25 SW)

The Coupler design + cavity

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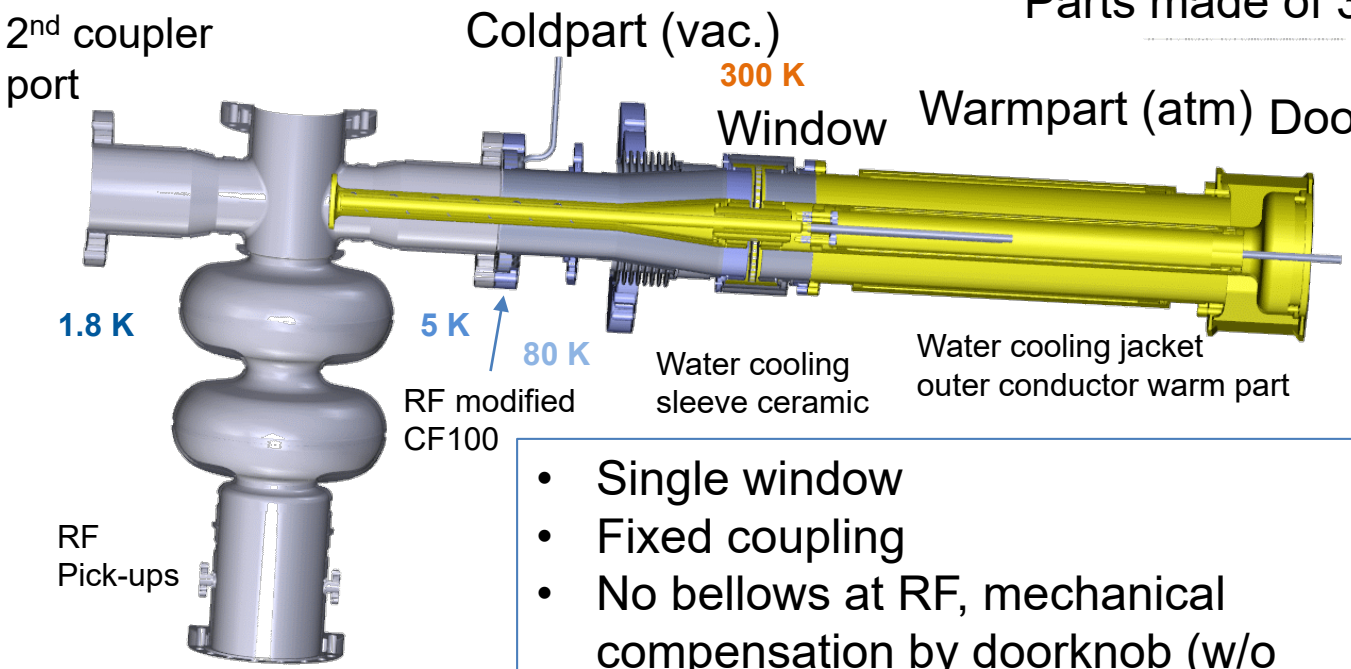
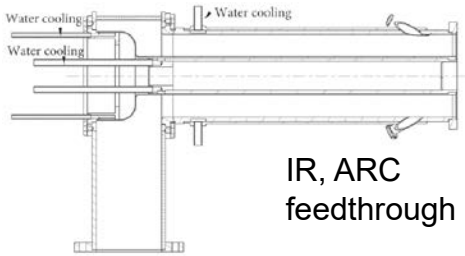
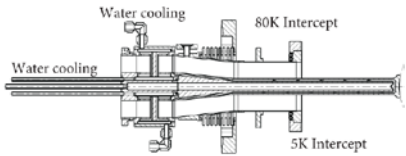
Parts made of 316 LN and OFHC Cu



Water cooling inlets inner conductor/doorknob



IR, ARC feedthrough



2-cell Booster cavity
1.3 GHz modified Cornell shape

- Single window
- Fixed coupling
- No bellows at RF, mechanical compensation by doorknob (w/o affecting RF performance)
- 120 kW CW, 1.3 GHz
- Coldpart outer conductor Cu coated 20±5 µm

