



Comparison of Electromagnetic Shower Widths in the Vacuum and Air Filled NDOS Detector of NOvA

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Our Geant Problems:



- Observe nonsense electron widths in our NDOS (Near Detector On Surface) detector
- High energy primary electrons bend abruptly and radically during shower development
- Found well developed, expected electromagnetic showers in NDOS when filled with vacuum
- If we substitute air for the vacuum, the problem manifests
- Only observe this behavior in events with electromagnetic activity
- Specifically, we have noticed the problem with electrons and positrons propagating through geometries filled with air



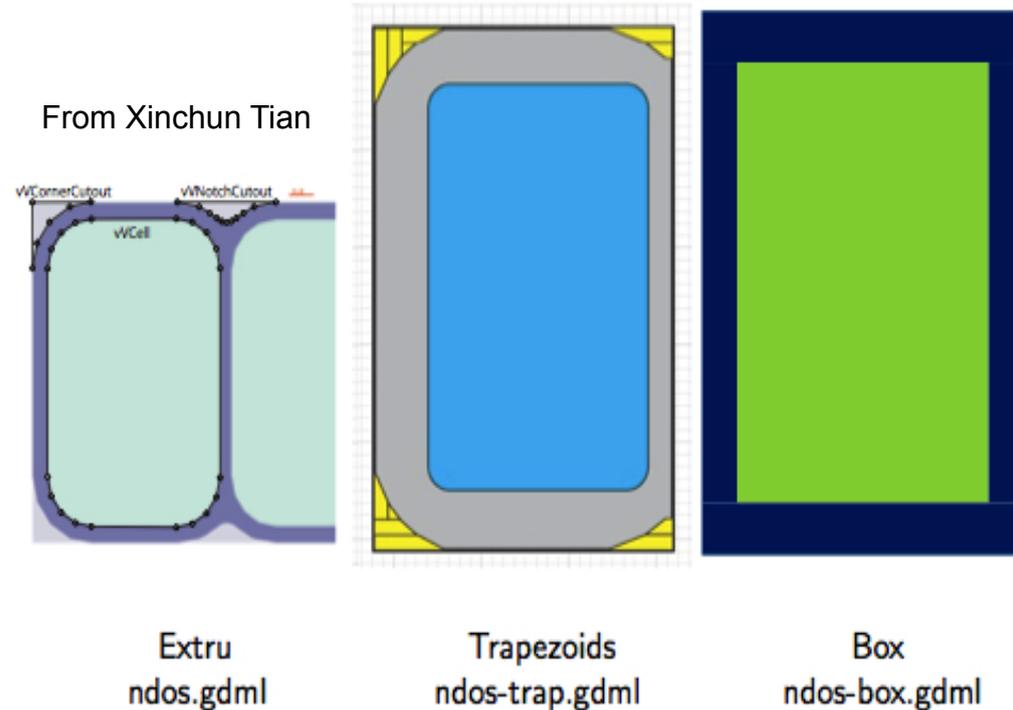
In This Study:

- Generated 2000 single electrons in each of the geometries studied
- All had vertex $(50.9, 38.9, 202.3)$ cm and momentum $(0, 0, 2)$ GeV
- This vertex chosen to avoid areas of inactive detector
- All events in all geometries generated with the tagged release S11.04.30 of the NovA offline software
- Used Geant 4 version G4.9.4
- Calculated the shower width of each event, defined as the distance from each hit to the shower axis weighted by each hit's energy
- Found this number for each geometry filled with air and with vacuum

Geometries Used



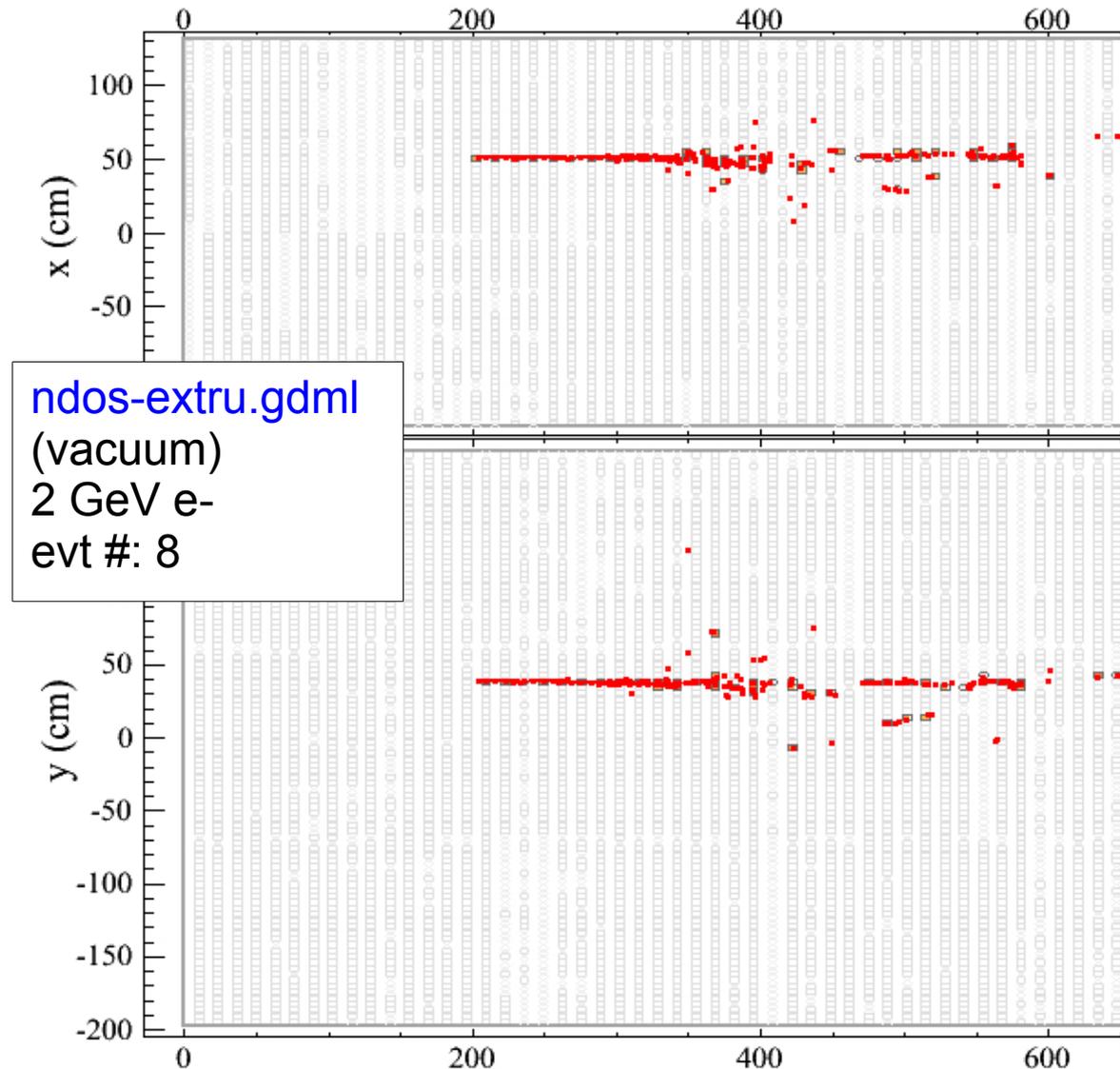
- We made two new simplified geometry files for the study
- [ndos.gdml](#) uses extrusions, cells closest to real detector
- [ndos-trap.gdml](#) uses trapezoids to fill gaps between cells
- Found overlaps in [ndos.gdml](#), so we made the simplest possible [ndos-box.gdml](#) without overlaps
- We have three geometries, fill each with air and vacuum, this gives 6 total geometry files to analyze
- I call [ndos.gdml](#) as [ndos-extru.gdml](#) to make it clear this is the file with extrusions (and avoid possible ambiguity)



