Very high energy electromagnetic cascades in the LPM regime with IceCube

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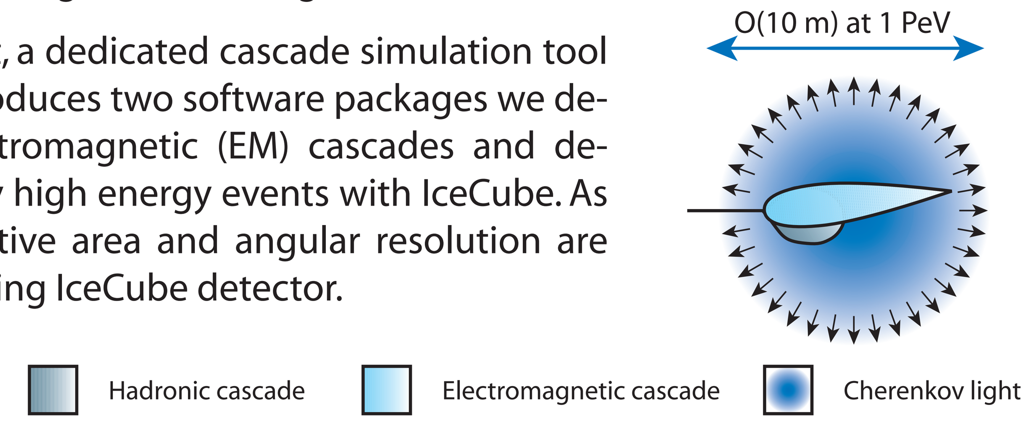
1 - Goal and principle of the analysis

This poster describes an ongoing analysis devoted to very high energy ν_e events in the IceCube detector [1]. We focus on the energy range where the LPM effect significantly increases the length of the cascades generated by $e^{\pm}$.

The problem can be summarised as follows:

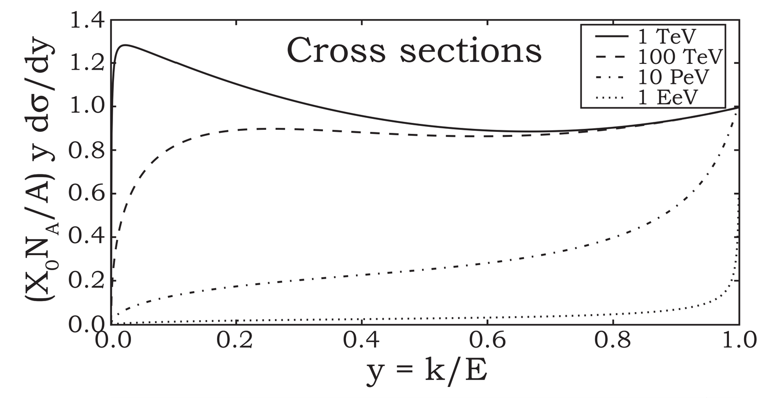
- At low energies, $e^{\pm}$ produced by charged current interactions interact giving small cascades in ice.
- Due to light scattering, the direction information of the initial particle is lost.
  - ➡ Angular resolution is poor.
- At very high energy (E > ~10 PeV), the LPM effect increases the length of showers.
  - ➡ It might be possible to get a better angular resolution.

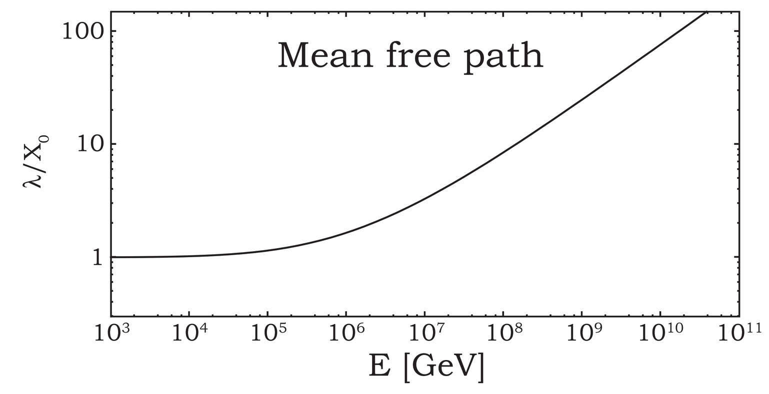
To study this kind of event, a dedicated cascade simulation tool is needed. This poster introduces two software packages we developed to simulate electromagnetic (EM) cascades and describes the analysis of very high energy events with IceCube. As a result, preliminary effective area and angular resolution are given for the 22 and 80 string IceCube detector.



