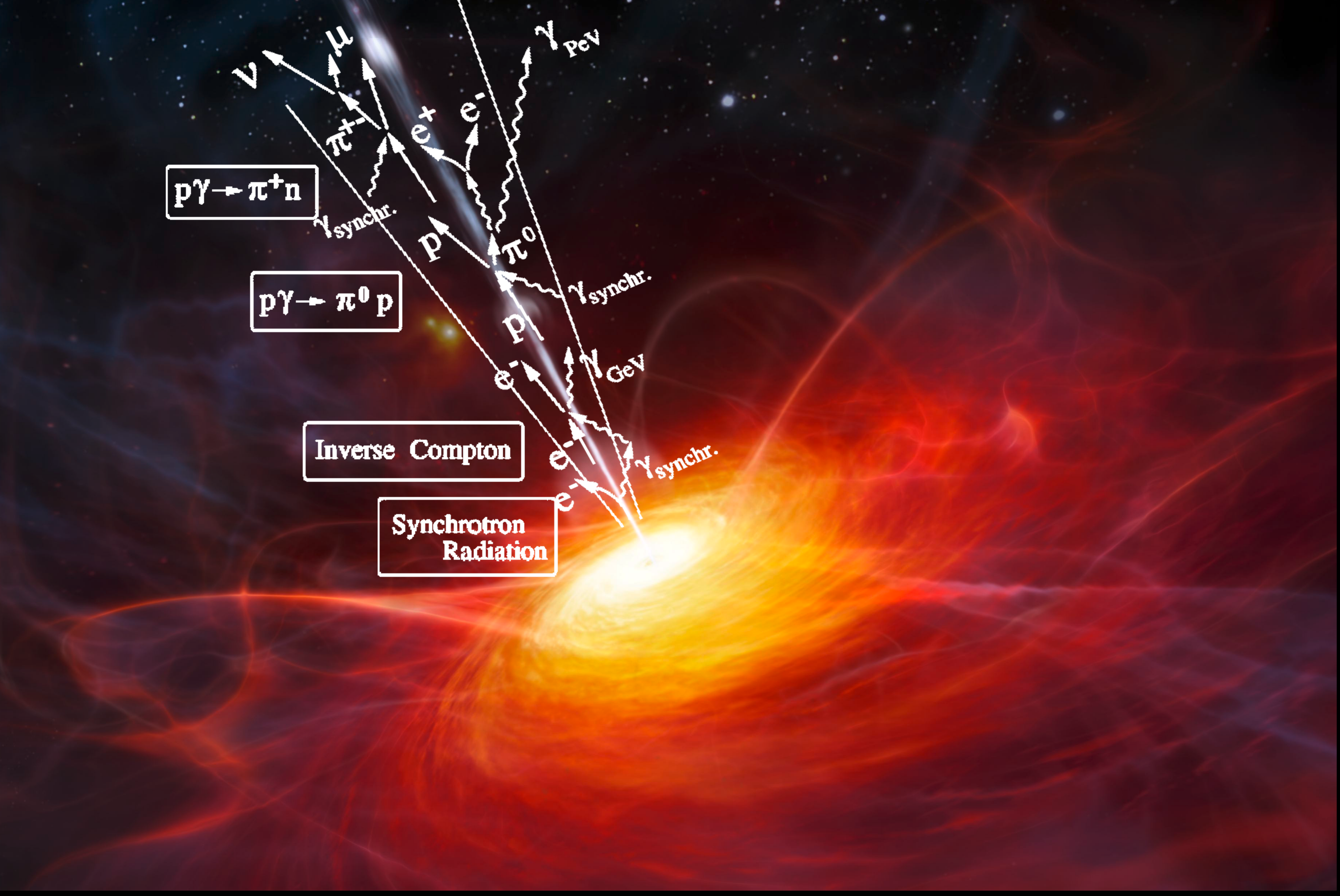

A search for neutrinos from Gamma Ray Bursts with the IceCube Neutrino Detector

