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Monitoring nuclear reactors with antineutrino detectors

The Angra Project:

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ABSTRACT

Nuclear reactors are an intense source of antineutrinos and the thermal power released in the fission process is directly related to the antineutrino flux. This allows us to use antineutrino detectors to monitor nuclear reactors through counting rates and spectral measurements, making them good candidate to become in the near future a new safeguards tool.

We describe the status of the Angra Project, aimed at developing an antineutrino detector for monitoring nuclear reactor activity. The experiment will use the Brazilian nuclear reactor Angra II, with 4 GW of thermal power, as a source of antineutrinos. A water Cherenkov detector of one ton target will be placed in a commercial container just outside the reactor containment, at about 30 m from the reactor core. A few thousand antineutrino interactions per day are expected over a thousand Hz background rate induced by cosmic rays at ground level. The strategies to maximize the signal to background ratio are presented.

MOTIVATION

~ 438 reactors worldwide:
The International Atomic Energy Agency - IAEA is charged to inspect nuclear facilities under safeguards agreements.

~200kg plutonium produced at each reactor cycle (~1.5years)
~90 tons of plutonium produced every year worldwide:
IAEA should verify that fissile materials are used for civil appliances.

IAEA is the verification authority:
Treaty on the Non-Proliferation of Nuclear Weapons (NPT):
IAEA should keep track of all plutonium produced !

Interesting project for the Brazilian science:
- **Possibility to do frontier experimental neutrino physics profiting from already existing facilities (Angra-I and Angra II nuclear reactors).**
- **Relative low cost investments compared with reactor costs.**
- **Possibility to do neutrino applied physics: nuclear safeguards applications.**

Why the interest in antineutrino detectors?

- **Antineutrinos can not be shielded and are produced in very large amounts in nuclear reactors (~ 10^{20} antineutrinos/s)**
- **Non-intrusive, Quasi-real Time, Remote reactor monitoring: thermal power & fissile material**
- **Energy spectrum of antineutrinos produced in reactors can reveal fissile composition of nuclear fuel**
- **Search for new methods on safeguards verification**

Reactor Thermal Power and Antineutrino flux

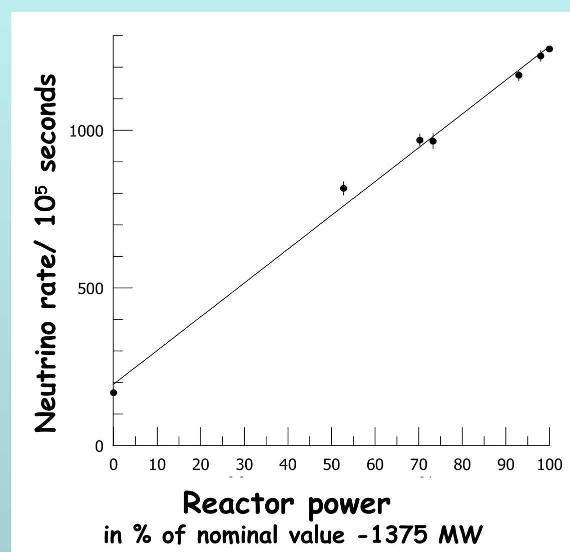
$\bar{\nu}_e + p \rightarrow e^+ + n$

(figure from Valery SINEV)

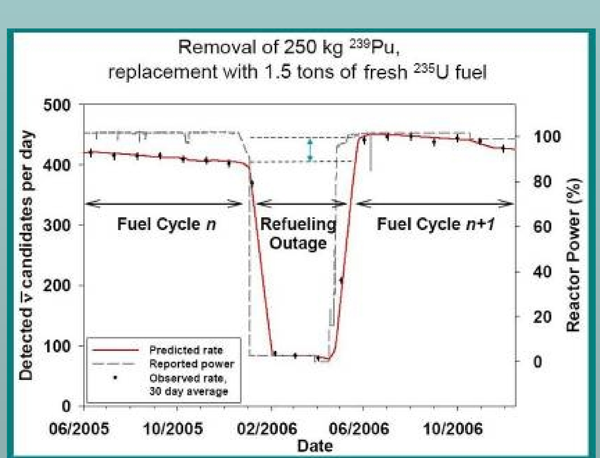
$$N_\nu = \gamma \cdot (1 + k) \cdot P_{th}$$

