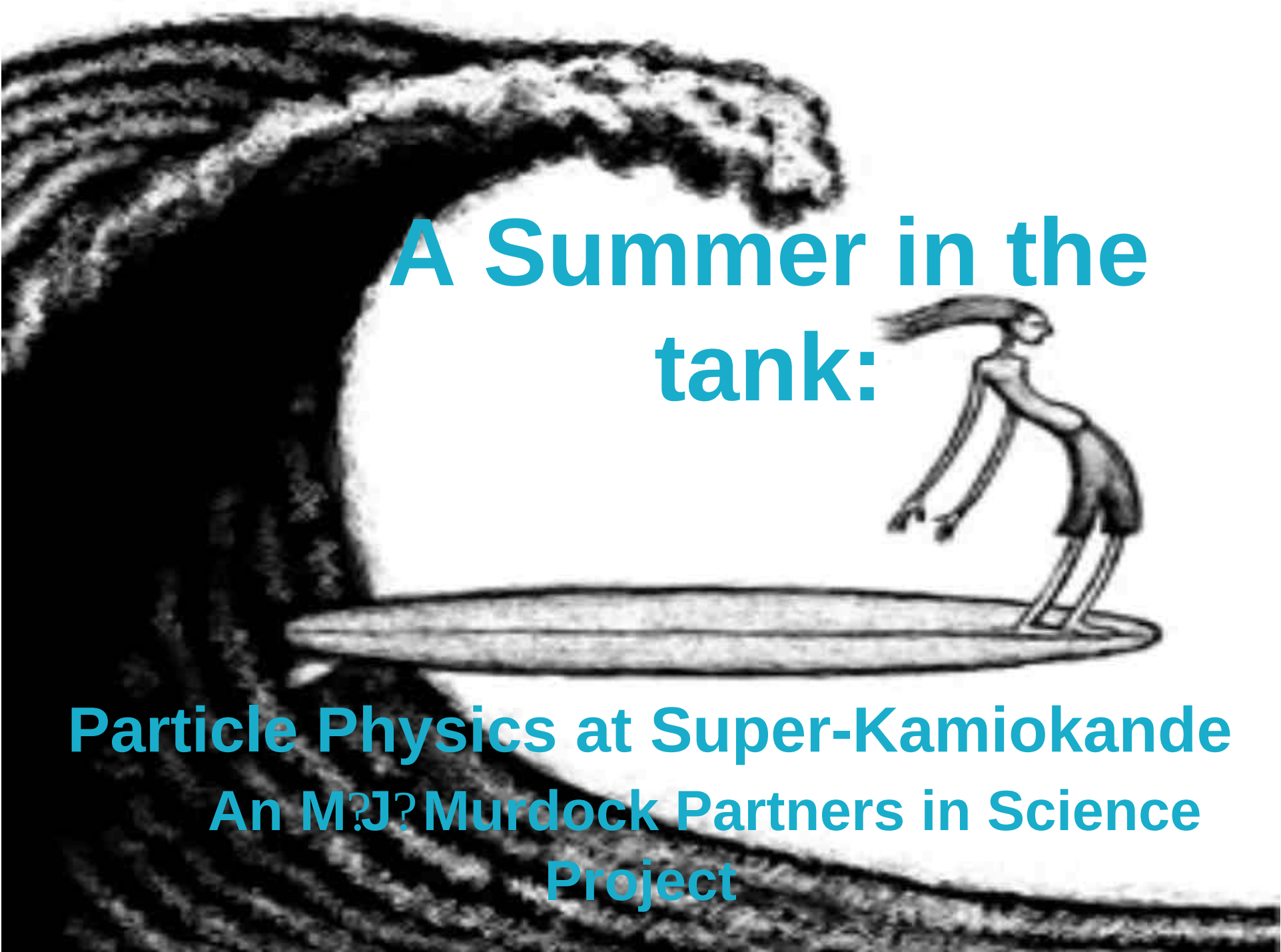
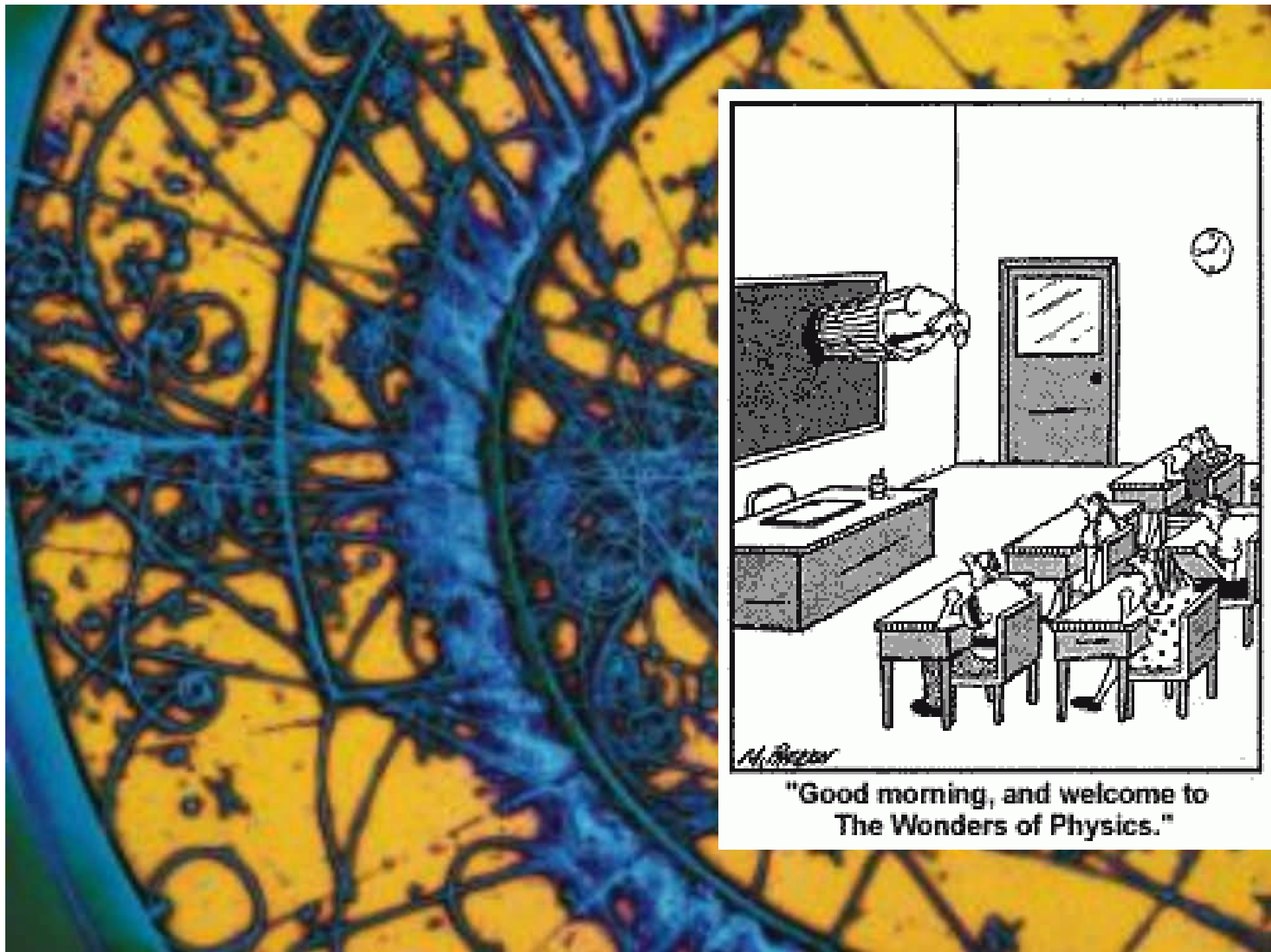


A black and white illustration of a person surfing on a large wave. The surfer is in a crouched position, leaning forward, with their hair blowing in the wind. The wave is large and curling, creating a tunnel-like shape behind the surfer. The background is white.

A Summer in the tank:

Particle Physics at Super-Kamiokande
An M²J² Murdock Partners in Science
Project



"Good morning, and welcome to
The Wonders of Physics."

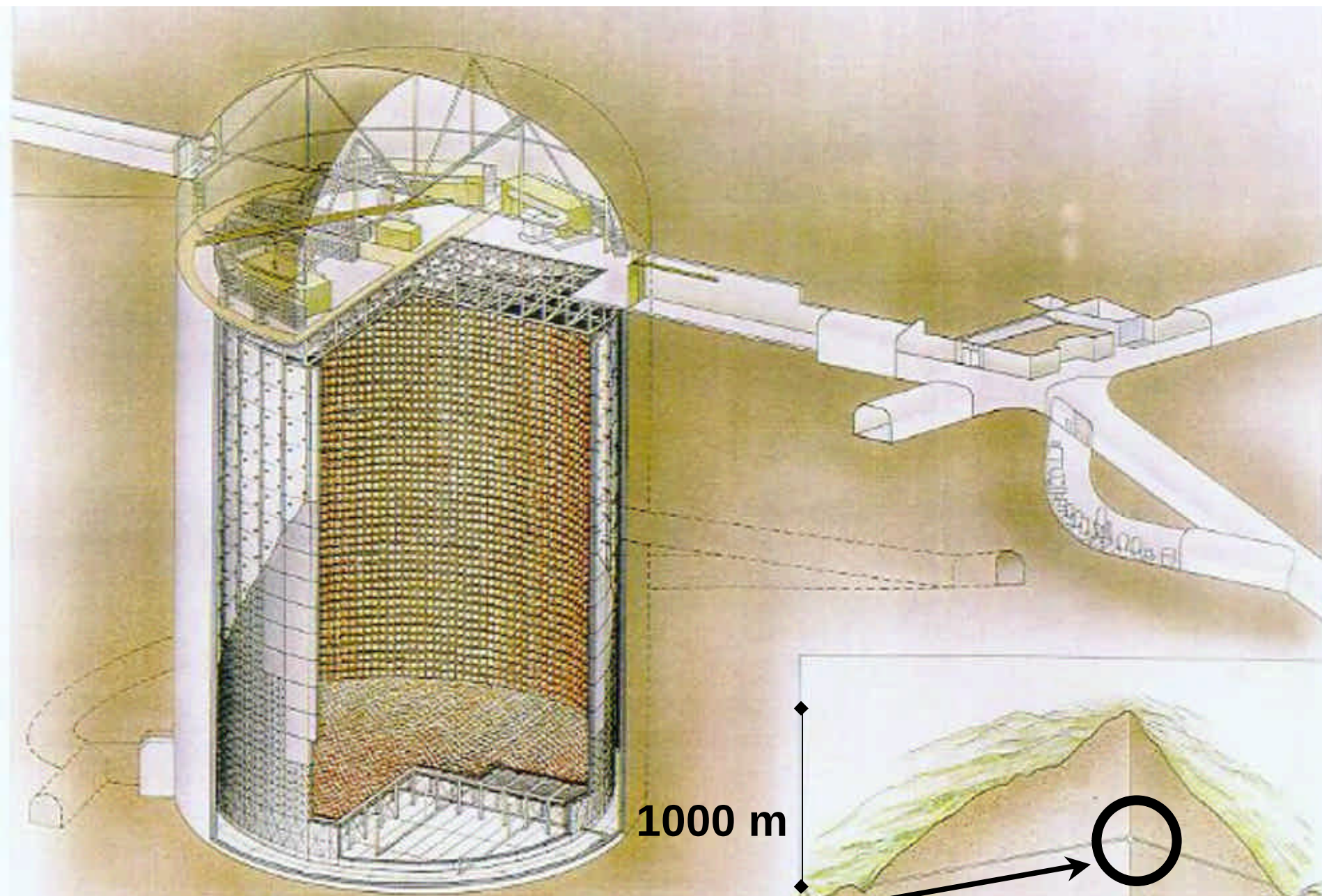
What is Super-Kamiokande (Super-K)?



 Collaborative project involving Japan, USA, Korea, & Poland with a focus on particle physics

~Proton decay

~Cosmic ray detection (Supernova search)



Here is Super-K!

Technically, Super-K is a:

Cerenkov Radiation Detector –

✚ contains 50, 000 tons (that's 11.2 million gallons) of ultra-pure water encased in a stainless steel cylinder (40 m high & 40 m in diameter)

✚ currently contains over 5000 photomultiplier tubes (PMTs) that constitute the inner detector (ID)

✚ and 1885 photomultiplier tubes



Getting
closer!







Route 41 to the mine



Toyama Town

1 光電子増倍管の目的：

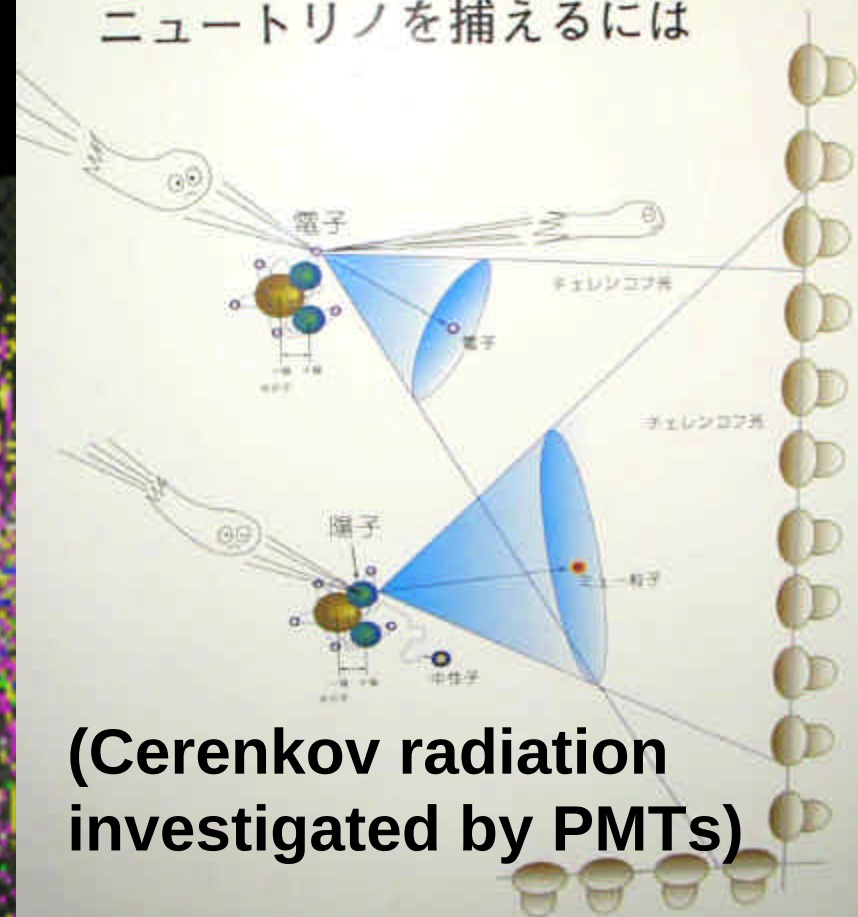
ゆうれい粒子"ニュートリノ"を捕える目

(Ghost-particles to be
"caught" by
PMTs)



2 光電子増倍管の働き：

ニュートリノを捕えるには



(Cerenkov radiation
investigated by PMTs)

A quick overview of how Super-K works

What's The BIG Fuss

About?

