



STAR Forward Silicon Tracker: Summary of Cosmic Ray Test Stand

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Various FST Cosmic Ray Test Stand analyses can be found at these links:

<https://starcluster.phy.uic.edu/twiki/bin/view/STAR/FSTCosmicTestStand>

<https://www4.rcf.bnl.gov/~sunxuhit/>

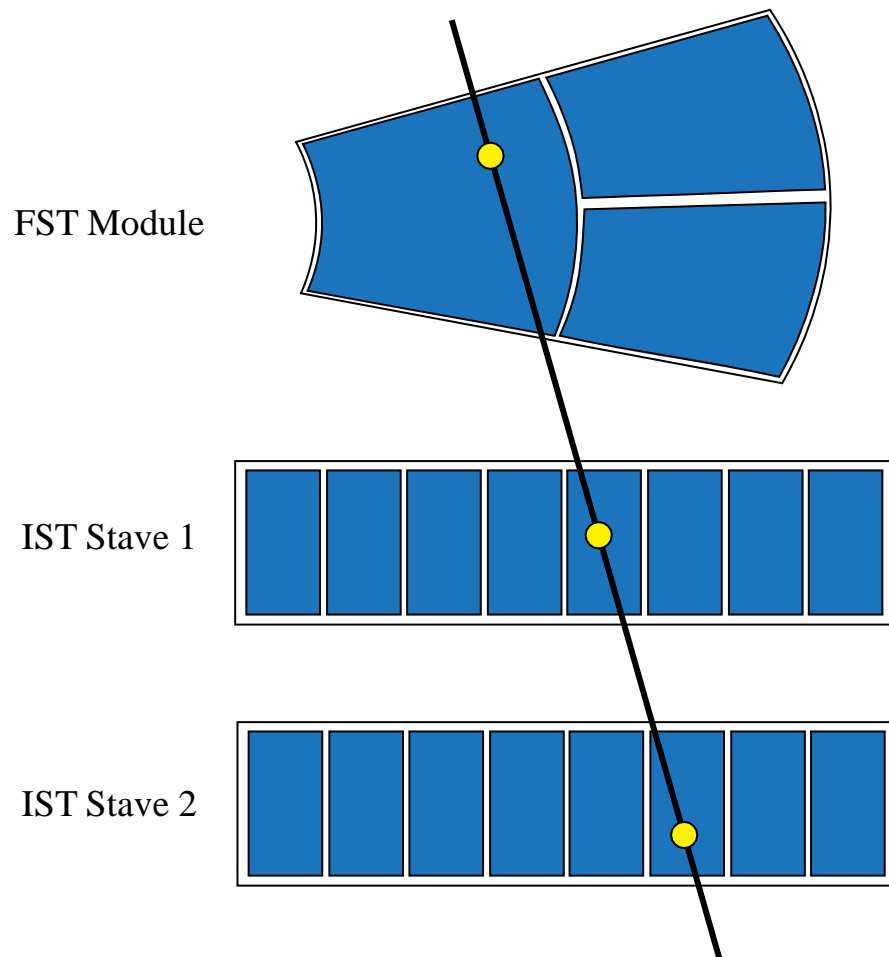
<https://www4.rcf.bnl.gov/~gwilks3/>



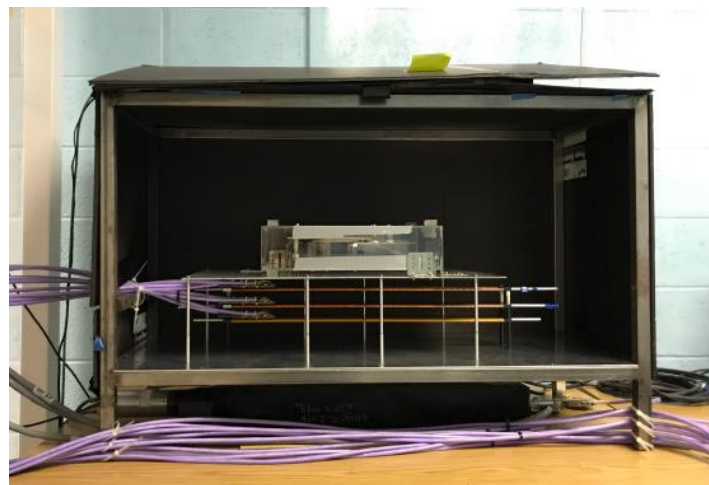
FST Cosmic Ray Test Stand



- Characterize prototype FST module performance.
 - Detection efficiency
 - Matched track efficiency
 - Spatial resolution
 - Signal
 - Noise
- Find dependencies on:
 - Voltage
 - Clustering method
 - Physical components
 - Additional wire-bonds/encapsulation



