MINERνA beam position

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Introduction

- We've seen the data/MC discrepancy in number of events *vs* E_ν. To discriminate between possible causes, we want other handles
- If beam focusing or detector position is at fault, a useful handle might be beam position, as measured by vertex position in the detector
- The strategy here is to just describe the data and MC (and any difference). I haven't made any attempt to explain what I see in terms of beam focusing or detector position
  - But we'd know what to look for in shifted MC samples, say

Sample

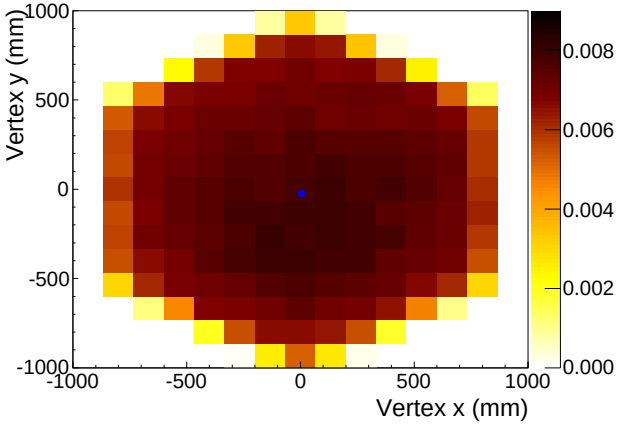
- Select ν_μ CC events in the MINERνA scintillator tracker fiducial volume (ν_μ CC = has MINOS-matched track)
- Using data from Sep 2013 to Jun 2015 (excluding special runs)
  - In MINERνA jargon: minervame1A–F
- Using a software version which doesn't have our best available simulation of intensity effects (v10r8p6)
- POT counts: MC 8e20; Data 4.9e20

Vertex position distributions

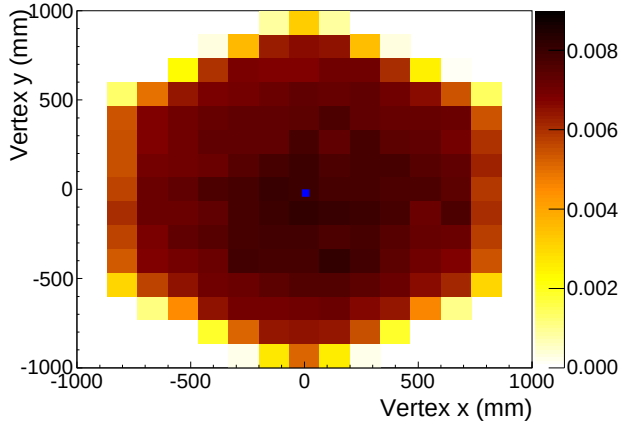
- The following plots show the vertex position distributions in data and MC, in fairly wide bins of E_ν
- y is really $y + \sin(3.3^\circ) * (z - z_0)$ to correct for beam angle
- I've area-normalized each one, and also show the ratio
- Each plot has a blue dot that shows the mean position
- The point is to show that the beam moves around in data and MC with energy. Detailed analysis comes later

Vertex positions, $E_\nu < 5$ GeV

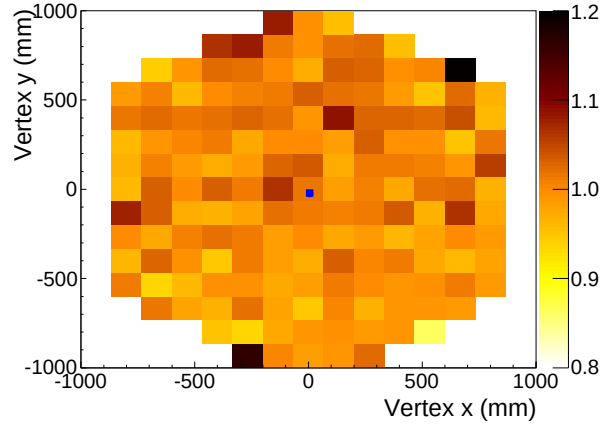
MC



Data

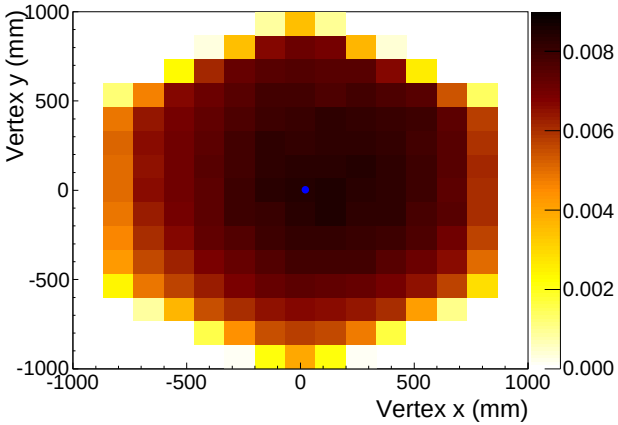


Data/MC

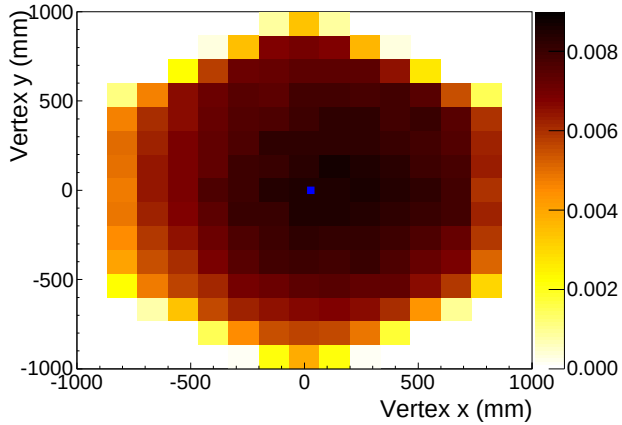


Vertex positions, $5 < E_\nu < 7.5$ GeV

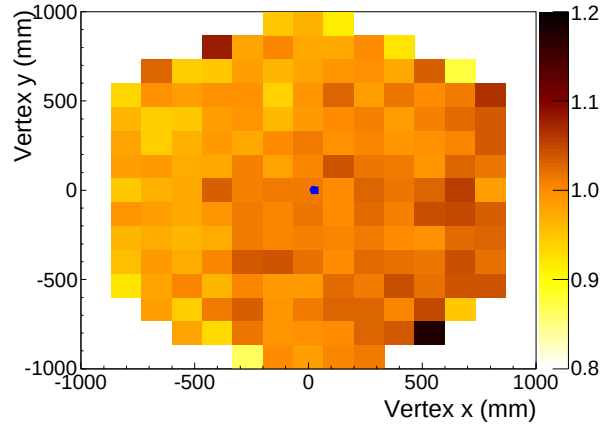
MC



Data

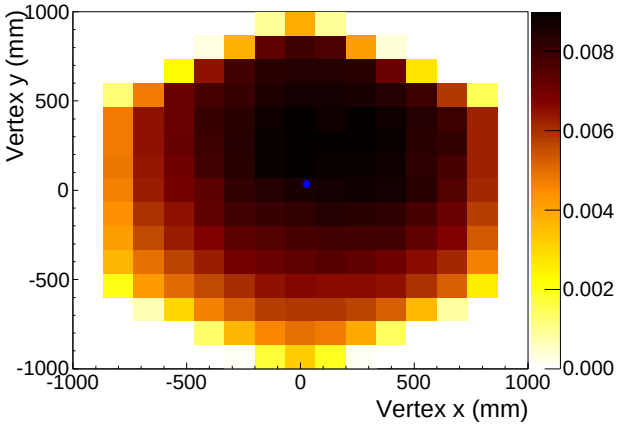


Data/MC



Vertex positions, $7.5 < E_\nu < 11$ GeV

MC



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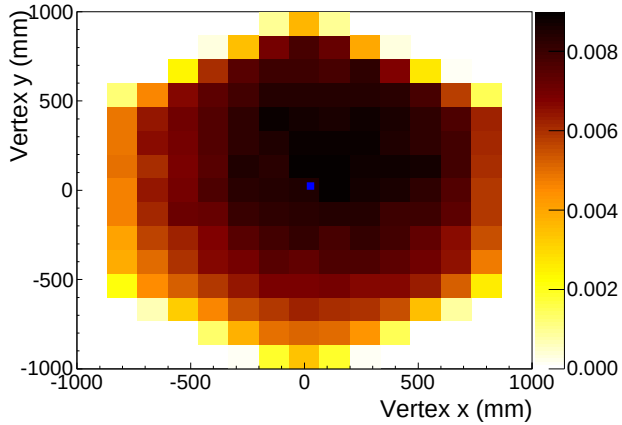
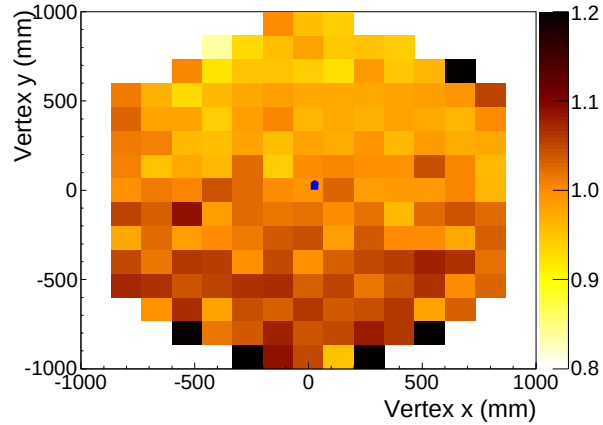
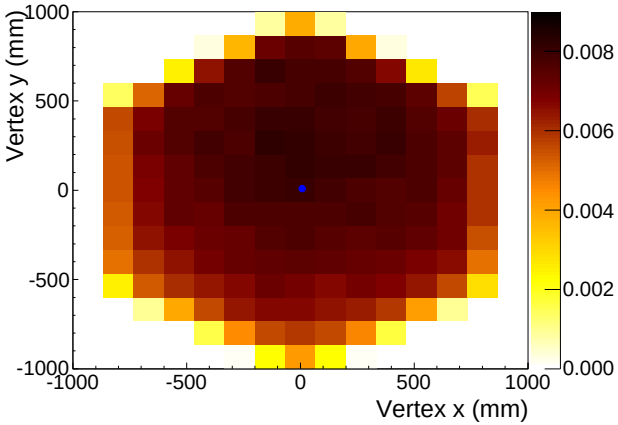


Data/MC

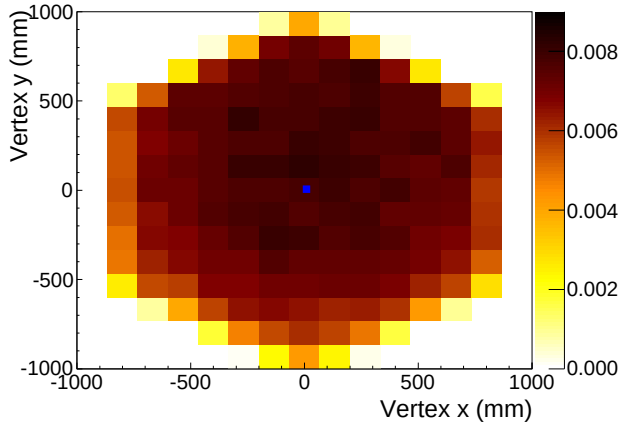


Vertex positions, $E_\nu > 11$ GeV

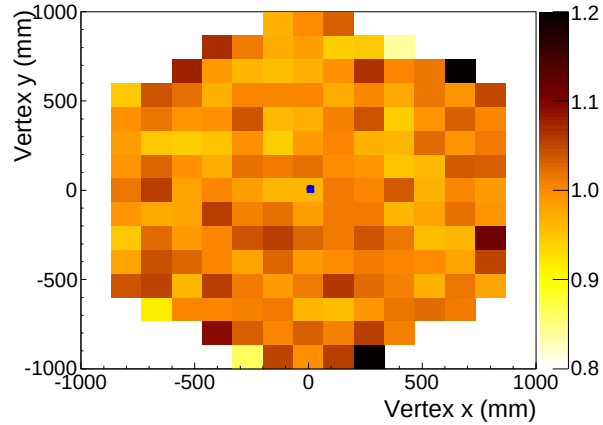
MC



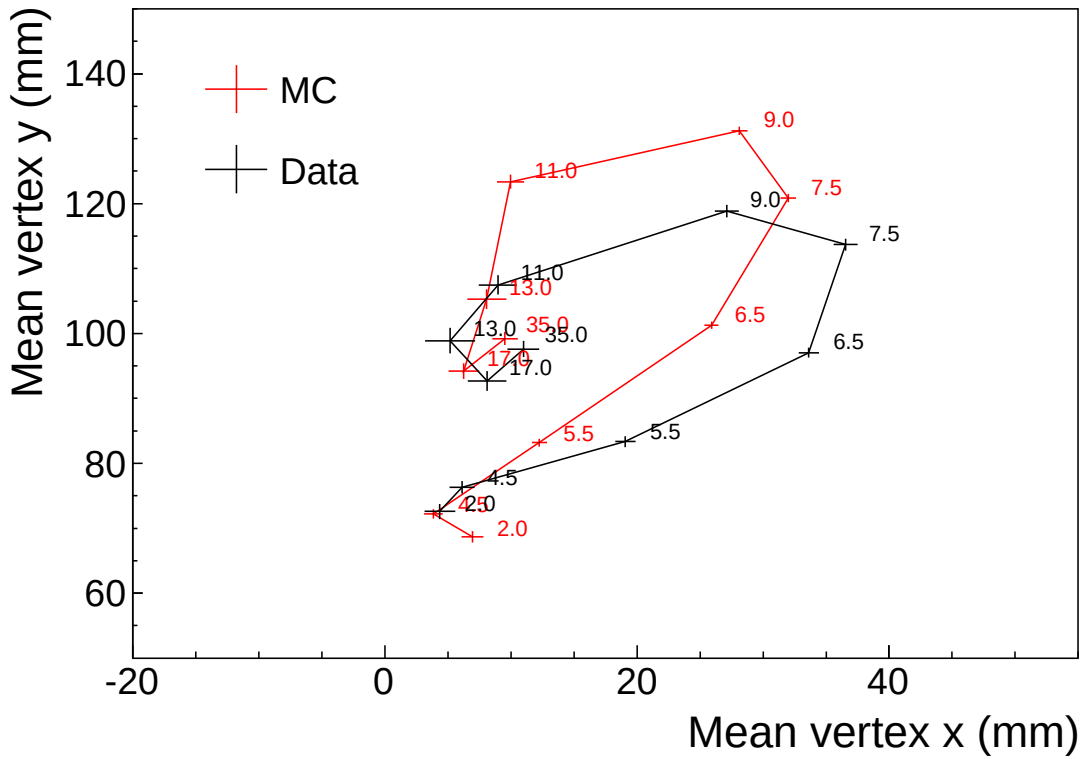
Data



Data/MC

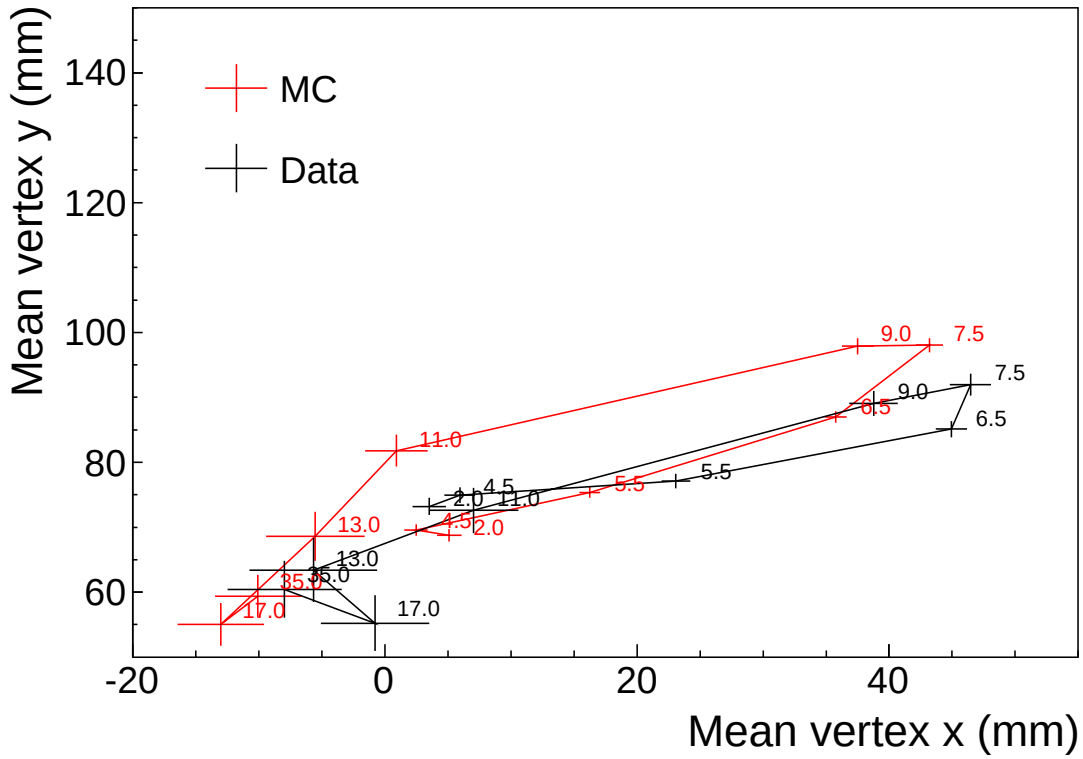


Mean vertex position as a function of energy



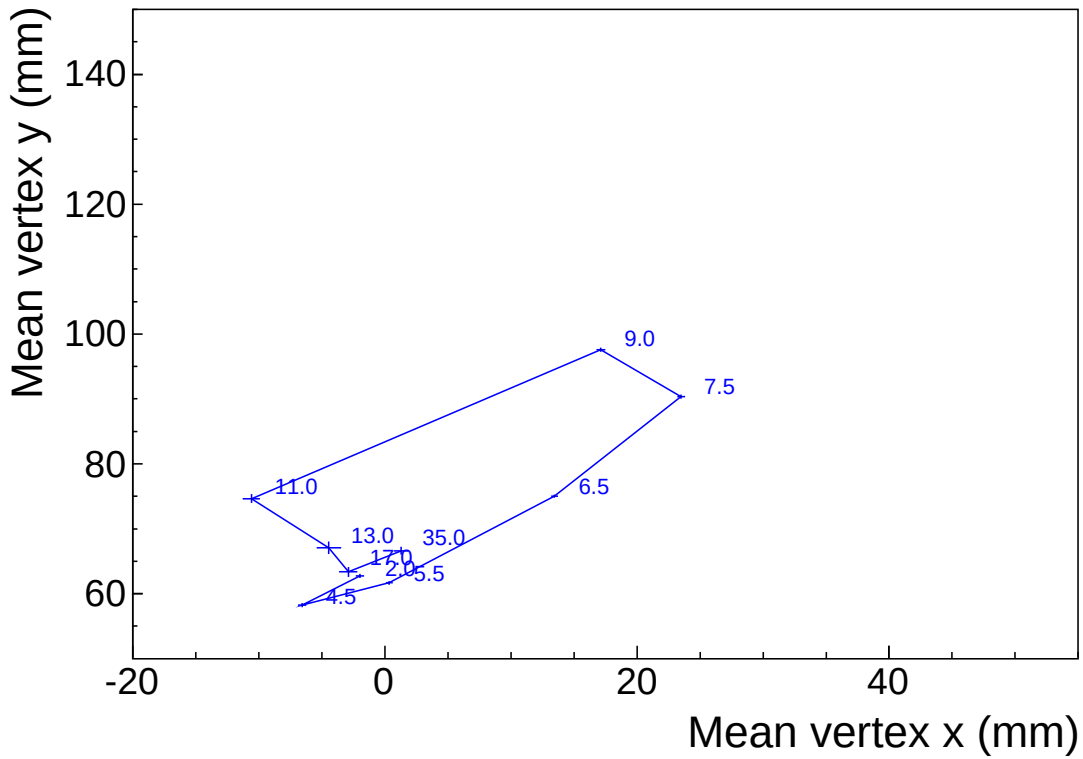
- Plot shows the mean vertex (x, y) as a function of E_ν (in narrower bins of E_ν than I showed on the previous slides)
- The text labels show the E_ν bin center in GeV
- Taking the mean suppresses the size of the effect, because the mean is taken over events in the fiducial volume
  - Alternatively, can fit a 2D Gaussian to the vertex distribution and plot its mean: that's in the backups, and is basically consistent with this plot

