CTA Meeting, Paris, 01–02.03.2007

The Neutrino – Gamma Ray Connection

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- The gamma – neutrino link
- Neutrino telescopes: facts and vision
- The KM3NeT Design Study, history and future
- Operational options
- Conclusions and Outlook

Hadronic acceleration, neutrinos and gammas

- Neutrinos are produced in the interaction of high energy nucleons with matter or radiation:

$$N + X \rightarrow \pi^{\pm}(K^{\pm}\ldots) + Y \rightarrow \mu^{\pm} + \nu_\mu(\bar{\nu}_\mu) + Y$$

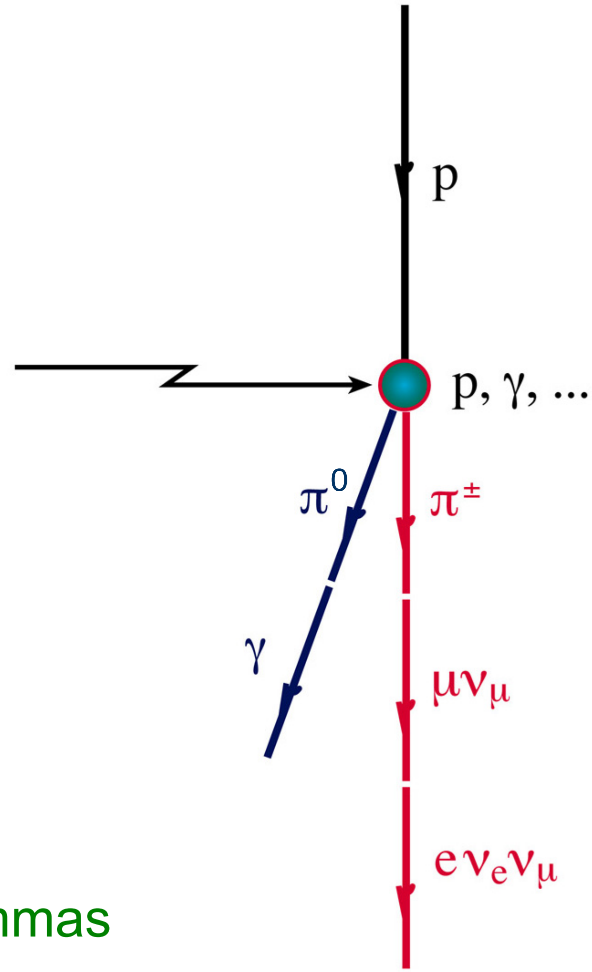
$$\downarrow$$

$$e^{\pm} + \bar{\nu}_e(\nu_e) + \bar{\nu}_\mu(\nu_\mu)$$

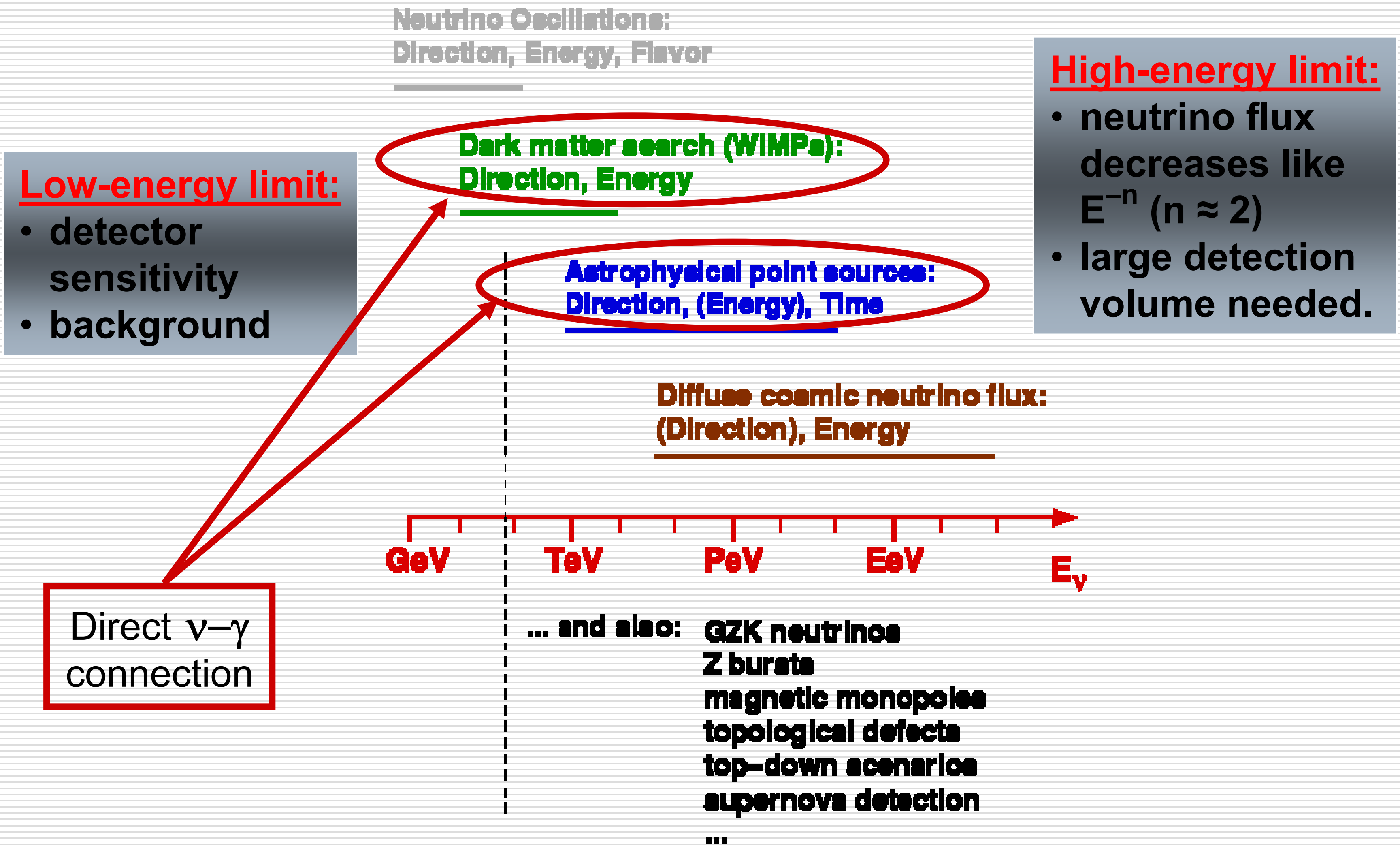
- Simultaneously, gamma production takes place:

