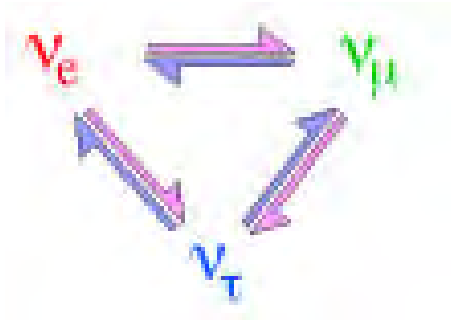
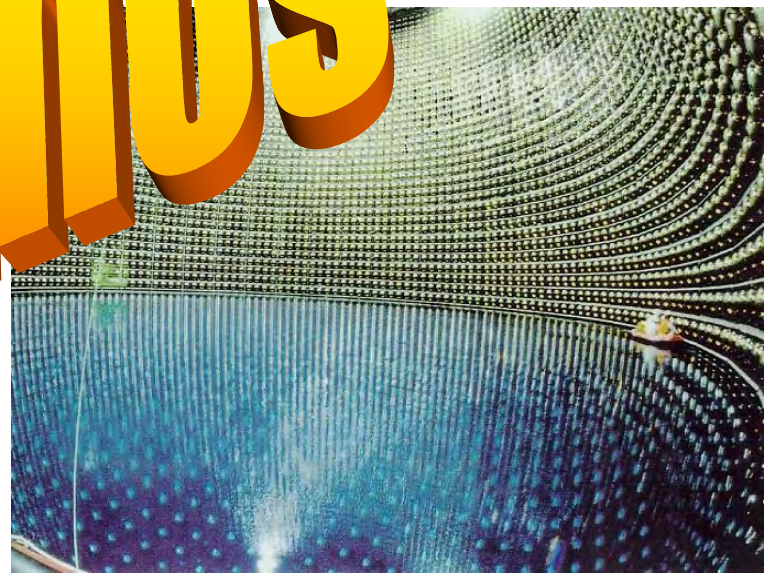
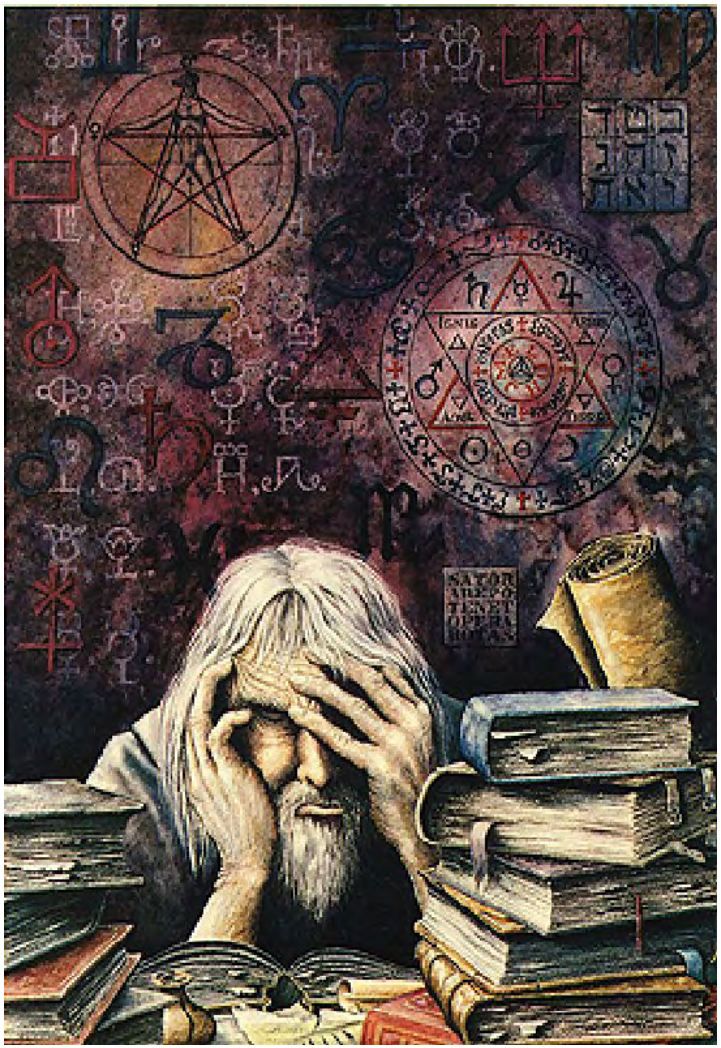
Die Akte X der Teilchenphysik



Neutrinos



Inhalt



- ★ Historie
- ★ Solare Neutrinos
- ★ Der doppelte Betazerfall
- ★ Ausblick und Zusammenfassung

Entdeckung der Radioaktivität

1895 W. Röntgen entdeckt X-Strahlen

1896 H. Becquerel entdeckt ionisierende Strahlung

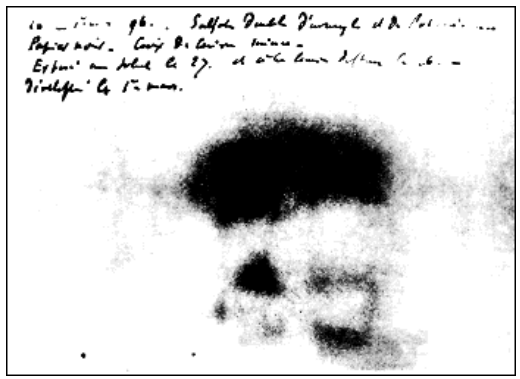
1898 Marie & Pierre Curie entdecken Radioaktivität indem sie Radium and Polonium isolierten

Madame Curie bekam 2 Nobelpreise

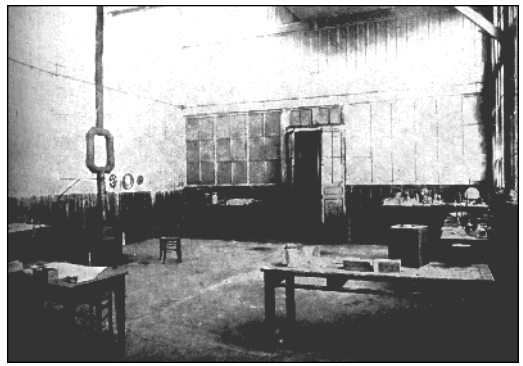
(1903 in Physik, 1911 in Chemie)

Hand von “von Kölliker”

Geschwärzte Photoplatte
les rayons uranique

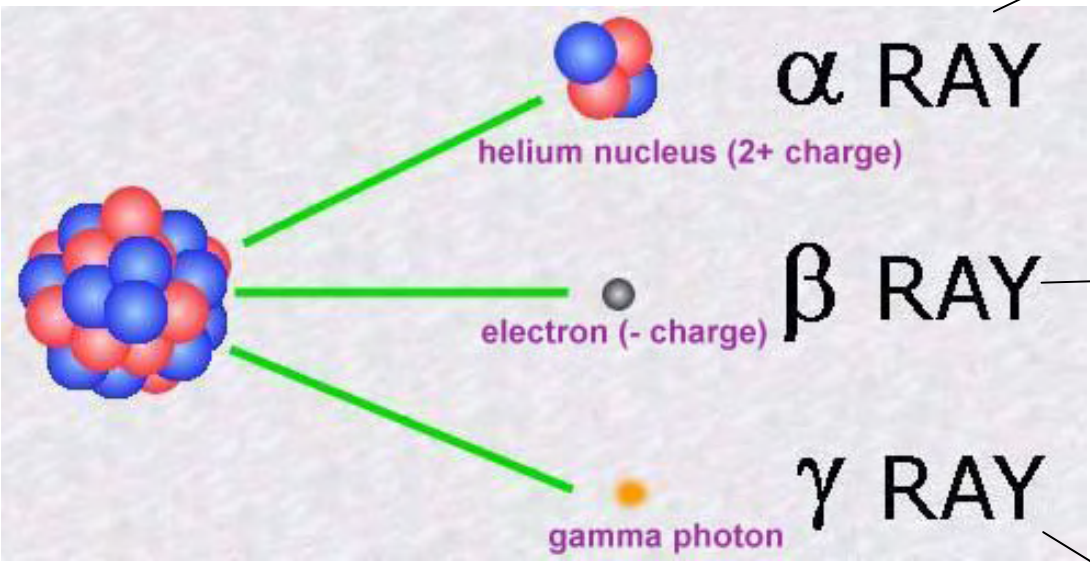


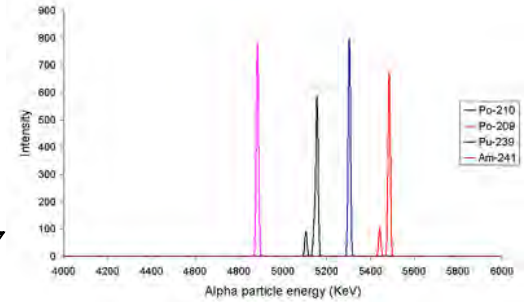
Laborraum von Madame Curie



Radioaktivität

Es gibt drei Arten von Radioaktivität





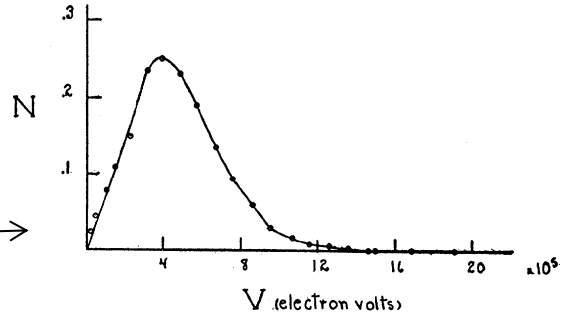
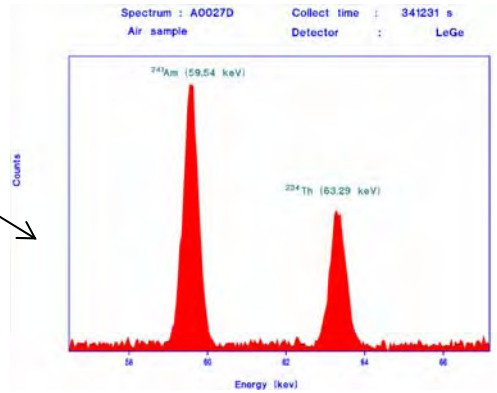


