Experimental Lecture #1
History

D. Jason Koskinen

NBIA PhD School: Neutrinos Underground and in the Heavens
June 23-27, 2014

Niels Bohr Institutet

The Niels Bohr
International Academy

Initial Comments

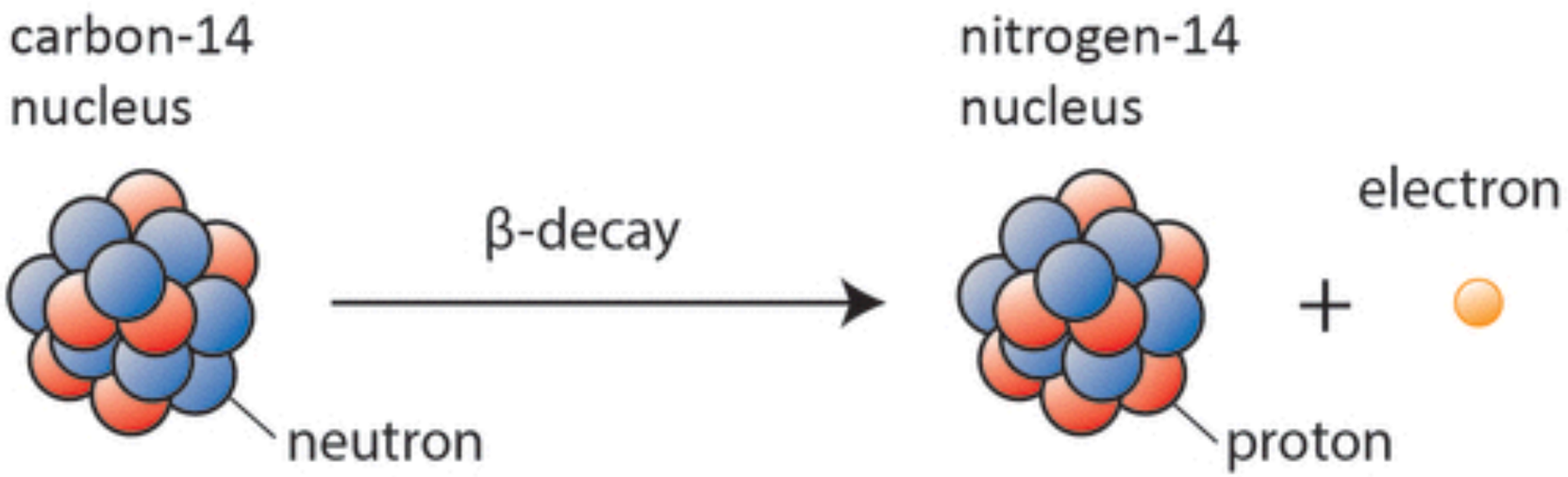
Initial Comments

- Specifics will be covered later
  - Neutrino sources
  - Neutrino detection
  - Experiments

Initial Comments

- Specifics will be covered later
  - Neutrino sources
  - Neutrino detection
  - Experiments
- Fill out notecards with your experiment/theoretical/pheno work and 1 experimental question or concept that you would to know, which will be collected during the problem sessions or you can hand to me

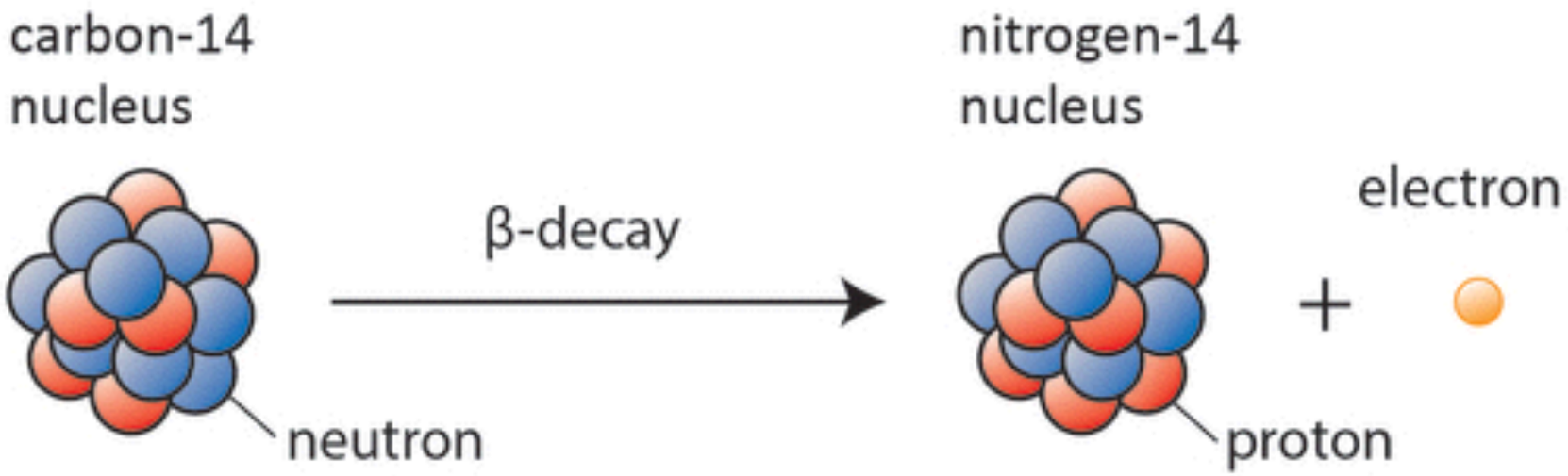
The Beginning… sort of



- 1910s
- No neutrino

*Tessa, Koumoundouros

The Beginning… sort of



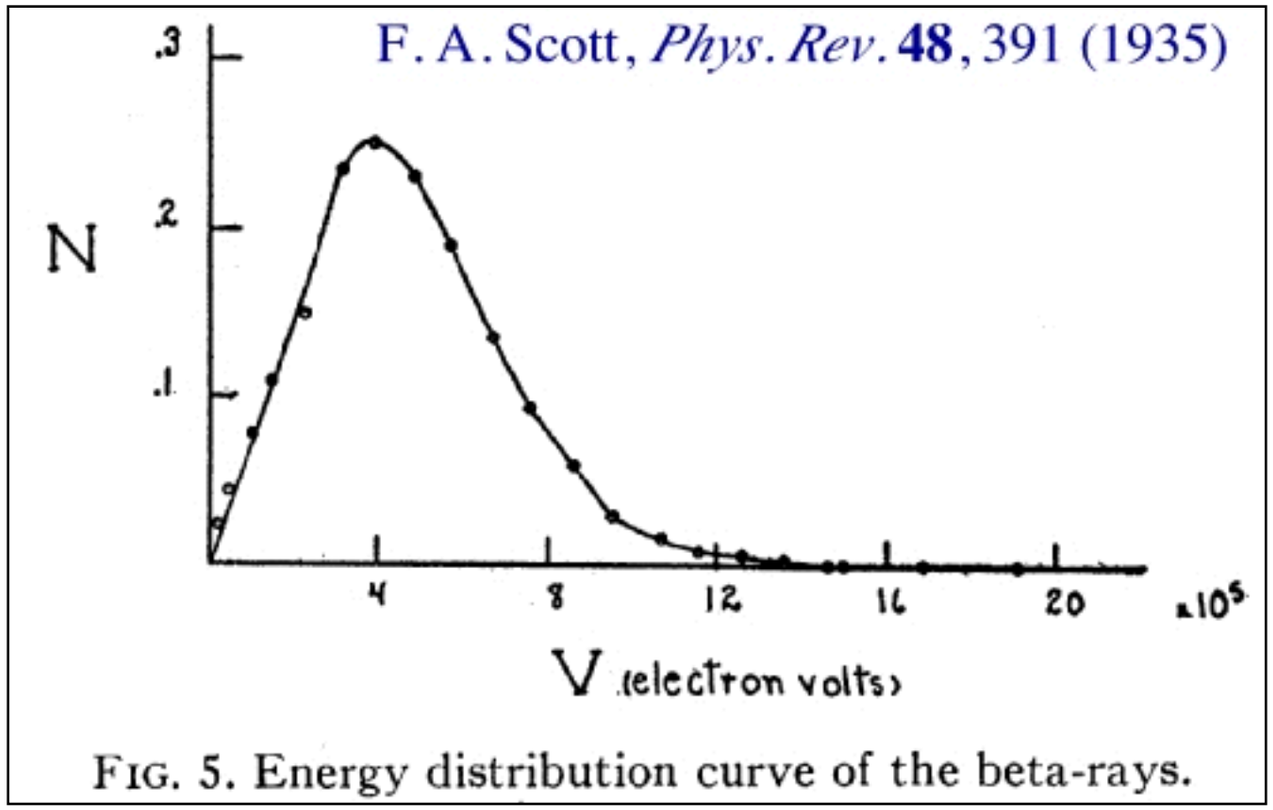
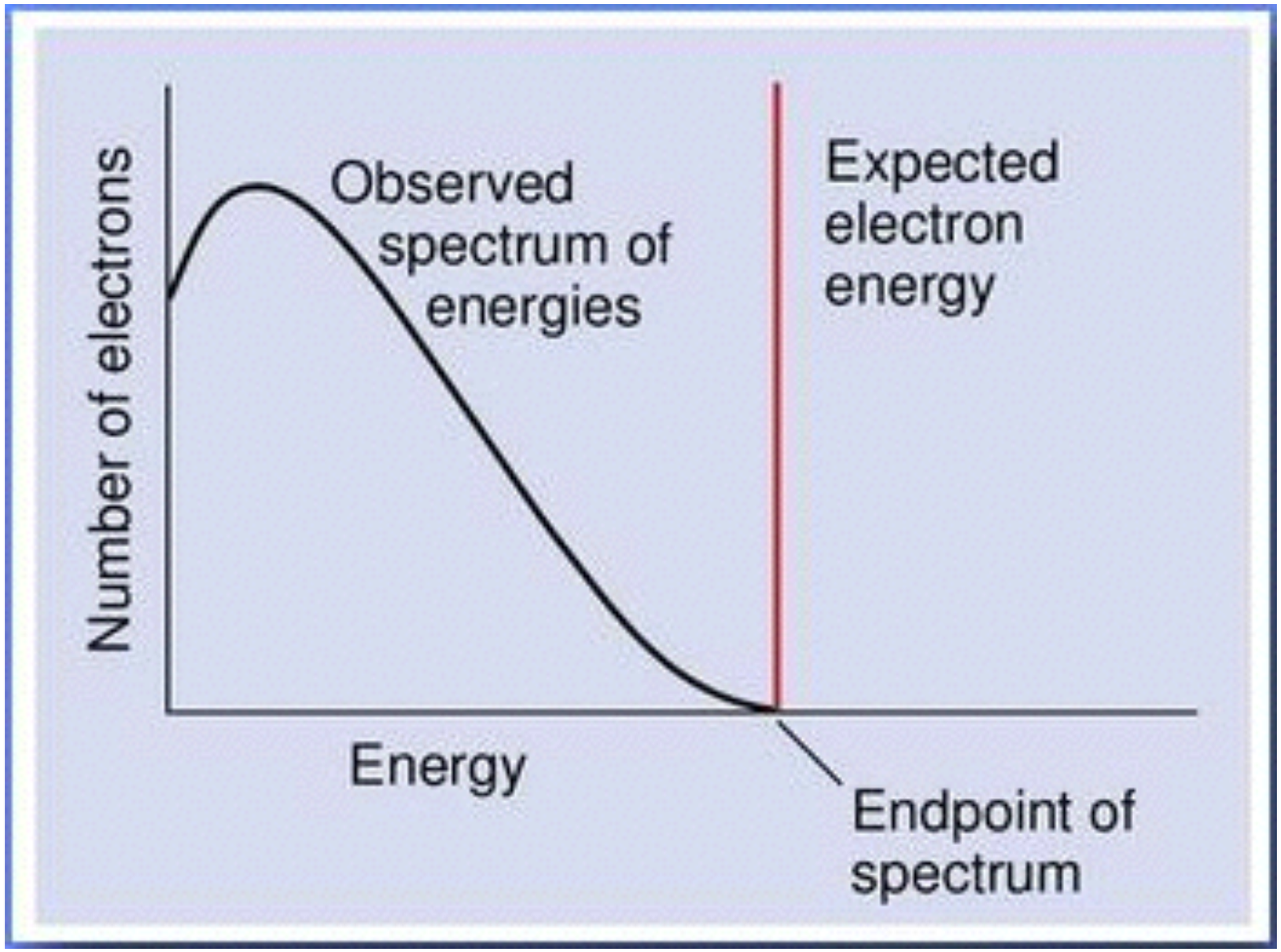


FIG. 5. Energy distribution curve of the beta-rays.

