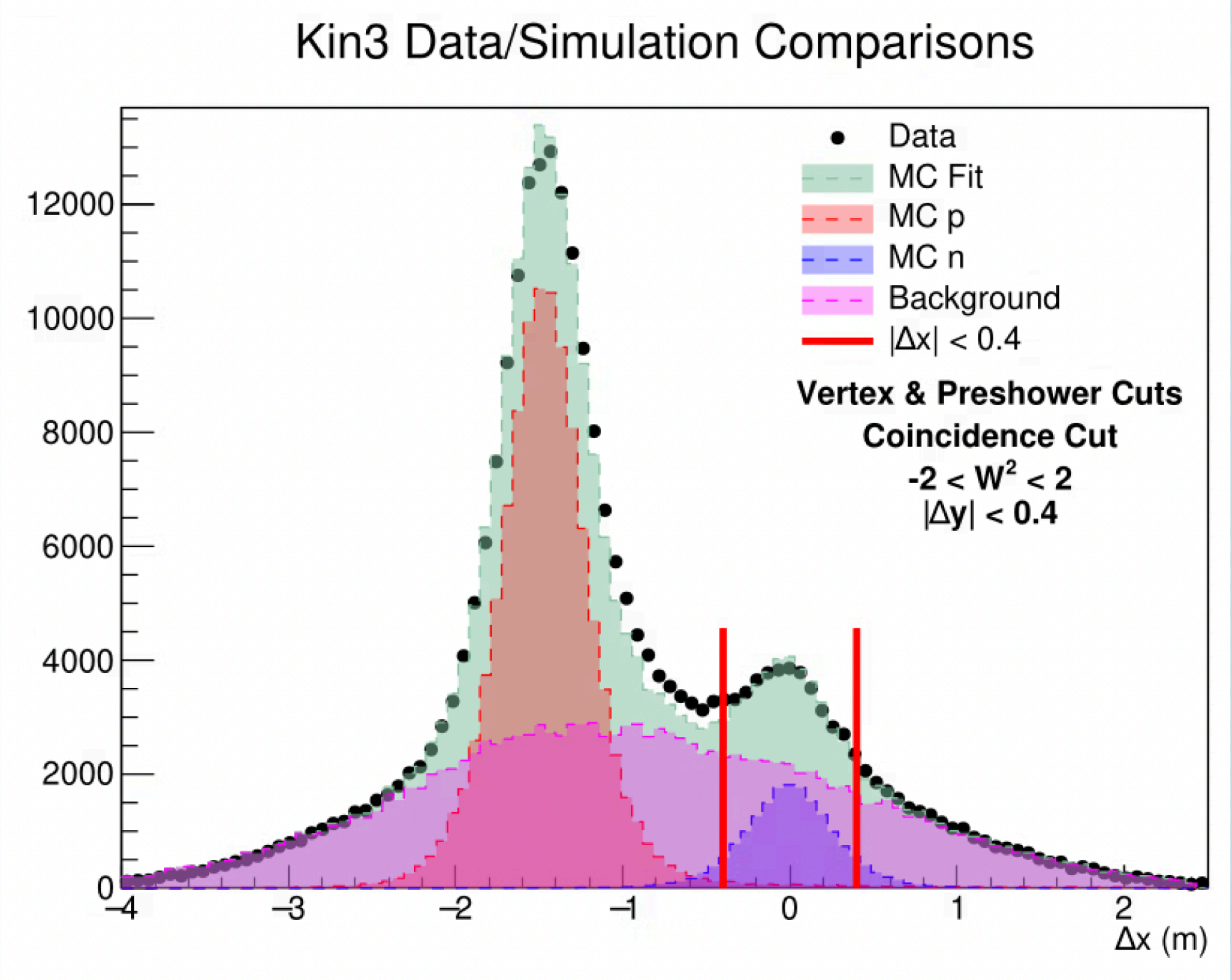
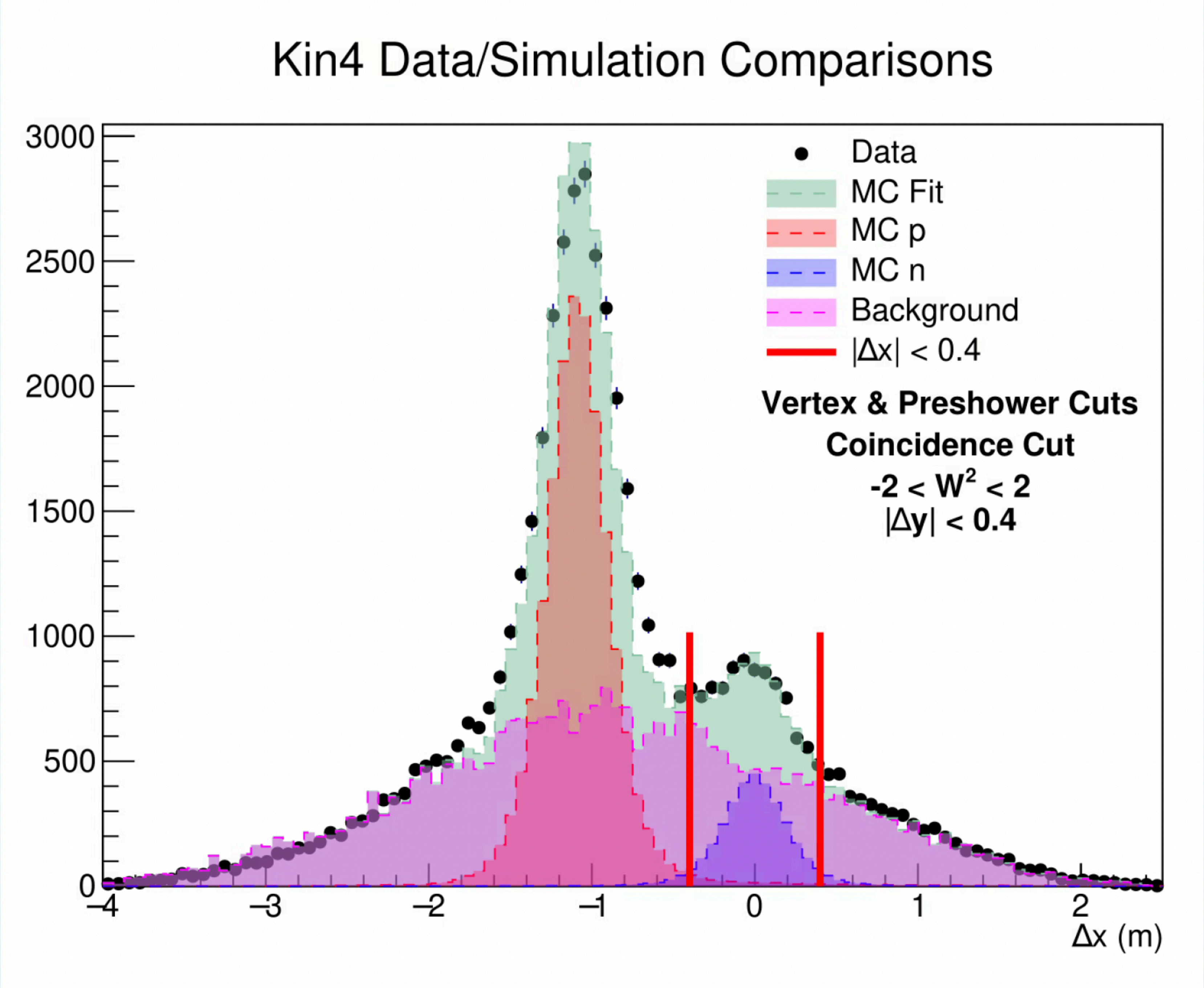
Strategies for Reducing Backgrounds in our FF analyses





