Ideas and Plans for DESY – Model-based Diagnosis & Control for Accelerators.

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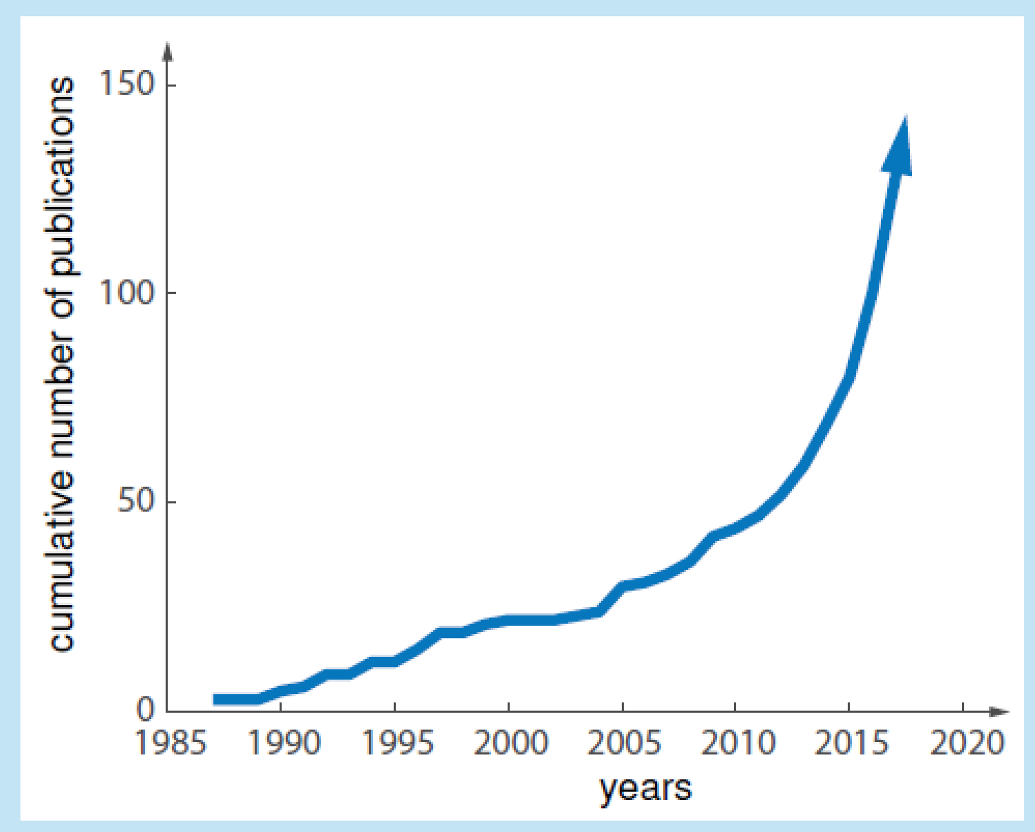
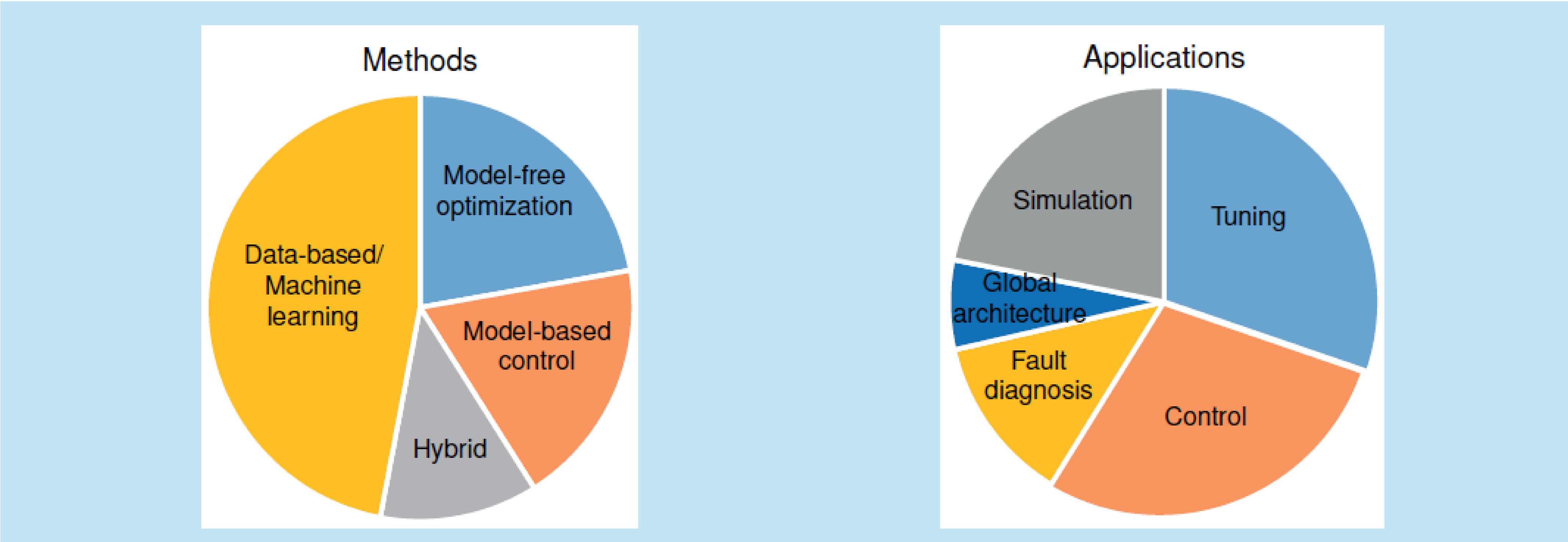
What is done worldwide?
Literature review in (“data-driven” v “advanced control”) ∧ “accelerators”



