Workshop on Superconducting Undulators for Advanced Light Sources- Summary

Sara Casalbuoni
European XFEL

Virtual Workshop on Superconducting Undulators for Advanced Light Sources
19-21 April 2021

Past workshops on superconducting undulators

Workshop on superconducting undulators and wigglers
Grenoble, 30th June and 1st July 2003

Superconducting undulators and other new ID sources

International workshop on superconducting undulators
28-29 April 2014 at RAL

Workshop on Superconducting Undulators at Advanced Light Sources
19-21 April 2021, on zoom
173 delegates

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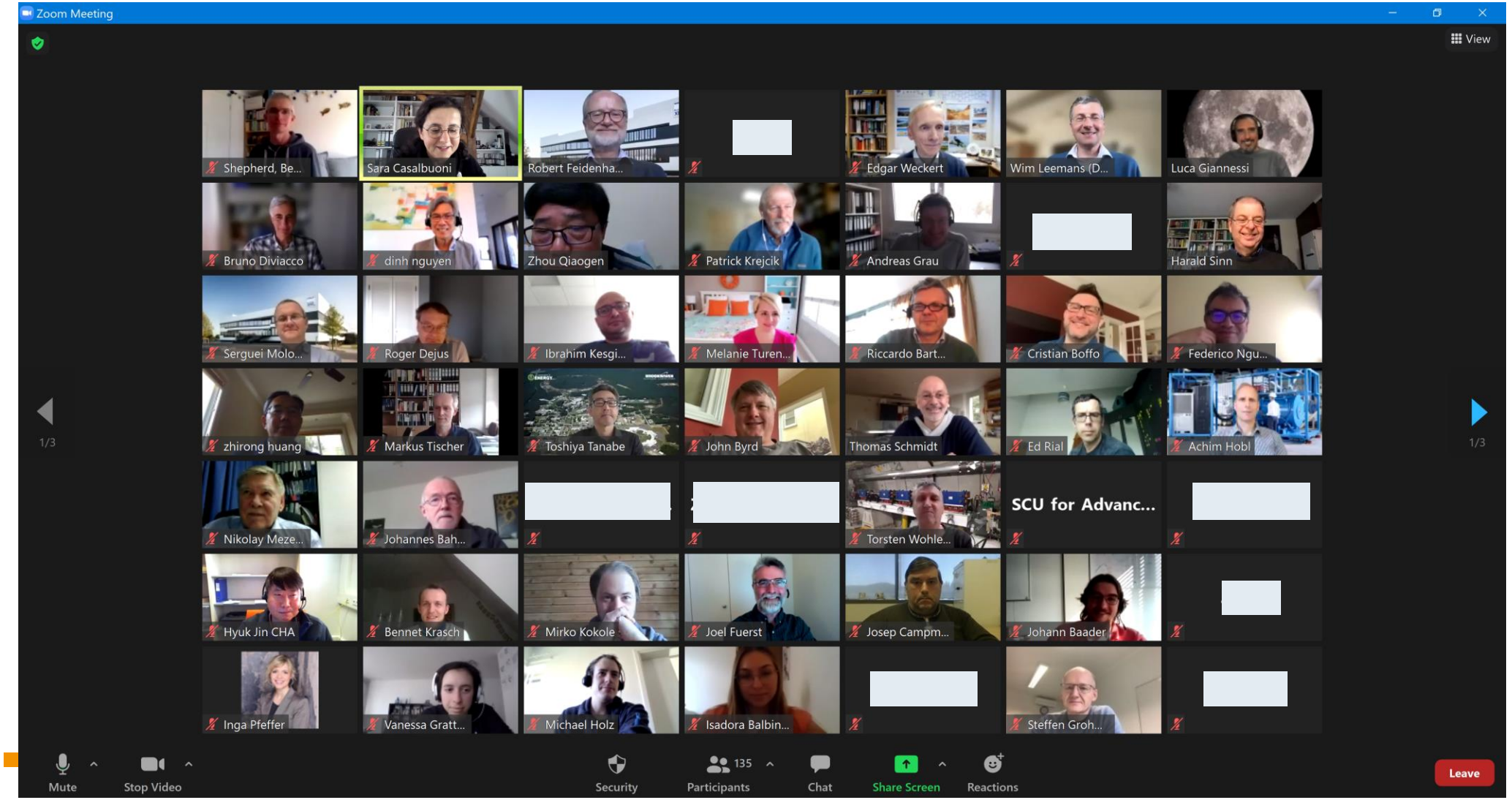