- Consists of 2 Inner Silicon Tracker (IST) staves aligned with FST module
- Tracking Method
 - Find all simple clusters in IST staves 1 & 2
 - Project track to FST module (x_{proj}, y_{proj})
 - Find clusters on FST using scan and simple algorithms (x, y)
 - Difference in projected and measured position on FST provides estimate of resolution ($x - x_{proj}, y - y_{proj}$)



Clustering Methods

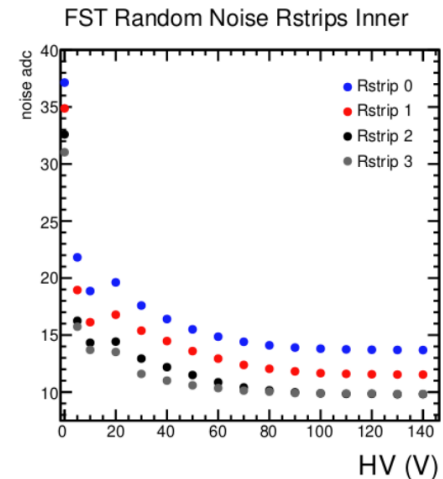
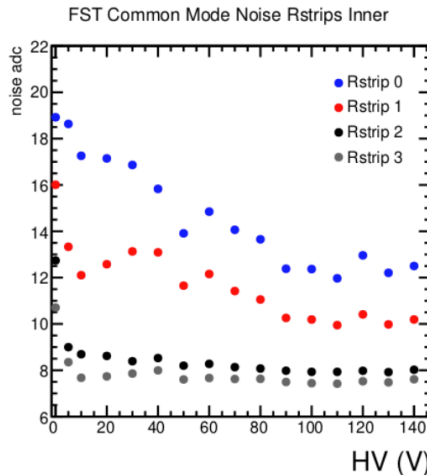
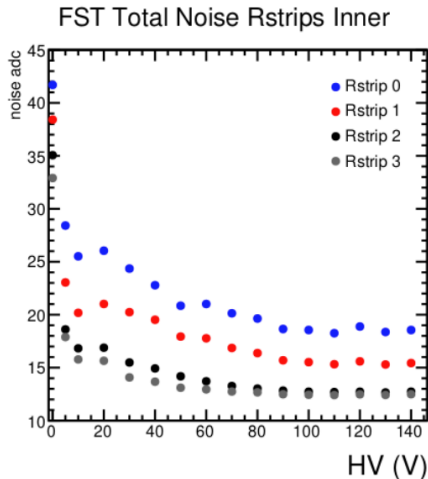
Simple Clustering

1. Find all hits ($\text{ADC} > 4 * \text{noise}$ in 2 time bins) on FST.
 2. Group neighboring hits into clusters.
 3. Cluster position is given by the ADC-weighted center of the hits.
- Thresholds were chosen by an optimal combination of S/N, resolution, detection efficiency and matching efficiency.