At present, in GEn-II, dilution from background completely dominates the size of our errors !
Furthermore, we do not have particularly good understanding of that background.

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July 24, 2024

There are multiple areas where we can clearly make gains

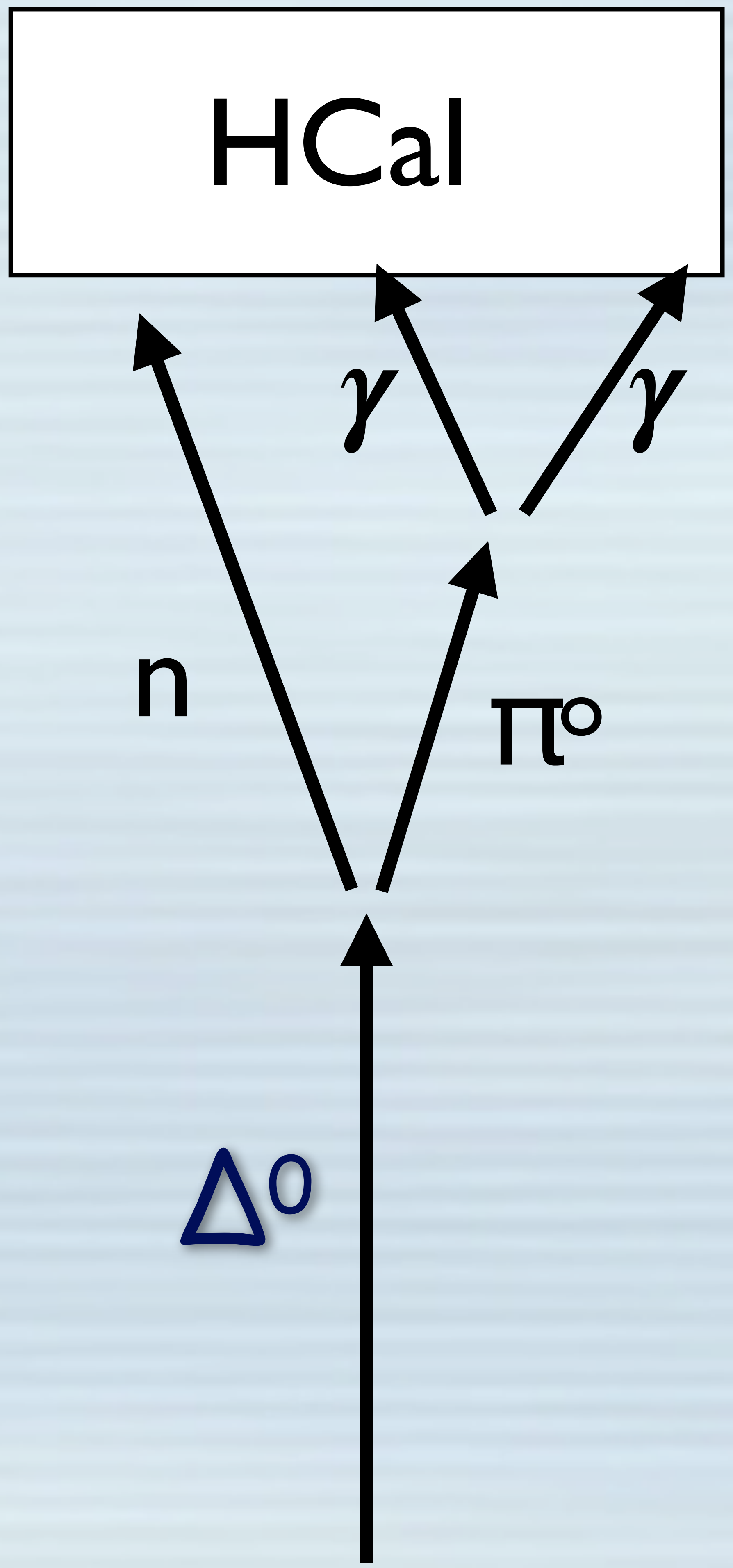
- Timing - at present we are using huge time windows for our coincidences. There are probably large gains to be had.
- Calibrations of all our detector systems need to be optimized.
- We should also consider novel ideas - if not to actually reduce our backgrounds, at least to better understand them.
  - My main focus today will be on identifying Δ^0 events, but I want to cover other stuff as well.