Condition Couplers: Dedicated teststand

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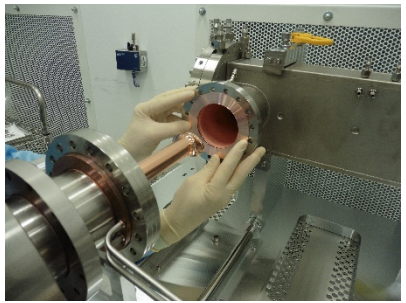
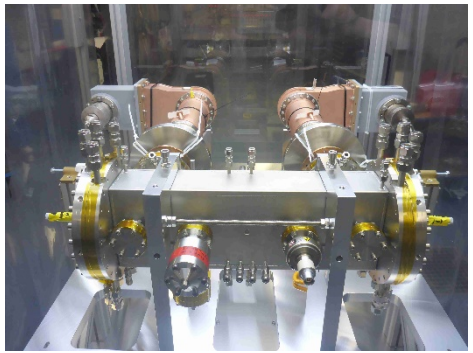
1. Installation in ISO 4 cleanroom

Golf Tee Antenna tip



2. Vertical transport to testing location

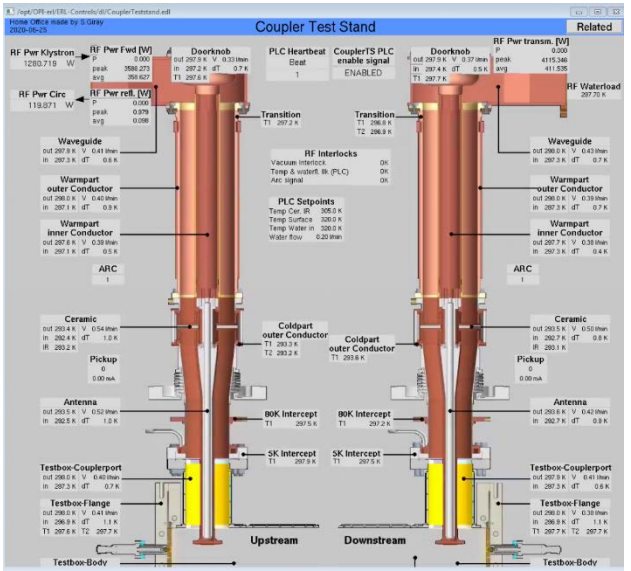


3. Horizontal position for conditioning+ baking

CPI 250 kW Klystron

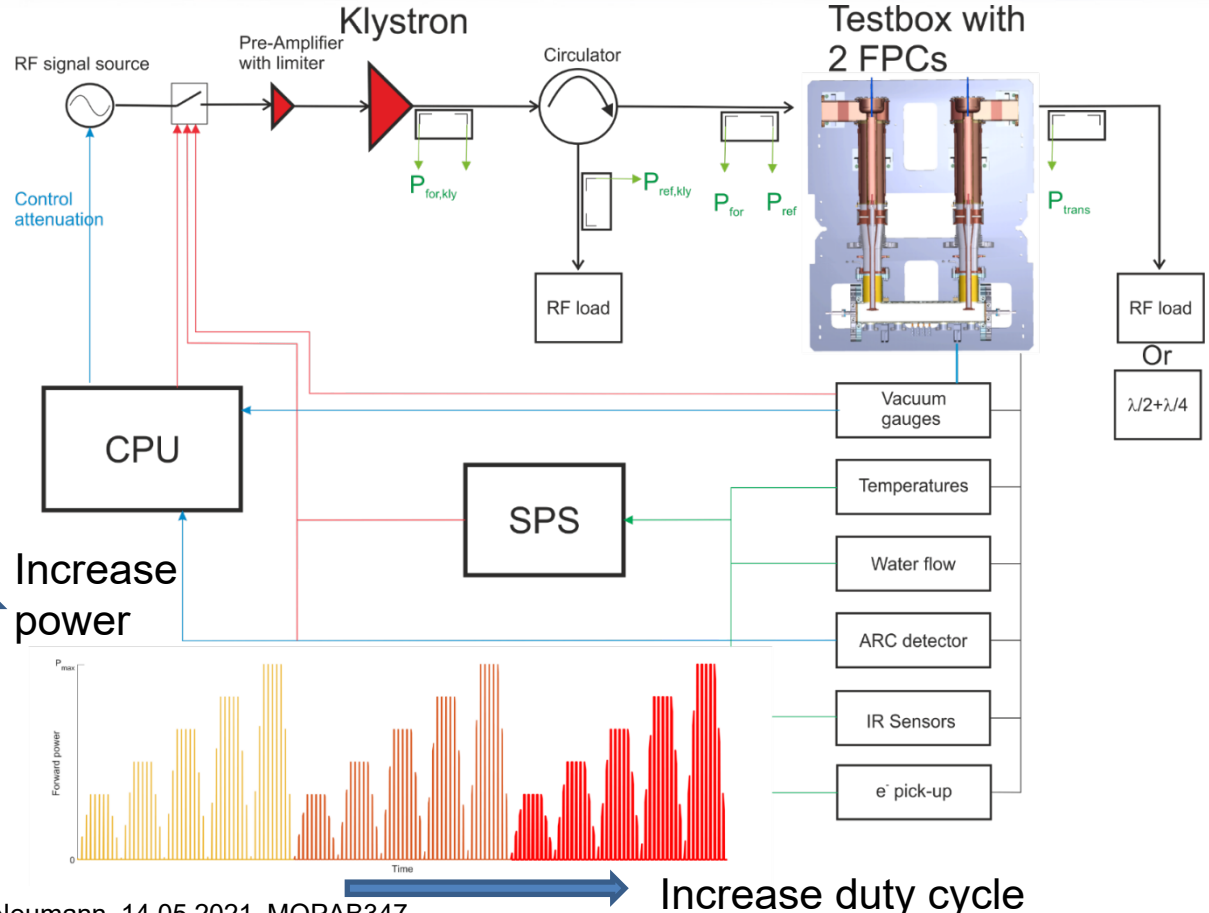
5. RF Power!

