



Event Rates at Neutrino Telescopes:

HOW THEY DEPEND ON UHE
CROSS SECTIONS & FLUXES

9/6/2007

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Particle Astrophysics III, August
30th, 2007

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Event rates - a simple model

Horizontal surface-detector

$$A_p = A \cos \theta$$

A

Earth

θ

A'

d

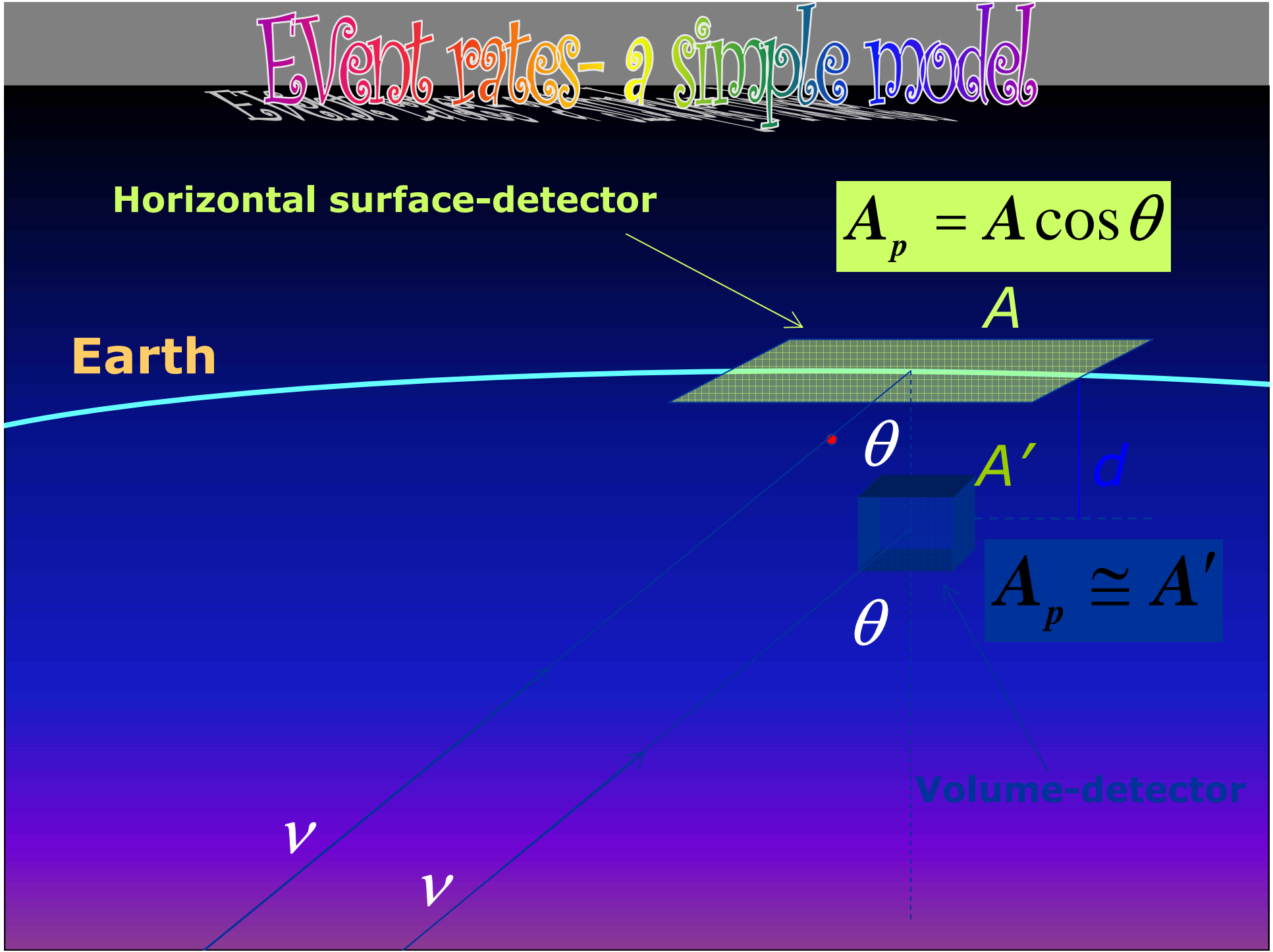
θ

$$A_p \cong A'$$

Volume-detector

v

v



The overall problem

Suppose your favorite neutrino telescope reports events above a PeV. How do you separate

- The flux of neutrinos to probe the physics of UHE sources
- The neutrino cross section to probe UHE particle physics?