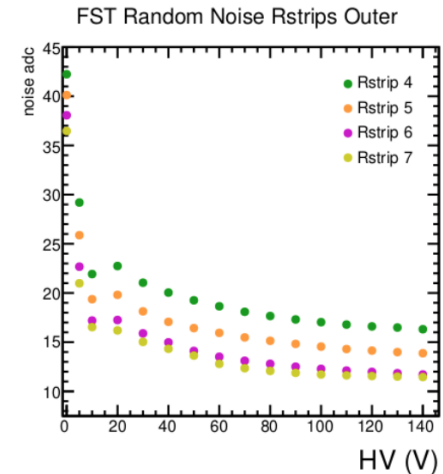
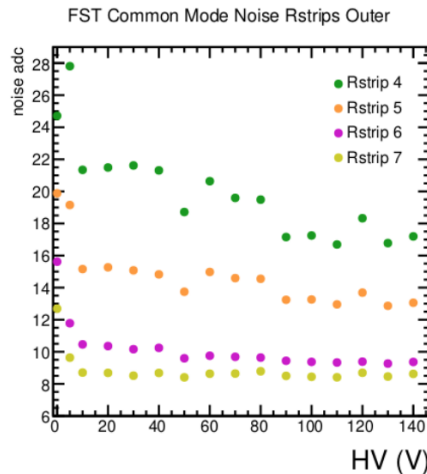
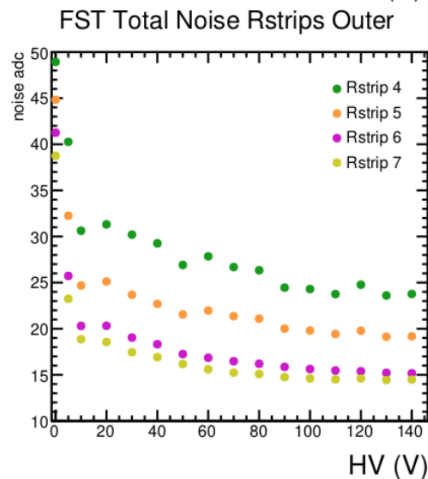
Scan Clustering

1. Find all seed hits ($\text{ADC} > 4 * \text{noise}$ in 2 time bins) and recover hits with $\text{ADC} > 2.5 * \text{noise}$ in 2 time bins or $\text{ADC} > 3.5 * \text{noise}$ in 1 time bin in the same event window.
2. Group all the hits in the same and neighboring ϕ -segmentations to a seed hit into clusters.
3. Cluster's radial position is determined by the largest radius and ϕ position by the ADC-weighted center of the hits.

Inner
Sensor



Outer
Sensor



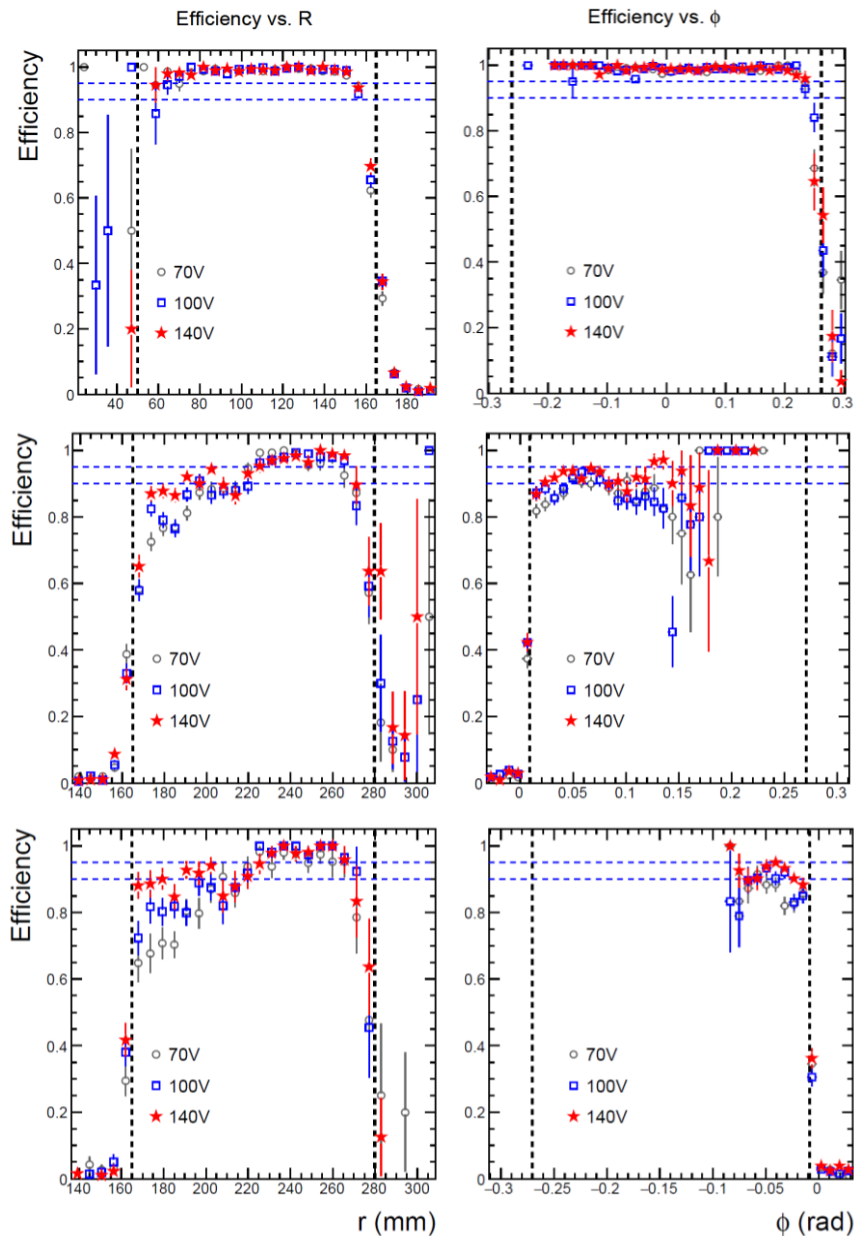
- All forms of noise (total, random and common mode) decrease with voltage.
- As Rstrip number increases, all noise types decrease for both inner and outer sensors.



