Latest results from the Neutrinos-Angra Project

23rd International Workshop on Next Generation Nucleon Decay and Neutrino Detectors (NNN24)
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For the Netrinos Angra Collaboration

- Introduction: Monitoring Nuclear Reactor with Neutrinos
- The Neutrinos Angra Project
- Analysis of 2020 dataset
- Final considerations

Neutrino Detectors in Nuclear Security

Historical Background

The development of nuclear weapons since WWII introduced new challenges to global security, making nuclear nonproliferation and monitoring essential.

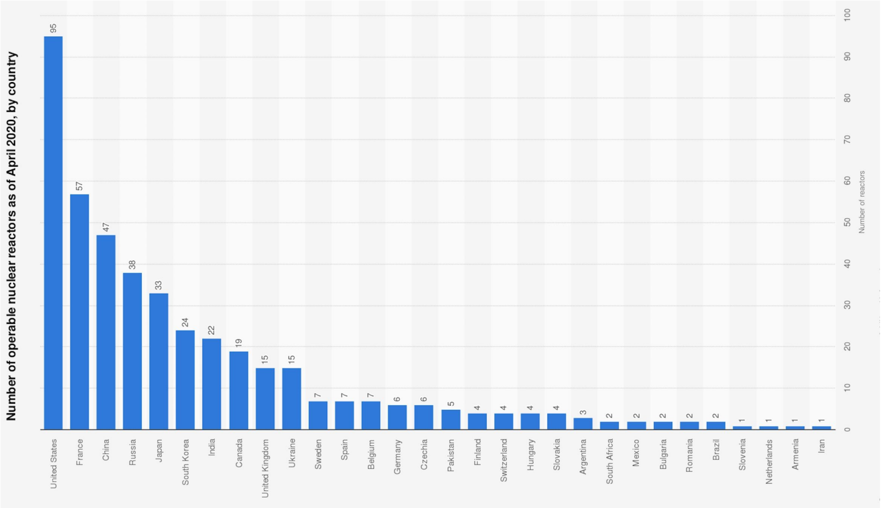
Role of Neutrino Detectors

Neutrinos, produced during nuclear fission, can pass through matter, making them a unique signature for monitoring nuclear activities from reactors to explosions.

Advances and Applications

Modern neutrino detection technologies have enabled new possibilities for near-field and far-field monitoring of nuclear reactors, helping to verify compliance with international treaties.

A.Bernstein et al., “Colloquium: Neutrino detectors as tools for nuclear security”, Rev.Mod.Phys. 92 (2020) 011003



Around 407 Nuclear Reactor in operation around the world.

https://www.worldnuclearreport.org/

Key Milestones in near-field Neutrino-Based Reactor Monitoring

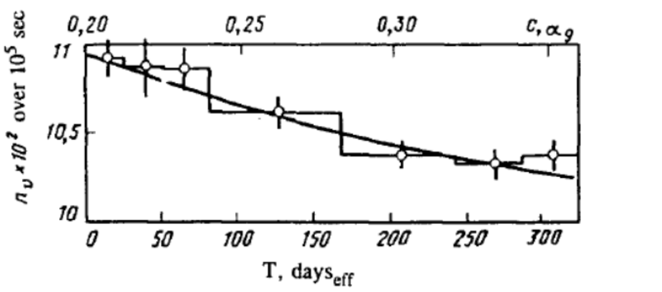
Initial Detection of Neutrinos (1950s)

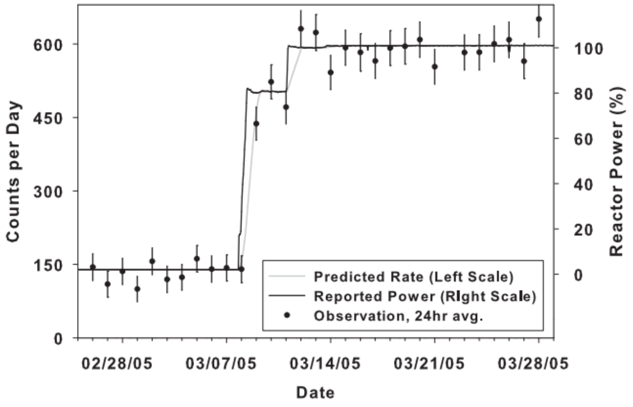
Reines-Cowan experiment at the Savannah River Site marked the first successful detection of neutrinos from a nuclear reactor, proving neutrinos' potential for nuclear monitoring.

