STAR FST Module Assembly and Test

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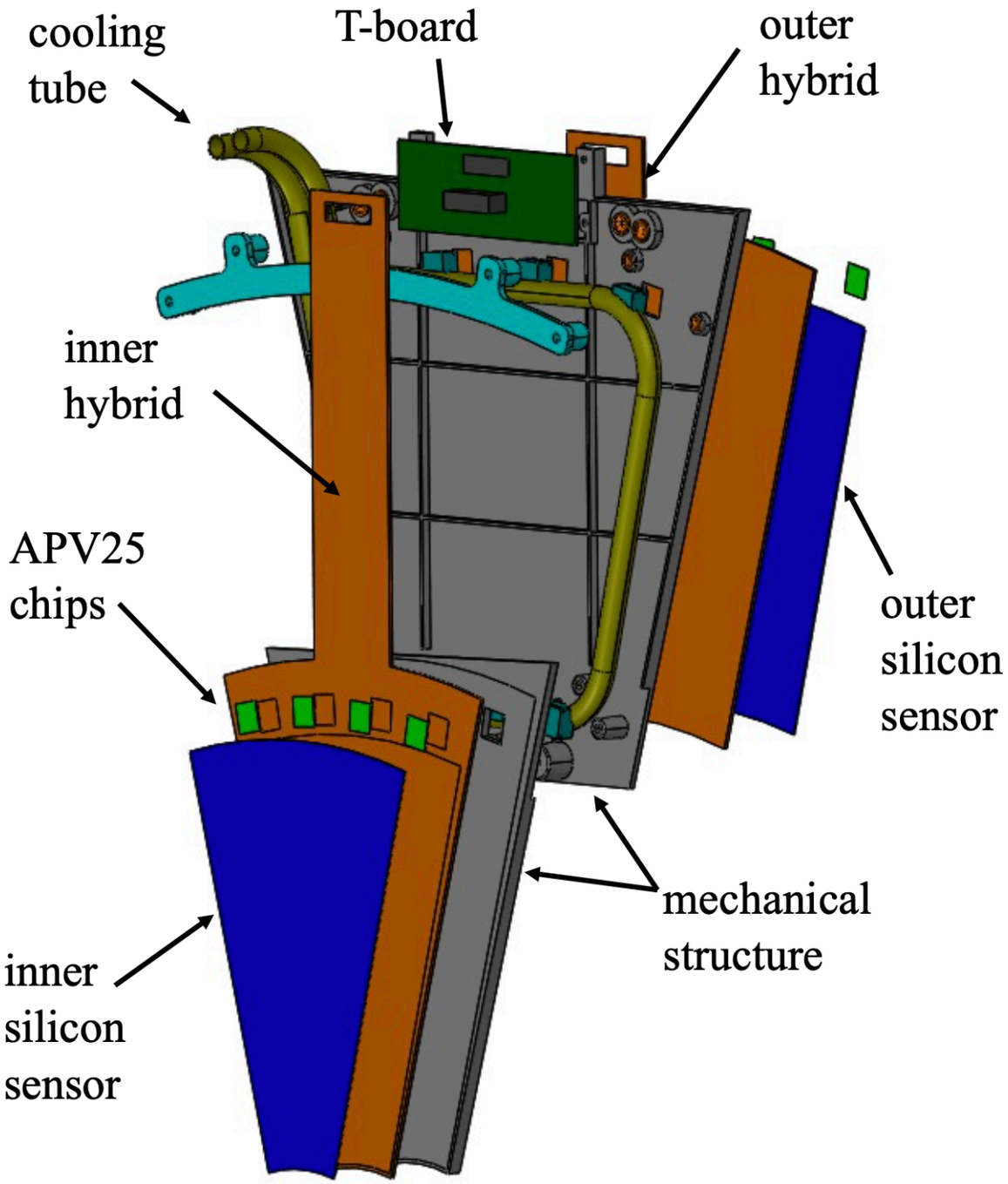
Module Assembly

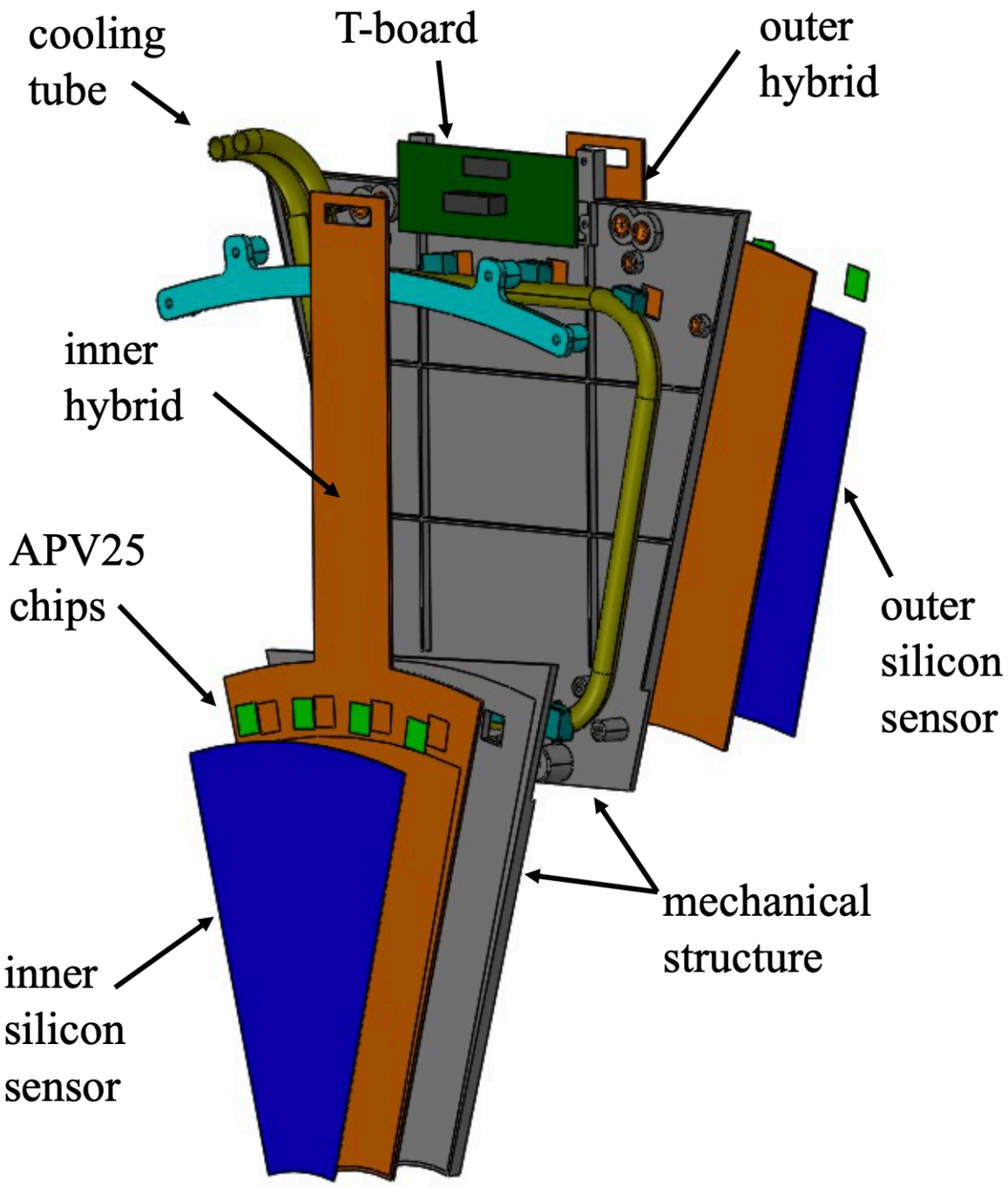


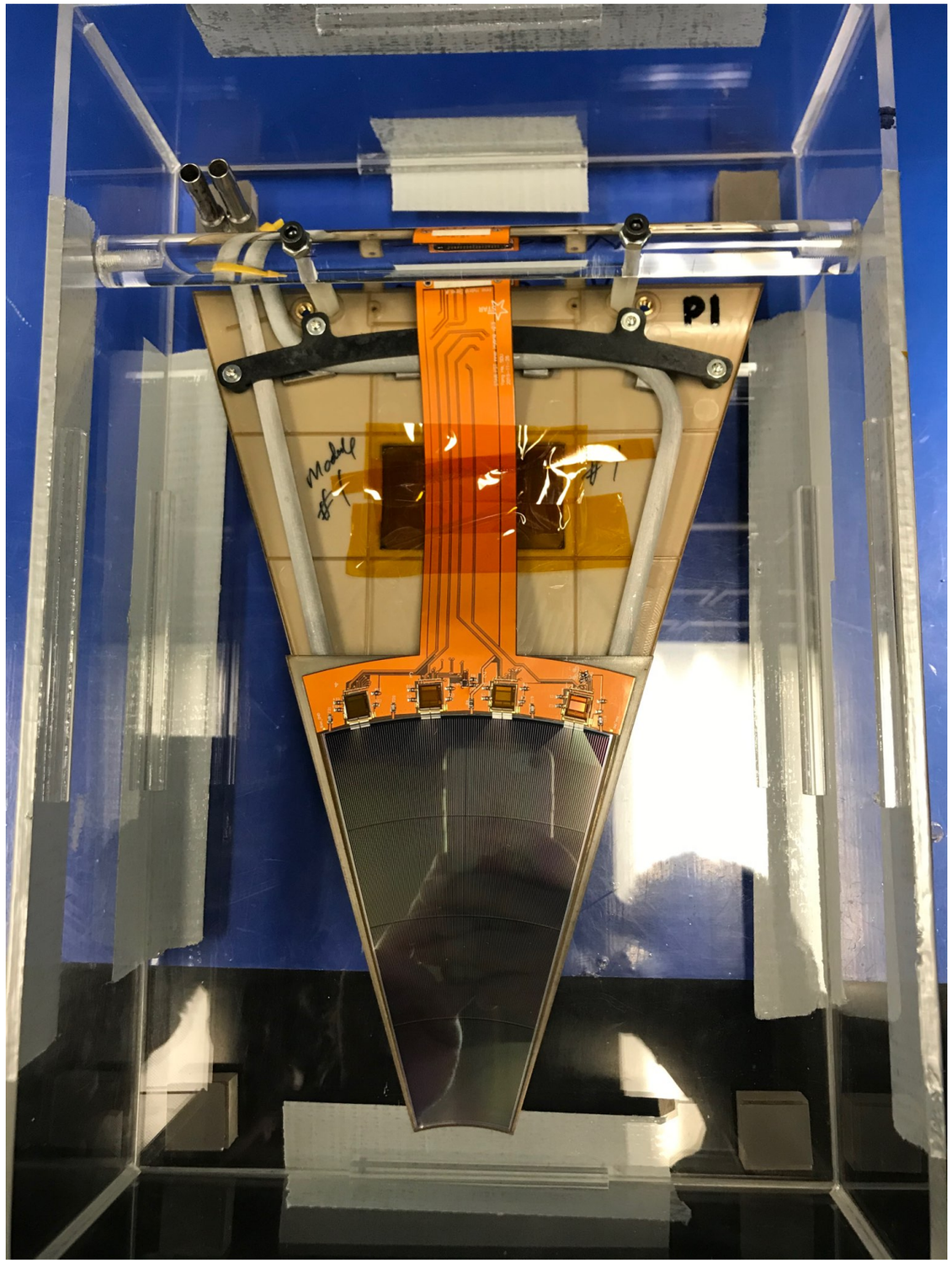
- **APV25: UIC**
  - ordered in 2015
- **Silicon sensor: UIC/BNL**
  - ordered in 2/2019
  - received 4s+6 in 8/2019
- **Hybrid: SDU/IU**
  - design signed off in 11/2019
  - received ~40 in 12/2019
- **Mechanical structure: NCKU**
  - See talk by Yi Yang

Module assembly

- Mount hybrids onto mechanical structure, and passive components onto hybrids (NCKU)
- Mount APV and sensor, QA test, evaluate performance (UIC/FNAL)

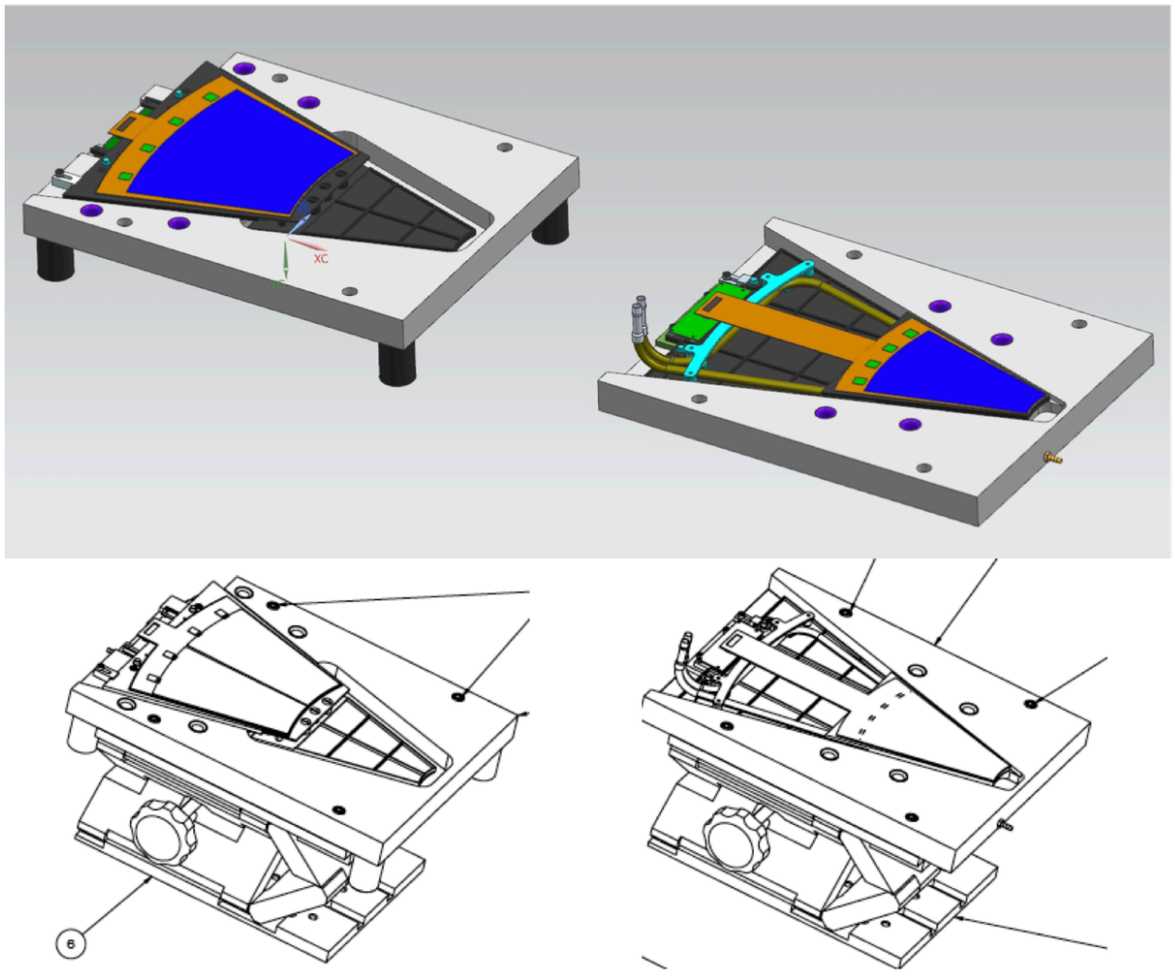
Module Assembly





Module Assembly

https://drupal.star.bnl.gov/STAR/blog/yezhenyu/forward-silicon-tracker-module-assembly



