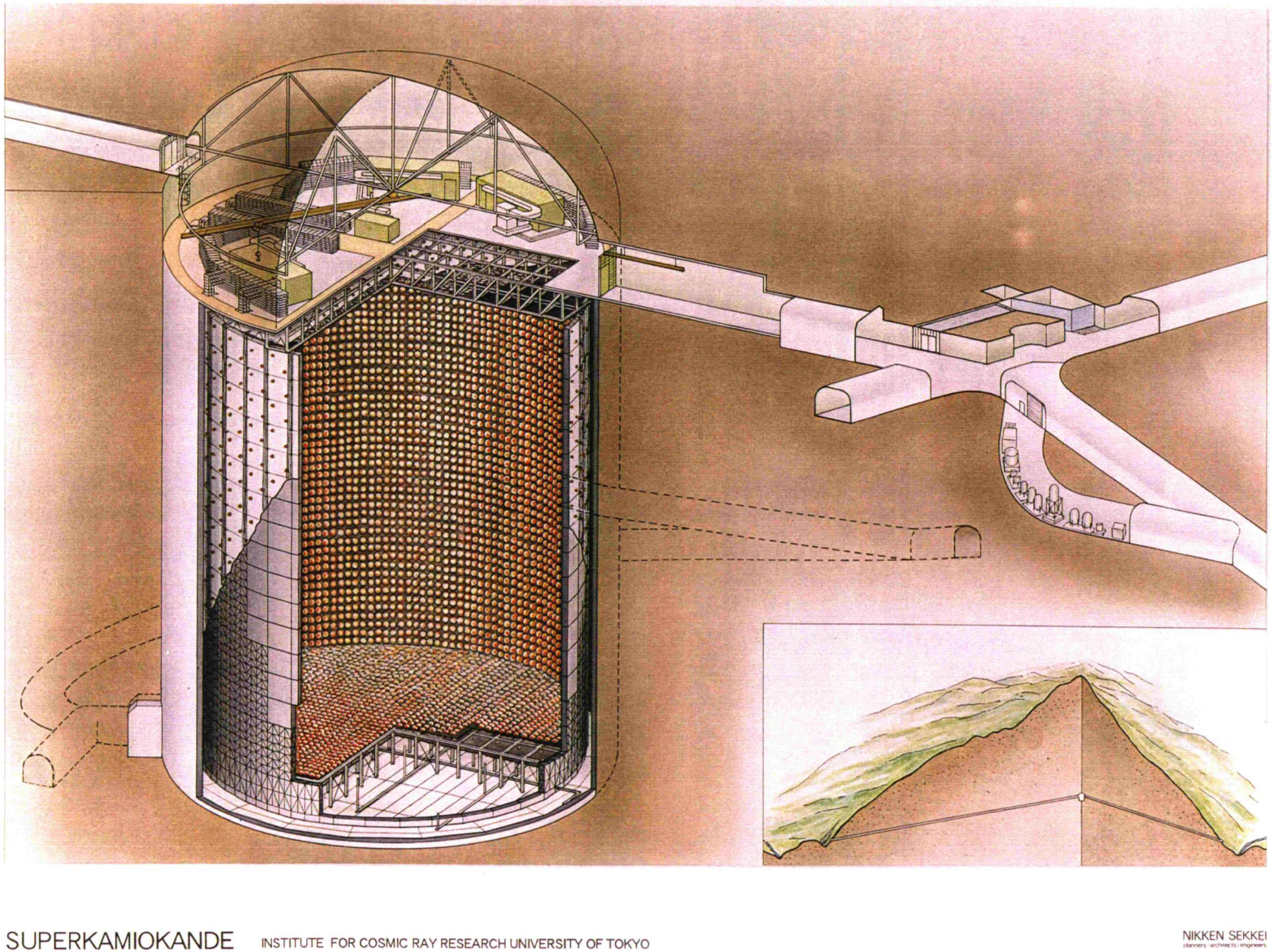
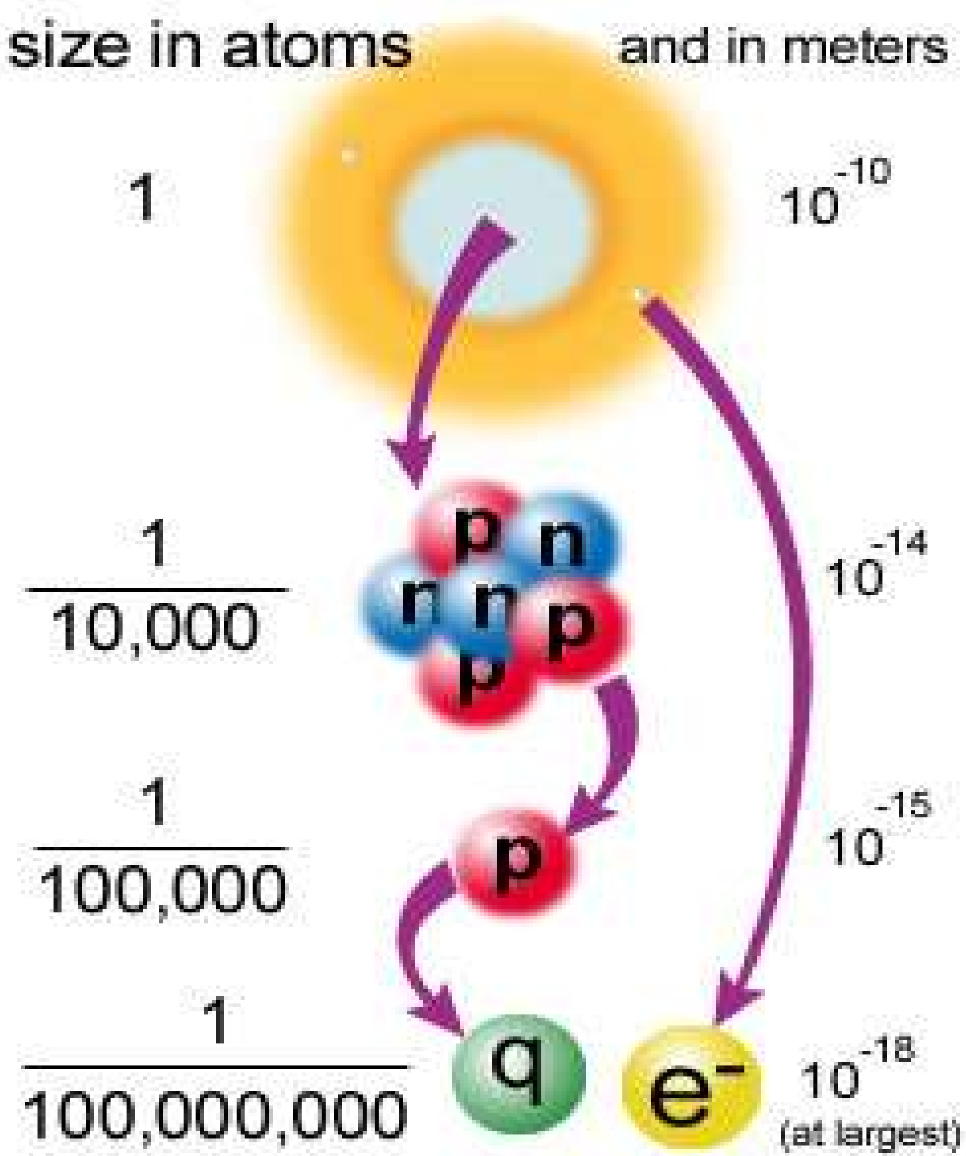
# Introduction to Super-K



# OUTLINE

- Neutrinos, and how to detect them
- How the detector works
    - Water Cherenkov detectors
    - Photomultiplier tubes
    - What can be reconstructed
- Super-K specifics and schedule
- What Super-K data look like
- Introduction to software (to be continued)

