CMS Barrel Timing Detector Assembly

Jin Wang on behalf of MTD China BTL group

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01 CMS MTD BTL Detector for HL-LHC

Physics motivation of MTD

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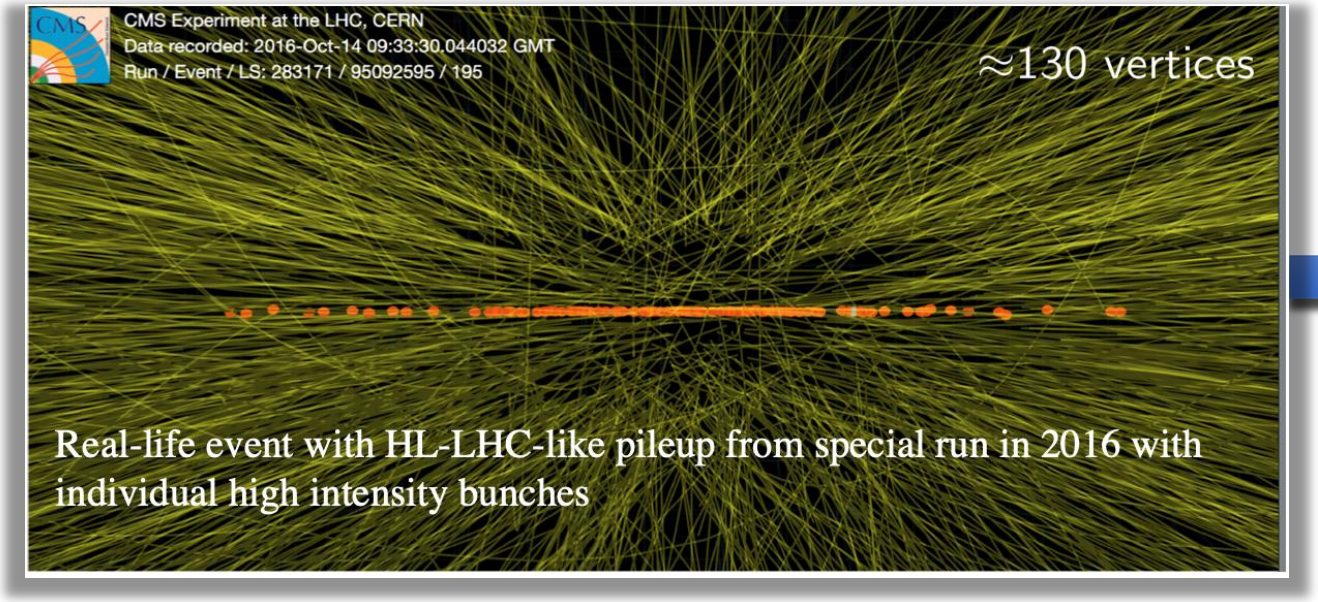
High luminosity → High pileup

- The MTD is a new CMS Phase-II detector for the HL-LHC
- It will be added to CMS to help meet the challenge of high luminosity.

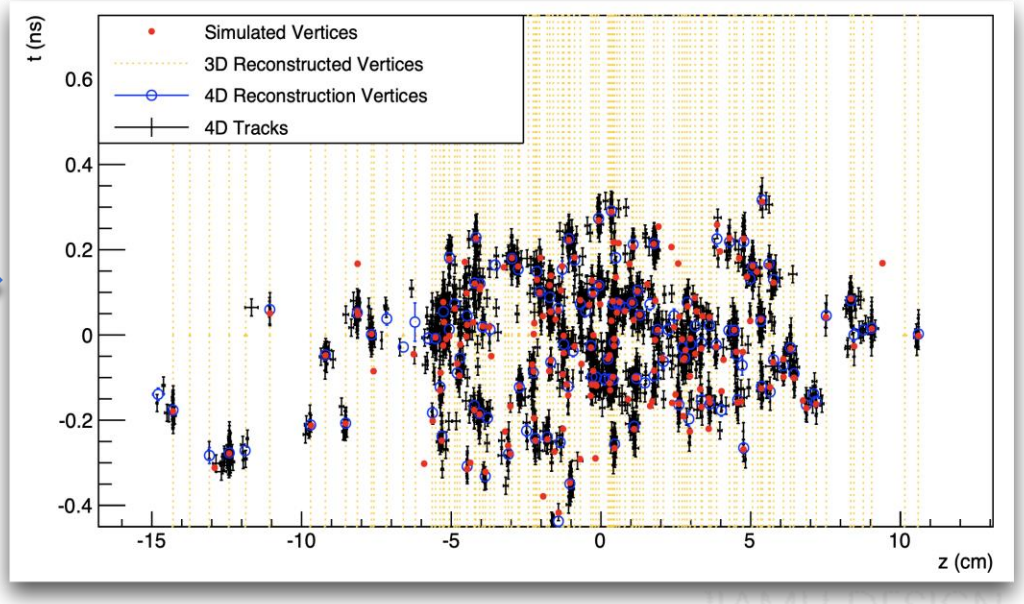


MTD can effectively suppress pileup, improving the overall accuracy of physical measurements

- It improves the precision of single Higgs measurements by 20-30%
- It increases the acceptance of Di-Higgs signals by 20%

MTD provides TOF information

- It reduces reducible background by 40% in the search for SUSY particles
- It significantly enhances sensitivity to long-lived particles



What is MTD BTL ?

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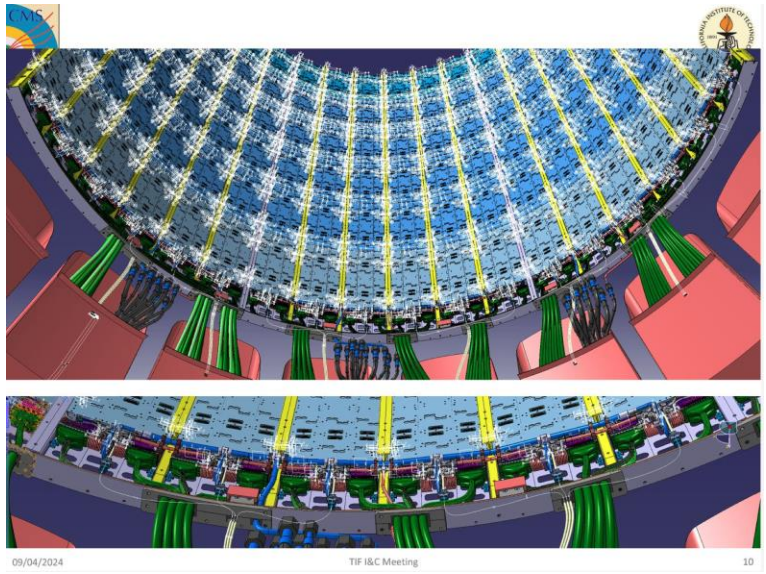
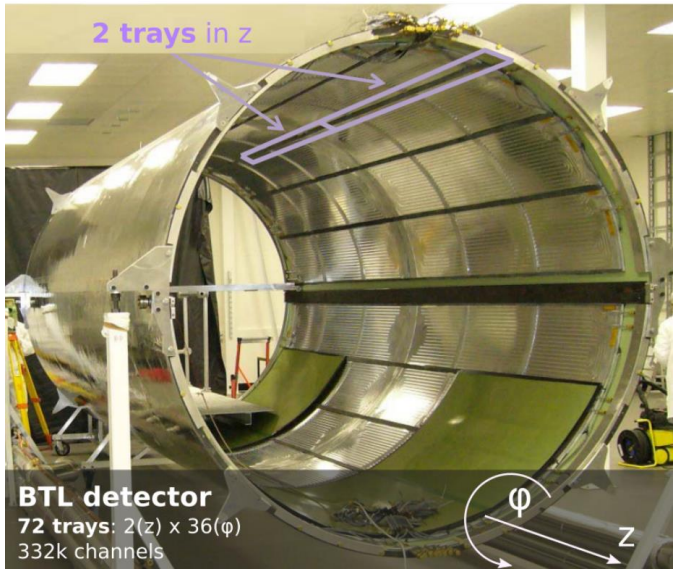
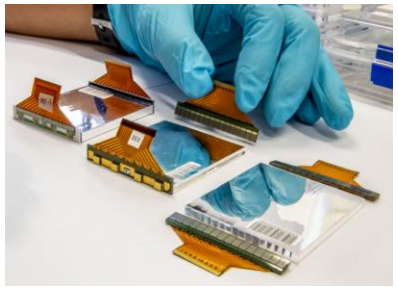
BTL (Barrel Timing Layer) provides high-precision timing in the barrel region, which is a single-layer MIP detector located in-between the outer tracker (OT) and the inner wall of the BTL-Tracker Support Tube (BTST).

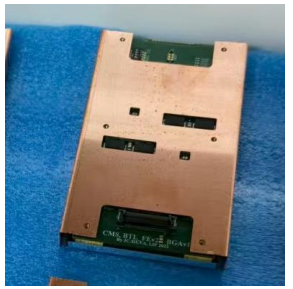
- Thin (< 4 cm), large area (38 m^2) detector covering $|\eta| < 1.5$
- ~10k Sensor Modules, each containing 16 LYSO crystal bars and two 16-channel SiPM arrays
- Read out with custom TOFHIR2 ASIC
- **Mounted on CO2 cooled trays** and installed on inner surface of BTL Tracker Support Tube (BTST)

It will measure time with ~30-60ps resolution !

