High Energy Neutrino Telescopes
The Nobel Prize in Physics 2002 – Information for the Public

October 8, 2002

This year's Nobel Prize in Physics is concerned with the discoveries and detection of cosmic particles and radiation, from which two new fields of research have emerged, neutrino astronomy and X-ray astronomy. The Prize is awarded with one half jointly to: Raymond Davis Jr, Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, USA, and Masatoshi Koshiba, International Center for Elementary Particle Physics, University of Tokyo, Japan, “for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos”, and the second half to Riccardo Giacconi, Associated Universities, Inc., Washington, DC, USA, “for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources”.

Here is a description of the scientists' award-winning achievements.

<table>
<thead>
<tr>
<th>Telescope</th>
<th>User</th>
<th>date</th>
<th>Intended Use</th>
<th>Actual Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical</td>
<td>Galileo</td>
<td>1608</td>
<td>Navigation</td>
<td>Moons of Jupiter</td>
</tr>
<tr>
<td>Optical</td>
<td>Hubble</td>
<td>1929</td>
<td>Nebulae</td>
<td>Expanding Universe</td>
</tr>
<tr>
<td>Radio</td>
<td>Jansky</td>
<td>1932</td>
<td>Noise</td>
<td>Radio Galaxies</td>
</tr>
<tr>
<td>Radio</td>
<td>Penzias, Wilson</td>
<td>1965</td>
<td>Noise</td>
<td>3K Cosmic Background</td>
</tr>
<tr>
<td>Radio</td>
<td>Hewish, Bell</td>
<td>1967</td>
<td>Pulsars</td>
<td></td>
</tr>
<tr>
<td>X-ray</td>
<td>Giacconi</td>
<td>1965</td>
<td>Sun, moon</td>
<td>Neutron stars, accreting binaries</td>
</tr>
<tr>
<td>X-ray</td>
<td>Military</td>
<td>1960s</td>
<td>Thermonuclear explosions</td>
<td>γ-ray bursts</td>
</tr>
<tr>
<td>Water - Cherenkov</td>
<td>IMB, Kamioka</td>
<td>1987</td>
<td>Nucleon decay</td>
<td>Solar ν’s and SN1987A</td>
</tr>
<tr>
<td>Water - Cherenkov</td>
<td>SuperK</td>
<td>1998</td>
<td>Nucleon decay</td>
<td>νμ↔ντ oscillations</td>
</tr>
</tbody>
</table>

A brief history of unexpected achievements
The Sun by NeutrinoGraph

M. Koshiba @ ICRC2003

Accomplished

Three things so far.

1) Established the solar neutrino observation with much better statistics.
2) Firmly established, at more than $9\sigma$, the non-zero masses of $\nu$'s and their oscillations.
3) Non-observation of nucleon decays is giving more stringent restriction on the possible type of future grand unified theory.
Skyplot of Reconstructed Neutrino Induced Events

SuperKamiokande
(A. L. Stachyra, 2002)

MACRO
(M. Ambrosio et al, 2001)
Observation Techniques

nebula

γ ray bursts

Development of cosmic-ray air showers

Actual Knowledge

Possible Origins

E < 10^{16} eV
Galactic

5, 10^{19} < E < 3, 10^{20} eV

10^{15} < E < 10^{18} eV
Extra-galactic?

10^{18} < E < 5, 10^{19} eV
Unknown

5, 10^{19} < E < 3, 10^{20} eV
Unexpected

JPM: 1APP-Les Houches 2001, slide # 3
Neutrinos do not have electromagnetic interactions

