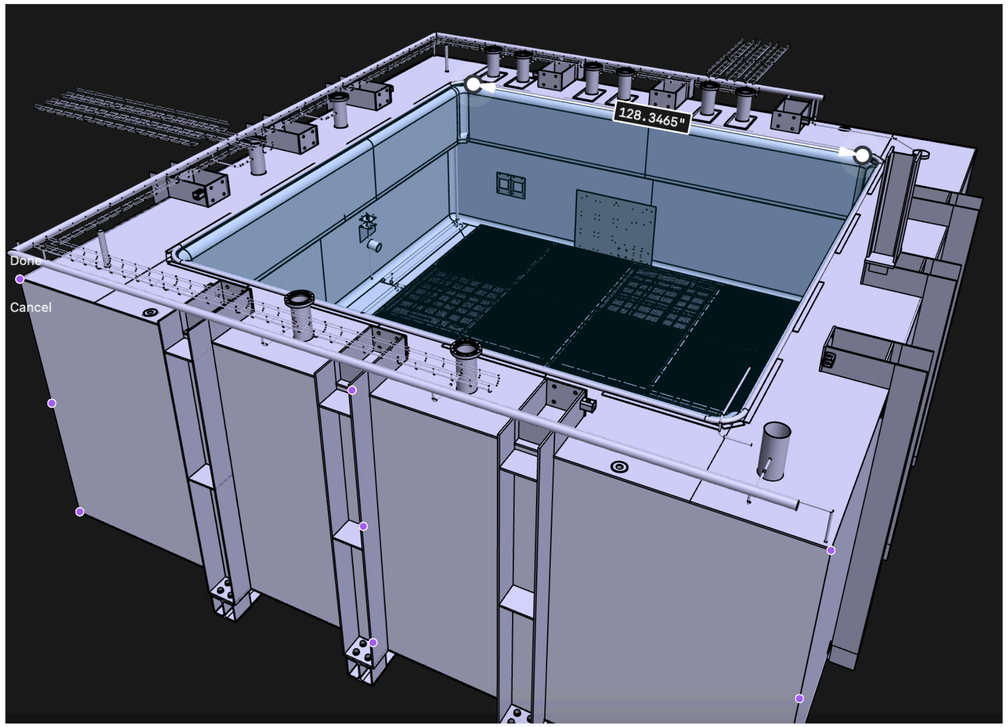
VD CB Light Simulation Update

March 20, 2024

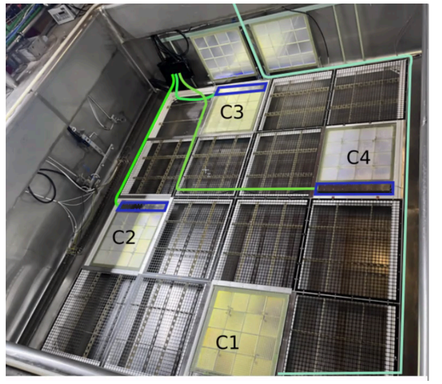
Wei



DEEP UNDERGROUND NEUTRINO EXPERIMENT

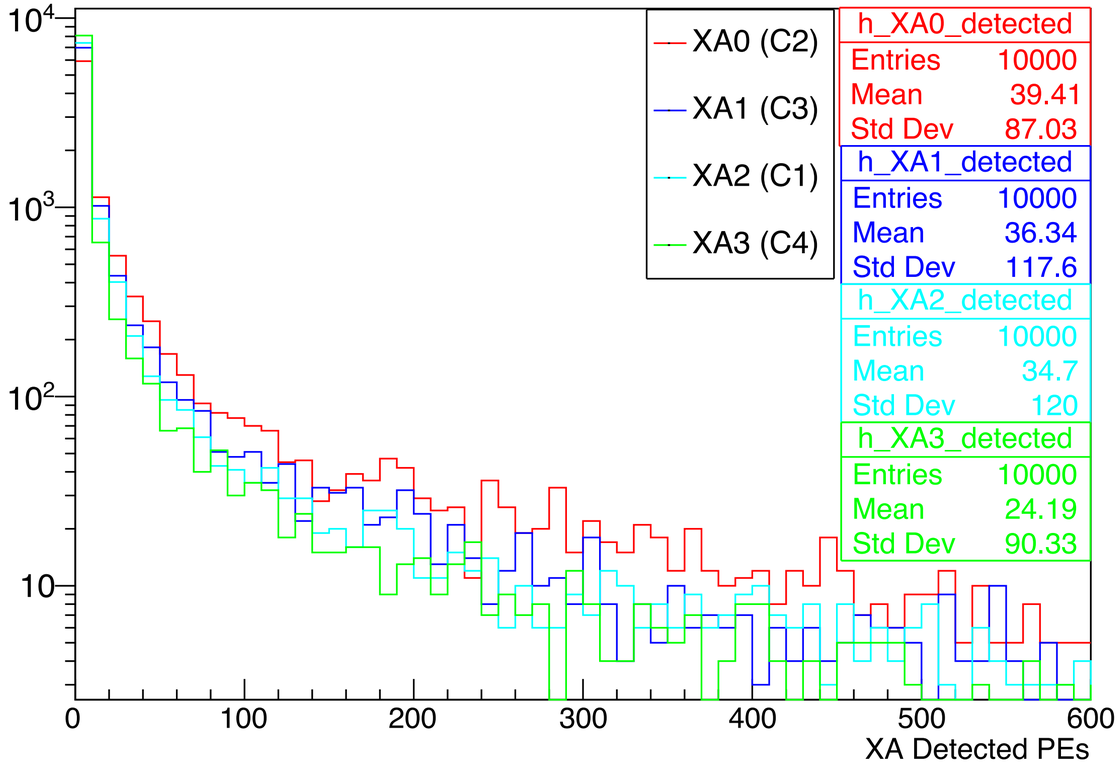
Stony Brook University

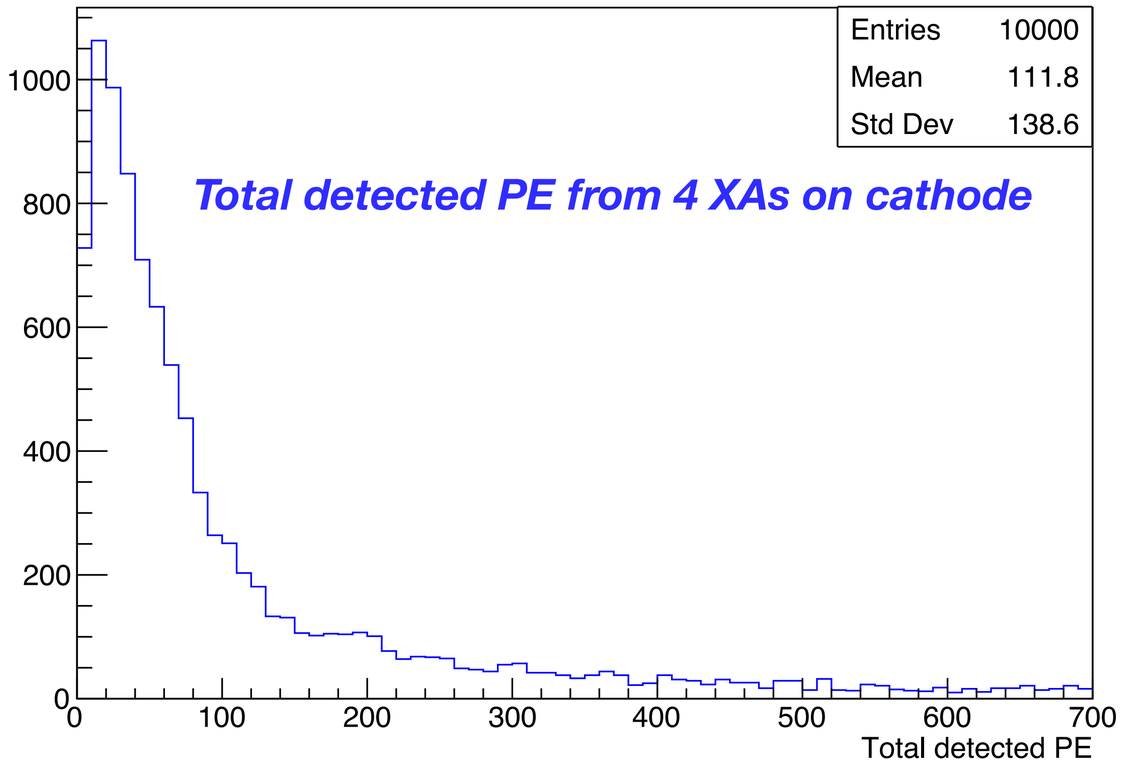
PNS from the side: Expected signal distributions



