CRT Simulation/Reconstruction

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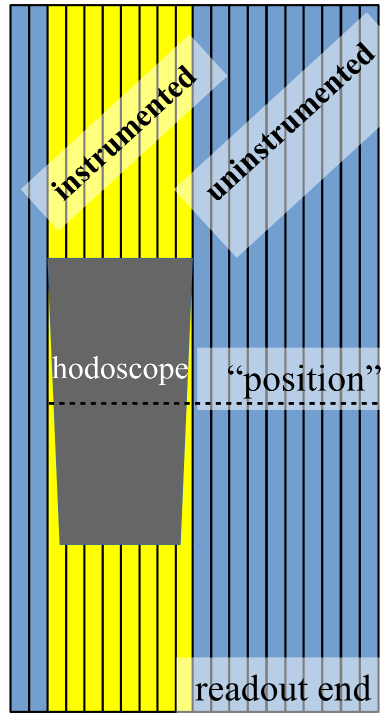
Outline

- Detector simulation validation
- CRT hit reconstruction
- Cosmogenic muon tagging efficiency
- Auto-veto
- CRT-PMT matching

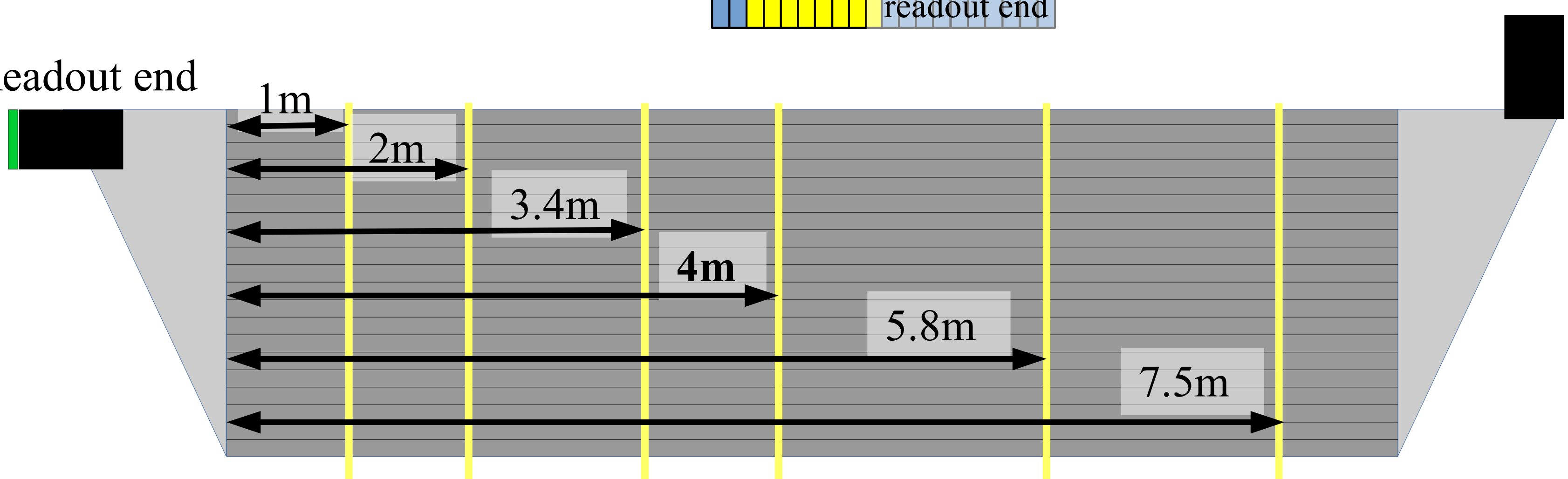
CRT Detector Simulation

- Light yield, attenuation, photodetector models
  - Full optical simulation with G4 or
  - Effective analytical model (used here but for now omitting dark noise, cross-talk)
- Front-end electronics
  - Readout latency
  - Hardware based interlayer coincidence
  - Merging of in-time hits occurring in a given scintillator strip
  - Typical value of pedestal, gain to represent result of charge sampling in ADC units
  - Time stamp generation including time walk with signal amplitude
  - Flagging of channel generating trigger
- The current model is applied to all three subsystems (top, sides, bottom) with only side CRT test data available – will develop top/bottom models when data becomes available

Light Yield Scan @ Test Stand



- Light yield from side CRT module at 6 positions using external muon telescope to provide trigger
- Data obtained using prototype optical readout with 4 channels reading out 8 of 20 scintillator strips (results compatible with production readout)
- ~Few PE variation exists across all CRT modules

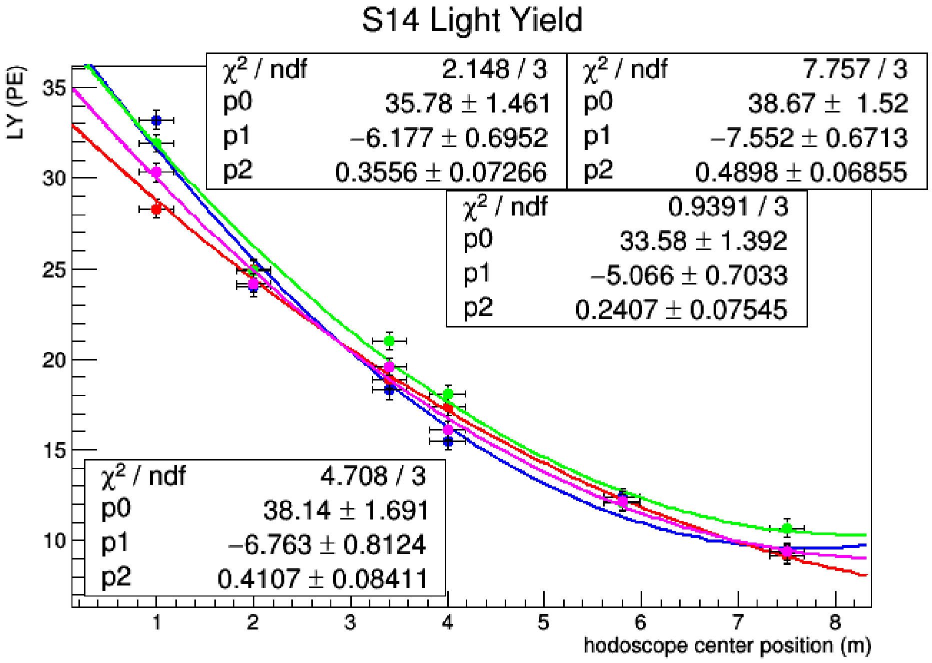


Measured at 6 positions

Extracting a LY Model

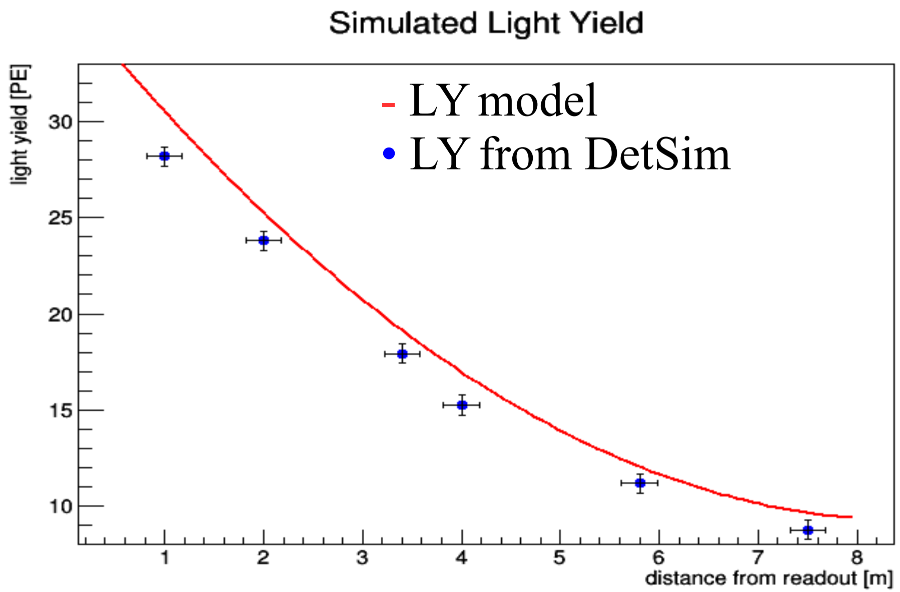
- LY vs. distance from read out (z) well modeled with simple exponential having attenuation length ~5m
- Opted for quadratic fit as other effects are present and are not completely captured by exponential model
- Whatever the choice of fit function, LY(z) will include scintillator LY, attenuation, photosensor optical coupling/quantum efficiency
- Caveat: light yield measured for MIPs cannot be simply scaled for other particles, need to include quenching of scintillation light (i.e. Birks' Law)

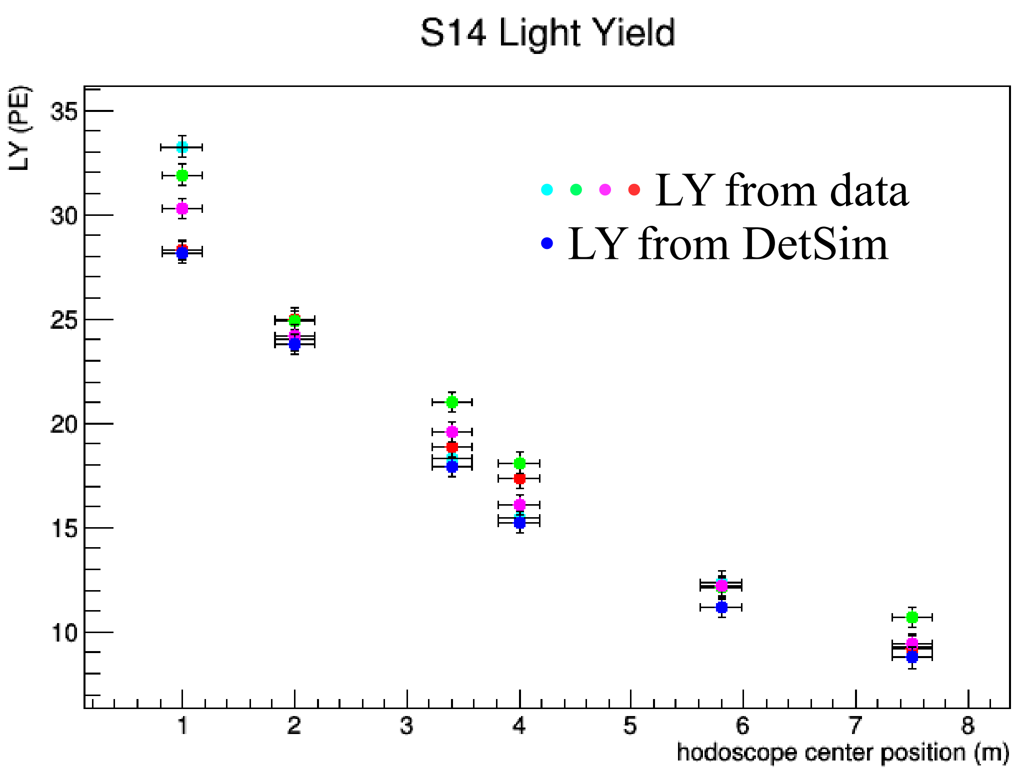
LY(z) for 4 SiPM channels each with quadratic fit

