Version 2910020

HIGH-ENERGY PHYSICS (HEP) TECHNOLOGIES WITH POTENTIAL APPLICATION TO QUANTUM SYSTEMS

Collaborate with CERN

A different perspective on your challenge

Based on our wide-ranging expertise in domains related to quantum technologies we can take a look at your technical challenges and provide new perspectives & advice

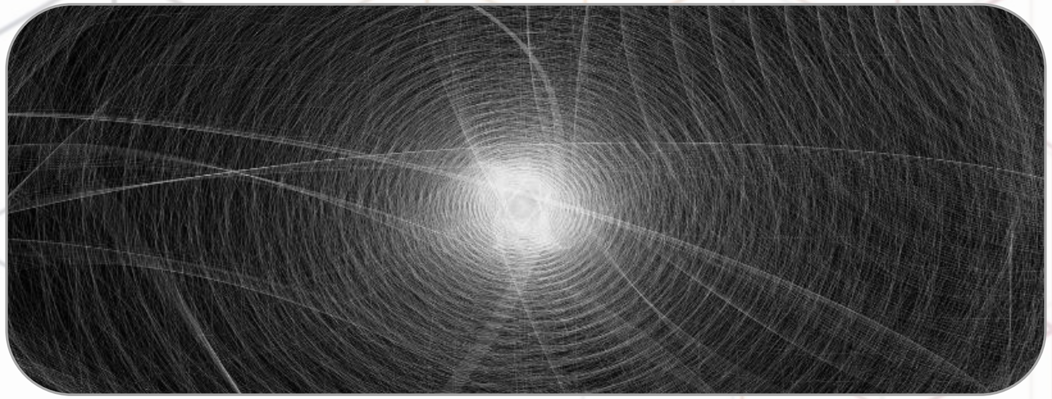
Co-development

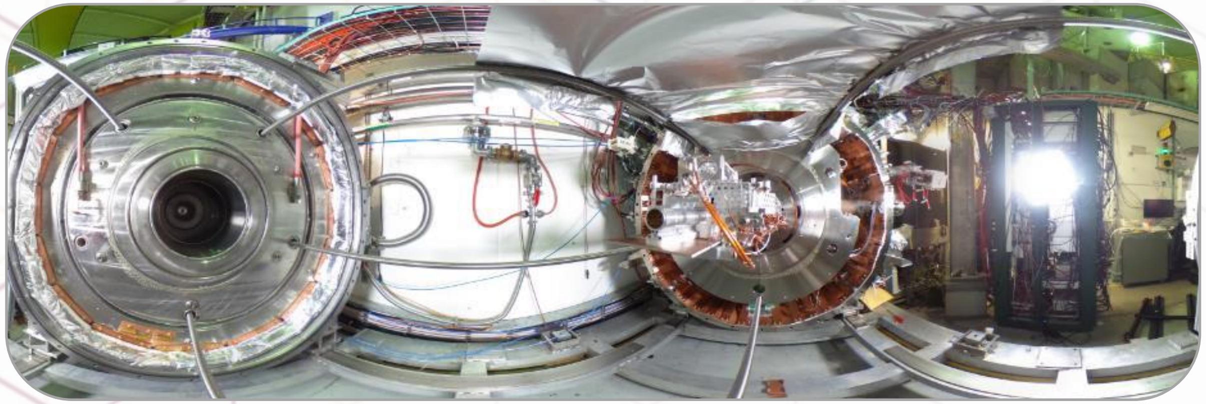
We can explore potential collaborative R&D projects to develop new quantum solutions

Access to unique technology

CERN's proprietary technologies and know-how can be licensed for use in your quantum systems

Key competence: Measurement & control of quantum-scale systems





what

CERN personnel have accumulated decades of experience in the design, manufacture and maintenance of devices for the precise measurement and control of particles, including for proton beams in CERN's accelerator complex and for decelerating antiprotons in order to study antimatter.

