Physics impact of shortening ArgonCube

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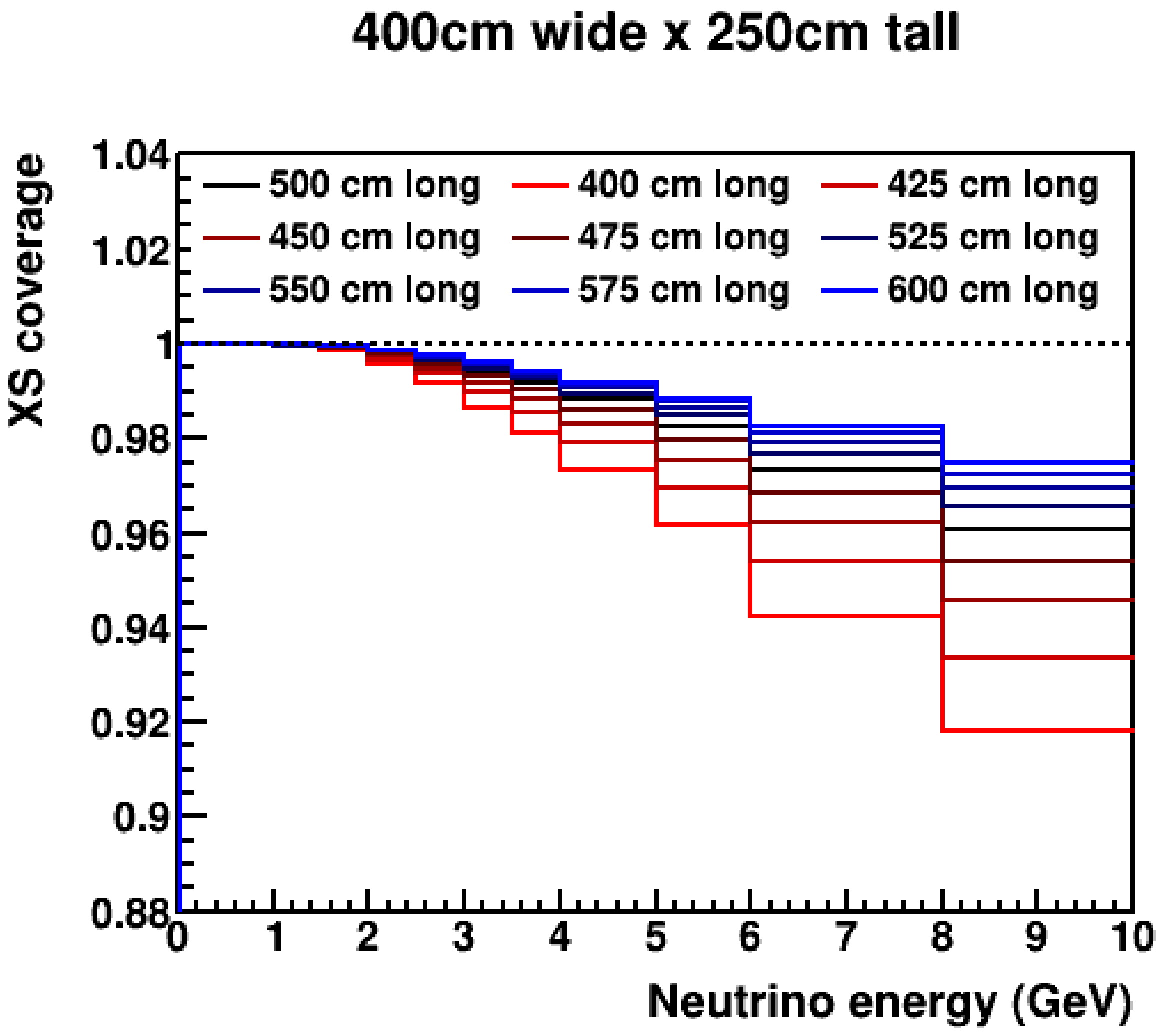
Revisiting detector size

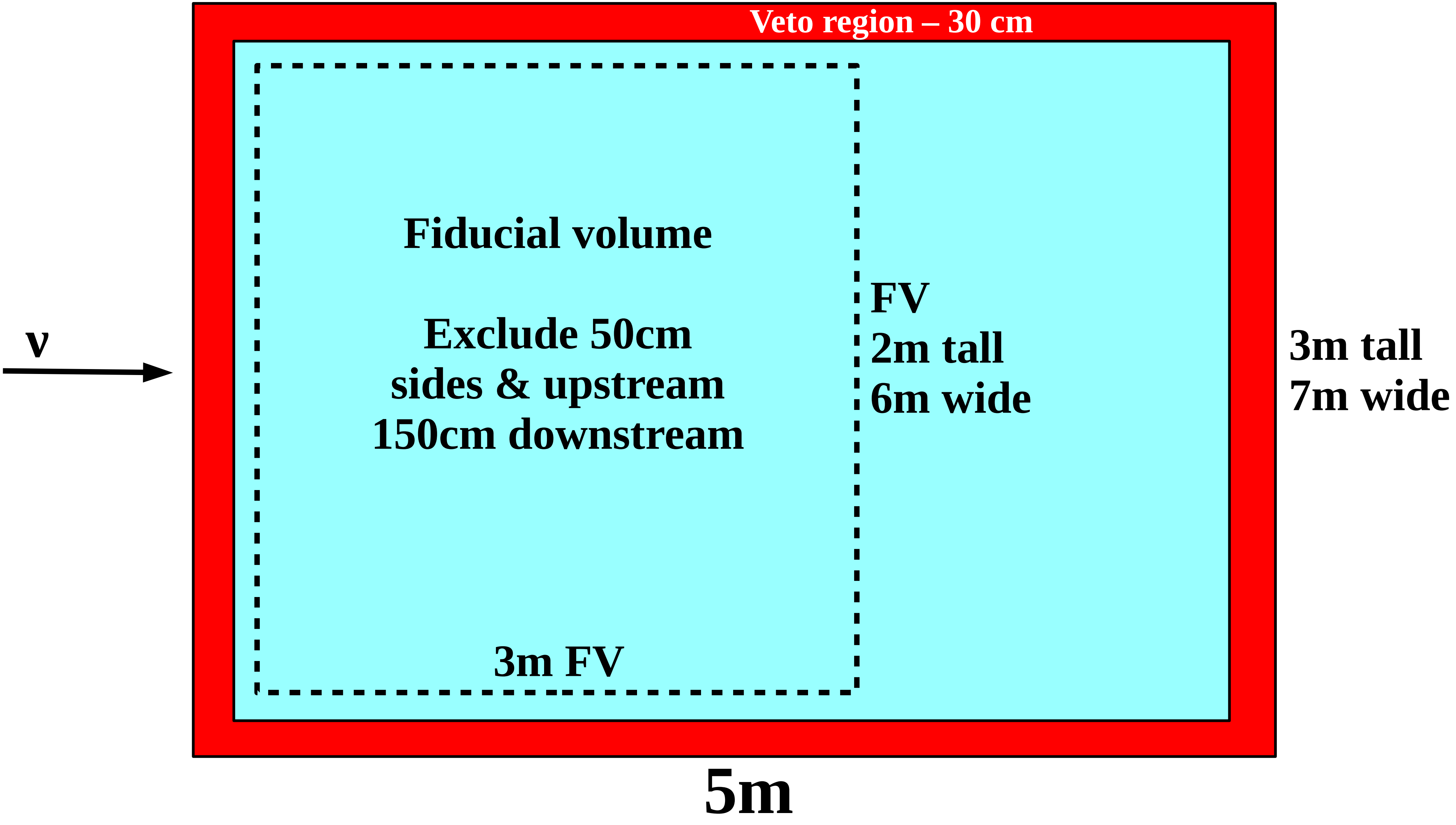
- Previous studies indicate that required LAr size is 5m in beam direction, 3x4m (for hadronic containment only) or 3x7m (for hadron + muon containment) transverse to beam
- Motivation was “full coverage” of events, leveraging translational and rotational symmetries
- Other things to consider:
  - Event rate for ν+e elastic
  - Acceptance for ν_μ CC

XS coverage vs. Z

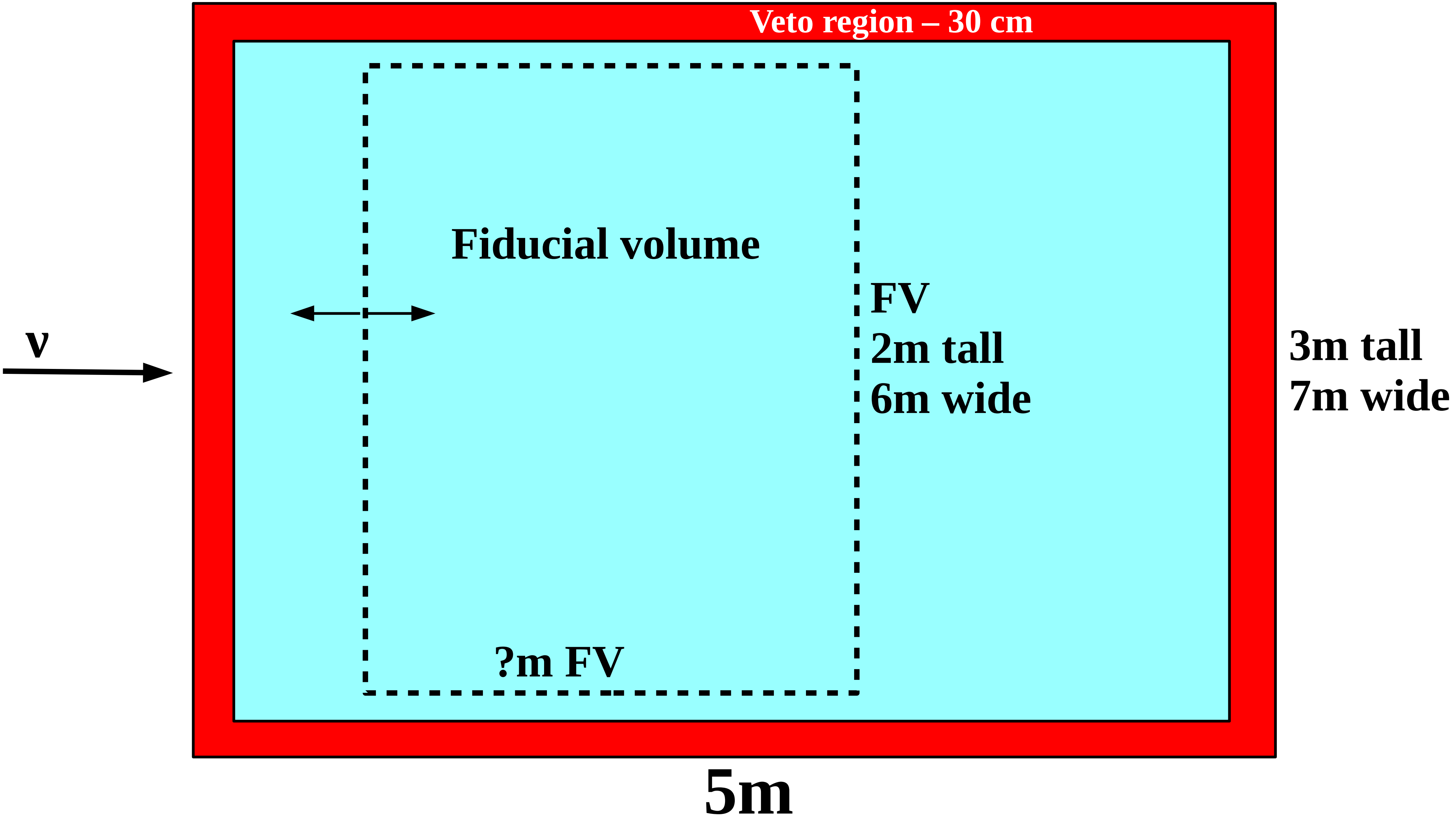


- X and Y are fixed at nominal 400cm wide x 250cm tall (hadronic side only)
- Black is nominal 500cm long, red is shorter, blue is longer
- (1-XS coverage) = what fraction of events cannot be well reconstructed no matter where the vertex is or how you rotate them about the neutrino