$$N + X \rightarrow \pi^0 + Y \rightarrow \gamma\,\gamma + Y$$

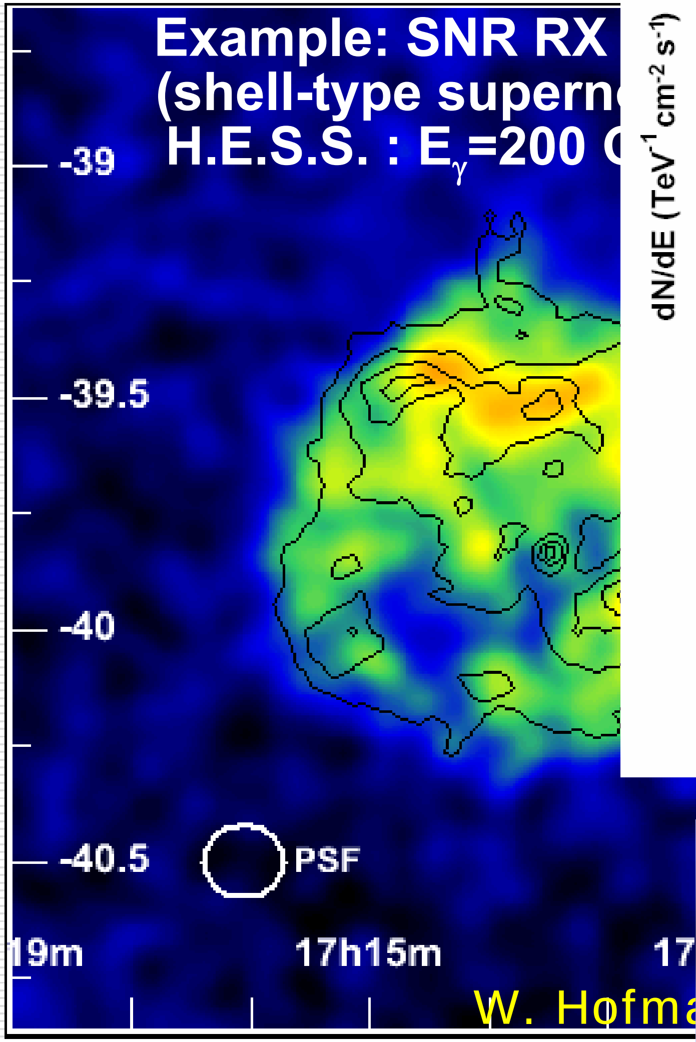
- Cosmic ray acceleration yields neutrinos and gammas with similar abundance and energy spectra!

