Lesson learnt in the planning and execution of the SLS-2.0 upgrade project

10th Low Emittance Rings Workshop 2025

DESY 8-10 October 2025

Hans-H. Braun

with slides provided by many colleagues

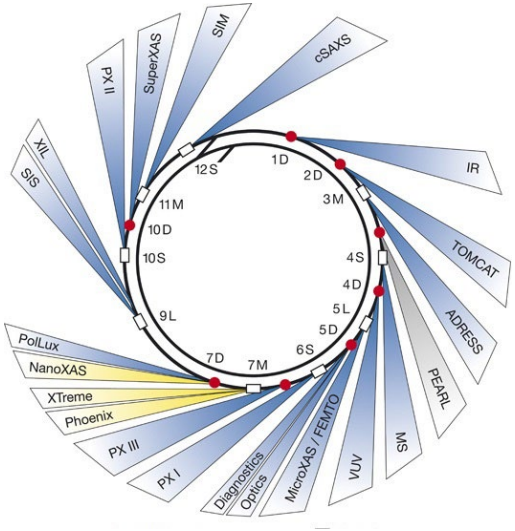
Content

- Introduction
- Project structure
- Design phase
- Magnets in general and permanent magnets in particular
- OHE Copper vacuum chambers
- Things easily to be underestimated
- Space and logistics
- Commissioning & Oscilloscopes
- Things you definitely need for an upgrade project
- Things you definitely don’t need

Introduction SLS and SLS2.0

Swiss Light Source, SLS

Operated for more than 20 years with
a very successful, international science program!



SLS top cited

Kristina N. Ferreira,
So Iwata *et al.*,
Architecture of the photosynthetic oxygen-evolving center,
Science **303** (2004).
DOI: 10.1126/science.1093087
SLS beamline PX I

Su-Yang Xu,
M. Zahid Hasan *et al.*,
Discovery of a Weyl fermion semimetal and topological Fermi arcs,
Science **349** (2015).
DOI: 10.1126/science.aaa9297
SLS beamline ADRESS

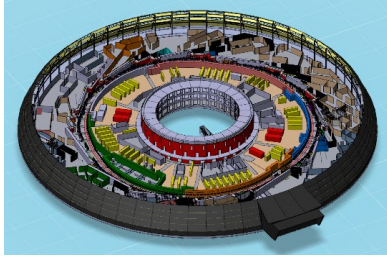
Bernhard Misof,
Xin Zhou *et al.*,
Phylogenomics resolves the timing and pattern of insect evolution,
Science **346** (2014).
DOI: 10.1126/science.1257570
SLS beamline TOMCAT

D. Hsieh,
M.Z. Hasan *et al.*,
A tunable topological insulator in the spin helical Dirac transport regime,
Nature **460** (2009).
DOI: 10.1038/nature08234
SLS beamline SIS

Bernhard Loll,
Jacek Biesiadka *et al.*,
Towards complete cofactor arrangement in the 3.0 Å resolution structure of photosystem II,
Nature **438** (2005).
DOI: 10.1038/nature04224
SLS beamline PX I

Five out of ~9'500, cited in total more than 10'000 times (Each paper cited more than 1'600 times).

SLS 2.0, Goals and methods



Project Goal

Continue to provide SLS users optimum conditions for their experiments

Methods

New storage ring in existing building with MBA magnet lattice and new insertion devices

→ *Increased photon brilliance* → *higher resolution, faster measurements, larger samples*

Increase of beam energy from 2.4 GeV to 2.7 GeV and s.c. superbends

→ *Higher X-ray flux*

→ *Access to higher photon energies*

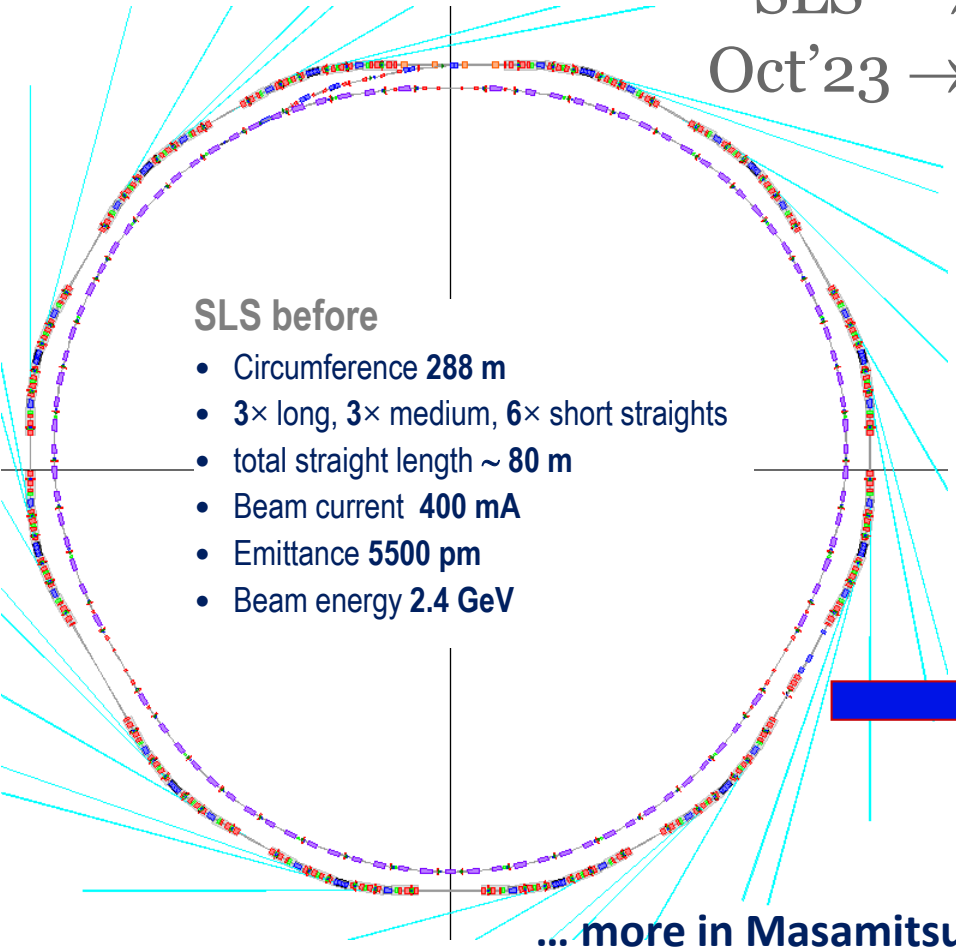
Some new beamlines, many upgraded beamlines

