**第一部分 国内外现状及趋势分析**

**Part I current situation and trend analysis at home and abroad**

包括本项目相关国内外总体研究情况和水平、最新进展和发展前景。限2000字以内，并分别简要列出国内、外各代表性的5家从事相关研究的主要机构及典型成果、代表性文献及相关专利、标准，并列出项目在相关方面的5项代表性成果、专利及标准。

Including the overall research situation and level at home and abroad related to the project, the latest progress and development prospects. It is limited to 2000 words, and briefly lists the main institutions and typical achievements, representative literature and relevant patents and standards of the five representative domestic and foreign institutions engaged in relevant research, and lists the five representative achievements, patents and standards of the project in relevant aspects.

阻性板室（Resistive Plate Chamber，RPC）是一种传统的平行板结构气体探测器，以其结构简单、适合大面积建造的特点，广泛应用于高能物理实验，通常作为外层的缪子触发探测器、强子量能器，以及应用于大面积的高海拔宇宙线观测实验。早期的RPC工作在流光模式下，信号幅度大，可以不需要前端放大而直接获取信号，但时间分辨和计数率能力较差；目前在运行实验的RPC通常工作在雪崩模式下，计数率能力得到大幅提升，并具有纳秒量级的时间分辨性能。ATLAS实验的缪子谱仪在桶部采用2mm气隙的RPC作为缪子触发探测器，总面积达到3600平方米，总通道数超过35万道，设计计数率能力为100 Hz/cm2，在ATLAS实验中已经稳定运行近15年，获得了丰硕的物理成果。

Resistive plate chamber (RPC) is a traditional gas detector with parallel plate structure. It is widely used in high-energy physics experiments because of its simple structure and suitable for large-area construction. It is usually used as a muon trigger detector and hadron calorimeter in the outer layer, as well as in large-area high-altitude cosmic ray observation experiments. The early RPC works in streamer mode, and the signal amplitude is large. It can directly obtain the signal without front-end amplification, but the time resolution and counting rate are poor; At present, the RPC in the running experiment usually works in the avalanche mode, the counting rate ability has been greatly improved, and has nanosecond time-resolved performance. The muon spectrometer in ATLAS experiment uses 2mm air gap RPC as muon trigger detector in the barrel, with a total area of 3600 square meters, a total number of channels of more than 350000, and a design counting rate of 100 Hz/cm2. It has been running stably in ATLAS experiment for nearly 15 years and has achieved fruitful physical results.

伴随着LHC计划升级到高亮度的HL-LHC，预计末态粒子通量也将提高一个量级，现有的ATLAS RPC不能够在这样高的计数率下正常运行。为了提高RPC的计数率能力，ATLAS提出了窄气隙RPC的方法，将RPC的气隙宽度降低到1mm，平均雪崩电荷量从原来的30 pC相应的降低到几个pC，并把电极板厚度从2mm降低到1.4mm，从而使计数率能力提升一个量级，同时也提高了探测器寿命。通过采用基于GeSi工艺的高灵敏度、高信噪比前端电子学，补偿窄气隙中降低了的气体增益，确保探测效率不受影响。在ATLAS Phase-II升级阶段，将采用这种新型的窄气隙RPC技术和前端电子学设计，在桶部内层新增加三层RPC探测器，总面积达到1400平方米，以确保在HL-LHC运行中的缪子触发效率。这种新型的窄气隙RPC，是未来高能量高亮度对撞物理实验必须发展的高计数率、抗老化探测器技术。

With the LHC plan to upgrade to the high luminosity hl-lhc, it is expected that the final state particle flux will also increase by an order of magnitude, and the existing ATLAS RPC cannot operate normally at such a high count rate. In order to improve the counting rate ability of RPC, ATLAS proposed the method of narrow air gap RPC, which reduced the air gap width of RPC to 1mm, the average avalanche charge from the original 30 PC to several PC, and the thickness of electrode plate from 2mm to 1.4mm, so as to improve the counting rate ability by one order of magnitude, and also improve the service life of the detector. By using high sensitivity and high signal-to-noise ratio front-end electronics based on Gesi process, the reduced gas gain in the narrow air gap is compensated to ensure that the detection efficiency is not affected. In the ATLAS phase II upgrade phase, this new narrow air gap RPC technology and front-end electronics design will be adopted, and three new RPC detectors will be added in the inner layer of the barrel, with a total area of 1400 square meters, to ensure the muon trigger efficiency in the hl-lhc operation. This new type of narrow air gap RPC is a high count rate and anti-aging detector technology that must be developed in the future high-energy and high luminosity collision physics experiments.

RPC和窄气隙RPC的研究工作，之前主要由意大利INFN主导，并负责完成了现有ATLAS全部RPC探测器的建造。ATLAS中国组从Phase-I阶段开始参与缪子谱仪的相关工作，在Phase-II阶段全面参与RPC探测器和电子学的研制和建造工作，包括探测器性能研究，探测器和读出板的设计、制作、批量制作工艺和质量控制，电子学的研制和测试等，已经具备了独立开展RPC探测器设计和建造的能力。

The research work on RPC and narrow air gap RPC was previously led by Italy INFN, which was responsible for completing the construction of all existing ATLAS RPC detectors. ATLAS China team has been involved in the relevant work of muon spectrometer since phase-I, and fully participated in the development and construction of RPC detector and electronics in phase II, including the study of detector performance, the design, production, batch production process and quality control of detector and readout board, and the development and testing of Electronics. It has the ability to independently carry out the design and construction of RPC detector.