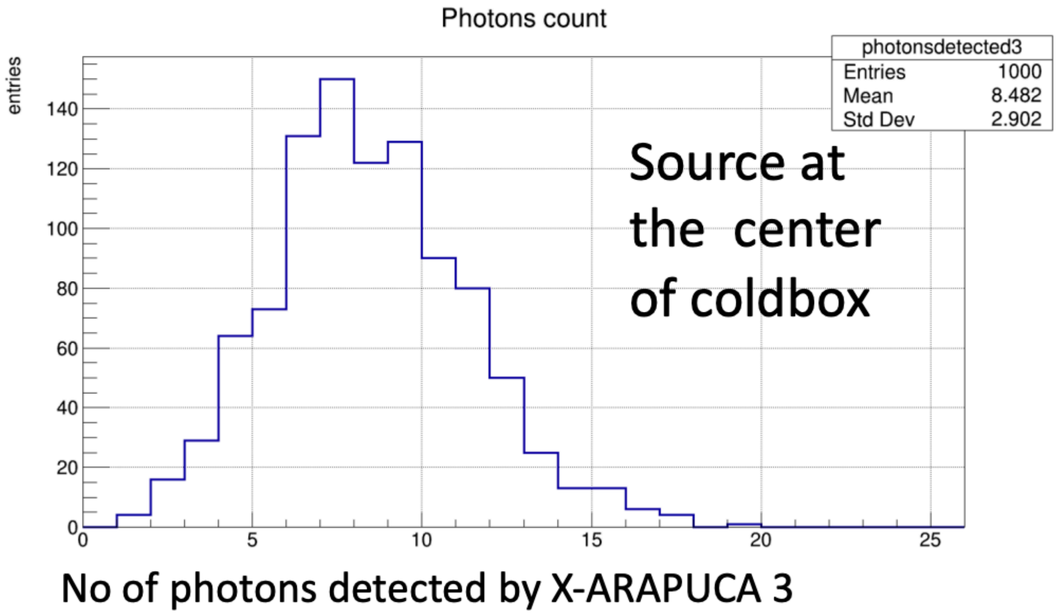
XA0 (C2) is the farthest XA from the PNS (see more captures in G4 sim)
XA3 (C4) is the closest XA to PNS

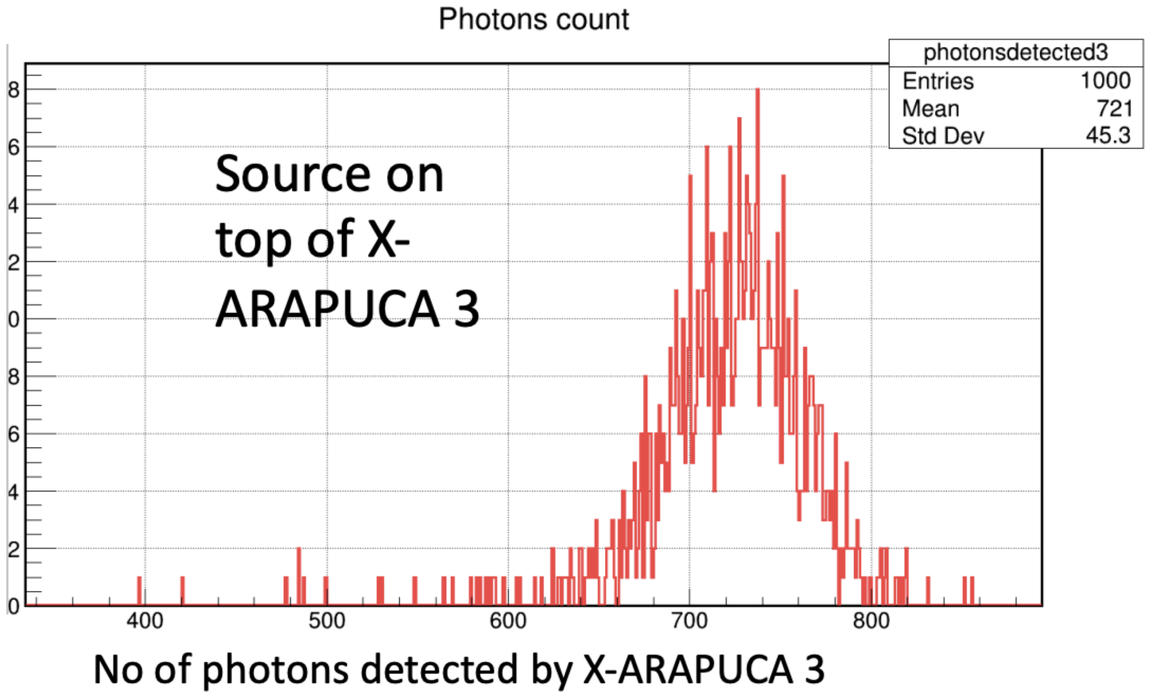
Peak at small PE: because most captures are far from XA 60cm x 60cm acceptance window → small solid angle (next slide)