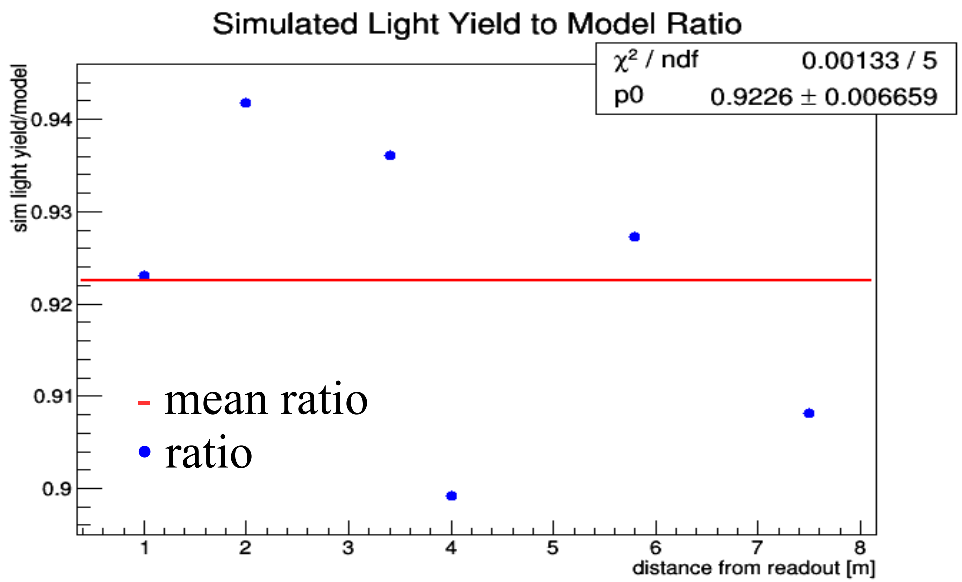


Comparing to Reality

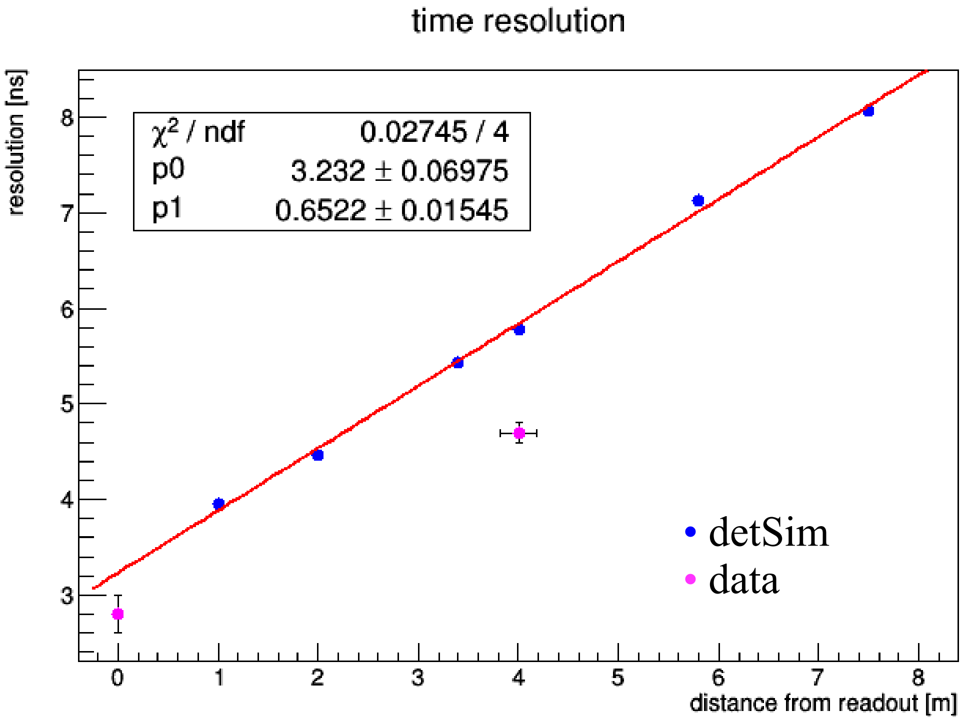
- Simulated LY is consistent with lowest LY data values
- Comparing to LY model (average of 4 channels' fit parameters) shows detSim produces 8% less light showing some minor tuning is needed

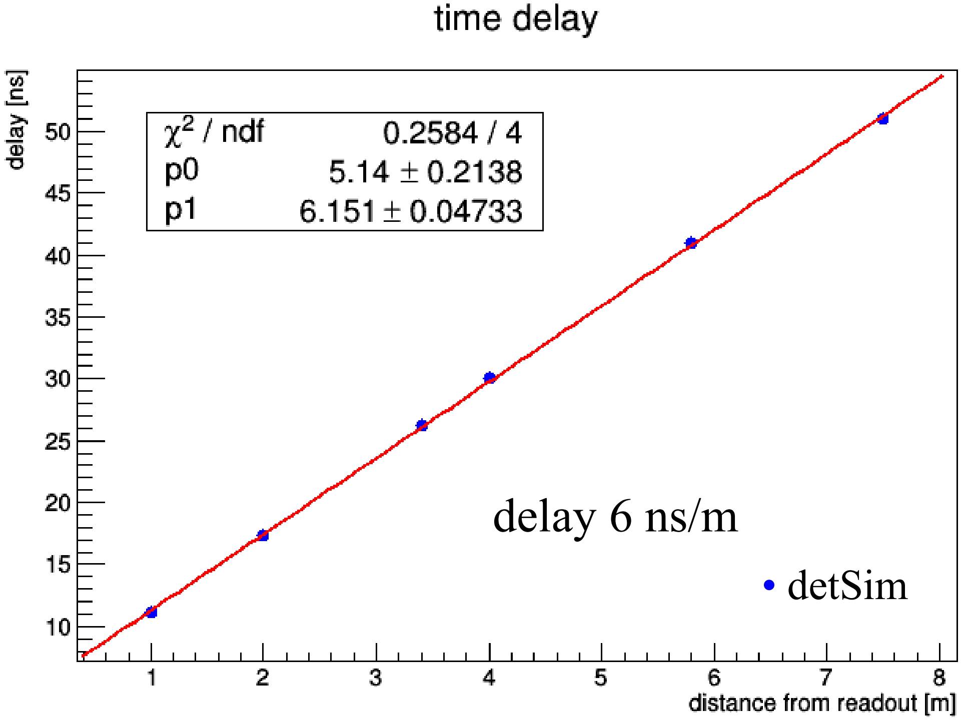






Time Resolution from DetSim

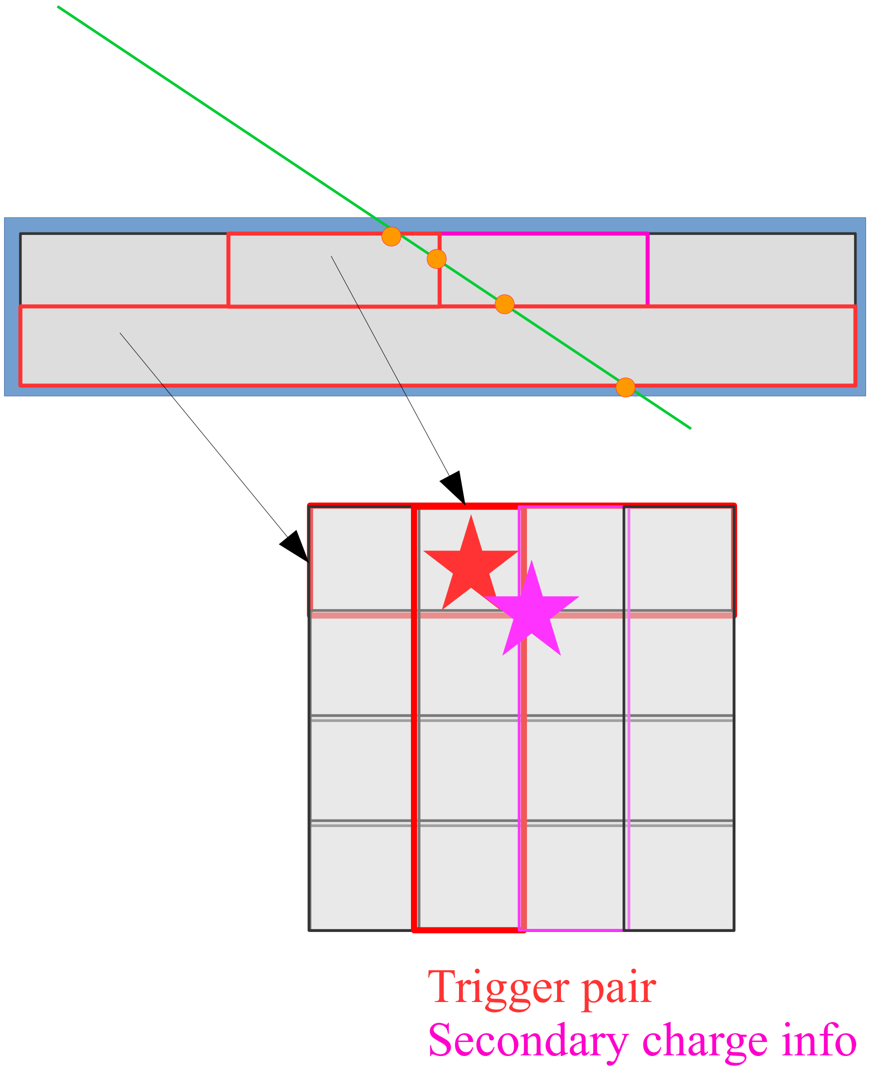




- We don't have a complete time resolution study yet for side CRT but do have preliminary results (no corrections e.g. time walk w/amplitude)
  - These results show simulated time resolution is ~ 15% larger than measured
  - Timing results from simulation will be conservative
- Time stamp generation model needs some tuning, will be done once detailed timing study performed at test stand

CRT Hit Reconstruction

- Turn CRT triggers into space-time points
- Each trigger requires at least one pair of strips from adjacent layers
- Simplest approach: calculate mean position/time of each trigger pair (used now)
- In calculating mean, weight each contribution by signal amplitude if more than 2 strips hit (in progress)



CRT Hit Resolution Summary

Region	X [cm]	Y [cm]	Z [cm]	T [ns]
Top – Roof	9	1	8	3
Top – E/W Rim	2	11	10	3
Top – N/S Rim	9	10	2	3
Side – E/W	9	26	229	11
Side – N	127	12	2	8
Side – S	274	253	2	10
Bottom	51	1	79	7

Now that the CRT geometry is stable, we can begin to improve the hit resolution

- For all systems' time resolution, need to optimize corrections
  - time walk with amplitude
  - propagation delay
- Side CRT
  - For full length modules, fibers are read out at both ends
  - For events where FEB at both ends is triggered, time difference can be used to reconstruct position along the module
  - For events where only one end triggers (works also for cut modules), may be able to leverage light output to refine hit position

Updated "True" Cosmogenic Muon Rates

Cosmogenic Muons Entering Sensitive Volumes					
Volume	CRT	Cryostat	LAr IV Only	LAr AV	LAr FV
Rate [kHz]	33.0	16.8	3.4	13.4	11.3

Cosmogenic Muons Stopping in Sensitive Volumes				
Volume	Cryostat	LAr IV	LAr AV	LAr FV*
Fraction [%]	20.0	5.7	17.9	17.8
Rate [kHz]	4.4	1.2	3.2	2.7

* only checked that muon passed through FV - may have stopped in AV outside of FV

