**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 a brief list of the five major institutions engaged in relevant research at home and abroad, as well as their typical achievements, representative literature and relevant patents and standards, as well as five representative achievements, patents and standards in relevant aspects of the project

为研究新发现的希格斯玻色子和寻找新物理，欧洲核子中心的大型强子对撞机（LHC）将升级，以提高亮度并收集超过10 倍的数据，即高亮度LHC。LHC 升级成为高能物理的焦点。因此，研发新探测器技术，发掘LHC 的物理潜力成了重点。高亮度LHC升级将分别在ATLAS实验上每隔25纳秒进行一次质子束团交汇，每次交汇将产生大约200个对撞，形成高度的对撞事例堆积（pile-up）背景，严重地影响信号探测和数据分析。因此，ATLAS实验相应的探测器需要重大的技术升级，以应对更加严苛的辐射环境和更密集的物理事例。

In order to study the newly discovered Higgs boson and find new physics, the Large Hadron Collider (LHC) of the European nuclear center will be upgraded to improve the luminosity and collect more than 10 times the data, namely the high luminosity LHC. LHC upgrade has become the focus of high energy physics. Therefore, the research and development of new detector technology to explore the physical potential of LHC has become the focus. The upgrade of high luminosity LHC will carry out proton cluster intersection every 25 nanoseconds in ATLAS experiment, and each intersection will produce about 200 collisions, forming a high pile up background of collision cases, which will seriously affect signal detection and data analysis. Therefore, the corresponding detector of ATLAS experiment needs major technical upgrading to deal with more severe radiation environment and more intensive physical cases.

本项目选取几个ATLAS实验升级中最关键的课题开展预研，其中包括研制全新的高颗粒度时间探测器，与升级硅径迹探测器与缪子探测器。

This project selected several key topics in the ATLAS experiment upgrade to carry out pre research, including the development of a new high granularity timing detector, and the upgrading of silicon track detector and muon detector.

高颗粒度时间探测器是近两年来粒子探测领域的一个崭新的方向。相对于现在ATLAS探测器数纳秒级的时间分辨率，该新探测器的时间分辨率可以把时间分辨率提高两个数量级，可以达到50皮秒。它将像个高速摄像机，高精度地记录粒子到达时间信息，有效地判断粒子径迹来自哪个对撞点，从而有效地降低堆积背景。高颗粒度时间探测器的研制将发展很多种新技术，包括高时间分辨的抗辐照传感器技术、前端电子学超快芯片技术、大面积超快探测器集成技术等，各国都积极研发相关技术。

High granularity timing detector is a new direction in the field of particle detection in the past two years. Compared with the nanosecond time resolution of the current ATLAS detector, the time resolution of the new detector can be increased by two orders of magnitude, up to 50 picoseconds. It will be like a high-speed camera, recording the time of arrival of particles with high accuracy, effectively judging which collision point the particle track comes from, so as to effectively reduce the accumulation background. Many new technologies will be developed for the development of high granularity timing detectors, including high time resolution radiation resistance sensor technology, front-end electronics ultrafast chip technology, large area ultrafast detector integration technology, etc. all countries are actively developing related technologies.

在抗辐照、高时间分辨率硅传感器方面，日本滨松公司与意大利的FBK研究所曾处于国际领跑地位。在2021年后，本项目组中国科学院高能物理研究所（高能所）与中国科技技术大学（科大）两个团队分别利用国产工艺研制出高时间分辨率抗辐照硅传感器，并且抗辐照性能超越滨松与FBK的传感器。在2023年，高能所与微电子所联合与日本滨松公司与意大利的FBK研究所竞争欧洲核子中心在ATLAS高颗粒度时间探测器上的硅传感器的国际招标，并最终赢得该招标，确立了国产传感器在该技术上的国际领跑地位。

1. In terms of radiation resistance and high time resolution silicon sensors, Hamamatsu of Japan and FBK Research Institute of Italy once led the world. After 2021, two teams from the Institute of high energy physics of the Chinese Academy of Sciences (IHEP) and the University of science and technology of China (USTC) have developed high-time resolution radiation resistant silicon sensors using domestic technology, and the radiation resistance performance is better than that of Hamamatsu and FBK sensors. In 2023, the Institute of high energy and the Institute of microelectronics jointly competed with Hamamatsu Corporation of Japan and FBK Institute of Italy for the international bidding of the silicon sensor on ATLAS high granularity timing detector of the European nuclear center, and finally won the bidding, establishing the international leading position of domestic sensors in this technology.

在探测器模块研制方面，高能所与西班牙IFAE研究所主导了传感器与超快芯片的先进封装研制；高能所与科大主导了探测器模块的自动化组装；高能所与法国团队主导了大面积多个探测器模块单元（detector unit）的研制。

1. In the aspect of detector module development, the Institute of high energy and Spain IFAE Institute led the advanced packaging development of sensors and ultrafast chips; Institute of high energy and University of science and technology led the automatic assembly of detector module; The Institute of high energy and the French team led the development of multiple detector units in a large area.

超快读出电子学方面，法国IJClab国家实验室、欧洲核子中心主导了该项目超快读出芯片的研发。高能所、南京大学主导了系统级读出电路、与前端读出电路板的设计 ，高能所、山东大学主导了高压电子系统的研制，山东大学还主导了该项目高速传输柔性电缆的研制。

1. In terms of ultrafast readout electronics, the French ijlab National Laboratory and the European nuclear center led the research and development of ultrafast readout chips in the project. Institute of high energy and Nanjing University led the design of system level readout circuit and front-end readout circuit board, Institute of high energy and Shandong University led the development of high-voltage electronic system, and Shandong University also led the development of high-speed transmission flexible cable of the project.

表1 国外代表性的5家从事相关研究的主要机构及典型成果、代表性文献

Table 1 five representative foreign institutions engaged in relevant research and their typical achievements and representative literature

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 序号Serial number | 研究机构Research institutions | 相关研究内容Related research contents | 代表性成果Representative achievements | 代表性文献Representative literature |
| 1. | 欧洲核子研European nuclear Institute究中心（CERN）Research Center (CERN) | 时间探测器Time detector | 研发了ALIPDE芯片，应用于ALICE实验的内径迹探测器升级The alipde chip has been developed and applied to the upgrade of inner diameter trace detector in Alice experiment | W.Snoeys, NIMA 924 (2019) 51-58W. Snoeys, NIMA 924 (2019) 51-58 |
| 2 | IJClab/OmegaIjlab/omega | 研发超快读出芯片Research and development of ultra fast readout chip | 研发出超快读出芯片系列ALTIROCDeveloped the ultra fast readout chip series altiroc | C.AgapopoulouC. AgapopoulouEt al，（2023）JINST 18 P08019Et al, (2023) jinst 18 p08019 |
| 3. | 日本滨松公司Hamamatsu Corporation of Japan | 抗辐照硅传感器研究Research on radiation resistant silicon sensor | 为ATLAS实验的径迹探测器与径迹探测器二期升级项目提供大部分硅传感器；研发出抗辐照LGAD时间传感器Provide most of the silicon sensors for the track detector and track detector phase II upgrading project of ATLAS experiment; Developed radiation resistance LGAD time sensor |  |
| 4 | INFNINFN |  |  |  |
| 5 | LBNLLBNL |  |  |  |

表2国内代表性的5家从事相关研究的主要机构及典型成果、代表性文献

Table 2 five domestic representative institutions engaged in relevant research and their typical achievements and representative literature

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 序号Serial number | 研究机构Research institutions | 相关研究内容Related research contents | 代表性成果Representative achievements | 代表性文献Representative literature |
| 1 | 中国科学院高能物理研究所Institute of high energy physics, Chinese Academy of Sciences | 先进半导体粒子探测器Advanced semiconductor particle detector | 研发了IHEP-IME抗辐照LGAD硅传感器，HGTD的模块组装，电子学。Ihep-ime radiation resistant LGAD silicon sensor, module assembly of HGTD and electronics have been developed. | Mei Zhao et al,Nucl.Instrum.Meth.A 1033 (2022) 166604 |
| 2 | 中国科学技术大学University of science and technology of China | 微结构气体探测器，先进半导体粒子探测器Microstructure gas detector, advanced semiconductor particle detector | 研发了USTC-IME抗辐照LGAD硅传感器，组装The ustc-ime radiation resistant LGAD silicon sensor was developed and assembled | C.H.Li,et al.,Nucl.Instrum.Meth.A1039(2022)167008 |
| 3 | 华中师范大学Central China Normal University | 像素探测器Pixel detector | 承担并完成LHC上ALiCE实验的径迹探测器模块组装任务；自主研制了 MIC系列 MAPS 像素探测器芯片Undertake and complete the track detector module assembly task of Alice experiment on LHC; Mic Series Maps pixel detector chips have been independently developed |  |
| 4 | 南京大学Nanjing University | 高速抗辐照读出电路研制Development of high speed radiation resistant readout circuit | HGTD探测器外设电路PEB的全功能验证系统(Modular PEB)的研制Development of full function verification system (modular PEB) for peripheral circuit PEB of HGTD detector | L. Han et al, Nucl.Instrum.Meth.A 1045 (2023) 16765150. Han et al, NIMA 1045 (2023) 167651 |
| 5 | 山东大学Shandong University | 研制先进的小条窄气隙室探测器;用于气体探测器信号读出的抗辐照读出电子学Radiation resistant readout electronics for gas detector signal readout | 研发和量产了高位置分辨、大面积的sTGC探测器；研发了基于VMM芯片的前端抗辐照、低功耗、高通道密度的读出电子学板Developed a front-end radiation resistant, low power consumption, high channel density readout electronics board based on VMM chip | 1. G.Iakovidis, et al, JINST,18, P05012.
2. X.Zhao, et. al., Nucl.Instrum.Meth.A

