

# Pointing Supernovae with SNO+

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Supernova explosions generate large bursts of neutrinos and anti-neutrinos which can be detected on Earth before any other signal emitted in the explosion. In this project we use simulations in neutrino detectors to evaluate the pointing accuracy of Supernovae in the sky.

# Supernovae

A supernova is the explosion of a star. It happens when there is a change in the core, or center, of a star.



Figure: Supernova. Credits: NASA/CXC/U.Texas.

# Supernovae



Figure: Supernova 1987A after the star exploded and before. Credits: NASA.

- Before the core-collapse, there are pre-supernova stages of massive stars in which neutrinos and anti-neutrinos are emitted.
- The detection of these particles could provide an advanced and valuable alert to the event of a supernova.

# Neutrino detectors

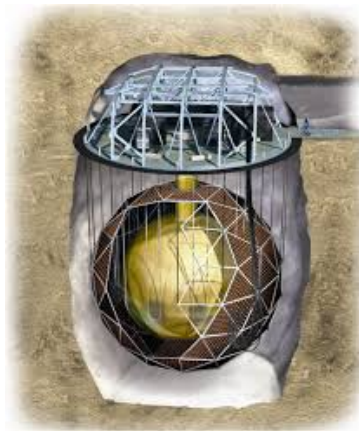


Figure: The SNO+ experiment.

# Inverse Beta Decay

Electron anti-neutrinos with at least  $1.806\text{MeV}$  of kinetic energy (threshold energy) interact with protons:

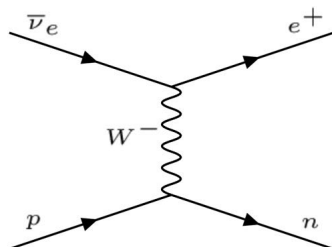
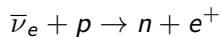


Figure: Inverse Beta Decay Feynman Diagram.

Monte-Carlo simulation of the interactions in the detector of anti-neutrinos originated in nuclear reactors:

- Bruce
- Darlington
- Pickering
- ..



# Nuclear Reactors Simulation

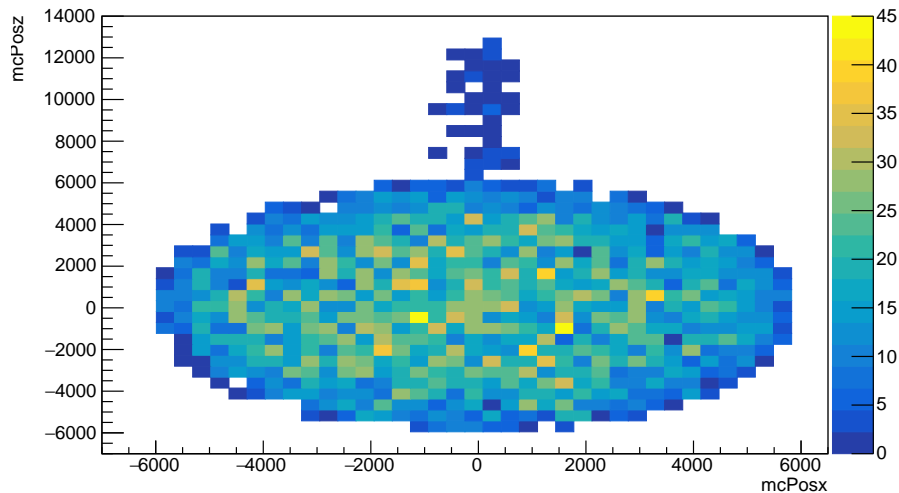


Figure: Detected interactions.

# Nuclear Reactors Simulation

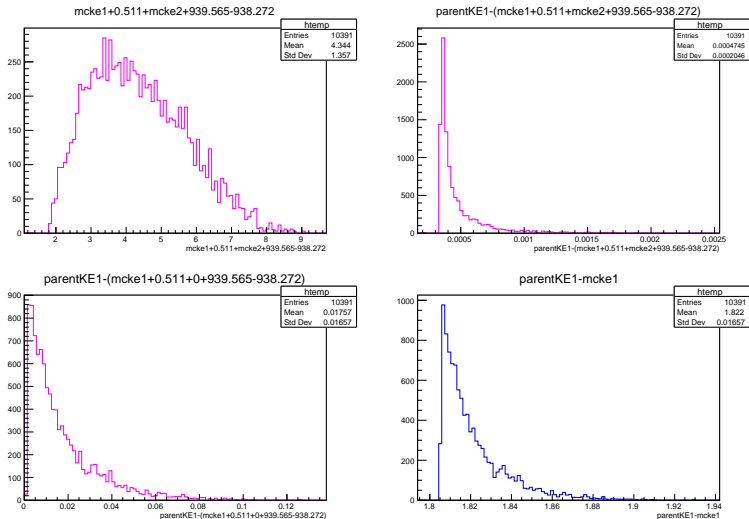


Figure: Reconstructing the energy of the anti-neutrinos.

# Nuclear Reactors Simulation

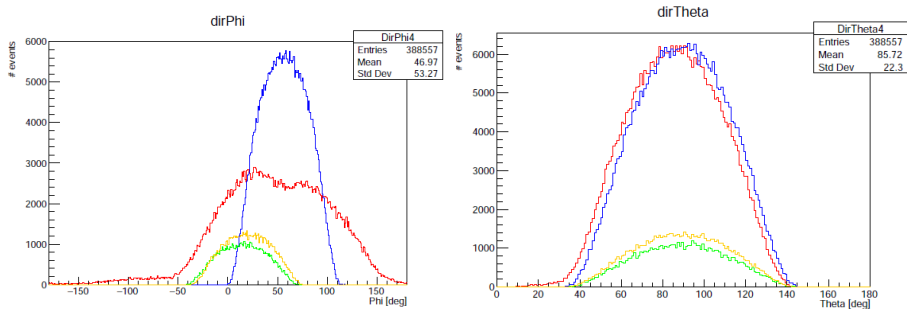


Figure: Angles that define the direction of the anti-neutrinos.

