Event reconstruction work at KSU using ReactorFsim

(David Thompson, KSU undergraduate)*

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Dave received a Goldwater Scholarship in part for this research project.

Method

- Likelihood fit to observed measurements of charge

$$\ell_i(q_i|\vec{r},E) = \sum_{NPE=0}^{NPE=25} e^{-\mu(\vec{r},E)} \frac{[\mu(\vec{r},E)]^{NPE}}{NPE!} Q_{NPE}(q_i);\ L(\mathbf{q}|\vec{r},E) = -\sum_{i=1}^{i=NPMT} \ln \ell_i(q_i|\vec{r},E)$$

$\sim$ convolution of Poisson with charge function

$Q_{NPE}(q_i) =$ charge distribution for given NPE (from SNO/Josh)–NEW

$Q_{NPE}(q_i) = \delta(q_i - Nq_0)$ OLD "Poisson fit" used for NUSAG.

- New features:
  - Neutrons/Positrons now defined "operationally" from "scope trace" output by clustering clumps of charge in time.
  - Charge distributions from SNO via Josh.

Details

$$\mu(\vec{r},E) = E\frac{d\langle\text{photons}\rangle}{dE}\frac{A_{PMT}}{4\pi|\vec{r}_{PMT}-\vec{r}|^2}[1-\epsilon_{ATT}(\vec{r}_{PMT},\vec{r})][1-\epsilon_{\Omega}(\vec{r}_{PMT},\vec{r})]\epsilon_{QE}$$

$=$ mean number of photoelectrons at cathode ~ 1/MeV

$NPE =$ actual number of photoelectrons

$$\frac{d\langle\text{photons}\rangle}{dE} = \frac{\text{scintillation photons}}{\text{MeV}} \approx 5300$$

$\frac{A_{PMT}}{4\pi|\vec{r}_{PMT}-\vec{r}|^2} =$ coverage of 1 PMT $\sim 0.20 \times 10^{-3}$

$\epsilon_{ATT}(\vec{r}_{PMT},\vec{r}) =$ correction for attenuation ~ 0.1

$\epsilon_{\Omega}(\vec{r}_{PMT},\vec{r}) =$ direction cosine correction in solid ang~ 0.01

$\epsilon_{QE} =$ quantum efficiency $= 20\%$

$Q_{NPE}(q_i) =$ charge distribution for given NPE (from SNO/Josh)