, 927 (2019) 257 |

表3 项目在相关方面的5项代表性成果、专利及标准

Table 3 five representative achievements, patents and standards of the project in relevant aspects

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 序号Serial number | 成果类型（文献、专利、标准）Type of achievements (documents, patents, standards) | 名称name | 作者author | 成果明细Achievement details |
| 1 | 文献literature | Design and testing of LGAD sensor with shallow carbon implantation， NIMA 1048 (2023) 167967Design and testing of LGAD sensor with shallow carbon implantation, NIMA 1048 (2023) 167967 | Kewei Wu et al, | 项目组高能所团队研发了抗辐照LGAD硅传感器，抗辐照性能超越国际著名的日本滨松与意大利FBK的传感器。赢得CERN的硅传感器的国际招标Developed radiation resistance LGAD silicon sensor and won the international bidding for silicon sensor of CERN |
| 2. | 文献literature | Performance of LGAD sensors with carbon enriched gain layer produced by USTC | C.H.Li, et al. | 项目组科大团队研发了抗辐照LGAD硅传感器。抗辐照性能超越国际著名的日本滨松与意大利FBK的传感器。 |
| 3 | **文献****literature** | Demonstration system of the HGTD peripheral electronics boards for ATLAS phase II upgrade，NIMA 1045 (2023) 167651 | L. Han et al, | 项目组高能所与南大团队研制了HGTD探测器外设电路PEB的全功能验证系统(Modular PEB)The full function verification system (modular PEB) of HGTD detector peripheral circuit PEB is developed |
| 4 | **文献****literature** | Development of the ABCStar front-end chip for the ATLAS silicon strip upgrade，JINST 12 (2017) C04017 | W. Lu, et al | 设计了抗辐照读出电子学芯片 ABC-STAR 的输入寄存、指令流水线、触发缓存、信号输出等数字逻辑功能模块，基于 SystemVerilog搭建验证平台。芯片通过最终评审，获准投入量产。 |
| 5 | **文献****literature** | Measuring attenuation in signal propagation in Resistive-plate chambers, JINST V16, P01001, Jan. 2021 | X.Y. Xie et al | 项目组科大团队研制了RPC探测器的关键技术 |

**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 guidancelines

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 guidance, and the supporting effect on the goal of the direction of the guidance. Limited to 1500 words.

本申报项目“高能量加速器关键技术研究”拟申报“大科学装置前沿研究”重点专项2023年度项目申报指南中的“1.3 ATLAS 探测器升级（共性关键技术）”，覆盖了相应指南方向的全部研究目标及其考核指标。包括ATLAS实验高粒度时间探测器升级，三个主要部分。项目指南方向的匹配性，对指南方向目标的支撑作用说明如下:

1.3 ATLAS detector upgrade (common key technologies)" in the 2023 project application guidance for the key special project of "frontier research on large scientific devices" of the application project "Research on Key Technologies of high energy accelerators" covers all research objectives and assessment indicators in the corresponding direction. It includes three main parts: the upgrade of high granularity timing detector of ATLAS experiment. The matching of the project guidance direction and its supporting effect on the guidance direction objectives are described as follows:

课题一“ATLAS实验高粒度时间探测器升级” 研制高粒度、高时间分辨率的探测器，这是ATLAS 升级中的一个全新探测器。本项目将研制硅传感器、前端读出电路板、探测器模块、高压系统等。利用这些新的技术，探测器的时间分辨率将从纳秒级提高到50 皮秒。本课题涵盖指南中的关于“高颗粒度时间探测器”所要求的全部内容，各项技术指标均不低于指南要求。

Topic 1 "ATLAS experiment high granularity timing detector upgrade" develops a detector with high granularity and high time resolution, which is a new detector in ATLAS upgrade. This task will develop silicon sensors, front-end readout circuit boards, detector modules, high-voltage systems, etc. Using these new technologies, the time resolution of the detector will be improved from nanosecond to 50 picoseconds. This topic covers all the contents required by the "high granularity timing detector" in the guidance, and the technical indicators are not lower than the requirements of the guidance.

项目目标及考核指标、考核方式/方法

1. 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.

**项目目标**

1. **Project objectives**

**（1）ATLAS实验高粒度时间探测器升级**

**(1) Upgrade of high granularity timing detector in ATLAS experiment**

高精度时间探测器是LHC 探测器技术的新前沿。得益于本团队最新进展，具有高时间精度的探测器将集成到高亮度LHC 中。

High precision time detector is a new frontier of LHC detector technology. Thanks to the latest progress of our team, the detector with high time accuracy will be integrated into the high luminosity LHC.

高粒度高时间分辨探测器是一种由低增益雪崩放大硅传感器（LGAD）组成的新型探测器。本团队设计的传感器具有世界领先的抗辐射性能。围绕这关键技术，本项目拟在国内技术基础上，推进全球领先的LGAD 硅传感器技术研发，提高传感器的一致性与良品率，以用于大面积粒子探测器，其时间分辨率优于50 皮秒；采用自动化系统组装大面积探测器模块；领导抗辐射和快速电子的设计，开发前端读出电路板；开发高压系统，以提高传感器高压偏置的稳定性；本团队将领导该探测器的国际团队在欧洲核子研究中心的集成与安装。

High granularity and high time resolution detector is a new type of detector composed of low gain avalanche amplified silicon sensor (LGAD). The sensor designed by our team has the world's leading radiation resistance performance. Focusing on this key technology, the project plans to promote the research and development of the world's leading LGAD silicon sensor technology on the basis of domestic technology, improve the consistency and yield of the sensor, so as to be used in large-area particle detectors with a time resolution of better than 50 picoseconds; Large area detector module is assembled by automatic system; Lead the design of radiation resistance and fast electronics, and develop front-end readout circuit boards; Develop a high voltage system to improve the stability of the sensor high voltage bias; This team will lead the integration and installation of the detector's international team at CERN.

**考核指标： 所研制的LGAD传感器与探测器模块时间分辨优于50皮秒**

1. **Assessment index: the time resolution between the LGAD sensor and detector module developed is better than 50 picoseconds**

**考核方法：测试报告、论文报告、同行评审。**

1. **Assessment method: test report, paper report, peer review.**

（a）利用Sr-90放射源发出的电子测量时间分辨率。让电子穿过两层紧靠在一起的LGAD。然后将放大后的信号进行波形采样，利用前沿定时得到两层LGAD的信号到达时间(TOA)。从时间差分布的宽度得出时间分辨率。

(a) The time resolution is measured by the electrons emitted from Sr-90 radiation source. Let electrons pass through two layers of LGAD close together. Then the waveform of the amplified signal is sampled, and the time of arrival (TOA) of the two-layer LGAD signal is obtained by using the leading edge timing. The time resolution is obtained from the width of the time difference distribution.

（b）利用CERN SPS的π介子束流或者DESY实验室的电子束流测量探测效率和时间分辨率。将束流的望远镜系统得到的束流粒子径迹外推至LGAD表面，得到预期的击中位置，统计对应的LGAD探测单元有信号的事件比例得到效率。将信号的TOA与系统的参考定时装置对照，得出时间分辨率。

(b) The detection efficiency and time resolution were measured by the pion beam of CERN SPS or the electron beam of desy laboratory. The beam particle track obtained by the beam telescope system is extrapolated to the LGAD surface to obtain the expected hit position, and the efficiency is obtained by counting the proportion of events with signals in the corresponding LGAD detection unit. The TOA of the signal is compared with the reference timing device of the system to obtain the time resolution.

**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** |
|  | 1：1: | □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 guidancelines/specifications □ engineering process □ standards □ papers □ invention patents □ others |  | 指标1.1Indicator 1.1时间分辨率time resolution | 小面积原型硅传感器时间分辨率好于50皮秒The time resolution of small area prototype silicon sensor is better than 50 picoseconds | 为ATLAS升级研制出正式的硅传感器，时间分辨率好于50皮秒A formal silicon sensor has been developed for ATLAS upgrade, with a time resolution better than 50 picosecondsSensor Sensor  | 探测器模块时间分辨率好于50皮秒The time resolution of detector module is better than 50 picosecondsModuleModule | 测试报告、同行评审。Test report and peer review. |
| …… |  |  |  |  |
| 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** |
| 1. | 硅时间探测器中期测试报告Interim test report of silicon time detector | 1 | 2026年2026 | 公开open |
|  | 2. | 硅时间探测器结题测试报告Final test report of silicon time detector | 1 | 2028年2028 | 公开open |
| 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.

**课题1:ATLAS实验高粒度时间探测器**

**Topic 1: ATLAS experimental high granularity timing detector**

研制出ATLAS实验高粒度时间探测器项目研制出全面积的LGAD硅传感器与探测器模块，时间分辨率达到50皮秒，达到项目验收指标，并完成测试报告。测试报告的内容为硅径迹探测器原型机的测试结果，其中包括实验中获得的LGAD硅传感器与探测器模块的时间分辨率等重要参数

1. The project of developing ATLAS experimental high granularity timing detector has developed a full area LGAD silicon sensor and detector module, with a time resolution of 50 picoseconds, meeting the project acceptance index, and completing the test report. The content of the test report is the test results of the prototype of the silicon track detector, including the time resolution and other important parameters of the LGAD silicon sensor and detector module obtained in the experiment

培养研究生5名以上，在国际杂志上发表文章5篇以上，国际会议报告10个以上。

1. Cultivate more than 5 postgraduates, publish more than 5 articles in international journals, and report more than 10 international conferences.

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.