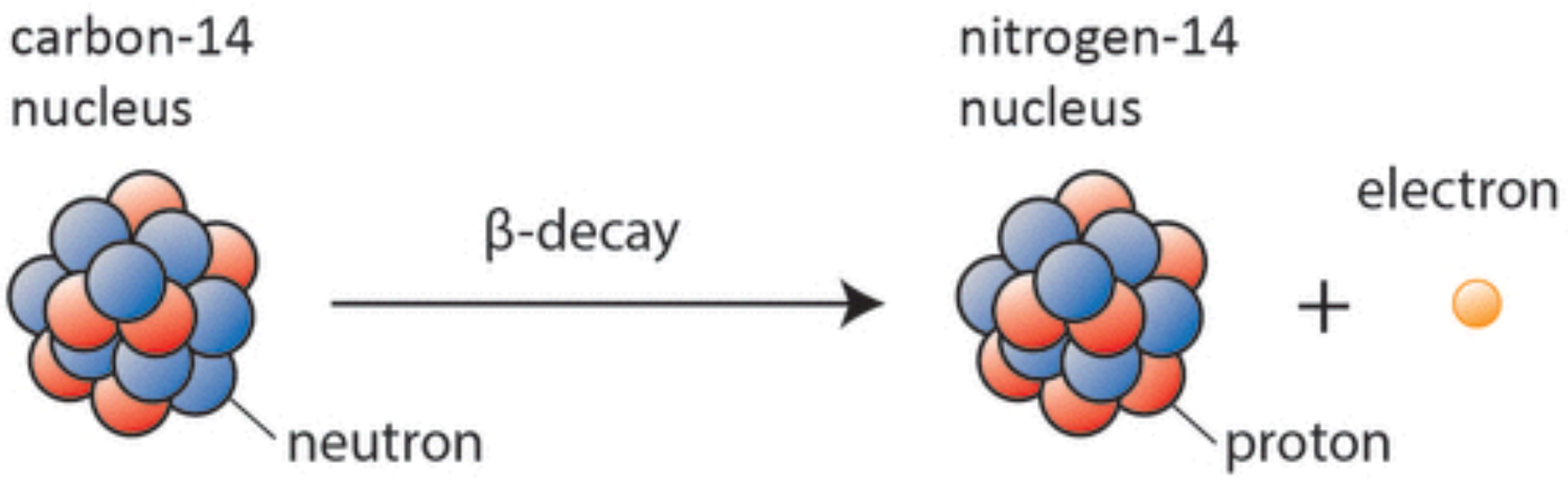
*Tessa, Koumoundouros

Beta-Decay Expectation



*D. Stewart, U of Warwick

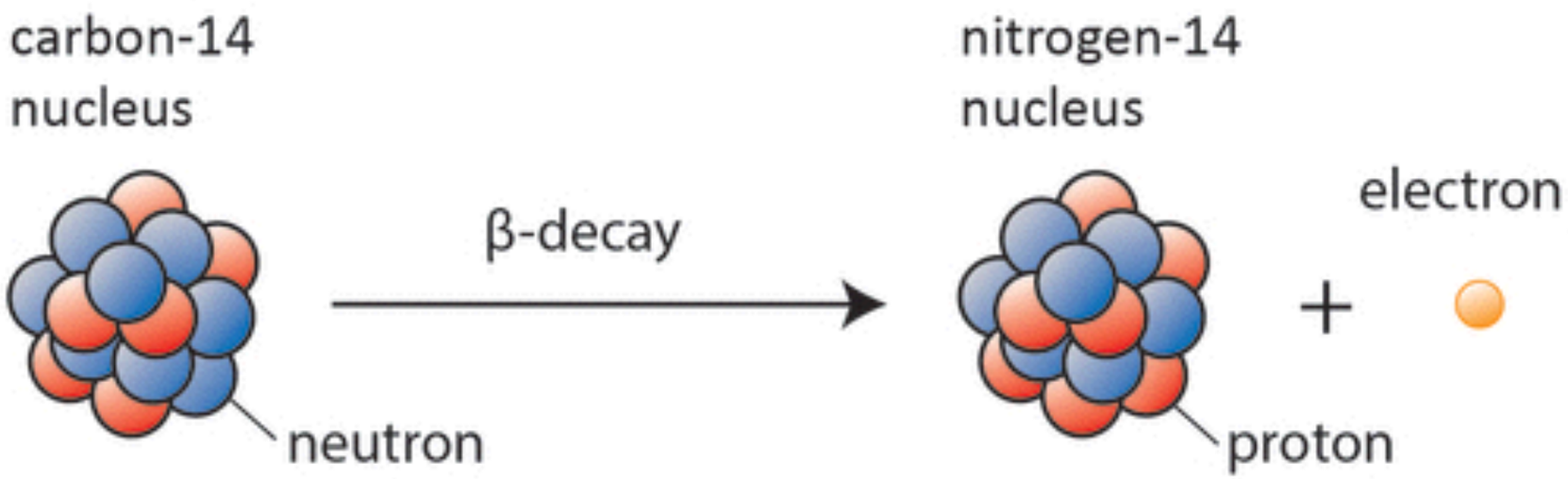
Explanations



*Tessa, Koumoundouros

Explanations

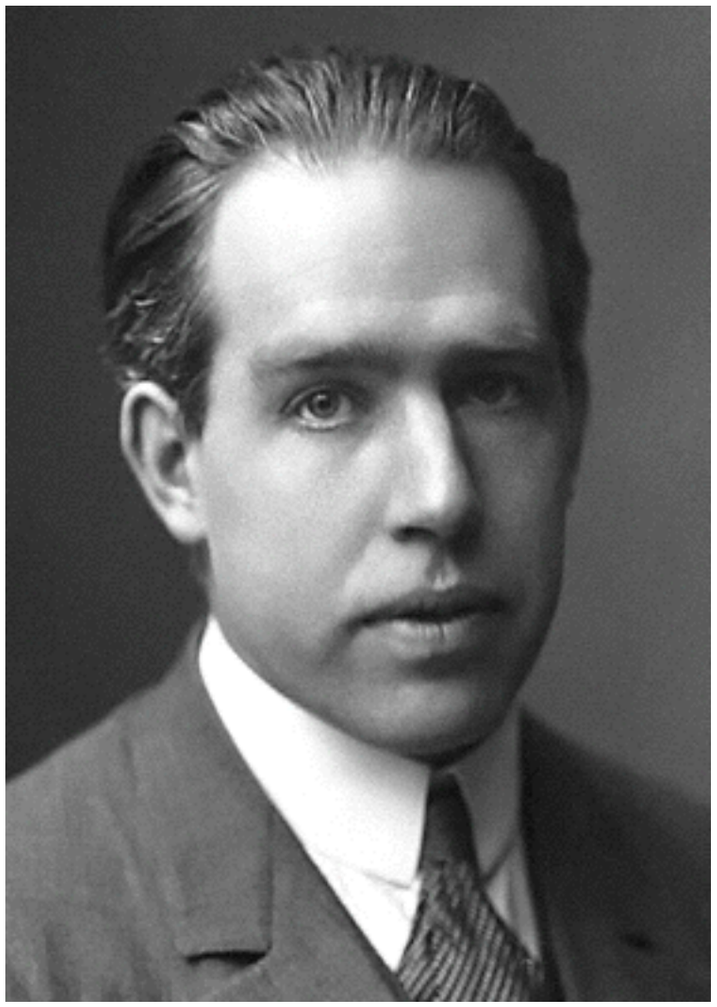
- No energy conservation within the nucleus

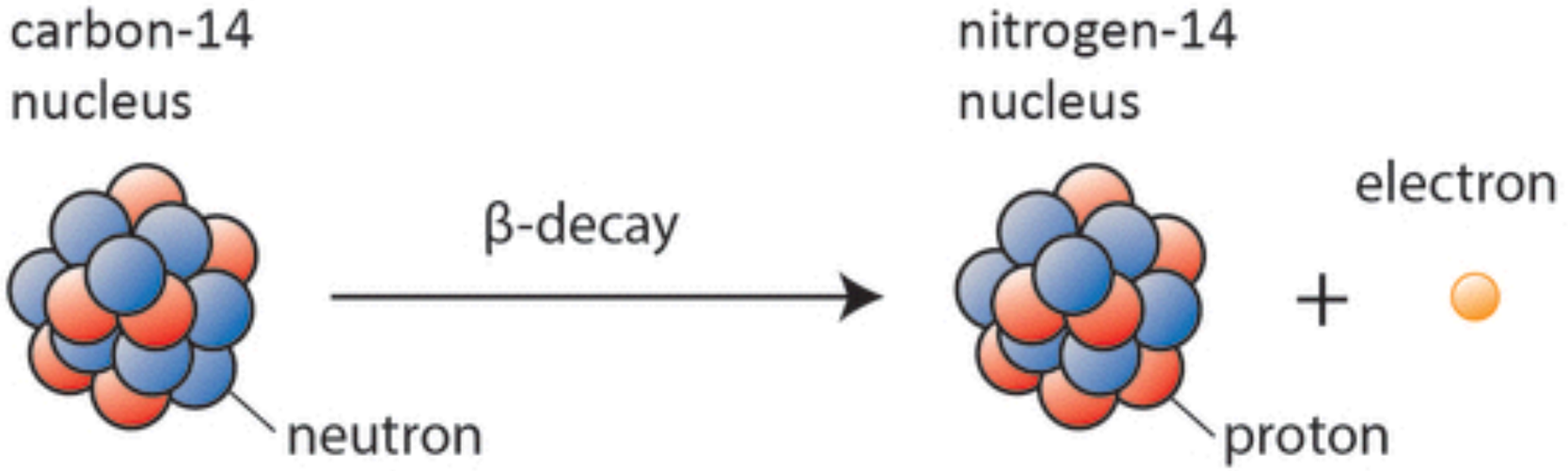


*Tessa, Koumoundouros

Explanations

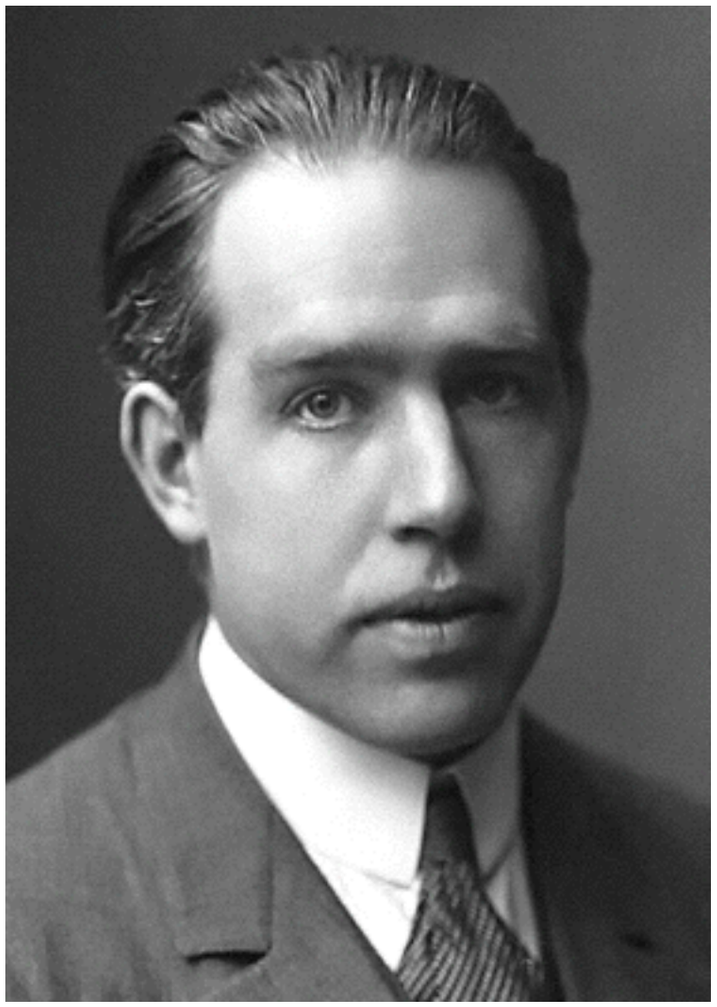
- No energy conservation within the nucleus



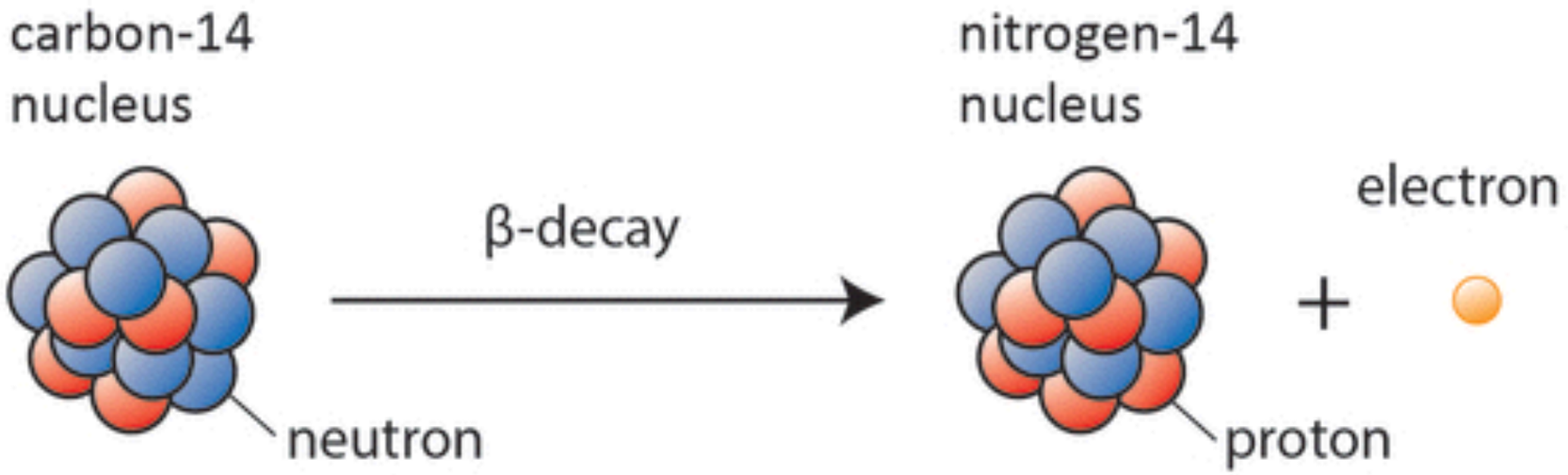


*Tessa, Koumoundouros

Explanations

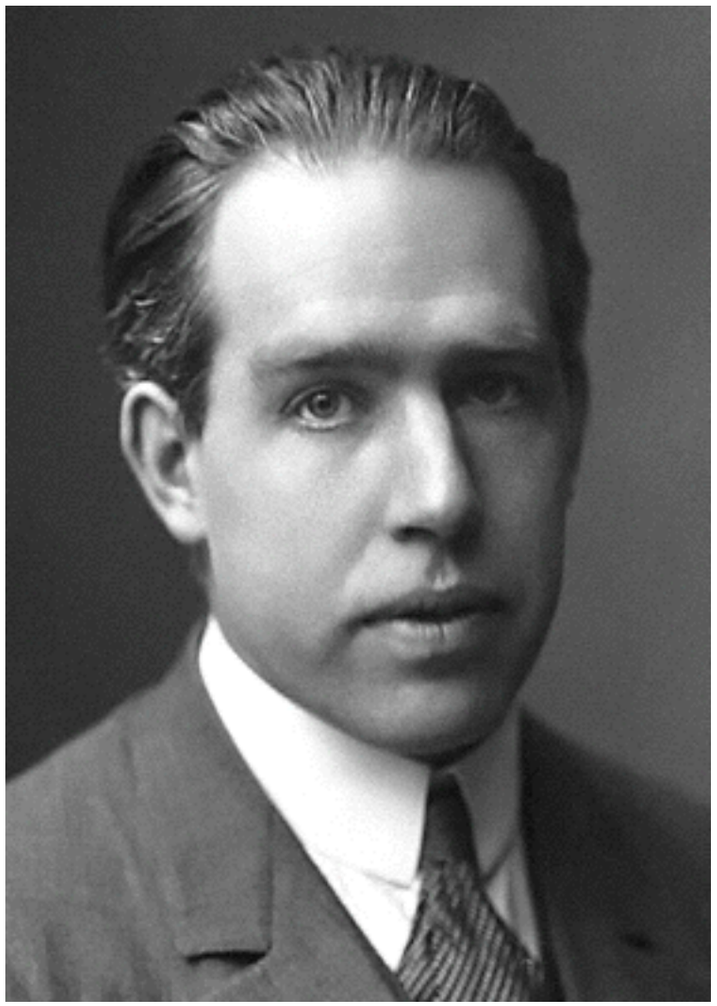


- No energy conservation within the nucleus
- 1930 Pauli comes postulates a neutral particle with almost zero mass and tiny cross-section