→ *New scientific opportunities*

New concepts for data acquisition, processing and storage

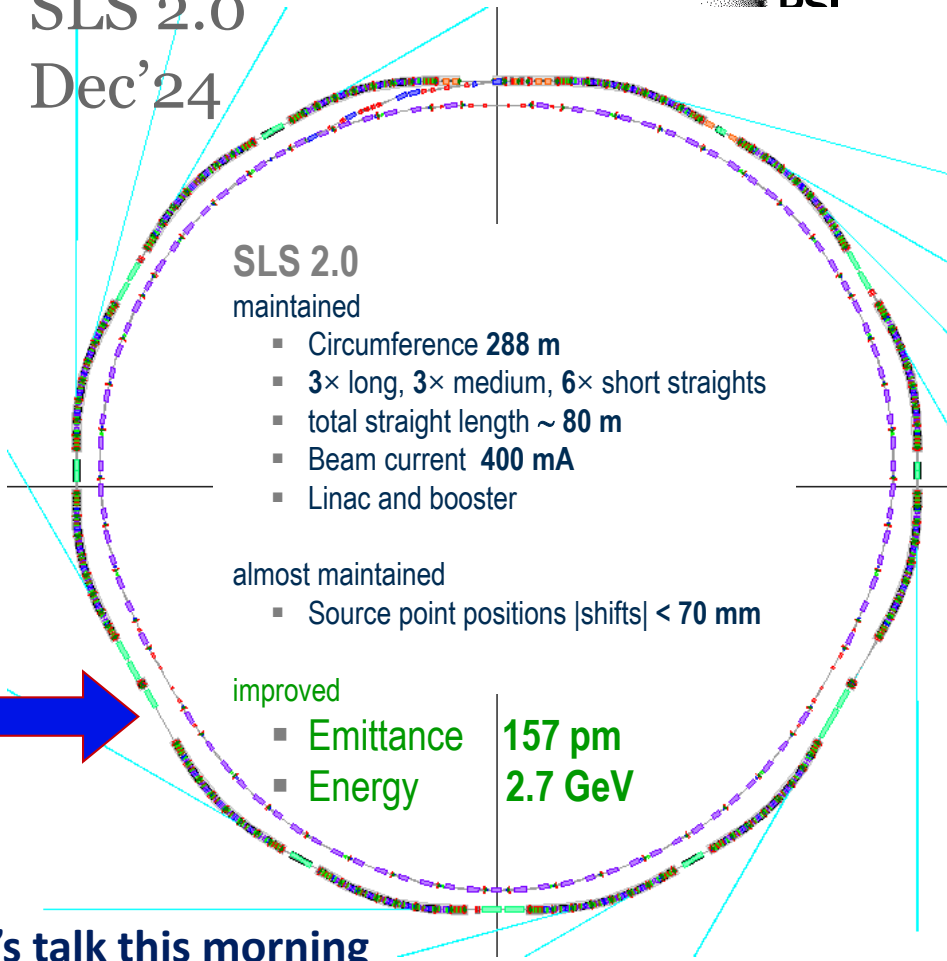
→ *Capability for increased data rate, improved and more standardized user interface across beamlines*

SLS → SLS 2.0
Oct'23 → Dec'24



SLS before

- Circumference **288 m**
- **3**× long, **3**× medium, **6**× short straights
- total straight length ~ **80 m**
- Beam current **400 mA**
- Emittance **5500 pm**
- Beam energy **2.4 GeV**



SLS 2.0

maintained

- Circumference **288 m**
- **3**× long, **3**× medium, **6**× short straights
- total straight length ~ **80 m**
- Beam current **400 mA**
- Linac and booster

almost maintained

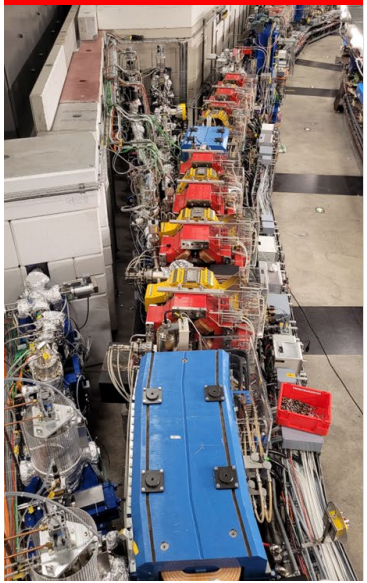
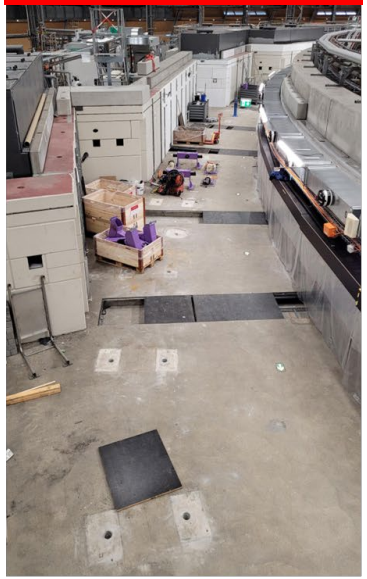
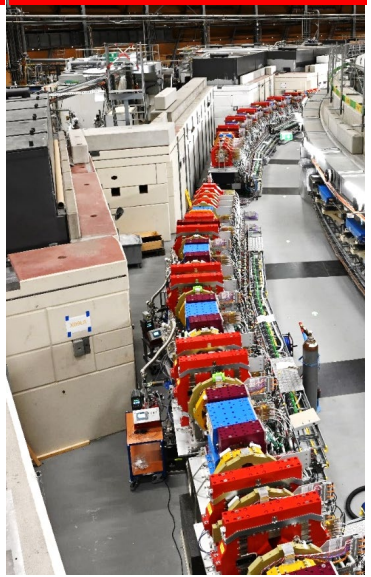
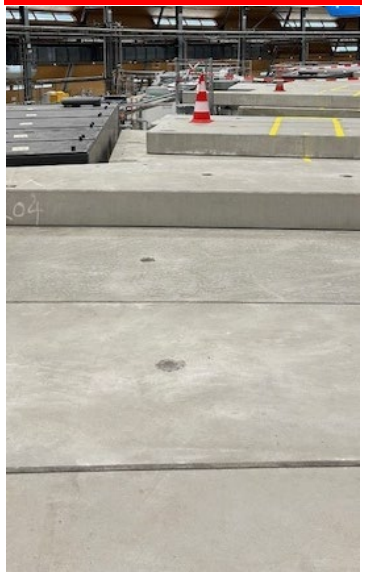
- Source point positions |shifts| **< 70 mm**

