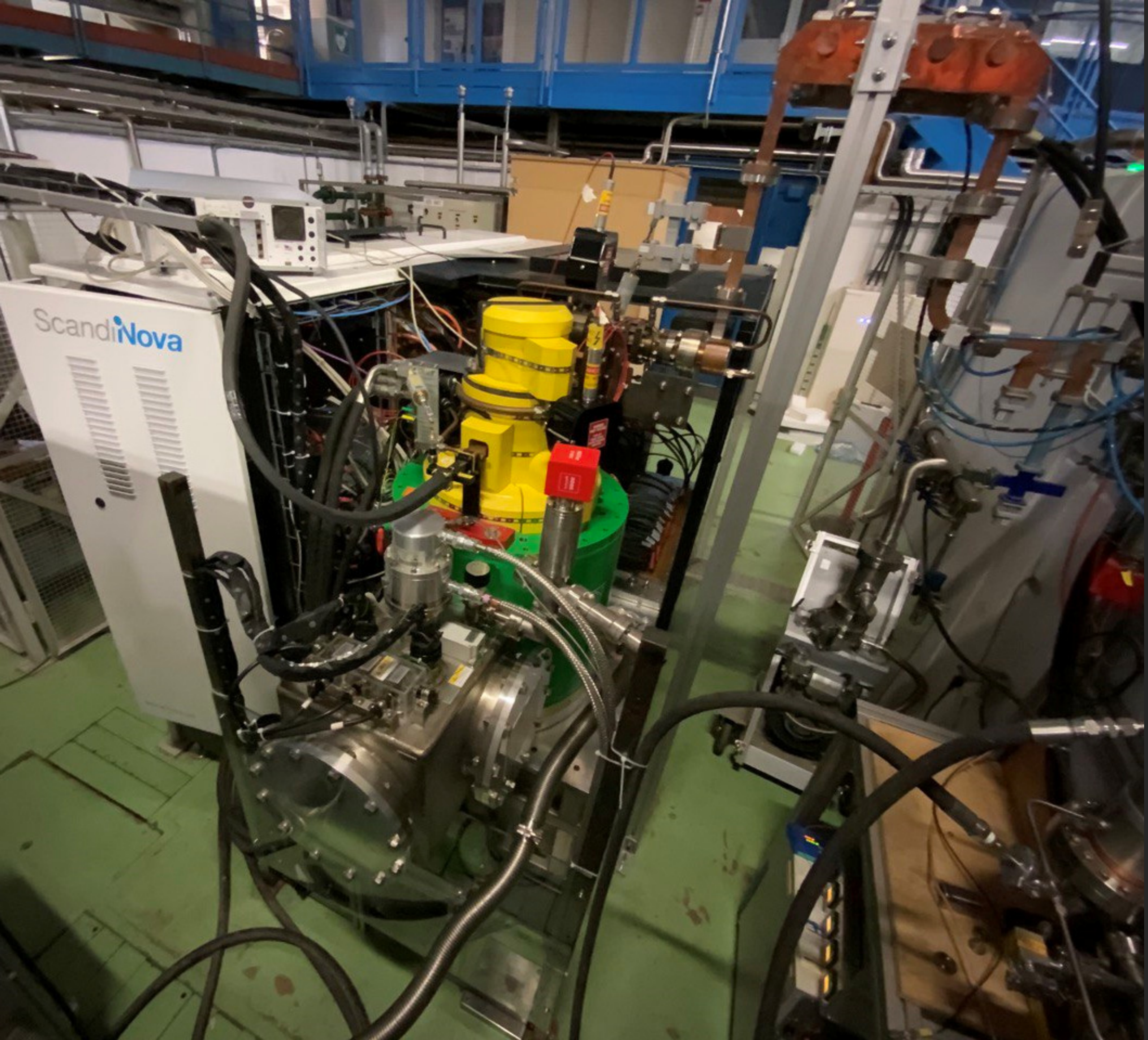

FIRST OPERATION OF A KLYSTRON FITTED WITH A SUPERCONDUCTING MGB_2 SOLENOID

N. CATALAN-LASHERAS, M. BORONAT, G. MCMONAGLE, I. SYRATCHEV, CERN
A. BAIG, A. CASTILLA-LOEZA, COCKCROFT INSTITUTE
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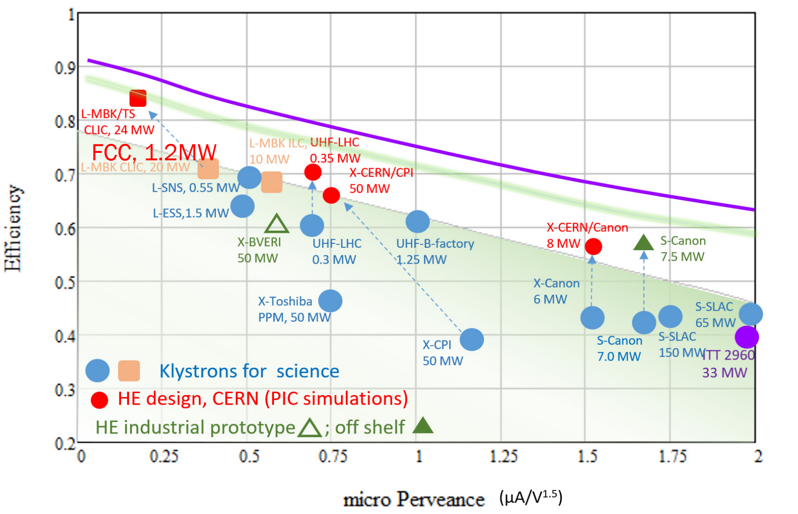
S. MICHIZONO , A. YAMAMOTO, KEK

OUTLOOK

- Motivation and plan
- Cable and magnet manufacturing
- Integration at CERN
- Performance of the klystron system
- Conclusions



