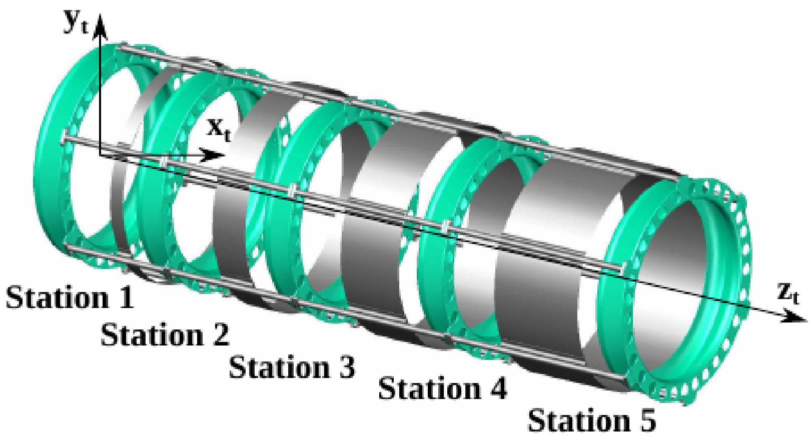
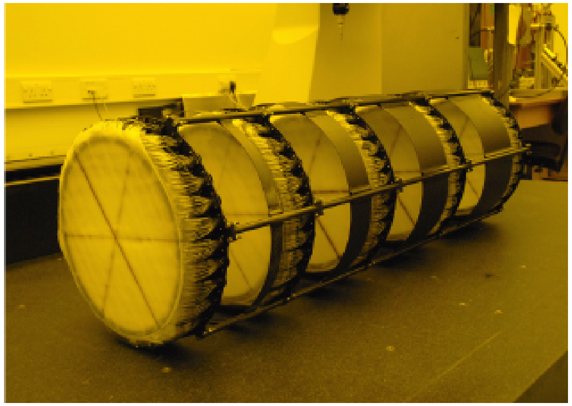
Emittance Evolution Update





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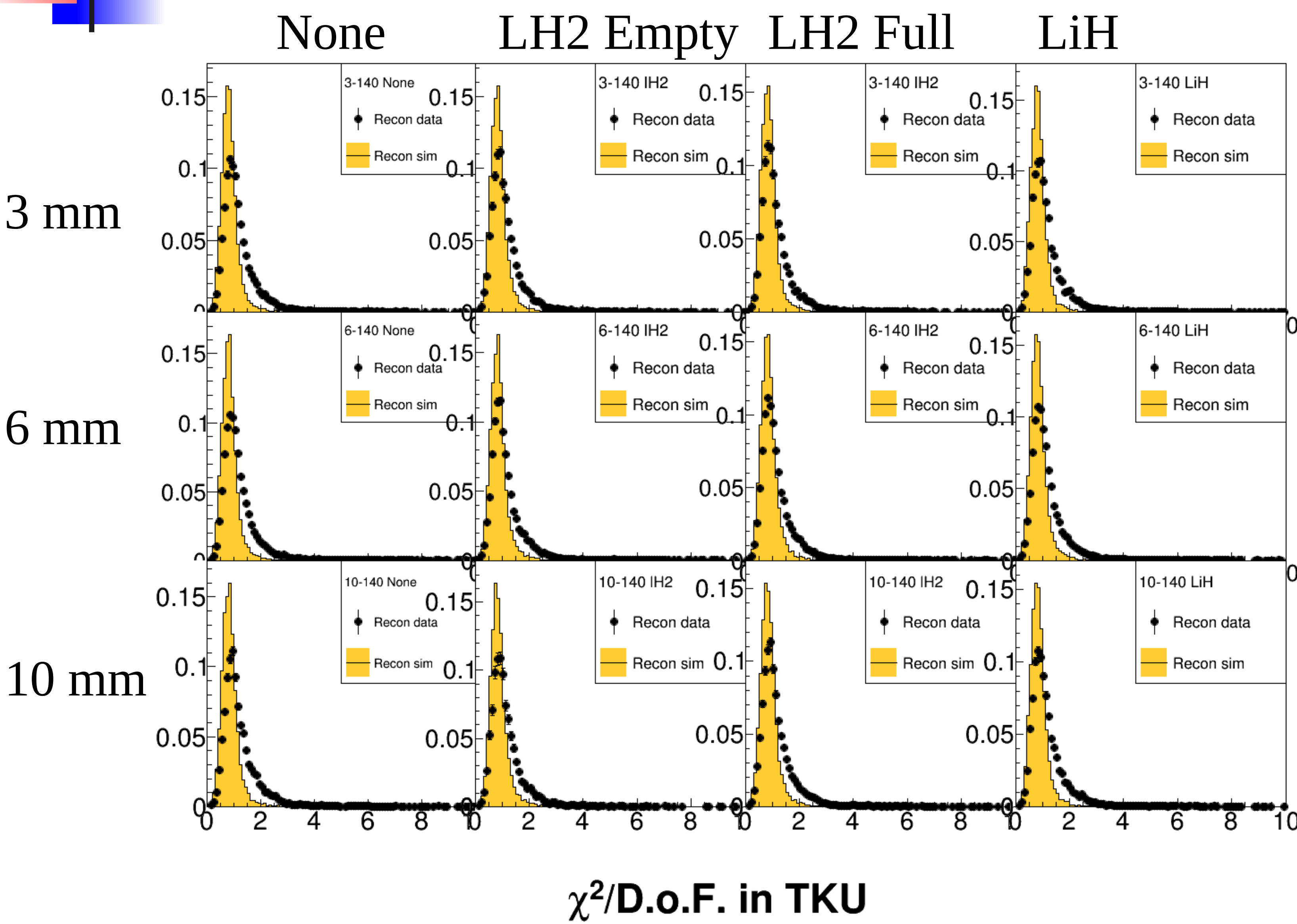
Status

- Since CM50
  - Characterised tracker noise; optimised NPE cut and added dark current model
  - Fixed and tuned tracker density issue
  - Implemented routine to enhance statistical sample for MC
  - Systematic uncertainties due to tracker misalignment, field non-uniformity

Chi2/dof (from CM50)

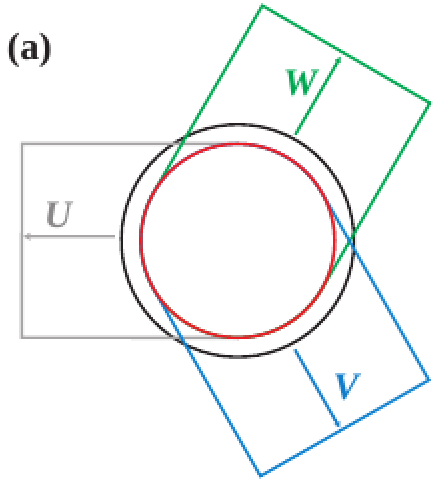


Sources of uncertainty

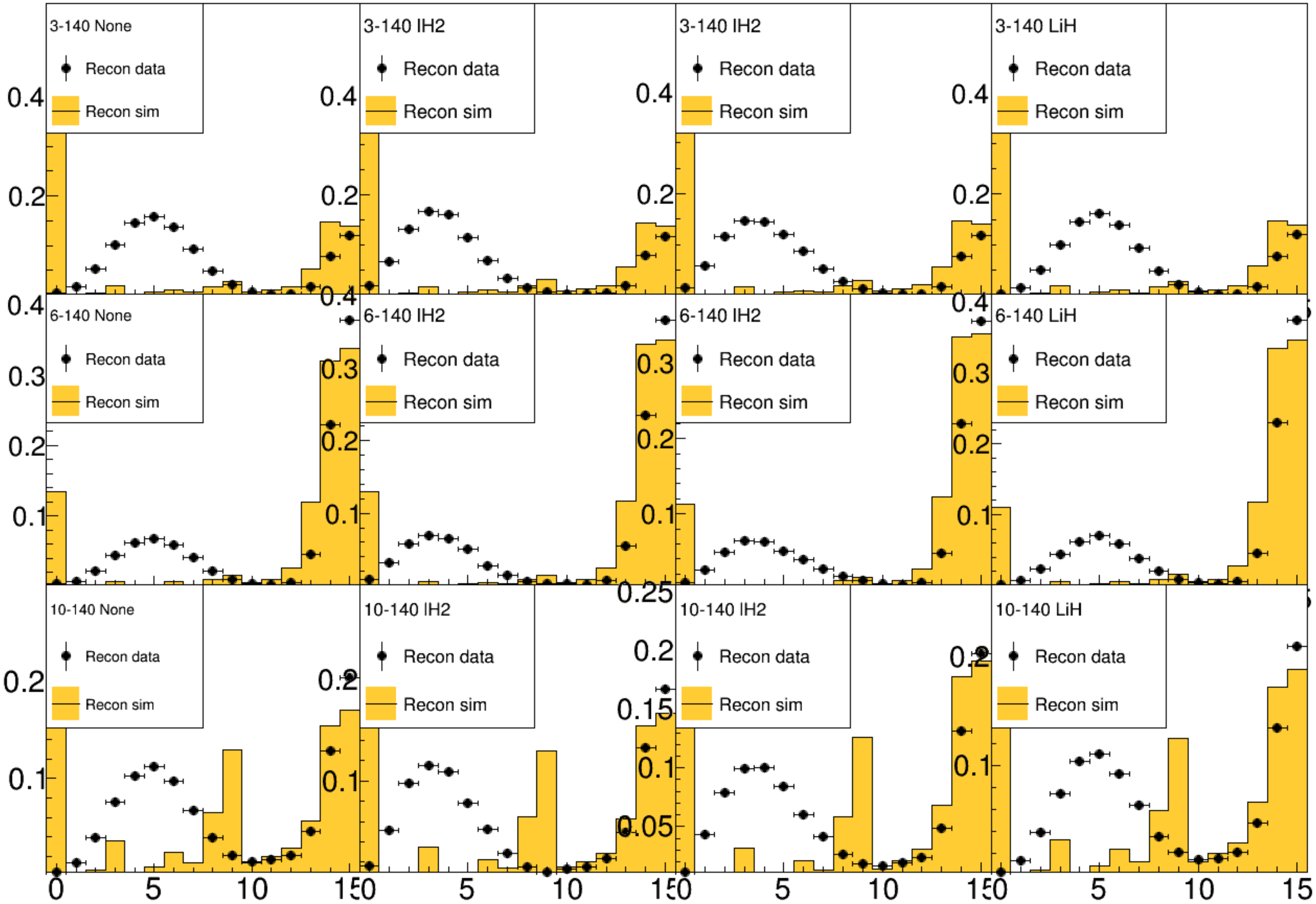
- Oh no!
  - E.g. 3-140 lH2 empty setting
    - MC has peak at 0.8; mean 0.9
    - Data has peak at 0.9; mean 1.2 → longer tail
- What are sources of uncertainty?
  (1) Scattering and energy straggling in reconstruction
  (2) Field non-uniformity
  (3) Tracker rotation compared to solenoid field
  (4) Detector noise
- (1) and (2) have reasonable model in MAUS
- (3) – I believe Chris Hunt has studied and found no effect
- What about detector noise?