Dependence on detector features

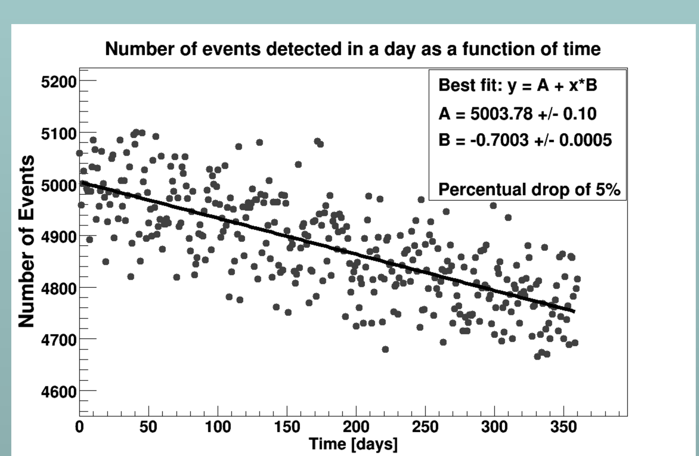
Burn-up: Dependence on fuel composition



Fuel Burnup as a function of time



(figure from SONGS Collaboration)



(simulation results, ANGRA Collaboration)

THE NEUTRINOS-ANGRA PROJECT DETECTOR DESIGN: WATER CHERENKOV

A challenging configuration has been adopted by the Neutrinos-ANGRA Project: a water Cherenkov detector (loaded with Gd) running above ground. These choices were made to comply with safety rules of ELETRONUCLEAR, the power plant operator and also to test new techniques on antineutrino detection for safeguards applications, in cooperation with the IAEA.

Central detector dimensions: ~ 2.00m x 1.60m x 1.40m

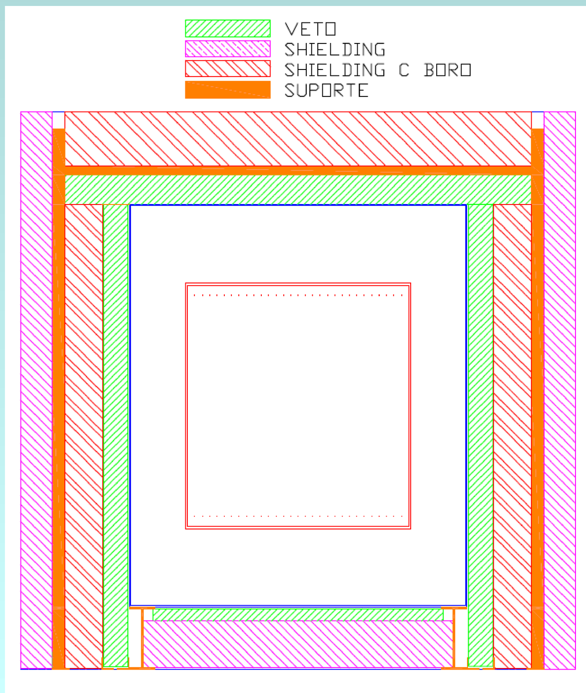
Target Fiducial volume: 1.36m x 0.98m x 0.90m ~1 ton

External Shield: borated water or poly; Muon veto: extruded plastic scintillator strips;
Central detector target: water + 0.1% Gd viewed by 40 PMT's (8" Hamamatsu R5912)

