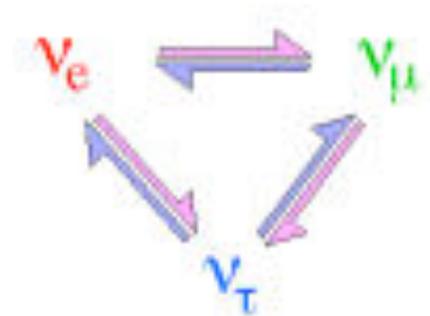
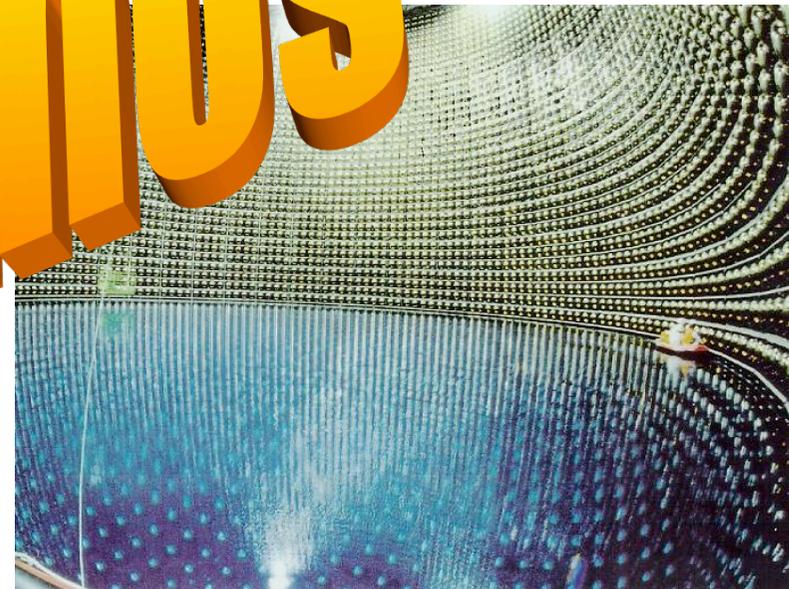




Die Akte X der Teilchenphysik

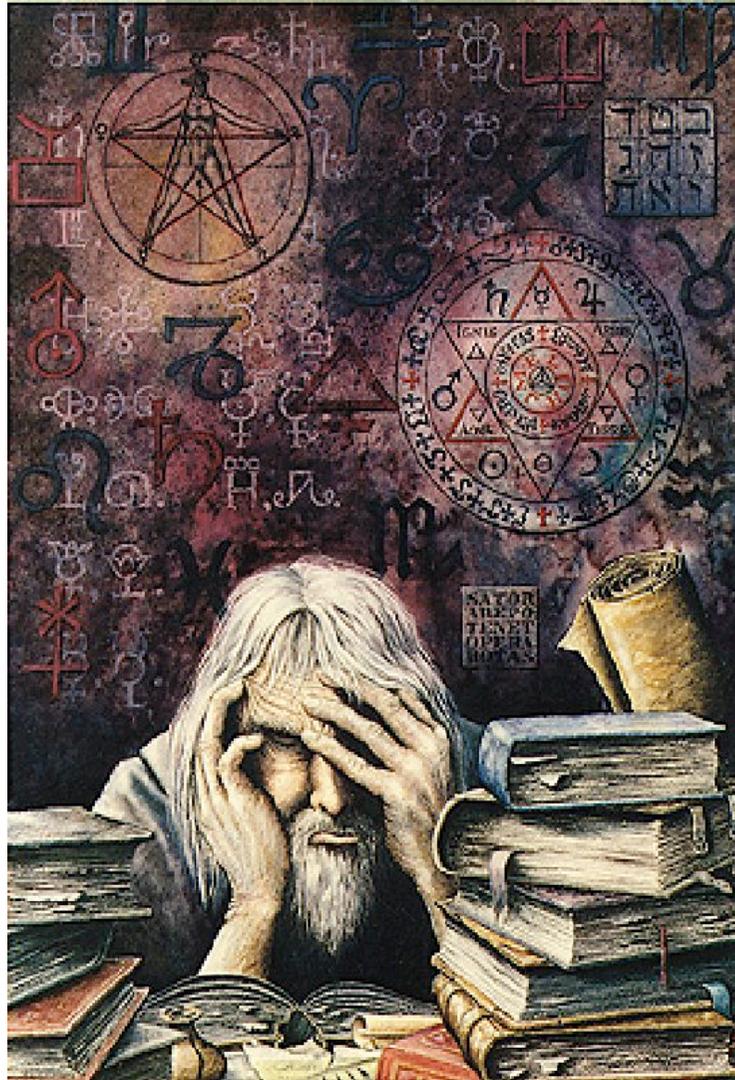


Neutrinos





Inhalt



- ★ Historie
- ★ Solare Neutrinos
- ★ 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

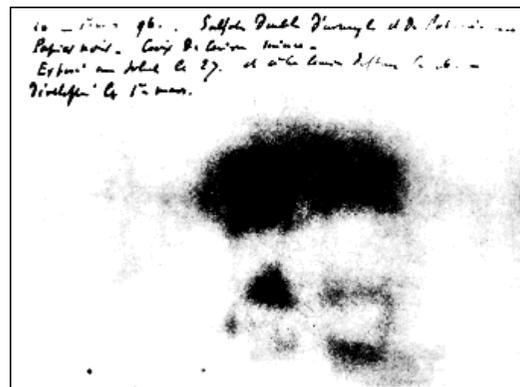
Madame Curie bekam 2 Nobelpreise

(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

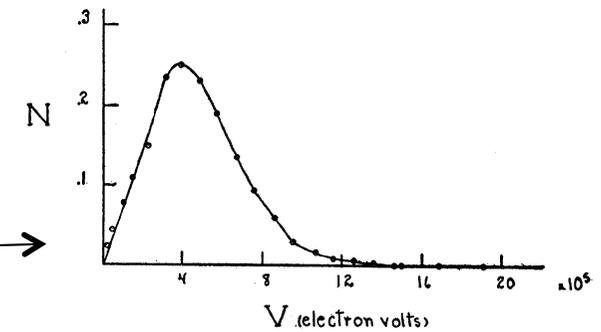
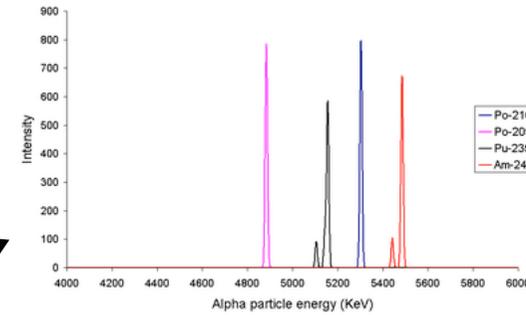
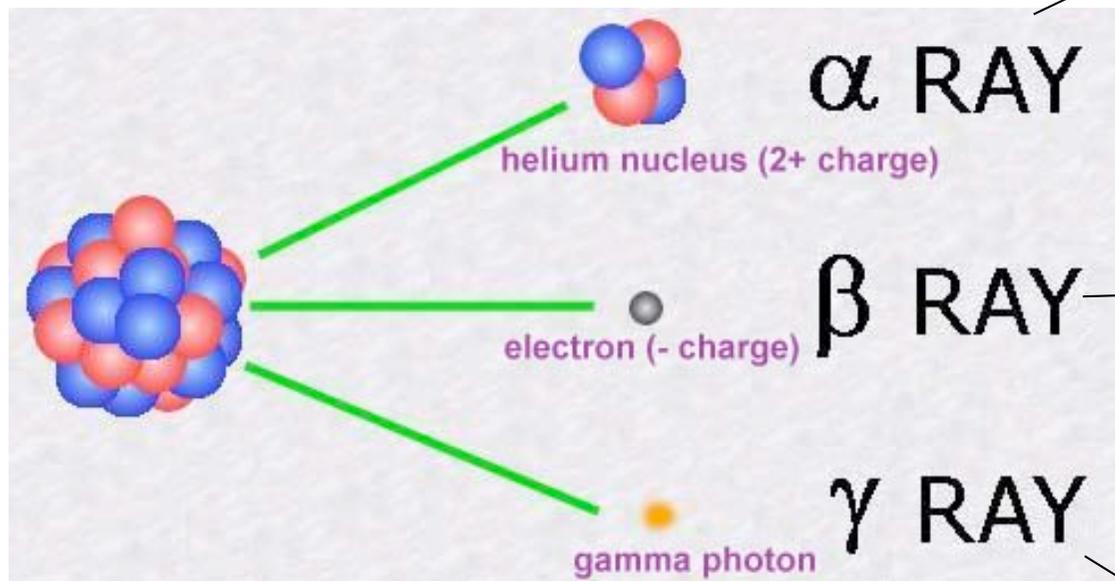
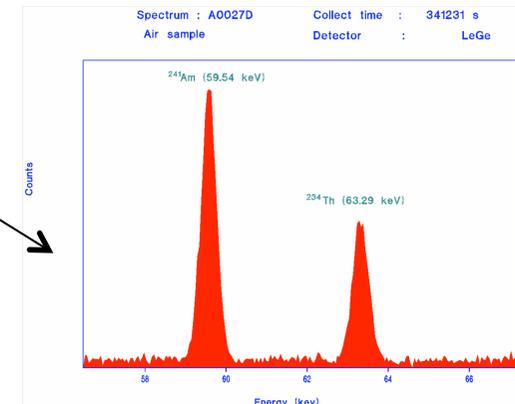