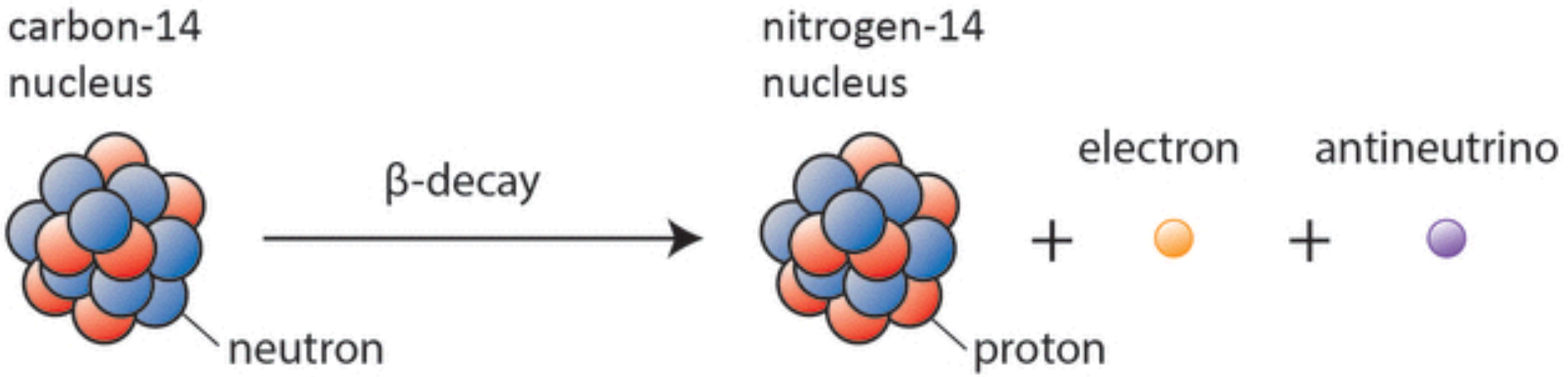


*Tessa, Koumoundouros

Explanations



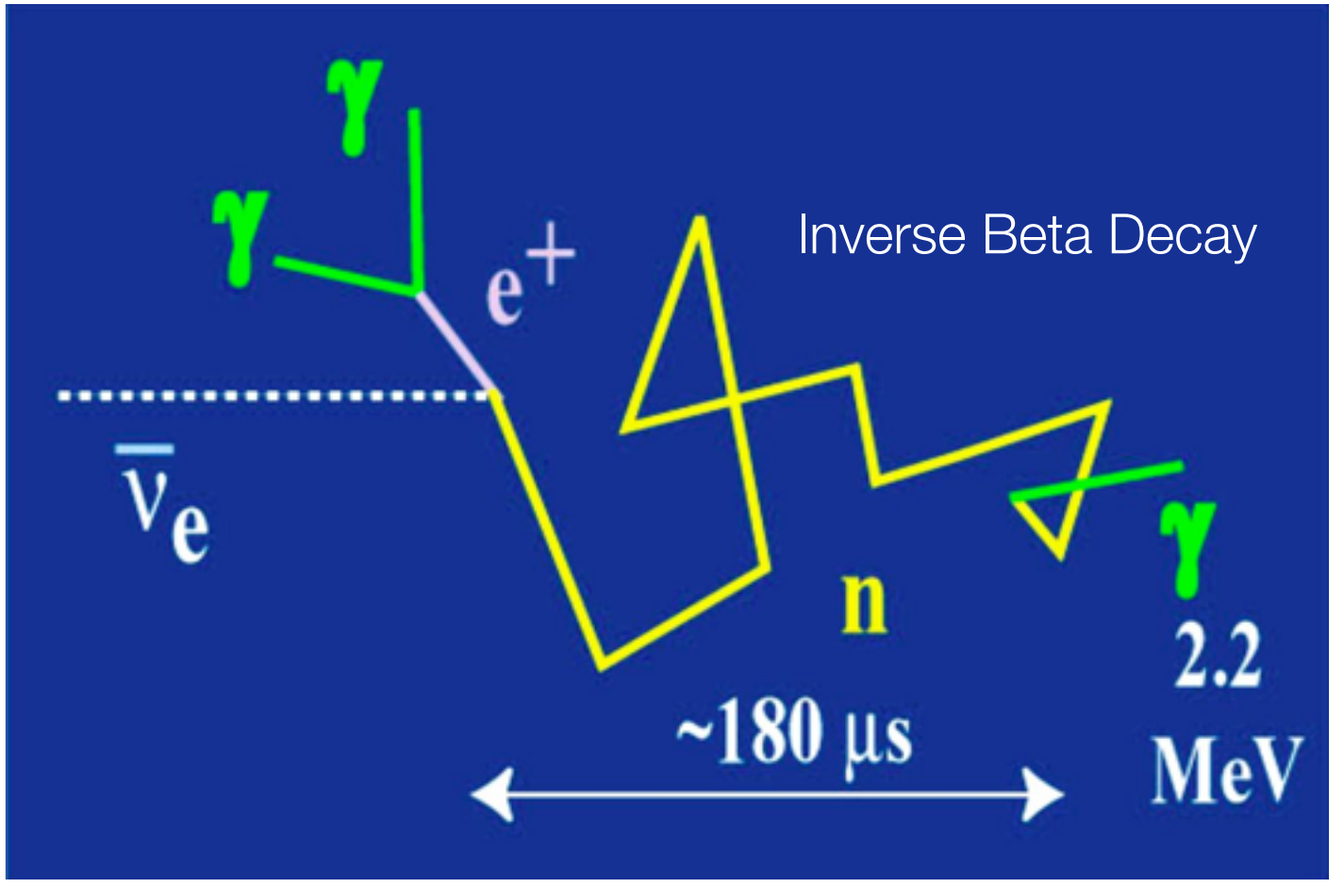
- No energy conservation within the nucleus
- 1930 Pauli comes postulates a neutral particle with almost zero mass and tiny cross-section



*Tessa, Koumoundouros

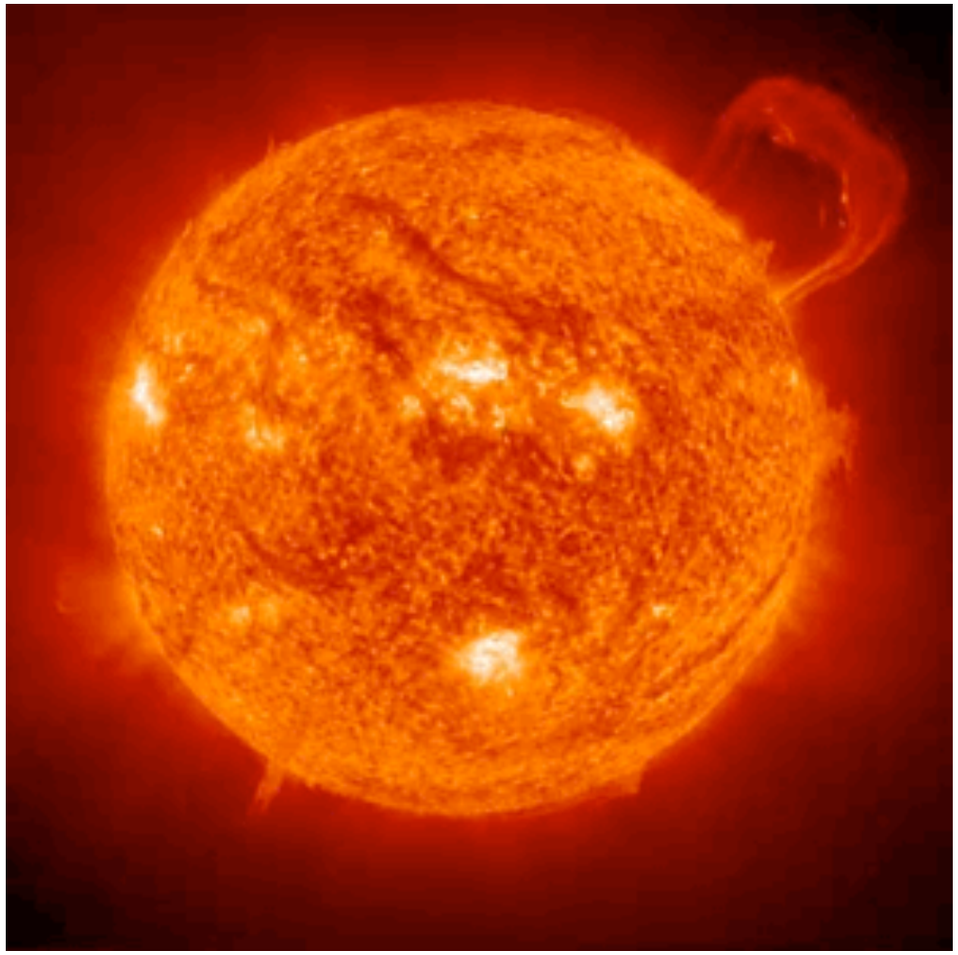
Direct Observation

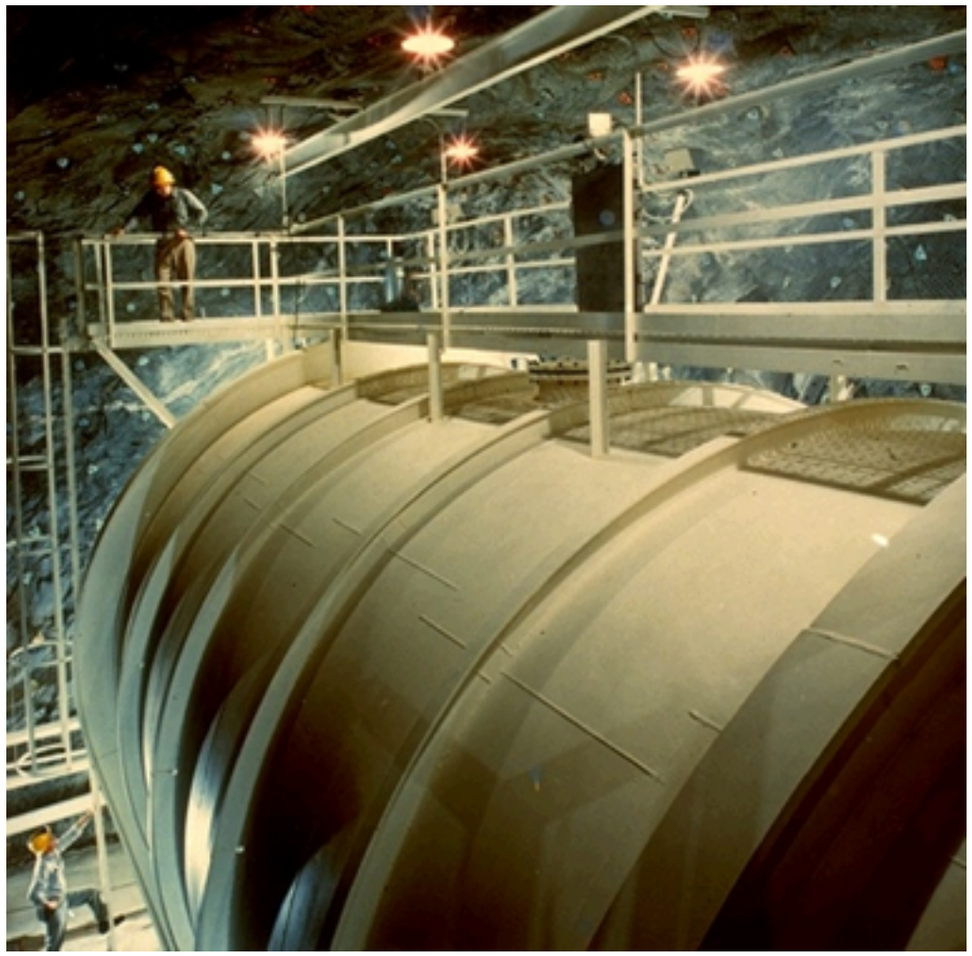
- Early 1950s Reines and Cowan look for neutrino using inverse beta-decay
- Set up detector next to nuclear reactors (Hanford first and then Savannah)



Biggest Reactor Nearby is the Sun

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

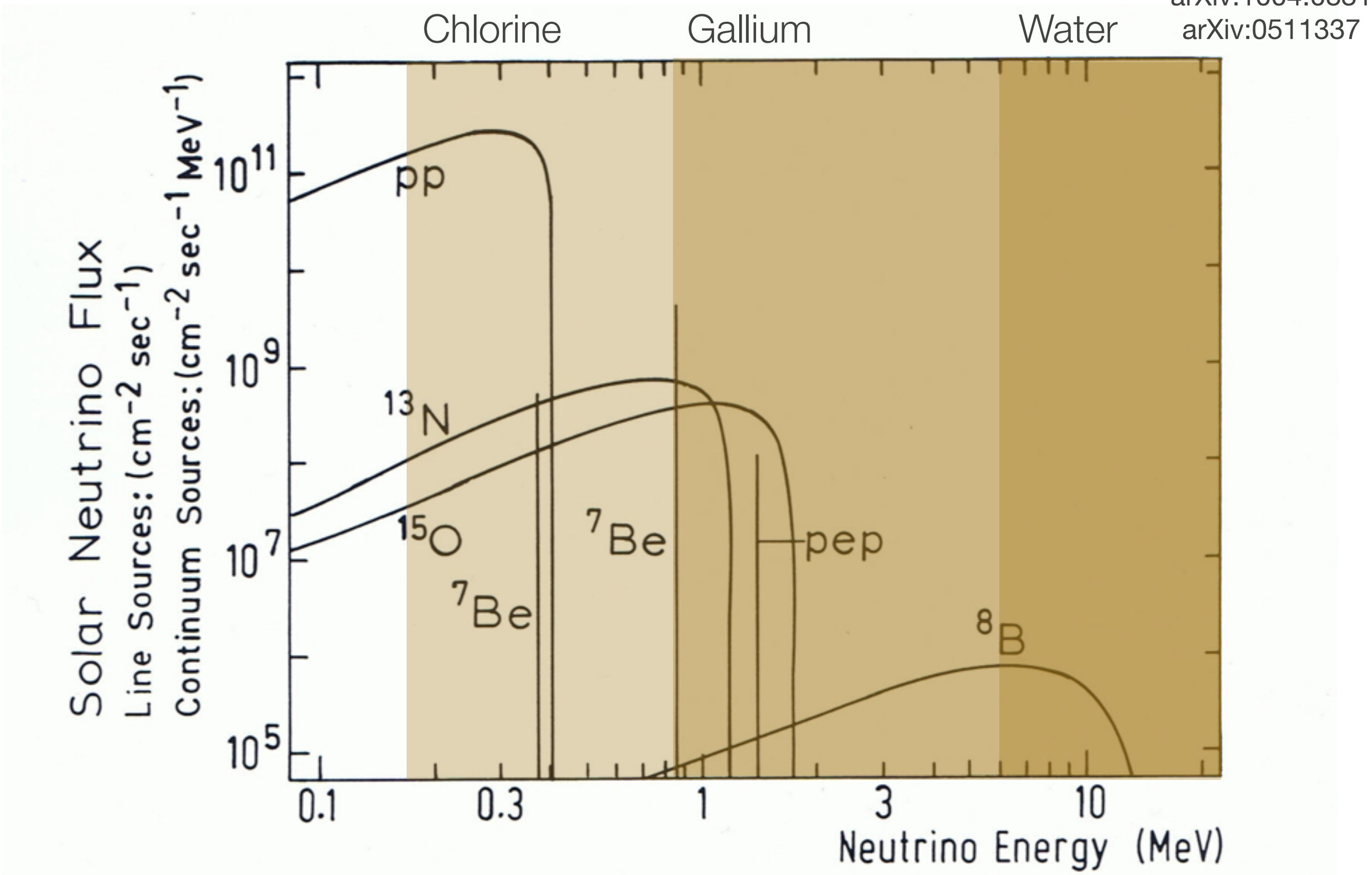




- 1968 Ray Davis and John Bahcall observe solar neutrinos using dry-cleaning fluid at the Homestake Mine

