**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.

国内外总体研究情况：

General research at home and abroad:

 硅微条探测器主要用于带电粒子的空间分辨测量，被广泛用于国内外的各种粒子探测实验装置上。国内近年来有华中师范大学等参与 LHC 上 ALICE 顶点探测器升级，高能所、湘潭大学等自主研发硅探测器，取得显著进展。然而在大面积硅径迹探测器系统设计与建造方面的基础相对薄弱，有待进一步高。

 Silicon micro strip detector is mainly used for the spatial resolution measurement of charged particles, and is widely used in various particle detection experimental devices at home and abroad. In recent years, CCNU has participated in the upgrading of Alice vertex detector on LHC, and IHEP and Xiangtan University have independently developed silicon detectors, making significant progress. However, the foundation for the design and construction of large area silicon track detector system is relatively weak and needs to be further improved.

硅像素探测器主要分为混合型和单片型两种，混合型探测器由于sensor和读出ASIC相互制约较少可以独立进行设计和优化，且具备很好的抗辐照能力和计数能力，因而已经有较多的应用，如LHC上ATLAS像素探测器、CMS像素探测器等。不过目前像素探测器的研究主要还是侧重于位置精度的提高，部分具备时间测量功能的像素探测其时间分辨大多在25 ns水平，逐渐无法满足下一代高亮度粒子实验对于像素径迹探测器的需求。

Silicon pixel detectors are mainly divided into two types: hybrid and monolithic. Hybrid detectors can be designed and optimized independently due to less mutual constraints between sensor and readout ASIC, and have good radiation resistance and counting ability, so they have been widely used, such as ATLAS pixel detector and CMS pixel detector on LHC. However, at present, the research of pixel detector mainly focuses on the improvement of position accuracy. The time resolution of some pixel detectors with time measurement function is mostly at the level of 25 ns, which gradually can not meet the requirements of pixel track detector for the next generation of high Luminosity particle experiment.

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

And briefly list the main institutions and typical achievements of five representative institutions engaged in relevant research at home and abroad

|  |  |  |  |
| --- | --- | --- | --- |
| 序号Serial number | 单位unit | 典型成果Typical achievements | 文献literature |
| 1 | LBNL USALBNL USA | 为ATLAS和CMS研制RD53系列混合型硅像素探测器读出ASICDevelopment of readout ASIC of rd53 series hybrid silicon pixel detector for ATLAS and CMS | Aleksandra Dimitrievska, Andreas Stiller, “RD53A: A large-scale prototype chip for the phase II upgrade in the serially powered HL-LHC pixel detectors,” NIMA, Vol. 958, 2020, 162091.Aleksandra dimitrievska, Andreas Stiller, "rd53a: a large scale prototype chip for the phase II upgrade in the serially powered hl-lhc pixel detectors," NIMA, Vol. 958, 2020, 162091  |
| 2 | CERNCERN | 研制出高精度时间分辨混合型硅像素探测器读出ASIC TimePix系列High precision time-resolved hybrid silicon pixel detector readout ASIC timepix series has been developed | (1) S. Levasseur et al., “Development of a rest gas ionisation profile monitor for the CERN proton(1) S. Levasseur et al., "development of a rest gas ionisation profile monitor for the CERN proton synchrotron based on a Timepix3 pixel detector,” 2107 JINST 12 C02050.Synchrotron based on a timepix3 pixel detector, "2107 jinst 12 c02050 (2) X. Llopart, J. Alozy, et al. “Timepix4, a large area pixel detector readout chip which can be tiled on 4 sides providing sub-200 ps timestamp binning.” 2022 JINST 17 C01044.(2) X. llopart, J. alozy, et al. "timepix4, a large area pixel detector readout chip which can be tiled on 4 sides providing sub-200 PS timestamp binning." 2022 jinst 17 c01044  |

**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.

课题二包括研制空间分辨率优于 25 微米的径迹探测器模块，完成组装成径迹探测器系统集成并参与运行；研究具有好于100ps时间分辨率的抗辐照传感器和前端电子学关键技术。这两部分研究内容与指南1.3 ATLAS 探测器升级(共性关键技术)内容相匹配，有利于提高ATLAS实验的物理潜力。

The second task includes the development of track detector module with spatial resolution better than 25 μ m, the completion of the assembly of track detector system integration and participation in operation; The radiation resistant sensor with better time resolution than 100ps and the key technology of front-end electronics are studied. The research contents of these two parts match the contents of ATLAS detector upgrade (common key technologies) in guide 1.3, which is conducive to improving the physical potential of ATLAS experiment.

（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.