Electron Event with Vacuum



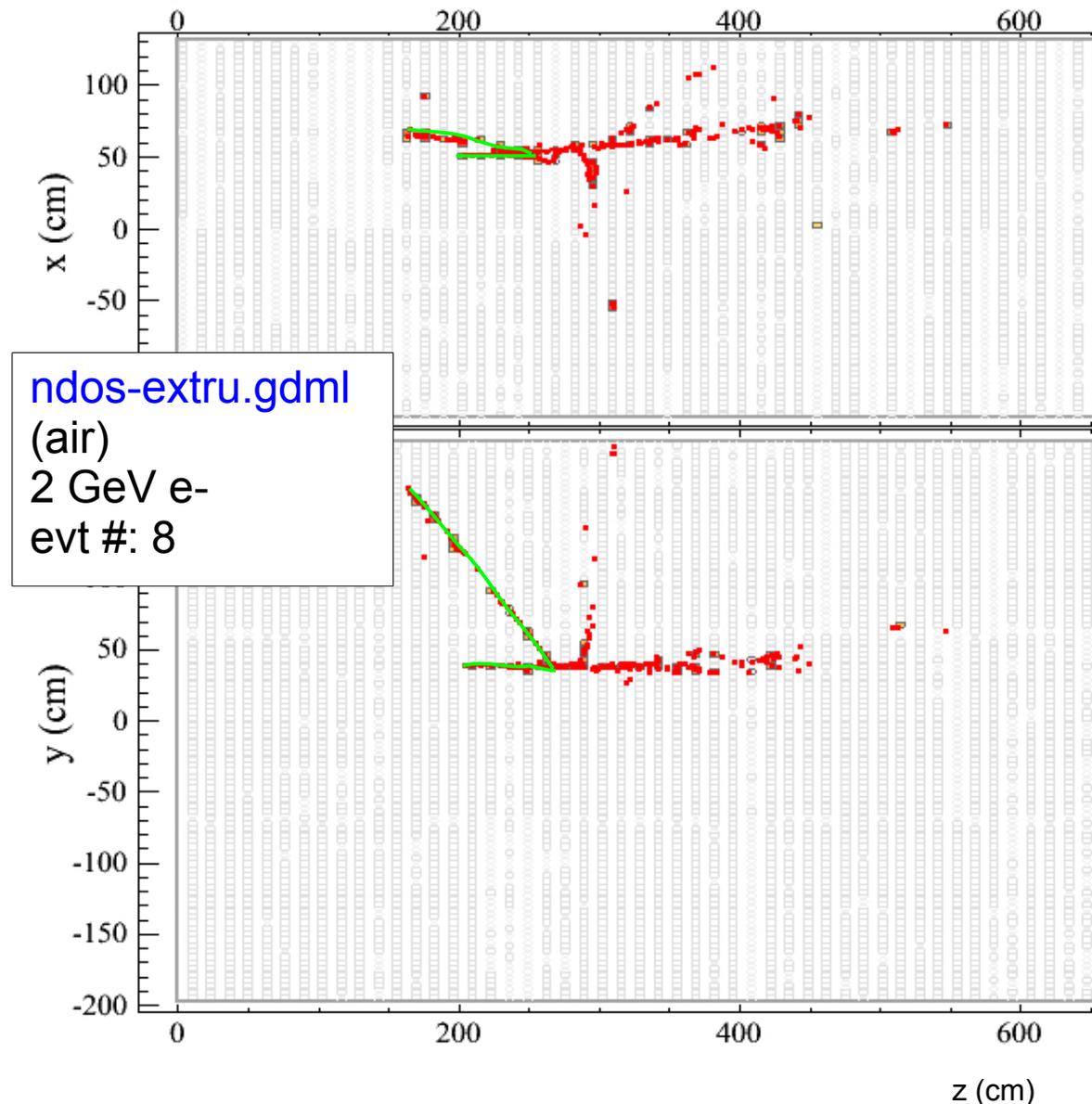
- Event number 8 from ndos-extru.gdml geometry filled with vacuum
- We see a well developed shower, as we expect in our NDOS detector