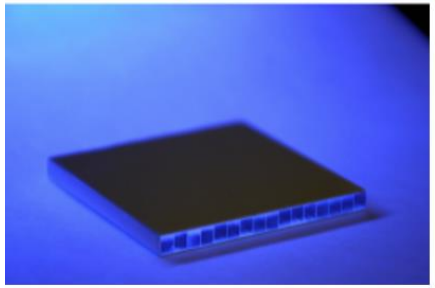


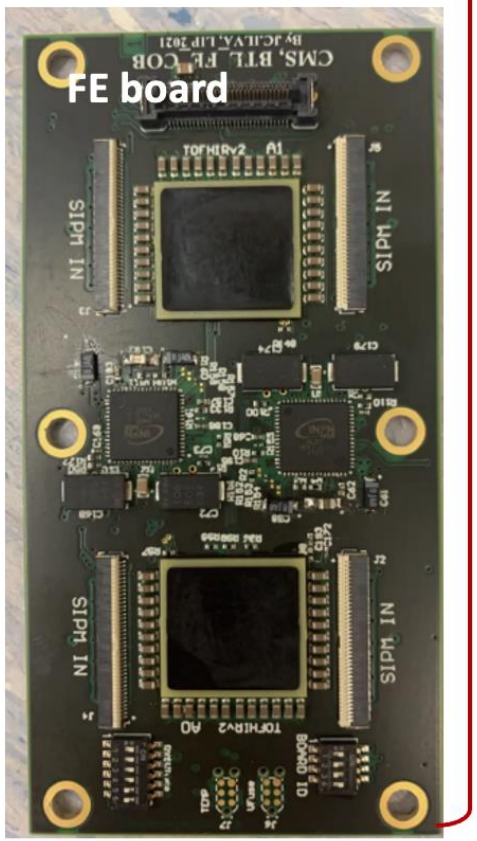


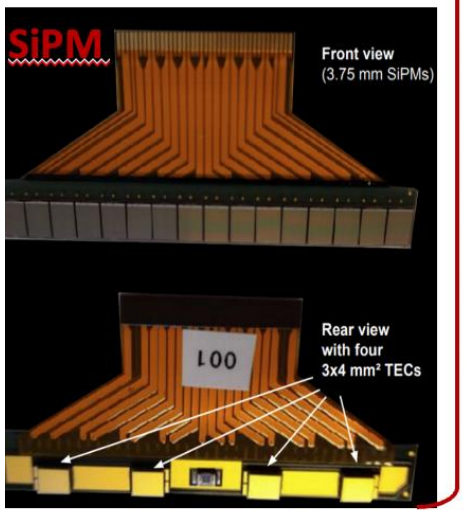


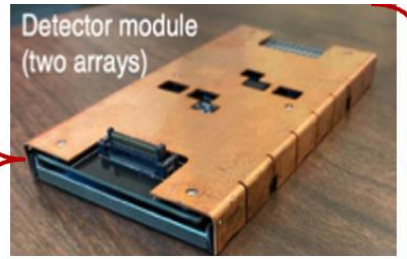


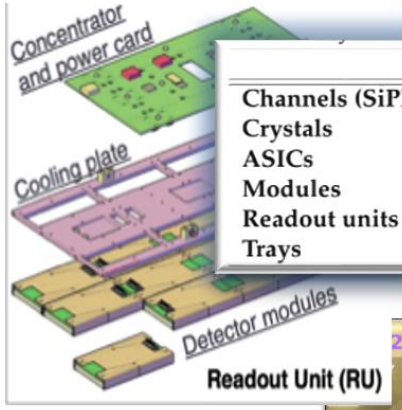
BTL Assembly Workflow Overview



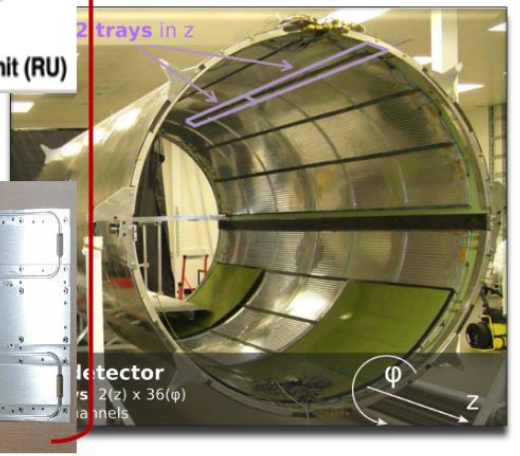








	Module	RU	Tray	Total
Channels (SiPMs)	32	768	4608	331776
Crystals	16	384	2304	165888
ASICs	1	24	144	10368
Modules	-	24	144	10368
Readout units (RU)	-	-	6	432
Trays	-	-	-	72



Cooling Plate

Cooling plate assembly and QC is ongoing at CERN

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

- Virginia
- Caltech
- Milan
- Beijing

Trays will be shipped to CERN, integrated into the BTST

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02 MTD BTL Module Assembly and QA/QC

Assembly and QA/QC of Sensor Module

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Assembly materials

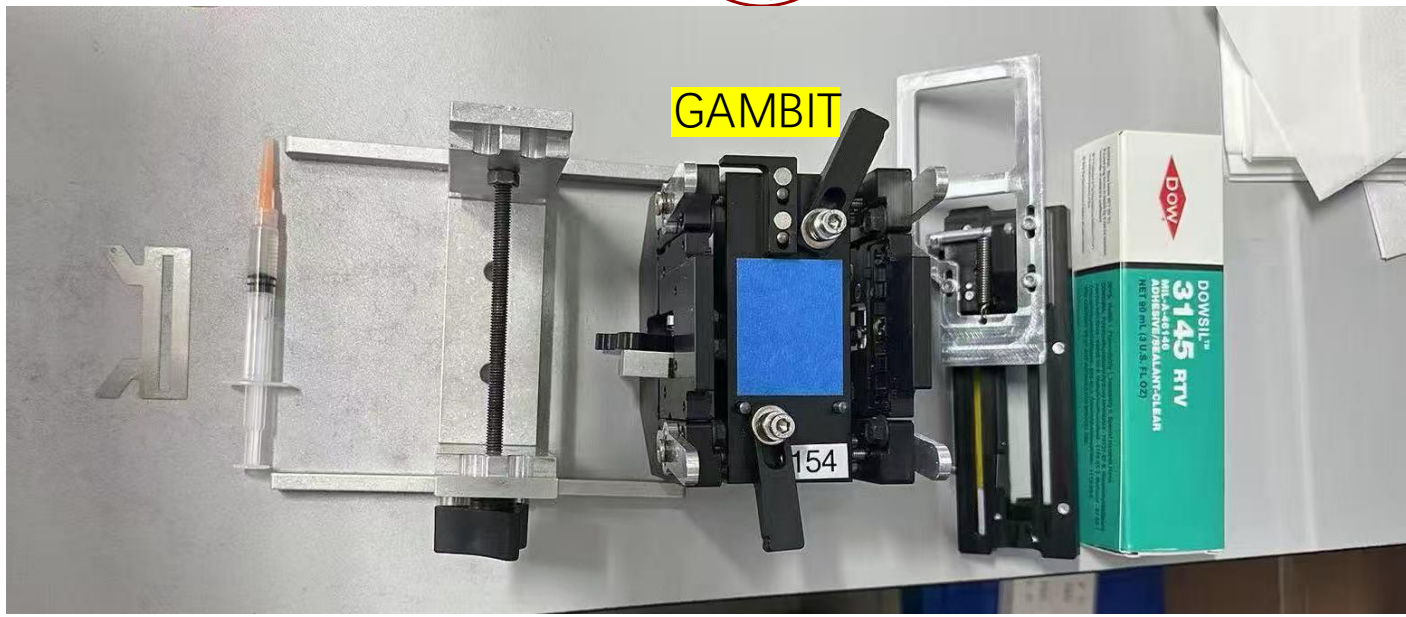
- RTV with a high refractive index close to that of LYSO