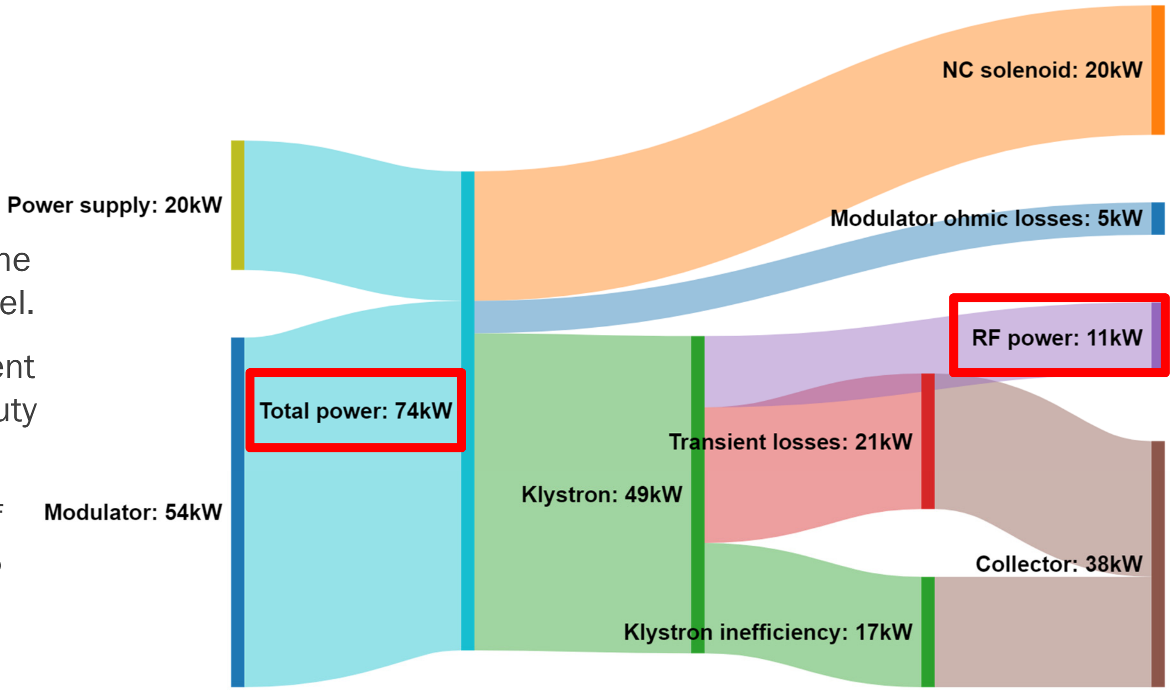
MOTIVATION

- New projects are rated by their efficiency and sustainability performance
- Recent years have seen tremendous effort to make more efficient klystrons
- Among effects studied: E field expansion in the drift tubes; Ohmic loses; Space charge depression; Bunch saturation; Bunch congregation; Bunch stratification; Radial bunch expansion; Reflected electrons.

J. Cai and I. Syratchev, "Design Study of X-band High Efficiency Klystrons for CLIC," 2020 IEEE 21st International Conference on Vacuum Electronics (IVEC), 2020, pp. 121-122, doi: 10.1109/IVEC45766.2020.9520585.

SOLENOID FOR PULSED KLYSTRONS

- Solenoidal field needed to confine the electron beam in the klystron channel.
- Electromagnet sits at constant current even for pulsed klystrons with low duty cycle
- In the x-band facility consumption of the electromagnet represents ~30% of the total power source



AC power/RF efficiency = 15.2%

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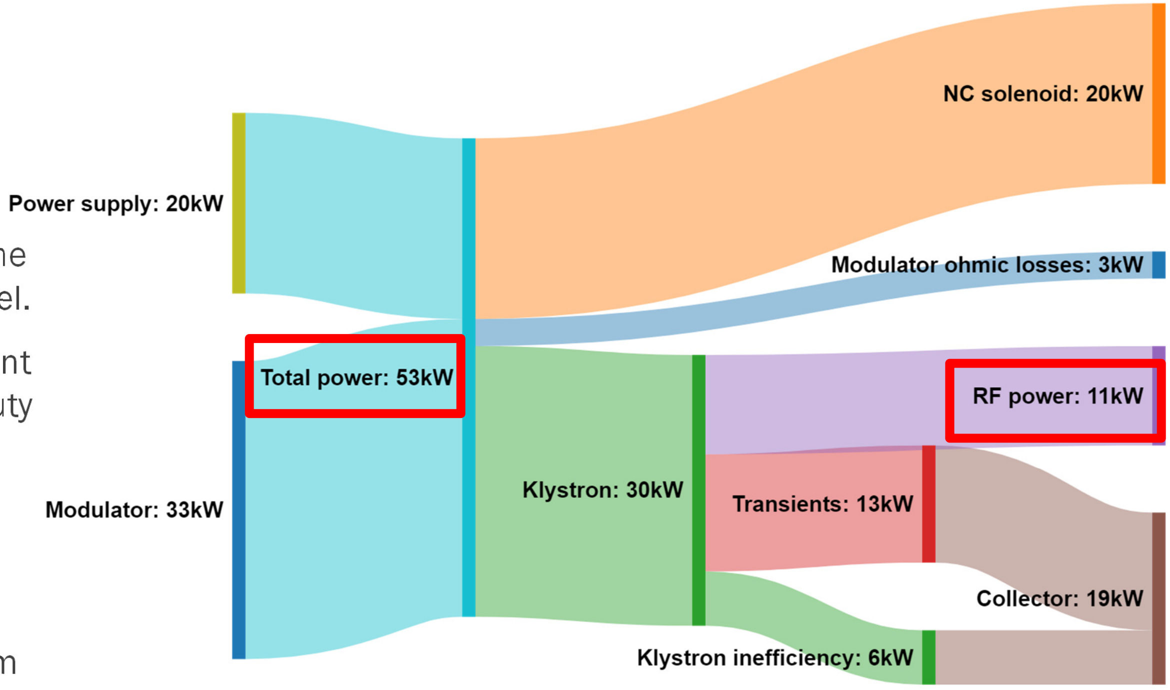
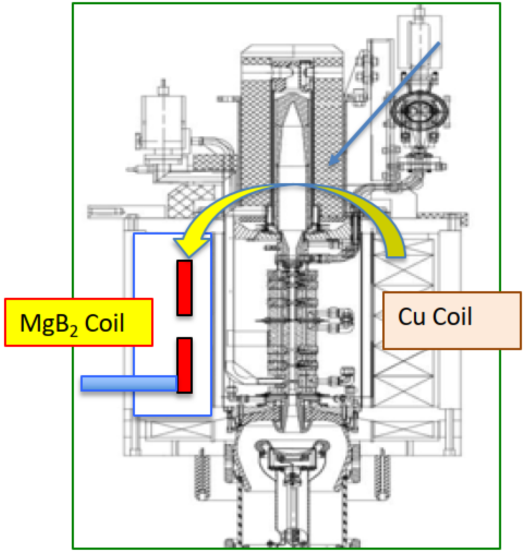
- Electromagnet sits at constant current even for pulsed klystrons with low duty cycle
- In the x-band facility consumption of the electromagnet represents ~30% of the total power source
- With a gain in klystron efficiency from 40% to 65% and an optimized pulse we can save 20 KW per RF unit
- The solenoid will then represent 37% of the power`