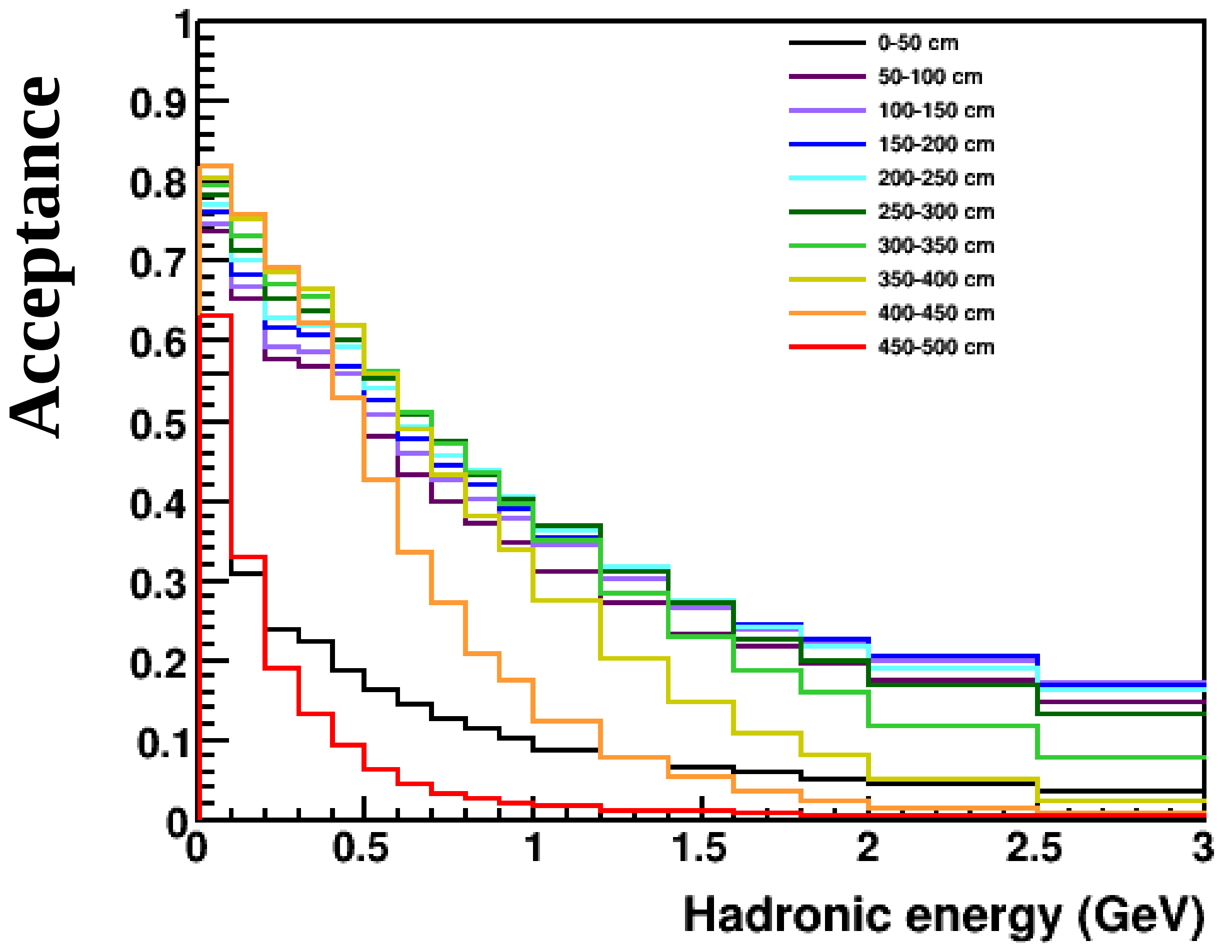
Fiducial, veto definitions



Acceptance vs. detector size



Hadronic acceptance

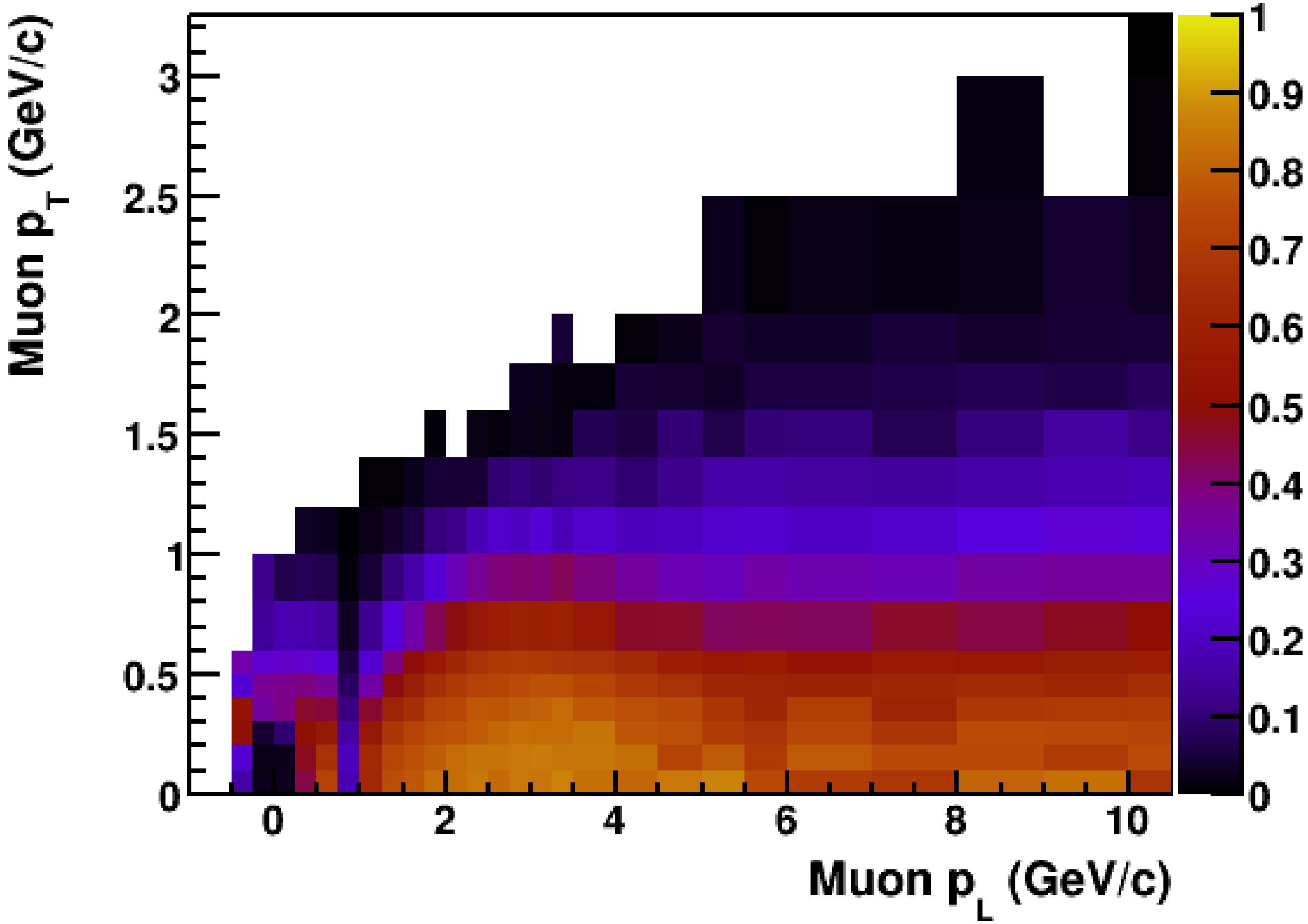


- In 50cm slices of vertex position
- Not quite the same as shortening the detector due to backscatter, which can be seen at very low hadronic energy
- Stable vs. hadronic energy up to 2m from downstream edge

Comments

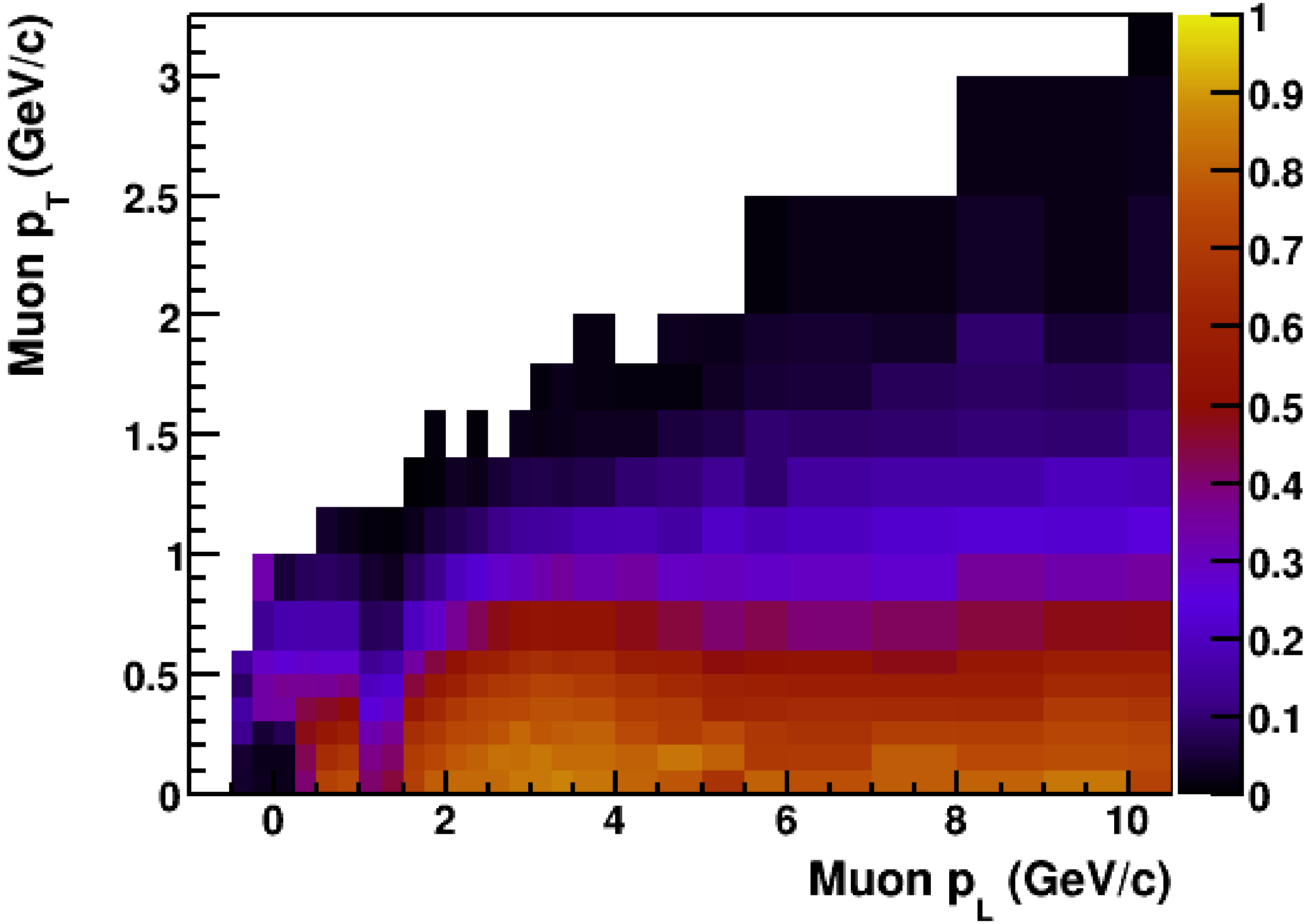
- "Awesome region" where acceptance is not changing as a function of Z position is between 50cm from upstream end and 2m from downstream end
- This is all dependent on GENIE, detector model, etc.
- It is critical to be able to study rates in different slices as a data-driven cross check of the acceptance estimate
- Detector must be significantly longer than this
- Since acceptance gets worse for more downstream vertices, shortening F.V. by X% reduces the well-reconstructed event rate by >X%

Acceptance vs. muon kinematics 200 < vertex z < 250cm



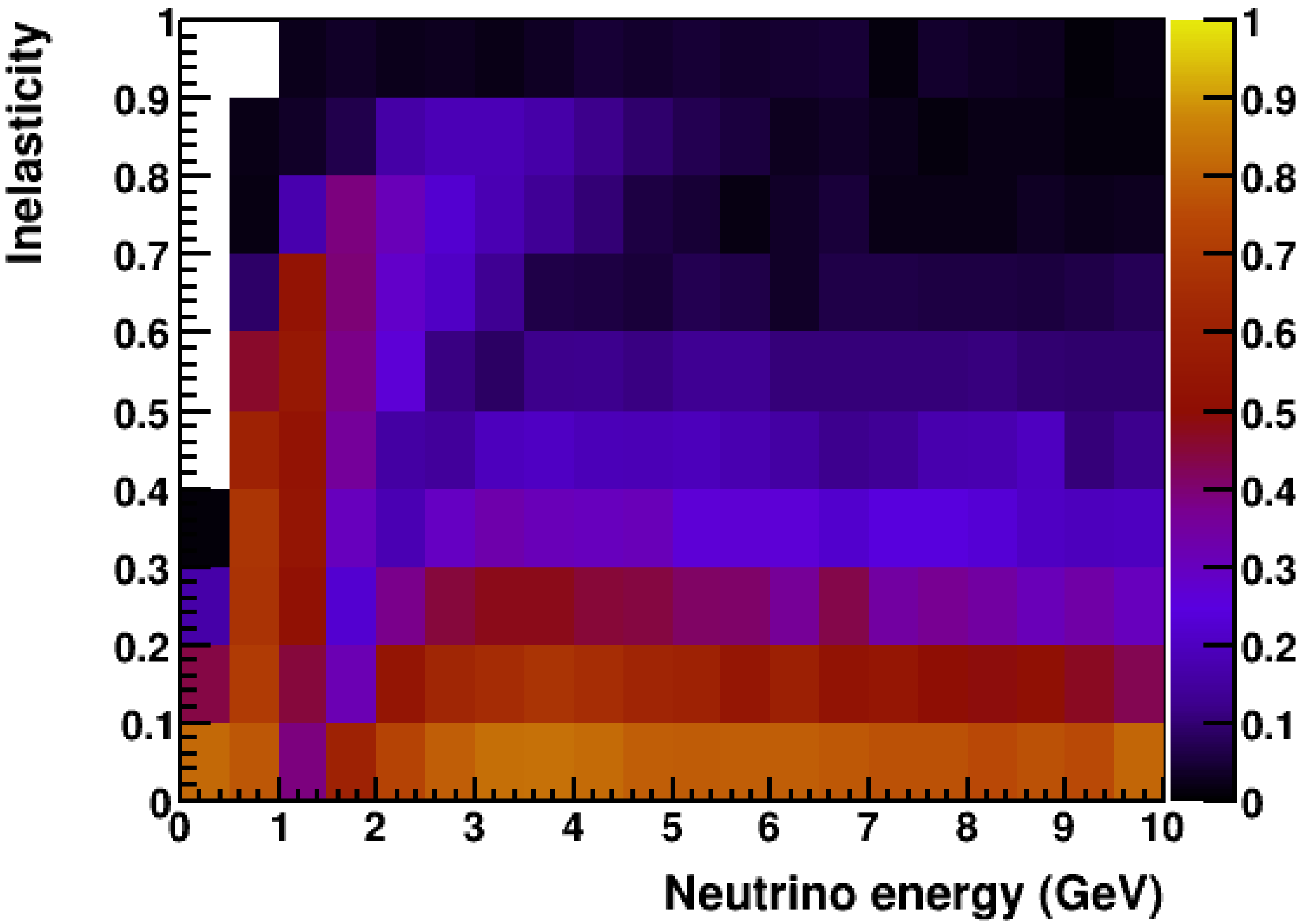
- For a given vertex position, there is an acceptance hole due to passive material between LAr and gas TPC

