Noise for P-ONE: ^{40}K

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Project Overview

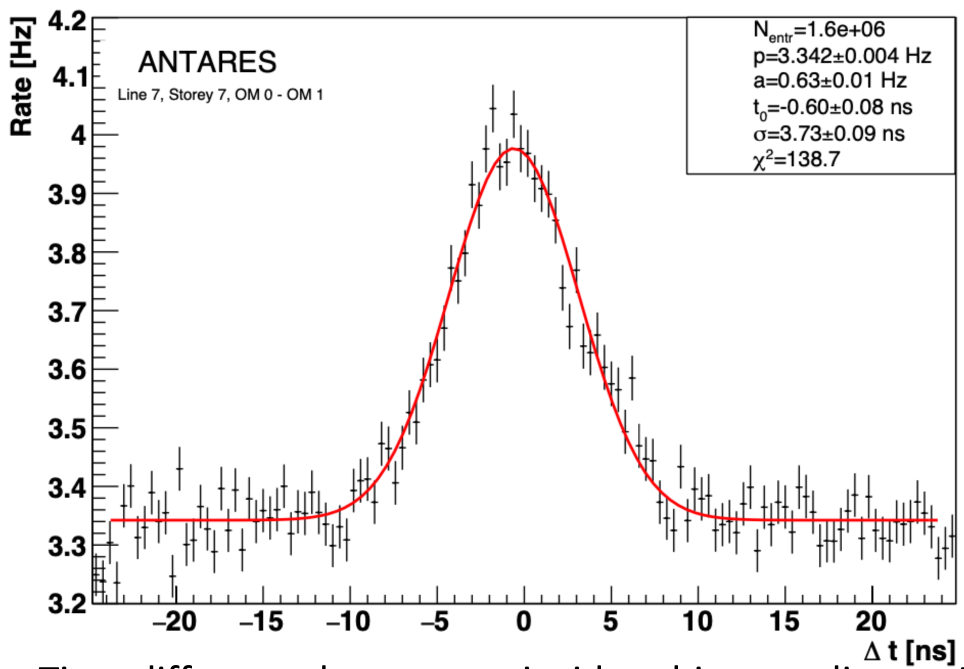
- Summer project: Understanding the structure of noise in Cascadia Basin with STRAW

- Model noise for P-ONE
  - Focused on ^{40}K
  - Other sources as well (scintillation, bioluminescence)

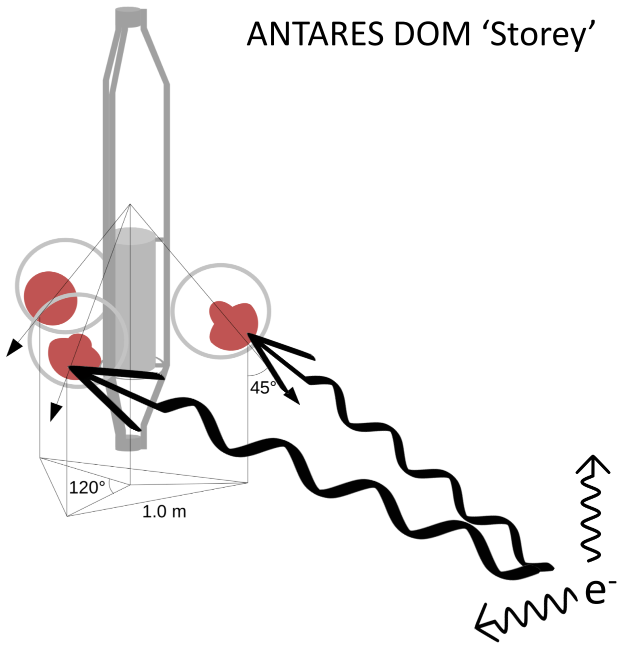
- STRAW data
  - Isolate ^{40}K noise from other sources
    - Find where most prevalent
- GEANT4 simulations
  - Create model
  - See if it matches with data

Understanding and Isolating ^{40}K

- Found a paper describing how ANTARES **uses ^{40}K coincidences** between DOMs to calibrate them
  - Can use ^{40}K decay to measure detector efficiency over time and recalibrate
  - Can try to recreate this with STRAW data



Time difference between coincident hits on adjacent DOMs
This normal distribution can be used to calculate ^{40}K concentration in seawater and compared to the actual concentration to measure detector efficiency



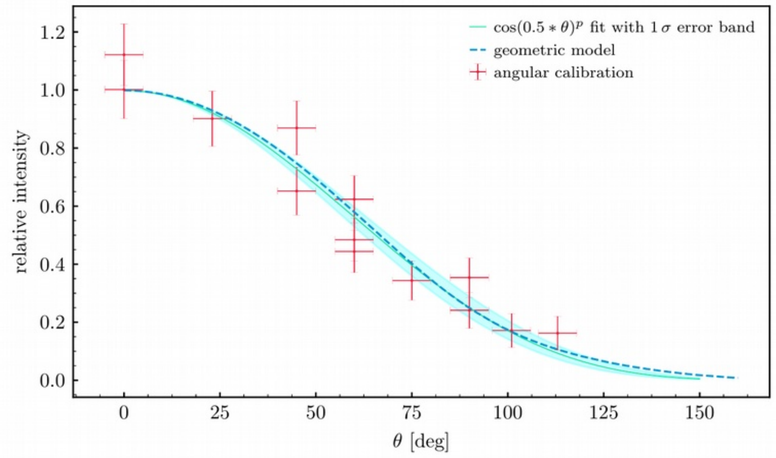
Cartoon of genuine coincidence:
^{40}K decay e^- emits Cerenkov photons which both hit the detector at approx. the same time, Δt is the difference between these detections