Solar Neutrinos

arXiv:1004.0831
arXiv:0511337

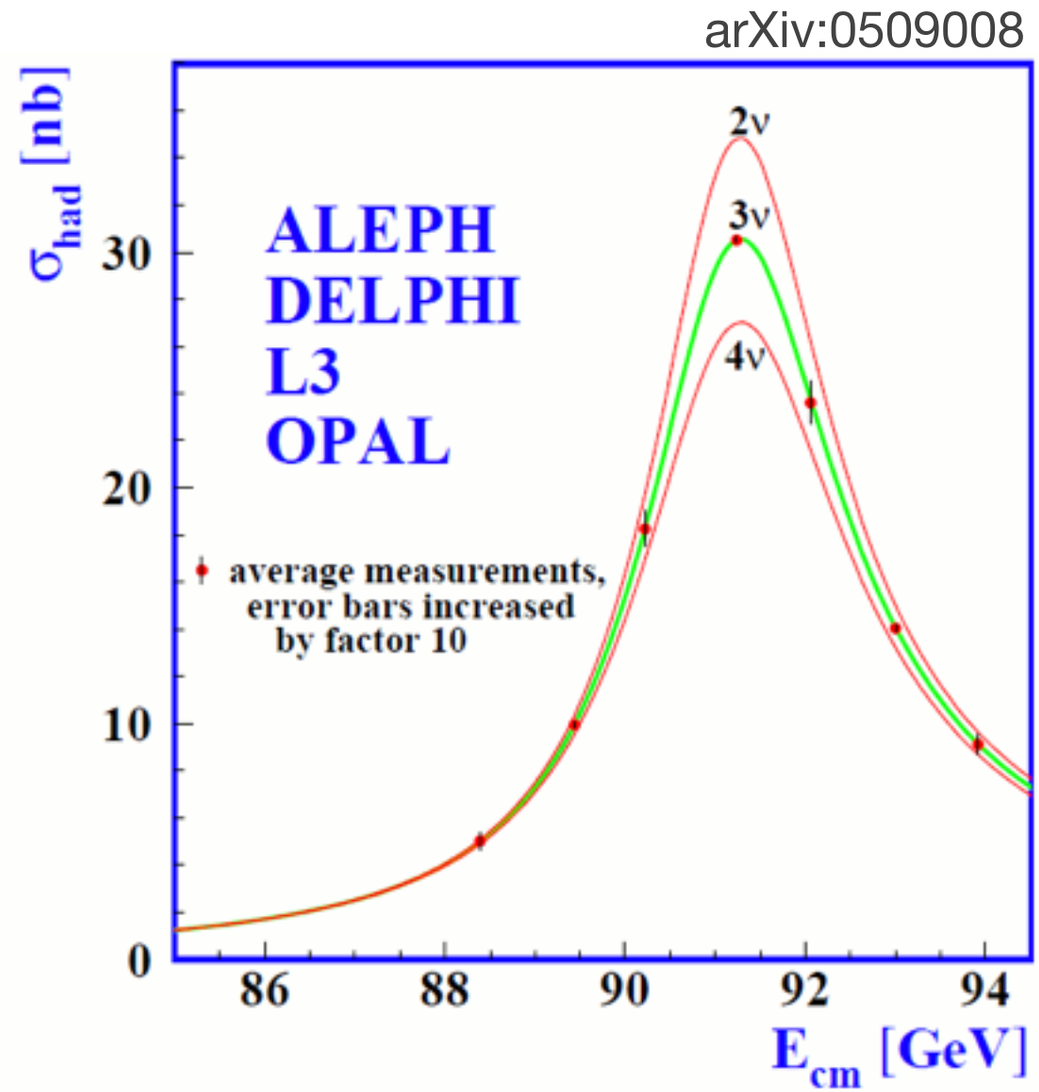


How Many Neutrinos?

- Nuclear/Solar experiments confirmed an electron-type neutrino and anti-neutrino
- A beam experiment in 1962 using pion decays (which do not decay to electrons, only muons) established the muon neutrino
- 1975 the tau lepton was discovered, which implied the existence of the tau neutrino
- More neutrinos?

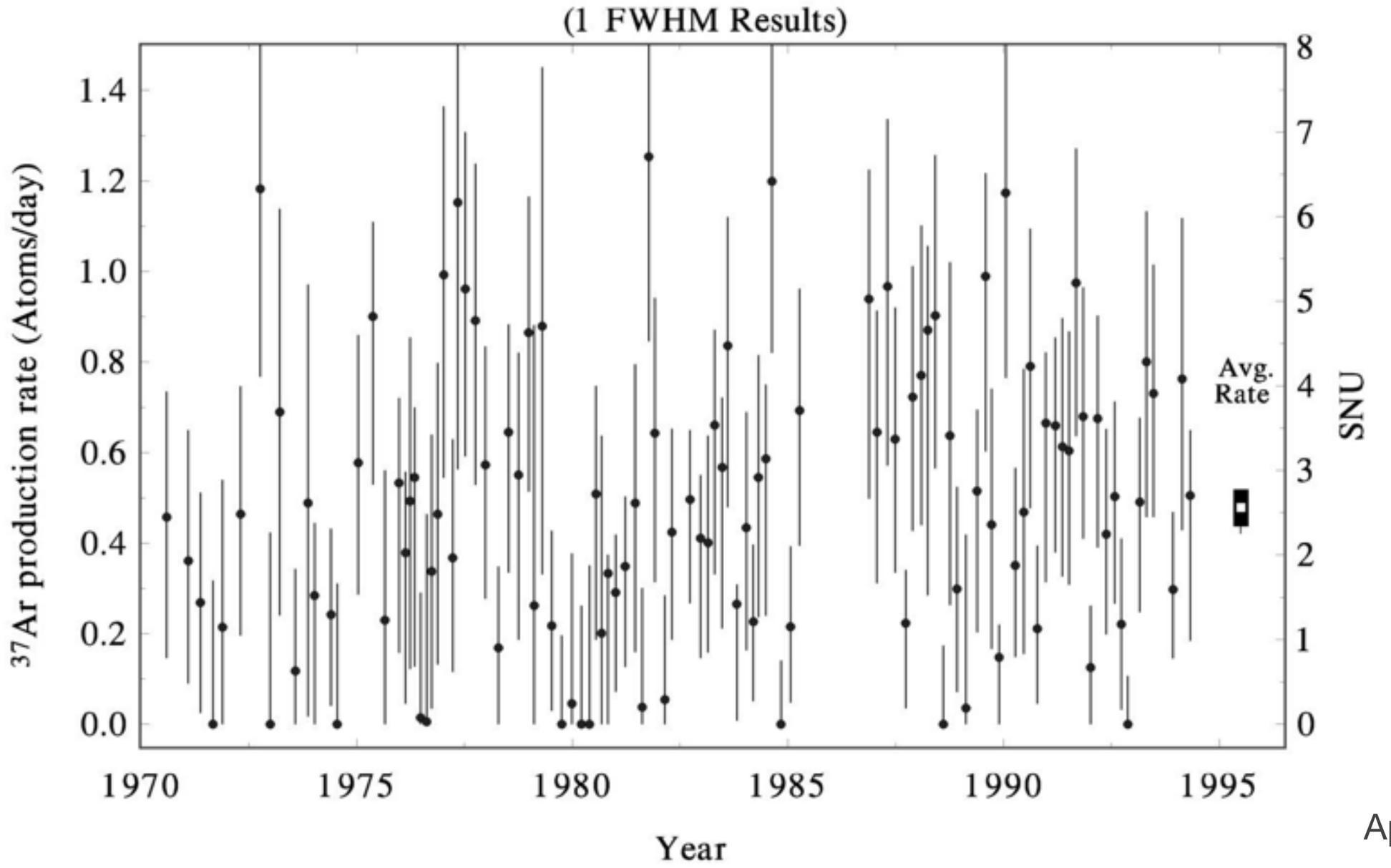
How Many Neutrinos?

- Instead of trying to detect ‘new’ neutrinos examine their impact
- Z^0 couples to elementary particles
- Z^0 decays to elementary particles regardless of charge
- Z^0 decay is strongly coupled to the number of ‘active’ neutrinos



Conundrum

- Solar model based on luminosity, composition, temperature, etc makes a prediction for solar neutrinos



ApJ 496:505

Solar Neutrino Problem - Solutions

Solar Neutrino Problem - Solutions

- Experiment is wrong

Solar Neutrino Problem - Solutions

- Experiment is wrong
  - Additional data was consistent

Solar Neutrino Problem - Solutions

- Experiment is wrong
  - Additional data was consistent
  - Separate experiments confirmed deficit

Solar Neutrino Problem - Solutions

- Experiment is wrong
  - Additional data was consistent
  - Separate experiments confirmed deficit
- Solar model is wrong

Solar Neutrino Problem - Solutions

- Experiment is wrong
  - Additional data was consistent
  - Separate experiments confirmed deficit
- Solar model is wrong
  - Improved modeling/theory (heat transfer, pressure, numerical modeling) made small refinements

Solar Neutrino Problem - Solutions

- Experiment is wrong
  - Additional data was consistent
  - Separate experiments confirmed deficit
- Solar model is wrong
  - Improved modeling/theory (heat transfer, pressure, numerical modeling) made small refinements
  - Better observations

Solar Neutrino Problem - Solutions

- Experiment is wrong
  - Additional data was consistent
  - Separate experiments confirmed deficit
- Solar model is wrong
  - Improved modeling/theory (heat transfer, pressure, numerical modeling) made small refinements
  - Better observations
- Neutrinos are wrong

Solar Neutrino Problem - Solutions

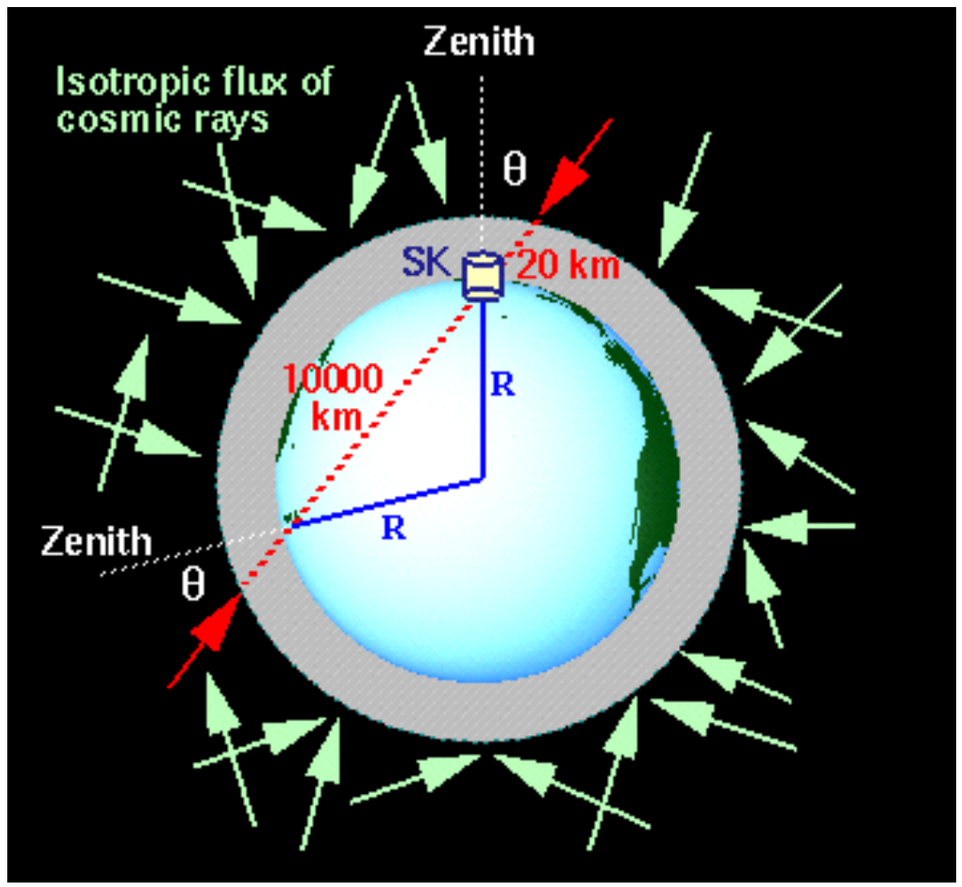
- Experiment is wrong
  - Additional data was consistent
  - Separate experiments confirmed deficit
- Solar model is wrong
  - Improved modeling/theory (heat transfer, pressure, numerical modeling) made small refinements
  - Better observations
- Neutrinos are wrong
  - Yup

