KSU Simulation Work and a Few Thoughts

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Some modest technical achievements

- Fast simulation now
  - Correctly passes detector parameter information (e.g., density, Gd concentration) to tracking/physics routines.
  - Photons are tracked to 100 keV, then stopped.
  - Better organization of PAW analysis package.
- New post-doc D. Onoprienko has re-started Geant4 work.
  - Geant removes need to re-invent wheel.
  - But increases opacity to user.
  - And is slow-- too slow to study different detector parameters?

Goals for Next Meeting

- Re-do “event generator” class to facilitate more kinds of events than nubar interactions (e.g., neutrons from Cf fission, muons, etc.)
- Allow a cylindrical geometry.
- Write some documentation.
- Show some first results from full simulation.
- Have product accessible from a Fermilab repository (checkout via cvs).

Is this going anywhere?

- Educational for me and perhaps others, but not yet well directed.
- Need to define the problems and the studies that can lead to solutions.
- Example:
  - How thick should the gamma catcher be?
  - Study:
    - Generate detector models with different thickness (0, 5,15, 25, and 75 cm).
    - Look at
      - Positron, neutron energy resolution.
      - Positron, neutron spatial resolution.
      - Number of events that fail cuts due to lost gammas (too low energy).
      - Effect on feed-in from non-Gd doped regions.
  - Need a way to quantitatively decide the answer. (MC confirms common sense pretty well).

Example study

- Spherical detector with
  - R_0=2.00 m radius fiducial
  - R_2=2.75 m outer radius; 20% PMT coverage with 20% QE PMT.
  - R_1 = variable radius of non-Gd doped scintillator.
    - $0<r<R_0$ → active+0.1%Gd.
    - $R_0<r<R_1$ → active, no Gd.
    - $R_1<r<R_2$ →inert.
  - λ_{Gd}=4 m; λ_{Sc}=10 m.
- 160K nubar events generated uniformly with Beacom cross section.
- Simple CHOOZ cuts:
  - 0.5 MeV < $E(e^+)$ < 12 MeV.
  - 6 MeV < E(n) < 12 MeV.
  - $T(n)-T(e^+)<100\ \mu$s.

Simple event reconstruction

- This works surprisingly well (from CHOOZ):
- Define likelihood

$$-\mathcal{L}(E,\vec{r}) = \sum_{pmt} \log \frac{[\mu_n(E,\vec{r})]^{m_n}}{m_n!} \exp[-\mu_n(E,\vec{r})]$$

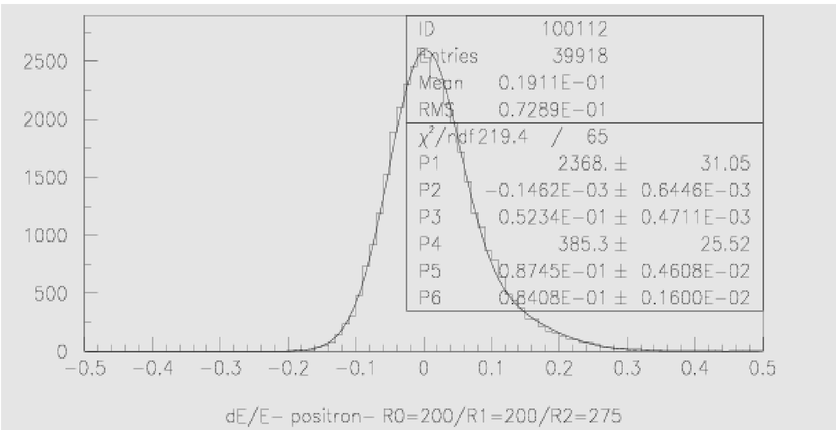
$$\mu_n(E,\vec{r}) = E\frac{dn}{dE}\epsilon_{QE} \times \frac{A_{PMT}}{4\pi|\vec{r}_n-\vec{r}|^2} \times \frac{\vec{r}_n\cdot(\vec{r}_n-\vec{r})}{R_{PMT}|\vec{r}_n-\vec{r}|} \times \exp\left(-\frac{s_{Gd}}{\lambda_{Gd}} - \frac{s_{\not{G}d}}{\lambda_{\not{G}d}}\right)$$