Can also get false coincidences from random chance

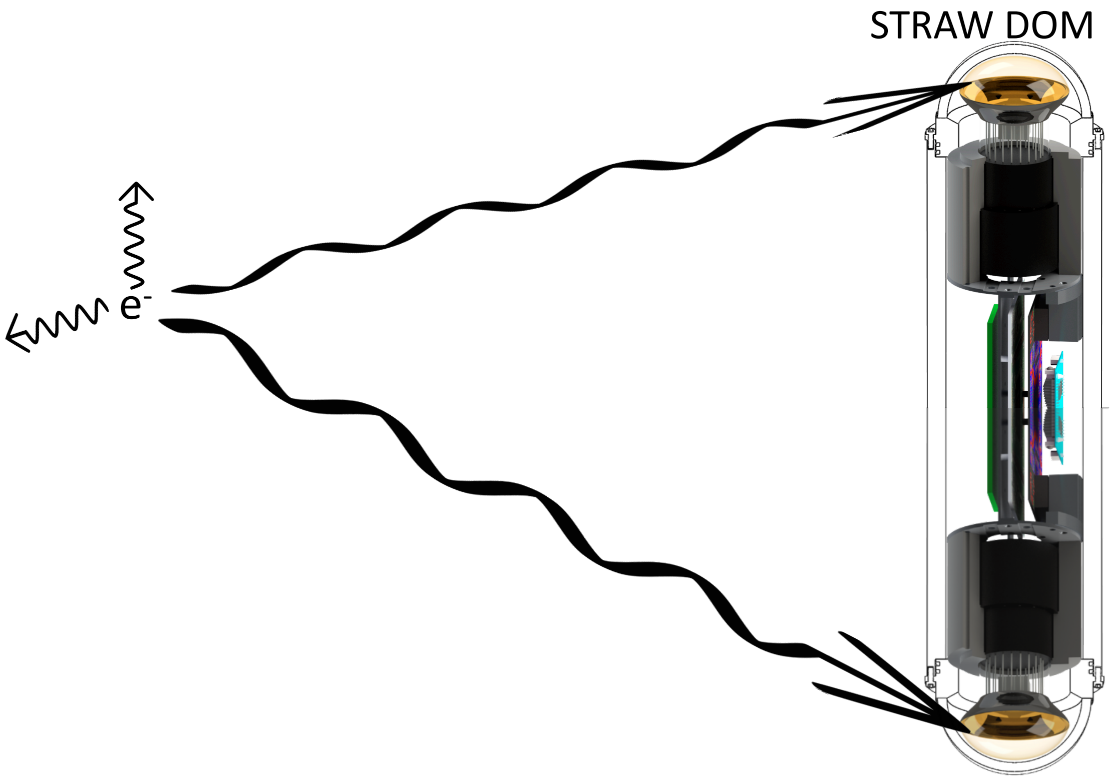
Paper: https://arxiv.org/abs/1805.08675

Can we do this with STRAW data?

- STRAW DOM small (3”) and PMTs are 180° apart
- Low angular acceptance at angles where coincidences most likely
- Do not expect as many coincidences between up and downward facing PMTs (compared to ANTARES)



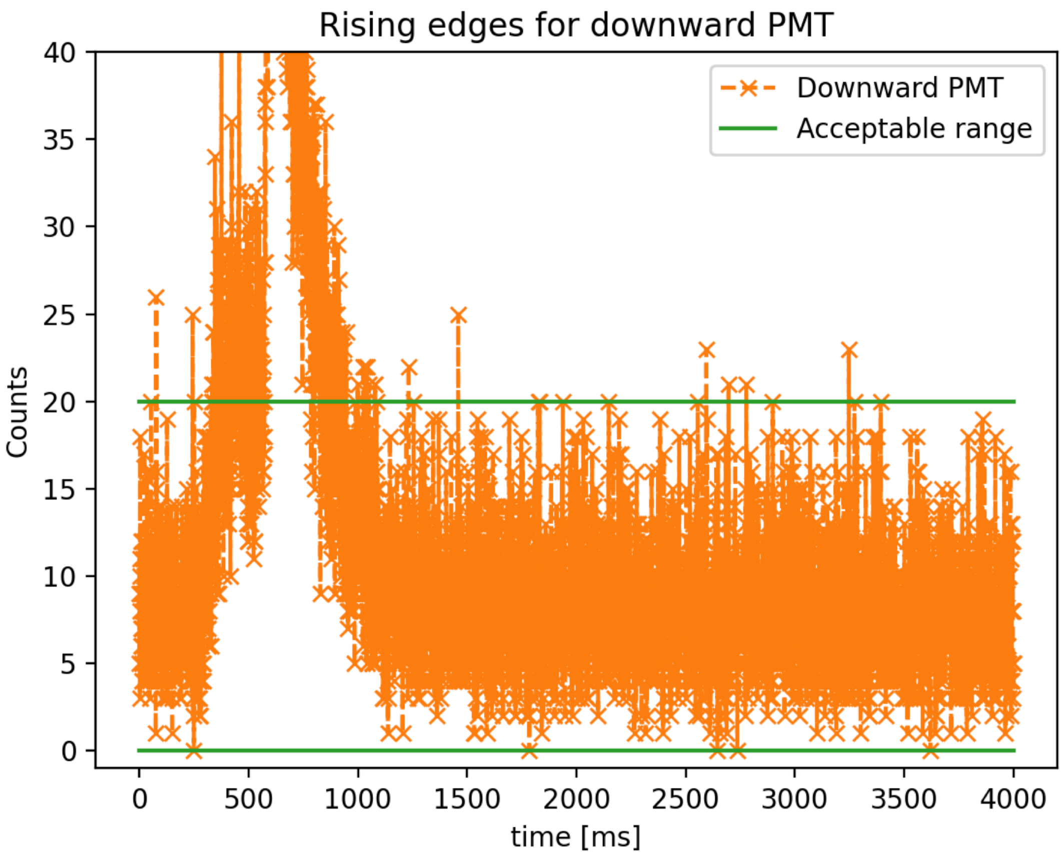
Angular acceptance of sDOM,
Taken from [STRAW paper]



Due to orientation of sDOM PMTs genuine coincidences much less likely compared to ANTARES

STRAW Data: Finding ^{40}K

- Look at lowest noise threshold
  - Only take lowest noise times
    - Noise from ^{40}K will not contribute very much to noise
    - Need to look at lowest times (1-20 detections/ms)