Galactic Magnetic Field vs Gravitational Lensing

1 pc = 3.086 \times 10^{16} m

<table>
<thead>
<tr>
<th>Process</th>
<th>Cutoff Energy</th>
<th>Mean free path</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>(p + \gamma_{2.7K} \rightarrow \pi^+ + X)</td>
<td>(\geq 5 \times 10^{19} \text{ eV})</td>
</tr>
<tr>
<td>Nuclei</td>
<td>(A + \gamma_{2.7K} \rightarrow \Delta^+ + X)</td>
<td>(\geq 5 \times 10^{13} \text{ eV}/\text{n})</td>
</tr>
<tr>
<td>(\gamma)-rays</td>
<td>(\gamma + \gamma_{2.7K})</td>
<td>(\geq 10^{14} \text{ eV (at } 10^{20} \text{ eV)})</td>
</tr>
<tr>
<td>(\nu)</td>
<td>(\nu + \nu_{1.95 K} \rightarrow (W/Z_0) + X)</td>
<td>(\geq 4 \times 10^{22} \text{ eV})</td>
</tr>
</tbody>
</table>
Possible Origin of the Ultra Energetic Cosmic Rays

Top-down: decays of particles produced by topological defects or relic particles
Z decays due to UHE $\nu$ interaction on relic $\nu$'s (Weiler, 1982)
GZK vs: UHECR photopion production on CMB (Berezinsky & Zatsepin, 1970, Yoshida & Teshima, 1993 Engel, Sekel, Stanev, 2001)

- Extra-galactic: jets of AGNs, GRB fireballs accretion shocks in galaxy clusters, galaxy mergers
- Galactic: young SNR (p or heavy ion acceleration), pulsars, magnetars, microquasars (binaries with jets in radio)
High Energy spectrum extends up to at least 70 TeV in form of power law. Not expected from IC modeling. Hadronic component?

H. Voelk- TAUP2003
It is almost trivial ...

- AGNs:
  - Most models assume a central black-hole and accretion disk.
  - Particle acceleration occurs either near the black hole or in the jet.
- Neutrinos would verify hadronic acceleration scenario
Furthermore...

<table>
<thead>
<tr>
<th>Type</th>
<th>Likely Composition</th>
<th>Main Evidence</th>
<th>Contrib. to $\Omega$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible Matter</td>
<td>Ordinary matter (p, n, dust, gas)</td>
<td>telescopic obs.</td>
<td>0.01</td>
</tr>
<tr>
<td>Baryonic Dark Matter</td>
<td>Ordinary matter too dim to see (brown dwarf, MACHOs)</td>
<td>BBN, obs D abundance</td>
<td>0.05</td>
</tr>
<tr>
<td>Nonbaryonic Dark Matter</td>
<td>Exotic particles, axions, WIMPS</td>
<td>Rotation curves</td>
<td>0.3</td>
</tr>
<tr>
<td>Cosmological Dark Energy</td>
<td>energy of empty space</td>
<td>CMB radiation</td>
<td>0.6</td>
</tr>
</tbody>
</table>

$\Omega = \text{(density of matter or energy / critical density)}$

Assumption:
(At least some) dark matter in Galaxy due to neutralinos, density $\approx 0.3 \text{ GeV/cm}^3$

angular distribution

1963 – Penzias and Wilson

\[ \sigma_T \approx 20 \mu K \]

\[ \theta_{\text{Angular}} \sim 7^\circ \]
Neutrino Sources

• Active Galactic Nuclei

• Cataclysmic Phenomena

• Dark Matter of the Universe

Relics of the Grand Unification Era

THE UNEXPECTED

Diffused fluxes
Point sources

Background

Environmental noise
atmospheric muons
atmospheric neutrinos
The Neutrino Telescope world map

First Generation:
$E_\mu > 1\text{GeV}$
$A_{\text{eff.}} \sim 100-1000 \text{ m}^2$

Second Generation:
$E_\mu > 5-100\text{GeV}$
$A_{\text{eff.}} \sim 0.1-1\text{km}^2$
Detection Principle

$\cos \theta > 0$

$\cos \theta < 0$

$\nu_\mu \leftrightarrow \nu_\tau$, $L \approx 1\text{-}100\text{Mpc}$

@source $\nu_e: \nu_\mu: \nu_\tau \approx 1:2:0$

@earth $\nu_e: \nu_\mu: \nu_\tau \approx 1:1:1$

Surprises: $\nu$ decays
Effective Area

Geometrical acceptance $\otimes$ Reconstruction Efficiency

Estimated by Monte Carlo Integration

\[
(area) \cdot \left( \frac{N_{\text{reconstructed}}}{N_{\text{generated}}} \right)
\]