硅微条探测器：

Silicon micro strip detector:

目标：硅径迹探测器模块建造，包括验证硅微条传感器和读出电子学的抗辐照性能等关键指标，掌握硅微条探测器模块高精度组装、高低温环境可靠性测试等关键技术，保障探测器模块空间分辨率达到25微米的要求。径迹探测器系统集成，包含硅微条探测器模块集成到桶板、桶板组合成径迹探测器系统的安装、调试等关键技术研究。

Objective: the construction of silicon track detector module, including the verification of key indicators such as the radiation resistance performance of silicon micro strip sensor and readout electronics, mastering key technologies such as high-precision assembly of silicon micro strip detector module, high and low temperature environment reliability test, and ensuring that the spatial resolution of detector module reaches the requirement of 25 microns. Track detector system integration, including the research on key technologies such as the integration of silicon micro strip detector module into barrel plate and the installation and debugging of the barrel plate combined track detector system.

考核指标：硅微条探测器模块达到空间分辨率优于 25 微米

Assessment index: the spatial resolution of silicon micro strip detector module is better than 25 μ M

考核方式：合作组安排束流测试

Assessment method: the cooperative group arranges beam test

新一代有时间信息的硅像素探测器：

A new generation of silicon pixel detectors with time information:

目标：研发时间分辨率在100皮秒以下的抗辐照传感器及前端电子学。

Objective: to develop radiation resistance sensors and front-end electronics with a time resolution of less than 100 picoseconds.

考核指标：传感器和电子学时间分辨率均好于100 ps

Assessment index: the time resolution of sensor and electronics is better than 100 PS

考核方式：传感器将设计并制备出像素型的低增益雪崩二极管器件，用放射源对其辐照前后的时间分辨特性进行标定。电子学将设计读出电子学电路模块和小型的数据获取系统，对电子学进行性能测试和技术验证，时间精度可以通过测试信号相对于时钟的间隔或两通道之间的时间差的晃动进行评估。

Assessment method: the sensor will design and prepare a pixel type low gain avalanche diode device, and calibrate its time-resolved characteristics before and after irradiation with a radiation source. Electronics will design readout electronics circuit modules and small data acquisition systems to test and verify the performance of electronics. The time accuracy can be evaluated by the interval of the test signal relative to the clock or the shaking of the time difference between the two channels.

**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** |
| 2. 研制硅微条径迹探测器空间分辨率达到 25 微米；研发时间分辨率在 100 皮秒以下的抗辐照传感器及前端电子学。2. the spatial resolution of silicon micro strip track detector is 25 μ M; Develop radiation resistance sensors and front-end electronics with a time resolution of less than 100 picoseconds. | 1：1: | □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 process □ standards □ papers □ invention patents □ others |  | 指标1.1Indicator 1.1 |  |  |  |  |
| …… |  |  |  |  |
| 硅径迹探测器模块；有时间信息的硅像素探测器Silicon track detector module; Silicon pixel detector with time information | □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 process □ standards □ papers □ invention patents □ others  |  | 硅微条径迹探测器空间分辨率Spatial resolution of silicon micro strip track detector | 原型模块25 微米Prototype module 25 μ M | 预生产模块 25 微米Pre production module 25 μ M  | 径迹探测器25微米Track detector 25 microns | ATLAS 合作组安排束流测试ATLAS cooperation group arranges beam test |
| 硅像素探测器时间分辨率Time resolution of silicon pixel detector | 好于 10nsBetter than 10ns  |  好于 1nsBetter than 1ns  |  好于 100psBetter than 100ps  | 仿真验证和实验室测试Simulation validation and laboratory testing |
| …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.

硅微条径迹探测器：

Silicon micro strip track detector:

研制出高精度硅微条探测器模块，并参与径迹探测器系统的安装和联调。提供硅微条探测器模块空间位置分辨率的测试报告。

The high-precision silicon micro strip detector module was developed and participated in the installation and joint commissioning of the track detector system. Provide test report of spatial position resolution of silicon micro strip detector module.

新一代有时间信息的硅像素探测器：

A new generation of silicon pixel detectors with time information:

完成原型传感器，提供时间分辨性能的测试报告；实现前端电子学关键技术突破，提供电子学时间精度测试报告。

Complete the prototype sensor and provide the test report of time-resolved performance; Realize the key technology breakthrough of front-end electronics, and provide the test report of electronics time accuracy.

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.

硅径迹探测器模块建造，包括验证硅微条传感器和读出电子学的抗辐照性能等关键指标，掌握硅微条探测器模块高精度组装、高低温环境可靠性测试等关键技术，保障探测器模块空间分辨率达到25微米的要求。径迹探测器系统集成，包含硅微条探测器模块集成到桶板、桶板组合成径迹探测器系统的安装、调试等关键技术研究。

The construction of silicon track detector module includes verifying key indicators such as the radiation resistance of silicon micro strip sensor and readout electronics, mastering key technologies such as high-precision assembly of silicon micro strip detector module, high and low temperature environment reliability test, and ensuring that the spatial resolution of detector module reaches the requirement of 25 microns. Track detector system integration, including the research on key technologies such as the integration of silicon micro strip detector module into barrel plate and the installation and debugging of the barrel plate combined track detector system.

