Brain Imager Simulation: Full Body Phantom

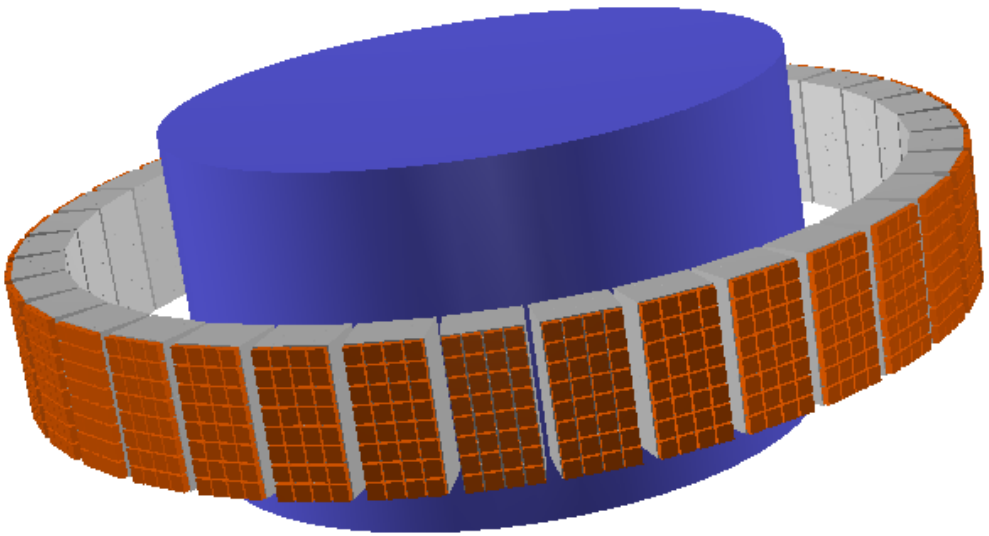
PET-TOF

December 4, 2013

Introduction

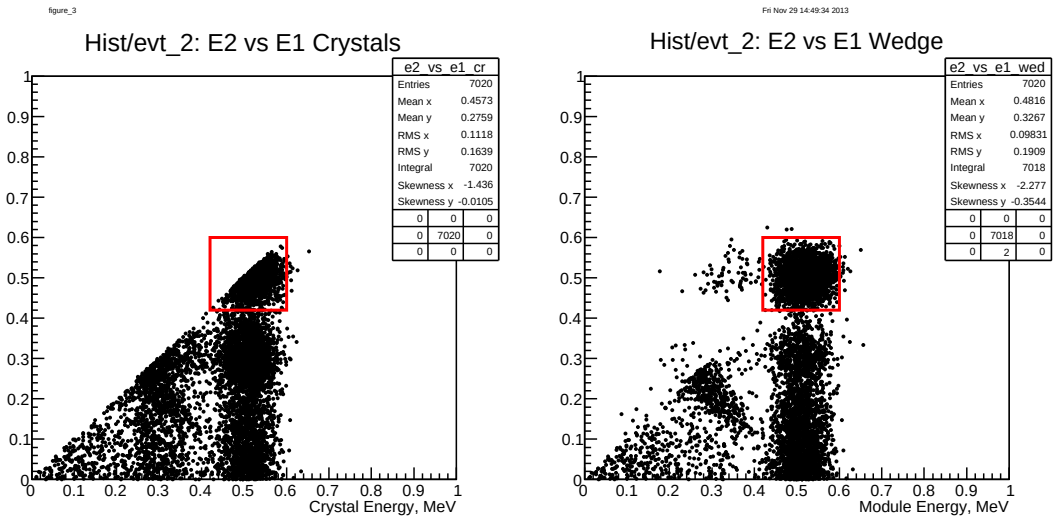
- use the Geant4 simulation in Mu2e framework to get better understanding of the brain imager performance
- last time: simplistic “brain phantom”, a water cylinder with R=10cm, H=10cm
- radiation source: point in the center or distributed uniformly over the phantom volume
- imager: R_{in} = 240 mm, 5x5x15 mm^3 LYSO crystals, σ_E/E = 15% FWHM
- understand impact of the random event pile-up on the readout