- Energy depended
- Direction depended
- Tracking Resolution

Good Tracking Resolution & Large Effective Area for all Energies and Directions
Effective Area

\[ \nu (\text{TeV}) \]


- sedimentation
- transmission-scattering length
- depth

\( E_{\nu} (\text{TeV}) \)

Effect of Neutrino events at 10-100 TeV
Baikal Neutrino Telescope

#OM 36 36 72 96 144 192 192 192 192 192 228

NT-200 NT-200+

C. Spiering
15 inch PMTs – QUASAR facing downwards
(sedimentation-50% of sensitivity lost in 150 days)

2500m² for atm. neutrinos
Baical Neutrino Telescope

Neutrino Induced Cascades

Data: 84
MC no osc atm $\nu$: 80.5

B. Lubsandorzhier- RICH2002

V. Balkanov et al
South Pole

Dark sector

AMANDA

Skiway

IceCube

Dome
AMANDA-A:  (1993-94)
4 strings @ 1000m
Very short scattering length (11-20cm)
Absorption length 59m@ 515 nm

AMANDA-B10:  (1995-97)
302 Oms( 8” PMT)/10 strings @ 1500-2000m
Short scattering length (3-5m)
Effective scattering length 20-25m
Absorption length 100m@ 515 nm
Angular resolution 3.9º

AMANDA-II:  (2000)
677 Oms( 8” PMT)/19 strings
(B10+375 Oms/9 strings @1150-2350)
Effective area >20000 m² for $E_\mu > 10$ TeV
Energy resolution (cascades) $\sigma(\log_{10} E) = 0.2$ for $E = 1-10$ TeV
Angular resolution 2.3º
Hot water drilling
Deployment now ... 

... will be at room temperature
AMANDA B-10: atmospheric vs
AMANDA-B10: Diffuse fluxes of H.E. extraterrestrial vs

Neutrinos induced cascades
AMANDA-II: Test Beams

**Atmospheric μ s**

- AMANDA-II (this work)
- Monte Carlo (CORSIKA)
- Sinegovskaya et al. [10] \( (E_{\mu} \approx 20 \text{ GeV}) \)

**Atmospheric ν s**

- FREJUS
- AMANDA II

1 sigma energy error

L. Kopke ICRC2003
AMANDA-II: Point Sources

The most significant excess, observed 68° Dec., 21.1 h RA, is eight events observed expected background of 2.1. Simulation reveals a probability of 51% to observe such an excess as a random fluctuation of the background.

$E_\nu > 10 \text{GeV}$

$\Phi_\mu \rightarrow 10^{-8} \text{ cm}^{-2} \text{s}^{-1}$, $\Phi_\nu \rightarrow 10^{-15} \text{ cm}^{-2} \text{s}^{-1}$