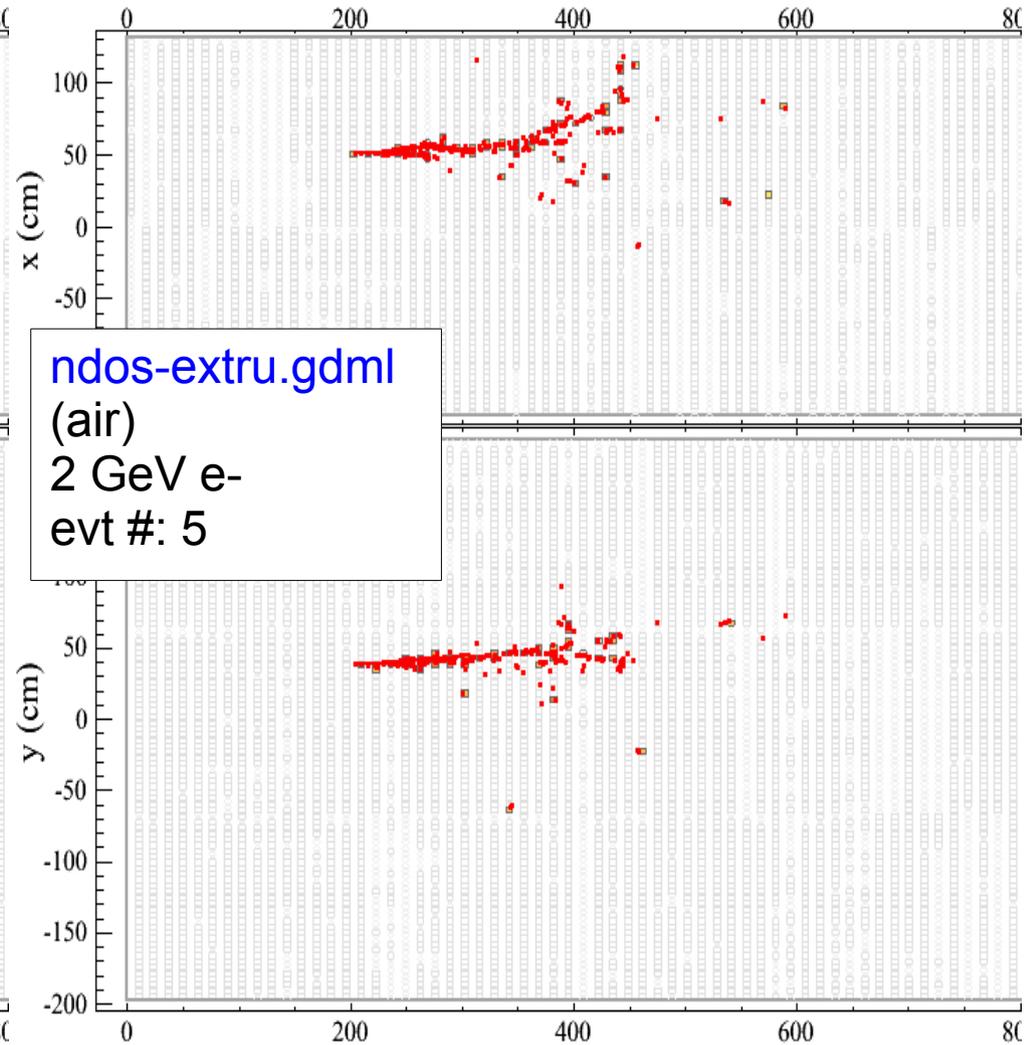
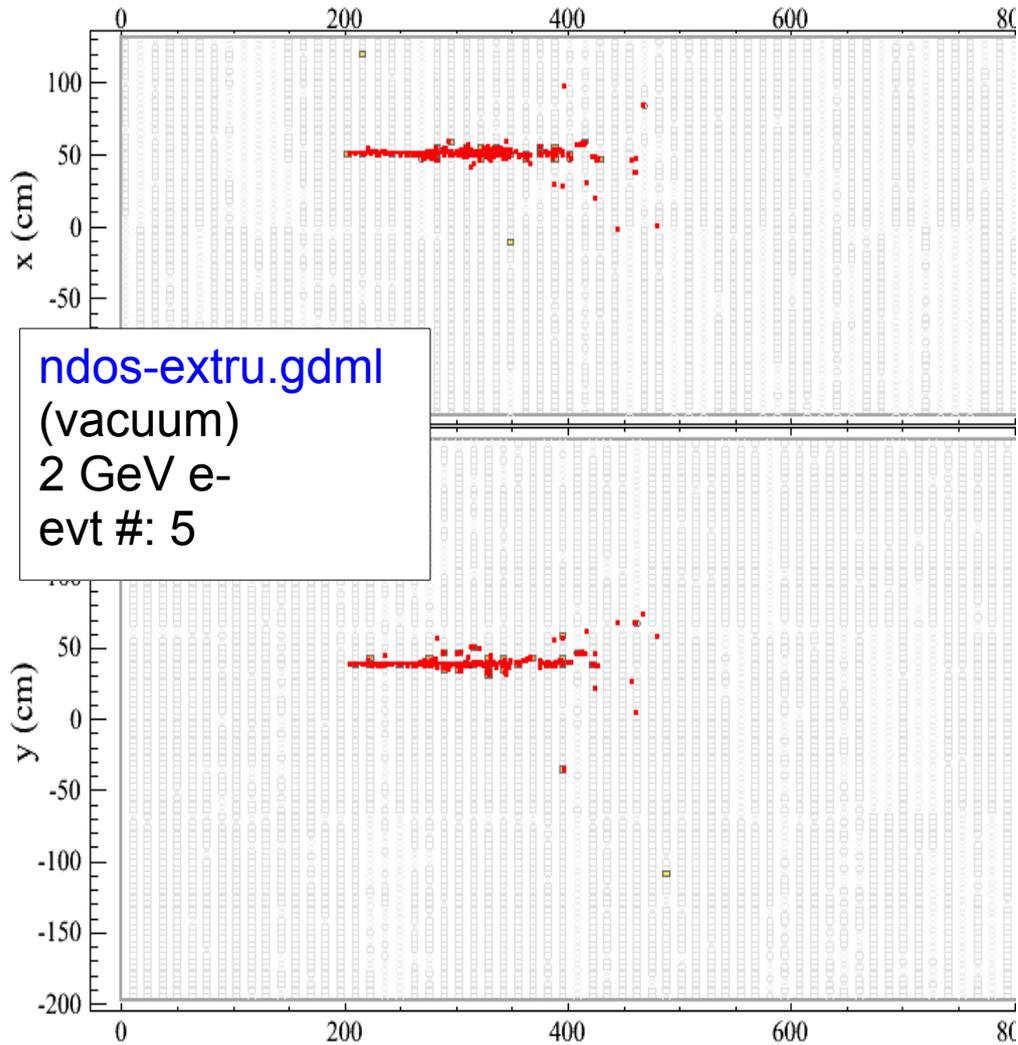
Electron Event with Air