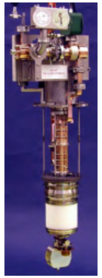


AC power/RF efficiency = 21.0%

SOLENOID DESIGN AND CHARACTERISTICS

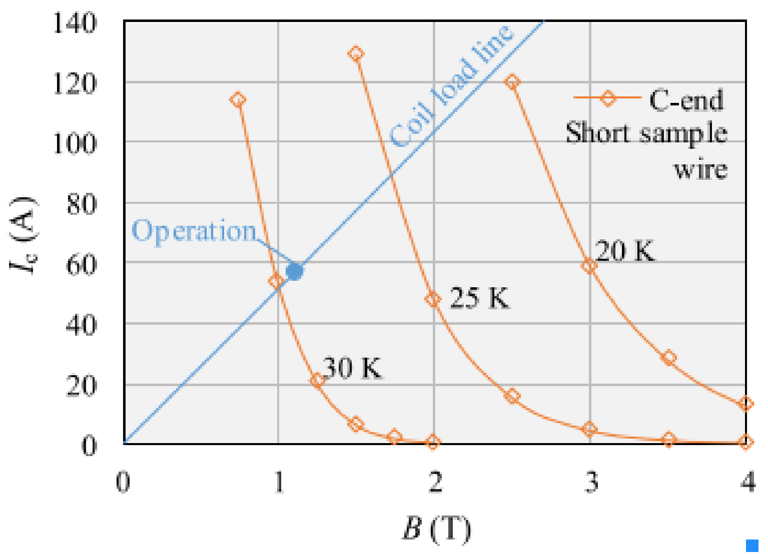
- Proposal from A. Yamamoto (KEK) to build a superconducting solenoid that could be tested and operational on the CERN X-band facility
- The required magnetic field is well below 1T so we can use MgB_2 working below 30 K to improve the cryocooler efficiency ad minimize costs

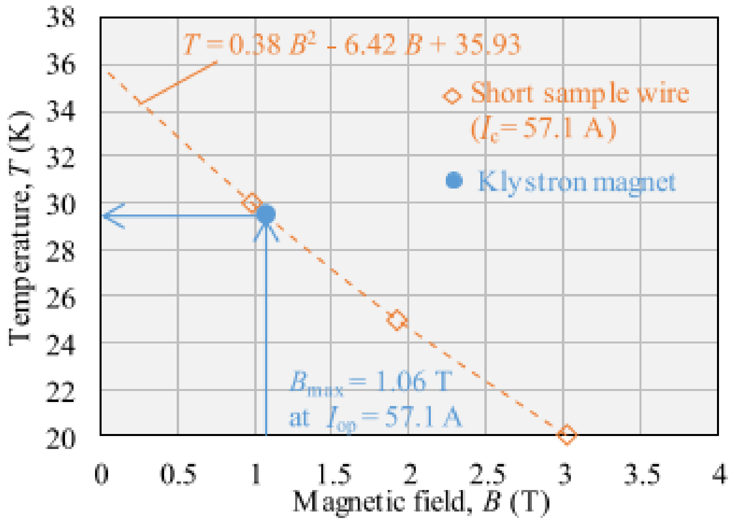




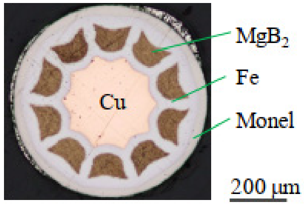
Coil technology	Unit	Cu	MgB_2
Central field	T	0.6	0.8
Current	A	2x300	57
Voltage	V	35	0
Cooling method		Water	Cryo-cooler
Temp	K	300	~25
Wall plug power	kW	**20**	**<3**

A. Yamamoto et al., "Applying Superconducting Magnet Technology for High-Efficiency Klystrons in Particle Accelerator RF Systems", IEEE Transactions on Applied Superconductivity, vol. 30, no. 4, pp. 1-4, Jun. 2020.doi:10.1109/TASC.2020.2978471





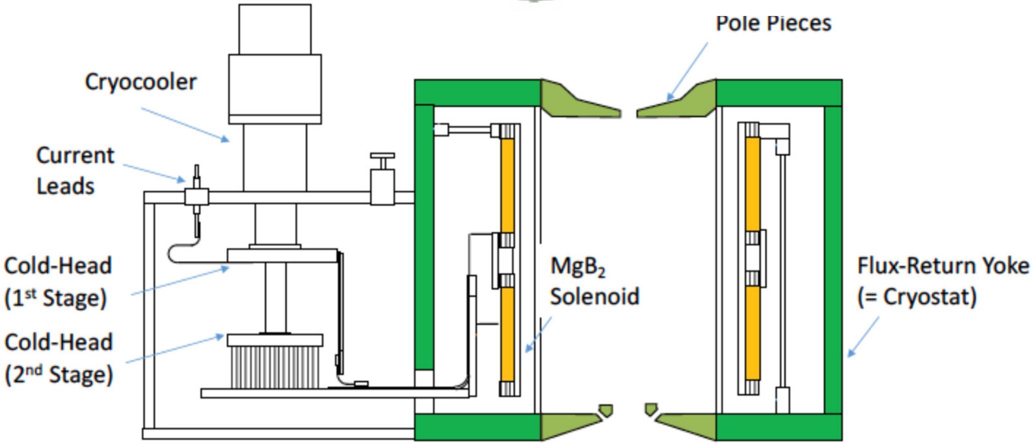
CABLE AND CABLE TESTS



- 8km MgB_2 wire manufactured by Hitachi. Based on experience for MRI magnets
- 21 samples measured. Very good homogeneity
- Critical temperature of the cable at the operational point is 29 K.
  - 57.1 A and 1.06 T field in the coil
- Works at 46% of the load-line

