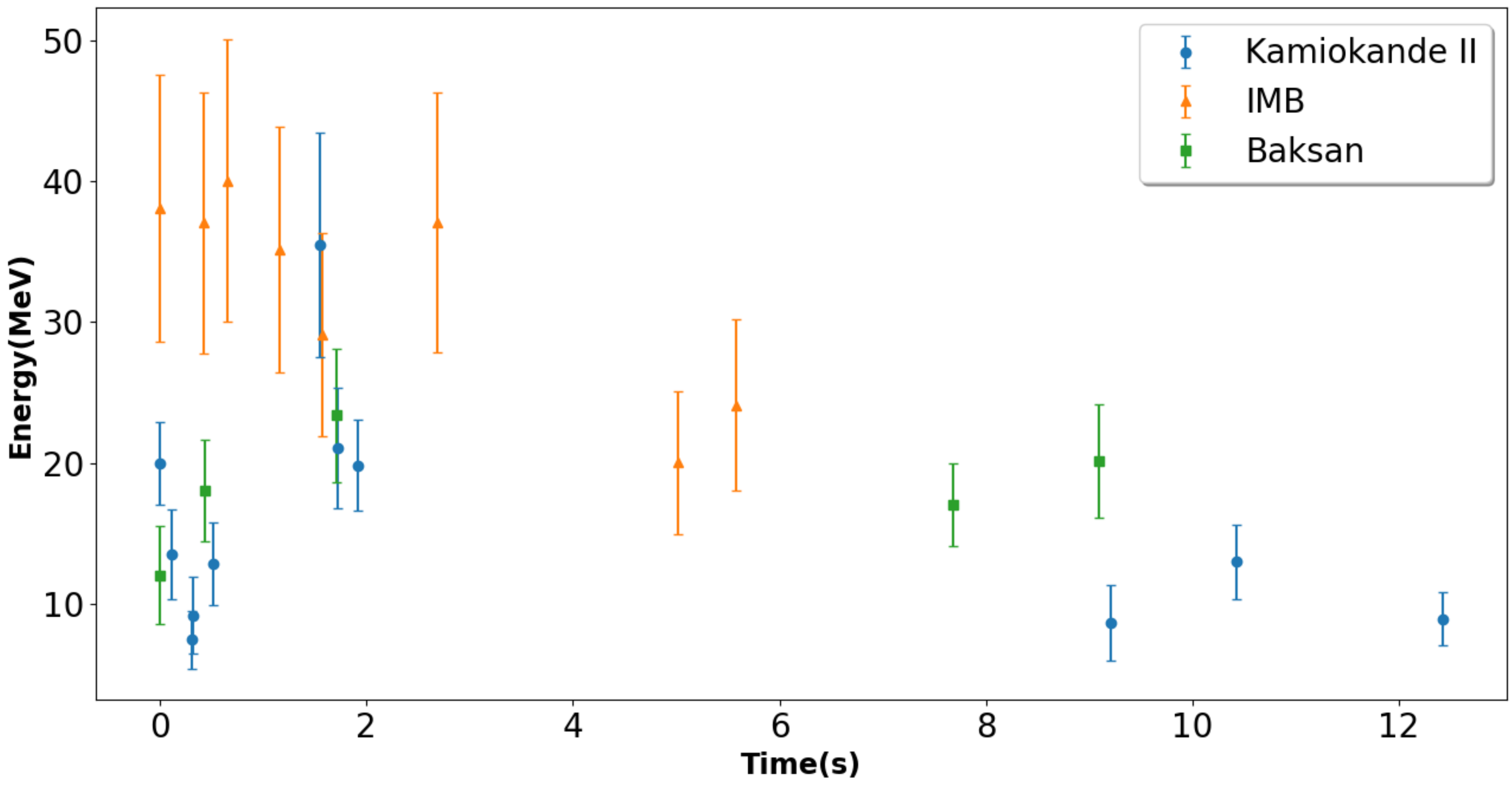
POTENTIAL SOURCES OF COSMIC NEUTRINOS

SUPERNOVAE

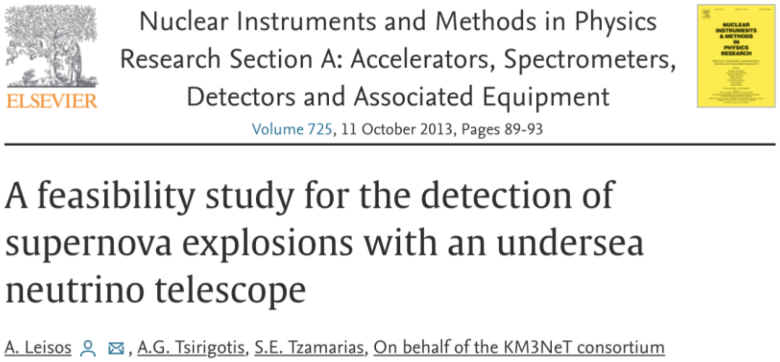
A supernova is a bright and powerful explosion of a massive star. Runaway nuclear reactions in a star caused it to explode outward, flinging gas, dust, light, and neutrinos across space.