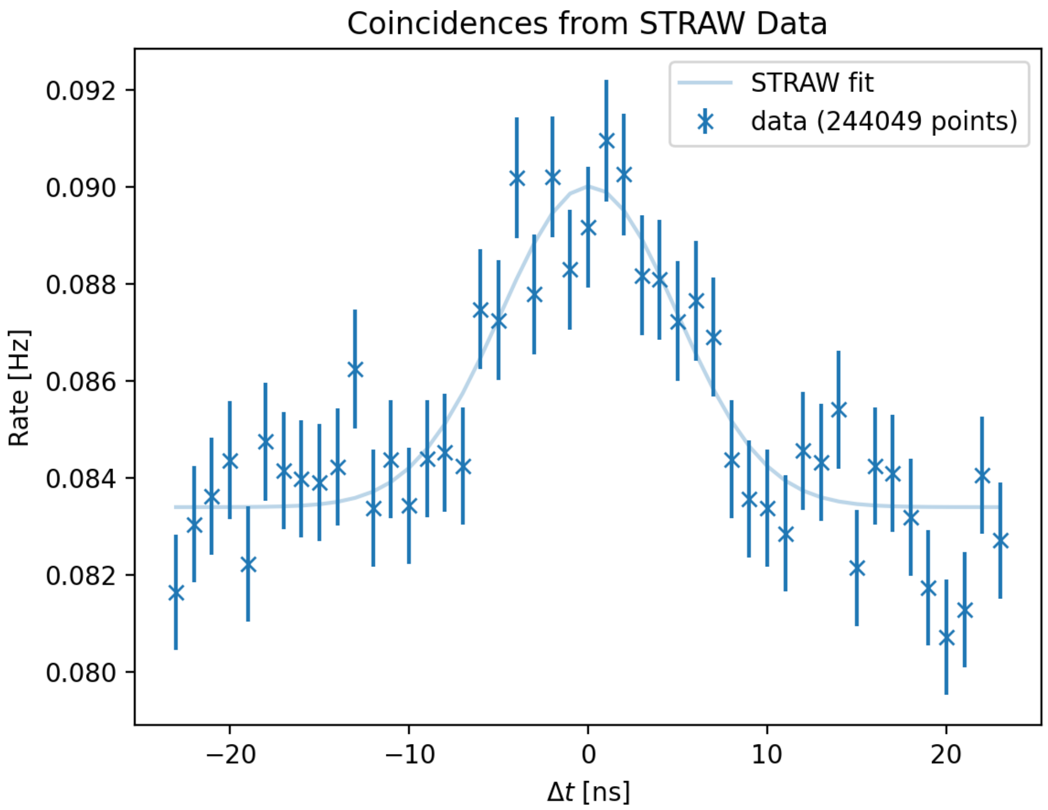


STRAW data file used in analysis with acceptable hit rate shown

Finding ^{40}K Coincidences

- Looked for coincidences with Δt ≤ ±25ns
- See desired normal distribution
- Can use this data to calculate salinity of Cascadia Basin
  - Can do the same with simulation and see if they match
  - A good measurement to try and get with STRAW

- Data collected between April-August 2020:
  - 23.5% SDOM1
  - 23.5% SDOM2
  - 23.5% SDOM3
  - 14.7% SDOM4
  - 14.7% SDOM5



$$f = p + ae^{-\frac{(\Delta t - \overline{\Delta t})^2}{2\sigma^2}}$$

p=83.34 ± 0.29 mHz

a=6.62 ± 0. 25 mHz

$\overline{\Delta t}$= 0.06 ±0.21 ns

σ=4.90 ± 0.21 ns

$\Delta\tau$ = 1ns (binwidth)

Coincidences found in STRAW data with Gaussian fit superimposed

Simulation

GEANT4 Simulation

- Want to use simulation to model noise
  - Check understanding
    - If we can match the data we know what's going on
  - Calculate effective volume for salinity calculation

GEANT4 Simulation

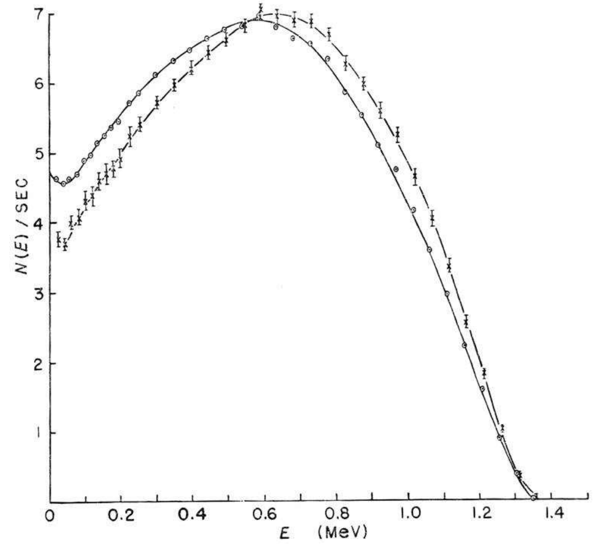
- Built simulation in GEANT4
  - Check understanding
    - If we can match data we know what's going on
    - Calculate effective volume for salinity calculation

- Particle source injects ^{40}K decay energy e^- according to plot
  - $\bar{E} = 0.7\ \mathrm{MeV}$ $\sigma_E = 0.4\ \mathrm{MeV}$
  - $E_{min} = 0.05\ \mathrm{MeV}$ $E_{max} = 1.31\ \mathrm{MeV}$

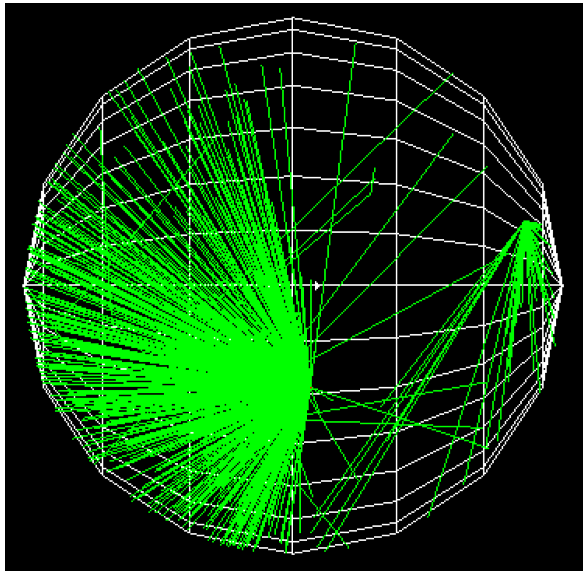
- Start with 3m sphere water volume

- Randomly distribute electrons in sphere

Energy of electron in ^{40}K beta decay



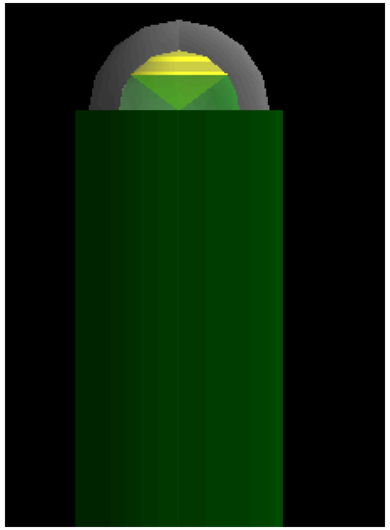
Taken from [“Experimental spectrum of e^- kinetic energy for the decay of ^{40}K to ^{40}Ca”]



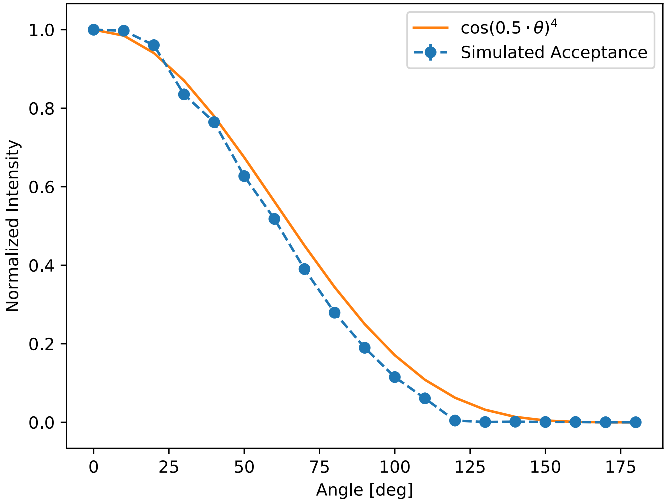
Two e^- fired in random locations with E according to plot, momentum in random direction