Acceptance vs. muon kinematics 50 < vertex z < 100cm



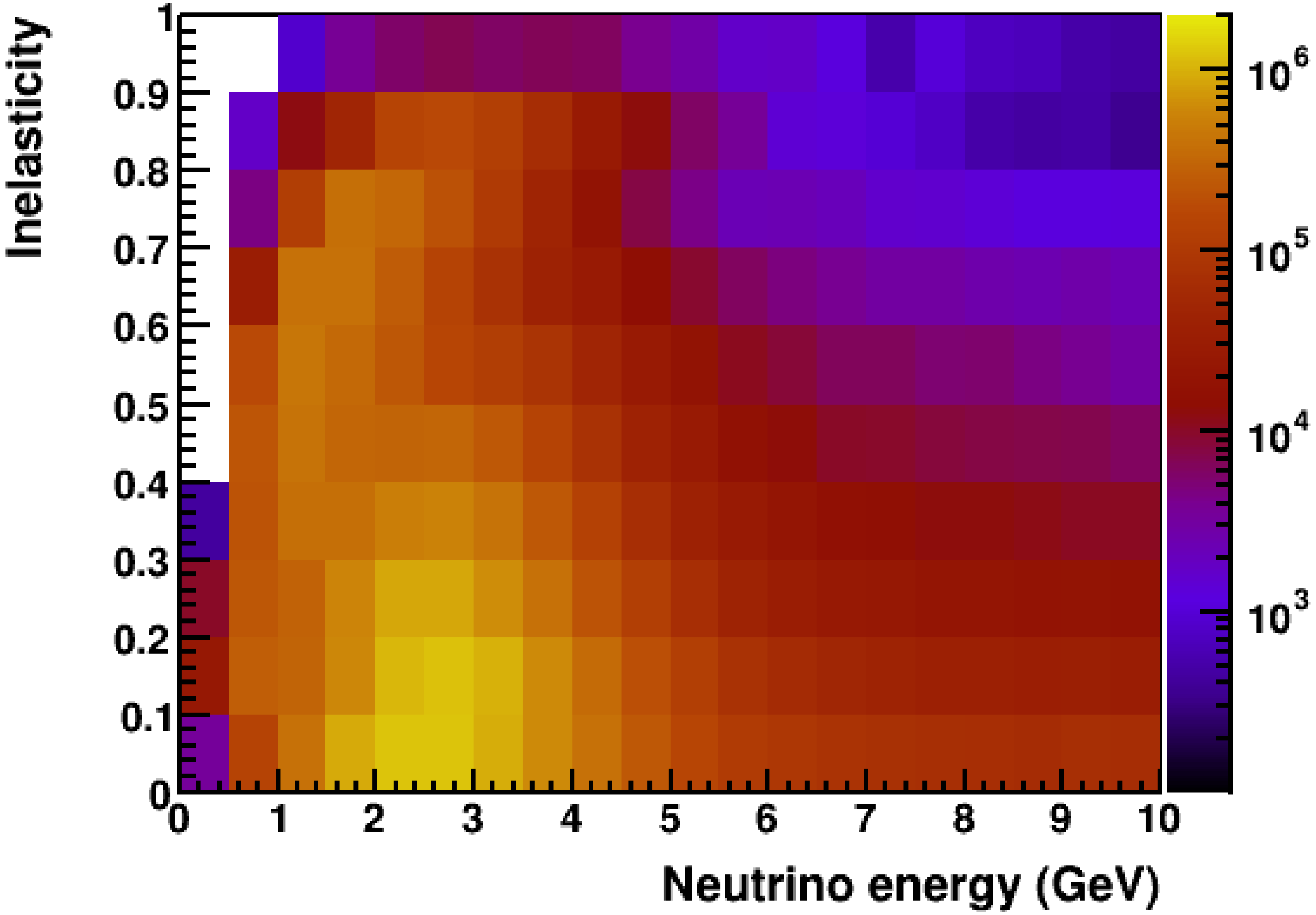
- Location of hole moves with vertex position
- It is critical that the LAr fiducial volume is much longer than the width of the gap
- Shorter LAr → more important to minimize dead material

Acceptance vs. neutrino energy 50 < vertex z < 100cm



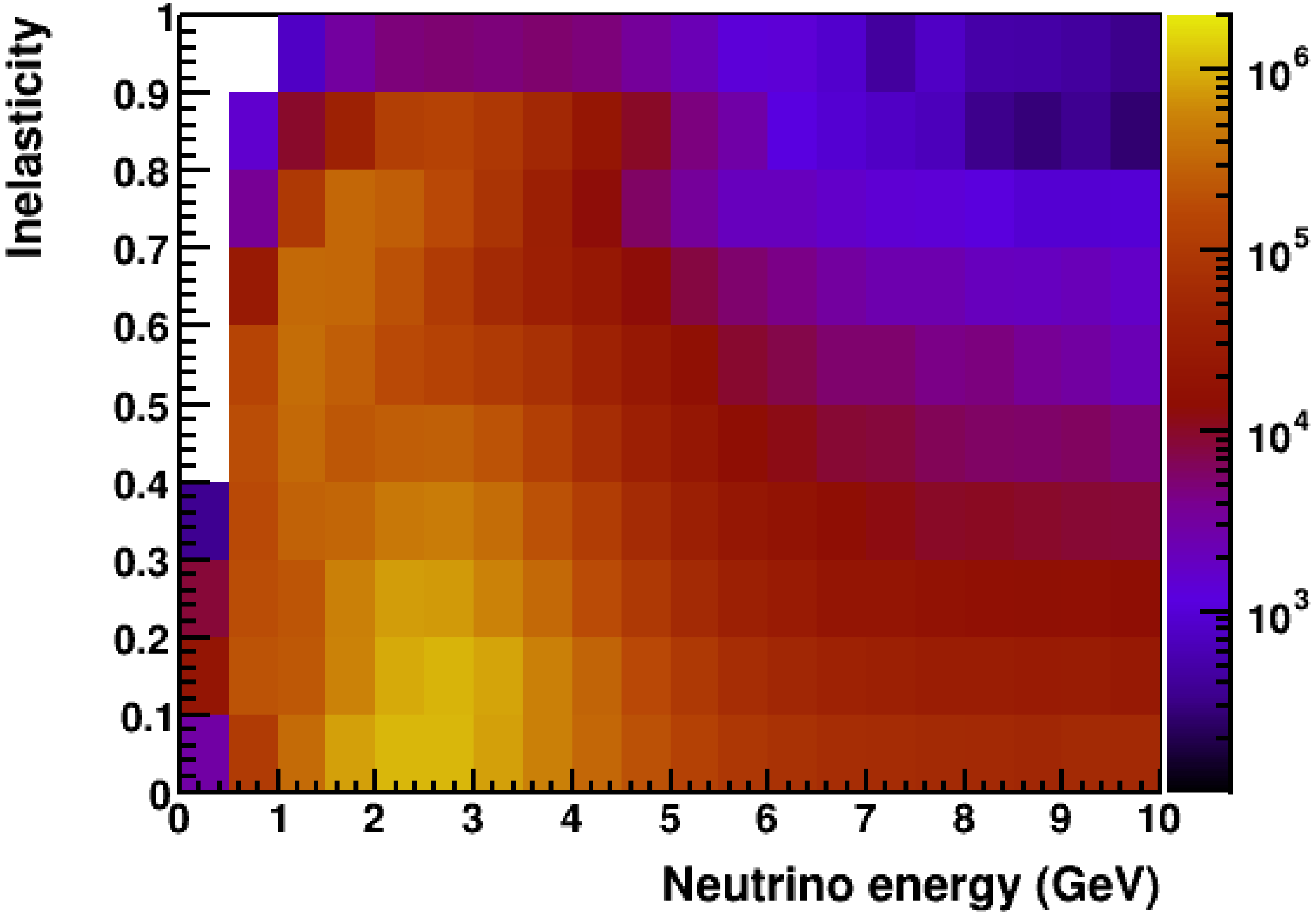
- Second oscillation maximum = 0.8 GeV is always contained for upstream vertex
- For shorter detector, muons at low y will always exit

Accepted CC ν_μ event rate per year



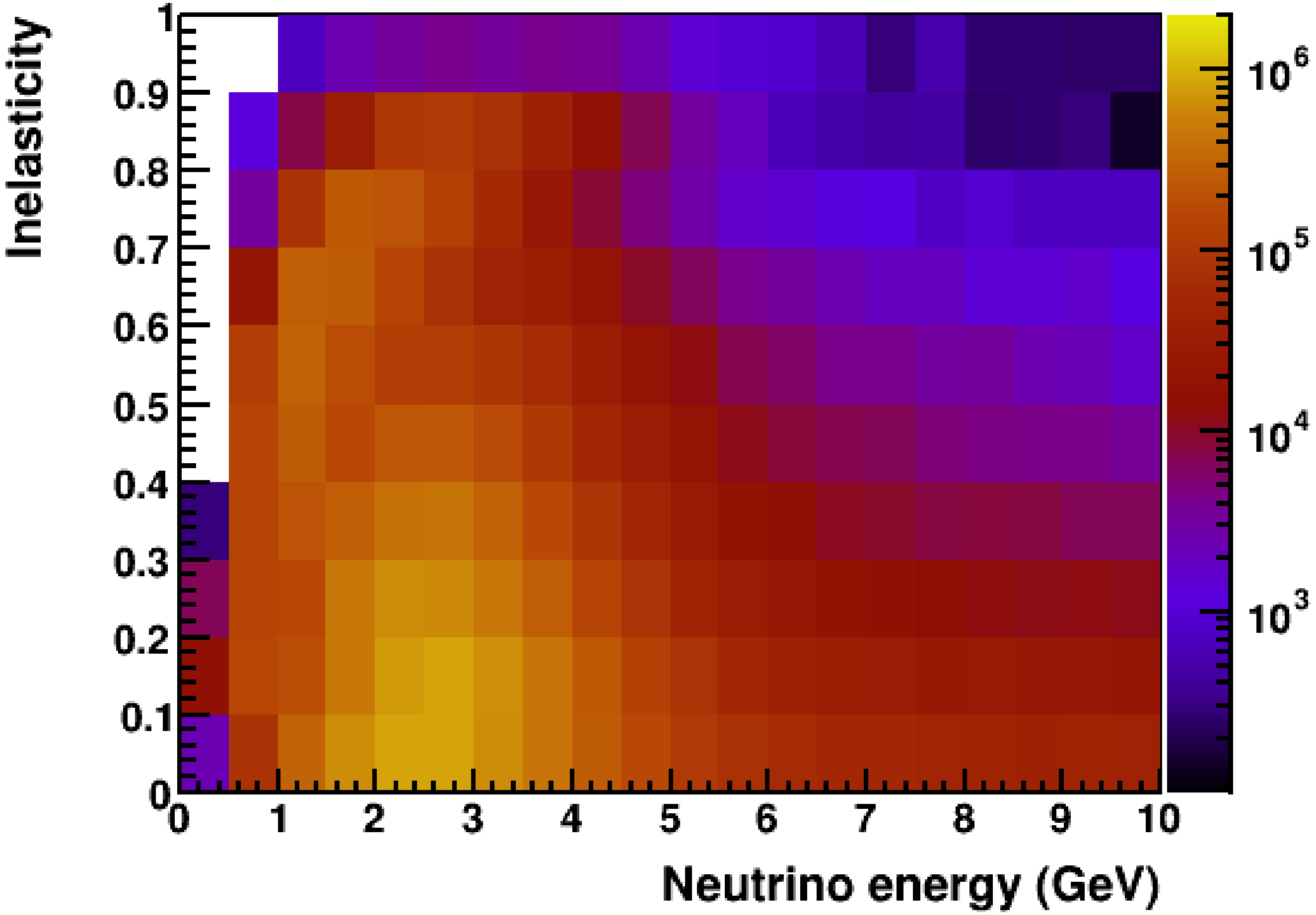
- Nominal 3x7x5 detector
- Shown is rate per bin per year at 1 MW
- 28M events total

Accepted CC ν_μ event rate per year



- Shortened 3x7x4.5
- Shown is rate per bin per year at 1 MW
- 24M events total

Accepted CC ν_μ event rate per year



- Shortened 3x7x4 detector
- Shown is rate per bin per year at 1 MW
- 19M events total

ν+e elastic rate

- ~100 events per year per ton Ar assuming 90% efficiency and threshold of 800 MeV
- 2 meters along beam direction cannot be used
  - Upstream 50cm required to avoid backgrounds from photons produced in upstream material
  - Downstream 150cm (11 radiation lengths) required for energy reconstruction
- ~3000/yr for 3x4x5, ~6000/yr for 3x7x5
- Shortening from 5m → 4m reduces ν+e rate by 33%