Power Law Fluxes and X-Sections

Specifically: given a flux
 $F \sim F_0 E^{-i}$, how do the rates in a
given energy range depend on the
flux spectrum and the cross
section $\sigma \sim \alpha \sigma_{SM} E^A$ for up-
going events and for down-going
events (showers, μ 's, τ 's)?

Our results in a nutshell

Roughly, in a given bin:

a) Down rates $\sim F_0 \cdot \sigma_{\text{evt}}$

b) Up rates $\sim F_0 \cdot \sigma_{\text{evt}} / \sigma_{\text{abs}}$

c) Up air rates $\sim F_0 \cdot \sigma_{\text{evt}} / (\sigma_{\text{abs}})^2$

Why these results?

- **Down** flux *not* attenuated, hit probability at detector $\sim \sigma_{\text{event}}$, so **Rate per bin** $\sim F_0 \cdot \sigma_{\text{event}}$
- **Up** flux *is* attenuated, $\sim 1/\sigma_{\text{abs}}$, hit probability at detector $\sim \sigma_{\text{event}}$, so **Rate per bin** $\sim F_0 \cdot \sigma_{\text{event}}/\sigma_{\text{abs}}$

Build up a simple rate model

$$R = A_p \frac{d\phi}{d\Omega} \int_l^{2R} 2\pi \frac{dl}{2R} \int_{l-l}^l e^{-x/\lambda_a} \frac{dx}{\lambda_i}$$

$$\sin \mathcal{G} = \frac{l}{2R}$$

A simple up-rate model

We assumed isotropic flux & uniform ρ ;
now integrate over sensitive detector
depth (x) and polar angle (θ integration)
and get the rate for up events:

