DESY. UPDATE ON LLRF SYSTEMS

Low Level Radio Frequency Workshop
Newport News, VA, USA
13-16 oct. 2025

Julien Branlard, for the LLRF team

HELMHOLTZ

DESY campus = construction site

CAST
Center for Accelerator Science and Technology (new control room)

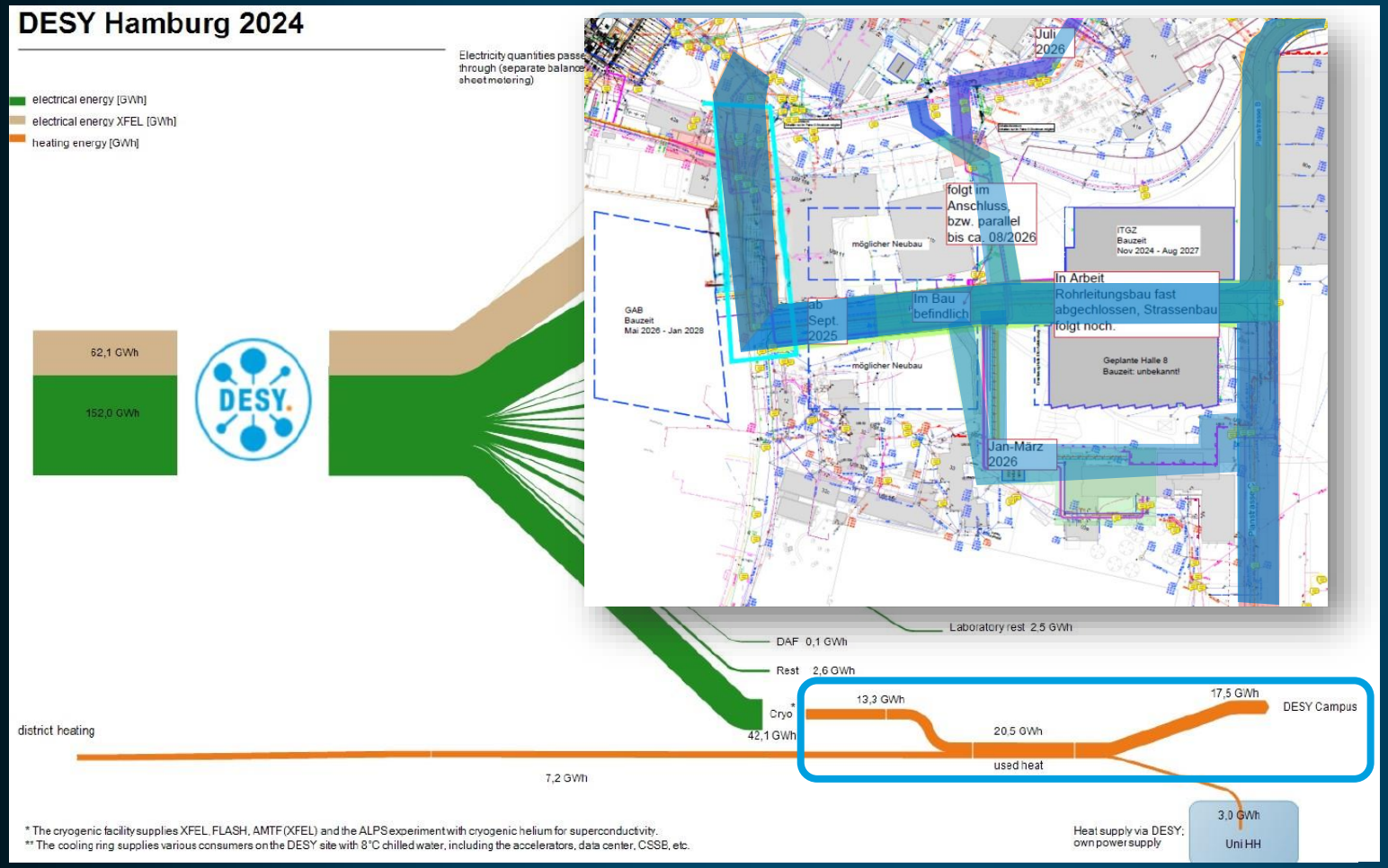
DESYUM
New visitor center (opening 2025)

DESY campus = construction site

Innovation Factory
(Deep tech, startup, research and technology transfer)

Innovation Factory 2
(opening 2027)

DESY campus = construction site



FLASH

Successive upgrades, back in operation since August 2025

FLASH
Free-Electron Laser in Hamburg

2021 - 2022 shutdown (10 months)

- ACC23 = 2 new cryomodules with cavities running on average at 28 – 29 MV/m
- ACC45 optimized waveguide distribution
- New energy 1.35 GeV
- **New main oscillator**

MO designed in collaboration with ISE, Poland licensed to KVG

Integrated jitter:
< 12 fs [10 Hz to 100 Hz]
< 1.8 fs [100 Hz to 1 kHz]
< 0.8 fs [1 kHz to 1 MHz]