Near-Field Monitoring Demonstrations (1980s-2000s)

Experiments at Rovno (USSR) and SONGS (USA) demonstrated that neutrino detectors could effectively track reactor states, power levels, and fuel changes from 20 meters.

Rovno: Klimov, Yu A, et al., Atomic Energy 76 (2), 123–127. (1994)





SONGS: Bowden, N S et al., Journal of Physics: Conference Series 136 (2), 022008. (2008)

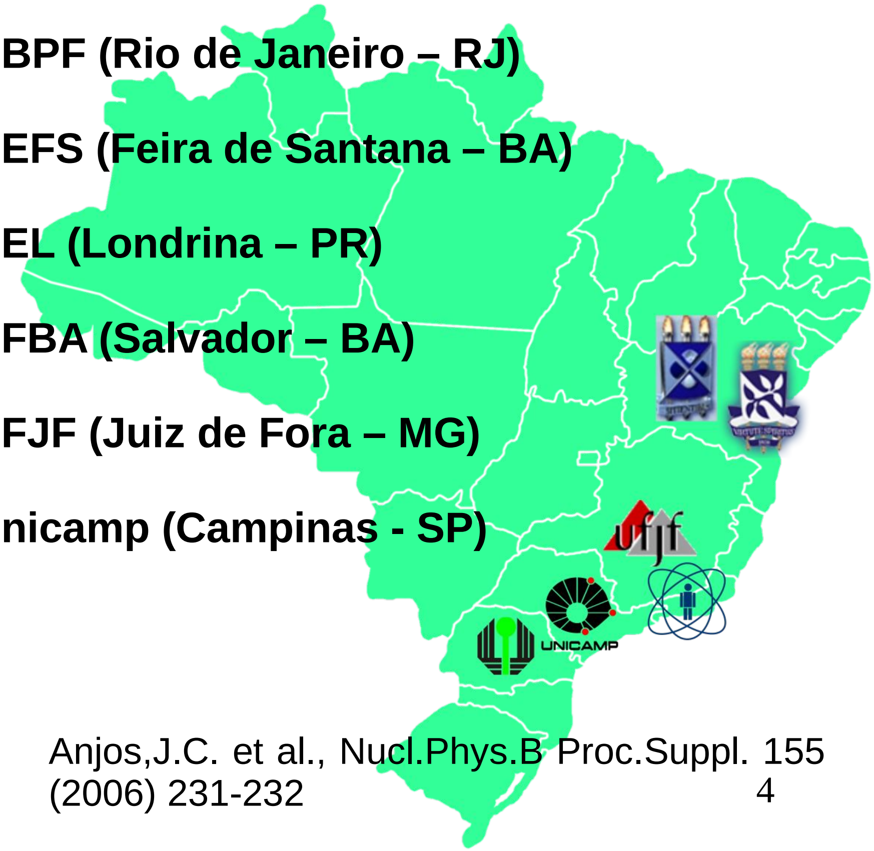
The Neutrinos Angra Collaboration

Major objectives:

- Non-invasive monitoring of reactor activity
- Estimation of the thermal power produced in the reactor core.
- Development of new antineutrino detection techniques.
- Contribution to the International Atomic Energy Agency (IAEA) safeguards and non-proliferation efforts.
- Integration of Latin American scientists and engineers into global scientific collaborations.

