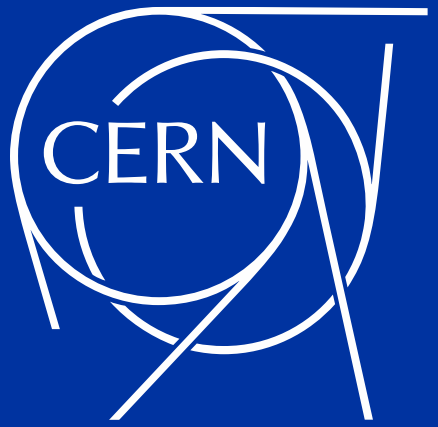


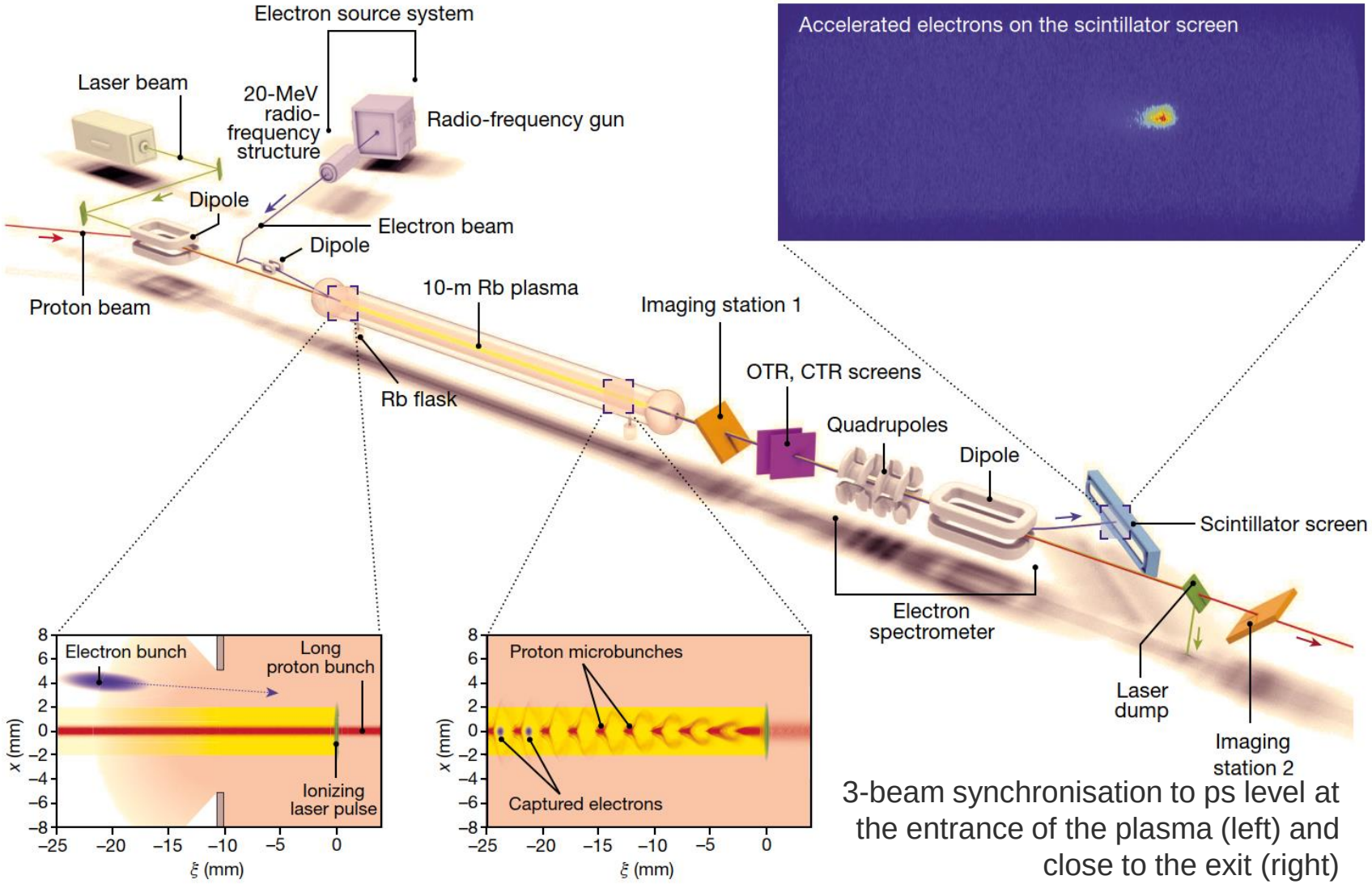
Status of the AWAKE run 2c photoinjector LLRF at CERN