针对新一代有时间信息硅像素探测器的研发，本课题将展开抗辐照传感器及前端电子学的设计。在传感器方面，团队将致力于研发像素型的低增益雪崩传感器，并开展辐照前后器件的时间分辨性能研究。在前端读出电子学方面，团队将通过国际合作研究具有时间测量功能硅像素探测器的前端读出电路关键技术，并着重针对含有时间信息的击中数据的高效缓存和快速读出展开研究，且还将完成数据汇总、配置命令解析等功能。

For the development of a new generation of silicon pixel detector with time information, this task will carry out the design of radiation resistance sensor and front-end electronics. In terms of sensors, the team will focus on the research and development of pixel type low gain avalanche sensors, and Research on the time-resolved performance of devices before and after irradiation. In front-end readout electronics, the team will research the key technologies of front-end readout circuit of silicon pixel detector with time measurement function through international cooperation, and focus on the efficient cache and fast readout of hit data containing time information, and will also complete the functions of data summary, configuration command analysis, etc.

（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.

硅微条径迹探测器：

Silicon micro strip track detector:

拟采用高能质子束方法进行验证微条传感器和读出电子学的抗辐照性能，通过合作组联合研制高精度工装夹具、自动化高低温冷却环境测试箱等确保硅微条探测器模块高精度和高低温环境可靠性。最终径迹探测器系统集成则由高精度的龙门吊和精密机械等方式进行品质监控。

The high-energy proton beam method is proposed to verify the radiation resistance performance of the micro strip sensor and readout electronics. The high-precision tooling fixture and automatic high and low temperature cooling environment test box are jointly developed by the cooperation group to ensure the high-precision and high and low temperature environment reliability of the silicon micro strip detector module. The final track detector system integration is monitored by high-precision gantry crane and precision machinery.

新一代有时间信息的硅像素探测器：

A new generation of silicon pixel detectors with time information:

传感器部分：

Sensor part:

传感器的研究包括仿真设计、工艺制备、时间性能研究及辐照性能测试。通过TCAD仿真研究器件结构及关键参数，优化工艺流程，在有效电荷收集效率的前提下实现器件内部像素化。在此基础上通过改变衬底材料、优化结构参数等方法提高器件的抗辐照性能，特别是辐照后器件的电荷收集与时间分辨性能。

The research of the sensor includes simulation design, process preparation, time performance research and irradiation performance test. Through TCAD simulation, the device structure and key parameters are studied, and the process flow is optimized to realize the internal pixelation of the device under the premise of effective charge collection efficiency. On this basis, the radiation resistance of the device is improved by changing the substrate material and optimizing the structural parameters, especially the charge collection and time resolution of the device after irradiation.

电子学部分：像素探测器的前端读出电路主要包括模拟处理单元电路和数据缓存读出电路，为了获取传感器输出信号的时间信息，模拟处理单元电路将采用放大甄别结合高精度时间数字变换的技术设计实现；数据缓存读出电路将基于数字电路设计流程实现，通过建模仿真确定电路基本架构，进而配合时序分析、流水线处理等高速数字电路设计方法实现高效的数据缓存和快速的数据读出。

Electronics: the front-end readout circuit of the pixel detector mainly includes the analog processing unit circuit and the data cache readout circuit. In order to obtain the time information of the sensor output signal, the analog processing unit circuit will be designed and implemented by using the technology of amplification and discrimination combined with high-precision time digital transformation; The data cache readout circuit will be realized based on the digital circuit design process. The basic circuit architecture will be determined through modeling and simulation, and then the efficient data cache and fast data readout will be realized with the timing analysis, pipeline processing and other high-speed digital circuit design methods.

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.

硅微条探测器：1. 利用东莞的伴生质子束开展了硅微条传感器、专用集成电路芯片的辐照测试并在高能所搭建了相应的器件测试平台。2. 在高能所实验室已研制出预生产阶段的硅微条模块，搭建了冷热箱测试系统。参与了合作组硅微条探测器模束流测试的实验与数据分析研究。3. 在卢瑟福实验室参与了硅微条探测器模块集成到桶板碳纤维基底的高精度组装与低温稳定测试。

Silicon micro strip detector: 1. the irradiation test of silicon micro strip sensor and ASIC chip was carried out by using the associated proton beam in Dongguan, and the corresponding device test platform was built in IHEP. 2. the silicon micro strip module in the pre production stage has been developed in the laboratory of IHEP, and the hot and cold box test system has been built. Participated in the experimental and data analysis of the mode beam current measurement of the silicon micro strip detector of the cooperation group. 3. participated in the high-precision assembly and low-temperature stability test of the silicon micro strip detector module integrated into the barrel carbon fiber substrate in Rutherford laboratory.