Conclusions

- Shortening ArgonCubeND to ~4.5m does not obviously break physics capability, but carries significant risk
  - Worse hadronic containment
  - Smaller volume over which containment is stable → increased dependence on interaction & detector models
  - More stringent requirements on passive material between detectors
- Reduction in rate is not problematic, rate is still high
- Reduction in ν+e rate is not ideal, could be compensated with additional detector width

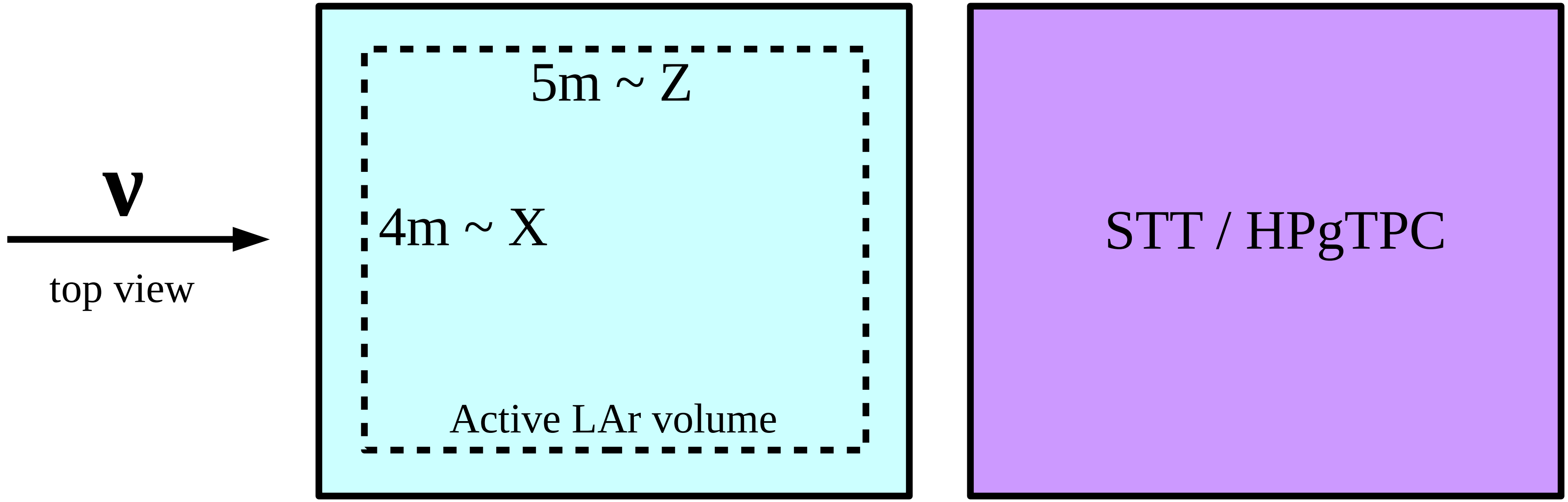
Backups

- The backups are my entire talk from January 2018 collaboration meeting on the physics motivation for the detector size

LAr ND minimum requirements

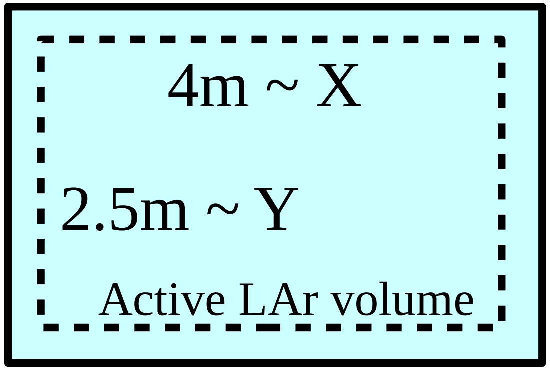
- LAr ND should be large enough to contain hadronic showers
- (Muon ID obviously critical, but is a topic for another presentation)
- Definition of "contain hadronic showers"
  - Reasonable efficiency across a wide range of kinematics
  - No phase space with zero acceptance
- Specific metric: >95% of hadronic energy, excluding neutrons and their descendants

Nominal detector size 4x2.5x5m

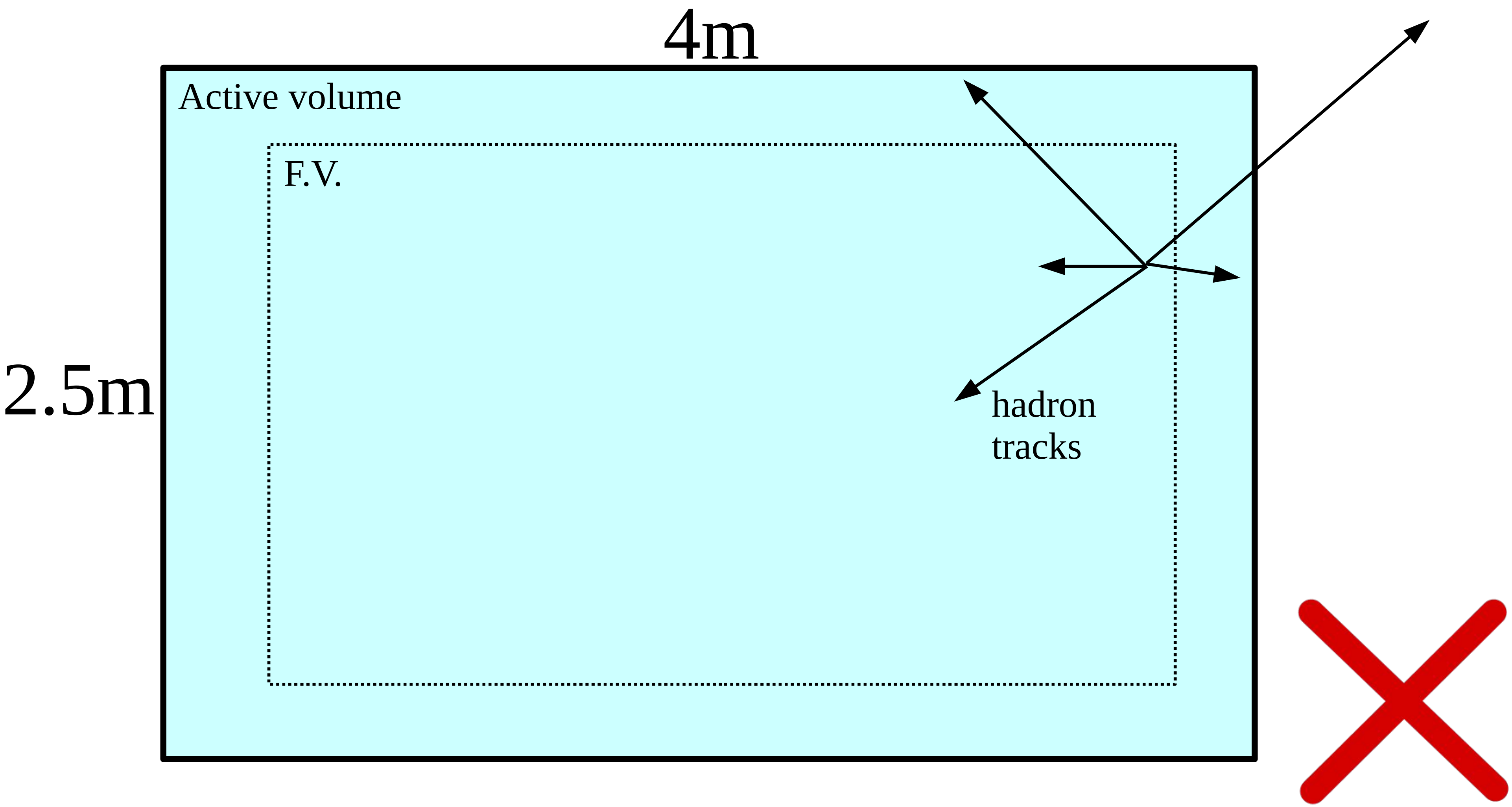


ν into page (down 5.8°)

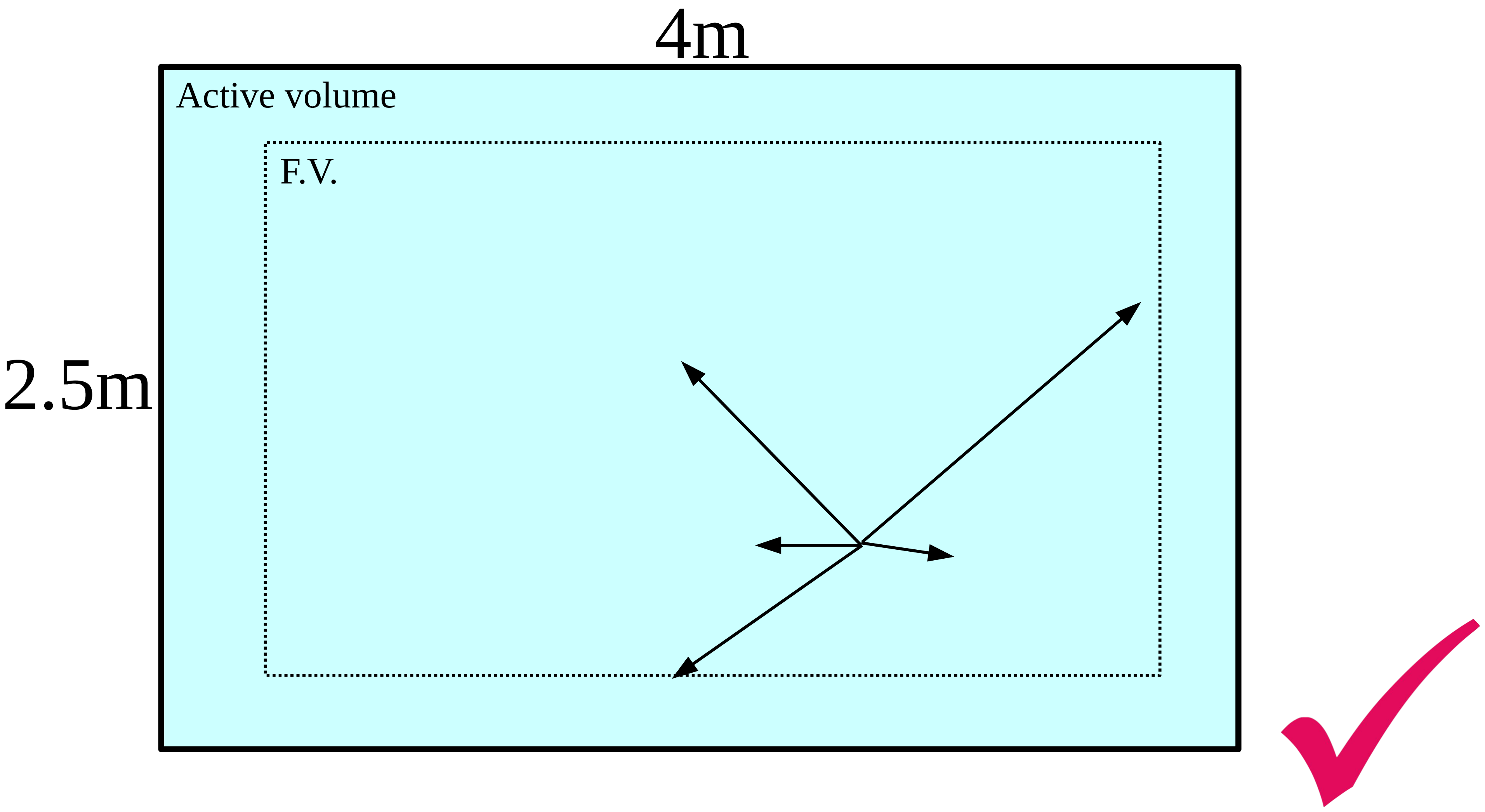
front view



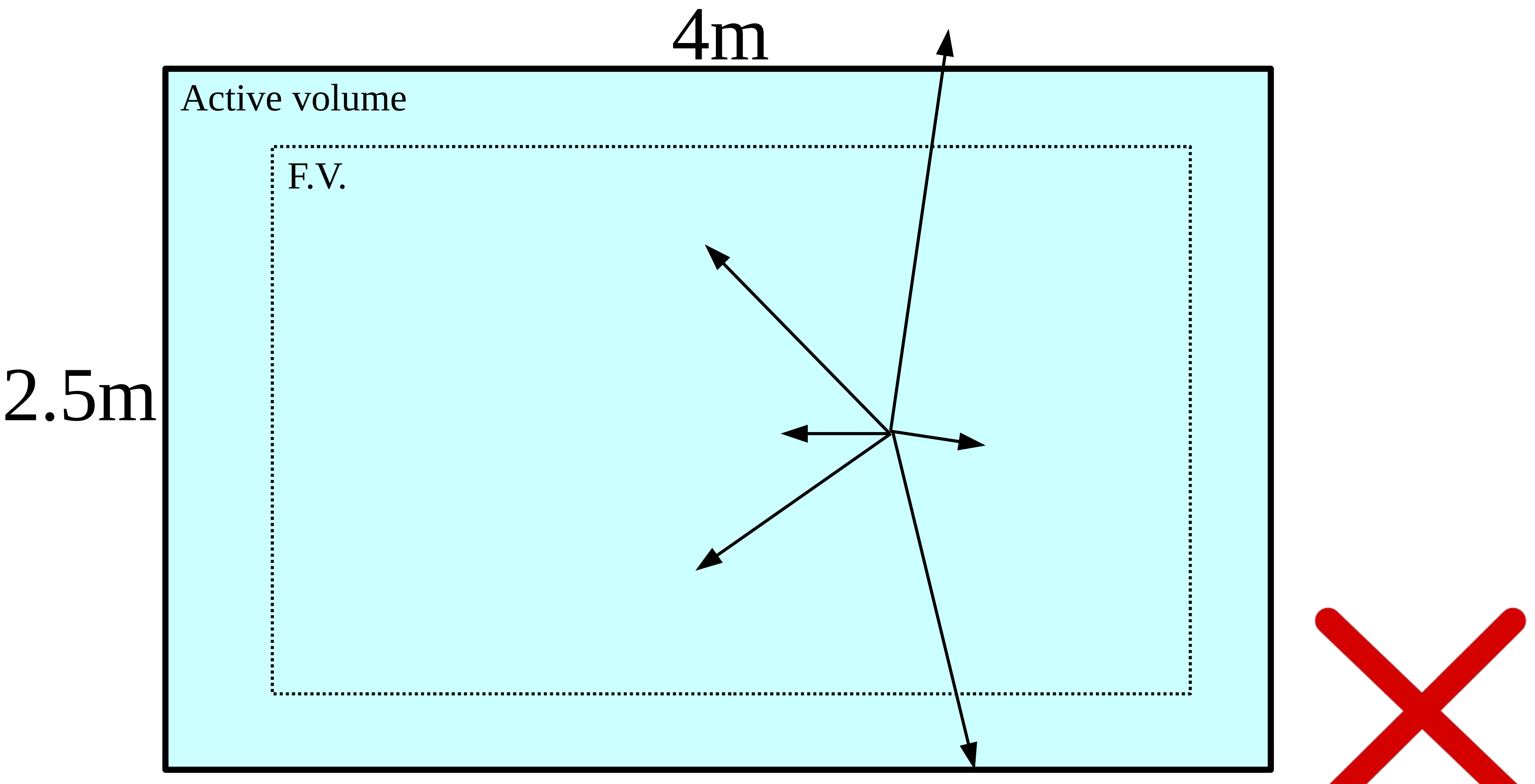
Detector as seen by ν beam (XY projection)