Simulated 4.7 MeV e^- in ColdBox Geometry



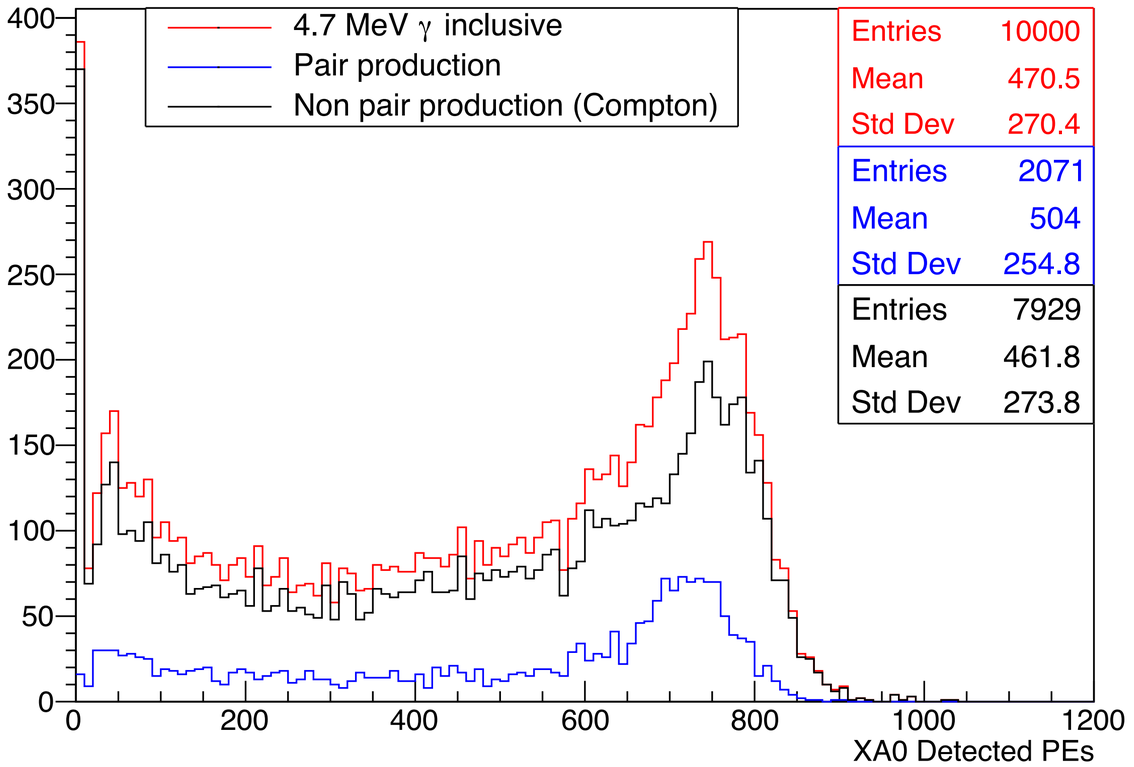


- ColdBox has small drift volume: a small change in source position makes huge difference in solid angle to the detector (and light yield)
- Focus on γ source (n-capture) right on top of any of the 4 XAs on cathode

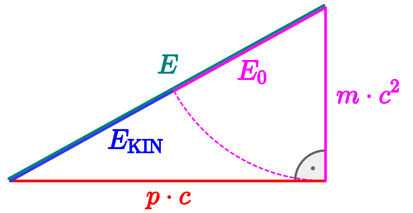
4.7 MeV γ: Physics processes

An example: Particle gun generated 4.7 MeV γ @ ~15 cm above XA0

- Two relevant processes at this energy: *Compton scattering* and *pair production*
  - 730-PE peak contribution from both Compton scattering(s) and pair production
  - Pair production is ~20% (identify e^+ in secondary particles)