## The last century of particle physics tells us ...




**The fundamental particles are:**

**QUARKS**

**(which make up protons & neutrons)**

**LEPTONS**

**e.g. electron and heavier kin, + neutrinos**

# Quarks and leptons come in "families"

## 3 QUARK FAMILIES

| | | |
|---|---|---|
| u | c | t |
| d | s | b |

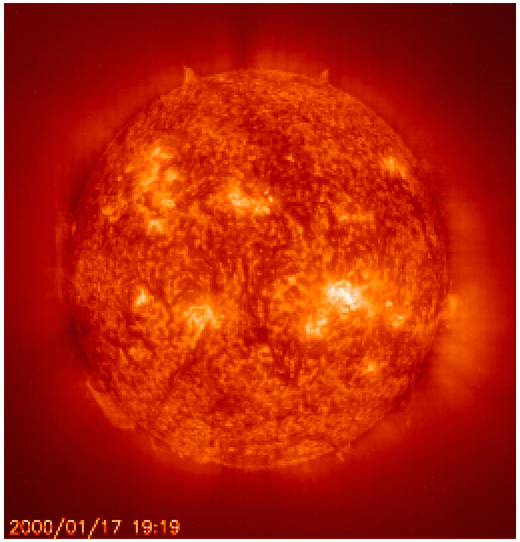
heavier $\longrightarrow$

## 3 LEPTON FAMILIES

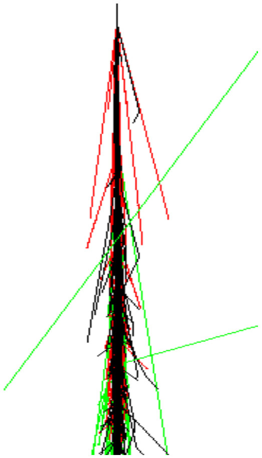
| | | |
|---|---|---|
| e | $\mu$ | $\tau$ |
| $\nu_e$ | $\nu_\mu$ | $\nu_\tau$ |

Neutrinos: very tiny mass and interact only weakly

# Neutrinos are created in:



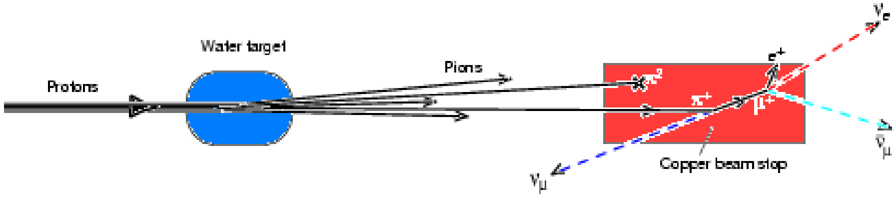

The Sun



The Atmosphere
(cosmic rays)

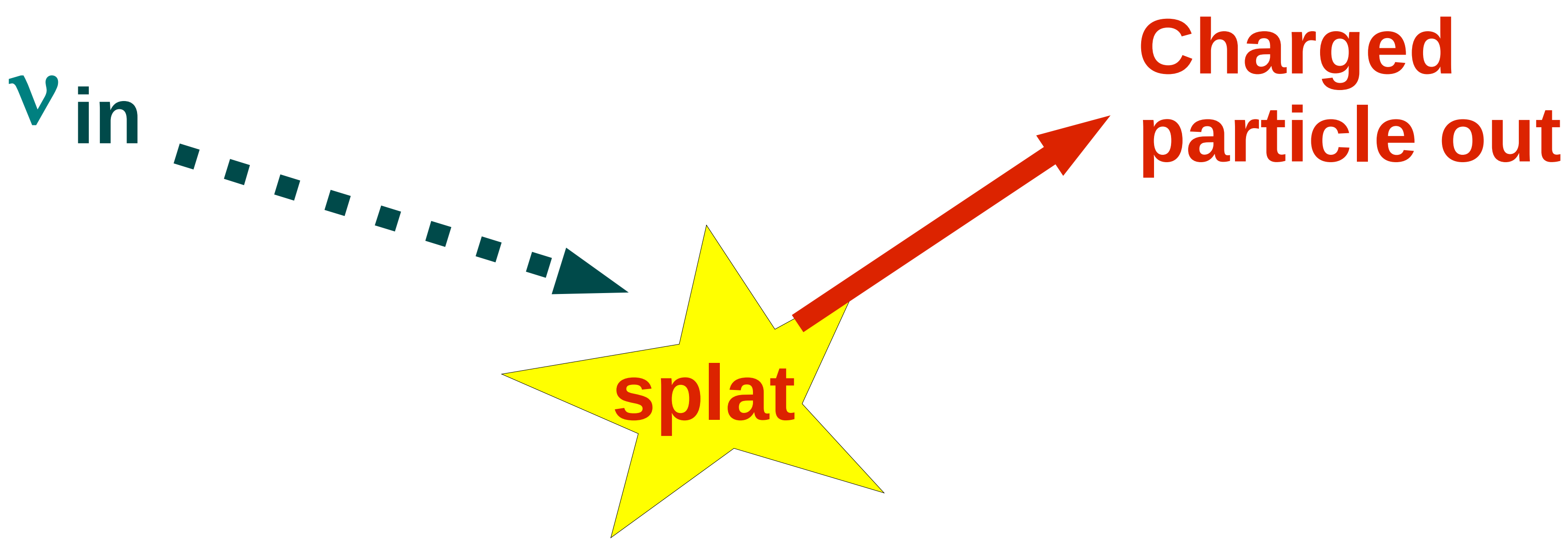
Nuclear
Reactors

Super
Novae




Accelerators

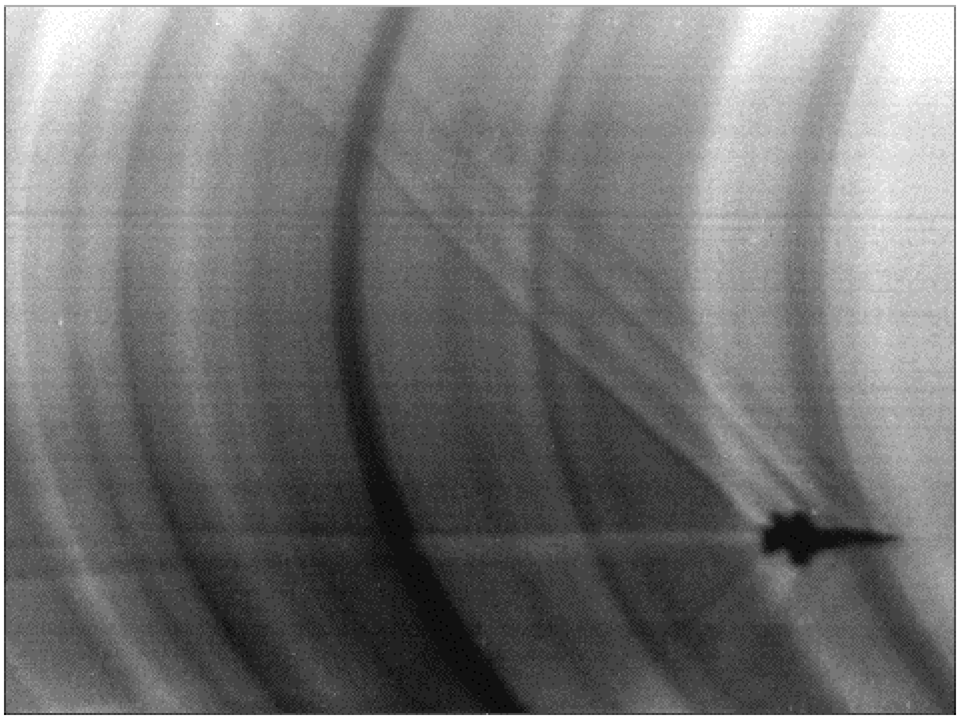
# How to detect neutrinos, which interact with matter so rarely?




