Pixel Vertex Detector Prototype MOST 2018-2023 (MOST2)

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Workshop on High Energy Circular Electron Positron Collider
European Edition — Satellite Meeting

17 April 2019

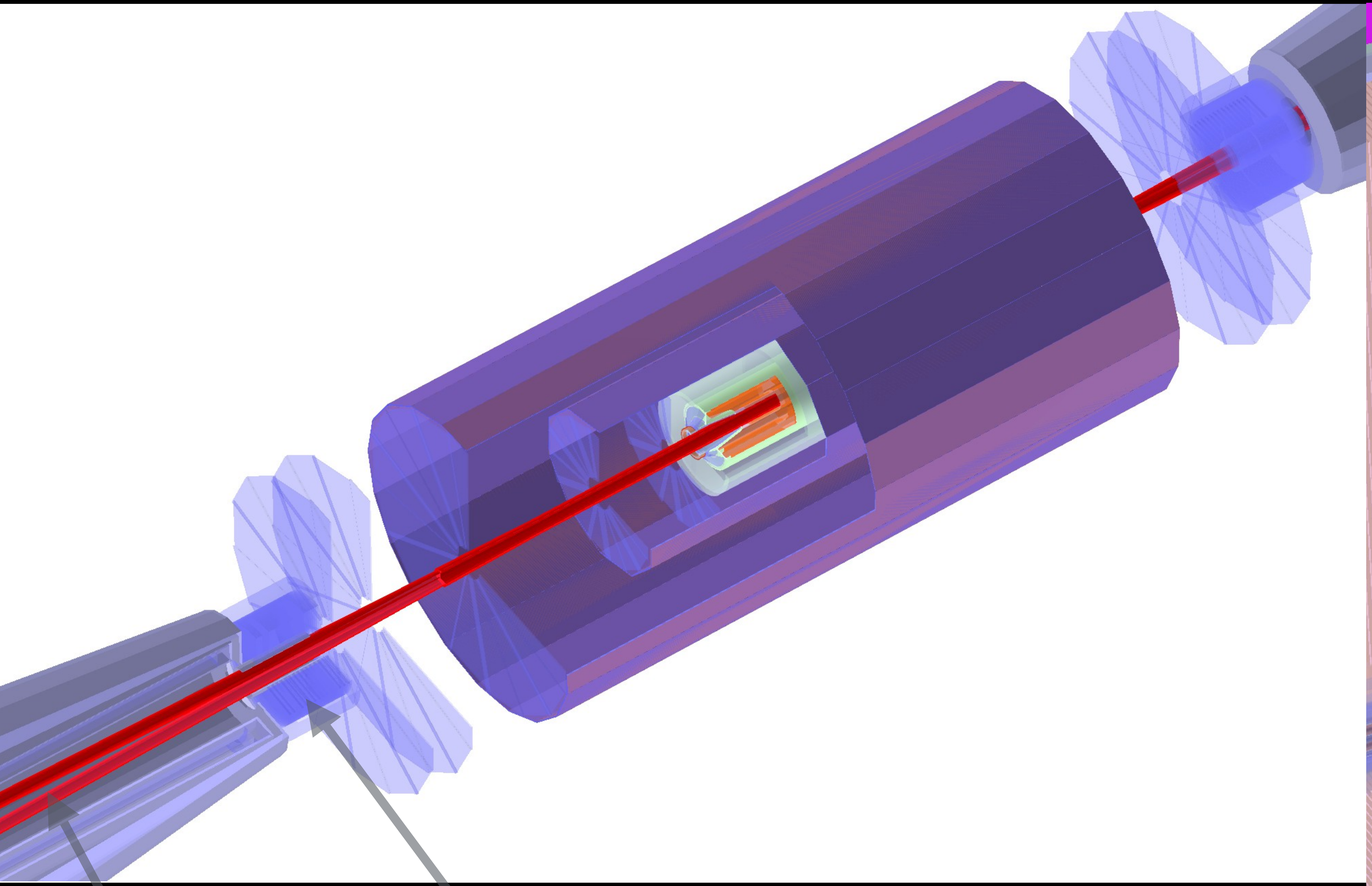
Institute of High Energy Physics
Chinese Academy of Sciences

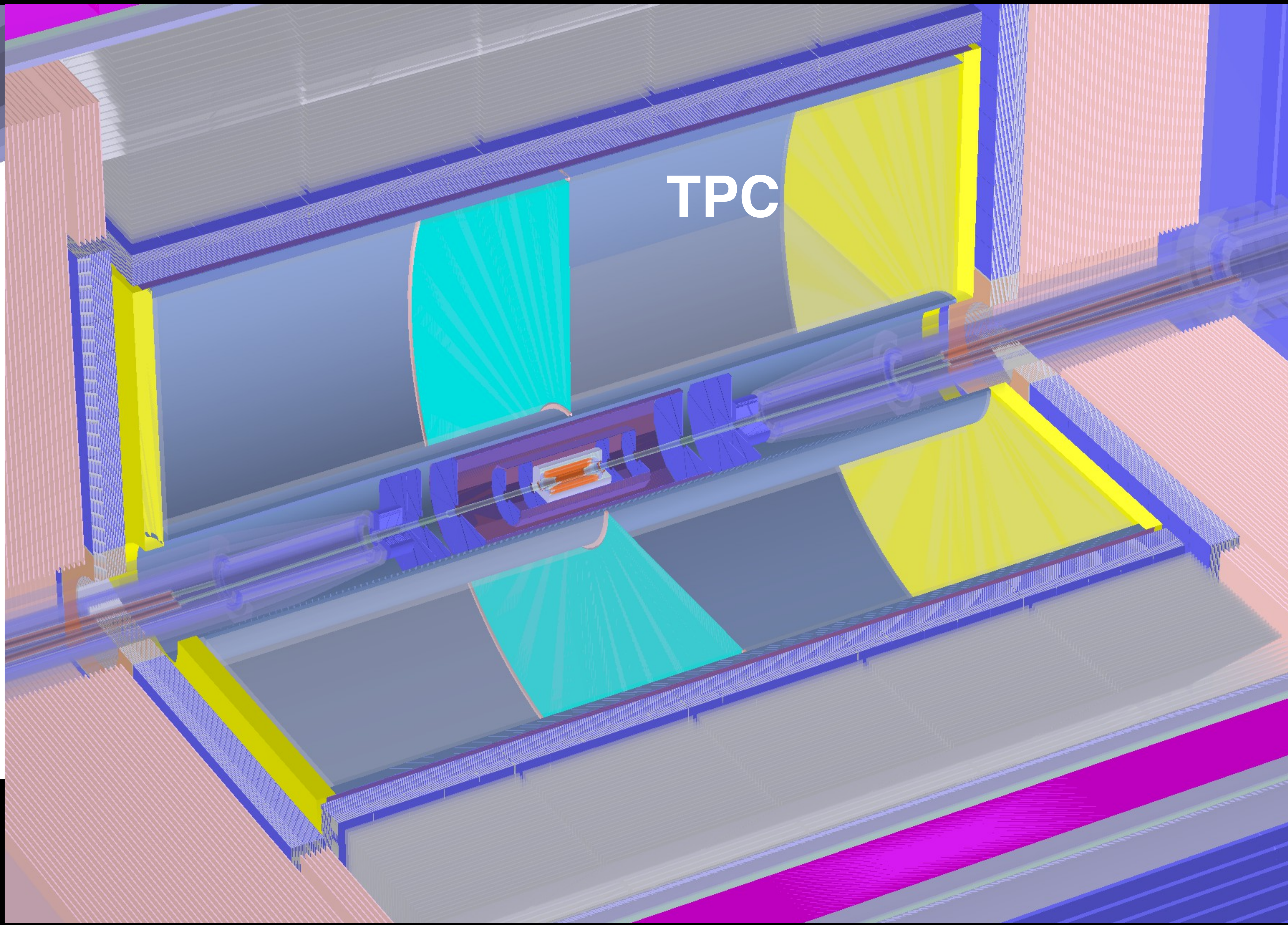
Institut de Física d'Altes Energies

Goals for today:

- Inform everyone about project
- Explore possible interesting extensions
- Identify areas where people could contribute
  - Contributions to baseline project —> need to be clarified soon
  - Contributions to extensions —> less time contrained
- Anual Meeting: April 29-30, 2019 (we are one year into the project)

CEPC CDR baseline conceptual detector





MDI

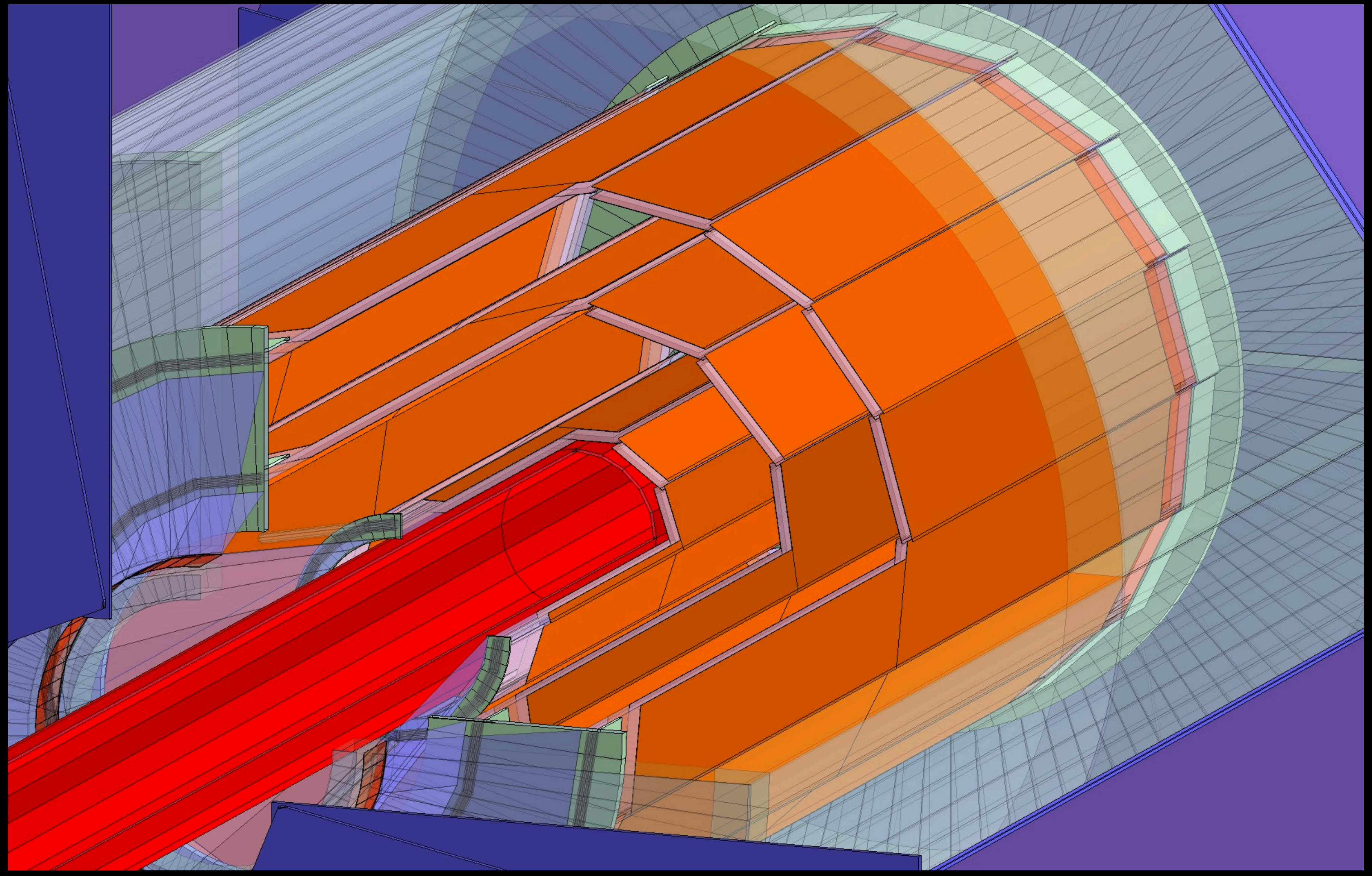
Lumical

Beam pipes

L* = 2.2 m
Cross angle = 33 mrad

Baseline Pixel Detector Layout

3-layers of double-sided pixel sensors



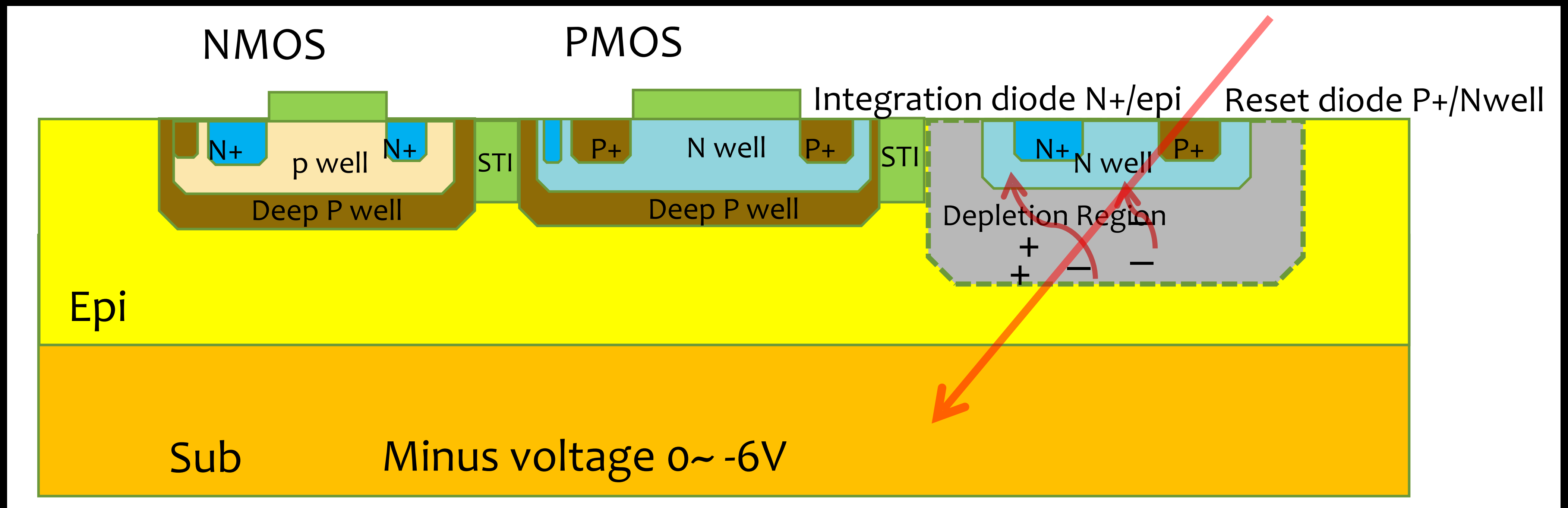
- ✦ ILD-like layout
- ✦ Innermost layer: $\sigma_{SP} = 2.8\ \mu m$
- ✦ Polar angle $\theta \sim 15$ degrees