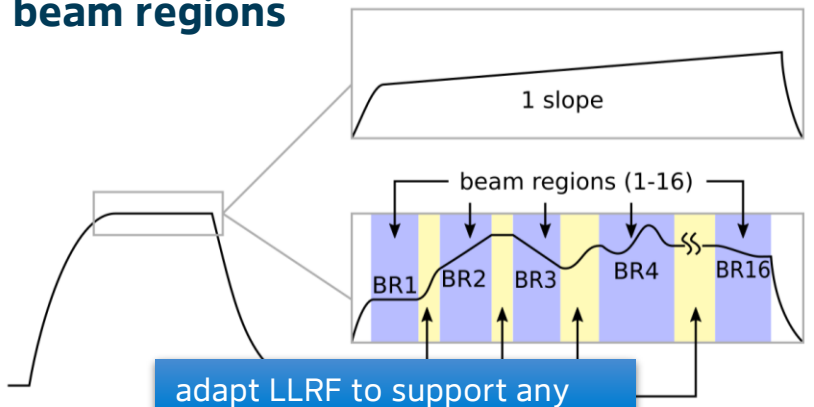
2024 – 2025 shutdown (14 months)

- photon beam line upgrade
  - variable gap + apple-X undulators (FLASH1 beamline)
  - new injector laser + provide external seeding
- LLRF
  - modernizing legacy **monitoring system** (new racks, VME → MTCA)
  - improving **RF reference distribution** to bring benefit of new MO to end users

EuXFEL

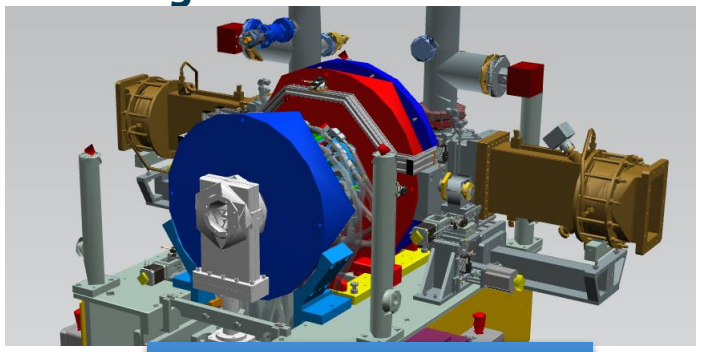
Recent developments, currently shutdown (1st warmup since 2017 !), restart January 2026

beam regions



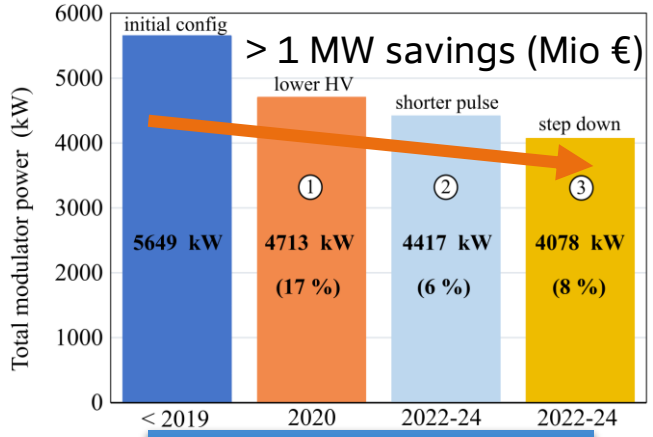
adapt LLRF to support any arbitrary setpoint waveform