apps

Systems requiring the precise monitoring and control of particles

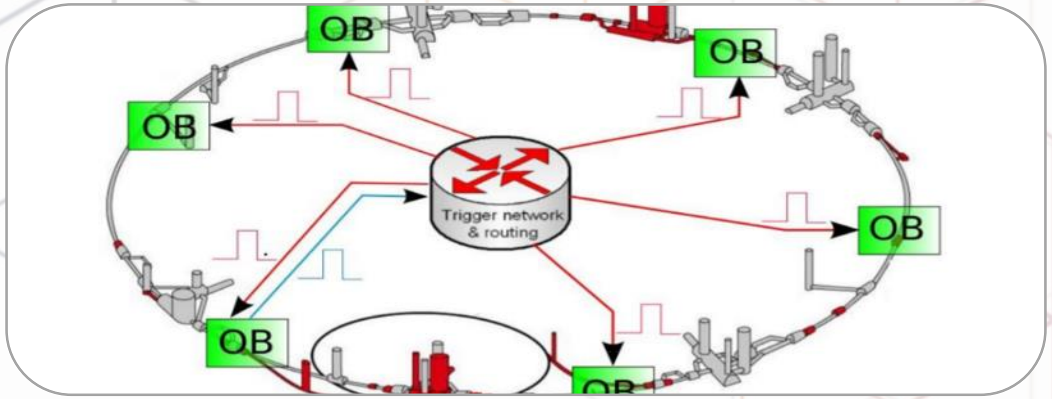
tech specs

- Expertise in the design and operation of devices, such as Penning traps, for the capture, storage, and manipulation of particles with extremely high precision.
- Design of bespoke hardware & software for particle beam diagnostics.
- Qualifying off-the-shelf components, particularly for operation in harsh environments, such as ultra-high vacuum.

added value

- Expertise in device development for high-precision applications
- Unique facilities, including the Antiproton Decelerator (AD)
  → **Gain new perspectives on your challenges**
- Continuous R&D investment
  → **Access the latest technologies and developments**
- Many designs freely available through the Open Hardware Repository
  → https://www.ohwr.org/

Key technology: Picosecond Synchronisation



what

At CERN, particles circle the LHC over 11,000 times per second. This means components in the accelerator complex require minute timing accuracy and synchronisation. White Rabbit is a protocol based on industrial networking technology, developed at CERN for high-precision particle beam monitoring and control.

apps

Systems requiring high-precision control, timing & synchronisation

tech specs

- Sub-nanosecond accuracy and picoseconds synchronisation, derived from CERN's demanding requirements.
- Connects thousands of nodes.
- Typical distances of 10 km between network elements.
- Gigabit rate of data transfer.
- Fully open hardware, firmware and software.
- Commercially availability from many vendors.
- Will become the High Accuracy Delay Request-Response Default PTP Profile.

added value

- Picosecond synchronisation
  → **Increased system performance and efficiency**
- Will define the new IEEE Precision Time Protocol (PTP)
  → **Learn from experts on this proven technology**
- Freely available through the Open Hardware Repository
  → https://www.ohwr.org/project/white-rabbit/wikis/home
  → https://white-rabbit.web.cern.ch

Key competence: FPGAs for quantum simulators

hls4ml

what

In HEP experiments, quantum objects are studied and monitored using single-particle sensors connected to a data acquisition system based on custom electronics (FPGAs and ASICs). This is a very similar approach to that used in quantum simulators.