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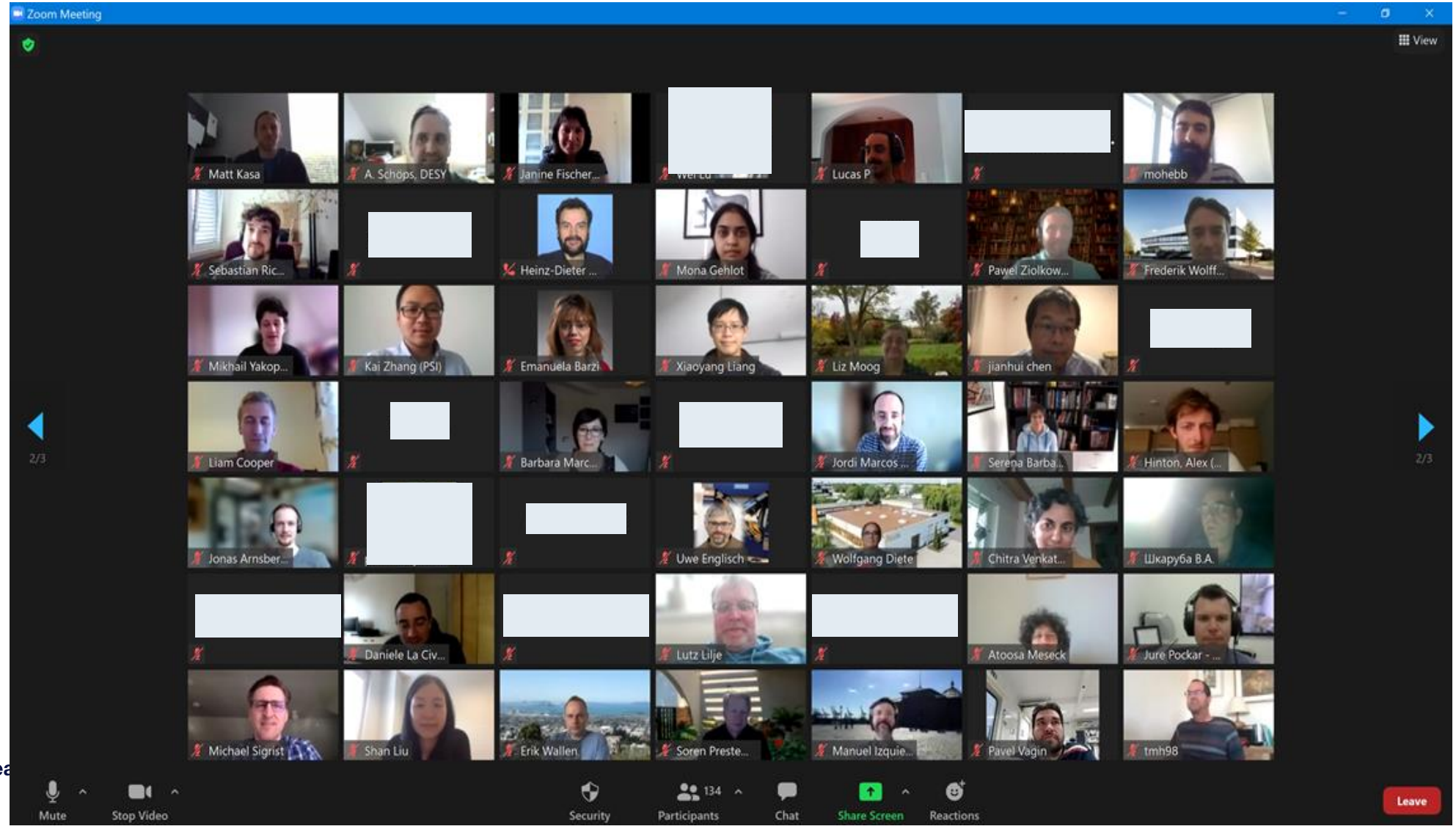