new RF gun



adapt LLRF for 2 input ports and probe pick-up

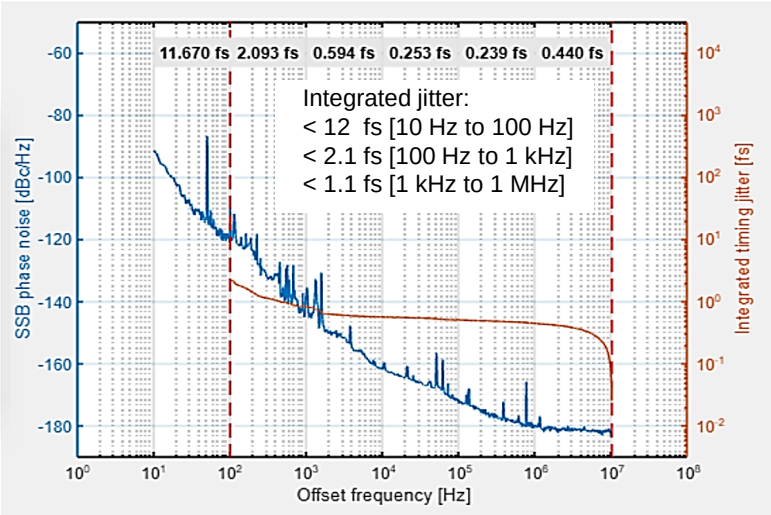
energy savings



adapt LLRF to compensate for HPRF non-linearities

new MO

benefit 1-to-1 from FLASH MO development

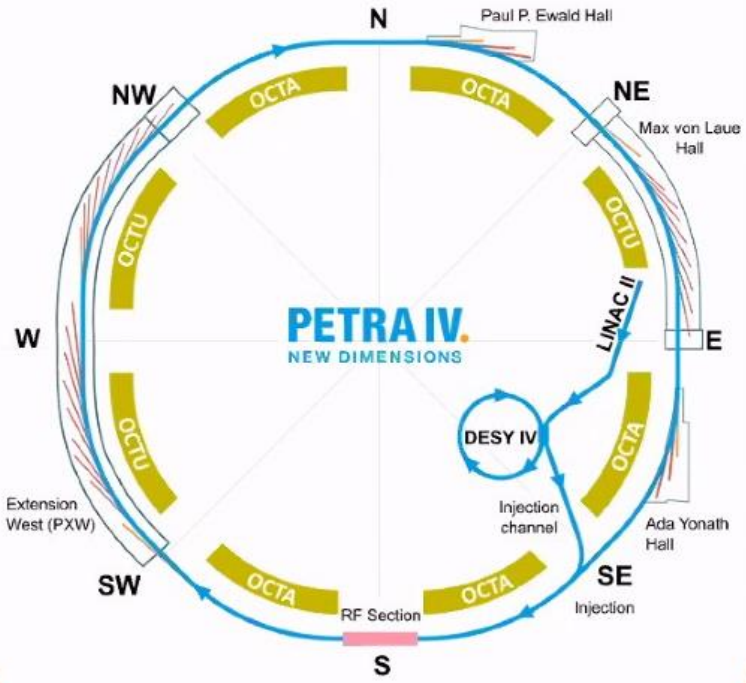


PETRA IV

PETRA III upgrade (construction phase 2029 – 2032)

Civil Construction and Infrastructure

Accelerator Complex



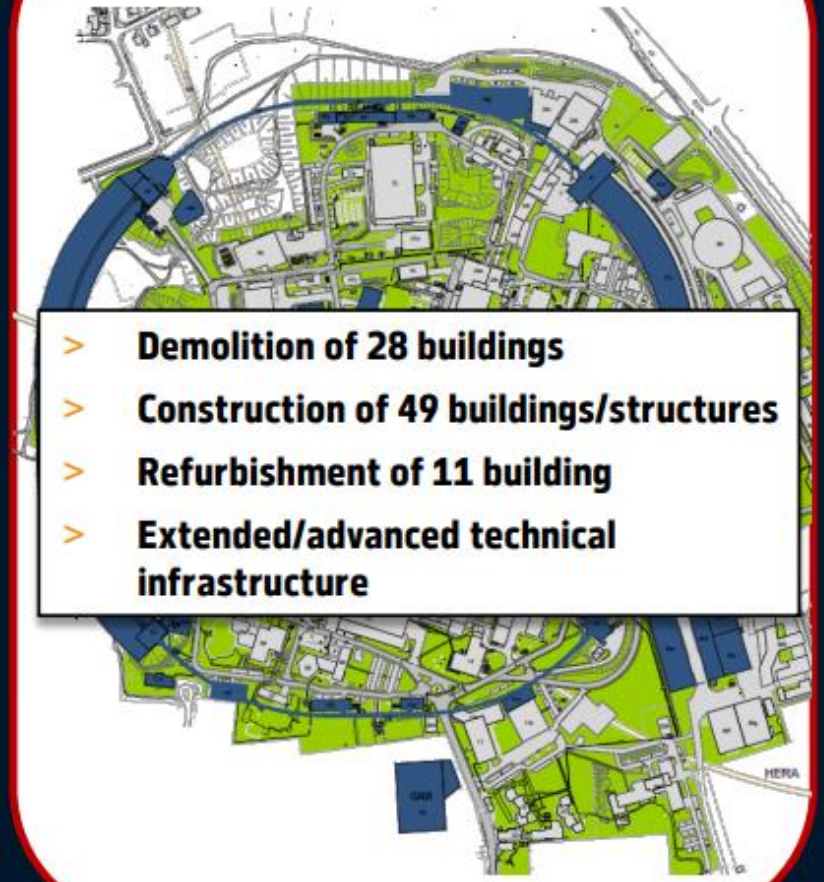
Experimental Facilities

Courtesy H. Reichert

PETRA IV

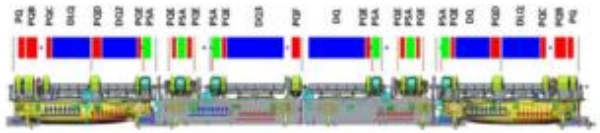
PETRA III upgrade (construction phase 2029 – 2032)