Literature review
The analysis of the literature review in the field of AI, machine learning and advanced control methods for the application of particle accelerators is shown. The literature review presented here does not claim to be exhaustive but shows an obvious trend of the exponential increase of interest in the field. [Status: October 2018]



Data-based / Machine learning
Neural Networks, generic adversarial networks, Bayesian optimization, support vector machines, SVD, independent component analysis, kernel density estimation

Model-free optimization
Gradient descent, extremum seeking, particle swarm algorithms, genetic algorithms, robust conjugate direction search

Model-based control
Supervisory control, adaptive control, robust control (IQCs), iterative learning control, distributed control, internal model control, model predictive control

Hybrid approaches
Support vector machines and first principles, parity equations and clustering, hybrid neural networks, neural networks and expert systems, regression and SVD, independent component analysis and regression

Simulation
OCELOT, beam dynamics

Tuning
FEL quality, SASE tuning, beam dynamics, mode switching, phase shift if RF system, magnet settings, magnet correction, magnet optimization

Control
Orbit control, RF control with amplitudes and phases, low level RF control, iterative feedforward low level RF control, resonance control, fast and slow bam feedback control, temperature control of RF gun, water system control

Fault diagnosis
Predictive maintenance, anomaly detection, quench detection, reliability and availability, fault detection (for beam lifetime, beam diagnosis, beam loss),

What has been done at DESY?

Simulation
> OCELOT: A software framework for synchroton light sources and FEL studies [Agapov, Geloni, Tomin, Zagorodnov]

Tuning
> Tuning of the photon pulse energy and beam loss by heuristic model free optimization techniques (Simplex method) [Agapov, Geloni, Tomin, Zagorodnov]

Control
> Feedforward (model-based) iterative learning control for disturbance rejection of the RF system [Schmidt]
> Optimal and robust MIMO controller design for the low level RF system (by H-infinity control) exploiting physical understanding (symmetries of the RF system) [Pfeiffer]

Fault diagnosis
> Hybrid anomaly detection of quenches in the RF system based on a model-based nonlinear parity space approach followed by a classification step using support vector machines [Nawaz]
> Factor graph approach to stochastic model-based fault diagnosis: residual generation by a Kalman filter, residual classification by a Gausian mixture model [Nawaz]

Goal: build on existing knowledge at DESY especially in the field of fault diagnosis