Brazilian Institutes:

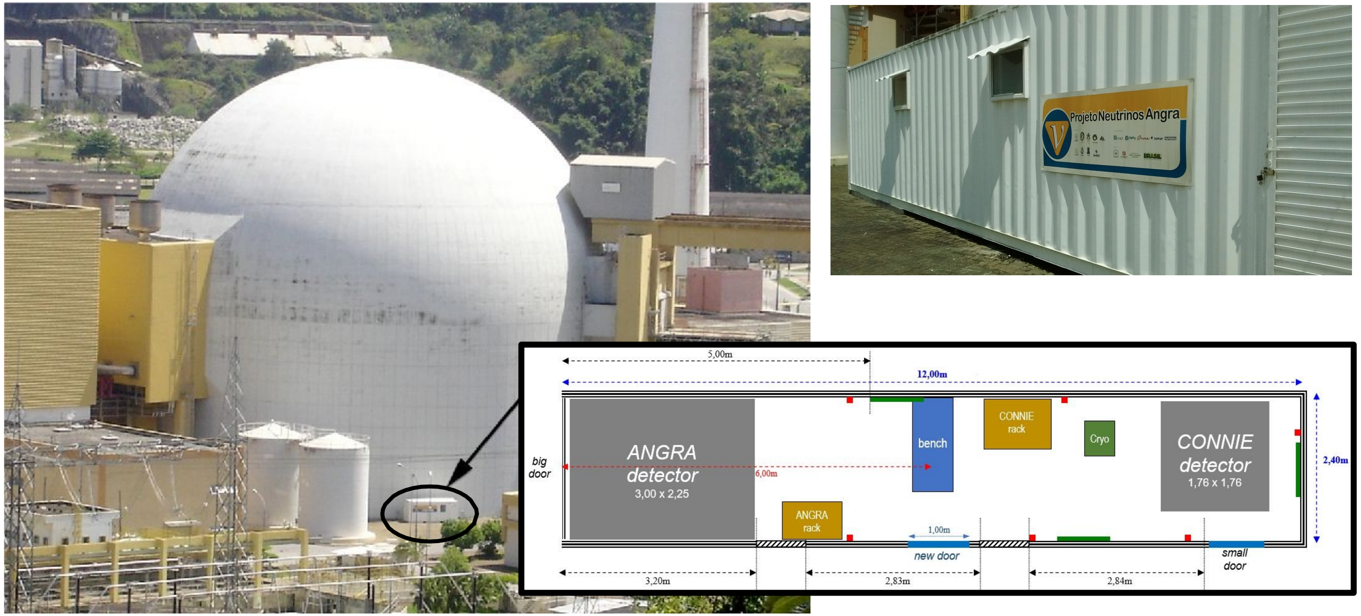
- **CBPF (Rio de Janeiro – RJ)**
- **UEFS (Feira de Santana – BA)**
- **UEL (Londrina – PR)**
- **UFBA (Salvador – BA)**
- **UFJF (Juiz de Fora – MG)**
- **Unicamp (Campinas - SP)**



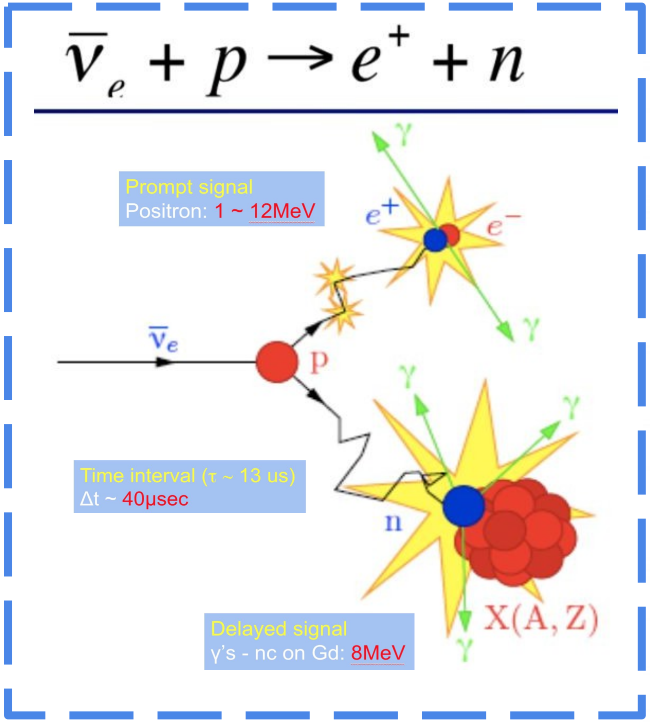
Anjos,J.C. et al., Nucl.Phys.B Proc.Suppl. 155 (2006) 231-232