国外主要机构：意大利INFN

典型成果：ATLAS在运行RPC探测器的建造

文献：CERN-LHCC-2017-017,Technical Design Report for the Phase-II Upgrade of the ATLAS Muon Spectrometer

Main foreign institutions: Italy INFN

Typical achievement: Construction of ATLAS RPC detector in operation

Document: cern-lhcc-2017-017, technical design report for the phase II upgrade of the ATLAS muon spectrometer

项目代表性成果：

Project representative achievements:

***Measuring attenuation in signal propagation in Resistive-plate chambers***, JINST V16, P01001, Jan. 2021

***Measuring attention in signal propagation in resistant plate chambers***, jinst V16, p01001, Jan. 2021

**第二部分 研究目标及内容**

**Part II research objectives and contents**

一、项目目标及考核指标

1、 Project objectives and assessment indicators

（一）申报项目与所属指南方向的关联关系

（1） The relationship between the declared items and the direction of the guidelines

包括项目与所属指南方向的匹配性，对指南方向目标的支撑作用。限1500字以内。

Including the matching between the project and the direction of the guide, and the supporting effect on the goal of the direction of the guide. Limited to 1500 words.

RPC：

RPC:

为了应对高亮度HL-LHC带来的高粒子通量、高辐照剂量、高数据量等挑战，对于ATLAS缪子谱仪来说，必须在桶部内层新增三层缪子触发探测器，以确保缪子触发效率，并提高覆盖面积。研制高计数率的窄气隙RPC探测器和核电子学，并按照ATLAS协议规定，完成相应的制造、安装和调试任务，符合并完全覆盖指南中ATLAS缪子谱仪部分的方向和目标。

In order to meet the challenges of high particle flux, high radiation dose and high data volume brought by high luminosity hl-lhc, for ATLAS muon spectrometer, three muon trigger detectors must be added in the inner layer of the barrel to ensure the muon trigger efficiency and improve the coverage area. Develop a narrow air gap RPC detector with high counting rate and nuclear electronics, and complete the corresponding manufacturing, installation and commissioning tasks in accordance with the ATLAS agreement, meeting and fully covering the direction and objectives of the ATLAS muon spectrometer in the guide.

（二）项目目标及考核指标、考核方式/方法

（2） Project objectives, assessment indicators, assessment methods/methods

限2000字以内（不包括表格），并填写下表。

Limited to 2000 words (excluding forms), and fill in the following table.

窄气隙RPC缪子触发探测器及读出电子学，根据ATLAS Phase-II升级需求，设定研究目标为提高RPC的计数率能力，提高时间分辨性能，保证探测器具有高探测效率，并完成协议规定的探测器制作、安装和测试任务。

The narrow air gap RPC muon trigger detector and readout electronics, according to the ATLAS phase II upgrade requirements, set the research goal to improve the RPC count rate ability, improve the time resolution performance, ensure the detector has high detection efficiency, and complete the detector production, installation and testing tasks specified in the agreement.

考核指标包括：计数率能力达到1 kHz/cm2以上，探测效率高于95%，时间分辨优于1 ns。以上性能指标通过宇宙线测试、放射源测试、或由ATLAS缪子探测器升级合作组安排的束流测试等方法进行考核。

The evaluation indexes include: the counting rate ability reaches more than 1 kHz/cm2, the detection efficiency is higher than 95%, and the time resolution is better than 1 ns. The above performance indicators are evaluated by cosmic ray test, radioactive source test, or beam test arranged by ATLAS muon detector upgrade cooperation group.

**项目目标、预期成果与考核指标表**

**Project objectives, expected results and assessment indicators**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **项目目标****Project objectives** | **预期成果名称****Name of expected results** | **预期成果****Expected results****类型****type** | **对应的****Corresponding****课题****topic** | **考核指标****Assessment indicators** | **考核方式（方法）及评价手段****Assessment methods and evaluation means** |
| **指标****index****名称****name** | **立项时已有指标值/状态****Existing index value/status at project initiation** | **中期指标值/状态****Mid term indicator value/status** | **完成时指标值/状态****Indicator value/status at completion** |
|  | 1：窄气隙RPC探测器1: Narrow air gap RPC detector | □新理论 □新原理 □新产品 □新技术 □新方法 □关键部件 □数据库 □软件 □应用解决方案 ■实验装置/系统 □临床指南/规范 □工程工艺 □标准 □论文 □发明专利 □其他 □ new theory □ new principle □ new product □ new technology □ new method □ key components □ database □ software □ application solutions ■ experimental devices/systems □ clinical guidelines/specifications □ engineering processes □ standards □ papers □ invention patents □ others  | ATLAS实验缪子探测器升级Upgrade of MUSON detector in ATLAS experiment | 计数率Count rate | 原型探测器1 kHz/cm2Prototype detector 1 khz/cm2 |  | 工程机>1 kHz/cm2Engineering machine>1 khz/cm2 | ATLAS验收ATLAS acceptance |
| 探测效率detection efficiency | RPC样机>95%RPC prototype>95% |  | 工程机>95%Engineering machine>95% | ATLAS验收ATLAS acceptance |
| 时间分辨Time resolution | >1 ns>1 ns |  | <1 ns<1 NS | ATLAS验收ATLAS acceptance |
| 2：2: | 同上Ibid |  | 指标2.1Indicator 2.1 |  |  |  |  |
| …… |  |  |  |  |
| …And | 同上Ibid |  | 指标index |  |  |  |  |
| …… |  |  |  |  |
| **科技报告考核指标****Assessment index of scientific and technological Report** | **序号****Serial number** | **报告类型****Report type** | **数量****number** | **提交时间****Submission time** | **公开类别及时限****Disclosure category and time limit** |
|  |  |  |  |  |
| 其他目标与考核指标完成情况Completion of other objectives and assessment indicators |

