High granularity timing detector (HGTD) activity at IHEP/NJU

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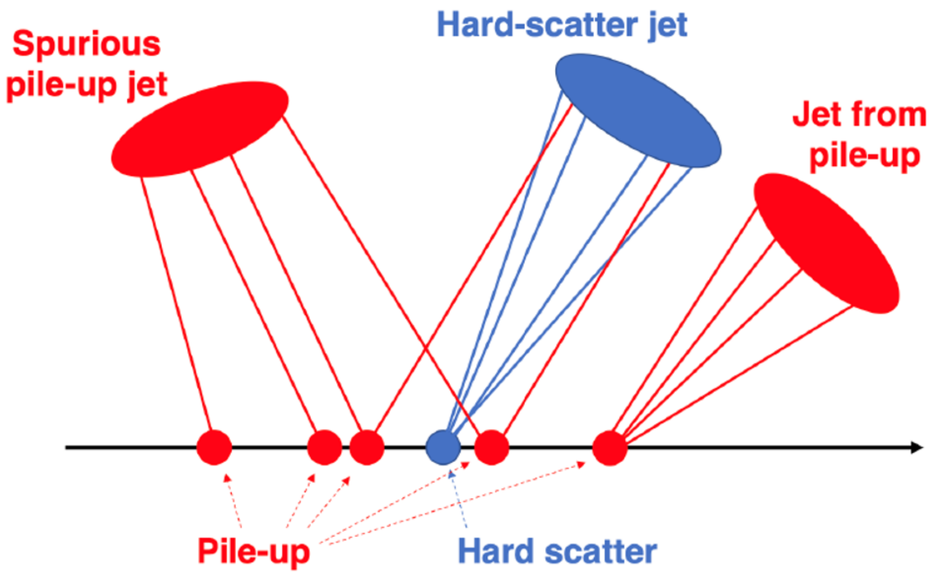
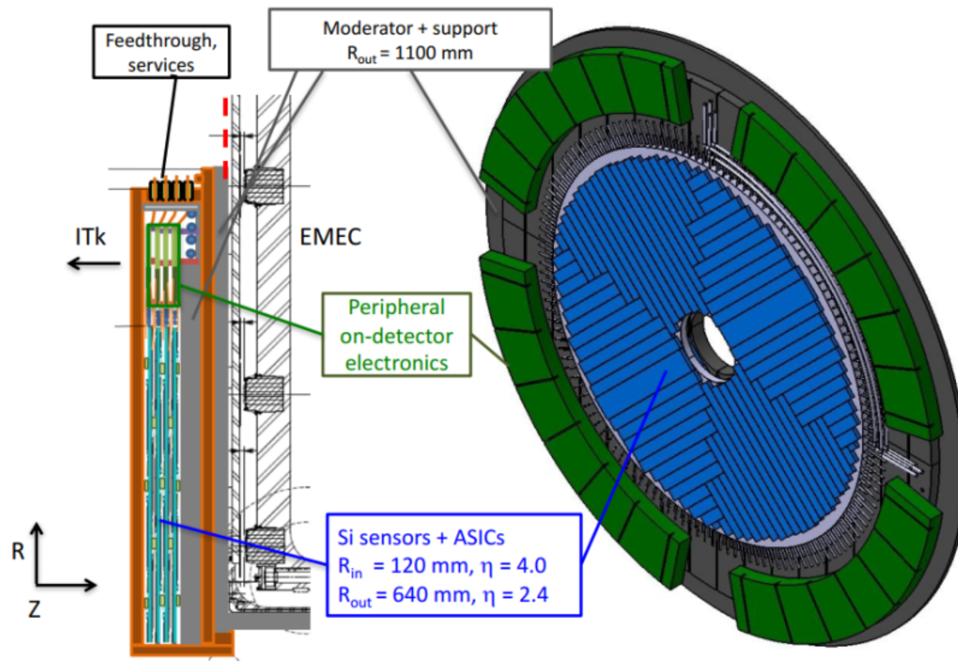
On behalf of IHEP/NJU HGTD team

The 6th CLHCP workshop, 6 -9 Nov 2020, Zoom

High-Granularity Timing Detector (HGTD)

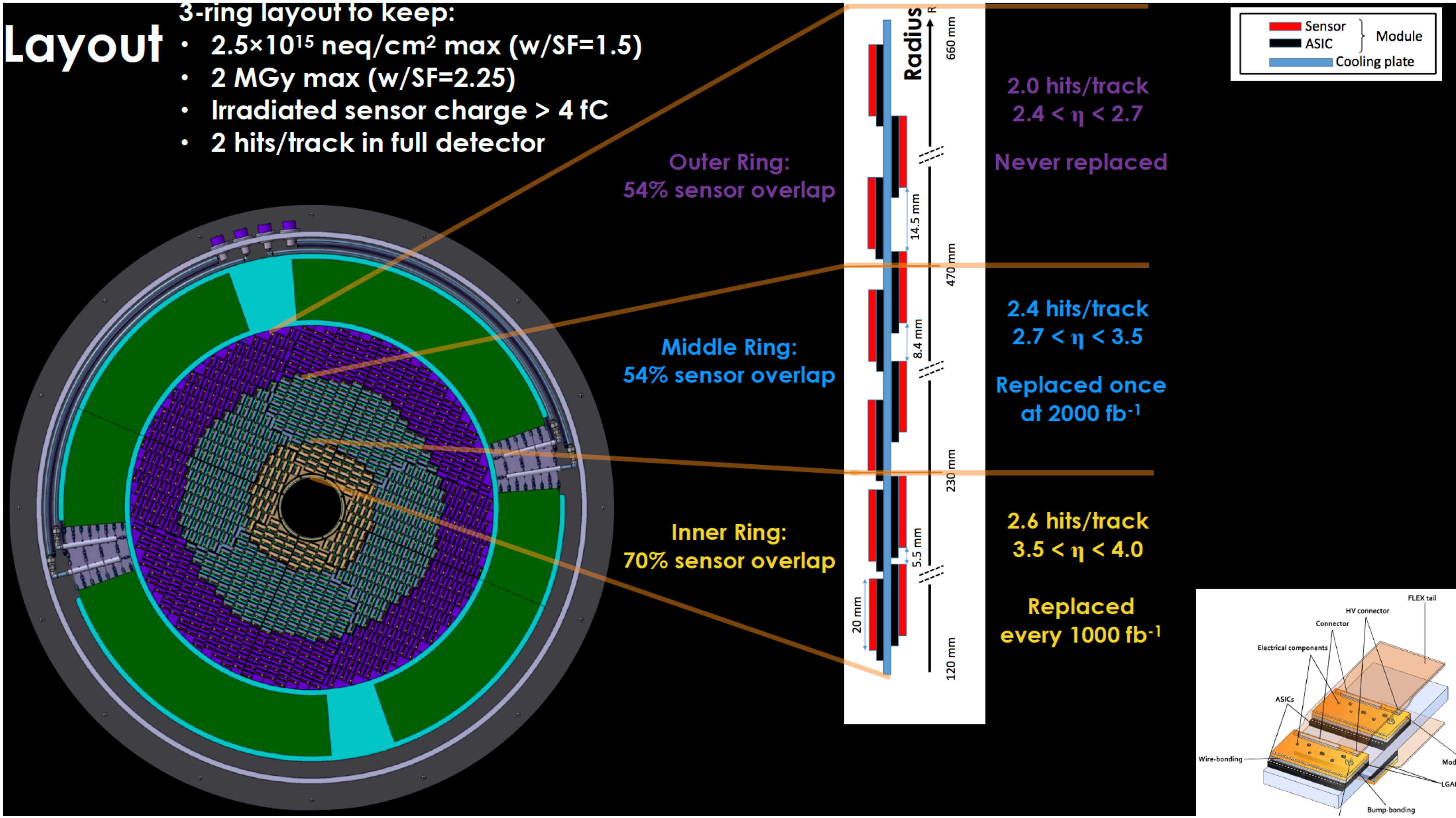
- HGTD approved by CERN Research Board on Sep 2020
- HGTD aim to reduce pileup contribution at HL-LHC
  - Timing resolution is required to be better than 50ps
  - $6.4m^2$ area silicon detector and $\sim 5\times10^6$ channels
  - Radiation hardness: 2.5×10^{15} N_{eq}/cm^2 and 2MGy