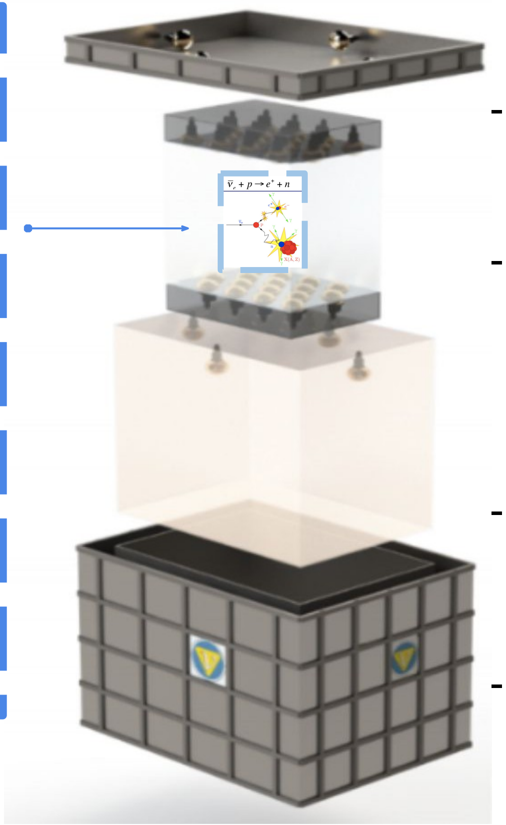
The Neutrino Laboratory

Commercial container located in proximity of the reactor dome (~30 m), housing two projects: Neutrinos Angra, dedicated to monitoring, and CONNIE, dedicated to the measurement of coherent elastic scattering of neutrinos.



The Neutrinos Angra Detector





- Top veto (active): 4 PMTs
  25 cm height - pure water
- Neutrino Target (active): 32 PMTS
  ~ 1 ton GdCl3 doped water
  (0,2%)
- Inner Veto (active): 4
  PMTs 25 cm thick -
  pure water
- Shield (passive):
  25 cm thick- pure
  water

Front-end Electronics and Data Aquisition

Front-End Electronics:

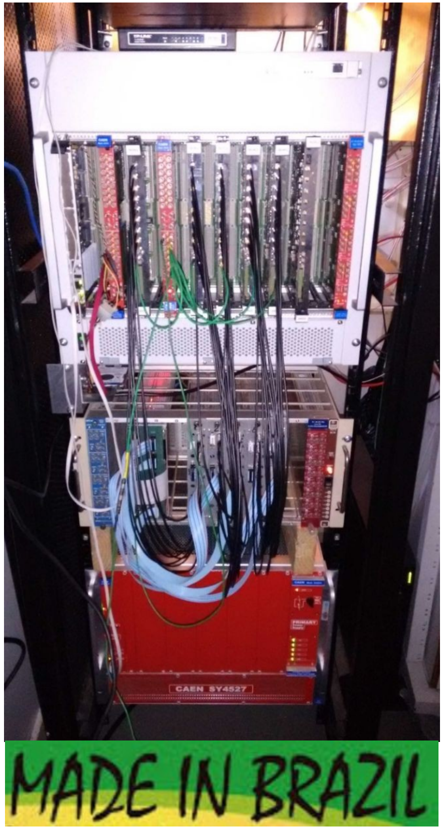
Custom circuitry amplifies and shapes signals from PMTs, providing both analog and discriminated outputs for the trigger system. Each channel can process up to 20 photoelectrons before saturation.

Digitization Process

Signals are digitized by NDAQ modules with a 125 MHz sampling rate. An FPGA manages the data flow using FIFO memory to capture signal data before and after triggering.