（三）项目预期成果的呈现形式及描述

（3） Presentation and description of expected results of the project

**限1000字以内。**

Limited to 1000 words.

RPC课题：

RPC topic:

完成满足ATLAS Phase-II升级指标要求的BIS-1和BIS2-6型窄气隙RPC设计，完成BIS型RPC读出板和探测器的制作和测试，建立相应的制作流程和质量控制方法，并参与探测器的工程安装和调试工作。

Complete the design of BIS-1 and bis2-6 narrow air gap RPC that meet the requirements of ATLAS phase II upgrade index, complete the production and testing of bis RPC readout board and detector, establish the corresponding production process and quality control method, and participate in the engineering installation and commissioning of detector.

二、项目研究内容、研究方法及技术路线

2、 Project research content, research method and technical route

（一）项目的主要研究内容

（1） Main research contents of the project

拟解决的关键科学问题、关键技术问题，针对这些问题拟开展的主要研究内容，限3000字以内。

The key scientific and technical problems to be solved and the main research contents to be carried out for these problems are limited to 3000 words.

RPC:

Rpc:

为了应对高亮度HL-LHC带来的高粒子通量背景和堆积效应，并解决现有RPC触发探测器计数率能力不足和长期运行以来的老化问题，ATLAS缪子谱仪需要在桶部内层新增三层RPC探测器，以保持系统整体的缪子触发效率，并提高整个谱仪的有效覆盖面积。新增的三层RPC探测器将采用新一代的窄气隙结构，气隙宽度为1 mm（现有ATLAS RPC的气隙宽度是2 mm），通过减少气隙中雪崩的发展长度来减小雪崩电荷量，从而提高其计数率能力和工作寿命，同时也可以使时间分辨性能得到提升；用作电极板的电木板材料厚度也由原来的2 mm降低至1.4 mm，通过减小在电极板材料上的电压降，来进一步提升计数率能力。由于窄气隙结构带来的气体增益降低，则通过采用基于GeSi工艺的高灵敏度、高信噪比的前端电子学设计进行补偿，保持探测效率不受影响。根据探测器的几何特点，采用双端读出信号、利用信号的时间差进行定位，以减少电子学通道数，并提高位置分辨能力。以上技术路线，通过前期的技术攻关，已经经过原理性验证、原型探测器性能测试验证和工程样机的测试验证。在科技部和基金委的大力支持下，中国组深度参与了探测器和电子学的研制工作，并完成了4个工程样机的建造，验证了中国组在探测器性能研究和工程建造方面的能力。

In order to cope with the high particle flux background and accumulation effect brought by the high luminosity hl-lhc, and solve the problem of insufficient counting rate of the existing RPC trigger detector and the aging problem of long-term operation, ATLAS muon spectrometer needs to add three layers of RPC detectors in the inner layer of the barrel to maintain the overall muon trigger efficiency of the system and improve the effective coverage of the whole spectrometer. The new three-layer RPC detector will adopt a new generation of narrow air gap structure, with an air gap width of 1 mm (the existing ATLAS RPC air gap width is 2 mm). By reducing the avalanche development length in the air gap, the avalanche charge will be reduced, so as to improve its counting rate ability and working life, and also improve its time-resolved performance; The thickness of the electric board material used as the electrode plate was also reduced from 2 mm to 1.4 mm. By reducing the voltage drop on the electrode plate material, the counting rate ability was further improved. Due to the reduction of gas gain caused by the narrow air gap structure, the front-end electronics design with high sensitivity and high signal-to-noise ratio based on Gesi process is used to compensate, and the detection efficiency is not affected. According to the geometric characteristics of the detector, the dual terminal readout signal is used and the time difference of the signal is used for positioning, so as to reduce the number of electronic channels and improve the position resolution. The above technical route has passed the technical research in the early stage, and has been verified by principle, prototype detector performance test and engineering prototype test. With the strong support of the Ministry of science and technology and the NSFC, the Chinese team has been deeply involved in the development of detectors and electronics, and has completed the construction of four engineering prototypes, verifying the ability of the Chinese team in the performance research and engineering construction of detectors.

由于窄气隙RPC工作在这种非常极端的探测器结构和工作条件下，要完成总量达到1400余平方米的全新探测器建造，并确保所有探测器单元具有优异的、均匀的、一致的性能，需要在前期工作的基础上，对探测器的设计进行最终优化，并进一步完善制作工艺并建立起统一的批量制作工艺流程和质量控制方法，最终成功完成项目的工程建造、现场安装和调试。通过本项目的研究，全面掌握大面积窄气隙气体探测器建造的关键技术。

Because the narrow air gap RPC works under such extreme detector structure and working conditions, to complete the construction of a total of more than 1400 square meters of new detectors and ensure that all detector units have excellent, uniform and consistent performance, it is necessary to finally optimize the design of detectors on the basis of preliminary work, And further improve the production process and establish a unified batch production process and quality control method, and finally successfully complete the project construction, on-site installation and commissioning. Through the research of this project, we can fully grasp the key technology of the construction of large area narrow air gap gas detector.