Reminder of tracker recon

- Electronics signal makes a “digit”
- Neighbouring “digits” in the same plane make a “cluster”
  - Channel number → distance across the plane
- Crossings of “clusters” in a plane make “space points”
  - Two of three “clusters” makes a “doublet”
  - Three of three “clusters” makes a “triplet”
  - Space point has x-y-z coordinate
- Reject spurious space points using naive helix fit
  - “Pattern Recognition”
- Make a full fit to get the “best” fitted track



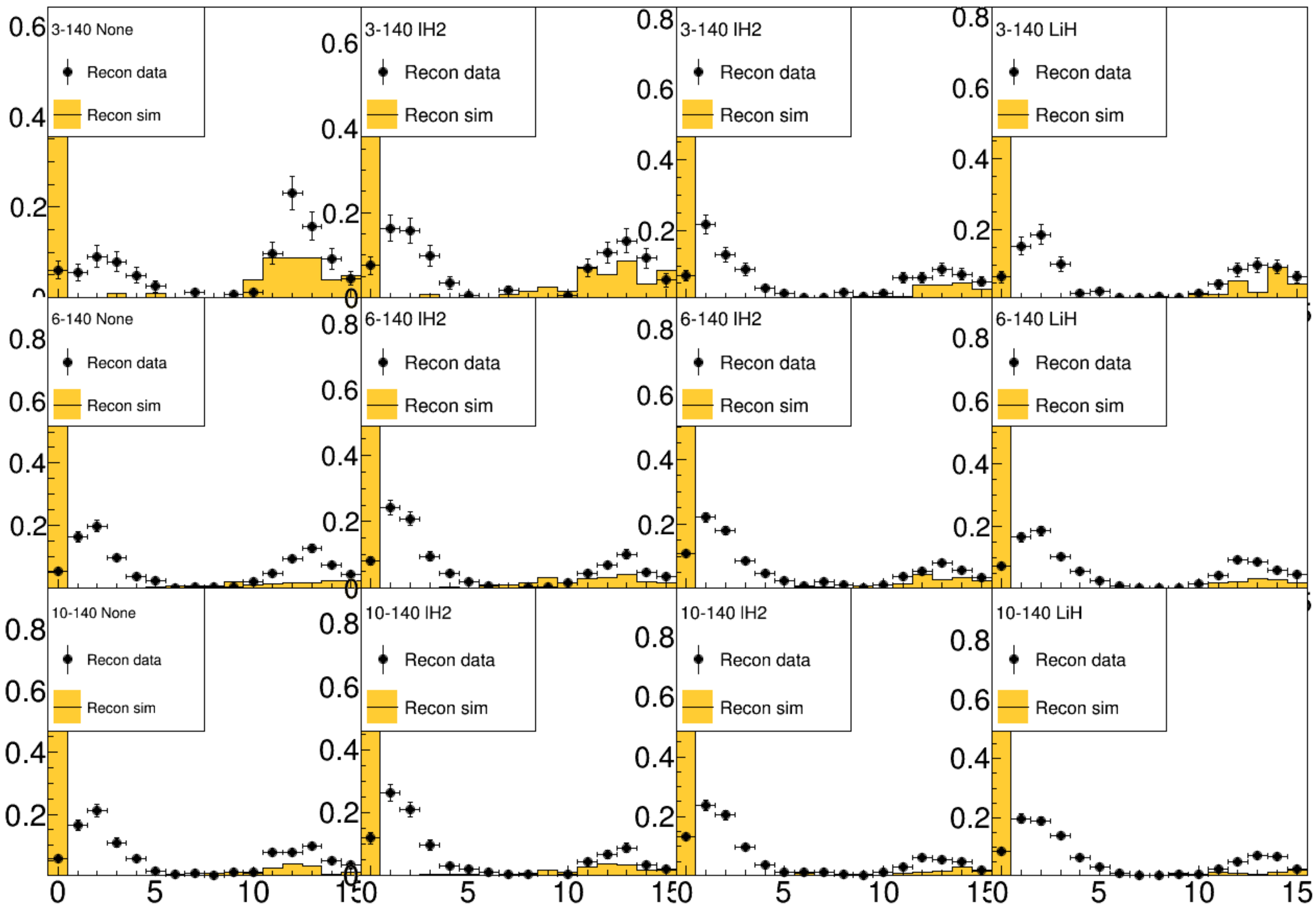
TKU clusters (from CM50)



Number of planes with clusters in TKU

For events that DO NOT form a track

TKD clusters (from CM50)



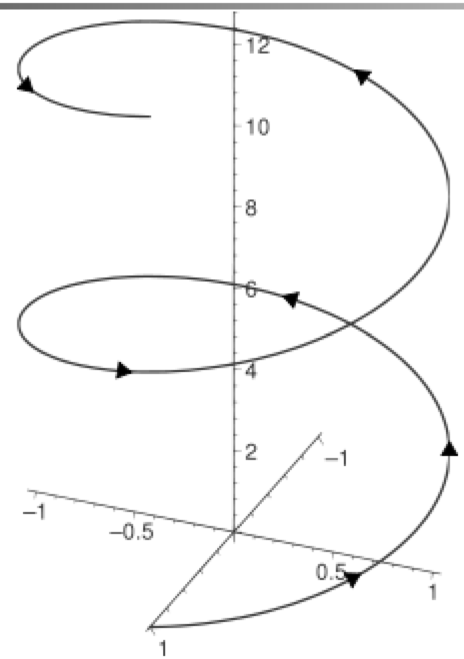
Number of planes with clusters in TKD

For events that DO NOT form a track

Detector noise

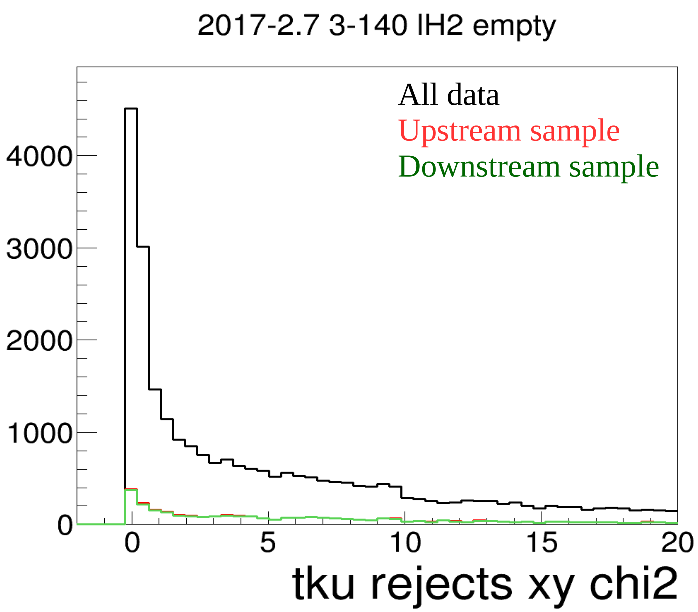
- There is no tracker noise model active in MAUS by default
  - But is noise an issue?
  - How much noise is there anyway?
  - If we switch on MC noise, is it right?
- Seek to decide if noise is significant contributor to resolution
  - Look at pattern recognition (PR)
  - Is PR rejecting space points as noise that could have made good tracks?
- Seek to characterise the noise in the data, and then ensure MAUS correctly reflects this effect

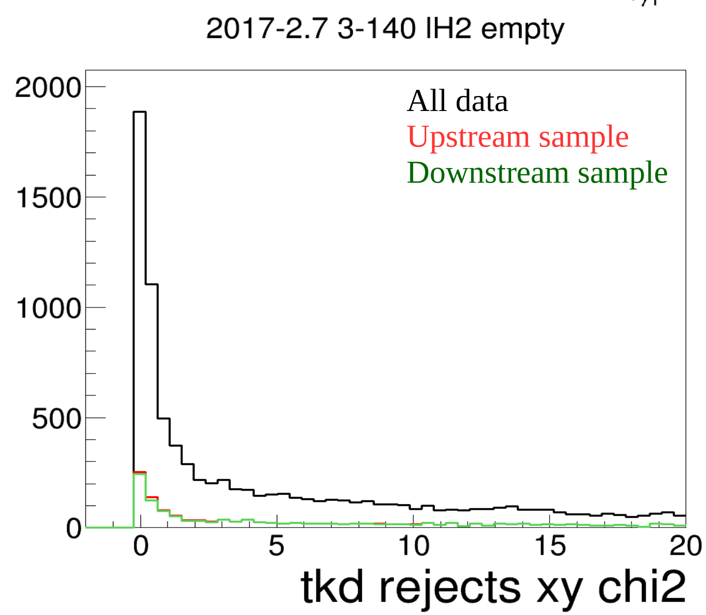
PR Routine



- PR Routine
  - Attempts to fit a circle to the projected space points in xy and returns xy_chi2
  - Attempts to fit a line to the space points in sz and returns sz_chi2
    - S is the distance between points around the circumference
  - Tries the fit over every possible combination of 5 and 4 space point tracks
  - Picks the lowest (sz_chi2)+(xy_chi2)
    - All "unused" space points are assumed to be "noise"

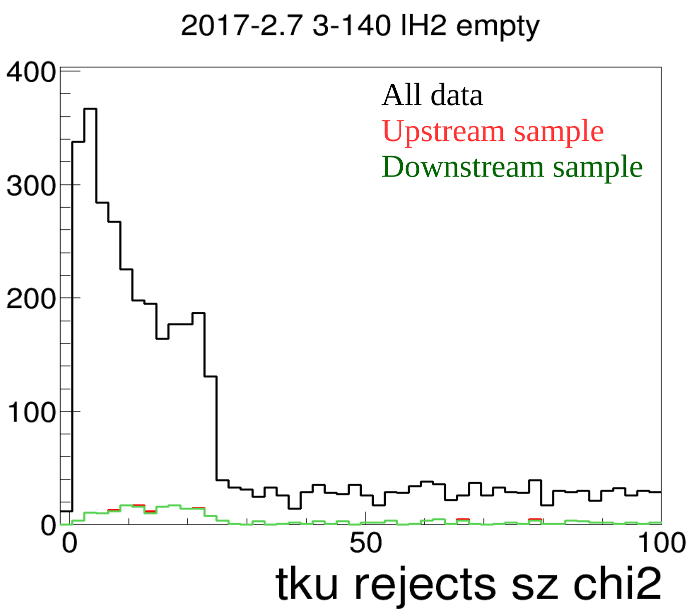
Pattern recognition

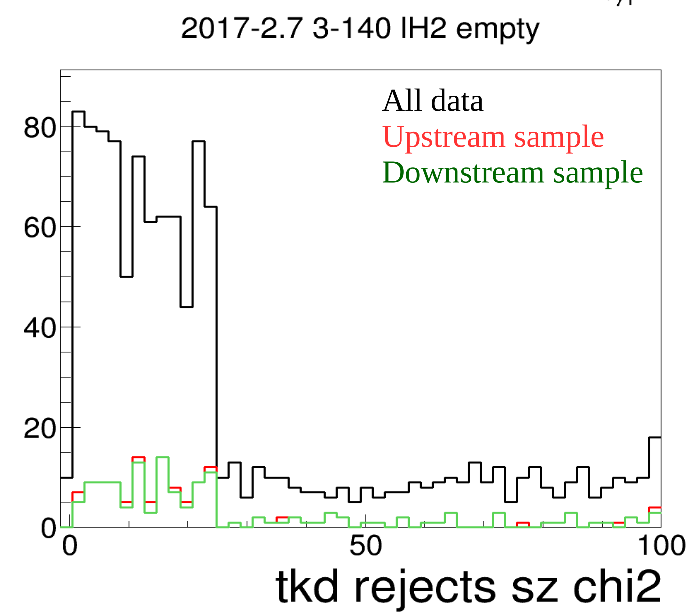




- Circle fit returns a chi2 value
  - Chi2 < 10 => accept track
- Plot Chi2 distribution of the second best 5 space point PR track candidate
  - This is the best candidate that did not make a track
  - “5 space point candidates only” to avoid double counting

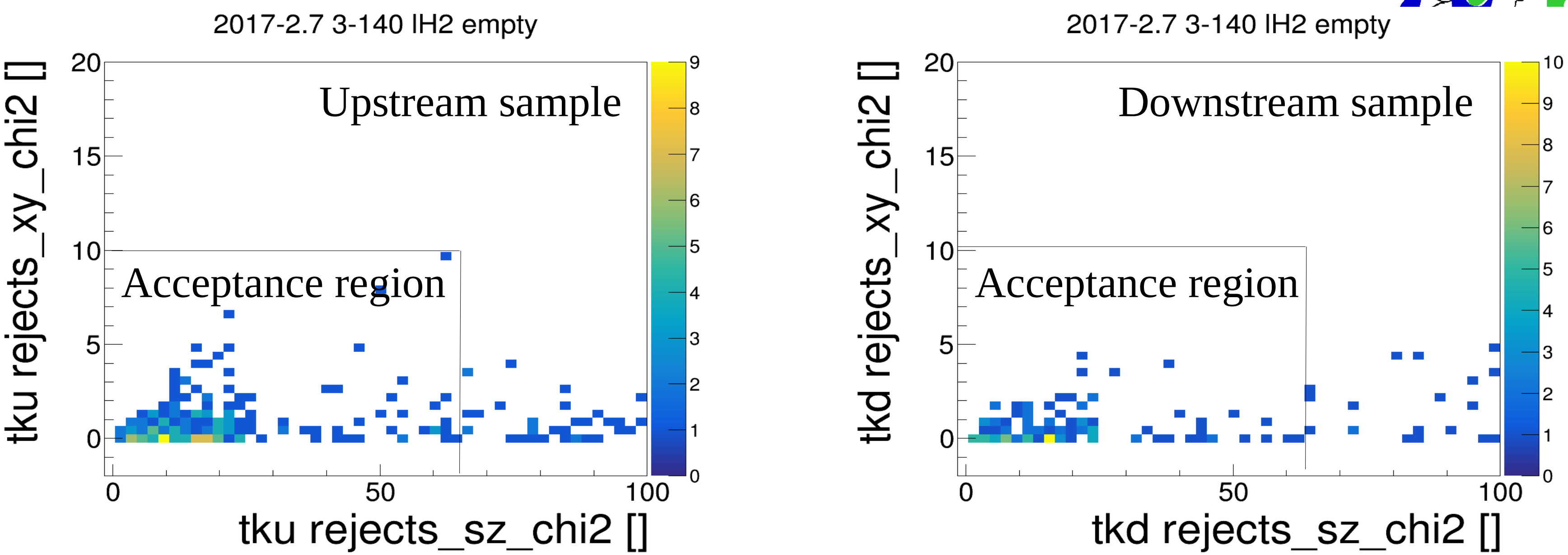
Pattern recognition





- Helix fit returns a chi2
  - Chi2 < 65 => accept track
- Chi2 distribution of the second best 5 space point PR track candidate
  - This is the best candidate that did not make a track
  - “5 space point candidates only” to avoid double counting

Pattern recognition



- Chi2 distribution of the second best 5 space point PR track candidate
  - This is the best candidate that did not make a track
  - 5 space point candidates only to avoid double counting
- Conclusion: there are lots of “unused” space points that could have made a track
  - Are we sure these are really noise?
  - What if some of the “data” is really noise and vice versa?