improved

- Emittance **157 pm**
- Energy **2.7 GeV**

… more in Masamitsu's talk this morning

View of the SLS 2.0 tunnel during dark time

3.10.2023	28.11.2023	7.3.2024	1.7.2024	3.9.2024
				

SLS 2.0 Master Milestones

PSI

8.10.2025

1 storage ring lattice defined 30.06.2020

3 SLS2.0 funding secured 01.01.2021

6 tunnel closure 20.12.2024

8 start user operation, BL-Grp.1 01.08.2025

10 re-start user operation 01.06.2026

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

2 beamlines & beamline positions defined 30.09.2020

4 ready for dark time 17.10.2022

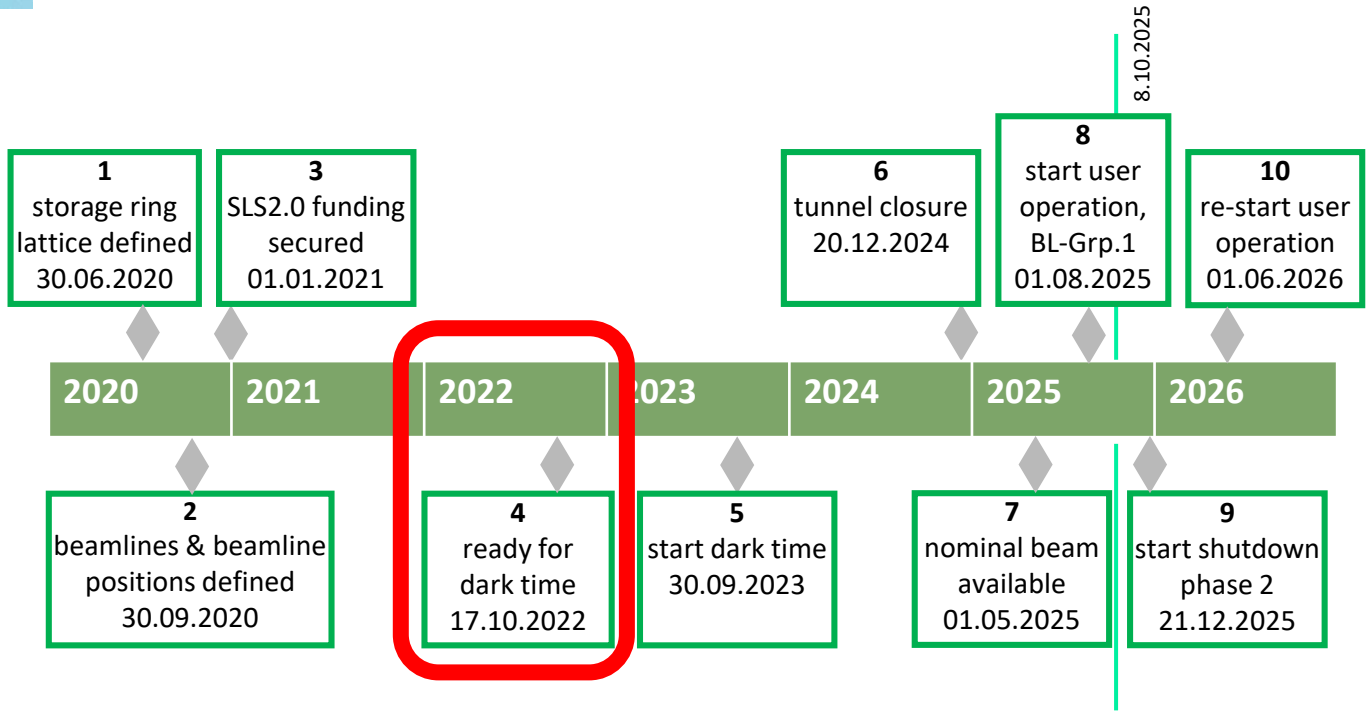
5 start dark time 30.09.2023

7 nominal beam available 01.05.2025

9 start shutdown phase 2 21.12.2025

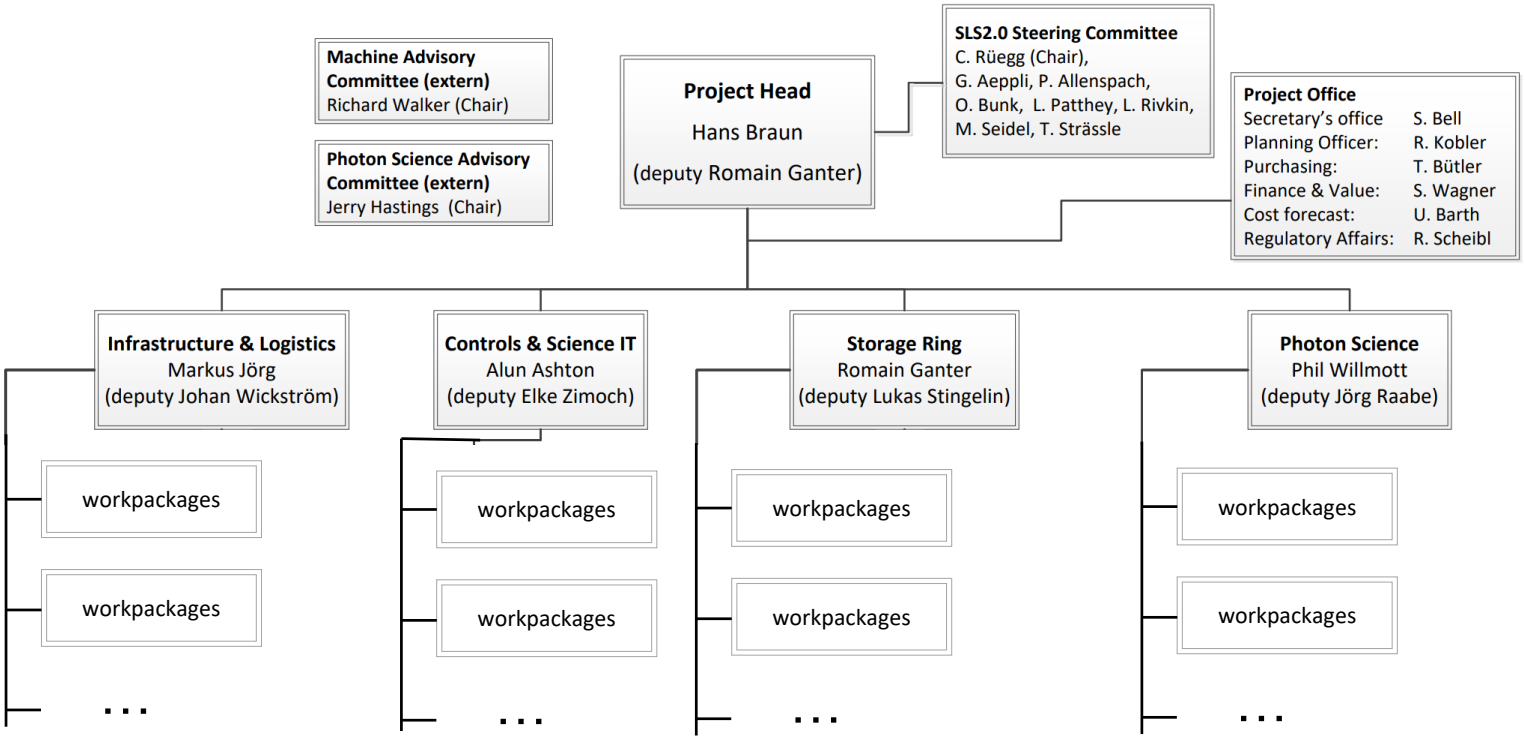
SLS 2.0 Master Milestones