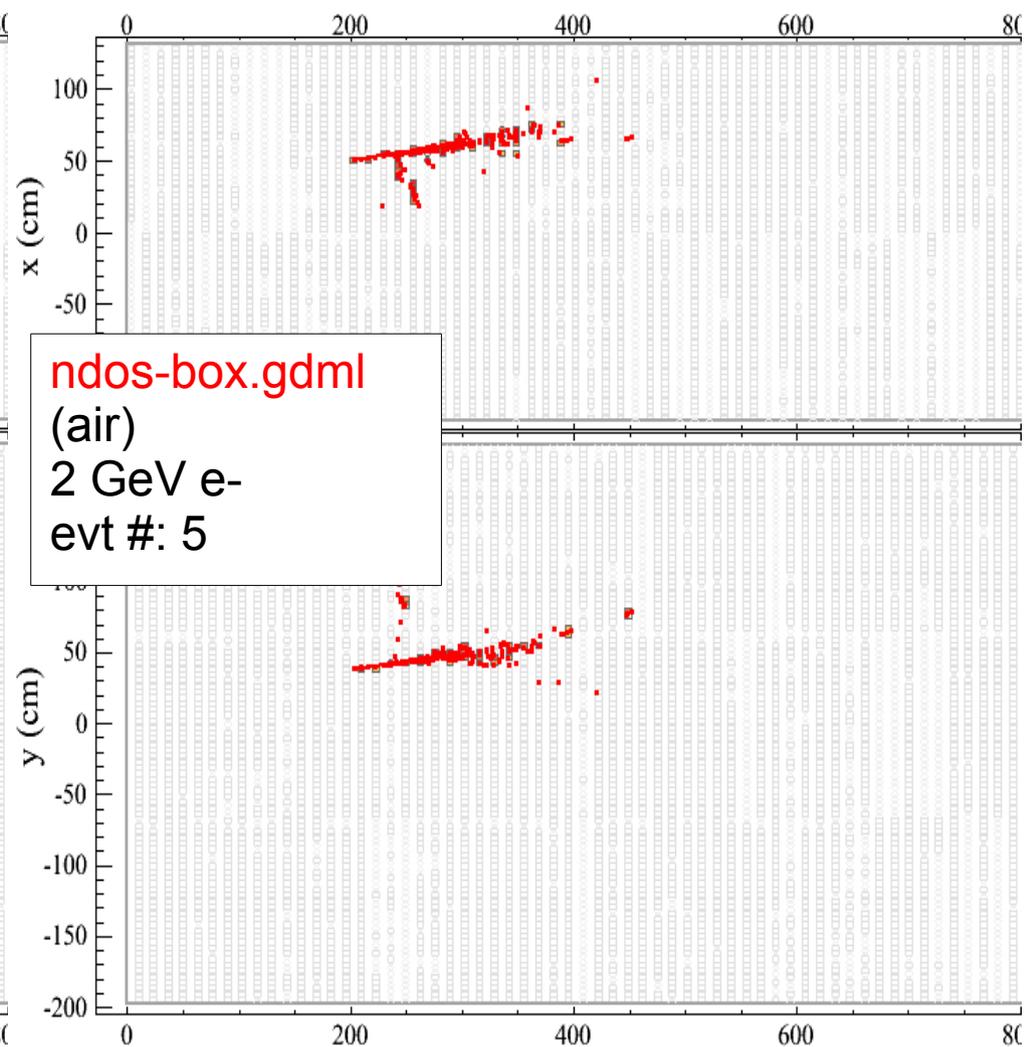
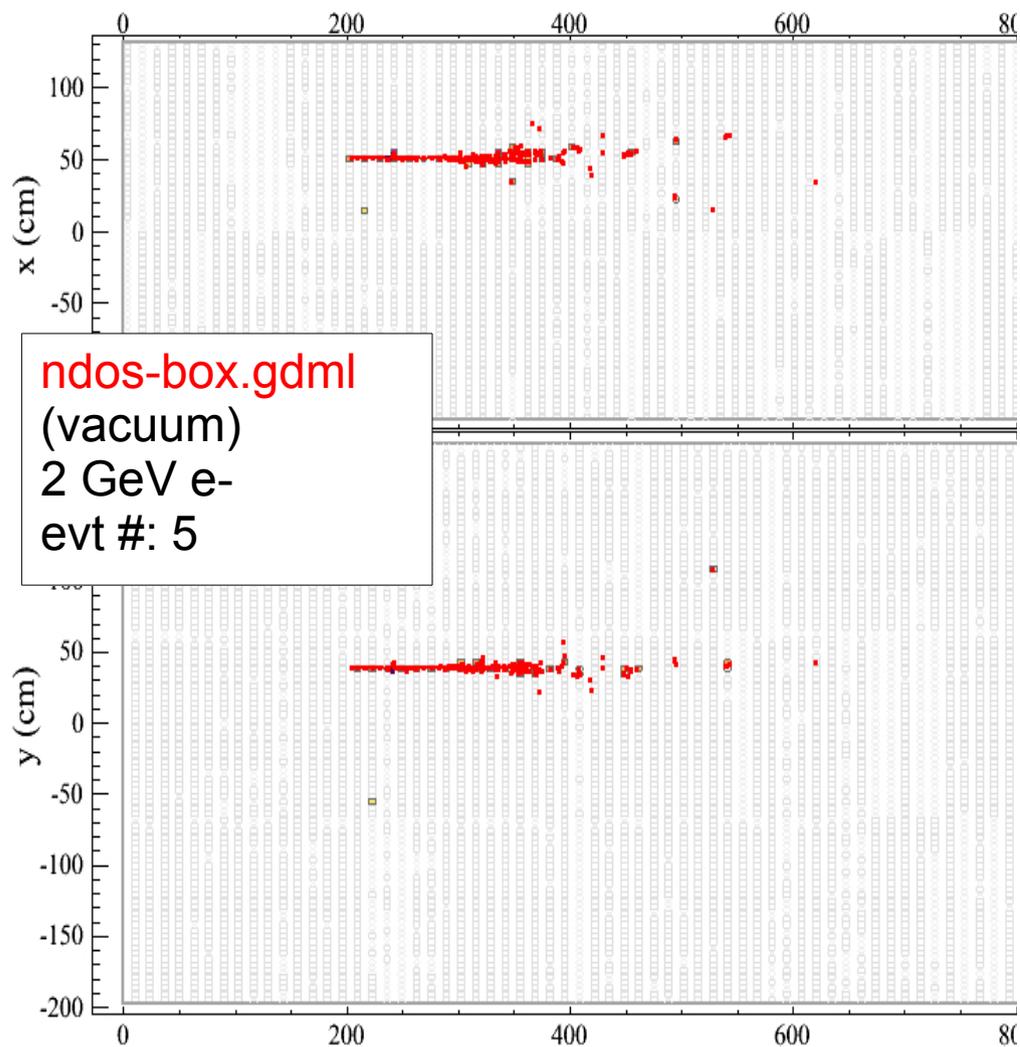
- Event number 8 from [ndos-extru.gdml](#) geometry filled with air
- Plotted the primary electron path separately, placed the trajectory on this event display in green
- Primary electron backscatters at $z = 260$ cm
- This is typical behavior for electrons in our geometries with air