新一代有时间信息的硅像素探测器：

A new generation of silicon pixel detectors with time information:

传感器部分：团队通过与外单位合作，完成了初步原型器件的制备，具备研发快时间分辨的传感器的设计仿真、工艺制备、器件测试等条件。

Sensor part: the team has completed the preparation of preliminary prototype devices through cooperation with external units, and has the conditions for developing fast time-resolved sensor design simulation, process preparation, device testing, etc.

电子学部分：团队在像素探测器读出芯片方面已经初步完成了好于10 ns时间精度的芯片设计；并且在系统级读出技术层面，曾研制出系列精度好于100 ps的电子学系统并成功应用于粒子物理实验中，上述的技术积累可以保证此方向研究工作的顺利展开。

Electronics: the team has preliminarily completed the chip design with better time accuracy than 10 ns in terms of pixel detector readout chip; At the level of system level readout technology, a series of electronic systems with accuracy better than 100 PS have been developed and successfully applied in particle physics experiments. The above technical accumulation can ensure the smooth development of research work in this direction.

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.

（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1：xxxxx

1. Topic 1:xxxxx

研究目标：

Research objectives:

主要研究内容：

Main research contents:

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:

考核指标及评测手段/方法：

Assessment indicators and evaluation means/METHODS:

参加单位任务分工

Division of tasks of participating units

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2、课题2：ATLAS 实验内径迹探测器升级

2. Topic 2: upgrade of inner tracker in ATLAS experiment

**子课题 2.1： 硅径迹探测器模块建造，径迹探测器系统集成和运行**

**Sub topic 2.1: silicon track detector module construction, track detector system integration and operation**

**研究目标：研发满足高亮度 LHC 要求的高精度硅微条径迹探测器。采用先进技术组装 探测器模块，实现 25 微米的空间分辨率，并通过束流测试验证。参与径迹探测器 系统集成和早期运行。**

**Research objective: to develop a high-precision silicon micro strip track detector that meets the requirements of high Luminosity LHC. The detector module is assembled with advanced technology to achieve a spatial resolution of 25 μ m, which is verified by beam current test. Participate in the integration and early operation of track detector system.**

**主要研究内容：1. 研究硅微条传感器辐照后的电荷收集效率、专用集成电路芯片辐照后的单粒子效应；2. 掌握硅微条传感器的高精度组装技术，开展硅探测器模块高低温稳定测试及空间位置分辨率的研究；3. 开展硅微条探测器模块集成到桶板、桶板组合成径迹探测器系统的安装和联调。**

**The main research contents are as follows: 1. study the charge collection efficiency of silicon micro strip sensor after irradiation and the single event effect of ASIC chip after irradiation; 2. master the high-precision assembly technology of silicon micro strip sensor, carry out the high and low temperature stability test of silicon detector module and Research on spatial position resolution; 3. carry out the installation and joint commissioning of the track detector system that integrates the silicon micro strip detector module into the barrel plate and the barrel plate.**

**拟解决的关键技术问题：硅径迹探测器模块建造，包括验证硅微条传感器和读出电子学的抗辐照性能等关键指标，掌握硅微条探测器模块高精度组装、高低温环境可靠性测试等关键技术，保障探测器模块空间分辨率达到25微米的要求。径迹探测器系统集成，包含硅微条探测器模块集成到桶板、桶板组合成径迹探测器系统的安装、调试等关键技术研究。**

**Key technical problems to be solved: the construction of silicon track detector module, including the verification of key indicators such as the radiation resistance performance of silicon micro strip sensor and readout electronics, mastering key technologies such as high-precision assembly of silicon micro strip detector module, high and low temperature environment reliability test, and ensuring the spatial resolution of detector module to meet the requirements of 25 microns. Track detector system integration, including the research on key technologies such as the integration of silicon micro strip detector module into barrel plate and the installation and debugging of the barrel plate combined track detector system.**

**考核指标及评测手段：硅微条探测器模块达到空间分辨率优于25微米。合作组安排束流测试。**

**Assessment index and evaluation means: the spatial resolution of silicon micro strip detector module is better than 25 μ M. The cooperation group arranged beam test.**

**参加单位任务分工：**

**Division of tasks of participating units:**

高能所：负责建设高能所硅微条模块研制实验室平台、传感器和读出芯片测试平台、东莞散列中子源伴质子束流辐照平台搭建，协调与英国卢瑟福实验室以及 CERN 的安装调试工作。

Institute of high energy: responsible for the construction of the silicon micro strip module development laboratory platform, sensor and readout chip test platform, Dongguan stray neutron source with proton beam irradiation platform, and coordinating the installation and commissioning with Rutherford laboratory and CERN in the UK.