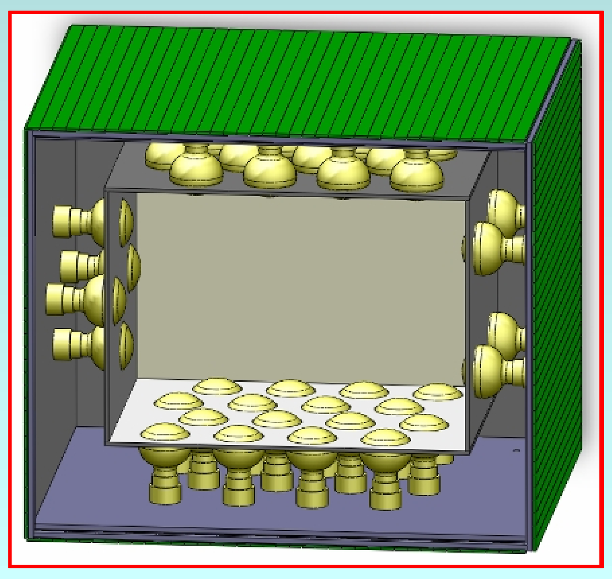
THE NEUTRINO LABORATORY @ ANGRA

conteiner: 1st laboratory in Angra

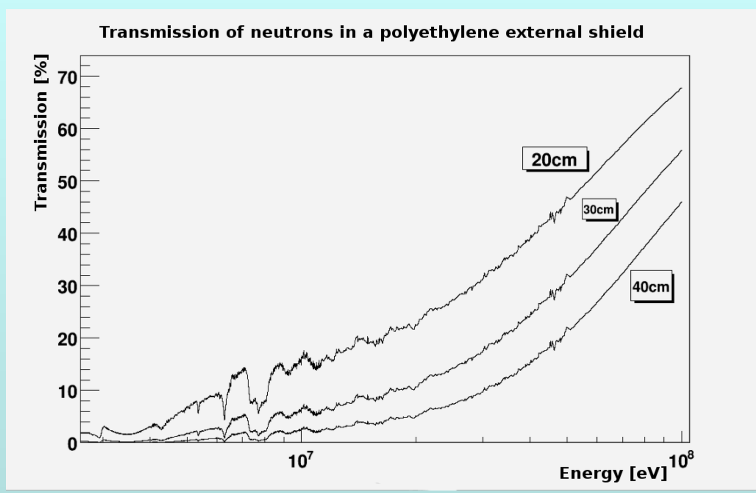
SCHEMATIC OF DETECTOR SYSTEM

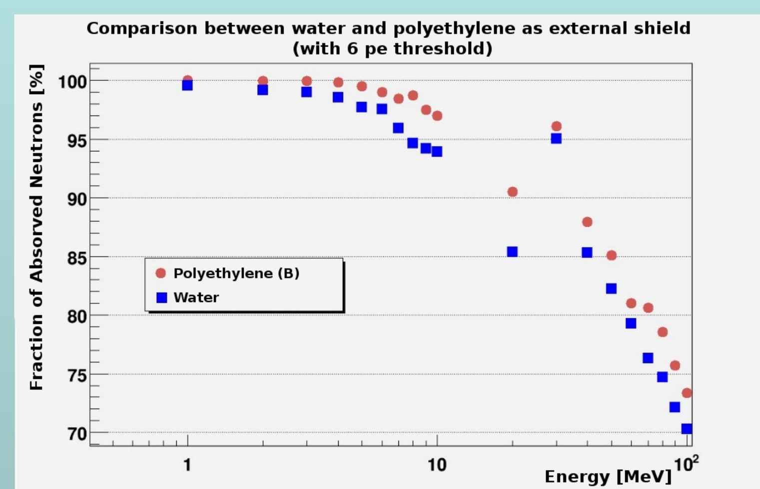


Central Detector



neutron shielding studies

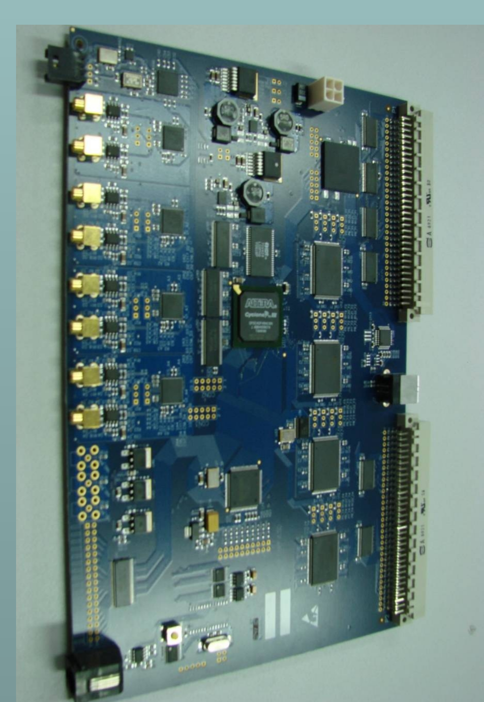




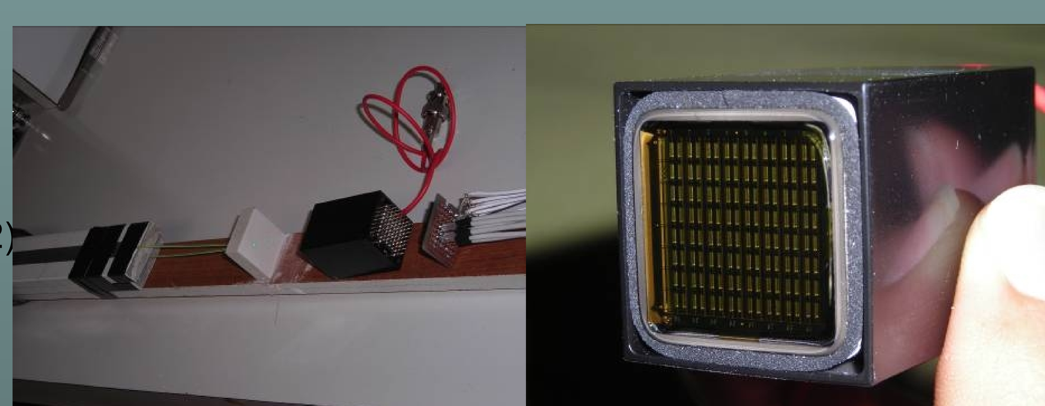
Data Acquisition System: VME DAQ card

Waveform digitizer: VME 6U standard
Each module:
ADC: 8 analog channels @ 125 MHz
or
4 analog channels @ 250 MHz
Dynamic range = 2 Vpp
Buffer per channel = 64k samples
TDC: 8 channels for time measurements
time resolution 81ps
dinamic range = 9.8 µs
2 firmware versions (8 ou 4 channels)
control and status registers
slow control:CAN communication