Trigger System

The system selects events using discriminated signals from the PMTs, generating a high-level trigger pulse if a minimum number of PMTs fire simultaneously. A veto signal blocks false triggers from background events.



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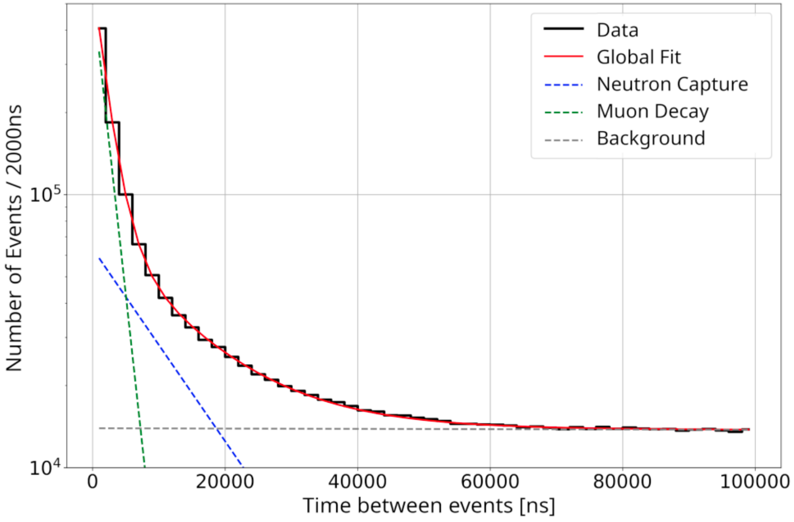
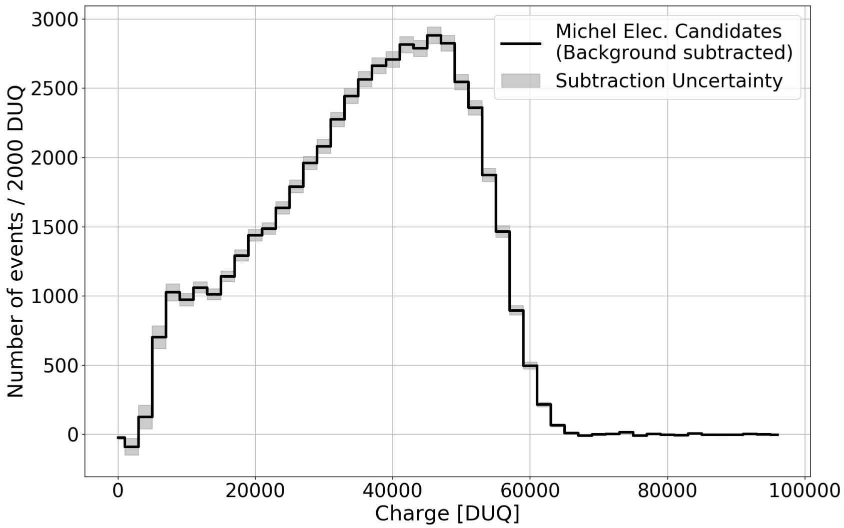
Detector assessment

Time analysis of consecutive events:

- Muon decay: (1.9 ± 0.3)μs
- Gd capture: (12.32 ± 0.05)μs



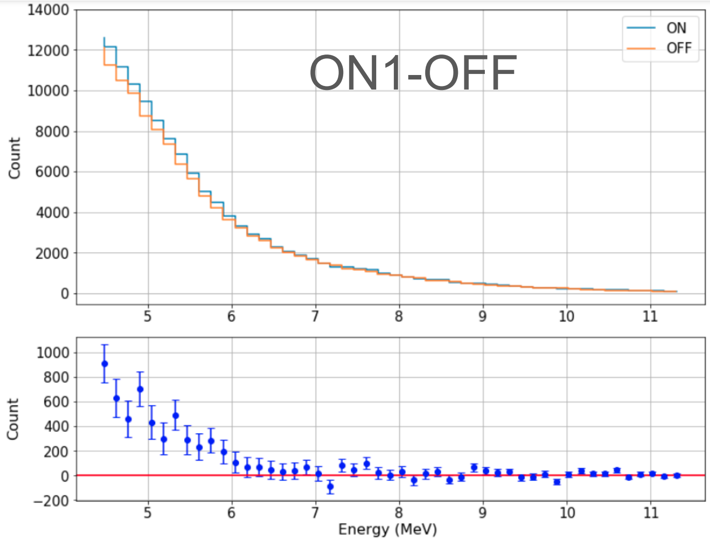
Michel electrons used to assess amplitude response.