Ben Woolley, Kristiaan Pelckmans, Steffen Doebert

06/12/2023

AWAKE: Proton driven plasma wakefield acceleration

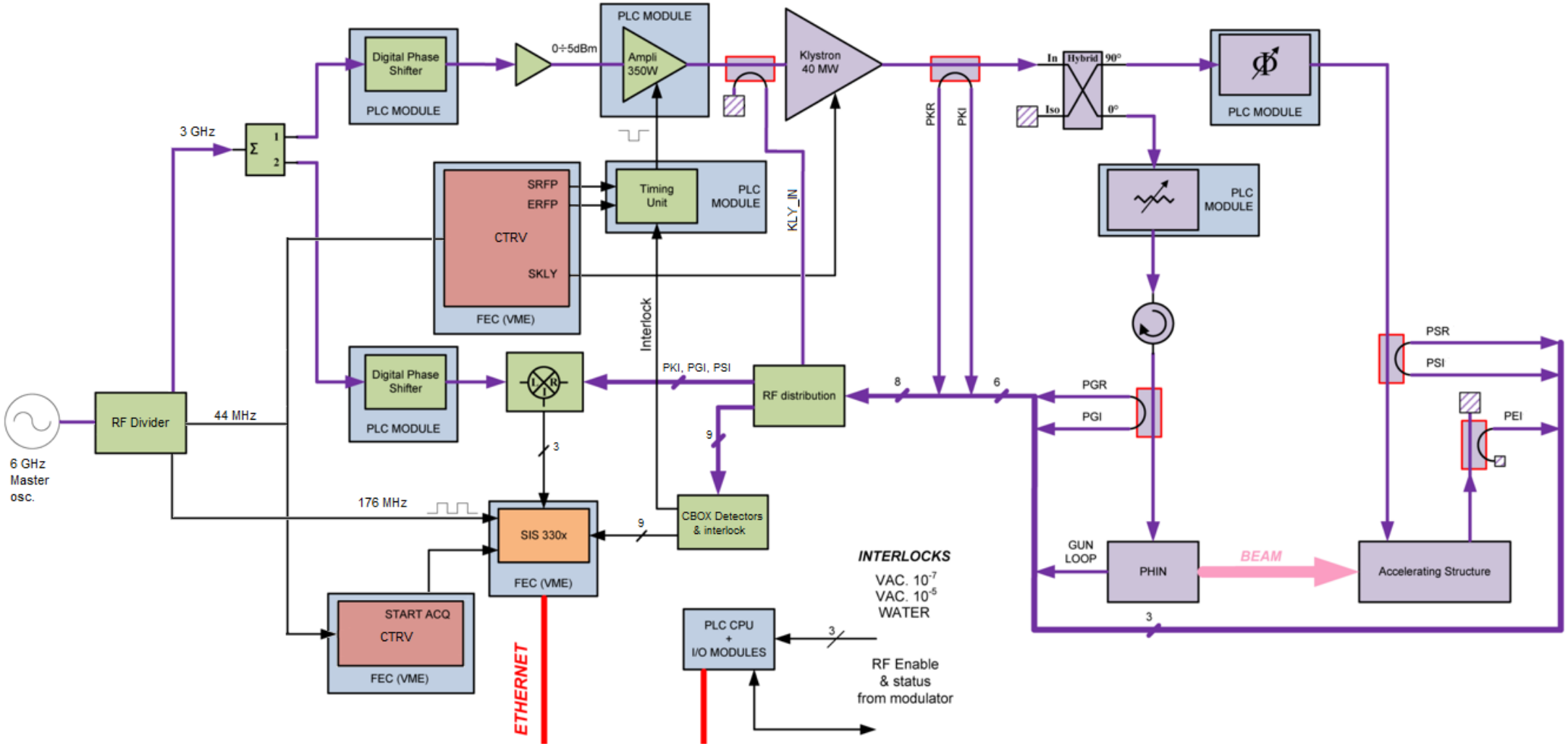
- **Unique to CERN**
  - Very successful: showed that a high energy (400 GeV) proton bunch reproducibly self-modulates, driving strong wakefields.
  - Externally injected low-energy (16 MeV) electrons were accelerated to 2 GeV in under 10 m.
- **Staged upgrades (Run 2):**
  - Run 2a: demonstrate reproducible self-modulation via electron seeding. (Done 2022)
  - Run 2b: New vapour source with density step to stabilise micro-bunches. (Ongoing 2023-24)



3-beam synchronisation to ps level at the entrance of the plasma (left) and close to the exit (right)