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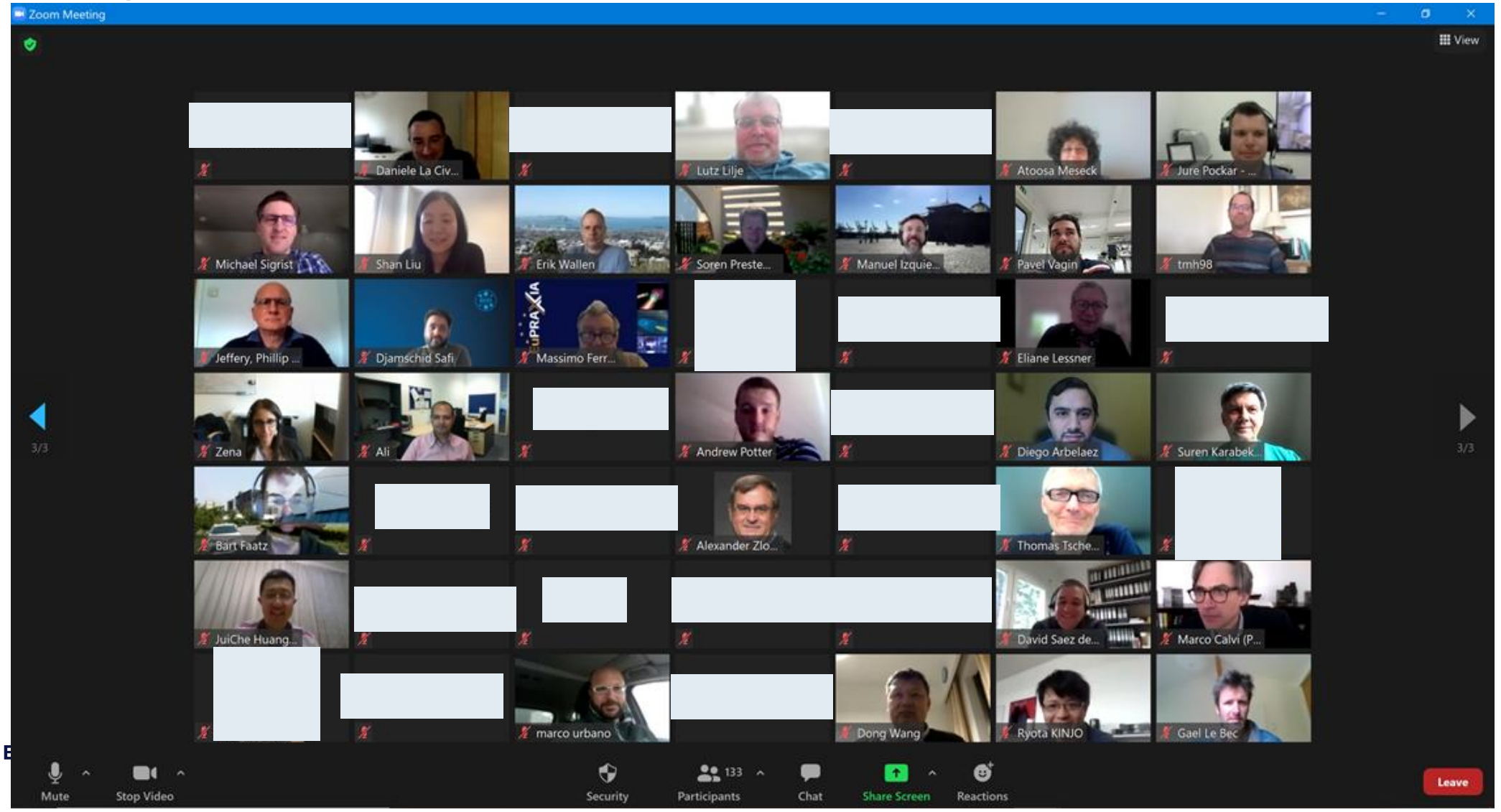
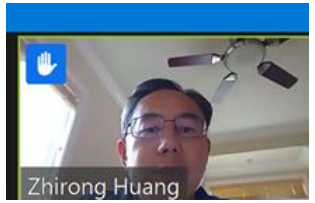