清华：负责派送学生和博士后参加硅微条探测器模块研制、传感器和读出芯片辐照测试，以及协助参加英国和 CERN 的工作。

Tsinghua: responsible for sending students and postdoctors to participate in the development of silicon micro strip detector module, radiation testing of sensors and readout chips, and assisting in the work of the UK and CERN.

**子课题 2.2：新一代有时间 信息的硅像素探测器的研发**

**Sub topic 2.2: research and development of a new generation of silicon pixel detector with time information**

**研究目标：研发时间分辨率在 100 皮秒以下的抗辐照传感器及前端电子学**

**Research objectives: develop radiation resistance sensors and front-end electronics with a time resolution of less than 100 picoseconds**

**主要研究内容：**

**Main research contents:**

 研发像素型 LGAD 传感器，实现100皮秒以下的时间分辨率。通过国际合作研究具有时间测量功能硅像素探测器的前端读出电路关键技术，并着重针对含有时间信息的击中数据的高效缓存和快速读出展开研究，完成数据汇总、配置命令解析等功能。

 Research and develop pixel type lgad sensor to achieve a time resolution of less than 100 picoseconds. Through international cooperation, the key technologies of the front-end readout circuit of the silicon pixel detector with time measurement function are researched, and the research is focused on the efficient cache and fast readout of the hit data containing time information, and the functions of data summary and configuration command analysis are completed.

**拟解决的关键技术问题：**

**Key technical problems to be solved:**

研究具有好于100ps时间分辨率的抗辐照传感器和前端电子学关键技术，在保证时间分辨的前提下，攻克像素化方面的技术难点。

The key technologies of radiation resistance sensor and front-end electronics with better time resolution than 100ps are studied, and the technical difficulties in pixelation are overcome on the premise of ensuring time resolution.

**考核指标及评测手段/方法：时间分辨优于100ps的硅像素探测器。前端电子学将设计读出电子学电路模块和小型的数据获取系统，对电子学进行性能测试和技术验证，达到好于100 ps精度的时间测量指标。时间精度可以通过测试信号相对于时钟的间隔或两通道之间的时间差的晃动进行评估，最终以测试报告的形式呈现。**

**Assessment index and evaluation means/METHODS: silicon pixel detector with time resolution better than 100ps. Front end electronics will design readout electronics circuit module and small data acquisition system to test and verify the performance of electronics, and achieve time measurement index of better than 100 PS accuracy. The time accuracy can be evaluated by the interval of the test signal relative to the clock or the shaking of the time difference between the two channels, and finally presented in the form of a test report.**

**参加单位任务分工：**

**Division of tasks of participating units:**

中国科学院高能物理研究所负责新一代有时间信息的像素探测器的传感器研究

IHEP physics, Chinese Academy of Sciences is responsible for the sensor research of the new generation pixel detector with time information

中国科学技术大学负责新一代有时间信息的硅像素探测器的前端电子学研究

The University of science and technology of China is responsible for the front-end electronics research of the new generation silicon pixel detector with time information

......

（多项课题时，可参考上述提纲自行添加相应内容）

(for multiple topics, please refer to the above outline to add corresponding contents)

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：ATLAS硅径迹探测器将是运行在高能量、高亮度前沿的大型带电粒子径迹探测系统，在保持极低的物质量的条件下，具有高效的模式识别能力与优异的径迹重建效率。其抗辐照性能、模块组装的数量和系统整合的复杂程度代表此类大科学装置技术的最前沿。

1. Innovation 1: ATLAS silicon track detector will be a large-scale charged particle track detection system running at the forefront of high energy and high luminosity. It has high pattern recognition ability and excellent track reconstruction efficiency under the condition of maintaining extremely low mass. Its radiation resistance, the number of modules assembled and the complexity of system integration represent the forefront of such large scientific devices.

2、创新点2：本项目将开发具有高精度位置分辨率和优于100 皮秒时间分辨率的基于低增益层的新型探测器，可用于新一代 ATLAS 像素探测器，同时实现高精度位置分辨和高精度时间分辨，进一步发掘物理潜力。

2. Innovation 2: this project will develop a new detector based on low gain layer with high-precision position resolution and better than 100 picosecond time resolution, which can be used in the new generation of ATLAS pixel detector, and realize high-precision position resolution and high-precision time resolution at the same time, so as to further explore the physical potential.

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.

