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CMS MTD BTL Timing Detector in Phase2 Upgrade

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中国物理学会高能物理分会第十四届全国粒子物理学术会议，Aug15th, 2024, Shanghai

Outline

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- What's MTD BTL?
- How do we build BTL?
- Progress on MTD BTL Detector
- Summary and Plan

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01 What's MTD BTL

Physics motivation of MTD

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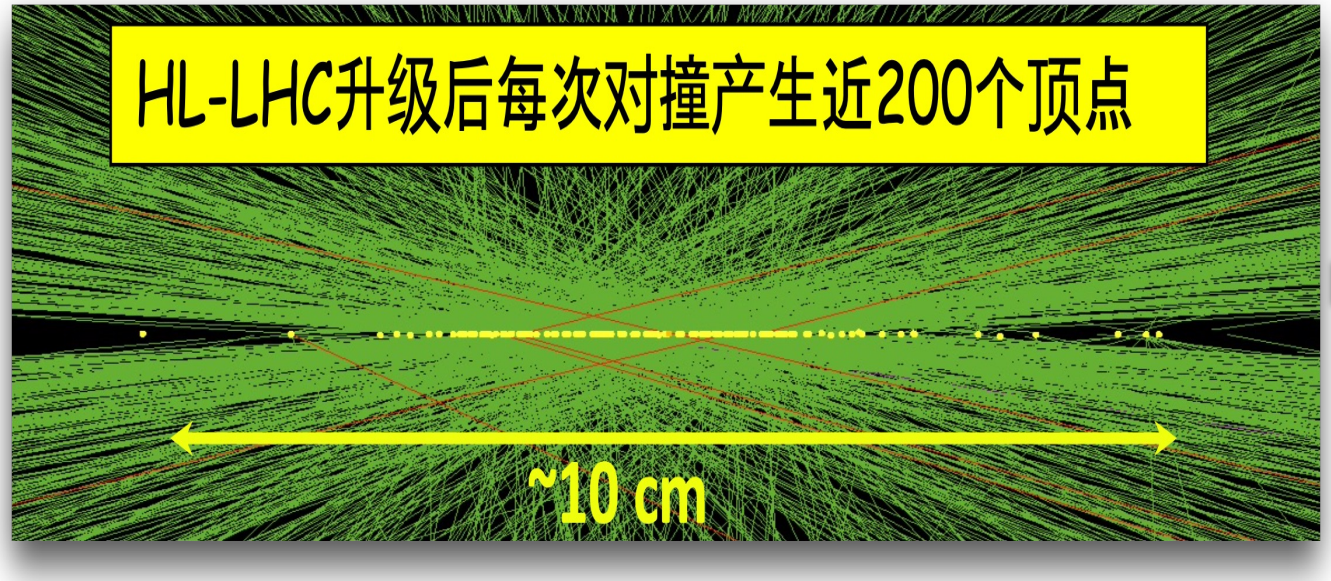
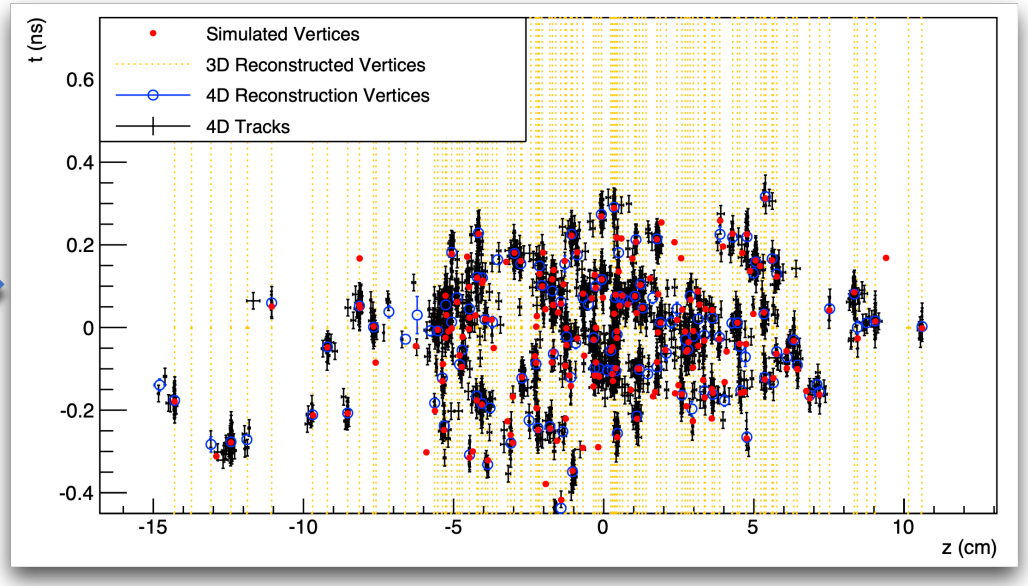
High luminosity → High pileup

The MTD will be added to CMS to help meet the challenge of high luminosity.

- HL-LHC, 3000 fb^{-1} at the cost of 140-200 simultaneous collisions (PU)
- MTD + upgraded tracker = Run2-esque PU mitigation





What is MTD BTL ?

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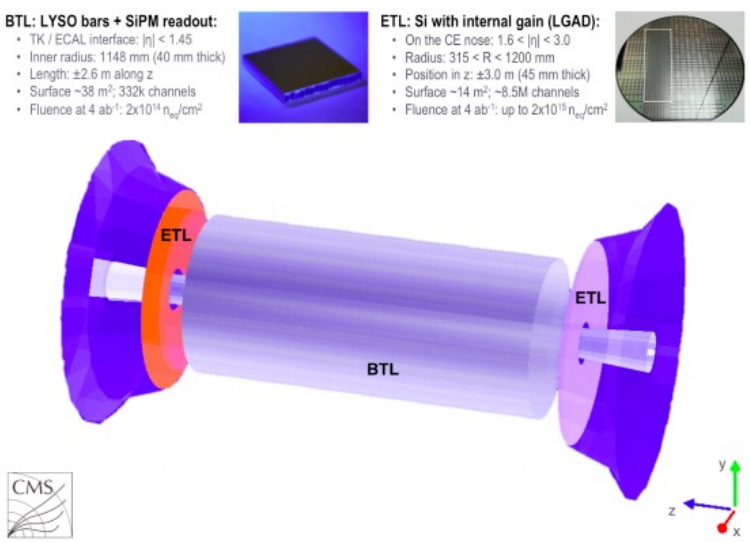
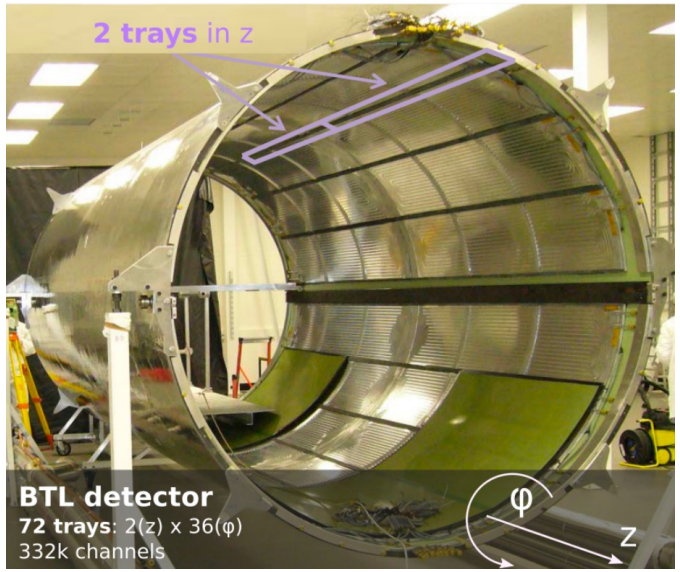
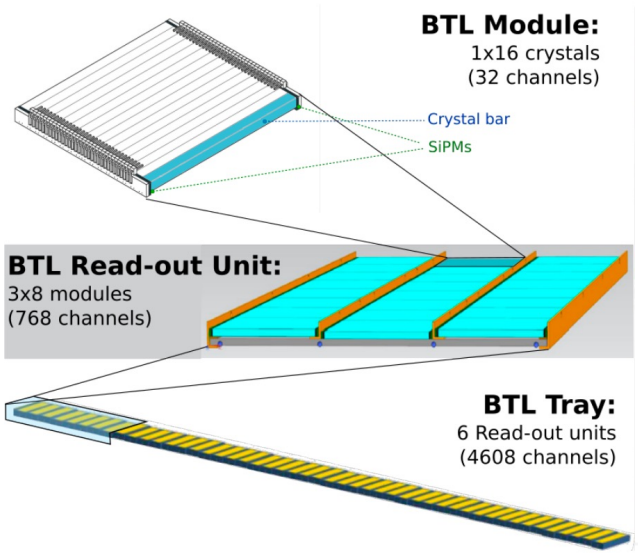
The Barrel Timing Layer (BTL) will measure time of arrival for >_0.7_GeV MIPs with ~30-60ps precision

- Thin (< 4 cm), large area (38 m^2) detector covering $|\eta| < 1.5$
- ~10k Sensor Modules, each containing 16 scintillating LYSO crystal bars and two 16-channel SiPM arrays
- Read out with custom TOFHIR2 ASIC
- Mounted on CO2 cooled trays and installed on inner surface of BTL Tracker Support Tube (BTST)







Schedule of MTD BTL

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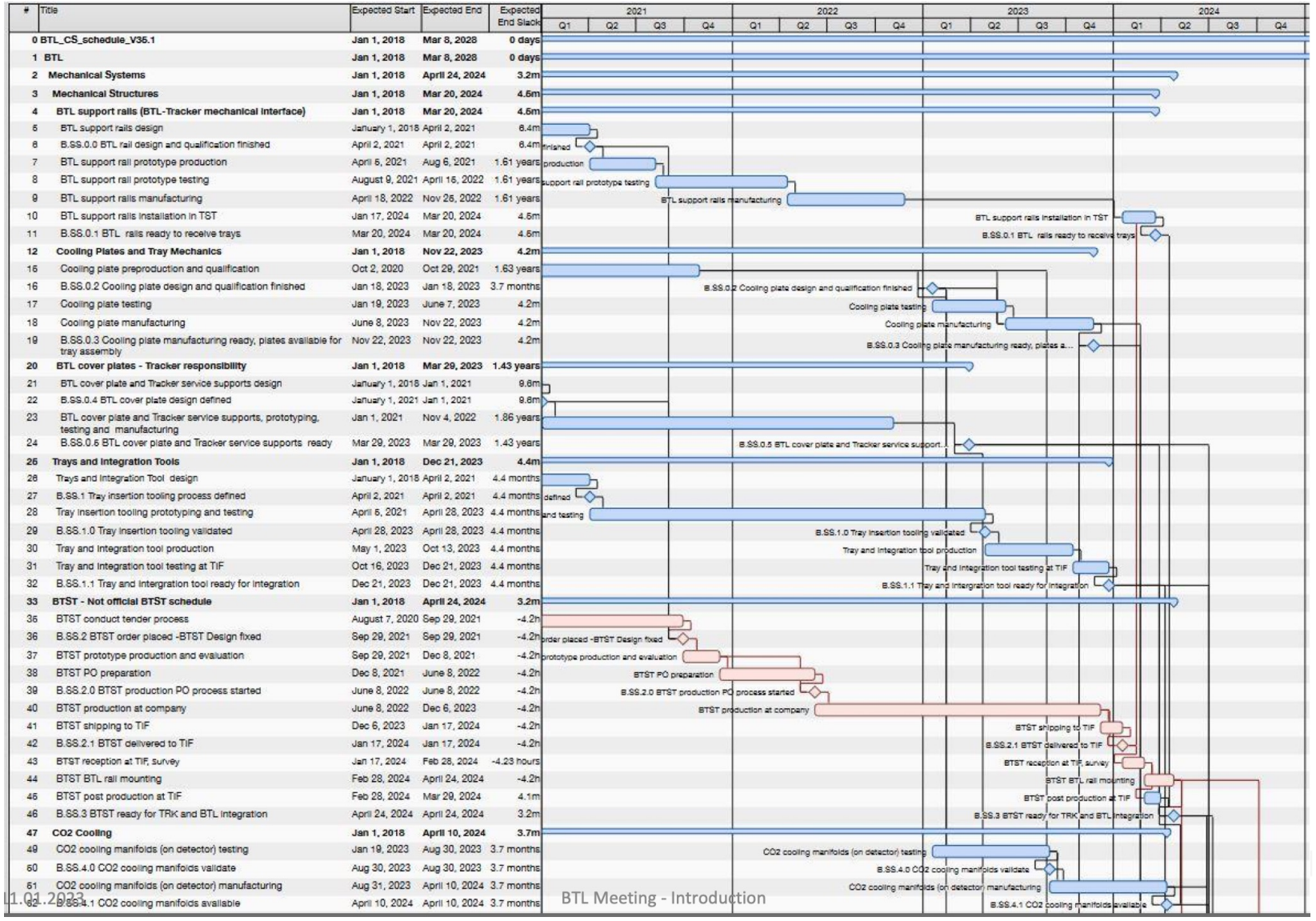
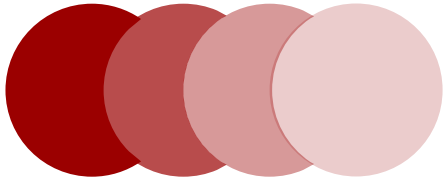
PKU Assembly timeline

