国家重点研发计划 · 项目年度交流会

高能环形正负电子对撞机关键技术研发和验证

课题：　　硅径迹探测器关键技术验证

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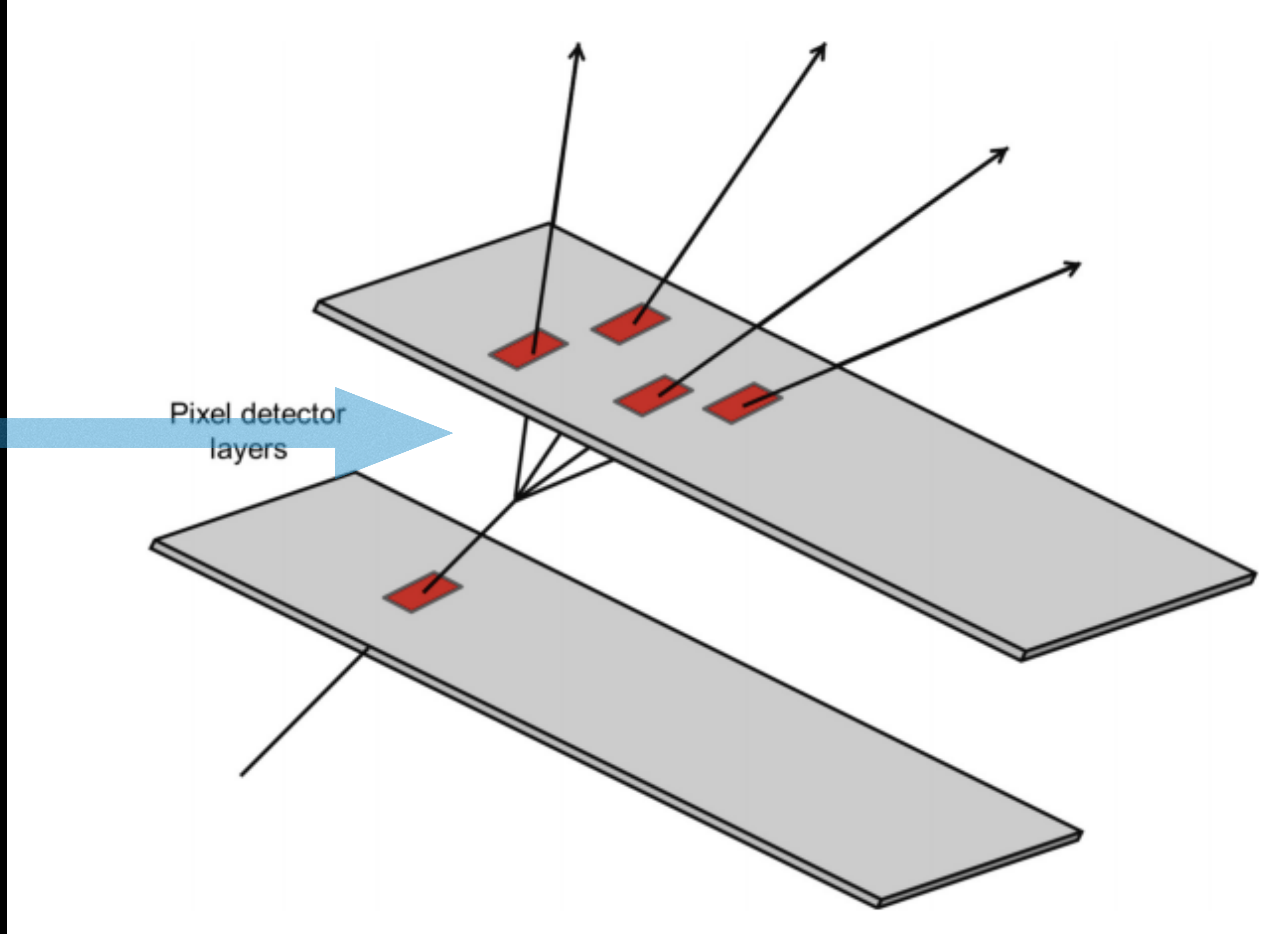
中国科学院高能物理研究所

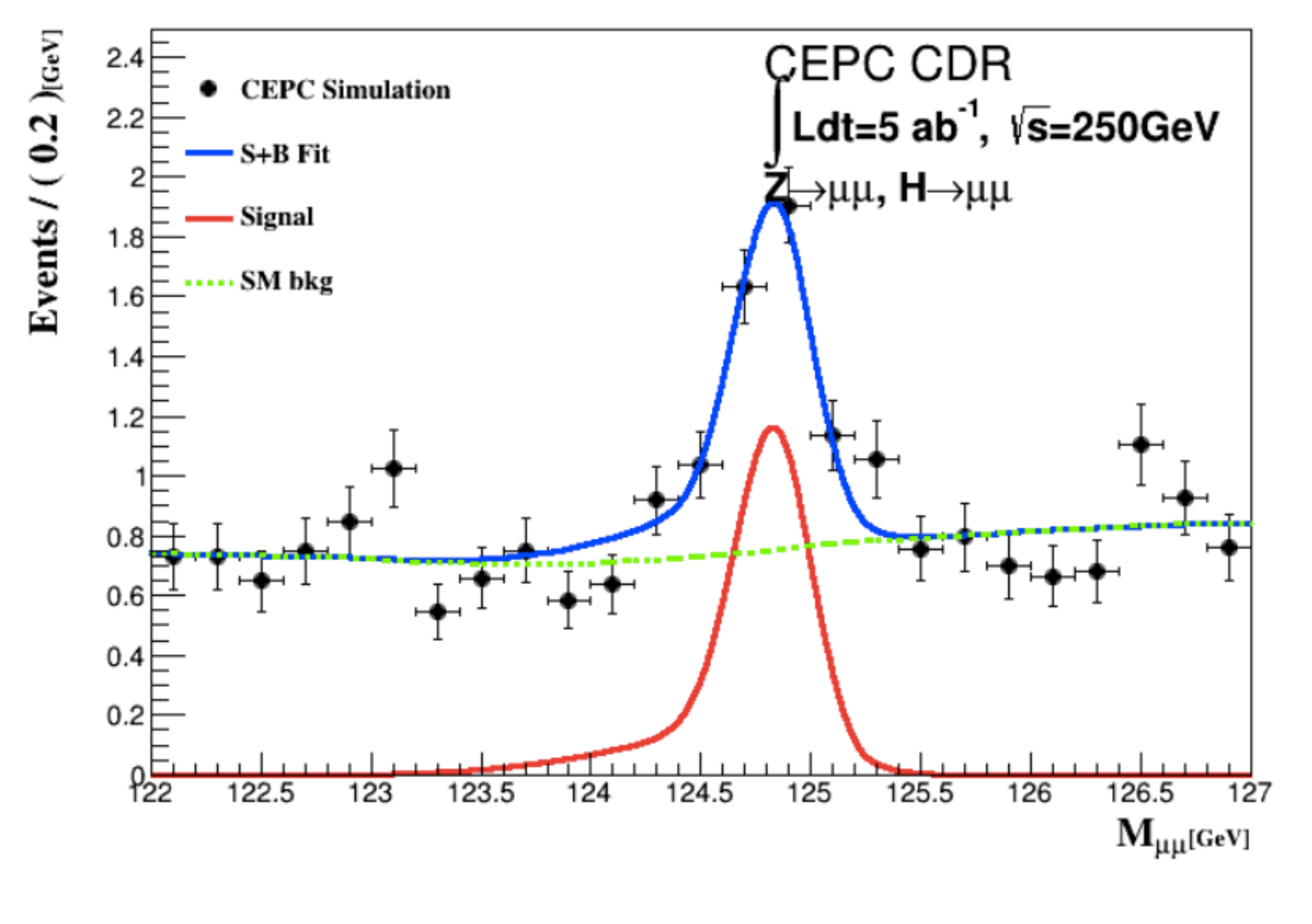
Institute of High Energy Physics Chinese Academy of Sciences

Task 2: Physics goal

- **Higgs precision measurement**
  - H → bb precise vertex reconstruction
  - H → μμ (precise momentum measurement)



