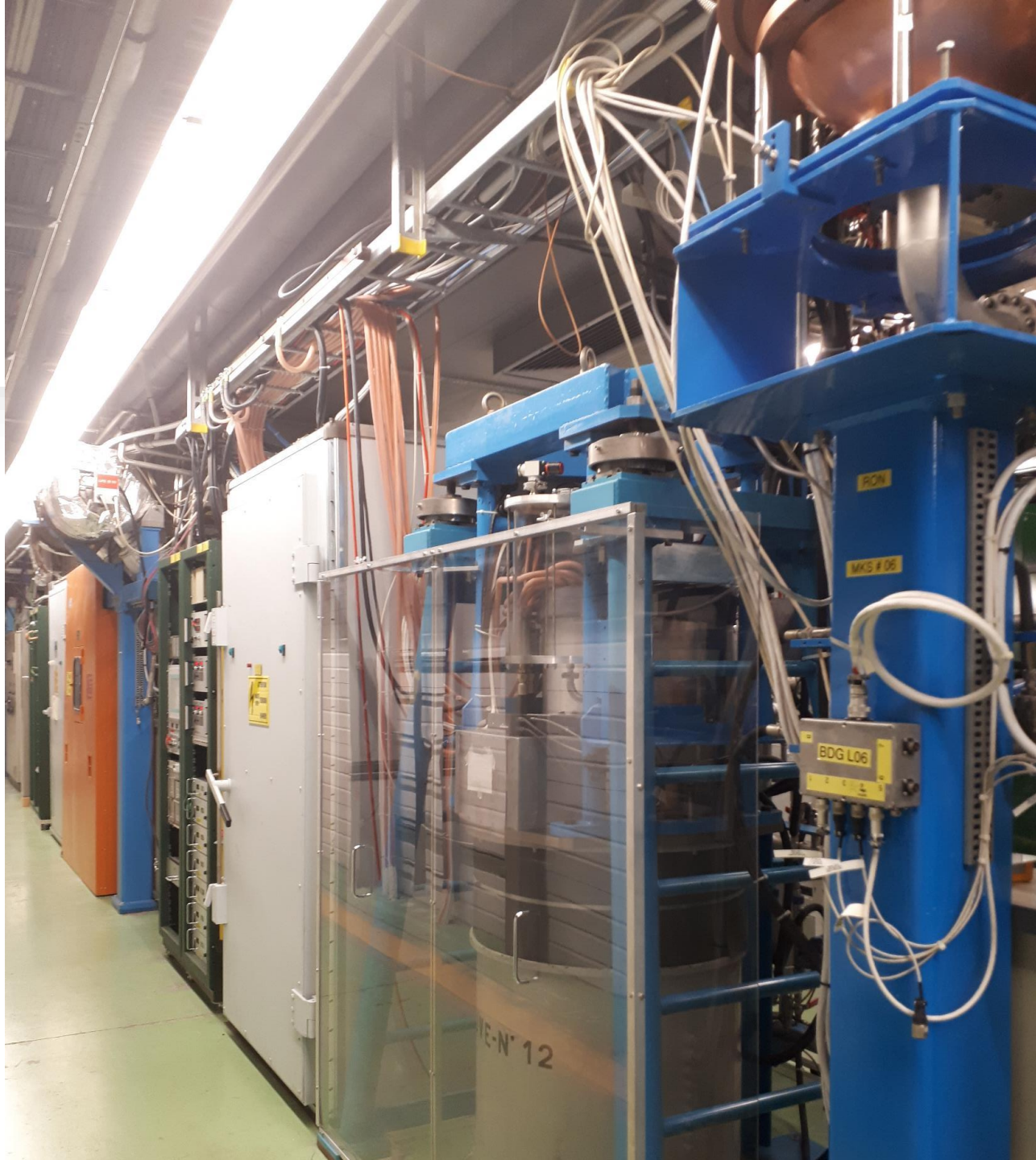
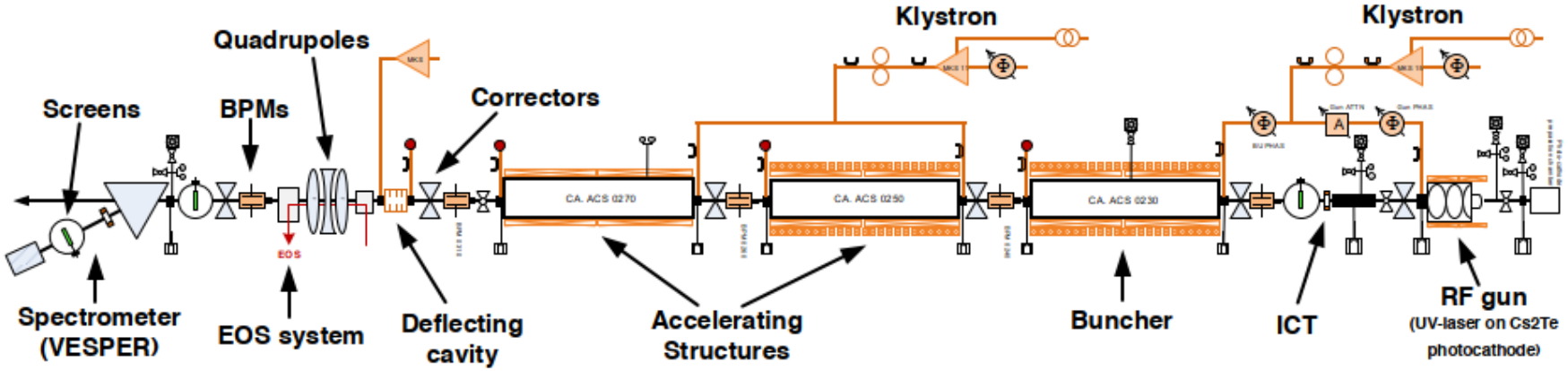
CLEAR RF system consolidation