# Nuclear Reactors Simulation

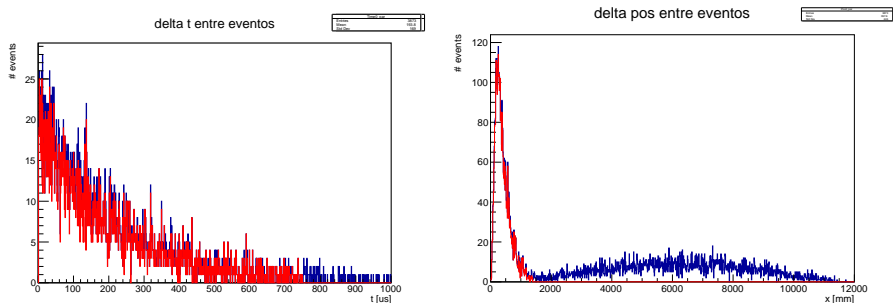


Figure: Finding pairs of events.

# Nuclear Reactors Simulation

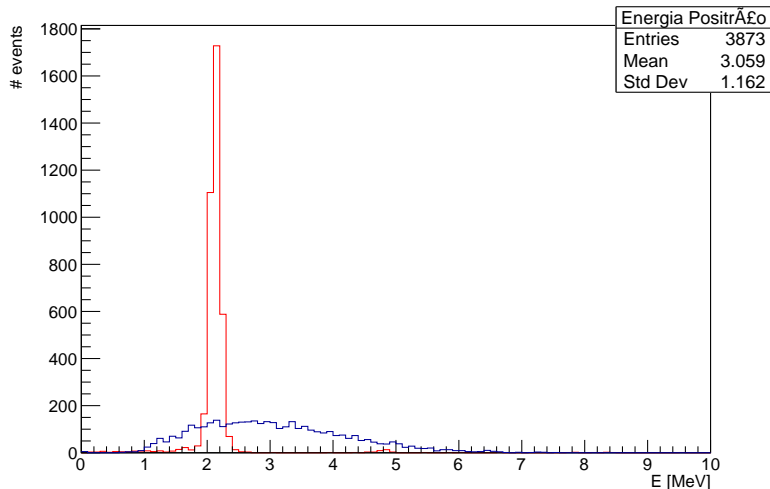
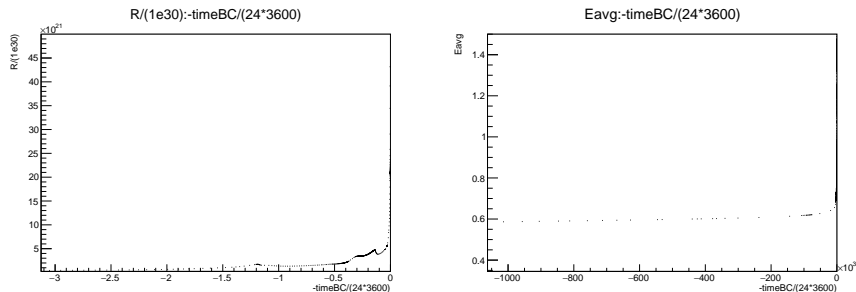


Figure: Finding pairs of events.

# Pre-Supernova neutrino spectrum

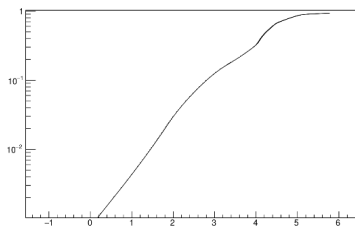
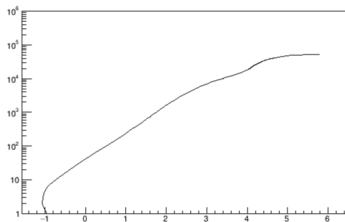
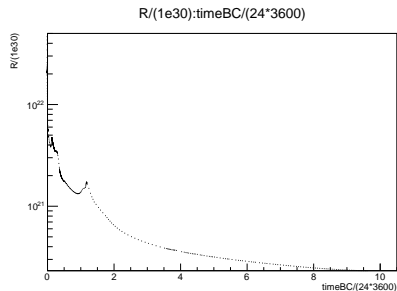
- Pre-supernova pair annihilation anti-neutrino spectrum data
- Star with 25 times the mass of the sun
- Considering the distances to Earth:
- Betelgeuse star (supernova candidate):  $\pm 720$  ly
- SN 1987a : 170000 ly

# Pre-Supernova neutrino spectrum



**Figure:** Rate of emitted anti-neutrinos by the supernova (left). Average energy of emitted anti-neutrinos (right).

# Pre-Supernova neutrino spectrum



**Figure:** Rate of emitted anti-neutrinos by the supernova vs number of detected if the star is located at the distance of Betelgeuse (above) and SN1987a (below).



- The reconstruction of the anti-neutrinos in the nuclear reactors simulation is fairly accurate but it is difficult to find their incoming direction.
- Pre-Supernova neutrino bursts could provide important information to detect a supernova a significant time before its light is detected and to create an alert system.