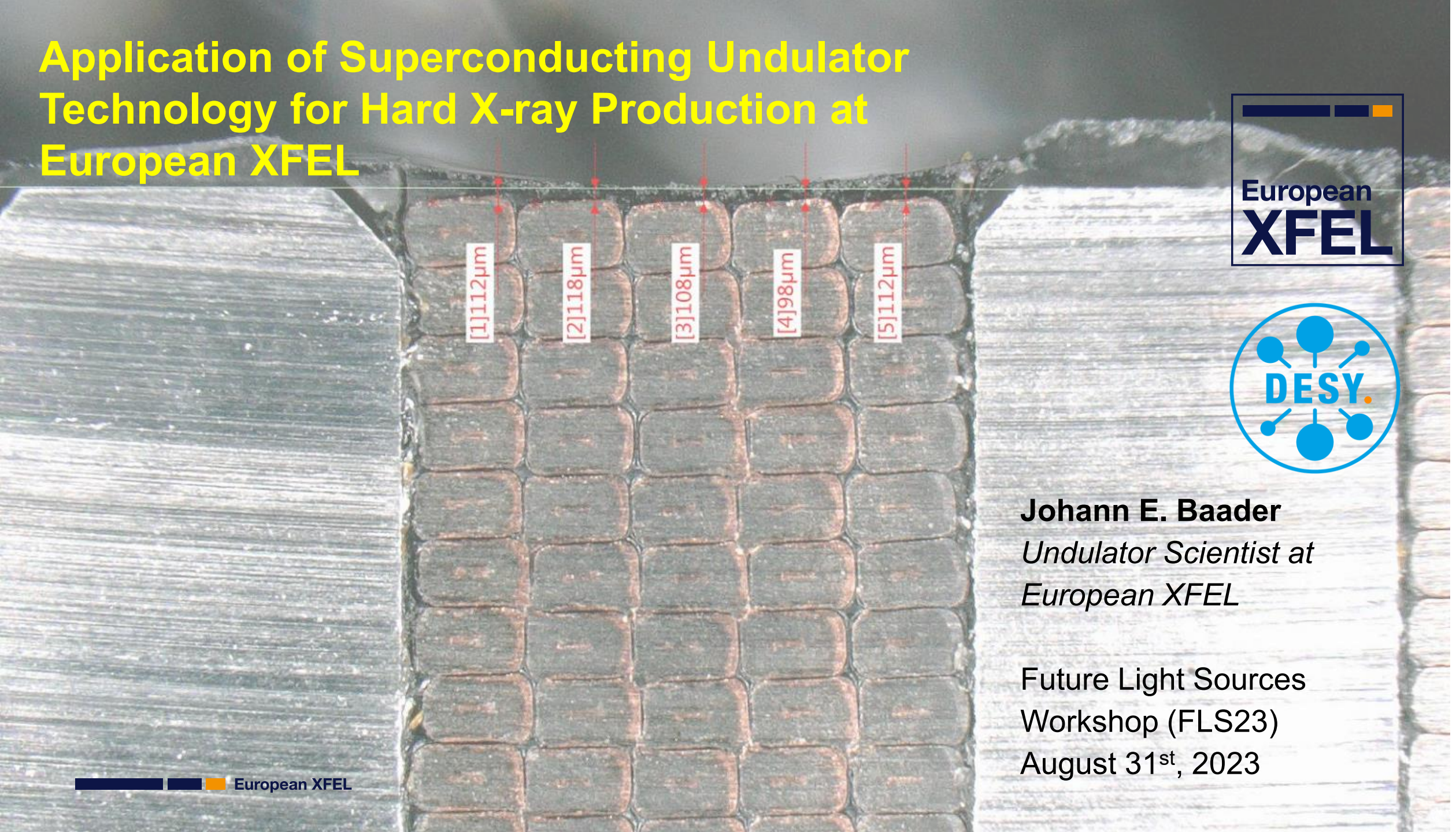
Application of Superconducting Undulator Technology for Hard X-ray Production at European XFEL



Johann E. Baader
Undulator Scientist at European XFEL

Future Light Sources Workshop (FLS23)
August 31st, 2023

Authors

- Suren Abeghyan, Levon Alanakyan, Johann Eduardo Baader, Sara Casalbuoni, Massimiliano Di Felice, Uwe Englisch, Gianluca Geloni, Vanessa Grattoni, Suren Karabekyan, Daniele La Civita, Christoph Lechner, Barbara Marchetti, Svitozar Serkez, Harald Sinn, Maurizio Vannoni, Grigory Yakopov, Mikhail Yakopov, Pawel Ziolkowski **(EuXFEL, Schenefeld, Germany)**
- Serena Barbanotti, Winfried Decking, Hans-Joerg Eckoldt, Christian Helwich, Nina Golubeva, Axel Hauberg, Kay Jensch, Sven Lederer, Lutz Lilje, Shan Liu, Rajinikumar Ramalingam, Tobias Schnautz, Evgeny Schneidmiller, Riko Wichmann, Torsten Wohlenberg, Igor Zagorodnov, Rene Zimmermann **(DESY, Hamburg, Germany)**
- Andreas Wolfgang Grau **(KIT, Karlsruhe, Germany)**
- Andrew Potter **(The University of Liverpool, Liverpool; Cockcroft Institute, Warrington, Cheshire)**
- Achim Hobl, Wolfgang Walter **(Bilfinger Noell GmbH, Wurzburg, Germany)**

European XFEL plans to develop the technology of SCUs as part of its facility development program

- Benefits
- SCU afterburner (FESTA)
- **S**uperconducting undulator **PRE-S**erie**S** m**O**dule (S-PRESSO)
- Mechanical tolerances
- Tunnel installation
- Measurement systems (SUNDAE1 and SUNDAE2)
- Advanced SCU coils

Superconducting Undulator (SCU) technologic: benefits for European XFEL

- The CW operation mode limits the electron beam energy to 7-8 GeV. A SASE SCU line (λ=18 mm) would allow to cover the same photon energy range as provided now by the installed PMUs for 17.5 GeV

- State of the art SCUs with a period length ~ 70 mm allow to cover the complete photon energy range offered by the present soft X-ray experiments at EuXFEL with the same electron beam energy, not possible with the installed PMUs

- SCU technology enables lasing at higher photon energies (>40 keV), fully exploiting the capability of the FEL linac with the highest electron beam energy worldwide

