Innovational Research Incentives Scheme
Grant application form 2008
Please refer to Explanatory Notes when completing this form

NWO
Vidi scheme

Registration form (basic details)

1a. Details of applicant

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-Doctorate (date: dd/mm/yy):	08/06/04
-Use of extension clause (see Notes):	no

1b. Title of research proposal
Exploring the Cosmos with Neutrinos

1c. Summary of research proposal (291 words)

The detection of high energy cosmic neutrinos will greatly advance our knowledge of high energy astrophysics as well as fundamental particle physics. Neutrinos carry information on the physics of the most energetic objects in the Universe, such as Gamma Ray Bursts and Active Galactic Nuclei, which are thought to accelerate particles up to energies far beyond the reach of man-made accelerators. Moreover, cosmic neutrinos may provide information on the particle nature for the mysterious dark matter.

The discovery of neutrino flavour oscillations a few years ago has exciting implications for the prospect of detecting high energy cosmic neutrinos. While traditionally muon neutrinos are considered, neutrino oscillations result in equal fluxes of the three neutrino types: ν_e, ν_μ and ν_τ. I propose to use all three types in the search for cosmic neutrino sources and in their subsequent study. This will increase the discovery potential and enhance the study of the energy spectra. I will develop specialised experimental methods for the reconstruction and classification of the different signatures produced by the three neutrino types, and their combination into the most sensitive exploration of the neutrino sky.

Several European projects are underway to build neutrino telescopes at the bottom of the Mediterranean Sea. The Antares detector is currently 80% complete and is entering the data-taking phase. At the same time, members of the European neutrino telescope community have formed the KM3NeT consortium which aims at the construction of a larger, more sensitive detector in the near future. These projects offer an unprecedented opportunity for studying the universe in a completely novel way. The program outlined in this VIDI proposal will result in the most powerful study of cosmic neutrino sources performed with Antares and enable detailed follow-up studies with KM3NeT.

keywords: astroparticle physics, neutrino astronomy, Antares, KM3NeT

1d. NWO Council area N
1e. Host institution The FOM institute for subatomic physics Nikhef

Research proposal

2. Description of the proposed research (3788 words)

2a. Research topic – Exploring the Cosmos with Neutrinos

Introduction

Most of our knowledge about the universe has been obtained through the observation of photons. In recent years, many intriguing sources of high energy (~10^{12} eV) gamma rays have been discovered [1]. However, at higher energies photons have considerable drawbacks for studying these objects. They are easily absorbed by matter in the source region. Moreover, at energies >10^{14} eV, photons are absorbed by the cosmic microwave background radiation, which means that they cannot reach us even from nearby galaxies.

A strong motivation for studying the universe at very high energies is formed by Cosmic Rays (CRs), which consist of protons and other nuclei that are accelerated somewhere in the Universe up to energies (10^{20} eV) that greatly exceed the reach of man-made particle accelerators. (The LHC accelerator that will turn on next year in Geneva, Switzerland, will reach 1.4×10^{12} eV.) Very recently, in October 2007, the Pierre Auger collaboration reported the first evidence that, at these energies, the CRs originate in nearby galaxies [2], where they are presumably accelerated in 'Active Galactic Nuclei' (AGN) associated with the super-massive black hole at the centre. However, due to the deflection by the magnetic fields in the Universe, the CRs only point back to their sources at the very highest energies, precluding detailed studies of a source's energy spectrum, which conveys the information on the acceleration mechanism. Moreover, in this way, only relatively close-by objects can by studied.

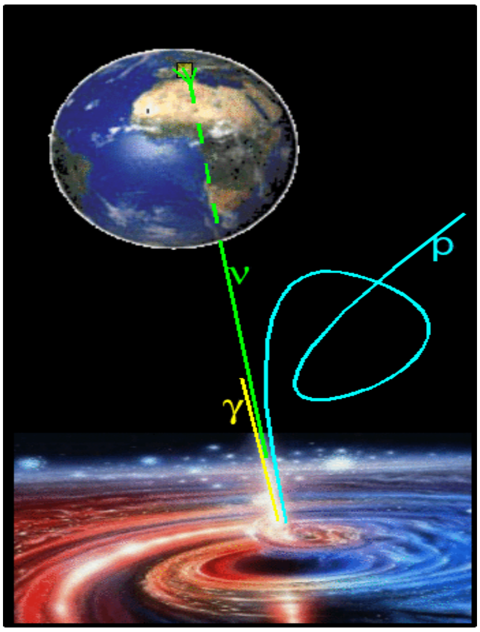

Figure 1: Cartoon depicting the motivation for using neutrino astronomy to study a cosmic source at the bottom. The produced high energy photons cannot travel through the universe, protons typically do not point to their source. Only the neutrinos travel through the Universe unhindered and in straight lines.

To study the Universe at energies beyond the range accessible to photons, and to 'look' deep inside the astrophysical objects where acceleration processes take place, another messenger particle can be used: the neutrino. Interacting only weakly with matter, neutrinos carry information from regions of space that are opaque to high energy photons. In contrast to protons, they are not deflected by magnetic fields, which means they point back to their sources. A wide range of objects is predicted to produce neutrinos. Their study will teach us about the physics of the most energetic phenomena in the Universe. With the Antares telescope currently coming online and the prospect of the KM3NeT observatory in the near future, there now is an excellent opportunity to explore the high energy Universe with neutrinos.

In this VIDI proposal I present a scheme to find and study sources of neutrinos in the most sensitive way possible. This scheme takes into account the recently discovered phenomenon of neutrino flavour oscillations, which gives us the opportunity to use neutrinos of the electron and tau type, in addition to the traditionally considered muon neutrinos. The additional signal will enhance the discovery potential. Moreover, due to the superior energy resolution for electron and tau neutrinos, this scheme will bring extra power to the study of their spectra which convey information on the physics of the source. This will allow us to optimally address some of the most pressing questions in both high energy astronomy and particle physics.