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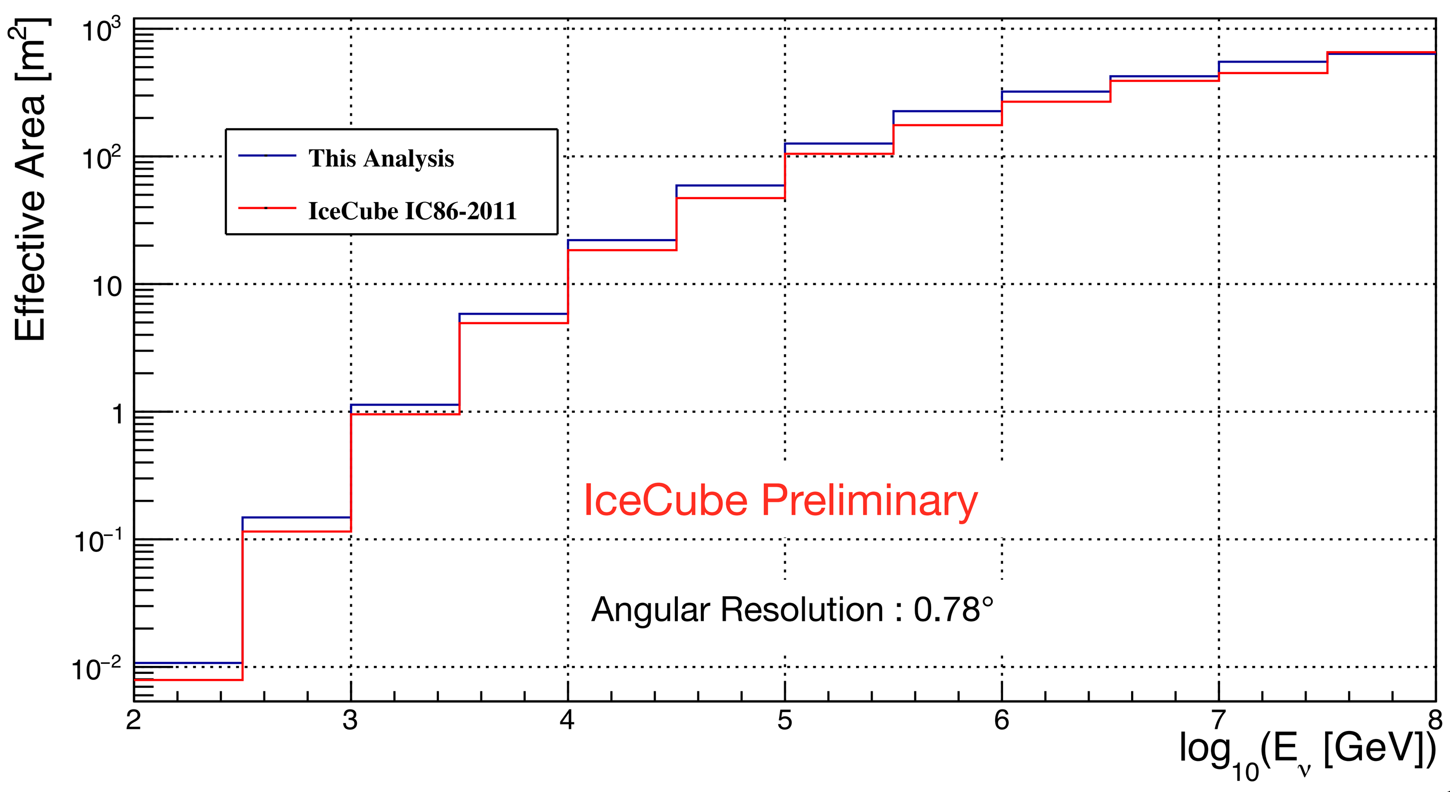
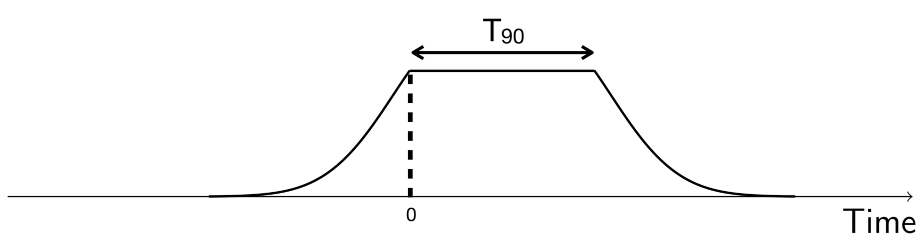
Introduction