Supernova remnant Cassiopeia A.
Credit: NASA/JPL-Caltech/STScI/CXC/SAO

SN Explosion



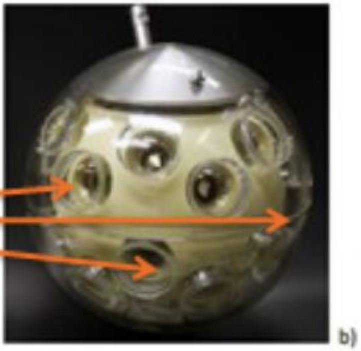
Measured neutrino events from SN 1987A



Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 725, 11 October 2013, Pages 89-93

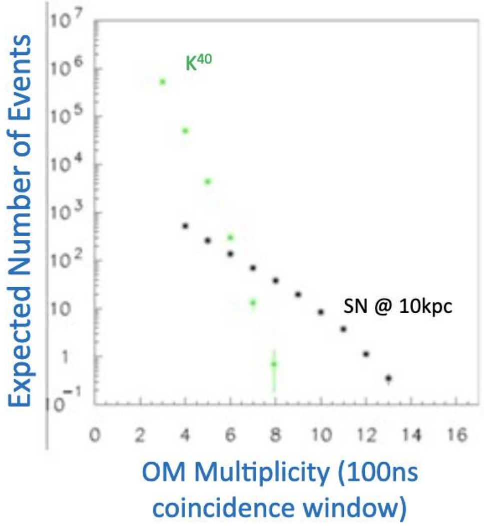
A feasibility study for the detection of supernova explosions with an undersea neutrino telescope

A. Leisos, A.G. Tsirigotis, S.E. Tzamarias, On behalf of the KM3NeT consortium

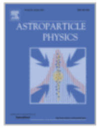


Coincidence between the small PMTs of the same OM, within 100 ns

e.g. "Coincidence Level" or "Multiplicity" 3



Astroparticle Physics
Volume 60, January 2015, Pages 41-46



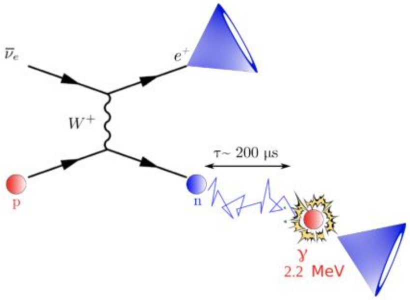
Supernova Relic Neutrino search with neutron tagging at Super-Kamiokande-IV

[10], [11], [12]. Although all six types of neutrinos are emitted from a core-collapse supernova, SRN's are most likely detected via the inverse beta decay (IBD) reaction $\overline{\nu}_e p \rightarrow e^+ n$ in existing detectors. Super-Kamiokande (SK) has previously carried out searches for SRNs from the expected IBD positrons without requiring the detection of a delayed neutron, placing an integral flux limit for $E_{\overline{\nu}_e} > 17.3\,\text{MeV}$ $(E_{\overline{\nu}_e} \approx E_{e^+} + 1.3\text{ MeV})$ in the absence of a signal [14], [15]. Since the detector cannot

Positive identification of $\overline{\nu}_e$'s by tagging (and counting) neutrons in delayed coincidence will play a critical role in both the suppression of backgrounds in those samples as well as in lowering the energy threshold. Kamland made the first attempt to search for the SRN flux down to 8.3 MeV by detecting IBDs with neutron capture on hydrogen in a one-kiloton liquid scintillator detector [13]. This paper will present a study to detect IBDs

Summary and outlook

In summary, a search for SRN $\overline{\nu}_e$ at SK-IV is first conducted via IBDs by tagging neutron capture on hydrogen. The neutron tagging efficiency is determined to be $(17.74 \pm 0.04_{stat.} \pm 1.05_{sys.})\%$, while the corresponding accidental background probability is $(1.06 \pm 0.01_{stat.} \pm 0.18_{sys.})\%$. No appreciable IBD signal in the distribution of neutron lifetime is found using 960 days of data. The number of observed IBD candidates are consistent with the expected accidental background. A model-independent…



(Dated: November 3, 2021)

A new search for the diffuse supernova neutrino background (DSNB) flux has been conducted at Super-Kamiokande (SK), with a 22.5×2970-kton·day exposure from its fourth operational phase IV. The new analysis improves on the existing background reduction techniques and systematic uncertainties and takes advantage of an improved neutron tagging algorithm to lower the energy threshold compared to the previous phases of SK. This allows for setting the world's most stringent upper limit on the extraterrestrial $\bar{\nu}_e$ flux, for neutrino energies below 31.3 MeV. The SK-IV results are combined with the ones from the first three phases of SK to perform a joint analysis using 22.5×5823 kton·days of data. This analysis has the world's best sensitivity to the DSNB $\bar{\nu}_e$ flux, comparable to the predictions from various models. For neutrino energies larger than 17.3 MeV, the new combined 90% C.L. upper limits on the DSNB $\bar{\nu}_e$ flux lie around 2.7 cm^{-2}·sec^{-1}, strongly disfavoring the most optimistic predictions. Finally, potentialities of the gadolinium phase of SK and the future Hyper-Kamiokande experiment are discussed.

