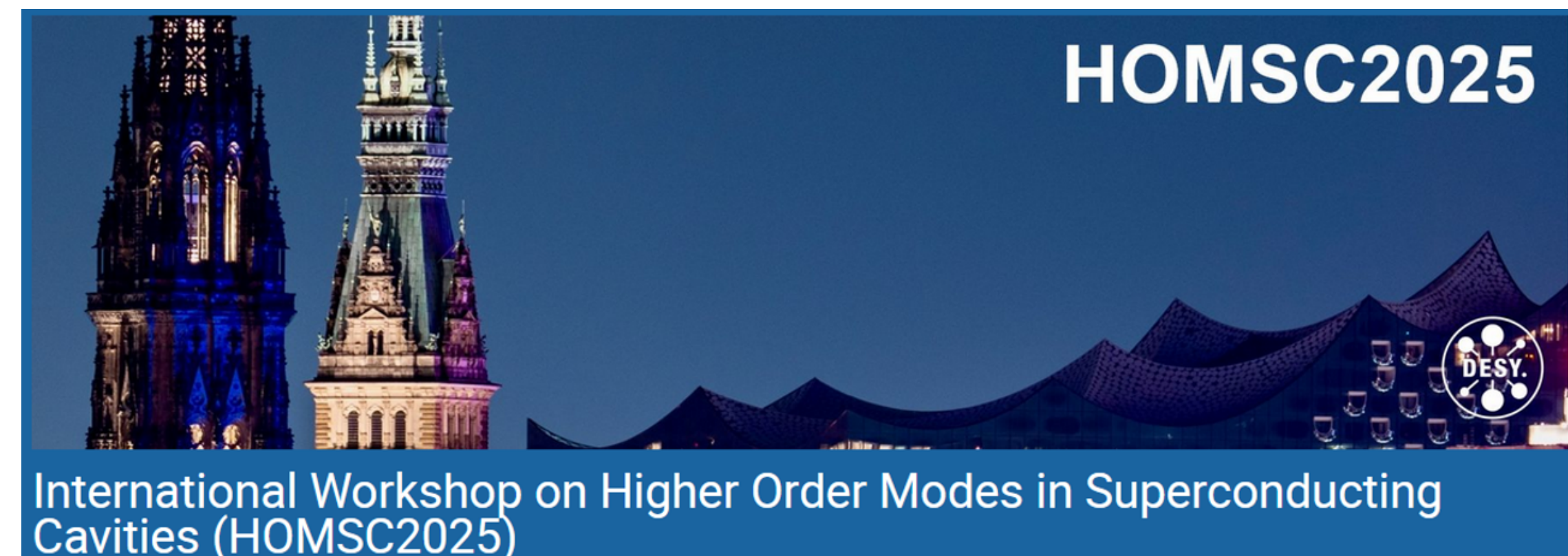


HOM damping requirements for future facilities

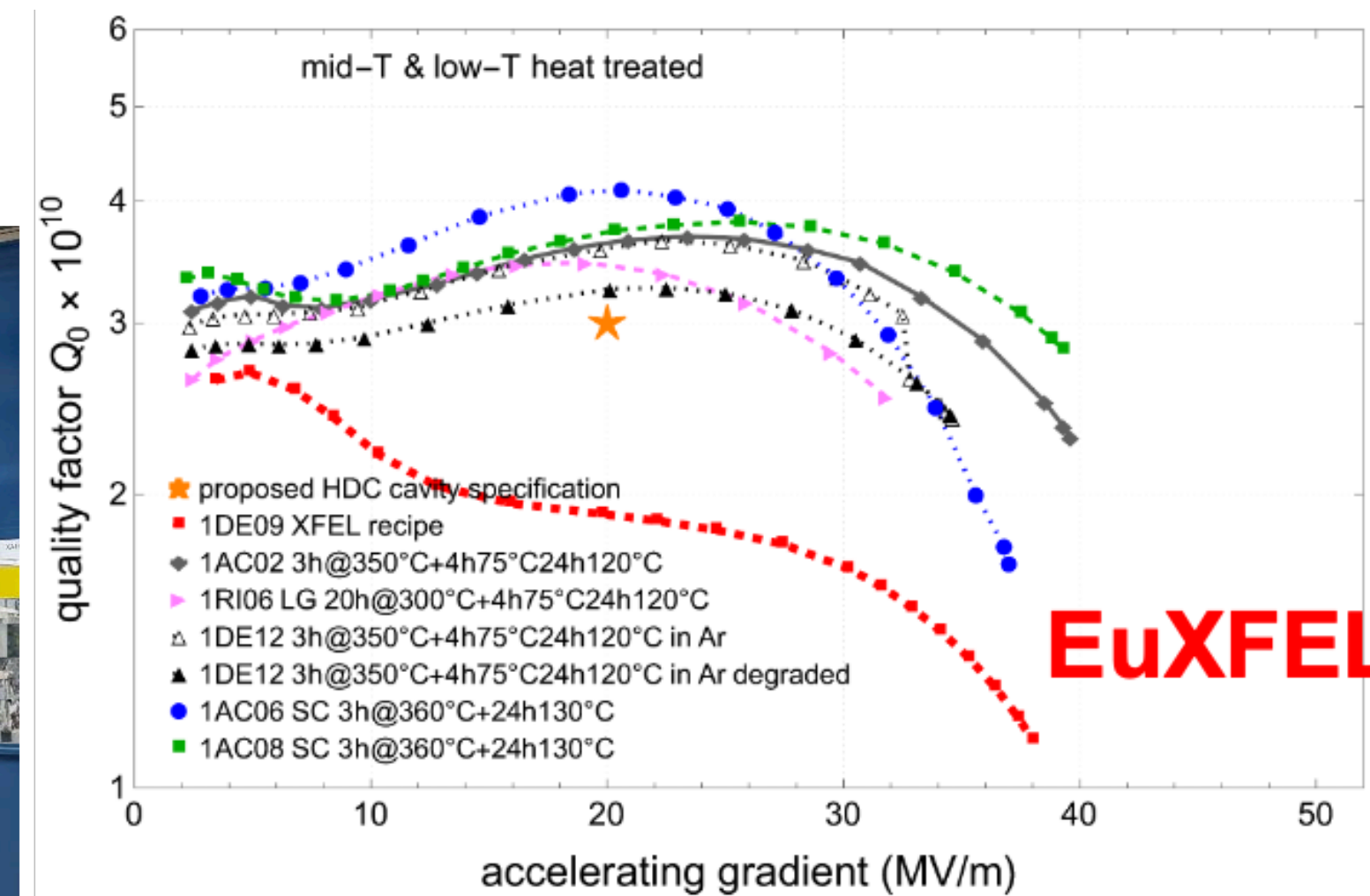
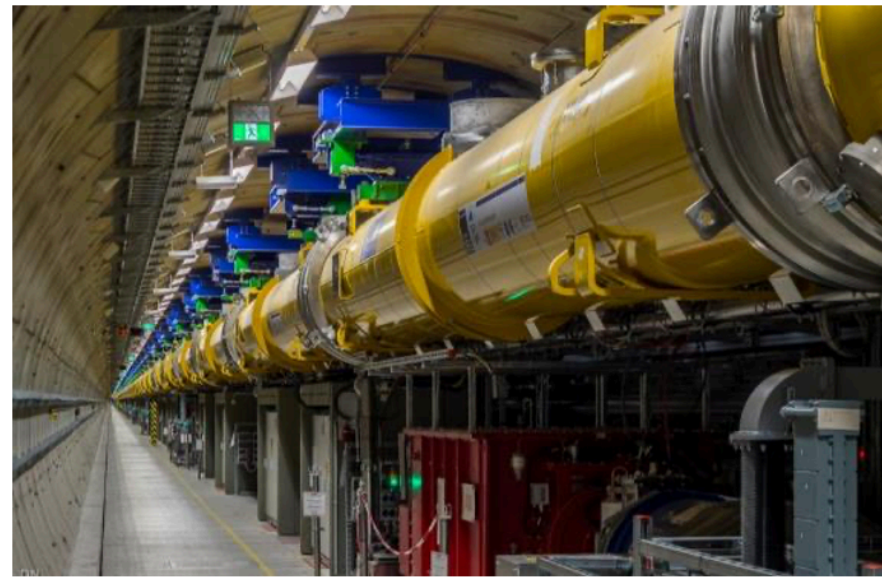
HOMSC'25 Workshop Summary