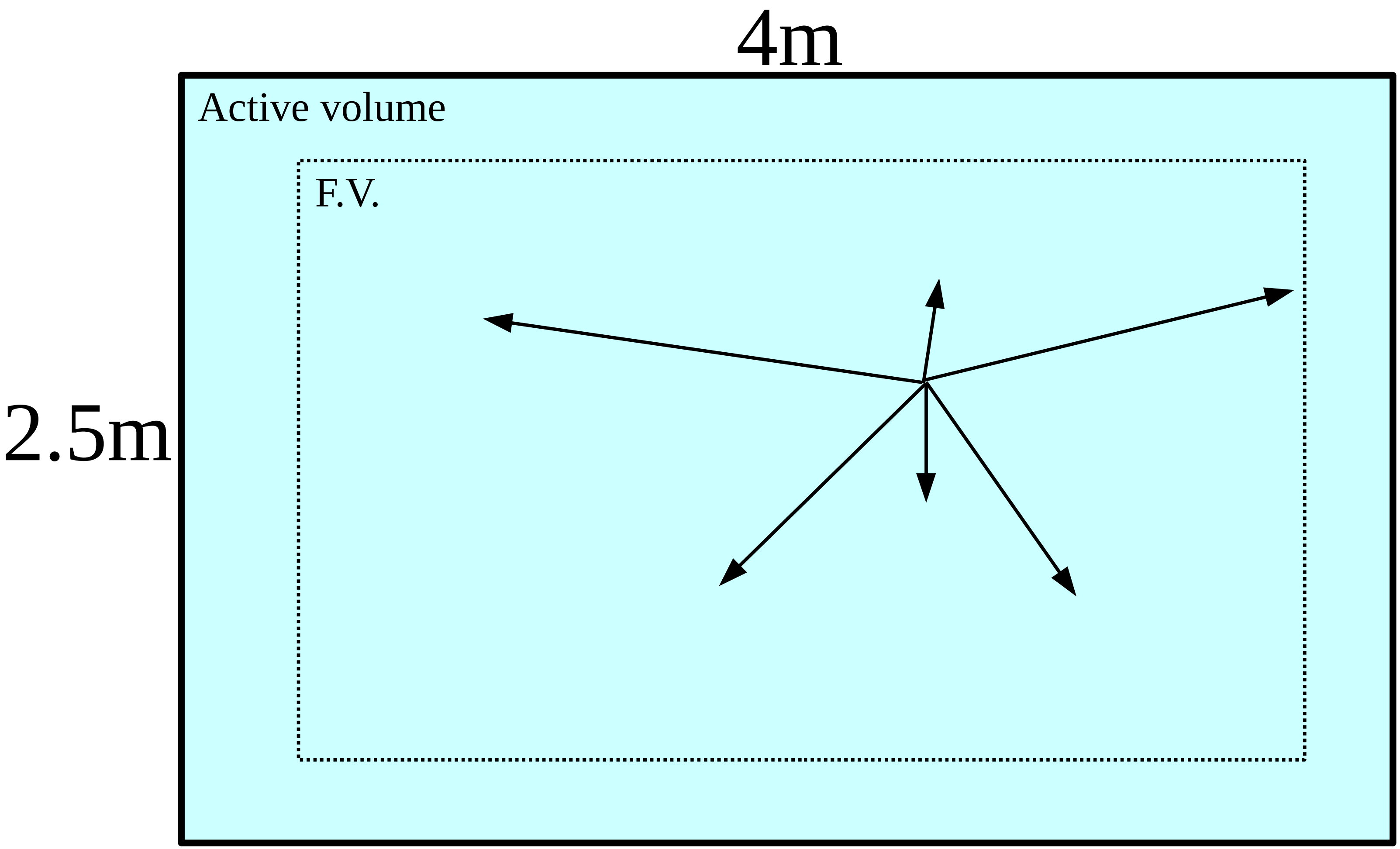
Same event, translated



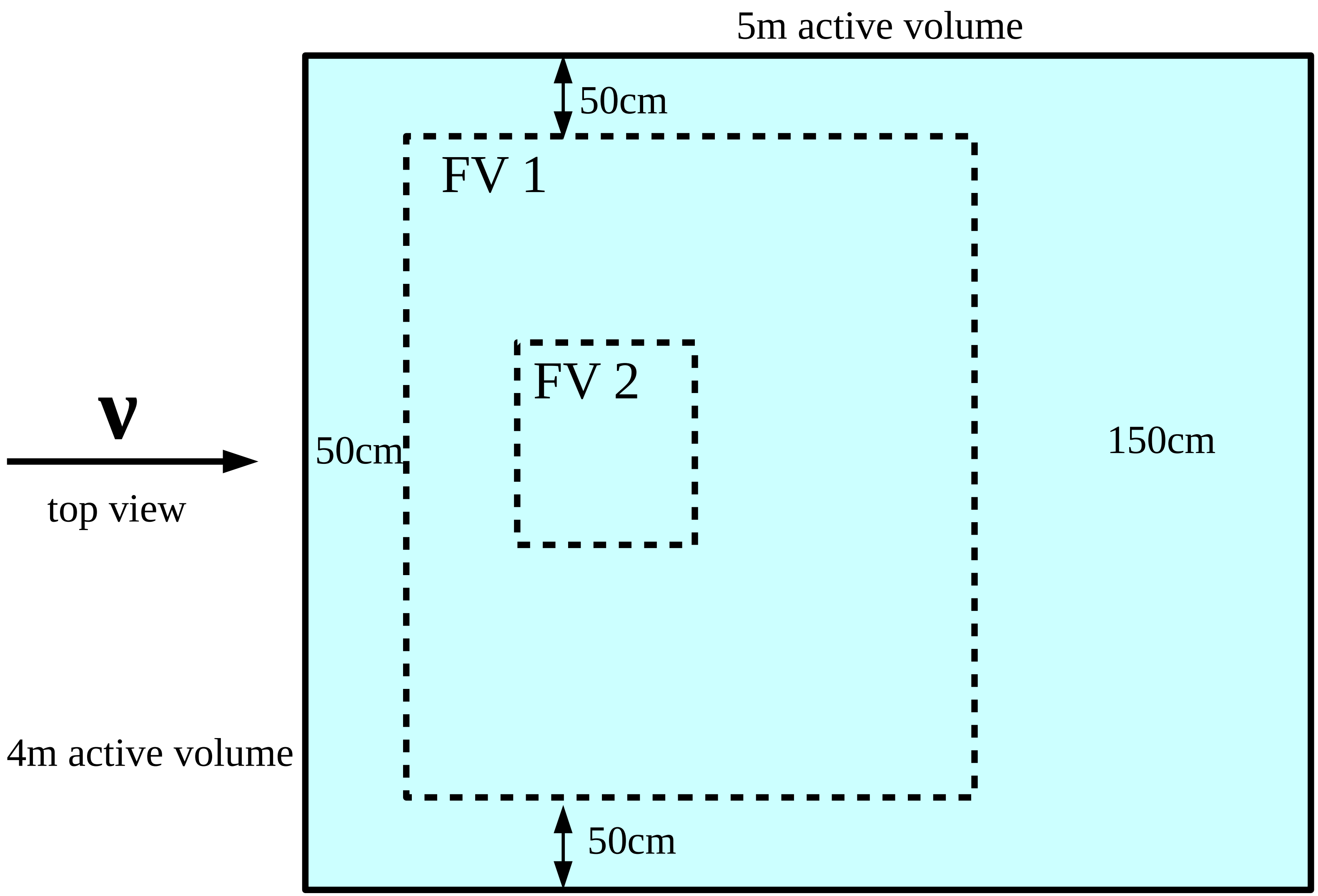
Event that is not contained with any translation



But is using phi symmetry

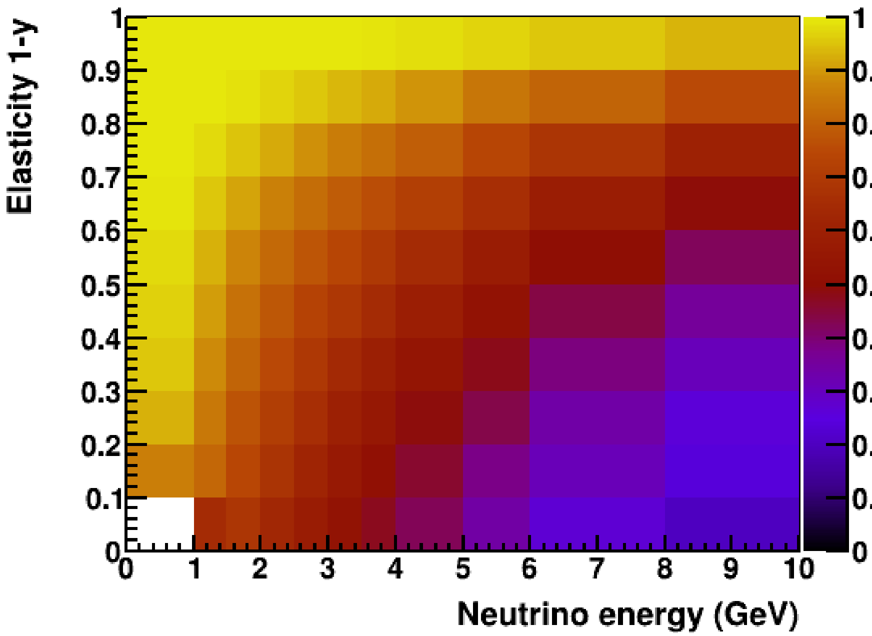


2 different fiducial volumes

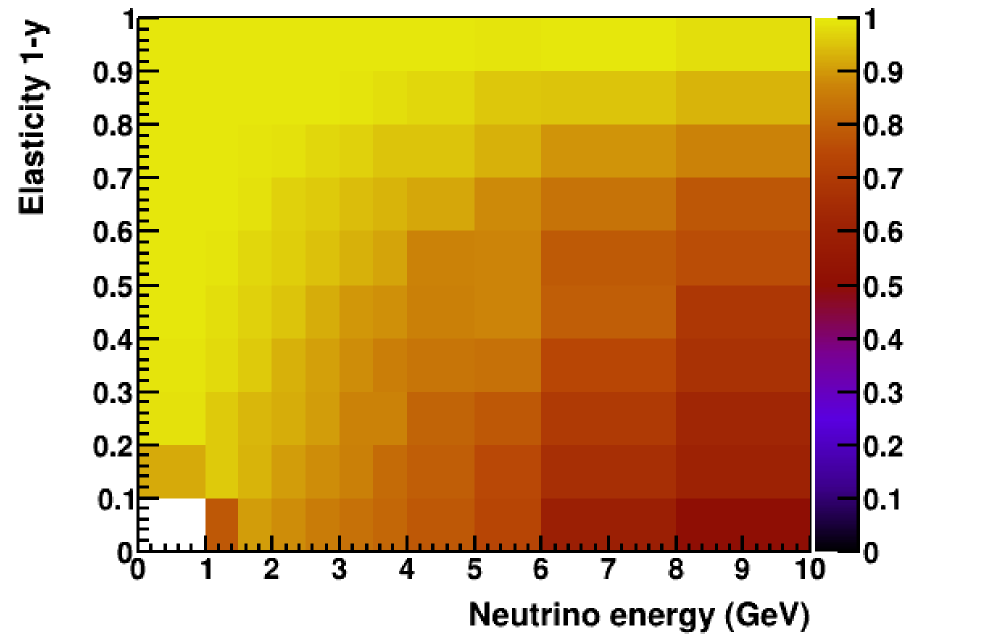


Acceptance for 4x3x5m LAr detector for different F.V.

Acceptance for 3x2x3m F.V.



