ArCube as part of DUNE ND

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ArgonCube collaboration meeting
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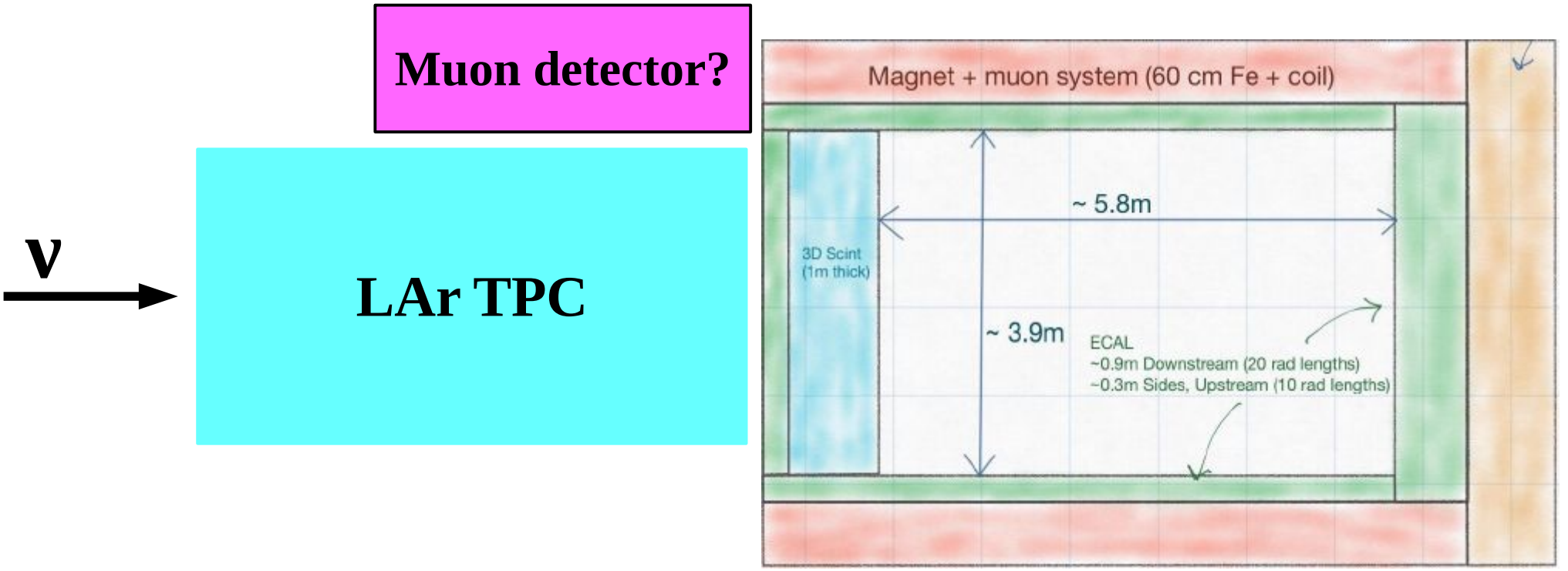
Pixel LAr at DUNE ND

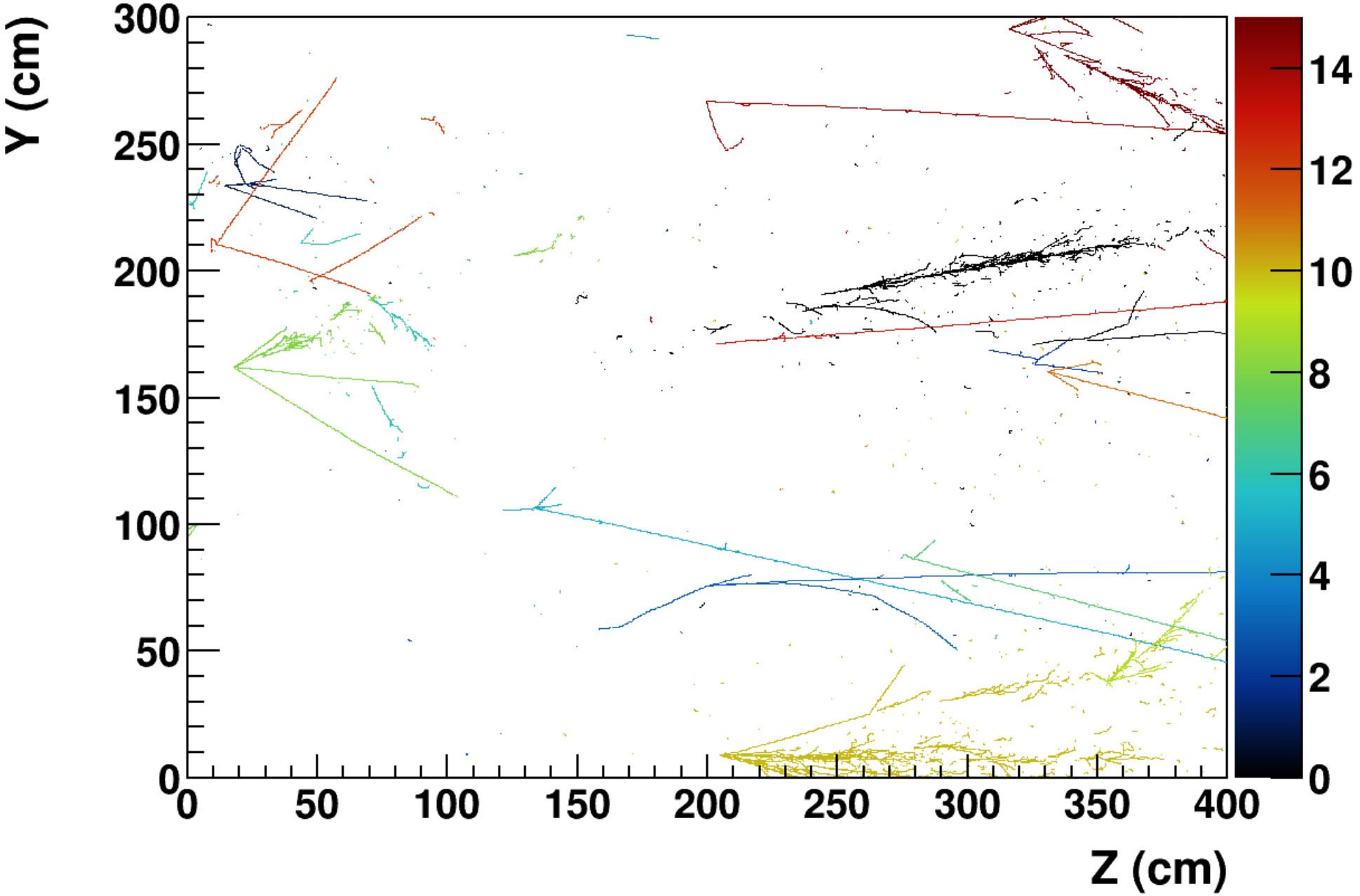


- DUNE ND plan: (pixel) LAr detector functionally coupled to low-mass, magnetized tracker, calorimeters, muon system

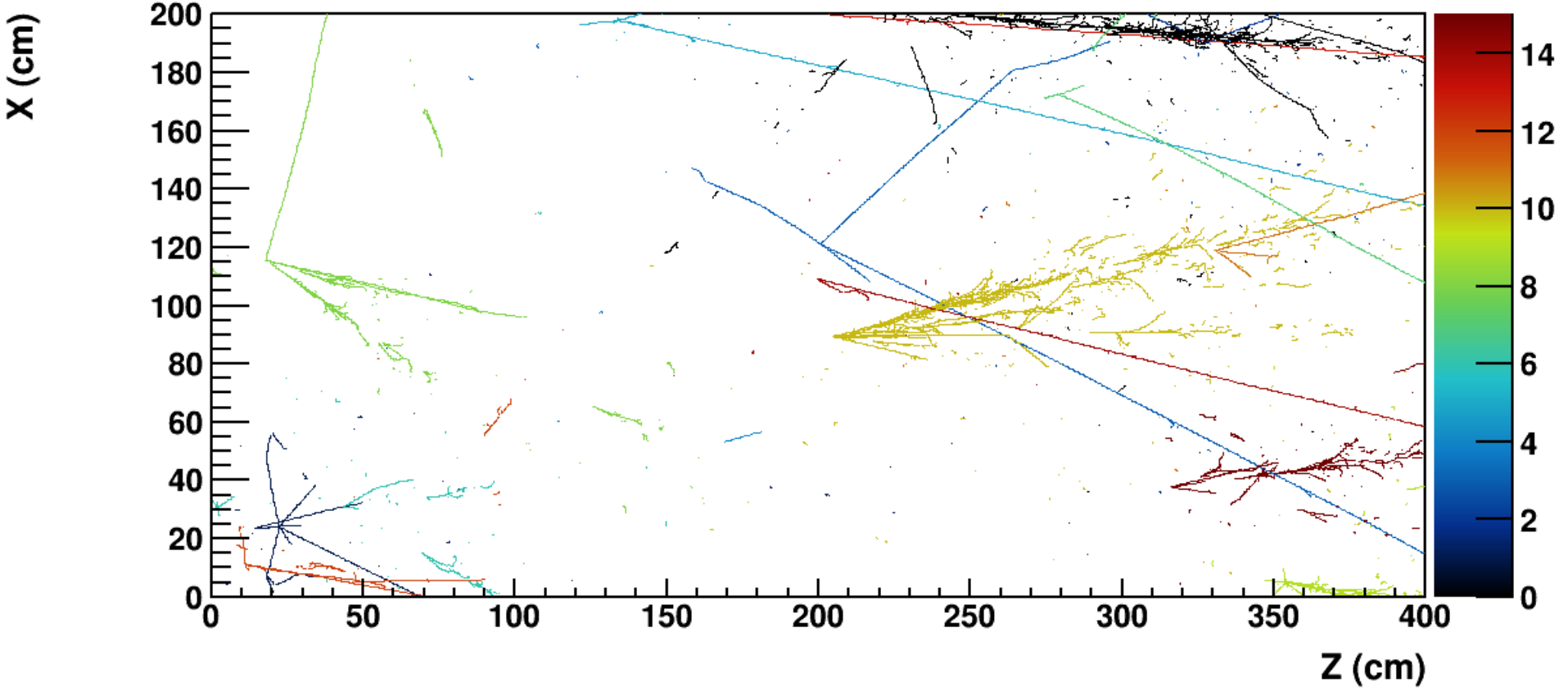
LAr ND design considerations

- Pile-up: ν beam @ 2MW: 0.2 interactions per spill per ton → 1 interaction per ~3.5 m^3 of LAr
- Containment of hadronic and electromagnetic showers for full cross section phase space
  - Containment of low-energy and/or high-angle muons
- Performance in specific high-impact measurements
  - ν+e elastic scattering for flux constraint
- Using python-based argon_box simulation developed by Dan Dwyer
  - https://github.com/dadwyer/argon_box

Pile-up

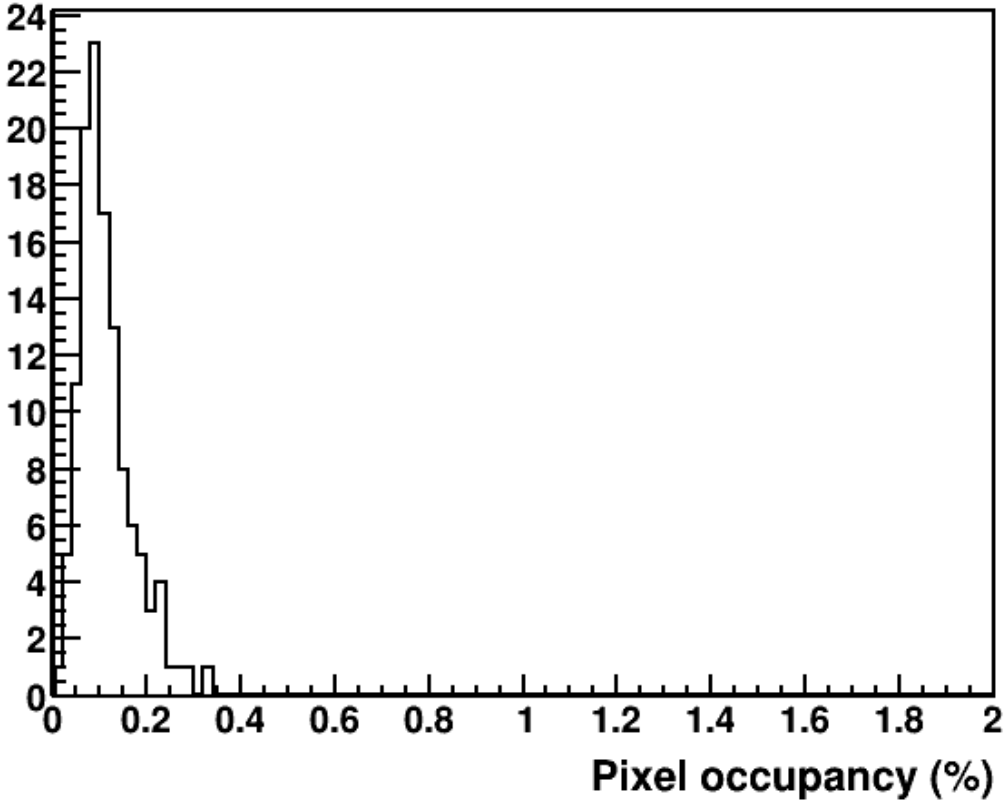

Y (cm)
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
Z (cm)
14
12
10
8
6
4
2
0

