

# First Look at DarkLight Commissioning Data

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DarkLight Collaboration Meeting  
May 18, 2026

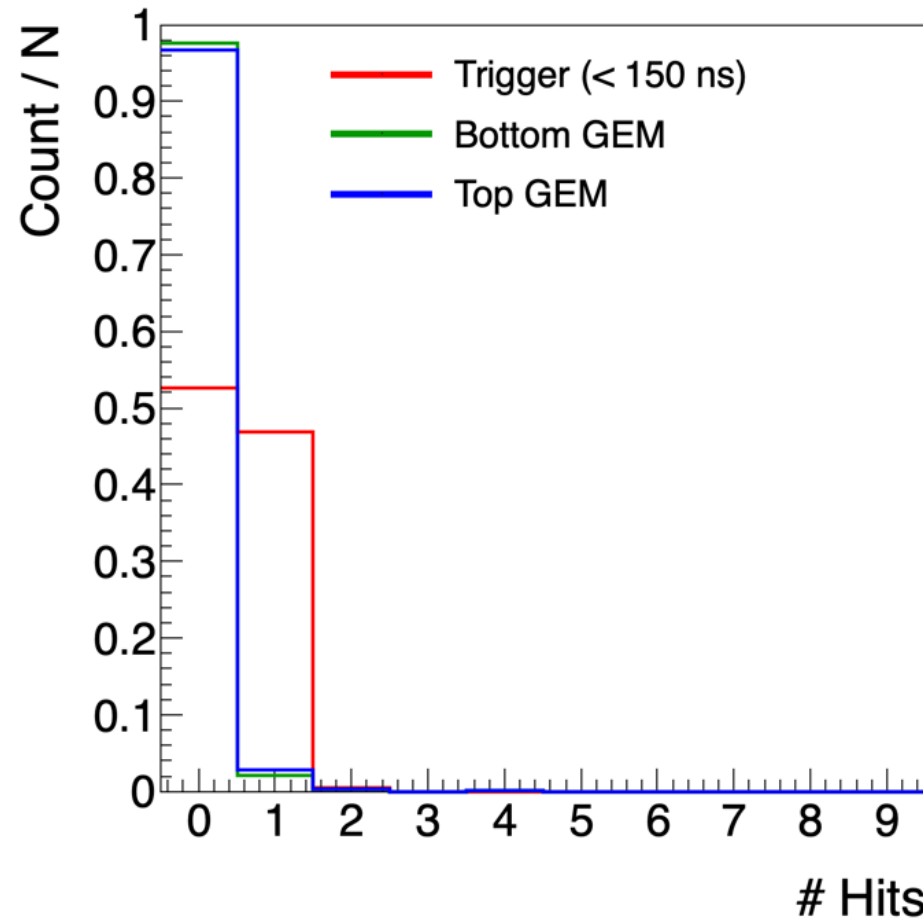
## Detector Hit Multiplicity

Number of hits per detector per event

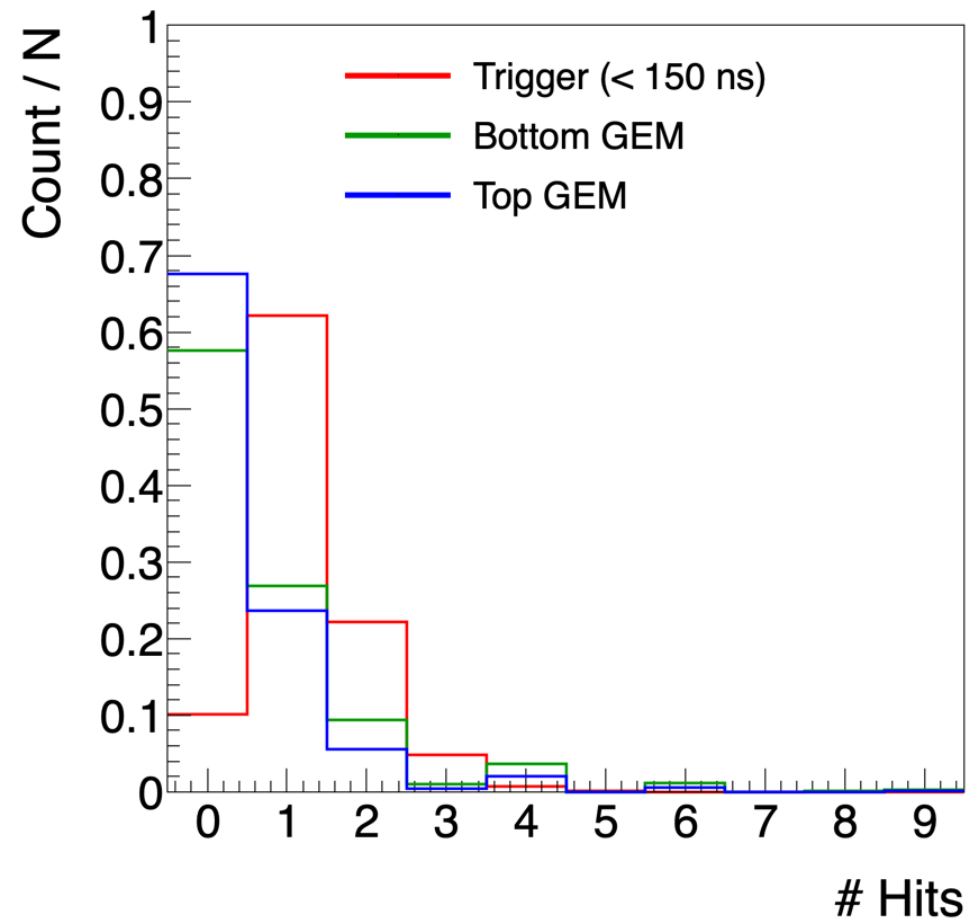
Stats: 1M events

Cuts: - Trigger hits in first 150 ns of readout

Run 3932: Cosmic Right



Run 4001: Elastic Right



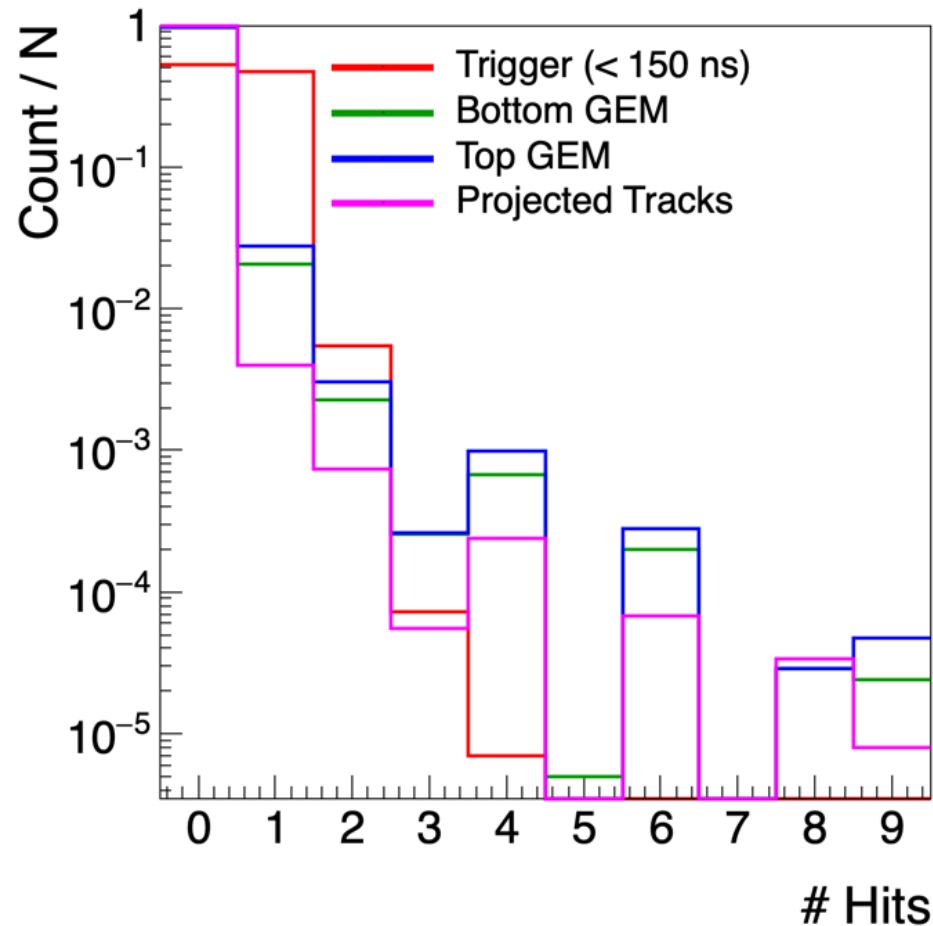
## “Track Multiplicity”

Number of tracks we can reconstruct by matching clusters in upper and lower GEMs

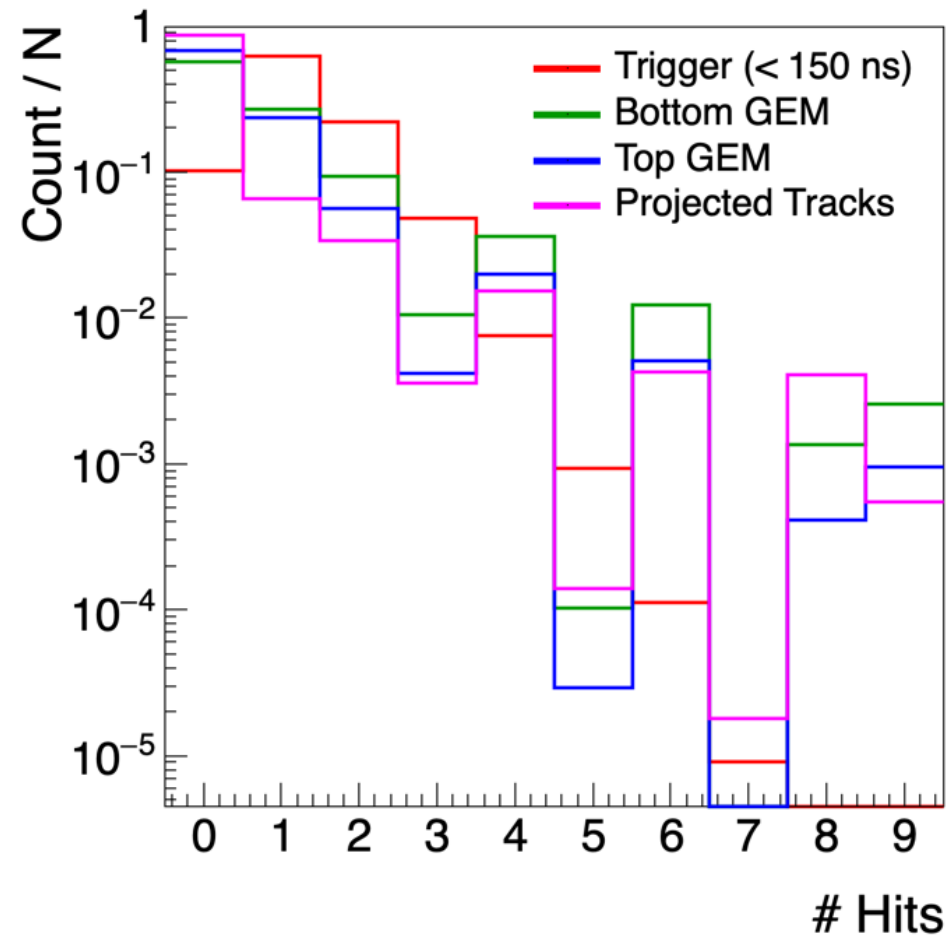
Stats: 1M events

Cuts: - Trigger hits in first 150 ns of readout  
- Tracks intersect trigger detectors

Run 3932: Cosmic Right



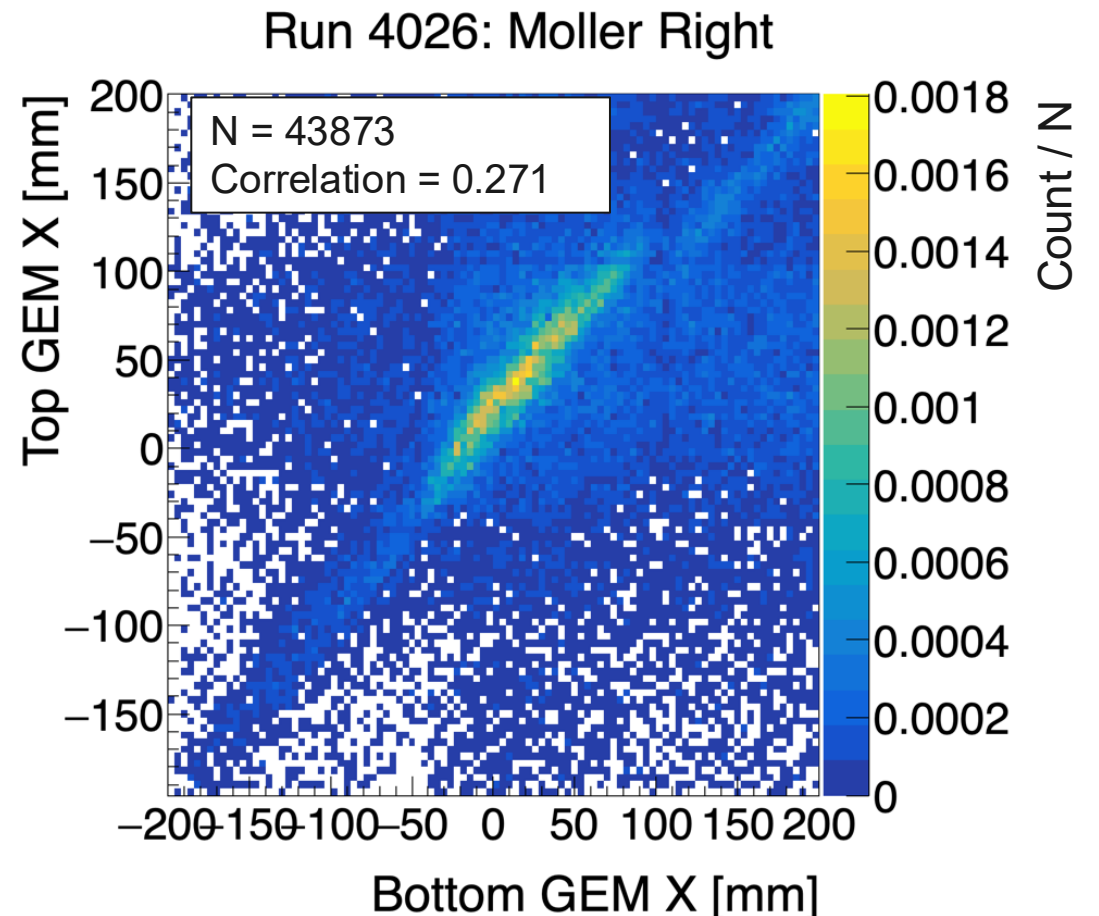
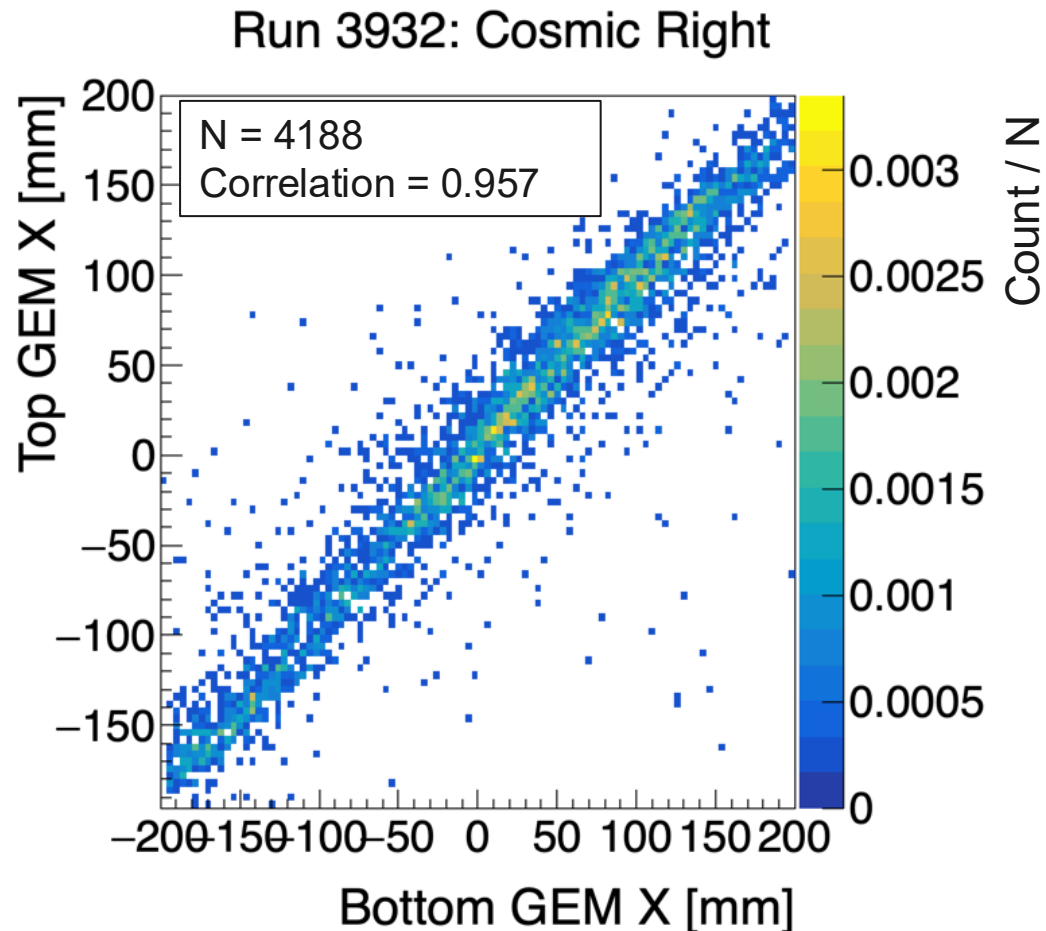
Run 4001: Elastic Right



