Maximum count rates in Constellation-X TES microcalorimeters

Enectalí Figueroa-Felciano
NASA Goddard Space Flight Center

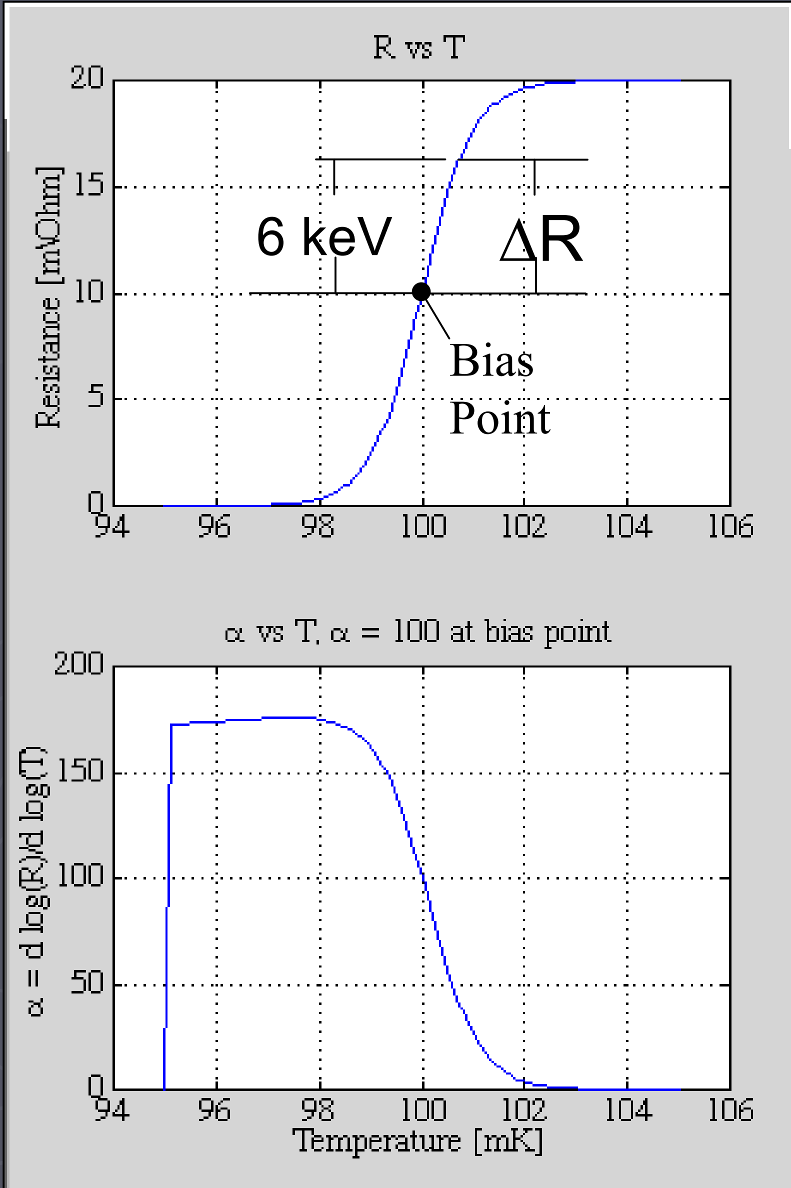
Is there a problem with TESs and high count rates?

- For Constellation-X, we need to be able to ***"<u>handle</u>"*** 1000 cts/s.
- To find out, we:
  a) Created a non-linear model of a TES detector
  b) Modeled the spectrum of photons from the Crab as seen through Constellation-X

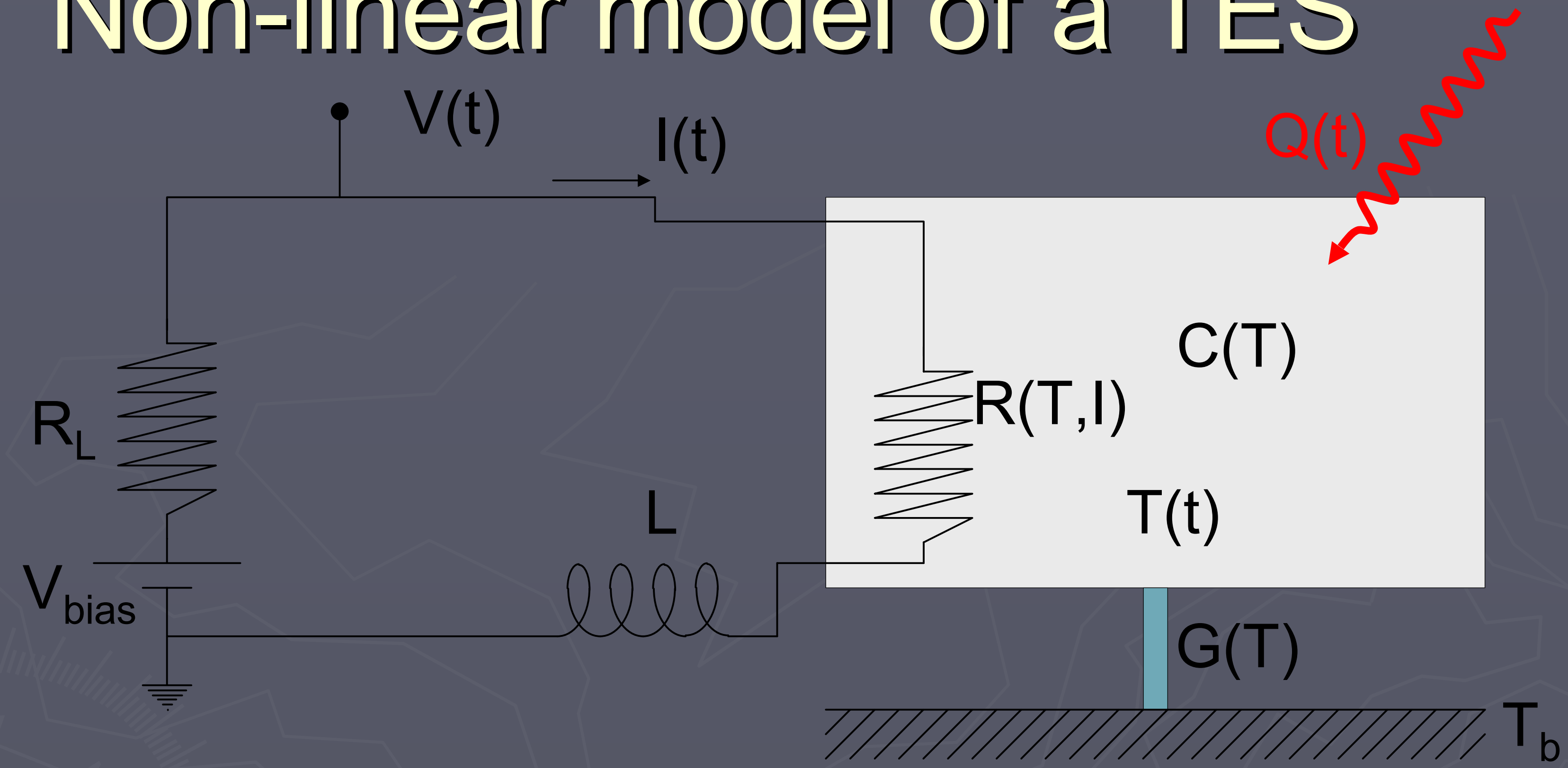
Parameters of our TES model

- $\alpha = 100,\ \beta = 0$
- $R_{quiescent} = 10\ \mathrm{m}\Omega$
- $R_{6keV} = 16\ \mathrm{m}\Omega$
- $R_n = 20\ \mathrm{m}\Omega$
- $\tau_{eff} = 100\ \mu s,\ \tau_o = 2500\ \mu s$
- $C = 2\ \mathrm{pJ/K}$
- $G = 0.804\ \mathrm{nW/K}$

