KfB

Strategieworkshop

Beschleuniger-Großprojekte
in „Deutschland“

ein Überblick

Viele Folien von und herzlichen Dank an:
Hans Weise, Winni Decking, Rainer Wanzenberg, Reinhard Brinkmann,
Andreas Jankowiak, Oliver Boine-Frankenheim, Frank Tecker

Kurzübersicht

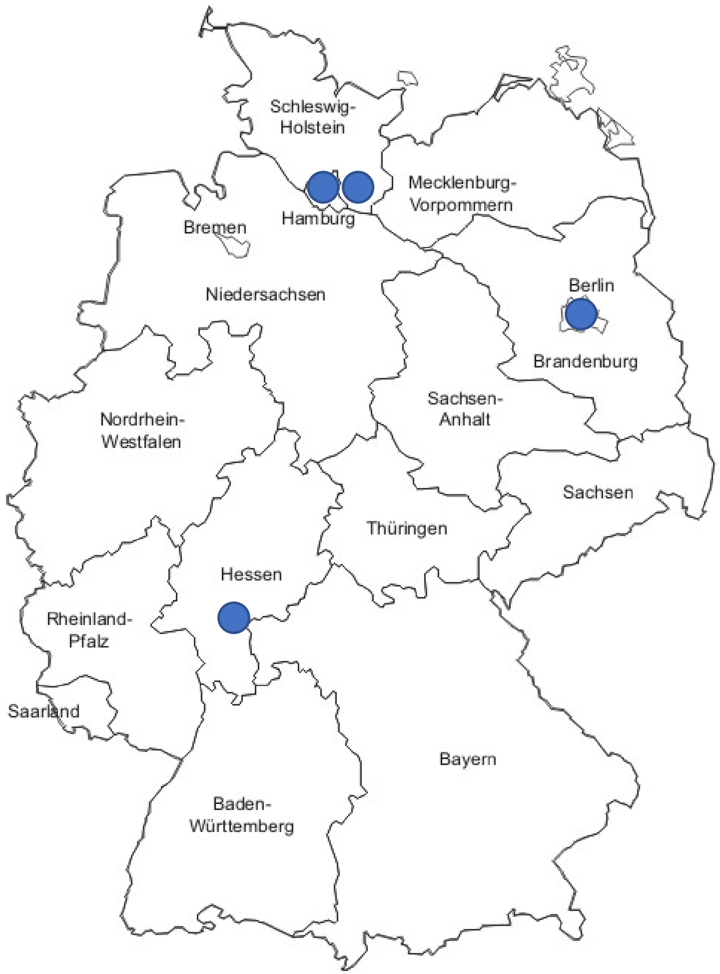
XFEL

PETRA IV

BESSY VSR

FAIR

HL-LHC



Kurzübersicht

XFEL

PETRA IV

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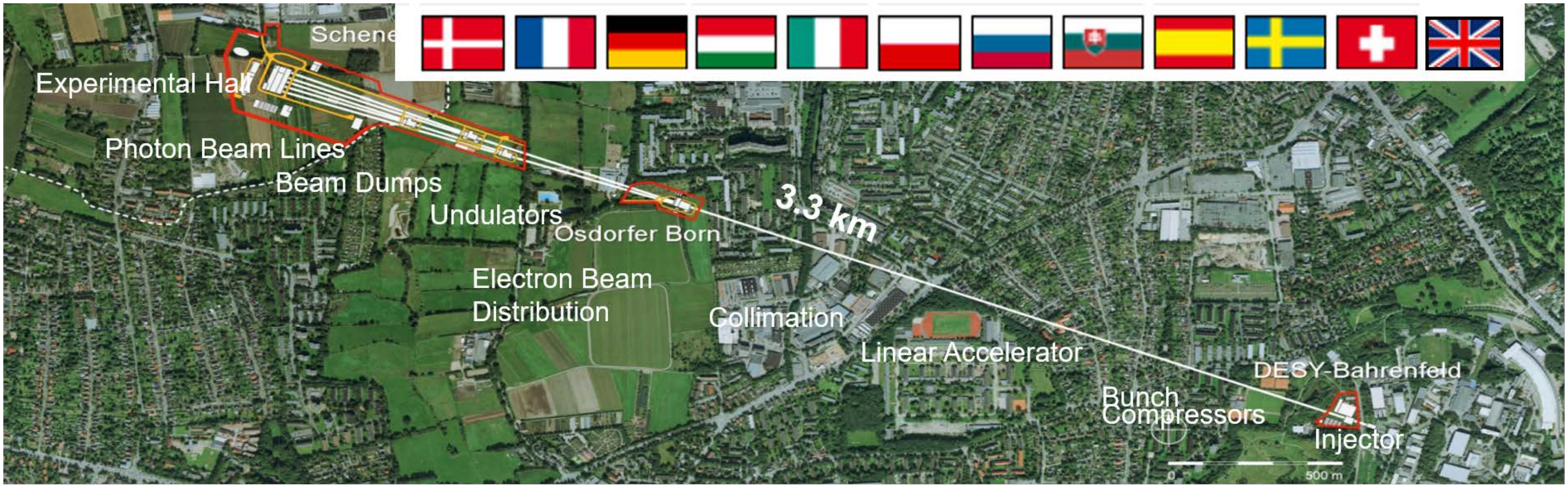
European XFEL at a Glance

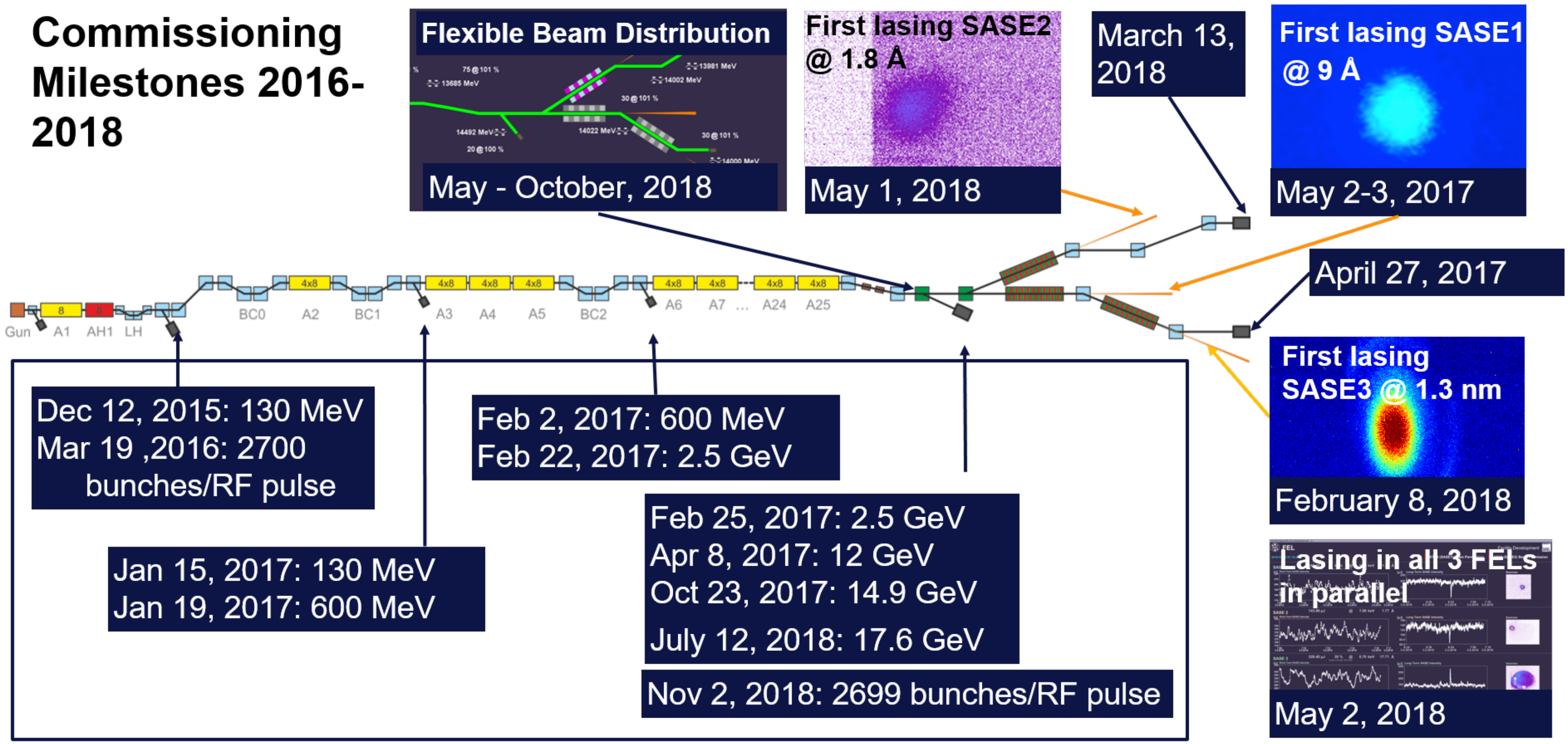
- International project realised in Hamburg area, Germany
- Accelerator and large parts of infrastructure built by international consortium under the coordination of DESY
- Accelerator operation and development by DESY
- Superconducting accelerator in 10 Hz pulsed mode with 97 modules / 776 cavities
- Up to 17.5 GeV and 27000 bunches/s
- Three variable gap undulators for hard and soft X-rays (250 eV to 25 keV)
- Initially 6 equipped experiments
- All accelerator and beamlines in tunnels 6 -25 m below surface