Need tracking detector with high spatial resolution, low material

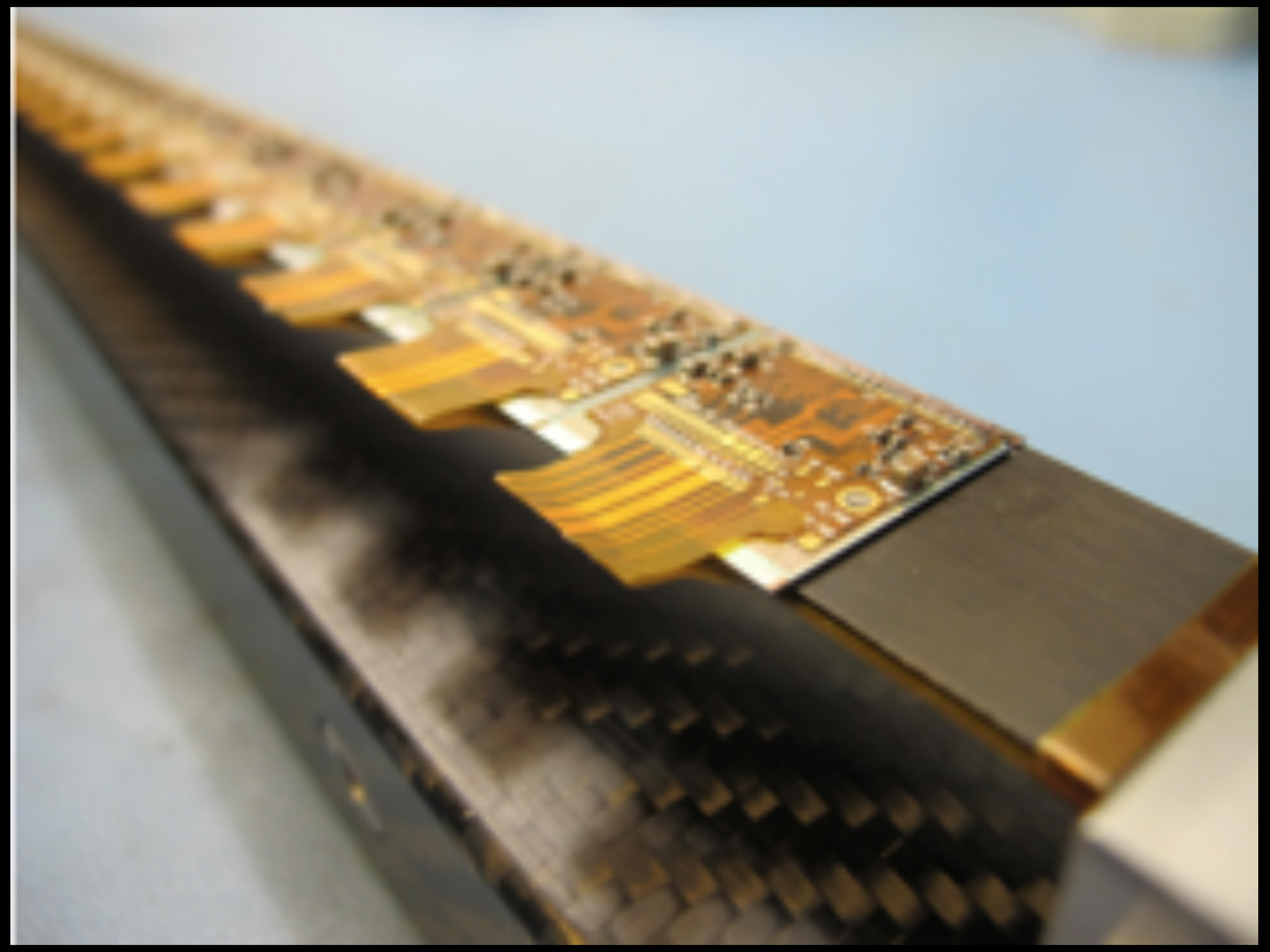


- **Main technology**
  - High spatial resolution technology → pixel detector
  - Low-mass detector technology
  - Radiation resistance technology

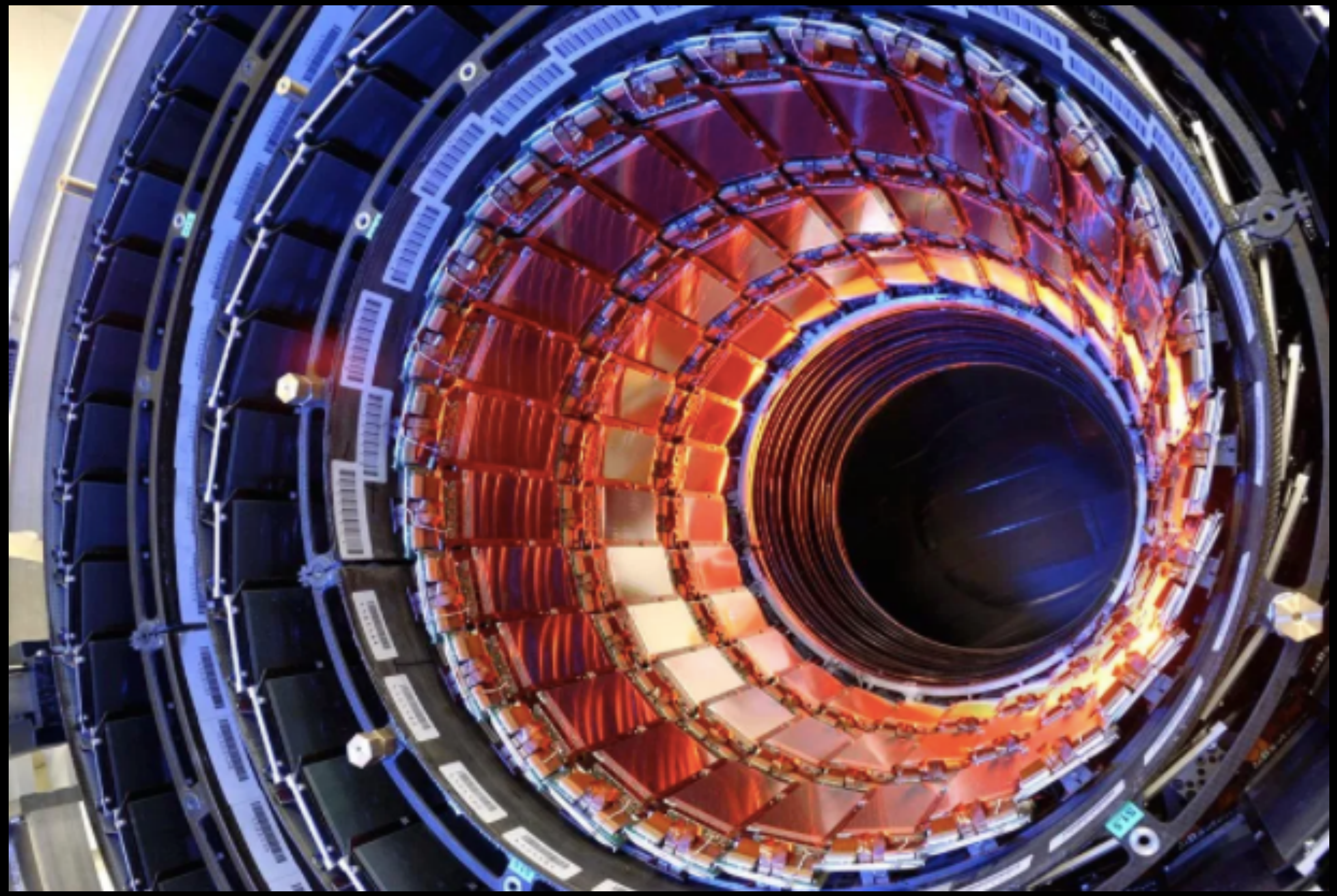
Task 2: Research Goal

- Produce a world class vertex detector prototype
  - Spatial resolution 3~5 μm (pixel detector)
  - Radiation hard (>1 MRad)
- Preliminary design of prototype
  - Three layer, module ~1 cm × 6(12) cm^2