4. Cooling water supplies, diagnostics RF and control system setup



Epics panel with a selection of sensors (missing water flow et al.)

General conditioning set up



- For given duty cycle power is ramped up and down to current target level
- Vacuum level controls:
  - Further power rise
  - Power hold
  - Power decrease
  - Switch Power off
- Additional interlock by:
  - Reflected power mismatch
  - Temperatures
  - Water flow
  - ARCs, electron activity
- TW and SW was tested

Properties under observation

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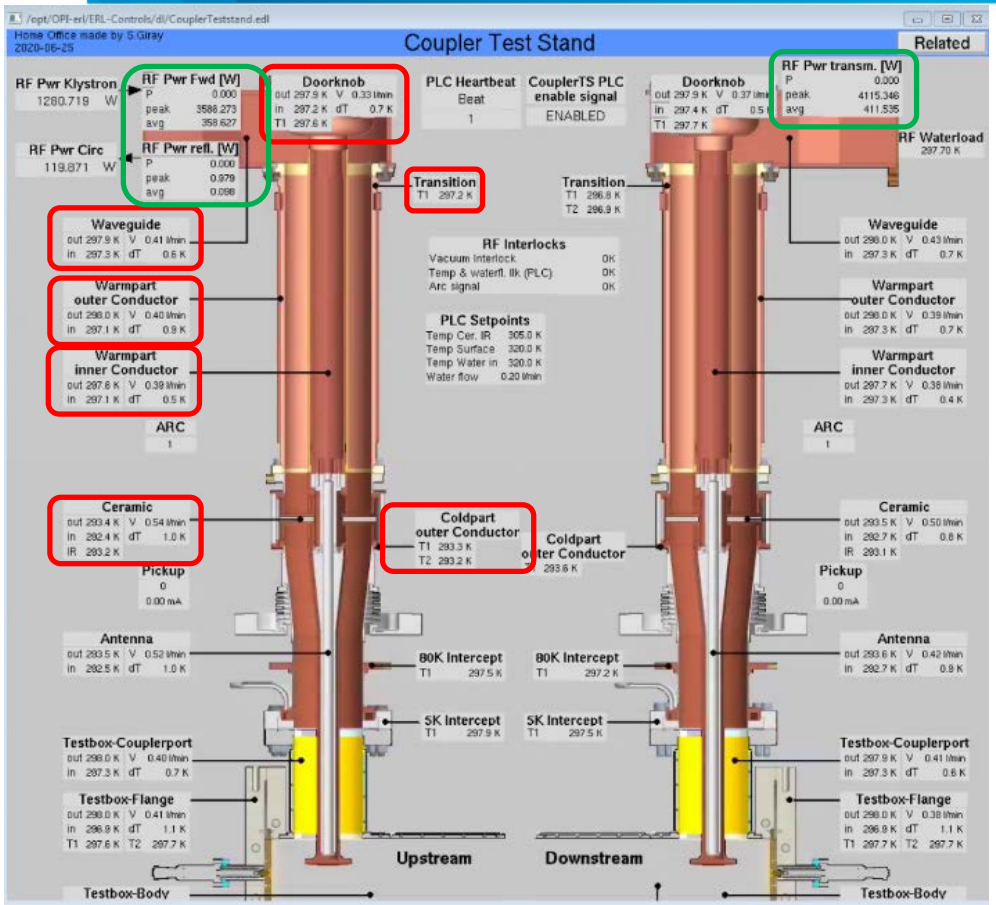
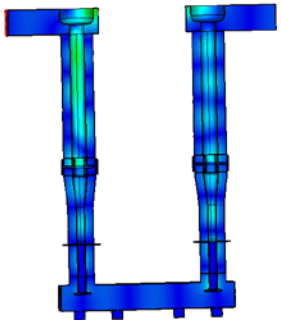