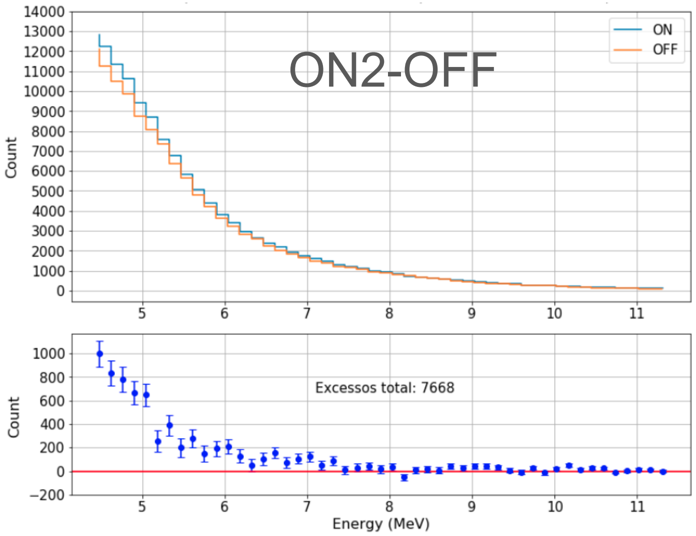


Monthly Spectral Analysis

30 days time interval
OFF: July 2020

ON 1: Aug-Sept 2020
ON 2: Sept-Oct 2020

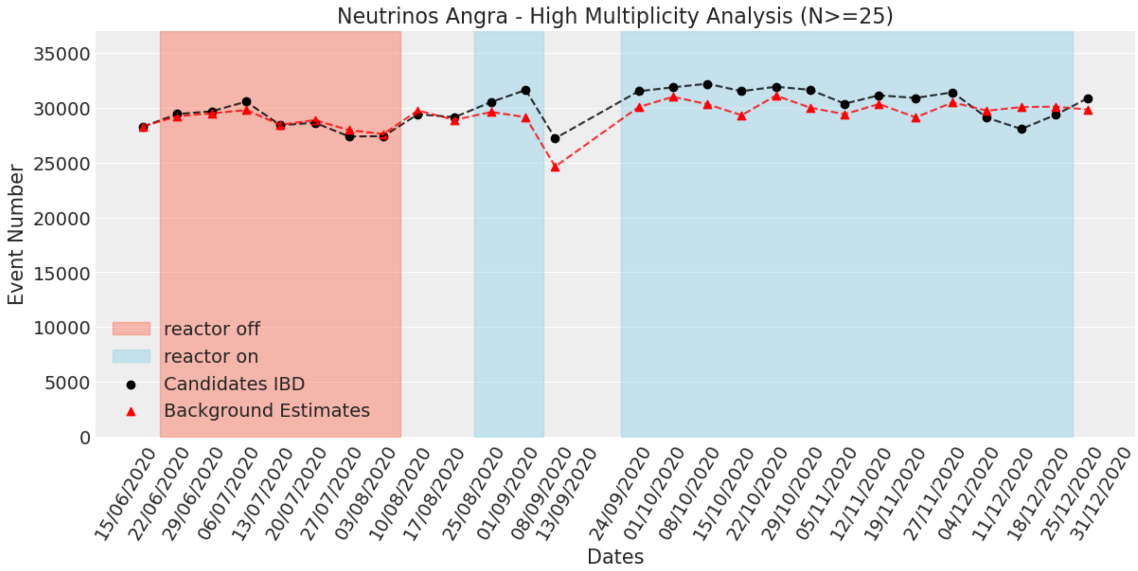


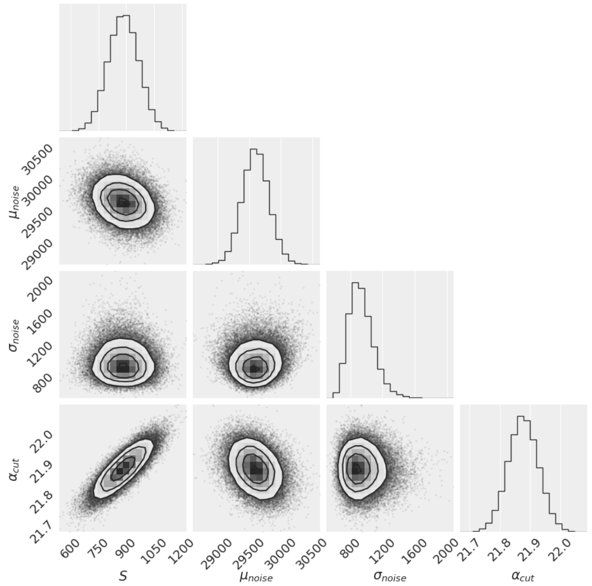


Clear Excess of reactor ON periods with respect to reactor OFF.

Weekly Time Serie Analysis

Background estimates with delayed time window.