PSI



Challenge: **Limit the gap!**

SLS 2.0 Project Structure



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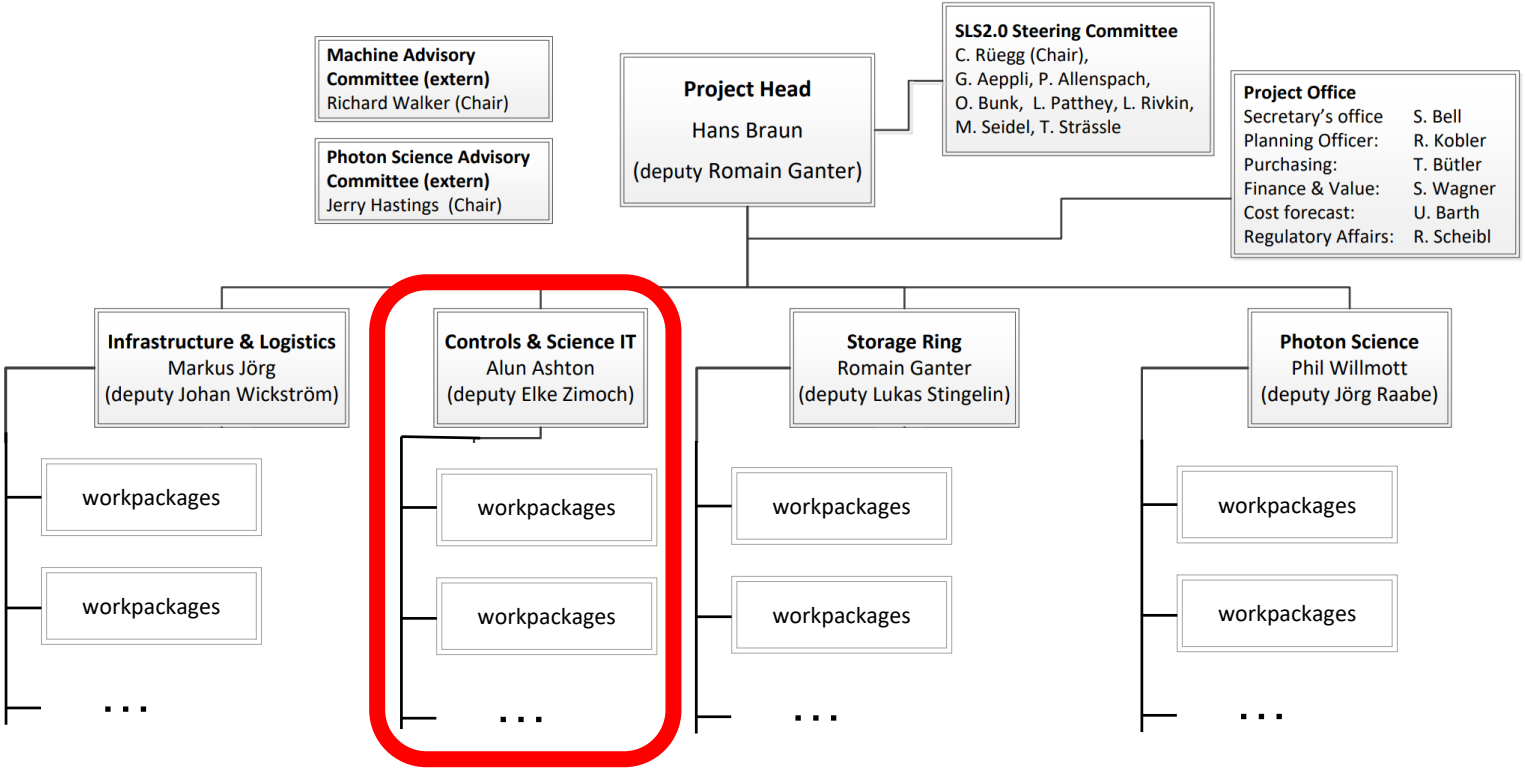


Design phase

- Emittance sounds good, but spectral brightness is the real goal.
  Inventory of all beamlines with the expected performances of IDs/bend sources should be part of the lattice and ID optimization
- Take optimum beam energy into account for this optimization
- Take energy consumption into account

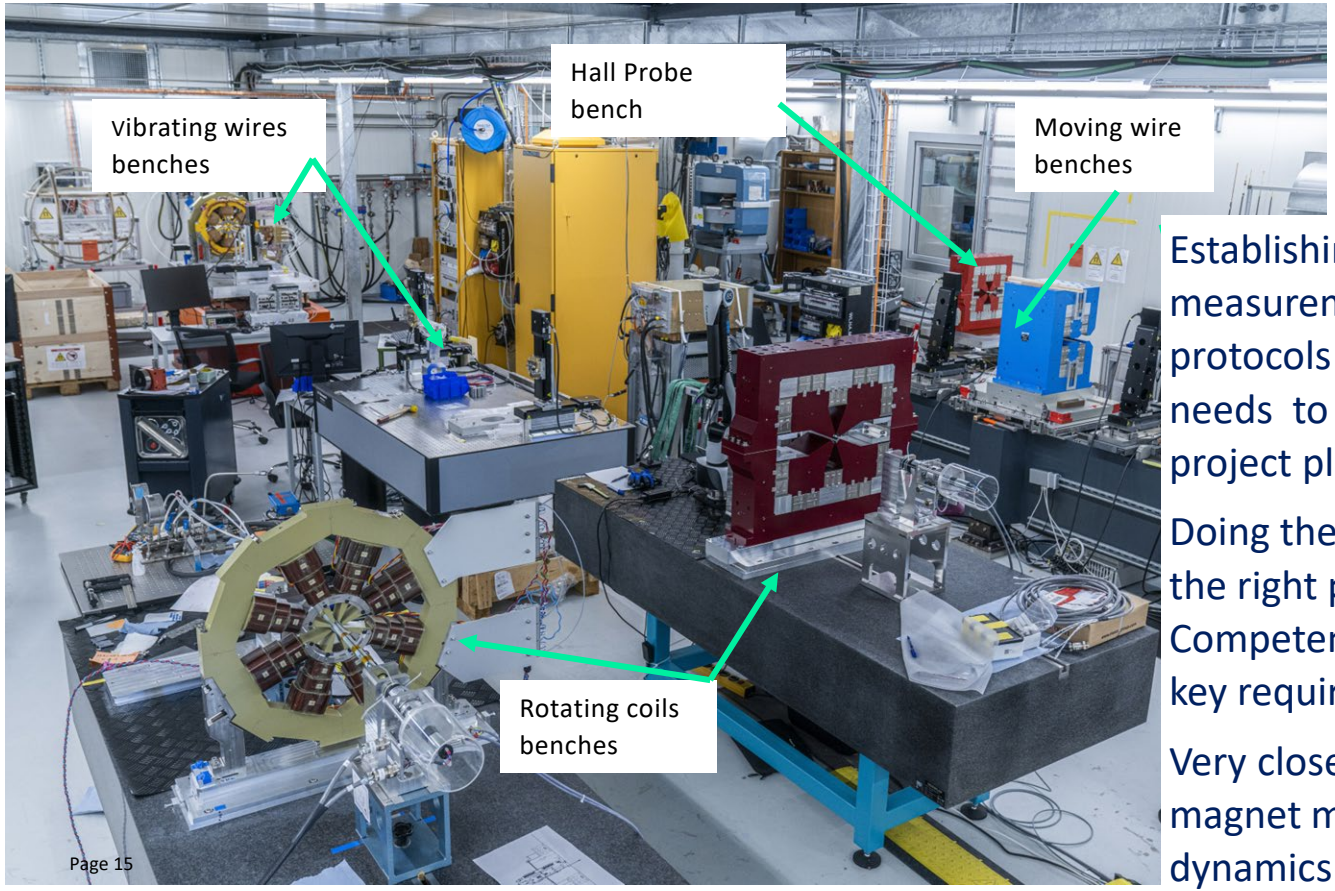
Magnets

Magnet measurement and correction

is demanding for 4^{th} generation rings because

- Combined function magnets
- Longitudinal gradient magnets
- Cross talk because of tight spacing and use of permanent magnets
- Tight specs
- Permanent magnets
- There are many