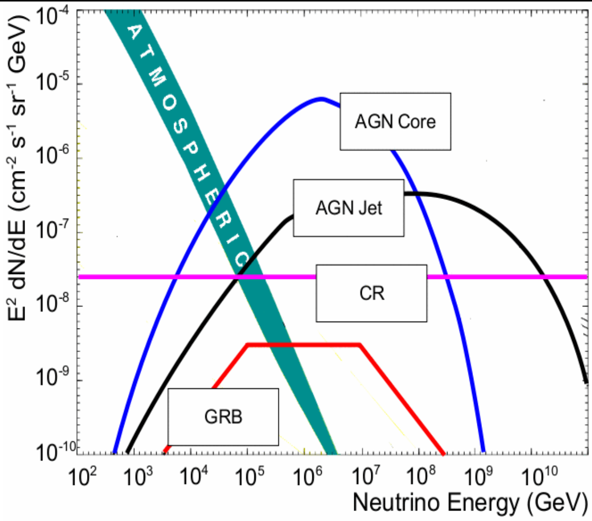

Figure 2: Model predictions of neutrino fluxes. Two models of AGN are shown, where the neutrinos originate in the core of the AGN , and in the relativistic jets of matter that are observed to eminate from some AGN. Also shown is a model for GRBs, and a generic model of the flux of neutrinos associated with the sources of the highest energy cosmic rays. (figure based on [6])

Discovery potential

Since neutrino telescopes study the sky in a completely novel way, they may well discover new, unexpected phenomena. However, there are also many models predicting neutrino production in known astrophysical objects. A few of the most exciting potential sources of cosmic high energy neutrinos are listed below.

- Active Galactic Nuclei
  In some galaxies, matter is accreted onto the super-massive black holes that inhabit the galactic centre, which causes strong non-thermal activity. These AGN have long been considered a natural candidate source for the extragalactic component of the cosmic rays. The recent observations by the Pierre Auger experiment [2] show exciting evidence supporting this notion. If AGN accelerate cosmic rays, they will also produce neutrinos. To study the acceleration mechanism, a measurement of the energy spectrum over a broad range is of key importance. However, only at the very high end of the spectrum do the CRs point back to their source. Neutrinos can be used over a large energy range and will therefore be vital for obtaining information on the physics of the source which is not obtainable from CR observations.

- Gamma Ray Bursts
  Gamma ray bursts (GRB) are short eruptions of gamma rays that are observed over cosmological distances (billions of light years). Models [3] predict that protons are accelerated in these explosions, which will also lead to the production of neutrinos, whose spectra convey the physics of the GRB. Neutrinos from GRBs are particularly interesting experimentally as the short duration of the burst allows us to look for associated neutrinos in a short time-window, making the search essentially background free.

- Galactic Supernova Remnants
  In our Galaxy, several spectacular sources of TeV gamma rays have been discovered [1]. Among them are expanding shells of matter which are the result of supernova explosions. The spectra show clear indications of particle acceleration. However, it is a matter of lively debate [4] whether some of these

objects are sites of proton acceleration. If they are, then they may be the origin of the galactic cosmic rays. Detecting neutrinos would settle the debate as it would be strong evidence for proton acceleration in these sources.

- <u>Dark Matter Particles</u>
  A question directly related to fundamental particle physics – and indeed one of the most intriguing ones – is the nature of dark matter. Astronomical observations show that 85% of the matter in the Universe consists of particles unknown to physicists. Models of dark matter based on extensions of the Standard Model of particle physics predict that the particles will congregate in massive objects such as the Sun or the Galactic centre, where they annihilate and produce high energy neutrinos [5]. If these neutrinos can be observed, they will yield invaluable clues on the nature of the dark matter particles.

All these sources produce a common experimental signature: an excess of neutrinos from one or more points in the sky. Therefore, rather than focussing on specific models, we should optimize the methods to search for this universal signature of point-like neutrino sources. Once sources are discovered, cross-correlating with optical observations allows identification of the objects and the neutrino spectra allow us to test models describing the physics of the sources.

Neutrino astronomy & flavour oscillations

Neutrinos are the ideal messenger particle to study acceleration sites of Cosmic Rays (CRs) as they will inevitably be produced when the CR protons interact with ambient matter or photons in the source region. This interaction produces charged pions, which subsequently decay into neutrinos[1]; e.g.:

$$p^+ + \gamma \rightarrow n + \pi^+ \text{ , with } \pi^+ \rightarrow \mu^+ \nu_\mu \text{ , followed by } \mu^+ \rightarrow e^+ \nu_e \nu_\mu . \quad (1)$$

The resulting neutrino energy spectrum closely mimics the proton spectrum and it can therefore be used to study the physics of the acceleration process.

Neutrinos exist in three varieties, called flavours: the electron neutrino ν_e, the muon neutron ν_μ, and the tau neutrino ν_τ. Each is associated with one of the three charged leptons: the electron, the muon, and the tau lepton. The production process (1) yields mostly muon neutrinos. Therefore, neutrino telescopes have traditionally been conceived as detectors of the muons that are produced in the charged current interactions of ν_μ. But recent discoveries in particle physics invite a more inclusive approach.

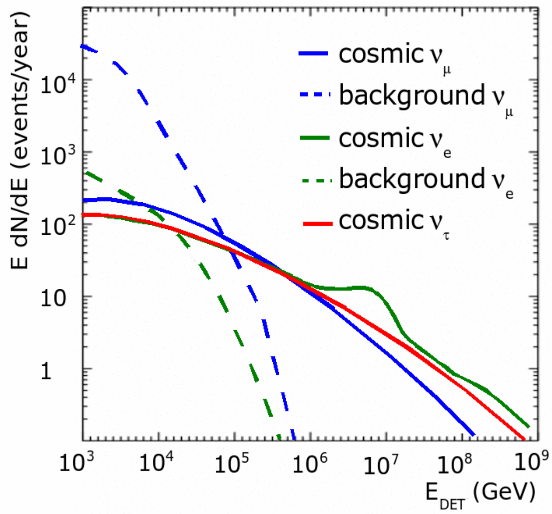

Figure 3: Predicted event rates in a km^3-scale detector for ν_e and ν_τ and for upgoing ν_μ as a function of the energy of the detected particles. The solid lines are for a generic cosmic neutrino spectrum (labeled 'CR' in Figure 2) . Dashed lines show the atmospheric neutrino background for muon and electron neutrinos. Around $E=6\times10^6$ GeV, the interaction rate of ν_e is enhanced by resonant scattering on atomic electrons. (figure based on [7]).

[1]We do not distinguish between neutrinos and anti-neutrinos. The last part of the reaction, the muon decay, is suppressed in sources with strong magnetic fields, where the muons loose their energy via synchrotron radiation before decaying.

A few years ago, various experiments studying neutrinos[2] produced in the atmosphere and in the Sun [8] showed conclusive evidence that neutrinos spontaneously change flavour as they propagate through space. The discovery of these 'neutrino flavour oscillations' revolutionized particle physics and showed that neutrinos have a small but non-zero mass, which may hint of new physics beyond the Standard Model of particle physics. There are also far-reaching implications for high energy neutrino astronomy.