- CRT mean total FEB trigger rate: 110 kHz

Cosmogenic Muon Tagging Efficiency

Cosmic Muon CRT Tagging Efficiency [%]				
Stage	**CRT**	**IV Only**	**AV**	**FV**
1 strip true	100	97.9	98.1	98.2
1 strip + coin	98.2	97.1	97.5	97.6
DetSim	96.5	95.1	95.7	95.8

Cosmic Muon CRT Vector Efficiency [%]				
Stage	**CRT**	**IV Only**	**AV**	**FV**
1 strip true	43.3	40.3	37.1	37.3
1 strip + coin	40.2	37.9	34.9	35.3
DetSim	37.5	35.5	32.5	32.9

- Tagging efficiency: at least one CRT trigger
- Vector efficiency: at least two tags from different CRT regions (e.g. top and bottom)
- Low vector efficiency is combination of stopping muon rate and low geometric CRT coverage below cryostat

Auto-Veto Rate

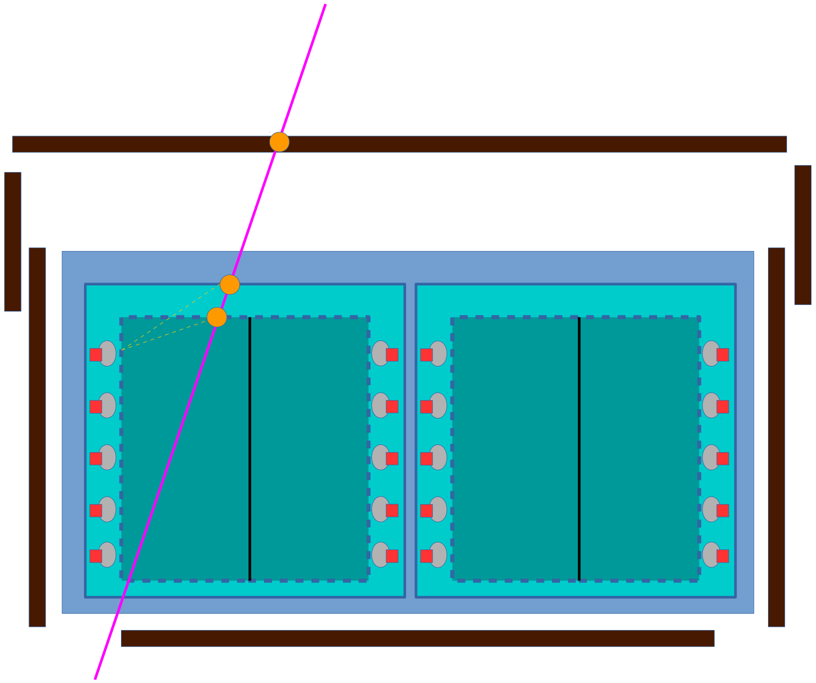
1 strip (Truth) [%]	All LAr	IV	AV (out of FV)	FV
ν_μ All/CC/NC	28 / 17	39 / 20	43 / 24	18 / 12
ν_e CC/NC Intrinsic	27 / 21	40 / 27	38 / 28	18 / 16
ν_e CC/NC Oscillated	23 / 16	35 / 22	36 / 21	14 / 11

DetSim [%]	All LAr	IV	AV (out of FV)	FV
ν_μ CC/NC	17 / 3	25 / 4	28 / 5	9 / 1
ν_e CC/NC Intrinsic	7 / 4	14 / 7	12 / 6	3 / 2
ν_e CC/NC Oscillated	7 / 2	12 / 3	13 / 3	2 / 1

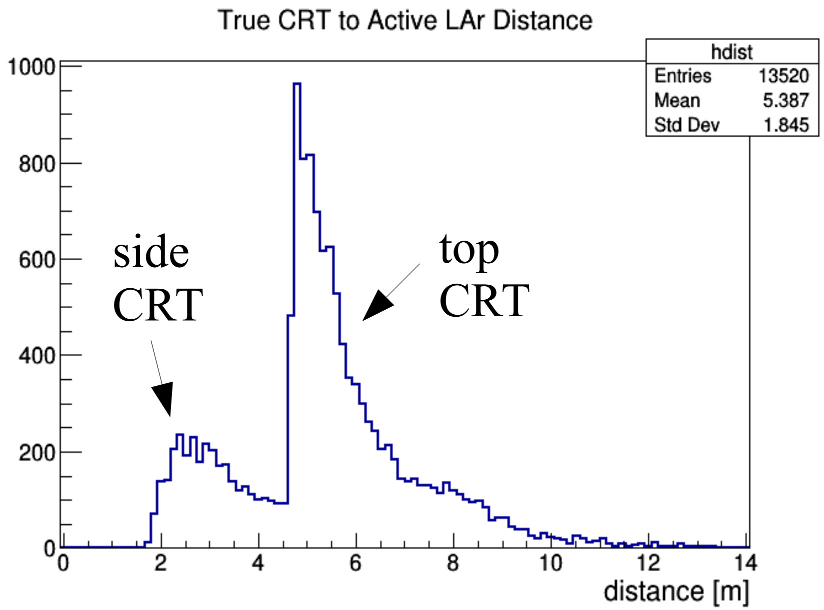
- Disclaimer: these results were derived from small (~few thousand events) samples and will be updated once larger production available
- Specified volume corresponds to location of true neutrino vertex
- Note that no Birks correction (scintillation quenching) is included in the light production model which would cause a loss in trigger efficiency for high dE/dx particles (e.g. protons)
- Birks correction expected to suppress auto-veto rate

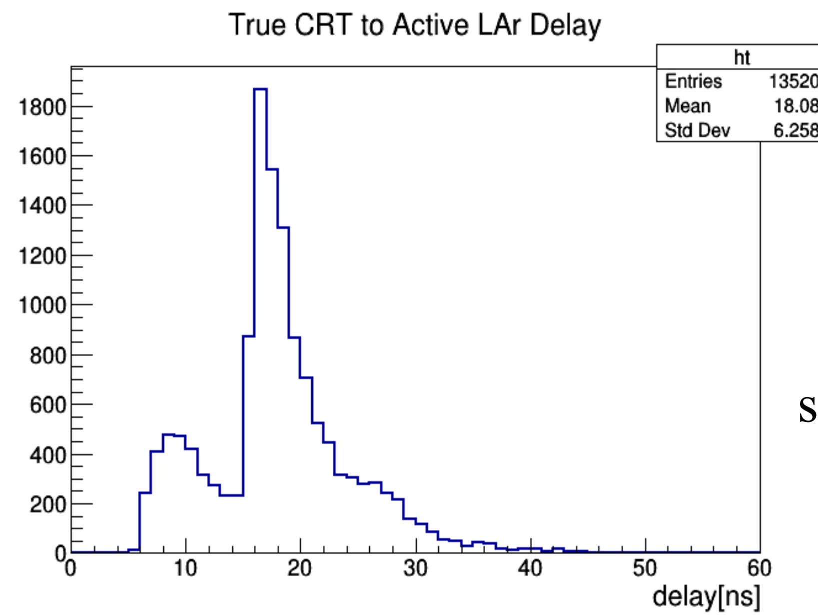
First Look at Matching CRT, PMT Hits

- Compute time delay between CRT and earliest possible PMT signal
- Calculate photon arrival time using straight line path, propagation velocity in LAr
- Light production in inactive LAr could preempt scintillation light associated with EM activity visible in active LAr
- Following slides show only results for cosmics – corresponding neutrino results will also be produced once large sample available

