Status of sensor and module development in USTC

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On behalf of the USTC HGTD group

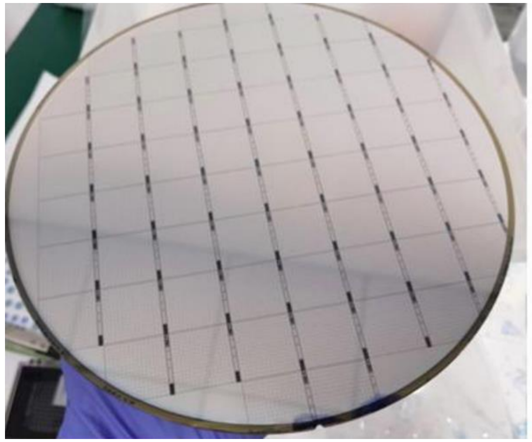
MOST ATLAS Detector Upgrade Project, 2025 Annual Meeting

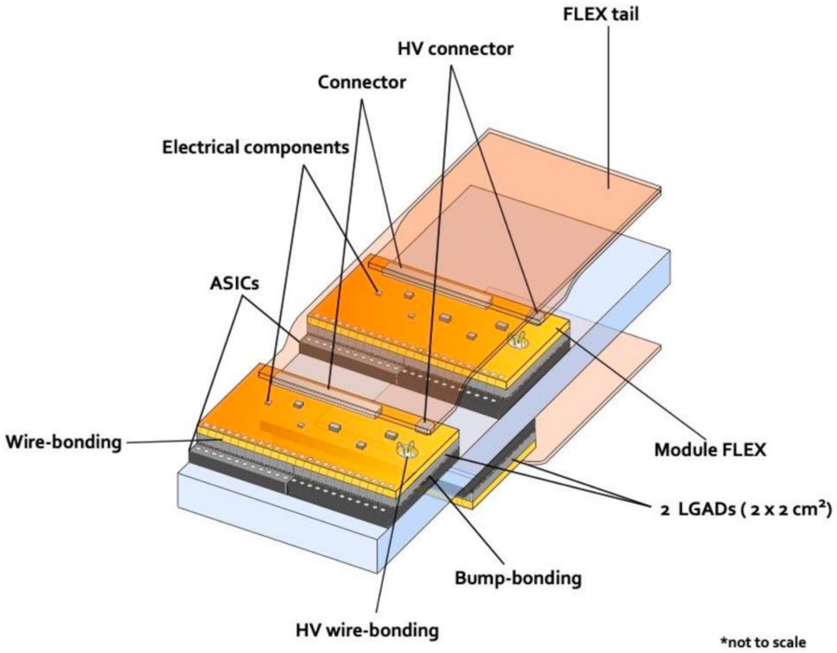
Outline

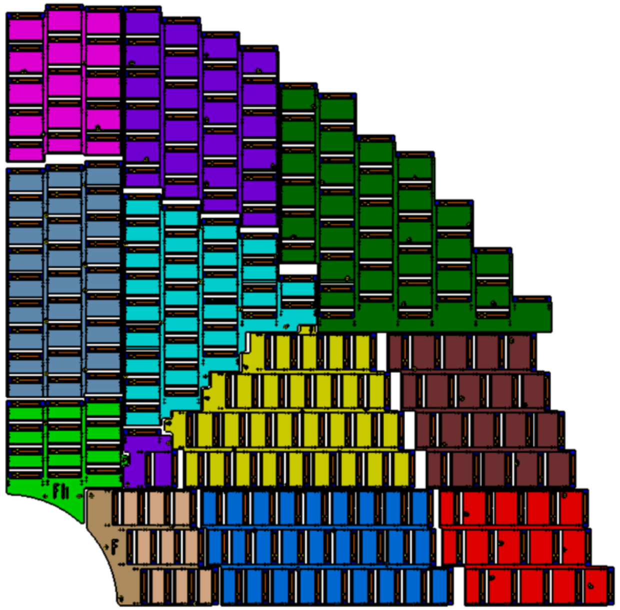
- Introduction
- Sensor status
- Module status
- Summary

Introduction

- USTC's commitment to the HGTD project: sensors and modules
- Sensors:
  - 10% of in-kind contribution (USTC-IME sensors)
- Modules:
  - 10% of module assembly and loading to detector units







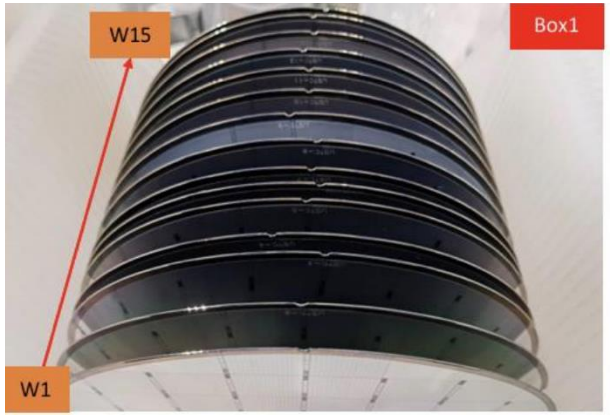
Overview

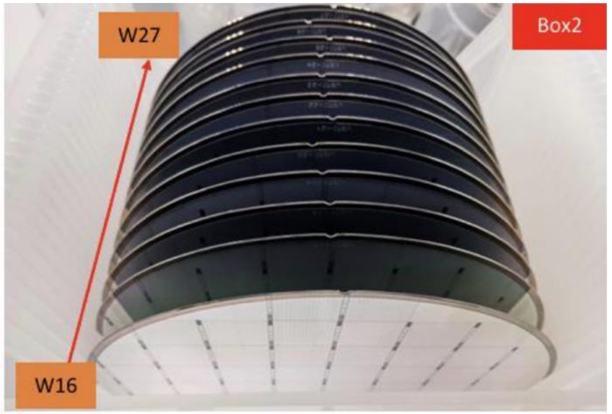
- USTC-IME sensor: 10% of HGTD (in-kind)
  - Pushing to start production at IME (IME saturated by CERN contract for now)
  - Detailed study of pre-production sensors
    - data management and re-analysis, inter-pad resistance of irradiated sensors
  - Preparation for production QC
    - Commission semi-auto probe station
    - Optimize IV test procedure
- Assembly and loading: 10% of HGTD
  - Completed preparation at USTC, but cannot get more hybrids (US restrictions)
    - Assemble at IHEP (share gantries, detailed plan being worked out with IHEP)
  - Module performance study at lab (measure time resolution with beta source)
- Actively contributing to test beam, demonstrator, DAQ and simulations

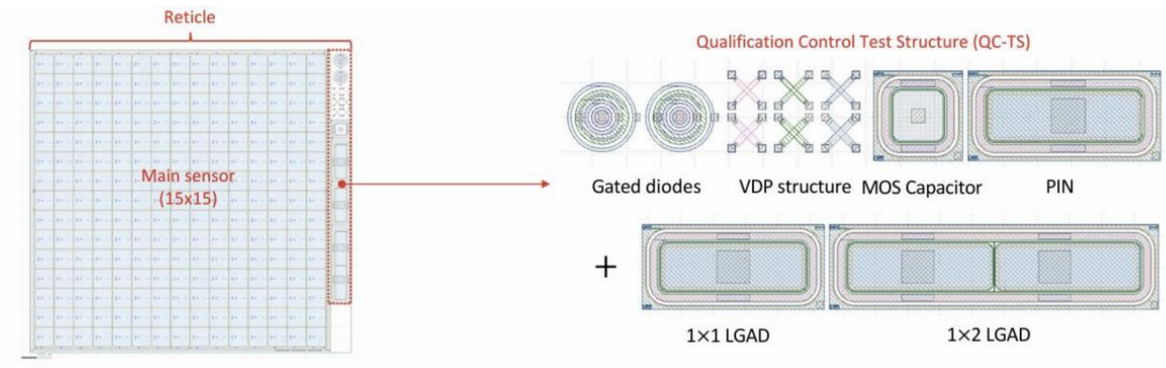
Sensor status

Senor status

- USTC-IME sensor pre-production:
  - Produced 27 wafers
  - Each wafer contains 52 LGAD sensors (15x15) and 52 QCTS (quality control test structure)