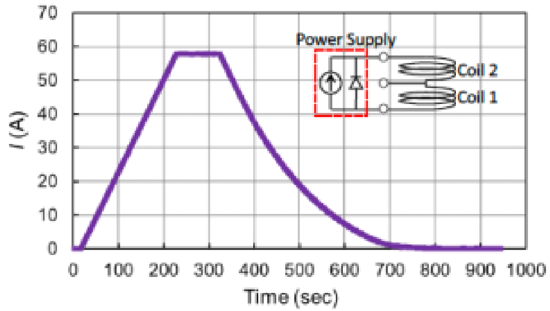
H. Tanaka et al., "Performance of MgB2 Superconductor Developed for High-Efficiency Klystron Applications", IEEE Transactions on Applied Superconductivity, vol. 30, no. 4, pp. 1-5, Jun. 2020. doi:10.1109/TASC.2020.2970391

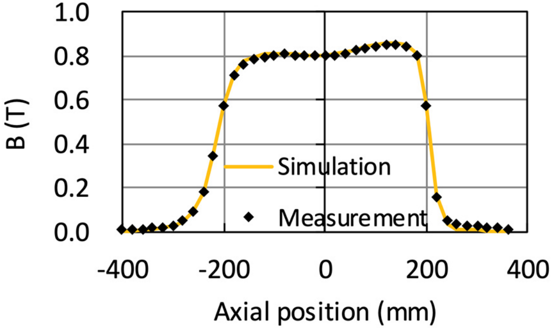
MANUFACTURING OF THE SC SOLENOID IN HITACHI

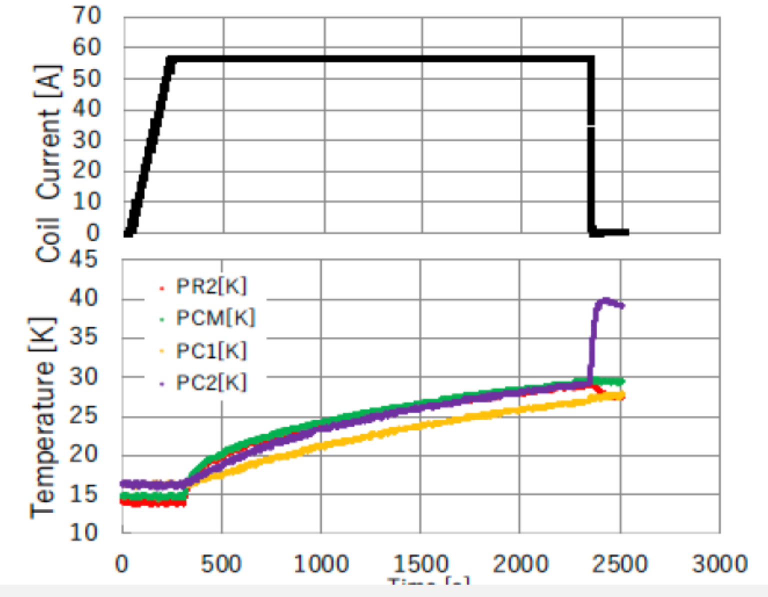


- Wind and react coils (2) in an iron cryostat that serves also as return yoke.
- HTS superconducting current leads (3)

Superconductor	MgB2	
Maximum B field	0.8	T
Current	57.1	A
Inductance	7.3	H
Max. field in coil	1.06	T
Operating temperature	<20	K
Stored energy	11.8	kJ
Weight	600	Kg
AC plug power	<3	kW







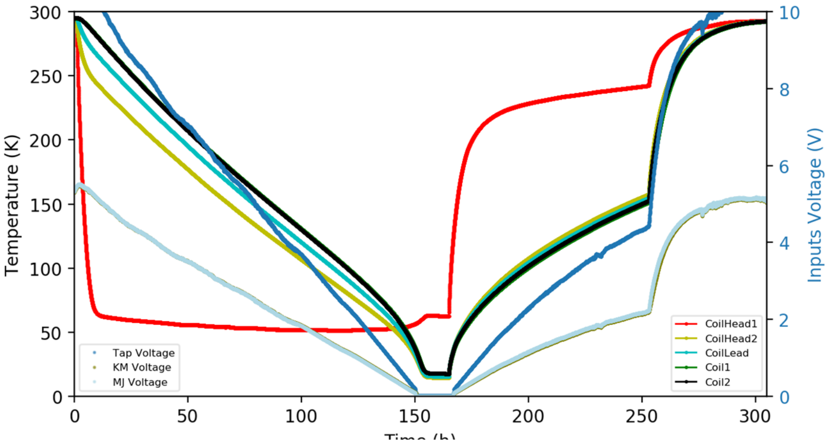
- Quench tests.
  - Self protected
- 10-hours excitation tests
- Power abort test
- Magnetic field measurements
  - Very good agreement

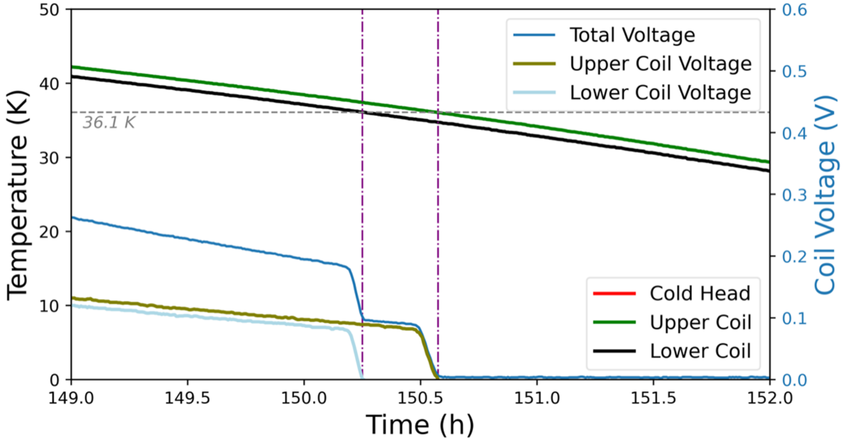
FIRST TESTS AT HITACHI

H. WATANABE *ET AL.*, "DEVELOPMENT OF PROTOTYPE MGB2 SUPERCONDUCTING SOLENOID MAGNET FOR HIGH-EFFICIENCY KLYSTRON APPLICATIONS", *IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 30, NO. 4, PP. 1-6, JUN. 2020.*
DOI:10.1109/TASC.2020.297223