Geoneutrino detection [edit]

Detection mechanism [edit]

Instruments that measure geoneutrinos are large scintillation detectors. They use the inverse beta decay reaction, a method proposed by Bruno Pontecorvo that Frederick Reines and Clyde Cowan employed in their pioneering experiments in 1950s. Inverse beta decay is a charged current weak interaction, where an electron antineutrino interacts with a proton, producing a positron and a neutron:

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

Only antineutrinos with energies above the kinematic threshold of 1.806 MeV—the difference between rest mass energies of neutron plus positron and proton—can participate in this interaction. After depositing its kinetic energy, the positron promptly annihilates with an electron:

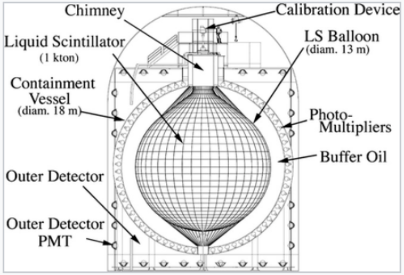
$$e^+ + e^- \rightarrow \gamma + \gamma$$

With a delay of few tens to few hundred microseconds the neutron combines with a proton to form a deuteron:

$$n + p \rightarrow d + \gamma$$

Detectors and results [edit]

Existing detectors [edit]



Schematic of the KamLAND antineutrino detector.

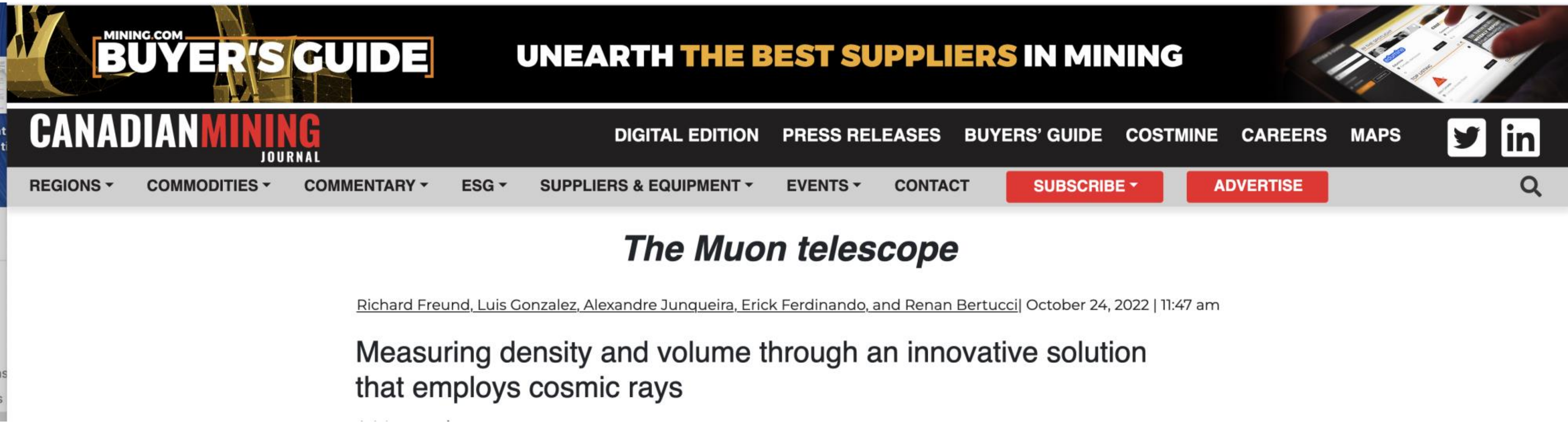
KamLAND (Kamioka Liquid Scintillator Antineutrino Detector) is a 1.0 kiloton detector located at the Kamioka Observatory in Japan. Results based on a live-time of 749 days and presented in 2005 mark the first detection of geoneutrinos. The total number of antineutrino events was 152, of which 4.5 to 54.2 were geoneutrinos. This analysis put a 60 TW upper limit on the Earth's radiogenic power from ^{232}Th and ^{238}U.[5]

A 2011 update of KamLAND's result used data from 2135 days of detector time and benefited from improved purity of the scintillator as well as a reduced reactor background from the 21-month-long shutdown of the Kashiwazaki-Kariwa plant after Fukushima. Of 841 candidate antineutrino events, 106 were identified as geoneutrinos using unbinned maximum likelihood analysis. It was found that ^{232}Th and ^{238}U together generate 20.0 TW of radiogenic power.[9]

Borexino is a 0.3 kiloton detector at Laboratori Nazionali del Gran Sasso near L'Aquila, Italy. Results published in 2010 used data collected over live-time of 537 days. Of 15 candidate events, unbinned maximum likelihood analysis identified 9.9 as geoneutrinos. The geoneutrino null hypothesis was rejected at 99.997% confidence level (4.2σ). The data also rejected a hypothesis of an active georeactor in the Earth's core with power above 3 TW at 95% C.L.[7]