2 - The LPM effect

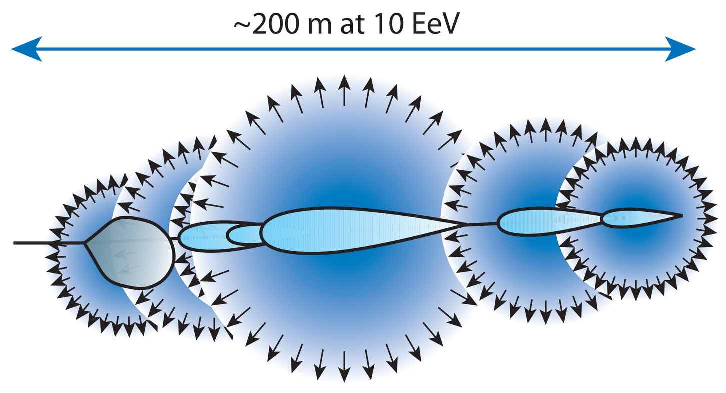
The Landau-Pomeranchuck-Migdal (LPM) effect [2] is responsible for a decrease of bremsstrahlung and pair-production cross-sections at very high energy. As the cross-sections decrease, the mean free paths increase. This in turn increases the length of cascades.





Whereas the length of a 1 PeV shower is about 10 m in ice, it can be greater than 200 m at 10 EeV.

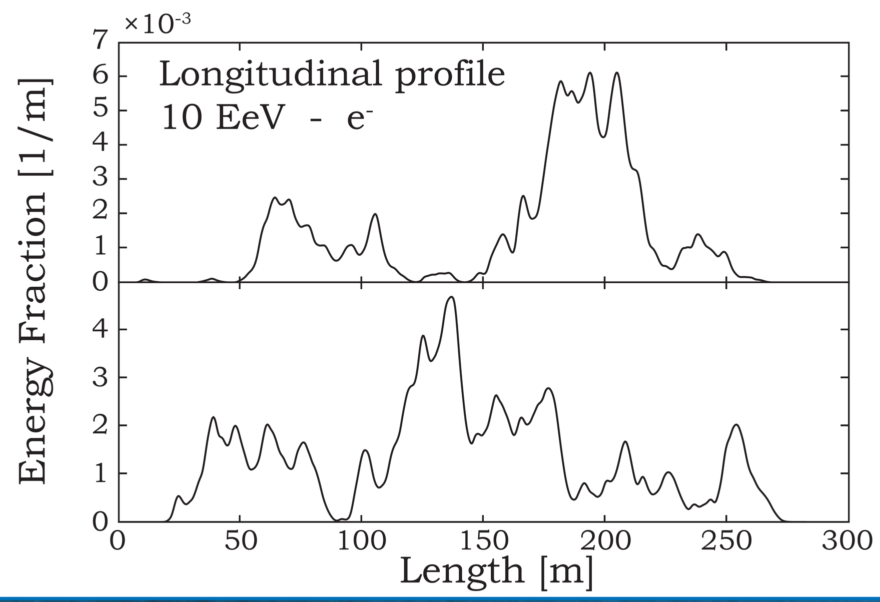
Good and bad: the cascade looks more like a muon track...



3 - Simulation tool: hybrid approach

Following [3], this 1 dimensional simulation code works using two modes depending on the energy of secondary particles E:

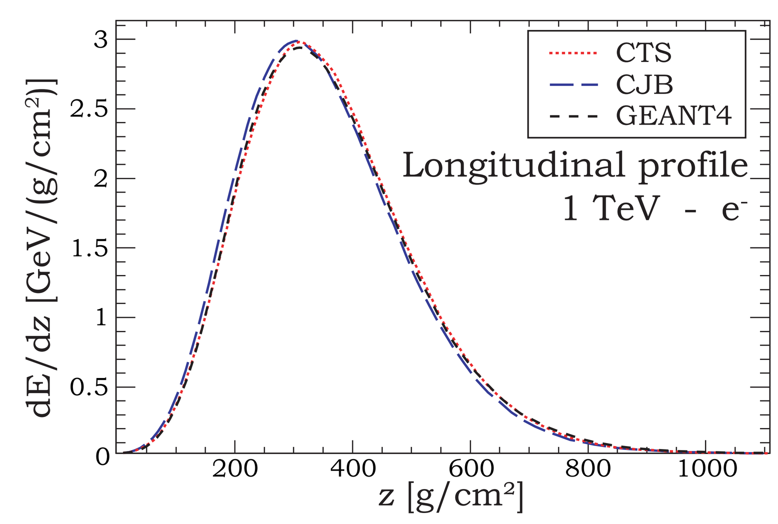
- If $E > E_{th}$, interactions are fully simulated using parameterised cross sections for bremsstrahlung and pair production, including the LPM effect.
- If $E < E_{th}$, the energy is deposited taking into account parameterised energy loss profiles.



Development easier and faster than for the full simulation.

Execution time:
3 minutes for 1 cascade at 10 EeV, with E_{th} = 50 TeV
(P IV, 2.8 GHz)

4 - Simulation tool: Monte Carlo approach



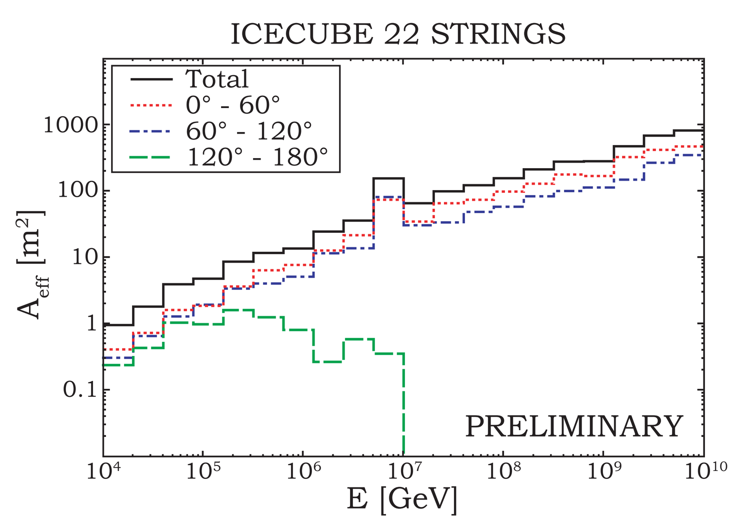
Following [4] (denoted CTS on the figure), a modified version of CORSIKA [5] working in ice is being developed to get a more accurate representation of cascades including the LPM effect (denoted CJB). Low energy comparisons were performed with GEANT4.

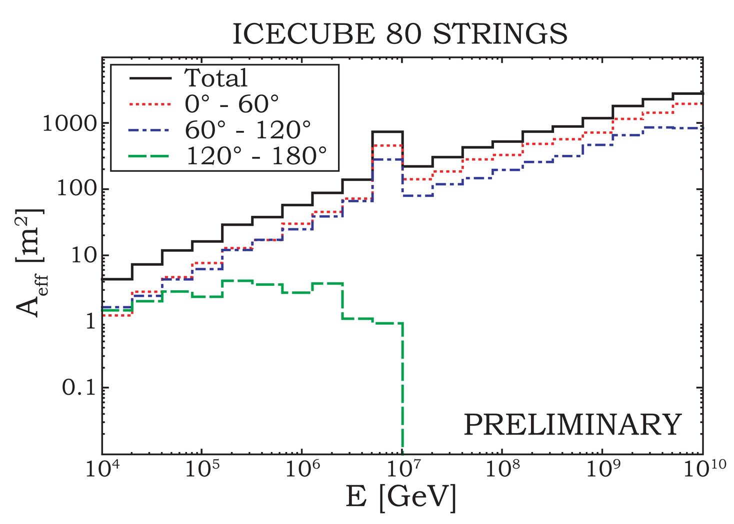
The development is still ongoing. The results shown on this poster are obtained with the hybrid approach.

Test runs show execution times of ~1 minute for one 10 EeV cascade with default energy cut-off values and thinning option enabled (P IV, 1.7 GHz).
Possible application: study of photo-production of muons in EM cascades or study of muons generated in hadronic cascades...