Low material budget
$\sim 0.15\% X_0$ per layer

		$R(mm)$	$\lvert z \rvert(mm)$	$\lvert cos\theta \rvert$	$\sigma(\mu m)$	$Readout\ time(us)$
Ladder 1	Layer 1	16	62.5	0.97	2.8	20
	Layer 2	18	62.5	0.96	6	1-10
Ladder 2	Layer 3	37	125.0	0.96	4	20
	Layer 4	39	125.0	0.95	4	20
Ladder 3	Layer 5	58	125.0	0.91	4	20
	Layer 6	60	125.0	0.90	4	20

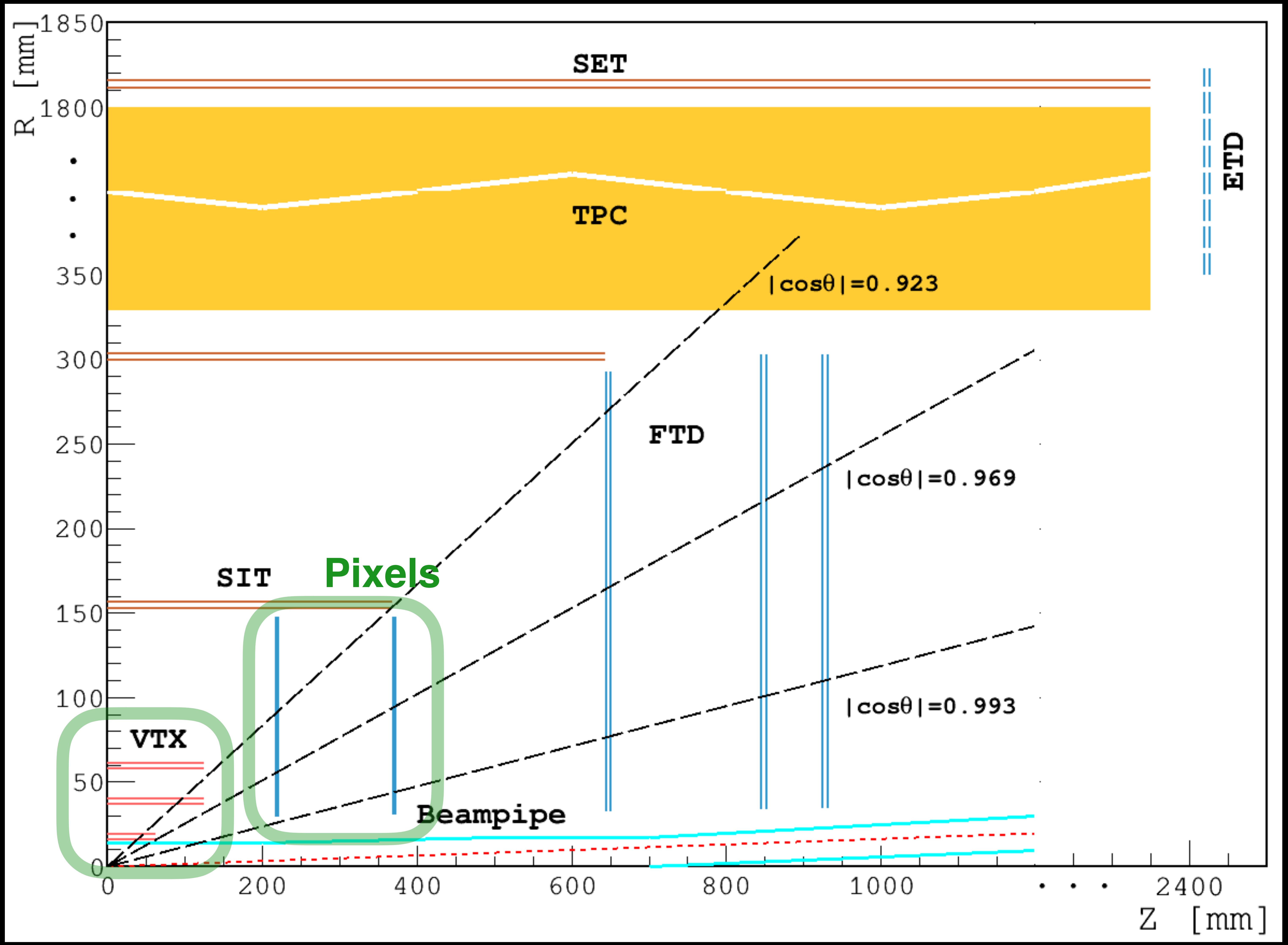
Implemented in GEANT4 simulation framework (MOKKA)

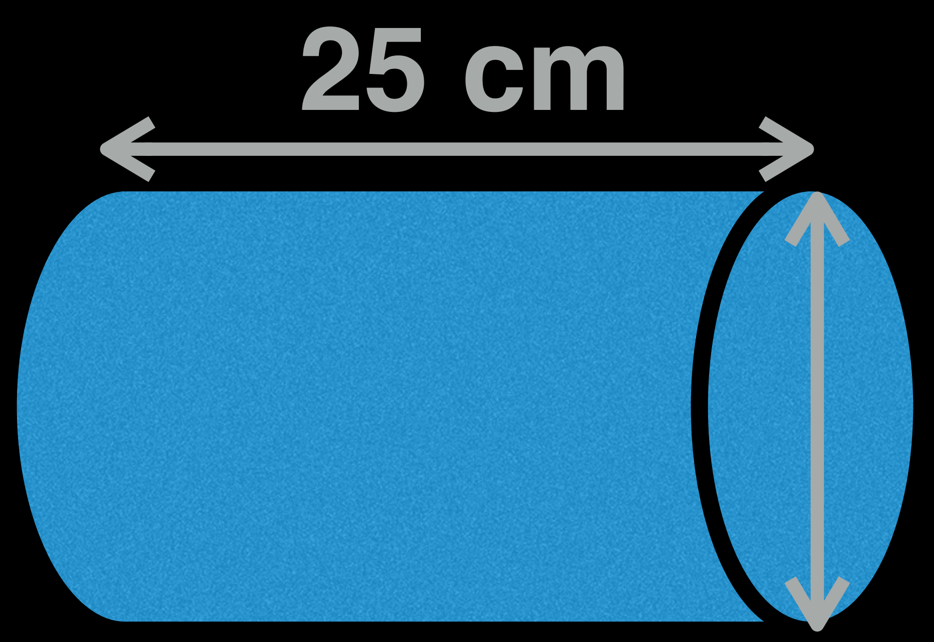
CMOS pixel sensor (MAPS)



Integrated sensor and readout electronics on the same silicon bulk with "standard" CMOS process:
- low material budget,
- low power consumption,
- low cost …