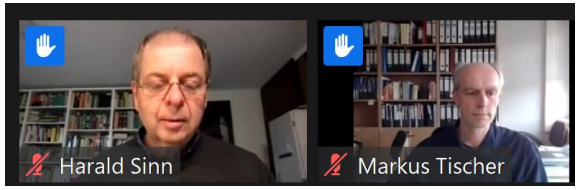
Agenda, lively discussions and focused chairs

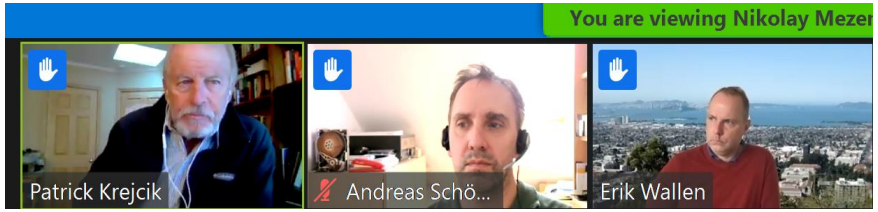
Day 1	
Session 1	W. Leemans
R&D and operational experience in America	Y. Ivanyushenkov
R&D and operational experience in Europe	B. Sheperd
R&D and operational experience in Asia & Russia	Z. Qiaogen
Session 2	J. Byrd
Discussion on SCUs operational aspects including tuning and polarization switching	R. Bartolini & T. Schmidt
SCUs at Bilfinger Noell	A. Hobl

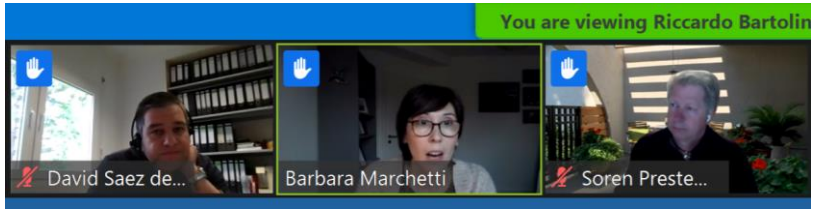
Day 2	
Session 1	M. Tischer
Present measurement systems	A. Grau
Future measurement systems	J. Baader
Magnetic design and manufacturing challenges of different SCU geometries	N. Mezentsev
Session 2	H. Sinn
Challenges in deploying SCUs on XFELs	B. Marchetti
Discussion: alignment and measurement strategies for several SCUs in one cryostat, tolerances, helical vrs. planar	D. Wang & P. Krejcik
Refrigeration system (cryocoolers versus cryoplant)	J. Fuerst

Day 3	
Session 1	A. Grau
Correction schemes, end field optimization, earth field compensation	D. Arbelaez
Potential and limitation of different materials, NbTi (4 and 2 K), Nb_3Sn, HTS including quench protection	S. Prestemon
Nb3Sn SCU coils	I. Kesgin
Session 2	S. Casalbuoni
HTS SCUs	M. Calvi









Wrap-up

- SCUs based on NbTi are successfully working in storage rings: APS, KIT synchrotron
  - All planar, except one helical at APS
  - Cooling: KIT/Noell cryogen-free => only cryocoolers; APS cryocoolers and liquid helium tank
  - High mechanical accuracies reached: no shimming applied
- Planar NbTi SCUs are commercially available:
  - first device KIT/Noell
  - Noell is now manufacturing a SCU for the Australian synchrotron
  - BINP has developed and is producing a SCU for DLS
- Compact Light Sources
  - First test at linac with an in vacuum NbTi planar SCU at CLARA (30 MeV, expected IR radiation)
  - Plans for a cryogen-free NbTi planar SCU at the EuPRAXIA@SPARCLab FEL in collaboration with FNAL