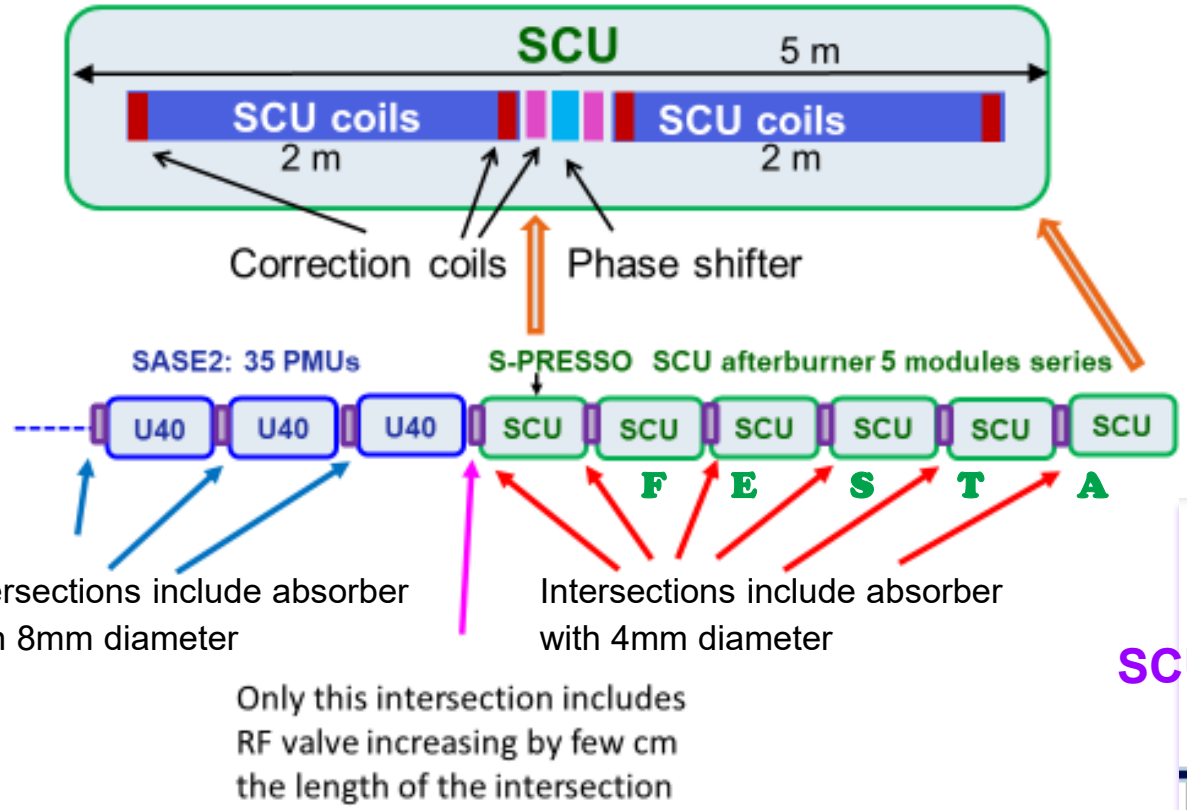
The workshop “Scientific Opportunities with very Hard XFEL Radiation” will be held at the German Electron Synchrotron DESY in Hamburg, Germany. It aims at identifying scientific questions and applications requiring very hard XFEL radiation (> 40 keV) in the context of future upgrades of the source and instruments of the European XFEL.

The workshop will bring together scientists from all over the world to present and discuss scientific opportunities and novel techniques that can leverage very hard XFEL radiation.

FESTA: the SCU afterburner planned for EuXFEL

S-PRESSO SUPERCONDUCTING UNDULATOR PRE-SERIES MODULE + FESTA FREE ELECTRON LASER SUPERCONDUCTING AFTERBURNER

Cryostat



U40 5 m

Intersection 1.1 m
same between PMUs and SCUs

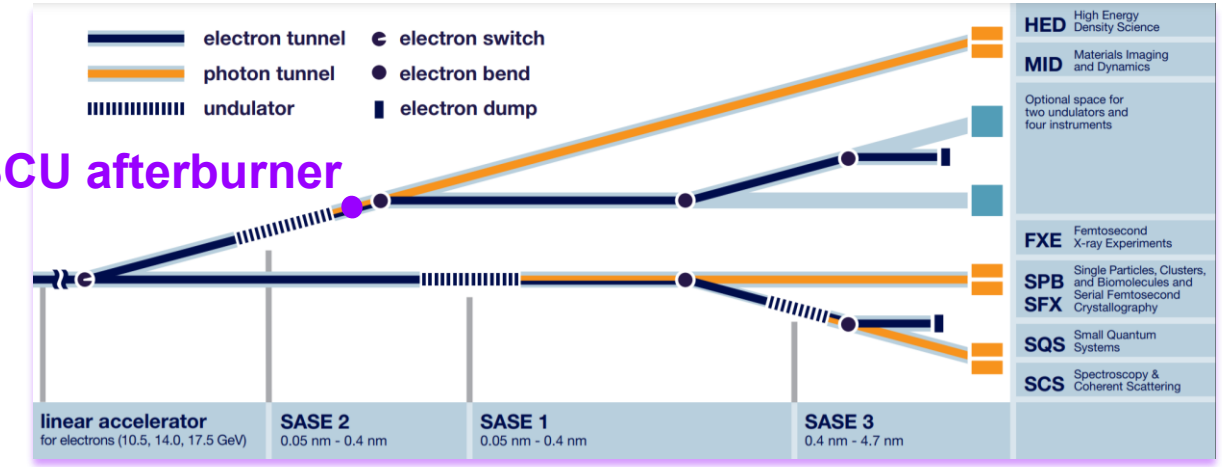
SCU 5 m

Cross section vacuum chamber

PMU h = 15 mm, v = 8.6 mm

SCU h = 10 mm, v = 5 mm

The cooling scheme of all modules will be based on **cryocoolers** as from the KIT/Noell design



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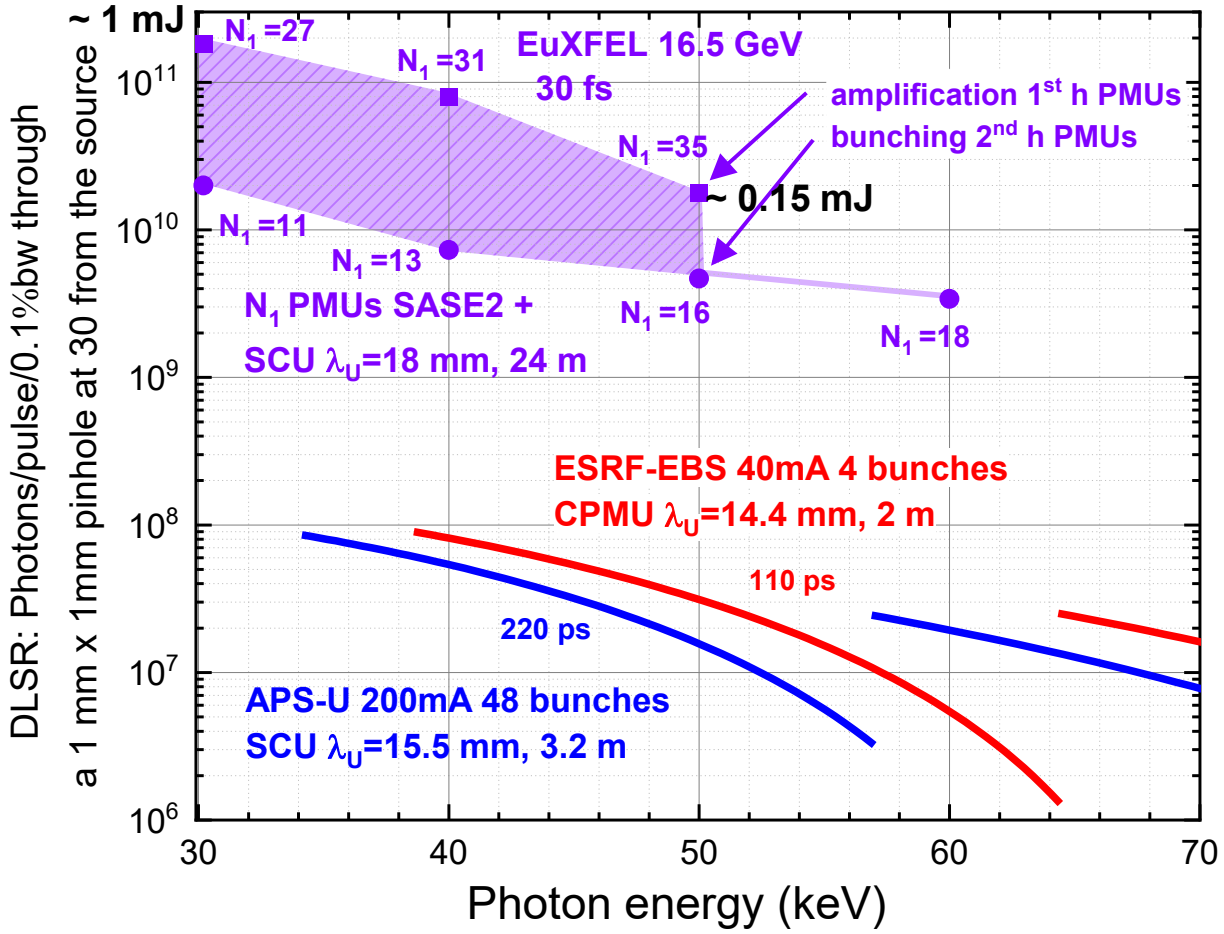
FESTA: the SCU afterburner planned for EuXFEL