Point Source



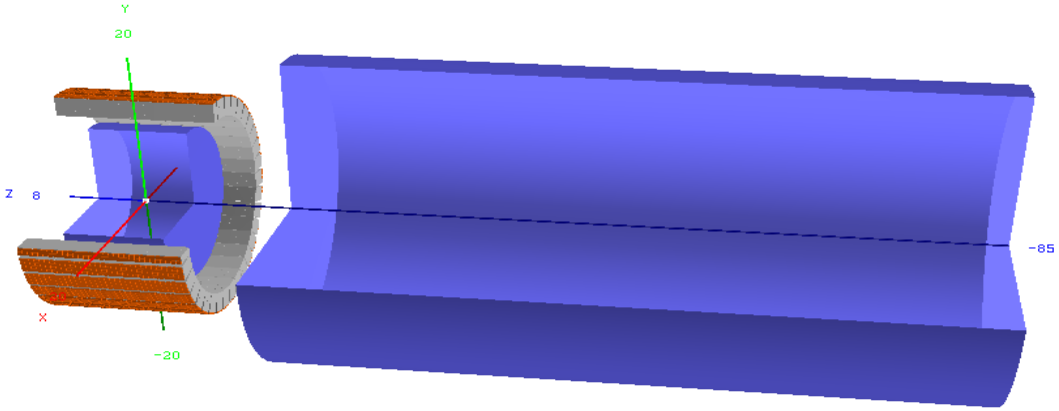
- simulate one annihilation per readout cycle (event, frame)
- use default geometry - 8 5x5x15mm LYSO crystals on the delay line, 4cm FOV
- on this drawing “blue” = vacuum
- perform cross check with Heejong’s simulation - docdb-342

Point Source : Cross check with Heejong



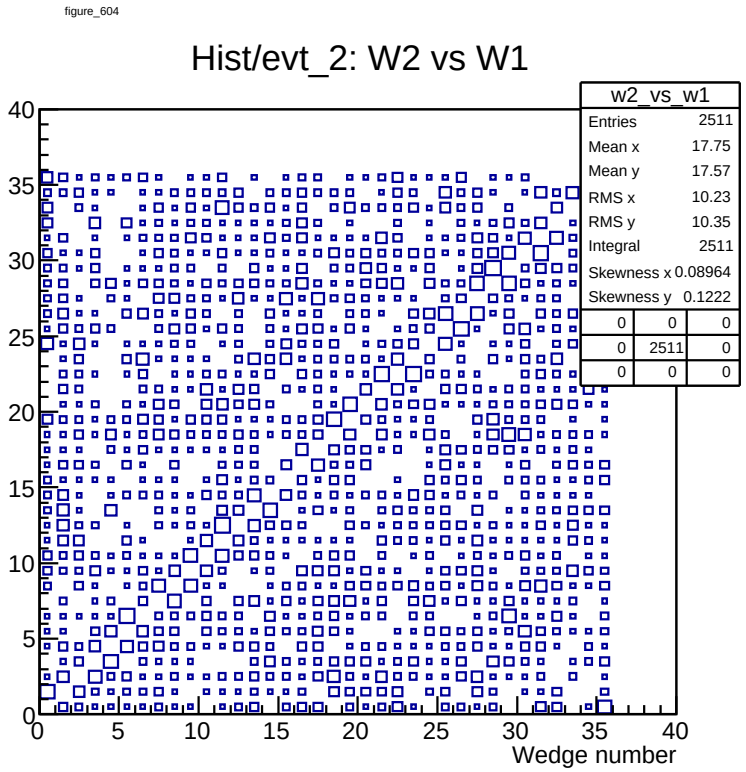
- Heejong(docdb-342) : point source in the center, trigger on $E_{module} > 0.4$ MeV: $\epsilon = 3.5\%$
- this MC: eff = 3.46%, well within 10%
- some of the scattered photons stay within the module
- for a cut on a single crystal energy, $0.42 < E_{crystal} < 0.6$:, eff = 1.9%
- last time, with 10 times less statistics, reported eff = 2.1%
- difference reproducible, turned out to be a statistical fluctuation (N_{passed} = 207 vs 188)