***Occasionally*, neutrinos interact to produce *charged* particles, which you can detect using various techniques**

# Water Cherenkov Detectors

**Charged particles moving faster than the speed of light in a medium emit *shock waves* of light**



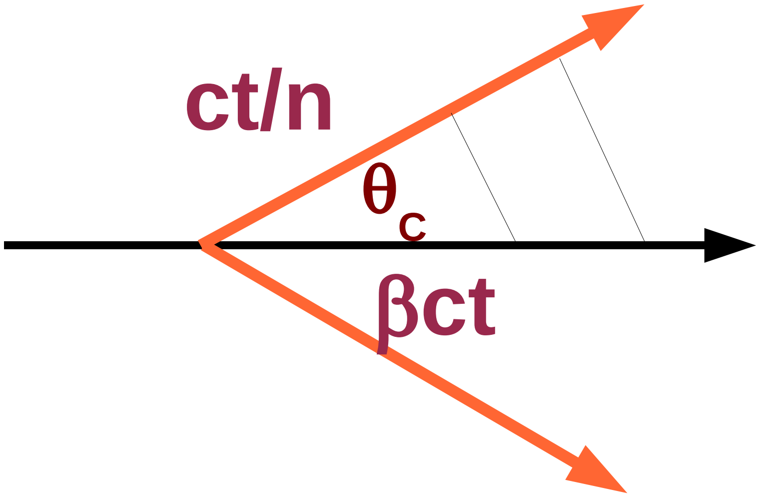
**We can observe Cherenkov radiation produced by the particles resulting from a $\nu$ interaction**

# Charged particle with β>1/n emits Cherenkov light

**Energy threshold** $$E_{th} = \frac{m}{(1-1/n^2)^{1/2}}$$

**Thresholds (MeV)**

| | |
|---|---|
| e | 0.73 |
| μ | 150 |
| π | 200 |
| p | 1350 |

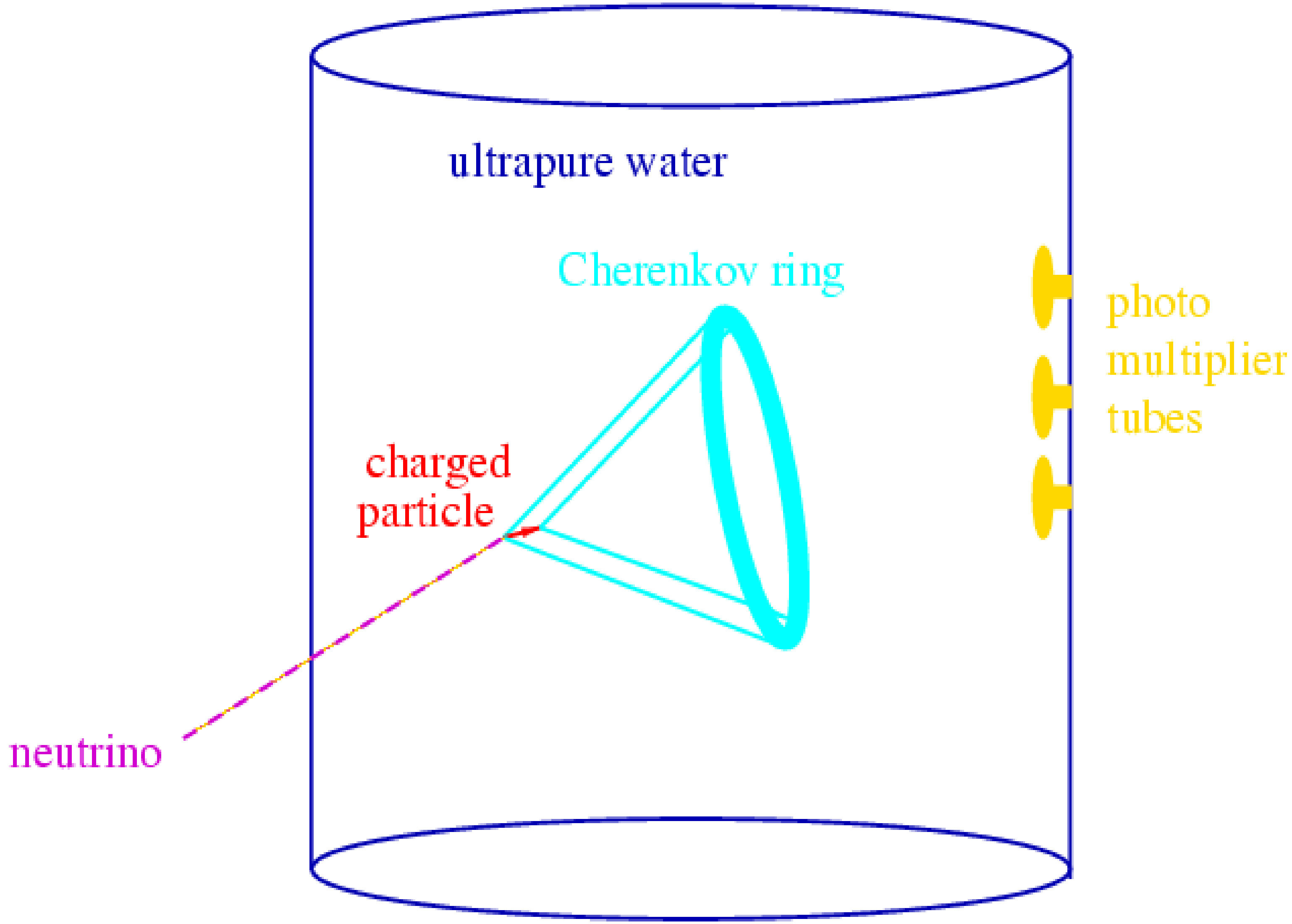



**Angle:** $$\cos\theta_c = \frac{1}{\beta n}$$ **depends on medium**

**$\theta_c = 42^0$ for relativistic particle in water**

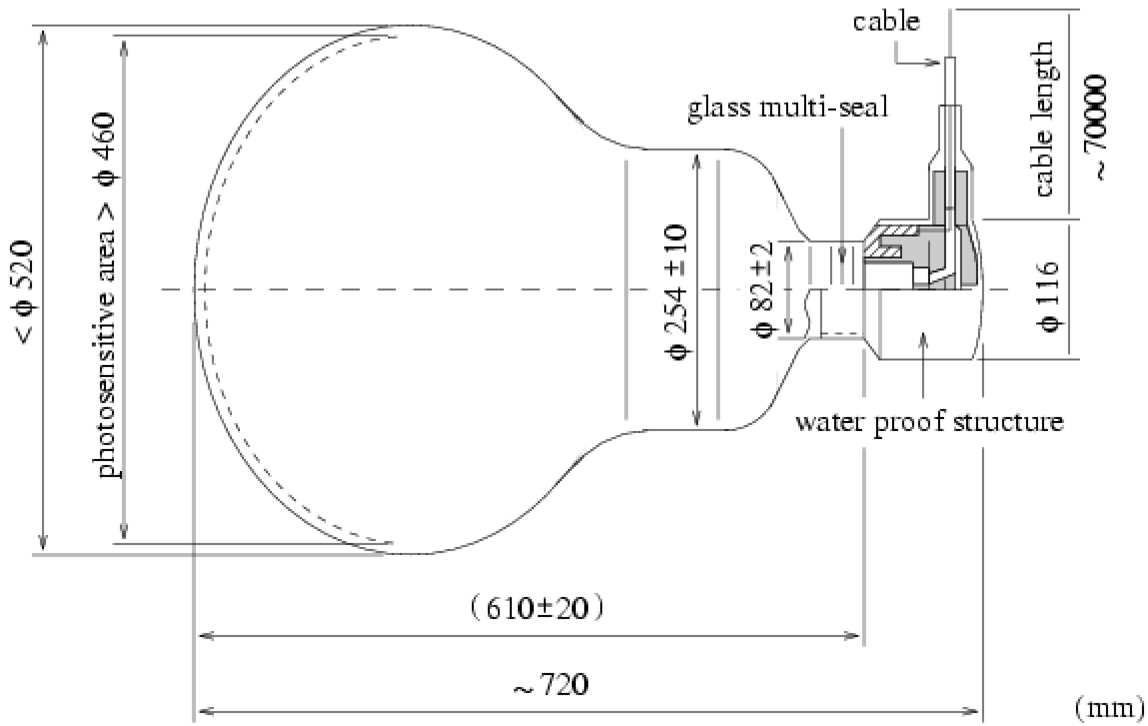
**No. of photons ∝ energy loss of particle**