Bayesian analysis with 4 parameters of interest: signal rate, background mean and standard deviation, ration between time different windows background rates

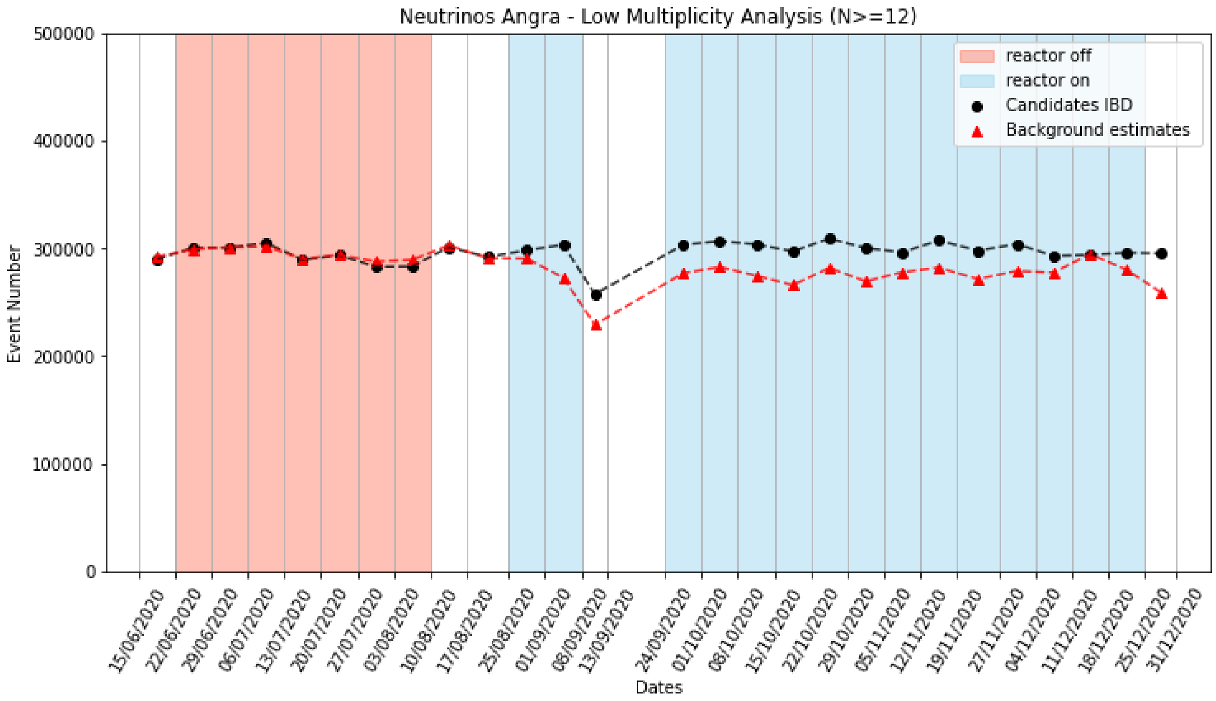




Statistsically significant signal rate.
Detection efficiency: ~5%

Work in progress: improving efficiency

Improving selection criteria.