apps

FPGAs for quantum simulators

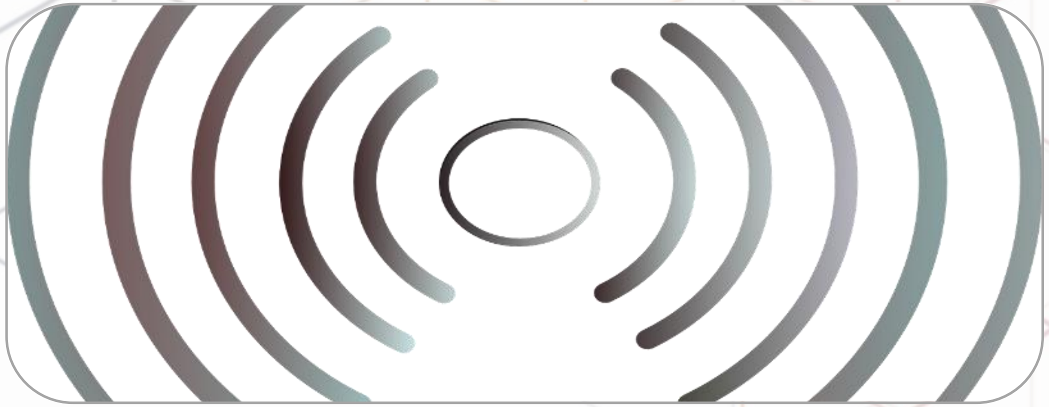
tech specs

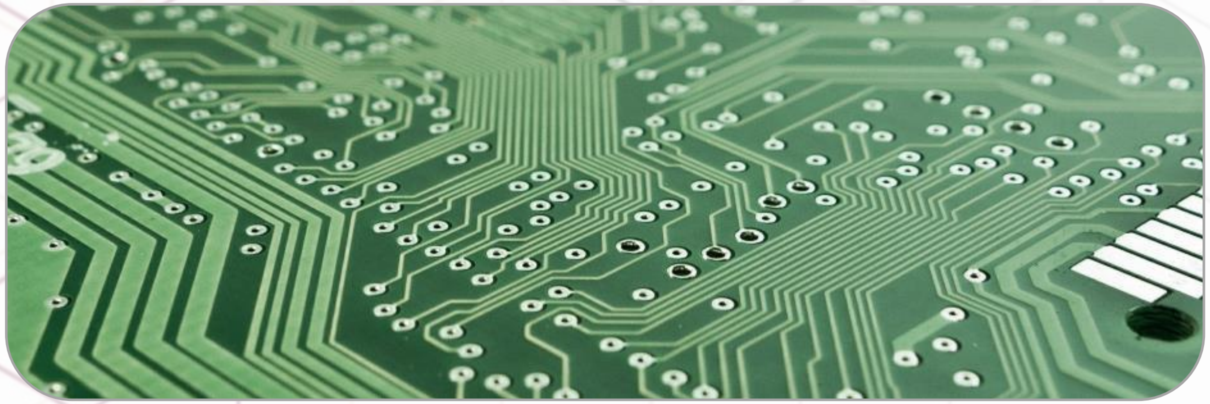
- Expertise in the development of High-Level Synthesis (HLS) software (e.g. the [HLS4ML project]) with possible application for automating FPGA programming and ASICs design. This might enable the creation of a software library that would allow the emulation of generic quantum circuits on FPGAs through HLS, and QC control algorithms could be developed, in a way similar to what is currently done at the LHC with hardware triggers.
- See https://arxiv.org/abs/1804.06913

added value

- CERN has built a system to adapt Neural Networks to FPGA architecture
  → **hls4ml** (open source) decreases drastically the firmware development time
- Efficient Neural Network design for FPGAs
  → Optimization of FPGA design through compression/quantization/parallelization
- Custom Neural Networks tested in the CERN experiments
  → Advice/consulting on ML & FPGA development from world class experts

Key competence: Digital Low-Level Radio Frequency (LLRF) control systems





what

The RF systems in CERN accelerators must be precisely controlled. Low-Level Radio Frequency (LLRF) control improves RF stability via electronic feedback and feedforward systems. CERN experts have expertise in the design of LLRF controls with powerful digital signal processing, enabling highly precise regulation of complex systems.

apps

RF systems requiring high precision and high stability

tech specs

Expertise and know-how in:

- Design of digital LLRF controls for the delivery of high-stability and high-precision RF.
- Design of firmware and software for digital LLRF control systems.
- Design of LLRF diagnostic systems.
- Use of Bridged Local Area Networks for highly-precise timing synchronisation of distributed LLRF systems (see White Rabbit).
- Design of fractional dividers for RF signal distribution.

added value

- Systems designed with industrial-scale production in mind
  → **Benefit from expertise acquired in real use case**
- Continuous research investment into LLRF systems
  → **Access to the latest technologies and developments**

Key competence: Cryogenic system design, measurement & control

what

Expertise and facilities to perform state-of-art benchmarking of cryogenic instrumentation, leveraging CERN know-how in heat transfer, refrigeration cycles, low temperature material properties and cryogenic engineering.