A 2013 measurement of 1353 days, detected 46 'golden' anti-neutrino candidates with 14.3±4.4 identified geoneutrinos, indicating a 14.1±8.1 TNU mantle signal, setting a 95% C.L limit of 4.5 TW on geo-reactor power and found the expected reactor signals.[27] In 2015, an updated spectral analysis of geoneutrinos was presented by Borexino based on 2056 days of measurement (from December 2007 to March 2015), with 77 candidate events; of them, only 24 are identified as geonetrinos, and the rest 53 events are originated from European nuclear reactors. The analysis shows that the Earth crust contains about the same amount of U and Th as the mantle, and that the total radiogenic heat flow from these elements and their daughters is 23–36 TW.[28]

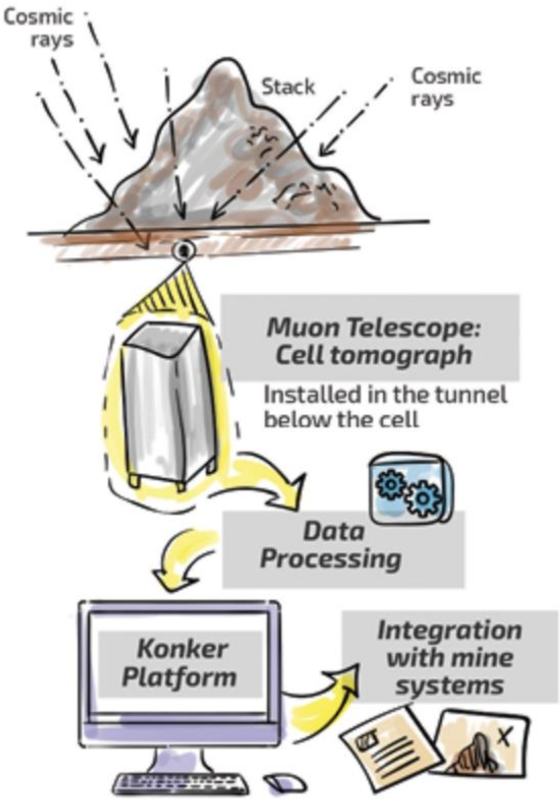
SNO+ is a 0.8 kiloton detector located at SNOLAB near Sudbury, Ontario, Canada. SNO+ uses the original SNO experiment chamber. The detector is being refurbished and is expected to operate in late 2016 or 2017.[29]

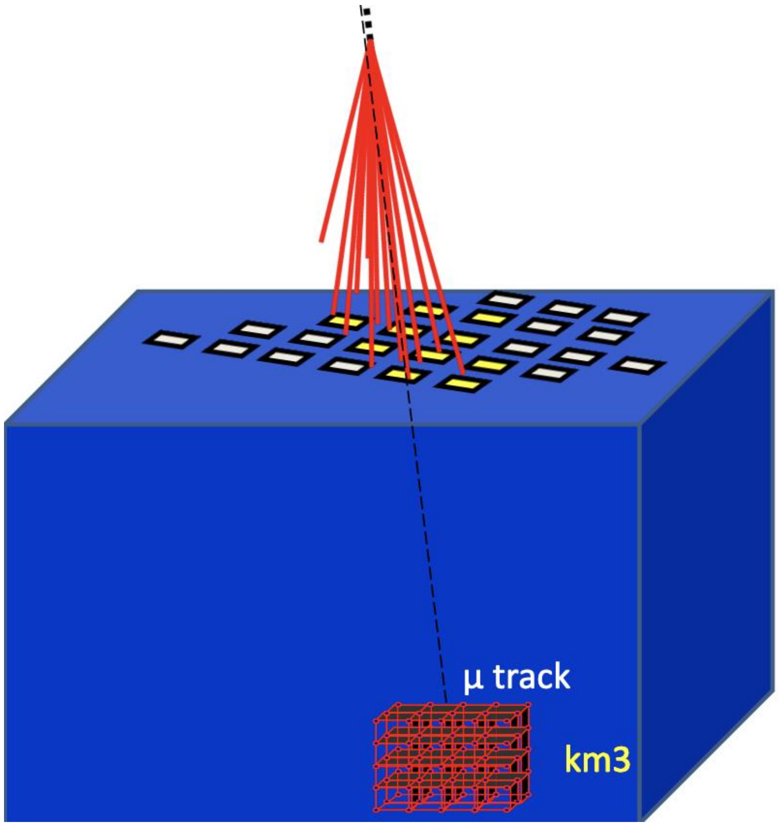


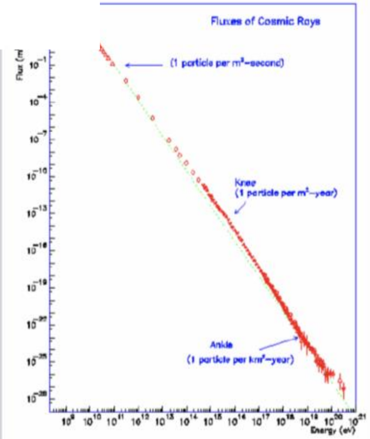
The Muon telescope

Richard Freund, Luis Gonzalez, Alexandre Junqueira, Erick Ferdinando, and Renan Bertucci| October 24, 2022 | 11:47 am

