# Detector Development for ALICE at CCNU

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**(On behalf of ALICE CCNU Team)**

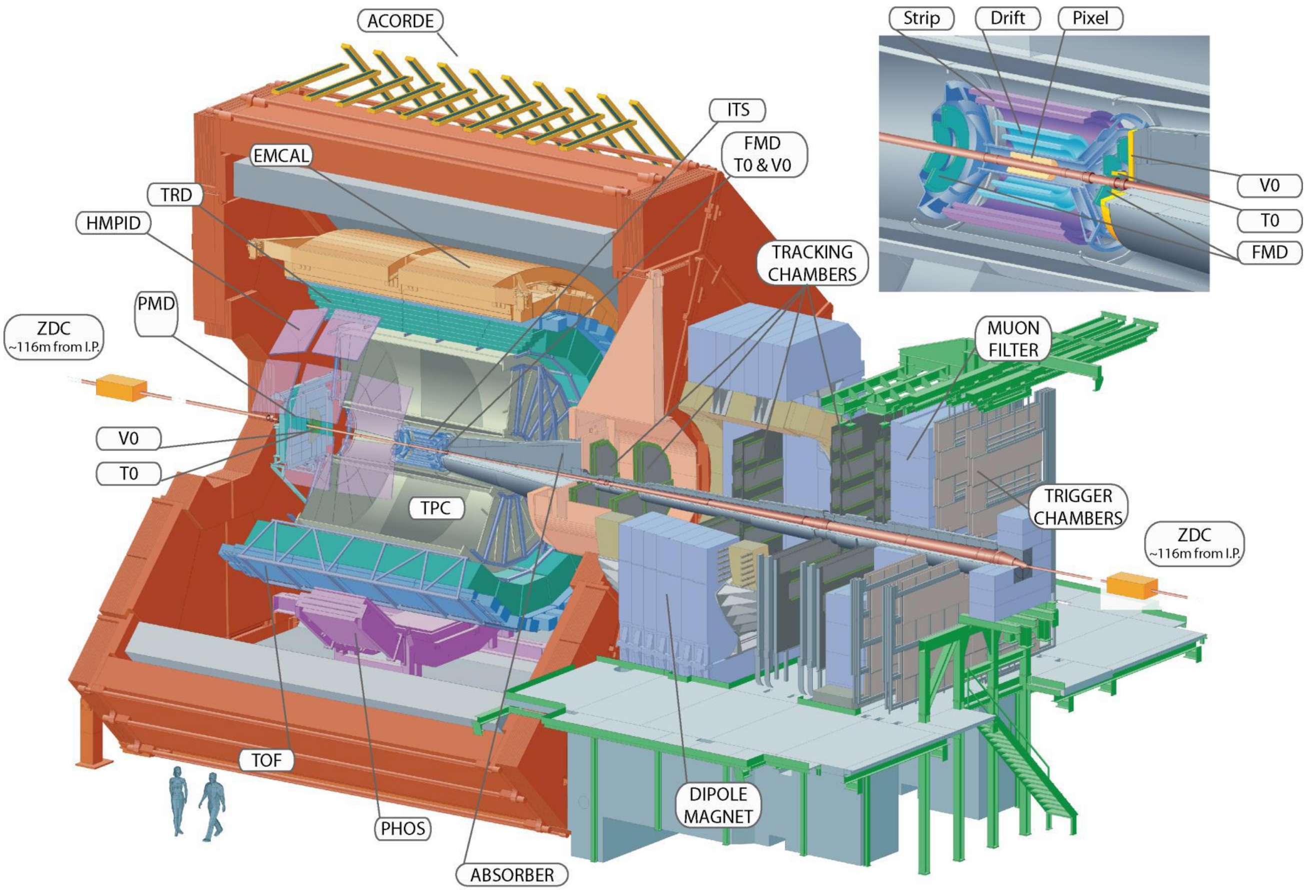
**Central China Normal University**

Workshop on Advances, Innovations, and Future Perspectives in High-Energy Nuclear Physics

# Outline

- **Detectors developed for ALICE 1 and ALICE 2**
- **On-going upgrade activities for ALICE 2.1**
- **Plans for ALICE3**

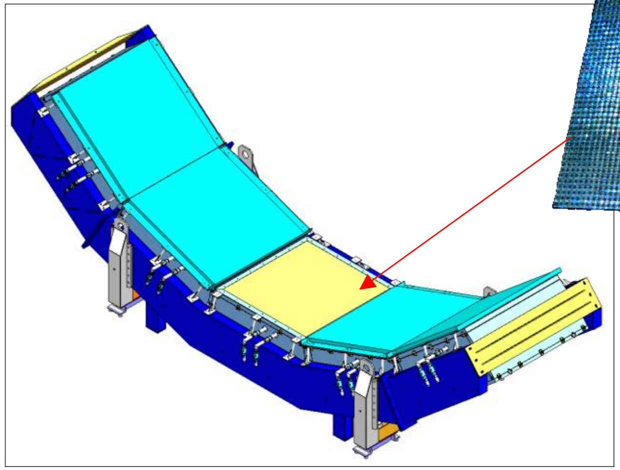
# Detector developed for ALICE 1

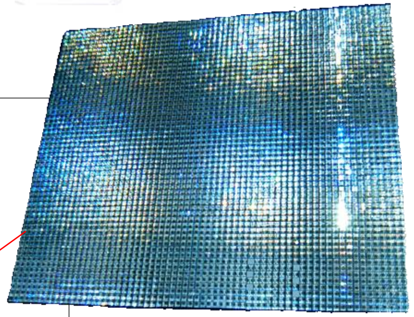



## PHOS

**Designed to measure photons, $\pi^0$'s and $\eta$'s in a broad $p_T$ range**

PbWO4



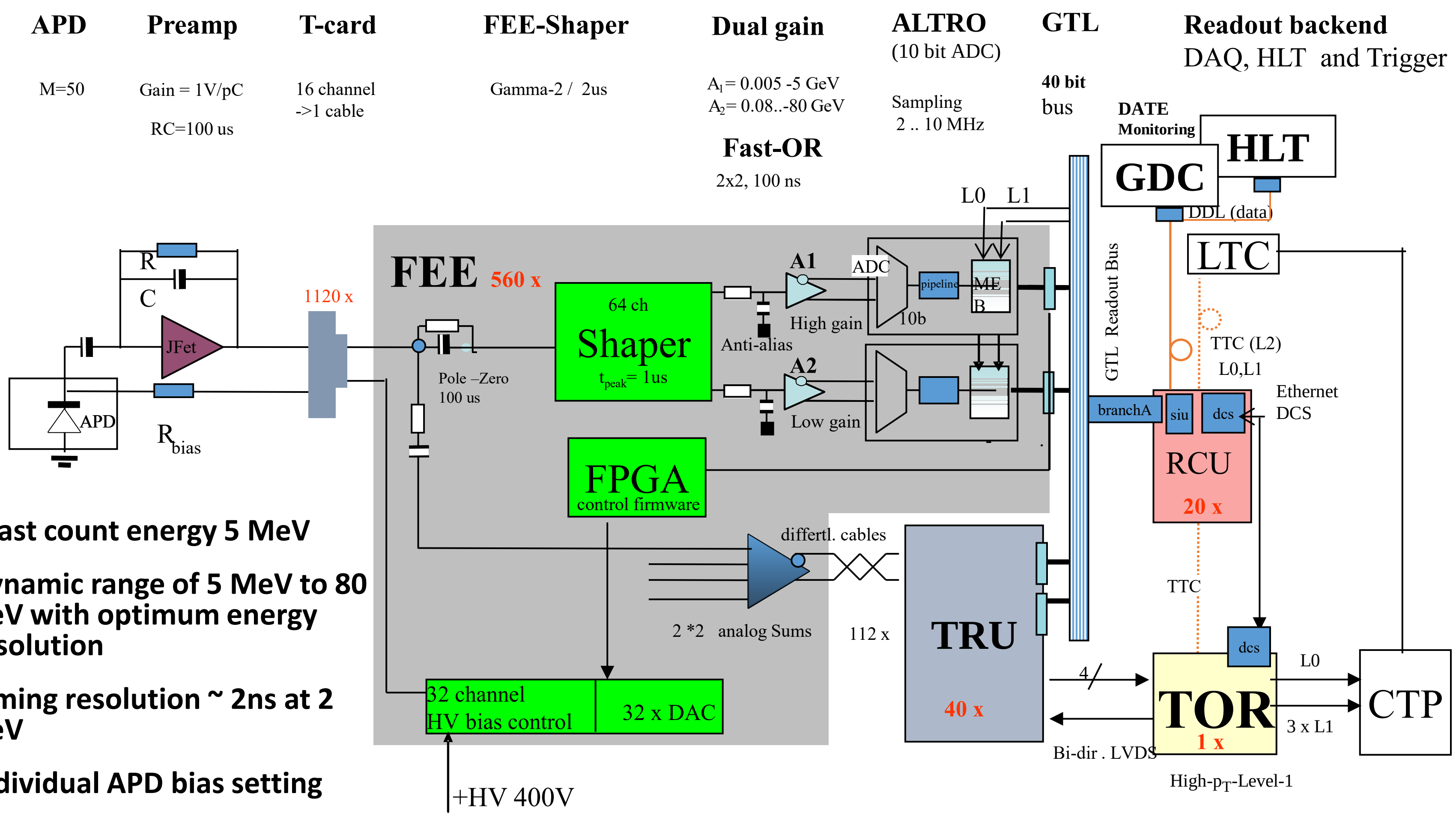


1 Module=3584 crystals

- Radiation length of 0.89 cm
- Interaction length of 19.5 cm
- Moliere radius of 2.0 cm
- Crystal dimensions of 2.2x2.2x18 $cm^3$
- Temperature coefficient of ~-2%/°C
- Operating temperature of –25 °C

# PHOS front end electronics

**Cooperated with CERN and Norway**

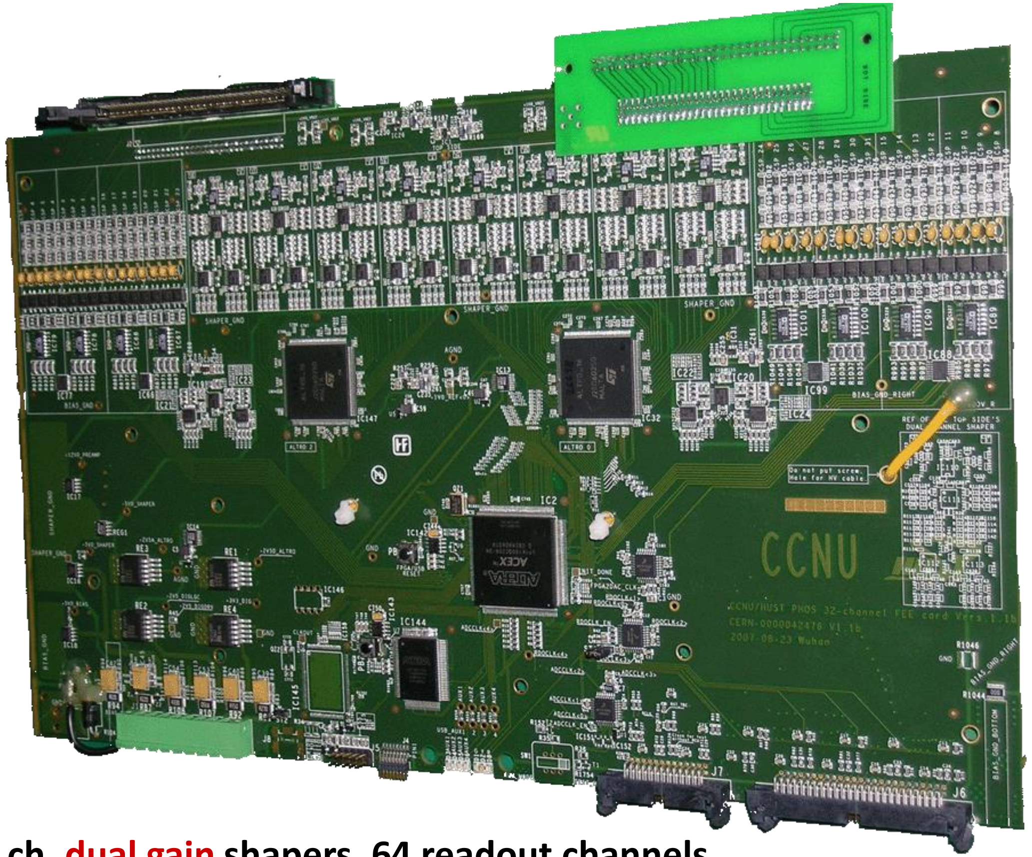


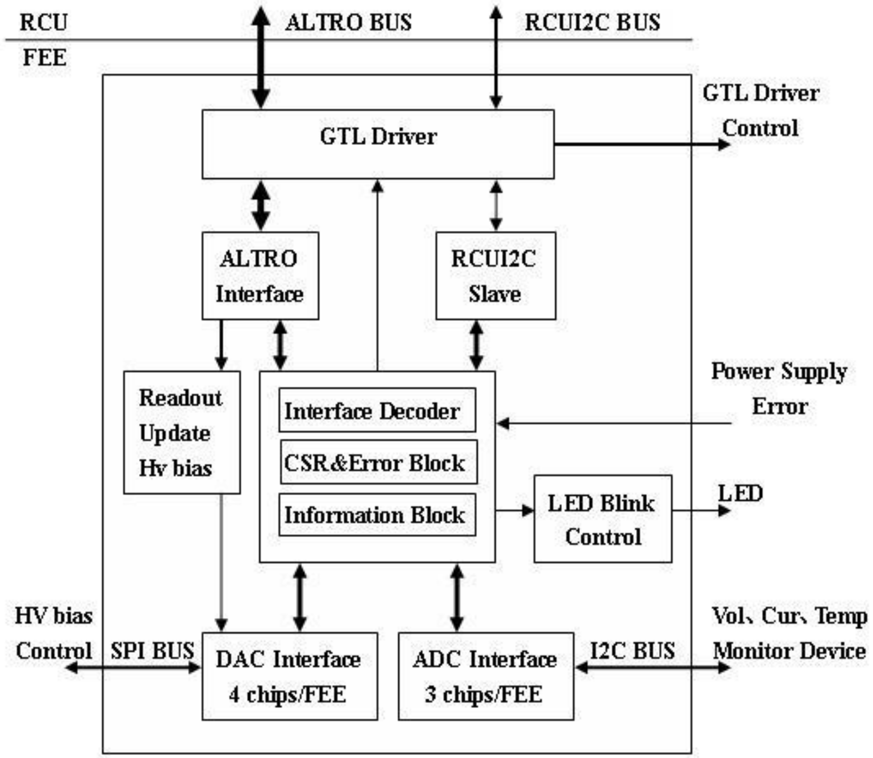

**PHOS FEE**


**PHOS TRU**

- **Least count energy 5 MeV**
- **Dynamic range of 5 MeV to 80 GeV with optimum energy resolution**
- **Timing resolution ~ 2ns at 2 GeV**
- **Individual APD bias setting**
- **L0 and L1 triggers**

[NIM A 565 (2006) 768]