Tracker Detector – PFA Detector



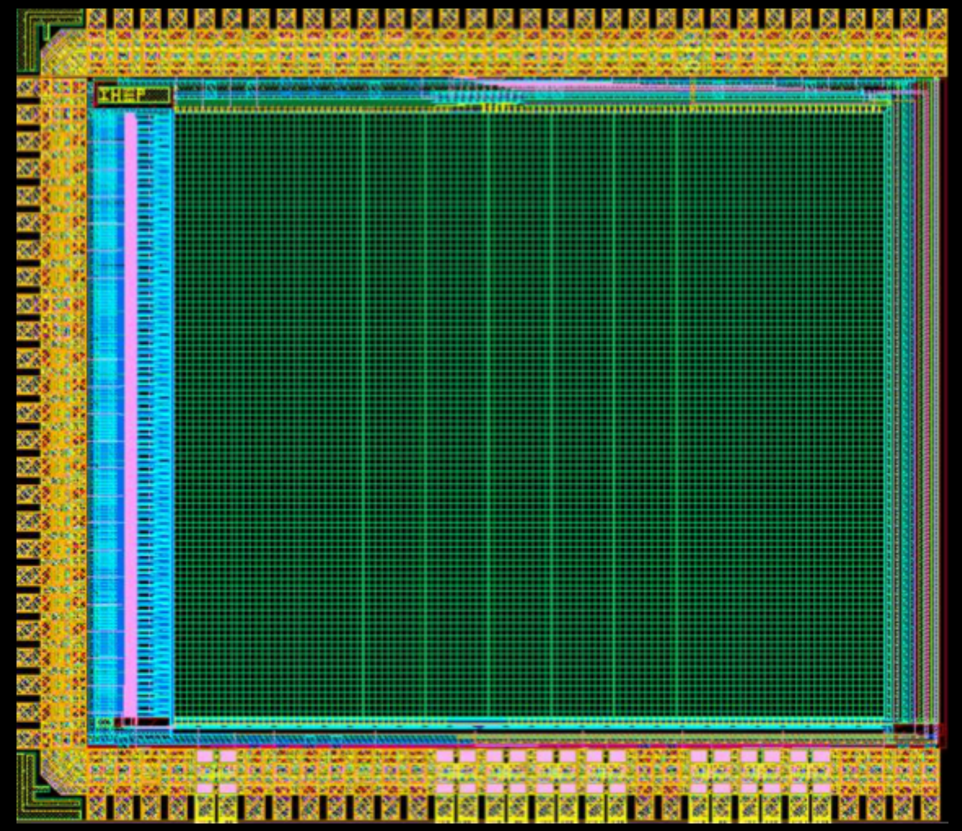


Total Silicon area ~ 68 m²

R&D goals and activities

- **Sensor R&D targeting:**

	Specs	Final Detector Goals:
Single point resolution near IP:	< 3-5 μm	Need improvement
Power consumption:	< 100 mW/cm²	Need to continue trying to lower by a factor of 2
Integration readout time:	< 10-100 μs	Need 1 μs for final detector
Radiation (TID)	> 1 MRad	Need 2.5× higher /year



- **Sensors technologies:**

	Process	Smallest pixel size	Chips designed	Observations
CMOS pixel sensor (CPS)	TowerJazz CIS 0.18 μm	22 × 22 μm²	2	Funded by MOST and IHEP
SOI pixel sensor	LAPIS 0.2 μm	16 × 16 μm²	2	Funded by NSFC

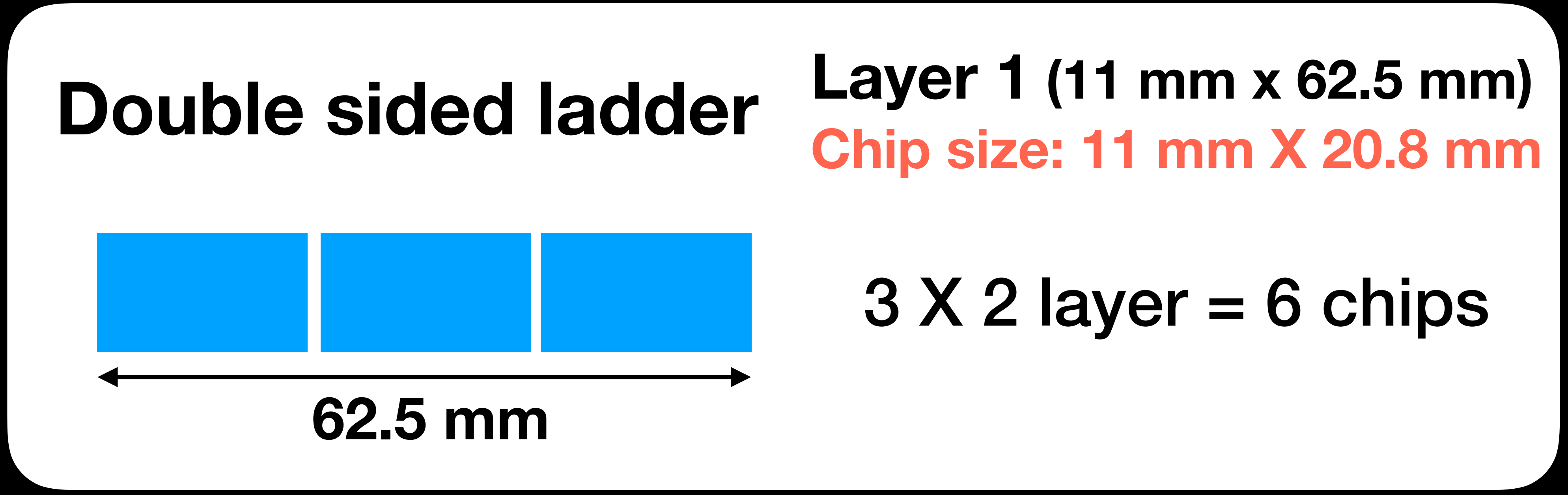
  - Institutions: CCNU, NWTU, Shandong, Huazhong Universities and IHEP (IPHC in Strasbourg, KEK)