$$R(T) = R_n\left[\frac{\tanh(10\alpha(T - T_c))}{2} + \frac{1}{2}\right]$$

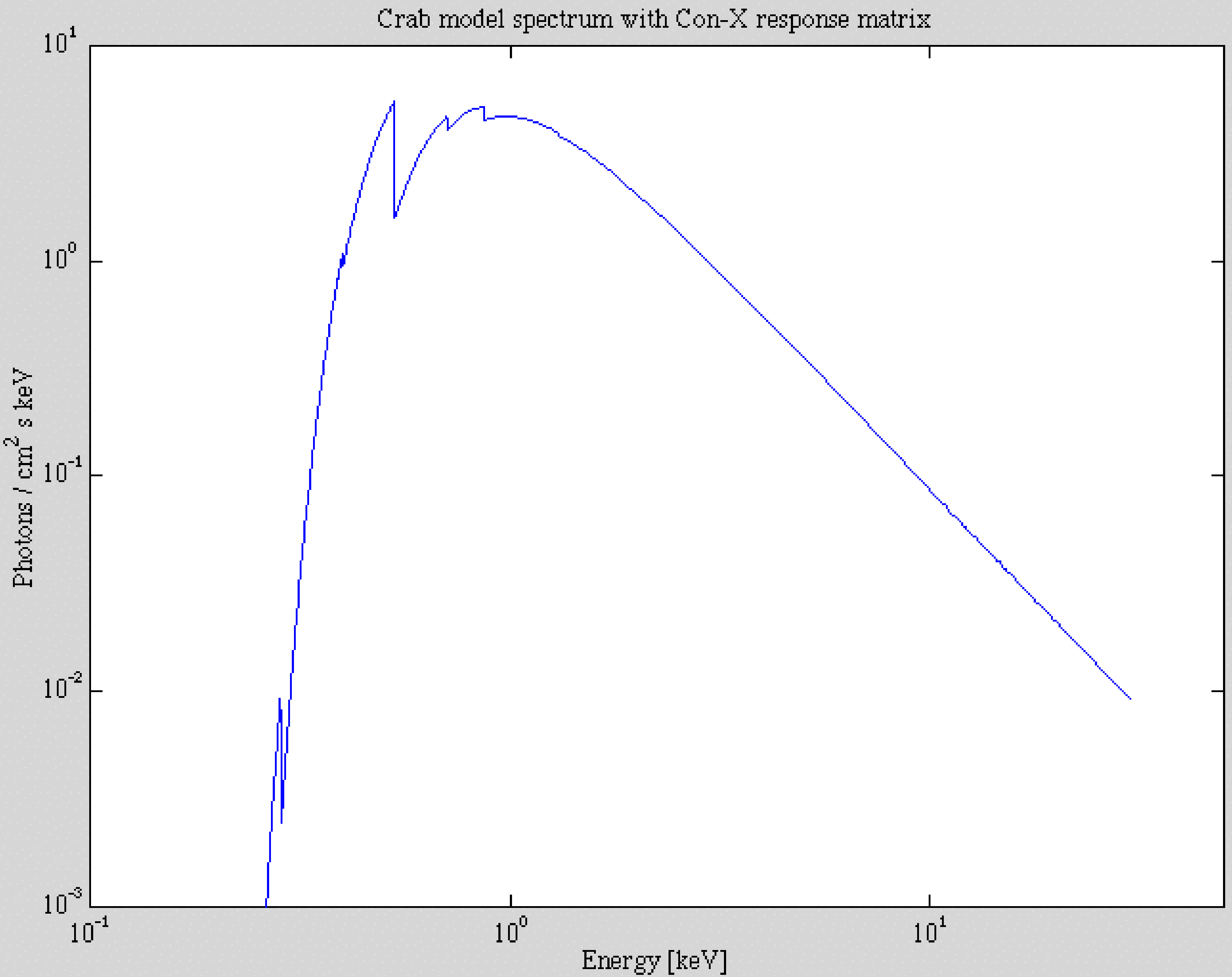


Non-linear model of a TES



$$L\frac{dI}{dt} = V_{\mathrm{bias}} - I(t)\Big(R_{\mathrm{L}} + R(T,I)\Big)$$

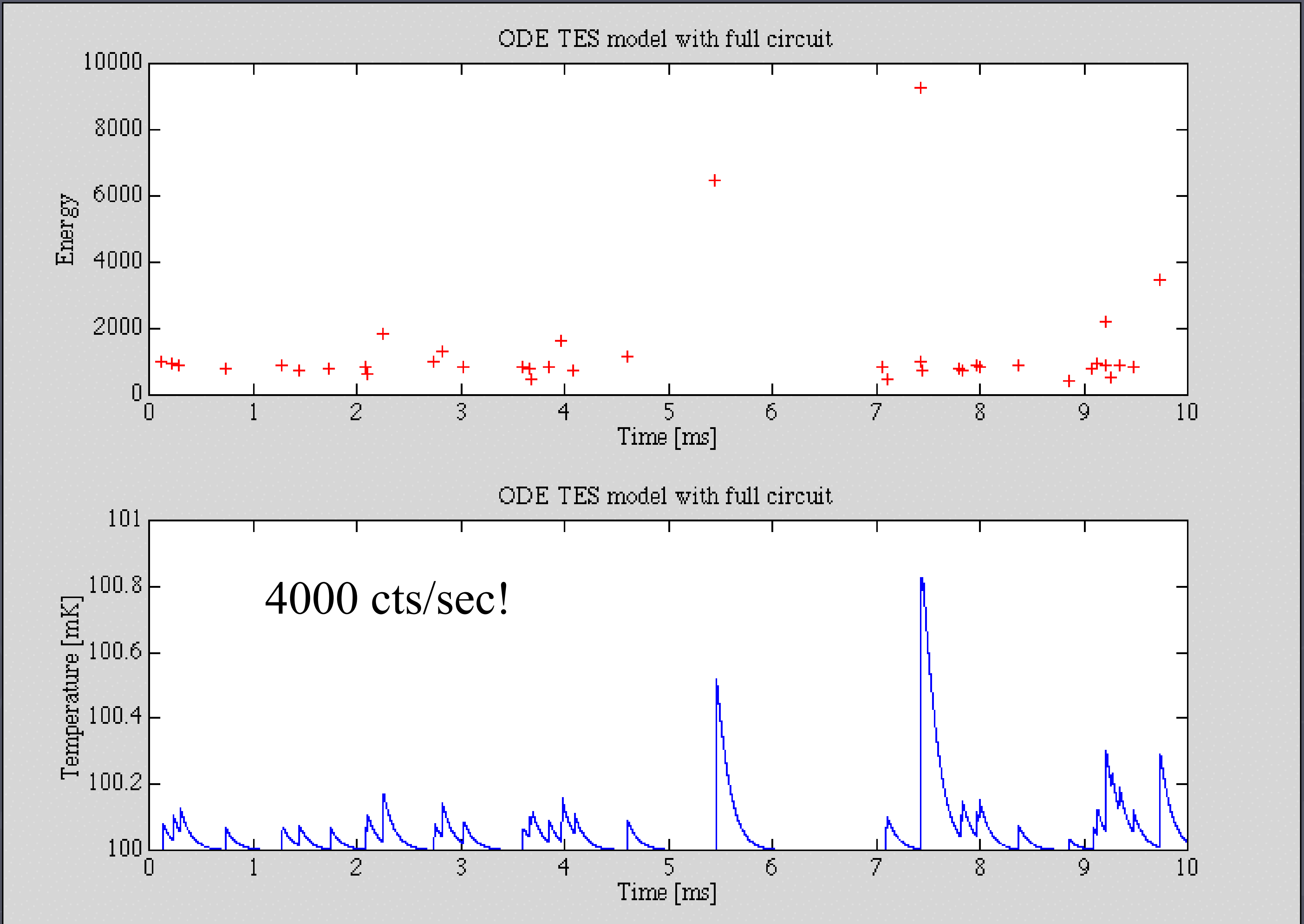
$$C(T)\frac{dT(t)}{dt} = I(t)^2 R(T,I) - K\big(T(t)^n - {T_{\mathrm{b}}}^n\big) + Q(t)$$


Crab model spectrum with Con-X response matrix
Photons / cm^2 s keV
Energy [keV]
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-1}
10^{0}
10^{1}