# The idea: a large volume of ultrapure water surrounded by photon amplifiers

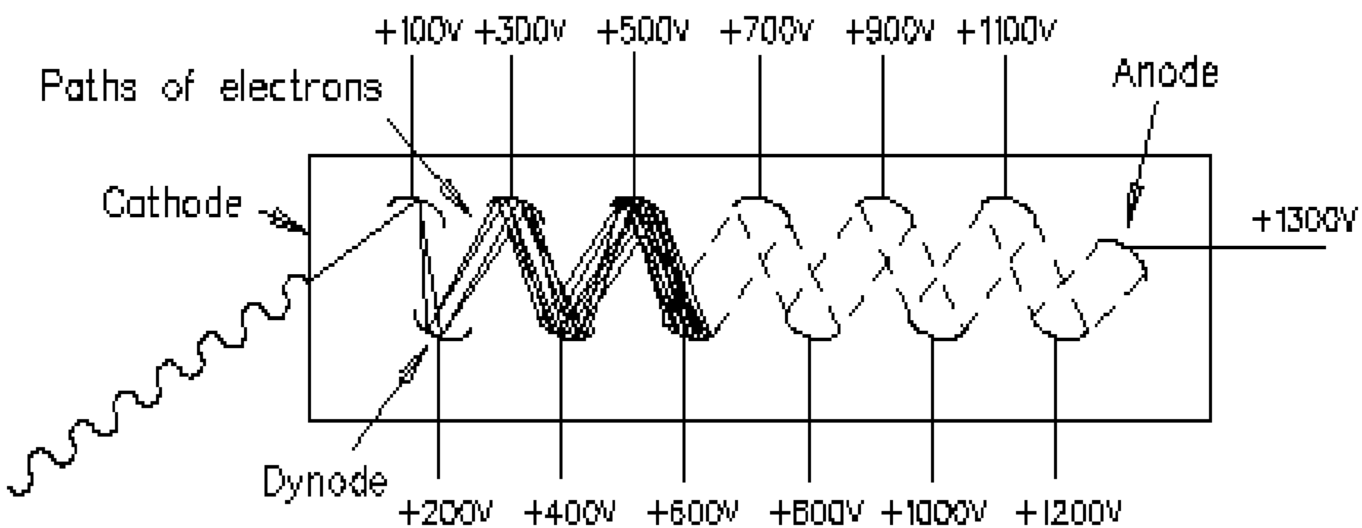



**Must be underground, to reduce cosmic rays**

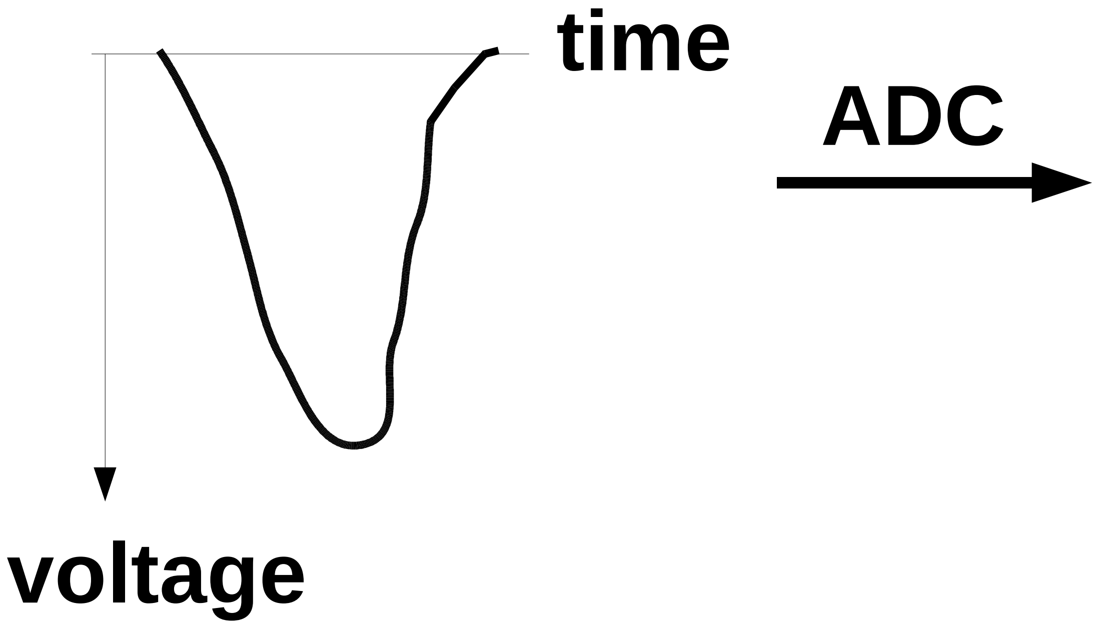
# Photomultiplier Tubes




**convert single photons into electrical pulses**



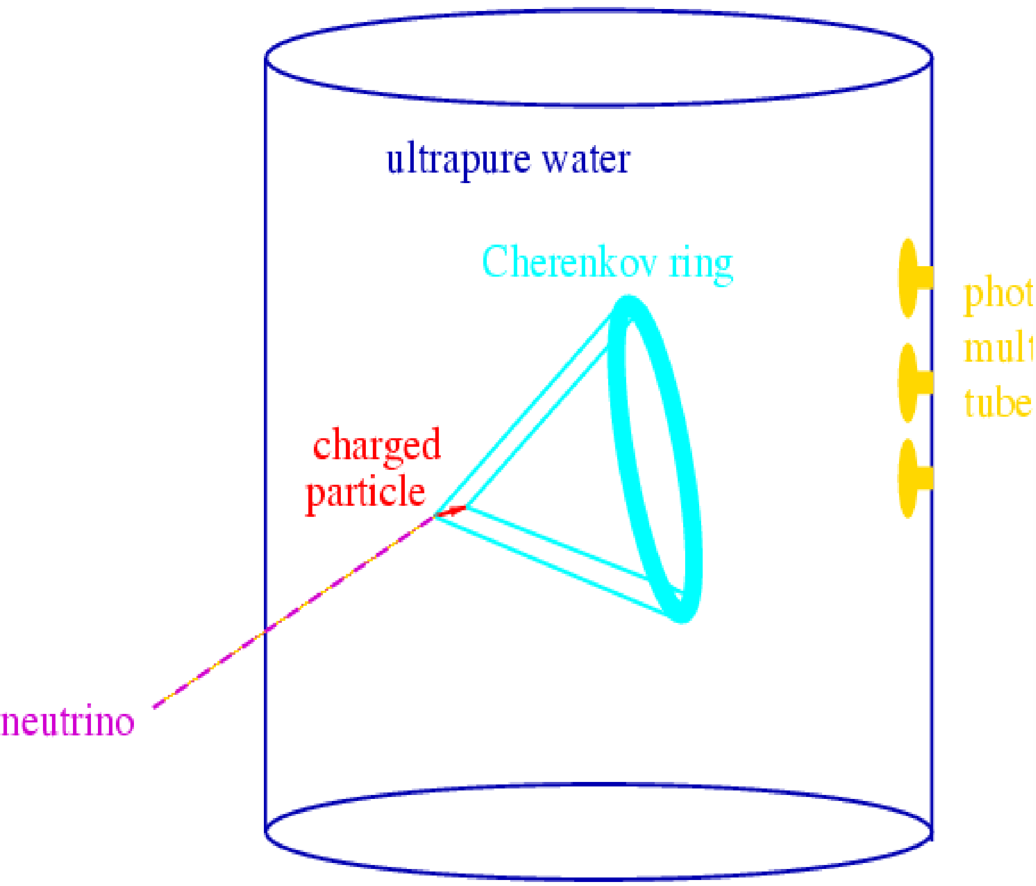
## The electrical pulses from each PMT are then *digitized*