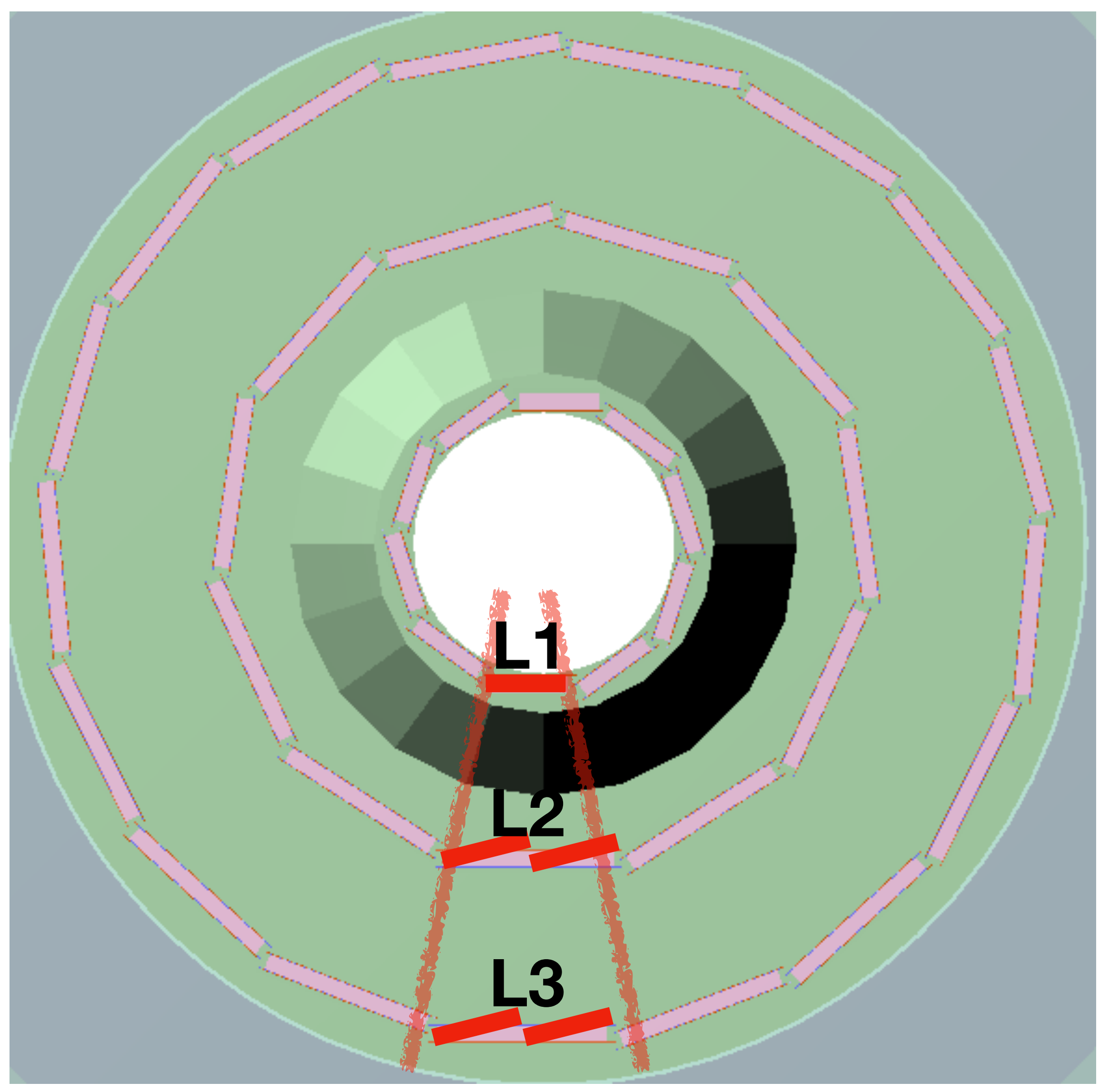
Vertex Session: Tuesday, 10:50 am

Task 2: Research Goal

- **Produce a world class vertex detector prototype**
  - Spatial resolution 3~5 μm (pixel detector)
  - Radiation hard (>1 MRad)

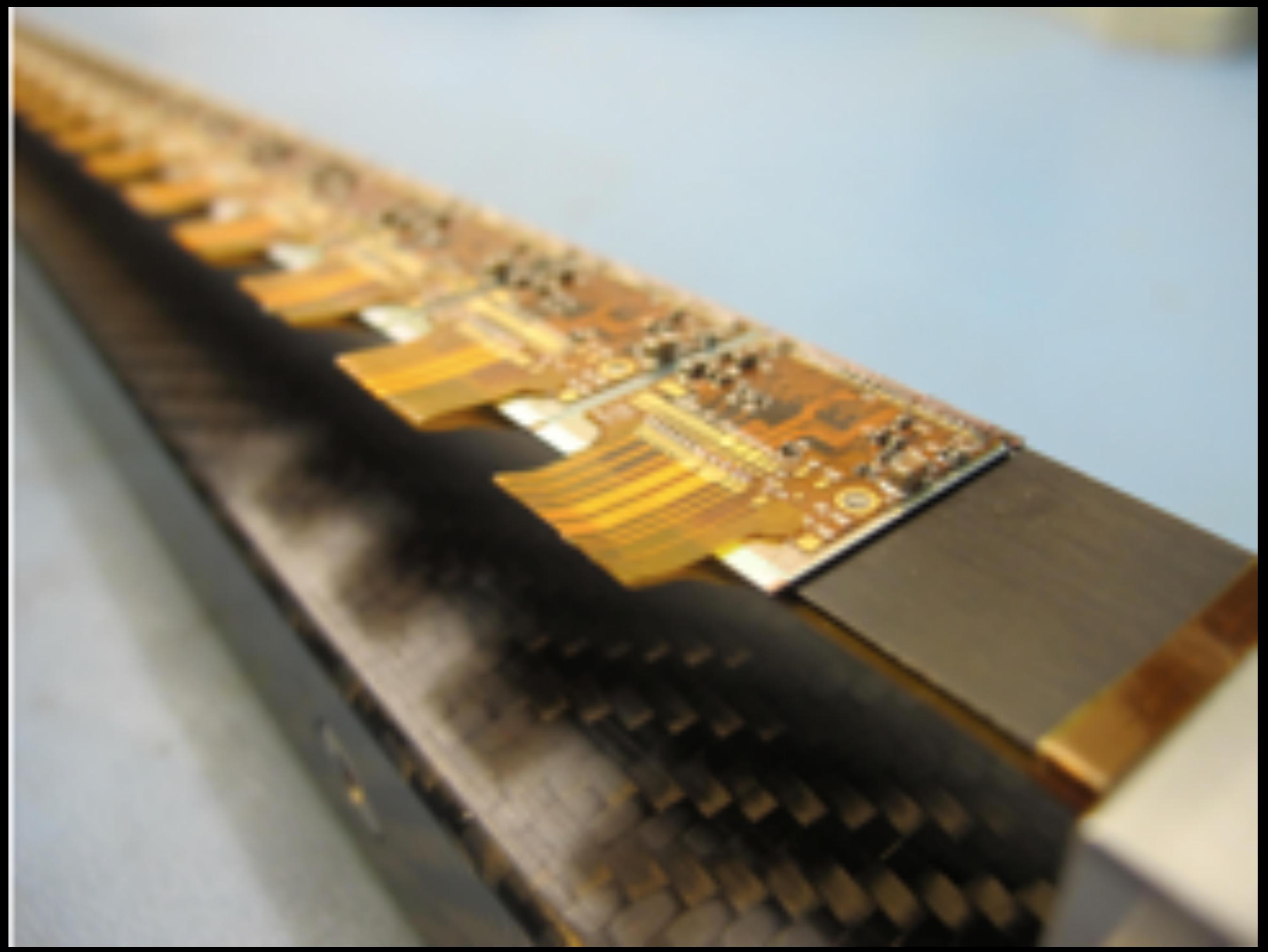
- **Preliminary design of prototype**
  - Three layer, module ~1 cm × 6-12 cm^2





- Develop full size CMOS sensor for use in real size prototype

Typical module



Resolution

ATLAS/CMS upgrade (15 μm)

Alice upgrade (8~10 μm)

This project (3~5 μm)

Task 2: Technical route and schedule

Use CMOS image sensor technology

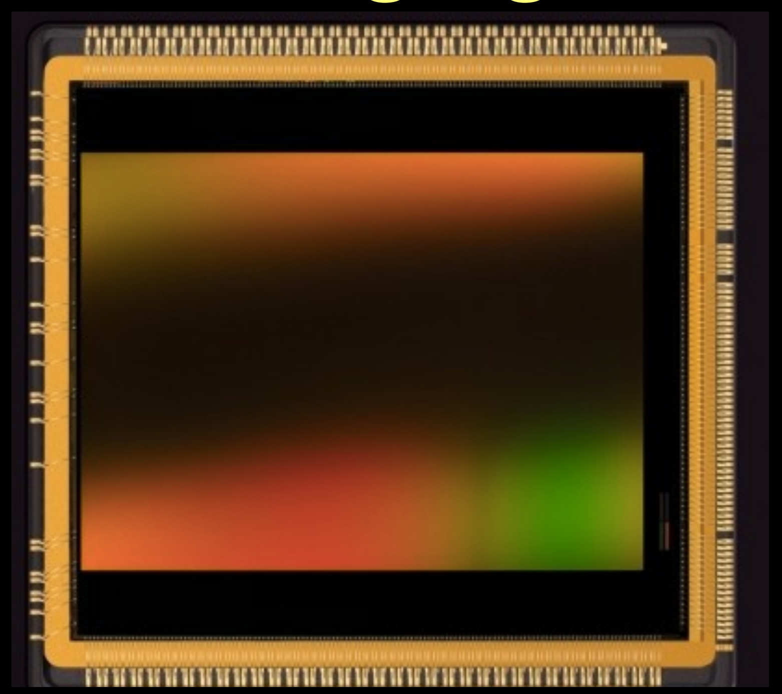
Optimize pixel circuitry, reduce size → High resolution