- Participate in TB of sensor in 2023
- Improved the assembly and QA/QC in 2023
- Assembly Center Certification in 2024
- Start batch assembly in the Autumn of 2024
- End assembly in the Summer of 2026
- Installed in the Autumn of 2026



#	Title	Expected Start	Expected End	Expected End Slack
0	BTL_CS_schedule_V35.1	Jan 1, 2018	Mar 8, 2028	0 days
1	BTL	Jan 1, 2018	Mar 8, 2028	0 days
2	Mechanical Systems	Jan 1, 2018	April 24, 2024	3.2m
3	Mechanical Structures	Jan 1, 2018	Mar 20, 2024	4.6m
4	BTL support rails (BTL-Tracker mechanical interface)	Jan 1, 2018	Mar 20, 2024	4.6m
5	BTL support rails design	January 1, 2018	April 2, 2021	6.4m
6	B.SS.0.0 BTL rail design and qualification finished	April 2, 2021	April 2, 2021	6.4m
7	BTL support rail prototype production	April 5, 2021	Aug 6, 2021	1.61 years
8	BTL support rail prototype testing	August 9, 2021	April 15, 2022	1.61 years
9	BTL support rails manufacturing	April 18, 2022	Nov 26, 2022	1.61 years
10	BTL support rails installation in TST	Jan 17, 2024	Mar 20, 2024	4.6m
11	B.SS.0.1 BTL rails ready to receive trays	Mar 20, 2024	Mar 20, 2024	4.6m
12	Cooling Plates and Tray Mechanics	Jan 1, 2018	Nov 22, 2023	4.2m
15	Cooling plate preproduction and qualification	Oct 2, 2020	Oct 29, 2021	1.63 years
16	B.SS.0.2 Cooling plate design and qualification finished	Jan 18, 2023	Jan 18, 2023	3.7 months
17	Cooling plate testing	Jan 19, 2023	June 7, 2023	4.2m
18	Cooling plate manufacturing	June 8, 2023	Nov 22, 2023	4.2m
19	B.SS.0.3 Cooling plate manufacturing ready, plates available for tray assembly	Nov 22, 2023	Nov 22, 2023	4.2m
20	BTL cover plates - Tracker responsibility	Jan 1, 2018	Mar 29, 2023	1.43 years
21	BTL cover plate and Tracker service supports design	January 1, 2018	Jan 1, 2021	9.6m
22	B.SS.0.4 BTL cover plate design defined	January 1, 2021	Jan 1, 2021	9.6m
23	BTL cover plate and Tracker service supports, prototyping, testing and manufacturing	Jan 1, 2021	Nov 4, 2022	1.86 years
24	B.SS.0.6 BTL cover plate and Tracker service supports ready	Mar 29, 2023	Mar 29, 2023	1.43 years
26	Trays and Integration Tools	Jan 1, 2018	Dec 21, 2023	4.4m
26	Trays and Integration Tool design	January 1, 2018	April 2, 2021	4.4 months
27	B.SS.1 Tray insertion tooling process defined	April 2, 2021	April 2, 2021	4.4 months
28	Tray insertion tooling prototyping and testing	April 5, 2021	April 28, 2023	4.4 months
29	B.SS.1.0 Tray insertion tooling validated	April 28, 2023	April 28, 2023	4.4 months
30	Tray and Integration tool production	May 1, 2023	Oct 13, 2023	4.4 months
31	Tray and Integration tool testing at TIF	Oct 16, 2023	Dec 21, 2023	4.4 months
32	B.SS.1.1 Tray and Intergration tool ready for Integration	Dec 21, 2023	Dec 21, 2023	4.4 months
33	BTST - Not official BTST schedule	Jan 1, 2018	April 24, 2024	3.2m
35	BTST conduct tender process	August 7, 2020	Sep 29, 2021	-4.2h
36	B.SS.2 BTST order placed -BTST Design fixed	Sep 29, 2021	Sep 29, 2021	-4.2h
37	BTST prototype production and evaluation	Sep 29, 2021	Dec 8, 2021	-4.2h
38	BTST PO preparation	Dec 8, 2021	June 8, 2022	-4.2h
39	B.SS.2.0 BTST production PO process started	June 8, 2022	June 8, 2022	-4.2h
40	BTST production at company	June 8, 2022	Dec 6, 2023	-4.2h
41	BTST shipping to TIF	Dec 6, 2023	Jan 17, 2024	-4.2h
42	B.SS.2.1 BTST delivered to TIF	Jan 17, 2024	Jan 17, 2024	-4.2h
43	BTST reception at TIF, survey	Jan 17, 2024	Feb 28, 2024	-4.23 hours
44	BTST BTL rail mounting	Feb 28, 2024	April 24, 2024	-4.2h
45	BTST post production at TIF	Feb 28, 2024	Mar 29, 2024	4.1m
46	B.SS.3 BTST ready for TRK and BTL integration	April 24, 2024	April 24, 2024	3.2m
47	CO2 Cooling	Jan 1, 2018	April 10, 2024	3.7m
49	CO2 cooling manifolds (on detector) testing	Jan 19, 2023	Aug 30, 2023	3.7 months
50	B.SS.4.0 CO2 cooling manifolds validate	Aug 30, 2023	Aug 30, 2023	3.7 months
51	CO2 cooling manifolds (on detector) manufacturing	Aug 31, 2023	April 10, 2024	3.7 months
52	B.SS.4.1 CO2 cooling manifolds available	April 10, 2024	April 10, 2024	3.7 months



02 How do we build BTL?

2.1. Test Beam

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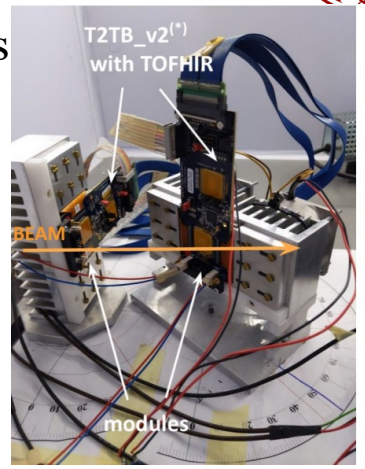
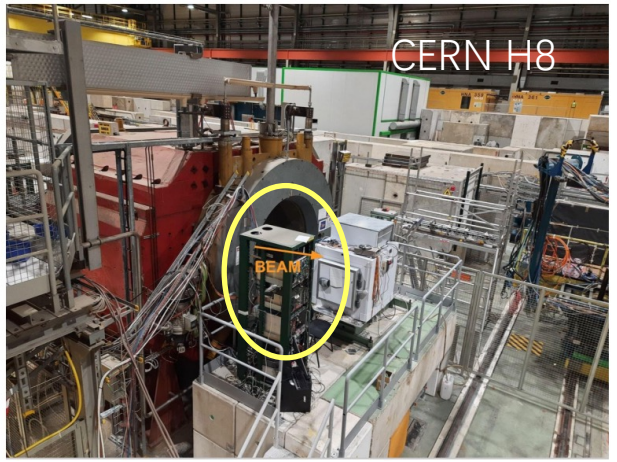
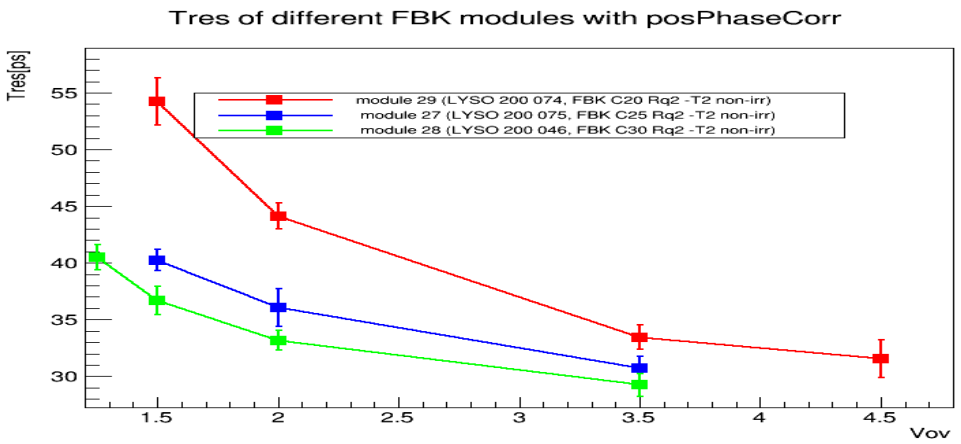
Conducted on CERN (180 GeV pion) and FNAL (120 GeV proton) beams

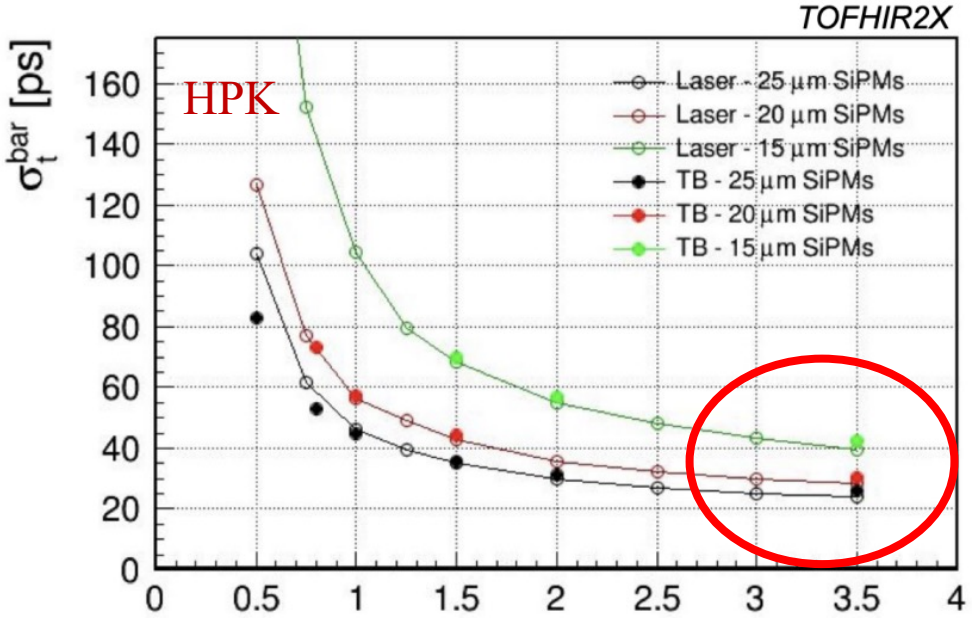




SiPM

- Main optimization and research parameters: Cell size of SiPM
  - The time resolution for modules with non-irradiated SiPMs of different cell-sizes (15, 20, 25 μm)
    - 25 μm has the best time resolution
- More tests were conducted, such as comparing the time resolution of SiPM from different manufacturers
- Optimization of SiPM parameters has been completed