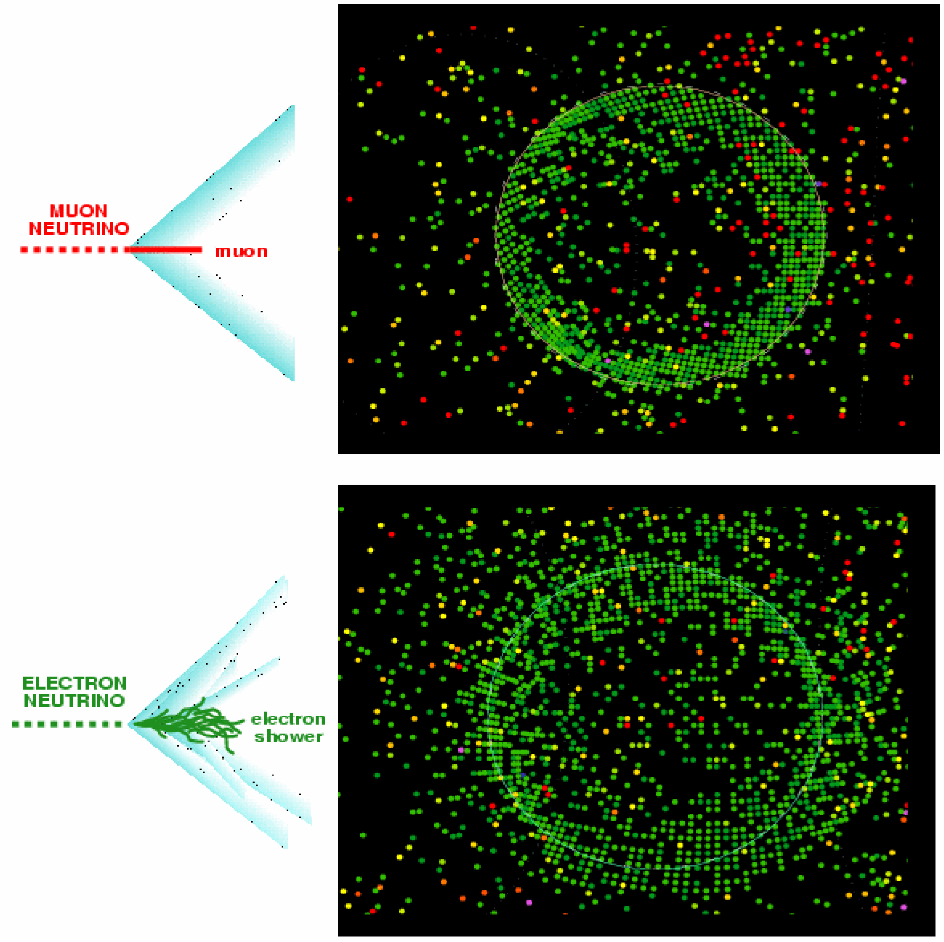



Numbers representing CHARGE and TIME of pulse

- Total charge observed in one PMT is proportional to the number of photon (and also proportional to energy loss)
- Time indicates when the light hit the PMT

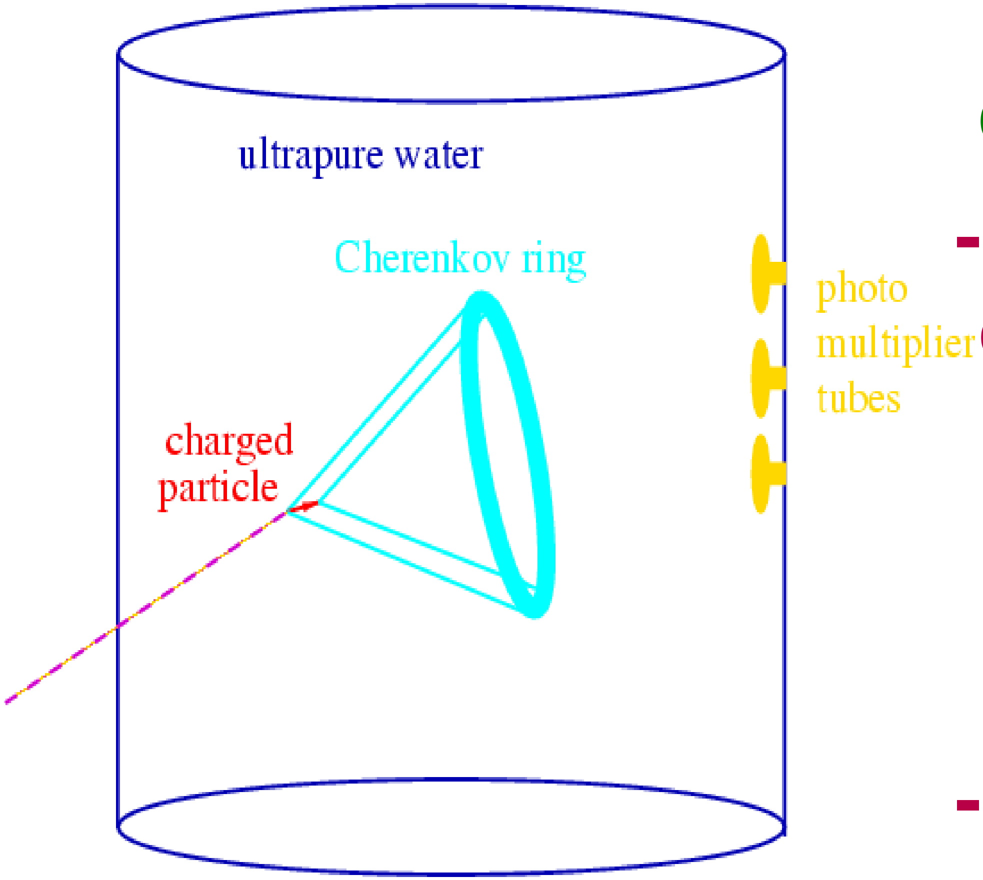
# Since you know where each PMT is you can turn these numbers into a ring-like pattern:




**Each dot represents a PMT hit by light**

# From the pattern of light can *reconstruct*




- The ***energy*** of the charged particle(s)

**Charge∝ photons∝ energy loss**

-The position (***vertex***) of the interaction

**Using charge, and especially time of flight of light: early times at some PMT means closer to that side of the detector**

