



## WP2: Low Level RF controls **16.12.2025**

DESY, HZB, CNRS

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**Task 2.1: Coordination of R&D on LLRF – *M1-M48***

2026 milestone M24

**Task 2.2: Efficient field control for high loaded-quality factor cavities – *M1-M48***

**Task 2.3: Vibration analysis and detuning control of cavities – *M1-M36***

2026 milestone M30

**Task 2.4: Integrated LLRF control using Ferro-Electric Fast Reactive Tuners– *M13-M48***

**Task 2.5: Energy efficient supervisory control and fault diagnosis– *M1-M48***

2026 milestone M33

### Task 2.1: Coordination of R&D on LLRF – M1-M48

- **Opened position** to support iSAS R&D activities
  - Candidate found, ~~starts in December 2025~~ **Counter-offer from industry...**
  - How the delay in hiring was mitigated → risk analysis WP2
- **Industrial Support**
  - Initial attempt with Cryoelectra didn't work
  - **Euclid Techlabs** is now the official industrial partner for WP2
- **Milestones in 2026**
  - 02 / 2026 Impact risk analysis WP2 (Task 2.1)
  - 08 / 2026 Energy efficient supervisory control and fault diagnostics (Task 2.5)
  - 09 / 2026 Vibration analysis and detuning control of SRF cavities (Task 2.3)

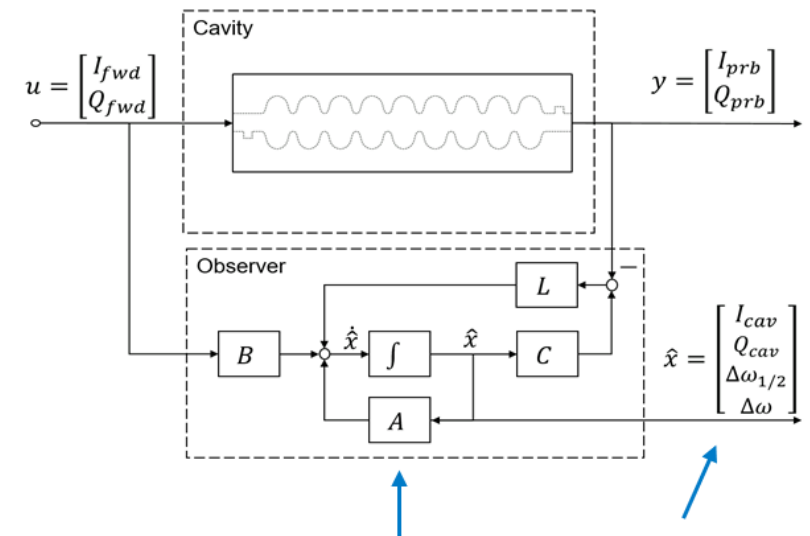
Timeline in project months (M)				M/D	#	Related WP	Related task	Description	Status	Risk level
Y1	M6	August	2024	D	35	WP2	2.1 Coordination of R&D on LLRF	ML implementation plan	Accounted for	On track
Y2	M24	February	2026	M	40	WP2	2.1 Coordination of R&D on LLRF	Impact risk analysis WP2	In progress	On track
Y3	M30	August	2026	M	6	WP2	2.5 Energy efficient supervisory control & fault diagnosis	Demonstration of energy-efficient SSA operation	In progress	On track
Y3	M33	November	2026	M	7	WP2	2.3 Vibration analysis & detuning control of cavities	Demonstration of detuning control techniques	In progress	On track

### ***Milestone M24 - Impact risk analysis WP2 (Task 2.1)***

- *Identified risks and mitigation strategies*
  - ***Hiring difficulties***
    - *Mitigation 1: offloading work on DESY personnel (i.e. no new hire)*
      - *Clearly should only be a temporary solution*
    - *Mitigation 2: (plan B) consulting from retirees (expertise extremely valuable)*
  - ***Availability of FE-FRT for integration to LLRF***
    - *Mitigation 1: simulation work*
    - *Mitigation 2: new approaches for detuning control can be implemented with piezo*
  - ***Working with industry on efficient control of SSPA***
    - *Mitigation 1: acquired our own amplifier to demonstrate proof of principle*
    - *Mitigation 2: plan to launch an in-kind contract with vendor sponsored by EuXFEL*