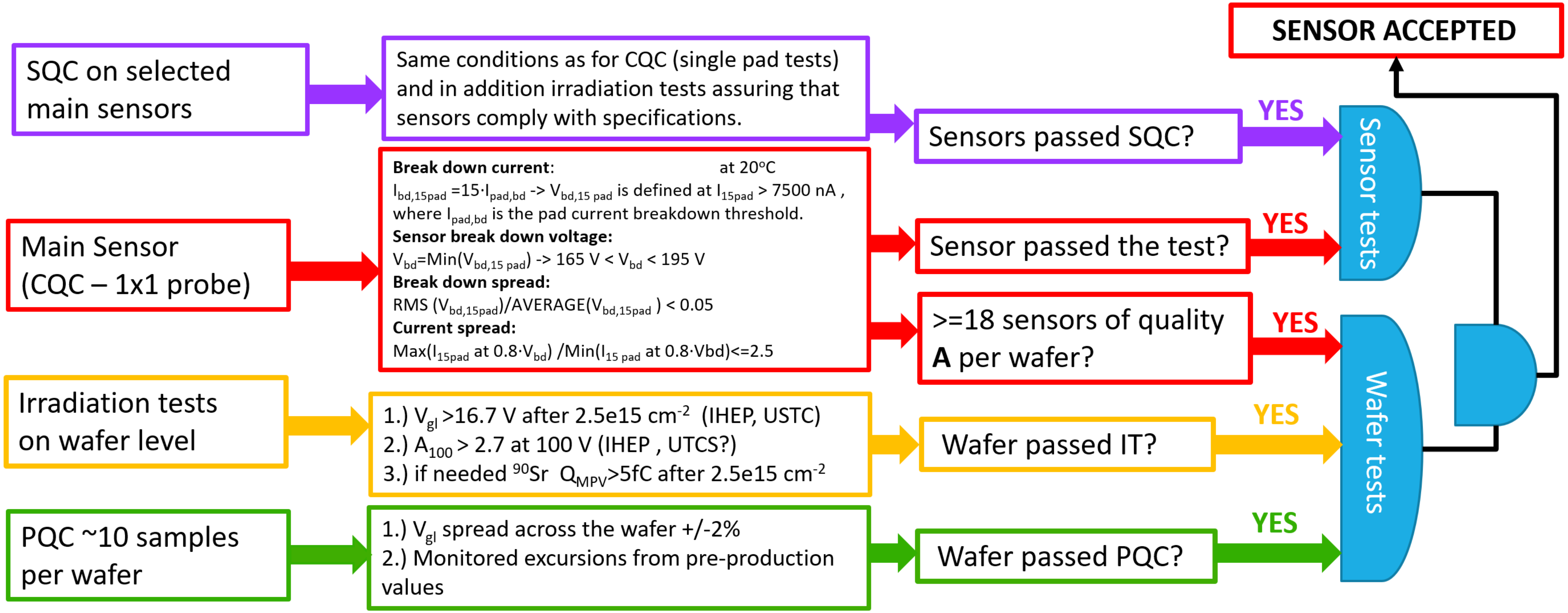






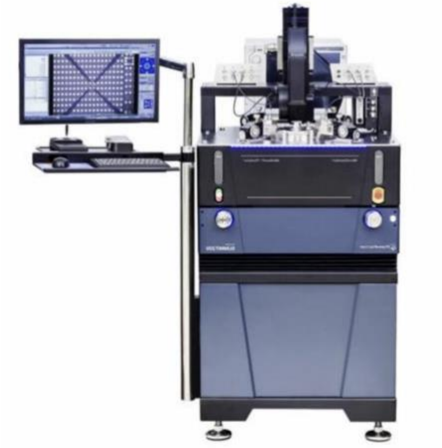
Acceptance criteria for USTC sensors

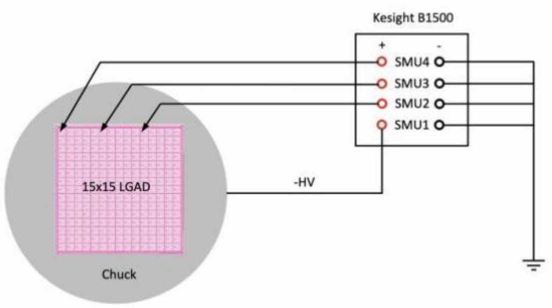
- Dedicated measurements have to be performed on wafers to verify the quality
- Wafers passing the following qualification tests can be accepted

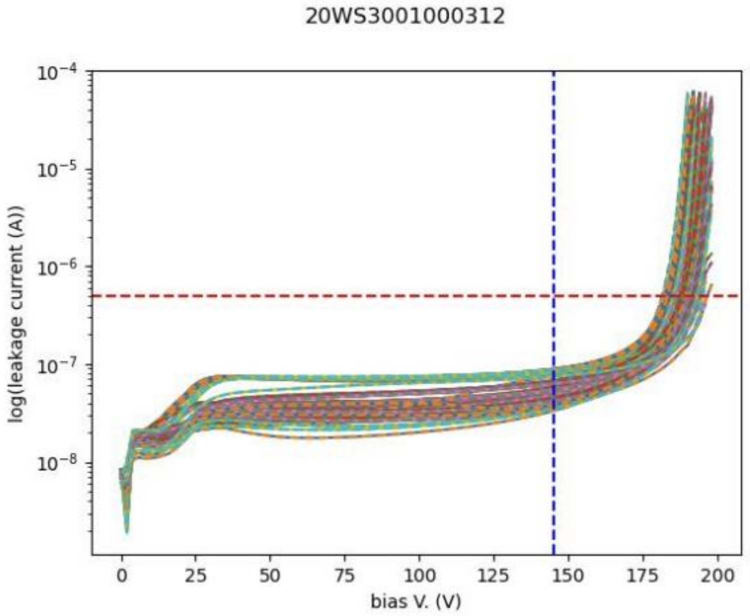


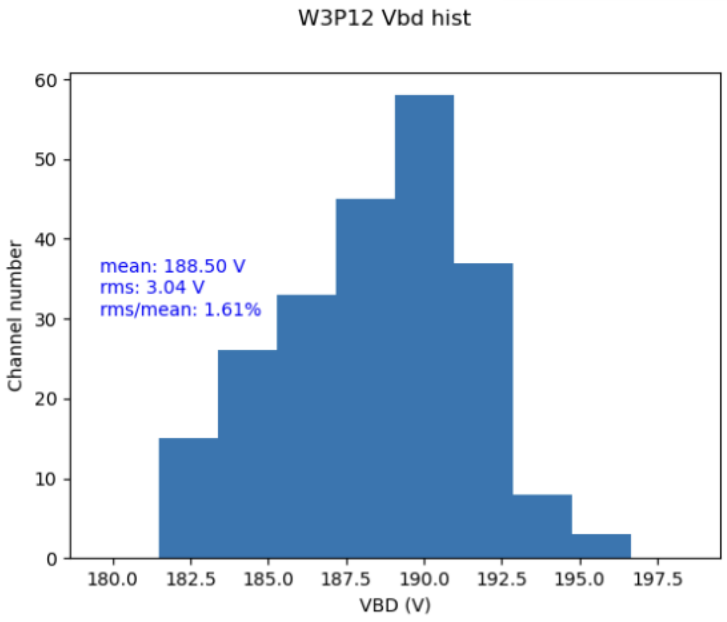
IV measurements

- Used probe station to measure the I-V curve of each channel → obtain the breakdown voltage (VBD)
- Acceptance criteria
  - Min VBD should be between 165 V to 195 V
  - RMS (Vbd)/Average(Vbd) < 0.05
  - Pad leakage current spread at 0.8Vbd: max/min ≤3