FST Detection Efficiency (Scan Clusters)



- Definition:
 - Projected position is within FST acceptance.
 - Measured cluster is within FST acceptance.
- Inner sensor $\geq 95\%$ for most of r and ϕ range at each voltage.
- Outer sensors:
 - Greater detection at higher voltages for lower projected r .
 - Similar detection at each voltage for greater projected r .
 - Higher voltage provides greater detection in ϕ .
- Module 4 results are shown, and results are similar for FST Module 3



Inner Sensor

Outer Sensor 1

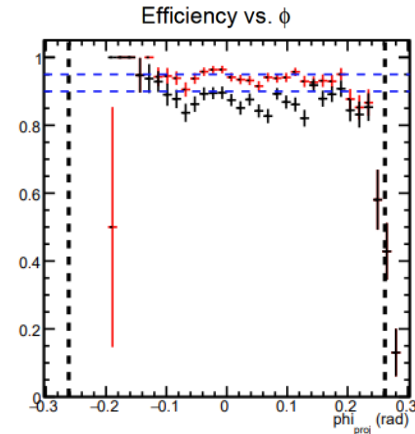
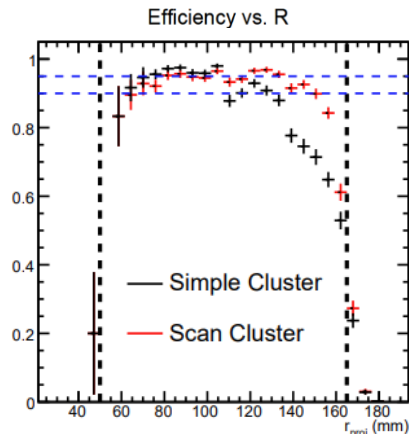
Outer Sensor 2



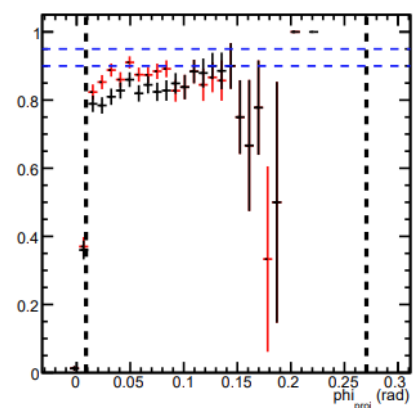
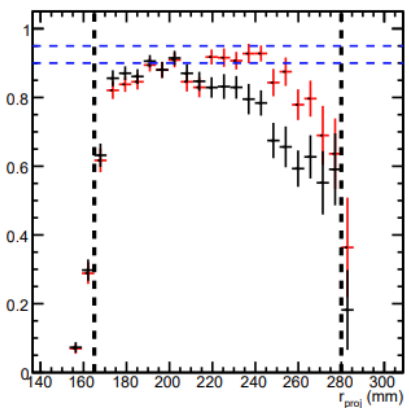
FST Matching Efficiency