FIG. 5. Energy distribution curve of the beta-rays.





Warum Neutrinos?



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

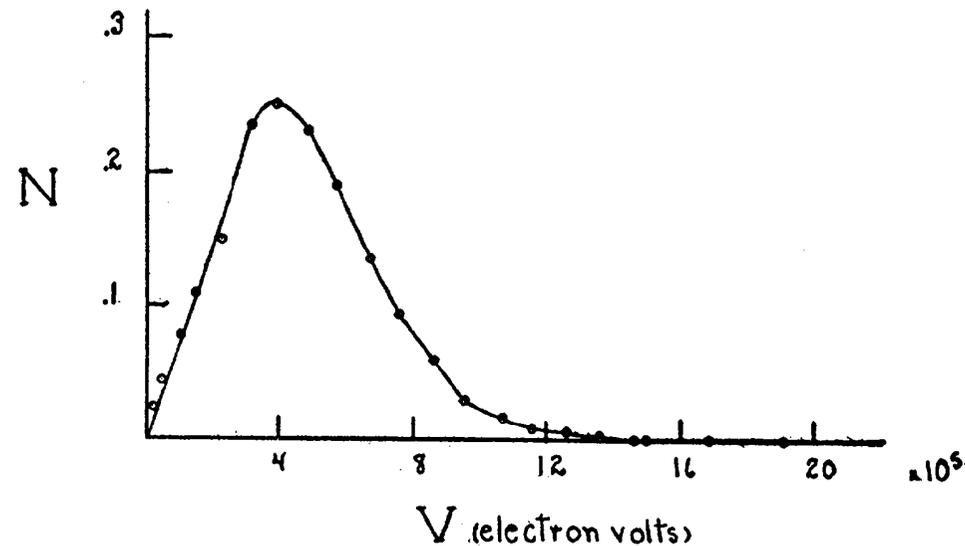


FIG. 5. Energy distribution curve of the beta-rays.

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,

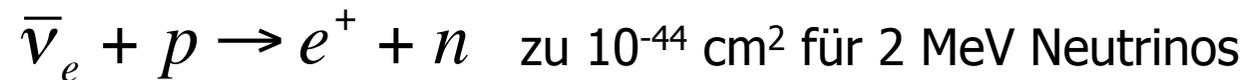
As the bearer of these lines, to whom I graciously ask you to listen, will explain to you in more detail, how because of the "wrong" statistics of the N and Li^6 nuclei and the continuous beta spectrum, I have hit upon a desperate remedy to save the "exchange theorem" of statistics and the law of conservation 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...



Die Erwartung



Bethe und Peierls berechnen 1934 mit Hilfe der Theorie von Fermi (1932)
den Wirkungsquerschnitt für die Reaktion



→ 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

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

→ 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

Neutrino-physik ist Physik unter Tage

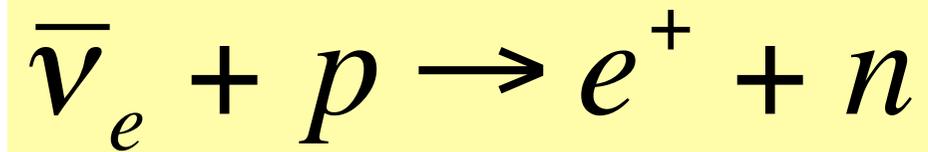




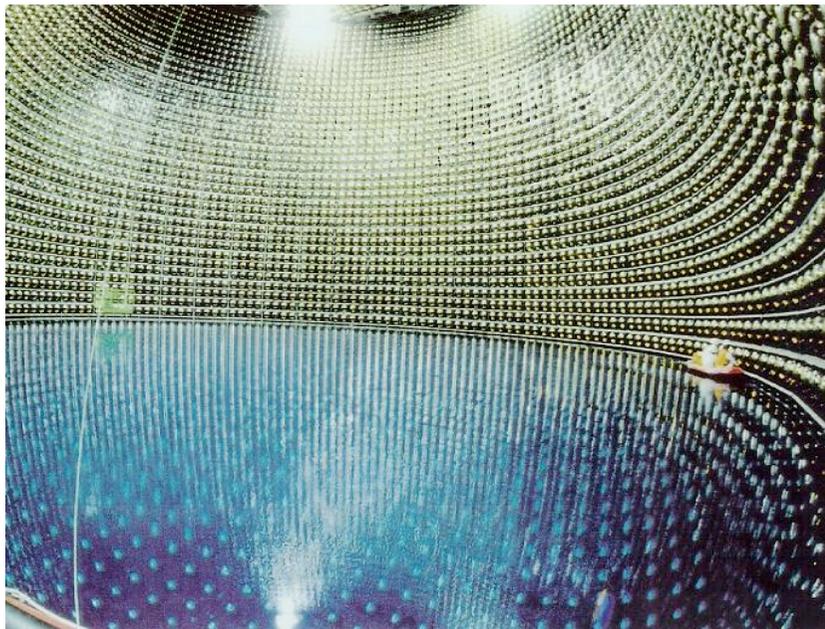
Die Entdeckung



C. Cowan, F. Reines 1953, 1956



Herr Auge



Projekt Poltergeist





RADIO-SCHWEIZ AG. **RADIOGRAMM - RADIOGRAMME** RADIO-SUISSE S.A.