ITk(Inner Tracker)内层径迹探测器是ATLAS实验上的核心探测器，涵盖了多项关键技术及应用，比如高位置分辨硅微条传感器、抗辐射集成电路设计和辐射效应评估、高精度模块组装及可靠性控制。这些技术不仅解决了实验物理领域面临的挑战，满足了预期的科学目标；也为其他如航天、核医疗等涉及国家安全和人民健康的领域积累了技术和经验。

ITK (inner tracker) inner track detector is the core detector in ATLAS experiment, covering a number of key technologies and applications, such as high position resolution silicon micro strip sensor, radiation resistant integrated circuit design and radiation effect evaluation, high-precision module assembly and reliability control. These technologies not only solve the challenges faced by the field of experimental physics, but also meet the expected scientific goals; It has also accumulated technology and experience for other fields related to national security and people's health, such as aerospace and nuclear medicine.

高精度位置分辨、高精度时间分辨的像素探测器及前端电子学不仅对于下一代高亮度粒子对撞实验的径迹探测有着非常重要的作用，该技术在核医学成像、核安全与核应用、同步辐射光源、空间科学卫星等诸多领域都将有重要的应用空间。比如，可以利用此类探测器及电子学构建四维扫描透射电子显微镜(4D STEM)记录电子在材料中的散射；构建用于软x射线成像的设备，等等。

The pixel detector with high-precision position resolution and high-precision time resolution and front-end electronics not only play a very important role in the track detection of the next generation of high Luminosity particle collision experiments, but also have important application space in many fields, such as nuclear medical imaging, nuclear safety and nuclear applications, synchrotron radiation sources, Space Science satellites and so on. For example, a four-dimensional scanning transmission electron microscope (4D stem) can be built using such detectors and electronics to record the scattering of electrons in materials; Constructing devices for soft X-ray imaging, and so on.

**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.

（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.

（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.

（四）项目牵头企业运行状况（项目牵头单位不是企业的，不需填写）

（4） Operation status of the leading enterprise of the project (if the leading enterprise of the project is not an enterprise, it is unnecessary to fill in)

填写下表，并在附件中提供该单位须提供近2年经会计师事务所审计的财务报告（包括资产负债表、损益表、现金流量表）。

Fill in the following table and provide in the appendix the financial report (including balance sheet, income statement and cash flow statement) audited by an accounting firm for the past two years.

|  |  |  |
| --- | --- | --- |
| 项term目order牵头企业概况Overview of leading enterprises | 企业名称Enterprise name |  |
| 行业/领域Industry/field |  |
| 经济性质economic nature | □国有企业 □集体企业 □ state owned enterprise □ collective enterprise □私营企业 □有限责任公司□ private enterprise □ limited liability company□股份有限公司 □其它企业□ limited liability company □ other enterprises | 企业特性Enterprise characteristics | □经认定的高新技术企业 □国家创新型企业 □其他：□ recognized high-tech enterprise □ national innovative enterprise □ others: |
| 上市情况Listing status | □深交所 □上交所 □新加坡□ Shenzhen Stock Exchange □ Shanghai Stock Exchange □ Singapore□香港 □创业板 □新三板□ Hong Kong □ gem □ new third board□纳斯达克□纽约交易所□ NASDAQ □ NYSE□其它：□ others: | 上级主管单位Superior competent unit | □大专院校 □中科院科研院所 □其他部委科研院所 □地方科研院所 □军队系统 □政府职能部门 □企业 □无主管□ colleges and universities □ scientific research institutes of the Chinese Academy of Sciences □ scientific research institutes of other ministries and commissions □ local scientific research institutes □ military system □ government functional departments □ enterprises □ no Supervisor□其他：□ others: |
| 公司注册地址Registered address of the company |  | 注册资本registered capital（万元）(10000 yuan) |  |
| 成立时间（年、月）Time of establishment (year, month) |  | 人员规模Personnel size |  |
| 主营方向Main business direction |  |
| 经营概况Business Overview |

|  |  |  |
| --- | --- | --- |
|  | 主要产品（列前3种产品）Main products (top 3 products) | 近三年年均销售额（万元）Average annual sales in recent three years (10000 yuan) |
| 1 |  |  |
| 2 |  |  |
| 3 |  |  |
| 上年度工业生产总值（万元）Total industrial output value of the previous year (10000 yuan) |  |
|  | 年year | 年year |
| 近2年主营业务收入（万元）Main business income in recent 2 years (10000 yuan) |  |  |
| 近2年利润（万元）Profit in recent 2 years (10000 yuan) |  |   |
| 近2年资产负债率（%）Asset liability ratio in recent 2 years (%) |  |   |
| 近2年实收资本收益率（%）Return on paid in capital in recent 2 years (%) |  |   |
| 近2年现金流量（万元）Cash flow of recent two years (10000 yuan) |  |  |

 |
| 研study发概况Development overview | 研发人员数量Number of R&D personnel |  | 上年度研究开发经费投入（万元）Research and development investment of last year (10000 yuan) |  |
| 上年度研究开发经费投入与主营业务收入的比（投入强度，%）Ratio of research and development funds input to main business income in the previous year (input intensity,%) |  |
|