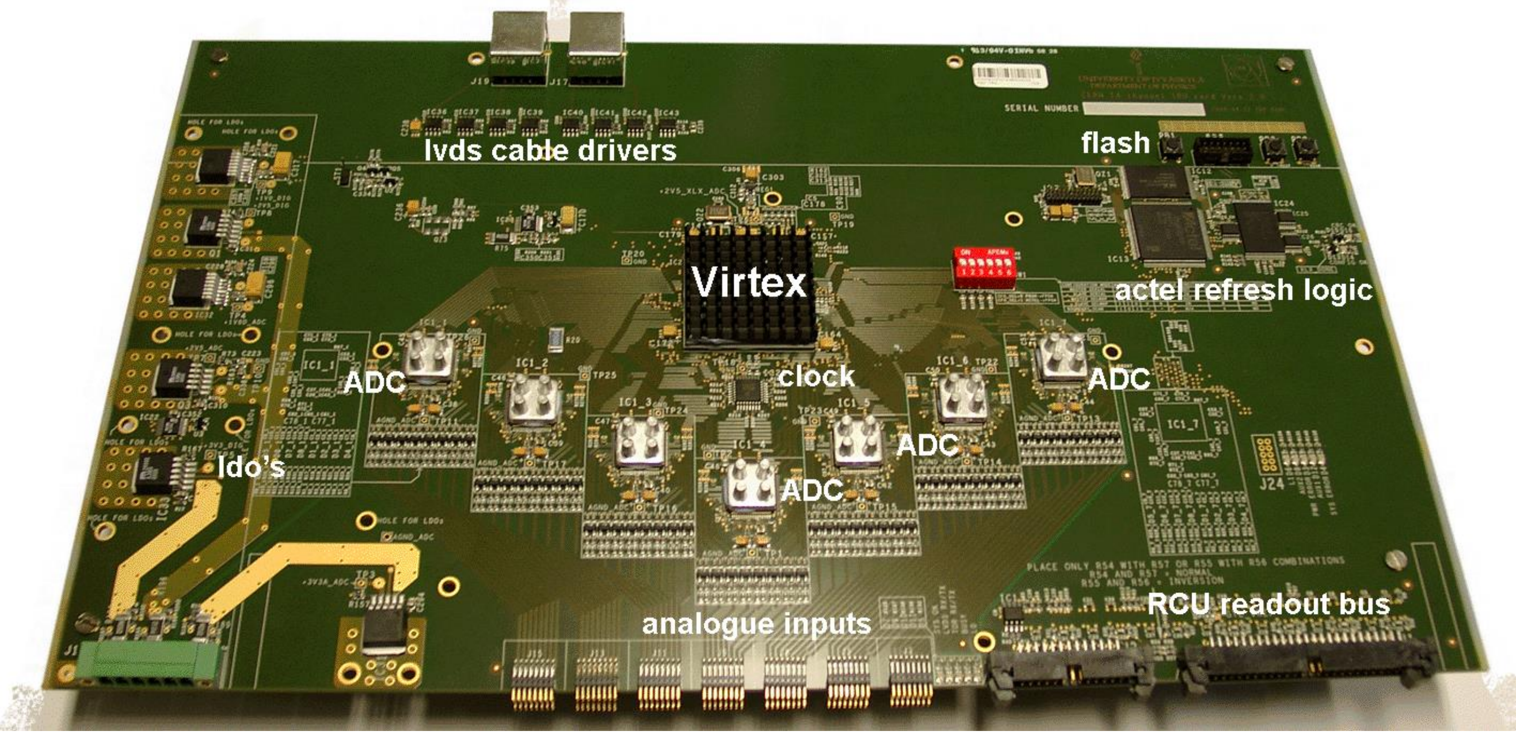



- 32 ch. dual gain shapers, 64 readout channels
- 10 bit ADC's (within ALTRO) 10 MHz
- 14 bit dynamical range 5 MeV - 80 GeV
- 32 HV regulators, 10 bit for APD bias with a precision of 0.20V in the range of 210-400V. Thus, the APD gain variation is ~0.66%
- Fast OR signal produced by 100 ns 2x2 summing shaper on FEE for trigger purposes
- GTL + readout and control bus
- 5.5 W, 349x210 $mm^2$

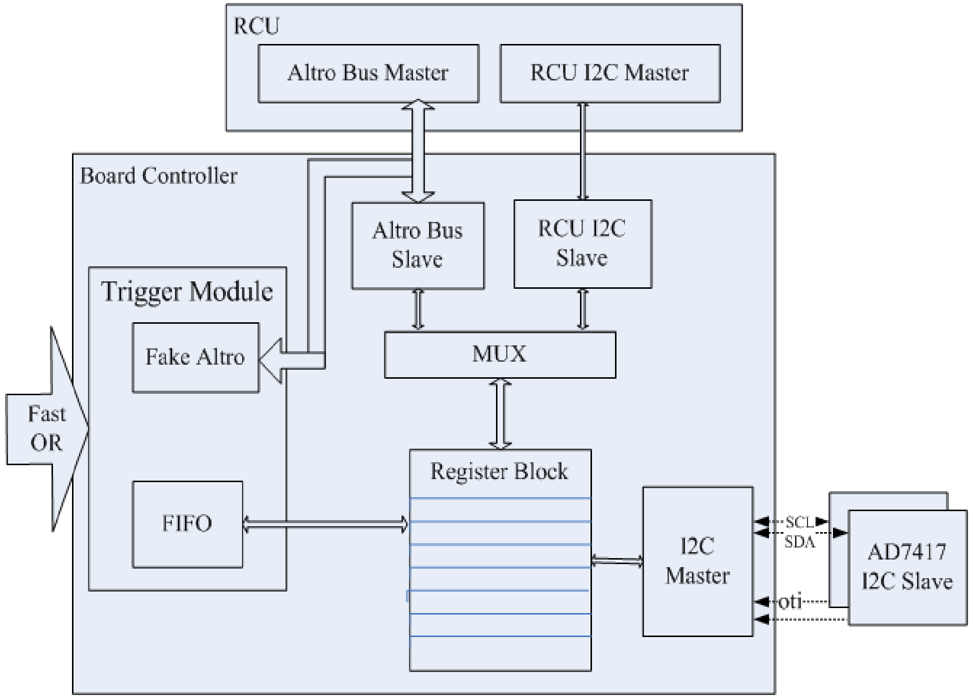
## Board Controller

- Response as a slave to the DCS subsystem of the RCU
- Default communication via the parallel GTL bus
- $I^2C$ serial RCU protocol also implemented
- Monitoring of voltage, current and temperature; interrupt when parameters out of range
- HV bias control and monitoring via SPI bus

## TRU: 12 layer board with Virtex-5
## 14 x ADS 5281 ( octal ADC 12 bit)




## TRU Board Controller



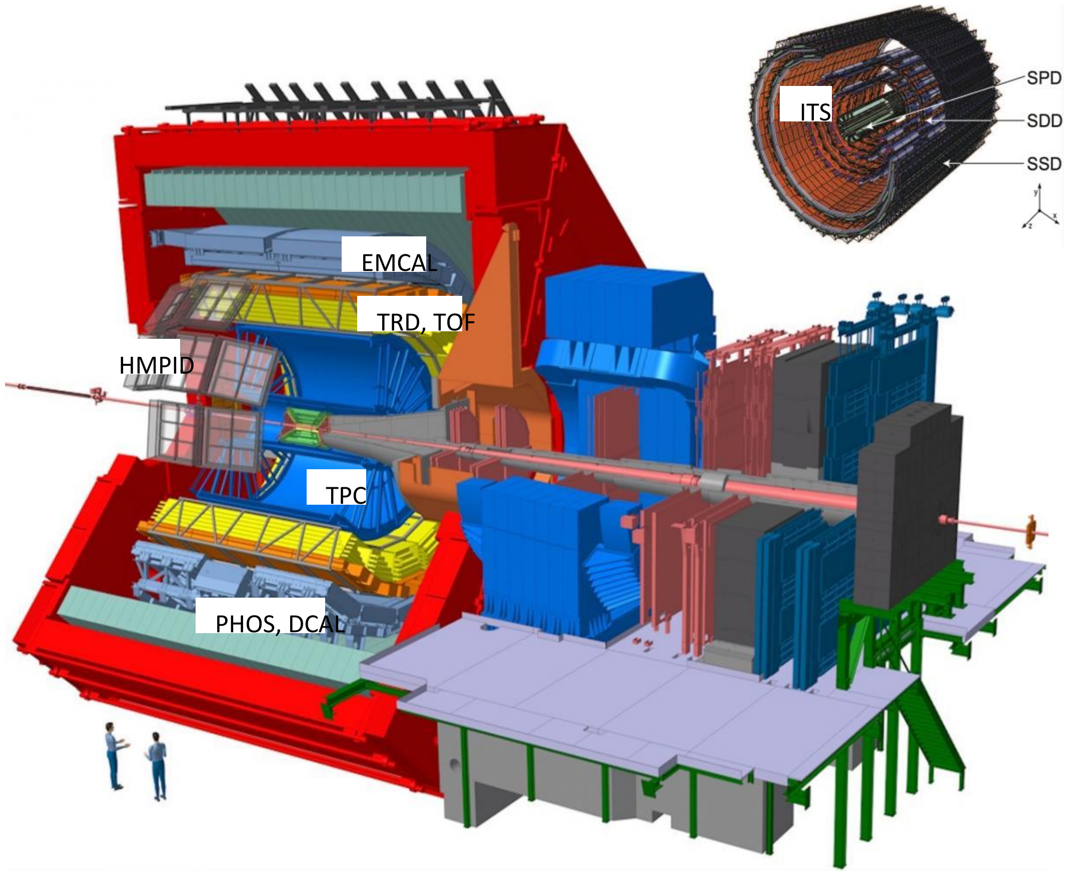

- 112 Fast-OR signals produced by 100 ns 2x2 summing shaper on 14 FEEs
- Transmitted to TRU via differential cables

- 112 analogue inputs -> 12 bit ADCs @ 40 MHz
- Digitized data -> processed in FPGA within 300 ns
- LVDS link <-> TOR
- 1 readout bus 40 bit RCU-> DAQ/HLT

- Trigger generation process implemented in FPGA
- L0-yes: 91 space-time sums get stored in a TRU buffer
- Fake ALTRO implemented for readout

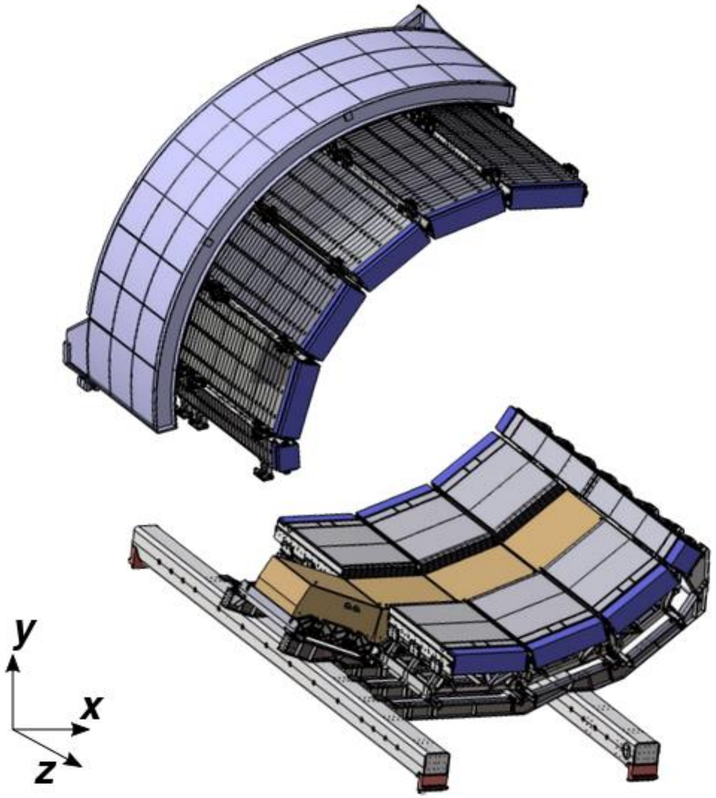
*NIM A 629 (2011) 80*

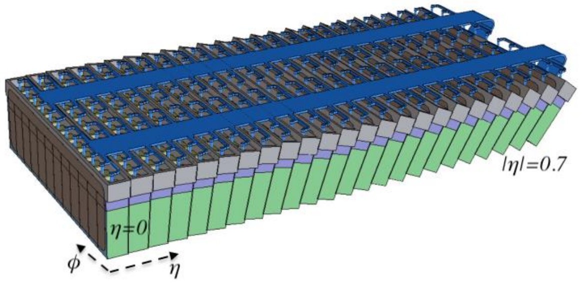
# Detector developed for ALICE 1.1



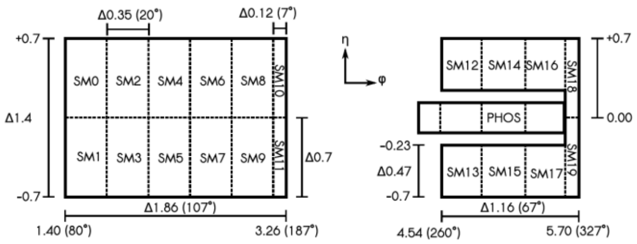

## EMCal & DCal

**Designed to measure electrons from heavy-flavor hadron decays, the electromagnetic component of jets, and spectra of direct photons and neutral mesons**




**12x14 modules**



# THE EMCAL Module Components

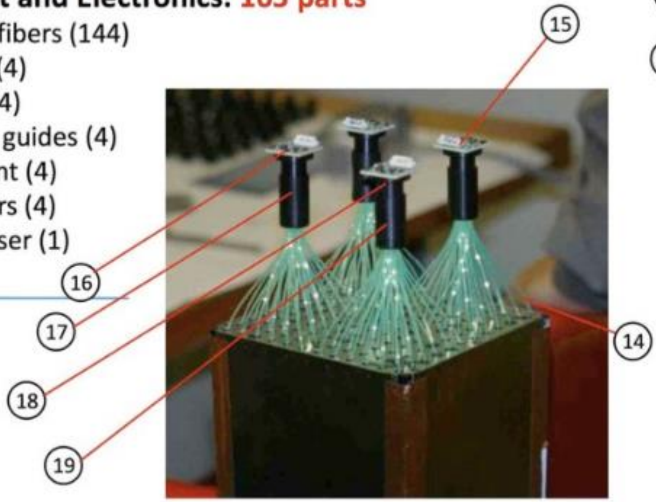
**Cooperated with Frascati/INFN**

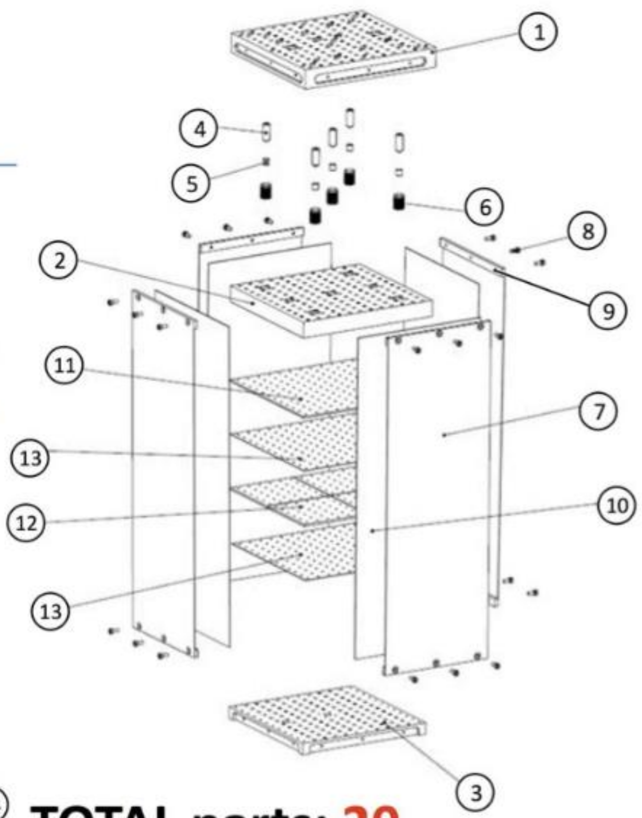
**Containment: 88 parts**
1) Back (holes: 144 thru for fibers + springs + mech. support), 1
2) Compression (holes: 144 thru for fibers + springs), 1
3) Front Plate (holes: 144 thru for fibers + springs + mech. support), 1
4) 5) Plungers (10)
6) Bellville washers (75)

**Tensioning and Insulation: 40 parts**
7) Stainless steel straps (4)
8) Screws (24)
9) Flanges (8)
10) Light tight stickers (4)

**Sandwich: 538 parts**
11) Lead tiles (76)
12) Scintillator tiles (308)
13) Bond paper sheets (154)

**Readout and Electronics: 165 parts**
14) WLS fibers (144)
15) APD (4)
16) CSP (4)
17) Light guides (4)
18) Mount (4)
19) Collars (4)
20) Diffuser (1)