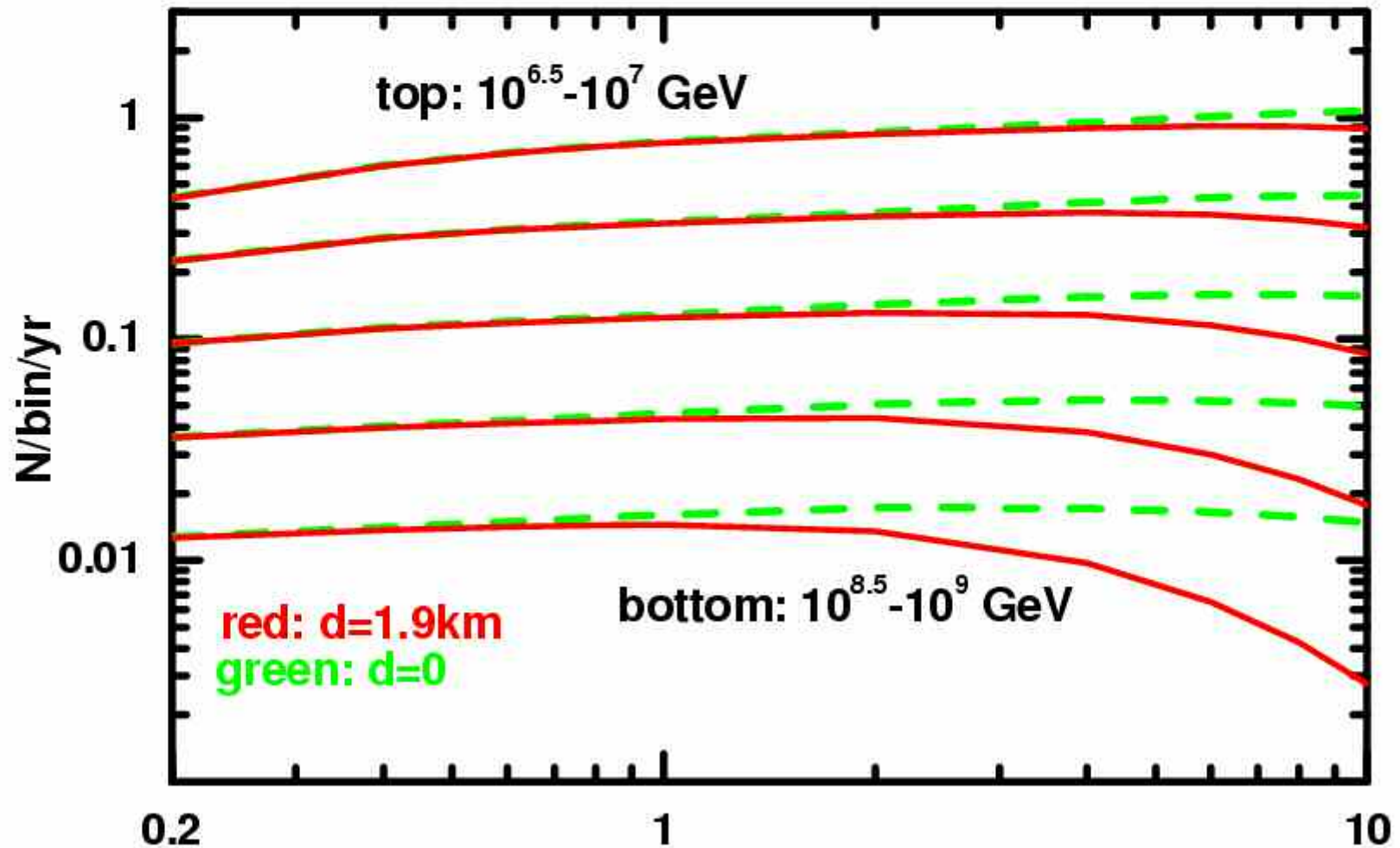
$$R(E) = \pi A_p F E \frac{\lambda_a}{R\lambda} (1 - e^{-l/\lambda_a}) (1 - e^{-(2R-l)/\lambda_a})$$

Detailed simulations include:

- All interactions
- Neutral current downscattering of higher energy flux into lower energy bins
- τ regeneration
 τ lifetime
- Lepton energy losses
- IceCube A_{eff} and V_{eff} published simulations
- Detector at depth of 1.9 km.