Detector noise

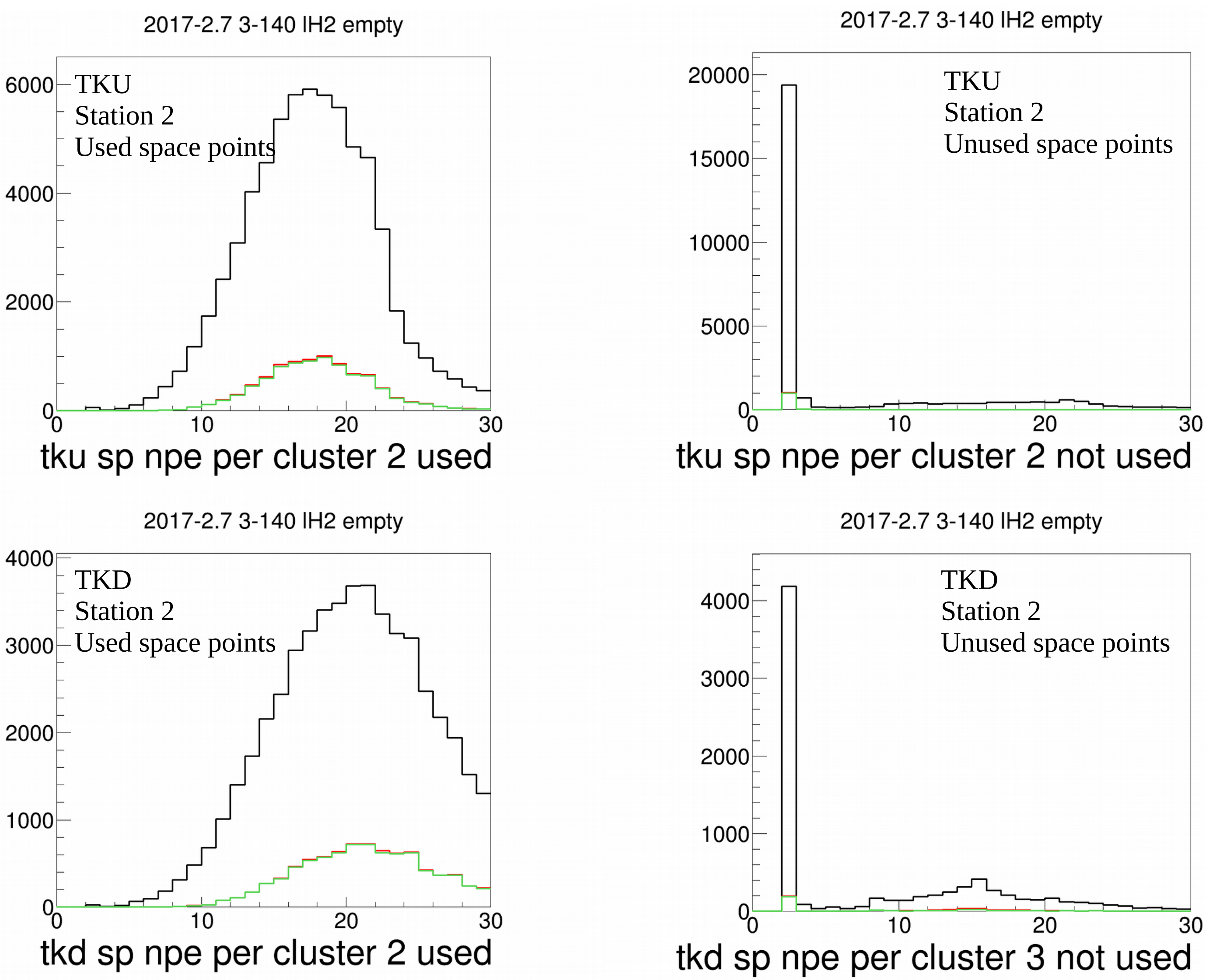
- Is noise a significant contributor to resolution
  - There are a significant amount of hits that are considered as noise but could have made a good track
  - Guess there are noise events that have been included in the track reconstruction
  - → quite possibly noise is a significant contributor
- Seek to characterise the noise in the data
  - Look at amount of light produced by “noise events” (NPE)
  - Look at physical location of noise events versus real events

Number of Photoelectrons

- Light appears in scintillator when particles go through
- Light travels down waveguides to photon counter
- Photon counter (VLPC) makes light into photoelectrons
- EM shower → electron multiplication
- → Number of Photoelectrons (NPE)

- What causes noise
  - Thermal noise in the VLPC makes some electrons appear
  - Light leaks into the system from elsewhere (we hope not!)
  - Non-beam particles make it into the detector
    - e.g. muon “knocks-on” an electron from surface of the detector into another detector element

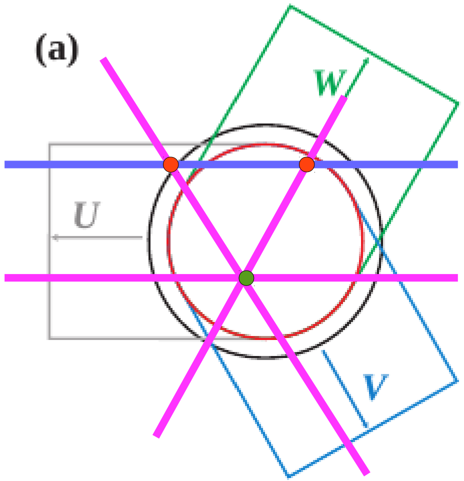
Number of Photoelectrons



All data
Upstream sample
Downstream sample

NPE - Conclusions

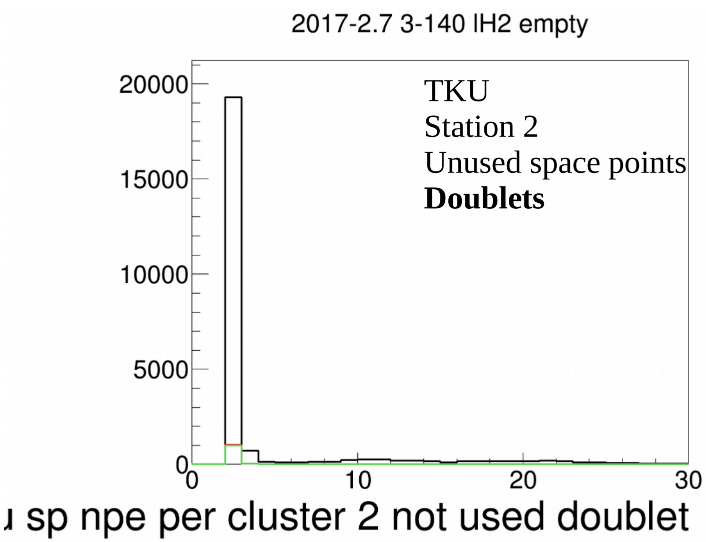
- Lots of “unused” spacepoints have 3-4 npe/cluster
- Almost no “used” spacepoints have 3-4 npe/cluster
  - Those events that do have 3-4 npe/cluster are rejected by some other cut
- Assume this is thermal noise
  - → propose 4 npe cut on data
- Note these space points are rejected anyway
  - → this might not be the source of our chi2 anomaly…
- Reminder:

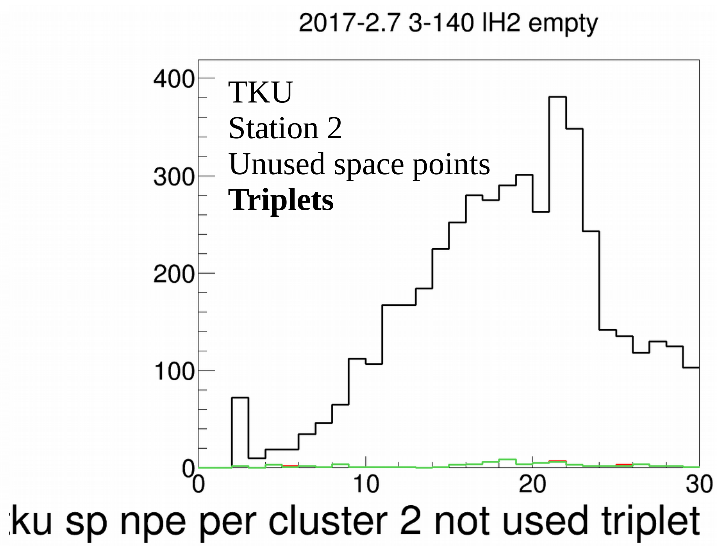


Two planes hit → doublet space point

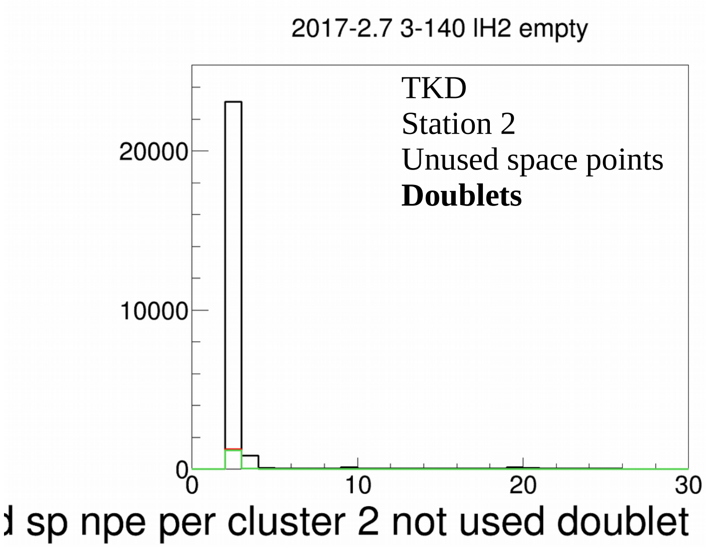
Three planes hit → triplet space point

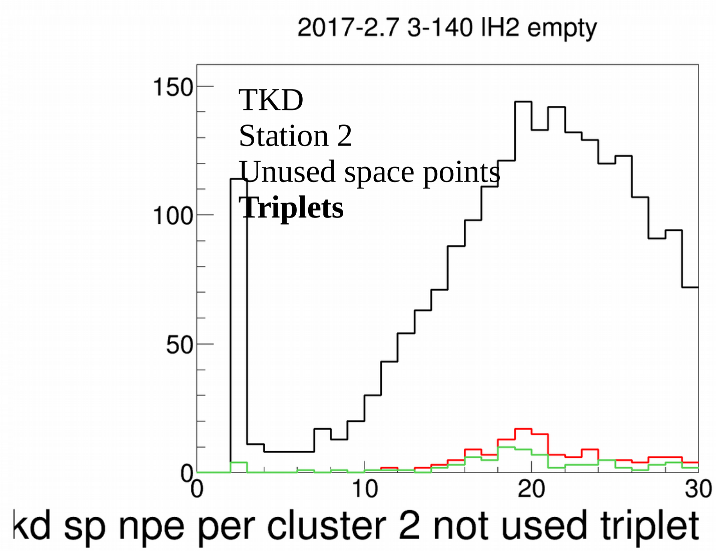
Number of Photoelectrons





All data
Upstream sample
Downstream sample

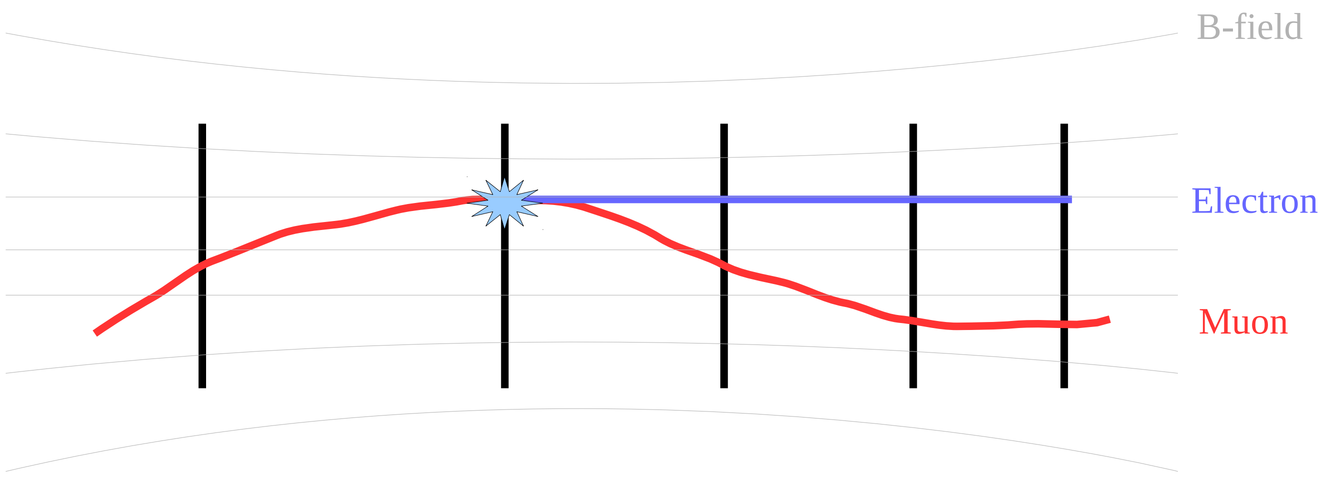




Triplet space points

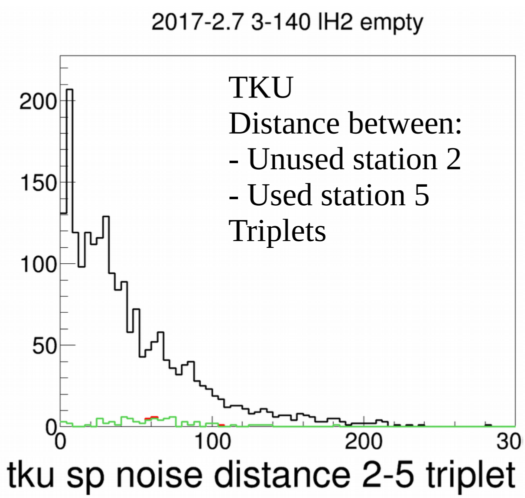
- Triplets are unlikely to be due to thermal noise
  - Unlikely to get coincidence of three planes unless the trackers are really noisy
    - → they are not
- What can cause triplets?
  - Something physical happening in the plane
  - Knock-on electrons?
    - Particle traversing the detector knocks an electon off one station and it hits the next station
  - Cross-talk in the scintillating fibre?
    - Light from a “real” hit goes into a neighbouring fibre
    - Cluster finding doesnt pick it up and we make extra space points

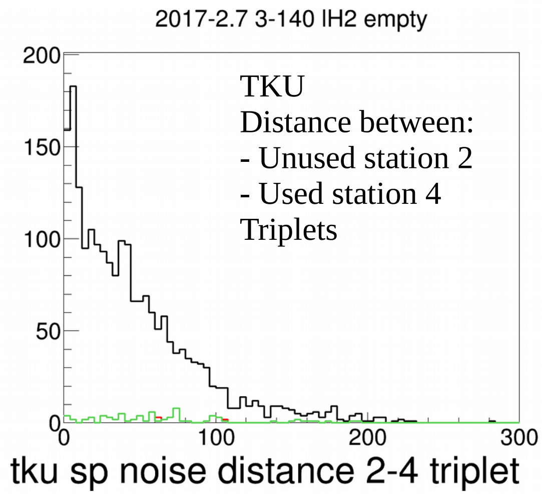
Knock-on electrons

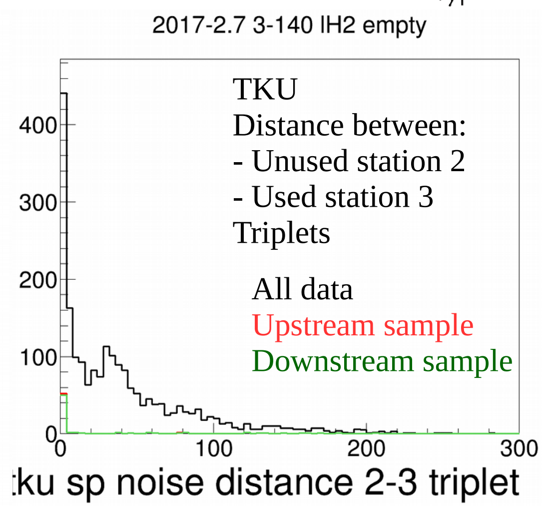


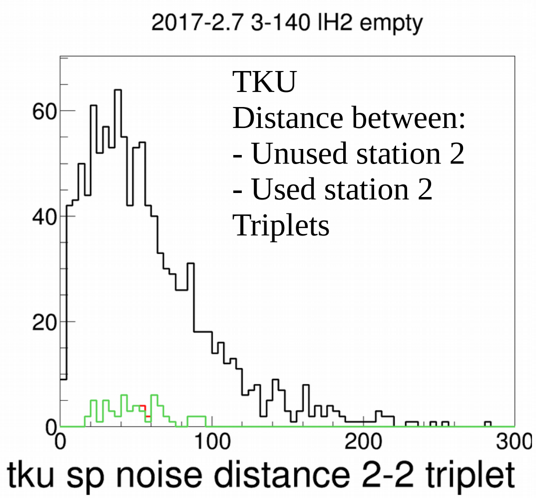
- Knock-on electron gets excited from station
- Traverses through several tracker planes
  - Travels along field lines! i.e. always pretty much straight
- Position of triplets should be correlated with space points in neighbouring stations
- As-opposed to cross-talk, which correlates space points in the same station
- Look at (x, y) distance, dr, in between “unused” space point and “used” space point in adjacent stations

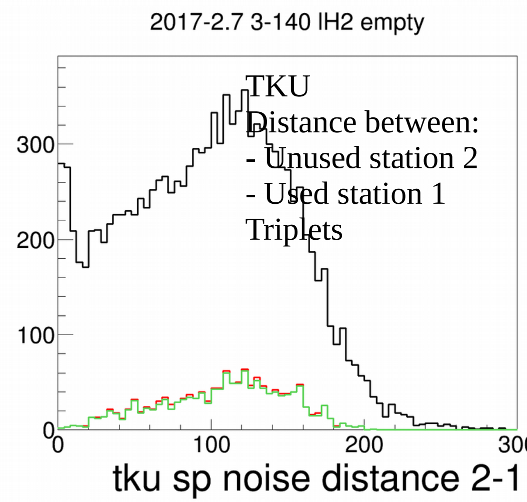
E.g. Noise in station 2 TKU

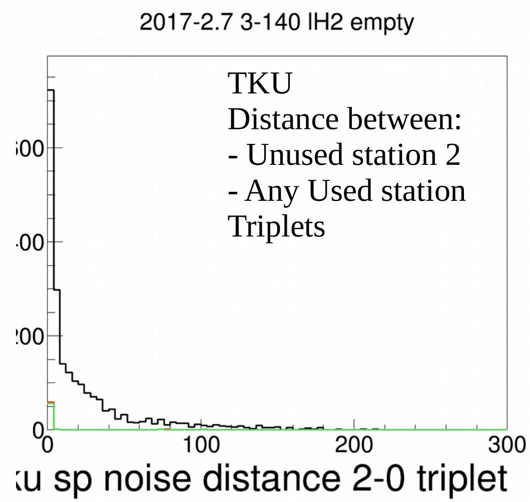




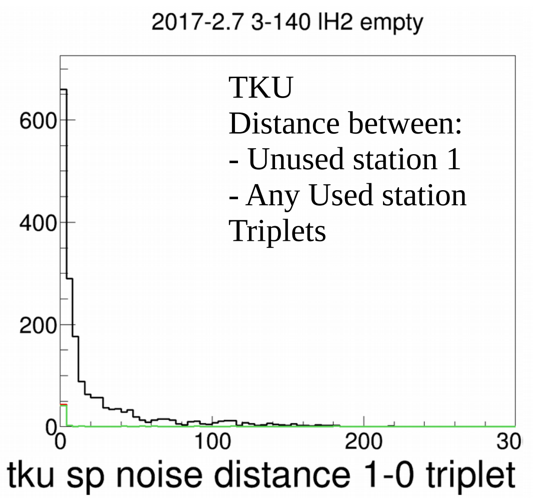


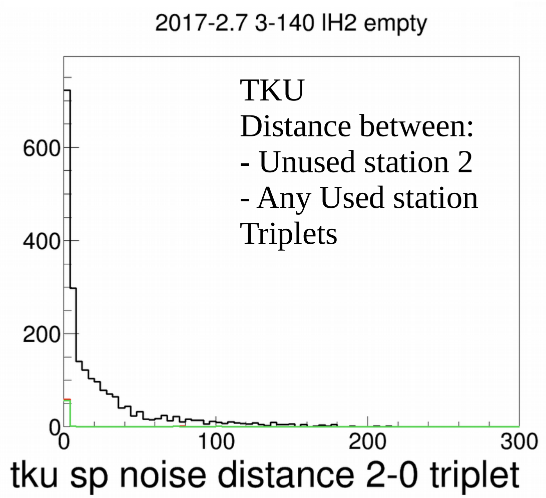


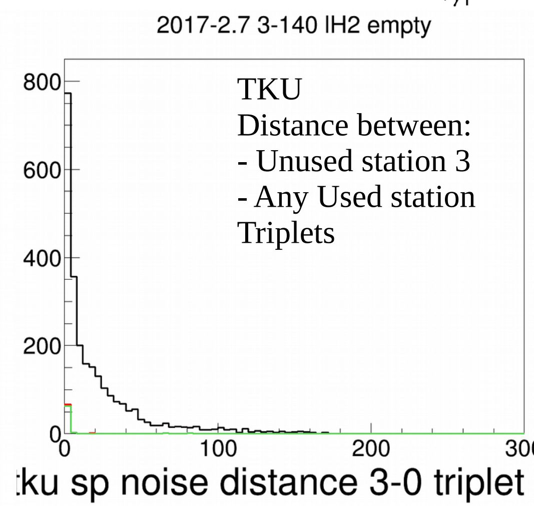


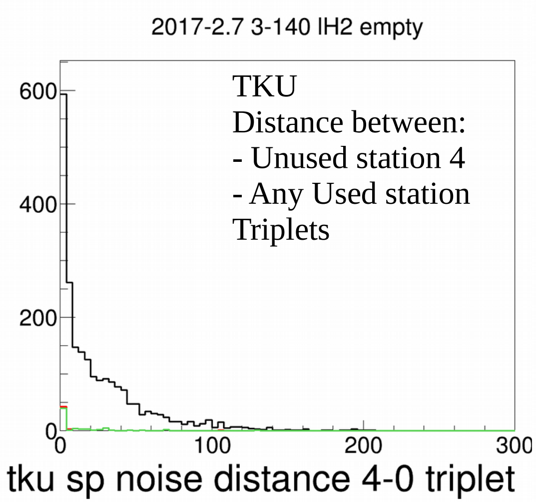


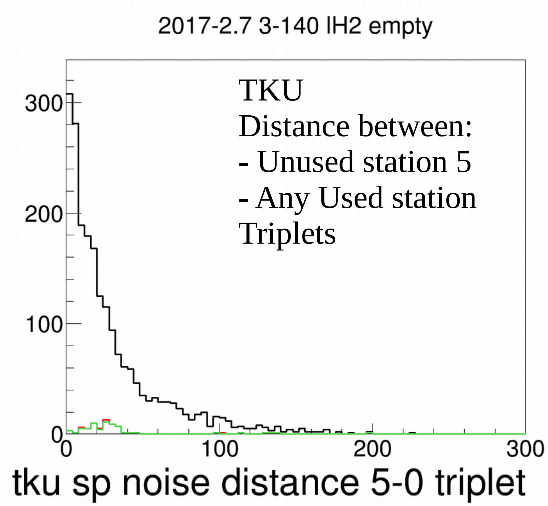
E.g. noise in all stations (TKU)