We need to be certain that we incorporate significant improvements for the next replay.

Background from Δ^0's

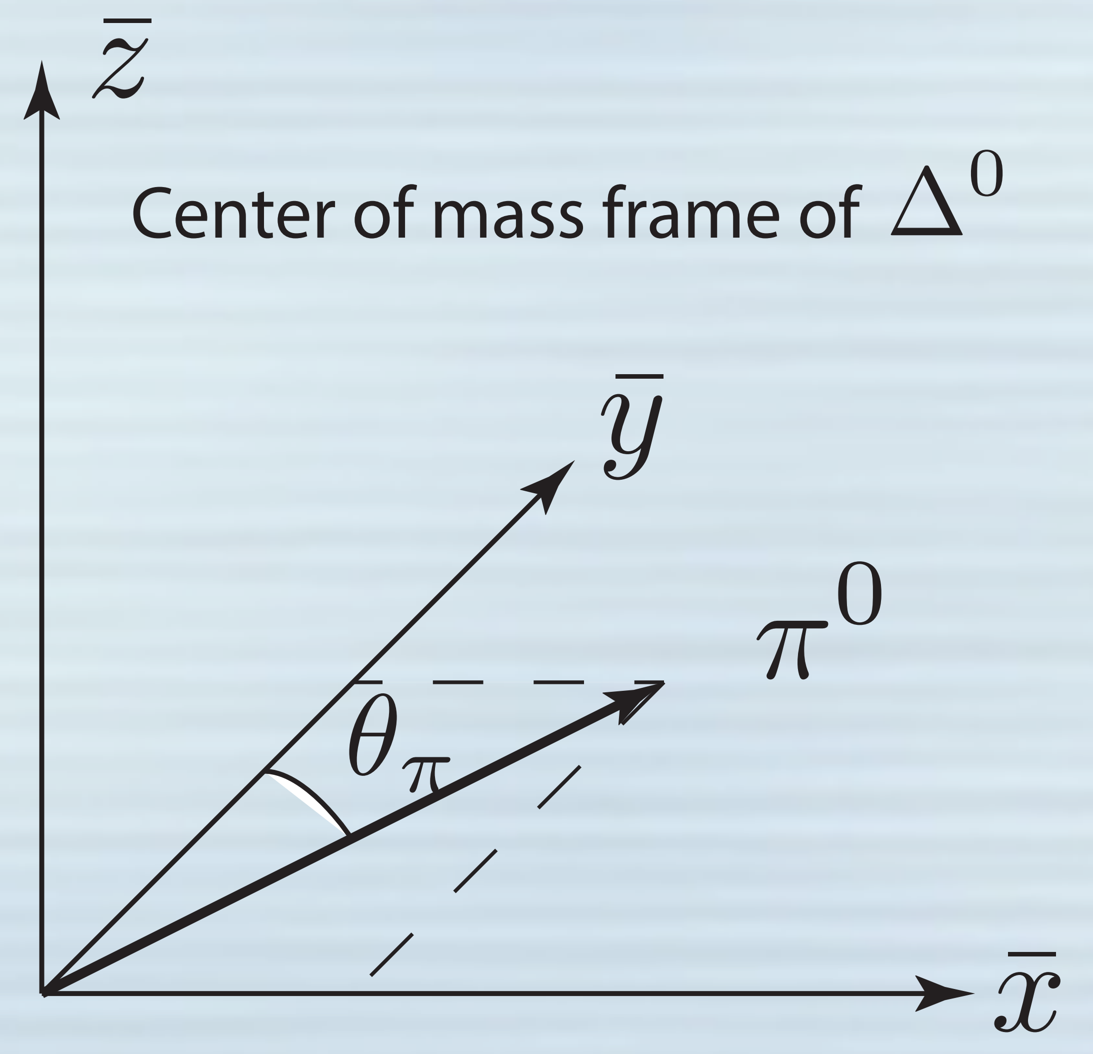
$$\Delta^0 \rightarrow \mathrm{n} + \pi^0 \rightarrow \mathrm{n} + \gamma + \gamma$$