SBZ1311 ZHM UM1844 FM BZJ116 MH CHICAGO ILL 56 14 1310
PLC 00253

Erhalten - Recd **VIA RADIO-SUISSE** Bulletin - Transmis

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Brieftelegramm

LT

NACHLASS
PROF. W. PAULI

PROFESSOR W PAULI
ZURICH UNIVERSITY ZURICH

Per Post ①

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 COHN
BOX 1663 LOS ALAMOS NEW MEXICO

No. 20 400 X 100 5/74



Das Standard Modell



THREE GENERATIONS OF MATTER

	I	II	III	CHARGE:	
MATTER CONSTITUENTS: FERMIONS QUARKS	2.75 UP	1300 CHARM	178000 TOP	$2/3$	91188 Z^0
	6 DOWN	110 STRANGE	4500 BOTTOM	$-1/3$	80430 W^+/W^-
	0.511 ELECTRON	105.7 MUON	1777 TAU	-1	$< 10^{-23}$ PHOTON
LEPTONS	$< 3 \cdot 10^{-6}$ NEUTRINO e	< 0.19 NEUTRINO μ	< 18.2 NEUTRINO τ	0	theory: 0 GLUON

FORCE CARRIERS: BOSONS

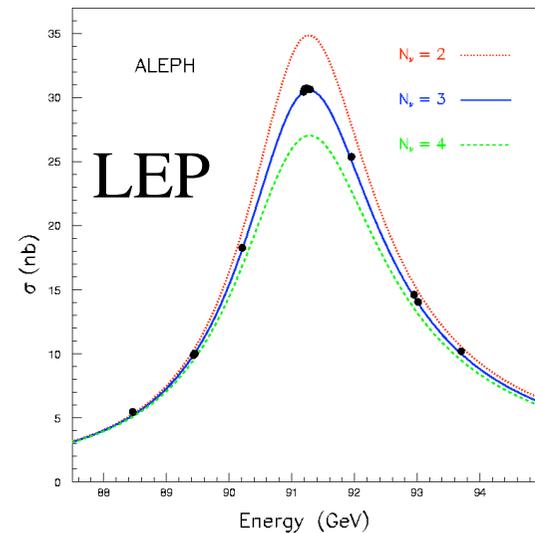
ALL MASSES IN MEV;
ANIMAL MASSES
SCALE WITH
PARTICLE MASSES

The Standard Model
fundamental particle zoo

Fermilab 95-759

1955: $m < 10 \text{ keV}$

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

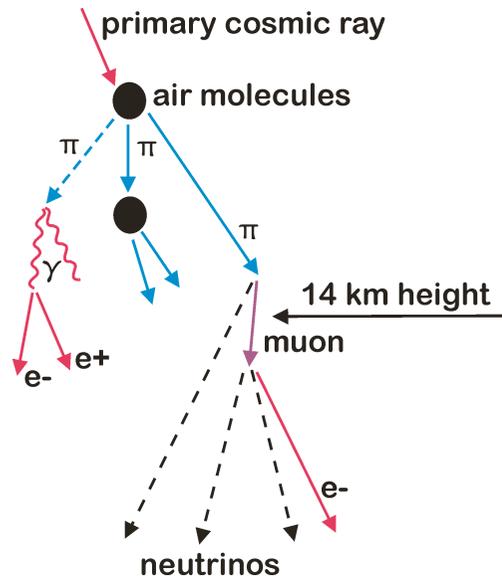
Betazerfall, neutrinolose doppelte Betazerfall

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

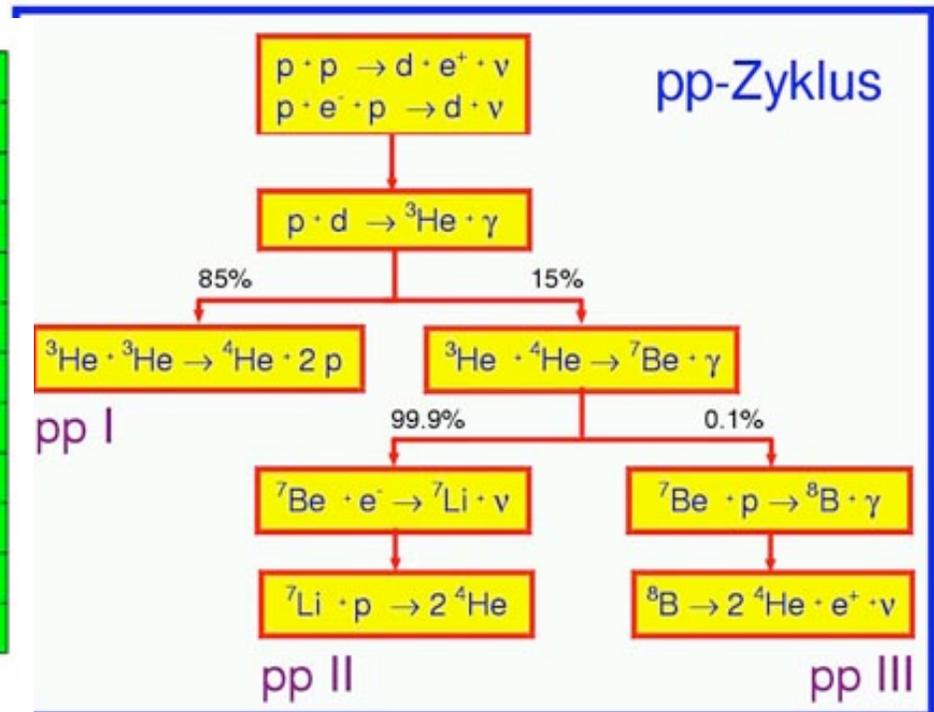
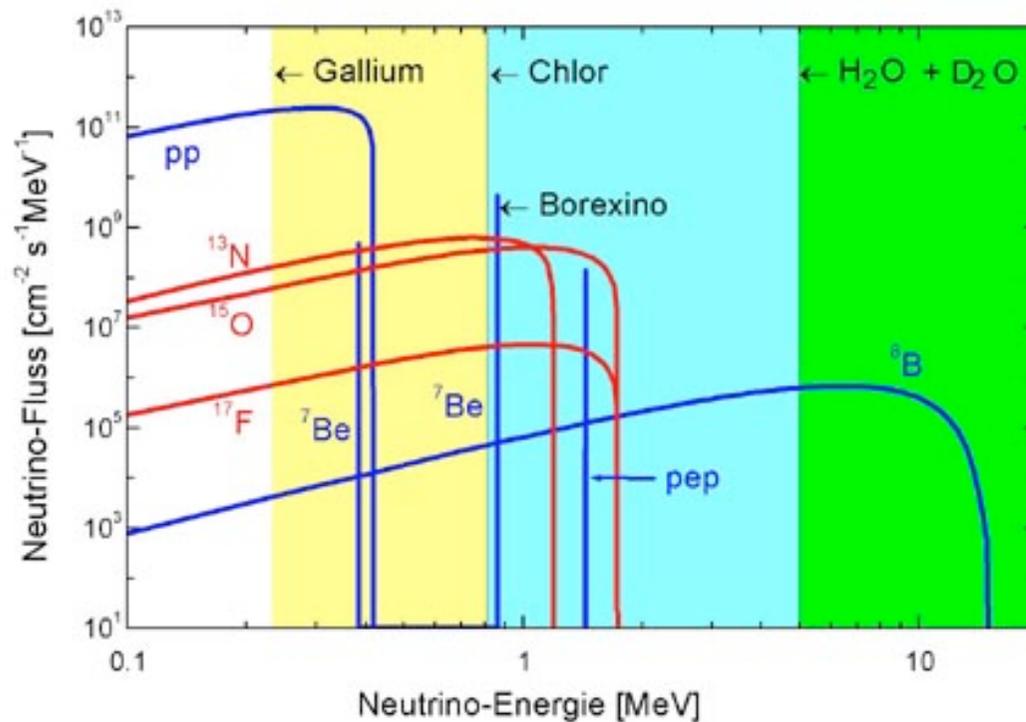
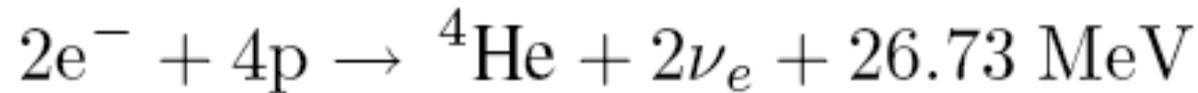
Eines der ältesten Probleme der Teilchenastrophysik