apps

Cryogenic systems and equipment

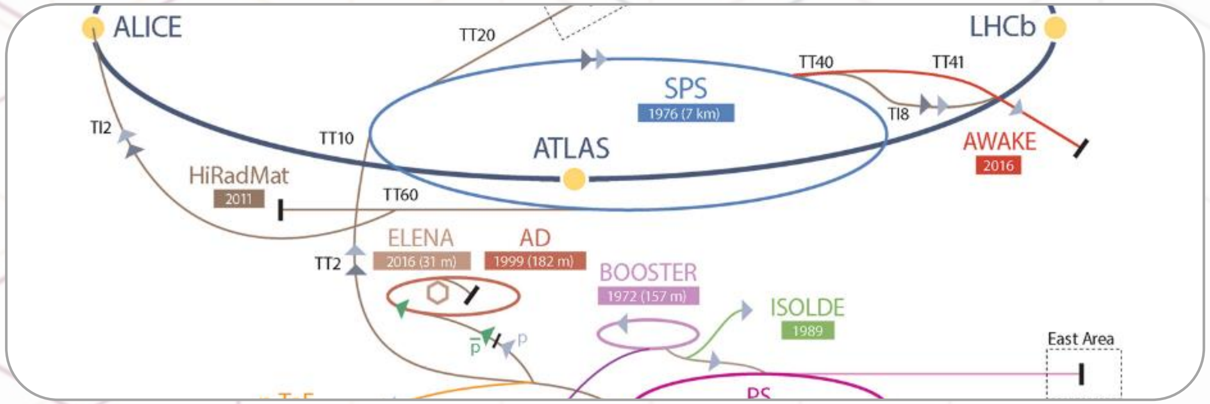
tech specs

- Expertise in thermodynamics.
- Design and operation of cryogenic systems using Helium, Nitrogen and Argon, particularly for remote cooling at a distance from the main machinery.
- Cryolab designed for scientifically backed-up benchmarking.
- Large scale cryogenic test vessels.
- Automated refrigeration cycles.
- Accelerated aging and ultra-low temperature material tests.
- Access to database with instrumentation test results.

added value

- Experience with a large range of cryogenic equipment and instrumentation from many manufacturers
  → **Hands on experience and advice** → **Easy and practical to apply**
- Possibility to create extreme testing conditions to help accelerate understanding of failure modes and effects
  → **Insights in options to improvement** → **Better instrumentation**

Key competence: Vacuum system design & control (HV, UHV, XHV)



what

The LHC is a complex system of interconnected vacuum vessels - under high (HV) to extremely high vacuum (XHV). In order to secure reliable and high-performance operation, CERN experts have developed significant expertise in vacuum systems and related technologies.

apps

HV, UHV or XHV systems

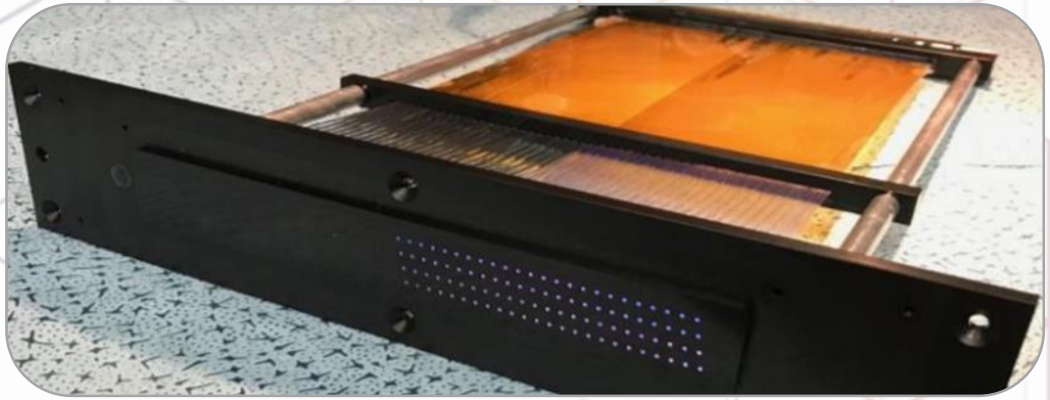
tech specs

- Mechanical and vacuum engineering.
- Sealing and leak-tightness technology.
- Simulation of gas transport in HV, UHV and XHV systems.
- Distributed control systems, interlocks and monitoring tools.
- Coatings, electroplating and surface cleaning techniques.
- Characterisation of the vacuum performance of materials and treated surfaces, including outgassing and permeation measurements.
- High temperature treatments under vacuum.
- XHV production and measurements.