Pile-up



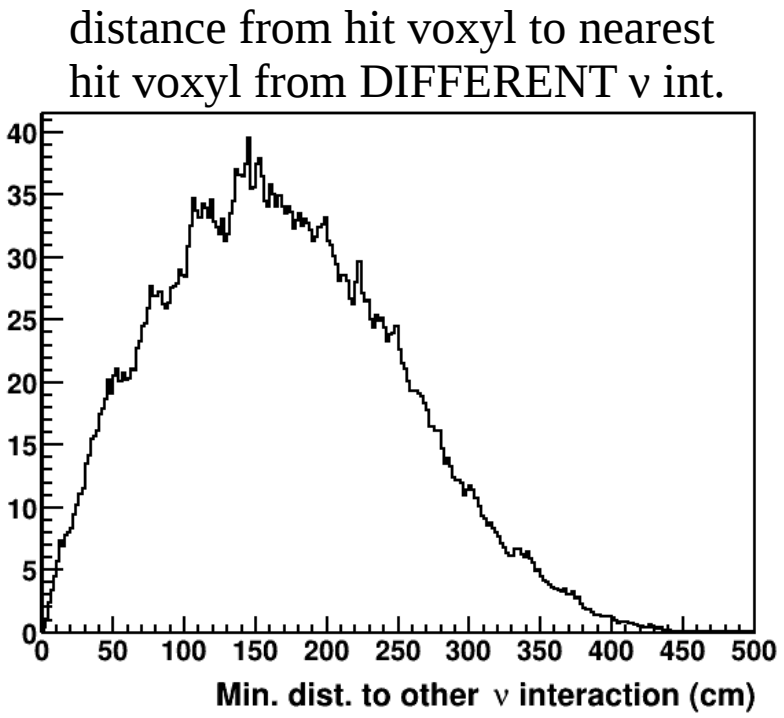
-Nearly every neutrino interaction overlaps with others in 2D
-In wire readout scheme, every wire would have charge from several neutrino interactions in every spill
-Events are fairly separated in 3D

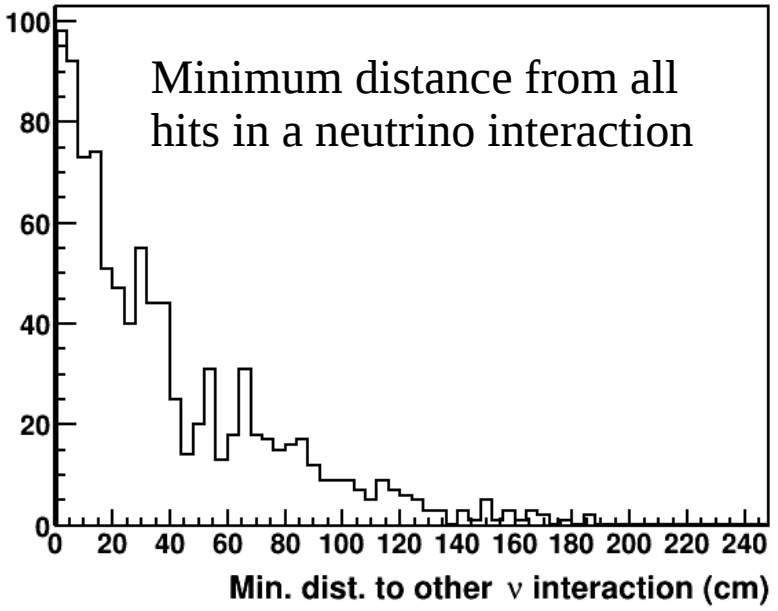
Pixel occupancy from neutrino interactions



- Assumes 50cm drift regions in 3x3x4m detector, 3mm pixels
- Neglects diffusion
- Rock muons will add ~0.1% per event
- Expected pixel occupancy < 1%

3D distance between neutrino interactions (excluding neutrons)



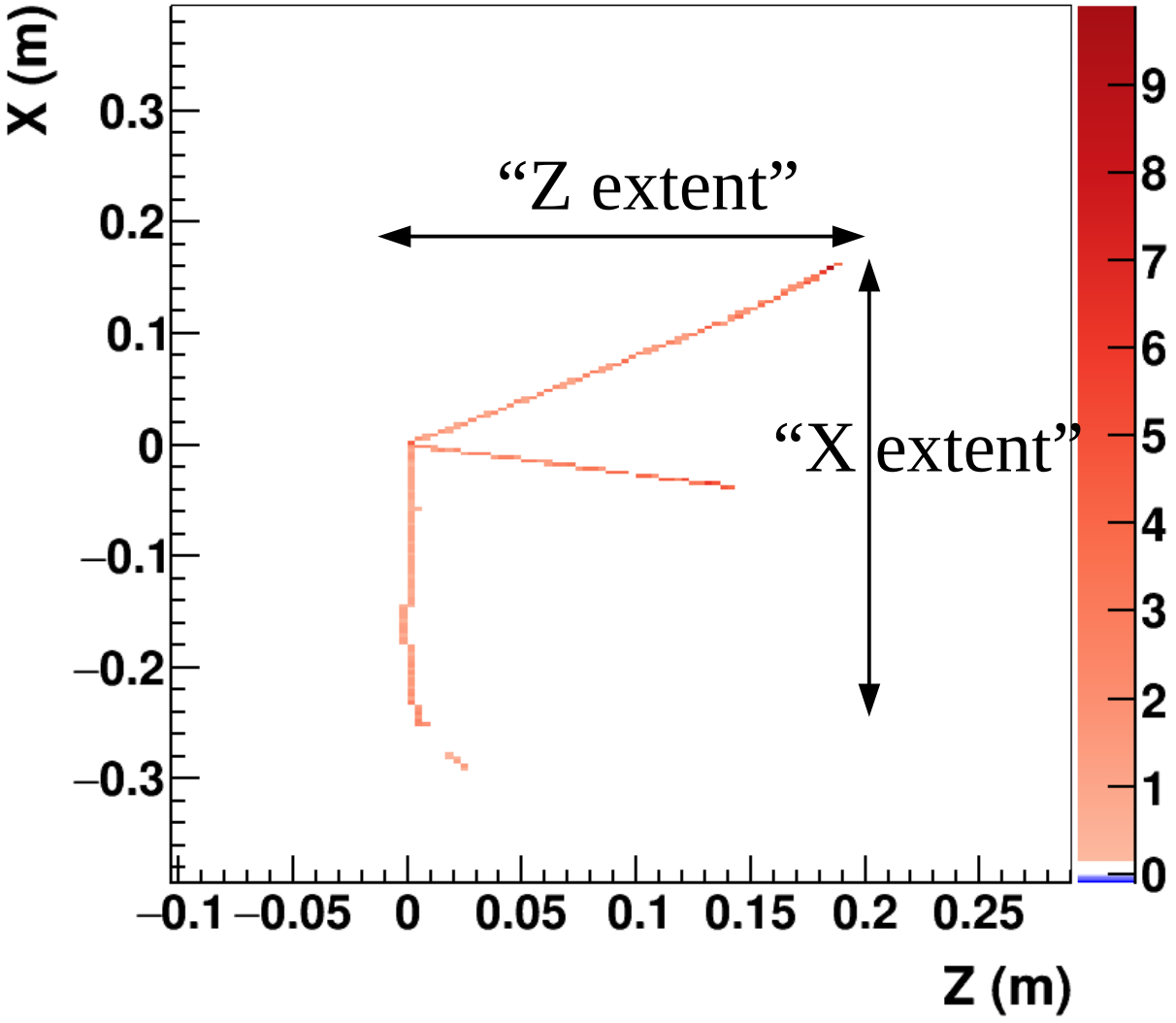


- Left: Distance from each hit to nearest hit from other neutrino interaction
- Right: Minimum distance over each interaction
- Conclusion: It is common for a track to cross near another event, but >75% of energy is >1m from other neutrino interaction products
- Higher-statistics analysis underway

LAr ND size requirements

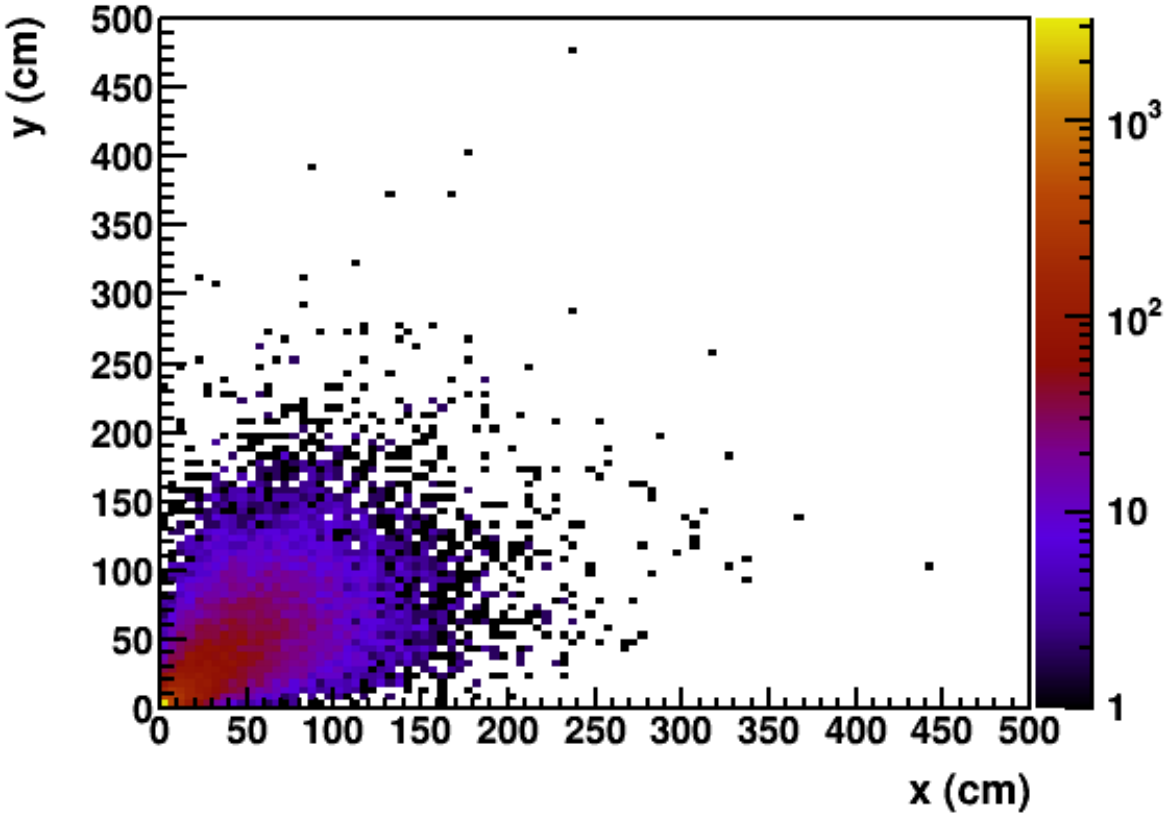
- For each event, ask:
  - What is the smallest LAr detector that contains 95% of the hadronic energy in this event?
  - What is the smallest LAr detector that contains the muon **and** 95% of the hadronic energy?
- Basically equivalent to:
  - For a LAr detector of fixed size, how big could we make the fiducial volume and still contain this particular event?