**TAUP-2003**

<table>
<thead>
<tr>
<th>Candidate</th>
<th>Dec. [°]</th>
<th>RA [h]</th>
<th>$n_{\text{obs}}$</th>
<th>$n_b$</th>
<th>$\Phi^{\text{lim}}_{\mu}$</th>
<th>$\Phi^{\text{lim}}_{\nu}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Markarian 421</td>
<td>38.2</td>
<td>11.07</td>
<td>3</td>
<td>1.50</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Markarian 501</td>
<td>39.8</td>
<td>16.90</td>
<td>1</td>
<td>1.57</td>
<td>1.5</td>
<td>1.8</td>
</tr>
<tr>
<td>PSR B1509</td>
<td>-59.14</td>
<td>10</td>
<td>7</td>
<td>2.0</td>
<td>1.2</td>
<td>3.9</td>
</tr>
<tr>
<td>Cir X-1</td>
<td>-57.17</td>
<td>7</td>
<td>4</td>
<td>2.0</td>
<td>1.2</td>
<td>3.9</td>
</tr>
<tr>
<td>GX339-4</td>
<td>-48.79</td>
<td>7</td>
<td>2</td>
<td>1.9</td>
<td>1.2</td>
<td>3.9</td>
</tr>
<tr>
<td>MACRO 821 throughgoing $\mu$s only</td>
<td>-2.0</td>
<td>-2.0</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>MACRO 1388 events</td>
<td>-48.79</td>
<td>7</td>
<td>2</td>
<td>1.9</td>
<td>1.2</td>
<td>3.9</td>
</tr>
<tr>
<td>SK 2369 events (4°)</td>
<td>9</td>
<td>(2)</td>
<td>5.4</td>
<td>0.7</td>
<td>5.3</td>
<td>3.0</td>
</tr>
<tr>
<td>SK 2369 events (4°)</td>
<td>8</td>
<td>(1)</td>
<td>5.7</td>
<td>0.8</td>
<td>5.4</td>
<td>3.1</td>
</tr>
<tr>
<td>SK 2369 events (4°)</td>
<td>4</td>
<td>(0)</td>
<td>4.4</td>
<td>0.6</td>
<td>5.0</td>
<td>2.9</td>
</tr>
<tr>
<td>NGC 1275</td>
<td>41.5</td>
<td>3.33</td>
<td>1</td>
<td>1.72</td>
<td>1.4</td>
<td>1.6</td>
</tr>
<tr>
<td>Cygnus OB2 region [14]</td>
<td>41.5</td>
<td>20.54</td>
<td>3</td>
<td>1.72</td>
<td>2.9</td>
<td>3.5</td>
</tr>
<tr>
<td>UHE CR Triplet</td>
<td>56.9</td>
<td>12.32</td>
<td>1</td>
<td>1.48</td>
<td>1.4</td>
<td>1.9</td>
</tr>
</tbody>
</table>
SPASE air shower arrays

• calibration of AMANDA angular resolution and pointing
  → resolution Amanda-B10 ~ 3.5° results in ~ 3° for upward moving muons (Amanda-II: ~ 2°)
GRB $\nu$ search in AMANDA

Search for $\nu_\mu$ candidates correlated with GRBs - background established from data

<table>
<thead>
<tr>
<th>Year</th>
<th>#GRB</th>
<th>bkg</th>
<th>observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>78</td>
<td>0.10</td>
<td>0</td>
</tr>
<tr>
<td>1998</td>
<td>99</td>
<td>0.20</td>
<td>0</td>
</tr>
<tr>
<td>1999</td>
<td>96</td>
<td>0.20</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>44</td>
<td>0.60</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>317</td>
<td>1.30</td>
<td>0</td>
</tr>
</tbody>
</table>

- effective $\mu$-area $\approx 50000$ m$^2$
  low background due to space-time coincidence
- No excess observed!
  assuming WB spectrum $4 \times 10^{-8}$ GeV/s/cm$^2$/sr
WIMP Search

Limits to the muon flux from WIMP annihilation in the center of the Earth with the AMANDA detector

astro-ph/0202370
Effective Area of IceCube

Effective area vs. zenith angle after rejection of background from downgoing atmospheric muons

Effective area vs. muon energy - after trigger
- after rejection of atm $\mu$
- after cuts to get the ultimate sensitivity for point sources (optimized for 2 benchmark spectra)

10/7/2003
C. Spiering- VLVNT Workshop
ANTARES Test Sites

~ 40 deployments and recoveries of test lines for site exploration
0.1 km² Detector with 900 Optical Modules, deployment 2002-200
Prototype Lines operated in 2003

- Profiler for Sea currant (ADCP)
- Probe for salinity and temperature (CTD)
- Probe for Sound velocity

- Junction Box
- LED Beacon
- Laser Beacon
- Seismograph
- Hydrophones

Anchor with electronics containers

5 Storeys of Optical Modules

Prototype Sector Line (PSL)

Mini Instrumentation Line (MILL)

Prototype Instrumentation Line (MILL)
Broken Optical Fibre in Line Cable

Fault position identified by light reflection methods “OTDR”