Special: New Learning Series on Genetics, page 70
Complexity—the Science of Surprise | Your Inner Savant
Discover
FEBRUARY 2002

The
11
Greatest
Unanswered
Questions
of Physics

QUESTION 4

Do neutrinos have mass?

Nuclear reactions such as those that create heavy elements also create vast numbers of ghostly subatomic bits known as neutrinos. These belong to a group of particles called leptons, such as the familiar electron and the muon and tau particles. Because neutrinos barely interact with ordinary matter, they can allow a direct look into the heart of a star. This works only if we are able to capture and study them, something physicists are just now learning to do.

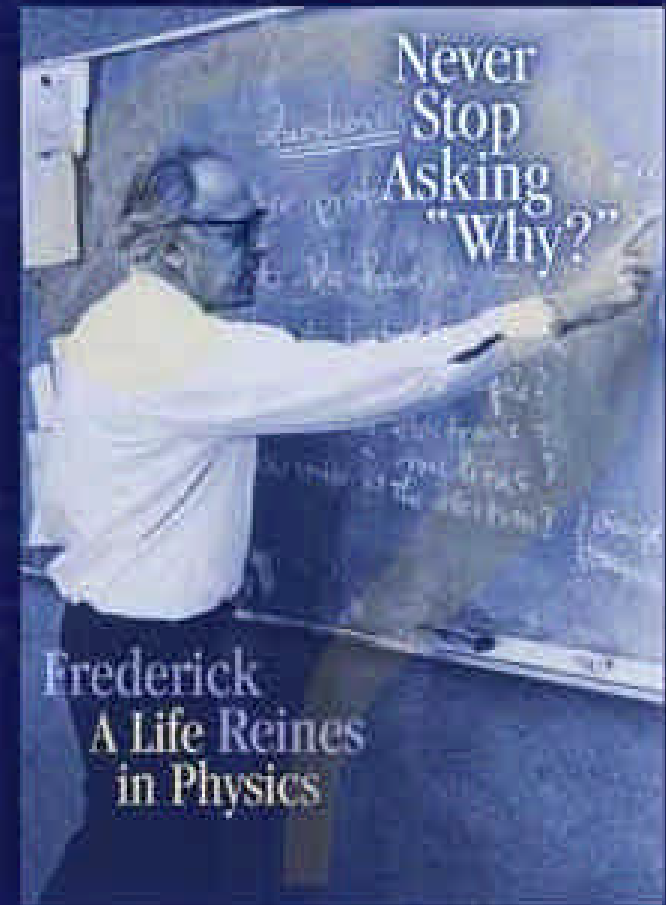
Not long ago, physicists thought neutrinos were massless, but recent advances indicate that these particles may have a small mass. Any such evidence would also help validate theories that seek to find a common description of three of the four natural forces—electromagnetism, strong force, and weak force. Even a tiny bit of heft would add up because a staggering number of neutrinos are left over from the Big Bang.

QUESTION 5

Where do ultrahigh-energy particles come from?

The most energetic particles that strike us from space, which include neutrinos as well as gamma-ray photons and various

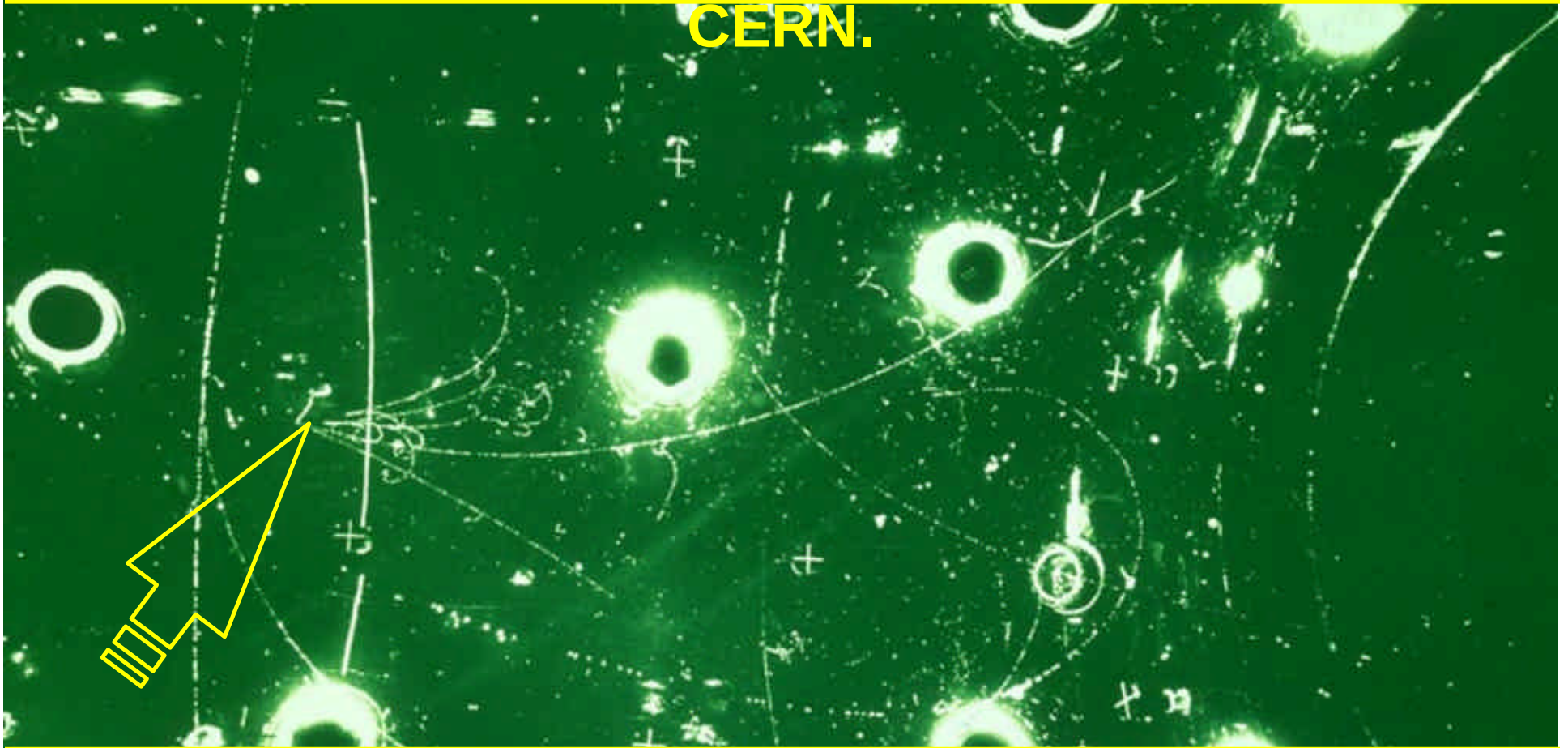
Frederick Reines (1995 Nobel Laureate) and the Neutrino



UCI Libraries

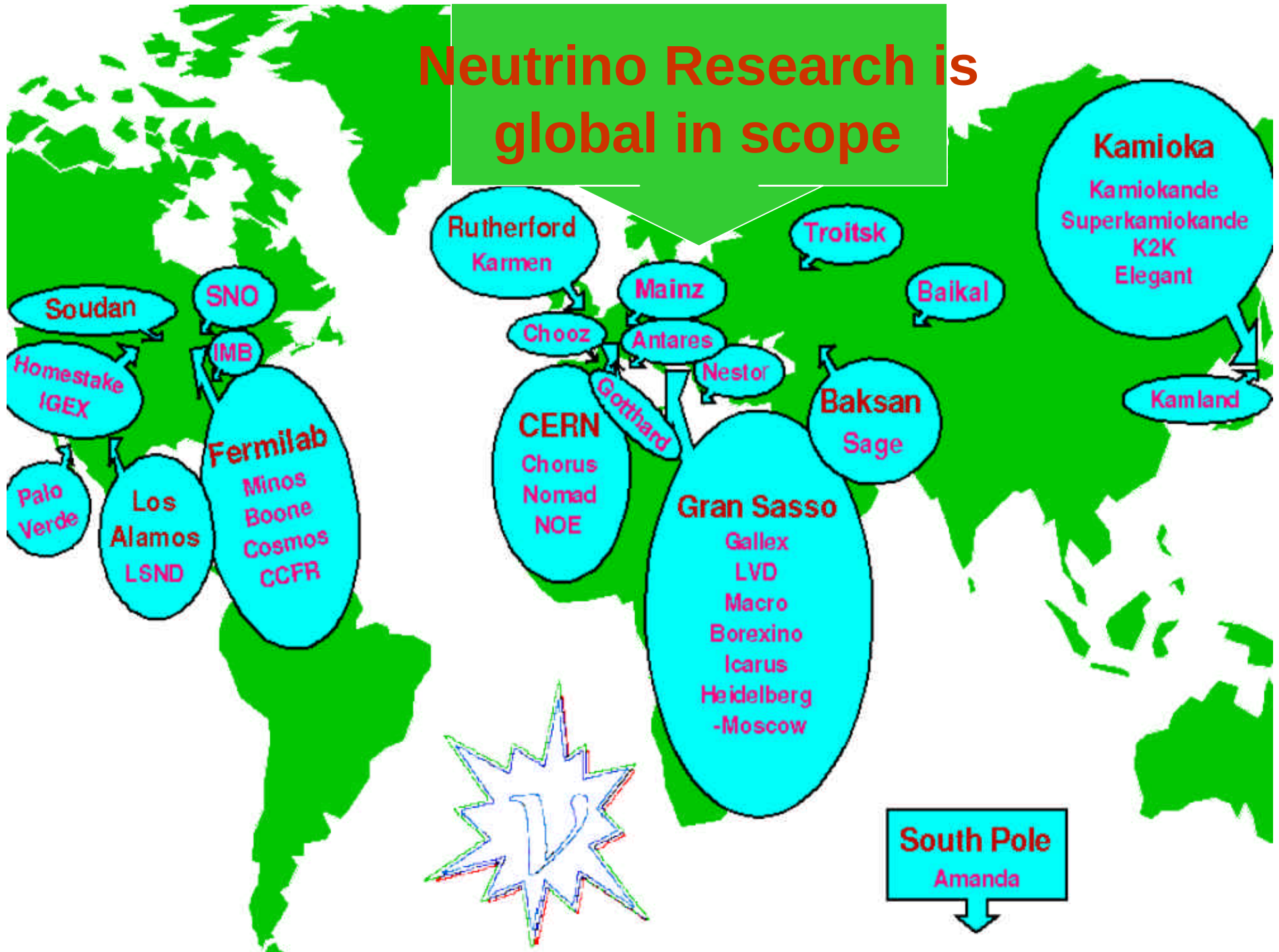
61055

**On September 3rd, 1973, the first observation of
“neutral current” interactions, were recorded at
CERN.**



**These particles are the debris of a nucleus in the
bubble chamber liquid, which has been struck by
one of the energetic, but invisible neutrinos.**

Neutrino Research is global in scope



Overview of Particle Physics

Standard Model of FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included in this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

BOSONS

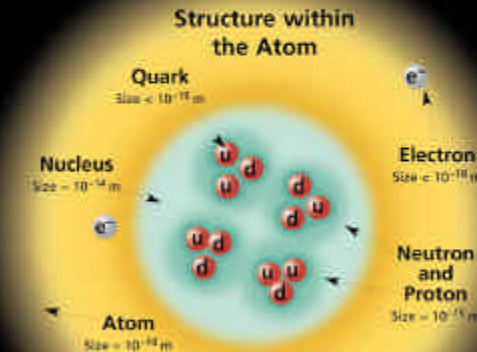
force carriers
spin = 0, 1, 2, ...

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge	Flavor	Approx. Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-8}$	0	u up	0.003	2/3
e electron	0.000511	-1	d down	0.006	-1/3
ν_μ muon neutrino	<0.0002	0	c charm	1.3	2/3
μ muon	0.106	-1	s strange	0.1	-1/3
ν_τ tau neutrino	<0.02	0	t top	175	2/3
τ tau	1.7771	-1	b bottom	4.3	-1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of $\hbar$, which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58 \times 10^{-25}$ GeV s = 1.05×10^{-34} J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electronvolt (eV), the energy an electron in crossing a potential difference of one volt. **Masses** are given in $e = mc^2$, where $1 \text{ GeV} = 10^9 \text{ eV} = 1.60 \times 10^{-10}$ joule. The mass of the proton is 1.67×10^{-27} kg.



If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 1 mm across and the entire atom would be about 10 km across.

Unified Electroweak spin = 1		
Name	Mass GeV/c ²	Electric charge
γ photon	0	0
W^-	80.4	-1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1		
Name	Mass GeV/c ²	Electric charge
g gluon	0	0

Color Charge

Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the color of visible light. There are eight possible types of color charge for gluons. As in electricity, color-charged particles interact by exchanging photons. In strong interactions, color-charged particles interact by exchanging gluons. Leptons, photons, and W and Z bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons

One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** ($q\bar{q}$) and **baryons** (qqq).