Mean vertex position as a function of energy: $\nu < 1\,\text{GeV}$



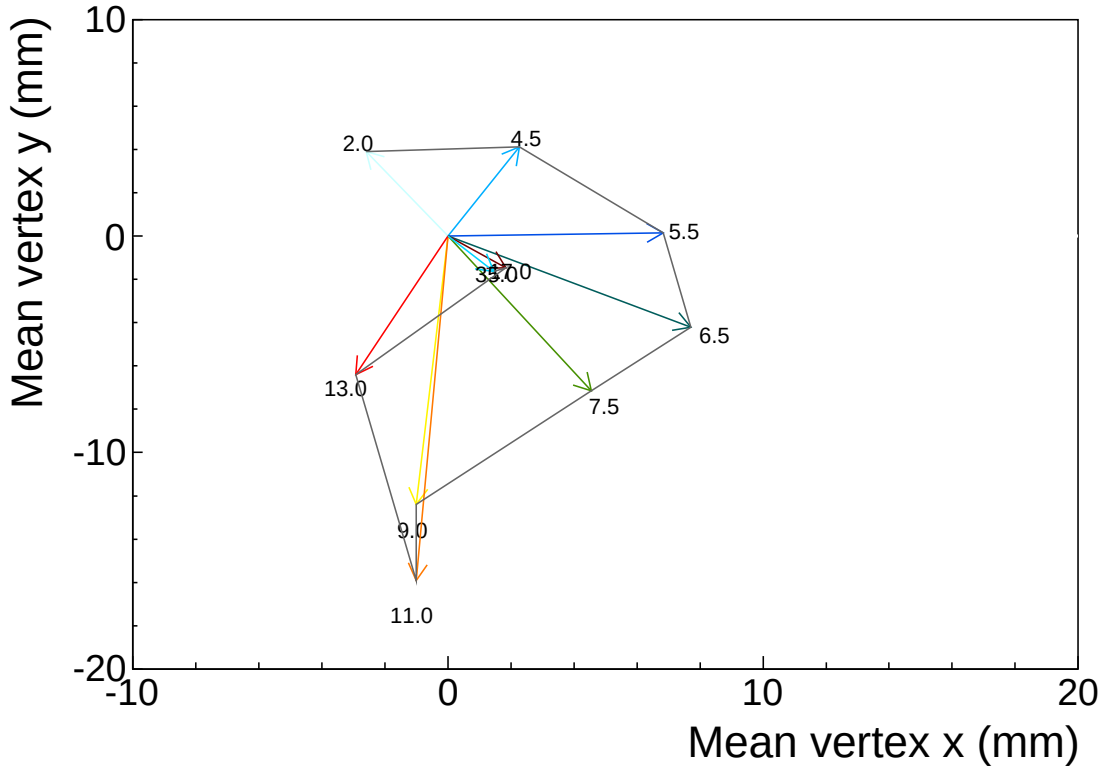
- But you might worry that vertex bias in high-recoil events is screwing this up, so do the same for events with reco $\nu < 1\,\text{GeV}$.
- Similar pattern of data/MC *difference*
- We'll look at the difference soon, but first I worried that this weird pattern of mean (x, y) is a reco/selection artifact...

Mean vertex position as a function of energy: truth



- So instead, loop through all genie generated events (even those not reconstructed) and select all events in the FV. Plot their true ($vtxx$, $vtxy$) in bins of true E_ν and make the same plot
- Similar shape, so it really is the beam that causes the vertex position to move around. But I don't know why

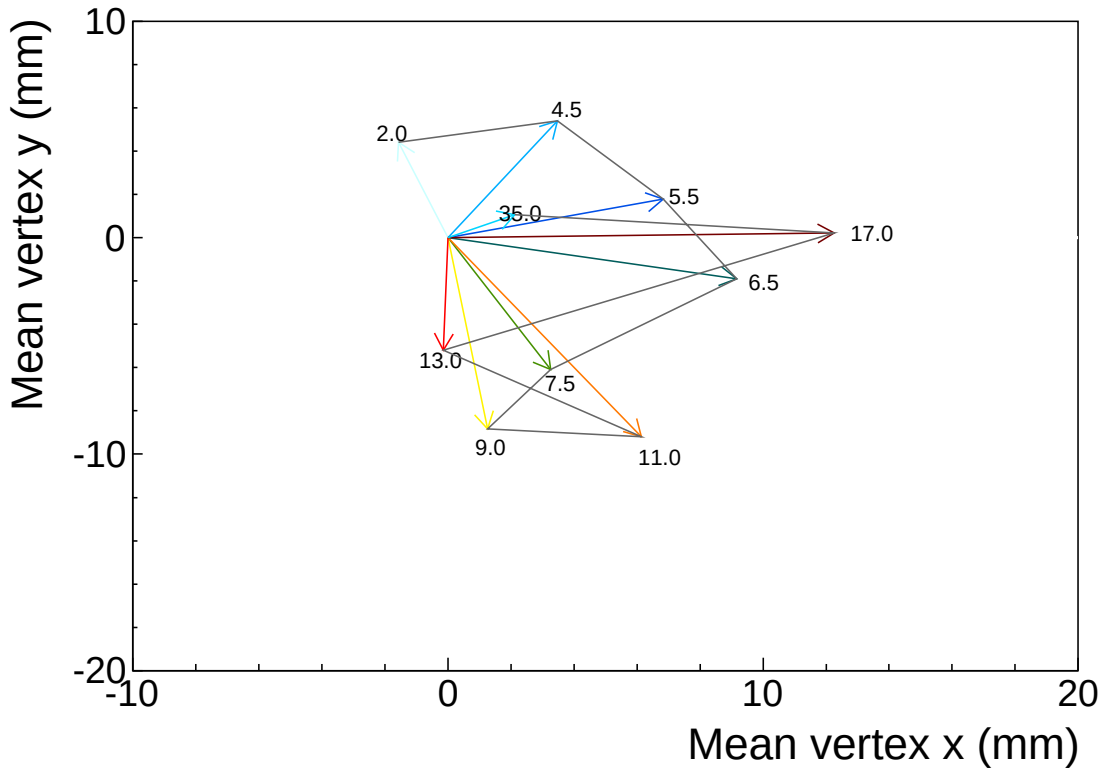
Data/MC vertex position *differences*



Axes mislabeled: should be "Data mean x - MC mean x" and similarly for y

- Back to the reco vertex position for selected events
- In each energy bin, find (mean x data) − (mean x MC) and similarly for y, and use them to form a vector
- I tried joining the tips of the arrows together with grey lines so you can follow the progression with energy. There really is one

Data/MC vertex position *differences*



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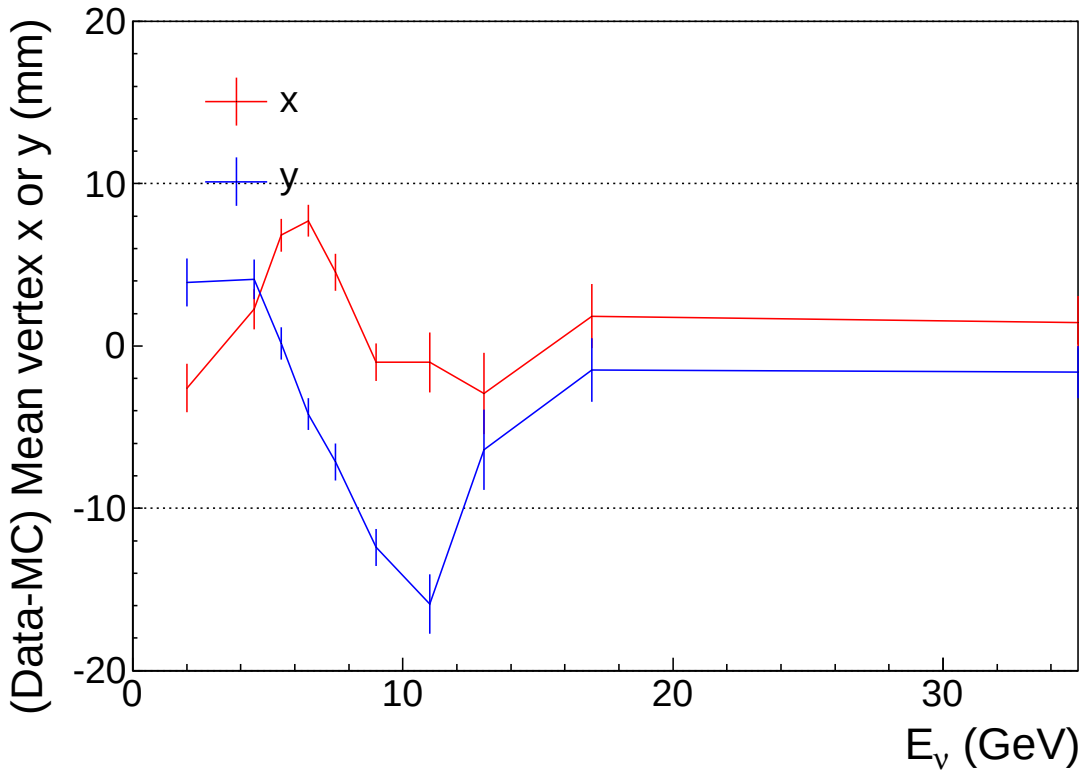
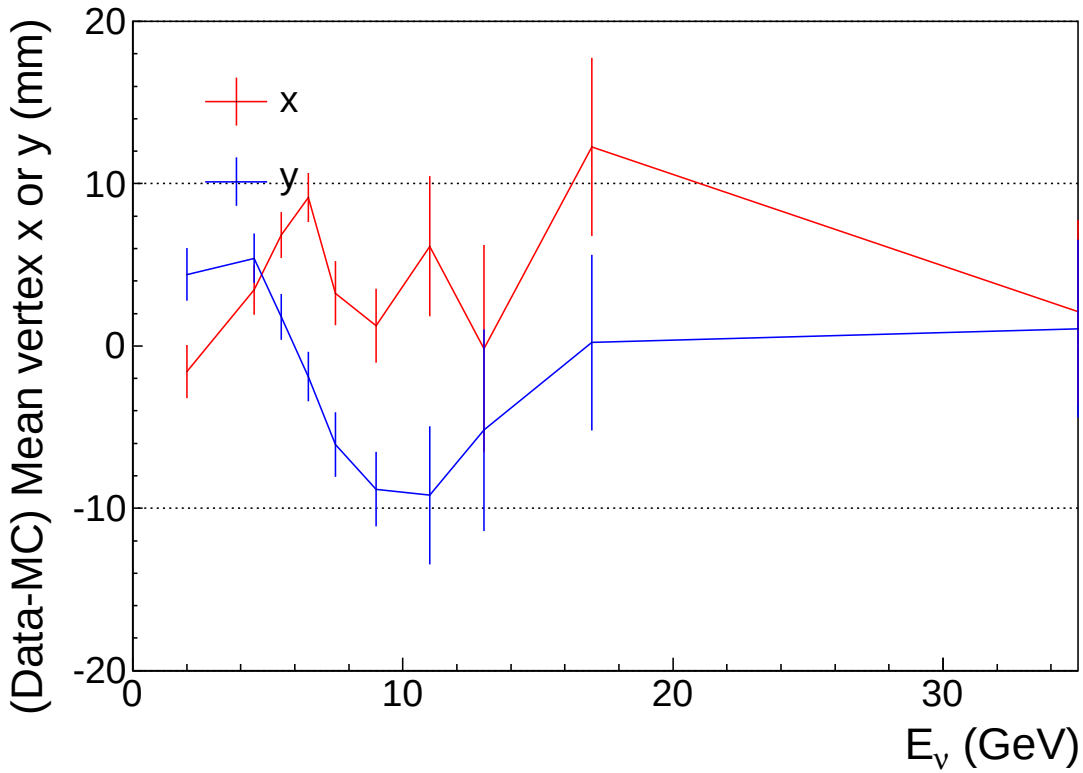
- Here's the same for $\nu < 1\,\text{GeV}$
- A little hard to see, but it's the same pattern until about 10 GeV
- Couldn't think of a way to show errors on this plot

Data/MC difference in x and y



- If you found the previous plot too clever by half, here is the data mean minus MC mean for x and y as a function of energy
- It's easier to see, but is arguably a little misleading since maybe the issue we're looking for isn't in x and y but in x' and y', rotated about the beam axis

Data/MC difference in x and y: $\nu < 1\,\mathrm{GeV}$



- Same for $\nu < 1\,\mathrm{GeV}$. Consistent with inclusive sample

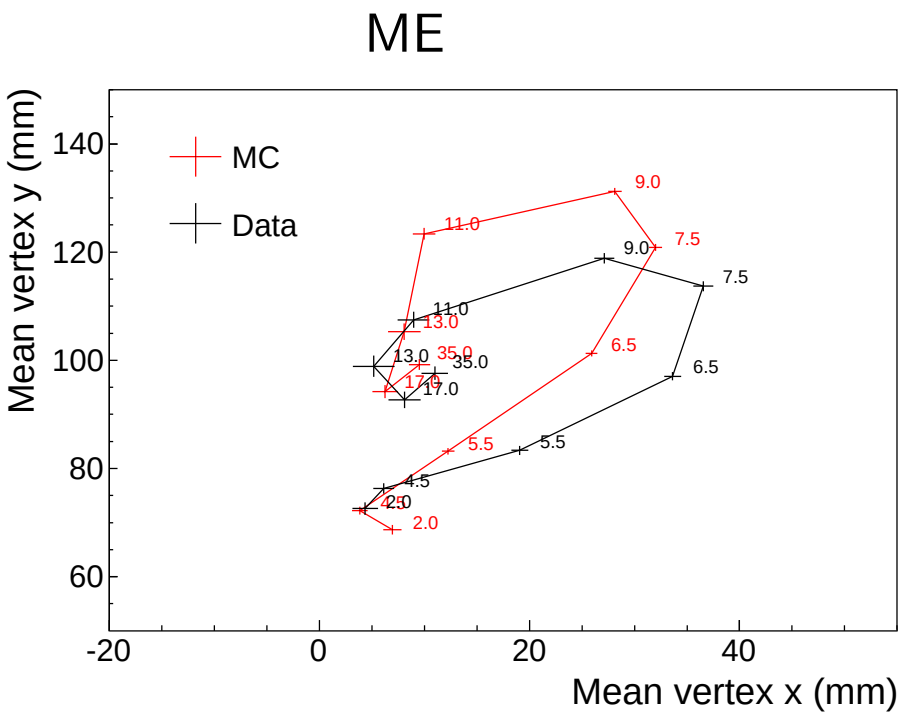
Conclusions

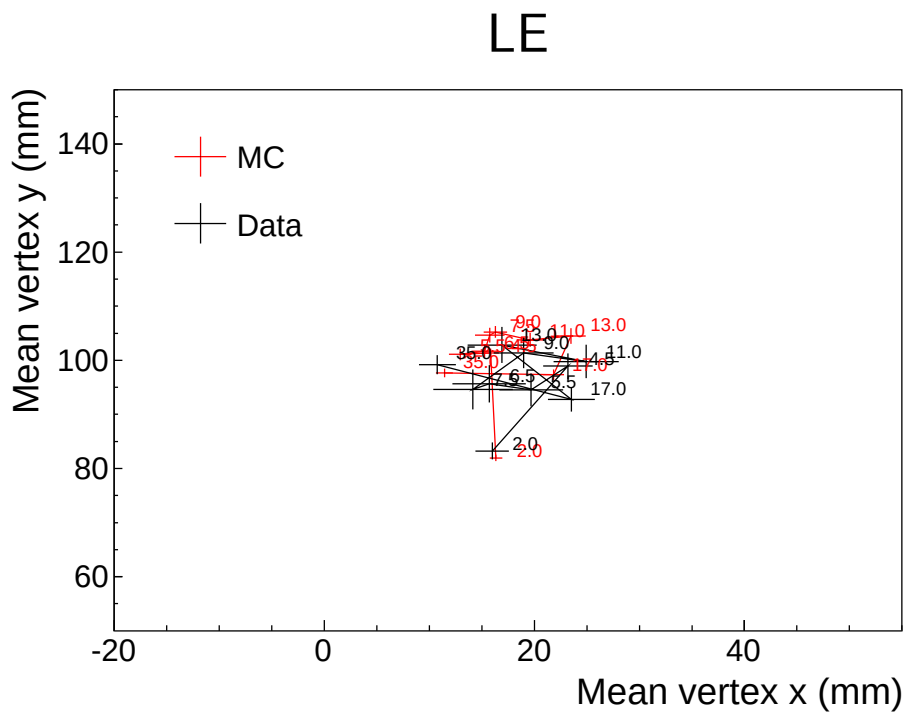
- Evidence for an energy-dependent data/MC difference in event vertex position
  - The data/MC difference "rotates" with energy, and seems robust to a change in the sample selection
- Needs to be compared with shifted MC to do any real interpretation
- (Further studies in backups: use fit instead of mean; do same analysis for LE; plot 1D data/MC position ratios in bins of E_ν)