5 - Effective area

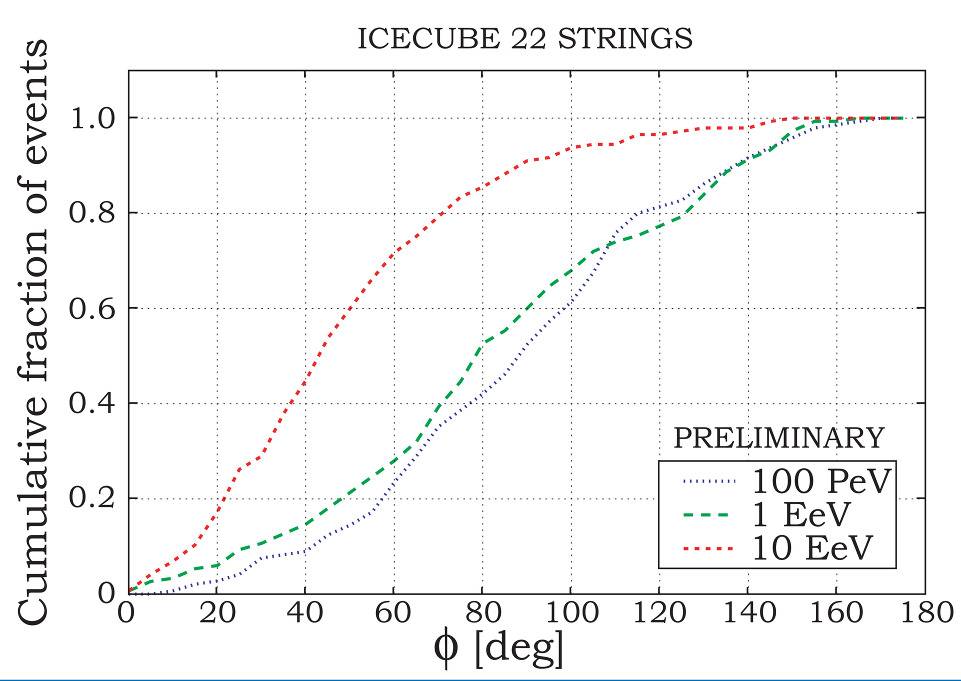
- Simulated ν_e with 10 TeV < E < 10 EeV.
- Cascades simulated with the hybrid approach.
- Trigger condition: 8 modules hit within a time window of 4 μs.
- Selection criteria: longitudinal size divided by lateral size.





6 - Angular resolution

- First attempt using a line fit ➡ initial track produced with the hit times.
- At 100 PeV, ~3% of the events reconstructed with an angular precision better than 20°.
- At 10 EeV, ~20% of the events reconstructed with an angular precision better than 20°.