Magnets

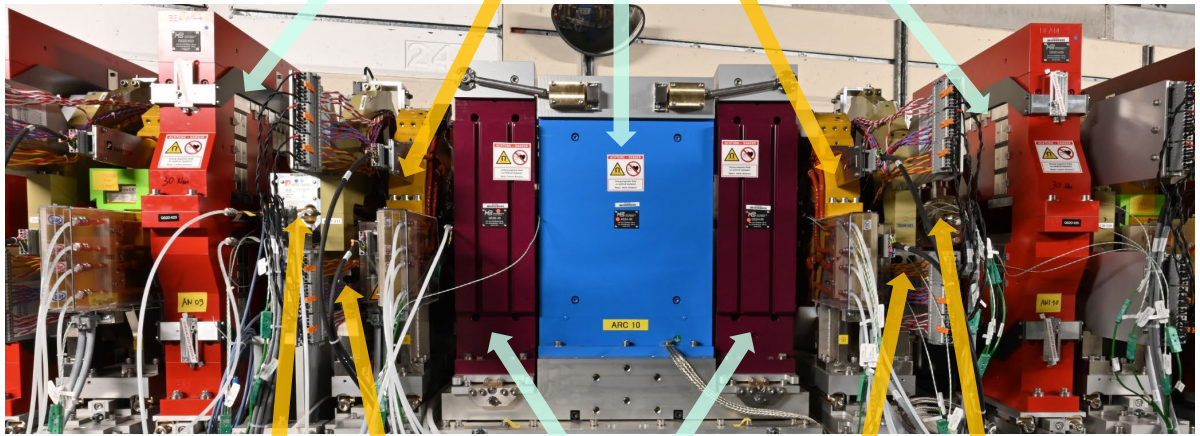


Establishing and testing good measurement and correction protocols takes a lot of time, which needs to be accounted for in the project plan.

Doing the series measurements needs the right people and enough of them. Competence and perseverance are key requirements.

Very close collaboration between magnet measurement team and beam dynamics team is a must.

One of 84 LGB-RB cells



PSI

NdFeB , Armco
PM Magnet

Cu, Armco
Electromagnet

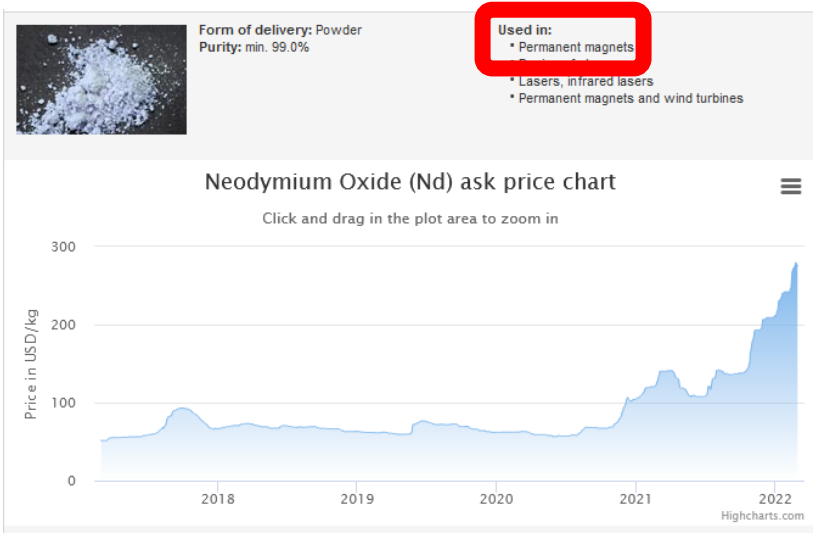
A very dense lattice with many permanent magnets requires special attention on magnetic cross talk.

→ simulation and measurement of magnet combinations to apply the right corrections.

→ **Giuseppe's talk tomorrow**

Permanent magnet procurement

Prices for raw material of permanent magnets can fluctuate considerably with time.
Contracts with suppliers have often a dynamic pricing according to a raw material index.
This can be a major cost risk!



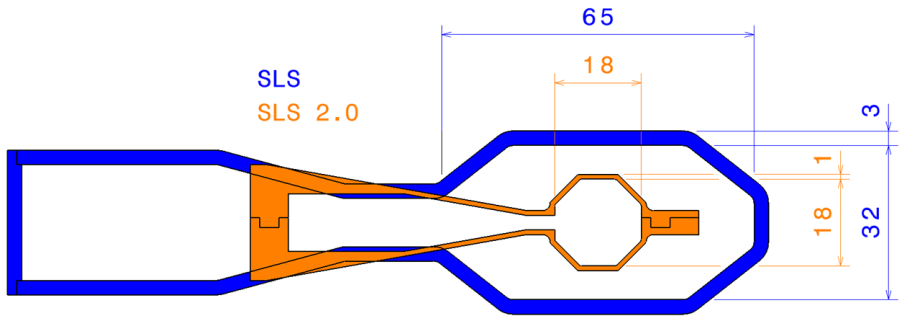
We bought 17 tons of NdFeB magnets in 2022

Permanent Magnets have very specific safety risks

A dedicated risk analysis and related training of personnel are essential for safety.

But it's difficult to foresee all possible risks

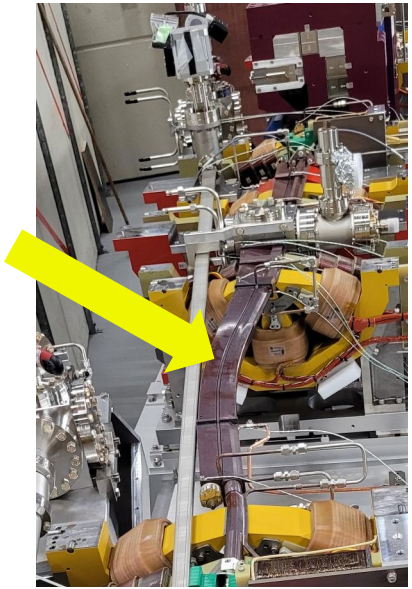
Arc Vacuum Chamber



SLS 1 chamber was built from 3 mm thick stainless steel, a very hard and stiff material

SLS 2.0 chamber is only 1 mm thick and built from OHE copper, a quite soft material.
We were very worried about damaging the vacuum envelope during assembly.

Cu chamber



Copper chamber after a dipole magnet
of wrong type (small gap, high field version) was moved in

Two lessons learned

1) Don’t use **dark blue** vs **bright blue** color to distinguish two magnet types for correct assembly.
2) Copper chambers are soft but tough. The chamber was bent by several centimeters but stayed UHV vacuum tight.

Things easily underestimated

- Required number of qualified electricians
- Required number of qualified mechanical designers
- Storage, assembly and maneuvering space

Dismantling

364 / 364	3’640t	Concrete blocks
50 / 50	315t	Girder
98 / 98	80t	Girder feet
39 / 39	95t	Dipoles
11 / 11	85t	Undulators
5 / 5		Cavities
26 / 26		Front ends
580m / 580m		cooling pipe
150 / 150		Racks