HGTD: layout and irradiation hardness

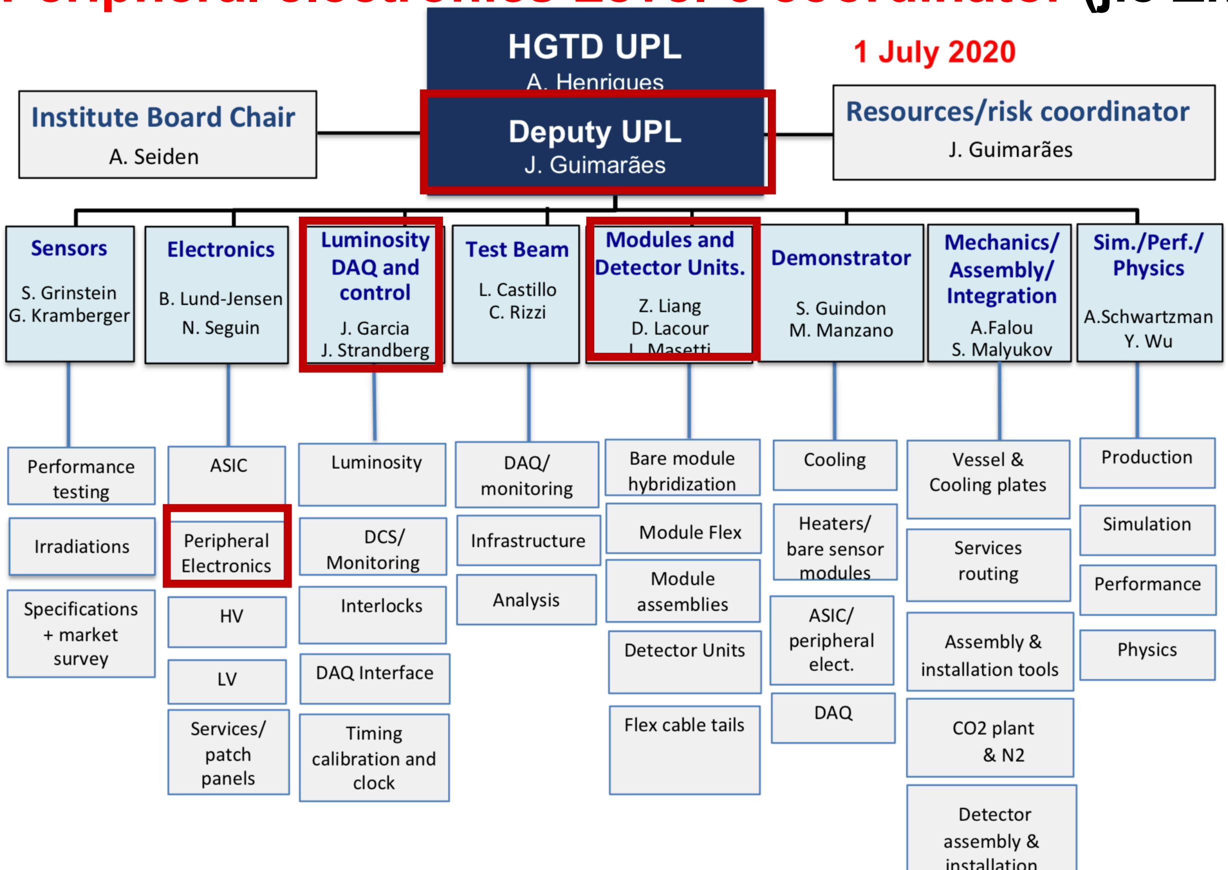
- 3-rings layout, two double layer of silicon detectors (6.4m^2)



IHEP/NJU team in HGTD

- IHEP/NJU team **(~15 faculty, ~10 postdoc, 10+ students)**
- **Takes Leading roles in ATLAS HGTD project**
  - **HGTD deputy project leader** (Joao Guimaraes Da Costa, IHEP)
  - **Module group Level-2 coordinator**(Zhijun Liang, IHEP)
  - **DAQ Level-2 coordinator** (Juanan Garcia, IHEP)
  - **Peripheral electronics Level-3 coordinator** (jie Zhang, IHEP)

1 July 2020

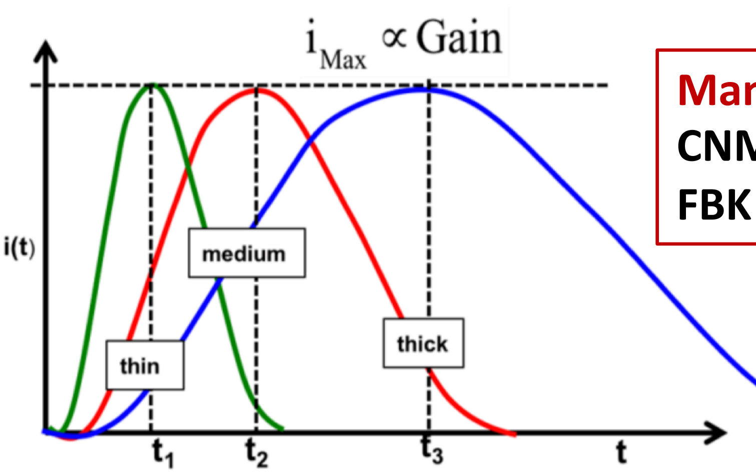


Ultra-fast silicon sensor R & D

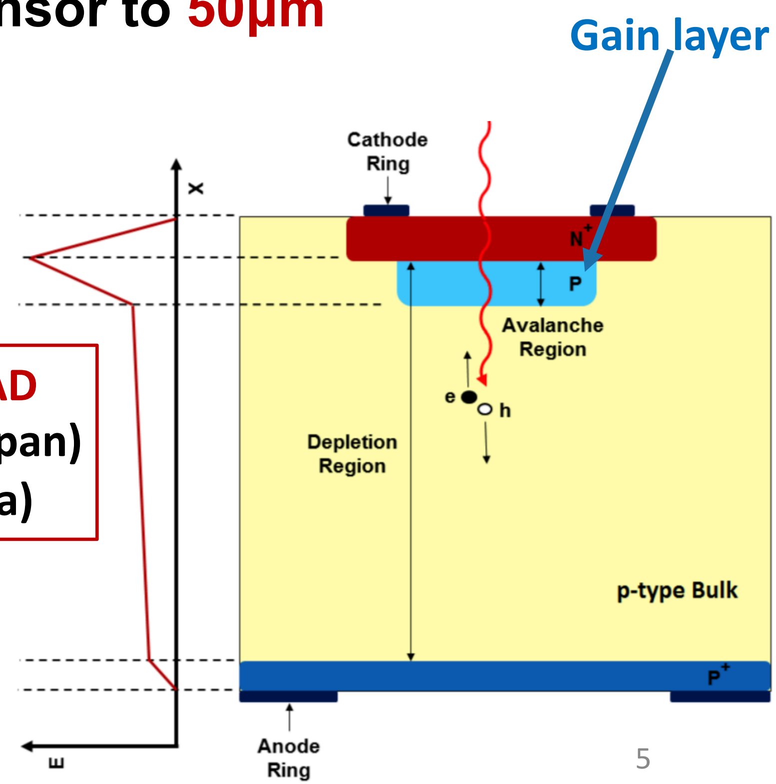
- **Low gain avalanche diode(LGAD) is developed for HGTD**
  - **Radiation hard, Medium gain, High S/B, fast timing, no self-triggering**

$$\sigma_t^2 = \sigma_{TimeWalk}^2 + \sigma_{LandauNoise}^2 + \sigma_{Distortion}^2 + \sigma_{Jitter}^2 + \sigma_{TDC}^2$$

- **Landau Noise term**
  - **Signal fluctuation due to non-uniform charge deposition**
  - **Minimized by reducing thickness of sensor to 50μm**
- **Jitter term**
  - **Need gain layer to increase S/N**
  - **Thin detector to decrease rise time**



Manufacturers of LGAD
CNM (Spain), HPK (Japan)
FBK (Italy), NDL (China)

