Simulating Outrigger Tanks around HAWC

How to configure individual tanks?

How to arrange outrigger array?

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Summer 2015

Background/Motivation

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

Mapping the Northern Sky in High-Energy Gamma Rays

HAWC Observatory

HAWC operates day and night, providing a large field of view for the observation of the highest energy gamma rays.

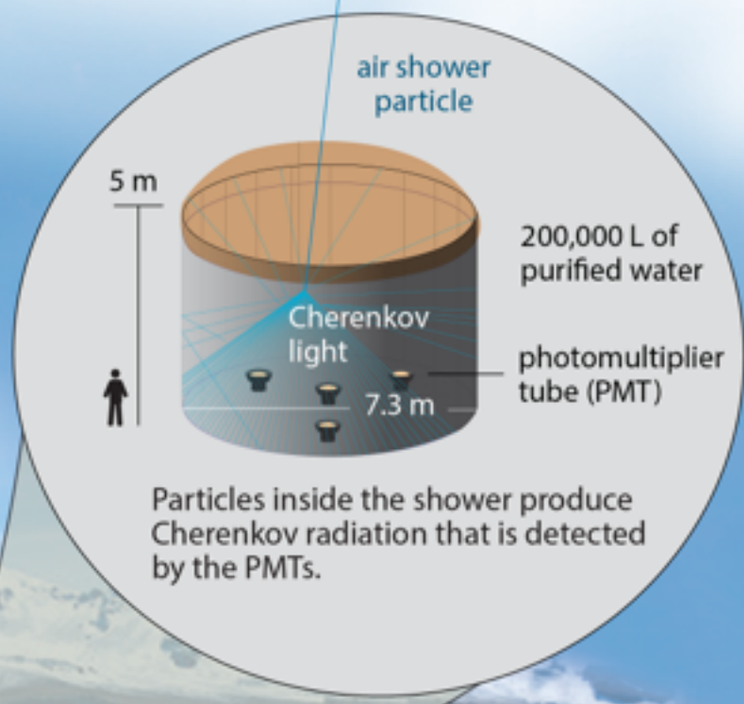
Pico de Orizaba
(5,626 m)

HAWC is located at 4,100 m above sea level, covering an area of 20,000 m^2.

150 m

Water Cherenkov tank

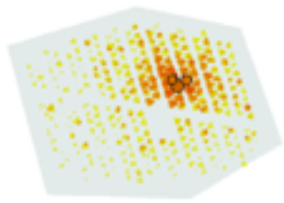
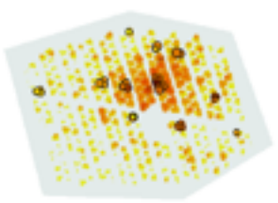
HAWC comprises an array of 300 tanks that record the particles created in gamma-ray and cosmic-ray showers.

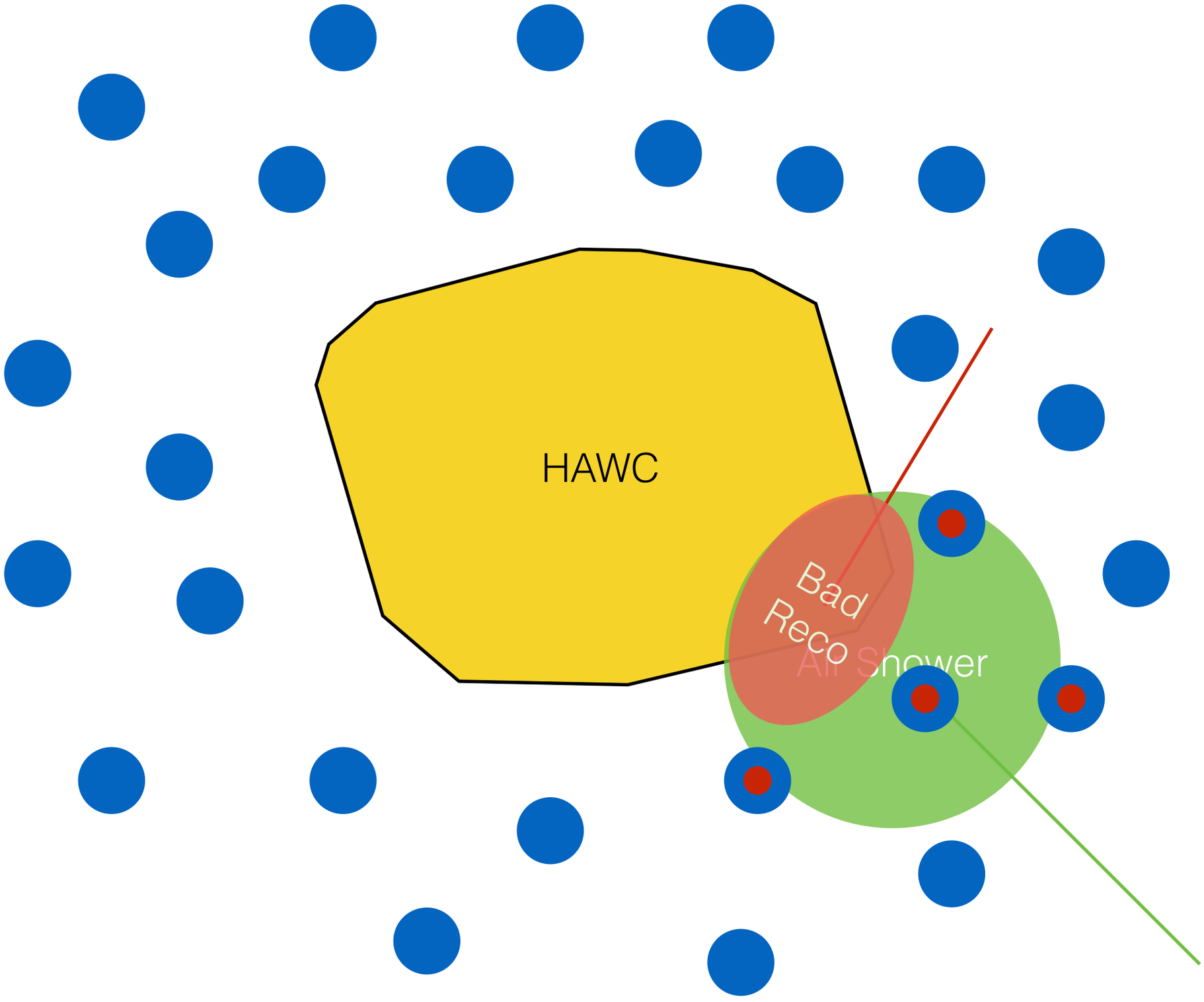


Particles inside the shower produce Cherenkov radiation that is detected by the PMTs.

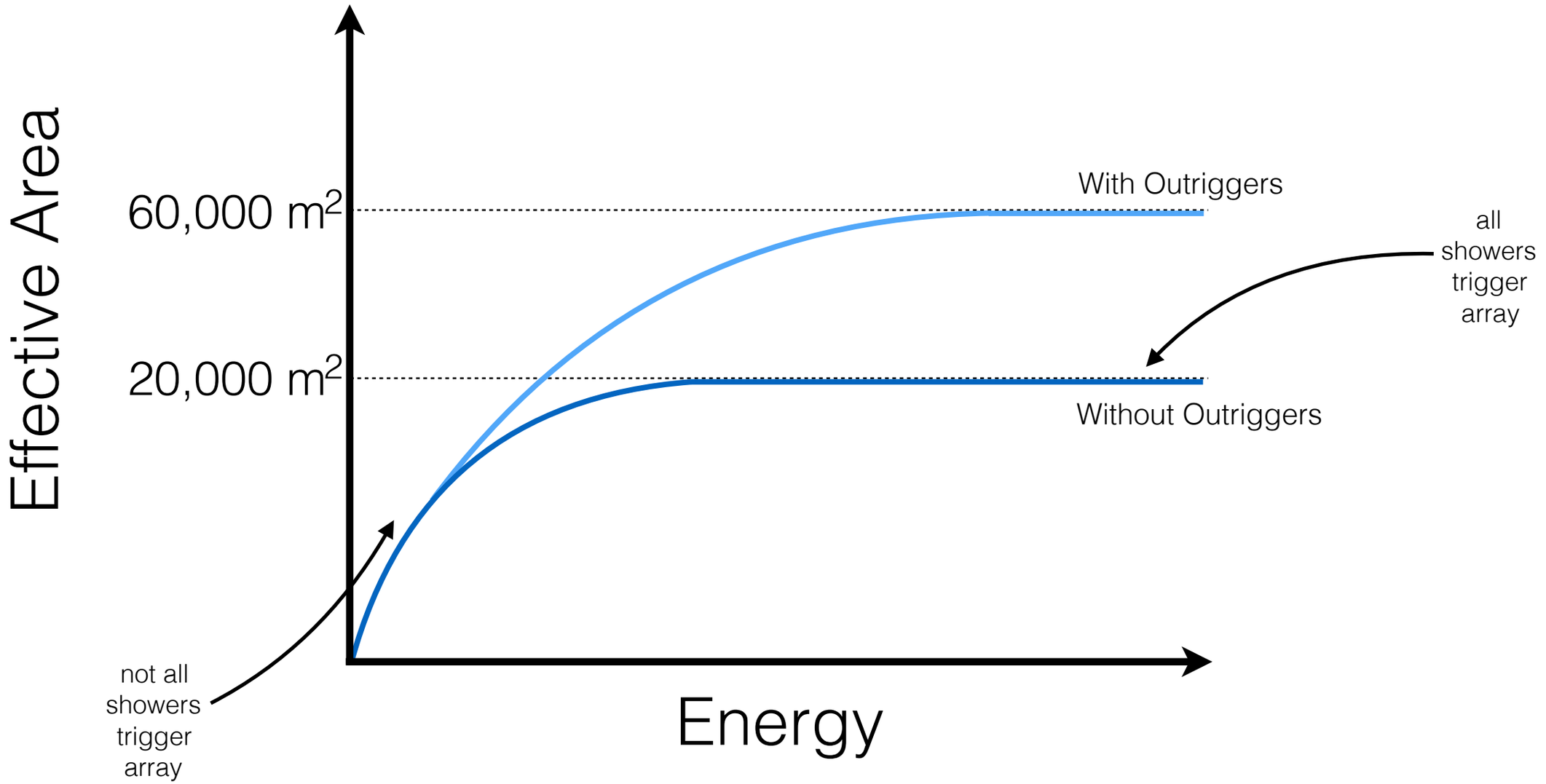
Gamma rays vs cosmic rays

HAWC selects gamma rays from among a much more abundant background of cosmic rays.

gamma-ray shower	cosmic-ray shower
	
"hot" spots concentrate around the core	"hot" spots are more dispersed


HAWC
Bad
Reco
Air Shower

Quantifying How the Outriggers Will Improve HAWC



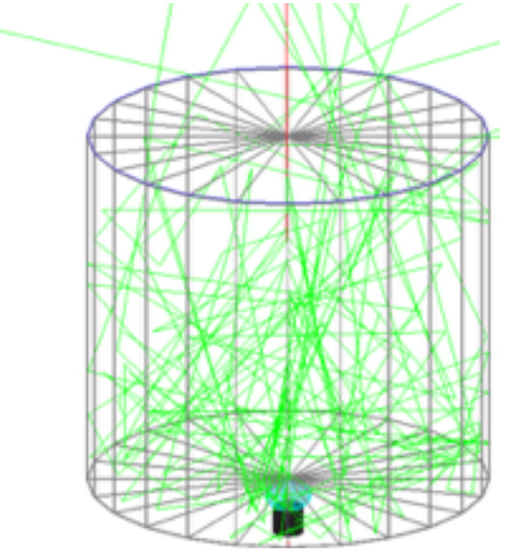
Increase effective area by a factor of 3!

How should these tanks be configured?

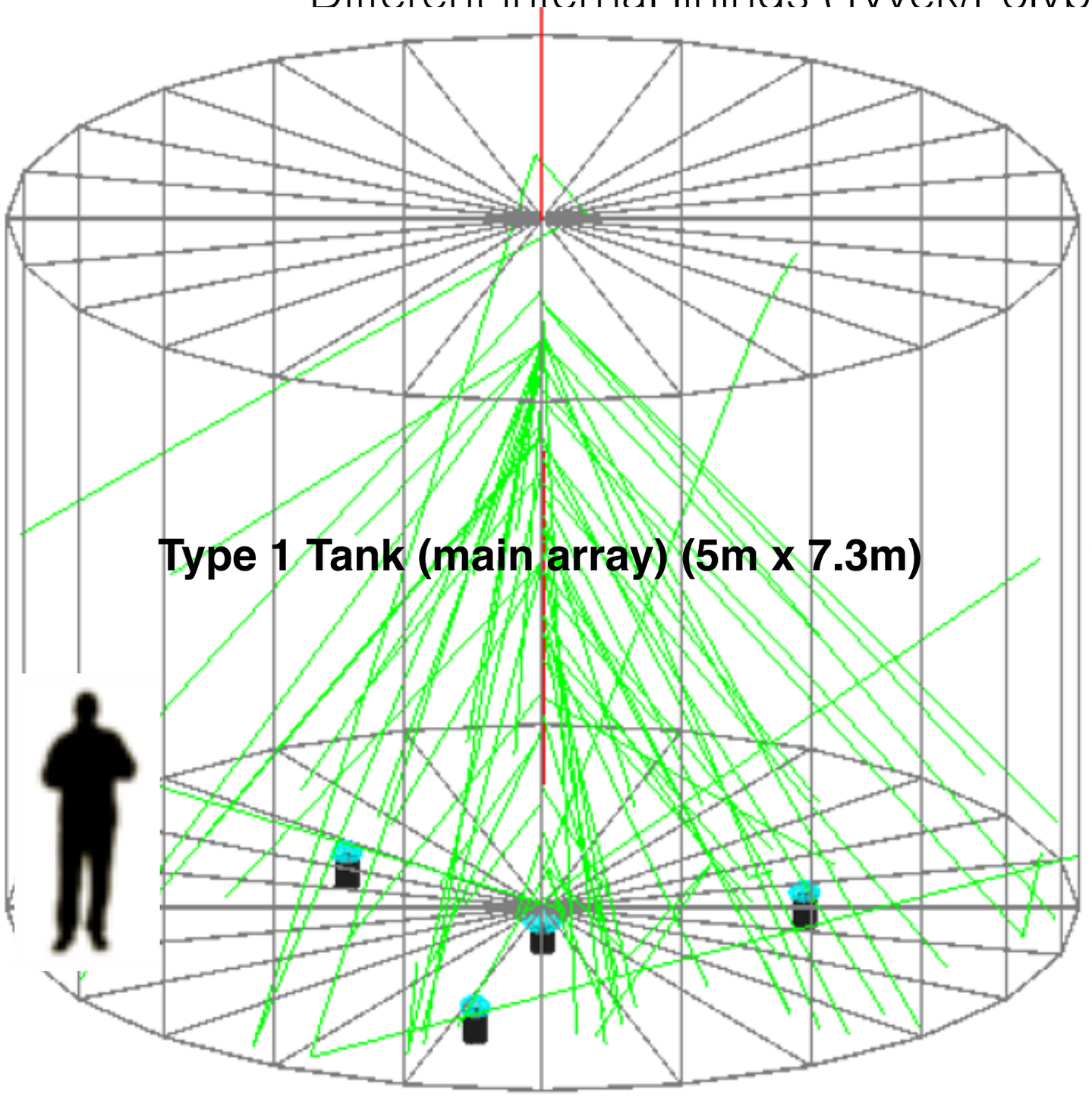
How should the tanks be arranged?

Different types of tank sizes (height x diameter):

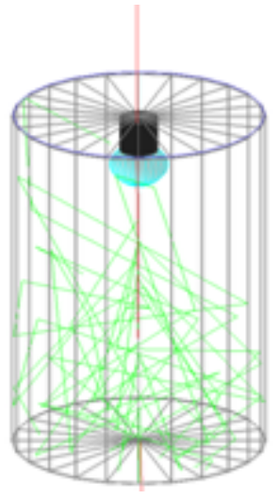
- Different PMT configurations (up/down facing)
- Different internal linings (Tyvek/Polypropylene)



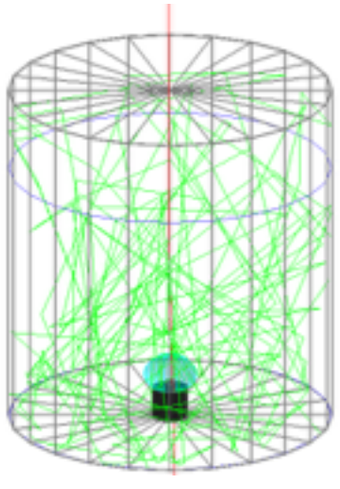
“Type 2” Tar



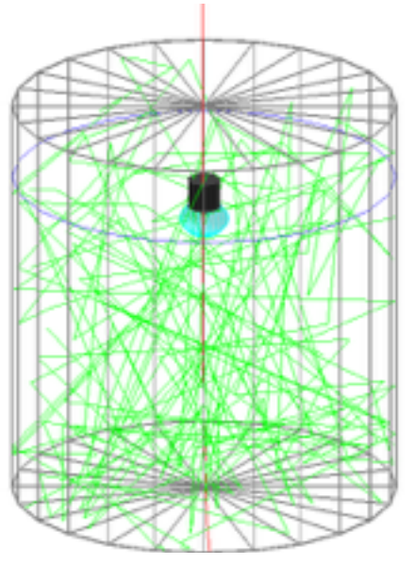
Type 1 Tank (main array) (5m x 7.3m)



1.5m x 1.1m)



“Type 4” TVC-2500 I Tank (1.65m x 1.55m)



“Type 5” TOL-3500 I Tank (2.1m x 2.0m)

Very easy to find large quantities of these kinds of water tanks in Mexico

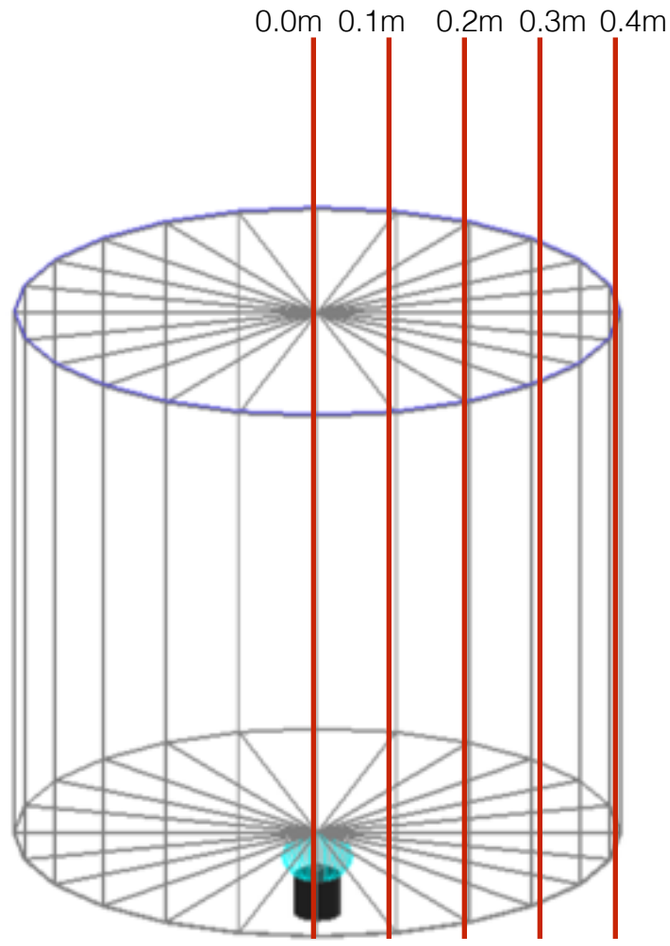
Relatively cheap addition to produce a significant improvement