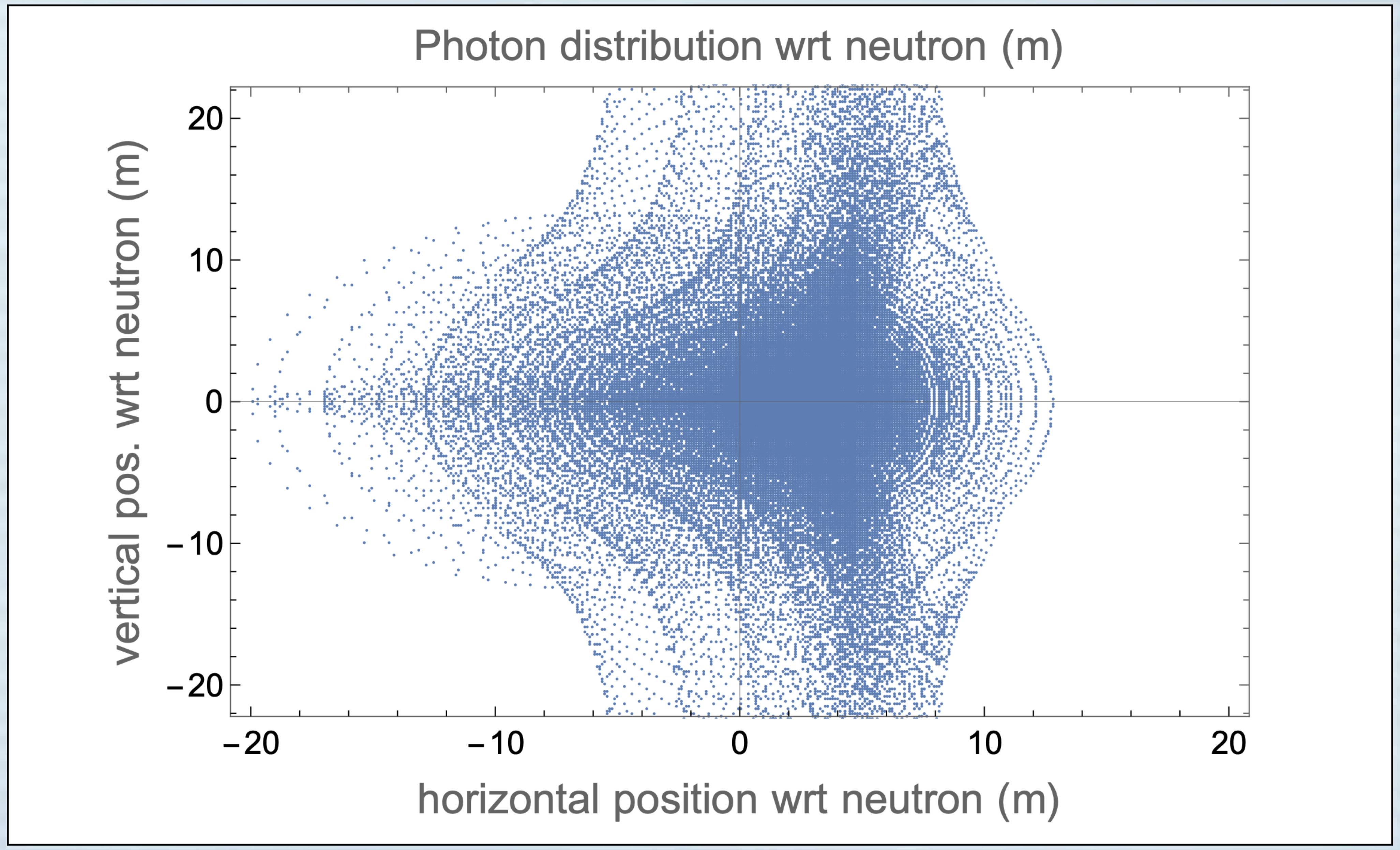
One type of inelastic event involves the creation of a Δ^0 which subsequently decays into a neutron and a π^o that in turn decays into two photons. A significant fraction of the time, at least one of the photons will hit HCal.



Not to scale! All this happens very close to the nucleus

Distribution of photons with respect to the origin (where the Δ^0 momentum intersects HCal)



