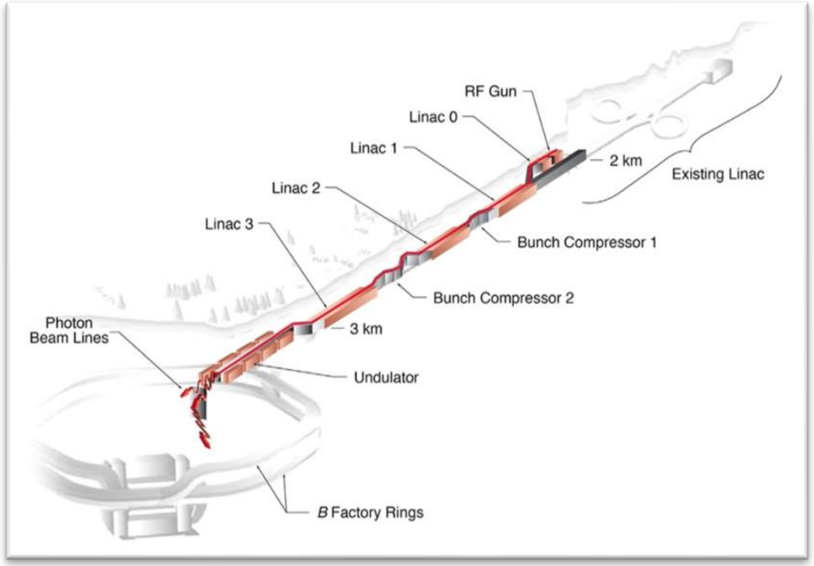
# Decentralized Control Approach for the Optical Synchronization System at the European XFEL

## In Favour of the Global Perspective

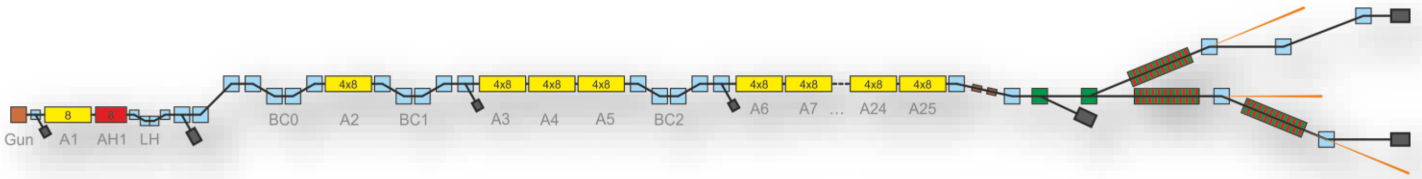
Maximilian Schütte, Annika Eichler, Jost Müller, Sebastian Schulz, Thorsten Lamb, Matthias Felber, Anne-Laure Calendron, Falco Zummack, Nick Kschuev, Tomasz Kozak, Holger Schlarb
DESY - MSK - LbSync
Hamburg, 30.09.2021

# Accelerators as Distributed Systems

## Motivation



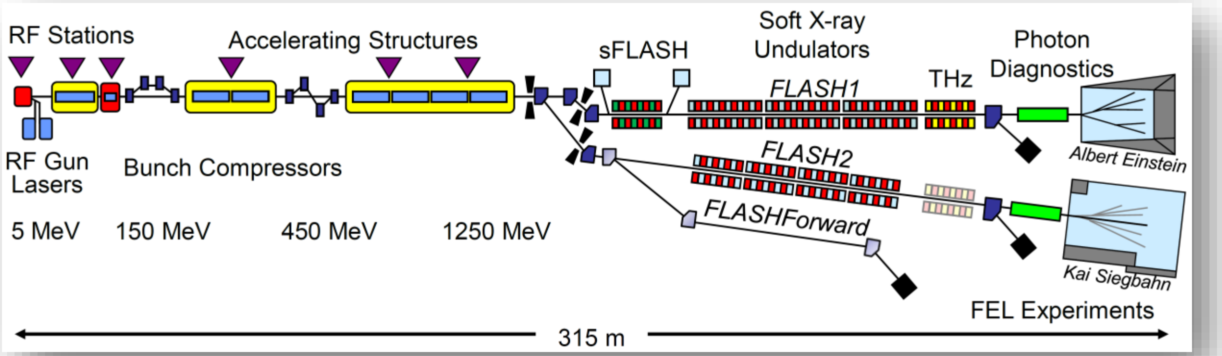

Source: SLAC national accelerator center.