Fault due to collapse of inner plastic tube under pressure

Cable dissection
Connector Leak in MIL

MIL recovered and diagnosed May 2003
Data from Prototype Sector

Low rate, burst fraction < 1%
burst fraction: time fraction above baseline * 1.2
baseline rate

High rate, burst fraction ~37%

Large variability of rates and burst fraction
Essentially bioluminescence
More than 90% of time below 200 kHz
ANTARES
12 line detector
2006

>2006
→ KM³
NEMO - Towards the km3 neutrino telescope

• R&D phase (1999-2002 …)
  – Site selection and characterization
    • Several sites close to the italian coasts have been studied. A site close to Capo Passero (Sicily) at ≈3500 m with optimal characteristics has been identified for the installation
  – R&D activities
    • Development of specific ASICS for the underwater front end electronics
    • Large area hybrid photomultipliers
    • Development of deep sea instrumentation
  – Feasibility study for the km3 detector
    • All the critical components and the deployment procedures have been examined
    • A preliminary project for a km3 detector has been developed
• Phase 1: Advanced R&D and prototyping (2002-2005)
  – Realization of a detector subsystem including all critical components
    • The system will be installed off Catania at the Underwater Test Site of the LNS
• Towards the km3 neutrino telescope (EU Design Study)
Site exploration activities

- Since 1998 continuous monitoring of a site close to the coast of Sicily
- More than 20 sea campaigns on the site to measure
  - water optical properties
  - optical background
  - deep sea currents
  - nature and quantity of sedimenting material
- Other sites explored for optical properties
  - Two sites in the Southern Thyrrenian Sea (Ustica and Alicudi)
  - Toulon (ANTARES site), in collaboration with Antares
The Capo Passero site

Site optical and oceanographical characteristics

- Absorption lengths (~70 m @440 nm) are compatible with optically pure sea water values
- Measured values are stable throughout the years (*important: variations on La and Lc will directly reflect in changes of the detector effective area*)
- Optical background is low (consistent with ⁴⁰K background with only rare occurrences of bioluminescence bursts)
- The site location is optimal (close to the coast, flat seabed, far from the shelf break and from canyons, far from important rivers)
- Measured currents are low and regular (2-3 cm/s average; 12 cm/s peak)
- Sedimentation rate is low
- No evidence of recent turbidity events
Preliminary project for a km$^3$ detector

**Schematic detector layout**

Reference layout used for the feasibility study

**Detector architecture**

- Reduce number of structures to reduce connections and allow underwater operations with a ROV ⇒ non homogeneous sensor distribution
- Modularity

1 main Junction Box
8 secondary Junction Boxes
64 Towers
16 storeys with 4 OM (active height 600 m)
4096 OM

Total instrumented volume ≈1 km$^3$
The NEMO tower

Deployment of the tower
Site characteristics

- **a broad plateau:** 8x9 km² in area, 7.5 nautical miles from shore
- **depth:** ~4000m
- **transmission length:** 55 ± 10m at λ=460 nm
- **underwater currents:** <10 cm/sec measured over the last 10 years
- **optical background:** ~50 kHz/OM due to K40 decay bioluminescence activity (1% of the experiment live time)
- **sedimentology tests:** flat clay surface on sea floor good anchoring ground.
NESTOR TOWER

32 m diameter
30 m between floors

144 PMTs

Energy threshold as low as 4 GeV

20 000 m² Effective Area for E>10TeV
Ti floor
Successful deployment of one NESTOR star with 12 Optical Modules to 4000m using the cableship RAYMOND CROZE (France Telecom)

29th of March: The first deep sea muon data transmitted to shore
Data from a depth of 4000 m

Bioluminescence Contribution to the Total Trigger Rates

Bioluminescence Occurs for the $1.1\% \pm 0.1\%$ of the Active Experimental Time
Nestor-2003: $\mu$-track reconstruction
Preliminary

Zenith Angular Distribution

- $\chi^2$ probability > 0.1
- track selection according to the charge-likelihood
- more than 3.5 p.e.s per hit per track
- impact parameter > 6 meters