20WS3001000312

1.1	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.1
1.2	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2
1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2
1.2	1.1	1.1	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.2
1.2	1.2	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.1	1.2
1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.3
1.1	1.0	1.1	1.1	1.2	1.2	1.1	1.1	1.1	1.1	1.2
1.1	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2
1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.3
1.2	1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.2
1.1	1.0	1.0	1.1	1.1	1.1	1.1	1.0	1.1	1.1	1.1

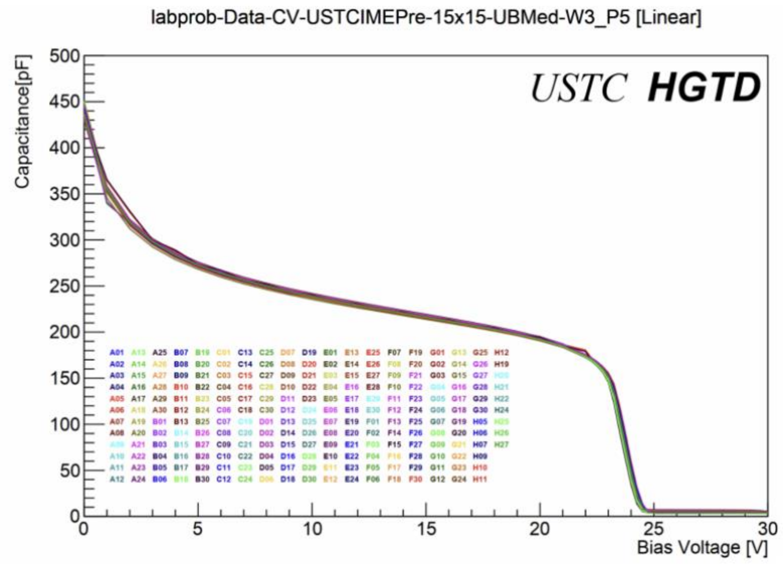
IV measurements

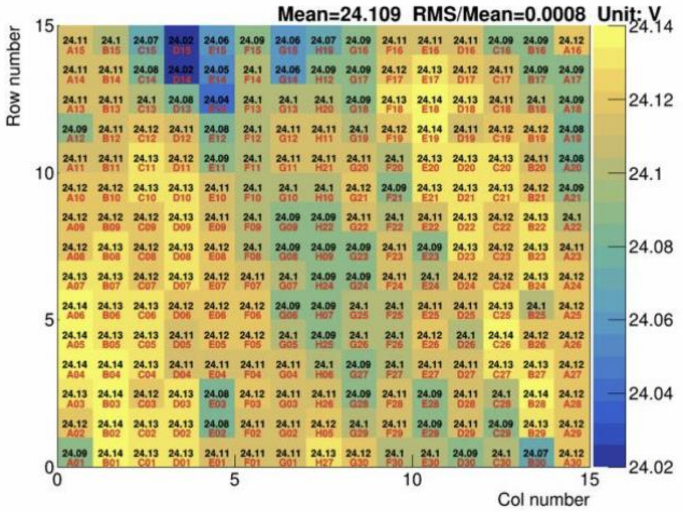
Production version	Wafer No.	Implantation	LGADs	VBD mean	Labelled	Thinned	Backside (Al)	UBMed	Diced	Yield	Quality
USTC-IME Pre-production	W1	B+1C	15x15	~ 182.8 V	Done					17/52 ~ 33 %	
	W2	B+1C	15x15	~ 186.5 V	Done	Done	Done		Done	2/52 ~ 4 %	
	W3	B+1C	15x15	~ 193.7 V	Done	Done	Done	Ready		26/52 ~ 50 %	Good
	W4	B+1C	15x15	~ 190.8 V	Done	Done	Done	Ready		24/52 ~ 46 %	Good
	W5	B+1C	15x15	~ 191.7 V	Done	Done	Done	Ready		24/52 ~ 46 %	Good
	W6	B+1C	15x15	~ 188.5 V	Done	Done	Done	Ready		22/52 ~ 42 %	Good
	W7	B+1C	15x15	~ 184.9 V	Done	Done	Done	Ready		22/52 ~ 42 %	Good
	W8	B+1C	15x15	~ 186.2 V	Done	Done	Done	Ready		22/52 ~ 42 %	Good
	W9	B+1C	15x15	~ 195.6 V	Done					13/52 ~ 25 %	
	W10	B+1C	15x15	~ 193.6 V	Done					16/52 ~ 31 %	
	W11	B+1C	15x15	~ 192.3 V	Done	Done	Done	Ready		26/52 ~ 50 %	Good
	W12	B+1C	15x15	~ 193.1 V	Done	Done	Done		Done	13/52 ~ 25 %	
	W13	B+1C	15x15	~ 188.8 V	Done	Done	Done	Ready		21/52 ~ 40 %	Good
	W14	B+1C	15x15	~ 191.6 V	Done	Done	Done	Ready		18/52 ~ 35 %	Good
	W15	B+1C	15x15	~ 193.0 V	Done					12/52 ~ 23 %	
	W16	B+1C	15x15	~ 152.4 V	Done					23/52 ~ 44 %	
	W17	B+1C	15x15	~ 150.4 V	Done					27/52 ~ 52 %	
	W18	B+1C	15x15	~ 137.7 V	Done					25/52 ~ 48 %	
	W19	B+1C	15x15	~ 146.5 V	Done					26/52 ~ 50 %	
	W20	B+1C	15x15	~ 138.9 V	Done					20/52 ~ 36 %	
	W21	B+1C	15x15	~ 127.5 V	Done					18/52 ~ 35 %	
	W22	B+1C	15x15	~ 143.6 V	Done					21/52 ~ 40 %	
	W23	B+1C	15x15	~ 130.6 V	Done					15/52 ~ 29 %	
	W24	B+1C	15x15	~ 151.8 V	Done	Done	Done		Done	21/52 ~ 40 %	
	W25	B+1.3C	15x15	~ 116.9 V	Done	Done	Done		Done	10/52 ~ 19 %	
	W26	B+1.5C	15x15	~ 111.8 V	Done	Done	Done		Done	13/52 ~ 25 %	
	W27	B+0.7C	15x15	~ 158.1 V	Done	Done	Done		Done	25/52 ~ 48 %	

9 wafers passed the acceptance criteria

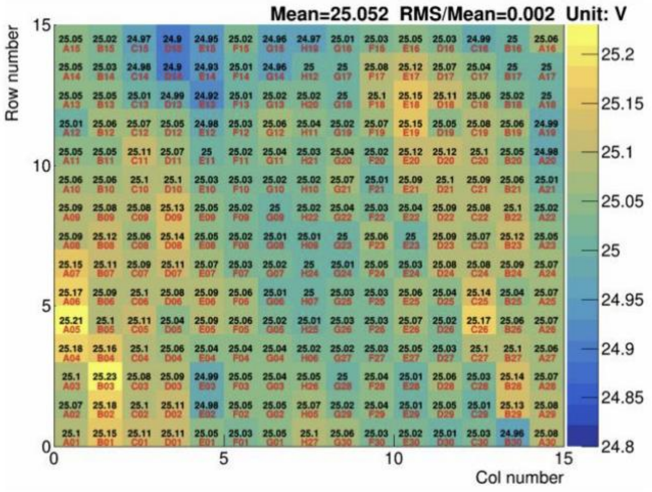
CV measurements

- Performed the C-V measurement of LGAD sensors after dicing
- Used probe card to measure the C-V curve of each channel → obtain the gain-layer depletion voltage (Vgl) and the full depletion voltage (Vfd)