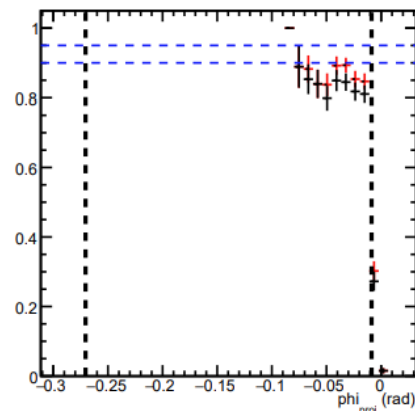
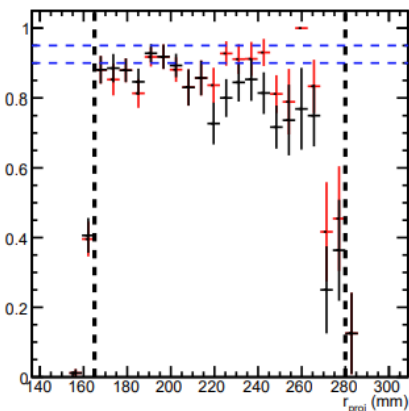
- Definition:
 - Projected position is within FST acceptance.
 - Measured cluster is within:
 - 1.5 Rstrip lengths of projected position.
 - ~ 2.5 -10 ϕ segmentations depending on Rstrip.
- Matching efficiency with scan clustering outperforms simple clustering.
- Scan clustering improves matching efficiency for greater radial position (outer Rstrips).
- Module 4 results are shown, and results are similar for FST Module 3



Inner Sensor



Outer Sensor 1



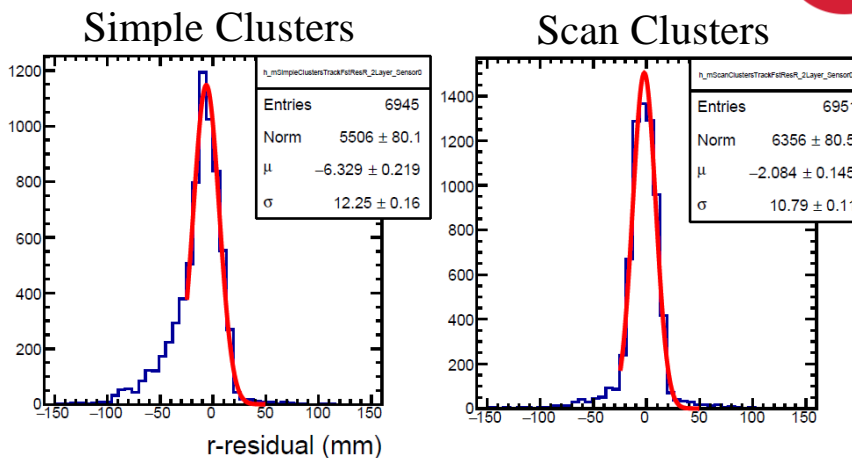
Outer Sensor 2



FST Spatial Resolution (Radial)



- Scan clustering reduces negative tail in residual distribution.
 - Greater resolution for radial position primarily for inner sensor (more statistics for inner sensor).
- Variation due to voltage is generally consistent within statistical uncertainties



Module 3 Resolution

Inner Sensor

	70V (mm)	100V (mm)	140V (mm)
Scan	10.88 ± 0.10	11.02 ± 0.11	11.37 ± 0.12
Simple	12.02 ± 0.14	12.25 ± 0.16	12.36 ± 0.16

Outer Sensor 1

	70V (mm)	100V (mm)	140V (mm)
Scan	11.11 ± 0.20	10.06 ± 0.10	11.13 ± 0.16
Simple	11.30 ± 0.20	10.80 ± 0.20	11.29 ± 0.17