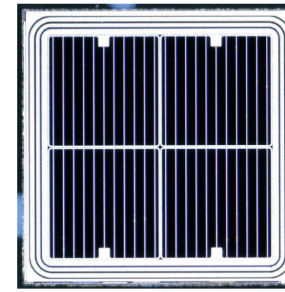


Sensors testing at IHEP

Ultra-fast silicon sensor R & D in IHEP

- **IHEP & Beijing Normal U. developed IHEP-NDL sensor**
  - **Time resolution reached 30 pico-second (ps)**
  - **Collected charge is >30fC before irradiation**
    - **ATLAS requirement is >15fC**
  - **Performance close to Hamamatsu LGAD before irradiation**

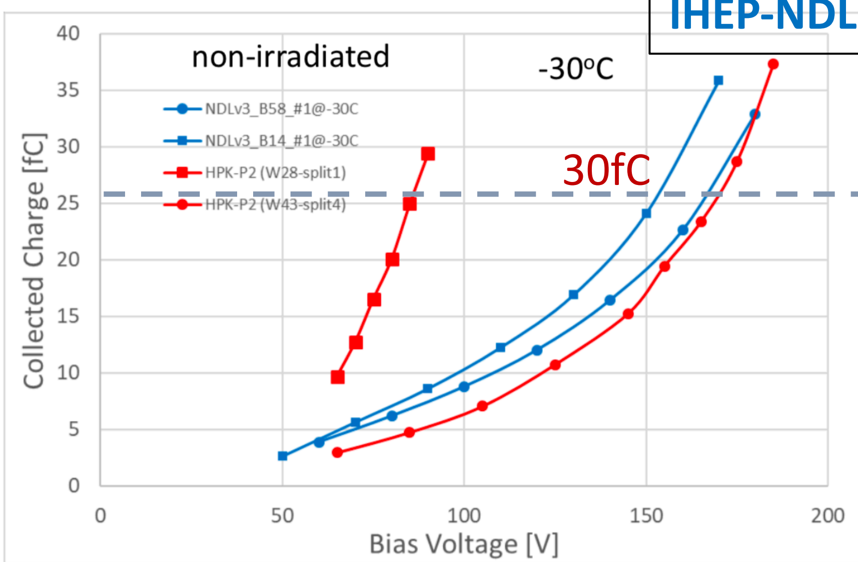
IHEP-NDL sensor



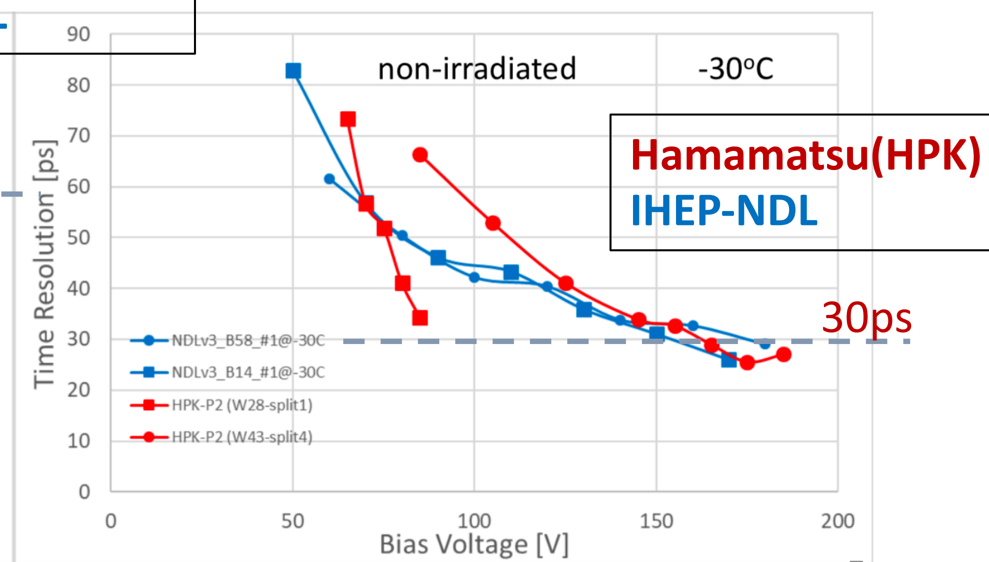
IHEP-NDL performance Verified by Ljubljana group

Time resolution in beta tests before irradiation

Hamamatsu(HPK)
IHEP-NDL



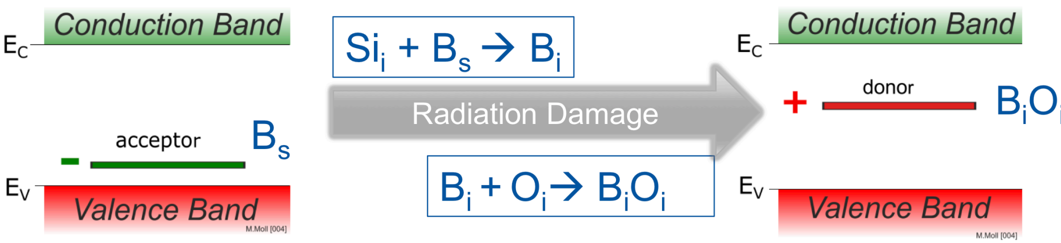
Collected charge in beta test before irradiation

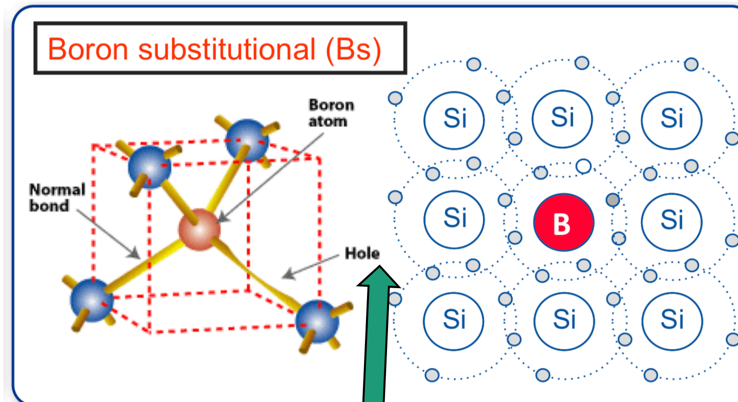


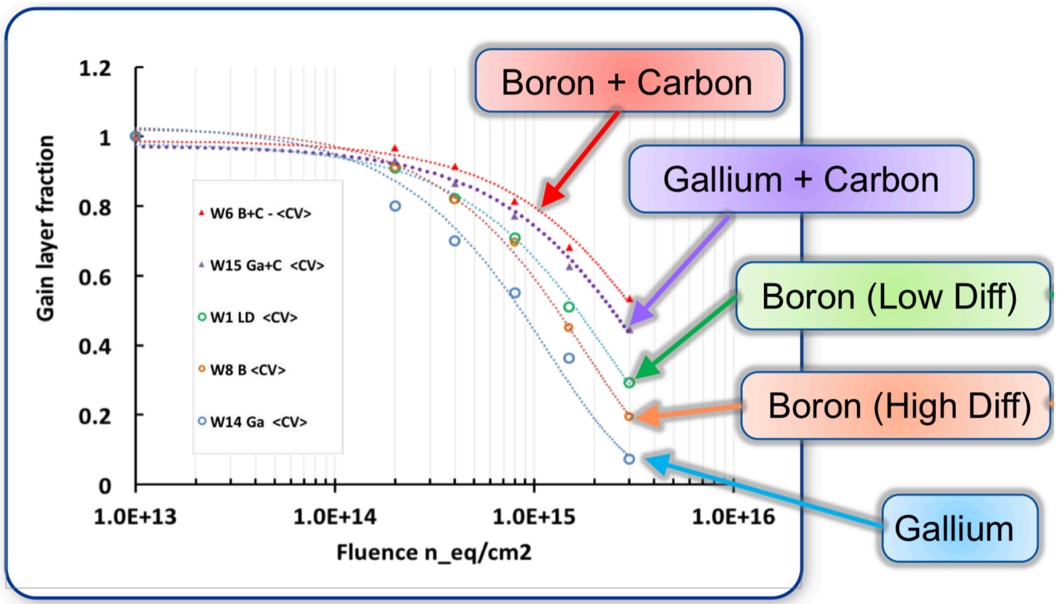
Ultra-fast silicon sensor: irradiation hardness