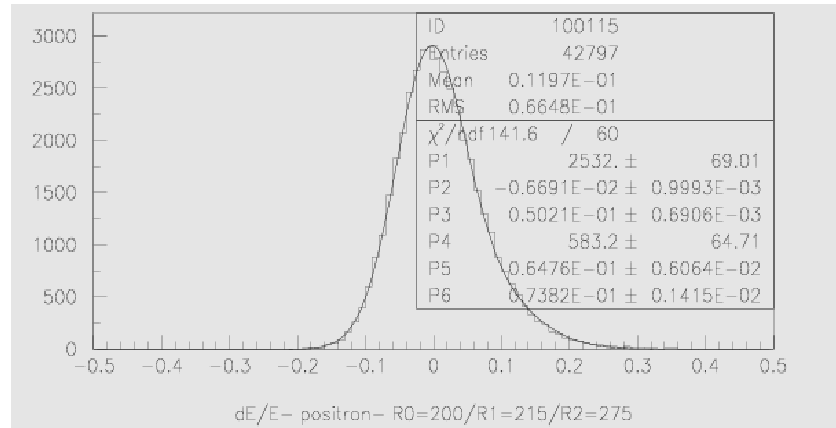
- Vary E and only the "1/r²" part and iterate, using simple weighted averages as starting guess.

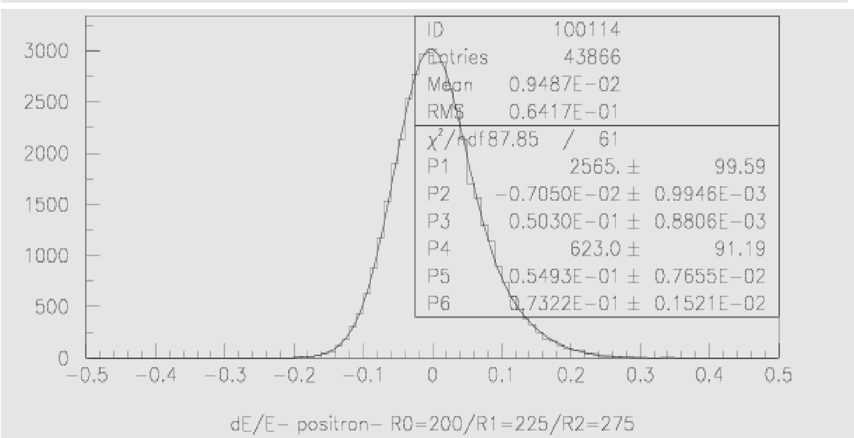
$$E^{(i)} = \frac{E^{(i-1)}\sum_{pmt} m_n}{\sum_{pmt} \mu_n(E^{(i-1)},\vec{r}^{(i-1)})}; E^{(0)} = \frac{\sum_{pmt} m_n}{\frac{dn}{dE}\epsilon_{QE}}$$

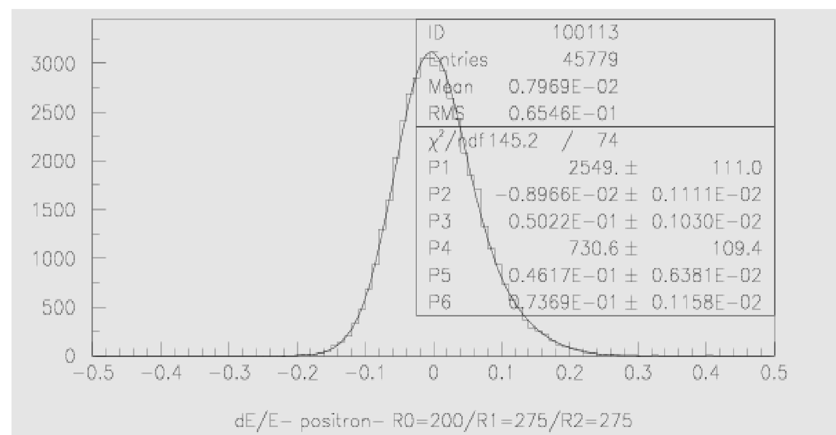
$$\vec{r}^{(i)} = \frac{\sum_{pmt}[\mu_n(E^{(i-1)},\vec{r}^{(i-1)}) - m_n]\vec{r}_n}{\sum_{pmt}[\mu_n(E^{(i-1)},\vec{r}^{(i-1)}) - m_n]}; \vec{r}^{(0)} = \frac{\sum_{pmt} m_n\vec{r}_n}{\sum_{pmt} m_n}$$