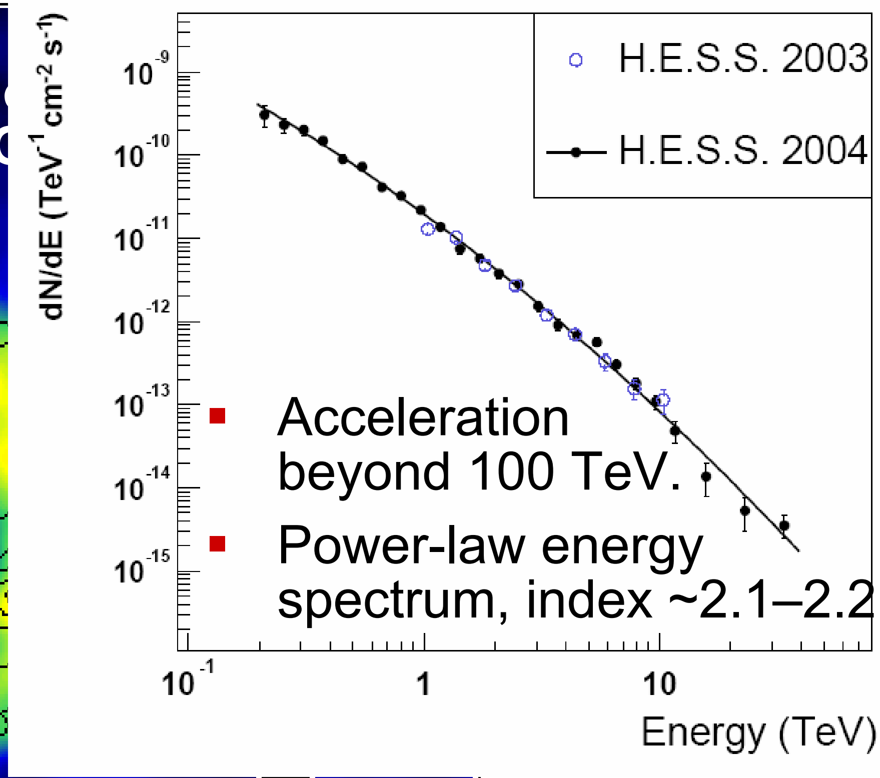


Astro- and Particle Physics with Neutrinos



Example: ν's from Supernova Remnants



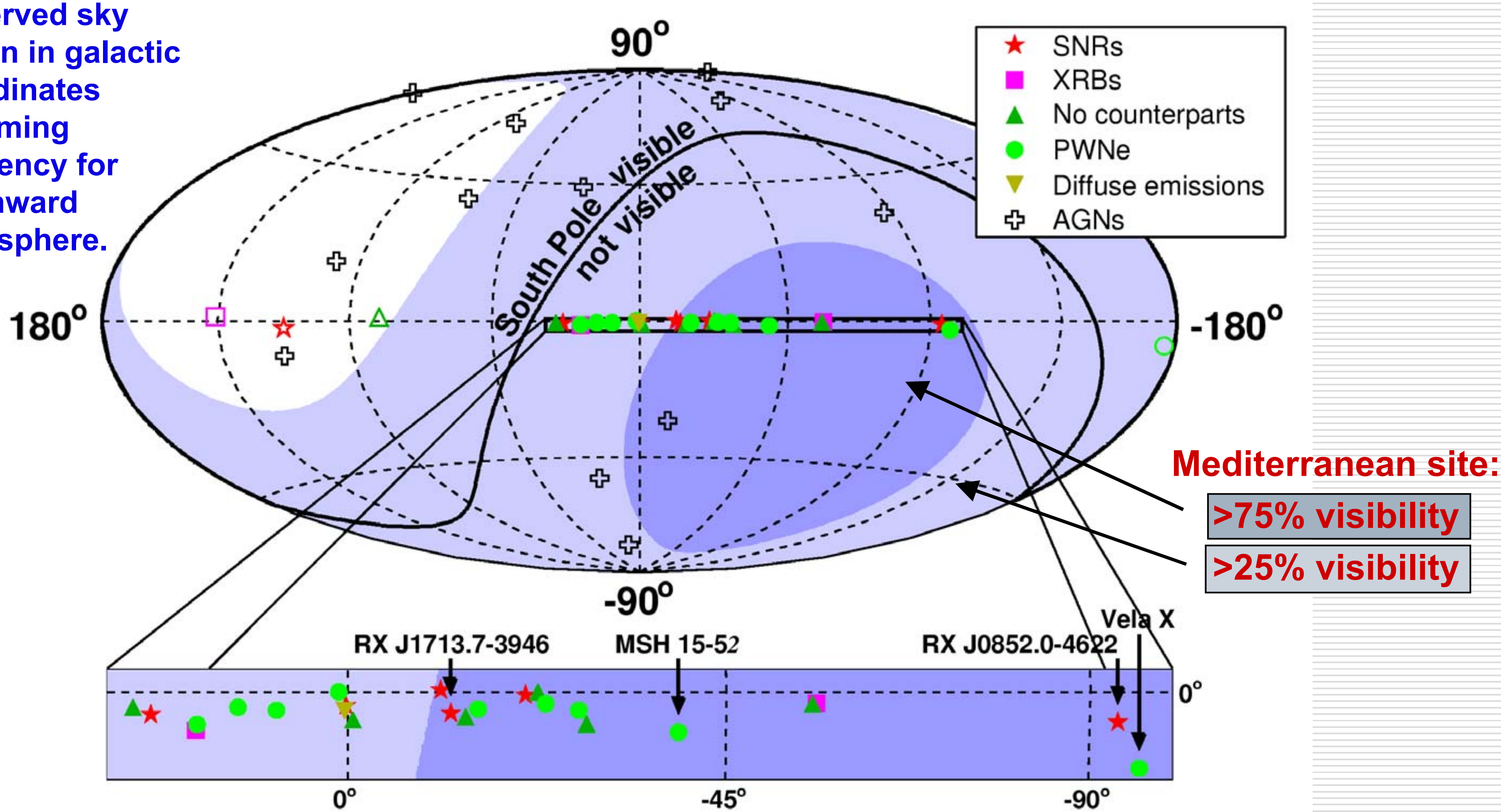


- Acceleration beyond 100 TeV.
- Power-law energy spectrum, index ~2.1–2.2.

- Spectrum points to hadron acceleration → ν flux ~ γ flux
- Typical ν energies: few TeV