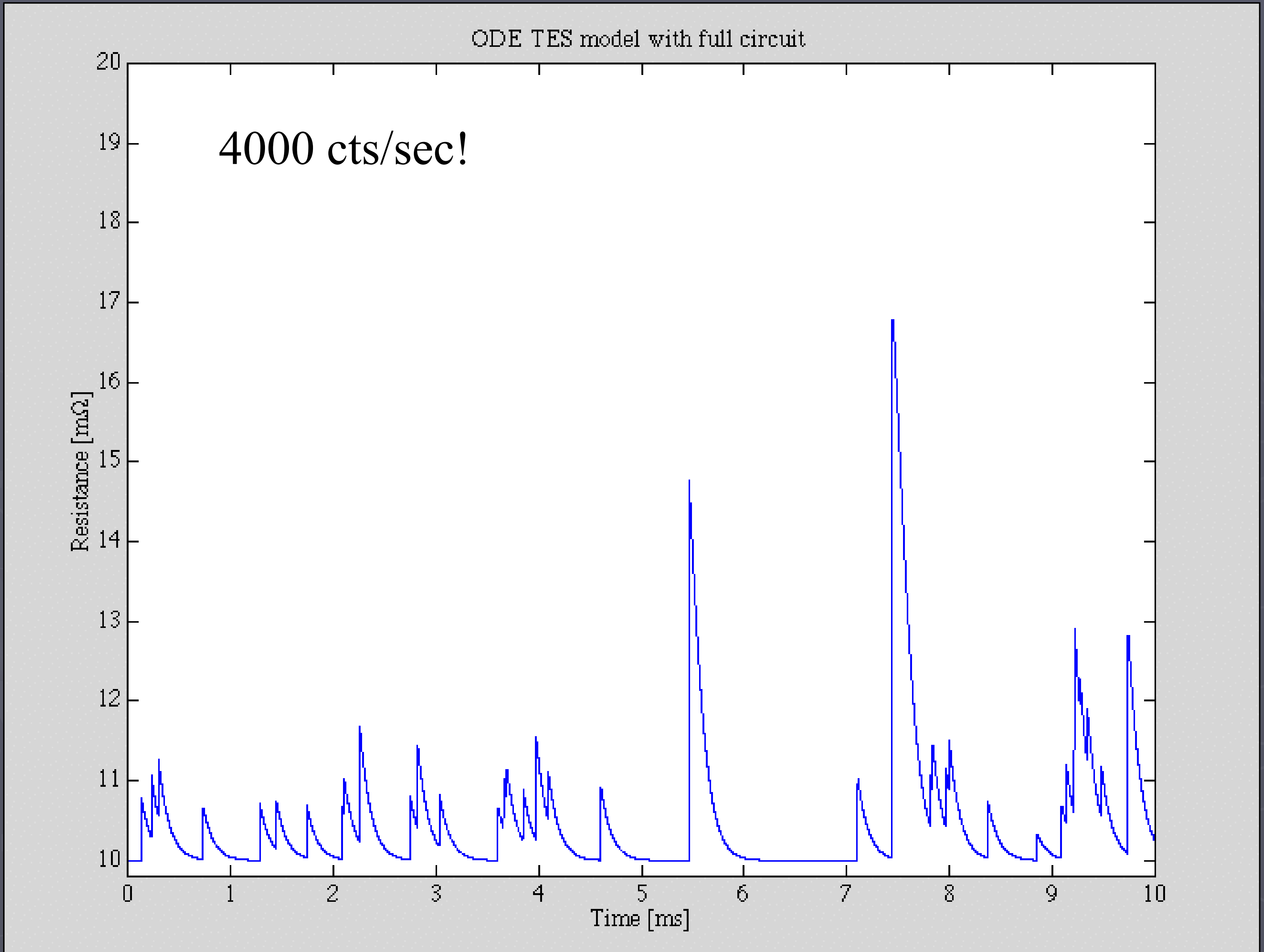
How many counts per pixel?

- 80000 cts/sec integrated flux
- 20000 cts/sec/array
- Assuming the Crab is a point source (very conservative), this would be distributed among 9 pixels
- We assume the central pixel receives about 4000 cts/sec. Note this is 4 times our required rate!