FIG. 5. Energy distribution curve of the beta-rays.

?



Warum Neutrinos?

F. A. Scott, *Phys. Rev.* **48**, 391 (1935)

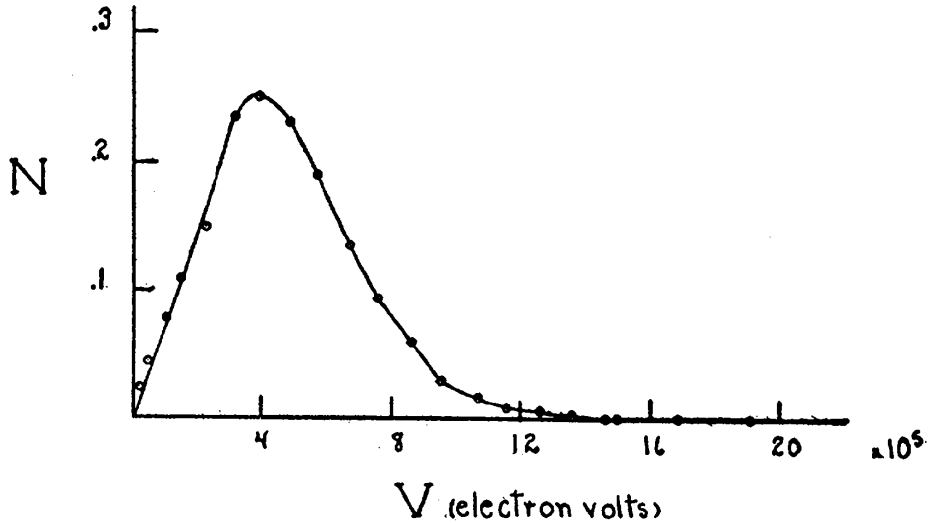


FIG. 5. Energy distribution curve of the beta-rays.

Warum ist das Energiespektrum der Elektronen aus dem Betazerfall ein kontinuierlich?

Bohr: *At the present stage of atomic theory, however, we may say that we have no argument, either empirical or theoretical, for upholding the energy principle in the case of β-ray disintegrations*

Die Lösung?

4th December 1930

Dear Radioactive Ladies and Gentlemen,

As the bearer of these lines, to whom I graciously ask you to listen, will explain to you in more detail, how because of the "wrong" statistics of the N and Li^6 nuclei and the continuous beta spectrum, I have hit upon a desperate remedy to save the "exchange theorem" of statistics and the law of conservation of energy. Namely, the possibility that there could exist in the nuclei electrically neutral particles, that I wish to call neutrons, which have spin 1/2 and obey the exclusion principle and which further differ from light quanta in that they do not travel with the velocity of light. The mass of the neutrons should be of the same order of magnitude as the electron mass and in any event not larger than 0.01 proton masses. The continuous beta spectrum would then become understandable by the assumption that in beta decay a neutron is emitted in addition to the electron such that the sum of the energies of the neutron and the electron is constant...

Geburtstagsfeier

Die Erwartung

Bethe und Peierls berechnen 1934 mit Hilfe der Theorie von Fermi (1932)

den Wirkungsquerschnitt für die Reaktion

$\bar{\nu}_e + p \rightarrow e^+ + n$ zu 10^{-44} cm^2 für 2 MeV Neutrinos

→ mittlere freie Weglänge in Wasser 1600 Lichtjahre

→ Neutrinos reagieren so gut wie gar nicht

→ Pauli: Ich habe etwas furchtbares getan. Ich habe ein Teilchen postuliert, das niemals beobachtet werden kann

→ $$R = N_T \times \phi \times \sigma \approx N_T \times 10^{10} cm^{-2} s^{-1} \times 10^{-44} cm^2 \times 10^5 s/Tag$$

→ Man braucht einen Detektor aus mehreren Tonnen Material für ein Ereignis pro Tag

→ Harari (1988): Neutrino physics is largely an art of learning a great deal by observing nothing

Neutrinophysik ist Physik unter Tage

Der Versuch

THE UNIVERSITY OF CHICAGO
CHICAGO 37 · ILLINOIS
INSTITUTE FOR NUCLEAR STUDIES

October 8, 1952

Dr. Fred Reines
Los Alamos Scientific Laboratory
P.O. Box 1663
Los Alamos, New Mexico

Dear Fred:

Thank you for your letter of October 4th by Clyde Cowan and yourself. I was very much interested in your new plan for the detection of the neutrino. Certainly your new method should be much simpler to carry out and have the great advantage that the measurement can be repeated any number of times. I shall be very interested in seeing how your 10 cubic foot scintillation counter is going to work, but I do not know of any reason why it should not.

Good luck.