Typical module



Typical tracker



Resolution

ATLAS/CMS upgrade (15 μm)

Alice upgrade (8~10 μm)

World leading

This project (3~5 μm)

Task 2: Technical route and schedule

Use CMOS image sensor technology

Optimize pixel circuitry, reduce size

Special design and latest technology

→ High resolution

→ Radiation hard

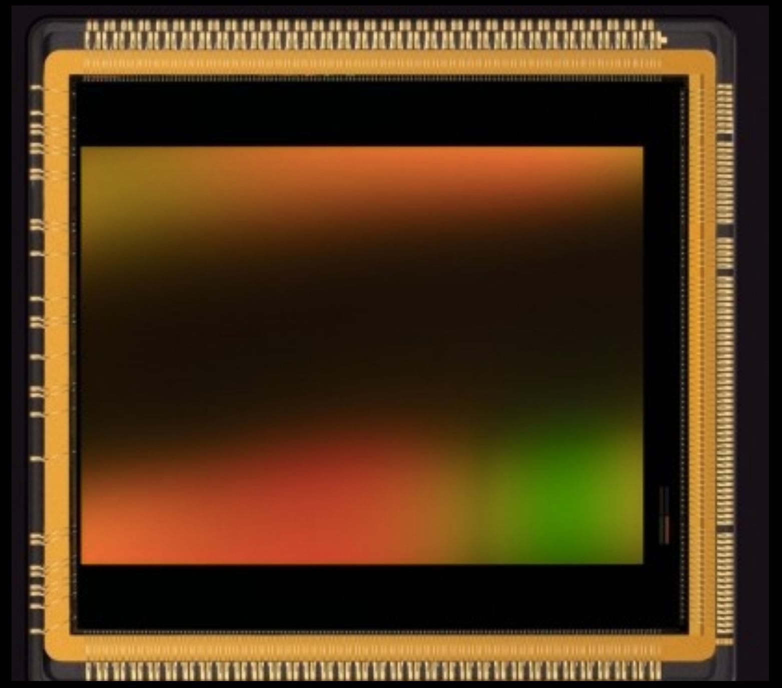
Use carbon fiber, polyamide, graphene, and other light materials for mechanical structure

→ Low mass

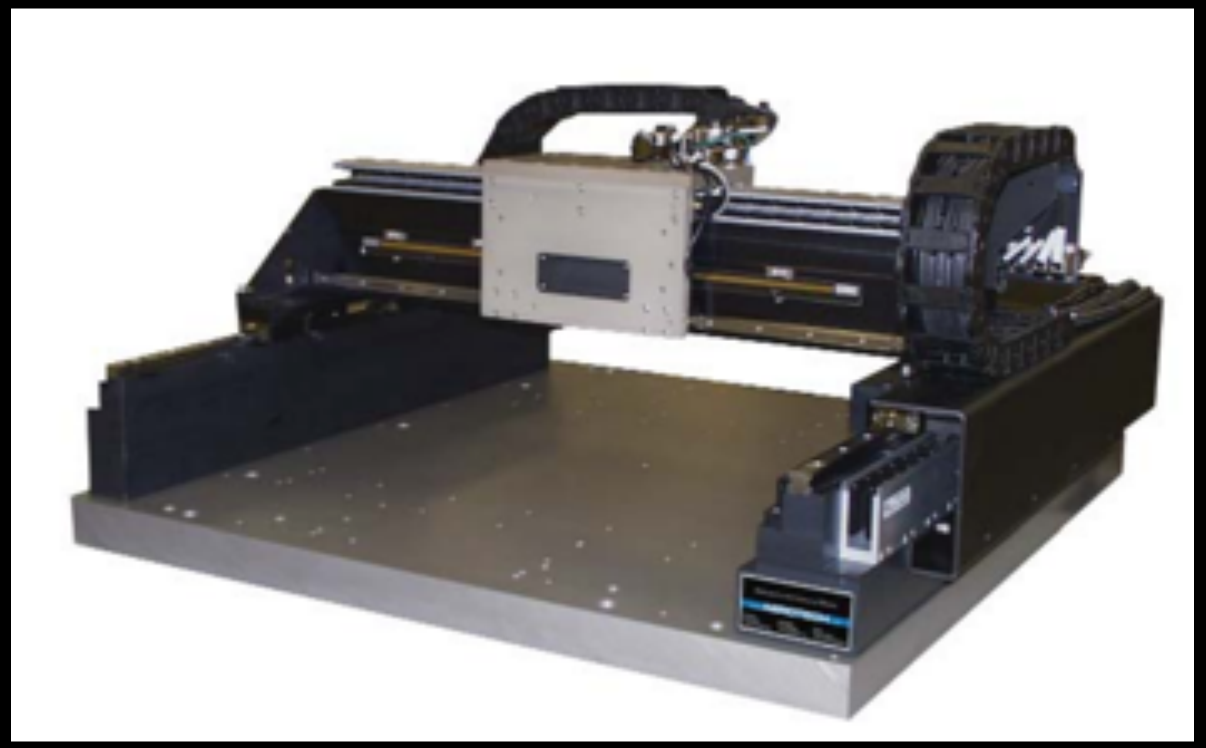
Robot automatic mechanical assembly

→ High accuracy

CMOS imaging sensor



Gantry



项目启动

Data acquisition R&D

Design of mechanical structure

Sensor design, fabrication

Prototype assembly

Beam testing

第一年 第二年 第三年 第四年 第五年

项目结题

Achievement Presentation and Assessment Methods

Silicon Detector 研制出硅径迹探测器原型机	☐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 ☐工程工艺 ☐标准 ☐专利 ■论文 ☐其他	课题 2：硅径迹探测器关键技术验证	硅径迹探测器原型机的空间分辨率	无	研制出小型传感器芯片，像素单元尺寸小于或等于 25 微米 ×25 微米。	3-5 微米	同行专家评审。(通过束流实验，离线分析数据获得空间分辨率。该测试结果写入原型机设计与测试报告，以供同行专家评审)
			所设计的抗辐照硅传感器能承受的总剂量	无	完成传感器的初步设计，通过仿真初步验证其抗辐照性能	1 MRad	同行专家评审(提供传感器的设计与测试报告供专家评审)

Assessment method and means of evaluation:

- Peer expert review
- **Beam test** and offline analysis; report to be included in final report (2)

- Peer expert review
- Provide sensor **design** and **test** report for expert evaluation