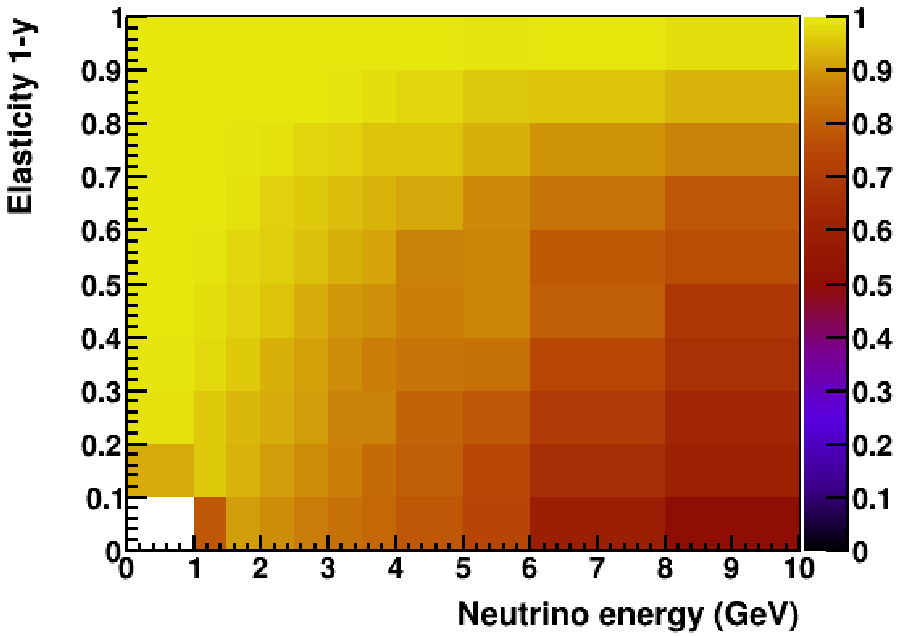
Acceptance for central 1x1x1m region



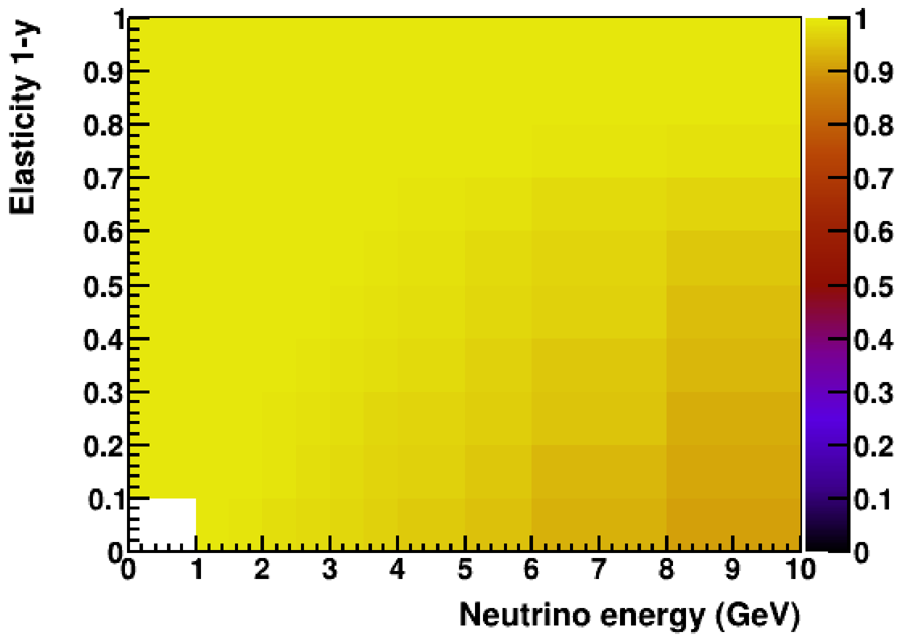
- ν_μ CC events only, y axis is $1\text{-}y = E_\mu/E_\nu$
- When hadronic energy is large, only ~20% of fiducial events are contained, but that goes up to ~50% if you restrict to a 1x1x1m volume in the very center

Acceptance vs. XS coverage

Acceptance for central 1x1x1m F.V.

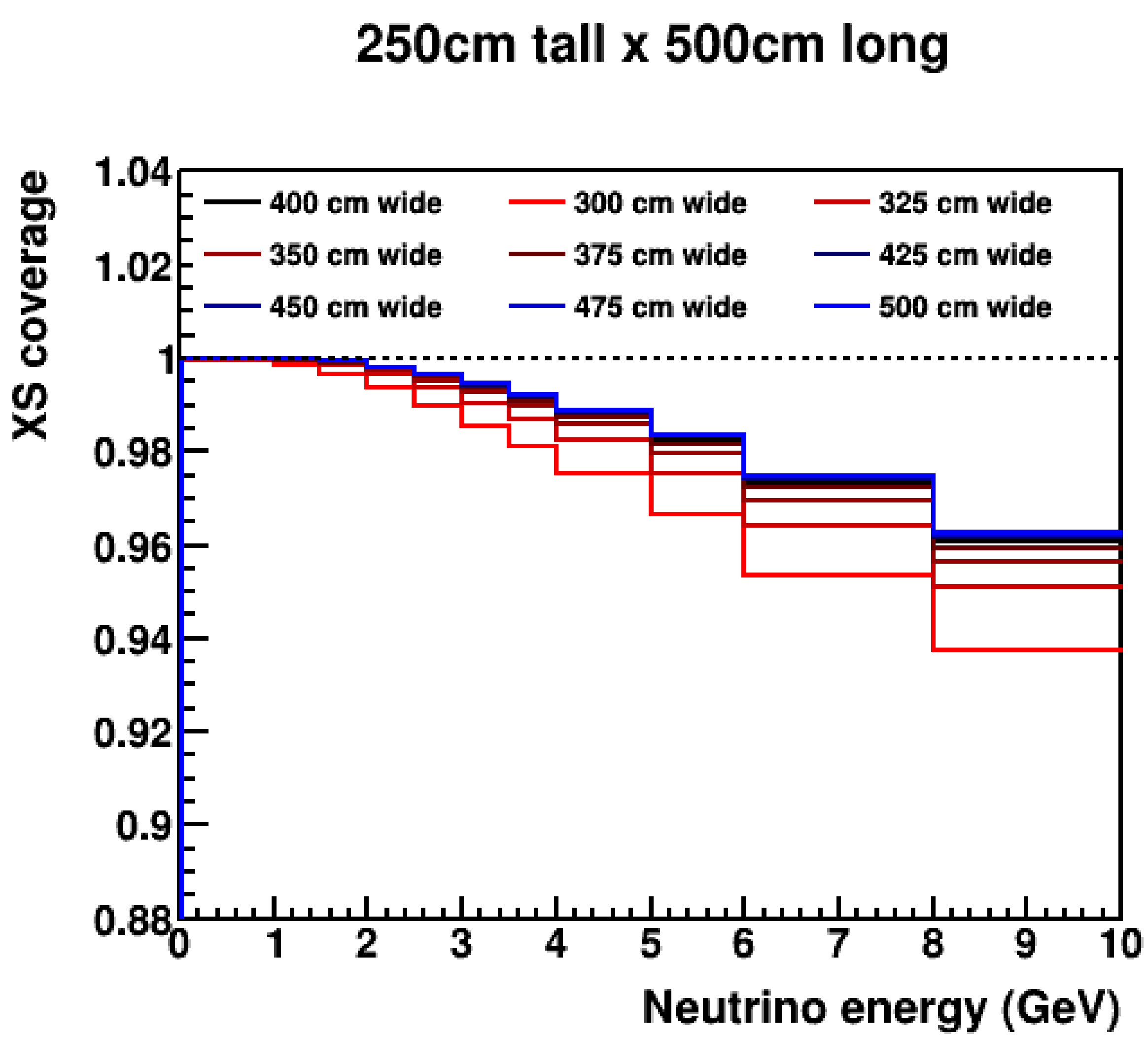


XS coverage for 3x2x4 region



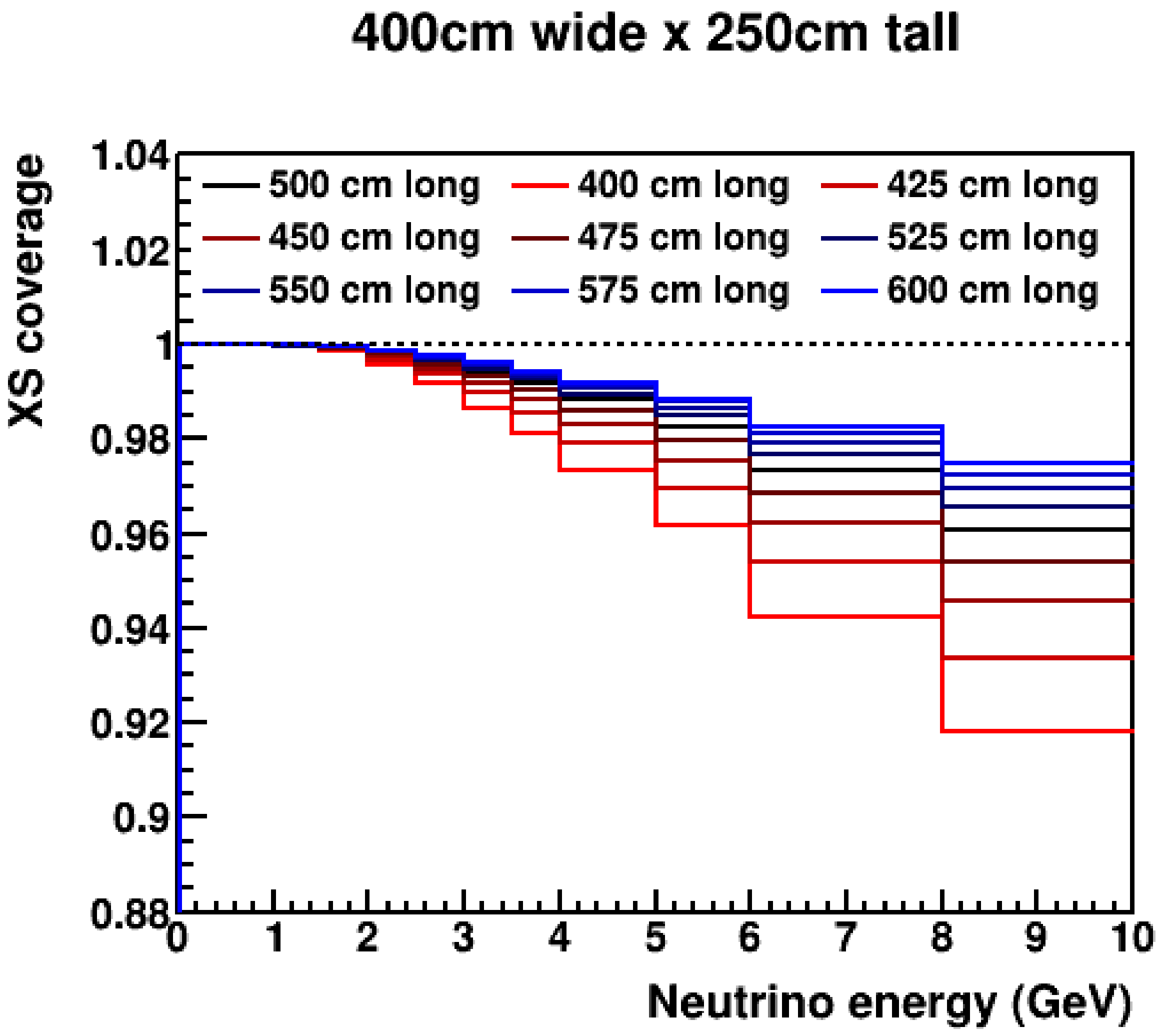
- “XS coverage” includes translation and phi symmetry, in a region 1m smaller than detector size in each dimension (i.e. 50cm buffer around the edge)