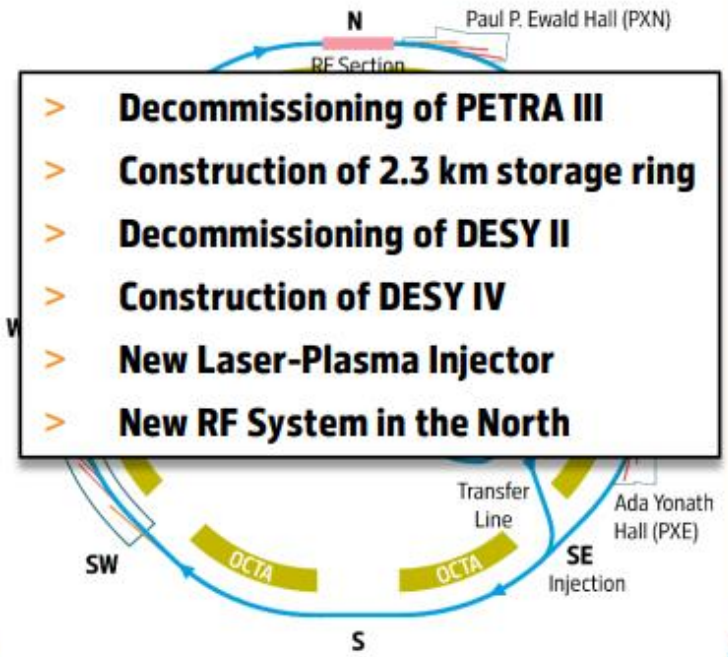
Civil Construction and Infrastructure



- Demolition of 28 buildings
- Construction of 49 buildings/structures
- Refurbishment of 11 building
- Extended/advanced technical infrastructure

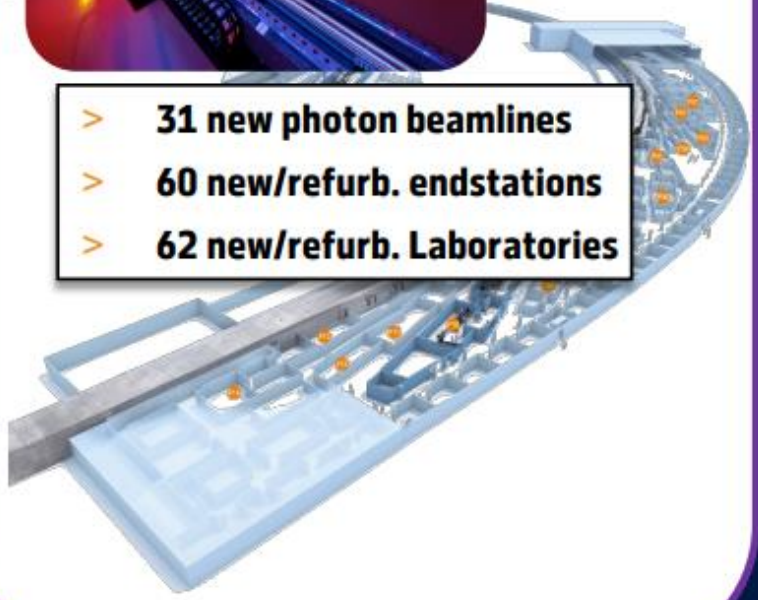
Accelerator Complex





- Decommissioning of PETRA III
- Construction of 2.3 km storage ring
- Decommissioning of DESY II
- Construction of DESY IV
- New Laser-Plasma Injector
- New RF System in the North

Experimental Facilities



- 31 new photon beamlines
- 60 new/refurb. endstations
- 62 new/refurb. Laboratories

Courtesy H. Reichert

PETRA IV

PETRA III upgrade (construction phase 2029 – 2032)

PETRA IV upgrade

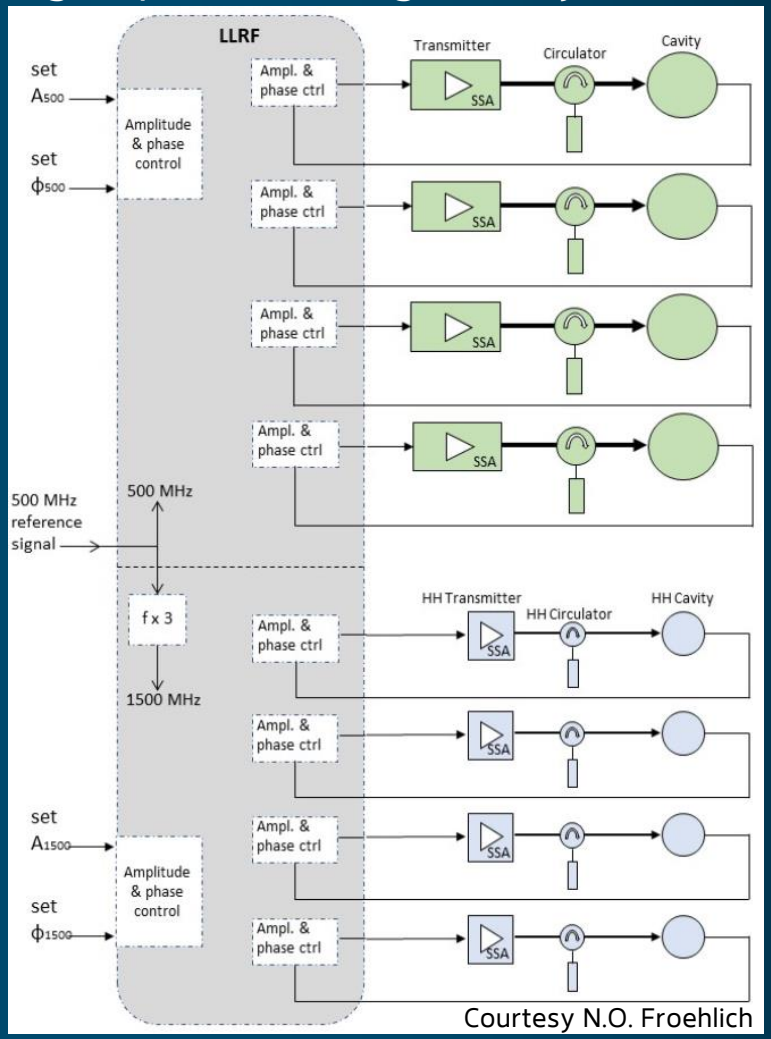
- Upgrade LLRF (MTCA.4-based)
  - **24 cavities** at 500 MHz each **80 kW SSA**
  - **24 cavities** at 1.5 GHz each **10 kW SSA**