Sky Coverage of Neutrino Telescopes

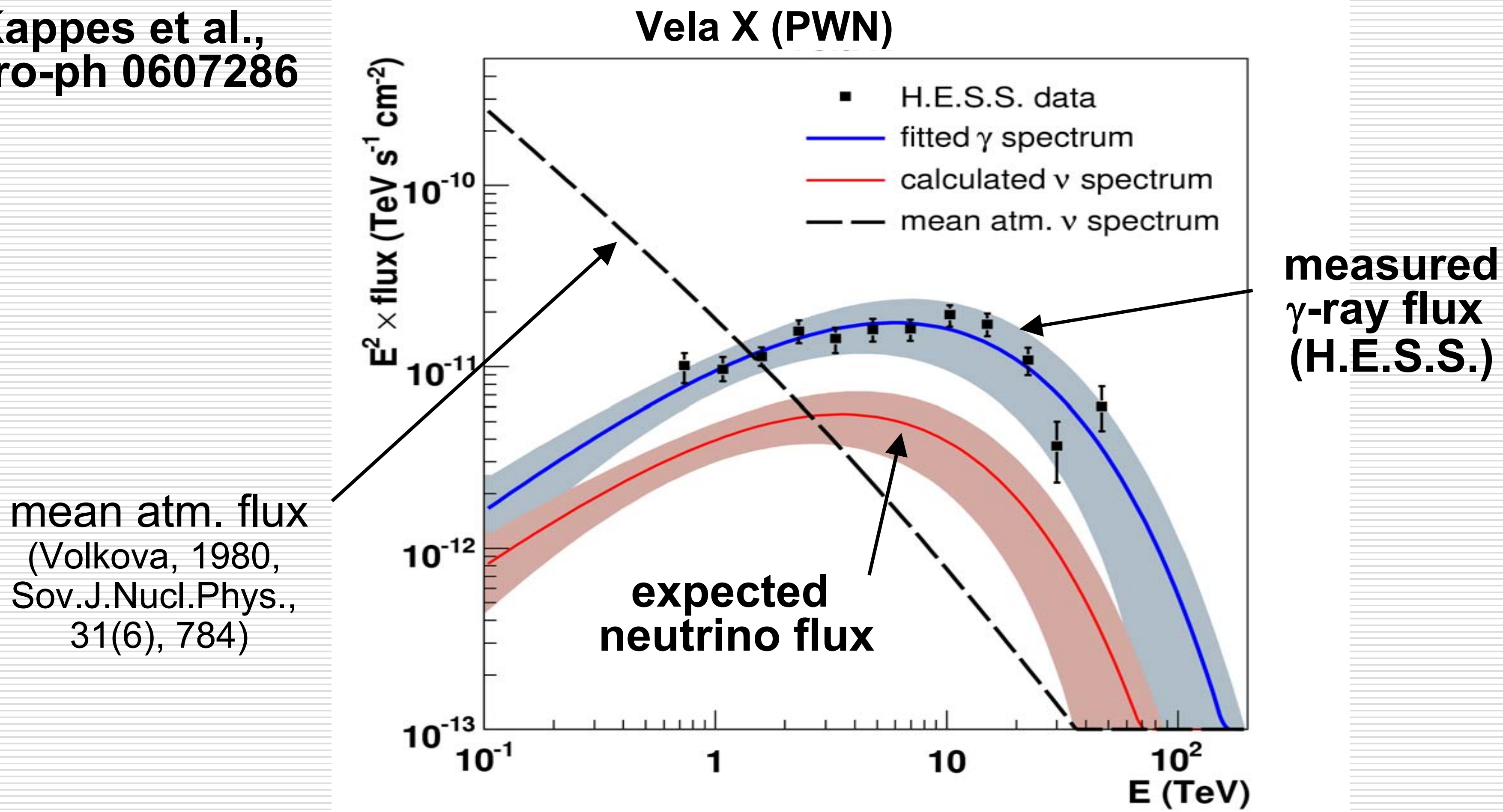
Observed sky region in galactic coordinates assuming efficiency for downward hemisphere.



→ We need Northern ν telescopes to cover the Galactic Plane

Precise ν Flux Predictions from γ ray Mmt's!

A.Kappes et al., astro-ph 0607286



- 1 σ error bands include systematic errors (20% norm., 10% index & cut-off)

Expected signals

A.Kappes et al., astro-ph 0607286

	Type	Ø [o]	Eν > 1 TeV Src	Eν > 1 TeV Bkg	Eν > 5 TeV Src	Eν > 5 TeV Bkg
Vela X	PWN	0.8	9 – 23	23	5 – 15	4.6
RX J1713.7–3946	SNR	1.3	7 – 14	41	2.6 – 6.7	8.2
HESS J1825–137	PWN	0.3	5 – 10	9.3	2.2 – 5.2	1.8
Crab Nebula	PWN	<0.1	4.0 – 7.6	5.2	1.1 – 2.7	1.1
HESS J1303–631	NCP	0.3	0.8 – 2.3	11	0.1 – 0.5	2.1
LS 5039* (INFC)	Binary	<0.1	0.3 – 0.7	2.5	0.1 – 0.3	0.5

NCP: No counterpart at other wavelengths *no γ-ray absorption

- Neutrino astronomy is a low-statistics domain!
- Sensitivity to galactic sources in reach → important design criterion
- Enhanced signals/sensitivity for
  - transient sources
  - opaque sources
  - sources at higher energies ("PeVatrons")

Even few neutrinos from unambiguously identified source would be a scientific breakthrough!