Assembly tool : GAMBIT

➢ **Control RTV thickness, SiPM/LYSO alignment, and others**

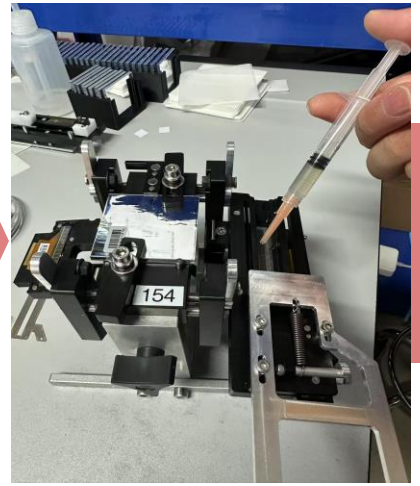
Standardization of Assembly flow

- The humidity, time, and other ranges for placing the module

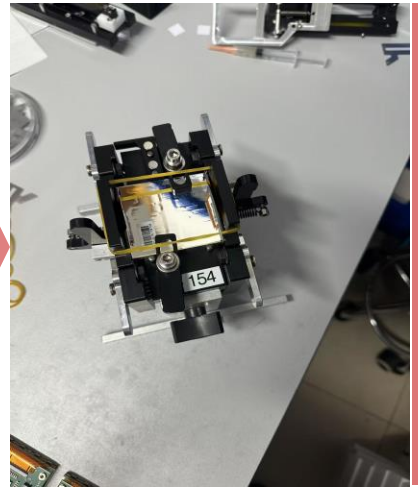


Put RTVA

Use RTVA to brush the glue



Lift cup and add rubber ring



Keep it in the box with humidity 40%-60% for 24h

Assembly and QA/QC of Sensor Module

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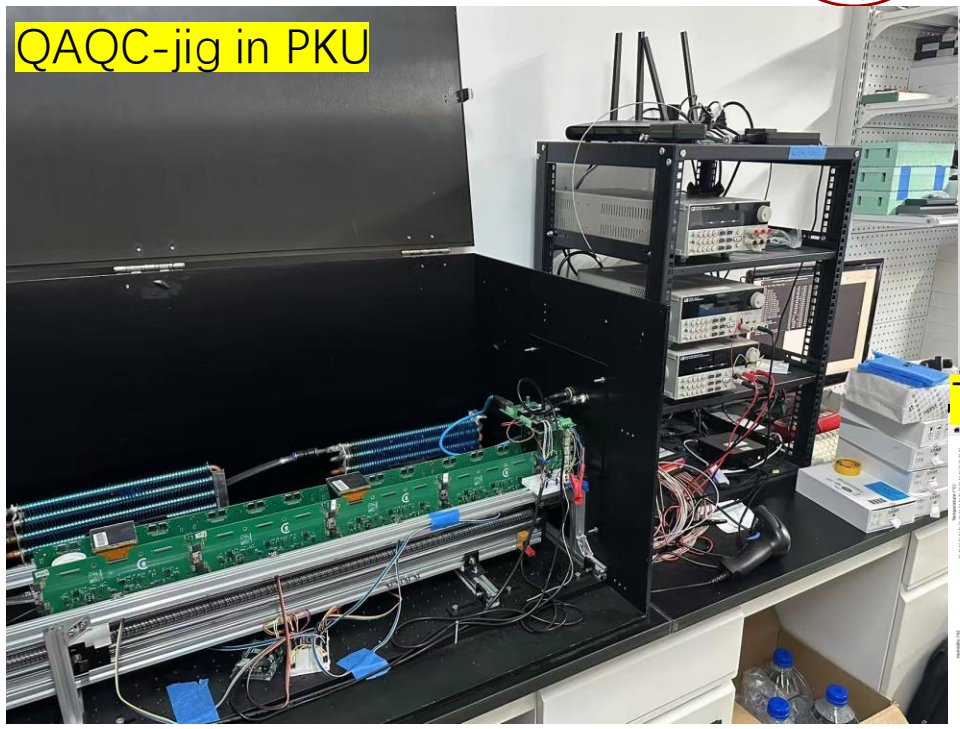
QA/QC of Sensor Module

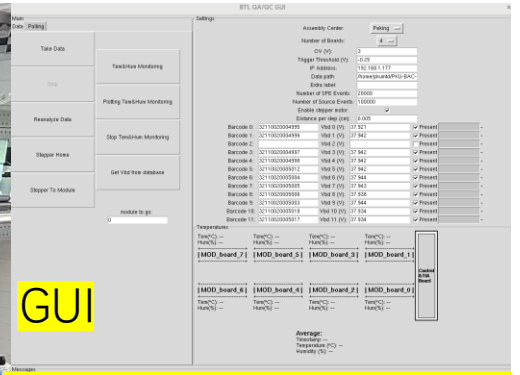
- Using Na22 as the source and the 511 keV photon from the annihilation of electron and positron as the signal
- Components: Electronic module, constant temperature dark box, data collection system, and source movement system
- Measure the light yield of each channel to show the assembly quality

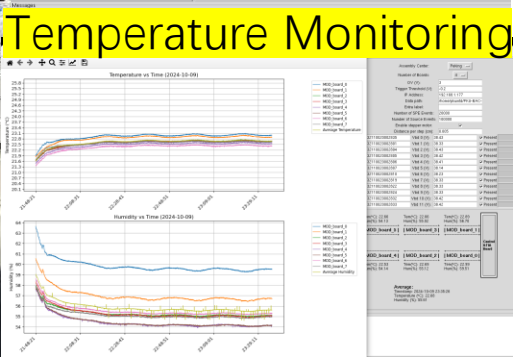
✓ **Students from Peking University, Tsinghua University, and Beihang University have participated in the assembly work together.**

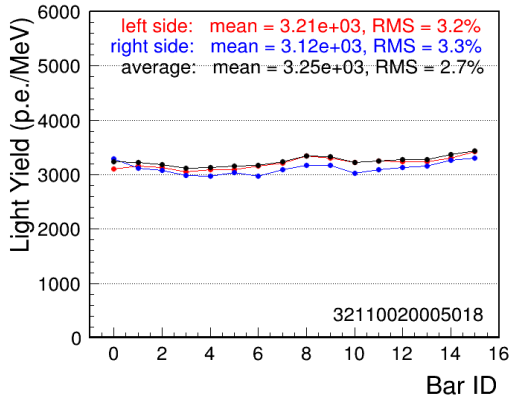
✓ As of July, the assembly and QA/QC of all SMs have been completed

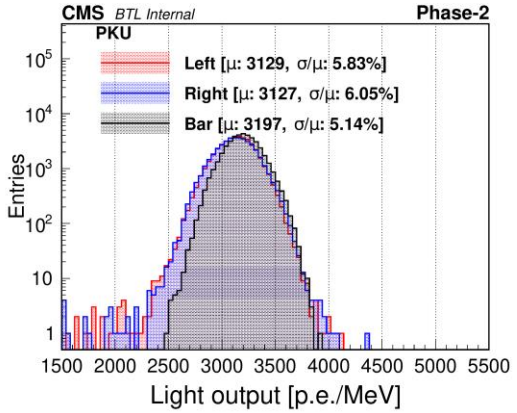
✓ The SM good product rate is above **95%**

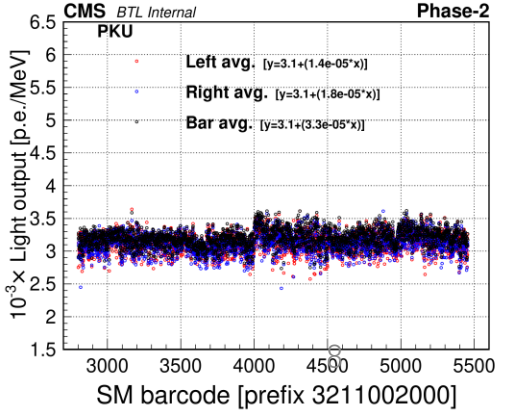












Assembly and QA/QC of Detector Module

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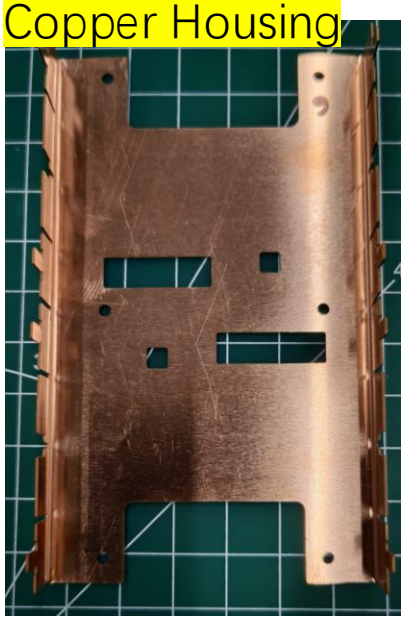
Detector Module : Sensor module, FE front-end electronic board, and copper shell for heat exchange