Dmitry Bazyl on behalf of WG1 (Vyacheslav Yakovlev (FNAL), Pei Zhang (IHEP), Dmitry Bazyl (DESY))



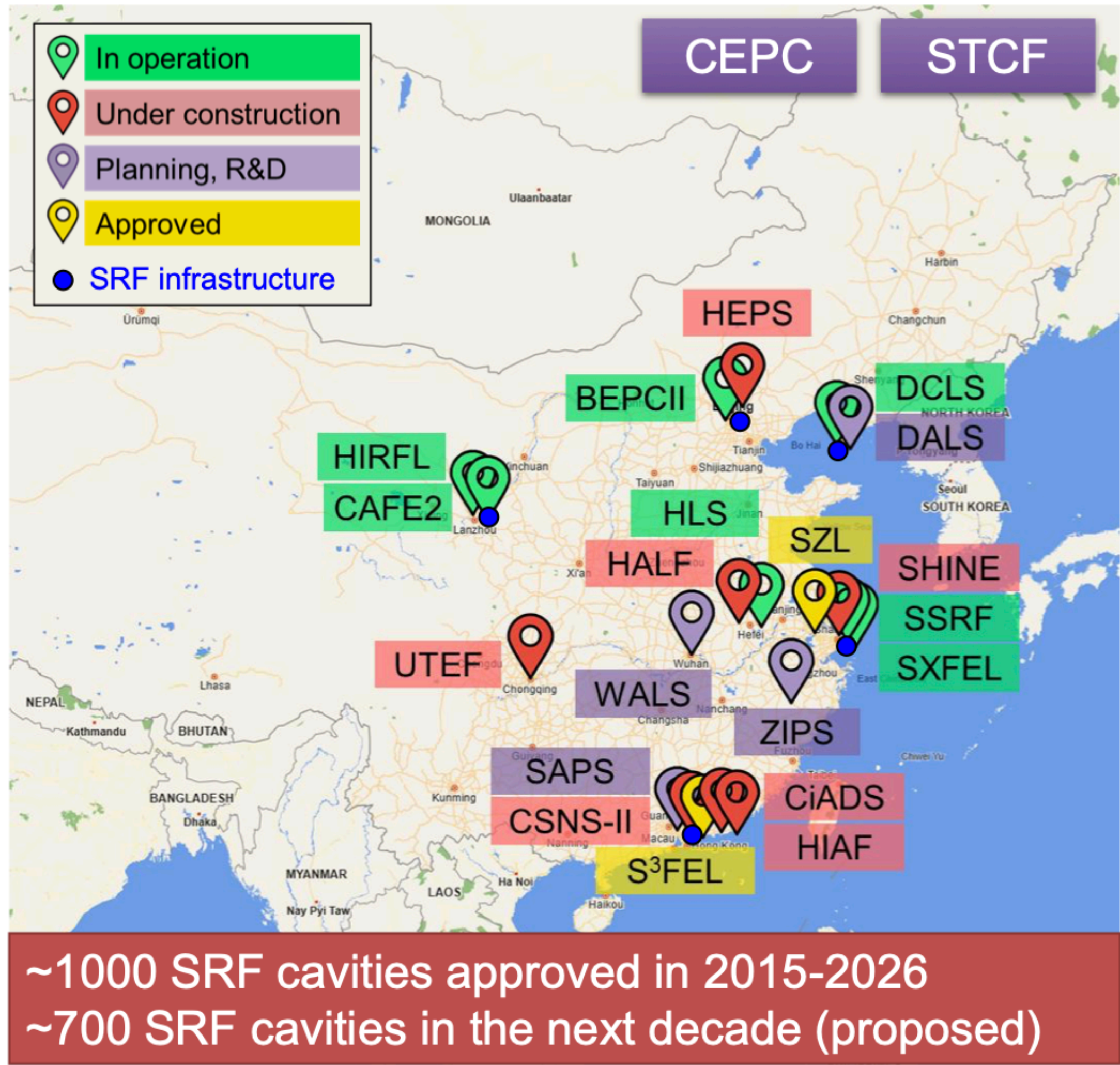
International Workshop on Higher Order Modes in Superconducting Cavities (HOMSC2025)