Preparation

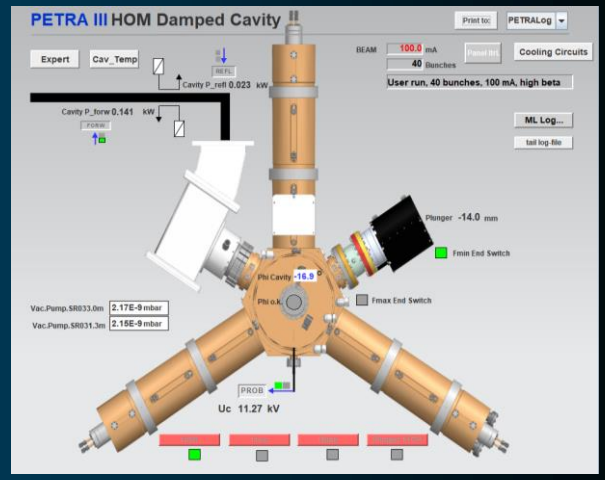
- **Test stand** **500 MHz HOM-damped cavity** installed and in operation at PETRA III with **demons--trator LLRF system**

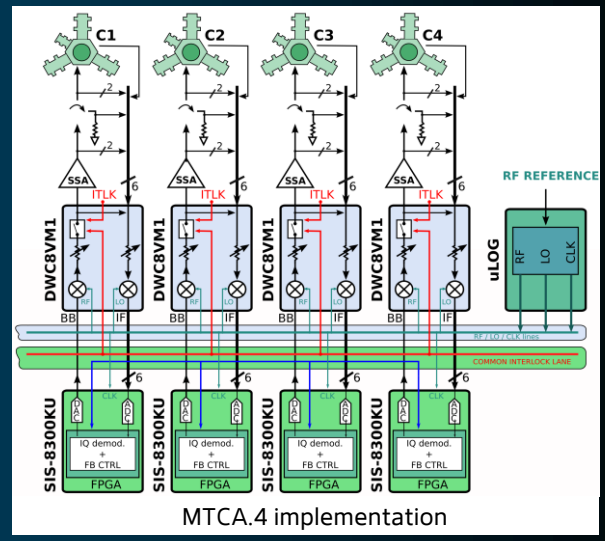
Hiring process

6 groups of 4+4 single cavity controls



Courtesy N.O. Froehlich





MTCA.4 implementation

R&D

Preparation for the EuXFEL CW upgrade

Scope include **CW** and **Long Pulse** operation,
referred to as **High Duty Cycle (HDC)**

- distributed gradients ranges and Qext
- worse case: Ecav = 18-20 MV/m, Qext = 6e7
- expected microphonics ~ 3 Hz (rms)

