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Watchman Simulations with BACCARAT

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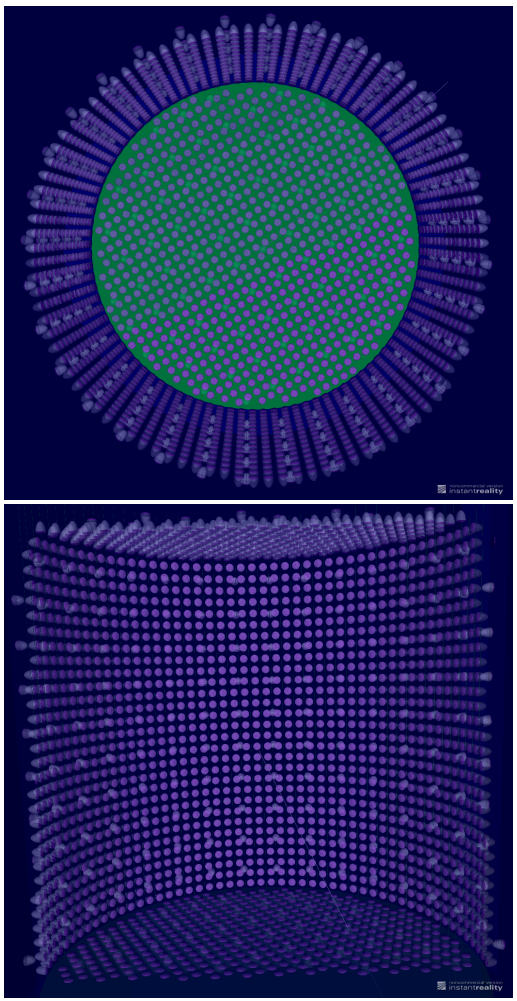
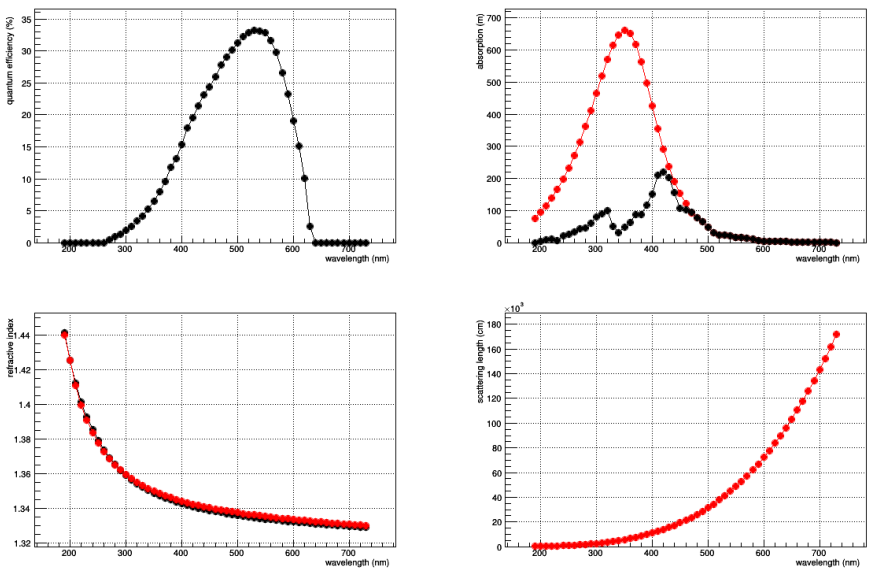
Summary



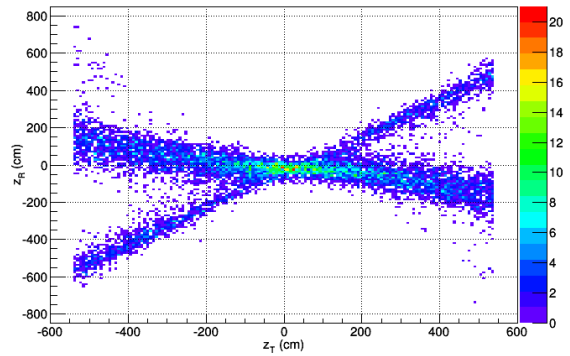
- Using BACCARAT, I've built the nominal WATCHMAN detector design:
  - 12 inch PMTs with elliptical shape
  - 4328 PMTs in the inner volume (2880 side and 724 top and bottom each)
  - 482 PMTs in the veto region (320 side and 81 top and bottom each)
  - 0.1 % Gadolinium loaded water
  - completely black inner volume, completely white veto region
- Optical properties are mostly RMSim
  - Water absorption, Rayleigh scattering, refractive index from RMSim
  - PMT quantum efficiency for high-QE 12" tubes