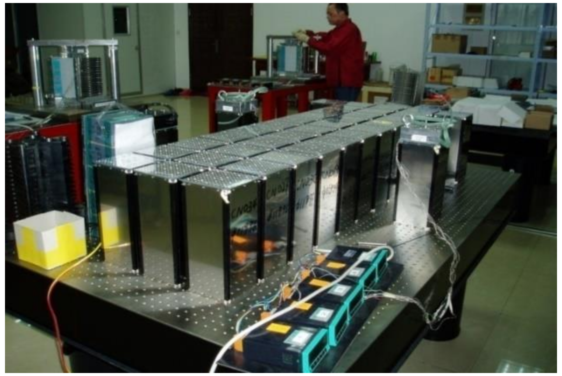




**TOTAL parts: 20**

**TOTAL components: 831**

Plus cabling, GMS and mech. supports

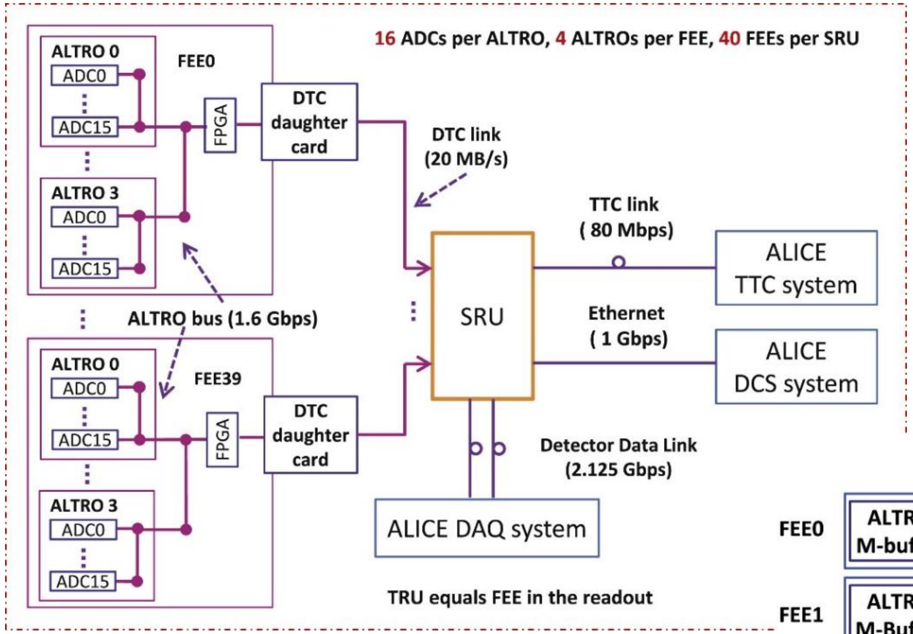
| Parameter | Value |
|---|---|
| Tower Size (on front face) | $6.0 \times 6.0 \times 24.6\,\mathrm{cm}^3$ |
| Tower Size (at $\eta = 0$) | $\Delta\eta \times \Delta\varphi \simeq 0.0143 \times 0.0143$ |
| Sampling Ratio | 1.44 mm Pb / 1.76 mm Scint. |
| Layers | 77 |
| Scintillator | Polystyrene (BASF143E + 1.5%pTP + 0.04%POPOP) |
| Absorber | natural lead |
| Effective radiation length $X_0$ | 12.3 mm |
| Effective Molière radius $R_M$ | 3.20 cm |
| Effective Density | $5.68\,\mathrm{g/cm}^3$ |
| Sampling Fraction | 1/10.5 |
| No. of radiation lengths | 20.1 |

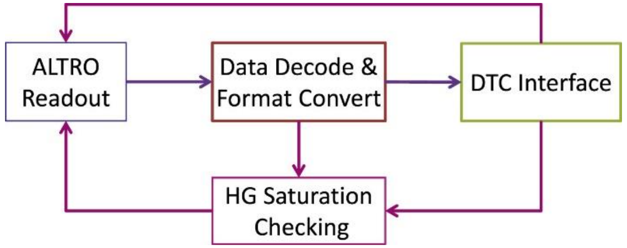


**One super-module produced by CCNU**

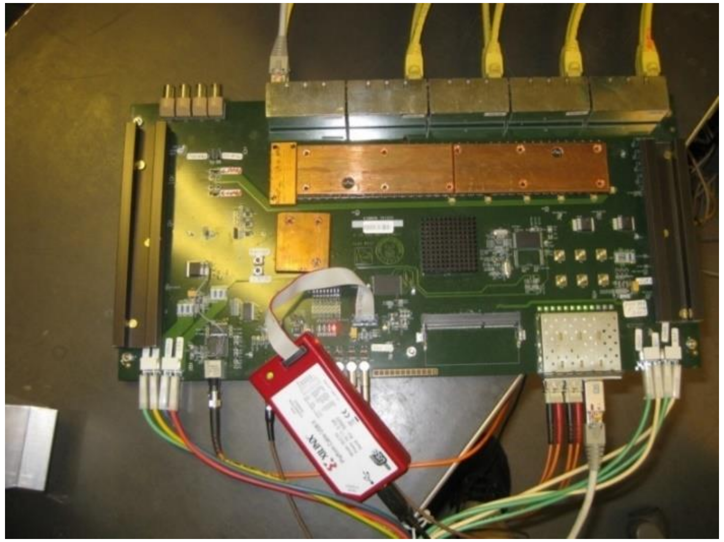
*JINST 18 (2023) P08007*

**Optimized CSP for EMCal**

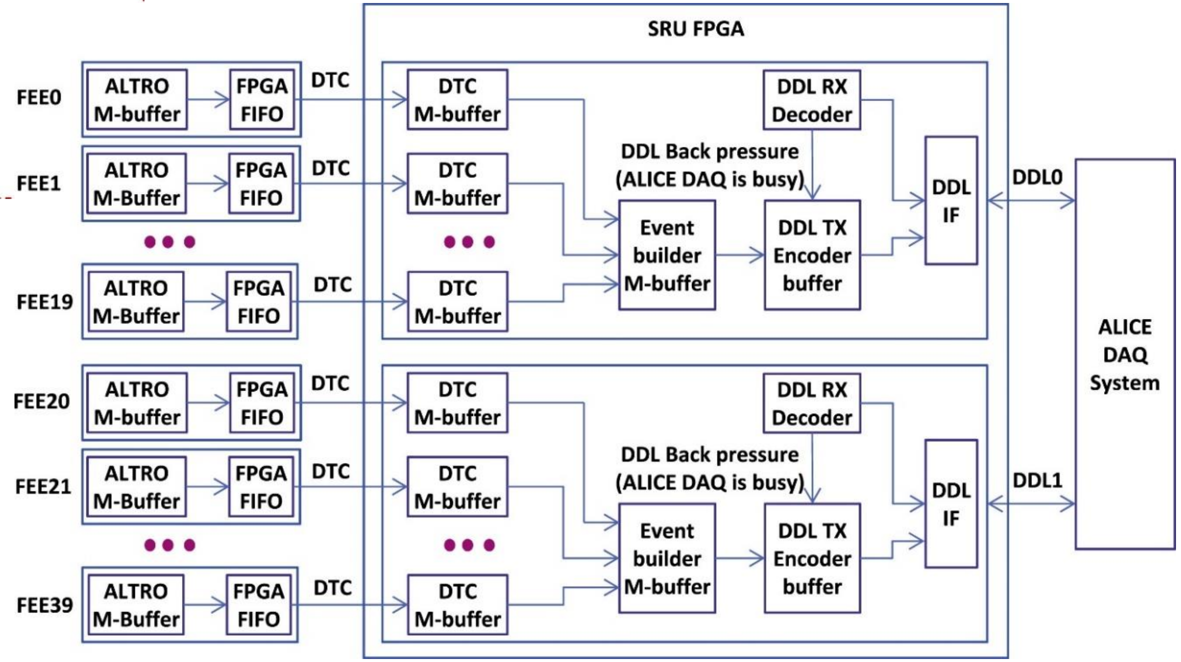



**Modified the FEE firmware for point-to-point readout**



**SRU**



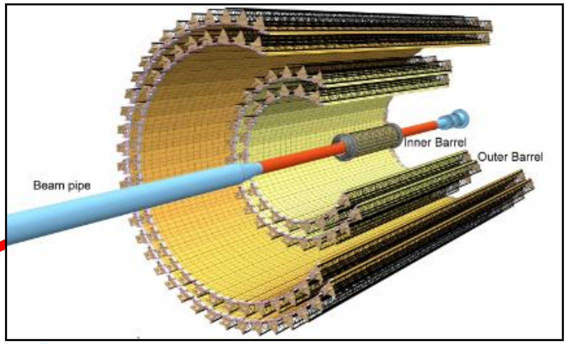

**The FPGA firmware in the SRU includes functions of RCU, DCS, and SIU boards**

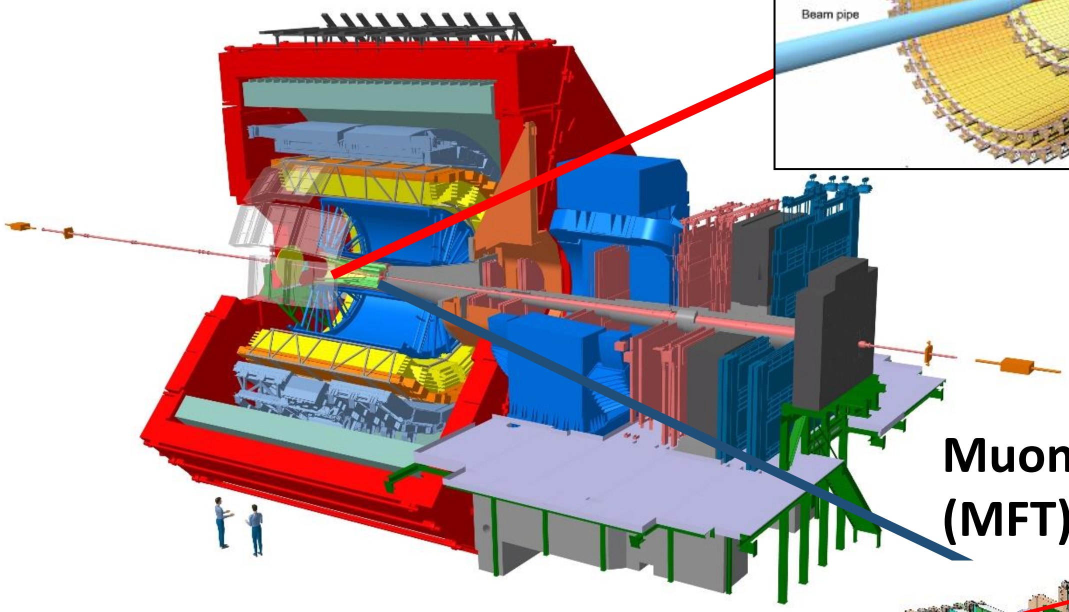
***Cooperated with CERN and ORNL***

NIMA 735 (2014) 157

# Detectors developed for ALICE 2

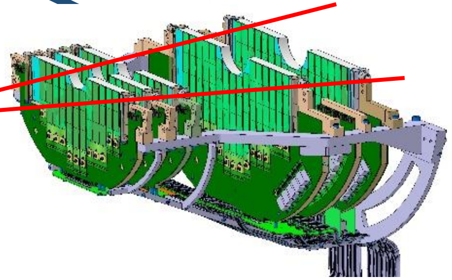
## Inner Tracking System 2 (ITS2)



- **Impact parameter resolution improved by a factor ~3 (5) in rφ (z) @ $p_T$ = 500 MeV/*c***
- **Improve tracking efficiency and momentum resolution at low $p_T$**
- 7-layer barrel fully equipped with dedicated Monolithic Active Pixel Sensors (MAPS): **ALice PIxel DEtector (ALPIDE)**
- Radial coverage: 23 – 400 mm
- η coverage: |η| ≤ 1.3
- Total active area about 10 $m^2$
- 24,000 ALPIDE chips (12.5G pixels)
- Spatial resolution: 5 μm

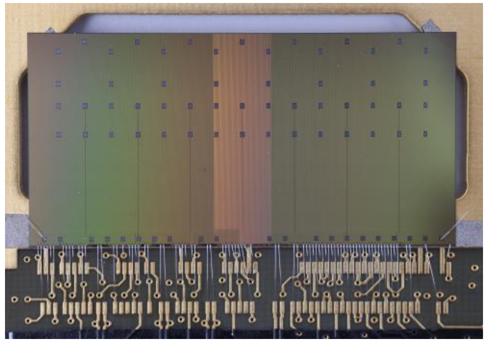
## Muon Forward Tracker (MFT)



- 5 circular pixel double-plane disks
- 0.7% $X_0$ per disks
- 912 **ALPIDE** chips
- Pseudo-rapidity coverage: $-3.6<\eta<-2.5$

- **Complementing muon spectrometer at forward rapidity**
  - Muon tracks extrapolated and matched to the MFT clusters
  - High pointing accuracy to separate charm and beauty signals

# Involvement in ALPIDE R&D

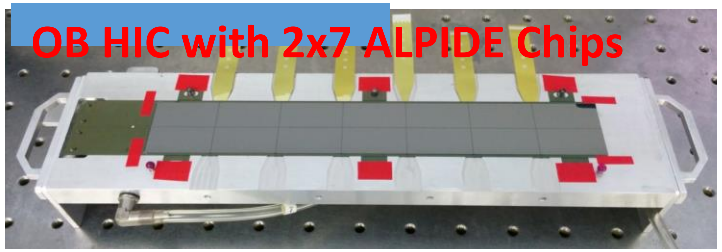


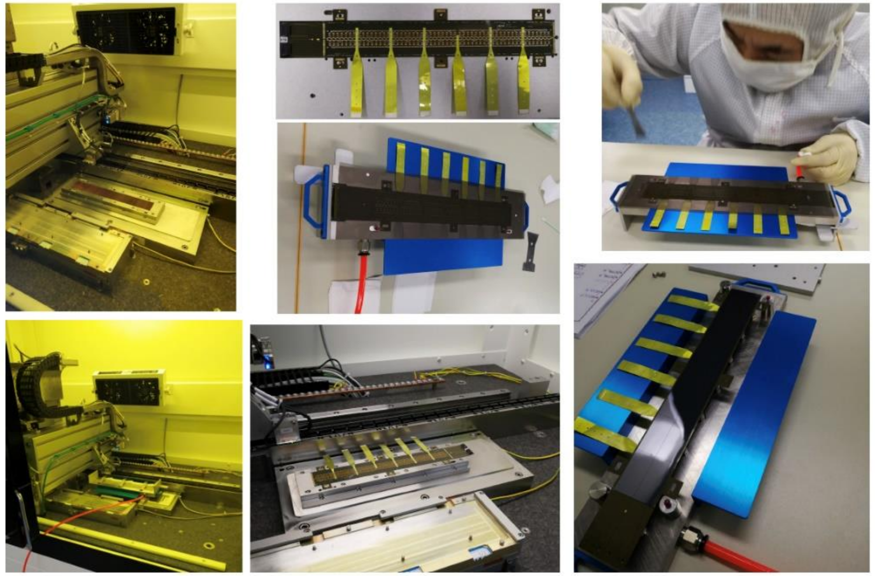
**ALIPIDE chip on a test carrier**

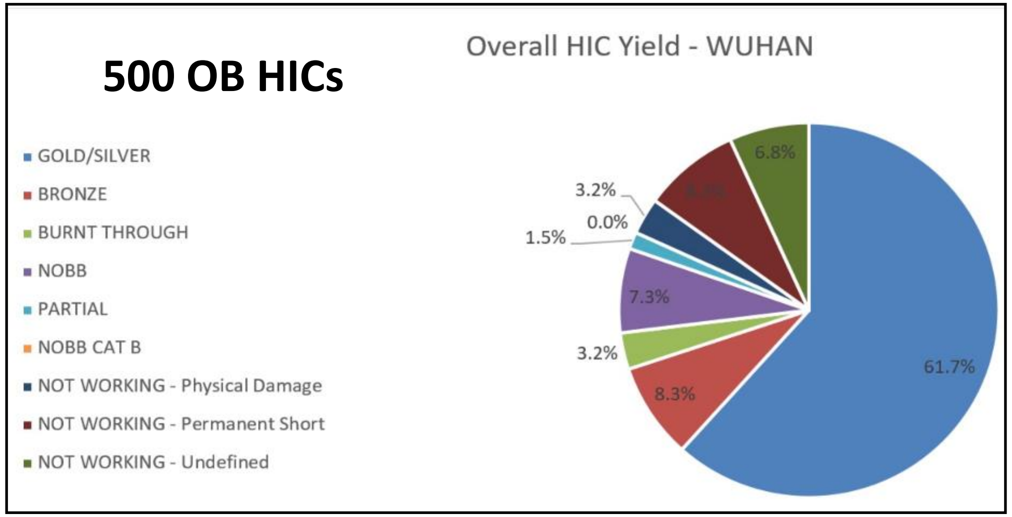
- **The Address Encoder and Reset Decoder data-driven readout architecture** has been implemented and tested, showing significant advantages in terms of **both readout time and power consumption** compared to the traditional rolling shutter readout architecture
- **A novel source–drain follower (SDF)** has been designed and characterized as part of the effort to **optimize the effective sensing node capacitance** of the MAPS for the ALICE ITS upgrade