What is needed for a smooth operation until 2030

- Quick overview of the system
- High-power RF future needs
- LLRF necessary consolidation
- Resources



CLEAR RF Systems



- **HPRF: 4-5 S-band Modulator/Klystron systems, 1 X-band system**
- **LLRF klystron: Klystron drive amp, amplitude and phase control, interlocks (safety), 3GHz diagnostic signals, PLC, FESA**
- **RF reference signal generation (3 GHz reference oscillator synchronized with a 10 MHz signal) and synchronization, frequencies: 12, 3, 1.5 GHz, 750,500,250, 19.2 MHz; RF clocks: 96, 192 MHz, all analogue no remote control**
- **Fast, low jitter timing (ps level), based on obsolete ECL counters for laser and instrumentation**

Klystrons and Modulators for CLEAR

- Currently 4-5 S-band klystrons in operation, 2 essential, 1 for RF deflector, 1 for CTF2 test area, test modulator
  Four old PFN modulators, one solid state Scandinova

- One x-band station for CTF2/CLEAR with old Scandinova Modulator

Maintenance contract with Scandinova exists.

Consolidation 2026-2030:

- If money was no issue: Buy two new Scandinova modulators: ~ 1.4 MCHF → Increase rep.rate and stability

- Alternative: Keep existing modulators alive as they are: spare parts exists, Scandinova maintenance contract

Buy or repair at least two TH2100 klystrons or equivalent: ~ 0.3-0.7 MCHF,
Difficult situation with klystron vendors concerning cost and delays !
Preferred solution would be repair of broken klystrons

Life extension for CLEAR up to 2030, LLRF

Consolidation between 2026-2030: Goals: more stability, better maintainability, higher repetition rate

1. Find and implement alternative for fast /low jitter timing (ECL counters obsolete, no spares), → VTU ?

2. Renovate\Replace synchronous frequencies and clock generation and distribution (as well based on ECL counters)

3. Improve drive amplifier spare situation (only budget)

4. LLRF of klystron and diagnostics

Go digital, replace klystron LLRF with uTCA a la Uppsala, in theory working prototype by 2025, needs to be integrated in CERN control system and CLEAR safety chain
→ Uppsala University is working on a prototype system for AWAKE, already at CERN ready for testing

Very good synergy with AWAKE and future FCCee needs as well as standardisation of LLRF systems at CERN !

Maintenance and consolidation resources

- Right now, minimum effort and basically no official LLRF support

- 2026-2030: Keep operational budget and person power constant (increase LLRF):
  Additional investment cost for consolidation:

Item	Rough cost (kCHF)	Remarks
HPRF	300 -600	Depending on Scenario
LLRF	300	
M to P	400	4 years Grad