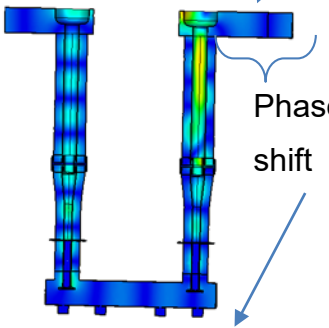
CST FD Solver: P_{in}=0.5 W rms

TW → SW

Field amplitude x2

Reflecting end

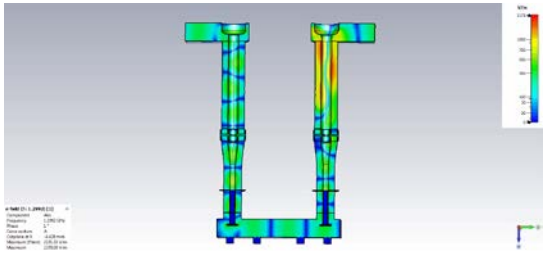




Phase shift

Max. field at transition, fluctuates between FPCs 5.7 A/m

Max. field localized 10.6 A/m



TW electric field pattern

First pulsed results during setup of the system

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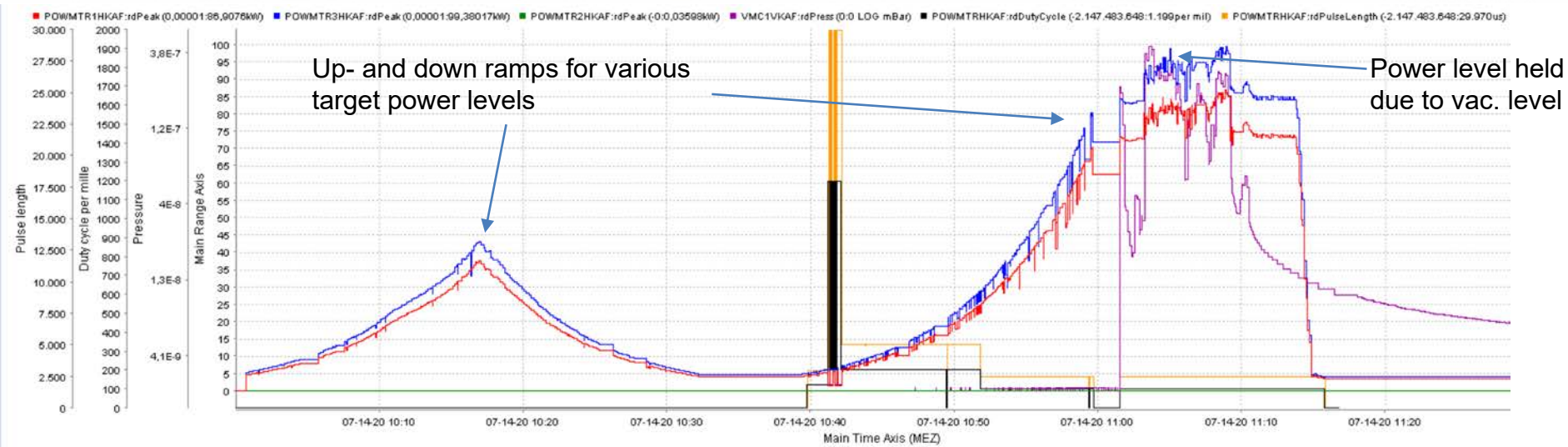

- In first conditioning attempts, still debugging the system we achieved:
  10% DC, 95 kW, f_{rep}=40 Hz, 2.5 ms pulse length in July 2020
  some increased vacuum activity, still linear temperature response, no arcs, no trips
  No multipacting was observed
- Since then, the procedures were refined, diagnostics improved and the control program reworked
- Up to know, two pairs conditioned, third on the way, delays due to pandemic restrictions