## GEM Cluster Position Correlations

If clusters in upper and lower GEMs are created by the same particle, their positions should be linearly correlated.

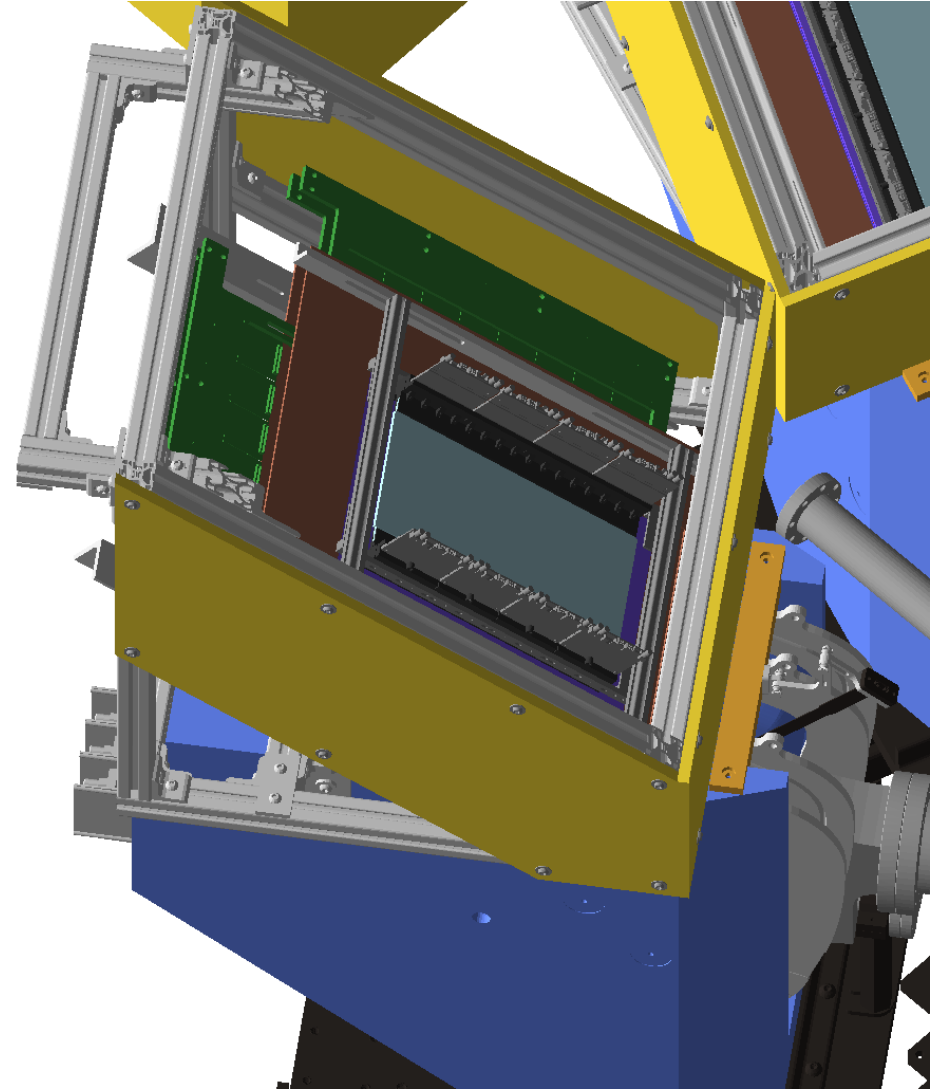
Selection: Events with one cluster in each GEM



## GEM Cluster Projections versus Trigger Hits

Match GEM clusters  $\rightarrow$  project tracks onto trigger.

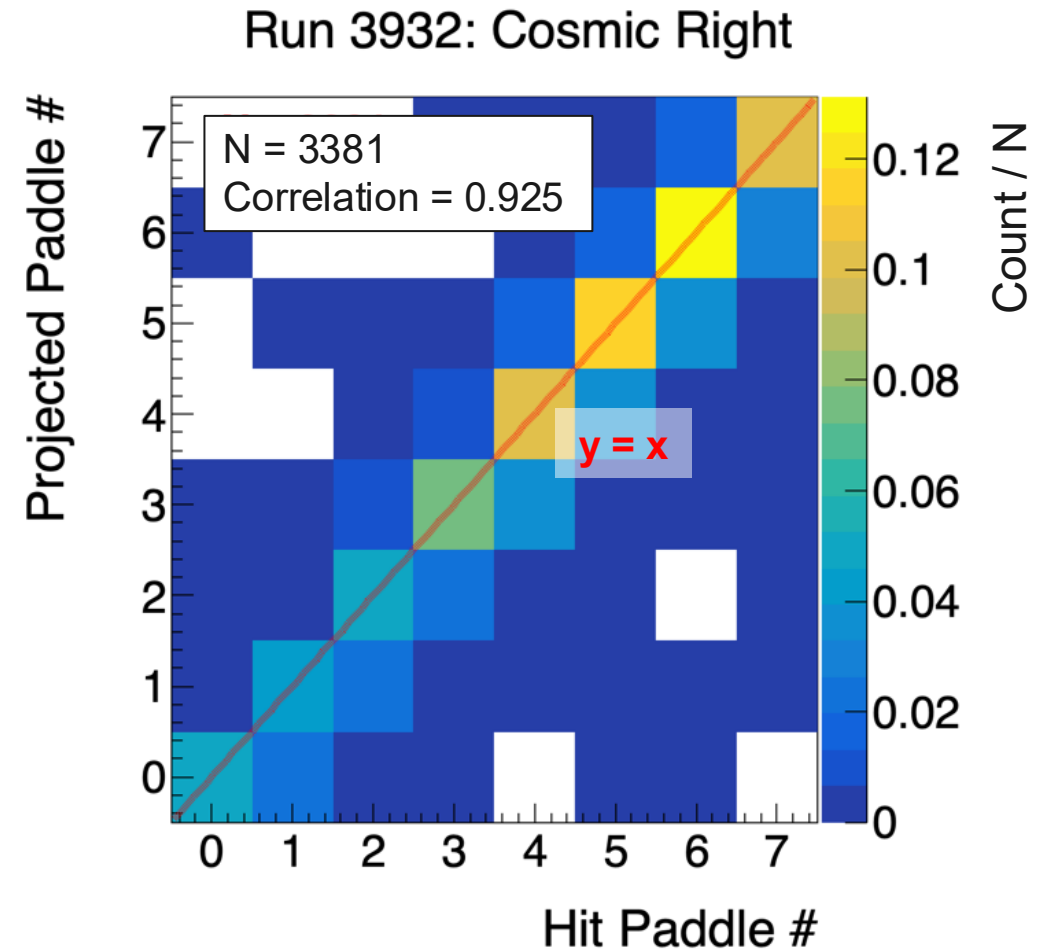
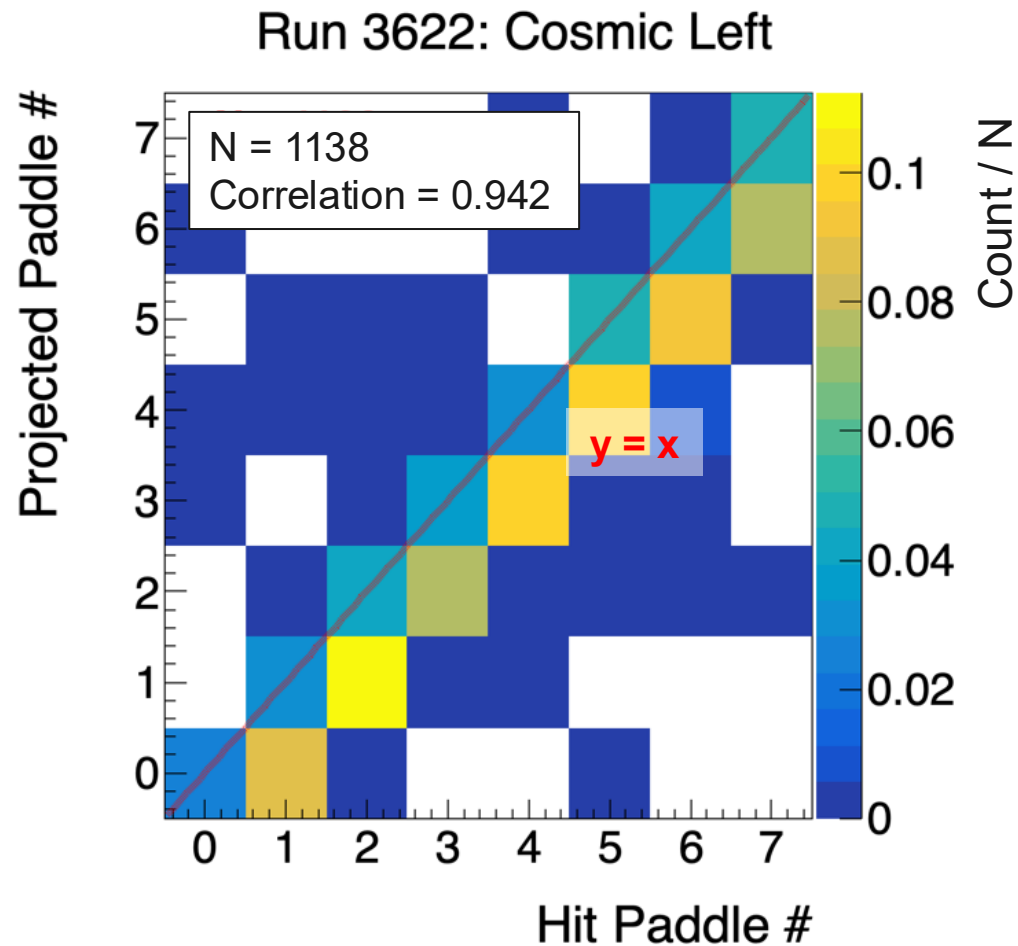
- We expect projected hits at same position as trigger hits.
  - Constant offset implies incorrect position of detectors
  - Slope offset implies incorrect angle of detectors
  - Calculation of trigger hit Y may also be inaccurate



## GEM Cluster Projections versus Trigger Hits

Projected paddle versus hit paddle in cosmic ray data.