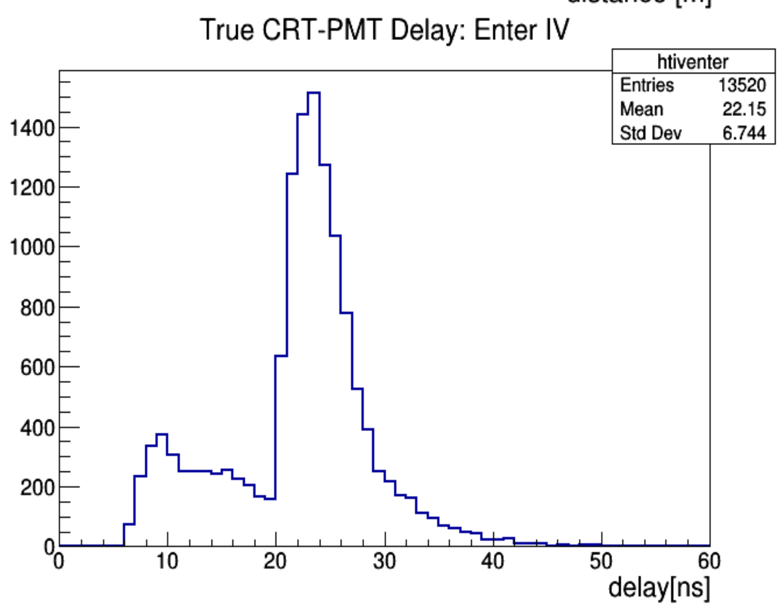


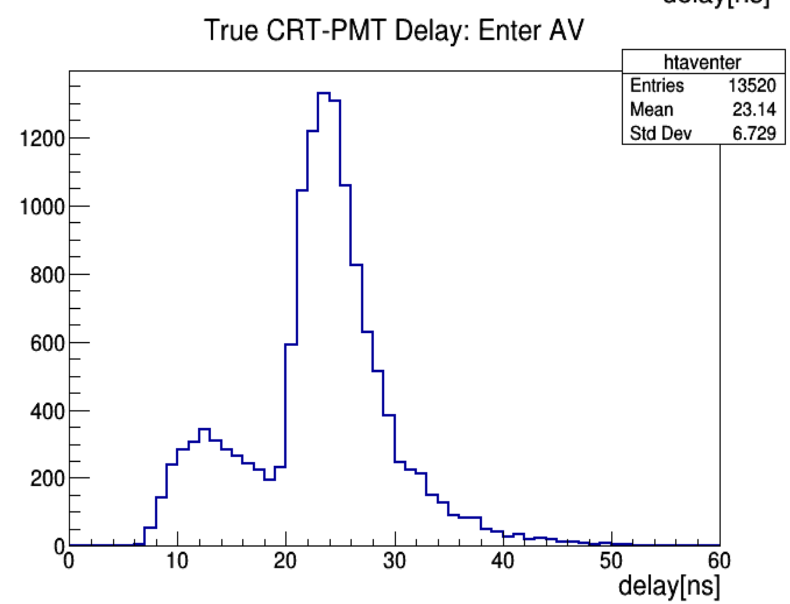
True CRT-PMT Delay



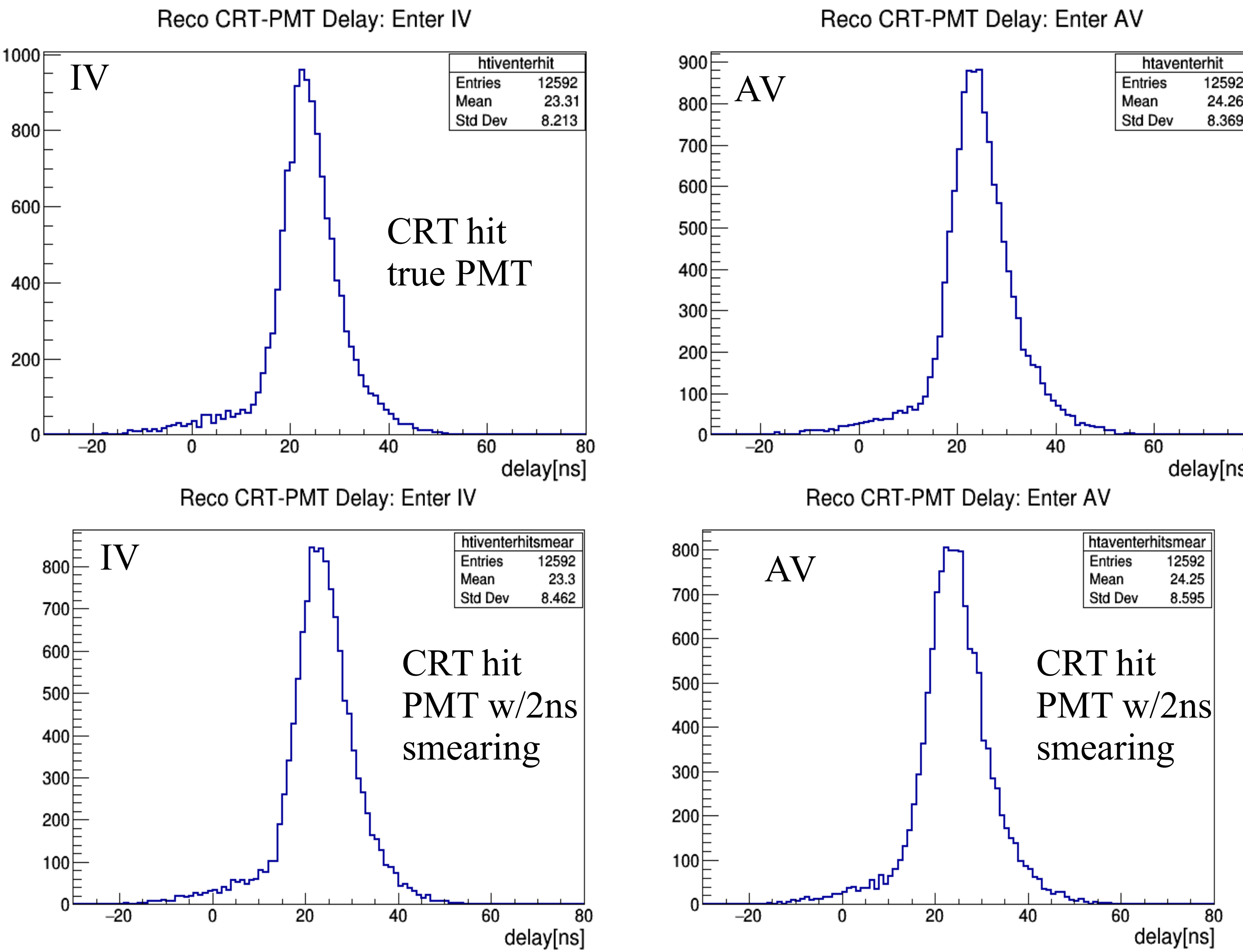


shortest delay
6 ns





Reco. CRT-PMT Delay



Assume light from IV always preempts that from AV

Fraction
> 0 ns = 98%
> 6 ns = 96%

Summary

- CRT detector simulation has been validated with data from side CRT test stand with some tuning need
- CRT hit reconstruction has been implemented, validated with truth matching study
- First look at cosmogenic muon tagging efficiency with detector simulation showing we meet our goal of 95%
- First look at auto-veto rate with detector simulation to be confirmed with better statistics
  - BNB ν_μCC 9%
  - BNB intrinsic ν_eCC 3%
  - BNB signal ν_eCC 2%
-

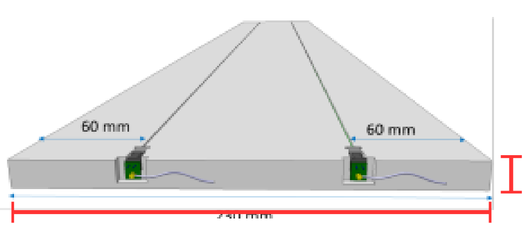
Next Steps

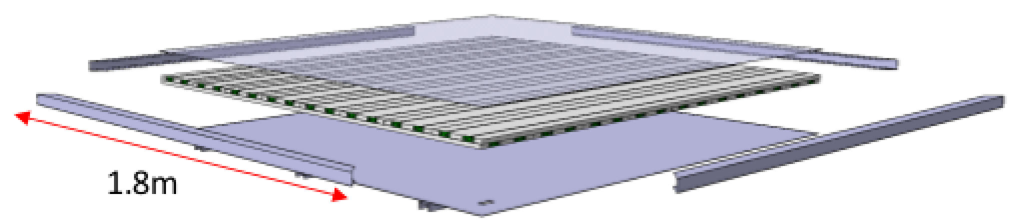
- Tune side CRT detector light yield, time stamp generation models, add quenching
- Improvements to hit reconstruction
- Implement CRT track reconstruction
- Focus during next week's SBN Analysis Workshop
  - CRT hit/track → PMT hit/flash matching
  - CRT hit/track → TPC track matching

BACKUP

CERN Subsystem

- Scintillator
  - Bulk: cast polystyrene
  - Fluors: pTP (2% by weight), PPO (1% by weight), POPOP (0.03,0.05% by weight)
  - Diffuser: Reflective paint
- Modules
  - 16 strips
  - 2 layers X-Y
  - 2 WLS fibers / strip
  - Single ended readout, mirrored at far end
  - 1 SiPM / fiber
- FEB
  - CAEN A1702
  - 1 / module
- Front-end Logic
  - Coincidence of 2 fibers in a strip above threshold
  - Coincidence between X & Y layers in module

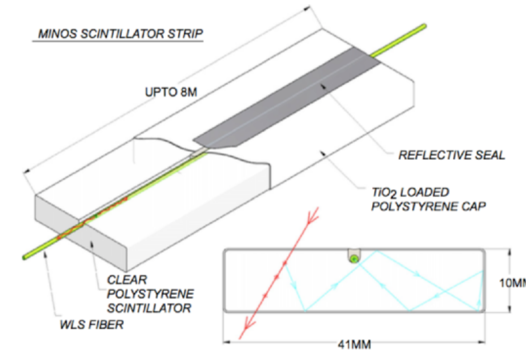


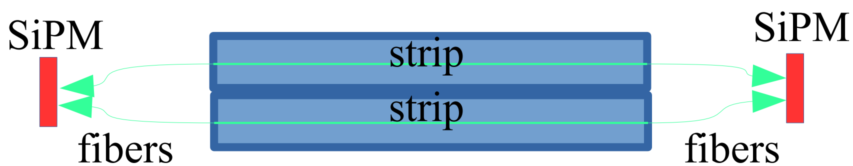


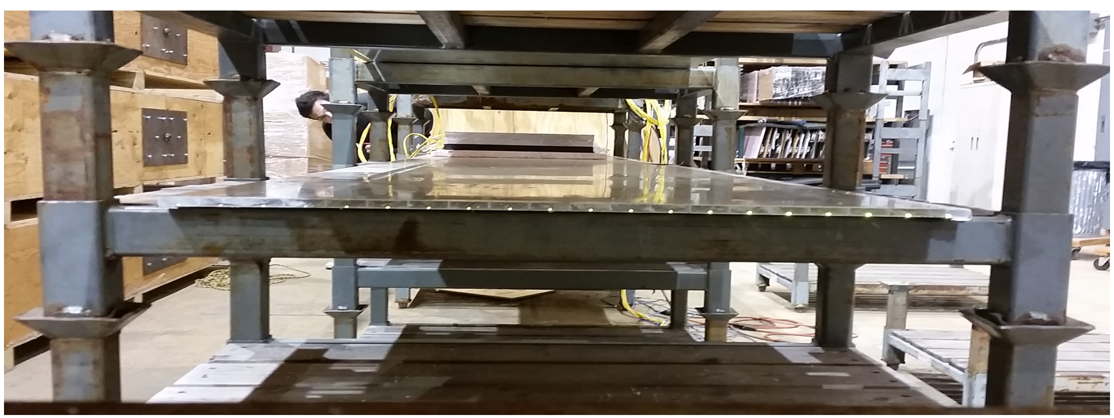
MINOS Subsystem

- Scintillator
  - Bulk: extruded polystyrene
  - Fluors: PPO (1% by weight), POPOP (0.3% by weight)
  - Diffuser: TiO2 (15% by weight) coextruded 0.25mm thick
- Modules
  - 20 strips
  - Single layer
  - 1 WLS fiber / strip
  - Dual ended readout
  - 1 SiPM / end / 2 fibers

- FEB
  - CAEN A1702
  - 1 / end / 3 modules
- Front-end Logic
  - At least one SiPM channel above threshold / FEB
  - Hardware based coincidence between adjacent layers