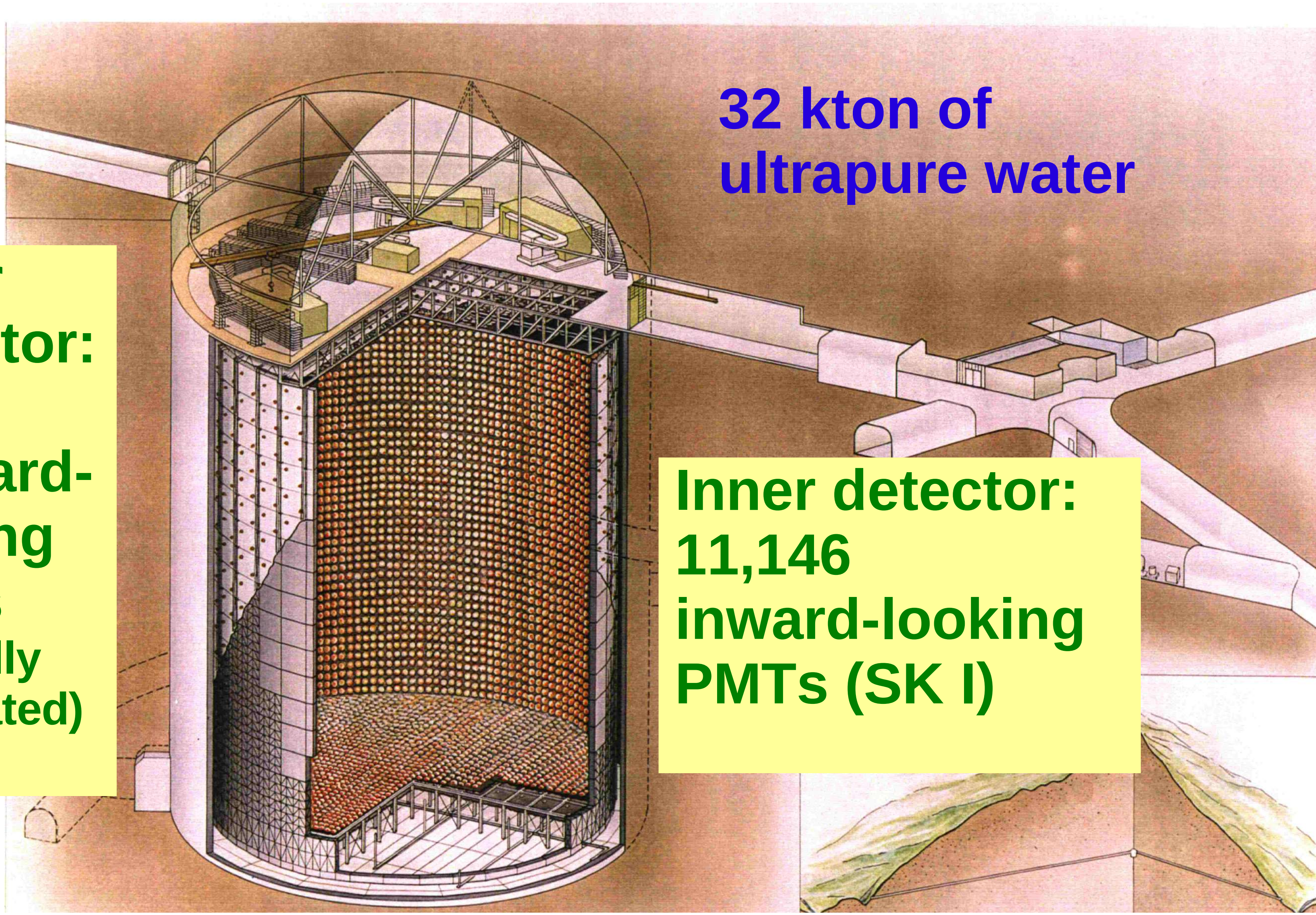
- The ***direction(s)*** of the charged particle(s)

