环形正负电子对撞机简报

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CIRCULAR ELECTRON POSITRON COLLIDER NEWSLETTER

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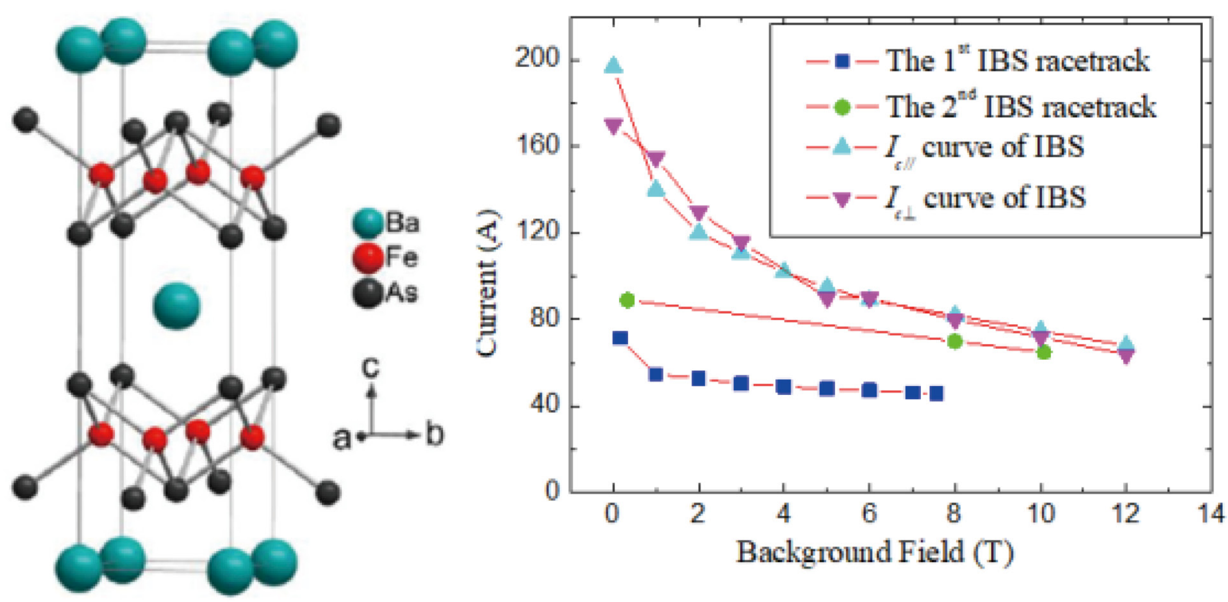
长尺度铁基超导线圈通过 10 特斯拉下性能测试

2021 年 2 月 2 日，中科院高能物理所高场超导磁体团队及中科院电工所铁基超导材料团队在《超导科技》(Supercond. Sci. Technol. 34 035021) 发表最新成果：基于百米铁基超导带材研制的长尺度跑道型线圈，在 10 特斯拉二极磁场下，实现超过零场环境 80% 的高载流性能，首次验证了大尺寸铁基超导线圈在高场领域应用的可行性，及其载流性能对背景场强相对不敏感的高场应用优越性。这是继 2016 年研制出首根百米级铁基超导带材 (IEEE Trans. Appl. Supercond. 27 7300705)、2019 年完成小尺寸铁基超导螺线管线圈 24 特斯拉性能验证 (Supercond. Sci. Technol. 32 04LT01, 070501) 后的又一重要进展。

审稿人高度评价此项工作的重要意义："这一新成果将对超导材料及磁体技术领域产生重要影响"、"证明了铁基超导材料用于发展下一代粒子加速器的巨大潜力"等。铁基超导材料是 2008 年发现的新一类高温超导材料，因其大于 100 特斯拉的上临界场，以及较低的制作成本，在高磁场应用领域具有独特的潜在优势。科研团队通力合作，推进了铁基超导高场磁体技术预研。

未来，合作团队将在此基础上，继续大幅度提升铁基超导线带材的载流及机械性能，推进高性能铁基超导高场磁体技术的进一步探索及示范验证。性价比大幅度提升的新一代高场超导磁体技术，不仅可以推动高性能粒子加速器及可控核聚变等大科学装置的建设及相关基础科学的发展，在能源、医疗、电力、交通等民生领域也将有着广泛的应用。