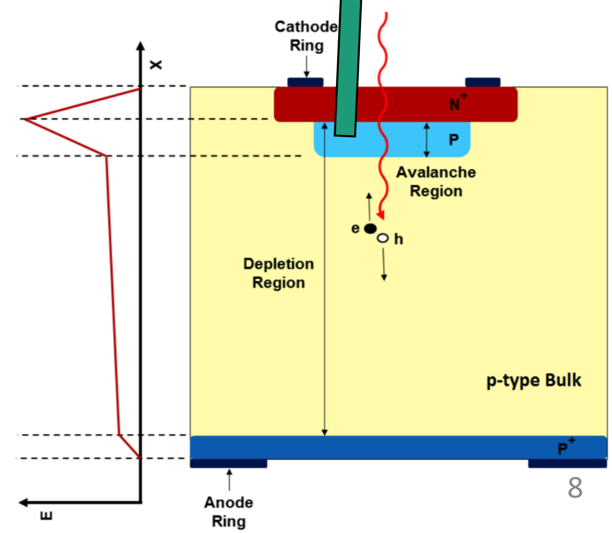
HGTD irradiation hardness requirement

- Total ionization does (TID) **>=200MRad**
- Fluence **$>=2.5*10^{15}N_{eq}/cm^2$**
- Sensors suffered from acceptor removal effect (removing gain layer)





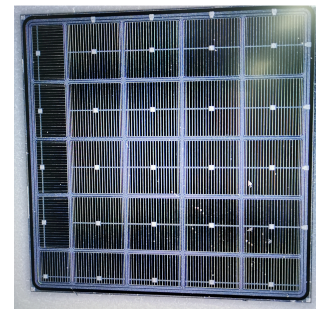


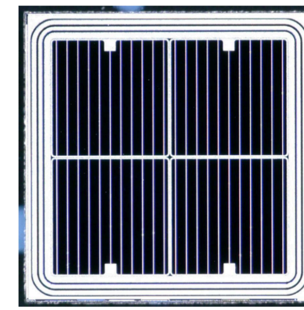


[G.Paternoster, FBK, Trento, Feb.2019]

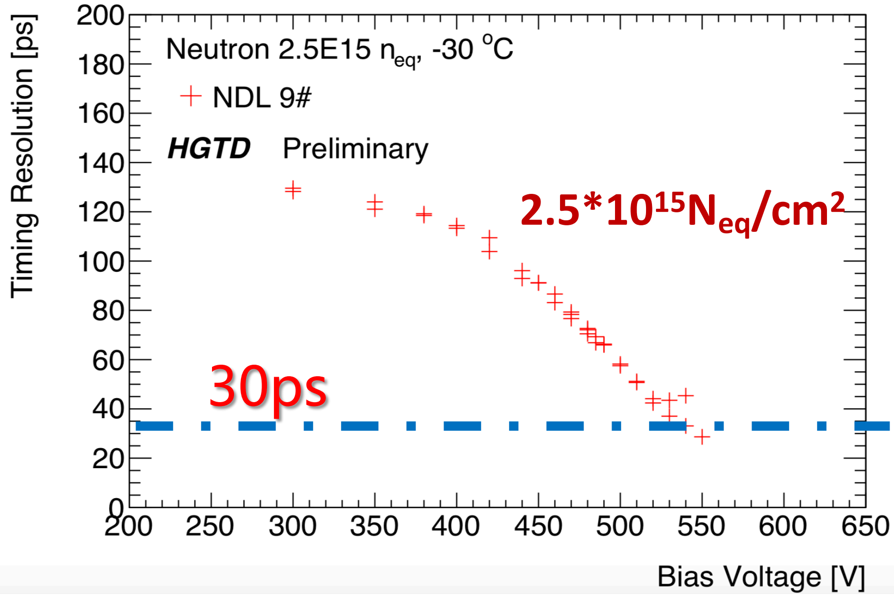
Ultra-fast silicon sensor : IHEP-NDL sensors

- **Preliminary results of irradiated IHEP-NDL LGAD**
  - **Time resolution reached 30ps at high fluence $2.5*10^{15}N_{eq}/cm^2$**
  - **Collected charge is ~4fC after irradiation (4fC is ATLAS requirement)**
- **Next step (2021):**
  - **Improve irradiation hardness**
  - **Develop full size (4*2cm) sensors**
  - **Compete with HPK/FBK in market survey**

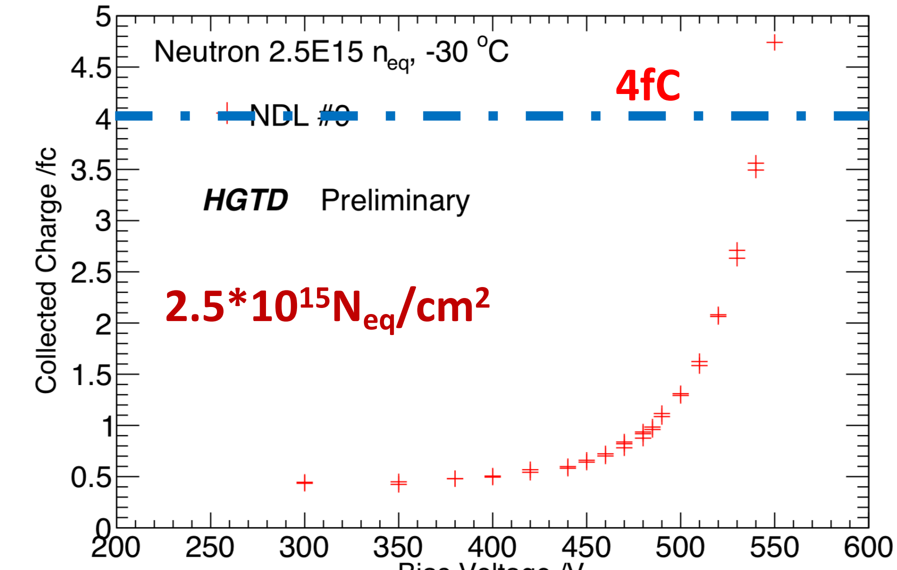




Time resolution after irradiation



Collected charge after irradiation

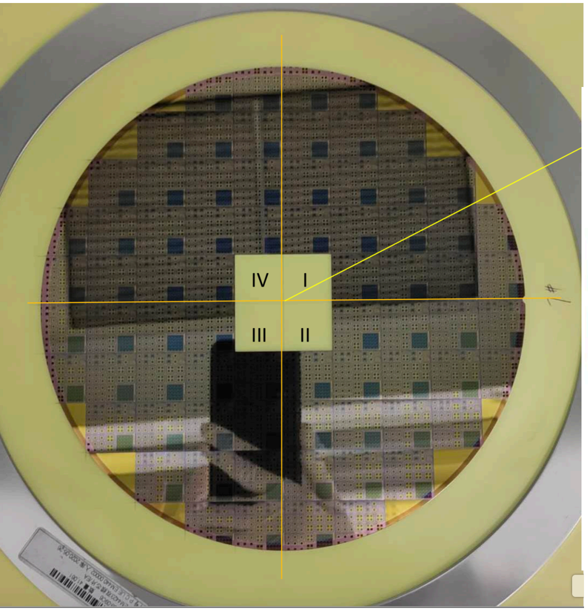


Ultra-fast silicon sensor: IHEP-IME sensors

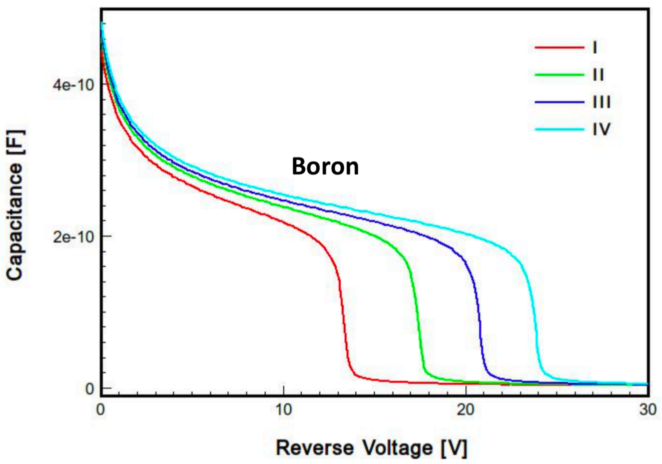
- IHEP & Institute of micro-electronics (IME) LGAD sensor
  - **IHEP team designed**, IME fabricated 1st prototype this September.
  - Depletion voltage are similar to designed value (4 doping design)
  - Good time resolution (30-40ps) and high charge collection (20-30 fC)
  - Next step:
    - Irradiation hardness study
    - Design full size sensor