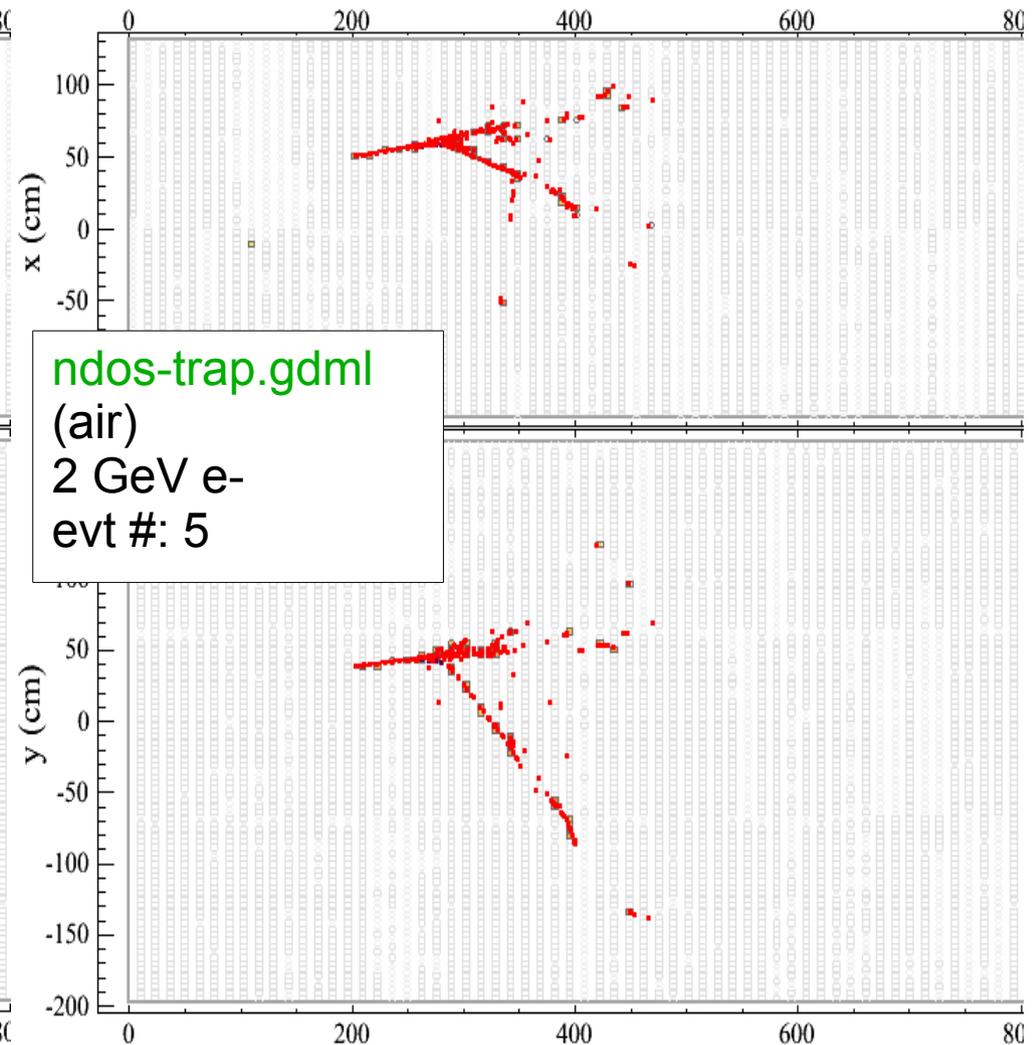
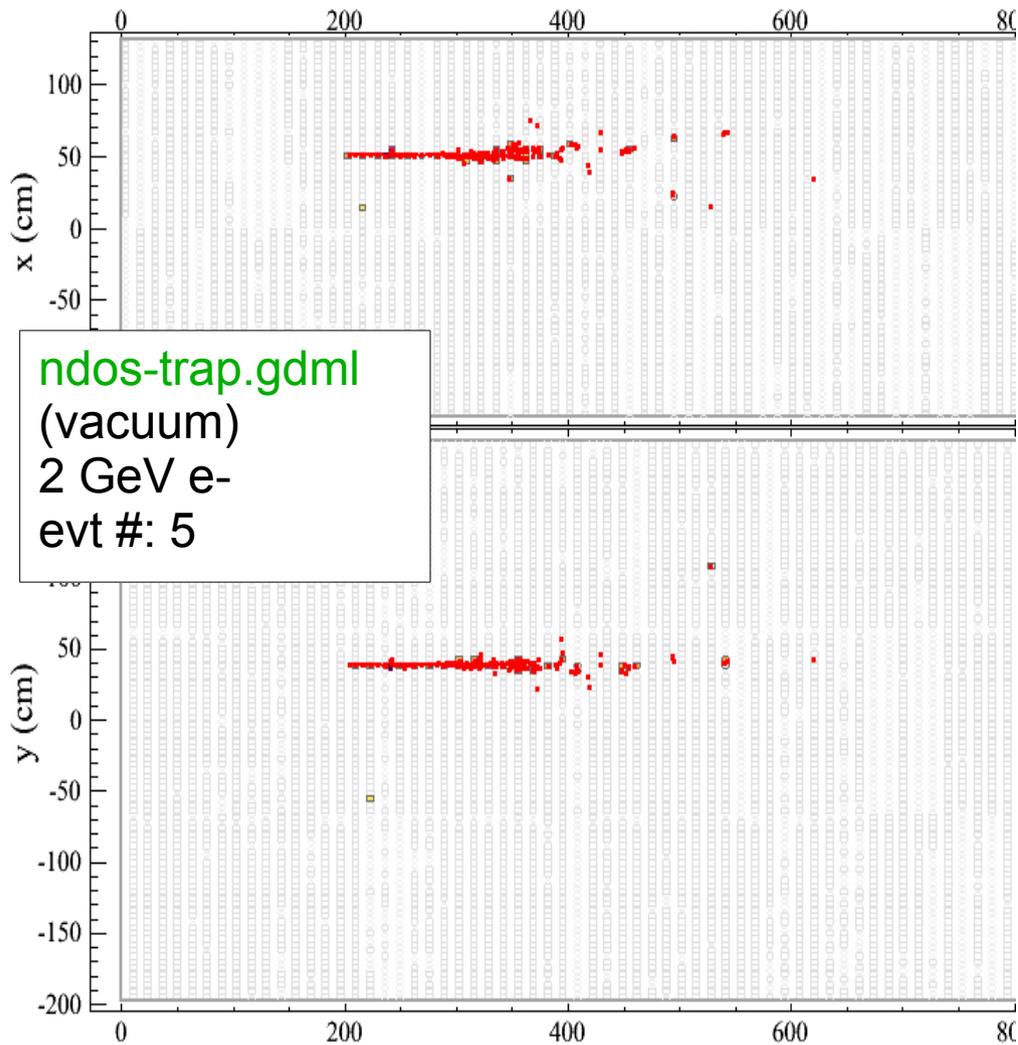
ndos-extru.gdml Electron Event