Measuring density and volume through an innovative solution that employs cosmic rays







E~ 10^{14} - $5 \cdot 10^{15}$ eV: 2500 showers/m^2/year

Single station detection: 360m^2 geometrical area (effective area depends strongly on selection cuts)

E> 10^{16} eV: 1 shower/m^2/year

TO BE STUDIED

35% of the detected showers include a muon which arrives at the Neutrino Telescope (depth 4000m) with an energy >300GeV

General Remark: 3 stations operating for 10 days can identify an angular offset of the KM3NeT with an accuracy of 0.05°

Extensive Air Shower Reconstruction using the timing information from the RF-system of the Astroneu array

S Nonis[2]**, A Leisos**[1]**, A Tsirigotis**[1]**, G Bourlis**[1]**, K Papageorgiou**[2]**, I Gkialas**[2]**, I Manthos**[3] **and S Tzamarias**[3]

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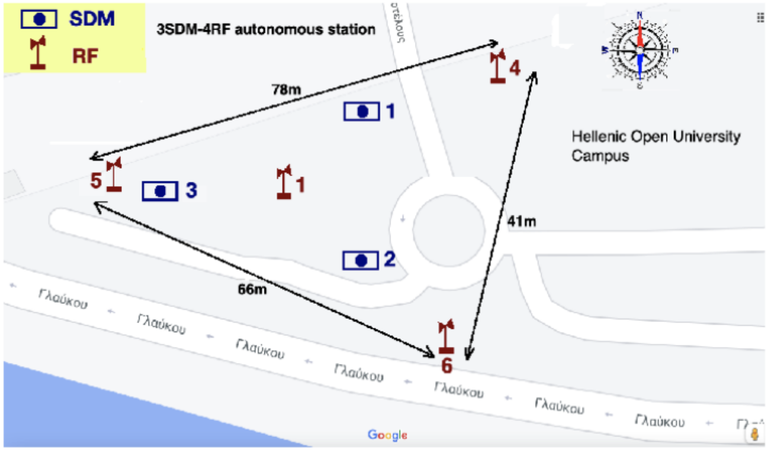
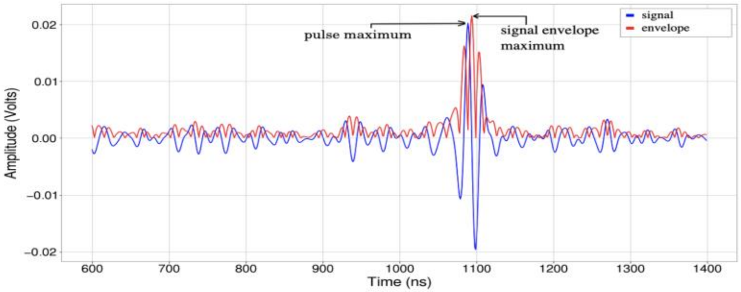
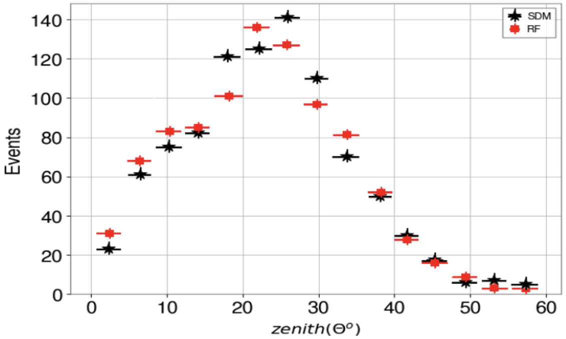
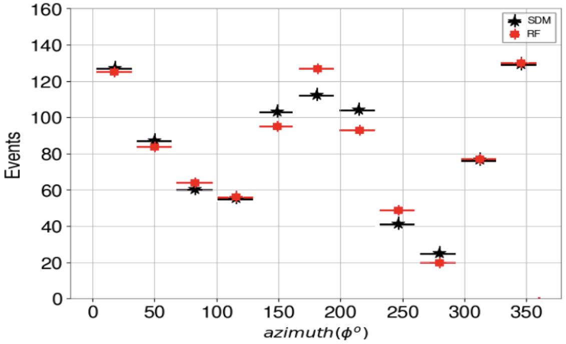
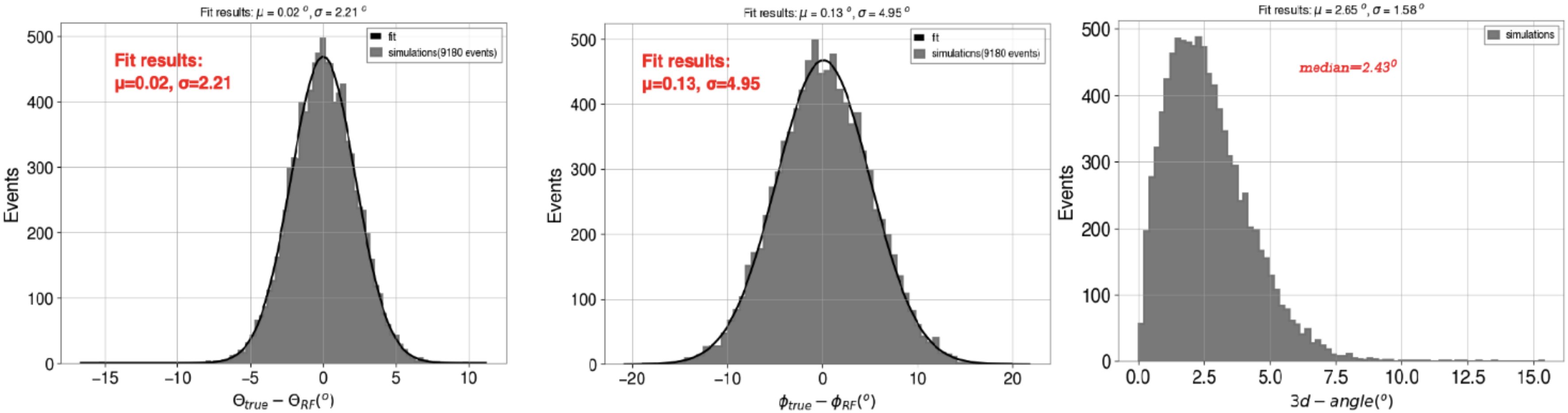