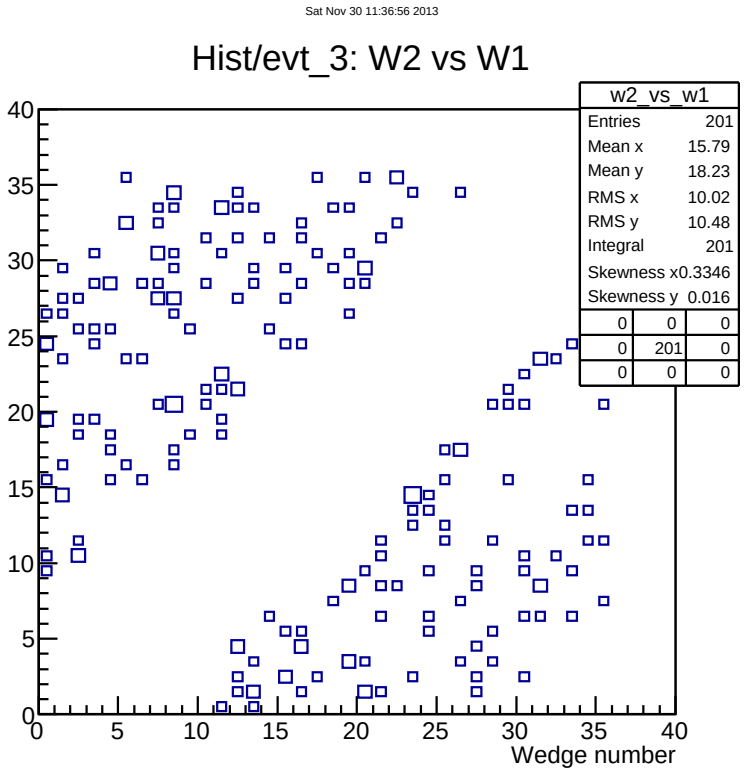
Next Step: Simplified Full Body Phantom



- FOV of 4 cm is significantly smaller than the brain size
- last time: consider an imager with FOV = 16cm, with 32 crystals on a delay line
- add a torso - a cylinder with R=200mm and H = 70cm, also made of water
- 10% of decays - in the brain, 90% - from the torso
- expect the rate of true coincidences (efficiency) not to change significantly
- points of interest - rate of singles, random coincidences, occupancies