- **Hans Weise (*DESY, Germany*)** reported on SRF activities at DESY in context of the upcoming high-duty-cycle (HDC) upgrade of the European XFEL. Promising results of cavity heat treatment at DESY have been presented. It was emphasized that new SRF technologies are being developed at DESY (e.g. CW SRF photoinjector).



EuXFEL Recipe

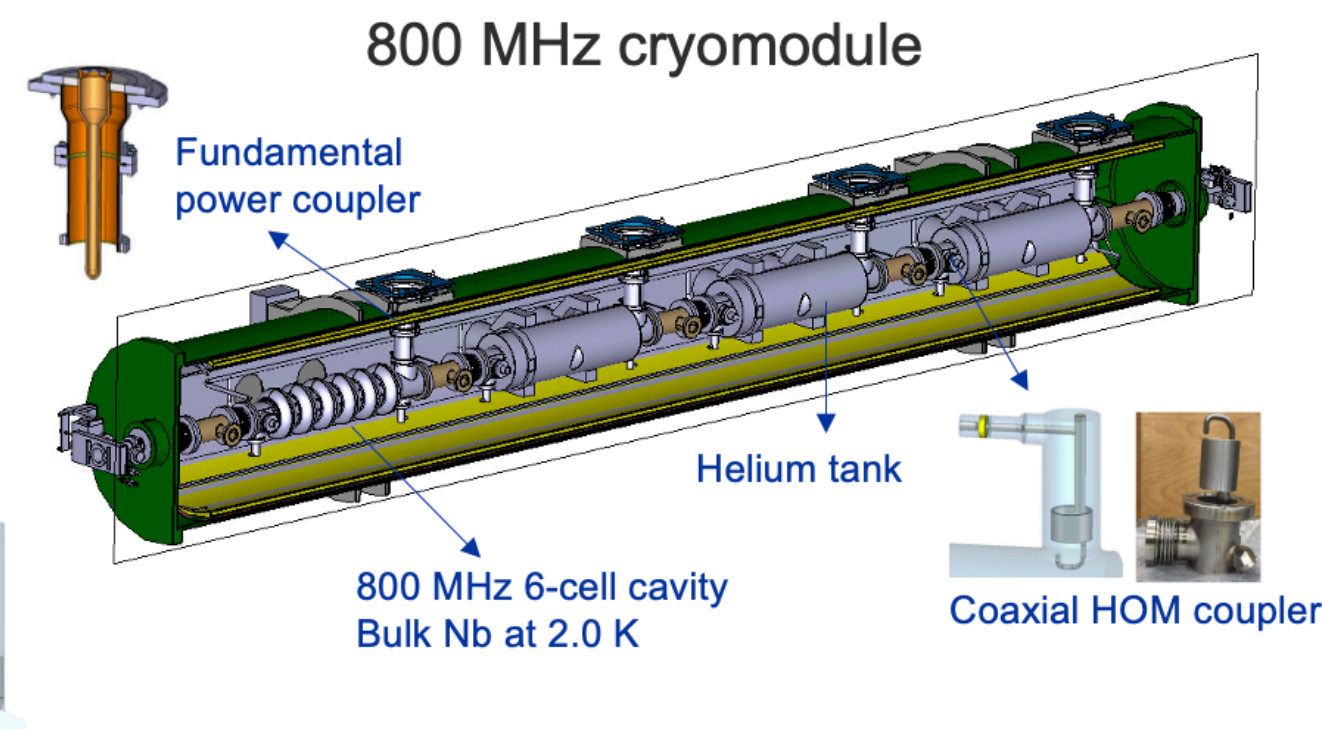
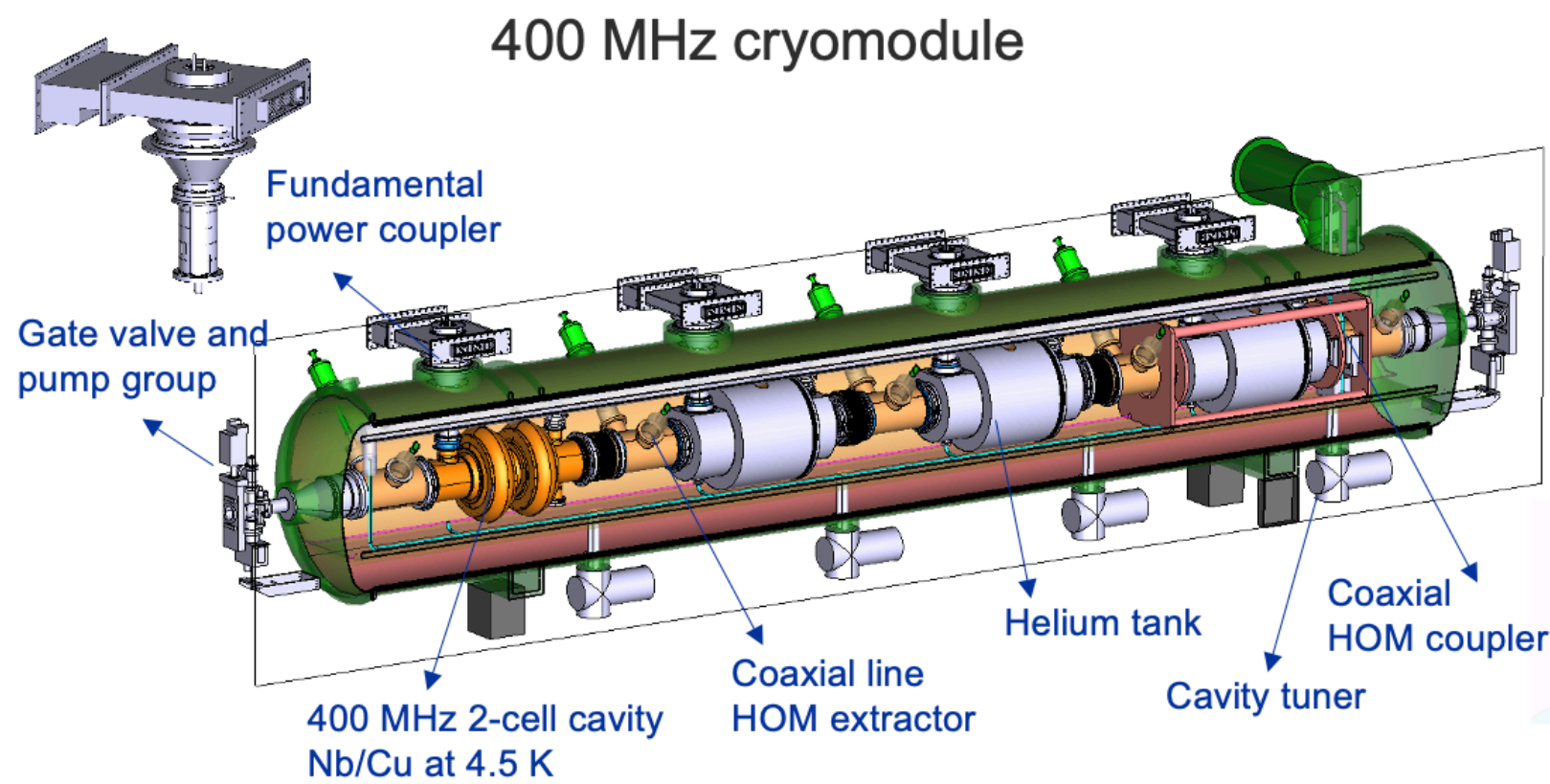
- **Pei Zhang (IHEP, China)** provided a comprehensive overview of the upcoming projects in China. SRF technology adopted by most projects under construction, while new proposals mixed with NCRF and SRF. SRF infrastructures at various facilities have been built and in operation.