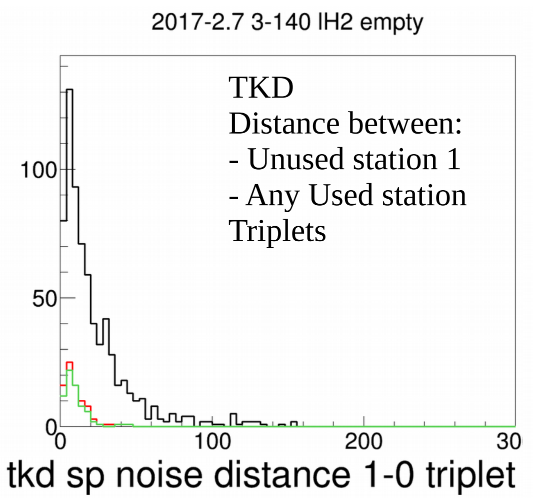


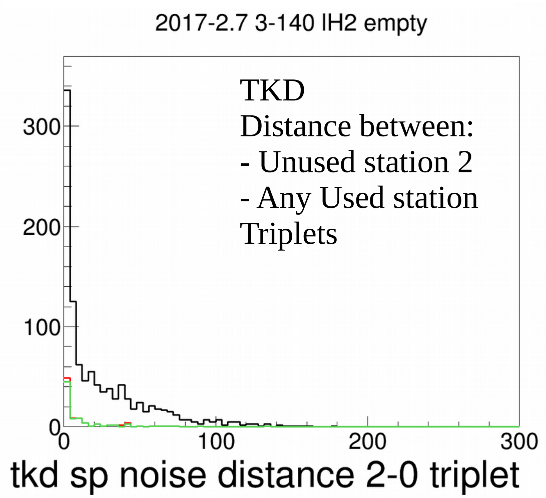


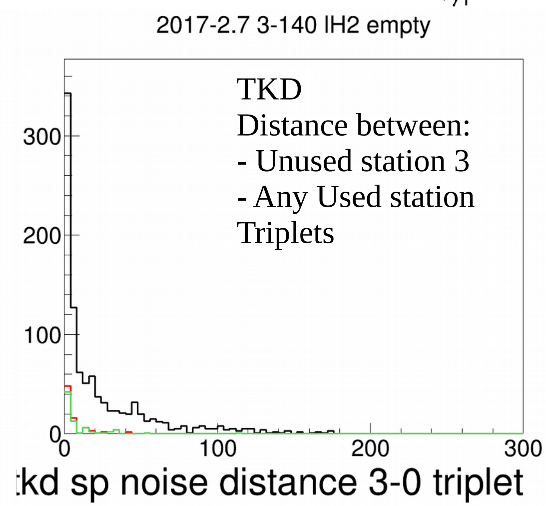


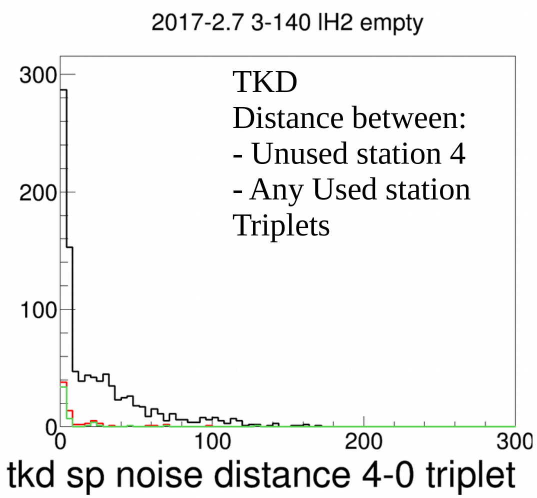
All data
Upstream sample
Downstream sample

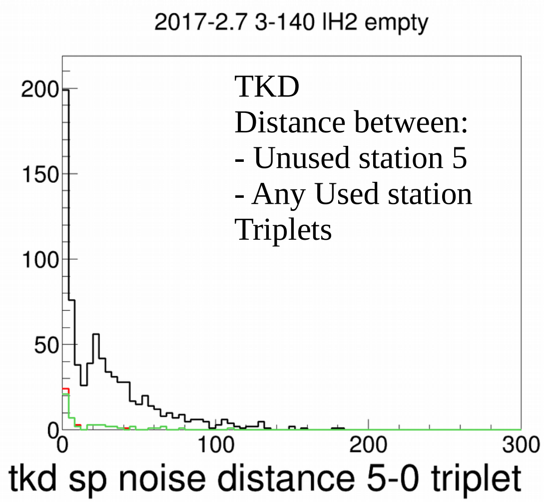
E.g. noise in all stations (TKD)











All data
Upstream sample
Downstream sample

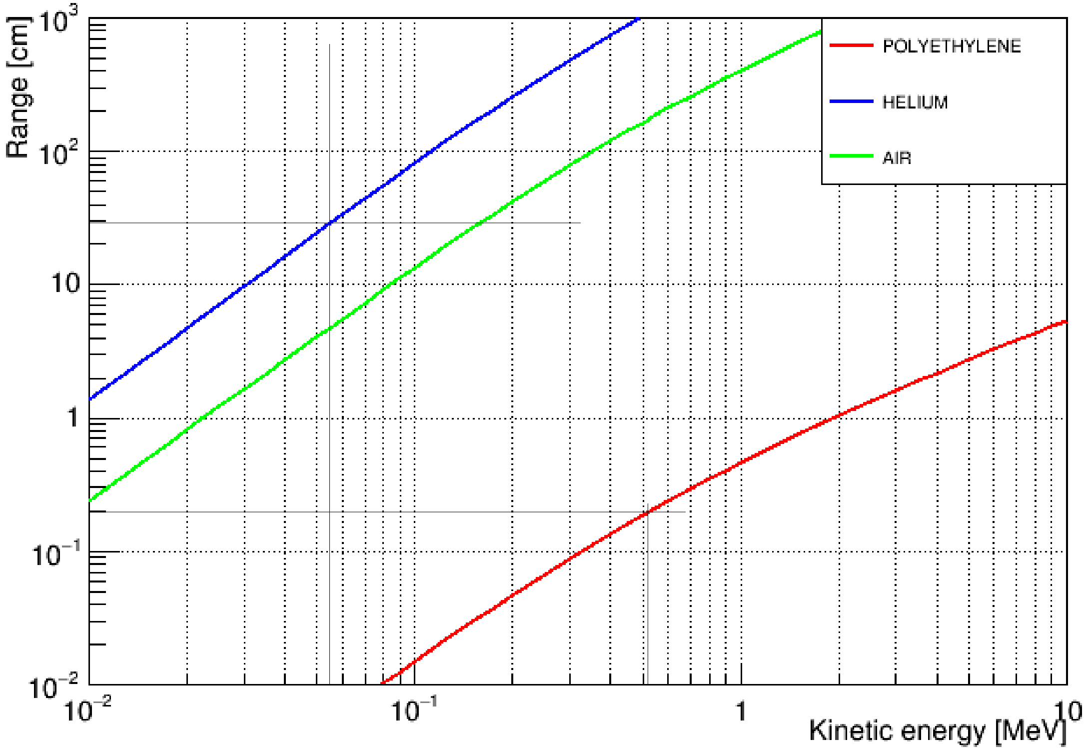
Stats

- ~100 “low dr unused space points” in the upstream sample per plane
  - Out of 9055 events
  - → ~500 per tracker in unused sample
  - Unknown number in used sample (enough to smear?)
  - ~80 % from upstream plane
  - ~20 % from upstream plane + 1

Conclusion

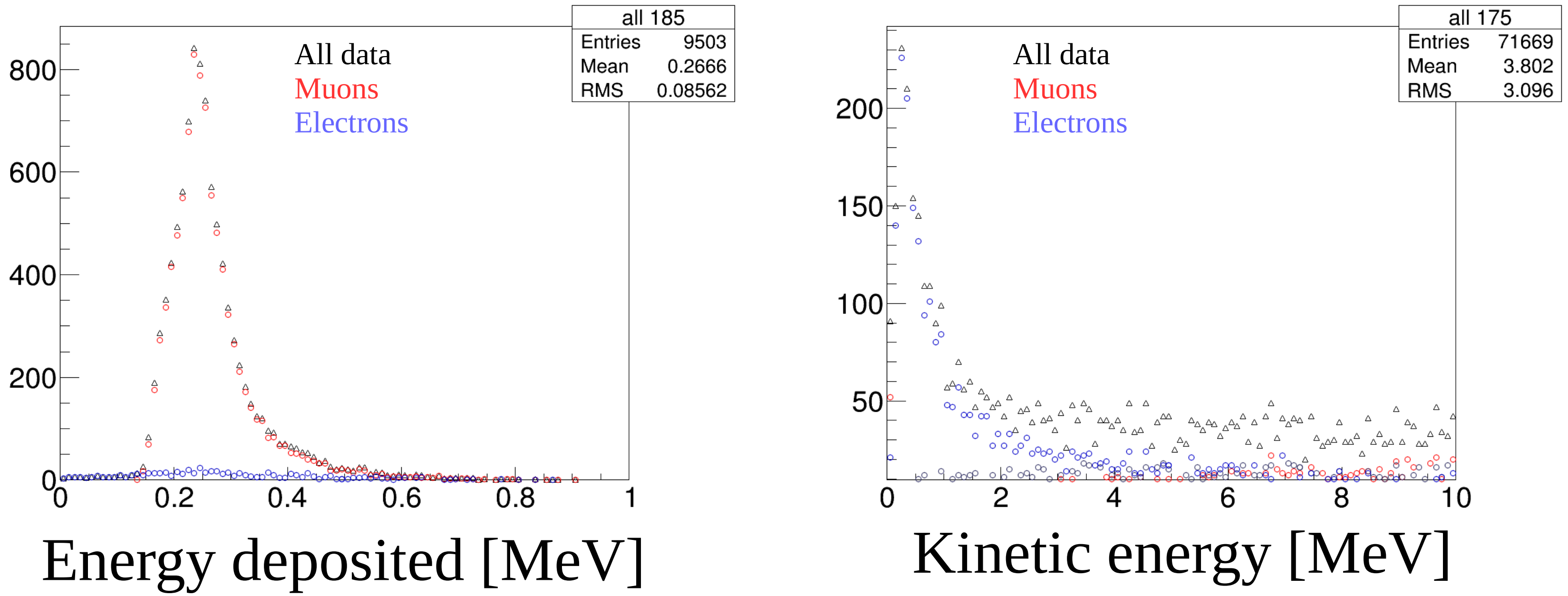
- Nearly all triplet noise can be attributed to knock-on electrons
  - Some of this noise is in the “good muon” sample
- A significant proportion of doublet noise can be attributed to thermal noise
  - None of this noise is in the “good muon” sample
  - Propose increase photoelectron cut to 4 photoelectrons
- Some doublet noise is unaccounted
  - Guess knock-on electrons are at fault
- Some features may still exist
  - But good place to start

Order of magnitude...



