Anomaly detection

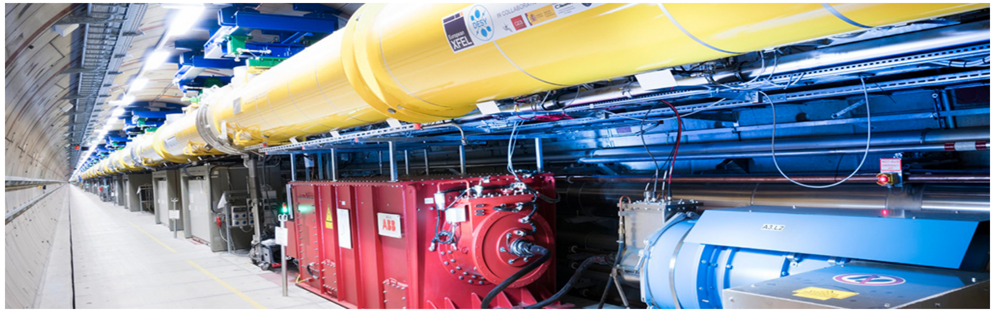
At DESY

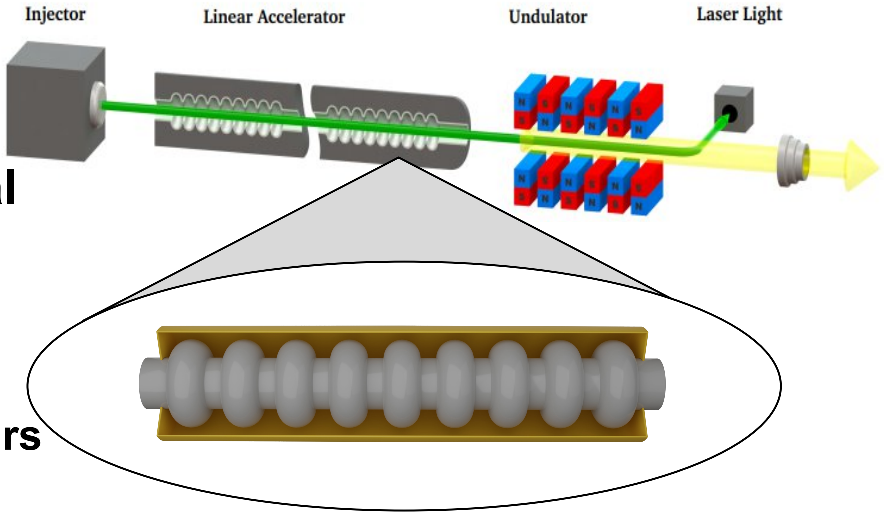
Annika Eichler with Lynda Boukela

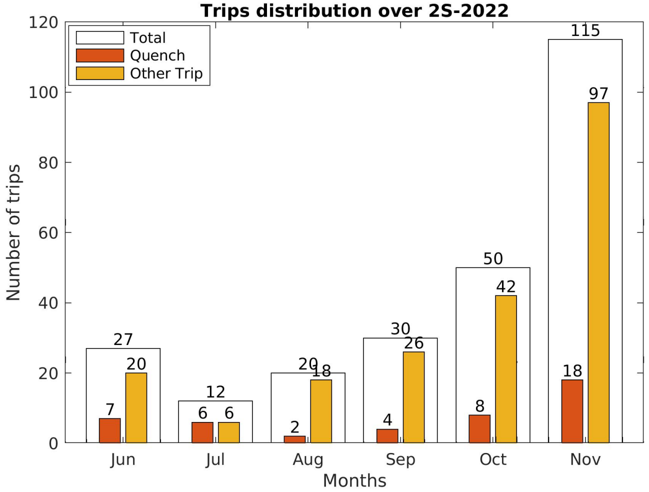
The European X-ray Free Electron Laser (XFEL)

Quench detection: facts

- The EuXFEL is the largest accelerator for X-ray free electron laser generation in the world
  - Electron acceleration to high energies of up to **17.5 GeV**
  - **Several hundred** users benefit from extremely **intense laser** every year
  - The Linac uses **800** of 1.3 GHz superconducting cavities







- **Safe** and optimal operation is **crucial**
  - Faulty events diagnosis
  - **Quenches** are a priority
    - Significant **down-time (11 hours in 2022)**
    - Facility degradation
    - Energy and financial losses