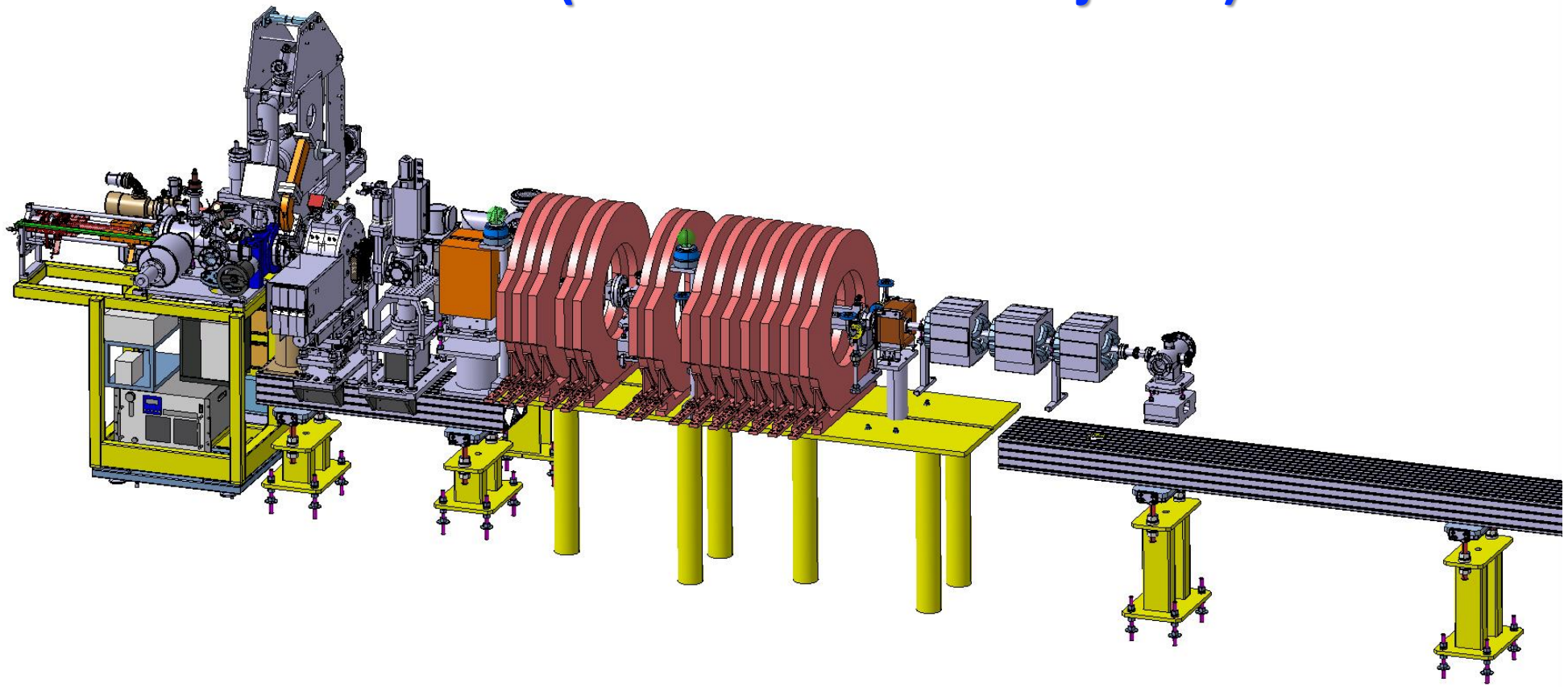
May be consolidation can be partly financed out of operation budget, but there is at least a spending profile problem since the consolidation effort should be started now. Could CLEAR become part of the Consolidation Efforts ?

Person power: Clearly a LLRF problem, right now 0 in APT even so CLEAR is an official running facility
Consolidation effort would need likely a Quest/Origin for 4 years (starting 2025).
Could be shared with AWAKE and FCCee because largely similar work.

HPRF: likely OK, a change of klystron type would generate significant work, Current support needs to be maintained.