## Milestone M30 – Energy efficient supervisory control and fault diagnostics (Task 2.5)

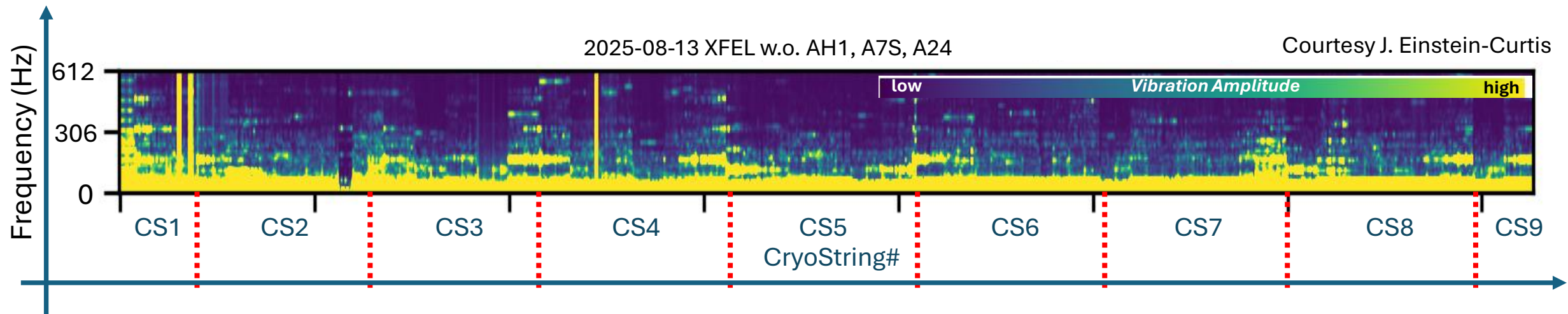
- Develop fault diagnosis and anomaly detection of LLRF systems using ML approaches
  - Luenberger Observer to estimate cavity bandwidth and detuning
  - Publication in arXiv, pending approval in in Physical Review special topic Accelerator and Beam
  - iSAS mentioned in acknowledgement
- Development of anomaly detection in FW based on ML
  - Publication at IPAC 2025
    - <https://doi.org/10.18429/jacow-ipac25-thps134>
- Calibration influence of environmental based on ML
  - Publication at IPAC 2025
    - <https://doi.org/10.18429/jacow-ipac25-thps135>