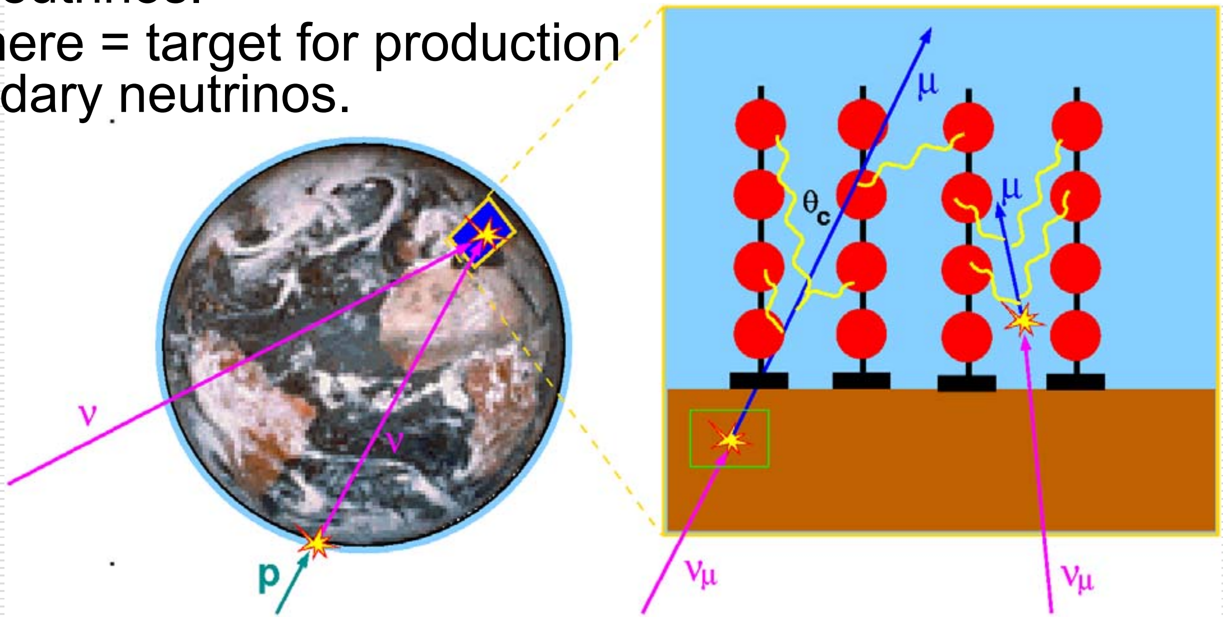
The Principle of Neutrino Telescopes

Role of the Earth:

- Screening against all particles except neutrinos.
- Atmosphere = target for production of secondary neutrinos.

Cherenkov light:

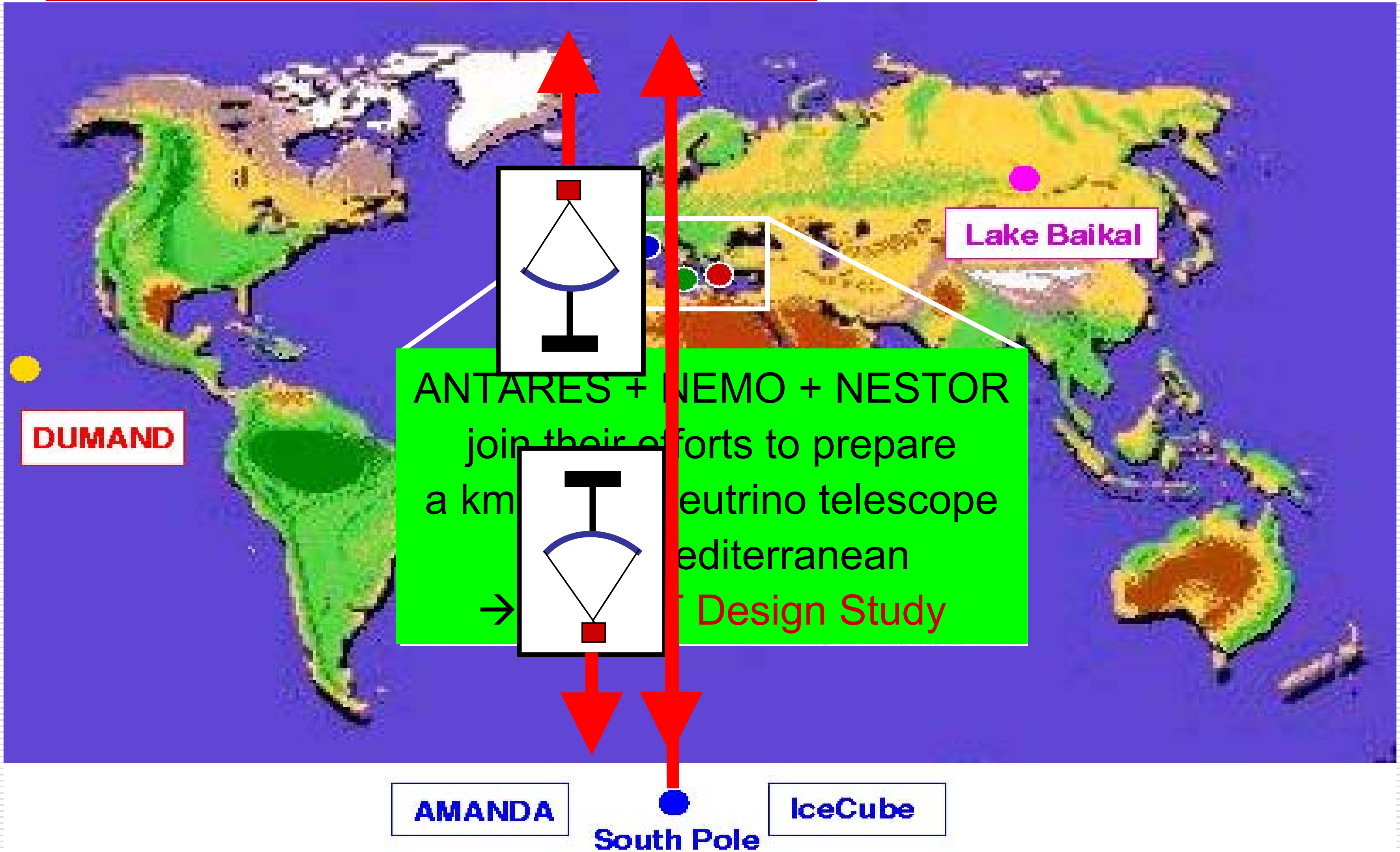
- In water: $\theta_C \approx 43°$
- Spectral range used: ~ 350-500nm.