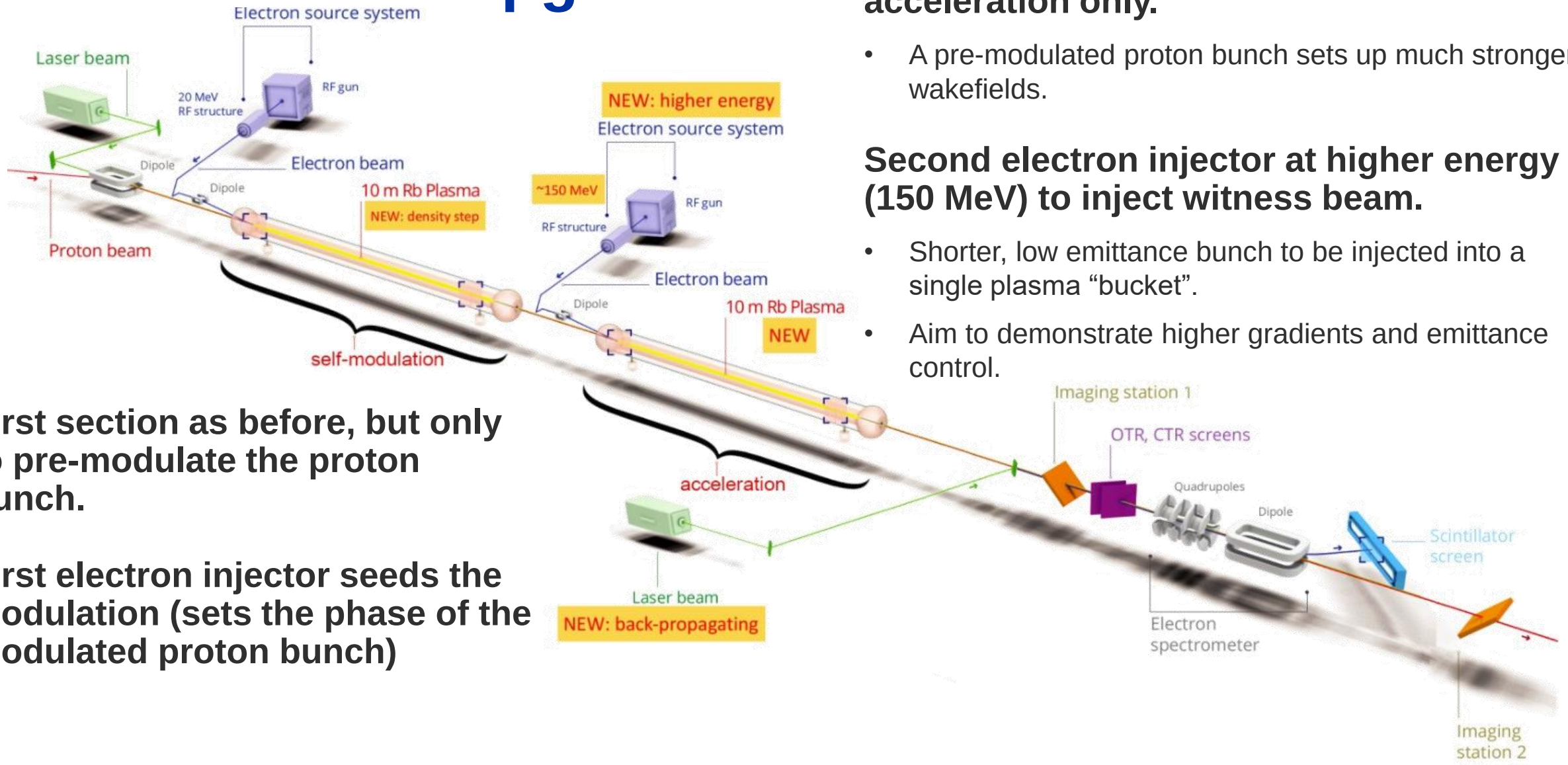
Adli, E., Ahuja, A., Apsimon, O. *et al.* Acceleration of electrons in the plasma wakefield of a proton bunch. *Nature* **561**, 363–367 (2018). https://doi.org/10.1038/s41586-018-0485-4

Current Electron Injector RF System architecture



Analog system based on aging/obsolete technology. Diode detectors and base-band phase measurements. Slow PLC based, open-loop control.

AWAKE Run 2c Upgrade



First section as before, but only to pre-modulate the proton bunch.

First electron injector seeds the modulation (sets the phase of the modulated proton bunch)

Addition of a second plasma cell for acceleration only.

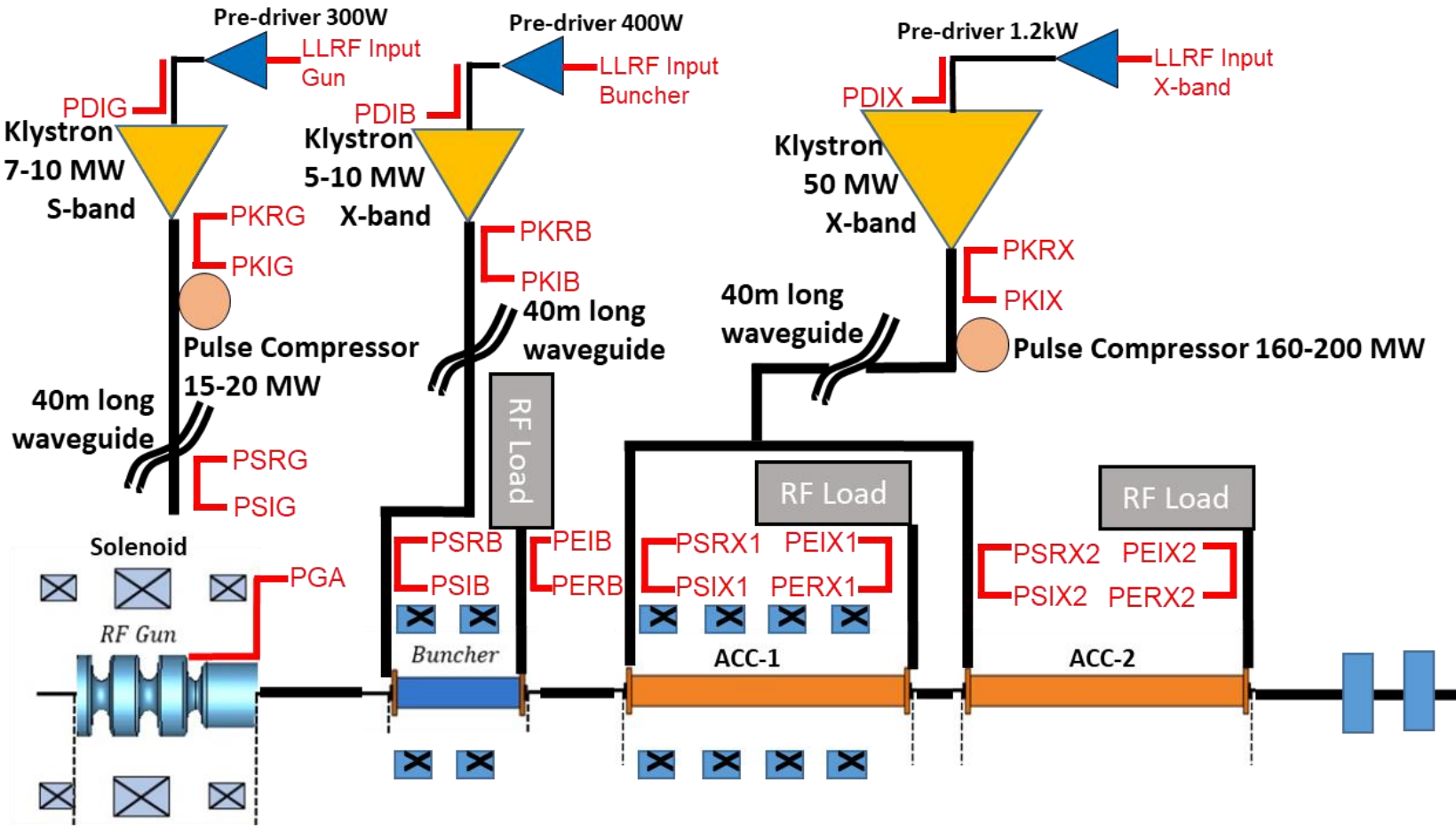
- A pre-modulated proton bunch sets up much stronger wakefields.