> 4’215t material were moved out of SLS

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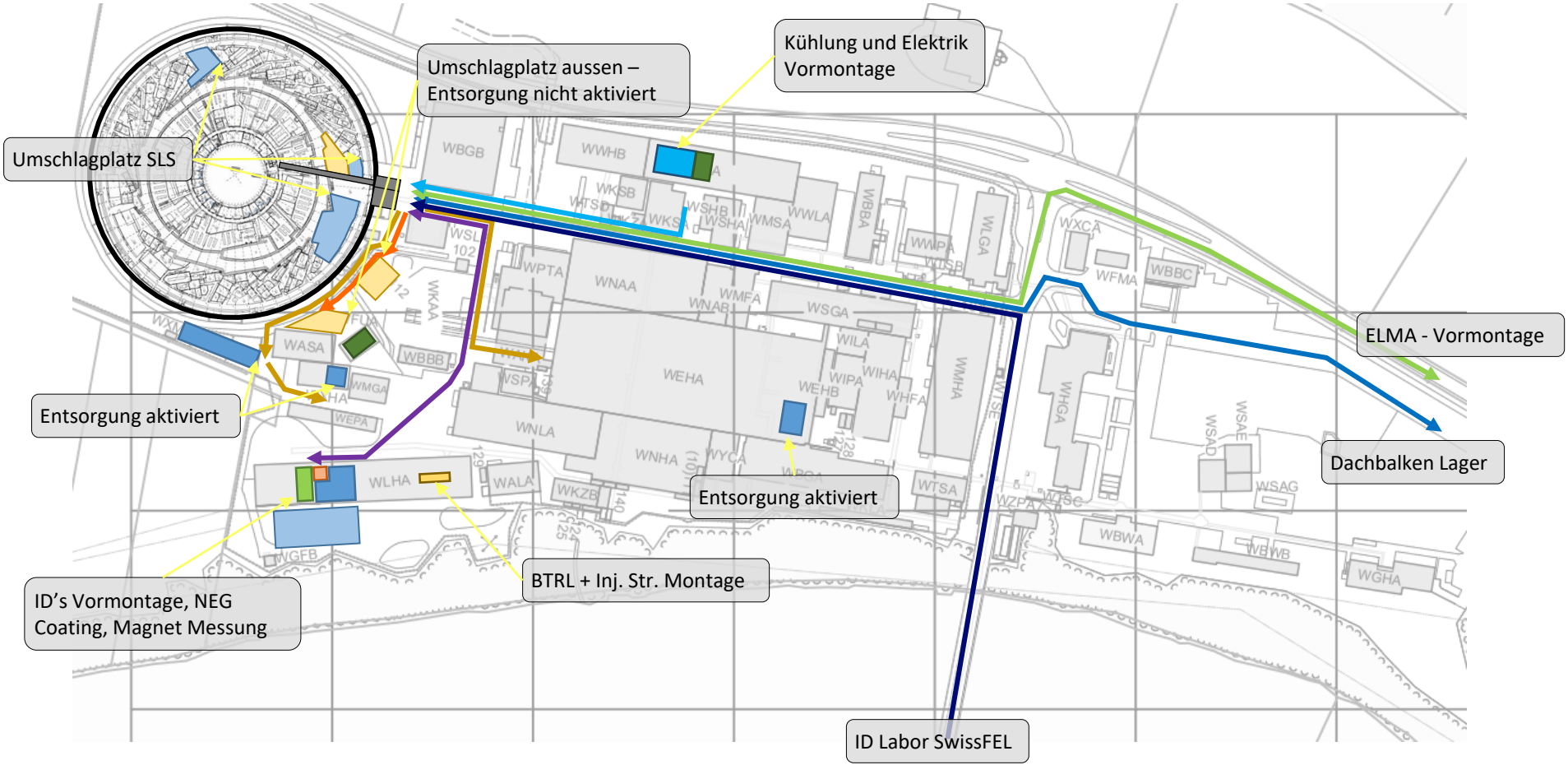
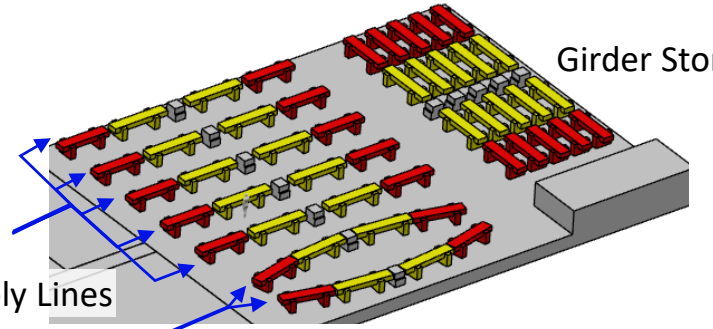
PSI

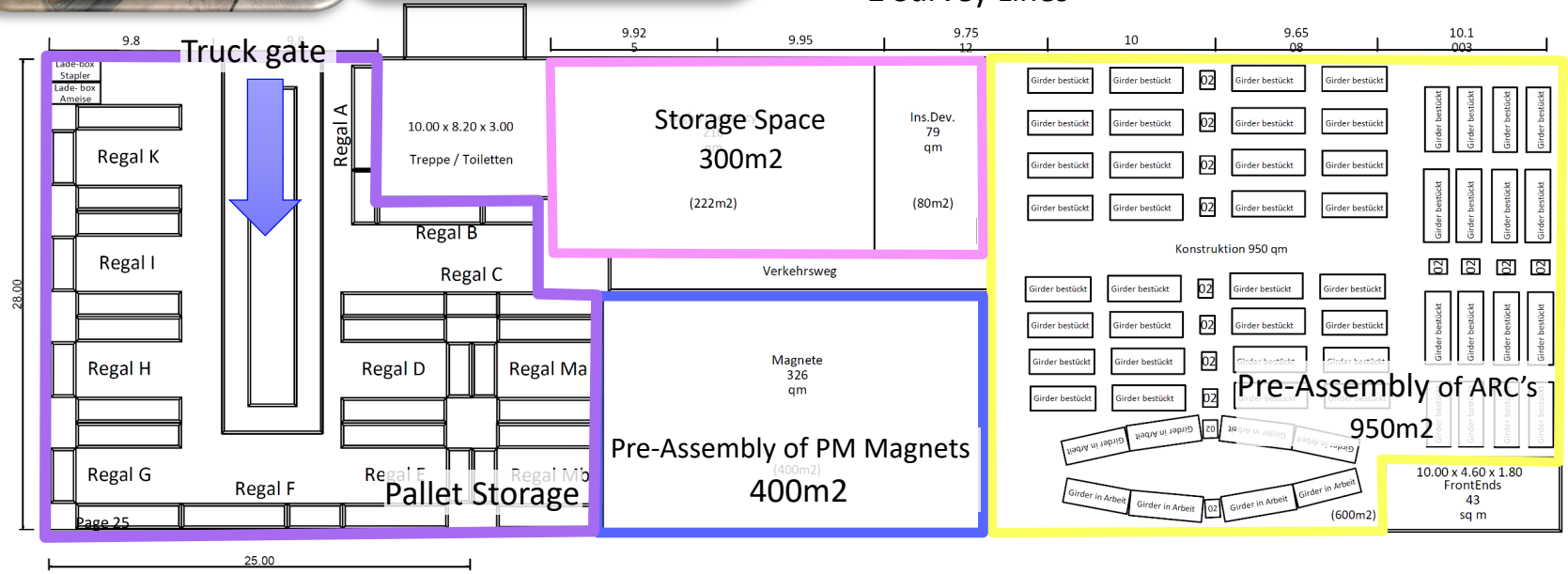
This corresponds to 3 freight trains of 750m length each