**Using time and charge pattern to determine cone direction**

**Use software "fitters"**

# Super-Kamiokande

**Water Cherenkov detector in Mozumi, Japan**

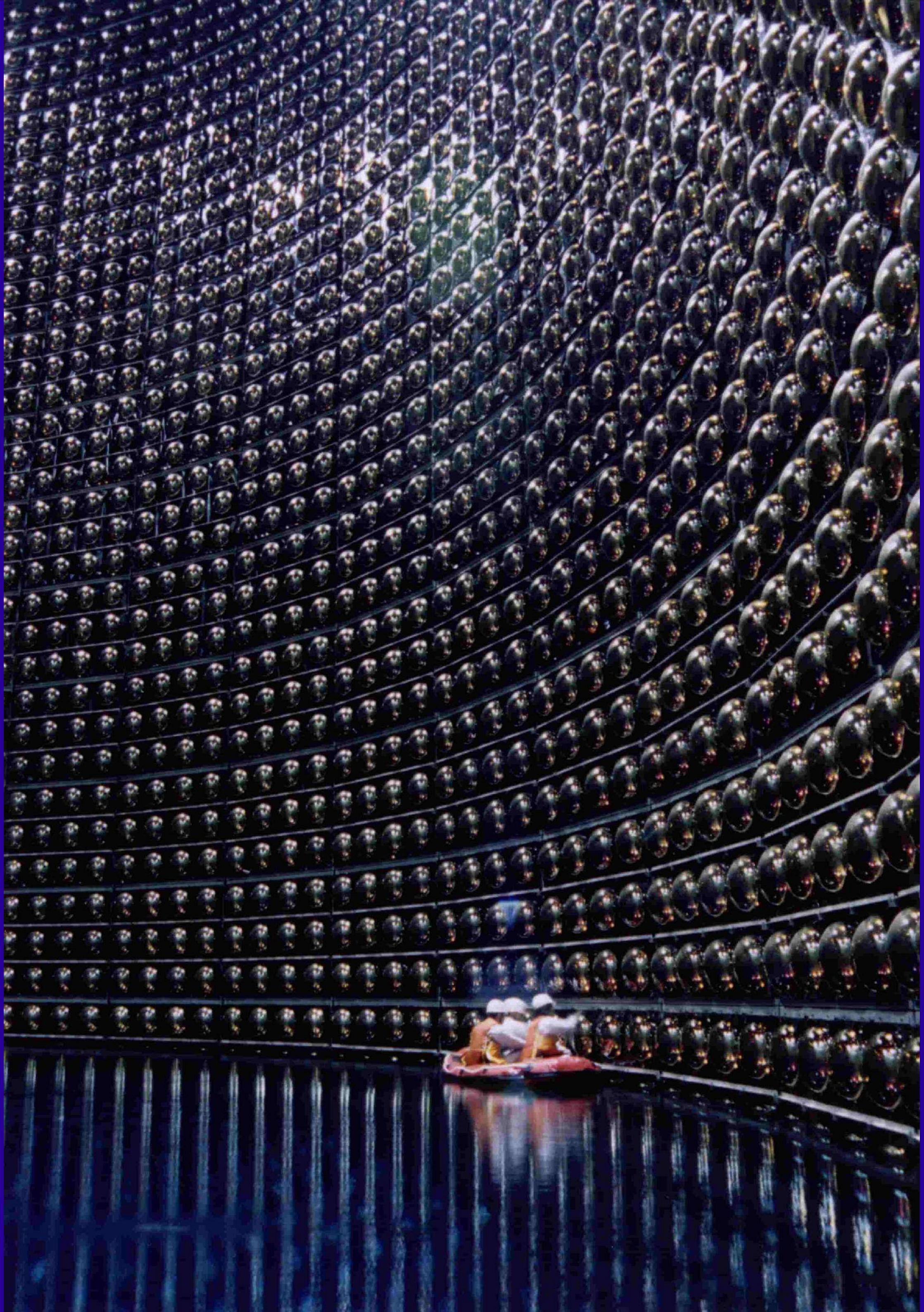


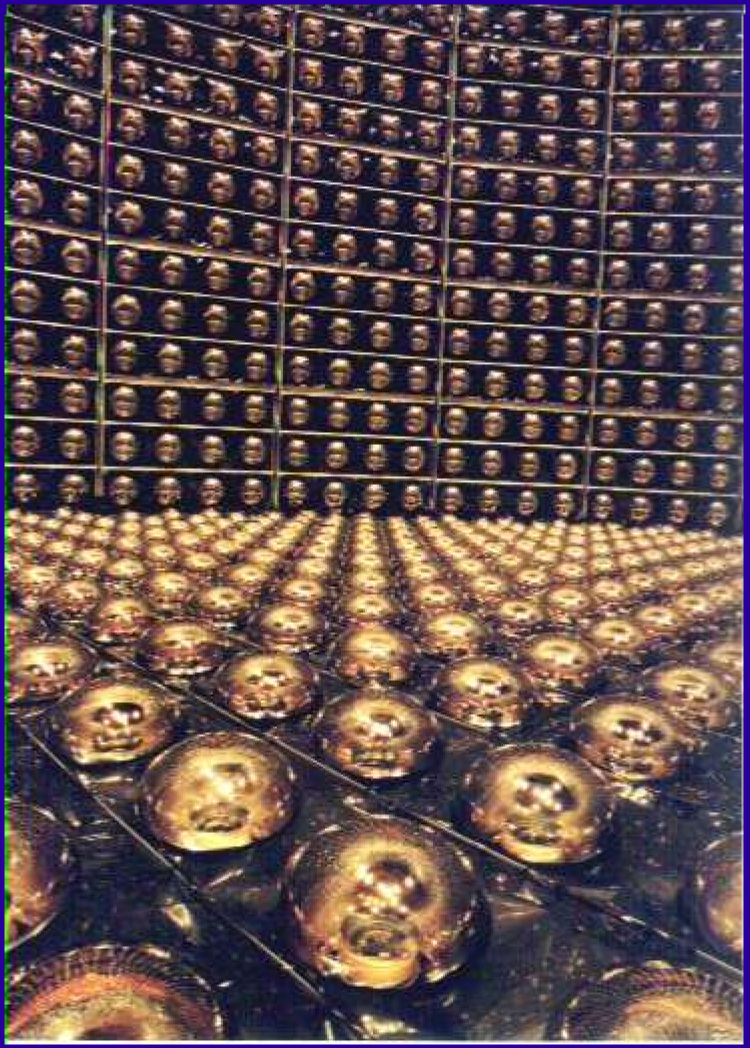
**32 kton of ultrapure water**

**Outer detector: 1889 outward-looking PMTs (optically separated)**

**Inner detector: 11,146 inward-looking PMTs (SK I)**

**40 m high, 17 m radius, at depth of 2800 mwe**





# Super-K Accident    November 12, 2001

**2/3 of PMTs destroyed in chain reaction implosion**

## Reconstruction during 2002: surviving inner detector tubes redistributed and available spares installed (~ uniformly)

**Acrylic/ fiberglass shells for shock protection**

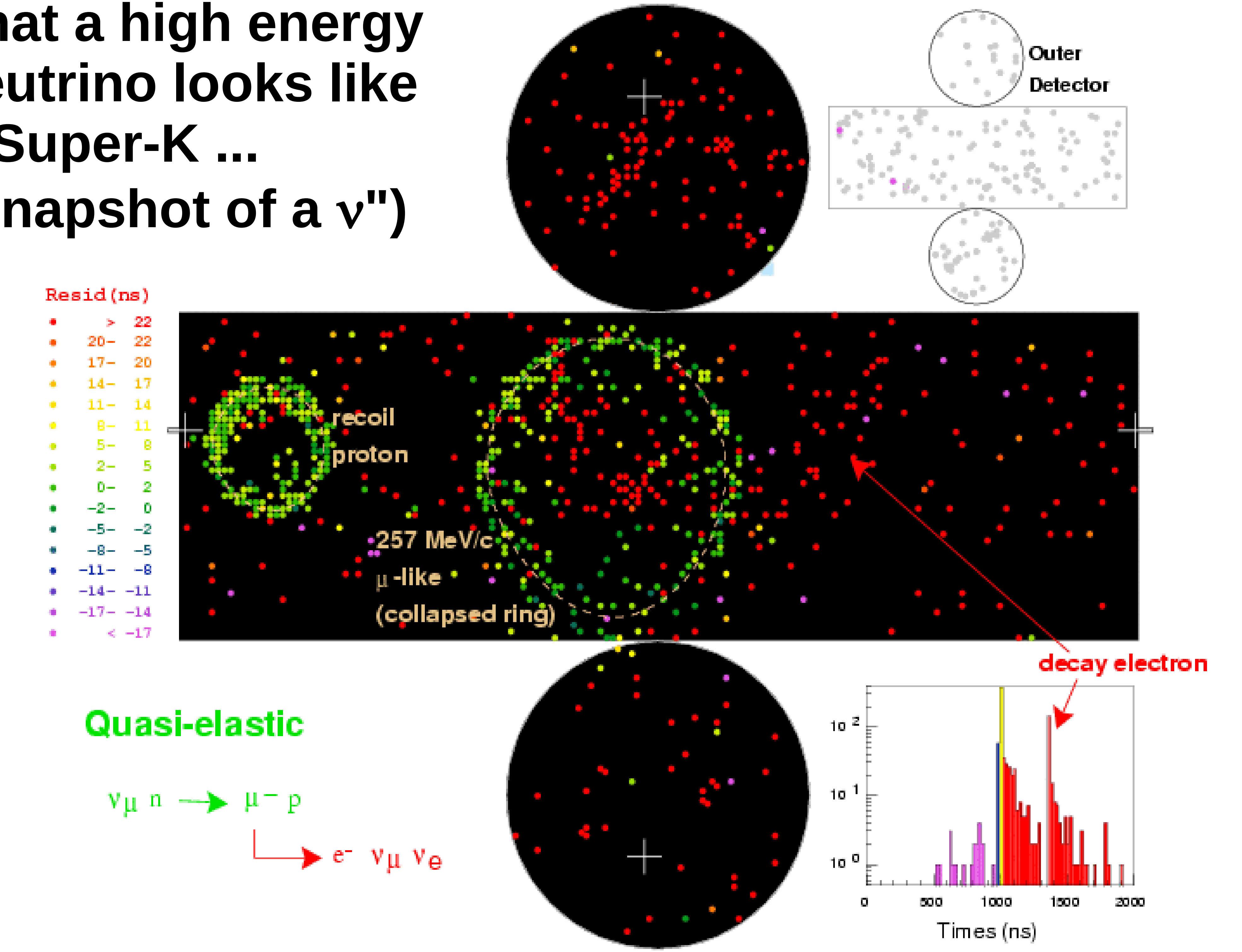
**Since Jan '03, back online with 47% of PMT's!!**

**“Super-K II”**

**Future of Super-K:**
**full reconstruction, back to 11,000**
**ID PMTs during winter of 2005/2006**

**Preparation this summer in Japan**

# What a high energy neutrino looks like in Super-K ... ("snapshot of a ν")



## What Super-K data look like:

- **Organized into 'EVENTS', corresponding to *triggers***

- **When a certain number of PMTs fire within a certain amount of time, the PMTs are 'read out' and the digitized data stored**