A perfect conditioning example

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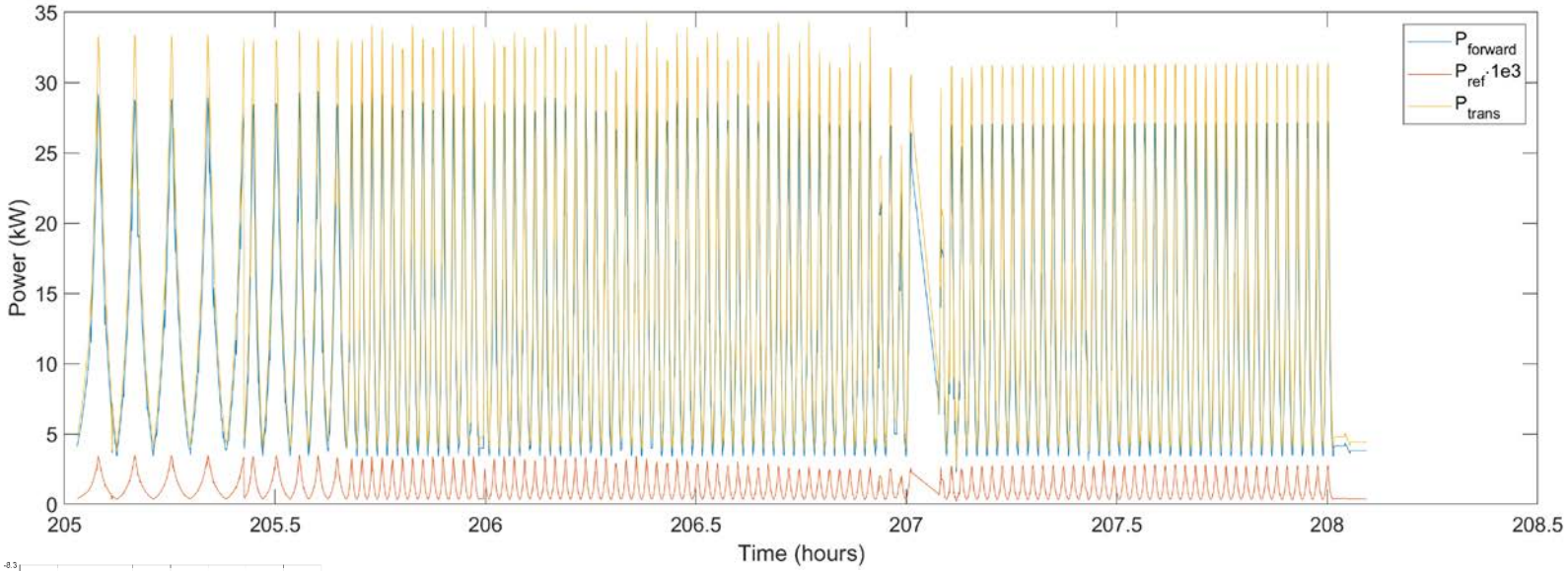
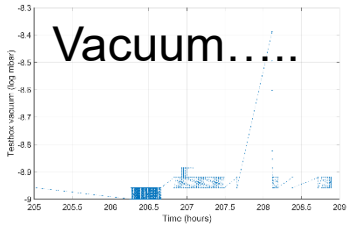
Pulses from 1‰ to 980‰, then CW