Second electron injector at higher energy (150 MeV) to inject witness beam.

- Shorter, low emittance bunch to be injected into a single plasma “bucket”.
- Aim to demonstrate higher gradients and emittance control.

Second Electron injector

- 160 MeV electron energy
- Emittance 2mm mrad
- S-band photo cathode gun
- X-band buncher
- X-band accelerating structures with 80 MV/m
  - Option for 3x, 55 MV/m structures also studied.
- 3 drive signals to be to be controlled.



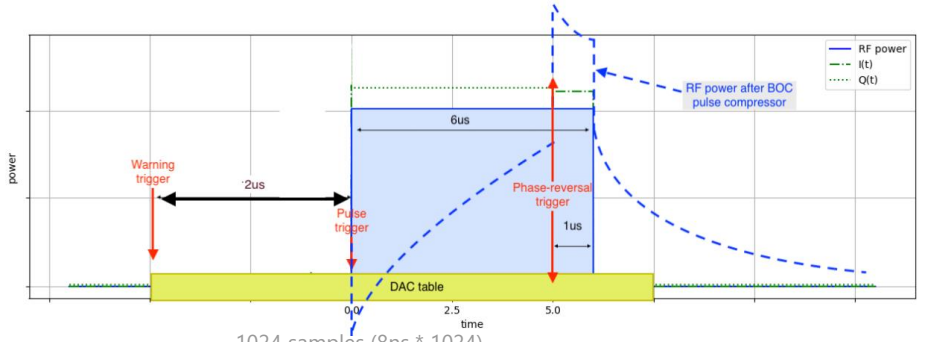
LLRF system specifications for run 2c

- **3GHz and 12GHz signals to be acquired and generated.**
  - Arbitrary amplitude and phase control is required to operate the system in a closed loop fashion and to provide the necessary phase manipulation for the RF pulse compressors.
- **Timing jitter between seed and witness e-bunches to be below 50fs to achieve optimal placement of the witness e- bunch into the plasma wakefield.**
  - LLRF modulator must have an additive phase jitter of less than 30 fs.
- **Slow drifts must be compensated for by the LLRF system.**
  - Temperature variations in signal cables, long waveguides, driver amplifiers, klystrons, pulse compressors.

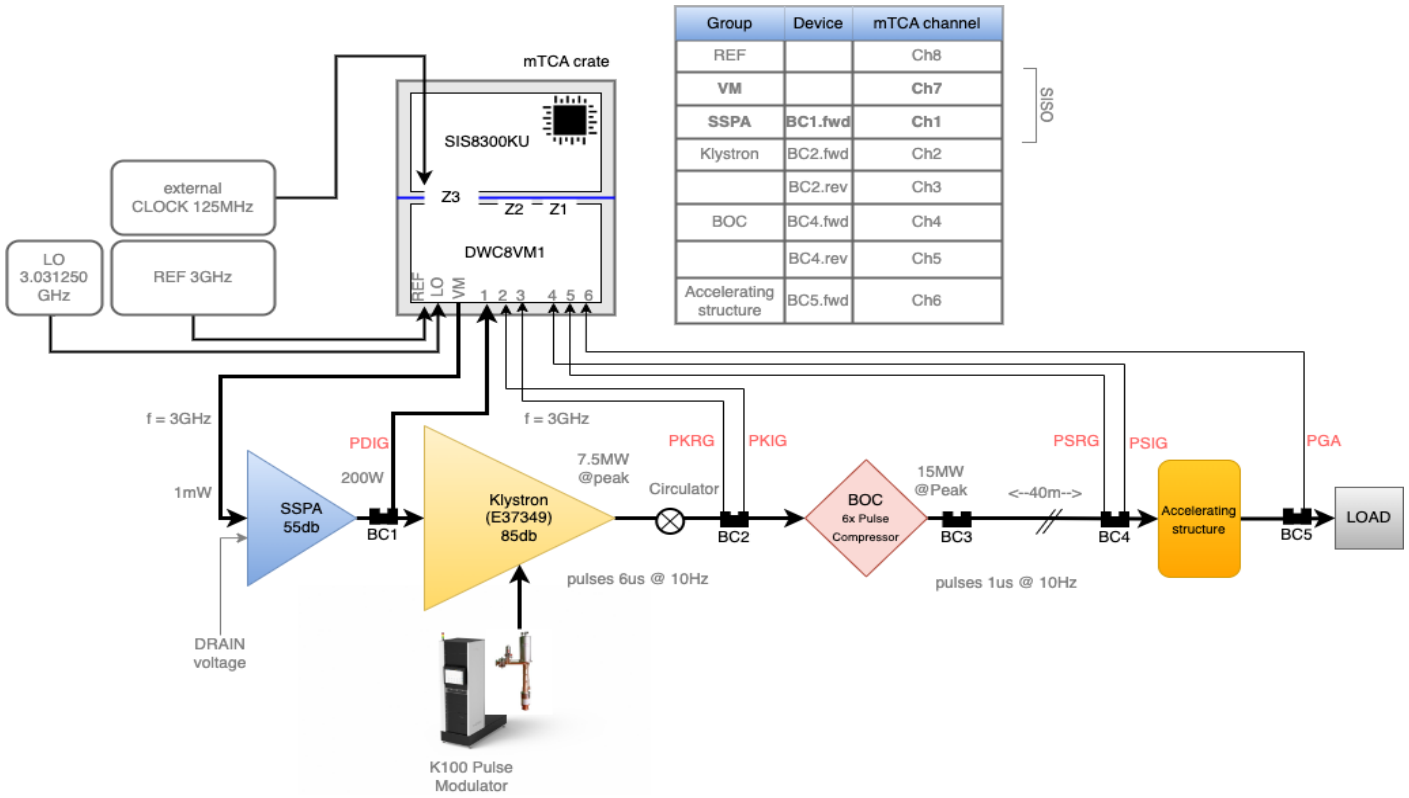
	S-band	X-band
Operating frequency	2.997899 GHz	11.9915962 GHz
Pulse length	1-10 µs	100-1500 ns
Bandwidth	> 20 MHz	> 20 MHz
Pulse repetition rate	9.97 Hz	9.97 Hz
Number of signals to be acquired	14 + Reference	18 + Reference
Number of signals to be generated	2	2
Jitter	<30 fs	< 30 fs
Amplitude stability	10^{-4}	10^{-4}