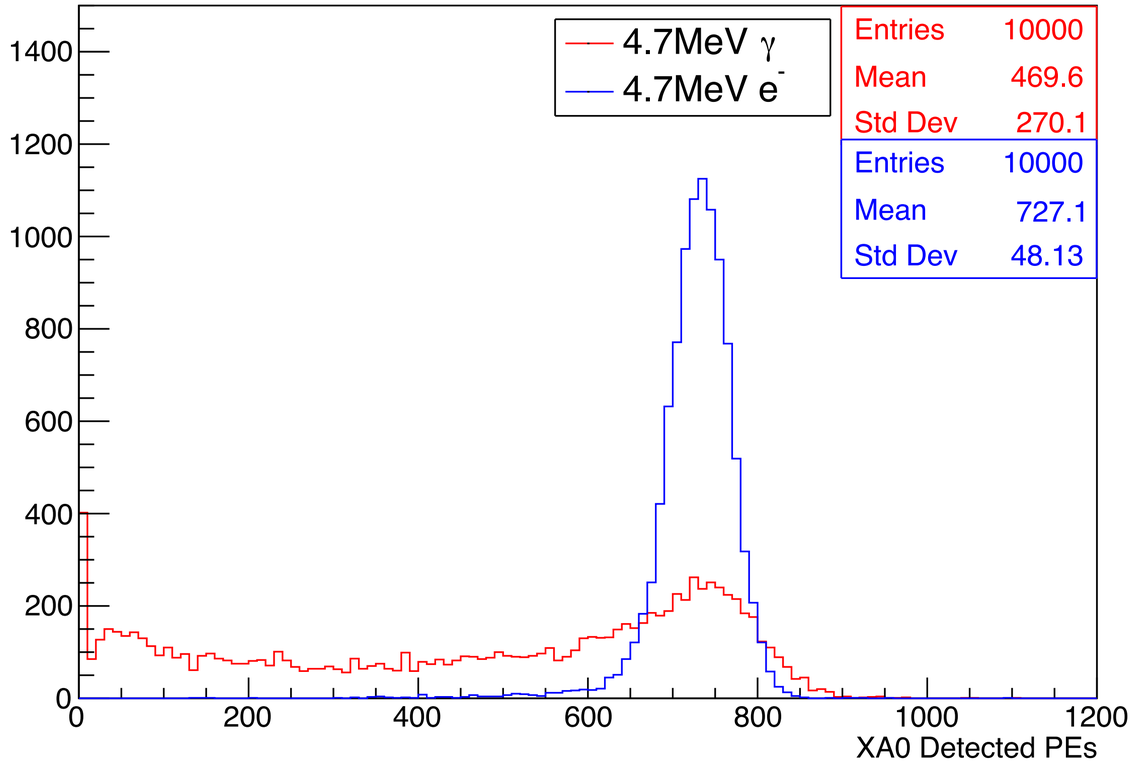


4.7 MeV γ: Cross check with simulated e^-



Same example: Particle gun generated 4.7 MeV γ @ ~15 cm above XA0

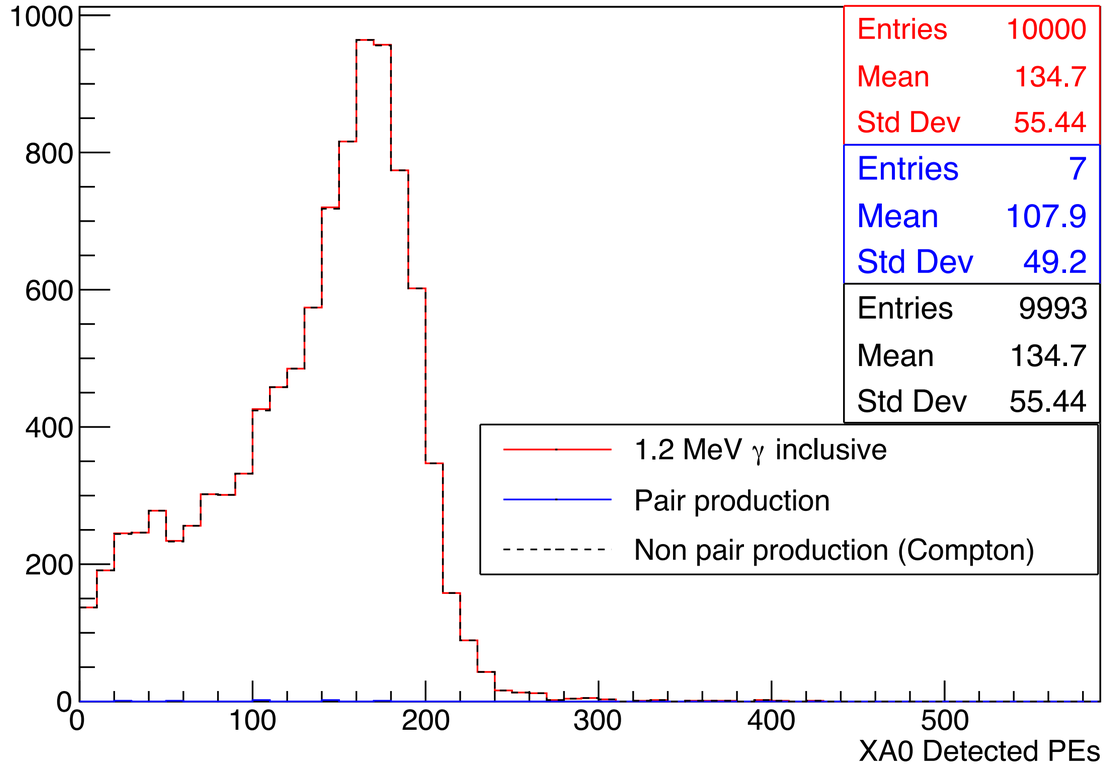
- Overlaid: simulated e- with momentum p = 4.7 MeV
  - Corresponds to 4.217 MeV kinetic energy, i.e. deposited energy
  - The 730PE-peak comes from **4.22 MeV total energy deposit (*not 4.7MeV!*)**



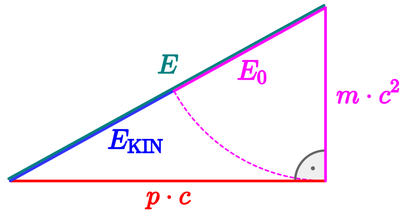
1.2 MeV γ

Another example: one of the other commonly released is 1.2 MeV γ
Particle gun generated 1.2 MeV γ @ ~15 cm above XA0 center

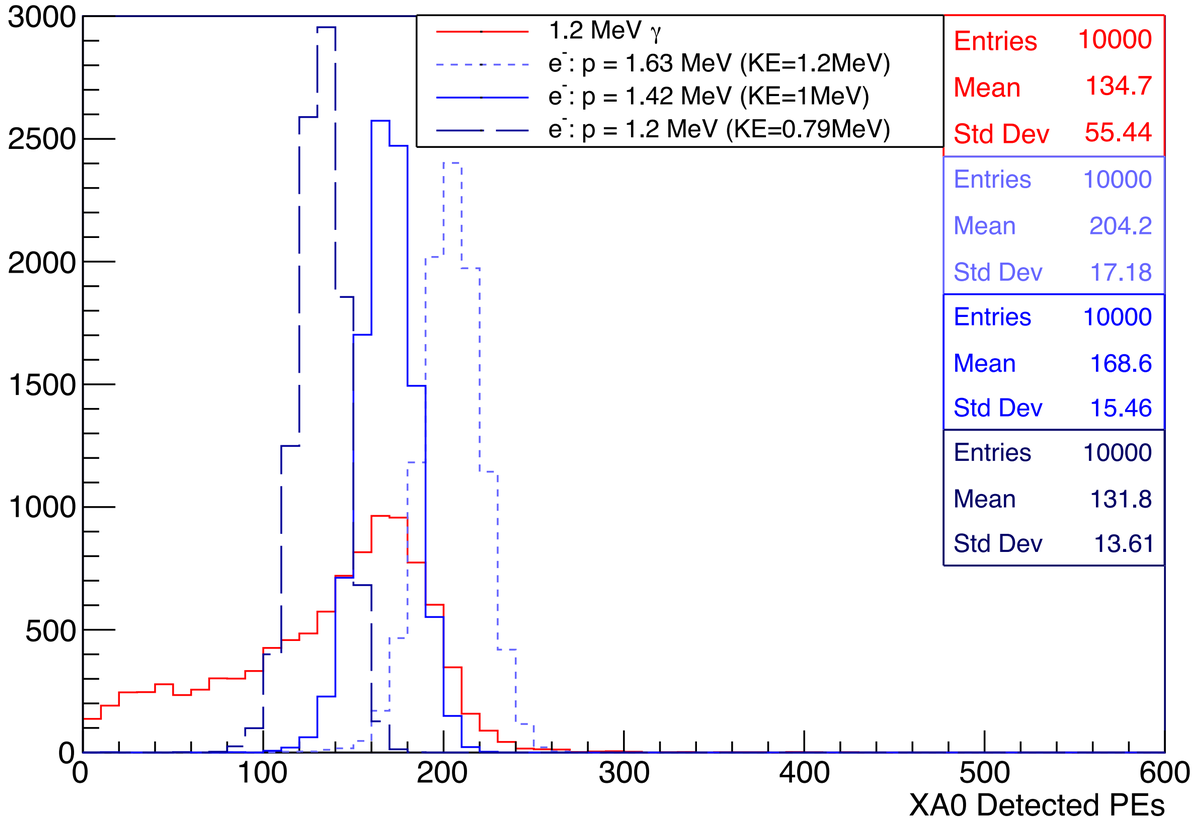
- At this energy, dominated by Compton scattering (>99.9%), peak at 170 PE



1.2 MeV γ: Cross check with simulated e^-



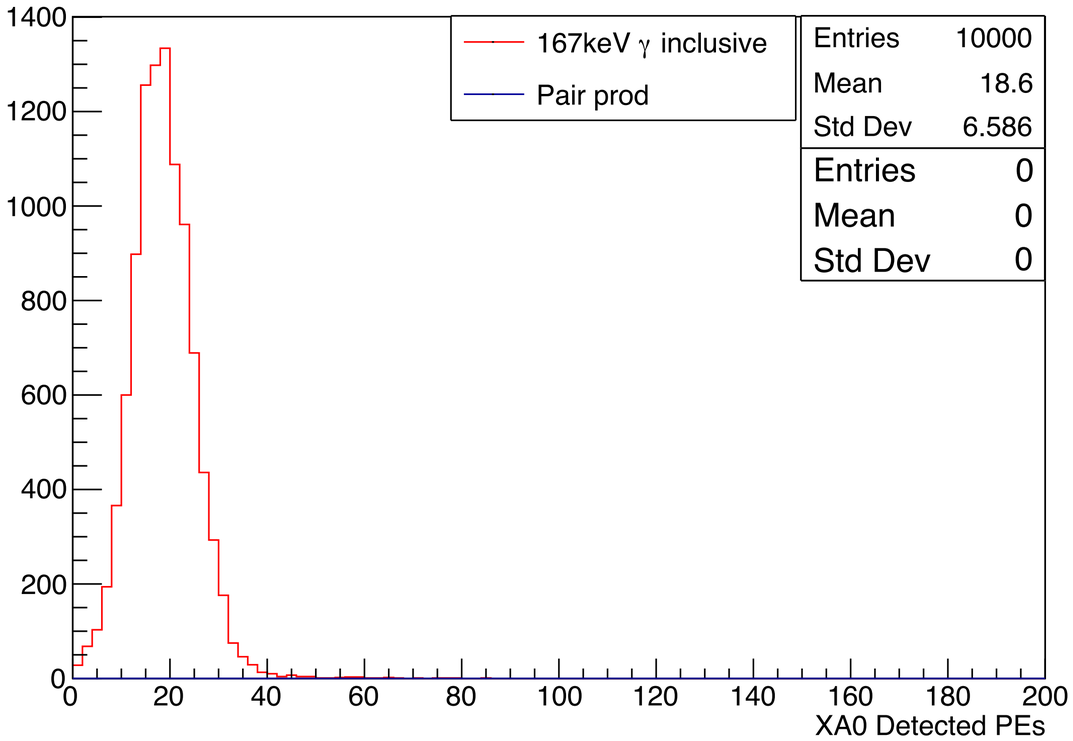
- Overlaid is simulated e^- at same location with different momentum p (different KE)
  - The 170PE-peak corresponds to **1 MeV total energy deposit (electron p=1.42MeV)**



