Back-of-the-envelop trigger calculations

Ivano Lippi - INFN Padova

Questions

What is the limit of the multiplicity trigger ?

i.e.

What is the minimum effective threshold
with less than 1 KHz noise rate and 100% efficiency ?

and

What determines the limit and how can improve ?

Dark Noise

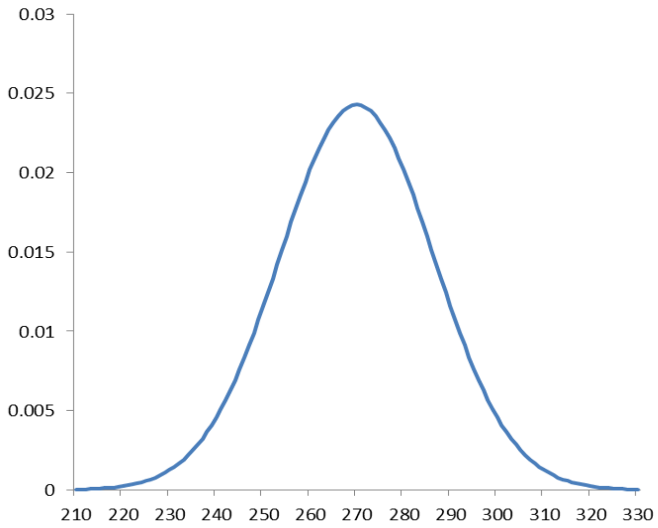
N_{pmt} is the total number of PMTs (18000)

f is the dark noise rate of each PMT (50 KHz)

τ is the trigger window width (300 ns)

The average number of PMTs with a hit in each trigger window is $N_0 = N_{pmt} \times f \times \tau$ (270)

The distribution ρ of the number N of PMTs with a hit in each trigger window is a Gaussian:



$$\mu = N_0 \; ; \; \sigma = \sqrt{N_0}$$

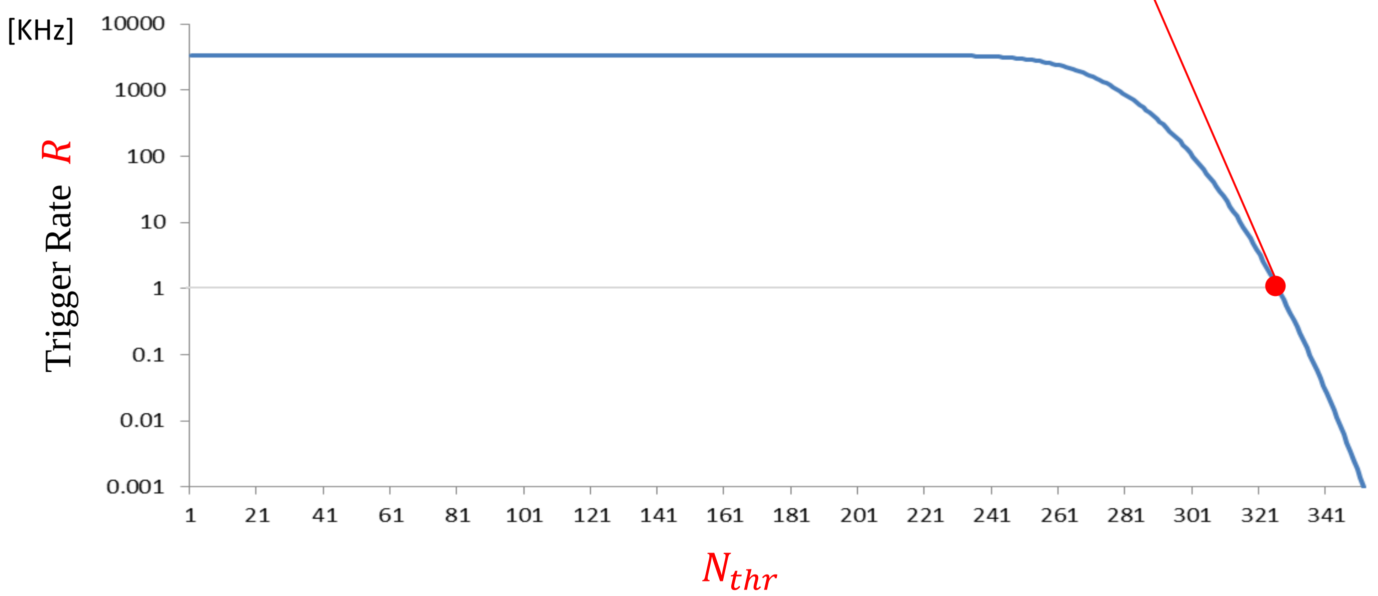
$$\rho(N) = \frac{1}{\sqrt{2\pi N_0}} e^{-\frac{(N - N_0)^2}{2 N_0}}$$