Outer Sensor 2

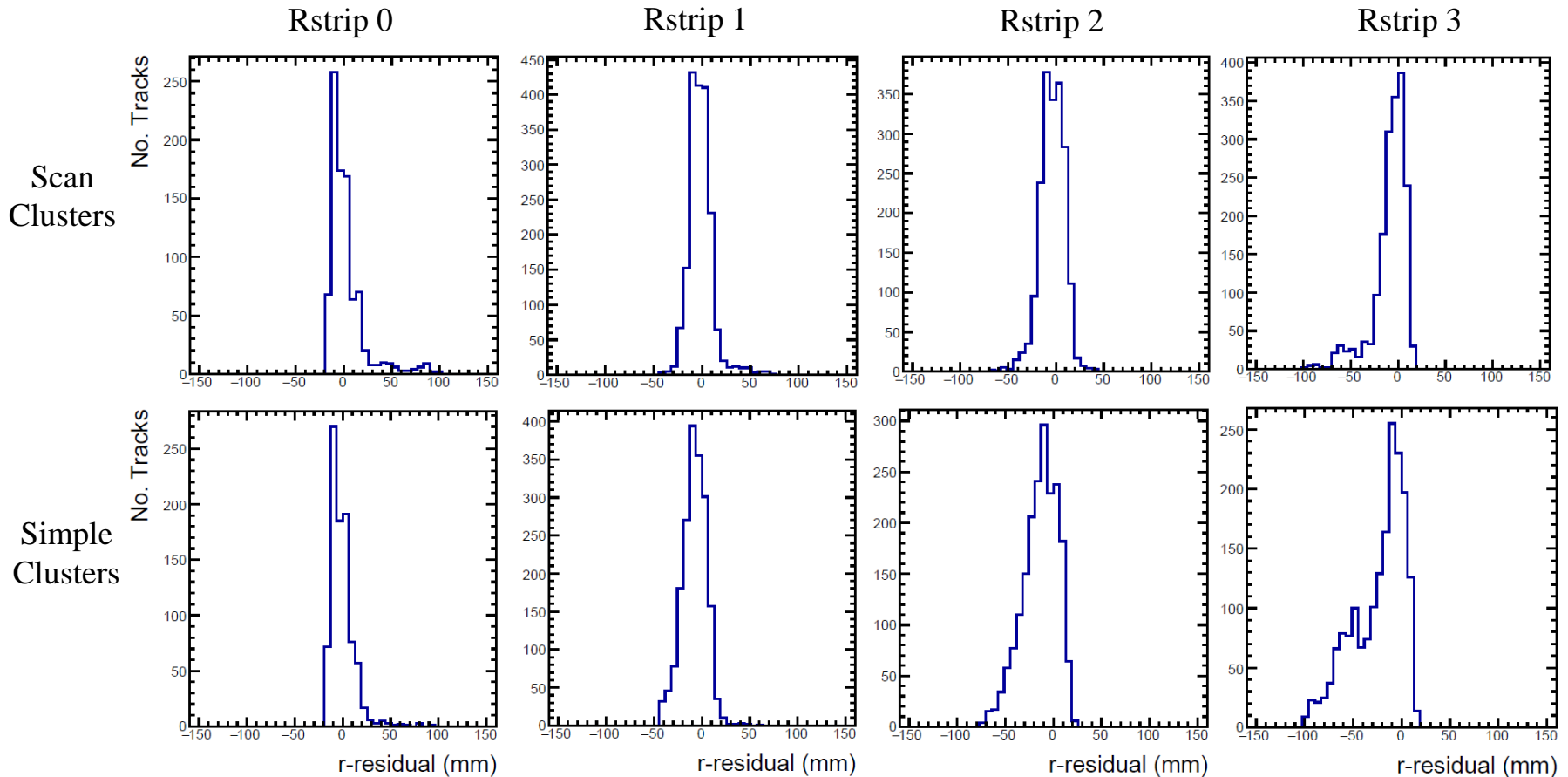
	70V (mm)	100V (mm)	140V (mm)
Scan	10.62 ± 0.28	11.07 ± 0.31	11.05 ± 0.27
Simple	11.04 ± 0.32	11.70 ± 0.40	11.45 ± 0.32

Module 4 Resolution

	70V (mm)	100V (mm)	140V (mm)
Scan	10.78 ± 0.10	10.91 ± 0.11	10.79 ± 0.11
Simple	12.34 ± 0.15	12.00 ± 0.20	12.25 ± 0.16