LLRF control

- preferred approach would be **1 SSPA / cavity**

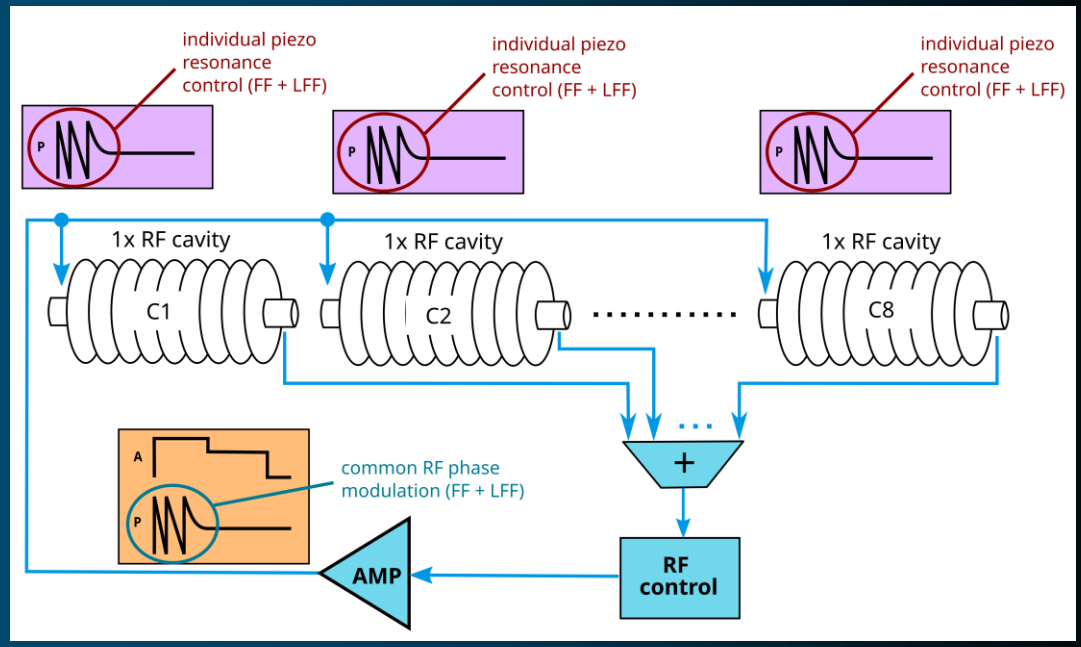
BUT

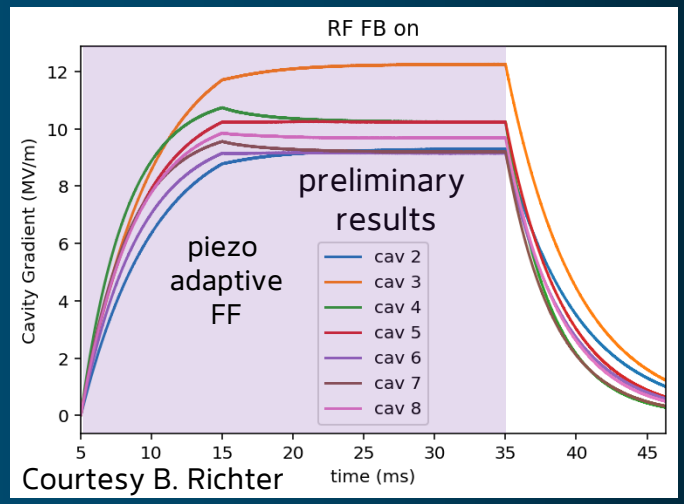
- we might have to settle for **vector sum control** (8-16 cavities)

➔ **Currently following both approaches**

- investigating **common-mode RF** and **individual piezo** control **(resonant filling)**

See Bozo Richter's poster Wed. afternoon
"Resonant filling for long pulse operation of EuXFEL using iterative-based FF"





GDR

Qext = 1.5 - 2.1e7
Pout = 1.7 - 2.2 kW
Ecav = 9 - 10.5 MV/m

Observer-based detuning computation

Piezo adaptive FF

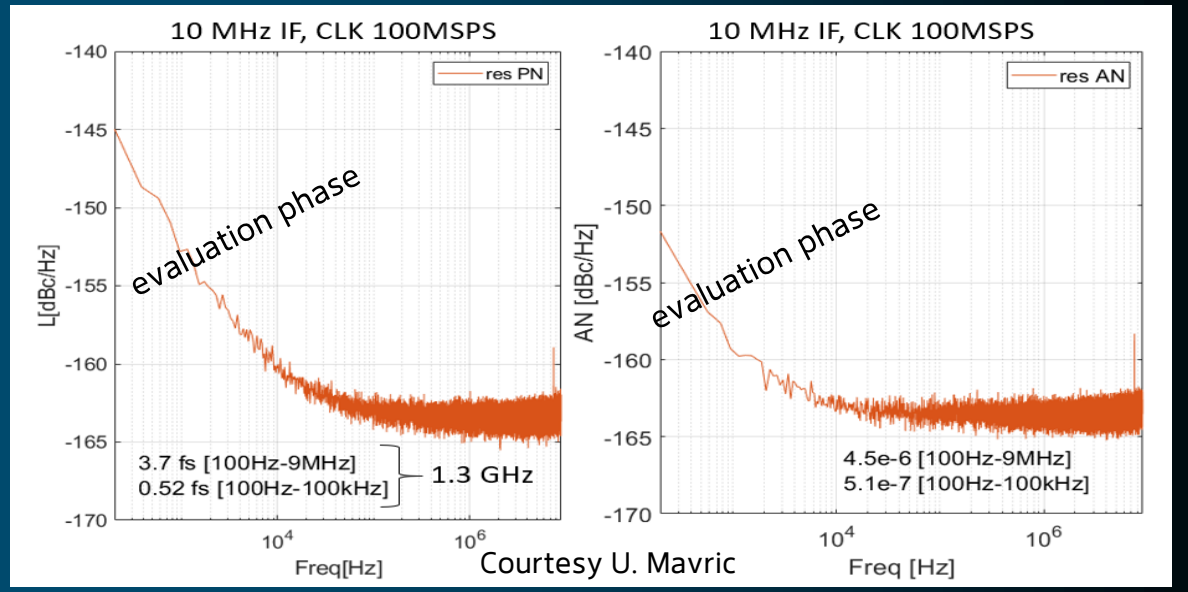
RF FB

R&D

New MTCA developments for LLRF

SIS8310 (Struck) → next generation, high-precision ADC

- Phase Noise: 0.52 fs [100 Hz – 100 kHz]
  Ampl. Noise: 5.1e-7 [100 Hz – 100 kHz]
- Prototyping phase
- Production planned for 2026