Preassembly, Storage space planning and transport paths

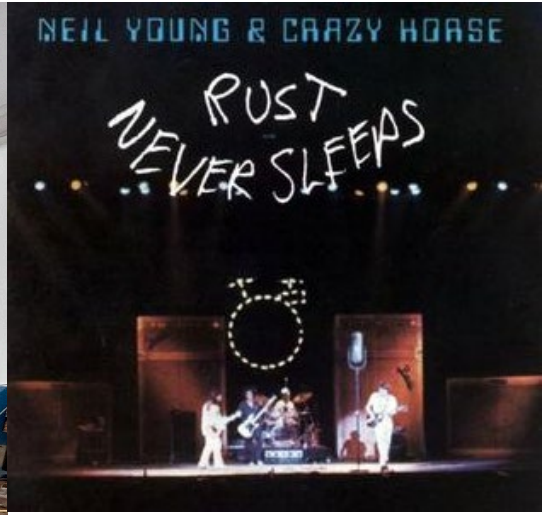


SLS 2.0 Storage and pre-assembly hall outside PSI





On site tent storage for components of the old ring



SLS 2.0 - Subproject Infrastructure & Logistics

Energy consumption (1)

Prediction in 2020

PSI

Increased beam quality:

Electron energy from **2.4 to 2.7 GeV**

Improvement of brilliance of ≈**35**

Increased Energy Efficiency by:

Use of permanent magnets

Use of solid-state RF amplifiers

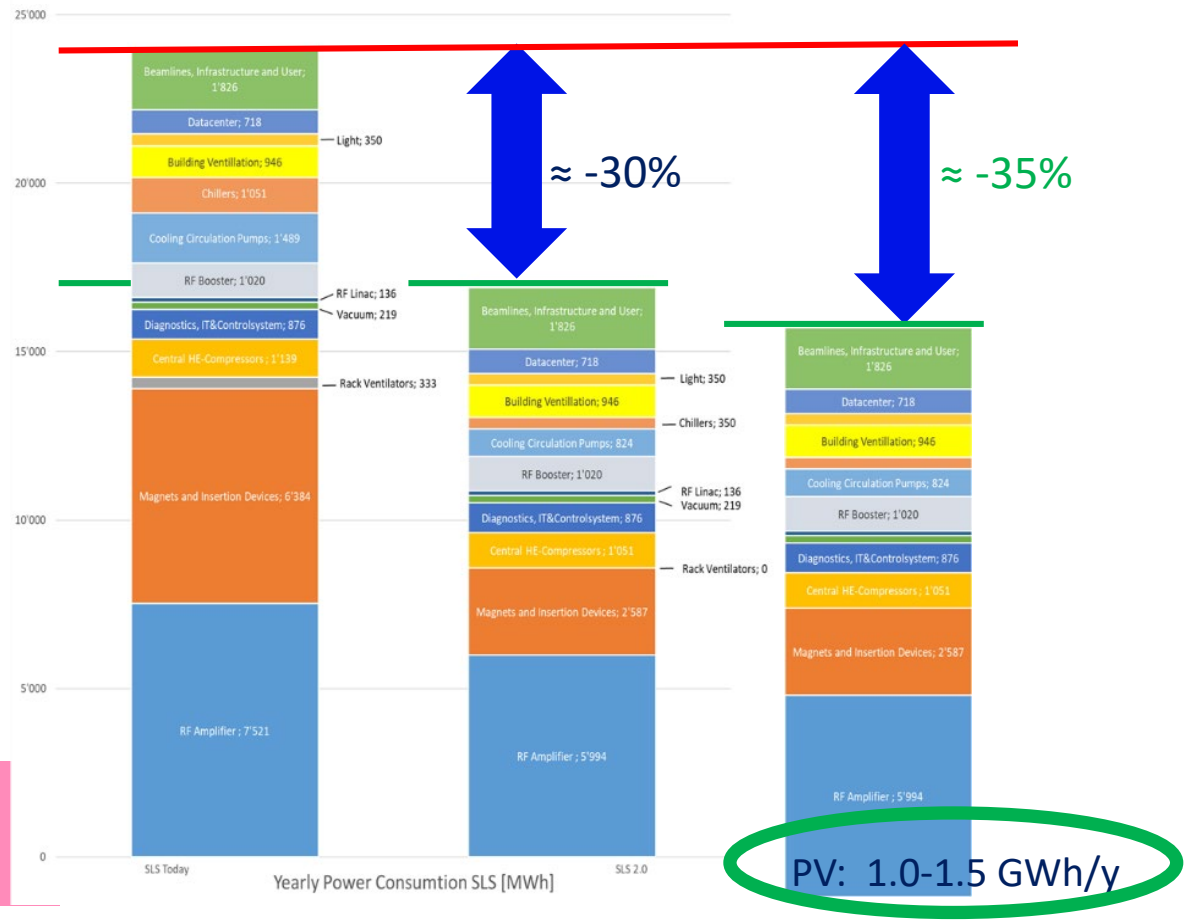
Optimized cooling infrastructure

Energy Consumption: **24** → **17 GWh/a**

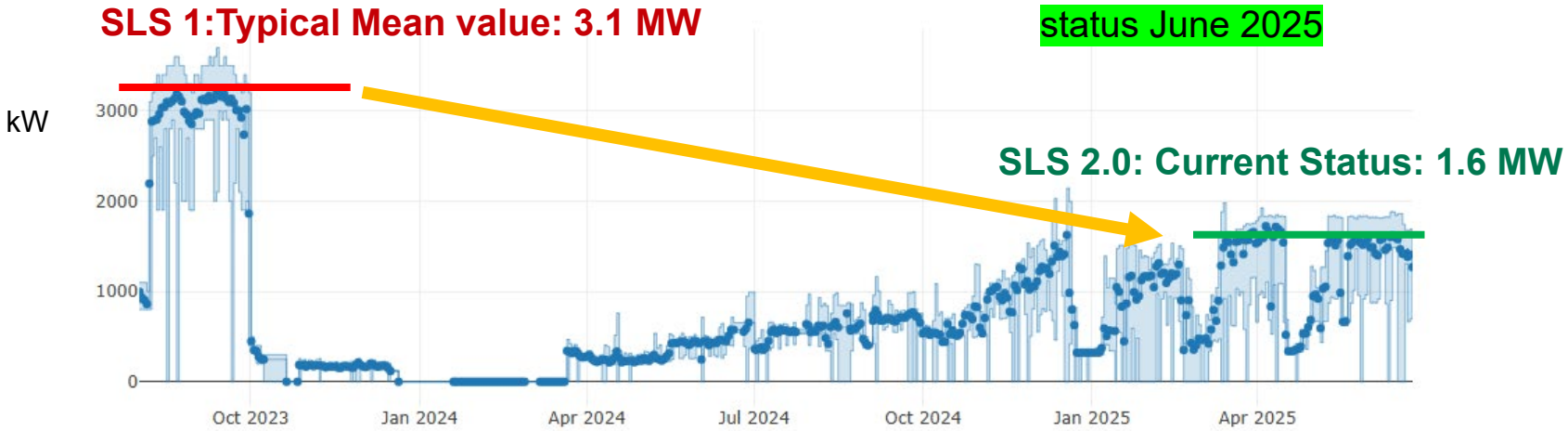
Add-on: New PV-System (approx. 1.25 GWh/a)

«Photons of the sun provide photons for our experiments»

Simultaneously achieving a **35 % reduction in total energy consumption** and a **35-fold enhancement** in **beam quality / brilliance**!