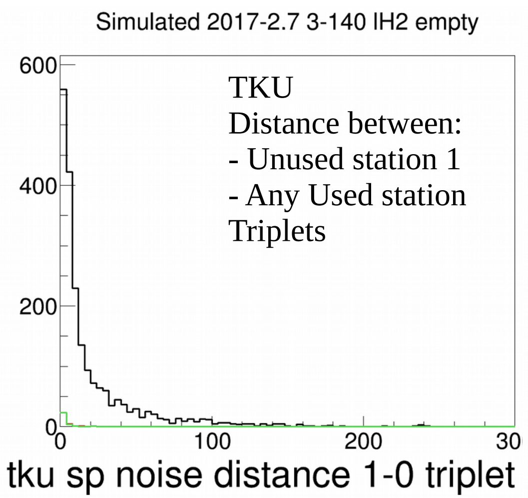
- Electron range in polyethylene, Helium (and air)
  - 30 cm He stops electrons with < 0.05 MeV
  - 0.2 cm polythene stops electrons with < 0.5 MeV

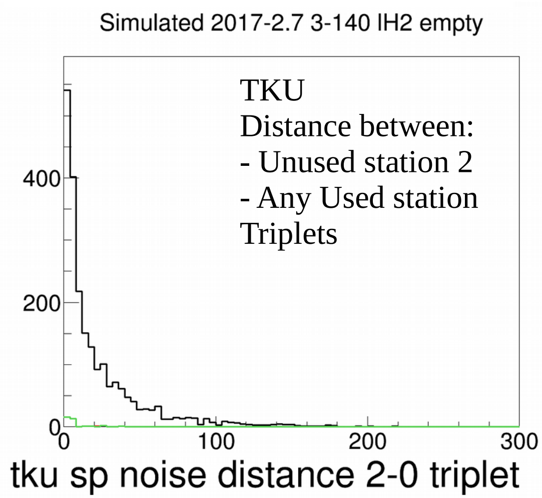
G4 Model for Delta Electrons

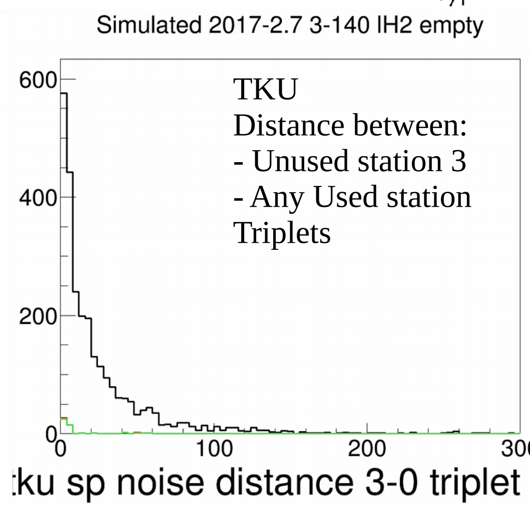


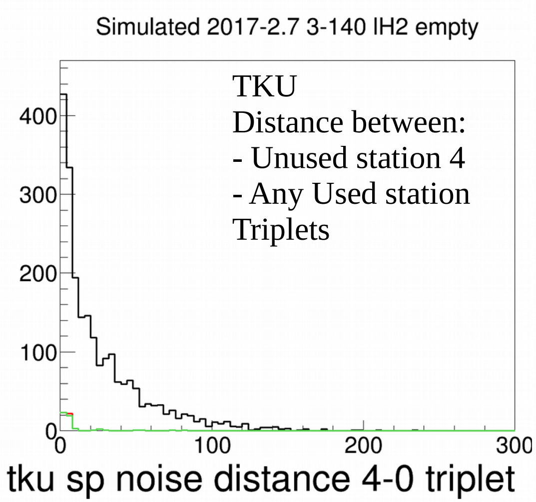
- Following some digging/bug fixing in MAUS
  - We have a few low energy electrons in MAUS
  - (About 1% of muons make an electron)

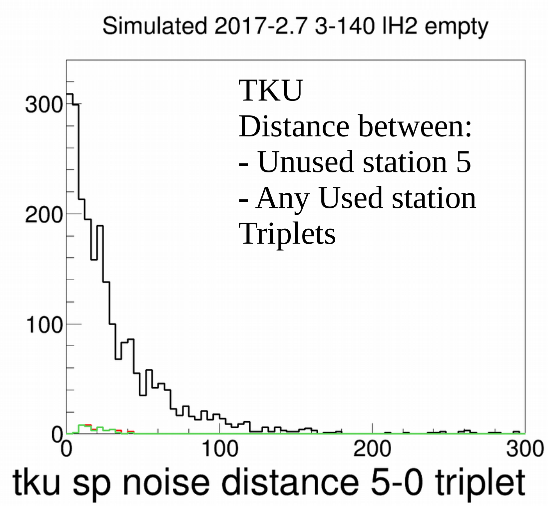
Simulated noise (TKU)





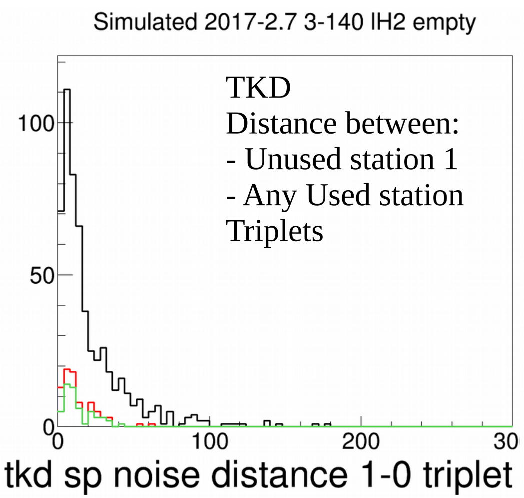


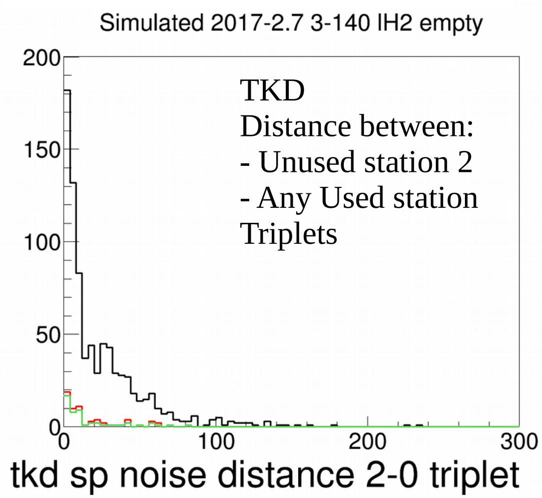


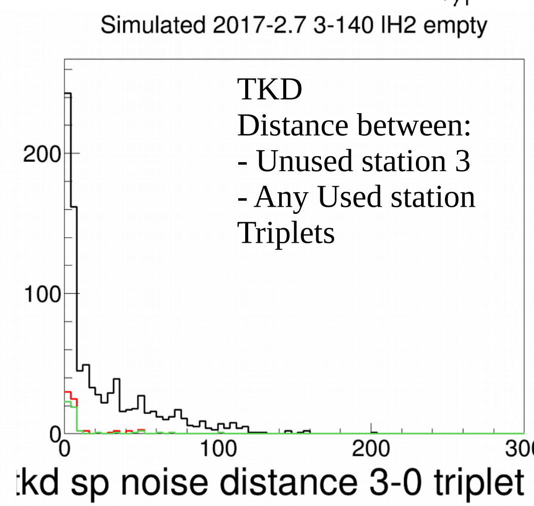


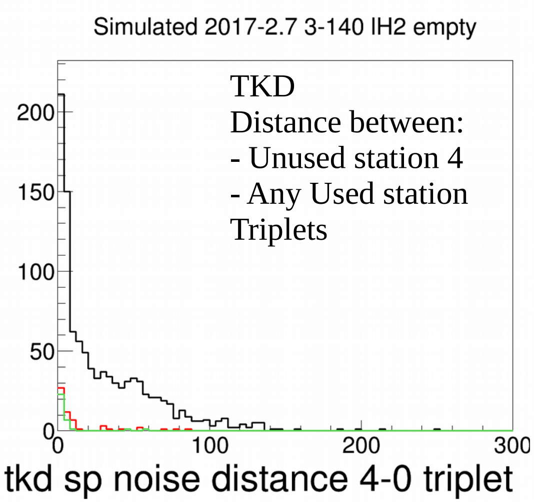
All MC
Upstream sample
Downstream sample

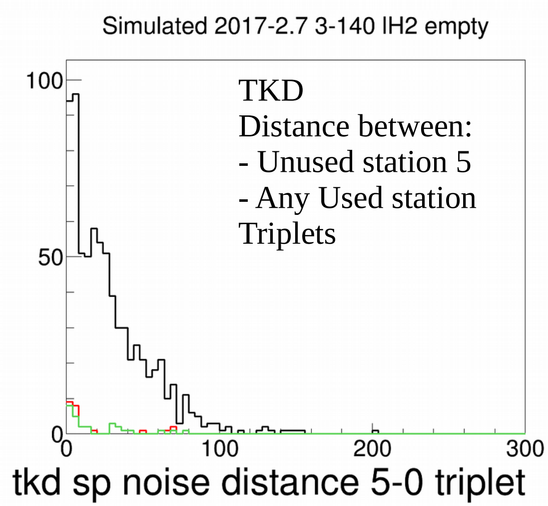
Simulated noise (TKD)