European XFEL

Superconducting linear accelerator demonstrates design performance:
Reached design energy of 17.5 GeV
Accelerated full bunch train of 27000 bunches/second

Commissioning Milestones 2016-2018



Upgrades

- Self Seeding in the hard X-ray regime:
  - SASE2 chicanes installed and operational
  - Commissioning with beam started in SASE2
  - SASE1 chicanes available
- SASE3 Helical Afterburner and Two Color Scheme
  - Hardware installation starts in Winter shutdown 2019/2020
  - Hardware complete and first photons in 2021
- Still two empty tunnels suitable for FELs;
  Let's call them SASE4 and SASE5
  - Ideas to extend photon energy range in hard and soft x-ray regime are developed
  - Technical and scientific cases are explored
  - Proof of principle tests, e.g. Harmonic Lasing Self-Seeding (HLSS) have already been demonstrated at SASE3 reaching 4.5 keV
- R&D towards CW operation and a second fan

SRF R&D for XFEL

R&D @ DESY → future cw upgrade

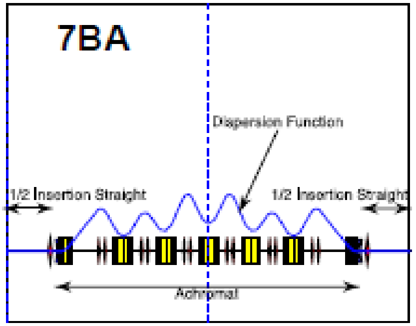
- srf gun development
  optimum cavity treatment
  beam dynamics simulation
  dedicated diagnostics
  …

- Niobium material and treatment:
  Large grain Nb
  N_2 infusion/doping,
  special treatment recipes

- cw srf modules

- …

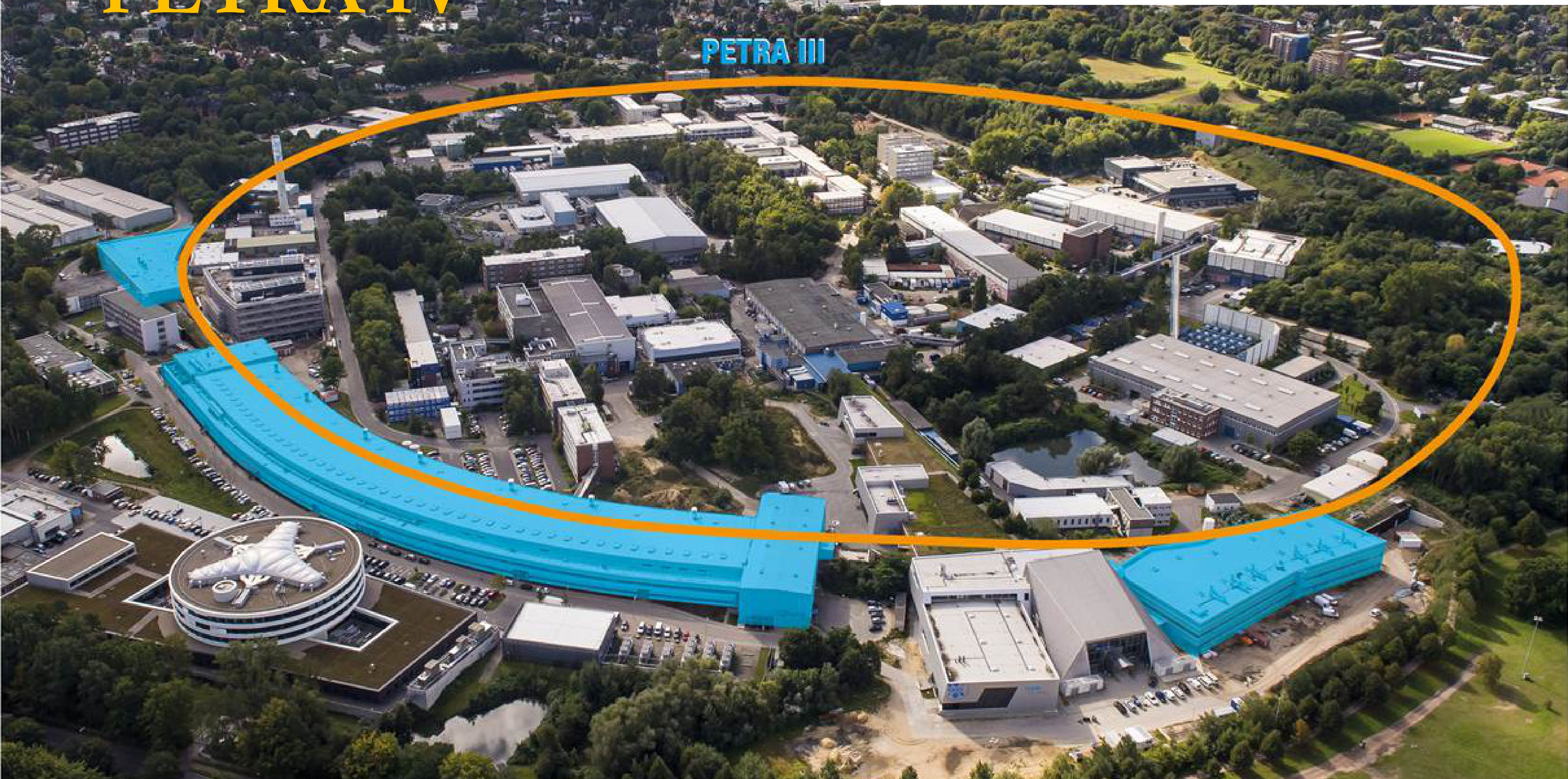
PETRA III
↓
PETRA IV



Strong Focusing and Low Dispersion

First used for MAX-IV.