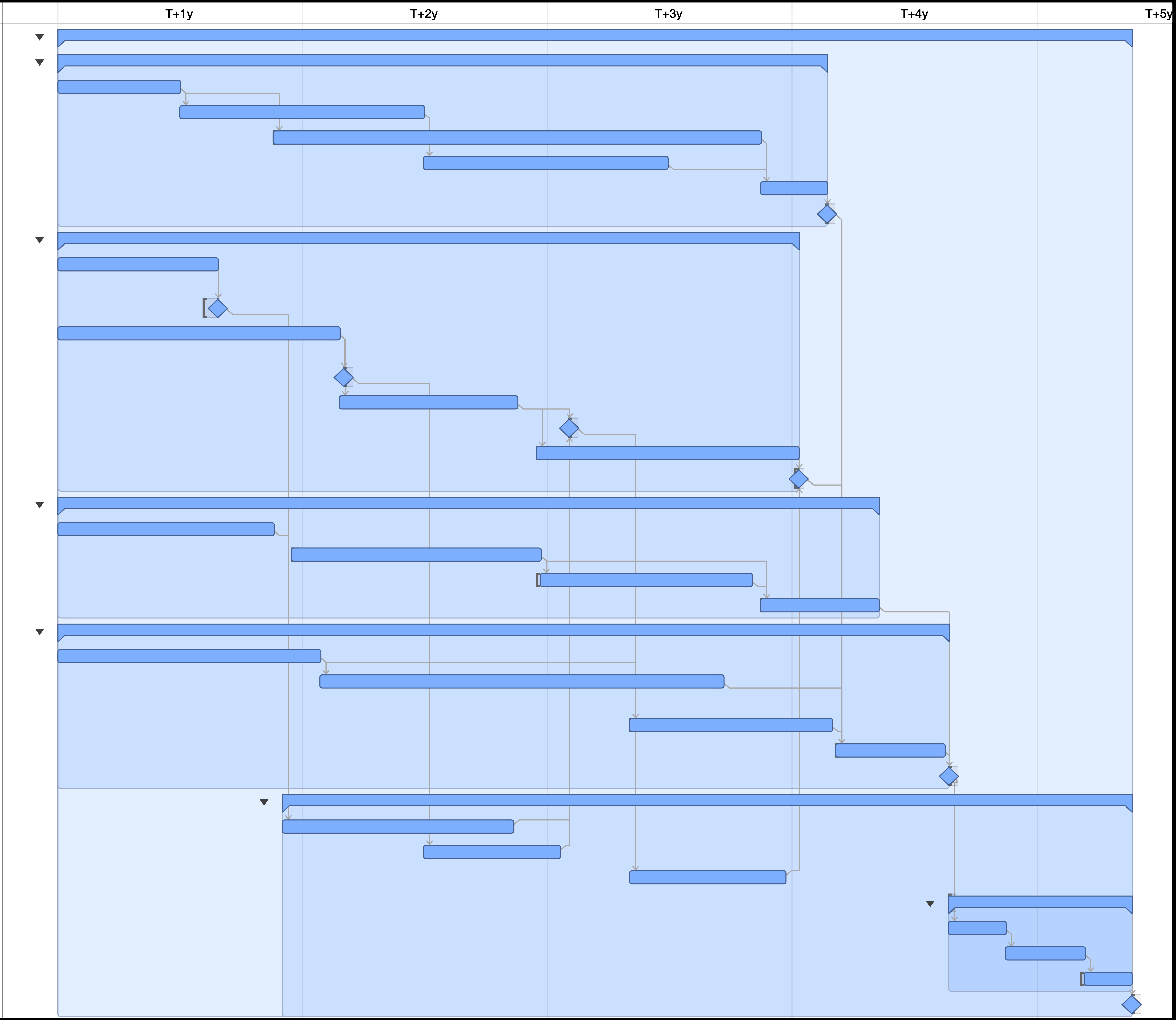
(2) Final report: ”CEPC Detectors Test Report”

Goal for the first year

- Achieve the target in task book for first year
  - Preliminary designs of mechanics, readout electronics and ASIC
  - Completed first sensor CMOS chip design
  - Ready for Multi-project wafer (MPW) submission

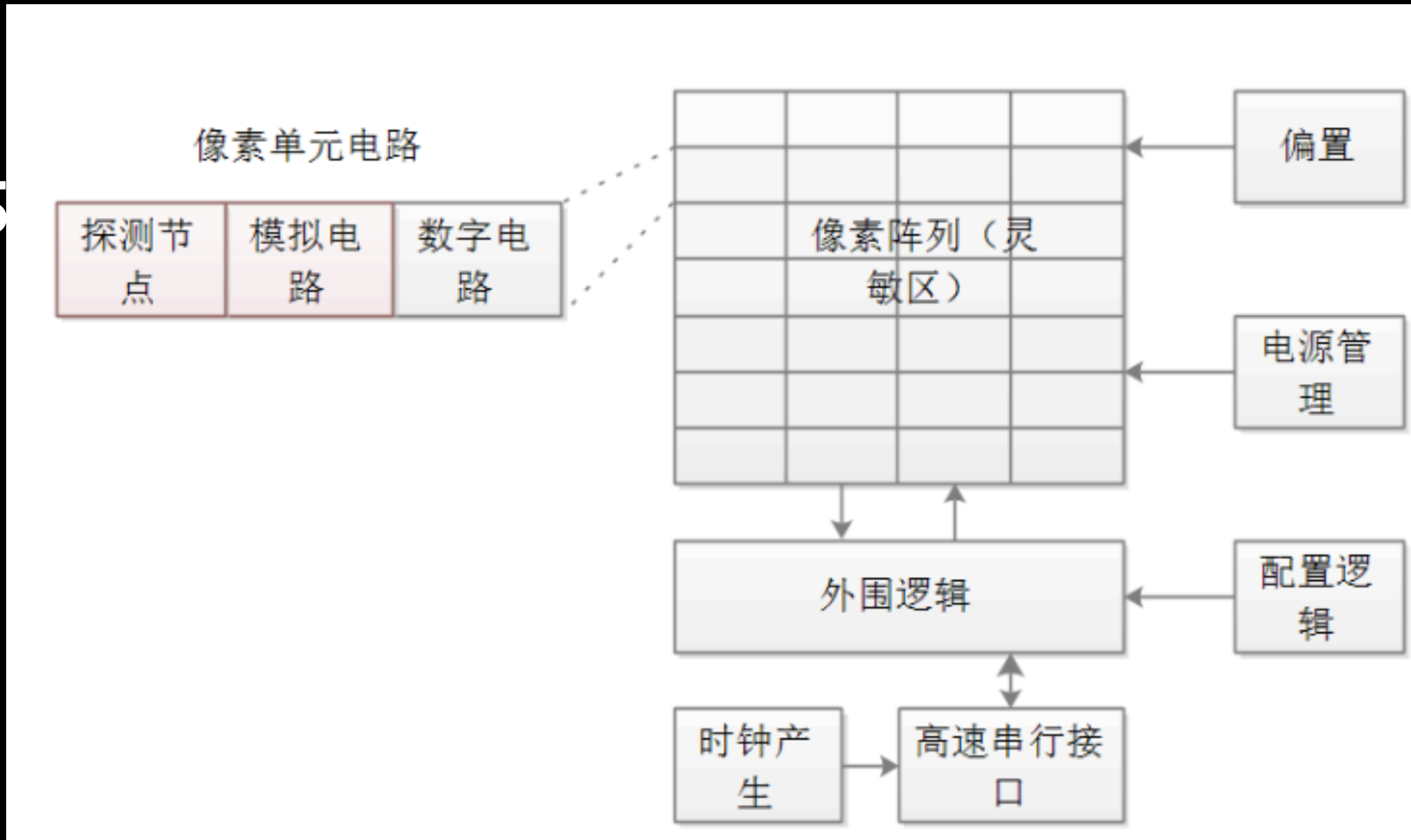
年度	任务	考核指标	成果形式
2018年5月—2019年4月	进行探测器模块与原型机整机的力学支撑结构初步设计；设计传感器像素内的前端电子学设计、抗辐照电路器件初步设计、芯片外围读出电路等功能模块设计，并提交第一次传感器的多项目硅晶圆（MPW）流片加工；研制MPW 芯片的读出电路板与数据获取系统；在探测器系统方面，制定探测器模块的组装流程。	1. 完成探测器模块结构的初步设计。 2. 完成传感器芯片各个主要功能模块（传感器像素单元与芯片外围读出模块等）的初步设计。	课题年度技术进展报告

Title	Effort
▼ 1) 硅径迹探测器关键技术验证	963w
▼ 1.1) 力学支撑结构	248w
• 1.1.1) 探测器模块的结构设计	26w
• 1.1.2) 探测器整体结构设计	52w
• 1.1.3) 支撑结构的工程图设计	104w
• 1.1.4) 加工模块的力学支撑结构	52w
• 1.1.5) 加工探测器整机支撑结构	14w
◆ 1.1.6) 完成所有力学支撑结构的研制	0d
▼ 1.2) 传感器	188w
• 1.2.1) 传感器像素内的电子学设计，抗辐照元件设计	34w
◆ 1.2.2) 第一次多项目晶圆（MPW）流片	0d
• 1.2.3) 外围数字电路、触发、时钟与电源等模块设计，与芯片抗辐照性能模拟	60w
◆ 1.2.4) 第二次多项目晶圆（MPW）流片	0d
• 1.2.5) 整合全功能的小面积芯片设计	38w
◆ 1.2.6) 第三次多项目晶圆（MPW）流片	0d
• 1.2.7) 设计大面积，全功能的传感器芯片	56w
◆ 1.2.8) 第一次工程批硅晶圆加工	0d
▼ 1.3) 数据获取系统	169w
• 1.3.1) 为初次MPW的芯片研制前端电路板	46w
• 1.3.2) 研制单个传感器芯片的数据获取系统	53w
• 1.3.3) 研制单个探测器模块的数据获取系统	45w
• 1.3.4) 研制探测器原型机的数据获取系统	25w
▼ 1.4) 探测器原型机整体设计与组装	208w
• 1.4.1) 制定探测器模块的组装流程。	56w
• 1.4.2) 制定探测器原型机的组装流程，开发自动组装系统	86w
• 1.4.3) 组装与调试首批探测器模块	43w
• 1.4.4) 组装与调试探测器原型机	23w
◆ 1.4.5) 完成探测器原型机的组装调试	0d
▼ 1.5) 测试与数据分析	150w
• 1.5.1) 对第一次MPW的芯片做测试	49w
• 1.5.2) 对第二次MPW的芯片做测试	29w
• 1.5.3) 对第三次MPW的芯片做测试	33w
▼ 1.5.4) 束流测试与数据分析	39w
• 1.5.4.1) 束流测试实验	12w
• 1.5.4.2) 数据分析	17w
• 1.5.4.3) 发表测试结果，撰写终期报告	10w
◆ 1.5.5) 完成项目终期报告	0d