Normalized emittance	0.4 mm mrad
Initial energy spread	3 MeV
Current	5 kA

The simulations do not consider wake fields and tapering. A flat top 3 fs bunch is considered

Estimated range of photons per pulse achievable by tuning the SCU afterburner on the fundamental

- amplifying the output of the fundamental of the PMUs
- using the bunching of the second harmonic of the PMUs

- More detailed studies considering wake-fields, tapering, 'real' bunch distribution and optimized electron bunch properties are ongoing

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S-PRESSO

- **S-PRESSO**: **S**uperconducting undulator **PRE-S**erie**S** m**O**dule has been specified
- The contract has been assigned to Bilfinger Noell GmbH; TDR received
- Aims of S-PRESSO are to test:
  - the alignment of the two 2 m long SCU coils in the 5 m long cryostat
  - the mechanical tolerances necessary for the FEL process
  - the implementation of the module in the accelerator. Needed space and infrastructure for FESTA is defined in the TDR
- S-PRESSO will be used to further amplify the fundamental produced by the PMUs of SASE2 in the hardest X-ray part of the spectrum which they can generate, and measure its contribution to the FEL process
- Harmonic configuration tests at larger photon energies are planned

Period	18 mm
Peak field	1.82 T
K	3.06
Vacuum gap	5 mm
First field int. (x,y)	< 0.004 T mm
Second field int. (x,y)	< 100 T mm^2
$\Delta K/K$ rms	<0.0015
Roll off at ±2 mm	$< 5 \times 10^{-5}$
Beam heat load	10 W
Pressure beam vacuum chamber at room temperature	$< 10^{-7}$ mbar

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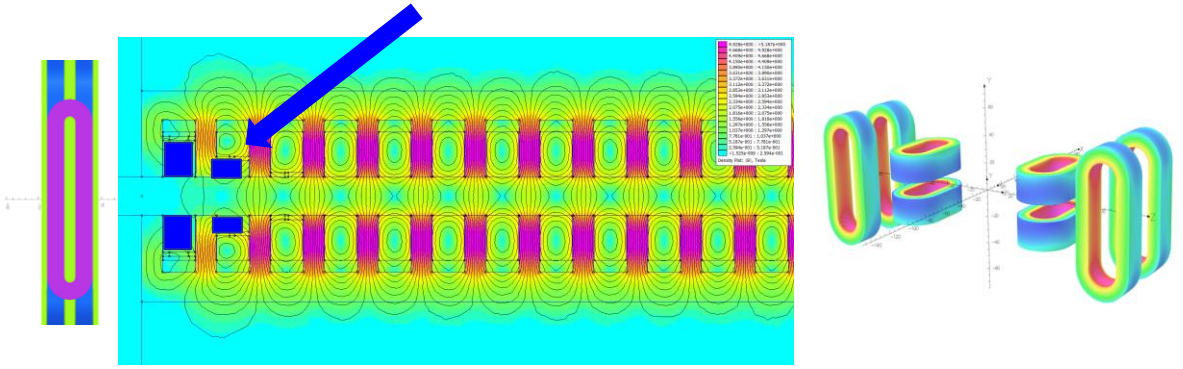
S-PRESSO

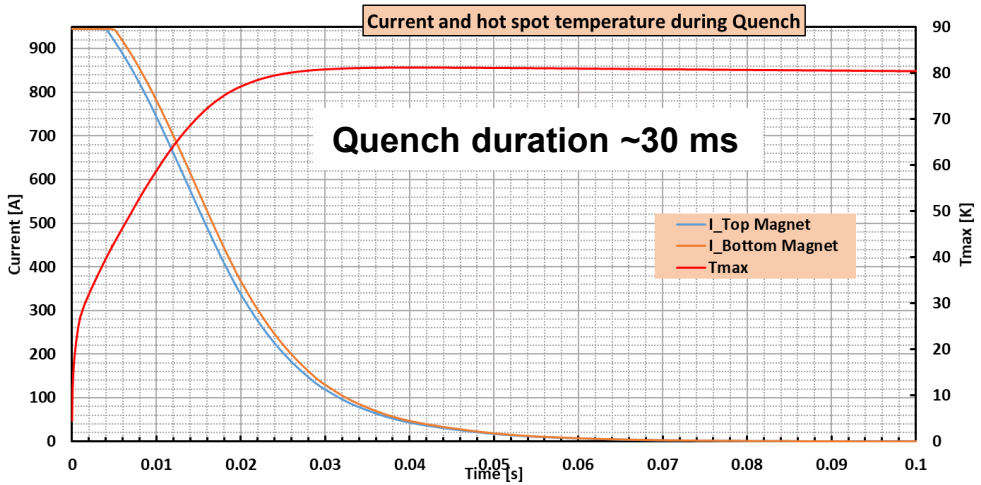
- Insulated NbTi wire
- Main coils: rectangular 1.08 mm x 0.68 mm
- Correction coils: round ø 0.254 mm
- Shim coils: round ø 0.152 mm
- Magnetic gap 6.5 mm
- 6 cryocoolers
- 2 power supplies; nom. current 900 A