*NIMA 785 (2015) 61*; *831 (2016) 147*

# Production of OB HICs



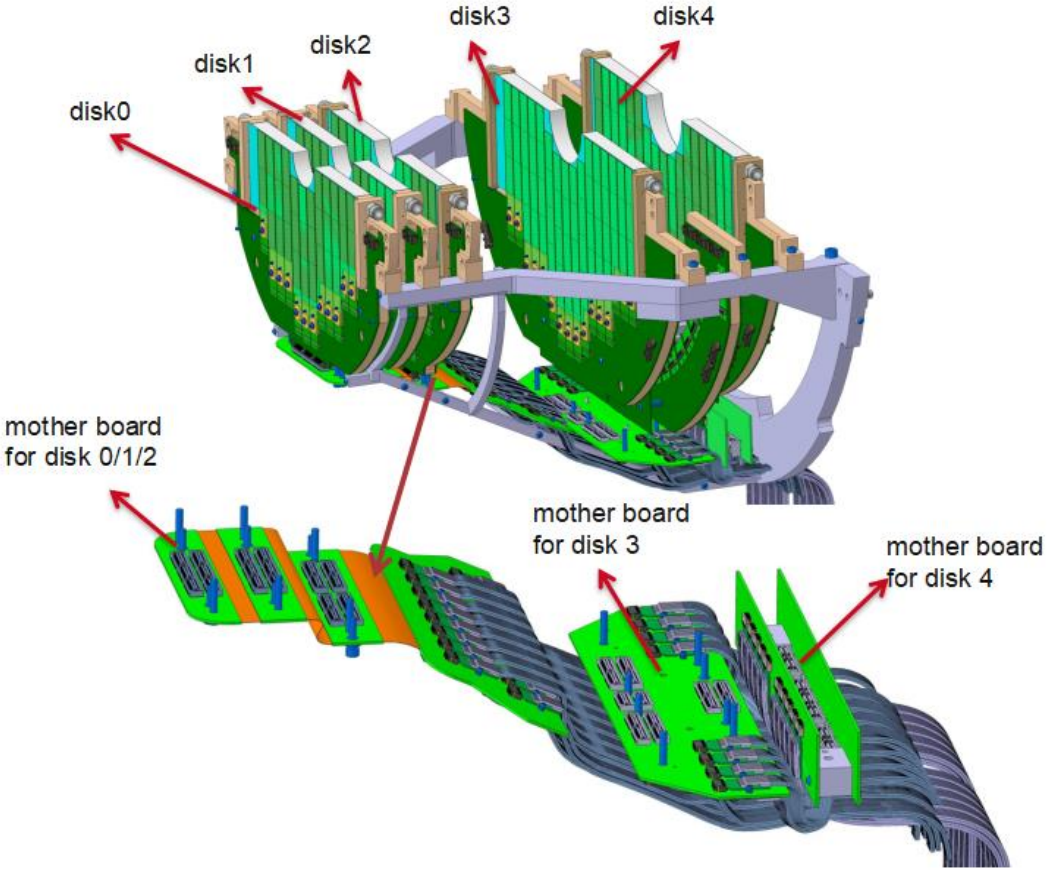



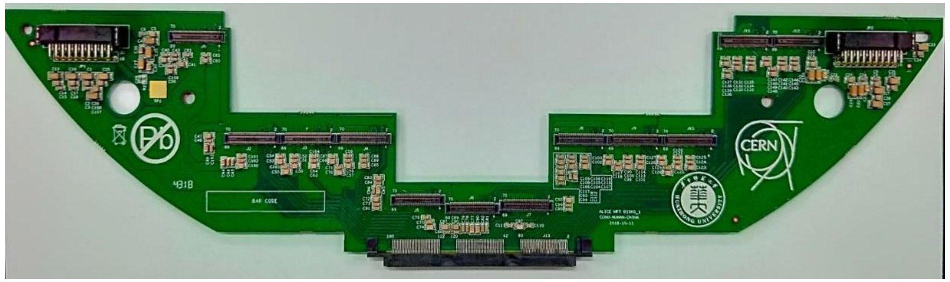


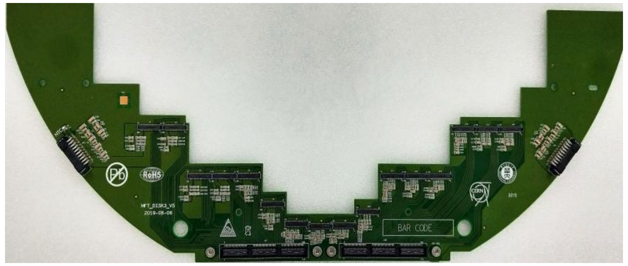

- **Chip alignment with ALICIA**
- **FPC gluing**
- **HIC wire bonding**
- **Functioning test**
- **Endurance test**

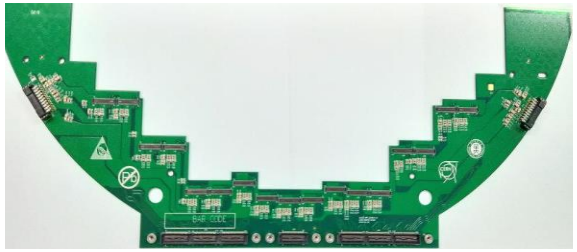

**Clean room for ITS2 OB HIC production**

## *Cooperated with France*



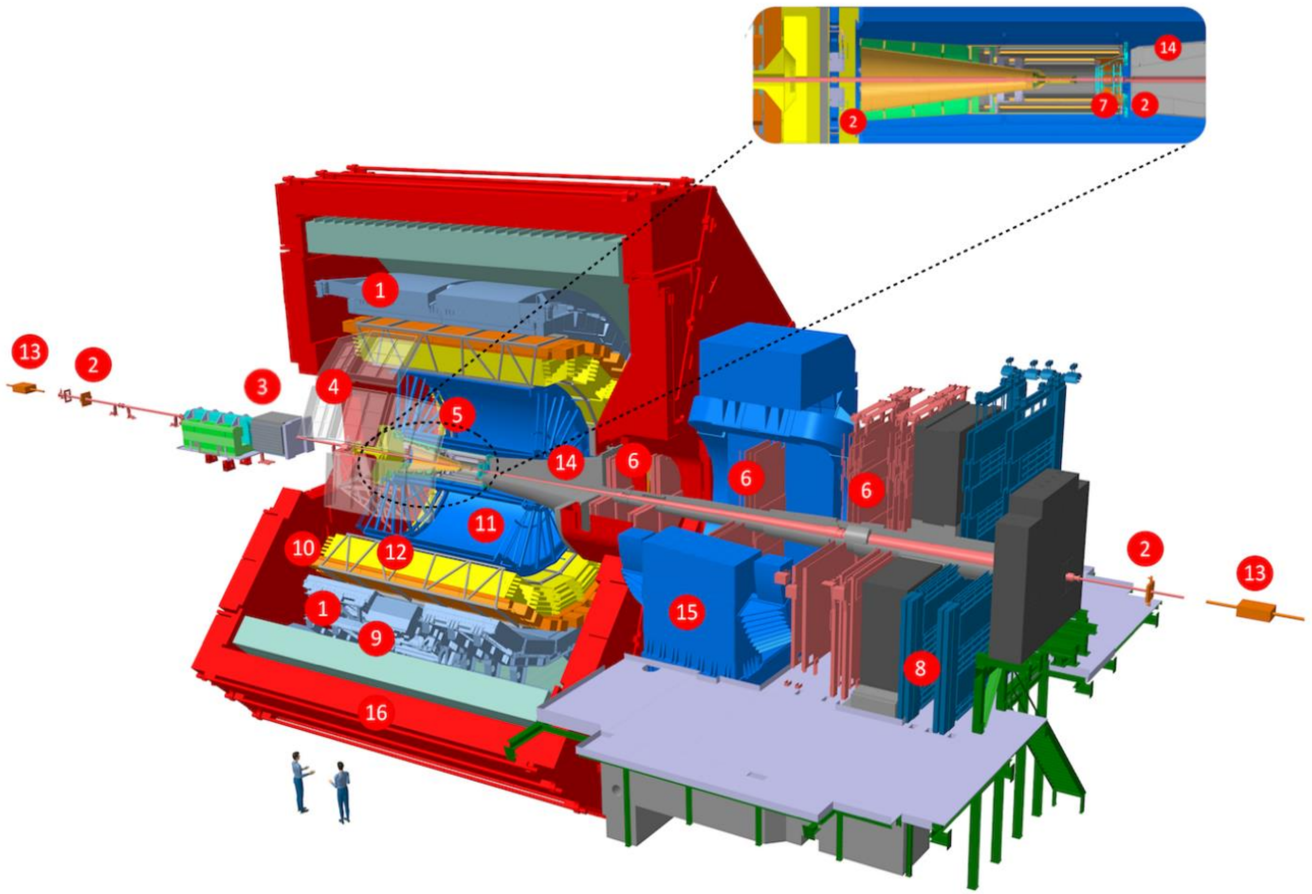





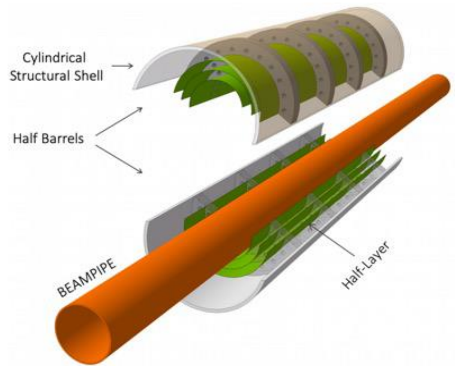


**Design and production of 5 different MFT disk boards connected to the motherboard**

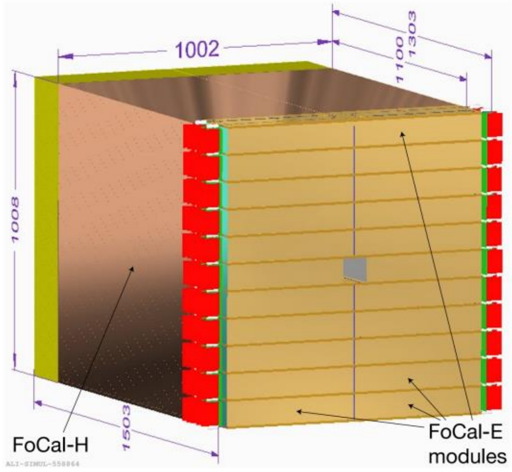
# On-going upgrade activities for ALICE 2.1



1. **EMCAL** | Electromagnetic Calorimeter
2. **FIT** | Fast Interaction Trigger
3. **FoCal** | Forward Calorimeter (in front of compensator magnet)
4. **HMPID**| High Momentum Particle Identification Detector
5. **ITS**| Inner Tracking System
6. **MCH**| Muon Tracking Chambers
7. **MFT**| Muon Forward Tracker
8. **MID**| Muon Identifier
9. **PHOS/CPV**| Photon Spectrometer
10. **TOF**| Time Of Flight
11. **TPC**| Time Projection Chamber
12. **TRD**| Transition Radiation Detector
13. **ZDC**| Zero Degree Calorimeter
14. **Absorber**
15. **Dipole Magnet**
16. **L3 Magnet**

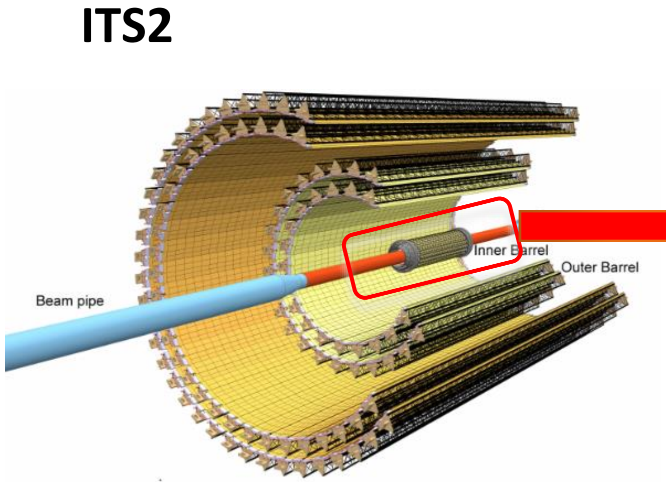


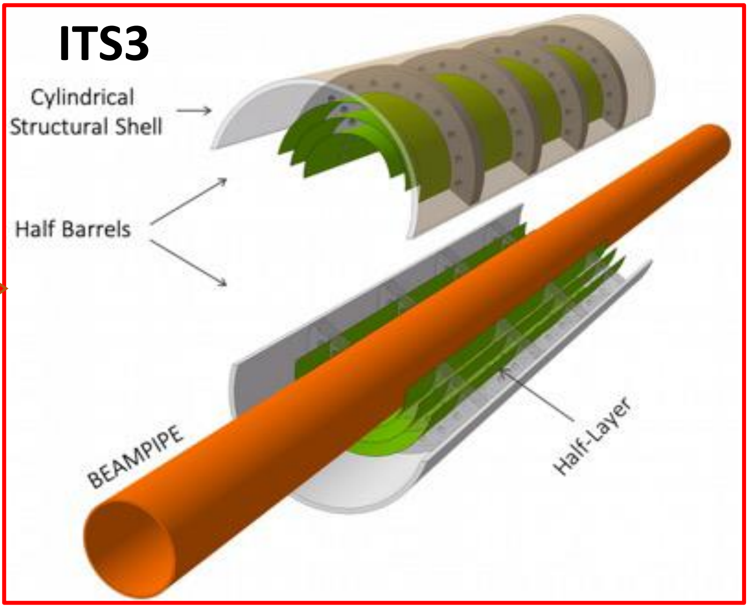

ITS3

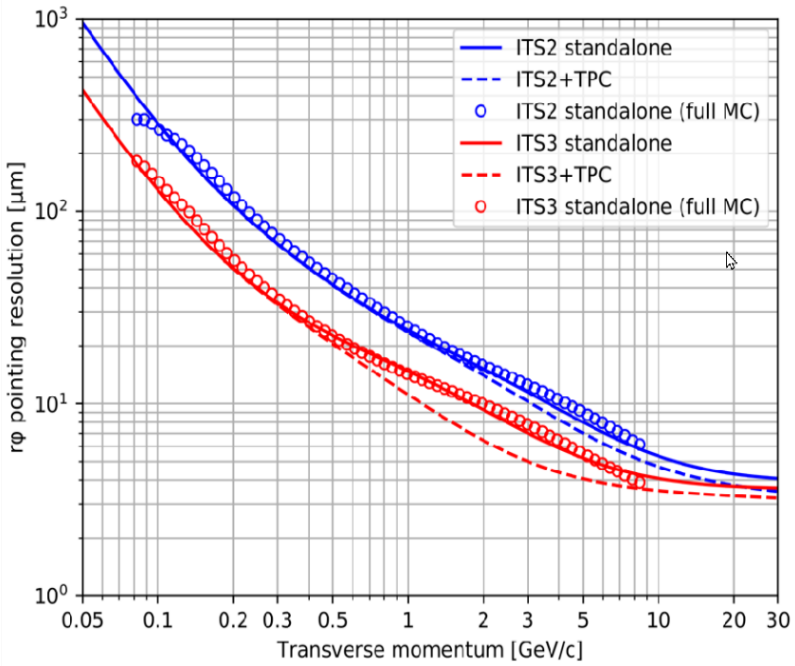



FoCal

# ITS3



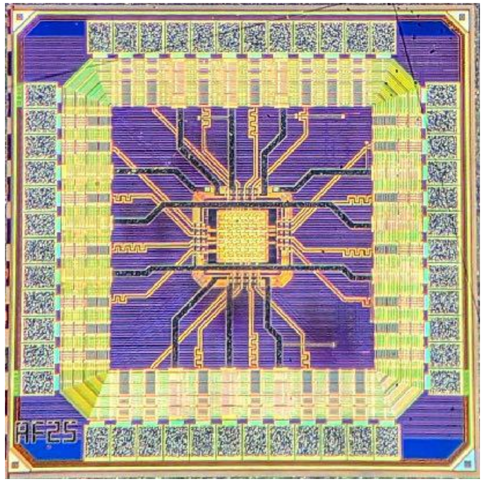

- **Replacing the 3 IB of ITS2 with 3 truly cylindrical pixel layers**
  - **6 ultra-thin wafer-size curved sensors**
  - **Supported by carbon foam ribs**
  - **Air coolings**