CMOS Sensor design

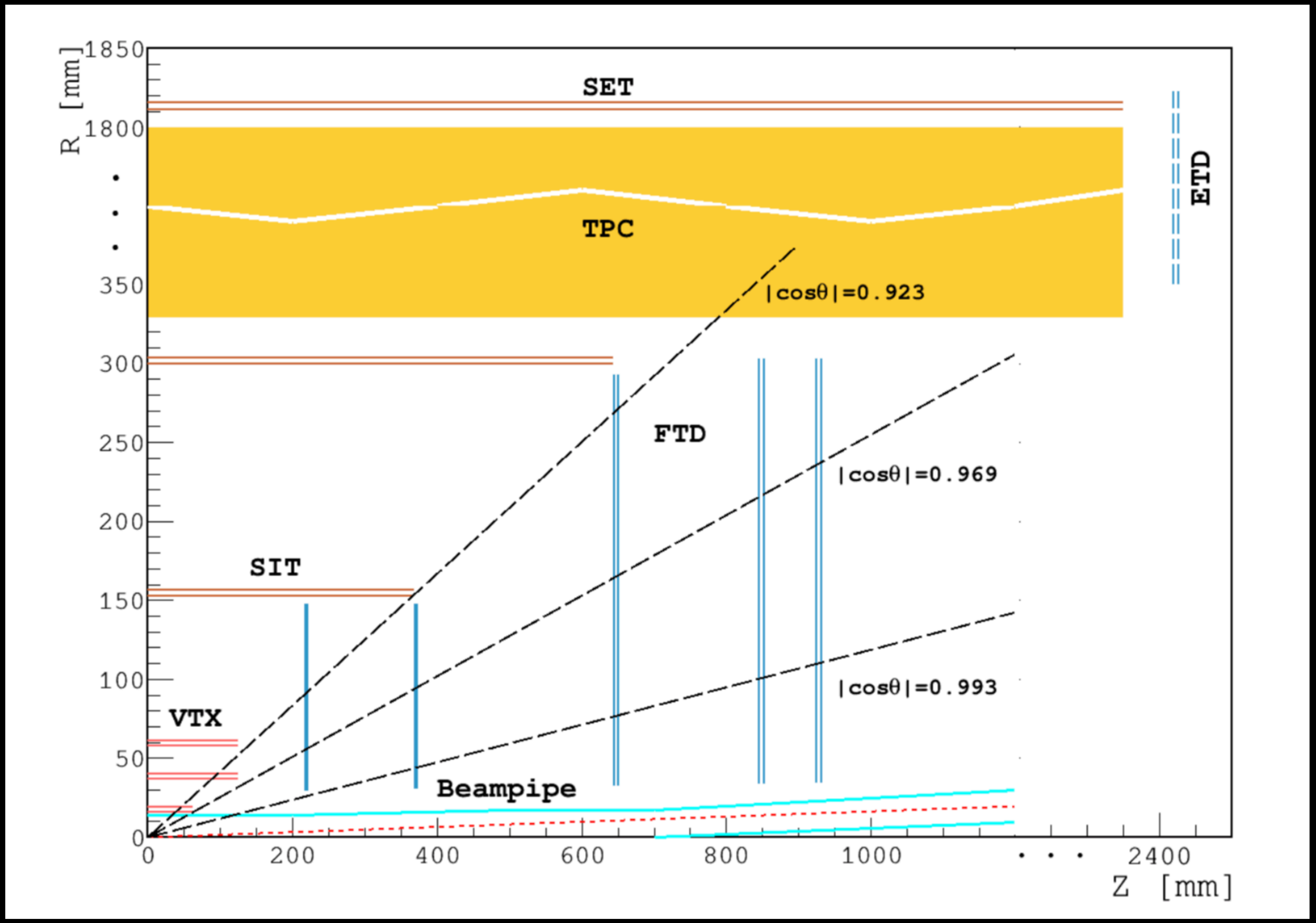
- Finalizing the 1st sensor chip
  - design review meeting Tuesday afternoon A415
  - Multi-wafer project to be submitted in June
    - feature: Small pixel size -> high resolution.
    - High readout speed -> for CEPC Z pole high lumi
    - Most of Functional block in place
  - Sensor design be covered in Wei's talk.
  - Testing system R & D in Liang's talk



	ALPIDE	ATLAS-MAPS (MONOPIX / MALTA)	MIMOSA	JadePix/ MIC4 (MOST1)	This project
Pixel size	✓	X	✓	✓	✓
Readout Speed	X	✓	X	X	✓
TID	X (?)	✓	✓	To be tested	✓