**课题1:ATLAS实验高粒度时间探测器**

**Topic 1: ATLAS experimental high granularity timing detector**

**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:**

 解决LHC升级后高亮度对撞带来的对撞点堆积与辐照量增加的问题，本项目通过研发抗辐照、高时间精度的先进探测器，高精度地记录粒子到达时间信息，有效地判断粒子径迹来自哪个对撞点，从而有效地降低堆积背景。高颗粒度时间探测器的研制将发展很多种关键的新技术，包括高时间分辨的抗辐照传感器技术、超快电子学技术、大面积超快探测器集成技术等。

 To solve the problem of collision point accumulation and the increase of radiation amount caused by the high luminosity collision after the LHC upgrade, the project developed an advanced detector with radiation resistance and high time accuracy to record the arrival time information of particles with high accuracy, effectively determine which collision point the particle track comes from, and effectively reduce the accumulation background. The development of high granularity timing detector will develop many key new technologies, including high time resolution radiation resistance sensor technology, ultrafast electronics technology, large area ultrafast detector integration technology, etc.

针对这些问题拟开展的主要研究内容

Main research contents to be carried out for these problems

**主要研究内容**

**Main research contents**

研究目标为拟研制大面积、抗辐照、高时间分辨的粒子探测器，从而解决LHC高亮度升级后带来的大量对撞顶点堆积的技术难题。另外高时间分辨探测器的研制所将发展出的抗辐照传感器、快速读出芯片等技术对未来高能对撞机大装置的发展，以及航天航空和医学成像等高辐照环境下的应用非常重要。

The research goal is to develop a large-area, radiation resistant and high time-resolved particle detector, so as to solve the technical problem of a large number of collision vertices after the LHC high luminosity upgrade. In addition, the technologies such as radiation resistance sensors and fast readout chips that will be developed by the development of high-time resolution detectors are very important for the development of large-scale high-energy collider devices in the future, as well as the applications in high radiation environments such as aerospace and medical imaging.

本课题研究内容有如下几部分：

The research contents of this topic are as follows:

**抗辐照超快传感器研制**

* + - * 1. **Development of anti irradiation ultrafast sensor**

硅传感器是高时间分辨探测器的眼睛，研究内容是研发一种超快、抗辐照的低增益雪崩放大硅传感器（LGAD），时间分辨能好于50皮秒，能承受2.5×1015 neq/cm2的等效中子通量的辐照，满足ATLAS实验第二期升级的需求。

Silicon sensor is the eye of high time resolution detector. The research content is to develop an ultra fast and radiation resistant low gain avalanche amplified silicon sensor (LGAD), which has a time resolution of better than 50 picoseconds and can withstand 2.5 × The irradiation of equivalent neutron flux of 1015 neq/cm2 meets the needs of the second phase of ATLAS experiment.

研究内容为研究并优化低增益雪崩放大硅传感器的半导体器件设计，以提高其抗辐照性能与时间分辨率；通过国际合作研发其器件制作所用的相关半导体工艺，提高全面积LGAD传感器的良品率，优化其雪崩增益大小、噪声、漏电流与功耗和抗辐照性能。

The research content is to study and optimize the semiconductor device design of low gain avalanche amplifier silicon sensor to improve its radiation resistance and time resolution; Through international cooperation in the development of relevant semiconductor processes used in the fabrication of its devices, the yield of the fully integrated LGAD sensor is improved, and its avalanche gain, noise, leakage current, power consumption and radiation resistance are optimized.

**超快探测器的模块集成技术**

* + - * 1. **Module integration technology of ultrafast detector**

超快探测器模块集成是探测器的核心。研究目标为探索出超快探测器模块设计方案，在探测器模块系统级别实现好于50皮秒的时间精度。

Ultrafast detector module integration is the core of the detector. The research goal is to explore the design scheme of ultrafast detector module, and achieve a time accuracy of better than 50 picoseconds at the detector module system level.

研究内容为研制高时间分辨探测器探测器模块，攻关超快传感器和读出芯片高密度高速集成的关键技术；研制大面积超快探测器多模块组stave的样机，攻关把数十个探测器模块在stave样机上高精度组装技术，以及多模块近万个读出通道的高精度同步与联调的技术。

The research content is to develop the detector module of high time resolution detector, and tackle the key technology of high-density and high-speed integration of ultrafast sensor and readout chip; The prototype of large-area ultra fast detector with multi module group has been developed, and the high-precision assembly technology of dozens of detector modules on the prototype has been tackled, as well as the high-precision synchronization and joint debugging technology of multi module nearly 10000 readout channels.

**设计研制外围电子学系统原型。**

* + - * 1. **The prototype of peripheral electronics system is designed and developed.**

HGTD的外围电路连接各个探测单元与探测器外触发和数据获取系统，是HGTD探测器不可或缺的重要组成部分。外围电路位于HGTD探测器外圈，保证探测器数据高速传输。主要研究内容为在几何空间的限制，设计出高抗辐照能力，低功耗，强干扰前端电子学。

The peripheral circuit of HGTD connects each detection unit with the external trigger and data acquisition system of the detector, which is an indispensable and important part of HGTD detector. The peripheral circuit is located in the outer ring of HGTD detector to ensure the high-speed transmission of detector data. The main research content is to design the front-end electronics with high radiation resistance, low power consumption and strong interference under the restriction of geometric space.

**d）柔性电子学尾板**

**d) Flexible electronics tailboard**

柔性电子学尾板是连接前端探测器LGAD电子学与外围电子学板的桥梁。主要研究内容是研制具有较低物质量的柔性板方案，以及优化电路设计，降低时间抖动与提高信号质量。

The flexible electronics tail board is a bridge connecting the front-end detector LGAD electronics and the peripheral electronics board. The main research content is to develop a flexible board with low mass, and optimize the circuit design, reduce the time jitter and improve the signal quality.

**E）高压电子系统**

E) High voltage electronic system

高压电子系统需要为LGAD传感器提高一个稳定偏置电压。每个模块都需要该偏置高压。主要研究内容为研制多通道、高精度的高压电子学系统，通过优化电路设计减少纹波，提高精度。其中，研制测量系统，测量漏电流并且精度好于100nA。另外，针对多通道供电可能存在的串扰问题，研制通道间隔离方案与优化接地的方案。

High voltage electronic system needs to increase a stable bias voltage for LGAD sensor. This bias high voltage is required for each module. The main research content is to develop a multi-channel, high-precision high-voltage electronics system, reduce ripple and improve accuracy by optimizing circuit design. The measurement system is developed to measure the leakage current and the accuracy is better than 100na. In addition, for the crosstalk problem that may exist in multi-channel power supply, the isolation scheme between channels and the optimized grounding scheme are developed.

（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.

**课题1:ATLAS实验高粒度时间探测器**

**Topic 1: ATLAS experimental high granularity timing detector**

针对LHC升级后高亮度对撞带来的对撞点堆积与辐照量增加的问题，拟自主设计并采用国产工艺，研制抗辐照LGAD传感器、探测器模块的先进封装、高速的前端读出电子学系统、高精度高压电源系统等。

Aiming at the problems of collision point accumulation and increase of radiation amount caused by high luminosity collision after LHC upgrade, it is planned to independently design and adopt domestic technology to develop radiation resistance LGAD sensor, advanced packaging of detector module, high-speed front-end readout electronics system, high-precision high-voltage power supply system, etc.

在抗辐照超快传感器研制方面，针对LGAD原型硅传感器抗辐照能力的问题，拟在国内微电子所8寸工艺线上，采用高能量离子深注入的方式进行LGAD传感器增益层的p+掺杂；在抗辐照设计方面，优化碳掺杂，保护增益层中晶格上的硼原子，减缓辐照损伤引起的受主移除效应，进一步提高国产LGAD硅传感器的抗辐照能力。通过TCAD等计算机仿真工具，调整LGAD硅传感器制作流程中掺杂等关键工艺，提升其时间分辨率等关键性能。

In the development of radiation resistance ultra fast sensor, aiming at the problem of radiation resistance ability of LGAD prototype silicon sensor, it is proposed to use high-energy ion deep implantation to p+dope the gain layer of LGAD sensor on the 8-inch process line of domestic Microelectronics Institute; In terms of radiation resistance design, carbon doping is optimized to protect the boron atoms on the lattice in the gain layer, slow down the acceptor removal effect caused by radiation damage, and further improve the radiation resistance of domestic LGAD silicon sensors. Through TCAD and other computer simulation tools, the key processes such as doping in the production process of LGAD silicon sensor are adjusted to improve its time resolution and other key performance.

在探测器模块研制方面，项目组拟基于国内的先进芯片封装工艺，自主研制封装方案，将前端读出超快ASIC芯片与高时间分辨LGAD传感器通过球焊方式高密度集成，研制出高时间分辨率的探测器模块。另外，通过与国内精密控制的单位合作，研制探测器模块自动组装工艺，实现智能化组装。

In the aspect of detector module development, the project team plans to independently develop the packaging scheme based on the domestic advanced chip packaging technology, and develop the detector module with high time resolution by integrating the front-end readout ultra fast ASIC chip and high time resolution LGAD sensor through ball welding. In addition, through cooperation with domestic precision control units, the automatic assembly process of detector module is developed to realize intelligent assembly.

在电子学方面，项目组拟自主研制高速外围电子读出板，通过设计与优化多层电路板布线与优化，实现复杂功能，其中包括连接数十个探测器模块，整合来自探测器模块测量到的时间和亮度数据，转换为高速的光信号，发送到探测器外的数据获取系统。同时，PEB接收并分发时钟和触发信号给探测器模块，还为其提供传感器的高压和专用集成电路ASCI的低压。另外，还要保证PEB能够满足HGTD探测器安装环境的抗辐照和散热条件。

In electronics, the project team plans to independently develop high-speed peripheral electronic readout boards, and realize complex functions through the design and optimization of multilayer circuit board wiring and optimization, including connecting dozens of detector modules, integrating the time and luminosity data measured by the detector module, converting them into high-speed optical signals and sending them to the data acquisition system outside the detector. At the same time, PEB receives and distributes clock and trigger signals to the detector module, and also provides it with high voltage of the sensor and low voltage of ASIC ASCI. In addition, it is also necessary to ensure that PEB can meet the radiation resistance and heat dissipation conditions of HGTD detector installation environment.