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

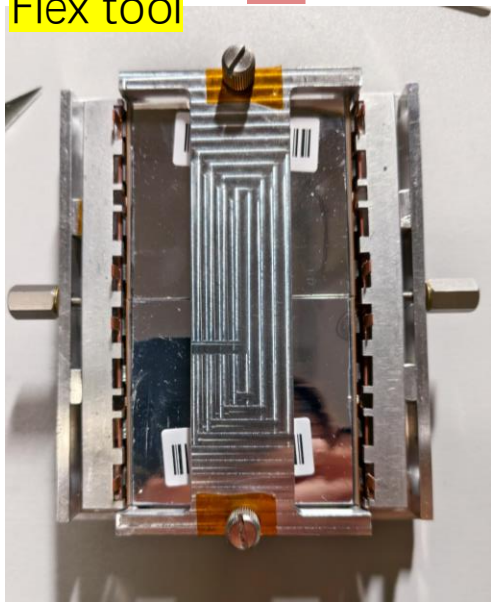
Copper Housing

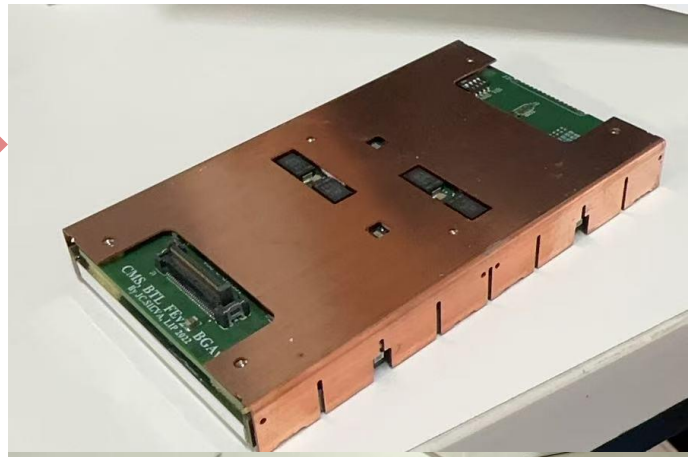


Front-end

2* Sensor Modules

Flex tool





Assembly and QA/QC of Detector Module

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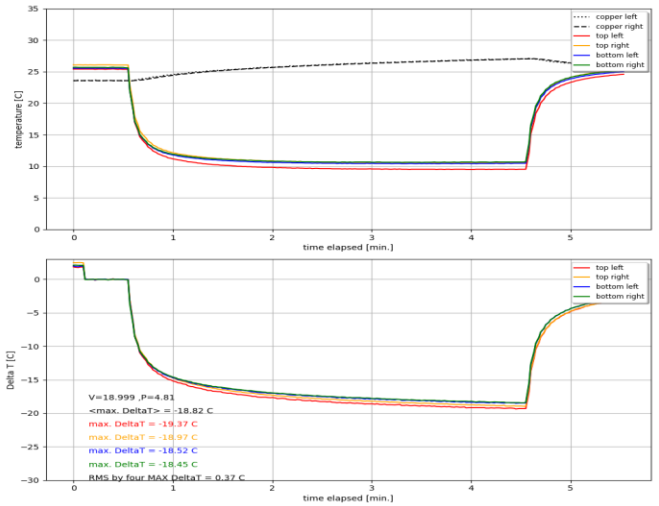
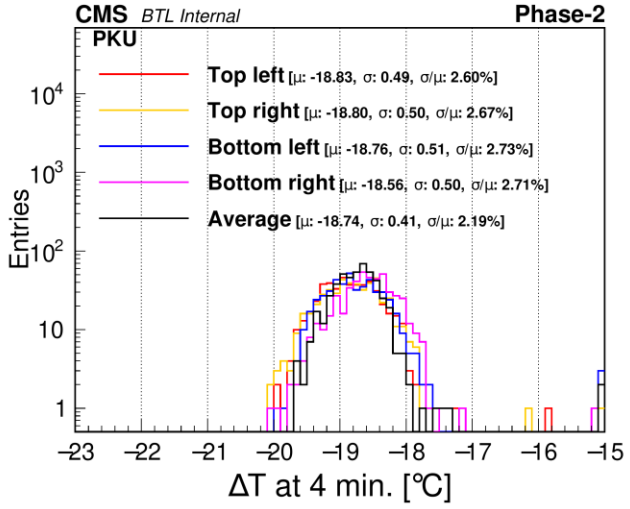
DM QAQC

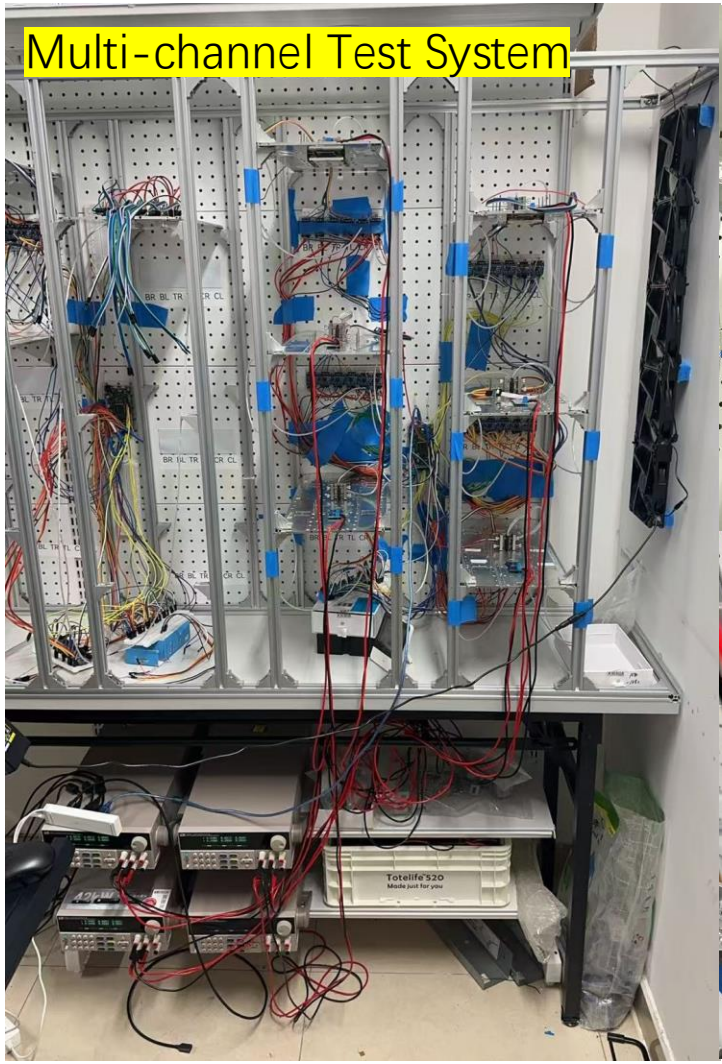
- About 600 DMs are assembled, and 500 have been tested
- **Using multi-channel test system**
- Test resistence of each DM
- Test delta T between cold plate and SiPM 4 minutes after applying the high voltage

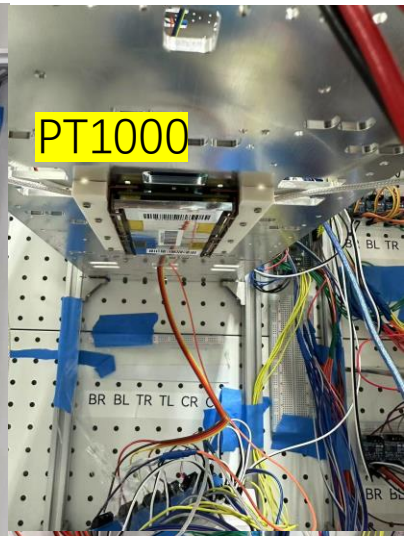
✓ **Students from Peking University, and Beihang University have participated in the assembly work together.**

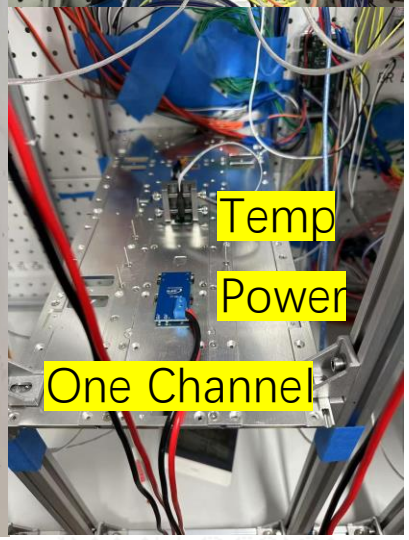
✓ The DM good product rate is above 98%











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03 MTD BTL Tray Integration and QA/QC

BTL Tray Mounting and Integration

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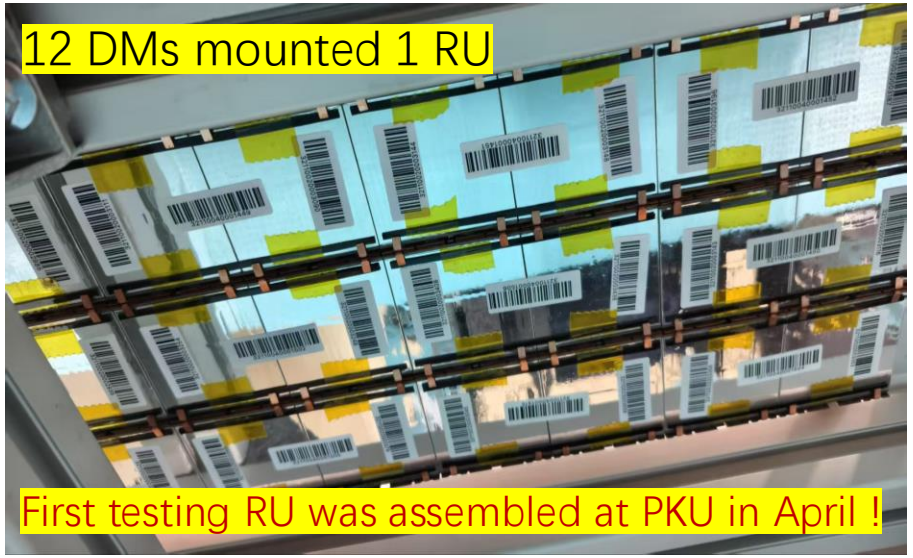
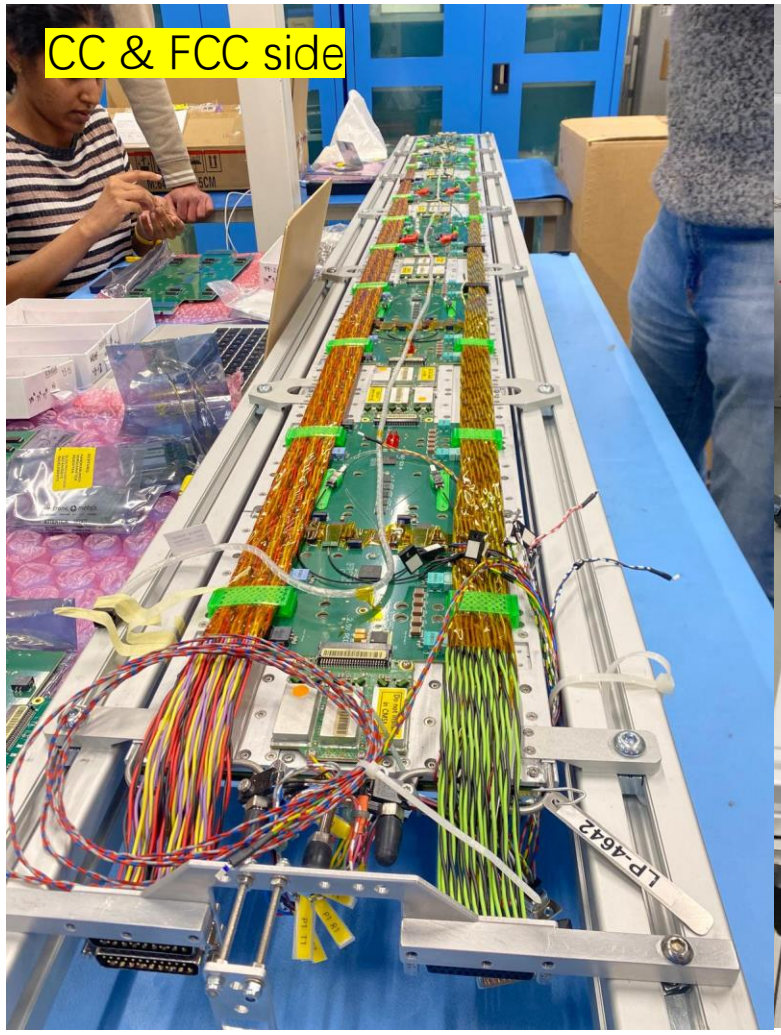
MTD BTL Tray