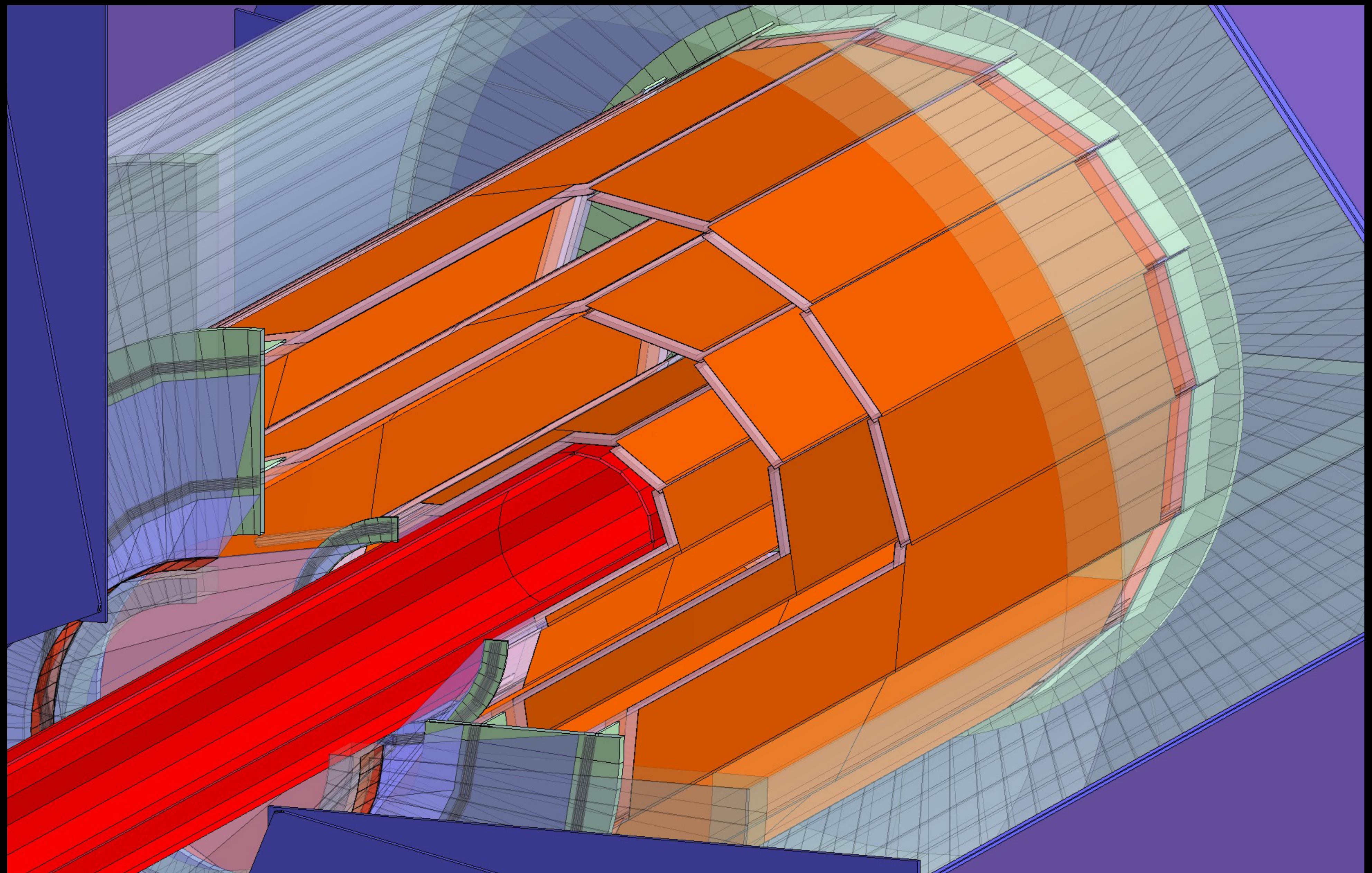
Pixel Detector Layout design

- **Baseline: 3 double side layers ladders**
- Further optimiztion of this layout is on going
  - Whether we need double layer ladders ?
  - Need 4 or 5 ladders ?
  - Improve impact parameter resolution
  - Expect to finish it by end of 2019
  - **To be covered in Gang's talk**



- Material budget ≤ $0.15\%X_0$/layer

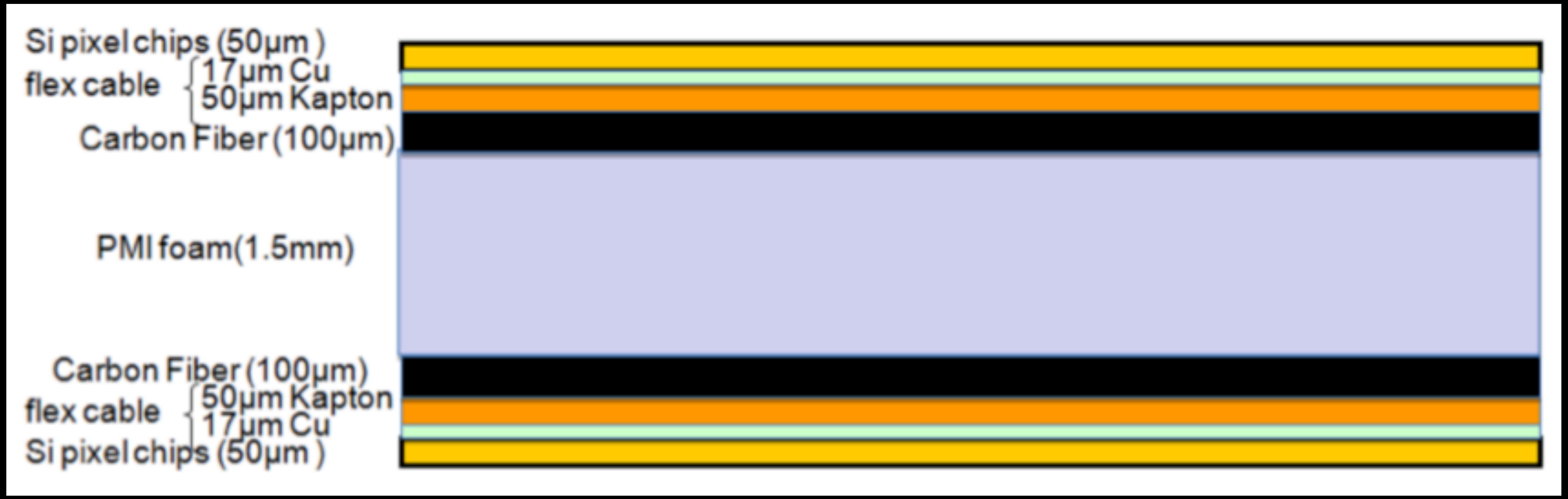
		R (mm)	$\|z\|$ (mm)	$\|\cos\theta\|$	σ(µm
Ladder 1	Layer 1	16	62.5	0.97	2.8
	Layer 2	18	62.5	0.96	6
Ladder 2	Layer 3	37	125.0	0.96	4
	Layer 4	39	125.0	0.95	4
Ladder 3	Layer 5	58	125.0	0.91	4
	Layer 6	60	125.0	0.90	4



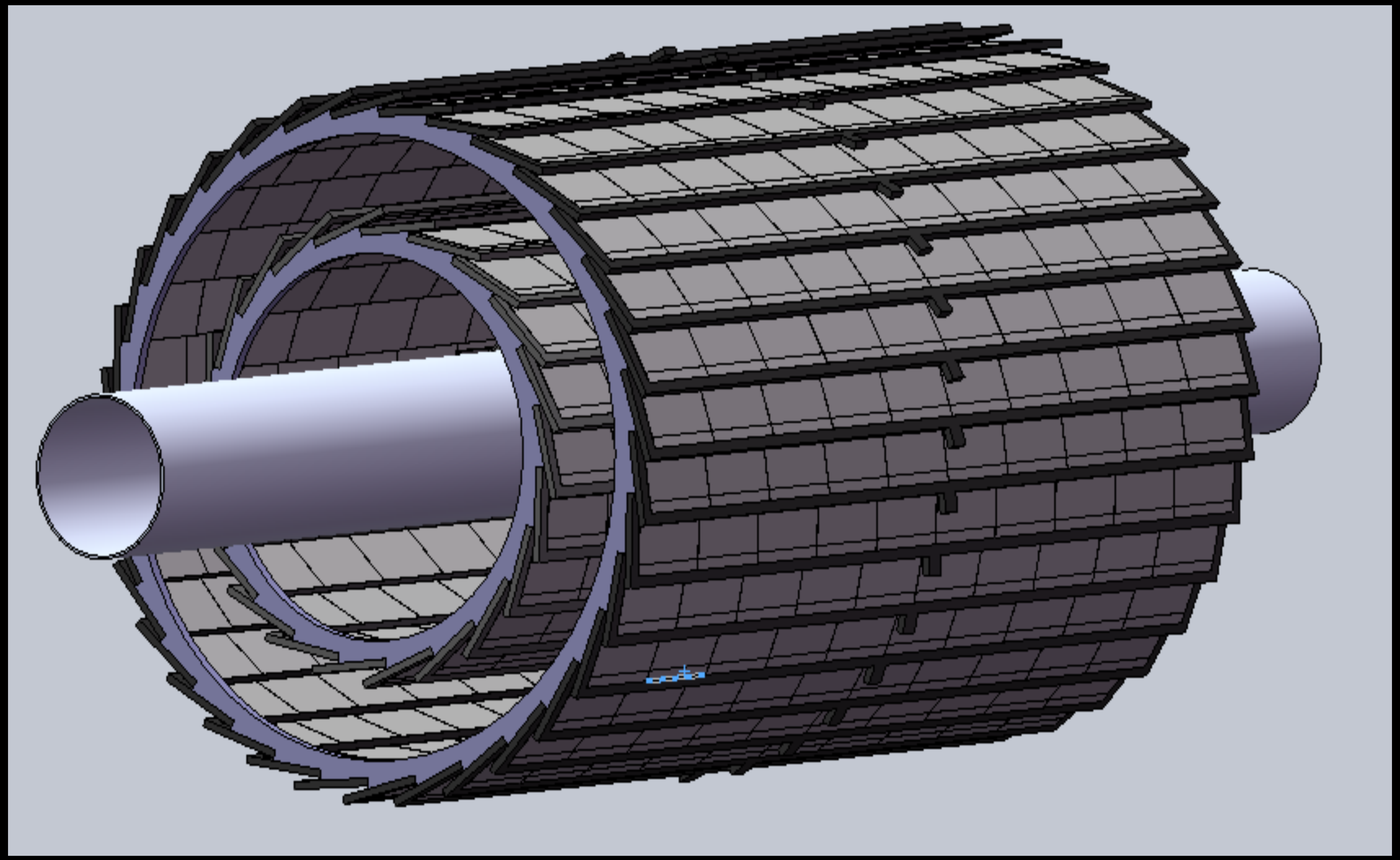
Pixel Detector Layout design

- Preliminary engineering design for Pixel tracker prototype
  - Double side module design
  - Support structure of tracker prototype
  - Cooling design