Example: “extent” of hadronic showers in LAr



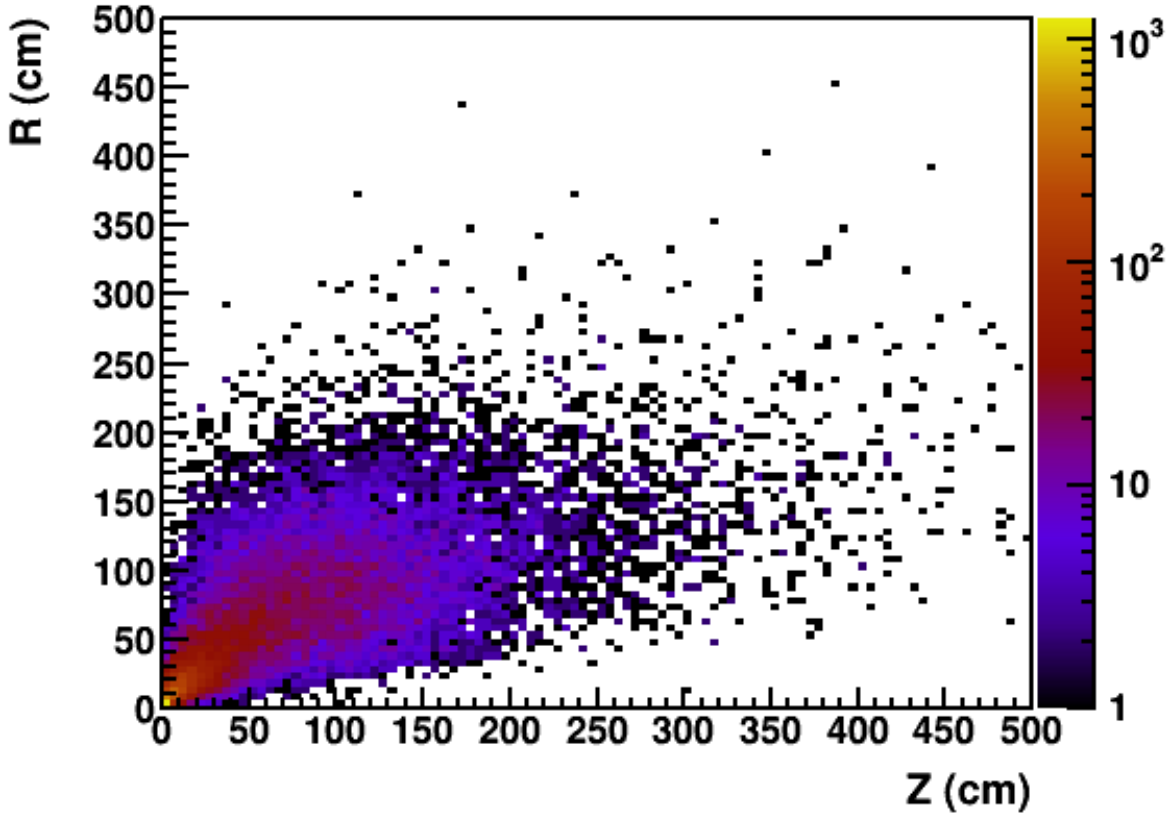
- Event display in XZ plane, where color is hit energy in MeV (in 3x3mm voxyls)
- “Extent” of this event is 20cm in Z and 40cm in X
- Also a Y dimension which is used, but is not shown here
- Smallest detector is 40x20cm, or for 3x4m detector, FV is 260x380cm

Transverse extent – hadrons only



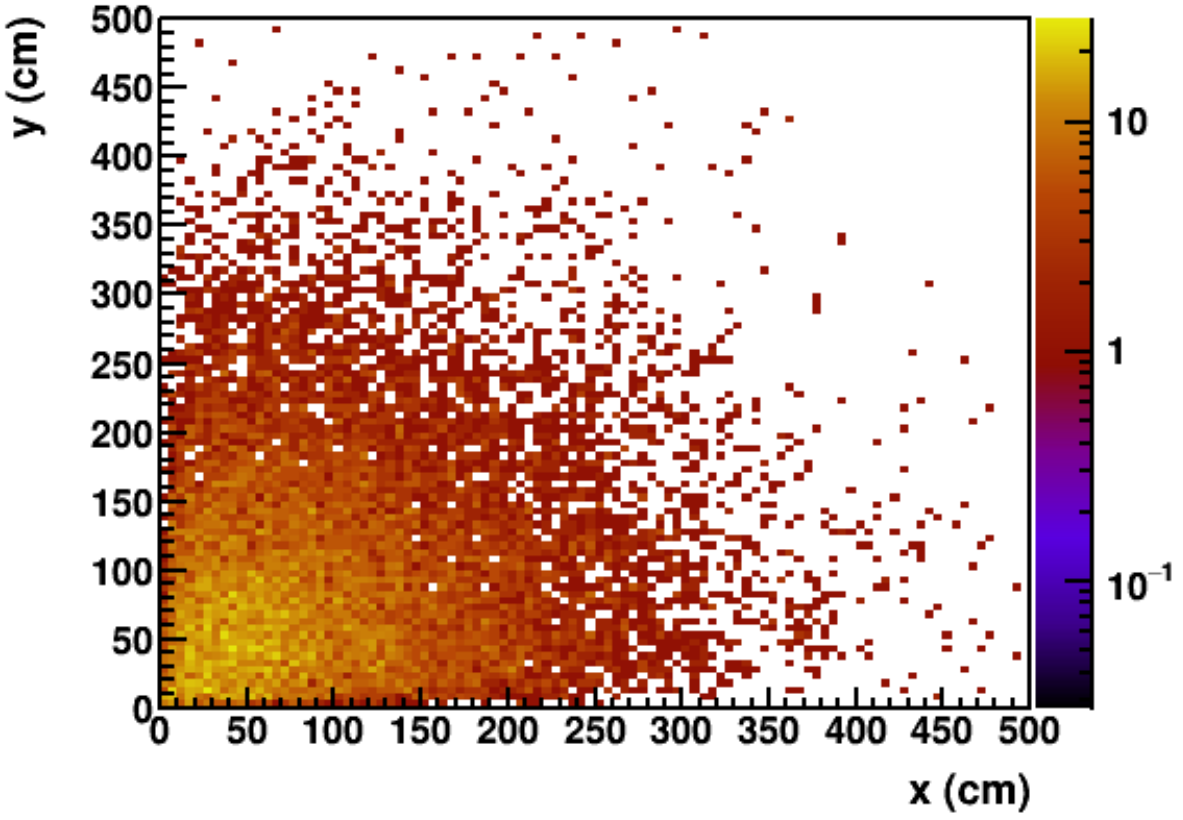
- 90% events are contained in a square of 1.20m
- 99% events < 2.05m

Longitudinal extent – hadrons only



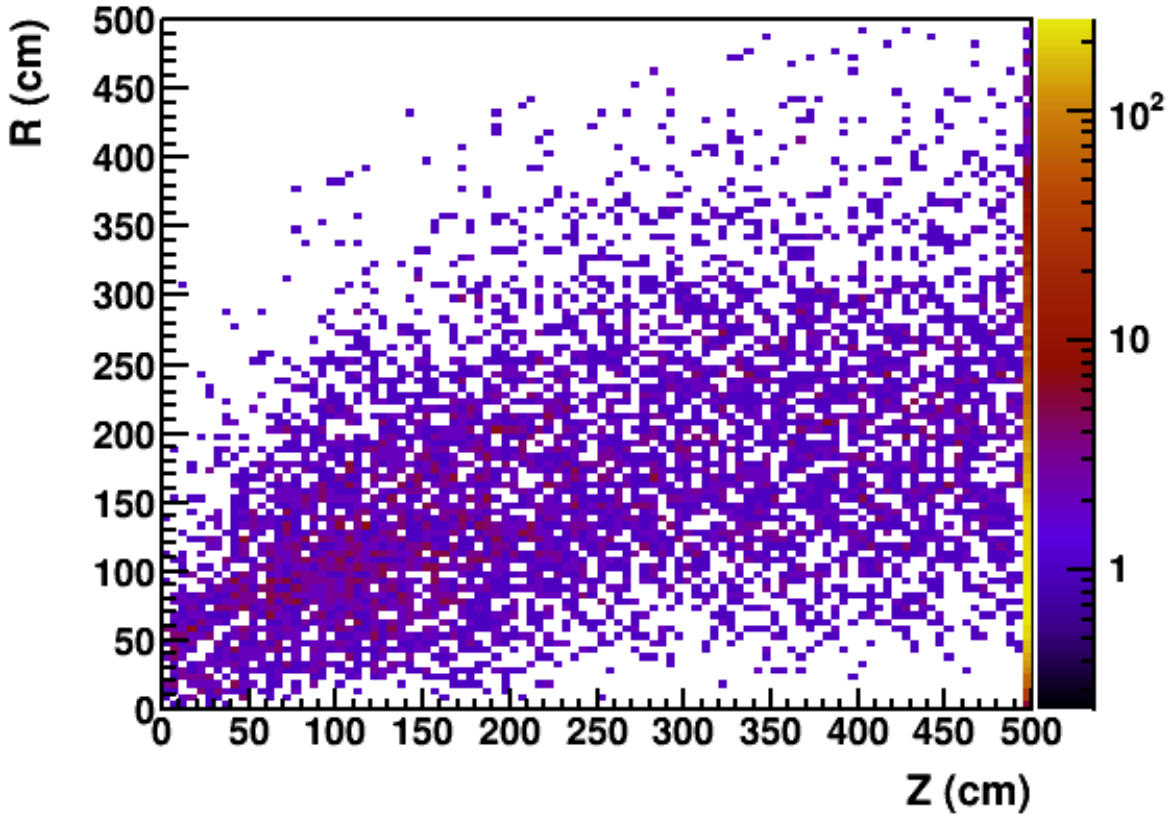
- R is the maximum of X and Y, event by event
- 90% of events have Z < 1.75m
- 99% of events have Z < 3.45m

Transverse extent – lepton + hadrons



- 90% events are contained in a square of 2.70m
- 99% events < 3.95m

Longitudinal extent – lepton + hadrons



- Overflow bin included (5m ~ 2 GeV)
- We aren't trying to contain muons in Z, so this is less interesting than transverse plot

Detector size conclusions

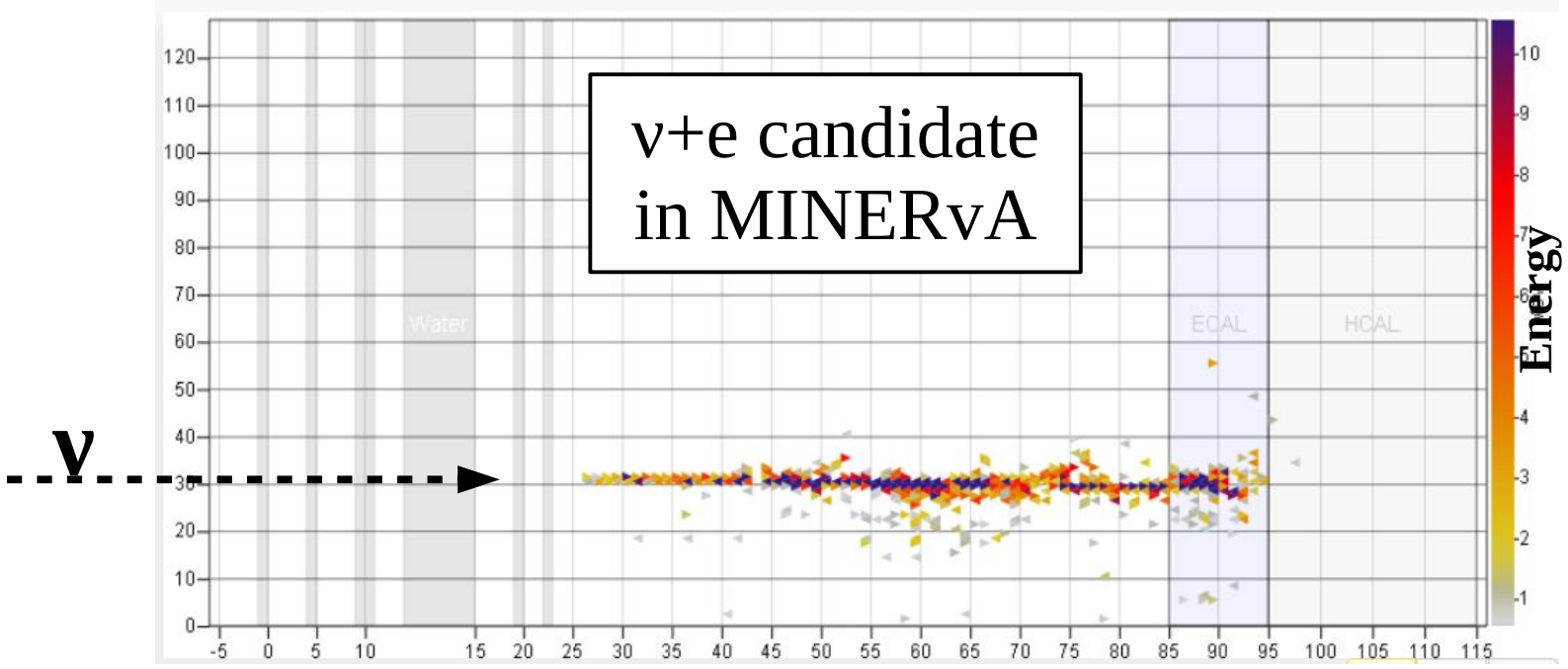
- For hadronic containment only (assuming side muon detector, for example), need ~3m side length
- To include high-angle leptons, need at least ~4m side length
- Underway: high statistics update to assess expected statistics vs. E_ν-E_μ for various detector sizes

Neutrino-electron scattering

- Pure EW process with known cross section:

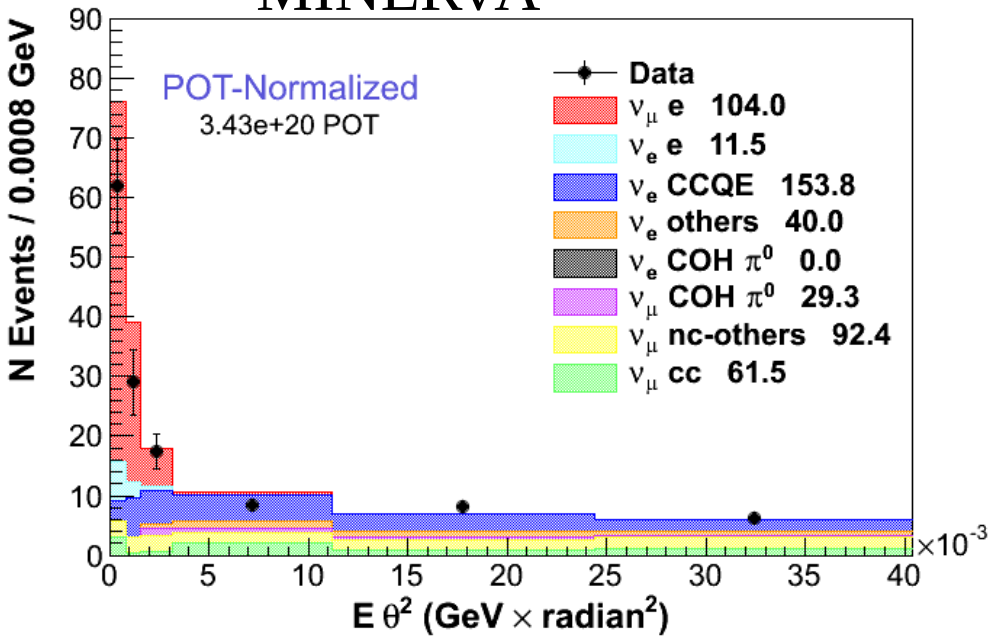
$$\frac{d\sigma(\nu_\mu e^- \to \nu_\mu e^-)}{dy} = \frac{G_F{}^2 m_e E_\nu}{2\pi}\left[\left(\frac{1}{2} - \sin^2\theta_W\right)^2 + \sin^4\theta_W (1-y)^2\right]$$

- Signal is single electron, with kinematic constraint $E_e\theta^2 < 2m_e$ – very forward electron

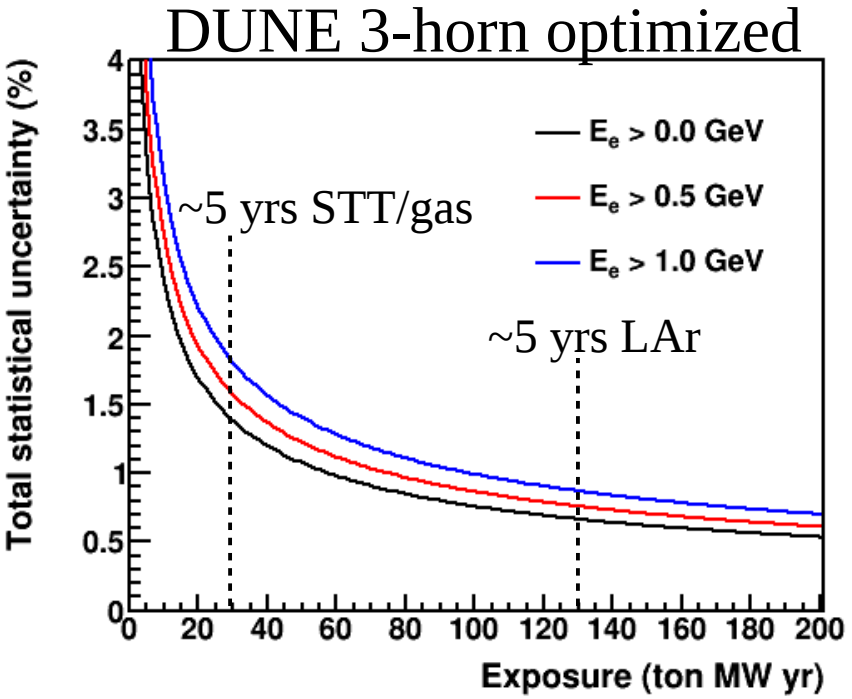


Flux normalization measurement

MINERvA



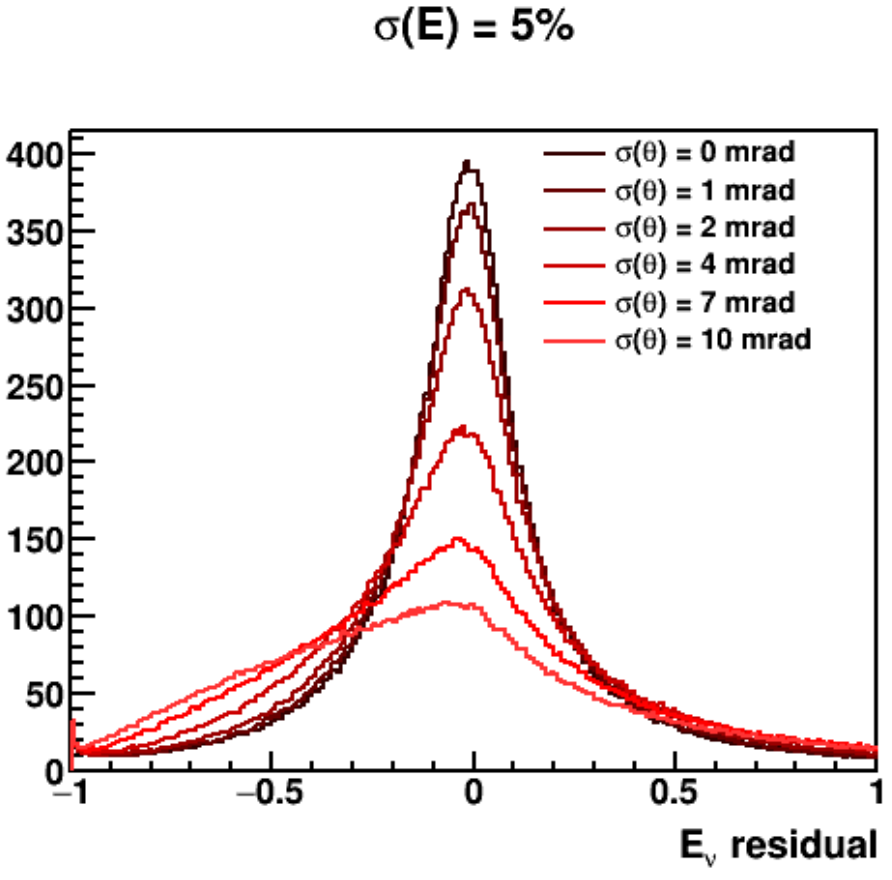
DUNE 3-horn optimized



- Known cross section → measure the absolute flux
- Signal separated from background (forward ν_e CC) by cutting on $E_e\theta^2$
- Done by MINERvA with 12% statistical and 5% systematic
- DUNE can do this with 1-2% statistical and few% systematic
- All DUNE ND candidates have better resolution than MINERvA

Shape information from ν+e

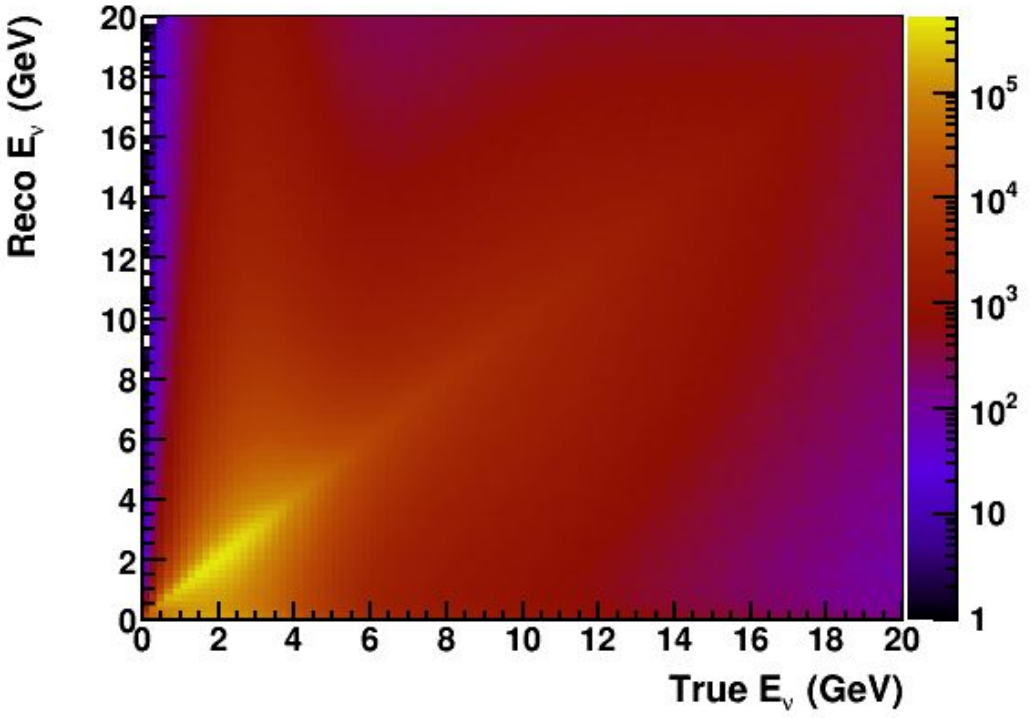
$$E_\nu = \frac{E_e}{1 - \frac{E_e(1-\cos\theta)}{m}} \approx \frac{E_e}{1 - \frac{E_e\theta^2}{2m}}$$

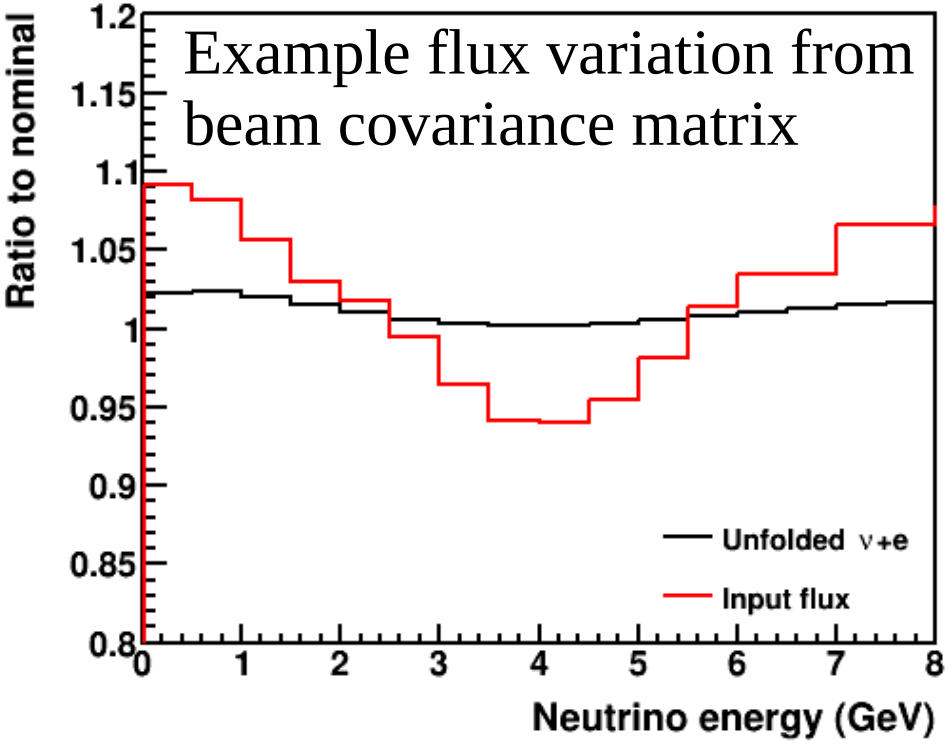


- E_ν is very sensitive to reconstruction of $E_e\theta^2$
- Intrinsic beam dispersion is ~2mrad
- Resolution deteriorates quickly with angular resolution and becomes asymmetric