本课题还自主研制柔性电子学尾板，通过优化电路设计，压低时间抖动，保证信号传输的质量与电源传输的效率；研制高精度的高压电子学系统，为LGAD传感器提高温度的工作电压。

This project also independently develops flexible electronics tailboard, which can reduce the time jitter and ensure the quality of signal transmission and the efficiency of power transmission by optimizing the circuit design; A high-precision high-voltage electronics system is developed to improve the working voltage of temperature for LGAD sensor.

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.

**课题1:ATLAS实验高粒度时间探测器**

**Topic 1: ATLAS experimental high granularity timing detector**

高颗粒度时间探测器是近两年来粒子探测领域的一个崭新的方向。相对于现在ATLAS探测器数纳秒级的时间分辨率，该新探测器的时间分辨率可以把时间分辨率提高两个数量级，可以达到50皮秒。高颗粒度时间探测器的研制将发展很多种新技术，包括高时间分辨的抗辐照传感器技术、前端电子学超快芯片技术、大面积超快探测器集成技术等，各国都积极研发相关技术。另外，该技术未来有望用于粒子物理以外的更多领域，其中包括质子治癌中质子CT等医学应用、材料、生物样品研究中的X射线三维成像以及空间站与科学卫星等空间应用。

High granularity timing detector is a new direction in the field of particle detection in the past two years. Compared with the nanosecond time resolution of the current ATLAS detector, the time resolution of the new detector can be increased by two orders of magnitude, up to 50 picoseconds. Many new technologies will be developed for the development of high granularity timing detectors, including high time resolution radiation resistance sensor technology, front-end electronics ultrafast chip technology, large area ultrafast detector integration technology, etc. all countries are actively developing related technologies. In addition, the technology is expected to be used in more fields besides particle physics in the future, including medical applications such as proton CT in proton cancer therapy, X-ray three-dimensional imaging in materials and biological sample research, and space applications such as space stations and scientific satellites.

**可行性分析：**

**Feasibility analysis:**

本项目组高能所与科大两个团队分别利用国产工艺研制出高时间分辨率抗辐照硅传感器。所开发的高时间精度LGAD 硅传感器原型的时间分辨率优于50 皮秒，能够承受LHC 升级后的超高辐照剂量（2.5×1015 neq/cm2的等效中子通量），满足ATLAS实验第二期升级的需求。它是目前同类的LGAD 硅传感器原型中全球性能最优秀的，其性能显著好于国际著名的日本滨松公司与意大利FBK 研究所的LGAD原型传感器。在2023年，高能所与微电子所联合与日本滨松公司与意大利的FBK研究所竞争欧洲核子中心在ATLAS高颗粒度时间探测器上的硅传感器的国际招标，并最终赢得该招标。上述LGAD 硅原型传感器的研制成功，为本项目为ATLAS实验研制正式的全面积LGAD 硅原型传感器，以及基于传感器，进一步研制探测器模块以及配套的电子学系统打下坚实的基础。

The two teams of Institute of high energy and University of science and technology of the project team respectively developed high-time resolution radiation resistant silicon sensors by using domestic technology. The time resolution of the developed LGAD silicon sensor prototype with high time accuracy is better than 50 picoseconds, and it can withstand the ultra-high radiation dose (2.5 μ m) after LHC upgrade × Equivalent neutron flux of 1015 NEQ/cm2), which meets the needs of the second phase upgrade of ATLAS experiment. It is the world's best LGAD silicon sensor prototype of its kind at present, and its performance is significantly better than the LGAD prototype sensor of the internationally famous Hamamatsu company of Japan and the FBK Research Institute of Italy. In 2023, the Institute of high energy and the Institute of microelectronics jointly competed with Hamamatsu Corporation of Japan and FBK Institute of Italy for the international bidding of the silicon sensor on ATLAS high granularity timing detector of the European nuclear center, and finally won the bidding. The successful development of the above-mentioned LGAD silicon prototype sensor has laid a solid foundation for the project to develop a formal full scale LGAD silicon prototype sensor for ATLAS experiment, and further develop detector modules and supporting electronic systems based on the sensor.

三、课题分解方案

3、 Project decomposition scheme

（一）课题分解情况

（1） Task 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 task item by item. Each topic is limited to 3000 words.

**1、课题1：ATLAS实验高粒度时间探测器升级**

**1. Topic 1: upgrading of high granularity timing detector in ATLAS experiment**

**研究目标：**

**Research objectives:**

本项目拟在国内技术基础上，推进全球领先的LGAD 硅传感器技术研发，提高传感器的一致性与良品率，以用于大面积粒子探测器，其时间分辨率优于50 皮秒；采用自动化系统组装大面积探测器模块；领导抗辐射和快速电子的设计，开发前端读出电路板；开发高压系统，以提高传感器高压偏置的稳定性；本团队将领导该探测器的国际团队在欧洲核子研究中心的集成与安装。

On the basis of domestic technology, the project plans to promote the research and development of the world's leading LGAD silicon sensor technology, improve the consistency and yield of the sensor, so as to be used in large-area particle detectors with a time resolution of better than 50 picoseconds; Large area detector module is assembled by automatic system; Lead the design of radiation resistance and fast electronics, and develop front-end readout circuit boards; Develop a high voltage system to improve the stability of the sensor high voltage bias; This team will lead the integration and installation of the detector's international team at CERN.

主要研究内容：

Main research contents:

**LGAD抗辐照硅传感器**

**LGAD radiation resistant silicon sensor**

研究内容为研究并优化低增益雪崩放大硅传感器的半导体器件设计，以提高其抗辐照性能与时间分辨率；通过国际合作研发制作所用的相关半导体工艺，并将该工艺国产化。在工艺方面，采用高能量离子深注入的方式进行LGAD传感器增益层的p+掺杂；在抗辐照设计方面，优化碳掺杂，保护增益层中晶格上的硼原子，减缓辐照损伤引起的受主移除效应。课题组参与ATLAS合作组中LGAD超快传感器的抗辐照性能测试，测试不同雪崩倍增区域的掺杂设计下的时间探测精度、电荷收集率，雪崩增益大小、噪声、漏电流与功耗和抗辐照性能等的变化，结合TCAD器件仿真，掌握LGAD的原型传感器的核心设计与其性能测试技术。

The research content is to study and optimize the semiconductor device design of low gain avalanche amplifier silicon sensor to improve its radiation resistance and time resolution; Through international cooperation, research and develop the relevant semiconductor process used in the production, and localize the process. In terms of technology, P+doping in the gain layer of LGAD sensor is carried out by high energy ion deep implantation; In terms of radiation resistance design, carbon doping is optimized to protect the boron atoms in the lattice in the gain layer and slow down the acceptor removal effect caused by radiation damage. The research group participated in the radiation resistance performance test of LGAD ultra fast sensor in ATLAS cooperation group, and tested the time detection accuracy, charge collection rate, avalanche gain, noise, leakage current and power consumption, radiation resistance performance and other changes under the doping design of different avalanche multiplication regions. Combined with TCAD device simulation, the research group mastered the core design and performance test technology of LGAD prototype sensor.

**探测器模块：**

**Detector module:**

课题组拟在探测器模块研制前期基础上进一步主导ATLAS实验大面积超快探测器的研制。项目组拟通过高密度集成的工艺把多探测器模块集成为大面积探测器单元（detector units）。课题组计划将前端读出超快ASIC芯片与高时间分辨LGAD传感器通过球焊方式集成，再在集成柔性电路板成为模块。另外，项目组拟利用可编程的龙门机器系统，把多个探测器模块以数十微米的精度安装在支撑结构上；再高密度的前端外围电路板实现多个模块的高速数据与时钟信号传输与控制信号输入，最终研发出完整的超快探测器探测器单元。

The research group plans to further lead the development of large-area ultrafast detector in ATLAS experiment based on the early development of detector module. The project team plans to integrate multiple detector modules into large-area detector units through high-density integration process. The research group plans to integrate the front-end readout ultra fast ASIC chip with the high time-resolution LGAD sensor by ball welding, and then become a module on the integrated flexible circuit board. In addition, the project team plans to use the programmable gantry machine system to install multiple detector modules on the support structure with the accuracy of tens of microns; The high-density front-end peripheral circuit board realizes the high-speed data and clock signal transmission and control signal input of multiple modules, and finally develops a complete ultrafast detector unit.

**外围电子学**

**Peripheral Electronics**

研制HGTD探测器的外设读出电路（PEB），PEB的PCB是外围电子学至关重要的组成部分，它承载着电子元件并提供电气连接。在满足HGTD探测器有限的安装空间和强烈粒子辐照的环境下，PEB需实现如下功能：连接数十个探测器模块，整合来自探测器模块测量到的时间和亮度数据，转换为高速的光信号，发送到探测器外的数据获取系统。同时，PEB接收并分发时钟和触发信号给探测器模块，还为其提供传感器的高压和专用集成电路ASCI的低压。另外，还要保证PEB能够满足HGTD探测器安装环境的抗辐照和散热条件。

项目组拟领导国际团队，主导PEB设计和制造，克服面临着布局、制造精度、元件密度和技术发展等方面的挑战。首先，PCB设计需要考虑探测器模块电路布局和布线的复杂性。在设计过程中，需要合理安排元件的位置和连接，以确保信号传输的稳定性和可靠性。这需要充分理解HGTD电路的功能和要求，并进行多层堆叠和布线规划，对高速信号传输进行模拟与仿真。其次，PCB制造过程需要高度的精确性和可控性。制造过程中的每个步骤，包括印刷、蚀刻、镀金和焊接，都需要精确的控制，以确保PCB的质量和性能。任何制造过程中的偏差或缺陷都可能对PCB的功能产生不利影响。此外，随着ATLAS电子学元器件和连接器的小型化和功能的增加，PCB上的元件密度也越来越高。这给布线和散热带来了挑战。在有限的空间内，需要精确地布置元件并开展微孔、埋盲孔设计、提供有效的散热系统，以确保PCB的稳定性和可靠性。

Develop a peripheral readout circuit (PEB) for HGTD detectors, a PCB that is a vital component of peripheral electronics, carrying electronic components and providing electrical connections. In order to meet the limited installation space of HGTD detectors and the environment of strong particle irradiation, PEB needs to realize the following functions: connect dozens of detector modules, integrate the time and brightness data measured from the detector module, convert it into a high-speed optical signal, and send it to the data acquisition system outside the detector. At the same time, PEB receives and distributes clock and trigger signals to the detector module, and also provides it with the high voltage of the sensor and the low voltage of ASIC ASCI. In addition, it is necessary to ensure that the PEB can meet the anti-irradiation and heat dissipation conditions of the HGTD detector installation environment.