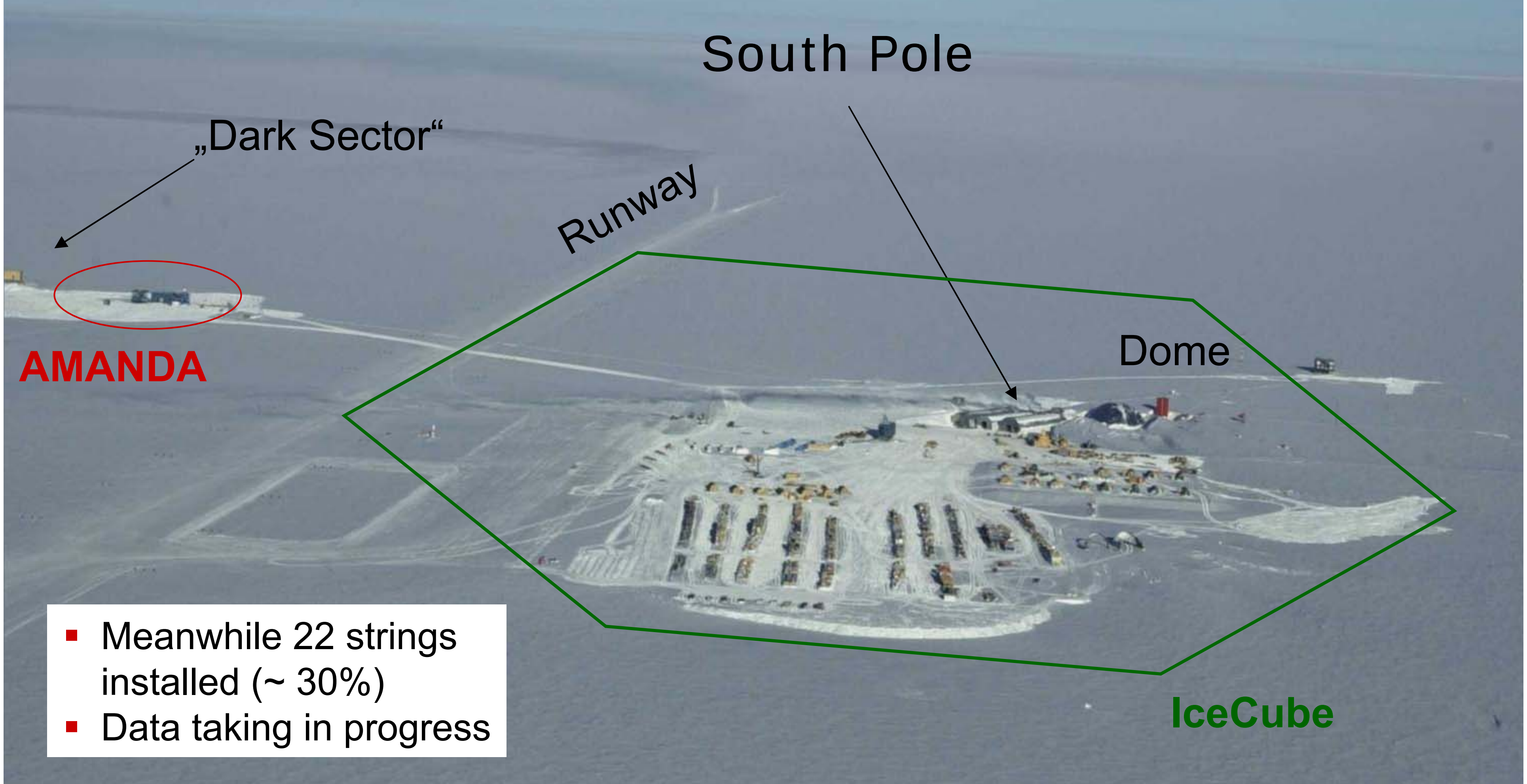
Angular resolution in water:

- Better than ~0.3° for neutrino energy above ~10 TeV, 0.1° at 100 TeV
- Dominated by angle(ν,μ) below ~10 TeV (~0.6° at 1 TeV)