Assembly Fixture/Tooling

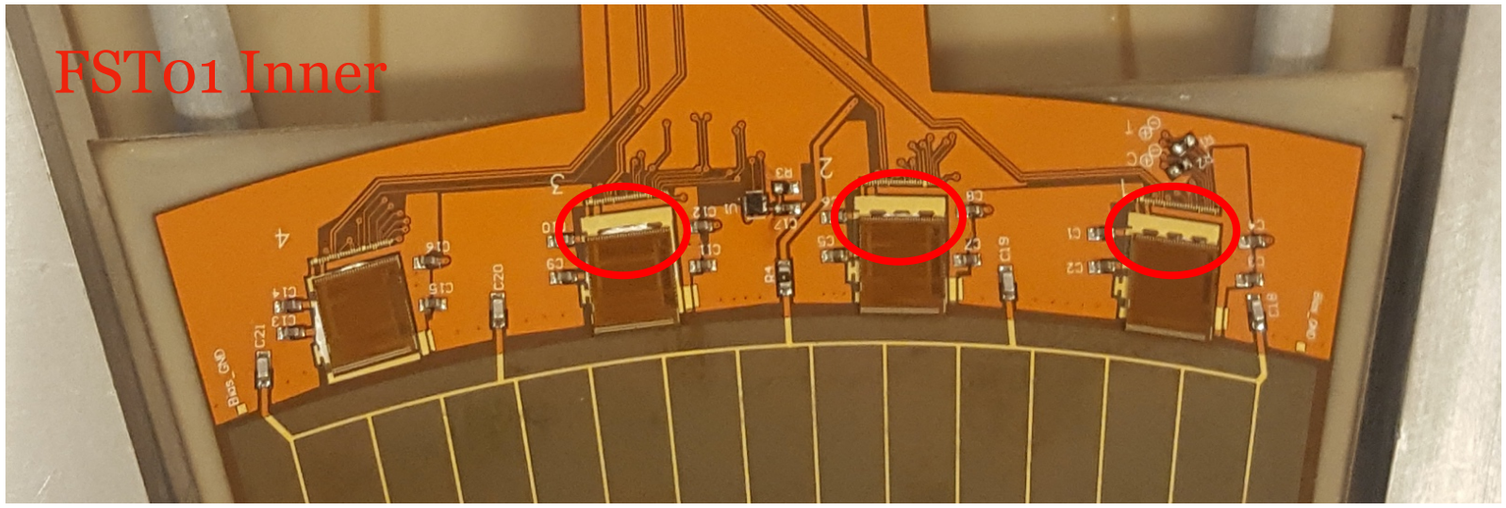
1. Design completed by FNAL on 12/18/2019
2. Parts fabricated at UIC around 1/20/2020
3. Parts assembled and surveyed (<30μm)

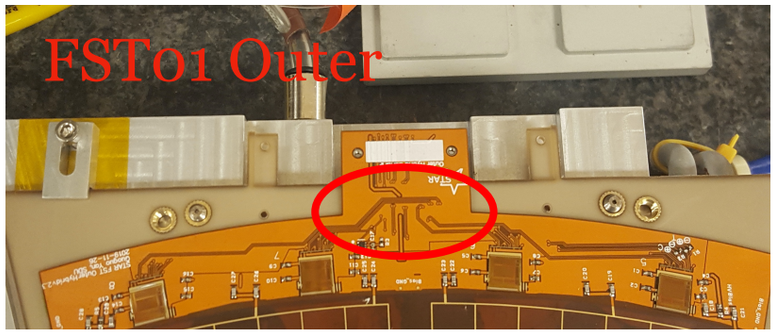
Assembly Procedure

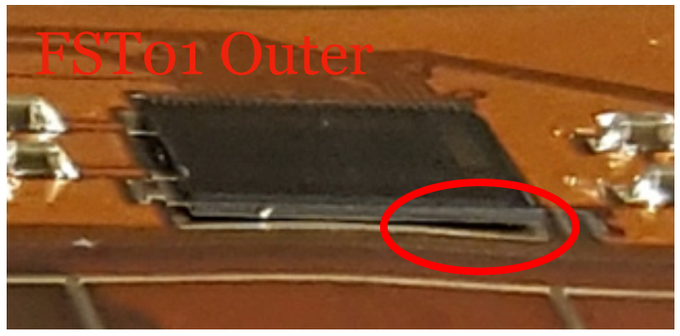
1. Mounting and wire-bonding APV
2. Readout test
3. Mounting and wire-bonding Sensors
4. Survey (not done for prototype)
5. Readout test
6. Encapsulation
7. Readout test

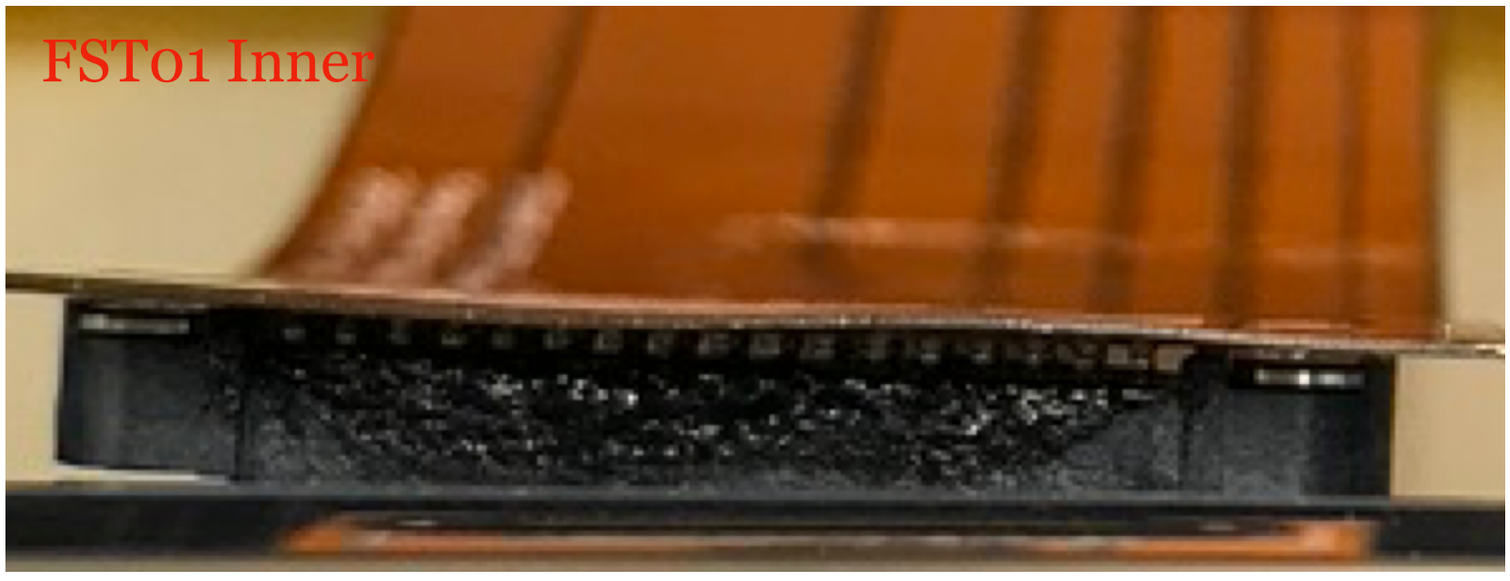
- **Prototype module**: 3 modules, each with 3 Silicon sensors and 8 APVs
  - Original plan: assembly 9/2019-2/2020; testing 3/2020-4/2020
  - In reality: assembly 9/2019-7/2020; testing: 3/2020-8/2020
- **Production:** 48 modules, each with 3 Silicon sensors and 8 APVs
  - Original plan: assembly 1/2021-4/2021; installation and testing on supporting structure: 5/2021-6/2021
  - Current plan*: assembly 3/2021-6/2021; installation and testing on supporting structure: 5/2021-7/2021
    *assuming all components ready by 2/28/2021. Also need to check with FNAL about the schedule

Module Assembly: FST01 & FST02









First batch of bare modules received from NCKU on 2/24/2020

Common issues:

- Air trapped between the hybrids and the mechanical structure
- Uneven surfaces of the module
- Hybrids not well aligned and not fully attached to the mechanical structure
- Flux not fully cleaned up on hybrids

FST01 (3/3/2020-3/18/2020):

- Mounted all APVs, 1 inner and 1 outer sensor
- Inner: no readout due to several open electrical connections between connector and hybrid*
- **Outer: working, extensive cosmic ray test**

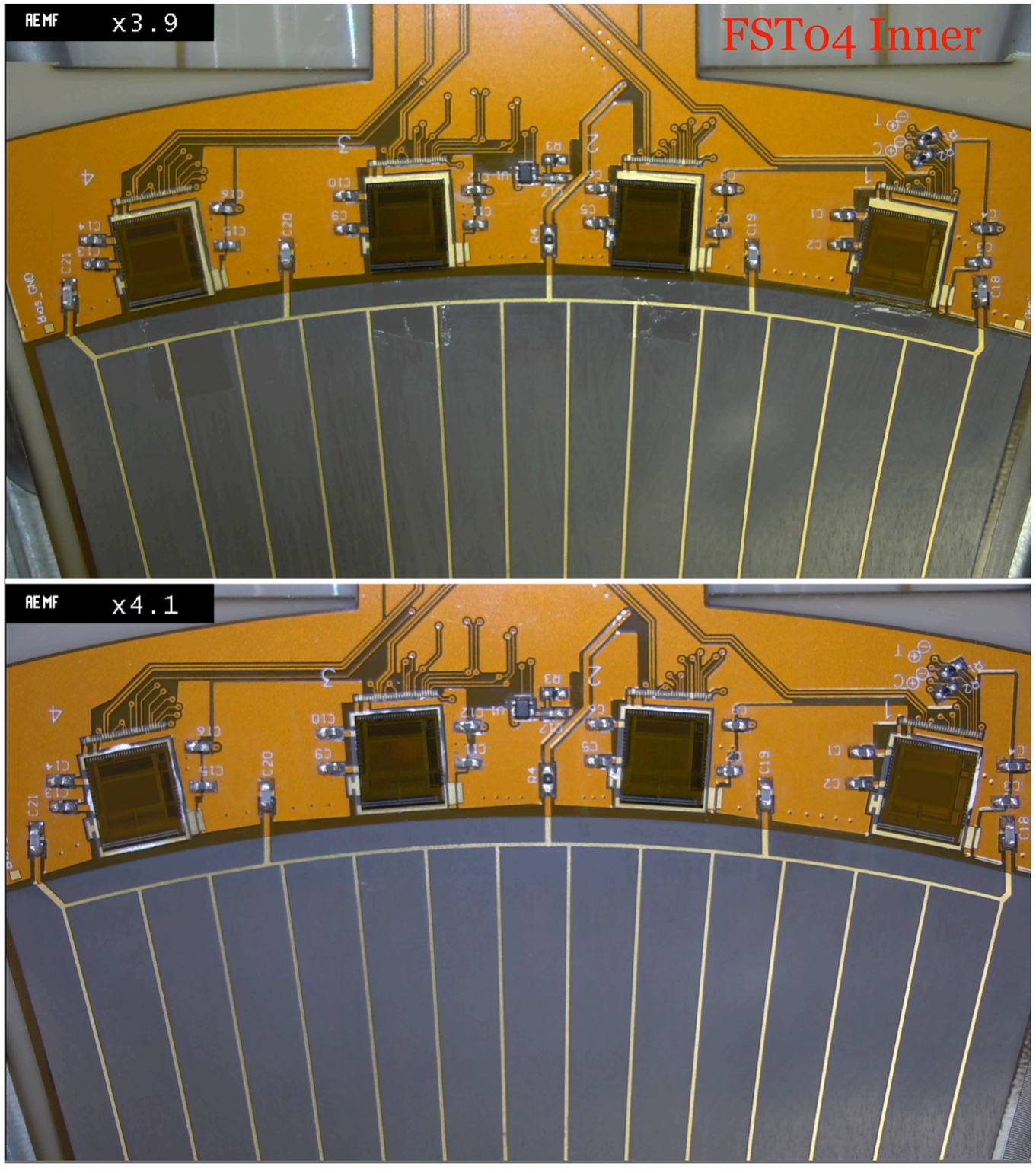
FST02 (3/5/2020-3/9/2020):

- Mounted APVs, replaced one chip
- Inner: several open electrical connections*
- Outer: shorted SCLK and VDD connections**

* Compromised connector soldering due to either soldering quality and/or (un)plugging connector

** Likely shorted by connector soldering

Module Assembly: FST03 & FST04



Second batch of bare modules from NCKU (FST03 received on 6/28, FST04 on 7/13) with much improvement w.r.t. the first batch – see Yi's talk.

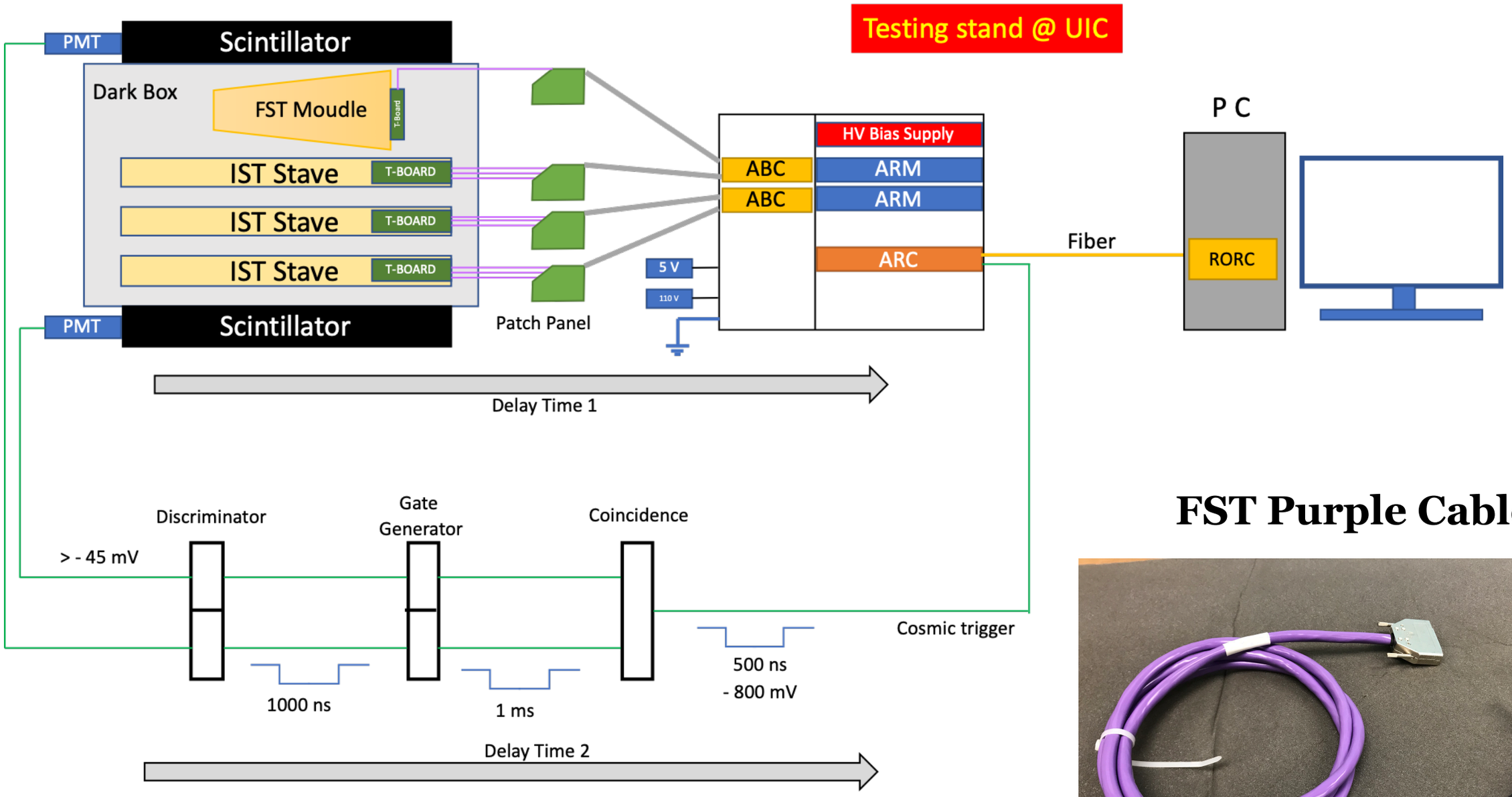
FST03 (6/29/2020-7/7/2020):

- **First fully assembled and working module.**
- In placing the chips, they were shifted to the sensor direction by 500 (200) microns for the inner and outer section. Had to manually move the chips.
- In wire-bonding the chips, adhesion under some pads was not so good and created some issues but got all in by adjusting the power. Deflection of the whole module.
- In wire-bonding the sensors, bias bonds went in but noticed some deflection of the sensors. See gaps between the corners of the sensor and hybrid.
- **Cosmic ray test started on 7/7/2020**

FST04 (7/16/2020-):

- All the APVs are mounted and wire-bonded.
- In placing the inner chips, they were shifted to the sensor direction by 350-700 microns towards the sensor direction, and 300 microns to the left.
- In placing the outer chips, they were shifted by about 100 micron to the right.
- **Expect to finish assembly and QA test this week.**