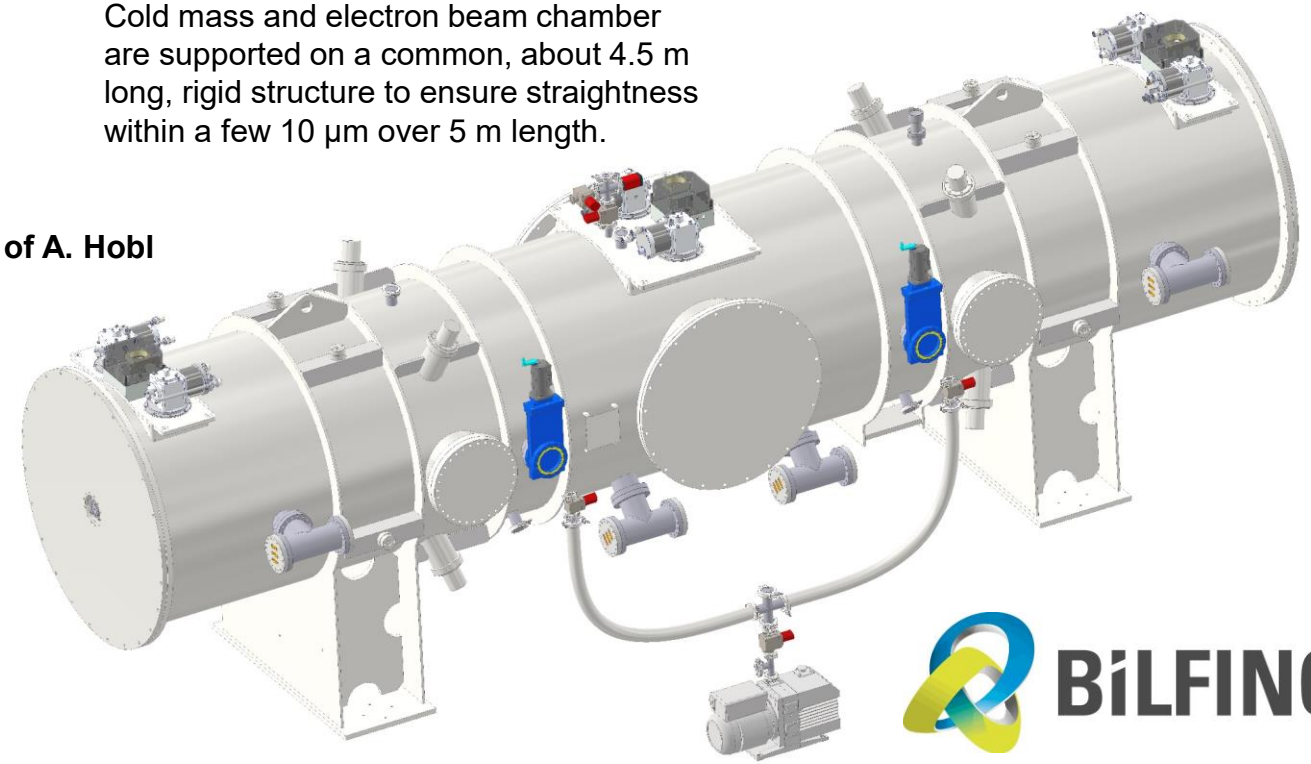
Coils for correction of horizontal and vertical field integrals



Cold mass and electron beam chamber are supported on a common, about 4.5 m long, rigid structure to ensure straightness within a few 10 µm over 5 m length.

Courtesy of A. Hobl





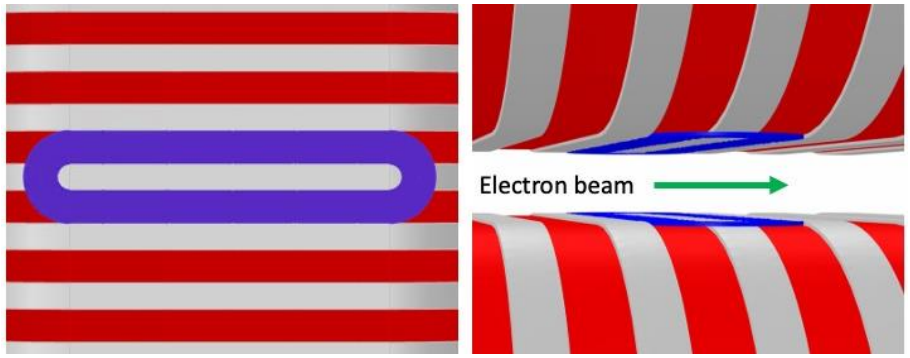
Mechanical tolerances and alignment

$\Delta K_{RMS}/K = 0.0015$
$\Delta K/K = 0.006$

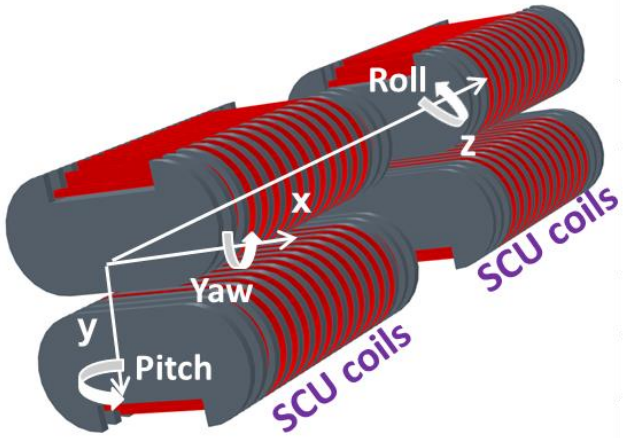
compatible with a reduction in the FEL power by 5%

Pole height	Winding hor. shift	Winding vert. shift	Pole width	Groove width
±20 µm	±15 µm	±20 µm	±10 µm	±10 µm

- Several shim coils powered by a maximum of 11 power supplies with max current of approx. 5 A might be applied



Specified maximum misalignment between the two 2 m long coils



x	± 200 µm
y	± 50 µm
pitch	< 0.1 mrad
yaw	< 0.1 mrad
roll	< 2 mrad

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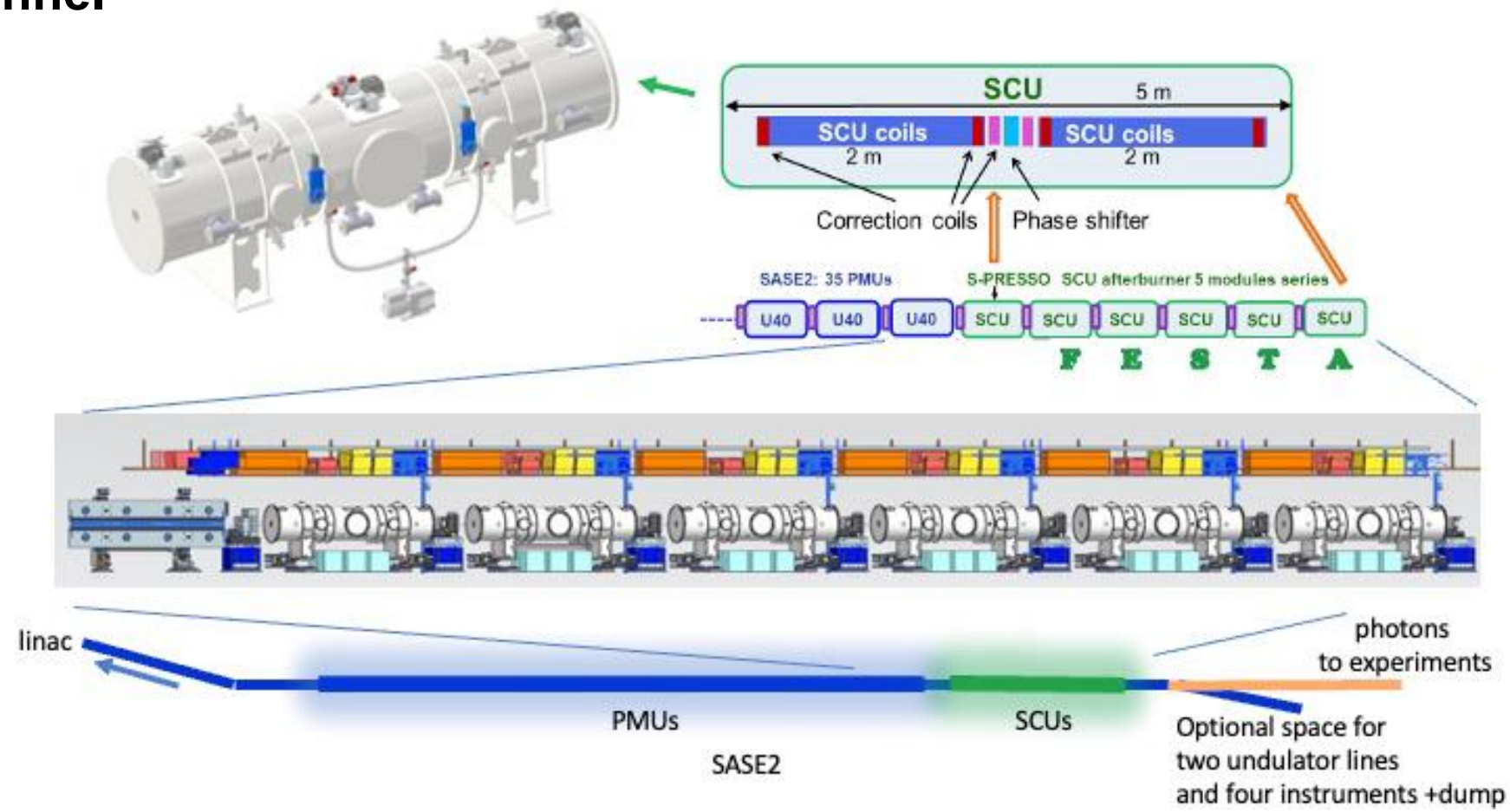
Implementation in the tunnel