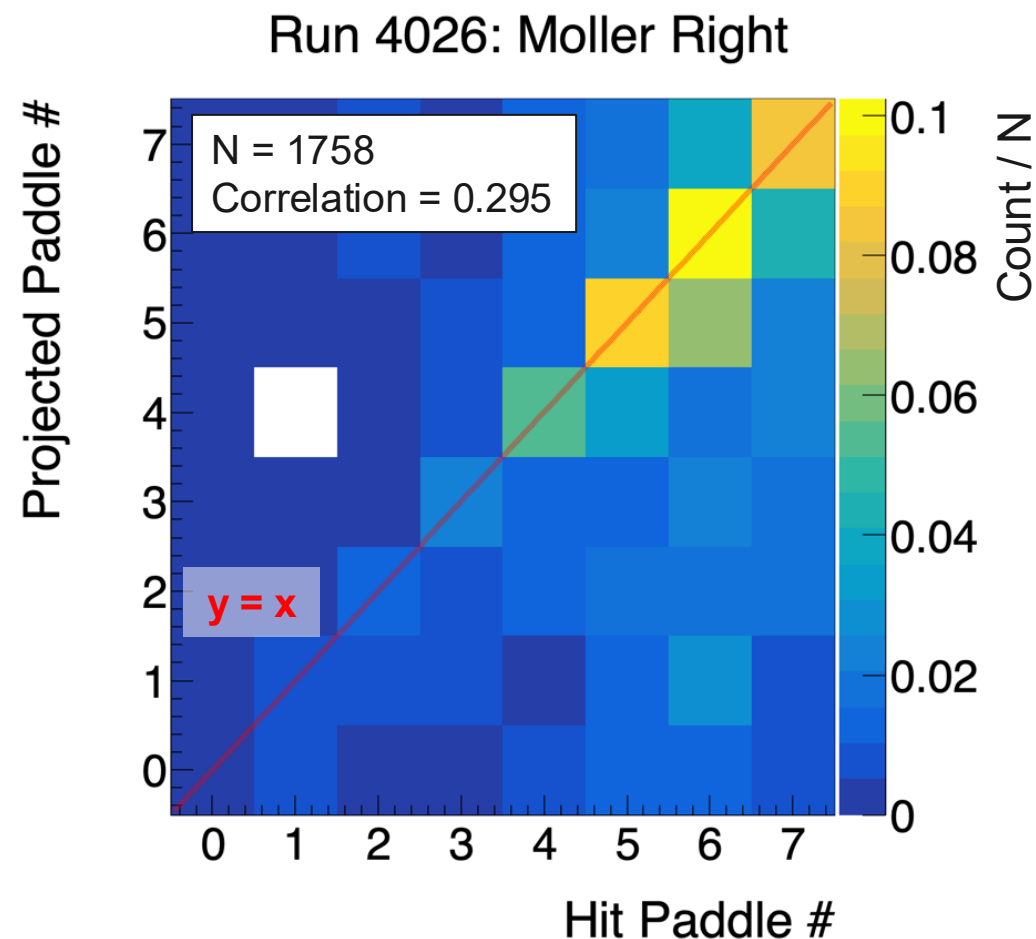
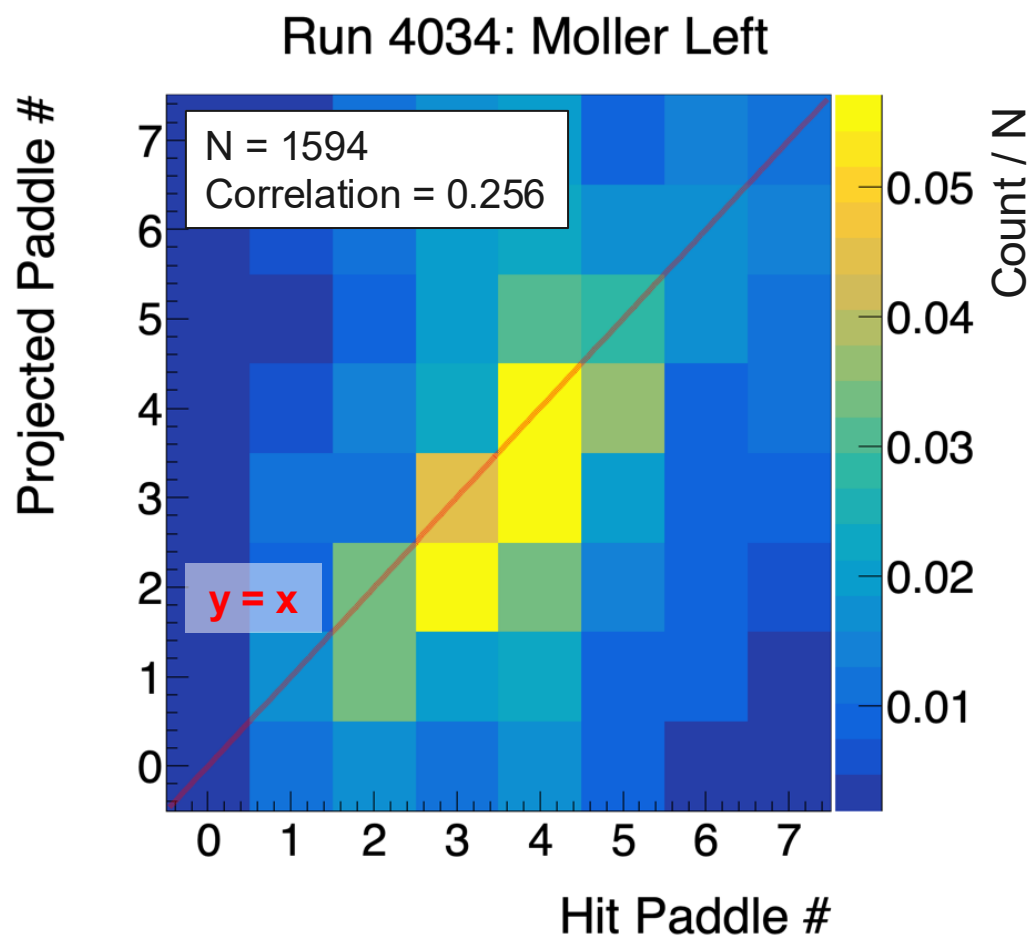
Selections: One track per event  
One trigger hit per event  
In time trigger only



## GEM Cluster Projections versus Trigger Hits

Projected paddle versus hit paddle in beam data.

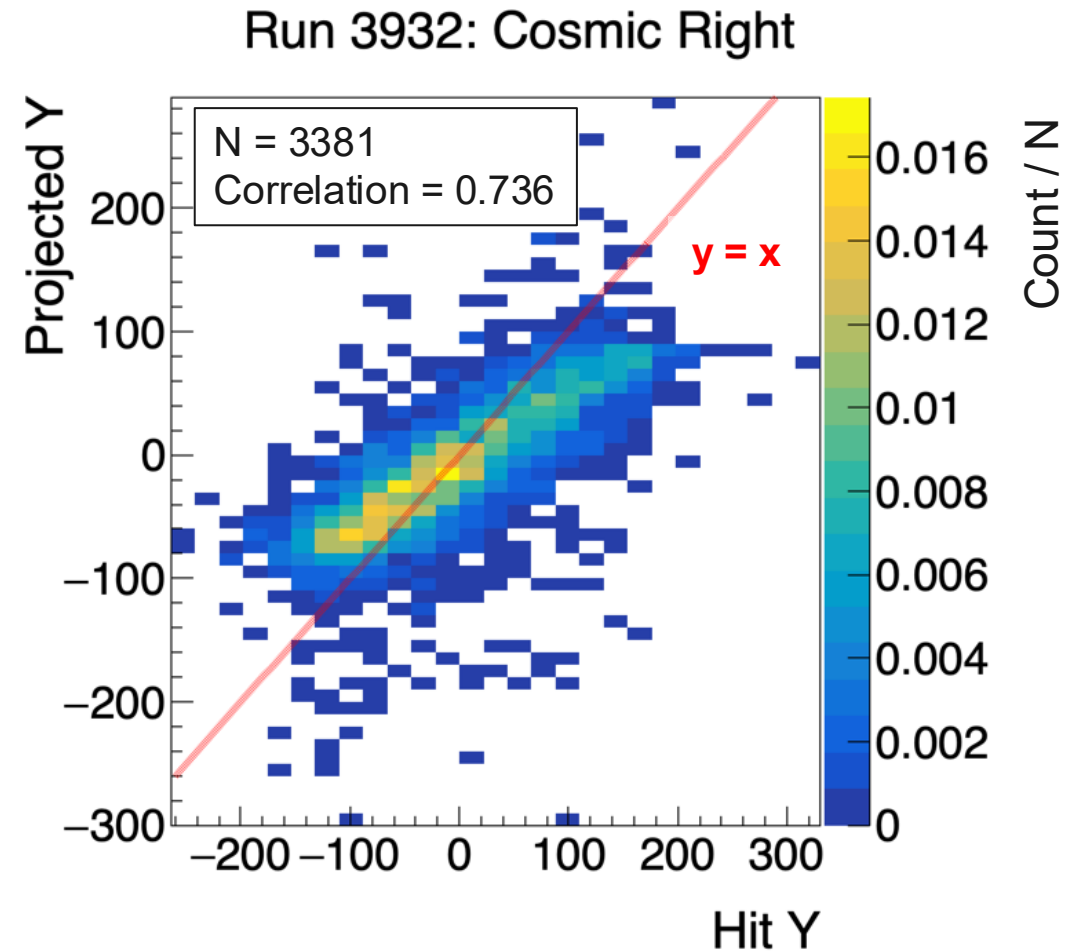
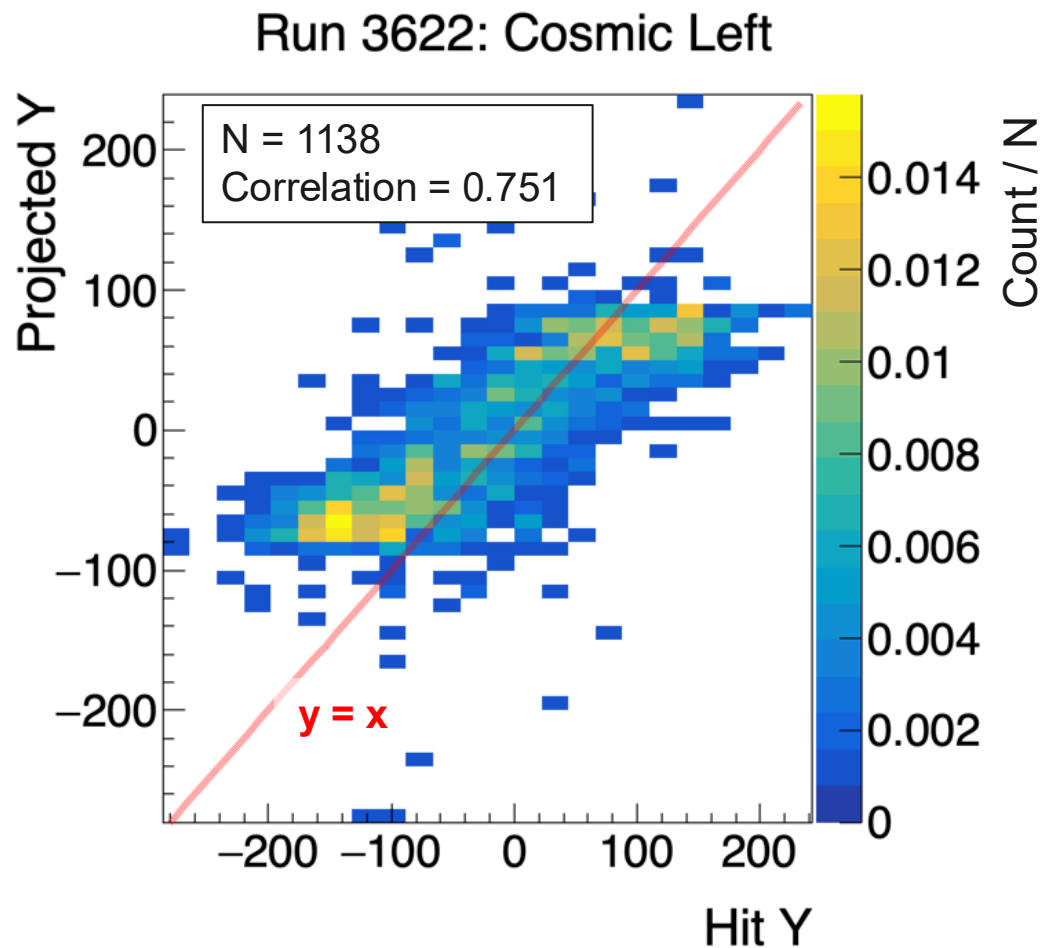
Selections: One track per event  
One trigger hit per event  
In time trigger only



## GEM Cluster Projections versus Trigger Hits

Projected Y versus hit Y in cosmic data.

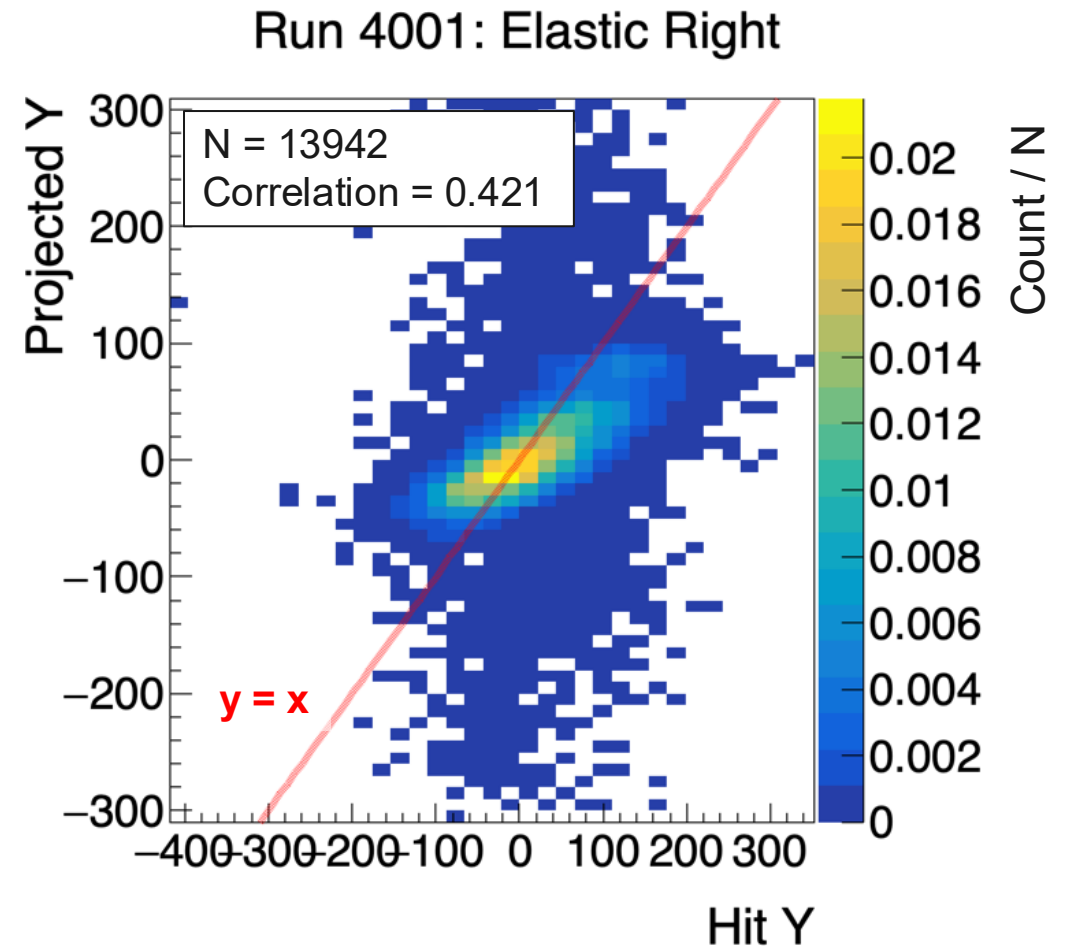
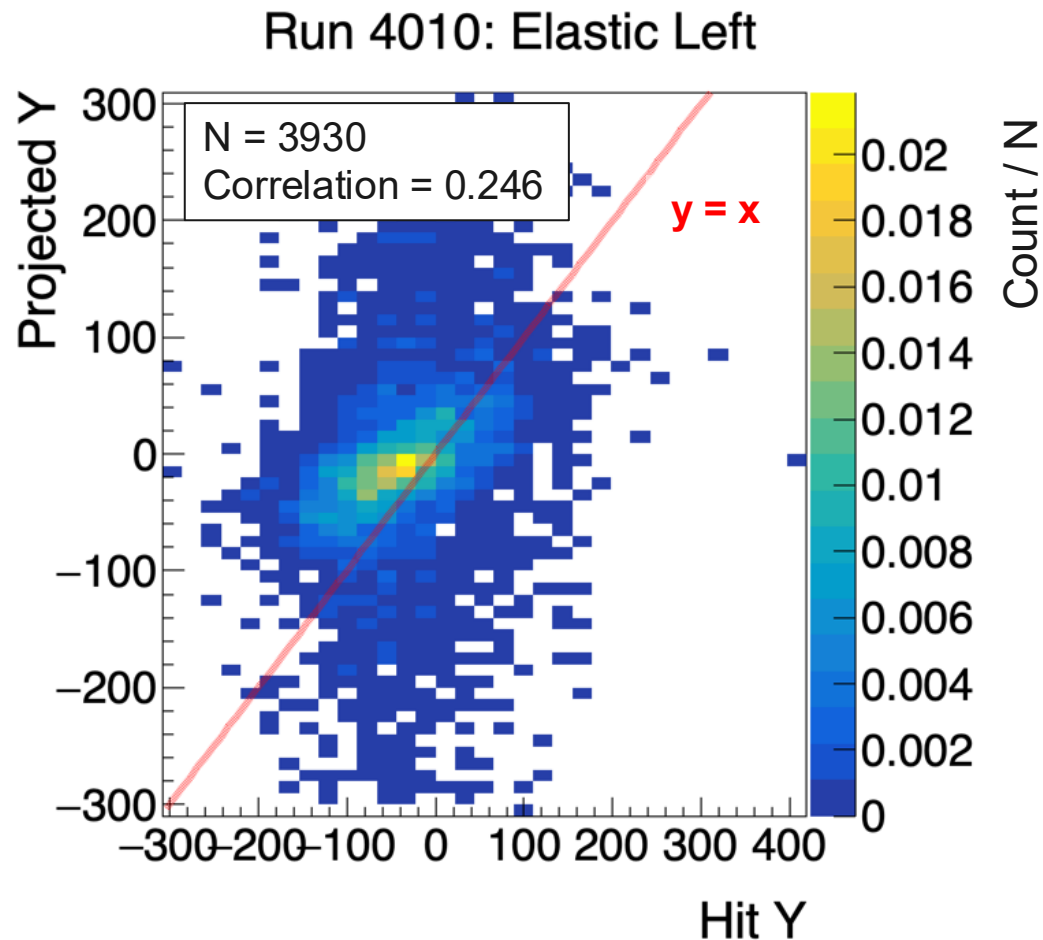
Selections: One track per event  
One trigger hit per event  
In time trigger only



## GEM Cluster Projections versus Trigger Hits

Projected Y versus hit Y in beam data.