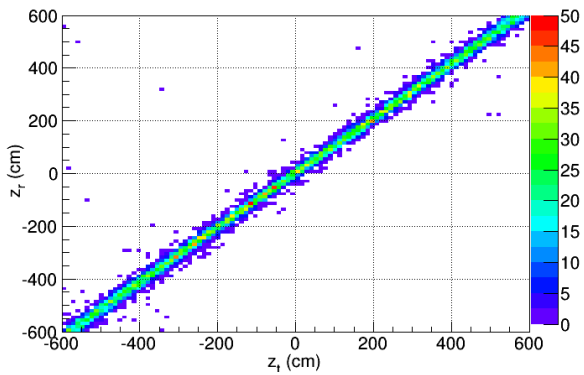
Water Optical Properties

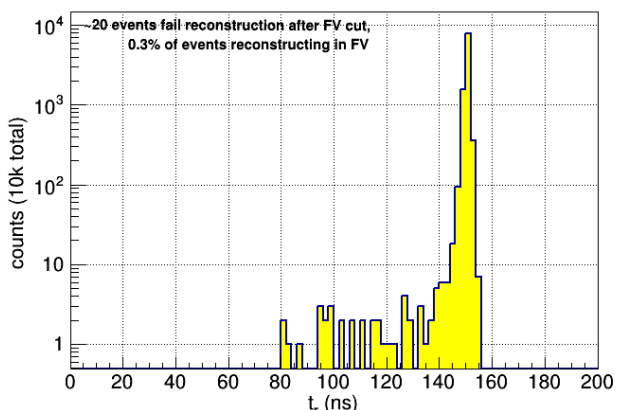


- The original baccarat optical properties (black) were changed to WCSim properties (red)
- Quantum efficiency from Marc, applied in offline analysis

Quick update - reconstruction seems to be working!



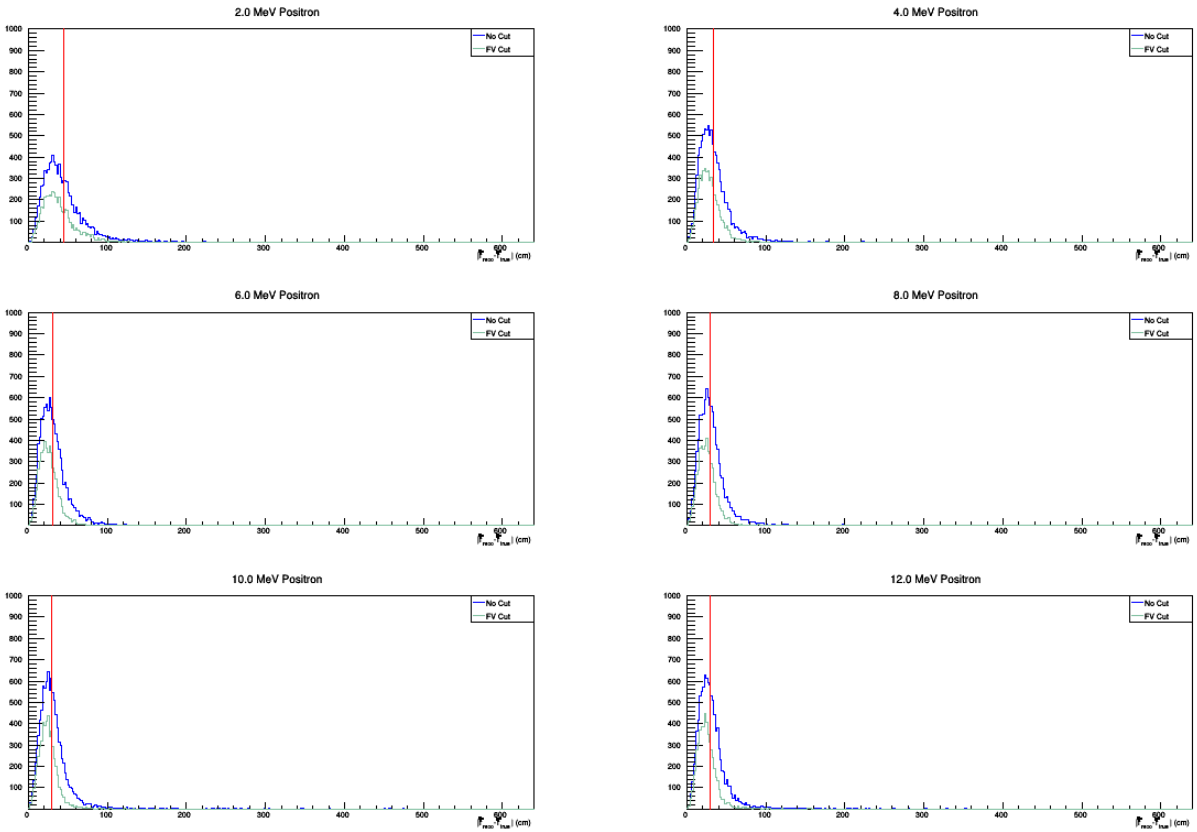




- Bug in optical boundary found (thanks Ben Land!)
  - Bonsai still fails on many events in the reconstruction
  - However, a simple timing-residual minimization seems to work really well. I'm using Minuit to minimize:

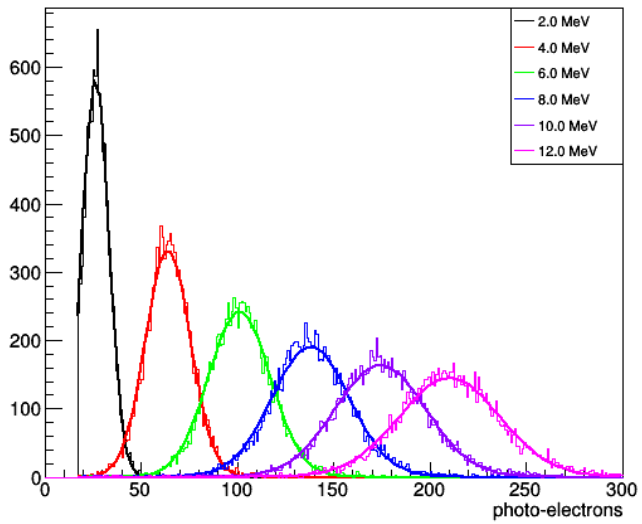
$$\sum_{i=0}^{N_{hit}} (t_i - t_0) - \frac{n}{c}|r_0 - r_i|$$

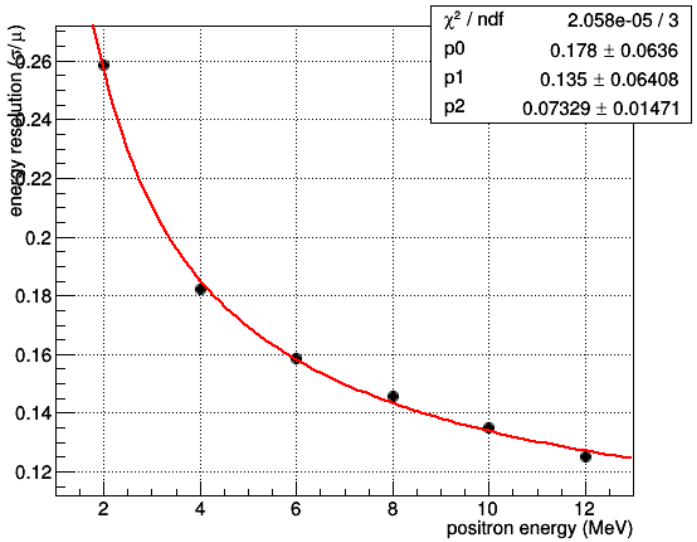
Position Reconstruction - events in entire inner volume