2.1. Test Beam

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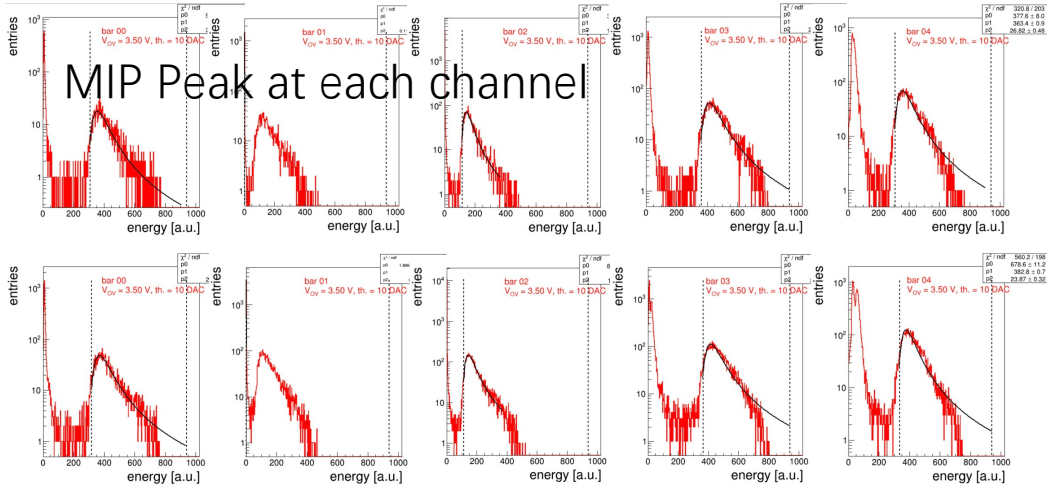
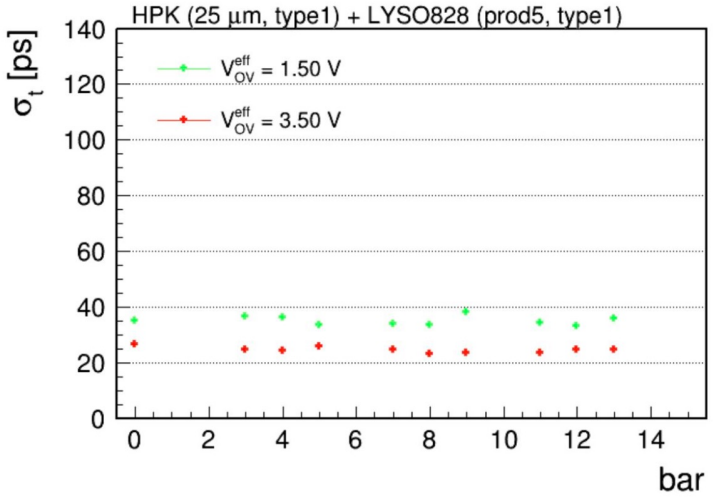
LYSO

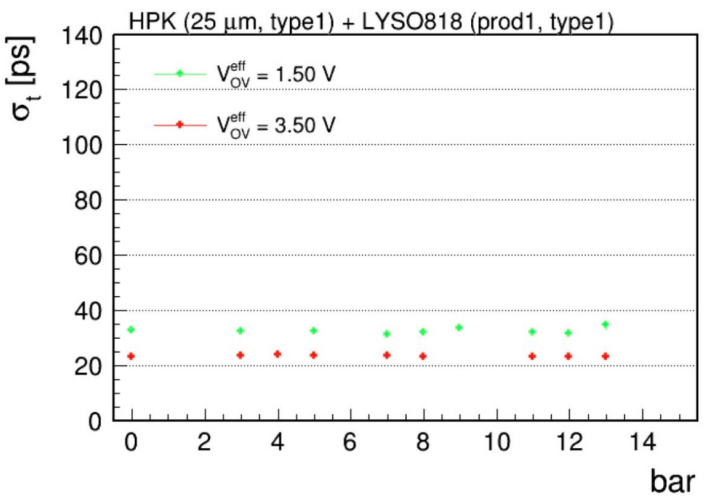
- Preliminary comparative tests were conducted on the quality of LYSO (size, yield, etc.) from various manufacturers
- Finally, perform time resolution testing on high-performance manufacturers using beam current
- The time resolution of manufacturers Prod1 and Prod5 was compared as follows
- LYSO optimization has been completed



prod5 52deg



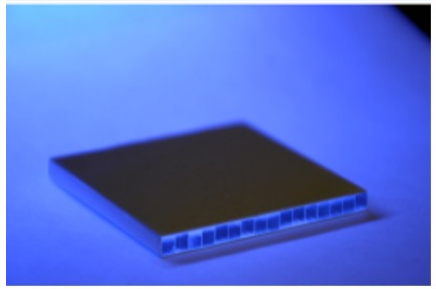
prod1 52deg

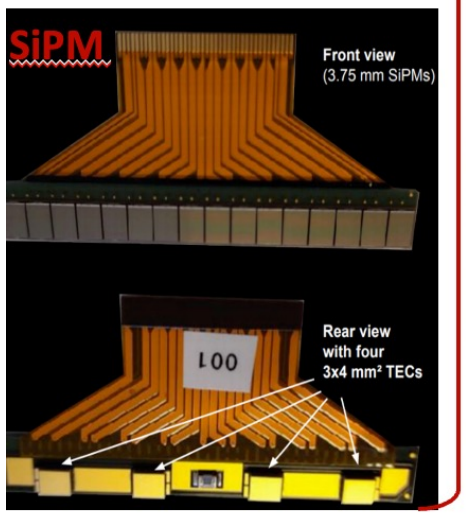


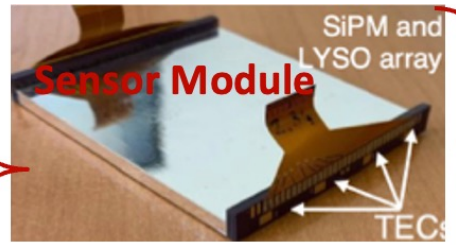
Results are measured at the optimal threshold

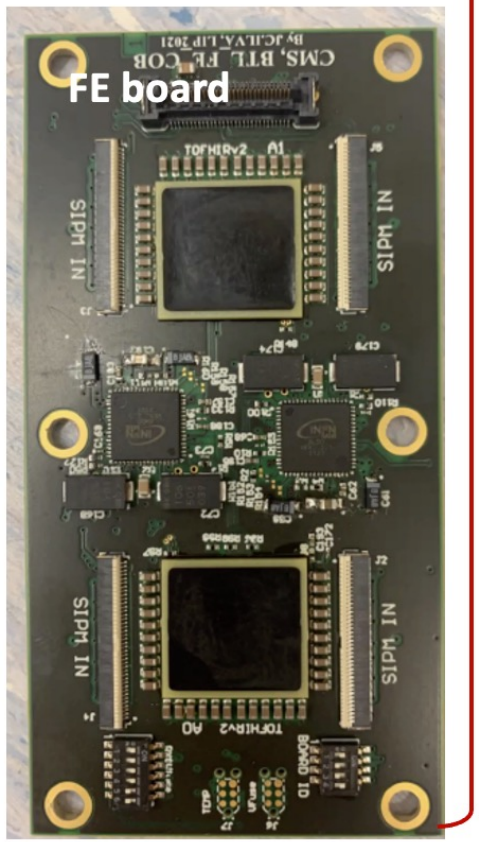
LYSO	Vov/V	angle/deg	t_{Res}/ps	error/%
prod1	1.50	32	38.2	6.9
		52	**32.2**	3.1
		64	30.9	9.0
	3.50	32	25.7	2.1
		52	**23.5**	1.2
		64	23.6	7.2
prod5	1.50	52	**35.1**	4.3
	3.50		**24.6**	4.0

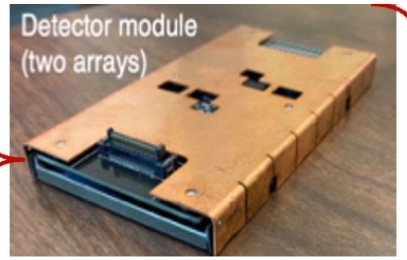
2 Assembly of MTD BTL

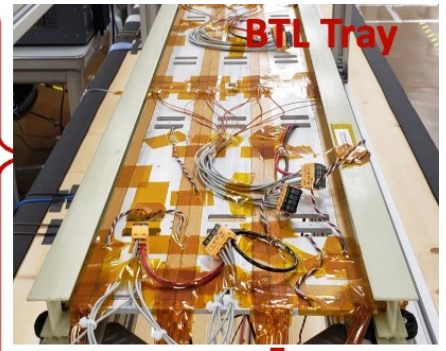


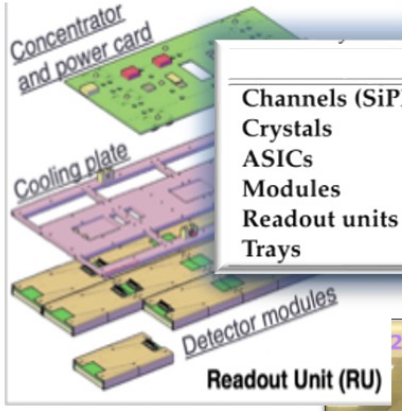




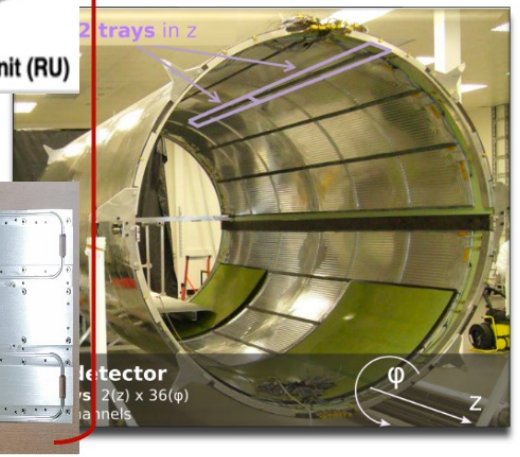








	Module	RU	Tray	Total
Channels (SiPMs)	32	768	4608	331776
Crystals	16	384	2304	165888
ASICs	1	24	144	10368
Modules	-	24	144	10368
Readout units (RU)	-	-	6	432
Trays	-	-	-	72



Cooling Plate

All components will be assembled and validated at 4 global BTL Assembly Centers (BACs)