	70V (mm)	100V (mm)	140V (mm)
Scan	10.26 ± 0.14	9.77 ± 0.14	9.95 ± 0.15
Simple	10.76 ± 0.16	10.33 ± 0.16	10.13 ± 0.16

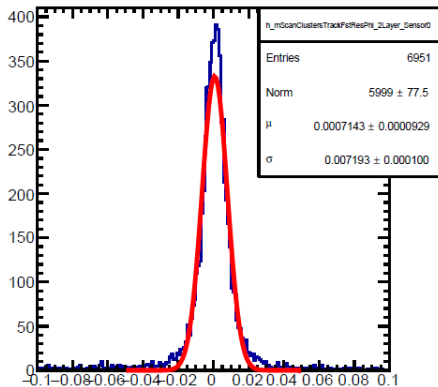
	70V (mm)	100V (mm)	140V (mm)
Scan	11.32 ± 0.26	10.83 ± 0.24	10.36 ± 0.22
Simple	11.91 ± 0.31	11.12 ± 0.27	10.96 ± 0.26



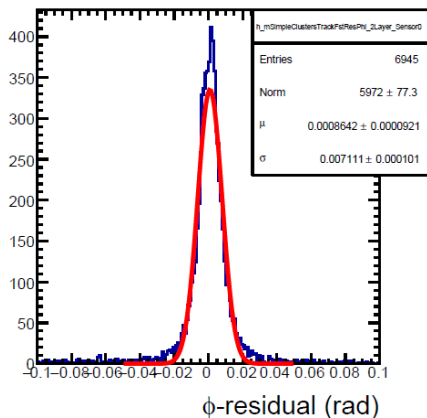
- Cross talk in Rstrips leading to detection on other Rstrips.
 - More prominent for outer Rstrips.
- Scan clustering reduces negative tail in residual distribution
 - Cross talk signal reduced for outer Rstrips.

FST Spatial Resolution (Azimuthal)

Scan Clusters



Simple Clusters



- Variations due to voltage and clustering algorithm are generally consistent within statistical uncertainties.
- Results are consistent in module 3 and other sensors.

Resolution Summary (Module 4)

	70V (rad)	100V (rad)	140V (rad)
Scan	7.136E-3 ± 0.087E-3	7.079E-3 ± 0.093E-3	7.193E-3 ± 0.100E-3
Simple	7.076E-3 ± 0.088E-3	7.108E-3 ± 0.094E-3	7.111E-3 ± 0.101E-3



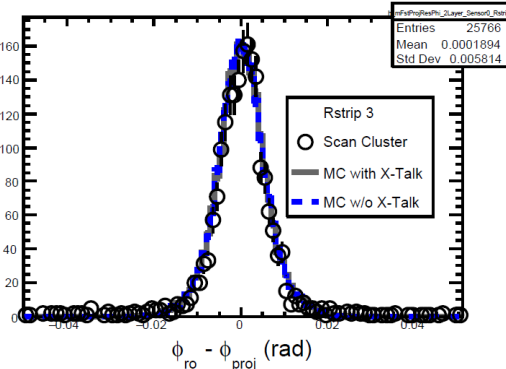
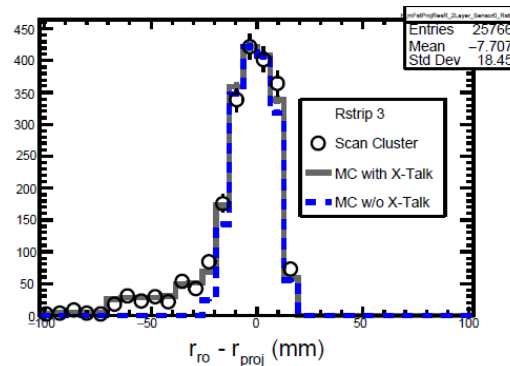
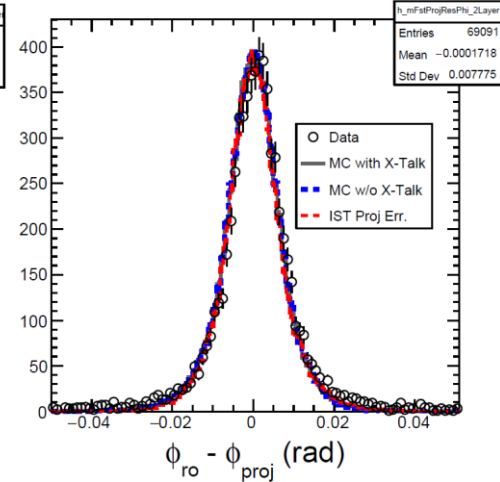
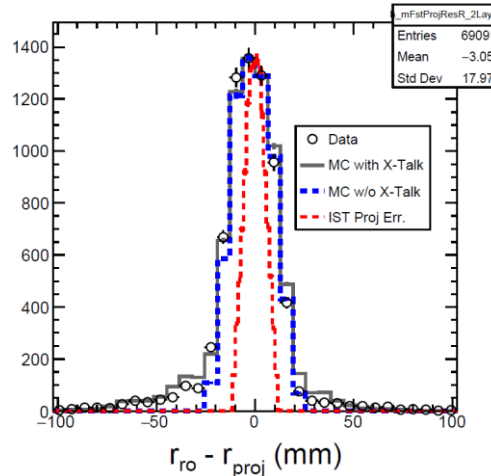
Toy MC Simulation