The Neutrino Telescope World Map



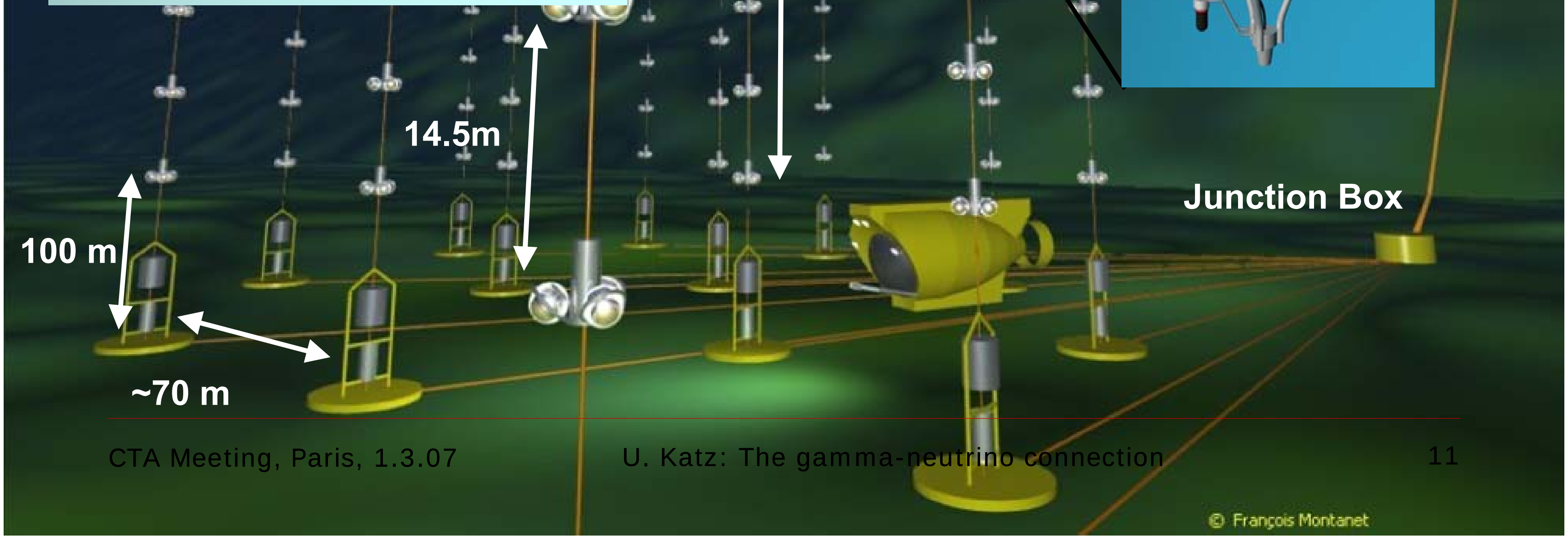
IceCube: a km^3 Detector in the Antarctic Ice



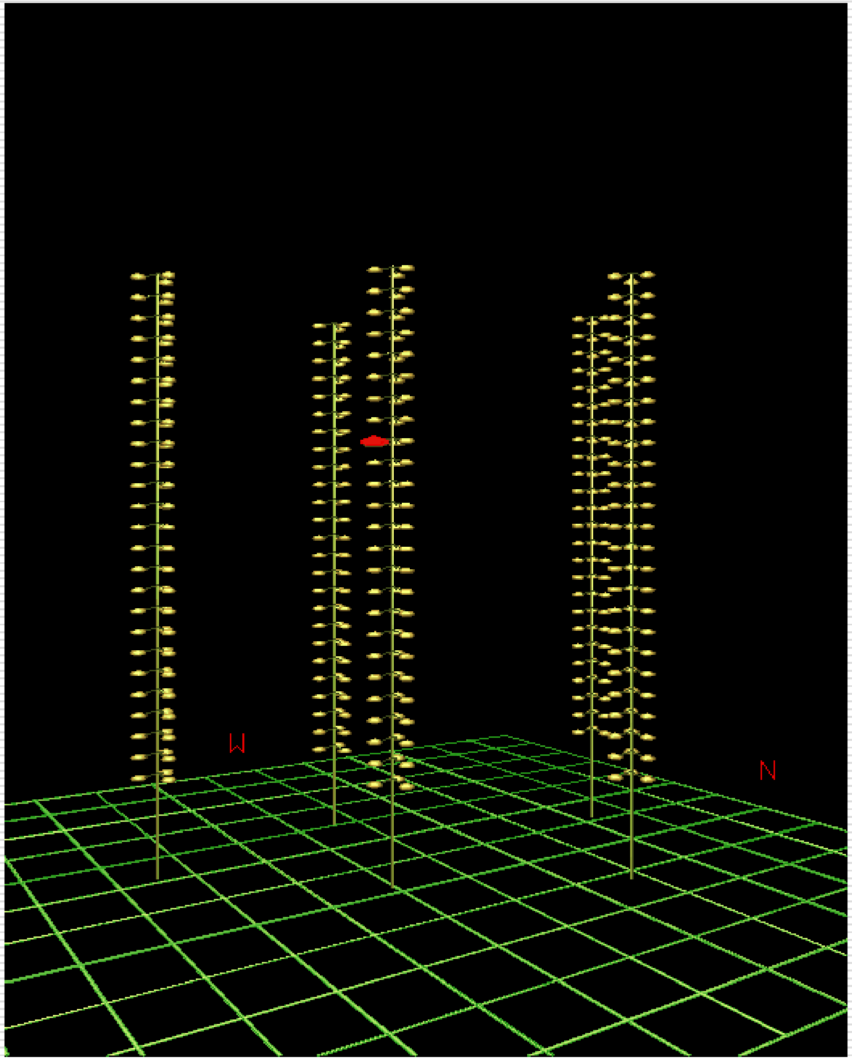
- Meanwhile 22 strings installed (~ 30%)
- Data taking in progress

ANTARES: A Pilot Project in the Mediterranean

- **String-based detector;**
- **Underwater connections by deep-sea submersible;**
- **Downward-looking photomultipliers (PMs), axis at 45^{O} to vertical;**
- **2500 m deep;**
- **Jan 2007: 5 strings deployed and connected, data taking in progress**



Progress in the Mediterranean Sea



- ANTARES:
  5 lines operational, first atmospheric muon events observed with all lines.
- NEMO:
  Successful test deployment, data taking
- NESTOR:
  Prototype module operated in 2003.
- KM3NeT: Upcoming.