FERMIONS

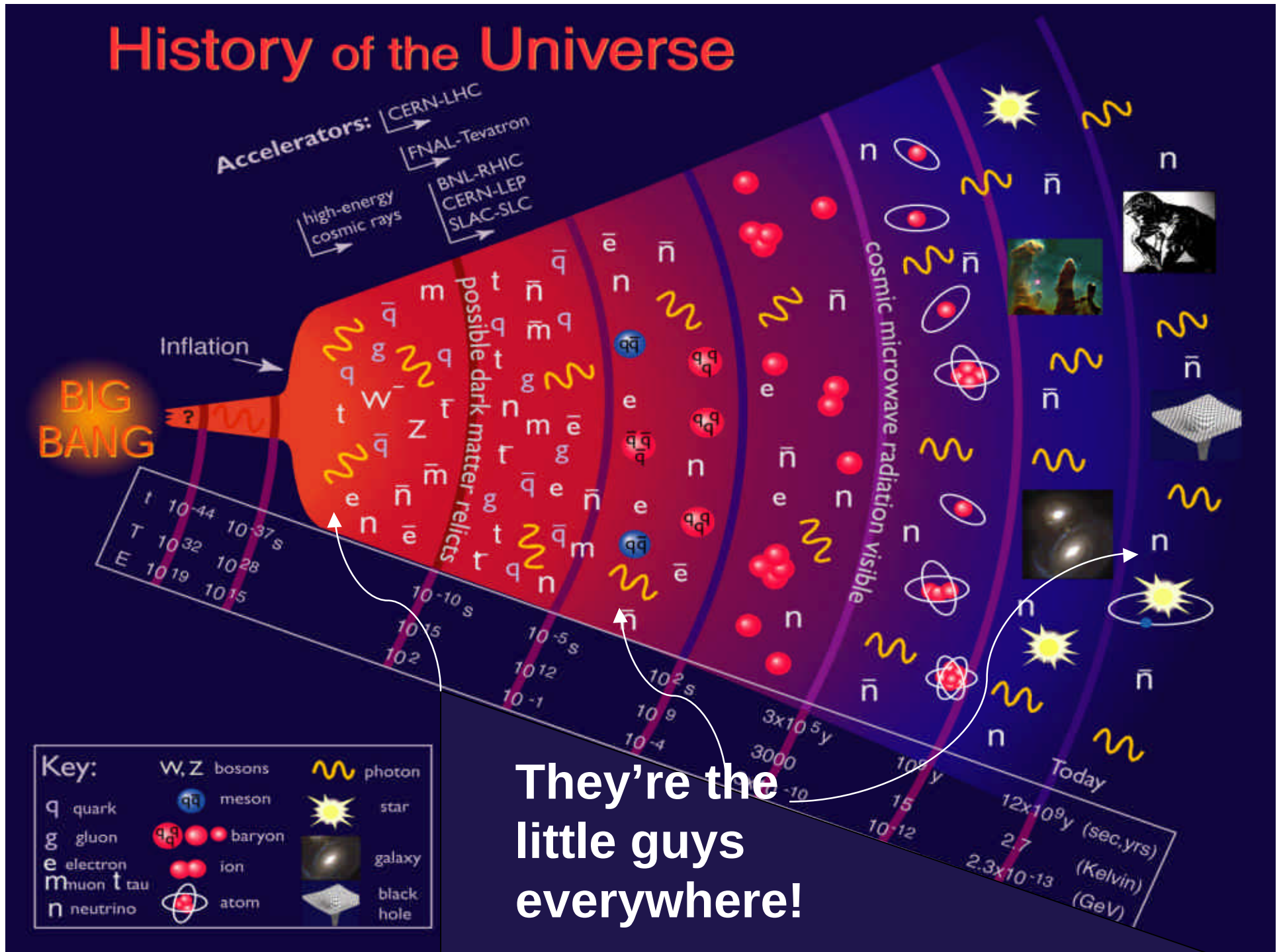
matter constituents

spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge	Flavor	Approx. Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-8}$	0	u up	0.003	2/3
e electron	0.000511	-1	d down	0.006	-1/3
ν_μ muon neutrino	<0.0002	0	c charm	1.3	2/3
μ muon	0.106	-1	s strange	0.1	-1/3
ν_τ tau neutrino	<0.02	0	t top	175	2/3
τ tau	1.7771	-1	b bottom	4.3	-1/3

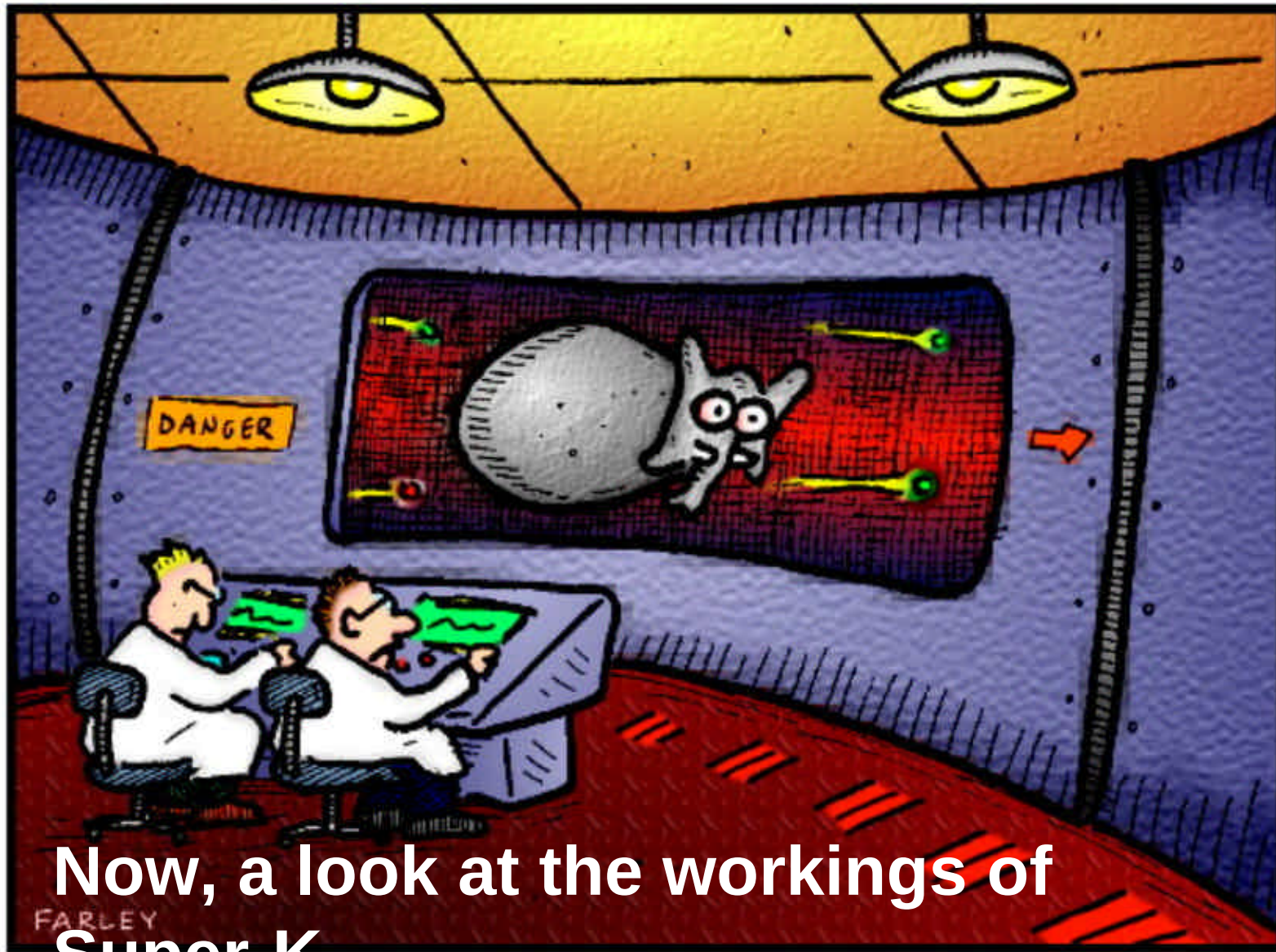
Neutral protons and neutrons form nuclei due to residual color forces between their color-charged constituents. It is similar to the residual electric forces between electrically neutral atoms to form molecules. It can also be seen between the hadrons.

History of the Universe



DOCTOR FUN

11 May 94



Deep within the atomic supercollider, the search continues for the elusive elephantino.

© Copyright 1994 David Farley. World rights reserved.
This cartoon is made available on the Internet for personal viewing only.
dgfl@midway.uchicago.edu
Opinions expressed herein are not those of the University of Chicago
or the University of North Carolina.



**When the
floor is
completed,
the ID will
house
11,146 PMTs,
each with a
diameter of
52 cm (20 in)**



大口型光電子増倍管

R3600-05 構造図

3-D STRUCTURE of
PHOTOMULTIPLIER TUBE
R3600-05

My job
is to
change
light
into
electrical
current

各部の名称 DESIGNATION

ガラスバルブ
GLASS BULB

光電面
PHOTO CATHODE

電子増倍部(11段)
DYNODE:11stages

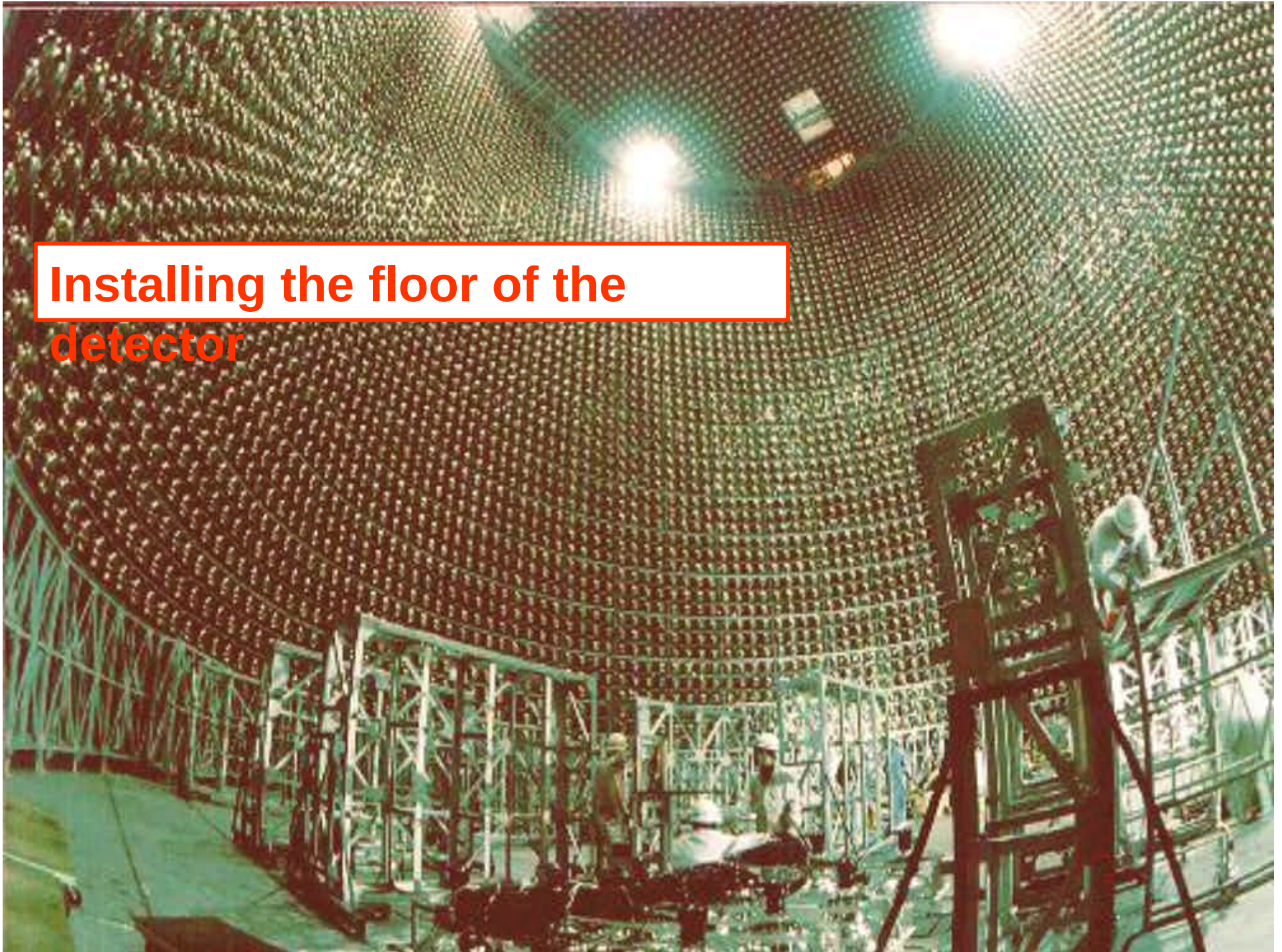
電圧分割回路
VOLTAGE DIVIDER

防水アッセンブリ
WATER PROOF
ASSEMBLY

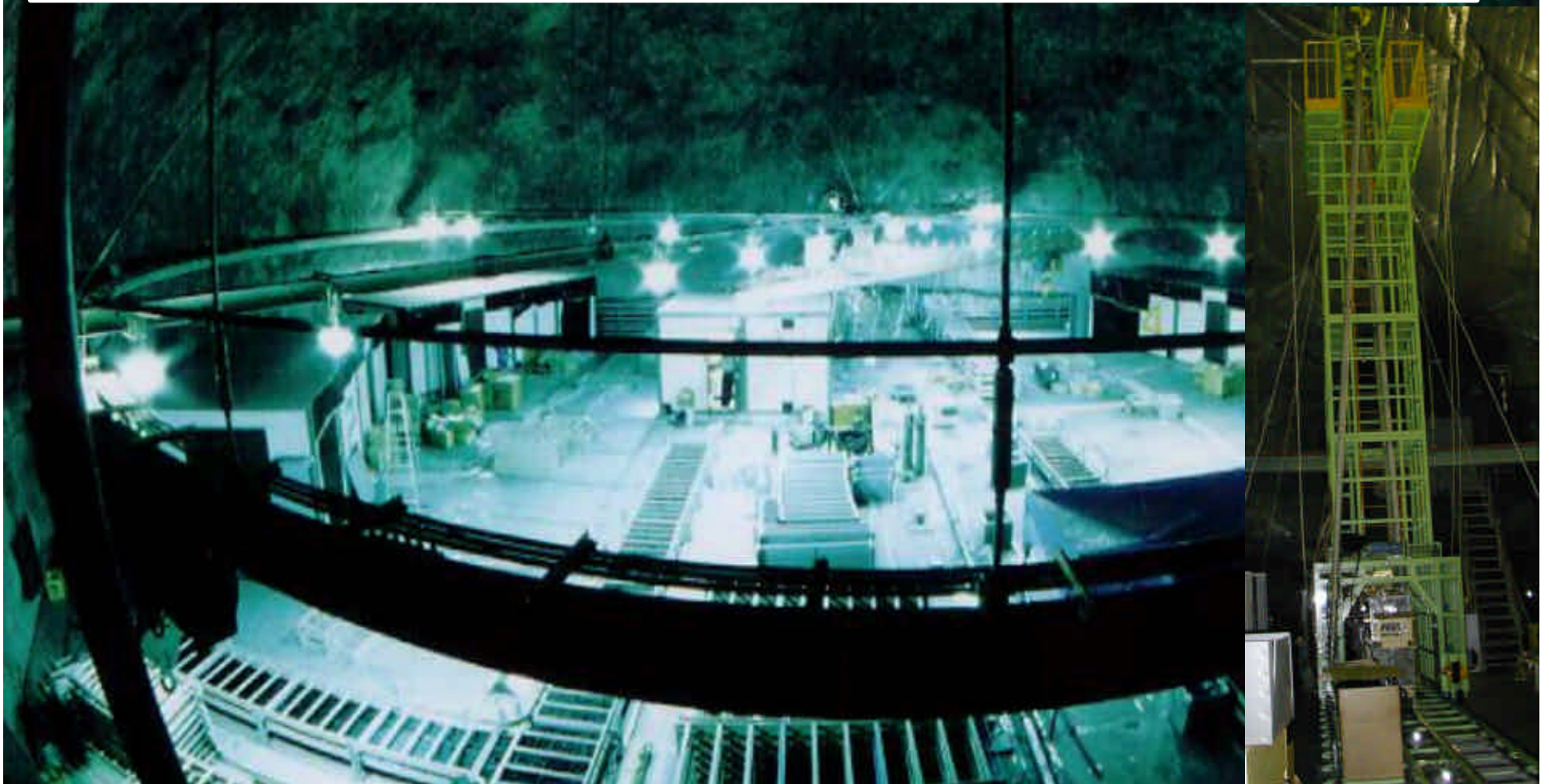
集束電極
FOCUSING ELECTRODE

全長:695mm(ケーブル含まず)
OVERALL LENGTH (without cable)
直径:518mm (MAX.)
DIAMETER
重量:13kg (ケーブル含む)
WEIGHT (with cable)