SCR - S-PRESSO control rack
ICR – Intersection control rack
SPR - S-PRESSO power supply racks
DR - diagnostic rack
Fire extinguishing system (not shown)
Vacuum system rack (not shown)

Cryocooler compressors
Vacuum pump carts: one station for SCU, but two stations for S-PRESSO. The neighbor's cell pump station does redundancy.



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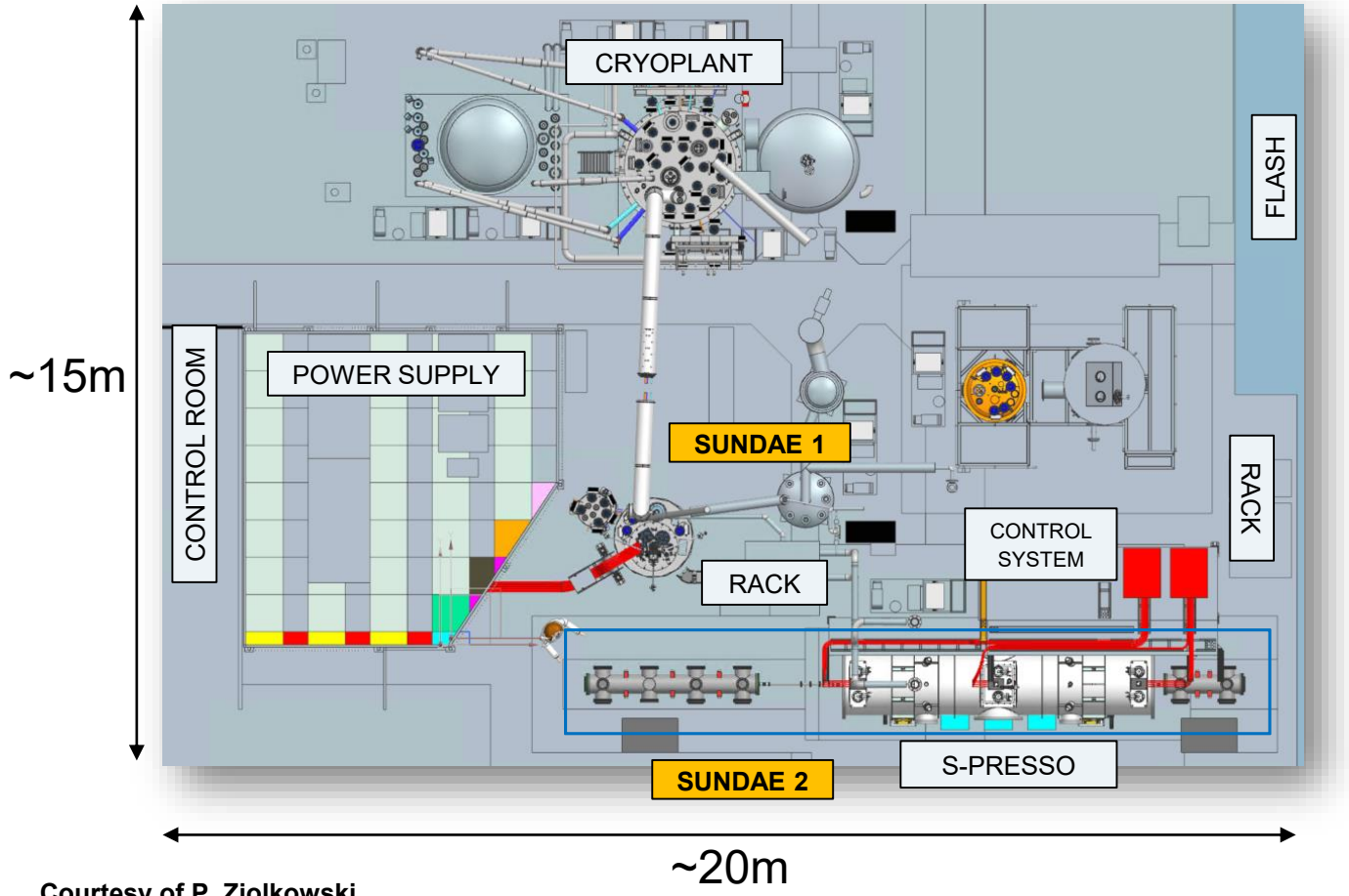
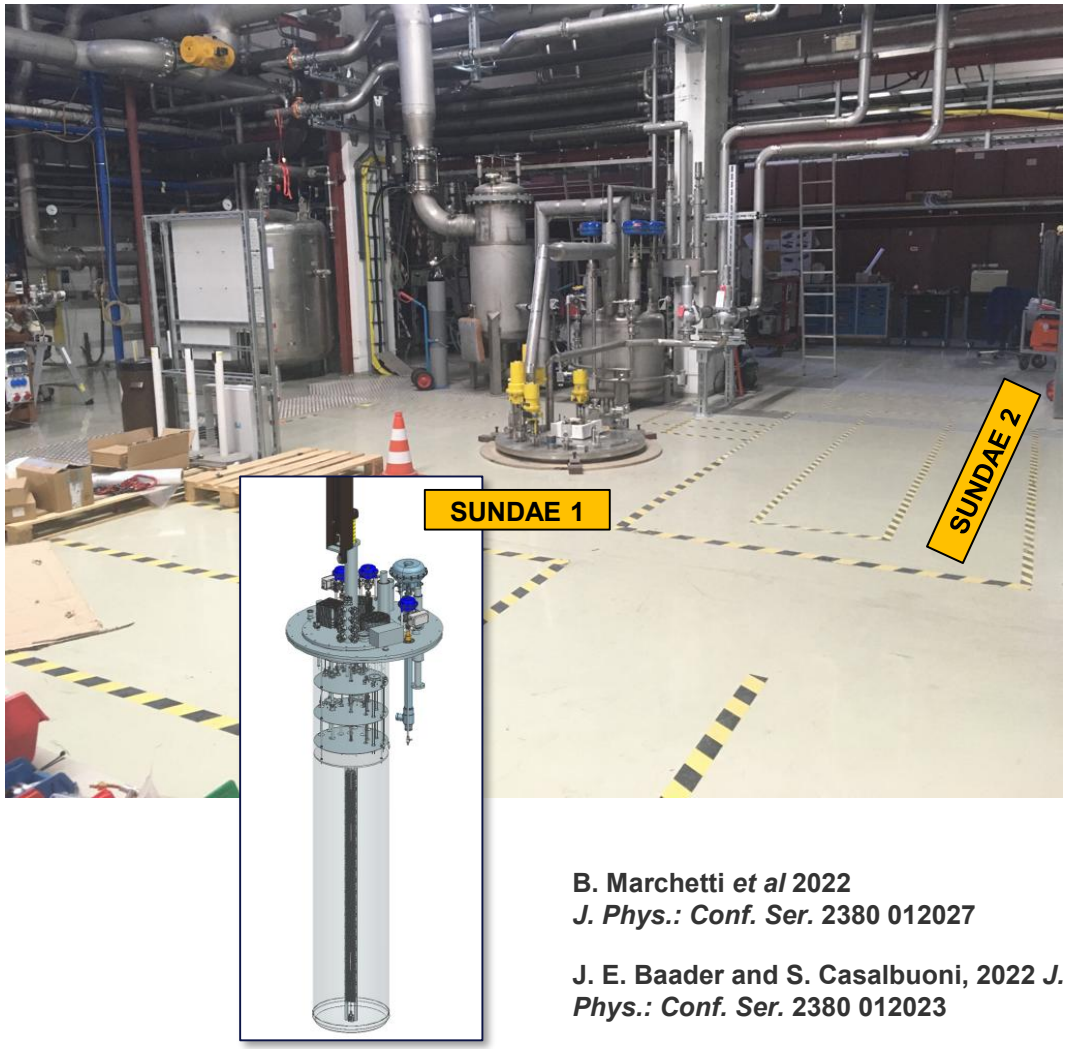
Vertical and horizontal test stands