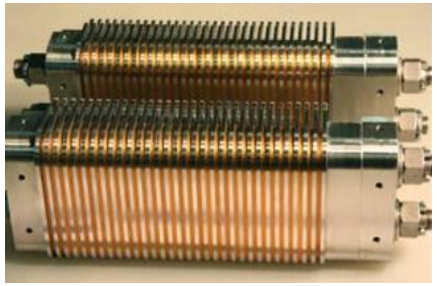
Wrap-up

- NbTi SCUs at DLSR
  - APS-U
    - ► Two 1.9 m in-line planar SCUs in a 4.8 m long cryostat
    - ► Two 1.9 m canted planar SCUs in a 4.8 m long cryostat
    - ► SCAPE-Variable polarization SCU (Delta like): switching polarization by orbit bumps
  - NSLSII-U: double mini beta lattice with two 2 m SCU14 with K=2.25
  - ALBA II: plans for planar SCUs (info from F. Perez and J. Campmany, not from this workshop)
  - SKIF: planar and R&D for tapered, helical and variable polarization SCUs
  - SLS II: HTS bulk tape SCU

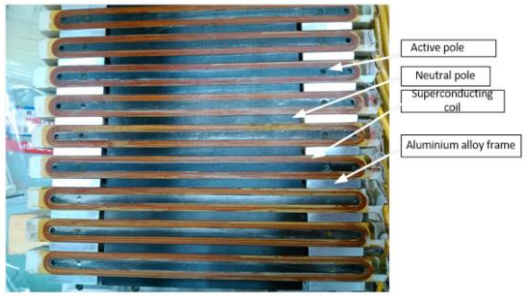
- Additional R&D on NbTi SCU
  - Helical devices for CompactLight, 5.5 GeV, 8-16 keV photons: 0.3 m prototype yokes (STFC)
  - To enlarge the tunabilty, period doubling at KIT: SCU coils 0.4 m long, period =17/34 mm

Wrap-up

- Design
  - Planar NbTi SCUs: vertical (APS, KIT/Noell, LBNL, STFC) versus horizontal coils (BINP, SHINE)

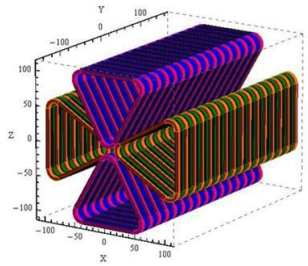


KIT/Noell

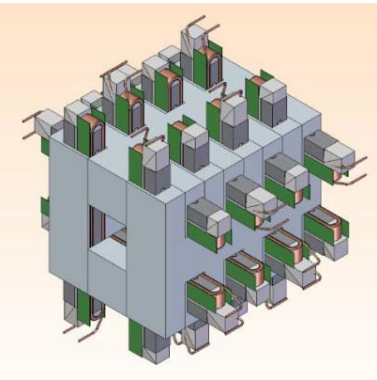


BINP

  - Helical, variable polarization



APS



BINP

Wrap-up

- Measurement systems to characterize the local magnetic field profile are available and working for present SCUs up to ~ 2 m length with magnetic gaps of 8-9 mm and vacuum gaps ~ 7 mm
  - Hall probes at room temperature (APS, BINP) and cold (KIT, planned at SHINE for v. gap = 4 mm, at NSLSII for SCW)
- Local field meas. at STFC on final cryostat cryogen-free, 4 mm warm bore: meas. length 0.5 m
- Field integrals of present measurement systems can be used for future applications
  - Most sensitive technique is the stretched moving wire
  - Rotating coil and stretched wire with DC current have the advantage of dynamic measurements
- R&D on local magnetic field profile measurement systems for smaller gaps are ongoing at many labs:
  - promising pulsed wire to reconstruct the magnetic field profile
  - Hall probe system developed at ALBA for 2 m long und., might be upgraded to 5 m long devices

Wrap-up

- Application of SCUs to XFELs: EuXFEL, LCLS, SHINE
  - NbTi since well proven in storage rings
  - Helical or planar? Helical geometry can increase the efficiency of the FEL process up to 10-20% , but introduces additional issues on tolerances => all labs decided for planar
  - Cooling: Cryocoolers vrs. Cryoplant. Cryoplant clear choice for a SCU SASE line.
  - Segmentation: measurements and cooling.
  - Intersections: warm or cold?
  - Alignment and mechanical accuracies
  - Industrialization