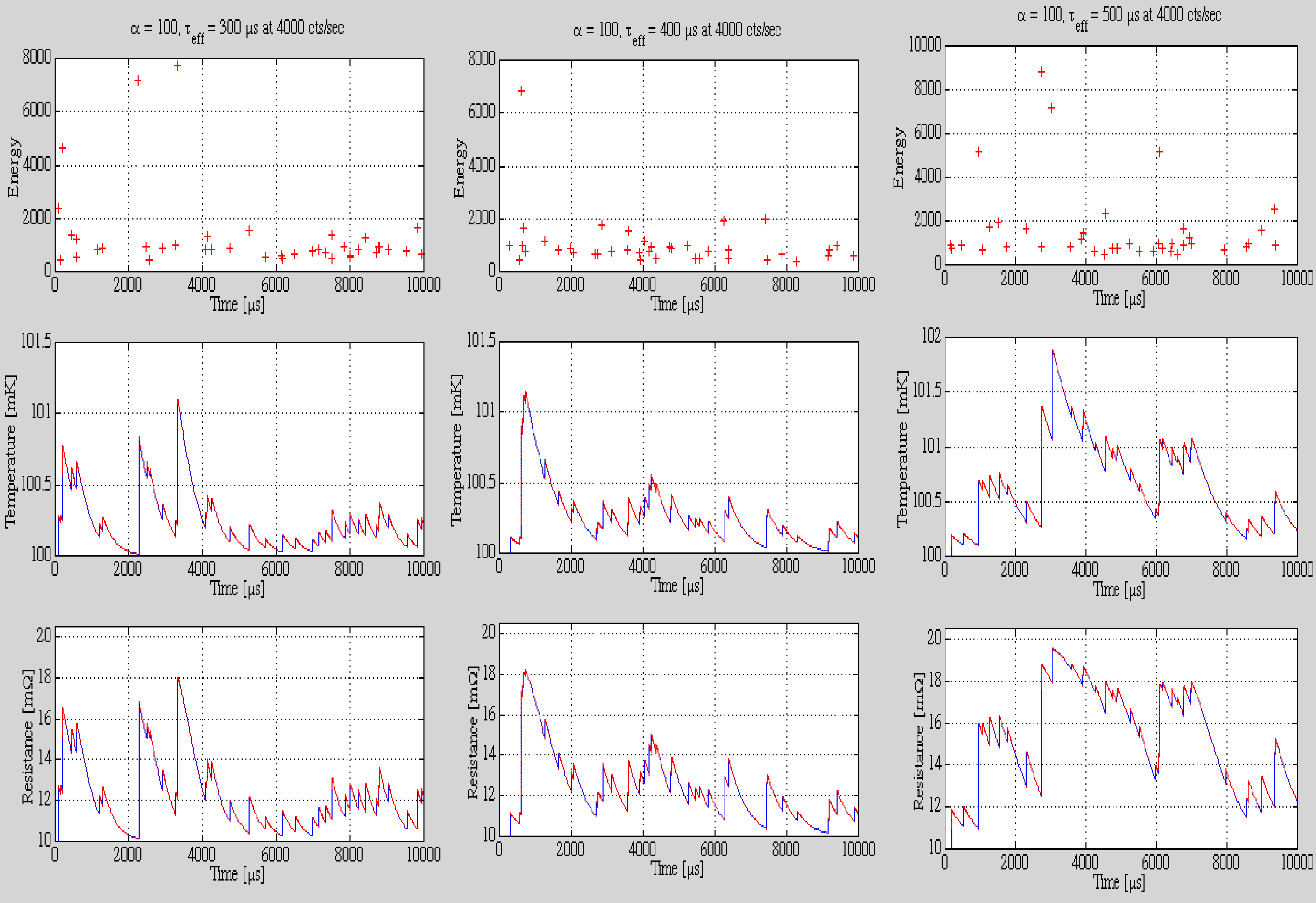
Crab-like point source on pixel



Crab-like point source on pixel

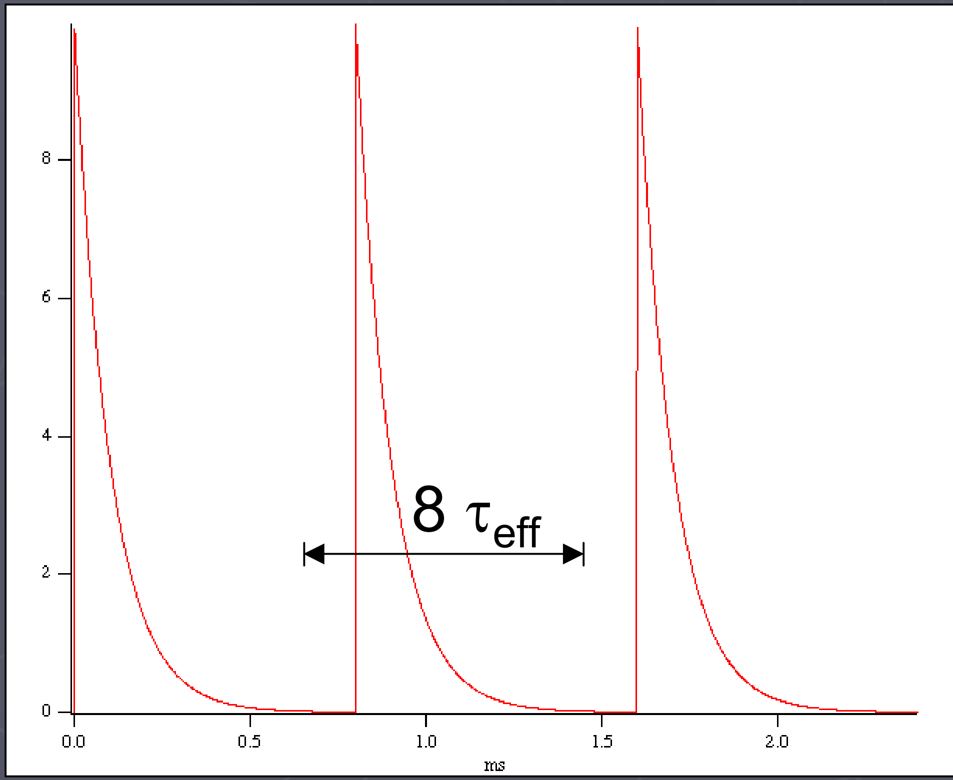


Crab-like point source for τ_{eff} = 300, 400, and 500 μs

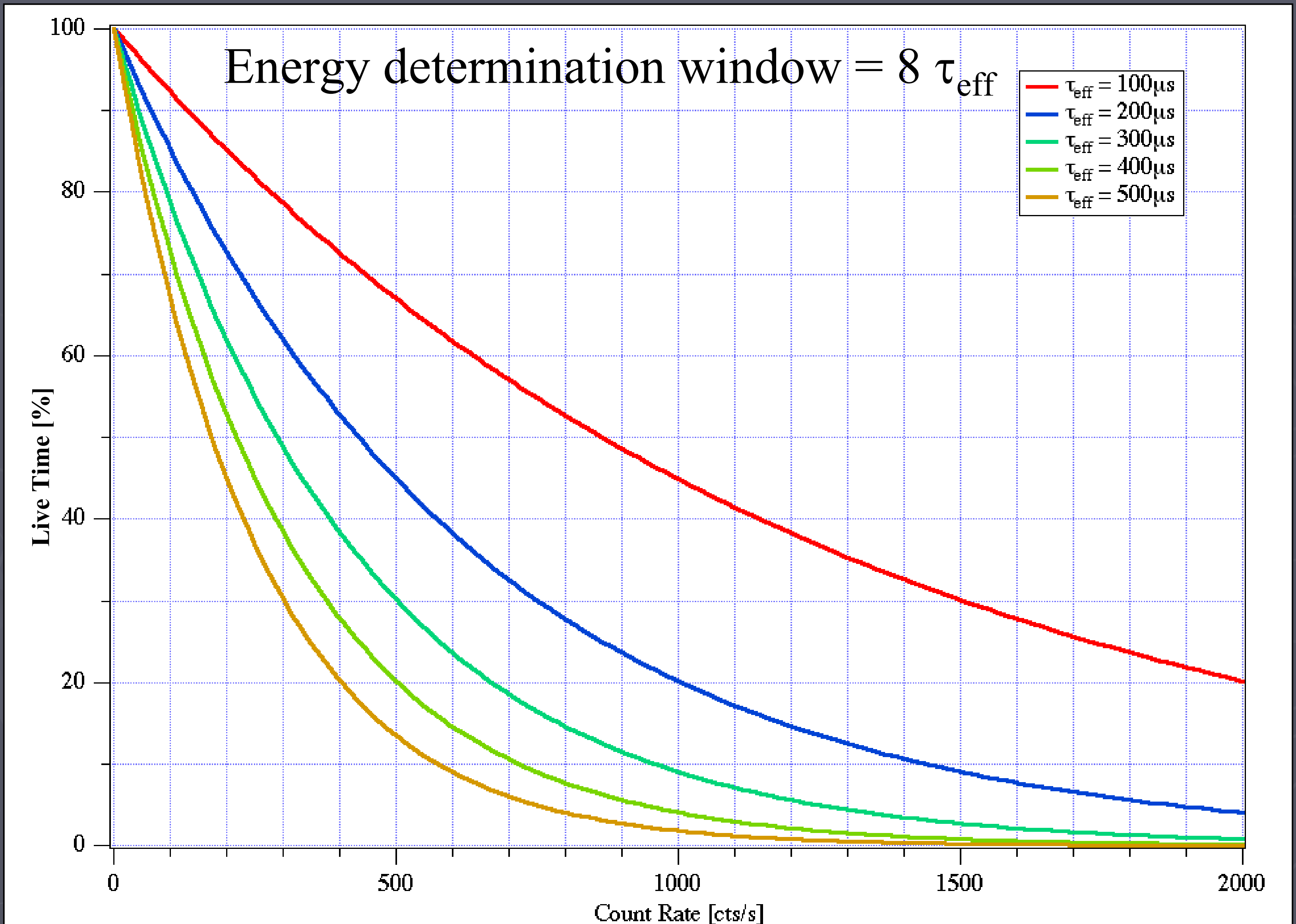


What is the throughput for Highest-Resolution Spectroscopy?

- To get the best resolution, one needs to use an optimal filter.
- An optimal filter needs a record length of about 8 τ_{eff}, where τ_{eff} is the decay time of the pulse