Standard Sonnenmodell



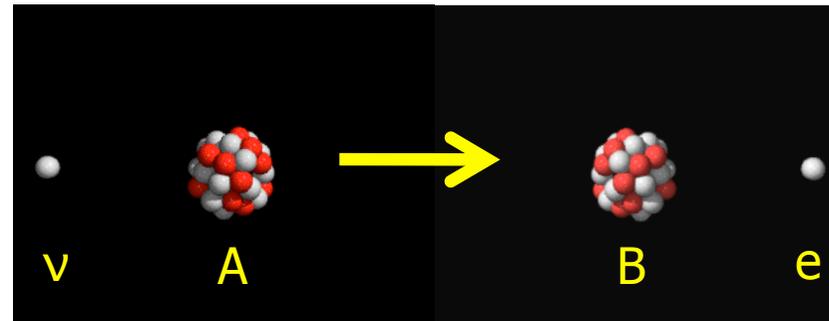
Annahme: Sonne produziert Energie durch Kernfusion



60 Milliarden Neutrinos durchqueren jeden cm^2 von uns jede Sekunde



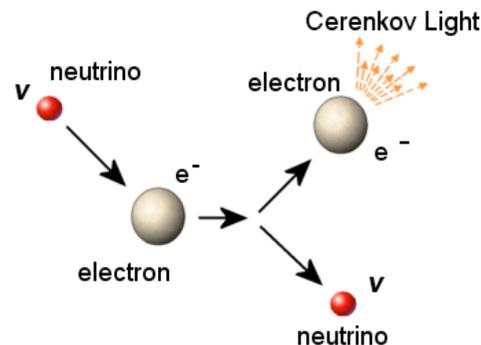
radiochemisch (CC)



+ : kleine Energien - : keine Echtzeit

Elastische Elektron-Neutrino Streuung (ES)

+ : Echtzeit



- : hohe Energie

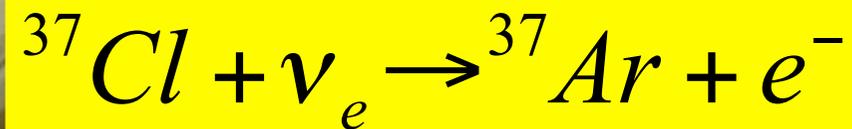
Reaktionen am Deuterium (CC + NC)



Homestake Experiment



Ray Davis Jr.



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

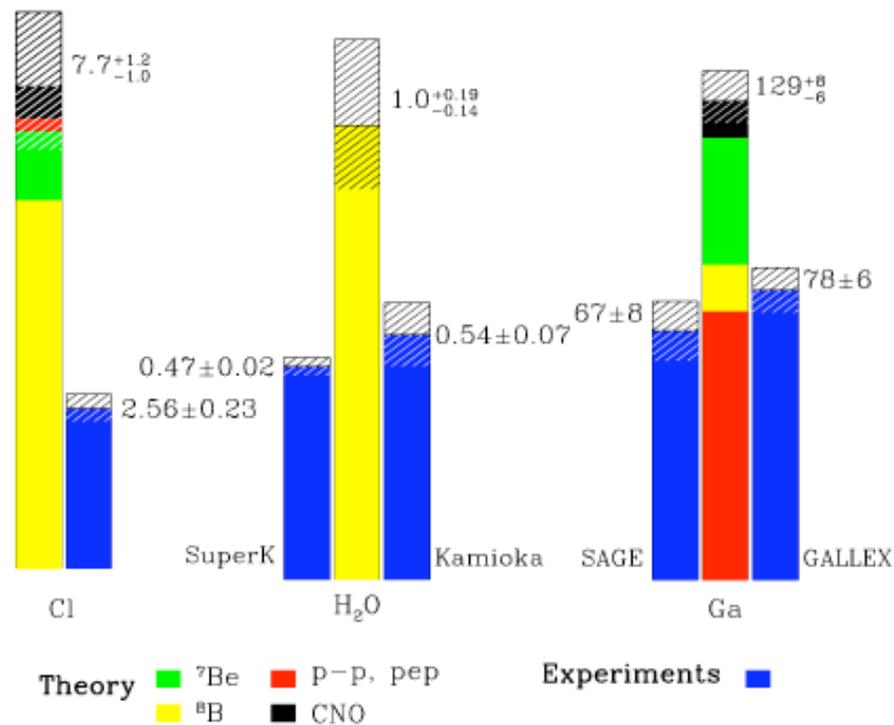


Stand der Dinge 2002



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

Total Rates: Standard Model vs. Experiment
Bahcall-Pinsonneault 98



Wer ist schuld? Die Sonne oder die Neutrinos?

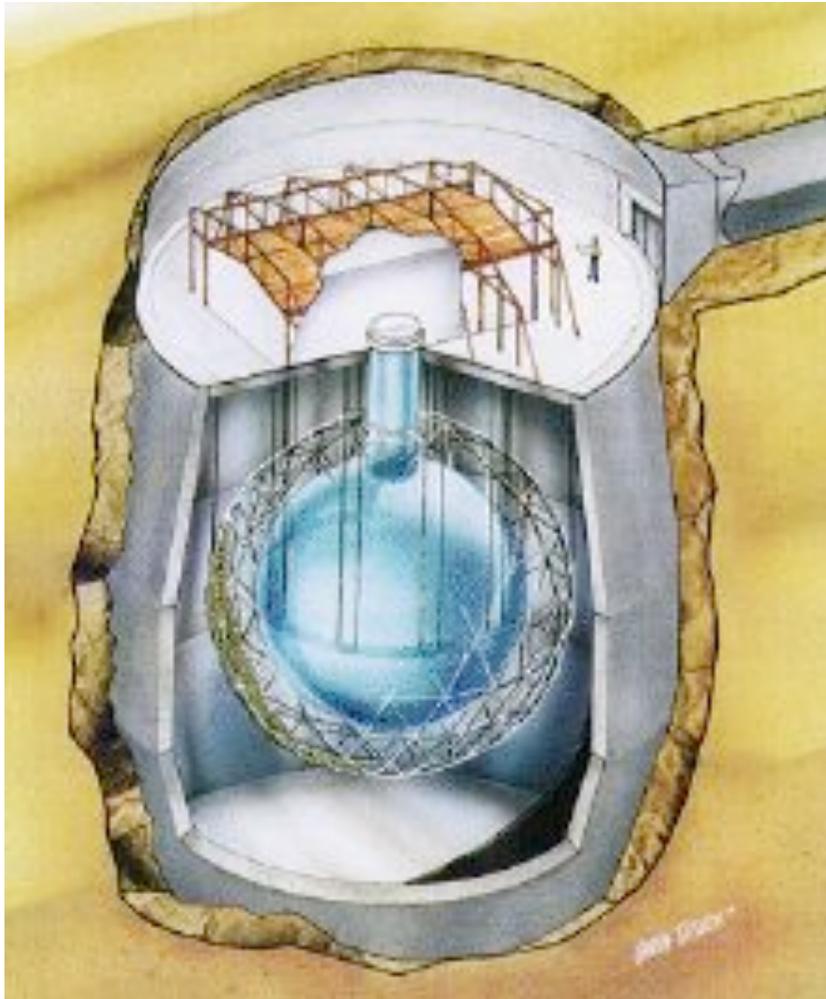


The Sudbury

Neutrino Observatory (SNO)



SNO – The smoking gun



1000 t schweres Wasser (D₂O)

