Convolutional Neural Network Reconstruction of Neutrino Event Interaction Vertex in IceCube

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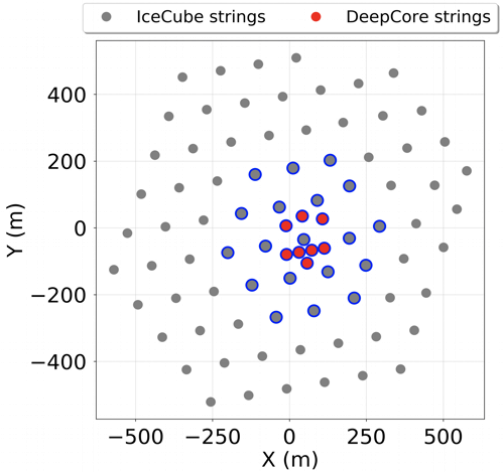
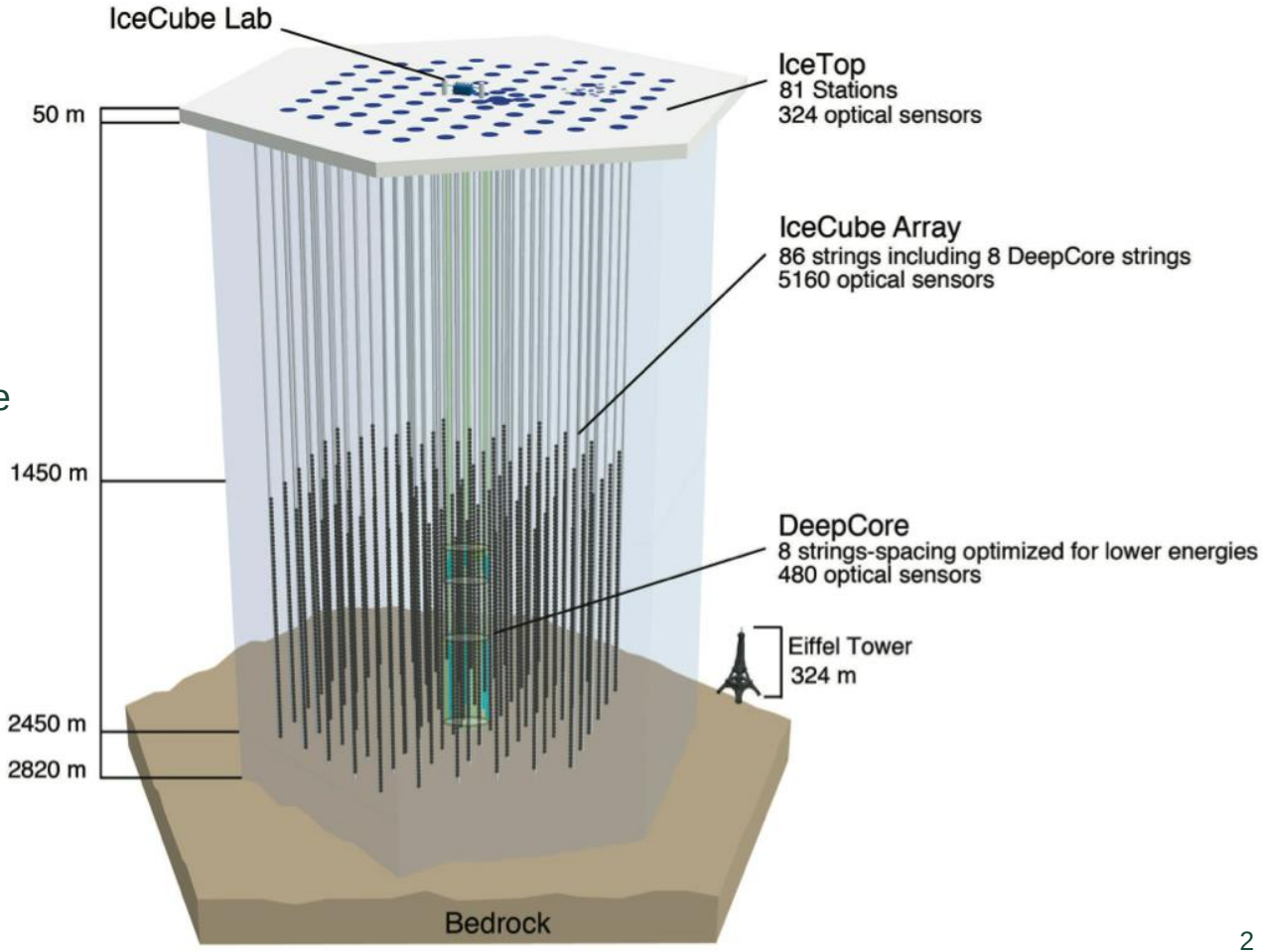
IceCube Collaboration