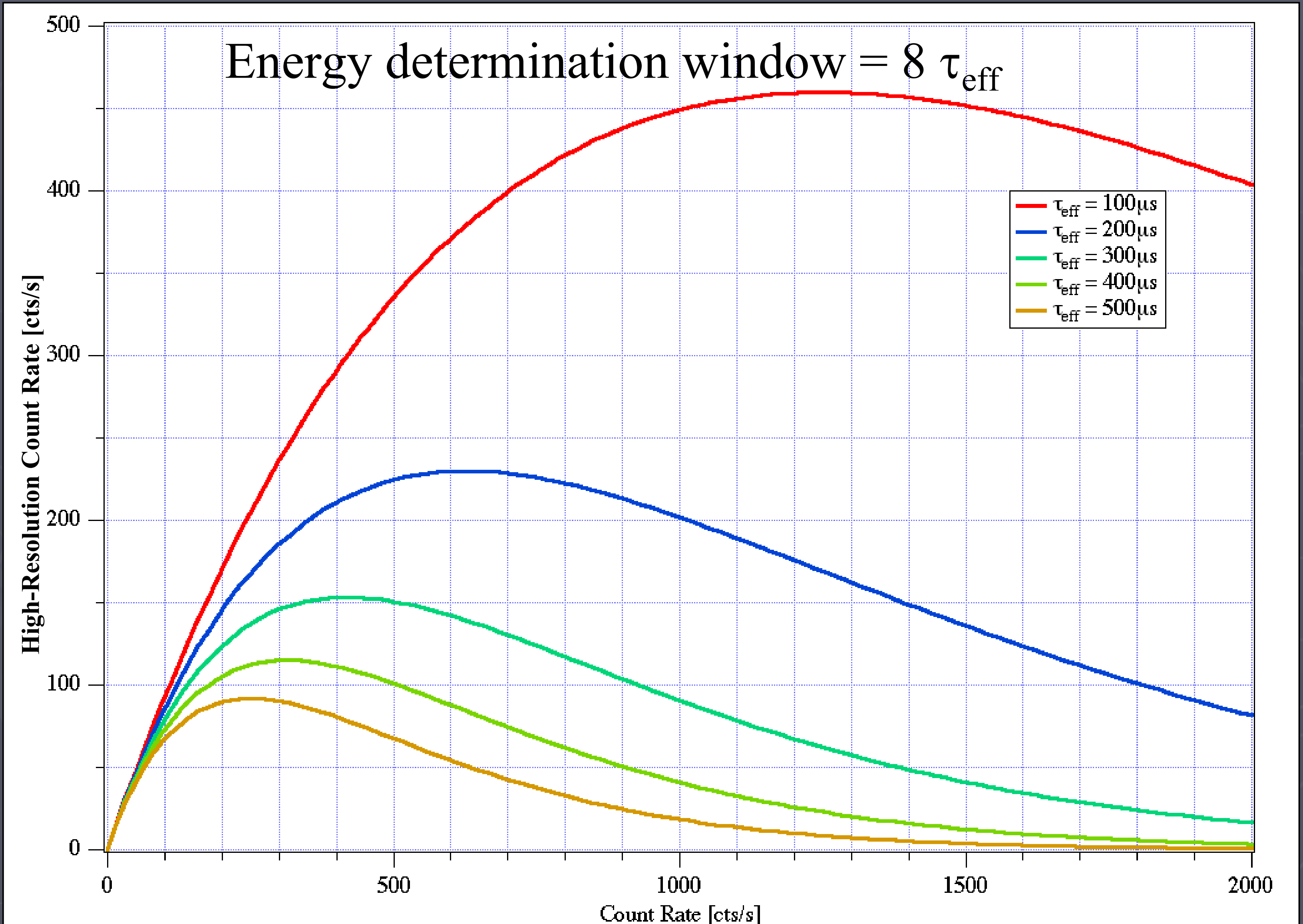
Live Time vs Count Rate

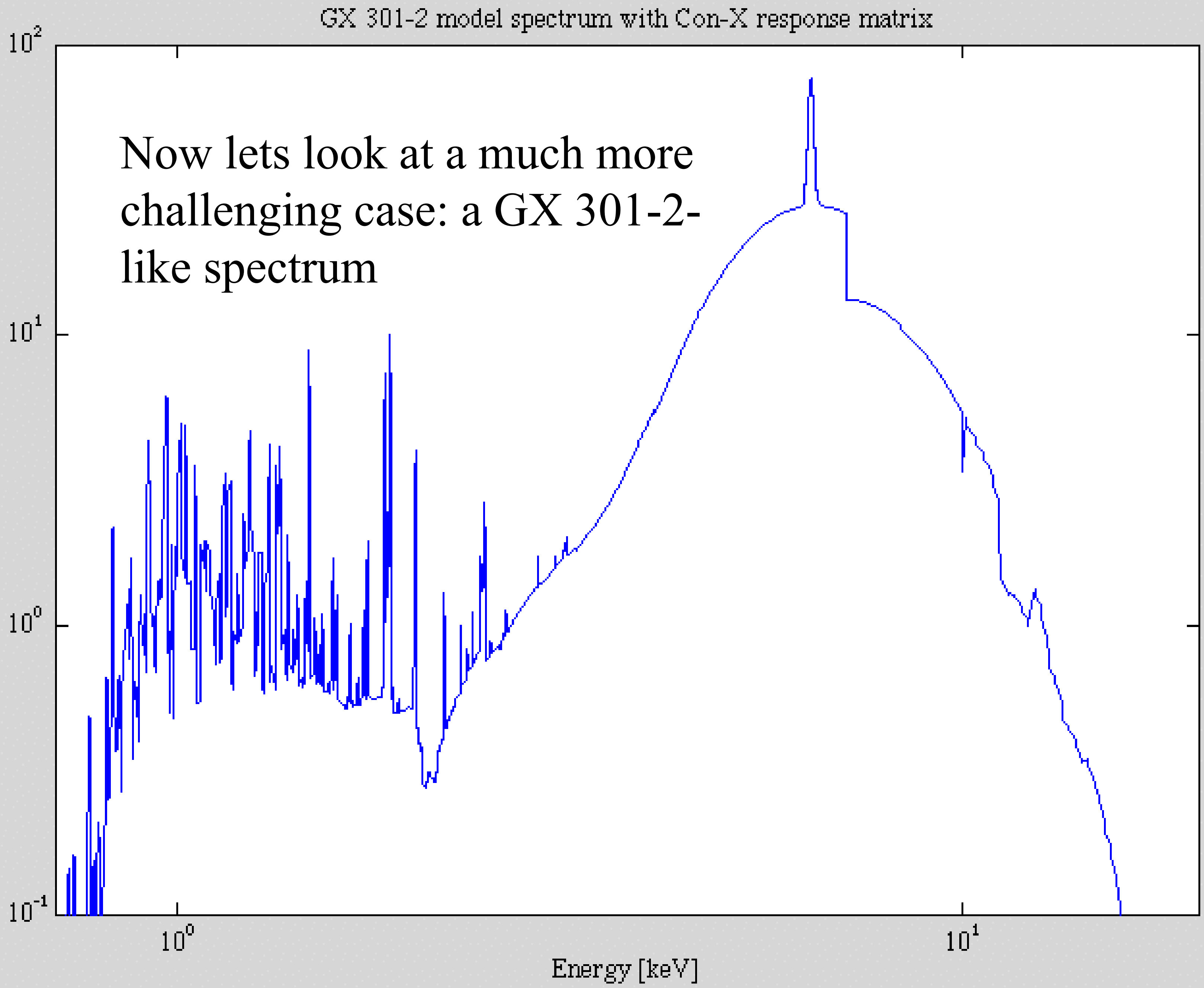


Conclusions

- Transition-Edge Sensors for Constellation-X are not saturated by 1 Crab point sources.
- Decay times of 500 μs will still allow the TES to function without saturation for Crab fluxes.
- Dead time effects are the same as semiconductor microcalorimeters