Courtesy U. Mavric

RFSoC

- 3rd gen. Zynq UltraScale+ (ZU47DR)
- 8x 14-bit ADCs at 5 GSPS
- 8x 14-bit DACs at 10 GBPS
- PCIe gen 4 (front and rear)
- First production batch Spring 2026

Applications

- Beam diagnostics and fast orbit feedback for PETRA IV
- LLRF for MYRRHA (accelerator-driven nuclear reactor in Belgium)

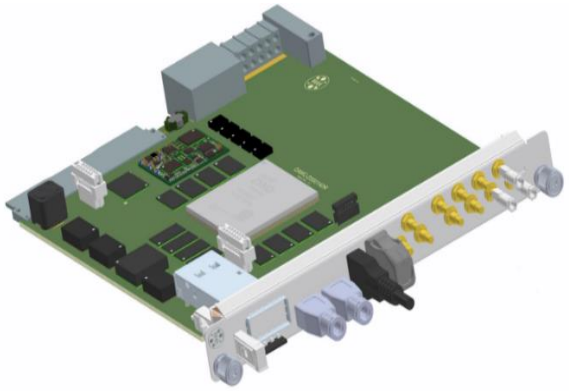

Courtesy B. Boghrati

image: https://www.sckcen.be/en

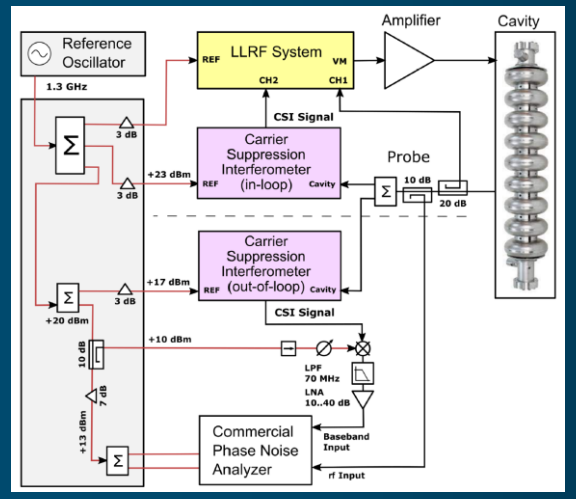
R&D

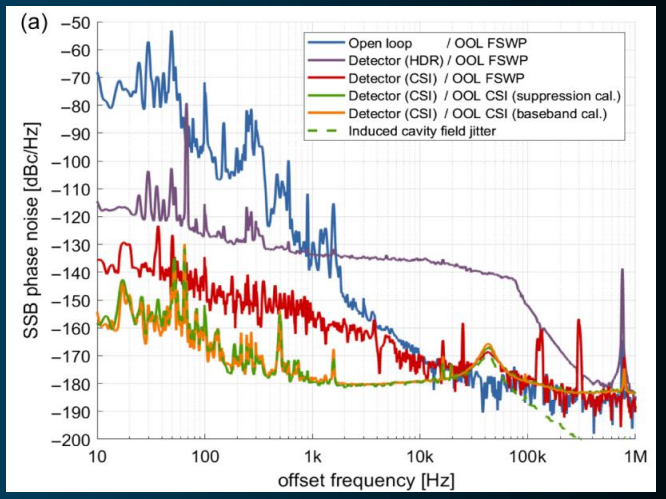
Integrate CSI (carrier suppression interferometer) to LLRF control

Carrier Suppression Interferometer

- Demonstrated in the lab
  60 dB noise floor improvement

L. Springer, *et al.* "Phase Noise Measurements for L-Band Applications at Attosecond Resolution" in *IEEE Transactions on Instrumentation and Measurement*, vol. 71, pp. 1-7, 2022, Art no. 8003307, doi: 10.1109/TIM.2022.3170975