Vgl RMS/Mean: 0.0008



Vfd RMS/Mean: 0.002

Very good uniformity

Irradiation test and beam test

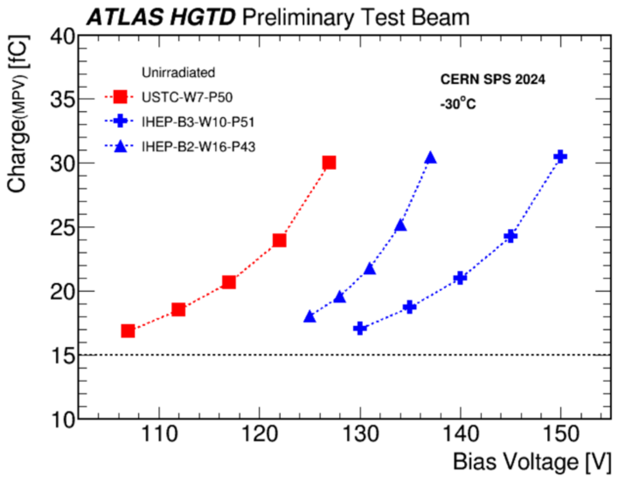
- Sensors should withstand irradiation up to $2.5 \times 10^{15}\ n_{eq}/cm^2$ and 2 MGy
- Irradiation test: USTC-IME sensors have been irradiated with neutrons at TRIGA at Ljubljana, Slovenia

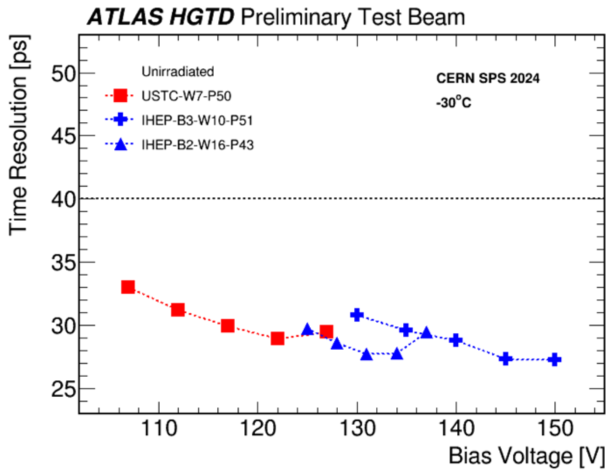
Table 4: Sensor performance requirements after irradiation to $2.5 \cdot 10^{15}\ n_{eq}/cm^2$ and 2 MGy at $V_{op.min}$, -30°C.

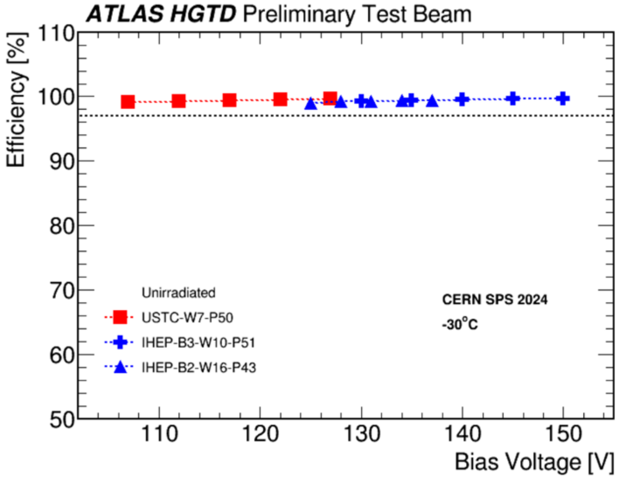
Hit efficiency at normal incidence with discrete testing electronics central part of pad ~1x1 mm^2)	>95%
Time resolution (using discreate testing electronics)	<50 ps
Power consumption at $V_{op,min}$	< 100 mW/cm^2
total maximum leakage current (D=50 μm)	<160 μA/cm^2
Collected charge $V_{op,min}$	>4 fC
pad leakage current at $V_{op,min}$	<5 μA
Maximum $V_{op.max}$ (limited by SEB)	11 V/μm ·D
Interpad-resistance at $V_{op,min}$	>10 MΩ
Leakage current stability	to remain stable within +/-5% when corrected for temperature exhibiting no long-term drifts (on days scale) or prompt excursions
micro-discharge ("ghost hits") hits at $V_{op,min}$	<1 kHz

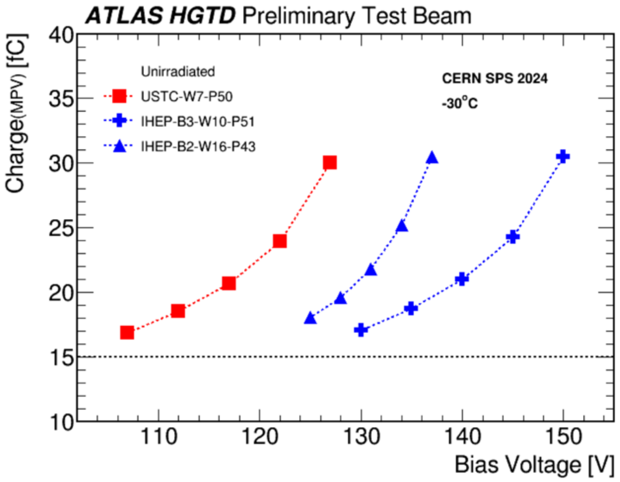
Irradiation test and beam test

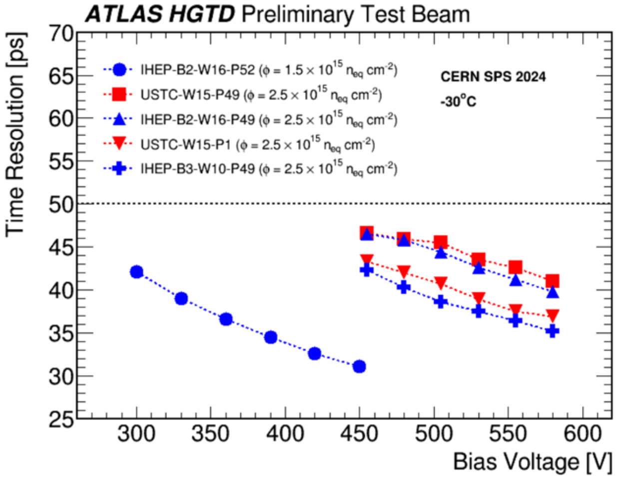
- Performance tested with 120 GeV π at CERN-SPS