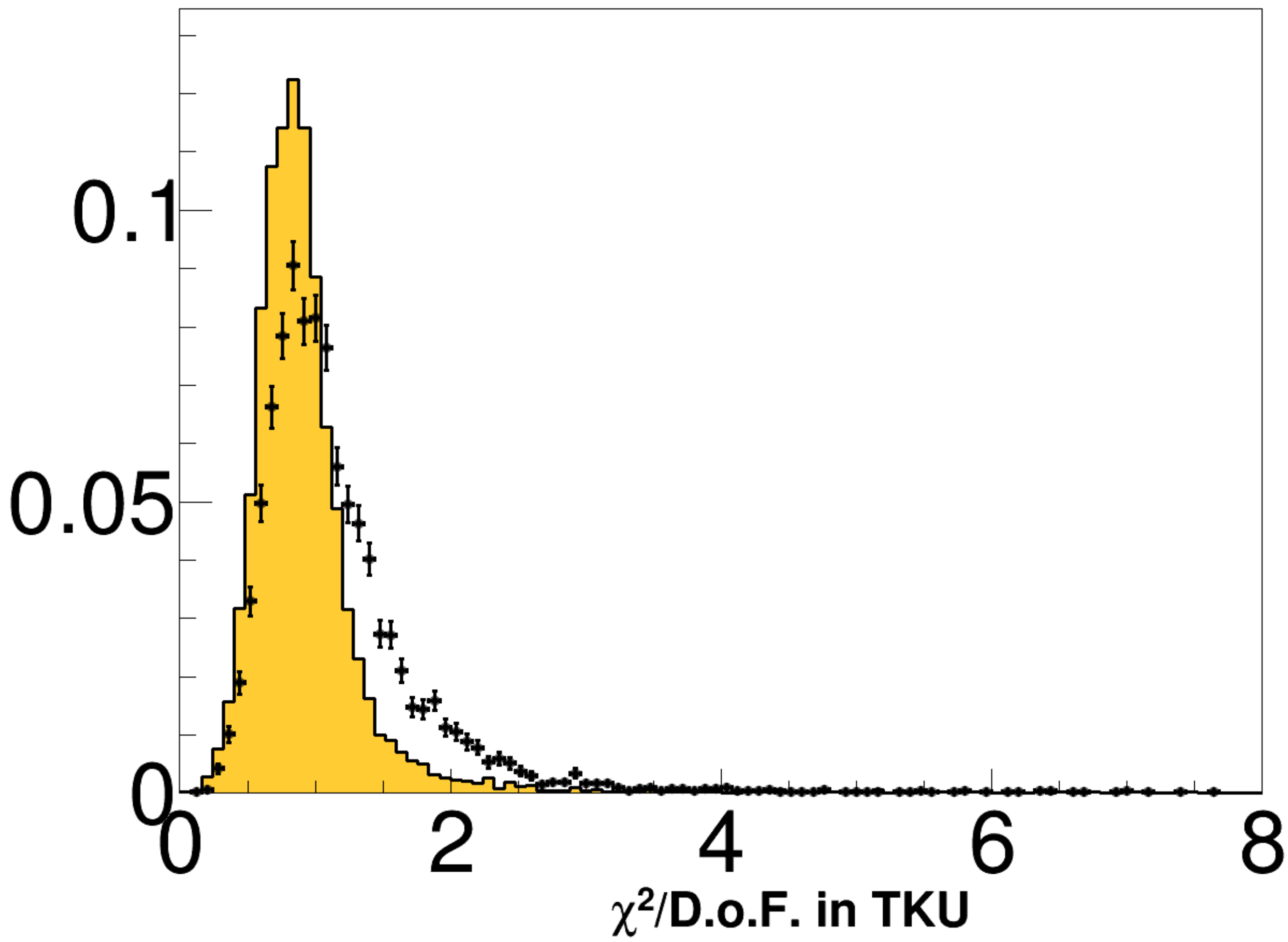






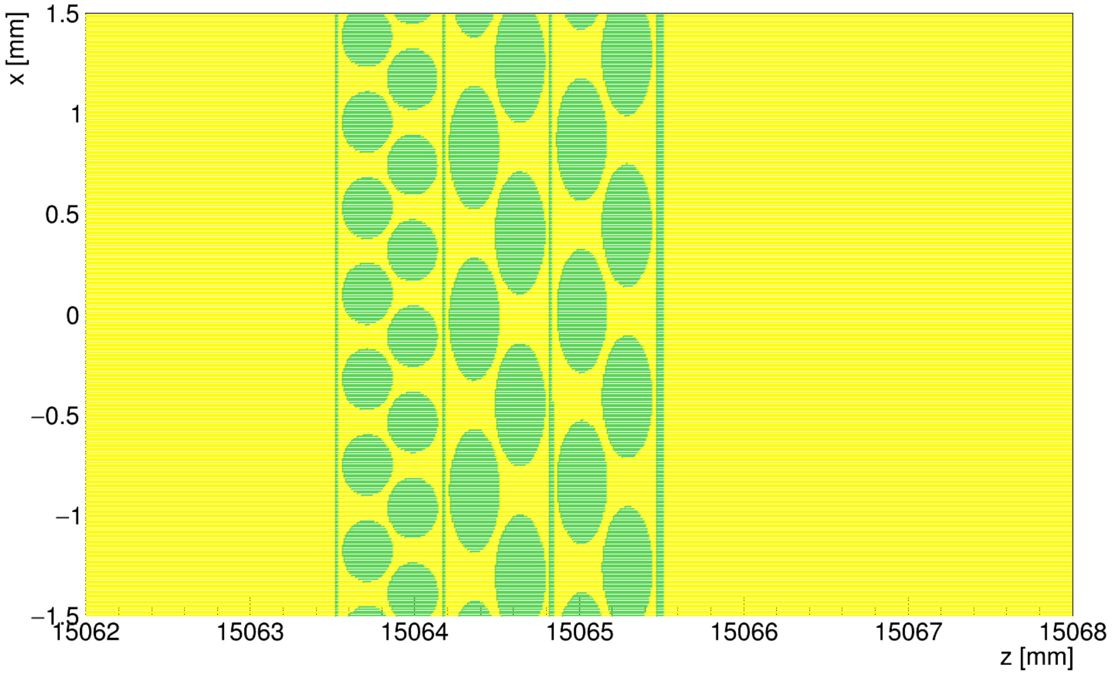
All MC
Upstream sample
Downstream sample

Chi2 – after updates



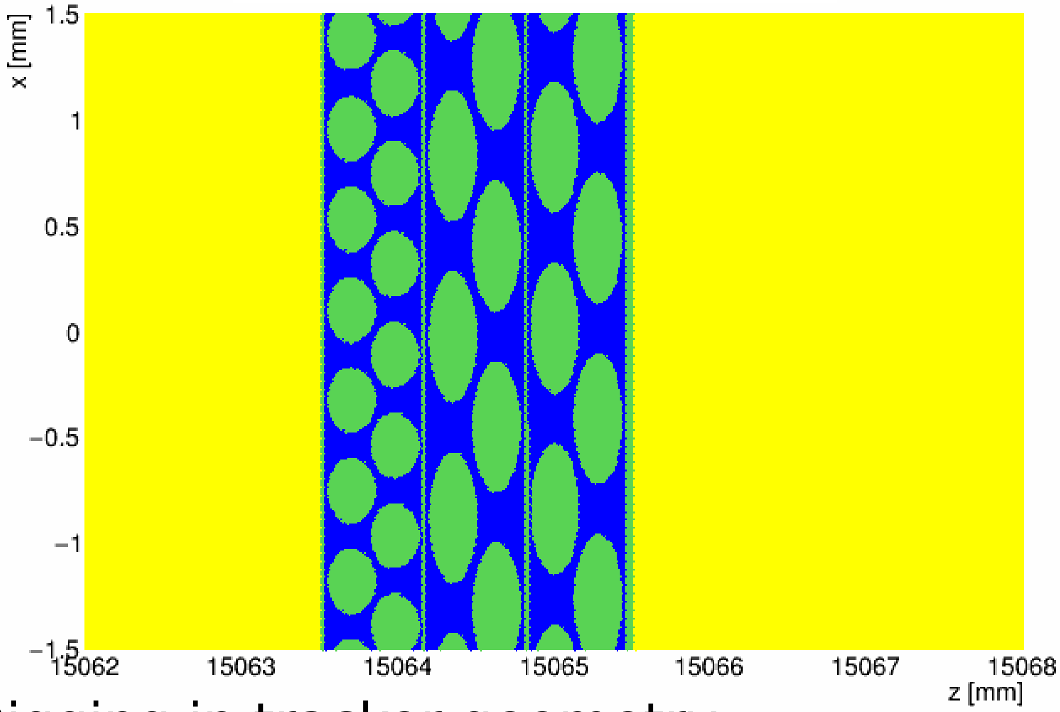
- Little/no improvement in the chi2
  - Keep digging...

Tracker Geometry



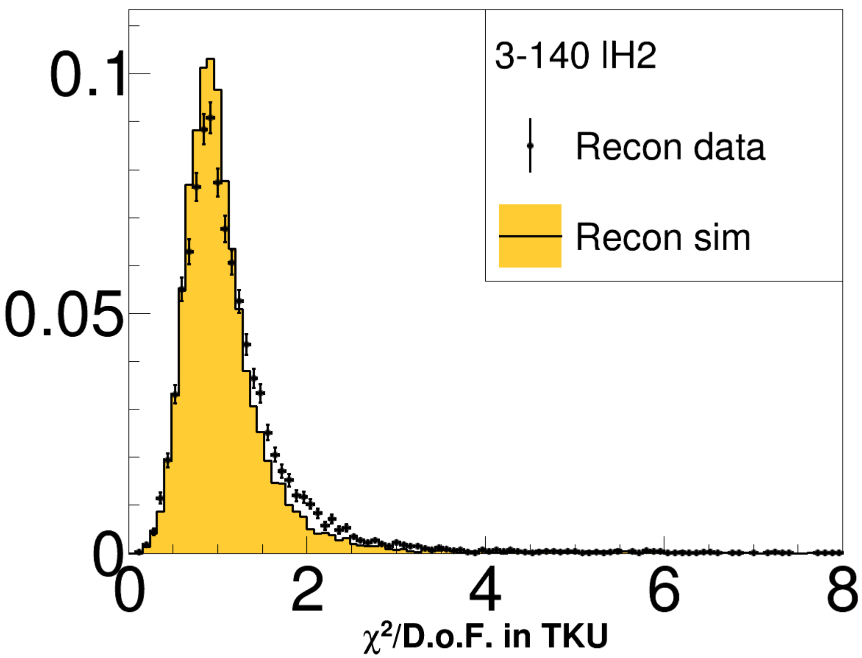
- Digging in tracker geometry
  - Yellow is He
  - Green is polystyrene

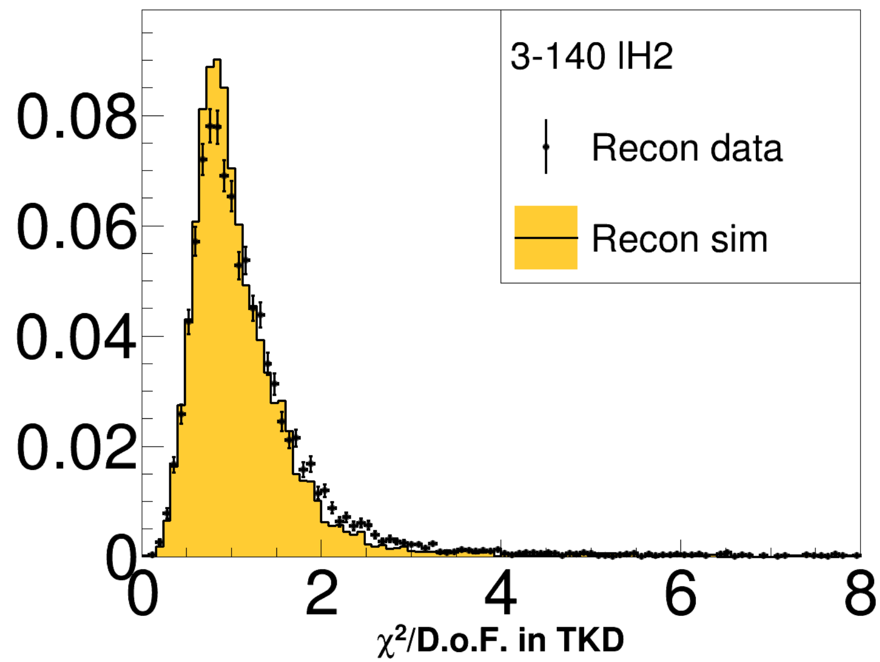
Tracker Geometry (Fixed)



- Digging in tracker geometry
  - Yellow is He
  - Green is polystyrene
  - Blue is glue; optimised density to 2 g/cm^3