Special design and latest technology → Radiation hard

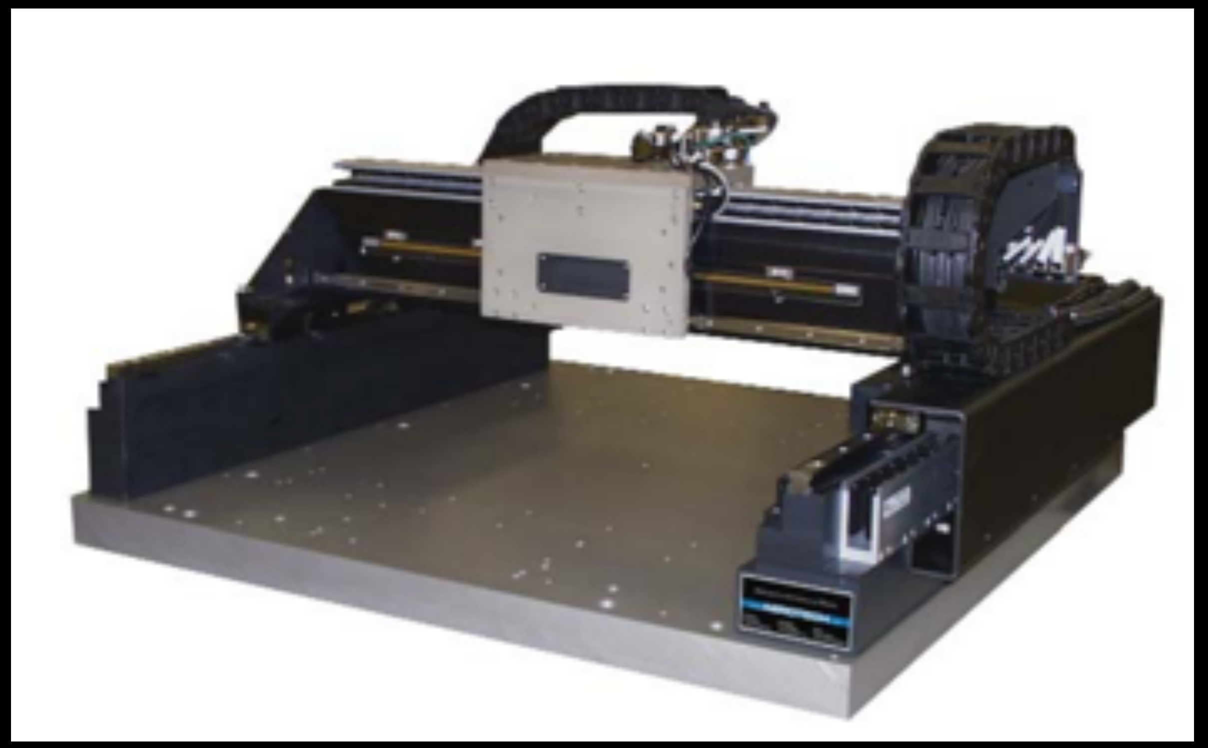
Use carbon fiber, polyamide, graphene, and other light materials for mechanical structure → Low mass

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

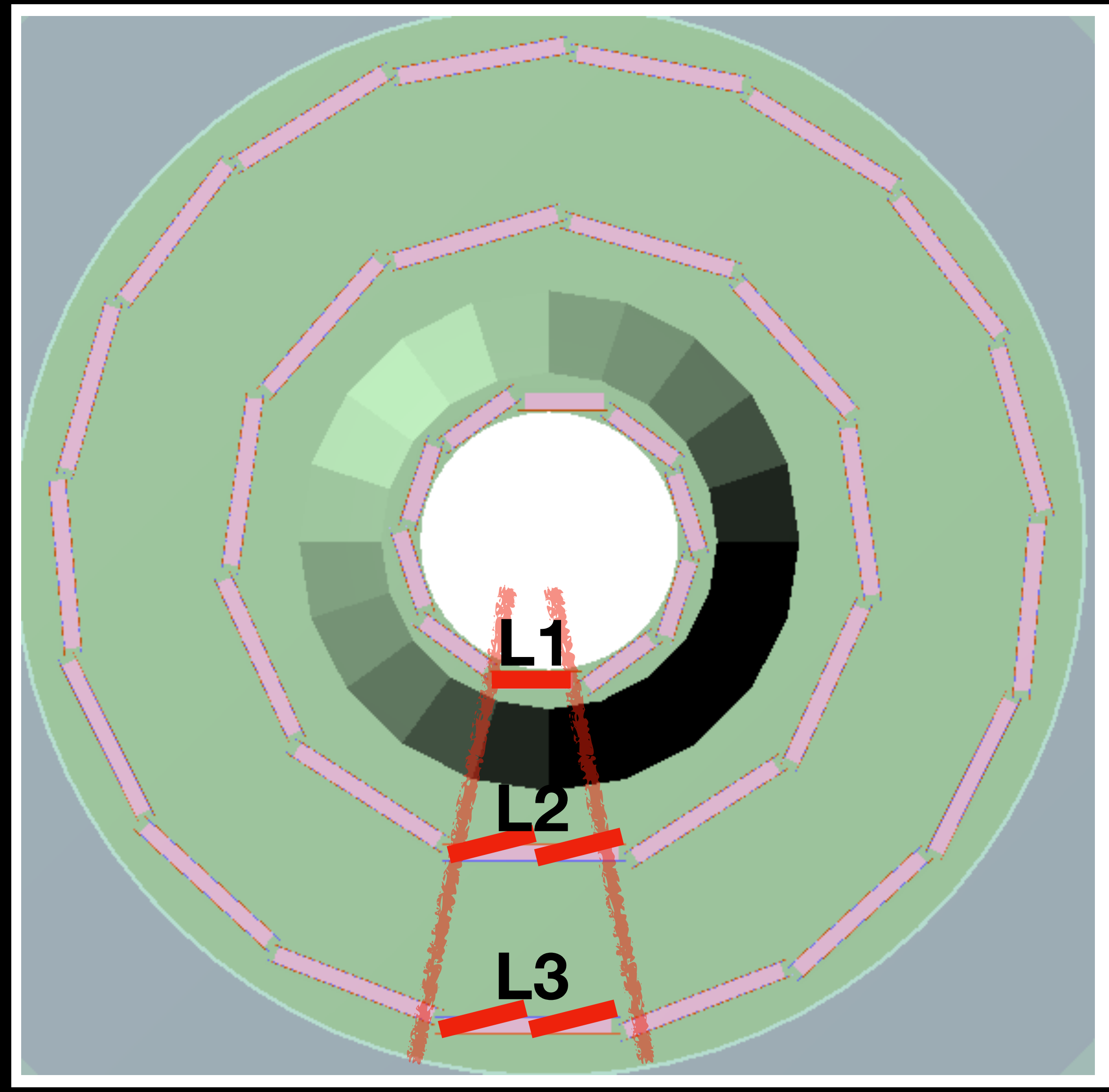
Prototype assembly

Beam testing

第一年 第二年 第三年 第四年 第五年

项目结题

Baseline MOST2 Project and Extensions



- **Baseline**
  - Large CMOS chip
  - Three layers “loosely defined”
  - Tested on test beam

- **Extensions**
  - Highly desirable: Full size mechanical prototype
    - Think about new pixel detector layout, cable routing, cooling, readout electronics integration, detector installation and mounting
  - Highly desirable: Extended specifications for chip (closer to final requirements)
  - Explore different sensor technologies/vendors (HV-CMOS/HR-CMOS)
  - Investigate active/advance cooling methods
  - Extend prototype to include forward pixel disks