（二）项目拟采取的研究方法

（2） Research methods to be adopted for the project

1、针对项目研究拟解决的问题，拟采用的方法、原理、机理、算法、模型等

1. For the problems to be solved in the project research, the proposed methods, principles, mechanisms, algorithms, models, etc

限2000字以内。

Limited to 2000 words.

RPC课题：

RPC topic:

根据窄气隙RPC缪子触发探测器现阶段急需解决的关键问题，课题计划在以下方面针对性开展研究。

According to the key problems of narrow air gap RPC muon trigger detector that need to be solved at this stage, the project plans to carry out targeted research in the following aspects.

1）气隙制作工艺研究和均匀性控制。窄气隙RPC面积大（长度超过1.7米，宽度1.1米）、气隙宽度小（1 mm），气隙的精度要控制在±10微米以内。除了要对决定气隙厚度的垫片和边框的加工方法和加工工艺进行专门的研究以外，还需要建立专用的自动化垫片排布和点胶、涂胶设备，并对制作的流程和各种参数进行专门的优化，确保探测器整体的制作精度和均匀性。

1) Air gap fabrication process research and uniformity control. The narrow air gap RPC has a large area (more than 1.7 meters in length and 1.1 meters in width) and a small air gap width (1 mm). The accuracy of the air gap should be controlled within ± 10 microns. In addition to the special research on the processing method and process of the gasket and frame that determine the air gap thickness, it is also necessary to establish a special automatic gasket arrangement, dispensing and coating equipment, and optimize the manufacturing process and various parameters to ensure the overall manufacturing accuracy and uniformity of the detector.

2）读出板制作的平整性控制。RPC读出板将采用蜂窝板结构制作，重量轻、强度高，蜂窝板的平整性将决定最终探测器的平整性，因此要求读出板具有优于100微米的平整度。因此需要建立和优化相应的批量生产工艺和质量控制方法。

2) Flatness control of readout board fabrication. The RPC readout board will be made of honeycomb structure with light weight and high strength. The flatness of the honeycomb board will determine the flatness of the final detector. Therefore, the readout board is required to have a flatness better than 100 μ M. Therefore, it is necessary to establish and optimize the corresponding batch production process and quality control methods.

3）前端电子学批量制作和质量控制方法研究。前端电子学是窄气隙RPC正常运行的核心器件，批量制作中的质量控制尤为重要，需要为此建立专用的质量控制方法和批量测试方法。

3) Research on mass production and quality control methods of front-end electronics. Front end electronics is the core device for the normal operation of narrow air gap RPC. The quality control in batch production is particularly important. Therefore, it is necessary to establish a special quality control method and batch test method.

4）探测器性能测试。所有完成的单层探测器需要通过宇宙线测试来检验其性能。RPC探测器面积大、通道多，批量制作的时间紧，需要设计和建设大规模多层结构的探测器测试平台和数据获取系统。

4) Detector performance test. All completed single-layer detectors need to pass cosmic ray test to verify their performance. RPC detector has large area, many channels, and the time for batch production is tight. It is necessary to design and build a large-scale multi-layer detector test platform and data acquisition system.

5）安装和调试。随着工程建造的进展，制作和测试完成的探测器将分批运送到CERN实验现场，经过性能检测后，根据工程安装安排，逐步安装到ATLAS实验装置上，并进行现场的测试和调试。

5) Installation and commissioning. With the progress of engineering construction, the detectors manufactured and tested will be delivered to CERN experimental site in batches. After performance testing, they will be gradually installed on ATLAS experimental device according to the engineering installation arrangement, and will be tested and debugged on site.

2、项目研究方法（技术路线）的可行性、先进性分析

2. Feasibility and advancement analysis of project research method (technical route)

限2000字以内。

Limited to 2000 words.

RPC课题：

RPC topic:

大面积RPC作为一种传统的气体探测器，已经经历了长时间的发展，积累了大量的探测器制作、测试和质量控制方面的经验，并在多个大型实验中得到了成功的应用。针对窄气隙的特点，中国组已经在探测器设计和制作、电子学研制和测试、双端读出性能研究、大面积蜂窝结构读出板制作和质量控制等方面开展了卓有成效的研究工作。

As a traditional gas detector, large area RPC has experienced a long time of development, accumulated a lot of experience in detector production, testing and quality control, and has been successfully applied in many large-scale experiments. According to the characteristics of narrow air gap, the Chinese group has carried out fruitful research work in the design and manufacture of detectors, electronics development and testing, research on double ended readout performance, fabrication of large-area honeycomb readout boards and quality control.

在这些前期研究的基础上，并结合在国际合作中累积的大量经验，对RPC设计、建造和质量控制中关键环节进行进一步的精细优化和调整，并建立起标准化的工艺和方法，确保高质量的完成工程建造任务。

On the basis of these preliminary studies and in combination with the accumulated experience in international cooperation, the key links in RPC design, construction and quality control are further refined and adjusted, and standardized processes and methods are established to ensure high-quality completion of engineering construction tasks.