Final considerations

Neutrinos Angra is successfully monitoring the Angra-II nuclear reactor since 2020.

The project has been entirely conceived, designed, constructed and run in Brazil. Small local projects are important for brazilian science.

Neutrino detector are also efficient neutron detector. This can be used to monitor spent fuel movements near the plant.

Thanks to the organizers for the support.

Obrigado! Thanks!

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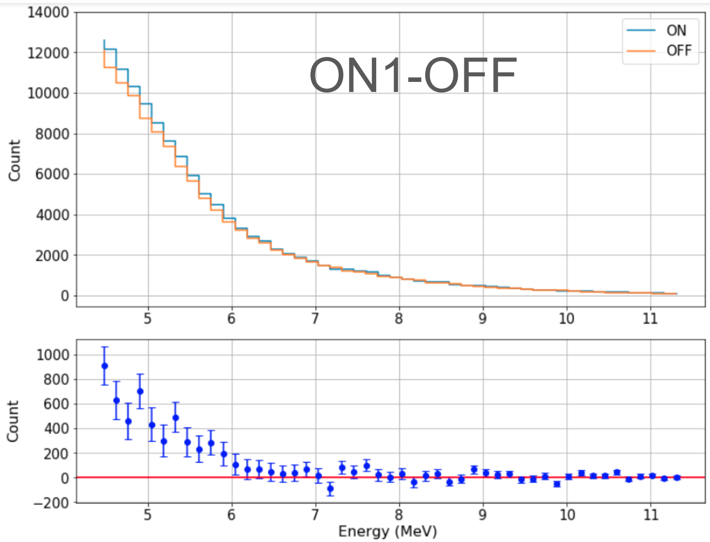
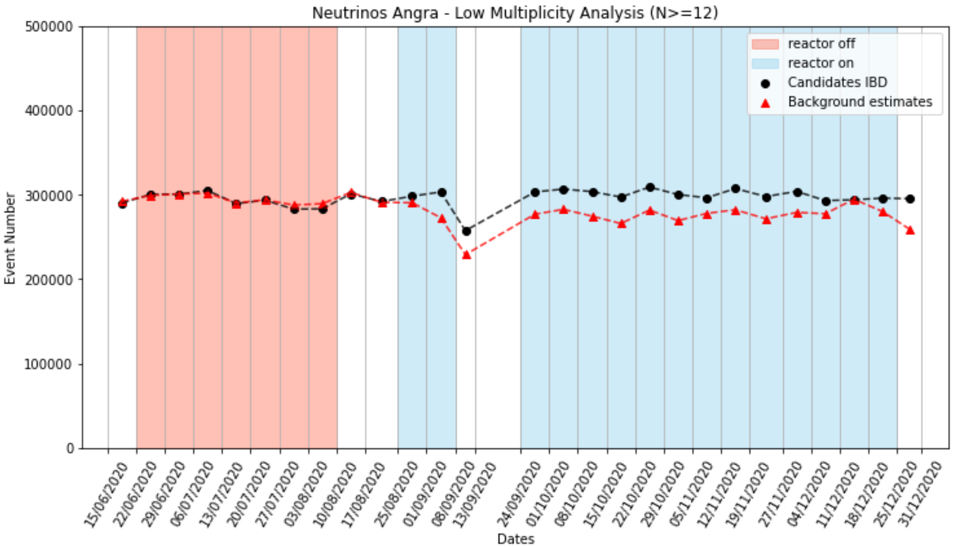
Neutrinos Angra Highlights





Specral and Time Series analysis show the capability of Angra-II reactor monitoring with a water cherenkov detector.