Test Stand Status

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Cosmics

Some data about polystyrene (scintillator base material)

Z/A	0.53768 mol g^{-1}
Density ρ	1.060 g cm^{-3}
Nuclear interaction length λ_I	77.1 cm
Radiation length X_0	41.31 cm
Mean excitation energy I	68.7 eV
Minimum ionization energy $dE/dx\|_{min}$	2.025 MeV/cm

What about the Bethe formula?

$$-\left\langle \frac{dE}{dx} \right\rangle = \rho K \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

- $K = 4\pi N_A r_e^2 m_e c^2 = 0.307075$ MeV mol^{-1} cm^2
- $T_{max} = 2 m_e c^2 \beta^2 \gamma^2 / [1 + 2\gamma m_e/M + (m_e/M)^2]$ is the highest kinetic energy that can be imparted to a free electron in a single collision by a particle with mass M
- The $\delta(\beta\gamma)$ can be calculated based on Sternheimer et al, Phys. Rev. B 26, 6067 (1982)—note that in their convention the correction doesn't have the factor 1/2
  $X = \log_{10} \beta\gamma$
  $X < X_0 \rightarrow \delta(X) = 0$
  $X_0 < X < X_1 \rightarrow \delta(X) = 4.6052X + a(X_1 - X)^m + C$
  $X_1 < X \rightarrow \delta(X) = 4.6052X + C$
  where X_0, X_1, a, m, and C are material-specific constants
- Minimum ionizing energy for muon is 318 MeV, using this we obtain $\langle dE/dx \rangle =$ 2.036 MeV/cm, which is quite close to the 2.025 MeV/cm from the data table

Cosmics

Generally we consider the distribution of energies to be a Landau
The Landau distribution is defined by

$$f(\lambda) = \frac{1}{2\pi i} \int_{c+i\infty}^{c+i\infty} e^{s \ln s + \lambda s} ds$$

due to the long tail, the moments are undefined.

However, as derived in J. E. Moyal, Phil. Mag. 46 (1955) 263, the Landau distribution can be well approximated by

$$f(\lambda) = \frac{1}{\sqrt{2\pi}} e^{-\lambda + e^{-\lambda}}$$

which later became known as the Gumbel distribution.
The moments of the Gumbel distribution are defined: for $\lambda = (x - \mu)/\sigma$, the mode (MPV) is μ and the mean is $\mu + \gamma_E \sigma$ (where $\gamma_E \approx 0.577216$ is the Euler-Mascheroni constant)

For energy loss in a material, we can write the energy loss distribution as

$$\Delta E = \frac{1}{\sqrt{2\pi}} e^{-\lambda + e^{-\lambda}}$$

where the independent variable λ is

$$\lambda = \frac{\Delta E - [\Delta E]_{MPV}}{\xi}$$

the width parameter ξ is

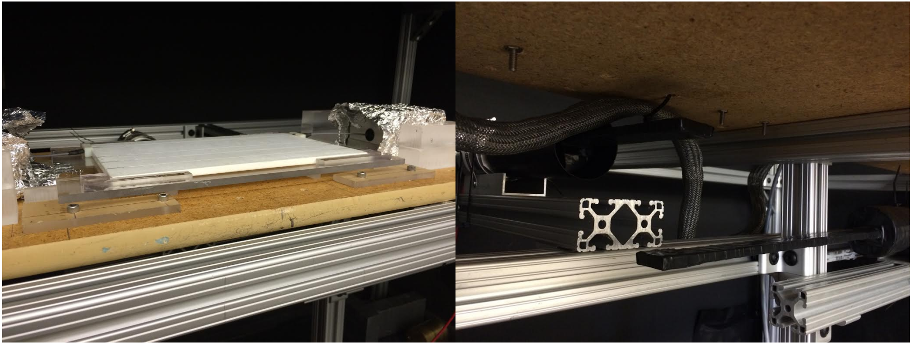
$$\xi = \frac{K}{2}\frac{Z}{A}\frac{1}{\beta^2}\rho\Delta x$$

and the most probable value of the energy loss can be determined by a modified Bethe formula

$$[\Delta E]_{MPV} = \xi \left[\ln \frac{2 m_e c^2 \beta^2 \gamma^2 \xi}{I^2} - \beta^2 + 1 - \gamma_E \right]$$