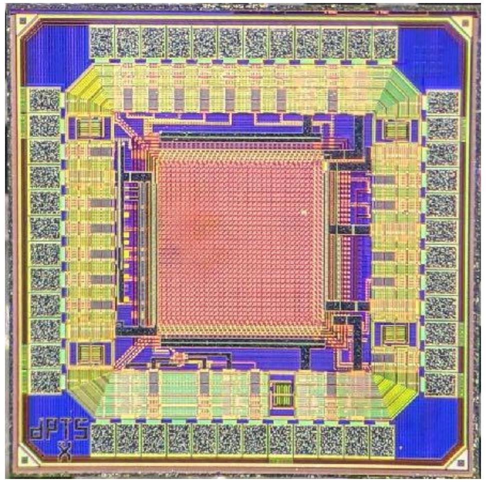
- **Pointing resolution improves by a factor of two compared to ITS2 at $p_T$ up to 5 GeV/*c***

# On-going upgrade activities – ITS3

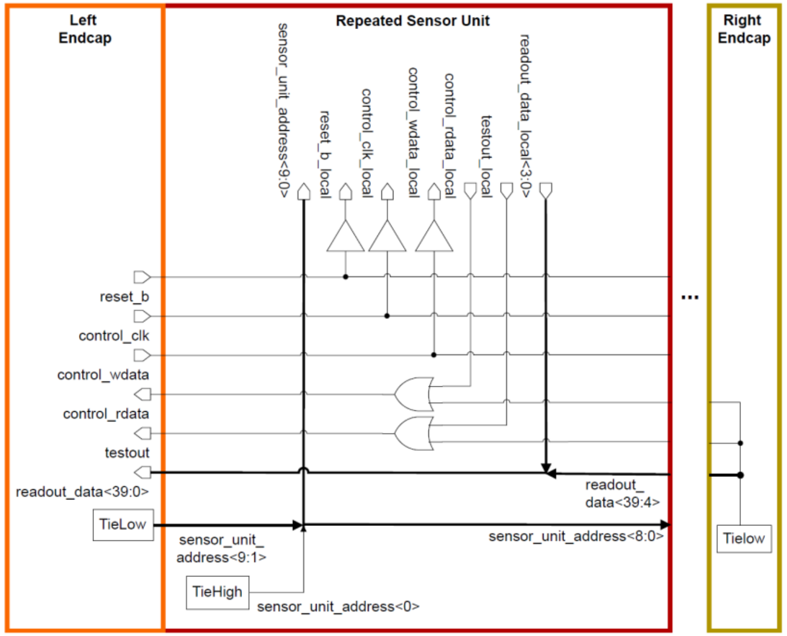
*Cooperated with CERN*

**APTS** for study of charge collection



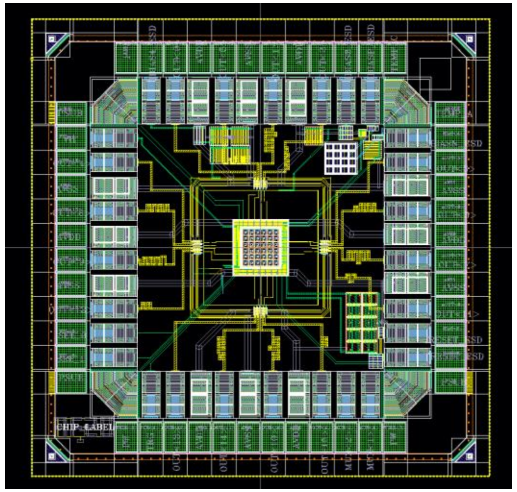


**DPTS** for validation of full analog to digital readout chain

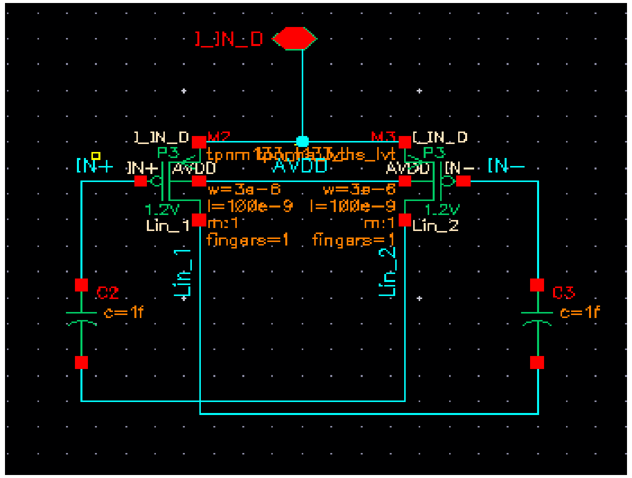



Logic diagram of stitched backbone communication

- **Sensor design** (Wenjing Deng & Qiaomu Tong)
  - Further improvement of APTS (different pixel pitches, DRC error correction, modulization, and etc.)
  - Analyzing the power consumption distribution of MOSS chip and exploring new ways to reduce the leakage current
  - Study signal transmission structure for signal transmission over long distance
- **Sensor characterization** (Wenjing Deng & Zijun Zhao)

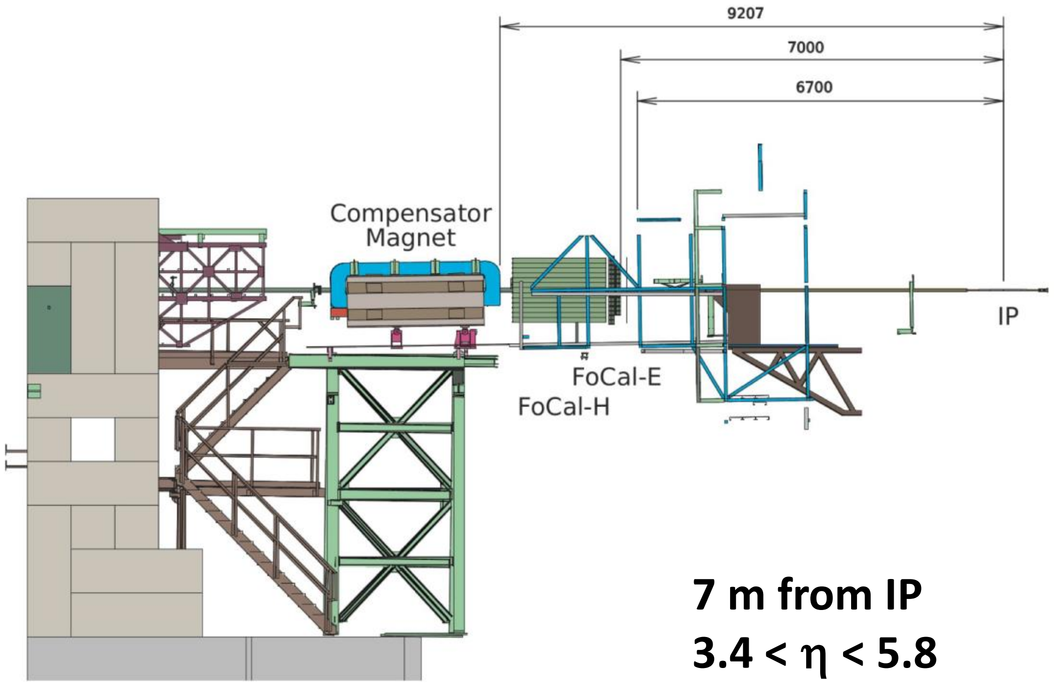


Layout of an APTS chip with a pitch of 20 μm

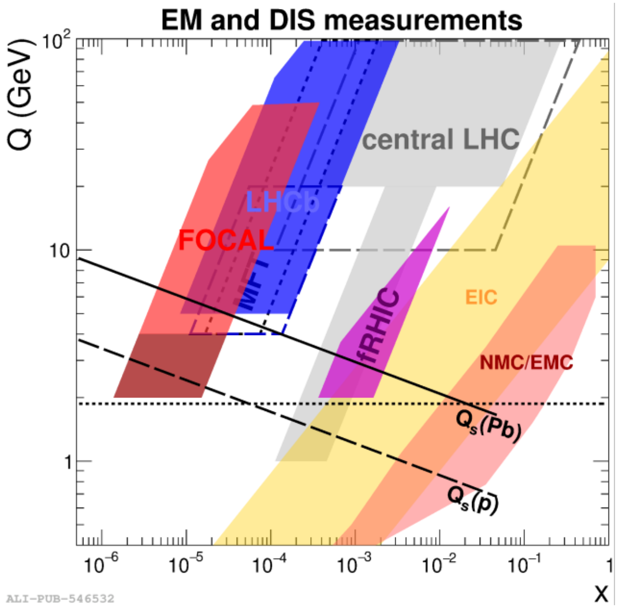


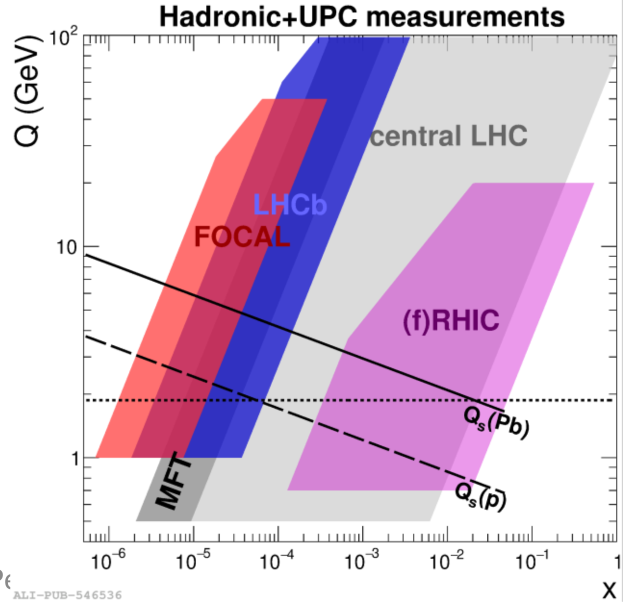

Differential signal transmission structure

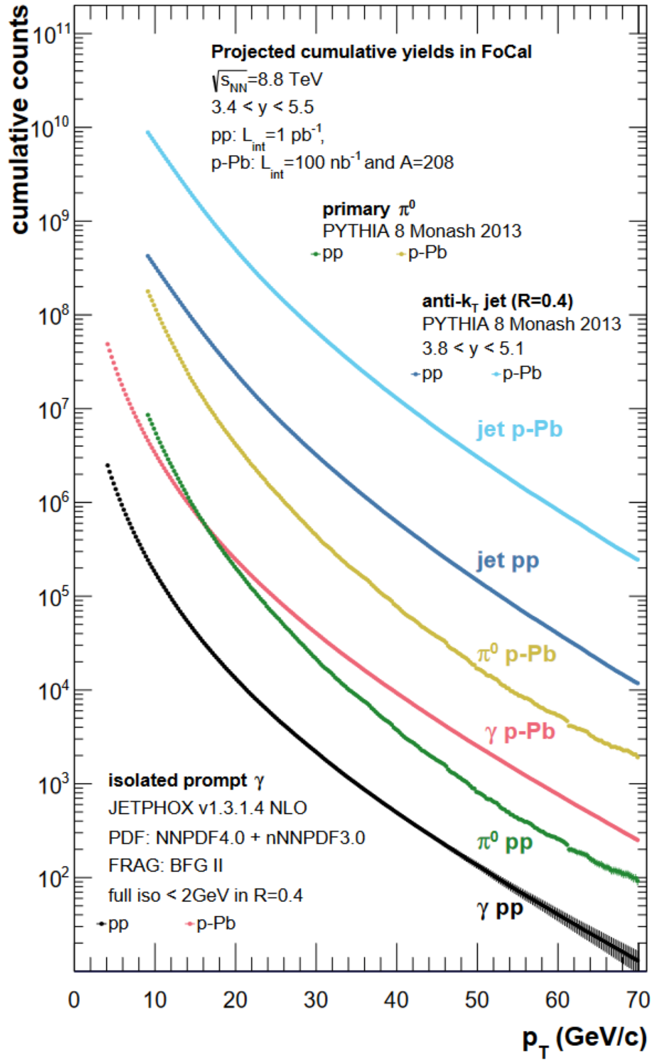
# FoCal




**7 m from IP**
**3.4 < η < 5.8**



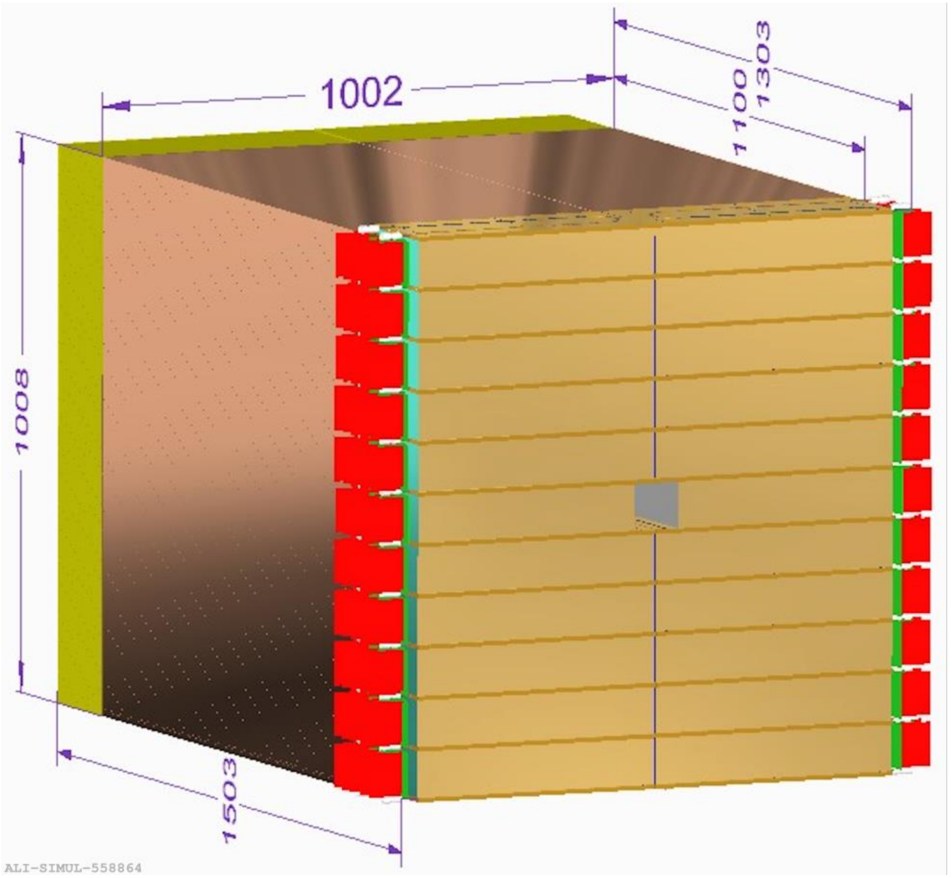




*ALICE-PUBLIC-2023-001*

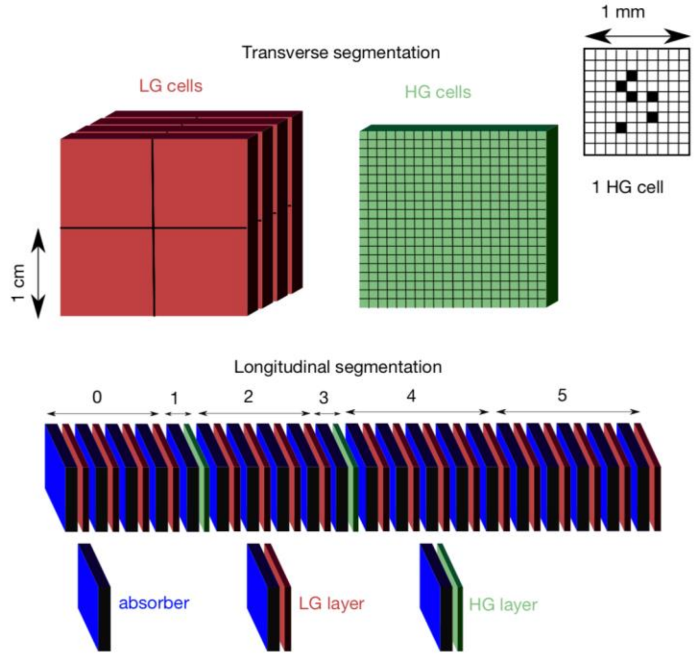
**Main goal:**

- measurement of **direct photon production at forward rapidity in pp and pPb** to probe gluon density at small x, forward $\pi^0$ in pp, pPb, PbPb
- constrain gluon nuclear PDF at **small Bjorken-x ($x<10^{-4}$):** structure of protons and nuclei not well constrained experimentally