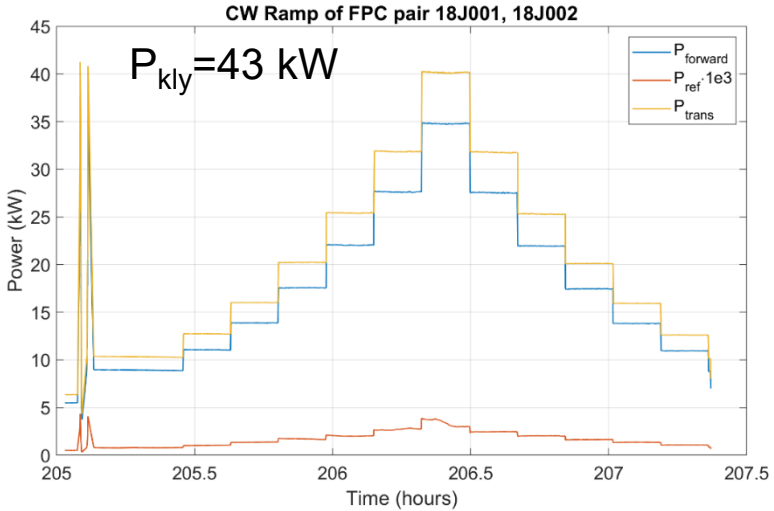


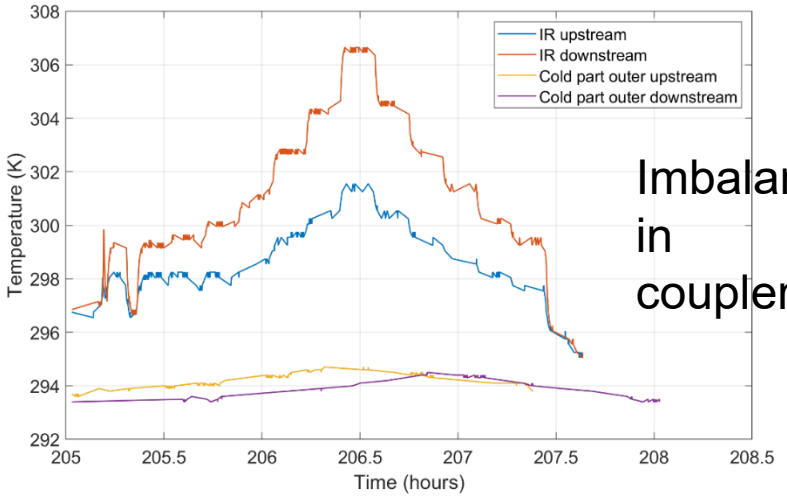


Goal: up to 30-40 kW CW TW w/o any failues w.r.t. vacuum, temperatures, arcs, multipacting, etc…
Factor six above current power goal

A. Neumann, 14.05.2021, MOPAB347

CW TW results





Imbalance in couplers?

- Ca 0.25 K/kW at ceramic window→ about 55 °C at 120 kW TW expected
- Simulations expected 60°C at IR window at 120 kW TW!
- Observed imbalance by small deviations of geometry, will be compensated at cavity by varying gasket thickness
- For 6mA target Q_L, the variation of penetration depth is more relaxed