While cosmic neutrino sources mostly produce neutrinos of the ν_μ variety, flavour oscillations will transform these neutrinos into mixture of ν_e, ν_μ and ν_τ as they travel through space. For all cosmic sources of neutrinos, the distance is so large that, on Earth, all flavours are equally abundant. That is: regardless of the exact composition at production, on Earth the fluxes of ν_e, ν_μ and ν_τ will be equal!

It turns out that the previously unanticipated ν_e and ν_τ can also be detected by high energy neutrino observatories. I propose to fully exploit these events. Including them will increase the sensitivity by the increase of the data sample, which approaches a factor 3 for large detectors (see Figure 3). Moreover, the three neutrino types leave signatures in the detector that make them truly complementary from an experimental point of view. While ν_μ offer excellent pointing resolution, ν_e and ν_τ have strongly reduced backgrounds and offer superior energy resolution, which makes them of key importance for studying the spectra, which convey the physics of the sources.

Furthermore, as the equality of fluxes is a robust prediction from our current understanding of particle physics, measuring the ratio of fluxes will offer a test of several scenarios of new physics. Examples [9] include exotic models in which neutrinos decay and scenarios with strong CP violation in neutrino mixing, which would be exciting since it links to the matter-antimatter asymmetry in the Universe.

2b. Approach

Neutrino Telescopes

The properties that make the neutrino the ideal messenger particle, also make it difficult to detect. Most neutrinos pass through the Earth without ever leaving a trace. Due to this low interaction probability, neutrino observatories require very large detection volumes. To achieve this, they use a natural volume of sea water, which is turned into a sensitive detector by instrumenting it with light sensitive detectors; see Figure 4. When a neutrino interacts with a proton or neutron in or near the instrumented volume, charged particles such as electrons and muons, are produced, which emit visible light by means of the Cherenkov effect. The highly energetic neutrino produces secondary particles with high energy, which makes their Cherenkov light detectable with the sparsely instrumented detector. Due to the large background from down-going atmospheric muons, muons are required to be up-going, since such muons can only be caused by neutrinos that have traversed the Earth.

The detection technique has been proven to work in Antarctic ice [10] by the Amanda detector. Its larger successor, called IceCube, is currently under construction. By using water instead of ice, detectors in the Mediterranean Sea offer an improved directional resolution, which enhances the power of neutrino source searches. Moreover, their geographical location allows these detectors to observe several important sources that are not easily observable from the South Pole, including the Galactic Centre and many of the AGN from which Auger may have detected cosmic rays.

[2]These experiments detect neutrinos of much lower energy and different physical origin. There is little overlap in the science goals between these experiments and high energy neutrino telescopes.

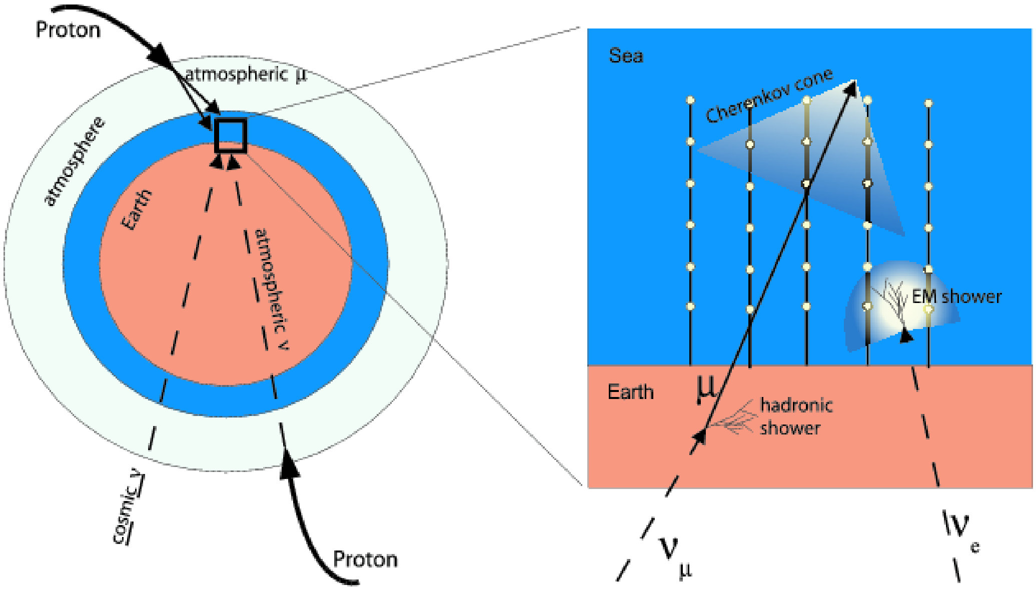

Figure 4: Detection principle of a neutrino telescope. Muon neutrino interactions produce a muon, which traverses the full detector. Electron (and some tau) neutrinos produce a localised shower of secondary charged particles. The Cherenkov light produced by these particles is detected by an array of sensors, located along vertical strings. The main backgrounds consists of down-going atmospheric muons and up-going muons produced by atmospheric ν_μ.

The research I propose involves two neutrino telescope projects.

- **ANTARES:** The Antares collaboration [11] is currently completing the first high energy neutrino observatory in the Mediterranean Sea. Near Toulon, France, 40 km off the coast, at a depth of 2.4 km, 900 photo-detectors will monitor a water volume of roughly 200x200x400 m^3. Currently, the construction is ~80% complete and the first (atmospheric) neutrinos have already been detected; see Figure 5.

- **KM3NeT:** Initiatives for the construction of a much more sensitive detector are already well under way. While Antares may discover the first cosmic neutrino sources, a larger detector is likely to be needed to study them in detail. In 2006, the KM3NeT consortium[3] was formed, consisting of members of Antares and two other pilot projects aimed at the construction of a large neutrino telescope: Nemo and Nestor [12]. The KM3NeT detector will have an instrumented volume of at least 1 km^3 and will be a factor 20 more sensitive than Antares. The project will soon be entering the prototyping phase.

The experimental program I propose would initially be implemented within the Antares experiment. It will lead to the most sensitive search for sources of high energy neutrinos, which will be a major result of the experiment. While KM3NeT is not expected to be fully constructed by the end of the this VIDI program, the work will immediately start to provide important input for the design of the KM3NeT detector in order to ensure optimal performance for all three neutrino flavours. When KM3NeT comes on-line, we may already have discovered the first sources and the developed methods can be used to study their spectral characteristics in detail with increased precision.