Single Tank Simulation Using GEANT4

Simulate incoming vertical particles

- Muons
  - 100 MeV
  - 500 MeV
  - 1 GeV
  - 5 GeV

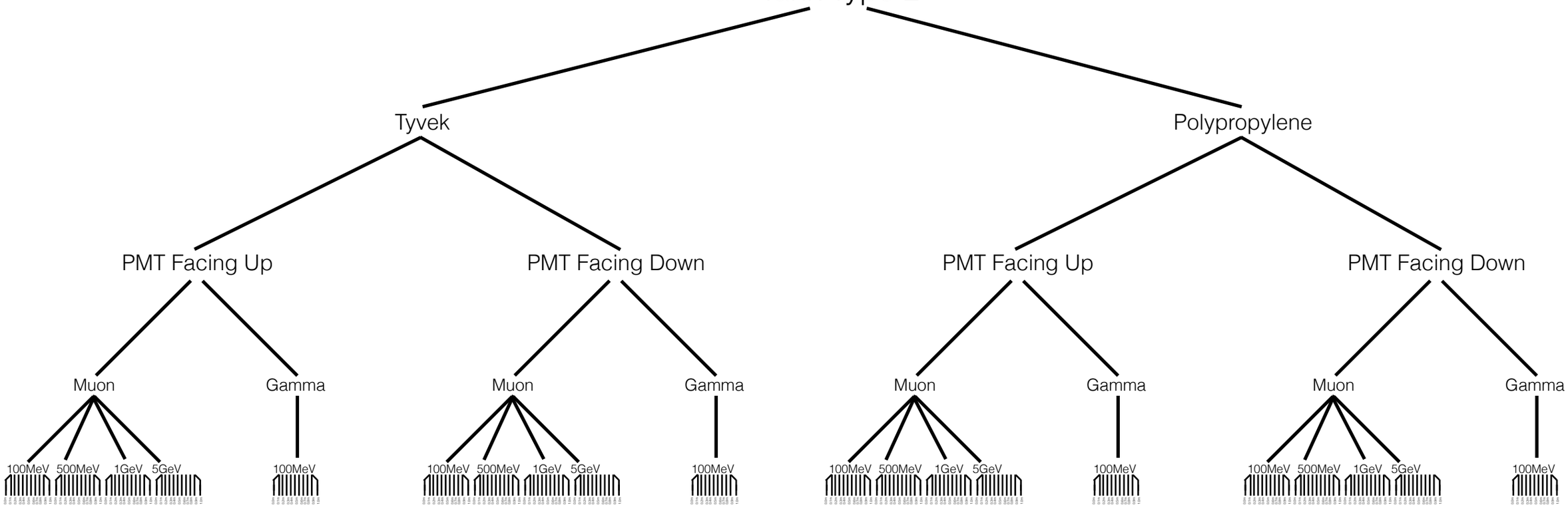
- Gammas
  - 100 MeV



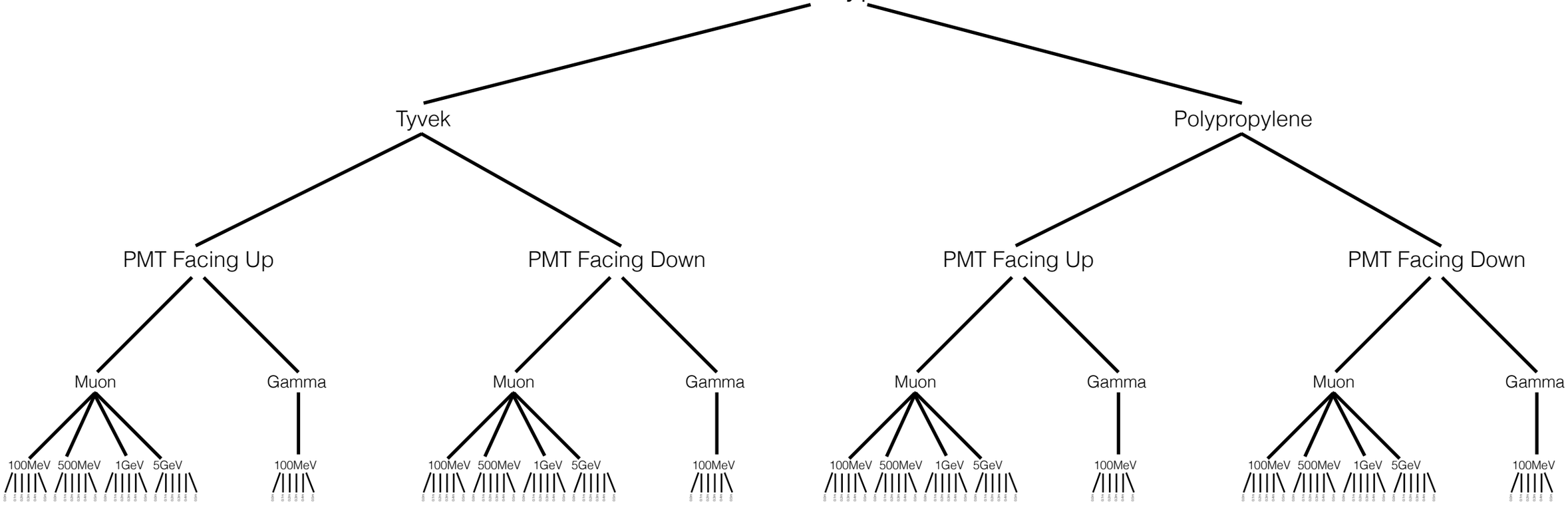
Inject 1000 of these particles
into the tank at varying radial distances
from the center of the tank…

… for each tank type/PMT orientation/tank lining/particle type/particle energy combination

Tank Type 2



Tank Type 3

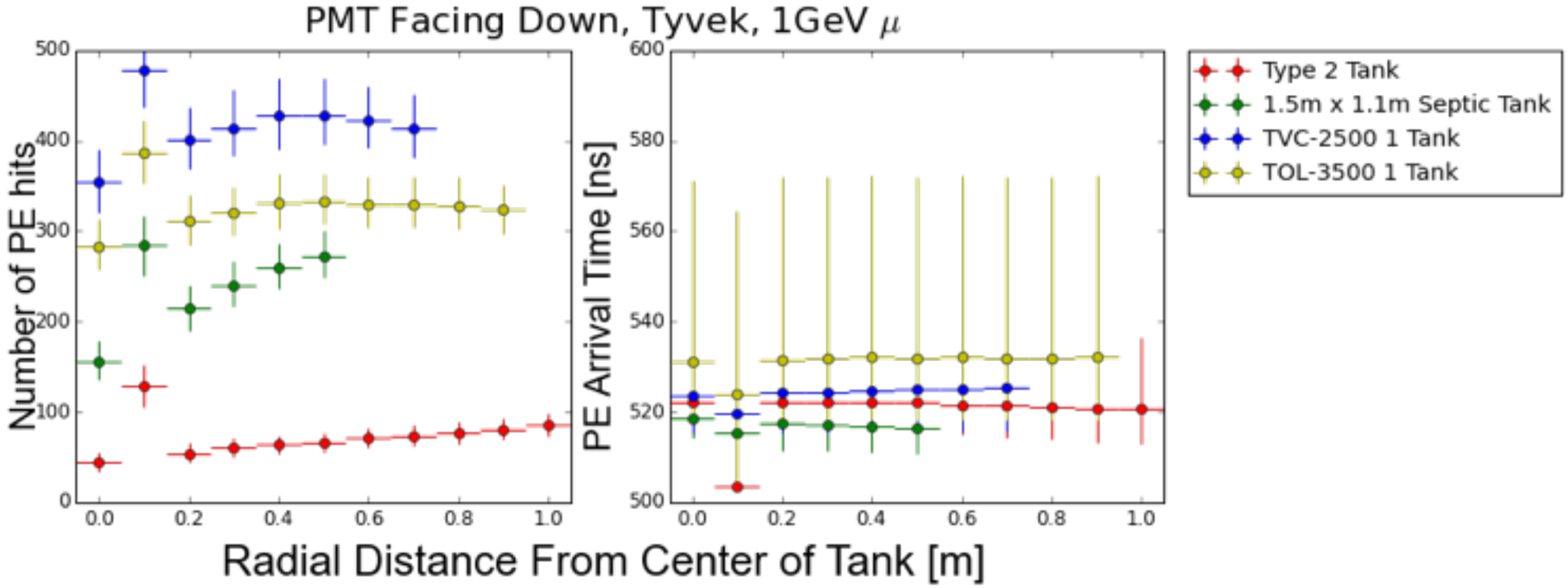


… and again with type 4 and 5

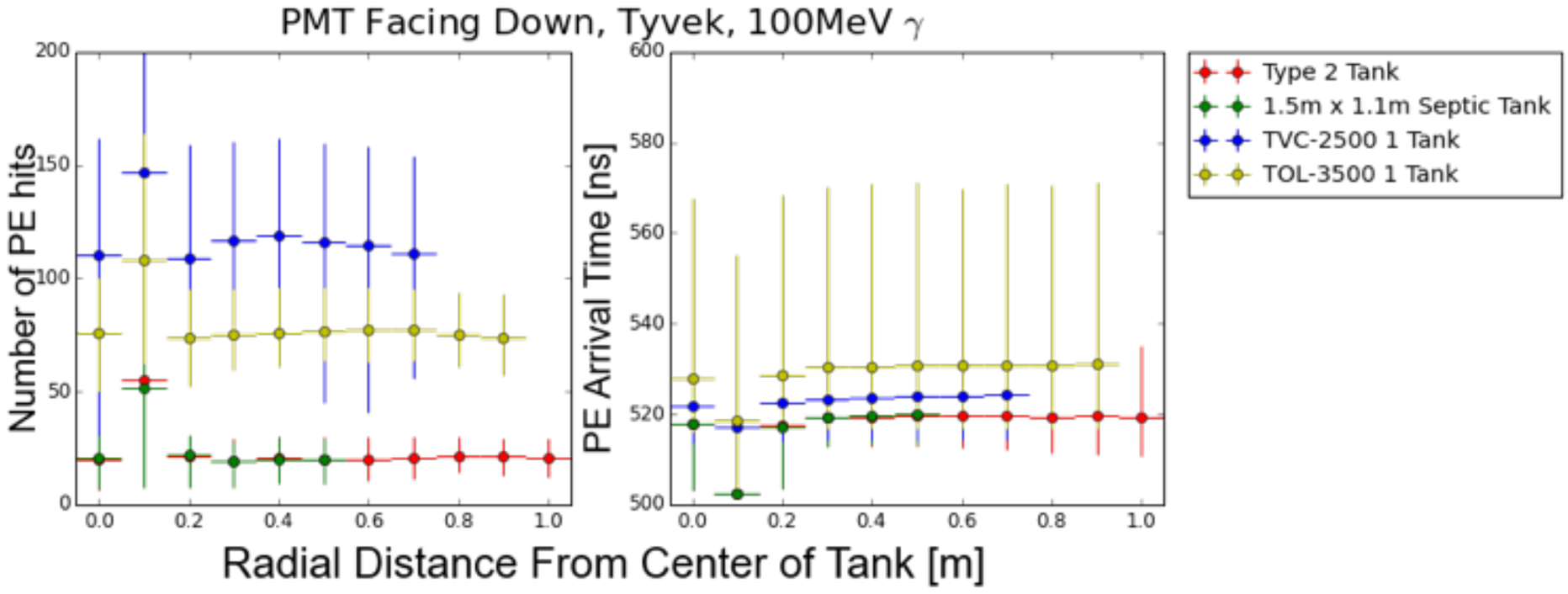
700 runs, 700,000 particles

Tank Comparisons: Plot all four tank types on top of each other

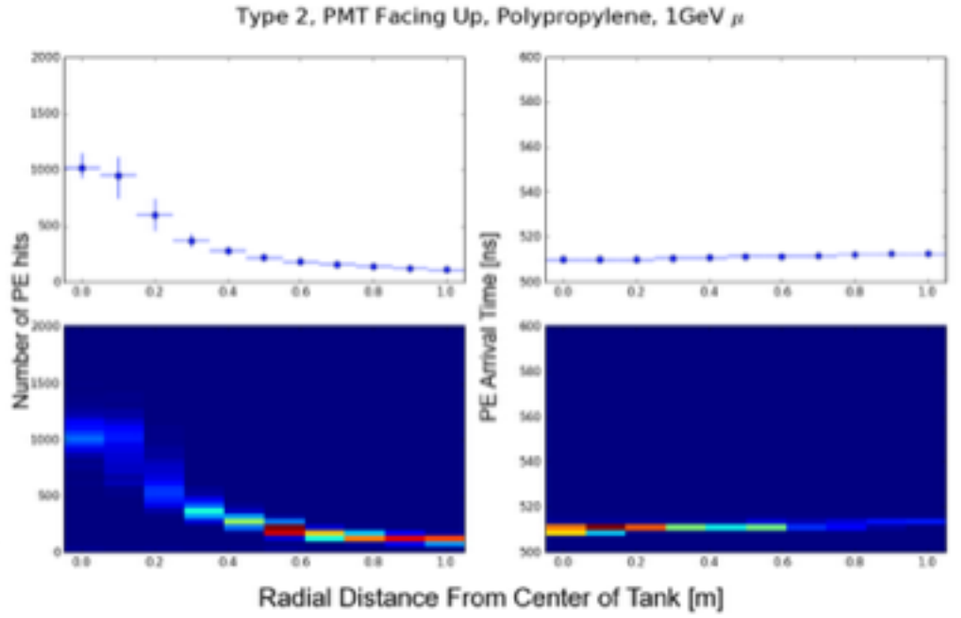
Example Muon:



Example Gamma:



General Trends

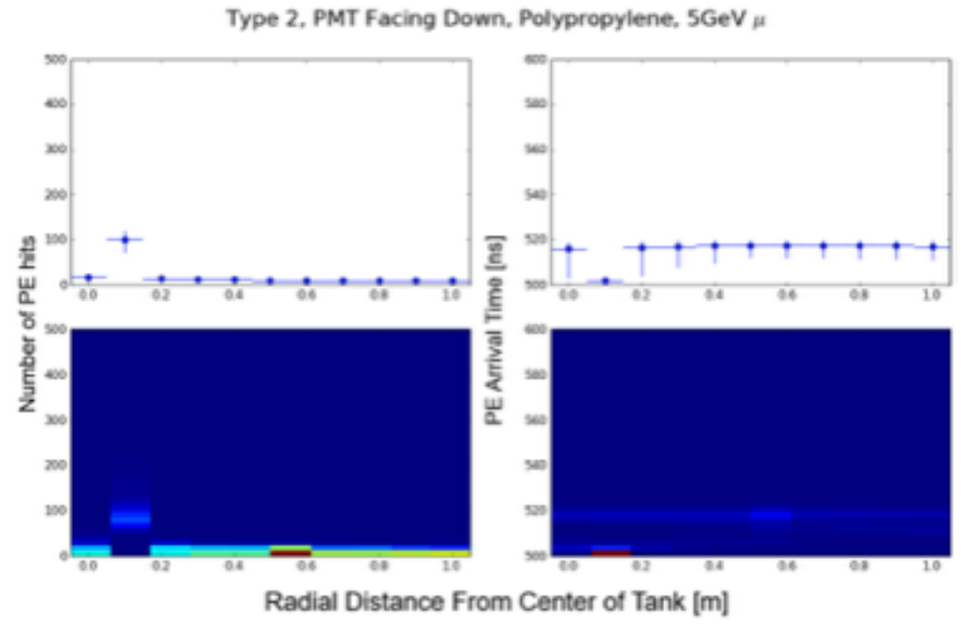


More light with upfacing

- but numPE falls off with radial distance
- Upfacing with Polypropylene is essentially the same as up facing with Tyvek, but with a bit less overall light

Downfacing PMT shows steady (and sometimes increasing) numPE with radial distance

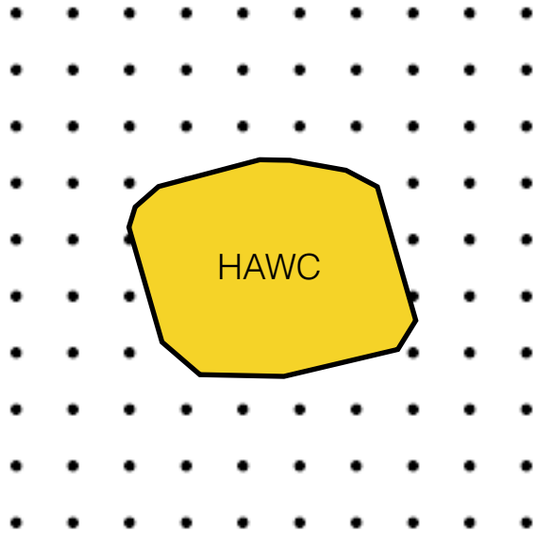
- low levels of light
- very low levels of light with Polypropylene



Use Upfacing tanks with Polypropylene, or Downfacing Tanks with Tyvek

How should we arrange the outrigger array?

Place the tanks in a grid-layout?



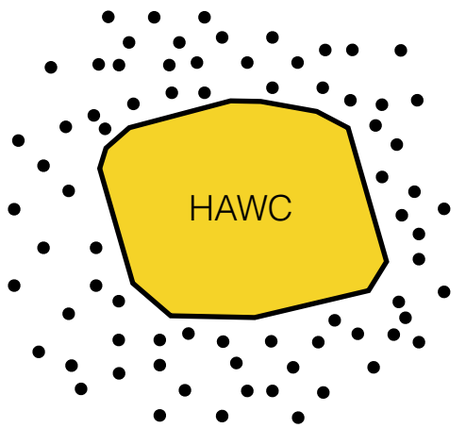
Can create lane artifacts

Random distribution?

Could come out more concentrated and uniform, might not

Less chance for arrangement bias

Not predictable



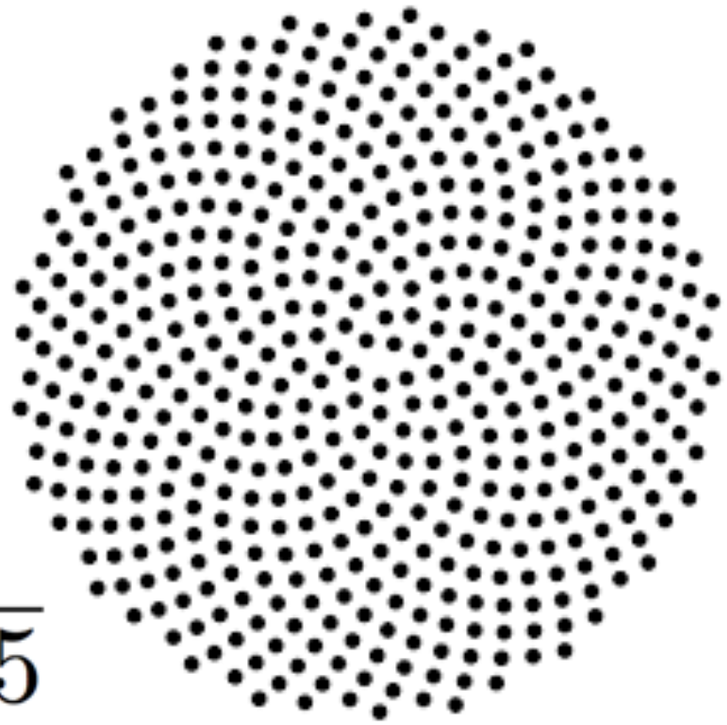
Want something with uniform, efficient coverage with no arrangement bias that is predictable