NSF-1913607

IceCube

- Detects astrophysical and atmospheric neutrinos using Cherenkov radiation
- Optical sensors (DOMs) detect photons from the cone of light





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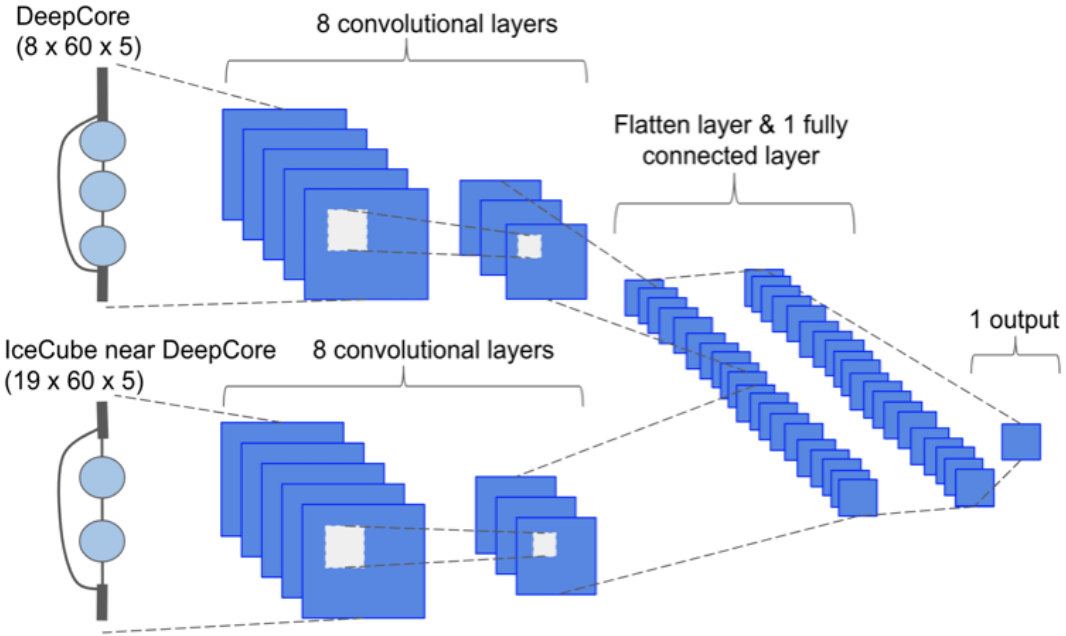
FLERCNN - Fast Low Energy Reco using CNNs

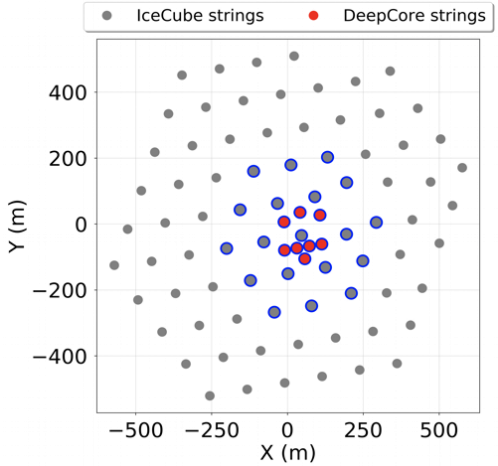
Method established by Jessie Micallef
and previously presented by Shiqi Yu

Goal: use a CNN to reconstruct vertex for low energy (5-100 GeV) events; compare to current likelihood-based methods



CNN uses per-DOM approach: summarize all pulses that hit each DOM

- Sum of charge
- time of first hit
- time of last hit
- charge weighted mean
- charge weighted σ