该研究工作得到了中科院战略先导专项（B 类）"下一代高场超导磁体关键科学与技术"以及国家重点研发计划"变革性技术关键科学问题"重点专项的支持。



（左）IBS 超导材料晶体结构（右）基于百米铁基超导带材的跑道型线圈在磁场下的载流性能
(left) Crystal structure of the 100-m 7-filamentary Ba122 IBS tape and
(right) the quench current of the racetrack coil with respect to the background field

Large-size Iron-based Superconducting Coil Passes Performance Test at 10 Tesla

The high field superconducting magnet team of the Institute of High Energy Physics and the advanced superconductor team of the Institute of Electrical Engineering published their latest cooperative achievements on Feb. 2. The study, entitled "First performance test of the iron-based superconducting racetrack coils at 10 T," was published in Superconductor Science and Technology (SUST).

Based on 100-meter-long 7-filamentary Ba122 iron-based superconductors (IBS), two racetrack coils were fabricated and tested at up to 7.5 T and 10 T, respectively. The highest quench current reached 86.7% of Ic of the short sample at 10 T, and 81.25% of the quench current under self-field.

The results show that the high field performance of the IBS racetrack coils is less dependent on the background field strength compared with other practical superconducting materials, which is similar to the IBS solenoid coils tested previously at 24 T. This shows that IBS can be a promising candidate material for high field magnet applications. It represents a new milestone since the first 100-meter-long IBS conductor was developed in 2016 and the performance test of the IBS solenoid coils at 24 T was conducted in 2019.

This work is highly regarded by SUST reviewers, who said "the new results can have a strong impact on the conductor and magnet community," and also said that the results "demonstrated the great potential of iron-based superconductors in the development of next-generation accelerators," etc. IBS represent a new class of high-temperature superconducting material discovered in 2008. Their upper critical field is higher than 100 T and their fabrication cost is relatively low, giving them unique potential advantages in high magnetic field applications.

For the next step, the team will continue to improve the current-carrying capacity and mechanical properties of IBS and develop higher performance IBS model coils and magnets.

The new generation of high field superconducting magnets with greatly improved cost performance will not only promote the construction of next-generation particle accelerators and the development of related basic science, but will also have a wide range of applications in the fields of advanced energy, medical equipment, electricity and transportation, etc.

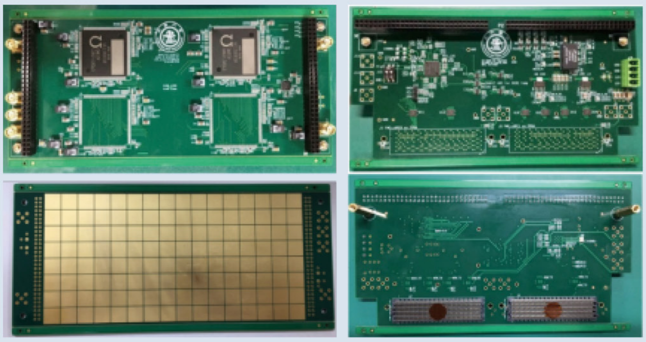
This work is supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (Grant No. XDB25000000), the National Key R&D Program of China (Grant No. 2018YFA0704200), and the National Natural Science Foundation of China (Grant Nos. 11675193 and 11575214).

基于 PETIROC 芯片的快时间分辨读出电子学设计取得重要进展

希格斯工厂的重要物理目标是在“干净”的正负电子对撞环境下精确测量希格斯的性质，特别是强子衰变末态。为此，设计高性能强子量能器是其中的关键之一。国际上基于粒子流算法的强子量能器技术样机主要有半数字化读出强子量能器 (SDHCAL) 和模拟读出强子量能器（AHCAL）。SDHCAL 样机是一款基于玻璃阻性板气体探测器的高颗粒度强子量能器，敏感介质由 48 层玻璃 RPC 和读出板构成，其读出感应单元为 1cm×1cm，信号由 HARDROC 芯片读出，在 CERN 束流测试中实现了良好的能量和位置分辨率。

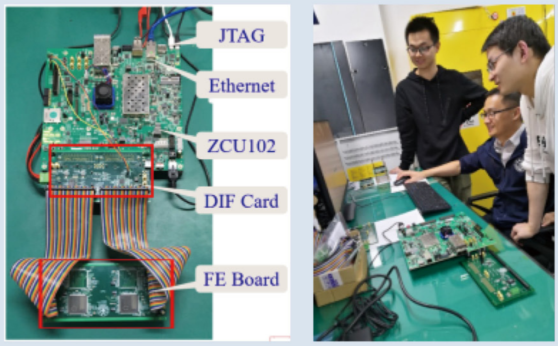
考虑到中子簇射形成的信号时间相比带电强子有延迟，如果能引入高精度时间测量信息，将显著提高中子和带电强子的区分效率，从而进一步提升强子喷注的能量分辨率。