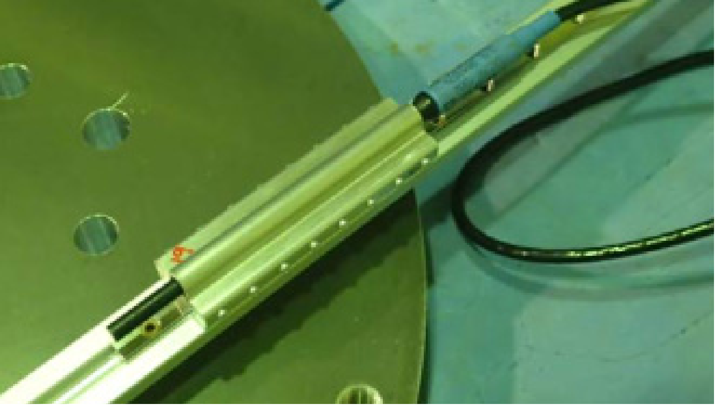
COOL-DOWN

- Two twin coils cooled by conduction.
  - Insulation vacuum
  - Helium only on the cryocooler/cold head
  - Air cooled-compressor Cryocooler plus cold head



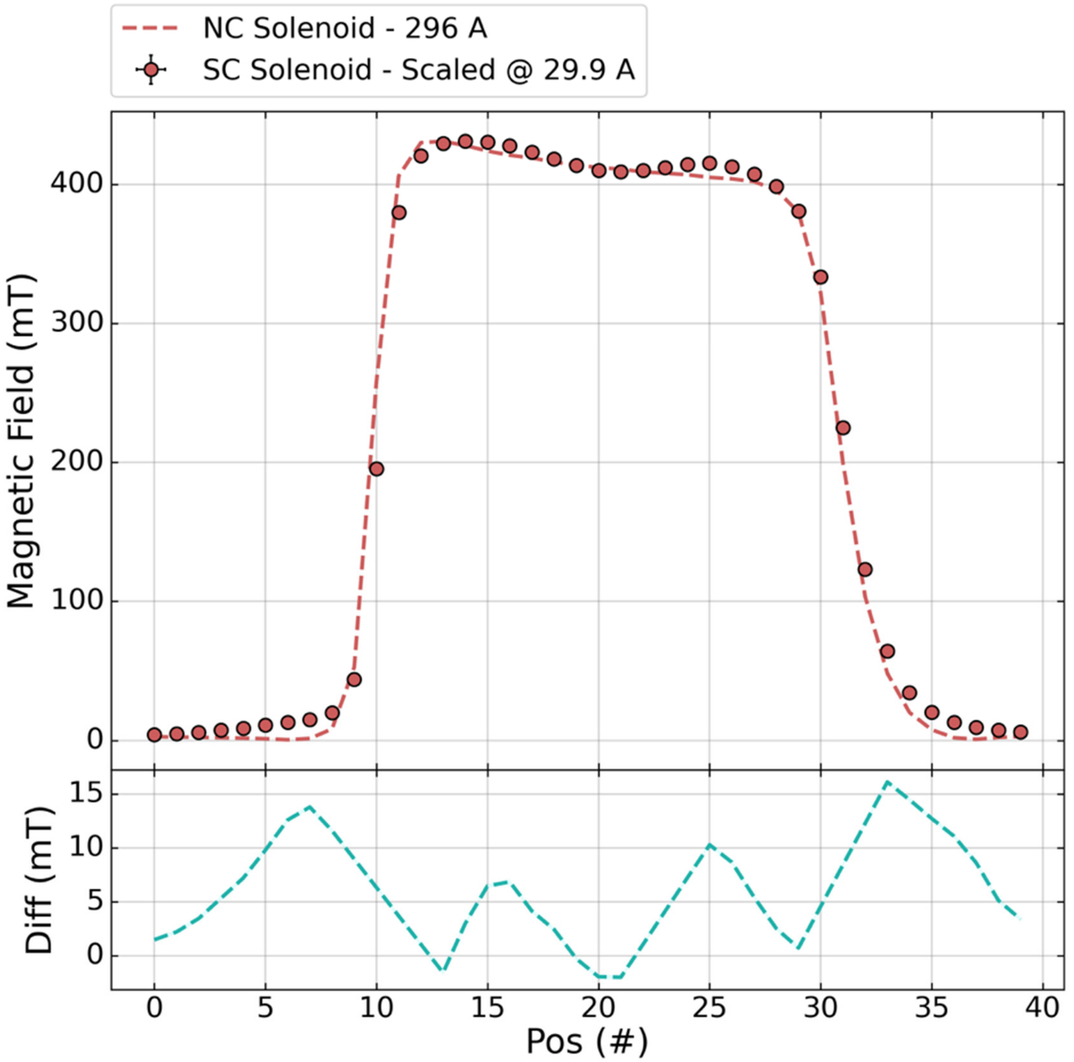


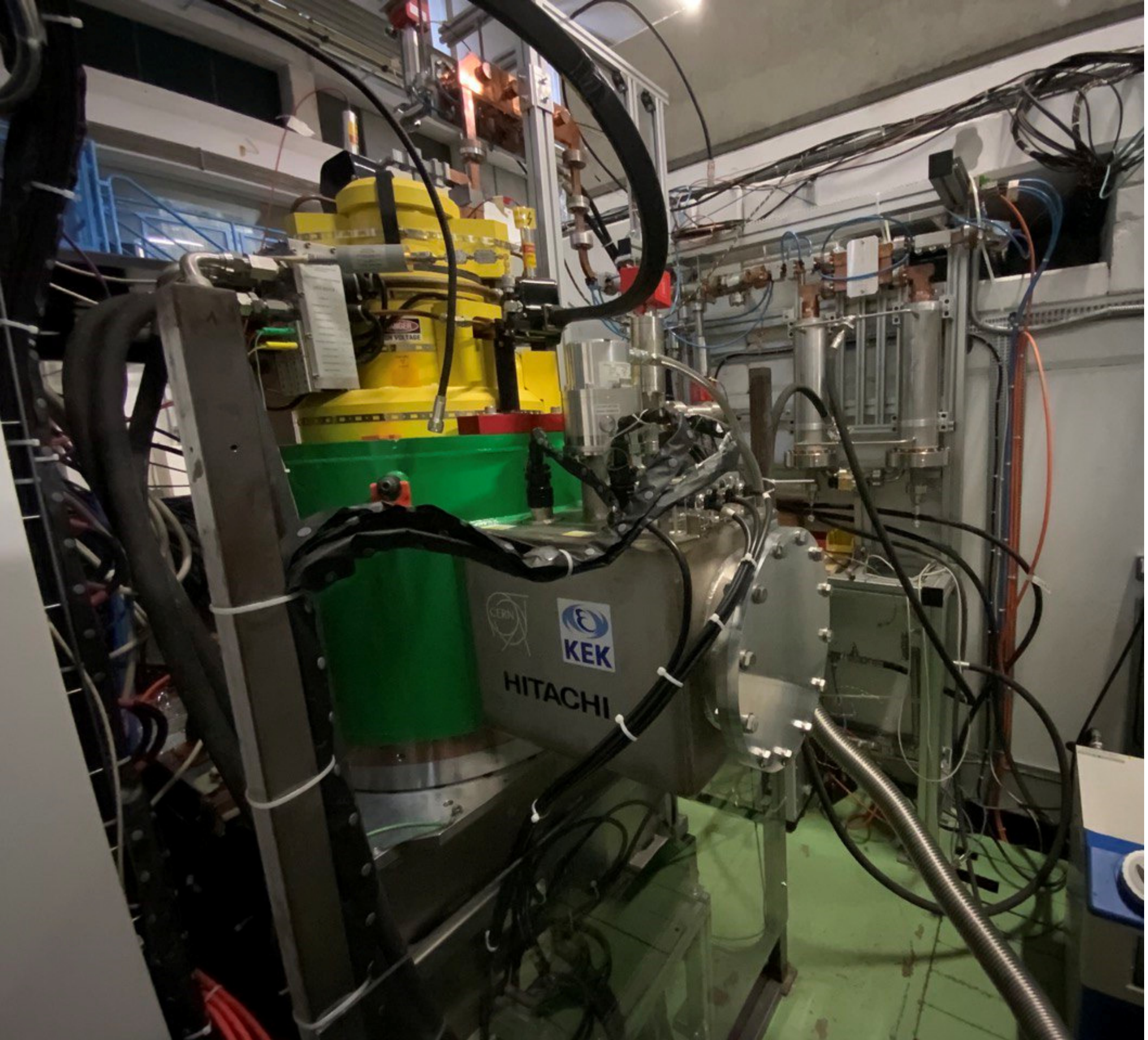
- Available instrumentation:
  - Temperature sensors. Thermo-couples and PtCo sensors
  - Voltage taps
  - Heaters (not used at CERN)



MAGNETIC MEASUREMENTS

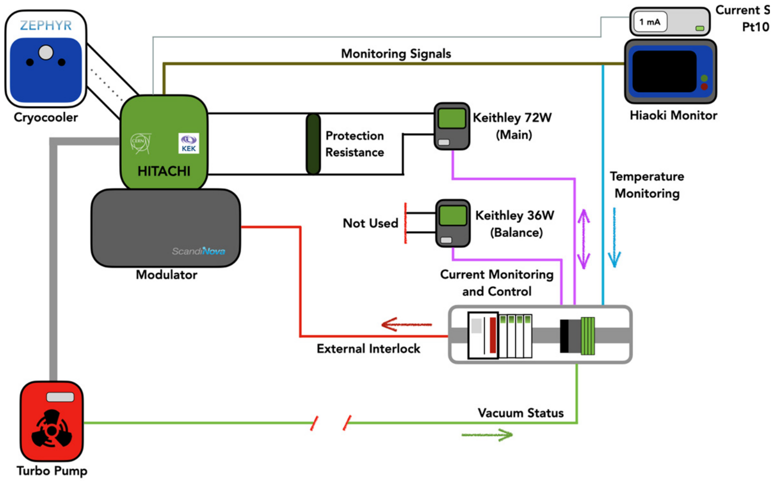
- Measurements done with a hall probe