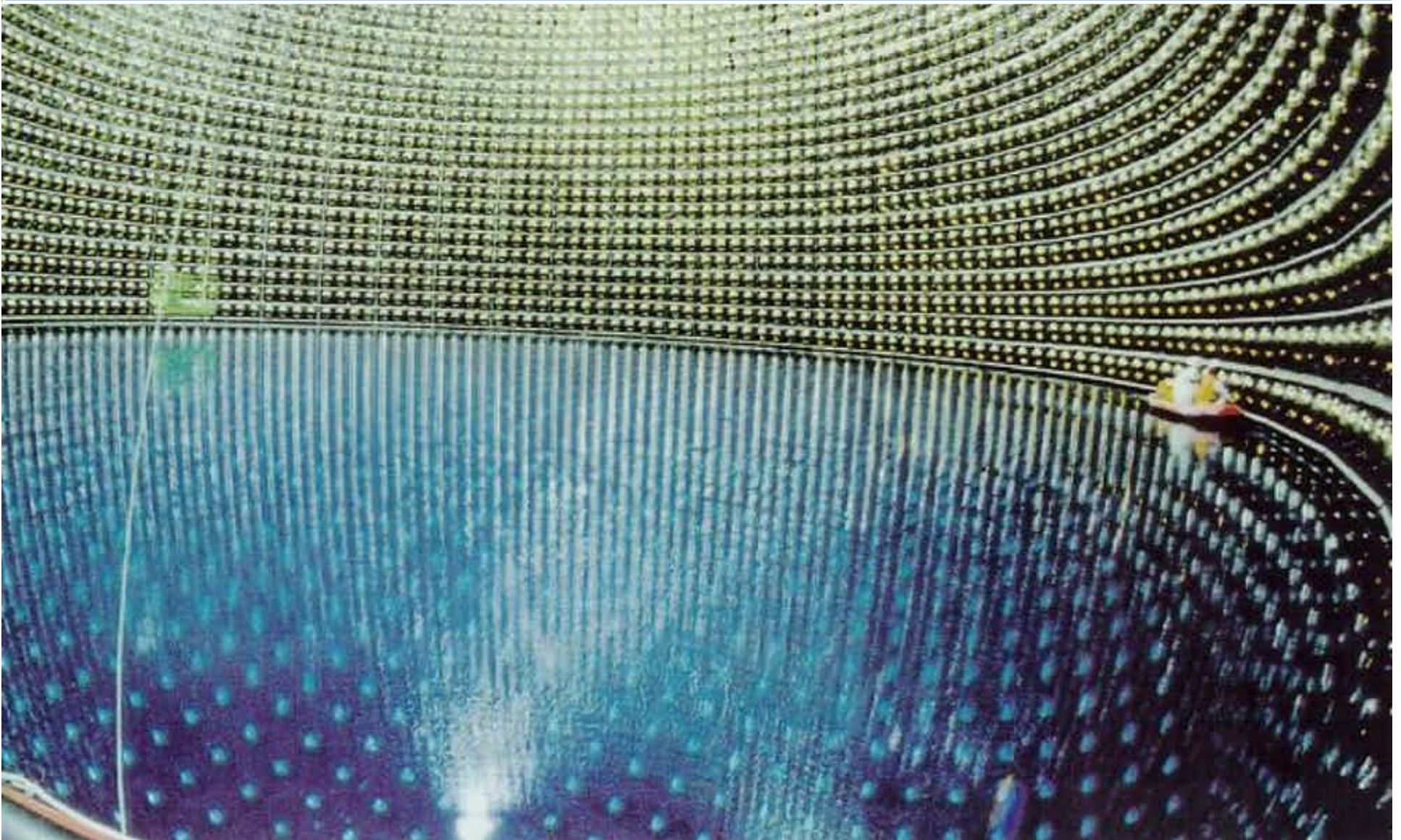
Installing the floor of the detector



**The dome above the tank houses
data acquisition electronics & a
linear particle accelerator**



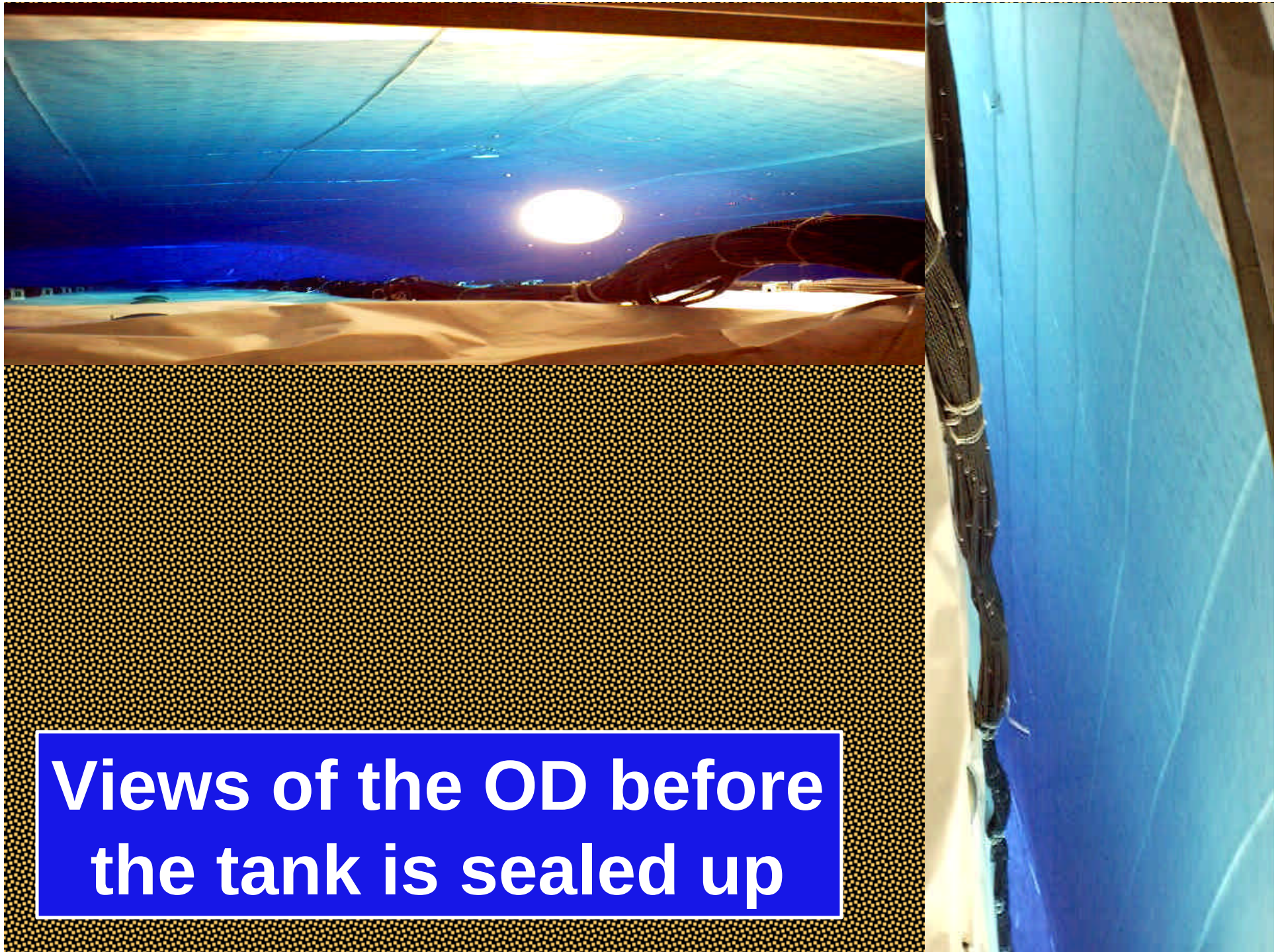
**Filling the tank with 11.2 million
gallons of ultra-pure H₂O**



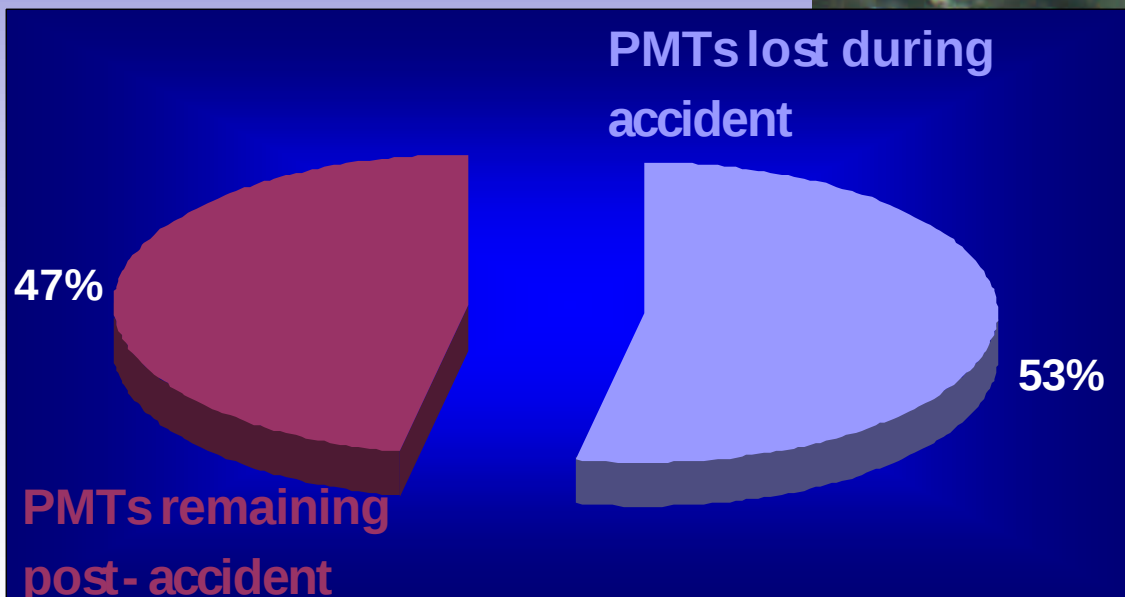
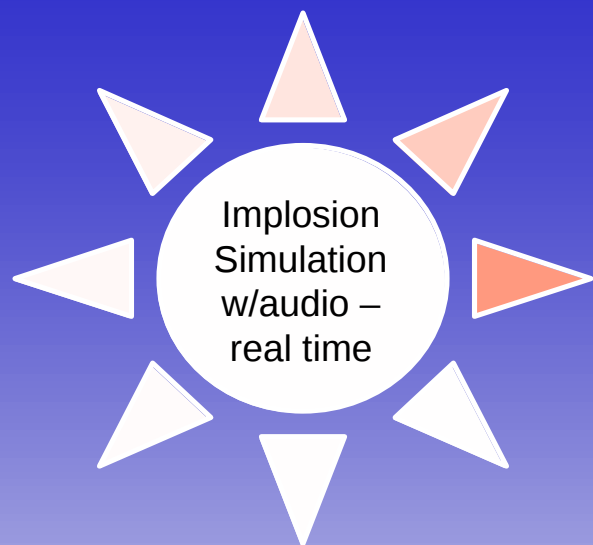
How the ultra-pure water is created