Cosmic Test Stand @ UIC

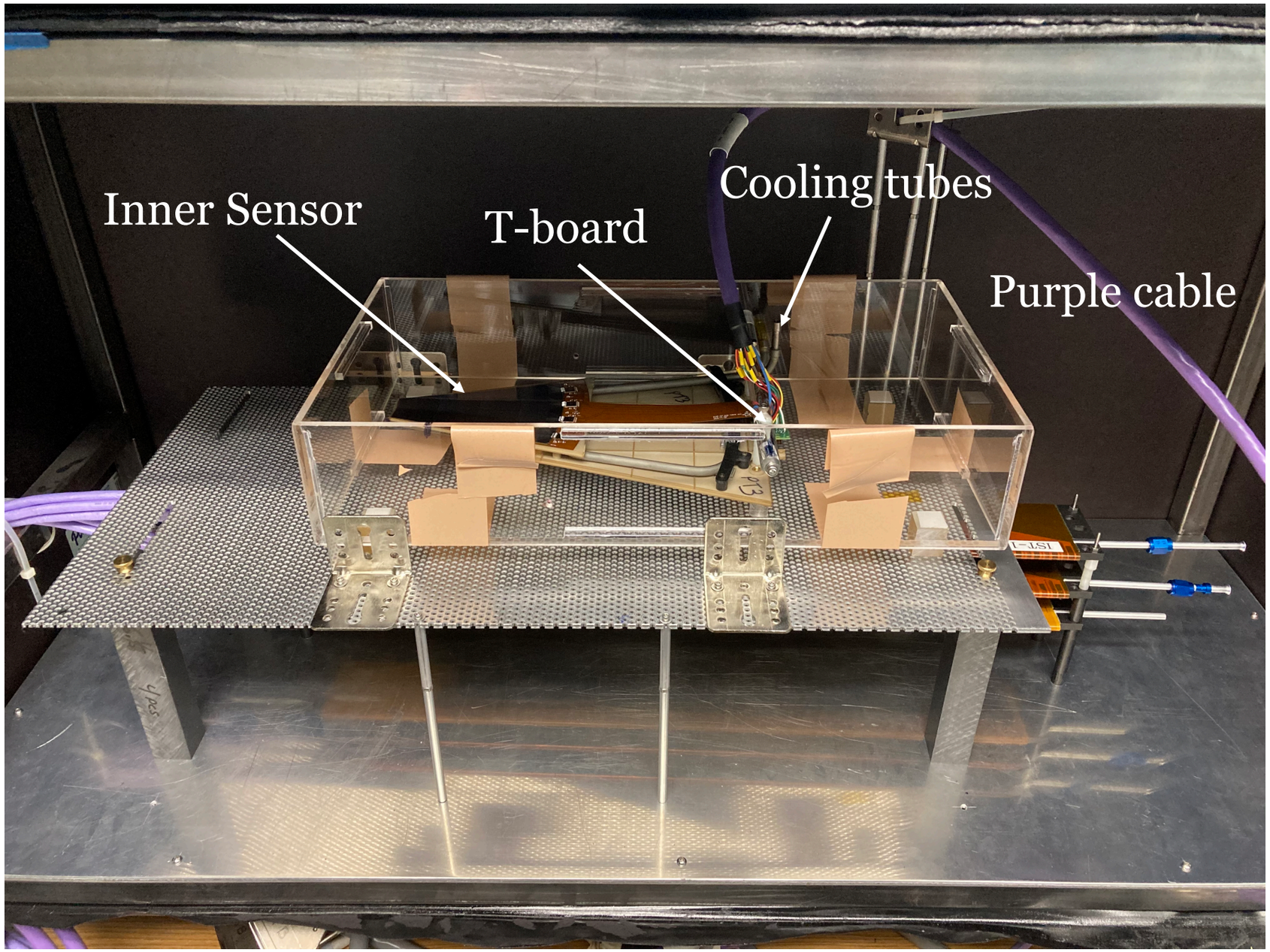


*** Readout with 2 out of 4 cables had a chip missing. To be followed up with Mike.**

FST Purple Cable*

From Mike Capotosto

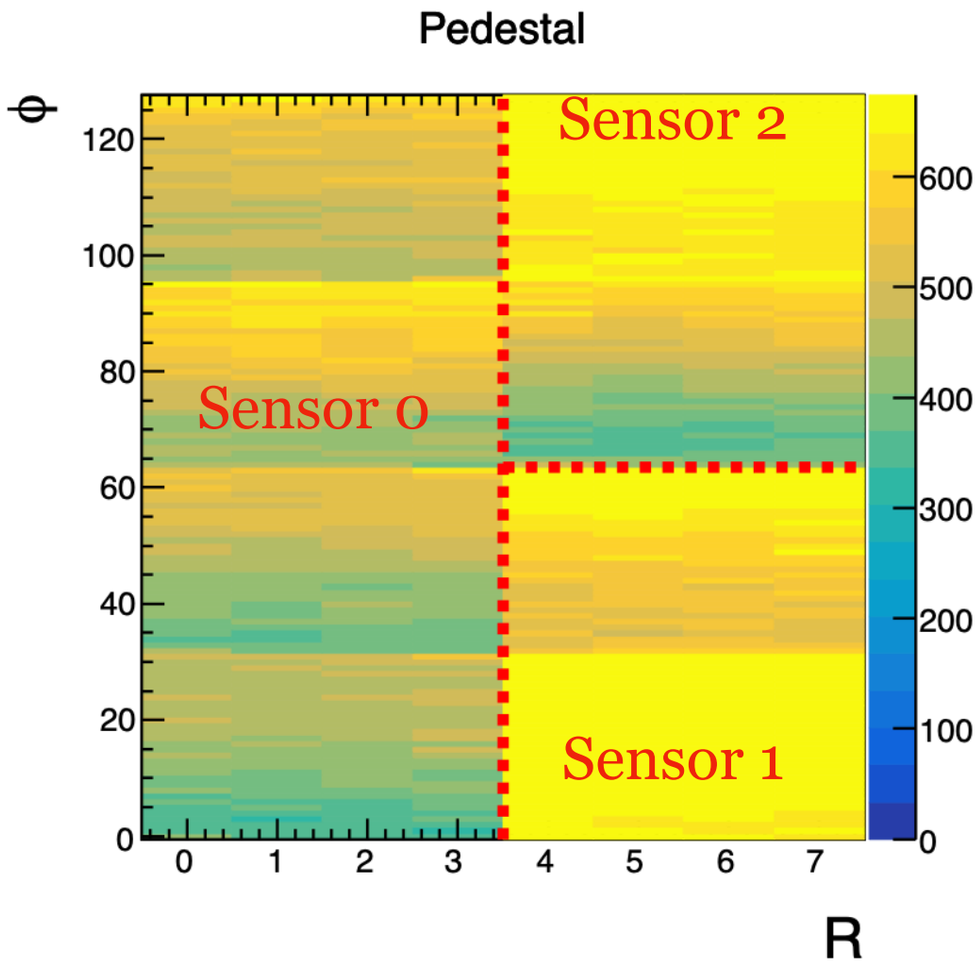
Cosmic Test Stand Setup at UIC

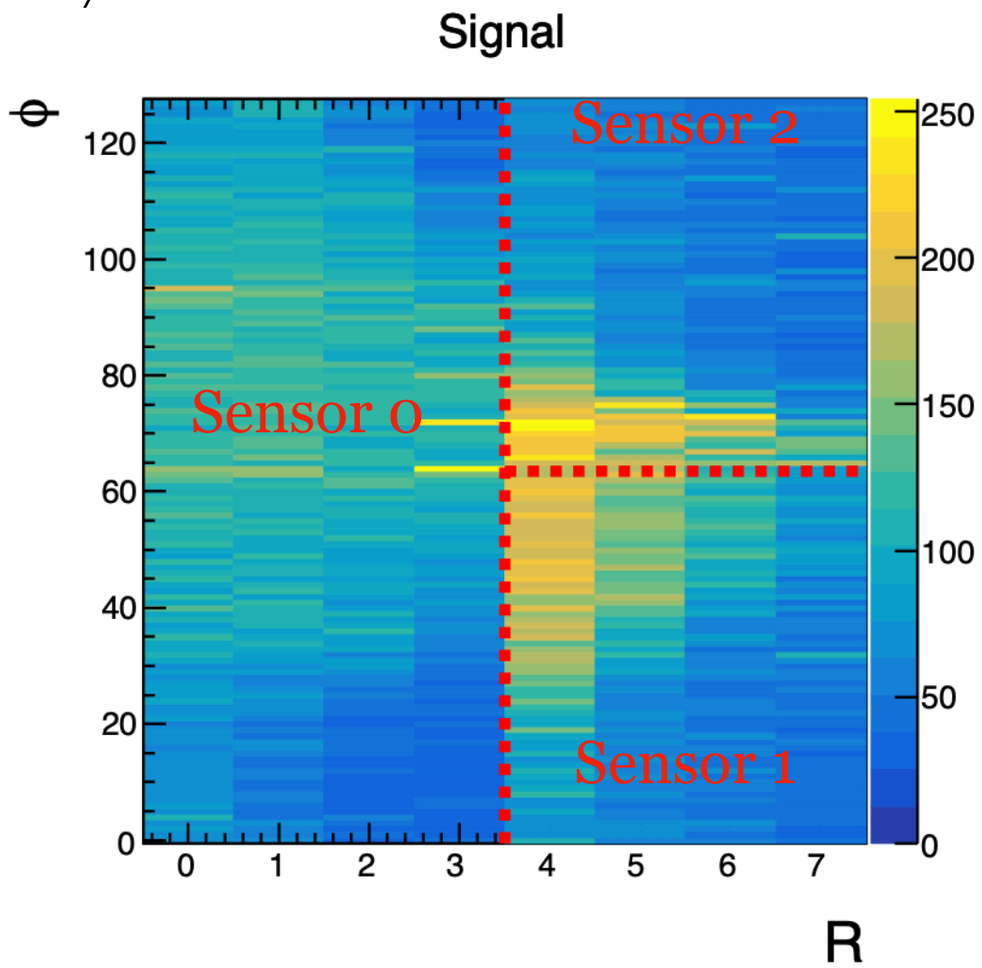


- Inner sector facing up and overlapped with active IST staves.

