IHEP-INFN Collaboration on Medical Physics

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on behalf of DNTA
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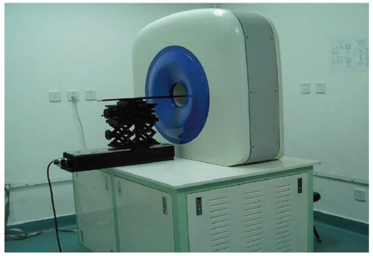
2021-7-8

Outline

- **On-going Work in IHEP for Medical Physics**
- **Current Collaboration between IHEP and INFN**
- **Future Perspectives**

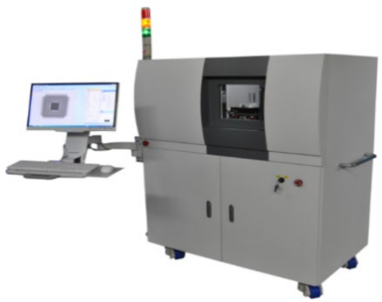
Overviews of DNTA



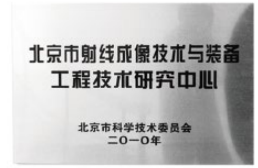
Animal PET

Animal PET/CT

γ-ray detection



90kV Micro-CT

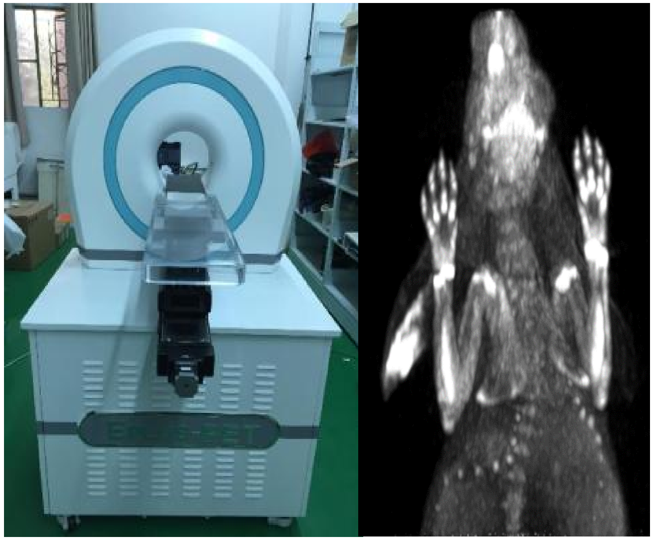


- **Division of nuclear technology and application is the technological transfer unit of IHEP.**
- **Non-profit department, which is application-oriented and focused on instrument and equipment industrialization.**
- **Different research areas**
  - **Nuclear medical imaging technology**
  - **Nuclear radiation detecting technology**
  - **X-ray imaging technology**

Nuclear medical imaging Equipment

Medical research equipment

animal PET(PET/CT) and rat imaging



Primate PET and rabbit imaging

Clinical diagnostic equipment

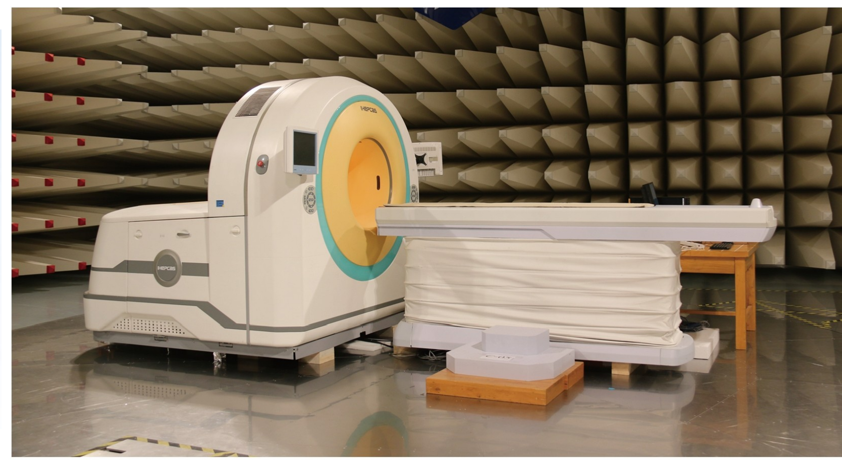
Whole Body PET

Breast PET-PEMi

Dual nuclide system

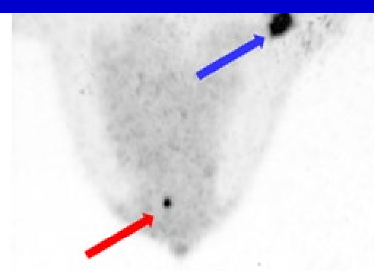
Nuclear medical imaging Equipment

- **The breast PET(PEMi) used for breast cancer diagnosis.**
- **The whole body PET system with proprietary intellectual property rights.**

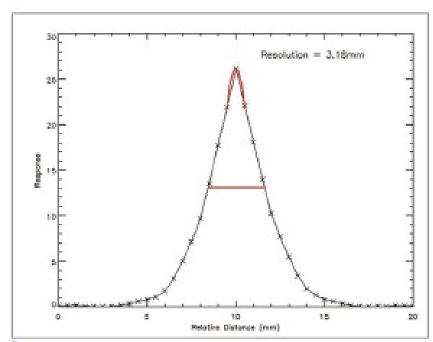


Certified by CFDA in China!

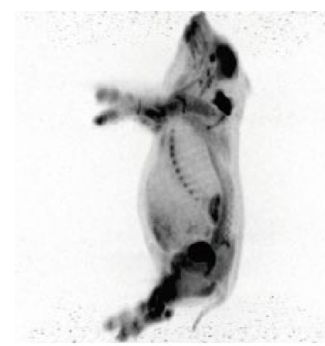
PET



PEMi

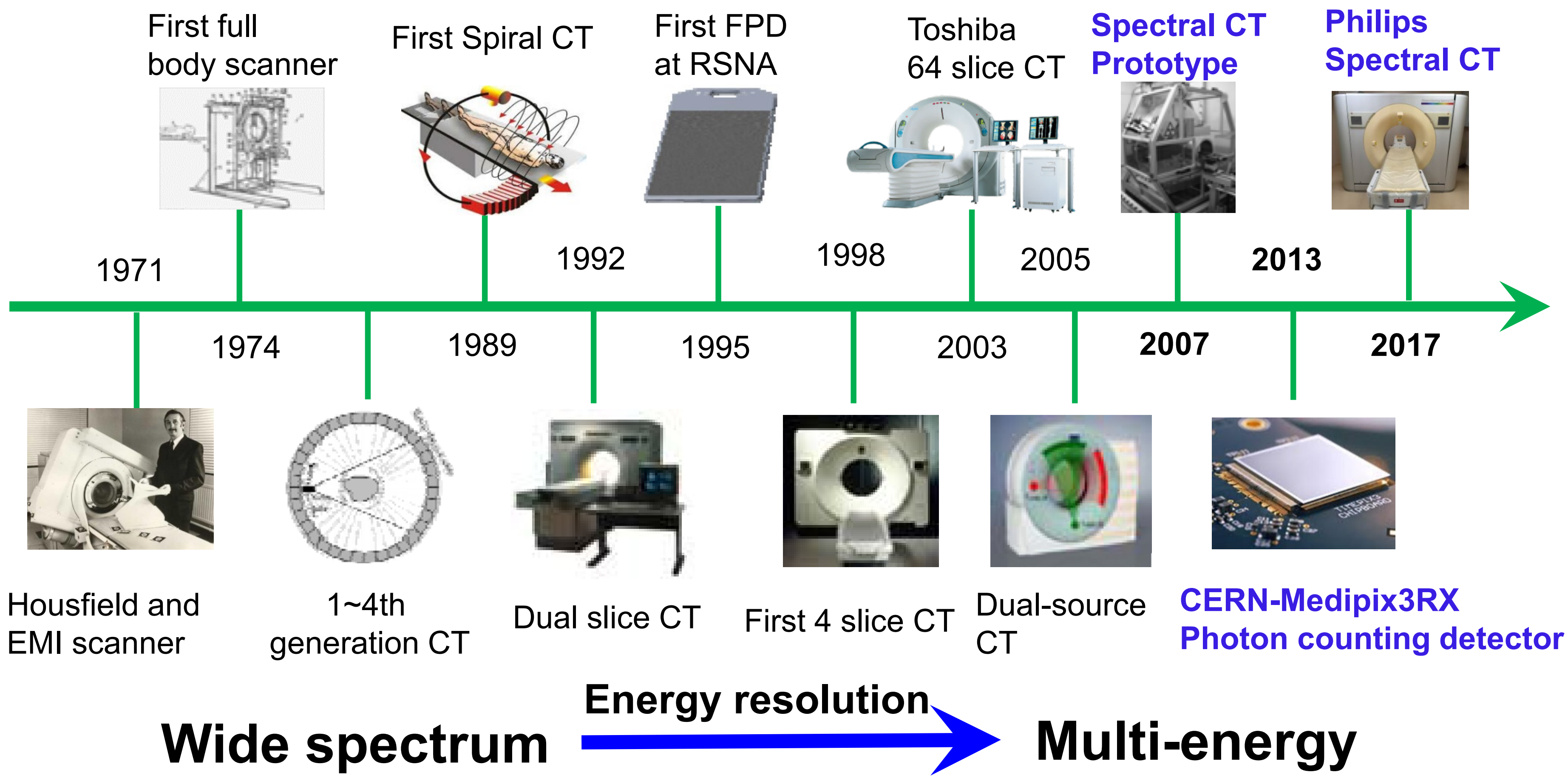


Resolution



Animal image

Developing of Computed Tomography

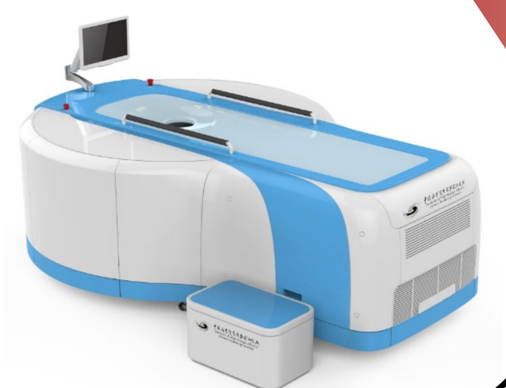


CT has gone through the stages of non-spiral CT, spiral CT, multi-slice CT, and now it is progressing to multi-spectral imaging

X-ray imaging Equipment

Key Components
Energy Resolution
Photon Counting
Detector

System Development
Breast CT



System Development
Small animal CT

Next generation for Spectral CT

X-ray imaging Equipment

System Characteristics:

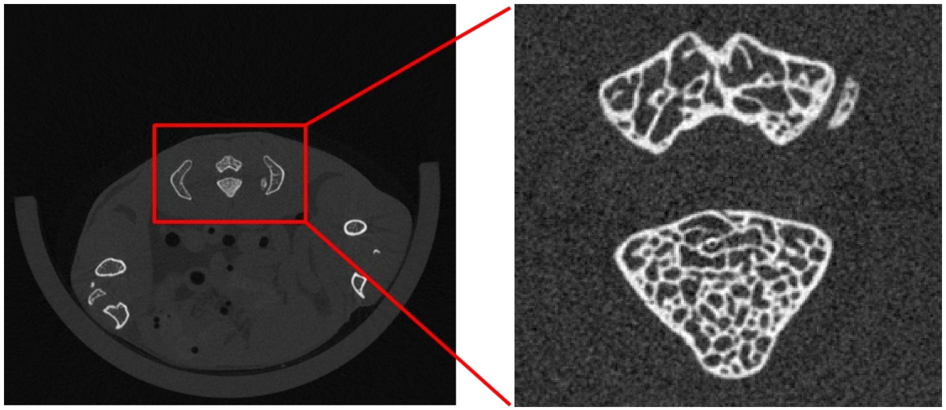
- Photon counting detector with multi-energy thresholds
- 3D energy spectrum imaging with high SNR, which is realized for the whole body structure of small living animals
- Advanced reconstruction algorithm
- Meets the application needs of biomedical research in bone research, tumor research, etc.