D. Einfeld *et al.*, Proc. PAC 95, Dallas TX



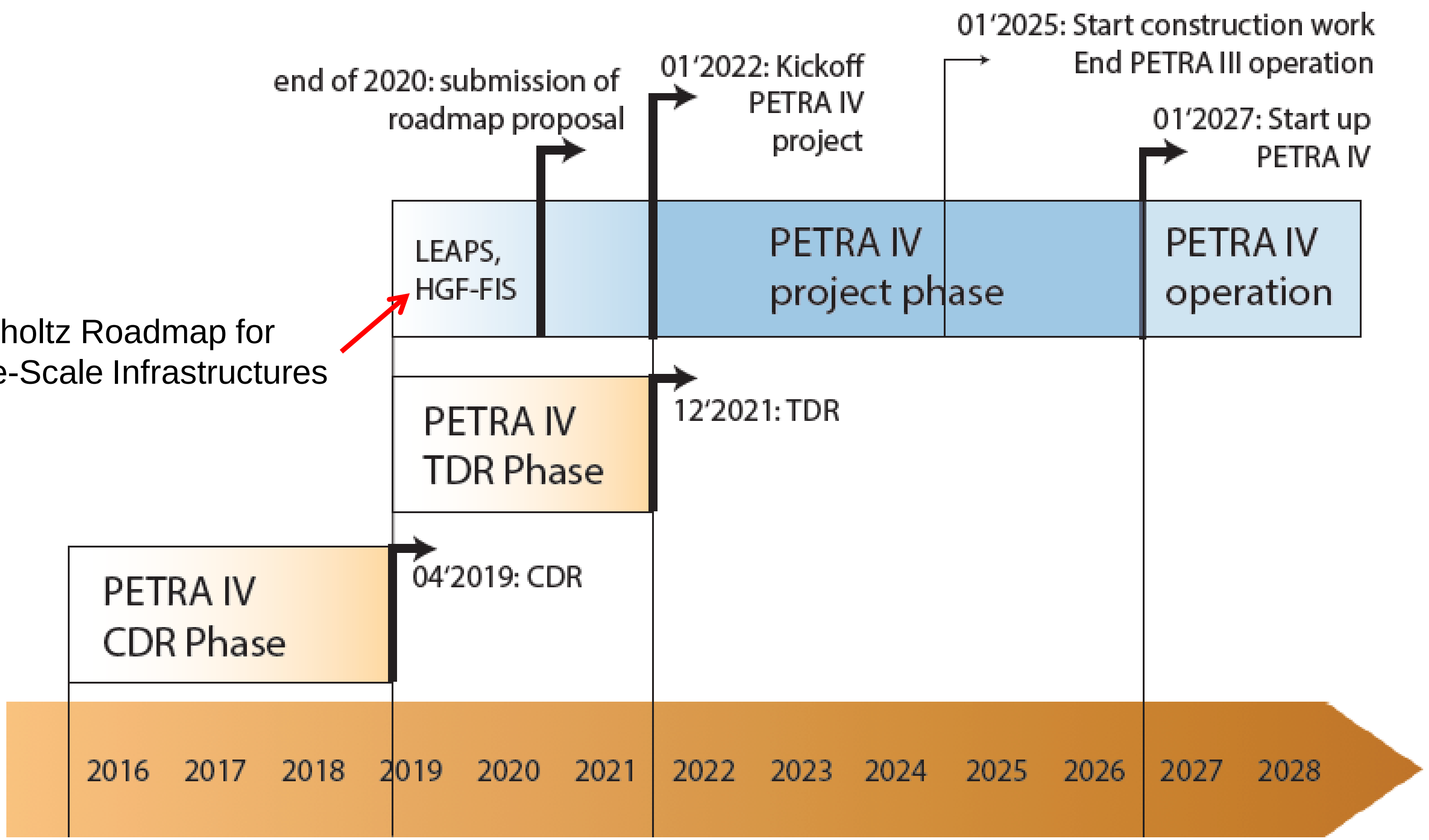
PETRA IV – Timeline

Presently: CDR preparation phase

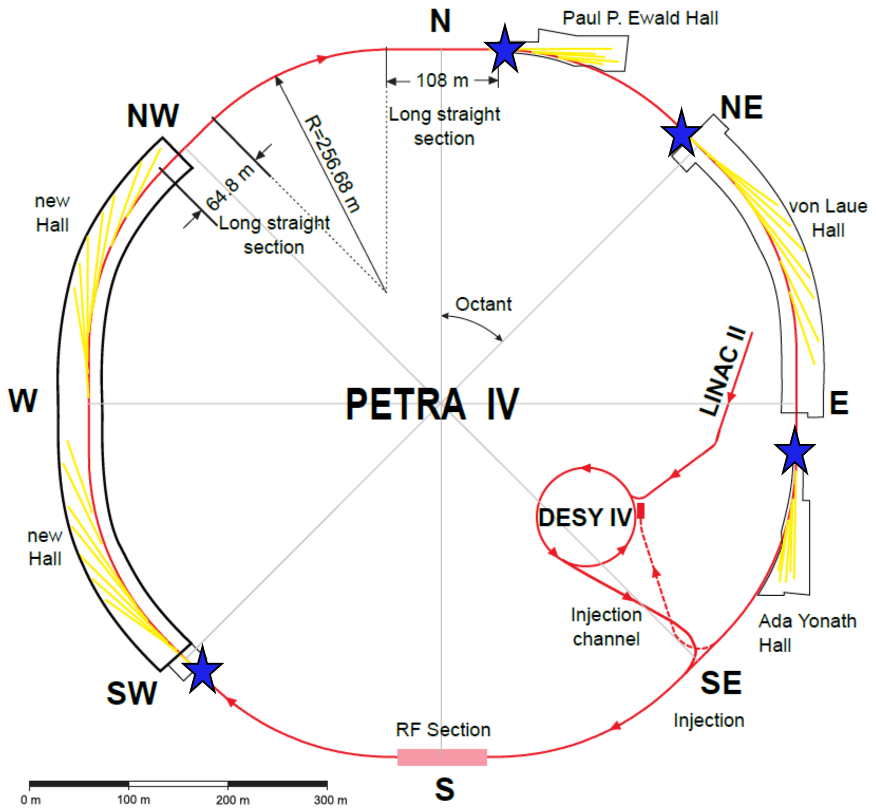
FIS-process pre-proposal submitted

Helmholtz association:
FIS = **F**orschungs**I**nfra**S**truktur
Large-scale research infrastructure

Helmholtz Roadmap for
Large-Scale Infrastructures



PETRA IV conceptual design



Baseline: H7BA – ESRF style lattice
8 cell / arc, 26.2 m cell length
+ 4 undulator cells in the long straight sections ★
(10 m long undulators)

Storage Ring:
Baseline: H7BA style lattice (64 cells) on axis injection,
Option (considered during TDR) maintain several beamlines
(23 m long cell with strong magnets)

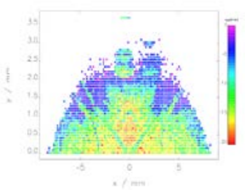
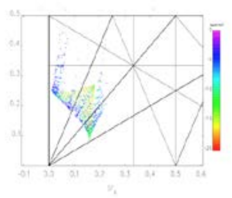
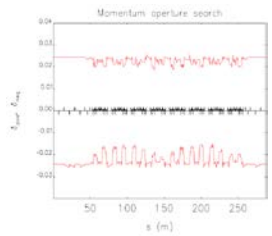
Injector:
new booster synchrotron, DESY IV
low emittance ~ 20 nm rad
refurbished Linac II
with full intensity gun
Option
consider the possibility to include in the future an injector based on laser plasma wakefield acceleration

Technical sub-sytems:
Magnets, bore radius 13 mm
Option: 9 … 10 mm
Vacuum system, 10 mm inner radius
Option: 7 mm

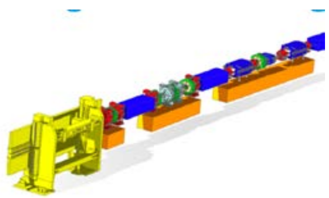
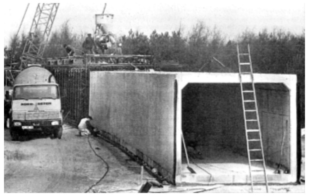
PETRA IV – parameters and challenges

Dynamic Aperture and nonlinear dynamics
→ Sufficient for on axis injection (> 1 mm mrad)

Momentum acceptance and Touschek lifetime
→ MA is sufficient for >1h lifetime in timing and >4h lifetime in brightness mode

Alignment tolerances and start-up simulation
→ 30 μm (rms) alignment tolerances on girder
PETRA III: Max von Laue Hall, achieved 32 μm (rms)

PETRA legacy and tunnel stabilization
→ Building reinforcement and temperature stabilization (< 0.5 ^{0}C)