- Virginia
- Caltech
- Milan
- Beijing

Trays will be shipped to CERN, integrated into the BTST and commissioned in the Tracker Integration Facility

2.2 Assembly and QA/QC of Sensor Module

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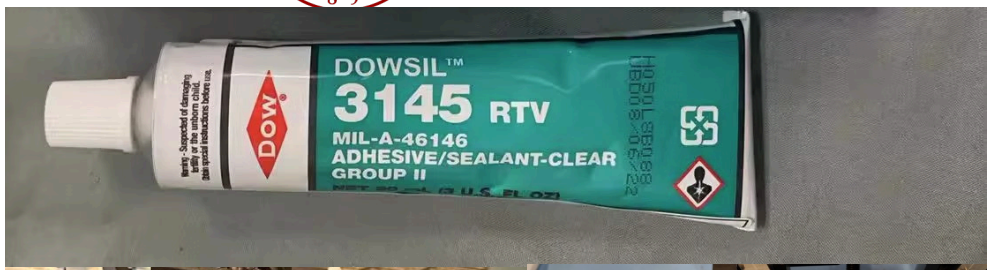
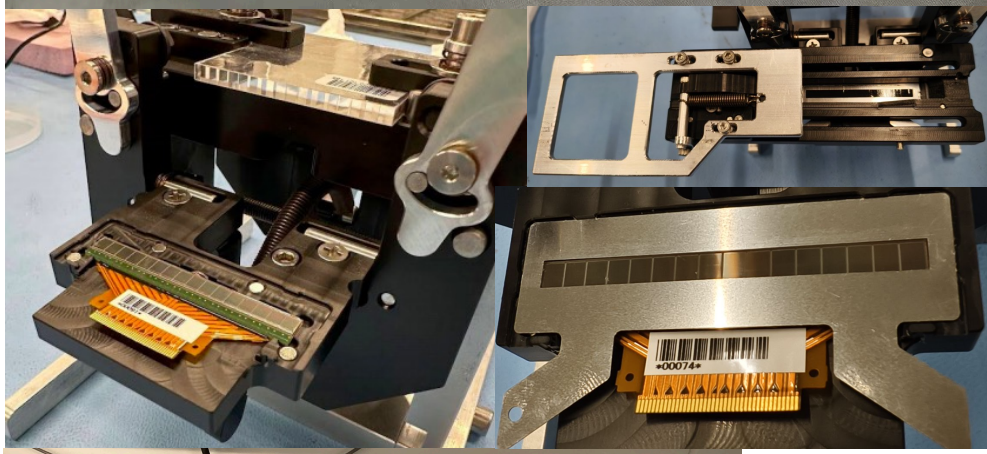
Assembly materials

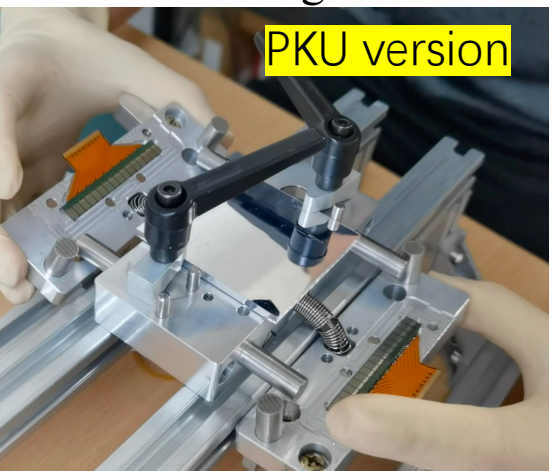
- RTV with a high refractive index close to that of crystals

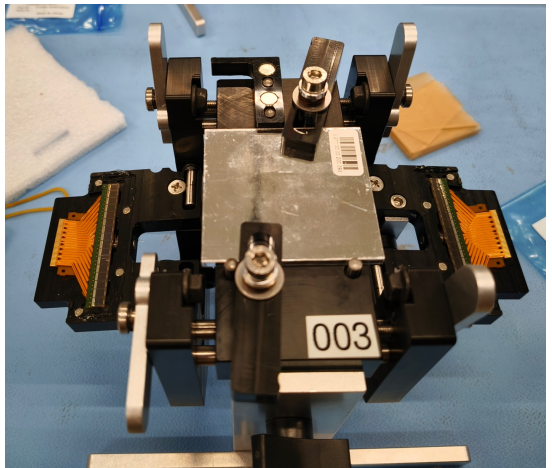


Assembly tool : GAMBIT

- **Custom GAMBIT tools control RTV thickness, SiPM/LYSO alignment, and tension during curing**
- Determine the position of LYSO crystal and perform calibration
- Ensure the stability of SiPM during the coupling process
- The gluing tools improvement have avoided human error factors during the assembly process







2.2 Assembly and QA/QC of Sensor Module

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GAMBIT performance tests and upgrade in the pre-production

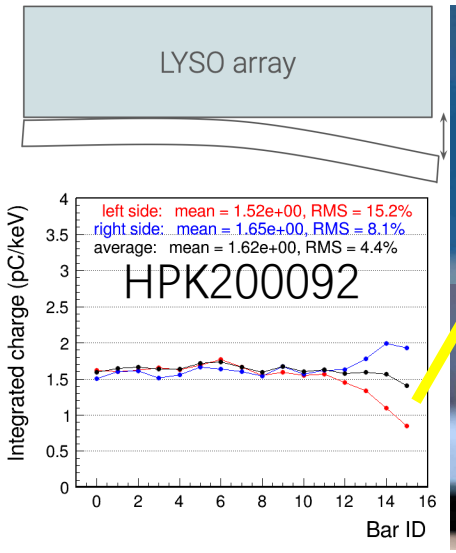
- Alignment of Crystal and SiPM → Adjust the height of the platform to approximately 200 μm
- Uneven adhesive thickness → Increasing the thickness of the Stencil and applying rubber bands for assistance

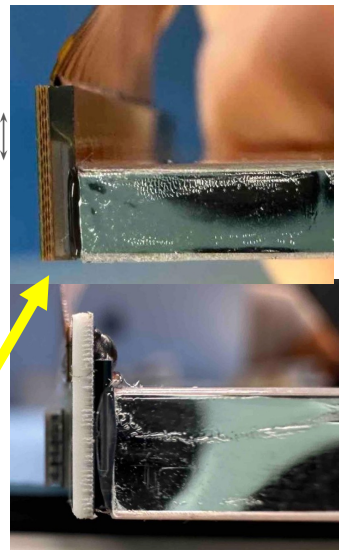
Standardization of Assembly flow

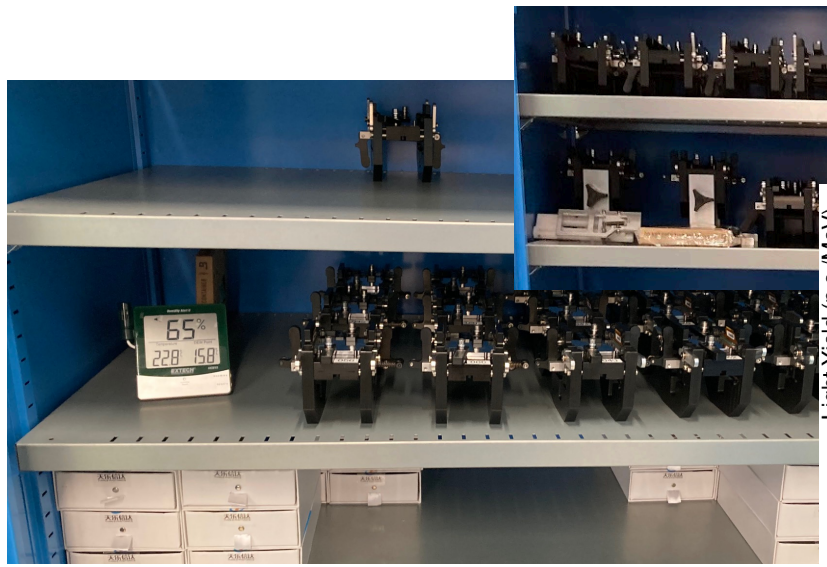
- Referring to the conditions that are most conducive to the uniform and smooth hardening of the RTV

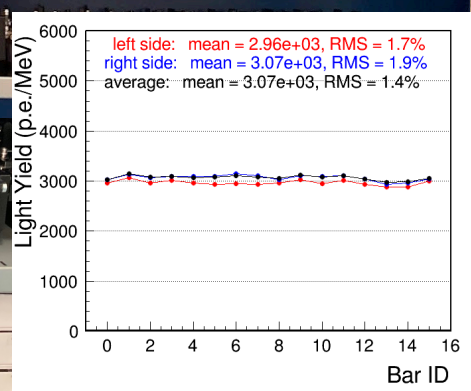
→ The humidity, time, and other ranges for placing the module after assembly have been standardized

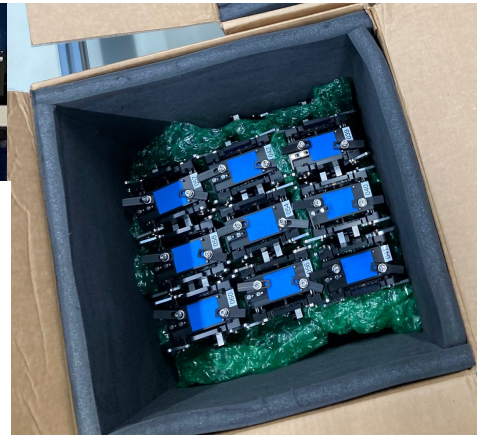
The development of LYSO+SiPM assembly tools GAMBIT has been completed and mass production has begun











2.2 Assembly and QA/QC of Sensor Module

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LYSO Intrinsic Spectrum

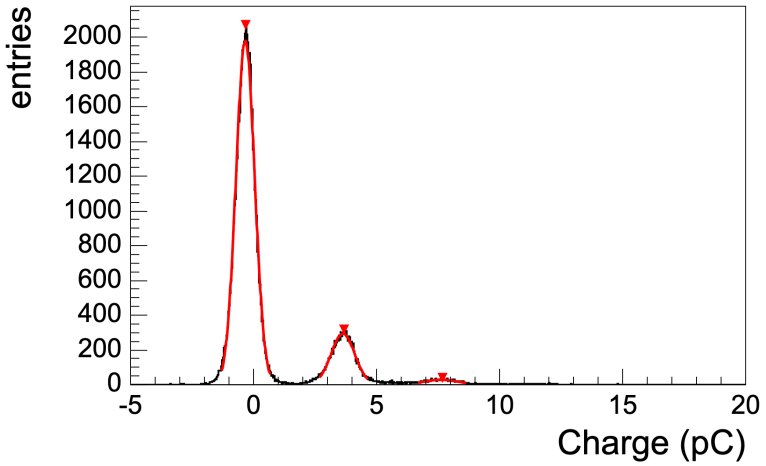
- ^{176}Lu: β decay → ^{176}Hf excited state: γ cascade decay
- 88 keV, 202 keV, 307 keV

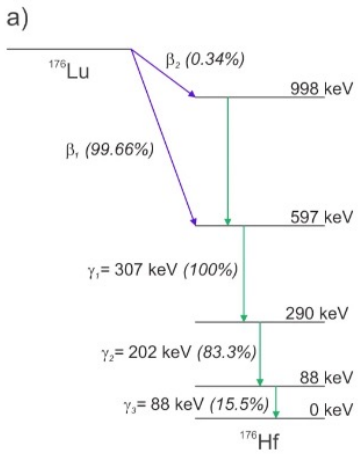
$$P(E) = \alpha_{88}\beta(E-88) + \alpha_{202}\delta(E-202) + \alpha_{290}\beta(E-290) + \alpha_{307}\delta(E-307) + \alpha_{395}\beta(E-395) + \alpha_{509}\delta(E-509) + \alpha_{597}\beta(E-597)$$