A bank of filters

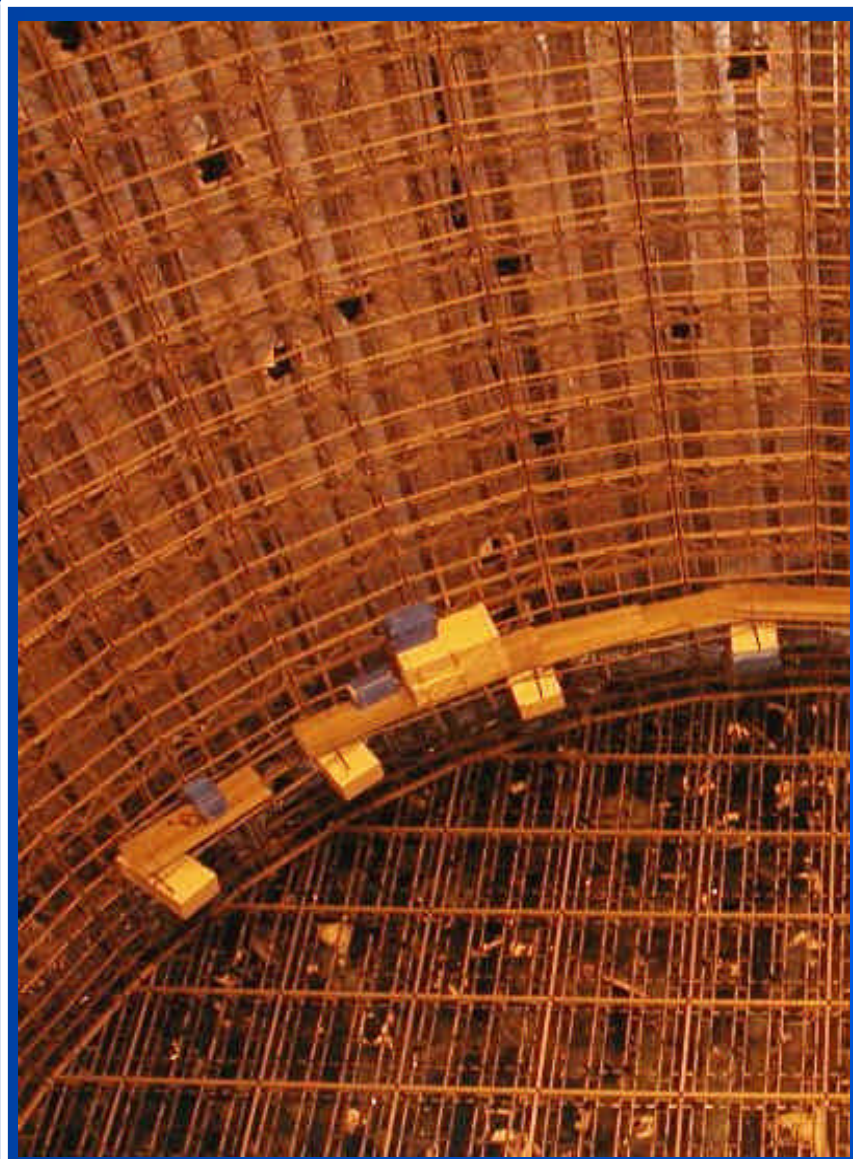


**Views of the OD before
the tank is sealed up**

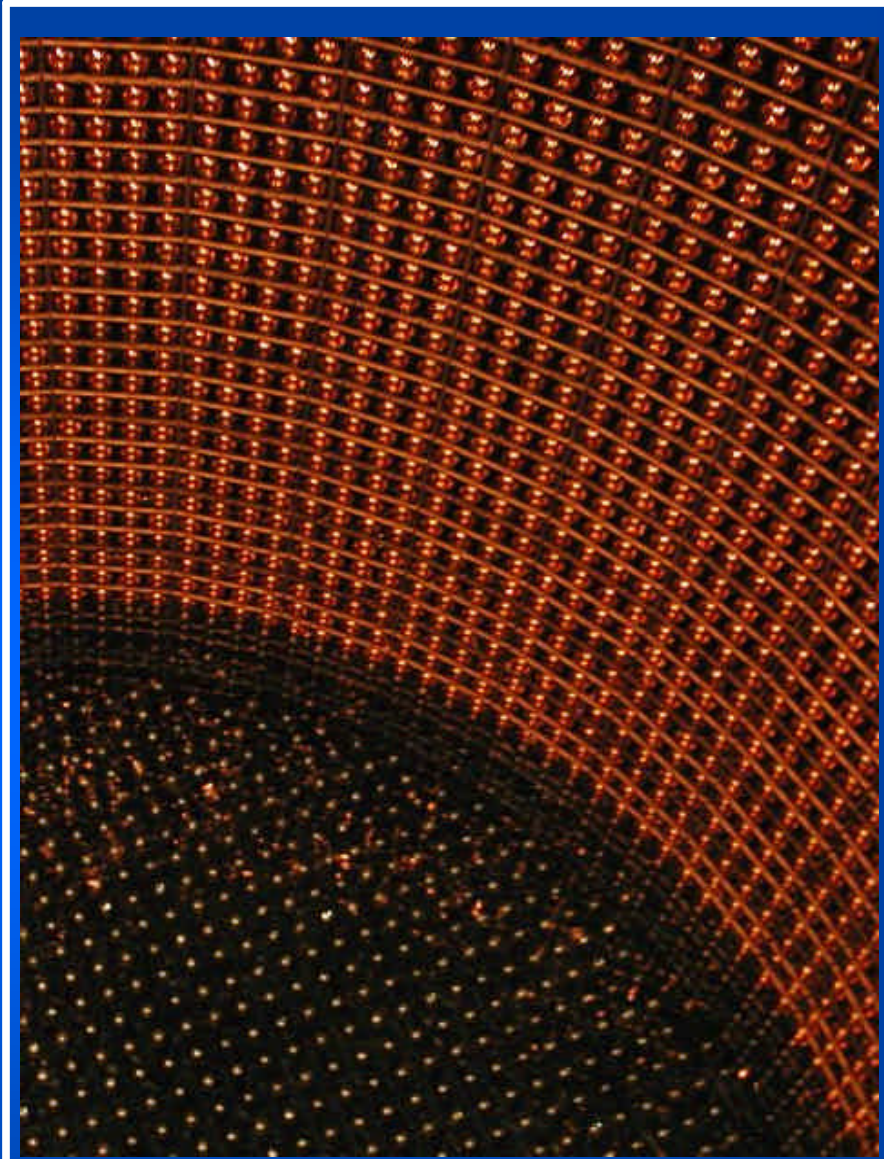


Post-accident – the floor of the inner detector

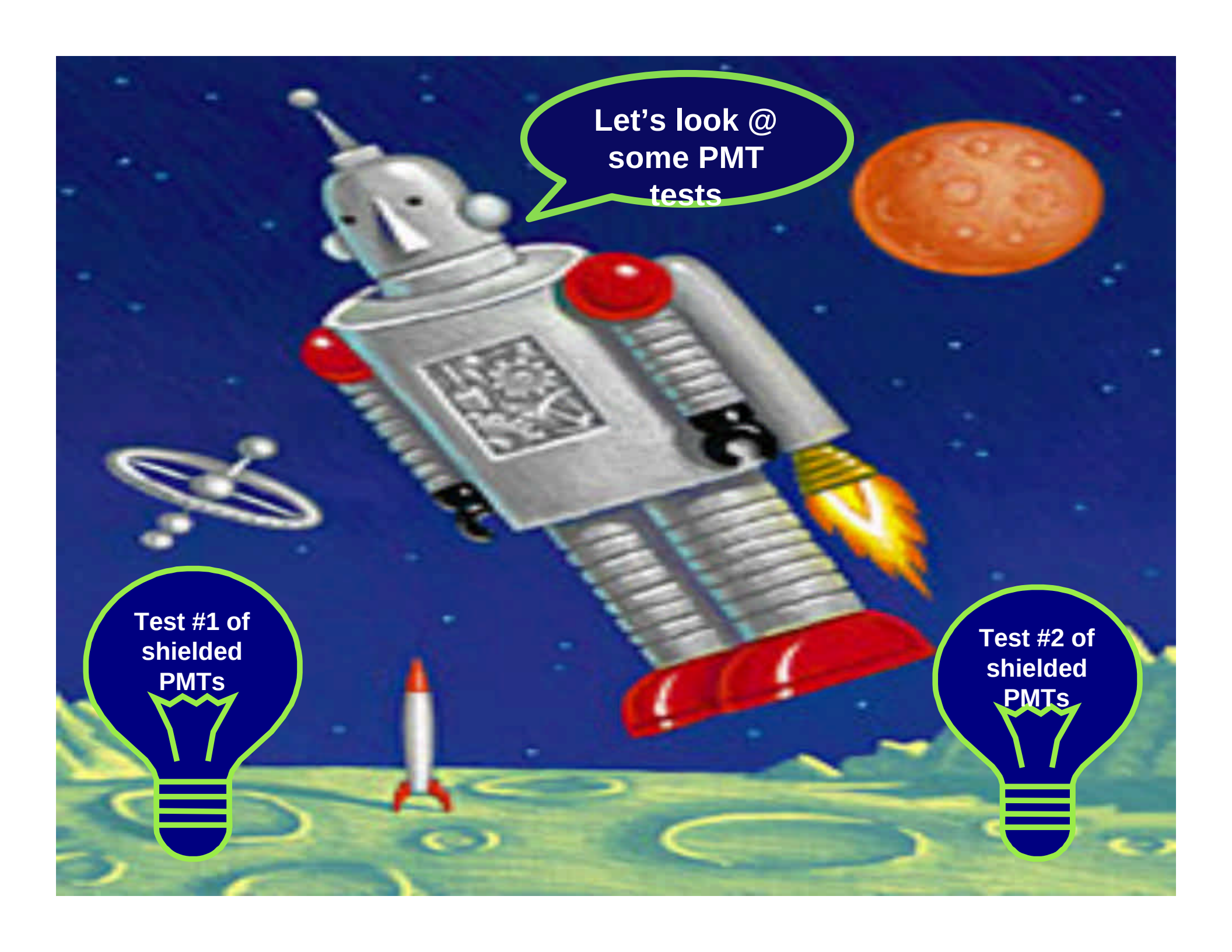
The fateful day occurred on November 12,
2001



**Post-accident &
after initial clean up**



Pre-accident



Let's look @
some PMT
tests

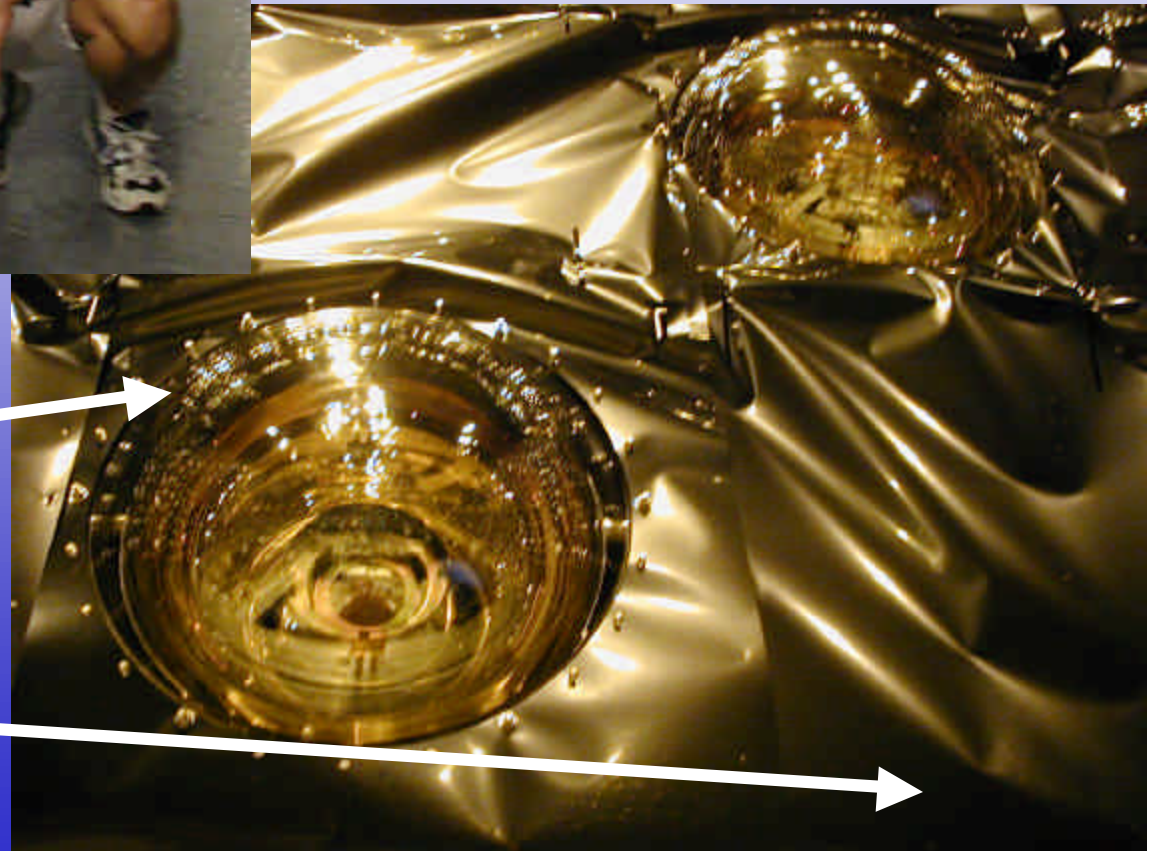
Test #1 of
shielded
PMTs

Test #2 of
shielded
PMTs

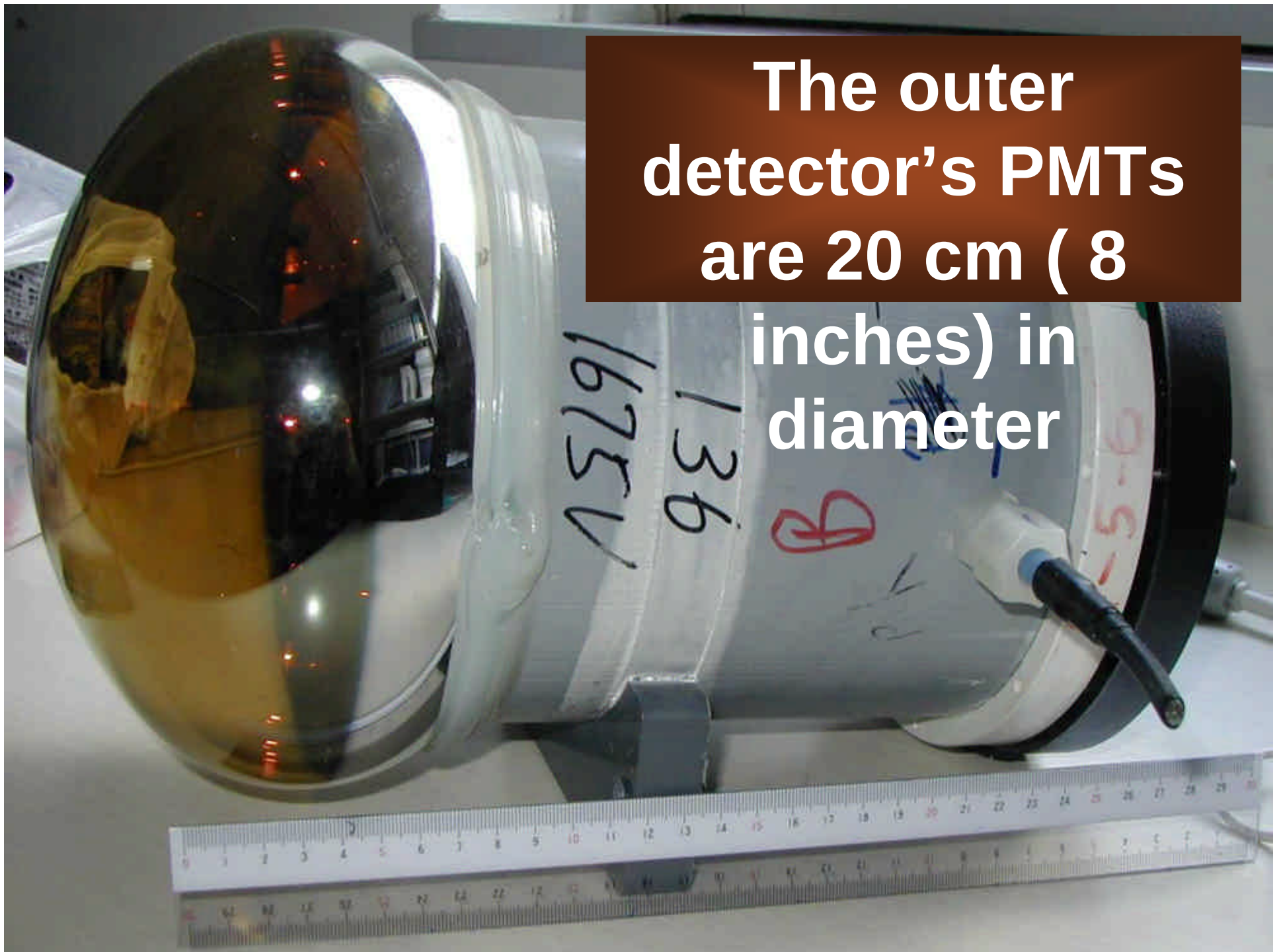
The BIG BOY – world's largest mass - produced PMTs