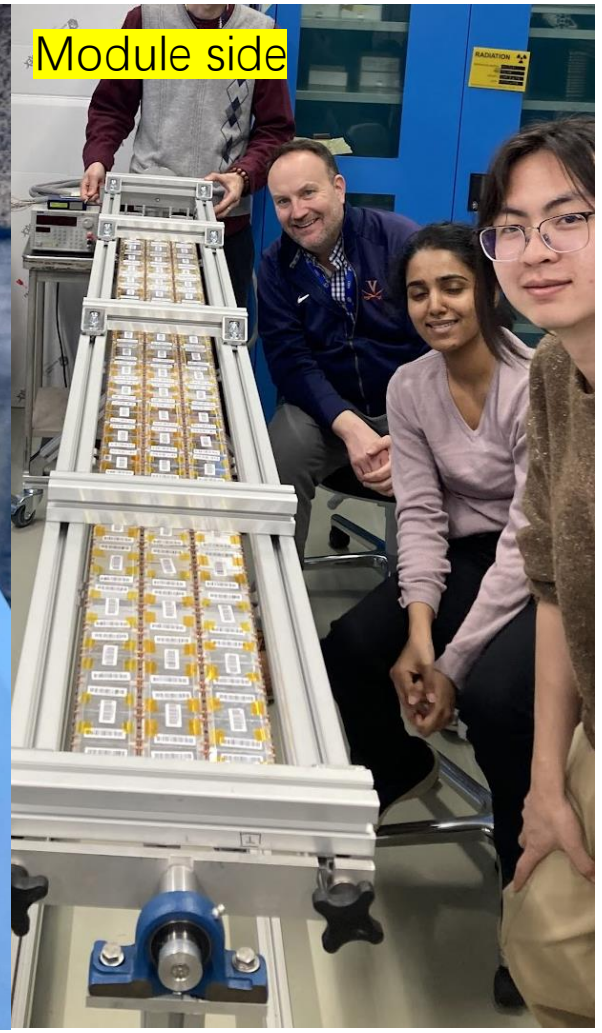
- A BTL Tray will cover a detector range of 10 degrees and 2.5 meters at η
- A total of 72 Trays cover the entire barrel of the MTD time detector

Assembly of BTL Tray

- 6 RUs, each includes a cooling plate, CC board, PCC boards, and 12 DMs



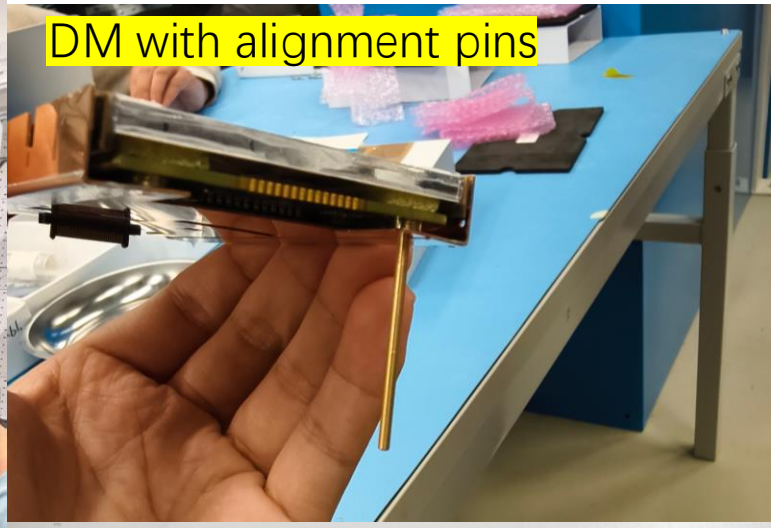


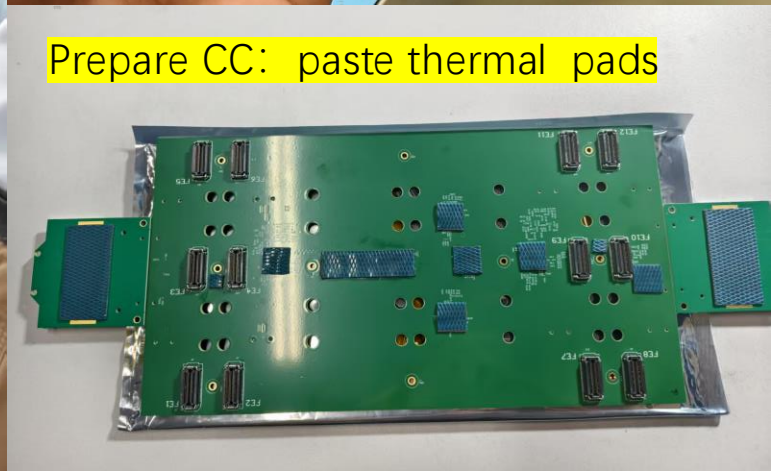


Assembly of BTL Tray

Main Steps

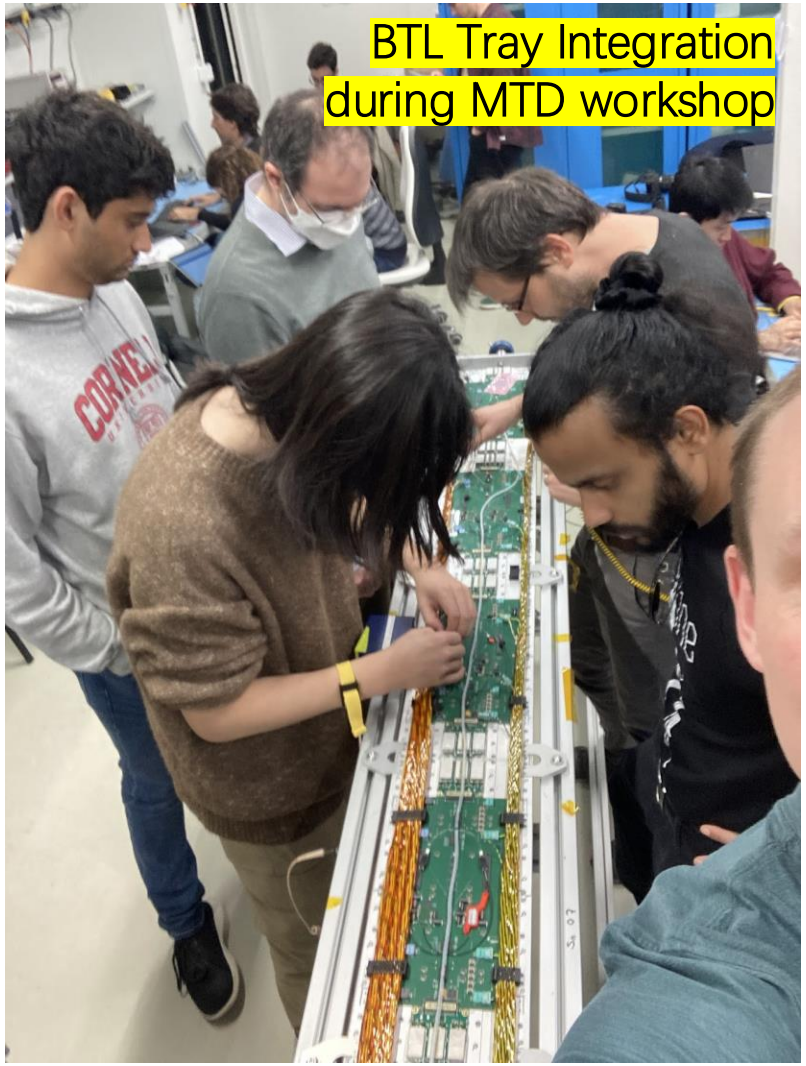
- Preparation & Mounting
  - Prepare tools and components
  - Use screws to fix CC boards, PCC boards, and detector modules
    - ✓ Prepare the cold plate, DM, CC, and PCC
    - ✓ Clean all assembly surfaces to prevent foreign objects from affecting precision
    - ✓ Use alignment pins for module positioning
    - ✓ Use screws to fix and connect the CC, PCC, and DM
    - ✓ Check the connection strength and stability





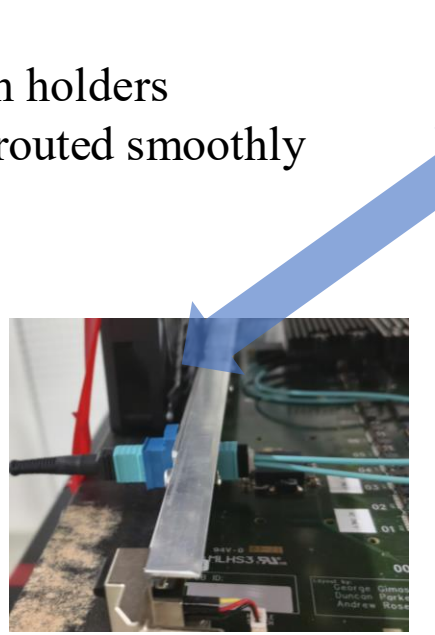
In May, we completed the first Tray at Peking University!!!

