Tau neutrinos

Energy loss and atmospheric flux

Thijs van Eeden - 2021-11-12

Energy loss

- τ produced in CC interaction: $\langle E_\tau \rangle = 0.75 \langle E_\nu \rangle$ [1]
- $l_\tau = \gamma c t_\tau \approx 50\,(E_\tau/\mathrm{PeV})$ m (neglecting energy loss)

- Average energy loss heavy leptons: $-\langle dE/dX \rangle \approx a + bE$
  - a: Ionisation (Bethe-Bloch formula)
  - b(E): Stochastic e^+e^- production (delta ray), brehmstrahlung and photonuclear
    - Brehmstrahlung suppressed by $1/m_l^2$

Energy loss

- Taken from [2]

- ~ 20 TeV:
  photonuclear energy loss ≈ electromagnetic loss

- Higher energies: photonuclear energy loss becomes dominant

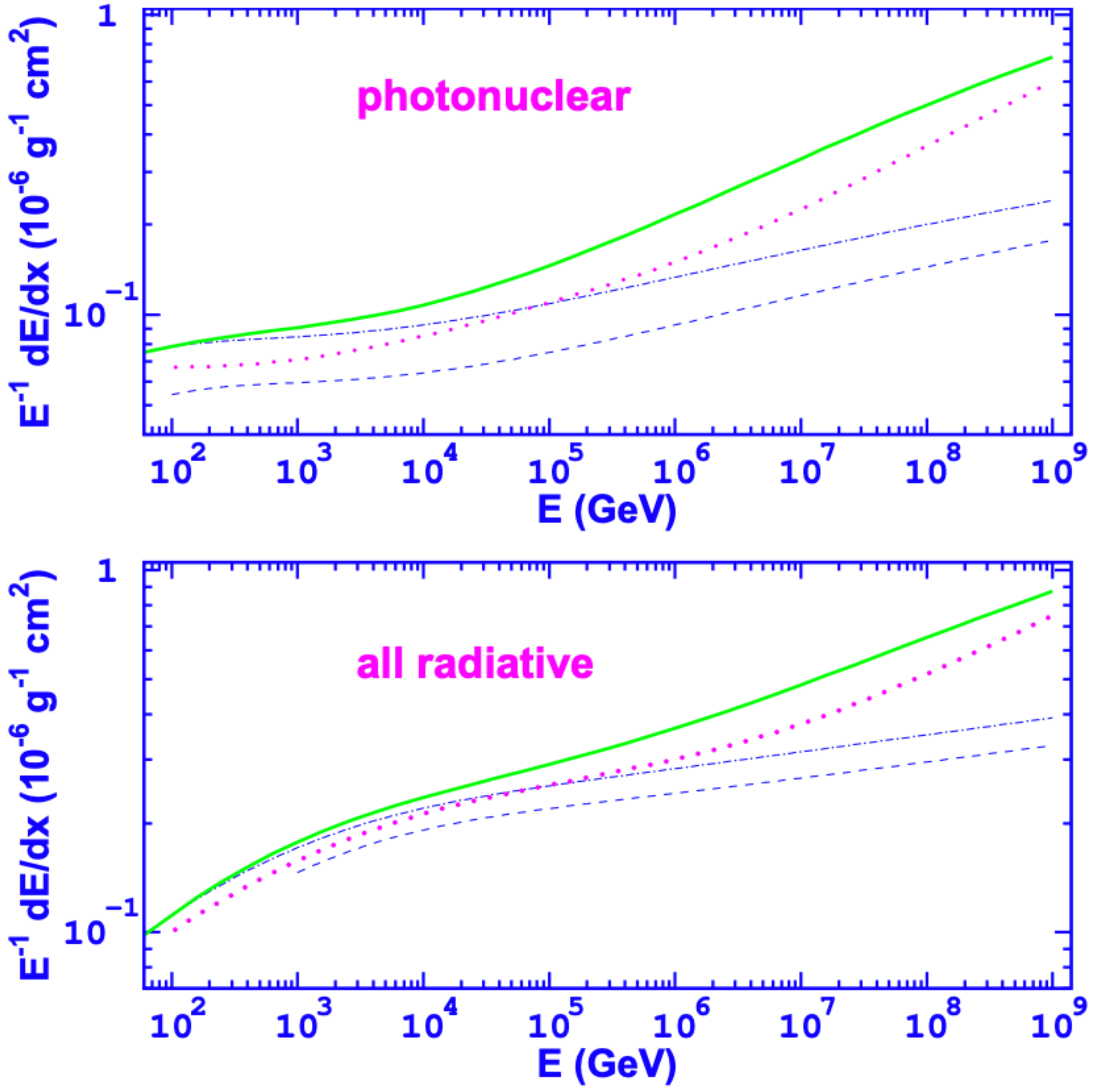

Fig. 3. τ-lepton energy losses in standard rock. Upper plot: energy losses due to photonuclear interaction. Lower plot: energy losses due to all radiative processes, including bremsstrahlung and direct e^+e^--pair production computed according to [50–56]. In each plot: dashed line is for non corrected soft part [30,31]; dash-dotted line for corrected soft part [29–31]; dotted line includes hard component of photonuclear cross-section according to [49]; solid line: includes hard component according to [29] (as it is treated in this work).

What do we use now?

Jpp

JSirene.cc

```
        for (size_t i = 0; i != CDF.size(); ++i) {

          double W = 1.0;                                         // mip

          if (is_deltarays(CDF[i].type)) {
            if (is_tau(*track)) W = getDeltaRaysFromTau(E); // delta-rays
            else                continue;
          }
```

JPDFToolkit.hh

```
/**
 * Equivalent EM-shower energy due to delta-rays per unit tau track length.
 *
 * Internal parameters are obtained with application [script] JDeltaRays[.sh].
 *
 * \param  E       tau energy [GeV]
 * \return         equivalent energy loss [GeV/m]
 */
inline double getDeltaRaysFromTau(const double E)
{
  static const double a = -2.374e-01;