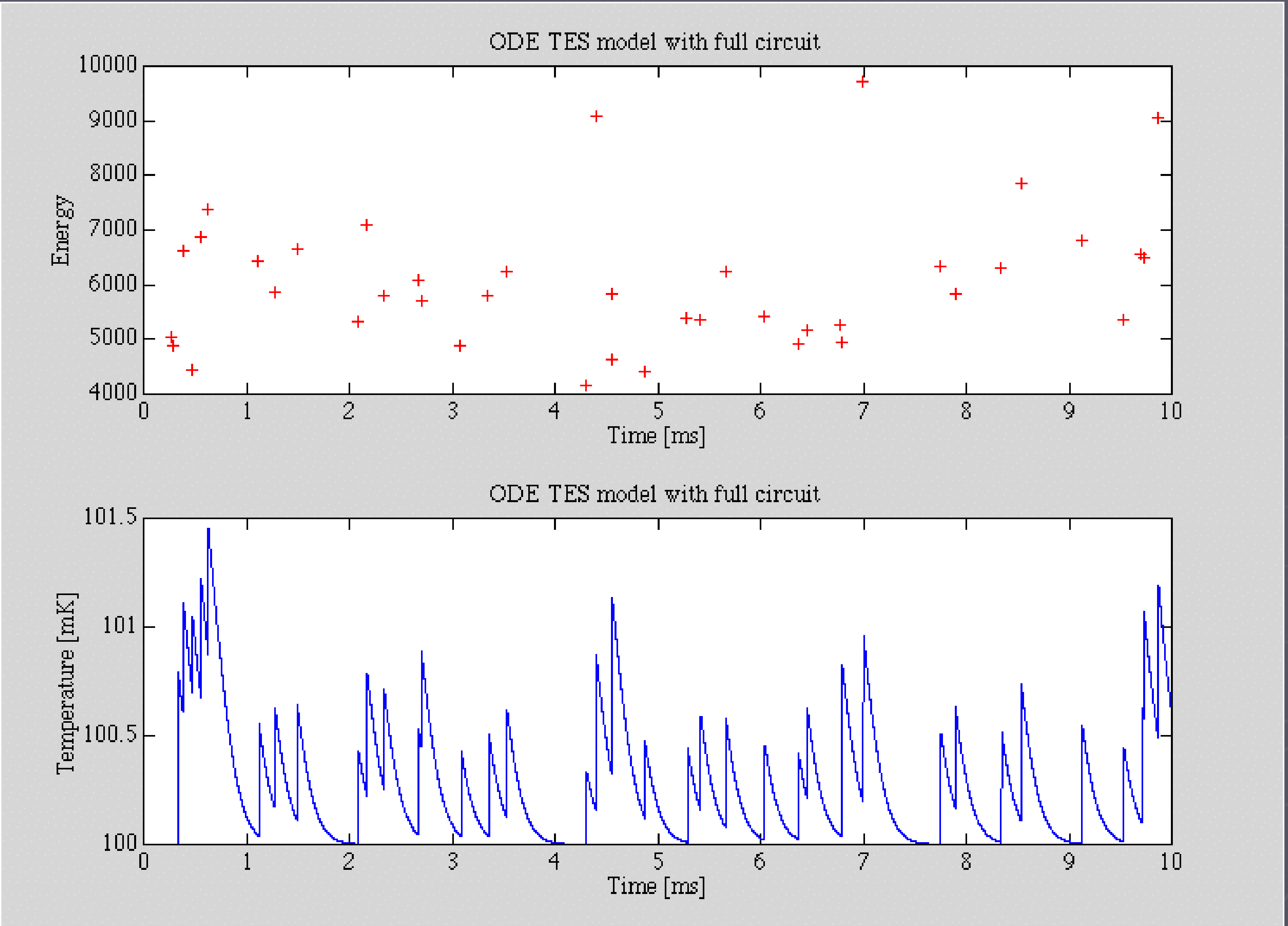
High-Res Rate vs Count Rate



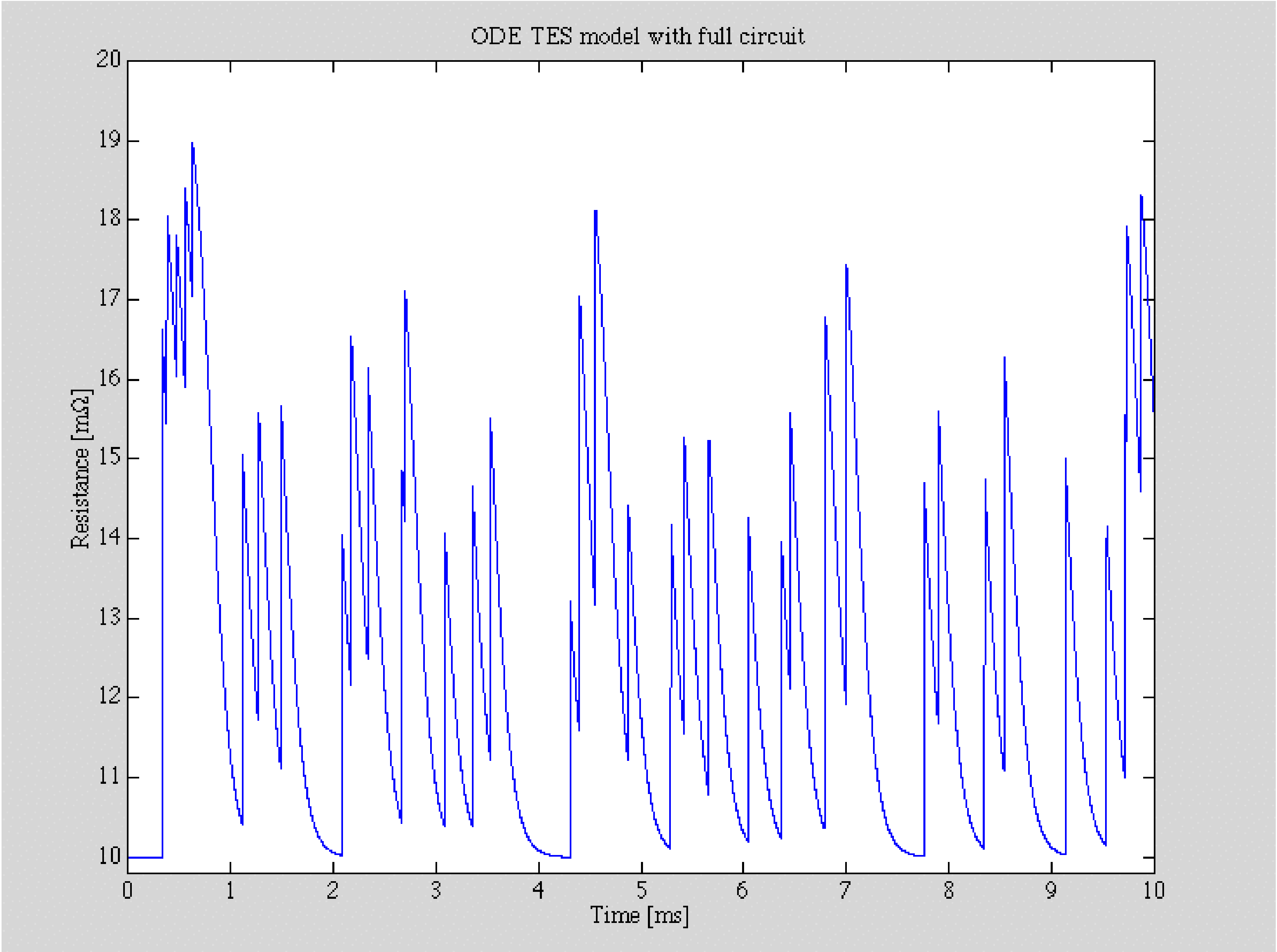


GX 301-2 model spectrum with Con-X response matrix
Now lets look at a much more challenging case: a GX 301-2-like spectrum
10^{2}
10^{1}
10^{0}
10^{-1}
10^{0}
10^{1}
Energy [keV]

Fictitious 1 Crab point source with GX 301-2 spectrum

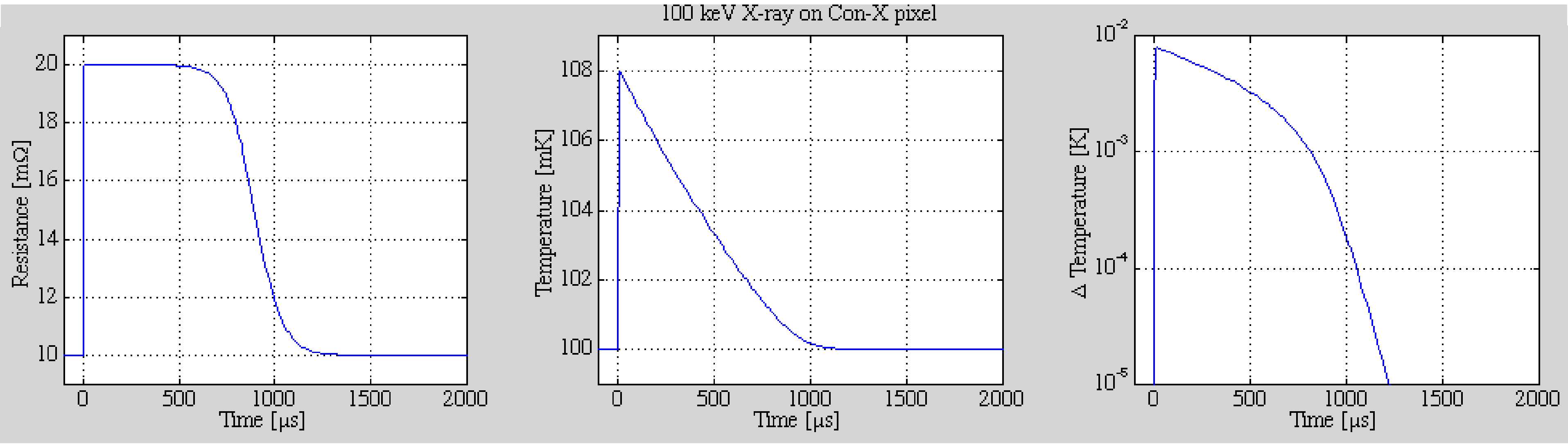


Fictitious 1 Crab point source with GX 301-2 spectrum

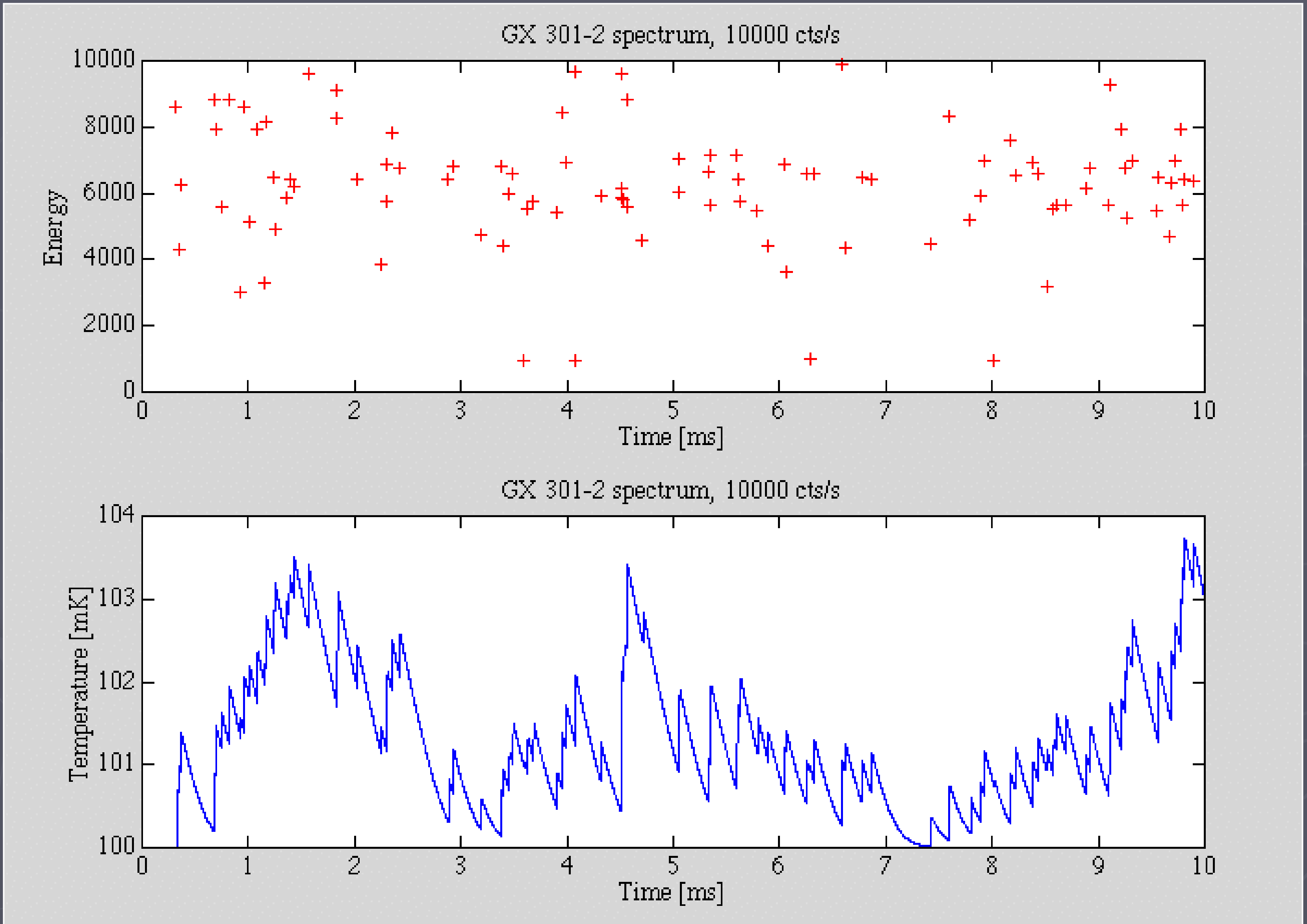


$\tau_o / \tau_{eff} > 25$ = Big Problems??