三、课题分解方案

3、 Project decomposition scheme

（一）课题分解情况

（1） Subject breakdown

围绕项目目标，根据需要可对项目目标进行任务分解，并简要说明各课题在项目中的具体作用，相互之间的逻辑关系，建议用图表描述。限2000字以内。

Around the project objectives, the project objectives can be decomposed according to needs, and the specific role of each topic in the project and the logical relationship between them are briefly described. It is recommended to use charts to describe. Limited to 2000 words.

🡪 to be modified together with other tasks...

🡪To be modified together with other tasks

（二）各课题内容

（2） Contents of each subject

逐项分段说明各课题的研究目标、主要研究内容、拟解决的重大科学问题或关键技术、考核指标及评测手段/方法等。每个课题限3000字以内。

Describe the research objectives, main research contents, major scientific problems or key technologies to be solved, assessment indicators and evaluation means/methods of each subject item by item. Each topic is limited to 3000 words.

1、课题x：ATLAS缪子探测器升级

1. Topic X: ATLAS muon detector upgrade

研究目标：针对ATLAS Phase-II的升级要求，研制高计数率的窄气隙RPC探测器和核电子学，全面提升RPC的计数率能力，提高时间分辨性能，保证探测器具有高探测效率，并按照ATLAS协议规定，完成相应的制造、安装和调试任务。

Research objectives: according to the upgrade requirements of ATLAS phase II, develop high count rate narrow air gap RPC detector and nuclear electronics, comprehensively improve the count rate ability of RPC, improve the time resolution performance, ensure the detector has high detection efficiency, and complete the corresponding manufacturing, installation and commissioning tasks in accordance with ATLAS protocol.

主要研究内容：

Main research contents:

为了应对高亮度HL-LHC带来的高粒子通量背景和堆积效应，并解决现有RPC触发探测器计数率能力不足和长期运行以来的老化问题，ATLAS缪子谱仪需要在桶部内层新增三层RPC探测器，以保持系统整体的缪子触发效率，并提高整个谱仪的有效覆盖面积。新增的三层RPC探测器将采用新一代的窄气隙结构，气隙宽度为1 mm（现有ATLAS RPC的气隙宽度是2 mm），通过减少气隙中雪崩的发展长度来减小雪崩电荷量，从而提高其计数率能力和工作寿命，同时也可以使时间分辨性能得到提升；用作电极板的电木板材料厚度也由原来的2 mm降低至1.4 mm，通过减小在电极板材料上的电压降，来进一步提升计数率能力。由于窄气隙结构带来的气体增益降低，则通过采用基于GeSi工艺的高灵敏度、高信噪比的前端电子学设计进行补偿，保持探测效率不受影响。根据探测器的几何特点，采用双端读出信号、利用信号的时间差进行定位，以减少电子学通道数，并提高位置分辨能力。以上技术路线，通过前期的技术攻关，已经经过原理性验证、原型探测器性能测试验证和工程样机的测试验证。在科技部和基金委的大力支持下，中国组深度参与了探测器和电子学的研制工作，并完成了4个工程样机的建造，验证了中国组在探测器性能研究和工程建造方面的能力。

In order to cope with the high particle flux background and accumulation effect brought by the high luminosity hl-lhc, and to solve the problem of insufficient counting rate ability of the existing RPC trigger detectors and the aging problem of long-term operation, ATLAS muon spectrometer needs to add three layers of RPC detectors in the inner layer of the barrel to maintain the overall muon trigger efficiency of the system and improve the effective coverage of the whole spectrometer. The new three-layer RPC detector will adopt a new generation of narrow air gap structure, with an air gap width of 1 mm (the existing ATLAS RPC air gap width is 2 mm). By reducing the avalanche development length in the air gap, the avalanche charge will be reduced, so as to improve its counting rate ability and working life, and also improve its time-resolved performance; The thickness of the electric board material used as the electrode plate was also reduced from 2 mm to 1.4 mm. By reducing the voltage drop on the electrode plate material, the counting rate ability was further improved. Due to the reduction of gas gain caused by the narrow air gap structure, the front-end electronics design with high sensitivity and high signal-to-noise ratio based on Gesi process is used to compensate, and the detection efficiency is not affected. According to the geometric characteristics of the detector, the dual terminal readout signal is used and the time difference of the signal is used for positioning, so as to reduce the number of electronic channels and improve the position resolution. The above technical route has passed the technical research in the early stage, and has been verified by principle, prototype detector performance test and engineering prototype test. With the strong support of the Ministry of science and technology and the NSFC, the Chinese team has been deeply involved in the development of detectors and electronics, and has completed the construction of four engineering prototypes, verifying the ability of the Chinese team in the performance research and engineering construction of detectors.

由于窄气隙RPC工作在这种非常极端的探测器结构和工作条件下，要完成总量达到1400余平方米的全新探测器建造，并确保所有探测器单元具有优异的、均匀的、一致的性能，需要在前期工作的基础上，对探测器的设计进行最终优化，并进一步完善制作工艺并建立起统一的批量制作工艺流程和质量控制方法，最终成功完成工程建造、现场安装和调试。通过本项目的研究，全面掌握大面积窄气隙气体探测器建造的关键技术。

Because the narrow air gap RPC works under such extreme detector structure and working conditions, to complete the construction of a total of more than 1400 square meters of new detectors and ensure that all detector units have excellent, uniform and consistent performance, it is necessary to finally optimize the design of detectors on the basis of preliminary work, And further improve the production process and establish a unified batch production process and quality control method, and finally successfully complete the project construction, on-site installation and commissioning. Through the research of this project, we can fully grasp the key technology of the construction of large area narrow air gap gas detector.