Note acrylic
shields and
empty
spaces



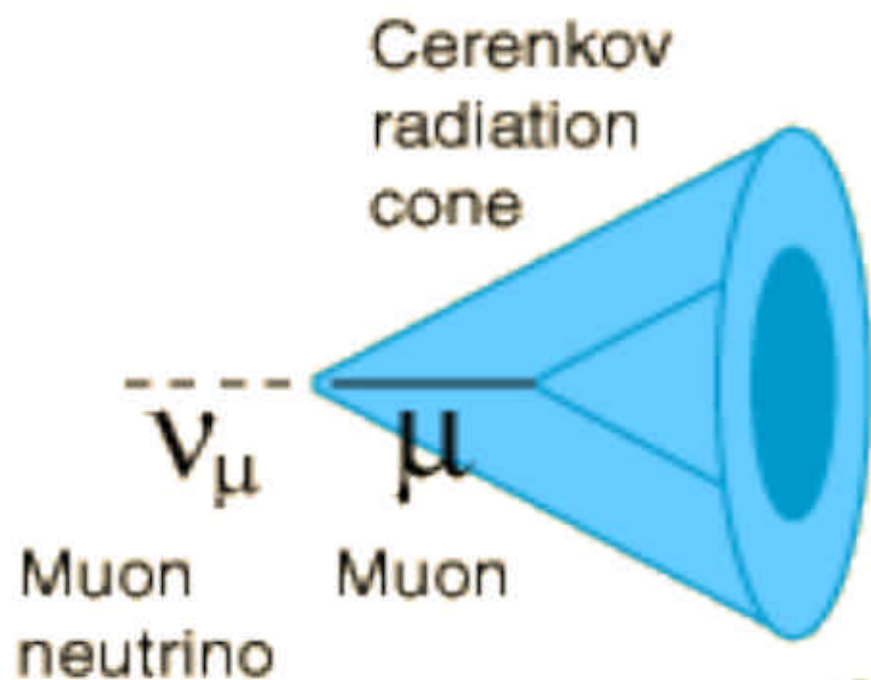
**The outer
detector's PMTs
are 20 cm (8
inches) in
diameter**



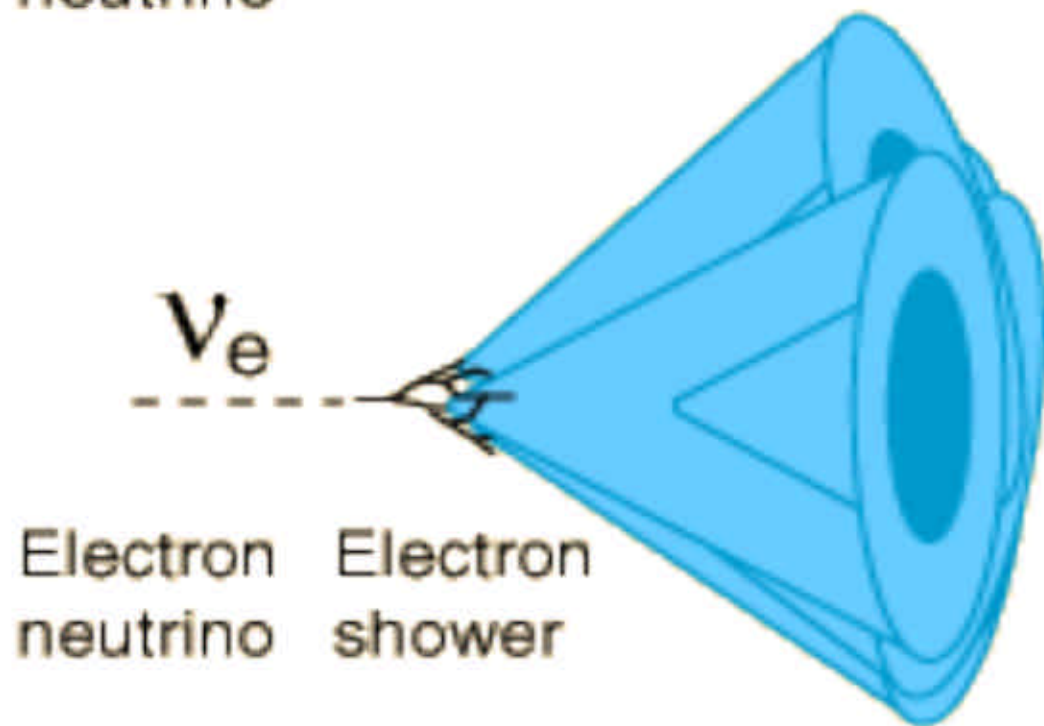


PHYSICS AT THE FARM : DISCOVERY OF THE MUON.

**Just what does Super-K
measure?**

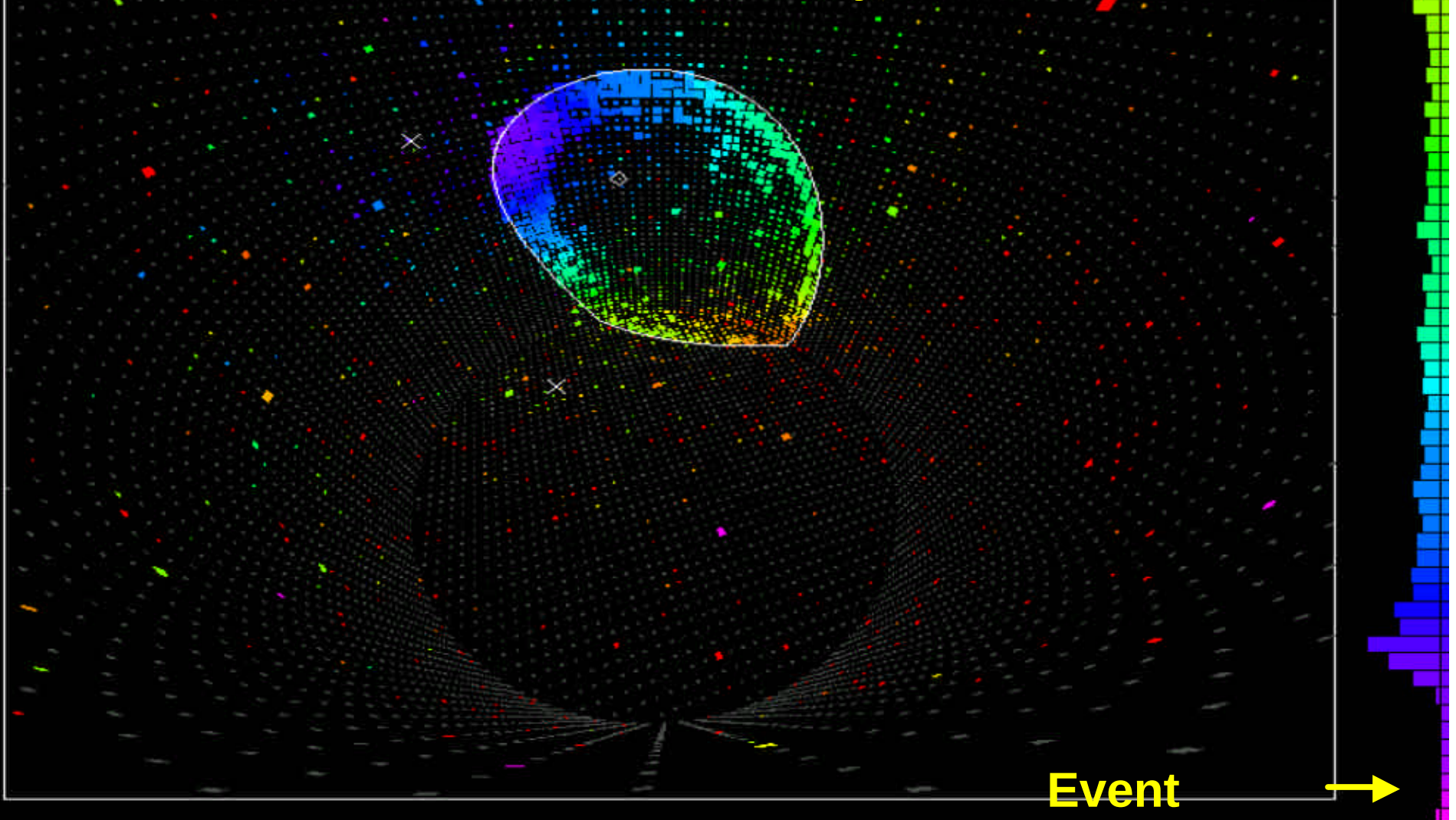


The Cerenkov radiation from a muon produced by a muon neutrino event yields a well defined circular ring in the photomultiplier detector bank.

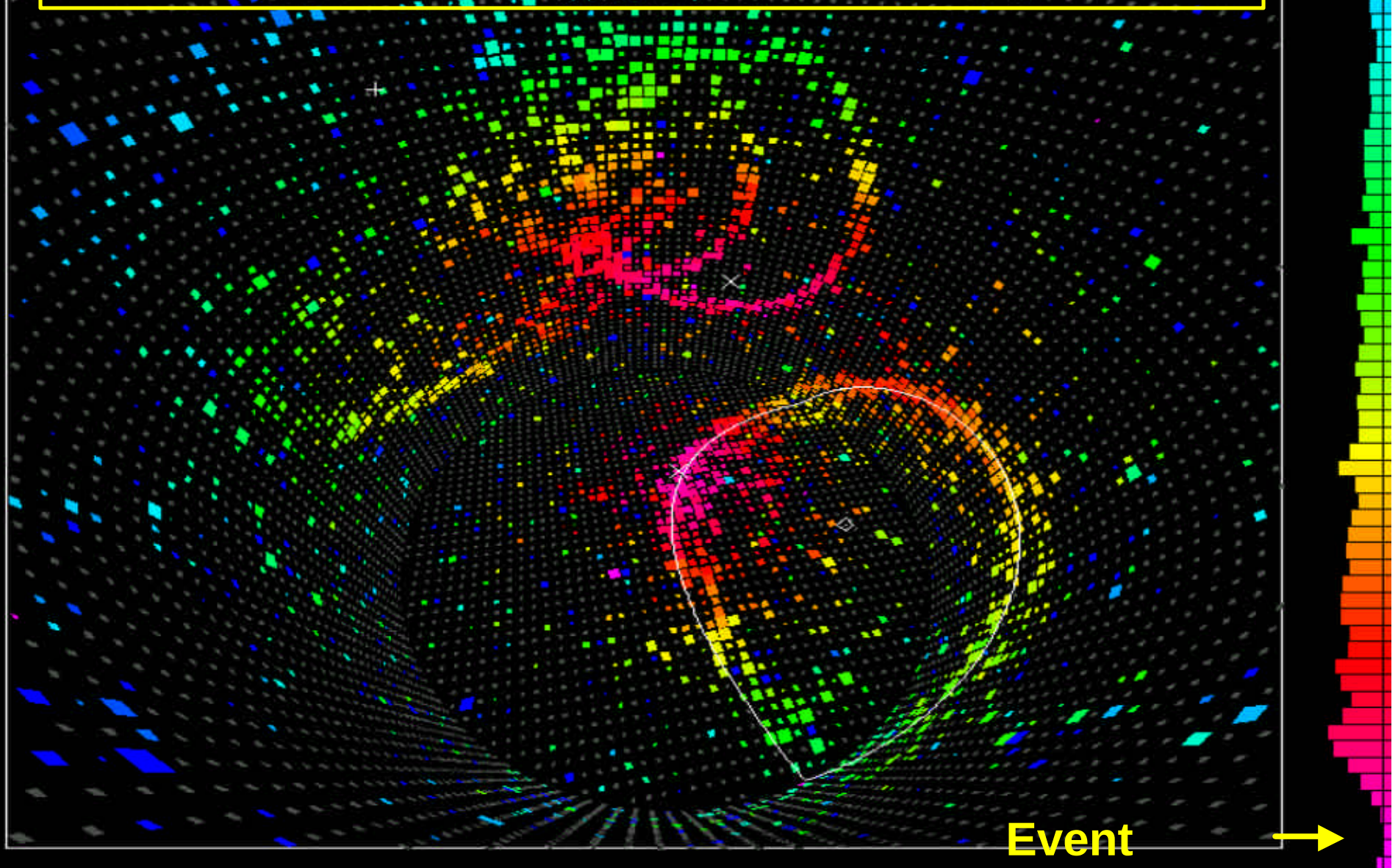


The Cerenkov radiation from the electron shower produced by an electron neutrino event produces multiple cones and therefore a diffuse ring in the detector array.

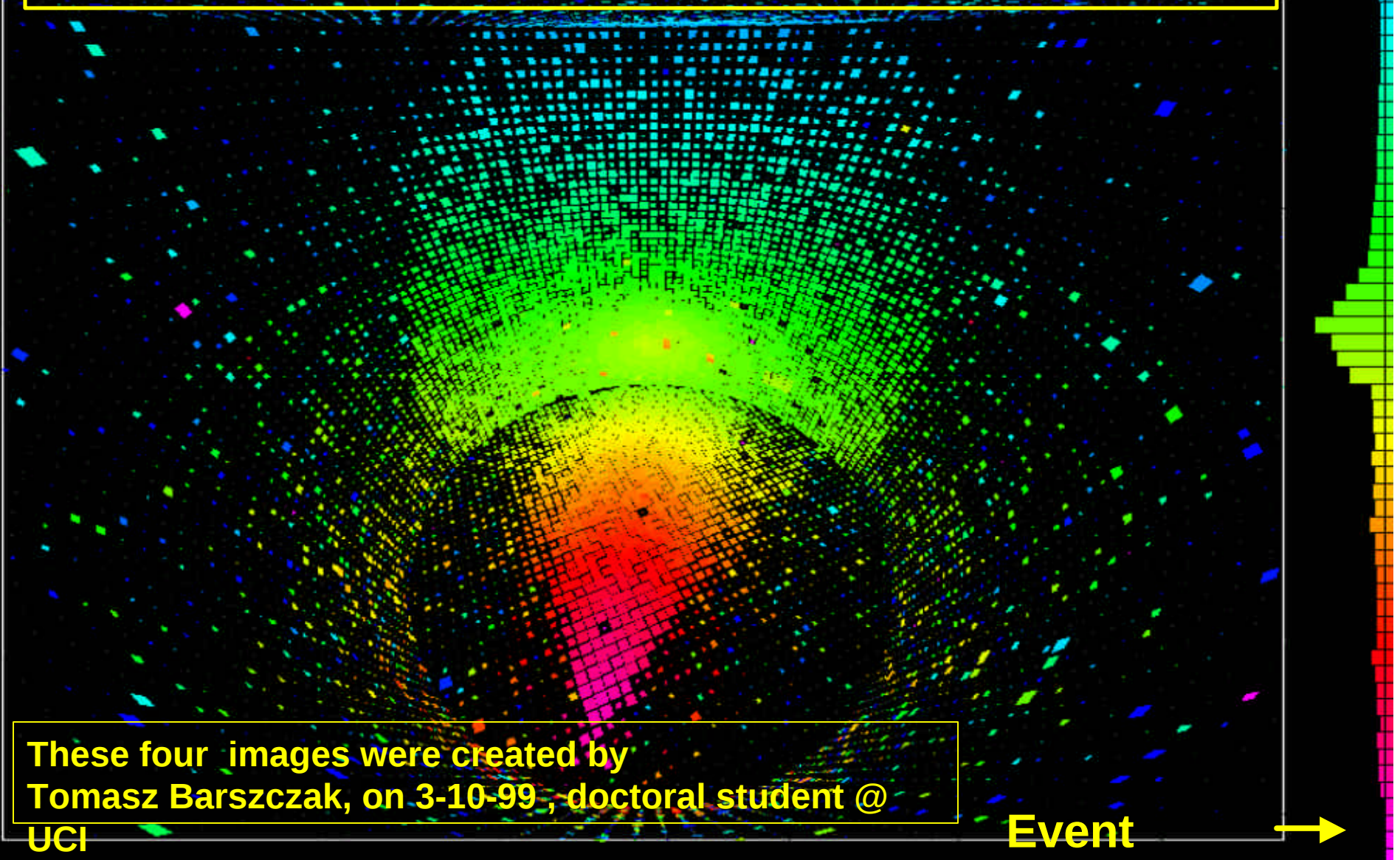
**A neutrino strikes a proton and produces a muon.
Color scale is time from 987 to 1080 ns with 2.3 ns
step. PMTs close to the vertex were hit earlier than
PMTs farther away.**



Multiple ring event. This event was one of the close candidates for proton decay into positron and pi zero. Recorded on 9-24-97, it did not pass analysis cuts. Time color scale spans 80 ns.