The project team intends to lead the international team to lead PEB design and manufacturing, overcoming the challenges of layout, manufacturing accuracy, component density and technology development. First, the PCB design needs to consider the complexity of detector module circuit layout and routing. In the design process, it is necessary to arrange the position and connection of components reasonably to ensure the stability and reliability of signal transmission. This requires a full understanding of the functions and requirements of HGTD circuits, multilayer stacking and wiring planning, and simulation and simulation of high-speed signal transmission. Secondly, the PCB manufacturing process requires a high degree of accuracy and controllability. Every step in the manufacturing process, including printing, etching, gold plating, and soldering, requires precise control to ensure the quality and performance of the PCB. Any deviation or defect in the manufacturing process can adversely affect the functionality of the PCB. In addition, with the miniaturization and increasing functionality of ATLAS electronic components and connectors, the density of components on PCBs is also increasing. This creates challenges for cabling and heat dissipation. In a limited space, it is necessary to precisely arrange components and carry out microvia, buried blind hole design, and provide an effective heat dissipation system to ensure PCB stability and reliability.

**柔性电子学尾板**

**Flexible electronics tailboard**

柔性电子学尾板是连接前端探测器LGAD电子学与外围电子学板的桥梁，采用具有较低物质量的柔性设计方案。在研发过程中，需要（1）严格控制信号走线的阻抗，降低反射，提高信号传输的质量；（2）控制柔性板的均匀度，压低信号跳变沿在传输中的jitter抖动；（3）严格控制电源平面和地平面的阻抗，以保证电源传输的效率。用于信号传输的柔性电子学板一般以2层板和4层板居多。根据以上要求，需要研究在2层板和4层板的设计下，信号传输线的阻抗、信号晃动、压降等性能参数，确定最优化的设计。在HGTD升级项目中，预计需要7500余块柔性电子学尾板。我国ATLAS实验团队将承担1/3的生产和测试任务。研究自动化的测试平台，将大大降低人力成本的支出。根据平面阻抗、信号晃动、压降等性能的测试需求，搭建适用于柔性电子学尾板的测试平台，对最后量产的柔性电子学尾板进行质量控制（QC）和质量保证（QA）。同时，建立柔性电子学尾板的测试数据库，以方便快速查找比对，发现后续测试中的问题。

The flexible electronics tail board is a bridge connecting the front-end detector LGAD electronics and the peripheral electronics board. It adopts a flexible design scheme with low mass. In the process of research and development, it is necessary to (1) strictly control the impedance of signal routing, reduce reflection and improve the quality of signal transmission; (2) Control the uniformity of the flexible board and reduce the jitter of the signal jump edge in transmission; (3) Strictly control the impedance of power plane and ground plane to ensure the efficiency of power transmission. Flexible electronic boards for signal transmission are generally 2-layer and 4-layer . According to the above requirements, it is necessary to study the impedance, signal sloshing, voltage drop and other performance parameters of the signal transmission line under the design of 2-layer and 4-layer plates to determine the optimal design. In the HGTD upgrade project, it is estimated that more than 7500 flexible electronics Tailboards will be required. The ATLAS experimental team in China will undertake 1/3 of the production and testing tasks. Research on automated test platform will greatly reduce the expenditure of labor costs. According to the test requirements of planar impedance, signal sloshing, voltage drop and other performance, a test platform suitable for flexible electronics tailboard is built to carry out quality control (QC) and quality assurance (QA) for the final mass-produced flexible electronics tailboard. At the same time, the test database of flexible electronics tailboard is established to facilitate quick search and comparison and find problems in subsequent tests.

**高压电子系统**

**High voltage electronic system**

LGAD传感器需要一个偏置电压，每个模块都需要该偏置高压，电压范围为0至-900V，单通道电流最大3mA，一共需要8032个通道。高压电源需要放置在19’标准的机柜中，通过屏蔽电缆（约80–100 m长）连接到端盖 PP-EC区域的低通滤波器单元。滤波后的高压通过约15米长的屏蔽电缆传输到HGTD上的连接器，再传输到PEB上，通过PEB将高压加到LGAD传感器上。高压系统的布局如图所示。

LGAD sensor requires a bias voltage, which is required for each module. The voltage range is 0 to -900v, and the maximum current of a single channel is 3mA. A total of 8032 channels are required. The high-voltage power supply needs to be placed in a 19 'standard cabinet and connected to the low-pass filter unit in the pp-ec area of the end cover through a shielded cable (about 80 – 100 m long). The filtered high voltage is transmitted to the connector on the HGTD through a shielded cable about 15 meters long, and then to the PEB. The high voltage is added to the LGAD sensor through the PEB. The layout of the high voltage system is shown in the figure.



国内的中国科学院高能物理所与山东大学共同负责其中的高压电源部分，该高压电源属于有特殊要求的定制产品，需要根据HGTD项目的需求，在国内调研合适的厂家负责生产1560通道的高压电源设备。

The domestic Institute of high energy physics of the Chinese Academy of Sciences and Shandong University are jointly responsible for the high-voltage power supply. The high-voltage power supply is a customized product with special requirements. According to the needs of the HGTD project, it is necessary to investigate suitable manufacturers in China to produce 1560 channel high-voltage power supply equipment.

高压电源的主要技术指标：

Main technical indicators of high voltage power supply:

|  |  |
| --- | --- |
| **参数****parameter** | **数值****numerical value** |
| **输出****output** |  |
| 极性Polarity | 反向reverse |
| 电压范围Voltage range | 0 to -900 V0 to -900 V |
| 电压精度Voltage accuracy | Better than 1VBetter than 1V |
| 电流current | ≥3 mA/channel≥ 3 ma/channel |
| 电流监控分辨率Current monitoring resolution | 好于100nABetter than 100na |
| 加高压速度High pressure speed | 1V/s to 10 V/s可调1v/s to 10 v/s adjustable |
| 降高压速度High pressure reduction speed | 1V/s to 50 V/s 可调1v/s to 50 v/s adjustable  |
| 电源纹波Power Ripple | <100mV;<100mv; |
| 效率efficiency | >75% >75% |

中国科学院高能物理所与山东大学将各自负责780个通道的购置及测试工作，经测试达到既定指标（如纹波、精度等）后将交付CERN投入使用。

The Institute of high energy physics of the Chinese Academy of Sciences and Shandong University will each be responsible for the purchase and testing of 780 channels. After reaching the established indicators (such as ripple, accuracy, etc.) through testing, they will be delivered to CERN for use.

**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:**

 解决LHC升级后高亮度对撞带来的对撞点堆积与辐照量增加的问题，本项目通过研发抗辐照、高时间精度的先进探测器，高精度地记录粒子到达时间信息，有效地判断粒子径迹来自哪个对撞点，从而有效地降低堆积背景。高颗粒度时间探测器的研制将发展很多种关键的新技术，包括高时间分辨的抗辐照传感器技术、超快电子学技术、大面积超快探测器集成技术等。

 To solve the problem of collision point accumulation and the increase of radiation amount caused by high luminosity collision after LHC upgrade, the project developed advanced detectors with radiation resistance and high time accuracy to record the time of arrival of particles with high accuracy, effectively determine which collision point the particle track comes from, and effectively reduce the accumulation background. The development of high granularity timing detector will develop many key new technologies, including high time resolution radiation resistance sensor technology, ultrafast electronics technology, large area ultrafast detector integration technology, etc.

**考核指标及评测手段/方法：**

**Assessment indicators and evaluation means/METHODS:**

**考核指标：所研制的LGAD传感器与探测器模块时间分辨优于50皮秒**

**Assessment index: the time resolution between the LGAD sensor and detector module developed is better than 50 picoseconds**

**考核方法：测试报告、论文报告、同行评审。**

**Assessment method: test report, paper report, peer review.**

（a）利用Sr-90放射源发出的电子测量时间分辨率。让电子穿过两层紧靠在一起的LGAD。然后将放大后的信号进行波形采样，利用前沿定时得到两层LGAD的信号到达时间(TOA)。从时间差分布的宽度得出时间分辨率。

(a) The time resolution is measured by the electrons emitted from Sr-90 radiation source. Let electrons pass through two layers of LGAD close together. Then the waveform of the amplified signal is sampled, and the time of arrival (TOA) of the two-layer LGAD signal is obtained by using the leading edge timing. The time resolution is obtained from the width of the time difference distribution.

（b）利用CERN SPS的π介子束流或者DESY实验室的电子束流测量探测效率和时间分辨率。将束流的望远镜系统得到的束流粒子径迹外推至LGAD表面，得到预期的击中位置，统计对应的LGAD探测单元有信号的事件比例得到效率。将信号的TOA与系统的参考定时装置对照，得出时间分辨率。

(b) The detection efficiency and time resolution were measured by the pion beam of CERN SPS or the electron beam of desy laboratory. The beam particle track obtained by the beam telescope system is extrapolated to the LGAD surface to obtain the expected hit position, and the efficiency is obtained by counting the proportion of events with signals in the corresponding LGAD detection unit. The TOA of the signal is compared with the reference timing device of the system to obtain the time resolution.