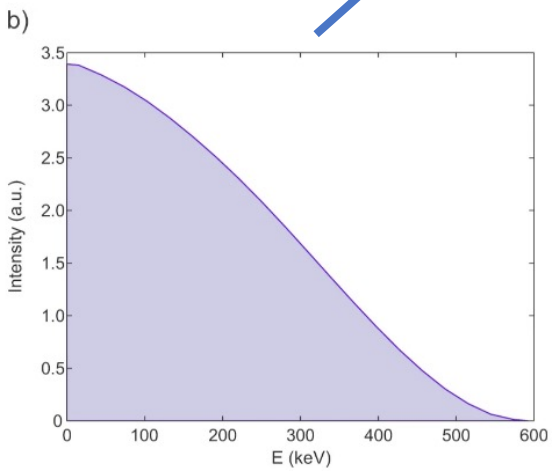
Single Photoelectron Charge

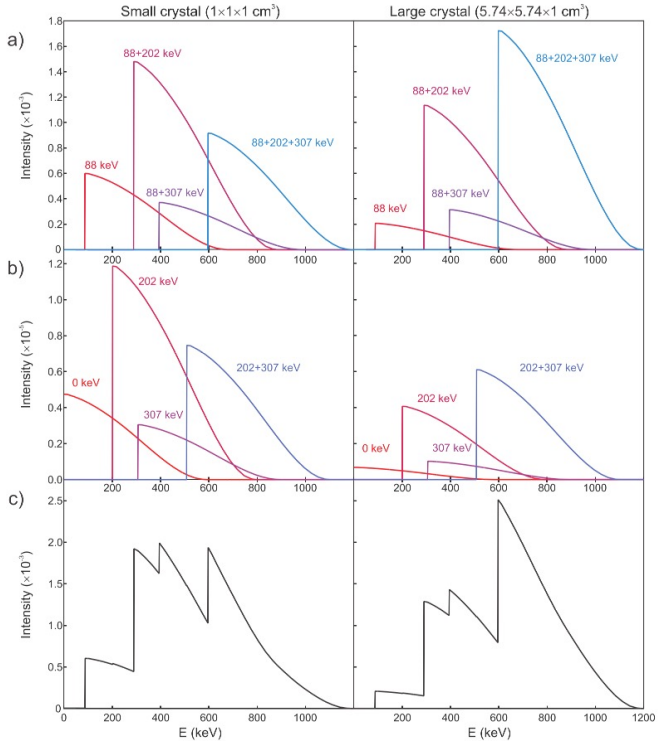
- SPE histogram presents the amount of charge carried by a single photon

The ratio is proportional to the light yield









2.2 Assembly and QA/QC of Sensor Module

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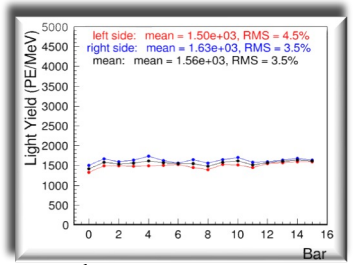
QA/QC of the Sensor module → Test its signal amplitude and uniformity

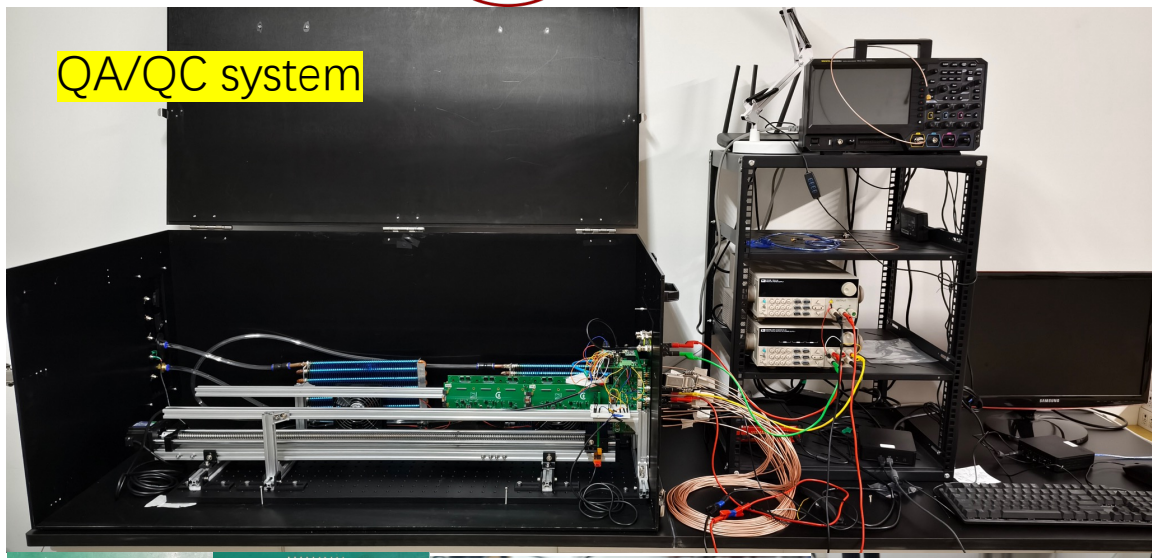
- Irradiating with a radioactive source
- Measurements including amplitude, time resolution, spectral type, crosstalk, as well as the performance of SiPM at different temperatures and TEC testing

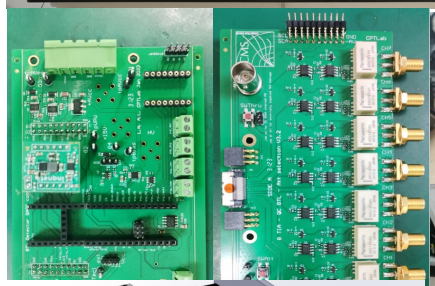


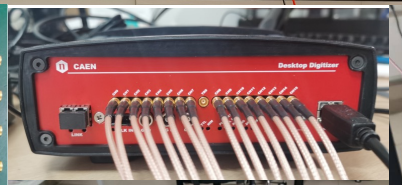
The QA/QC system (12 SM batch testing)

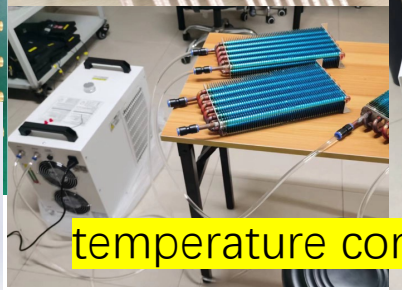
- Front amplification electronic module
- Constant temperature dark box and temperature control system
- Automated movement of radioactive sources
- The data collection system and other supporting structures

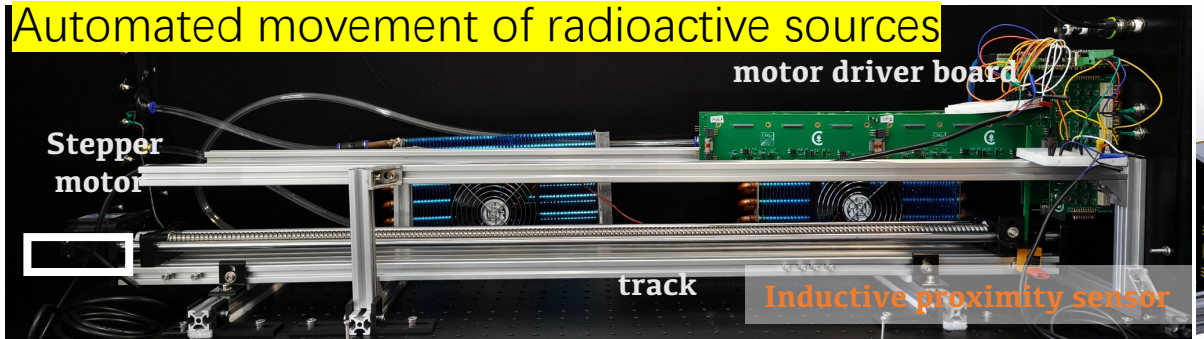
At present, the design of the QAQC system has been finalized, and the batch-produced board has been completed and provided to other BACs