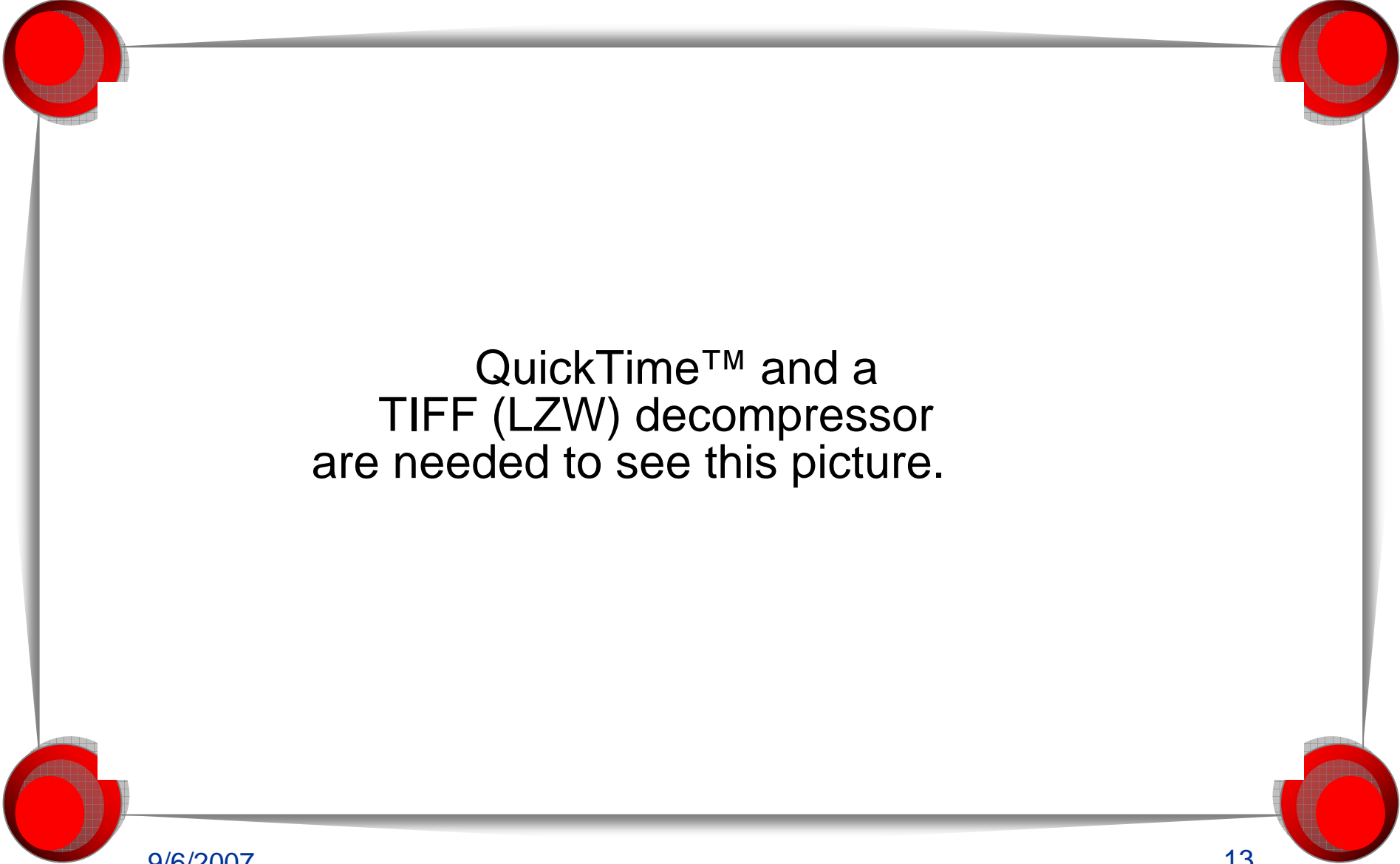
Case I: $\sigma_{\text{NC}}(\text{new}) = \alpha\sigma_{\text{NC}}(\text{SM})$; $\sigma_{\text{CC}}(\text{new}) = \alpha\sigma_{\text{CC}}(\text{SM})$