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CNN Computation Time

	Average time (s) per event	Events per day per single core
CNN on GPU	0.0077	11,000,000
CNN on CPU	0.27	320,000
Previous likelihood-based method on CPU	40	2,100

- CNN gives vast time improvements over likelihood-based methods
- Using computing cluster can make the computation time down significantly

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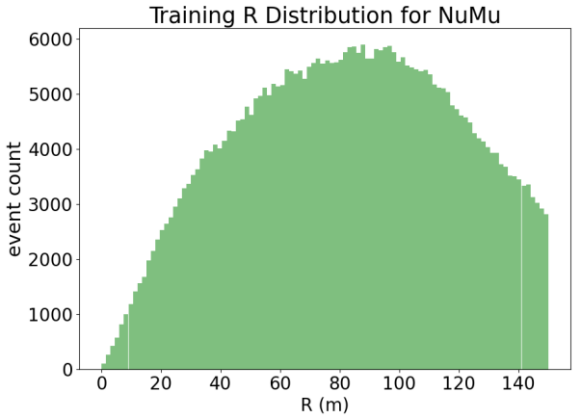
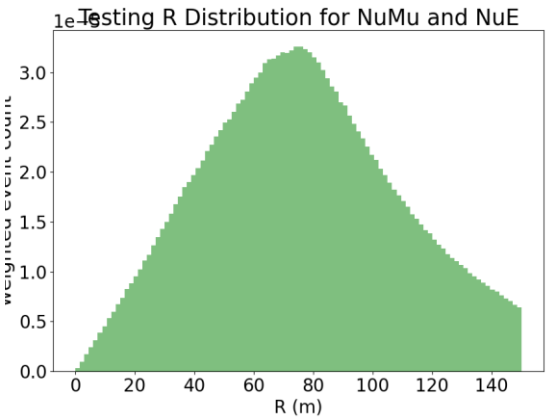
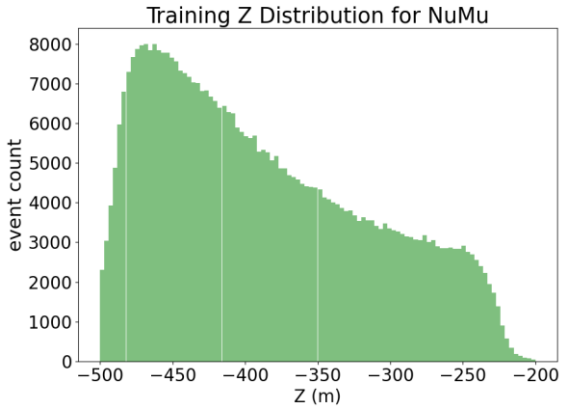
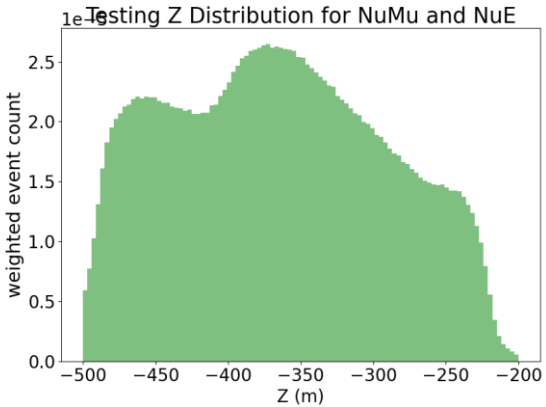
Training and Testing Output Distributions

- Training sample: NuMu CC Monte Carlo 1-500 GeV (generated for our CNN)
- CNN trained and tested on X, Y, and Z
  - Radius calculated from X & Y after testing
- Chose to look at DeepCore
  - R < 150
  - -500 < Z < -200
  - Where we have the most data
- Atmospheric flux model weights applied to testing sample