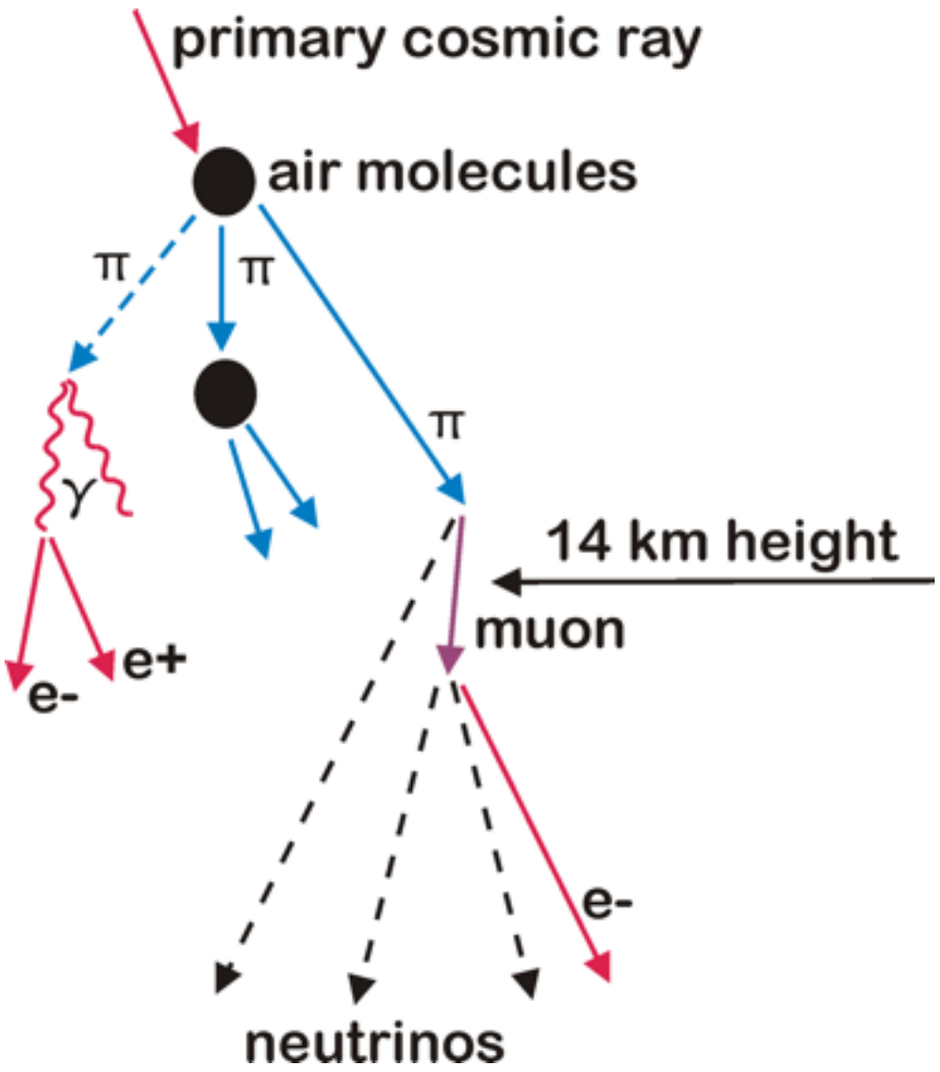
Solar Neutrino Problem - Solutions

- Experiment is wrong
  - Additional data was consistent
  - Separate experiments confirmed deficit
- Solar model is wrong
  - Improved modeling/theory (heat transfer, pressure, numerical modeling) made small refinements
  - Better observations
- Neutrinos are wrong
  - Yup
  - Had to wait for another problem

Further Conundrums

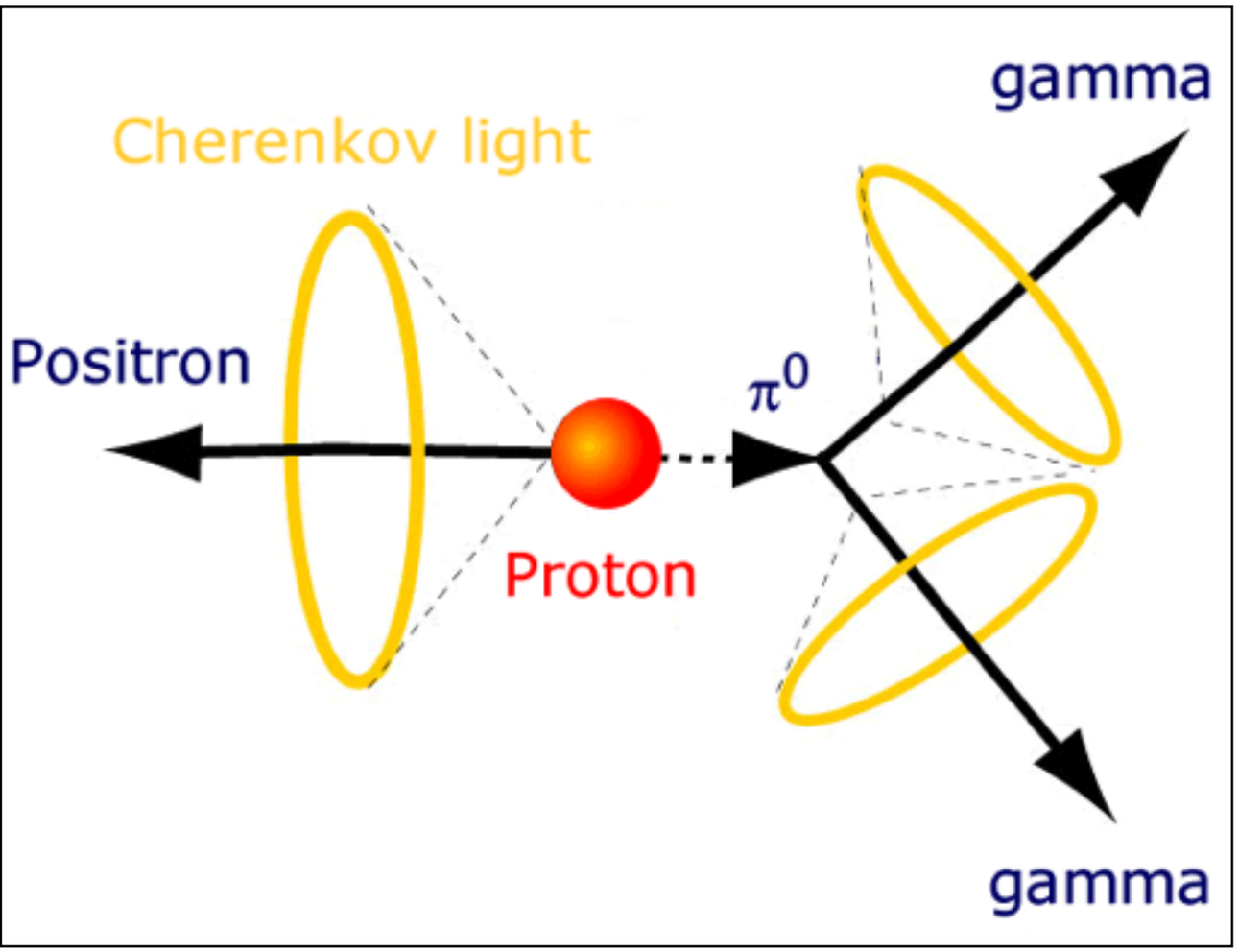
- Late 1980s and early 1990s had experiments looking for proton-decay and magnetic monopoles
- Background was neutrinos generated in the atmosphere





Proton Decay

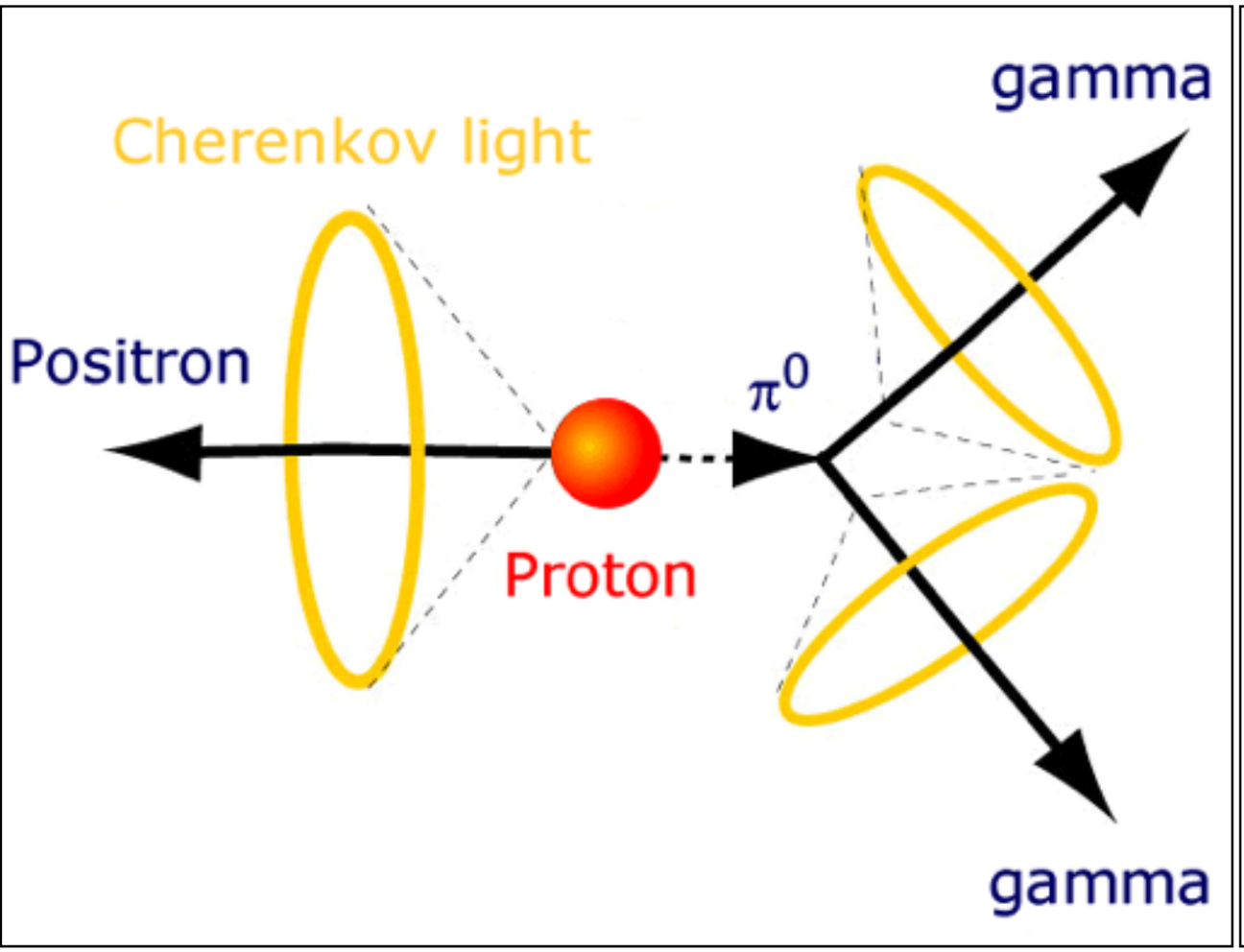
- Atmospheric neutrinos were/are a background
- While waiting around for a proton to decay, there was a lot of neutrino data

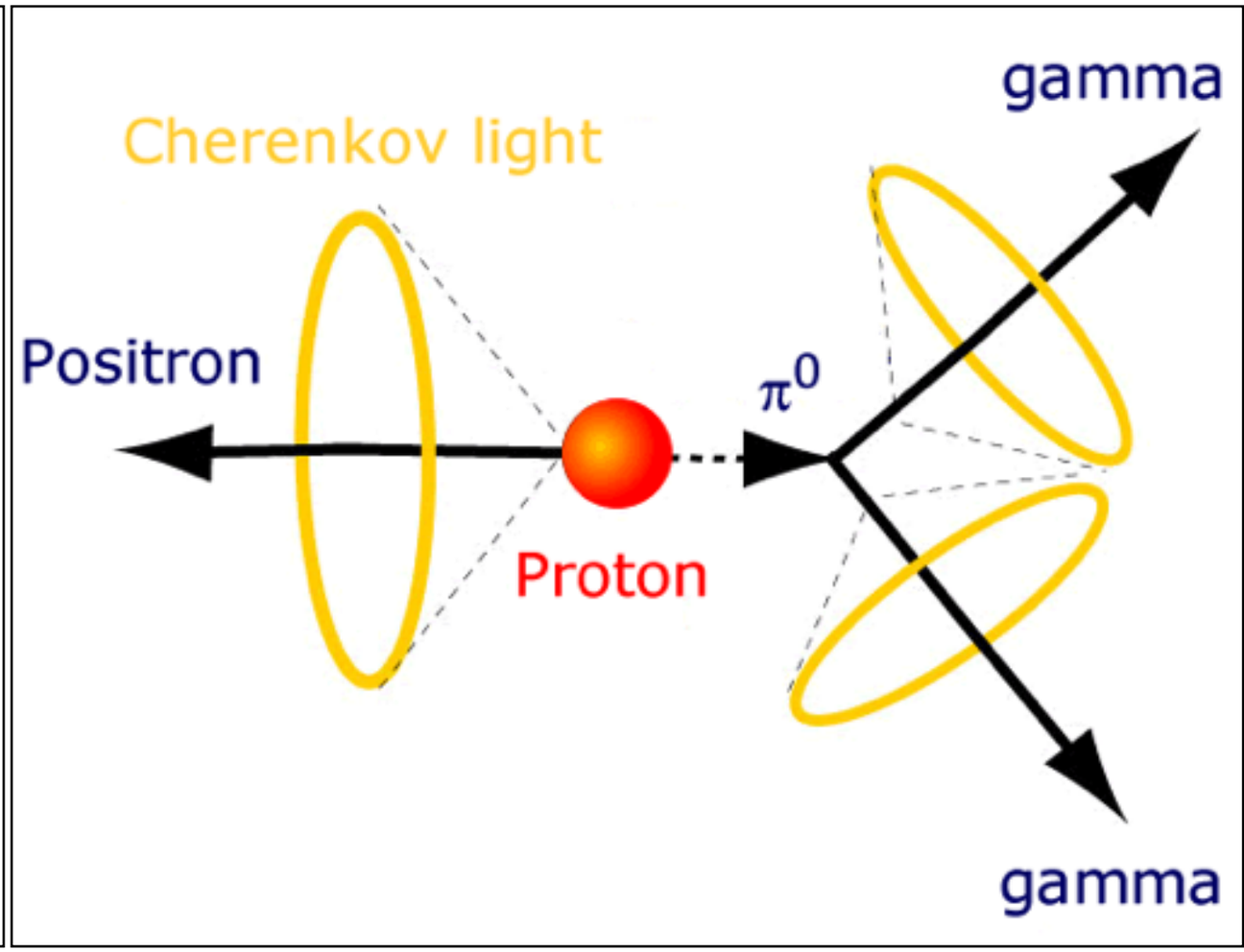


http://www-sk.icrr.u-tokyo.ac.jp/sk/physics/pdecay-e.html

Proton Decay

- Atmospheric neutrinos were/are a background
- While waiting around for a proton to decay, there was a lot of neutrino data