**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LGAD硅传感器研制与模块组装，外围读出电路研制与高压电子学系统

The Institute of high energy physics of the Chinese Academy of Sciences is responsible for the development and module assembly of LGAD silicon sensors, the development of peripheral readout circuits and high voltage electronics systems

中国科学技术大学负责LGAD硅传感器研制与模块组装

University of science and technology of China is responsible for the development and module assembly of LGAD silicon sensor

南京大学负责本项目外围读出电路研制

Nanjing University is responsible for the development of peripheral readout circuits for this project

山东大学负责柔性电子学尾板与高压电子学系统的研制

Shandong University is responsible for the development of flexible electronics tailboard and high voltage electronics system

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.

创新点1：本项目将研发ATLAS 实验高颗粒度和高时间分辨率探测器。它是第一个用于粒子物理对撞机实验的大规模硅基高精度时间探测器。相对于现在ATLAS探测器数纳秒级的时间分辨率，该新探测器的时间分辨率可以把时间分辨率提高两个数量级以上，可以达到50皮秒。它可以高精度地记录粒子到达时间信息，有效地判断粒子径迹来自哪个对撞点，从而有效地降低堆积背景。高颗粒度时间探测器的研制将发展很多种新技术，包括高时间分辨的抗辐照传感器技术、前端电子学超快芯片技术、大面积超快探测器集成技术等，各国都积极研发相关技术。时间分辨率将取决于该项目中将开发的所有精密器件，包括高精度硅传感器、高速读出电子学等。

Innovation point 1: this project will develop high granularity and high time resolution detector for ATLAS experiment. It is the first large-scale silicon-based high-precision time detector used in the particle physics collider experiment. Compared with the nanosecond time resolution of the current ATLAS detector, the time resolution of the new detector can be improved by more than two orders of magnitude, up to 50 picoseconds. It can record the arrival time of particles with high accuracy, and effectively determine which collision point the particle track comes from, so as to effectively reduce the stacking background. Many new technologies will be developed for the development of high granularity timing detectors, including high time resolution radiation resistance sensor technology, front-end electronics ultrafast chip technology, large area ultrafast detector integration technology, etc. all countries are actively developing related technologies. The time resolution will depend on all precision devices to be developed in the project, including high-precision silicon sensors, high-speed readout electronics, etc.

2. 创新点2：本项目开发的高时间精度LGAD 硅传感器原型的时间分辨率优于50 皮秒，能够承受LHC 升级后的超高辐照剂量（2.5×1015 neq/cm2的等效中子通量），满足ATLAS实验第二期升级的需求。它是目前同类的LGAD 硅传感器原型中全球性能最优秀的，其性能显著好于国际著名的日本滨松公司与意大利FBK 研究所的LGAD传感器原型。

2. innovation 2: the time resolution of the high-precision LGAD silicon sensor prototype developed in this project is better than 50 picoseconds, and can withstand the ultra-high radiation dose (2.5 × Equivalent neutron flux of 1015 NEQ/cm2), which meets the needs of the second phase upgrade of ATLAS experiment. It is the world's best LGAD silicon sensor prototype of its kind at present, and its performance is significantly better than the LGAD sensor prototype of the internationally famous Hamamatsu company of Japan and the FBK Research Institute of Italy.

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.

研发项目中拟研制的抗辐照、高时间分辨率的探测器具有高时间分辨率和抗辐照等优异性能，可以广泛应用于核物理实验与粒子物理实验、同步辐射成像与X射线成像、医疗成像、航空航天探测等重要领域。其中的新技术的研究成果未来将可以转化到相关的医疗仪器与同步辐射成像与X射线探测仪器的企业，并使其产品在高辐照环境下使用寿命更高或者得到更高的时间测量精度，从而带来可观的经济效益。另外，抗辐照硅探测器技术有望在将来应该在我国空间站与科学卫星项目中，成为其中关键技术。通过研制国产硅传感器，使更多的年轻科学工作者参与先进半导体探测器工艺研究，促进国内相关厂家掌握关键技术

The detector with radiation resistance and high time resolution to be developed in the R&D project has excellent performance such as high time resolution and anti radiation, and can be widely used in nuclear physics experiments and particle physics experiments, synchrotron radiation imaging and X-ray imaging, medical imaging, aerospace exploration and other important fields. The research results of the new technology will be transferred to the enterprises of relevant medical instruments and synchrotron radiation imaging and X-ray detection instruments in the future, and their products will have a longer service life or higher time measurement accuracy in the high radiation environment, thus bringing considerable economic benefits. In addition, radiation resistant silicon detector technology is expected to become one of the key technologies in China's space station and scientific satellite projects in the future. Through the development of domestic silicon sensors, more young scientists will participate in the process research of advanced semiconductor detectors and promote relevant domestic manufacturers to master key technologies

本项目的研制将解决大型强子对撞机上的关键技术问题，解决高亮度LHC对撞带来的对撞点堆积，为精确测量希格斯粒子耦合常数（特别是与夸克、轻子的耦合常数）与电弱作用关键参数与提高对新物理灵敏度打下基础。

The development of this project will solve the key technical problems on the Large Hadron Collider, solve the accumulation of collision points caused by the high luminosity LHC collision, and lay the foundation for accurately measuring the key parameters of Higgs particle coupling constant (especially the coupling constant with quarks and leptons) and electric weak interaction and improving the sensitivity to new physics.

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

限1000字以内。

Limited to 1000 words.

IHEP general description

本团队在建造升级探测器与物理分析，一直积极推动国际合作且做出了显著成果。高粒度时间探测器团队正在领导ATLAS 实验高时间分辨率探测器（HGTD）项目。本项目负责人担任HGTD 项目负责人，多名项目成员担任HGTD 重要管理职位。本团队开发了具有世界领先性能的硅传感器原型，性能优于日本滨松公司与意大利FBK 的传感器。本团队的传感器已被ATLAS 实验选用，本团队将负责提供88%的传感器。这为国产硅传感器在本项目中的进一步研发与大规模应用奠定了基础。另外，团队开发了探测器单元模块原型，柔性电路尾板原型、外围读出电路板的原型，高压电子系统原型。

Our team has been actively promoting international cooperation and has made remarkable achievements in the construction of upgraded detectors and physical analysis. The high granularity timing detector team is leading the ATLAS experimental high time resolution detector (HGTD) project. The project leader serves as the project leader of HGTD, and several project members hold important management positions of HGTD. Our team has developed a prototype of silicon sensor with world leading performance, which is superior to the sensors of Hamamatsu company in Japan and FBK in Italy. The sensors of our team have been selected by ATLAS experiment, and our team will be responsible for providing 88% of the sensors. This has laid a foundation for the further research and development and large-scale application of domestic silicon sensors in this project. In addition, the team developed the prototype of the detector unit module, the prototype of the flexible circuit tail board, the prototype of the peripheral readout circuit board, and the prototype of the high voltage electronic system.

（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 task leaders

限2000字以内。

Limited to 2000 words.

每人补充5篇文章/科研奖励

5 additional articles/research awards per person

项目负责人Joao Guimarães da Costa 于里斯本科技大学和约翰霍普金斯大学获得硕士学位，2000 年获得密西根大学博士学位，在哈佛大学从事博士后工作。2006-2015 年，他作为助理教授和副教授在哈佛大学从事粒子物理研究和教学工作。2015 年他被聘为中科院高能所研究员，2016 年获得国家“千人计划”高层次外国专家长期项目资助。他一直积极参与高能量粒子物理实验的探测器设计和物理研究。他曾在CERN 的重离子对撞实验（NA38），美国费米实验室的质子对撞机实验（CDF），以及LHC ATLAS 实验上作出贡献。他参与了CDF 径迹探测器及ATLAS 缪子探测器的设计和建造，领导了端部安装调试和NSW 探测器触发升级工作。他带领团队获得了ATLAS 第一个电弱物理测量结果，为希格斯玻色子寻找及质量测量和希格斯耦合作出重要贡献。他曾任哈佛大学ATLAS 组组长，ATLAS 缪子探测器指导组成员，ATLAS 标准模型物理组和希格斯WW 物理组召集人。他目前是中科院高能所ATLAS 组组长，ATLAS 像素、ITk 和HGTD 探测器研究所董事会成员。2021 年他当选ATLAS HGTD 项目负责人并连任至今，曾是HGTD 资源经理和副项目负责人。他自2021 年起成为ATLAS 执行委员会成员。他2016 年起担任CEPC 物理和探测器工作组召集人，是2018 年发布的物理和探测器概念设计报告主编辑。他曾担任CEPC 科技部国家重点研发计划项目负责人。

Joao guimar ã es da Costa, the project leader, received his master's degree from Lisbon University of science and technology and Johns Hopkins University, received his doctor's degree from the University of Michigan in 2000, and engaged in post doctoral work at Harvard University. From 2006 to 2015, he worked as an assistant professor and associate professor in particle physics research and teaching at Harvard University. In 2015, he was employed as a researcher at the Institute of high energy, Chinese Academy of Sciences. In 2016, he was funded by the long-term project of high-level foreign experts of the national "thousand talents plan". He has been actively involved in detector design and Physics Research of high-energy particle physics experiments. He has contributed to the heavy ion collision experiment (na38) at CERN, the proton collider experiment (CDF) at Fermilab, and the LHC ATLAS experiment. He participated in the design and construction of CDF track detector and ATLAS muon detector, and led the end installation and commissioning and NSW detector trigger upgrade. He led the team to obtain the first electric weak physics measurement results of ATLAS, and made important contributions to the Higgs boson search, mass measurement and Higgs coupling. He was the leader of ATLAS Group at Harvard University, the member of ATLAS muon detector steering group, and the convener of ATLAS standard model physics group and Higgs WW physics group. He is currently the head of ATLAS group of Institute of high energy, Chinese Academy of Sciences and a member of the board of directors of ATLAS pixel, ITK and HGTD detector research institute. In 2021, he was elected as the project leader of ATLAS HGTD and has been re elected since then. He was the resource manager and deputy project leader of HGTD. He has been a member of the ATLAS Executive Committee since 2021. He has been the convener of the cepc physics and detector working group since 2016 and is the chief editor of the physics and detector conceptual design report released in 2018. He once served as the project director of the national key R&D plan of the Ministry of science and technology of cepc.