Shape information from ν+e

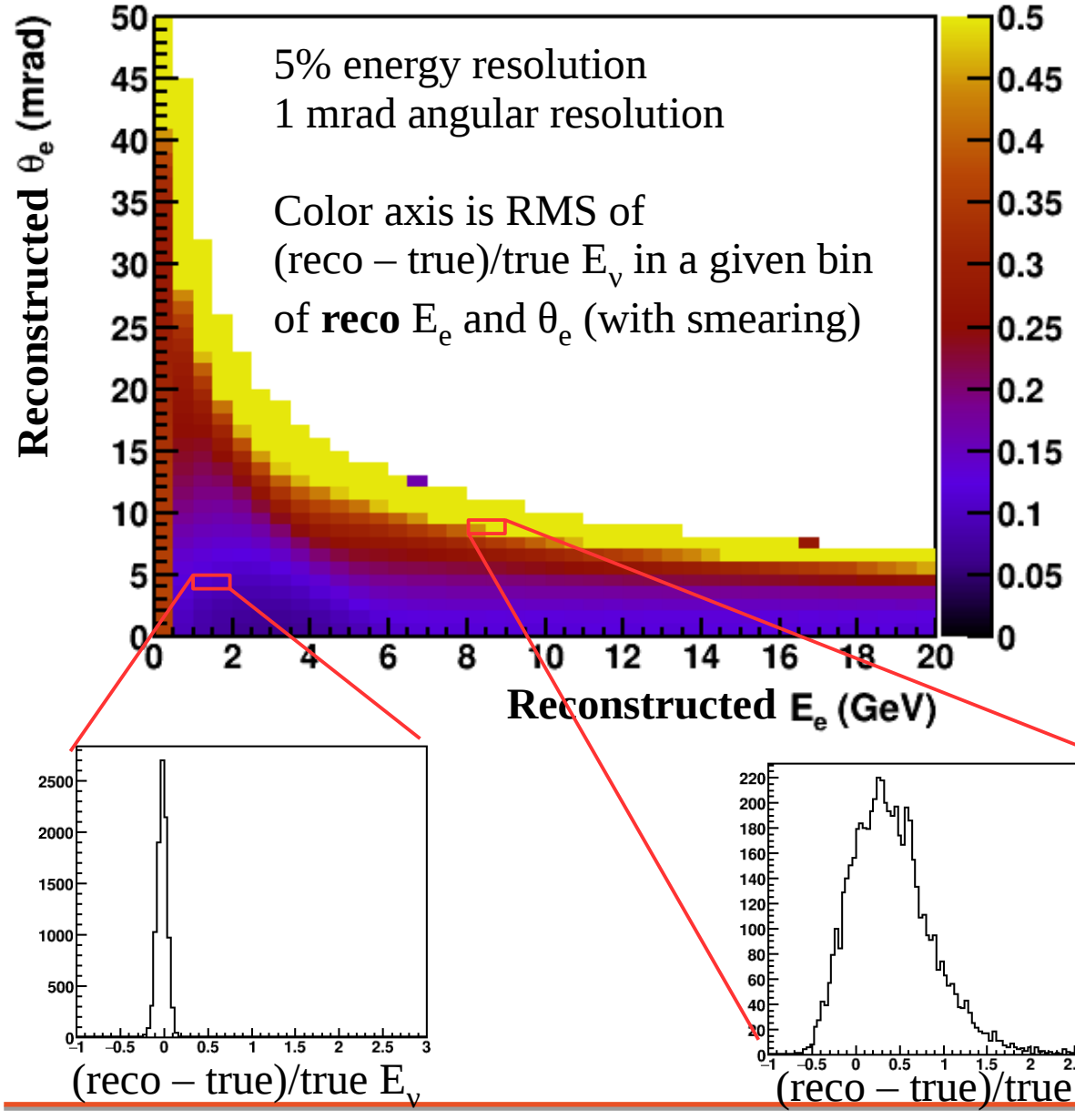
LAr-like resolutions





- Smearing matrix (left) using LAr-like resolutions – σ(E) = 5%, σ(θ) = 3% + MS
- Unsmearing using realistic alternative input fluxes misses key features

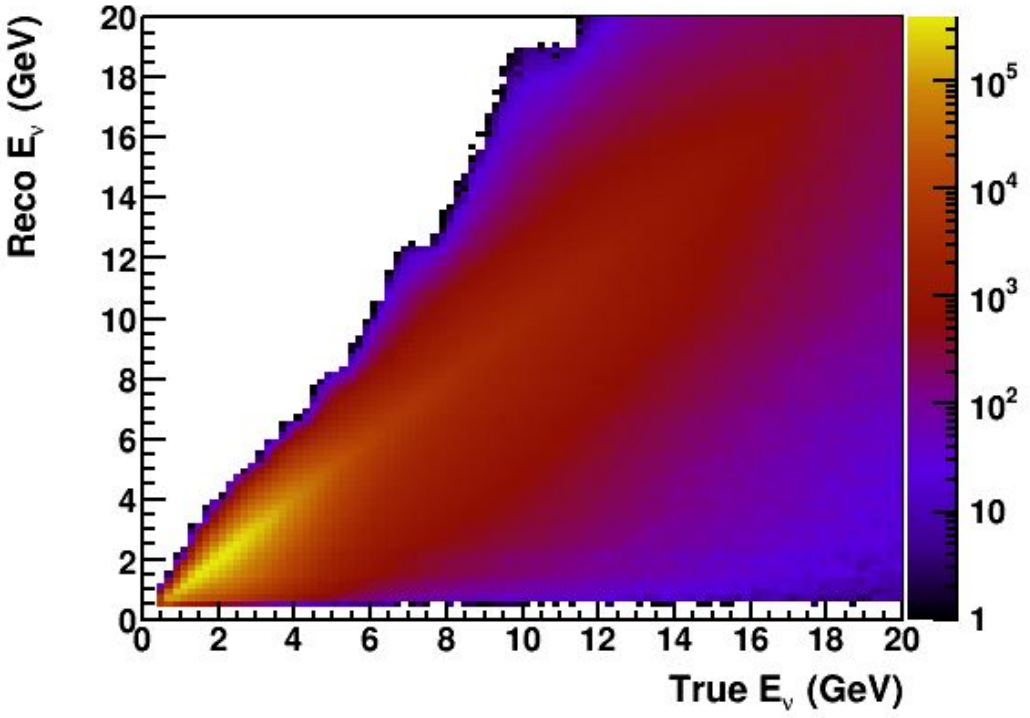
E_ν resolution vs. E_e-θ_e

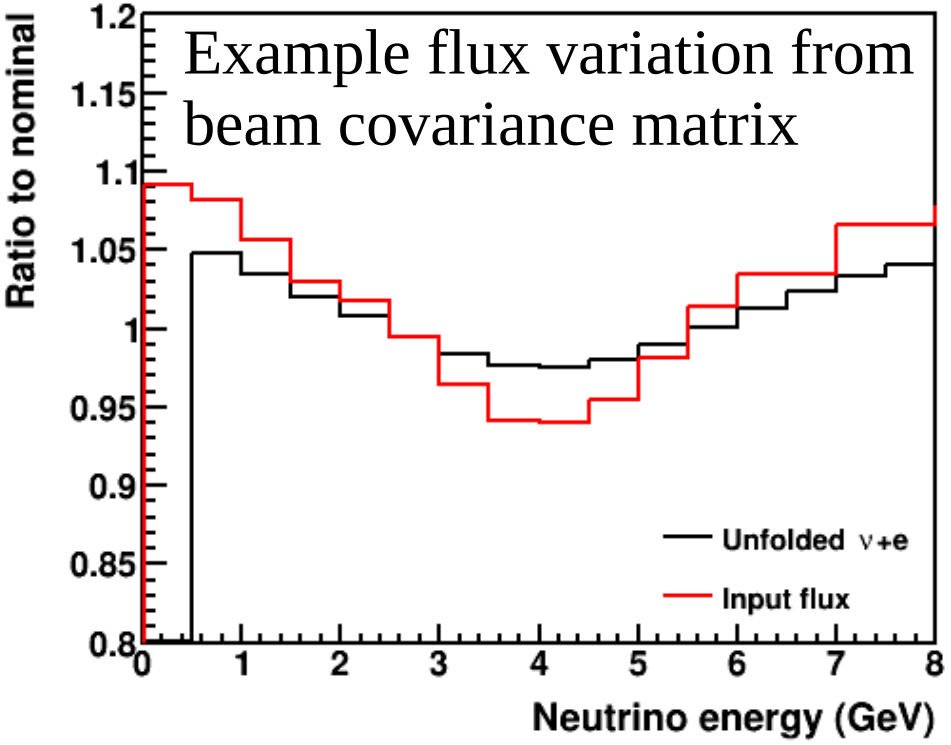


- New idea started at VietNus 2017 (with Wilkinson, Dennis, McFarland)
- Isolate region of E_e-θ_e with good E_ν resolution
- Select high-resolution region ($\Delta E/E < 0.3$)
- Or template fit to 2D E-θ distributions

Select events ΔE/E RMS < 0.3

LAr-like resolutions





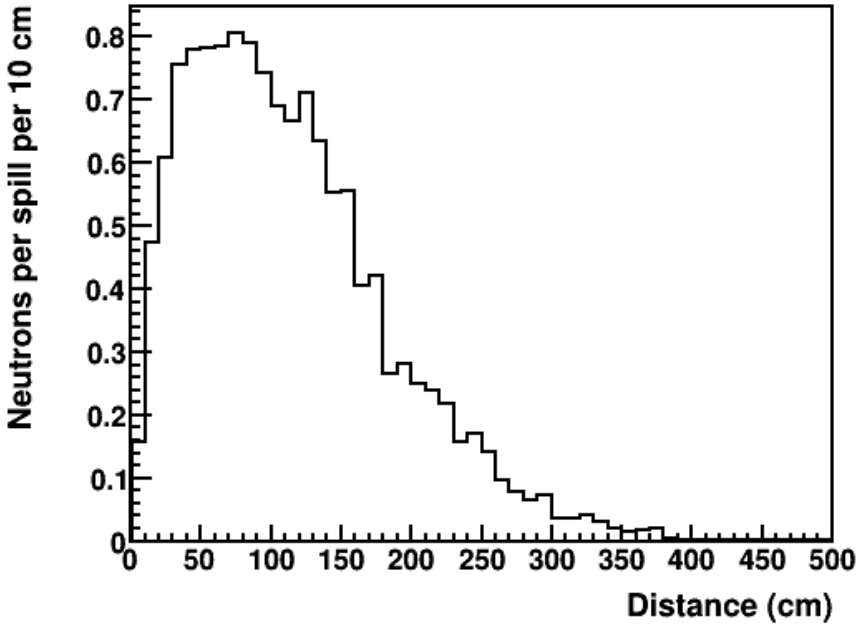
- Removing poor resolution events, we are able to see features in the flux even with LAr-like resolutions
- Template fit even more powerful
- Working on completing analysis with backgrounds, systematics, etc...stay tuned

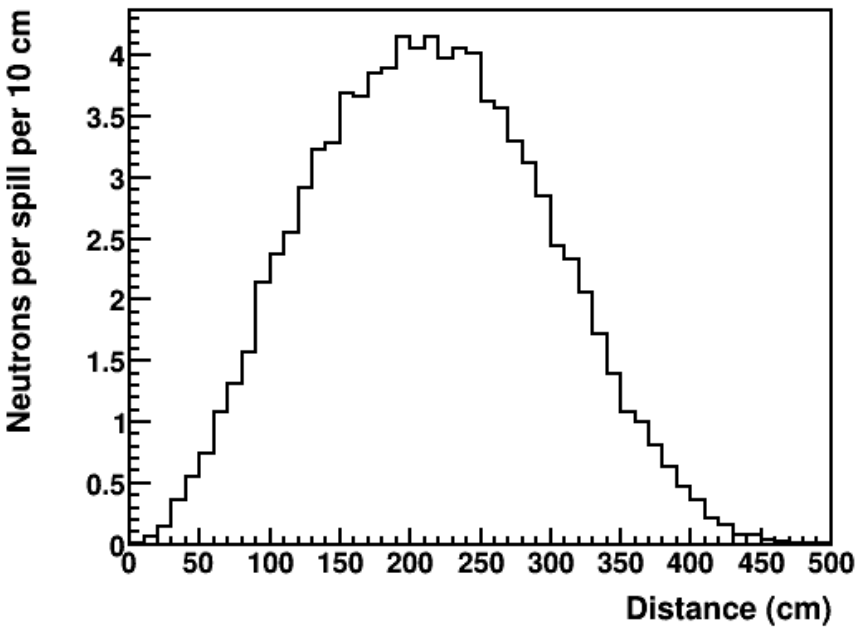
Conclusions

- Expect few*10,000 events in LAr 5-year ND run
- Selecting high-resolution ν+e subsample looks promising for shape measurement