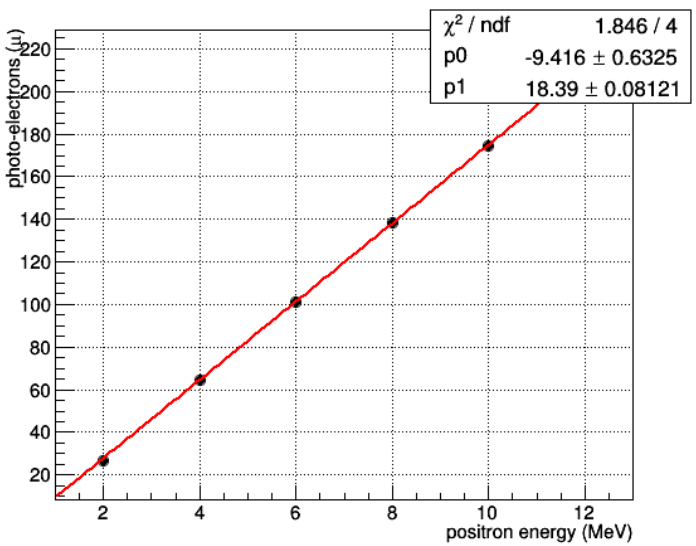


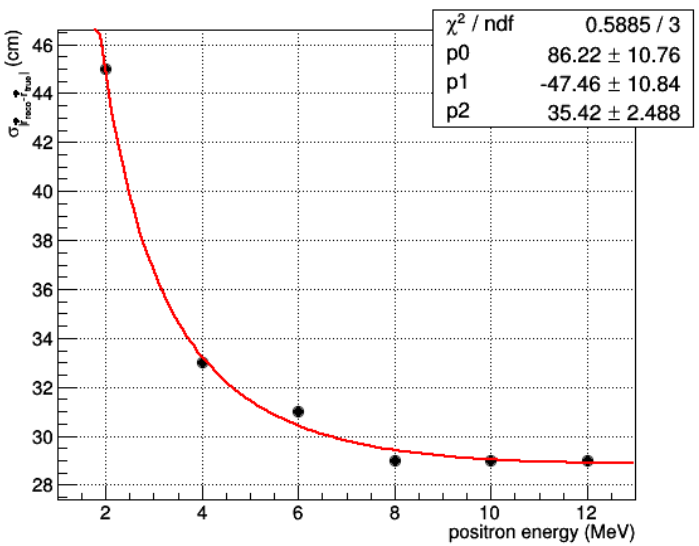
- Red line indicates events that reconstruct within 1σ of true vertex
- The blue curve is for all events, the green is for events that reconstruct inside the fiducial volume