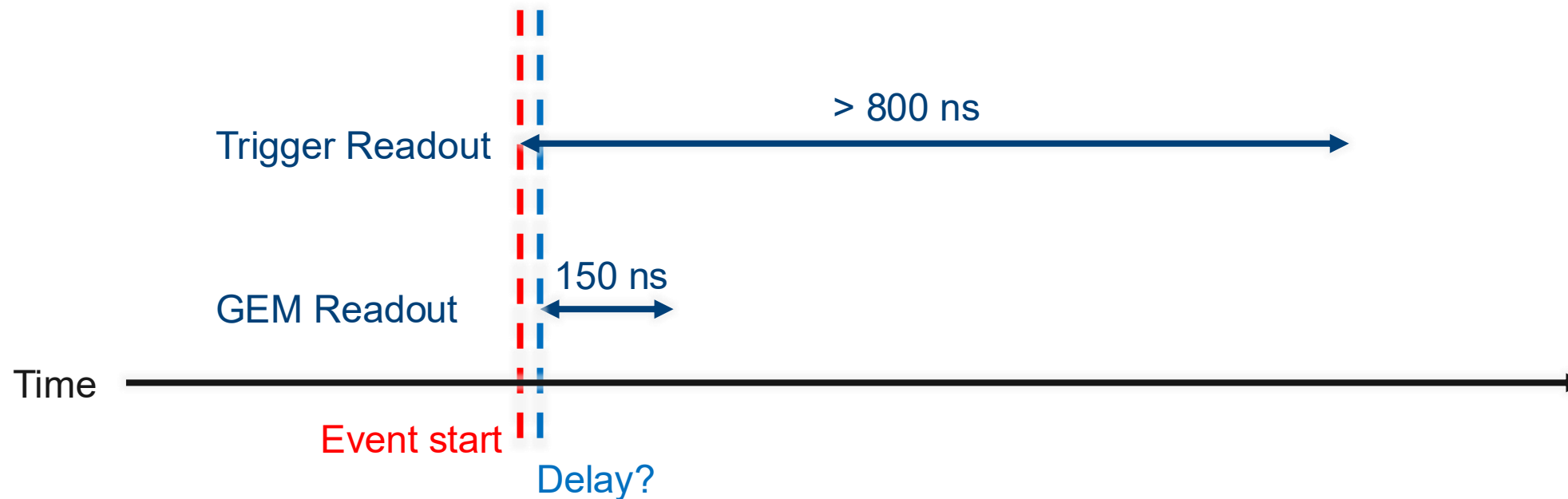
Selections: One track per event  
One trigger hit per event  
In time trigger only



## Timing Analysis

We want to match GEM clusters with trigger hits which are coincident in time.

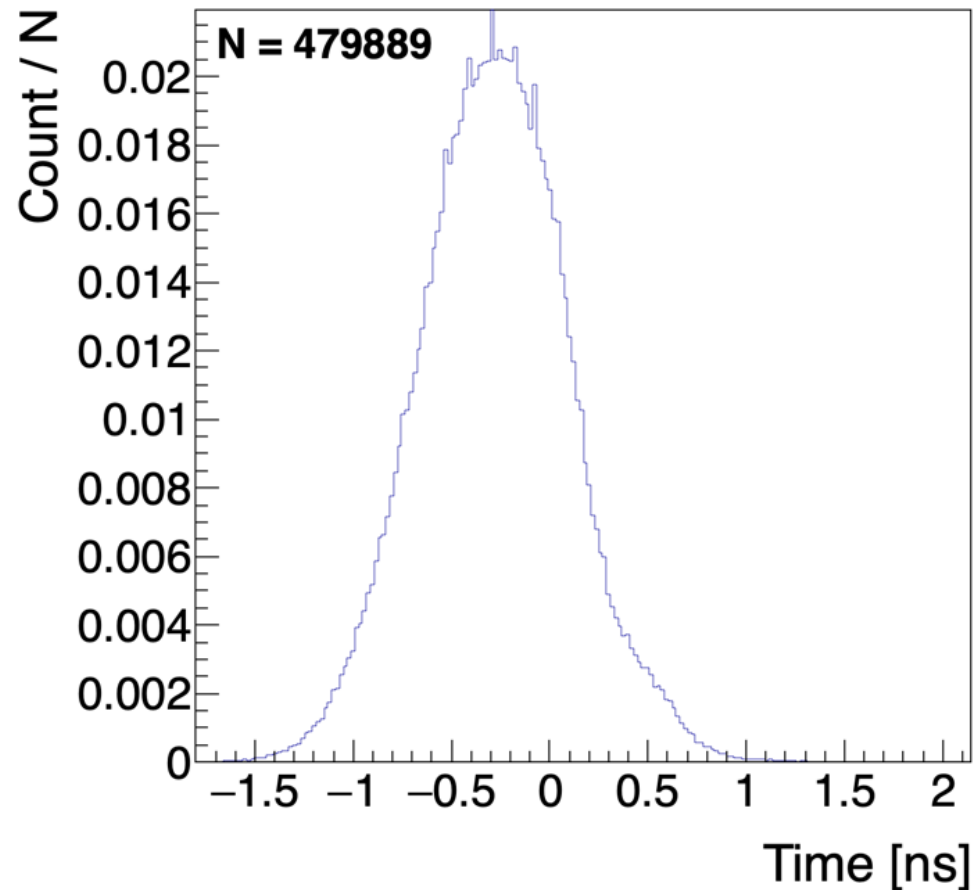
- When do GEM clusters and trigger signals get read out, relative to a particle interaction?
- What is the delay between the GEM and trigger readout, and is it constant?



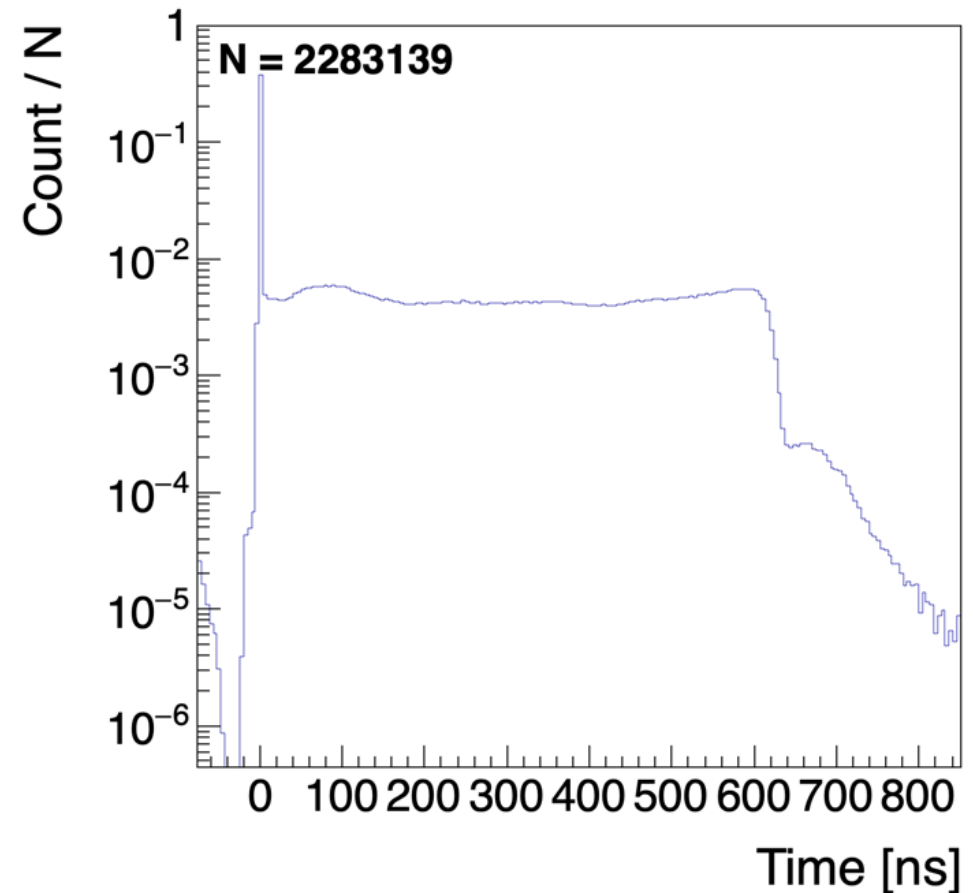
## Distribution of hit times

Times that trigger records hits relative to event readout time

Run 3932: Cosmic Right



Run 4001: Elastic Right

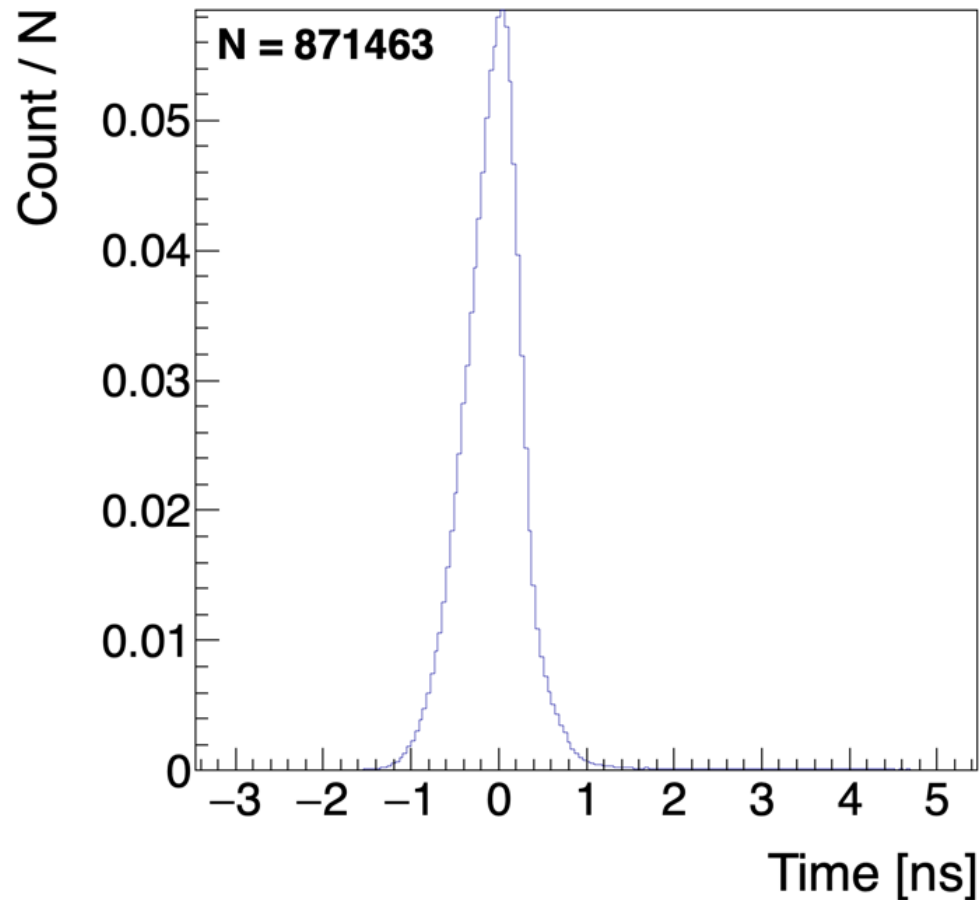


## Distribution of hit times in beam data

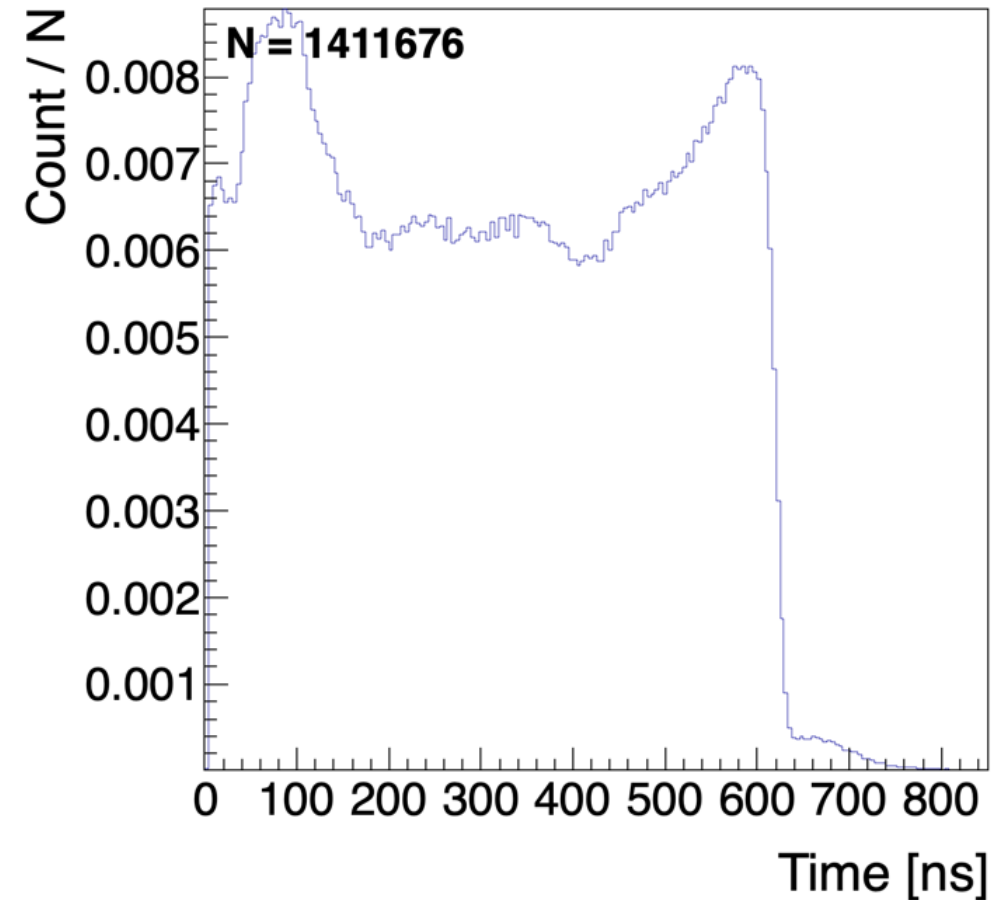
- “In time” cut = Trigger signals recorded in first  $\pm 5$  ns of readout