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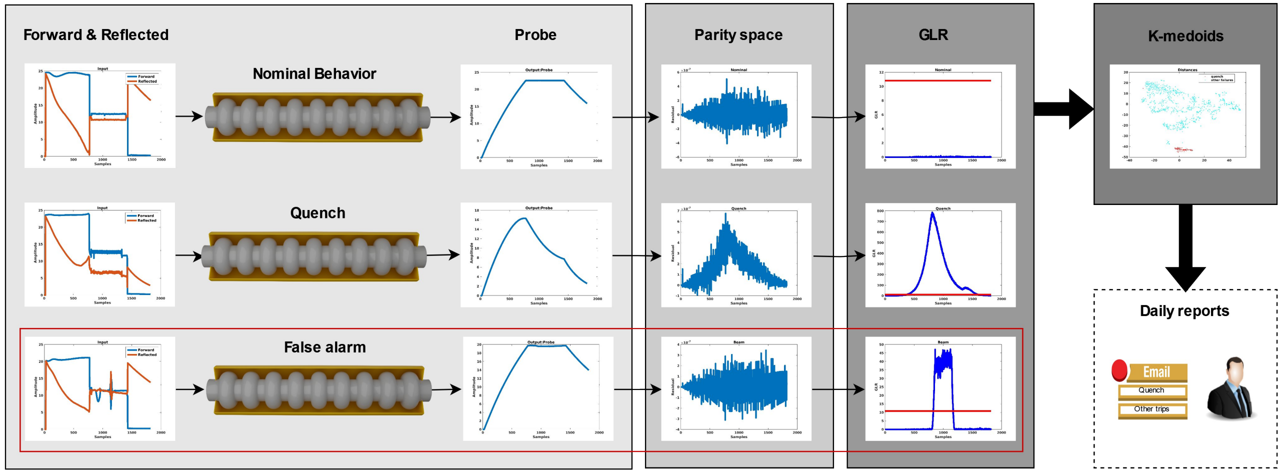
Quench detection: ML-powered approach

- Currently, diagnosis through the **QDS**
  - **QL-based**, thresholding over the average of previous 100 pulses.
  - **Robustness** issue
- New AI-powered diagnosis
  - Residuals from the model
  - Statistical test for evaluation
  - Clustering (preprocessing, two similarity measures).



Electromagnetic dynamics

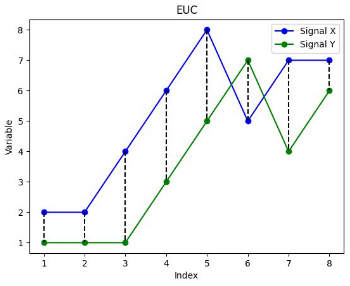
$$\begin{bmatrix} \dot{V}_{P,I}(t) \\ \dot{V}_{P,Q}(t) \end{bmatrix} = \begin{bmatrix} -\omega_{1/2} & -\Delta\omega(t) \\ \Delta\omega(t) & -\omega_{1/2} \end{bmatrix} \begin{bmatrix} V_{P,I}(t) \\ V_{P,Q}(t) \end{bmatrix} + 2\omega_{1/2} \begin{bmatrix} V_{F,I}(t) \\ V_{F,Q}(t) \end{bmatrix} - \omega_{1/2} \begin{bmatrix} V_{B,I}(t) \\ V_{B,Q}(t) \end{bmatrix}$$

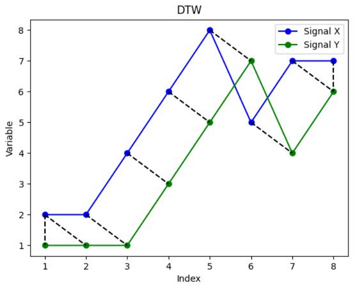
Mechanical detuning

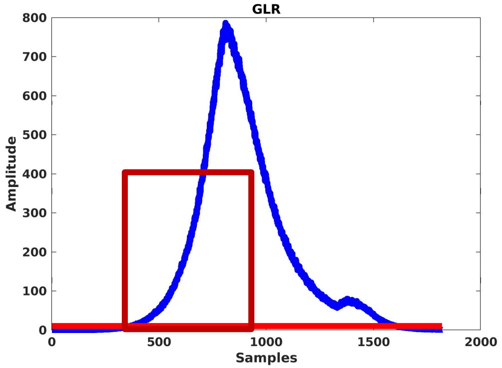
$$\Delta\dot{\omega}_n(t) = -\frac{1}{\tau_n}\Delta\omega_n(t) + K_n\left[V_{P,I}^2(t) + V_{P,Q}^2(t)\right]$$