XS coverage vs. X



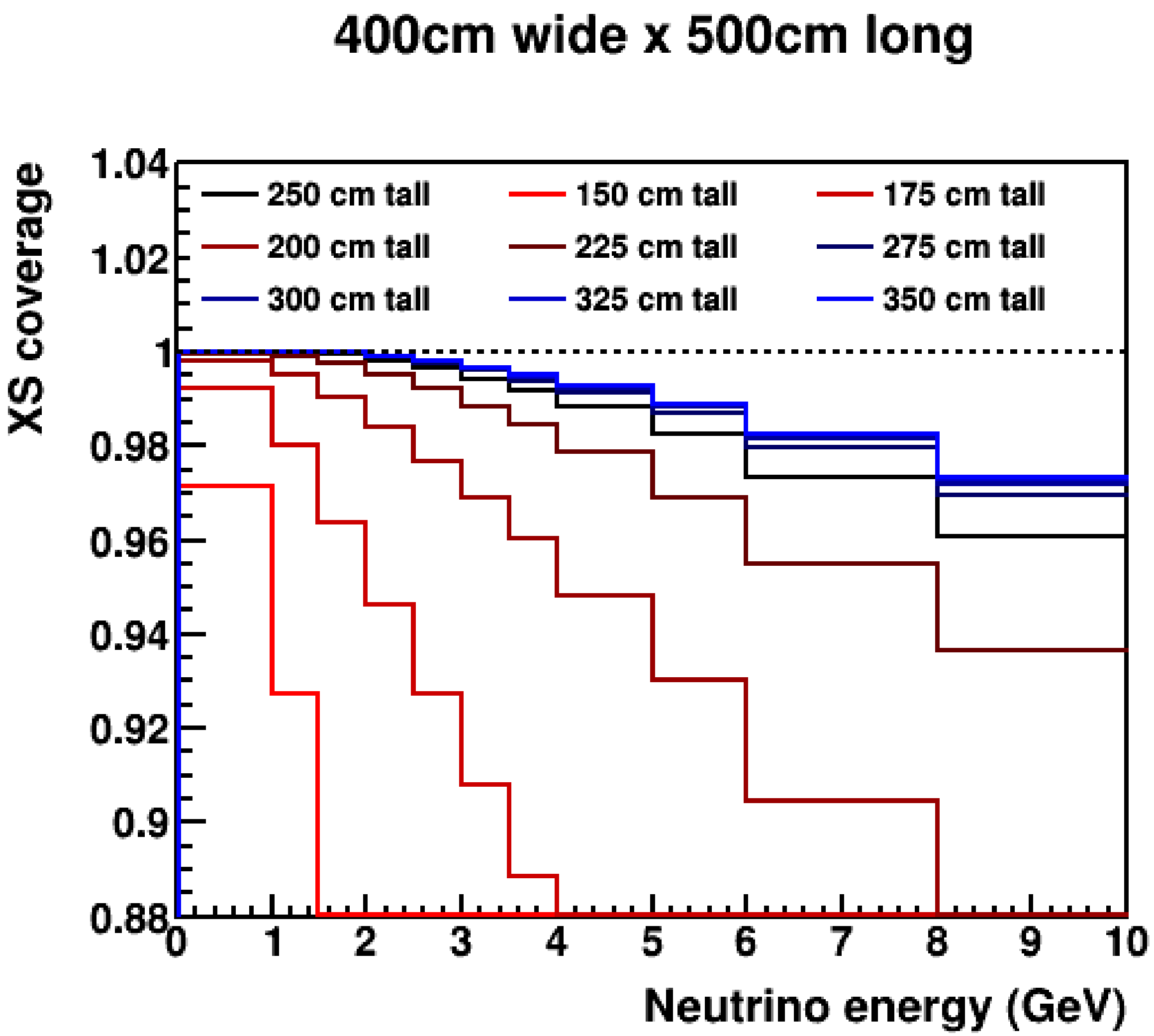
- Integrating out the 1-y variable, plot XS coverage for different size detectors
- Here, Y and Z dimensions are fixed at 250cm x 500cm
- Nominal X is 400cm, red is smaller, blue is larger
- For all sizes, 50cm buffer on all sides is assumed

XS coverage vs. Z



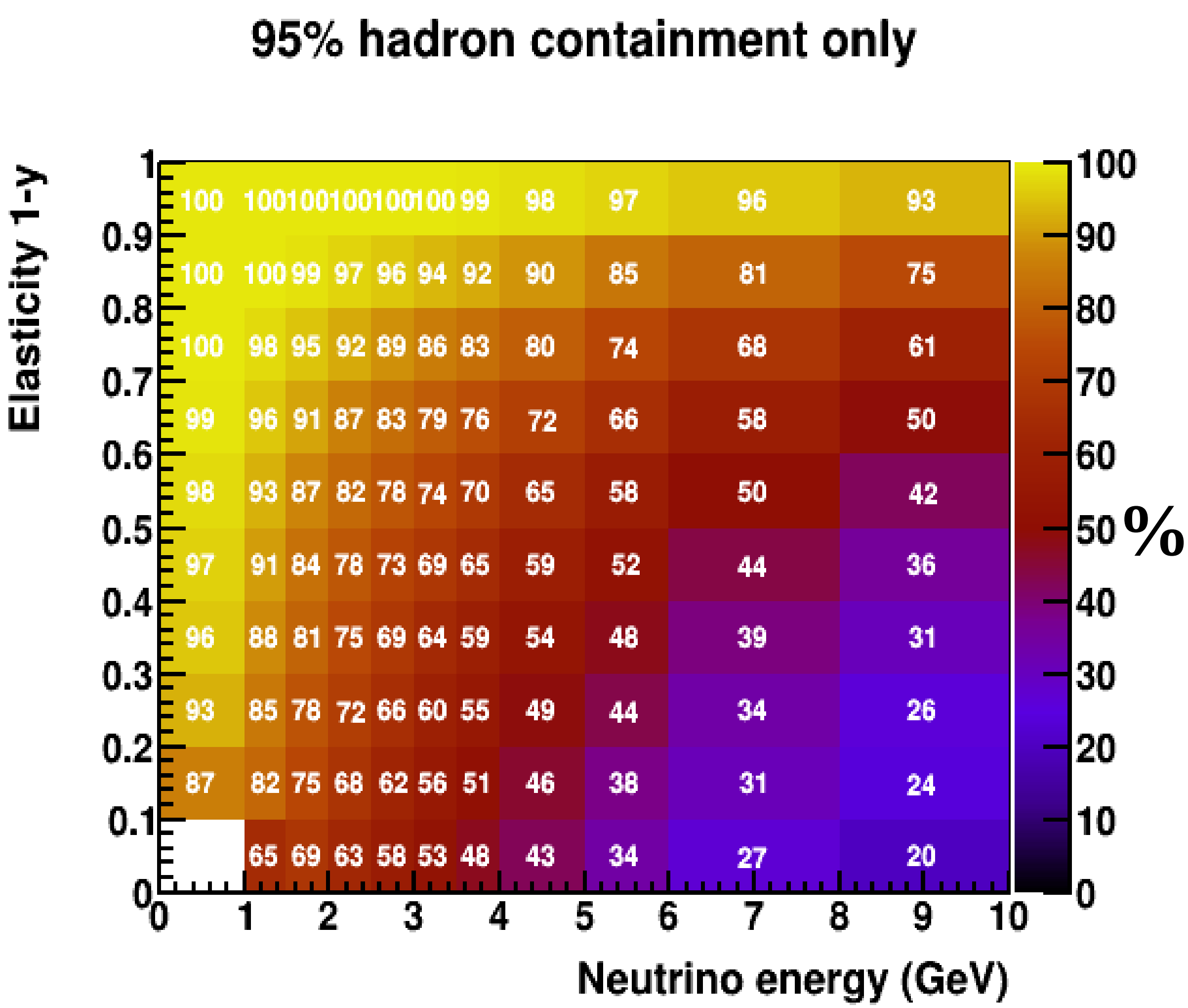
- X and Y are fixed at nominal 400cm wide x 250cm tall
- Black is nominal 500cm long, red is shorter, blue is longer

XS coverage vs. Y



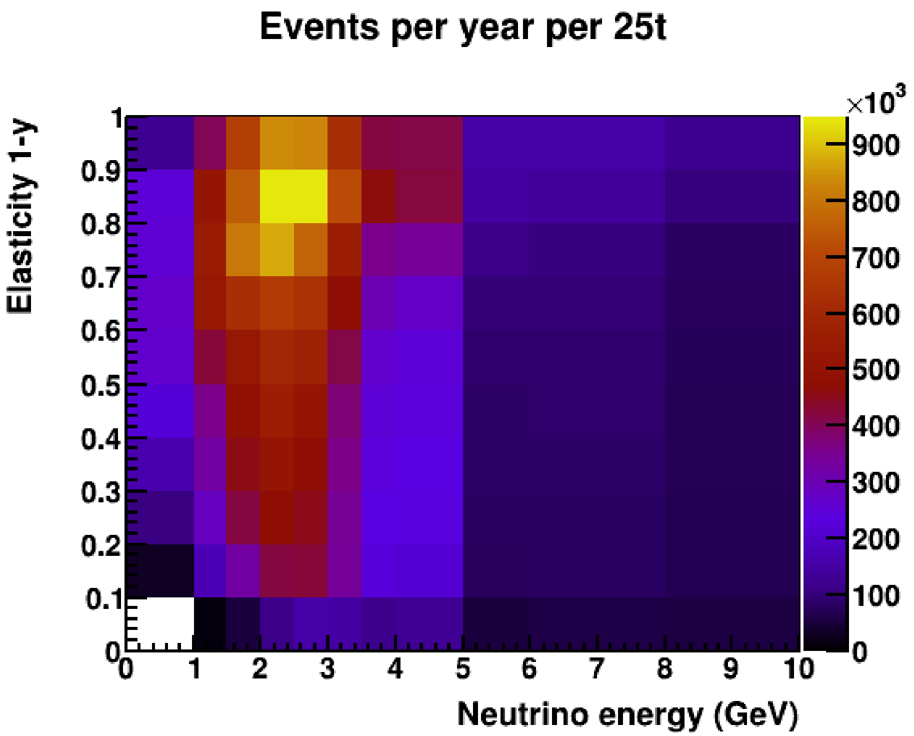
- X and Z are fixed at 400cm x 500cm
- Y (height) is varied, with black being nominal 250cm, red shorter, blue taller
- 250cm is right on the edge of significant loss of acceptance
- If Nature produces larger hadronic showers than GENIE, we could be in trouble
- 3m would be much safer

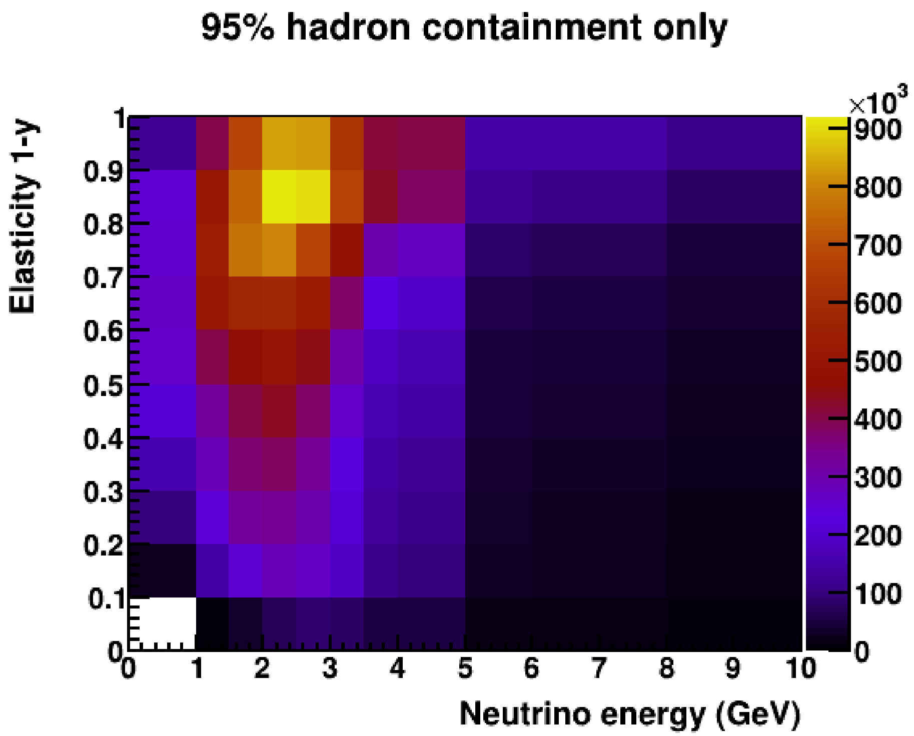
Hadronic shower acceptance



- 4x3x5m detector
- Fiducial volume is 3x2x3m
- 50cm upstream and side buffer
- 150cm downstream side
- Reject events with >20MeV in outer 30cm of detector

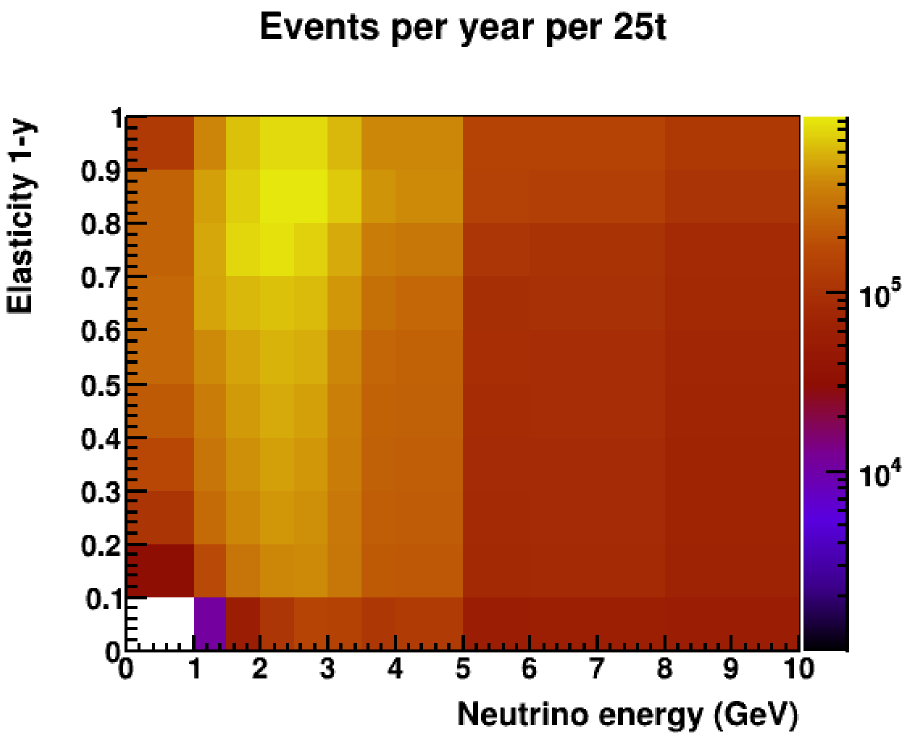
Event rates per bin per year for this F.V.