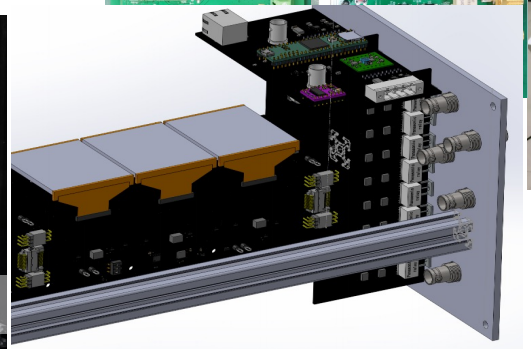












2.2 Assembly and QA/QC of Sensor Module

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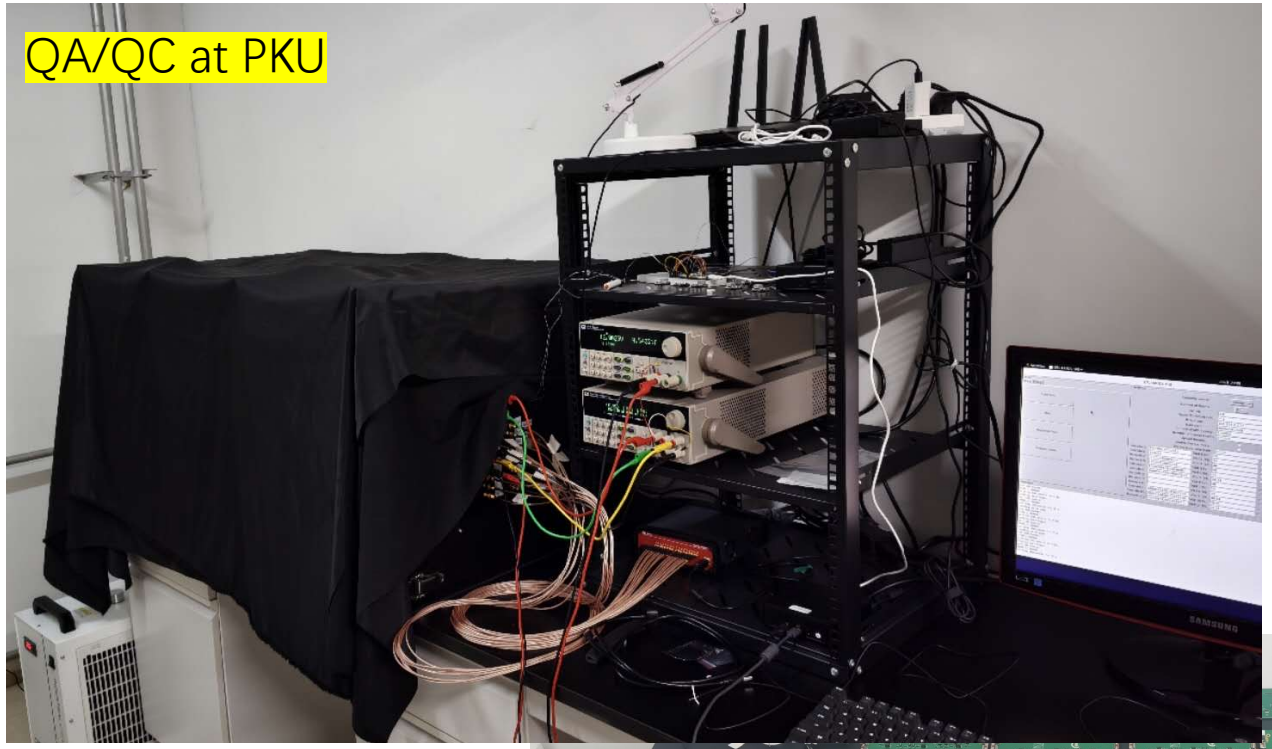
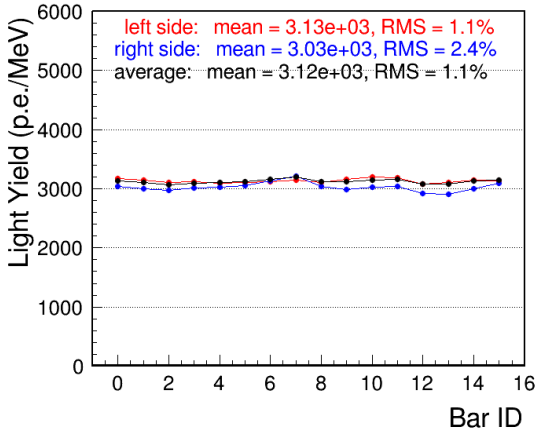
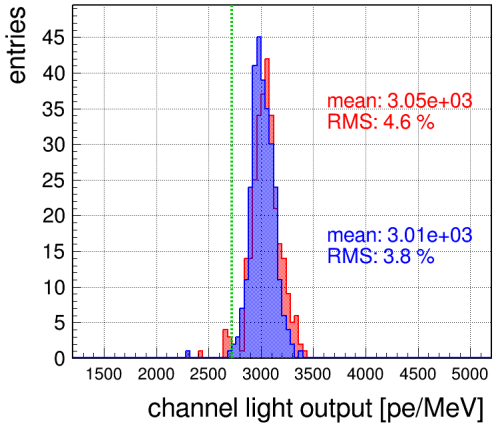
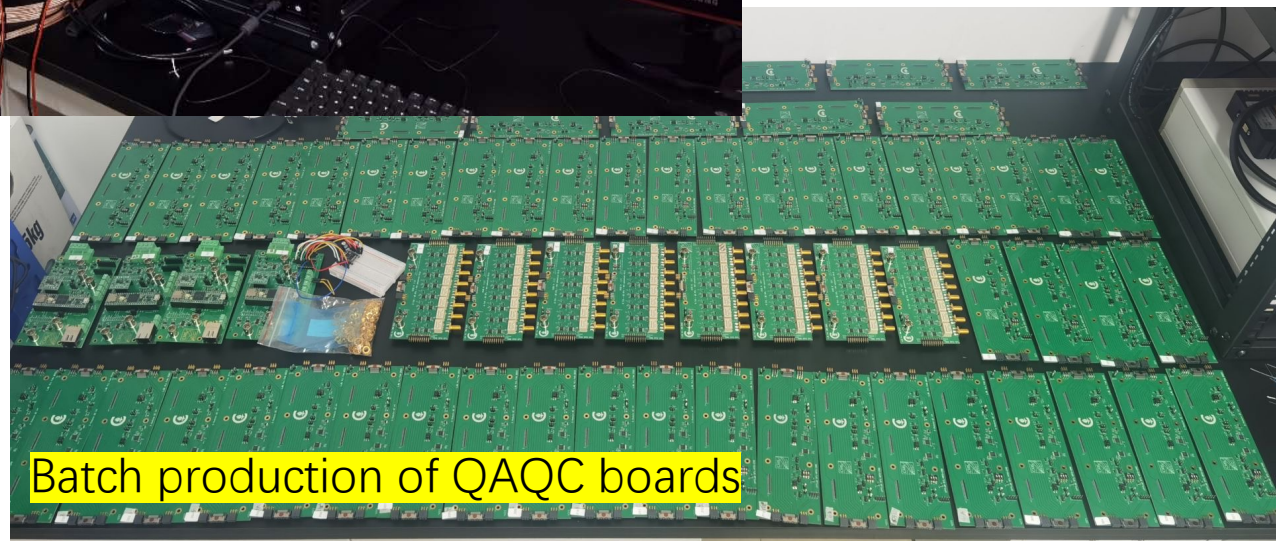
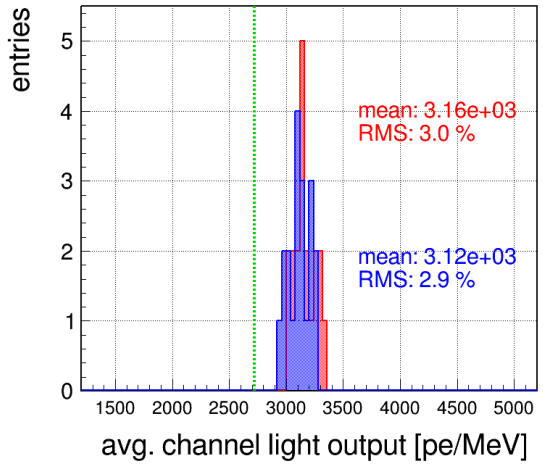






QAQC result of the SM for tray 1





2.3 Assembly and QA/QC of Detector Module

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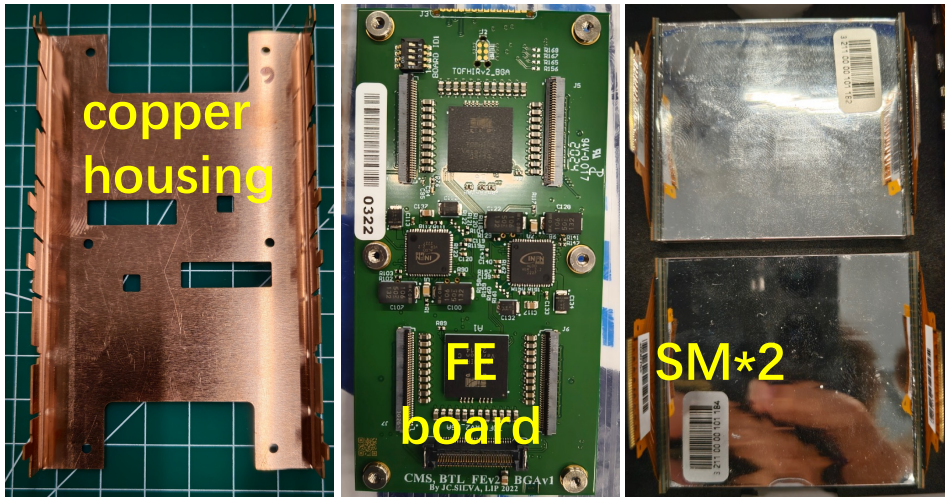
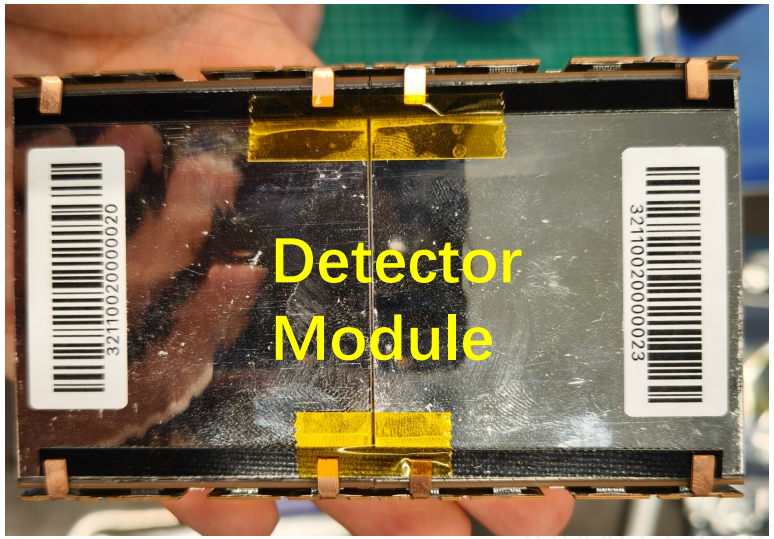
Detector Module : Sensor module, FE front-end electronic board, and copper shell for heat exchange



- FE board equipped with TOFHIR2 readout chip
  - ✓ obtain information such as the arrival time of signals at SiPM
  - ✓ It can ensure a Tres of better than 60ps the entire HL-LHC period

Assembly process of DM: **Thermal contact**

- Good contact between the outer end of TEC on SiPM and the copper
- Coverage of thermal pads on important chip surfaces on FE board
- Avoid contact between LYSO crystals and other components



At present, the latest version has undergone module assembly testing and the process flow has been basically determined.

The thermal contact implementation effect is good.

2.3 Assembly and QA/QC of Detector Module

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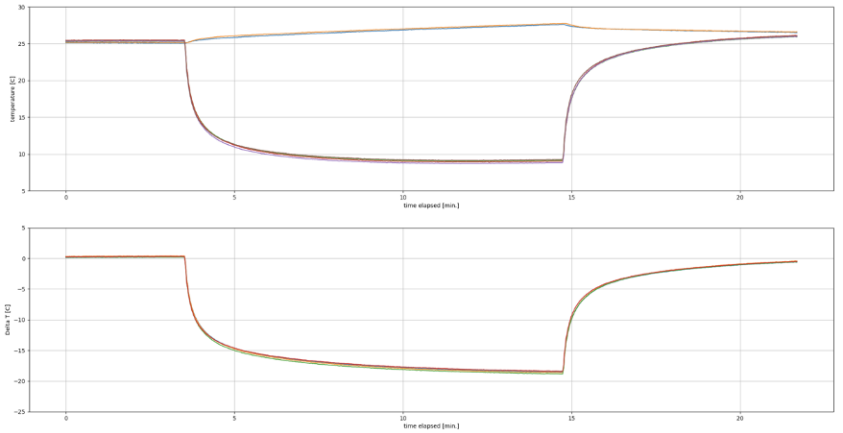
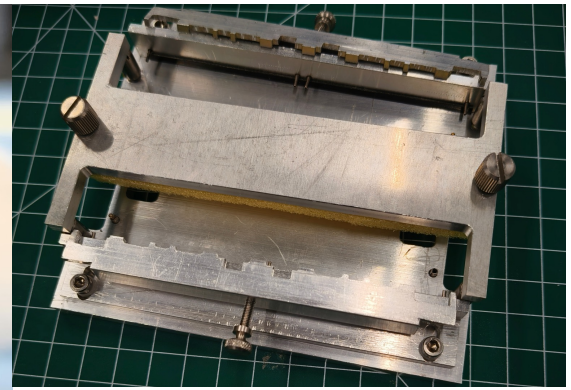
QA/QC of the DM mainly involves thermal coupling testing

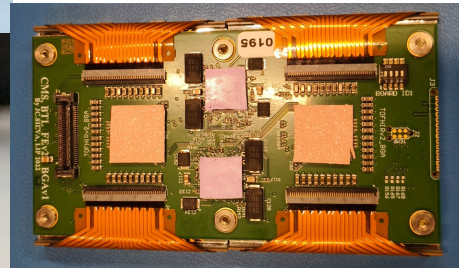
- the contact between the TEC and the Cooper shell
- the TEC working after power on

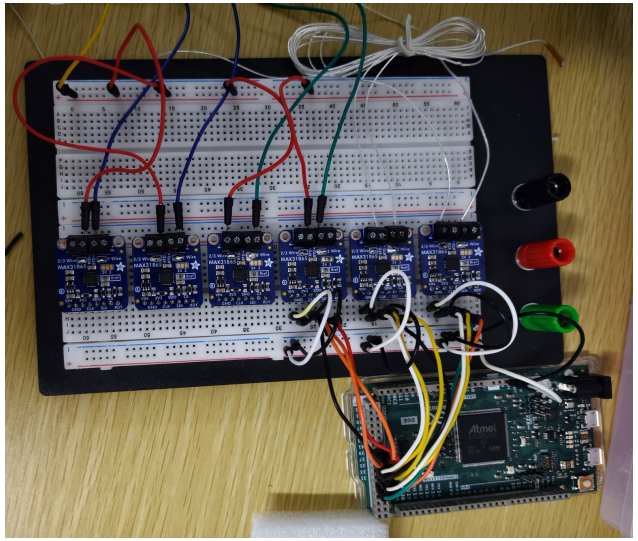


At present, Peking University has established a single module 6-channel QA/QC system.