$\sim NPE \times$ convolution of sum of three “Polya” functions

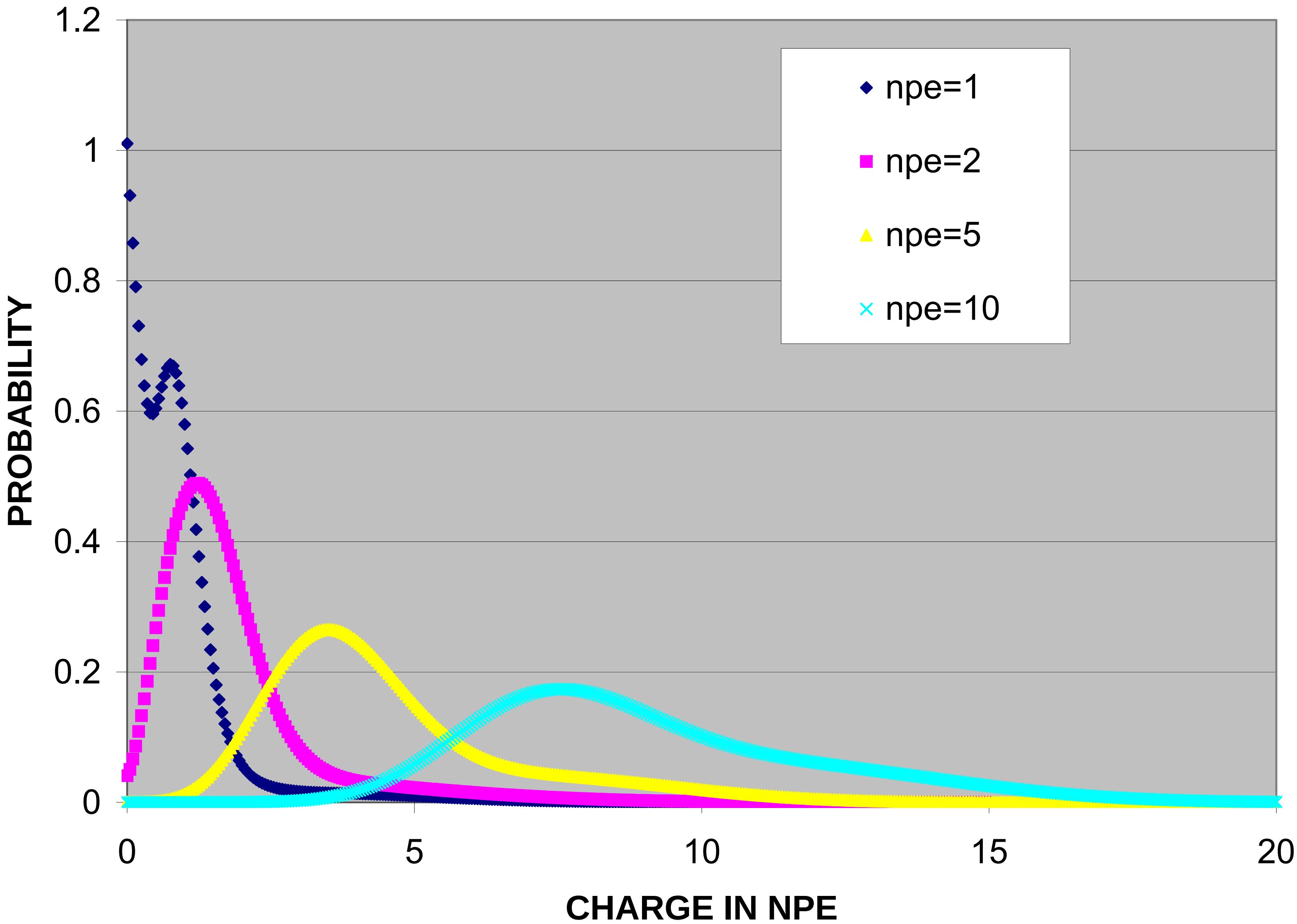
Summary of results

- Dave eventually achieve σ=15 cm for the positron, but only σ=25 cm for neutrons using the full "Polya" method with *noise turned off*. There were several late-summer breakthroughs, so I am optimistic about more improvement.
- Infuriatingly to him, and puzzling to me, he achieved his best result of σ=12 cm by just saying the hell with the full-blown charge distributions and fitting to a Poisson, as was performed originally (this is with the charge distributed by the full SNO parameterization!).
- By comparison, a simple charge-weighted PMT position determination has and intrinsic σ=25 cm, but a large (up to 45 cm) pull towards the center of the detector.
- He achieved a similar intrinsic resolution with a much smaller pull by weighting the PMT positions by their charge-squared. He used this as a first guess for the position in the full fits.
- He achieved an energy resolution of 12%/$\sqrt{E}$, somewhat worse than expected.