Simulating the sDOM

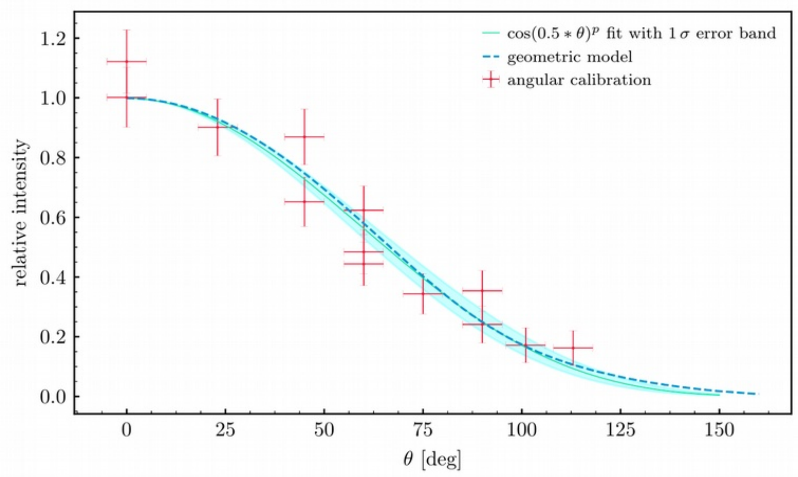
- Wanted simulated sDOM angular acceptance to match real sDOM
  - Match size and shape of actual sDOM
    - Add smearing of detected photons based on e⁻ TTS (6.5 ns FWHM)
  - Simulated DOM has similar angular acceptance
    - Quite a bit lower between 75°-120° where coincidences expected to happen most



Simulated sDOM:
Green is Ti, yellow is PMT, white is glass

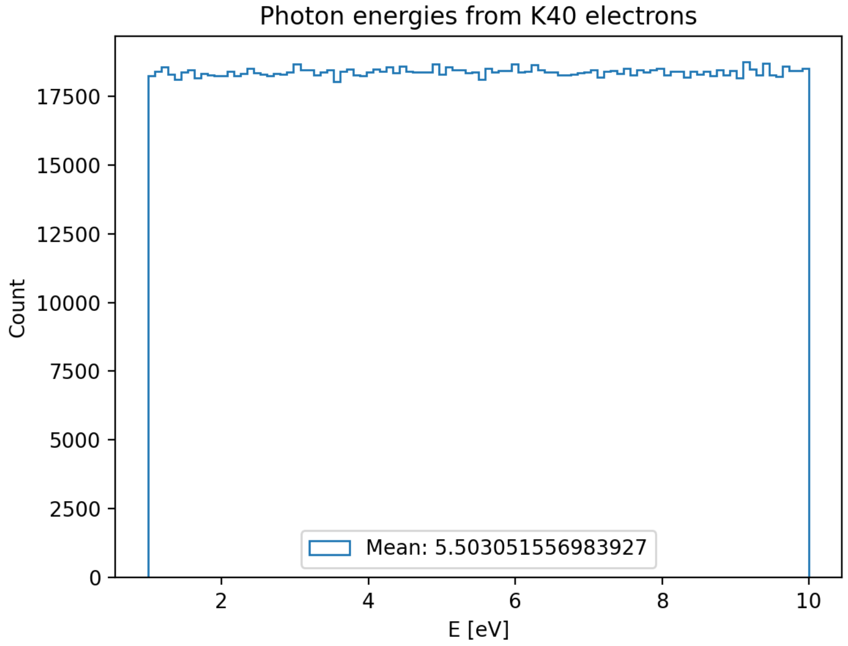


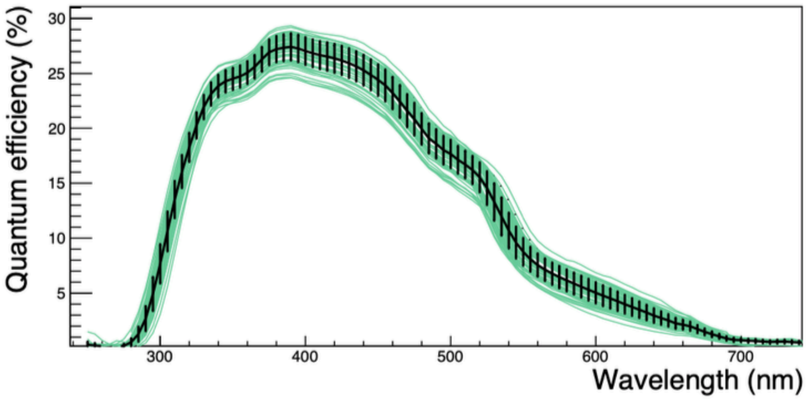
Angular acceptance of sDOM, Taken from STRAW paper

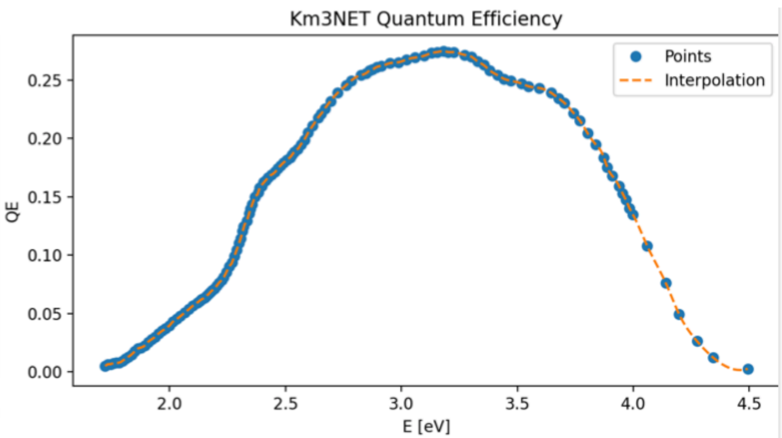


Quantum Efficiency

- Cerenkov photons are not emitted at ideal detection energies
  - $\bar{E}$ = 5.5 eV = 225nm
  - QE in these higher energies is ~0
- Need to filter this for proper simulation results