Dark Noise Threshold & Rate

The trigger rate R with multiplicity threshold N_{thr} is given by the sampling rate τ^{-1} (3.33 MHz) times the probability to get multiplicity $N > N_{thr}$ (the Gaussian distribution integral)

$$R = \frac{1}{\tau} \int_{N_{thr}}^{+\infty} \rho(N)\, dN$$

$\{ 1\ KHz\ @\ \ N_{thr} = 326\ \ (3.4\sigma) \}$



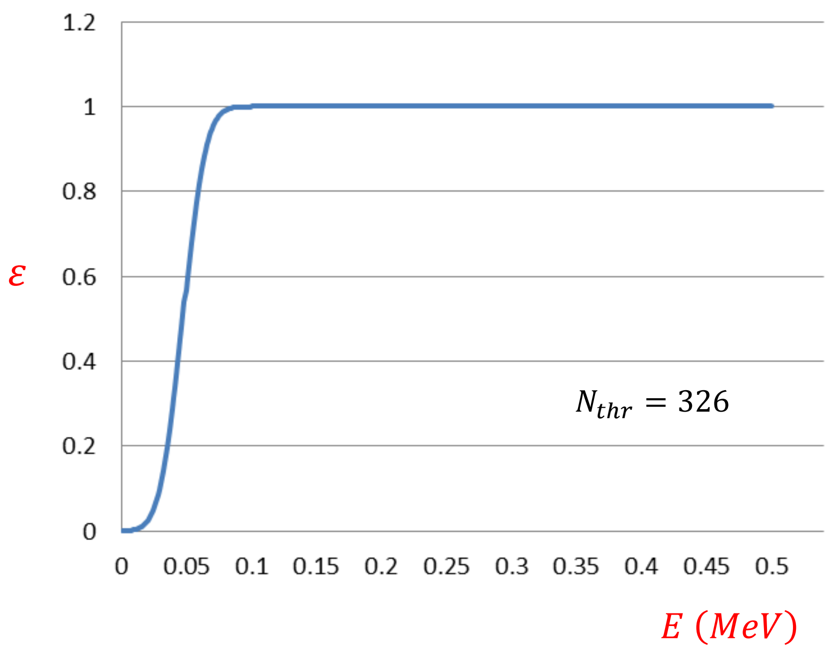
Trigger Efficiency

A physical event with energy deposition $E\ (MeV)$ generates $N_E = 1200 \times E$ photoelectrons

At small energies we can assume the corresponding PMTs multiplicity given by N_E

The N_E effect is to shift the average PMTs multiplicity: $N_0 \rightarrow N_0 + N_E$

The trigger efficiency ε is given by the integral of the $\rho(N)$ distribution with $\mu = N_0 + N_E$



$\varepsilon \approx 1$ already at $E \approx 0.1\ MeV$

Are we happy ? NO !

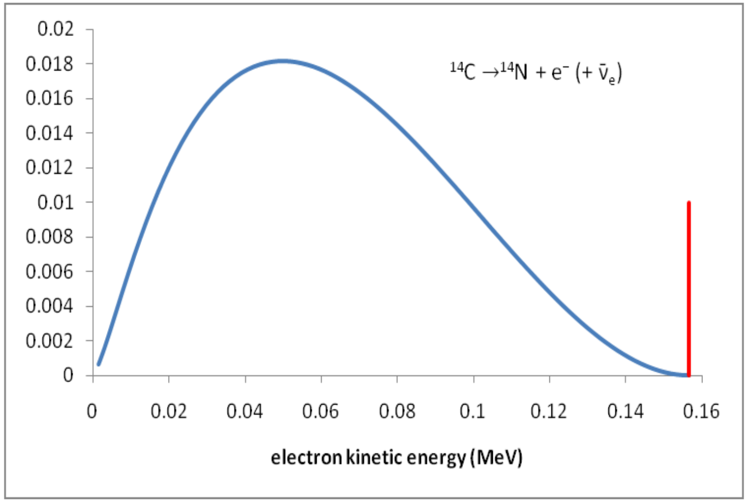
Any slightest energy background with high rate (> 1 KHz) would force us to increase the multiplicity threshold

^{14}C Background

^{14}C concentration (baseline) $= 10^{-17}(gg^{-1}) \rightarrow$ Q $= 2 \times 10^{-7}g$ in Juno (20 kt)

Isotope mass u and Avogadro number $A \rightarrow N = A \times Q \,/\, u = 8.6 \times 10^{15}$ atoms in Juno