Injector prototype in CTF2 for CLEAR and AWAKE

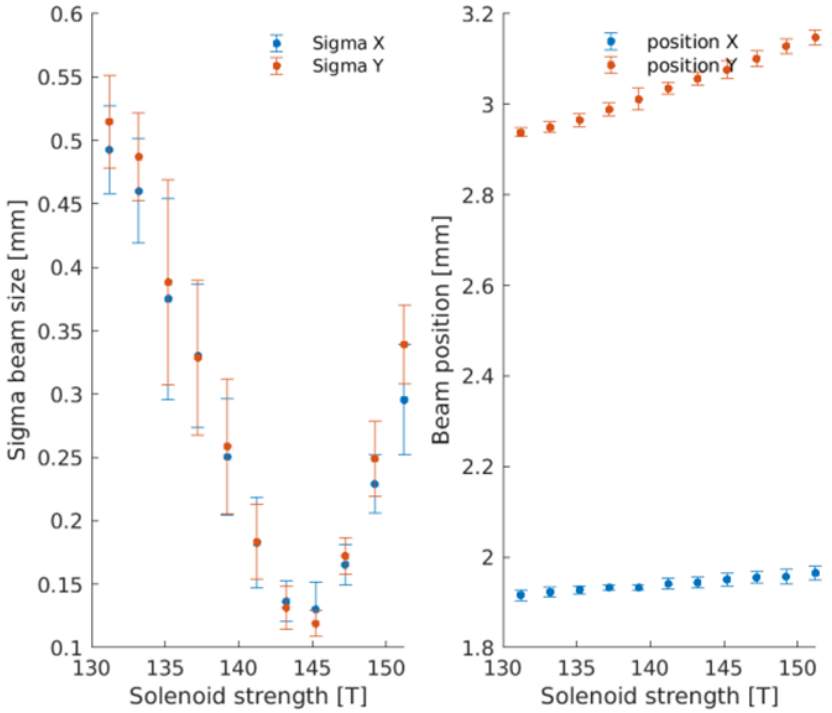
ARTI (AWAKE Run2 Test Injector)



Reduced scale prototype, 60 MeV, INFN gun, CLIC-structure as buncher and PSI-linearizing structure for acceleration.
Goal: demonstrate the velocity bunching and emittance preservation with x-band
Prototyping of key accelerator hardware and diagnostics
Gaining experience before installation in the AWAKE tunnel

ARTI status

- **RF-gun (INFN contribution)**
  and diagnostics operational and under commissioning
- **Magnets for second phase installed**
- **First ‘CLEAR user’ experiment planned in spring:**
  Vlad’s CBS experiment



CTF2 injector for CLEAR users

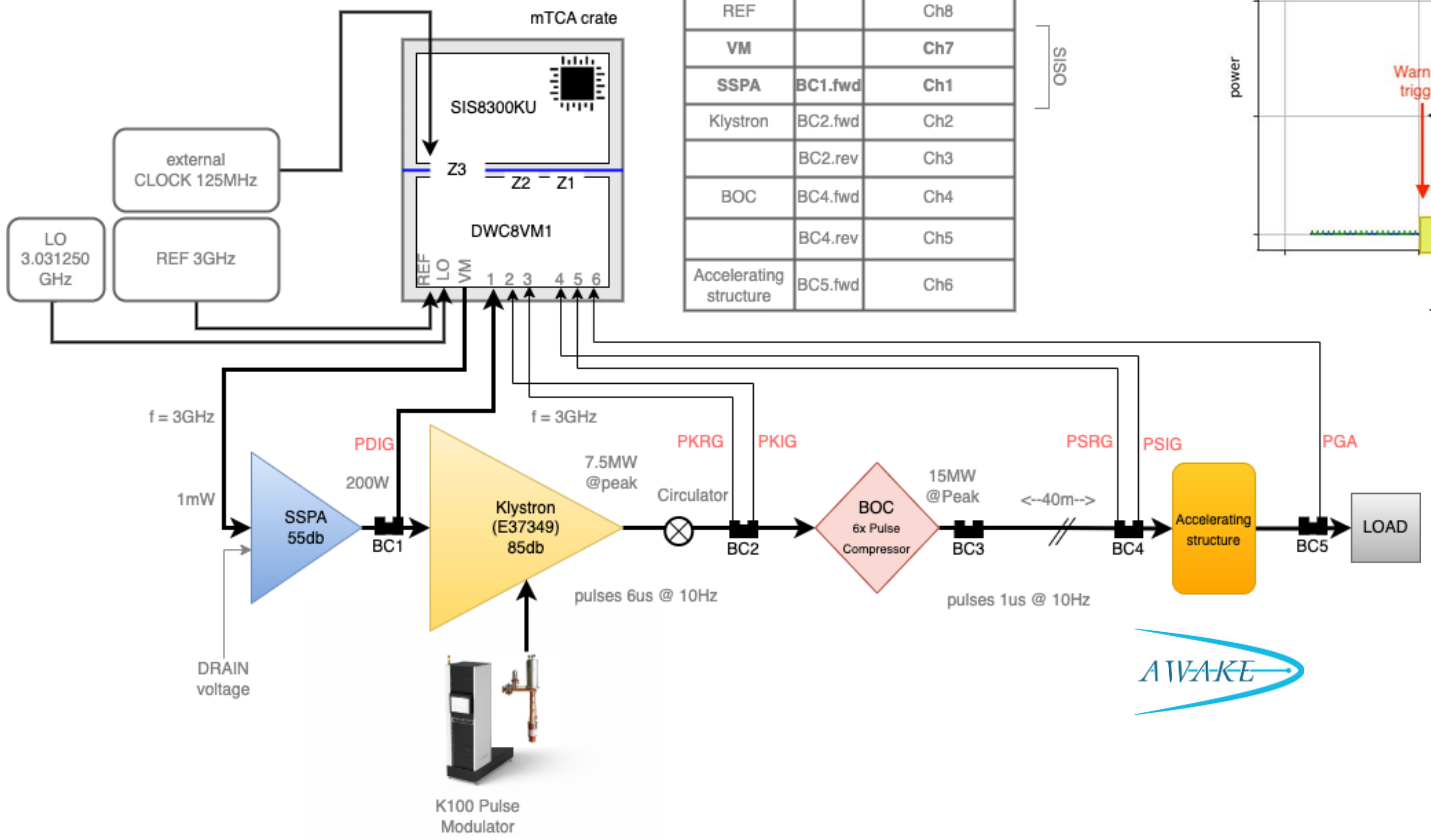
- **Potentially high-quality electron beam,**
  small emittance (1 um) , short electron bunch (200 fs), but low charge (100 pC) and single bunch
- **Can be used for some specific CLEAR users:**
  Instrumentation testing (bunch length)
  Compton Scattering Experiment due to laser parameters
  Some interest in THz related work