[3]In 2007, KM3NeT received support in the 6th and 7th Framework Programme of EU, and it appears on the E.U.'s ESFRI list of essential scientific infrastructures.

Experimental signatures in the Detector

All astrophysical neutrino sources of interest present the same basic experimental challenge. The signature consists of an excess of events from a particular direction in the sky over the background of atmospheric neutrinos. Barring exciting new physics, all cosmic sources will produce equal fluxes of ν_e, ν_μ and ν_τ. I believe that a generic search for point-sources using all neutrino flavours is therefore the best approach.

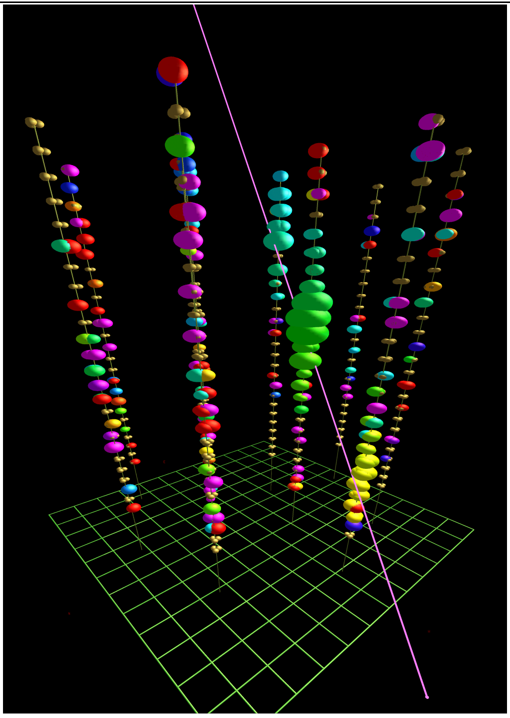

Figure 5: Display of one of the first upgoing muon neutrino candidates detected by the nearly completed Antares detector. The coloured spheres represent pulses of Cherenkov light. The colour encodes the detection time. The purple line is the reconstructed muon trajectory.

The irreducible background to cosmic neutrino sources consists of atmospheric neutrinos, which are produced when cosmic rays interact in the Earth's atmosphere. By randomly forming clusters of events, atmospheric neutrinos can mimic a cosmic source. Clearly, a good directional resolution helps to mitigate this. However, also the energy of the neutrinos can be used to distinguish signal from background. The atmospheric background neutrinos have a known, steeply falling, energy spectrum, whereas most models predict that cosmic neutrinos have a much harder spectrum (see Figure 2). An accurate energy measurement thus enhances the separation between signal and background. The three neutrino types produce different signatures in the detector, which are very complementary in terms of background levels, and angular and energy resolution:

- *muon neutrinos:* The conventionally used ν_μ have many favourable properties for point-source searches. Interactions of a ν_μ produce high energy muons, which can travel for several km through rock or sea-water. They can thus still be detected even when the neutrino interaction takes place far outside the detector. This enhances the detection efficiency. Moreover, the long muon path allows a precise measurement of the muon direction, which benefits the separation between signal and background. However, the energy measurement is poor, as the muons lose a large fraction of their energy before reaching the detector.

- *electron neutrinos:* Interactions of ν_e produce high energy electrons, which initiate an avalanche of secondary photons and electrons with a typical size of a few metres; see Figure 4. Such interactions can only be observed when occurring inside the instrumented volume, which reduces the detection efficiency compared to muon neutrinos. However, in contrast to ν_μ, the requirement that the neutrino is up-going is not needed for ν_e (nor ν_τ). Initial studies [13] show that the direction of the neutrino can be determined with an accuracy of a few degrees, which is inferior to the sub-degree resolutions that will be achieved for muon neutrinos. However, since the reaction products are fully contained in the detector, the ν_e energy can be measured with an accuracy of ~30%, which is vastly superior to ν_μ. Moreover, the atmospheric ν_e background is strongly suppressed compared to the ν_μ background.

- *tau neutrinos:* Tau neutrinos produce a variety of different signatures in the detector, depending on the energy and the decay mode of the produced tau lepton. Many of these events have a topology similar to ν_e, However, if the produced tau lepton is sufficiently energetic to travel a considerable distance before decaying, an experimental signature is produced that is unique to tau neutrinos. These events will be particularly valuable as the atmospheric ν_τ background is virtually absent. The unambiguous detection of even a single high energy ν_τ will therefore be strong evidence for an astrophysical origin.

Triggering and Reconstruction

The detection of neutrinos starts with the development of fast algorithms to identify the events of interest in the ~Tb/s data stream produced by the detector. Currently existing algorithms are optimized to select muon neutrinos with high purity. The Antares trigger system, which was developed at Nikhef, is flexible enough to allow for the inclusion of electron and tau neutrinos. A similar system is foreseen for KM3NeT. Next, we will develop methods to reconstruct the neutrino direction and energy from the observed intensity and timing of the detected Cherenkov light for each of the signatures produced by the three neutrino flavours. This is challenging as it requires incorporating detailed knowledge of the relevant particle physics processes, the (variable) sea water characteristics, and the optical background due to bioluminescent fauna. Having developed the muon reconstruction method currently used in Antares, I am in a unique position to lead this effort.

Calibration

A solid knowledge of the detector response is a prerequisite for a neutrino source search. A large portion of the work will be dedicated to understanding the detector response. The neutrino energy measurement can be calibrated by flashing light sources inside the detector volume. A measurement of the absolute orientation of the detector can be obtained by measuring a deficit in atmospheric muons that is caused by the Moon, which blocks the primary cosmic rays that produce the atmospheric muon flux. By comparing the location of the observed deficit with the know position of the Moon in the sky, the angular orientation of the detector can be determined. This is a crucial cross check as the deployment of the detector relies on a rather complicated cascade of various acoustic positioning systems.

Measuring acceptance and backgrounds

The next step in the quest for cosmic neutrinos sources is a detailed study of the backgrounds. Atmospheric muon and electron neutrinos form the main irreducible background. One of the first publishable results will be a precise measurement of the atmospheric neutrino flux. Besides yielding a detailed understanding of the backgrounds to point source searches, this measurement will characterize the acceptance of the detector using atmospheric muon and electron neutrinos. This study will also allow to quantify other sources of background, such as random configurations of optical background faking neutrino events and the contribution from neutral current neutrino interactions mimicking electron or tau neutrinos.