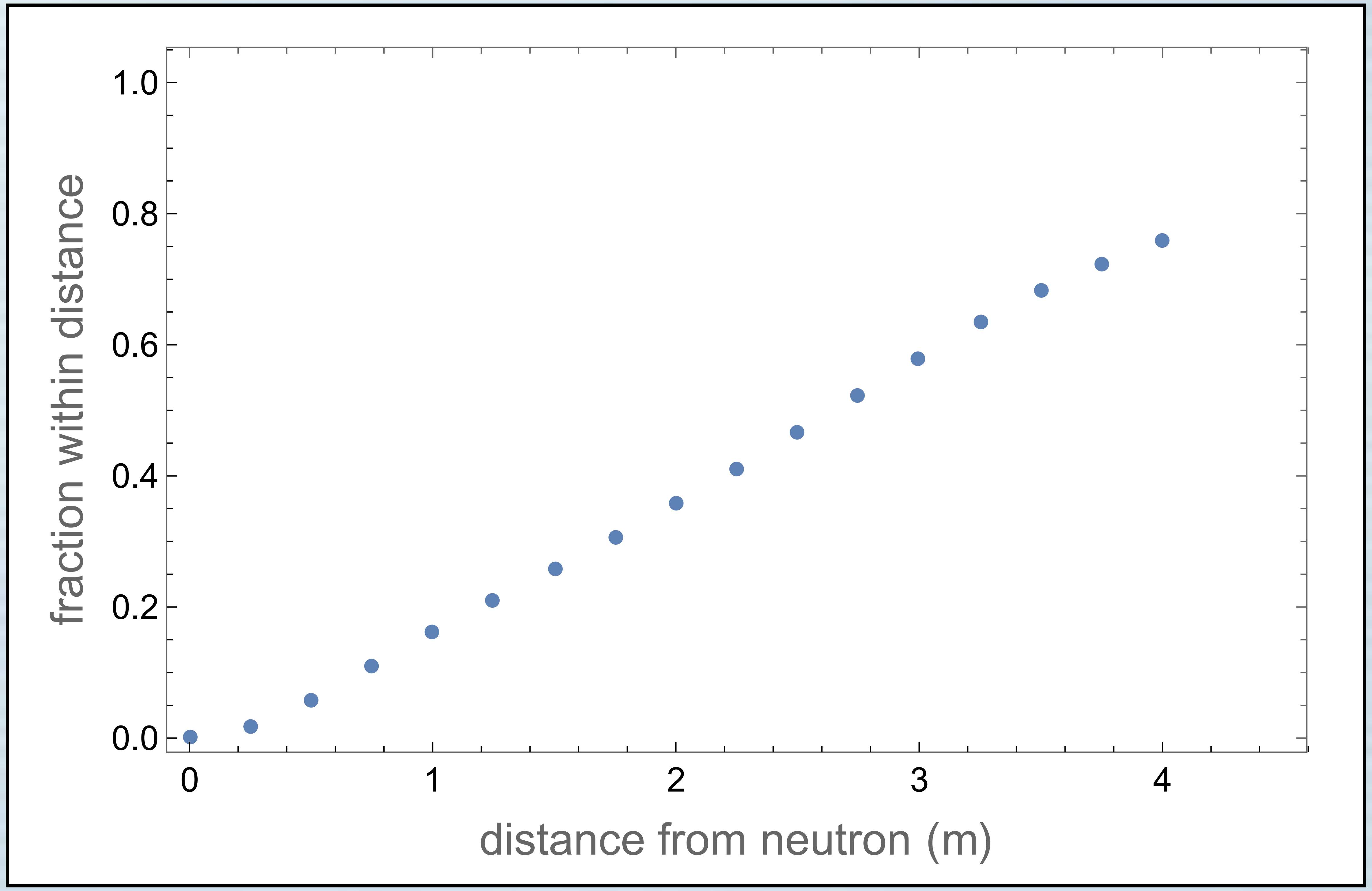


The y and y-bar axes are along the momentum of the Δ^0. Since we only care above the distance between the neutron and the photons, we can assume that the pion decays in the x-y plane without loss of generality. We should imagine the figure above rotated about the origin for the true distribution.

Fraction of gammas landing within a given distance of the neutron

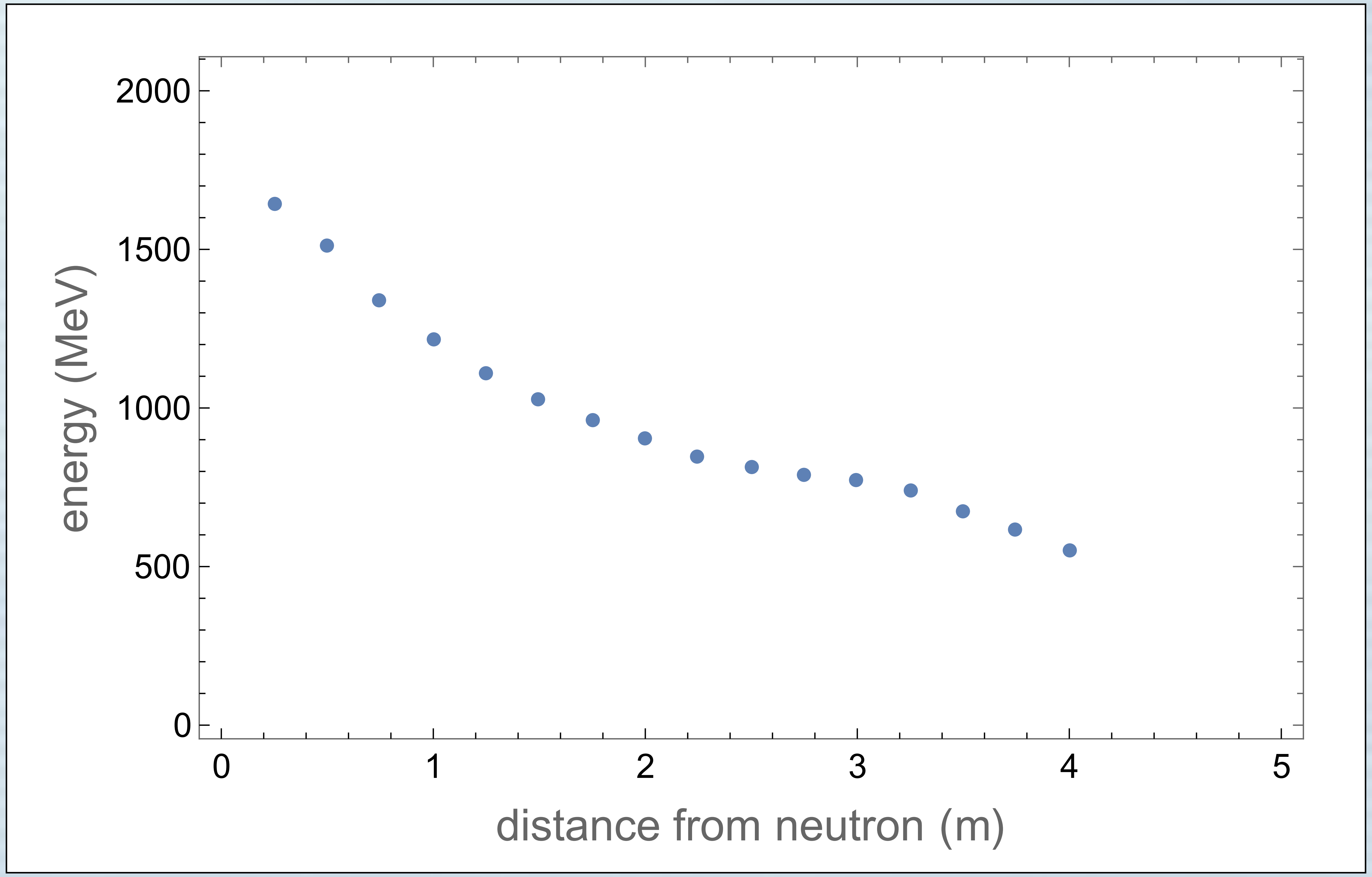
Shown is the fraction of Δ^0 events in which at least one photon lands within the indicated distance.

- Just under 20% of events have a photon within 1 meter.
- Nearly 80% of events have a photon within 4 meters.