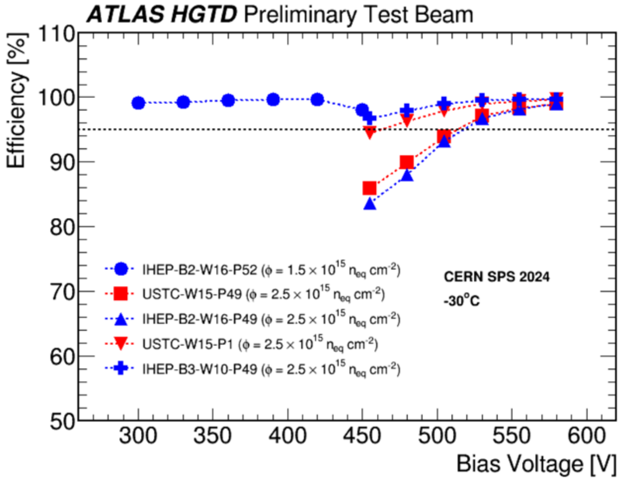






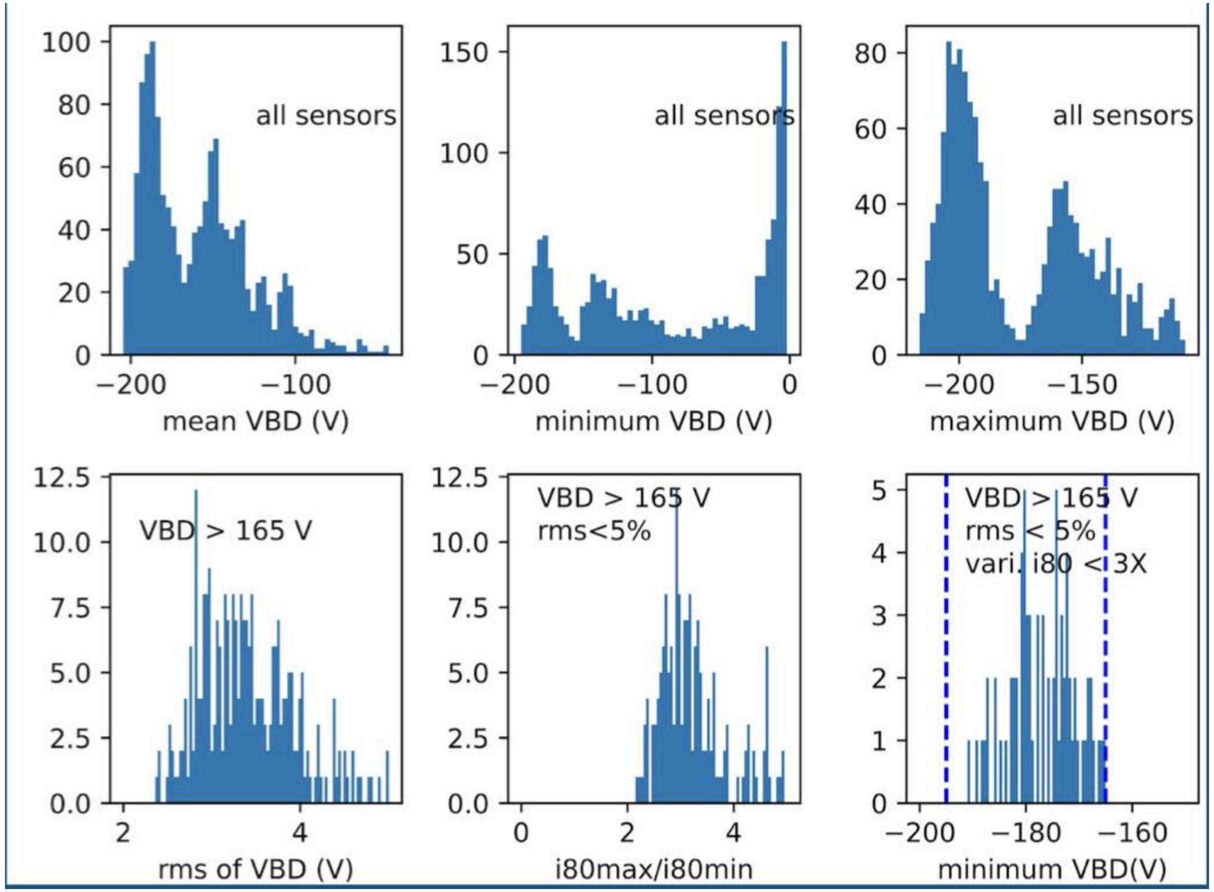






Analysis of pre-produciton USTC-IME

- Developed analysis scripts using information stored in produciton database:
- Serves as an interpretation of USTC-IME CQC IV data in DB
  - also a verification of data management

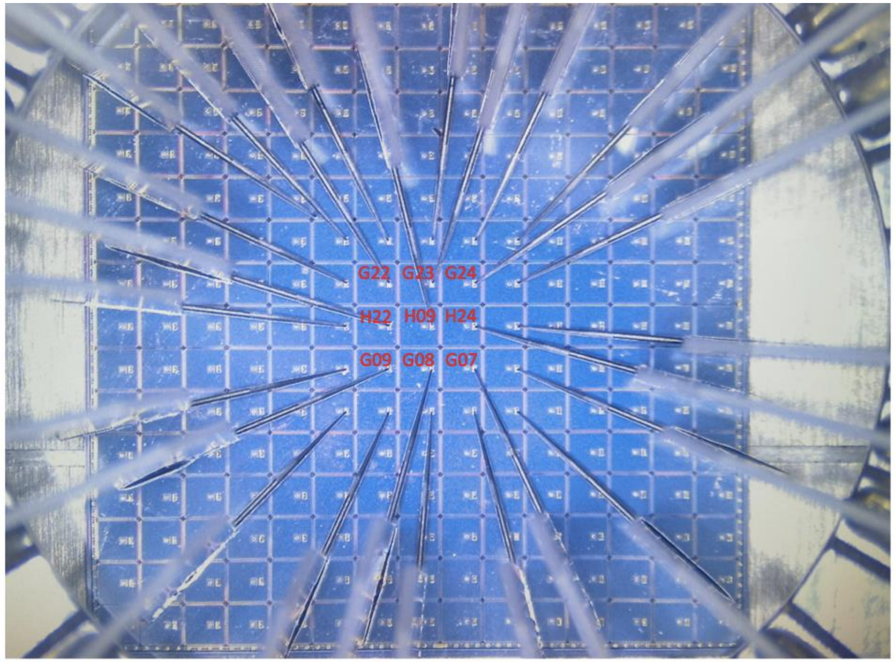


Ref: [presentation at March 31- April 5 HGTD week]()

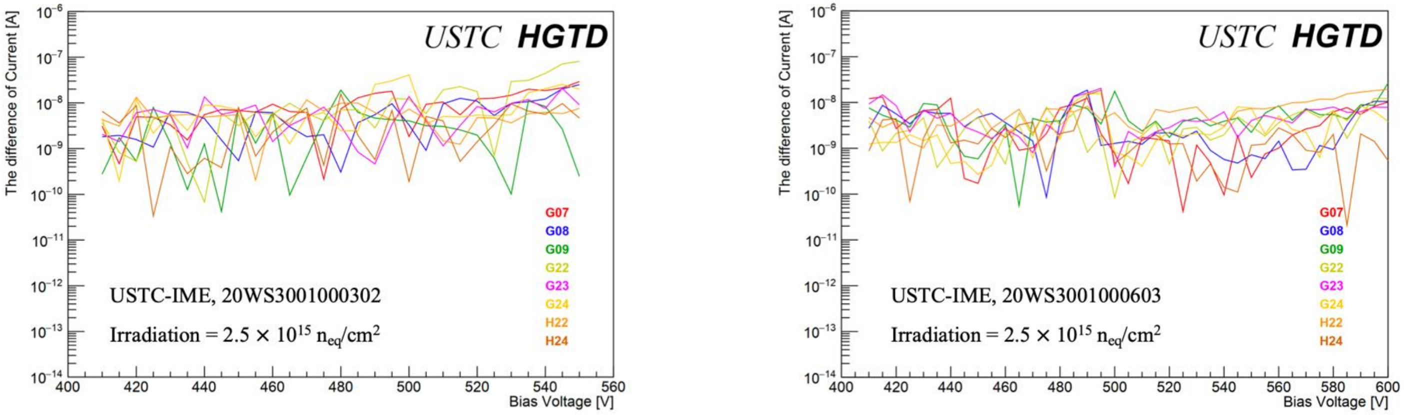
[Link to analysis scripts in gitlab]()

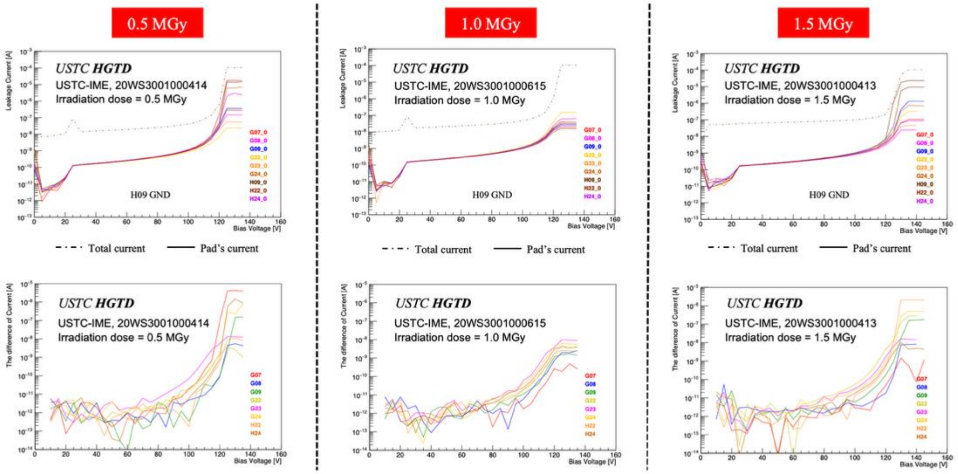
Inter-pad resistance verification at USTC