Combining all information to explore the neutrino sky

The collected sample of neutrino candidates will finally be used to search for sources of high energy cosmic neutrinos, revealing themselves as an excess of events from a particular direction in the sky. This search will incorporate all the information discussed above. Depending on the type of neutrino, each event will have its own angular resolution, energy resolution, and background estimate. In such a search, most of the pointing accuracy will be provided by the muon neutrinos, while even a small number of high purity electron or tau-neutrinos will provide confirmation of the genuineness of the cosmic source.

The observation of a single source with multiple neutrino flavours will greatly enhance the credibility of a claim of discovery. While this qualitative argument is important, it can also be quantified. We will develop the statistical methods to combine the different signatures in an optimal way in order to asses the significance the observed excesses. Having taken responsibility of the combination of channels and the assessment of the statistical significance in the effort that lead to the discovery of B_s oscillations, a major result of the CDF experiment at the Tevatron collider, I have very relevant experience for leading this effort.

2c. Innovation

The idea of exploiting the reduced background and enhanced energy measurement offered by electron and tau neutrinos in the search for high energy cosmic neutrino point-like sources is new in itself. As described above, new several new methods will be developed for identifying and reconstructing events from all three neutrino flavours and for combining them into a single analysis. We will also develop algorithms for classifying the various event topologies. Here, we will benefit from innovative multivariate classification methods such as neural networks and boosted decision trees.

The need for extensive detector simulations and the analysis of the large data volumes produced by Antares and KM3NeT will put high demands on the computing infrastructure. We will profit from ongoing innovations in distributed computing, known as the GRID, in which Nikhef plays a leading role.

2d. Plan of work

The program will start in 2009, after the completed Antares detector has been taking data for about one year. By this time, the behaviour of the detector will be understood well enough to start implementing reconstruction and classification algorithms for all neutrino flavours, which incorporate full knowledge of the water properties, detector response and optical background. A group of two PhD students and a post-doc, together with the applicant, would carry out the research program.

PhD student 1 will first focus on measuring muon neutrinos, which remain a pillar of any point-source search. This will include a measurement of the atmospheric ν_μ flux and lead to the first publication on point-sources from Antares by 2011.
PhD student 2 will develop methods to reconstruct electron neutrinos and use these methods to measure, for the first time, the small but observable atmospheric flux of high energy electron-neutrinos with Antares (to be published by 2012).
The post-doc will develop the methods needed for detecting tau neutrinos and the event classification. This may lead to the first unambiguous detection of a tau-neutrinos, which would be strong evidence for a cosmic origin.
The applicant will start by developing trigger algorithms for Antares to ensure all useful neutrino events are stored for analysis. While the reconstruction methods are being developed, he will develop the statistical methods to combine the events, leading to the most sensitive search using Antares before the end of the VIDI program. In parallel, he will provide early input into the KM3NeT design in order to maximize the physics potential using all neutrino types.

National and international collaboration

In Antares, 24 institutions, specialised in particle physics, astronomy and oceanography, from seven European countries collaborate. All of them also participate in the KM3NeT project. While the plan of work above will position the core of the research program with my group, there will be many opportunities of collaboration with colleagues in these experiments, which I will actively pursue. The proposed work will be carried out at the FOM institute for subatomic physics Nikhef. The Nikhef group has a strong presence in both projects. In Antares, they are responsible for the data acquisition and trigger systems, providing indispensable know-how for developing the triggering scheme for all neutrino flavours. In KM3NeT, the group is actively involved in the conceptual detector design to which we will contribute in order to guarantee optimal performance for ν_e and ν_τ in addition to ν_μ. Structural funding for the Nikhef astroparticle physics program was recently obtained from FOM. There are excellent relations with the astronomical institute 'Anton Pannekoek', which is physically located in the same building and which maintains a world-class reputation in high-energy astrophysics. Collaboration with the astronomical community will be of prime importance, particularly once we have discovered the first cosmic sources of neutrinos and will commence the study of the physics that drives them.

2e. Literature references

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[11] project web sites: http://antares.in2p3.fr , http://www.km3net.org

[12] project web sites: http://nemoweb.lns.infn.it/ , http://www.nestor.noa.gr/

[13] B. Hartmann, (PhD Thesis), University of Erlangen, 2006, arXiv:astro-ph/0606697v1

Cost estimates

3a. Budget

	2009	2010	2011	20012	20014	TOTAL
Staff costs: (in k€)						
Applicant						
Post-doc	49	53	56			158
PhD student1 PhD student1	35	42 35	45 42	48 45	 48	170 170
Support staff						
Non-staff costs: (k€)						
Equipment	6	4	4	2		16
Consumables						
Travel and subsistence	16	24	24	16	6	86
Other						
TOTAL	106	158	171	111	54	600

Since the Antares and KM3NeT experiments are international collaborations, travel will be frequent. Material expenses mainly cover the cost for computing equipment. The Salary of the applicant will be paid by Nikhef.

3b. Indicate the time (percentage of fte) you will spend on the research
100%

3c. Intended starting date
February 2009

3d. Have you requested any additional grants for this project either from NWO or from any other institution? no

Curriculum vitae

4a. Personal details
Title(s), initial(s), first name, surname: Dr. Adriaan Jacob Heijboer
Male/female: Male
Date and place of birth: 31-10-1975, Breda
Nationality: Dutch
Birth country of parents: Netherlands

4b. Master's ('Doctoraal')
University/College of Higher Education: University of Amsterdam
Date (dd/mm/yy): 31/10/1998
Main subject: Physics

4c. Doctorate
University/College of Higher Education: University of Amsterdam
Date (dd/mm/yy): 08/06/2004
Supervisor ('Promotor'): Prof. Dr. J.J. Engelen
Title of thesis: Track Reconstruction and Point Source Searches with ANTARES

4d. Work experience since graduating
(per appointment: fte, tenured term ('vast') / fixed-term ('tijdelijk') and supervisory responsibilities if any)
Oct 2004 – current, Postdoctoral Research Associate, University of Pennsylvania, full-time, fixed-term

4e. Man-years of research
(see Notes)
3 years, 2 months

4f. Brief summary of research over last five years (327 words)

PhD student: (Jan 1999 – June 2004)

In Antares, I developed and implemented the algorithm to reconstruct muon neutrinos. This method is now used to analyse the first data of the Detector. I was also responsible for developing the first multivariate technique to search for point-like sources of muon neutrinos by using information on both the neutrino direction and energy to discriminate signal from background. Other work included: Analysis of data taking with a prototype detector, developing several software packages to compute event rates, and authoring the Antares event display: a program to make graphical images of the observed data (see Figure 5).