Resolution/Reconstruction - positrons in inner volume

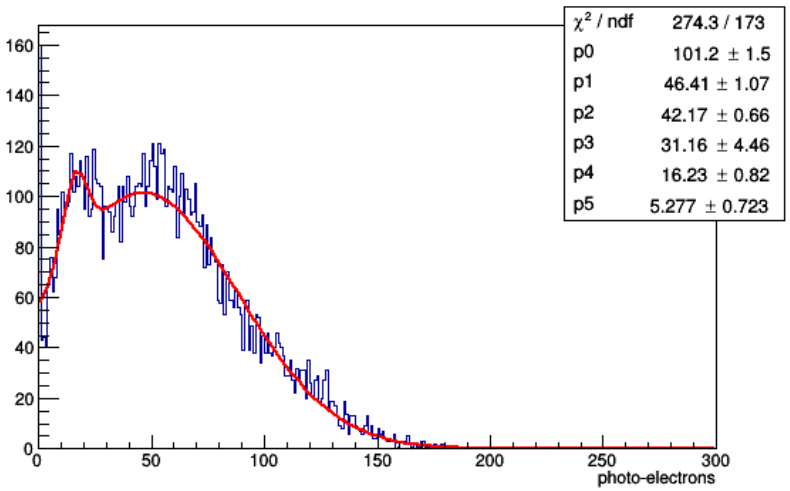


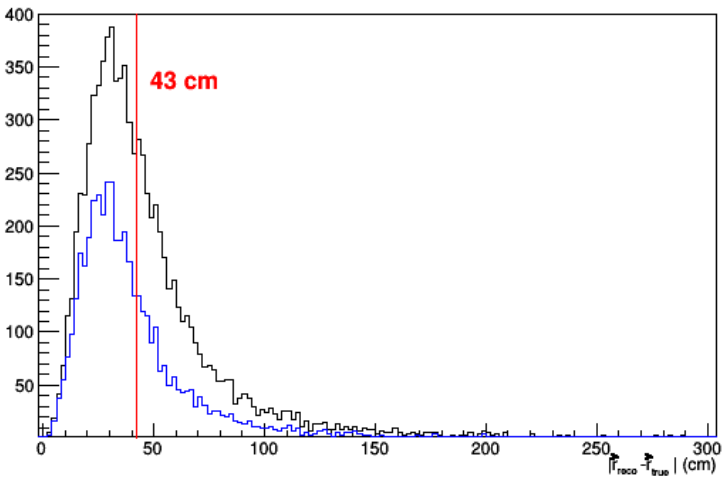


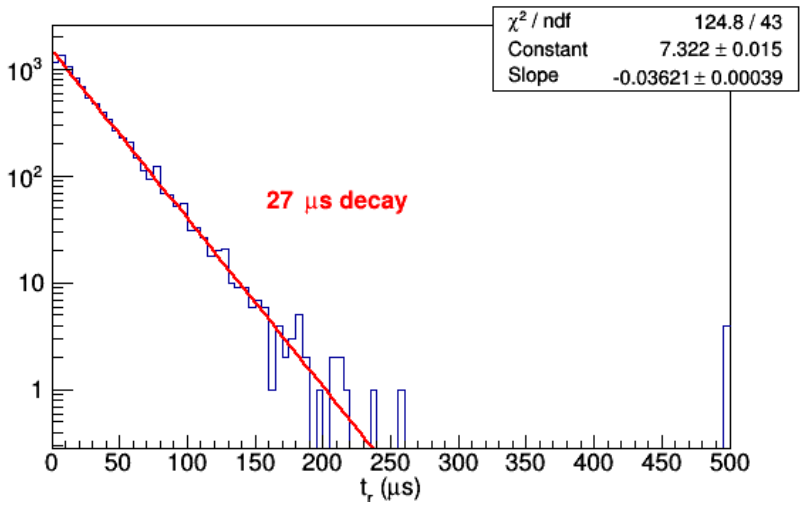




Neutron Captures - 200 keV in entire inner volume



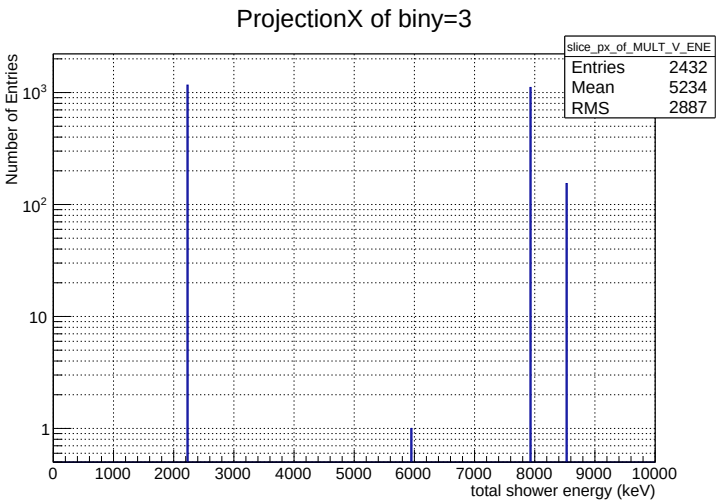




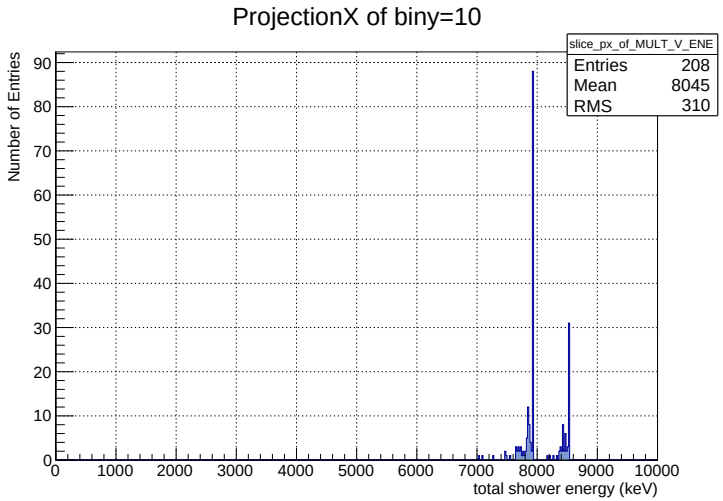
- 84.7% trigger efficiency
- 44.9% trigger+fiducial volume cut efficiency
- $\sim$ 0.03 % reconstruction failures after cuts

Neutron Captures - are the showers correct?