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 获得发明专利数量（项）Number of invention patents obtained (item) |  | 获得国际发明专利数量（项）Number of international invention patents (items) |  | 软件著作权（项）Software copyright (item) |  |

 |
| 制定国内标准（项）Formulation of domestic standards (items) |  | 制定国际标准（项）Formulation of international standards (items) |  |

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

清华大学最早参加 ATLAS ITk 项目，在实验室建设、人员投入方面起到了重要作用。

Tsinghua University was the first to participate in ATLAS ITK project, which played an important role in laboratory construction and personnel investment.

申请者团队依托核探测与核电子学国家重点实验室平台，在粒子物理实验ASIC芯片和读出电子学系统研究方面有丰富的经验积累。曾参加北京谱仪（BESIII）、高海拔宇宙线观测站（LHAASO）、低温高密核物质测量谱仪（CEE）等大科学装置项目建设，负责其中关键探测器电子学研制，并作出重要贡献。

Relying on the platform of the State Key Laboratory of nuclear detection and nuclear electronics, the applicant team has accumulated rich experience in the research of ASIC chips for particle physics experiments and readout electronics systems. He participated in the construction of large scientific device projects such as Beijing Spectrometer (BESIII), LHASSO and CEE, and was responsible for the development of key detector electronics and made important contributions.

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.

团队成员 RAL 和CERN合作，完成了探测器模块原型机的研制，参与设计了ITk硅微条探测器前端读出芯片ABCStar，并在高能所系统测试了芯片的主要性能表现，以及辐射效应包括总剂量效应和单粒子效应。在合作组内设置了QT任务，跟美国宾大合作，正在进行HCC芯片和模块级芯片组的单粒子效应实验评估工作，目前已经完成系统调试和准备工作，即将实验取数并继续数据分析工作。

Team members cooperated with ral and CERN to complete the development of the prototype of the detector module, participated in the design of the front-end readout chip abcstar of ITK silicon micro strip detector, and tested the main performance of the chip in IHEP, as well as the radiation effects including total dose effect and single event effect. QT task has been set up in the cooperation group. In cooperation with Penn University in the United States, it is carrying out the single event effect experimental evaluation of HCC chip and module level chipset. At present, the system debugging and preparation work have been completed, i.e. the experimental data retrieval and data analysis work will continue.

申请者团队曾参与ATLAS国际合作，在其中与密歇根大学合作，在读出电子学芯片研制领域，完成了MDT TDC ASIC的研制。在本项目研究中，针对好于100ps像素探测器读出电路设计，已与伯克利建立了合作关系。

The applicant team has participated in ATLAS international cooperation, in which it has completed the development of MDT TDC ASIC in the field of readout electronics chip development with the University of Michigan. In the research of this project, a cooperative relationship has been established with Berkeley for readout circuit design of better than 100ps pixel detector.

**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.

2024年度：

Year 2024:

硅微条：完成传感器与读出芯片的关键性能测试。通过模块站点考核，开始制备长硅微条模块。系统联调准备阶段; 与英国卢瑟福实验室合作完成多桶板小系统联调测试，积累测试经验。在CERN开展系统集成点准备工作，包括搭建桶板接收测试系统等重要工作。

Silicon micro strip: complete the key performance test of sensor and readout chip. After passing the module site assessment, the long silicon micro strip module was prepared. Preparation stage for system joint commissioning; Cooperate with Rutherford laboratory in the UK to complete the joint commissioning test of multi barrel small system and accumulate testing experience. Carry out the preparations for the system integration point at CERN, including the construction of barrel receiving test system and other important work.

时间像素：完成文献调研，分析并明确设计需求，确定具体技术路线，完成像素探测器传感器与前端电子学整体架构设计和功能模块划分；

Time pixel: complete literature research, analyze and clarify the design requirements, determine the specific technical route, and complete the overall architecture design and functional module division of pixel detector sensor and front-end electronics;

2025年度：硅微条： 测试传感器、芯片在不同辐照条件下的性能表现，参与批量生产阶段可靠性测试; 制备长硅微条模块。开始接收、测试运往 CERN 的首批桶板，完善工作流程。时间像素：传感器完成第一版设计。电子学进行第一版原型验证电路设计；

2025: silicon micro strip: test the performance of sensors and chips under different irradiation conditions, and participate in the reliability test in batch production stage; Prepare long silicon micro strip module. Begin to receive and test the first batch of barrels shipped to CERN, and improve the workflow. Time pixel: the sensor has completed the first version of the design. The first version of prototype verification circuit design for electronics;