Specifications:

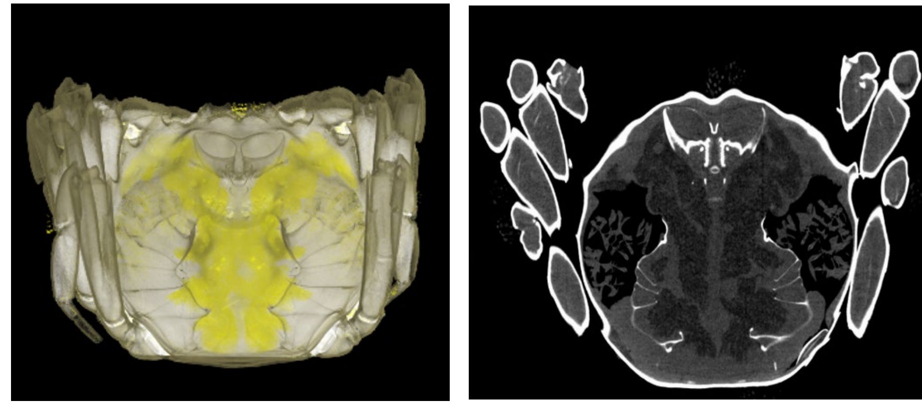
- X-Ray Source：90kV
- Detector：Photon Counting
- Spatial Resolution：≤ 20um
- Energy Threshold：2-8
- Image Array：512×512/2048×2048
- Fields of View：ϕ 65mm× L 200mm

Small animal Spectral CT

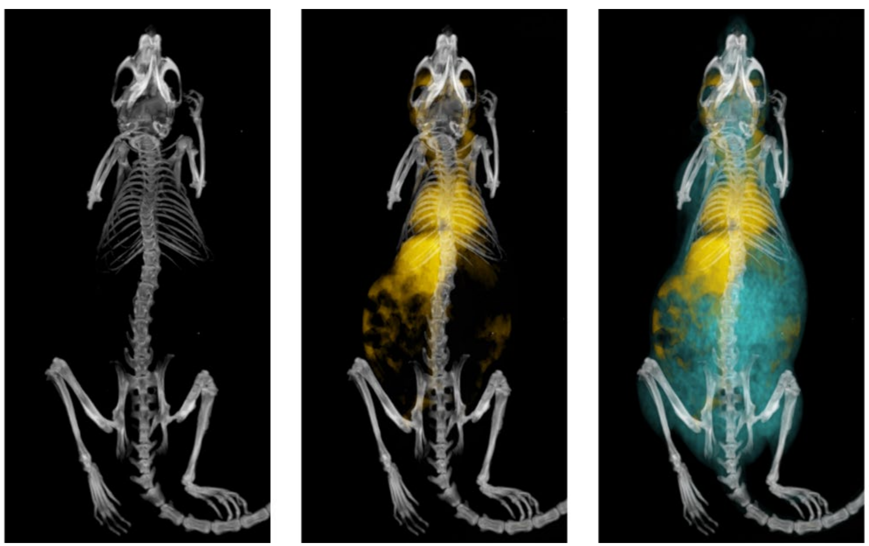
X-ray imaging Equipment



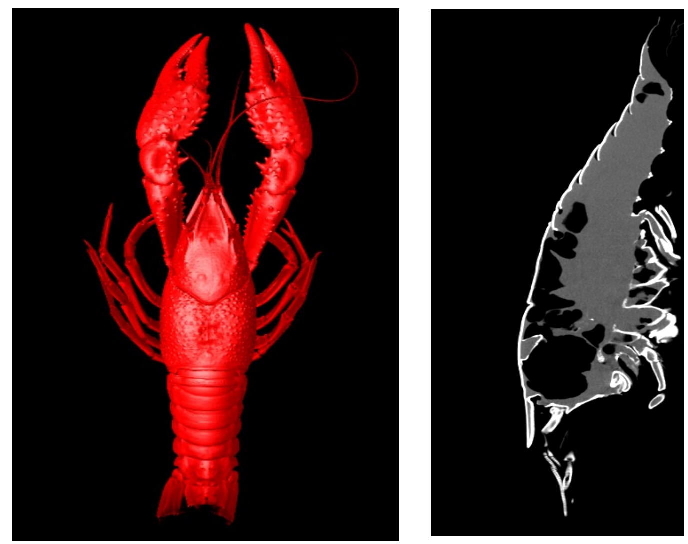
high resolution image(11um)



3D image of a crab



Enhanced color imaging of mice



3D image of a shrimp

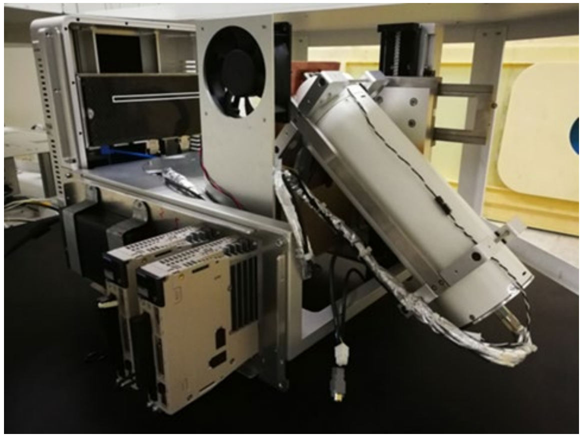
X-ray imaging Equipment

accurate positioning for microcalcification and small tumors at lower dose, to improve the detection rate of breast cancer census.

indicators	Mammography	breast CT	Our target
Imaging type	2D-DR	3D-CT	3D-CT
Radiation dose	6mGy	6mGy	3mGy
Details of the resolution	200μm	200μm	100μm
Contrast resolution	—	10‰	5‰
Whether need to compressed the breast	yes	no	no
Whether can multi-energy imaging	no	no	yes（≥4）

X-ray imaging Equipment

Prototype of Breast CT

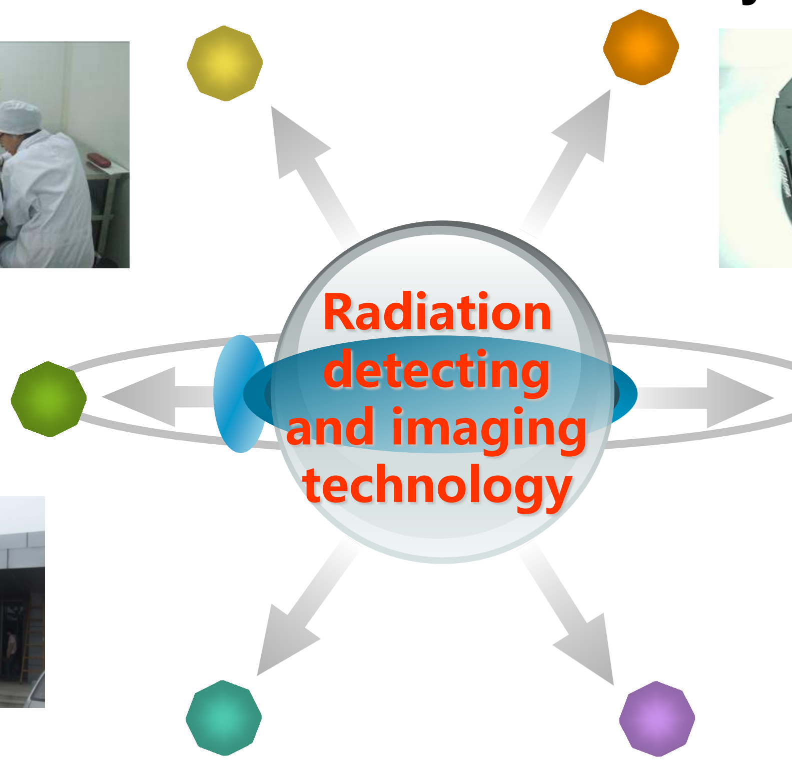


Inside view of the device

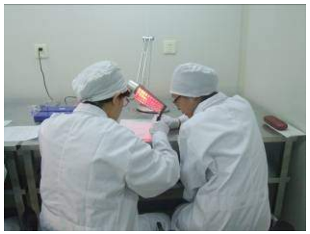
- ✓ Multi-energy imaging technology, high contrast, low dose (3mGy lowest)
- ✓ 3D imaging, isotropic high resolution(100um)
- ✓ K-edge enhanced imaging

Breast Spectral CT

Research Area and Direction

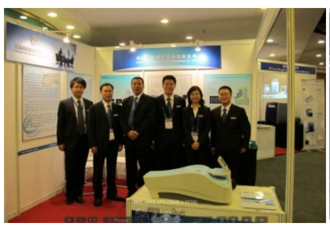


Core technology research

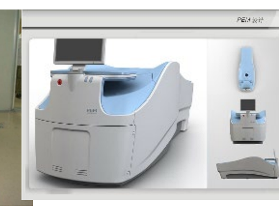



Key component developing

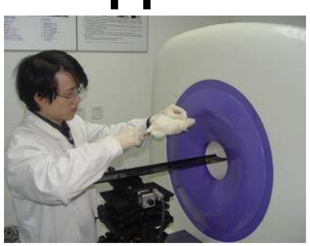
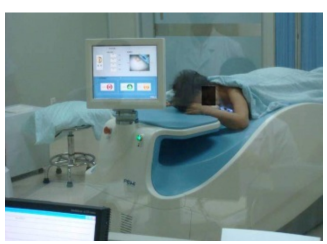