167 keV γ

Particle gun generated 167 keV γ source @15cm above XA0 center

- 100% Compton scattering, peak @~20PE



Particle gun - Altogether: 4.7MeV + 1.2MeV + 167keV γs

3 γ simulated at the same spacetime (x, y, z, t).

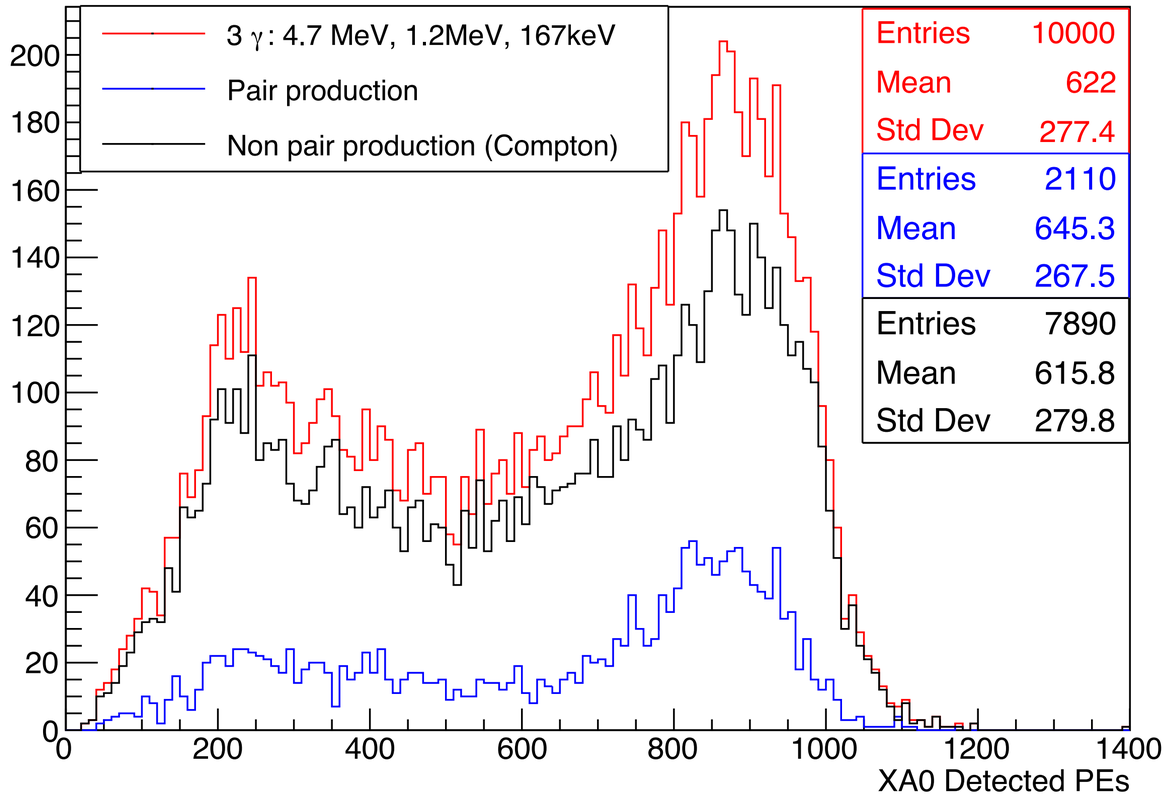
n-capture produced 3-γ cascade should produce similar signal distribution

Double peak structure:

875-PE peak from all 3 γ: an energy deposit of ~5.37 MeV (4.2+1+0.167)

225-PE peak from 2 γ: 1.2MeV γ + 167keV γ, an energy deposit of ~1.17 MeV (= 1+0.167)

Aim to look for this distribution in PNS-PDS data (and simulation)

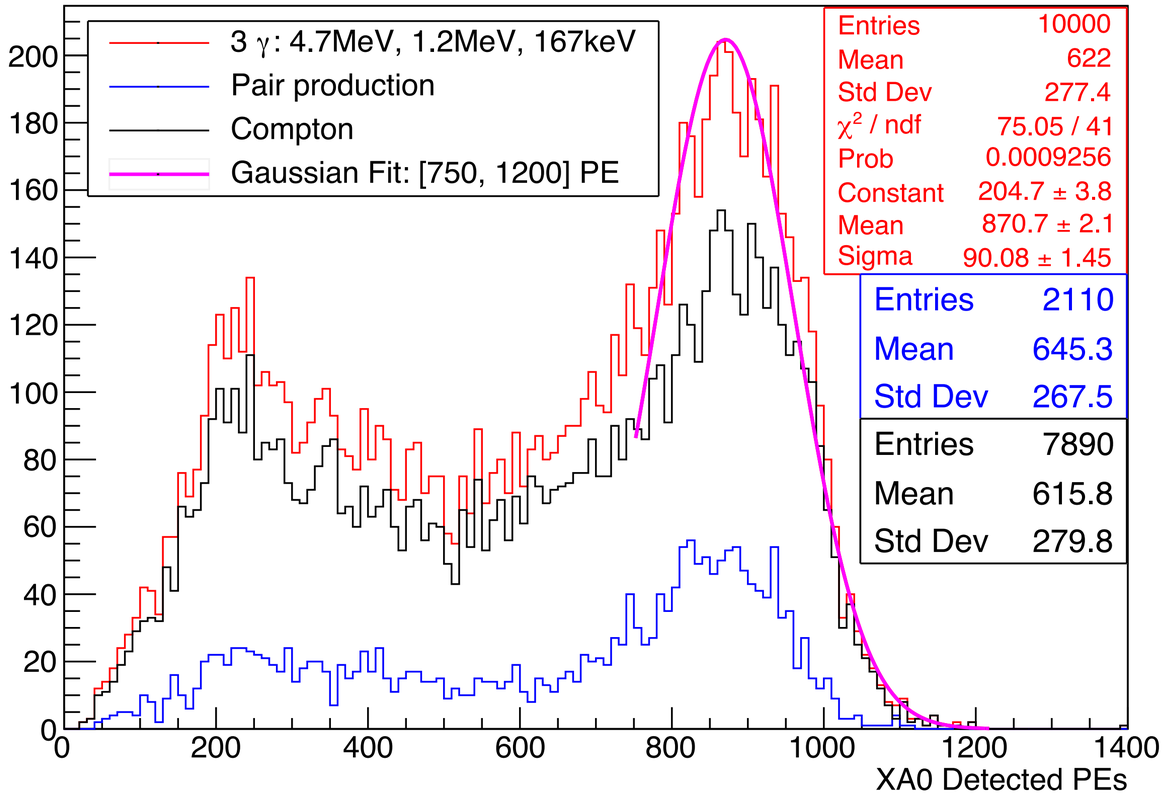


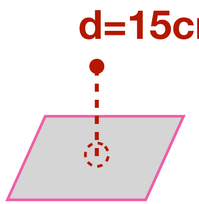
Particle gun - Altogether: 4.7MeV + 1.2MeV + 167keV γs