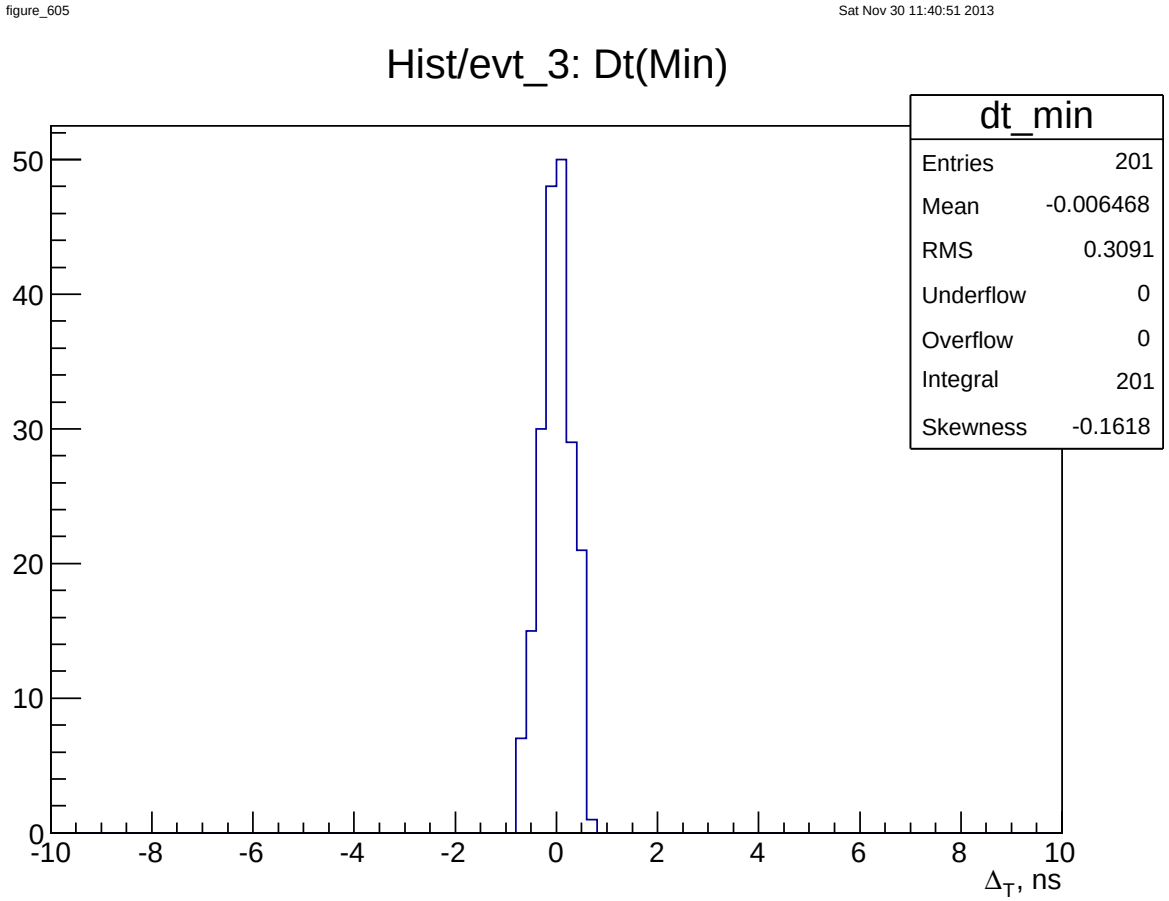
Geometrical correlations





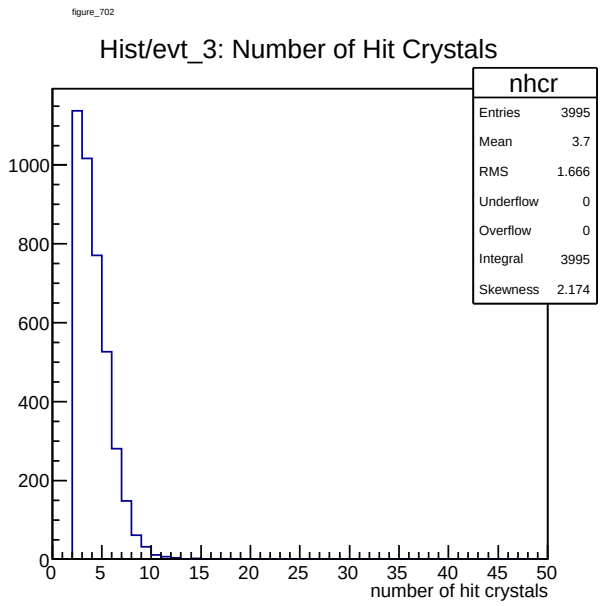
- left: events with at least 2 hit modules
- right: 2 modules with crystals 420 KeV < E < 600 KeV
- 100K events, 1 event / frame, brain fraction = 0.1 ==> A $\sim$ 2%
- consistent with $A = C \cdot \mathrm{FOV}^2$

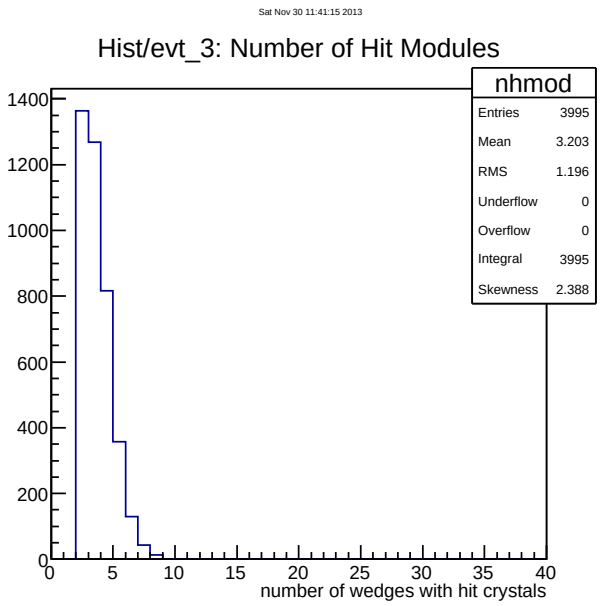
Timing Selection



- the annihilation time distributed uniformly in [0,1024] ns
- plot difference between the hit times in the two crystals
- all events have $\Delta T < 1$ ns, timing window +/2 ns doesn't affect the acceptance
- geometrical efficiency - about 2%