# FoCal detector design




## FoCal-E




- 20 layers: W(3.5 mm ≈ $1X_0$) + silicon sensors
- Two types: Pads (LG) and Pixels (HG)
  - Pad layers provide shower profile
  - Pixel layers provide position resolution to resolve shower overlaps

## FoCal-H

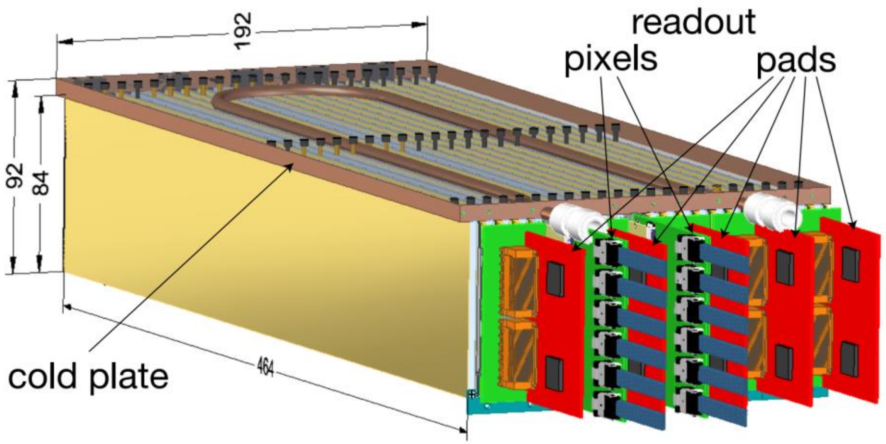
**Hadronic spaghetti calorimeter**

- Copper capillary tubes, length 110 cm ~ $7\lambda_I$ (Length limited by space before compensator magnet)
- 1 mm scintillating fibres inside 2.5 mm Cu tubes
- Bundle fibres and readout with SiPM

FoCal–H prototype, 9 x (6.5 x 6.5 x 110 $cm^3$)

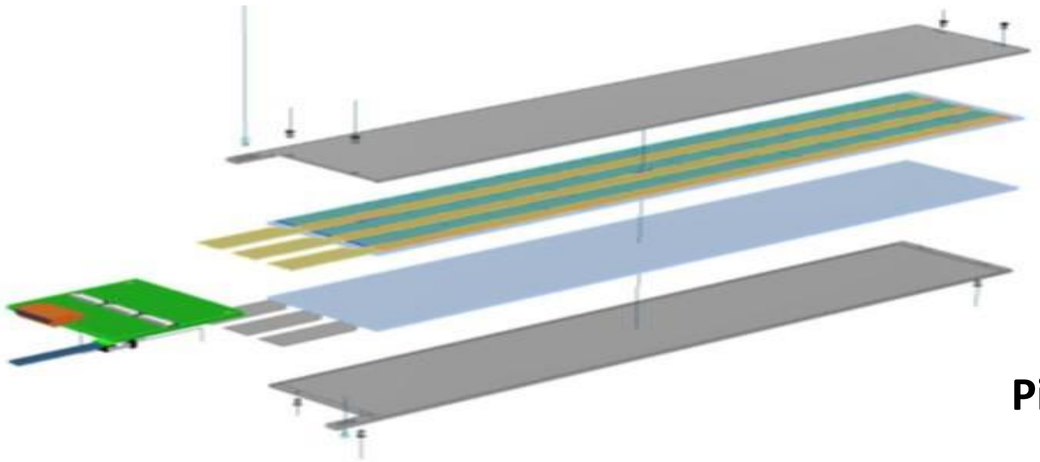
# FoCal-E module

## FoCal-E module




18 PAD layers + 2 pixel layers

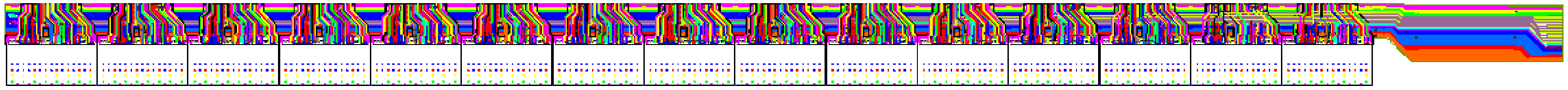
## Structure of pixel layer module



Pixel half layer

*Sketch*

*Total length of string ~50cm*



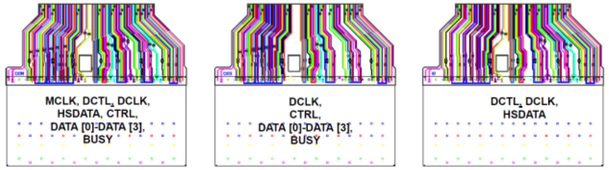
*Length of active area ~45cm*

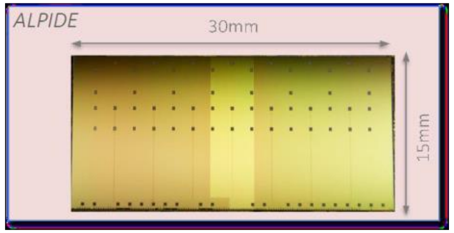
- sensitive area: 45 cm x 8 cm
- edge of detector for services
- stack vertically for full detector setup
- 22 modules in total

- full area coverage with 2 x 3 strings of 15 ALPIDE sensors
- 90 ALPIDE sensors per layer
- 44 pixel layers, 3960 ALPIDE sensors

# On-going upgrade activities - FoCal-E pixel layer

**Procedure of pixel half layer production**

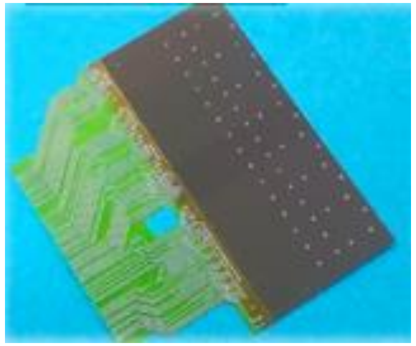


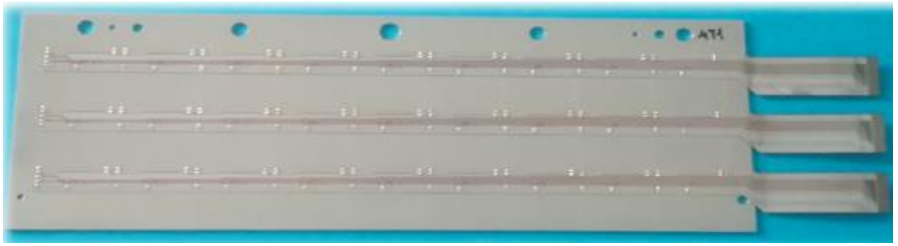




**ALPIDE**

**SpTAB**

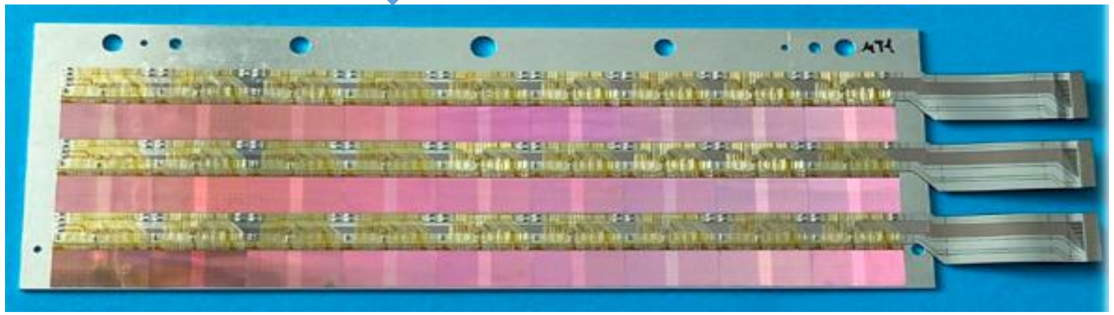
**ALPIDE bond to chipcable**





**Carrier board with flex**

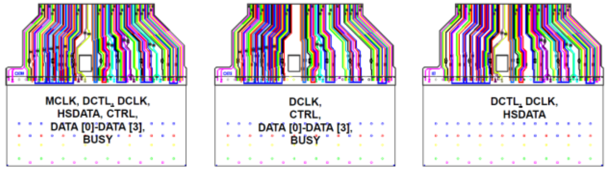
**SpTAB**

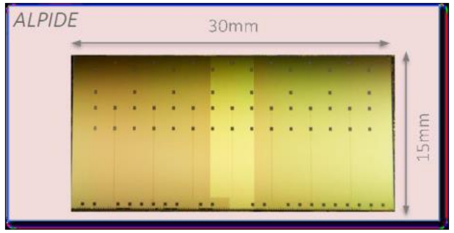


- **R&D on FoCal-E pixel layer**
- **Mass production of FoCal-E pixel layer modules**
- **Firmware development for the readout electronics**