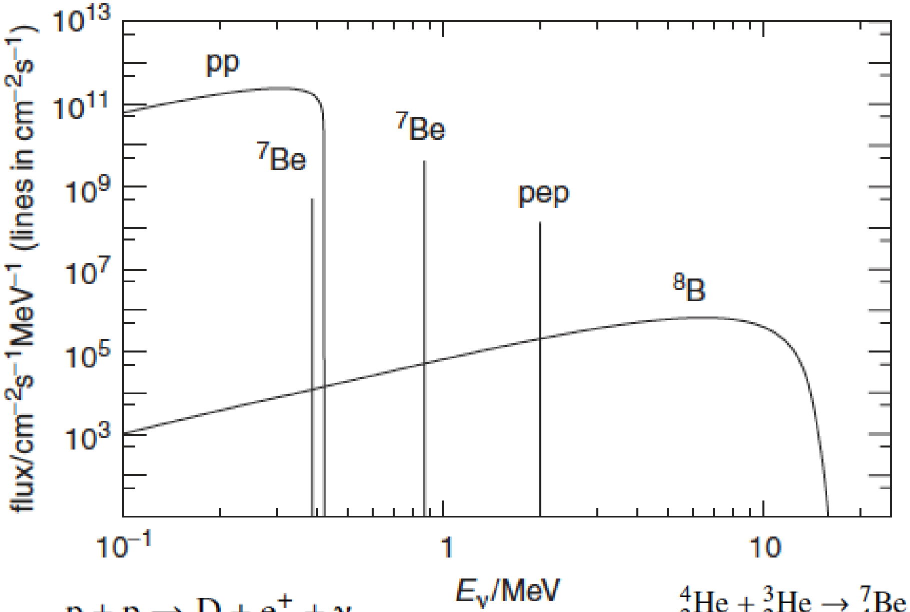







Fit results: μ = 0.02 ^{o}, σ = 2.21 ^{o}
Fit results:
μ=0.02, σ=2.21
fit
simulations(9180 events)
Events
500
400
300
200
100
0
−15
−10
−5
0
5
10
$\Theta_{true} - \Theta_{RF}(^{o})$
Fit results: μ = 0.13 ^{o}, σ = 4.95 ^{o}
Fit results:
μ=0.13, σ=4.95
fit
simulations(9180 events)
Events
500
400
300
200
100
0
−20
−10
0
10
20
$\phi_{true} - \phi_{RF}(^{o})$
Fit results: μ = 2.65 ^{o}, σ = 1.58 ^{o}
simulations
median=2.43^{0}
Events
500
400
300
200
100
0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
$3d - angle(^{o})$

Ηλιακά νετρίνα



$$p + p \rightarrow D + e^+ + \nu_e,$$

$$D + p \rightarrow {}^3_2\mathrm{He} + \gamma,$$

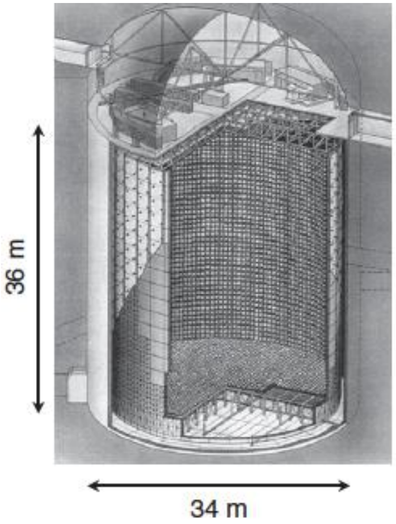
$${}^3_2\mathrm{He} + {}^3_2\mathrm{He} \rightarrow {}^4_2\mathrm{He} + p + p.$$