Post-Doc (October 2004 – Present)

After graduating, I joined the CDF experiment at the Tevatron proton-antiproton collider at Fermilab, near Chicago. I contributed to measurement of B_s oscillations. The B_s meson (which consists of an anti-beauty and a strange quark) spontaneously transforms back and forth between its particle and anti-particle state. We made first definite observation of this phenomenon, and measured the oscillation frequency with an accuracy of ~1%. This was a flagship measurement for the Tevatron program[4]. I took responsibility for combining results from different channels into the final measurement and to asses the statistical significance of the signal.

After the discovery of B_s oscillations, I have directed my research in CDF towards a search for the Higgs Boson – the last undetected cornerstone of the Standard Model of particle physics. I am performing a Higgs search in a channel that was hitherto unexplored at Run II of the Tevatron: associated production of a Higgs and vector boson, with the vector boson decaying hadronically.

While at CDF, I have also been responsible for the alignment of the Silicon sub-detector. For the duration of 2006, I have co-led a working group dedicated to technical aspects of B-physics analysis. In 2007, I have contributed to an effort to optimize the CDF trigger system for the detection of the Higgs boson.

4g. International activities

- Extensive experience in large, international collaborations: Antares, CDF
- Since Oct 2004, employed in United States.

4h. Other academic activities

- As a PhD student I have been an assistant for physics students during the exercise sessions for courses on special relativity course and scientific computer programming.
- From Jan 2005 to Jan 2006, I was co-convener of a working group in CDF that is devoted to technical aspects of B-physics analysis.
- While working on CDF, I have retained a level of activity in Antares. In February 2007, I was the first to reconstruct neutrino candidates in the partially completed detector. Furthermore, I frequently produce PR images (such as Figure 5) and animations for the collaboration, using the event display program that I authored.

4i. Scholarships and prizes

- In June 2007, I have been awarded a CERN fellowship, which will start May 2008.

[4]The two CDF publications on this are the first and fourth most cited experimental high energy physics papers of 2006.

List of publications

5. Publications:

Note on Author list in experimental High Energy Physics publications
By convention, articles published by (astro)particle physics experiments list all collaboration members as authors in strict alphabetical order. This policy reflects the substantial efforts in detector construction and maintenance, data acquisition, data reconstruction and calibration that all collaborators contribute to and which is a prerequisite to any data analysis. As a member of the Antares and CDF collaborations I have signed over 80 publications. Here, I present a brief selection of the publications to which I made a significant direct contribution separately from the complete list of published papers.

Selected publications & conference proceedings

- (S) "Point source searches with the ANTARES neutrino telescope"
  A. Heijboer , on behalf of the ANTARES Collaboration, proc. ICRC 2003, Tsukuba, Japan, 31 Jul - 7 Aug 2003.
- "Measurement of the Bs anti-Bs oscillation frequency", A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 97, 062003 (2006)
- "Observation of Bs anti-Bs oscillations" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 97, 242003 (2006)

- Average impact factors for your own field (only compulsory if your proposal is to be submitted to Medical Sciences, see Notes).

- International (refereed) journals (Full publication list)

1. "Search for chargino-neutralino production in p-pbar collisions at 1.96 TeV with high pT leptons" T. Aaltonen et al. [CDF Collaboration] Phys. Rev. Lett. 99, 191806 (2007)
2. "Search for new physics in high mass electron-positron events in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV" T. Aaltonen et al. [CDF Collaboration] Phys. Rev. Lett. 99, 171802 (2007)
3. "Search for a high-mass diphoton state and limits on Randall-Sundrum gravitons at CDF" T. Aaltonen et al. [CDF Collaboration] Phys. Rev. Lett. 99, 171801 (2007)
4. "Observation and mass measurement of the baryon Xi− " T. Aaltonen et al. [CDF Collaboration] Phys. Rev. Lett. 99, 052002 (2007)
5. "First Measurement of the W Boson Mass in Run II of the Tevatron" T. Aaltonen et al. [CDF Collaboration] Phys. Rev. Lett. 99, 151801 (2007)
6. "First observation of heavy baryons Σb and $\Sigma*$ " T. Aaltonen et al. Phys. Rev. Lett. 99, 202001 (2007)
7. "Measurement of the $p\bar{p} \to tt$ production cross- section and the top quark mass at 1.96 TeV in the all-hadronic decay mode" T. Aaltonen et al. [CDF Collaboration] Phys. Rev. D 76, 072009 (2007)
8. "Search for New Particles Leading to Z+ jets Final States in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV" T. Aaltonen et al. [CDF Collaboration] Phys. Rev. D 76, 072006 (2007)
9. "Measurement of the top-quark mass using missing ET + jets events with secondary vertex b−tagging at CDF II" T. Aaltonen et al. [CDF Collaboration] Phys. Rev. D 75, 111103 (2007)
10. "Search for heavy, long-lived particles that decay to photons at CDF II" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 99, 121801 (2007) [arXiv:0704.0760 [hep-ex]]
11. "Polarization of J/ψ and $\psi 2S$ mesons produced in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 99, 132001 (2007)
12. "Precise measurement of the top quark mass in the lepton+jets topology at CDF II" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 99, 182002 (2007)
13. "Measurement of $\sigma\chi c2\ B(\chi c2 \to J/\psi\gamma)/\sigma\chi c1\ B(\chi c1 \to J/\psi\gamma)$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV" A. Abulencia et al. Phys. Rev. Lett. 98, 232001 (2007)
14. "The ANTARES optical beacon system" M. Ageron et al. [ANTARES Collaboration] Nucl. Instrum. Meth. A 578, 498 (2007)
15. "Inclusive search for new physics with like-sign dilepton events in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 98, 221803 (2007)
16. "First Measurement of the Ratio of Central-Electron to Forward-Electron W Partial Cross Sections in p-pbar Collisions at sqrts = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] , Phys. Rev. Lett. 98,

251801 (2007)