Hit Map for FST03

Module03 HV70V

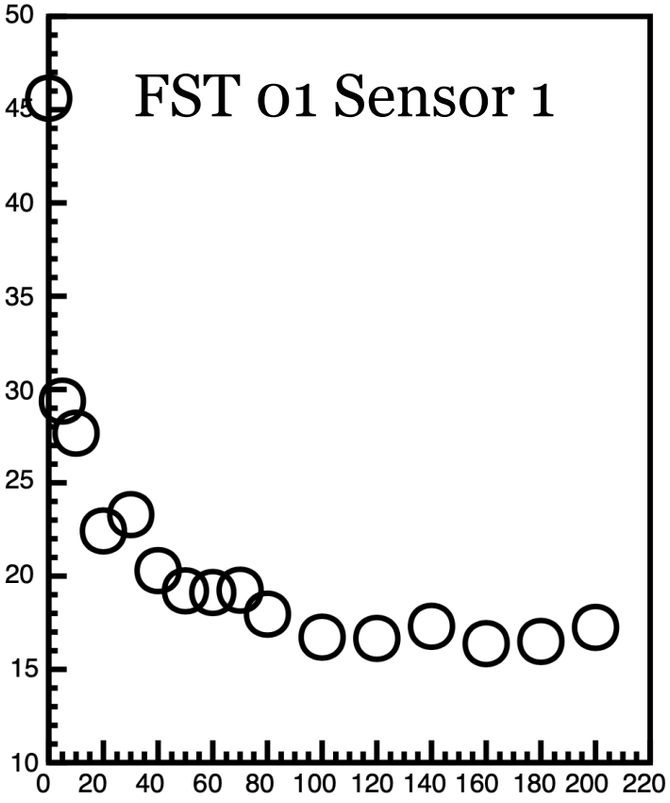




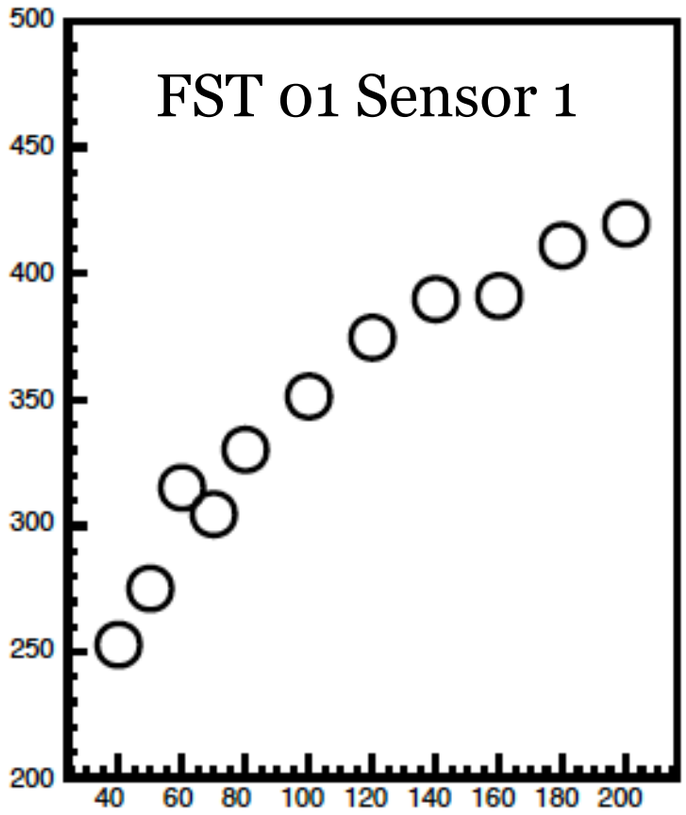
- Can read out all channels of FST03

Signal and Noise

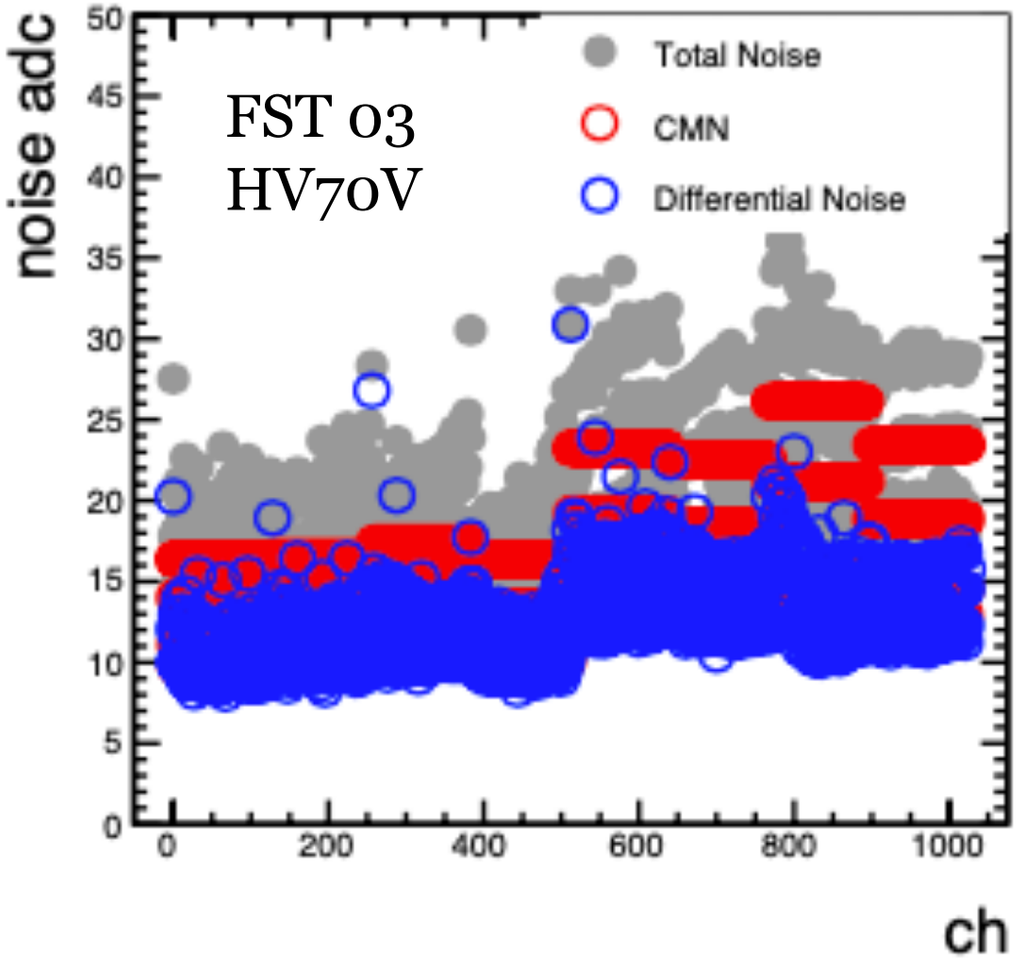
Noise



Signal



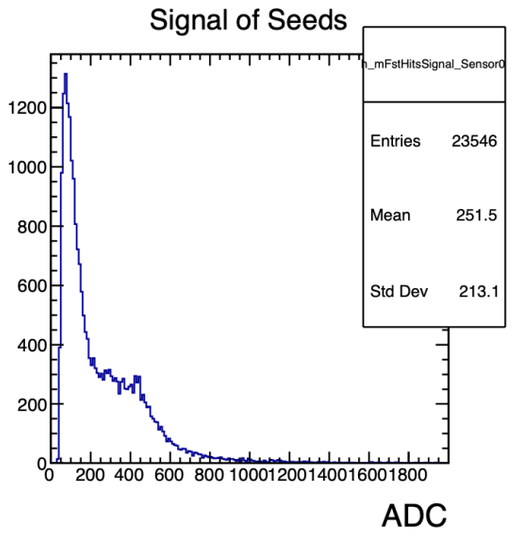
Noise

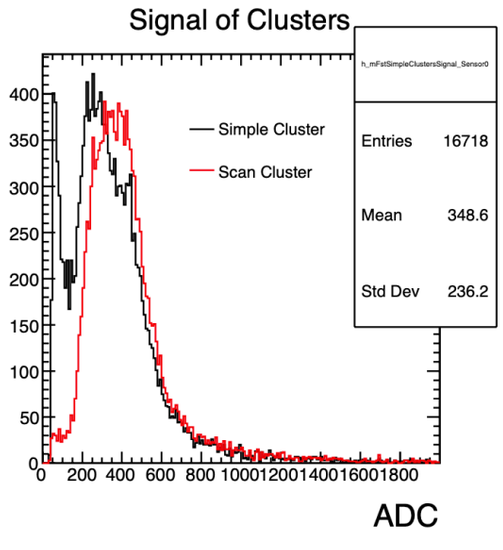


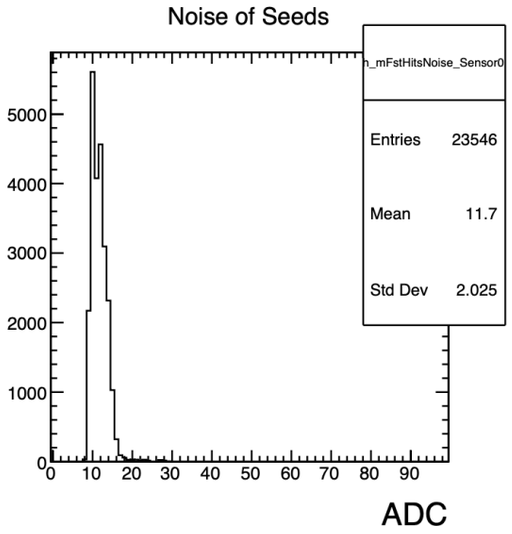
1. Noise decreases with increasing HV.
2. Signal increases with increasing HV.
3. Large Common Mode Noise(CMN).
4. Significant reduction in noise level after CMN correction (58-85%).

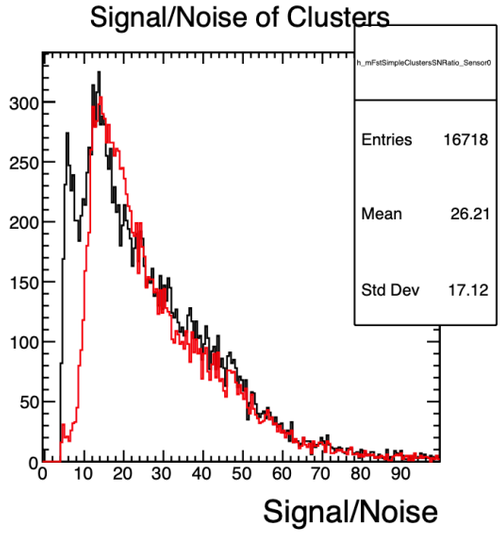
Signal and S/N for FST03

FST03 HV70V Sensor0

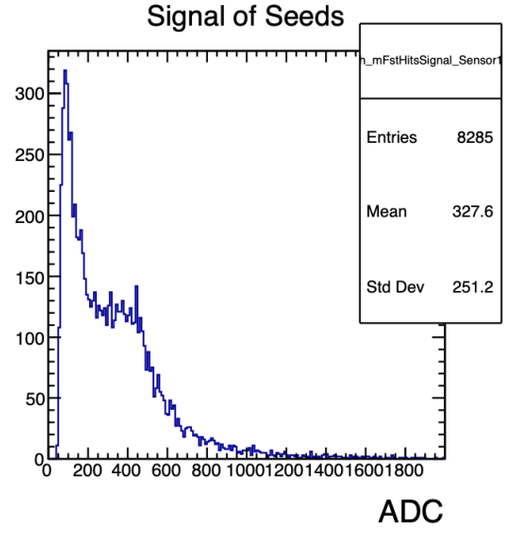


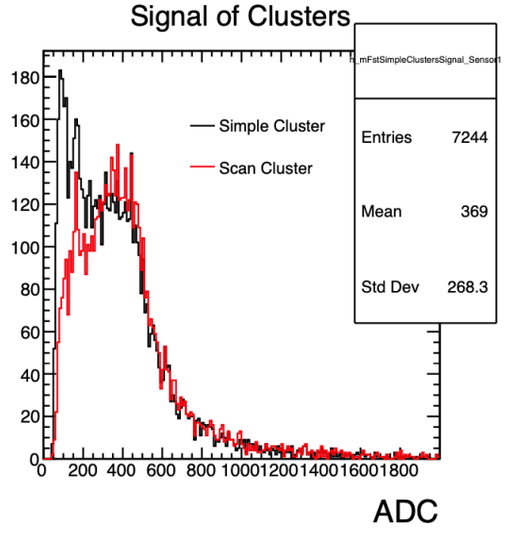


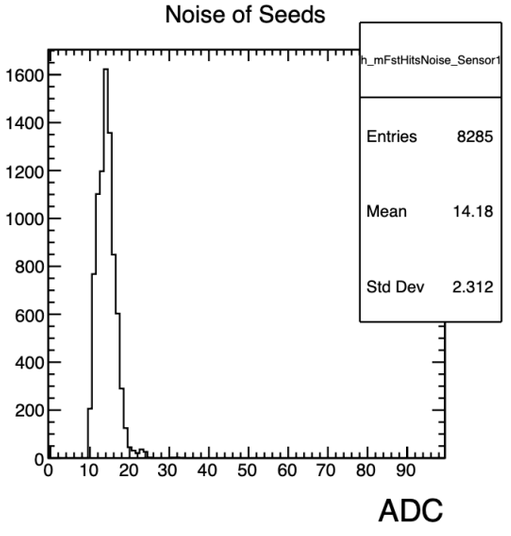


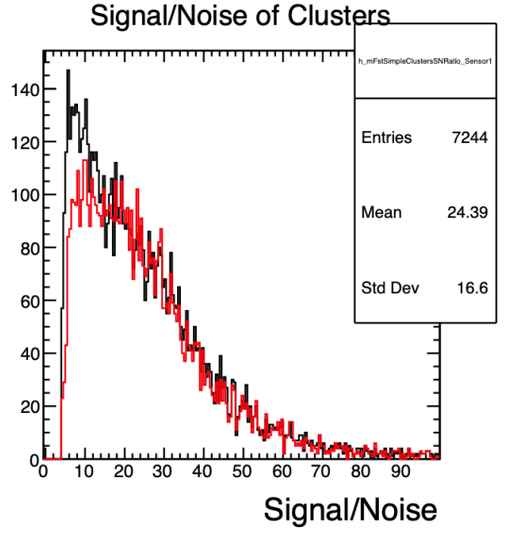


FST03 HV70V Sensor1



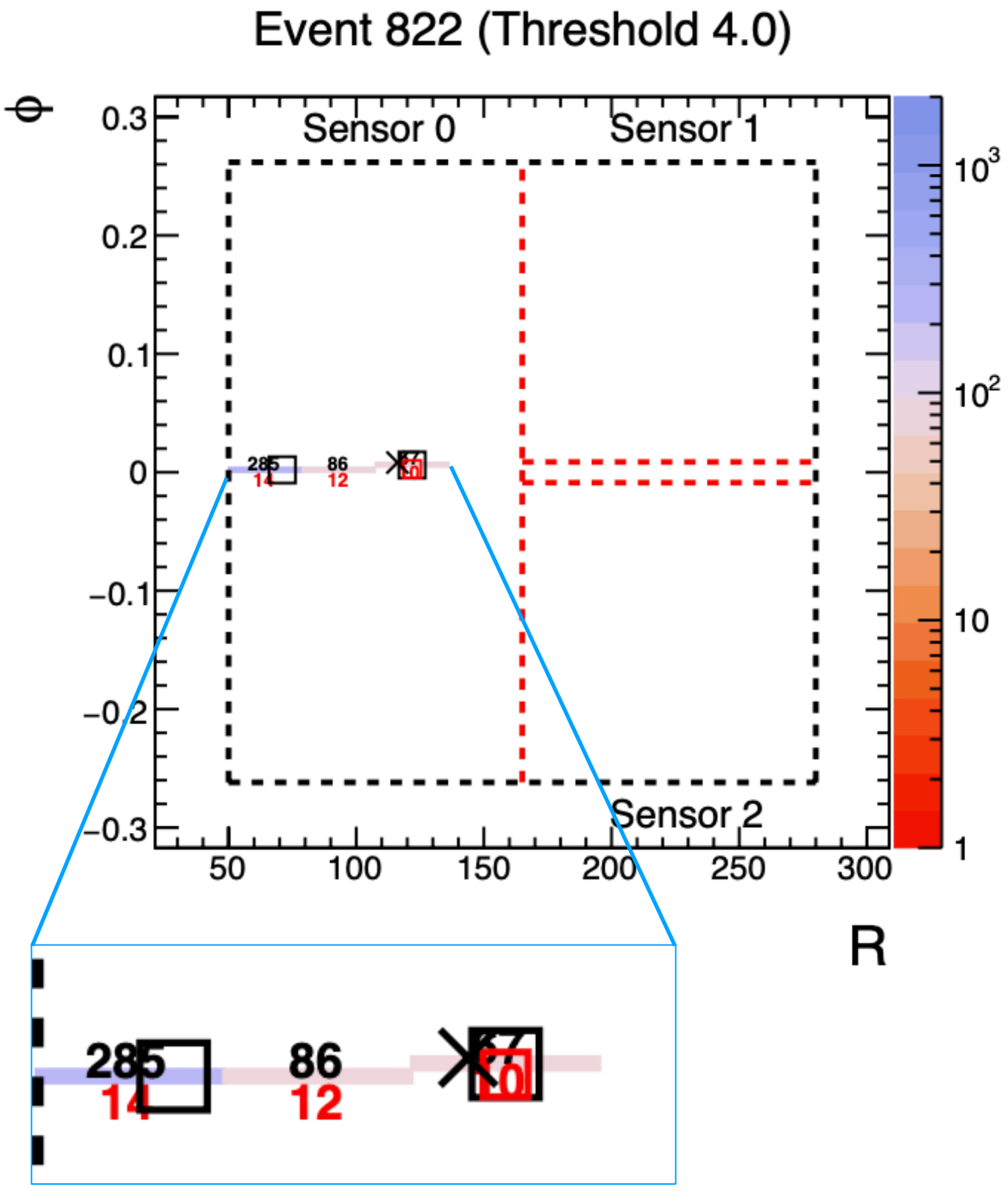






- Seed hit (for both simple and scan cluster algorithms): >4*noise and 2 time bin.
- Recovery hit (for scan cluster only): >2.5*noise and 2 time bin OR >3.5*noise and 1 time bin.
- Threshold and time bin requirements are tuned for FST01. Will double check with FST03.

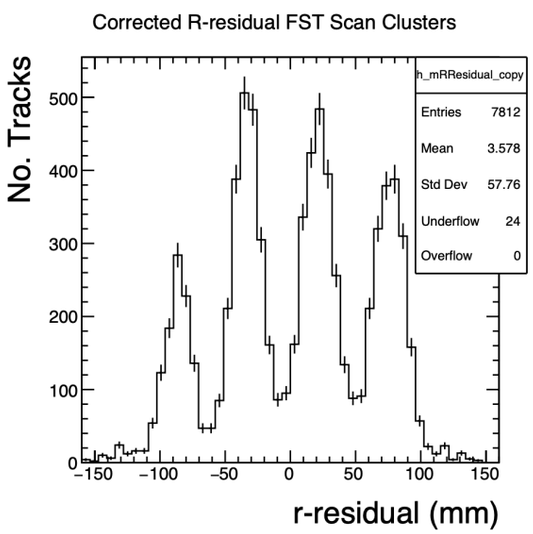
Cosmic Event Display

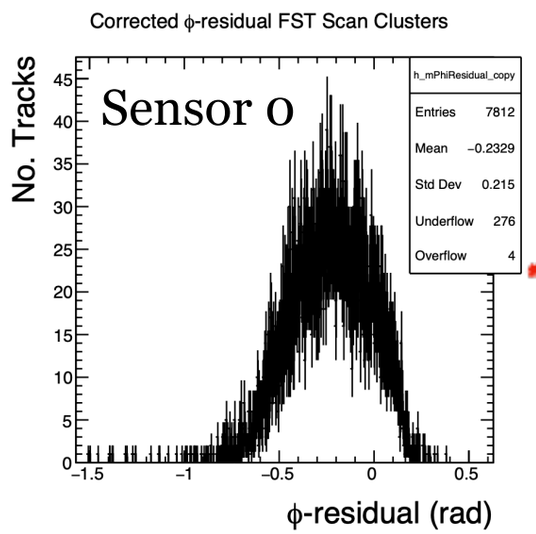


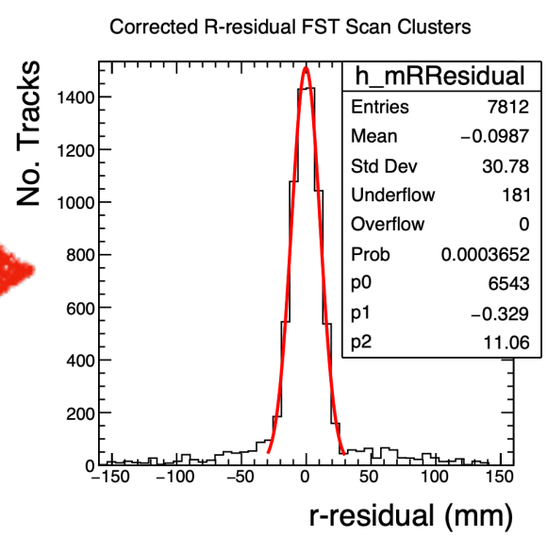
- Projected hit position (black cross)
- Simple cluster (black square)
  - Group the neighboring seed hits together
- Scan cluster (red square)
  - Group all the seed and recovery hits in one phi segmentation into one pre-cluster.
  - Combined neighboring pre-clusters into one cluster.
  - R-position given by the hit with the largest radius
  - Phi-position given by the ADC-weighted center