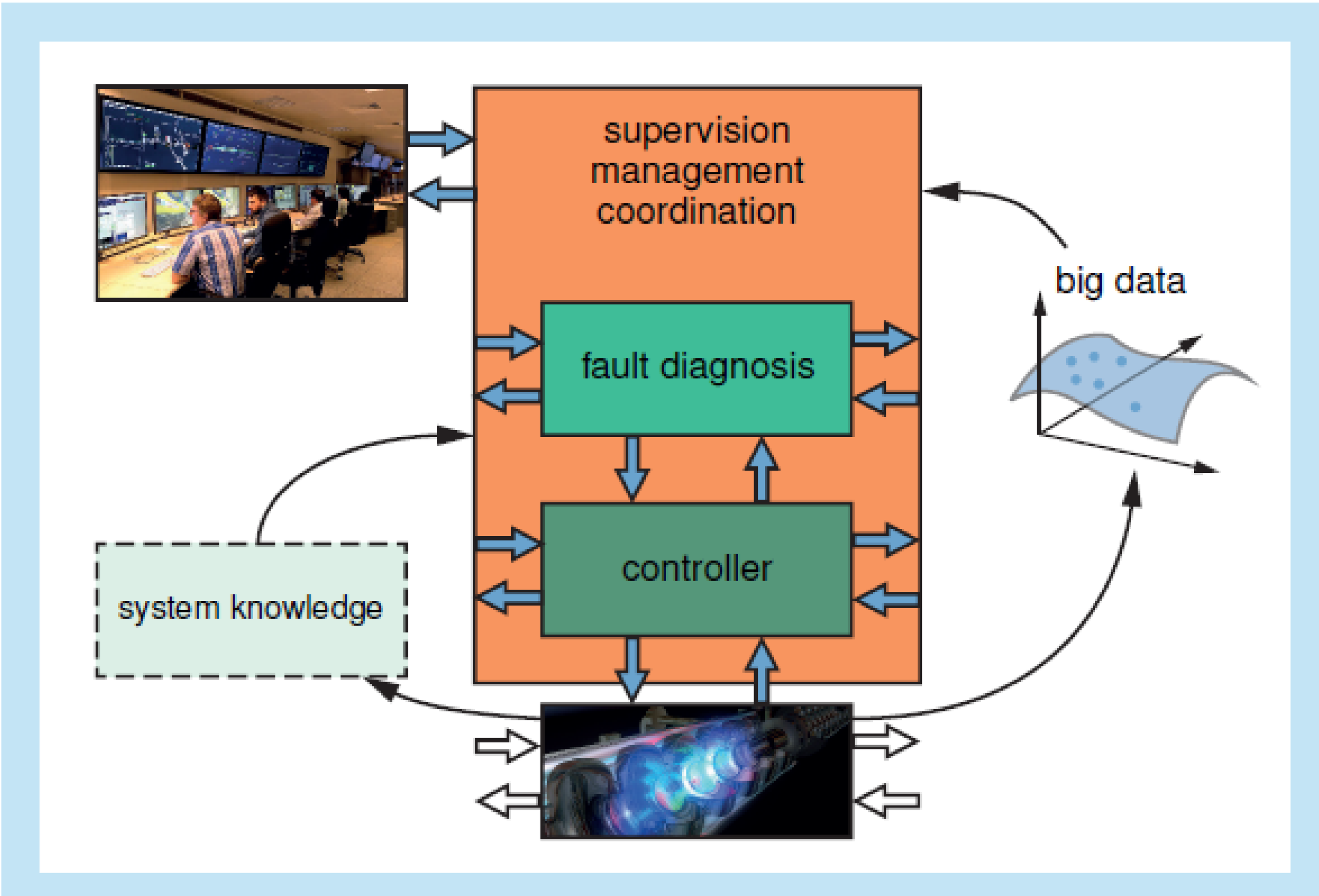
Goals and plans at DESY: Improve reliability, availability and performance of the accelerators at DESY (European XFEL, FLASH, PETRA III)

How to approach these goals:
> Optimal integration of physical knowledge and data-information for control and diagnosis.
> Distributed control and diagnosis approaches for the complex networked accelerator systems.
> Combined synthesis approach for the integration of control and diagnosis into the supervisory level of process automation.