- **Gamma Ray Bursts** (GRBs) together with Active Galactic Nuclei (AGN) are the most energetic phenomena in the Universe and they are among the leading candidates for the **sources of ultra-high energy cosmic rays**.
- Hadronic accelerations in these objects would imply **neutrino fluxes.**
- Neutrinos can travel **straight through the Universe** without deflection by magnetic fields (unlike cosmic rays) nor absorption by dust (unlike photons).
- Currently, neutrino telescopes have the sensitivity to observe such astrophysical neutrinos.
- Due to the **low event rate**, robust statistical methods are needed to achieve the necessary significance for signal discovery.
- Neutrinos are expected during **three phases**: precursor (before the γ emission), prompt (during the γ emission) and afterglow.
- Long (>2 s) and Short (≤2 s) GRBs are believed to originate from **different progenitors**. LGRBs could be related to the explosion of **very massive stars** whereas SGRBs could originate from mergers of binary **compact objects.**
- A **separate** LGRB/SGRB analysis allows the use of specific statistical methods in order to increase the sensitivity of the analysis.
- The **effective area,** with the angular resolution, translates the efficiency of the event selection into a flux (upper-limit) determination.
- A **novel event selection** has been designed leading to an improved effective area.

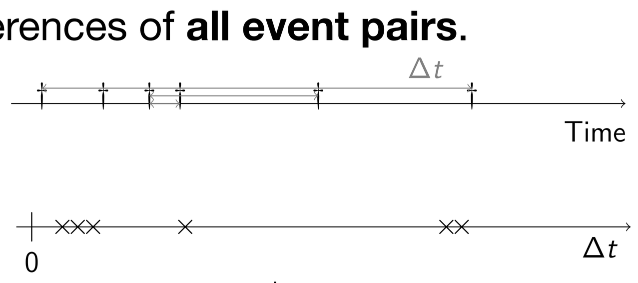


Long GRBs

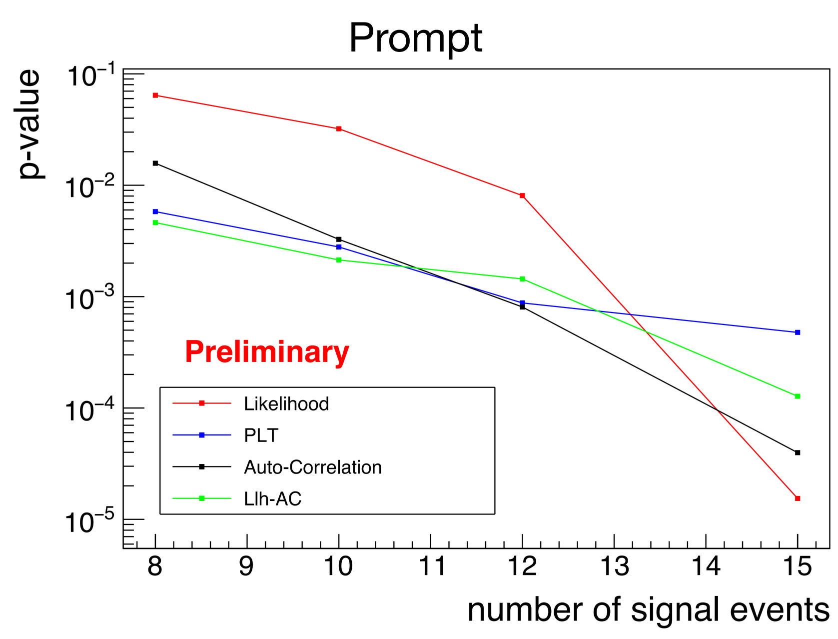
- Several statistical methods were compared using a **toy-model simulation**.
- Use of **491 LGRBs** detected by satellites (T_{90}, position, angular uncertainty, redshift).
- Generate 3 mHz of atmospheric neutrino background events **uniformly distributed** over the Northern Hemisphere and in time.
- **Angle** between events and GRBs simulated as Gaussian taking into account the GRB position uncertainty and the angular resolution of the track reconstruction.
- **Prompt signal** events follow a flat distribution during T_{90} with Gaussian tails.
- **Precursor events** are generated 2 minutes before the GRB trigger time at the source (the **redshift** effect is taken into account).