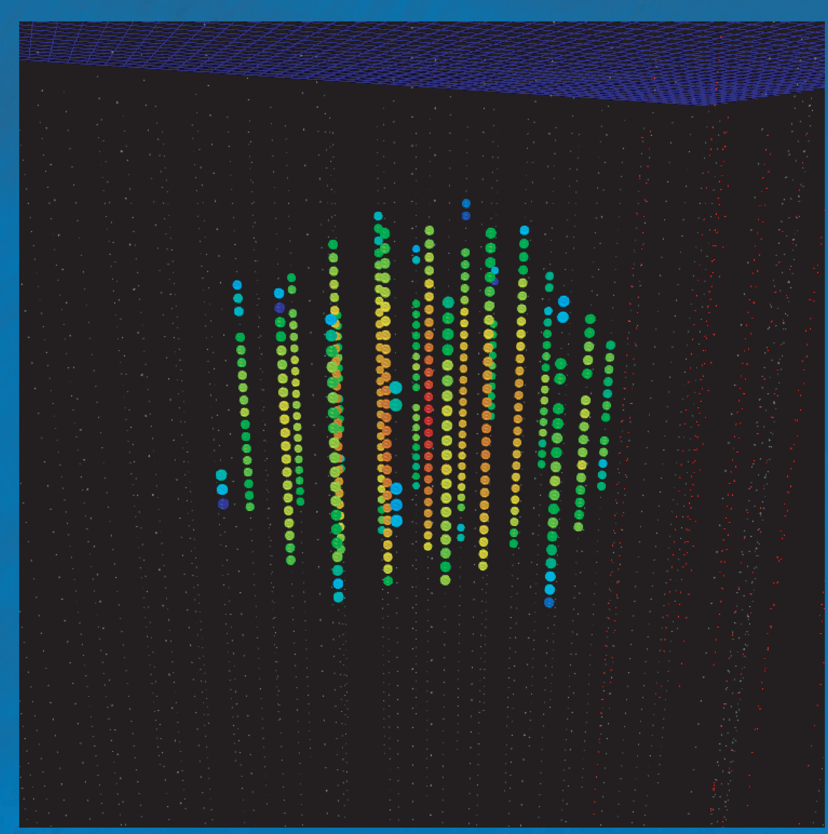
7 - Outlook

At very high energies, the LPM effect can increase the length of cascades to several hundred meters. This could lead to better angular resolution for high energy cascades.

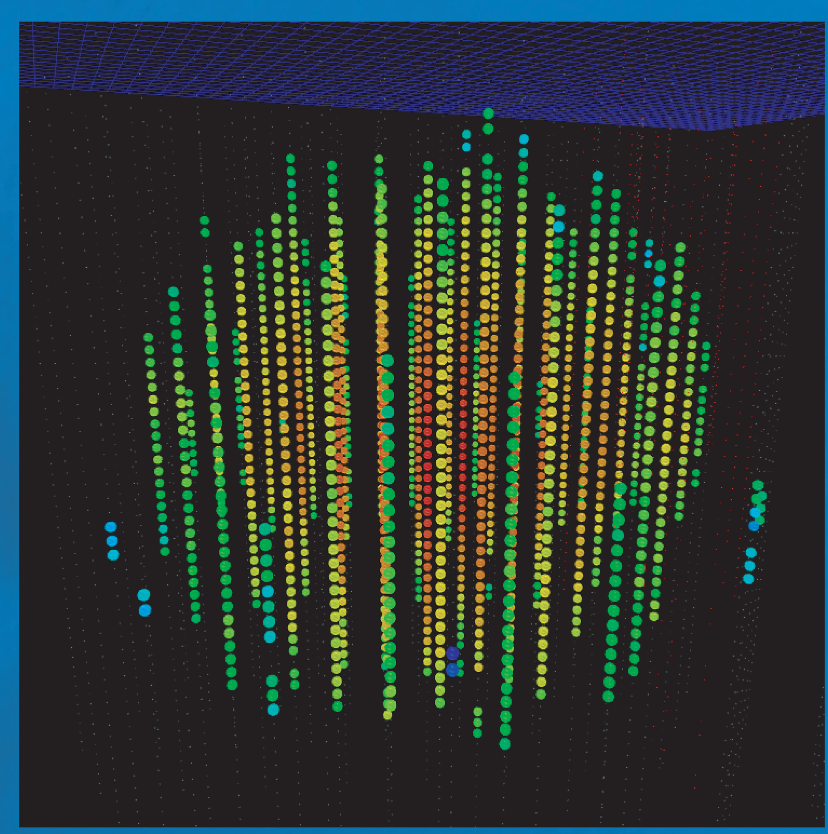
- We have developed two simulation tools in order to study these events.
- Effective areas have been calculated.
- First reconstruction attempts with a line fit method are encouraging.

In the future:

- Develop a dedicated reconstruction method using the full waveforms provided by IceCube Digital Optical Modules.
- Perform an analysis of data with the 22 string configuration of IceCube.



ν_e at 7.6 PeV
Zenith angle = 66°
80 string detector



ν_e at 12.5 EeV
Zenith angle = 30°
80 string detector

Notes and References

[1] DESY, D-15738 Zeuthen, Germany.

[1] A. Karle, *ICRC 2007 Proceedings*, 2007.
[2] L.D. Landau & I.J. Pomeranchuk, *Dokl. Akad. Nauk. SSR*, 92, 535 & 735, 1953. A.B. Migdal, *Phys. Rev.*, 103, 1811, 1956.
[3] V. Niess & V. Bertin, *Astropart. Phys.*, 26, 243, 2006.
[4] S. Bevan et al., *arXiv:0704.1025*, 2007.
[5] D. Heck et al., Report FZKA 6019, 1998: available from http://www-ik.fzk.de/corsika.