Luenberger observer estimates cavity **bandwidth** and **detuning**

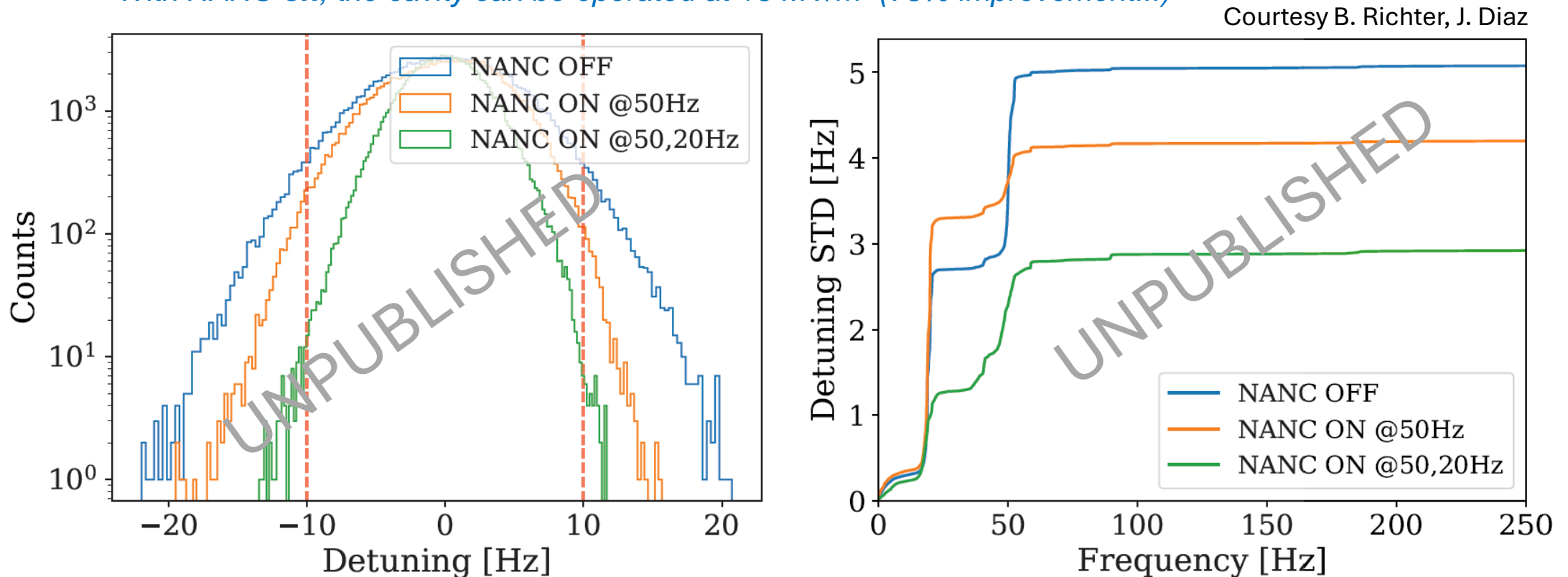
## Milestone M33 – Vibration analysis and detuning control of cavities (Task 2.3)

- Characterize environmental disturbances. **DONE + more to come**
  - Vibration measurement at XFEL (CMTB and AMTF)



## Milestone M33 – Vibration analysis and detuning control of cavities (Task 2.3)

- Microphonics suppression to allow high gradient operation
  - Development of Narrow bandwidth Active Noise Cancellation (NANC) algorithm and demonstration at SLAC (LCLS-II)
  - With NANC **off**, the cavity could operate at max 9 MV/m
  - With NANC **on**, the cavity can be operated at 16 MV/m (78% improvement!!!)



## WP2 – LLRF: plans to achieve milestones & deliverables

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Y2	M24	February	2026	M	40	WP2	2.1 Coordination of R&D on LLRF	Impact risk analysis WP2	In progress	On track
Y3	M30	August	2026	M	6	WP2	2.5 Energy efficient supervisory control & fault diagnosis	Demonstration of energy-efficient SSA operation	In progress	On track
Y3	M33	November	2026	M	7	WP2	2.3 Vibration analysis & detuning control of cavities	Demonstration of detuning control techniques	In progress	On track
Y3	M36	February	2027	M	8	WP2	2.2 Efficient field control for high loaded-quality factor cavities	Demonstration of RF control for CW/LP ops	In progress	On track
Y3	M36	February	2027	D	5	WP2	2.3 Vibration analysis & detuning control of cavities	Report on microphonics study & ML-based mitigation	In progress	On track
Y3	M36	February	2027	D	6	WP2	2.5 Energy efficient supervisory control & fault diagnosis	Report on interface study of LLRF with SSA	Not started	On track
Y4	M42	August	2027	M	9	WP2	2.5 Energy efficient supervisory control & fault diagnosis	Demonstration of ML and anomaly detection	In progress	On track
Y4	M45	November	2027	M	10	WP2	2.4 Integrated LLRF control using ferro-electric fast reactive tuners	Demonstration of FE-FRT microphonics compensation	In progress	On track
Y4	M46	December	2027	D	7	WP2	2.2 Efficient field control for high loaded-quality factor cavities	Report on LLRF RF control studies	Not started	On track
Y4	M47	January	2028	D	9	WP2	2.5 Energy efficient supervisory control & fault diagnosis	Report on anomaly detection & LLRF optimization	Not started	On track
Y4	M48	February	2028	D	8	WP2	2.4 Integrated LLRF control using ferro-electric fast reactive tuners	Report on integration of FE-FRT in LLRF	Not started	On track

→ 2026 Deliverables and Milestones are well on track