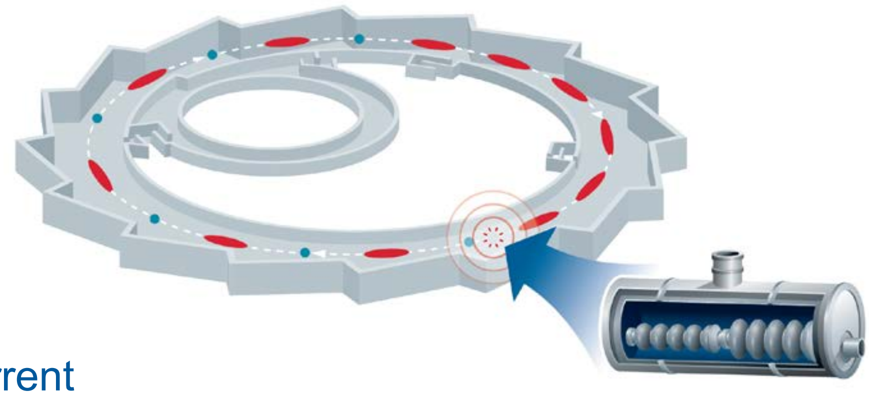
Parameter	Value (with 29 IDs)
Energy E	6 GeV
Length L	2304 m
Tune Q_x/Q_y	164.18 / 68.27
Nat. chromaticity ξ_x/ξ_y	-230 / -185
Damping part. number J_x	1.175
Nat. emittance ε_x	7.6 pm*rad
MCF α_c	1.485e-5
Energy spread σ_e	0.92e-3
Hor. damping time τ_x	19.5 ms
Ver. damping time τ_y	22.9 ms
Long. damping time τ_e	12.6 ms
Energy loss per turn U_0	4.0 MeV
Rf voltage (500 MHz)	8 MV

Notes: (lattice version 15.7)

- Zero-current values – without IBS!

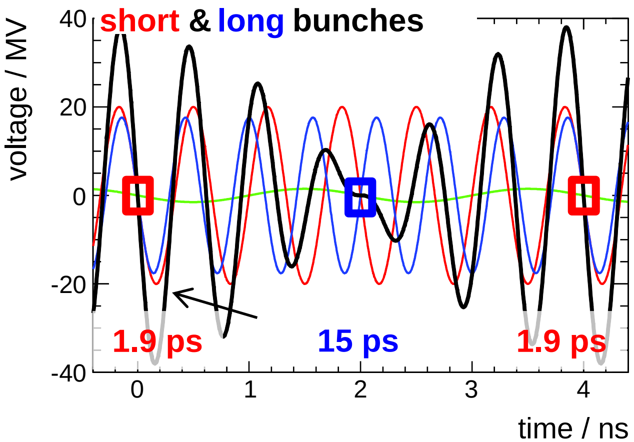
BESSY VSR

$$\sigma \propto \delta_0 \sqrt{\frac{E_0}{\omega_0} \cdot \frac{\alpha}{\omega_{rf} V_{rf}}} \qquad I \propto \alpha$$



high voltage (20 MV/m) cw multi-cell SC cavities allow to increase the total voltage gradient by two orders of magnitude
→ ca. 1/10 bunch length @ constant bunch current

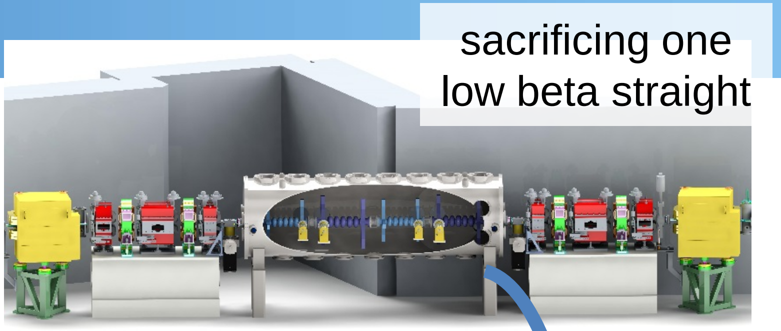
Combining two RF systems with different frequencies (1.5 GHz & 1.75 GHz) generates long and short buckets, which can be filled individually to generate optimized fill pattern.



1.5 MV @ 0.5 GHz
16 MV @ 1.5 GHz
14 MV @ 1.75 GHz

J. Feikes, P. Kuske, G. Wüstefeld, EPAC2006
G. Wüstefeld, A. Jankowiak, J. Knobloch, M. Ries, IPAC2011

VSR – variable pulse length storage ring



One cryo-module with:

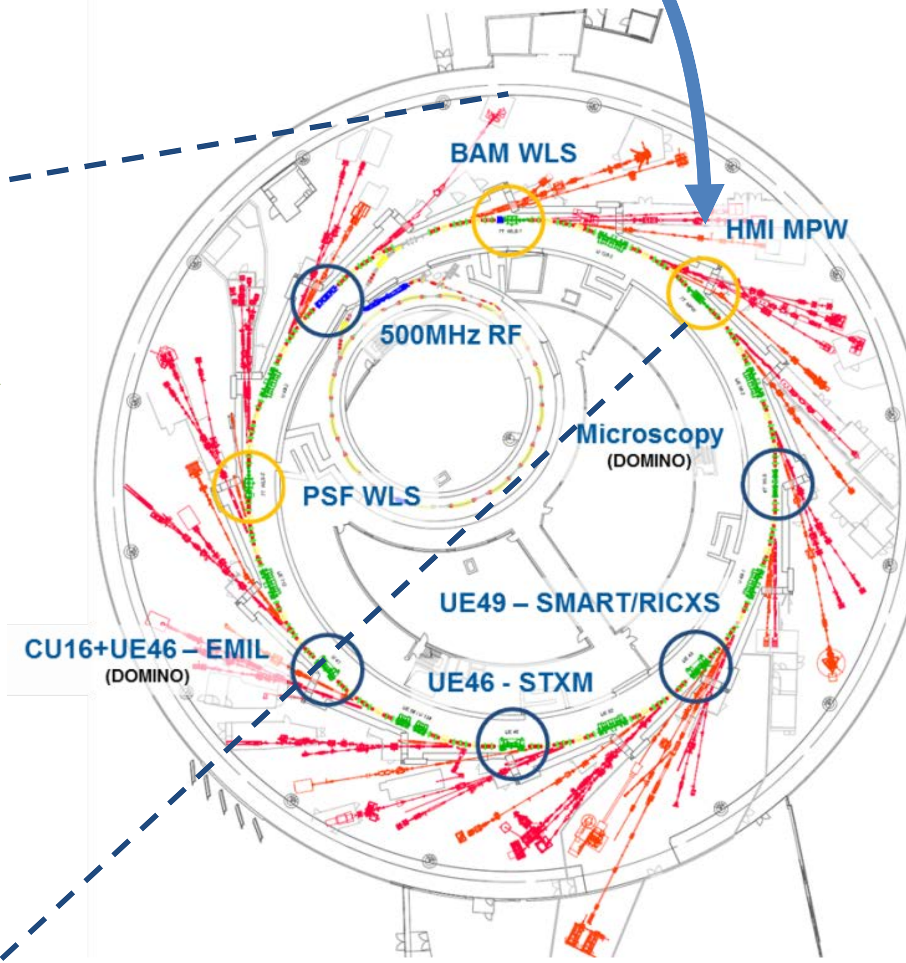
2 x 4 cell @ 1.5 GHz & 2 x 4 cell @ 1.75 GHz