The Outrigger Array

Using a Fermat Sunflower Spiral pattern to arrange the outrigger tanks

$$r = s\sqrt{n}$$

$$\theta = \frac{2\pi n}{g^2}$$



where g is the golden ratio: $g = \frac{1+\sqrt{5}}{2}$

PS10 Solar Array in Spain

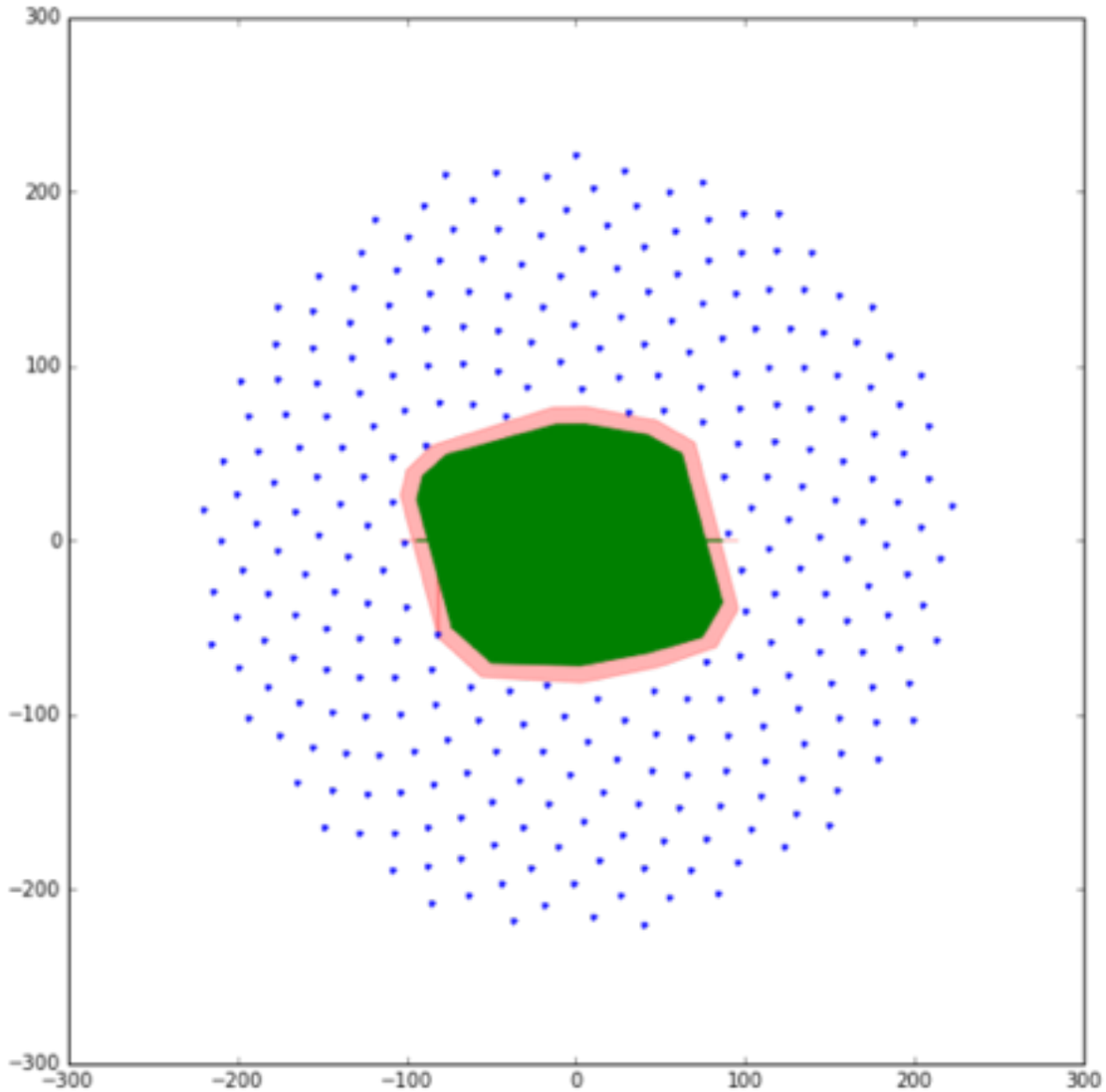
Given r and theta, you get

$$x = r\cos\theta$$

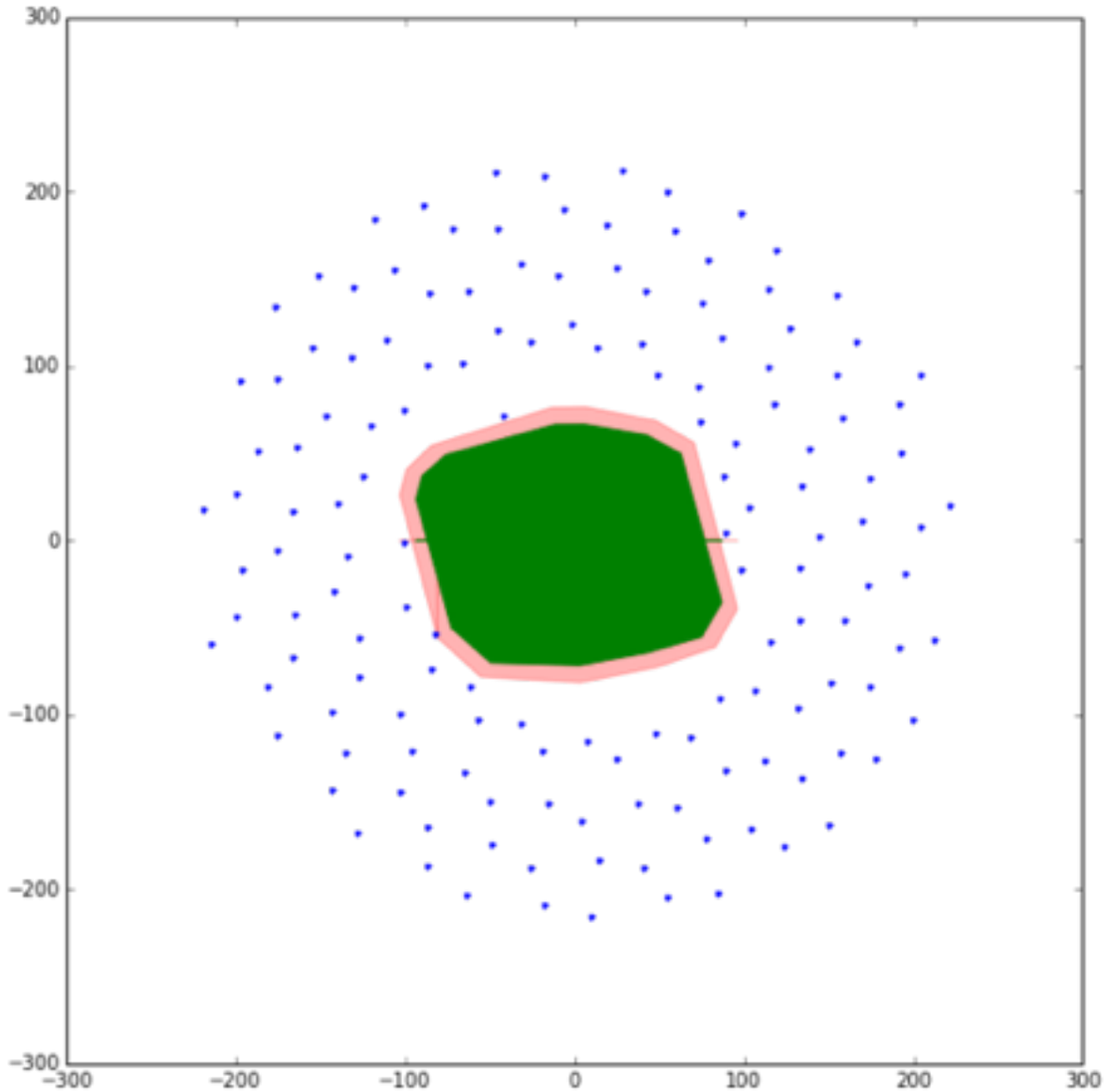
$$y = r\sin\theta$$

Scale = 12

Right side arrangement has the cut:
idx % 4 == 0 or idx+1 % 4 == 0



297 tanks



146 tanks

- No lane artifacts or biases, predictable, perfect uniform coverage
…and it looks cool

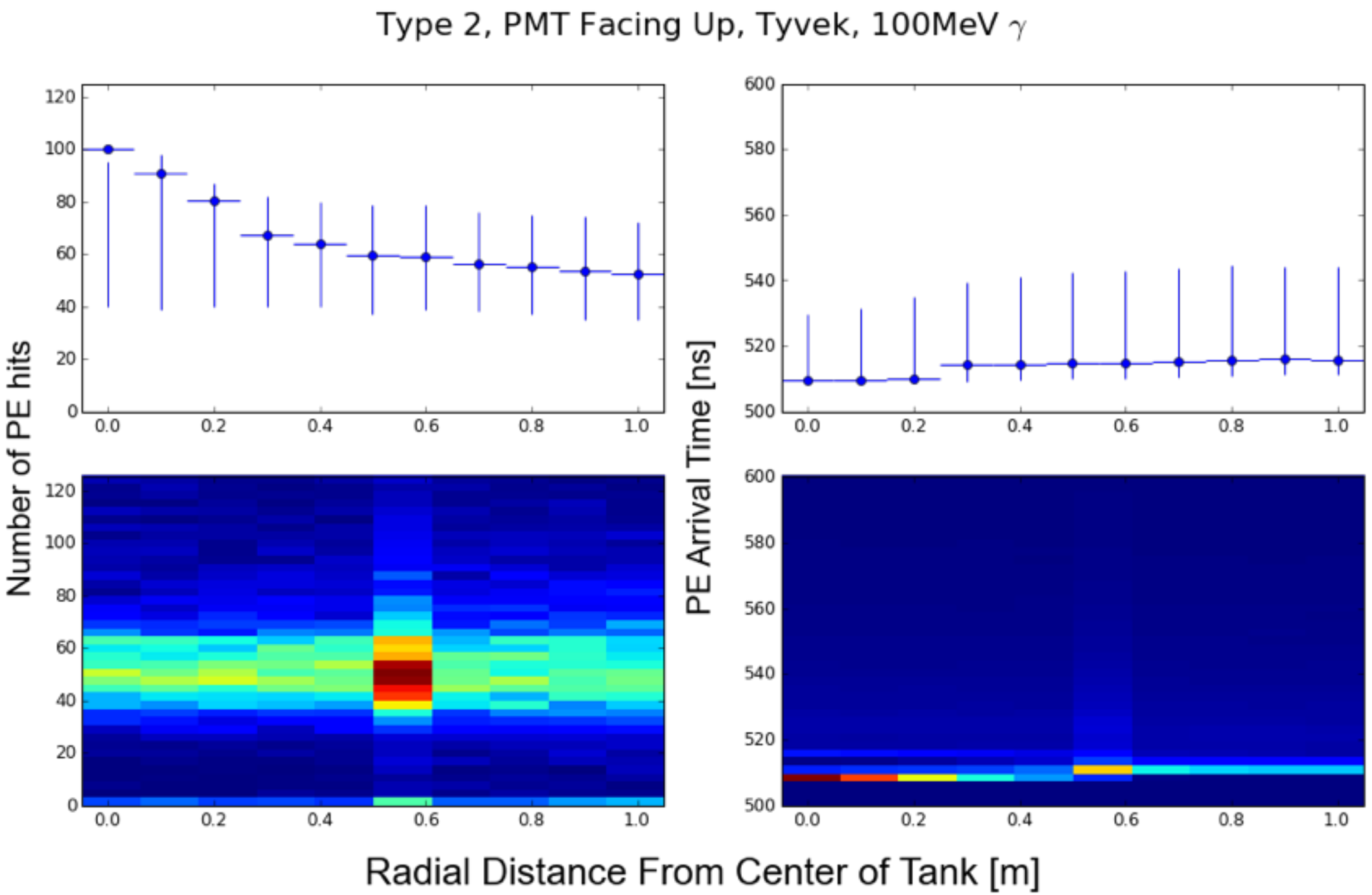
Conclusions

- General trends observed the tanks
  - More light observed in up-facing PMTs
  - More uniformity observed in down-facing PMTs with Tyvek-lined tanks
- Designing an outrigger array
  - Used sunflower spiral with s=12
  - Tried to come up with a rule to “decimate” the array and mask out some fraction of the channels

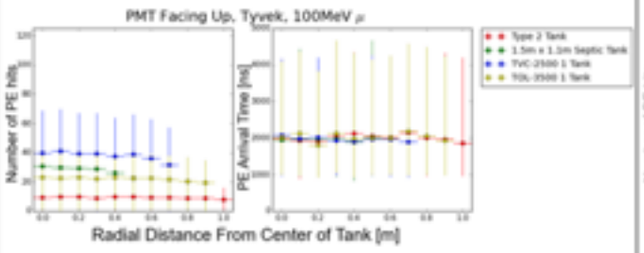
Extras

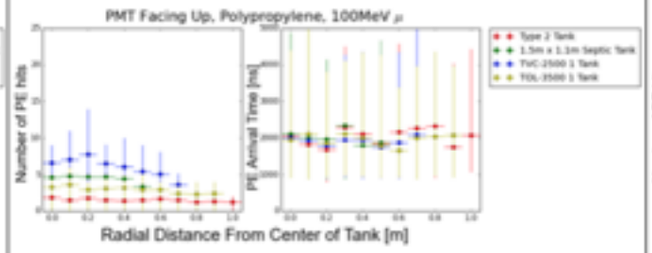
Plot light collected by PMT and arrival time distribution of collected photons as function of radial separation

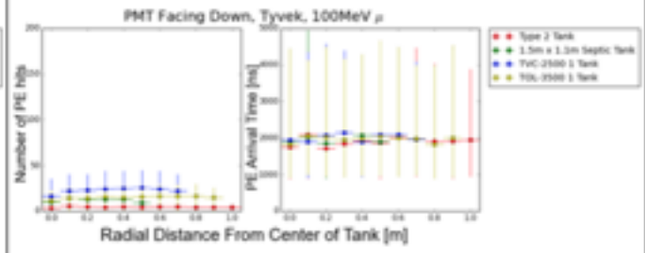
Example Gamma Simulation:

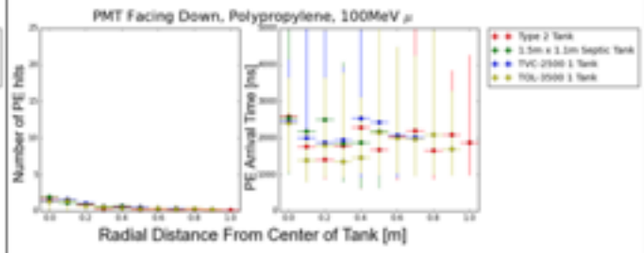


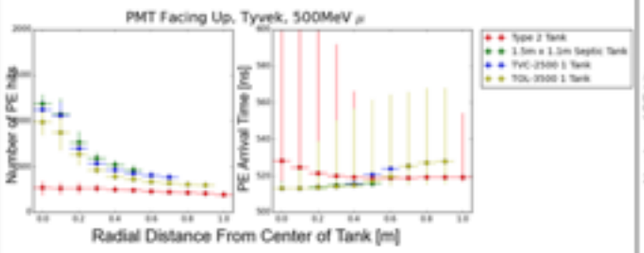
Muons

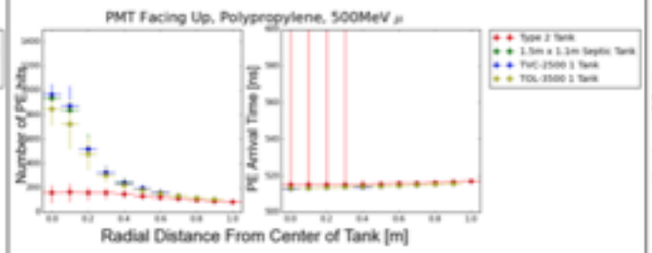


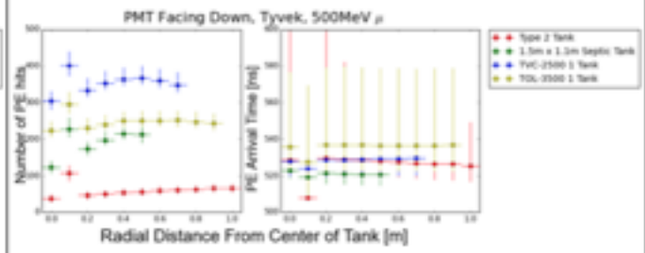


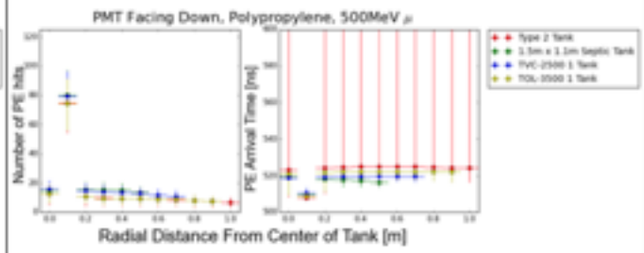


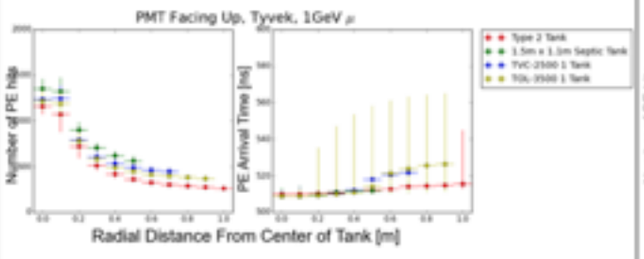


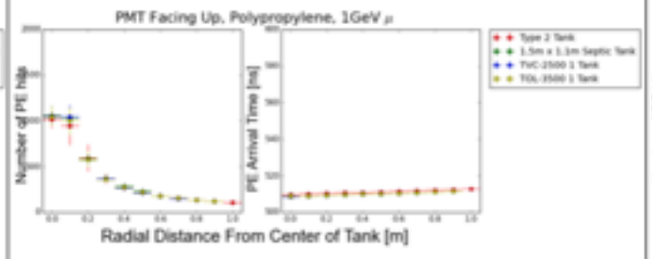


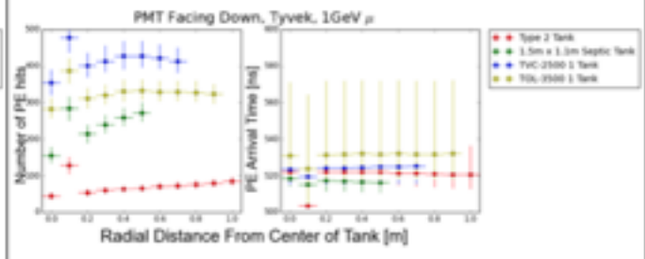


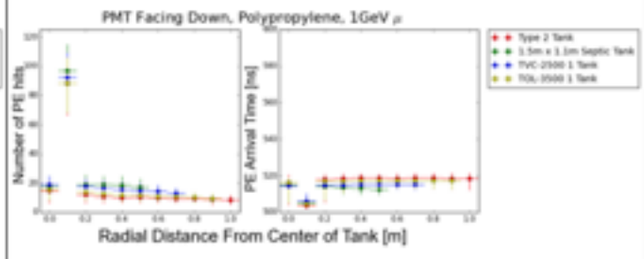


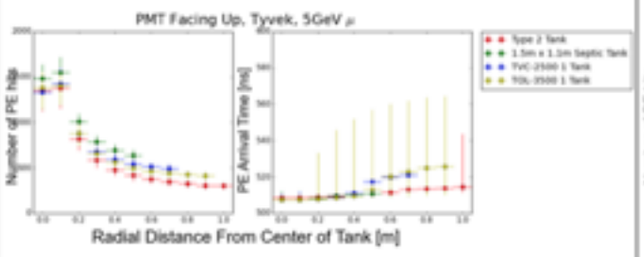


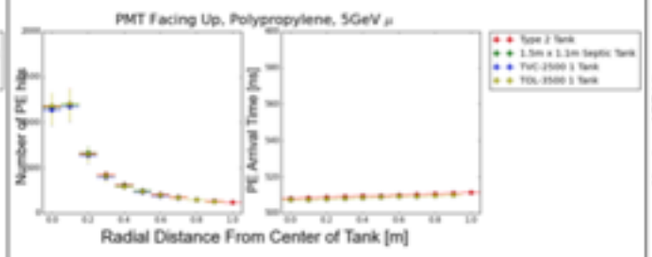


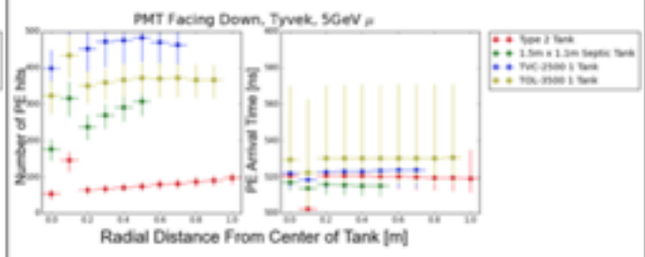


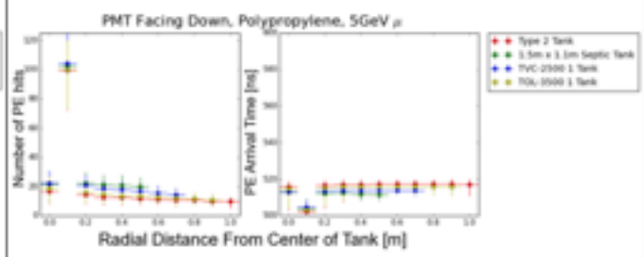




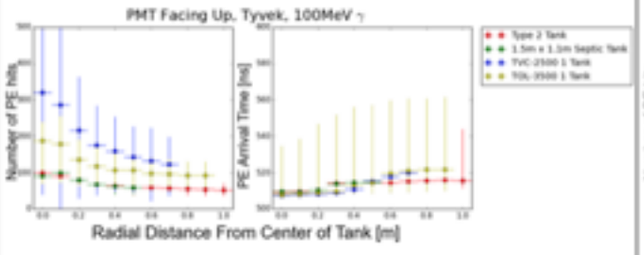


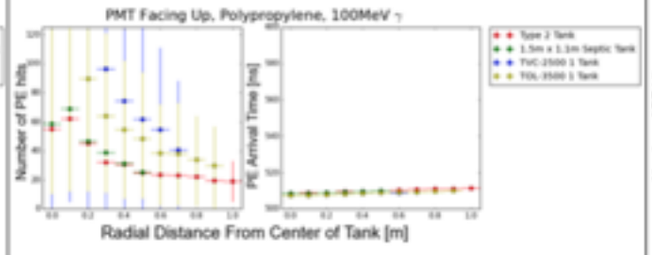


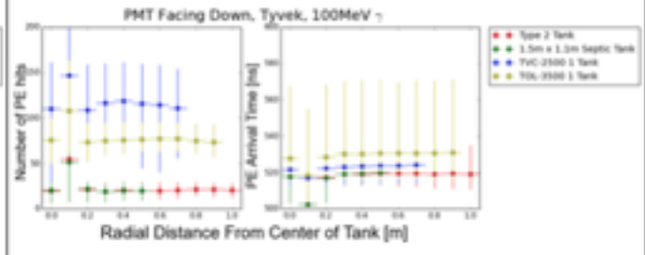


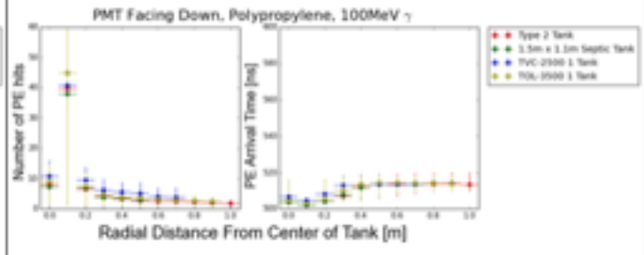


Gammas



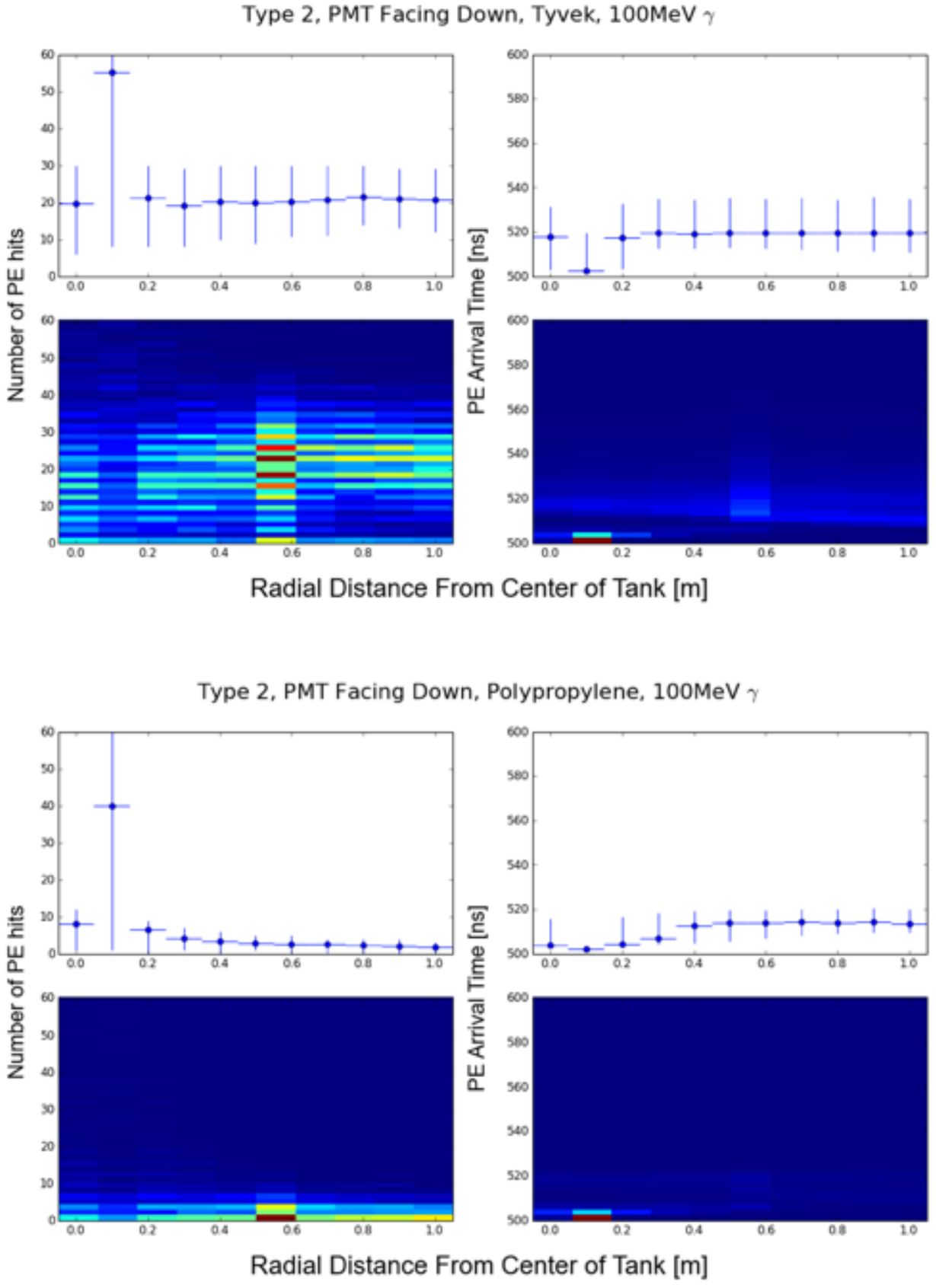


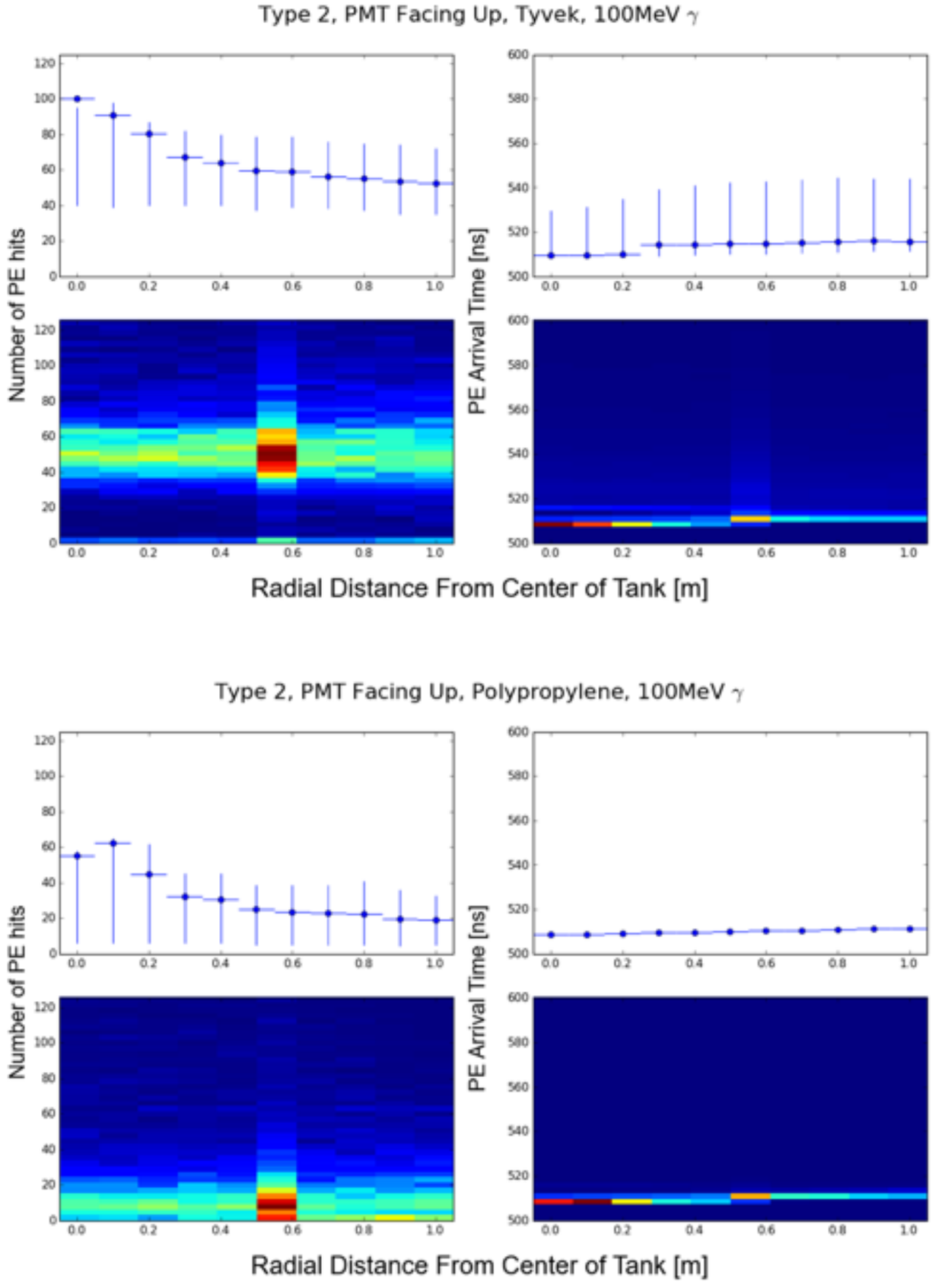




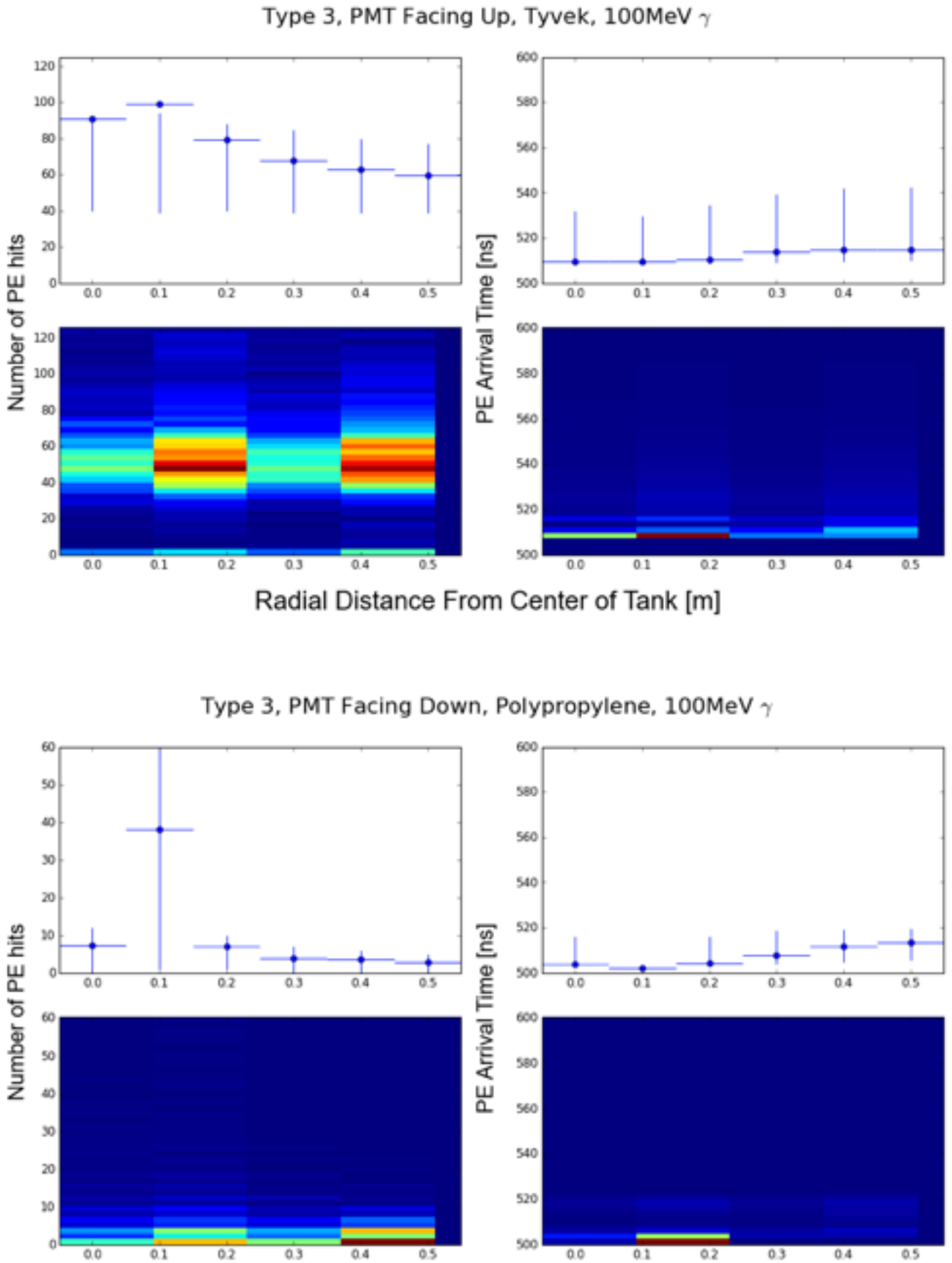
Up, Tyvek	Up, Polypropylene	Down, Tyvek	Down, Polypropylene

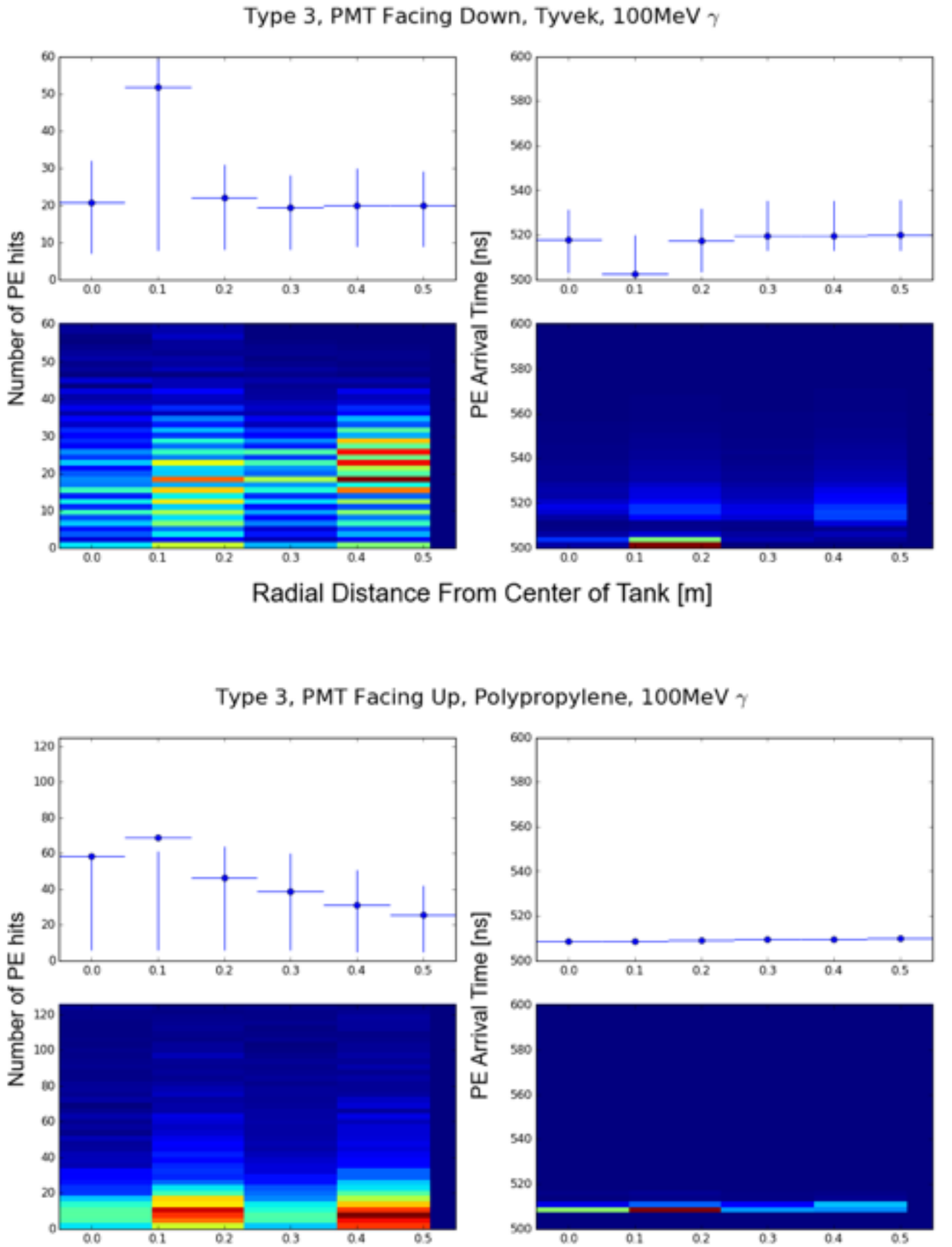
Type 2 Tank combinations:



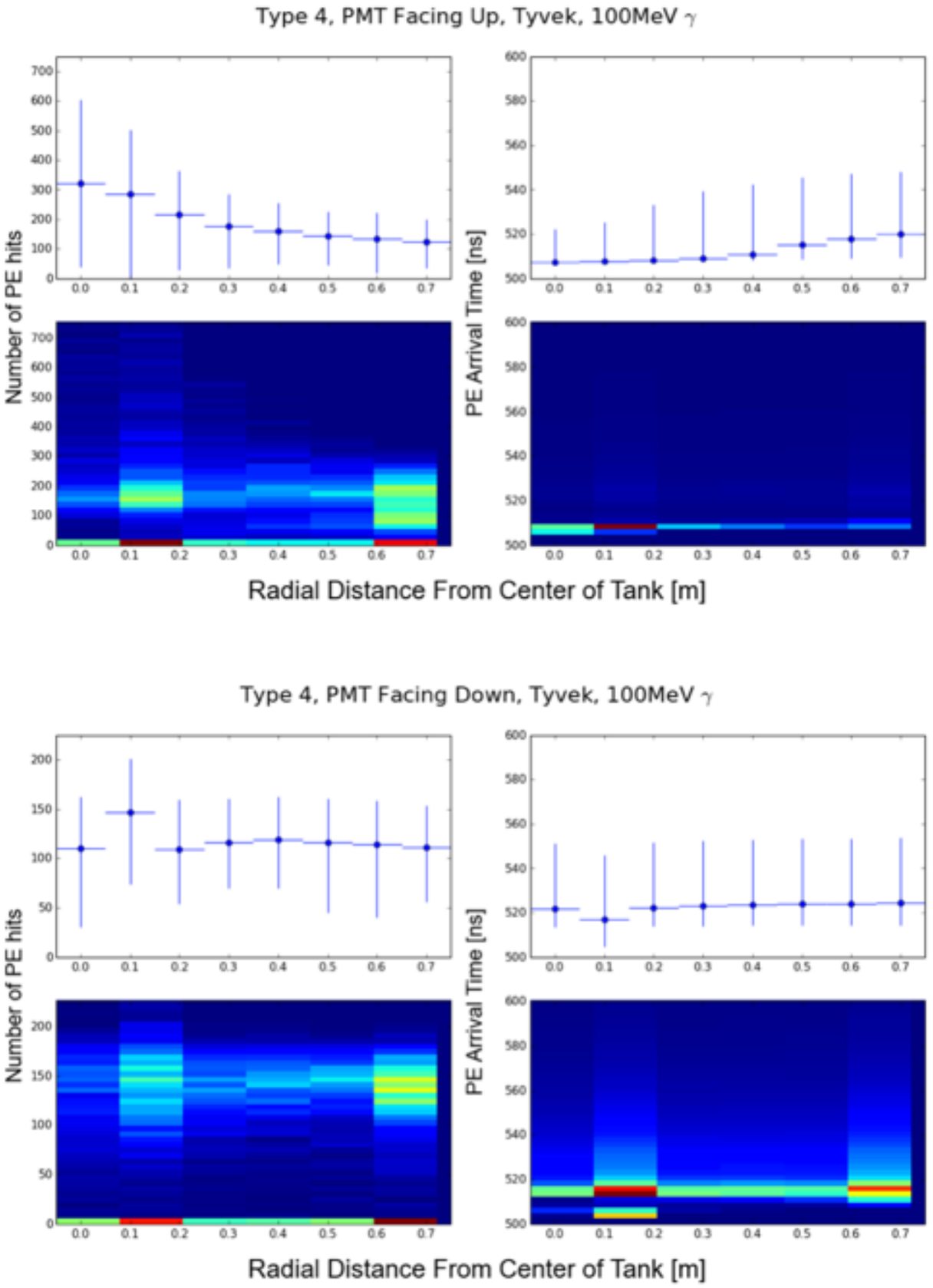


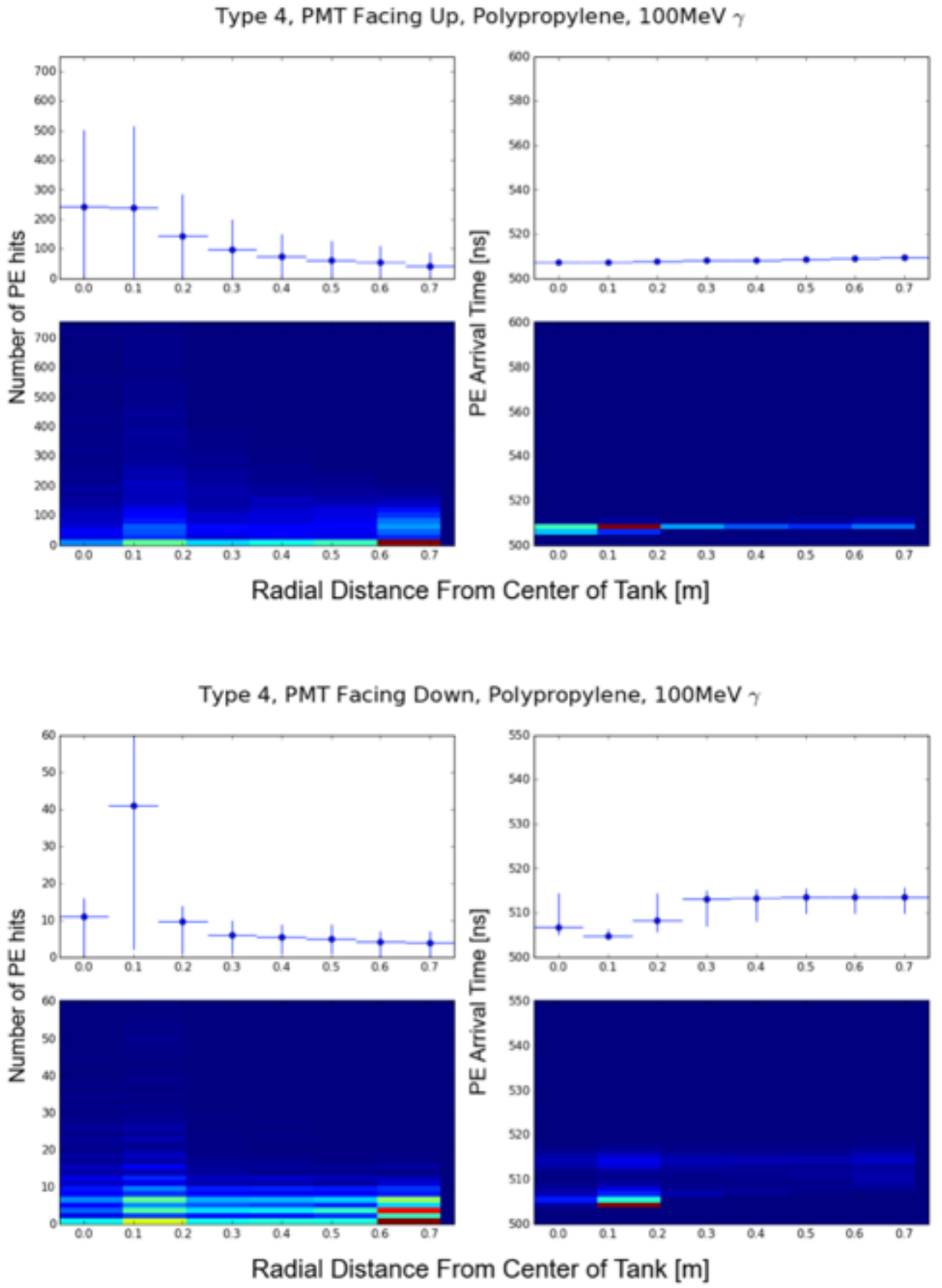
Type 3 Tank combinations:



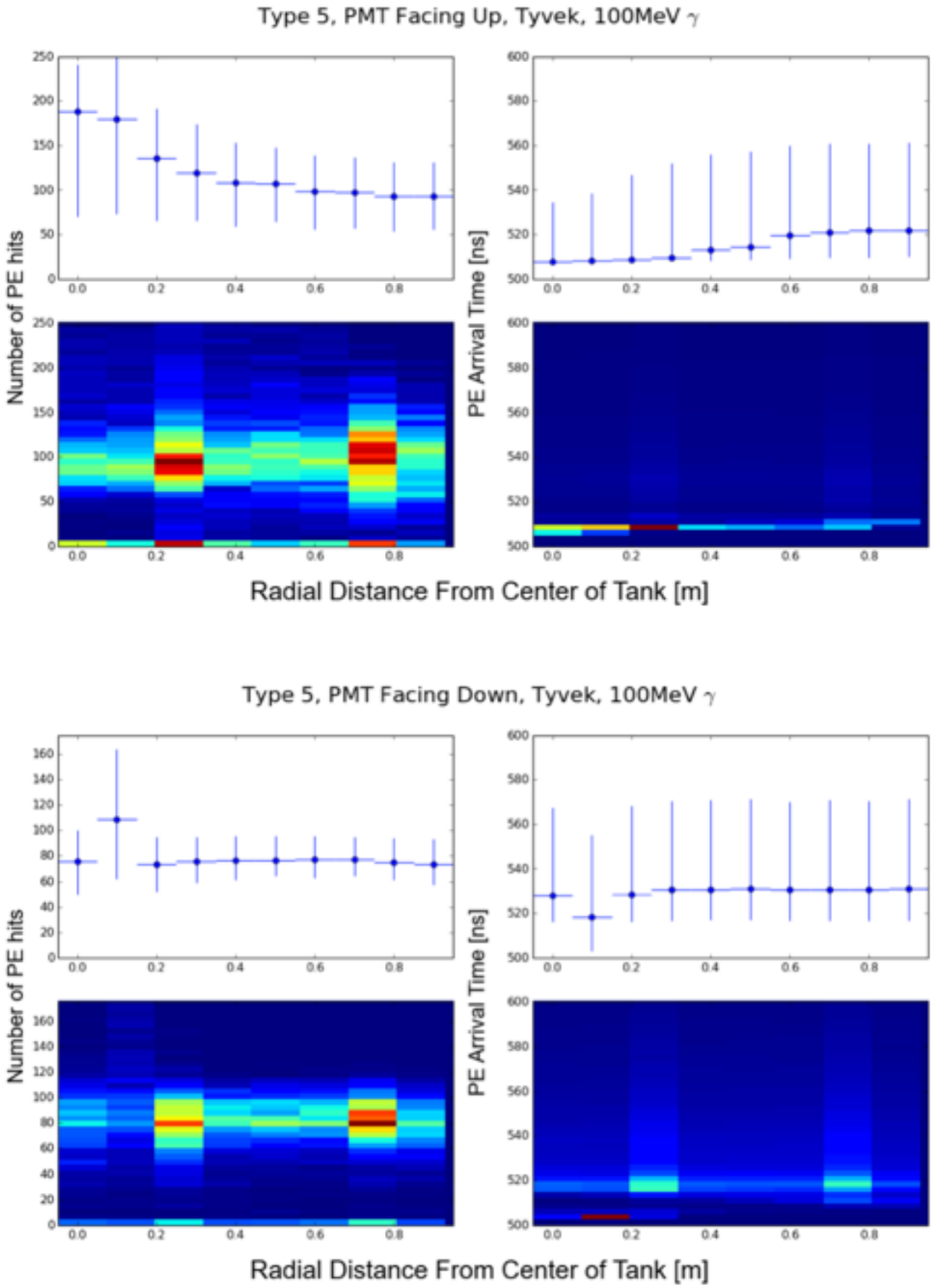


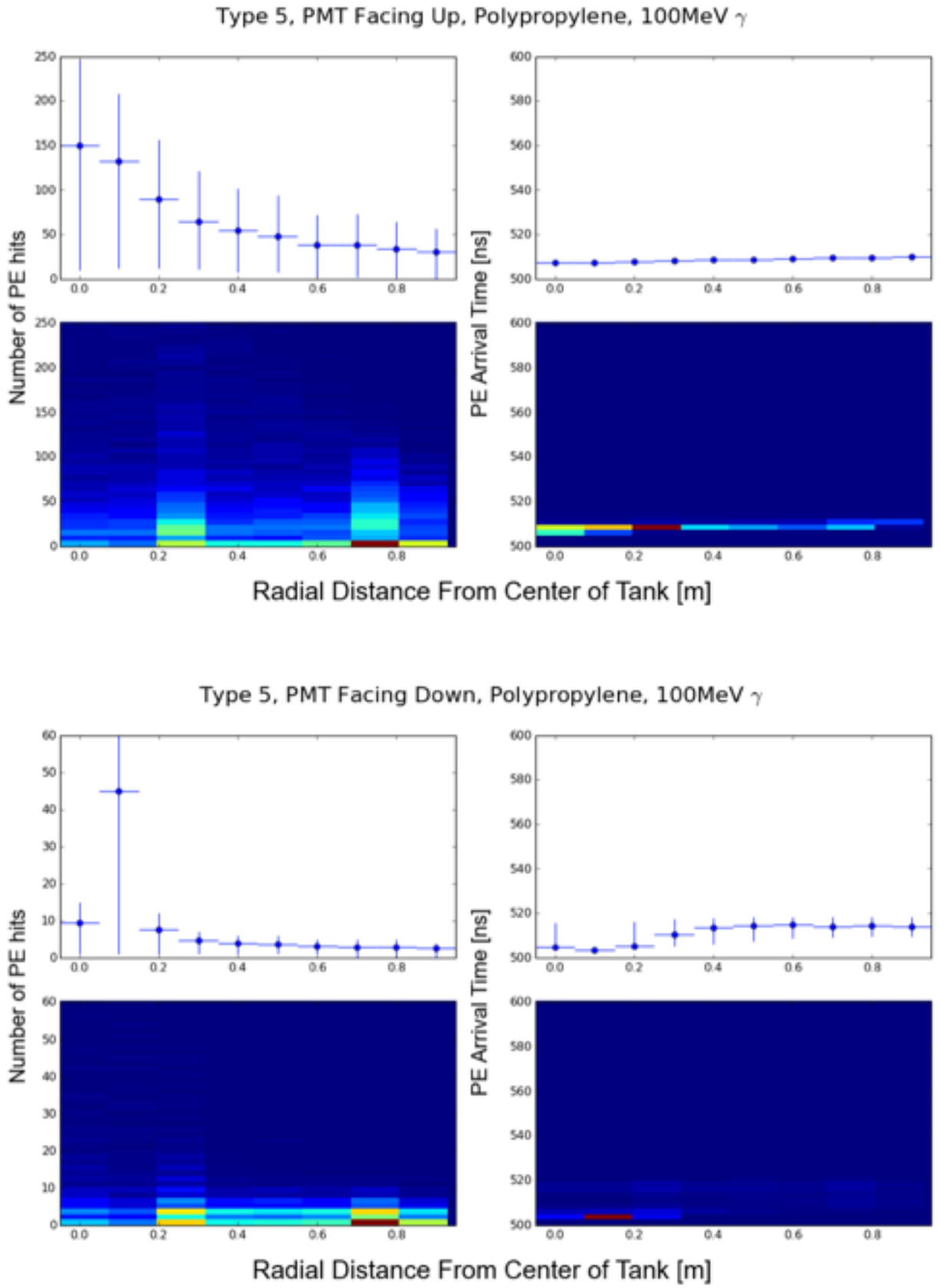
Type 4 Tank combinations:



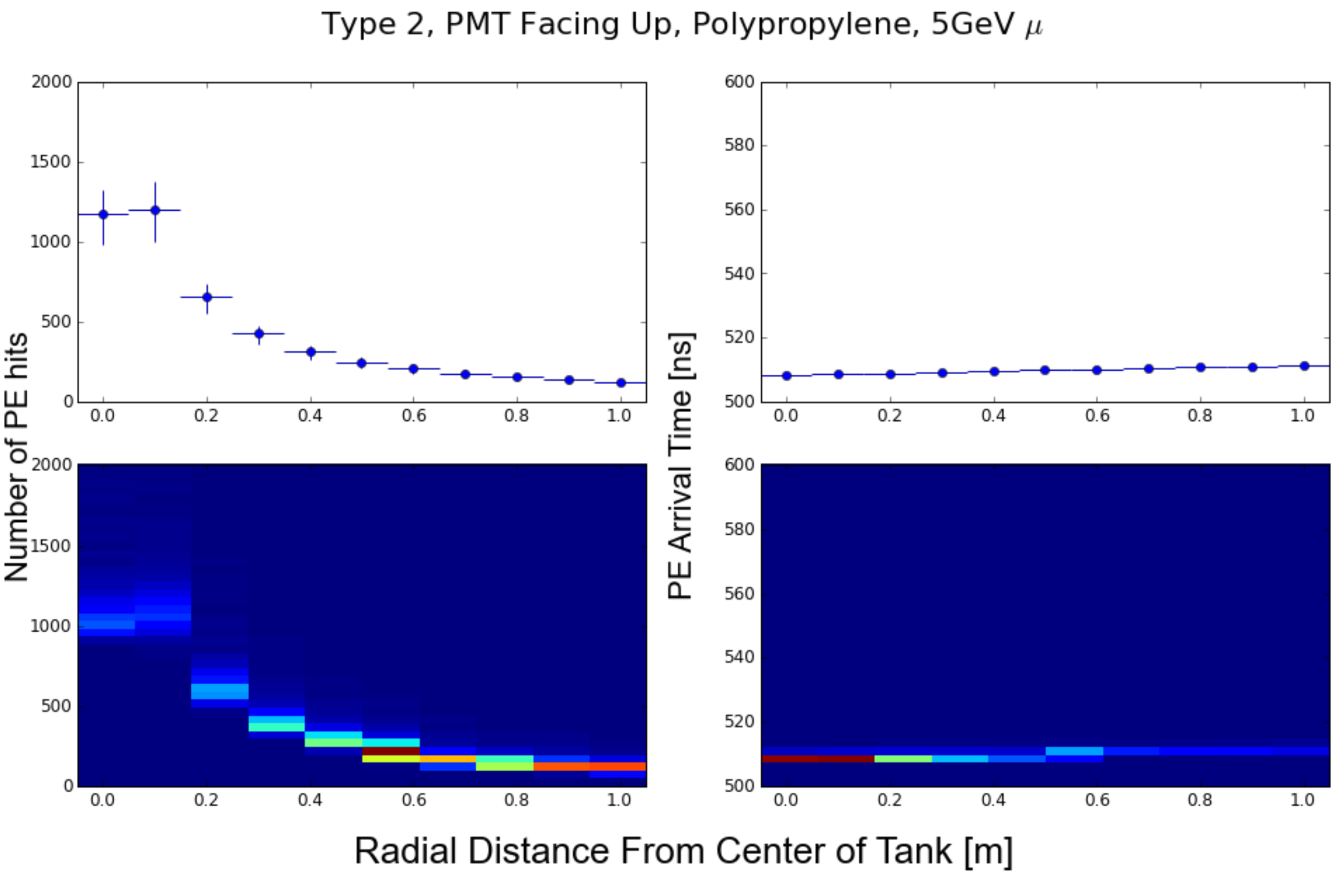


Type 5 Tank combinations:



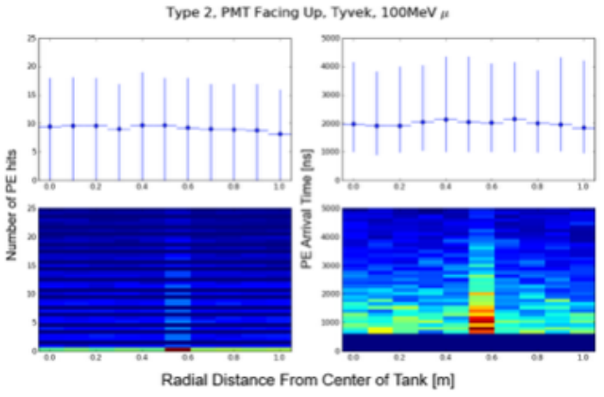


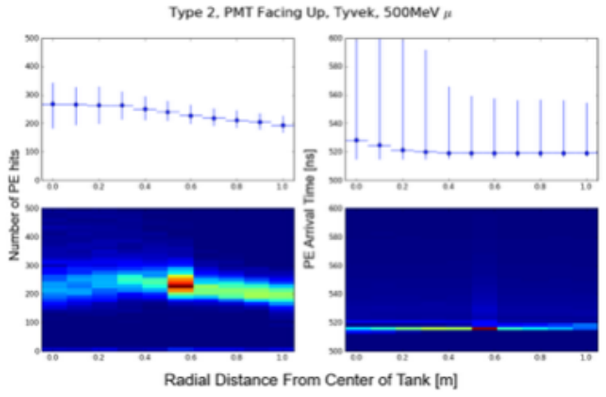
Example Muon Simulations

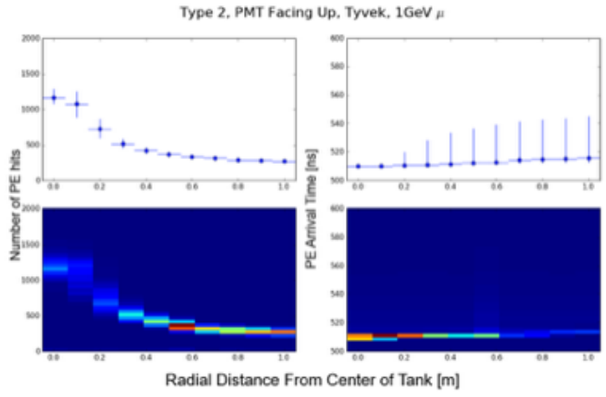


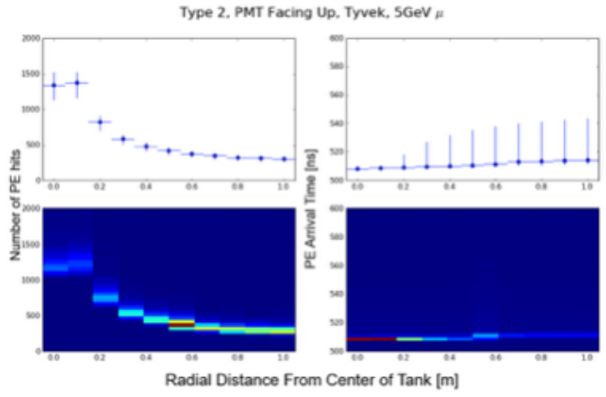
Energy ——————>

Up, Tyvek

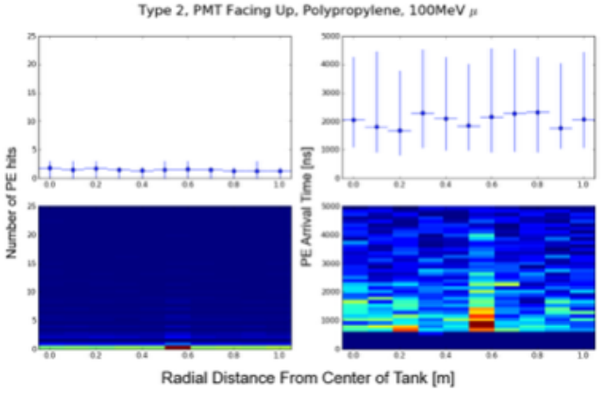


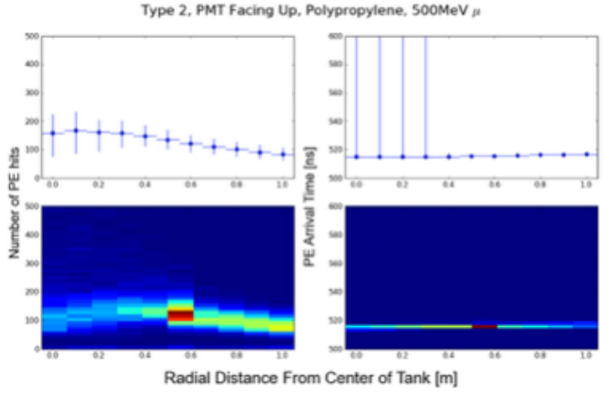


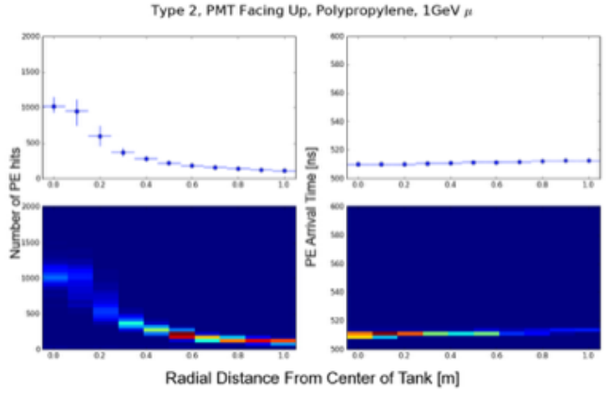


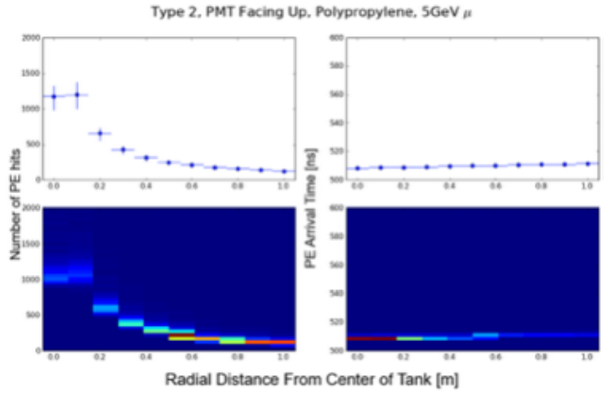


Up, Poly

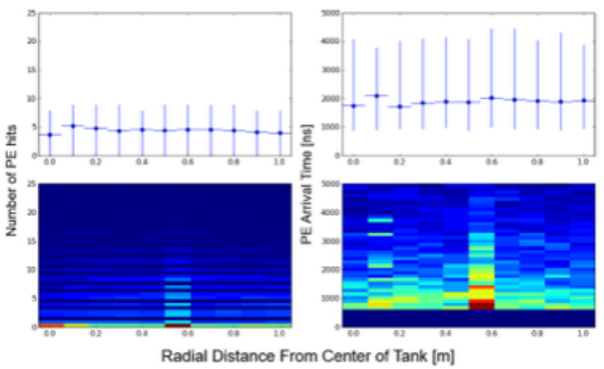


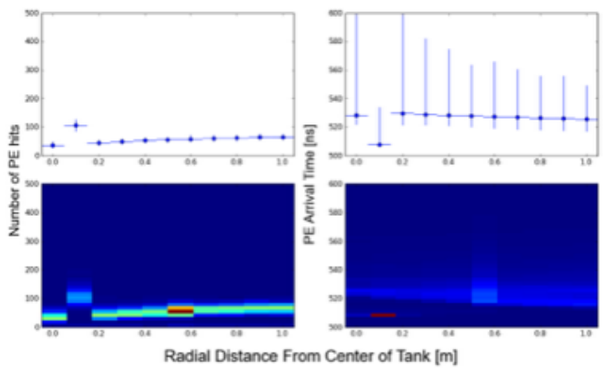


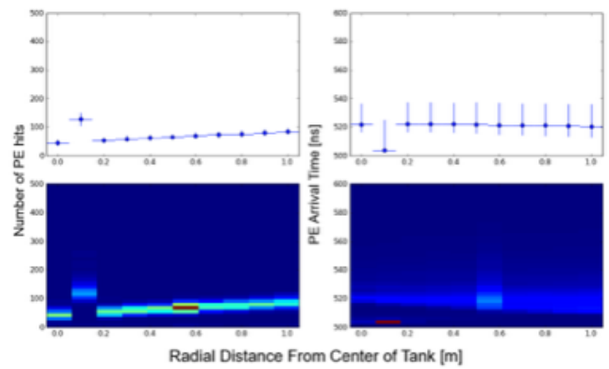


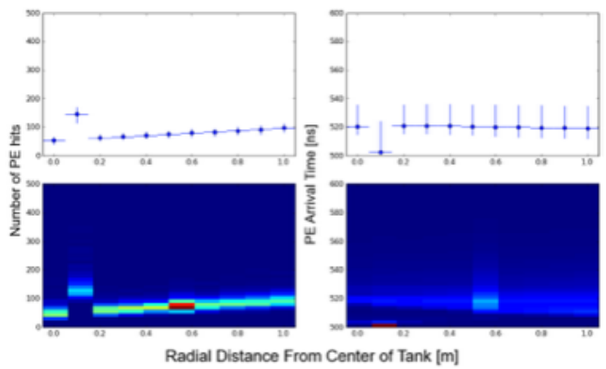


Down, Tyvek

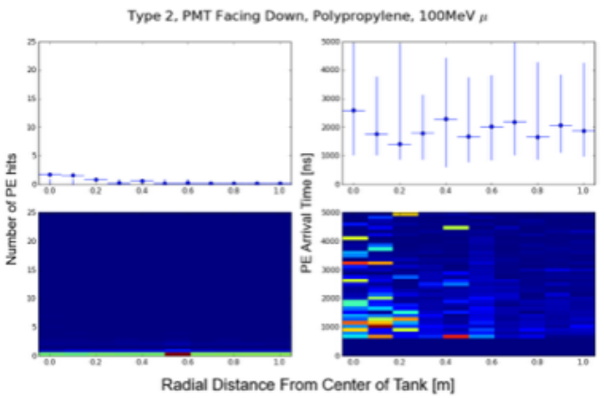


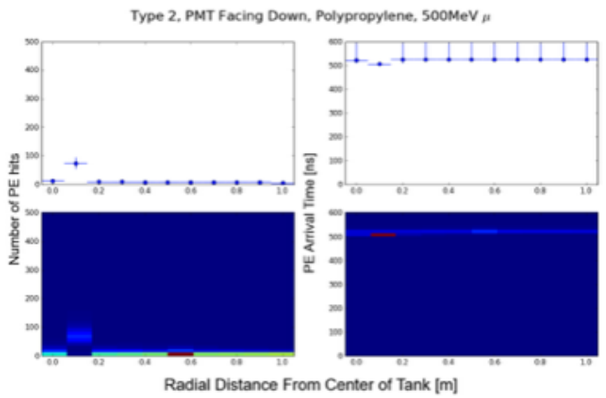


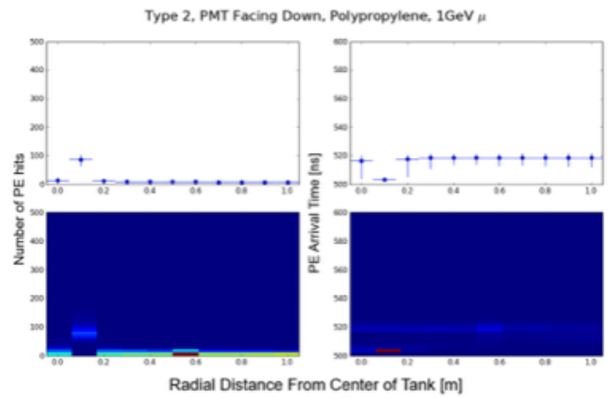


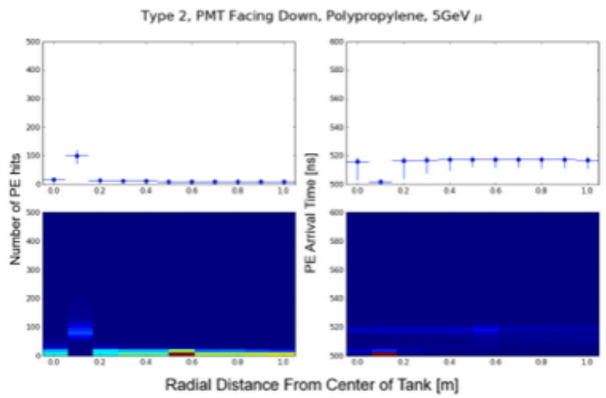


Down, Poly



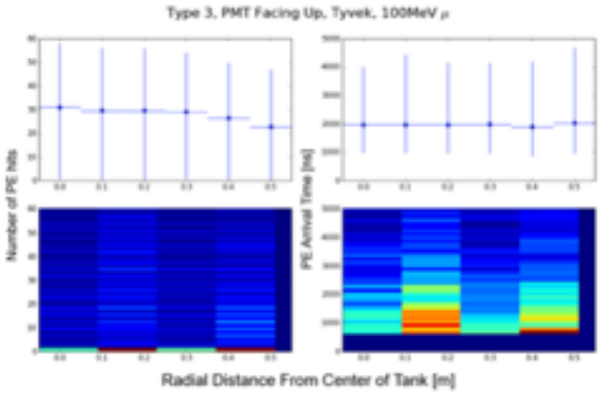


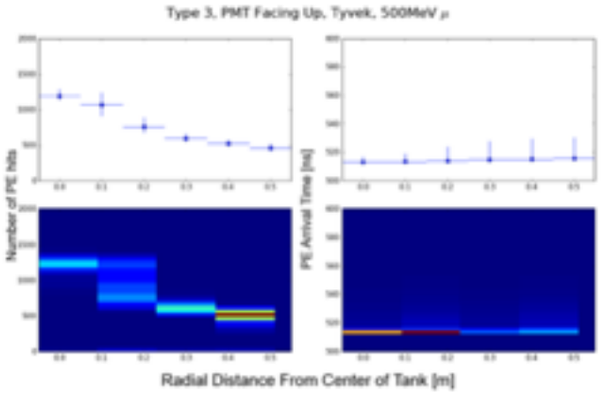


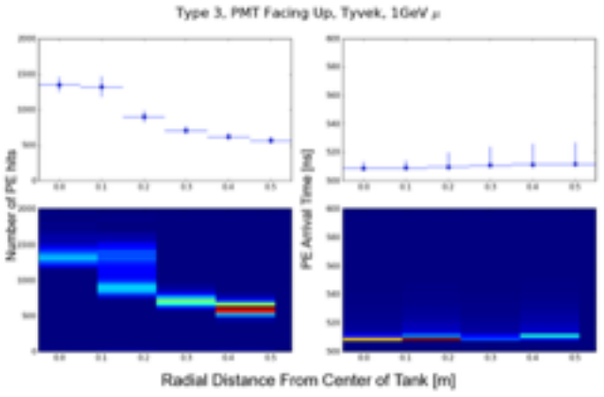


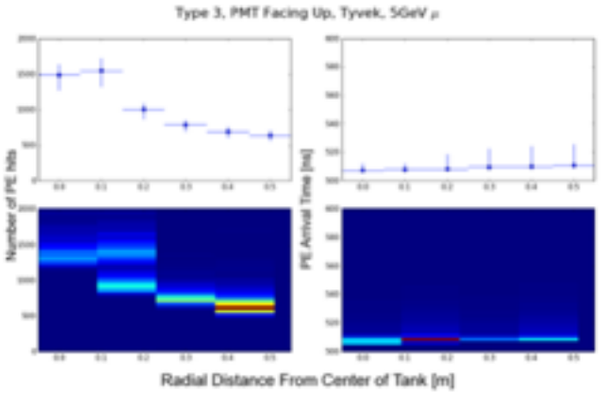
Energy ——————>

Up, Tyvek

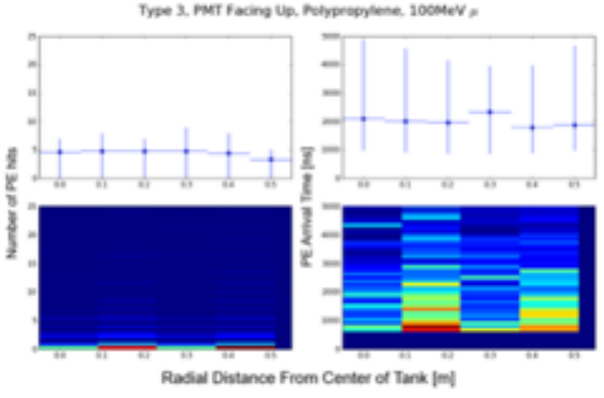


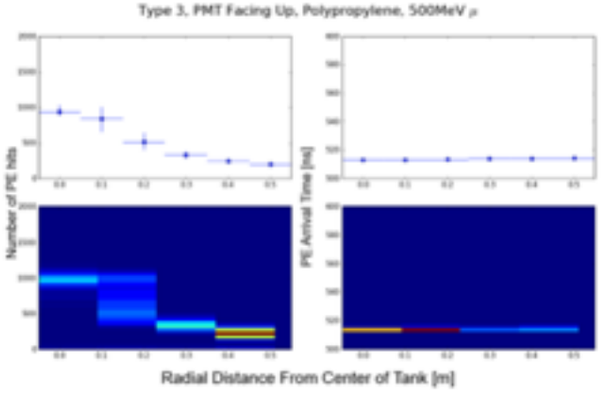


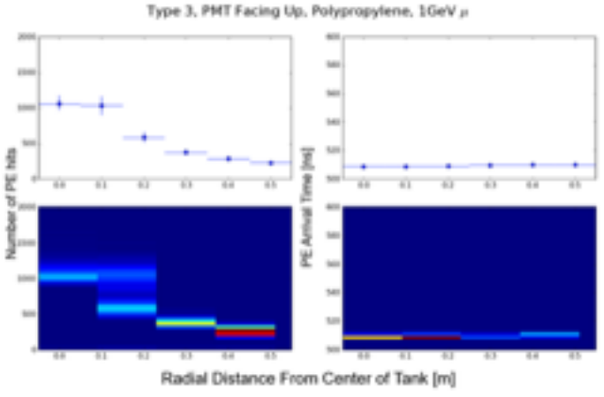


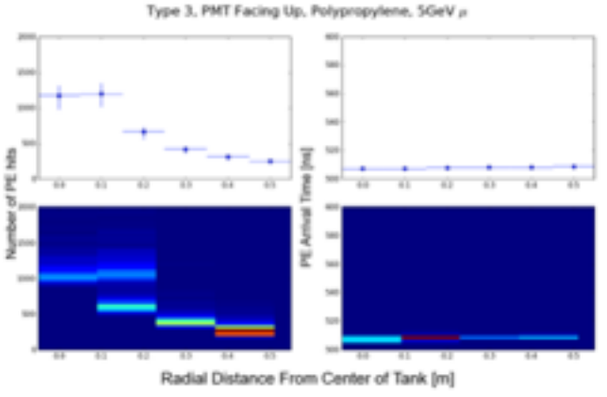


Up, Poly

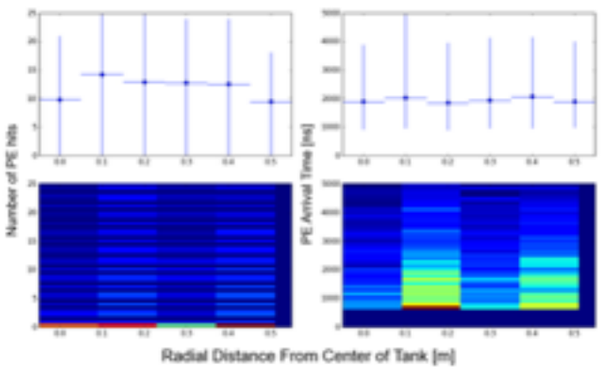


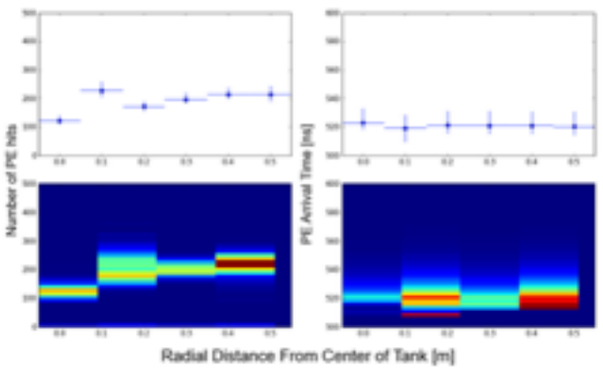


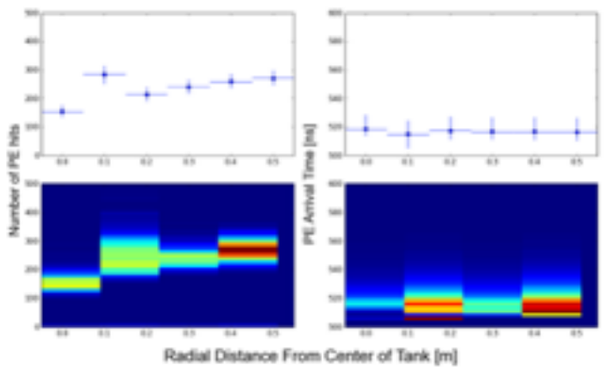


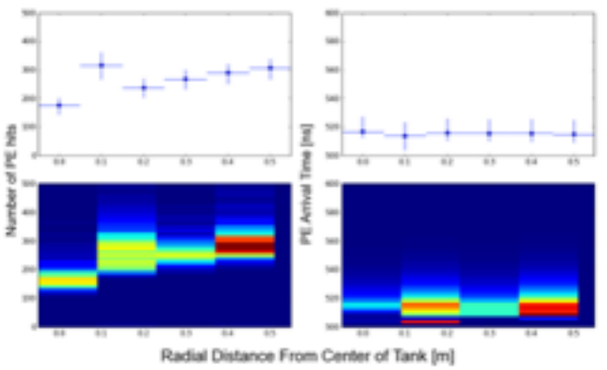


Down, Tyvek

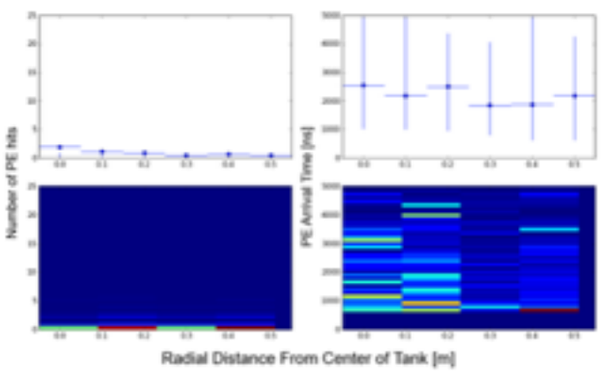


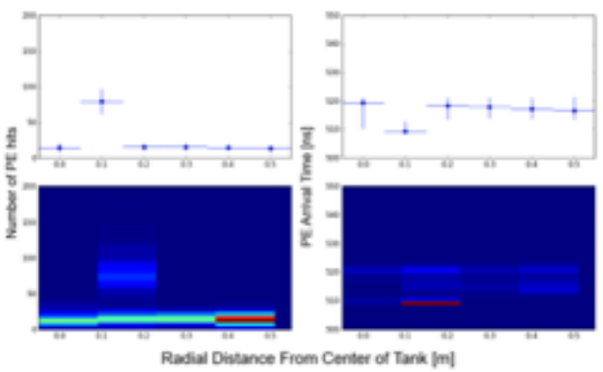


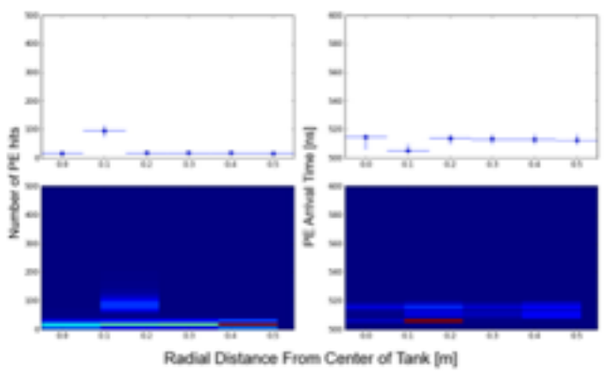


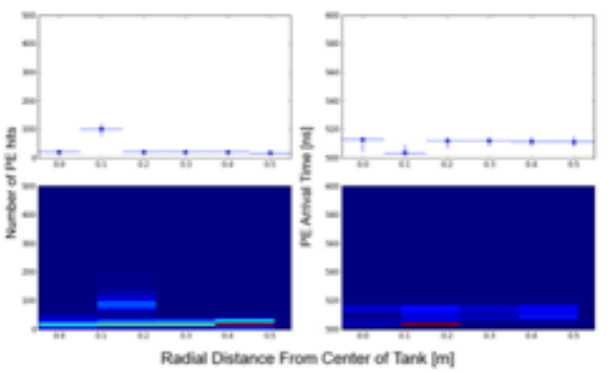


Down, Poly



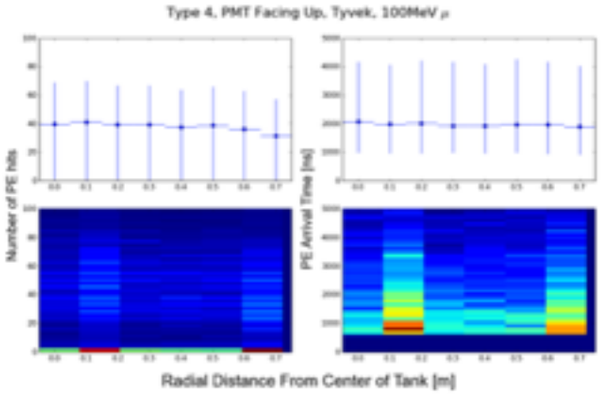


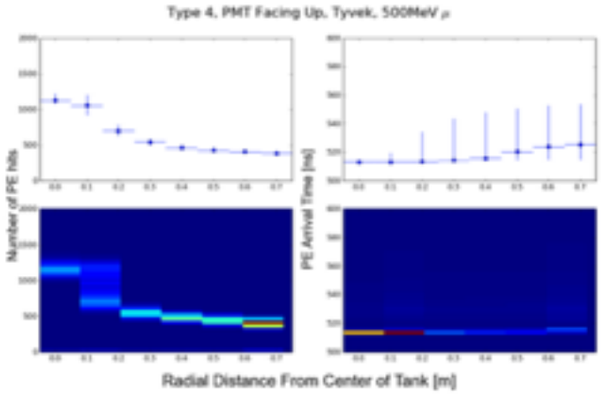