Backups

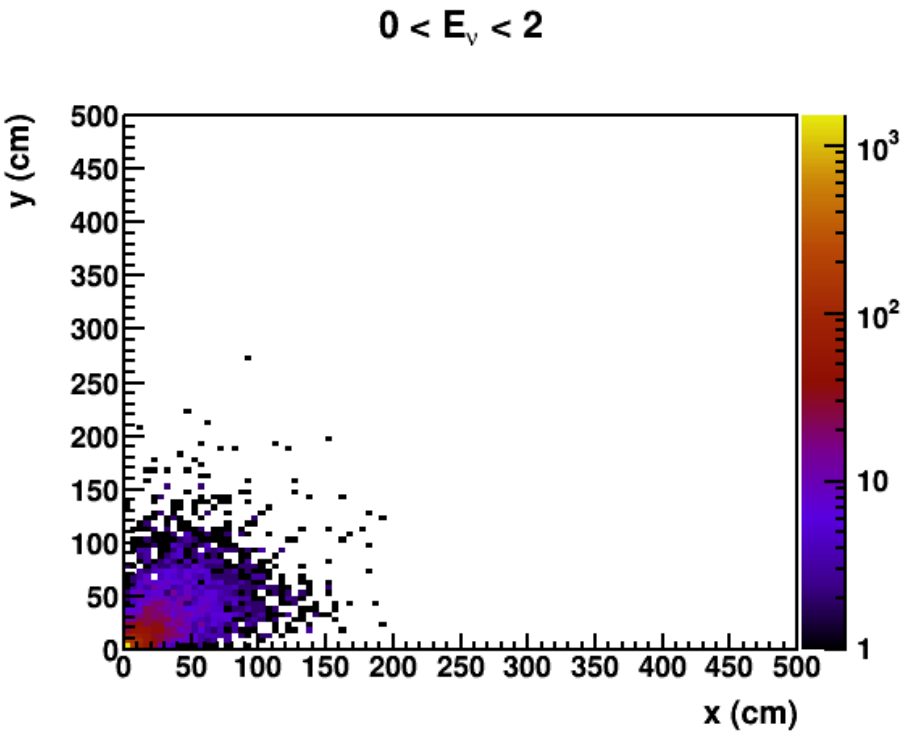
Neutrons will be very difficult

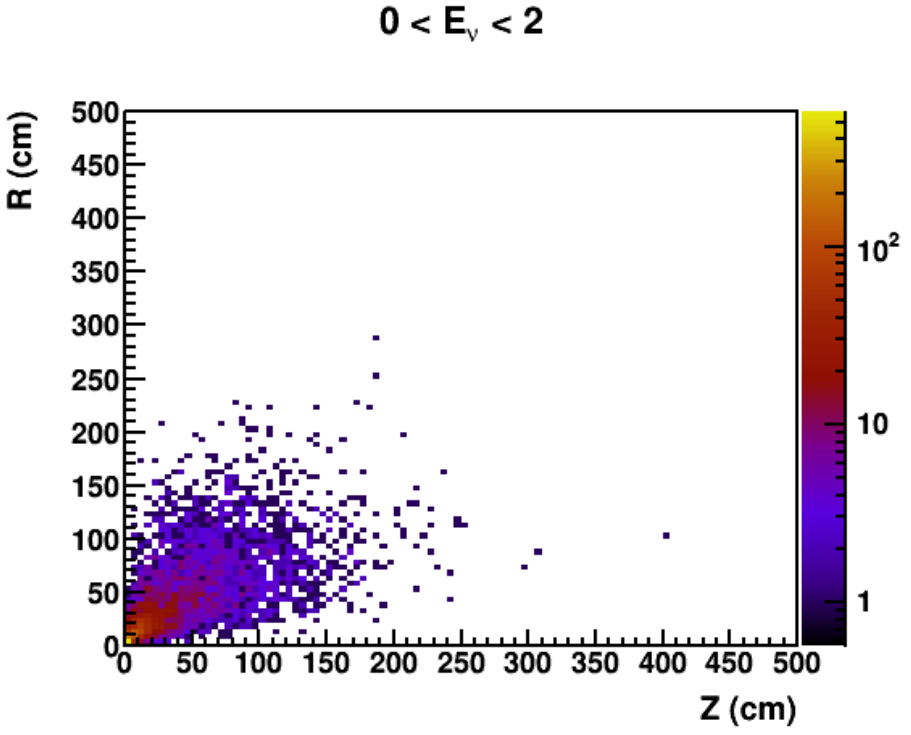




- Distance from interaction vertex to hit voxyls due to neutrons (multiple interactions allowed, but voxyls within 10cm sphere are counted as one, and tracks resulting from neutron scatters are counted as one)
- Left: neutrons from own interaction, Right: other interactions
- Y-axis is **per bin**, we are talking about ~50 neutron hits **per spill**