$\Delta E/E(e^+)$ for R_1-R_0=0,15,25,75 cm





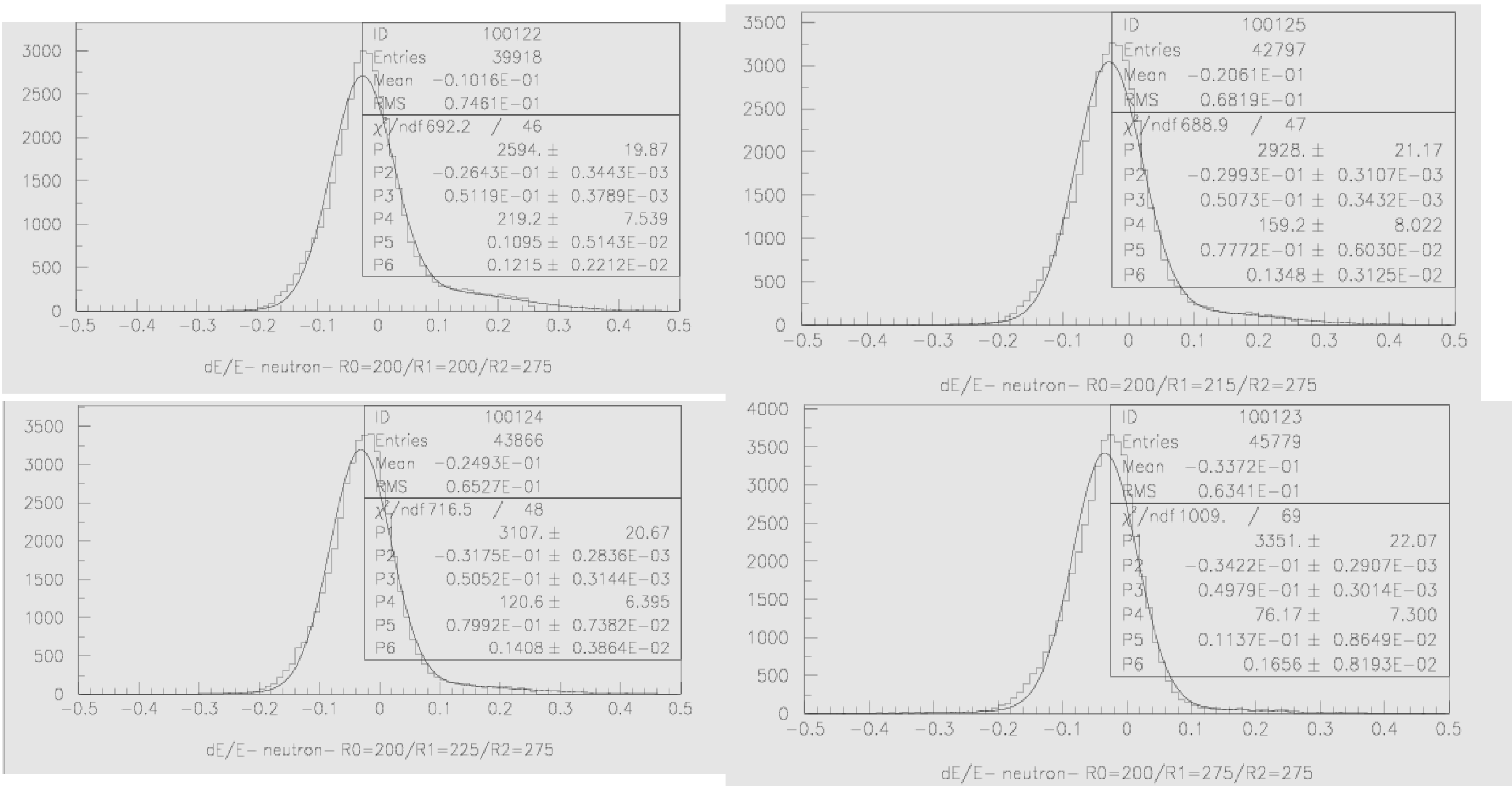




Positron features

- Efficiency rises from 25.0%(0 cm) to 28.6%(75 cm). Gamma catcher picks up ~4% of events near edge.
- Reconstruction algorithm “works”.
- Gamma catcher slightly improves resolution of “core” of distribution $\sigma(\Delta E/E)$: 5.2%→5.0%.
- More significant reduction in tail (8.7% pull→4.6% pull). This is likely where systematics will be.

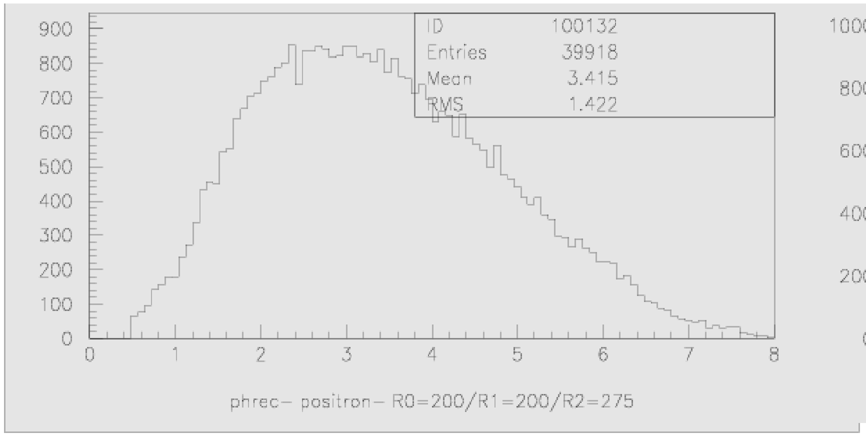
$\Delta E/E(n)$ for R_1-R_0=0,15,25,75 cm