- Homogeneity and reproducibility are very good!
- Small difference between magnets at the level of fringe fields
- Close to the cathode where beam rigidity is smaller. Probably important for performance

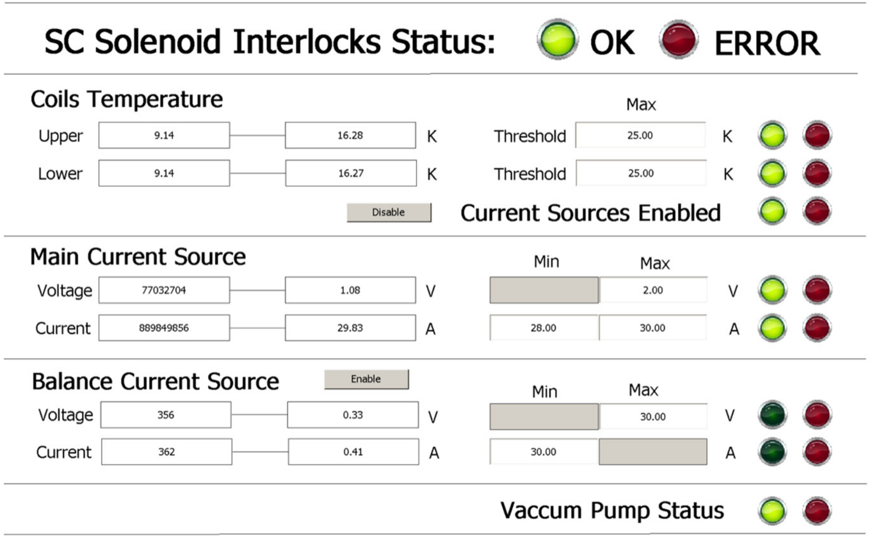




INSTALLATION IN THE KLYSTRON

- Full compatibility with klystron and modulator interfaces
- Larger volume required on the side of modulator
- Special care needed with handling as the load is asymmetric
- Vacuum pump permanently connected (insulation vacuum)