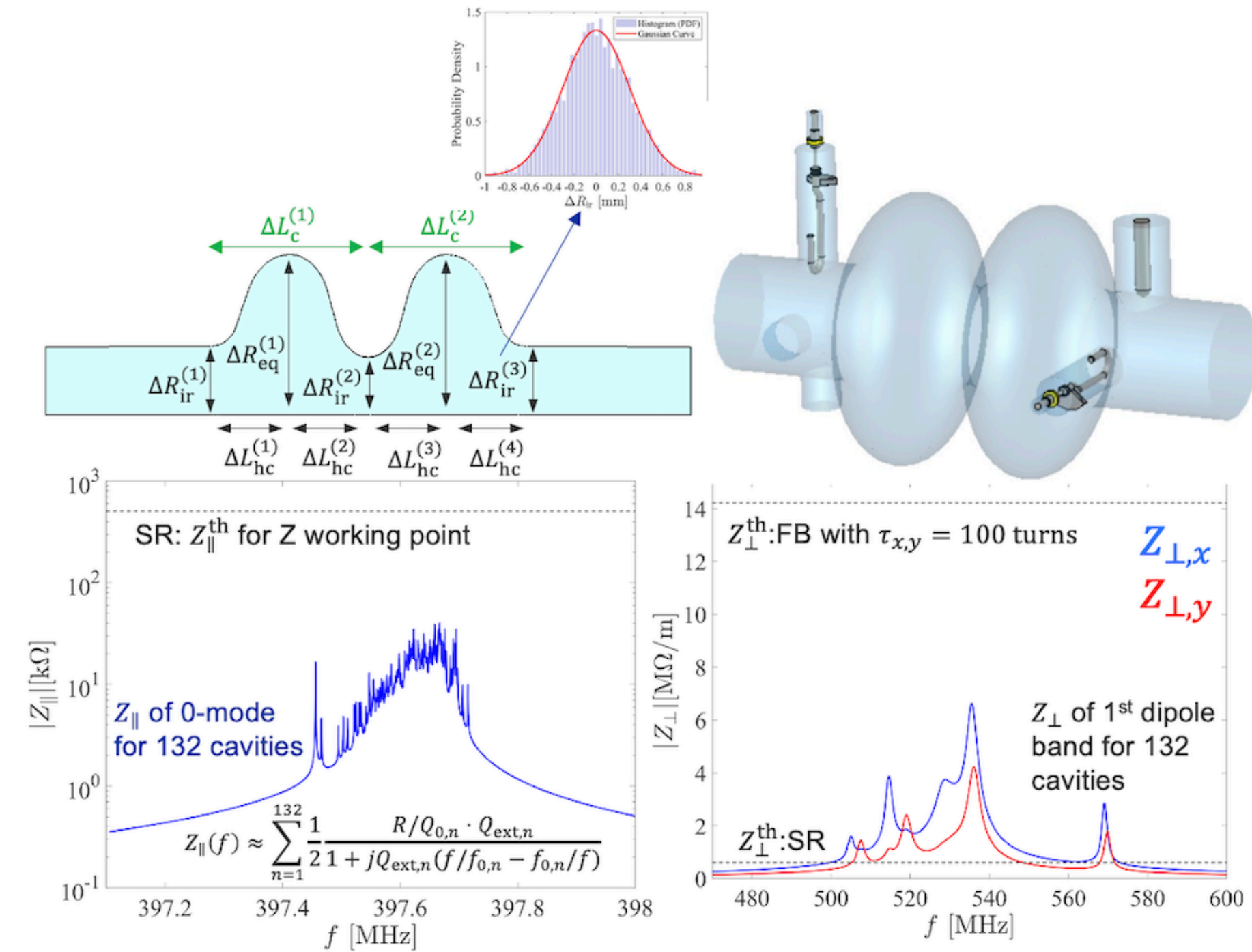
- Large accelerator facilities have seen rapid development in the last decade in China, including light sources, FELs, proton & heavy ion facilities
- Large collider projects after BEPCII are under discussion
- SRF technology adopted by most projects under construction, while new proposals mixed with NCRF and SRF
- SRF infrastructures at various facilities have been built and in operation

	Op.	Const.	Proposed
Collider	1	0	2
Sync. LS	3	3	4
FEL	2	1	2
Proton & Heavy ion	3	3	2

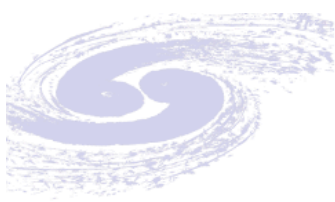
- **Shahnam Gorgi Zadeh (CERN, Switzerland)** reported on HOM damping strategies for FCC-ee SRF cavities. Two-cell 400 MHz and six-cell 800 MHz have been discussed. Multiphysics analysis results have been presented including sensitivity analysis of the cavity and multipacting of the HOM coupler.



- **4 cavities per cryomodule**
- **Fundamental Power Coupler (FPC):** fixed antenna, coupling tuned by varying the waveguide on the air side
- **HOM damping:** coaxial HOM couplers close to cavity and beamline absorbers located at the module extremities
- **Prototype development:** 400 MHz cryomodule under development at CERN; 800 MHz cryomodule design ongoing with Fermilab



- **Na Wang (IHEP, China)** provided overview on HOM Damping requirements for new circular accelerators. HOM parasitic power loss and coupled bunch instabilities are the main constraints from SRF HOMs.



Requirements from different machines

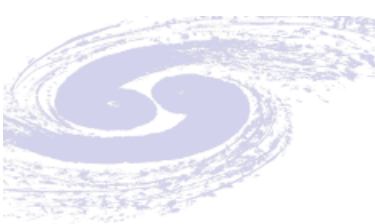
■ High energy e-p circular colliders

- HOM power and coupled bunch instabilities due to the HOMs are concentrated at Z mode.

	Higgs	W	Z	ttbar
Multi-bunch SR threshold (Long) $f\text{Re}Z_{ }e^{-(2\pi f\sigma_t)^2}$ [GHz·GΩ]	4.5	0.1	6.5E-4	171.2
Multi-bunch SR threshold (Trans) $\text{Re}Z_{\perp}e^{-(2\pi f\sigma_t)^2}$ [GΩ/m]	3.0	0.08	8.9E-4	72.7

Tight narrowband impedance requirements for Z (at least ~two orders lower compare to other energies)

- Due to the large circumference, the chromatic phase shift could not provide enough damping to the transverse coupled bunch instability, and the feedback damping is challenging to reach the required damping time within limited number of turns ⇒ The coupled bunch instability induced by the HOMs should be handled by the synchrotron radiation damping.
- The filling pattern is restricted by the HOM power if the *Q* is not well controlled.
- To meet these requirements, one cell cavities with deep HOM damping are dedicated in both CEPC and FCC-ee Z mode.



Requirements from different machines

■ Synchrotron radiation light sources

- As a user facility with many beamlines, beam stability/beam quality is more prominent → HOMs should not dilute emittance or beam energy spread even in resonance.
- Transverse HOMs are normally not dominant in the circular accelerators, either due to the strong feedback damping requirement given by the resistive wall instability or effective landau damping from chromaticity.
- Longitudinal HOMs are not easily to be damped by feedback, especially when interact with harmonic RF cavities, and better take care of during the design stage.
- A more comprehensive consideration can reduce redundancy in hardware design.