$${}^4_2\mathrm{He} + {}^3_2\mathrm{He} \rightarrow {}^7_4\mathrm{Be} + \gamma,$$

$${}^7_4\mathrm{Be} + p \rightarrow {}^8_5\mathrm{B} + \gamma,$$

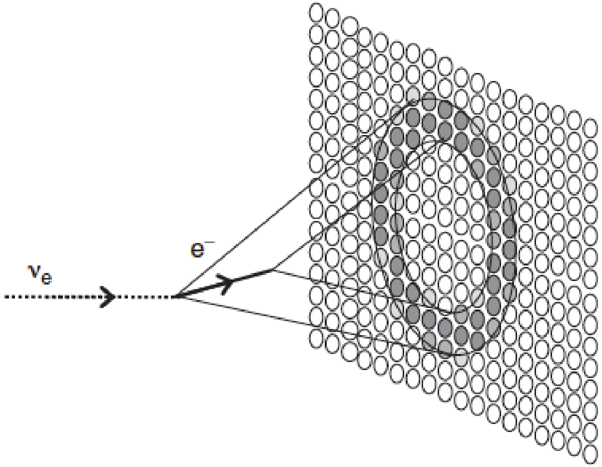
$${}^8_5\mathrm{B} \rightarrow {}^8_4\mathrm{Be}^* + e^+ + \nu_e$$

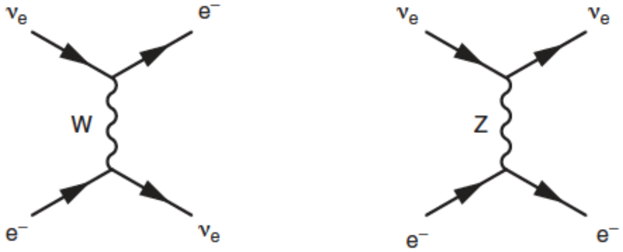
Super-Kamiokande



50 000 tons of water

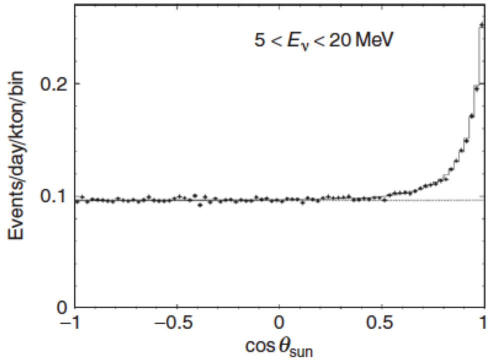
11 146 PMTs.



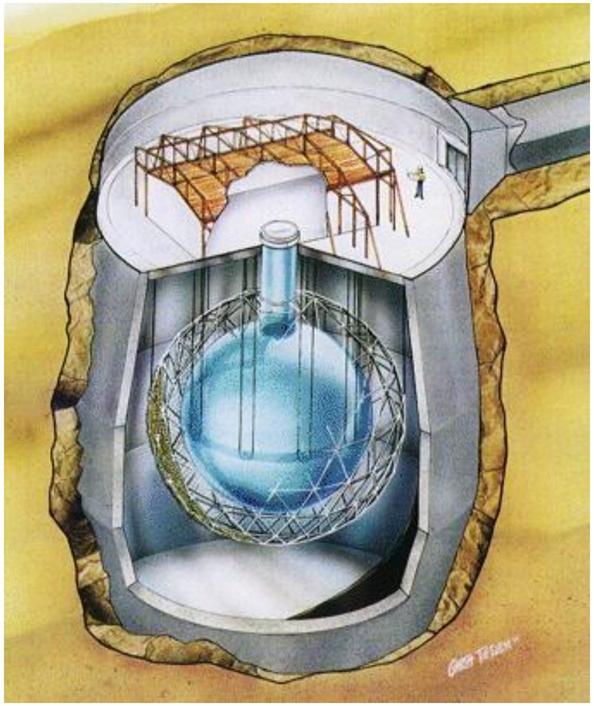


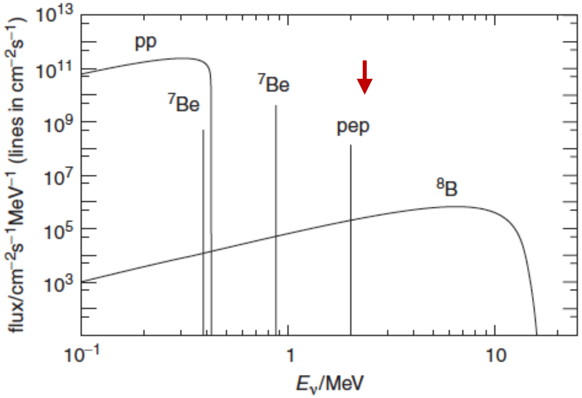
Υψηλό ενεργειακό κατώφλι για: $\nu_e + {}^{16}_{8}\mathrm{O} \rightarrow {}^{16}_{9}\mathrm{F} + e^-$

- Ο αριθμός Ch φωτονίων προσφέρει εκτίμηση της ενέργειας
- Στο ΣΚΜ $\frac{d\sigma_{\nu q}}{d\Omega^*} = \frac{G_F^2}{4\pi^2}\hat{s},$, αλλά στο ΣΕ η διεύθυνση του e πλησιάζει στην διεύθυνσι