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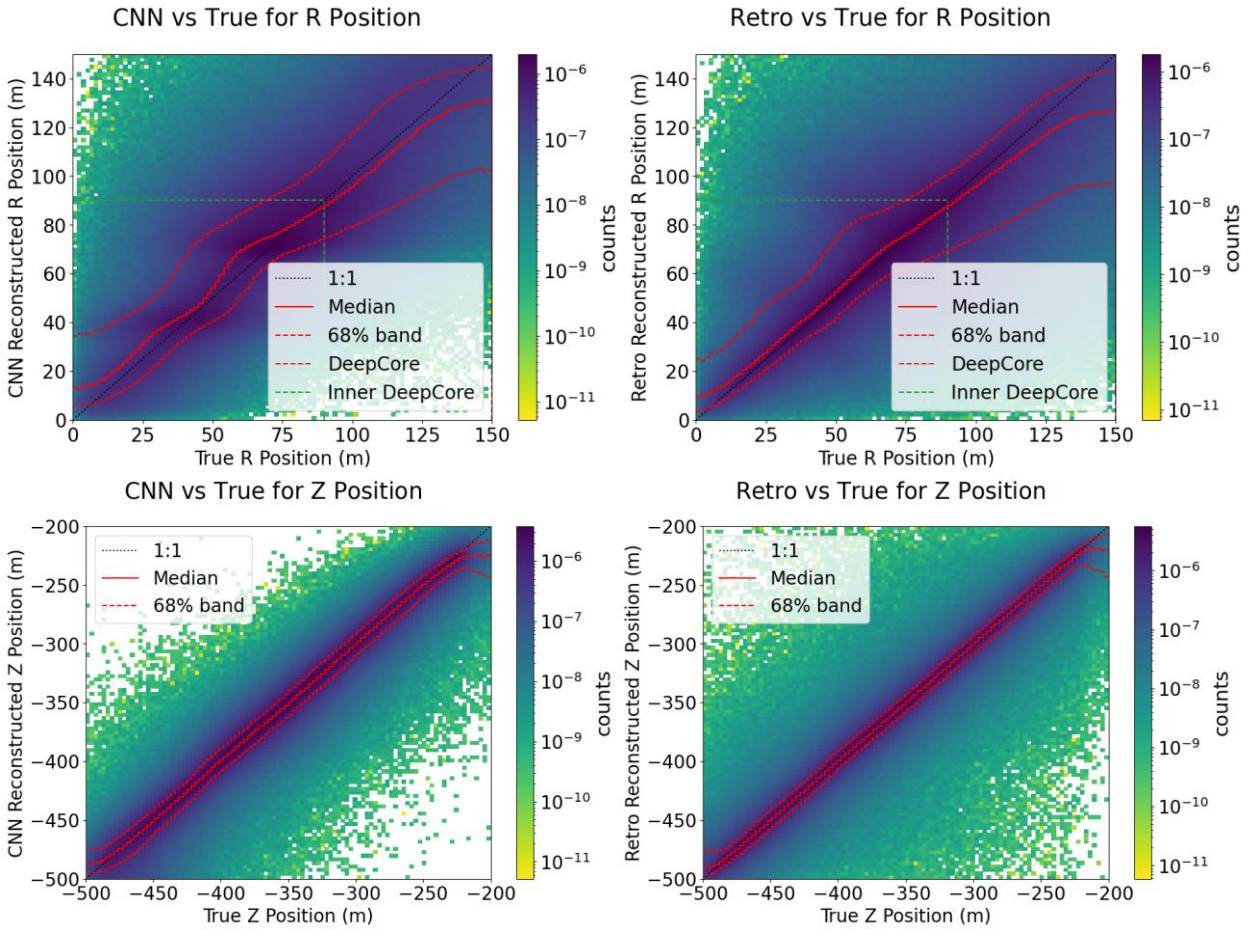
Reconstructed Position vs True Position

- Retro is the likelihood-based model used for comparison
- CNN and likelihood-based have similar results
- Chose to look at DeepCore
  - R < 150
  - -500 < Z < -200
- Within DeepCore, both give good results
- Outside of DeepCore, both CNN and likelihood-based's predictions get worse
- All plots are ν_μ and ν_e