Industrial promotion




System Integration

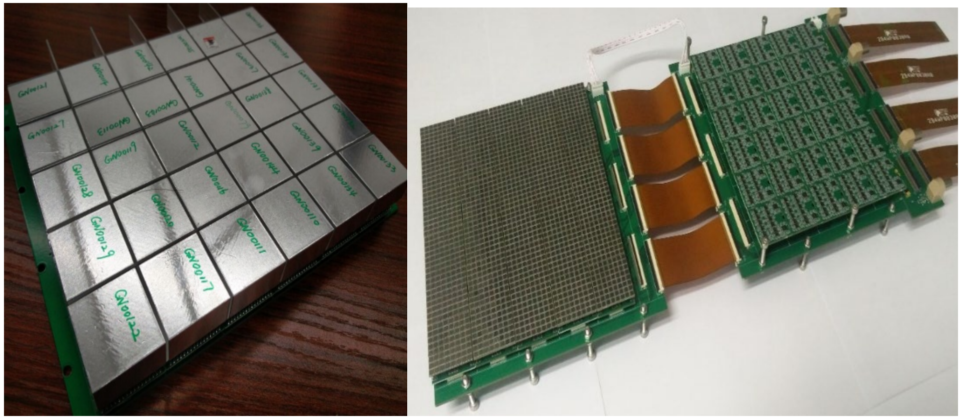



Application Research

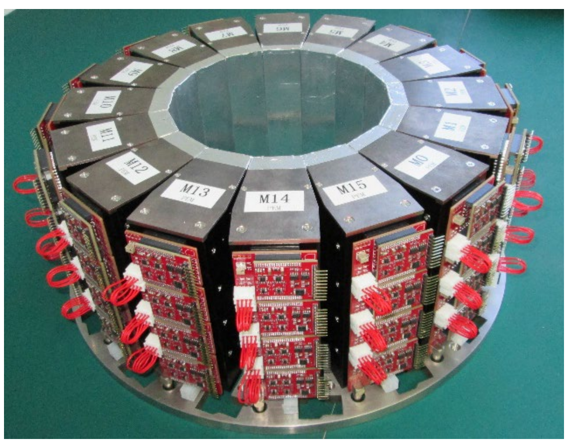



Talent Cultivation

The Detector System



SiPM detector system



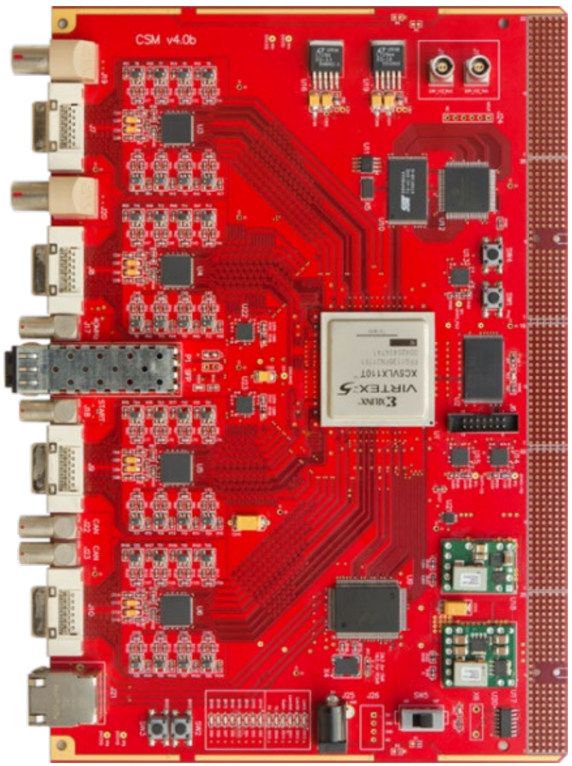
Breast PET detector system

Whole-body PET detector system

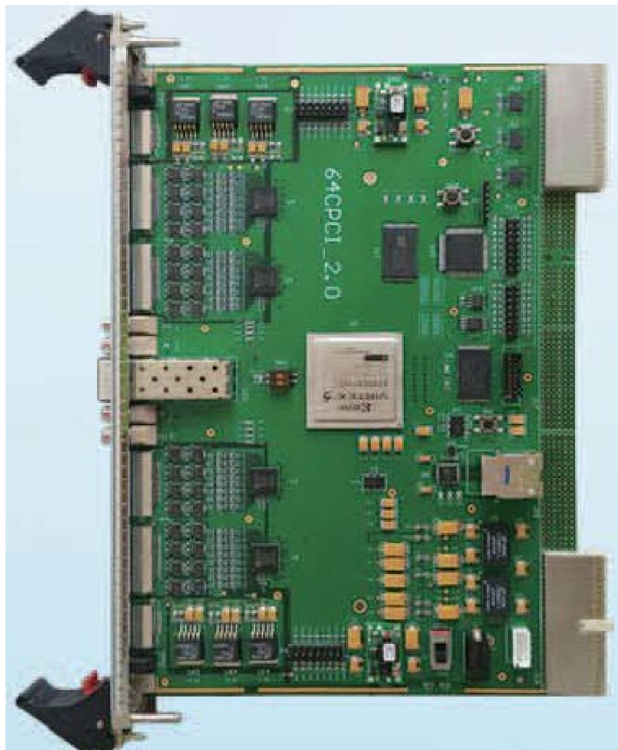
Self-designed series of detectors

The Data Acquisition System

- **Key technology**
  - Develop the data acquisition technology based on multi-channel and high-speed ADCs.
  - Finish different channels and different sampling rates DAQ boards.



16 channels DAQ



32 channels DAQ

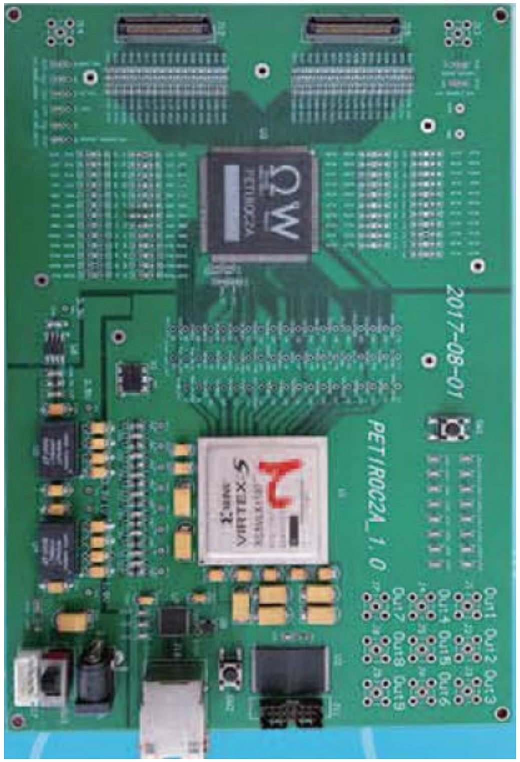
4 channels & 500MSPS DAQ

256 channels DAQ

The Data Acquisition System

- **Key technology**
  - Develop the data acquisition technology based on commercial ASICs and implement high integrated DAQ boards.

32 channels & 5.69GSPS DAQ

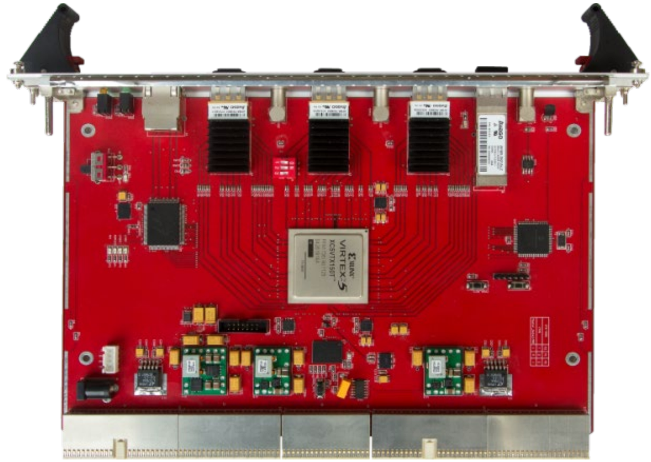


32 channels & SiPM dedicated DAQ

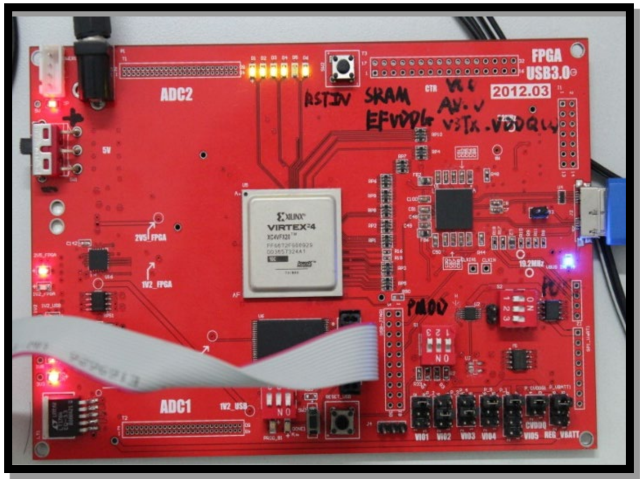
64 channels & PMT/SiPM dedicated DAQ

The Data Acquisition System

GigE transmission

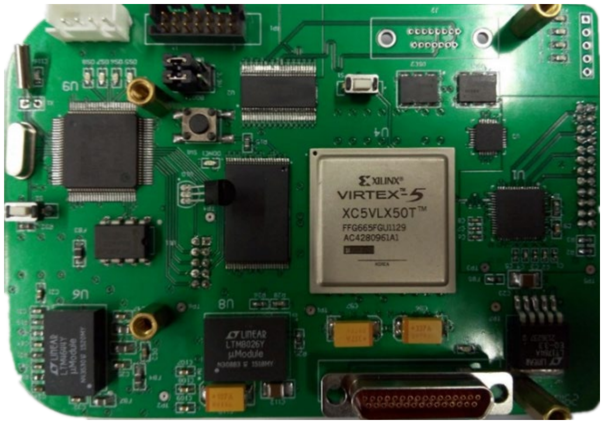


Fiber transmission



USB3.0

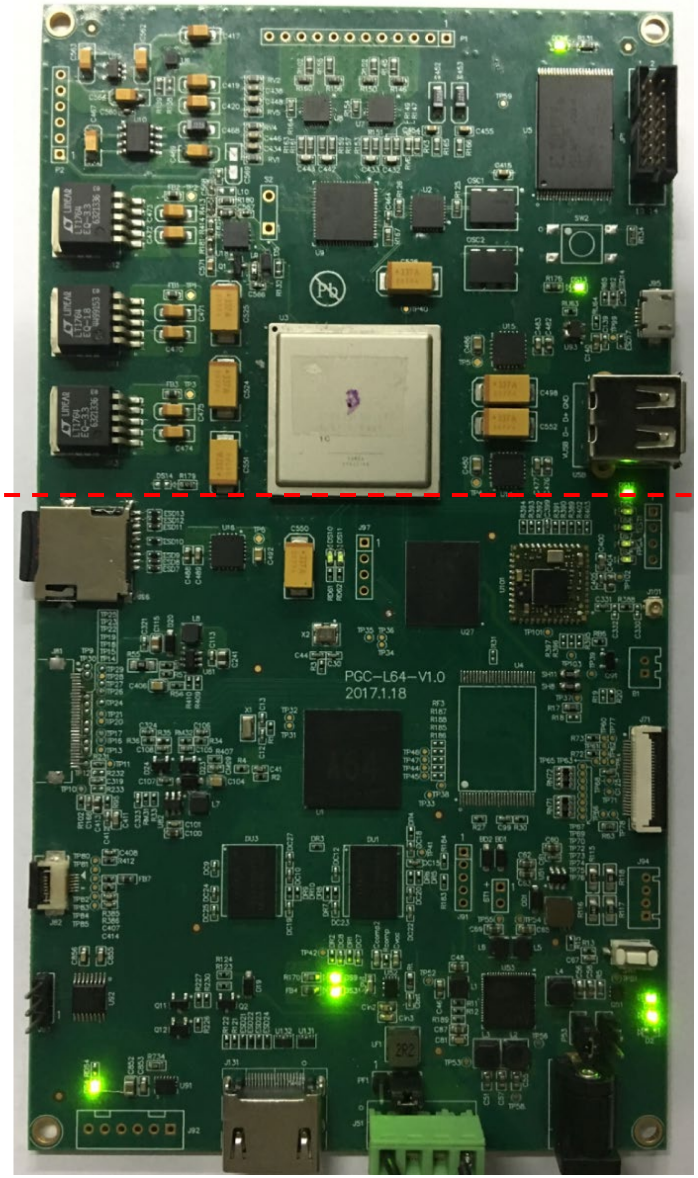
PCIe ×4



CameraLink

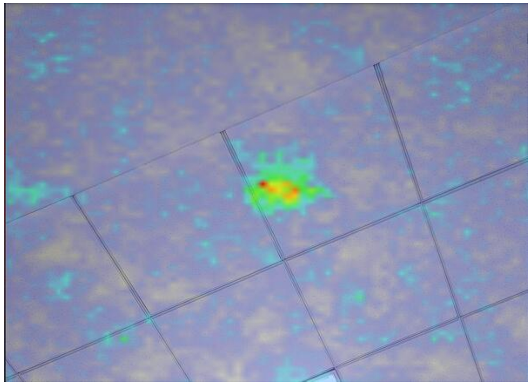
Design different data transmission technologies, such as 1x/10x GigE, USB3.0, CameraLink, PCIe, Fiber, etc al.

The Data Acquisition System



Key technology

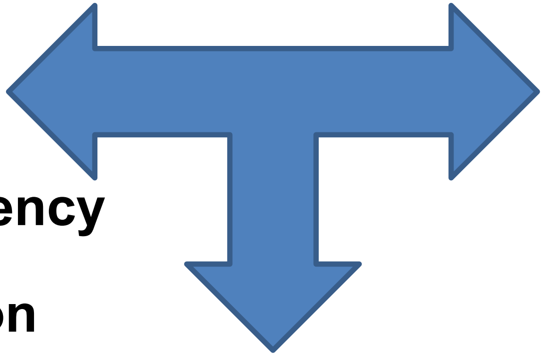
- Develop the data pre-processing technology based on FPGA, and implement hardware acceleration for imaging processing.
- Develop image processing algorithm and graphics display based on ARM.
- Implement migration of Android system and develop different APPs.