17. "Search for new physics in lepton + photon + X events with 929 pb(−1) of pp̄ collisions at √ s = 1.96 TeV" A. Abulencia et al. Phys. Rev. D 75, 112001 (2007)
18. "Observation of W Z Production" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 98, 161801 (2007)
19. "Measurement of the Inclusive Jet Cross Section using the kT algorithm in pp̄ Collisions at √ s = 1.96 TeV with the CDF II Detector" A. Abulencia et al. [CDF - Run II Collaboration] Phys. Rev. D 75, 092006 (2007) [Erratum-ibid. D 75, 119901 (2007)]
20. 20. "Search for anomalous production of multi-lepton events in pp̄ collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 98, 131804 (2007)
21. "Search for Exotic S = −2 Baryons in pp̄ Collisions at √ s = 1.96 T eV " A. Abulencia et al. [CDF Collaboration] Phys. Rev. D 75, 032003 (2007)
22. "Measurement of the Top Quark Mass in p̄ Collisions at √s = 1.96 TeV using the Decay Length Technique" A. Abulencia et al. [CDF - Run II Collaboration] Phys. Rev. D 75, 071102 (2007) [arXiv:hep-ex/0612061]
23. "Precision measurement of the top quark mass from dilepton events at CDF II" A. Abulencia et al. [CDF - Run II Collaboration] Phys. Rev. D 75, 031105 (2007) [arXiv:hep-ex/0612060]
24. 24. "Analysis of the quantum numbers J(PC) of the X(3872)" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 98, 132002 (2007) [arXiv:hep-ex/0612053]
25. "Measurement of the top-quark mass in all-hadronic decays in p anti-p collisions at CDF -II" T. Aaltonen et al. Phys. Rev. Lett. 98, 142001 (2007) [arXiv:hep-ex/0612026]
26. "Measurement of the B+ production cross section in p anti-p collisions at s**(1/2) = 1960 GeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. D 75, 012010 (2007)
27. "Measurement of the Helicity Fractions of W Bosons from Top Quark Decays using Fully Reconstructed tt Events with CDF II" A. Abulencia et al. [CDF II Collaboration] Phys. Rev. D 75, 052001 (2007)
28. "Observation of exclusive electron positron production in hadron hadron collisions" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 98, 112001 (2007) [arXiv:hep-ex/0611040]
29. "Search for W′ boson decaying to electron-neutrino pairs in p anti-p collisions at s**(1/2) = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. D 75, 091101 (2007)
30. "Measurement of the ratios of branching fractions B(Bs0 → Ds- pi+ pi+ pi-)/B(B0 →D- pi+ pi+ pi-) and B(Bs0 → Ds- pi+)/B(B0 → D- pi+)" A. Abulencia et al. [CDF - Run II Collaboration] Phys. Rev. Lett. 98, 061802 (2007)
31. "The data acquisition system for the ANTARES neutrino telescope" J. A. Aguilar et al. [ANTARES Collaboration] Nucl. Instrum. Meth. A 570, 107 (2007)
32. "Observation of Bs0 anti-Bs0 oscillations" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 97, 242003 (2006)
33. "Measurement of the Lambda/b0 lifetime in Lambda/b0 → J/psi Lambda0 in p anti-p collisions at s**(1/2) = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 98, 122001 (2007)
34. "Search for V + A current in top quark decay in p anti-p collisions at s**(1/2) = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 98, 072001 (2007)
35. 36. "Measurement of the tt Production Cross Section in pp̄ collisions at √s = 1.96 TeV in the All Hadronic Decay Mode" A. Abulencia et al. [CDF - Run II Collaboration] Phys. Rev. D 74, 072005 (2006) [arXiv:hep-ex/0607095]
36. "Measurement of the tt Production Cross Section in pp̄ collisions at √s = 1.96 TeV using Lepton + Jets Events with Jet Probability b− tagging" A. Abulencia et al. [CDF Collaboration] Phys. Rev. D 74, 072006 (2006)
37. "Observation of B0s → K+ K− and Measurements of Branching Fractions of Charmless Two-body Decays of B0 and Bs Mesons in pp̄ Collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 97, 211802 (2006) [arXiv:hep-ex/0607021]
38. "Search for excited and exotic muons in the μγ decay channel in pp̄ collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 97, 191802 (2006)
39. "Measurement of the Bs − Bs Oscillation Frequency" A. Abulencia et al. [CDF - Run II Collaboration] Phys. Rev. Lett. 97, 062003 (2006) [arXiv:hep-ex/0606027]
40. "First results of the instrumentation line for the deep-sea ANTARES neutrino telescope" J. A. Aguilar et al. [ANTARES Collaboration] Astropart. Phys. 26, 314 (2006)
41. "Measurement of the t anti-t Production Cross Section in p anti-p Collisions at √s = 1.96 TeV"
42. A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 97, 082004 (2006)43. "Search for a neutral Higgs boson decaying to a W boson pair in p antip collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 97, 081802 (2006)
43. "Top quark mass measurement from dilepton events at CDF II with the matrix-element method" A. Abulencia et al. [CDF Collaboration] Phys. Rev. D 74, 032009 (2006)
44. 45. "Measurement of the b jet cross-section in events with a Z boson in pp̄ collisions at s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. D 74, 032008 (2006)
45. "Search for new physics in lepton + photon + X events with 305 pb−1 of pp̄ collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration Phys. Rev. Lett. 97, 031801 (2006)
46. "Measurement of the ratio of branching fractions B(D0 → K + π −) / B(D0 → K − π +) using the CDF II Detector" A. Abulencia et al. [CDF Collaboration] Phys. Rev. D 74, 031109 (2006)
47. "Search for large extra dimensions in the production of jets and missing transverse energy in p anti-p collisions at s**(1/2) = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 97, 171802