See more in Mingyi's talk



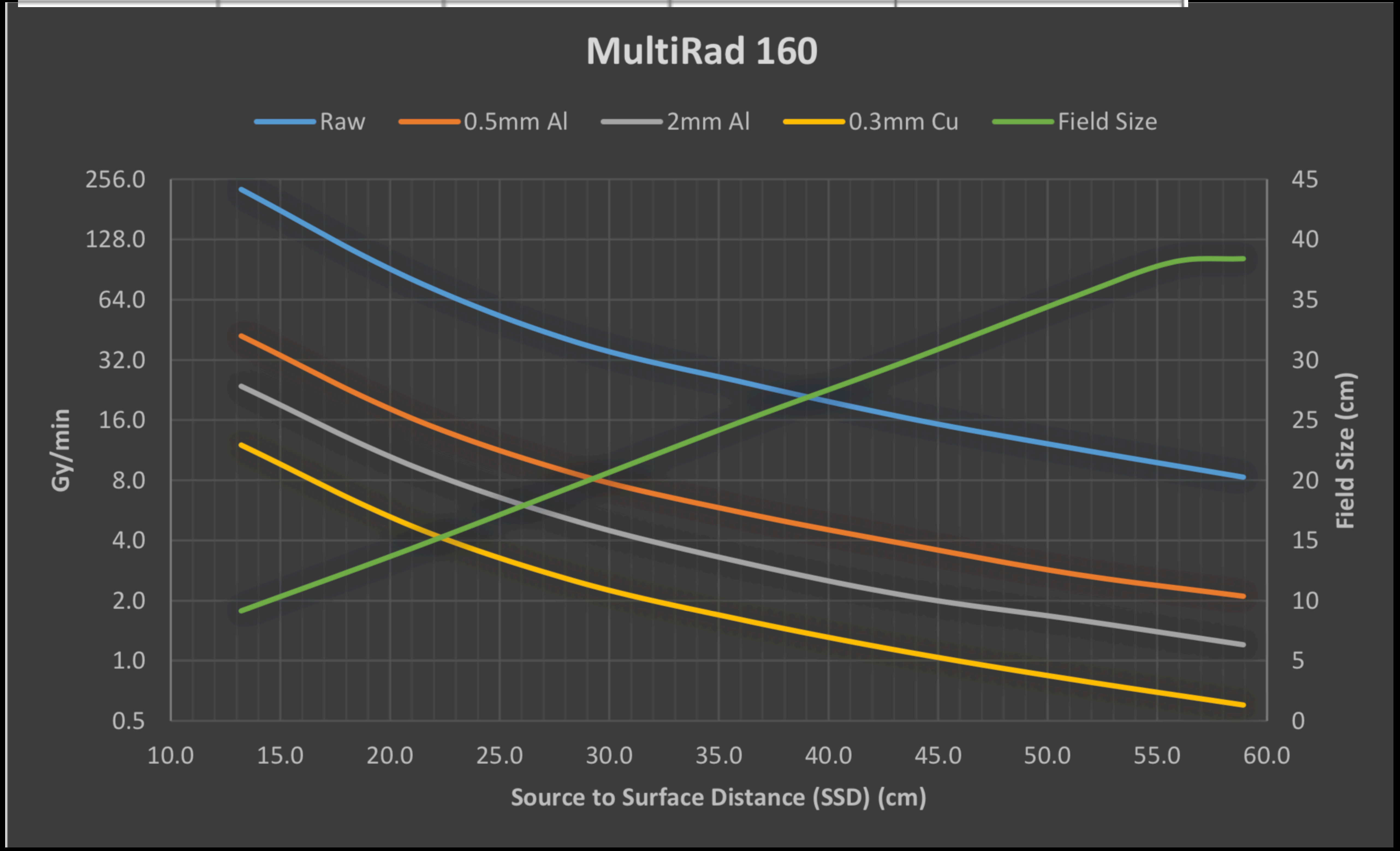
See more in Jinyu's talk



Irradiation facility

- MultiRad 160 X ray irradiator in IHEP setup
  - Can reach 1Mrad Total ionization dose within one day
  - Thanks Ying, Weiwei and Xiaoshan

所设计的抗辐照硅传感器能承受的总剂量	无	完成传感器的初步设计，通过仿真初步验证其抗辐照性能	1 MRad	同行专家评审(提供传感器的设计与测试报告供专家评审)



International collobration

- Express of interest in MOST2 project:
- Livepool (UK): Tracker mechanical design
- Oxford(UK): CMOS sensor design validation, mechanical design
- RAL(UK): Pixel module design
- Queen Mary(UK): module mechanical design (Zero mass concept)
- Strasbough (FR): CMOS sensor design, Tracker mechanical design
- University of Massachusetts (US): Tracker mechanical design, thermal design

Towards the mid-term review

- Sensor testing is important for midterm
- DAQ design for multi-sensors and for pixel prototype to be ramped up

2019年 5月 | 2020年 4月	细化探测器整体支撑结构设计，绘制该结构的工程图，开始加工模块的结构；对第一次 MPW 的芯片做测试以验证其功能，其中包括初步小剂量的辐照测试；完成芯片的像素阵列与外围读出电路等功能模块之间的集成，并进行第二次多项目晶圆（MPW）流片加工；开始设计探测器单元模块的读出电子学与数据获取系统。	1. 完成传感器芯片上所有功能模块的初步设计，并把各功能模块的设计集成，完成第二次传感器流片的设计，通过仿真初步验证其抗辐照性能。 2. 研制出单个传感器芯片的读出电子学、数据获取系统，对第一次 MPW 流片传感器芯片进行初步测试。 3. 完成多个传感器组成的探测器单元模块的读出电子学与数据获取系统的初步设计。	课题中期技术进展报告