CW TW results

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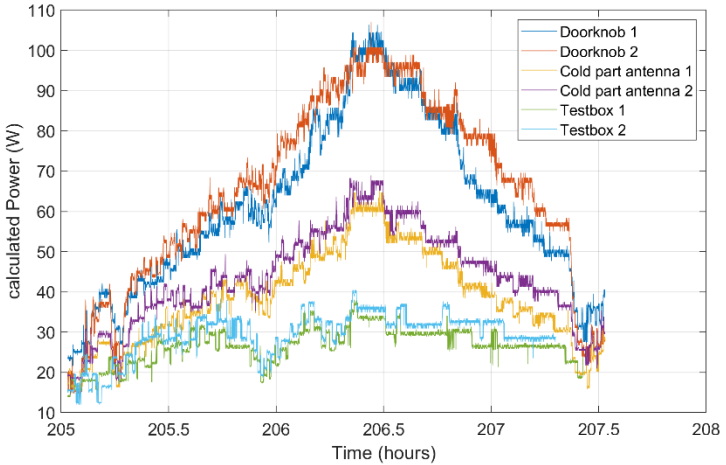
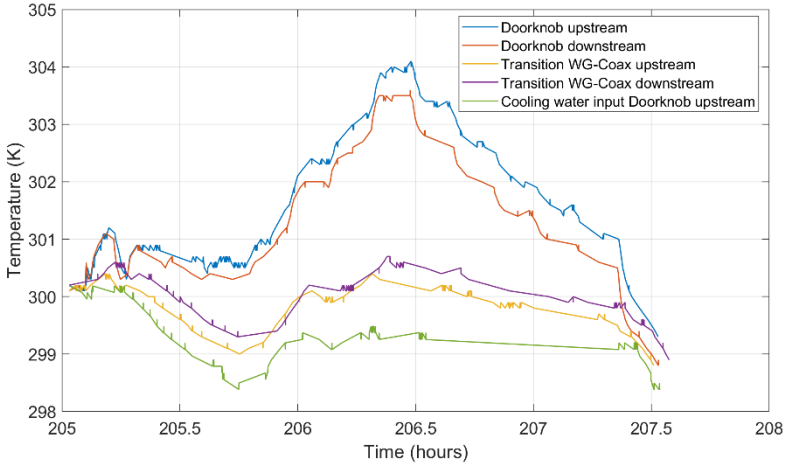
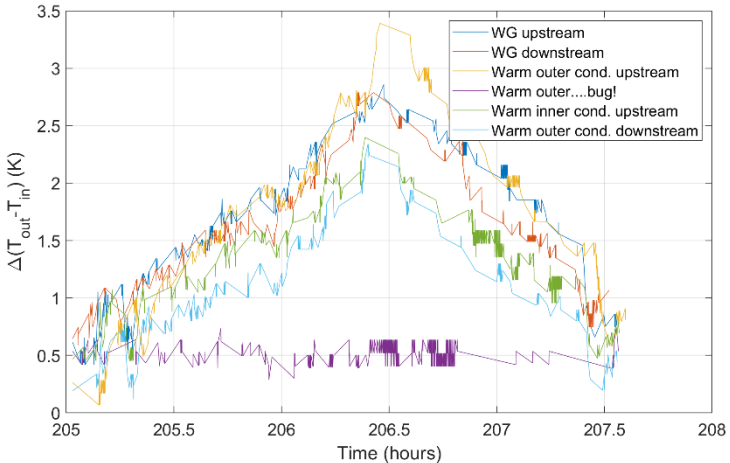
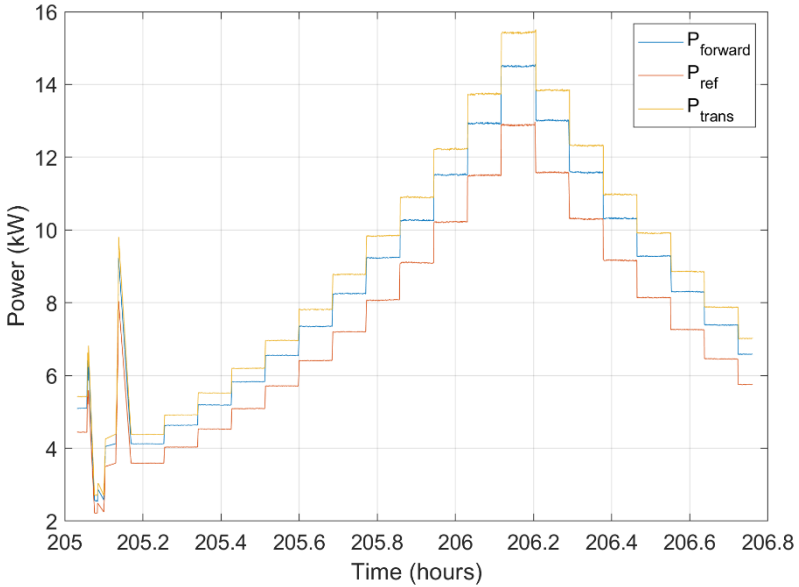


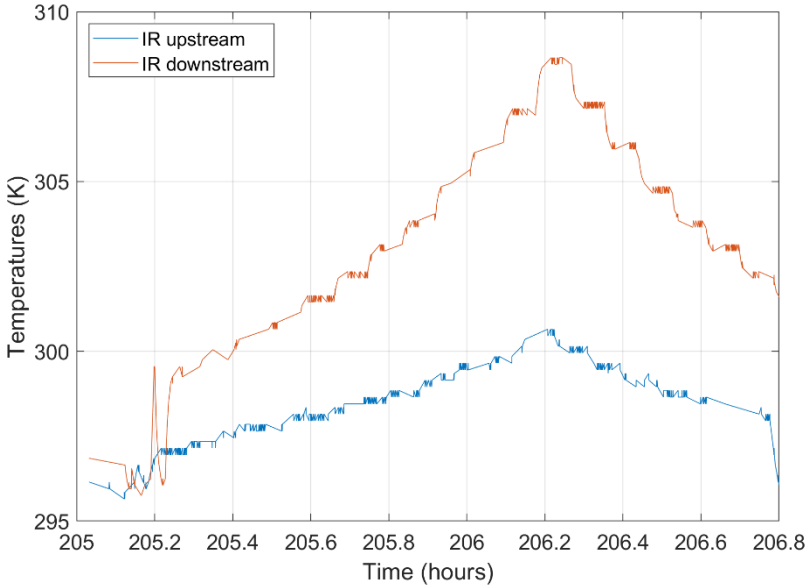


Power deposited in cooling water ~ 400 W at 35 kW



WG, warm part, door-knob “hot spots” besides ceramic window





$\Delta T/\Delta P_{in}$=0.78 K/kW in SW regime. Here, fields at maximum doubled compared to TW regime → corresponds to four times the power level

IR window warmer than in full power TW, but still within tolerances

A scan of different reflective end distances should be studied (phase shifter), but what SW regime establishes in the FPC?