Courtesy of P. Ziolkowski



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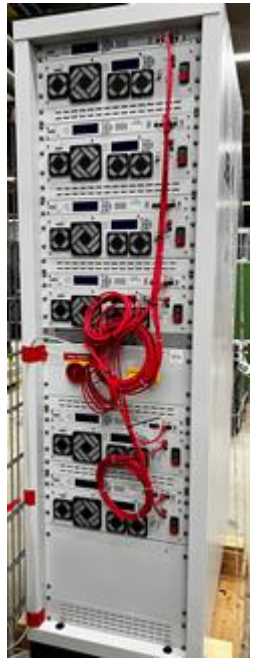
SUNDAE1

- Test coils up to 2 m long
- 2 power supplies +/-1500 A (Jema)
- 6 power supplies 10 A (Jema)
- 4 current leads 1000 A
- 4 current leads 500 A
- Fixed He level
- Operation temperature: ~ 2 K or ~ 4 K

- Linear motion system (Hositrad):
  - single axis vertical translator with 2.4 m travel range
  - accuracy: 1 µm
  - Operation temperature: ~ 2 K or ~ 4 K

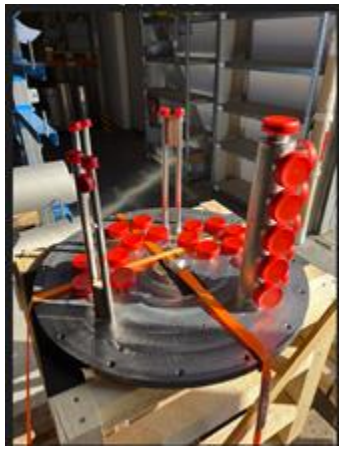
Power supplies

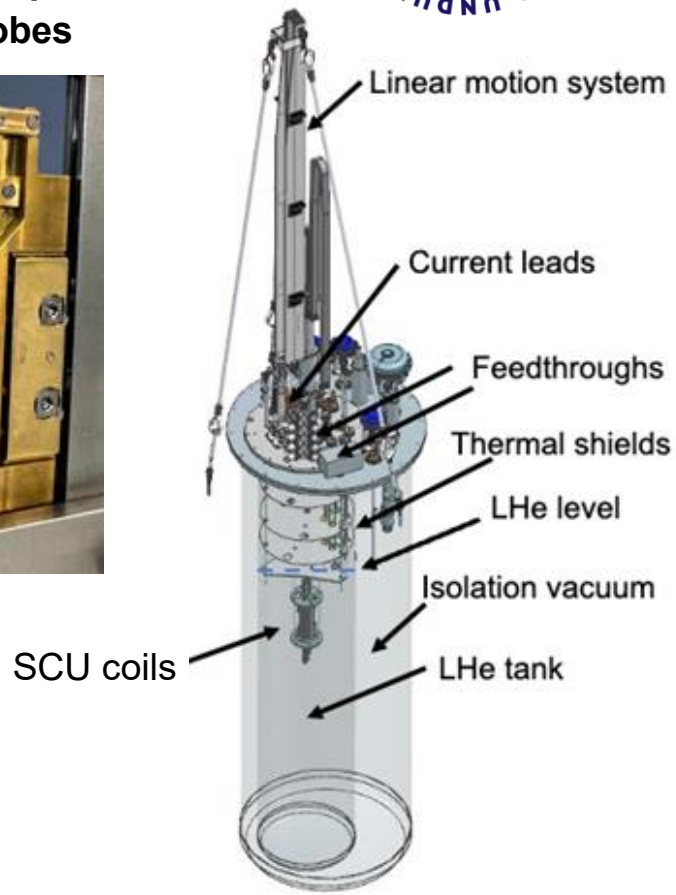


Sledge for up to 3 Hall probes

Control rack

Lid by Cryovac





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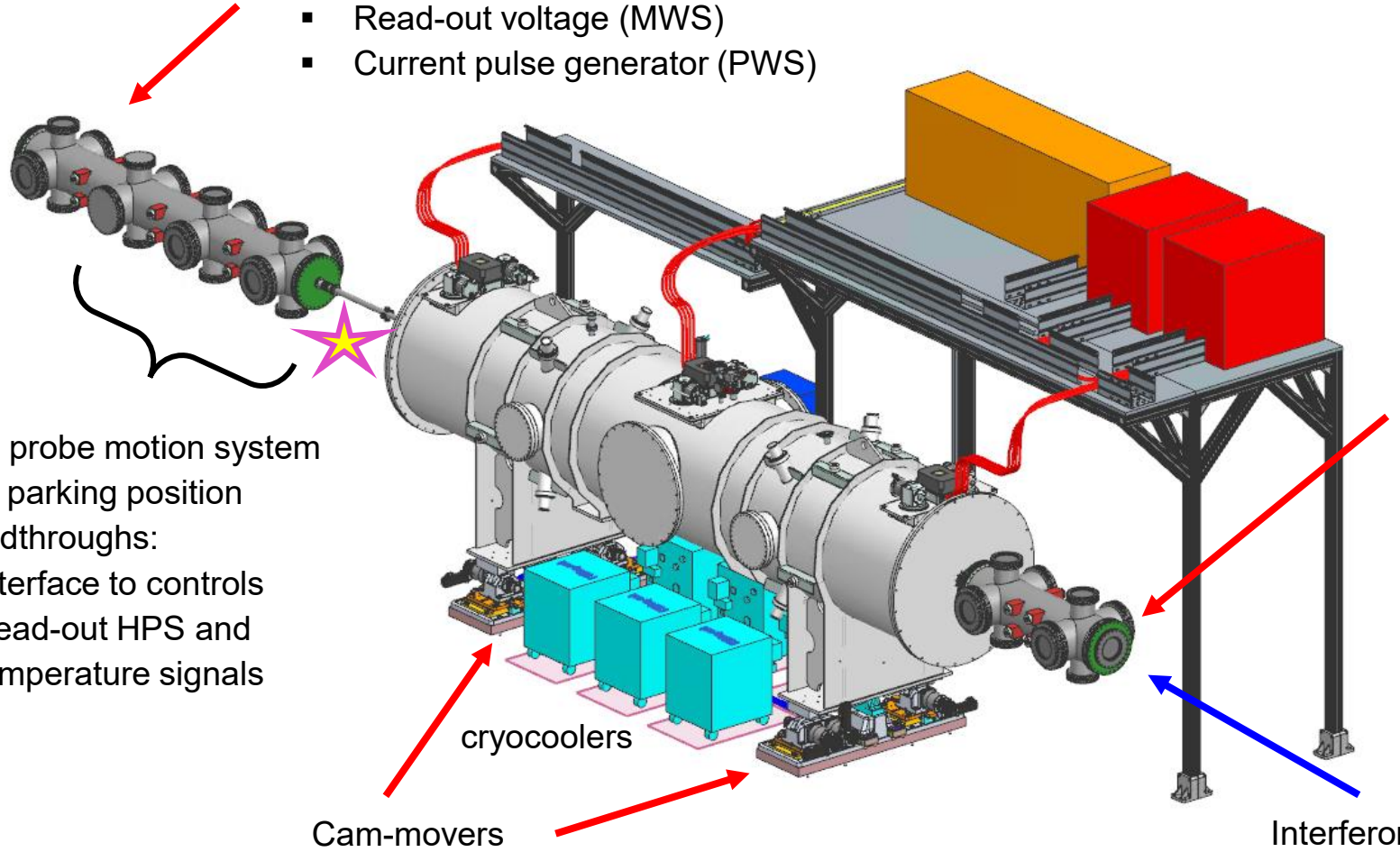
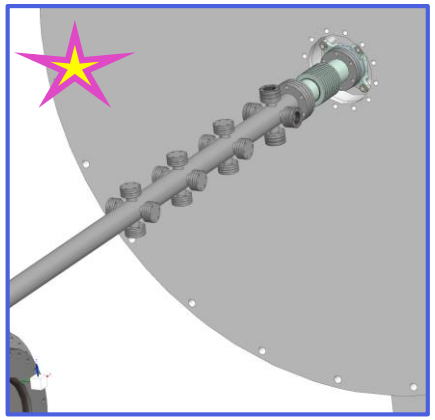
SUNDAE2