See more in Kewei Wu's talk later at detector parallel session

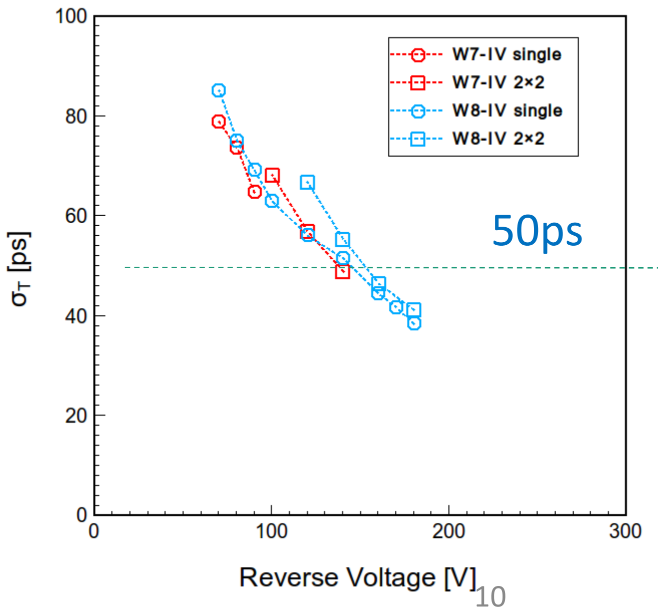
IHEP-IME sensors



Capacitance vs voltage (4 doping design)



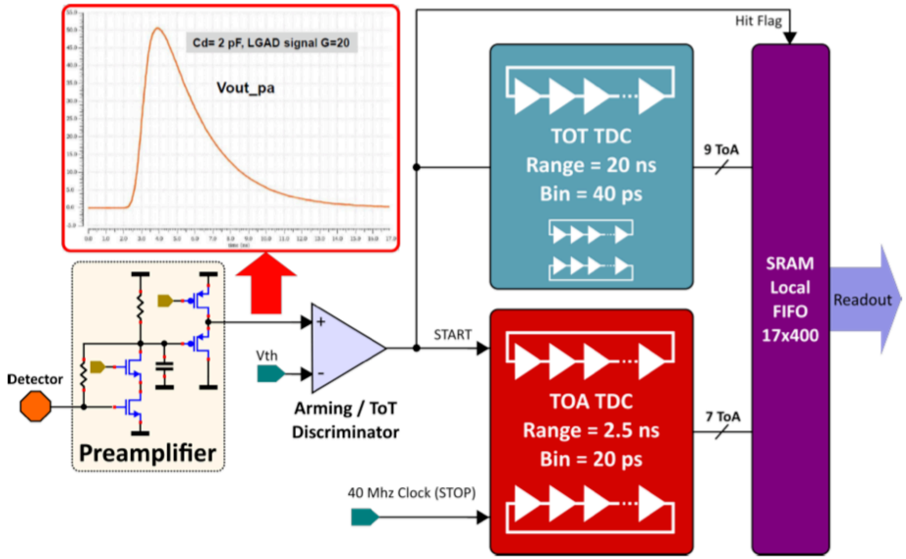
Time resolution before irradiation



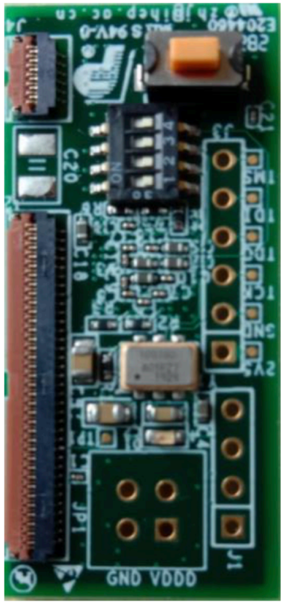
Fast readout ASIC

- **Feature of HGTD readout ASIC**
  - Ultra-Fast readout chip (10ps), Radiation hardness (200Mrad)
  - Use TDC for Time of Arrival (TOA) and Time Over Threshold (TOT)
  - Status: small prototype (ALTIROC1) testing, full-size ASIC in 2021
- **IHEP/NJU developed full-size ASIC emulator**
  - Beginning communication studies with FELIX DAQ system
- **IHEP contributed to irradiation study of ALTIROC1_v3**

Schematic of ASIC (ALTIROC)



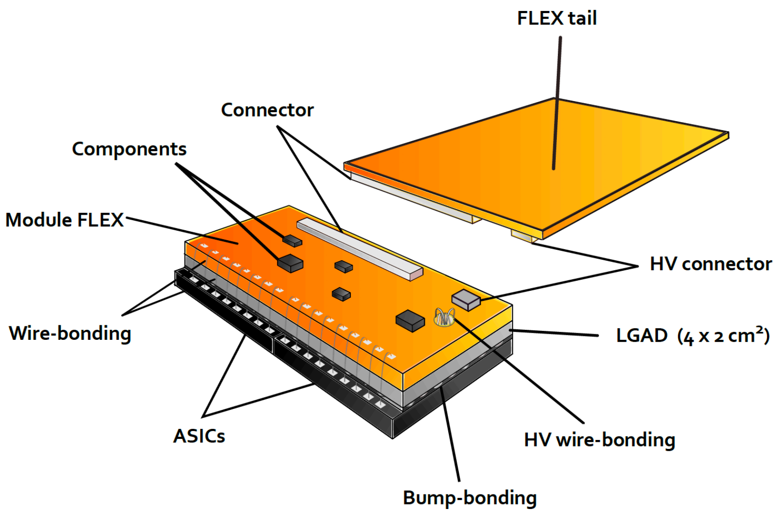
ASIC emulator (IHEP/NJU)



X ray machine in IHEP
For ASIC irradiation study

HGTD Module R& D

- IHEP is playing a leading role in module R& D
  - IHEP performed 2 round of prototyping of mini-modules(6.5 x 6.5mm^2)
  - Timing resolution at module level ~40ps



~8000 module, 4 x 2 cm^2
2 ALTIROC ASICs
Bump bonded to
1 LGAD sensor
Wire boned to Flex cable
15 x 30 channels
1.3 x 1.3 mm^2 granularity

LGAD sensors

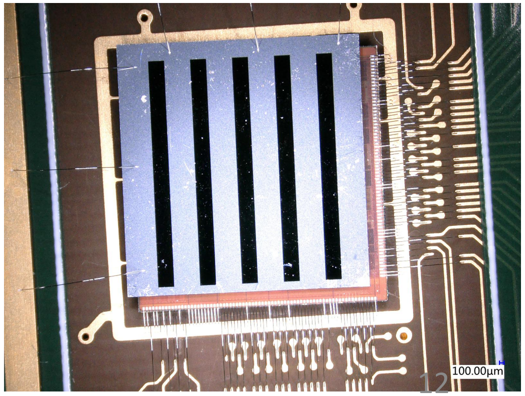
ALTIROC1 ASIC

Bump bonding →

Bare module (sensor+ASIC)

Wire Bonding On test board →

Mini-modules

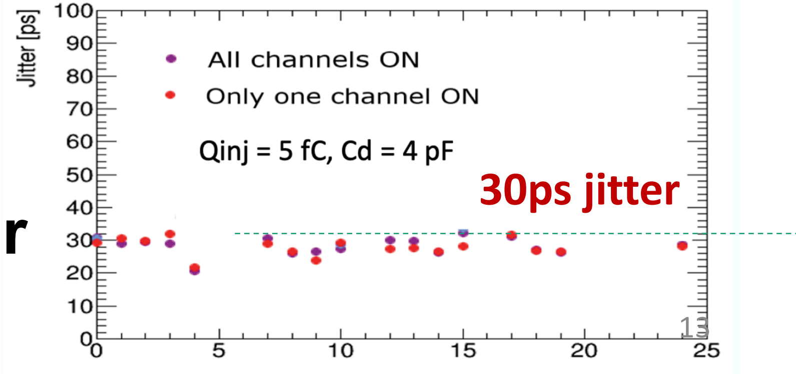


HGTD Module R& D

- **Performance of IHEP modules at test beam**
  - **Timing resolution at module level ~40ps**
  - **Major result in HGTD TDR**