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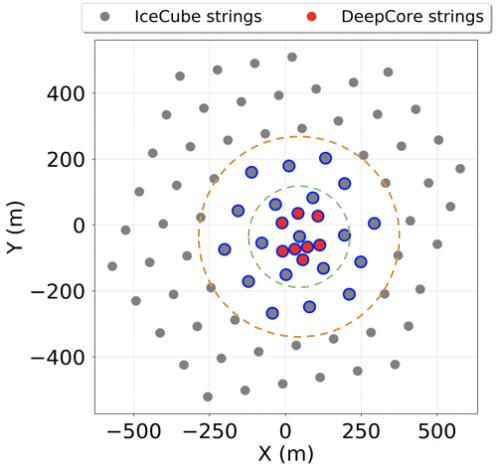
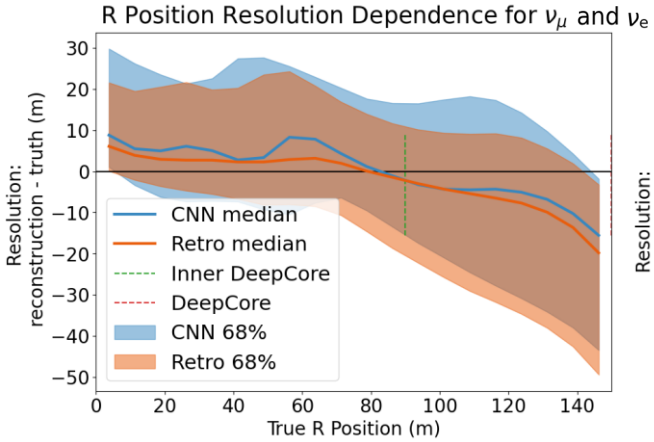
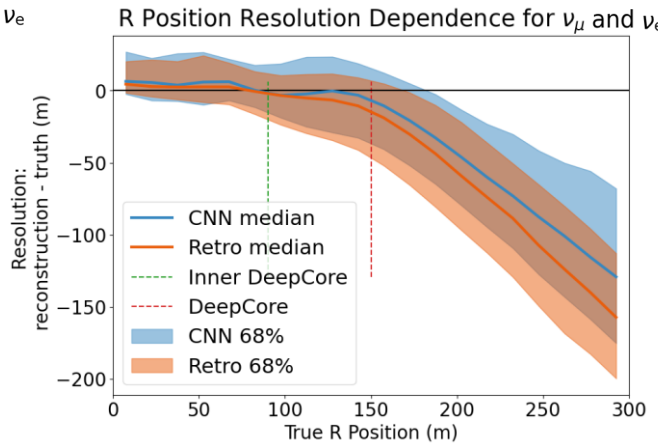
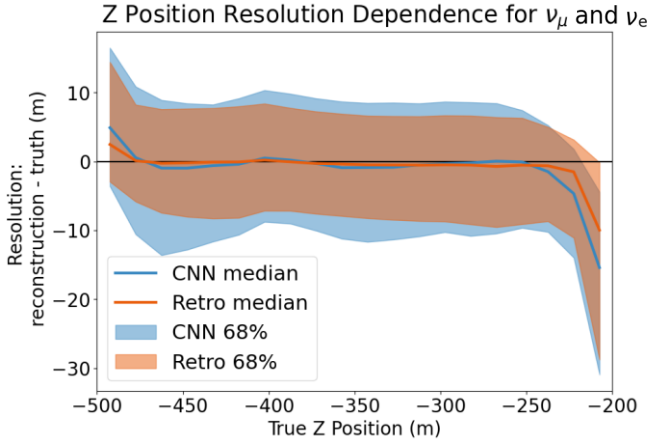
Likelihood-based and CNN Resolution vs Truth

- Chose to look at DeepCore
  - R < 150
  - -500 < Z < -200
- Larger cuts show where both reconstructions degrade
  - R < 300
- CNN is comparable to likelihood-based