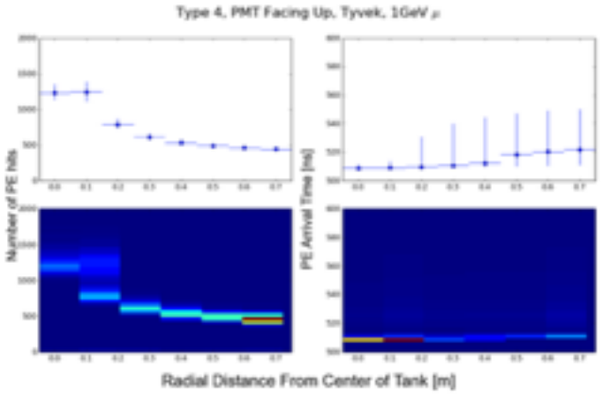


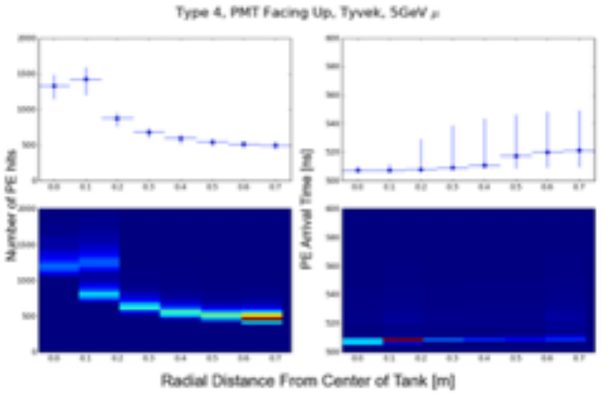
Energy ——————>

Up, Tyvek

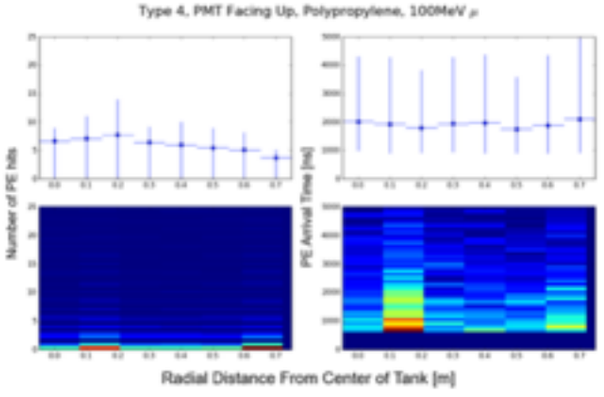


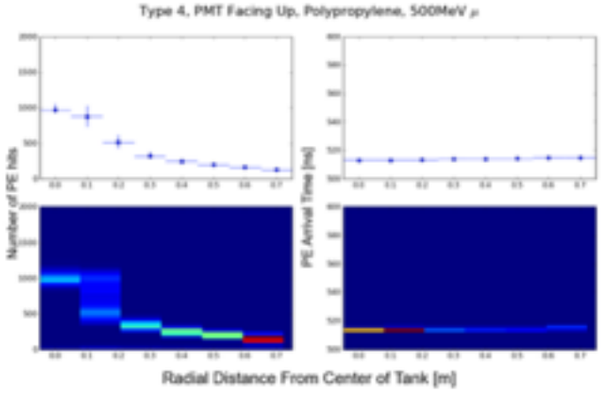


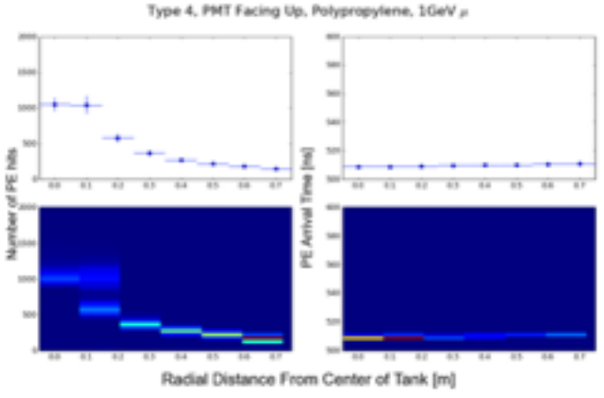


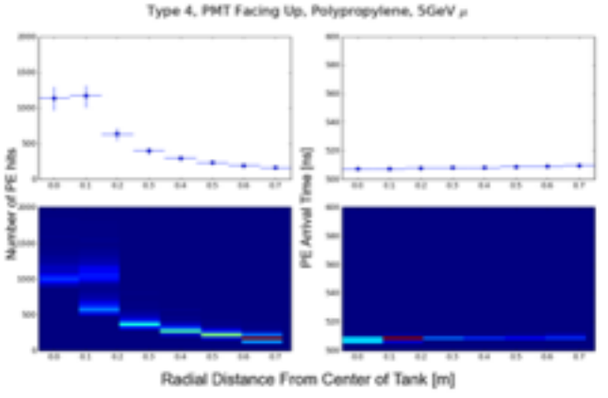


Up, Poly

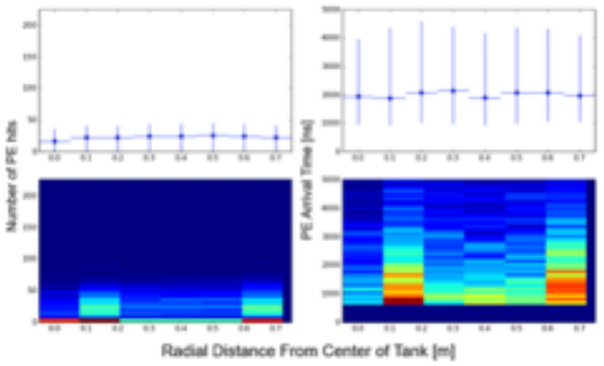


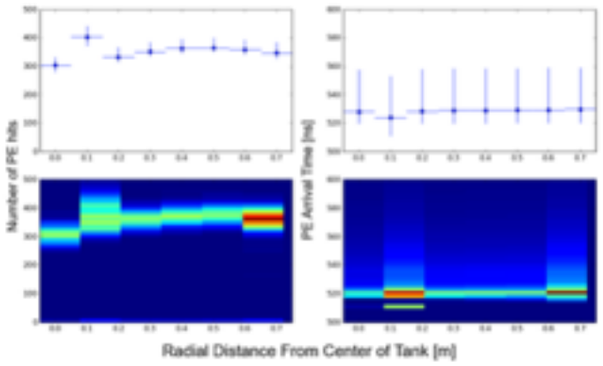


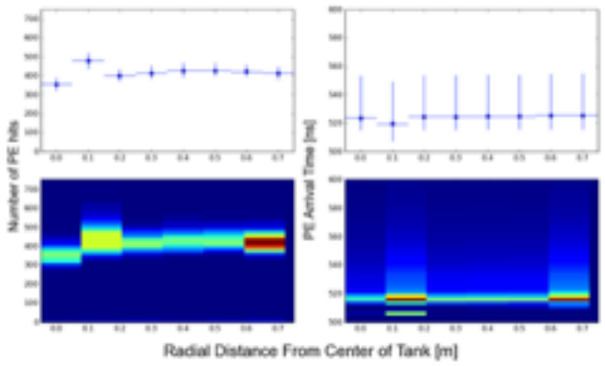


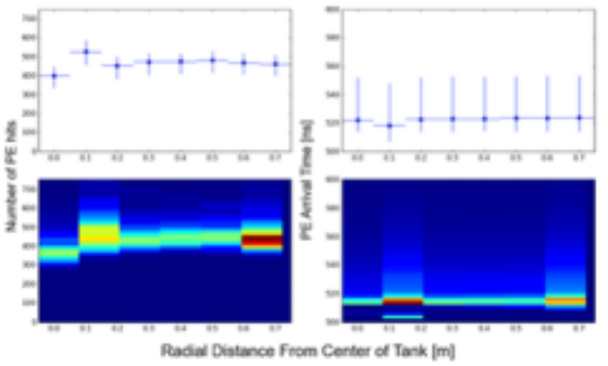


Down, Tyvek

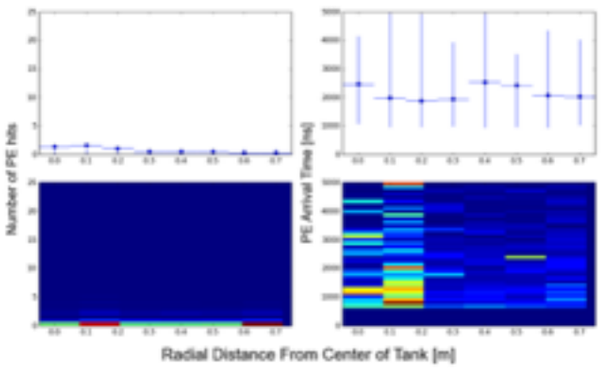


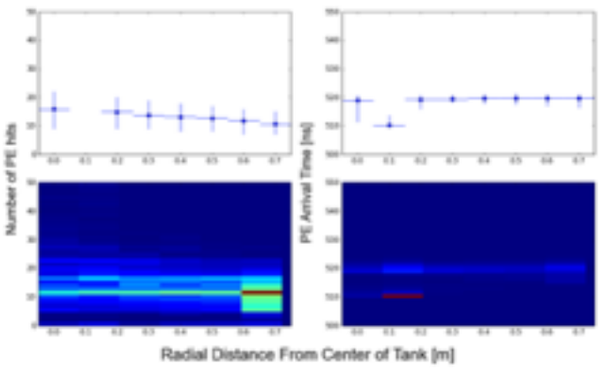


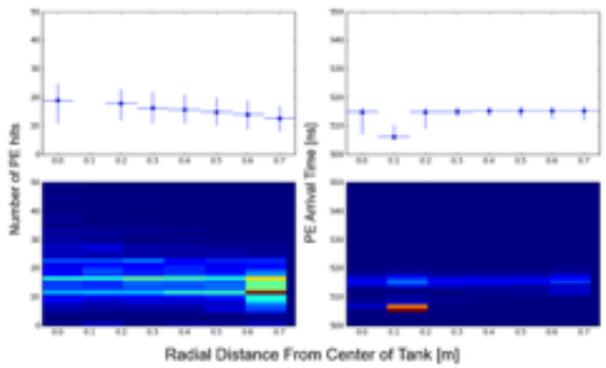


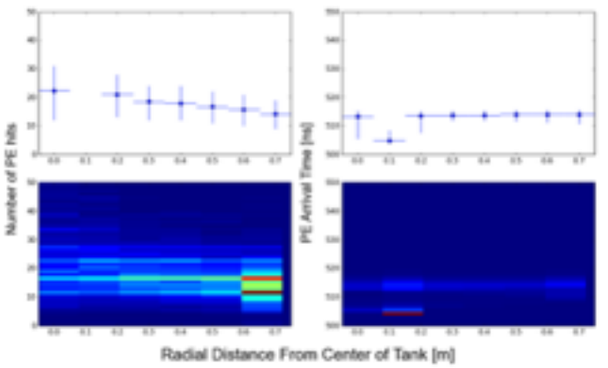


Down, Poly



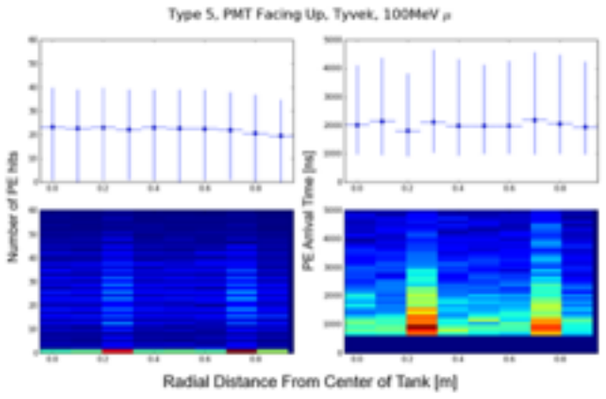


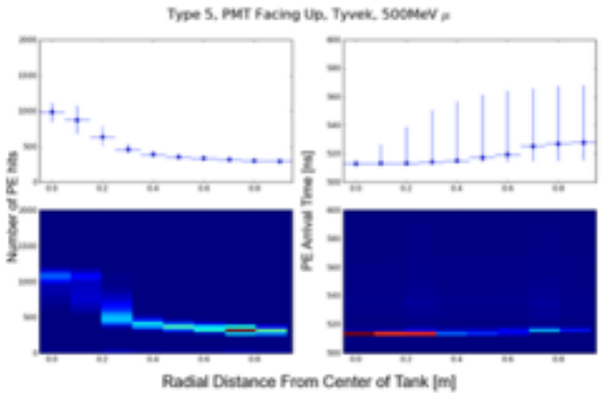


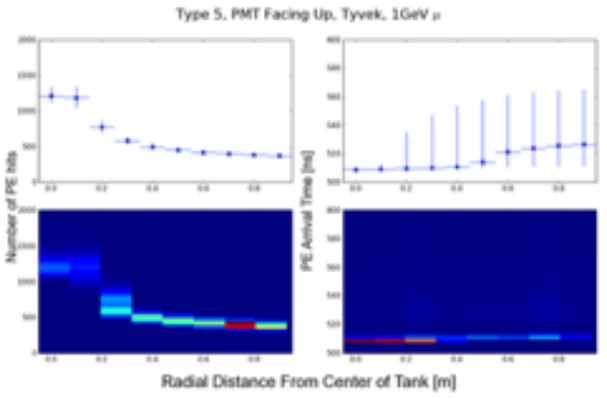


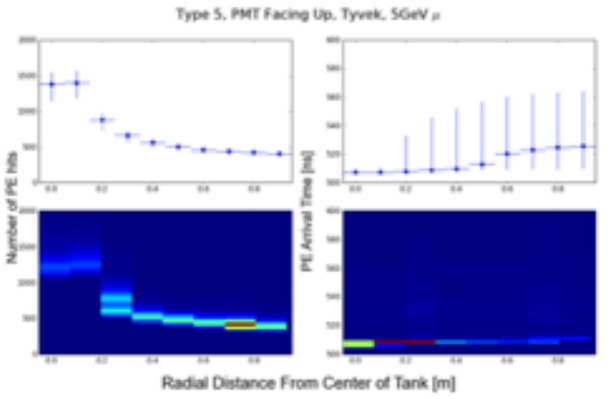
Energy ——————>

Up, Tyvek

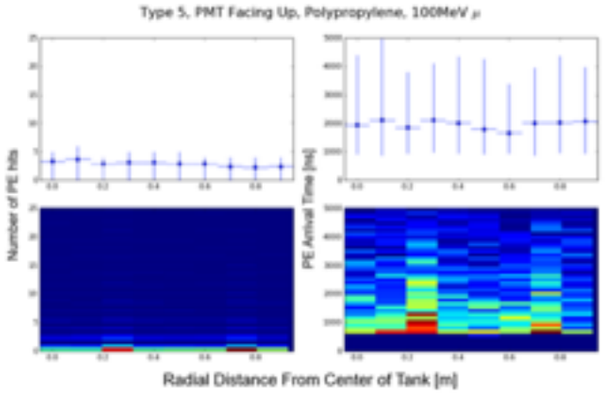


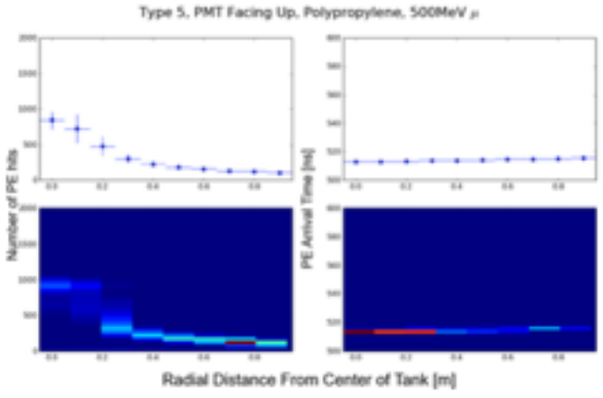


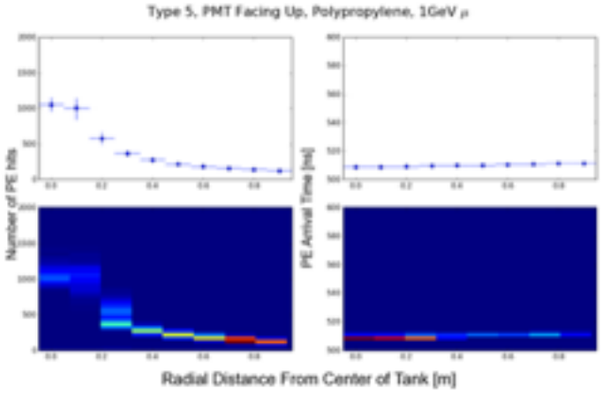


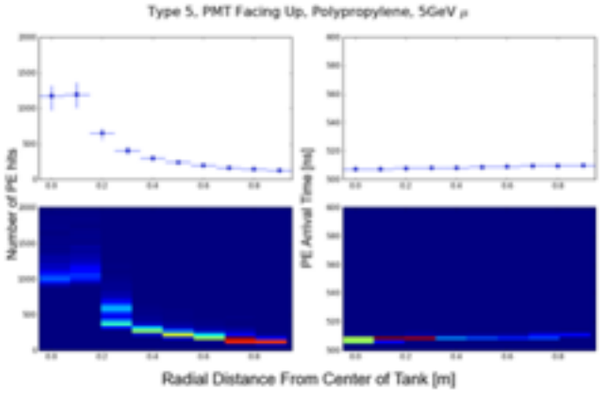


Up, Poly

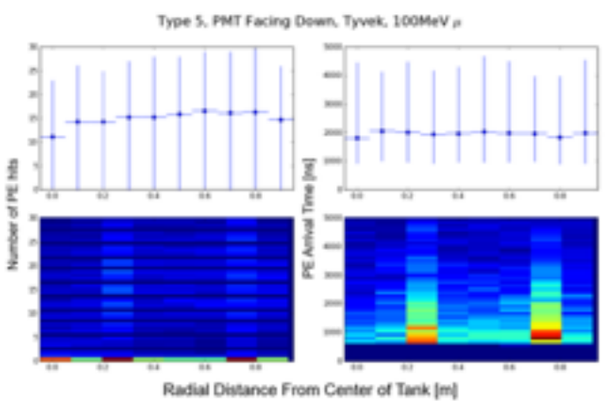


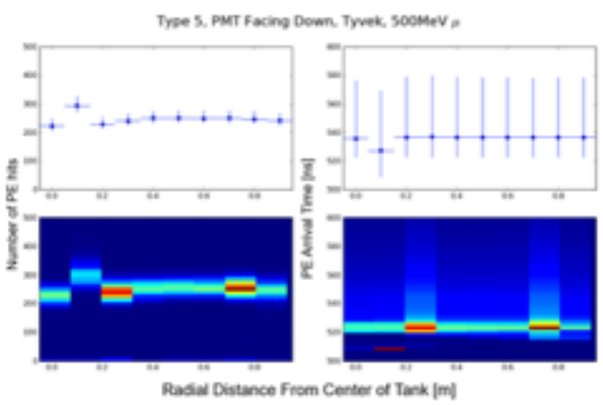


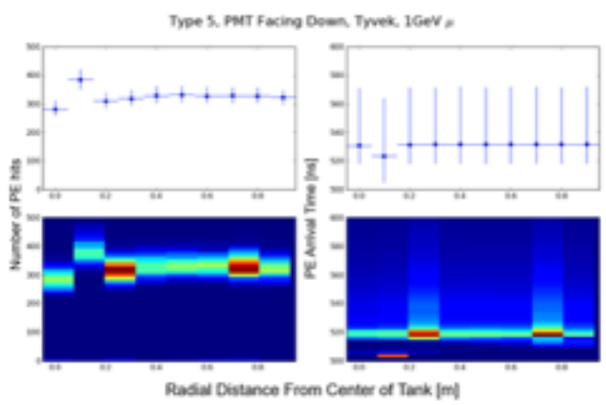


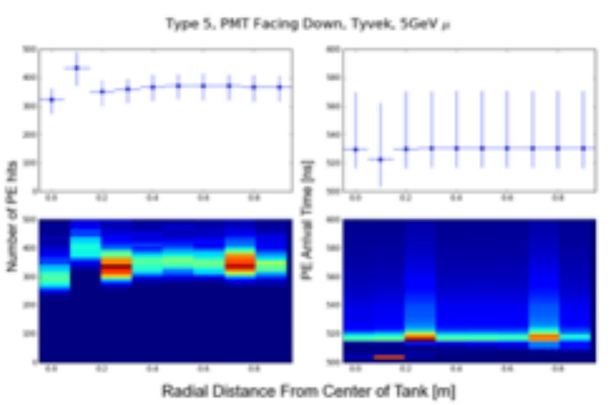


Down, Tyvek

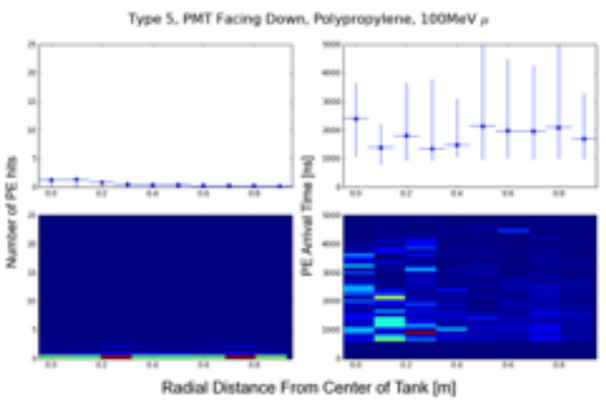


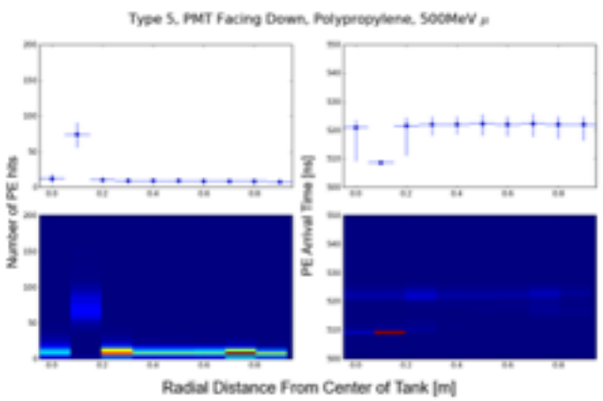


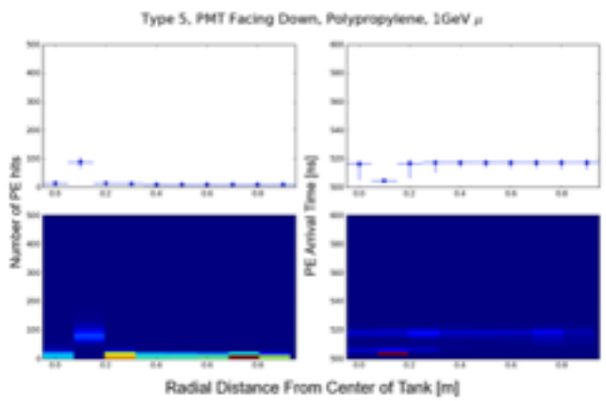


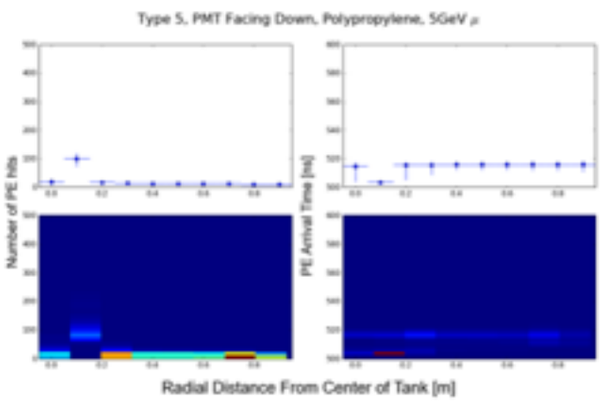


Down, Poly

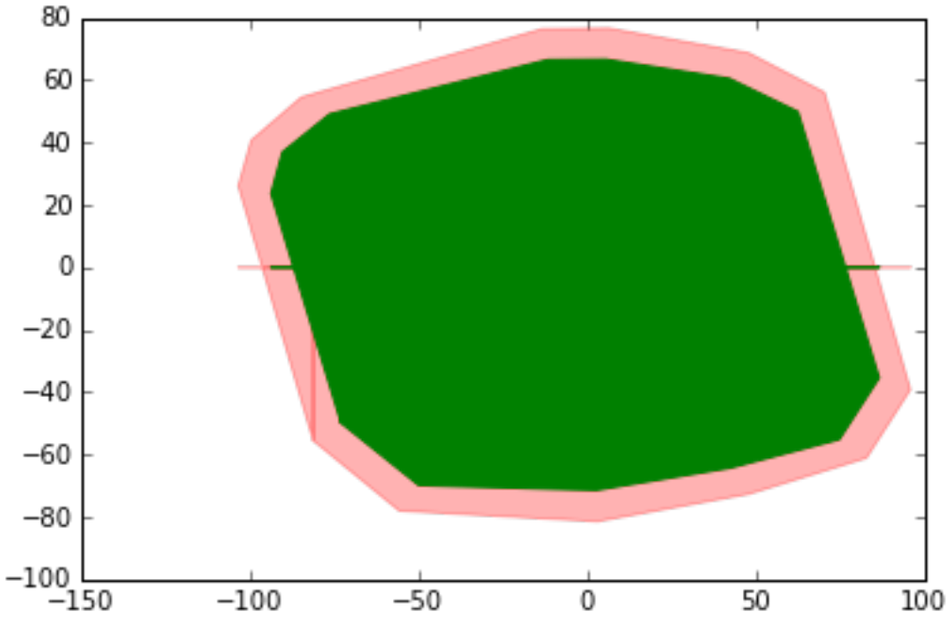


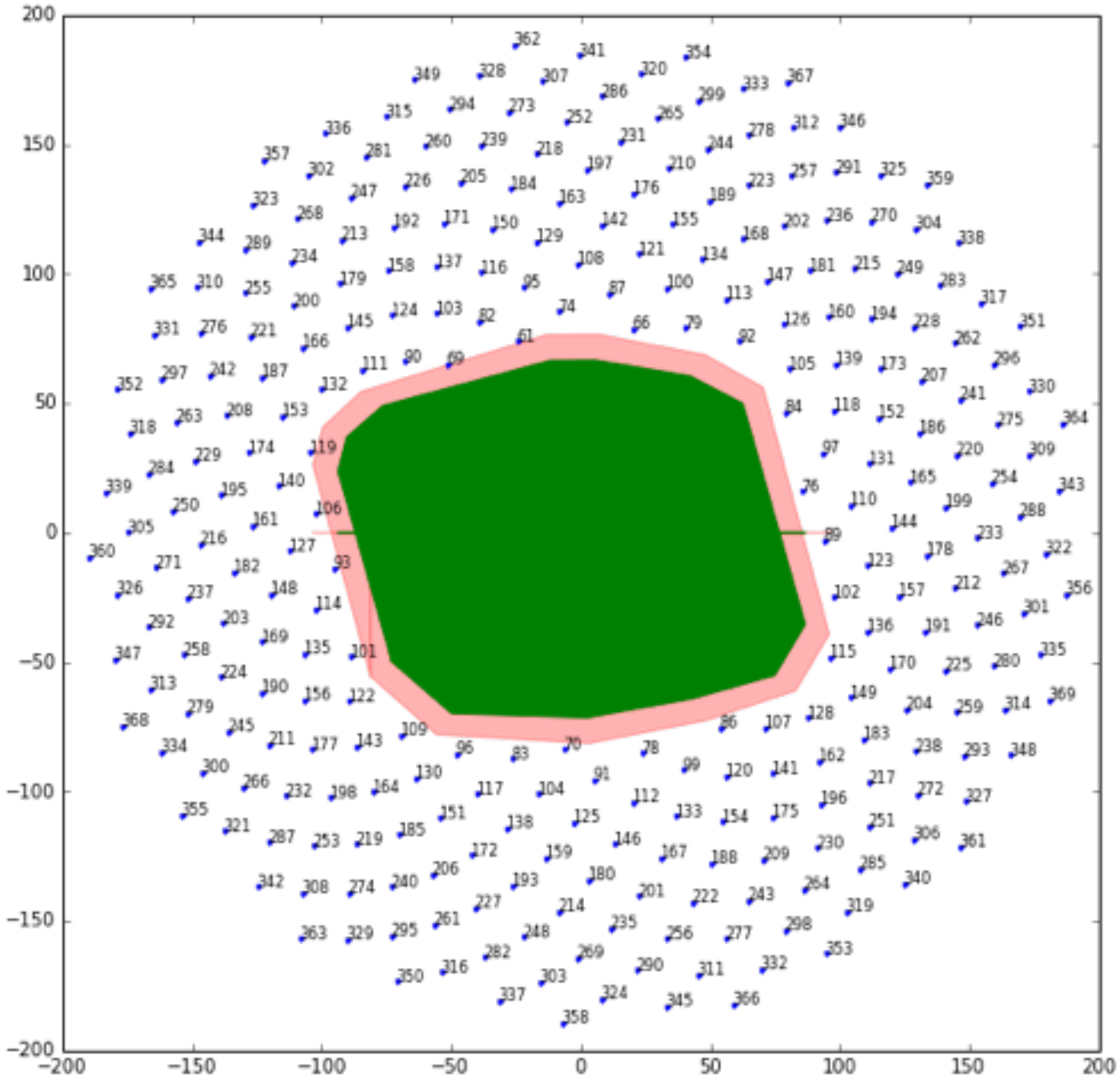






Finding the right spiral:





The green polygon in the center is the area covered by the main HAWC array.