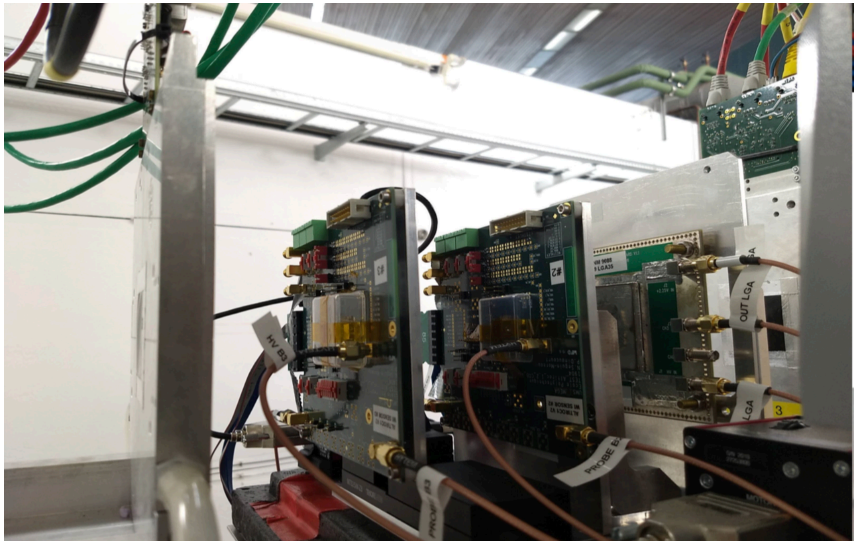
- **Next step**
  - **Improve assembly to reduce jitter**

Jitter of ASIC

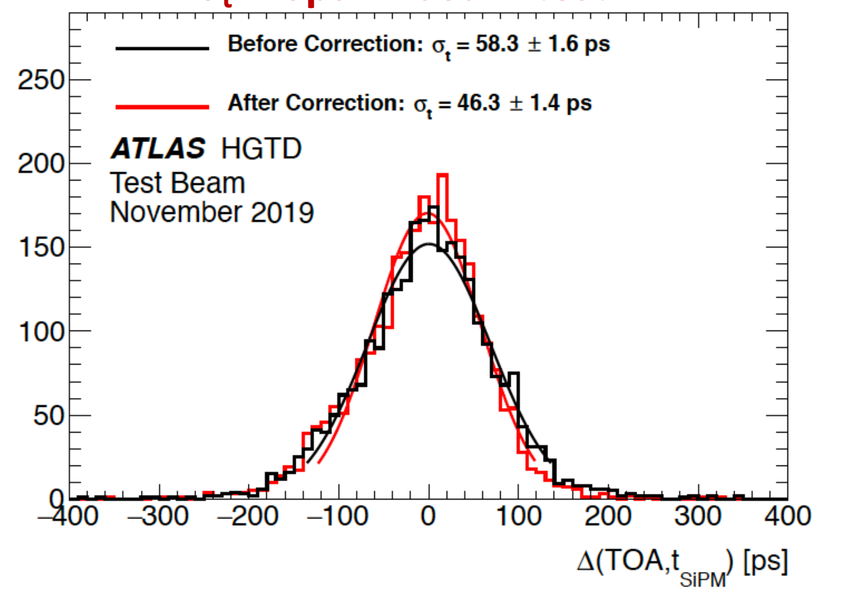


mini-module prototyped by IHEP

Mini-Module at test beam



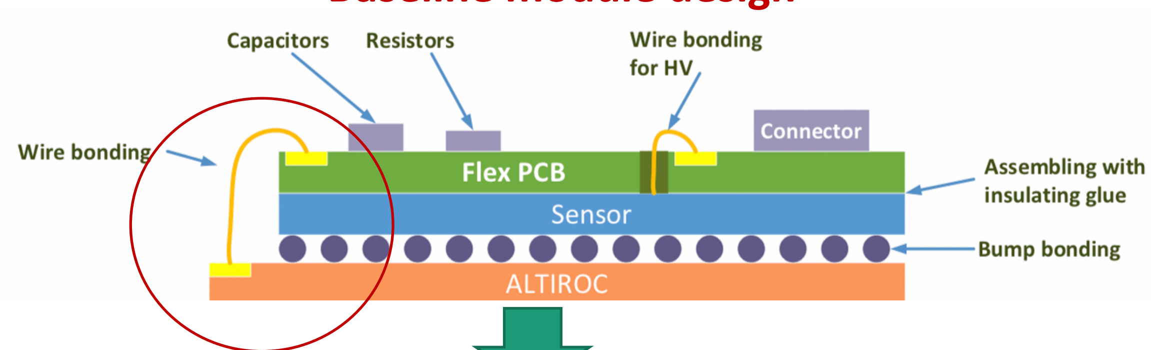
σ_t=46ps In beam test



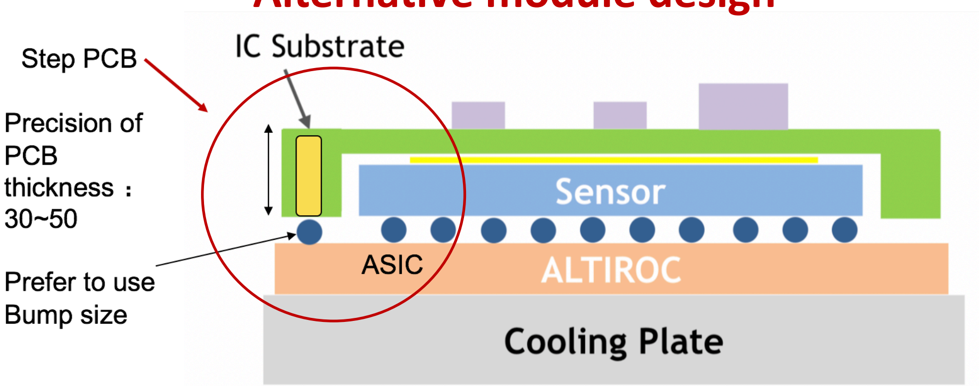
HGTD Module R& D

- **IHEP is playing a leading role in module R& D**
  - **Alternative module design with full bump bonding**
    - **Avoid wire bonding, simplify the assembly process, more robust**
  - **Design module flex and flex cable prototyping**
  - **Next step: full size (4 x 2 cm^2) module prototyping in 2021**