Backup slides

Compare to the same thing in LE beam, as suggested by Debbie

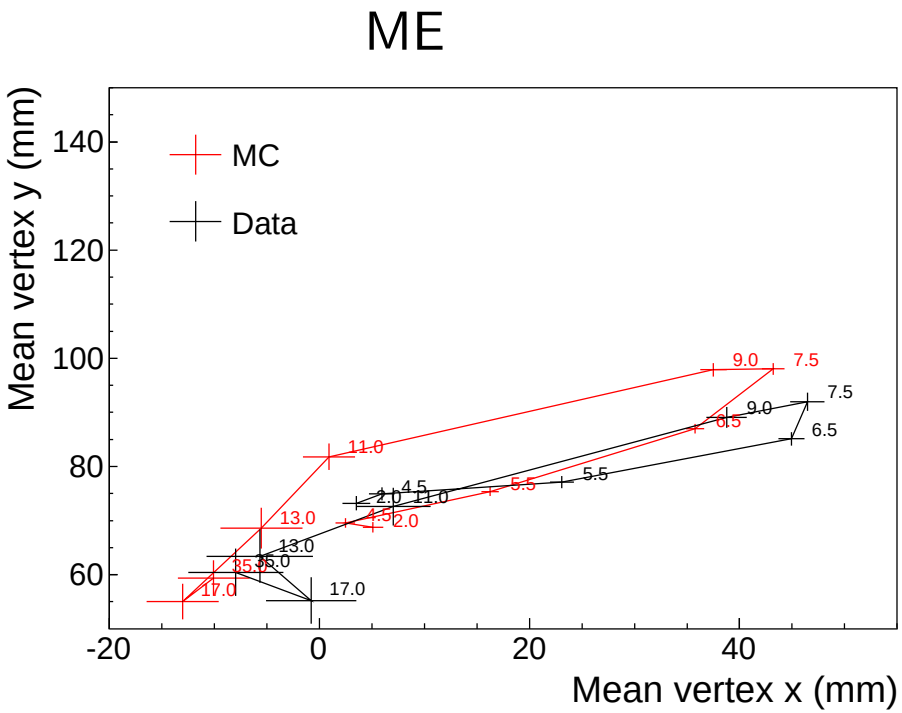
Mean vertex position as a function of energy: LE vs ME

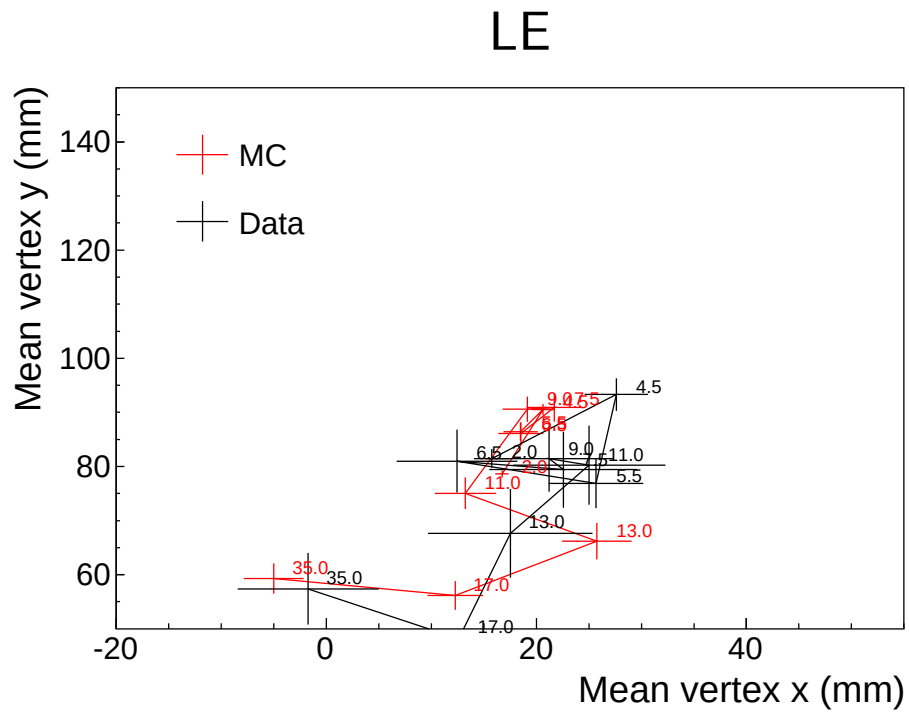




- Make the 2D (vtxx, vtxy) plot in bins of energy. For each one, calculate the mean position in x and y, for data and MC (vtxy is really $y + \sin(3.3^\circ) * (z - z_0)$ to correct for beam angle)
- Now plot all of those means on one plot. The text labels show the E_ν bin center in GeV.

Mean vertex position as a function of energy: $\nu < 1\,\text{GeV}$: LE vs ME





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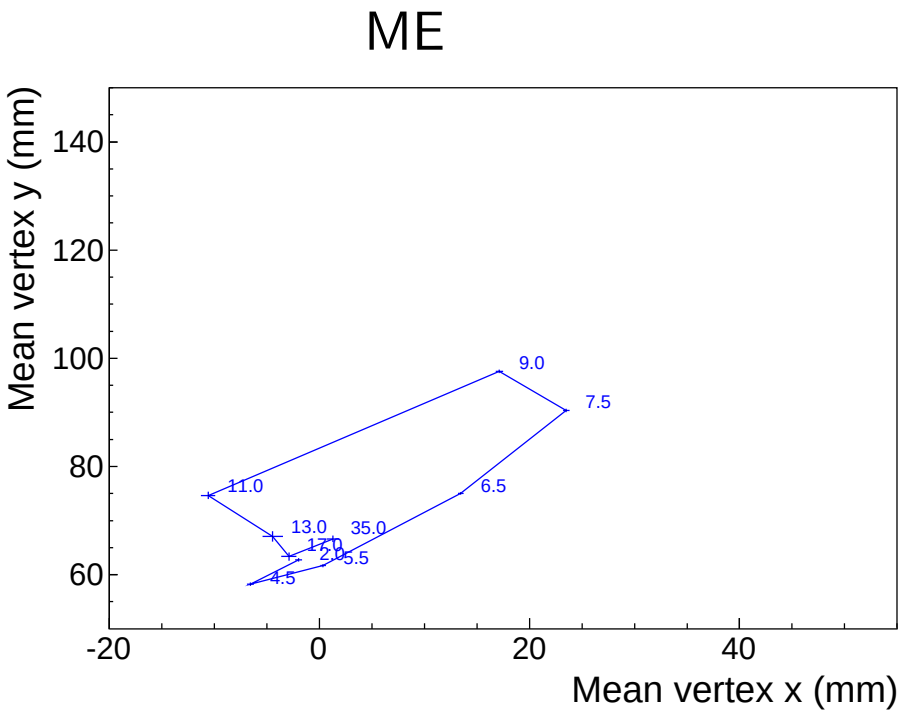
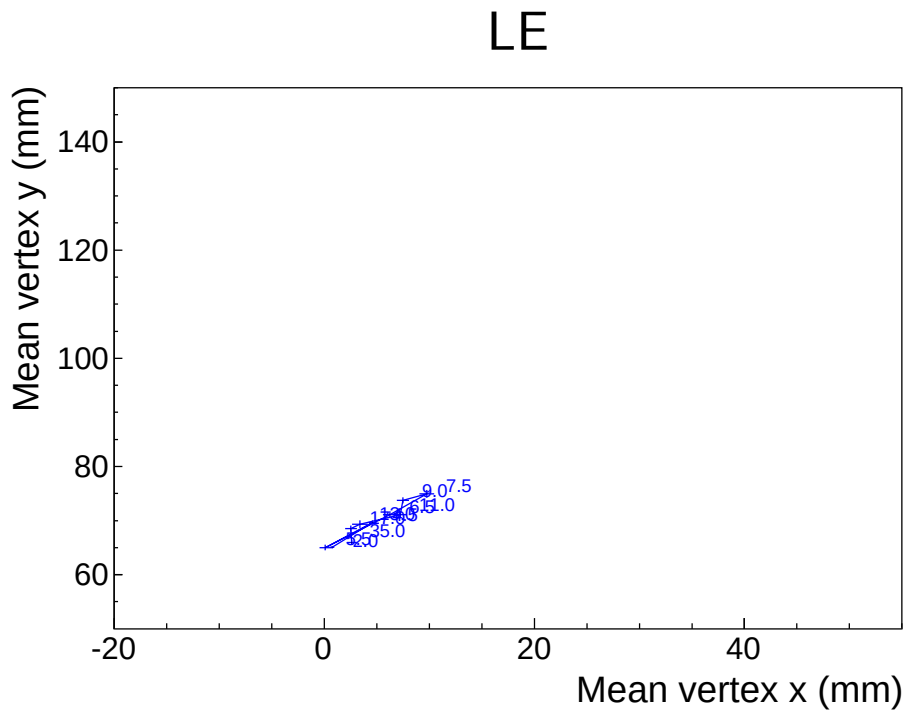
- Similar pattern of data/MC *difference*
- We'll look at the difference soon, but first I worried that this weird pattern of mean (x, y) is a reco/selection artifact...

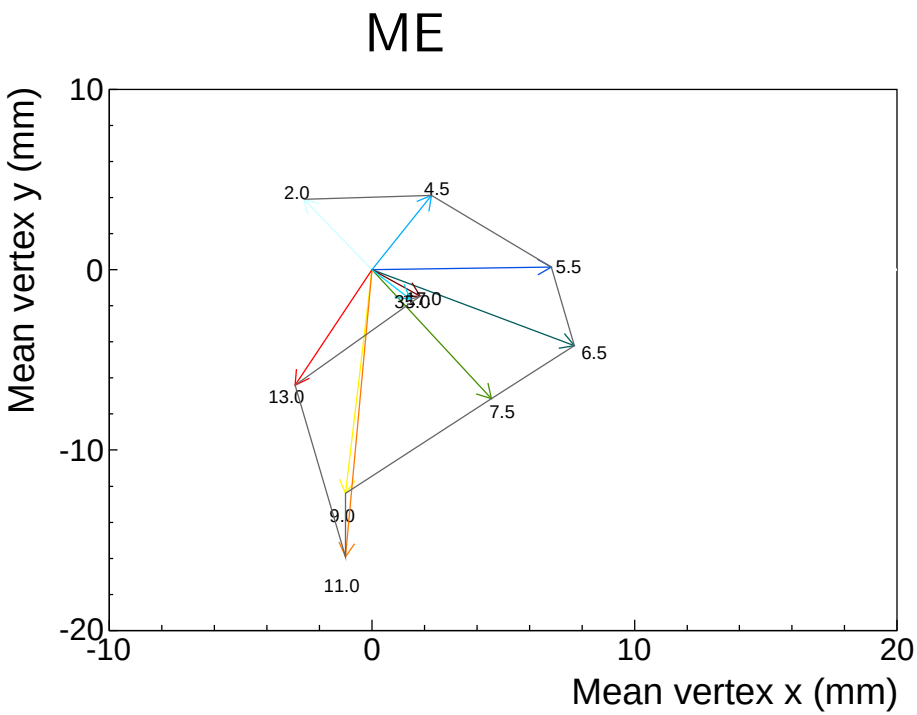
Mean vertex position as a function of energy: truth: LE vs ME

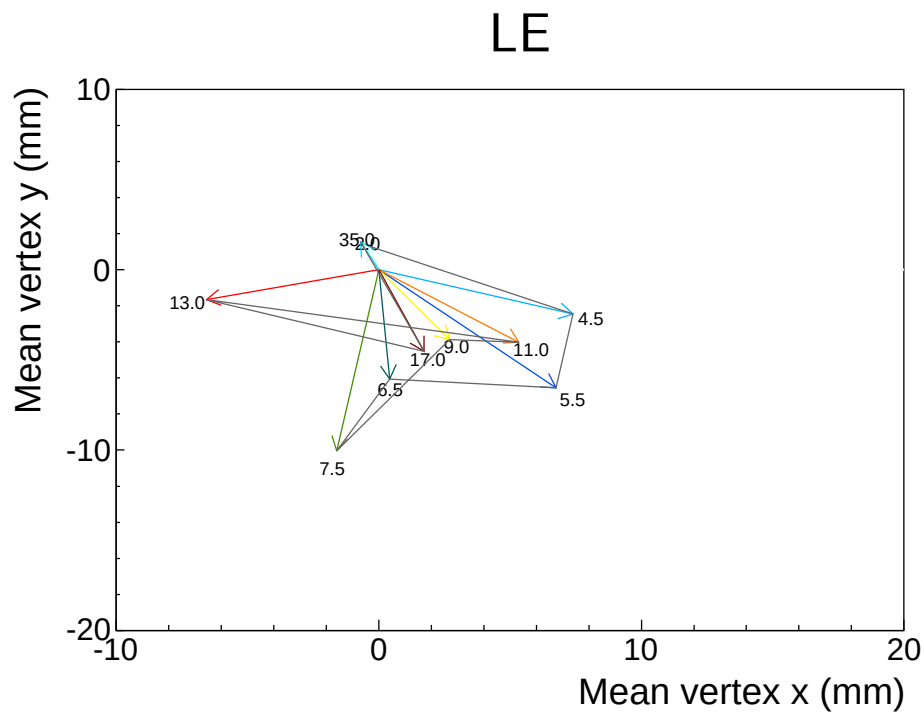




- So instead, loop through the Truth tree (ie all genie generated events) and select all events in the FV. Plot their true ($vtxx, vtxy$) in bins of true E_ν and make the same plot
- Similar shape.

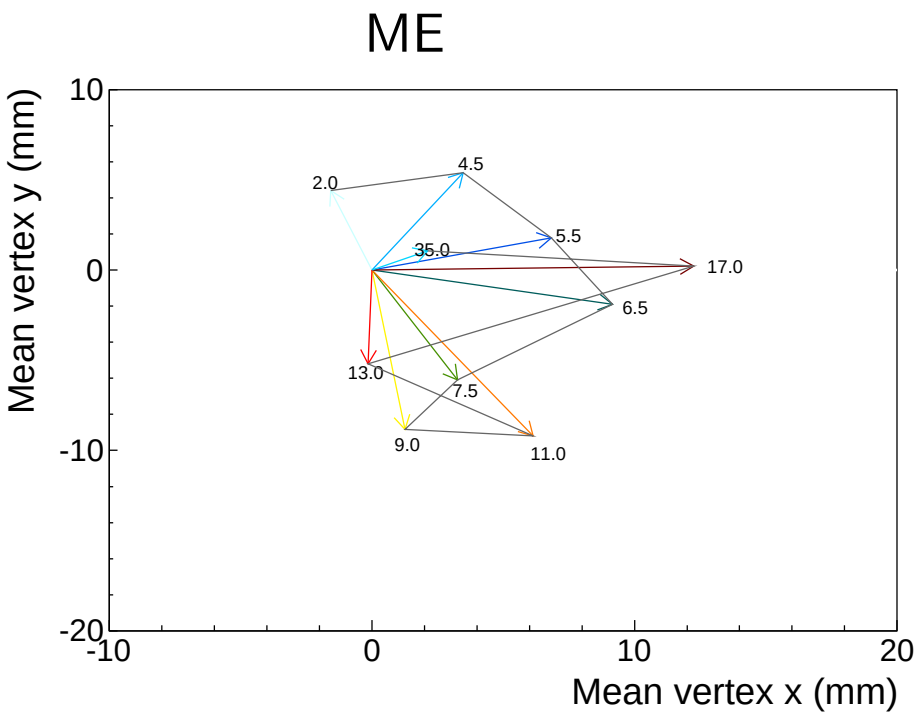
Data/MC vertex position *differences*: LE vs ME