Cosmics and Source

Some photographs of the cosmics set up



We have both phototubes under the table so that source/LED scans can be run without total deconstruction

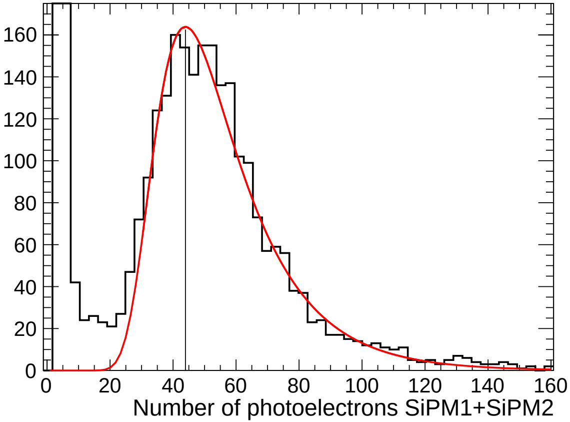
We have the upper tube as close to the panel as possible to minimize the fraction of particles that trigger both tubes but miss the panel

Cosmics

A little about the geometry...

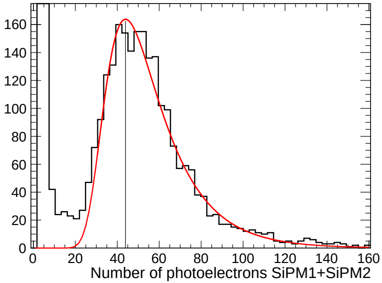
- The two phototubes are separated by about 3.25", and each has a 1" $\times$ 1" scintillator
- The maximum angle off-normal is $\theta_{max} = \tan^{-1}(3.25/1) \approx 0.298 \approx 17^\circ$
- The pathlength L is related to the thickness Δx by $L = \Delta x \sec\theta$, meaning $L_{max} = \Delta x \sec\theta_{max} \approx 1.05\Delta x$
- Panel thickness 0.300" $= 0.762$ cm
- For the sake of simplicity, we'll ignore the 5% possible deviation in pathlength... for MIP we get $[\Delta E]_{MPV} = 1.37$ MeV and $\xi = 0.0750$ MeV

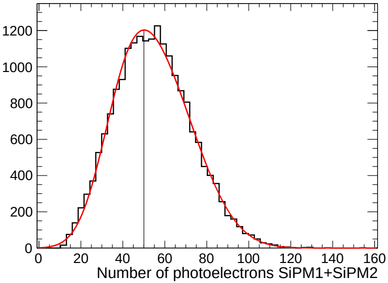
Cosmics



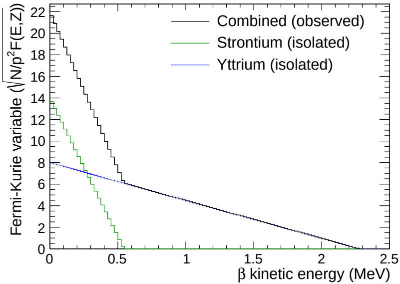
$[\Delta E]_{MPV} = 43.9 \pm 0.5$ photoelectrons and $\xi = 9.3 \pm 0.2$ photoelectrons

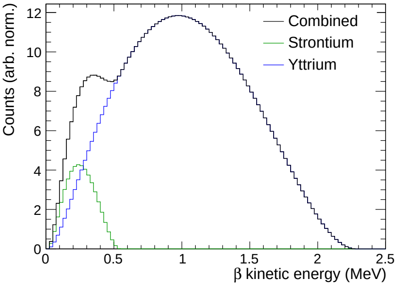
Cosmics and Source





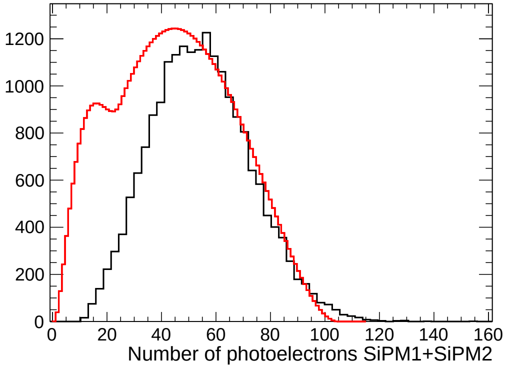
What does the Strontium source spectrum look like?