Sincerely yours,

Enrico

Enrico Fermi

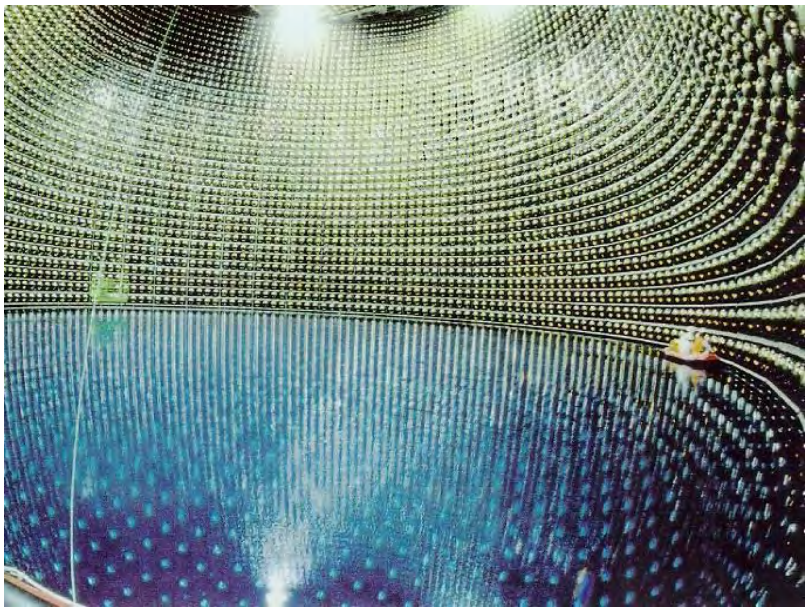
EF:vr

Die Entdeckung

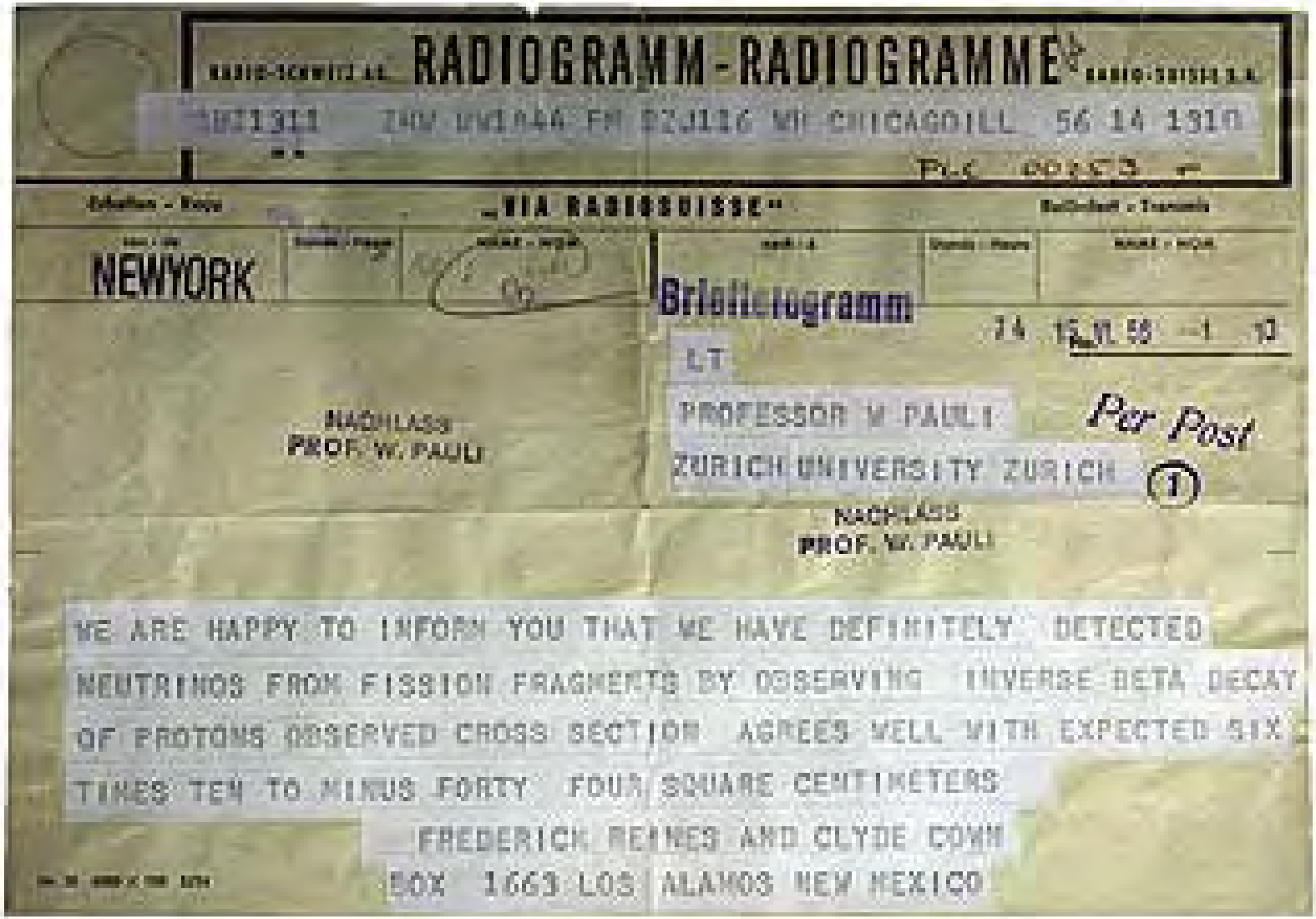
C. Cowan, F. Reines 1953,1956

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

Herr Auge



Projekt Poltergeist



RADIO-SCHWEIZ A.G. RADIOGRAMM-RADIOGRAMME RADIO-SUISSE S.A.

"VIA RADIOSUISSE"

NEWYORK

Brieftelegramm

14 15.11.56 1 13

LT

PROFESSOR W PAULI

ZURICH UNIVERSITY ZURICH

Per Post

NACHLASS PROF. W. PAULI

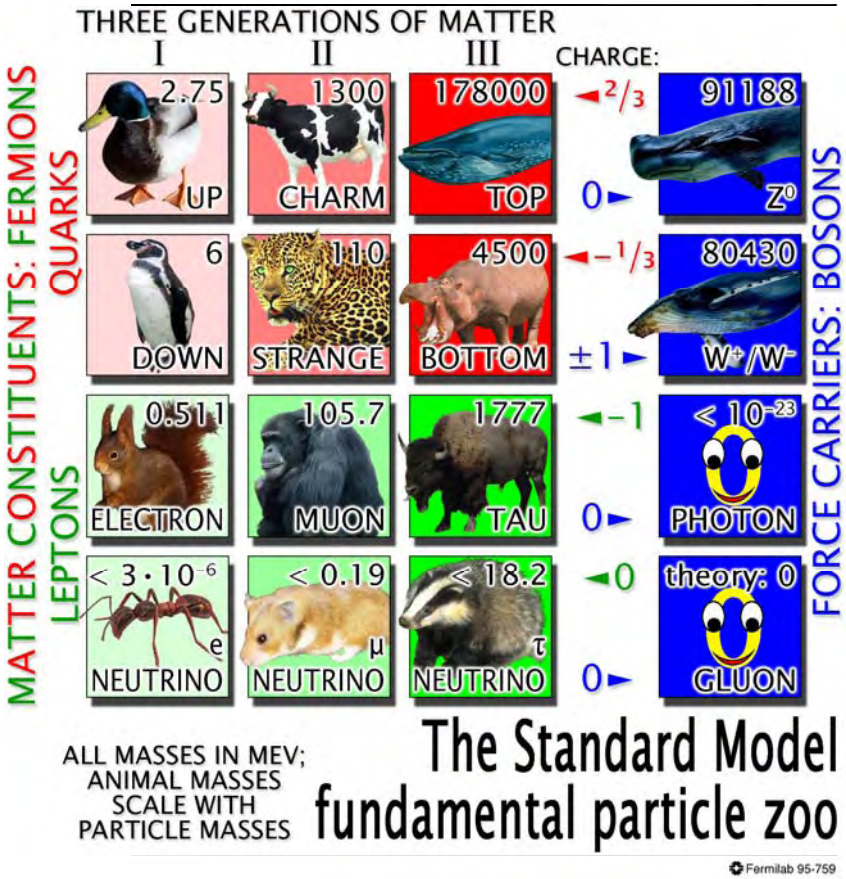
NACHLASS PROF. W. PAULI

WE ARE HAPPY TO INFORM YOU THAT WE HAVE DEFINITELY DETECTED NEUTRINOS FROM FISSION FRAGMENTS BY OBSERVING INVERSE BETA DECAY OF PROTONS OBSERVED CROSS SECTION AGREES WELL WITH EXPECTED SIX TIMES TEN TO MINUS FORTY FOUR SQUARE CENTIMETERS

FREDERICK REINES AND CLYDE COWN

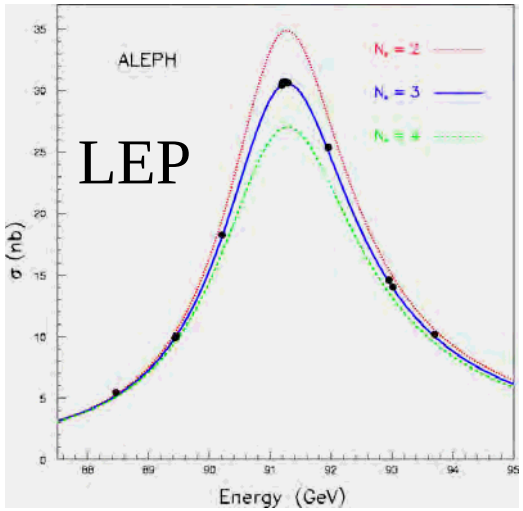
BOX 1663 LOS ALAMOS NEW MEXICO

Das Standard Modell



1955: m < 10 keV

Neutrinos sind im Standard Modell masselose Teilchen



Neutrino Massen

Ist es wahr, dass Neutrinos keine Ruhemasse besitzen?

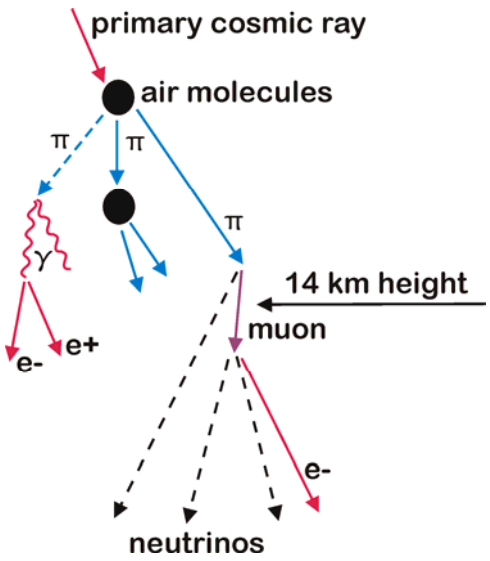
Direkte Suche nach der absoluten Masse des Neutrinos

