Neutrino Detection in Salt Domes under LOFAR

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International Workshop on Saltdome Shower Array

nuclear physics research
Outline

High-Energy $\nu$ Program

**ZEchstein SALT Neutrino Array (ZESANA)**

Directly linked to

- LOFAR and its CR program (KVI, Uni Nijmegen, ASTRON)
- development of next generation of radio and signal-processing techniques
- cross calibration with other experiments (PAO ?)
National APP topics in NL*

✓ Compact Objects (GRB’s, mergers, collapsers, magnetars, SNR’s)
✓ Dark Matter & Exotic Particles
✓ Fundamental Physics

*Preliminary streamlining by “Comité Astroteeltjesfysica Nederland” CAN
Messengers and Detectors

• Messengers
  – Cosmic Rays and $\nu$’s
  – Gravitational waves

• Detectors
  – LOFAR/PAO/Extensions
  – ANTARES/KM3NeT (deep-sea)
  – (mini-Grail, LISA-p)

& THEORY
New site in the Netherlands
LOFAR: Low Frequency Array

- interferometer in frequency range of 10 - 200 MHz
- array of 100 stations of 100 dipole antennas
- baselines of 10 m to 400 km
- fully digital: received waves are digitized and sent to a central super computer (IBM Blue Gene @ university of Groningen)
- Science:
  - Cosmology: HI at z >10 (époque of re-ionization)
  - Surveys: >10^8 new sources
  - All-Sky monitor: transient events

See http://www.lofar.org
LOFAR: a digital telescope

All-sky map from LOFARs Initial Test Station: 30 MHz (10-40), 60 antennas, 3° resolution.

Courtesy: Michiel Brentjes ASTRON/RUG
LOFAR: a sensor network

Courtesy: KNMI NL

04-02-2005/AMvdB
Int. WS Saltdome Shower Array SLAC 3-4 Feb. 2005
LOFAR as CR or $\nu$ detector

inclined 100 EeV air shower

field strength:
~ 1 mV/m/MHz

from: Heino Falcke
Uni Nijmegen, ASTRON
**CR coherent synchrotron radiation**


**Fig. 15.** Reconstructed pulses emitted by the maximum of a $10^{17}$ eV shower with flaring Agnetta et al. (1997) $\Gamma$-pdf, broken power-law energy distribution from $\gamma = 5-1000$ and $R_0 = 4$ km, using an idealised rectangle filter spanning 40–160 MHz and “conservative $\theta$” scenario. Solid: centre of illuminated area, short-dashed: 100 m from centre, dash-dotted: 250 m from centre

**Fig. 17.** Radial dependence of $|E(R, \omega)|$ for a full $10^{17}$ eV air shower with flaring Agnetta et al. (1997) $\Gamma$-pdf, “conservative $\theta$” approach, $R_0 = 4$ km and a broken power-law energy distribution from $\gamma = 5-1000$, data from Allan et al. (1970), horizontal lines from top to bottom: emission strength needed for a 3$\sigma$-detection with an individual LOPES antenna or an array of 10 or 100 LOPES antennas
LOPES @ Kascade (FZK)

- **LOPES** (LOFAR Prototype Station, Heino Falcke et al*)
- First CR events recently detected

First Results

Fig. 2: Left: Coincidence transients detected with CODALEMA after 33-65 MHz numerical filtering. From Top to Bottom: trigger, distant (1 km), NE, E, NW and SW antennas respectively. Right: Location in the sky of sources of successive events.

From: Heino Falcke, 2nd Symposium “Astroparticle Physics in the Netherlands”

From: A. Bellétoile et al, SF2A 2004 CODALEMA @ Nançay France
High-energy CR spectrum

Bram Achterberg
Colloquium Kapteyn
15 November 2004

Pierre Auger Observatory!
Marginal explanation by conventional models

Observed UHECRs vs. simulations

Distant sources
Close sources
Galactic background
Built a UHE $\nu$ detector

UHE $\nu$’s provide complementary information
- ✓ sources are transparent
- ✓ Universe is transparent
- ✓ no charge; no influence from EM fields
- ✓ velocity is known
- ✓ direct link between $\gamma$ and $\nu$ spectrum
How (one option ...)

• Detect UHE $\nu$’s using rock salt in Northern Europe (Groningen)
• Monitor UHE CR’s with LOFAR
• Develop:
  – radar techniques for salt domes
  – techniques to install antennas in salt domes
  – understanding of UHE CR and $\nu$ interactions with matter
  – calibrate various detector systems (PAO ↔ LOFAR)
Underground salt layers

- Salt pillars
- Zechstein salt
- Cavern

* © TNO-NITG
Footprint of LOFAR

salt domes
Salt in Groningen

Veendam

Zuidwending

Onstwedde

Assen

Stadskanaal

Emmen

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Zuidwending salt dome

3D model of the Zuidwending salt dome: view from the East. The active horizon is the top of the salt.

Purple: Triassic; Dark green: Lower Cretaceous; Light green: Upper Cretaceous Orange: Lower Tertiary; Yellow: Miocene-Quaternary.
Zuidwending Dome?

Aardgasbuffer Zuidwending: a fast Compressed Natural Gas storage Gastransport Services, Akzo Nobel Salt, NUON (Energy Valley)

04-02-2005/AMvdB Int. WS Salt dome Shower Array SLAC 3-4 Feb. 2005
Salt domes under LOFAR

Halite (rock salt)
- $L_d(<1\text{GHz}) > 500 \text{ m w.e.}$
- Depth to $>10\text{km}$
- Diameter: 3-8 km
- $V_{\text{eff}} \sim 100-200 \text{ km}^3 \text{ w.e.}$
- No known background
- $>2\pi$ steradians possible
First preliminary results (Chiba)

\[
\tan \delta = 2 \times 10^{-4}
\]

NaCl, Dielectric Materials and Applications (A. R. von Hippel ed.), 1954

\[
L_\alpha = \frac{1}{\alpha} = \frac{\lambda}{\pi \sqrt{\epsilon \tan \delta}}
\]

in situ measurements

- Hockley mine, USA
- Asse mine, Germany
- Halstadt mine, Austria
- Waldeck mine, Austria
- Kamaishi, Japan
- Mt. Jura, France

Dielectric resonator: 1GHz, 5.5GHz, 8.2GHz, 11GHz, 25GHz

Teflon, Granite, Lime stone, NaCl powder, NaCl synthesized, Hippel 25GHz
R & D Needed

- Radio attenuation length measurement
- Ultra-sensitive underground radar techniques (receiver antennas)
- Cross calibration with other experiments (PAO, acoustic, WSRT, ...?)
Conclusion

• Radio techniques for detection of UHE $\nu$ are very promising and provide an important step for the next generation of $\nu$ telescopes

• LOFAR, the largest radio telescope in the world, can be used for UHE CR and $\nu$ detection; it can be complemented with ZESANA using ‘standard’ techniques