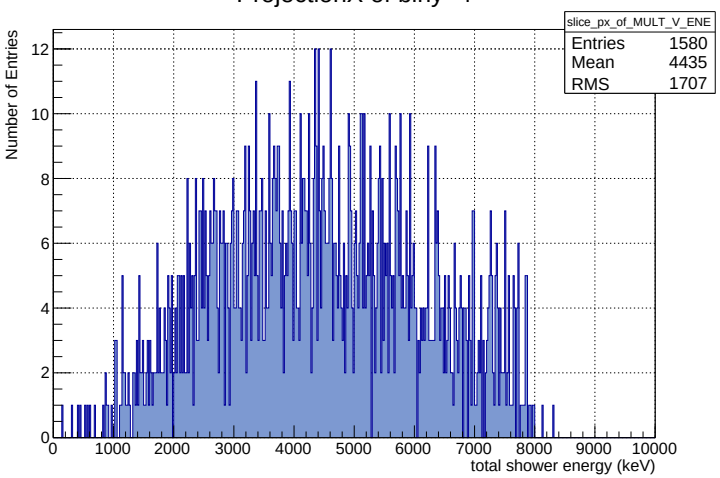
Shower multiplicity=1



Shower multiplicity=7

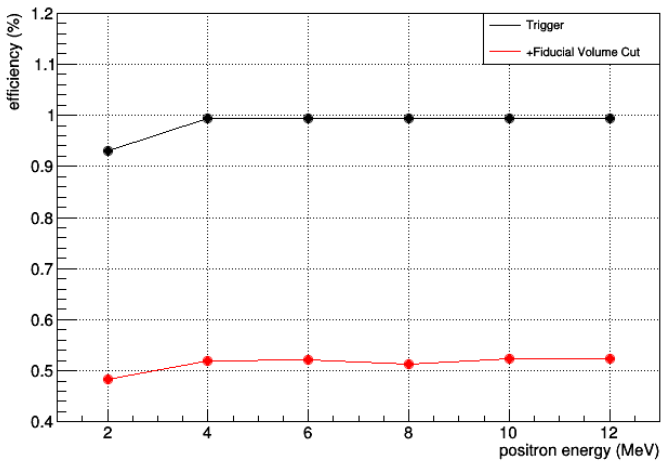


Shower multiplicity=2



- All gammas from "nCapture" process
- Isotopes of gd are visible in m=1 case: 5.94 (gd-158), 7.9 (gd-157), and 8.5 MeV (gd-155), along with hydrogen (2.2 MeV)

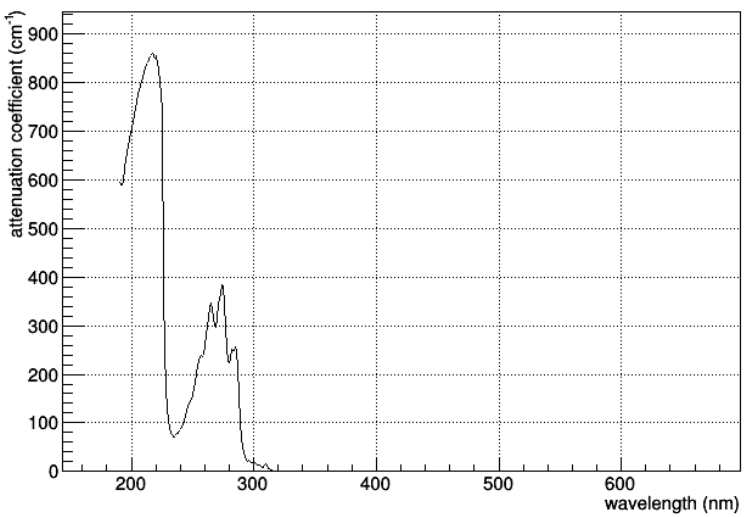
Trigger/FV Cut Efficiency - events in entire inner volume

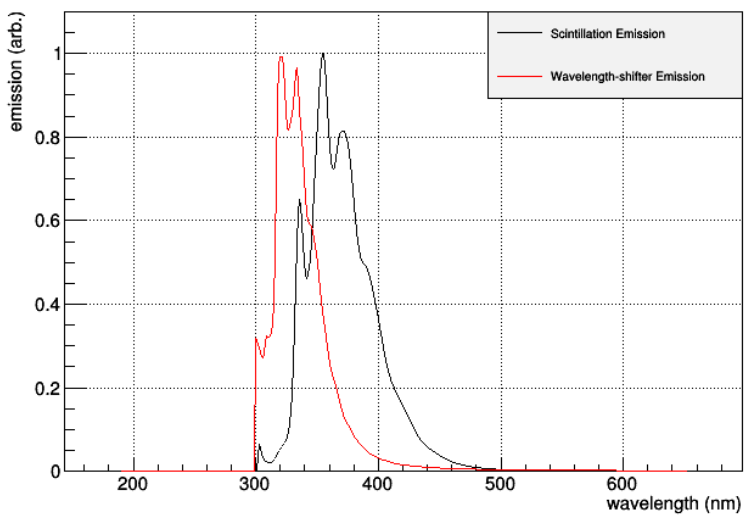


cut	ϵ_{e^+}	ϵ_n	$\epsilon_{e^+ + n}$
trigger	0.845	0.847	0.716
$+$FV	0.441	0.449	0.198
$+\Delta t < 100\ \mu$s	–	0.438	–

WbLS - Representative Cocktail from P. Feng (SNL-CA)

- 1% scintillator composed of 99% organic solvent, 1% "primary" (fluorophore), and 0.01% wavelength shifting (WLS) compound
- Organic solvent also has WLS properties
- Scintillation emission treated as the spectrum resulting from fluorescense energy transfer to the WLS (0.01%), nearly 100% efficient process
- WLS process in geant4 used as solvent absorption/emission (100% efficient in simulation, ∼17% in reality)