- Plans
  - EuXFEL- afterburner at SASE2: 5 modules with two times 2 m long SCUs and a phase shifter
  - LCLS- collaboration with ANL: two/three times 1.5 m long SCUs with cold intersections
  - SHINE-all SASE line: 40 modules 5 m long with 4m long SCU coils

Wrap-up

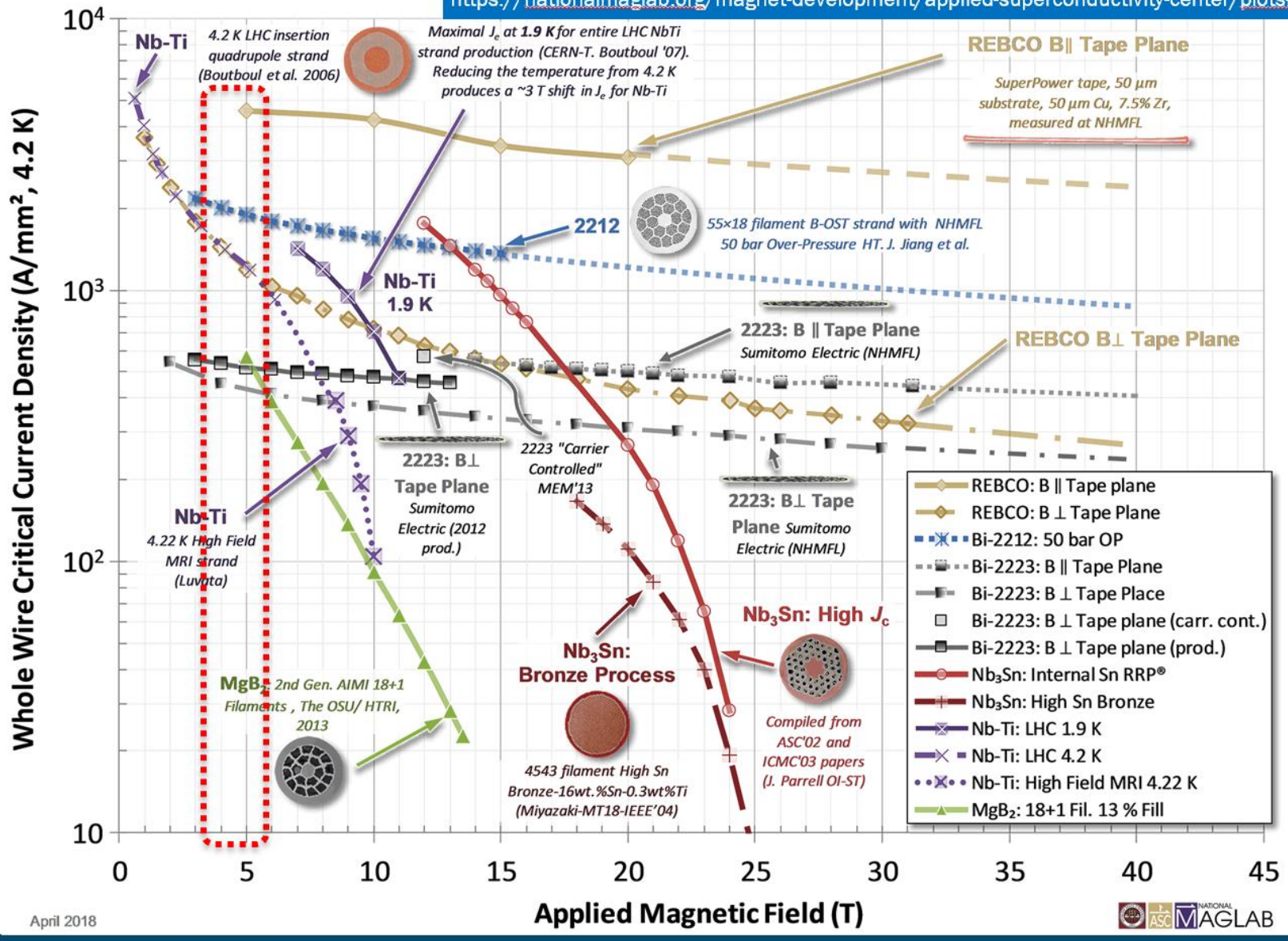
- Correction schemes
  - Local: Preferable to rely on precise fabrication and assembly. As in permanent magnet undulators, additional space is needed.
    - ► Induction shimming (KIT)
    - ► Addition of iron pieces in core pockets (NSRRC)
    - ► Small coil loops around poles (KIT, LBNL)
    - ► HTS loop coils and heater switches on the vacuum chamber (LBNL)
  - Global: for first and second field integrals, and ambient field
    - ► Corrector coils wound in the last groove: kick + dipole like field along the undulator
    - ► Helmholtz like coils at the undulator end: kick