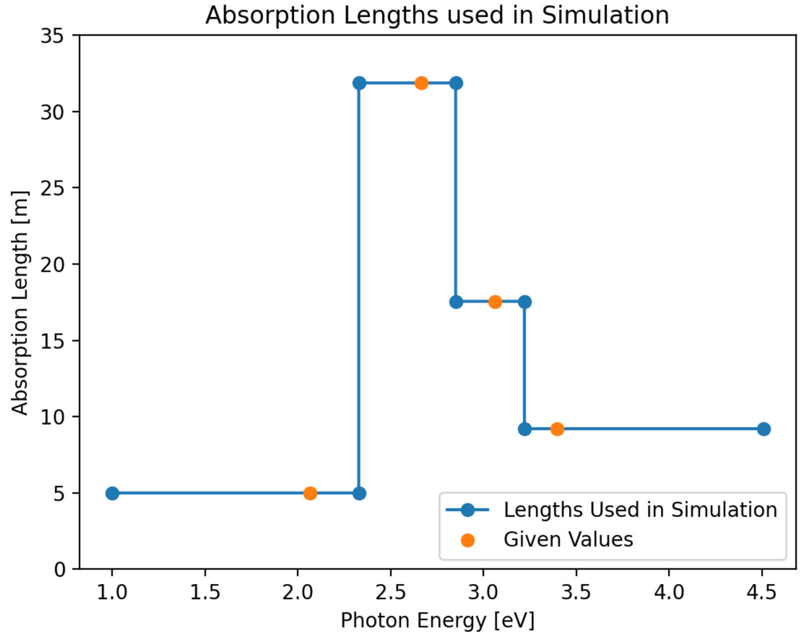


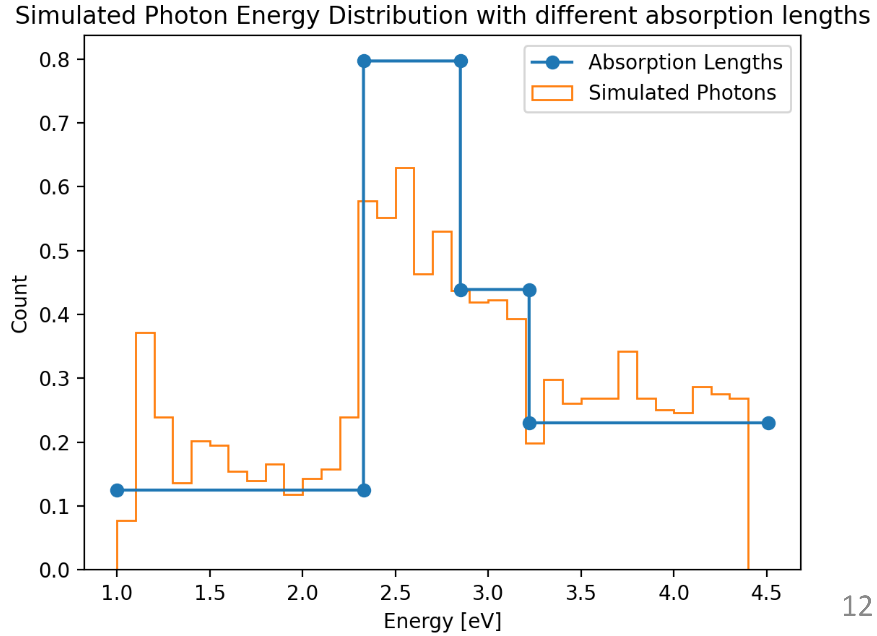
QE of same PMT from Km3NET, QE=0 E>4.5eV

Absorption Length

- Added absorption length as a function of photon energy
  - Values from Andy & Christian
    - Used attenuation length for 2.1eV

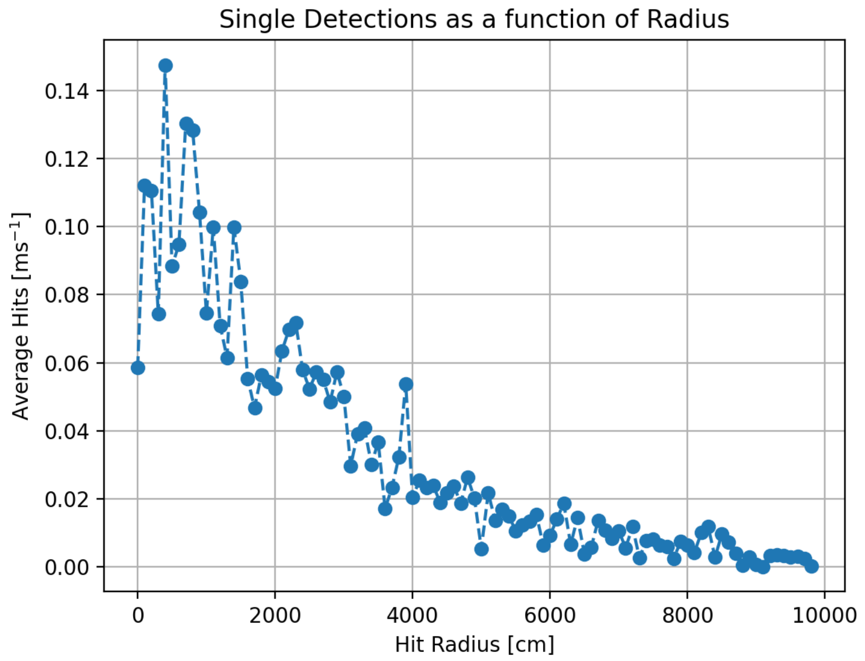
  - Geant4 photons will be absorbed according to this distribution
  - Test shows photons follow absorption length

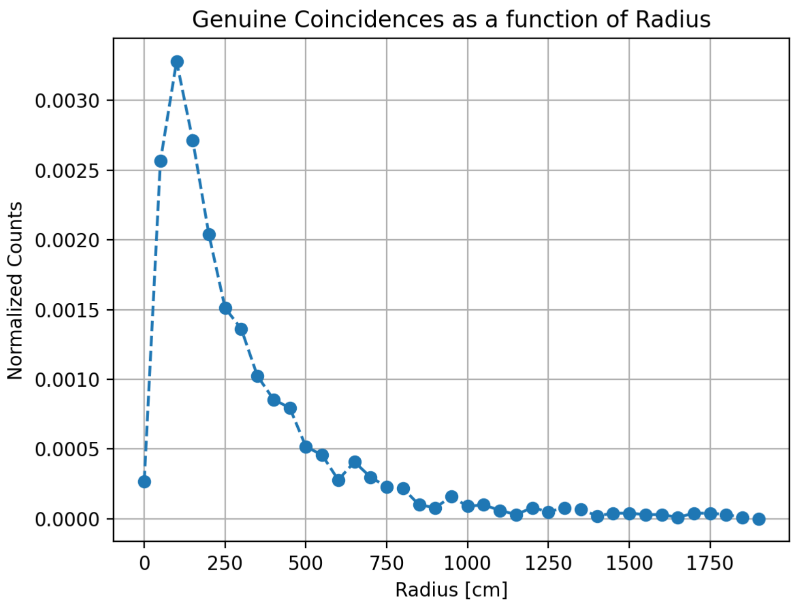




World Size

- Long Absorption/Scattering Lengths in Water
  - Need 50+m volume for single detections
  - Only ~20m for genuine coincidences