根据窄气隙RPC缪子触发探测器现阶段急需解决的关键问题，课题计划在以下方面针对性开展研究。

According to the key problems that need to be solved urgently in the narrow air gap RPC muon trigger detector at this stage, the project plans to carry out targeted research in the following aspects.

1）气隙制作工艺研究和均匀性控制。窄气隙RPC面积大（长度超过1.7米，宽度1.1米）、气隙宽度小（1 mm），气隙的精度要控制在±10微米以内。除了要对决定气隙厚度的垫片和边框的加工方法和加工工艺进行专门的研究以外，还需要建立专用的自动化垫片排布和点胶、涂胶设备，并对制作的流程和各种参数进行专门的优化，确保探测器整体的制作精度和均匀性。

1) Air gap fabrication process research and uniformity control. The narrow air gap RPC has a large area (more than 1.7 meters in length and 1.1 meters in width) and a small air gap width (1 mm). The accuracy of the air gap should be controlled within ± 10 microns. In addition to the special research on the processing method and process of the gasket and frame that determine the air gap thickness, it is also necessary to establish a special automatic gasket arrangement, dispensing and coating equipment, and optimize the manufacturing process and various parameters to ensure the overall manufacturing accuracy and uniformity of the detector.

2）读出板制作的平整性控制。RPC读出板将采用蜂窝板结构制作，重量轻、强度高，蜂窝板的平整性将决定最终探测器的平整性，因此要求读出板具有优于100微米的平整度。因此需要建立和优化相应的批量生产工艺和质量控制方法。

2) Flatness control of readout board fabrication. The RPC readout board will be made of honeycomb structure with light weight and high strength. The flatness of the honeycomb board will determine the flatness of the final detector. Therefore, the readout board is required to have a flatness better than 100 μ M. Therefore, it is necessary to establish and optimize the corresponding batch production process and quality control methods.

3）前端电子学批量制作和质量控制方法研究。前端电子学是窄气隙RPC正常运行的核心器件，批量制作中的质量控制尤为重要，需要为此建立专用的质量控制方法和批量测试方法。

3) Research on mass production and quality control methods of front-end electronics. Front end electronics is the core device for the normal operation of narrow air gap RPC. The quality control in batch production is particularly important. Therefore, it is necessary to establish a special quality control method and batch test method.

4）探测器性能测试。所有完成的单层探测器需要通过宇宙线测试来检验其性能。RPC探测器面积大、通道多，批量制作的时间紧，需要设计和建设大规模多层结构的探测器测试平台和数据获取系统。

4) Detector performance test. All completed single-layer detectors need to pass cosmic ray test to verify their performance. RPC detector has large area, many channels, and the time for batch production is tight. It is necessary to design and build a large-scale multi-layer detector test platform and data acquisition system.

5）安装和调试。随着工程建造的进展，制作和测试完成的探测器将分批运送到CERN实验现场，经过性能检测后，根据工程安装安排，逐步安装到ATLAS实验装置上，并进行现场的测试和调试。

5) Installation and commissioning. With the progress of engineering construction, the detectors manufactured and tested will be delivered to CERN experimental site in batches. After performance testing, they will be gradually installed on ATLAS experimental device according to the engineering installation arrangement, and will be tested and debugged on site.

拟解决的重大科学问题或关键技术问题：

Major scientific problems or key technical problems to be solved:

通过窄气隙技术路线，可以全面提升RPC的计数率能力、时间分辨率、工作寿命等主要性能，是RPC未来发展的主导方向；ATLAS BI RPC的建造，将是1mm气隙的RPC探测器首次在粒子物理实验的大规模应用。

Through the narrow air gap technology route, the main performance of RPC, such as counting rate capability, time resolution, and working life, can be comprehensively improved, which is the dominant direction of RPC development in the future; The construction of ATLAS Bi RPC will be the first large-scale application of 1mm air gap RPC detector in particle physics experiments.

考核指标及评测手段/方法：计数率能力达到1 kHz/cm2以上，探测效率高于95%，时间分辨优于1 ns。以上性能指标通过宇宙线测试、放射源测试、或由ATLAS缪子探测器升级合作组安排的束流测试等方法尽心考核。

Assessment index and evaluation means/METHODS: the counting rate ability is above 1 kHz/cm2, the detection efficiency is higher than 95%, and the time resolution is better than 1 ns. The above performance indicators have been carefully evaluated by cosmic ray test, radioactive source test, or beam test arranged by ATLAS muon detector upgrade cooperation group.

参加单位任务分工

Division of tasks of participating units

中国科学技术大学：全面主持RPC和电子学的研制和建造工作，负责RPC气隙的制作工艺研究和质量控制、读出蜂窝板的制作和平整性控制、前端电子学的制作和测试方法研究、探测器的批量测试、以及ATLAS现场的安装和调试工作。

University of science and technology of China: comprehensively presided over the research and construction of RPC and electronics, and was responsible for the research on the manufacturing process and quality control of RPC air gap, the production and flatness control of readout honeycomb panel, the research on the production and testing methods of front-end electronics, the batch test of detectors, and the installation and commissioning of ATLAS on site.