Betazerfall, neutrinolose doppelte Betazerfall

Suche nach Effekten, die nur für massive Neutrinos möglich sind

Neutrino-Oszillationen

Neutrino Quellen



Kernreaktoren $\bar{\nu}_e$

Beschleuniger

Radioaktivität der Erde $\bar{\nu}_e$

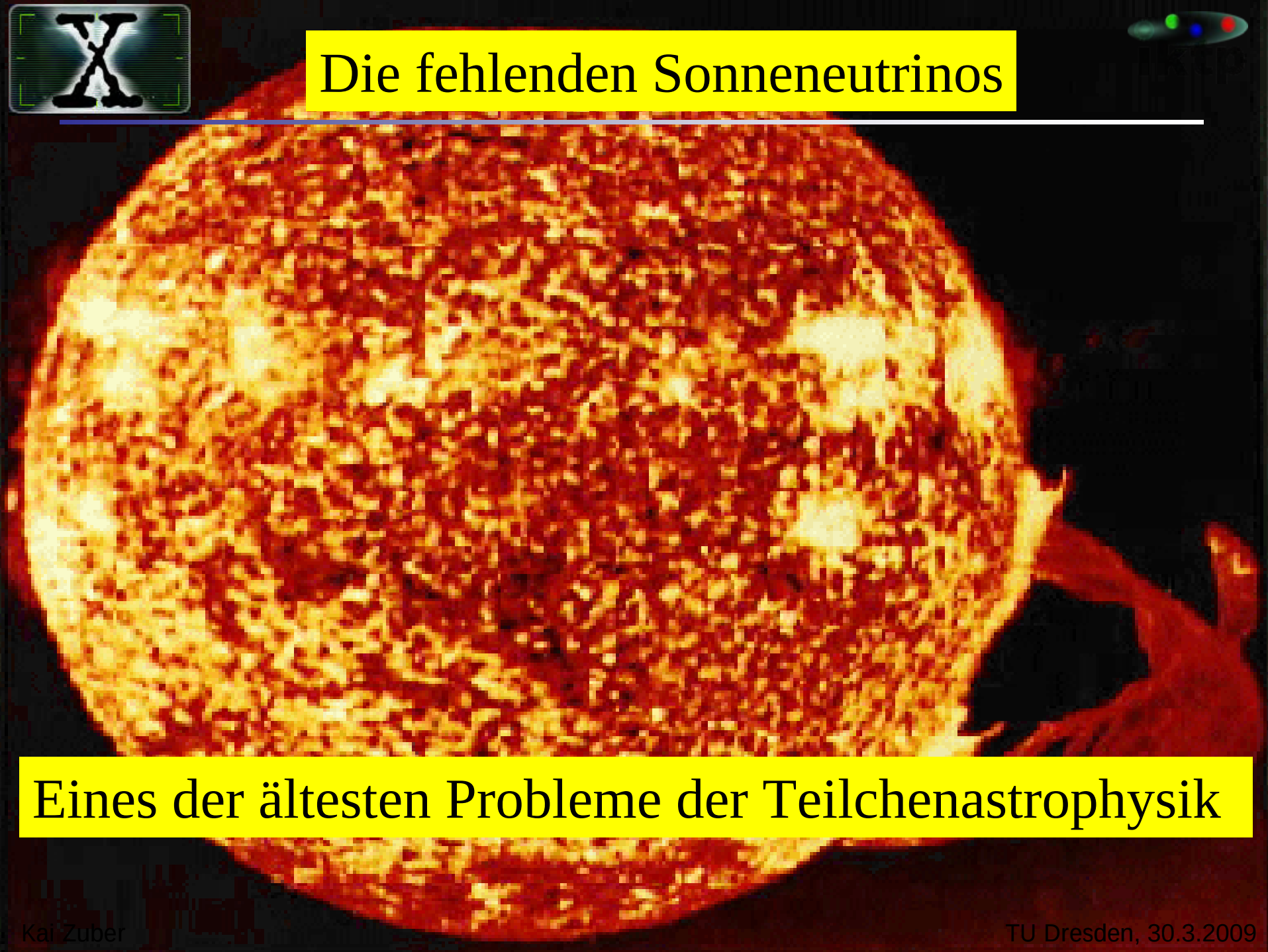
Die Atmosphäre

Die Sonne ν_e

Supernovae

Der Urknall

Die fehlenden Sonneneutrinos

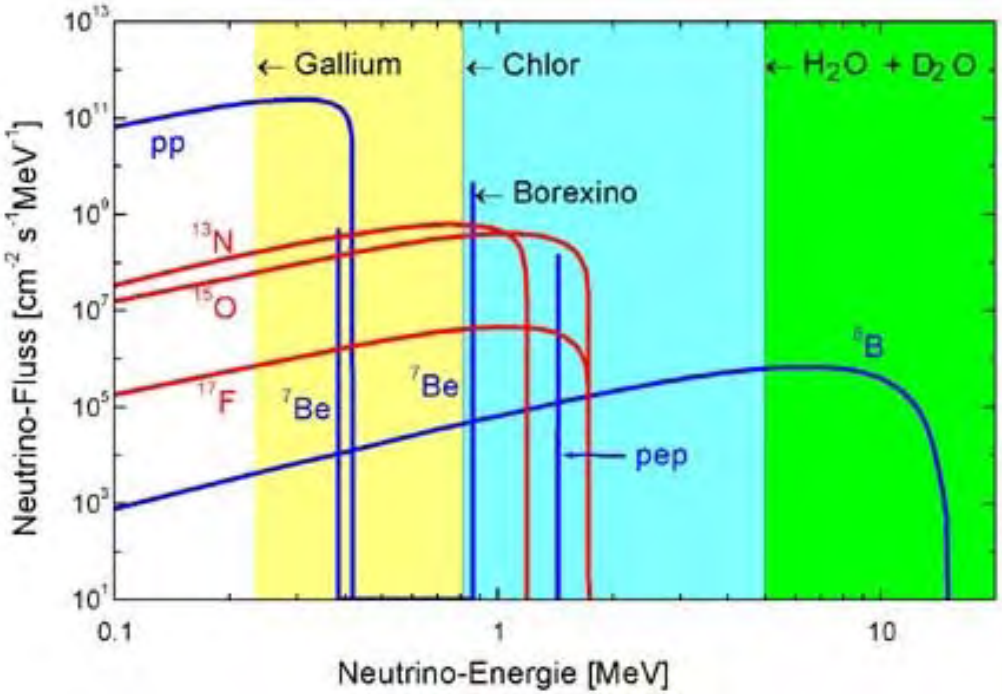


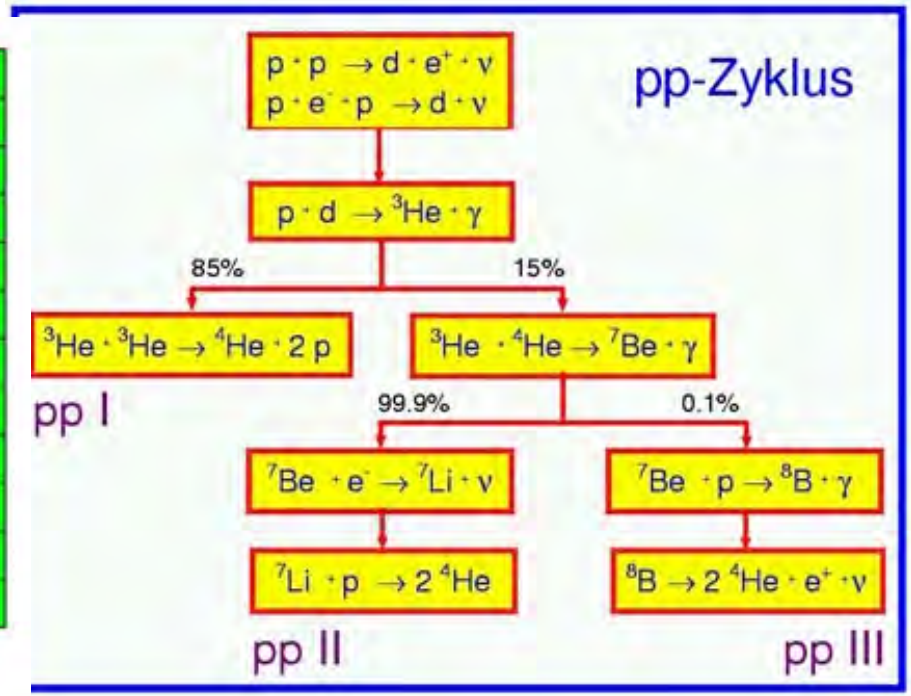
Eines der ältesten Probleme der Teilchenastrophysik

Standard Sonnenmodell

Annahme: Sonne produziert Energie durch Kernfusion

$$2e^- + 4p \rightarrow {}^4He + 2\nu_e + 26.73\ MeV$$





60 Milliarden Neutrinos durchqueren jeden cm² von uns jede Sekunde

Nachweismethoden

radiochemisch (CC)

$$\nu_e + (A, Z) \rightarrow e^- + (A, Z+1)$$

+: kleine Energien -: keine Echtzeit

1 SNU = 10^{-36} Einfänge/Target atom/s

Elastische Elektron-Neutrino Streuung (ES)

$$\nu_x + e^- \rightarrow \nu_x + e^-$$

+: Echtzeit -: hohe Energie

Reaktionen am Deuterium (CC + NC)