为此，SDHCAL 合作组计划研制具有优异时间分辨性能的 MRPC 探测器，由上海交通大学团队负责设计和研制多通道快时间分辨读出电子学系统。团队采用 32- 通道高性能专用集成芯片 PETIROC（时间测量精度 < 40ps）来实现前端信号处理，运用激光微孔和埋孔工艺，自主设计和研制了 128 读出单元（1cm×1cm）的 FEB 前端读出板和 DIF 数据传输转接板（参见图一），DIF 板设计有低噪声电源和去抖动高精度时钟用于提高系统的时间测量精度。



图一：FEB 前端读出板（左图）和 DIF 板（右图）

Figure 1：Front-End Board (left)
and Detector Interface Board (right)



图二：读出电子学系统测试平台（左图）和设计团队（右图）

Figure 2：Readout FEB test setup (left)
and SJTU electronics group (right)

设计团队同时设计了基于 Xilinx ZCU102（Zynq UltraScale + SoC 嵌入式 FPGA）的数据获取系统，主要功能包括串口通信和以太网通信，实现对 PETIROC 芯片的配置和数据读出。目前已经完成 FEB 前端读出板，DIF 转接板等硬件设计、制作和测试工作，同时数据获取系统也基本完成，实现了基于以太网的数据传输，整体测试平台如图二所示。本项目是科技部国家重点研发计划“高能环形正负电子对撞机相关的物理和关键技术预研究”项目“探测器关键技术预研”课题的任务之一，由上海交通大学团队负责研制。

Progress of Fast Timing Readout Electronics based on PETIROC ASIC

The main goal of the Higgs factory is to measure the Higgs properties with ultimate precision, especially in hadron decay final states within "clean" electron-positron collision environment. Hence, it is crucial to design a high-performance hadron calorimeter. Currently, there are two PFA-based technological prototypes of hadron calorimeter under intensive studies, one is Semi-Digital Hadron CALorimeter (SDHCAL) and the other is Analog Hadron CALorimeter (AHCAL). The SDHCAL prototype is a high-granularity hadron calorimeter based on Glass Resistive Plate Chamber (GRPC). Its sensitive medium is composed of 48 layers of GRPC and readout plates. The size of readout sensor unit is 1cm × 1cm, and the signal is processed by the HARDROC ASIC chip. The SDHCAL prototype has achieved good energy and position resolution with CERN test beam.

Considering signal time of hadronic shower formed by neutrons is delayed, comparing with that from charged hadrons, high-precision time measurement is critical, which helps to improve separation between neutrons and charged hadrons, therefore further improve the jet energy resolution.

To this end, the SDHCAL group plans to develop MRPC detector with excellent timing resolution, Shanghai Jiao Tong University group is responsible for the design and development of a multi-channel fast timing readout electronics system. They employ the 32-channel PETIROC ASIC chip with timing resolution better than 40ps processing the signal induced from MRPC. The front-end readout board (FEB) with 128 read-out units (1cm × 1cm) is designed and developed in which laser blind via and buried via technology are applied (Figure 1). Then the Detector InterFace card (DIF) for data transmission and PETIROC configuration is designed and manufactured. The DIF board includes a low-noise power supply and a jitter cleaner clock to serve for time measurement of the system.

They also designed a data acquisition system based on Xilinx ZCU102 (Zynq UltraScale + SoC embedded FPGA). The main functions include serial communication and Ethernet communication to achieve the configuration and data readout of the PETIROC chip. At present, the design and performance tests of a front-end readout board (FEB), a DIF adapter board and the data acquisition system are completed, data transmission based on Ethernet has been successfully realised. The test platform is shown in Figure 2.