Shower rates (per energy bin per yr) vs α

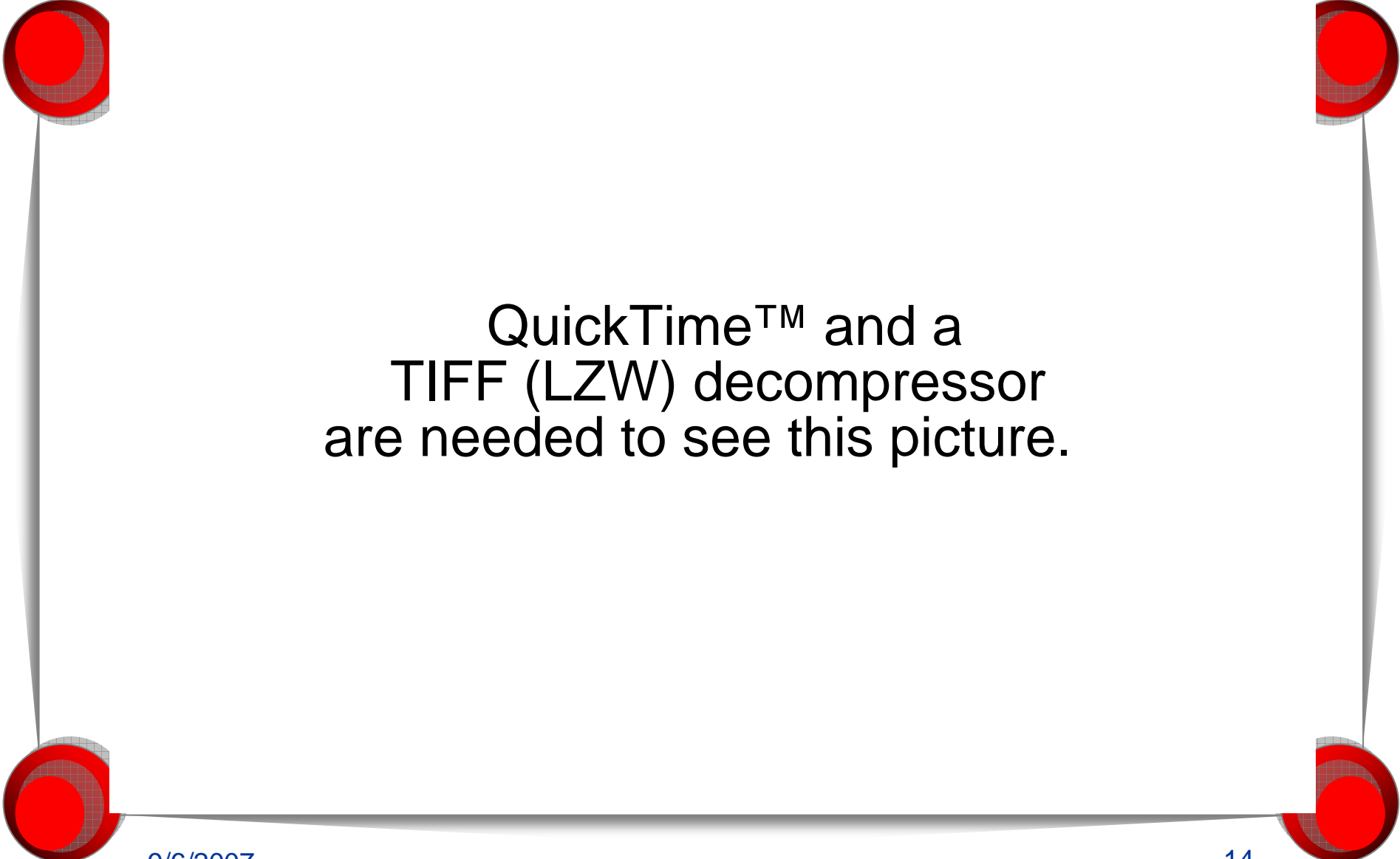


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TIFF (LZW) decompressor
are needed to see this picture.