operating at **1.8 K LHe** temperature

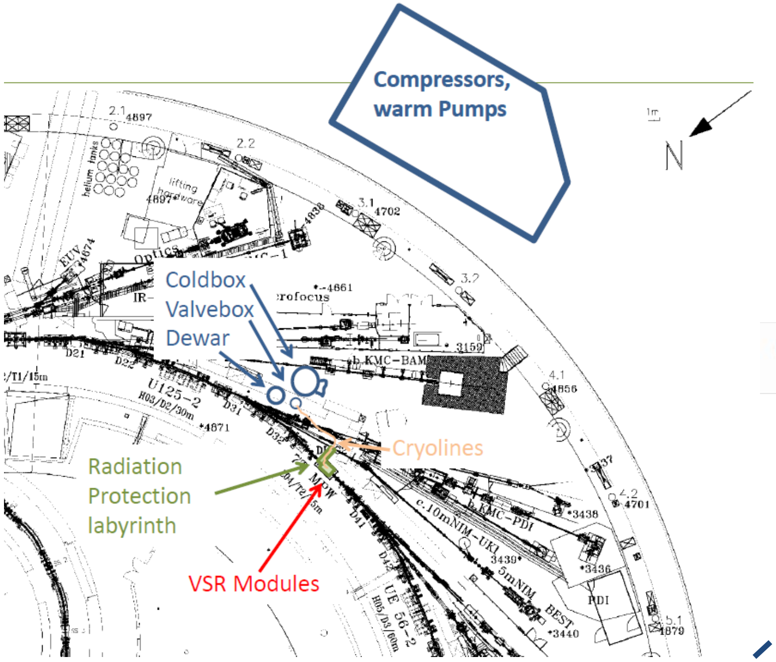
active length: **1.50 m** with **20 MV/m**

total gradient: **2π 50 MV×GHz (x 60 increase)**

A. Velez, A. Neumann, F. Glöckner, J. Knobloch et al. HZB



Installation of 1.8 K Cryo-System

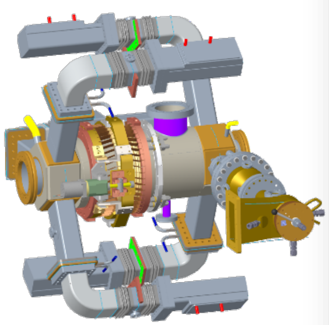


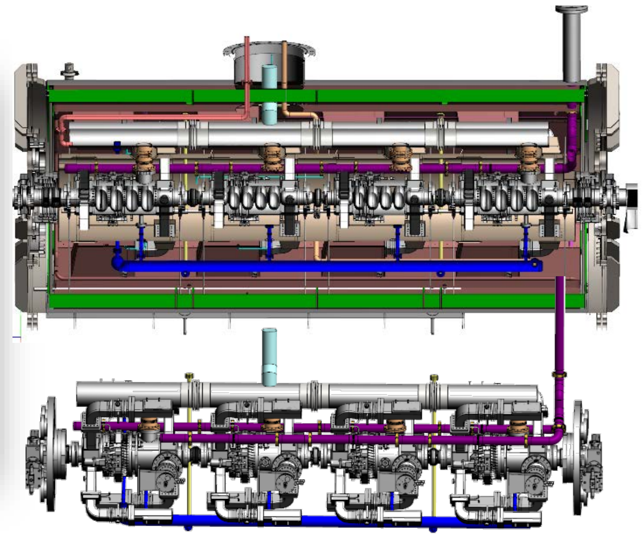
BESSY VSR – status and realisation

4 cell, 1.5/1.75 GHz waveguide damped HOM cavities
(based on bERLinPro designs)

1.8K cryo plant

Module design & system integration





2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026

tendering
cavities &
SSA transmitter &
couplers

installation &
commissioning
cryo-plant

prep. phase cryo-module
2 x 1.5 GHz
(assembly, test, beam test)

full BESSY VSR
2 x 1.5 GHz & 2 x 1.75 GHz
(assembly, test, user operation)

BESSY-VSR – Main challenges

- **short, intense bunches - scaling behaviour bunch-length vs. current**
- **development and operation of high gradient superconducting cavities**

  1.5 GHz and 1.75 GHz @ 20 MV/m gradient cw
  → 200W @ 1.8 K cooling plant (30% margin), 260 W @ 4.5K, 2 kW @ 50 K
  → particle free (clean) vacuum around cavity straight, 10^{-10} mbar
  → module integration (space, synchrotron radiation) in general

- **HOM damping to fight coupled bunch instabilities**

  induced by sc cavity impedance, higher order modes of sc cavities
  → proper HOM damping design of sc cavities, waveguide HOM dampers
  → sufficiently strong bunch by bunch feedback

- **operation with large (transient) beam loading and in regime of possible Robinson instability**

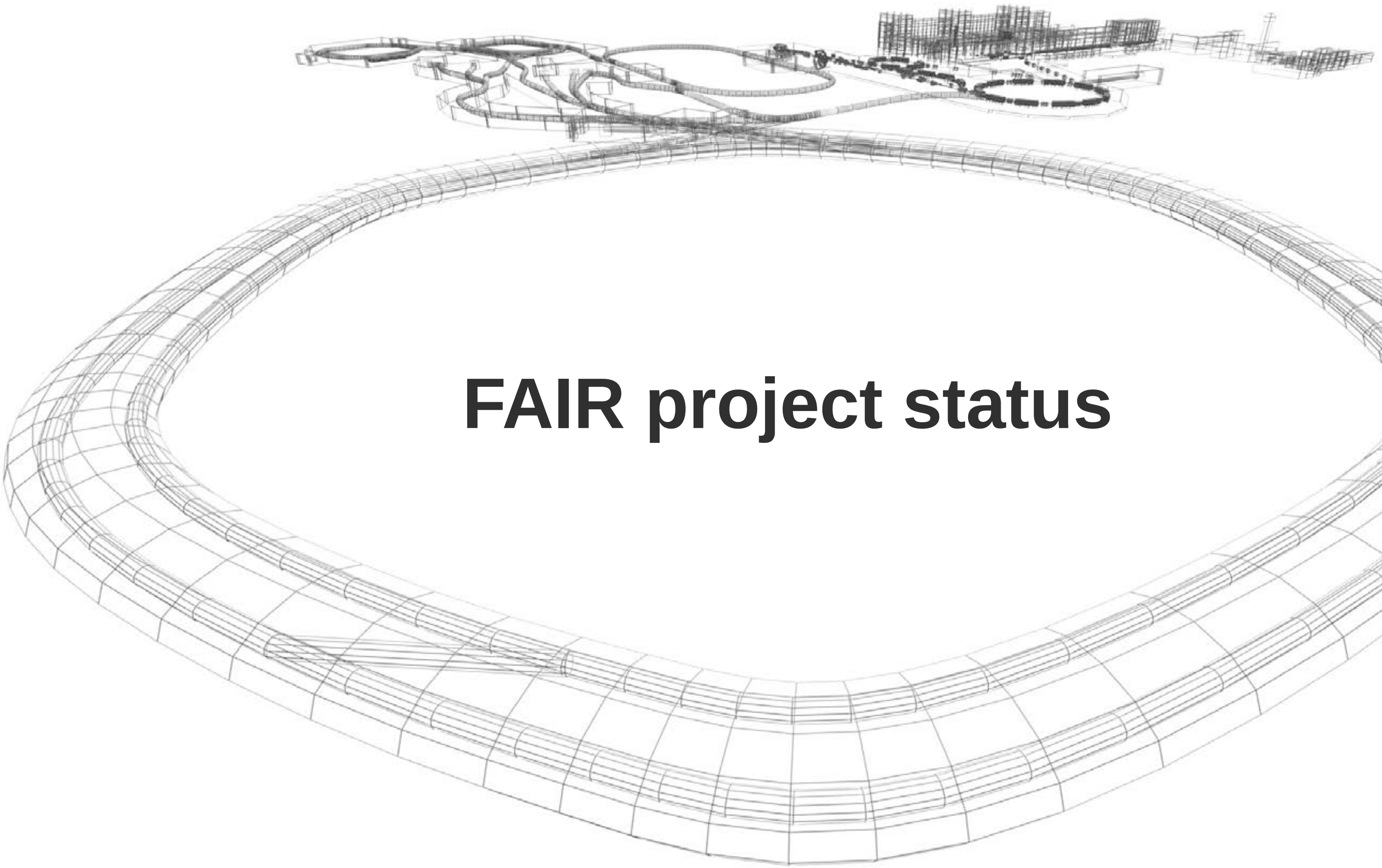
  lifetime reduction, phase shift over bunch train, losses
  → careful set up and control of RF-parameters
  → appropriate low-level RF-control

- **top up operation: injection from booster in short VSR bunches, lifetime**

  bunch length in booster 60 ps, injection efficiency > 90%
  → bunch "compression" in booster at least by factor 2 needed

solved by some modification of the booster and optimization of injection!