Cases of partial failures and limits

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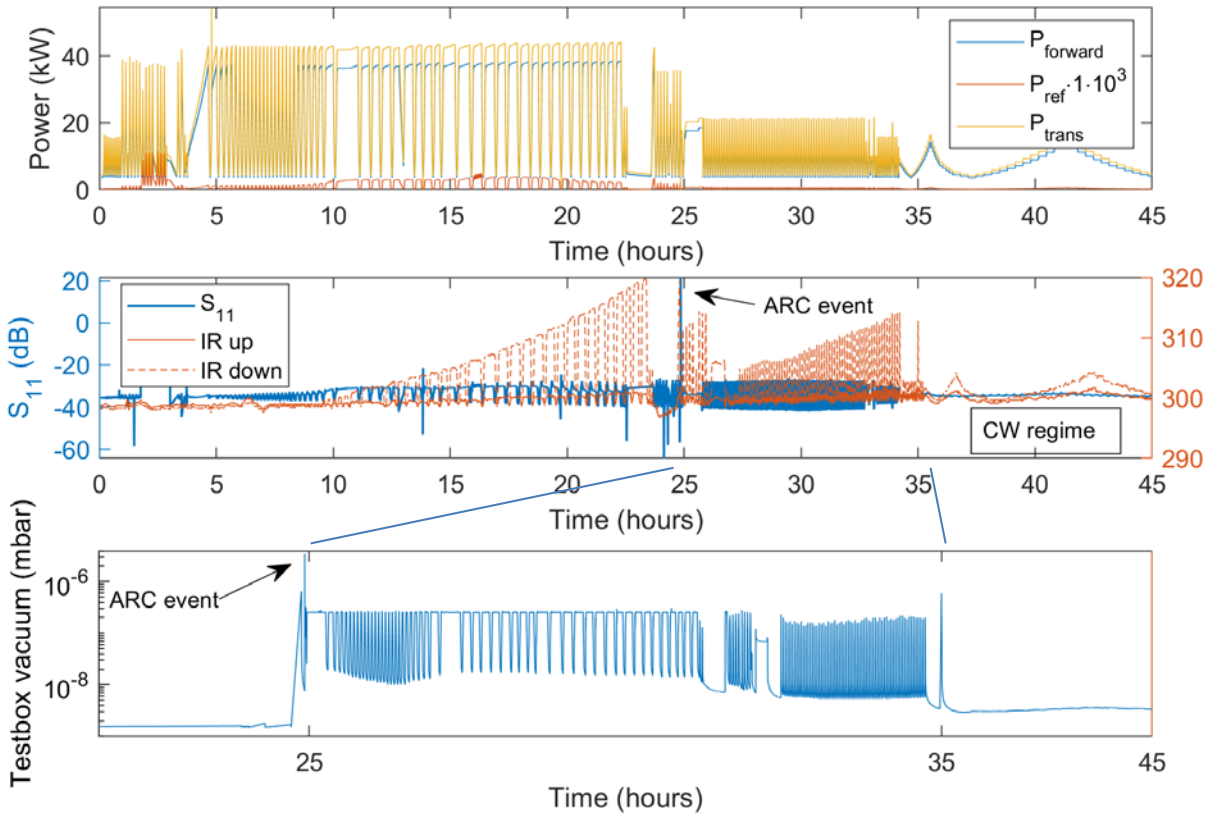

After strong vacuum+ARC interlock event
→ increased vacuum activity above about 13 kW power threshold
→ Linear temperature rise at ceramic window with power becomes exponential above threshold
→ Coupler candidate for inspection and cleaning

Reasons:
Non uniform metallization (TiN) of window?

Still 18 kW TW is achieved, enough for stage 1 beam (6 mA) current.

Summary

- 2 pairs out of 4 total conditioned, both pairs reach level for 6 mA operation
- 2nd pair showed activity at second window, will be inspected in clean room to decide on further treatment
- 3rd pair should be conditioned in two weeks (status of 16th May)
- Final pair will target for the full power range of 120 kW CW in travelling wave and 30 kW in standing wave regime, if it works eventually 150 kW (current Klystron limit)
- All conditioned coupler cold parts are stored under nitrogen and will be exposed to air only during string assembly in ISO 4 cleanroom

Acknowledgements

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Diagnostics, conditioning system:
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Control system, panels:
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Clean room and technical support:
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Cooling water:
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+ people I hopefully did not forget