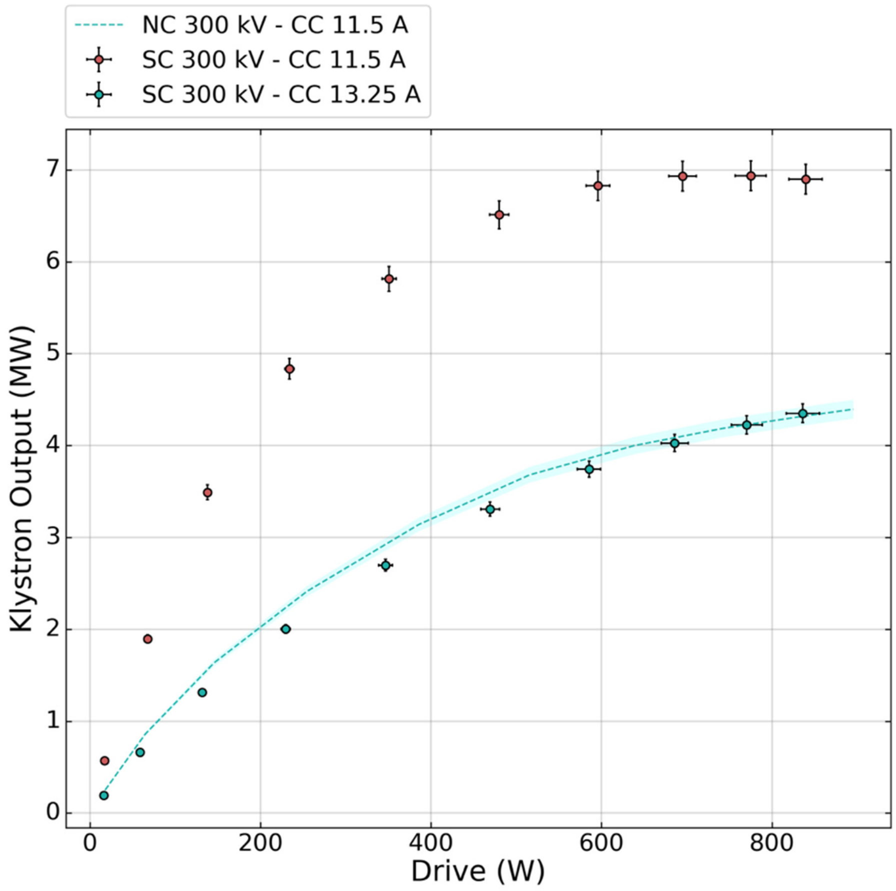


INTERLOCKS AND SAFETY

- From two to three feeds (**current**, **cooling**, vacuum)
- Interlocks on vacuum and temperature to protect the solenoid
- Interlock on solenoid current to protect the klystron

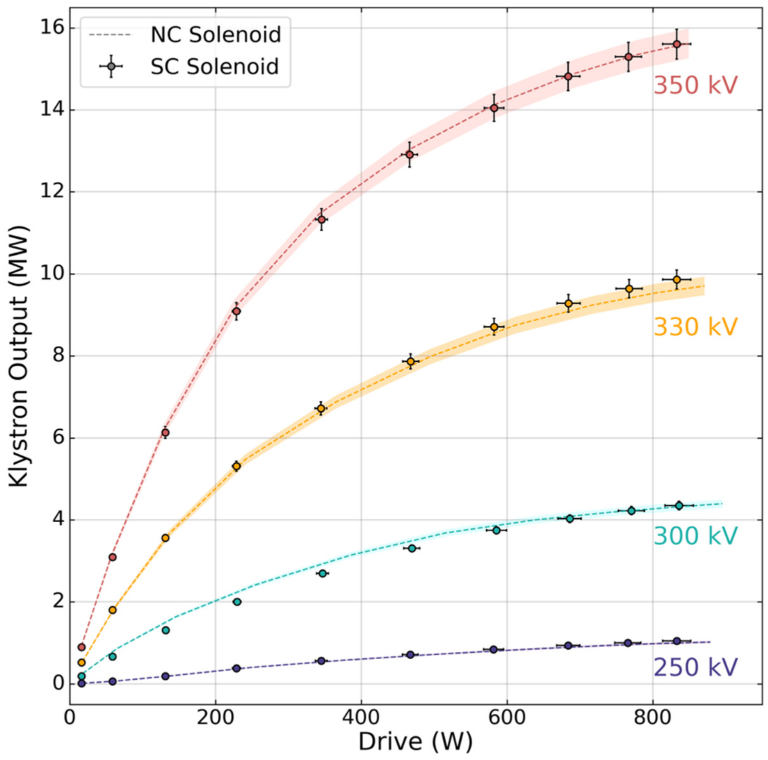
FIRST MEASUREMENTS

- Measurements could not be done at nominal conditions as load not conditioned to full power
  - Max power ~20 MW
  - Originally optimized at CPI for nominal power @ 50 MW
- Current adjusted for central field.
- Nominal counter-coil settings for NC solenoid
- SC gain curve shows higher gain and faster saturation
- Counter-coil current adjusted for smaller beam to match original gain