Data from W. E. Meyerhof, Phys. Rev. 74 (1948) 263

Overlay of the source spectrum with measured distribution



There seems to be some inefficiency at low energies, though further investigation is needed

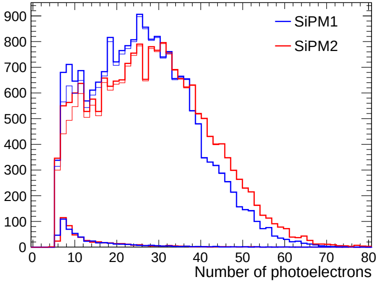
Reminder—we use the SiPMs to self-trigger on the source, so there's inherently a low energy cut-off

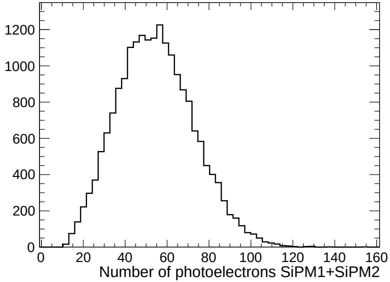
Brief summary

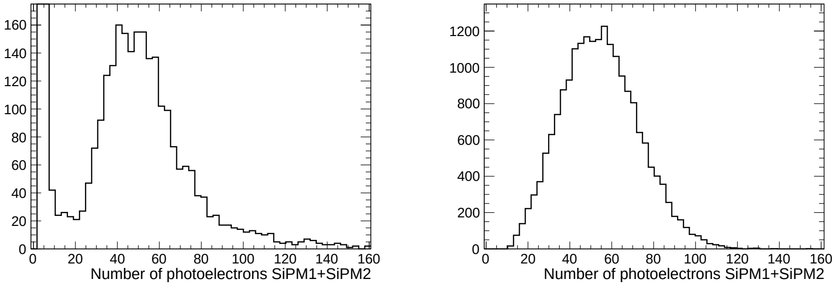
- **Cosmics have been measured with a mean of 43.9 pe and a with of 9.3 pe**
- **We are prepared and able to cosmics measurements as soon as we get the full size tiles from BNL**
- We can also do an LED scan as soon as we receive them—we plan to do LED scans with the tile inverted, i.e. facing away from the LED so that light going directly into the fiber isn't an issue
- We are seeking input to going further using cosmics to characterize the energy deposited in the tile
- It may also be possible to use the Strontium-90 source to calibrate the energy, though further investigation is needed
- The sampling of the light in the fiber relative to the total light produced may be an important additional consideration

Extra material

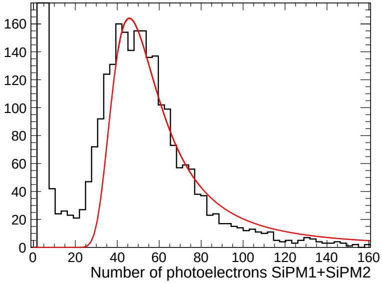
Source distribution, comparison between each SiPM and the sum

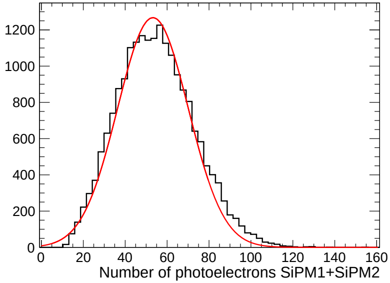






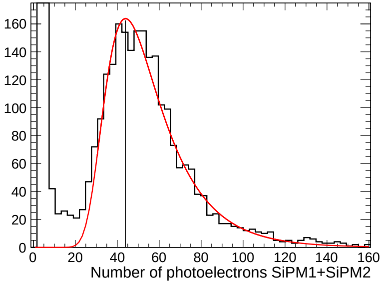
Raw distributions

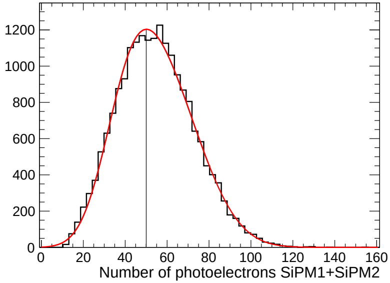




Built-in Landau for cosmics, Built-in Gaussian for source

Cosmics and Source





Gumbel for cosmics, modified Gaussian for source