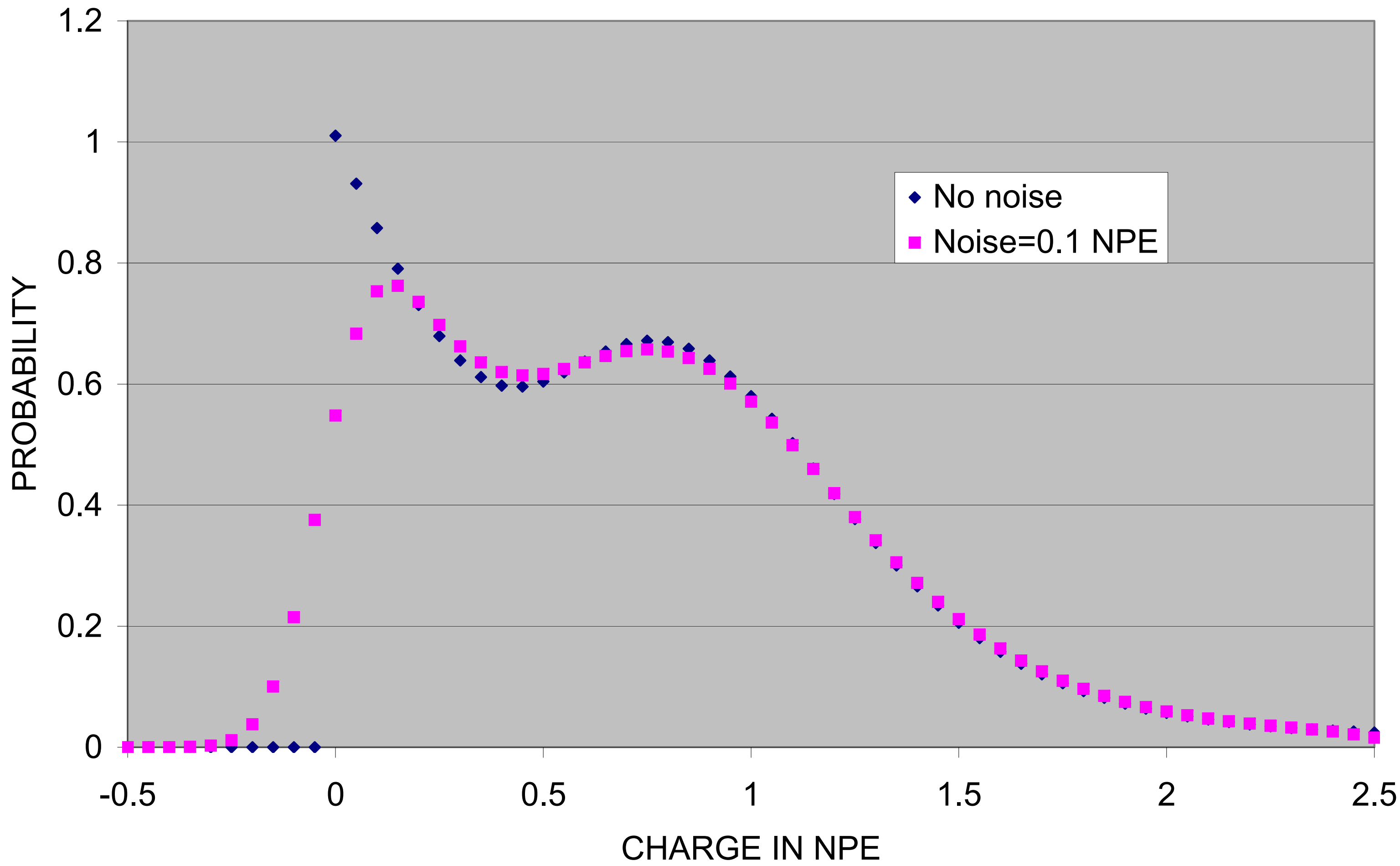
Big change compared to last spring

- The full charge smearing shifted much of the NPE=1 peak towards 0 charge.
- We should probably just cut this low charge out and readjust the overall quantum efficiency assumed in the fit.