Through-going muon. The muon entered through the flat circular part of the detector near the bottom of the picture. Recorded on 5-30-96. Time color scale spans 262 ns.



What about background effects?

Dealing with radio

Here's the humidity
– 50 gal/day

Fresh
air
intake



Movin' 50 m³/min



Let's change hot, humid air
to cool, dry air

Into the mine we go!



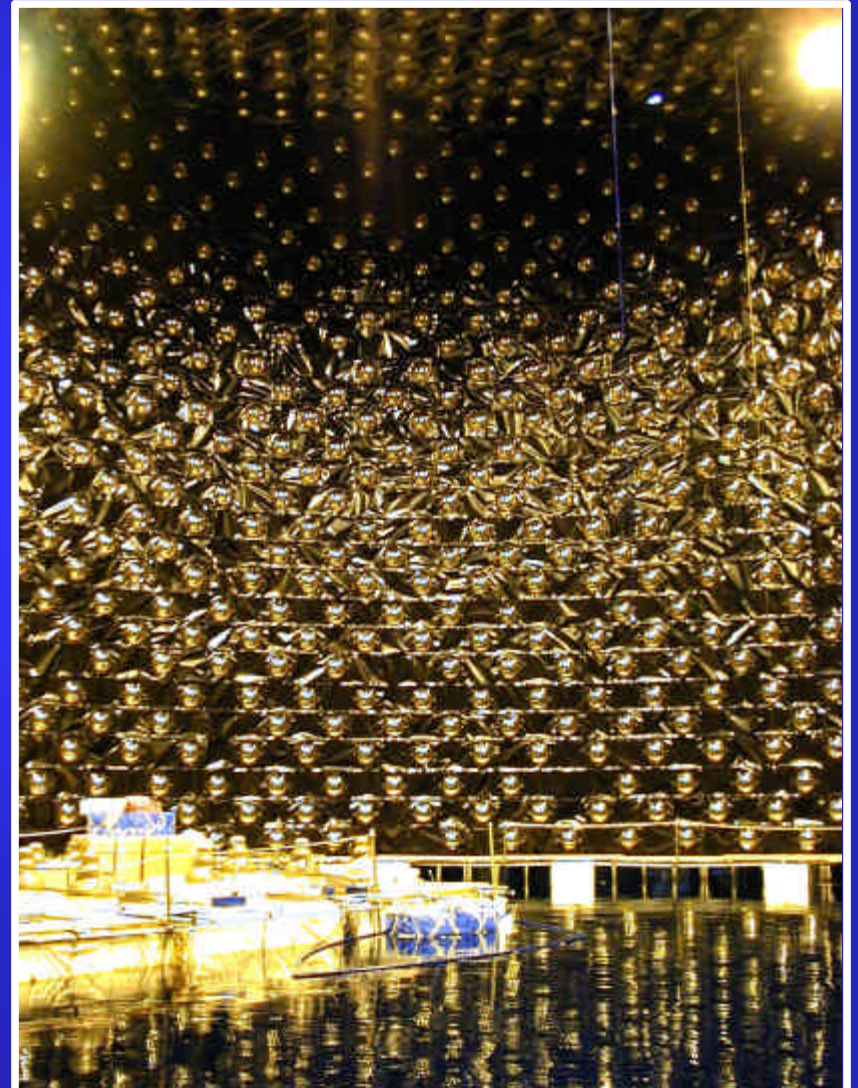
The typical repair cycle for the

OD

~Drain the cylindrical tank – 2.1 m of depth across of a diameter of 40 m over 8 hrs

~How many gallons of H_2O is that?

~ 696, 856 gallons

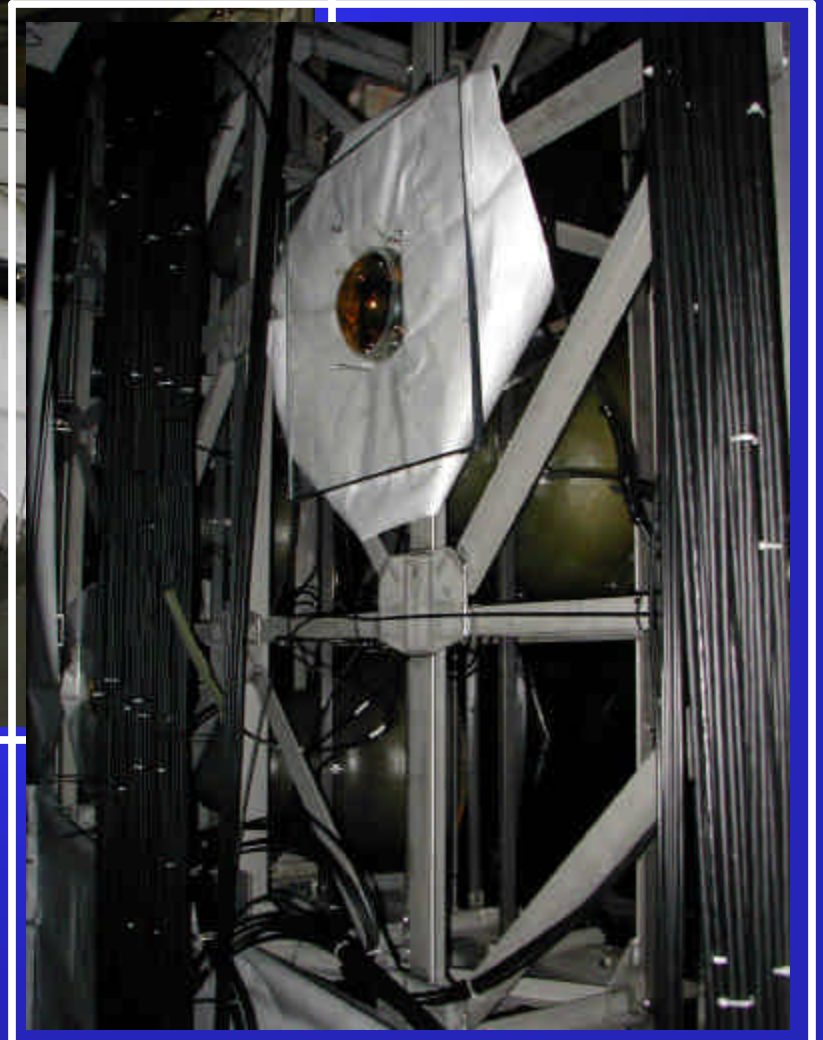


The typical repair cycle for the

OD

Day 1 –

~Install newly
assembled PMTs
w/wave-shifters



The typical repair cycle for the

OD

Days 2 & 3 -

~Hang tyvek sheets and
expose PMTs



The typical repair cycle for the

OD

During the repair cycle, two activities occur simultaneously:

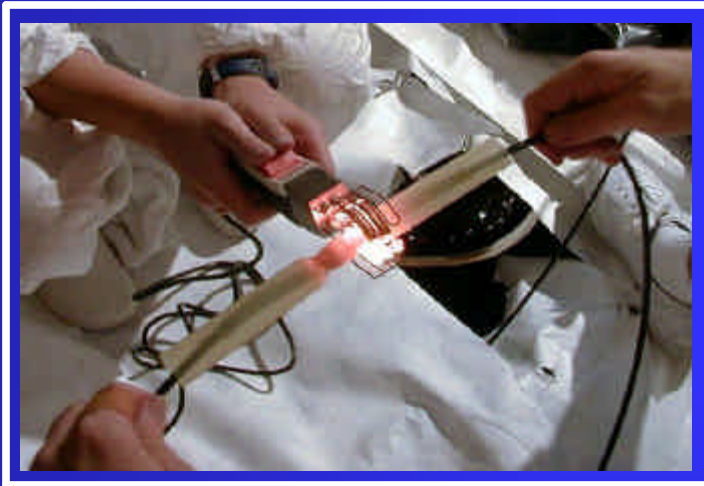
1st - assembly of up to 75 PMT/wave-shifter units



The typical repair cycle for the

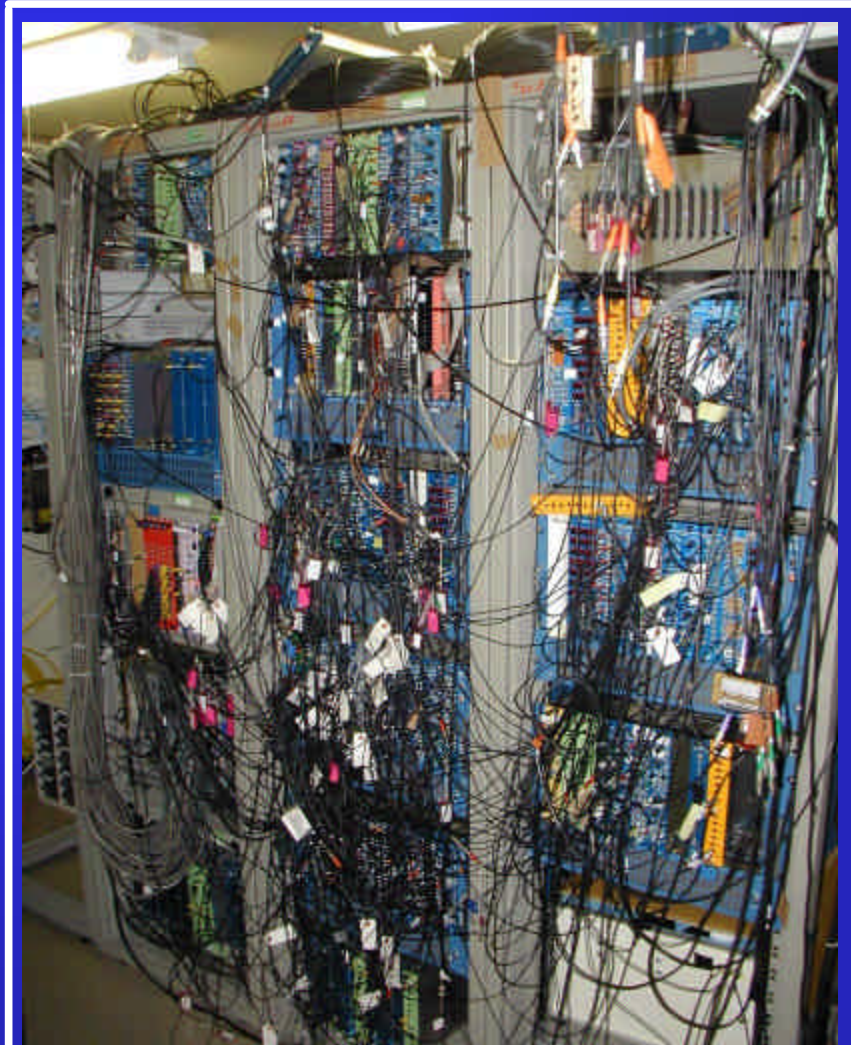
OD

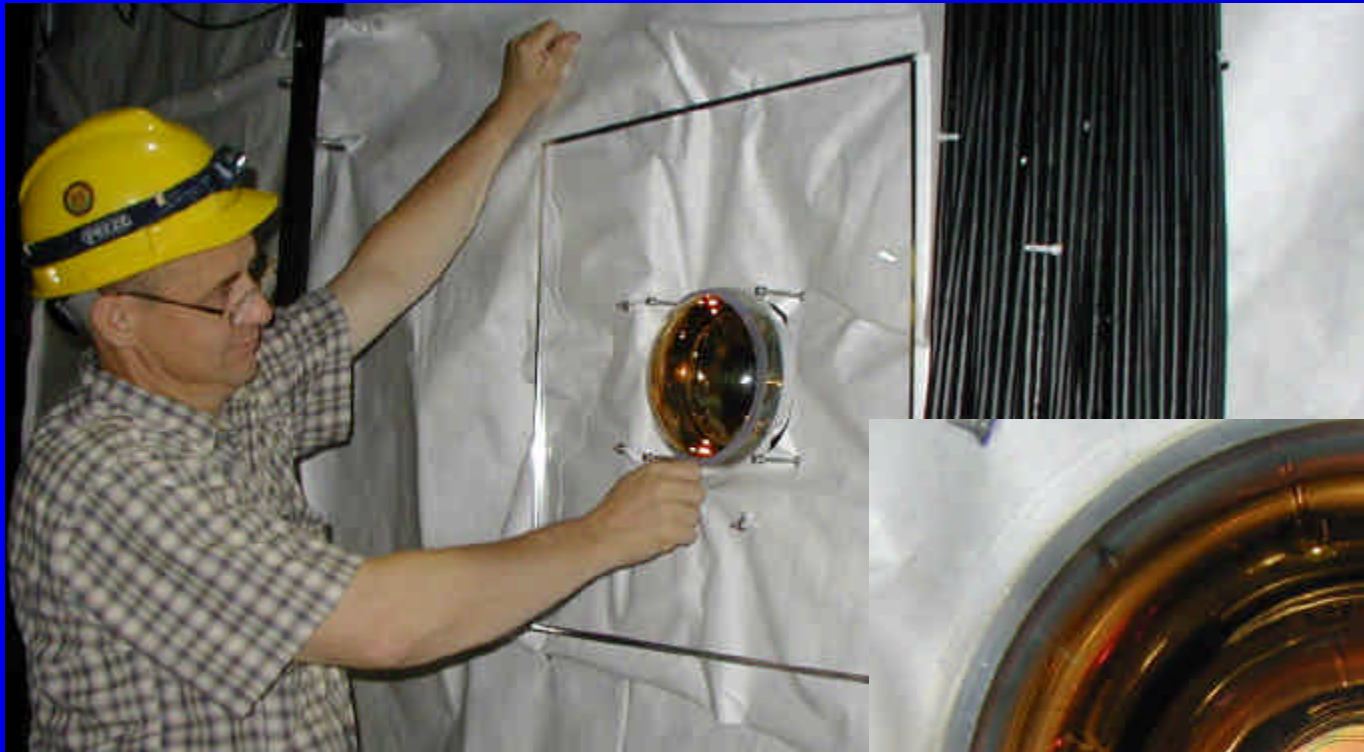
2nd - Splicing in the replacement PMTs with existing cables