1.3 GHz 超导加速模组研制项目启动会召开

2 月 26 日，中科院高能所承接的大连先进光源 1.3GHz 超导加速模组研制项目启动会在高能所召开。高能所所长王贻芳院士、大连化学物理研究所杨学明院士、高能所加速器中心主任潘卫民以及项目组人员等 40 余人参加了会议。

会上，项目负责人潘卫民介绍了项目的背景、研制内容、技术指标及组织实施计划。他表示该项目时间紧、难度大，项目组将全力以赴、通力合作，在大连化物所的有力配合下确保如期完成。杨学明表示高能所已在高品质因数 1.3GHz 9-cell 超导腔等核心技术上取得了国际先进的重要成果，希望双方在本项目上保持密切合作，并期待模组预研取得成功。

王贻芳指出，1.3GHz 超导加速器技术是我国和国际先进加速器技术发展和应用的重要方向，是国内外自由电子激光装置、环形正负电子对撞机 CEPC 和国际直线对撞机 ILC 的关键技术，高能所必须在这一领域保持核心竞争力，并逐步实现国际领先。他表示高能所将全力为项目的顺利实施提供保障。

本项目将研制一台高品质因数连续波 1.3GHz 超导加速器模组样机，满足高重频自由电子激光装置运行要求。

1.3 GHz superconducting accelerating module development project kick-off meeting held at IHEP

On February 26, 2021, the launch meeting of the 1.3GHz superconducting accelerating module development project for the Dalian Advanced Light Source was held at the Institute of High Energy Physics (IHEP) of the Chinese Academy of Sciences (CAS). More than 40 experts including Yifang Wang, Director of the IHEP, Xueming Yang, Academician from the Dalian Institute of Chemical Physics (DICP), Weimin Pan, Director of the Accelerator Center of IHEP attended the meeting.

During the meeting, the project leader Weimin Pan introduced the project background, development content, technical indicators and organizational implementation plan of the project. He said that the project is time-critical and difficult, the project team will go all out and work together to ensure that it is completed on schedule with the strong cooperation of DICP. Xueming Yang stated that IHEP has achieved many internationally advanced and important results in core technologies such as the high quality factor 1.3 GHz 9-cell superconducting cavity. He hopes that both institutes will maintain close cooperation on this project and look forward to the success in the module development.

Yifang Wang pointed out that the 1.3 GHz superconducting cavity is a key technology of free electron laser (FEL) facilities, the Circular Electron-Positron Collider (CEPC), and the International Linear Collider (ILC). IHEP must maintain competitiveness in this field and gradually achieve international leadership. He said that IHEP will make every effort for a smooth implementation of the project.

This project will develop a high quality factor continuous wave 1.3 GHz superconducting accelerating module prototype to meet the operating requirements of high repetition rate FEL facilities.

人大代表王贻芳：“十四五”争取完成 CEPC 所有技术设计和技术预研

“最近，我们生产的环形正负电子对撞机（CEPC）中的核心部件‘超导高频腔’取得突破，可以媲美国际最好水平。另外，速调管的第一阶段样机去年也基本达标。这两个部件是 CEPC 最关键的设备，也是科研团队此前心里最没有底的设备，但我们最终实现了国内制造，并达到国际领先水平。”3 月 4 日，在两会期间接受科技日报记者采访时，全国人大代表、中科院院士、中科院高能物理研究所所长王贻芳，语气中带着一丝兴奋。他表示，目前 CEPC 正在优化设计方案，科学家们力图通过技术方案的设计、各种参数的重组，使设备达到最高性能，争取“十四五”完成 CEPC 所有的技术设计和关键技术预研。

对于 CEPC，科学家们寄予厚望，他们希望借此研究希格斯粒子、宇宙早期演化、反物质丢失、暗物质等一些未解的关键科学问题和新的物理规律。

“CEPC 有上万个部件，每个部件都要稳定可靠、‘万无一失’，如果每个部件都容忍哪怕万分之一的失效率，那一万个部件凑起来，设备的稳定运行将无从谈起。”为了“万无一失”，王贻芳带领团队向极致要质量。

CEPC 将由加速器和探测器两部分组成。超导高频腔，是加速器的加速部件，“加速器通过微波加速，而微波被收纳在一个金属材质的超导高频腔中，如果超导腔的超导材料无瑕疵、电阻很低，微波的损耗就会降到最低，设备运行所需的低温功率就会降低，这会让设备运行更稳定、更节省造价和运行费用。”王贻芳说，他们生产的超导高频腔微波损耗率之低已经媲美国际水平。

