Atmospheric neutrino oscillations at the Super-Kamiokande detector

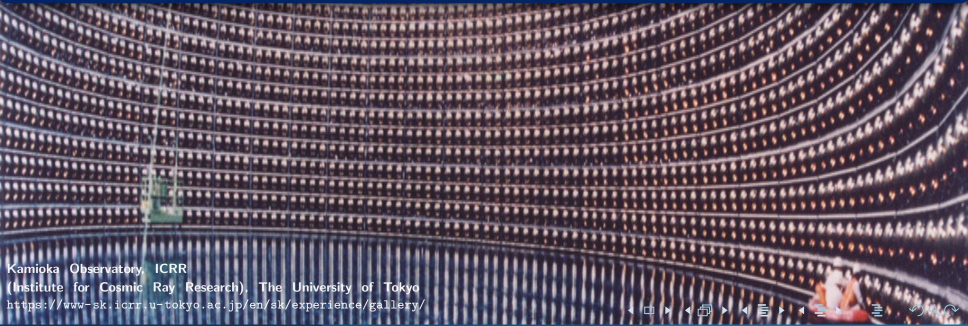
Maria Kondzielska

Warsaw, June 5, 2024

Supervisor: Dr. Magdalena Posiadała-Zezula
Division of Particles and Fundamental Interactions

Outline

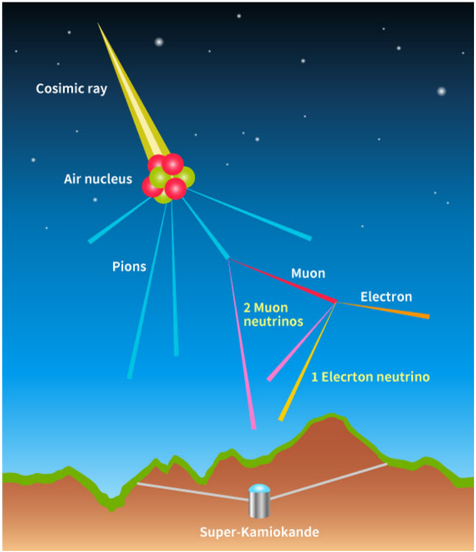
Introduction



Kamioka Observatory, ICRR
(Institute for Cosmic Ray Research), The University of Tokyo
https://www-sk.icrr.u-tokyo.ac.jp/en/sk/experience/gallery/

Atmospheric neutrino production

Atmospheric neutrinos - about Super-Kamiokande Physics

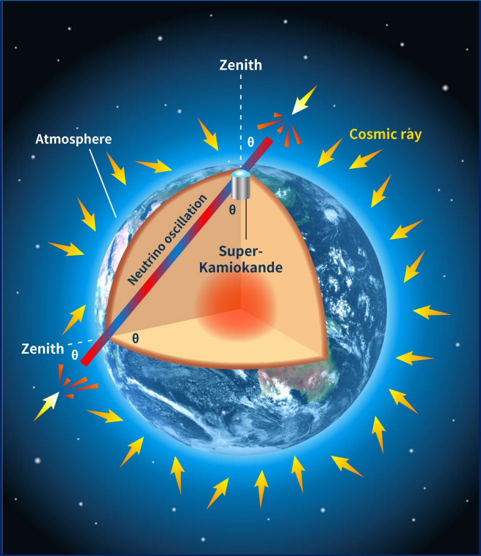


- Primary cosmic rays (p, He, ...) collide with nuclei in the upper atmosphere
- (mostly) pions and kaons are produced:

$$\pi^+ \to \mu^+ + \nu_\mu$$
$$K^+ \to \mu^+ + \nu_\mu$$
$$\mu^+ \to e^+ + \overline{\nu_\mu} + \nu_e$$

- Expected ratio: $\nu_\mu / \nu_e \sim 2$
- Neutrino energies: $\sim$ 100 MeV-10 TeV

Atmospheric Neutrino Oscillations



Propagation paths of upward and downward going neutrinos. Atmospheric neutrinos - about Super-Kamiokande Physics

θ - zenith angle

Isotropic neutrino flux

→numbers of downward going ν and upward going ν_e: agree with expectations
→number of upward going ν_μ: smaller than expectations
→muon neutrino events show up/down asymmetry

- muon neutrino deficit
- atmospheric neutrino anomaly
- neutrino oscillations as an explanation

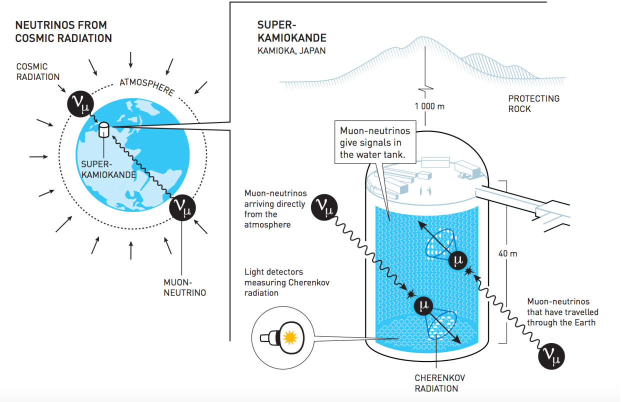
The Super-Kamiokande Detector

Kamioka Observatory, ICRR
(Institute for Cosmic Ray Research), The University of Tokyo
https://www-sk.icrr.u-tokyo.ac.jp/en/sk/experience/gallery/