Wrap-up

The classic Peter Lee plot

BCMT BERKELEY CENTER FOR MAGNET TECHNOLOGY

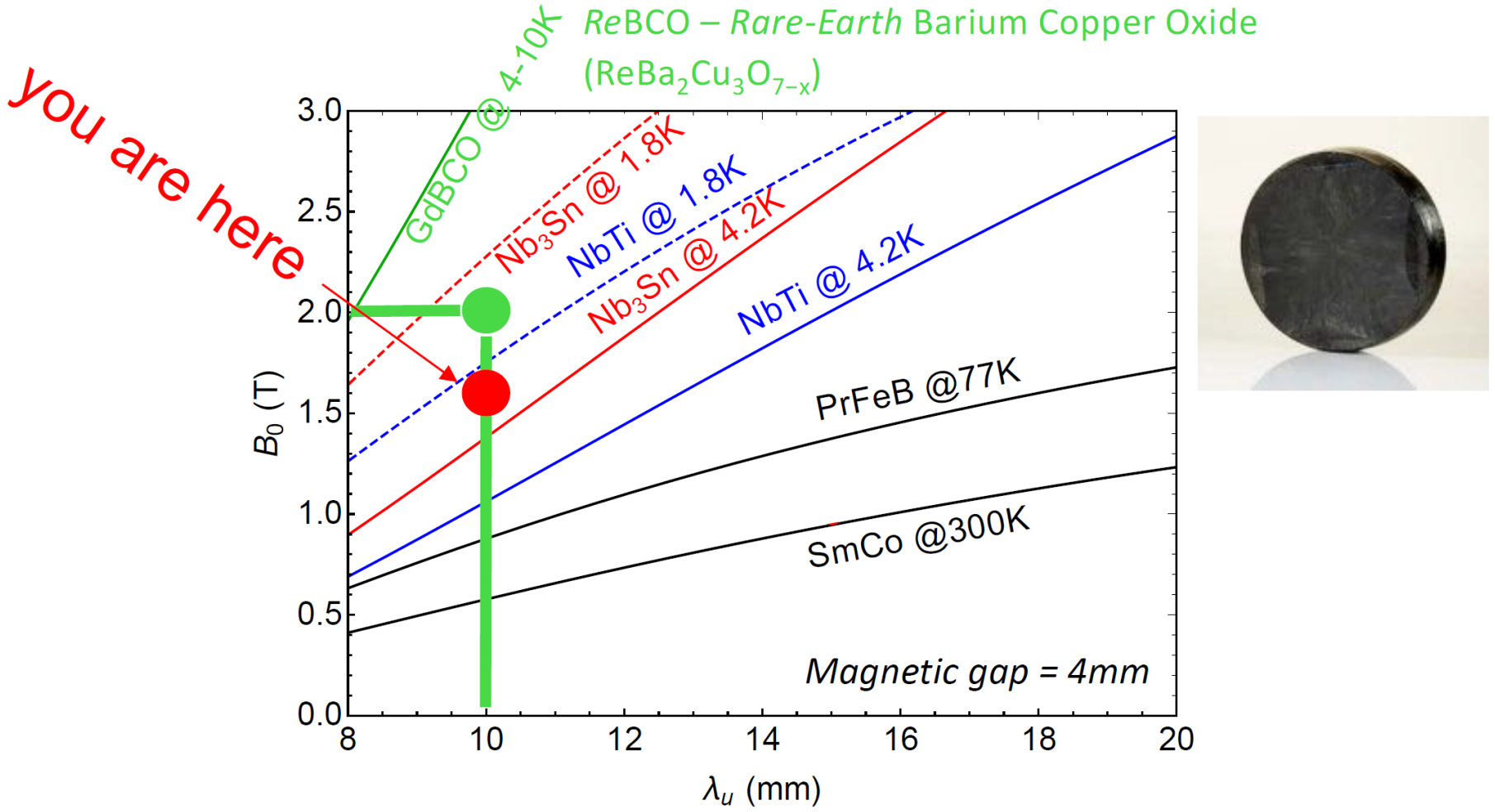
https://nationalmaglab.org/magnet-development/applied-superconductivity-center/plots#engineering