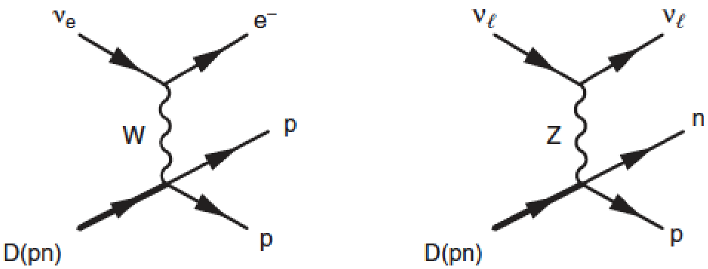


Sudbury Neutrino Observatory (SNO – Canada)





12m diameter vessel
1000 tons , D_2O
9,600 PMTs



D binding energy= 2.2MeV

$$\nu_e + D \rightarrow e + p + p$$

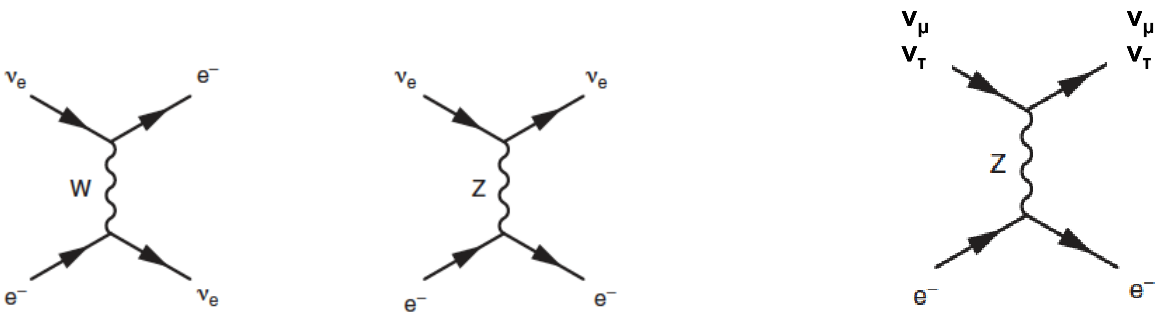
Το e ανιχνεύεται από Ch ring, αλλά έχει ισοτροπική γωνιακή κατανομή και δεν δείχνει την διεύθυνση του Ηλίου

$$\text{CC rate} \propto \phi(\nu_e)$$

$$n + {}^2_1H \rightarrow {}^3_1H + \gamma$$

Το γ (6.25 MeV) θα καταλήξει σε e που ανιχνεύονται από Ch, αλλά έχει ισοτροπική γωνιακή κατανομή και δεν δείχνει την διεύθυνση του Ηλίου.
Επίσης $n + {}^{35}Cl \rightarrow {}^{36}Cl + \gamma$(8 MeV)

$$\text{NC rate} \propto \phi(\nu_e) + \phi(\nu_\mu) + \phi(\nu_\tau)$$

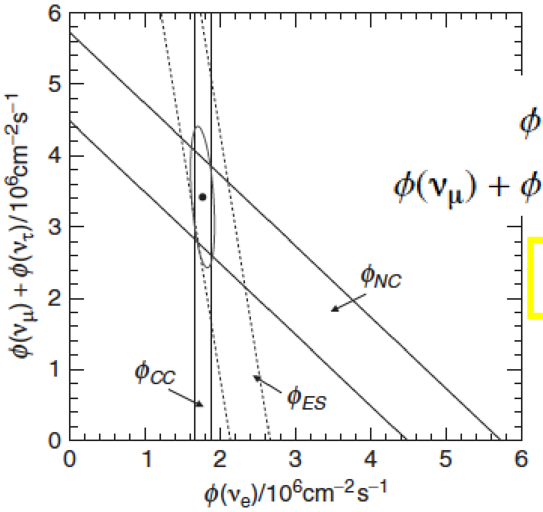


$$\text{ES rate} \propto \phi(\nu_e) + 0.154\left[\phi(\nu_\mu) + \phi(\nu_\tau)\right]$$

$$\text{CC rate} \propto \phi(\nu_e)$$

$$\text{NC rate} \propto \phi(\nu_e) + \phi(\nu_\mu) + \phi(\nu_\tau)$$

$$\text{ES rate} \propto \phi(\nu_e) + 0.154\left[\phi(\nu_\mu) + \phi(\nu_\tau)\right]$$



$$\phi(\nu_e) = (1.76 \pm 0.10) \times 10^{-6}\,\text{cm}^{-2}\,\text{s}^{-1}$$

$$\phi(\nu_\mu) + \phi(\nu_\tau) = (3.41 \pm 0.63) \times 10^{-6}\,\text{cm}^{-2}\,\text{s}^{-1}$$

$$\boxed{\phi(\nu_e)_{pred} = (5.1 \pm 0.9) \times 10^{-6}\,\text{cm}^{-2}\,\text{s}^{-1}}$$