- **Anthony Gilfellon (UKRI STFC, United Kingdom)** reported on dipole mode wakefields and beam dynamics tracking simulations for the UK XFEL main accelerating linac. Multiphysics analysis has been presented including kick factor analysis and particle tracking.

UK XFEL Overview: Facility (not to scale)

UK XFEL is a multi-stage project to pursue 'next-generation' XFEL capabilities for the UK

UKXFEL Facility Talk: Wednesday 8th October 10:30 am

- **Injector section**
 - Two VHF NC guns
 - Varying bunch charge beams interleaved
 - Leaves section at 100 MeV
 - Maximum bunch repetition rate of 1 MHz

Main Accelerating section

- 600 1.3GHz TESLA 9-cell cavities
- Gradient of ~ 14 MV/m
- 8 linearising 3.9 GHz cavities
- 2 bunch compressors

Switchyard

- Fast kickers to separate out 1MHz beam to (say) 10 x 100 kHz beams
- Variants are possible

FEL lines

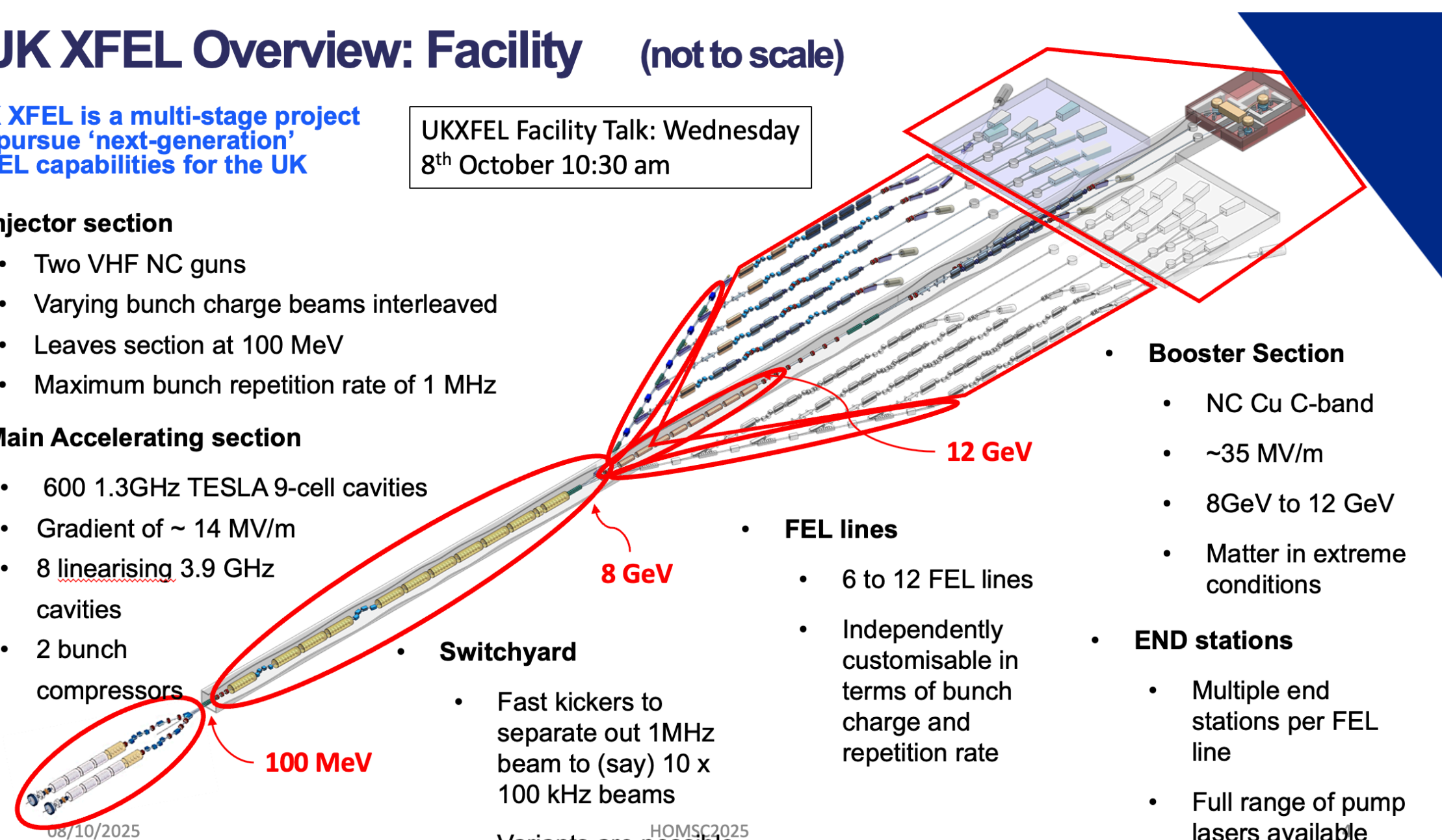
- 6 to 12 FEL lines
- Independently customisable in terms of bunch charge and repetition rate