梁志均担任课题一《ATLAS实验高粒度时间探测器升级》的课题负责人。他是中国科学院高能物理研究所的研究员，担任高能所ATLAS组的副组长。他在ATLAS实验和CEPC中从事电弱物理和硅探测器开发的工作。2010年至2014年，他在牛津大学担任博士后研究助理。2012年和2013年，他被任命为ATLAS电弱物理小组和LHC电弱物理小组的共同召集人。他在电弱过程的精密测量中发挥了重要作用。2014年至2016年，他作为加州大学圣克鲁兹分校的博士后学者开发了抗辐射硅探测器。2016年，他获得中国科学院的“百人计划”的支持回国，在高能所工作。从2019年至今，他被任命为ATLAS高精度定时探测器（HGTD）升级项目的模块和探测器单元组Level-2共同召集人。他在研制基于低增益雪崩二极管（LGADs）的国产IHEP-IME抗辐射LGAD传感器的开发中起到了重要作用。IHEP开发的LGAD传感器目前是所有LGAD原型中最抗辐射的。CERN在采购ATLAS 实验HGTD传感器的过程中选择了高能所团队开发的LGAD传感器。在2022年至2024年期间，他担任ATLAS合作组织的出版委员会成员。另外，他一直在为CEPC进行硅顶点探测器的研发工作。他领导了一个全尺寸顶点探测器原型的组装，并在DESY的测试束实验中研究了探测器的空间分辨率好于5微米，达到世界先进水平。

Liangzhijun served as the task leader of the first topic, upgrading of high granularity timing detector in ATLAS experiment. He is a researcher at the Institute of high energy physics, Chinese Academy of Sciences, and serves as the deputy leader of ATLAS group of the Institute. He is engaged in the work of weak physics and silicon detector development in ATLAS experiment and cepc. From 2010 to 2014, he served as a postdoctoral research assistant at Oxford University. In 2012 and 2013, he was appointed as the co convener of ATLAS electroweak Physics Group and LHC electroweak physics group. He played an important role in the precise measurement of the electric weak process. From 2014 to 2016, he developed radiation resistant silicon detectors as a postdoctoral scholar at the University of California, Santa Cruz. In 2016, he returned home with the support of the "Hundred Talents Program" of the Chinese Academy of Sciences and worked in the Institute of high energy. Since 2019, he has been appointed as the co convener of the module and detector unit group level-2 of ATLAS high precision timing detector (HGTD) upgrade project. He played an important role in the development of domestic ihep-ime radiation resistant LGAD sensor based on low gain avalanche diodes (LGADs). The LGAD sensor developed by IHEP is currently the most radiation resistant of all LGAD prototypes. In the process of purchasing ATLAS HGTD sensor, CERN selected LGAD sensor developed by the team of Institute of high energy. From 2022 to 2024, he served as a member of the publishing Committee of ATLAS cooperation. In addition, he has been developing silicon vertex detectors for cepc. He led the assembly of a full-scale vertex detector prototype, and in desy's test beam experiment, he studied that the spatial resolution of the detector was better than 5 μ m, reaching the world's advanced level.

（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.

项目组依托“核探测与核电子学国家重点实验室”、“粒子物理与粒子辐照教育部重点实验室”等国家、省部级实验室，设计、建造和升级了ATLAS 实验、北京谱仪等大科学装置项目。本团队在探测器和电子领域有多年经验，并与欧洲核子研究中心、德国DESY等国外单位建立了密切合作关系。 团队建有半导体和气体探测器洁净间、RPC 测试实验室、先进核电子学测试组装平台，并有引线键合机等关键探测器研究设备。

Relying on national, provincial and ministerial laboratories such as the "State Key Laboratory of nuclear detection and Nuclear Electronics" and the "Key Laboratory of particle physics and particle irradiation of the Ministry of education", the project team designed, built and upgraded large scientific device projects such as ATLAS experiment and Beijing Spectrometer. Our team has many years of experience in the field of detectors and electronics, and has established close cooperation with European Nuclear Research Center, German desy and other foreign units. The team has a clean room for semiconductor and gas detectors, RPC testing laboratory, advanced nuclear electronics testing and assembly platform, and key detector research equipment such as wire bonders.

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

科大目前拥有先进大面积气体探测器研制平台、先进闪烁探测器研究平台、半导体探测器研制与测试平台、低温探测器研究平台、高精度探测器性能综合测试平台、先进核电子学测试与组装平台、物理实验专用集成电路芯片（ASIC）研究平台、高速数据传输测试平台、中子应用技术研究平台、学科交叉应用慢正电子束平台等。通过参与国家重大项目，在中科院、学校两级的支持下，实验室不断完善实验装备，提高技术水平，积淀雄厚的研发实力，逐步建设成为国内核探测与核电子学领域的科研与技术中心。科大所研制的LGAD原型样机性能达到世界领先水平，满足HGTD项目需求。

At present, USTC has an advanced large-area gas detector development platform, an advanced scintillation detector research platform, a semiconductor detector development and test platform, a low-temperature detector research platform, a high-precision detector performance comprehensive test platform, an advanced nuclear electronics test and assembly platform, an ASIC research platform for physical experiments, a high-speed data transmission test platform, a neutron application technology research platform Interdisciplinary application of slow positron beam platform. By participating in major national projects and with the support of the Chinese Academy of Sciences and the University, the laboratory has continuously improved its experimental equipment, improved its technical level, accumulated strong R&D strength, and gradually built itself into a scientific research and technology center in the field of nuclear detection and nuclear electronics in China. The performance of the LGAD prototype developed by the University of science and technology has reached the world leading level, meeting the requirements of the HGTD project.

南京大学是ATLAS 实验中国组的发起单位之一，参加并出色完成了ATLAS 探测器的LAr 量能器的部分建造任务。2006 年至今参加了多期国家基金委和科技部ATLAS实验相关的国家重大科研项目，其中2019年参与了“国际(地区)合作与交流项目”项目《ATLAS实验探测器Phase 2升级》，负责了HGTD探测器外设电路PEB的预研。

Nanjing University is one of the initiators of the ATLAS experimental China group, and has participated in and successfully completed part of the construction tasks of the lar calorimeter of ATLAS detector. Since 2006, he has participated in several major national scientific research projects related to ATLAS experiment of the national foundation of science and technology and the Ministry of science and technology. In 2019, he participated in the "ATLAS experimental detector phase 2 upgrade" project of the "International (regional) cooperation and exchange project", and was responsible for the pre research of the peripheral circuit PEB of HGTD detector.

山东大学参与人员所在的粒子科学技术研究中心依托“粒子物理与粒子辐照”教育部重点实验室承担了国际上多个大科学装置（ATLAS、NICA、HERD、BESIII、STCF等）的建造和实验分析工作。曾出色完成了ATLAS探测器TGC的建造任务，以及ATLAS第一阶段升级中sTGC探测器的批量生产任务，与ATLAS国际团队保持着长久的合作关系。

Relying on the Key Laboratory of "particle physics and particle irradiation" of the Ministry of education, the particle science and technology research center where the participants of Shandong University are located has undertaken the construction and experimental analysis of many large scientific devices (ATLAS, Nica, herd, BESIII, STCF, etc.) in the world. He has excellently completed the construction of the ATLAS detector TGC and the mass production of the stgc detector during the first phase of ATLAS upgrade, and has maintained a long-term cooperative relationship with the ATLAS international team.

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.

在ATLAS 实验第二阶段探测器升级的国际合作框架下，项目组与欧洲核子中心 （CERN） 、卢瑟福实验室、利物浦大学、牛津大学、法国IJClab和Omega实验室，西班牙IFAE研究所等已有较多深入合作，并有多个合作成果。其中，项目组与CERN、法国IJClab和Omega实验室与西班牙IFAE研究所合作研制出ATLAS实验高粒度时间探测器的原型模块，并在CERN的束流实验中初步研制其性能。

Under the framework of international cooperation in the upgrading of detectors in the second phase of ATLAS experiment, the project team has had more in-depth cooperation with CERN, Rutherford laboratory, University of Liverpool, University of Oxford, ijlab and Omega laboratories in France, and IFAE Research Institute in Spain, and has achieved many cooperation results. Among them, the project team has cooperated with CERN, ijlab and Omega laboratories in France and IFAE Institute in Spain to develop the prototype module of ATLAS experimental high granularity timing detector, and preliminarily developed its performance in CERN beam experiment.

基于中国科学院与德国亥姆霍茨联合会的资助，高能物理研究所与德国DESY 研究所在硅探测器模块设计、束流测试等方面建立广泛合作关系，定期人员交流等，合作成果包括束流望远镜EUDAQ 的数据获取系统。

Based on the funding from the Chinese Academy of Sciences and the Helmholtz Federation of Germany, the Institute of high energy physics and the German desy Institute have established extensive cooperative relations in the design of silicon detector modules, beam testing and other aspects, and regular personnel exchanges. The cooperative achievements include the data acquisition system of the beam telescope eudaq.