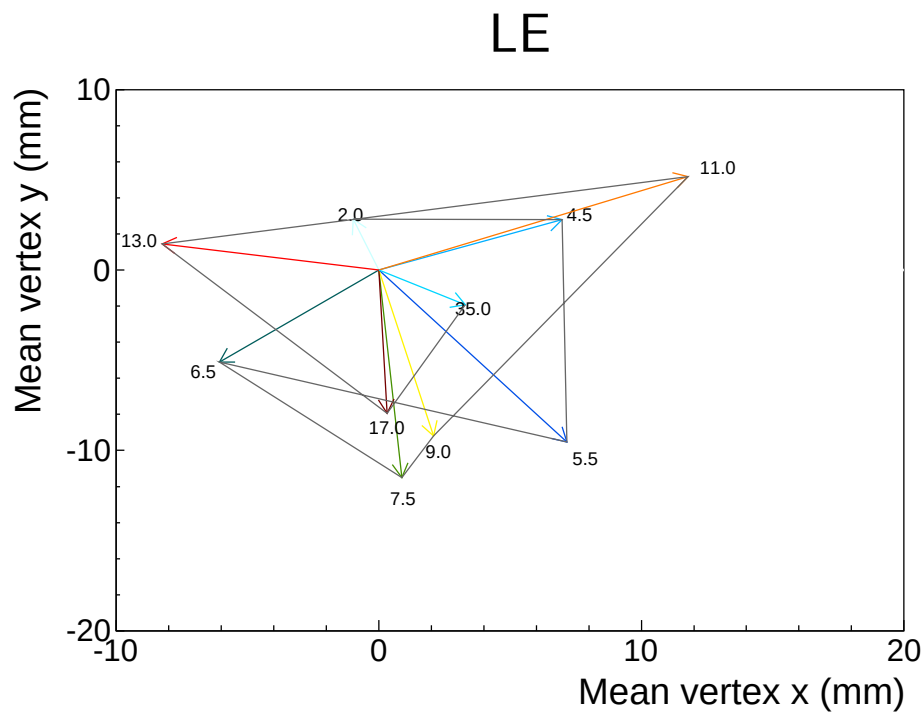




- In each energy bin, find (mean x data) – (mean x MC) and similarly for y, and use them to form a vector
- It looks like the deviation is in the same direction for a given "point" on the focusing peak, maybe. A clue?
- I think we did have a similar data/MC ratio in the focusing peak in LE, right? Cheryl's plots show one, but that's RHC

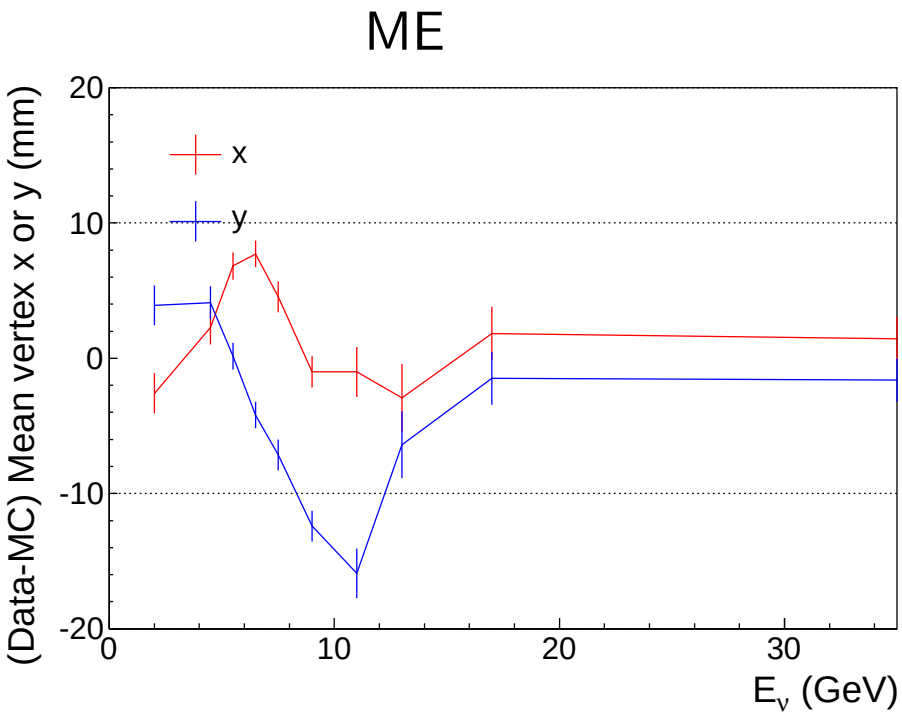
Data/MC vertex position *differences*: LE vs ME

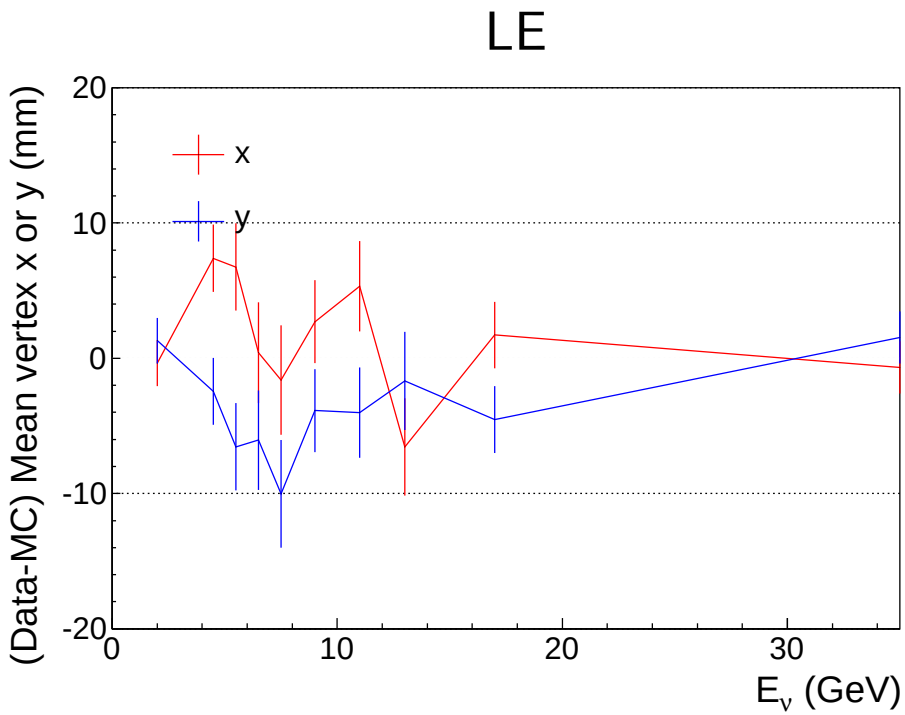




- Here's the same for $\nu < 1\,\text{GeV}$
- A little hard to see, but it's the same pattern until about 10 GeV
- Couldn't think of a way to show errors on this plot

Data/MC difference in x and y: LE vs ME





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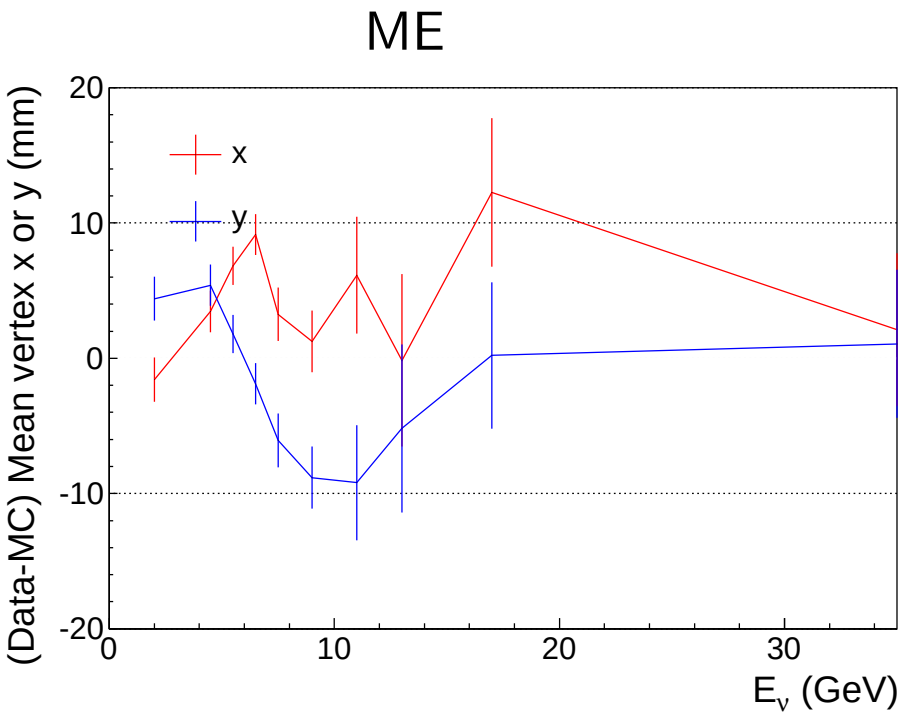
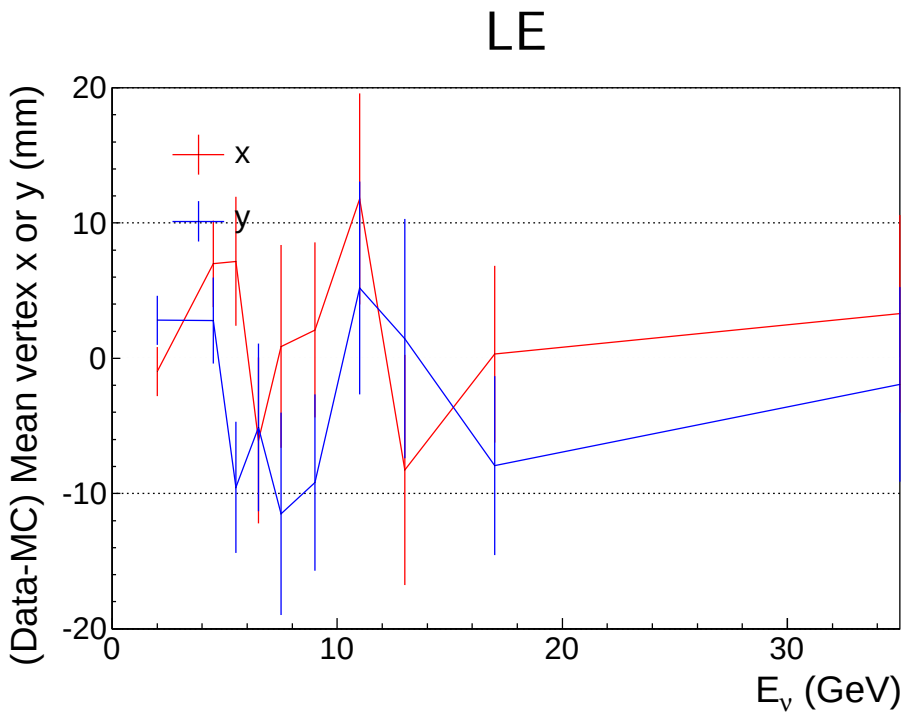
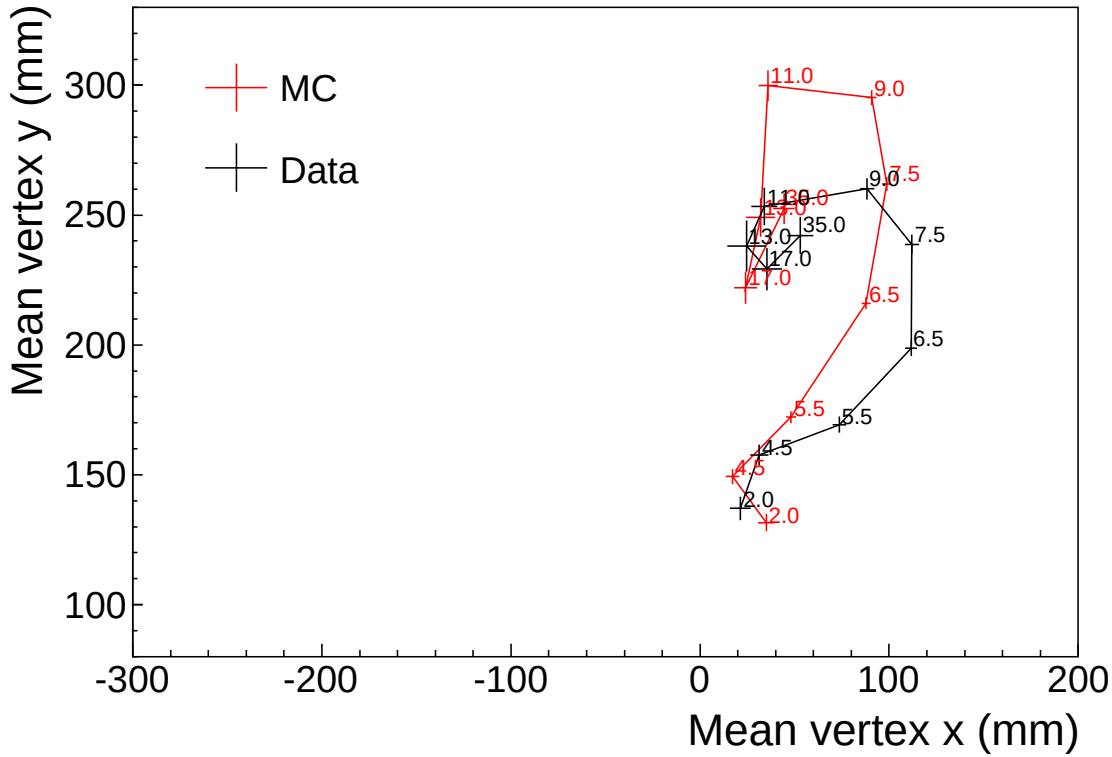




- Same for $\nu < 1\,\mathrm{GeV}$

Back to ME beam from here on

Mean vertex position as a function of energy. From fit



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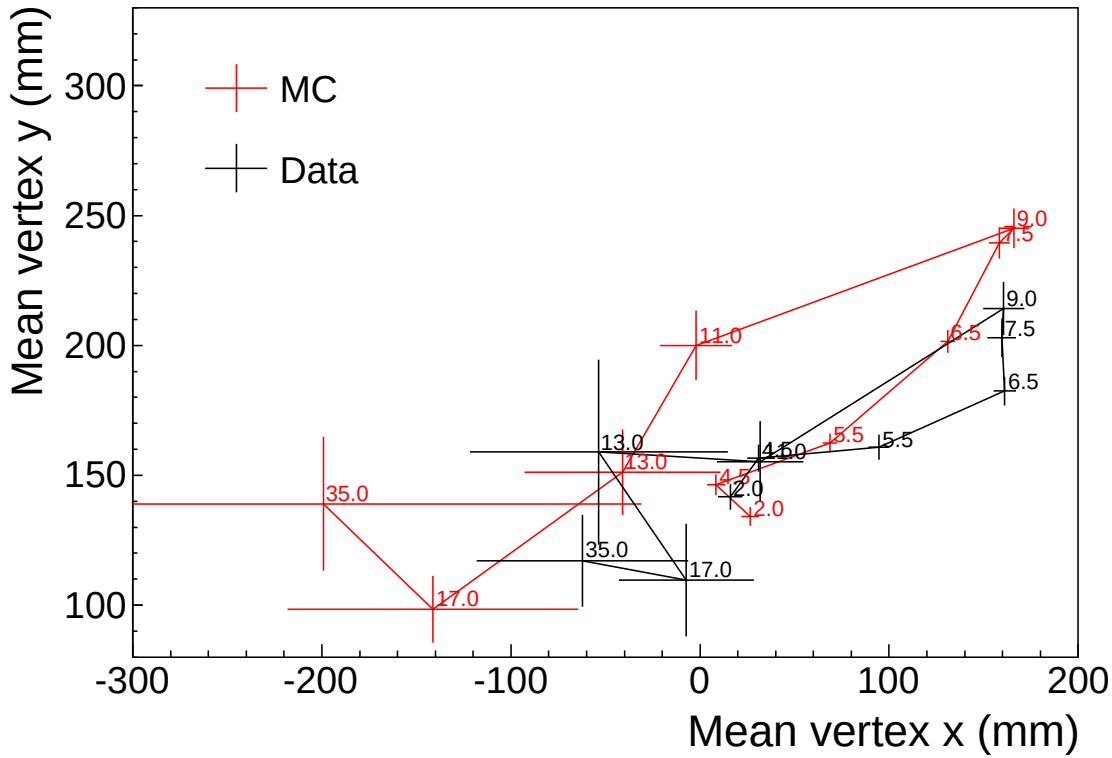

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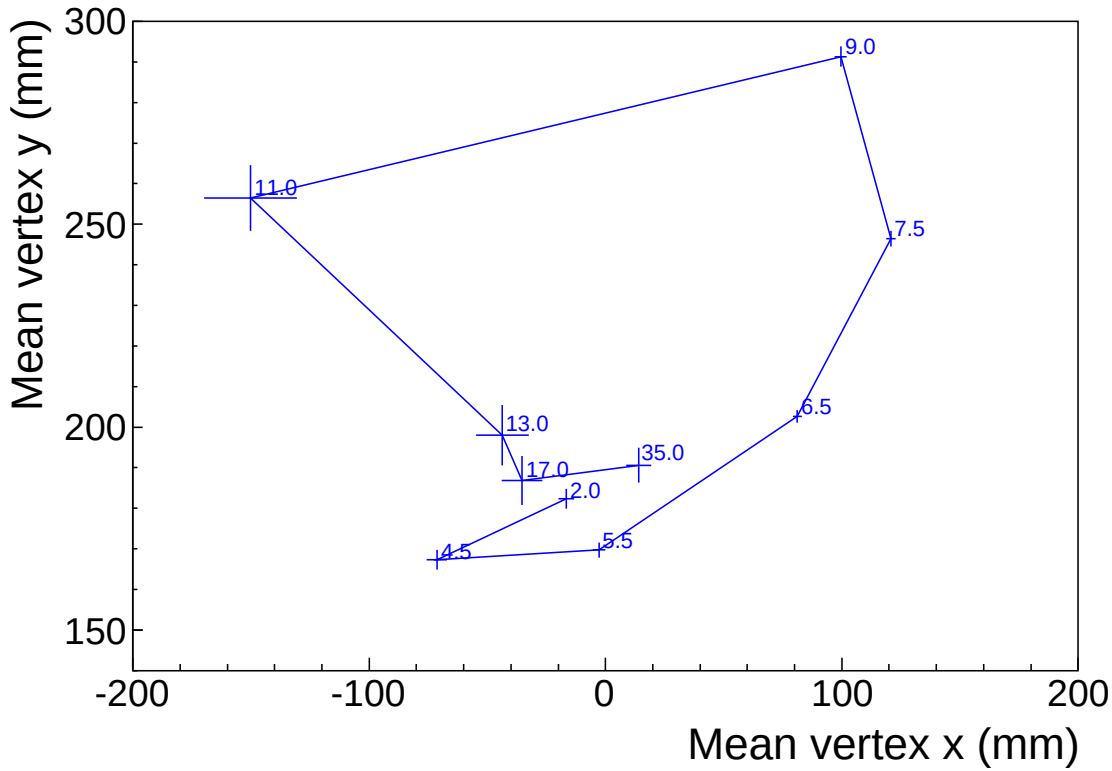
Mean vertex position as a function of energy: truth. From fit