**List of pmt no.'s, time, charge, for each 'hit'**

- **Several triggers with different criteria (High energy, low energy...)**

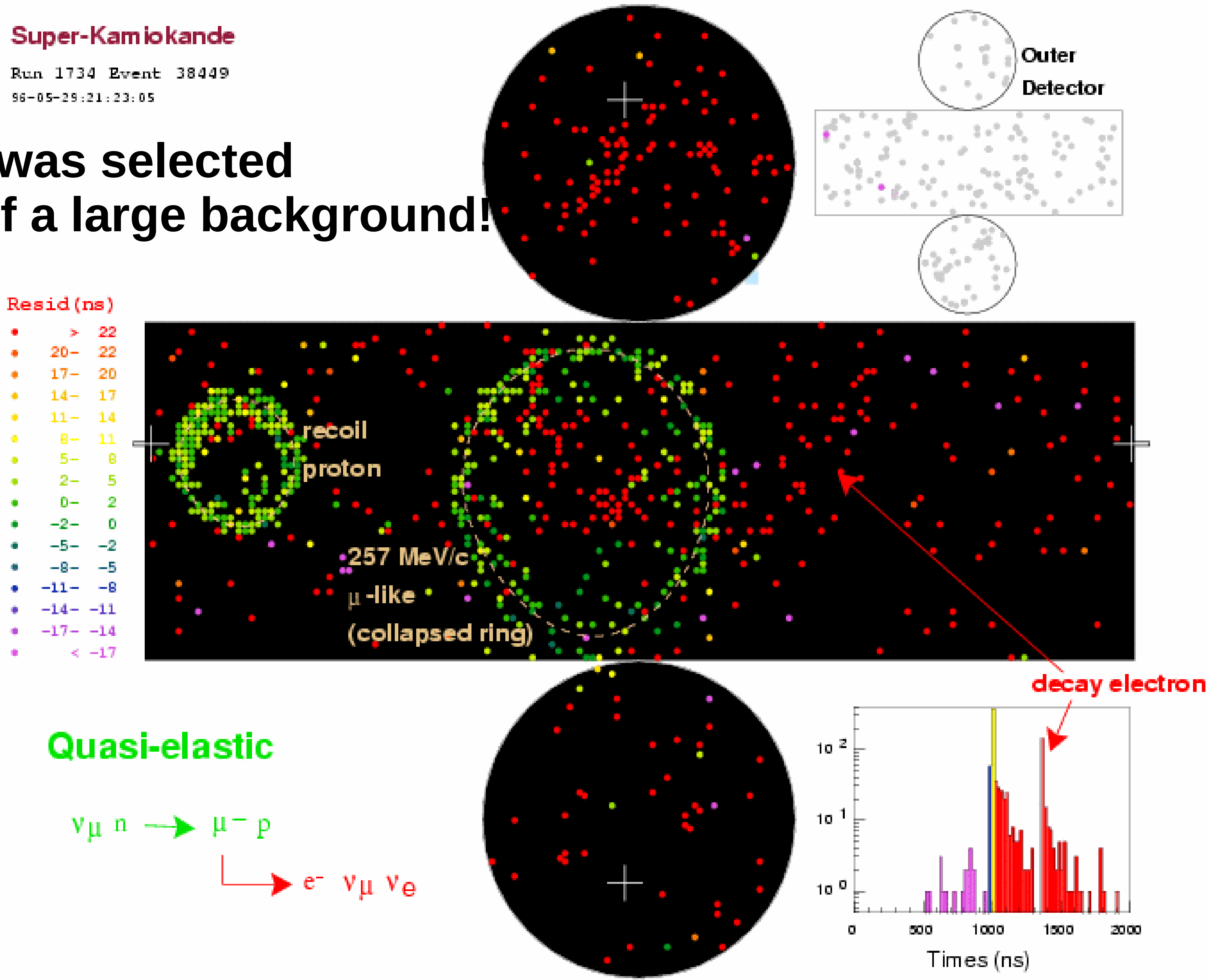
- **Typical rate: 10-100 Hz**

  **Cosmic rays, muons, radioactivity, junk..**

  **(Neutrinos only ~tens/day!)**

- **Events grouped into 'subruns' (few minute-long chunks of data) and runs (hours- 1 day)**

## This was selected out of a large background!

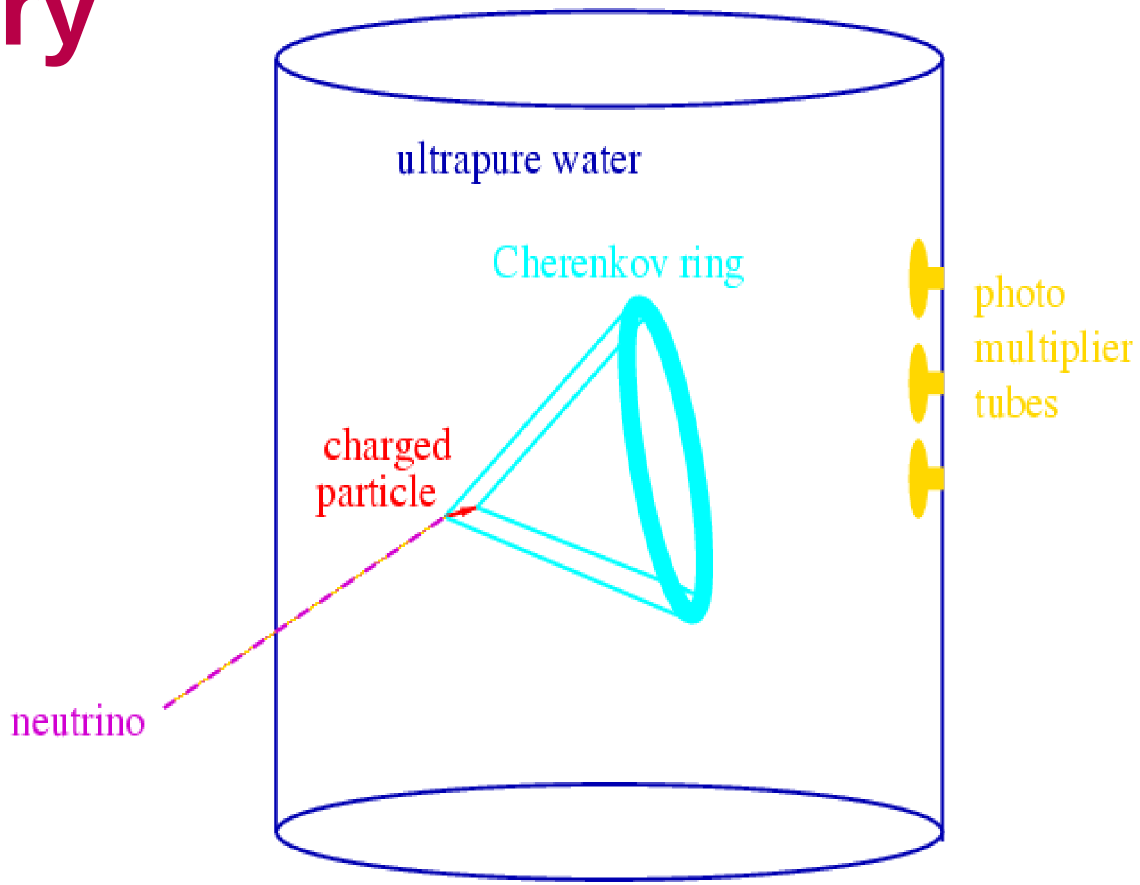



**Quasi-elastic**

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

$\hookrightarrow e^-\ \nu_\mu\ \nu_e$

# Summary




**Neutrino → Charged particle → Cherenkov light → Photomultiplier tube hit → Digitized pulse (charge, time) → Reconstructed energy, vertex, direction**

## Now the nitty-gritty:
## getting your hands on the data

Data may be viewed and manipulated using Super-K software

- mostly in Fortran, some C; moving toward C++

Available from cvs (Concurrent Versioning System) repository (in Japan)

## The Event Display

# e.g. superscan

- step through events
- various options for information display
- time or charge mode

## Accessing SK data to manipulate:

- Get code from repository, modify as needed

- Create Makefile for compilation using Imake

- Compile and link against SK libraries (available locally)

- Run on raw or processed data files

**I'll post detailed instructions!**

## A sample program:

- Open data file (skopenf)
- Loop over events
    - Read one event (skread)
      (information stashed locally)
    - Loop over PMT hits
        - For each hit, fill charge
          and time histograms
- Close data file (skclosef)
- Output histogram

**Later, view histogram with PAW (or Root)**

# First exercises:  (physics Linux cluster)

1. Run superscan to eyeball data files

2. Set up and run sample program to histogram total charge per event

3. Modify program to histogram PMT hit times

I will post the necessary materials and instructions early next week!