$\alpha = 4.65 \pm 0.9$

700 Data events

M.C. Prediction (atmospheric muons)  
Data Points
NESTOR-2004
4 -Floors
10000 m² effective area for E>10TeV

2006: 15% of a Km² NESTOR Detector

Effective area for 7 Nestor Towers and E = 10 TeV
(30 m between floors, 150 m between towers)

Resolution < 1°
The KM3NeT Project

Design Study for a
Deep Sea Facility in the Mediterranean for
Neutrino Astronomy and Environmental Sciences

Institutes participating in the Design Study:

**Cyprus:** Univ. Cyprus

**France:** CEA/Saclay, CNRS/IN2P3 Marseille, CNRS/IN2P3 Strasbourg, Univ. Haute Alsace

**Germany:** Univ. Erlangen

**Greece:** Hellenic Open Univ., NCSR “Demokritos”, NOA/Nestor Inst., Univ. Athens, Univ. Crete, Univ. Patras

**Italy:** INFN (Bari, Bologna, Catania, LNS Catania, LNF Frascati, Genova, Messina, Pisa, Roma-1)

**Netherlands:** NIKHEF (Univ. Amsterdam, Free Univ., Univ. Utrecht, Univ. Nijmegen)

**Spain:** IFIC (CSIC, Univ. Valencia), U.P. Valencia

**United Kingdom:** Univ. Leeds, Univ. Sheffield, Univ. Liverpool
• What is our aim?:
a deep-sea km$^3$-scale observatory for high energy neutrino astronomy and associated platform for deep-sea science

• Why we need an FP6 Design Study?:
to enable the European neutrino astronomy community to prepare for the timely and cost-effective construction of the next-generation neutrino telescope

• Why we need it now?:
“... both in view of the size of the enterprise and of a timely competition with IceCube, the Committee finds it urgent that a single coherent collaboration be formed, ...”
Recommendation from ApPEC peer review meeting, Amsterdam, 3-4 July 2003

The Mediterranean Sea offers optimal conditions
• water quality, depth, temperature, ...
• existing infrastructure
• current expertise for sea water $\nu$ telescopes concentrated in European countries
• a perfect stage for a large Europe-led science project
Physics Perspectives of KM3NeT

HENAP Report to PaNAGIC, July 2002:

“The observation of cosmic neutrinos above 100 GeV is of great scientific importance. ...“

“... a km$^3$-scale detector in the Northern hemisphere should be built to complement the IceCube detector being constructed at the South Pole.”

“The detectors should be of km$^3$-scale, the construction of which is considered technically feasible.”

Astronomy via high-energy neutrino observation

Production mechanisms of high-energy neutrinos in the universe (acceleration mechanisms, top-down scenarios, . . . )

Investigation of the nature of astrophysical objects

Origin of cosmic rays

Indirect search for dark matter

Associated science
Sky Observable by Neutrino Telescopes

(Region of sky seen in galactic coordinate assuming 100% efficiency for $2\pi$ down)

South Pole

Mkn 501
CRAB
SS433
Not seen

Mediterranean

Not seen
Mkn 501
CRAB
SS433
GX339-4
VELA

Need Neutrino Telescopes in both hemispheres to see whole sky
Point Sources - Sensitivities

MACRO + SK + AMANDA-B10
AMANDA
AMANDA + IceCube + ANTARES + NESTOR
IceCube + KM3NeT

Sensitivity to muon flux ($\mu$ / cm$^2$ s)

Declination (degrees)

Ch. Spiering, astro-ph/0303068
Diffuse $\nu$ Flux

- Energy spectrum will provide important constraints on models of particle acceleration and energy budget at cosmological scales

- Present theoretical upper limits are at the edge of current experiments’ sensitivities
  => Precise flux measurement needs km$^3$-scale detector

- Accessible energy range limited by atmospheric neutrino flux ($\sim 10^5$ GeV) and detector size ($\sim 10^8$ GeV)

- Measurements at these energies require sensitivity for neutrinos from above due to opacity of Earth

- Cosmic neutrinos arrive in democratic flavour mix
  Sensitivity to $\nu_e$, $\nu_\tau$ and NC reactions important
Dark Matter

- Neutrinos produced in co-annihilation of WIMPs gravitationally trapped in Earth, Sun or Galactic Centre provide sensitivity of $\nu$ telescopes to Dark Matter.
- May solve long-standing questions of both particle- and astrophysics.
- KM3NeT will observe Galactic Centre—exciting prospects.