- **Eventually decision needed if some hardware goes to AWAKE in 2027**

- **Current view: Profit from installation for some experiments and then dedicate to AWAKE**
  CTF2 could be a good place to become at some point a FCCee electron source test facility

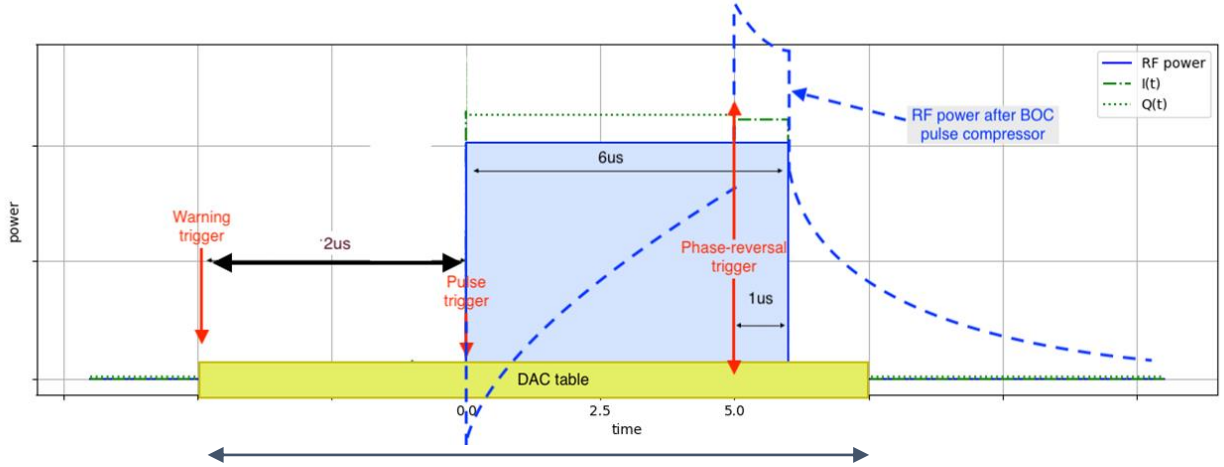
Spare slides

Setup: LLRF



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

OSIS



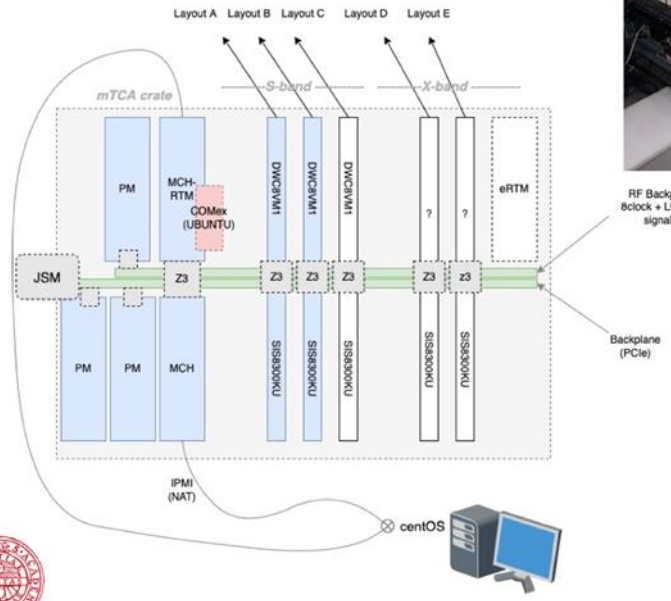
1024 samples (8ns * 1024)