Further work on the automation implementation to improve its work efficiency







2.4 Assembly and QA/QC of BTL Tray

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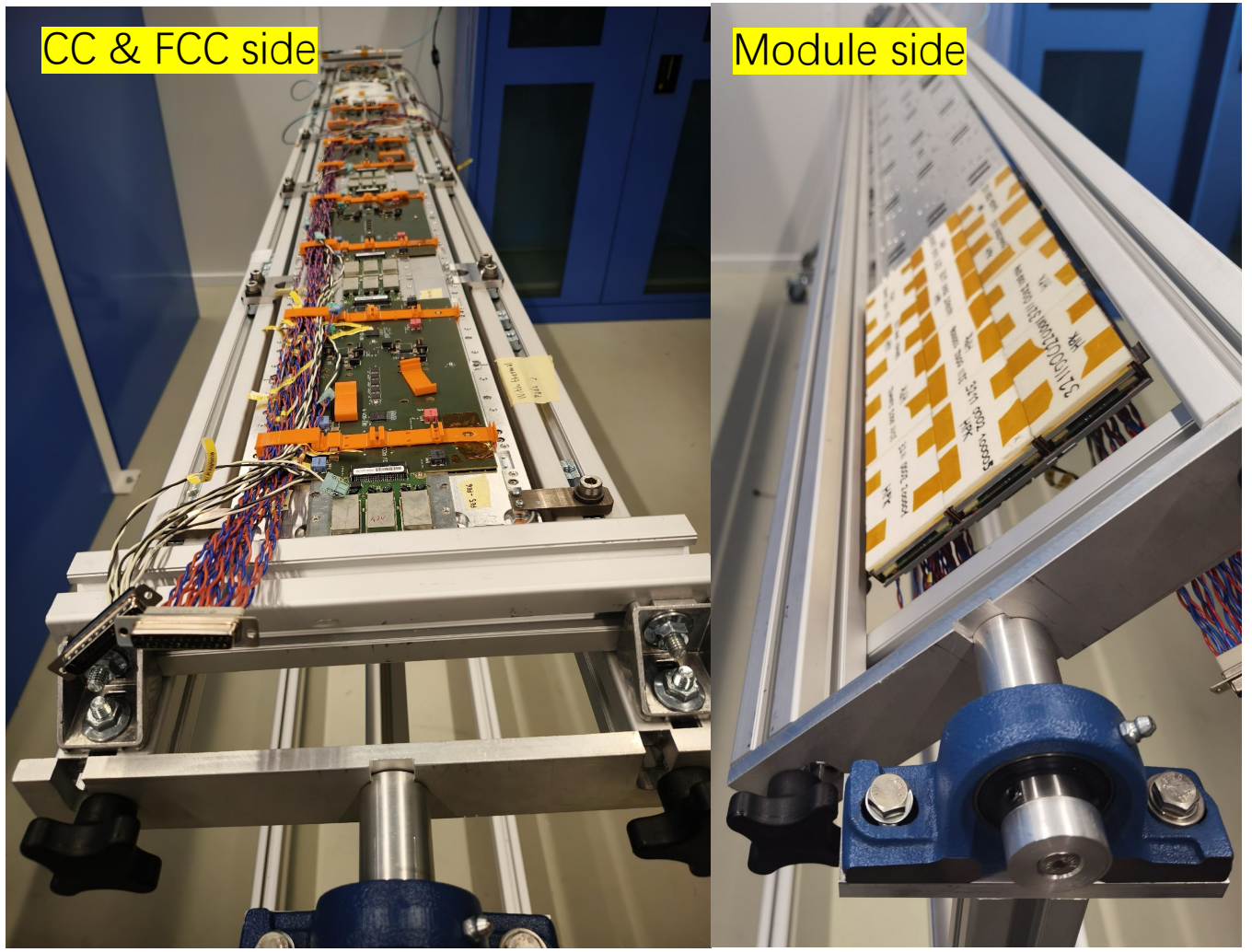
MTD BTL Tray

- A BTL Tray will cover a detector range of 10 degrees and 2.5 meters at η
- A total of 72 Trays cover the entire barrel of the MTD time detector

Each tray consists of 6 Readout Units

- Each RU includes a cooling plate, CC board, PCC board, and 12 DMs.
- The acquisition of time, temperature, etc. has been achieved
- Cooling plate and CO2 circulation installed on it ensure the normal operation of the module and chip



2.4 Assembly and QA/QC of BTL Tray

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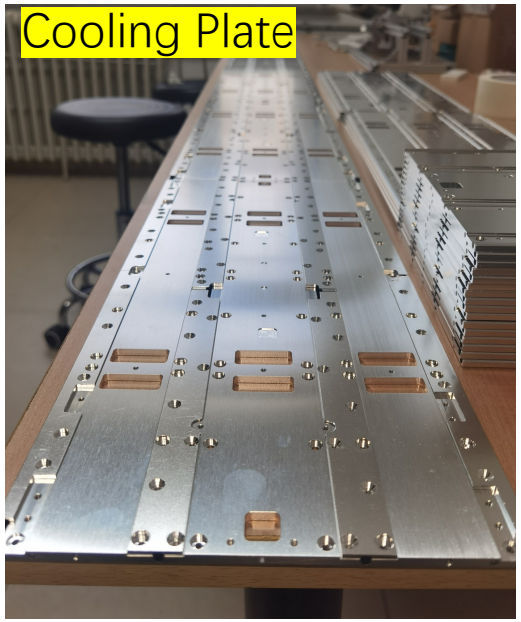
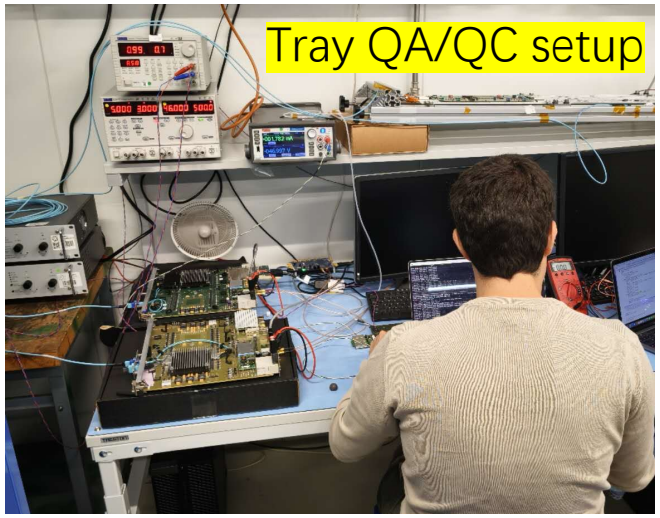
Tray assembly and QAQC

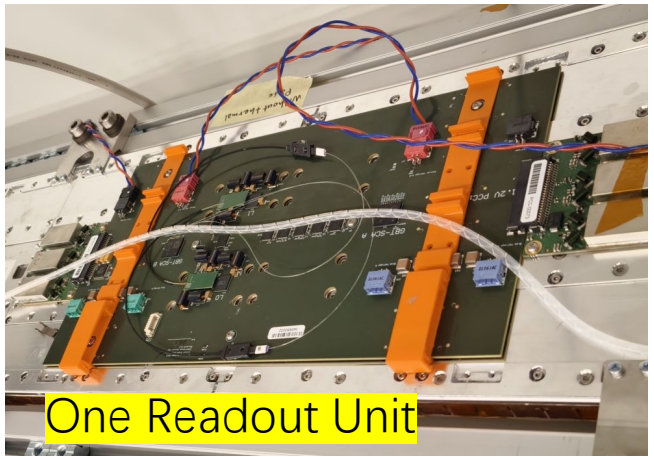
- In March 2024, the first RU was established during the pre-production phase at CERN
- The first 5 sets of Cooling Plates used for cooling testing were produced by PKU and sent to CERN and each BACs
  - Assembly research, cooling testing, and transport testing.

- Offline testing requires additional testing of the power supply system, which has been completed
- **The first tray of production has been completed at CERN (July 2024) and the final tray Assambly process is being finalized**

- The tray QA/QC system based on Serenity board is currently being established.
  - Tray one is currently undergoing QA/QC, including bias power supply, temperature testing, etc., while optimizing QA/QC







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03 Progress on MTD BTL Detector

3.1 MTD BTL Sensor design

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- The MTD pre ADR and SiPMs PRR conference will be held on June 8, 2023
- CMS collaboration team reviews MTD BTL sensor design
- This meeting is one of the milestones of the MTD project
  - **The engineering design scheme for the BTL sensor was approved**
  - **Set the parameters of SiPM**
  - **Selected manufacturers for batch ordering**
- The Chinese MTD BTL team (北大，清华，北航) is one of the main contributors to sensor research

SiPM technical choices and specifications, and overall performance results

SiPM Procurement Readiness Review

8 June 2023

3.2 Detector module workshop

The first complete **detector module** was produced **at CERN by the end of 2023**