***Cooperated with Norway***

# Jigs for production of pixel half layer modules

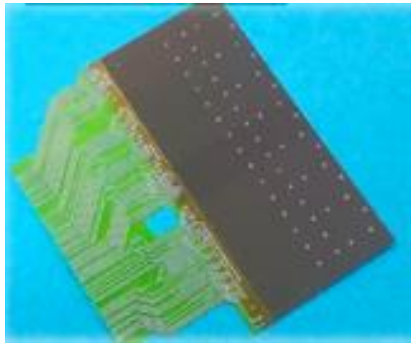


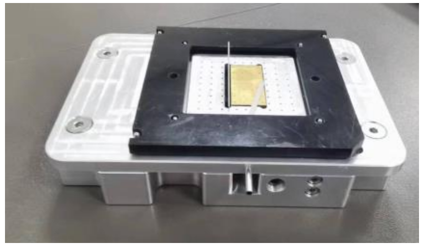




ALPIDE

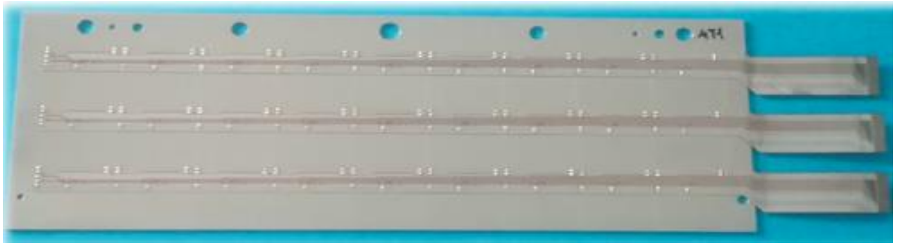
SpTAB

ALPIDE bond to chipcable



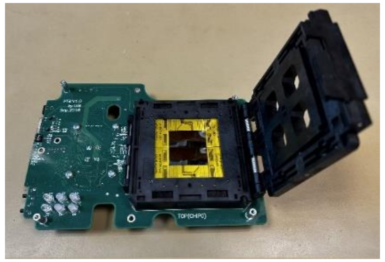


Single ALPIDE mounting jig



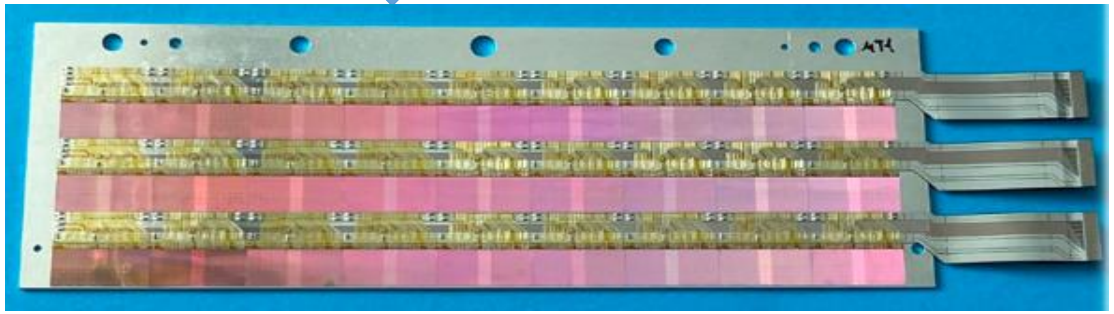
Carrier board with flex

SpTAB

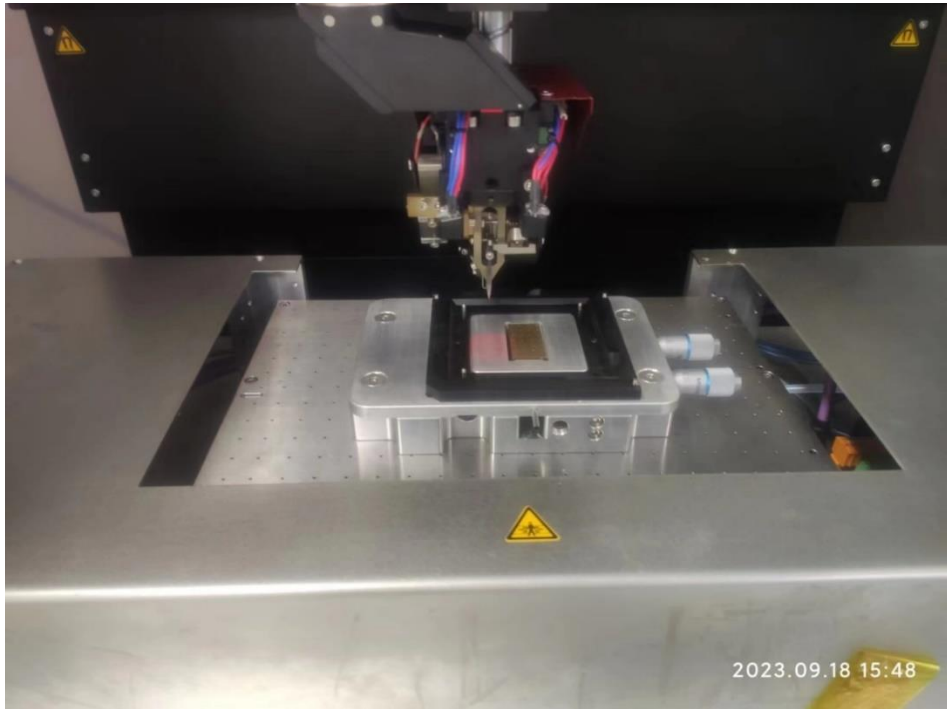


Production test box

Pixel layer assembly jig

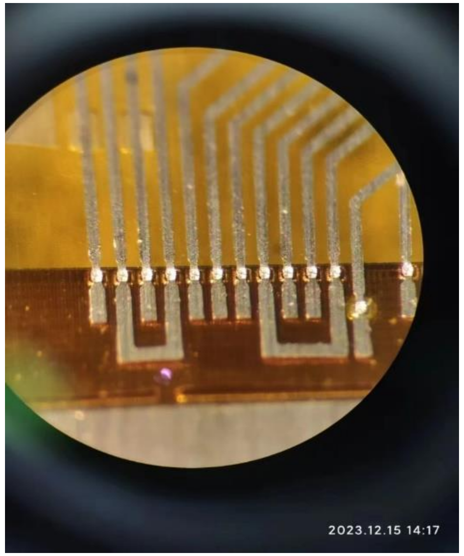


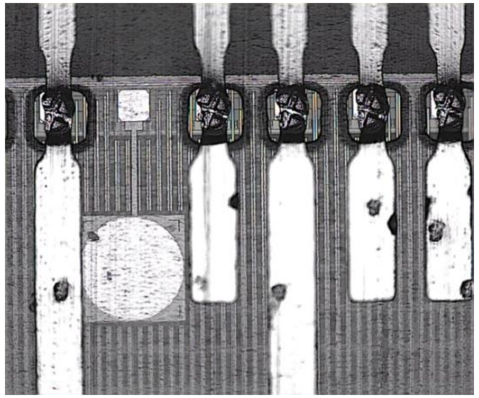
# ALPIDE to chip-cable bonding

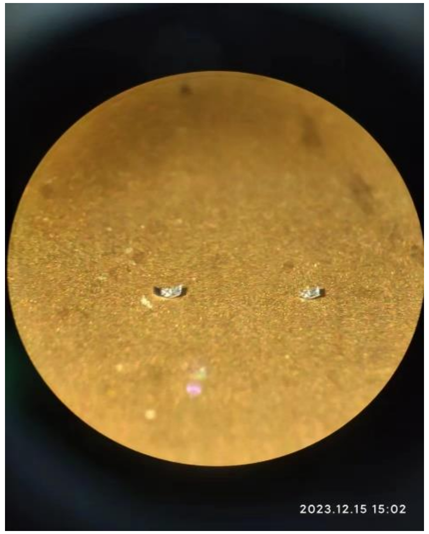



Bonder table lowered by 2 cm to hold the single ALPIDE mounting jig


**ALPIDE bonded to chip-cable**

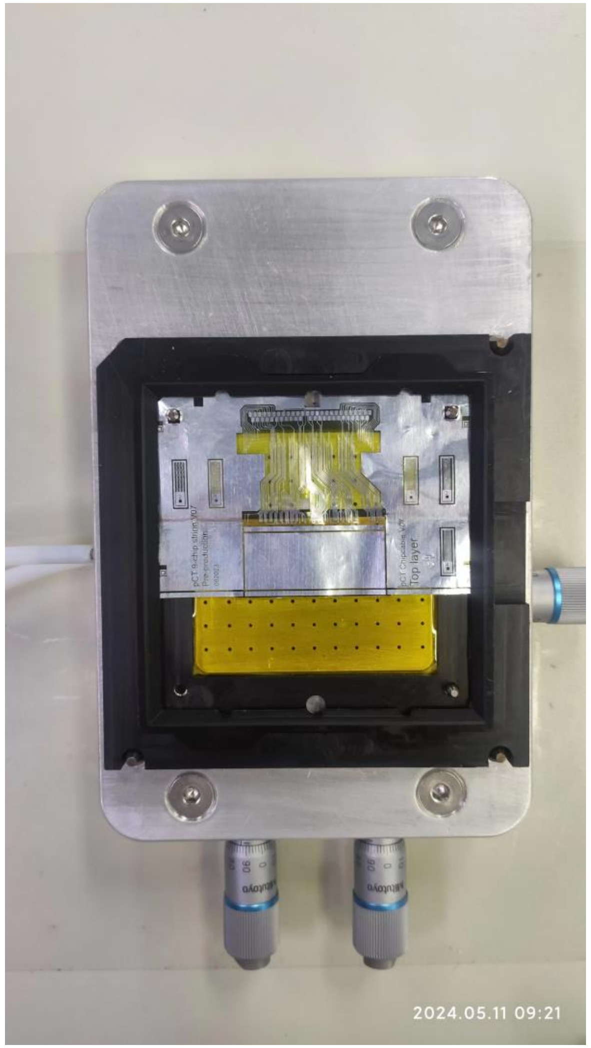


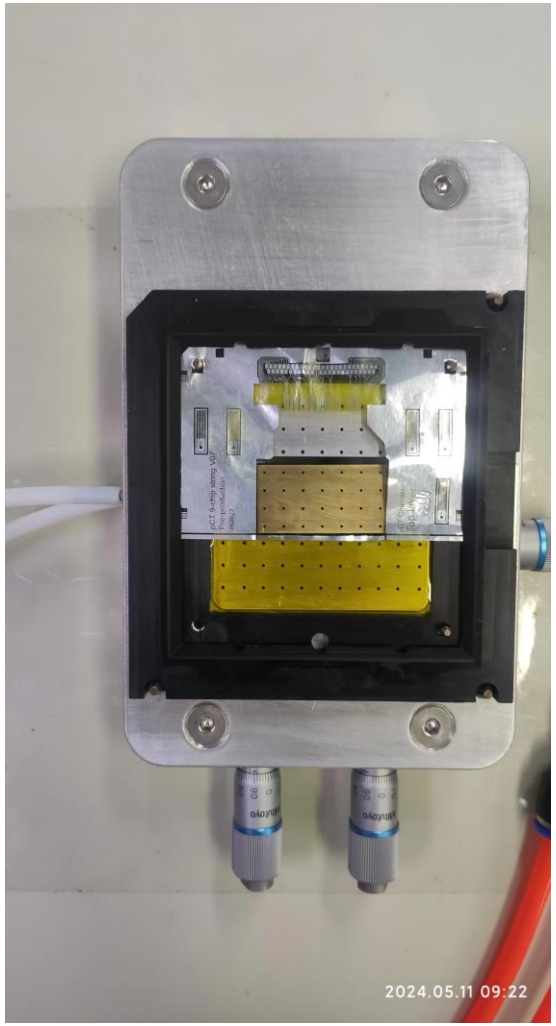



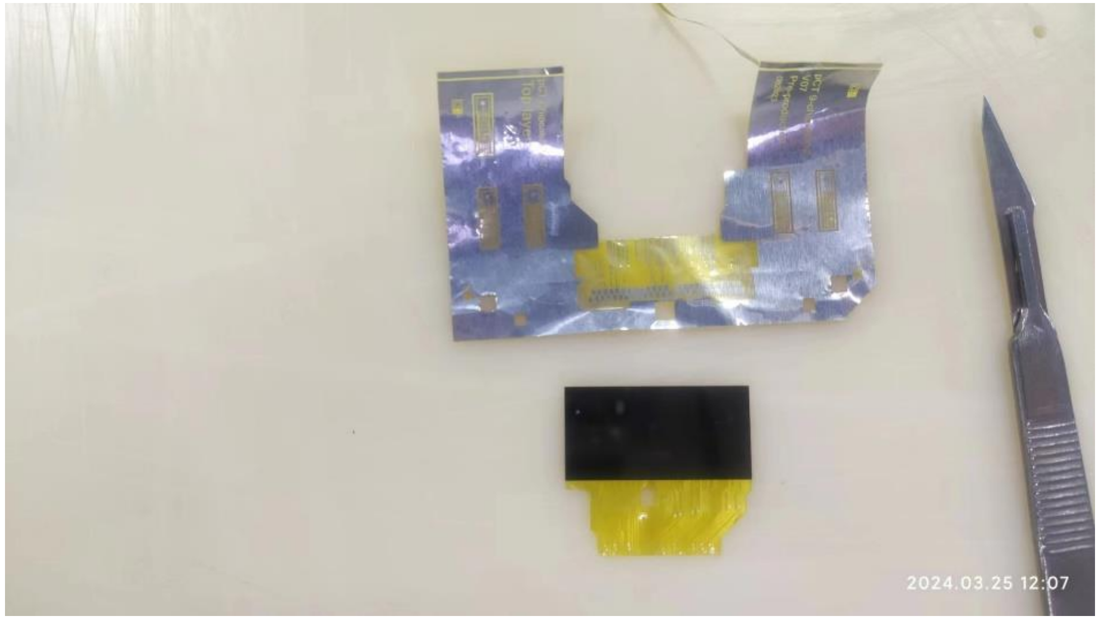



**Peel test**

# Cut off the part for assembly

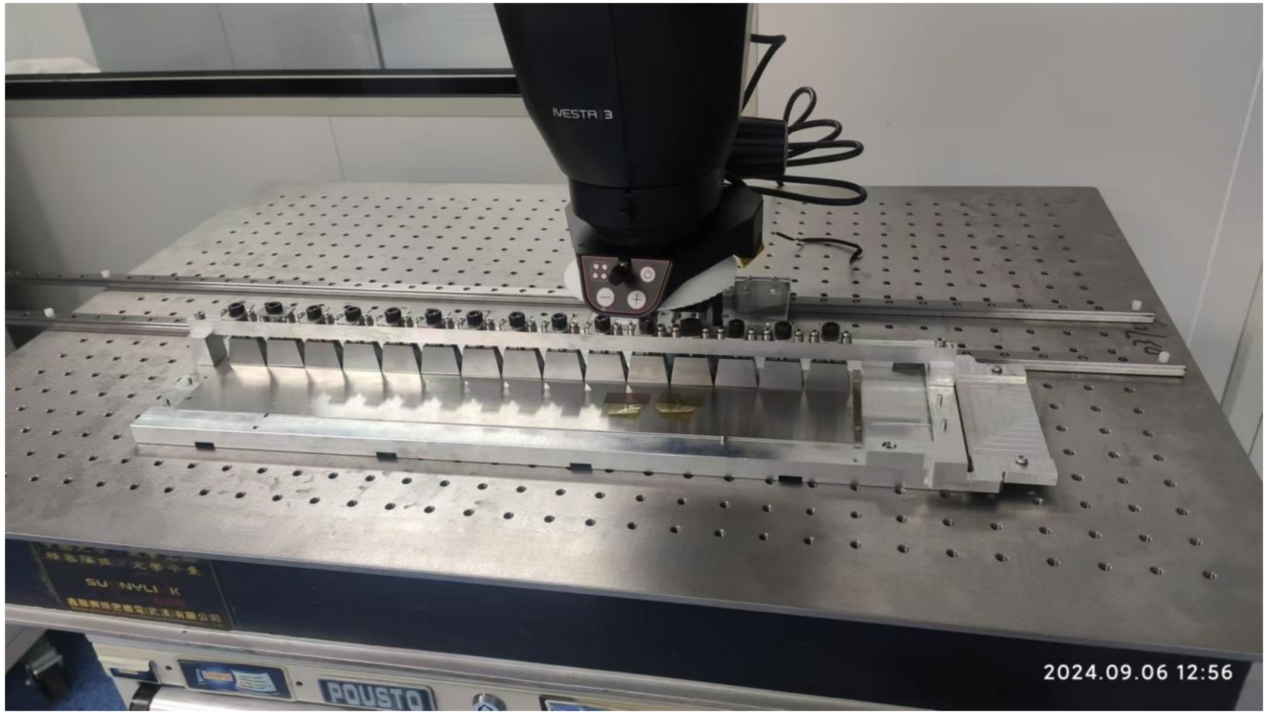


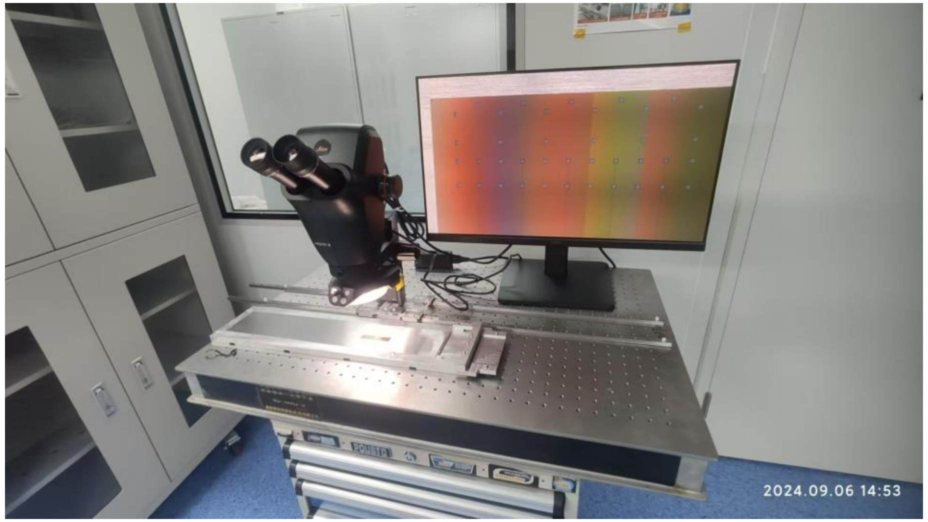



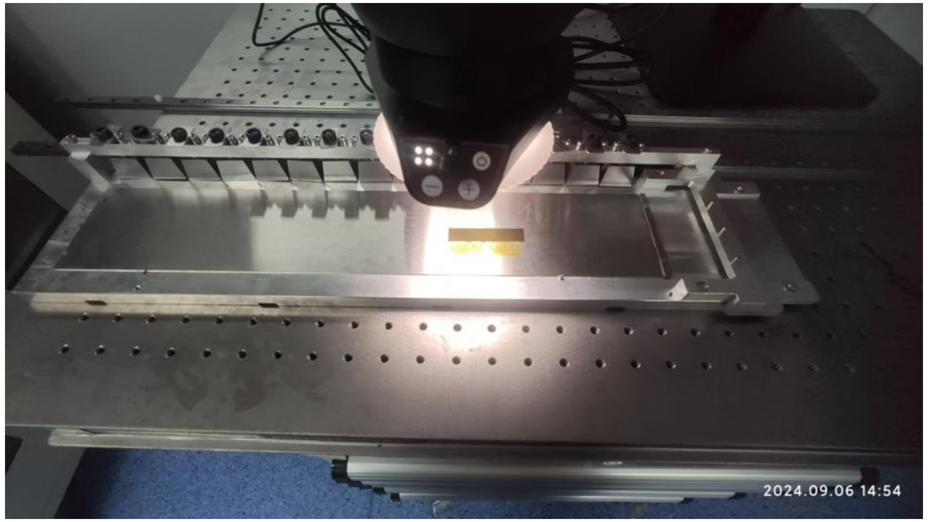

**Cut tool will be developed**

# Lab preparation for half pixel layer assembly



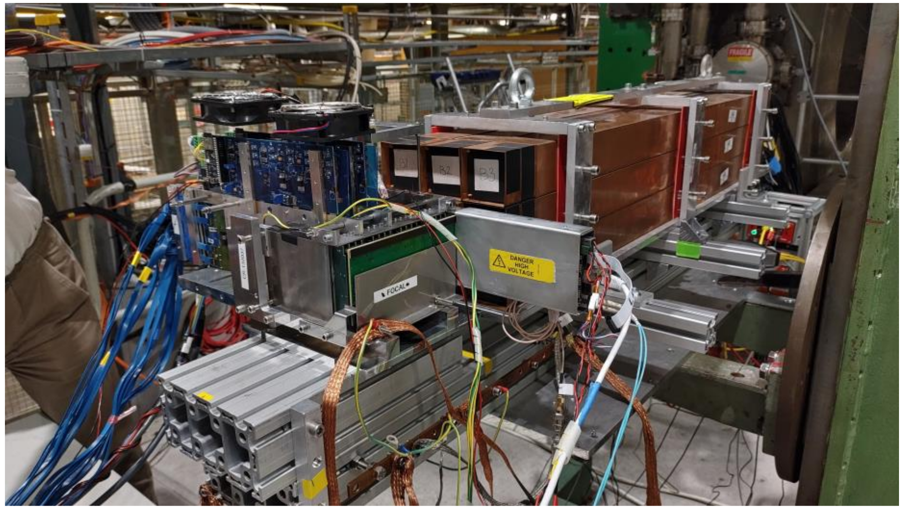

- **Make the microscope movable**

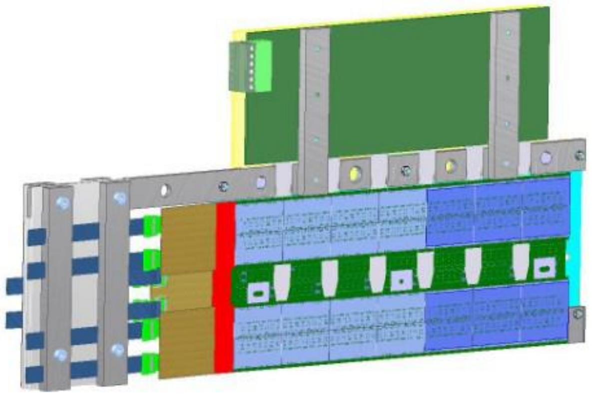



- **Align ALPIDEs with module assembly jig under microscope**

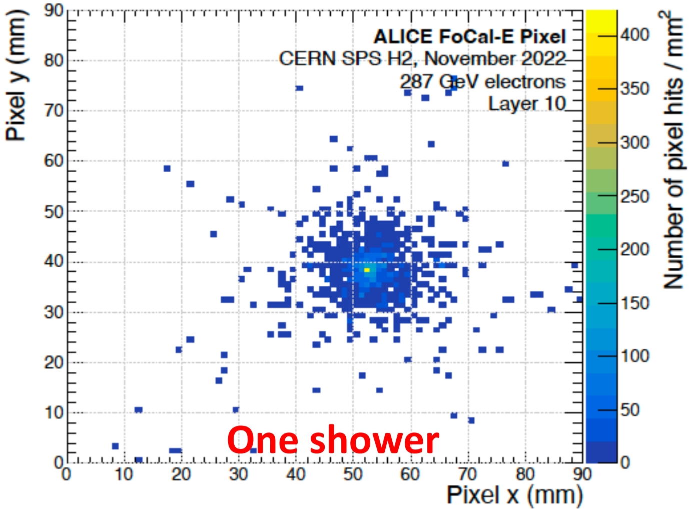
# Analysis of beam test data with FoCal prototype