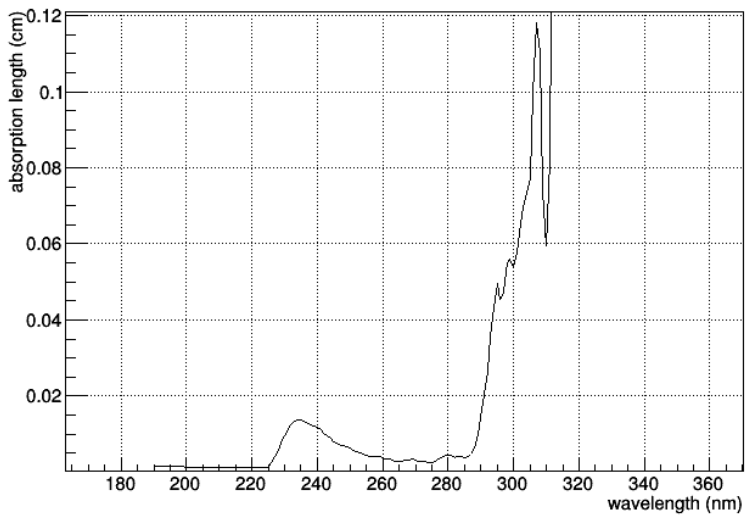
WbLS Optical Parameters from P. Feng (SNL-CA)

Scintillation:

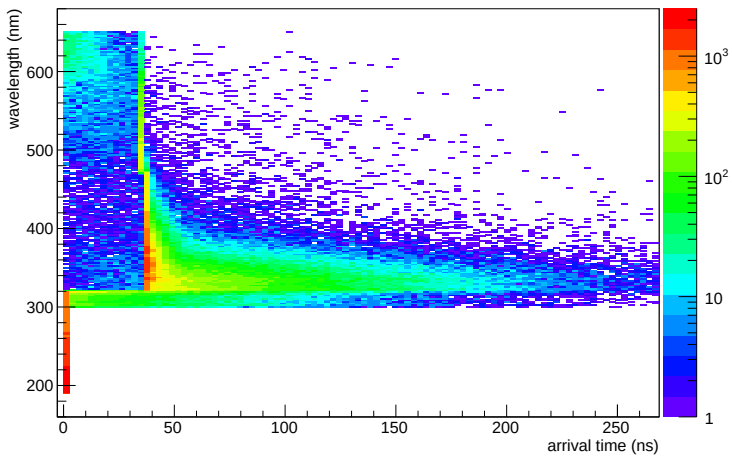
- FAST/SLOWCOMPONENT (previous slide)
- SCINTILLATION YIELD=100./MeV
- RESOLUTIONSCALE=1.0
- FASTSCINTILLATION RISETIME=0.5 ns
- FASTTIMECONSTANT=3.5 ns
- SLOWTIMECONSTANT=32 ns
- YIELDRATIO=1

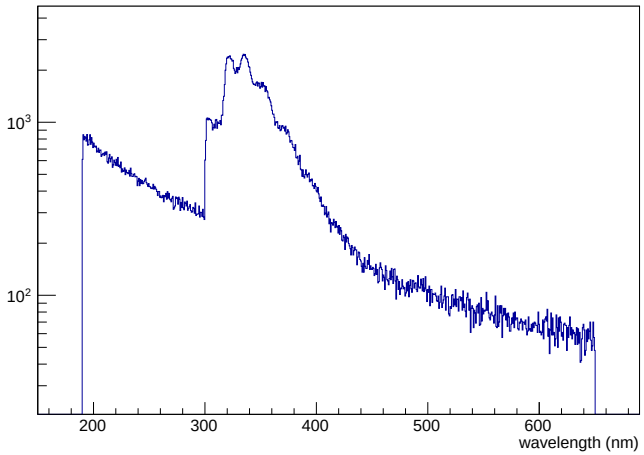
Wavelength shifting:

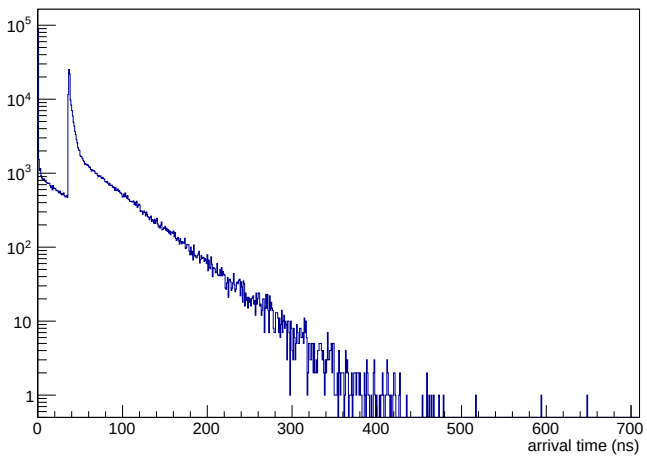
- WLSABSLENGTH (below, inverse of previous slide)
- WLSCOMPONENT (previous slide)
- WLSTIMECONSTANT=35 ns (exponential)