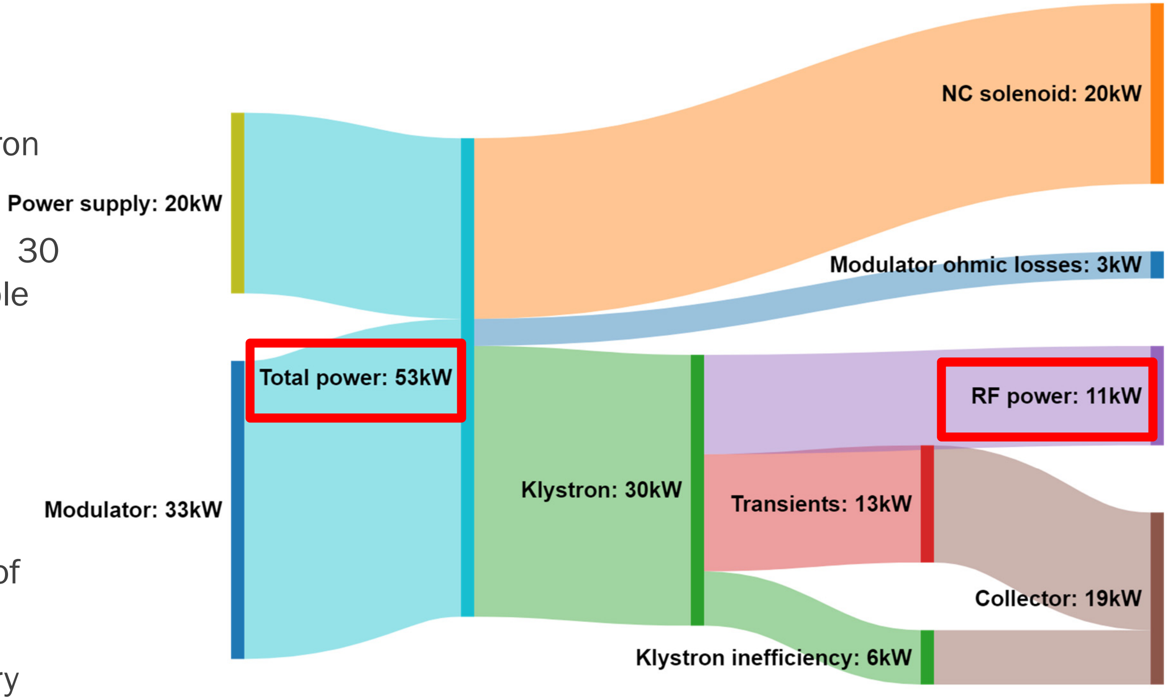
RE-TUNING OF THE COUNTER- COIL

- Counter-coil re-tuned by an additional 20% in current to recover performance
- Same correction is valid for every klystron gain
- Counter-coil current settings are valid for all set-points



CONCLUSIONS

- SC technology can be applied to klystron solenoid
- Energy consumption reduced by 90 % 30 ->3 kW. Further reductions still possible
- Magnetic field very similar to the conventional magnet
- No interception
- Some adjustments needed to recover performance inside the tuning range of the power supply
- Large operational margin makes it very stable and robust against failures



AC power/RF efficiency = 21%

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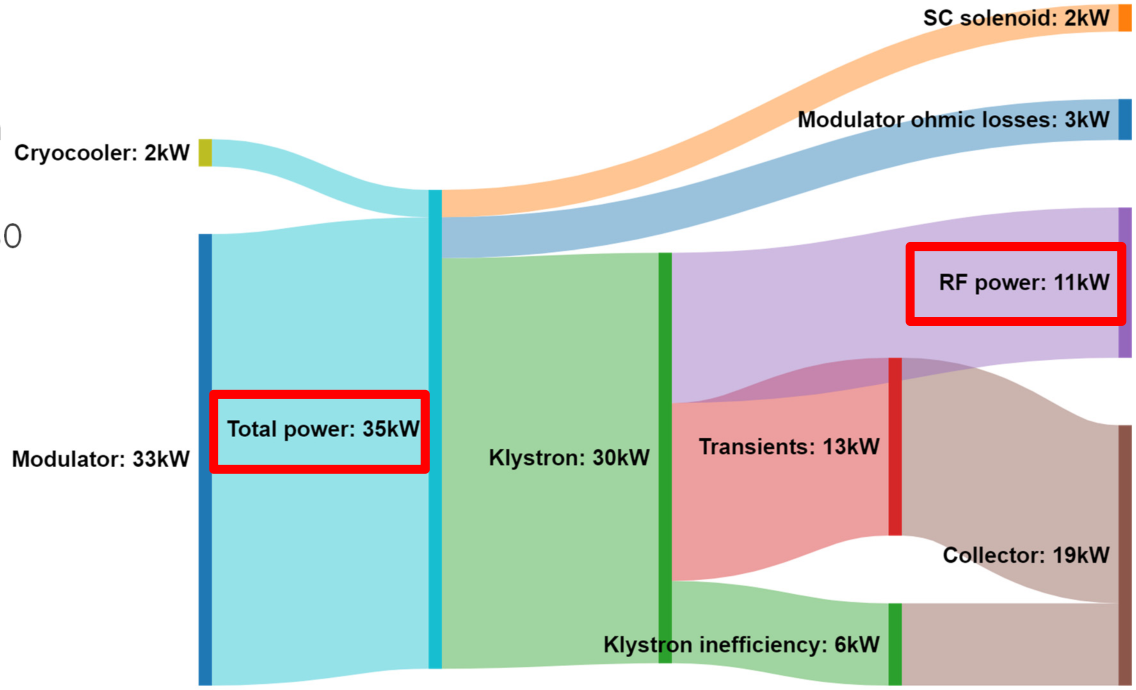
<u>With a high efficiency klystron , modulator AND a SC solenoid we will save >50% of the power for the same output RF power!</u>



AC power/RF efficiency = 31.7%

ANNOUNCEMENT

- I.FAST Workshop on efficient RF sources
- Klystrons, IOTs, Solid state, tetrodes, Magnetrons, etc.

https://indico.cern.ch/event/1138197/

Workshop on efficient RF sources

4–6 Jul 2022
Chateau de Bossey
Europe/Zurich timezone

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Following a series of successful workshops on the initiative of the EUCARD and ARIES EU-funded programs, we would like to announce the next Workshop on Efficient RF sources to be held in Chateau de Bossey (Geneva, Switzerland) on the 4-5-6 July 2022. The workshop is part of the I.FAST initiative for **"Sustainable concepts and technologies"**

The workshop is aimed at displaying the recent advances on energy efficient technology for RF sources mainly used in accelerators. As in previous events, we expect a number of experts from public and private sector to participate in the meeting and the discussions around the efficiency of klystrons, IOTS, Solid state amplifiers and RF systems in general.

Organizing Committee Chairs: Nuria Catalan Lasheras (CERN), Mike Seidel (PSI)

Scientific Committee Chair: Igor Syratchev

Processing of Personal Data at CERN: OC11

Starts 4 Jul 2022, 09:00
Ends 6 Jul 2022, 14:00
Europe/Zurich

Chateau de Bossey
Chemin Chenevière 2, 1279 Bogis-Bossey, Switzerland

Igor Syratchev
Mike Seidel
Nuria Catalan Lasheras

There are no materials yet.

THANKS