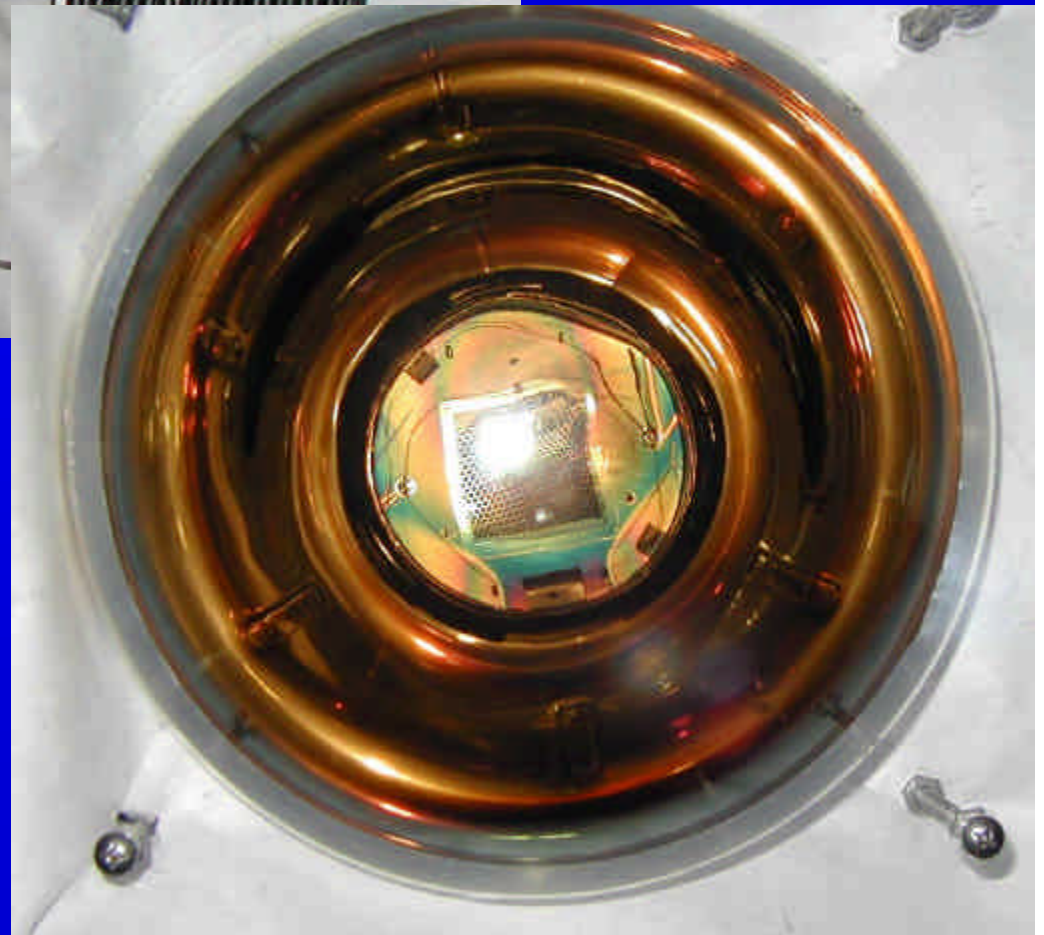
The typical repair cycle for the OD

- and testing cable continuity via the Mother of All NIM Crates!





**Final touches
on installing an
outer detector
PMT**



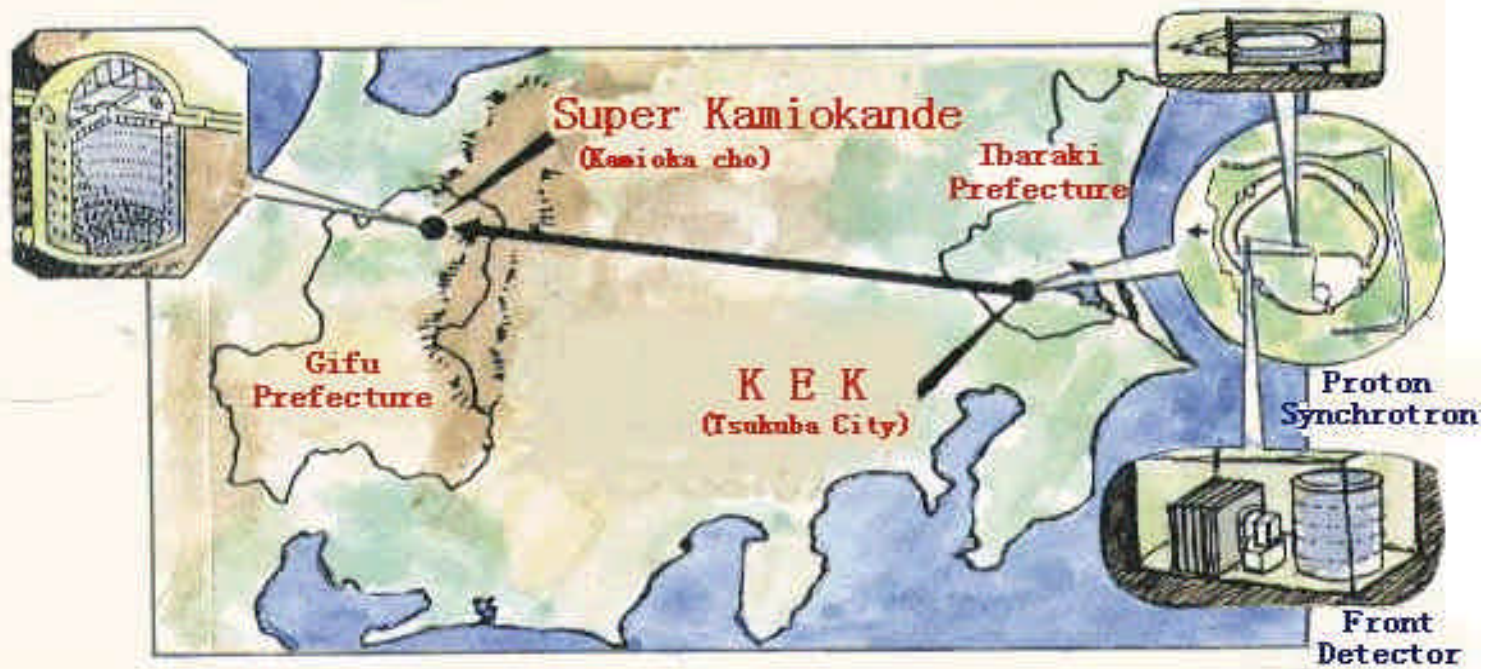
What is next for Super



➡ More neutrino parameters

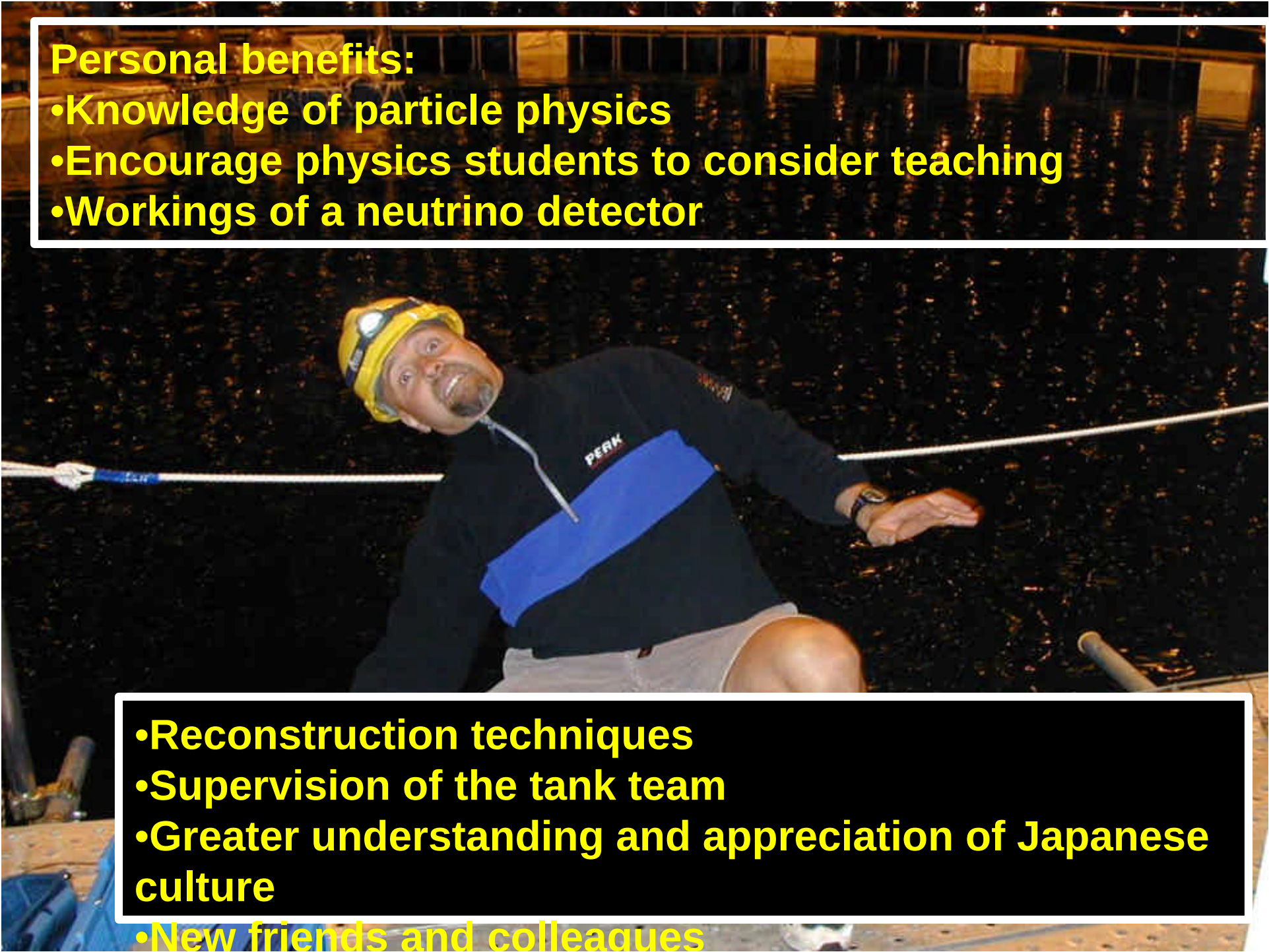
➡ Future supernovae





Super-K's
Long Baseline

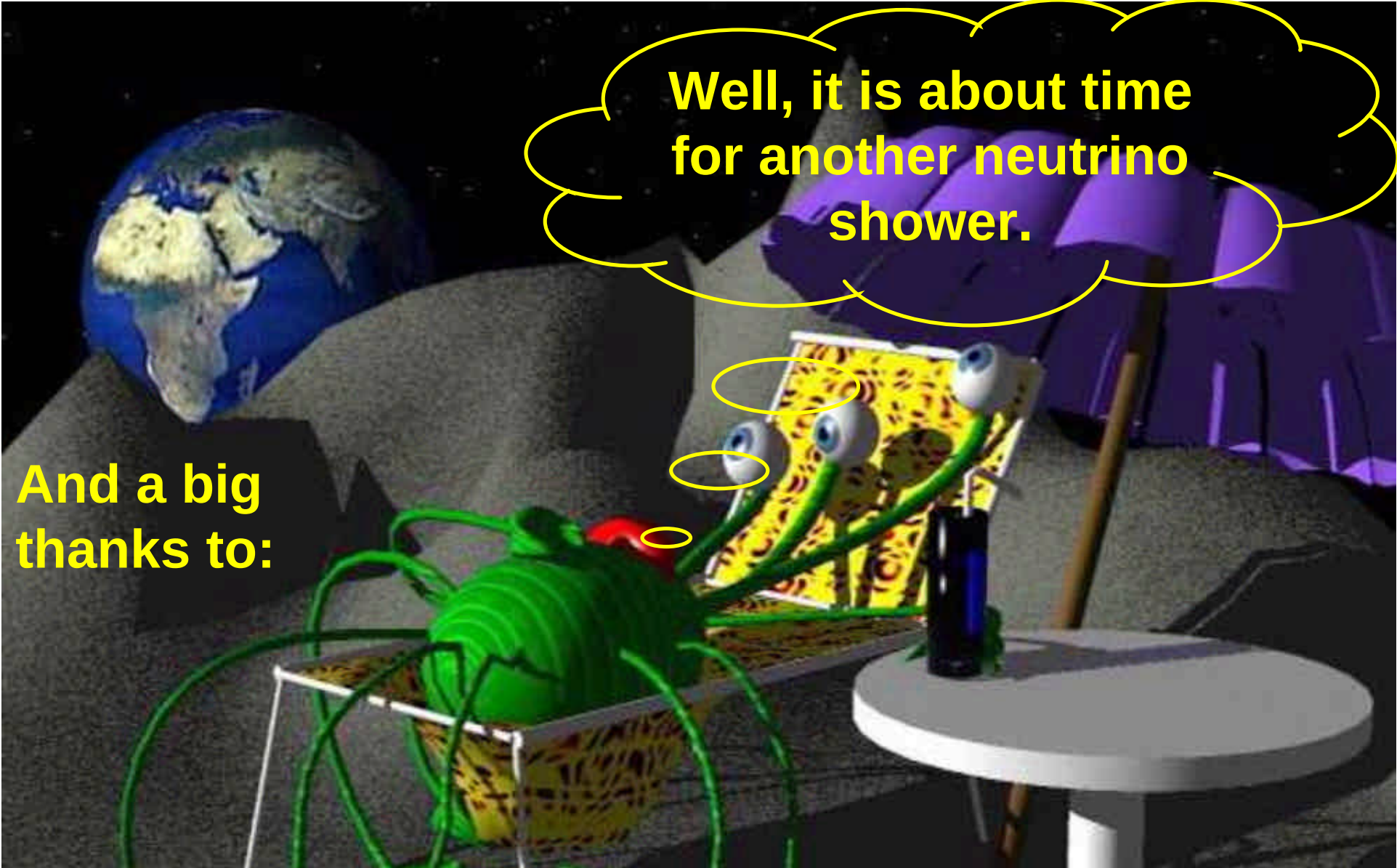
Exo.

A man wearing a yellow helmet with a headlamp and a black jacket with a blue diagonal stripe is rappelling down a white rope. He is looking up and smiling. The background is dark with some lights visible in the distance.

Personal benefits:

- Knowledge of particle physics
- Encourage physics students to consider teaching
- Workings of a neutrino detector

- Reconstruction techniques
- Supervision of the tank team
- Greater understanding and appreciation of Japanese culture
- New friends and colleagues



Well, it is about time
for another neutrino
shower.

And a big
thanks to:

M.J. Murdock Foundation University of Washington

Dr. Jeffery Wilkes

Hans Berns