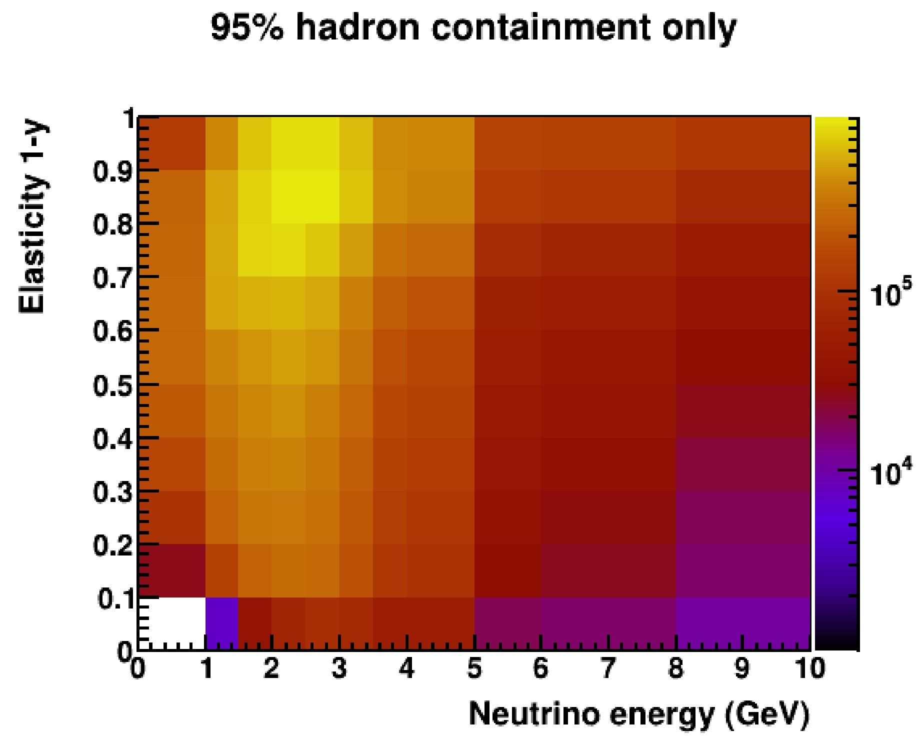




- ~1M per bin in the peak
- 10,000s events per bin in the worst bins of the tail

Event rates per bin per year for this F.V.



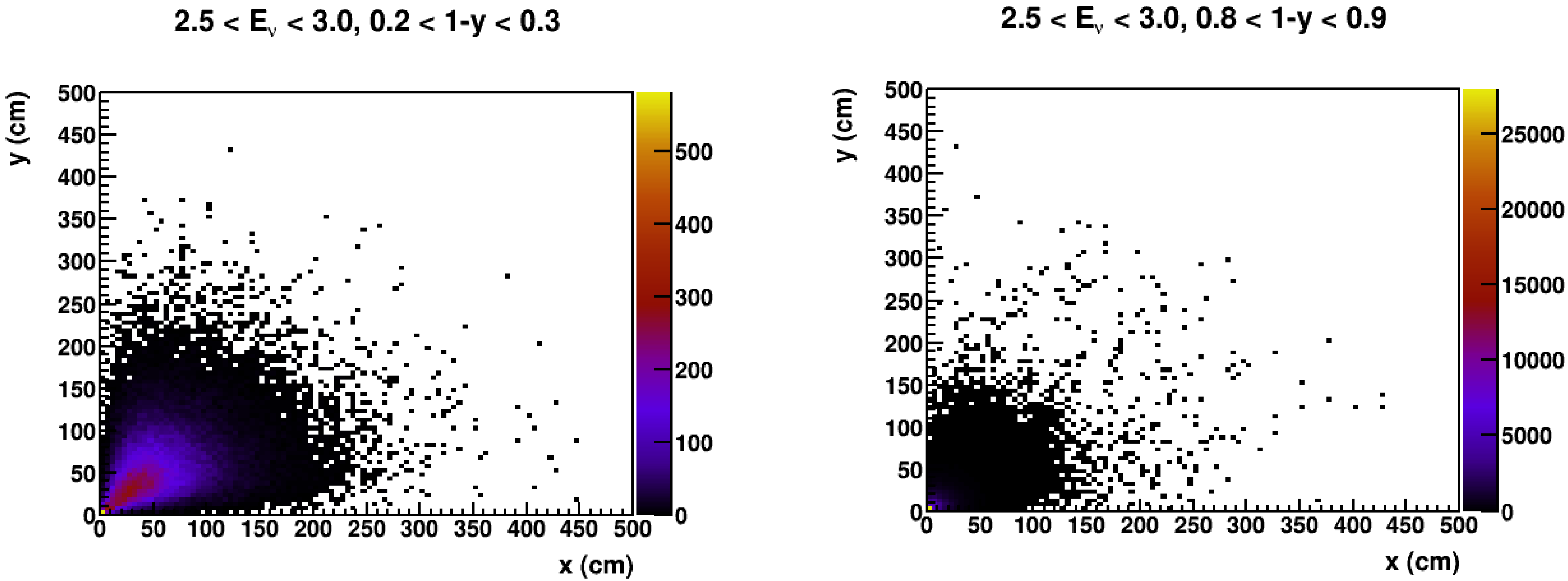


- ~1M per bin in the peak
- 10,000s events per bin in the worst bins of the tail

Conclusions

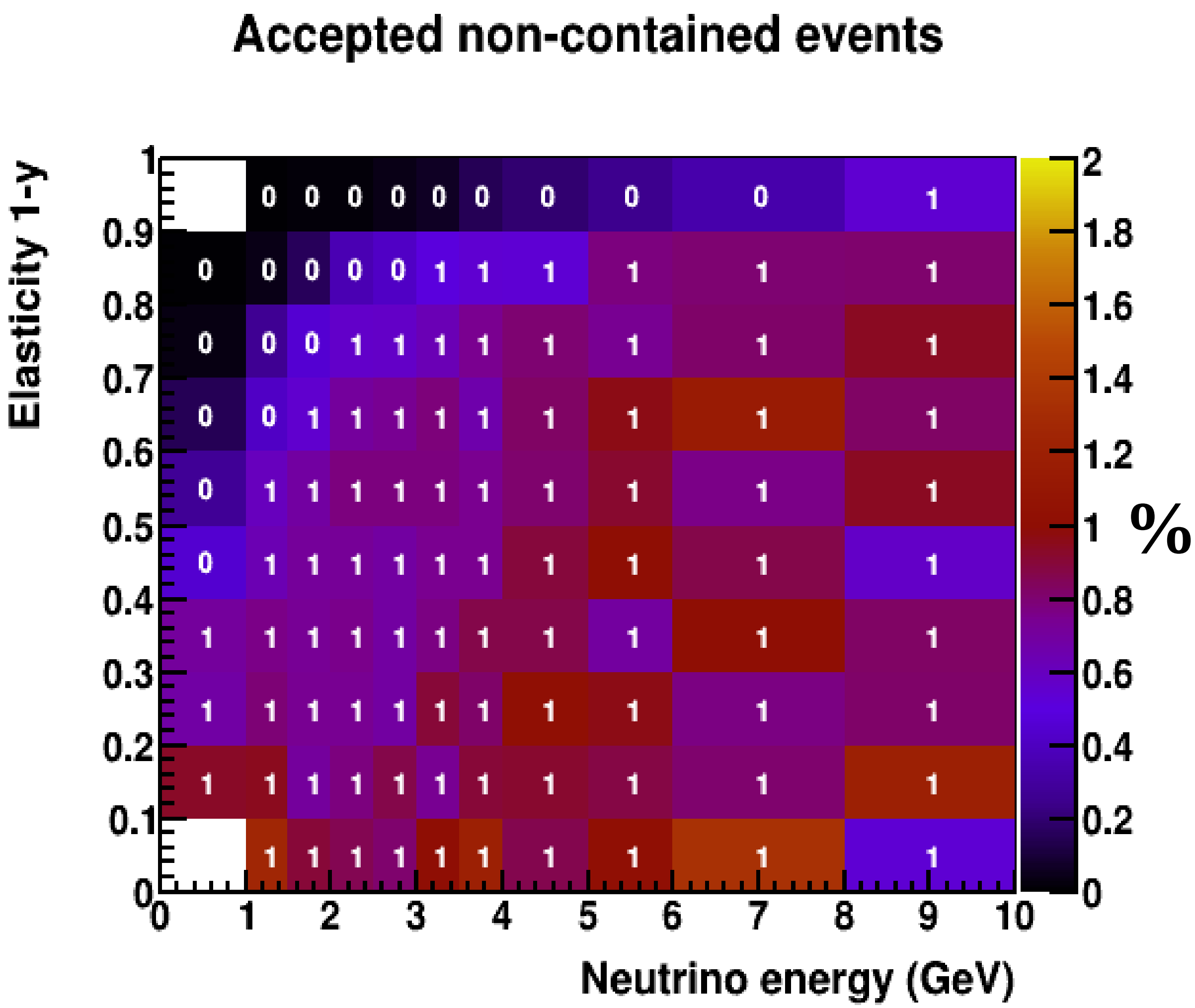
- 4m in longer transverse dimension is fine
- 5m in ~beam direction is fine
- 2.5m in shorter transverse dimension requires faith
- Extra 50cm is very beneficial – puts us in a regime where the acceptance is not rapidly changing with detector size

Size of hadronic showers simulated in G4



- In each E_ν-y bin, take distribution of size of hadronic shower in XYZ simulated in thousands of events
- Use this distribution as a proxy for the cross section, which depends on many variables (Q^2, N_π, E_π, N_p, N_n, etc.)

Containment cut purity



- Percent of events which have <20MeV in outer 30cm region, but have <95% hadronic energy contained in detector
- ~1% at high hadronic energy
- Not very sensitive to choice of 20MeV or 30cm
- Also looked at making this fractional to the visible energy in detector, negligible differences

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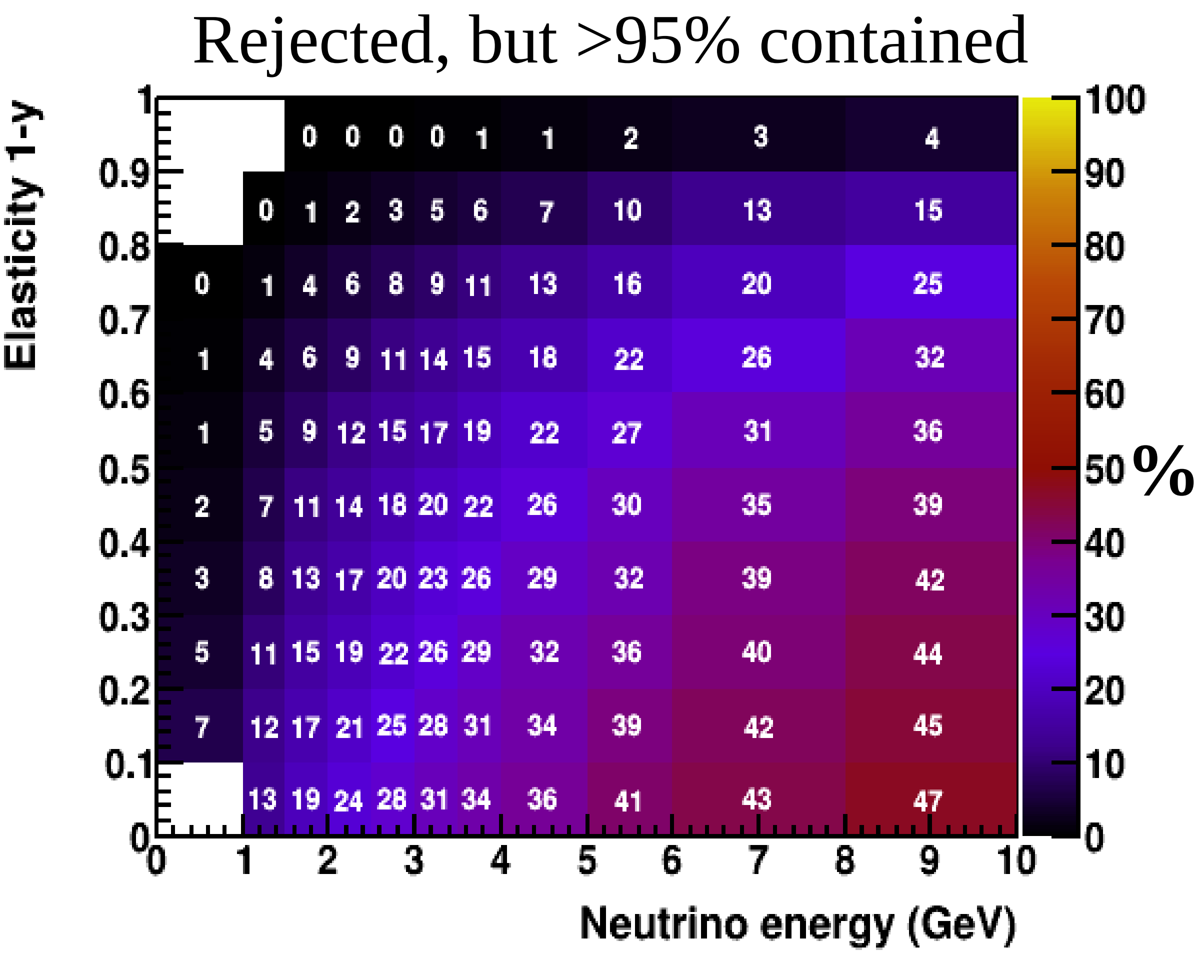
Containment cut inefficiency



- Percent of events which have >95% hadronic energy contained, but >20MeV in outer 30cm region
- Significant losses in very high hadronic energy, where events frequently "end" near the edge

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