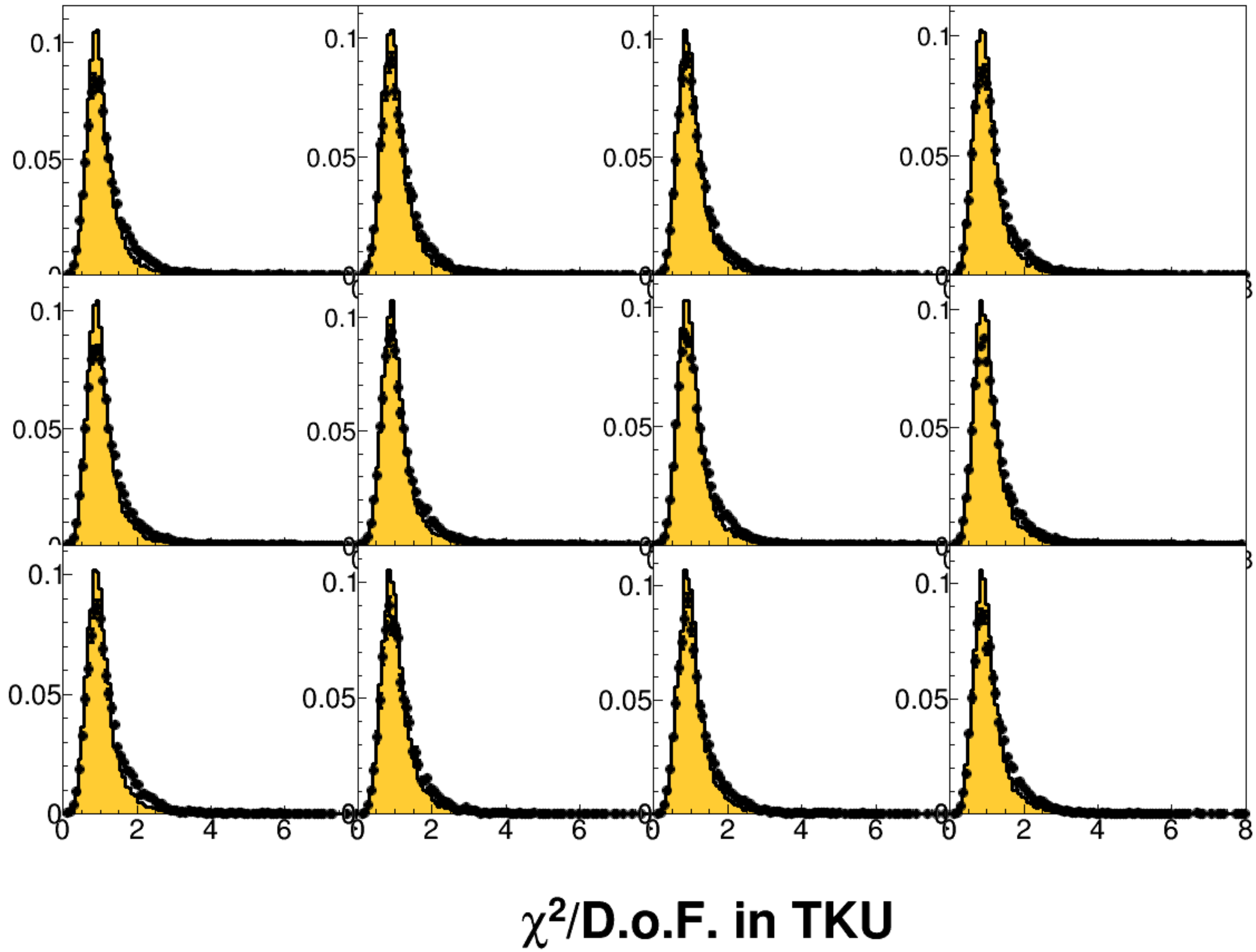
Tracker Geometry



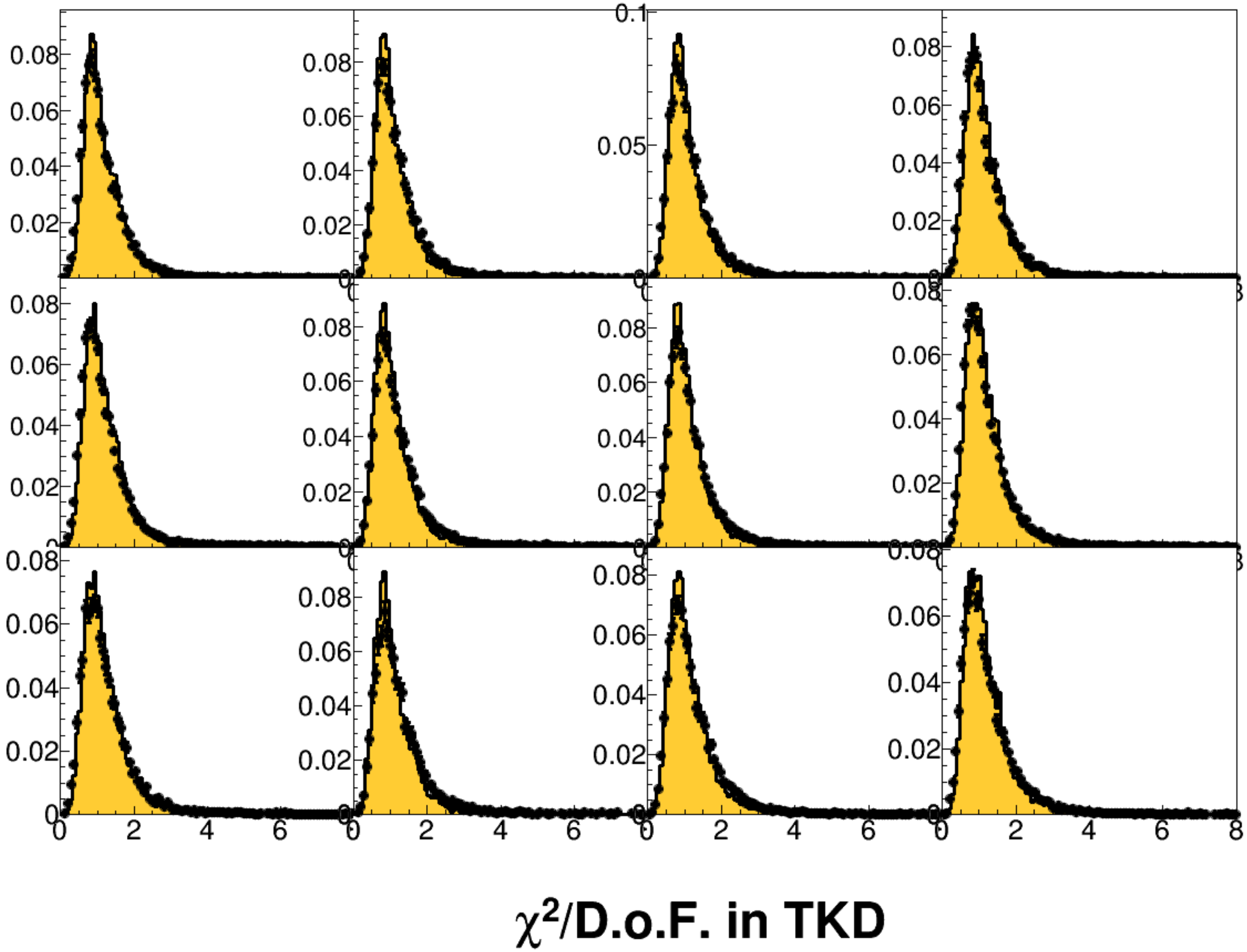


- Quite a bit better
  - Denser glue can improve the comparison
  - Is density > 2 g/cm^3 physical?

TKU Chi2 following material fix



TKD Chi2 following material fix



Systematic Uncertainties

- Say the real experiment is different to our **nominal** model
  - How does that effect the reconstruction and analysis
- Sample and smear the beam at TKU
- Simulate using a **varied** geometry
  - e.g. Translate the tracker
  - e.g. Tilt the tracker
  - e.g. Vary End field
- Reconstruct using the **nominal** geometry
- Calculate the **varied** correction from MC → Recon
- Systematic uncertainty is the difference between:
  - **nominal** correction (with **nominal** geometry)
  - **Varied** correction and (with procedure above)

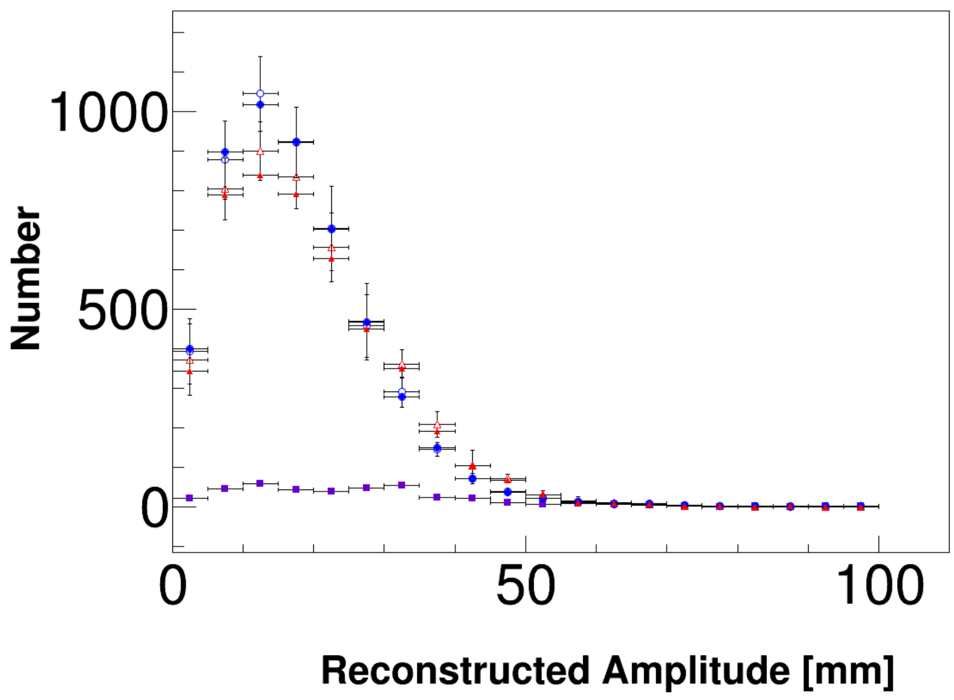
Systematic Uncertainties

E.g. for 6-140 lH2 empty data

		2.5	7.5	12.5	17.5	22.5	27.5
tku position	1 mm	0.05	0.09	-0.03	-0.01	-0.01	-0.09
tku rotation	1 mrad	0.04	0.04	-0.02	0.01	0.00	-0.07
tku E2 coil	5.00%	0.06	0.04	-0.02	0.01	-0.03	-0.07
tkd position	1 mm	-0.08	0.07	-0.02	0.04	0.00	-0.12
tkd rotation	1 mrad	-0.02	0.03	0.06	0.06	0.05	-0.06
tkd E2 coil	5.00%	-0.04	0.03	0.00	0.05	-0.04	-0.06
		32.5	**37.5**	**42.5**	**47.5**	**52.5**	**57.5**
tku position	1 mm	-0.01	0.03	-0.07	-0.08	-0.10	0.08
tku rotation	1 mrad	0.03	0.00	-0.11	0.05	-0.05	0.00
tku E2 coil	5.00%	0.06	-0.02	-0.04	-0.05	-0.05	-0.08
tkd position	1 mm	-0.05	0.03	0.03	-0.02	-0.17	-0.40
tkd rotation	1 mrad	0.01	0.03	0.14	-0.03	0.00	-0.10
tkd E2 coil	5.00%	0.03	-0.05	0.10	0.02	0.10	-0.50

Systematic Uncertainties

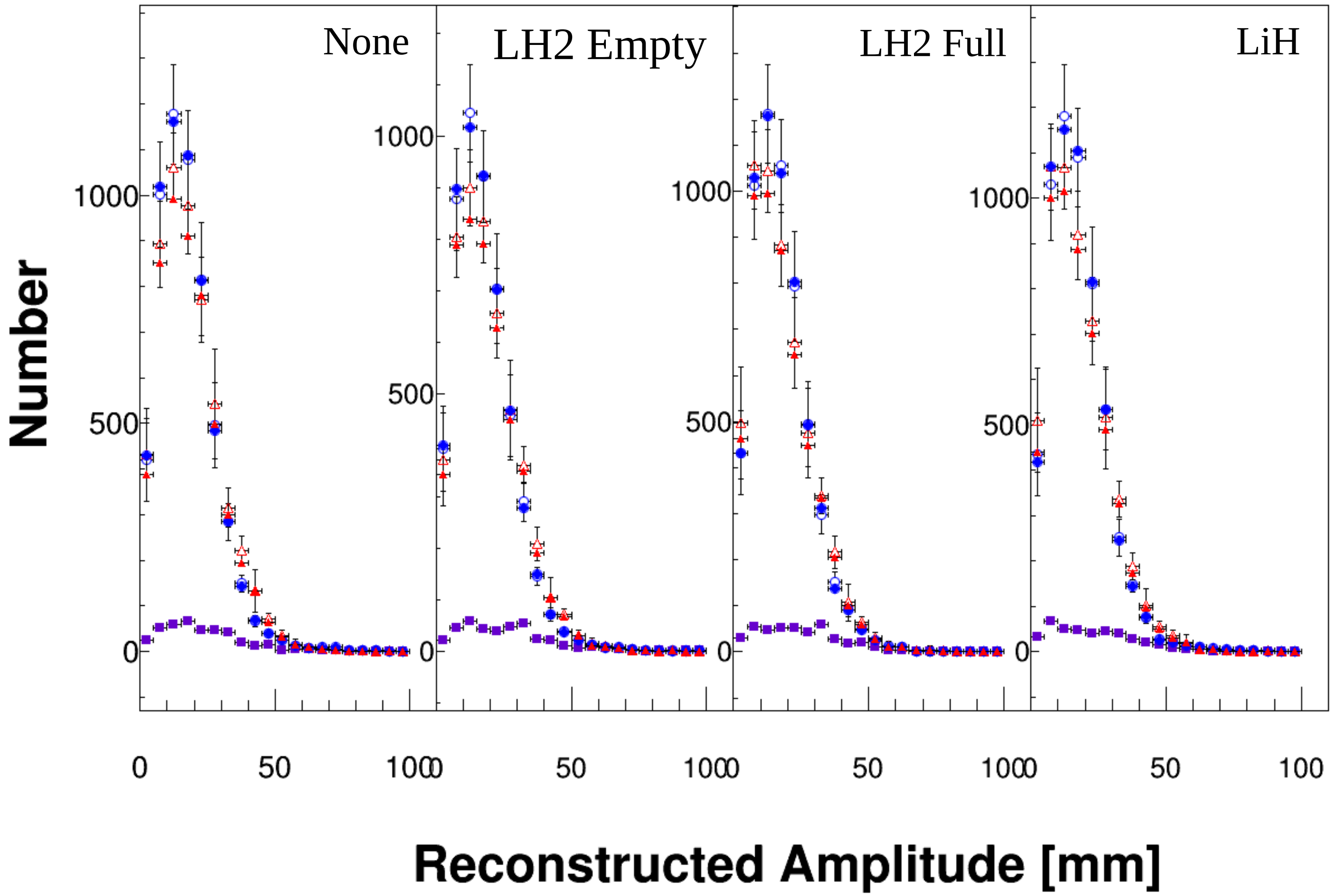
E.g. for 6-140 lH2 empty data



- Statistical and systematic errors added in quadrature
  - Look at the open points
  - Blue is upstream
  - Red is downstream

Systematic Uncertainties

6-140 mm data



Conclusions

- Tracker model looks much more robust
  - Model for noise
  - Material model
- Systematic error calculation discussed
  - Needs a second pass on the calculations
  - Plot systematic uncertainty separate to statistical
  - Add in 3-140, 10-140 data
  - More statistics
- Try to beat down the uncertainty
  - Apply Chris Hunt algorithm to rotation
  - Apply improved field map
- Conscious of timeline to IPAC...