ndos-box.gdml Electron Event



ndos-trap.gdml Electron Event





Shower Width Algorithm

- Define the shower center as the average position of hits in the shower, weighted by the energy of the hit (E_i)
- Define the shower axis as the line joining the primary particle vertex and the shower center
- Define the hit distance (d_i) for each hit to be the distance from each hit to the shower axis
- Then define the average shower width to be the average hit distance, weighted by energy, as given in the equation below

d_i = distance from hit i to shower axis

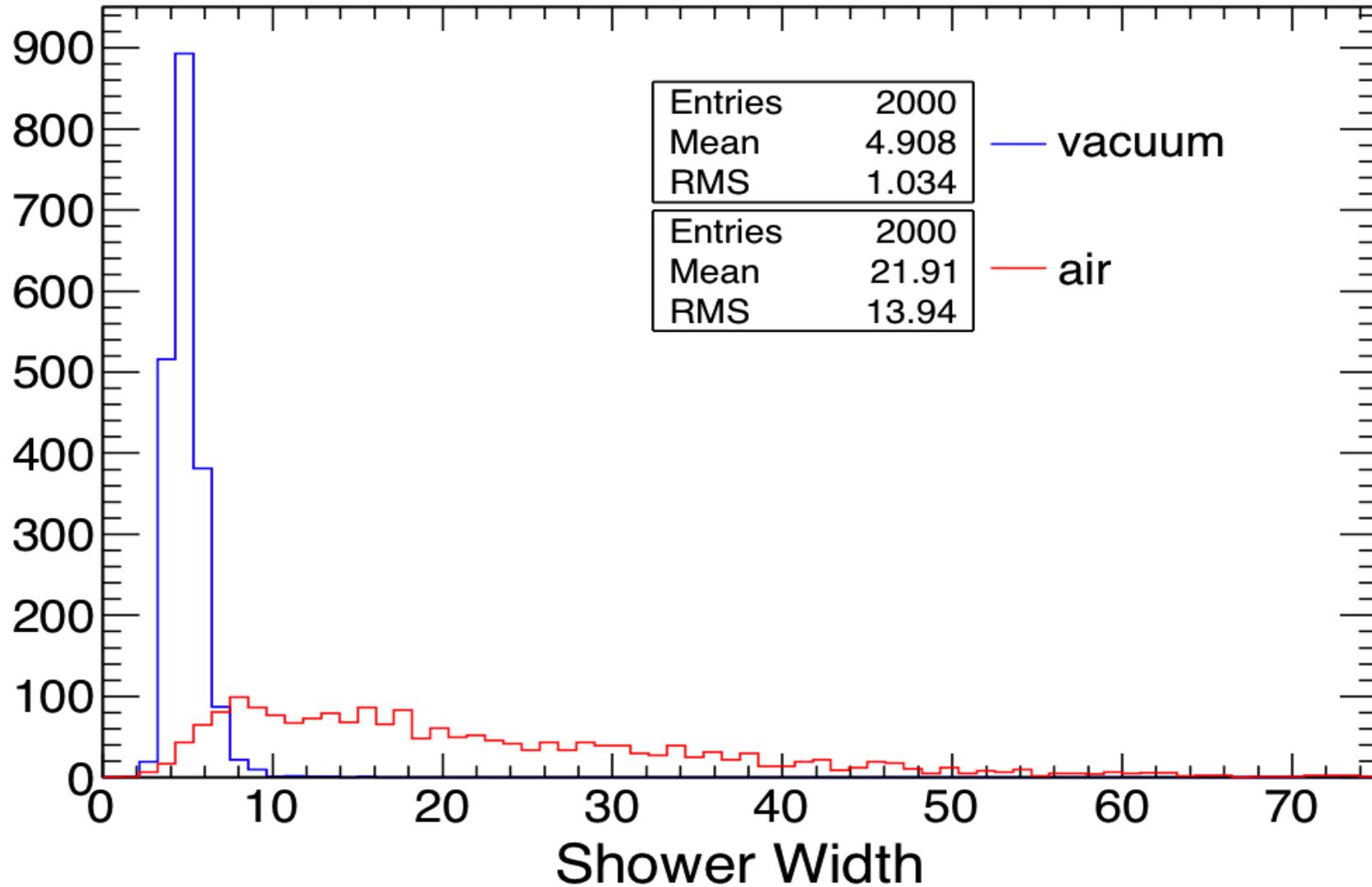
E_i = Energy of hit i

$$\text{Shower width} = \frac{\sum_i^{N_{\text{hits}}} d_i E_i}{\sum_i^{N_{\text{hits}}} E_i}$$