875-PE@5.37MeV Gaussian fit: sigma/mean ~ 10%

This is the simulated calibration uncertainty (i.e., broadening due to γ interaction)

Statistical resolution @875PE is 1/$\sqrt{875}$ ~ 3.4%

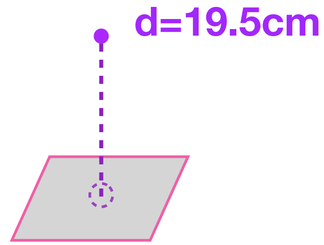


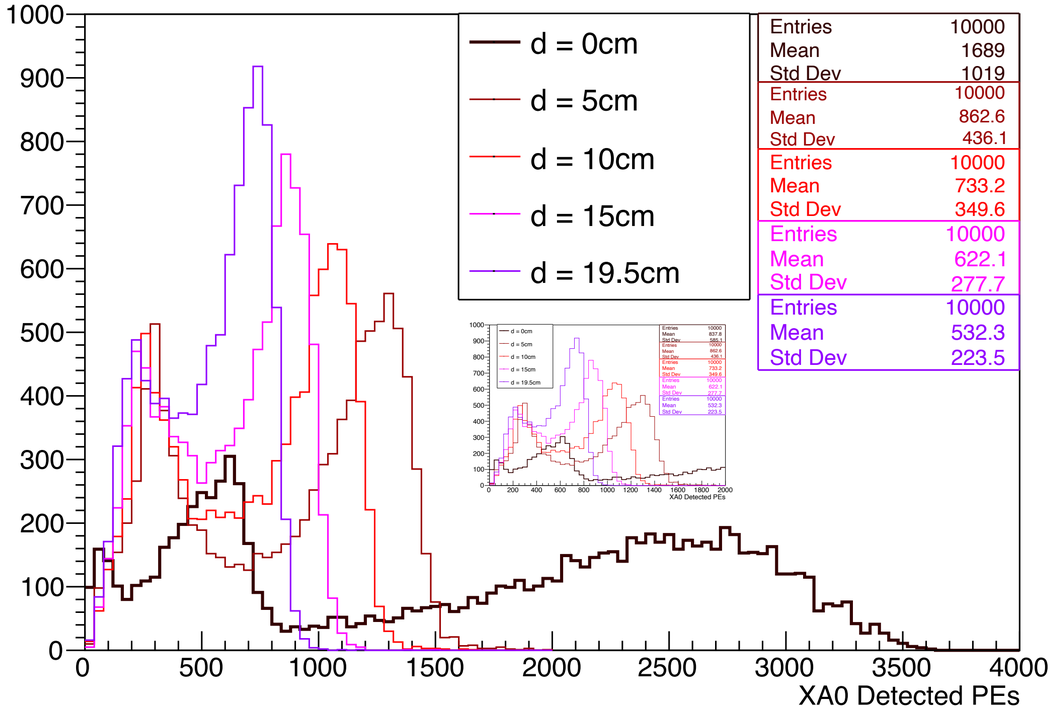


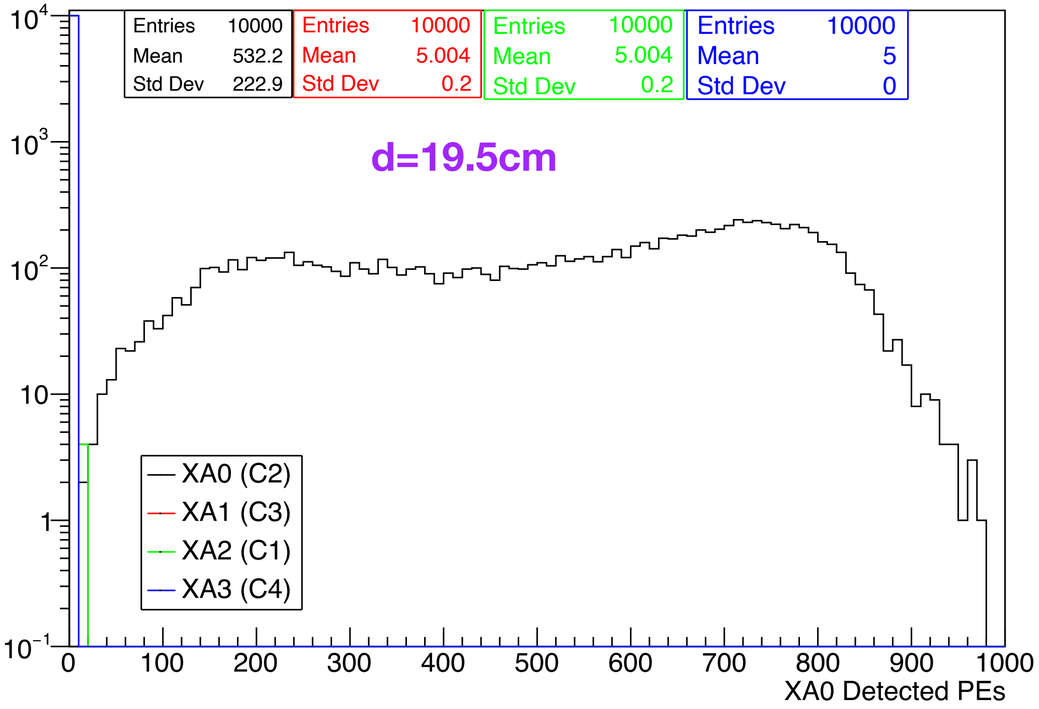
Dependence on 3-γ position: drift direction - x

Left plot: larger PD signal when source is closer to XA (expected)
Double peak structure well-preserved

Right plot: one conservative cut can be: XA0 > 500 PE, XA1,2,3 < 10 PE
This data selection rule doesn't depend on CRP
But to derive position-wise LY map, we need CRP position information





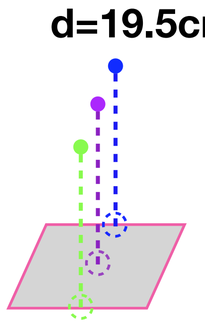


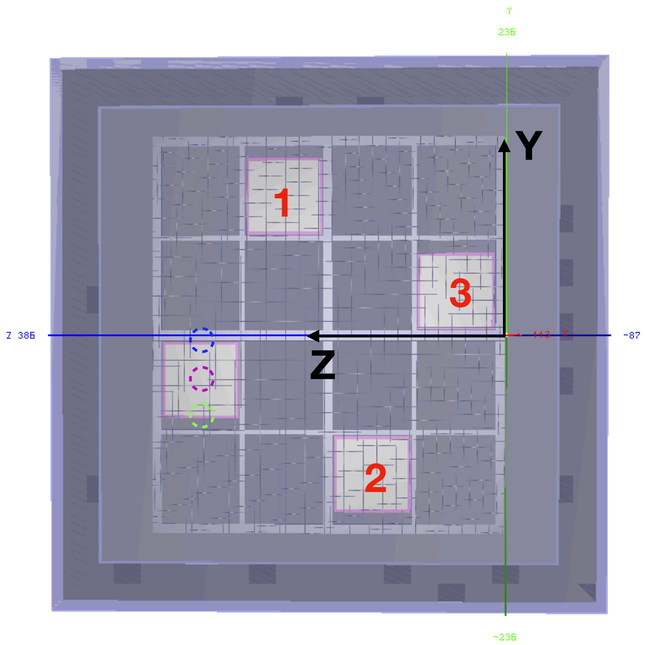
Dependence on 3-γ position: X-Arapuca plane / y direction