上海交通大学：全面参与RPC探测器的制作和测试工作，重点参与并部分完成读出蜂窝板的制作和平整性测试、单层探测器的制作和测试、现场安装与调试工作。

Shanghai Jiaotong University: fully participated in the production and testing of RPC detector, focusing on the production and partial completion of readout honeycomb panel and flatness test, the production and testing of single-layer detector, and site installation and commissioning.

四、主要创新点

4、 Main innovations

围绕基础前沿、共性关键技术或应用示范等层面，简述项目的主要创新点。每项创新点的描述限500字以内。

The main innovation points of the project are briefly described around the basic frontier, common key technologies or application demonstration. The description of each innovation point is limited to 500 words.

1、创新点1：xxxxx

1. Innovation point 1:xxxxx

缪子探测器课题的窄气隙技术路线可以全面提升RPC 的计数率、时间分辨率、工作寿命等性能，是RPC 未来发展的主导方向；这将是1mm 气隙的RPC 探测器首次在粒子物理实验的大规模应用。

The narrow air gap technology of muon detector can comprehensively improve the performance of RPC, such as counting rate, time resolution, and working life, which is the dominant direction of RPC development in the future; This will be the first large-scale application of 1mm air gap RPC detector in particle physics experiments.

五、预期经济社会效益

5、 Expected economic and social benefits

项目的科学、技术、产业预期指标及科学价值、社会、经济、生态效益。限1500字以内。

The expected indicators of science, technology, industry and scientific value, social, economic and ecological benefits of the project. Limited to 1500 words.

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**第三部分 申报单位及参与单位研究基础**

**Part III research basis of application units and participating units**

一、申报单位的已有工作基础、研究成果、研究队伍等

1、 Existing work foundation, research achievements, research team, etc. of the applicant

（一）项目、课题牵头单位在该研究方向的前期任务承担及综合绩效评价（验收）情况、相关研究成果

（1） Preliminary task undertaking, comprehensive performance evaluation (acceptance) and relevant research results of the project and subject leading unit in this research direction

限1000字以内。

Limited to 1000 words.

RPC课题：

RPC topic:

中国科学技术大学在ATLAS Phase-II升级中，主持并顺利结题了国家重点研发计划项目：大型强子对撞机（LHC）实验探测器升级项目，并在其中主持ATLAS实验谬子探测器升级课题。通过该项目的执行，全面参与了ATLAS Phase-II升级的RPC和电子学的研制工作，并重点完成了蜂窝结构读出板的设计、制作和测试；双端读出方法的模拟研究、性能测试和设计优化；批量制作工艺和质量控制方法研究，为升级工作的顺利开展做出了重要贡献，并为工程建造打下了基础。

During the ATLAS phase II upgrade, the University of science and technology of China hosted and successfully concluded the national key R&D program: the Large Hadron Collider (LHC) experimental detector upgrade project, and hosted the ATLAS experimental detector upgrade project. Through the implementation of the project, I have fully participated in the development of RPC and electronics for ATLAS phase II upgrade, and focused on the design, fabrication and testing of honeycomb readout board; Simulation study, performance test and design optimization of the two terminal readout method; The research on batch production process and quality control method has made important contributions to the smooth development of the upgrading work and laid the foundation for the engineering construction.

（二）项目及课题负责人的科研水平及主要成果

（2） Scientific research level and main achievements of project and subject leaders

限2000字以内。

Limited to 2000 words.

RPC课题负责人孙勇杰：

Sunyongjie, principal of RPC project:

毕业于中国科学技术大学，博士学位，现任副教授。长期从事高能物理实验新型气体探测器研发工作，多次承担并顺利完成大型高能实验中探测器子系统的研制和工程建造工作，包括RHIC-STAR TOF探测器MRPC的工程制作和质量控制，STAR MTD系统LMRPC的研制、设计和工程建造，BES-III端盖TOF升级MRPC探测器的研制和工程建造，FAIR-CBM TOF MRPC探测器的研制等大型工程任务。

He graduated from the University of science and technology of China with a doctorate degree and is now an associate professor. He has been engaged in the research and development of new gas detectors for high-energy physics experiments for a long time, and has repeatedly undertaken and successfully completed the research and engineering construction of detector subsystems in large-scale high-energy experiments, including the engineering production and quality control of rhic-star TOF detector MRPC, the research, design and engineering construction of star MTD system lmrpc, the research and engineering construction of BES-III end cap TOF upgraded MRPC detector, Large engineering tasks such as the development of fair-cbm TOF MRPC detector.

（三）项目、课题牵头单位相关科研条件支撑状况

（3） Supporting status of relevant scientific research conditions of leading units of projects and projects

包括国家（重点）实验室、国家工程（技术）中心、国家重大科研基础设施（含大型仪器设备）等情况，限1000字以内。

Including national (key) laboratories, National Engineering (Technology) centers, national major scientific research infrastructure (including large-scale instruments and equipment), etc., limited to 1000 words.