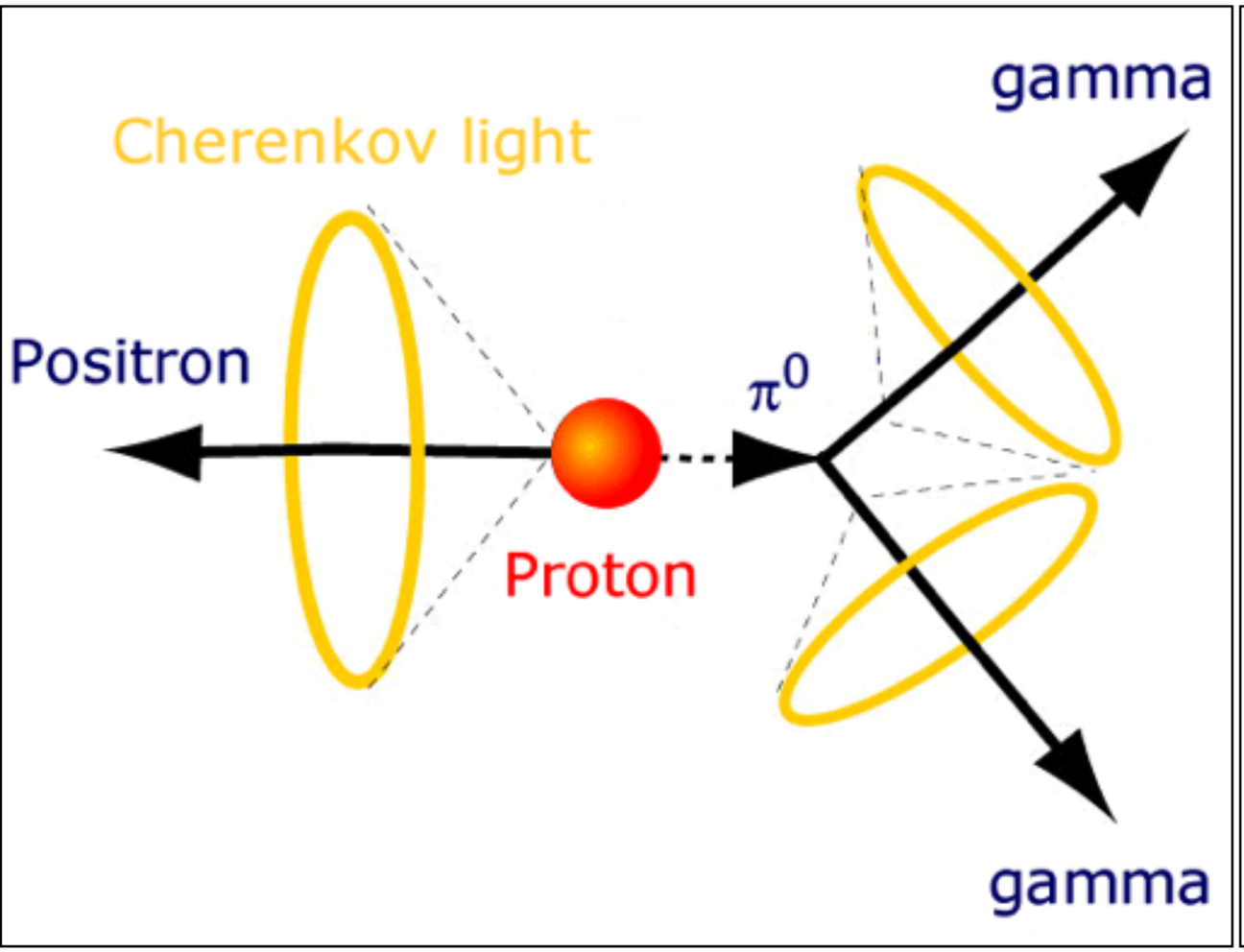


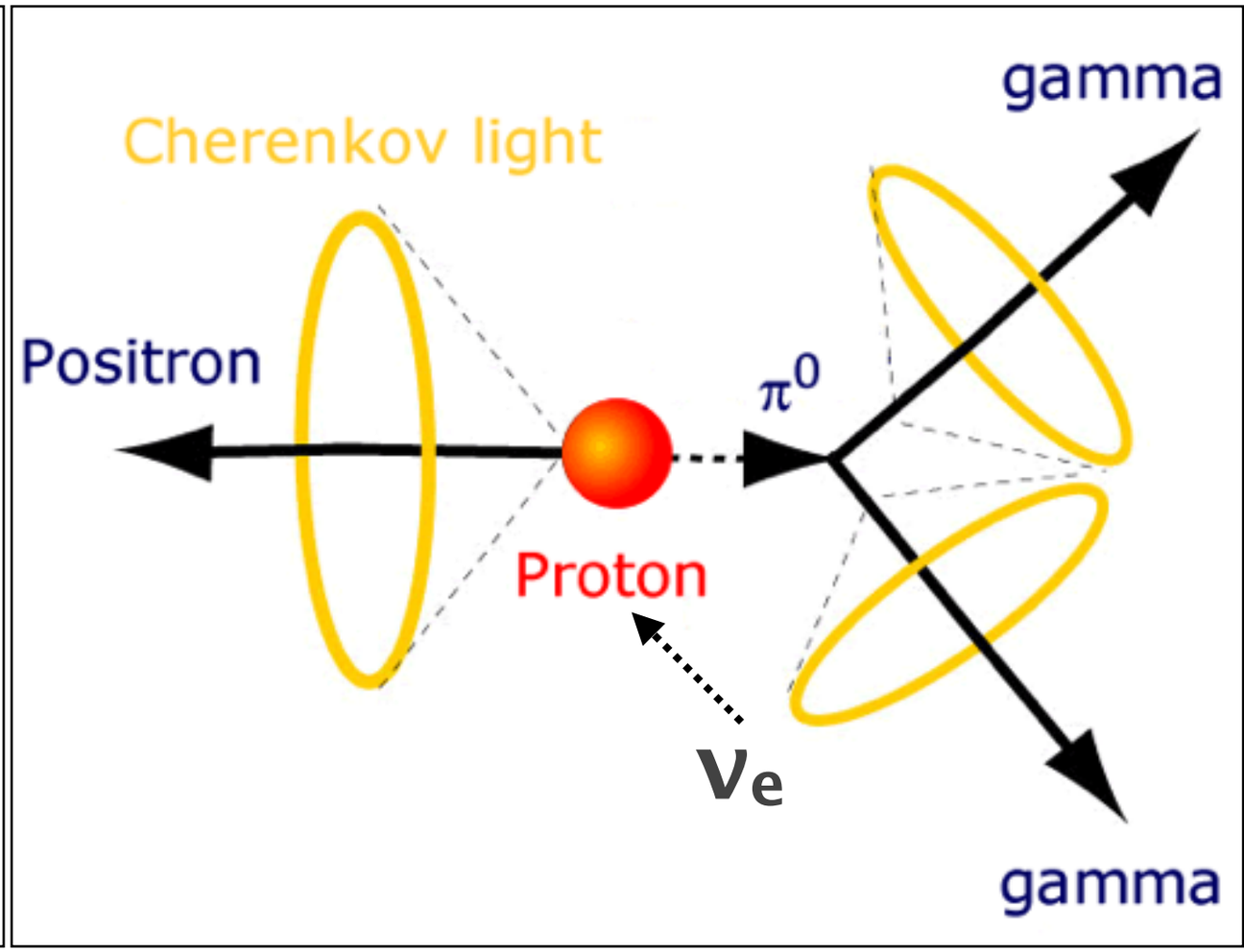


http://www-sk.icrr.u-tokyo.ac.jp/sk/physics/pdecay-e.html

Proton Decay

- Atmospheric neutrinos were/are a background
- While waiting around for a proton to decay, there was a lot of neutrino data

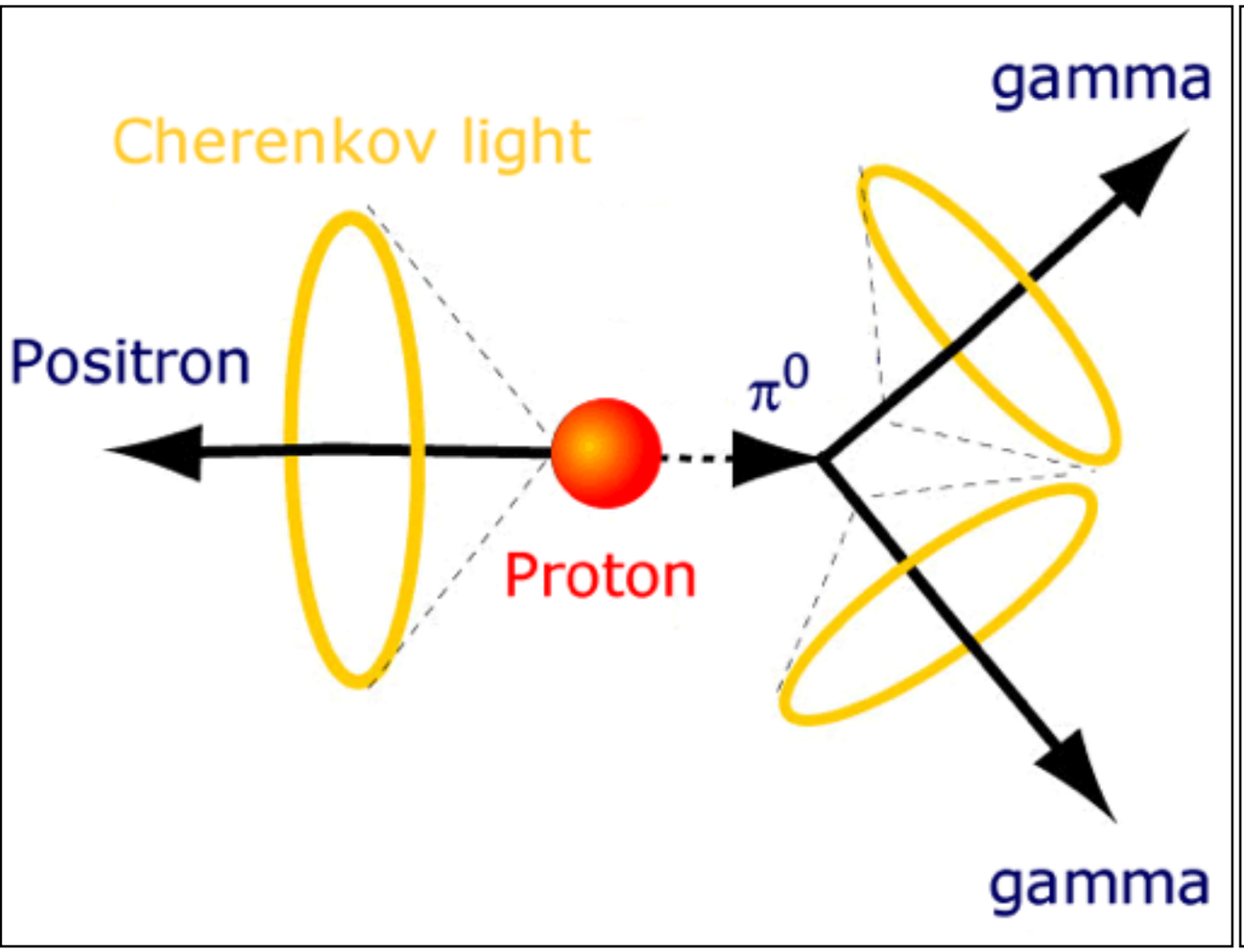


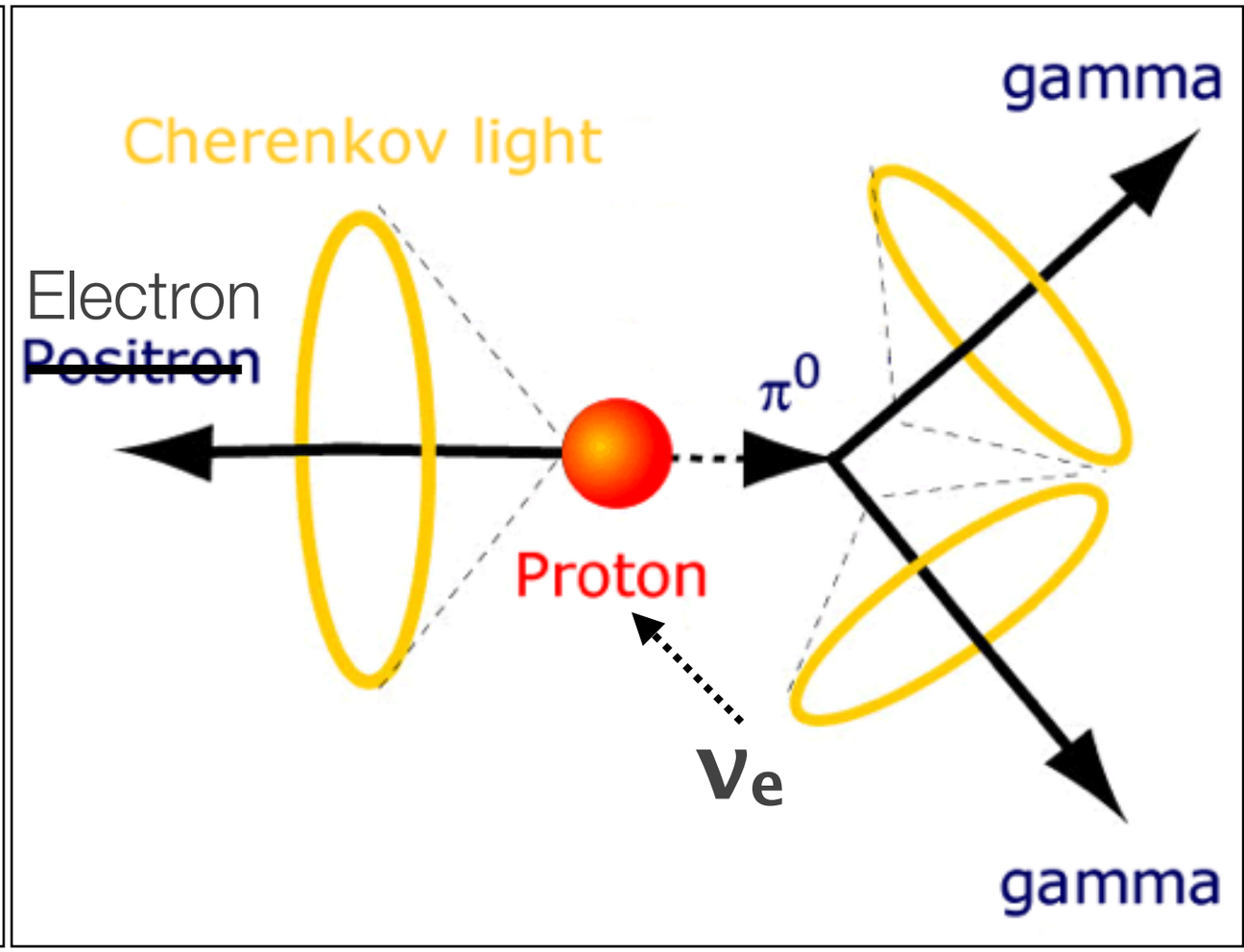


http://www-sk.icrr.u-tokyo.ac.jp/sk/physics/pdecay-e.html

Proton Decay

- Atmospheric neutrinos were/are a background
- While waiting around for a proton to decay, there was a lot of neutrino data