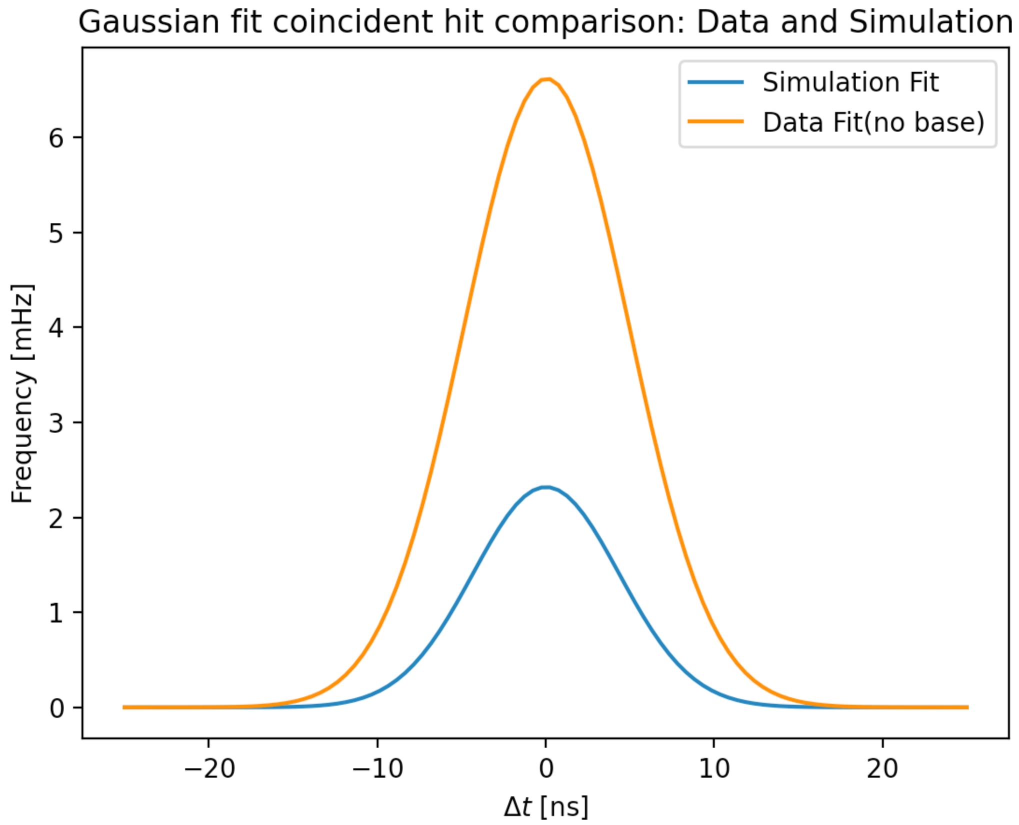




Simulated Data

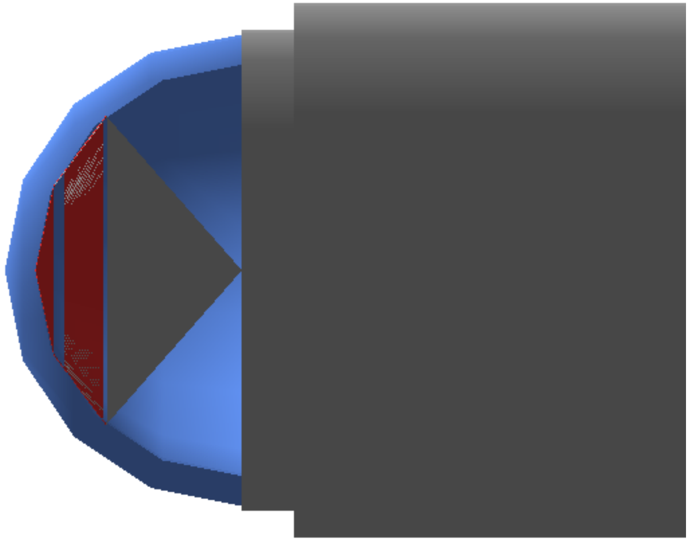
- Can run same coincidence finding code on simulated data
  - Get similar normal distribution to data
    - If we model ^{40}K correctly should have similar fit parameters
  - Peak not quite right
    - Expect peak to be closer to data
    - Simulated curve only 30% of data curve (curve area)

Example data output from simulation with Gaussian fit

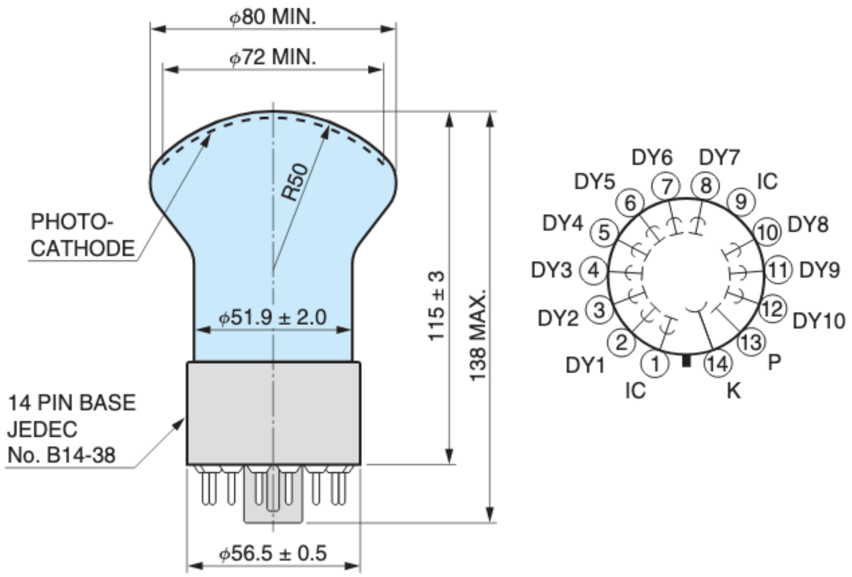


Revisiting Simulations

- Updated G4 PMT model
  - Small updates to housing structure
  - Radius of curvature increased from 38 mm to 50 mm
    - Gives PMT a much larger photocathode area
    - Should result in higher hit and coincidence rates