Lifetime $\tau = 8267\ years = 2.6 \times 10^{11}\ s \rightarrow$ decay rate $R = N/\tau = 33\ KHz$



Very roughly, to get rid of the ^{14}C :

- 0.16 MeV → 192 PMTs multiplicity
- $N_{thr} = 326 + 192 = 518$
- Trigger rate $R \approx 0$
- Efficiency curve shifted by 0.16 MeV

^{14}C Effects on Trigger

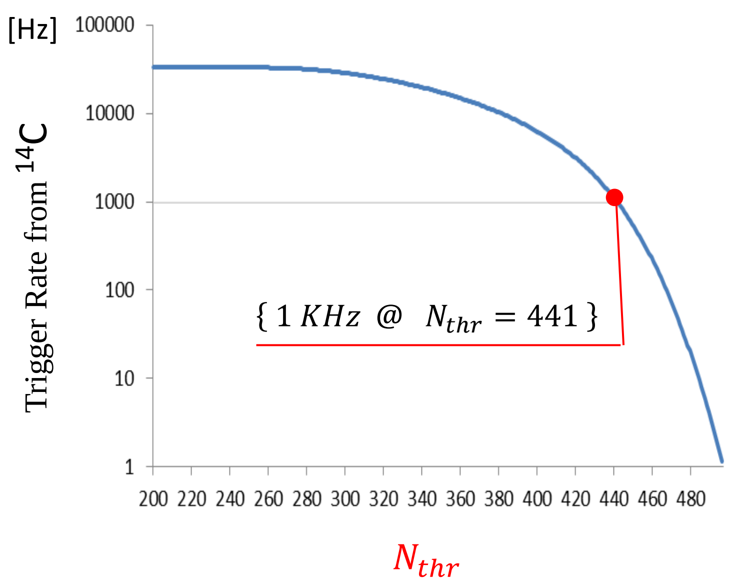
Convoluting the ^{14}C energy spectrum with the PMTs dark noise fluctuations we get a more refined estimate.

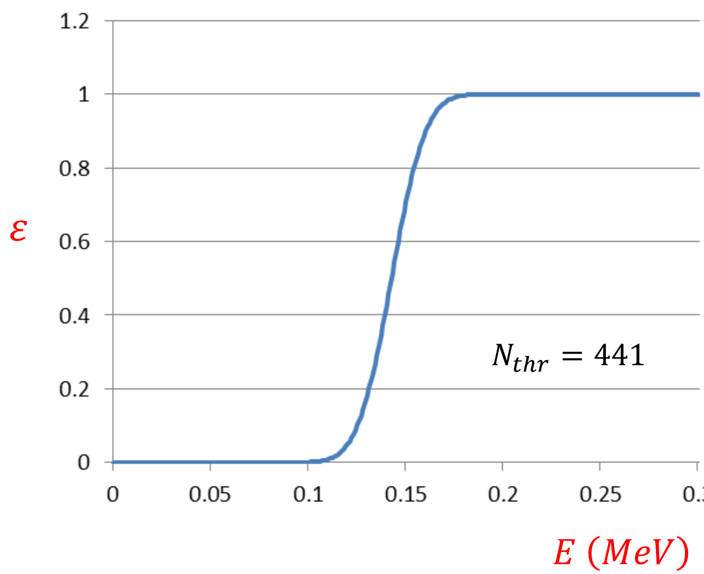
The ^{14}C decay rate can be reduced from 33 KHz to 1 KHz rate with multiplicity threshold $N_{thr} = 441$

With this threshold, the 99 % of the 3.33 MHz sampling rate, gives dark noise trigger rate $R \approx 0$

The corresponding efficiency curve shift is less than 0.1 MeV with $\varepsilon > 99\%$ at .175 MeV

Bottom line: physical energy threshold $E_{thr} \approx 0.2\ MeV$ efficiency $\varepsilon = 1$ noise rate $R \ll 1\ KHz$





Conclusions

I tried to determine the lower effective physical threshold with a sustainable background rate:

The trigger limit is given by the ^{14}C β decay process

The result is:

- Effective physical energy threshold $E_{thr} \leq 0.2\ MeV$
- Efficiency $\varepsilon = 1$ already at the threshold
- Overall dark noise and ^{14}C background rate $R \ll 1\ KHz$ (all from ^{14}C β decay)

There is no room for significant improvements:

- The dark noise rate contributes only through statistical fluctuations $\left(\sim \sqrt{N} \right)$
- The ^{14}C concentration contributes quasi-logarithmically
- The vertex correlation trigger cannot filter the point-source ^{14}C β decay