PAUL SCHERRER INSTITUT

Summary of the results

Wrap-up



[Scaling laws: E.R. Moog, R.J. Dejus, and S. Sasaki , Light Source Note: ANL/APS/LS-348
James Clarke, FLS 2012, March 2012, Ryota Kinjo Physical Review Special Topics, Accelerator and Beams 17, 022401 (2014)]

Wrap-up

- NbTi workhorse for low (T,B): operation <4.5K, at 1.9 K increase of Jc by about 70%
- Operation in accelerator environment not yet demonstrated for Nb3Sn and HTS magnets

Wrap-up

- Nb3Sn
  - Quench protection understood
  - Requires heat treatment up to 600-700^{o} C (phase change => dimension change => brittle), hardly compatible with the small mechanical tolerances required to reach high magnetic field quality necessary for undulators. However,
  - LBNL 1.5 m long coil:
    - ► Long training of individual coils
    - ► One coil led to low performance and required replacement to achieve target field
    - ► fast quench protection
    - ► Max phase error 11 deg; 9.2 deg phase error corrected with active HTS loop coils to 5.4 deg
  - Collaboration ANL/FNAL/LBNL:
    - ► 0.5 m long coils, Nb3Sn SCU offers at least 20% undulator field increase compared to a NbTi SCU with th same magnetic gap (9.5mm) and period length (18mm).
    - ► Planned 1.1 m coils

Wrap-up

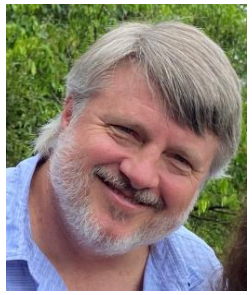
- HTS
  - Uniformity, repeatability, mechanical properties, quench protection, available length for the tape, and production rate of high quality HTS blocks
  - Planar HTS tape (developed at Noell tested at KIT, ANL without joints, simulations at CERN)
  - Laser structure HTS tape (proposed by LBNL, explored at KIT without joints)
  - Enhanced CPMU (SPRING-8)
  - HTS bulk (proposed by Kyoto University, explored at PSI, ESRF)

Wrap-up

- Tremendous progress has been done in the past years on SCU development
- Planar NbTi SCUs are becoming a mature technology and they are commercially available
- The number of labs working on SCUs is increasing as well as the interest of the light sources community in this technology
- Many R&D projects are ongoing to explore alternative geometries, materials, measurements techniques and cooling schemes
- **Very exciting field!**

Acknowledgments

Thanks to:

- All Speakers for preparing excellent talks and making the effort to include activities ongoing in other labs!
- R. Bartolini, W. Dong, P. Krejcik, T. Schmidt for steering the two very stimulating discussion sessions
- All delegates for their active participation
- John  Andreas  Wim  Soren  Harald  Markus 
  for their constructive input in putting together the program
- Rena Gebhardt and Nicoletta Mattioli (EuXFEL) for organizing the webpage. Nicoletta for organizing the zoom session and helping uploading the talks.

Thank you for your attention !

Looking forward to meeting you all soon in person