Homestake Experiment

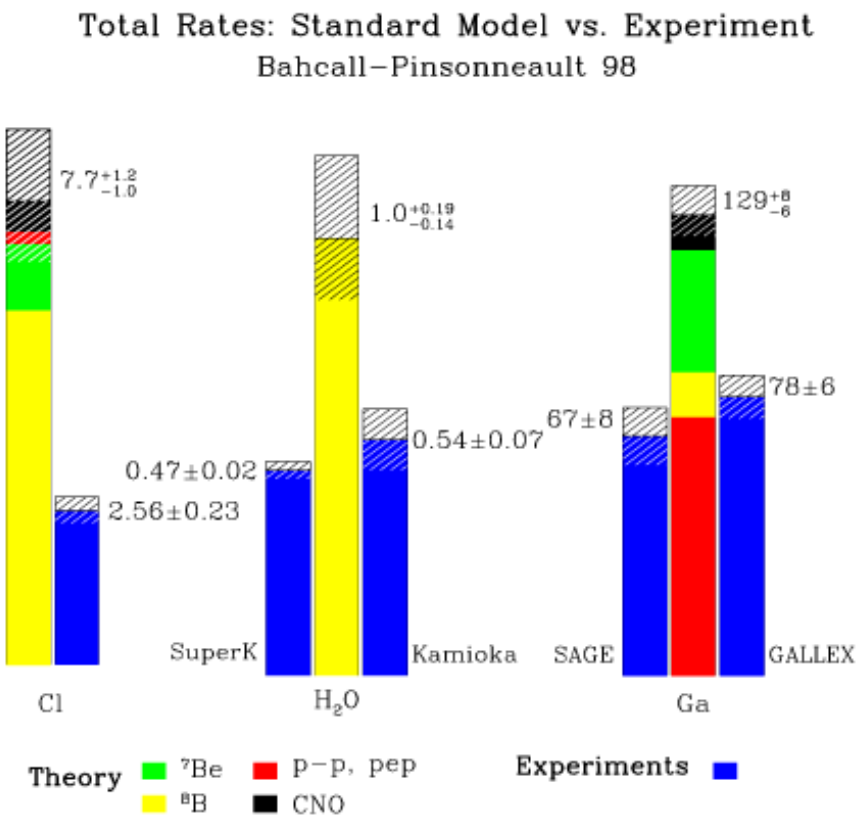
Ray Davis Jr.

$$^{37}Cl + \nu_e \rightarrow {}^{37}Ar + e^-$$

The art of low-level physics or how to get 10 atoms out of 600 t

Stand der Dinge 2002

Alle Experimente messen nur 30-50% der erwarteten solaren Neutrinos

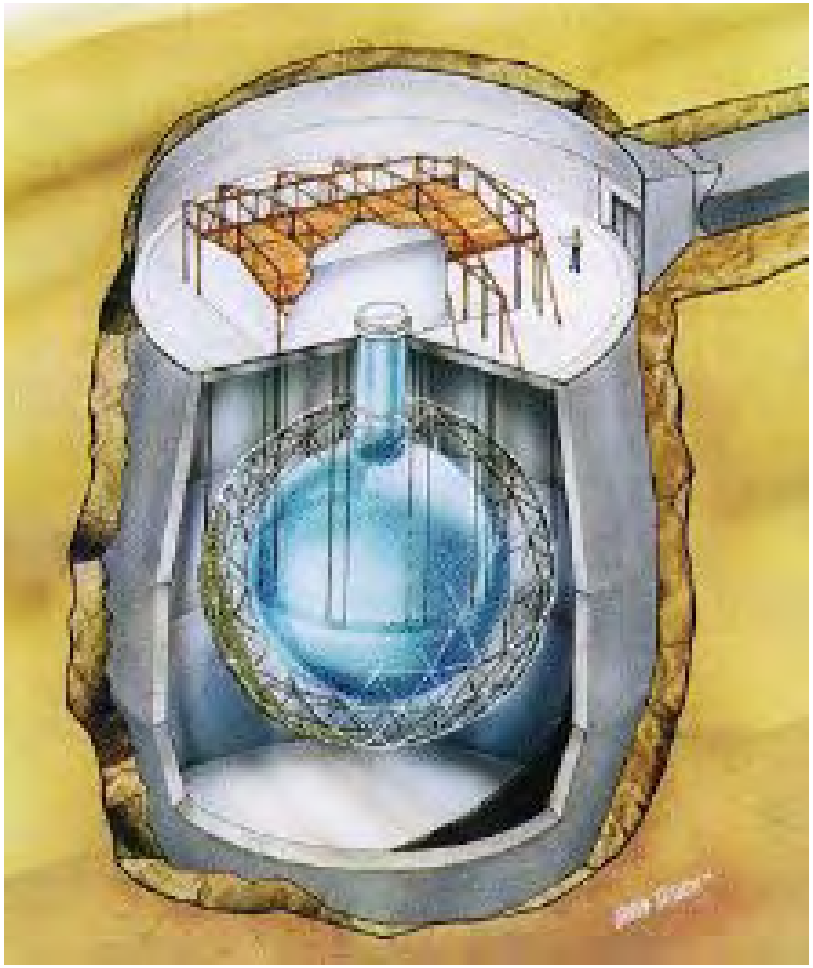


Wer ist schuld? Die Sonne oder die Neutrinos?

The Sudbury

Neutrino Observatory (SNO)

SNO – The smoking gun



1000 t schweres Wasser (D_20)