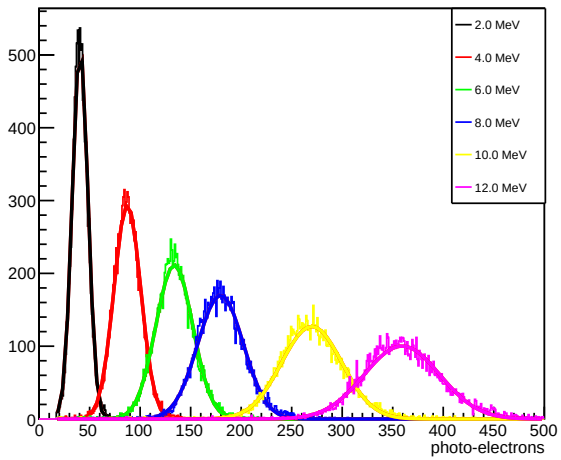
Photon wavelength vs. arrival times

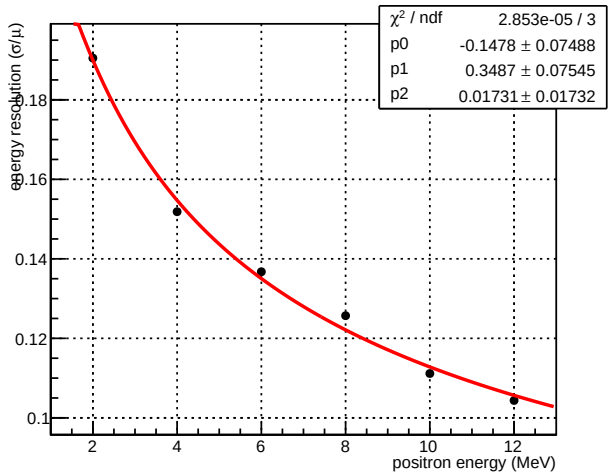


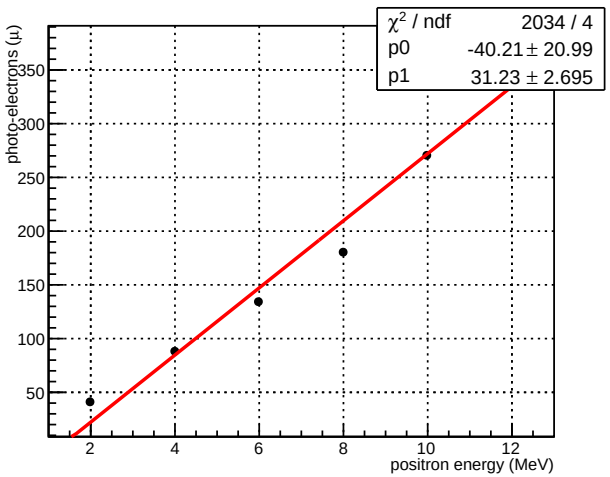


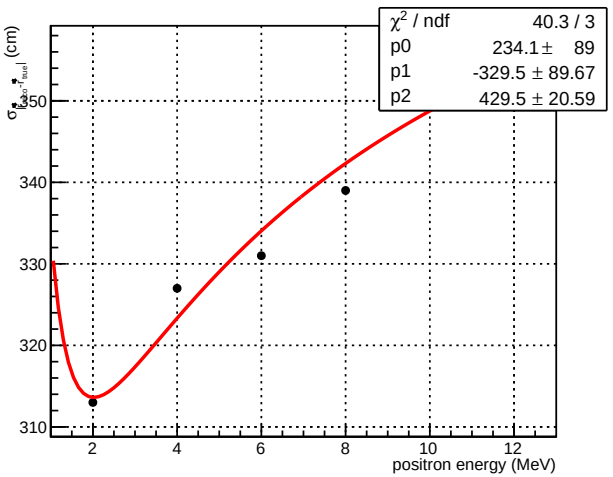


WbLS Resolution/Reconstruction









note: ∼83% of WLS shifted photons are lost

To Do: New Function in Minuit

- Use pulse shape from WLS and scintillation in the timing minimization:

$$\sum_{i=0}^{N_{hit}} f(t_i - t_0) - \frac{n}{c}|r_0 - r_i|$$

- with $f(t_i - t_0)$ to be determined, depending on fraction of WbLS, solvent

Comments/Concerns

- Solvent WLS properties is killing quite a lot of Cerenkov photons (solvent quantum efficiency is not included here)
- We're getting factor of $\sim$2 increase in light output overall (again, qe not included)
- Pulse shape is much longer: scintillator and solvent have longer tail not included here ($\sim$150 ns-200 ns)
- Pending whether we can recover vertex reconstruction resolution