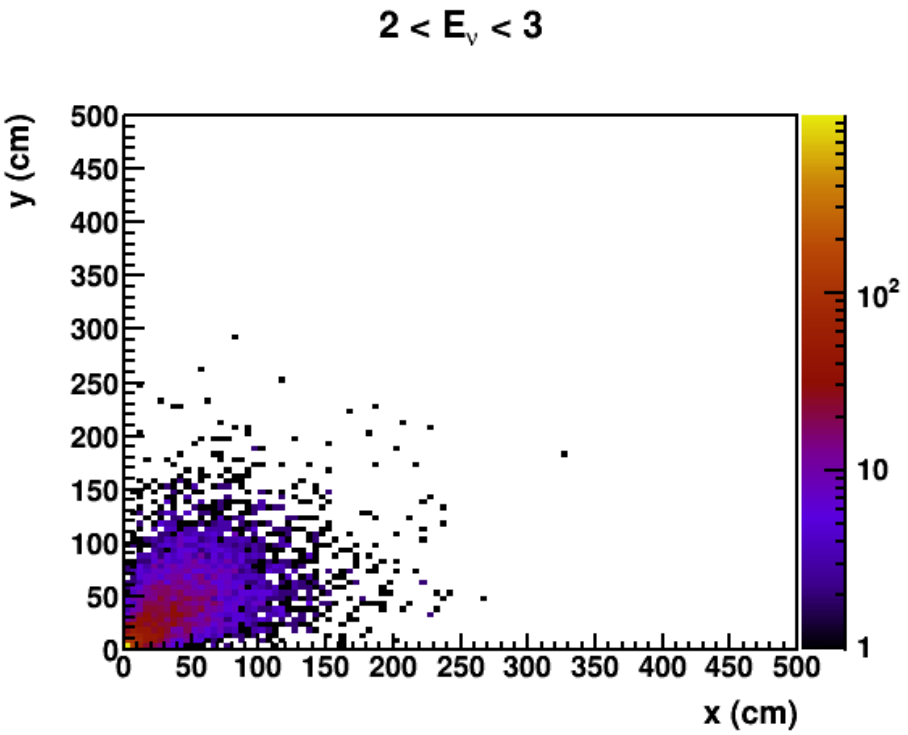
Neutrino energy dependence 0-2 GeV

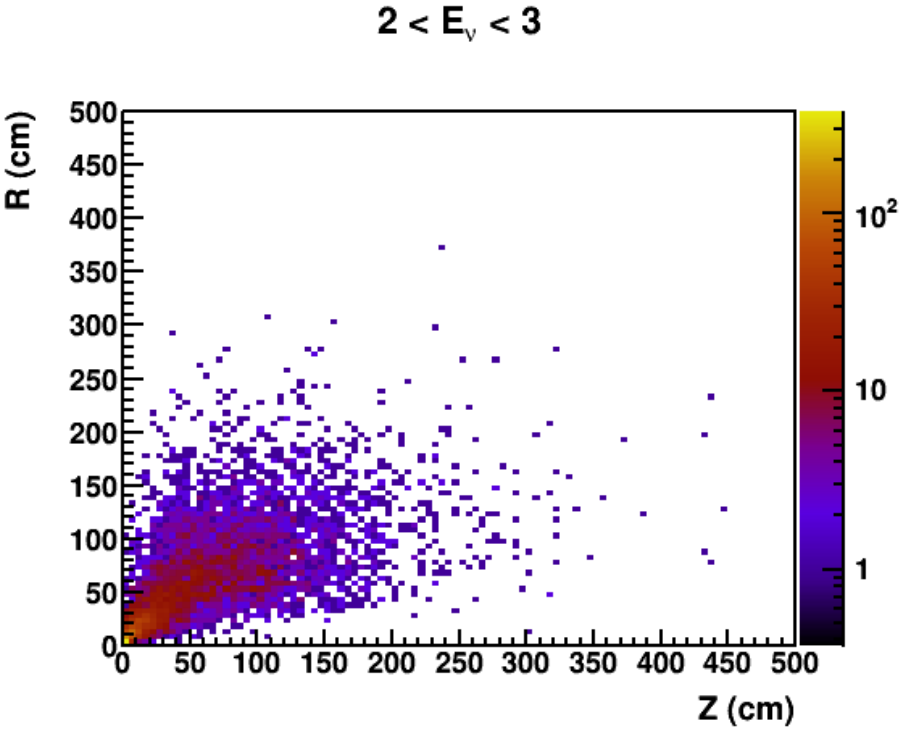




- 99% of events within
  - 150cm in X and Y
  - 180cm in Z

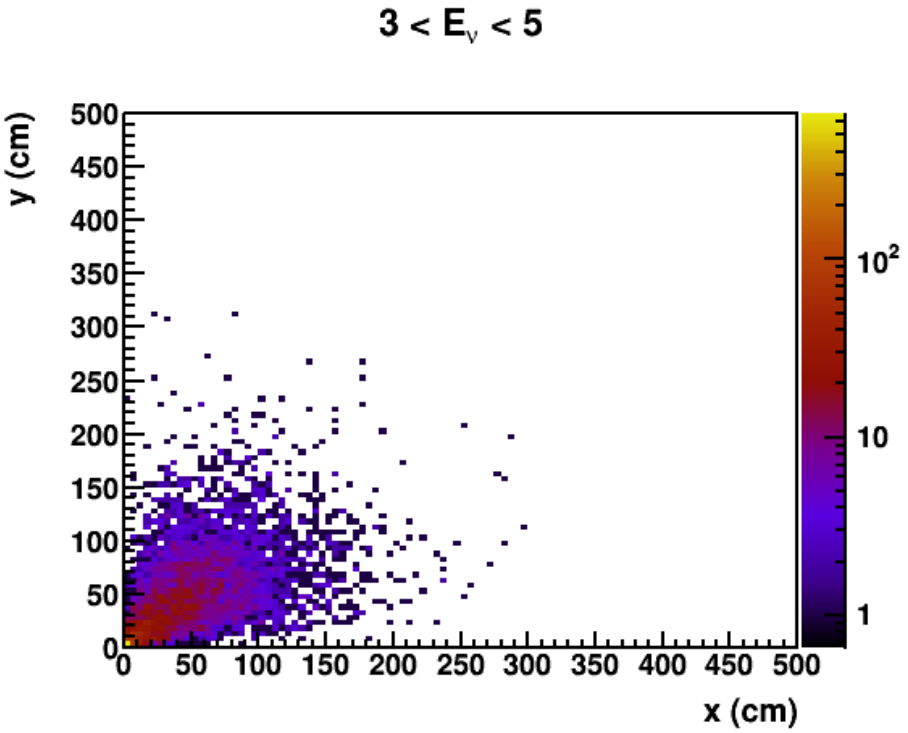
Neutrino energy dependence 2-3 GeV

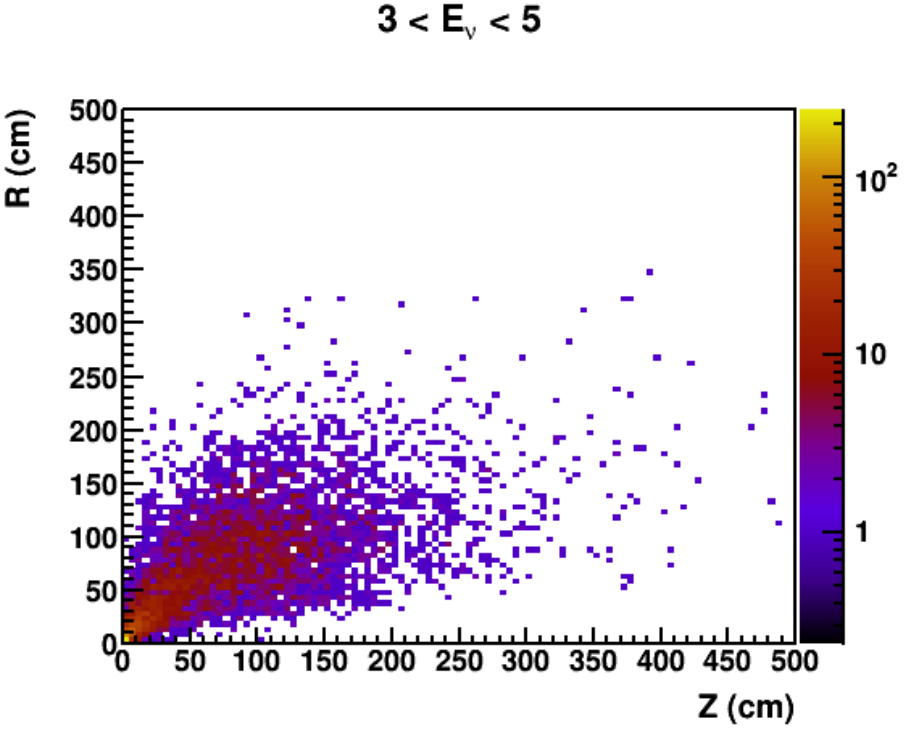




- 99% of events within
  - 190cm in X and Y
  - 260cm in Z

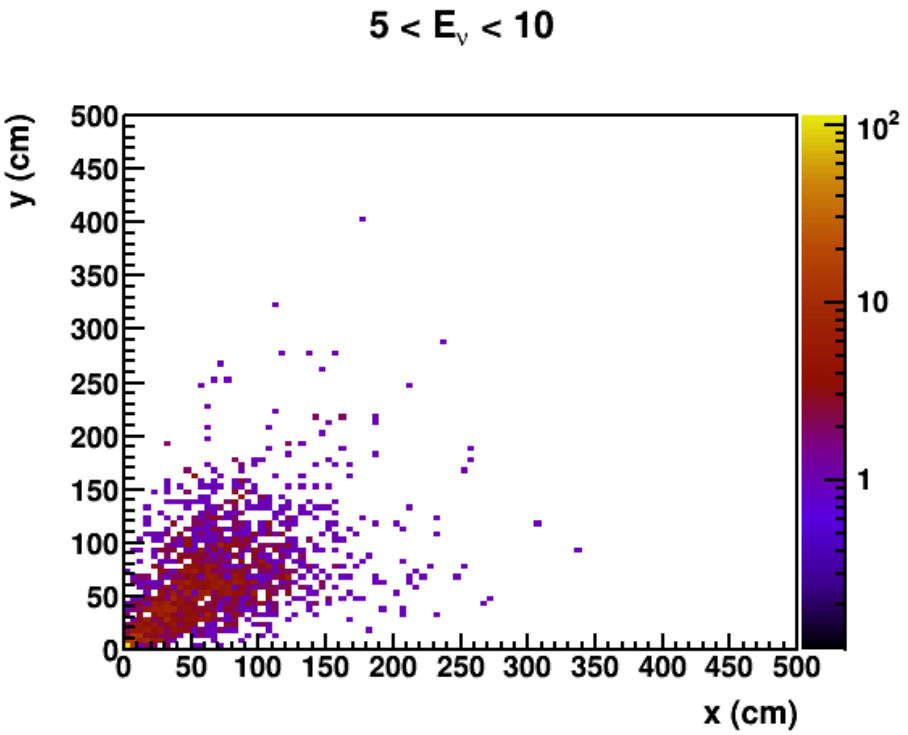
Neutrino energy dependence 3-5 GeV

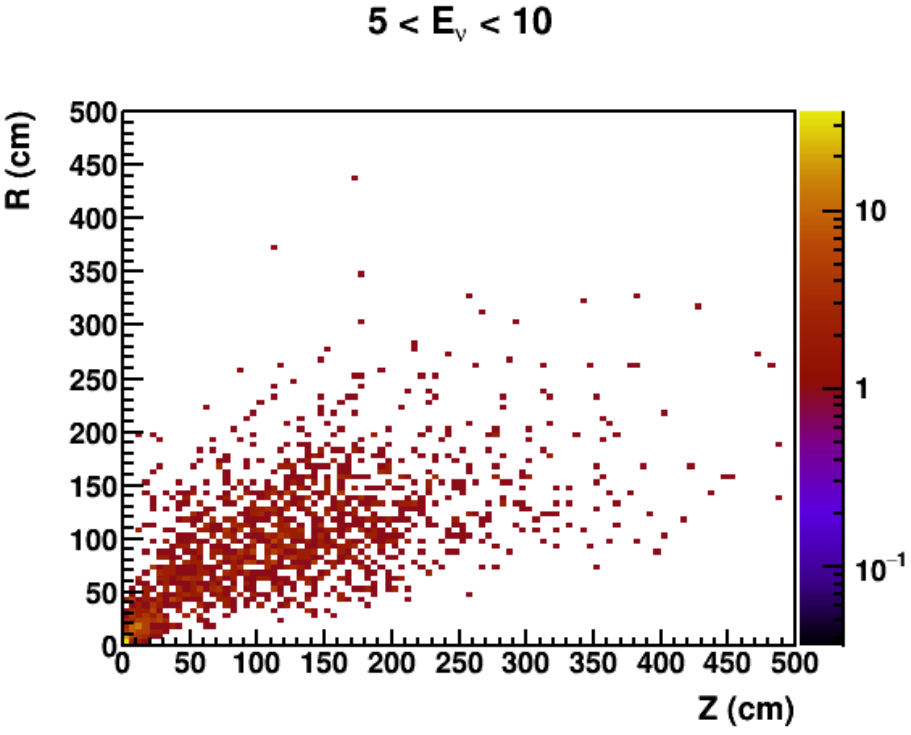




- 99% of events within
  - 210cm in X and Y (90% within 125cm)
  - 325cm in Z (90% within 160cm)

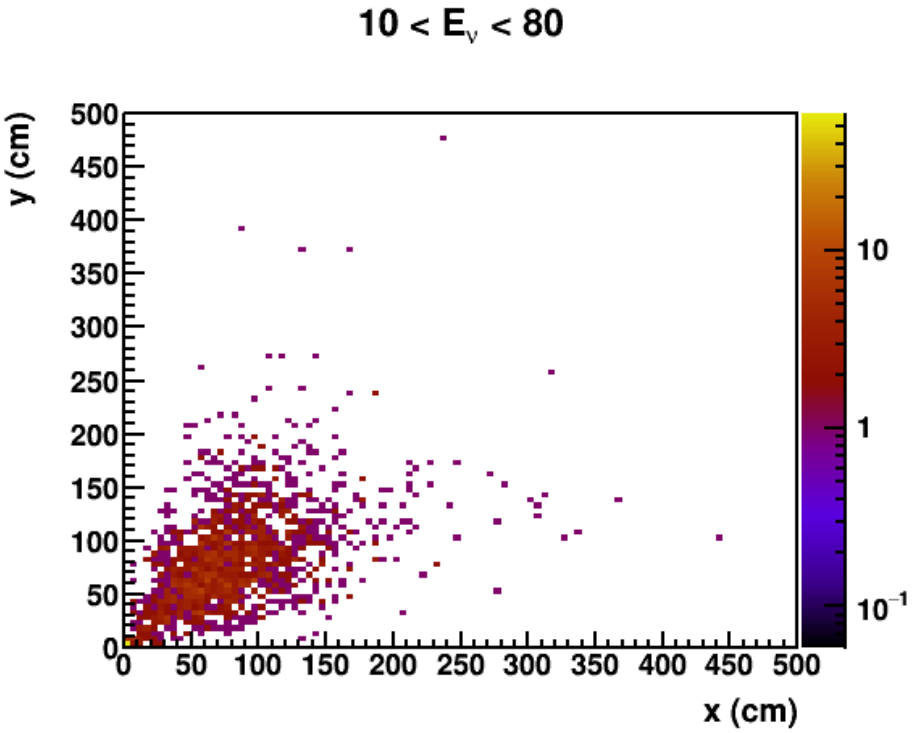
Neutrino energy dependence 5-10 GeV

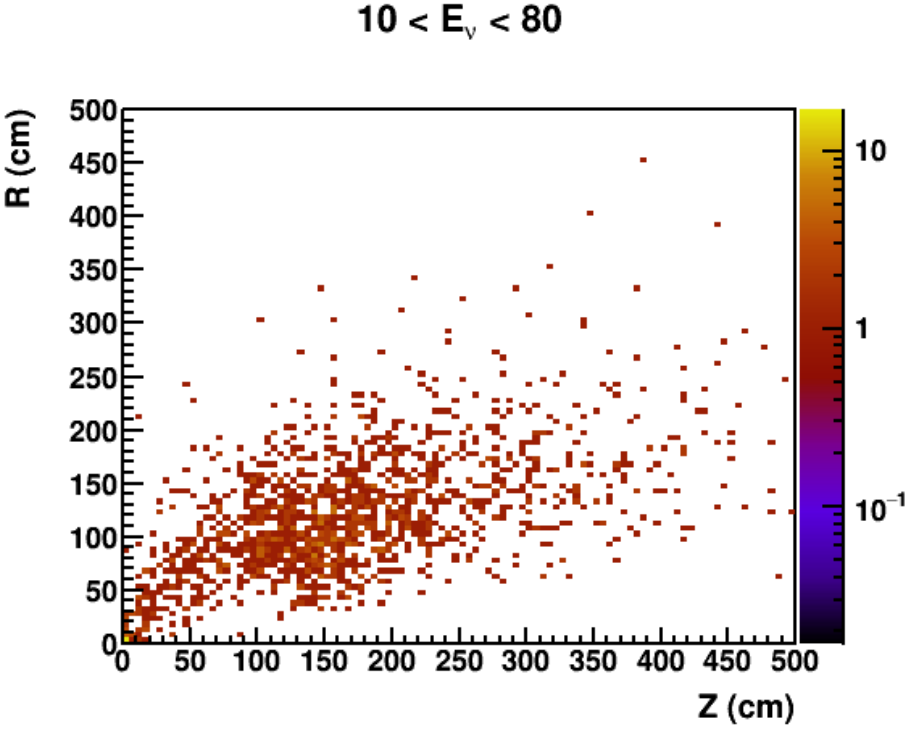




- 99% of events within
  - 255cm in X and Y (90% within 150cm)
  - 390cm in Z (90% within 235cm)