- UHV translation stages (MWS and PWS)
- Feedthroughs:
  - Interface to controls
  - Read-out voltage (MWS)
  - Current pulse generator (PWS)



- Hall probe motion system and parking position
- Feedthroughs:
  - Interface to controls
  - Read-out HPS and temperature signals

- UHV translation stages (MWS and PWS)
- Feedthroughs:
  - Interface to controls
  - Read-out voltage (MWS)
  - Current pulse generator (PWS)

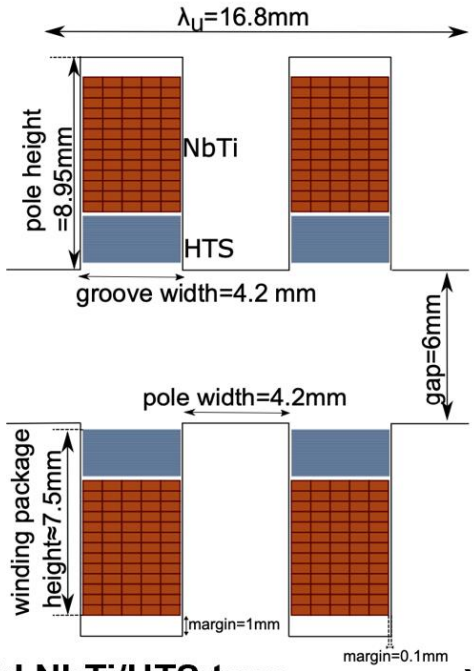


Optical detection point for the PWS

J. E. Baader *et. al*, *IPAC23,* MOPM101

Advanced SCU coils

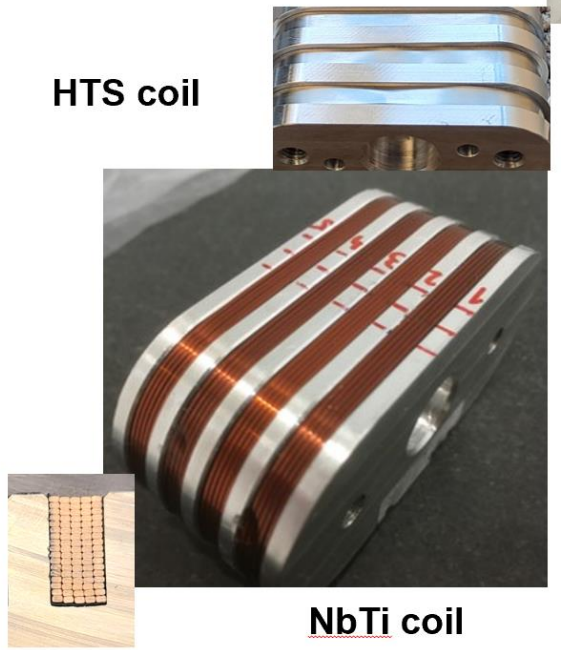
- R&D in house to:
  - build the know-how inside the facility to the state-of-the-art technology
  - further improve the know-how to be later on transferred to industry
  - study different materials and winding schemes