Additional Topics:
- Particle physics (flavour oscillations, cross sections)
- Top-down scenarios
- Magnetic monopoles

The Unexpected
Objectives and Scope of the KM3NeT Design Study

Establish path from current projects to KM3NeT

- critical review of current technical solutions
- thorough tests of new developments
- assessment of quality control and assurance
- explore and establish possible cooperation with industry

envisaged time scale of design, construction and operation poses stringent conditions
Design Study Target Values

- **Detection principle:** water Cherenkov
- **Location in Europe:** in the Mediterranean Sea
- **Detection view:** maximal angular acceptance for all possible detectable neutrino signals including down-going neutrinos at VHE
- **Angular resolution:** close to the intrinsic resolution ($<\sim 0.1$ degrees for muons with $E_\nu > 10$ TeV)
- **Detection volume:** 1 km$^3$, expandable
- **Lower energy threshold:** a few 100 GeV for upward going neutrinos with possibility to go lower for ν from known point sources
- **Energy reconstruction:** within factor of 2 for muon events
- **Reaction types:** all neutrino flavours
- **Duty cycle:** close to 100%
- **Operational lifetime:** $\geq 10$ years

But these parameters need optimisation!
Technical Design of the ν Telescope

• Cost-effectiveness: \(<\sim 200\) MEuro per km³

• Architecture: strings vs. rigid towers vs. flexible towers vs. new solutions

• Photo detectors

• Mechanical solutions

• Readout: electronics, data acquisition, data transport

• Calibration and slow control

• Cables and connectors: dry vs. wet

• Simulations: design optimisation and assessment; impact of environmental conditions

Construction of the telescope within 5 years after end of the Design Study

• Detailed assembly procedures
  Distributed production lines

• Evaluation of logistics needs

• Quality control and assurance model
Installation and Maintenance

- **Deployment**: fast procedures; parallelisation of operations
- **Shore infrastructure**: supply units; on-shore computing; internet connection
- **Maintenance**: flexible, low-cost access to sea-operation equipment; rapid recovery procedures; cost-effective repair options

Exploitation Model

facility exploited in multi-user and interdisciplinary environment

- Reconstructed data will be made available to the whole community
- Observation of specific objects with increased sensitivity will be offered (dedicated adjustment of filter algorithms)
- Close relation to space-based observatories will be established (alerts for GRBs, Supernovae etc.)
- “Plug-and-play” solutions for detectors of associated sciences
Operation Model

centralised services for tasks exceeding the capacity of single institutes

• Maintenance centre for detector components (closely related to sea-operation base)
• Computer facilities allowing for external operation and control
• Data storage and distribution (relation to GRID?)
• Software development and maintenance, in particular for on-line filter

Funding and Governance

• Invite and coordinate world-wide participation
• Explore national, European and regional funding sources
• Assess and study models for contractual structures
• Address legal questions related to the international structure and in particular to a possible detector deployment in international waters
## Work Packages