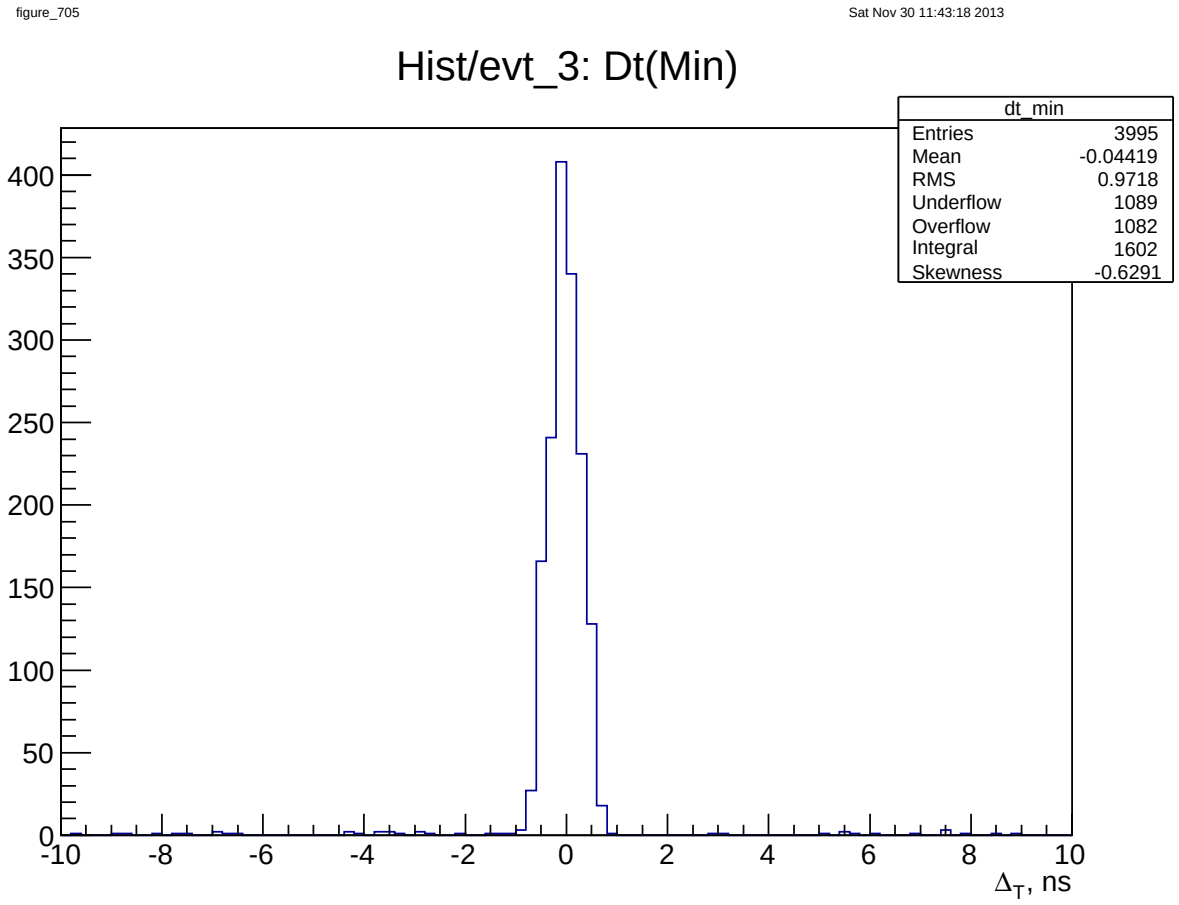
Occupancies for a fixed dose : 1 mCi





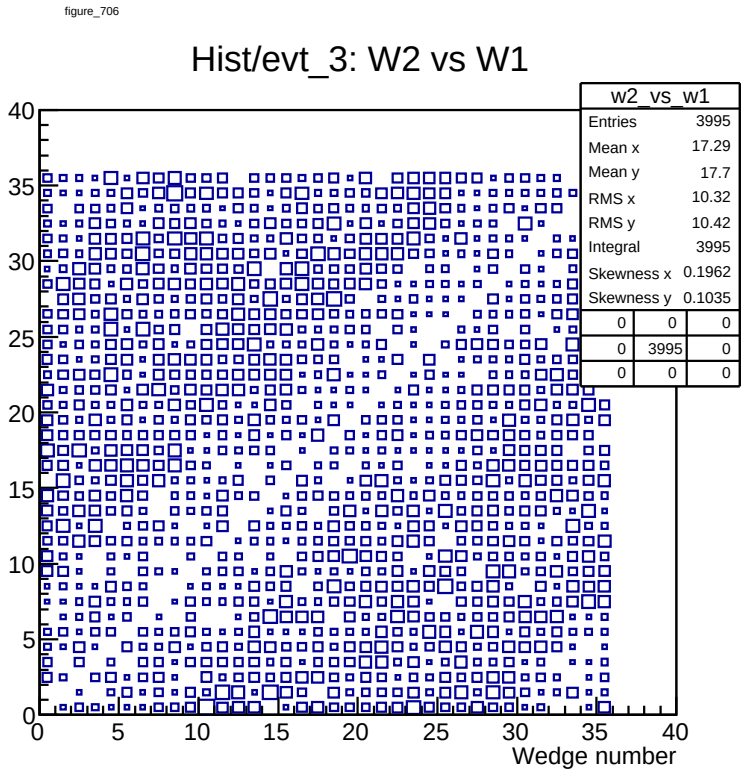
- use the same phantom+imager geometry
- assume dose of 1 mCi (0.1 of the standard dose), 10% of it - in the brain
- from ICRP-106: for FDG-18, a brain takes about 7% of the total dose, close
- 1024 channes at 5GHz = 200ns, < 7.5 annihilations> within 200 ns window, 10% - in the brain
- $\sim$ 3-4 crystals with hits, 3 modules, per 144 columns (or 3% per column)
- readout: (3-4 channels + 3 trigger channels)*2 = 12-14 channels, 10% of the total
- disable hit modules, continue with the rest 90% of the detector?