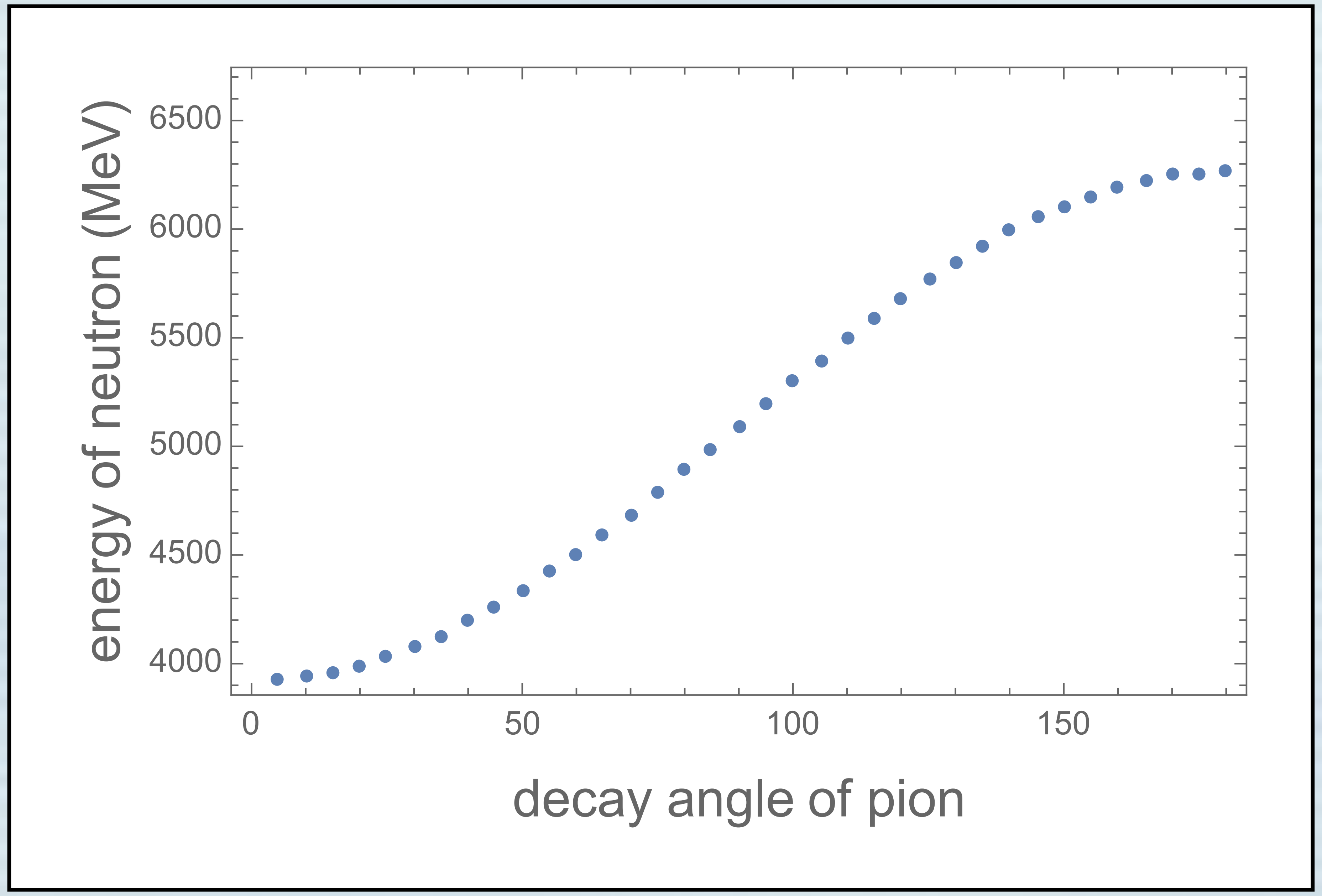


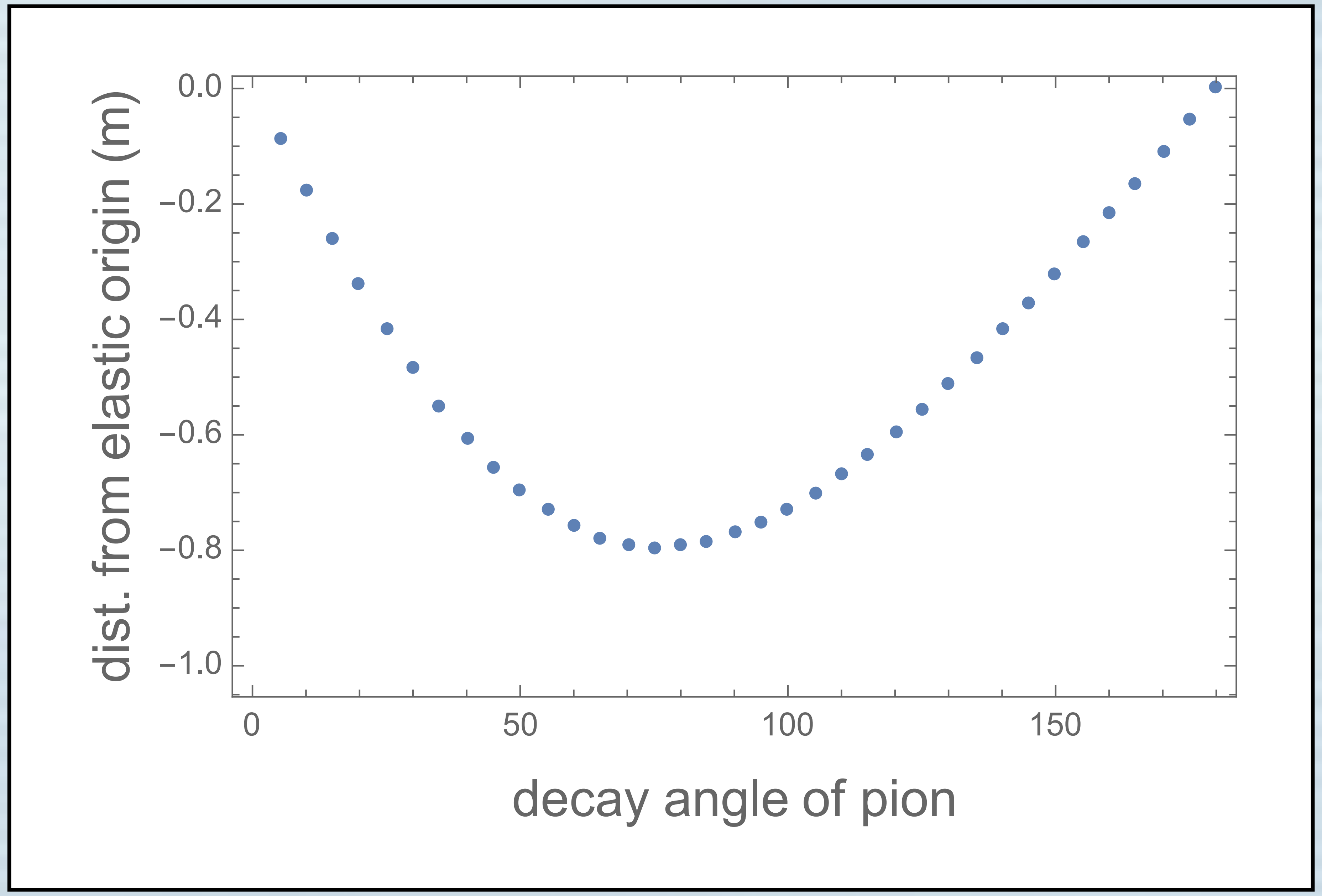
Average energy of photons binned by distance to the neutron.