Prototype of neutrino DAQ VME card

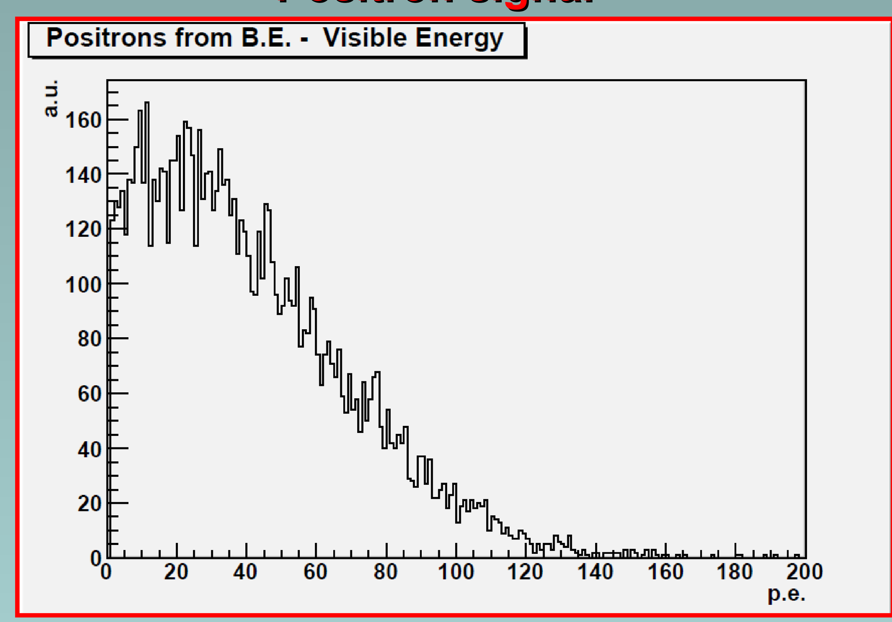


Outer Veto – plastic scintillator + optical fiber

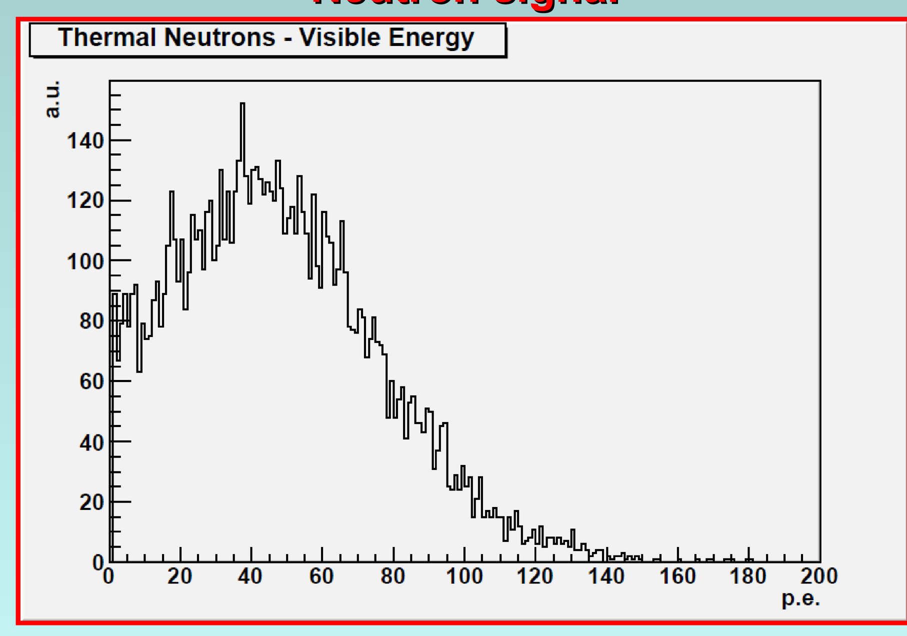


EXPECTED FEATURES OF THE ANGRA WATER-CHERENKOV DETECTOR

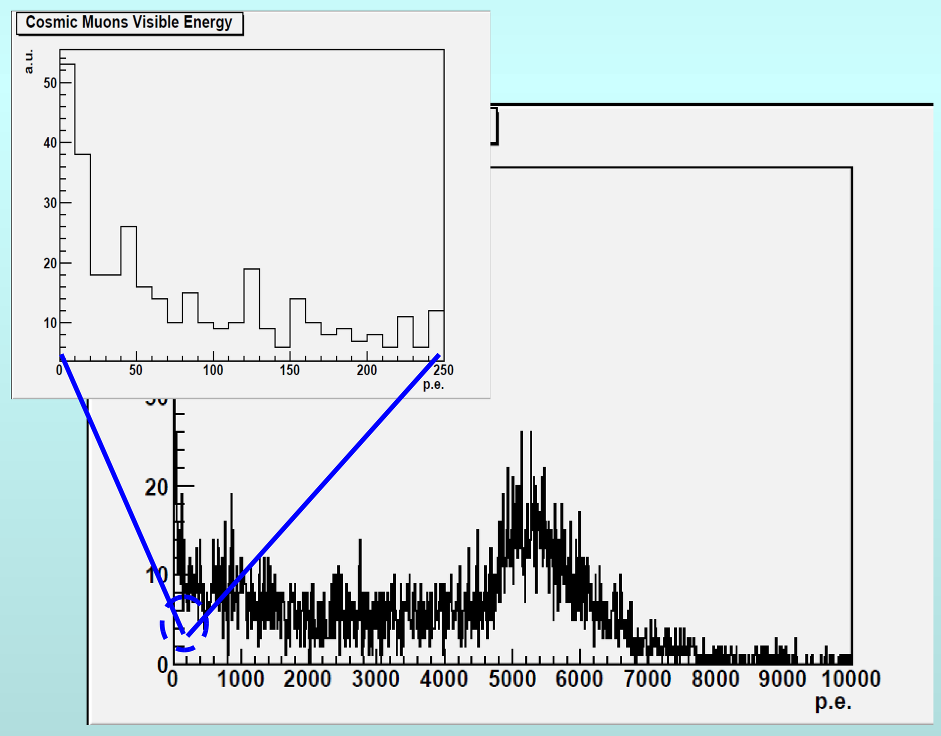
Positron signal



Neutron signal



Muon signal



EXPECTED RATES AT THE DETECTOR

- **Neutrino interactions: 4,400/day (~ 0.05 Hz)**
- **Neutrino signal: ~ 1.000 events/day (~ 0.01 Hz)**
- **Muon rate at target: ~ 350 Hz**
- **Cosmic ray induced neutron rate: ~ 70 Hz (no shielding)**
- **Neutron background rate: ~ 4 Hz (with 30cm polyethylene shielding)**

⇒ the background rate has to be reduced by a factor at least ~10^4

Time window: 100 µs ⇒ muon rate 3.5 Hz
Muon veto efficiency: 95% ⇒ muon rate 0.175 Hz
Muon Energy cut efficiency: 90% ⇒ muon rate ~ 0.02 Hz

Neutrino signal = 1,000 events/day
Muon background = 2,000 events/day
Neutrino signal/(muon background) = 0.5
Main problem will be neutron spallation background: under study

CONCLUSIONS

Previous experiments demonstrated a good capability of using antineutrinos for nuclear reactor distant monitoring.

- **Thermal power and fuel composition measurement can be achieved.**
- **Antineutrino detection at surface is a challenge but may be achieved.**

ANGRA project status:

- **Neutrino Laboratory @ ANGRA is OPERATIONAL.**
- **GEANT4 simulation is running and guiding final detector design.**
- **Electronics is almost ready to production phase.**
- **PMTs are being purchased.**
- **Remote operations are implemented (link CBPF – AngraLab).**
- **Muon Veto detector is in development phase.**
- **Starting data taking expected by March 2011.**

Good opportunity to develop experimental neutrino physics in Brazil and to contribute to new non proliferation safeguards techniques.

Short baseline Neutrino Oscillations :
Collaboration with experiment Double Chooz

Bibliography:

A. Bernstein et al, arXiv:0908.4338
J. C. Anjos et al, AIP Conference Proceedings 1222, 427-430 (2010)