Run 4001  
Elastic Right

In Time



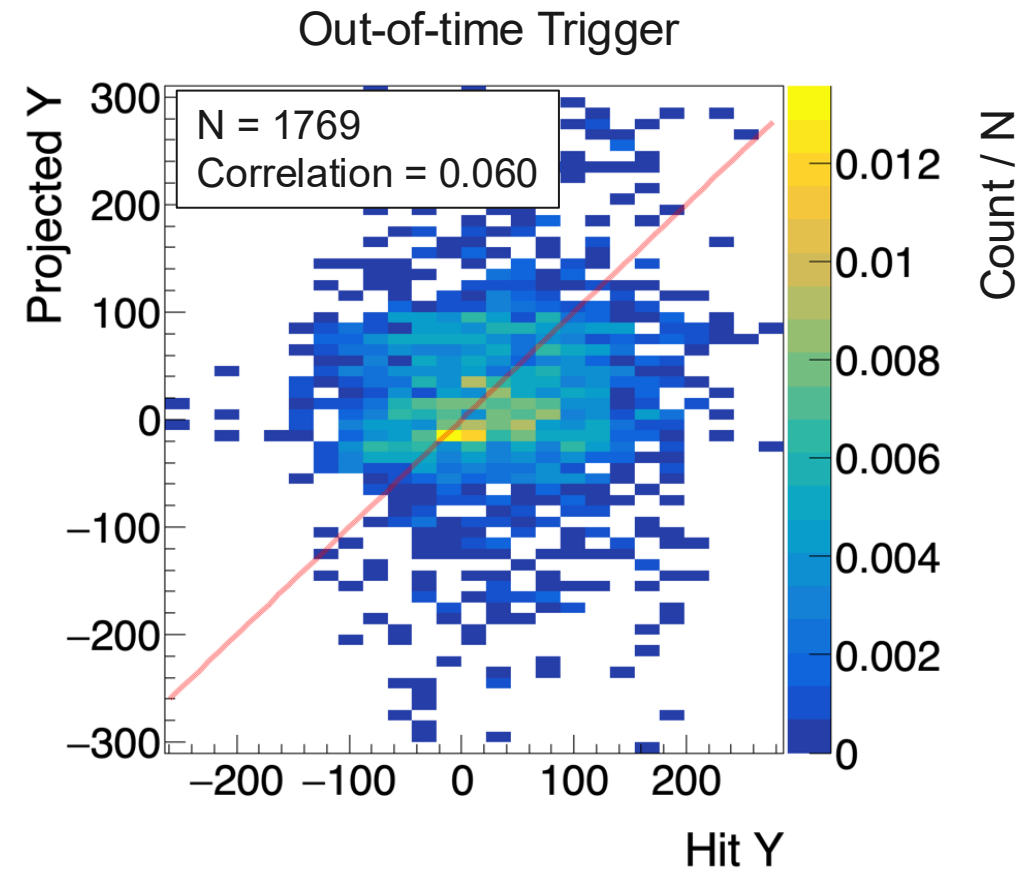
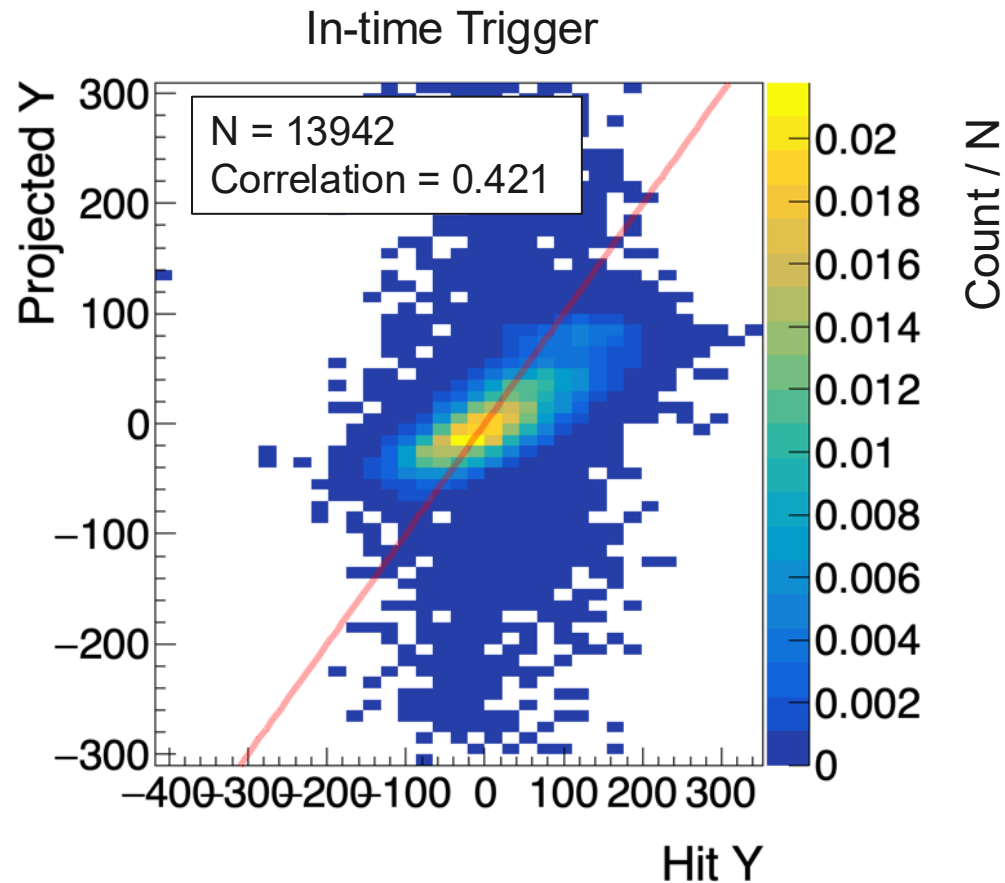
Out of Time



## Effect of the In-Time Cut

The positions of in-time trigger hits are more strongly correlated with GEM cluster projections.

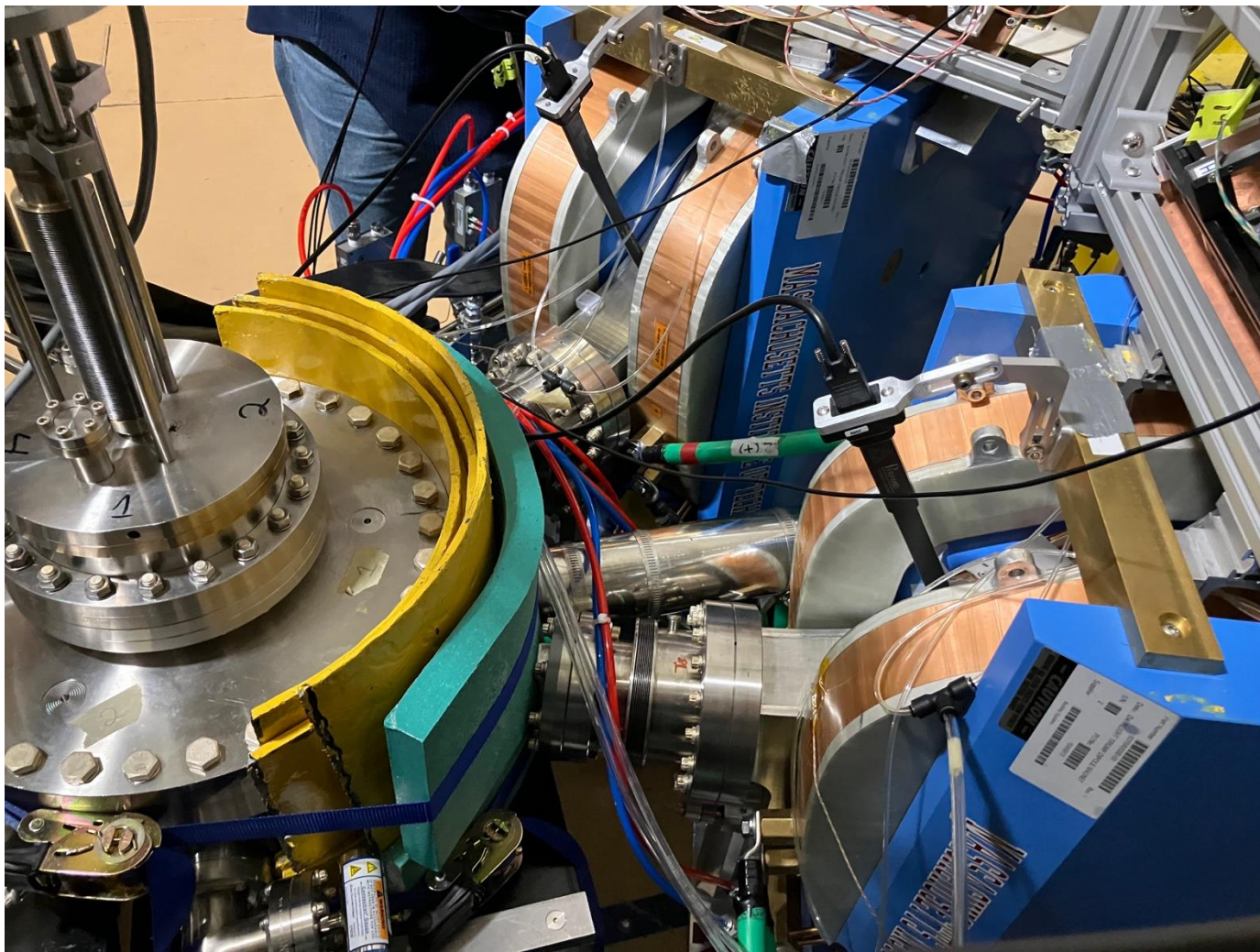
Run 4001	Elastic Right
Selections:	One track per event One trigger hit per event



- Many parts of the analysis software at all levels need work or need to be written
- Immediate next steps following this work
  - Understand timing of GEM clusters relative to trigger readout
  - Build out track reconstruction
- Goals for this year
  - Understand trigger resolution, efficiency, and noise

```
SideAnalyzer.cpp 3 x
darklight-cooker > src > plugins > analysis > GEMTrack > src > SideAnalyzer.cpp > collectTracksPrecut()
172 void SideAnalyzer::collectTracksPrecut()
173 {
174     dlTrack tempTrack;
175     // Create all possible combinations between Lower Hits and Upper Hits:
176     for (const auto &lower_hit : lower_gem_hits_master)
177     {
178         for (const auto &upper_hit : upper_gem_hits_master)
179         {
180             tempTrack.status = side;
181             tempTrack.id = (side == LEFT) ? 0 : 1;
182
183             tempTrack.position.SetXYZ(lower_hit.X(), lower_hit.Y(), lower_hit.Z());
184             tempTrack.direction = (upper_hit - lower_hit).Unit();
185
186             tempTrack.gem_hits_master[0] = lower_hit;
187             tempTrack.gem_hits_master[1] = upper_hit;
188
189             // ----- Daniel wanted lower_hit and upper_hit in local coordinates as well
190             double lower_hit_master[3]{lower_hit.X() / 10.0, lower_hit.Y() / 10.0, lower_hit.Z() /
191             double lower_hit_local[3]{0.0, 0.0, 0.0};
192
193             if (side == LEFT)
194                 handle->Left_GEM[0]->MasterToLocal(lower_hit_master, lower_hit_local);
195             else if (side == RIGHT)
196                 handle->Right_GEM[0]->MasterToLocal(lower_hit_master, lower_hit_local);
197             tempTrack.gem_hits_local[0] = TVector3(lower_hit_local[0] * 10, lower_hit_local[1] * 10
198
199             double upper_hit_master[3]{upper_hit.X() / 10.0, upper_hit.Y() / 10.0, upper_hit.Z() /
200             double upper_hit_local[3]{0.0, 0.0, 0.0};
201             if (side == LEFT)
202                 handle->Left_GEM[1]->MasterToLocal(upper_hit_master, upper_hit_local);
203             else if (side == RIGHT)
204                 handle->Right_GEM[1]->MasterToLocal(upper_hit_master, upper_hit_local);
205             tempTrack.gem_hits_local[1] = TVector3(upper_hit_local[0] * 10, upper_hit_local[1] * 10
206             // ----- Daniel's part ends here -----
207
208             tempTrack.dxdy[0] = upper_hit.X() - lower_hit.X();
209             tempTrack.dxdy[1] = upper_hit.Y() - lower_hit.Y();
210
211             // STEP 1: Get trigger plane equation (using Paddle 0) - initialize it for now
212             std::array<double, 4> plane_equation = paddle_coordinates[0].m;
213
214             // STEP 2: Compute intersection point with trigger plane:
215             TVector3 P0 = tempTrack.position;
216             TVector3 dir = tempTrack.direction;
217             TVector3 n(plane_equation[0], plane_equation[1], plane_equation[2]);
```

# Questions and Discussion



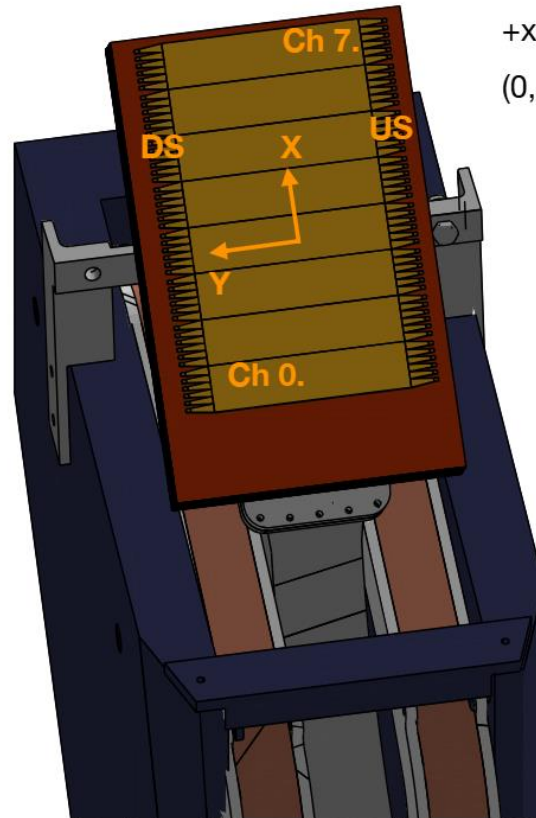
**Backup**

- 1M events each
- GEMs at 3950V

\*Many dead strips in left bottom GEM

Run	Date	Setup	Readout	Dipole	Beam
3622*	4 Jan 2026	Cosmic	L+Trig	--	--
3932	15 Jan 2026	Cosmic	R+Trig	--	--
4001	21 Jan 2026	e-e-	R+Trig	0/95	15 MeV, 5uA, 13us, 1.5%, 1100Hz
4010	``	e-e-	L+Trig	95/0	``
4026	``	e-e-	Full	90/30	``
4034	``	e-e-	Full	12.8/90	``