  static const double b =  5.143e-01;
  static const double c = -4.213e-02;
  static const double d =  1.804e-03;
  static const double Emin = 2.19500; // [GeV]

  if (E > Emin) {

    const double x = log10(E);                          //
    const double y = a + x*(b + x*(c + x*(d)));         // [MeV g^-1 cm^2]

    return y * DENSITY_SEA_WATER * 1.0e-1;              // [GeV/m]
  }

  return 0.0;
}
```

- Jpp gets tau length from gSeaGen
- Treats tau as MIP with delta rays
- Brehmstrahlung negligible —> omitted

- No photonuclear interactions yet
- I guess: no shortening of tau length due to energy losses

Atmospheric flux

- Oscillation from conventional ν_e, ν_μ to ν_τ
  - Peaked for upward due to longest path length Earth

- Prompt neutrino flux from charm quark pairs
  - Isotropic

Atmospheric flux

- Oscillation from conventional ν_e, ν_μ to ν_τ
  - $L \approx 10^4$ km, $P(\nu_\mu \rightarrow \nu_\tau) \approx 10^{-3}(E_\nu/\mathrm{TeV})^{-2}$ [1]
  - Matter effects not taken into account: would reduce oscillation further
  - Low flux, even low compared to prompt

Atmospheric flux

- Prompt neutrino flux from charm quark pairs [3]:
  - $p\text{Air} \to D_s \to \tau\nu_\tau \to \nu_\tau\nu_\tau X$
    - $\text{BR}(D_s \to \tau)$of few percent
  - $p\text{Air} \to b \to c\tau\nu_\tau \to c\nu_\tau\nu_\tau X$ (negligible)

TABLE II. Charged current event rate per year per km^3 water equivalent volume from the prompt $\nu_\tau + \bar{\nu}_\tau$ flux.

Threshold	NLO QCD	TIG
100 GeV	58	98
1 TeV	18	18

TABLE III. Charged current event rate per year per km^3 water equivalent volume from $\nu_\mu + \bar{\nu}_\mu \to \nu_\tau + \bar{\nu}_\tau$ oscillations, assuming $\sin^2(2\theta) = 1$.

Threshold	$\Delta m^2 = 5 \cdot 10^{-4}$ eV^2	$\Delta m^2 = 6 \cdot 10^{-3}$ eV^2
100 GeV	71	9100
1 TeV	0.036	5.2

References

1. https://arxiv.org/pdf/astro-ph/0608486.pdf
2. https://arxiv.org/pdf/hep-ph/0312295.pdf
3. https://arxiv.org/pdf/hep-ph/9811268.pdf