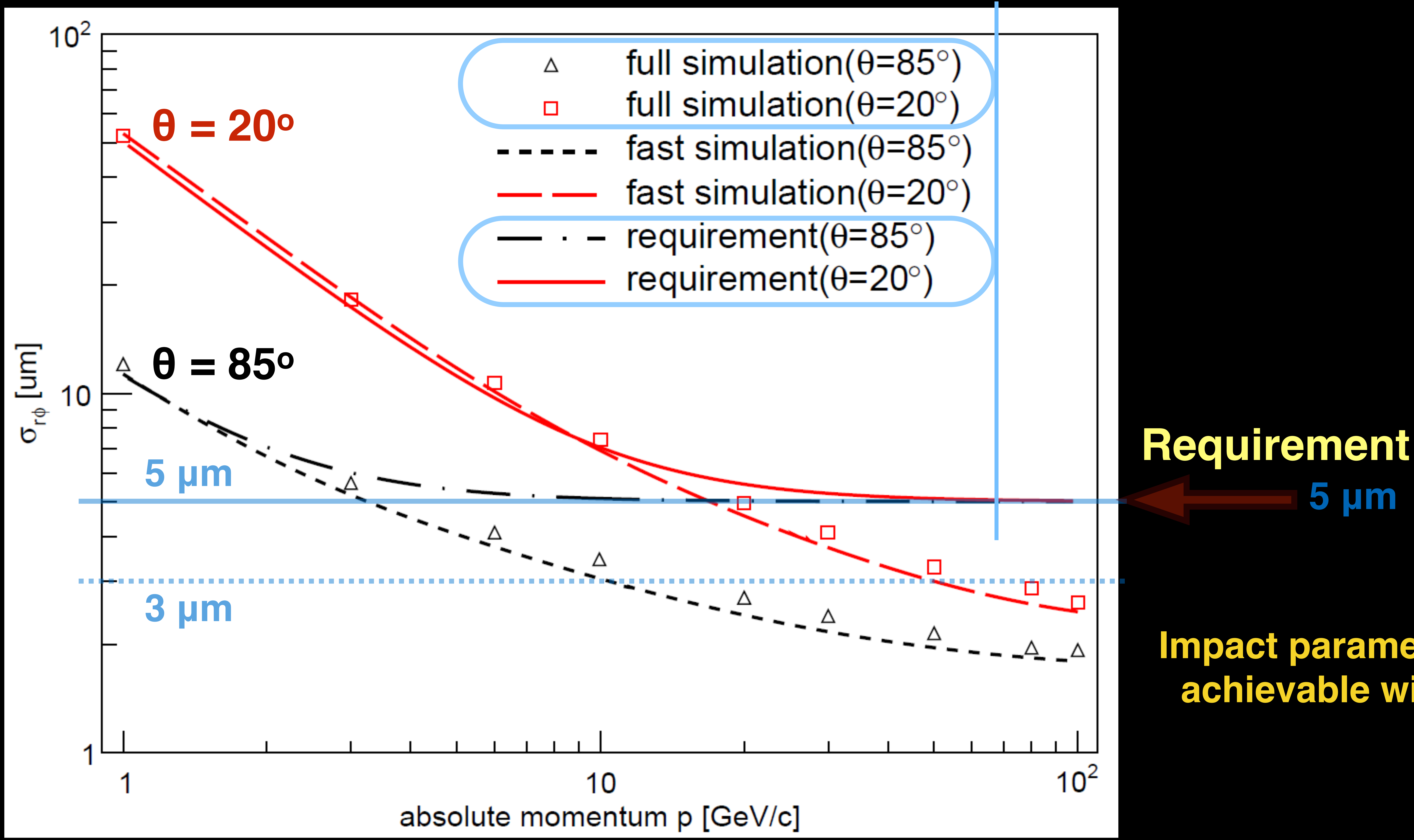
Thank you

Future plan

- 2nd Year :
  - Engineering designs of mechanics structure
  - Second CMOS sensor MPW submitted
- 3rd Year:
  - Mechanical structure completed
  - Second CMOS sensor MPW tested
  - CMOS sensor design optimized and completed
- 4th Year:
  - Silicon wafer processing of large area sensor submitted
  - Assembling and installing the prototype
- 5th Year:
  - Test beam and data analysis
  - Finish assembling of prototype

Performance studies: Impact parameter resolution

Transverse impact parameter resolution for single muons



Impact parameter resolution goal achievable with current design

“大科学装置前沿研究”重点专项2018年度项目申报指南

3. 新一代粒子加速器和探测器关键技术预研

3.1 高能环形正负电子对撞机关键技术验证

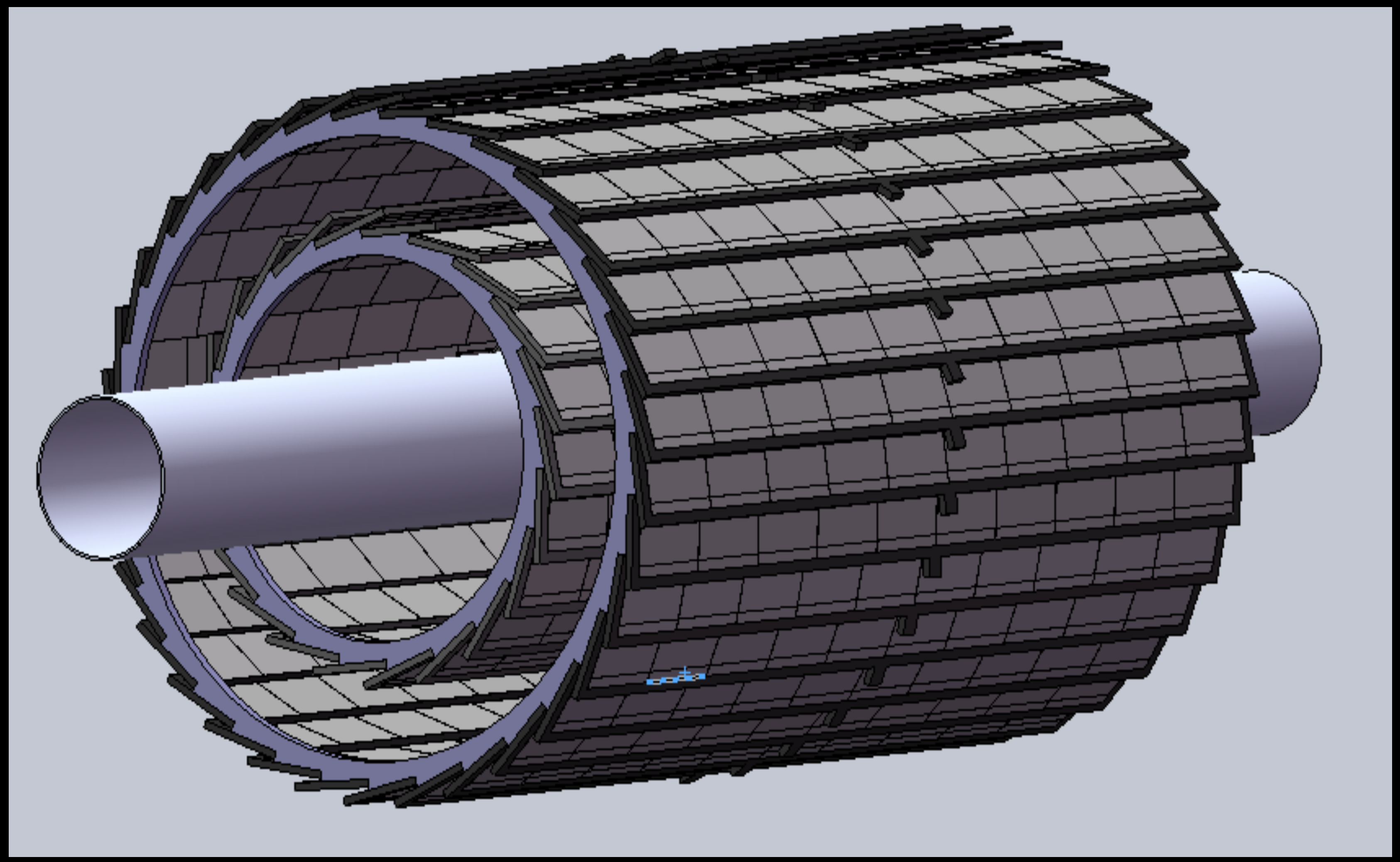
Research content: Prototype Verification of Key Technologies and High Resolution Detection Technologies for Electron Positron Colliders

Assessment indicators:

Validation of key technologies for high energy circular electron positron accelerators. Complete the prototype of the enhancer alternating two-pole low-field magnet. The magnetic field is from 31-620 Gs, the field uniformity is 5×10^{-4}; Complete the prototype of bending vacuum chamber and RF shielded bellows, the total leakage rate is less than 2×10^{-10} Torr · L/s; Complete the prototype of electron and positron beam electrostatic separator, the maximum working field strength is 2MV/m, field uniformity is (1‰) 10×10 mm^2; Complete the design of polarized beam collision in the Z energy region, beam polarization degree is larger than 50%, life time is larger than 60 minutes; Complete the prototype of polarization beam core device, spiral superconducting undulator.

Verification of High Resolution Detecting Technology on High Energy Accelerator. Complete the prototype of inner silicon track detector, verify the main design indicators through beam test, spatial resolution is 3-5 microns (um); Design a silicon detector with 1MRad Total ionization dose; Complete the original prototype of high granulated imaging type of HCAL, solving the key issues for process and test. Doing beam test to certify the main design conclusion.

Highlight of silicon tracker task



- First version of CMOS sensor design finished
  - Ready for MPW submission in June 2019
  - Feature: High resolution and fast readout
  - Big step towards large area full function sensor
- Preliminary engineering design for Pixel tracker prototype
  - Double side module design
  - Support structure of tracker prototype
  - Cooling design