The Super-Kamiokande Detector

→ 50-kton ring-imaging water Cherenkov detector
→ 39 m diameter
→ ∼ 13 000 PMTs (light sensors)
→ 27.2 kton fiducial volume
→ located 1000 m underground in Kamioka mine, Japan
→ inner and outer detector (veto)

Johan Jarnestad, The Royal Swedish Academy of Sciences

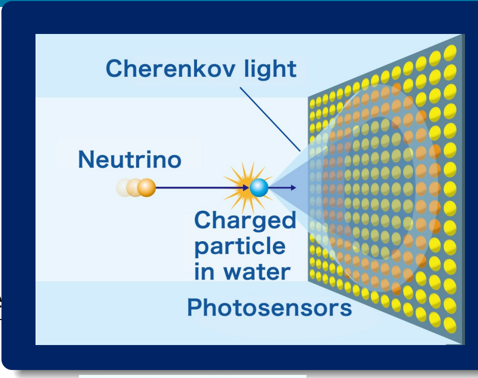


Cherenkov effect

→ a charged particle moving with a speed greater than the speed of light in a medium emits Cherenkov radiation
→ the threshold: $\beta > 1/n$
→ in case of water $n = 4/3$
→ the particle needs to move with $3/4c$

→ the maximum cone angle of emission

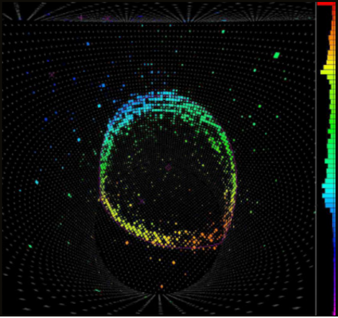
for water at room temperature: 41°

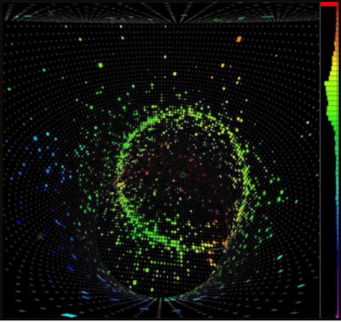


Particle	Threshold total energy [Me
e^-/e^-	0.78
μ^+/μ^-	160
p	1400

Event display

http://dx.doi.org/10.2172/946806





$$\nu_\mu + n \rightarrow p + \mu^-$$

$$\overline{\nu_\mu} + p \rightarrow n + \mu^+$$

μ-like:

- clear Cherenkov ring edge
- only direct Cherenkov light from μ

$$\nu_e + n \rightarrow p + e^-$$

$$\overline{\nu_e} + p \rightarrow n + e^+$$

e-like:

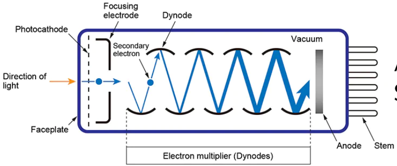
- fuzzy Cherenkov ring edge
- Cherenkov light from electromagnetic showers
- e^+ and e^- are heavily scattered

Backup

PMT - Photo Multiplier Tubes

How do PMTs detect Cherenkov light?

- photons strike photocathode
- electrons are generated (photoelectric effect)
- electrons are multiplied (secondary emission)
- current is proportional to light intensity

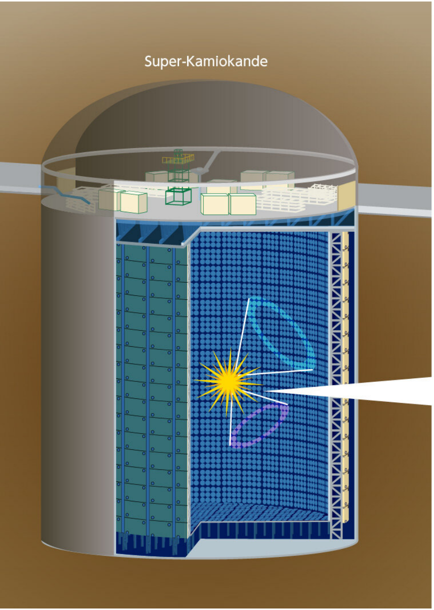


→ high sensitivity for faint light detection

A 20-inch PMT installed in the Super-Kamiokande inner detector.

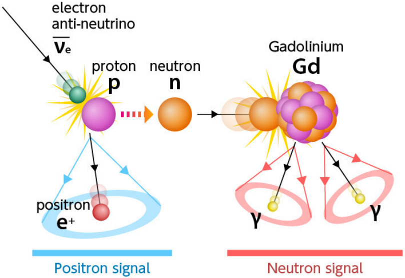
https://www.laserfocusworld.com/detectors-imaging/article/14185918/photomultiplier-tubes-do-what-other-photon-counters-cant

Neutron Tagging



Antineutrino detection by signal coincidence:

$$\overline{\nu_e} + p \to n + e^+$$



- $e^+e^- \to \gamma\gamma$ annihilation
- neutron capture by Gd $\to$ release of γ by excited Gd*

https://phys.org/news/2020-08-super-kamiokande-neutrinos-ancient-supernovae.html