The average energy of photons that land relatively close to the neutron can be quite high.



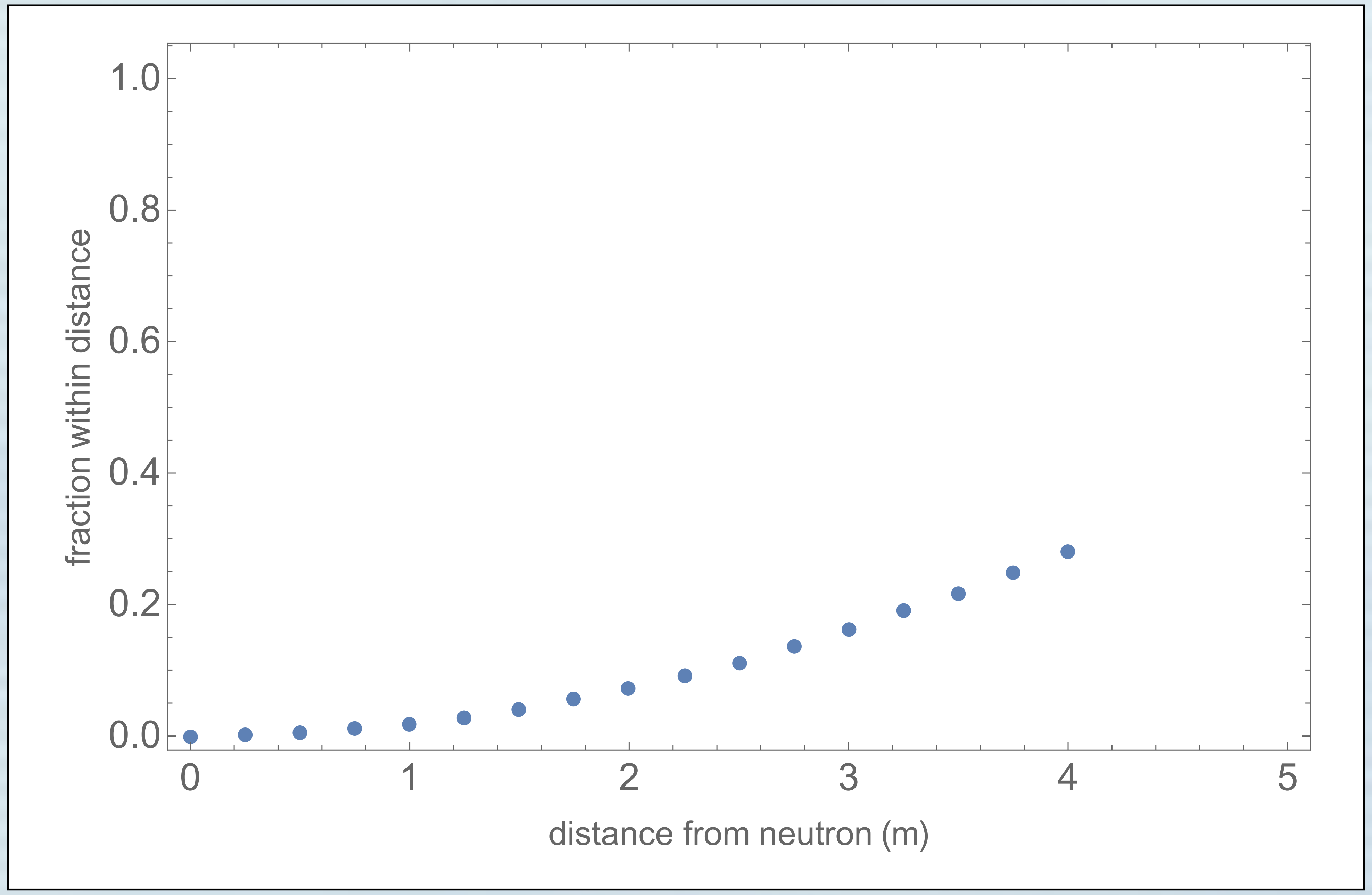
The energy of the neutron on HCal depends on the decay angle of the pion wrt the Δ^0 momentum