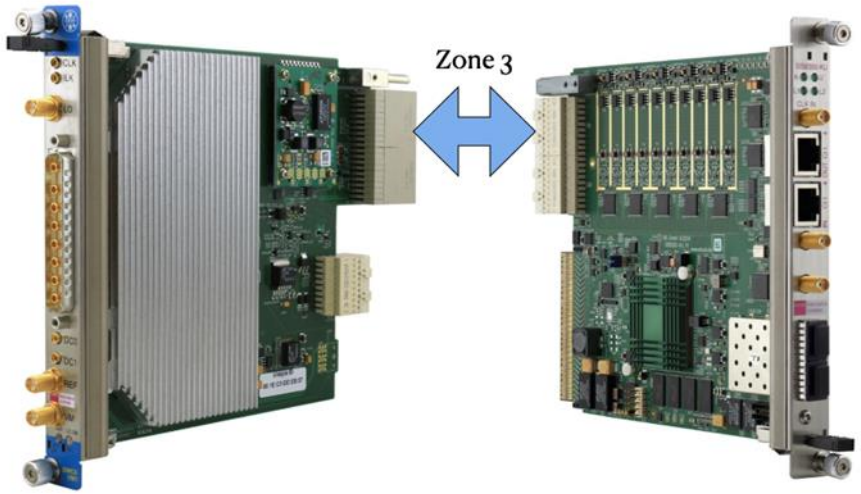
	S-band	X-band
Operating frequency	2.997899068 GHz	11.991596272 GHz
Pulse length	1-10 μs	100-1500 ns
Bandwidth	> 20 MHz	> 20 MHz
Pulse repetition rate	9.97 Hz	9.97 Hz
Number of signals to be acquired	14 + Reference	18 + Reference
Number of signals to be generated	2	2
Jitter	<30 fs	< 30 fs
Amplitude stability	10^{-4}	10^{-4}

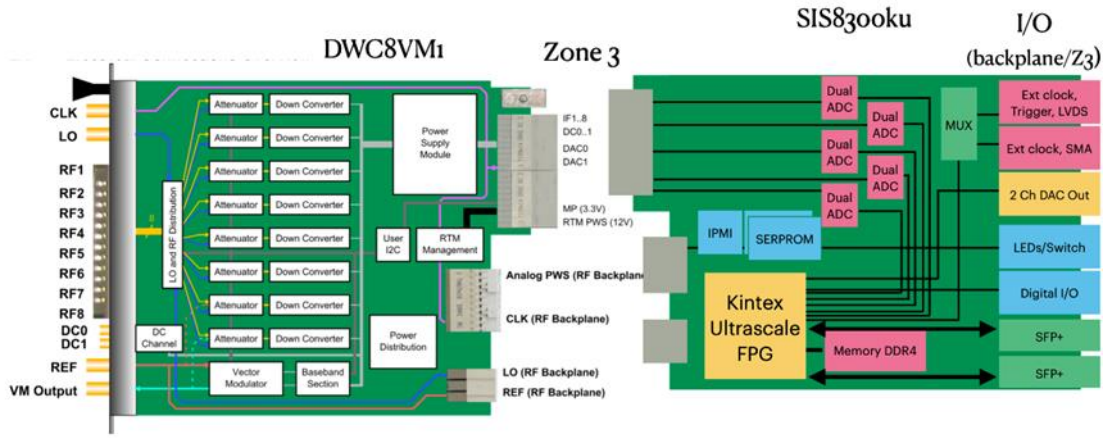
AWAKE 2C specification - prepared by Ben Woolley

Setup: mTCA LLRF

MTCA crate in UU:







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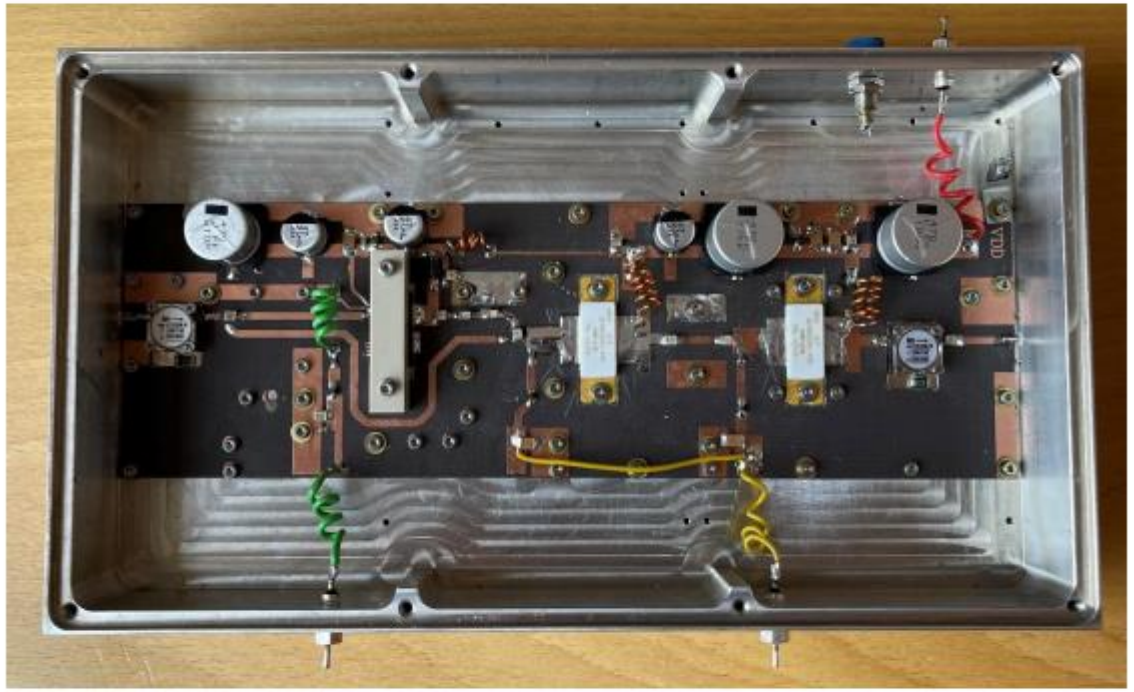
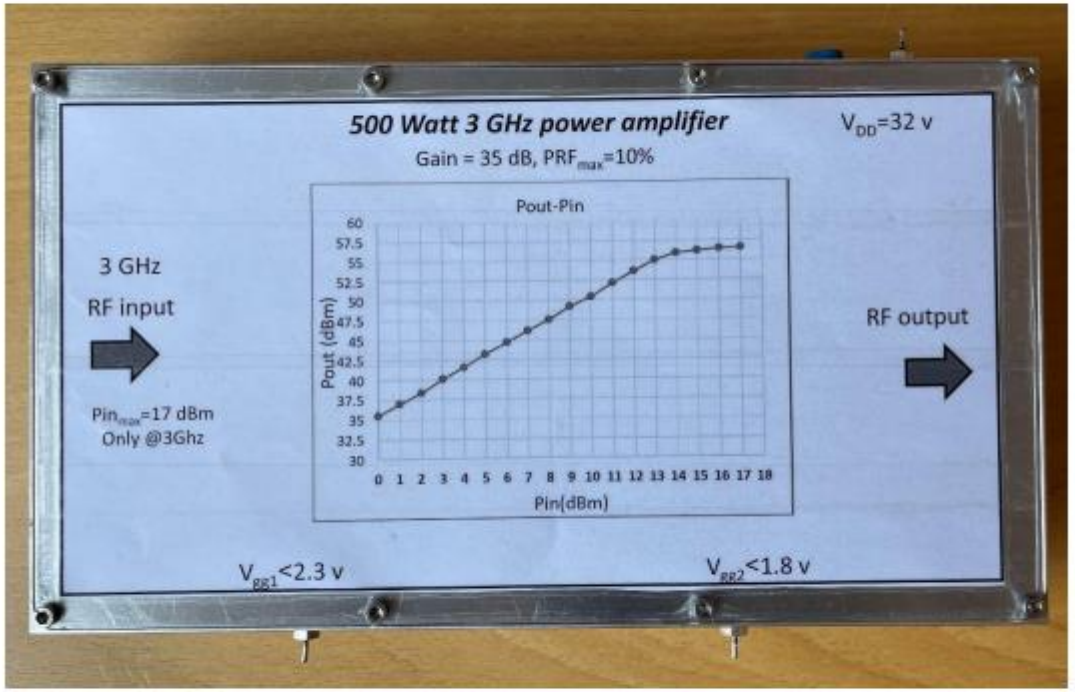
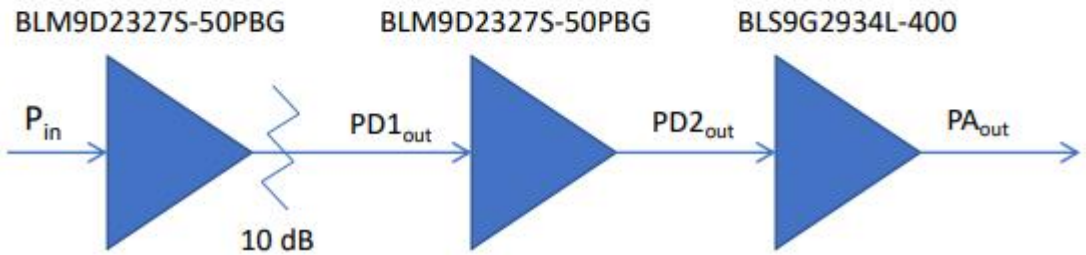
500-Watt Power amplfier – all stages