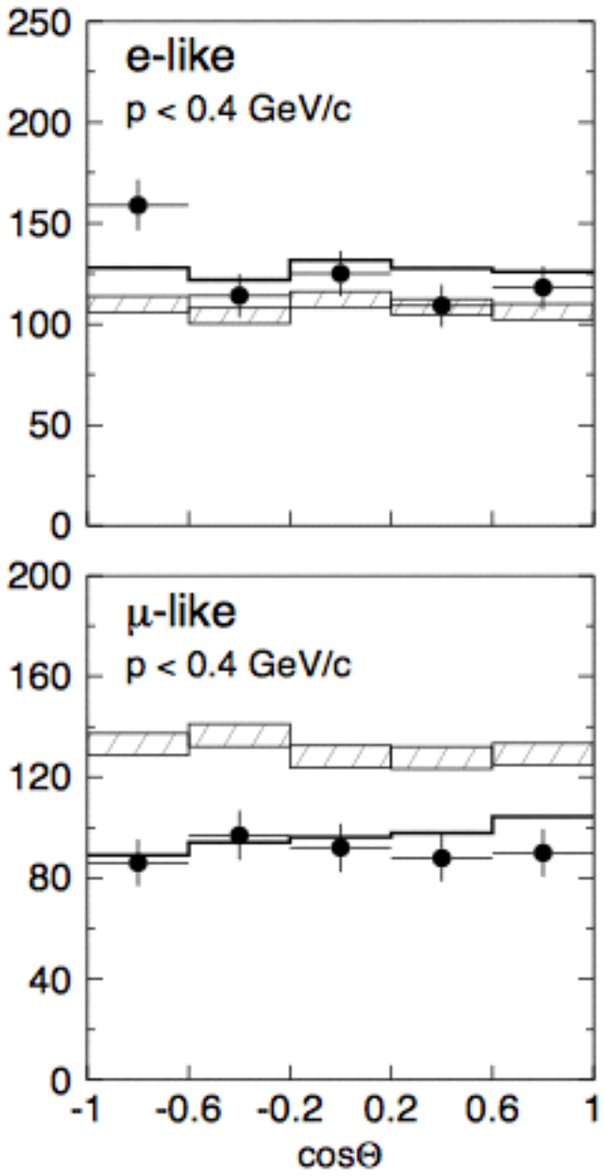


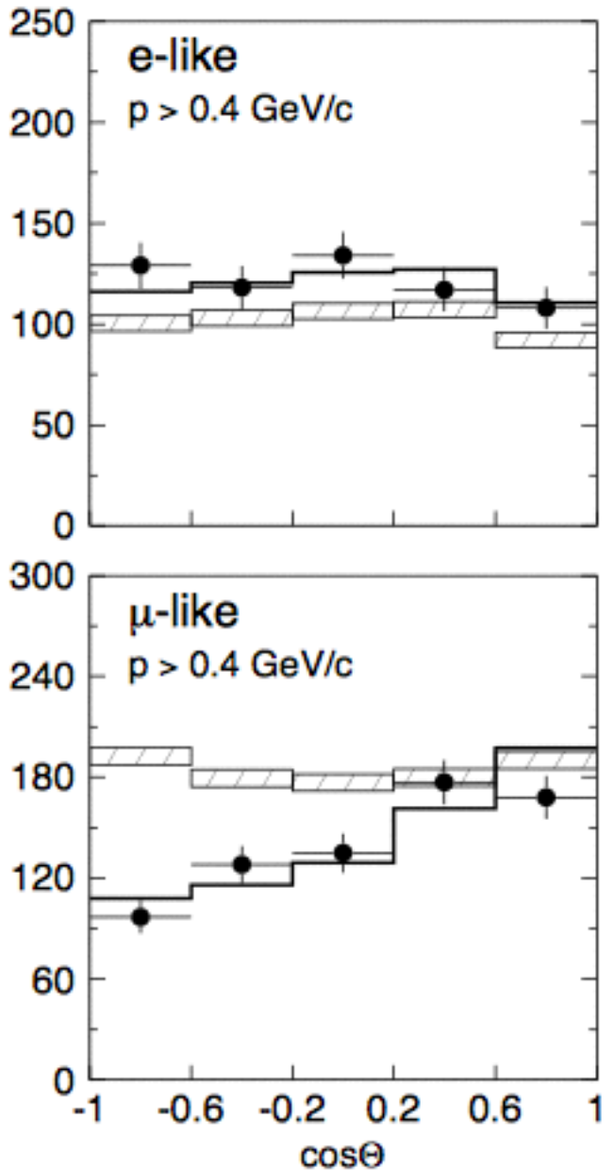
http://www-sk.icrr.u-tokyo.ac.jp/sk/physics/pdecay-e.html

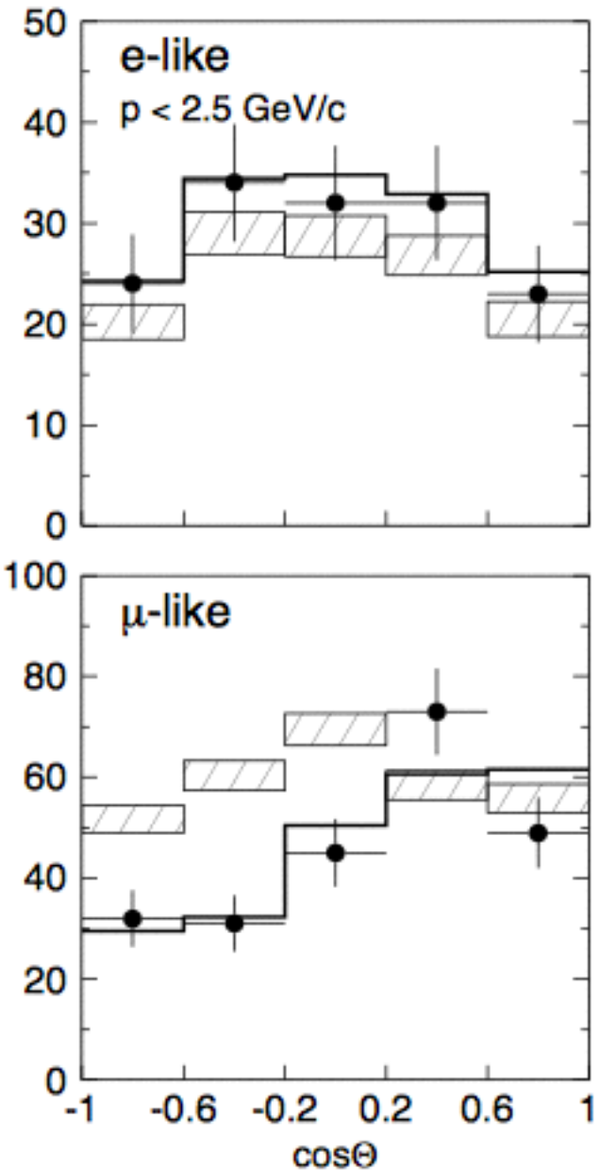
sub-GeV

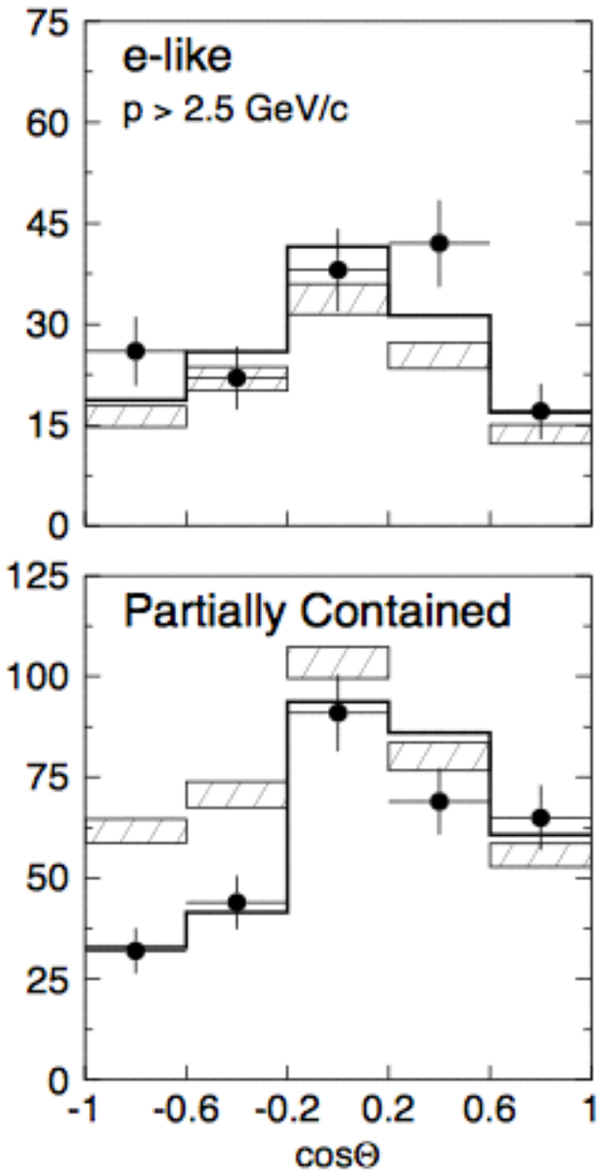
multi-GeV

arXiv:9807003







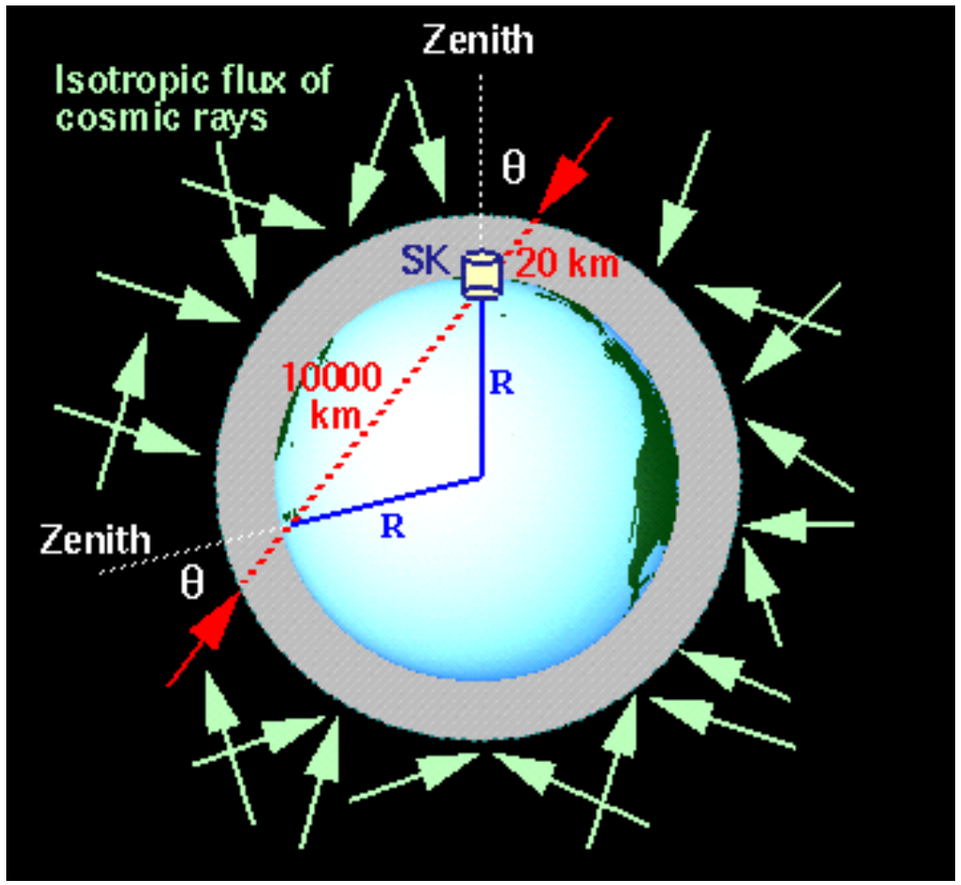


Super-K

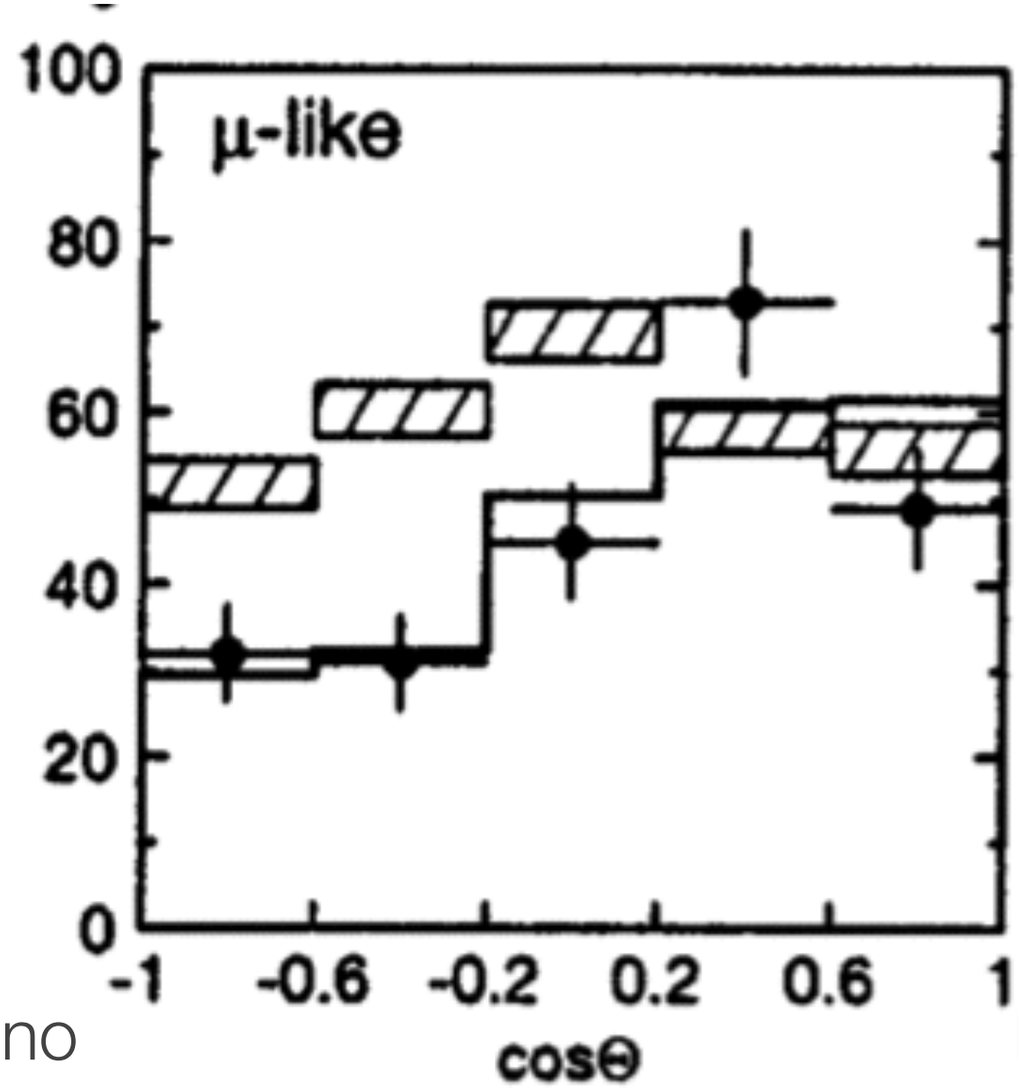
A. Gursky

Super-K

- Neutrinos going down match prediction
- Neutrinos going up do not match prediction