LLRF architecture

- Use SIS8300KU and DWC8VM1 AMC+RTM.
- Uppsala University as collaborator to develop the LLRF system for tests at CERN's CLEAR (formerly CTF) facility.
- Last year's WS we asked DESY and KVG to launch the development of the DeRTM-LOG 3GHz for REF, LO and CLK distribution on the RF backplane.
- For X-band stations use middleware (a la DESY[1]) to up/down convert between 3GHz and 12GHz.



1024 samples (8ns * 1024)

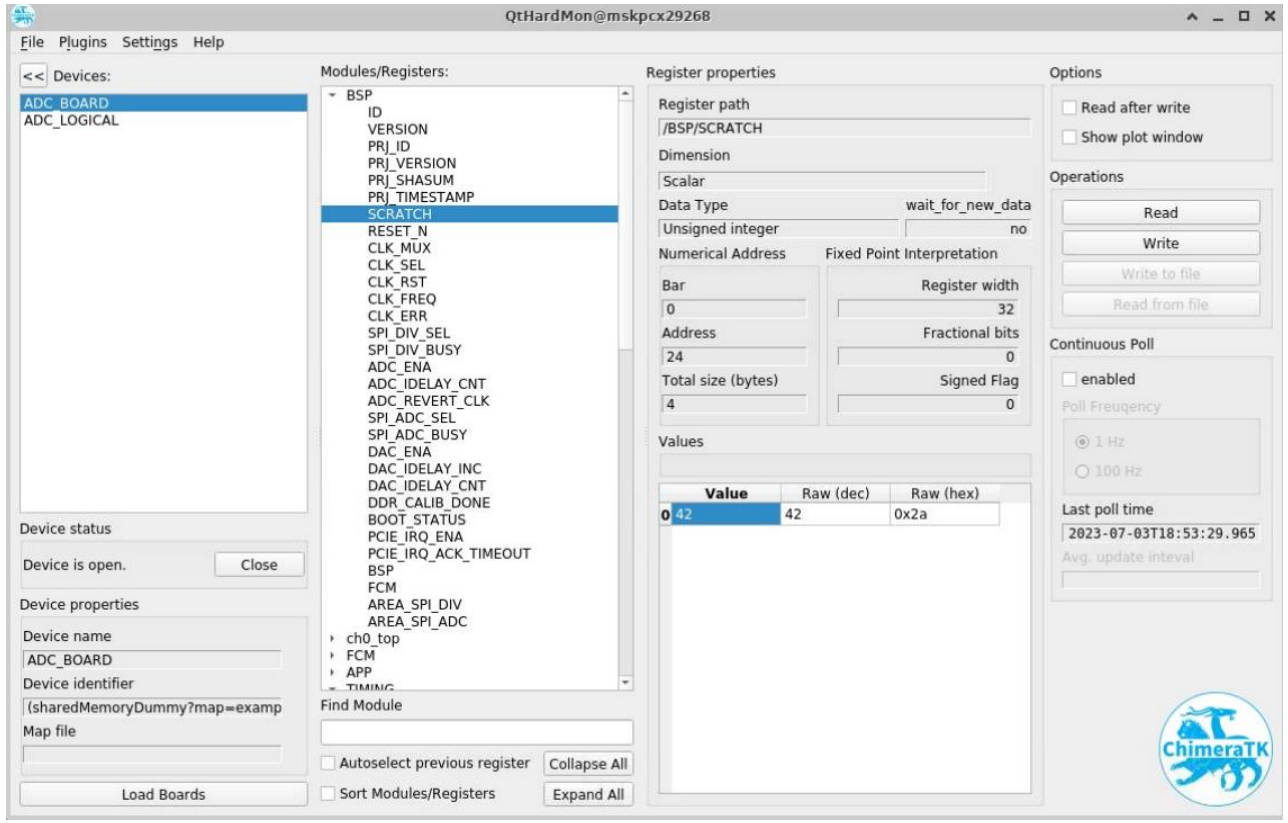


Group	Device	mTCA channel
REF		Ch8
VM		Ch7
SSPA	BC1.fwd	Ch1
Klystron	BC2.fwd	Ch2
	BC2.rev	Ch3
BOC	BC4.fwd	Ch4
	BC4.rev	Ch5
Accelerating structure	BC5.fwd	Ch6