Trends for detector

Gas Detector :

- ✓ High resolution
- × Low detection efficiency
- × low energy resolution



Scintillation Detector:

- ✓ High detection efficiency
- × Low resolution
- × Low energy resolution

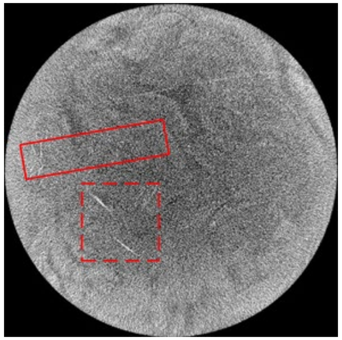
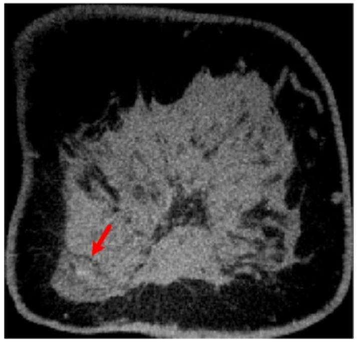


Image degradation

Semiconductor Detector :

- ✓ Energy resolution : ~1%@662KeV
- ✓ Spatial resolution : ~50um
- ✓ Low noise, high dynamic range

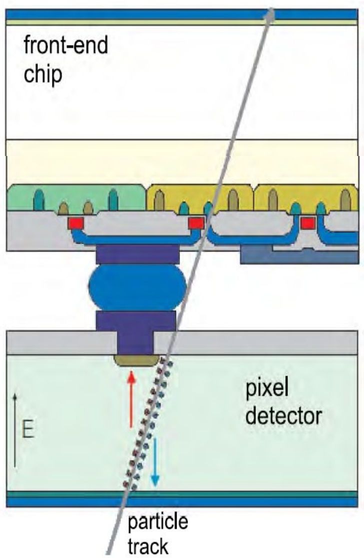


Low resolution

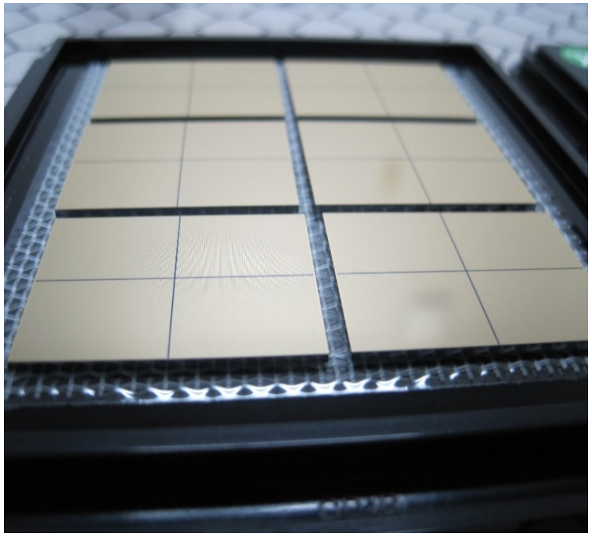
Semiconductor detector is the future of medical imaging equipment.

Photon Counting Detector in IHEP

- **Detector design for X-ray imaging equipment**
- **Hybrid pixel structure: Sensor + Flip-chip bonding + FEE**
  - Sensor： CZT/CdTe Array
  - Flip-chip bonding：Indium ball
  - FEE：multi-channel and high integrated， ASIC is necessary



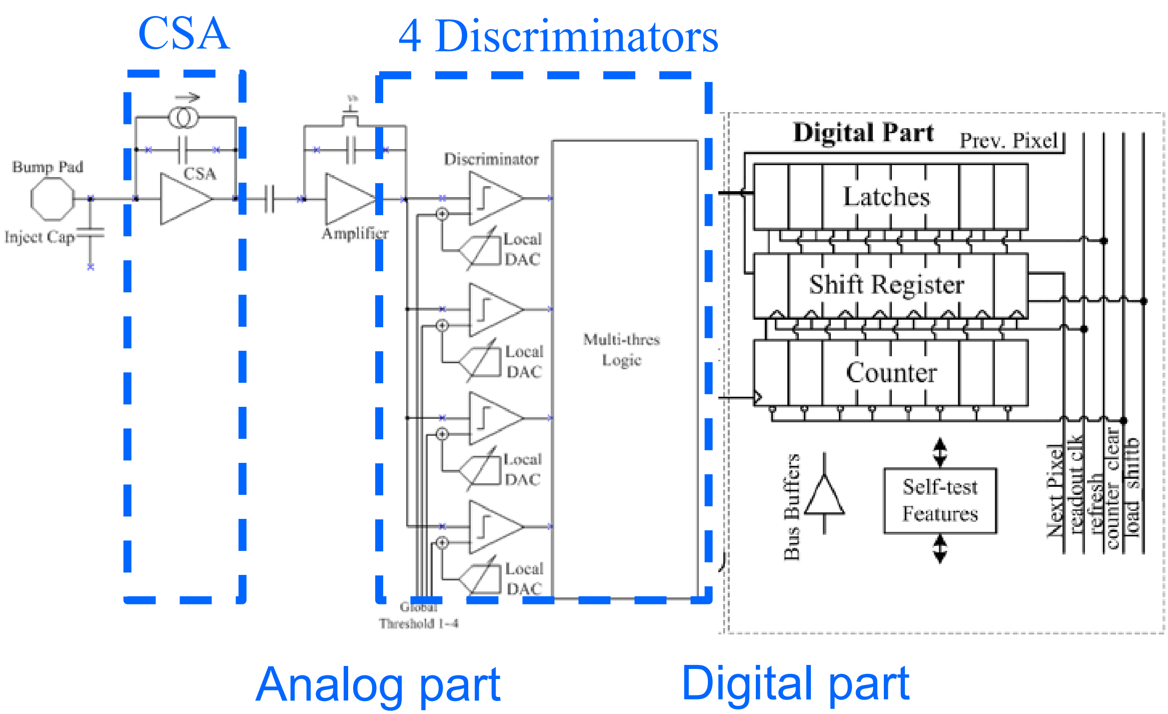
Hybrid pixel structure



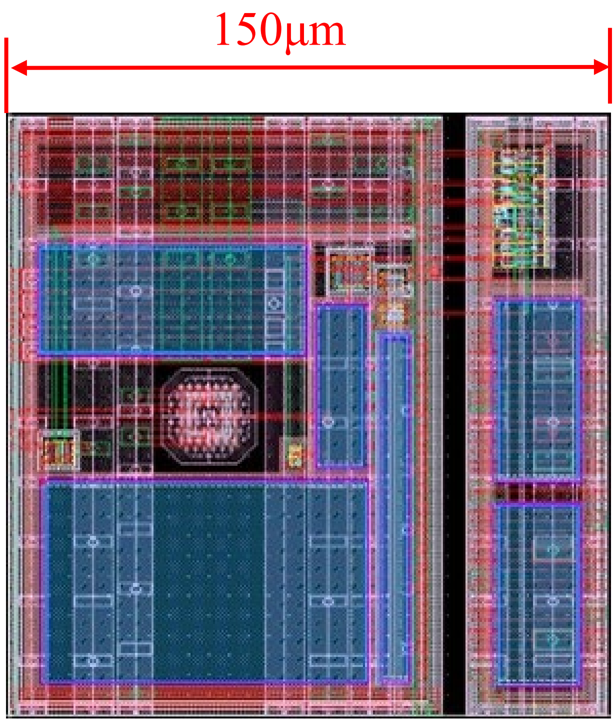
CdTe Sensor Array

FEE board

Photon Counting Detector in IHEP



The pixel readout schematic



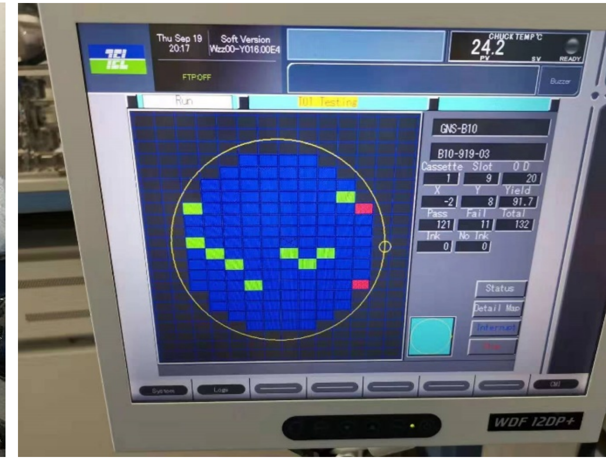
150μm×150μm

（by Experimental Physics Division in IHEP）

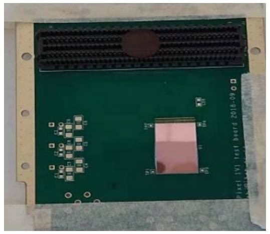
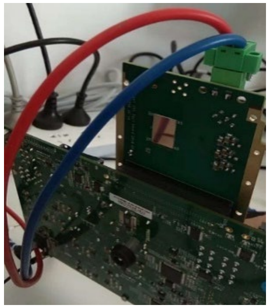
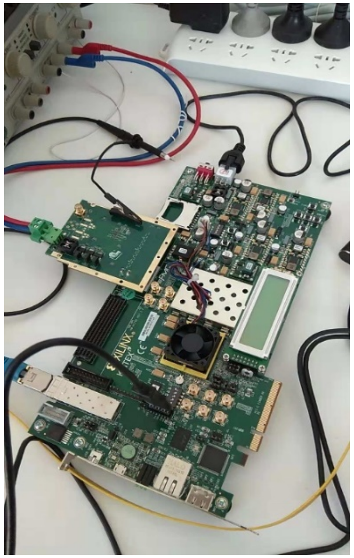
Implement the 'zero noise' detection