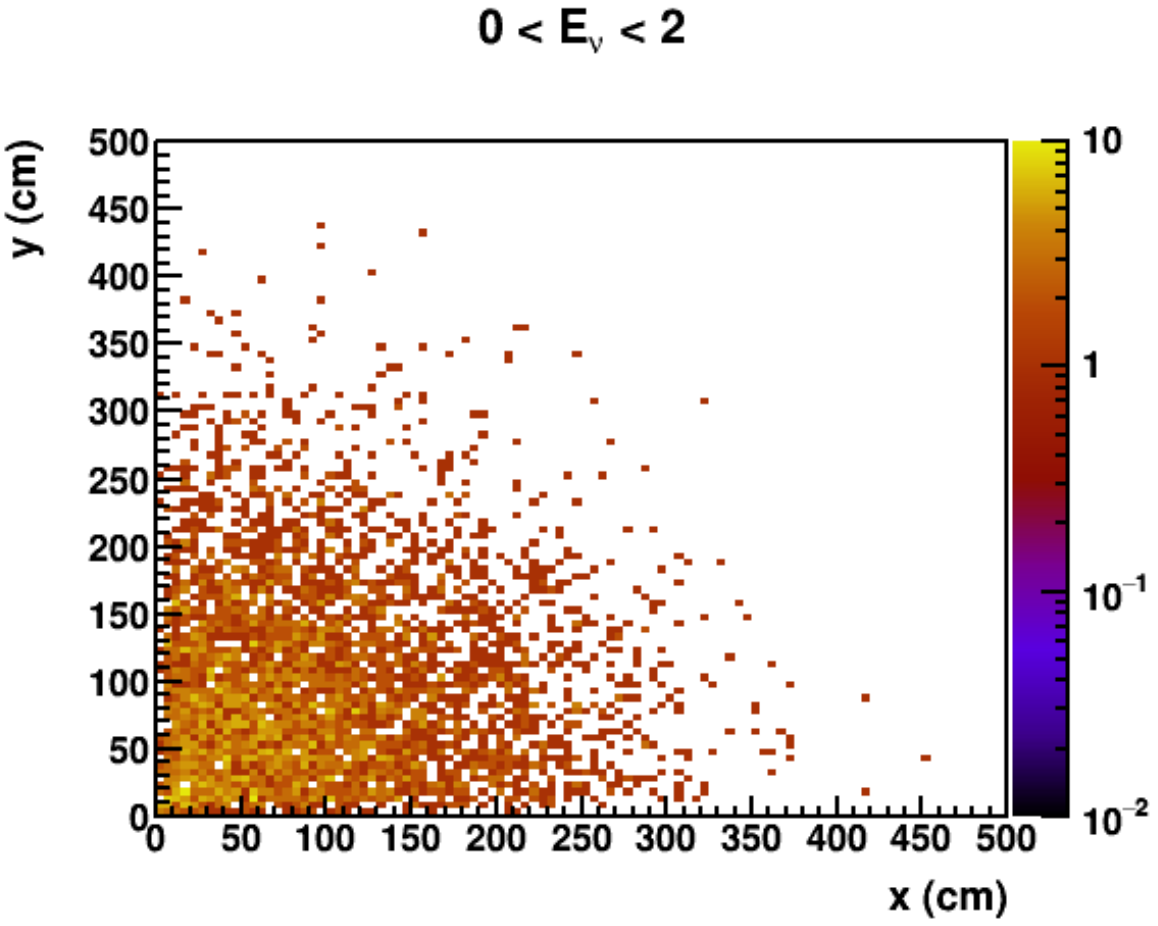
Neutrino energy dependence >10 GeV





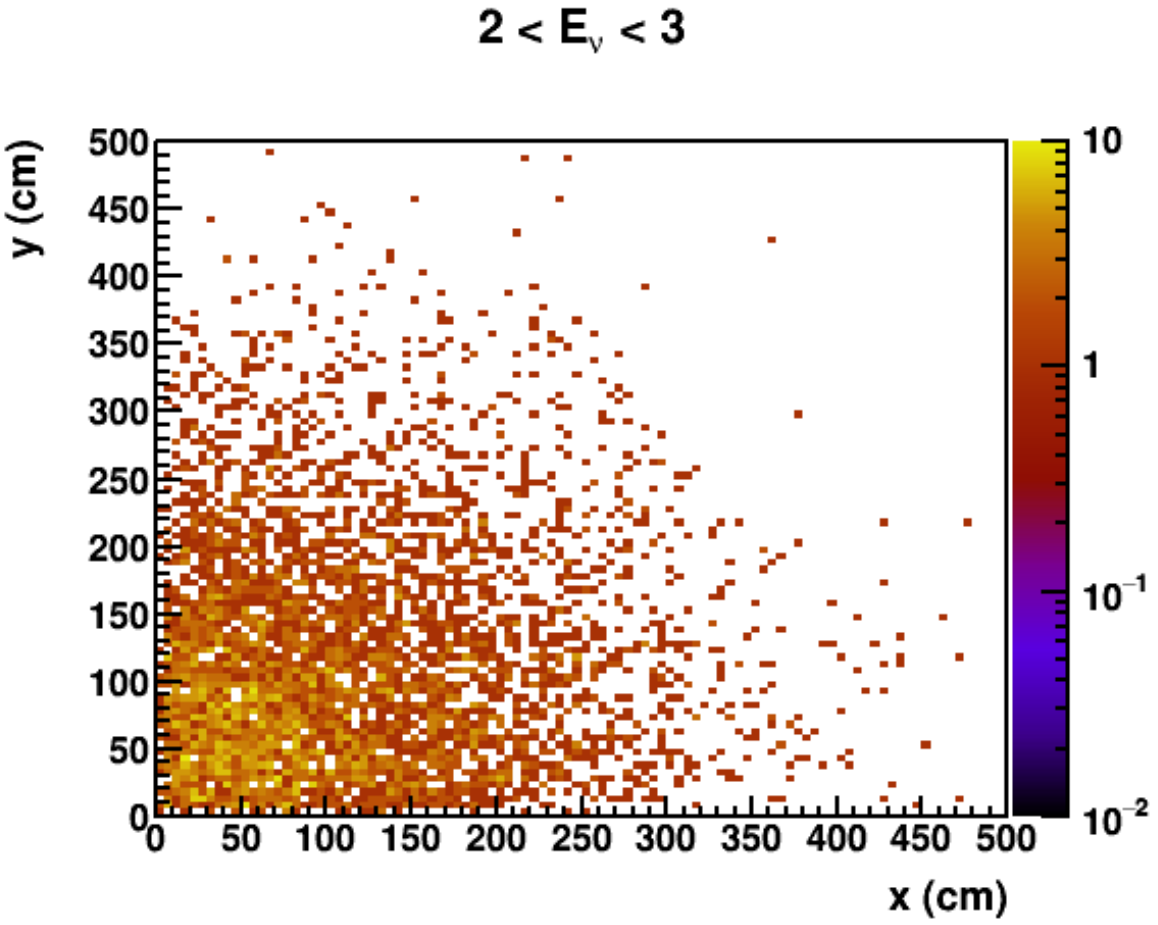
- 99% of events within
  - 280cm in X and Y
  - 445cm in Z

Transverse extent – lepton+hadrons 0-2 GeV



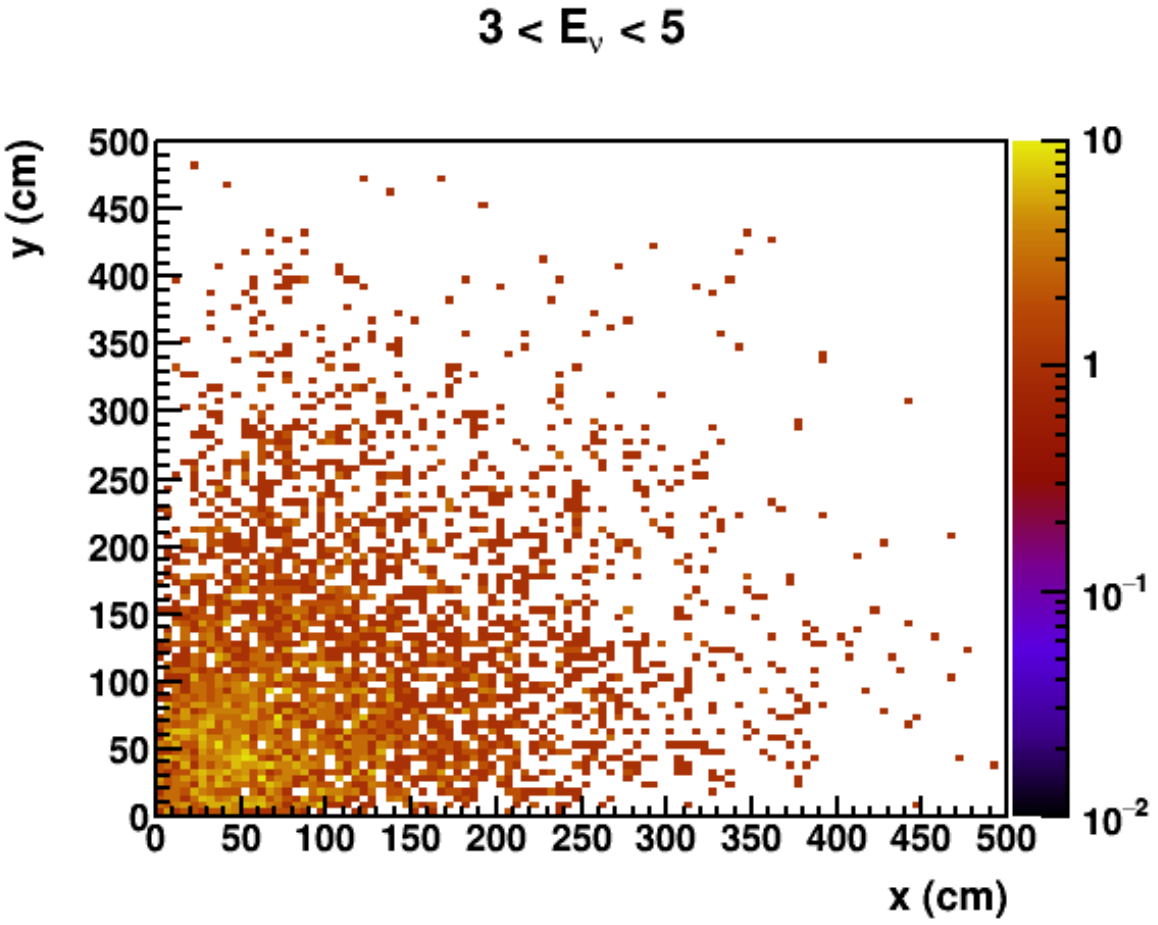
- 90% of events contained within 2.45m square
- 99% < 3.45m

Transverse extent – lepton+hadrons 2-3 GeV



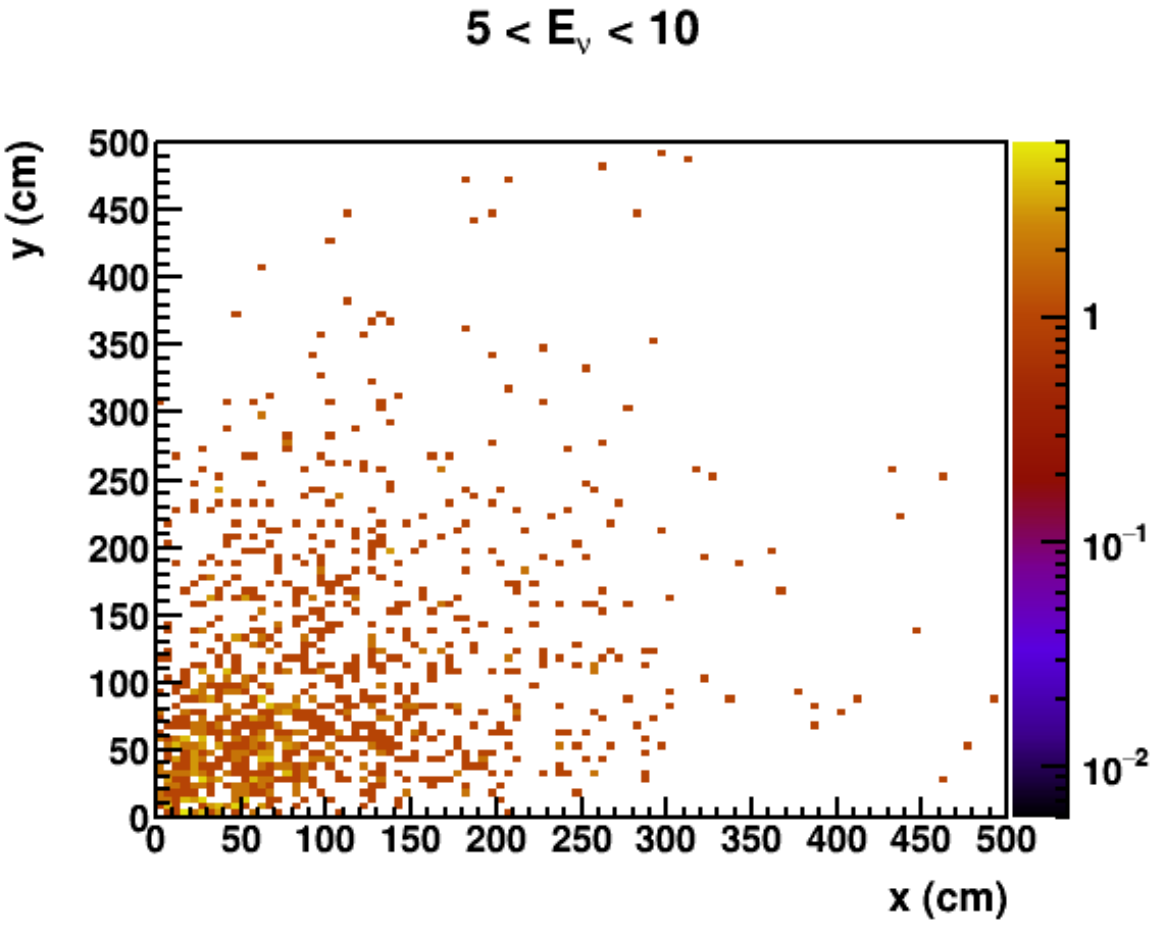
- 90% < 2.80m
- 99% < 4.00m

Transverse extent – lepton+hadrons 3-5 GeV



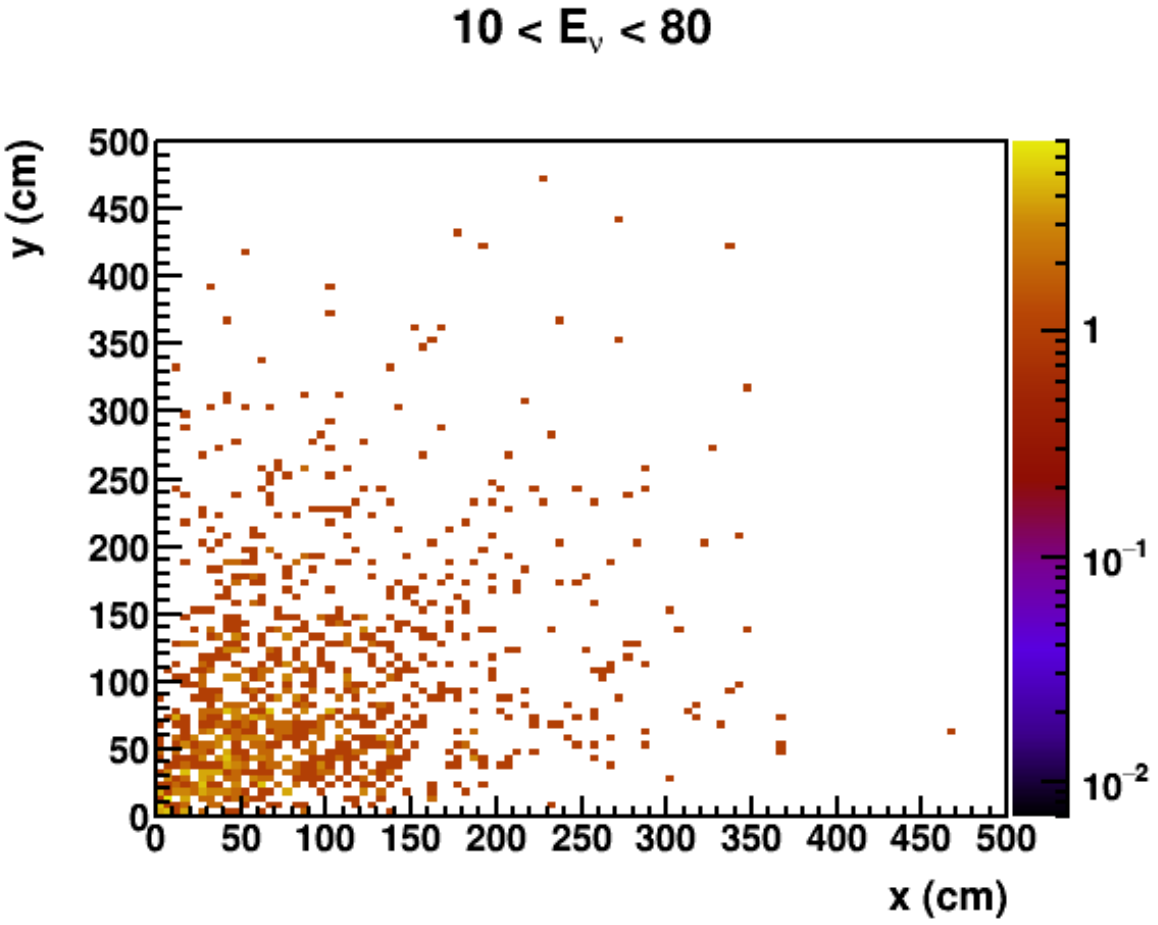
- 90% < 2.85m
- 99% < 4.10m

Transverse extent – lepton+hadrons 5-10 GeV



- 90% < 2.85m
- 99% < 4.50m

Transverse extent – lepton+hadrons >10 GeV



- 90% < 2.45m
- 99% < 3.70m
- But very low statistics