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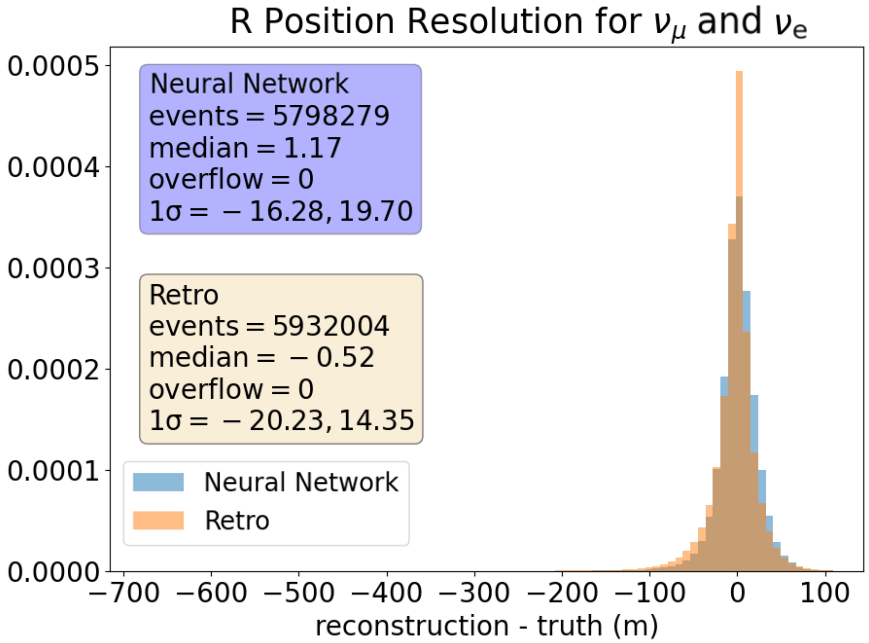
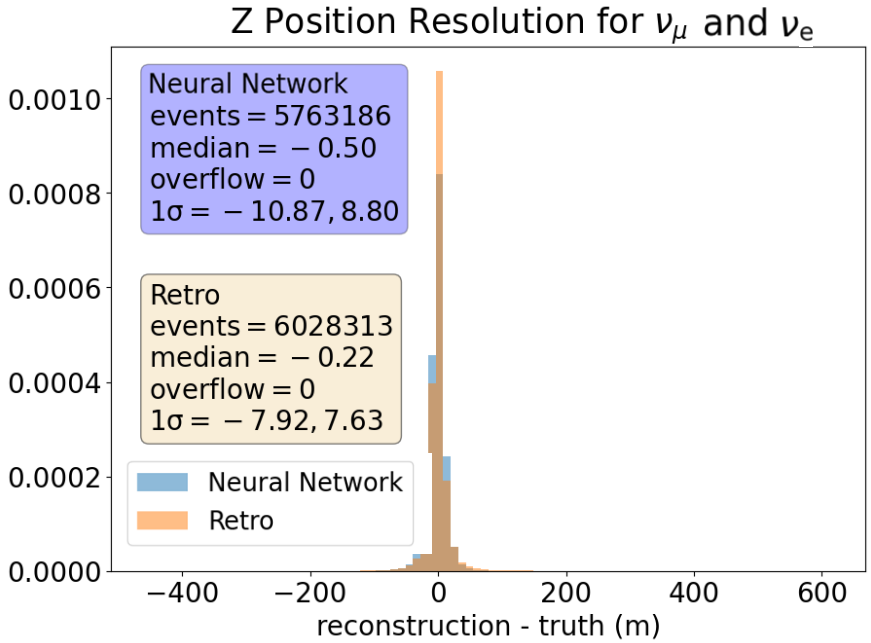
Resolution Plots





- Likelihood-based and CNN's 1σ are comparable
- Both medians are close to zero

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Confusion Matrices

CNN R < 150	*True Contained*	*True Cut*		*Likelihood-based R < 150*	*True Contained*	*True Cut*
CNN Contained	85.4914%	2.5628%		*Likelihood-based Contained*	86.7657%	3.3193%
CNN Cut	3.1182%	8.8277%		*Likelihood-based Cut*	1.8439%	8.0712%
CNN -500 < Z < -200	*True Contained*	*True Cut*		*Likelihood-based -500 < Z < -200*	*True Contained*	*True Cut*
CNN Contained	87.0742%	0.4471%		*Likelihood-based Contained*	90.1845%	1.3630%
CNN Cut	3.9193%	8.5595%		*Likelihood-based Cut*	0.8089%	7.6436%

- CNN and likelihood-based performing comparably
- CNN applying a harsher cut than likelihood-based
- Both cut more from the radius (R) than the depth (Z)

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Summary and Next Steps

- CNN has comparable reconstruction results to likelihood-based methods
- CNN is significantly faster than likelihood-based methods
- Best results where we have the most training and testing data