Photon Counting Detector in IHEP

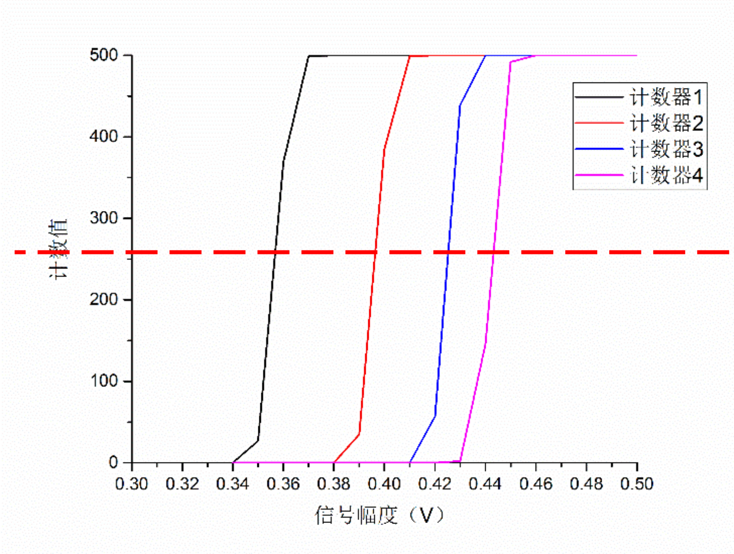

12 wafers

Die testing，Yield: 80%~90%

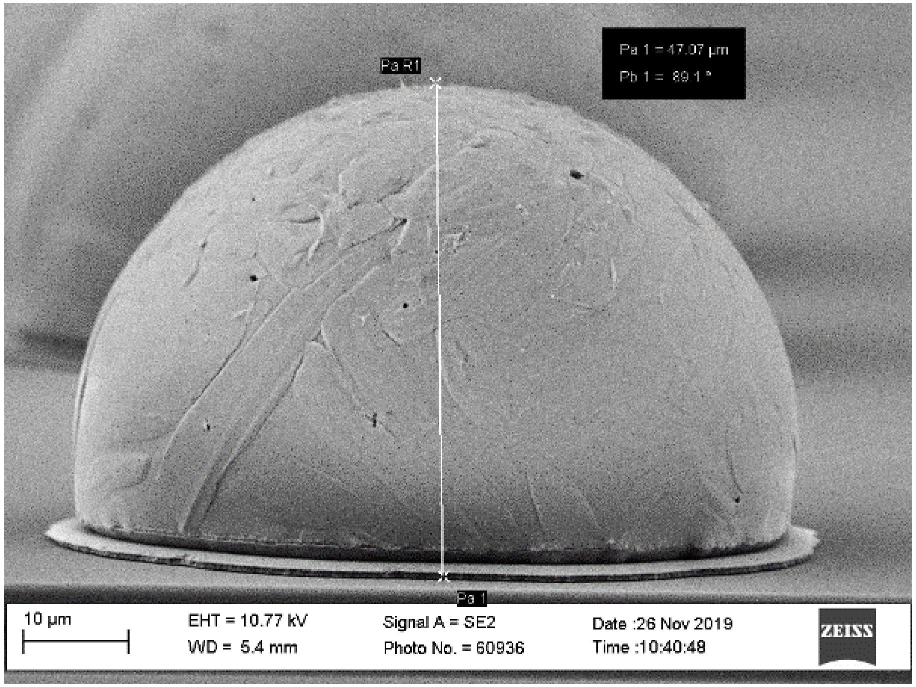
Testing board

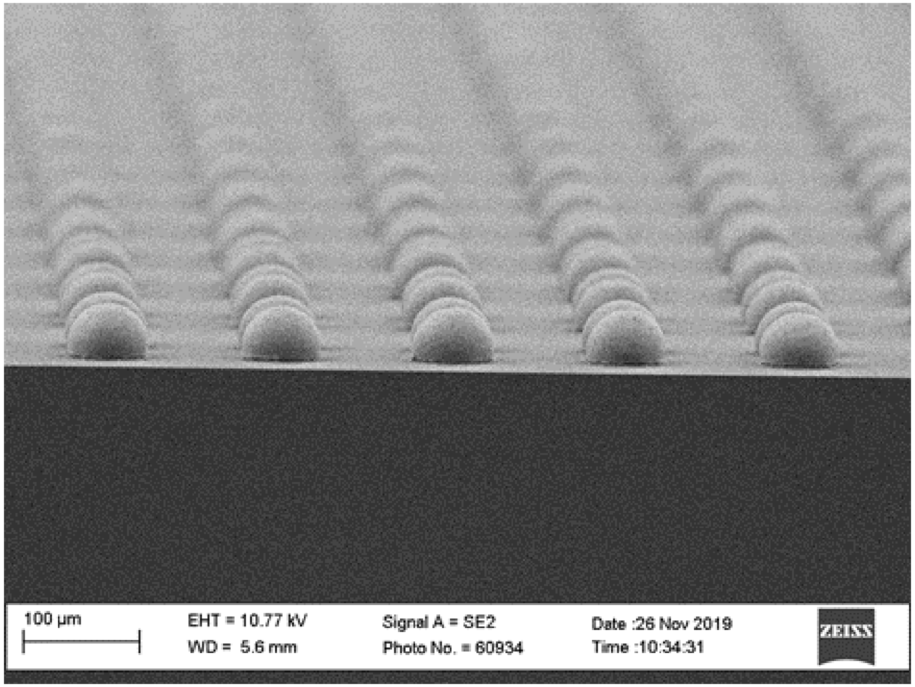


4 thresholds S-Curve

Photon Counting Detector in IHEP

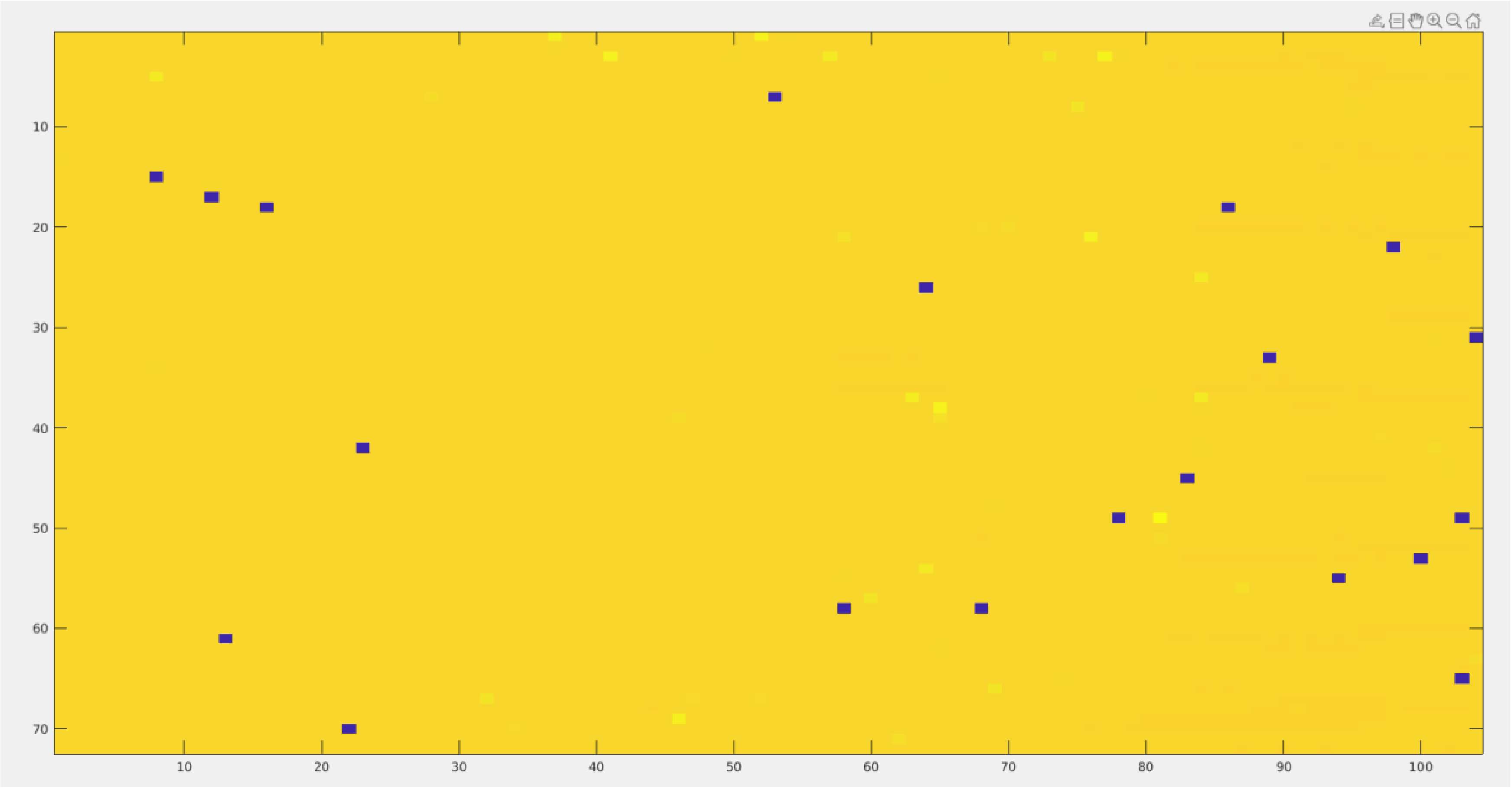
- **Flip-chip bonding**
  - Using Indium bump for the bonding





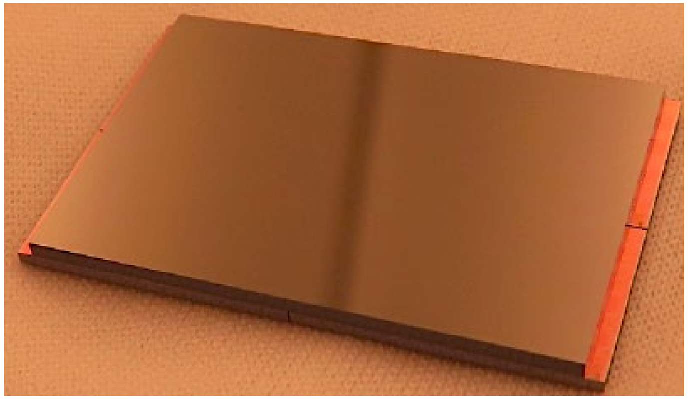
Bump size is 56um

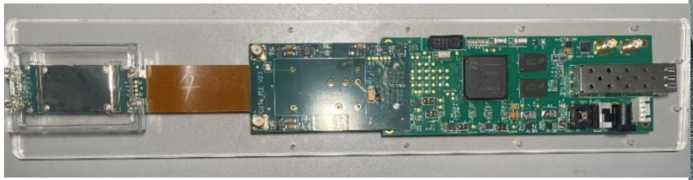
Photon Counting Detector in IHEP

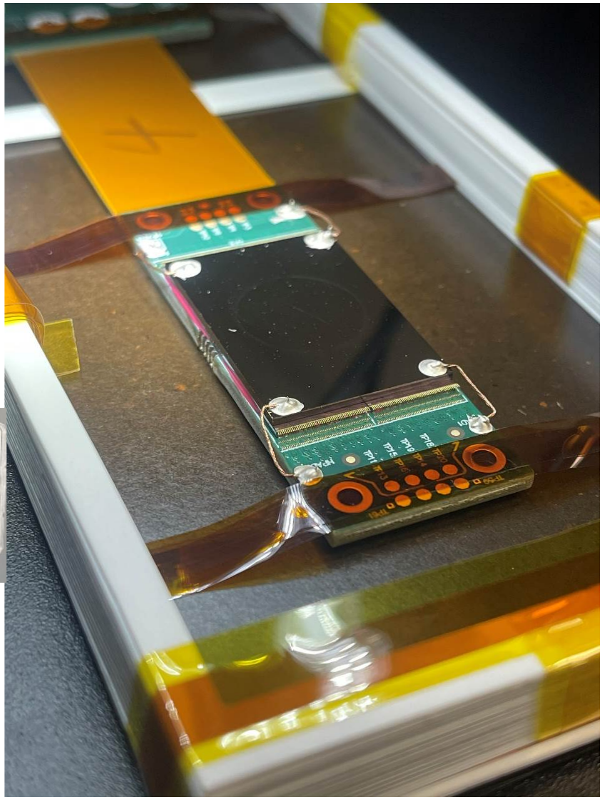


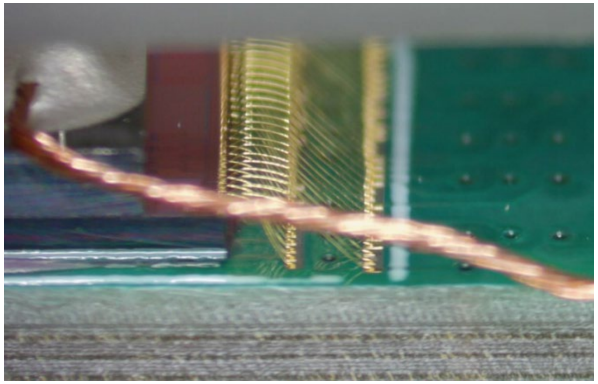
Bad pixel：20
Pixel Array：72×104
Reject ratio：0.27%