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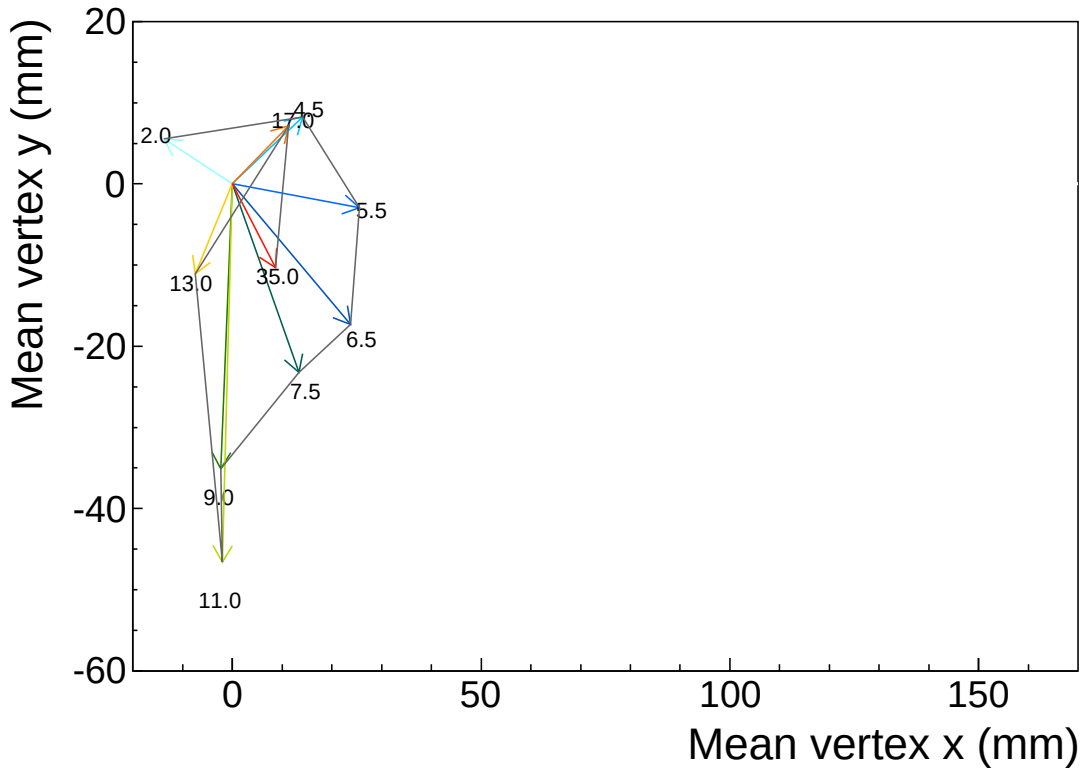
- Similar shape.

Data/MC vertex position *differences*. From fit



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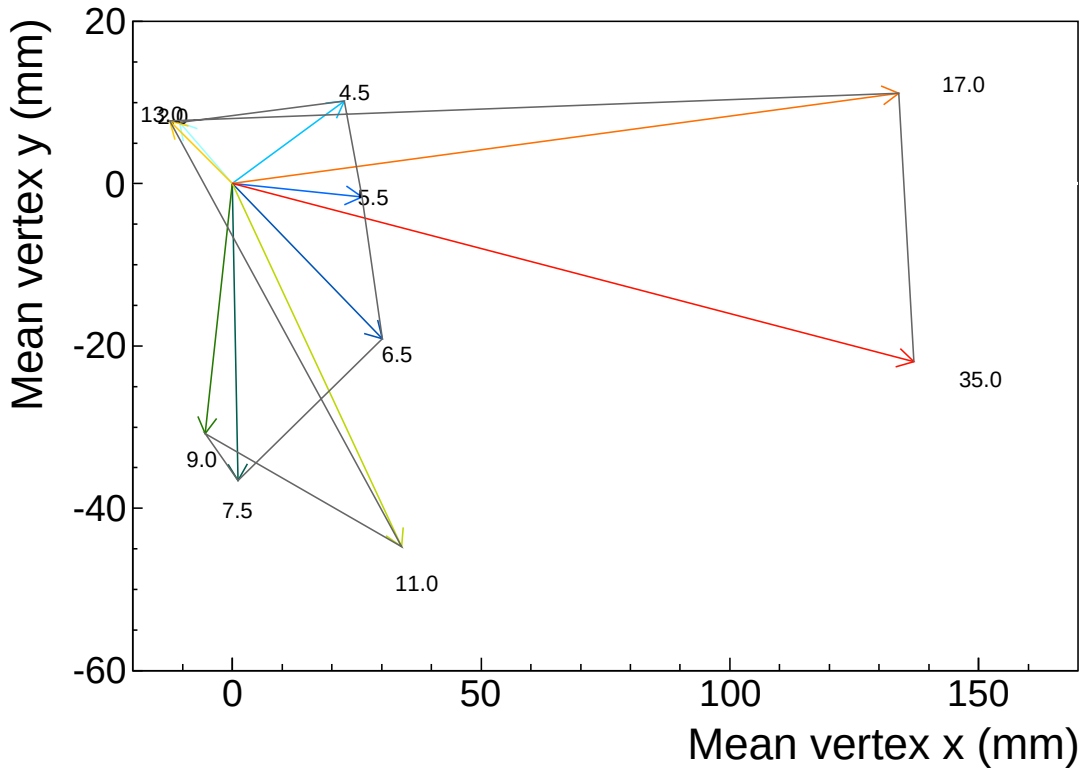

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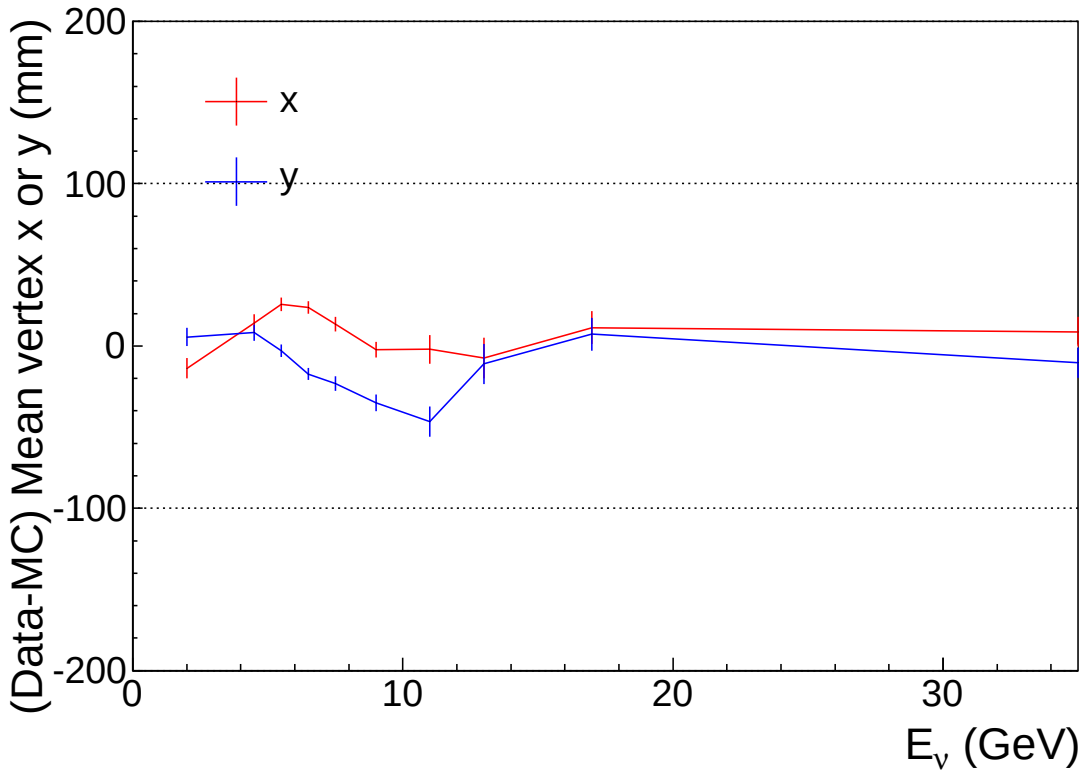

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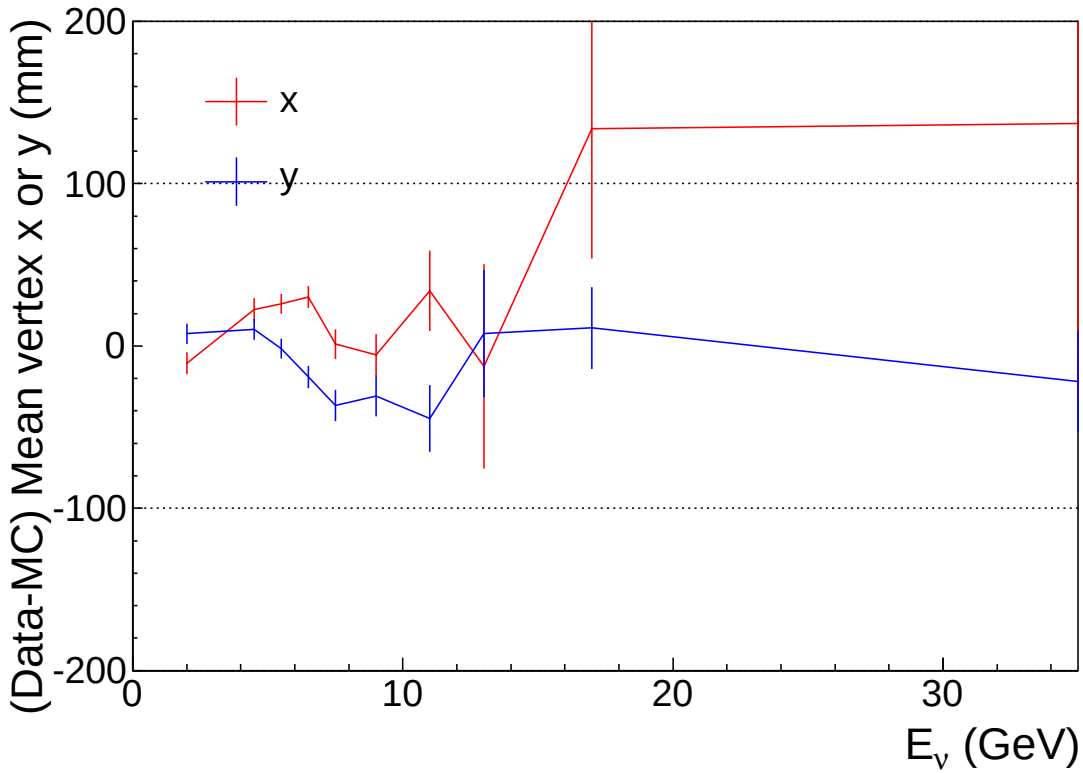
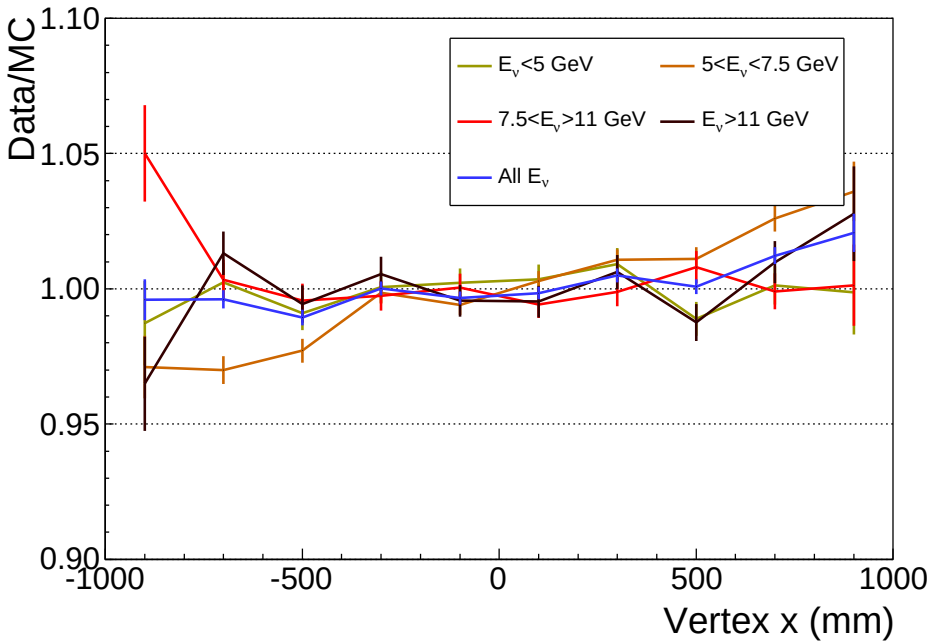
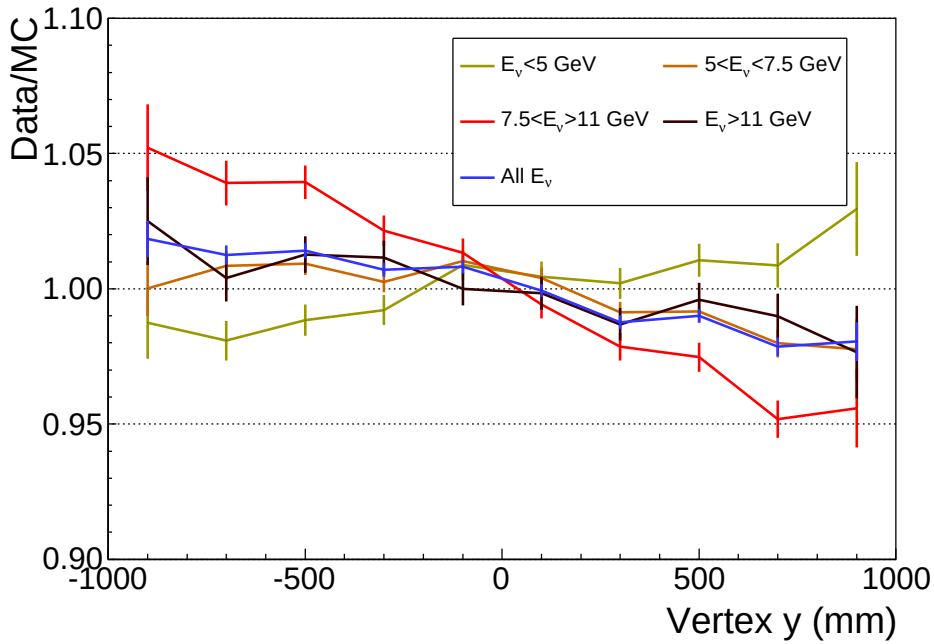
Data/MC difference in x and y: $\nu < 1\,\mathrm{GeV}$. From fit



- Same for $\nu < 1\,\mathrm{GeV}$

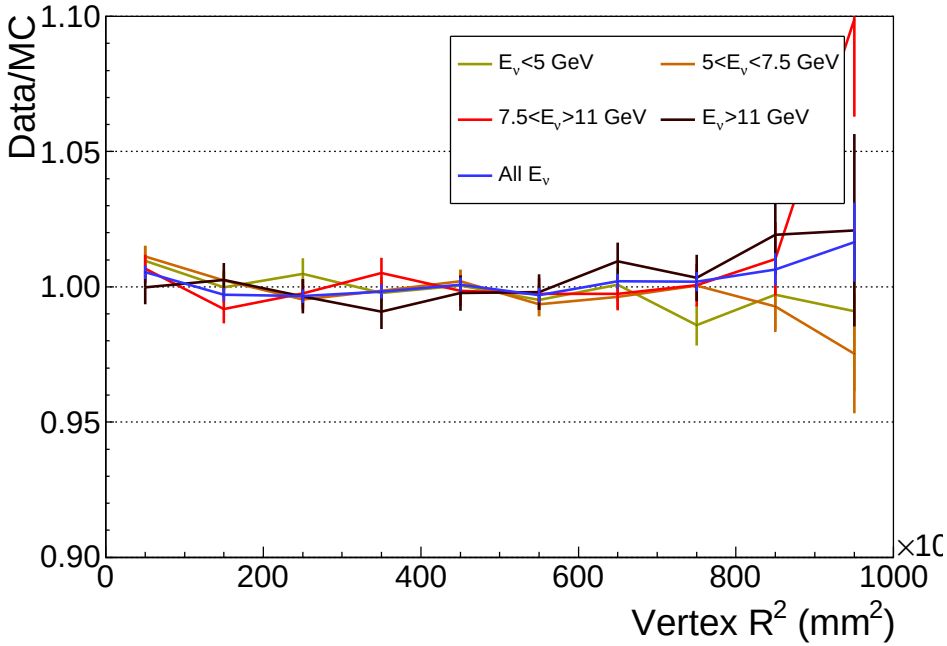
Data/MC ratios in vertex x and y





- Make data and MC plots of vertex x or y. Area-normalize each then take the ratio
- Clear difference in y, not so clear in x