Baseline module design



Alternative module design

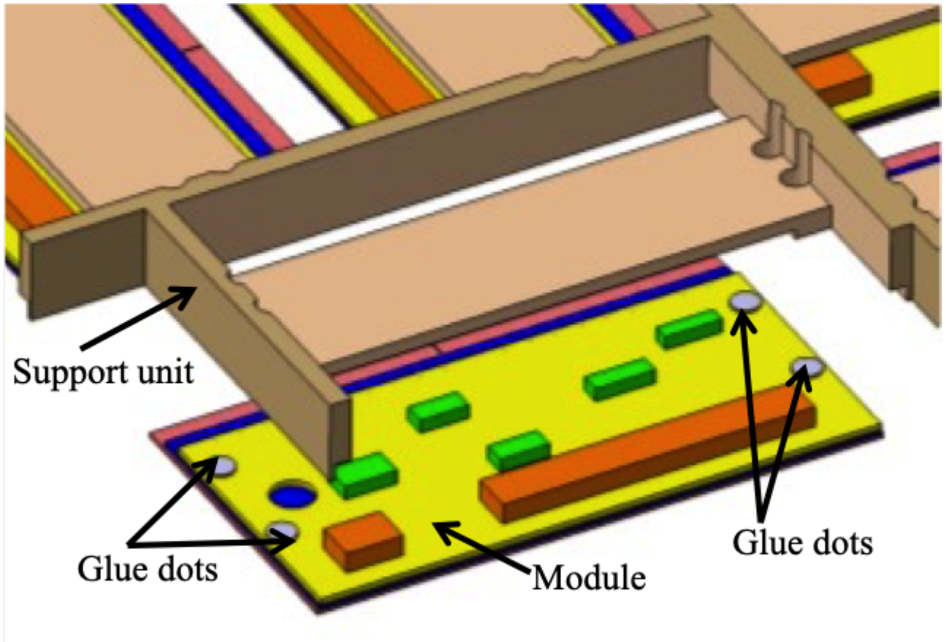


Flex cable prototyping at IHEP

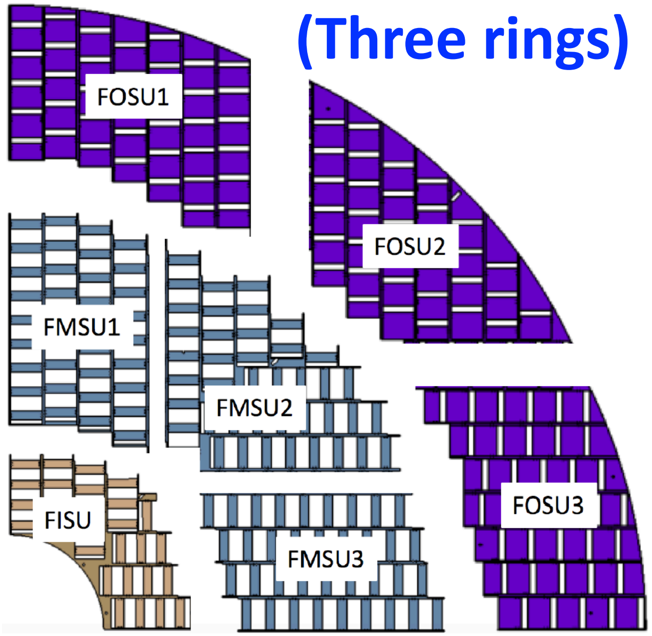
Module and detector units

- Modules will be loaded into carbon fiber support unit
- IHEP is the leading HGTD detector production site
- Six module assembly and loading sites at HGTD
  - IHEP; USTC SINANO (China)
  - IFAE (Spain); LPNHE/IJCLab/IRFU(France);
  - Mainz (Germany);, MAScIR (Morocco)

Modules loading on support unit



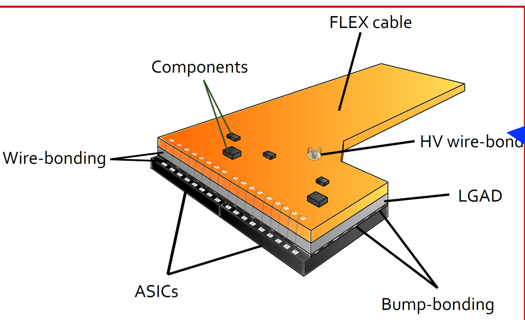
Support unit maps (Three rings)



Peripheral Electronics and DAQ

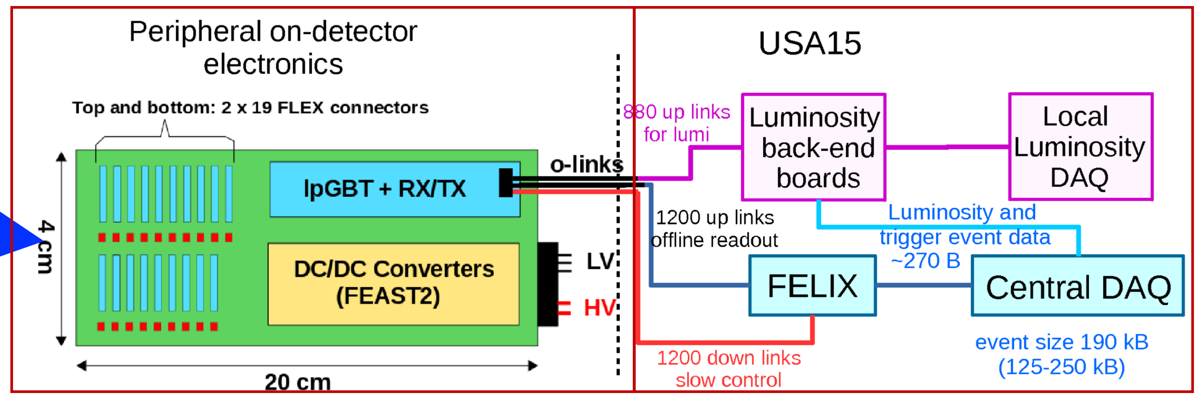
- **IHEP/NJU are leading the Peripheral board (PEB) design**
  - **Proposed rigid board + flexible PCB board design→ Became baseline**
- **IHEP is leading HGTD Data acquisition system (DAQ) group**
  - **Design DAQ demonstrator, design the data format for up/down link**