SLS 2.0 - Subproject Infrastructure & Logistics

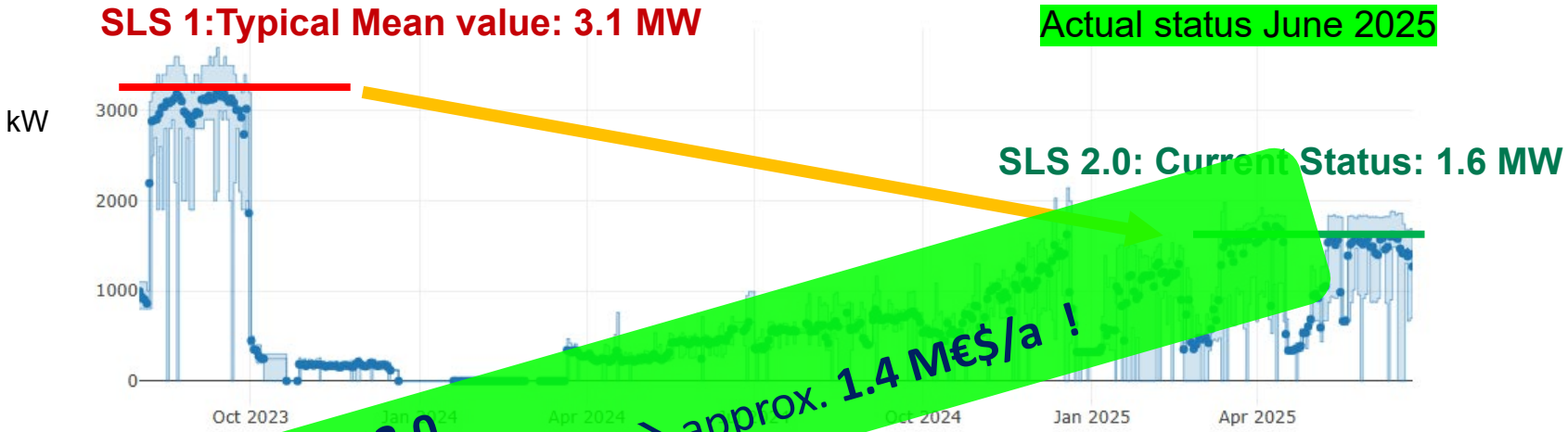


Status / Outlook Energy consumption

- ✓ Magnets on nominal power
- ✓ RF Storage ring with 400 mA nominal current
- At time, when all beamlines and the cooling system is in full operation: plus approx. 200-400 kW
- Prediction for full operation: 2 MW, **- 35 % power consumption compared to SLS 1**
- Reduction in energy consumption: approx. 7.5 GWh/a
- Production of PV system: approx. 0.8 GWh/a

SLS 2.0 - Subproject Infrastructure & Logistics

PSI



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Commissioning, Control Rooms & Oscilloscopes

Control room of our ancestors

Control room today

… but when you start a new ring using a new timing system for the first time
a few key signals on one oscilloscope can still speed up things a lot!

Things you definitely need for an upgrade project

Project beer

Project koozy

Project doughnut

Project coffee mug

Things you definitely don’t need

1) The fantastic progress with 3D CAD systems in recent decades allows
   to have easily scalable 3D STP files for any single components of a new ring

2) The fantastic progress of 3D printers in recent decades allows
   to easily print scaled plastic models of any item which can be modelled as a STP file

Things you definitely don’t need

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3) The combination of 1) and 2) led to the assumption that project managers love to have funny little scaled plastic models of almost any single component of the new ring in their office, home, car …

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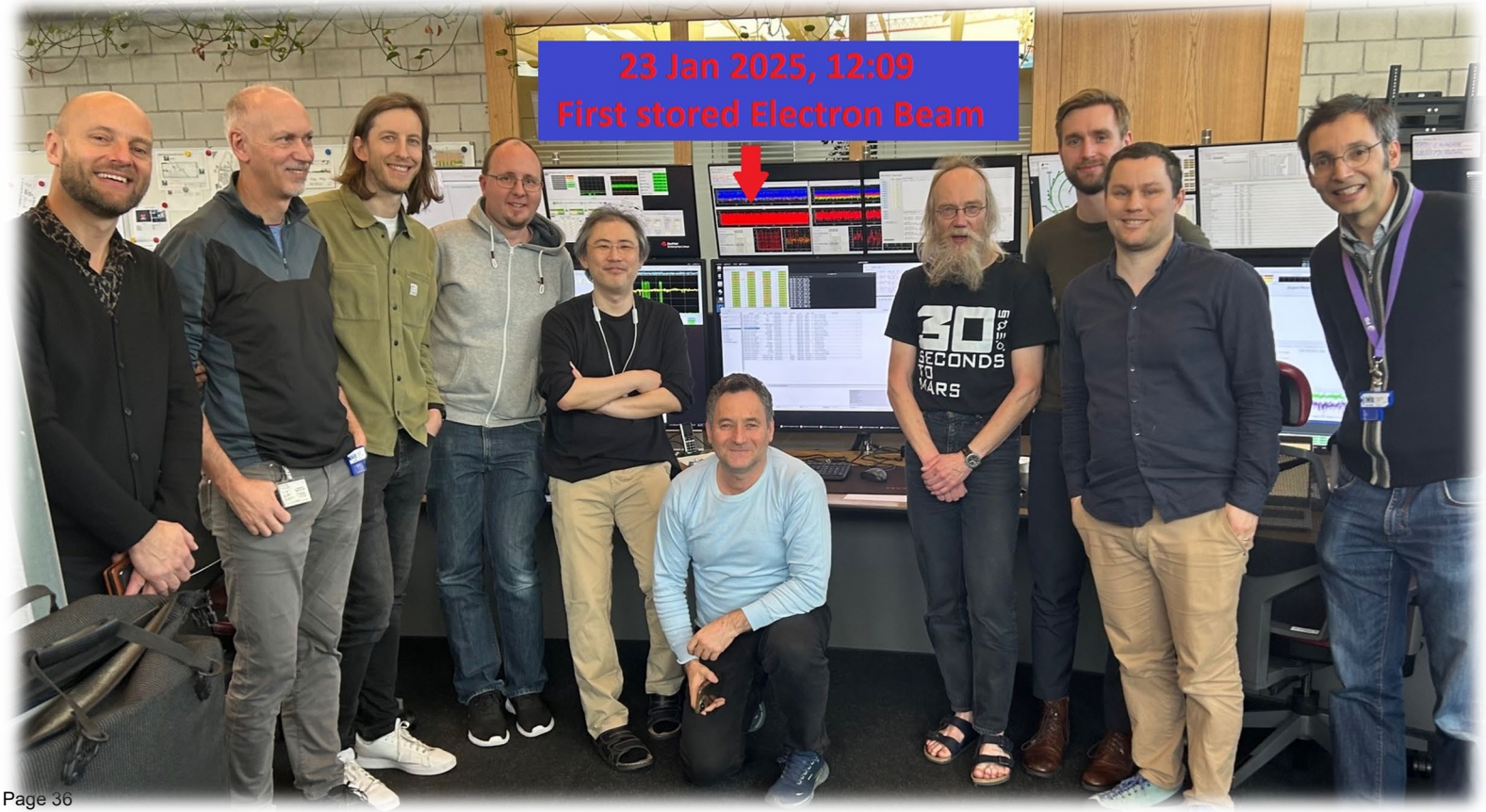
Please

Installing the SLS2.0 ring

23 Januar 2025, 12:09: First Stored Beam in SLS2.0



Final remarks

SLS 2.0 profited very much from

- The pioneering MAX IV work of building the first MBA ring
- The experience gained at ESRF with the conversion of a 3rd to a 4th generation ring
- The advice of our MAC and PSAC


Thank you for your attention
SINQ