## Trigger paddle local coordinate:



+z: out of the trigger plane away from magnets

+y: left along the long side of paddle

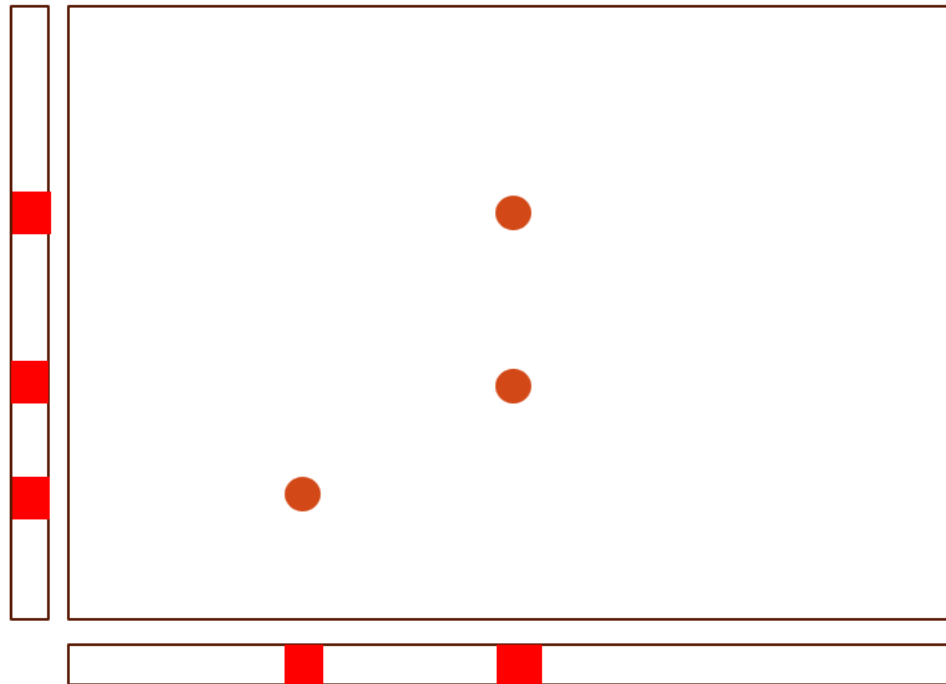
+x: Up along the short side of paddle

(0, 0, 0): center of the paddle

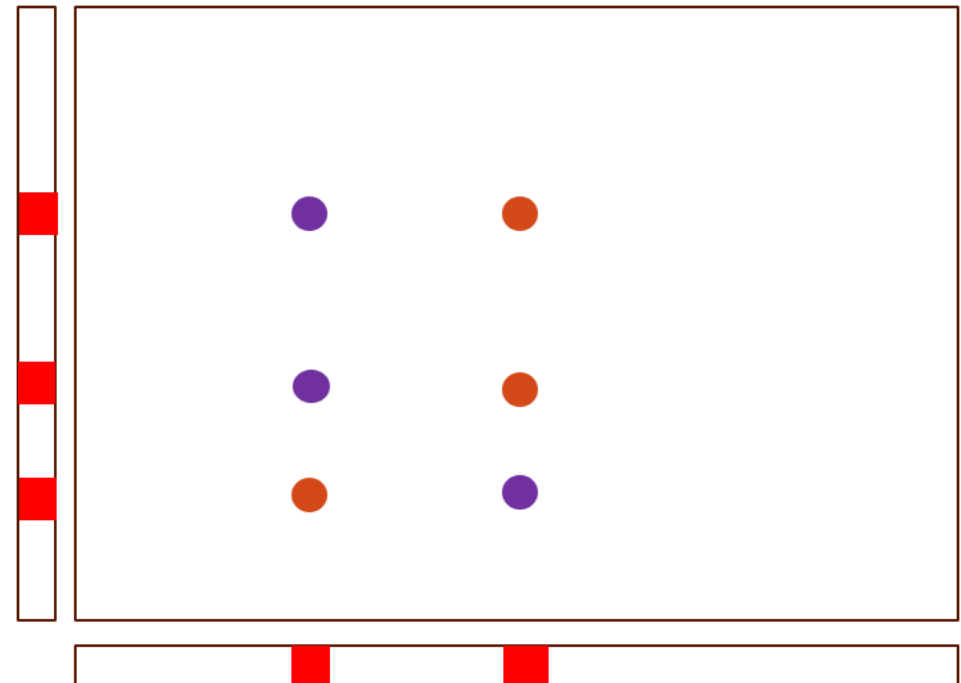
-Y = Non-Dispersive Coordinate

X = Dispersive Coordinate  
(proportional to paddle number)

- 1D clusters identified along X and Y axes (see Andy’s report)
- 2D clusters defined as all possible combinations of X and Y clusters



**Locations of physical particle interactions**



**Recorded 2D positions of GEM clusters**

*What is a “trigger hit”?*

- Trigger paddle records two signals left (L) and right (R)
  1. L and R pulse times must be coincident within  $\pm 6$  ns
  2. L and R must have pulse widths 20-60 ns

*What does “in-time” mean?*

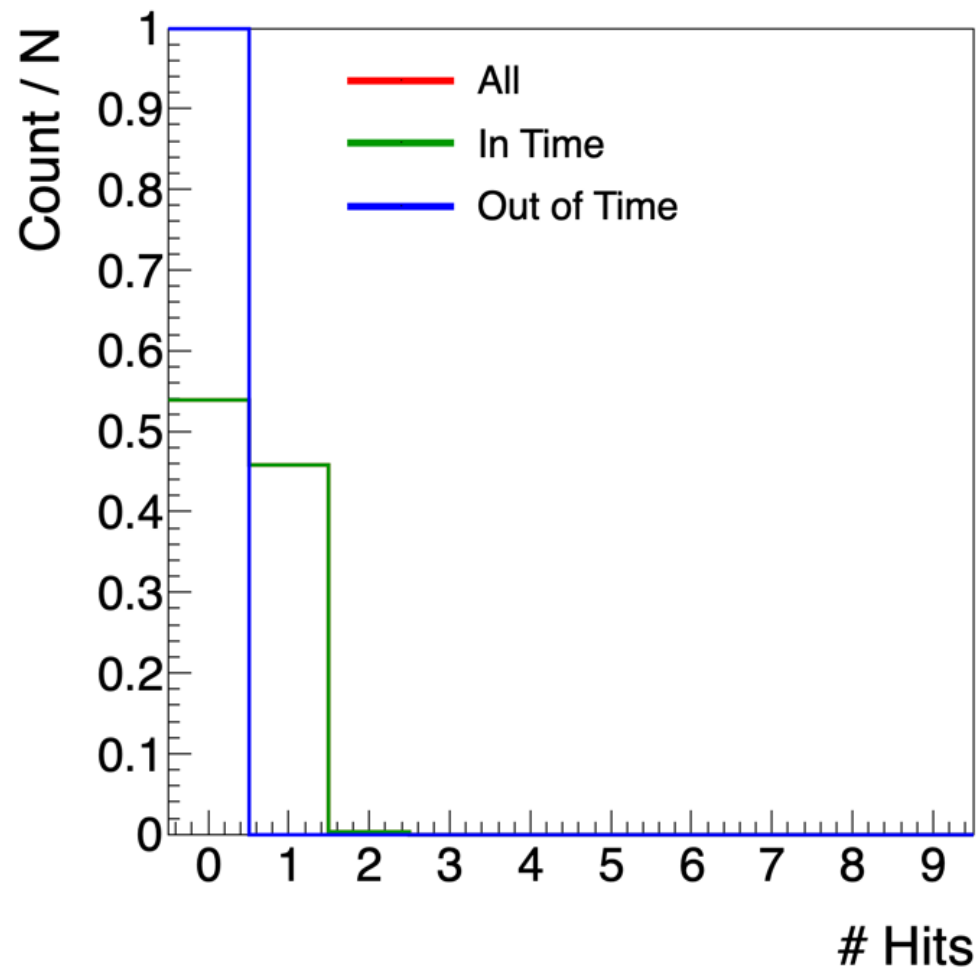
- Trigger hit is “in time” if L and R are both within  $\pm 5$  ns of event reference time

- Trigger Analysis
  - Time decoding – **done**
  - Hit position calculation – **done but needs work**
  - Hit timing calculation – **done but needs work**
  - Noise analysis – **work in progress**
  - Resolution and efficiency analysis – **not done**
- GEM Analysis
  - Cluster identification - **done but needs work**
  - Resolution, efficiency, and noise analysis – **work in progress**
  - Cluster 2D position disambiguation – **not done**
  - Cluster timing estimation – **not done**
- Track identification
  - Spatial matching of GEM hits – **done**
  - Spatial matching of GEM and trigger hits – **work in progress**
  - Temporal matching of GEM and trigger hits – **not done**
- Track selection
  - Timing requirements – **work in progress**
  - Angle and trajectory cuts – **work in progress**
  - Addressing track overlap issues – **not done**