FAIR project status



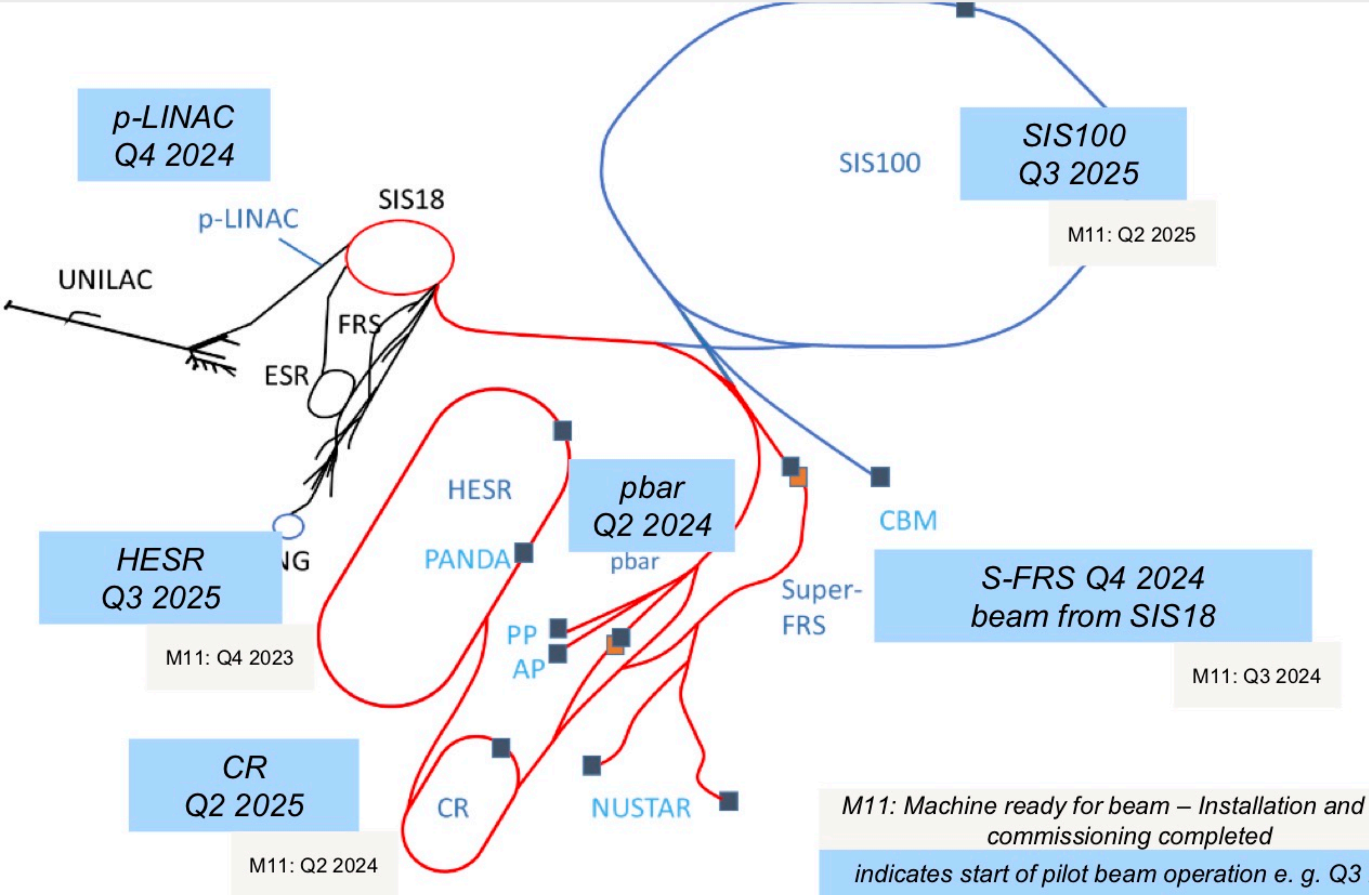
Status FAIR construction / components

SIS100 tunnel segment

SIS100 sc dipole modules in GSI storage area: half of the dipoles delivered and accepted.

Kick-off of Super-FRS magnet testing facility at CERN: First of series (FoS) multiplet.