Source: European XFEL GmbH / Deutsches Elektronen Synchrotron DESY

**What can we gain by optimizing over the full distributed subsystem structure?**

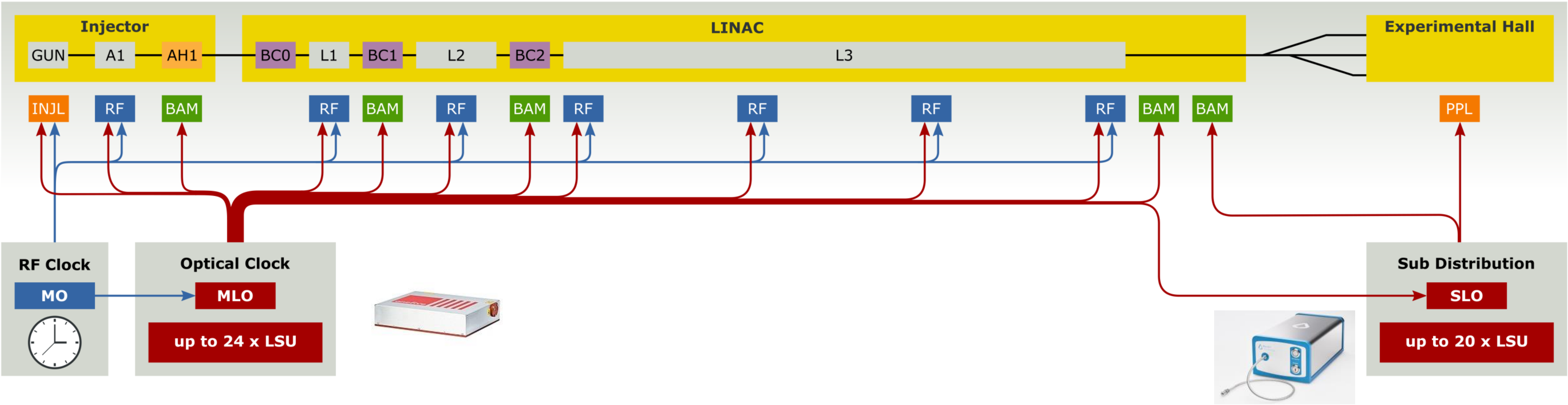
- Accelerators are mainly comprised of cooperative **repeated subsystems** (cavity controls, timing, magnets, …).
- Performance is achieved by tuning feedforward and feedback parameters (gains).
- Interconnection is often only taken into consideration during heuristic tuning.




Source: Deutsches Elektronen Synchrotron DESY

# Optical Synchronization at the European XFEL

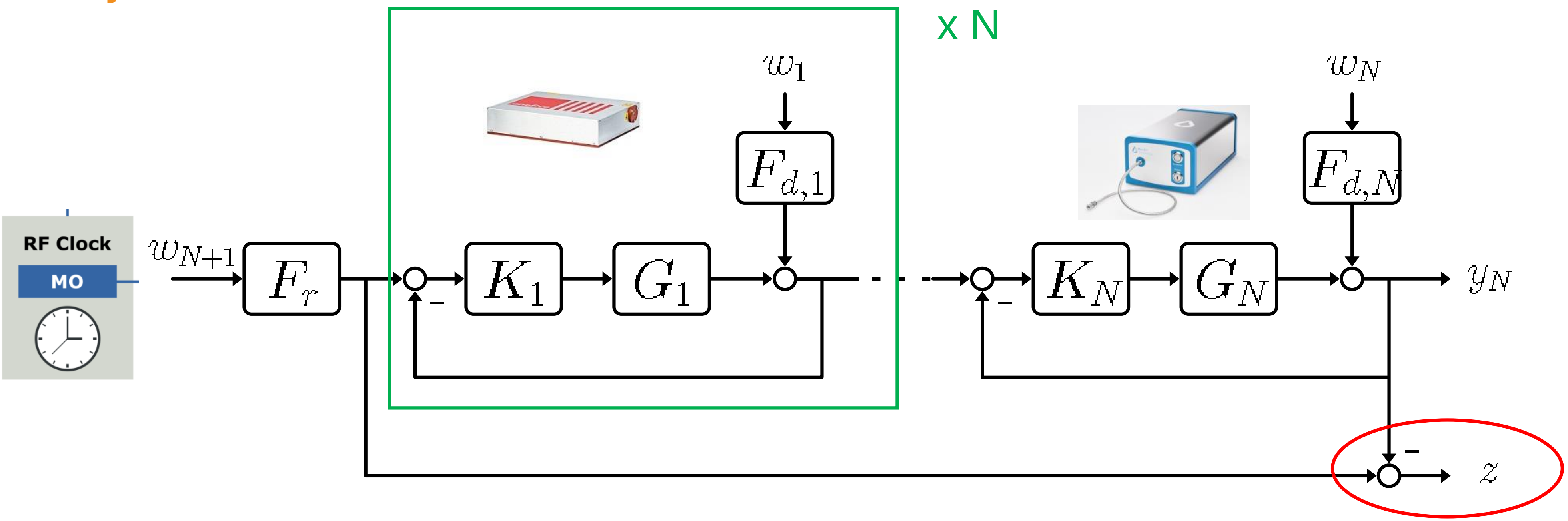
## Treelike Interconnection Topology




- Main Oscillator (MO) timing is distributed optically to end-stations in injector, LINAC and experimental hall (e.g. pump-probe lasers).
- Integrated jitter MO – PPL < 10 fs.
- Tree like interconnection structure with great spatial distance between stations.
- Each node described by Phase-locked-loop (PLL) theory.
- Dozens of decision variables (feedback gains).