ndos-extru.gdml Results



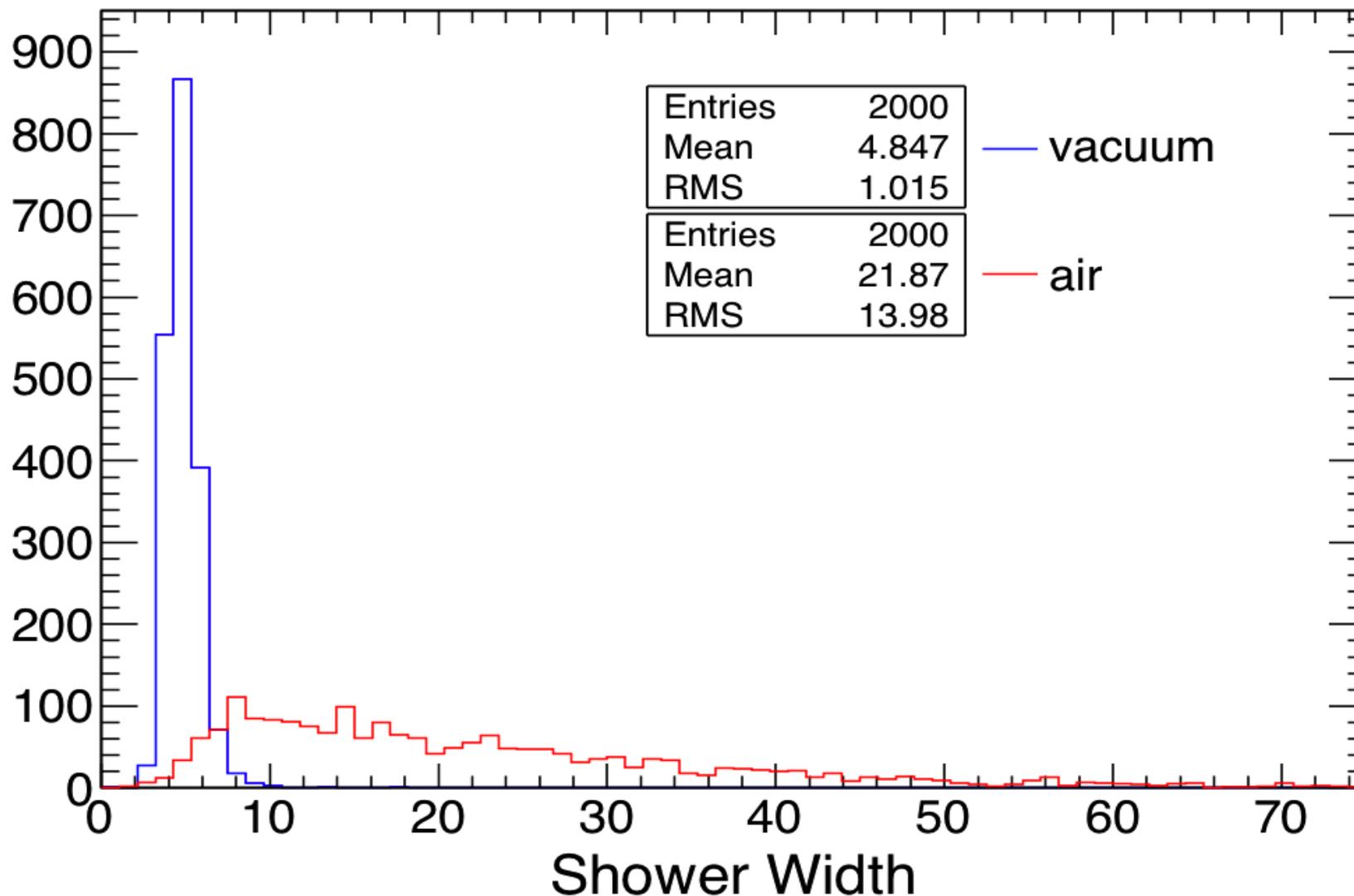
Comparison of ndos-extru.gdml filled with vacuum and air



ndos-box.gdml Results



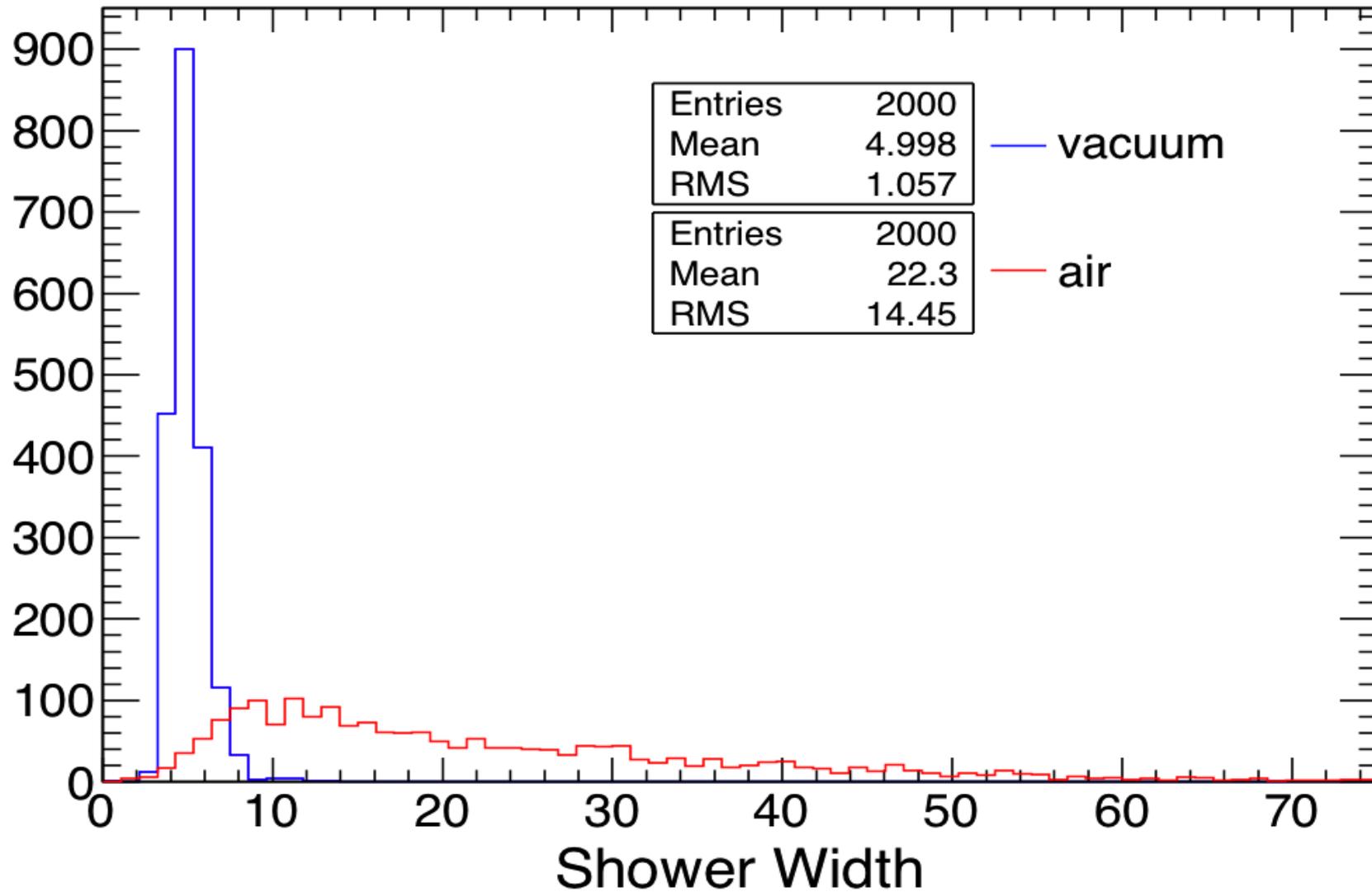
Comparison of ndos-box.gdml filled with vacuum and air