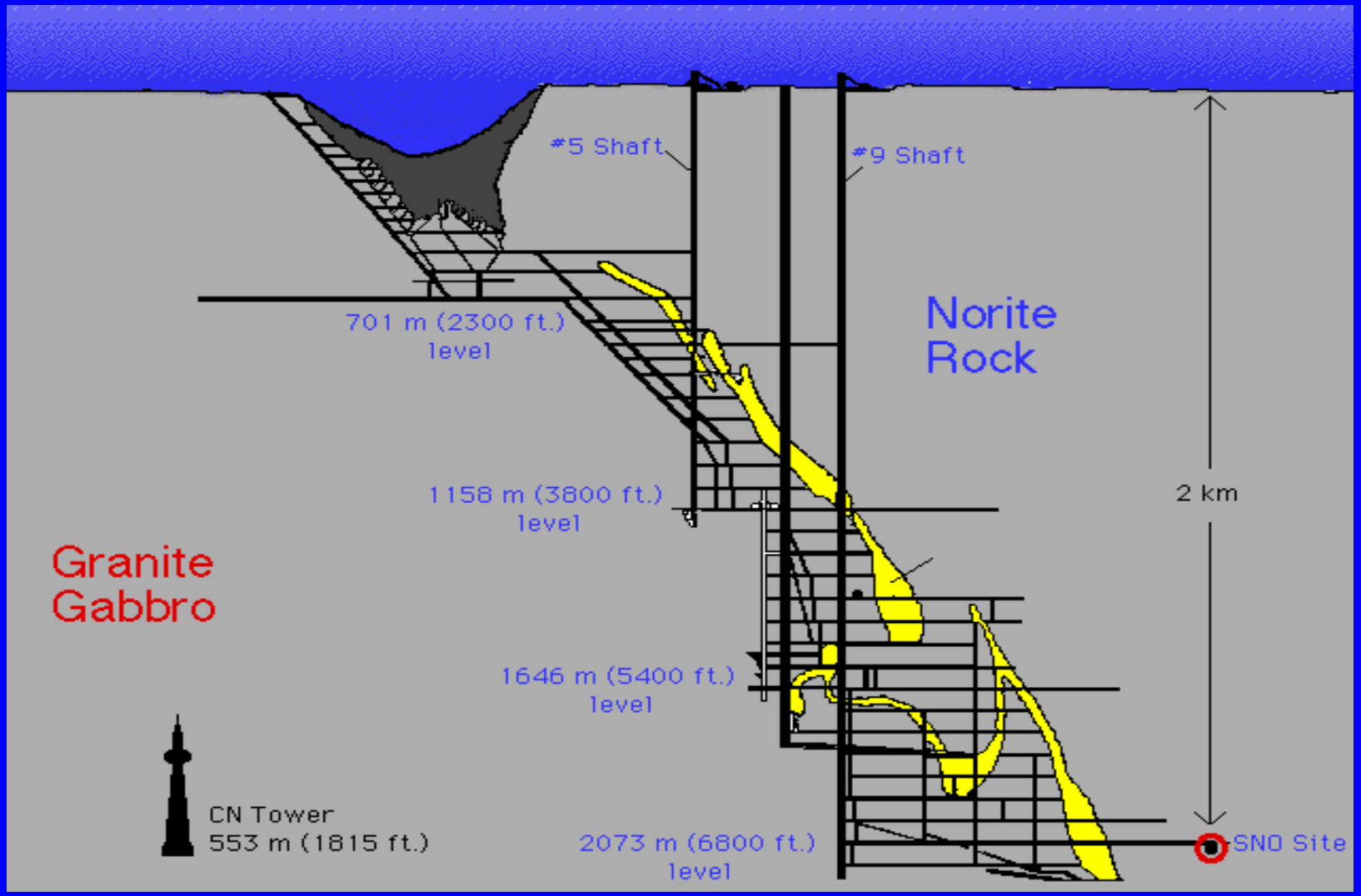
CC $\nu_e + d \Rightarrow p + p + e^-$

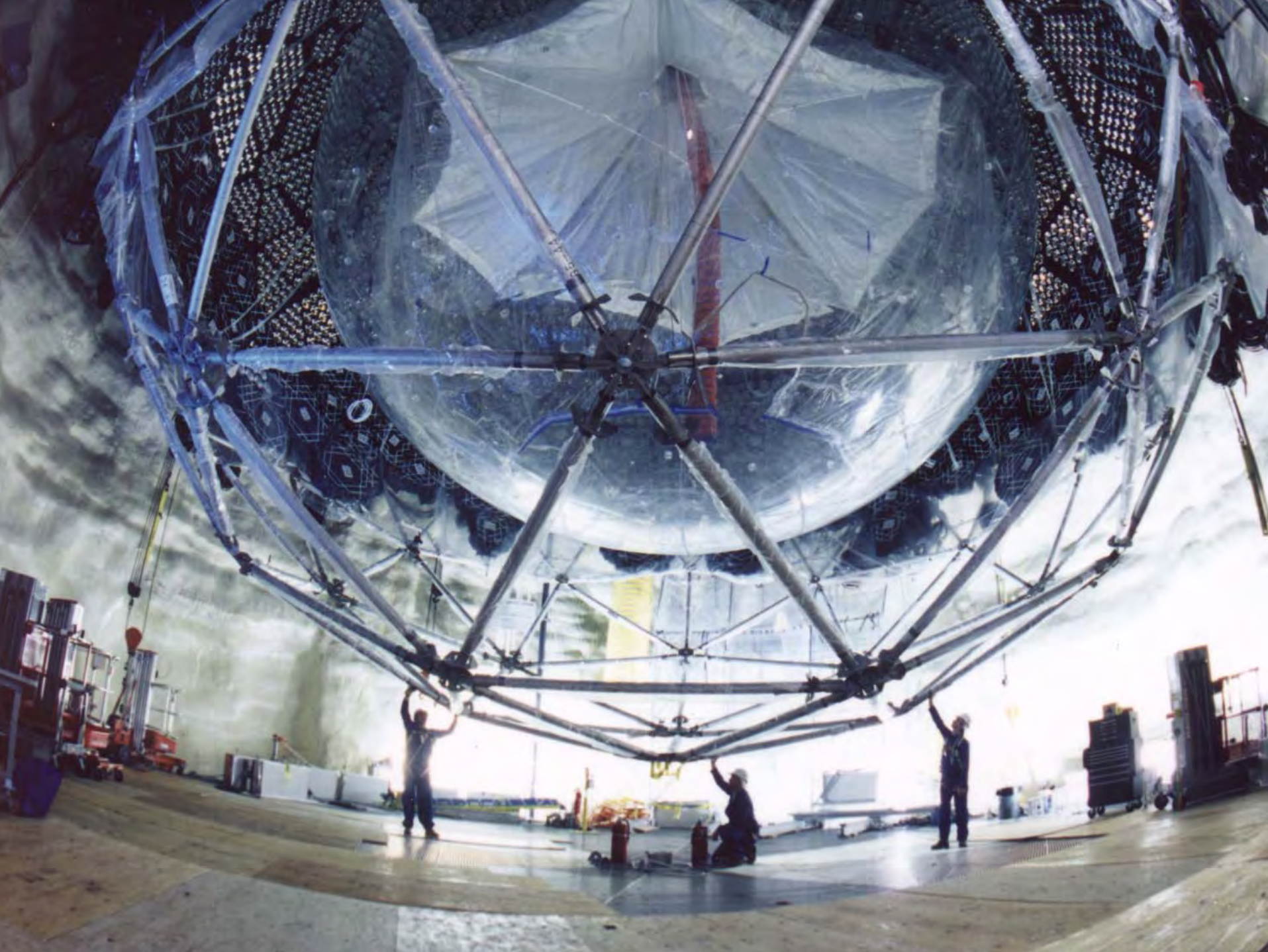
NC $\nu_x + d \Rightarrow p + n + \nu_x$

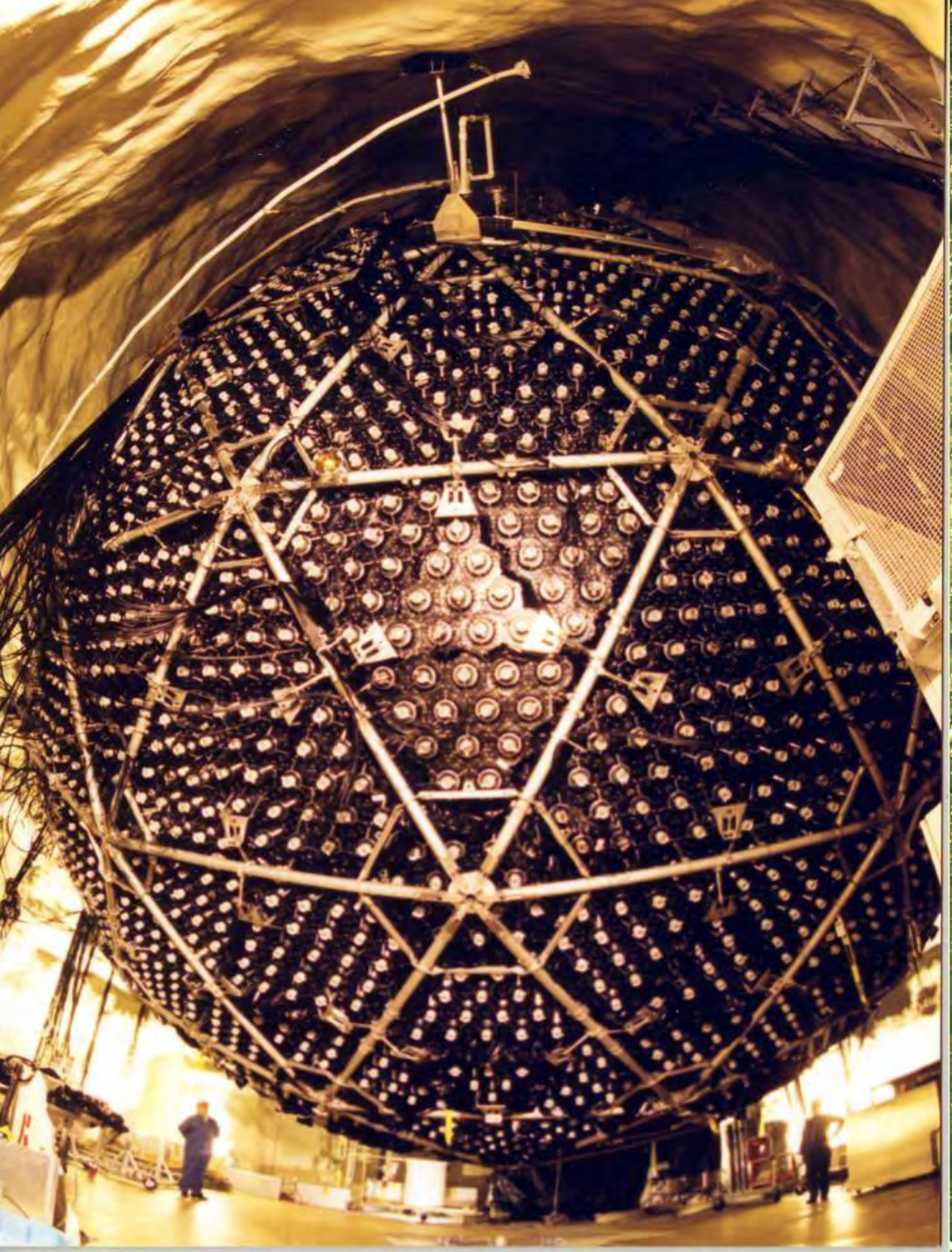
ES $\nu_x + e^- \Rightarrow \nu_x + e^-$