KM3NeT Design Study: The last years

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

- Initial initiative Sept. 2002.
- VLVνT Workshop, Amsterdam, Oct. 2003.
- ApPEC review, Nov. 2003.
- Inclusion of marine science/technology institutes (Jan. 2004).
- Proposal submitted to EU 04.03.2004.
- Confirmation that Design Study will be funded (Sept. 2004).
- KM3NeT on ESFRI list of Opportunities, March 2005.
- 2nd VLVνT Workshop, Catania, 08-11.11.2005.
- ESFRI presentation, Brussels, Nov. 2005.
- Design Study contract signed, Jan. 2006 (9 M€ from EU, ~20 M€ overall).
- Start of Design Study project, 01.02.2006.
- Kick-off meeting, Erlangen, April 2006.
- First year report, due 15.03.2007.

And: Essential progress of ANTARES, NEMO and NESTOR in this period!

KM3NeT Design Study: Participants

- Cyprus: Univ. Cyprus
- France: CEA/Saclay, CNRS/IN2P3 (CPP Marseille, IreS Strasbourg, APC Paris-7), Univ. Mulhouse/GRPHE, IFREMER
- Germany: Univ. Erlangen, Univ. Kiel
- Greece: HCMR, Hellenic Open Univ., NCSR Demokritos, NOA/Nestor, Univ. Athens
- Ireland: Dublin Institute of Advanced Studies (since 1.Nov.2006)
- Italy: CNR/ISMAR, INFN (Univs. Bari, Bologna, Catania, Genova, Napoli, Pisa, Roma-1, LNS Catania, LNF Frascati), INGV, Tecnomare SpA
- Netherlands: NIKHEF/FOM (incl. Univ. Amsterdam, Univ. Utrecht, KVI Groningen)
- Spain: IFIC/CSIC Valencia, Univ. Valencia, UP Valencia
- UK: Univ. Aberdeen, Univ. Leeds, Univ. Liverpool, Univ. Sheffield

Particle/Astroparticle institutes (29+1) – Sea science/technology institutes (7) – Coordinator

The KM3NeT Design Study work packages

- WP1: Management of the Design Study
- WP2: Physics analysis and simulation
- WP3: System and product engineering
- WP4: Information technology
- WP5: Shore and deep-sea infrastructure
- WP6: Sea surface infrastructure
- WP7: Risk assessment and quality assurance
- WP8: Resource exploration
- WP9: Associated sciences

The KM3NeT Vision

- KM3NeT will be a multidisciplinary research infrastructure:
  - Data will be publicly available;
  - Implementation of specific online filter algorithms will yield particular sensitivity in predefined directions
    → non-KM3NeT members can apply for observation time;
  - Data will be buffered to respond to GRB alerts etc.
  - Deep-sea access for marine sciences.
- KM3NeT will be a pan-European project
  - 8+1 European countries involved in Design Study;
  - Substantial funding already now from national agencies.
- KM3NeT will be constructed in time to take data concurrently with IceCube.
- KM3NeT will be extendable.

Target price tag: 200 M€/km^3 or less

KM3NeT: Path to Completion

Time schedule (partly speculative & optimistic):

01.02.2006	Start of Design Study
Fall 2007	Conceptual Design Report
February 2009	Technical Design Report
2008-2010	Preparatory Phase in FP7
2010-2012	Construction
2011-20xx	Data taking

Call for Preparatory Phase projects published in Dec. 2006, restricted to ESFRI projects.

Gamma—Neutrino: Operational Options

- "Target of opportunity":
  - Neutrino triggers gamma
    [e.g. IceCube/MAGIC cooperation, E. Bernardini]
  - Neutrino triggers optical (then gamma?)
    [see e.g. M. Kowalski, A. Mohr, astro-ph/0701618]
  - Gamma/optical triggers neutrino
    [KM3NeT: direction-dependent event filters, details yet to be worked out]
- Multimessenger investigations
  - Correlated analysis of data, requires data access, standardized data formats, agreements, etc.
    → question of policy and resources!
  - Feedback on design decisions?

Example: IceCube—MAGIC cooperation

Target of opportunity test run, Sept-Dec '06

AMANDA on-line filter selected events consistent with any of five γ sources (sometimes) accessible to MAGIC and sent alerts.

MAGIC took on-source data when possible (for five alerts)

Once final neutrino background determined, results will be exchanged and compared with pre-determined thresholds for γ rate.

Neutrino events by themselves are consistent with prel. background estimates.

Need to develop procedure and statistical treatment further.

MAGIC telescope, La Palma

Presented at WIN07, Kolkata, India, January 2007

Conclusions and Outlook

- There is an intrinsic gamma—neutrino connection in TeV+ astroparticle physics that is worth while to be explored.
- The neutrino telescope projects IceCube (Antarctica) and ANTARES, NEMO and NESTOR (Mediterranean Sea) have proven the feasibility of large-scale deep-sea neutrino telescopes.
- Exciting data from these experiments can be expected in the near future.
- ANTARES, NEMO and NESTOR have united their efforts to prepare together the future, km^3-scale deep-sea detector KM3NeT. The EU-funded KM3NeT Design Study (2006-09) provides substantial resources for an intense 3-year R&D phase.
- Efforts coordinated between the gamma and the neutrino communities may yield increased sensitivity and open additional options.