CC



NC

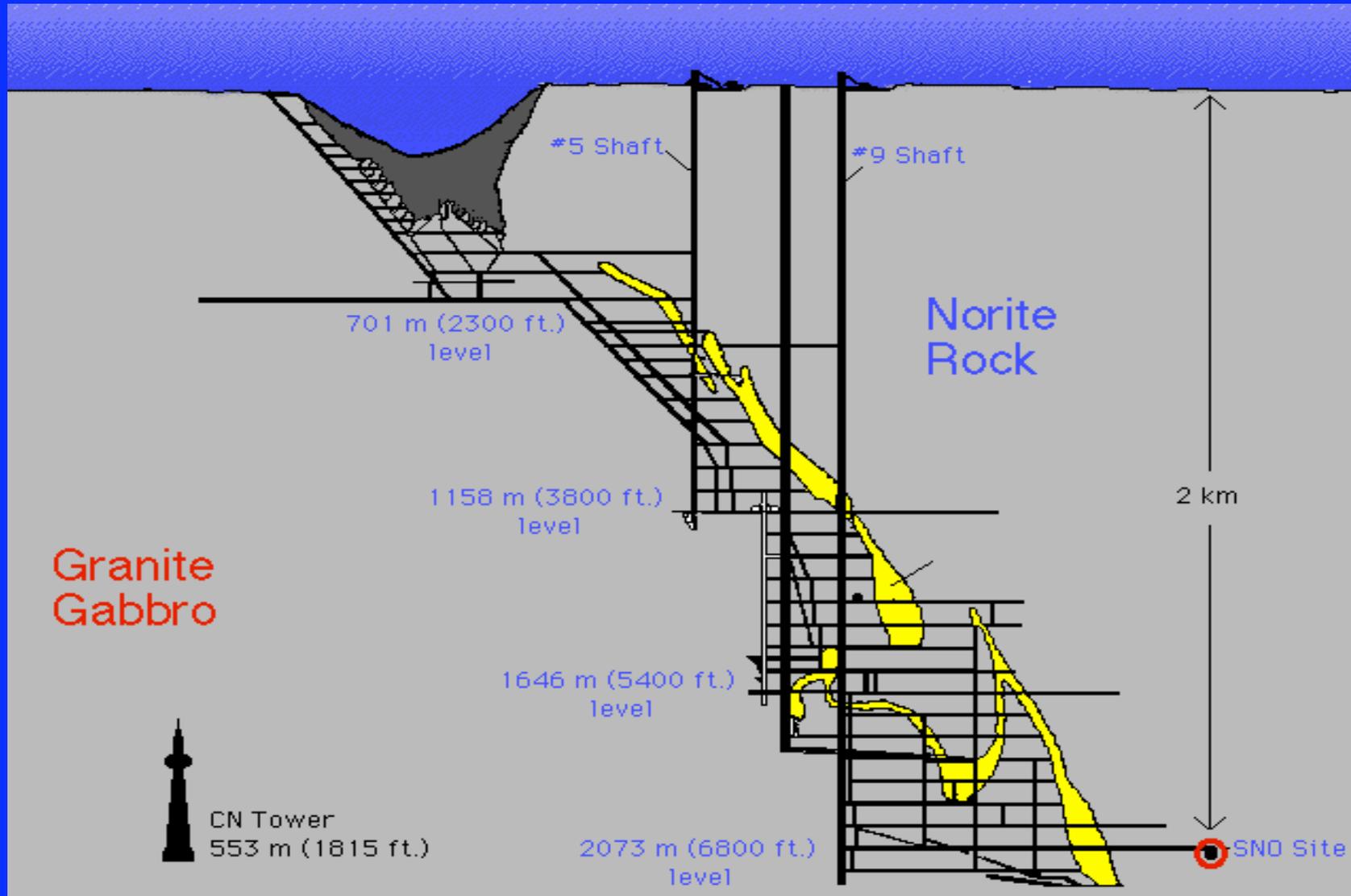


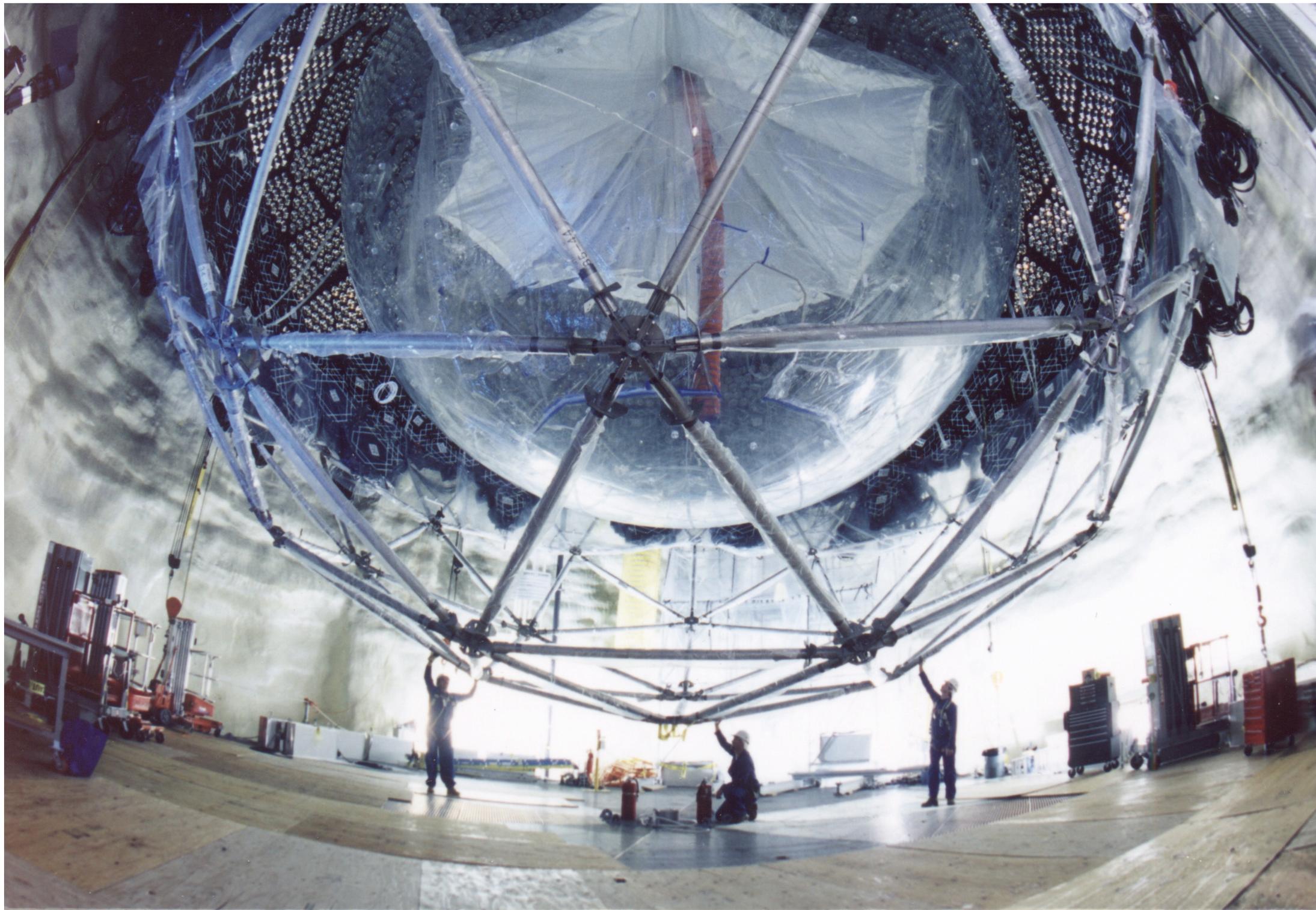