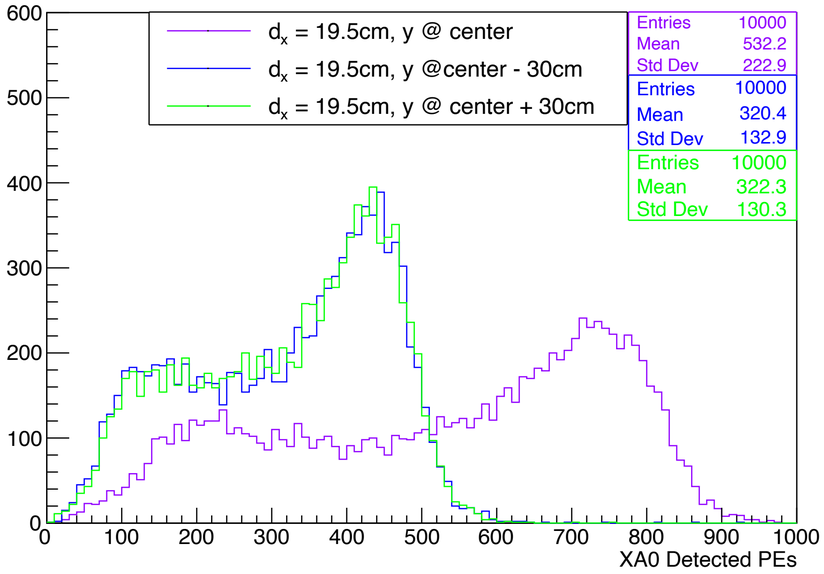
Signal distribution further shifts to low PE side if capture happens at the 4 square edges of XA (@ 19.5cm drift distance in x)

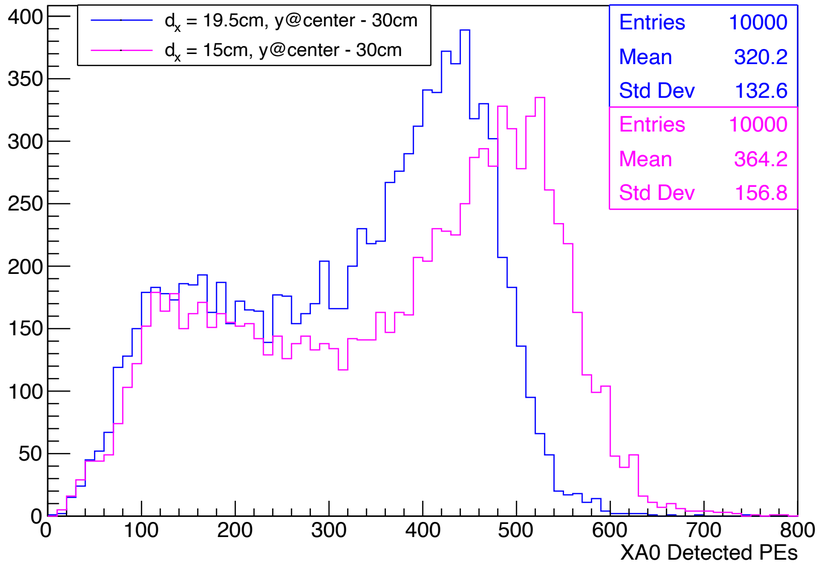
Double peak structure still visible, but start to merge

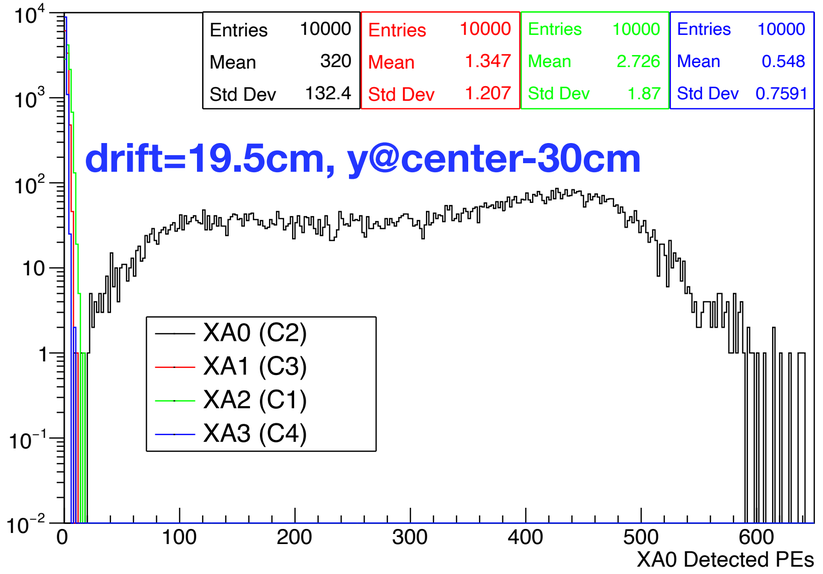
One conservative cut can be: XA0 > 250 PE, XA1,2,3 < 10 PE