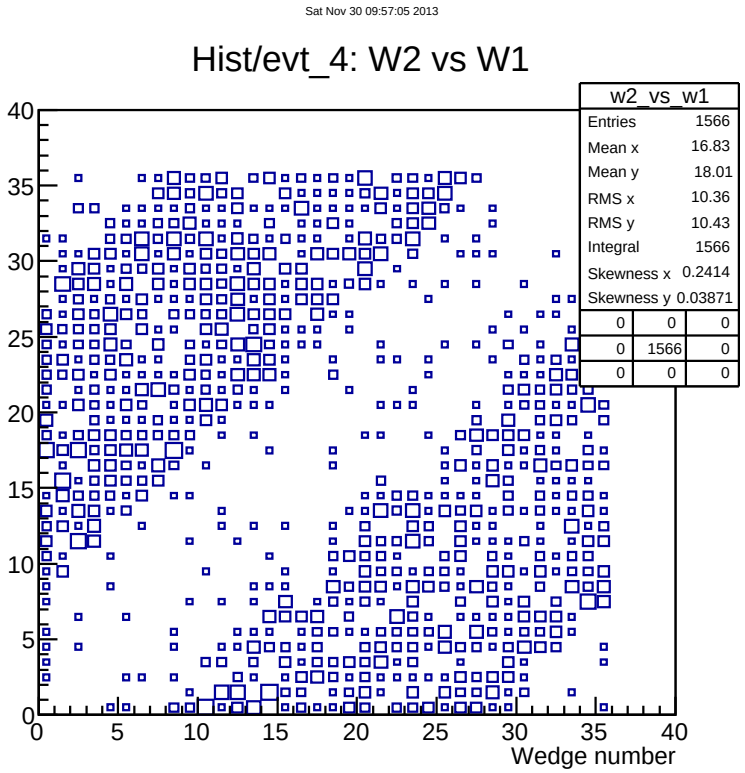
Timing coincidences



- background is negligible
- with calibrated detector, can use the timing window of +/- 2ns

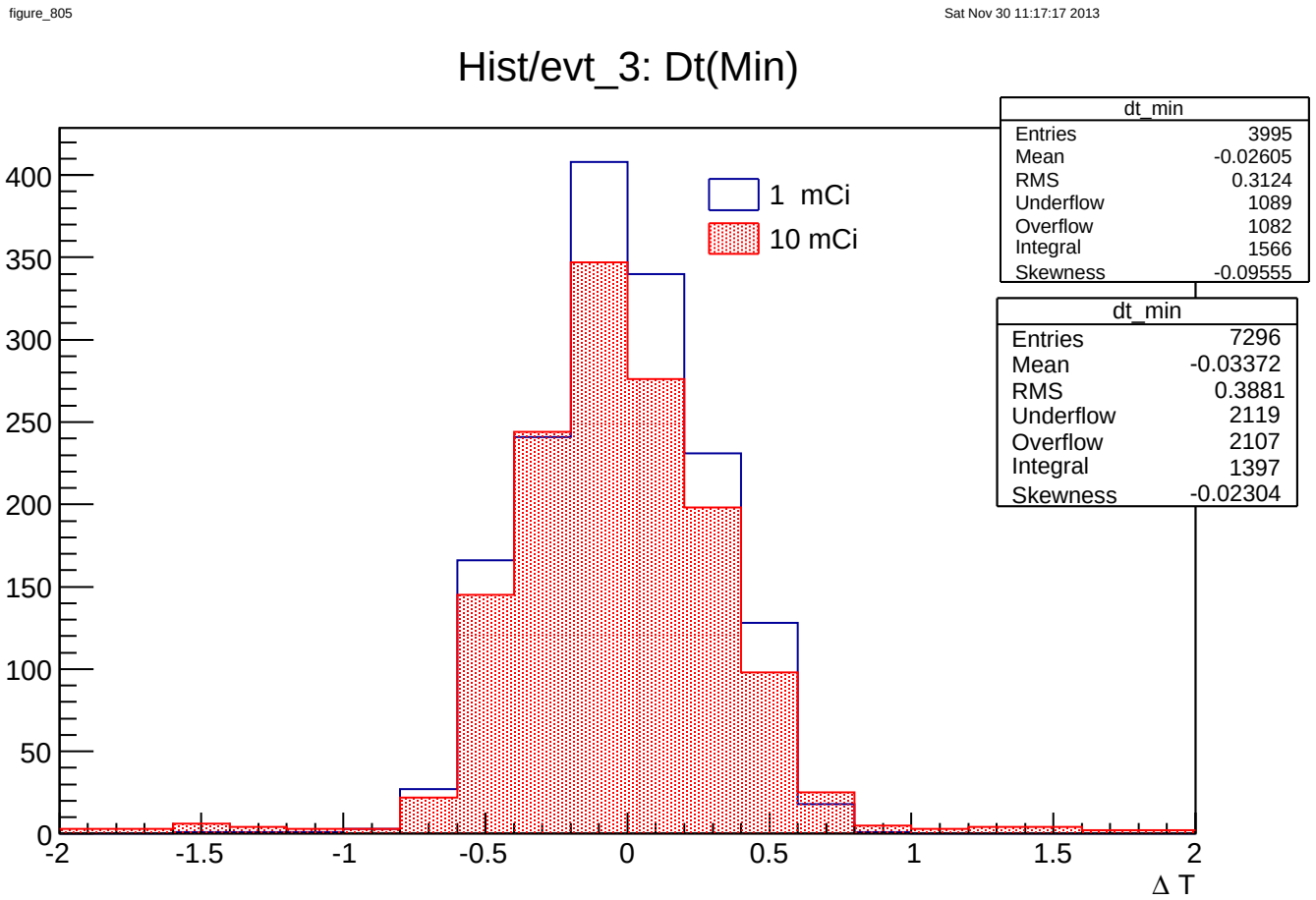
Geometry correlations in presence of the pile-up