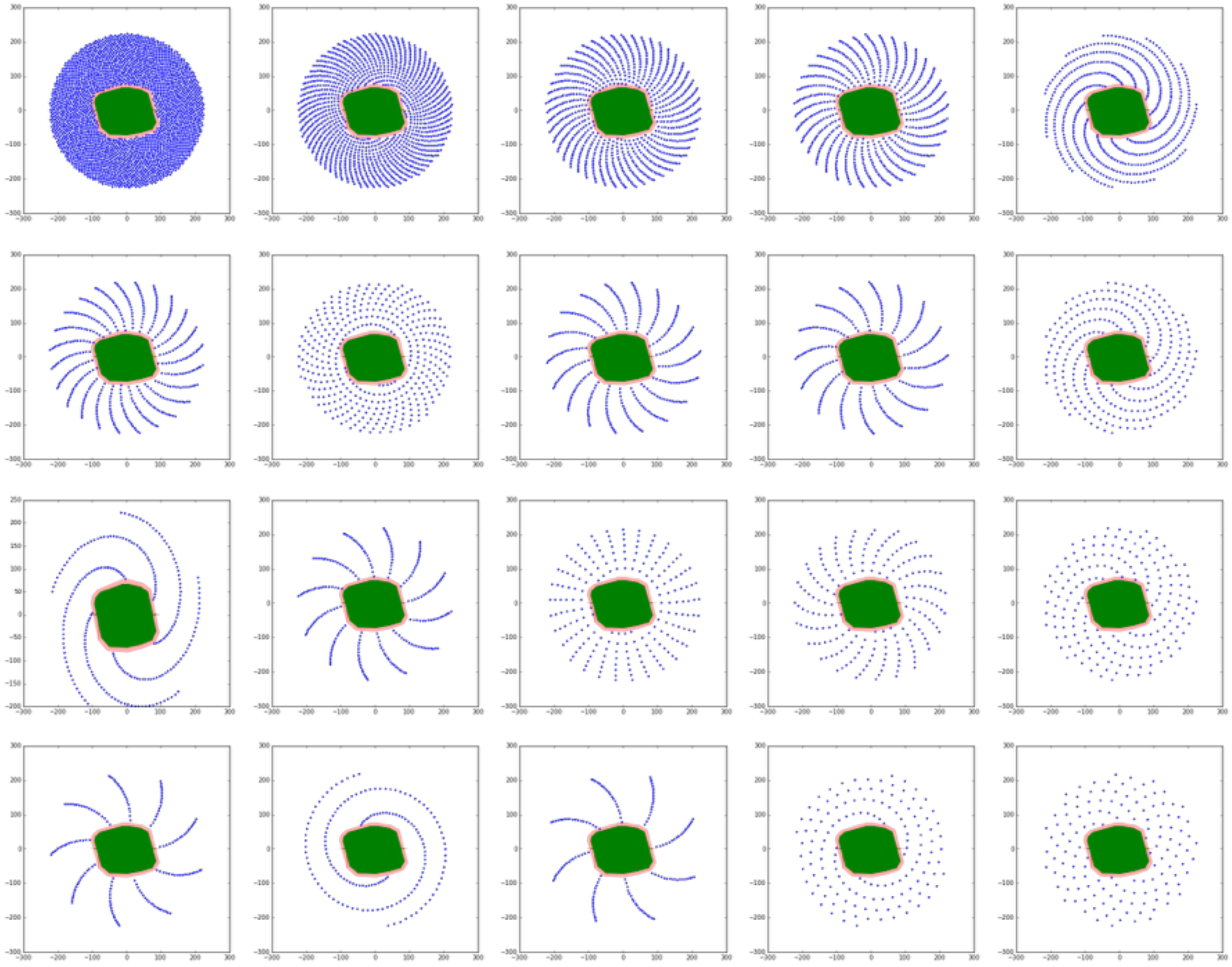
The red outer edge is a 10m perimeter separation between the main array and the outrigger array.

Outriggers within perimeter and outside 225m cut

Axis are coordinate positions in meters (Main Array Tank N11 is at 0, 0)

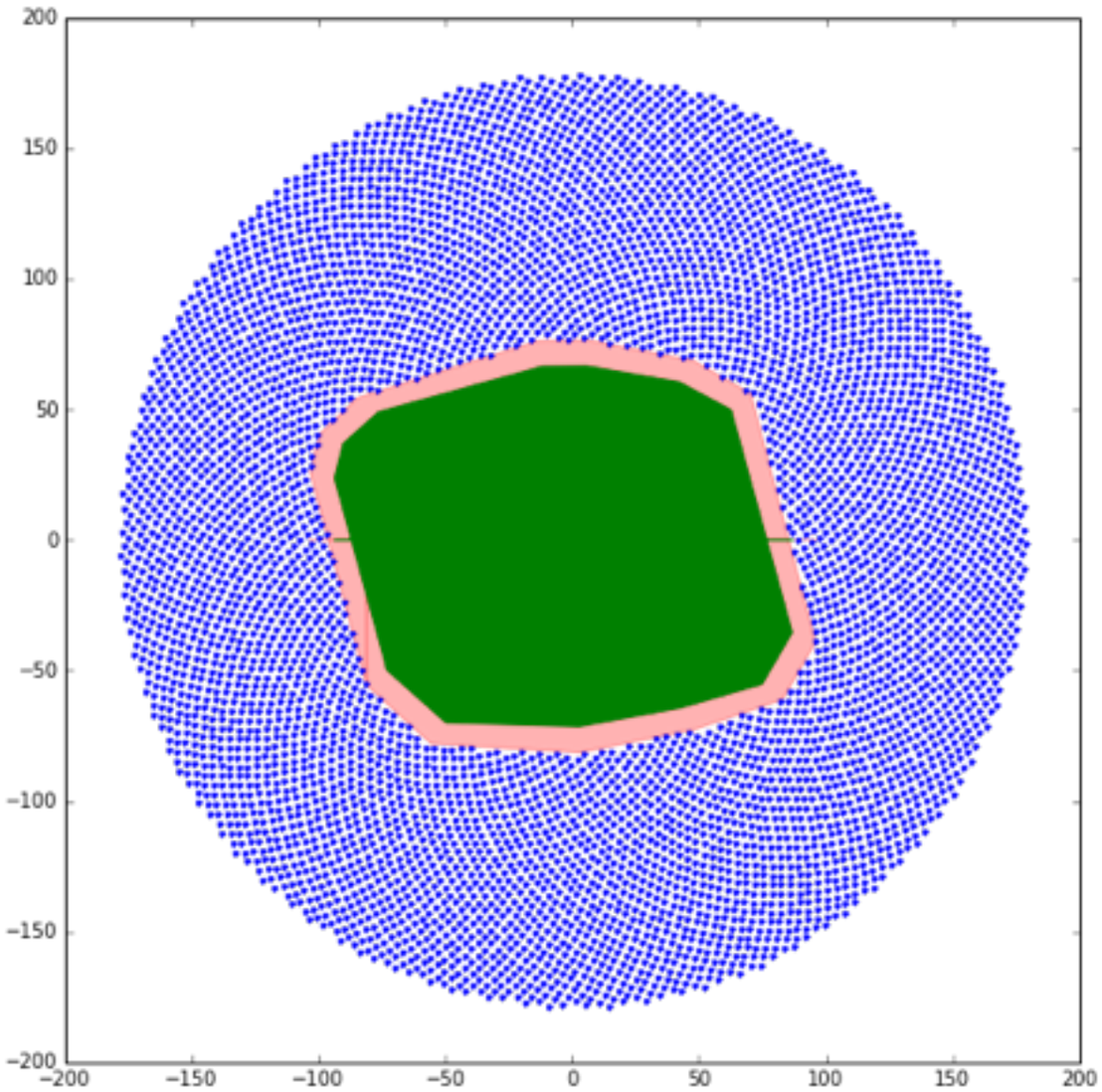
Index starts at 0 in center of spiral and increases with theta and r (indices inside perimeter are removed)

scale = 6 cut = idx % i == 0 for i in range(1, 21):

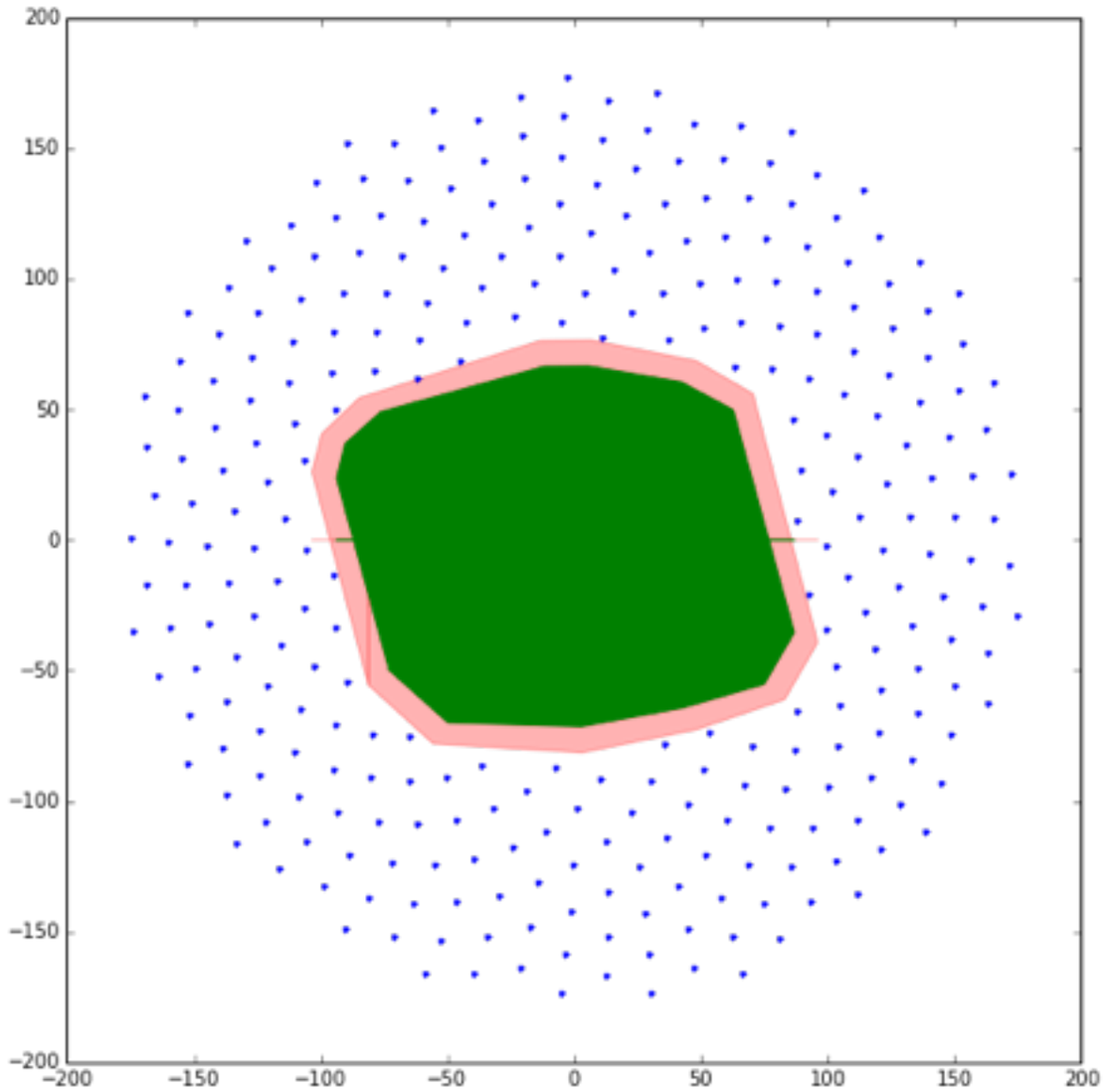


Scale = 2

Right side arrangement has the cut:
cut = idx % 20 == 0



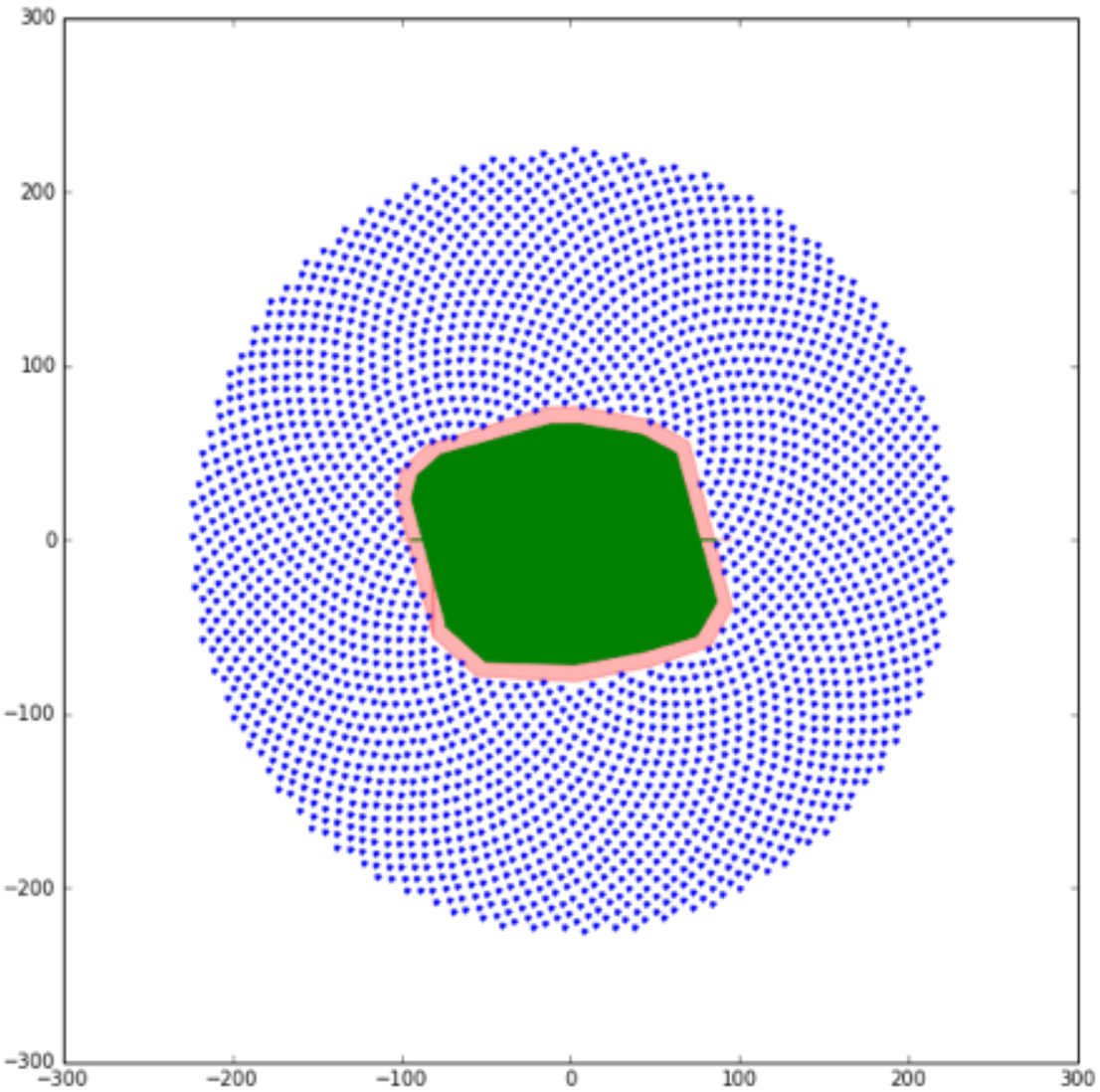
6025 tanks



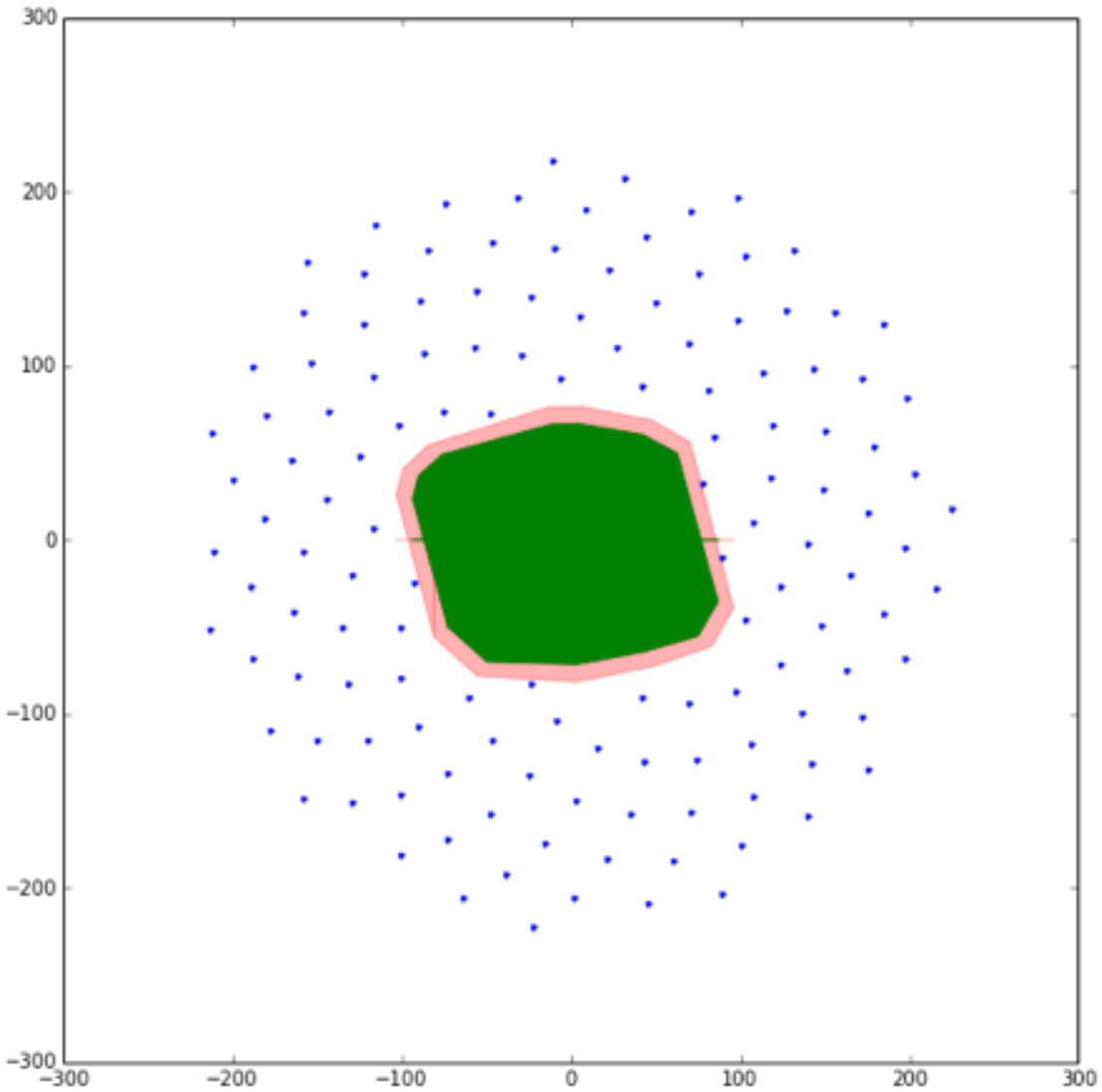
300 tanks

Scale = 4

Right side arrangement has the cut:
cut = idx % 20 == 0



2673 tanks



134 tanks