Photon Counting Detector in IHEP







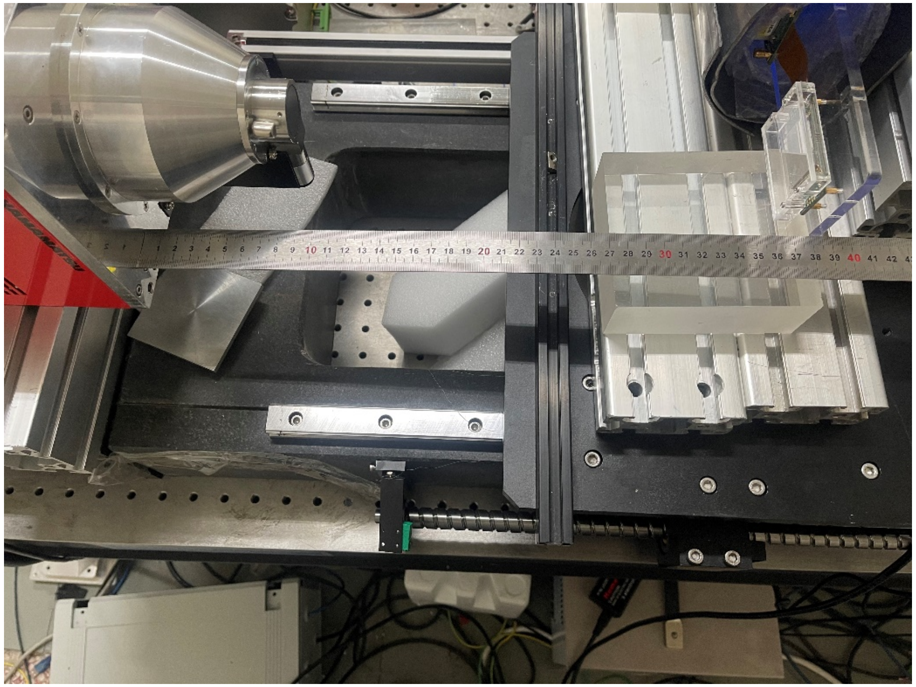


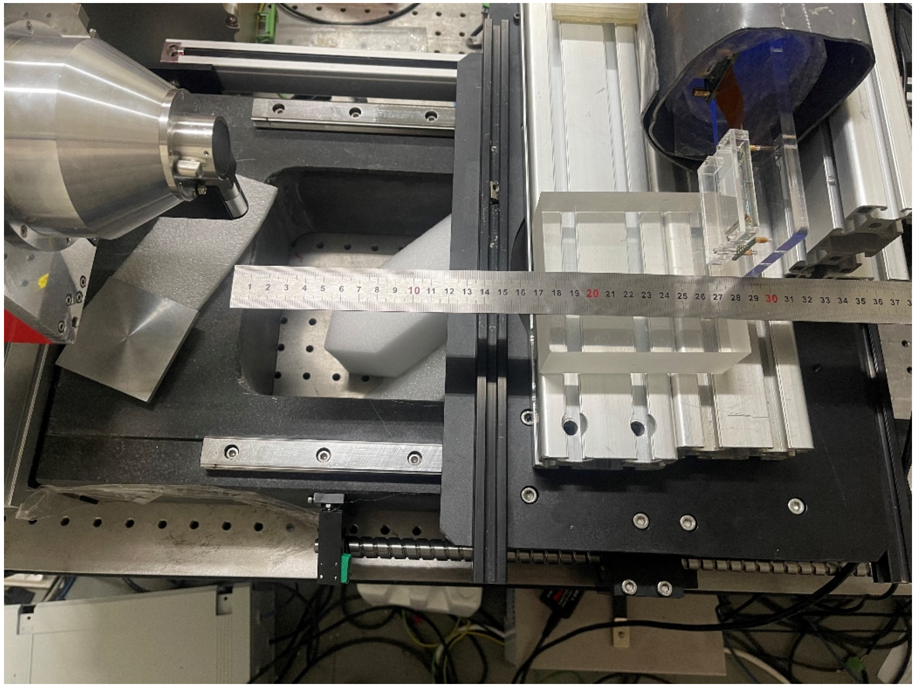
Sensor： CdTe
Array：144×208
Pixel size：150μm
Area：21.6 mm×31.2mm
Energy bins：4
Readout clock：40MHz
channel：9
Frame：1.2KHz

Bonding with 1mil gold wire leads

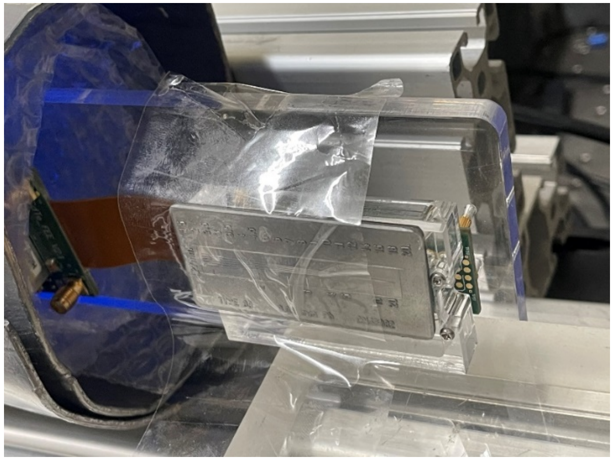
Photon Counting Detector in IHEP

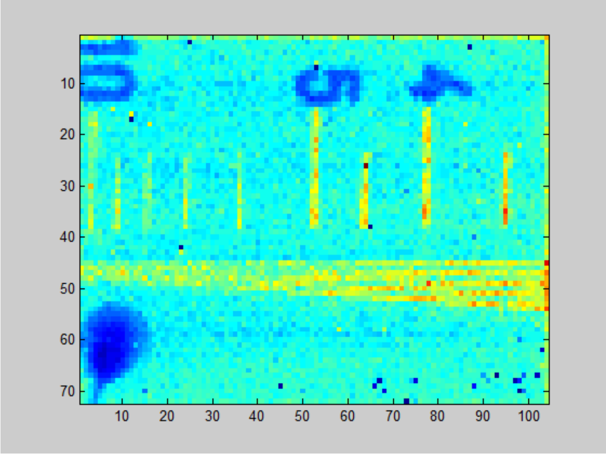
- **Test Condition**
  - ✓ The X-Ray tube is Hamamatsu L10321；
  - ✓ The distance between detector and tube: ~28cm；
  - ✓ The readout clock is 12.5MHz；
  - ✓ The thickness of CdTe is 1mm，High Voltage is -300V；