ES

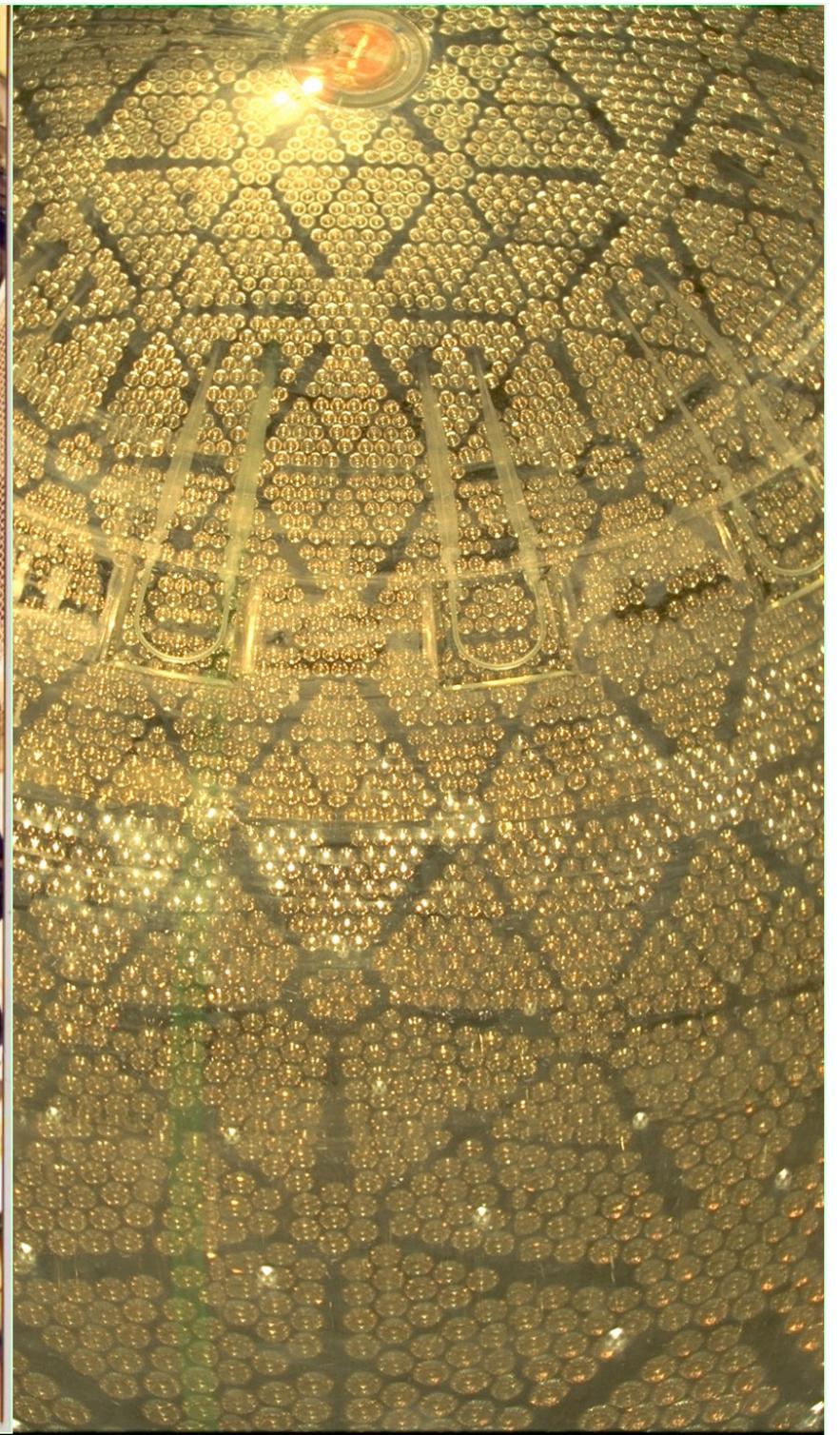
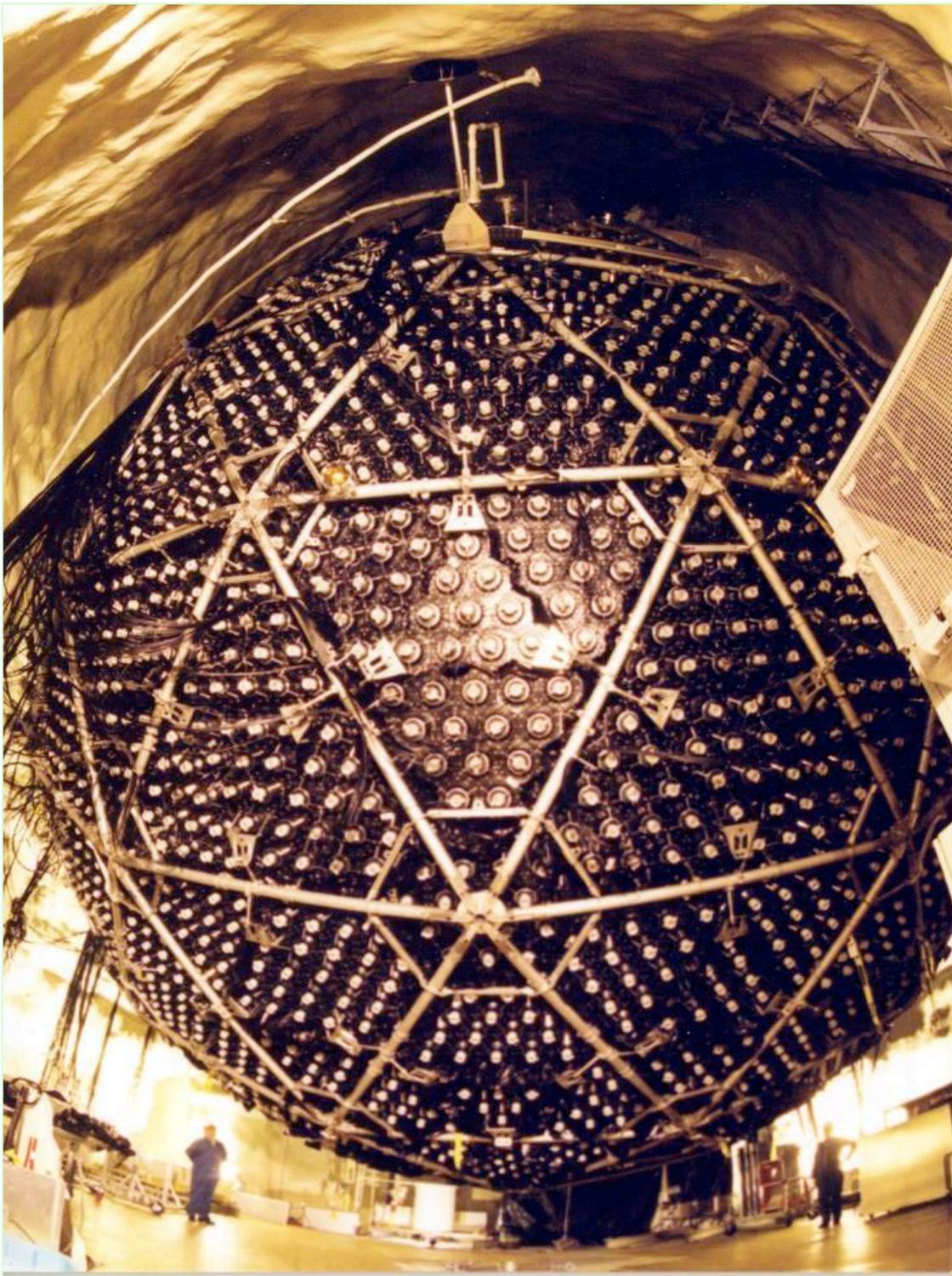