ndos-trap.gdml Results



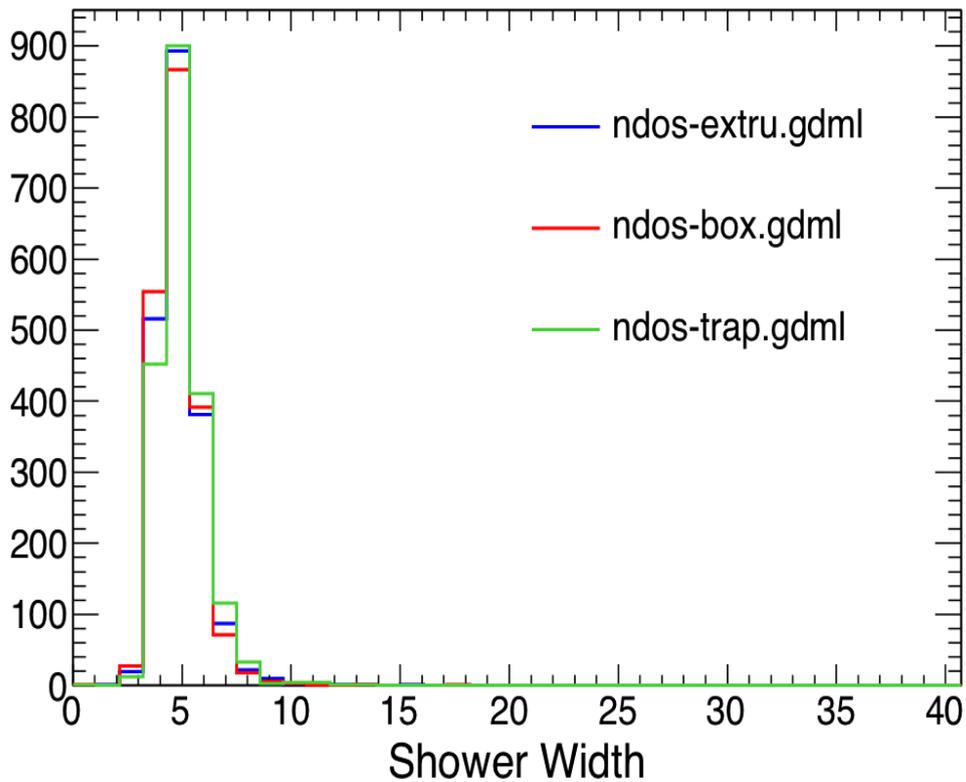
Comparison of ndos-trap.gdml filled with vacuum and air



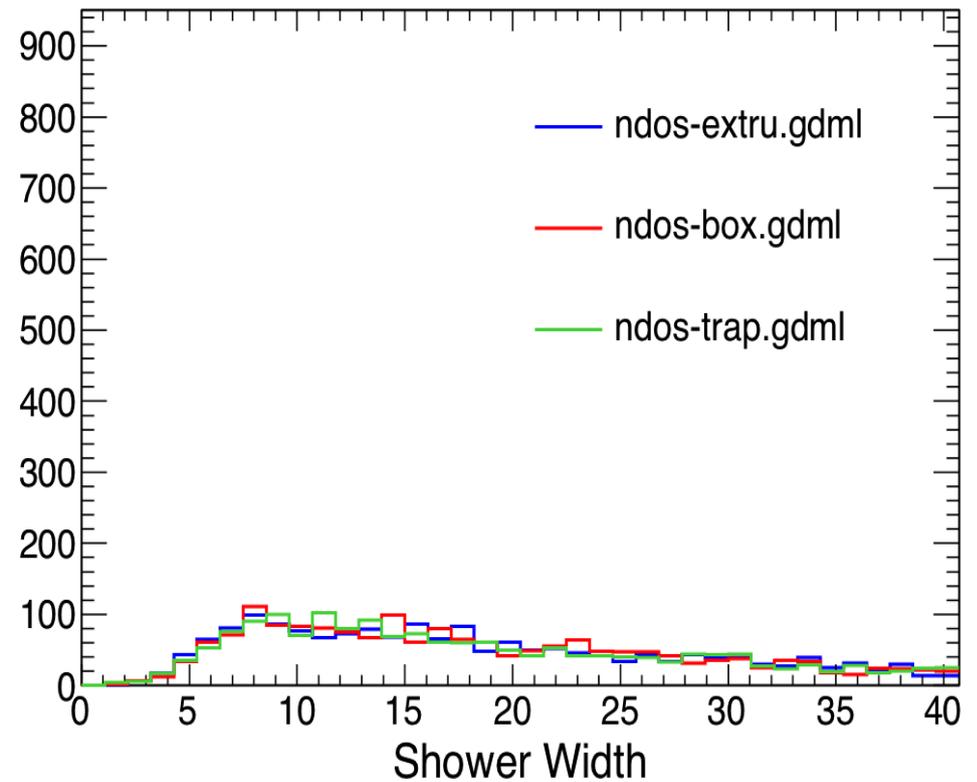
Comparison of 3 Geometries



Comparison of geometries filled with vacuum



Comparison of geometries filled with air



Summary & Conclusions



	vacuum			air		
Geometry	ndos-extru	ndos-box	ndos-trap	ndos-extru	ndos-box	ndos-trap
Mean Width (cm)	4.908	4.847	4.998	21.91	21.87	22.30
% change from ndos	0	-1.24	1.83	347	346	355

- We don't observe a difference between shower widths in the three NDOS geometries with vacuum
- We see adding air to the three versions of NDOS geometries consistently increase the average width by a factor of 4.5
- There is definitely a problem with NDOS geometries with air; causes are still undetermined. Can you help?