Hybrid NbTi/HTS tape

V. Grattoni and S. Casalbuoni, ASC2022

HTS coil

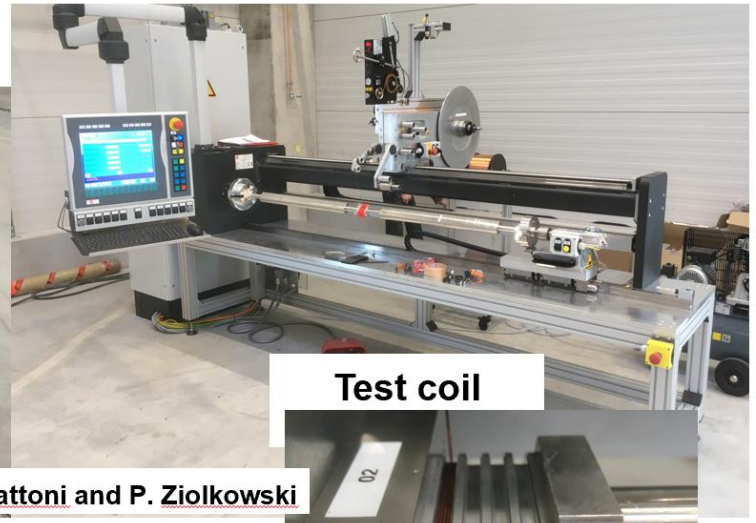


NbTi coil

Winding package

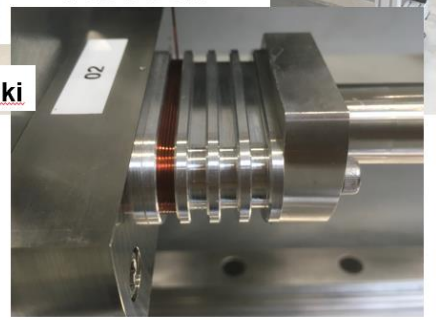
Impregnation chamber

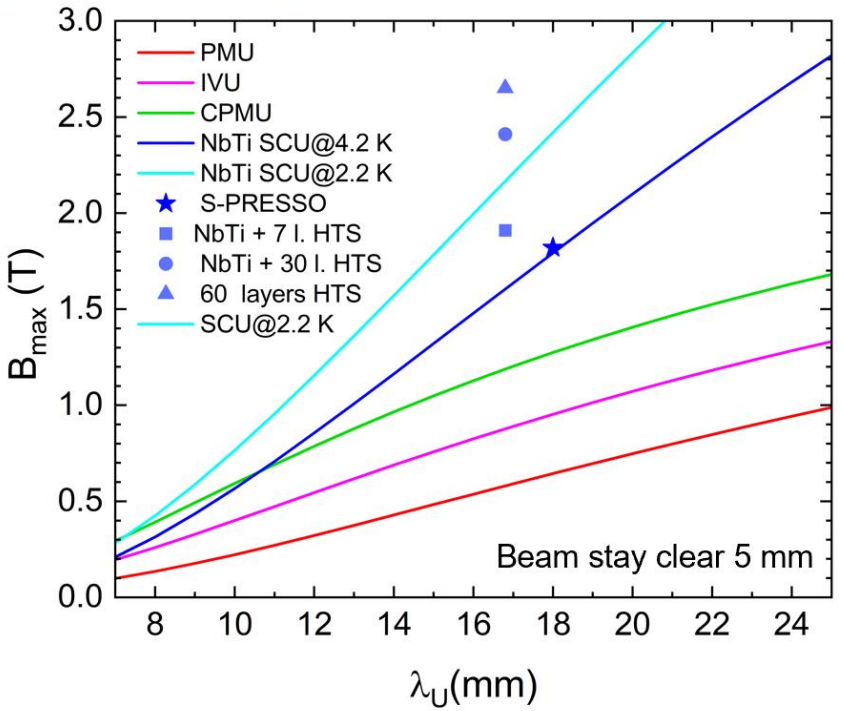
Winding machine



Courtesy of V. Grattoni and P. Ziolkowski

Test coil

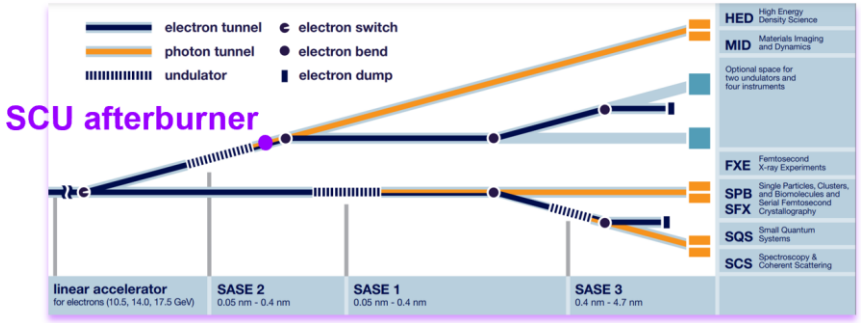


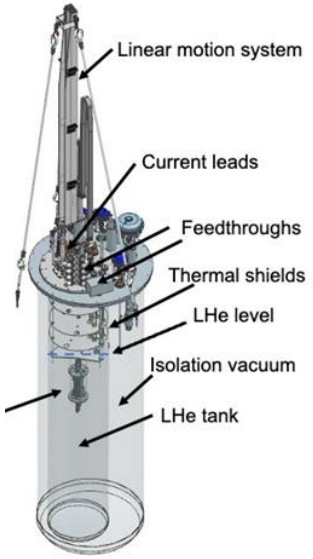


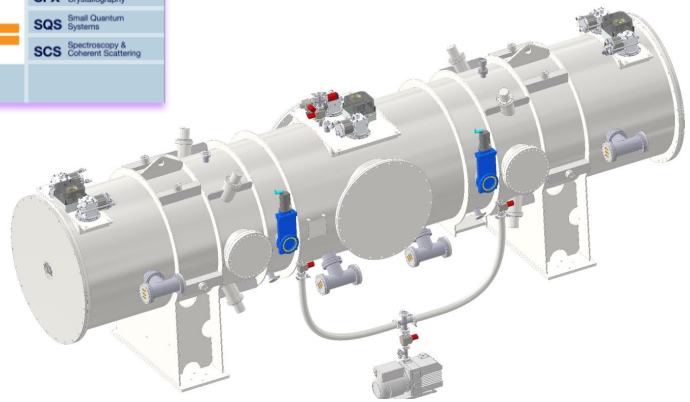
48m x 19m x 10m

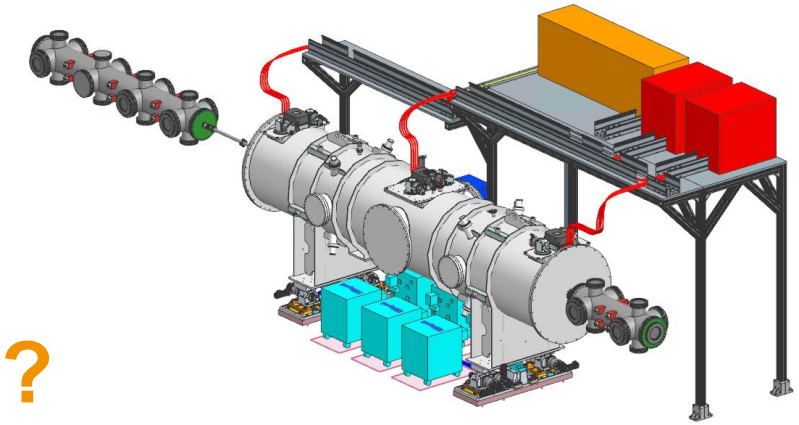
In summary, EuXFEL aims to demonstrate the operation of SCUs in X-Ray FELs

- Benefits: CW mode; potential to lase at higher photon energies (>40 keV)
- SCU afterburner is planned
- The first module S-PRESSO has been specified, the contract assigned to Bilfinger Noell GmbH, the TDR received and production has started
- Complex tunnel integration is ongoing, and all points are addressed and are on track
- Two test facilities to characterize SCU coils and SCU undulators are under development
- R&D on advanced SCU coils









Question?