$$\frac{CC}{ES} = \frac{\nu_e}{\nu_e + 0.14(\nu_\mu + \nu_\tau)}$$

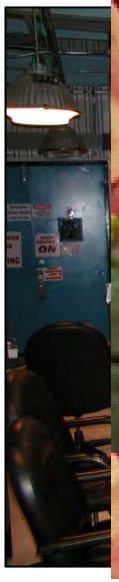
Der SNO Detektor

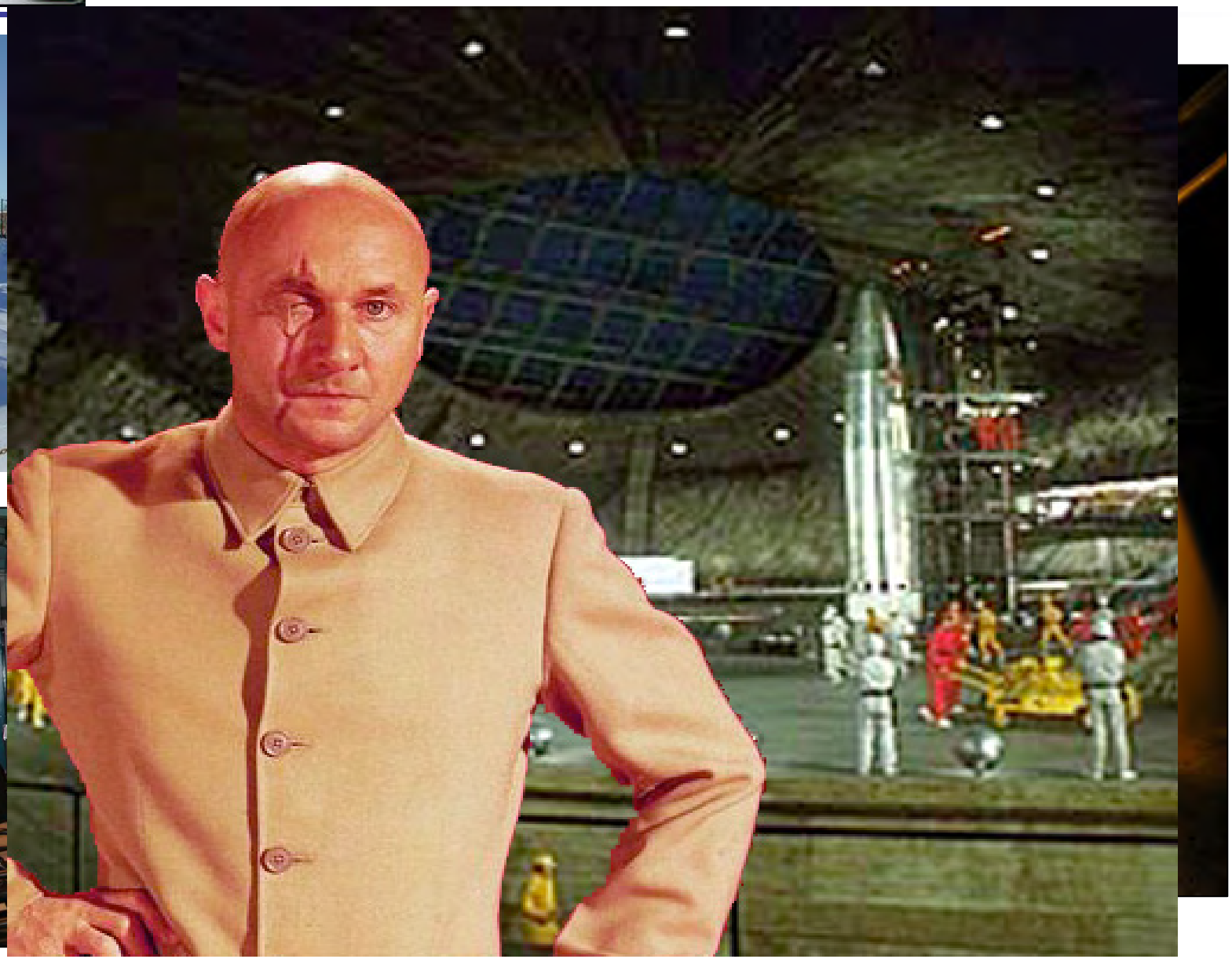






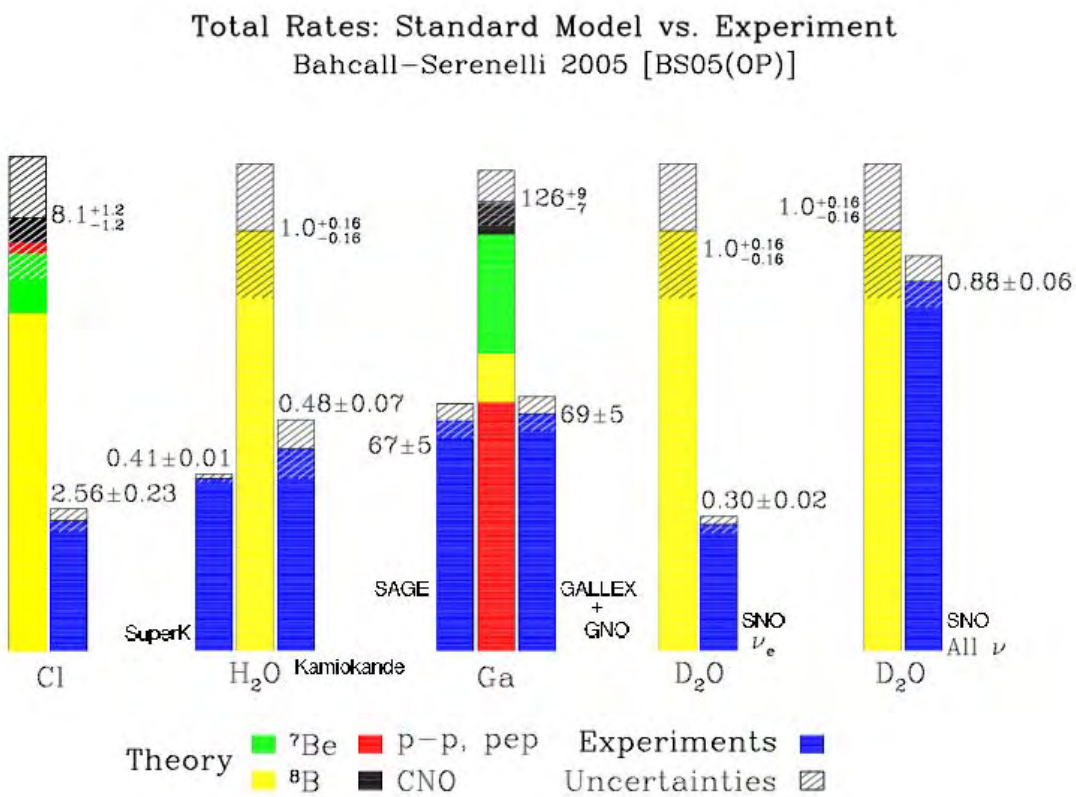
A SNOw day





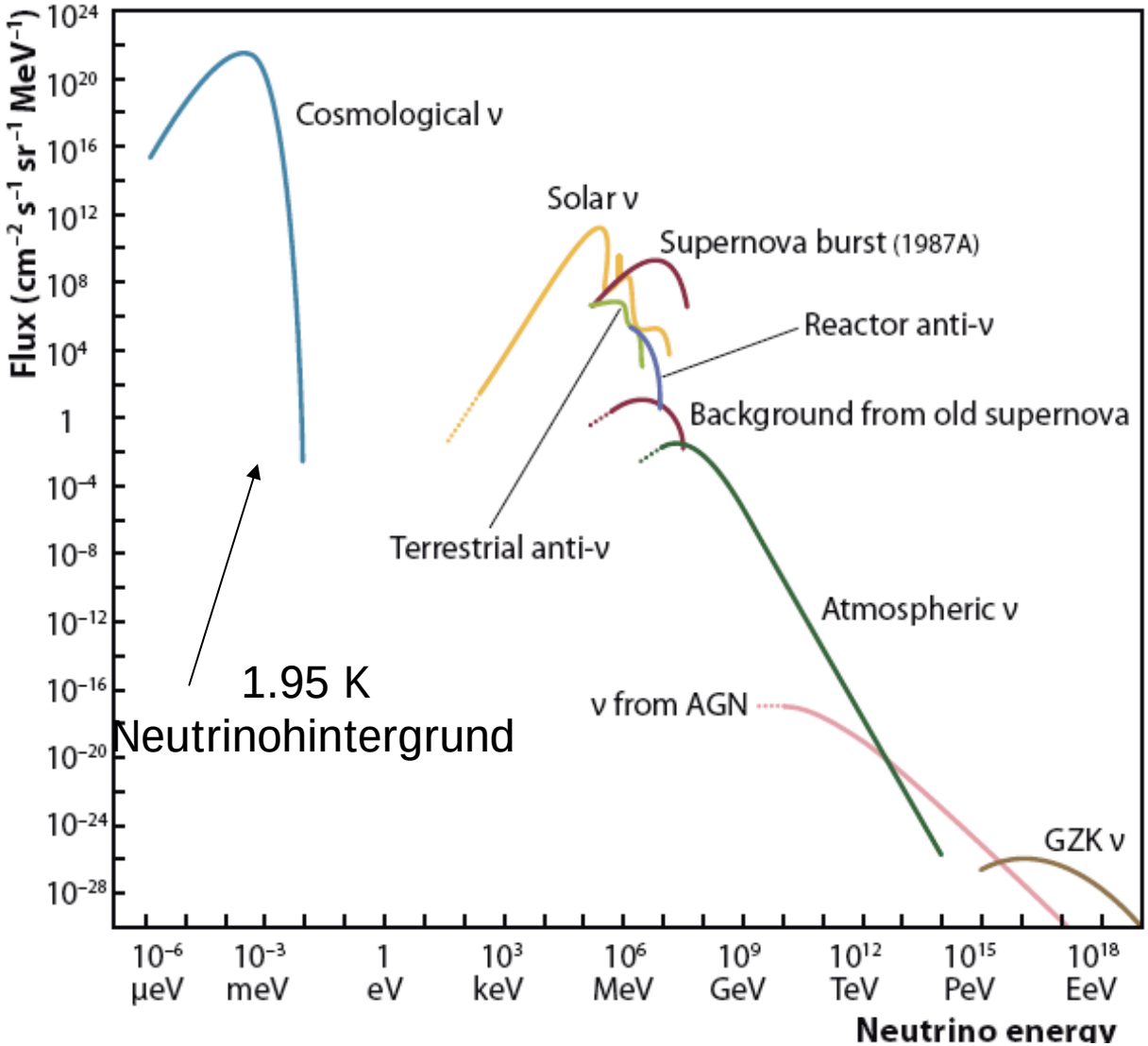
Stand der Dinge 2007

Es kommen alle erwarteten solaren Neutrinos, aber 60-70% im falschen Flavour!!!