1: https://indico.fnal.gov/event/21836/contributions/64954/attachments/40833/49435/PUBLIC_VERSION_-_LLRF19_MReukauff_Talk.pdf

DESY FWK BSP: an external perspective

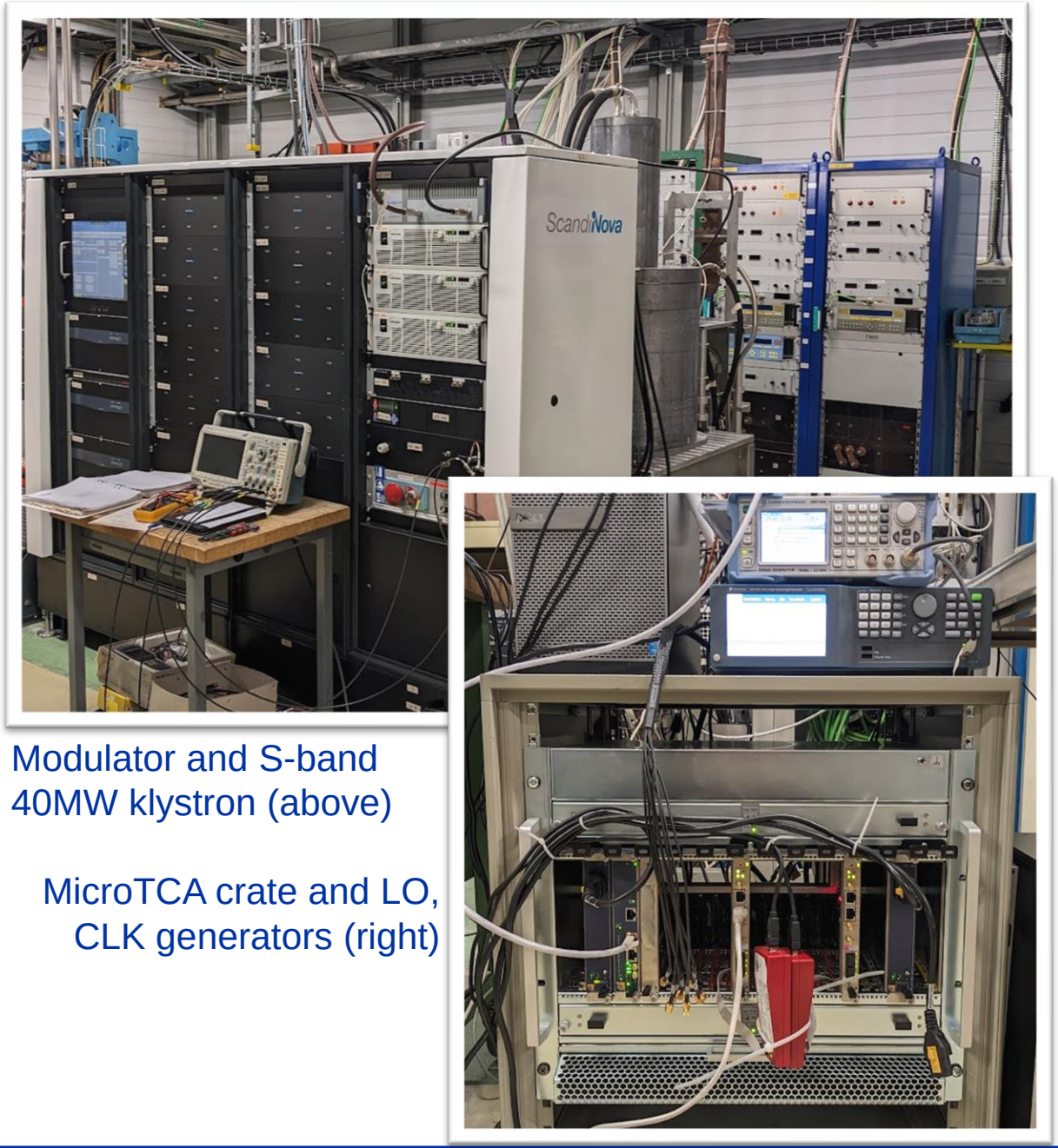
- The FWK/demo facilitated the developer to go from absolute beginner to modest expert in +/-1 year.
- The FWK/demo is now (fall 2023) in a stable phase with initial glitches ironed out.
- The appeal (for us) is that FWK/demo keeps the delay overhead (between ADC > DAC) down without too much tuning.
- Understanding the FWK/demo helped understanding other efforts as well.
- The core of FWK/demo includes efficient memmap management.



