Detection of tau neutrino by Cherenkov telescopes

1) Earth-Skimming method

- Pointing MAGIC down from Roque de Los Muchachos (altitude 2200 a.s.l.) the sea surface is ~165 km away, yielding a large volume in viewed.

2) Monte Carlo simulation chain

1) Neutrino propagation in Earth: ANIS
   
   
   We included local topography of detector site

2) Extensive Air shower Simulations: CORSIKA
   
   T. Pierog and D. Heck CORSIKA website: https://web.lhp.kit.edu/corsika
   
   Complied with option:
   - TAUFL - tau decay by PYTHIA
   - IACT (Bermiehar package) – cherenkov photon distribution for any defined array geometry
   - CURVED EARTH, CHERENKOV, THIN, QGSJET II, VOLUMEDET, SLANT

3) MC simulations

   - For zenith angle (θ): 87, 84, 80 deg; 10 bins in azimuth
   - Shower are used several times (100 shower shifted 10 times around center of detector) in total 1000 showers for each injection depth (X<sub>n</sub>)
   - X<sub>n</sub> from detector level to the top of the atmosphere, at least every 50 g/cm²

<table>
<thead>
<tr>
<th>Energy</th>
<th>1</th>
<th>2.15</th>
<th>4.64</th>
<th>10</th>
<th>21.5</th>
<th>46.5</th>
<th>100</th>
<th>215</th>
<th>465</th>
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<tbody>
<tr>
<td></td>
<td>P(eV)</td>
<td>P(PeV)</td>
<td>P(eV)</td>
<td>P(PeV)</td>
<td>P(eV)</td>
<td>P(PeV)</td>
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<td>✔</td>
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<td>✔</td>
</tr>
</tbody>
</table>

   - for H.E.S.S. like two/four telescopes (IACT-2/IACT-4) and for a few CTAs array considered in K. Bernardini et al, Astropart. Phys. 43 (2013) 177 with so-called Production conditions

4) Example of shower images on camera

   - Clear separation between shower interacting a the top of the atmosphere and deep tau induced shower
   - Signature: looking for inclined bright events with small value of Alpha/Miss parameter
   - Size, Length and Width distribution depend on energy of primary tau lepton (more bright event leads to larger image size).
   - Distance, Miss and Alpha distribution almost the same for 1-1000 PeV
   - The shape of distributions is almost independent of array configuration, due to large size ( ~> 1km) Cherenkov pool distributions at detector level

5) Trigger efficiency

   - Trigger efficiency: number of simulated showers with a positive trigger decision over the total number of shower generated for fixed energy and zenith angle.

   Trigger conditions:
   L1: 3 pixels on camera above 4 µe; L2: at least 2 neighboring triggered telescopes

6) Identification efficiency

   - Multi-parameter analysis (genetic algorithms)

   \[ d = (\text{size, length, distance, miss, alpha}) \]

   \[ f = \frac{\sum_{i=1}^{N} |S_i - T_i|}{N} \]

   Maximize cost function: \( f(S_i, T_i) = \frac{|S_i - T_i|}{max} \)

   \( S_i, T_i \) are signals and targets

   SIGNAL: Induced shower with injection vertical depth \( X_n > 600 \text{g/cm}^2 \)

   BACKGROUND: Induced showers with \( X_n < 100 \text{g/cm}^2 \)

   Optimal scenario: 100% signal, 0% background

   Selection criterion:

   - CTA-E (99.7%)

8) Event rate prediction

   - At energy larger than (0.1) PeV detection of earth-skimming tau neutrinos with IACTs becomes promising for (short) transient signals (D.G. and E. Bernardini, A. Kappes, Astropart. Phys. 61 (2015) 12)

   - In recent paper results for ideal detector with 10% trigger efficiency for lepton tau induced showers.

   - This simulation will increase the trigger efficiency and calculated rate at least of about factor 3 to our previous calculation.

   Expected event rate for a detector located at La Palma/VERITAS compared with what expected for IceCube

<table>
<thead>
<tr>
<th>Flux at</th>
<th>Flux at</th>
<th>Flux at</th>
<th>Flux at</th>
<th>Flux at</th>
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</thead>
<tbody>
<tr>
<td>0.01 PeV</td>
<td>0.1 PeV</td>
<td>1 PeV</td>
<td>10 PeV</td>
<td>100 PeV</td>
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<tr>
<td>6.4</td>
<td>4.5</td>
<td>2.6</td>
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<td>8.6</td>
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<td>3.2</td>
<td>0.7</td>
<td>3.5</td>
<td>7.6</td>
</tr>
</tbody>
</table>

   - For all models studied in this work which predict neutrino fluxes, the event rate can be comparable to IceCube or even better
   - In case of sites surrounded by mountains results shown higher event rate (by at least factor 2).