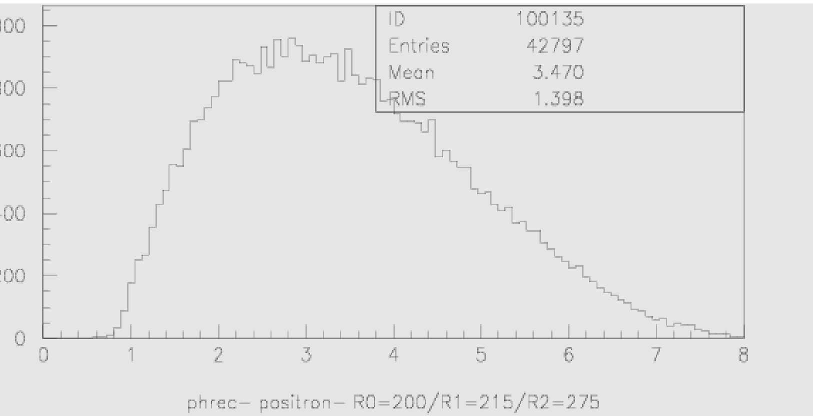


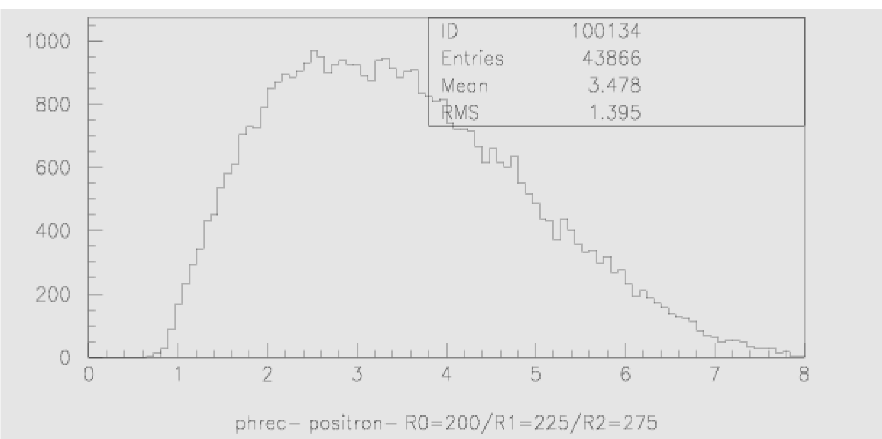
Neutron features

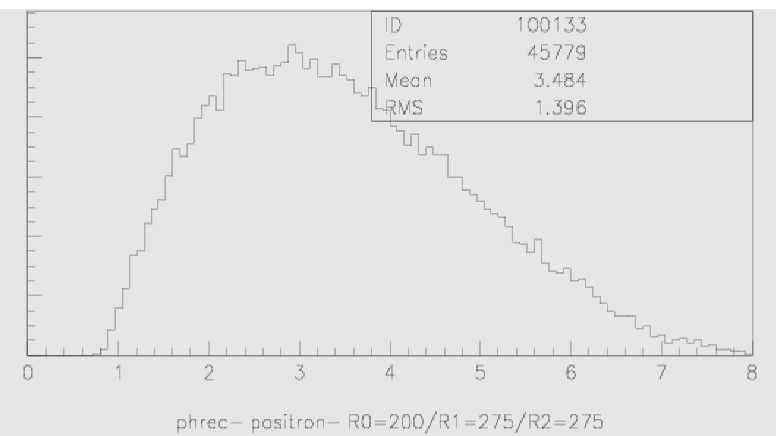
- Poorer fit to double Gaussian. I believe this is due to the more spatially extended distribution of the energy. Details depend on modeling Gd gamma cascade correctly.
- Small effect on core $\sigma(\Delta E/E)$ (5.1%→5.0%).
- Again, more significant effect on tail; pull goes from 8%→13%.