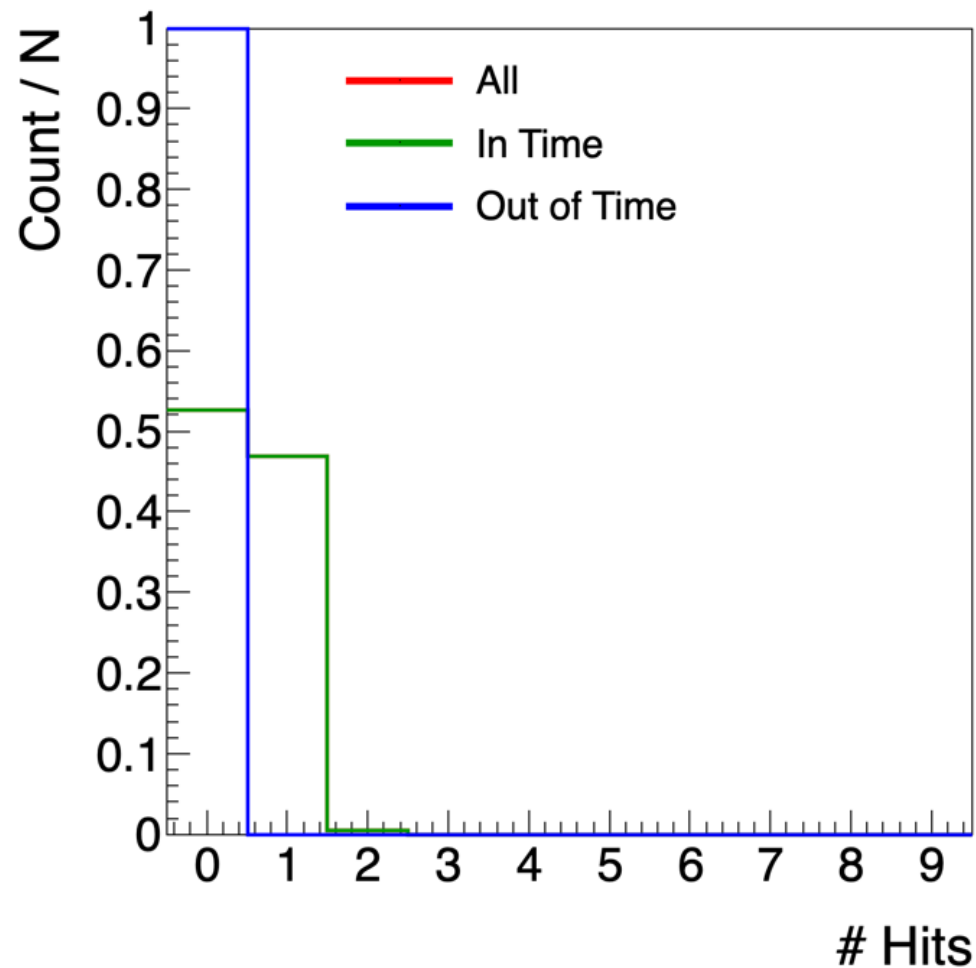
# Trigger Hit Multiplicity

## Trigger Hit Multiplicity

Run 3622: Cosmic Left

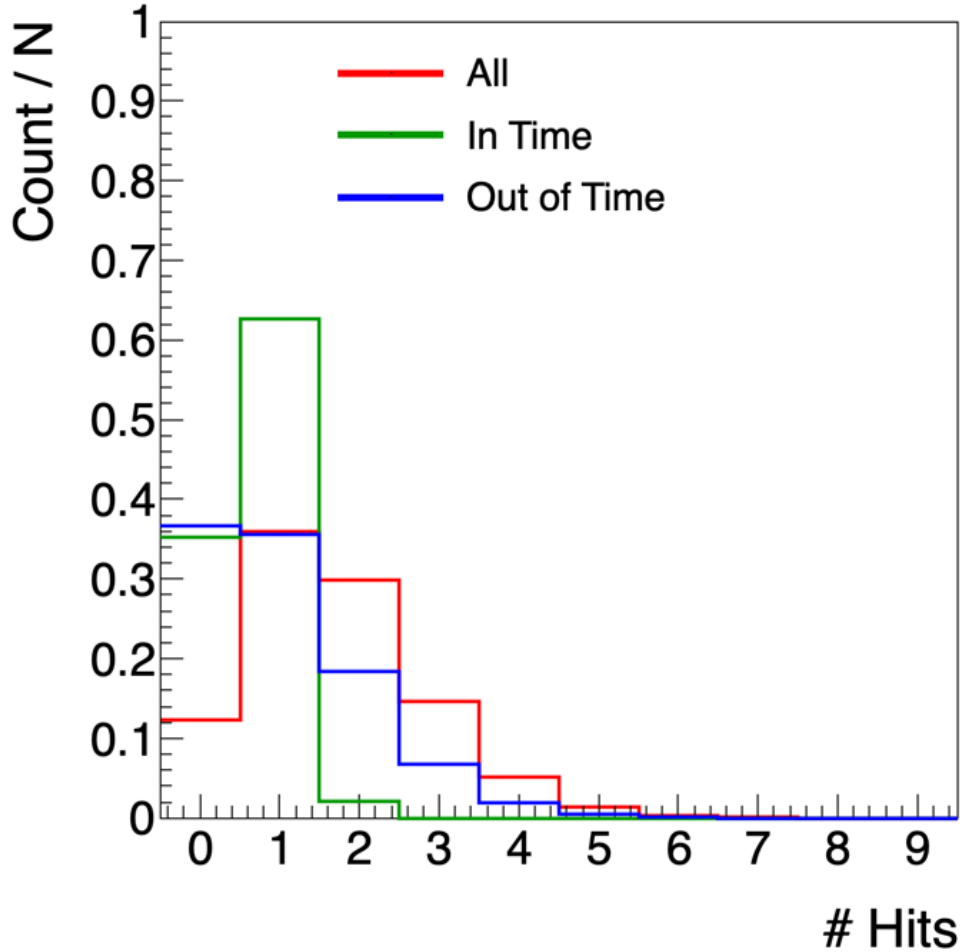


Run 3932: Cosmic Right

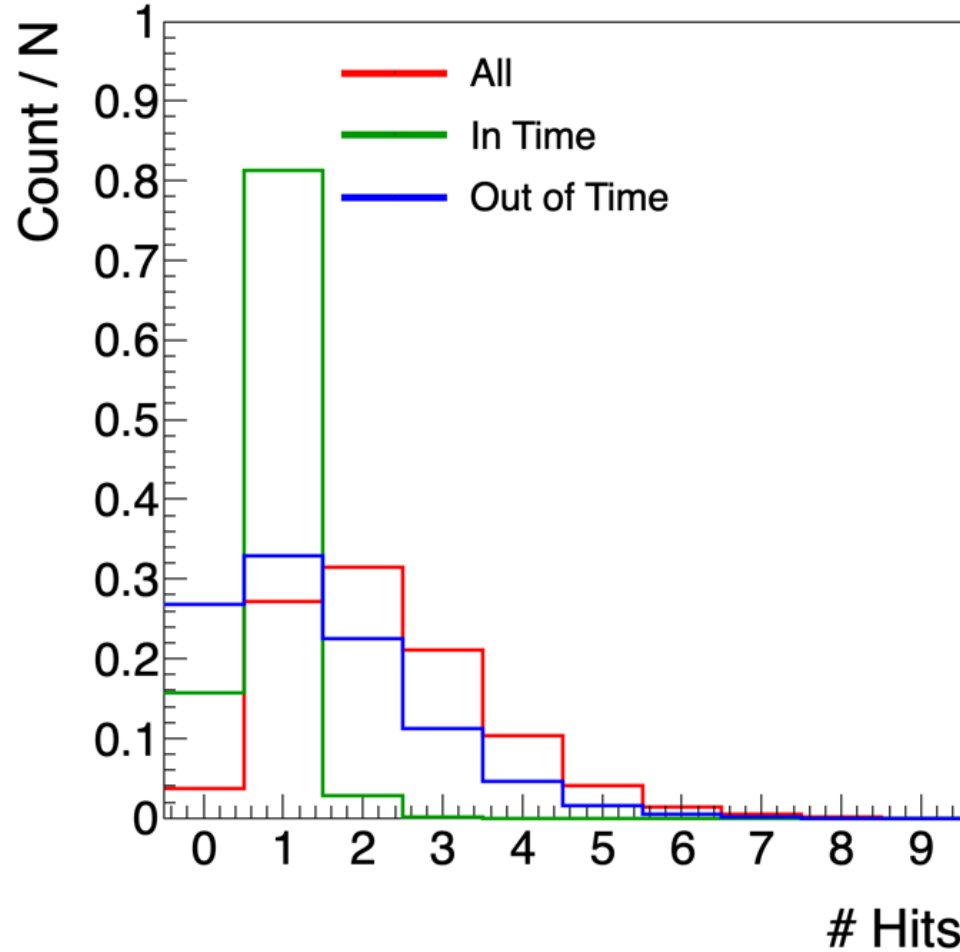


### Trigger Hit Multiplicity

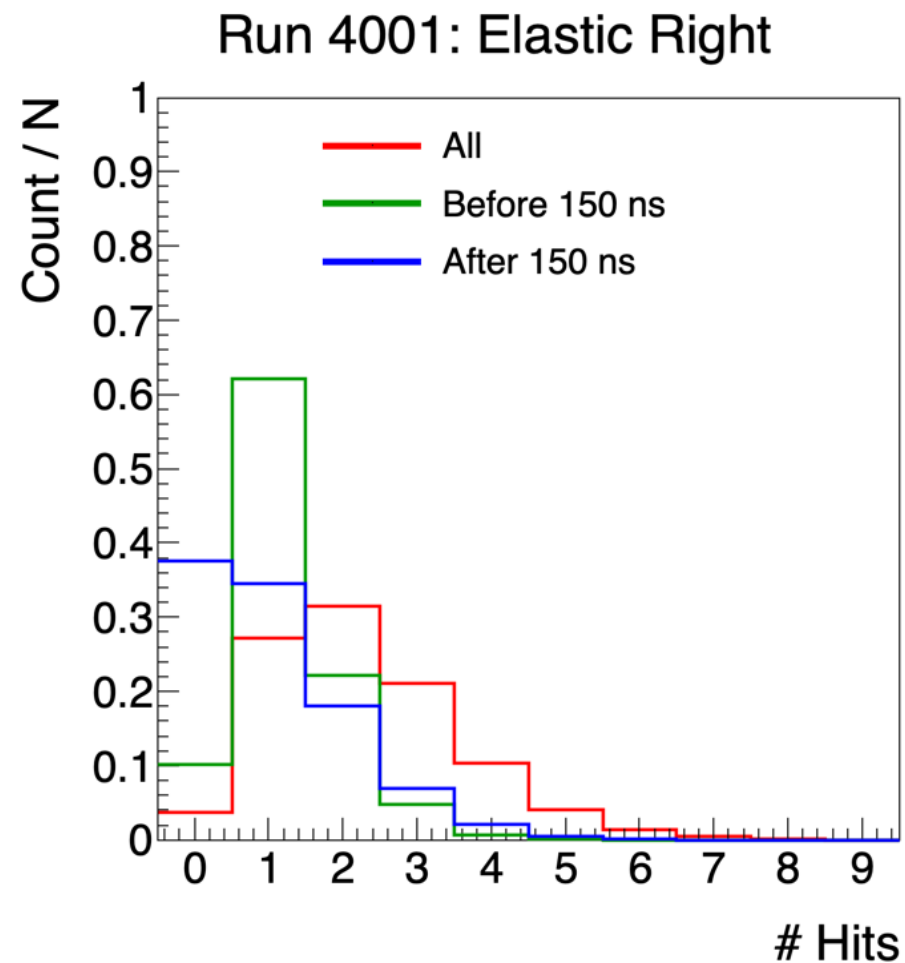
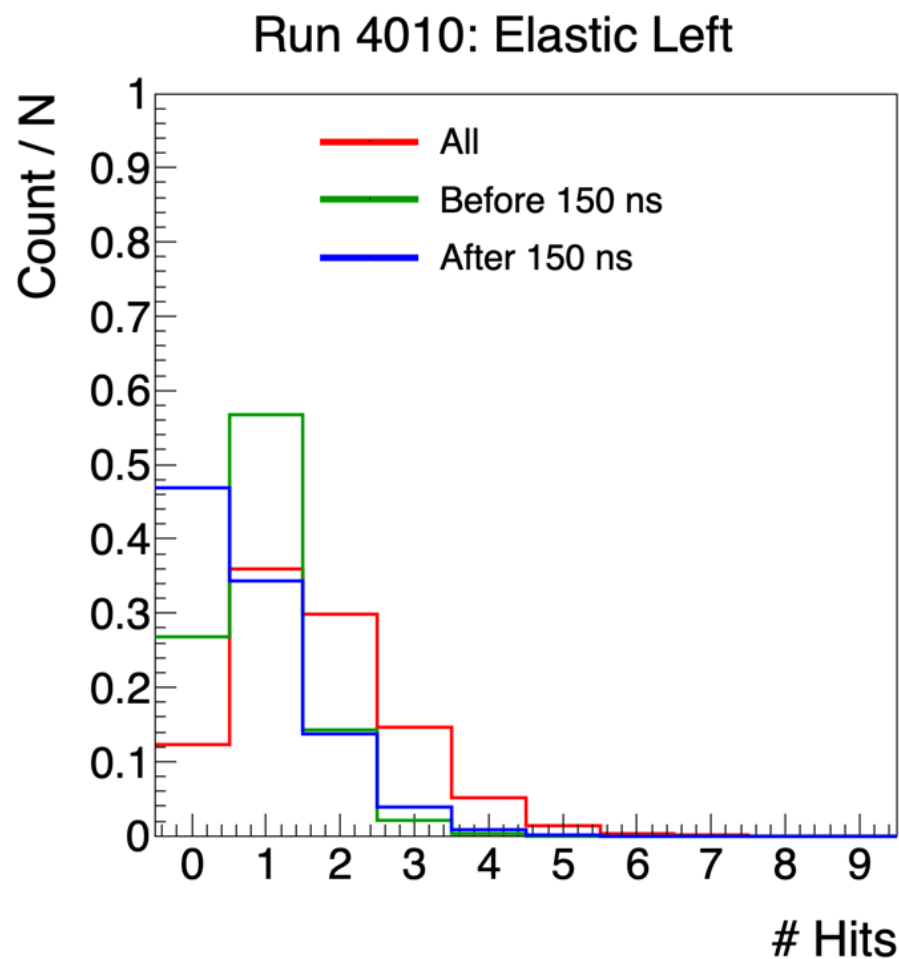
Run 4010: Elastic Left