CEPC

**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.

第一年（2024年）：

First year (2024):

完成抗辐照LGAD硅传感器的预生产的研制任务，开始进行大面积辐照LGAD硅传感器的正式生产研制。完成探测器模块原型，外围电子学、高压电子系统与柔性电路尾板的研发，通过ATLAS合作组的（Final design review，FDR）评审，进入预生产研制。

The research and development task of pre production of anti irradiation LGAD silicon sensor was completed, and the formal production and development of large-area irradiation LGAD silicon sensor was started.

The prototype of detector module, peripheral electronics, high-voltage electronic system and flexible circuit tail board have been completed, which have passed the final design review (FDR) review of ATLAS cooperation group and entered the pre production development.

第二年 （2025）：

The second year (2025):

 完成大面积抗辐照LGAD硅传感器的研制任务，通过实验验证其时间分辨率达到50皮秒，完成项目中期的测试报告。探测器模块，外围电子学、高压电子系统与柔性电路尾板通过预生产，并通过欧洲核子中心与ATLAS合作组的评审，进入正式生产的研制阶段。年底前，完成外围读出电路板与柔性电路尾板的正式生产的研制任务。

 The task of developing large-area radiation resistant LGAD silicon sensor was completed. The time resolution was verified to be 50 picoseconds by experiments, and the mid-term test report of the project was completed.

The detector module, peripheral electronics, high-voltage electronic system and flexible circuit tail board have passed the pre production and the review of the European nuclear center and ATLAS cooperation group, and entered the development stage of formal production. Before the end of the year, complete the research and development task of the formal production of peripheral readout circuit boards and flexible circuit Tailboards.

第三年 （2026）：

The third year (2026):

完成探测器高压电子系统和探测器模块的正式生产的研制任务。

Complete the development task of the formal production of the detector high-voltage electronic system and detector module.

第四年（2027）：

The fourth year (2027):

完成多个探测器模块探测器单元（detector unit）的正式生产任务。所研制的探测器在CERN进行最后组装和调试。

Complete the formal production of multiple detector module detector units. Following the ATLAS schedule, The developed detector is finally assembled one wheel and debugged at CERN.

第五年（2028）：

The fifth year (2028):

 通过实验验证所研发的探测器模块的时间分辨率达到50皮秒，完成项目的测试报告。

 Commissioning at CERN, Through the experimental verification, the time resolution of the developed detector module can reach 50 picoseconds, and the test report of the project is completed.

**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.

项目负责人全面负责项目实施，成立“咨询委员会”对课题研究中关键技术及问题提供指导和建议，计划每个季度召开“项目进度汇报”。 项目负责人与各子课题负责人建立定期的项目进度与协调会，对各课题给予指导、协助课题负责人解决课题进行中遇到的重要问题， 确保课题顺利、如期开展。由于ATLAS实验均为大型国际合作。必须保证项目在合作组的合作协议框架下进行。不同课题间有些技术和方法具有一定共性，因此各课题之间需有良好的交流。

The project leader is fully responsible for the implementation of the project, establishes an "Advisory Committee" to provide guidance and suggestions on key technologies and issues in the research, and plans to hold a "project progress report" every quarter. The project leader and each sub project leader establish regular project progress and coordination meetings, give guidance to each project, assist the project leader to solve the important problems encountered in the process of the project, and ensure the smooth and timely implementation of the project. Because ATLAS experiments are large-scale international cooperation. The project must be carried out within the framework of the cooperation agreement of the cooperation group. Some technologies and methods have certain commonalities among different topics, so there should be good communication between different topics.

在项目执行的每一年的年末，召开项目年度总结的会议，邀请所有项目参与者、“咨询委员会”的专家和科技部的领导参加。会上讨论项目经费执行情况、研发进展情况与成果产出，讨论结果将会形成书面报告，经内部审核后提交给科技部。

At the end of each year of project implementation, the annual summary meeting of the project will be held, and all project participants, experts of the "Advisory Committee" and leaders of the Ministry of science and technology will be invited to participate. At the meeting, the implementation of project funds, R&D progress and results output will be discussed. The results of the discussion will form a written report, which will be submitted to the Ministry of science and technology after internal review.

课题负责人负责本课题的研究活动安排，一般情况需要每两周开一次例会，开展课题组内部的学术交流，按项目计划进度安排研究工作。项目将会建立专门的宣传网页和会议网页。对外，项目的进展和成功会即使在网页上宣传；对内，各种会议报告和其它材料会整理存档，在项目内部实现信息共享。

The person in charge of the project is responsible for the arrangement of the research activities of the project. Generally, a regular meeting should be held every two weeks to carry out academic exchanges within the research group and arrange the research work according to the project schedule. The project will set up special publicity and conference pages. Externally, the progress and success of the project will be publicized on the website; Internally, various meeting reports and other materials will be sorted and archived to realize information sharing within the project.

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.

本项目的骨干成员多数是国内外大型高能物理合作组的成员，如北京谱仪、大亚湾实验、欧洲强子对撞机ATLAS实验等。在各合作组项目研制过程中，有非常丰富的协同合作研究基础和经验。项目将严格执行国家和科技部对“国家重点研究计划”的政策要求， 各参与单位依托的国家级和省部级重点实验室，将在研究人员、支撑人员、研究生、实验室场地、实验室设备和相关配套设施上给予大力支持，以保障项目顺利实施，达到预期目标。

Most of the key members of this project are members of large-scale high-energy physics cooperation groups at home and abroad, such as Beijing Spectrometer, Daya Bay experiment, European Hadron Collider ATLAS experiment, etc. In the process of project development of each cooperation group, it has a very rich foundation and experience in collaborative research. The project will strictly implement the policy requirements of the state and the Ministry of science and technology for the "national key research plan". The national and provincial key laboratories supported by the participating units will provide strong support in terms of researchers, supporting personnel, graduate students, laboratory sites, laboratory equipment and related supporting facilities, so as to ensure the smooth implementation of the project and achieve the expected goals.

项目将严格执行国家和科技部对“国家重点研究”的政策要求，项目各参加单位及各参与单位所在国家、教育部重点实验室，将在研究人员、支撑人员和研究生等人力资源、实验室场地和相关条件上给予支持，以保障项目顺利实施，达到目标。

The project will strictly implement the policy requirements of the state and the Ministry of science and technology for "national key research". The participating units of the project and the key laboratories of the state where the participating units are located and the Ministry of education will provide support in terms of human resources, laboratory sites and related conditions such as researchers, supporting personnel and postgraduates, so as to ensure the smooth implementation of the project and achieve its objectives.

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.

项目的成果主要是论文发表，设计报告，测试报告，与探测器和加速器的原型机。我们将严格遵守科技部相关政策和条例、以及高能物理国际合作实验的政策和协议。本项目获得的资源、材料、信息，各协作单位有权共享和用于开展与其项目相关的研究：在项目执行期限内，独立完成的成果和形式的知识产权归完成单位拥有；由双方协同完成的成果和形成的知识产权由双方共同享有，并以主要完成单位为主：因使用双方提供的材料，专利形成的成果，知识产权归属另有规定的，以双方具体协议为准。

The main achievements of the project are the publication of papers, design reports, test reports, and prototypes of detectors and accelerators. We will strictly abide by the relevant policies and regulations of the Ministry of science and technology, as well as the policies and agreements of international cooperative experiments in high energy physics. All collaborating units have the right to share and use the resources, materials and information obtained by the project to carry out research related to the project: during the implementation period of the project, the intellectual property rights of independently completed achievements and forms belong to the completing unit; The intellectual property rights of the achievements and formed by both parties shall be jointly owned by both parties, and mainly by the main completion unit: if the ownership of intellectual property rights of the achievements and formed by patents due to the use of materials provided by both parties is otherwise specified, the specific agreement of both parties shall prevail.

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.

**表5 项目执行可能面临的风险**

**Table 5 possible risks in project implementation**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 序号Serial number | 风险类别Risk category | 风险risk内容content | 风险发生Risk occurrence可能性possibility | 涉及的研发任务R&D tasks involved | 预防风险或减少风险损失的措施Measures to prevent risks or reduce risk losses |
| 1 | □技术风险□市场风险□ technical risk □ market risk■政策风险□其他■ policy risk □ others | 抗辐照读出芯片禁运Irradiation resistant readout chip embargo | □高■中□低□ high ■ medium □ low | 课题1：ATLAS实验高粒度时间探测器升级Topic 1: upgrading of high granularity timing detector in ATLAS experiment | 充分利用国际合作，依托ATLAS合作组解决禁运问题；Make full use of international cooperation and rely on ATLAS cooperation group to solve the embargo problem; |
| 2 | ■技术风险□市场风险■ technical risk □ market risk□政策风险□其他□ policy risk □ others | 所研制的传感器与探测器吗模块模块的良率低The developed sensor and detector module has low yield | □高□中■低□ high □ medium ■ low | 课题1：ATLAS实验高粒度时间探测器升级Topic 1: upgrading of high granularity timing detector in ATLAS experiment | 在研发阶段，充分研究模块组装与传感器研制的技术，制定备案。在正式研制阶段，制定详尽计划实时监控LGAD传感器与探测器模块的质量，确保为ATLAS实验提供的探测器都是有优秀的性能。During the research and development stage, the technology of module assembly and sensor development shall be fully studied and documented. In the formal development stage, a detailed plan was formulated to monitor the quality of LGAD sensor and detector module in real time to ensure that the detectors provided for ATLAS experiment have excellent performance. |
|  | □技术风险□市场风险□ technical risk □ market risk■政策风险□其他■ policy risk □ others | General delay of LHC and ATLAS schedule due to other activies outside our control | □高■中□低□ high ■ medium □ low | All tasks  | Work with collaboration to minimize the delay. The general delay will affect our impact on the project.  |