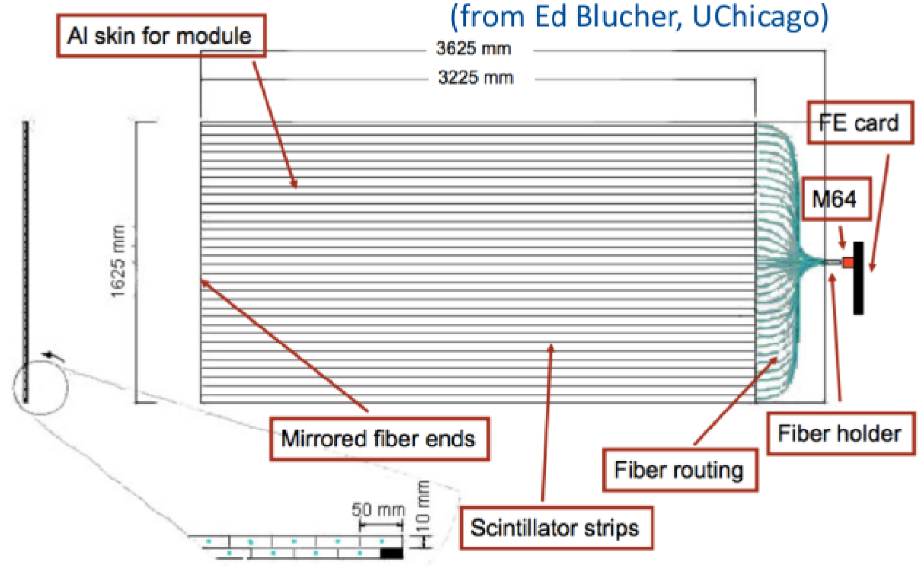




Double Chooz Subsystem

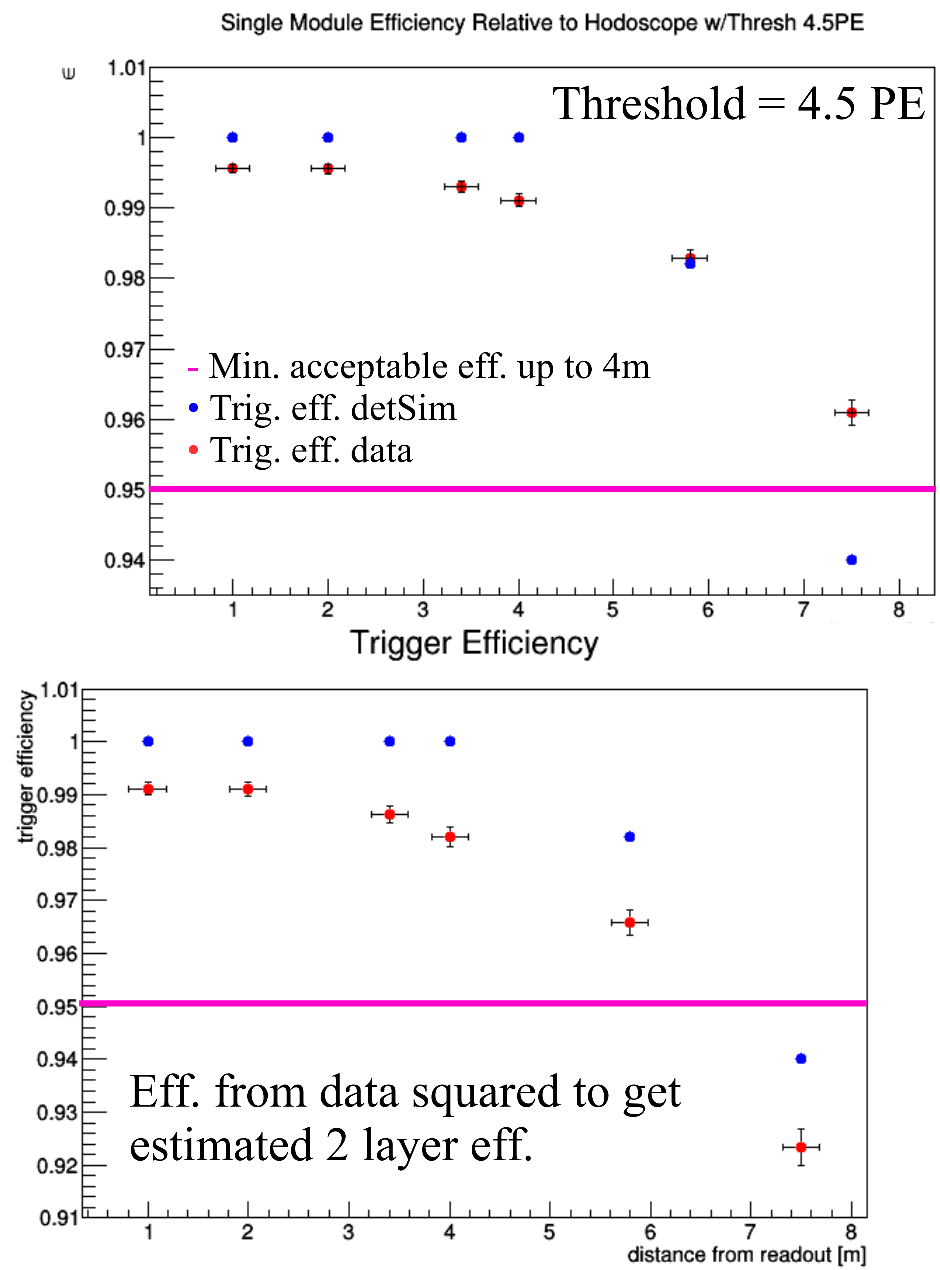
- Scintillator
  - Bulk: extruded polystyrene
  - Fluors: pTP (1% by weight), POPOP (0.03% by weight)
  - Diffuser: TiO_2 (15% by weight) coextruded 0.25mm thick
- Modules
  - 64 strips
  - Dual layer X-X
  - 1 WLS fiber / strip
  - Single ended readout
  - 1 PMT channel / fiber
- FEB
  - NEVIS custom
  - 1 / module
- Front-end Logic
  - At least one PMT channel above threshold per layer

(from Ed Blucher, UChicago)

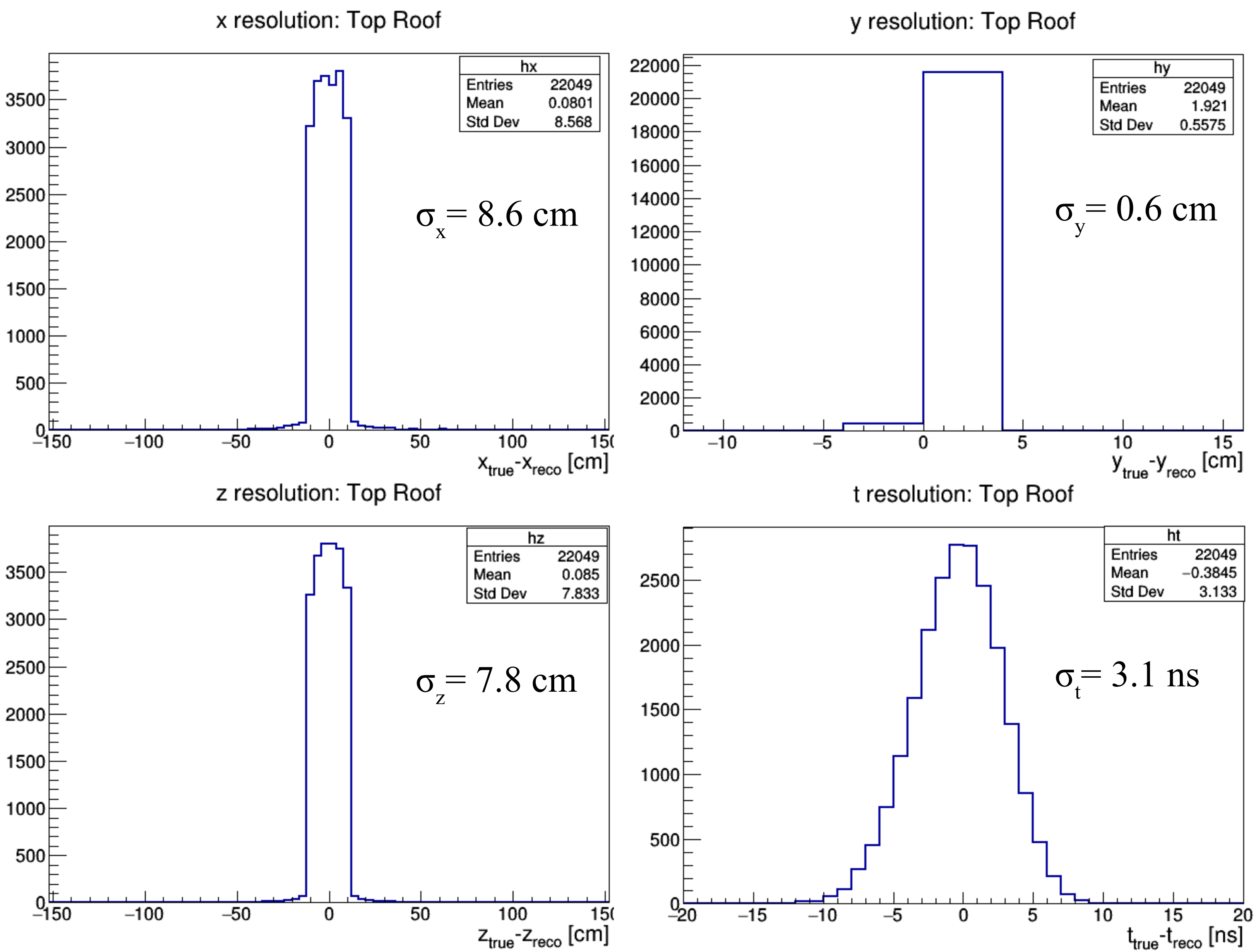


Trigger Efficiency

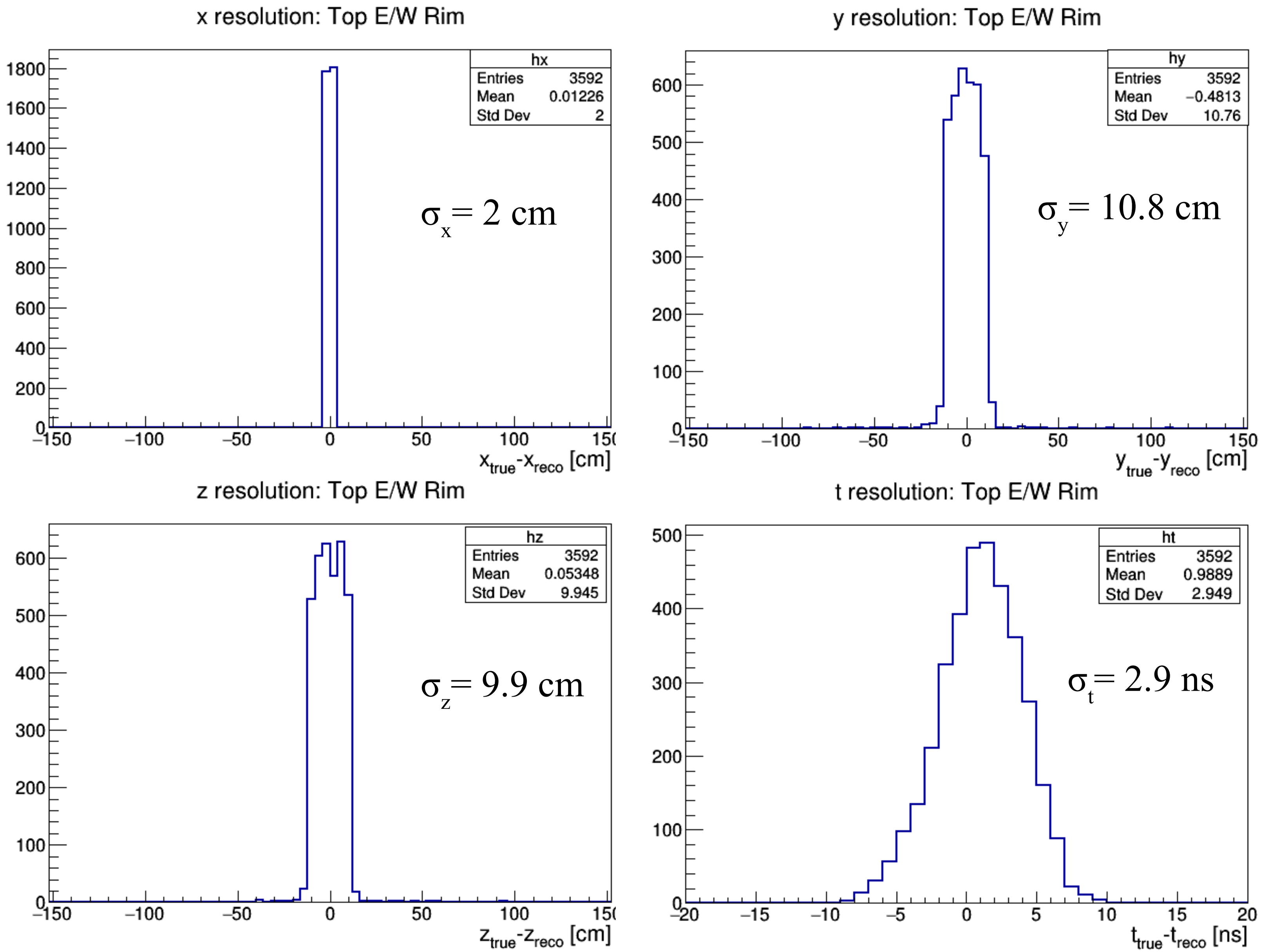
- Default DetSim trigger config. requires coincidence between adjacent layers
- Test stand measurement used just a single layer
- Simulated eff. looks consistent with expectations from test stand data considering all tracks normally incident and centered on strip