Data/MC ratios in vertex r^2

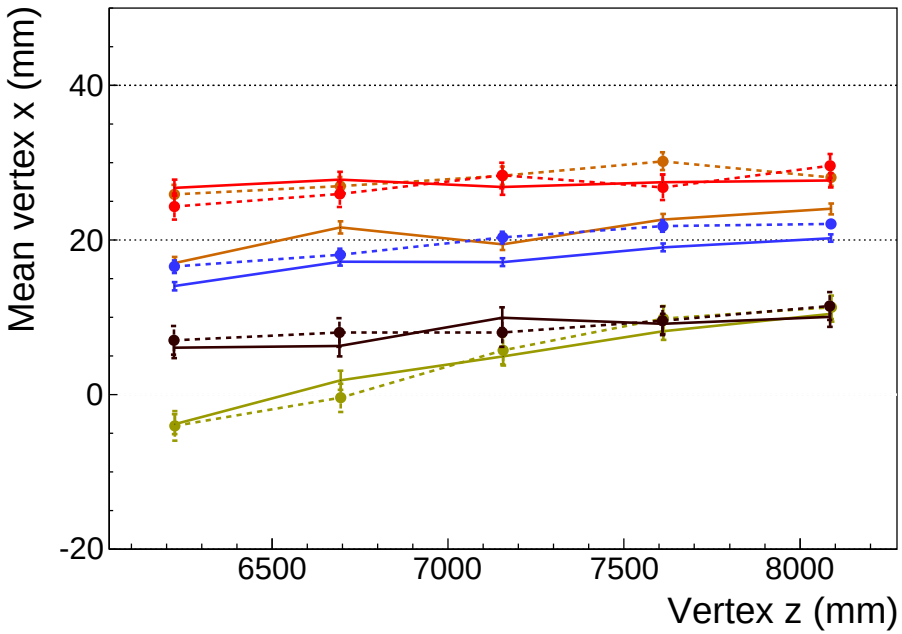


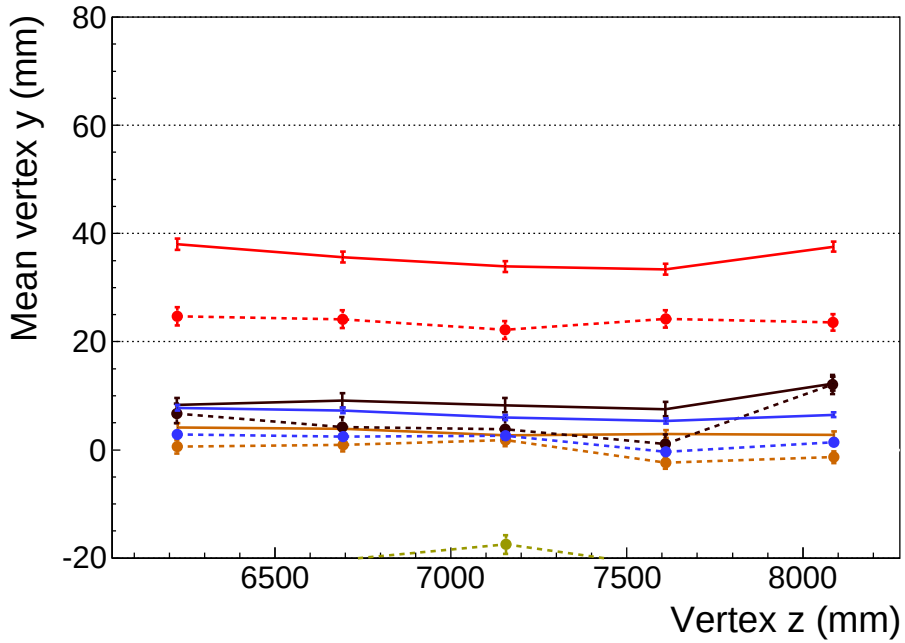
- Same as before, in vertex r^2 about the beam center
- Expected beam center in y is a function of z based on a fit to a later plot. The formula is $y_{\text{center}} = -0.0176z + 152.6$ in mm.
- Possibly an effect in high energy, but not clear

Vertex position as a function of z

- I tried looking at how the data/MC difference in vertex position varies with z
- So make the vertex x and y plots in slices of z. In each slice, take the mean of the histogram. Do the same in data and MC
- Results on next slide
- There's a data/MC offset of a few–10 mm everywhere that doesn't seem to depend on z much, but the biggest effects are in the falling edge of the focusing peak

Vertex position as a function of z





E_ν<5 GeV MC

E_ν<5 GeV Data

5<E_ν<7.5 GeV MC

5<E_ν<7.5 GeV Data

7.5<E_ν>11 GeV MC

7.5<E_ν>11 GeV Data

E_ν>11 GeV MC

E_ν>11 GeV Data

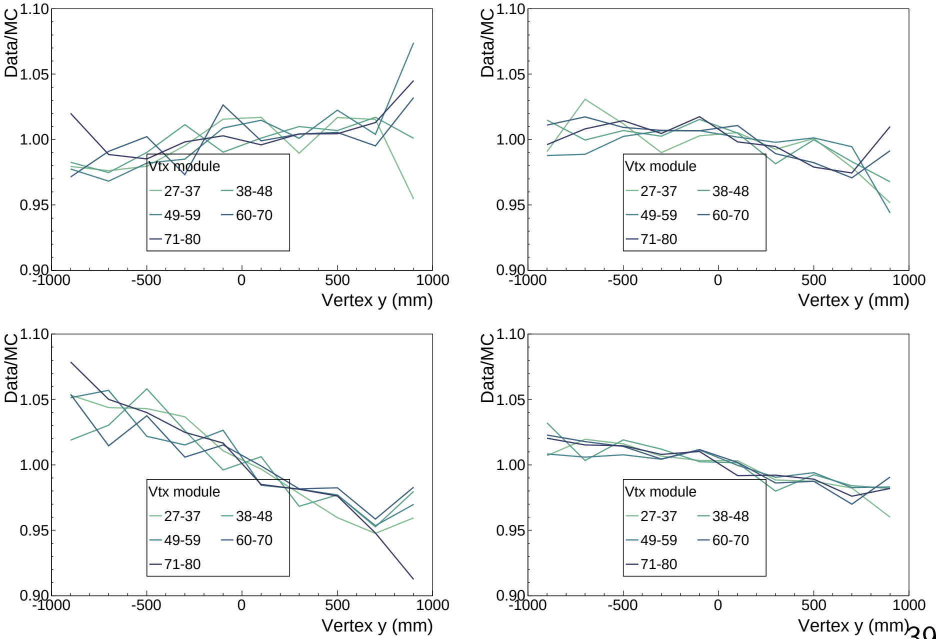
All E_ν MC

All E_ν Data

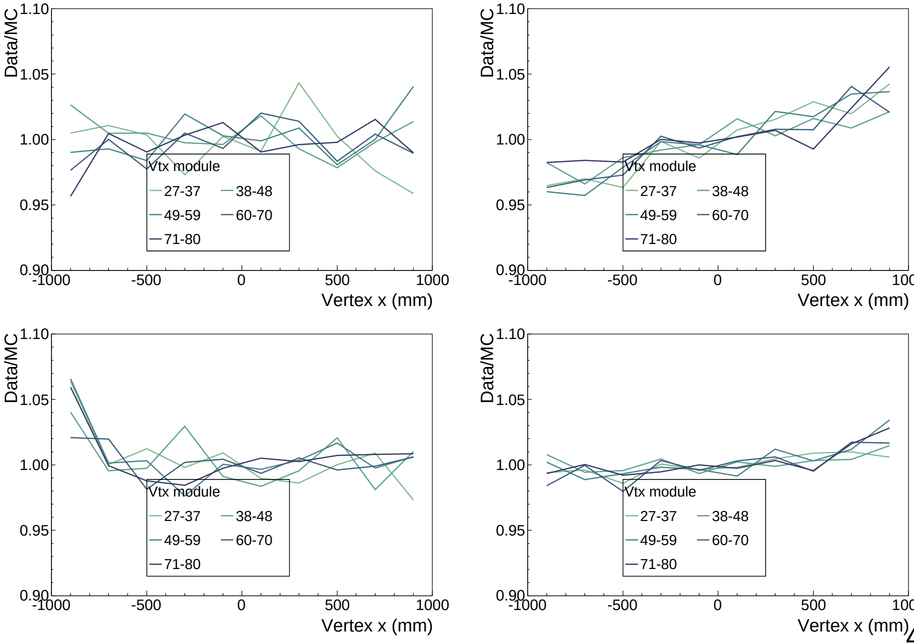
Conclusions

- Evidence for energy-dependent data/MC differences in event position
- I don't think they're big enough to explain the data/MC difference in E_ν as a detector position being wrong
- What effect would something like a horn transverse offset have on beam position at MINERνA?

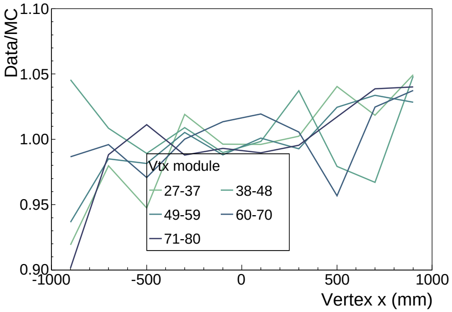
y All times, low, med, high, all E_ν (in reading order)

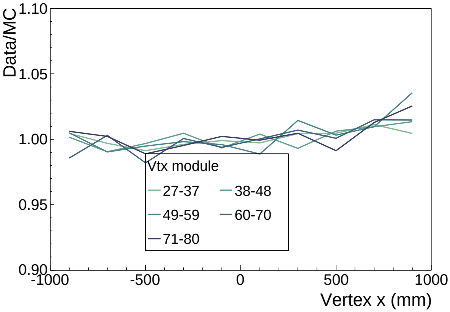


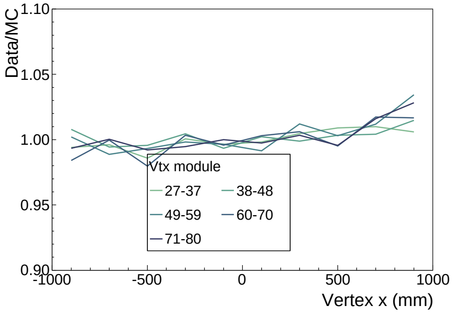
x ratios, low, med, high, all E_ν (in reading order)



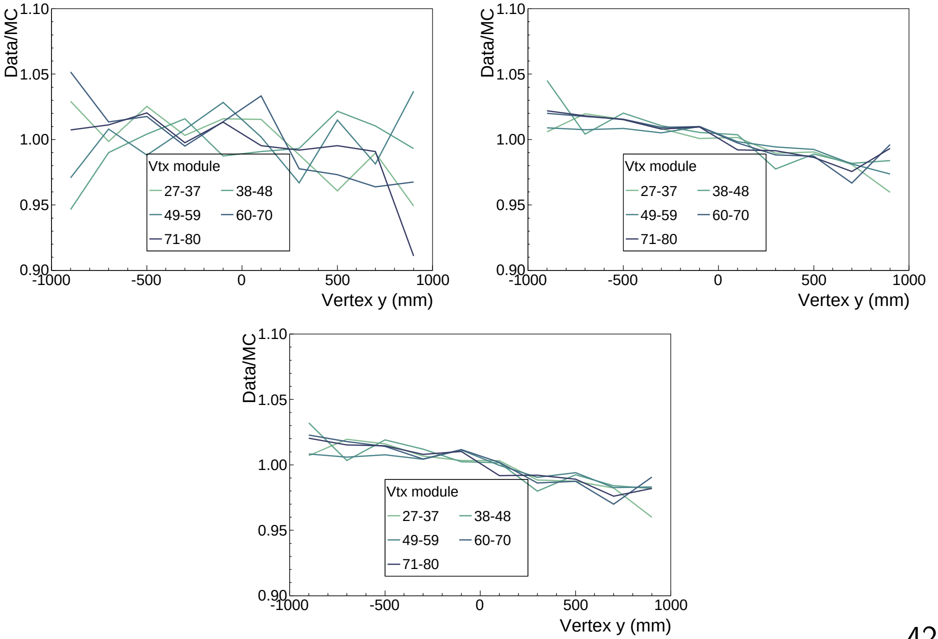
x All E_ν, early, late, all times (in reading order)

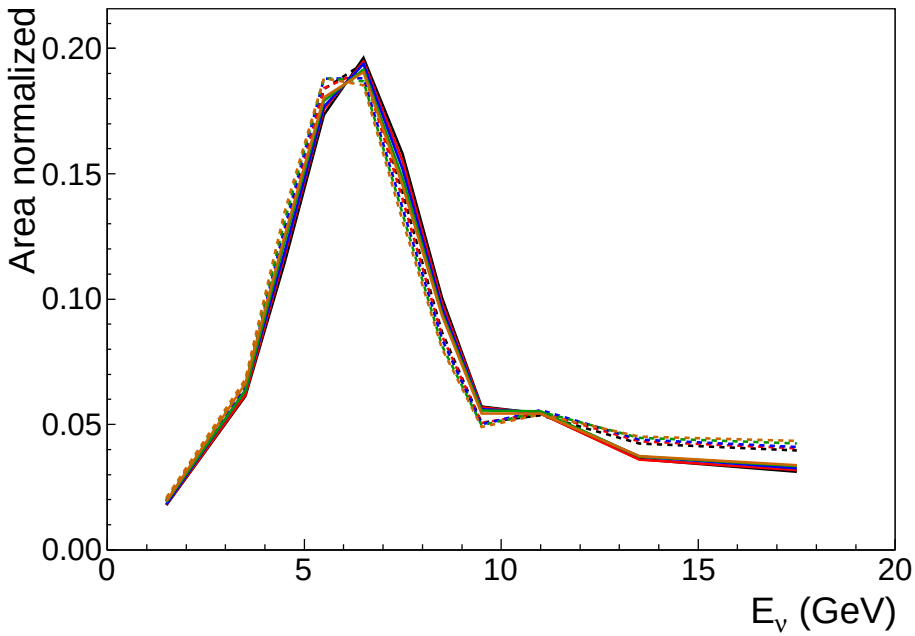


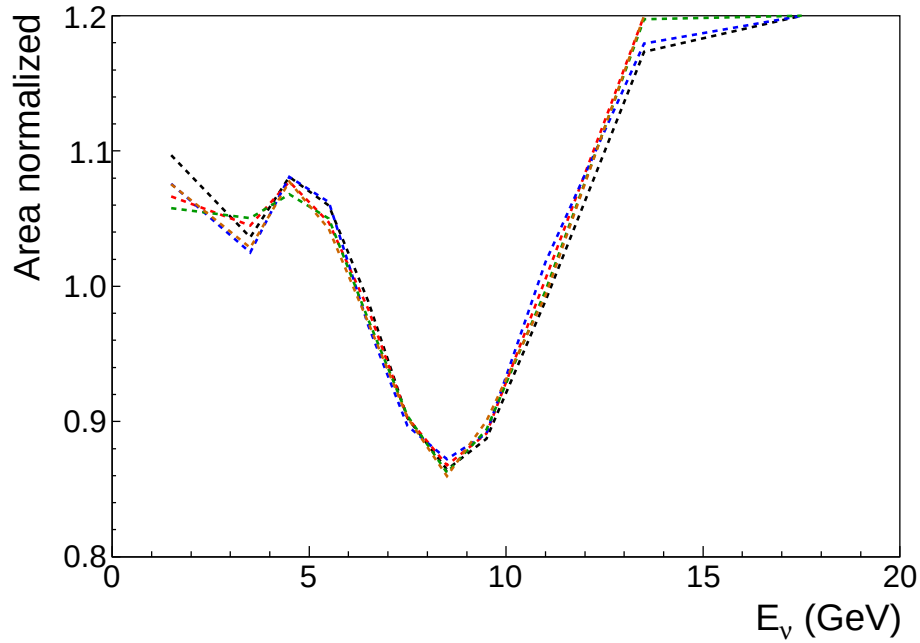




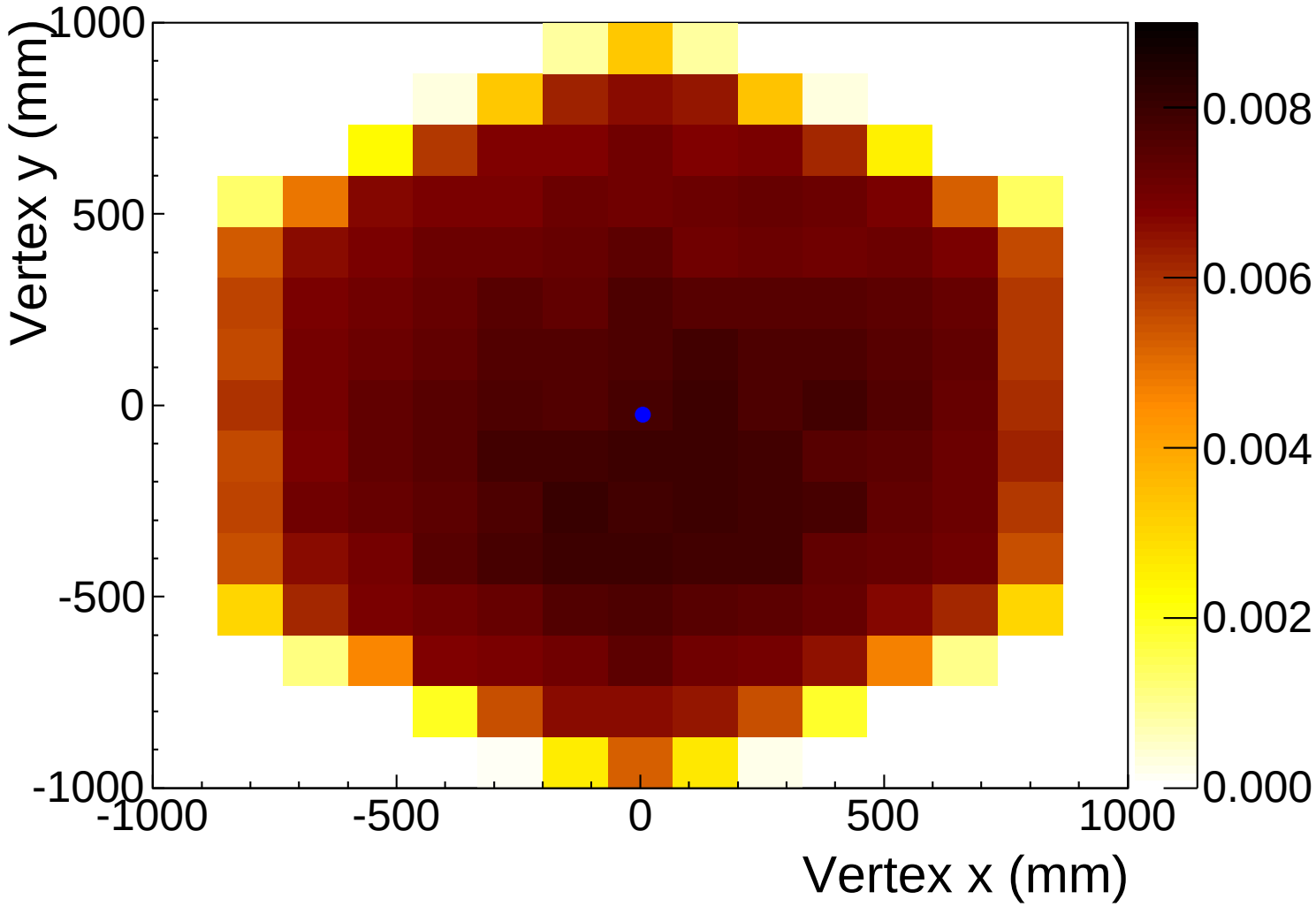
y All E_ν, early, late, all times (in reading order)