Klystrons and Modulators for CLEAR

3 GHz klystron situation: TH2100

- by 2025 essentially out of spares
- Thales does not seem to want to repair those klystrons anymore, a new one cost ~300 kCHF body only (compared to 150 kCHF last purchase), not responsive on request for quotation (visit last week might change that)
- PSI repaired some at CPI (cost 120 kCHF) but took 4 years, CPI has a huge delay problem
- Canon has an alternative (100k, klystron body) but need to buy solenoid and adapt modulator sockets. Examples from PSI exist but it represent some work and money. Let's estimate another 100K per klystron for the first one.

In principle need to decide and launch order before end of the year !

Thyratron CX1836A: We have several spares but in unclear condition
In principle this model is still available on the market
Thyratron replacement with solid-state has been demonstrated with a prototype

→ Strategy: use the spares and build more solid-state switches

S-Band Klystron Cost/Risk Comparison 2023

	Canon E37327A	CPI TH2100 Re-gun	CPI TH2100 Repair & Test	New TH2100
Klystron	17,172,000 Yen (123k CHF)	$104295 (97k CHF)	$169535 (158k CHF)	>>€200k (200k CHF)
Solenoid	4712000 Yen (34k CHF)			
Solenoid Power supply	8k CHF			
Klystron Plate/Socket	4.5k CHF			
Waveguide / Shielding	8k CHF			
Other costs	Beckhoff Module (??)	$14067 inspection (13k CHF)	$14067 inspection (13k CHF)	
Shipping		$3k	$3k	
TOTAL	179k CHF	113k CHF	174k CHF	>>200k CHF
Comments	• New klystron / Solenoid and Power Supply • Future klystron replacements simplified. • 7 months delivery time • Waveguide position not identical • Lower efficiency maybe not suitable for SLS limit is around 240kV (30MW needs 285kV 300Amps)	• Cheapest solution • Un-tested, therefore higher risk that desired output power not achieved. • Gaurantee only for 1k filament hours • Old tube – depending on the failure type or age of the tube • Delivery time likely to be >>1 year	• Arc free tube >40MW. • Old tube • Delivery likely to be >>1.5 years.	• New klystron • Delivery ~1.5 years • Observed recent degredation in new TH2100 tubes from factory. Both INFN and Taiwan experienced issues with new tubes.

Klystron options

	Units	Thales TH2100L	TH2100 CPI Repair	CPI VKS-8245C	Canon E37333	Canon E37327A
Klystron Cost*		€240k	$125k	$285k	$170k	$124k
Solenoid Cost*		$40k	$40k	$72k	$59k	$41.5k
Peak RF Power	MW	45	45 (>40 MW)	45	45 *(70)*	45
Klystron Voltage	kV	318	330	315	350	326
Klystron Current	A	360	300	350	410	380
Max RF pulse duration	us	6us in SF6	3us in SF6	4.5us in SF6	4.5us *(3us)*	4.5us
Max DC pulse duration	µs	7us	6us	6.5us	6.2us	6.5us
Drive Power	W	Typ. <180W	Typ. 130	Max 1000W	Max 500W	Max 500W
P_{RF}	Hz	100Hz	100 Hz	100Hz	100Hz	100Hz
Gain	dB	55	55	47	49.5	49.5
Efficiency		43	43	43	35%	39%
Solenoid Coils		3	3	3(6)	1	1
Max Solenoid Voltage	V	45, 45, 100	45, 45, 100	TBC	300	250
Max Solenoid Current	A	43, 43, 43	43, 43, 43	35, 40, 30	24	21
			2nd Choice			1st Choice

*Prices from 2020