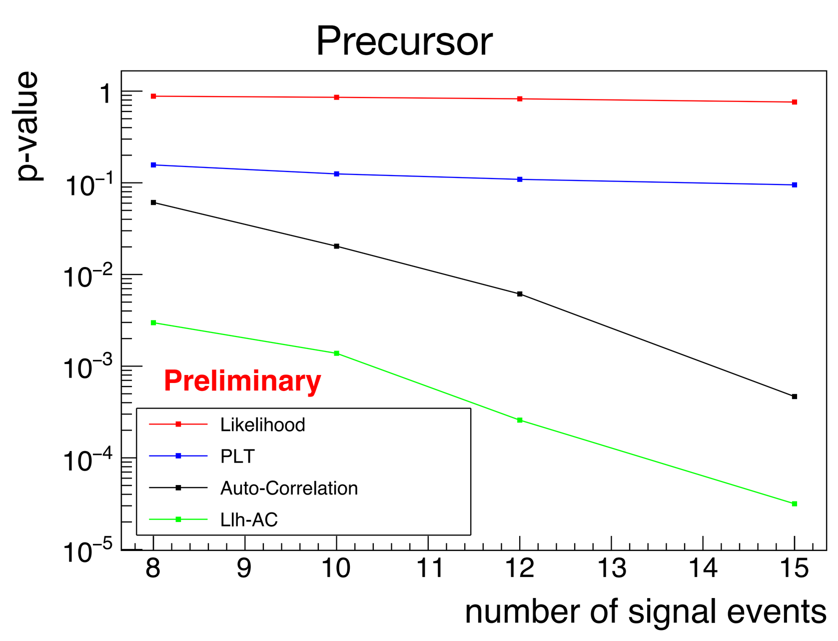


- **Auto-Correlation:**
  - The method generates a distribution with the time differences of **all event pairs**.
  - The distribution is binned and the probability of a certain number of events per bin is computed and compared between data and background.



- **Likelihood:**
  - Defines a test statistic as $T = \sup_{n_s}\left[-n_s + \sum_{i=1}^{N_{event}} \log\left(\frac{n_s S_i}{<n_b> B_i} + 1\right)\right]$ with S and B the signal and background PDFs and n_s (n_b) the expected number of signal (background) neutrinos.
- **PLT*:**
  - This method considers the signal as a **perturbation** of the background.
  - As in the Likelihood case it uses signal and background PDFs but the maximisation is performed as a function of the **perturbation location**.
- A **hybrid method** using Likelihood and the Auto-Correlation was also considered and it gives **promising** results.