-Kristiaan Pelckmans

Progress so far…

- **System shipped to CERN from Uppsala, installed in the form CLIC test facility.**
- **RF signal acquisition, generation and feedback/forward loops tested.**
- **Use of DESY BSP and python GUI.**
- **External trigger injection through RJ45 connector on SIS8300KU AMC, distributed to mLVDS lines.**
  - Currently under test/development (still some bugs to iron out)
- **Work progressing well on a DESYRDL to CERN/Cheby convertor script.**



Modulator and S-band 40MW klystron (above)

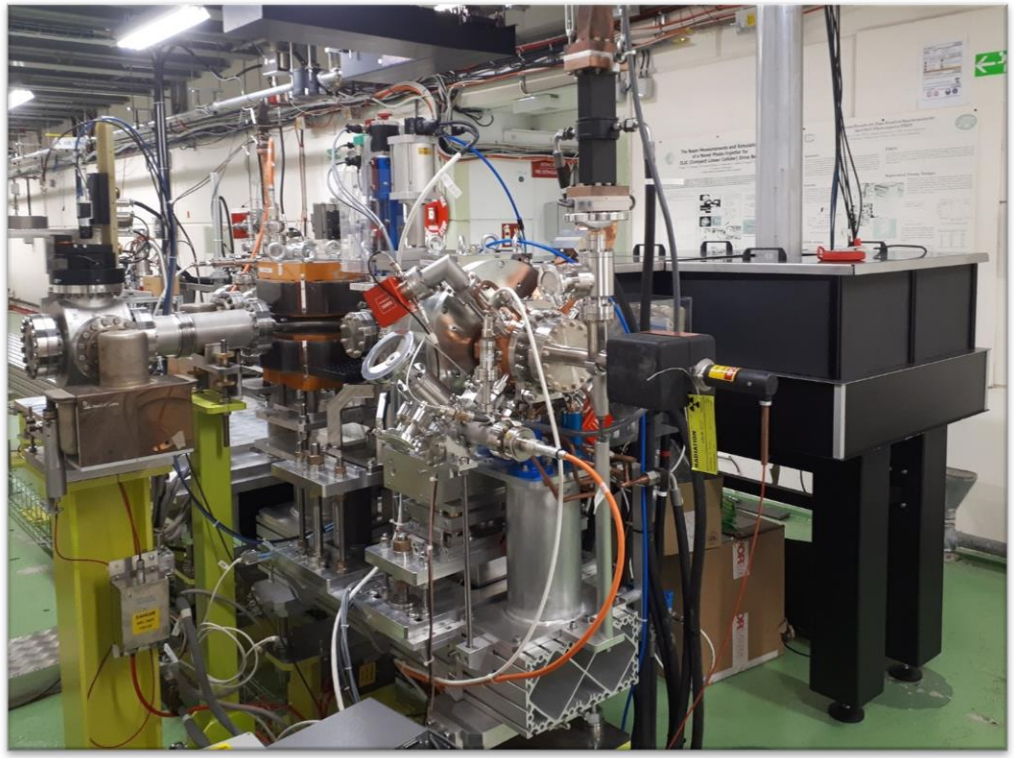
MicroTCA crate and LO, CLK generators (right)

Next steps

- **Fully validate the external trigger injection and synchronise to the CLEAR accelerator complex.**
- **Replace DESY RDL register map with CERN Cheby based one.**
- **Develop FESA class for acquisition and control.**
- **Install CTRA (CERN timing infrastructure card), to fully integrate into the CERN controls infrastructure.**
  - AMC FMC carrier (AFC) and CERN developed timing receiver FMC.
- **Connect the VM to the RF power plant and close the loops.**
- **3GHz DeRTM-LOG still under development at DESY and KVG. We would like to use this for the final system with 5+ cards.**

AFC FMC carrier: https://ohwr.org/project/afc

DeRTM-LOG



AWAKE Run 2c photocathode gun installed in former CLIC Test Facility

Advertisement: Cheby + Reksio

Register map tool now open source:

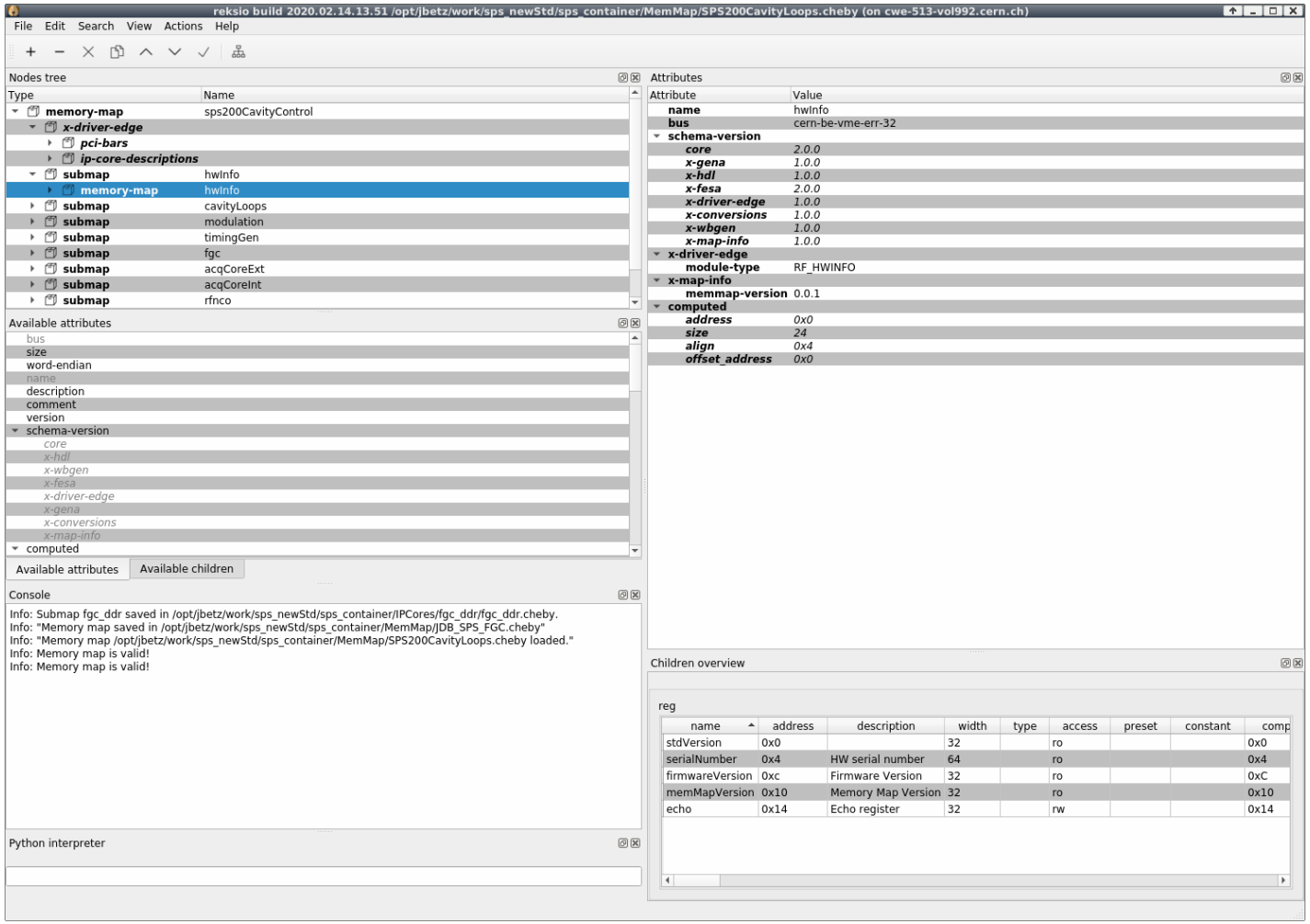
Cheby:

- **File format to describe the HW/SW interface (the memory map)**
- **A set of tools to generate HDL, drivers, documentation... from these files**

https://gitlab.cern.ch/be-cem-edl/common/cheby

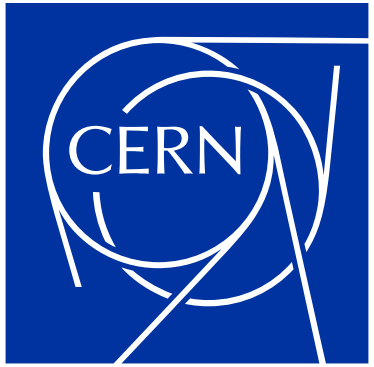
Reksio: GUI to interface with Cheby.

https://gitlab.cern.ch/Cheburashka/gui



Thank You!

Questions?



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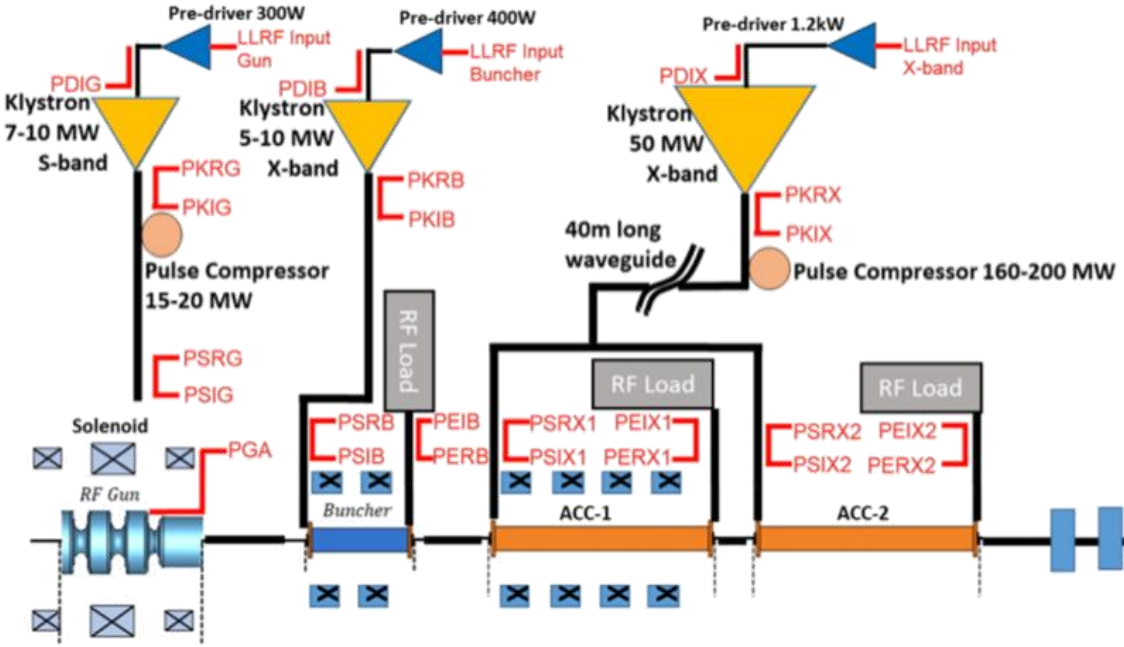
Extra Slides

AWAKE run 2c upgrade

- **Two RF photocathode guns with S-band and X-band structures.**
- **Requires pulse to pulse stability of 30 fs → active stabilisation with LLRF loops.**
- **Prototype microTCA LLRF system, currently undergoing tests at CERN through collaboration with Uppsala University.**



RF GUN 2 with signals to treated by the LLRF in red.

	2023	2024	2025	2026	2027	2028
Design						
Implementation						
Deployment						

AWAKE Run 2c Experimental area