# Numerical Optimization Model

## Chained System




- Repeated a typical PLL model as found in the synchronization system $N$ times.
- Optimized feedback gains $K_i$ for minimized RMS error between last station and reference ( $z$ ).

# Numerical Optimization Results

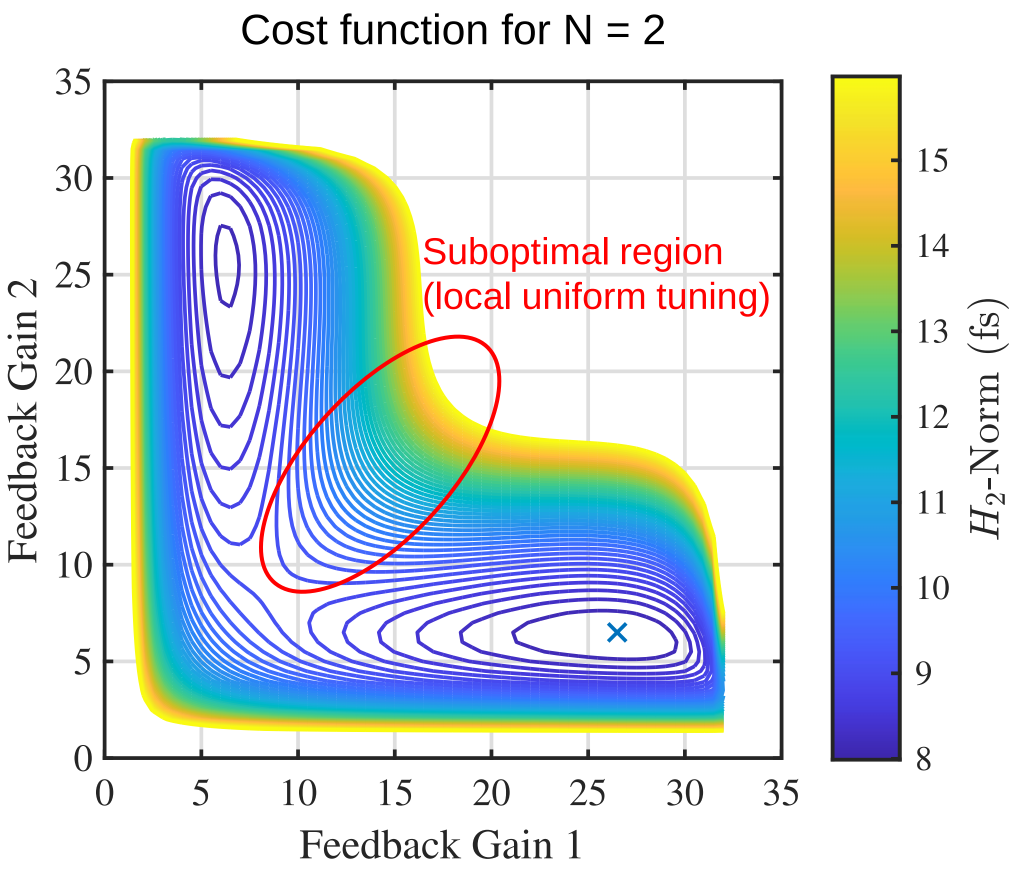
## Relative to Local Baseline

TABLE I

STATIC OUTPUT FEEDBACK PERFORMANCE VS. UNIFORMLY TUNED BASELINE ($H_2$-NORM IN FEMTOSECONDS)

| $N$ | Optimal | Baseline | SI | Rel. Improvement |
|---|---|---|---|---|
| 2 | 7.99 | 9.90 | 8.59 | 12.41 % |
| 3 | 10.28 | 16.46 | 10.97 | 33.35 % |
| 4 | 12.27 | 29.39 | 15.55 | 47.10 % |
| 5 | ? | 56.09 | 20.30 | 63.81 % |
| 6 | ? | 111.51 | 25.03 | 77.55 % |