Since the 70’s the degree of automation was pushed forward drastically due to cheap and reliable microcomputers, progress in the areas of sensors, actuators, bus-communication systems, and human-machine interfaces. With this, the human operator has been removed from the lower-level control. At the same time, processes have become more and more complex, i.e., they are composed of connected sub-processes, where control actions on one sub-process strongly affects the neighbors.

This increased complexity makes manual process control and supervision hardly possible, which results in a strong need for automation and a capable supervisory control structure. The current standard in process automation consists of a lower-level tier with a controller and a fault diagnosis block, overseen by supervisory control for optimizing performance, availability and reliability.

To exploit the system optimally, the control and diagnosis block need to be integrated into the supervisory level and designed in a combined way. Here the improvements in embedded and distributed computation enable advanced and distributed control and diagnosis concepts. Furthermore all available information, physical knowledge and data information, should be optimally exploited.



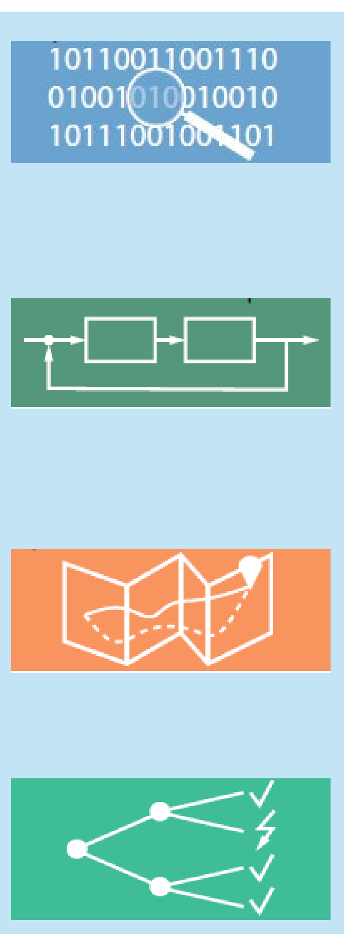
Methods to apply

Data Mining
> Analyze the current status of the accelerators with respect to availability and reliability
> Identify the most critical components
> Analyze capabilities of DAQ system (possibilities for longterm and online analysis), what extensions are needed?

Control
> Model-based, robust, adaptive learning-based controller design
> Optimal (optimization based) controller design
> Distributed esign approaches
> Implementation satisfying real-time requirements

Fault diagnosis
> Hybrid approaches combining model-based ones (observers, filters, parity space) and data-based ones (classification algorithms)
> Statistical analysis of lower level components which are very often used

Supervisory control
> Controller reconfiguration exploiting redundancies by distributed approaches
> Hybrid optimization tools
> Predictive maintenance



Possible specific parts and components to start with

Distributed control of the RF for fault-tolerance
Fault-tolerance control with controller reconfiguration can be realized based on a quench detection. If a quench has been detected the supervision layer has to immediately lower the field gradient in the respective cavity to prevent a failure. In order to maintain the beam quality, a distributed RF cavity control approach can be used as a fault-tolerant controller.

Data-based control feed-forward control of klystrons
Disturbances of the klystron high voltage change the gain and phase. Either the disturbance pattern can be learned from past-data and online disturbance rejection based on classification can be applied, or observer-based approaches with adaptive feed-forward cancellation. Combining both, e.g., by initializing the observer with the help of the data-based results, is to be studied.

Fault diagnosis of the RF system of PETRA III
Currently beam dumping is triggered when local, experience-based thresholds are exceeded. Using intelligent learning methods, the broadband frequency spectrum (0.5-1.5 GHz) exited by the beam could be analyzed for reliable fault diagnosis and might allow to take appropriate counteractions to let the stored beam circulate further. This requires monitoring large data sets (time/frequency/several locations) and the analysis of appropriate higher-order models.

Predictive maintenance on electronic board level (MicroTCA)
Statistical analysis for fault diagnosis of lower level components (electronic modules, power supplies and fans) is planned to be implemented on the MicroTCA modules to identify at an early stage potential electronics faults or future malfunctions for predictive maintenance. The XFEL provides an ideal test bench, since here several hundred boards of the same type are being used in a well-controlled environment.

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