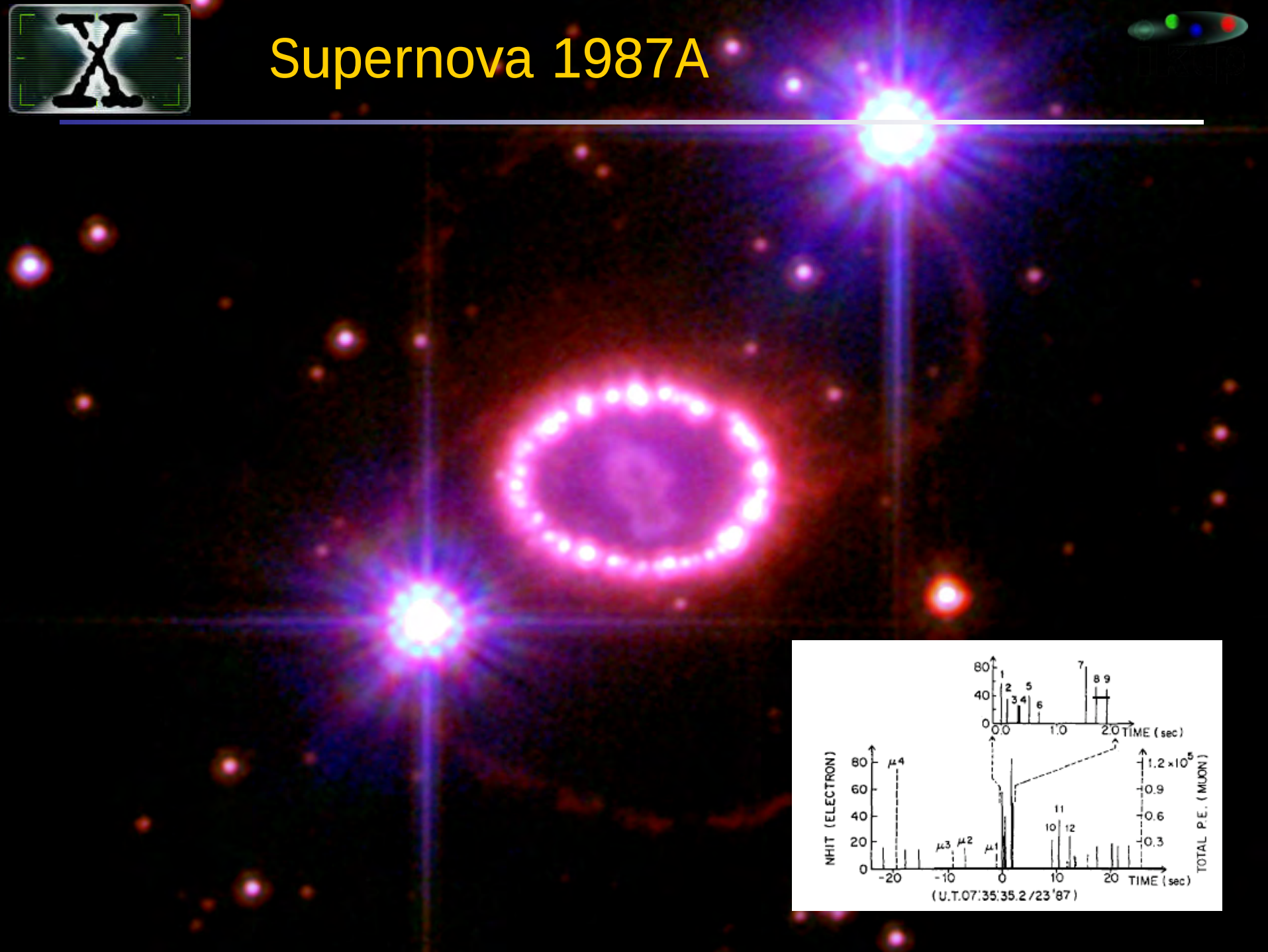


Die Neutrinos sind schuld!!!

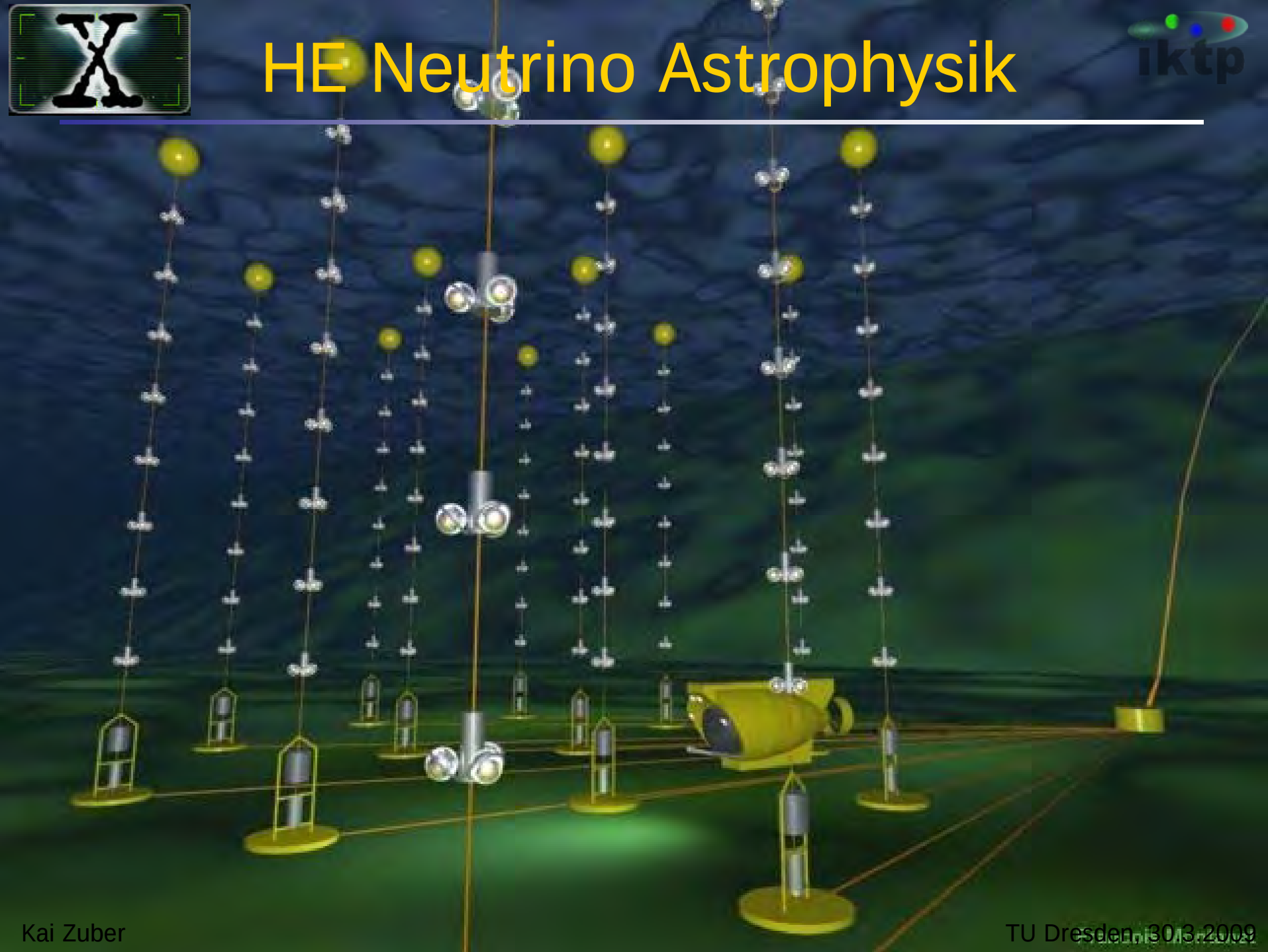
Neutrino Astrophysik



Supernova 1987A



HE Neutrino Astrophysik



HE Neutrino Astrophysik

Zusammenfassung

- ★ Die Neutrinophysik hat in den letzten 15 Jahren enorme Fortschritte gemacht
- ★ In Oszillationsexperimenten konnte klar bewiesen werden, dass Neutrinos eine nicht-verschwindende Ruhemasse haben
- ★ Das Problem der fehlenden Sonnenneutrinos ist gelöst
- ★ Die nächsten Schritte sind die absolute Massenbestimmung mit Hilfe des Beta- und Doppelbeta-Zerfalls, Vermessung der Mischungsmatrix (CP-Verletzung), Neutrino-Astrophysik

Erwarte das Unerwartete