<table>
<thead>
<tr>
<th>Task</th>
<th>Descriptive title</th>
<th>Leading participant</th>
<th>Short description and specific objectives of the task</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP1</td>
<td>Management of the Design Study</td>
<td>Erlangen</td>
<td>Management of the administrative, financial, legal, contractual and social aspects of the Design Study; audit and report activities; coordination of work packages and technical activities; knowledge and information management; development of KM3NeT cost models and definition of criteria on KM3NeT design and site decisions.</td>
</tr>
<tr>
<td>WP2</td>
<td>Astroparticle Physics</td>
<td>IN2P3</td>
<td>Definition of benchmark neutrino fluxes; development of event simulation software; development of simulation software (including detector geometry, background sources, light propagation, modelling of online filter and detector response); software development for modelling and assessing accuracy of calibration procedures.</td>
</tr>
<tr>
<td>WP3</td>
<td>Physics Analysis</td>
<td>HOU</td>
<td>Development of algorithms and software for offline event selection and classification; development and optimisation of reconstruction algorithms for different event types; determination of the physics sensitivity as a function of the environmental parameters and of the total cost of the KM3NeT infrastructure; development of data storage and distribution models.</td>
</tr>
<tr>
<td>WP5</td>
<td>Information technology</td>
<td>FOM</td>
<td>Development of the readout and data handling technology, i.e. signal detection, transmission and digitisation as well as data processing and distribution. Definition of access protocols to scientific data.</td>
</tr>
</tbody>
</table>
Associated Sciences

- Great interest in long term deep-sea measurements in many different scientific communities:
  - Biology
  - Oceanography
  - Environmental sciences
  - Geology and geophysics
  - ...

- Communication with ESONET established

- Plan: include the associated science communities in the design phase to understand and react to their needs
**KM3NeT Milestones**

- **End 2004**  
  Start design study
- **Mid 2006**  
  Conceptual design ready
- **End 2007**  
  Technical design ready
- **2008 – 2012**  
  Construction
- **2009 – XXXX**  
  Operation

The selection of the optimal site for the infrastructure presents a unique challenge to our scientific community due to the intricate interplay between scientific, technological, financial and socio-political/regional considerations. It is our intention to deliver a clear prioritisation of site qualities based on scientific, technological and financial aspects only. However, depending on the strength of this prioritisation, the final site selection may well be determined by socio-political/regional considerations. Whether weak or strong, this Design Study prioritisation will provide a sound, rational basis for decision-makers.
Acoustic detection

Bipolar acoustic pulse (width \( \sim 10 \, \mu s \)): homogeneous medium (water/ice) expansion when heat due to ionization and other energy losses is deposited by showers. At typical frequencies 10 kHz sound waves propagate kms in water.

Disk transverse to primary direction of few degrees

Limiting factors: acoustic pattern highly directional \( \Rightarrow \) limits the solid angle accessible to sensors, ambient noise (mammals, wind, thermal, human factors).

Sulak et al, 1979: bunches of \( 10^{11} \) protons of \( \sim 200 \, \text{MeV} \) simulate \( 10^{20} \, \text{eV} \) showers \( \Rightarrow \) proved sound generation.

Baikal: since 2001 coincidences hydrophones + EAS \( \Rightarrow \) 46 events in \( \pm 0.5 \, \text{ms} \), 20 expected from uniformly distributed background \( \Rightarrow \) 2 \( \sigma \) excess.

Main noise: ice cracking.

T. Montaruli – TAUP2003
THE COSMOLOGICAL FORGE

THE COSMIC BEAM
EXTREME ENERGY COSMIC RAYS & NEUTRINOS

THE NATURAL DETECTOR
EARTH ATMOSPHERE
INTERACTION

THE CASCADE PROCESS
EXTENSIVE AIR SHOWER
ELECTROMAGNETIC CASCADE
HADRONIC CASCADE

Fluorescence light
Cerenkov light

O. Catatalano – ICRC2003

EUSO: Extreme Universe Space Observatory
• Astronomer’s dream site
  – Good weather
  – Less artificial light
• Mt. Hualalai provide a good view of Mt. Loa and situated in the dryer west side of island.
• Mt. Loa provide long base line, ~90 km wide and 4 km high.
Summarising Remarks

• Exciting physics perspectives of neutrino telescopes
• A km³-scale telescope in the Northern hemisphere is needed to complement IceCube in sky-coverage and to exploit the full potential of neutrino astronomy
• The Mediterranean offers optimal conditions. The current expertise in water Cherenkov neutrino telescopes is united in Europe
• The European groups have agreed on a common coordinated effort towards KM3NeT

Let’s Go For It!