此外，给超导高频腔提供微波功率的速调管样机在去年也基本达标，其功率和效率达到目前的国际先进水平，“核心指标是效率，转化效率高的话，速调管的耗电少、成本低。我们设计的一款国际最高效率的速调管正在制造，今年年底就会出来。另外我们还要追求寿命长，可靠性高，这还需要时间来验证。”

展现在 CEPC 面前的，还有一片星辰大海。王贻芳透露，目前，团队还在继续研究、优化设计束流对撞点，使得粒子探测器的性能最优。

“对撞点附近的空间有限，直径大约五六米，长度大约六七米，而内部核心的束流对撞点只有十微米，束流管道直径也只有约两厘米，要在束流管道外包裹一层层设备，填满直径五六米的空间，需要设备间严丝合缝地设计、装配，并预留空间，方便电缆走线及未来的维修、拆卸。”王贻芳说，另一个挑战在于，对撞点附近的辐射本底强，探测器是否能耐受，还需要摸索验证。如何降低辐射，如何让束流更聚焦等问题，科研团队还在优化。

“设备的每一项技术都在探索中迭代，我们还要预估未来 3-5 年的技术发展潜力，并将那时的技术指标作为目前的设计基准，这要求我们对技术，对未来发展速度的预估都必须是正确的。”

（来源：科技日报）

Yifang Wang: Strive to complete all CEPC technical designs and pilot studies on key technologies during the 14th Five-Year Plan

Recently, we have made a breakthrough in the development of ‘superconducting high-frequency cavity’, one of the core components of our Circular Electron-Positron Collider (CEPC), and it is comparable to the best standards in the world. In addition, the first-stage prototype of the klystron has basically met the requirement last year. These two devices are the most critical components of CEPC, and the R&D team had worried the most in the past. But we finally achieved domestic manufacturing and reached the international leading level." On March 4, 2021, at an interview by the Science and Technology Daily during the National People’s Congress (NPC), Yifang Wang, a representative of NPC, academician of the Chinese Academy of Sciences, and director of the Institute of High Energy Physics (IHEP) of the Chinese Academy of Sciences, is excited about the recent progresses. He said that CEPC is currently optimising the design plan, and scientists are trying to achieve the highest performance of the facilities and strive to complete all the technical designs and pilot studies on key technology of CEPC during the "14th Five-Year Plan” (2021-2025).

"CEPC has tens of thousands of components, and each component must be stable and reliable. Even if each component can tolerate 1 ten-thousandth of failure rate, the stable operation of the facility will be impossible when all components are put together.” Yifang Wang said, he is leading the team in pursuing perfection.

CEPC has two major parts: accelerator and detectors. The superconducting high-frequency cavity is the component for accelerating particles in accelerator. "The particles will be accelerated by microwaves. And the microwaves are contained in a metal superconducting high-frequency cavity. If the superconducting material of the cavity is flawless and has low resistance, the loss of energy of microwave will be minimised, and the power consumption during operation will be reduced, which will make the facility more stable and also can reduce costs.” Yifang Wang said, the loss of energy in superconducting high-frequency cavity produced by IHEP is already one of the lowest in the world.

In addition, the prototype of the klystron that provides microwave power to the superconducting high-frequency cavity basically reached the designed target last year, and its power and efficiency reached the current international advanced level. "The core indicator is efficiency. With high conversion efficiency, the power consumption of the klystron will be low. The klystron with the highest efficiency in the world that we have designed is being manufactured and is expected to be available by the end of this year. In addition, we must pursue long life and high reliability of the klystron, which will take time to verify."

Yifang Wang revealed that at present, the team is also continuing to study and optimise the design of beam collision point for a better performance of the particle detector.

"The space near the collision point is very limited, with a diameter of about five to six meters and a length of about six to seven meters. The collision will happen in an area within a diameter of only 10 microns. The diameter of the beam pipe is only about two centimetres. It is necessary to design and assemble the equipments very closely around the collision point, and also reserve space to facilitate cable routing and future maintenance and disassembly.” Yifang Wang said. Another challenge is that the radiation background is strong near the collision point. Whether the detector can tolerate it still needs to be studied and verified. How to reduce radiation, how to improve the beam focusing, there are still many issues waiting for the R&D team to optimise.

"Each technology of the facility is being improved in the process of exploration. We have to estimate the technological development potential in the next 3-5 years, and use the technical indicators at that time as the current design benchmark. This requires us to have clear awareness of the speed and direction of future technology development."

(Source: Science and Technology Daily)

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环形正负电子对撞机简报（季刊）
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