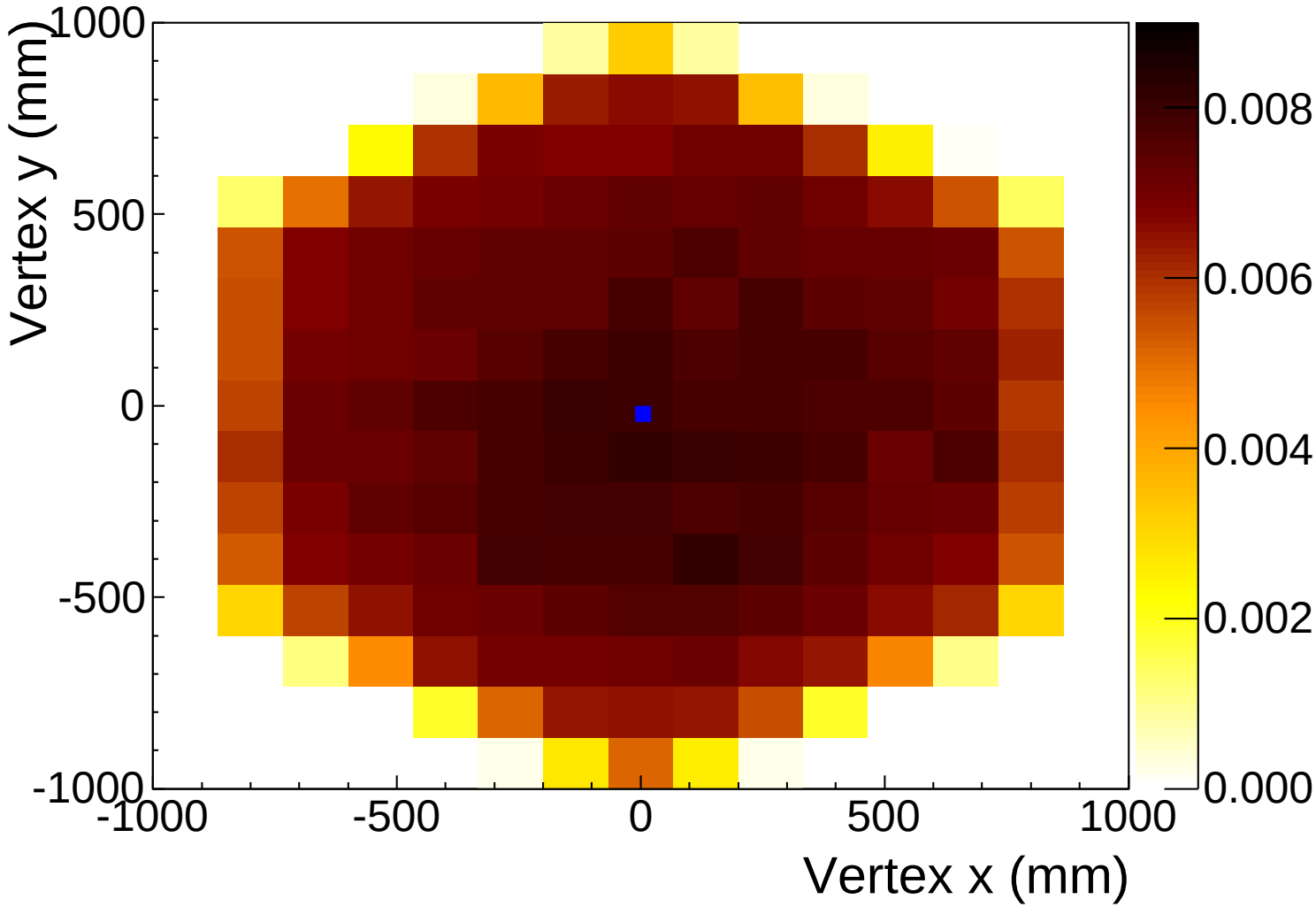

Area normalized
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
E_ν (GeV)


Area normalized
1.2
1.1
1.0
0.9
0.8
0
5
10
15
20
E_ν (GeV)

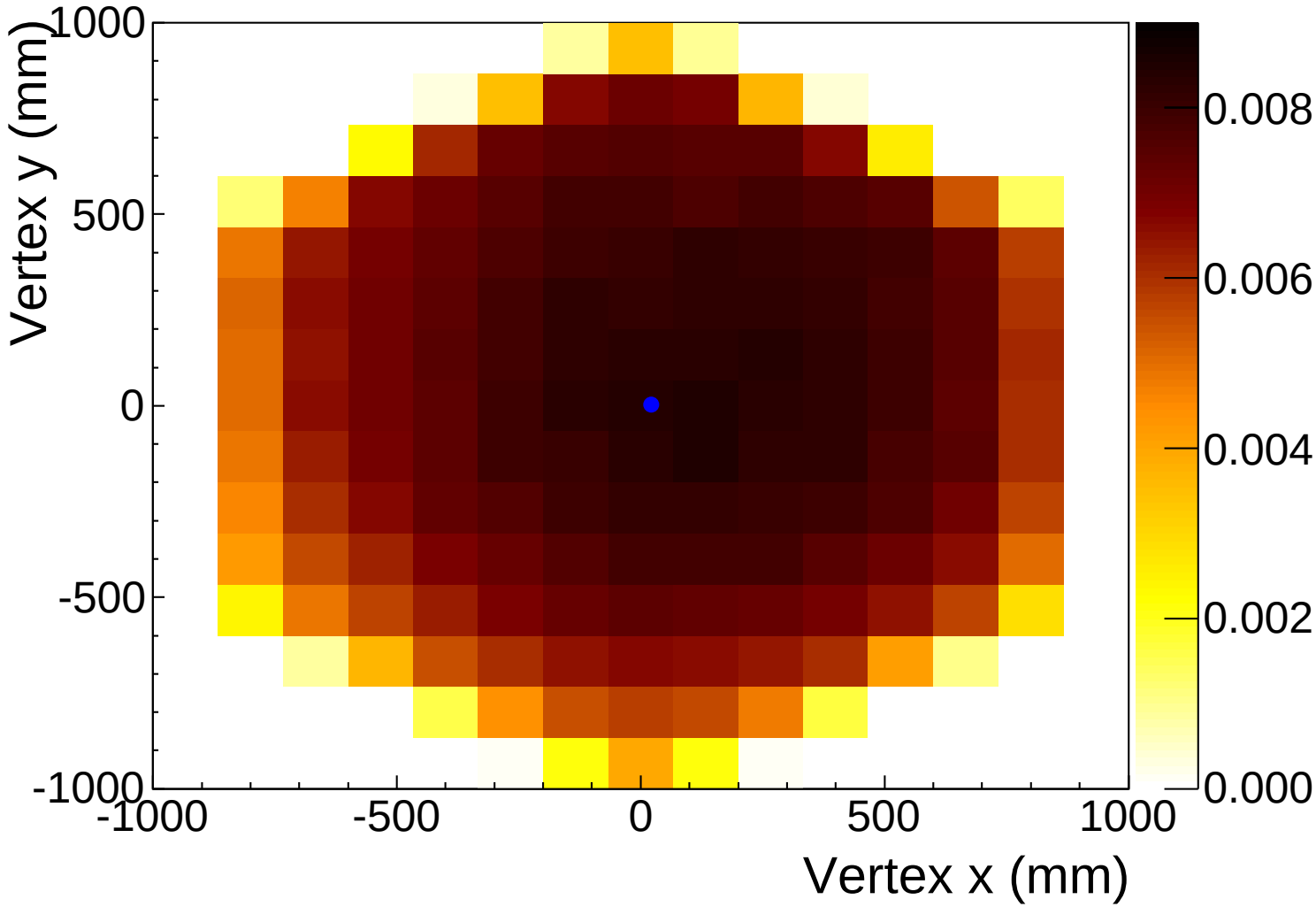
lowEnu MC


Vertex y (mm)
1000
500
0
-500
-1000
-1000
-500
0
500
1000
Vertex x (mm)
0.008
0.006
0.004
0.002
0.000

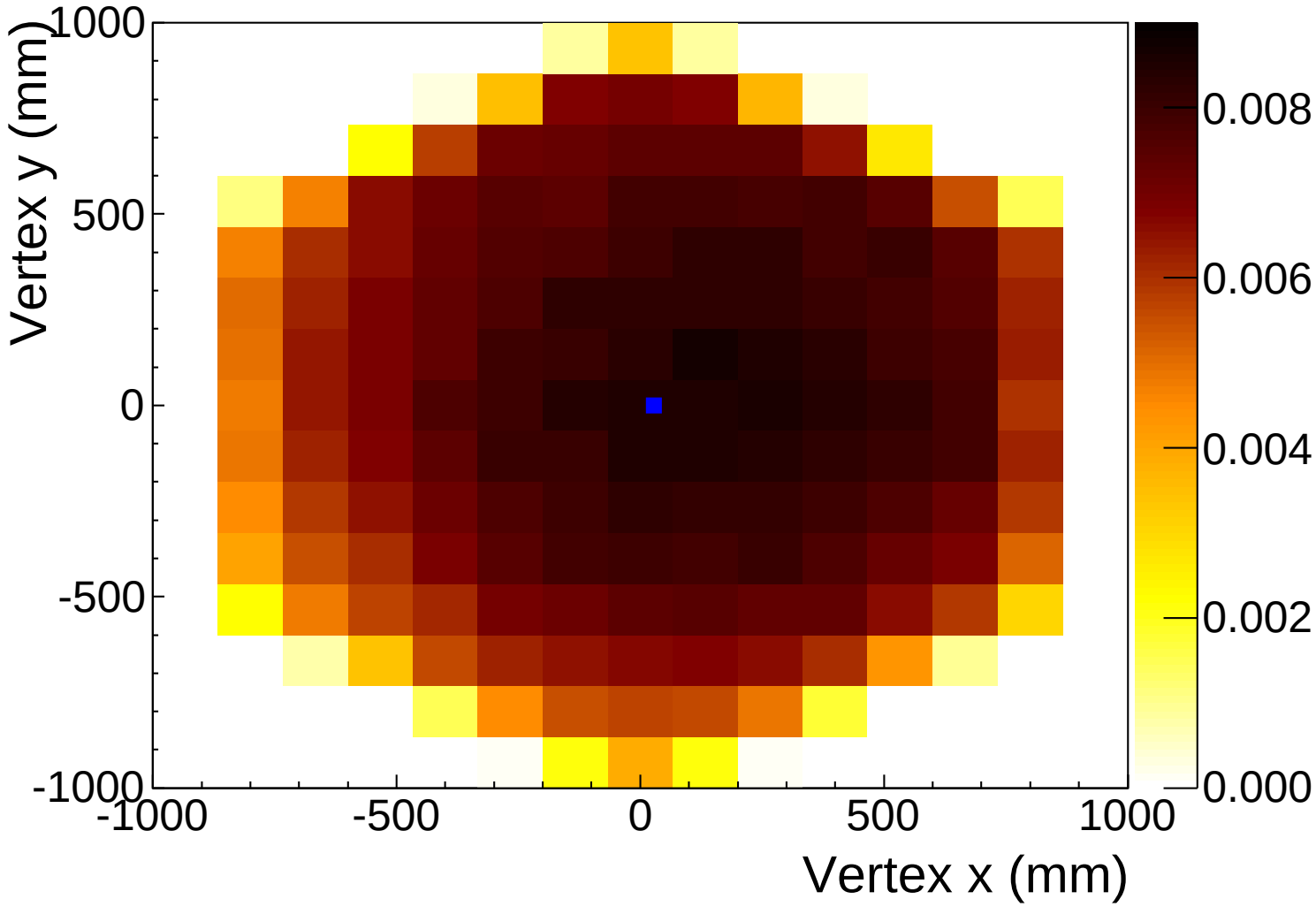
lowEnu Data


Vertex y (mm)
1000
500
0
-500
-1000
-1000
-500
0
500
1000
Vertex x (mm)
0.008
0.006
0.004
0.002
0.000

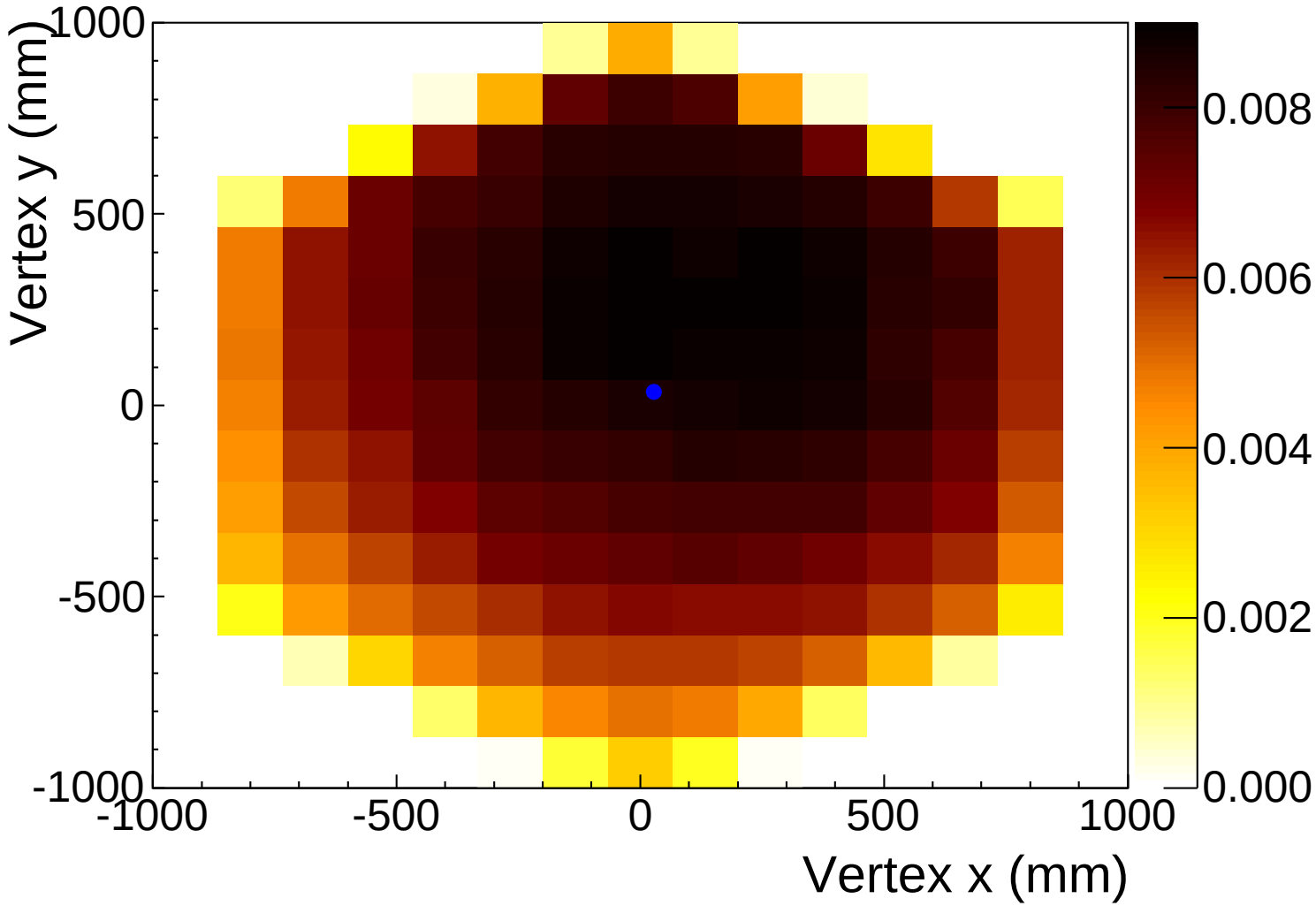
medEnu MC


Vertex y (mm)
1000
500
0
-500
-1000
-1000
-500
0
500
1000
Vertex x (mm)
0.008
0.006
0.004
0.002
0.000