- Train for uncertainty on these variables
- Explore additional cut based on uncertainty to improve resolution

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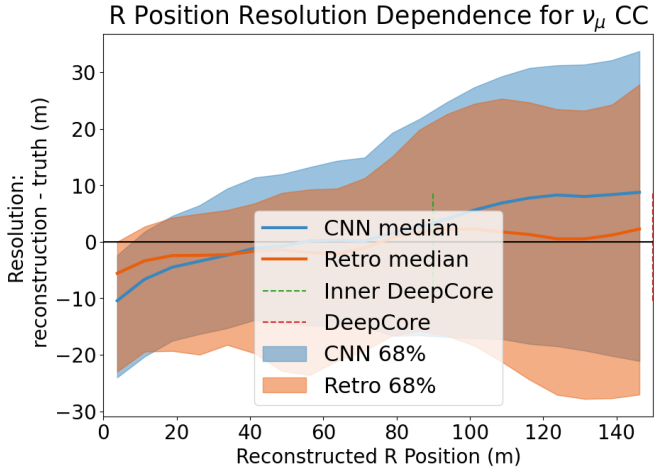
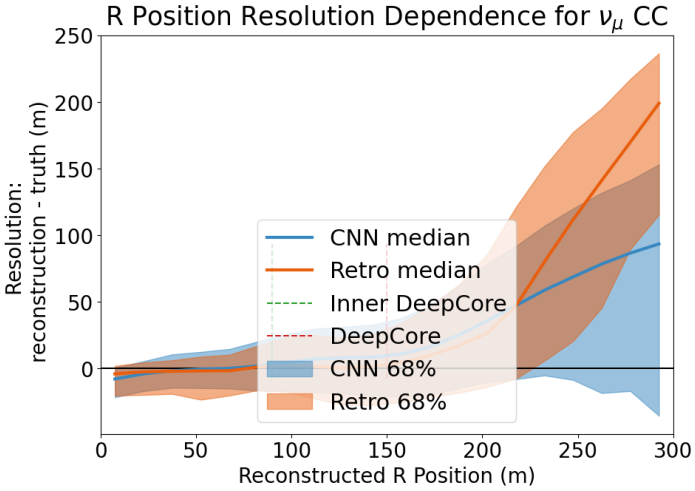
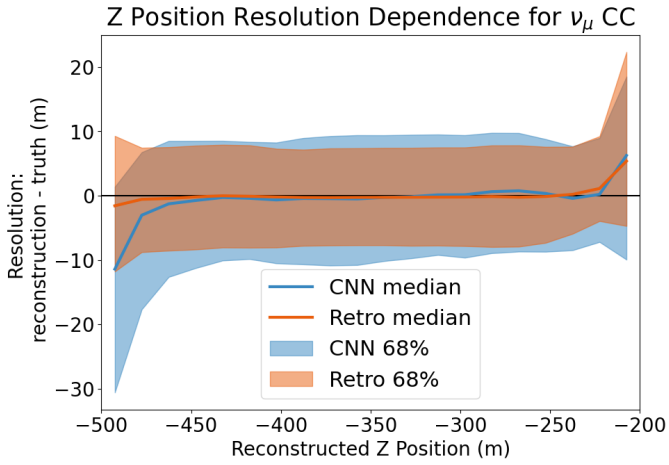
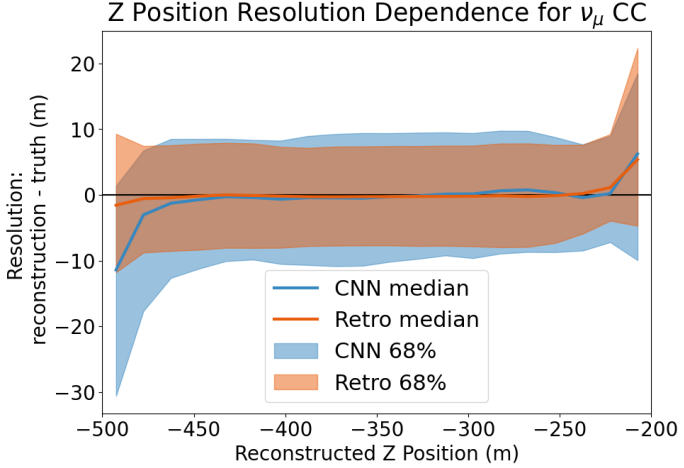
Resolution vs Reconstructed