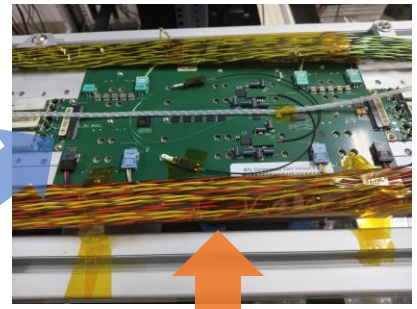
BTL Tray Integration

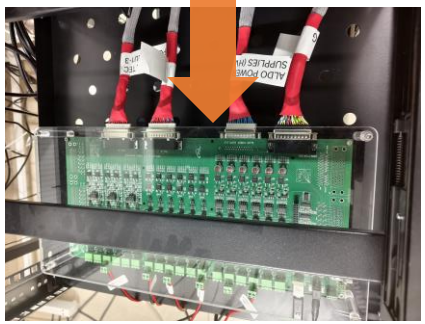


Main Steps

- Preparation & Mounting
  - Gather tools and components
  - Use screws to fix CC boards, PCC boards, and detector modules
- Optical Fiber Connection
  - Install and secure fibers with holders
  - Ensure fibers are clean and routed smoothly
- Electrical Cable Connection
  - Connect and secure power







Key Points

- Work is done in pairs for safety and accuracy
- Cleanliness and anti-static measures are important
- Proper routing and securing of fibers and cables ensure reliability

BTL Tray QA/QC and Local Lab Setup

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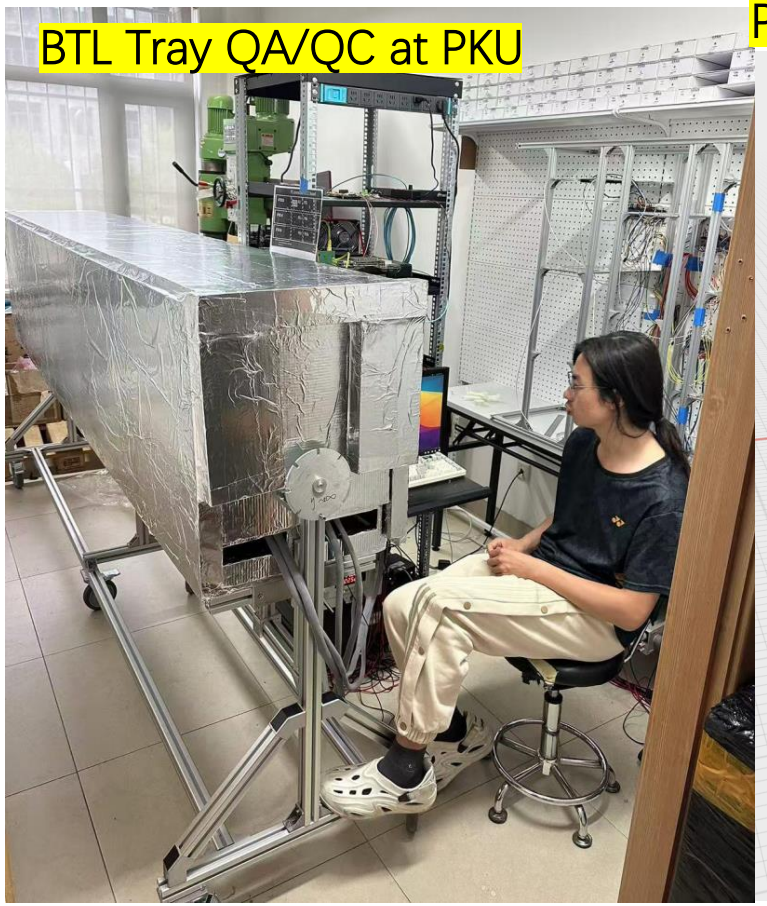
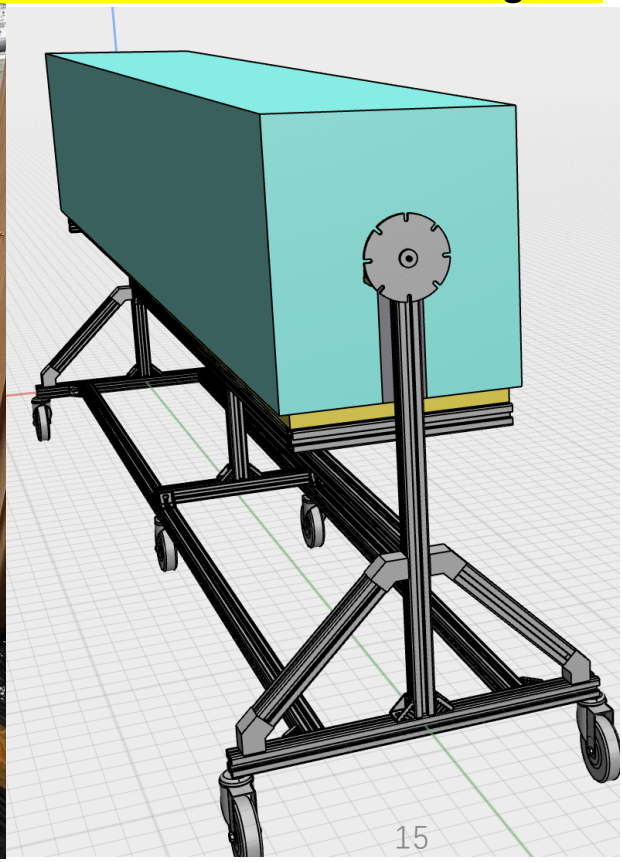
- QA/QC is essential for ensuring the assembly quality and long-term reliability of BTL trays
- All assembly centers have started tray Assembly and QA/QC

Local Lab Setup

- ✓ Designed and built an integrated assembly and test platform with a movable plane, enabling tray assembly and testing on the same frame.
- ✓ Developed a thermal dark box for testing, ensuring light-tightness and stable temperature.
- ✓ Installed water cooling and temperature monitoring systems to maintain a stable test environment.
- ✓ Developed the Serenity board test system and integrated power/control systems.



Platform & dark box designed



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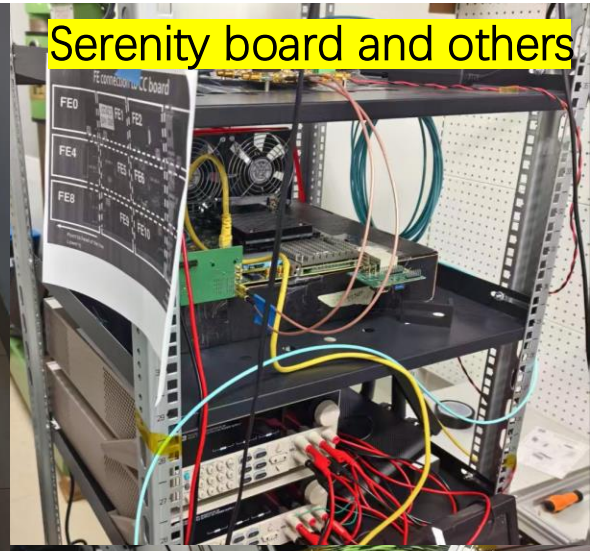