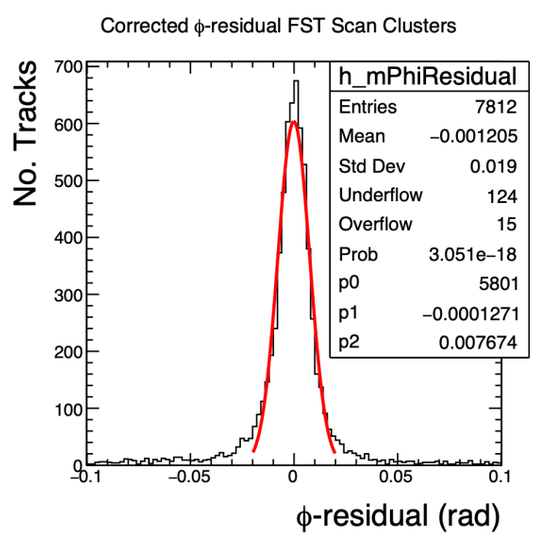
Alignment

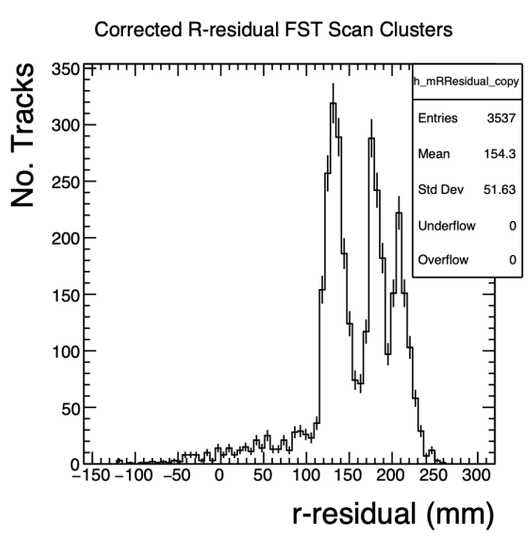
FST03 at HV70V

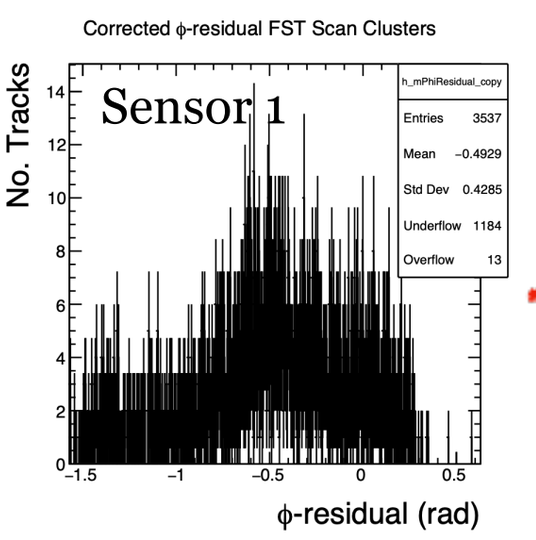


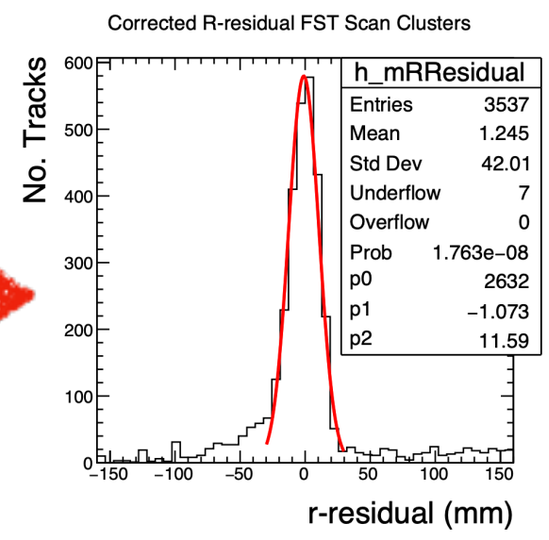


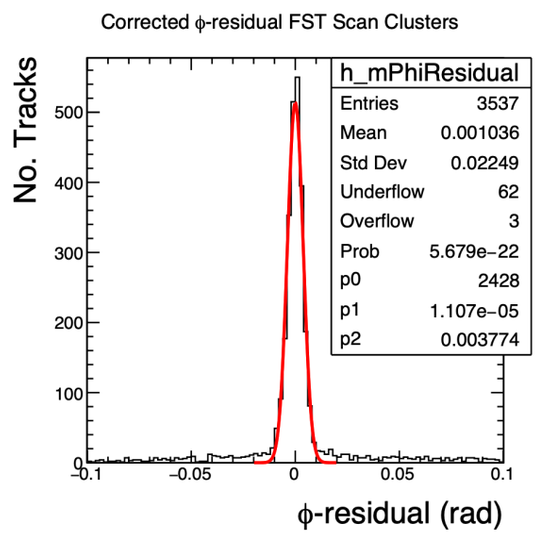


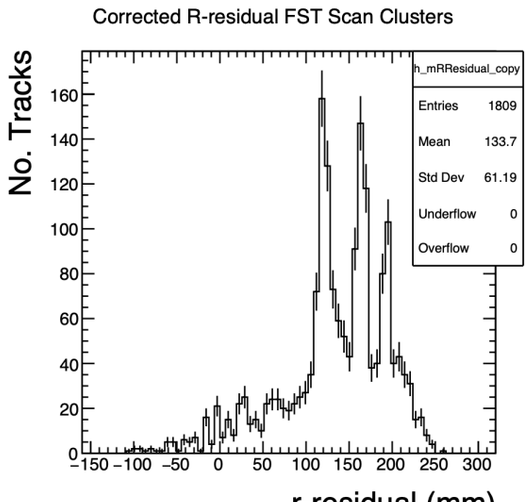


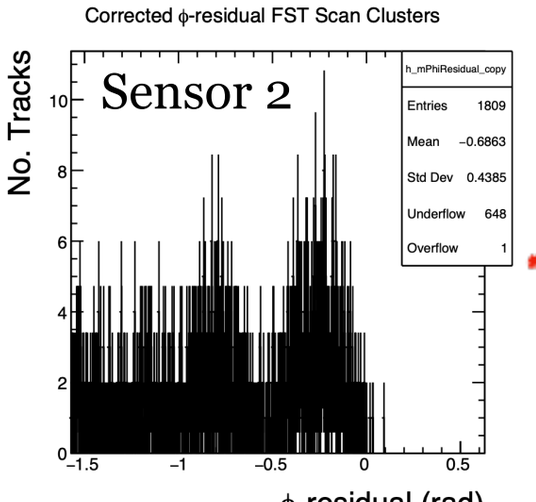


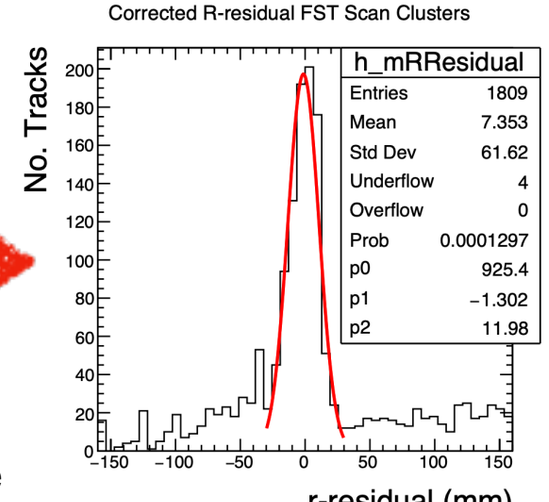


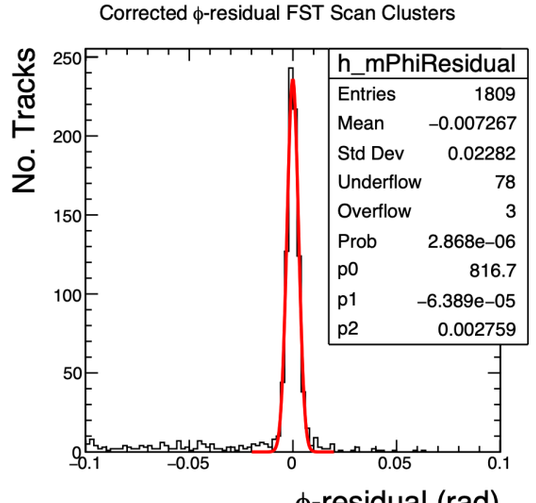






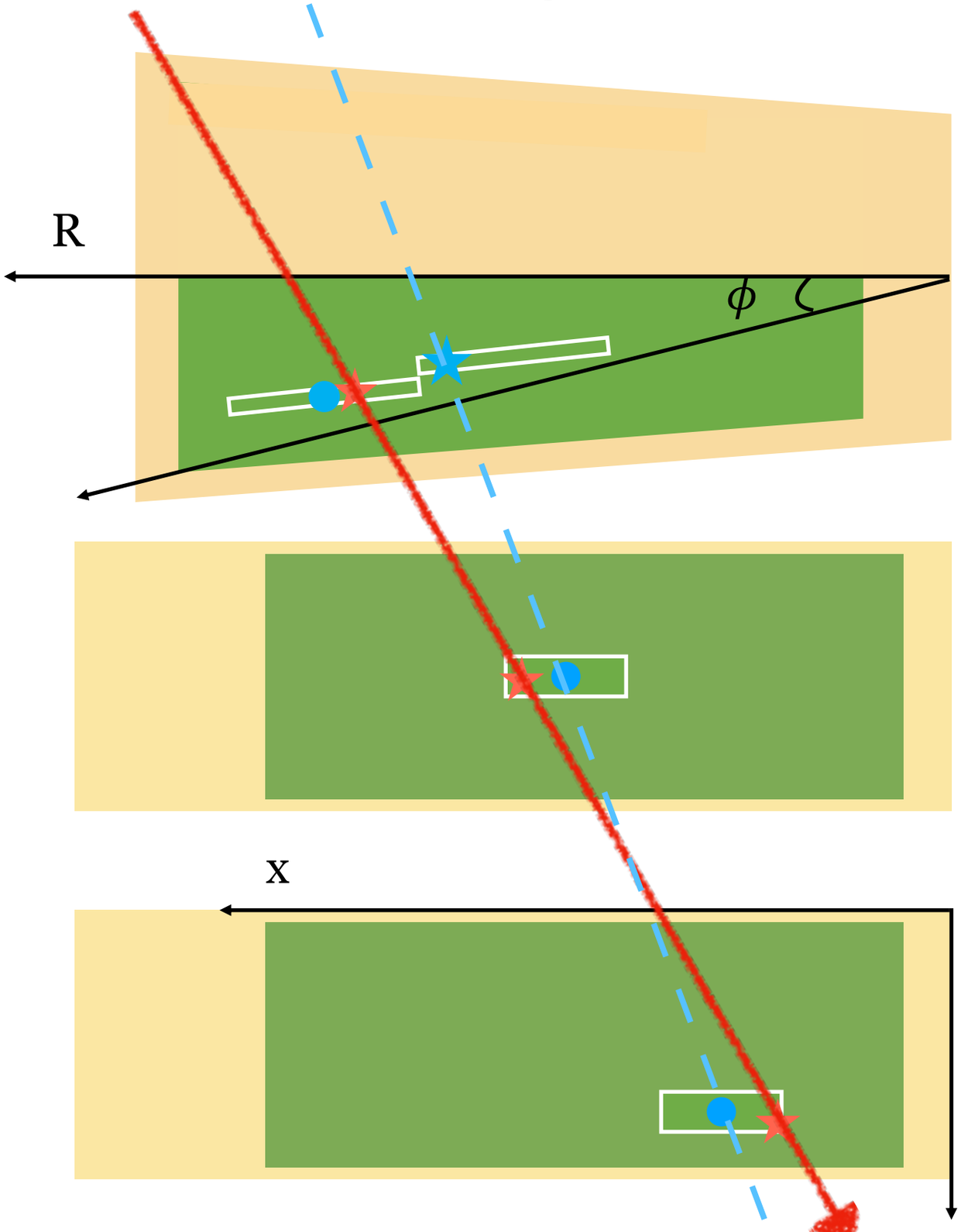






AR Upgrade

Toy MC Simulation

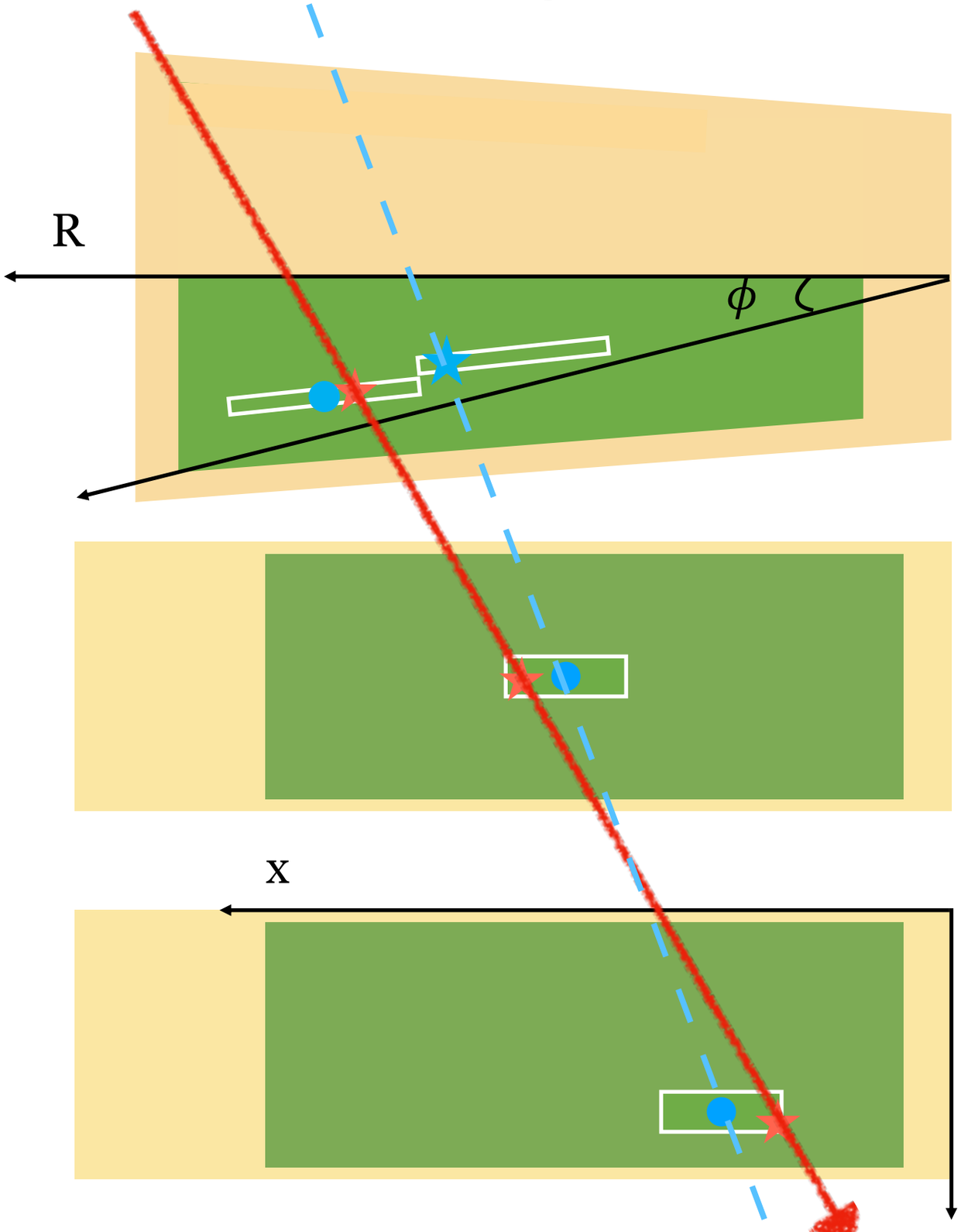


Toy MC: purely based on geometries

- IST: pitchX 6.275 mm. pitchY 0.596 mm
- FST: pitchR 28.75 mm, pitchPhi 4.1 mrad

- Red line: real track
- Red stars: real hit positions
- Blue circle: readout hit positions

Toy MC Simulation



Toy MC: purely based on geometries

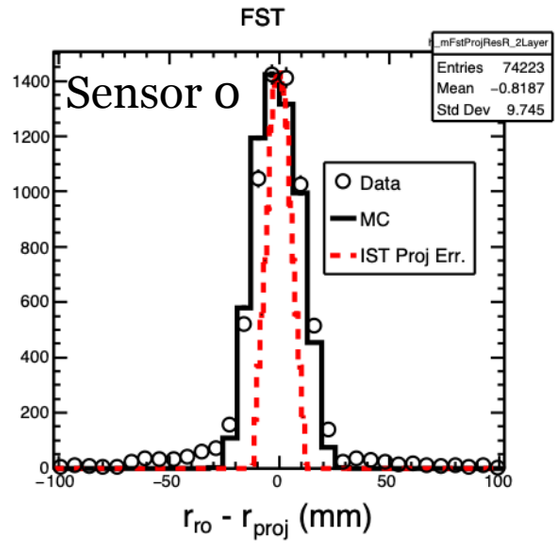
- IST: pitchX 6.275 mm. pitchY 0.596 mm
- FST: pitchR 28.75 mm, pitchPhi 4.1 mrad