$$\frac{\text{CC}}{\text{ES}} = \frac{\nu_e}{\nu_e + 0.14(\nu_\mu + \nu_\tau)}$$

Der SNO Detektor









A SNO_w day



Kai Zuber

TU Dresden, 19.6.2009

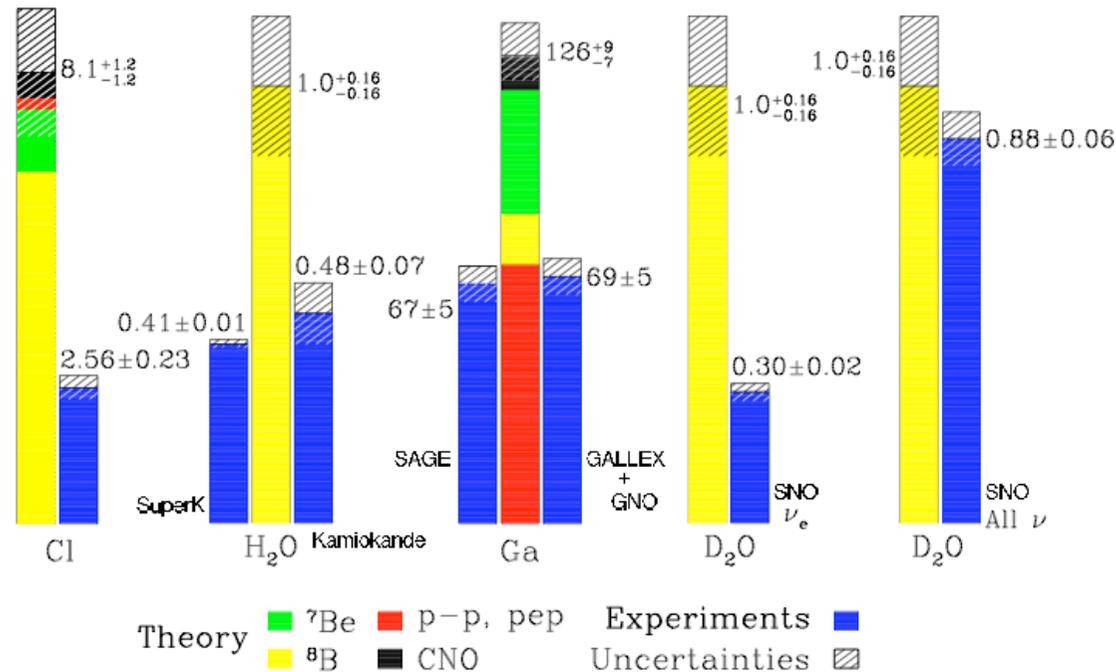


Stand der Dinge 2007



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

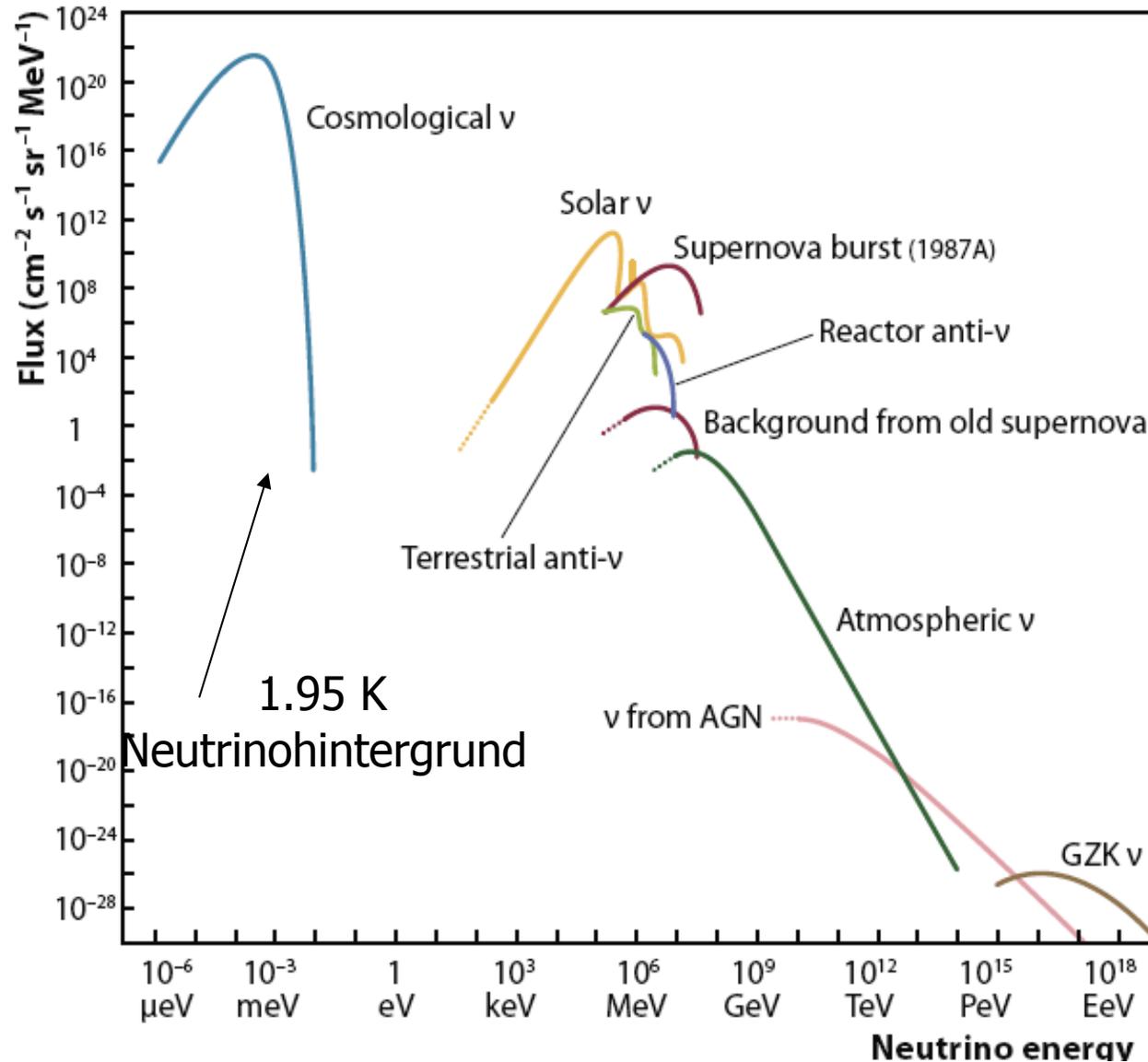
Total Rates: Standard Model vs. Experiment
Bahcall-Serenelli 2005 [BS05(OP)]



Die Neutrinos sind schuld!!!