Booster Section

- NC Cu C-band
- ~35 MV/m
- 8GeV to 12 GeV
- Matter in extreme conditions

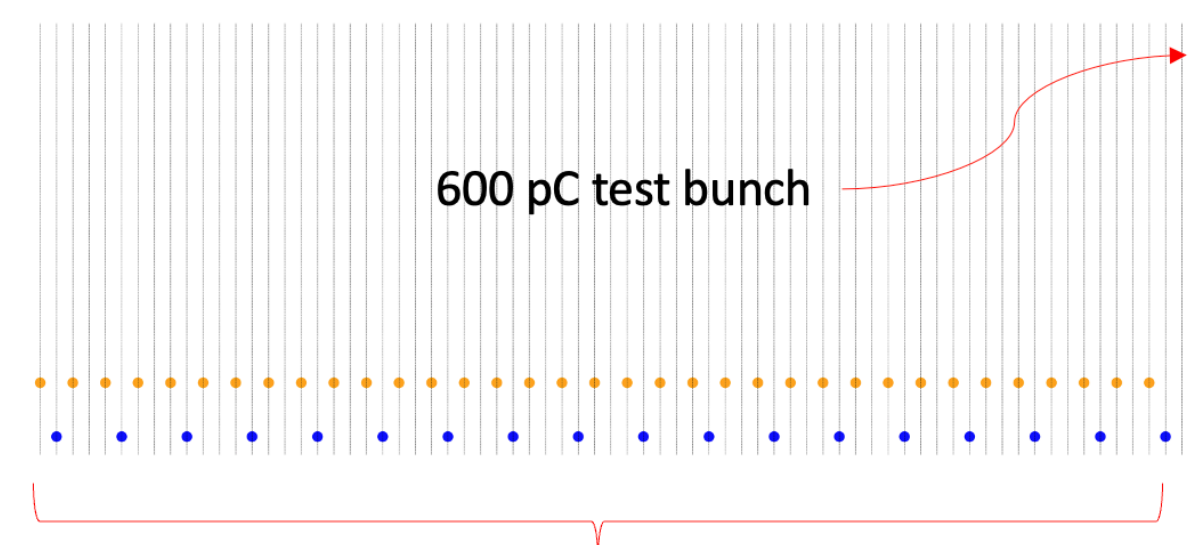
END stations

- Multiple end stations per FEL line
- Full range of pump lasers available



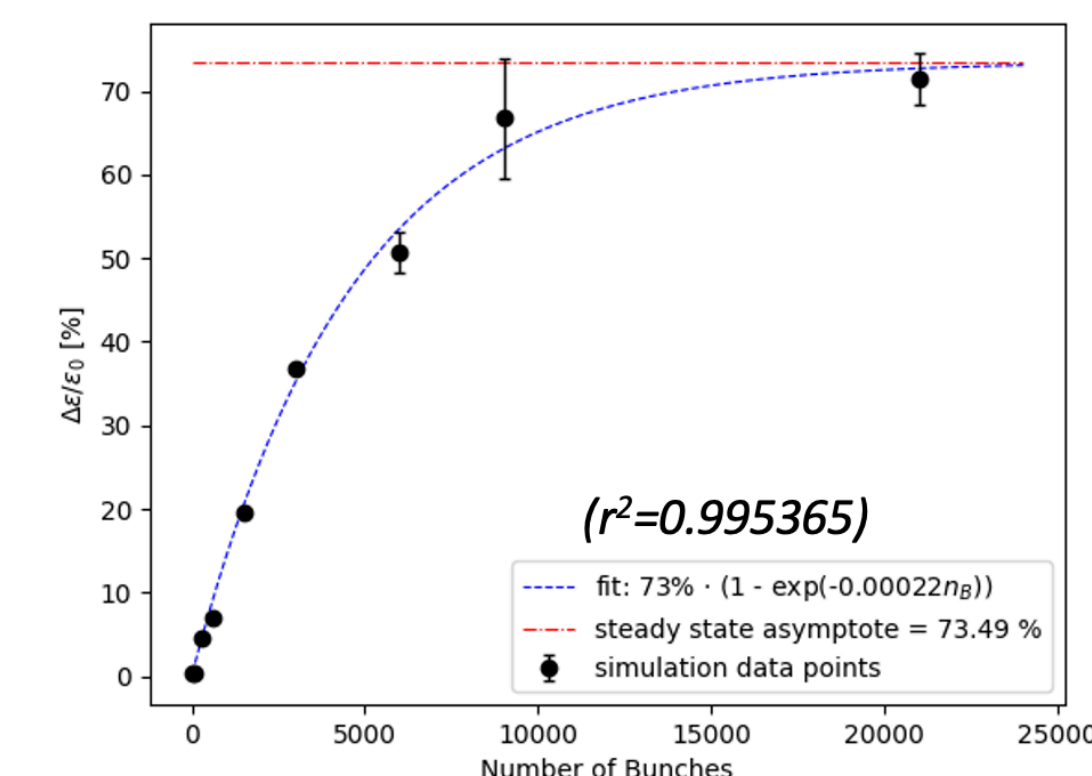
PLACET: Composite Beam Results

- We want to judge the effect of the steady-state LRTWs of a composite 75pC and 150pC beam has on a single 600 pC bunch.