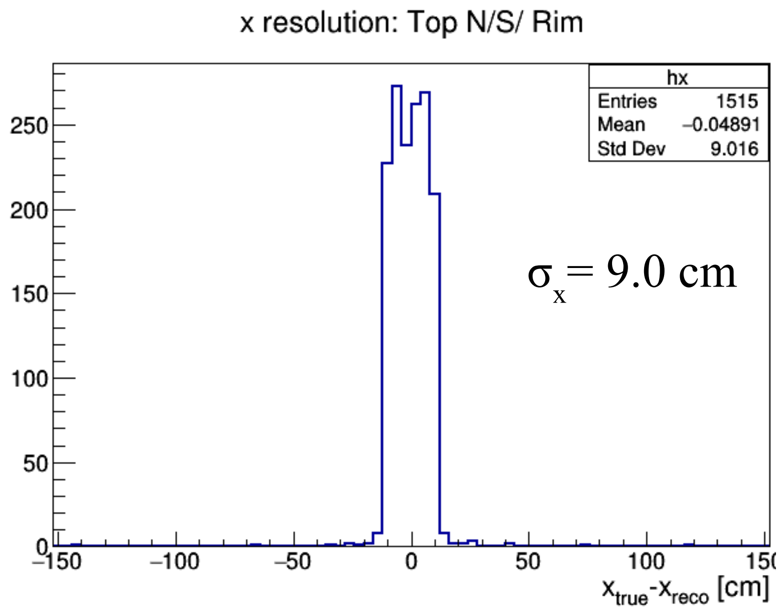
Top - Roof

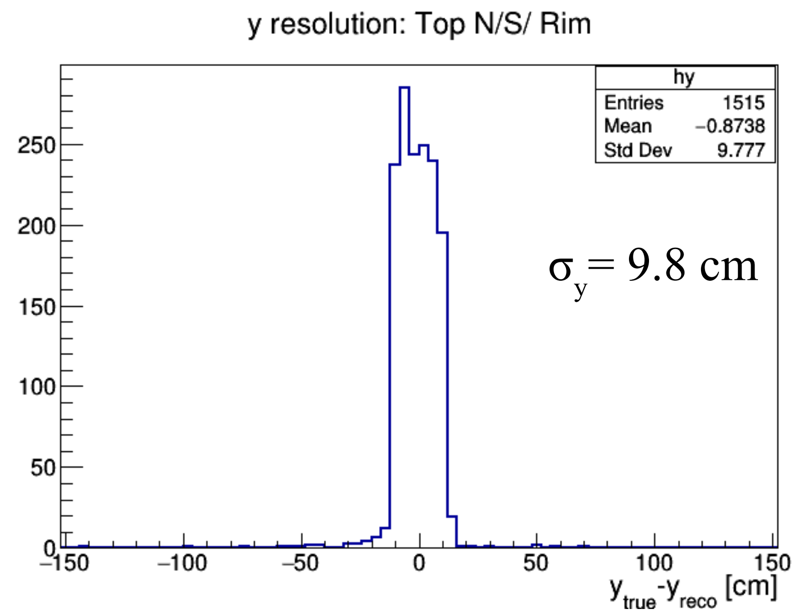

x resolution: Top Roof
hx
Entries 22049
Mean 0.0801
Std Dev 8.568
σx = 8.6 cm
xtrue-xreco [cm]
y resolution: Top Roof
hy
Entries 22049
Mean 1.921
Std Dev 0.5575
σy = 0.6 cm
ytrue-yreco [cm]
z resolution: Top Roof
hz
Entries 22049
Mean 0.085
Std Dev 7.833
σz = 7.8 cm
ztrue-zreco [cm]
t resolution: Top Roof
ht
Entries 22049
Mean −0.3845
Std Dev 3.133
σt = 3.1 ns
ttrue-treco [ns]

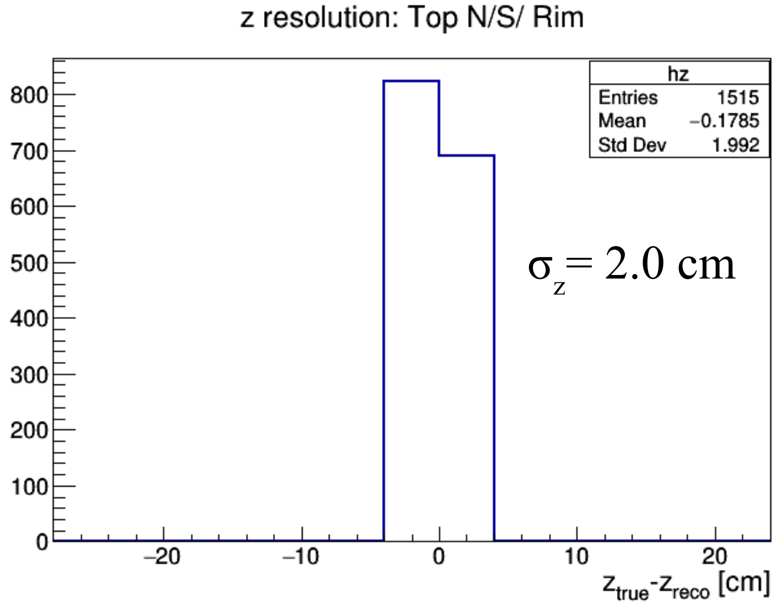
Top – E/W Rim

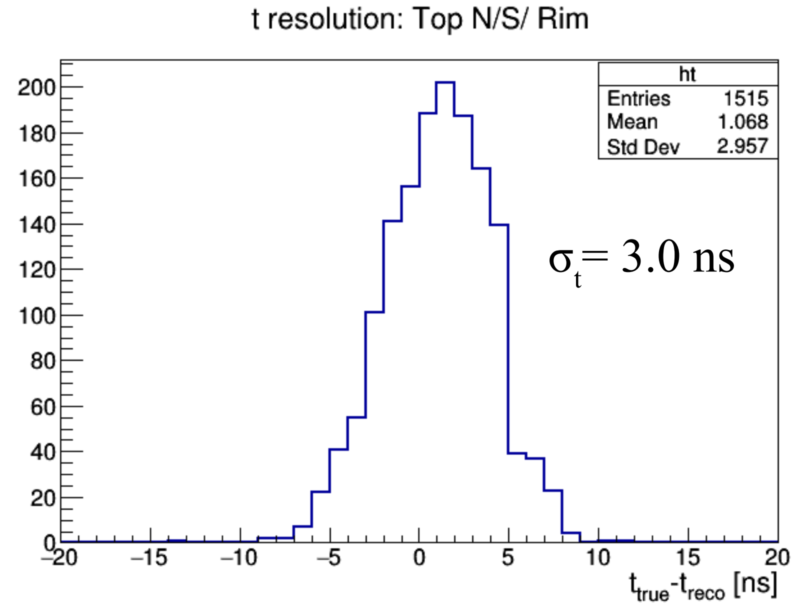

x resolution: Top E/W Rim
hx
Entries 3592
Mean 0.01226
Std Dev 2
σx = 2 cm
xtrue-xreco [cm]
y resolution: Top E/W Rim
hy
Entries 3592
Mean −0.4813
Std Dev 10.76
σy = 10.8 cm
ytrue-yreco [cm]
z resolution: Top E/W Rim
hz
Entries 3592
Mean 0.05348
Std Dev 9.945
σz = 9.9 cm
ztrue-zreco [cm]
t resolution: Top E/W Rim
ht
Entries 3592
Mean 0.9889
Std Dev 2.949
σt = 2.9 ns
ttrue-treco [ns]

Top – N/S Rim

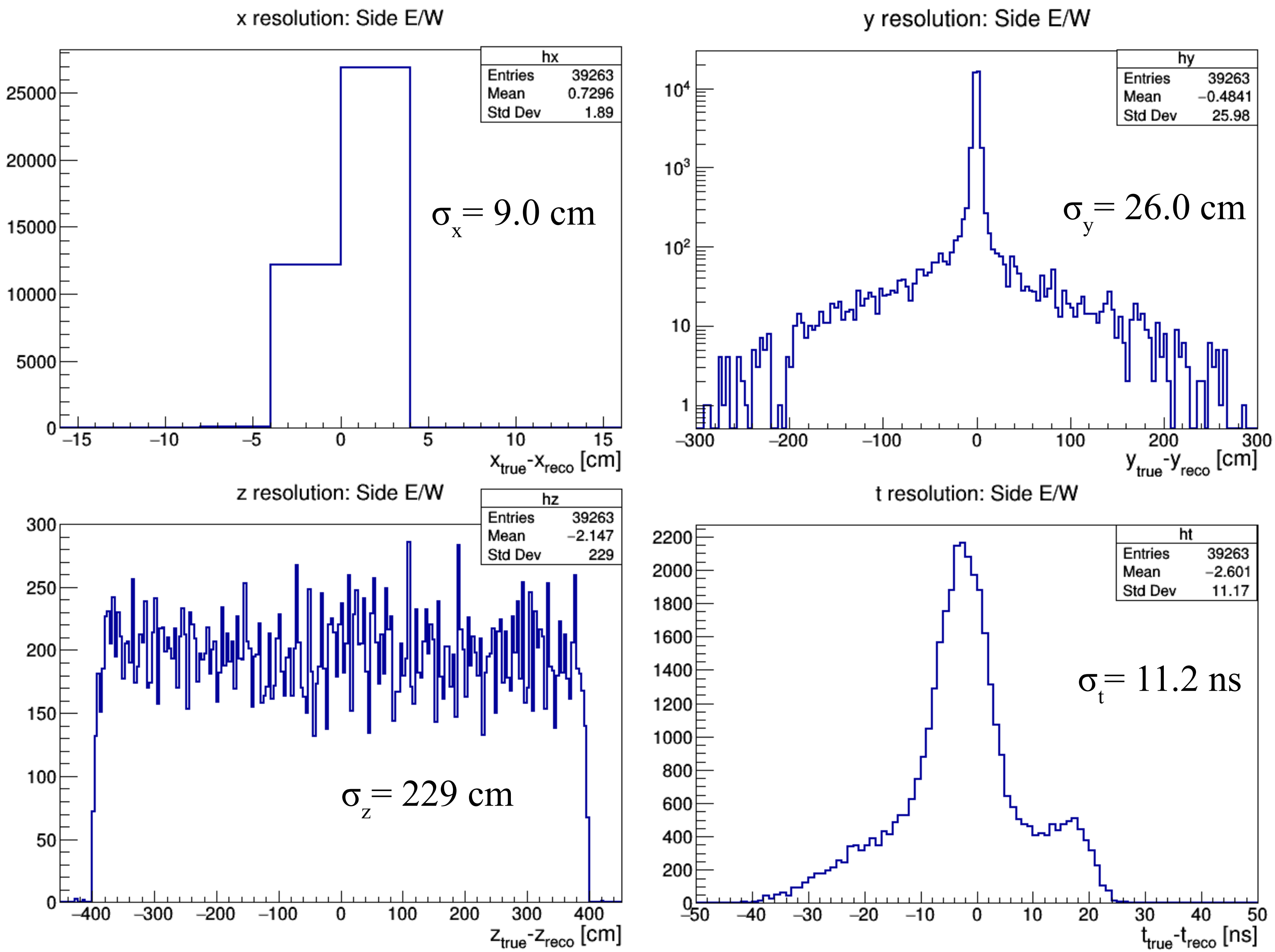

x resolution: Top N/S/ Rim
hx
Entries 1515
Mean −0.04891
Std Dev 9.016
σ_x = 9.0 cm
x_{true}-x_{reco} [cm]


y resolution: Top N/S/ Rim
hy
Entries 1515
Mean −0.8738
Std Dev 9.777
σ_y = 9.8 cm
y_{true}-y_{reco} [cm]