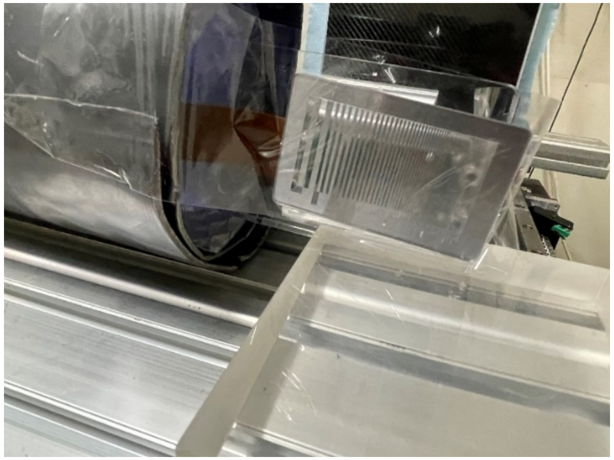


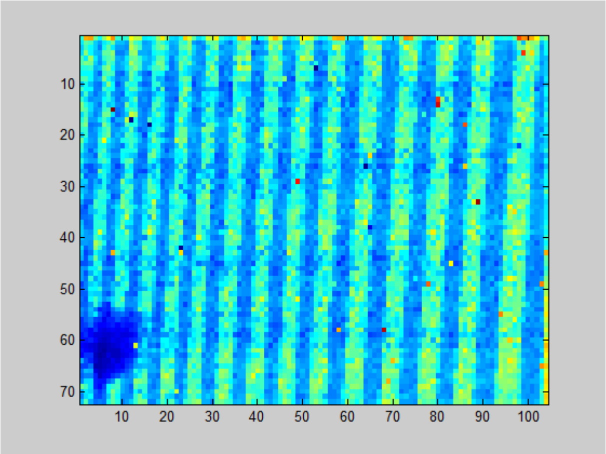


Photon Counting Detector in IHEP



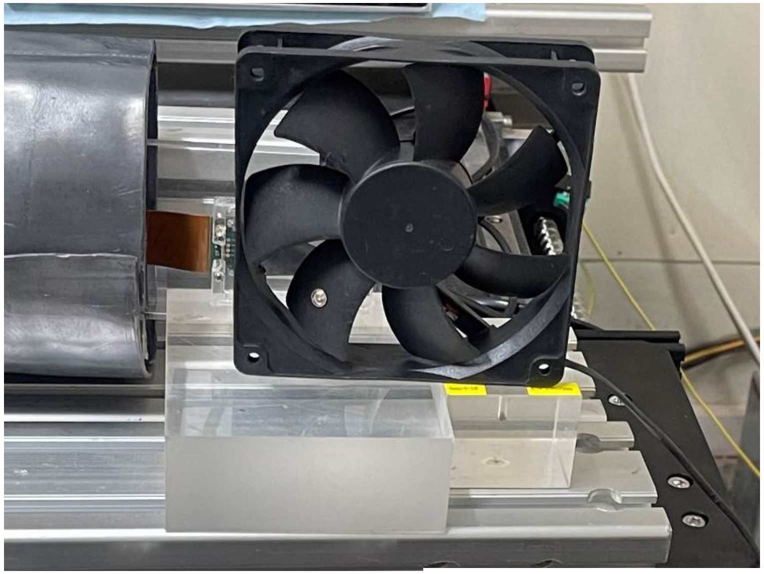


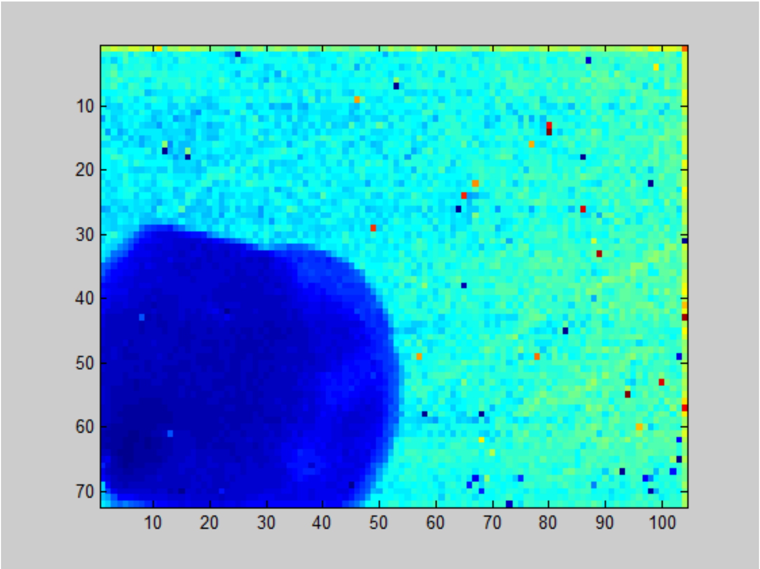


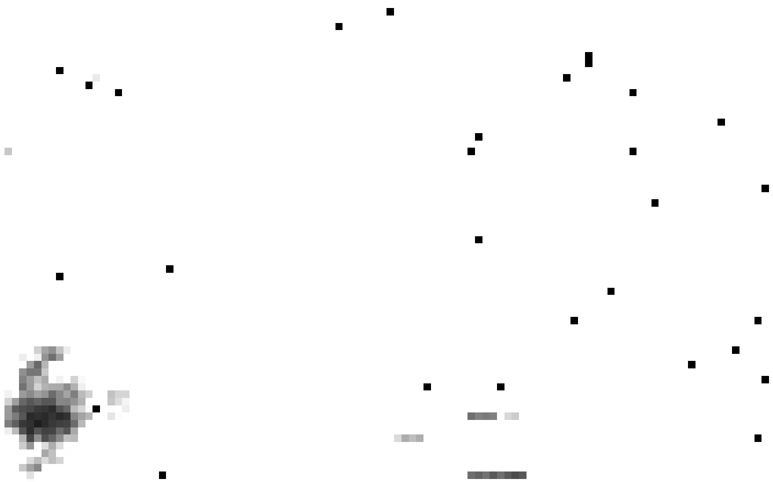


Tube Voltage100kV，Current 200uA

Photon Counting Detector in IHEP







Frame frequency:341.5 fps

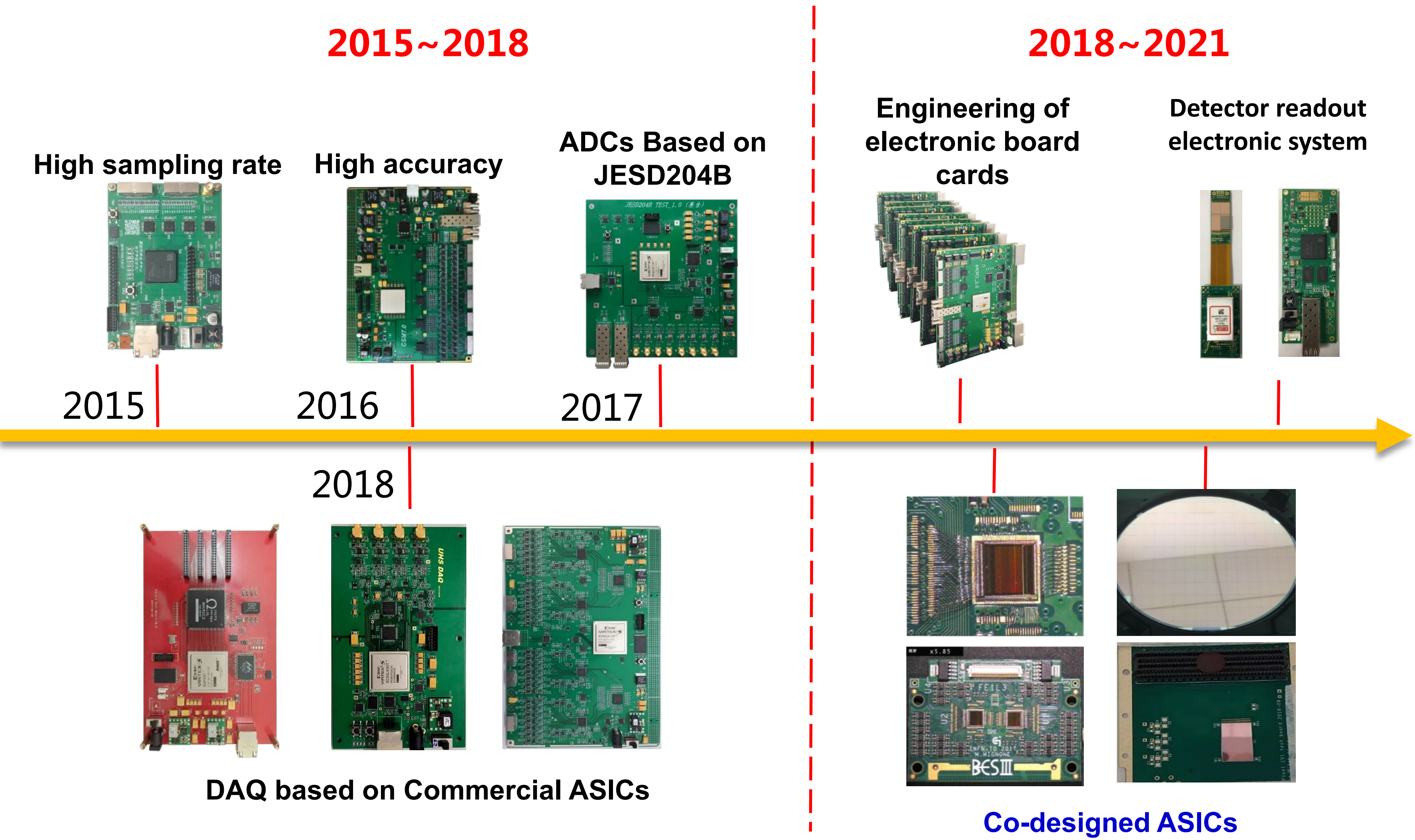
Photon Counting Detector in IHEP

- **Detector Module testing has been finished on May, and now it is in the calibration process.**
- **The full-scale detector will be assembled in 3~4 months, and be 8 modules together.**
- **The module size is 2×2 chips, and will be enlarged to 2×4 chips.**

Outline

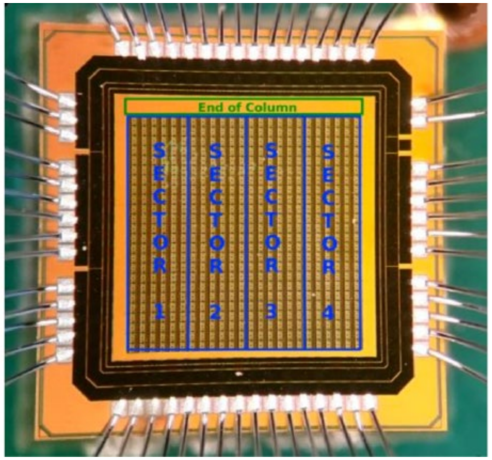
- On-going Work in IHEP for Medical Physics
- Current Collaboration between IHEP and INFN
- Future Perspectives

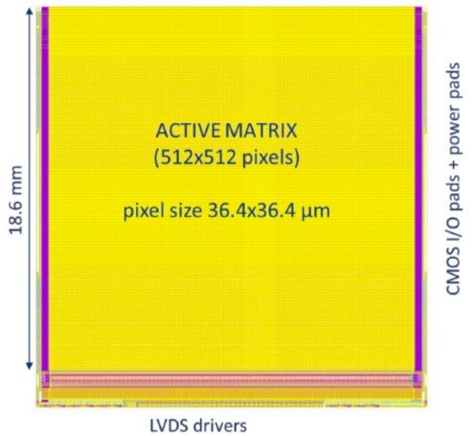
The Readout Electronic Technique



Collaboration with INFN: Pixel Readout ASIC

- Design framework for a system-grade pixel ASIC has been started at INFN (ARCADIA Collab.)
- Jiale Cai (IHEP-INFN PhD Program 2019)
- For this ASIC: Smaller pixel size (100μm) and on-chip charge sharing algorithm(Manuel will give more details)





Pixel Readout ASIC Prototype
Manuel Da Rocha Rolo (INFN), 2019 IHEP-INFN Bilateral Meeting

Collaboration with INFN: Pixel Readout ASIC

- Road map for the ASIC
  - Phase 1: First demonstrator of X-ray detector built on the CMOS MAPS developed in framework of ARCADIA.
  - Phase 2:Start from the 2x4 pixel organization of the ARCADIA main demonstrator chip and implement a 100x100um pixel for photon counting.

    Tape-out by mid-2022, DNTA builds DAQ in Q4 2022
  - Phase 3:Test on a medical instrument at IHEP in 2023.

γ-ray detection readout system

- **Readout electronics for CZT**
  - CZT + VATA450 + Xilinx FPGA
  - VATA450: CSA + Shaper + ADC

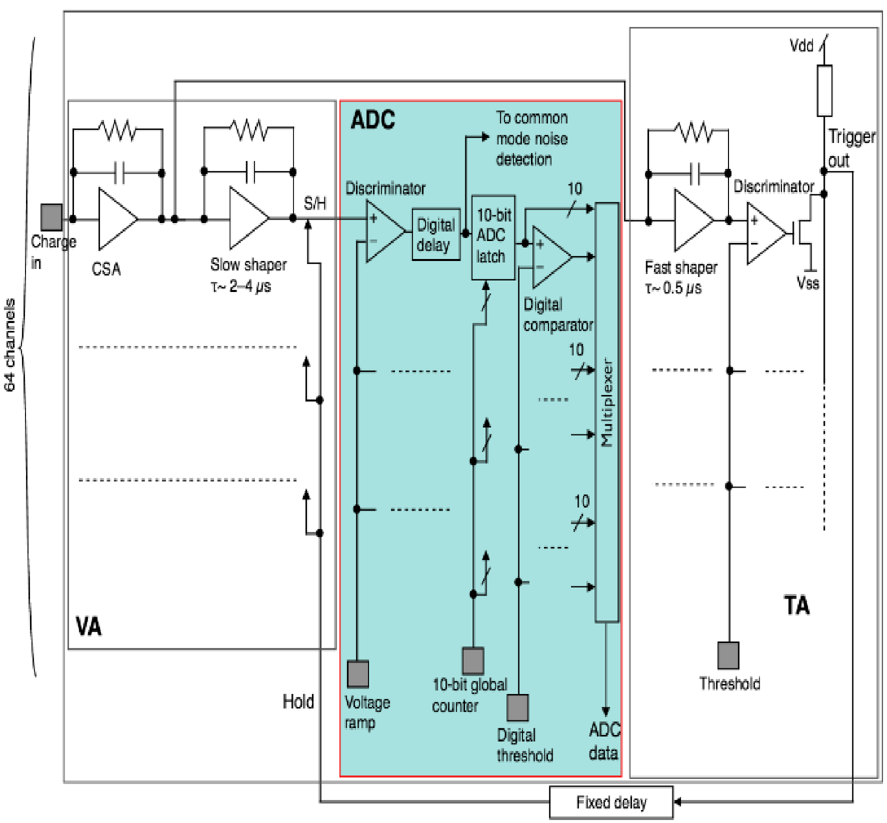
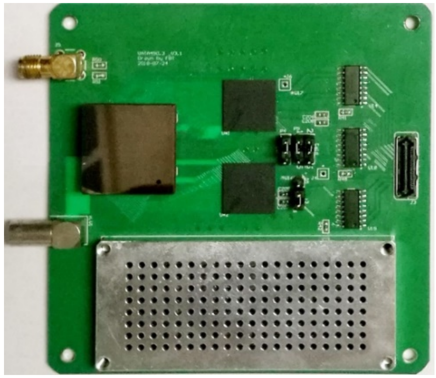
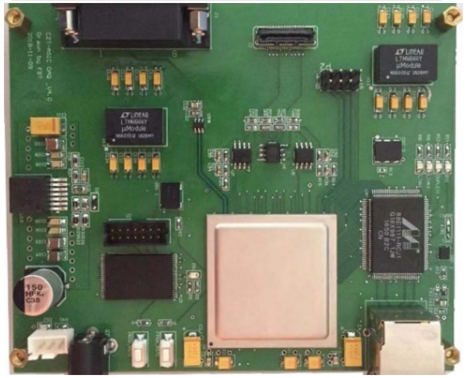


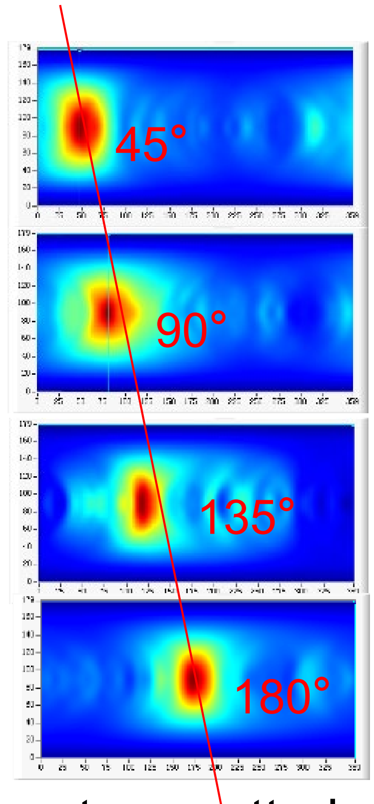
Figure 1: ASIC functional overview. Source: [RD02].