FAIR completion dates

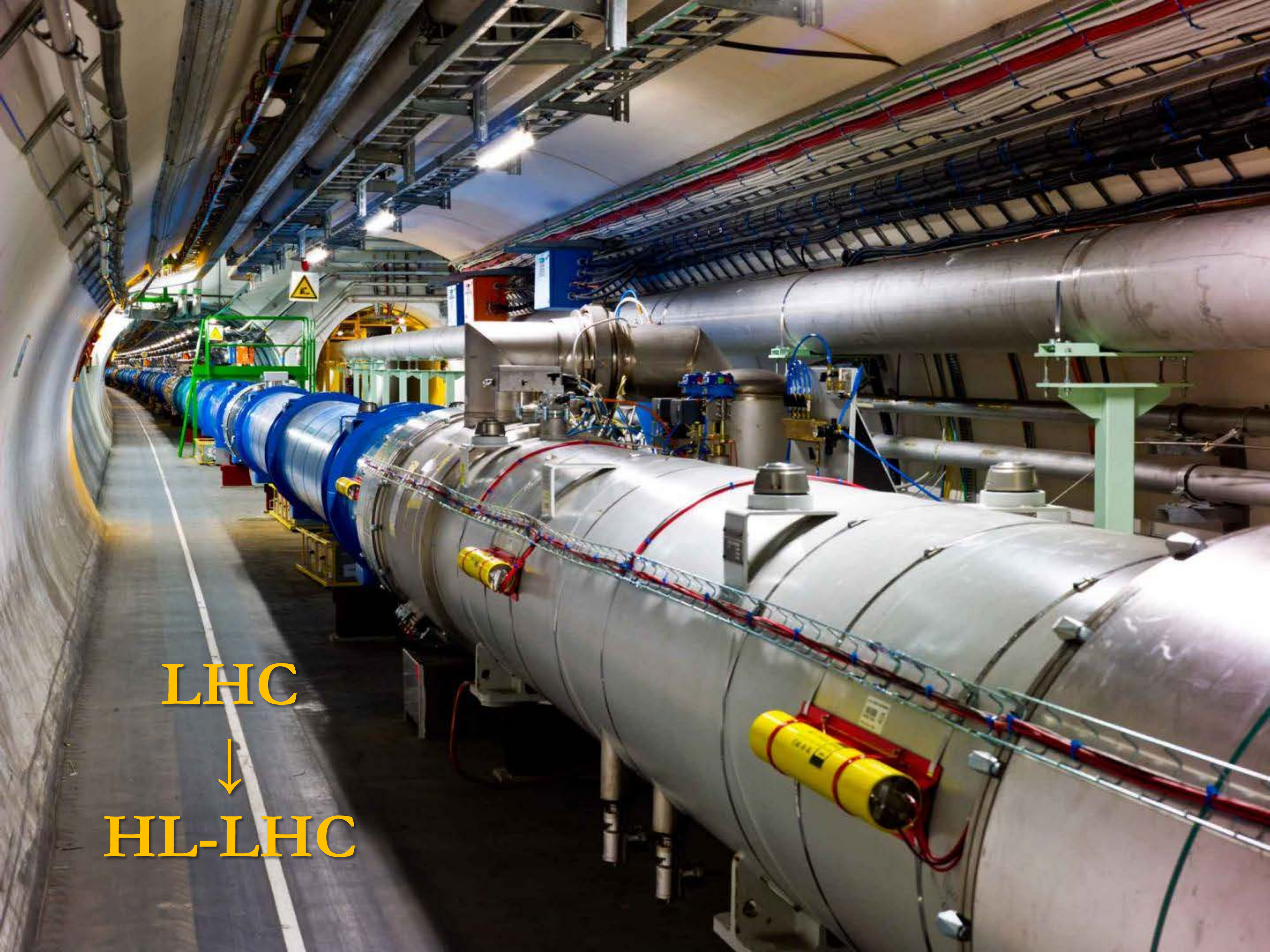


M11: Machine ready for beam – Installation and cold commissioning completed

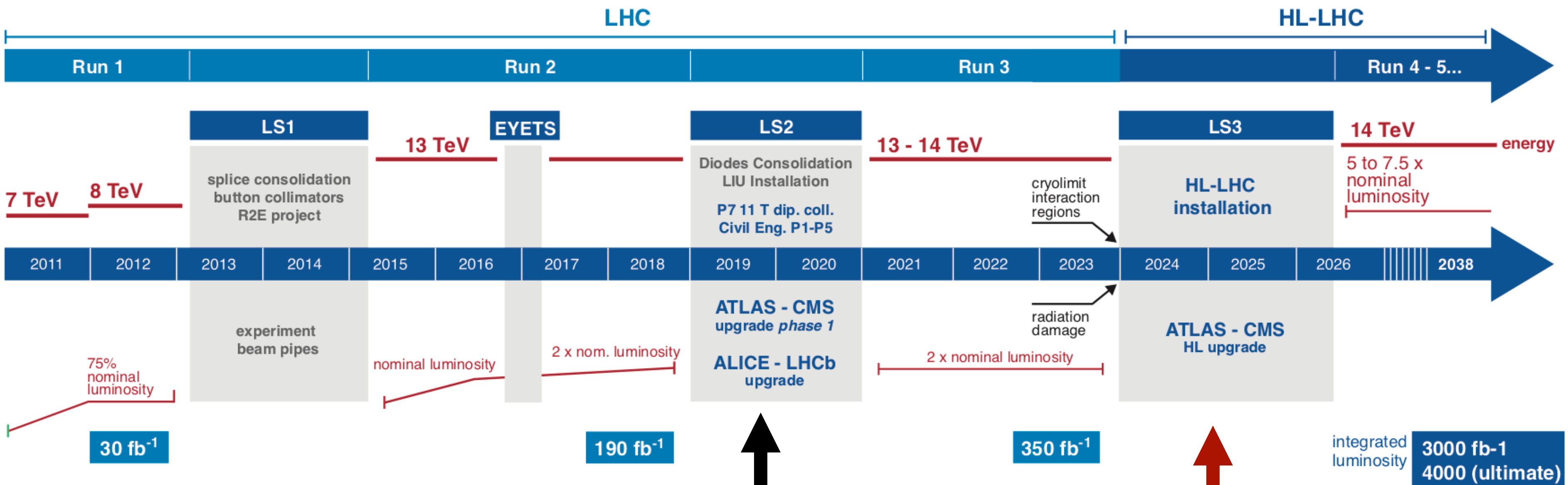
indicates start of pilot beam operation e. g. Q3 2025

FAIR accelerator physics R&D

- Fast ramping sc magnets for synchrotrons
- Large aperture sc magnets for fragment separators
- Fast beam cooling at medium and high energies
- Beam dynamics: Intensity limitations and advanced stabilization schemes
- Control of UHV pressures for intense ion beams
- Simulation tools and advanced optimization schemes for commissioning and intensity ramp up


LHC
↓
HL-LHC

HL-LHC parameters and timeline



LS2 (2019-2020):
- ❑ LHC Injectors Upgrade (**LIU**)
- ❑ Civil engineering for HL-LHC equipment P1, P5
- ❑ Installation of (part of) 11T Nb_3Sn dipoles for HL-LHC
- ❑ Phase-1 upgrade of LHC experiments

LS3 (2024-2026):
- ❑ HL-LHC installation
- ❑ Phase-2 upgrade of ATLAS and CMS

LIU will provide beams of intensity and brightness needed by HL-LHC (2.3×10^{11} p/bunch, ε~ 2.1 μm)