Requires new people

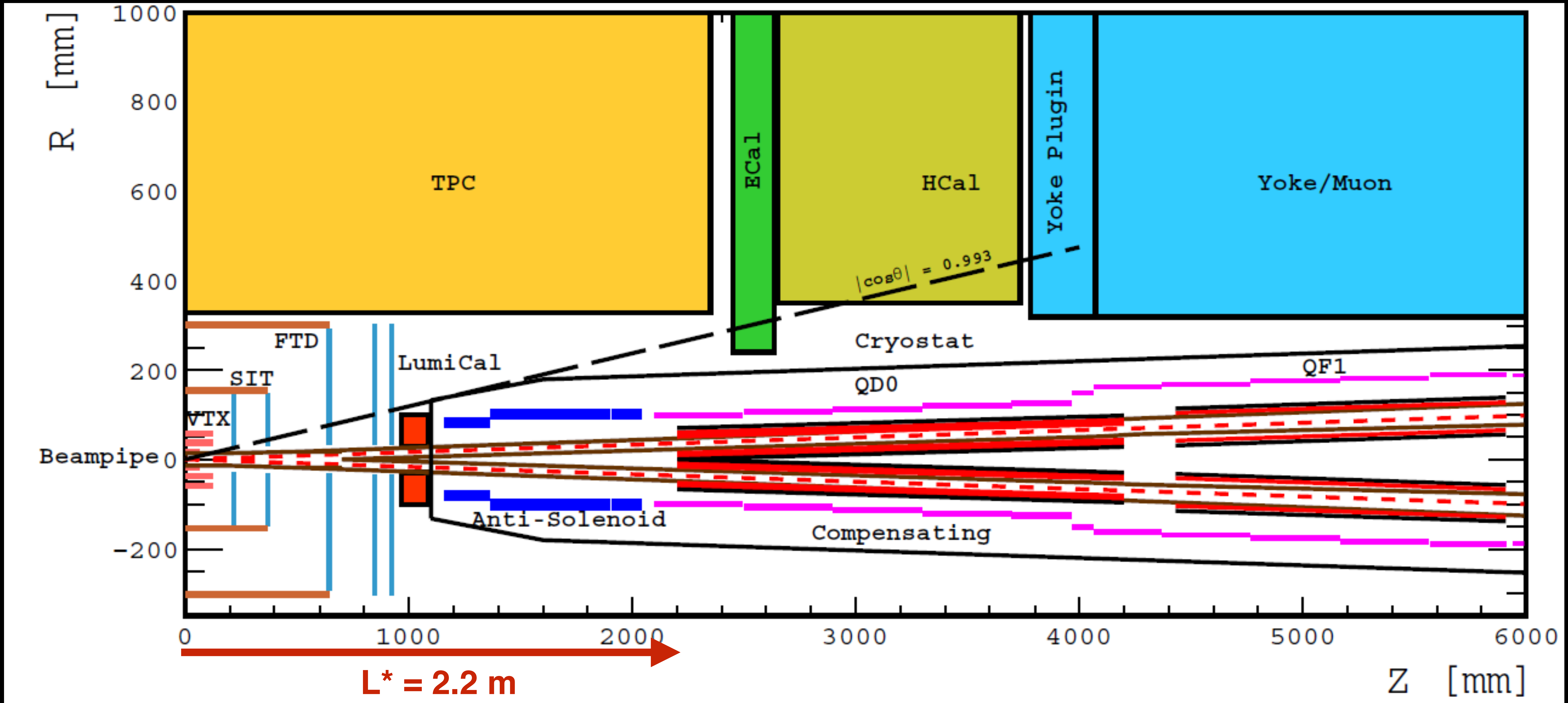
Machine–detector interface (MDI) in circular colliders

High luminosities → **Final focusing quadrupoles (QD0) need to be very close to IP**

Head-on collision crossing angle: **33 mrad**

Detector acceptance:
> ± 150 mrad

Solenoid magnetic field limited:
2-3 Tesla



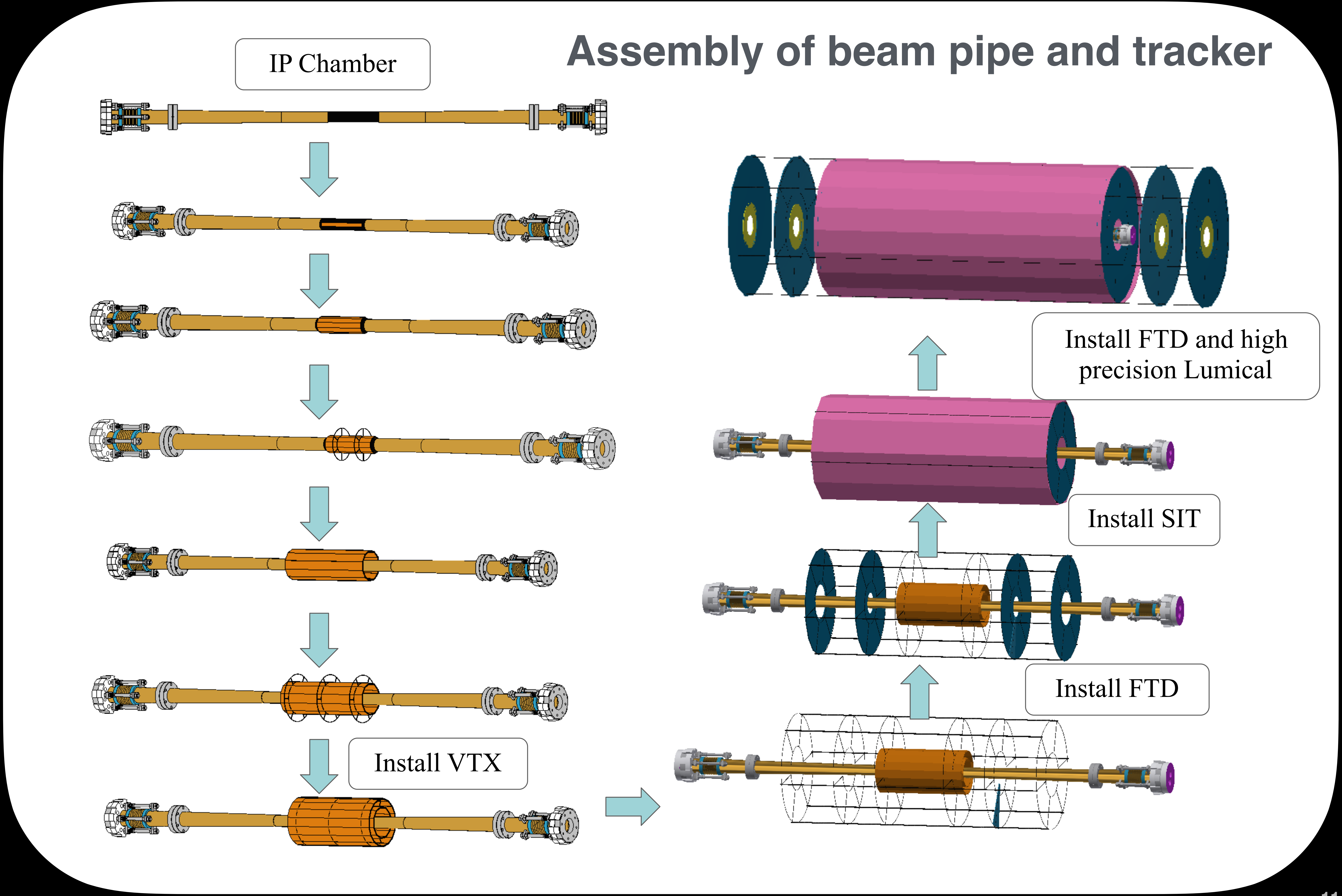
Cooling of beampipe needed → increases material budget near the interaction point (IP)