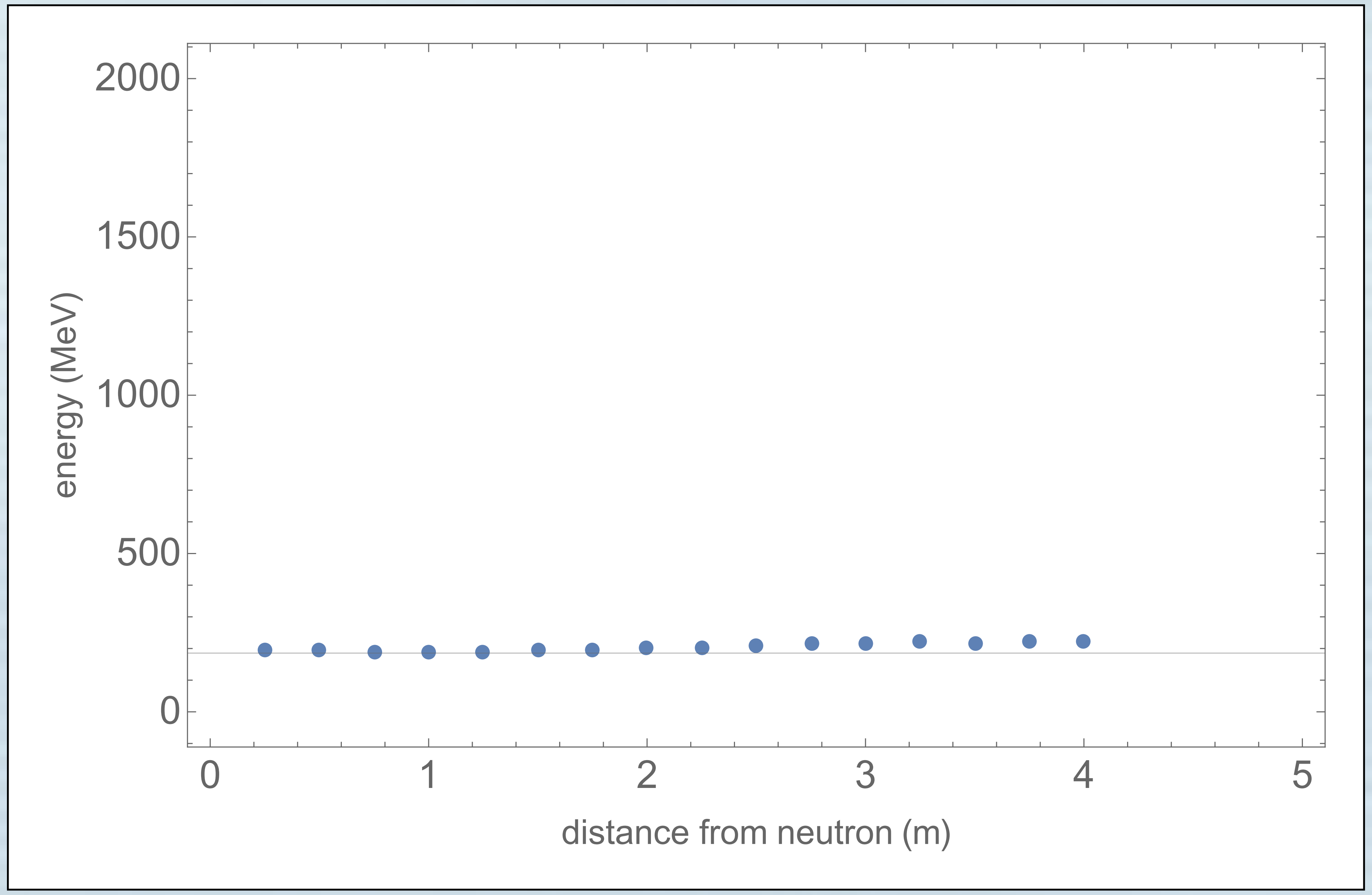




The energy of the neutron depends strongly on the pion/delta decay angle.

Photons corresponding to higher energy neutrons will be harder to detect





Steps for exploring the Δ^0 background in our data

- Convolve the probability of photons appearing at different distances with the spatial distribution of events over the face of HCal.
- Create a root file with HCal data that includes multiple clusters with moderately high energy.
- Study whether the frequency with which we detect photons agrees with expectations.

Returning to the issue of timing

- A 6.5 GeV neutron will take 57.3 ns to reach HCal
- A 4.0 GeV neutron will take 58.3 ns to reach HCal
- Fermi motion will cause far less variation in the energy of each neutron.

- We currently use a 16 ns window (+/- 8 ns) for Kin4.
- Even with the modest time resolution of our apparatus, it would seem that a 4-5 ns window (+/- 2 ns) should be doable.
- Such a time window would almost certainly reduce our background significantly.

Another idea that might be worth exploring

Under the assumption that there is no Fermi motion, we have our usual expression:

$$W^2 = M^2 + 2M\nu - q^2 \quad = \quad M^2 + M(E_0 - E_f) - 4E_0 E_f \sin^2\frac{\theta}{2}$$

If the initial electron energy E_0 and the scattering angle are fixed, the final energy of the electron is fixed:

$$E_f = \frac{M^2 + 2ME_0 - W^2}{2M + 4E_0 \sin^2(\theta/2)}$$

Without going into details (particularly because I am not confident that it is right!), the first expression can be generalized to account for Fermi motion:

$$W^2 = M^2 + 2E_0^n \nu - q^2 - 2\vec{p}_0^{\,n} \cdot \vec{q}$$

For each event, there are three points of interest on HCal:

- Where the hadron would hit if it had been purely elastic scattering with no Fermi motion.
- Where the hadron would hit based purely on the 4-momentum transfer with no Fermi motion)
- The point where the hadron actually hit.

Exploring some the correlations associated with the above quantities might have some value in recognizing events that are not purely quasielastic. It could be that we can develop some dynamic rather than global cuts for identifying background.

Moving forward

- We need a lively discussion and effort aimed at finding ways to reduce our background.
- We should pursue these goals vigorously while preparing for the next replay.
- If nothing else, we need to understand our background better than we do presently. While our current technique for dealing with the background is fine for now, it is not something that we can rigorously defend.

For those interested, I have prepared a tech note describing my Δ^0 studies.