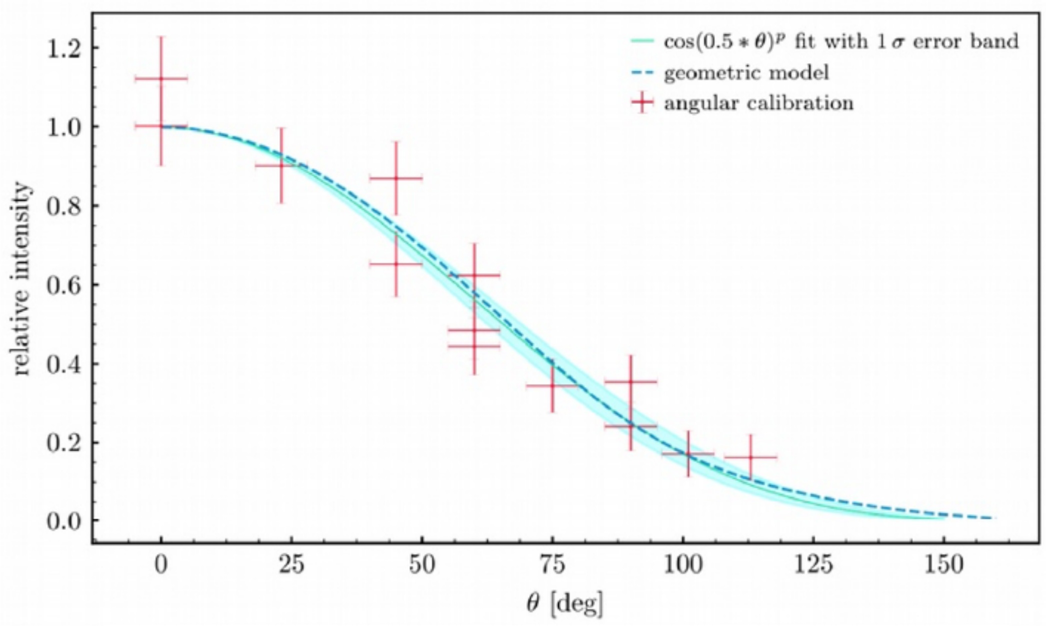
Cross section of part of the new sDOM model in Geant4. Grey is Ti, Red is PMT, Blue is glass

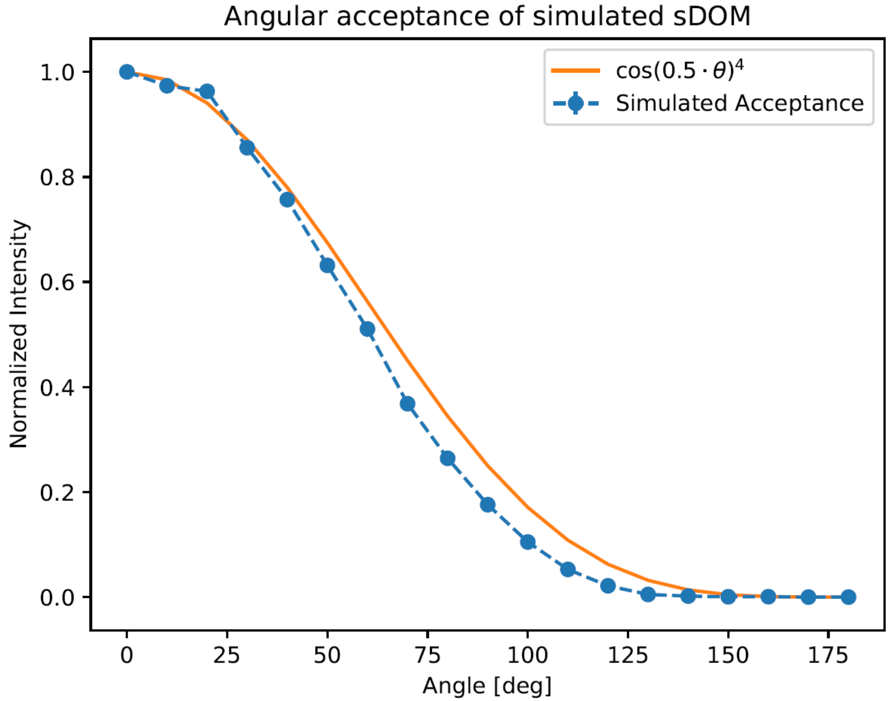


PMT schematic

Angular Acceptance

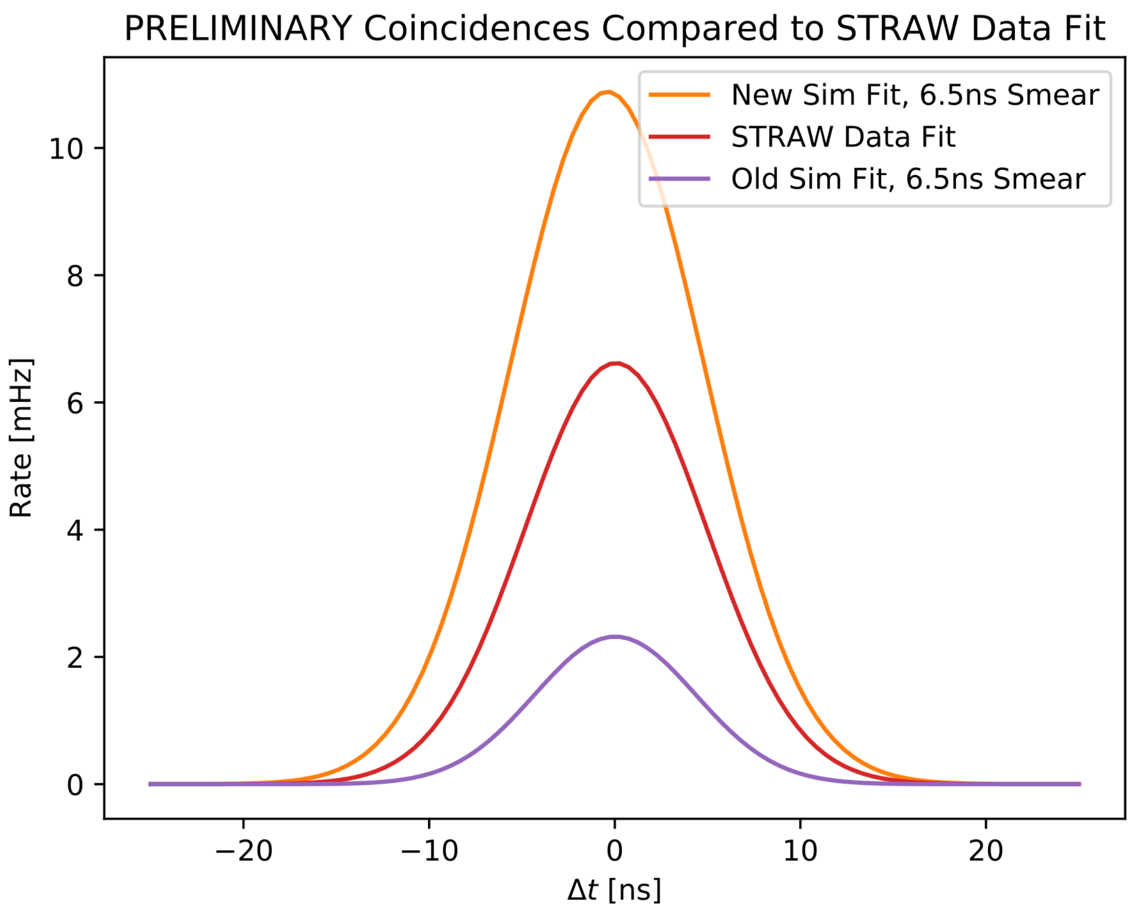
- Angular acceptance simulations were rerun with the new geometry
  - Larger photocathode radius of curvature should allow the PMT to detect more photons at large angles
  - Larger radius moves photocathode further from origin