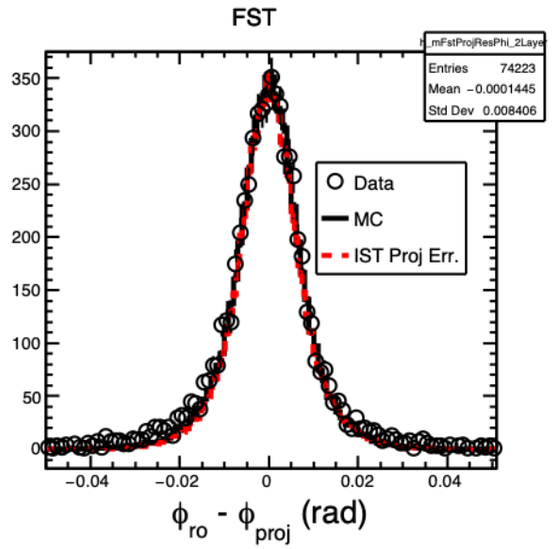
- Red line: real track
- Red stars: real hit positions
- Blue circle: readout hit positions

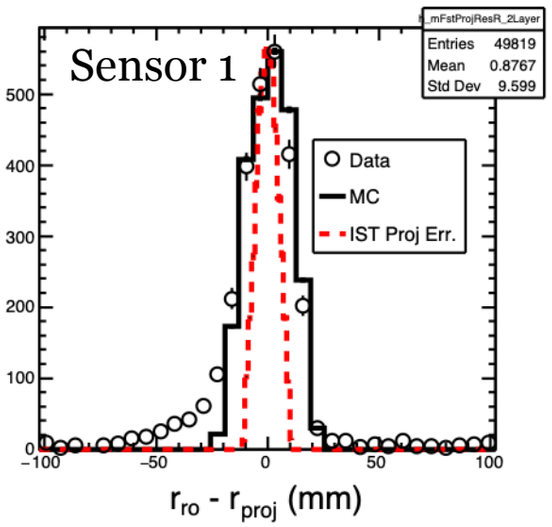
- Blue line: reconstructed track
- Blue star: projected FST hit position

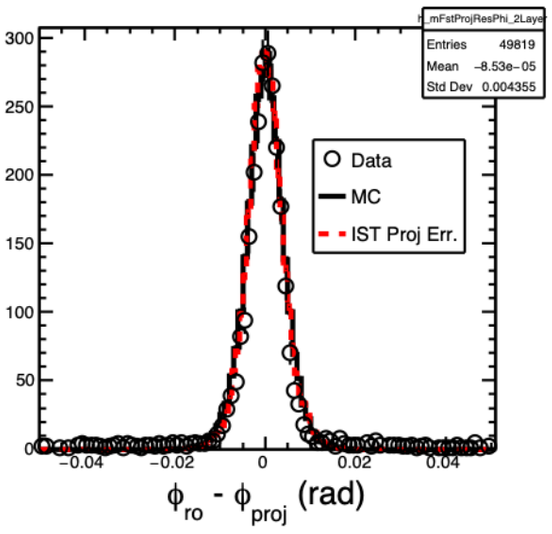
Toy MC and Data Comparison

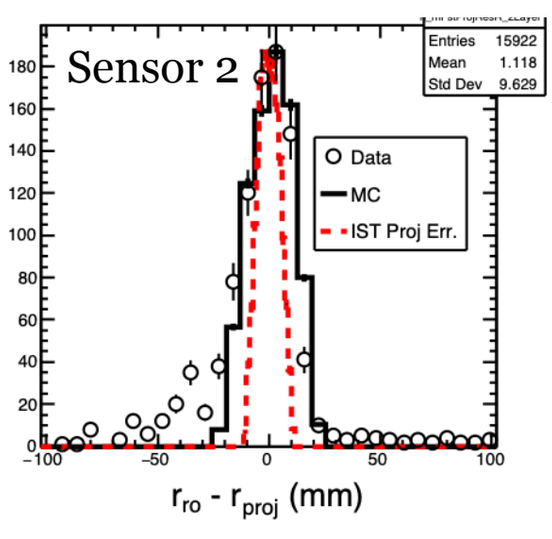
FST03 at HV70V

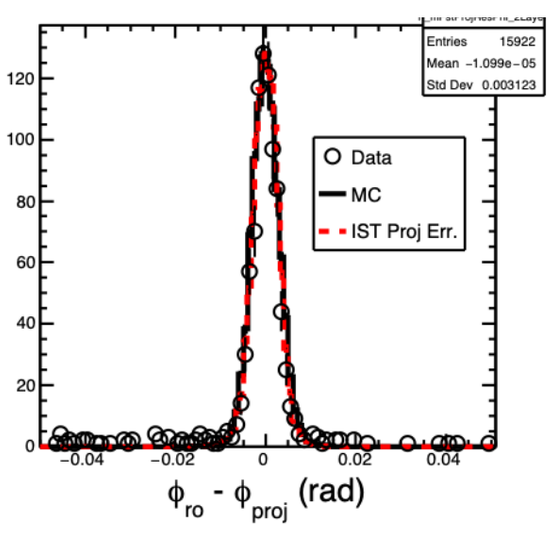








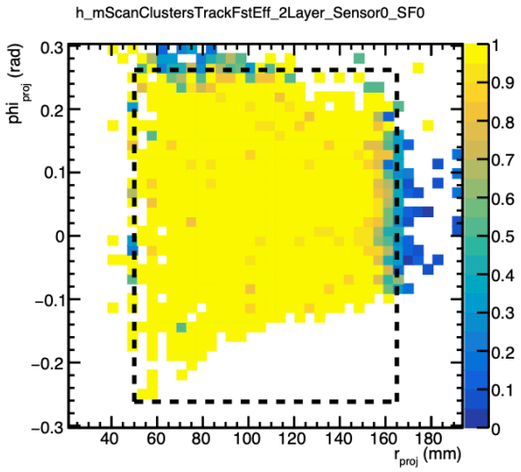


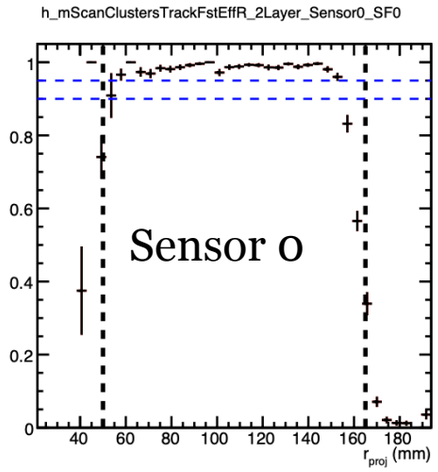


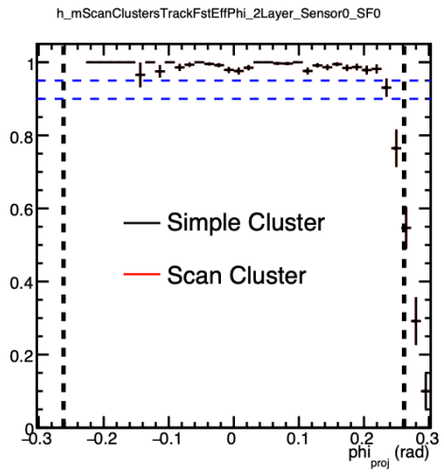
- Residual in phi is dominated by IST projection error. Data are well described by Toy MC.
- Tails in R-residual due to cross talk among R-strips and noise. Peaks well described by Toy MC.
- Plan to implement the measured efficiency and residual in a slow simulator to study the forward tracking performance in STAR simulation (see Shenghui's talk).

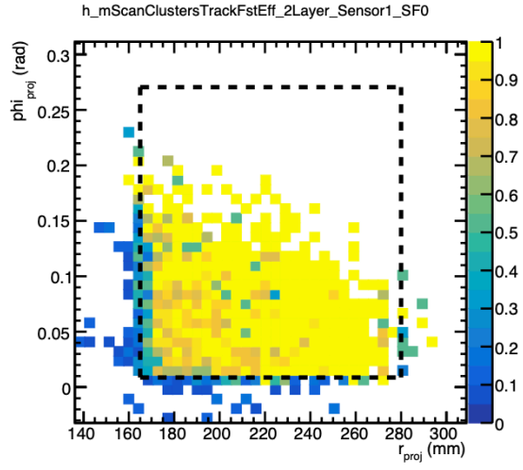
Detection Efficiency of FST03

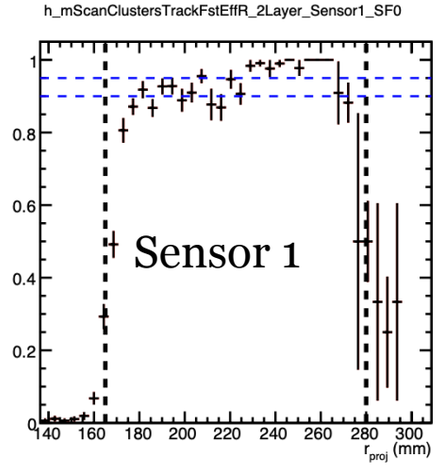
FST03 at HV70V

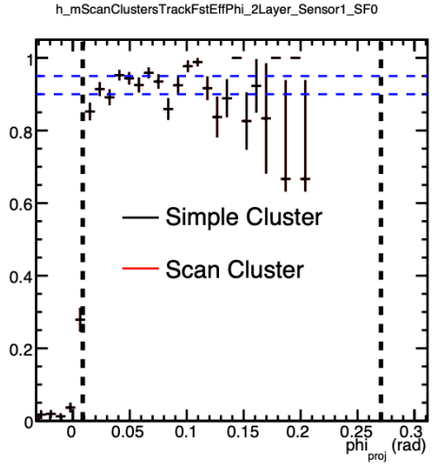


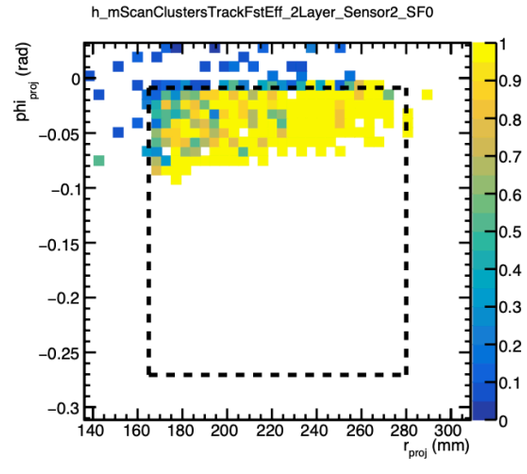


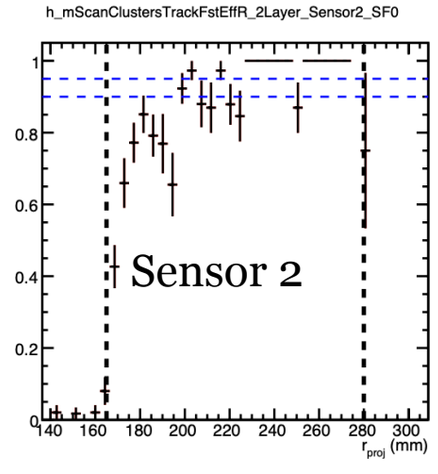


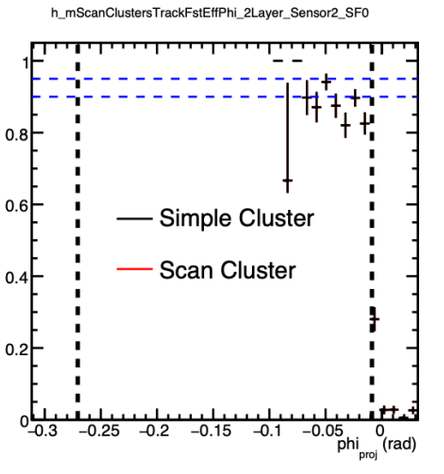








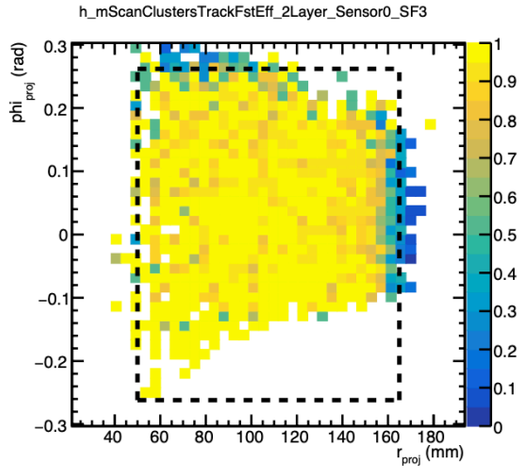


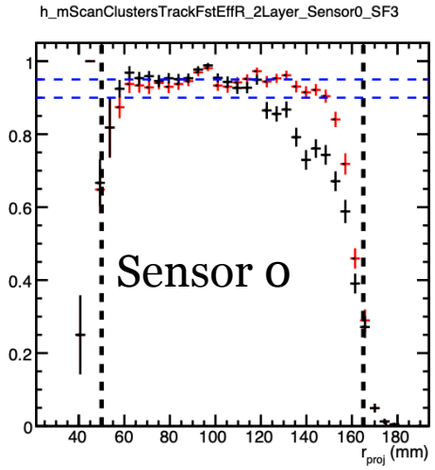


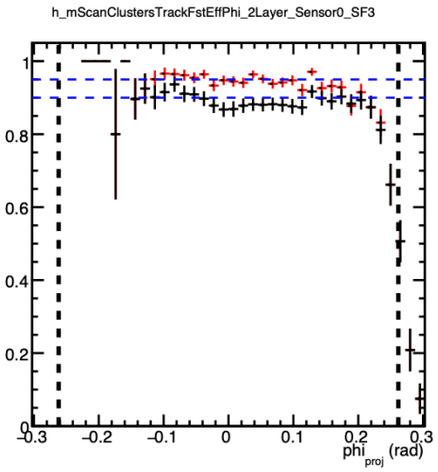
- Detection efficiency: ratio of number of readout signal to the incident cosmic ray.
- Detection efficiency larger than 95% in most area of Sensor 0.
- Detection efficiency between 90-95% in most area of Sensor 1&2.
- The drop at the edge could be due to IST projection error.