2026年度：

Year 2026:

硅微条：完成制作长硅微条模块，开始制作短硅微条模块。中国组生产的硅探测器模块将在英国卢瑟福实验室加载到桶板上，完成测试后运往CERN安装点。通过接收测试后，加载桶板集成到桶部探测器。时间像素：传感器完成第一版测试。电子学完成第一版原型验证电路性能的仿真验证；

Silicon micro strip: complete the production of long silicon micro strip module and start the production of short silicon micro strip module. The silicon detector module produced by the Chinese group will be loaded on the barrel at the Rutherford laboratory in the UK, and then transported to the CERN installation site after testing. After passing the receiving test, the loaded barrel plate is integrated into the barrel detector. Time pixel: the sensor has completed the first version test. Electronics completed the first version of prototype verification circuit performance simulation verification;

2027年度：

Year 2027:

硅微条：完成制作短硅微条模块。分阶段封闭桶部探测器，参与联调测试。

Silicon micro strip: complete the fabrication of short silicon micro strip module. Close the barrel detector in stages and participate in the joint commissioning test.

时间像素：传感器进行第二版设计。电子学完成第一版原型电路的性能评估测试；根据第一版电路的评估结果，优化电路结构和参数，完成第二版电路的设计和仿真；

Time pixel: the sensor is designed for the second edition. Electronics completed the performance evaluation test of the first version of prototype circuit; According to the evaluation results of the first version of the circuit, the circuit structure and parameters are optimized, and the design and Simulation of the second version of the circuit are completed;

2028年度：

Year 2028:

硅微条：完成联调测试，参与系统早期运行。

Silicon micro strip: complete the joint commissioning test and participate in the early operation of the system.

时间像素：完成像素探测器传感器与前端电子学的性能评估测试，完成技术设计文档的撰写，总结经验。

Time pixel: complete the performance evaluation and testing of pixel detector sensor and front-end electronics, complete the writing of technical design documents, and summarize experience.

**第五部分 项目组织实施、保障措施及风险分析**

**Part V project organization and implementation, safeguard measures and risk analysis**

一、项目组织实施机制

1、 Project organization and implementation mechanism

包括项目及课题的内部组织管理方式、协调机制等，限1000字以内。

Including the internal organization and management mode and coordination mechanism of the project and subject, which is limited to 1000 words.

二、保障措施

2、 Safeguard measures

项目实施的政策、组织和资源支撑条件，限1000字以内。

The policy, organization and resource support conditions for the implementation of the project are limited to 1000 words.

三、知识产权对策、成果管理及合作权益分配

3、 Intellectual property countermeasures, achievement management and cooperative rights distribution

限1000字以内。

Limited to 1000 words.

四、风险分析及对策

4、 Risk analysis and Countermeasures

从技术风险、市场风险、政策风险等几个方面分析项目实施可能面临的风险并提出对策。

This paper analyzes the possible risks faced by the project implementation from the aspects of technical risk, market risk, policy risk and so on, and puts forward countermeasures.

 芯片的抗辐射研究具有一定的敏感性，具有潜在的政策风险。目前进展顺利，接下来将继续争取合作组的支持，保证国内测试工作的开展。单粒子效应的研究依赖于束流，目前散裂的伴生质子束给我们提供很好的实验平台，但是束流监测方面的设备仍不够完善，实验结果存在一定的系统误差。将尽可能通过实验手段和数据分析方法降低误差。

 The research on radiation resistance of chips has certain sensitivity and potential policy risks. At present, it is progressing smoothly. Next, we will continue to strive for the support of the cooperation group to ensure the development of domestic testing work. The study of single event effect depends on the beam. At present, the associated proton beam of spallation provides us with a good experimental platform, but the beam monitoring equipment is still not perfect, and the experimental results have some systematic errors. The error will be reduced as much as possible through experimental means and data analysis methods.

 在新一代有时间信息的硅像素探测器研究任务中，团队将通过与美国单位（LBNL）合作，研究具有时间测量功能硅像素探测器的前端读出电路关键技术。由于国际形式存在一定的不确定性，因此可能会有研制产品对中国禁运的可能性。为应对此风险，团队可以派遣人员赴美国或者CERN开展继续研究和测试工作。

 In the research task of the new generation silicon pixel detector with time information, the team will study the key technologies of the front-end readout circuit of the silicon pixel detector with time measurement function through cooperation with the U.S. unit (LBNL). Due to certain uncertainties in the international form, there may be the possibility of developing products to be embargoed against China. To cope with this risk, the team can send personnel to the United States or CERN to carry out further research and testing.