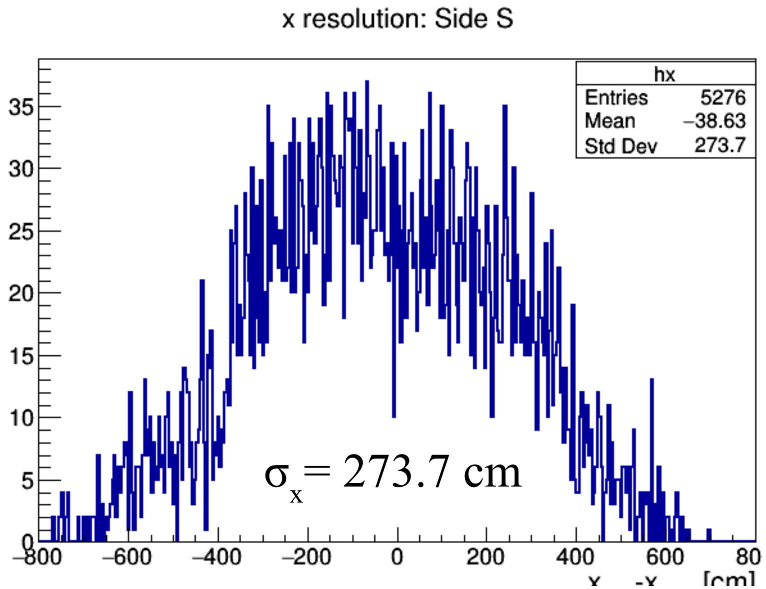

z resolution: Top N/S/ Rim
hz
Entries 1515
Mean −0.1785
Std Dev 1.992
σ_z = 2.0 cm
z_{true}-z_{reco} [cm]

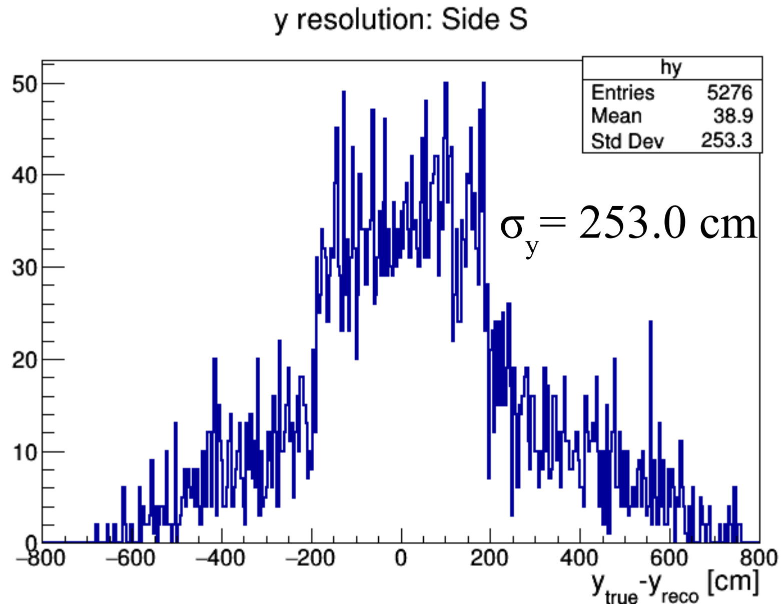

t resolution: Top N/S/ Rim
ht
Entries 1515
Mean 1.068
Std Dev 2.957
σ_t = 3.0 ns
t_{true}-t_{reco} [ns]

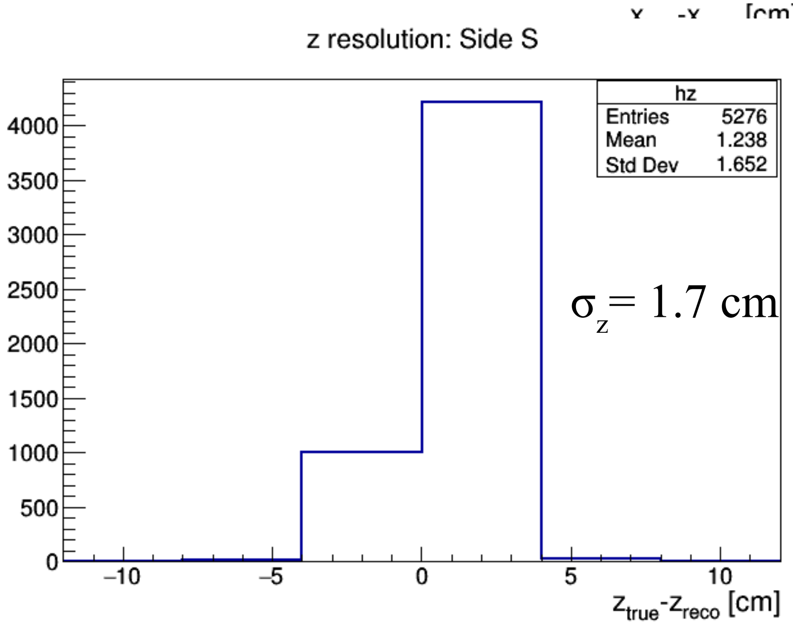
Side – E/W Wall

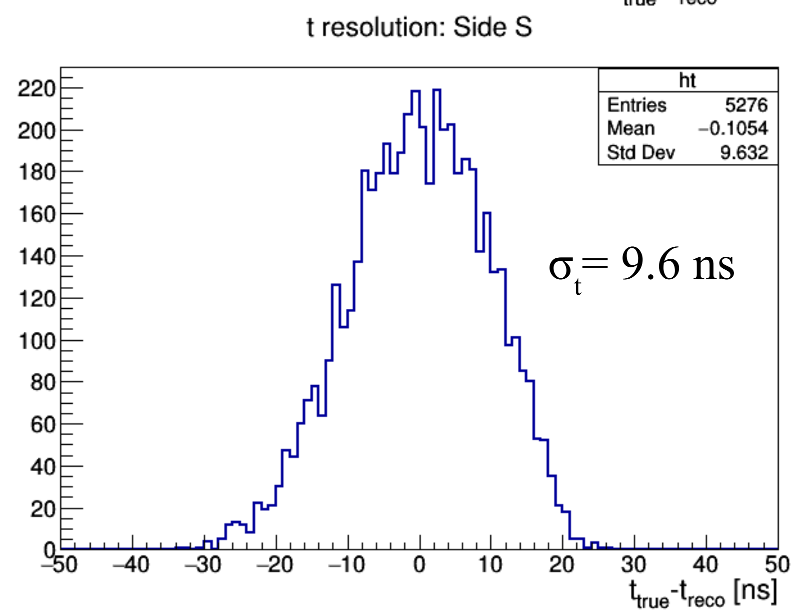

x resolution: Side E/W
hx
Entries 39263
Mean 0.7296
Std Dev 1.89
σx = 9.0 cm
xtrue-xreco [cm]
y resolution: Side E/W
hy
Entries 39263
Mean −0.4841
Std Dev 25.98
σy = 26.0 cm
ytrue-yreco [cm]
z resolution: Side E/W
hz
Entries 39263
Mean −2.147
Std Dev 229
σz = 229 cm
ztrue-zreco [cm]
t resolution: Side E/W
ht
Entries 39263
Mean −2.601
Std Dev 11.17
σt = 11.2 ns
ttrue-treco [ns]

Side – S Wall

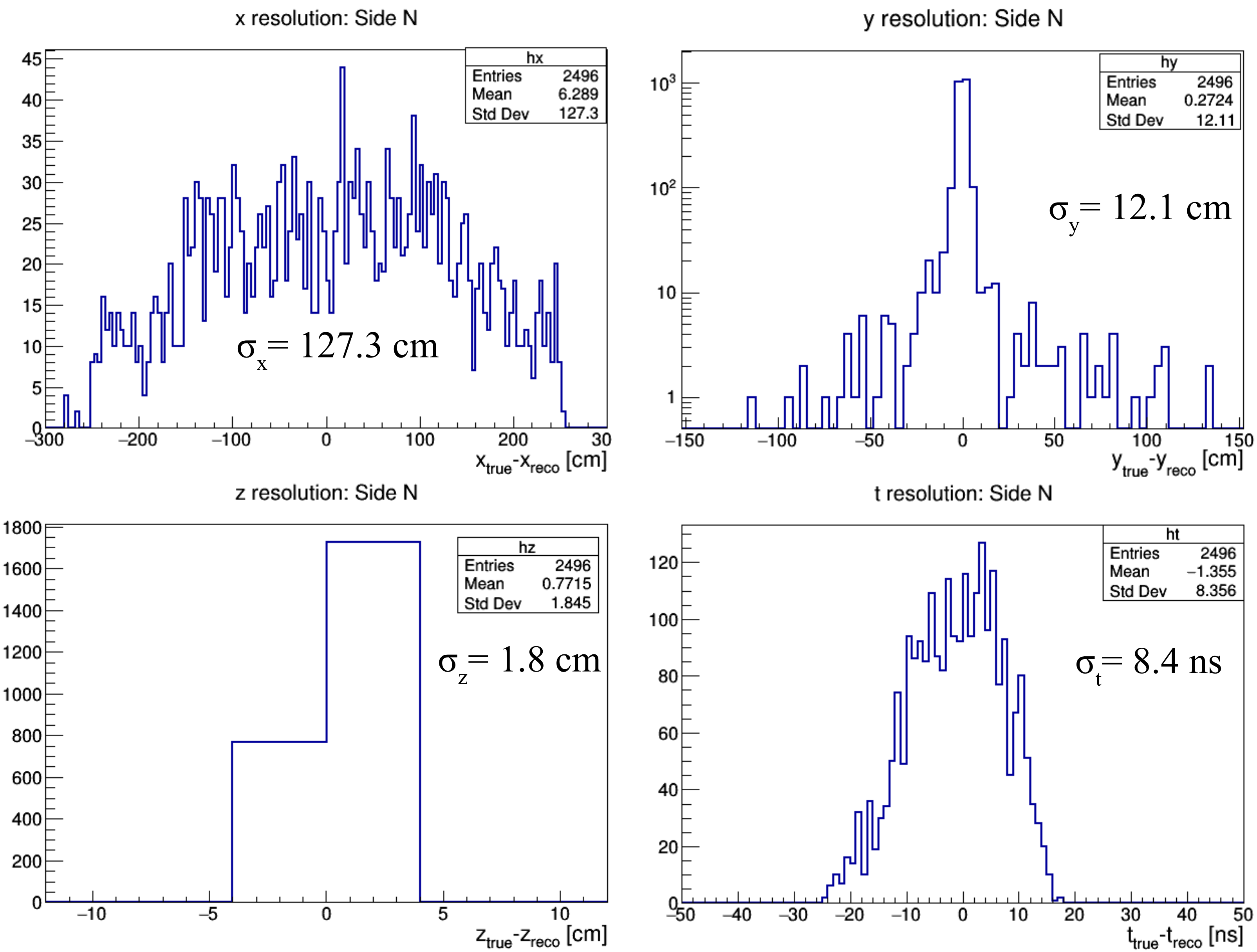

x resolution: Side S
hx
Entries 5276
Mean −38.63
Std Dev 273.7
σx = 273.7 cm
35
30
25
20
15
10
5
0
−800
−600
−400
−200
0
200
400
600
80


y resolution: Side S
hy
Entries 5276
Mean 38.9
Std Dev 253.3
σy = 253.0 cm
50
40
30
20
10
0
−800
−600
−400
−200
0
200
400
600
800
ytrue-yreco [cm]