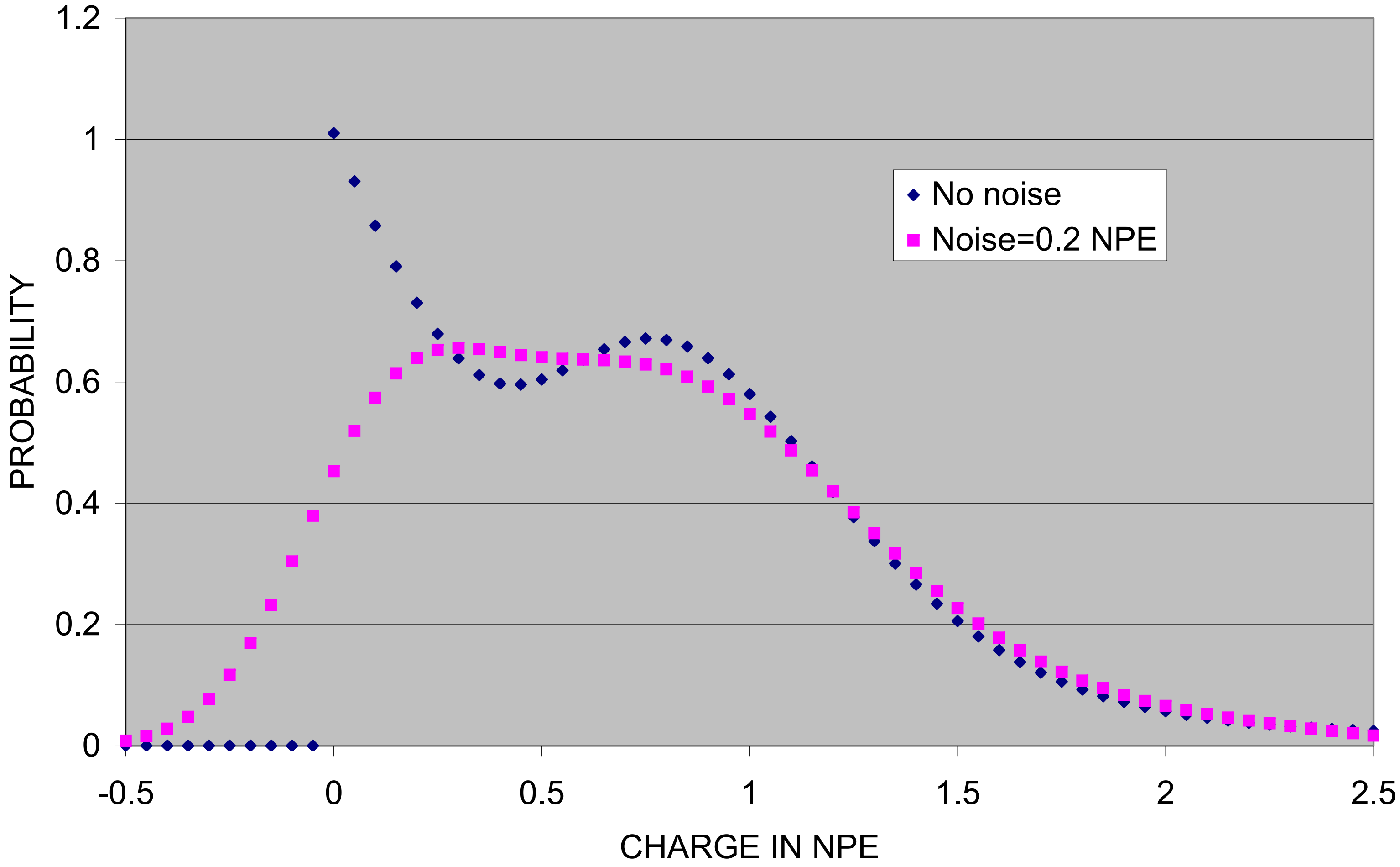
Charge distributions



A headache: sensitivity of NPE=1 distribution to noise model



More noise



1.2
1
0.8
0.6
0.4
0.2
0
PROBABILITY
-0.5
0
0.5
1
1.5
2
2.5
CHARGE IN NPE
No noise
Noise=0.2 NPE

Comments on noise

- Simulation
  - Need to put in noise only once. ReactorFsim made it a function of NPE.
  - Need to think about how readout will be done. In ReactorFsim, every little proton recoil generated a noise output in all PMT (never any true signal).
  - Best way in BWsim: add the noise after the full event generation is complete?
- Reconstruction
  - Need to adapt algorithm to make minimum cut on charge.

- Next at KSU with small army of undergrads: migrate work to BWsim, further work on Polya method, understand "electronics model better", incorporate timing information (at simulation and reco level).