added value

- Holistic and interdisciplinary experience accumulated over decades
  → **Proven capability to manage reliable operation in complex settings**
- Continuous research investment in the range of industrial vacuum to extremely high vacuum (XHV) systems
  → **Access to state of the art technologies and developments**
- Collaboration with one of the world's leading research institutes
  → **Possibility of using CERN labels for your branding and marketing**

Key competence: Thin film coatings for high-performance applications



what

CERN components must meet demanding expectations in performance and longevity. To achieve this, CERN experts have accumulated over 50 years of experience in the development and application of novel thin film coatings for functional and optical use, including in vacuum systems and high-energy detectors.

apps

Systems requiring thin films for high-performance and control

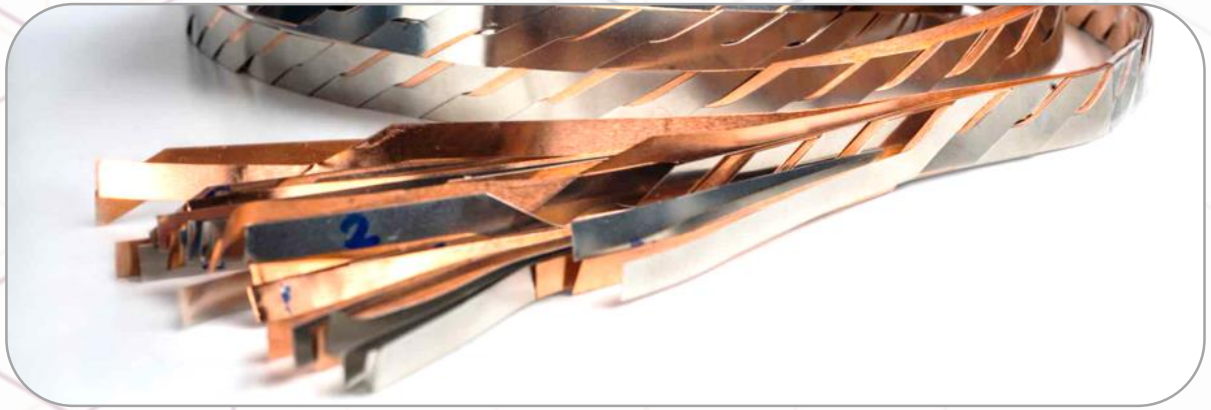
tech specs

- Physical Vapour Deposition (PVD) of materials, including surface preparation and treatment of substrates.
- Development of novel cold spray methods.
- Development of functional thin-film coatings for vacuum performance.
- Development and testing of new superconducting (SC) thin films.
- UV enhanced spectral reflectors for detectors systems.
- R&D into coating processes for organic materials in photocathodes and photomultipliers – particularly for their Wave Length Shifting (WLS) properties.

added value

- Benefit from CERN expertise and proprietary know-how
  → **Proven capability over several decades of application & use**
- Training possible at CERN
  → **Learn from leading experts**

Key technology: Superconducting (SC) materials



what

CERN uses a wide range of superconducting (SC) materials in the construction of its accelerators and experiments, and has developed specialised expertise - particularly in relation to the design, development and assembly of SC cables.

apps

Systems using SC materials and devices

tech specs

Know-how and experience with various SC materials like

- Niobium titanium (magnets and bus-bars)
- Magnesium diboride
- Niobium tin
- HTS cuprates, YBCO and BSCCO