Run 4001: Elastic Right

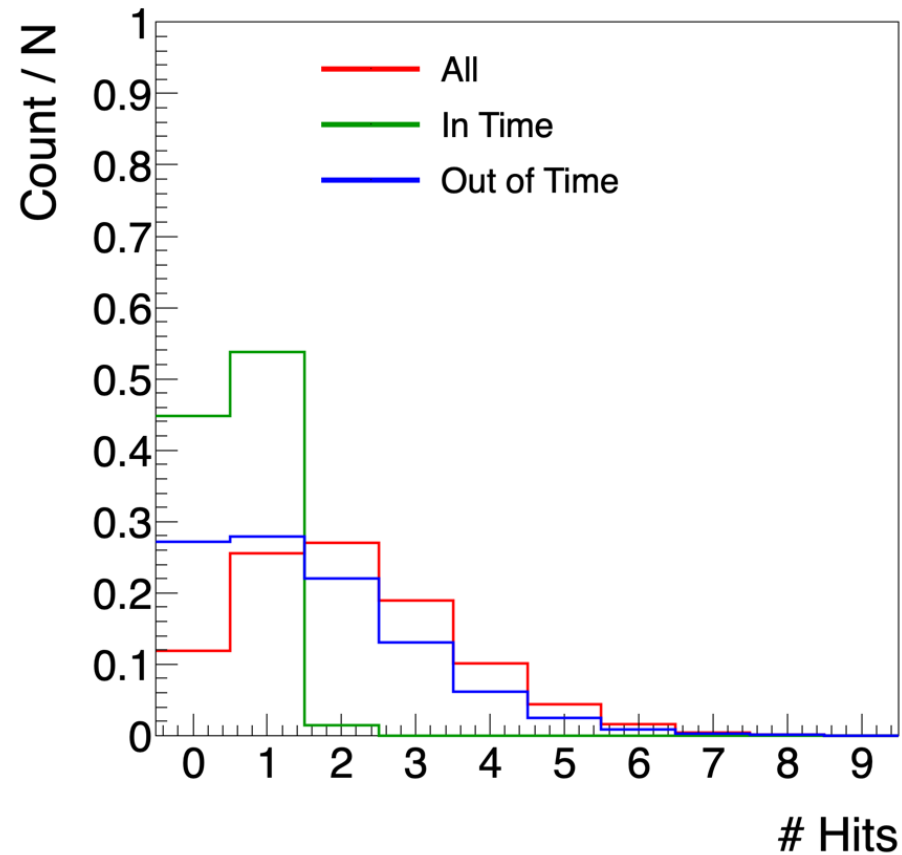


## Trigger Hit Multiplicity

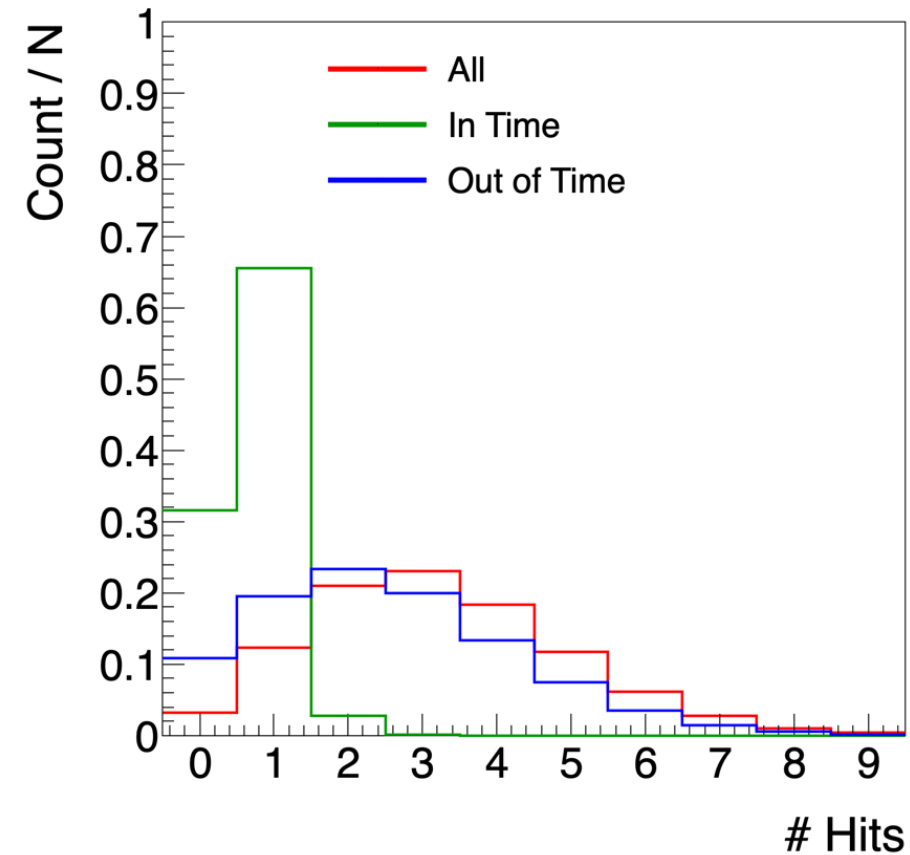


## Trigger Hit Multiplicity

Run 4034: Moller Left

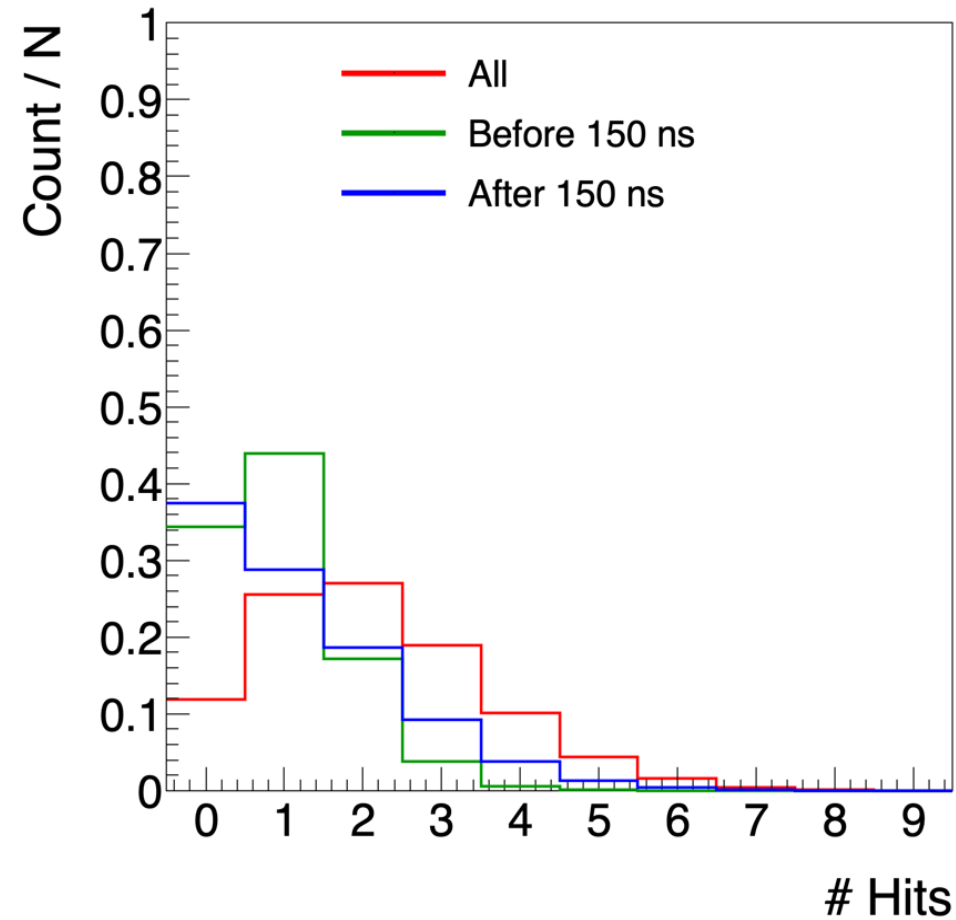


Run 4026: Moller Right

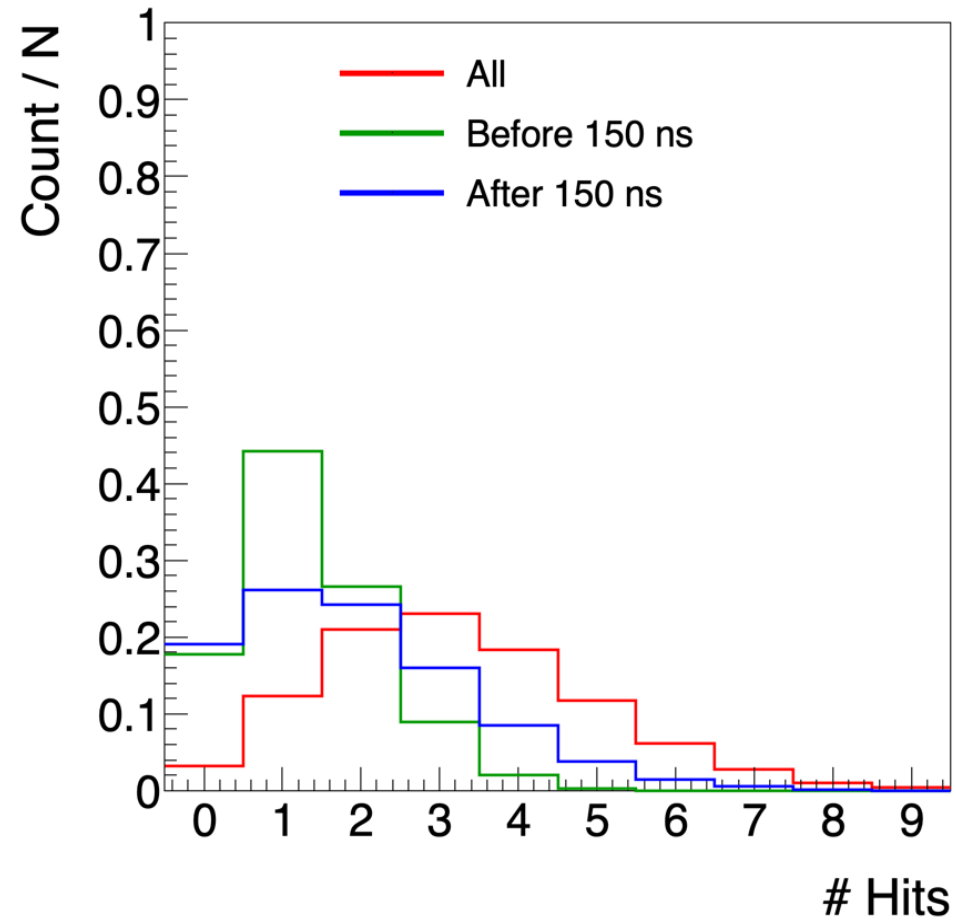


## Trigger Hit Multiplicity

Run 4034: Moller Left



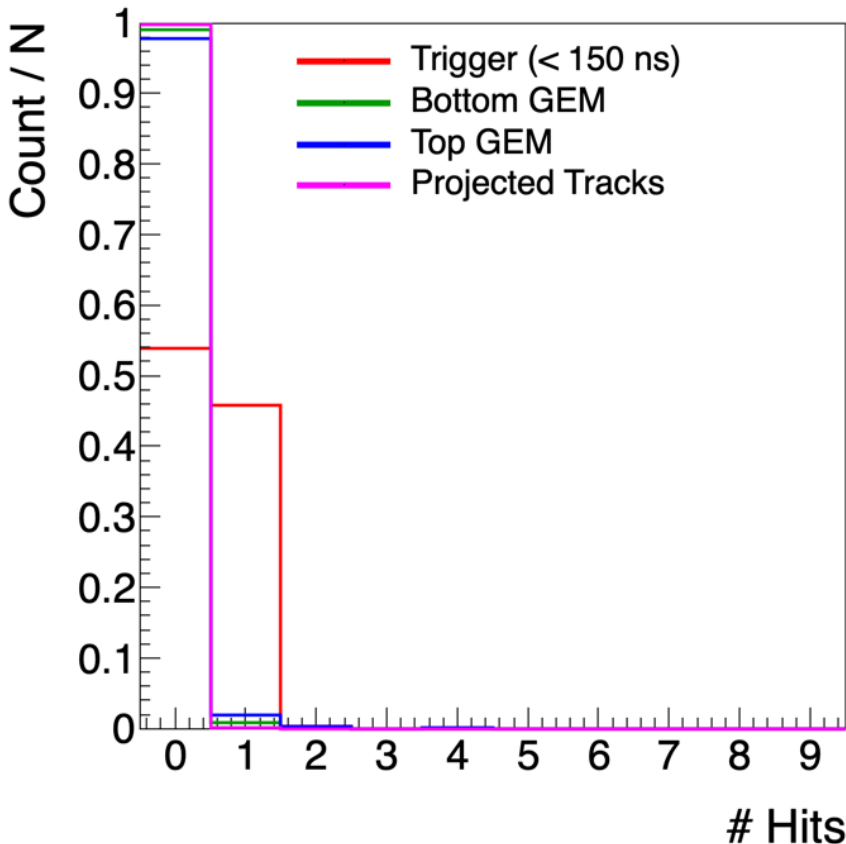
Run 4026: Moller Right



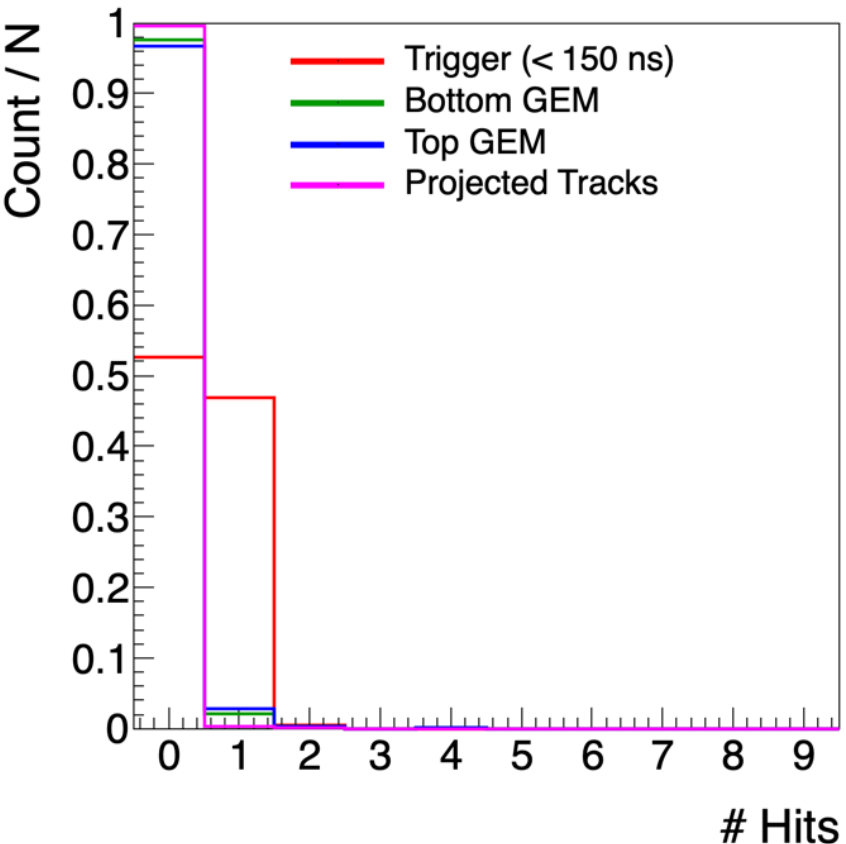
# Detector Multiplicity

## Detector Hit Multiplicity

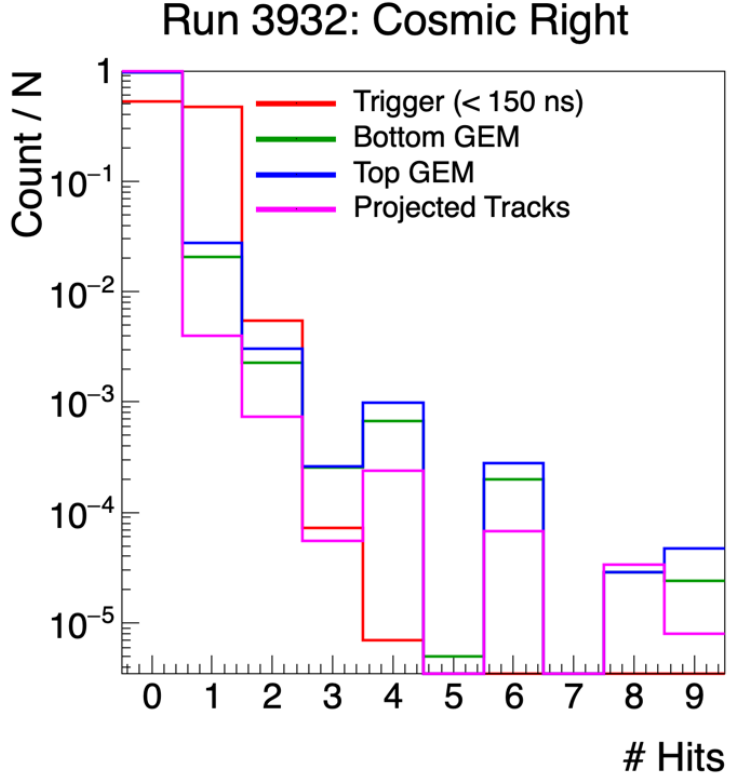
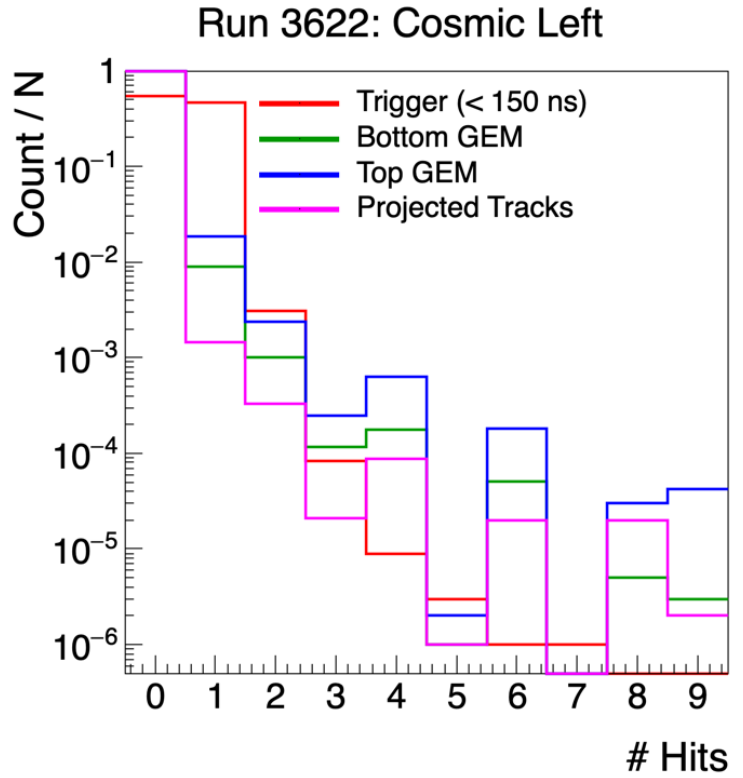
Run 3622: Cosmic Left



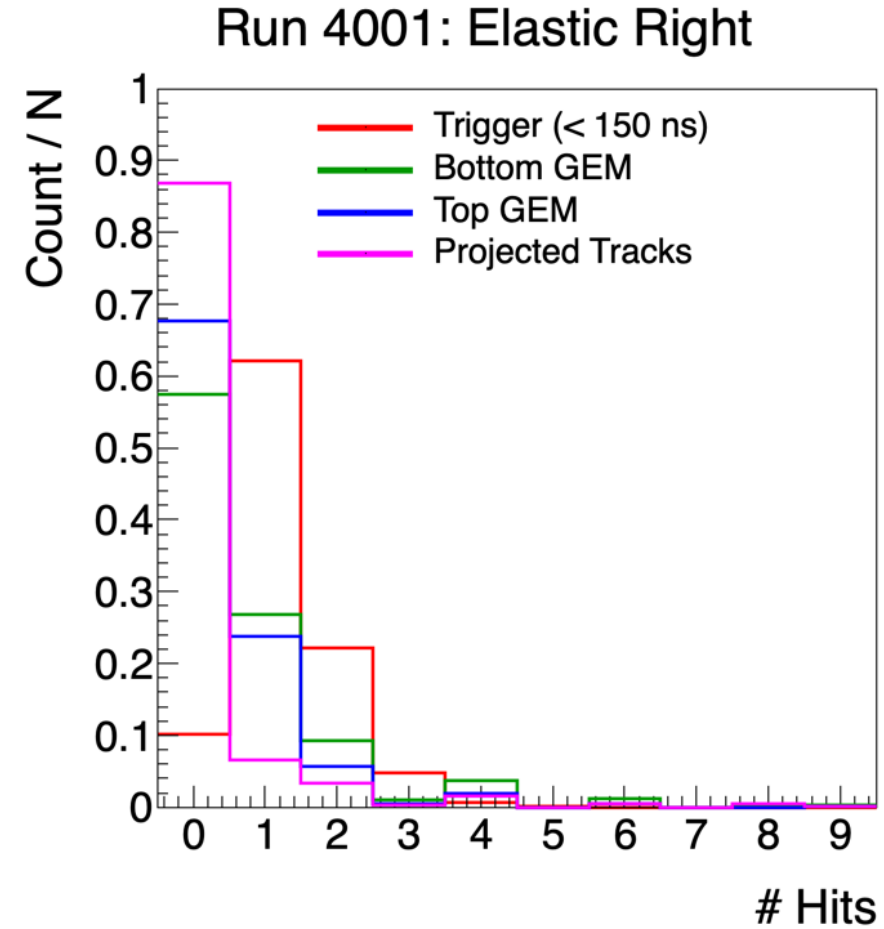
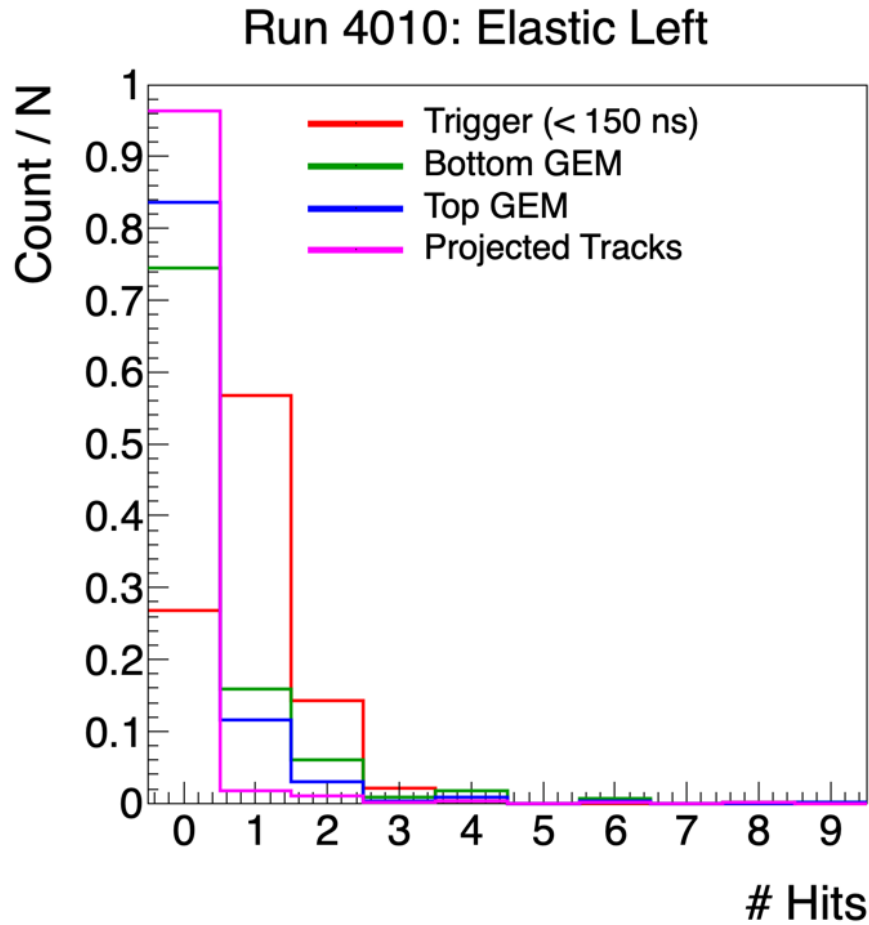
Run 3932: Cosmic Right



## Detector Hit Multiplicity



## Detector Hit Multiplicity



## Detector Hit Multiplicity