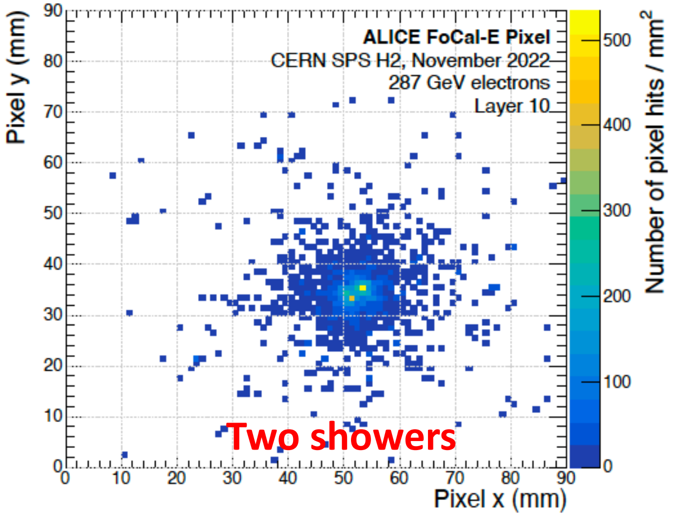


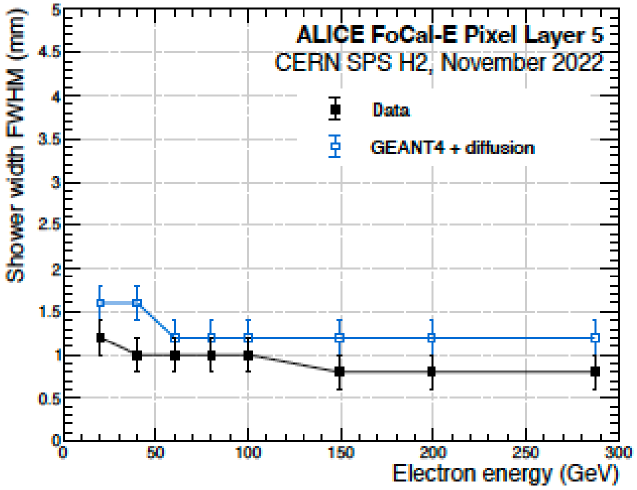


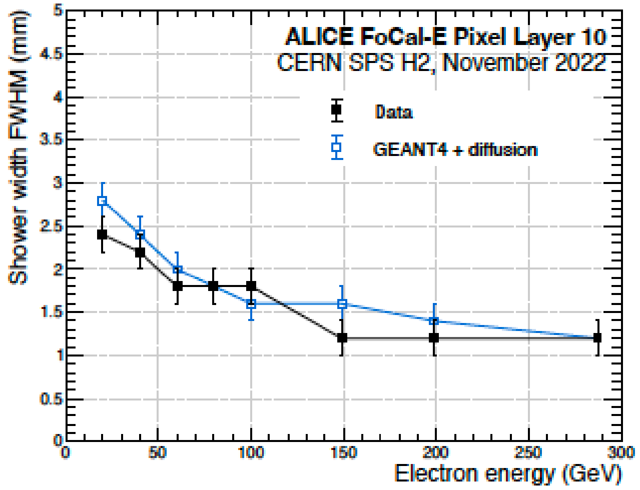
**ITS2 HIC based pixel layer prototype**

**Shower profile in pixel layer**



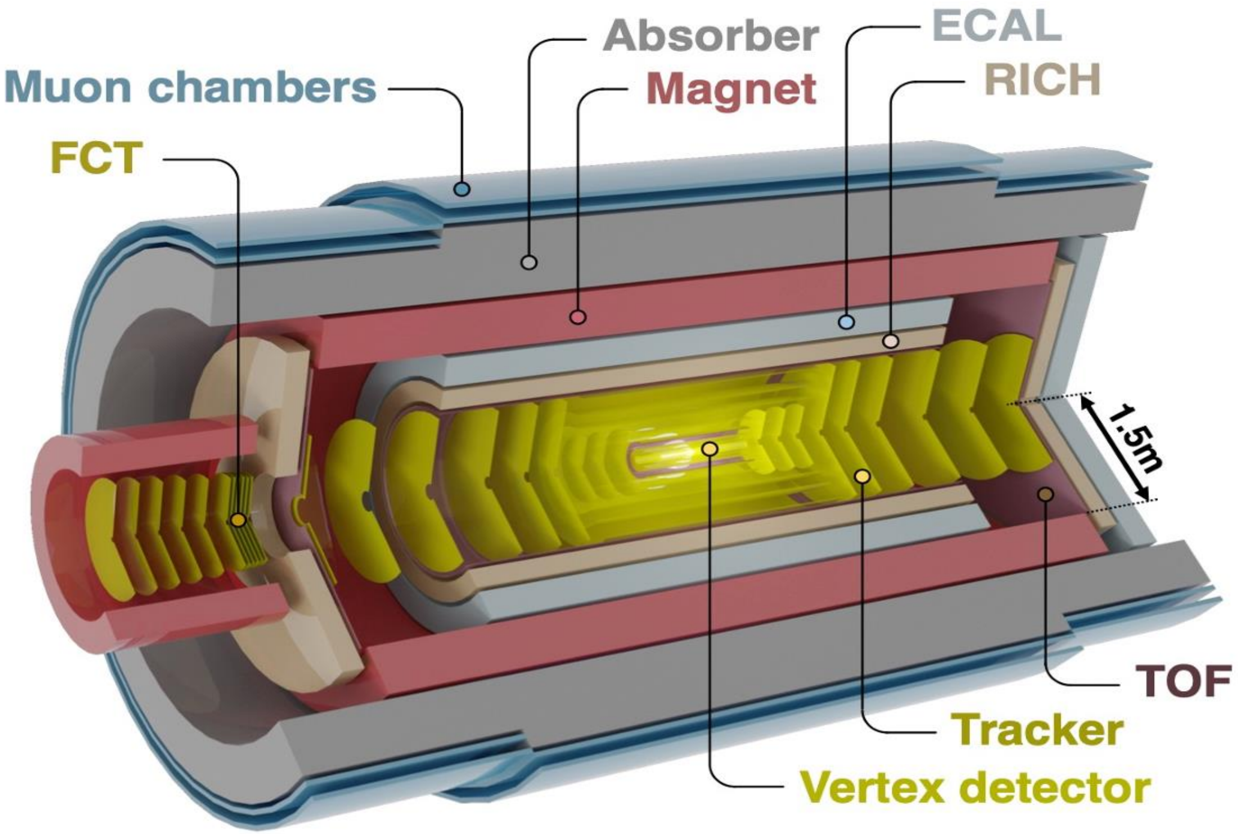




- **Shower width of 1 mm achieved**

*JINST 19 (2024) P07006*

# Plans for ALICE 3

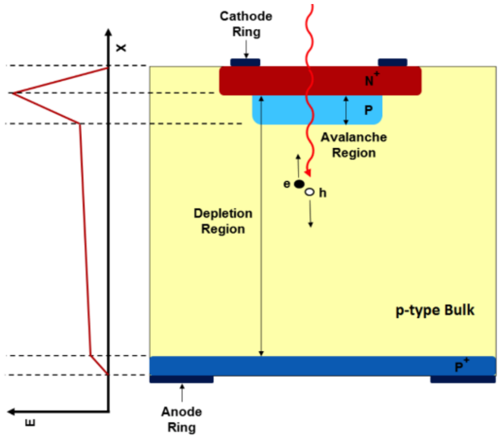



- **Next generation heavy-ion detector for the LHC Run 5 and 6**
  - **Full silicon tracker based on MAPS**
  - **TOF for particle identification ($\Delta$t ~ 20 ps)**
  - **……**

**We will contribute to the Inner Tracker (IT) and TOF**

# Plans of China Team for ALICE 3

- **Inner Tracker**
  - **R&D of sensors for VD and ML**
    - **Design and characterization**
  - **Mass production of ML HIC modules if it is possible**
  - **R&D of the readout electronics**
- **TOF**
  - **R&D of high timing resolution LGAD**
    - **Design and characterization**
  - **Mass production of TOF modules**
  - **R&D of the readout electronics**



# Summary

- **In the past more than 20 years, our contributions to ALICE detectors include**
  - **Electromagnetic Calorimeters (PHOS and EMCal)**
  - **ITS2 and MFT based on ALPIDE chips**
- **Right now we are involved in the upgrade programs for LS3**
  - **ITS3 – sensor design and characterization**
  - **FoCal – Pixel layer development**
- **Our plans for ALICE 3 are Inner Tracker (VD & ML) and TOF**

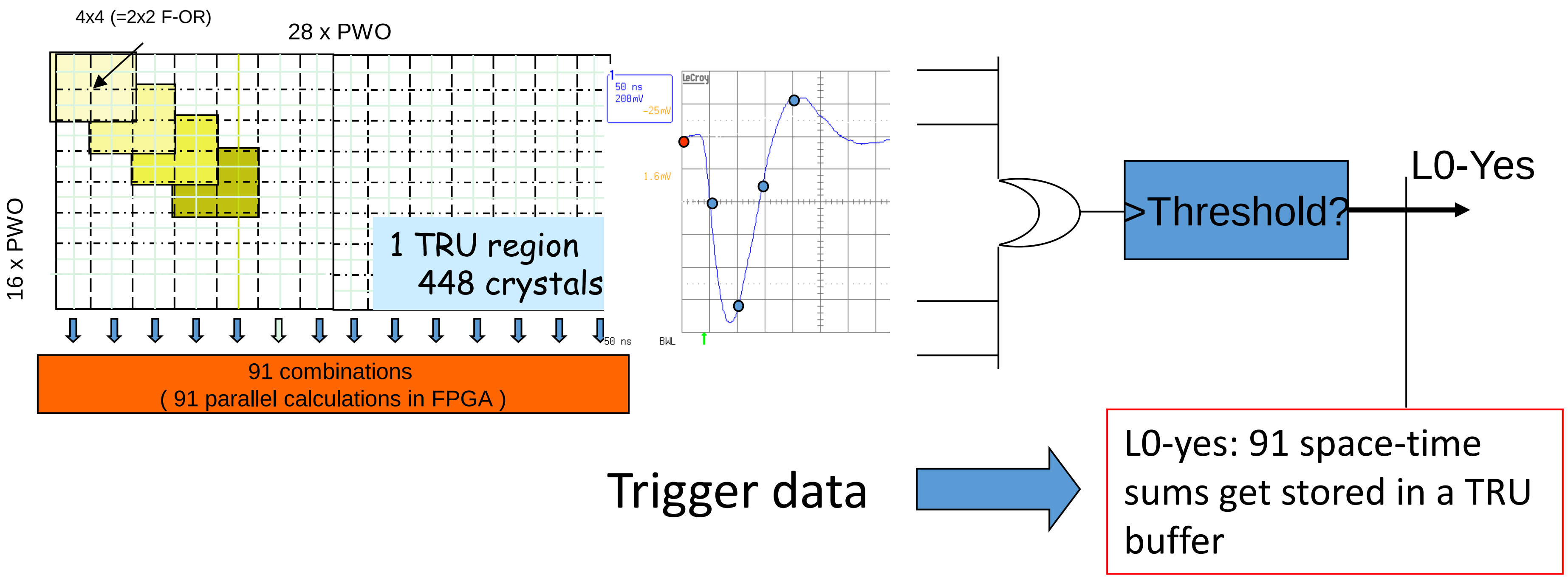
*Thank you for your attention!*

# FPGA internal process in TRU

1) Every 25 ns: 4x4 space sums in 91 parallel instances

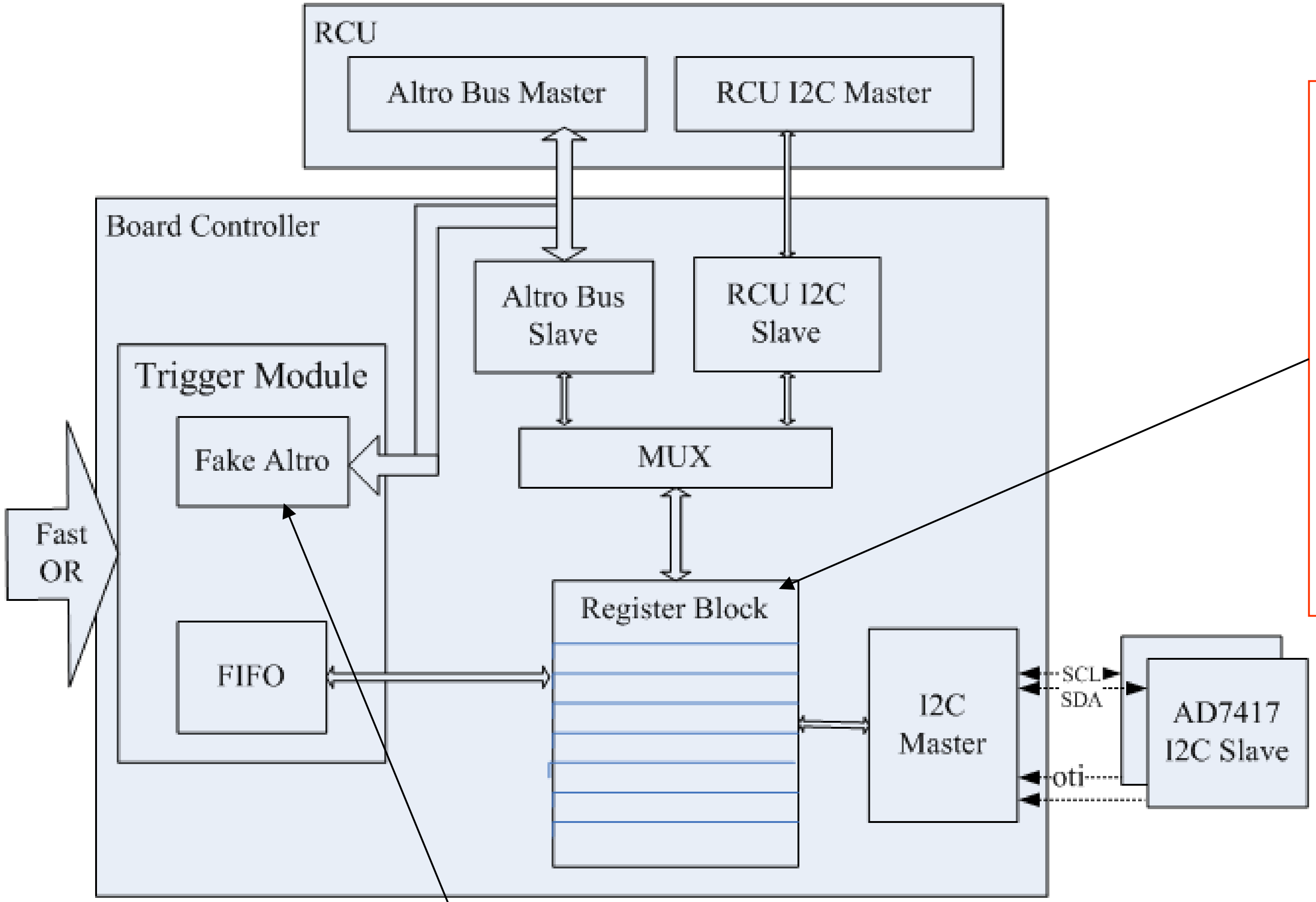
2) Time sum 5 bunches

3) OR over all Time sums Comparison over single threshold




NIM A 629 (2011) 80

# TRU board controller




**<u>First registers:</u>**
- Temperature/Voltage/Current monitoring
- ADS5270 pedestal correction
- Trigger thresholds
- Trigger enable/disable
- Interrupt and corresponding mask/thresh. Registers

<u>Trigger data readout</u>
"**fake Altro**"

# Mechanic parts for pixel layer mockup

- **Two mockup parts produced and assembled (with different order) for transportation to reduce possible damage**
- **One is made of Aluminum, the other of stainless steel**




**The transition card holder and spacers are bended during transportation**
**The aluminum parts bended more then the stainless-steel parts**