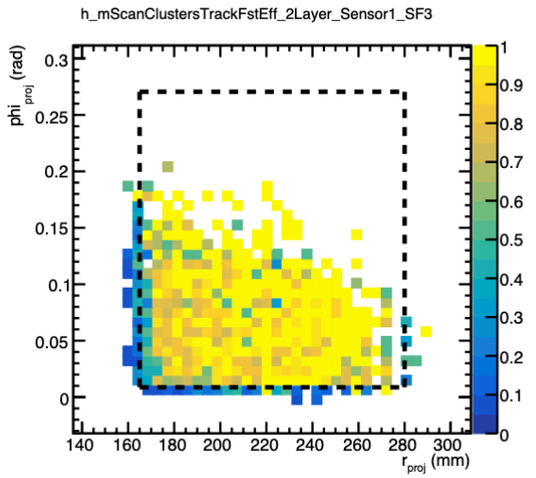
Matching Efficiency of FST03

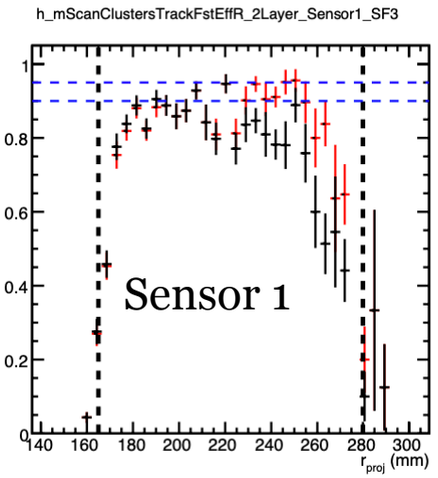
FST03 at HV70V

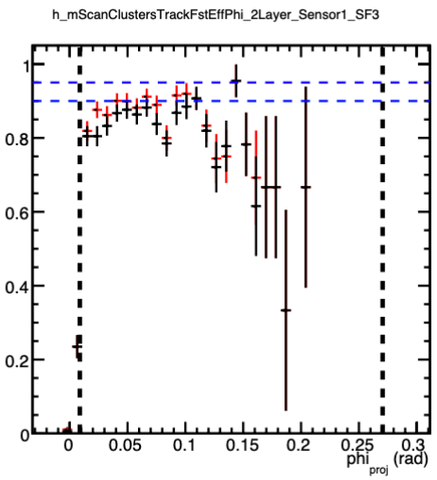


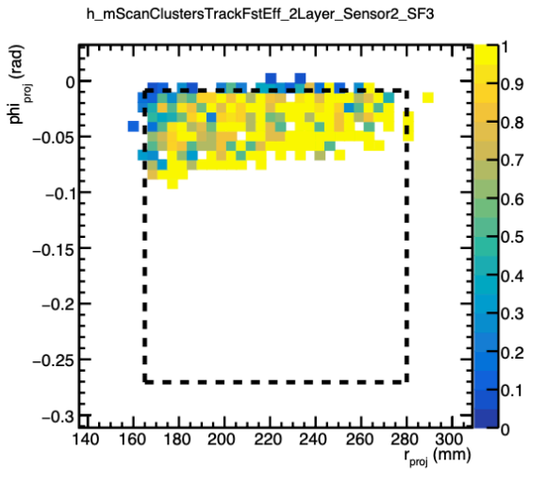


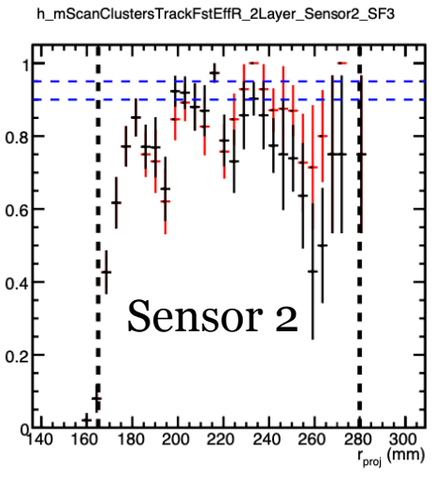


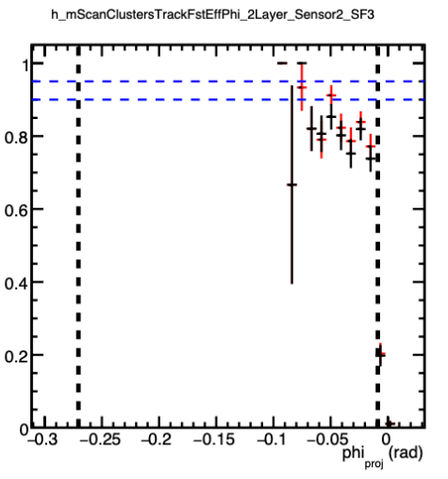








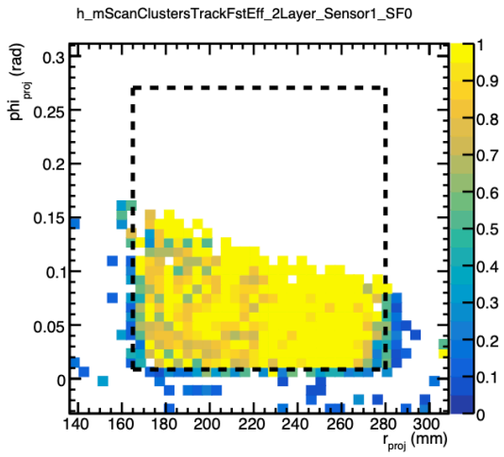


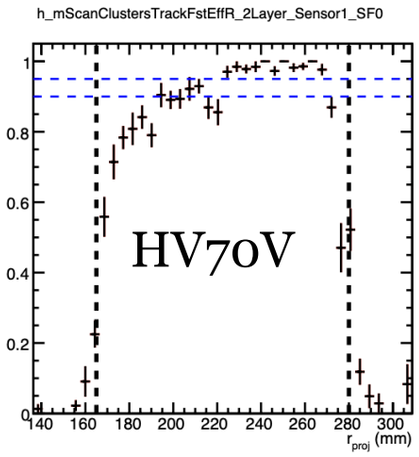


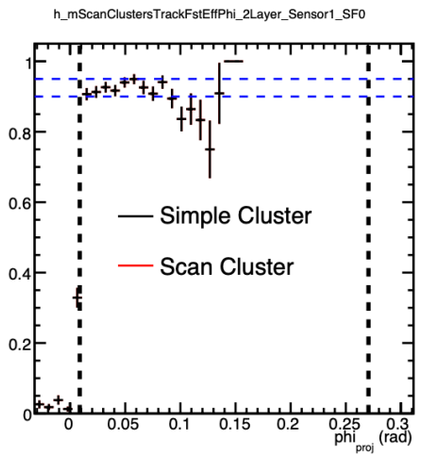
- Matching efficiency: ratio of number of readout signal with matching cut to the incident cosmic ray.
- Matching efficiency of scan cluster between 85-90% in most area.
- The drop at the edge could be due to IST projection error.

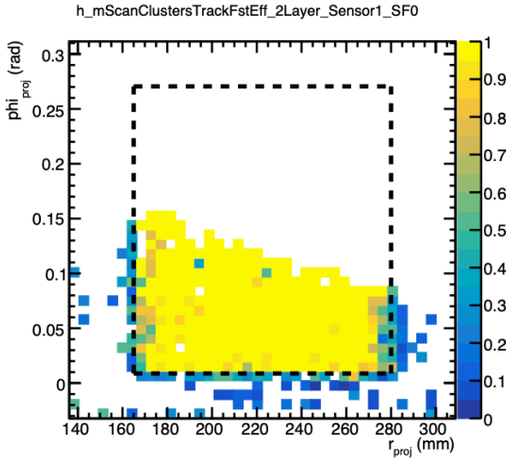
Detection Efficiency of FST01

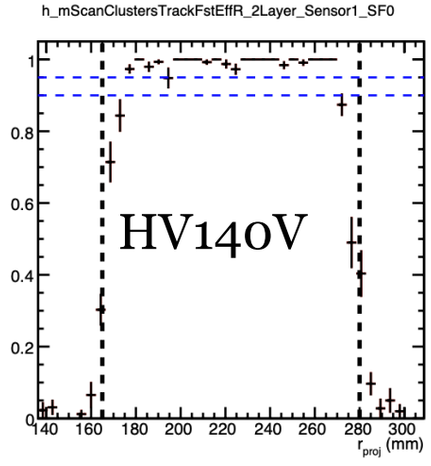
FST 01 Sensor 1

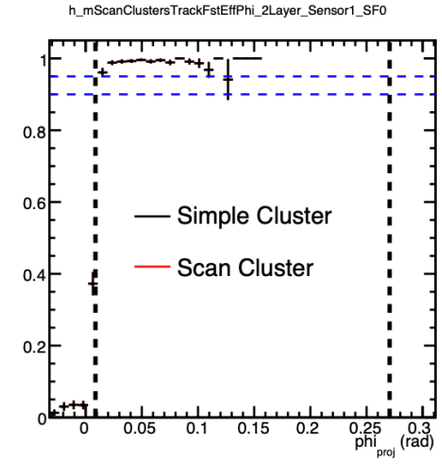


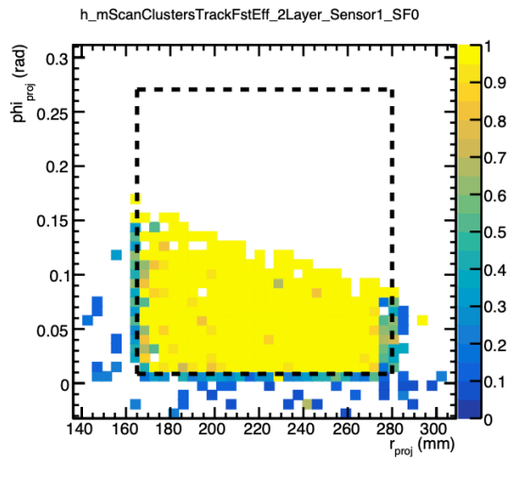


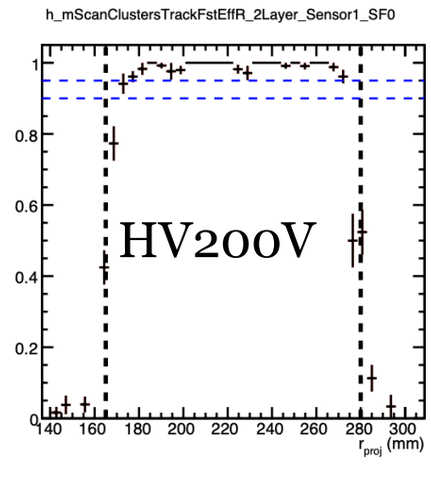


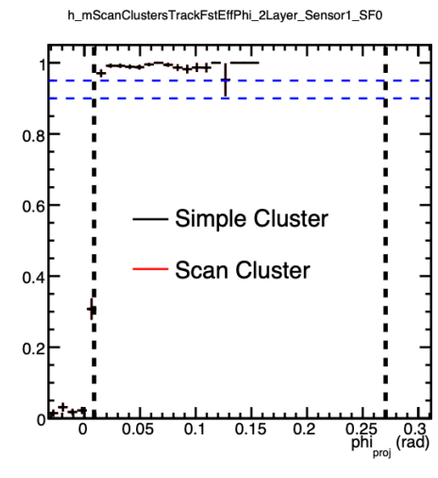






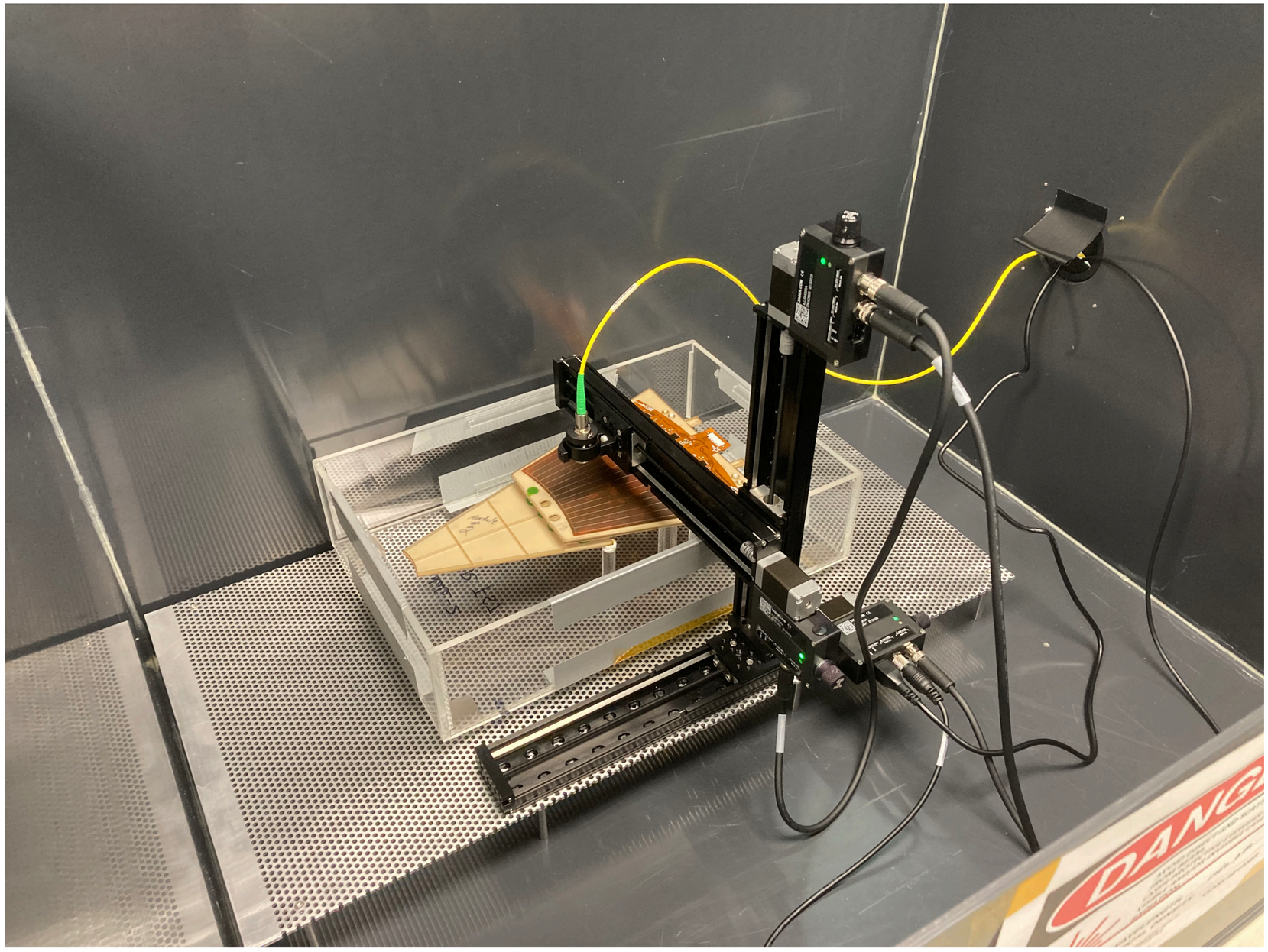






- Detection efficiency is larger than 95% in most of area with 140V and 200V.
- The drop at the edge is probably due to projection error from IST.
- May need to split the HV between inner and outer for operations

Laser Test Stand at UIC



Precision position measurement will be performed with laser after the cosmic ray tests.

- x-y-z stepping motors: range 20*20*20 cm, step size 0.047625 μm, repeatability<3 μm.
- infrared (1060nm) laser: 25 μm diameter at focus point.

Summary and Outlook

- Two batches of prototype modules assembled
  - Identified issues with the first batch of bare modules and provided feedbacks to NCKU. See improvements with the second batch.
  - Observed issues with two out of four cable/T-board assemblies, will follow up with Mike.
  - First partially assembled prototype FST01 available on 3/17/2020; First fully assembled and working prototype FST03 available on 7/7/2020.

- Cosmic ray test using IST staves for track reconstruction and projection
  - Significant reduction in the noise level after CMN subtraction. The first few channels have larger noise than others, indicating ADC timing needs to be adjusted. Will follow up with Gerard.
  - FST03: inner/outer sensor detection efficiency above 95/90% at 70V. Higher efficiency for FST01 outer sensor at higher HV. May need to split the HV between inner and outer for operations
  - Residual in phi well described by toy MC based on pure geometrical consideration. Residual in R indicates cross-talks among R-strips.

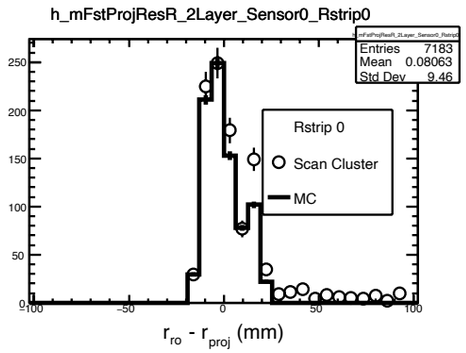
- Planned work
  - Complete the assembly and QA test for FST04. Provide feedback to NCKU on bare module quality.
  - HV scan for FST03 signal using cosmic ray; Precision position-dependent measurements with laser.
  - Study the tracking performance in STAR simulation by implement the measured efficiency and residual in a slow simulator.