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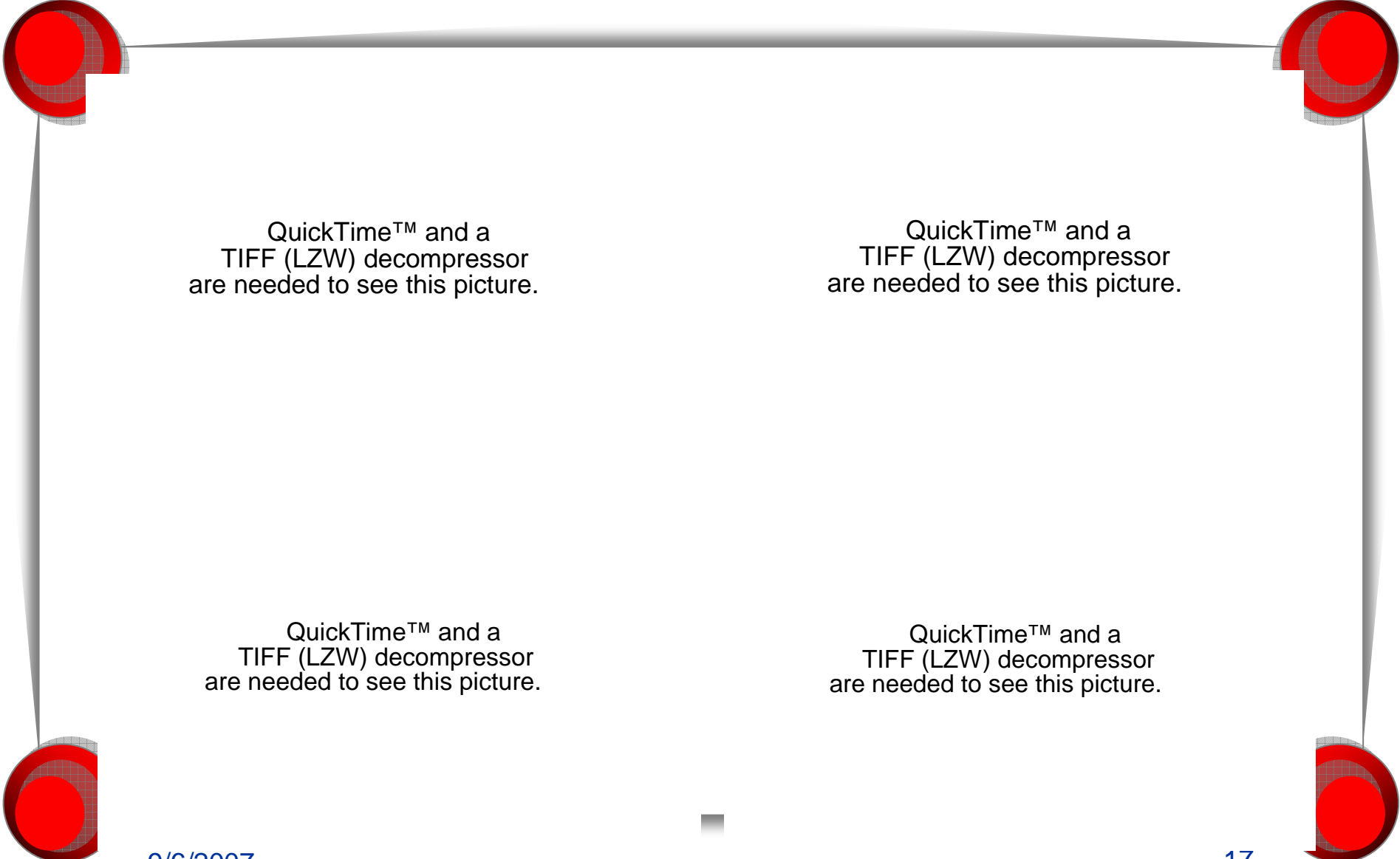
Down Events: $10^7 < E < 10^{7.5}$ GeV

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CONCLUSIONS

- Given some UHE events, we can expect simple cross section dependence for each event type!
- As a consequence, flux-independent cross section values and vice-versa can be extracted!