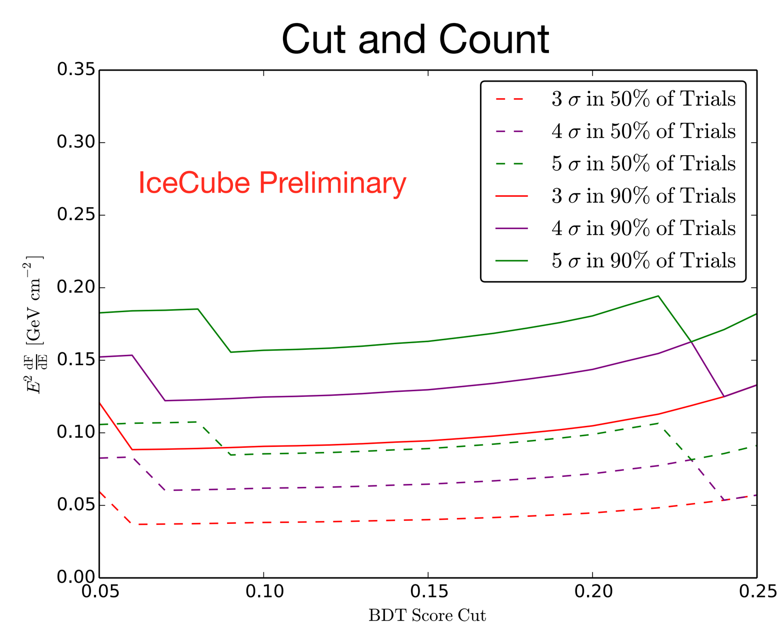


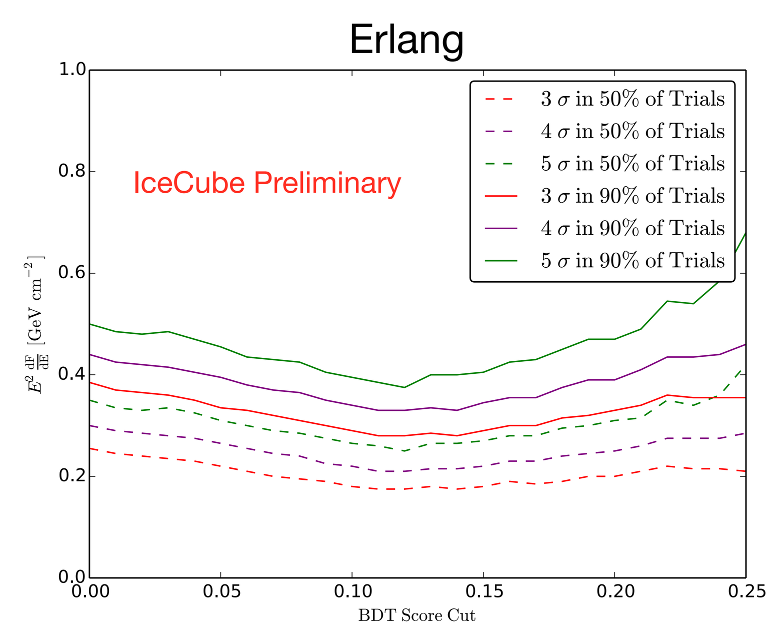


Results for a time window of 1h and an angular window of 15° (3° for A-C).

Short GRBs

- **First** dedicated search for neutrinos from Short GRBs.
- Two statistical methods were compared.
- In both cases, events are selected in an **angular window** around the GRB which takes into account the uncertainty of the GRB position and the event reconstruction.
- **Cut and Count:**
  - Select events on a 4 s time window around the GRB trigger time.
  - Use **Poisson statistics** to assess the significance.
- **Erlang distribution:**
  - The Erlang distribution gives the probability of having a time Δt to contain n events (in this analysis $n = 2$).
  - From the time differences between observed **consecutive events,** the Δt distribution to contain 2 consecutive events in the interval is constructed.
  - This distribution is compared to the expected Erlang distribution using a χ^2 test-statistic.
- The Cut and Count method has a better sensitivity for **prompt neutrinos** but it is not sensitive to the other phases.
- In order to be sensitive to the three neutrinos phases, the use of the Erlang distribution is **preferred**.
- The event selection involves a Boosted Decision Tree (BDT) algorithm that allows an efficient background and signal separation.
- The sensitivity is presented as a function of the BDT score in order to define the **optimal** cut value.





We expect that the optimisation of the statistical methods both for long and short GRBs combined with a more efficient event selection can result in a neutrino detection in relation with a GRB or in stringent upper-limits on the neutrino flux.

*Ramani S. Pilla, Catherine Loader, and Cyrus C. Taylor, Phys. Rev. Lett. 95, 230202

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