Modules

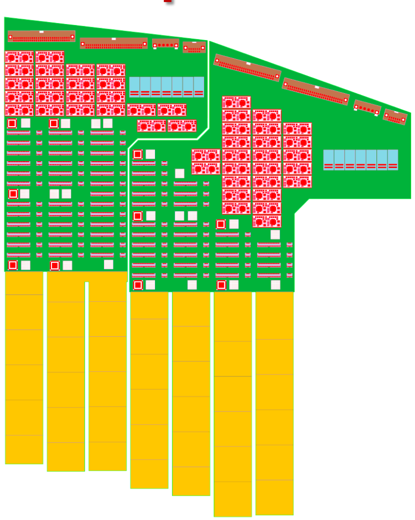


Peripheral Electronics

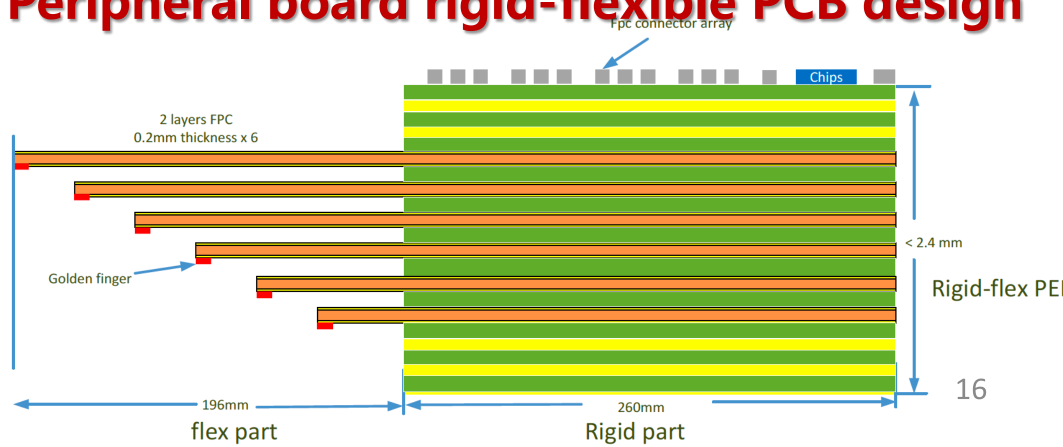
Data acquisition system



Peripheral

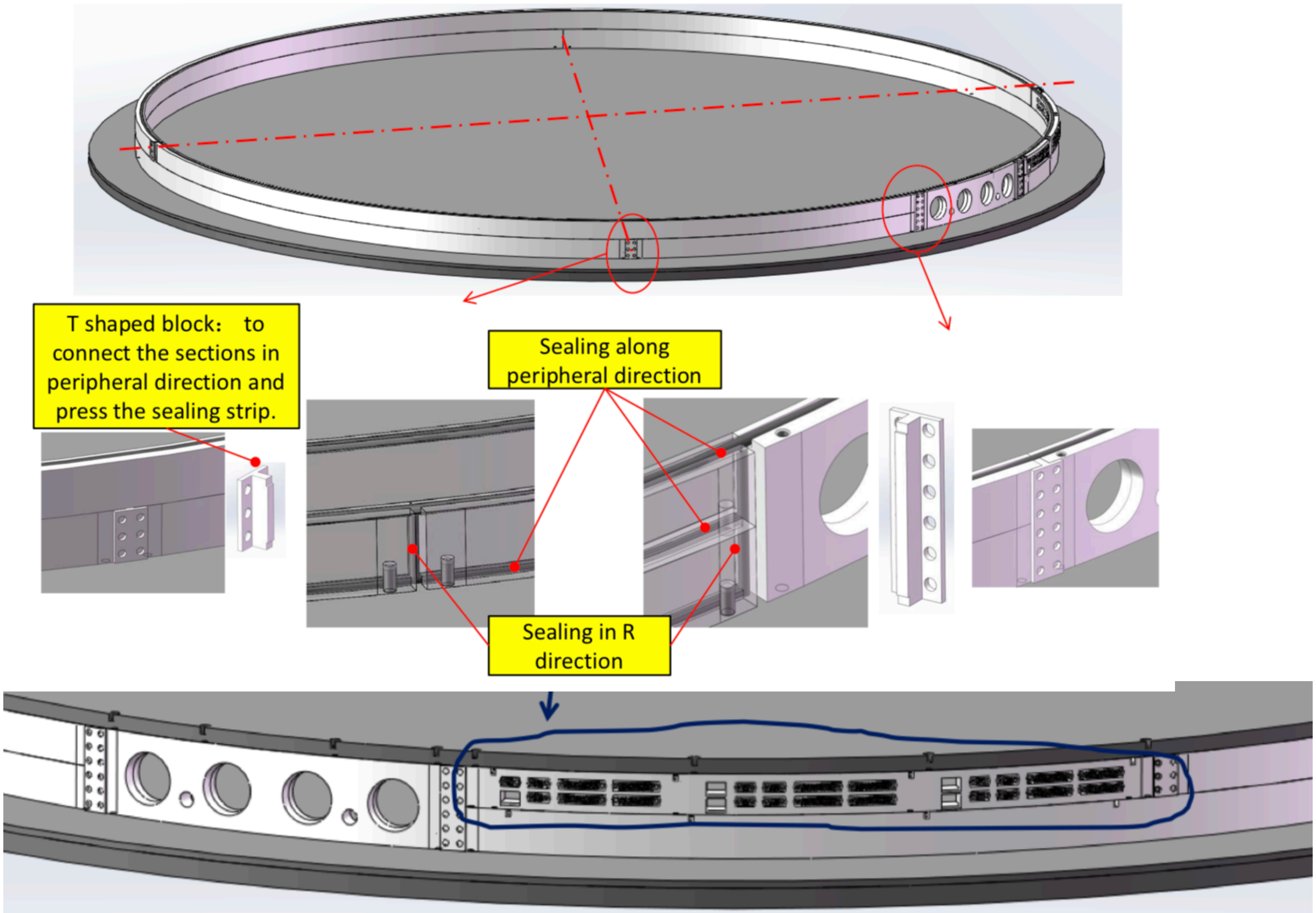


Peripheral board rigid-flexible PCB design



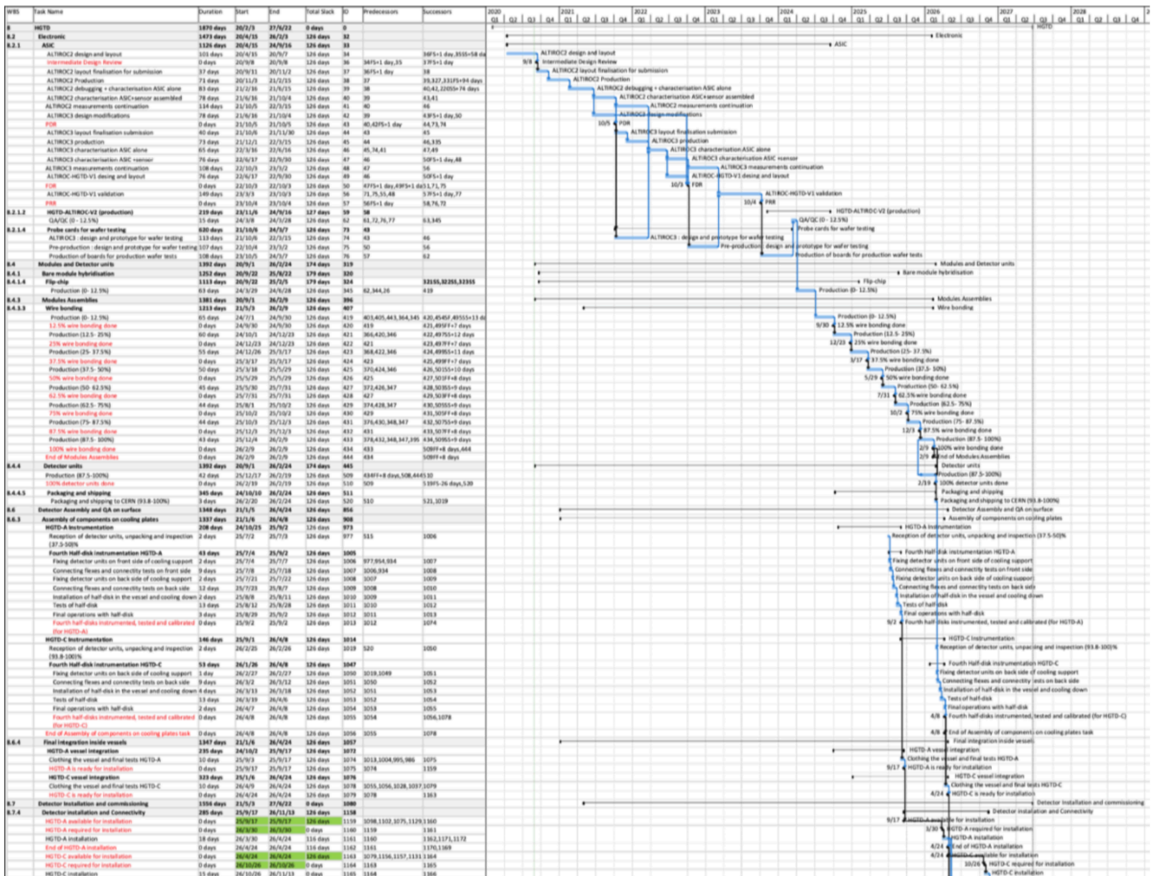
HGTD detector mechanical design

➢ **IHEP is leading the mechanical design of HGTD outer ring**



HGTD schedule

- **Large effort for UCG review in schedule**
  - **UCG material preparation led by IHEP (Joao Guimaraes Da Costa)**
  - **Full size sensor and module R & D by 2021**
  - **Module and detector units production (2024– 2025)**
    - **IHEP is one of the leading production sites**
  - **HGTD installation at CERN by end of 2026.**



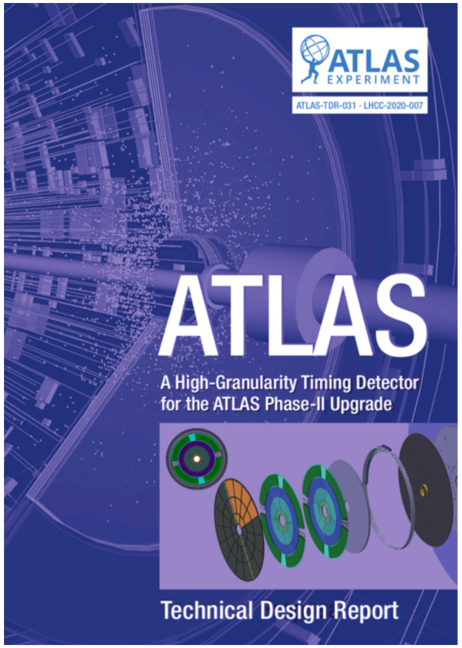
- **Critical Path:**
- ASIC Production
- Module Hybridisation
- Module Assembly
- Module Loading
- Installation at CERN

Includes ATLAS official schedule HGTD installation schedule:
HGTD-A installation: March 2026
HGTD-C installation: October 2026

Summary

- HGTD Project now fully approved → construction phase
- China should play a leading role in the HGTD construction
- Ultra-fast sensors and ASIC in HGTD is interesting new tech.
  - Fast timing, radiation hard, larger area silicon sensors.
  - Interesting for future experiments (Time of flight detector)
  - Medical imaging application: Proton CT (proposed in US)
- IHEP/NJU Contributions in HGTD
  - Design and testing LGAD sensors
  - Design of electronics
  - Design of modules and flex cables
  - Mechanics and Integration
  - Management, planning
  - TDR editing (Editors in key Chapters)

HGTD technical design report



IHEP-NDL v3: Irradiation hardness

- New IHEP-NDL (v3)
  - Active layer thickness from 33 → 50μm
  - Improve charge collection after irradiation