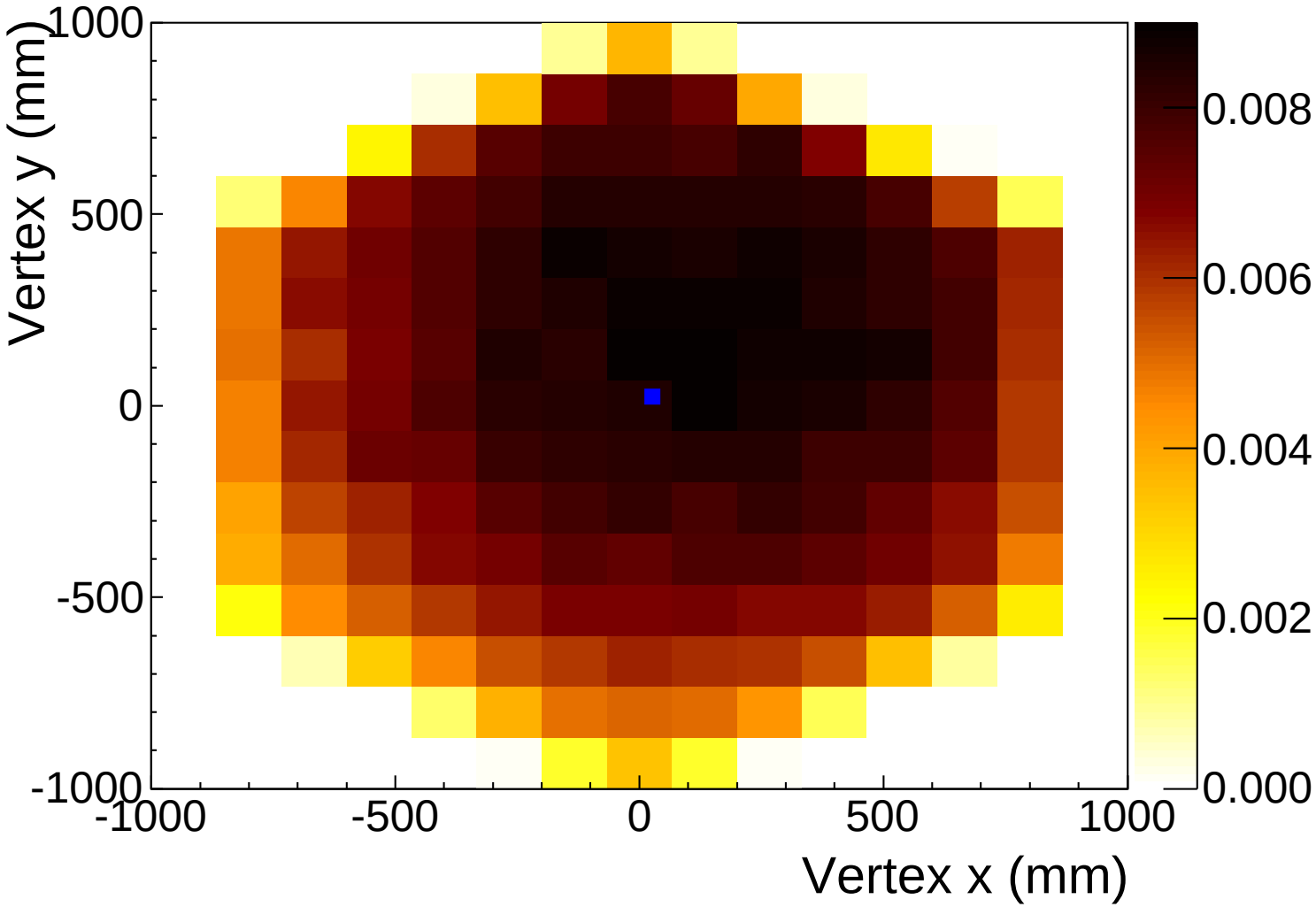
medEnu Data


Vertex y (mm)
1000
500
0
-500
-1000
-1000
-500
0
500
1000
Vertex x (mm)
0.008
0.006
0.004
0.002
0.000

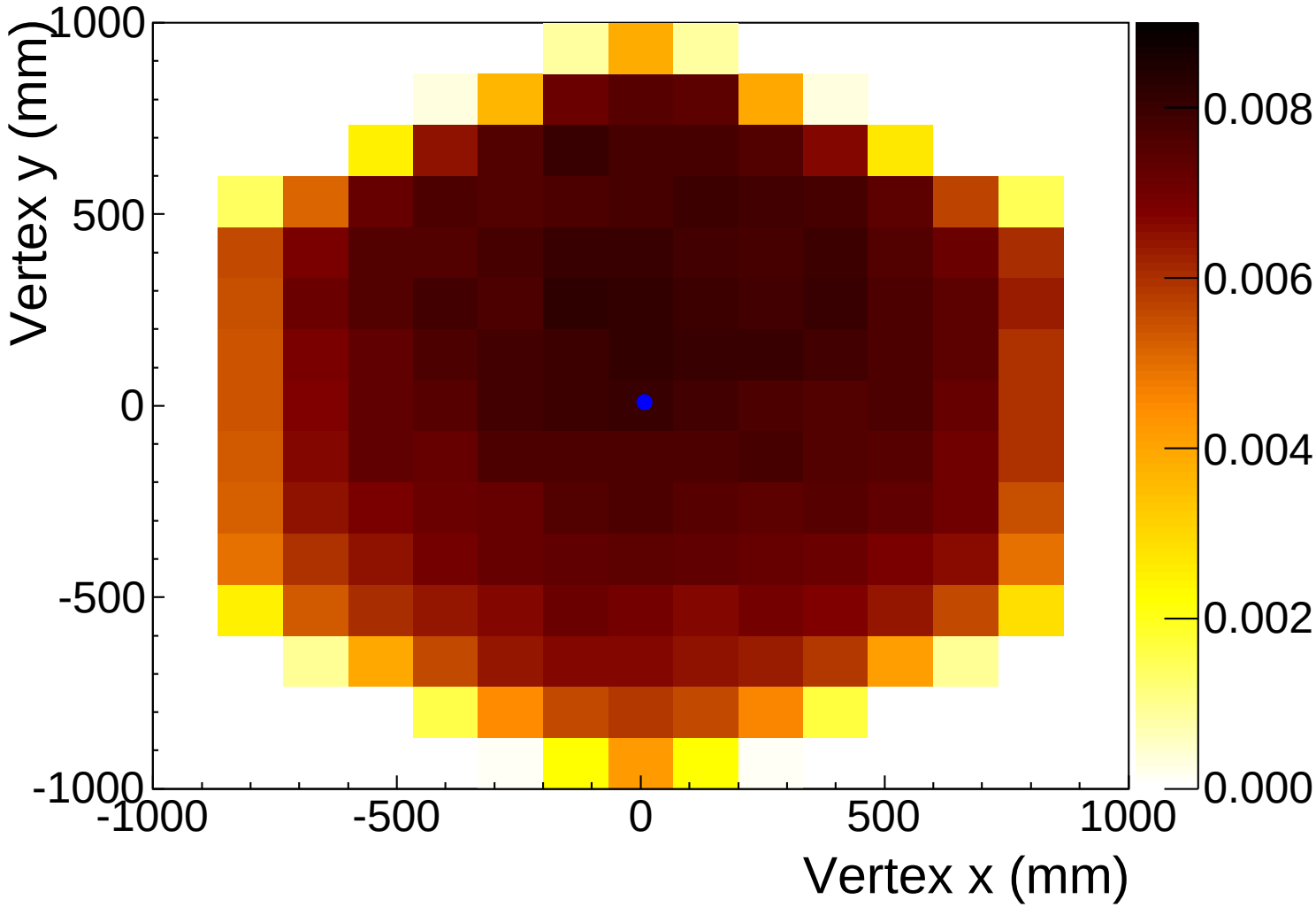
highEnu MC


Vertex y (mm)
1000
500
0
-500
-1000
-1000
-500
0
500
1000
Vertex x (mm)
0.008
0.006
0.004
0.002
0.000

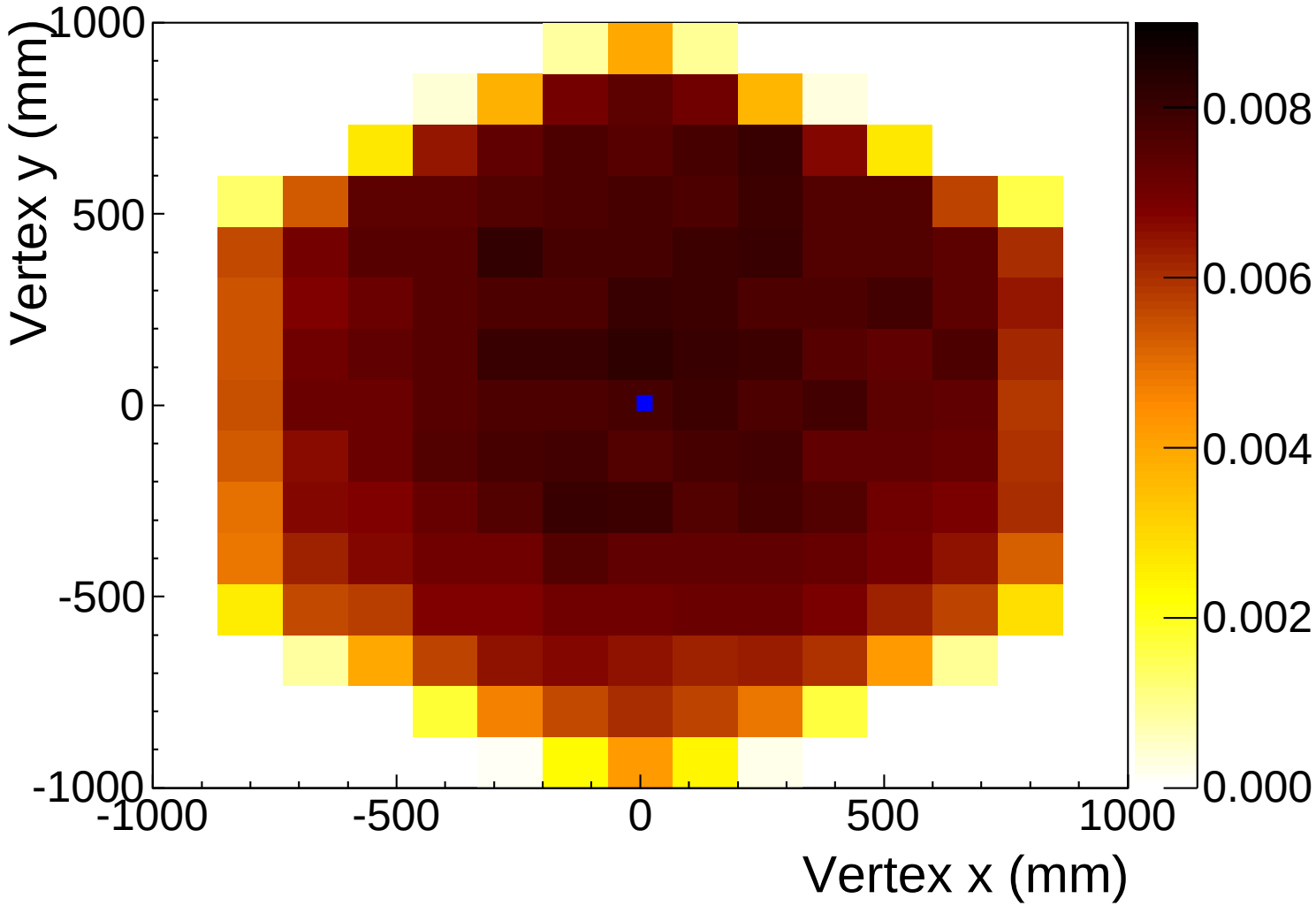
highEnu Data



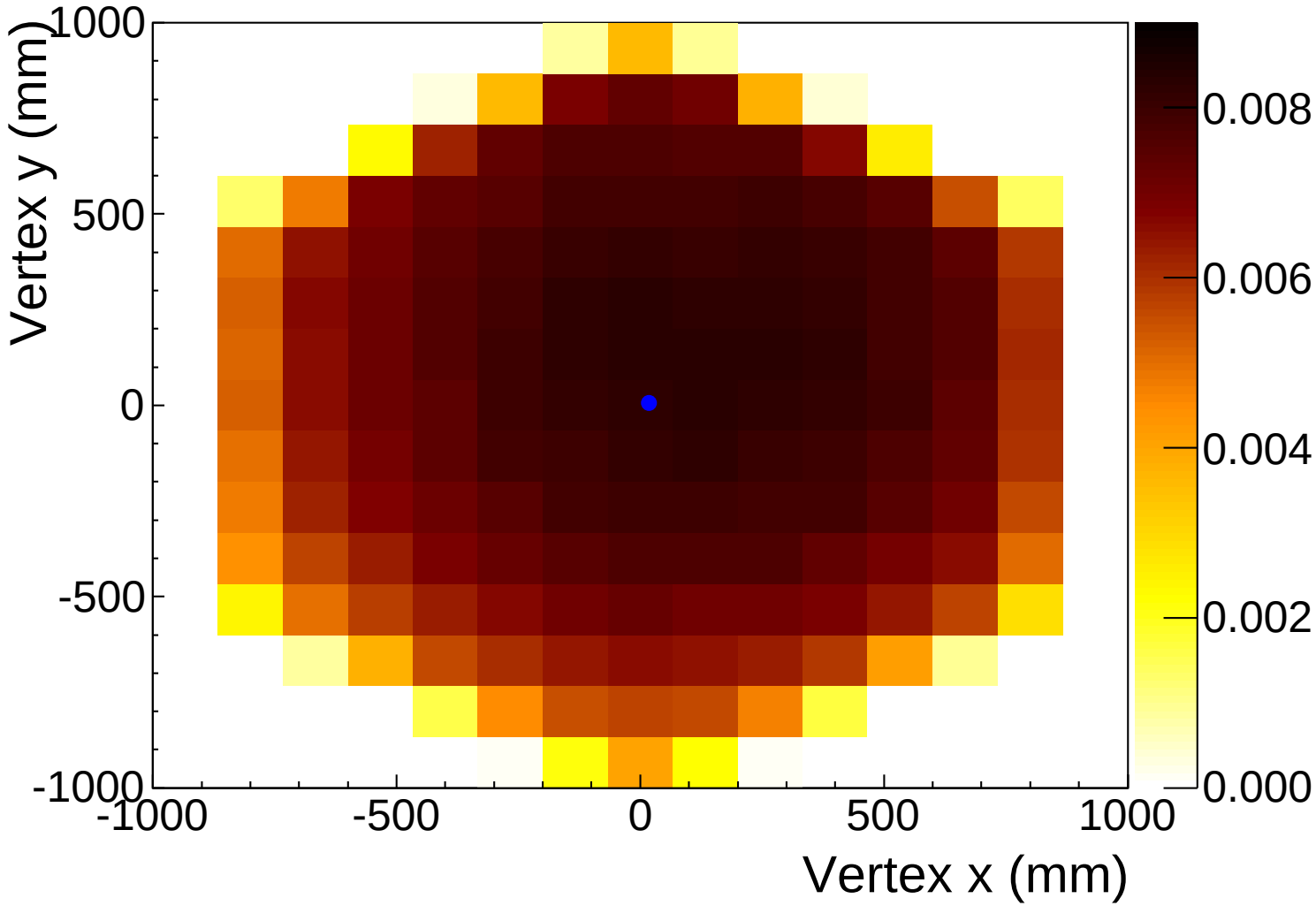
tailEnu MC


Vertex y (mm)
1000
500
0
-500
-1000
-1000
-500
0
500
1000
Vertex x (mm)
0.008
0.006
0.004
0.002
0.000

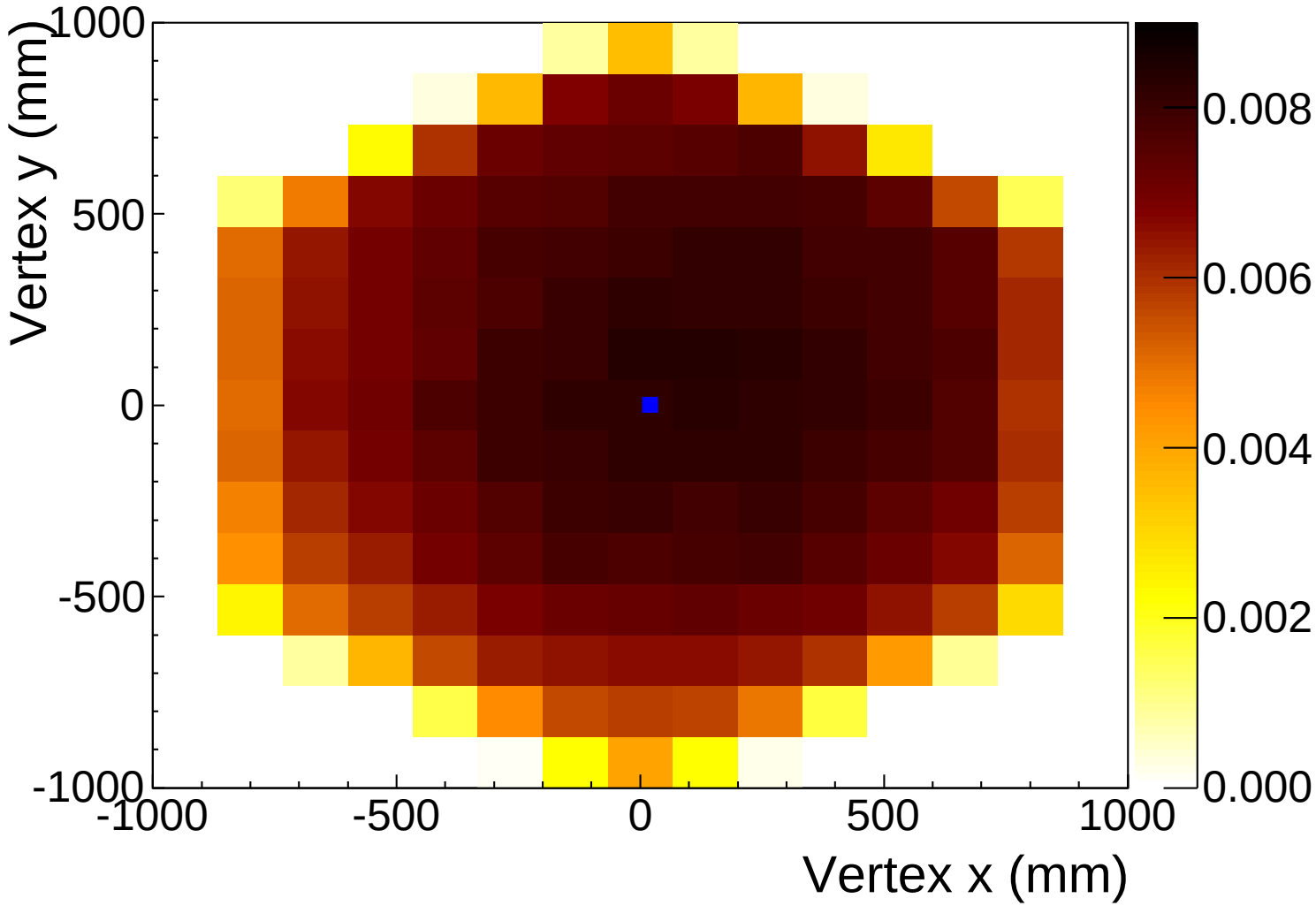
tailEnu Data



allEnu MC


Vertex y (mm)
1000
500
0
-500
-1000
-1000
-500
0
500
1000
Vertex x (mm)
0.008
0.006
0.004
0.002
0.000

allEnu Data


Vertex y (mm)
1000
500
0
-500
-1000
-1000
-500
0
500
1000
Vertex x (mm)
0.008
0.006
0.004
0.002
0.000