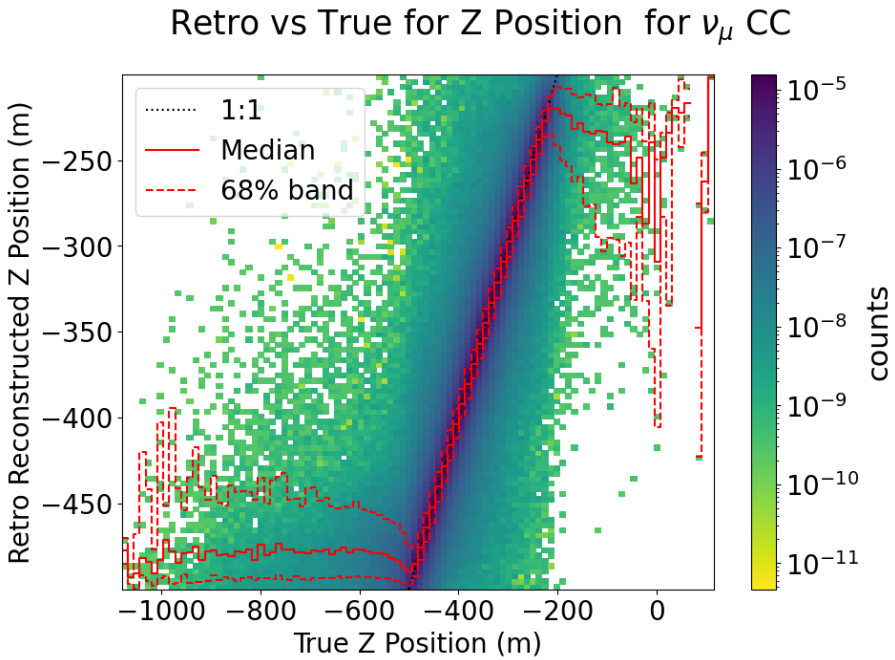


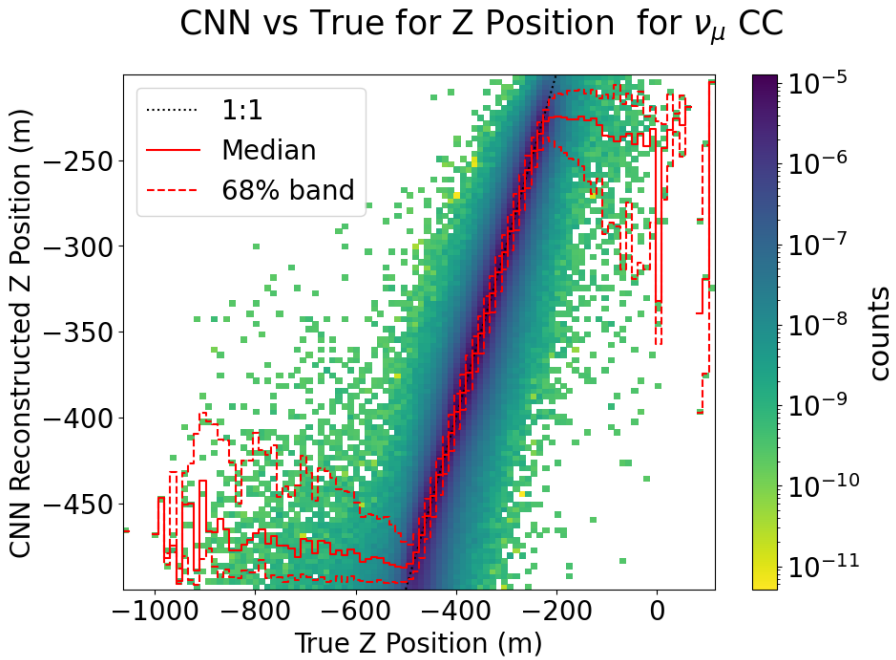






Unbounded Reconstructions vs True





Unbounded Reconstructions vs True