Change Flux index to 3 and 1



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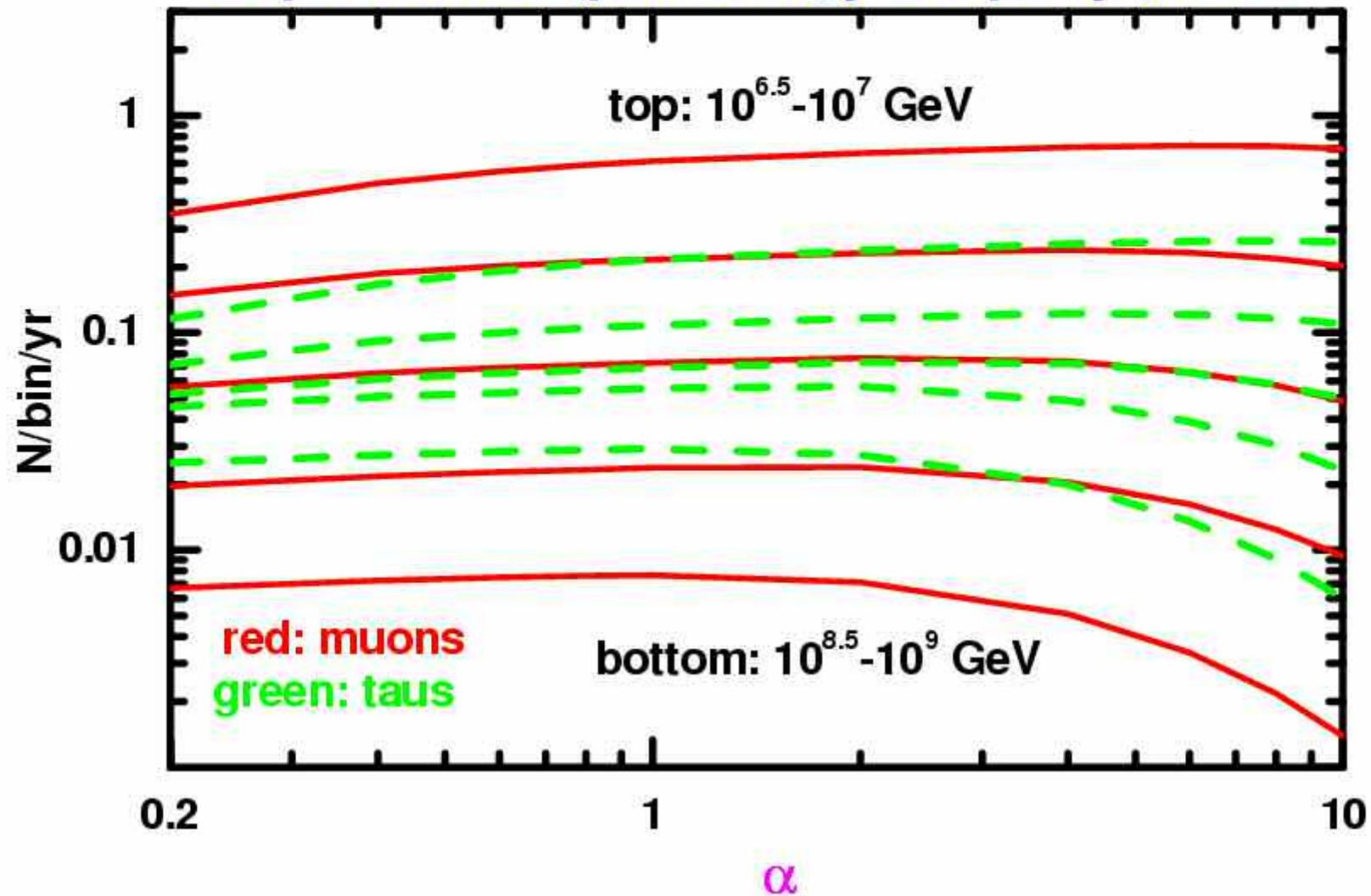
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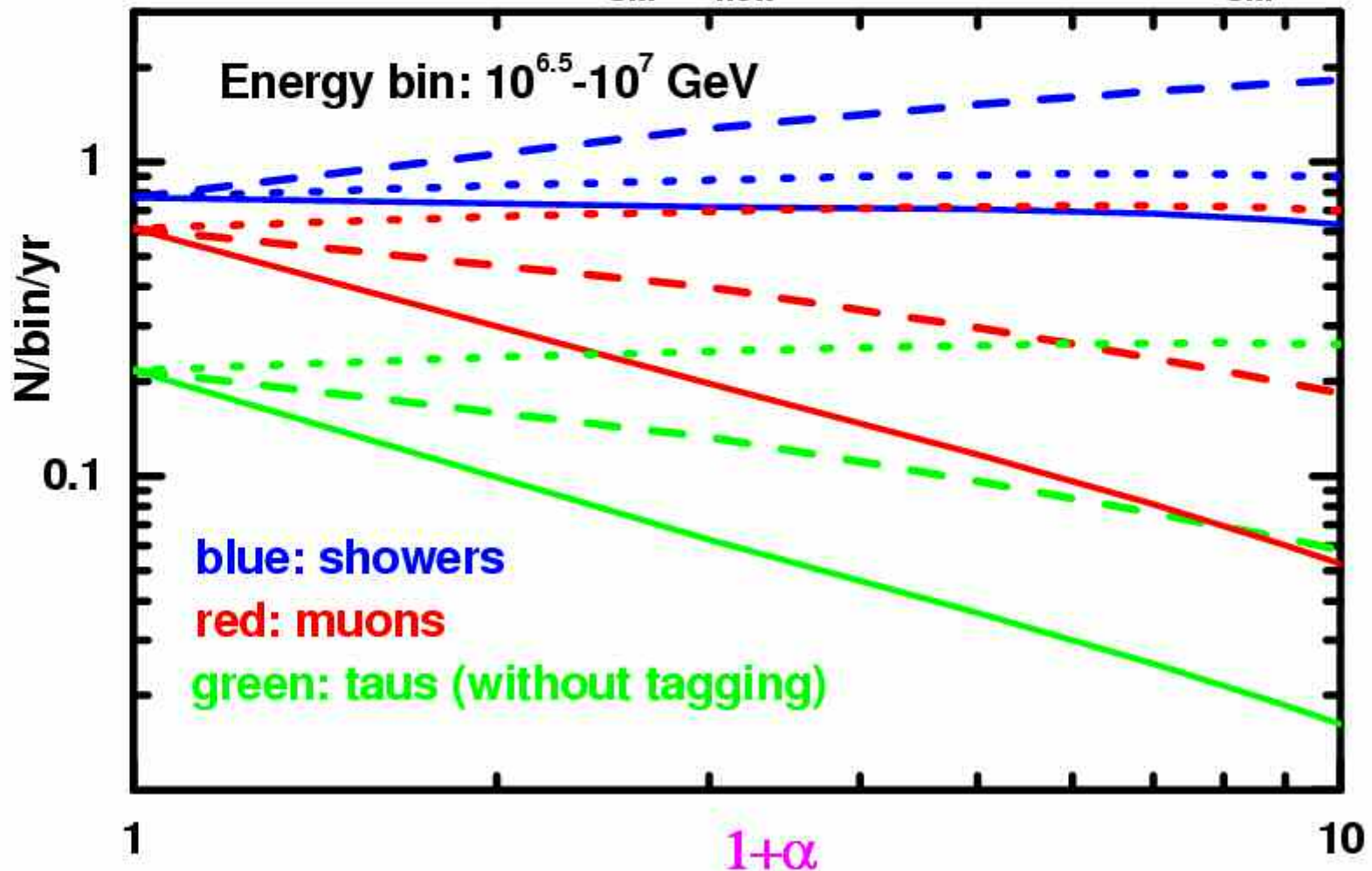
Lepton rates (per energy bin per yr) vs α