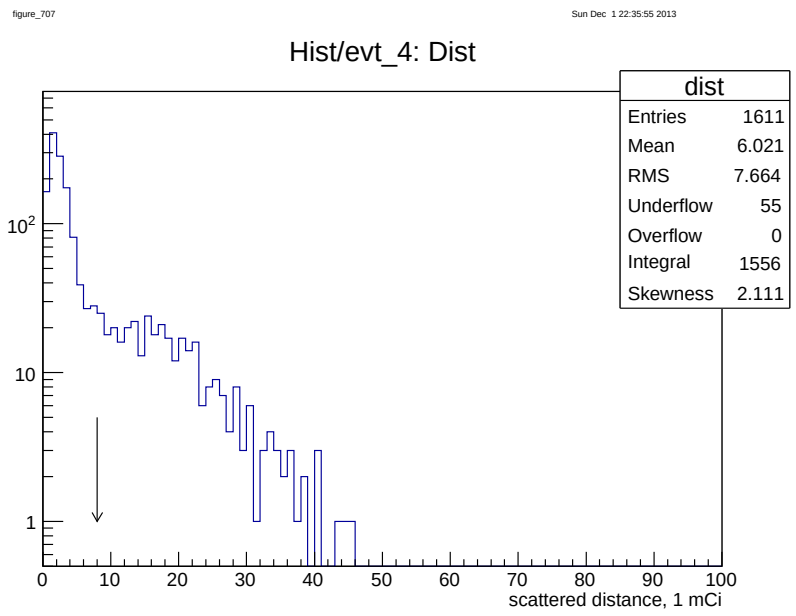
- left: 2 unscattered photons (420 < E < 600 KeV)
- right: add +/- 2ns timing window selection
- efficiency about 2% (<N> $\simeq$ 0.75)
- excluding (+/- N) neighbour wedges from the trigger should't affect the total efficiency
- need to double check events in the middle of the right plot

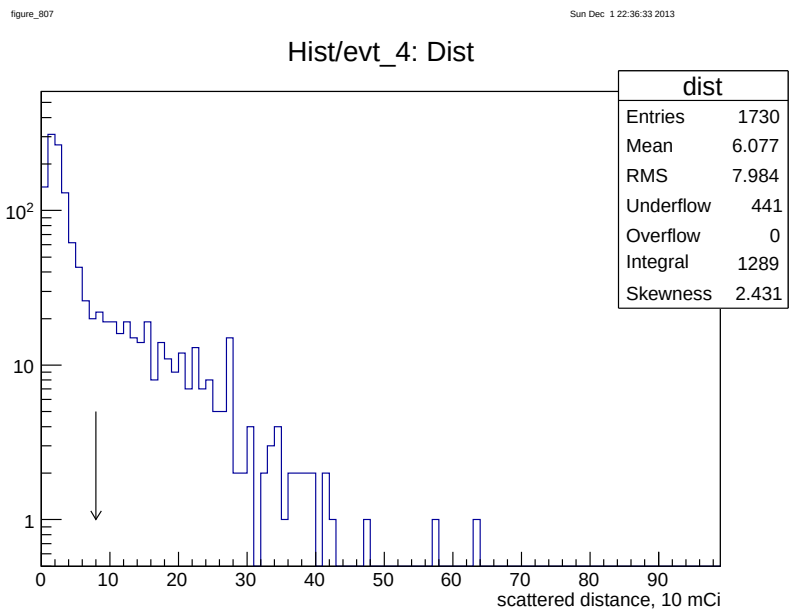
Dose effect: 10mCi vs 1mCi



- 10mCi : random coincidences also small
- suspect wrong analysis logic: for 10 mCi, the choice of the 2 wedges with the highest energy is affected by random coincidences within the 200ns window
- a 10-15% effect