$$n = 1, \ldots, N$$

$$\Delta\omega(t) = \sum_{n=1}^{N} \Delta\omega_n(t).$$







Residuals

$$r(t) = \frac{-\dot{V}_{P,I}(t) + \omega_{1/2}\left[-V_{P,I}(t) + 2V_{F,I}(t) - V_{B,I}(t)\right]}{V_{P,Q}(t)} - \frac{\dot{V}_{P,Q}(t) + \omega_{1/2}\left[V_{P,Q}(t) - 2V_{F,Q}(t) + V_{B,Q}(t)\right]}{V_{P,I}(t)}$$

Generalized likelihood ratio

$$\lambda_{\mathrm{GLR}}(k) = \frac{K}{2}\left(\frac{1}{K}\sum_{i=k-K+1}^{k} r(i)^{\top}\right)\Sigma^{-1}\left(\frac{1}{K}\sum_{i=k-K+1}^{k} r(i)\right)$$

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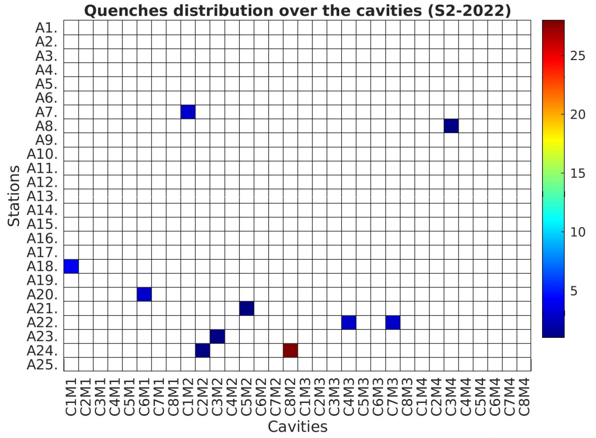
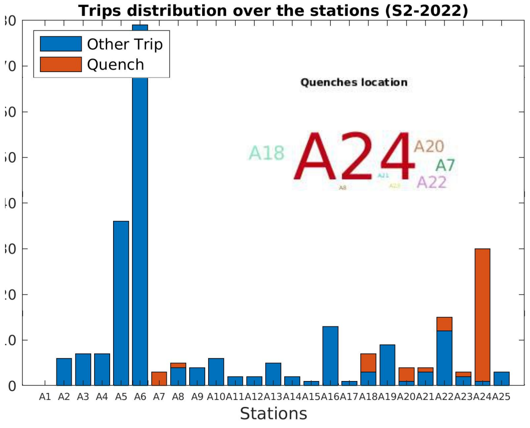
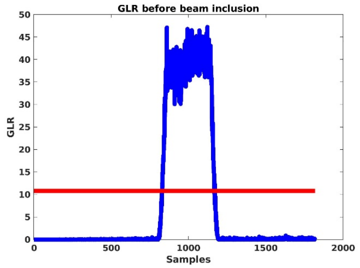
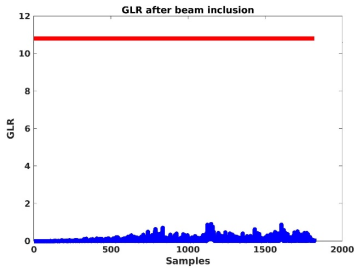
Quench detection: Performance

- Experimental evaluation
- Data from the second half of **2022** are analyzed
- The **ML** approach **outperforms** the current system
- Potential implementation on FPGA