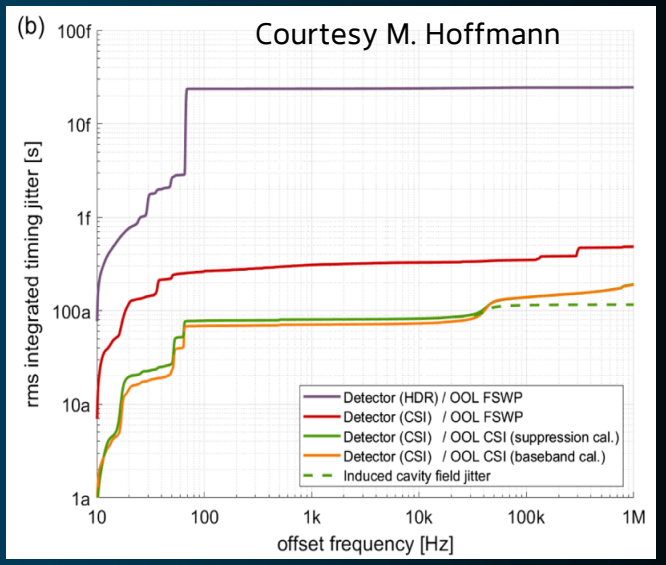




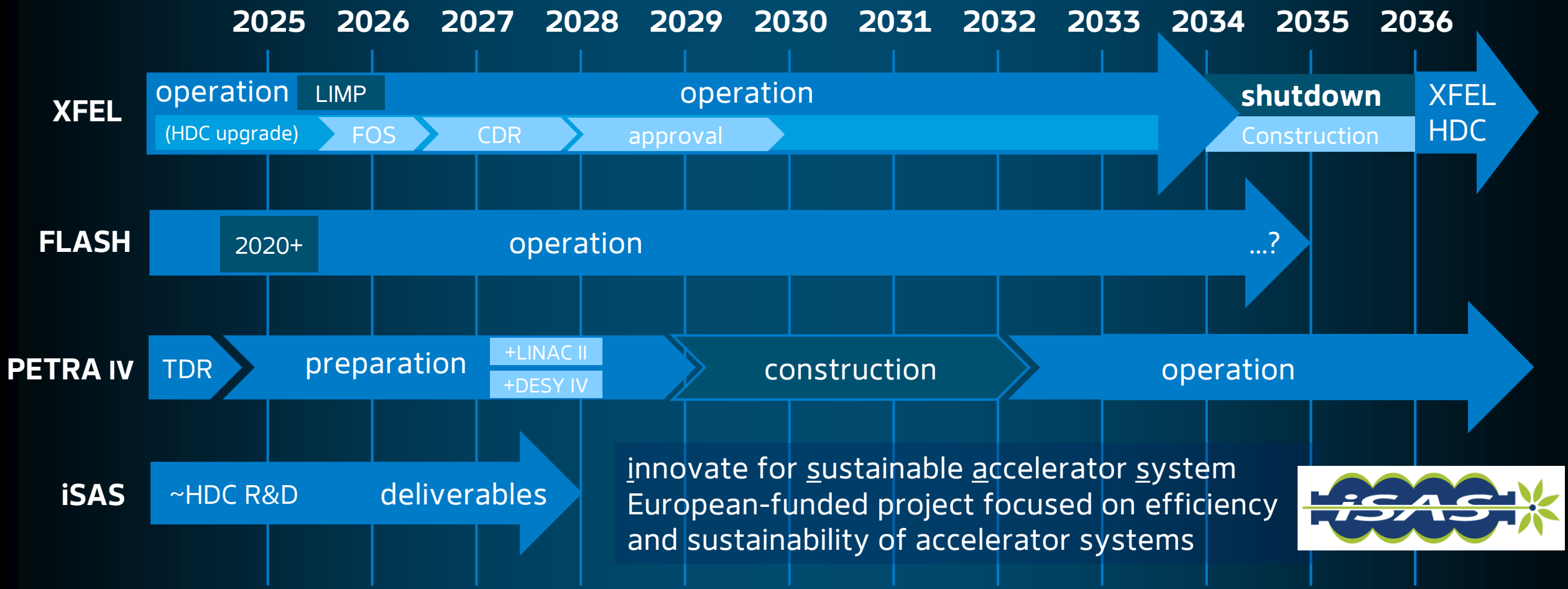
Used in the LLRF detection chain

- out-of-loop phase -160 to –180 dBc/Hz
- 100 as integrated jitter [10 Hz – 1 MHz]

F. Ludwig, et al. "RF controls based on carrier suppression detection with attosecond resolution", Phys. Rev. Accel. Beams 28, 072803 – Published 31 July, 2025



Summary : Projects Roadmap



innovate for sustainable accelerator system
European-funded project focused on efficiency and sustainability of accelerator systems

References

1.3 GHz master oscillator, developed by DESY / ISE, licensed to KVG GmbH
https://kvg-gmbh.de/product/main-oscillator/

J. Branlard *et al.* "RF-based energy savings at the FLASH and European XFEL linacs", in *Proc. LINAC'24*, Chicago, IL, USA, Aug. 2024, pp. 591-595. doi:10.18429/JACoW-LINAC2024-THZA003

L. Springer, *et al.* "Phase Noise Measurements for L-Band Applications at Attosecond Resolution" in *IEEE Transactions on Instrumentation and Measurement*, vol. 71, pp. 1-7, 2022, Art no. 8003307, doi: 10.1109/TIM.2022.3170975

F. Ludwig, *et al.* "RF controls based on carrier suppression detection with attosecond resolution", Phys. Rev. Accel. Beams **28**, 072803 – **Published 31 July, 2025**

THANK YOU FOR YOUR ATTENTION !

MSK : group outing Sept. 2025

Contact

DESY. Deutsches
Elektronen-Synchrotron

www.desy.de

Julien Branlard
MSK
julien.branlard@desy.de
+49 (0)40 8998 1599

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

European XFEL

DESY.