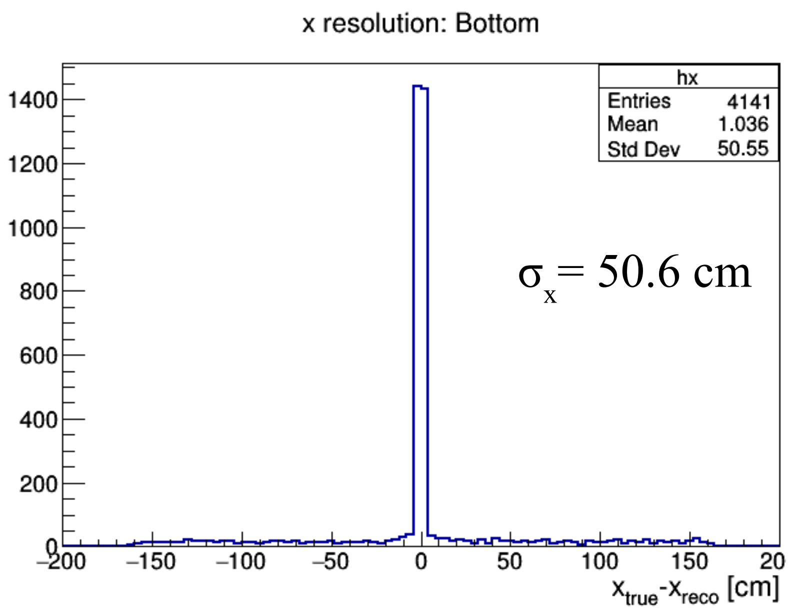

z resolution: Side S
hz
Entries 5276
Mean 1.238
Std Dev 1.652
σz = 1.7 cm
4000
3500
3000
2500
2000
1500
1000
500
0
−10
−5
0
5
10
ztrue-zreco [cm]

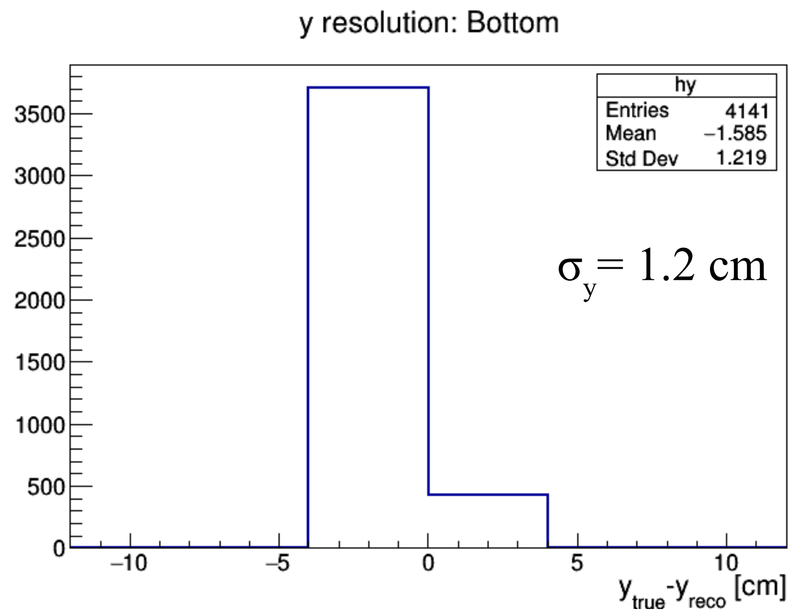

t resolution: Side S
ht
Entries 5276
Mean −0.1054
Std Dev 9.632
σt = 9.6 ns
220
200
180
160
140
120
100
80
60
40
20
0
−50
−40
−30
−20
−10
0
10
20
30
40
50
ttrue-treco [ns]

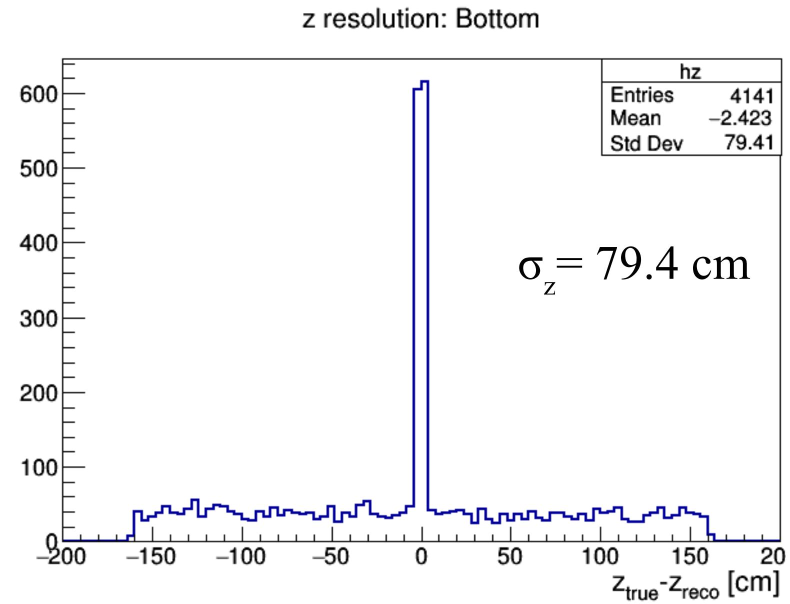
Side – N Wall

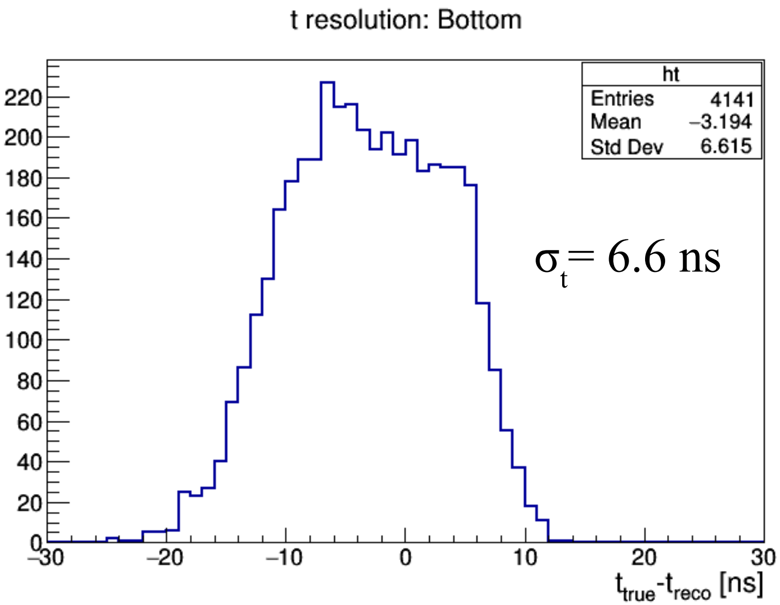

x resolution: Side N
hx
Entries 2496
Mean 6.289
Std Dev 127.3
σx = 127.3 cm
x_true-x_reco [cm]
y resolution: Side N
hy
Entries 2496
Mean 0.2724
Std Dev 12.11
σy = 12.1 cm
y_true-y_reco [cm]
z resolution: Side N
hz
Entries 2496
Mean 0.7715
Std Dev 1.845
σz = 1.8 cm
z_true-z_reco [cm]
t resolution: Side N
ht
Entries 2496
Mean −1.355
Std Dev 8.356
σt = 8.4 ns
t_true-t_reco [ns]

Bottom

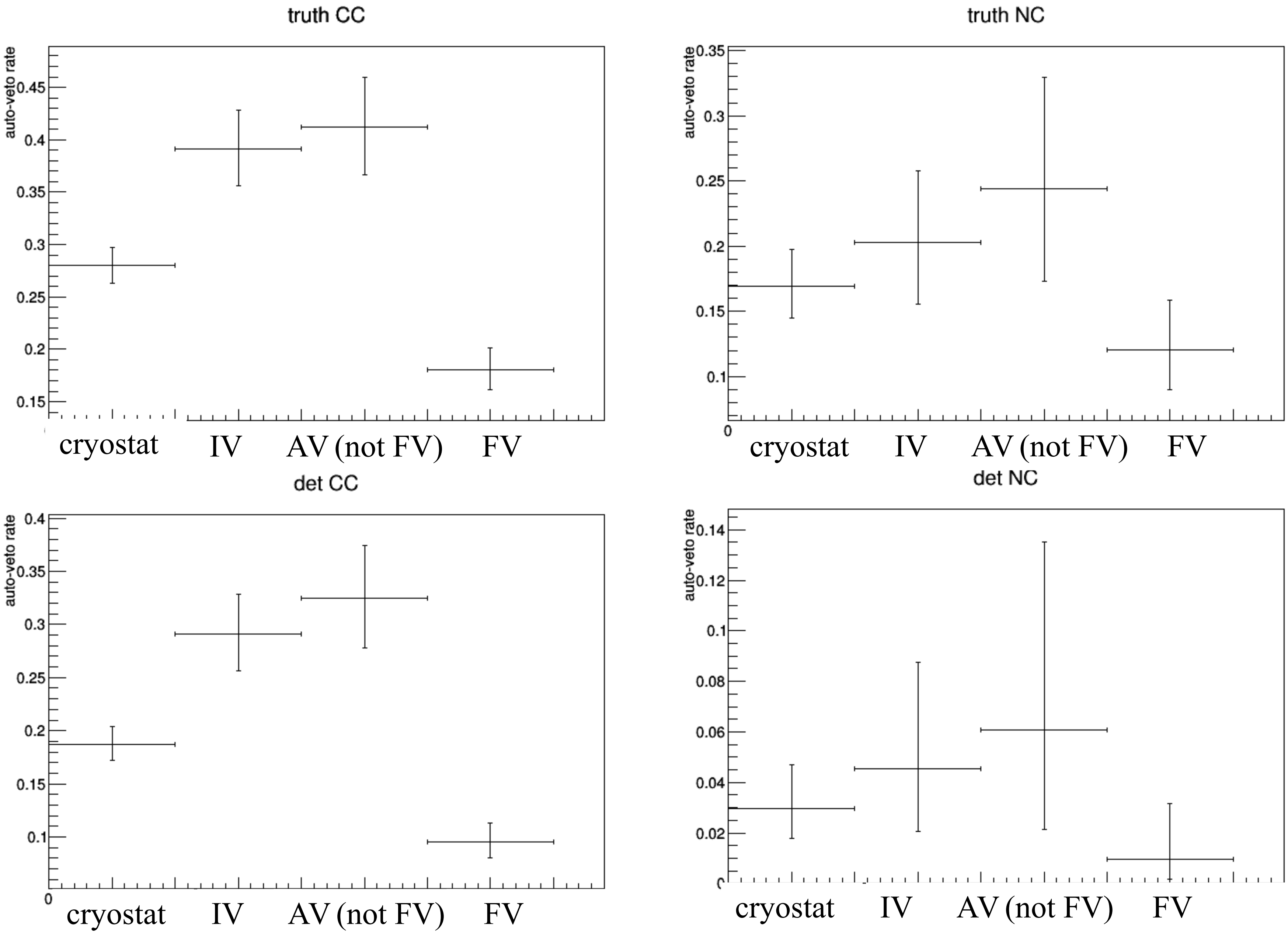

x resolution: Bottom
hx
Entries 4141
Mean 1.036
Std Dev 50.55
σx = 50.6 cm
xtrue-xreco [cm]


y resolution: Bottom
hy
Entries 4141
Mean −1.585
Std Dev 1.219
σy = 1.2 cm
ytrue-yreco [cm]


z resolution: Bottom
hz
Entries 4141
Mean −2.423
Std Dev 79.41
σz = 79.4 cm
ztrue-zreco [cm]


t resolution: Bottom
ht
Entries 4141
Mean −3.194
Std Dev 6.615
σt = 6.6 ns
ttrue-treco [ns]

Auto-Veto: BNB ν_μ



Auto-Veto: BNB Intrinsic ν_e