CZT+ASIC



FPGA Controller



Compton scattering imaging

γ-ray detection readout system

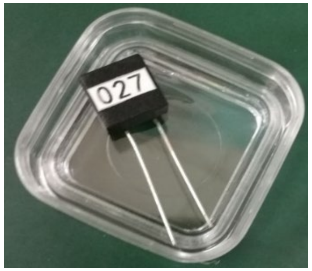
Expected ASIC Specifications

entry	specifications
Channels	121 (for anode) + 2 (for cathode)
Input range	>100fc
Count rate	>10k per-channel
ENC	< 65e/pf
Adjustable shaping time	
Adjustable gain	
Adjustable threshold per-channel	
TAC	

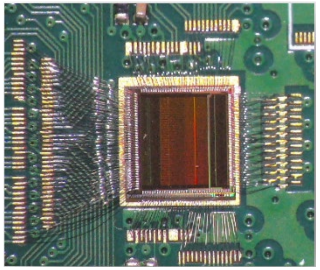
The goal is to get the 3D information from detector

Collaboration with INFN: TIGER-CZT ASIC

CZT Readout at IHEP with TIGER ASIC

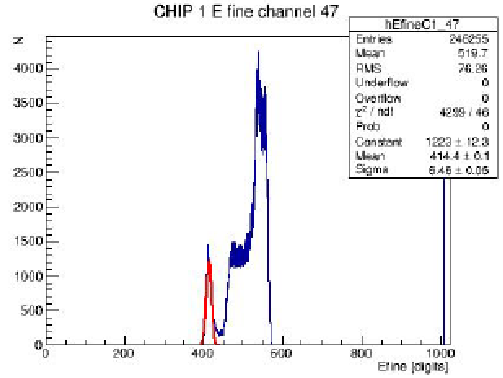


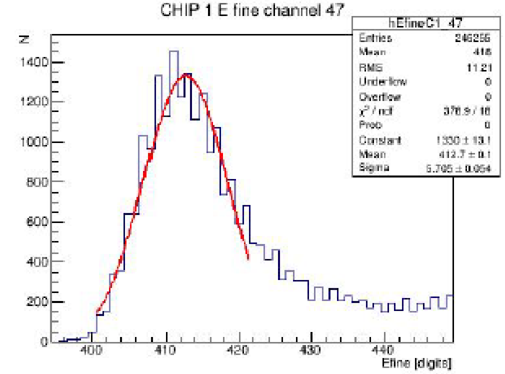
CZT Detector



TIGER ASIC

BESIII e-Kits





condition	signal	channel	ENC-total	energy resolution	Qin[fC]	other
1	pulse generator	63	1600	2.67%	23	on sensor
2	Test pulse	62	2900	4.69%	23.6	no sensor
3	Test pulse	47	2700	4.34%	23.6	sensor connect-off
4	Test pulse	47	2800	4.55%	23.6	sensor connect-on
5	CZT sensor	47	4100	7.07%	22.09	sensor signal

Energy Resolution - 2019 IHEP-INFN Bilateral Meeting

- **Test campaigns at IHEP using BESIII e-Kits with TIGERv1 and TIGERv2**
- **Readout of cathode and multi-anode array for 3D radiation detection**
- **TIGERv1 can get a resolution better than 5%**
- **New TIGER-CZT prototype will be ready in 6~9 months**

Collaboration with INFN: CZT Readout ASIC

- Road map for the ASIC
  - Phase 1: Send an TIGERv1 e-kit to IHEP, and do the characterization with DNTA staff and remote support in April 2021. Still on-going…..
  - Phase 2:Detailed study of the signal characteristics of the CZT anode/cathode, towards the optimization of the very front-end.
  - Phase 3:Start a new design or a design revision of the TIGER ASIC at the beginning of 2022.

Outline

- On-going Work in IHEP for Medical Physics
- Current Collaboration between IHEP and INFN
- Future Perspectives

Outlook

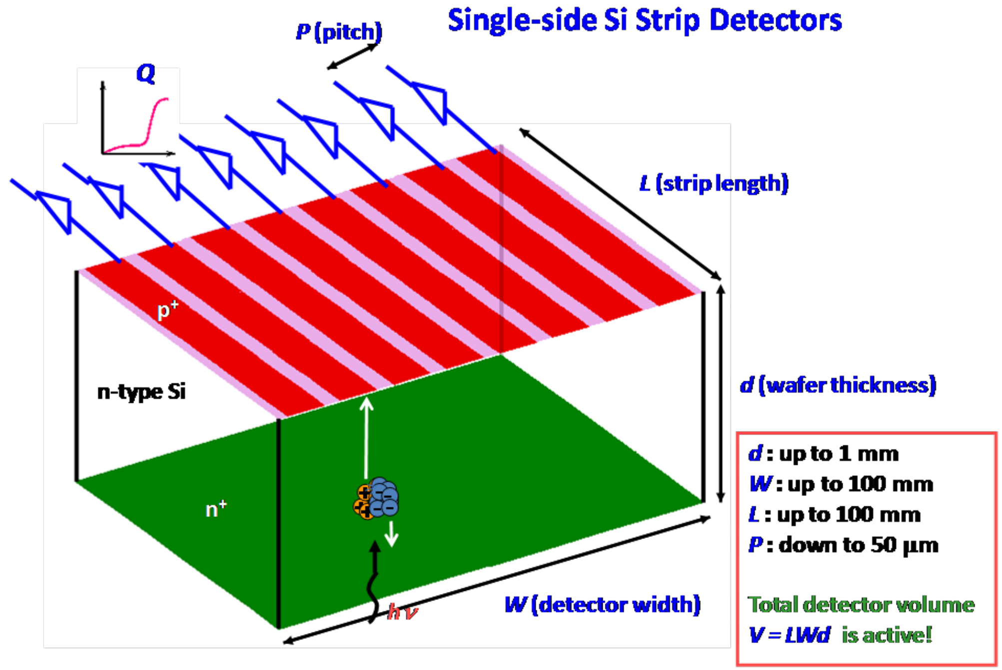
- **Finish new Pixel ASIC for photon counting CT in the field of medical physics**
- **New requirements for ASIC development in the field of X-Ray Diffraction and PET system**
- **Further collaborative IHEP-INFN effort on ASIC design, fostered by a Joint PhD Program in Microelectronics**

Collaboration with INFN: Si-strip Readout ASIC

Detector Specifications

Entry	Specifications
application object	X-ray diffraction
Strips	128 strips, 50μm pitch
Length of the strips	8mm
Global count rate	$\geq 1\times10^8$ cps
Energy resolution	< 380ev @ 8Kev
Sensor Thickness	500μm
Frame Rate	4.2KHz

Used for X-ray diffractometer



Collaboration with INFN: ASIC for PET Detector

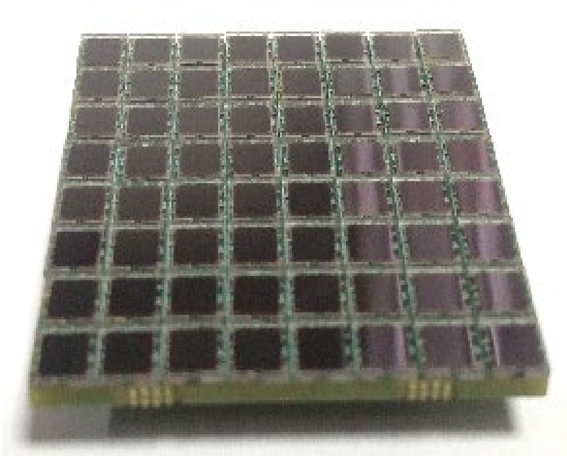
- **Detector requirement especially for specific system**

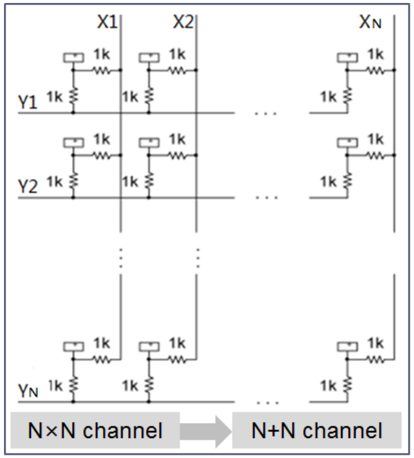
- High position resolution：≤1mm
- High time resolution：≤300ps
- High energy resolution：~10%@511keV

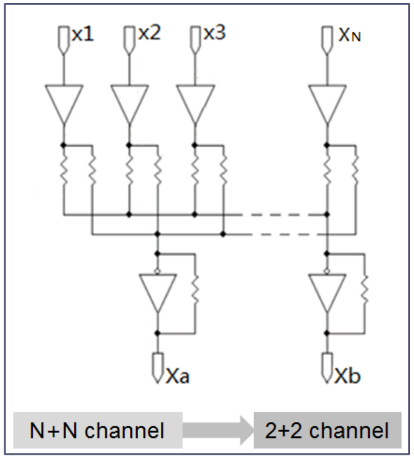
- **Currently used Detector solutions**

- SiPM array such as 8×8……
- Combining readout channels by resistance network

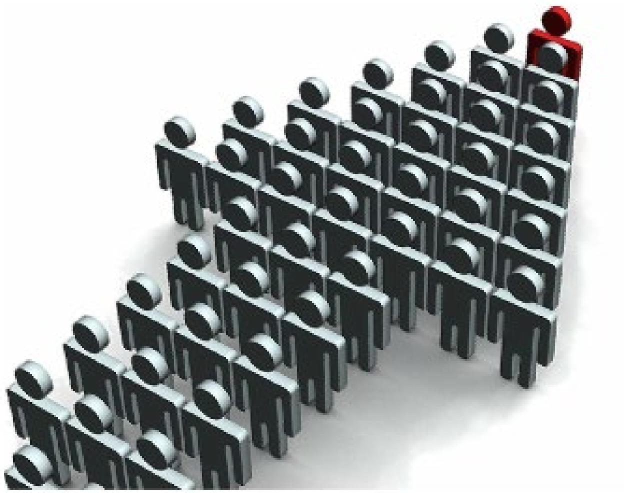
- AISC requirements
- Number of channels: 64
- Signal Polarity: positive or negative
- Dynamic range: 0~1500pC
- Independent measurement of charge and time
- TDC bin: ≤30ps
- event rate: ~500kcps







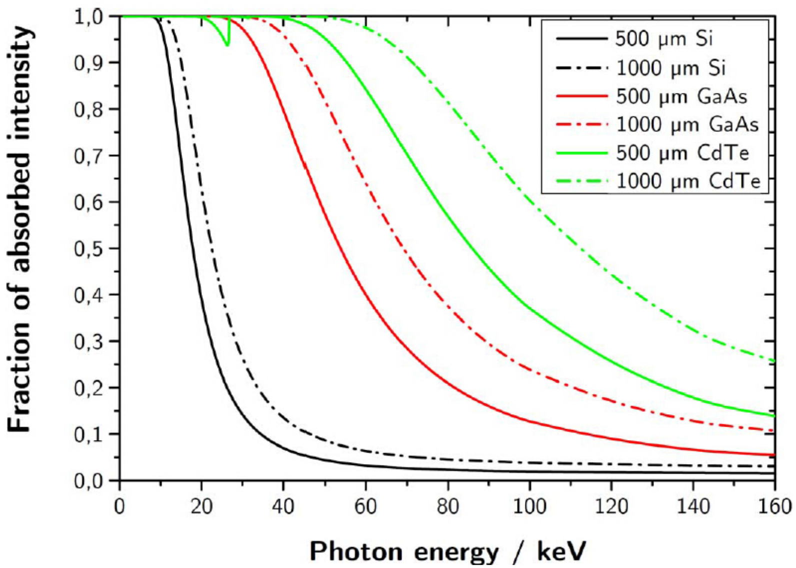
Thank you!



Comparison of different sensors

Sensor materials

- Si
- GaAs
- CdTe
- CZT



X-ray imaging : 20-160keV
γ-ray imaging : 20-662keV

Energy	Si 500um	Si 1000um	GaAs 500um	GaAs 1000um	CdTe 500um	CdTe 1000um
20keV	40%	65%	99%	99%	99%	99%
60keV	5%	7%	38%	62%	85%	95%
100keV	2%	2%	12%	22%	35%	60%
160keV	1%	1%	4%	10%	18%	30%

CdTe/CZT match the our requirements better.