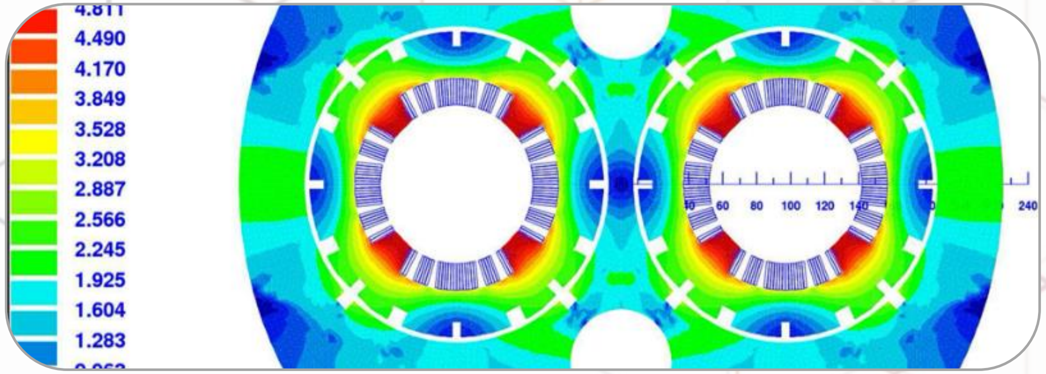
Know-how and experience with various techniques and forms

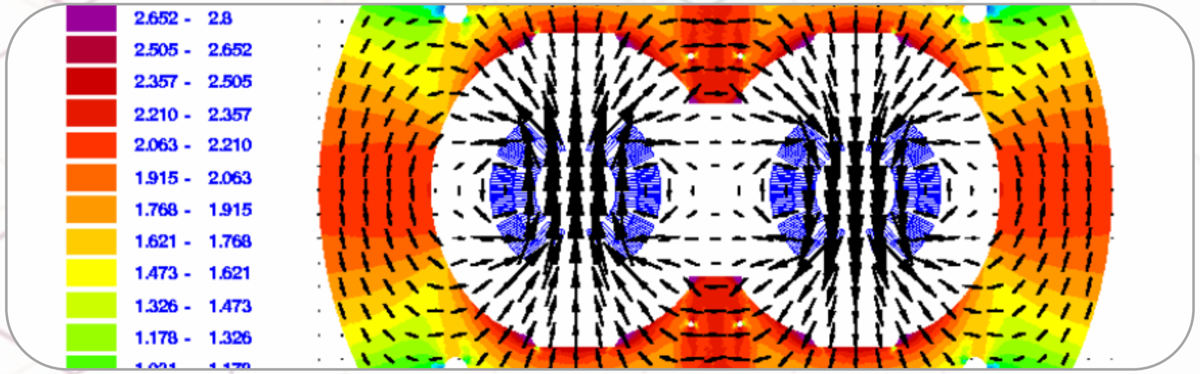
- Specification, analysis and development of wires & tapes
- Production and testing of Nb-Ti, Nb_3Sn and HTS cables
- Deposition of coatings and manufacturing of cavities

added value

- Internal experts and access to a wide network of companies and institutes specialized in the development and production of superconducting materials, wires and cables.
  → **Rapid access to relevant players and expertise**
- Comprehensive test facilities and expertise for characterizing and benchmarking wires and cables, and an extensive database of superconducting material and conductor characteristics.
  → **Selection, specification and validation of material solutions**

Key technology: Magnet design & modelling





what

CERN has vast, holistic experience with design and modelling of magnets for particle accelerators, including permanent and superconductive electromagnets, such as dipole-, sextupole-, octupole- and decapole-magnets. In addition, CERN uses in-house software tools for fast and accurate simulations.

apps

Machines and equipment with superconductive and/or magnet components

tech specs

Modelling of current density, quench protection, mechanical structure, stresses, stability and temperature taking into account many aspects:

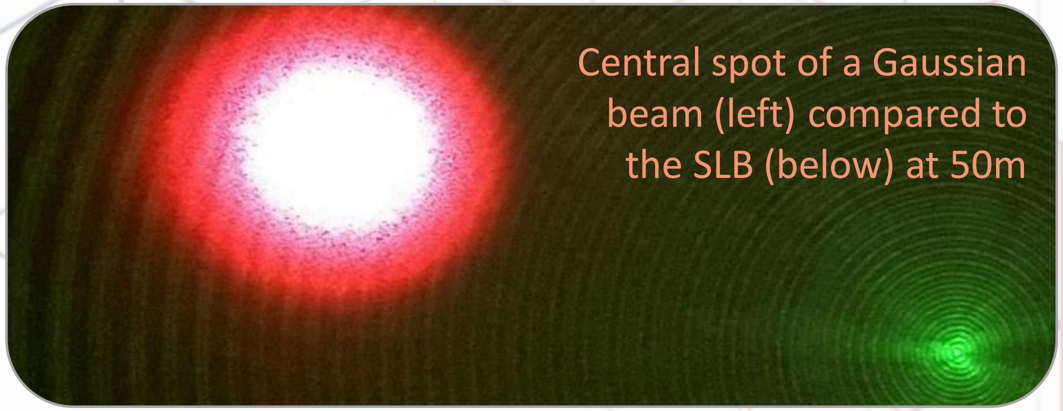
- LTS, HTS or non-superconductive technology
- cryostat / cooling technology
- maximum attainable field
- operational temperature
- bore field or gradient and field homogeneity
- current density
- choice of coils/wires and materials

added value

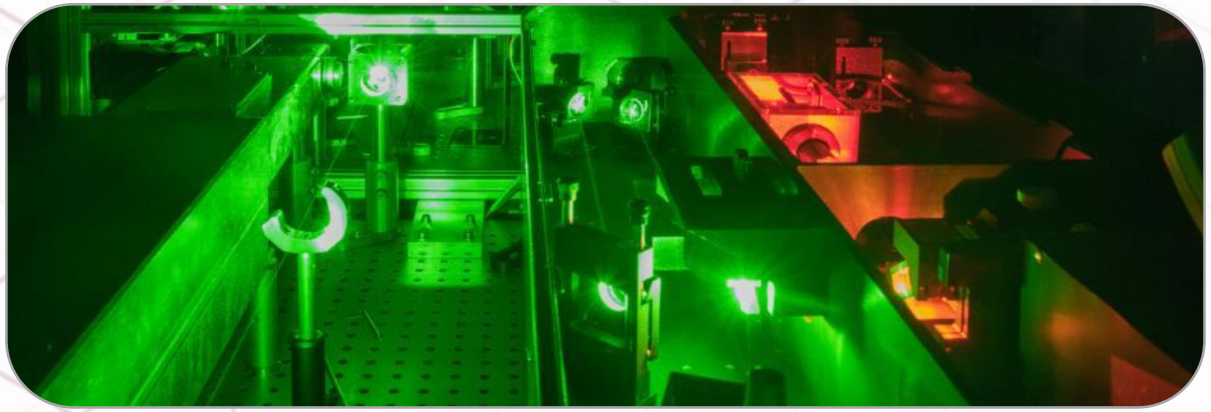
- CERN applies a multi-disciplinary, cross-functional design approach to cover all aspects of modelling
  → **skillset and experience needed to optimise magnet systems**

- Closed loop learning because at CERN we design, but also manufacture, assemble, test and operate the magnets we design
  → **vast amount of practical experience helps to make designs that work**

Key technology: Laser devices



Central spot of a Gaussian beam (left) compared to the SLB (below) at 50m



what

CERN has expertise in the development of laser devices for high-precision alignment and for resonance ionisation using tuneable laser radiation. Technologies include a simple system for generating a **structured laser beam (SLB)**, and a laser converter for producing **continuously tuneable single-longitudinal mode output.**

apps

- Quantum systems using lasers
- Resonance ionization
- Spectroscopy
- Metrology, particularly geodetic metrology
- Communication

tech specs

Structured Laser Beam (SLB) – co-developed with Institute of Plasma Physics of the Czech Academy of Sciences (IPP), Czech Republic

- Non-divergent, high-intensity central beam with a small spot-size, surrounded by concentric rings with clear contrast between them