Steady-state 75 & 150 pC composite beam

- in the results shown, one repeat unit of [150-75-150-X] contains 3 bunches



In the case of the composite beam, and using

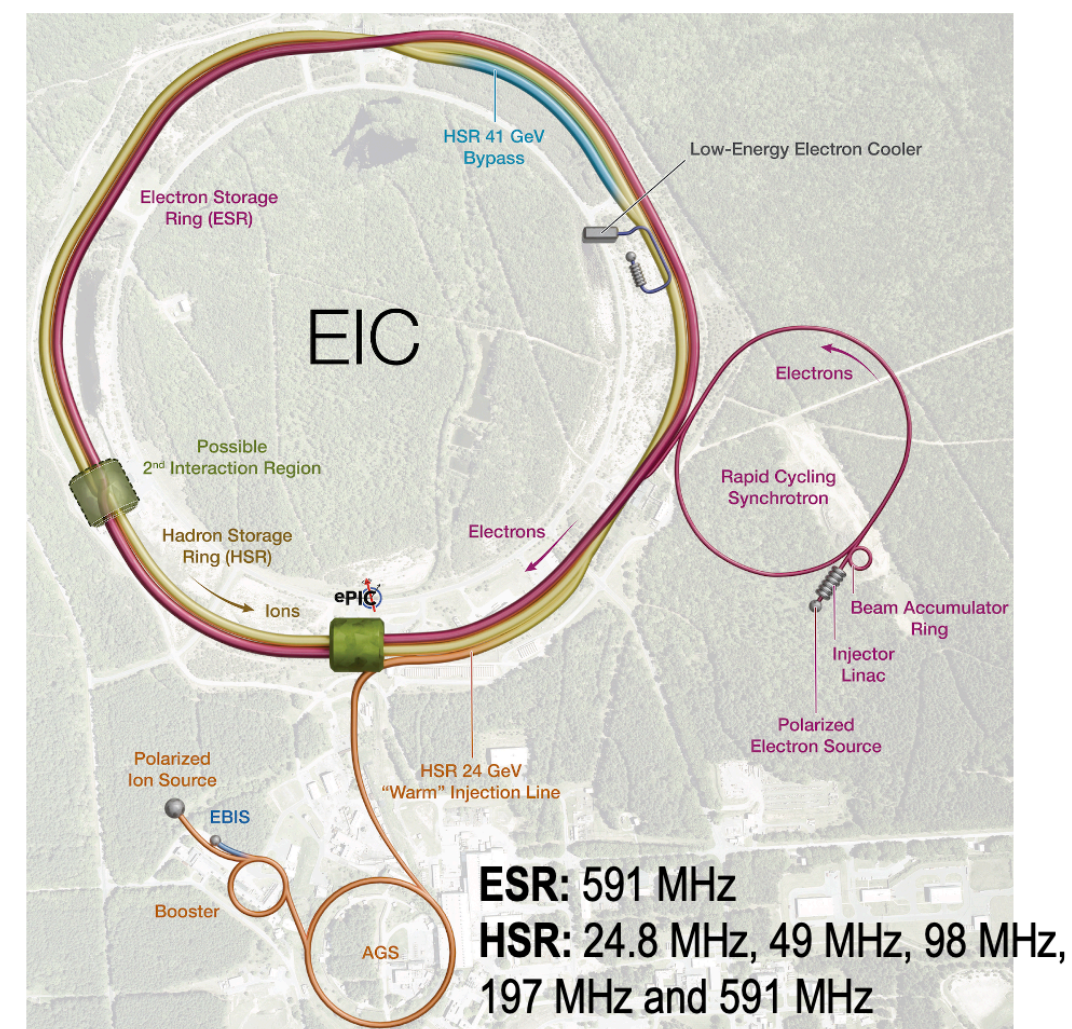
$$\frac{\Delta\epsilon}{\epsilon_0} = A(1 - e^{-Dn_B}),$$

$A = 73\%$ and $D = 2.2 \times 10^{-4}$ ($r^2=0.995365$)

- **Alexei Blednykh (BNL, United States)** discussed beam stability in the EIC ESR: Contribution of the 591 MHz RF Cavities. 2-cavity 591 MHz string contribution analyzed for single-bunch dynamics and HOM-driven effects. A longitudinal damper is required to suppress coupled-bunch instabilities driven by HOMs from the 2-cavity string.

EIC Project Overview

- **Electron Injection System**
 - DC Photoelectron Gun
 - 320 keV, ~85% polarization, 1.5 nC per bunch
 - S-band LINAC
 - 750 MeV energy, normalized emittance: ~80 μm (x), ~50 μm (y)
- **Beam Accumulator Ring (BAR, $C \approx 50$ m)**
 - 750 MeV energy, single-bunch accumulation: 28 nC
 - Design lead by the NSLS-II team
- **Rapid Cycling Synchrotron (RCS, $C \approx 1.4$ km)**
 - 0.750→18 GeV in 100 ms, 1 Hz
 - Spin-transparent lattice, 28 nC, normalized ϵ_n : 16-24 nm (x), 1.4-2.4 nm (y)
- **Electron Storage Ring (ESR, $C \approx 3.8$ km)**
 - Beam energy: 5-18 GeV, current : up to 2.5 A, SR power: up to 10 MW
 - Polarized bunches, swap-out injection
- **Hadron Storage Ring (HSR, $C \approx 3.8$ km)**
 - **Beam energy:** Injection at 23.8 GeV, accelerated to 41-275 GeV
 - **Beam current:** up to 1 A / 0.7 A with M = 1160 / 290 bunches
 - **Crossing angle:** 25 mrad with crab cavities
 - **Spin rotators** (longitudinal) for p, d, He³
 - **Cooler:** low-energy electron and stochastic cooling
 - **Luminosity:** up to 10^{33} - 10^{34} cm⁻²s⁻¹



Wakefield Simulations for 2-Cavity String

- **Simulated Vacuum Components**
 - Two Back-to-Back 591 MHz RF Cavities
 - Beam Line Absorbers, 274 mm aperture
- **Remaining Components to Simulate**
 - Bellows, 274 mm aperture
 - Tapered Transition (Arc to Straight Section)
 - Gate Valve, 180 mm aperture
 - Beam Pipes, 180 mm aperture, L~5 m
- No significant impact is expected from adding $W_{||}(s)$ and $W_{Dy}(s)$ of the remaining cryomodule components to the total wakefield.