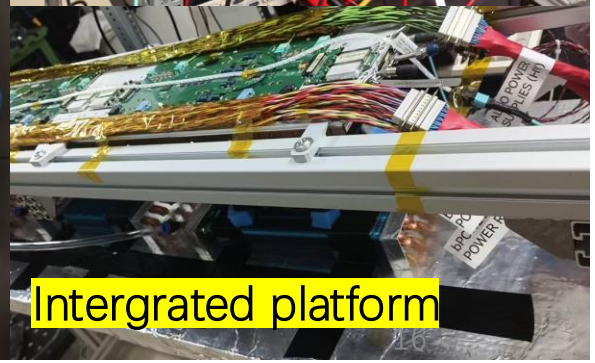

Key QA/QC Items for BTL Tray

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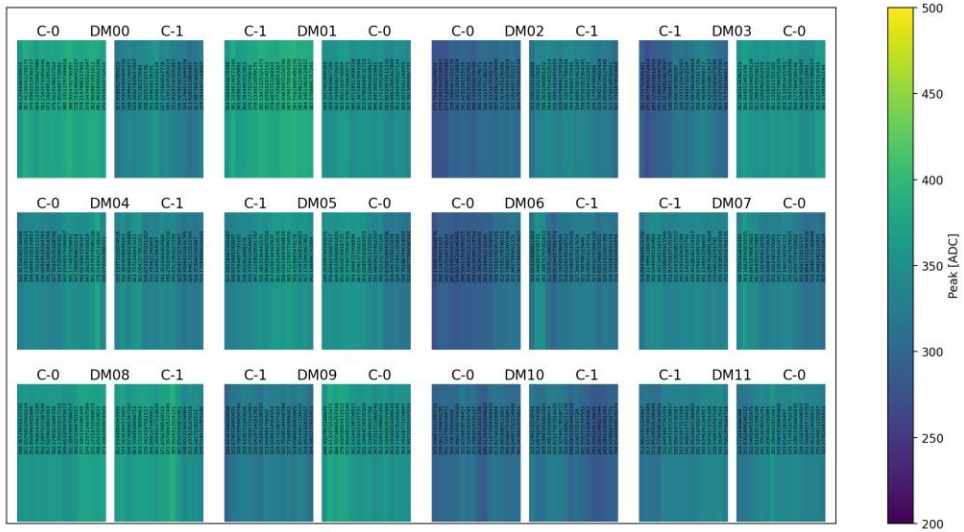
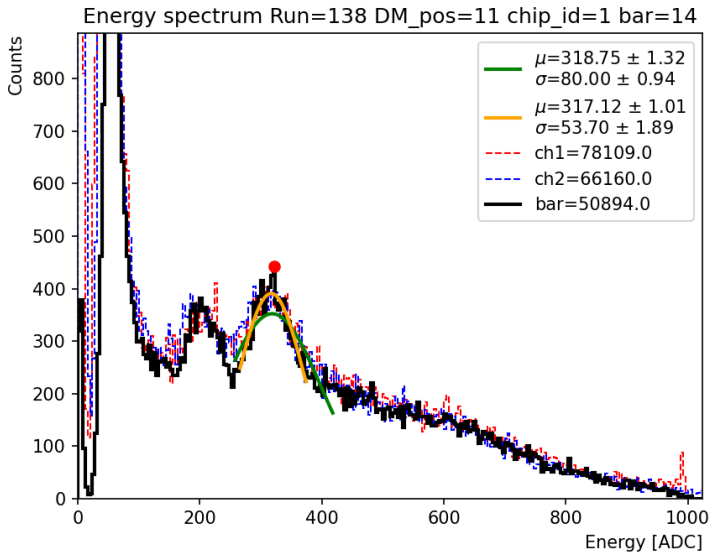
- Currently, PKU has completed the assembly of 4 BTL trays and is testing the fourth one.

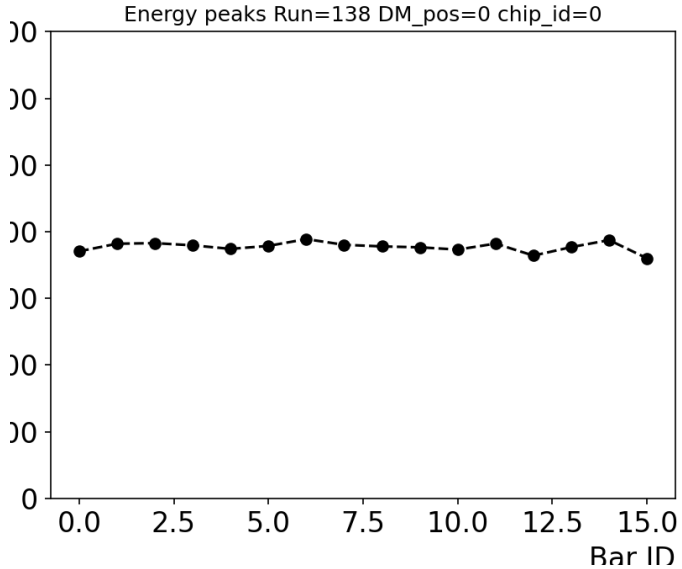
- These are the measurement results for one Readout Unit (RU) from a Tray assembled at Peking University.

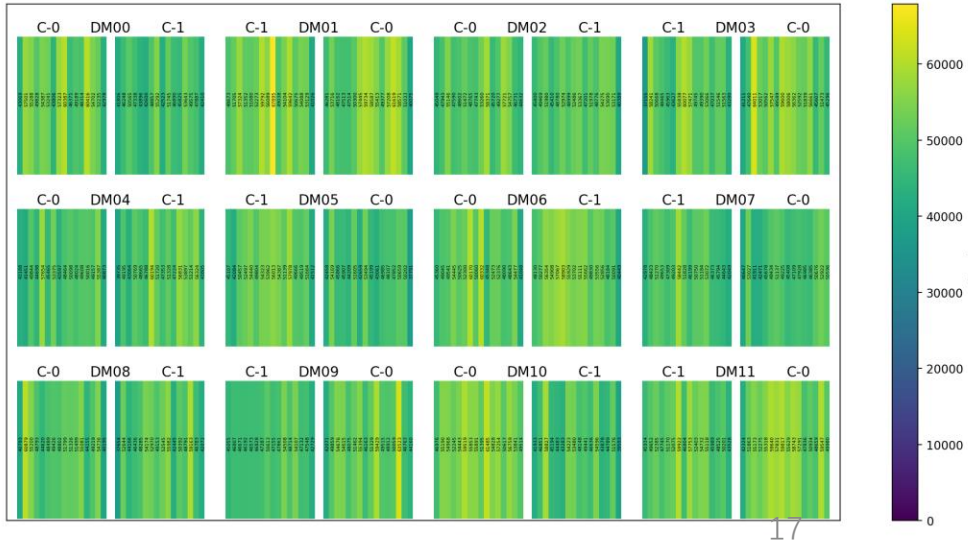
Use LYSO's intrinsic radioactivity to measure energy peak
of the 307 keV gamma peak

- ✓ Ensure continuity and confirm that all channels are alive
- ✓ Measure the response and confirm that the light output is preserved









Key QA/QC Items for BTL Tray

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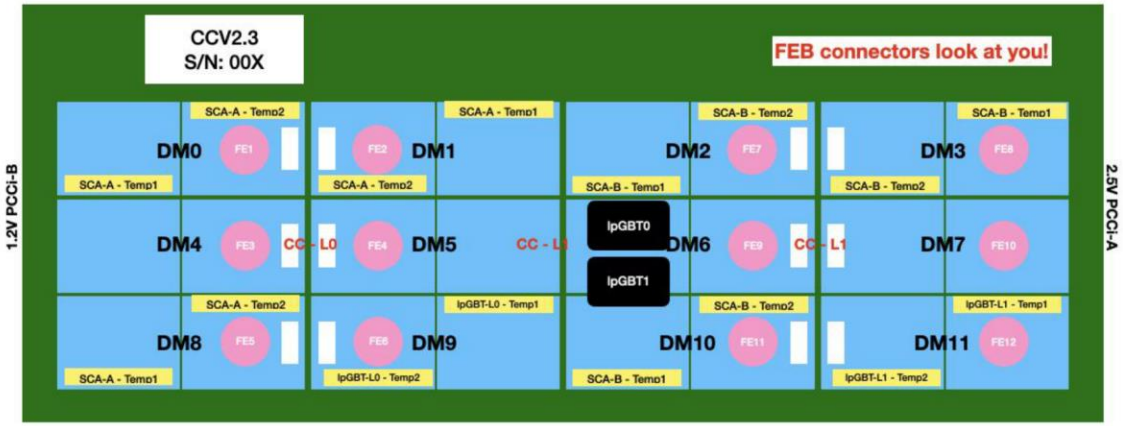
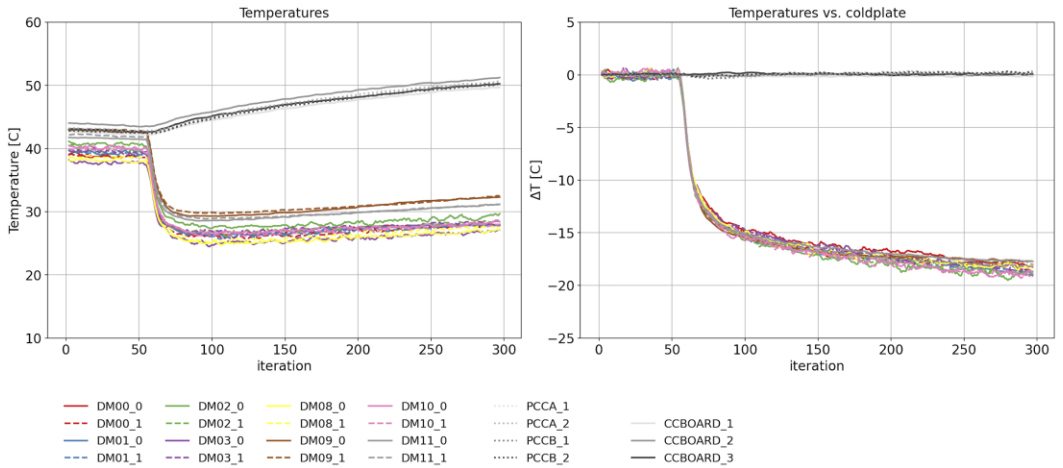
TEC Functionality Check:

✓ Monitor temperature to ensure the TEC is operating properly.