Can see effects directly on spectra

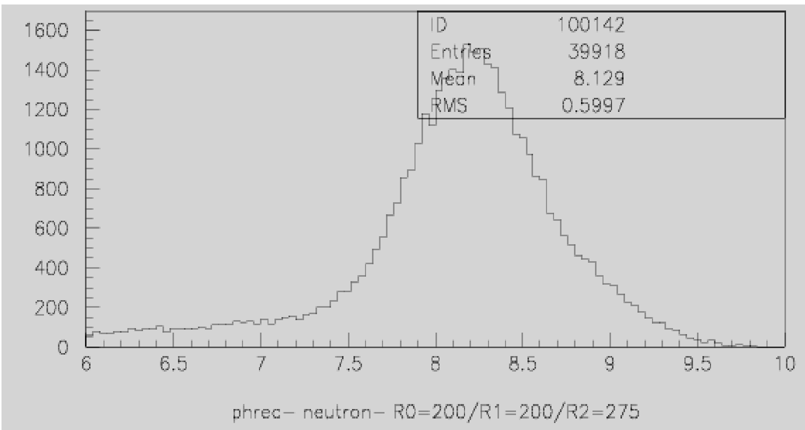


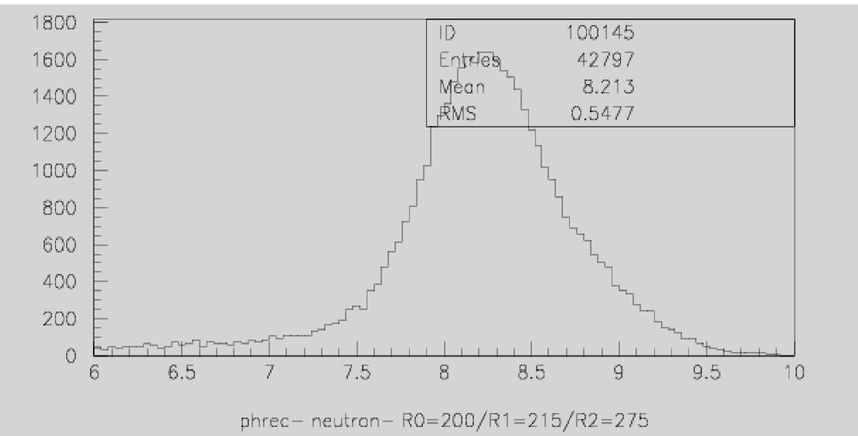






Neutrons


ID 100142
Entries 39918
Mean 8.129
RMS 0.5997
phrec– neutron– R0=200/R1=200/R2=275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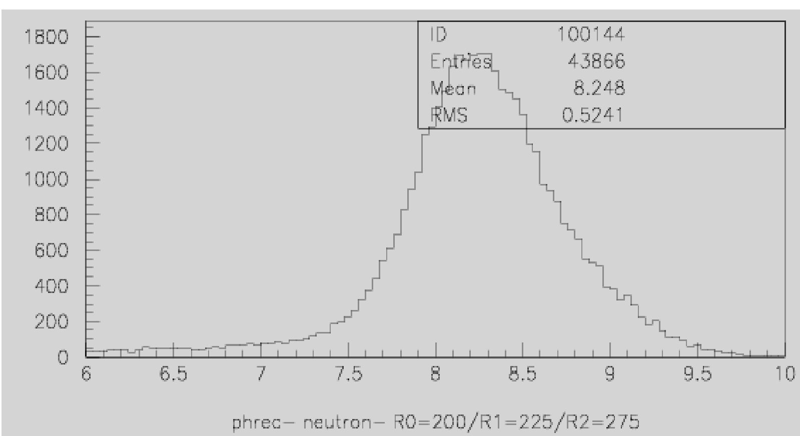
RMS 0.5477
phrec– neutron– R0=200/R1=215/R2=275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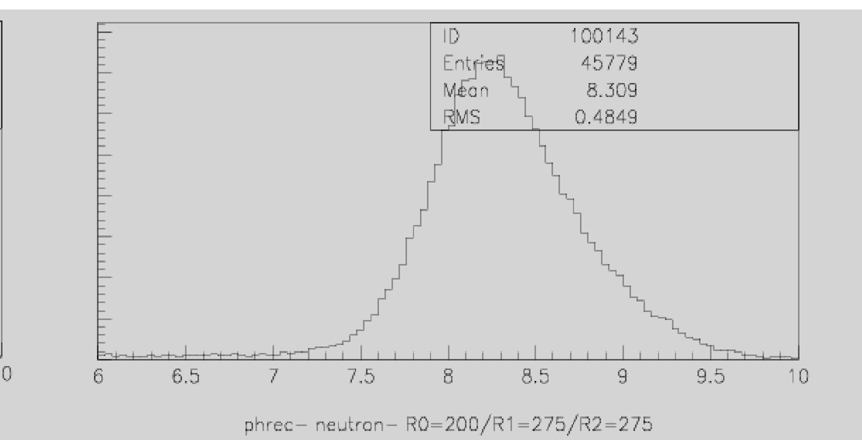
Mean 8.248
RMS 0.5241
phrec– neutron– R0=200/R1=225/R2=275


ID 100143
Entries 45779
Mean 8.309
RMS 0.4849
phrec– neutron– R0=200/R1=275/R2=275

Spectral effects

- Gamma catcher reduces low energy positron and neutron tails.
- Even a 15 cm thick region contains the full positron spectrum for a 0.5 MeV cut.
- Conclusions obviously depend on the energy cuts.

Other studies

- Systematics:
  - It is possible now to compute d(Rate)/d(parameter), parameter = Gd concentration, attenuation length, …..
  - I have a couple of undergrads who are (slowly) working on this.
- Calibration:
  - In a fast MC, this amounts to seeing whether d(Rate)/d(parameter) for calibration events can be shown to track the same quantity for neutrino events.
  - Needs development of new tools (software versions of “sources”).
- Backgrounds
  - The MC could establish the probability per event that background X mimics the signal→ needs event generator.
  - The separate problem is quantifying X→ Needs external physics and geologic data.
- Lots to do. Need people and <u>direction</u>.