(2006)
48. "Measurement of the t anti-t production cross section in p anti-p collisions at s**(1/2) = 1.96 TeV using missing E(t) + jets events with secondary vertex b-tagging" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 96, 202002 (2006)
49. "Measurement of the B/c+ meson lifetime using B/c+ → J/psi e+ nu/e" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 97, 012002 (2006) [arXiv:hep-ex/0603027]
50. "Search for high-mass resonances decaying to e mu in pp̄ collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 96, 211802 (2006)
51. "Search for Z′ → e+ e− using dielectron mass and angular distribution" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 96, 211801 (2006)
52. "Measurement of the top quark mass using template methods on dilepton events in proton antiproton collisions at √s = 1.96 TeV" A Abulencia et al. [CDF Collaboration] Phys. Rev. D 73, 112006 (2006)
53. "Observation of Bs → ψ(2S)φ and measurement of ratio of branching fractions B(Bs → ψ(2S)φ)/B(Bs → J/ψφ)" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 96, 231801 (2006)
54. "Measurement of σ(Λb0)/σ(B 0) × BR(Λb0 → Λ+ pi−)/BR(anti − B0 → D+ pi-) in pp̄ collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 98, 122002 (2007)
55. "Measurement of the dipion mass spectrum in X(3872) → J/ψπ + π − decays" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 96, 102002 (2006) [arXiv:hep-ex/0512074]
56. 57. "A search for scalar bottom quarks from gluino decays in pp̄ collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 96, 171802 (2006) [arXiv:hep-ex/0512072]
57. "Top quark mass measurement from dilepton events at CDF II" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 96, 152002 (2006)
58. "Measurement of mass and width of the excited charmed meson states D10 and D2*0" A. Abulencia et al. [CDF Collaboration] Phys. Rev. D 73, 051104 (2006)
59. "Search for anomalous semileptonic decay of heavy flavor hadrons produced in association with a W boson at CDF II" A. Abulencia et al. [CDF Collaboration] Phys. Rev. D 73, 051101 (2006)
60. "Measurement of the inclusive jet cross section using the k(t) algorithm in p anti-p collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF II Collaboration] Phys. Rev. Lett. 96, 122001 (2006)
61. "Search for H to b anti-b produced in association with W bosons in pp̄ collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 96, 081803 (2006)
62. "Search for second-generation scalar leptoquarks in pp̄ collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. D 73, 051102 (2006) [arXiv:hep-ex/0512055]
63. "Measurement of the inclusive jet cross section in pp̄ interactions at √s = 1.96 TeV using a cone-based jet algorithm" A. Abulencia et al. [CDF Run II Collaboration] Phys. Rev. D 74, 071103 (2006) [arXiv:hep-ex/0512020]
64. "Measurement of the top quark mass with the dynamical likelihood method using lepton plus jets events with b-tags in pp̄ collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. D 73, 092002 (2006) [arXiv:hep-ex/0512009]
65. "Measurement of the helicity of W bosons in top-quark decays" A. Abulencia et al. [CDF-Run II Collaboration] Phys. Rev. D 73, 111103 (2006)
66. "Search for charged Higgs bosons from top quark decays in pp̄ collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 96, 042003 (2006)
67. "A search for t → tauνq in tt production" A. Abulencia et al. [CDF Collaboration] Phys. Lett. B 639, 172 (2006) [arXiv:hep-ex/0510063]
68. "Precision top quark mass measurement in the lepton + jets topology in p anti-p collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 96, 022004 (2006)
69. "Top quark mass measurement using the template method in the lepton + jets channel at CDF II" A. Abulencia et al. [CDF Collaboration] Phys. Rev. D 73, 032003 (2006) [arXiv:hep- ex/0510048]
71. "Study of large hemispherical photomultiplier tubes for the ANTARES neutrino telescope" J. A. Aguilar et al. [ANTARES Collaboration] Nucl. Instrum. Meth. A 555, 132 (2005) [arXiv:physics/0510031]
72. "Direct search for Dirac magnetic monopoles in pp̄ collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 96, 201801 (2006) [arXiv:hep-ex/0509015]
73. "Search for neutral MSSM Higgs bosons decaying to tau pairs in pp̄ collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 96, 011802 (2006)
74. "Search for Bs → μ+ μ− and Bd → μ+ μ− decays in pp̄ collisions with CDF II" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 95, 221805 (2005) [Erratum-ibid. 95, 249905 (2005)] [arXiv:hep-ex/0508036]
75. "Measurements of Inclusive W and Z Cross Sections in p-pbar Collisions at sqrts =1.96 TeV" A. Abulencia et al. [CDF Collaboration] J. Phys. G 34, 2457 (2007) [arXiv:hep-ex/0508029]
76. "Measurement of the ratios of branching fractions B(Bs → Ds π +)/B(B 0 → D− π +) and B(B → D π)/B(B → D π)" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 96, 191801 (2006) [arXiv:hep-ex/0508014]
77. "Search for new high mass particles decaying to lepton pairs in pp̄ collisions at √s = 1.96 TeV" A. Abulencia et al. [CDF Collaboration] Phys. Rev. Lett. 95, 252001 (2005)
78. "Transmission of light in deep sea water at the site of the Antares neutrino telescope" J. A. Aguilar et al. [The ANTARES Collaboration] Astropart. Phys. 23, 131 (2005) [arXiv:astro- ph/0412126]
79. "Status of the ANTARES project" J. A. Aguilar et al. [The ANTARES Collaboration] Eur. Phys. J. C 33, S971 (2004) [arXiv:astro-ph/0310736]
80. "The ANTARES neutrino project: Status report" J. A. Aguilar et al. [The ANTARES Collaboration] Phys.

Atom. Nucl. 67, 1172 (2004)
81. "Sedimentation and fouling of optical surfaces at the ANTARES site" P. Amram et al. [ANTARES Collaboration] Astropart. Phys. 19, 253 (2003) [arXiv:astro-ph/0206454]
82. "The ANTARES optical module" P. Amram et al. [ANTARES Collaboration] Nucl. Instrum. Meth. A 484, 369 (2002) [arXiv:astro-ph/0112172]

-Other: Talks at workshops, conferences and national labs.

- International Workshop on Ultra High Energy Neutrino Telescopes, Chiba(Japan), July 2003
  Talk: Muon Track Reconstruction and Point Source Searches with ANTARES.
- Workshop on Technical Aspects of a Very Large Volume Neutrino Telescope in the Mediterranean Sea, Amsterdam (The Netherlands), October 2003.
  Talk: Method for reconstruction of muon tracks.
- The 18th European Cosmic Ray Symposium, Moscow(Russia), July 2002, Talk: Status of the ANTARES neutrino telescope
- 28th International Cosmic Ray Conference, Tsukuba (Japan), August 2003 Talk: Point source searches with the ANTARES neutrino telescope.
- Physics seminar, Brookhaven National Laboratory, May 2006
  Talk: Bs oscillations at CDF.
- Colloquium, NIKHEF, Amsterdam, July 2006
  Talk: Bs oscillations at CDF.
- LHC Alignment Workshop, CERN, Geneva, Switzerland, August 3-5, 2006
  Talk Alignment Experience from CDF
- Particle Physics Seminar, Stanford Linear Accelerator Center, Dec 2006
  Talk: Observation of Bs oscillations at CDF.
- 42nd Rencontres de Moriond on Electroweak Interactions and Unified Theories, La Thuile, Italy, 10-17 Mar 2007.
  Talk: Tevatron results on the discovery of sigma_b, Bs oscillations and the measurement of Delta m_s, the lifetime difference Delta Gamma_s and the cp-violating phase phi.

Signature

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