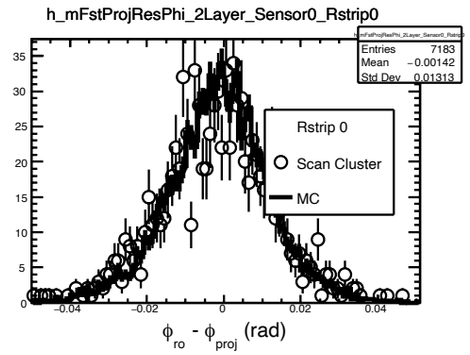
Backups

Toy MC Simulation w/o Cross-Talk

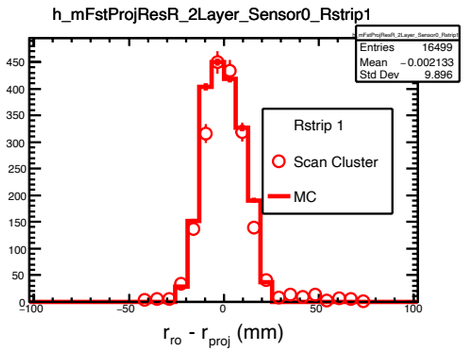
FST03 Sensor 0 at HV70V

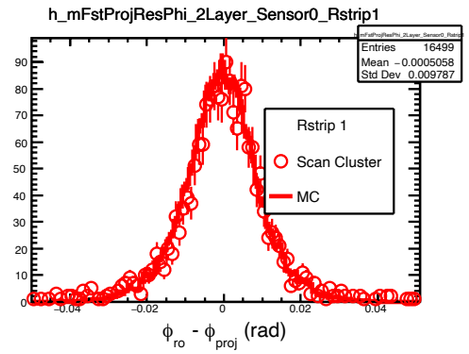
R-Strip 0



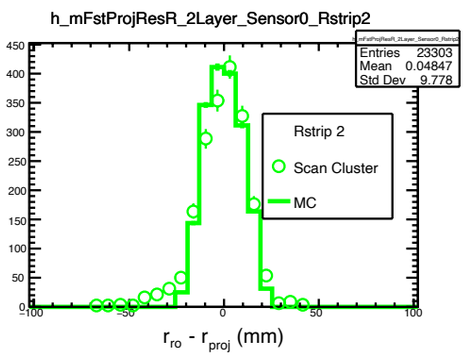


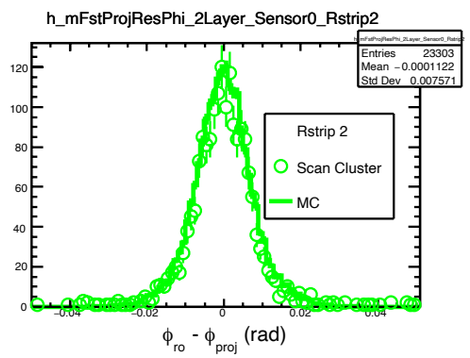
R-Strip 1



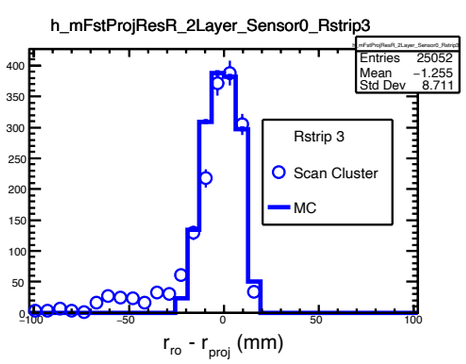


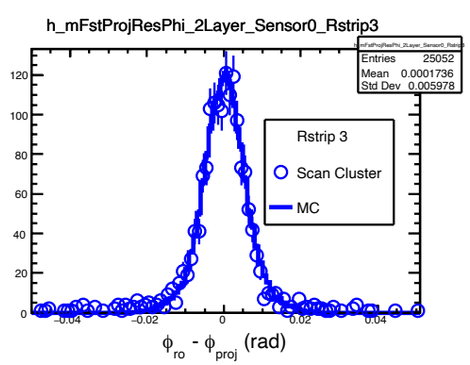
R-Strip 2





R-Strip 3



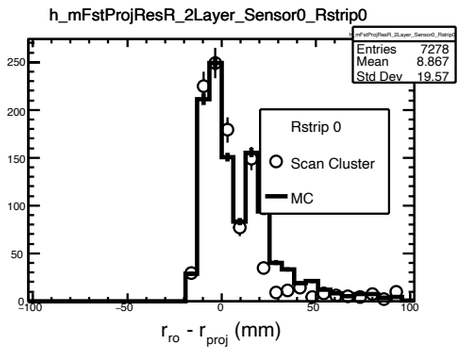


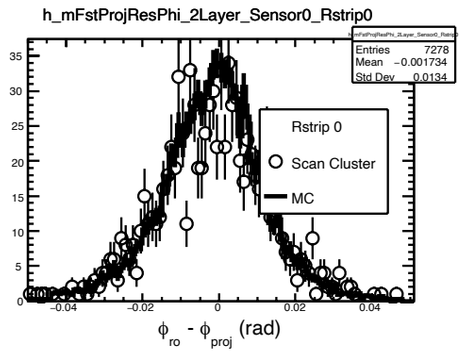
- Residual in phi is dominated by IST projection error. Data are well described by Toy MC.
- Tails in R-residual due to cross talk among R-strips and noise. Peaks well described by Toy MC.

Toy MC Simulation with Cross-Talk

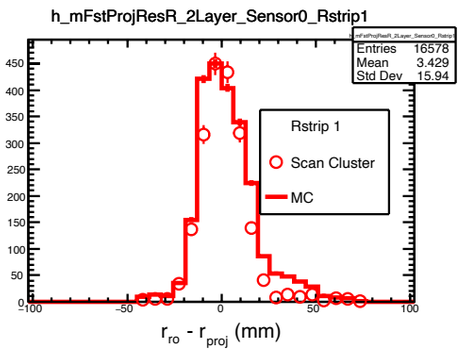
FST03 Sensor 0 at HV70V

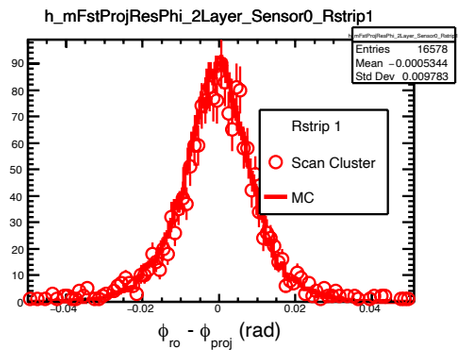
R-Strip 0



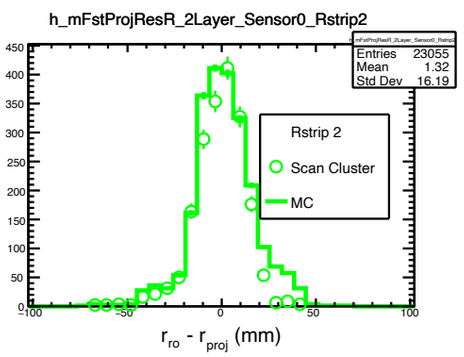


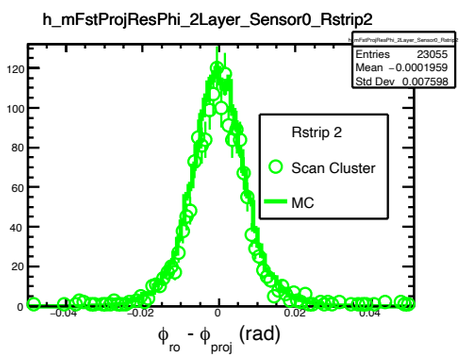
R-Strip 1



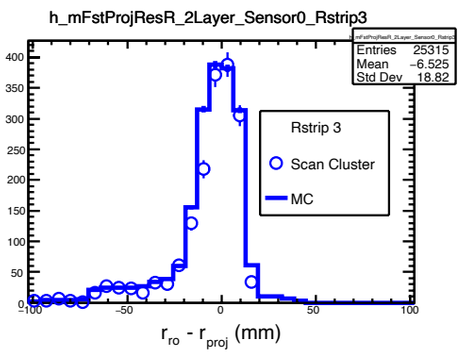


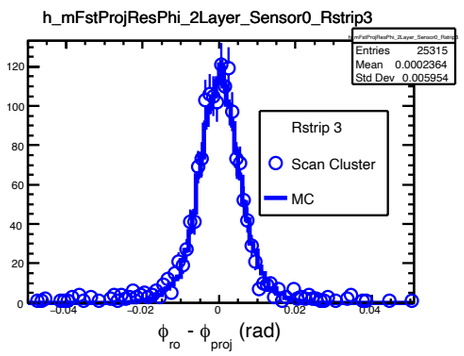
R-Strip 2





R-Strip 3



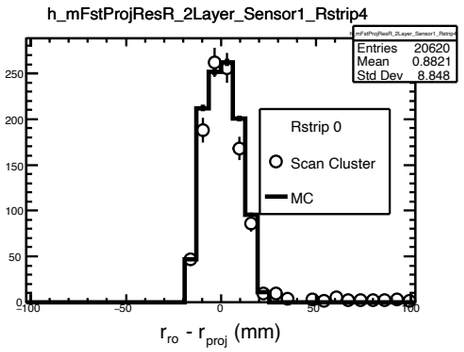


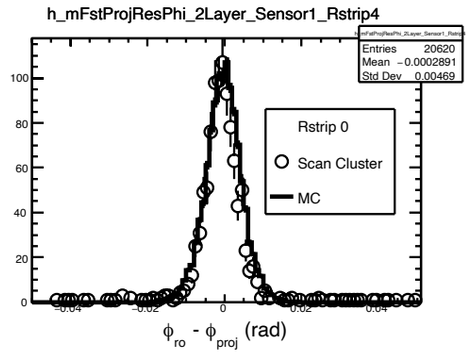
- With cross-talk and noise introduced, the MC can well reproduce data in both R and phi.
- Plan to implement the measured efficiency and residual in a slow simulator to study the tracking performance in STAR simulation.

Toy MC Simulation w/o Cross-Talk

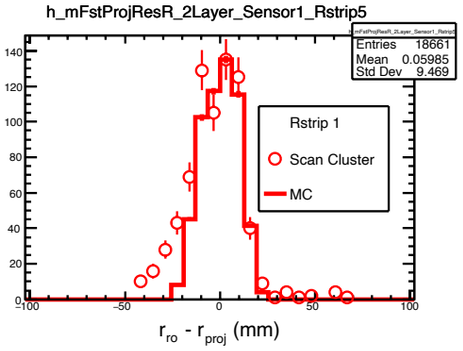
FST03 Sensor 1 at HV70V

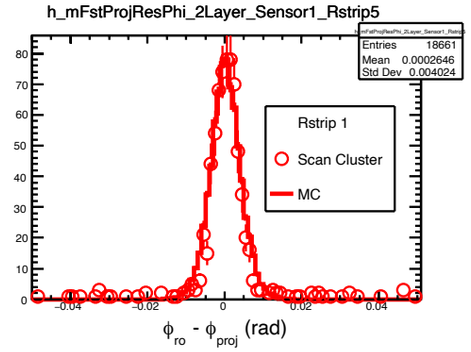
R-Strip 4



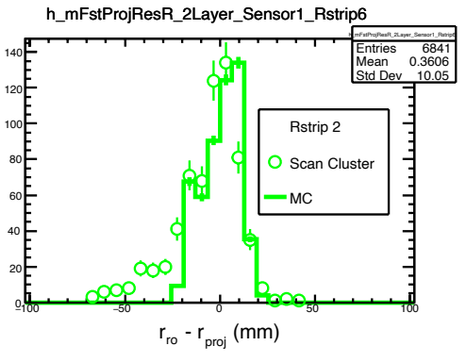


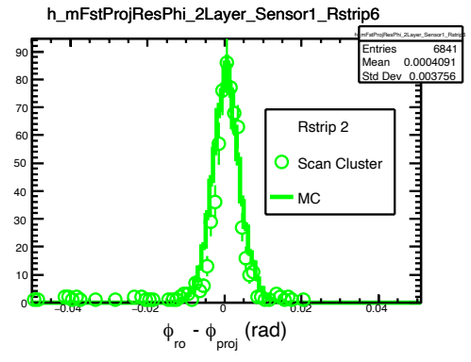
R-Strip 5



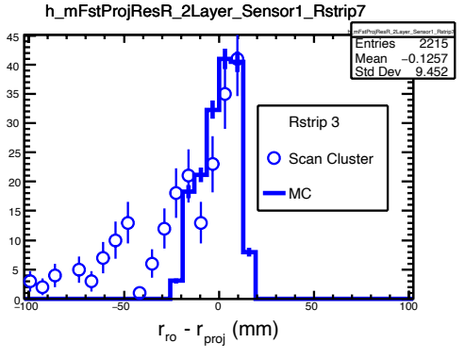


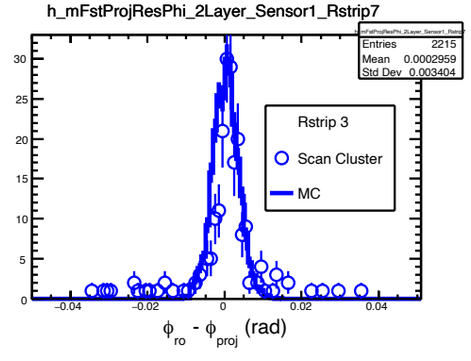
R-Strip 6





R-Strip 7



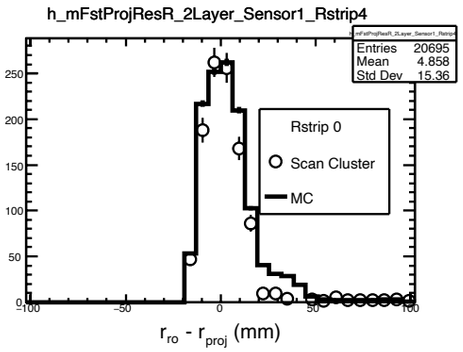


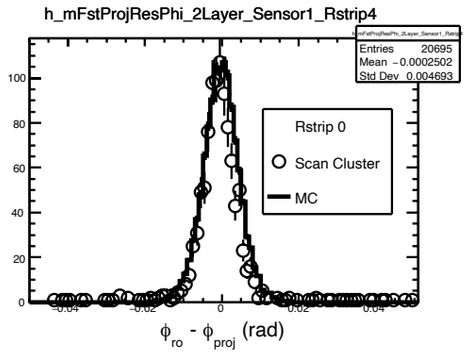
- Residual in phi is dominated by IST projection error. Data are well described by Toy MC.
- Tails in R-residual due to cross talk among R-strips and noise. Peaks well described by Toy MC.

Toy MC Simulation with Cross-Talk

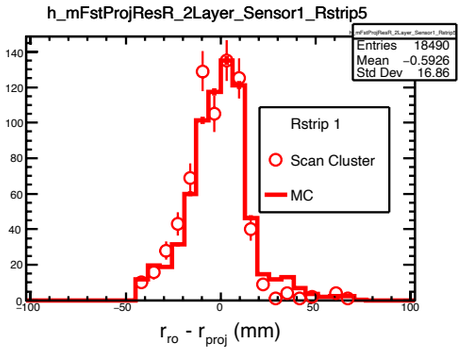
FST03 Sensor 1 at HV70V

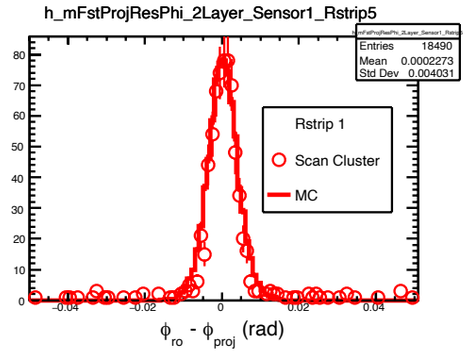
R-Strip 4



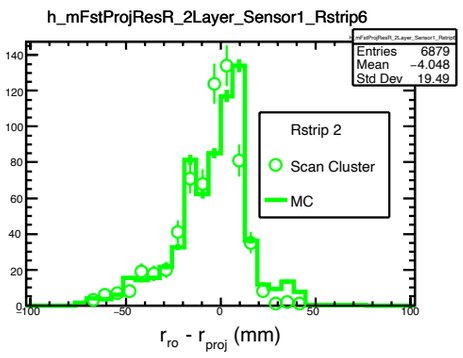


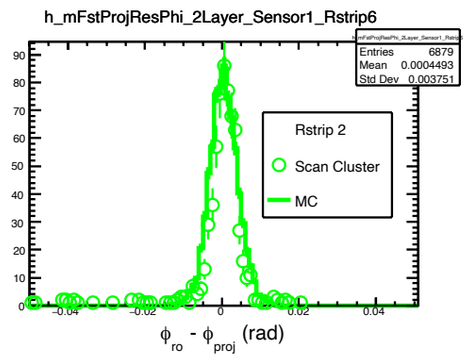
R-Strip 5



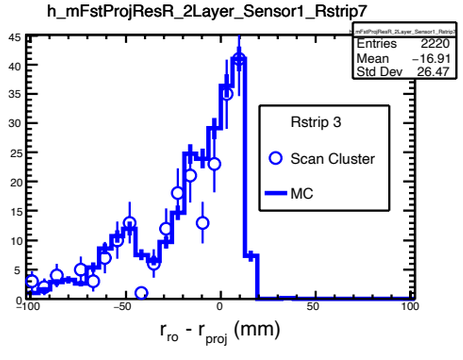


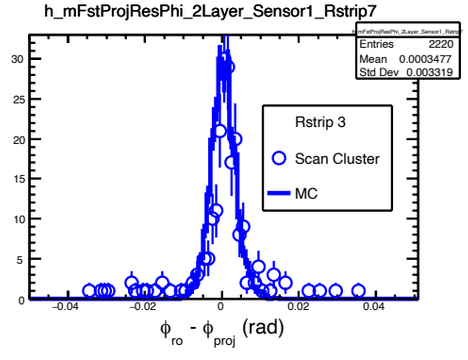
R-Strip 6





R-Strip 7





- With cross-talk and noise introduced, the MC can well reproduce data in both R and phi.
- Plan to implement the measured efficiency and residual in a slow simulator to study the tracking performance in STAR simulation.