Case I (**DOTTED**): σ_{new} defined on previous slide.

Case II (**DASHED**): $\sigma_{\text{SM}} + \sigma_{\text{new}} \text{ (NC-type)} = (1+\alpha)\sigma_{\text{SM}}$

Case III (**SOLID**): $\sigma_{\text{SM}} + \sigma_{\text{new}} \text{ (BH-type)} = (1+\alpha)\sigma_{\text{SM}}$



Example: Extract flux E-index

$$r_{i/j} = \frac{\int_{bi\#i} F \cdot E^i}{\int_{bi\#j} F \cdot E^j} \approx \frac{N(bi\#i)_{showersff} V(bi\#j)}{N(bi\#j)_{showersff} V(bi\#i)}$$

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Up shower rate, limiting case

- With the inequalities

$$2R \gg \lambda_a \gg \ell$$

$$Rate \rightarrow \pi V_{eff} F \frac{1}{R} \frac{\lambda_a}{\lambda_i}$$

Example: Extract flux norm

- $10^7 \text{ GeV} < E < 10^{7.5} \text{ GeV}$
- $V_{\text{eff}} \sim 2 \text{ km}^3$
- $R_{\text{earth}} \sim 6.4 \cdot 10^3 \text{ km}$
- $n_{\text{earth}}/n_{\text{ice}} \sim 3$
- $F_0 \sim 3 \cdot 10^{-15} \text{ GeV (cm}^2 \text{ s sr)}^{-1} @ 2 \cdot 10^7 \text{ GeV}$
- **Agrees better than it should with W-B input!**
- X-Section from down events also agrees!

Event rates vs. $\sigma_{SM} + \alpha \times \sigma_{new\ physics}$

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- “IceCube” event rates for $10^{6.5} - 10^7$ GeV for showers (solid), μ 's (dash) and τ 's (dot).
Upper curve is totally **elastic** new physics and **lower** is highly **inelastic** in each case.

The basic picture again

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