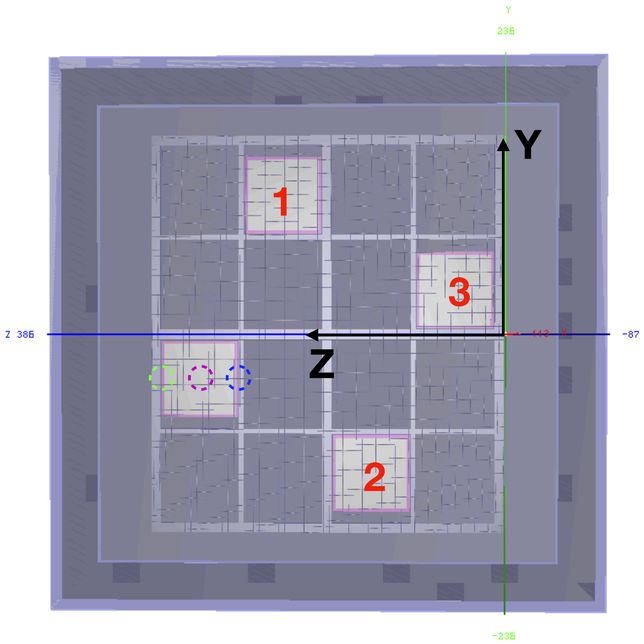


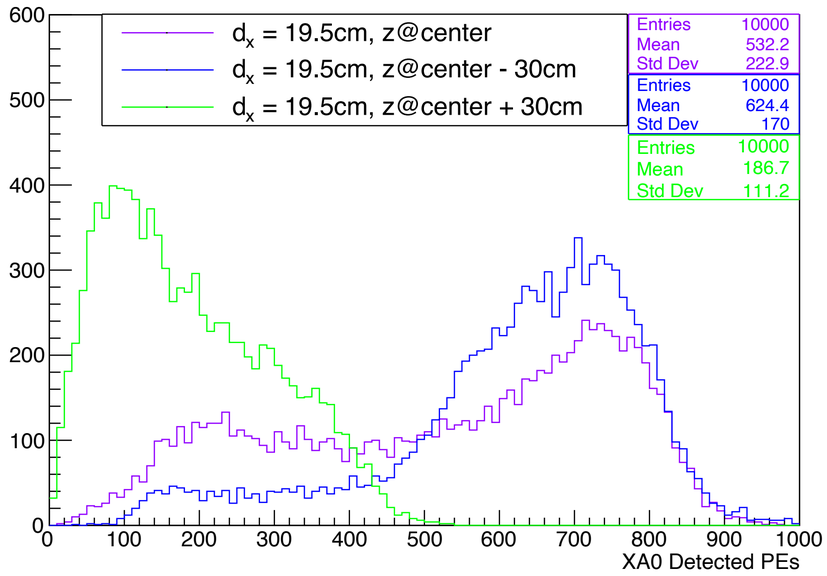


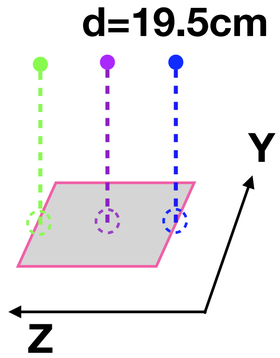
Dependence on 3-γ position: Cross check in z direction

Z direction phase space is slightly different
Center+30cm edge in z: smaller signal due to CB boundary (not the case in FD/ PD-VD)
Center-30cm edge in z: signal is larger than y direction (previous slide)

Same conservative cut in previous slide applies: XA0 > 250 PE, XA1,2,3 < 10 PE



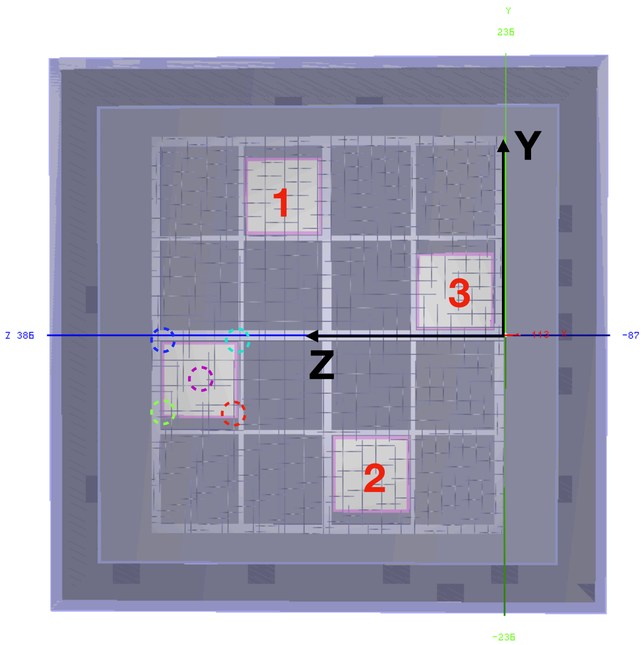


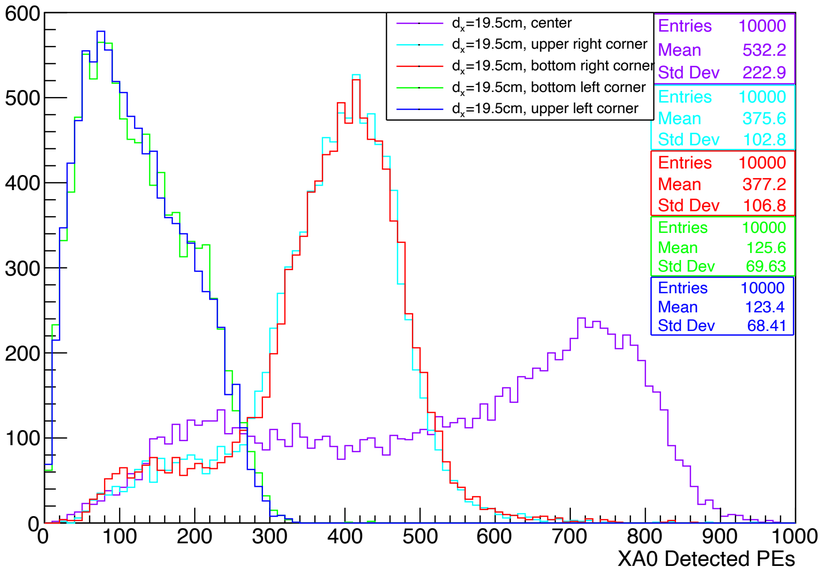


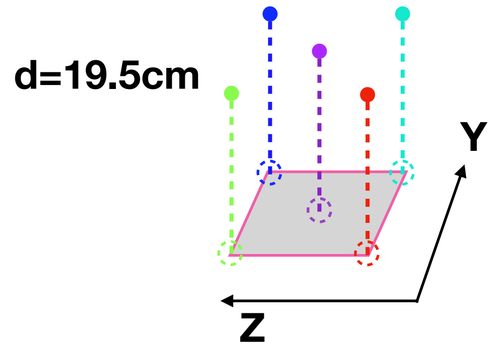
Dependence on 3-γ position: XA corners

Smaller signal at CB boundary (not the case in FD/PD-VD)

Same conservative cut in previous slide applies: XA0 > 250 PE, XA1,2,3 < 10 PE







- Summary
  - ***XA0 > 250 PE, XA1/2/3<10PE*** **:** selects captures on top of XA (60 cm x 60 cm x 19.5 cm)
    - Captures outside XA acceptance window (60cmx60cm) produce very small signals on XA
  - ***PDS energy calibration relies on double-peak distribution*** (the higher PE peak)
    - Joint **PDS+CRP analysis is critical:** need CRP position info to derive position-wise calibration
  - ***Deposited energy at largest PE peak is lower than cascade γ energy (i.e., < 6.1MeV)***

- Outlook:
  - Understand impact on signal from different cascade modes
  - Implement membrane XAs: need M1 & M2 position info…
  - Understand bkgs (cosmics, γs…)
  - …

Other cascade gammas?

- **4.7MeV + 1.2MeV + 167keV γs happens more often than other cascade γs**
  - Gammas total E is 6.1MeV (standard deviation is ~keV, very small, negligible)
  - *But do they have similar signal shape?*
  - Other cascade modes:
    - 4.7MeV, 837keV, 516keV
    - 3.089MeV, 2.8MeV, 167keV
    - 5.582MeV, 516keV
    - 2.7MeV, 2.8MeV, 516keV
    - 3.36 MeV, 2.56MeV, 167keV
    - 3.7MeV, 1MeV, 1.18MeV, 167keV
    - 2.1MeV, 2.6MeV, 1.1MeV, 167keV
    - …