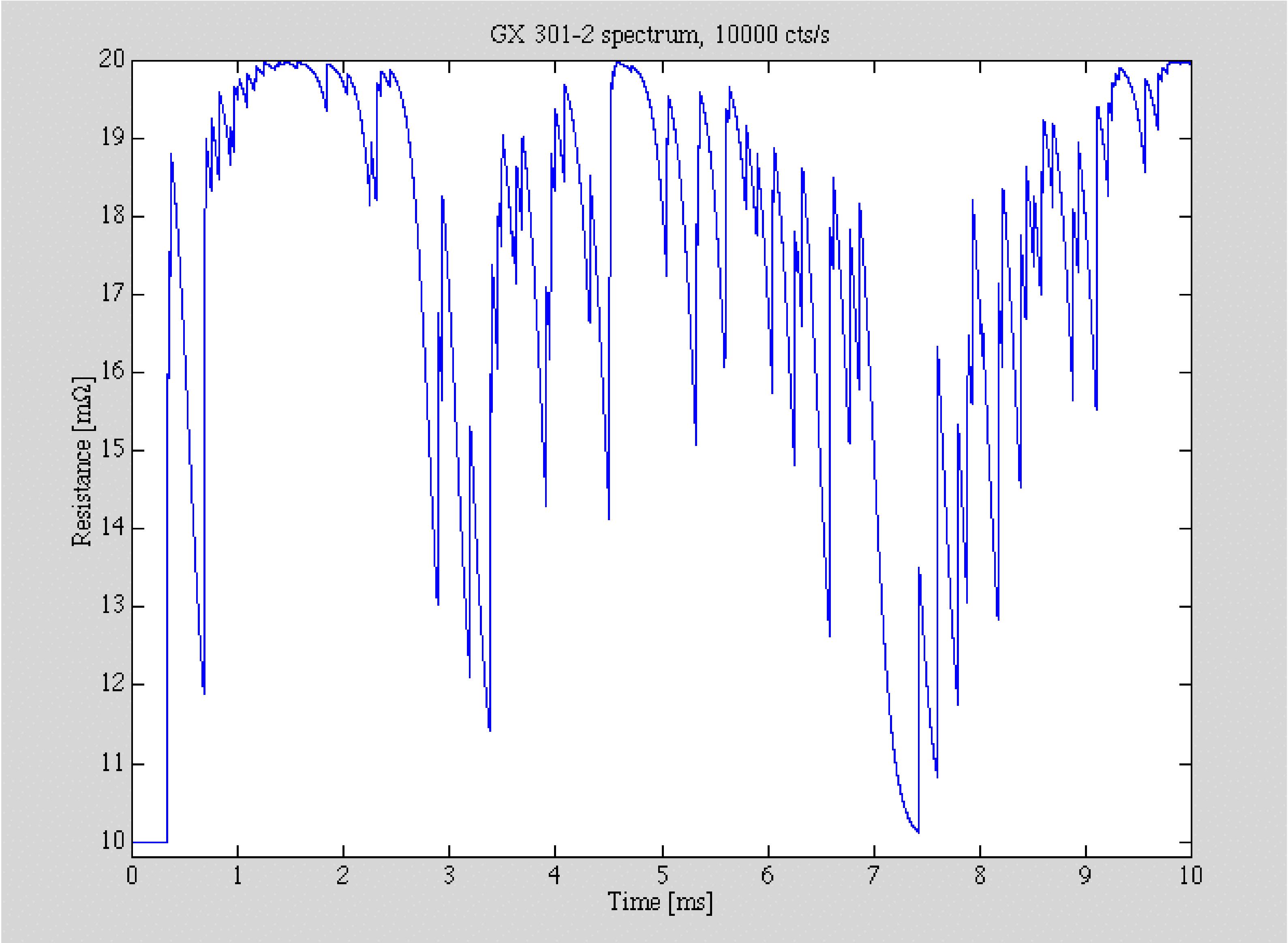
- If your decay time suddenly goes from 100 μs to 2000 μs, will you latch in the normal state? NO!!!
- Here is a 100 keV x-ray on a Con-X pixel:



Fictitious 2.5 Crab point source with GX 301-2 spectrum



Fictitious 2.5 Crab point source with GX 301-2 spectrum

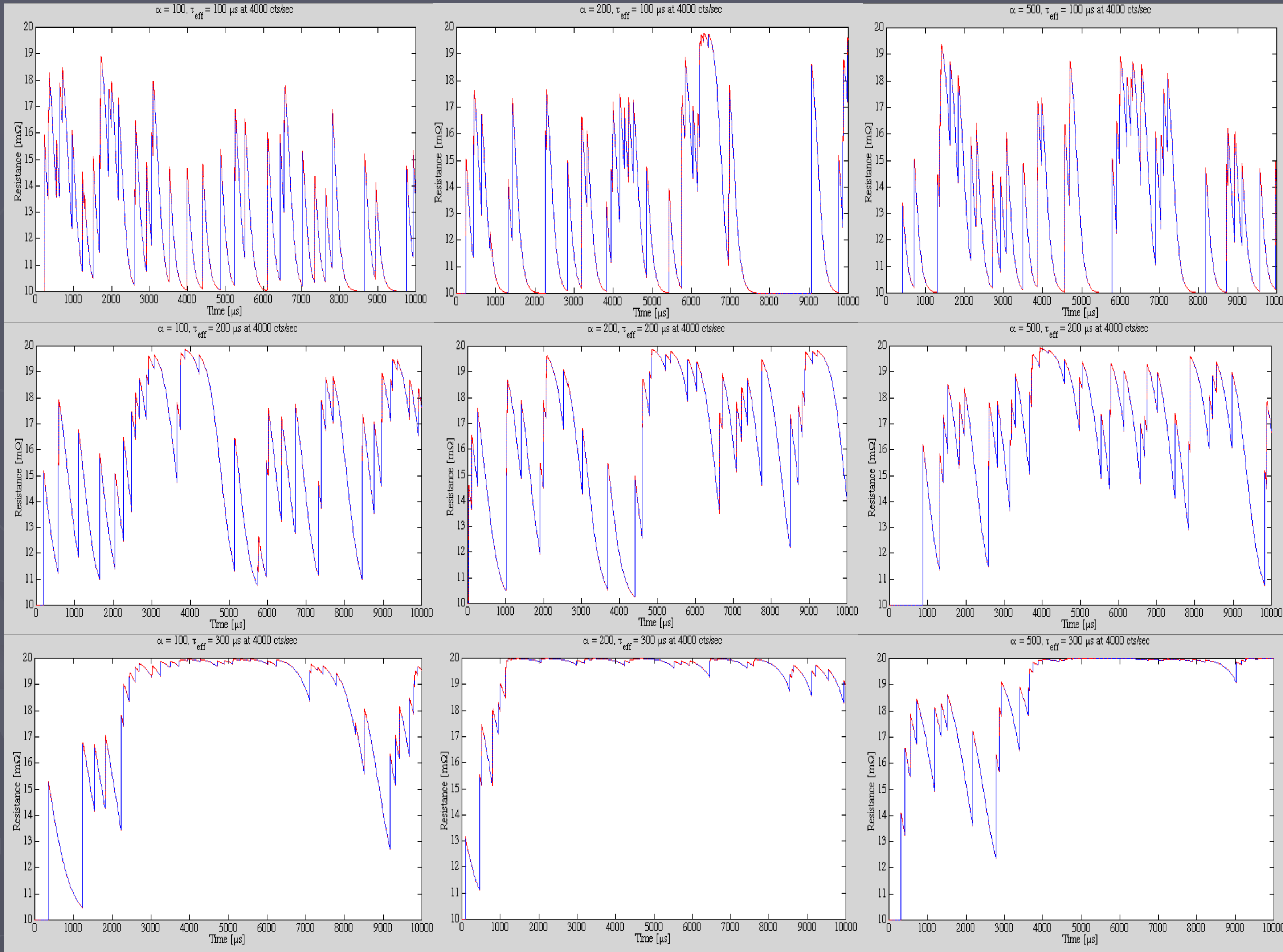


α = 100 α = 200 α = 500

τ_{eff}=100μs

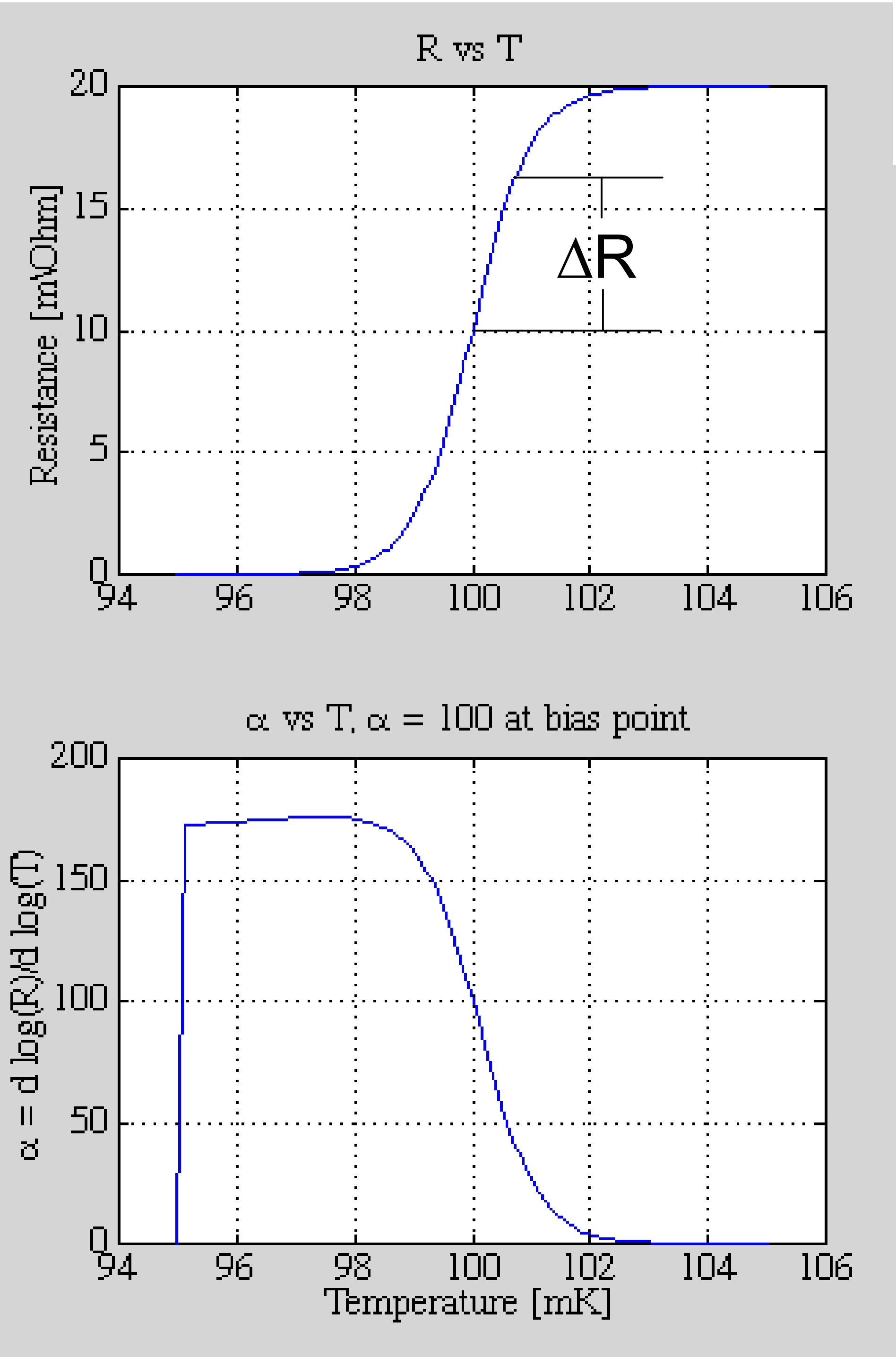
τ_{eff}=200μs

τ_{eff}=300μs

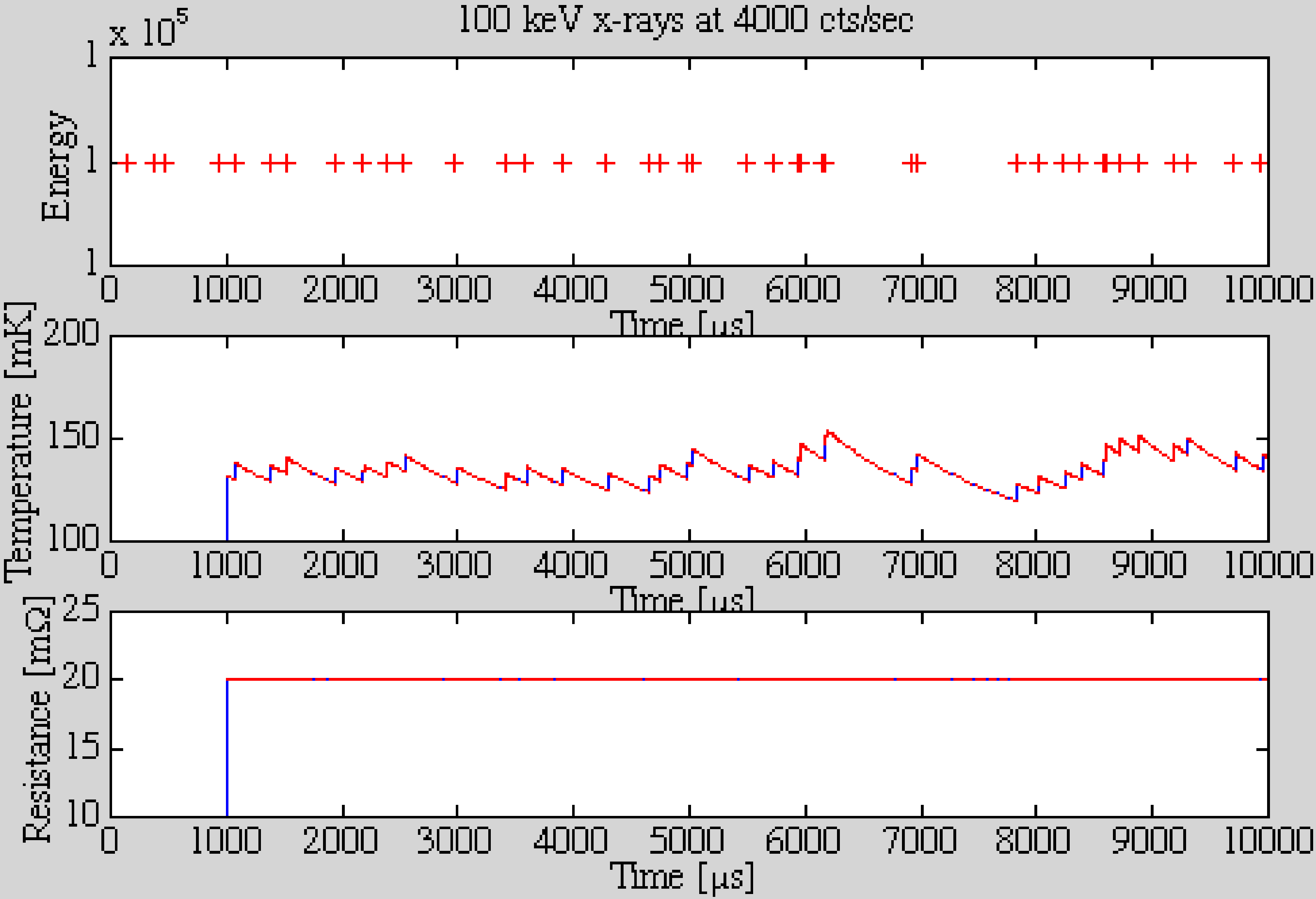


The problem with saturation

- For Con-X, we would like to design the TES so a 6 keV x-ray does not saturate the detector.
- When we **do** saturate, the decay time goes from τ_{eff} to τ_o.



Here’s a slew of 100 keV x-rays at 4000 cts/sec



How do we parametrize?

- We want to study saturation as we vary τ_{eff} and α
- We want to keep ΔR constant
- To keep ΔR constant we need to invert R(T,I) into T(R,I). Once we have ΔT, C = 6keV/ΔT, and

$$G = \frac{C/\tau_{eff}}{1+\alpha\frac{(T_c^n - T_b^n)}{nT_c^n}\frac{R-R_L}{R(1+\beta)+R_L}}$$