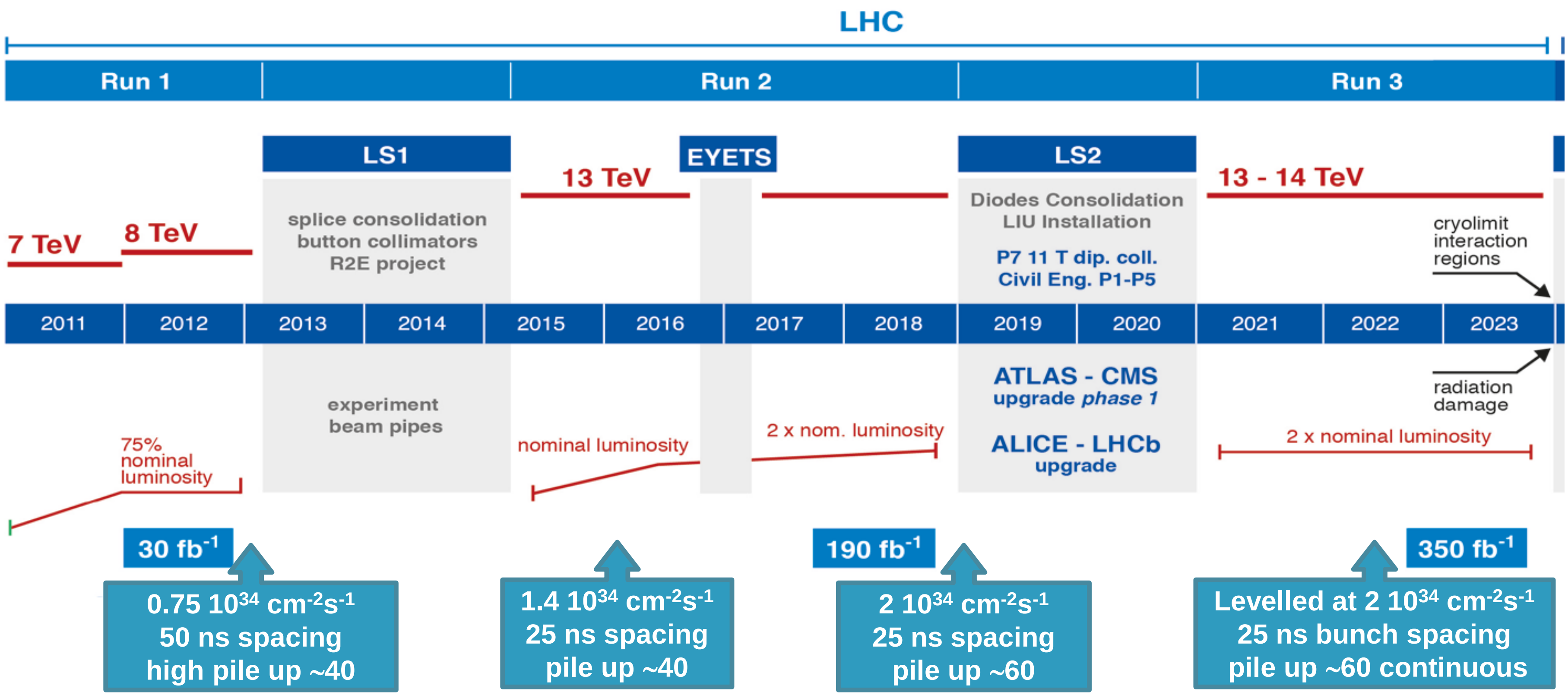
Linac 4: 160 MeV H^-

PSB: 1.4→ 2 GeV

PS: new injection and feedback systems

SPS: new 200 MHz RF system

LHC / HL-LHC Plan

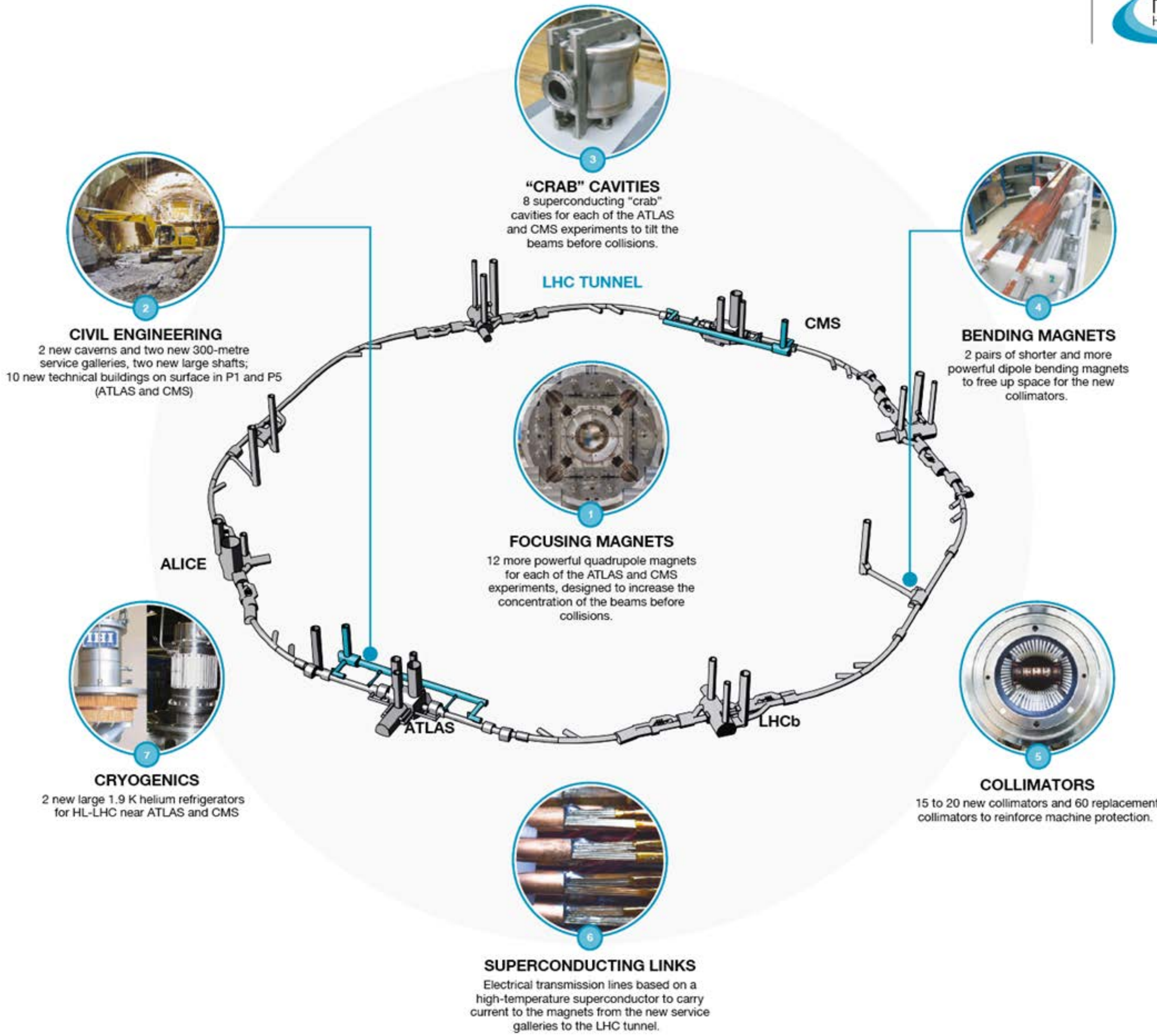


Technical limitation on the Instantaneous Luminosity:

1. **Collider** (cryolimit in the triplet region) at 2×10^{34} $cm^{-2}s^{-1}$ twice the nominal design luminosity)
2. **Experiments** (pile up in the detectors). Designed for peak of 40 they are actually dealing with 60!

Technical limitation on Integrated Luminosity:

1. **Collider** (radiation damage to the IT magnets – correctors and quadrupoles)
2. **Experiments** (radiation damage in the Inner Tracker)

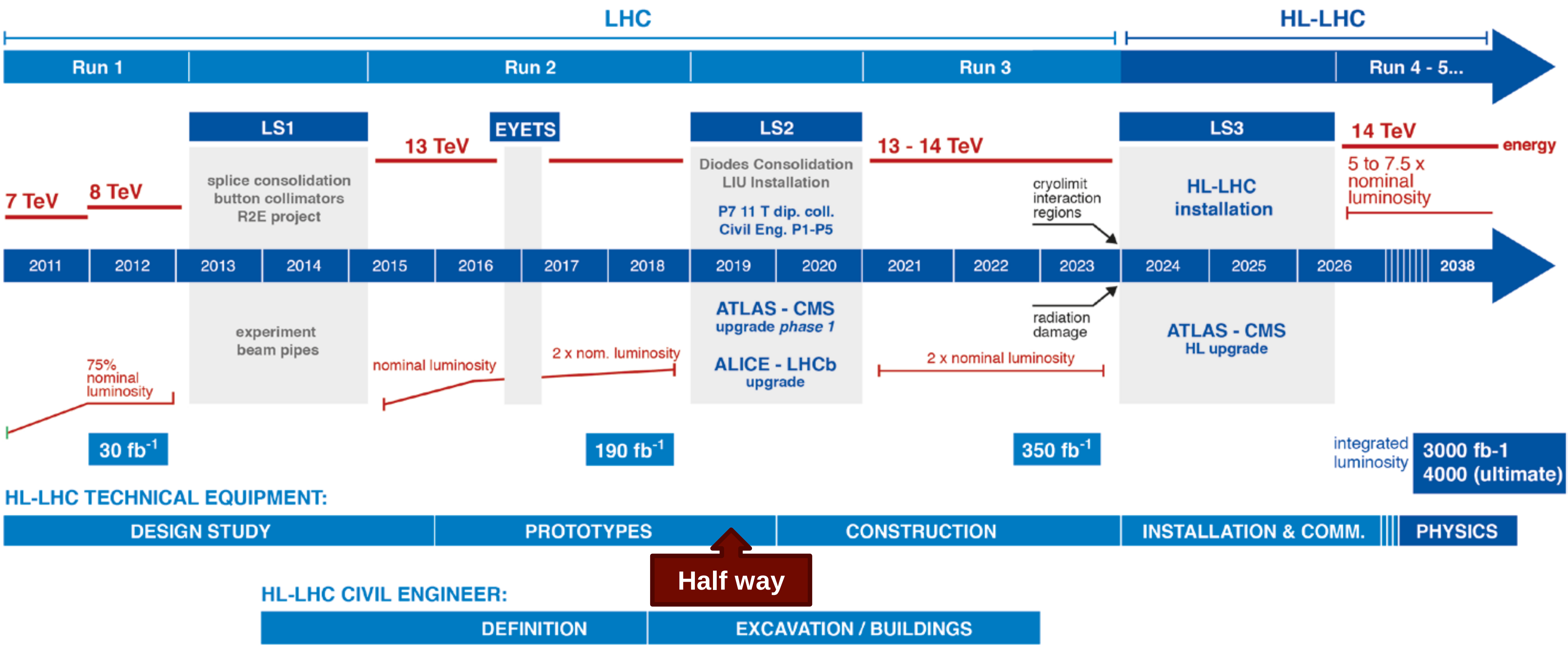


Rebuilding ~1.2km of LHC (the most complicated bit!)

But also touches very many other systems around the machine

- **New IR-quads Nb_3Sn (inner triplets)**
- **New 11 T Nb_3Sn (short) dipoles**
- **Other NbTi magnets in the IR**
- **Collimation upgrade**
- **Cryogenics upgrade**
- **Crab Cavities**
- **Cold powering**
- **Machine protection**
- **…**

LHC / HL-LHC Plan



- **Now deep into the construction phase …**
- **Some installations already during LS2 as well as civil engineering works**
- **Main installation work during a 30 month stop (LS3): 2024-2026**