- Infer resistance from the additional current caused by the bias shift of 1 V
  - Sensors irradiated by reactor neutrons with fluence $2.5 \times 10^{15}\ n_{eq}/cm^2$



Central pad grounded or supplied by 1 V



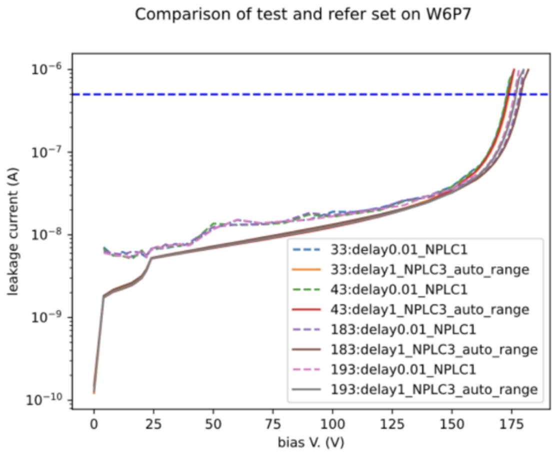


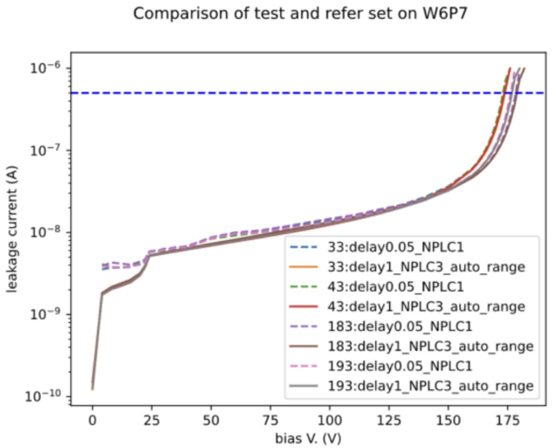
Conclusion:
R > 10 Mohm before VBD for all tested samples

Ref: [Presentation at March 31 – April 5 HGTD week]

Preparation for sensor production QC at USTC

- Setup a dedicated semi-automatic probe station for sensor production
  - Stick to per-pad measurement
- Optimzed the IV test setting (improved both speed and quality)
  - Lots of experimenting: so far achieved ~20 h/wafer
  - Furthur tuning still on-going

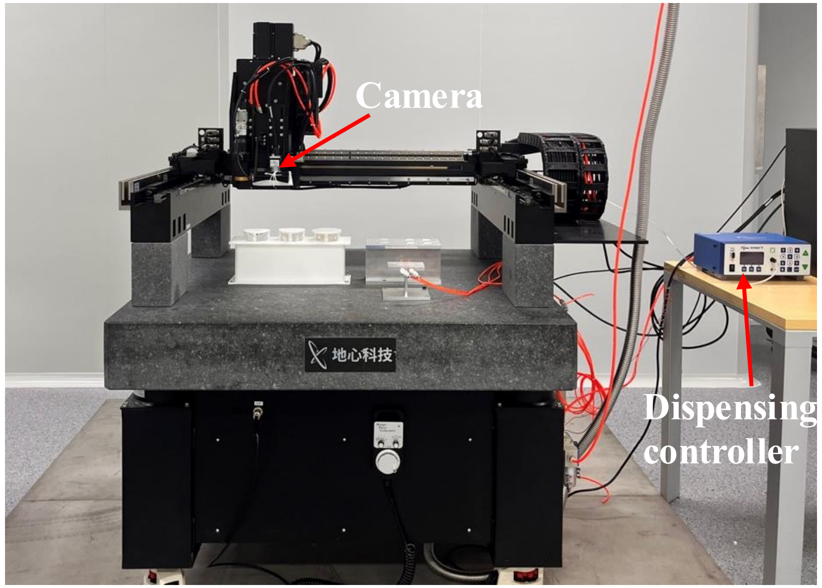




Module status

Module assembly at USTC

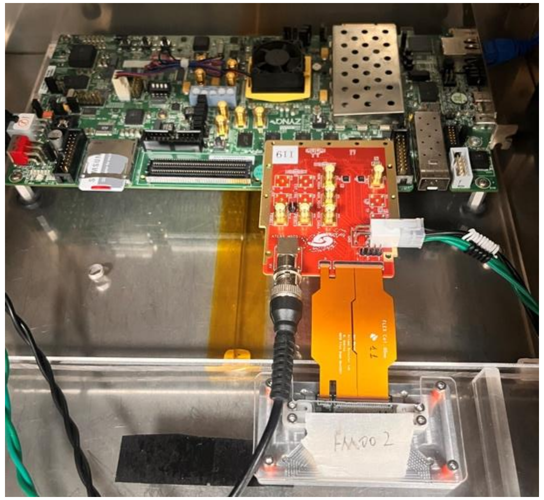
- Assembly method : gantry system
- Infrastructures ready for metrology, wire-bonding, thermal cycling and module test (DAQ), etc