RPC课题牵头单位：中国科学技术大学

RPC Project Leader: University of science and technology of China

依托“核探测与核电子学国家重点实验室”，在国内外粒子物理大科学工程的探测器和相关电子学的研发、建造方面发挥着关键作用：如成功完成北京谱仪（BESIII）触发和读出电子学、端盖飞行时间探测器、RPC谬子探测器电子学；大亚湾中微子探测器RPC电子学；“悟空”暗物质探测器电子学和量能器；ATLAS和CMS的谬子探测器(MDT, RPC,TGC)及触发电子学等；成功的将研发的高时间分辨的MRPC应用到STAR、BESIII和CBM实验分别作为谬子和飞行时间探测器。已开展开关电容阵列ASIC设计，并以江门地下中微子实验（JUNO）为背景展开高速波形数字化ASIC技术探索；已成功制作出国内首个有效面积达100cm×50cm的GEM探测器。团队所在实验室有气体探测器宇宙线测试系统、高精度探测器综合测试平台、先进核电子学测试和组装平台等基础设施，为项目的顺利开展打下了坚实基础。

Relying on the "State Key Laboratory of nuclear detection and Nuclear Electronics", it plays a key role in the R&D and construction of detectors and related electronics in the major scientific projects of particle physics at home and abroad: such as the successful completion of Beijing Spectrometer (BESIII) trigger and readout electronics, end cover time-of-flight detector, RPC detector electronics; Daya Bay neutrino detector RPC electronics; Wukong dark matter detector electronics and calorimeter; Fallacy detectors (MDT, RPC, TGC) and trigger electronics of ATLAS and CMS; The developed high time-resolution MRPC was successfully applied to star, BESIII and CBM experiments as fallacies and time-of-flight detectors, respectively. Switched capacitor array ASIC design has been carried out, and high-speed waveform digital ASIC technology has been explored in the background of Jiangmen underground neutrino experiment (Juno); The first domestic product with an effective area of 100cm has been successfully manufactured × 50cm GEM detector. The team's laboratory has infrastructure such as gas detector cosmic ray test system, high-precision detector integrated test platform, advanced nuclear electronics test and assembly platform, which has laid a solid foundation for the smooth implementation of the project.

二、参与单位、团队的选择原因及其优势

2、 Reasons for the selection of participating units and teams and their advantages

限1000字以内

Within 1000 words

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三、相关的国际合作与交流

3、 Relevant international cooperation and exchanges

说明申报团队现有的国际科技合作交流基础和渠道、主要合作对象、合作领域、合作方式和合作成果等内容，限1000字以内。

Explain the existing international scientific and technological cooperation and exchange basis and channels, main partners, cooperation fields, cooperation methods and cooperation achievements of the application team, which is limited to 1000 words.

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**第四部分 进度安排**

**Part IV schedule**

包括项目主要研究任务的研发进度、年度及重点节点（“里程碑”）安排、中期目标等。鼓励重大共性关键技术和应用示范研究类项目，采用甘特图等图表细化描述，限2000字以内。

Including the R&D Progress of the main research tasks of the project, the arrangement of annual and key nodes ("milestones"), medium-term objectives, etc. Encourage major common key technologies and application demonstration research projects to use Gantt chart and other charts for detailed description, which is limited to 2000 words.

RPC课题：

RPC topic:

2024年度：重点完成探测器和电子学工程建造的各项评审工作，包括最终技术设计评审、工程建造状态评审等，尽快启动材料的批量采购，开始正式的工程建造。探测器主要完成蜂窝读出板的材料采购和部分生产任务，电子学主要完成工程建造的材料采购。

In 2024: focus on completing various reviews of detector and electronics engineering construction, including the final technical design review, engineering construction status review, etc., and start the batch procurement of materials as soon as possible to start the formal engineering construction. The detector mainly completes the material procurement and some production tasks of the honeycomb readout board, and electronics mainly completes the material procurement of engineering construction.

2025年度：重点完成BIS探测器单层探测器的组装和测试任务，通过严格执行生产工艺流程和质量控制方法，建立批量测试的宇宙线测试平台，确保单层探测器性能达到升级指标；参与三层探测器结构的装配和性能测试工作，发现问题，及时改正。

2025: focus on completing the assembly and testing of the single-layer detector of the BIS detector, and establish a cosmic ray test platform for batch testing by strictly implementing the production process and quality control methods to ensure that the performance of the single-layer detector reaches the upgrading index; Participate in the assembly and performance test of the three-layer detector structure, and correct problems in time.

2026年度：建立并完胜气隙制作工艺流程，对大面积原型探测器开展性能测试，确保制作工艺稳定可靠；通过合作组评审并完成相应气隙的工程制作任务；继续参与三层探测器的测试工作，并参与CERN现场的组装和调试工作。

In 2026: establish and completely win the air gap manufacturing process, and carry out performance tests on large-area prototype detectors to ensure the stability and reliability of the manufacturing process; Pass the review of the cooperation group and complete the engineering manufacturing task of the corresponding air gap; Continue to participate in the testing of the three-layer detector, and participate in the assembly and commissioning of CERN on site.

2027年度：参与探测器现场安装和调试。在CERN建立探测器性能检测平台，发现问题及时修复。

Year 2027: participate in the field installation and commissioning of detectors. Establish a detector performance detection platform at CERN, and timely repair problems found.

2028年度：完成探测器的安装和调试，开始试运行。总结项目经验，撰写批量工艺方面的文章，准备结题。

Year 2028: complete the installation and commissioning of the detector and start the trial operation. Summarize project experience, write articles on batch process, and prepare for conclusion.