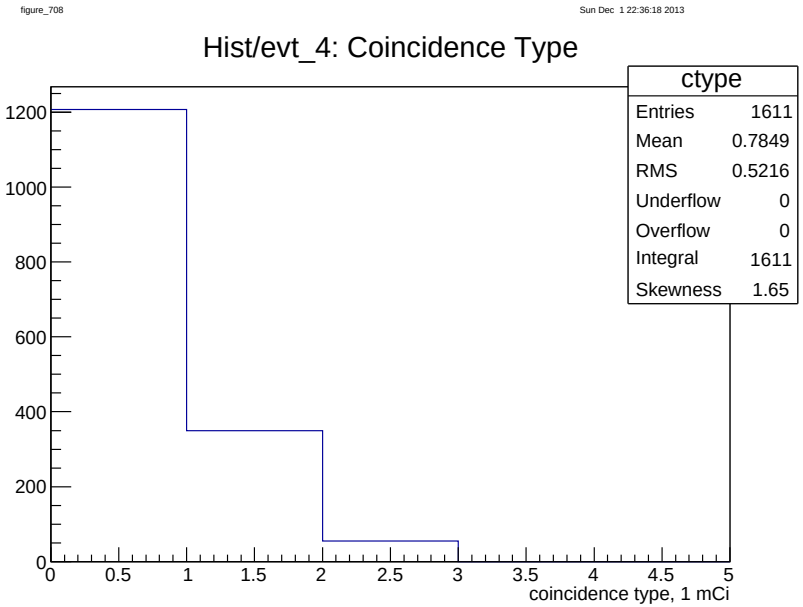
Photon Scattering in the Phantom

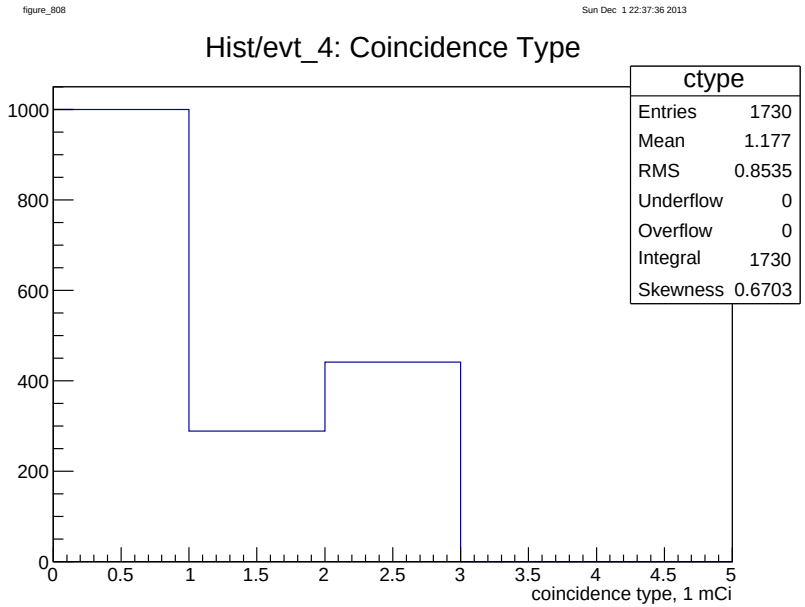




- plotted: distance between the true vertex and the line connecting centers of the two hit crystals
- scattered events: D > 8mm
- N(scattered)/N(total) $\sim$ 0.2, a function of the phantom (patient)

Random Coincidences





- random coincidence: 2 photons have different production vertices
- code: 0 - true coincidence, 1 - scatterer, 2 - random coincidence
- “randoms”: $\sim$ 3% for 1 mCi, $\sim$ 25% for 10 mCi - non-negligible
- much more pronounced effect for the full body scanners

Rates at 1 mCi

- rate @ 1mCi : 3.7e10*1e-3*2e-2*0.1 = 74 kHz , or <13mksec> between triggers
- assuming readout window of 50ns, the readout time @5GHz = 50*5*33nsec = 8.3 mksec
- expect the deadtime to be low
- everything in hands to calculate NECR (Noise Equivalent Counting Rate)
- low-resolution mode, R=10 H=10 brain, 5x5x5mm3 voxel: about 2.5e4 voxels
- 1000 events per voxel (3% stat accuracy) —> 2.5e7 events per scan
- scan time: 2.5e7/7.4e4 $\sim$ 300 seconds or 5 minutes
- for 1% stat accuracy per voxel need a 50 minute long scan
- need to start understanding the 3D image reconstruction efficiency

Summary

- for FOV = 16 cm, the brain imager acceptance is about 2%
- even with 32 crystals on a single line, expect occupancy in imager to be low
- for a dose of 1 mCi, expect rate < 100kHz, could keep the DAQ deadtime low
- emission from the body (0.9 of the total) doesn't have a big impact on the brain imaging