MDI Assembly and Installation

Engineering studies started

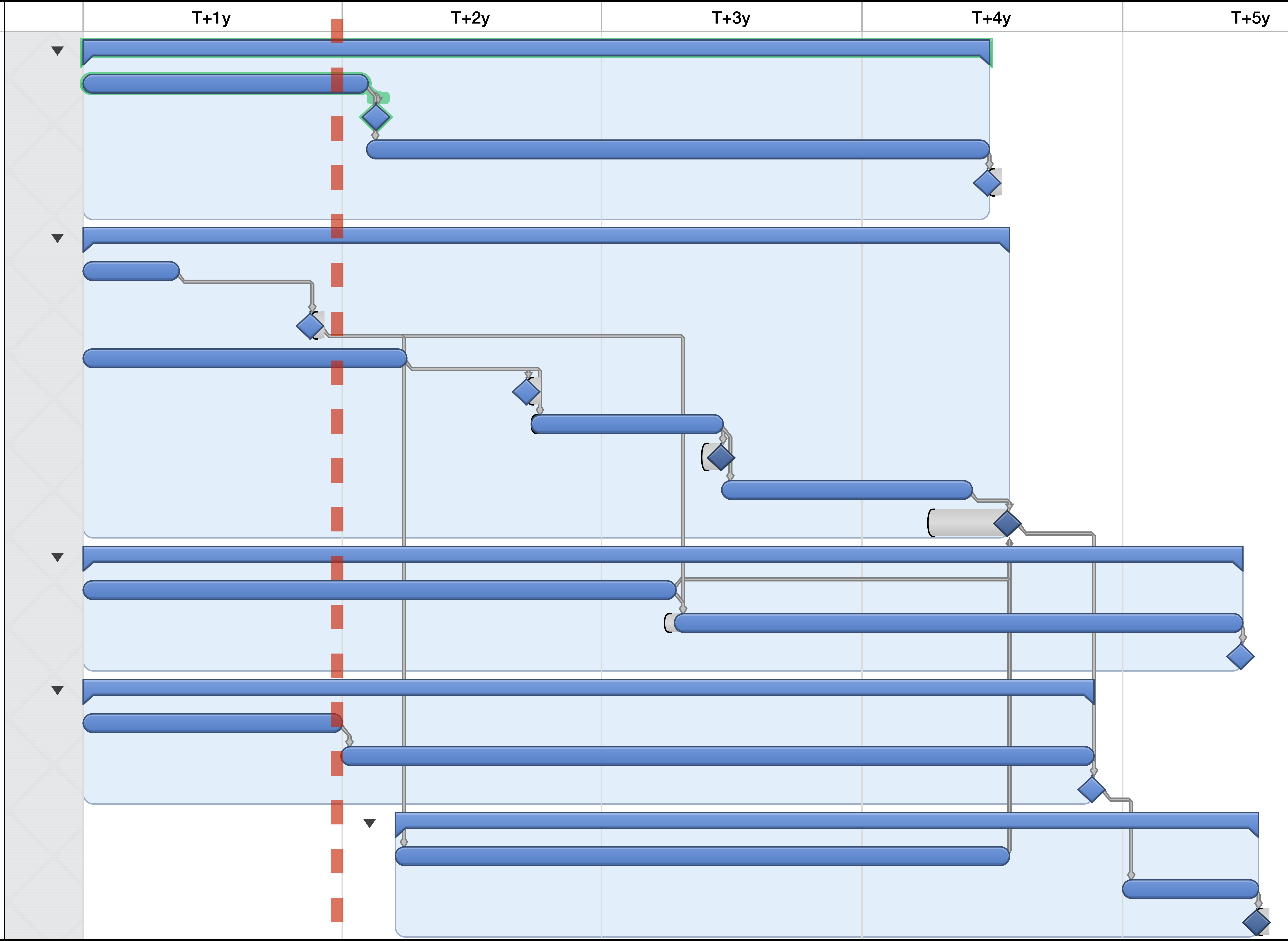
Different scenarios under study

Needs close collaboration between detector designers and MDI engineers



MOST2 Project Schedule

Title	Effort
1) Mechanics design	182w
1.1) Module structure design	57w
1.2) Fabricated Module support structure	
1.3) Finish the design for pixel detector prototype	125w
1.4) Manufacture support structure for detector prototype	
2) CMOS sensor	172w 2d
2.1) sensor and frontend electronics functional block design	19w
2.2) First MPW run	
2.3) Integrate all functional block	65w
2.4) Second MPW	
2.5) Debug and optimize frontend electronics	38w 2d
2.6) The third MPW	
2.7) Fiinsh design for full area, fully functionality chip	50w
2.8) First engineering run	
3) DAQ	233w
3.1) readout board for MPW runs	119w
3.2) the design of DAQ for pixel detector prototype	114w
3.3) Implement the DAQ design for prototype	
4) Module	203w
4.1) Electronics design for module	52w
4.2) Assembly procedure	151w
4.3) Produce the modules	
5) Test beam and irradiation	150w
5.1) Testing for MPW runs	123w
5.2) beam test and data analysis	27w
5.3) Publish paper and finish the final report	



第一年（2018.5-2019.4）

Main Milestones

- Task 1:
  - Low-field dipoles: physical and structural design of various small prototypes
  - Preliminary design of vacuum box and bellows, and electrostatic separator
  - Parameter selection of polarization working mode
- Task 2:
  - Preliminary designs of mechanics, readout electronics and ASIC
  - First ASIC MPW submitted
- Task 3:
  - Design of calorimeter prototype, and parameters optimized
  - Batch production of scintillator unit studied and started
  - Design front-end electronics

Outcome

- Annual report

第二年（2019.5-2020.4）

Main Milestones

- Task 1:
  - Manufacture the high-precision low field dipole magnet small experimental prototype
  - Finish engineering design of vacuum box and bellows, and electrostatic separator
  - Simulation program for storage ring polarization is developed
- Task 2:
  - Engineering designs of mechanics structure
  - Second ASIC MPW submitted
- Task 3:
  - Simulate whole HCAL prototype and develop software framework
  - Carry out production of scintillator units
  - Prototype absorber and supporting structure are designed.

Outcome

- Mid-term report

第三年（2020.5-2021.4）

Main Milestones

- Task 1:
  - Smal prototype of magnet fully tested
  - Design of magnet complete
  - Processing of the vacuum tube, the coating experiment device and the shielding bellows are completed
- Task 2:
  - Mechanical structure completed
  - Second ASIC MPW tested
  - ASIC design optimized and completed
- Task 3:
  - Batch production of readout electronics, development of data acquisition system
  - Development of beam test platform and cosmic ray test platform

Outcome

- Annual report

第四年（2021.5-2022.4）

Main Milestones

- Task 1:
  - Completed the formal prototype of the dipole magnet and measurement system
  - Prototypes of vacuum tube and RF bellows completed
  - High pressure experiment was carried out on the electrostatic separator
- Task 2:
  - Silicon wafer processing of large area sensor submitted
  - Assembling and installing the prototype
- Task 3:
  - Integrated calorimeter prototype.
  - Carry out the cosmic ray test of the prototype

Outcome

- Annual report

第五年（2022.5-2023.4）

Main Milestones

- Task 1:
  - Complete the performance test of dipole prototype
  - Complete tests of prototypes of vacuum tube, RF bellows and electrostatic separator
  - High pressure experiment was carried out on the electrostatic separator
- Task 2:
  - Test beam and data analysis
  - Finish assembling of prototype
- Task 3:
  - Test beam and data analysis
  - Finish assembling of prototype

Outcome

- Final report, paper and experimental equipment

Areas for contributions

- CMOS Sensor and ASIC chip
  - HR-CMOS Testing
  - HR-CMOS: Any open areas available?
  - HV-CMOS implementation

- Mechanics
  - Consulting role on mechanical design of ladders and structure
  - Design of any mechanical aspects
  - Investigation of cooling needs, R&D on cooling aspects
  - Adding forward disks to prototype project (needs full team)

- Readout and DAQ
  - Readout electronics and DAQ design
  - Support test beam