Procedure

1. Generate random angle for incident cosmic ray.
2. Create track through 2 IST and FST Module.
3. Use readout pixel position on IST staves and project track (projected FST position).
4. Use projected Rstrip to determine if readout position (original track) is shifted to another Rstrip using measured cross talk rates.
5. Drop FST hit based on projected Rstrip efficiency.

- Qualitatively reproduces residual distributions from Test Stand.
 - Cross talk, detection efficiency and IST projection error.
 - Overall distribution and individual Rstrip distributions.





FST Wire-bond Study



- Study of FST Module 3 and Module 4 before and after wire-bond encapsulation.
 - Module 4 has additional wire-bonds between sensor guard ring and hybrid bias pads for data with encapsulation.

Module 3

Mean S/N Summary (70V)

Enc.	Inner Sensor	Outer Sensor 1	Outer Sensor 2
w/o	28.08 ± 0.12	24.63 ± 0.16	23.21 ± 0.23
w/	28.19 ± 0.14	25.61 ± 0.16	24.86 ± 0.23

Mean S/N Summary (140V)

Enc.	Inner Sensor	Outer Sensor 1	Outer Sensor 2
w/o	30.43 ± 0.14	30.20 ± 0.17	29.39 ± 0.26
w/	31.06 ± 0.14	33.00 ± 0.17	29.87 ± 0.25

Module 4

Mean S/N Summary (70V)

Enc.	Inner Sensor	Outer Sensor 1	Outer Sensor 2
w/o	27.22 ± 0.12	22.39 ± 0.12	23.80 ± 0.23
w/	29.22 ± 0.14	23.94 ± 0.16	24.89 ± 0.22

Mean S/N Summary (140V)

Enc.	Inner Sensor	Outer Sensor 1	Outer Sensor 2
w/o	29.92 ± 0.14	24.92 ± 0.19	26.90 ± 0.25
w/	31.56 ± 0.14	26.32 ± 0.17	29.11 ± 0.25

- Encapsulation in module 3 provides higher mean S/N, in some sensors at 70V and 140V.
- Addition of wire-bonds and encapsulation in module 4 increases mean S/N significantly for all sensors at both 70V and 140V.
- No noticeable effects on resolution, detection efficiency or matching efficiency.



Summary and Outlook



- Efficiencies
 - Higher voltage improves *detection efficiency* over φ and greater r region on outer sensors.
 - Scan Clustering improves *matched track efficiency* for greater projected radial positions and all φ .
- Increasing voltage also decreases noise for all sensors.
- Spatial Resolution
 - Scan clustering provides greater radial resolution over simple clustering.
 - Variations from voltage are mostly within statistical uncertainties.
 - Cross talk present between Rstrips.
- Toy MC qualitatively reproduces residual distributions for position.
 - Accounts for cross talk, detection efficiency and IST projection error.
- Addition of wire-bonds and encapsulation increases mean S/N.
- Apply measurements of prototype module performance to STAR simulation.
 - Effect on momentum resolution.