OGP smartscope

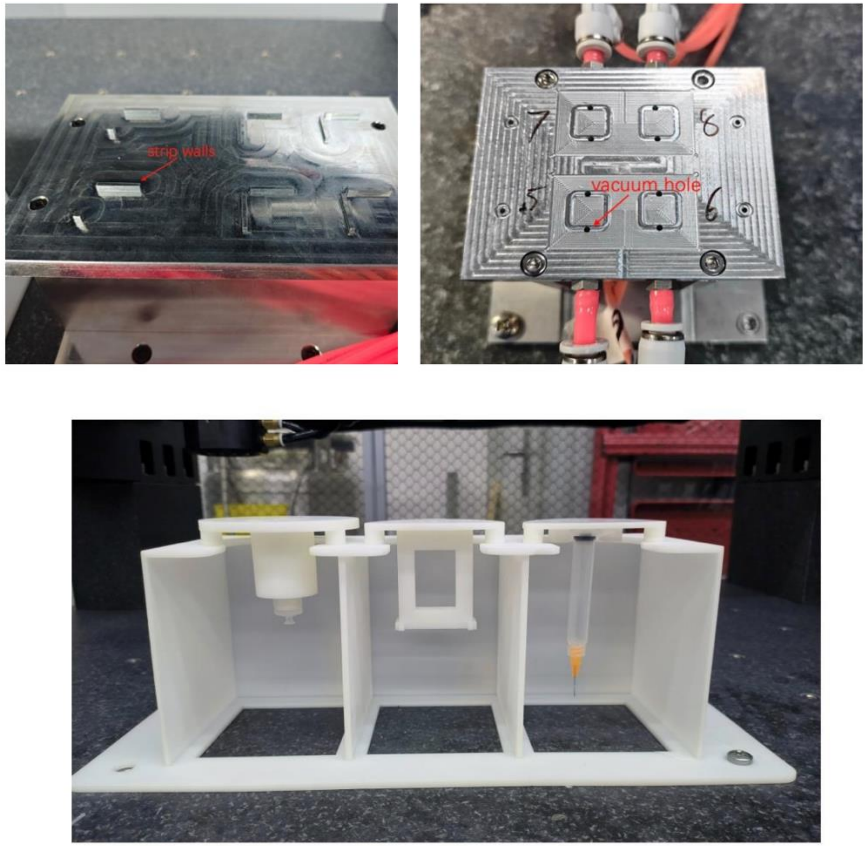
Wire-bonder BJ855

Bonder tester

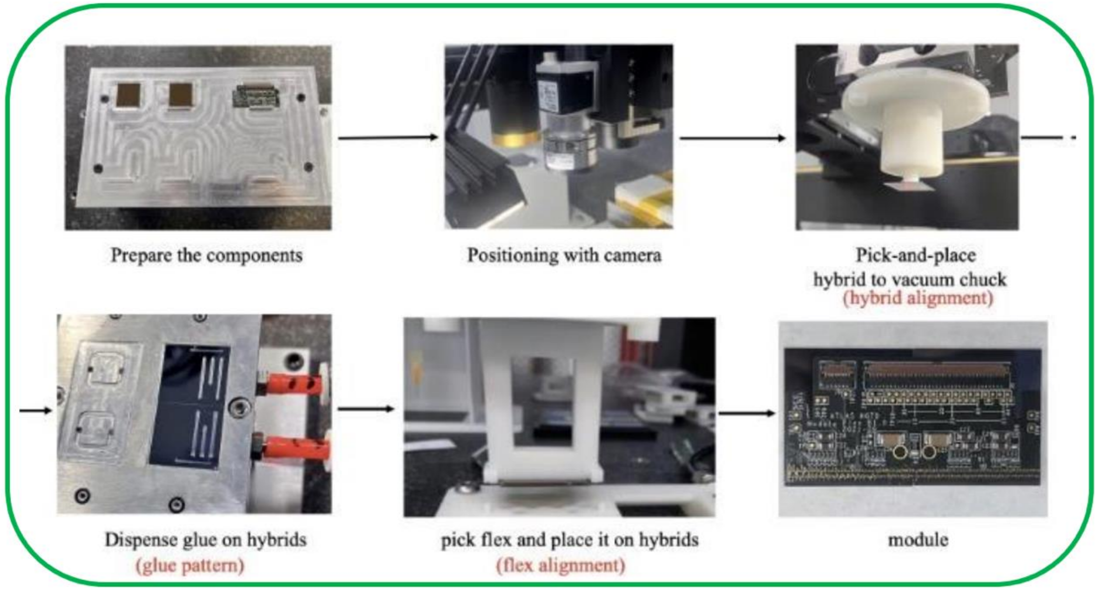


Assembly procedure

- Assembly procedure ready and validated



Customized tools



Wire-bonded module

20

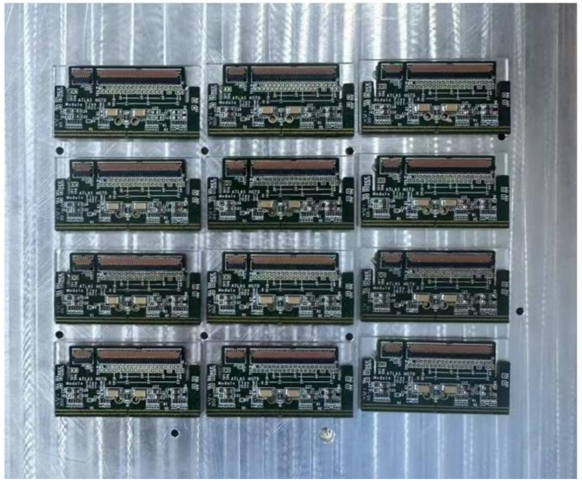
Modules assembled

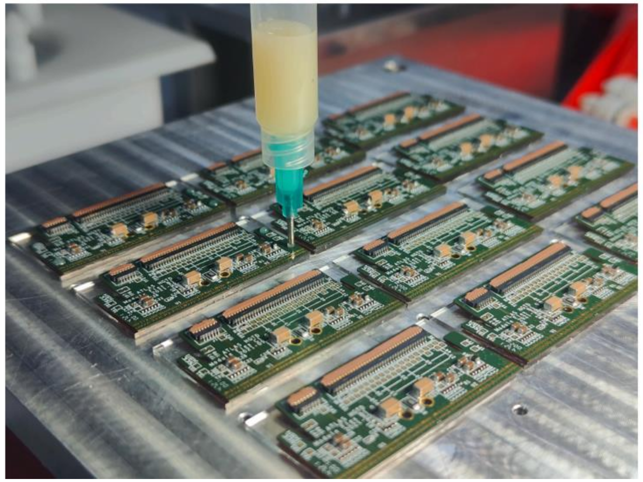
- Assembly procedure ready and validated

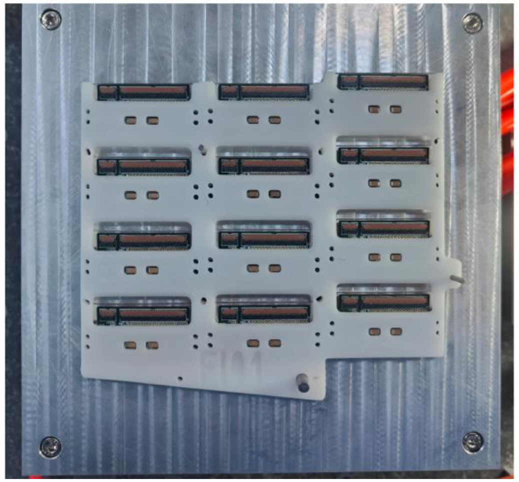
	Type	Sensor	Flip chip bonding	Metrology	WB	Charge scan validation	Radioactive source test	Thermal cycling
DM001	Digital	-	-	Assembled Manually	USTC	Done	-	Done
DM002	Digital	-	-	-	USTC	Done	-	Not yet
FM001	Full	IHEP-IME pre-production	NCAP	Done	USTC	Done	Done	60->75 cycles
FM002	Full	USTC-IME Pre-production	IFAE	Done	USTC	Done	Not yet	Not yet
FM003	Full	USTC-IME Pre-production	IFAE	Not yet	USTC	Done	Not yet	Not yet

Module loading

- DU loading procedure also ready and tested with dummies
  - Based on the same gantry system with a dedicated vacuum chuck
  - 12 Dummy modules (glass + flex) were fabricated to test loading procedure.
  - Dummy modules loaded into FI01SU
- Metrology measurement also performed on the dummy detector unit