Laying the foundation for the **manufacturing process** of detector modules

3.3 Gluing & Assembly Workshop

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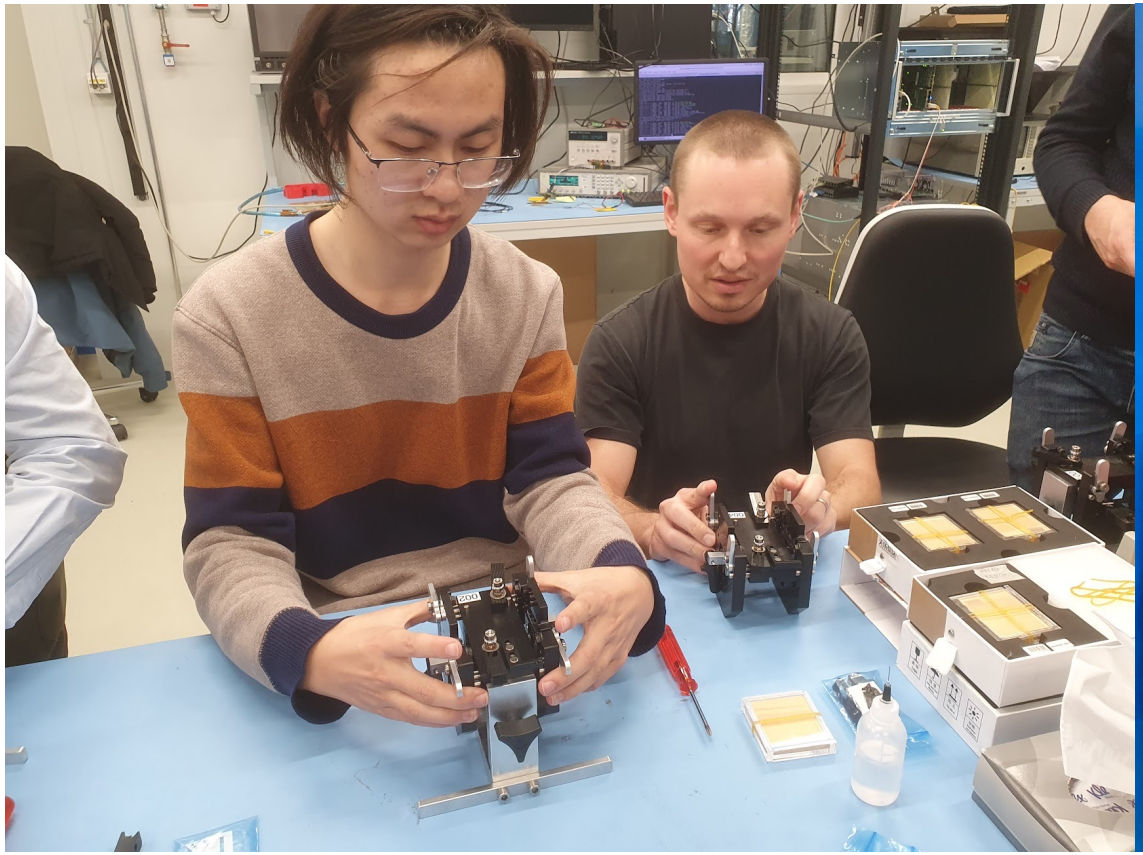
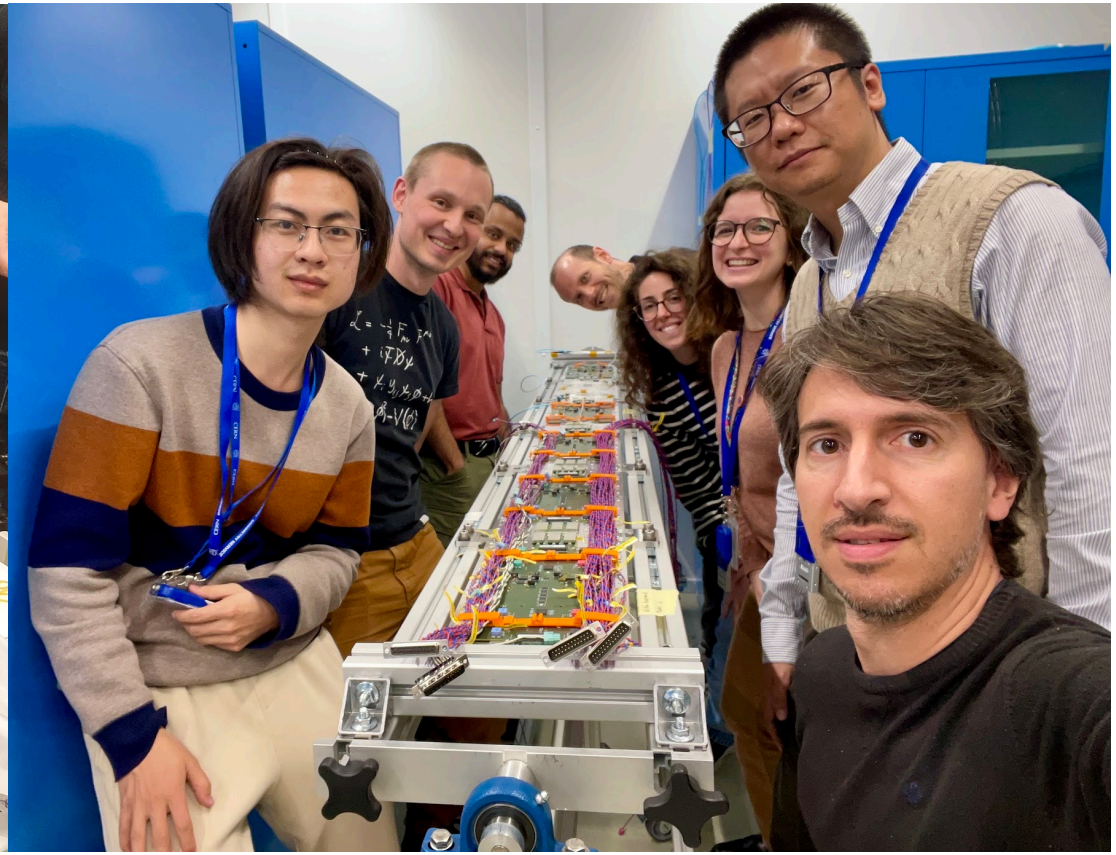
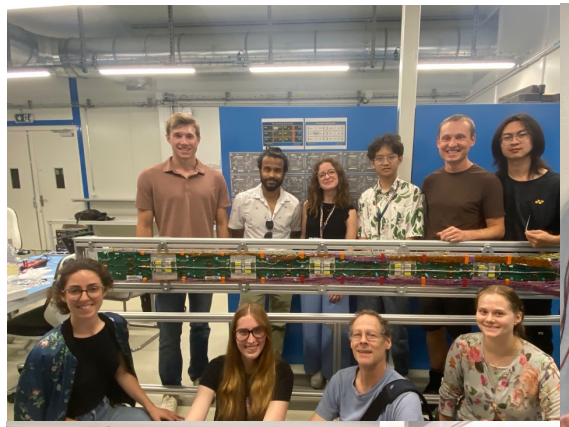
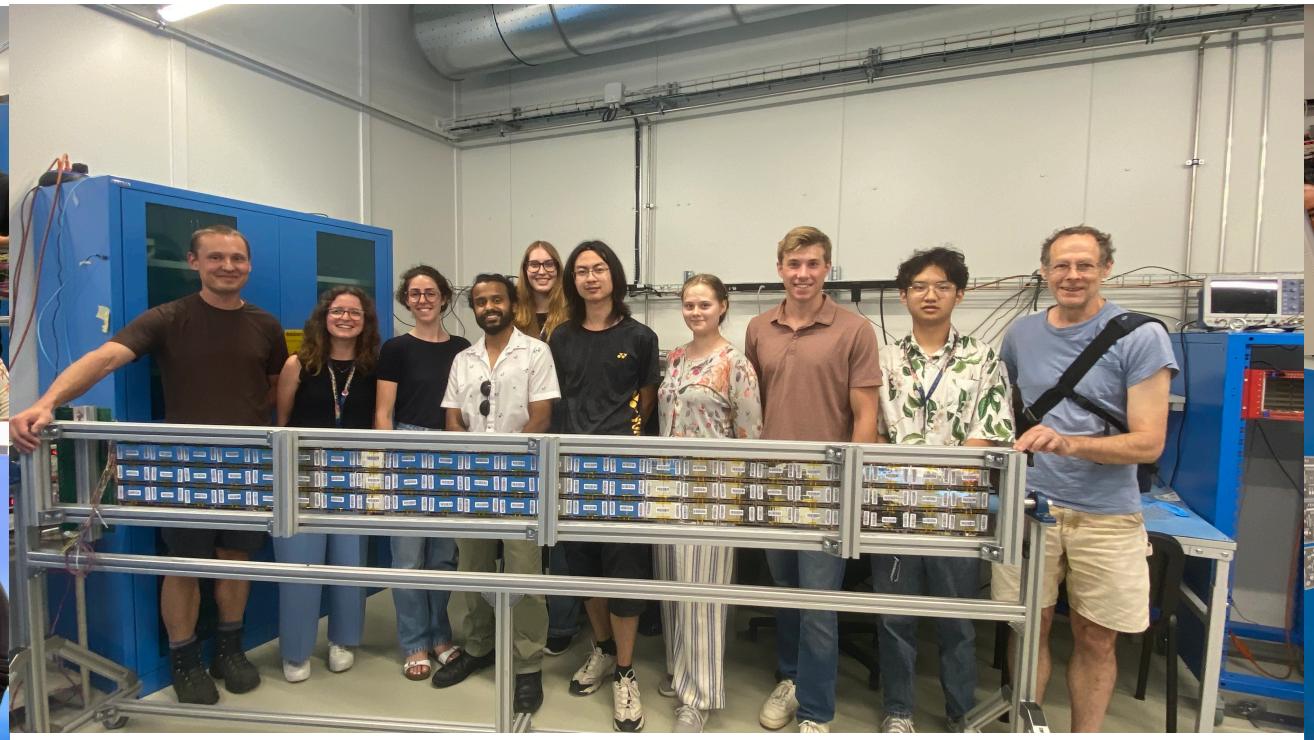




In March 2024 at CERN,
Complete the assembly of the whole RU for the first time

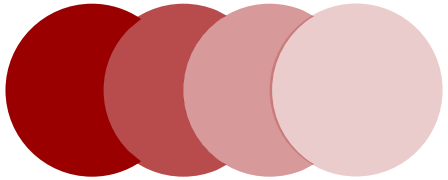
3.4 MTD BTL Tray Workshop


In July 2024, at CERN,

Comepleted the assembly of the entire Tray for the first time,

QA/QC was carried out, and the assembly process was basically determined



04 Summary and Plan

Summary and Plan

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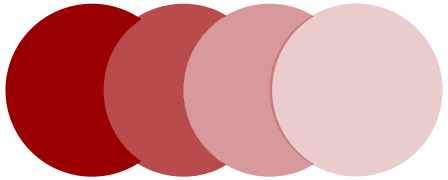
Summary

- ✓ Optimized sensor design through TB, finalize plan, and pass CMS review
- ✓ Completed the construction of the QA/QC and conduct small-scale module tests
- ✓ The assembly scheme of SM, DM, and BTL Tray has been basically determined
- ✓ Completed the assembly of the first Tray and QA/QC

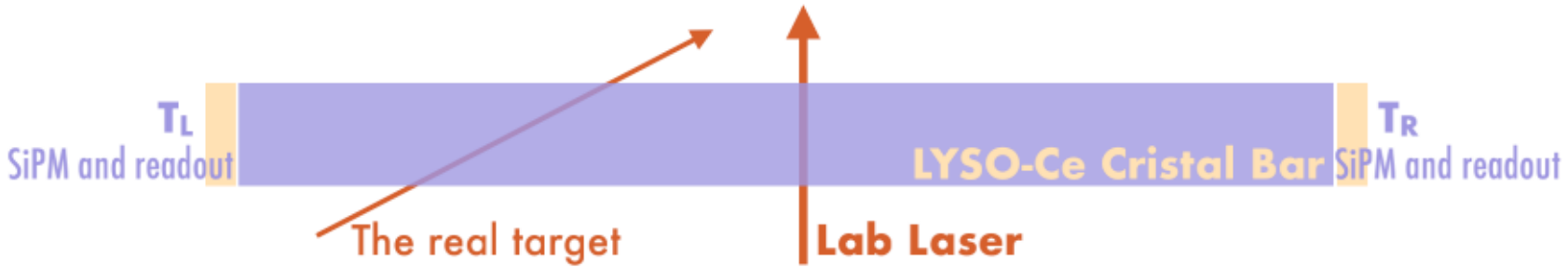
Plan

- ➢ Determine the final assembly plan
- ➢ Improve the QA/QC system
- ➢ Accept assembly batches of SiPM and LYSO for production
- ➢ In September 2024, assembly work will start

Thanks for your attention!



Back up



$$T_{ave} = 1/2(T_L + T_R) \qquad \sigma_{ave} = 1/2\sqrt{\sigma_L^2 + \sigma_R^2}$$

$$\sigma_{diff} = 2 \times \sigma_{ave}$$

$$T_{diff} = T_L - T_R \qquad \sigma_{diff} = \sqrt{\sigma_L^2 + \sigma_R^2}$$