Coincident Hit Analysis

- Larger photocathode surface should improve coincidence rate to match data
  - Simulations scaled with QE
  - New simulation overshoots whereas the old one underestimated



Potential Sources of Disagreement

- Simulations were run with a photocathode diameter of 75.3 mm rather than the 72 mm minimum
- PMT surface was assumed to be spherical
- Variation in PMT dimensions as well as positioning in housing

Future Work

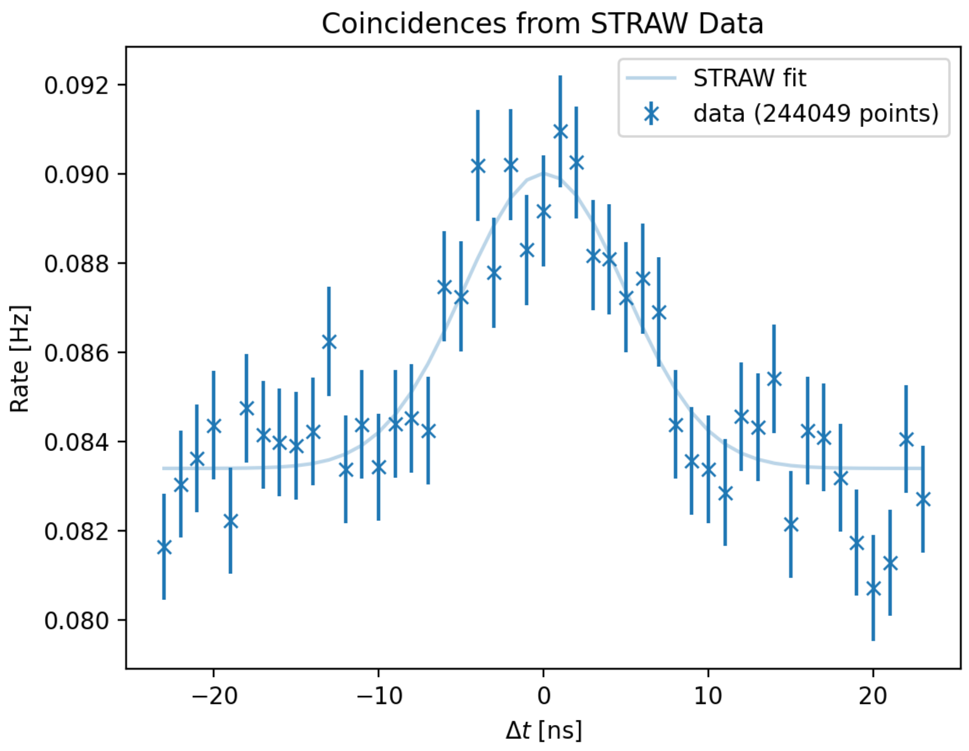
- Continue investigating disagreements between simulation and data
- Estimate systematic errors on simulation
- Try to use simulation to accurately calculate the Cascadia Basin salinity

Questions?

Backup

Calculate Salinity

- From ANTARES paper, salinity can be found with:
  - $R_c = \frac{a\sigma\sqrt{2\pi}}{\Delta\tau}$ (coincidence rate)
  - $R_c = B_q V_c \rightarrow B_q = \frac{R_c}{V_c}$
    - B_q ^{40}K decay rate/volume, can find salinity from this
    - V_c effective volume for detection (from simulation)
- Need simulation to finalize calculation (effective volume)
  - Can also add other noise sources to simulation to build complete noise model



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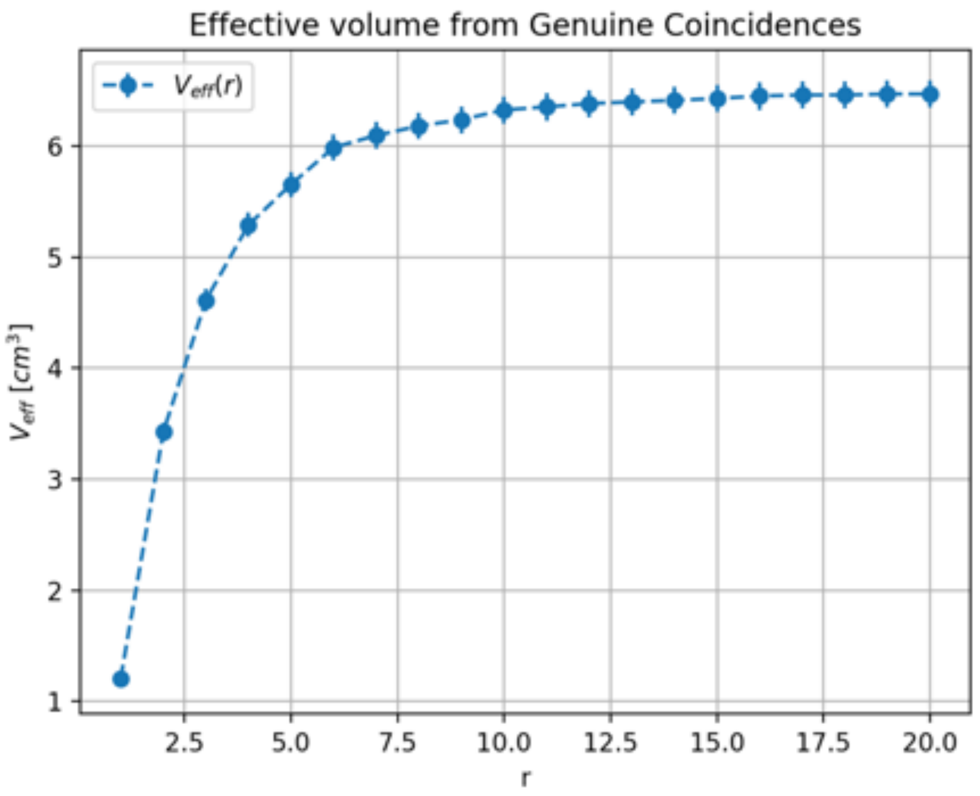
Calculating Effective Volume

- $V_{eff} = V_{gen}\frac{n_d}{n_{gen}}$
  - n_d= # detected photons
  - n_{gen}=# generated electrons

- V_{eff} is necessary volume if every generated particle produced a genuine coincidence
  - Will be extremely low since actual detector detects few genuine coincidences
- Used position of generating e^- to find $n_d(r)$
- Find V_{eff} = 6.47 ± 0.12 cm^3



Calculation of effective volume by radius

Single Hit Rate

- Continued to simulate single hit rate
  - Simulation scaled with QE as well as an angular factor to make up for discrepancy between angular acceptance
  - Results still lower than single hit rate from STRAW data