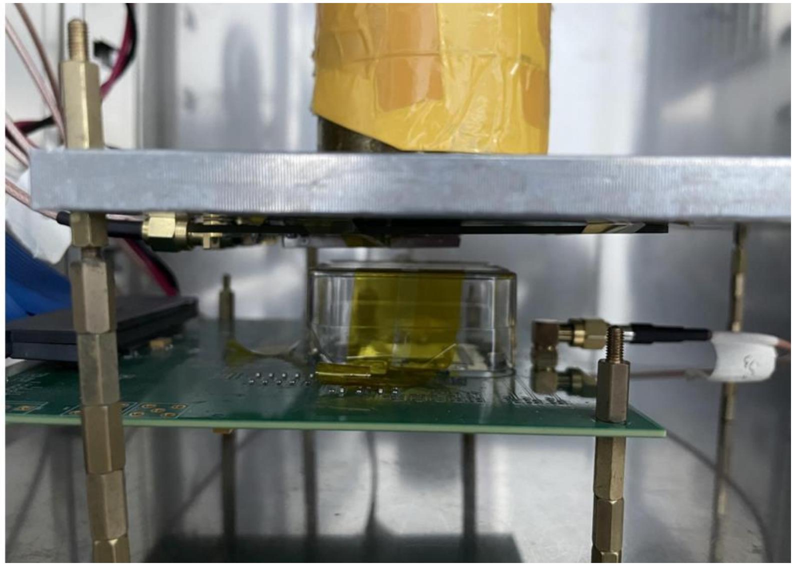


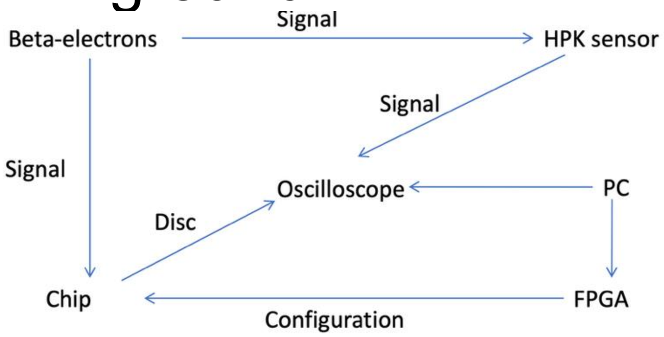


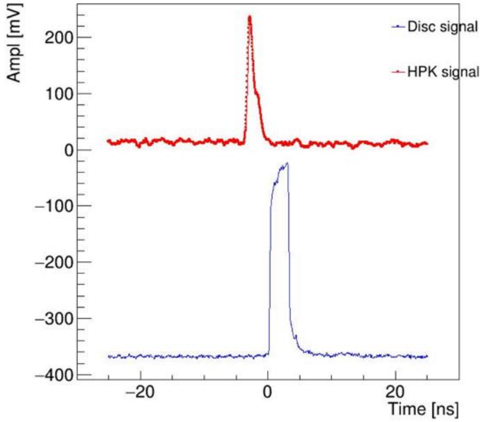


Module performance study at USTC

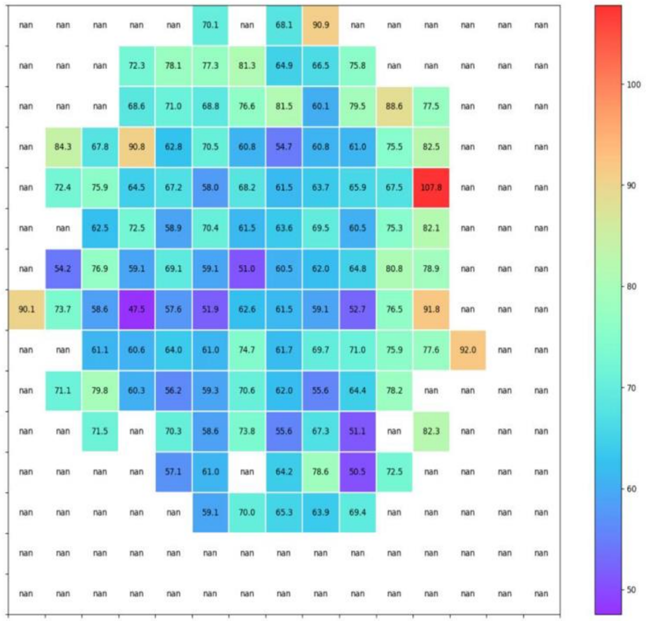
- Study hybrid timing performance with Sr-90 source at USTC
- Use single-pad HPK sensor as reference to study the timing of DISC output from ATLIROC3
  - currently obtained σ_t~70 ps at 20 deg C
- Re-discovered the noise from HV ground







ATIROC3 hybrid with Sr-90
HPK single-pad LGAD as ref
z-scale:resolution in ps



Ref: presentation at March 31 – April 5 HGTD week

DAQ and demonstrator

- USTC students and postdocs at CERN contributing to probe station setup, test beam, demonstator and DAQ
- DAQ tests and software development: presentation at Feb HGTD week

Assembly plan

- USTC is on the US entity list
  - Can not get any more ALTIROC chips to USTC site
  - CERN vetoed the option of module assembly in a company contracted by USTC
- Solution: plan to collaborate with IHEP on the assembly
  - Do the assembly at IHEP
  - Merge the share of the two sites (IHEP 34%, USTC 10%) into one common site (IHEP+USTC, 44%)
  - Joint efforts of IHEP+USTC: personpower, equipment, etc

Summary

- USTC-IME sensor: 10% of HGTD (in-kind)
  - Pre-production accomplished and conducted detailed study of pre-production sensors
  - Pushing to start production at IME
  - Preparation for production QC ongoing well
- Assembly and loading: 10% of HGTD
  - Completed preparation at USTC
  - Module performance study at lab (measure time resolution with beta source)
  - Due to US restrictions, plan to do the assembly at IHEP (share gantries, detailed plan being worked out with IHEP)
- Actively contributing to test beam, demonstrator, DAQ and simulations

Backup

USTC-IME pre-production sensors

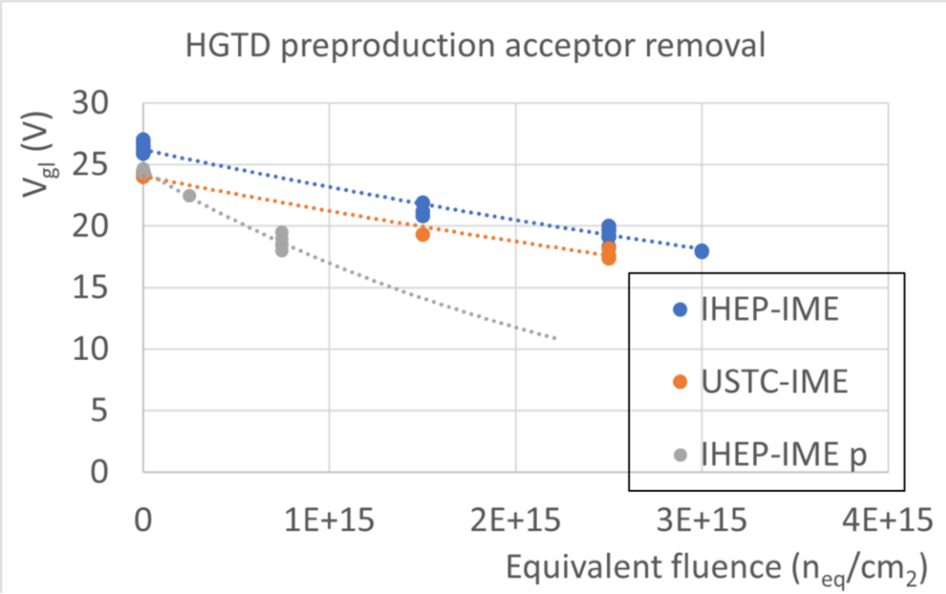
	ATLAS ID	USTC-IME ID	thicknes s(um)	Average Vbd (V)	good sensor number per wafer	sensor yield	UBM
1	20WS0100110002	w2	300	186.5	2	4%	no
2	20WS0100110024	w24	300	151.8	14	27%	no
3	20WS0100110015	w15	**775**	193	12	23%	yes
4	20WS0100110023	w23	**775**	130.6	15	29%	yes
5	20WS0100110003	w3	300	193.7	26	50%	yes
6	20WS0100110004	w4	300	190.8	24	46%	yes
7	20WS0100110005	w5	300	191.7	24	46%	yes
8	20WS0100110006	w6	300	188.5	22	42.00%	yes
9	20WS0100110007	w7	300	184.9	22	42.00%	yes
10	20WS0100110008	w8	300	186.2	24	46%	no
11	20WS0100110011	w11	300	192.3	26	50%	no
12	20WS0100110013	w13	300	188.8	22	42.00%	no
13	20WS0100110014	w14	300	191.6	18	35.00%	no

early preproduction – not fully post-processed and not necessary within the specs

core preproduction – all finished in accordance with specs and requirements

core preproduction – not UBM-ed in accordance with specs and requirements

we have also 2 test wafers for UBM testing – not within the specs



HGTD preproduction acceptor removal
V_{gl} (V)
30
25
20
15
10
5
0
0
1E+15
2E+15
3E+15
4E+15
Equivalent fluence (n_{eq}/cm_2)
IHEP-IME
USTC-IME
IHEP-IME p