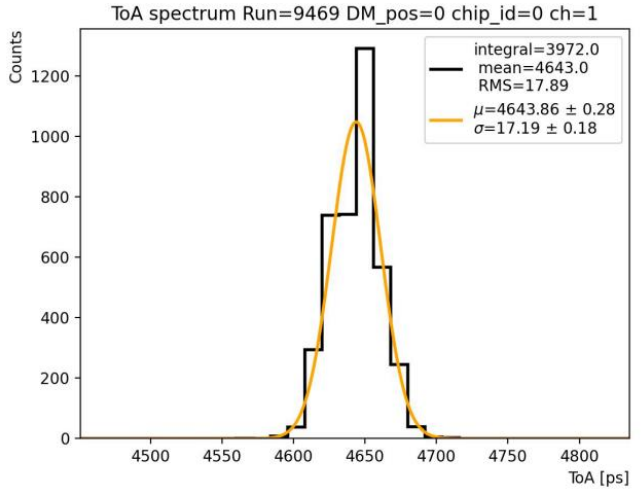




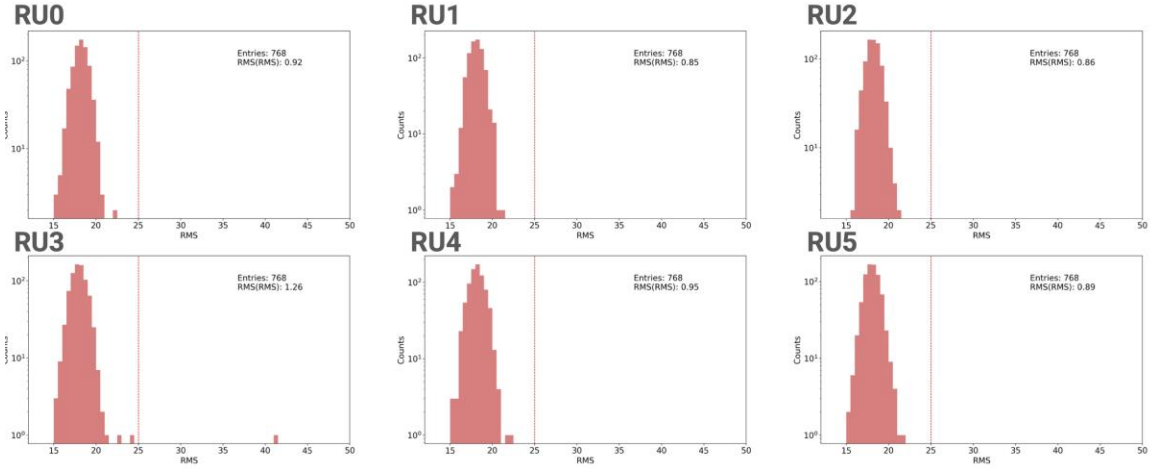
Trigger on digital test pulses and measure the time of arrival

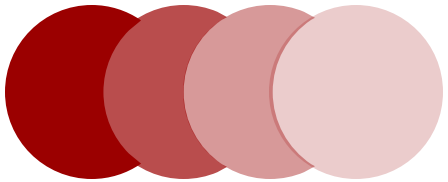
✓ Ensure continuity and confirm that all channels are alive

✓ measure TDC resolution



Summary plot for Tray1 at PKU





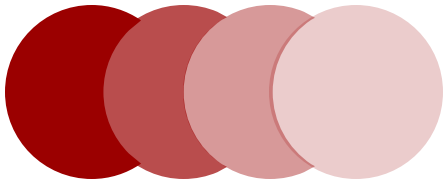
Summary

Summary

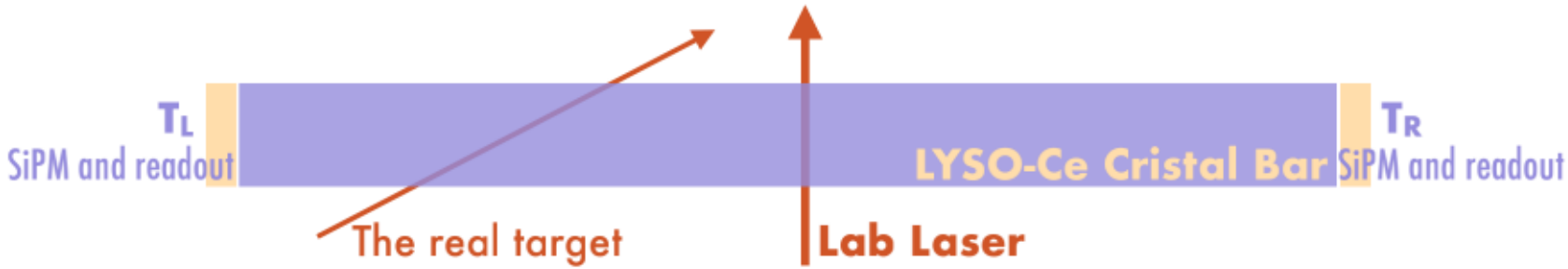
北京大学

- MTD, a new CMS Phase-II detector for the HL-LHC will be added to CMS to help meet the challenge of high luminosity
  - ✓ BTL is a single-layer MIP detector which will measure time with ~30-60 ps resolution
- At PKU, we are deeply involved in the integration and assembly of BTL trays, taking responsibility for one quarter of the total tray production as an official assembly center
  - ✓ This year, our focus has shifted from sensor R&D to the large-scale Assembly of BTL modules and trays
  - ✓ Peking BAC has completed the assembly of all SMs, ~600 DMs and 4 BTL Trays
  - ✓ Students from **Peking University, Tsinghua University and Beihang University** have participated in the assembly work together.
  - ✓ **At the same time, PKU has transported the first tray to CERN and is conducting further tests**
    - **The first assembly center to achieve this goal !**
- Tray integration at CERN in 2025/2026, CMS commissioning with BTL in 2027

Thanks for your attention!



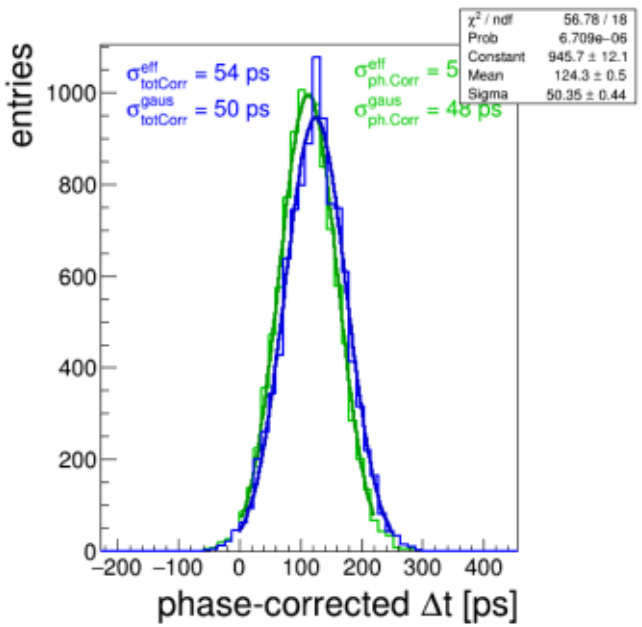
Back up



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

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

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



Experiment	r (m)	σ_T (ps)	r/σ_T ($\times 100$) (m $\times$ ps^{-1})
STAR-TOF	2.2	80	2.75
ALICE-TOF	3.7	56	6.6
CMS-MTD	1.16	30	3.87

Table 1.3: Nominal radiation doses and fluences at various locations of the timing layers after 3000 fb^{-1}. The last two columns show the radiation levels providing a safety margin of a factor 1.5. The fluence is normalized to 1 MeV neutron equivalent in silicon.

				3000 fb^{-1}		1.5$\times$3000 fb^{-1}	
Region	$\lvert\eta\rvert$	r (cm)	z (cm)	n_{eq}/cm^2	Dose (kGy)	n_{eq}/cm^2	Dose (kGy)
Barrel	0.0	116	0	1.65×10^{14}	18	2.48×10^{14}	27
Barrel	1.15	116	170	1.80×10^{14}	25	2.70×10^{14}	38
Barrel	1.45	116	240	1.90×10^{14}	32	2.85×10^{14}	48
Endcap	1.6	127	303	1.5×10^{14}	19	2.3×10^{14}	29
Endcap	2.0	84	303	3.0×10^{14}	50	4.5×10^{14}	75
Endcap	2.5	50	303	7.5×10^{14}	170	1.1×10^{15}	255
Endcap	3.0	31.5	303	1.6×10^{15}	450	2.4×10^{15}	675

Table 1.1: Expected scientific impact of the MIP Timing Detector, taken from Ref. [8].

Signal	Physics measurement	MTD impact
H $\rightarrow \gamma\gamma$ and H$\rightarrow$4 leptons	+15–25% (statistical) precision on the cross section $\rightarrow$ Improve coupling measurements	Isolation and Vertex identification
VBF$\rightarrow$H$\rightarrow \tau\tau$	+30% (statistical) precision on cross section $\rightarrow$ Improve coupling measurements	Isolation VBF tagging, p_T^{miss}
HH	+20% gain in signal yield $\rightarrow$ Consolidate searches	Isolation b-tagging
EWK SUSY	+40% background reduction $\rightarrow$ 150 GeV increase in mass reach	MET b-tagging
Long-lived particles (LLP)	Peaking mass reconstruction $\rightarrow$ Unique discovery potential	β_{LLP} from timing of displaced vertices