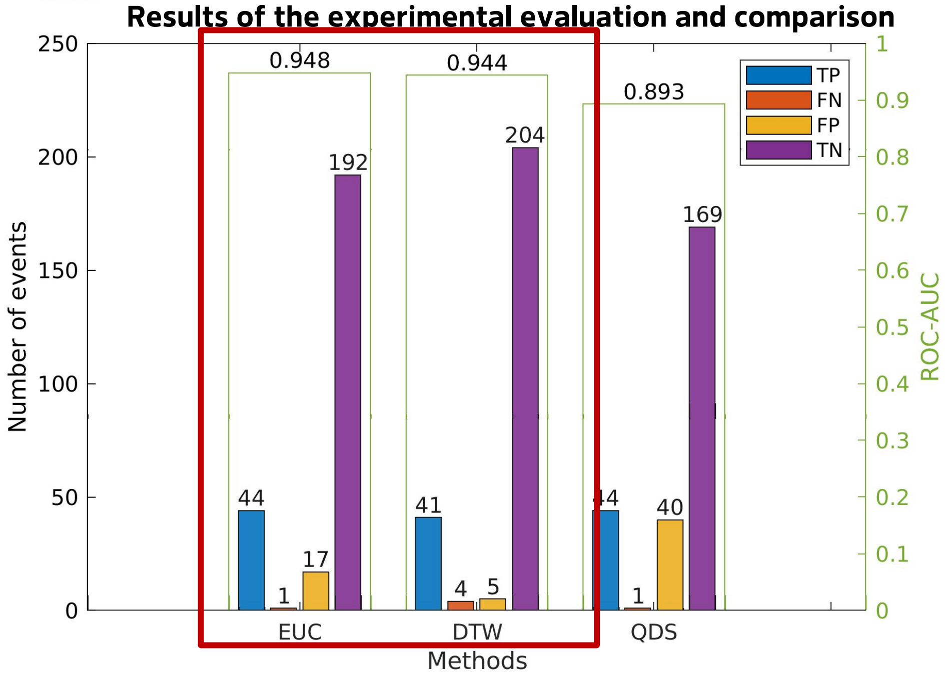






Challenges:

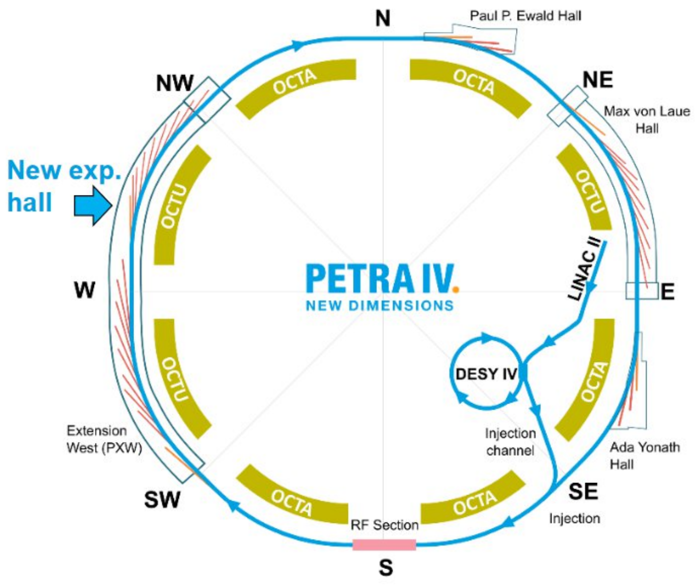
- Beam information inclusion
- Long term diagnosis
- Constrained real-time DAQ
- Further distinction and understanding



PETRA IV

BPM Faults

- Detection of faulty measurements.
- Detect before the next turn
- Status: at the very beginning
- Hardware: FPGA implementation.



Courtesy: H. Schlarb

In summary

We want

Applications

Needs (limitations of current methods, what is not working as desired) of the application>>**Efficient and Robust quench detection, At-Edge detection of faulty BPM measurements, Machine safety, operation optimization, reduce false alarms**

Methods (to be tested and or that has been tested)>>**Model based residuals+ classification based on a KNN model tested offline, ANN for BPM**

Challenge/difficulties (what are the risks?) >> **Bandwidth limitations, fast and computationally-cheap solution (ideally FPGA), explainability, robustness (work for different operating points/energies)**

Implementation (online/offline, what frequency,...) >> **Online (9MHz), FPGA, prototype(BPM)**

Measures (how could you measure the success of the project)>>**Downtime caused by fake quenches (Eq to time energy and money)**

General aspects:

What you want to get out (your goals) >> **standard solutions (portable, reusable, modular (flexible))**

How could you envision to work together >> **collaborations via co-supervision, visits, hackathons, articles**

Thank you