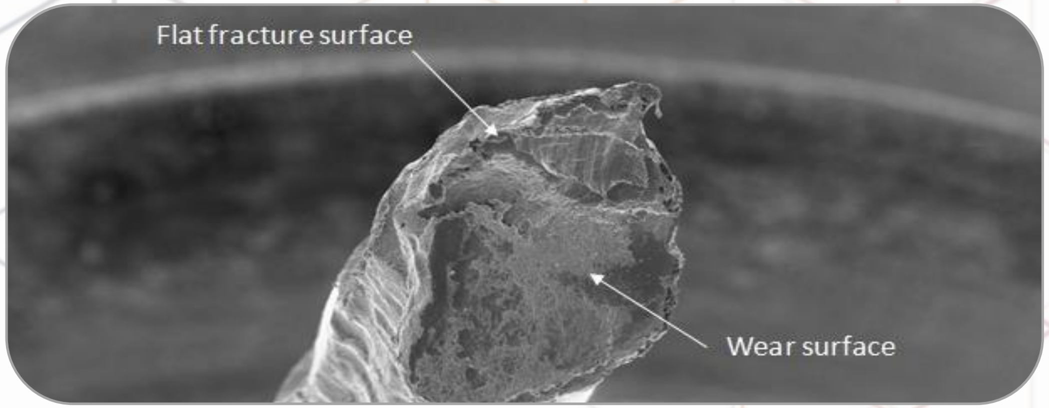
Single-longitudinal Mode Laser Converter – co-developed with Macquarie University, Australia

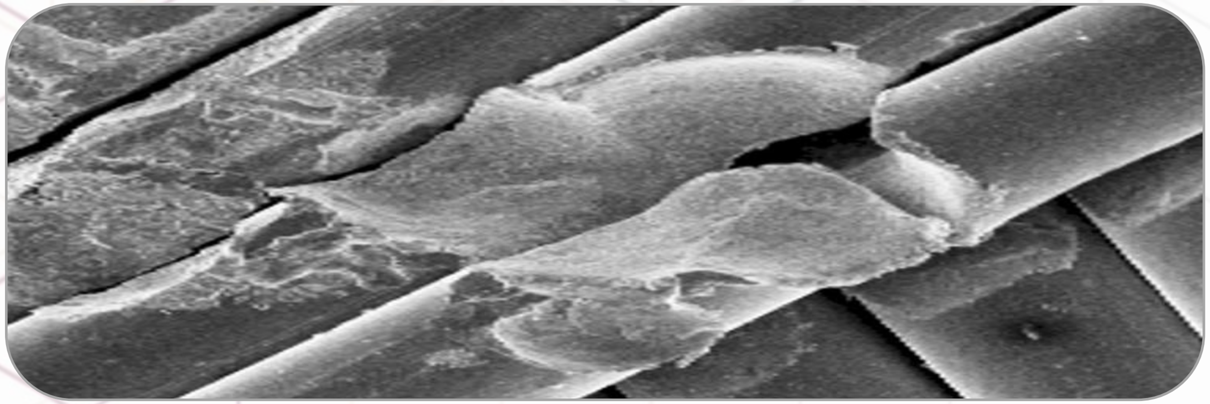
- Enables conversion of standard broadband lasers to single longitudinal mode output, diversification of their wavelength range at high power, and enhanced power spectral density.

added value

- Access to novel technologies
  → **SLB, Single-longitudinal Mode Laser Converter**
- Experience operating unique facilities
  → **E.g. CERN-ISOLDE resonance ionization laser ion source (RILIS)**
  https://rilis-web.web.cern.ch/
- Interpretation and solution
  → **New perspectives on your engineering challenges**

Key competence: Advanced material characterisation





what

Material characterisation and analysis for quality control. Includes non-destructive testing and dimensional control. Static and dynamic mechanical tests, measurements, and failure analyses. Use of advanced technologies like ultra high precision CMM, phased array ultrasound testing, computed micro-tomography and dimensional metrology.

apps

Material characterisation expertise for materials operating in harsh environments (cryogenic, high vacuum, high magnetic field strength, high radiation), and/or where there are high demands on material performance

tech specs

Expertise and know-how, accumulated over decades, in…

- Non-destructive testing and analysis
- Microstructural characterization – using numerous techniques, including optical and electron microscopy, Focused Ion Beam (FIB) microscopy
- Thermal, electrical, and magnetic analyses
- Failure analysis – including corrosion issues
- Mechanical testing – tensile strength, hardness, etc.
- Irradiation testing
- Optical analyses – e.g. of scintillating and light-emitting materials

added value

- Historical knowledge
- Interpretation and solution
  → **Unique perspectives on your material science and engineering challenges**
- Continuous research investment
  → **Access to the latest technologies and developments**