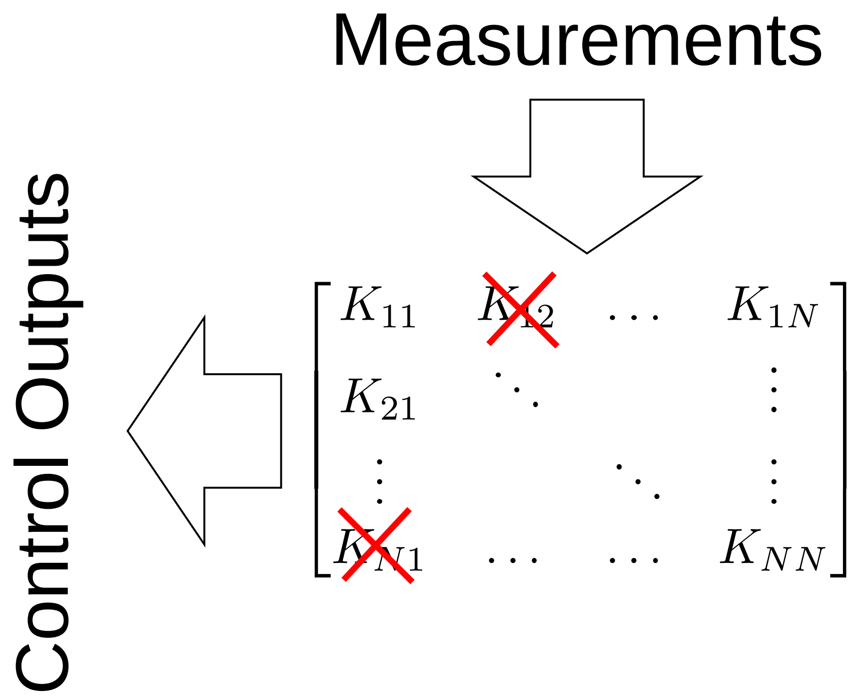
- Investigating proportional feedback gain at each of N stations.
- The more systems are involved, the better the distributed approach performs.
- Distributed approach performs overall close to the global optimum.
- Uniform local tuning is clearly suboptimal (main diagonal).
- Better to relax one system and aggressively tune the other.

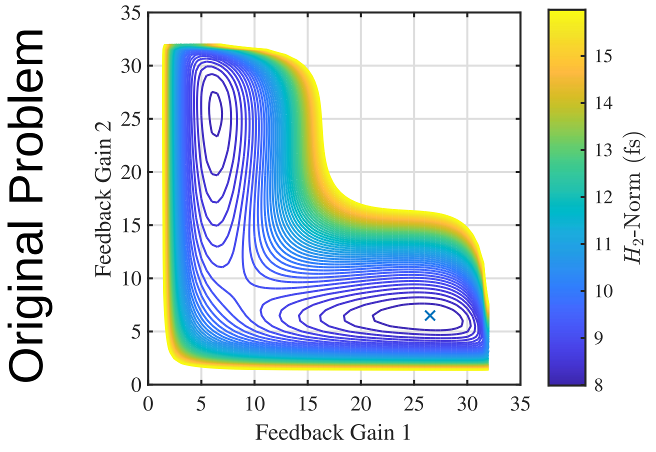


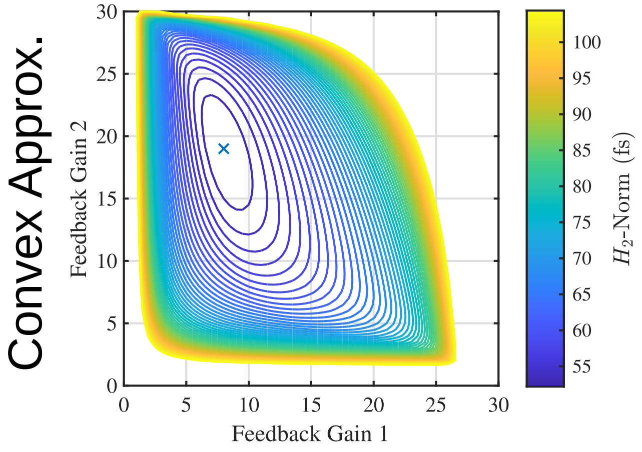
# Challenges for Distributed Systems

## Complexity of the Optimization Problem

- We need are looking for optimal feedback parameter matrix.
- Matrix needs to be sparse, as for example feedbacks from experimental hall to injector are infeasible.
- This structure constraint makes the optimization problem non-convex, no efficient numerical solvers available.
- Recent **Sparsity Invariance Framework** characterizes convex approximations of the original problem that has minima close to the optimal solution of the original problem.



# Thank you

**Contact**


DESY. Deutsches
Elektronen-Synchrotron

www.desy.de

Maximilian Schütte
DESY – MSK – LbSync
maximilian.schuette@desy.de