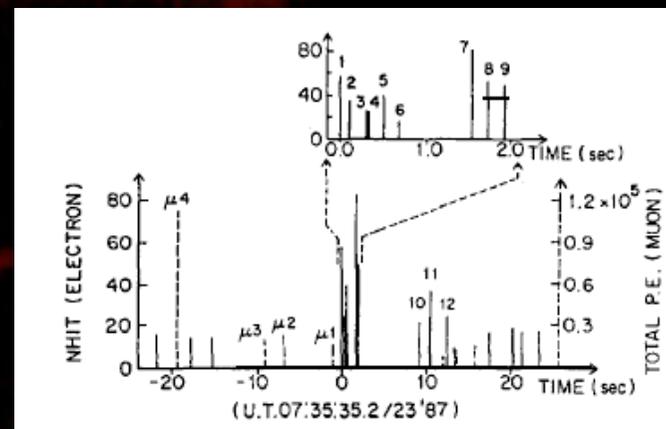
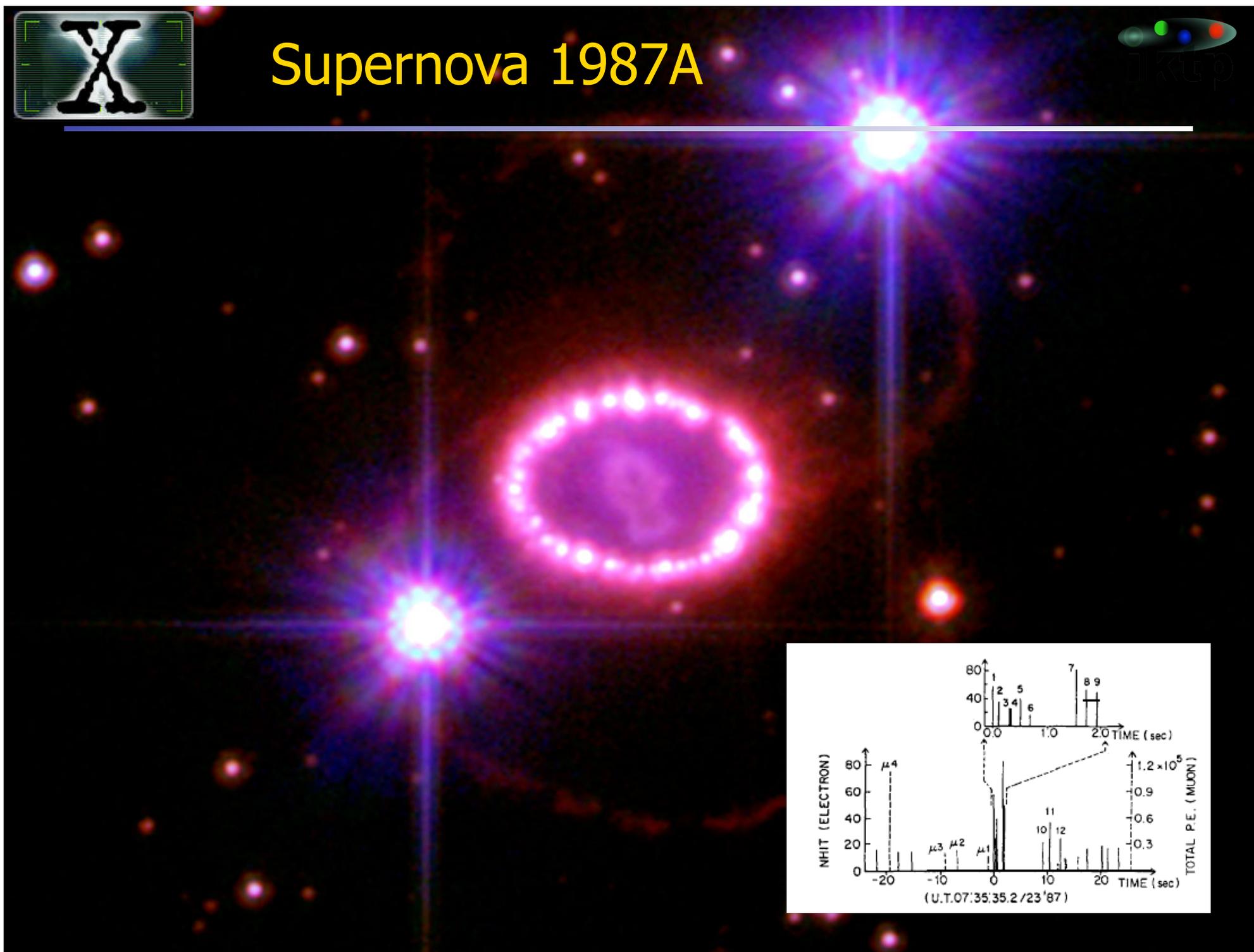


Neutrino Astrophysik



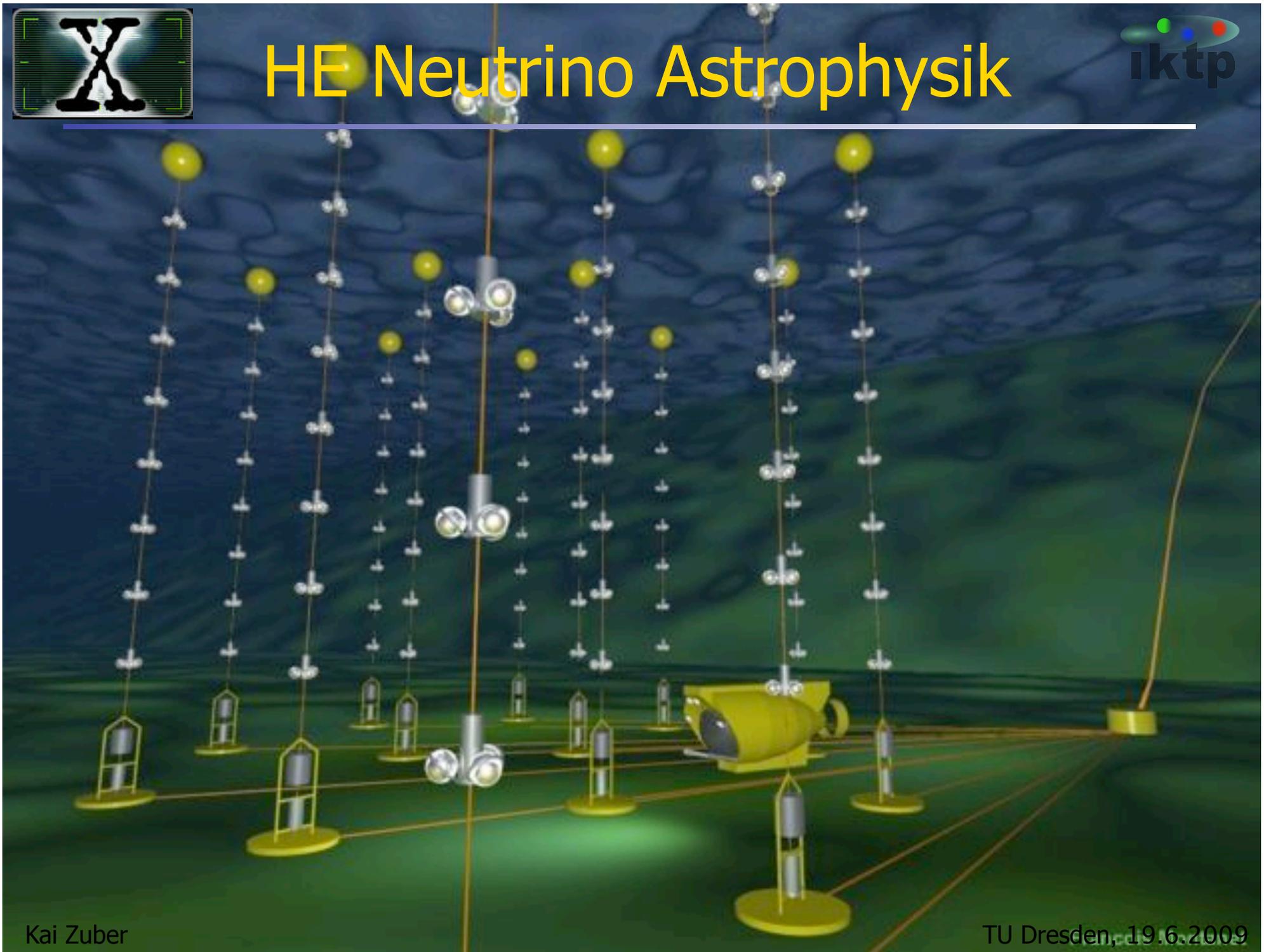


Supernova 1987A





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, Neutrino-Astrophysik usw.

Aber der wirkliche Reiz...



Erwarte das Unerwartete...