Neutrino going up



Neutrino going down

Neutrino Deficit

Neutrino Deficit

- Seen in solar and atmospheric neutrinos

Neutrino Deficit

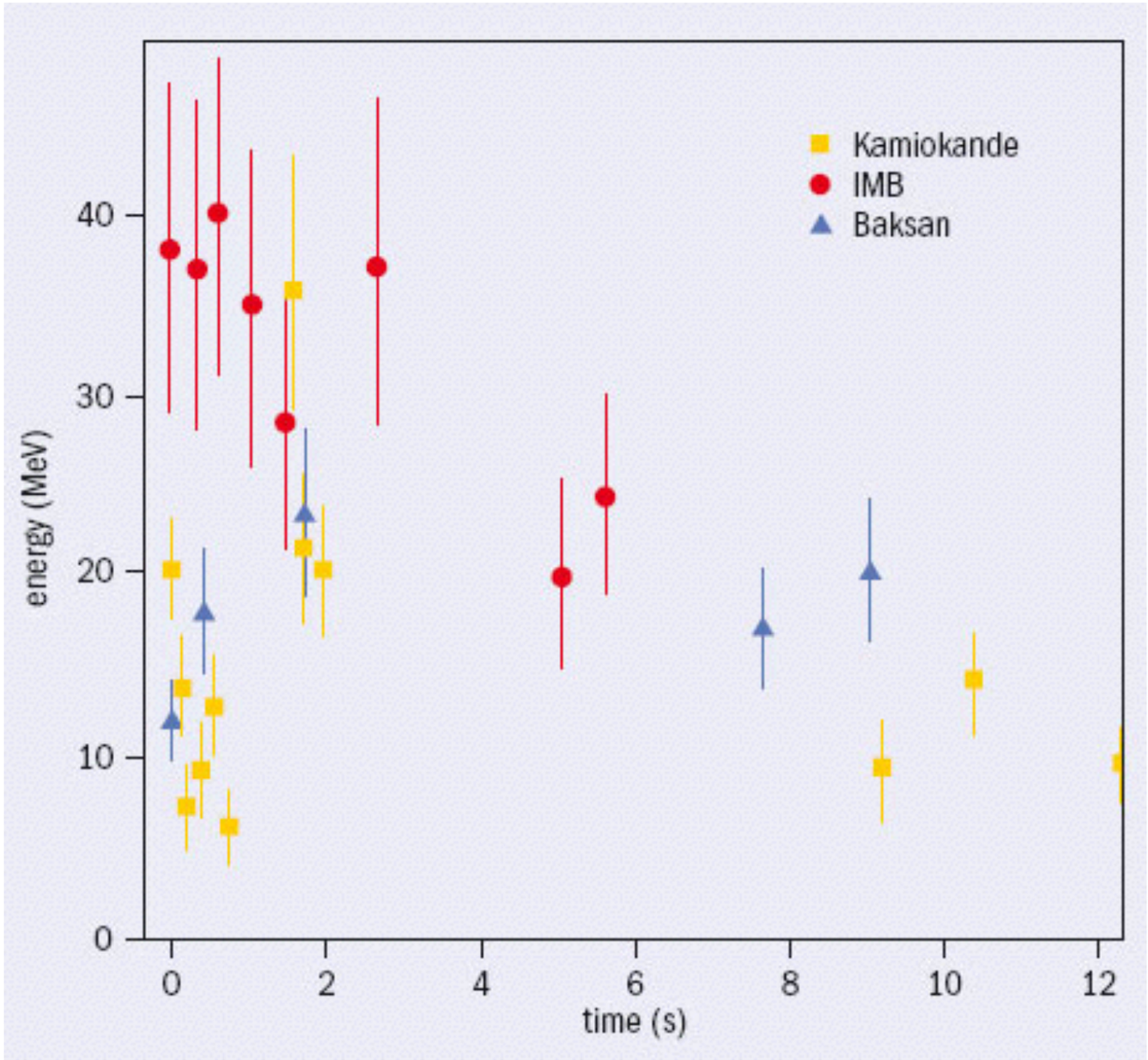
- Seen in solar and atmospheric neutrinos
- Can be explained by neutrino oscillation

Neutrino Deficit

- Seen in solar and atmospheric neutrinos
- Can be explained by neutrino oscillation
- No observation of proton-decay or magnetic monopoles

1987A

- Supernova explosion in Large Magellanic Cloud ~52 kiloparsecs (kpc) away



CERN Courier, Jan 2007

Neutrino Astronomy

Neutrino Astronomy

- Supernova explosions near enough to detect neutrinos ‘should’ have a rate of 3/century

Neutrino Astronomy

- Supernova explosions near enough to detect neutrinos ‘should’ have a rate of 3/century
- In 2014, we’re still waiting for another nearby supernova

Neutrino Astronomy

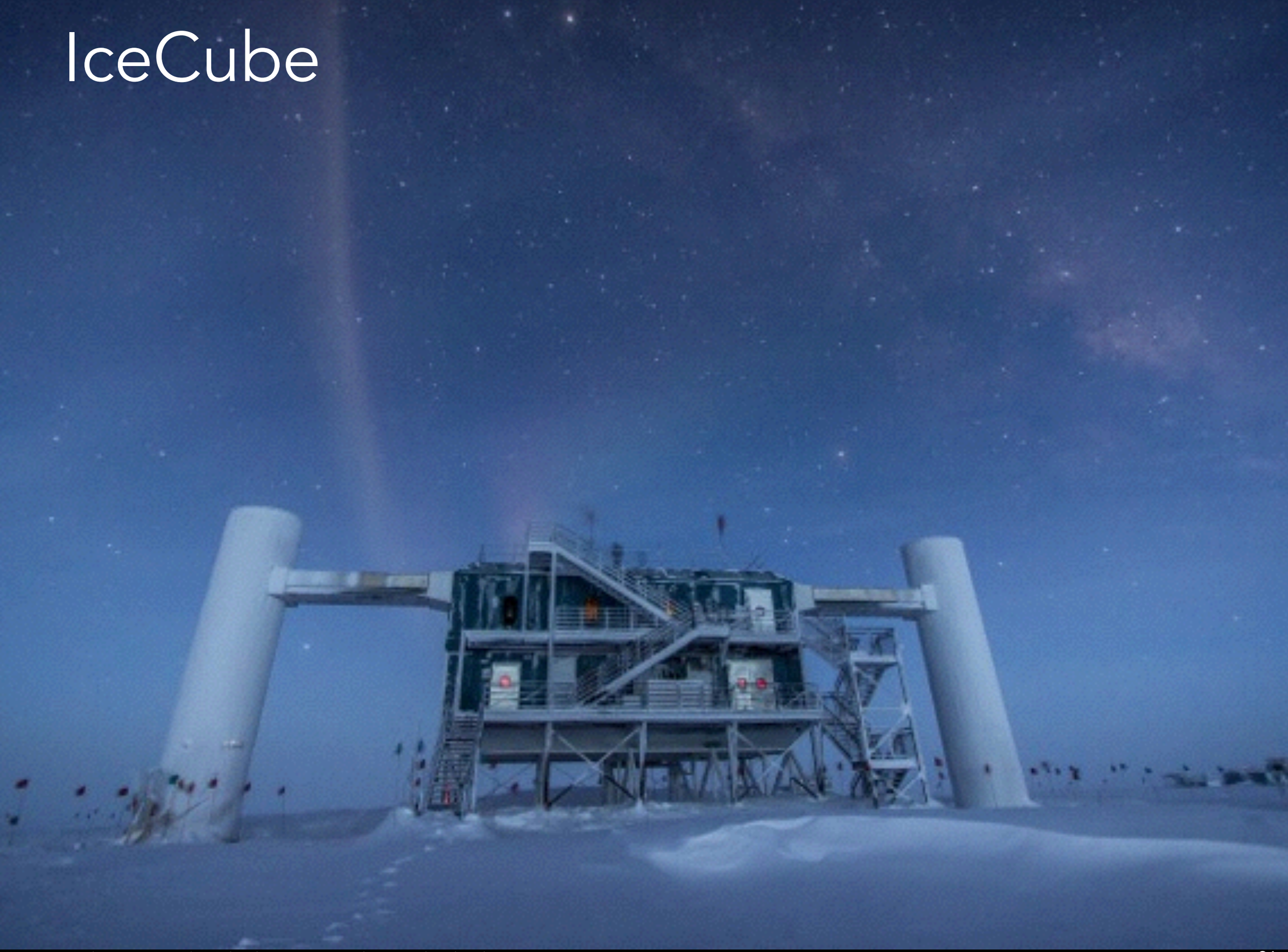
- Supernova explosions near enough to detect neutrinos ‘should’ have a rate of 3/century
- In 2014, we’re still waiting for another nearby supernova

CERN COURIER

Jan 30, 2007

SN1987A heralds the start of neutrino astronomy

IceCube

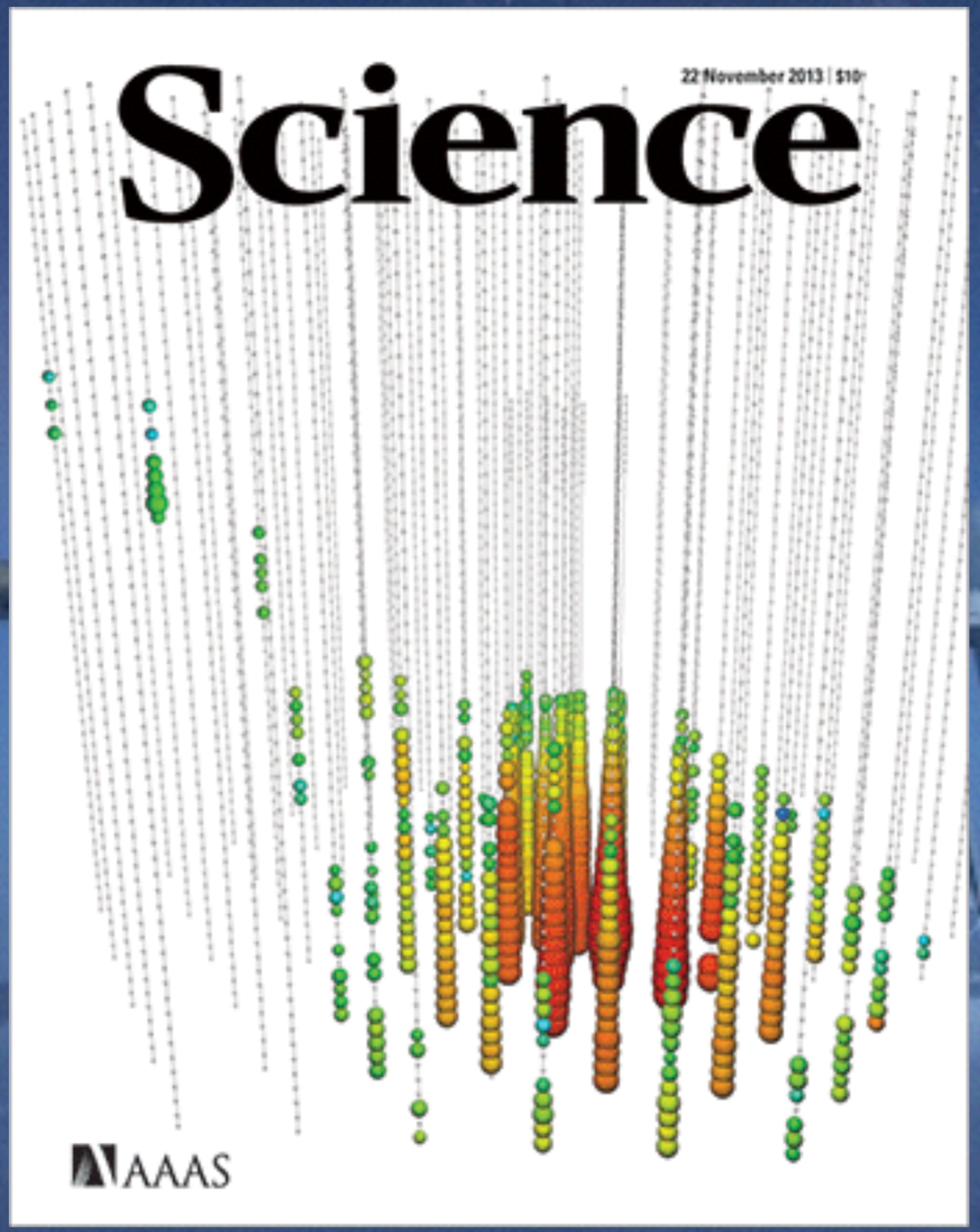


IceCube

- 1 km^3 detector for high energy neutrinos at the South Pole

IceCube

- 1 km^3 detector for high energy neutrinos at the South Pole
- Found evidence for cosmic neutrinos at very high energies



Break