III. Physikalisches Institut

RWTH AACHEN UNIVERSITY

IceCube
South Pole Neutrino Observatory

Vom Stift zum Südpol

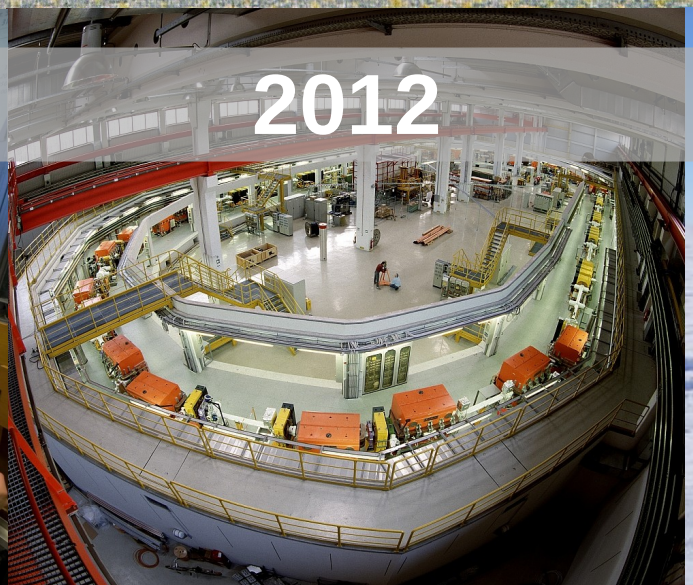
Erfahrungen als Astroteilchenphysiker

Martin Rongen
23.01.2019, Düren

2009

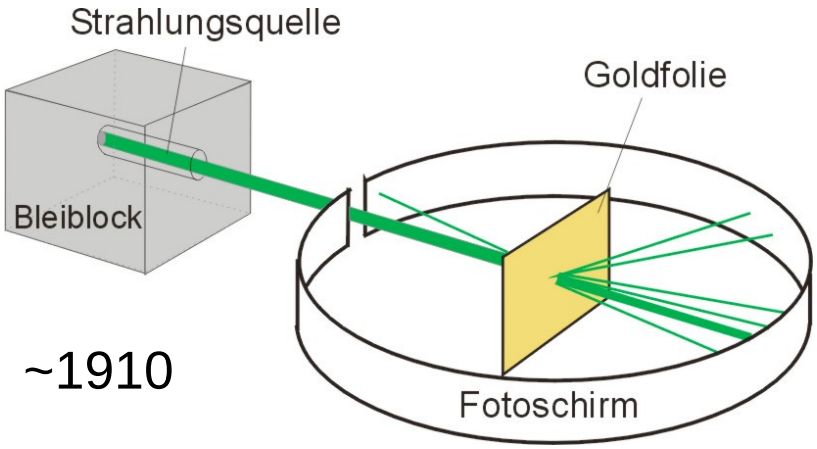
2009-12

2012

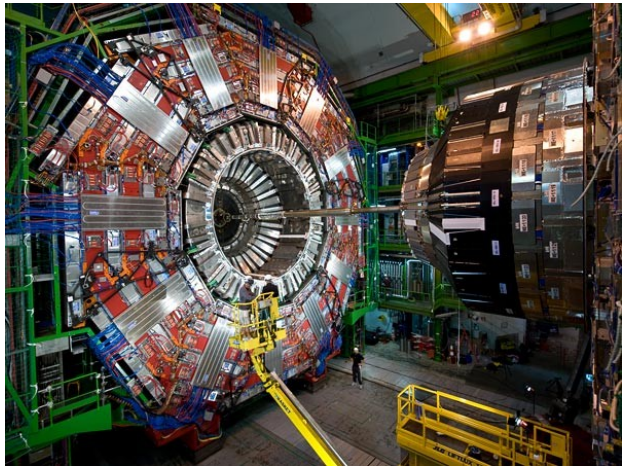


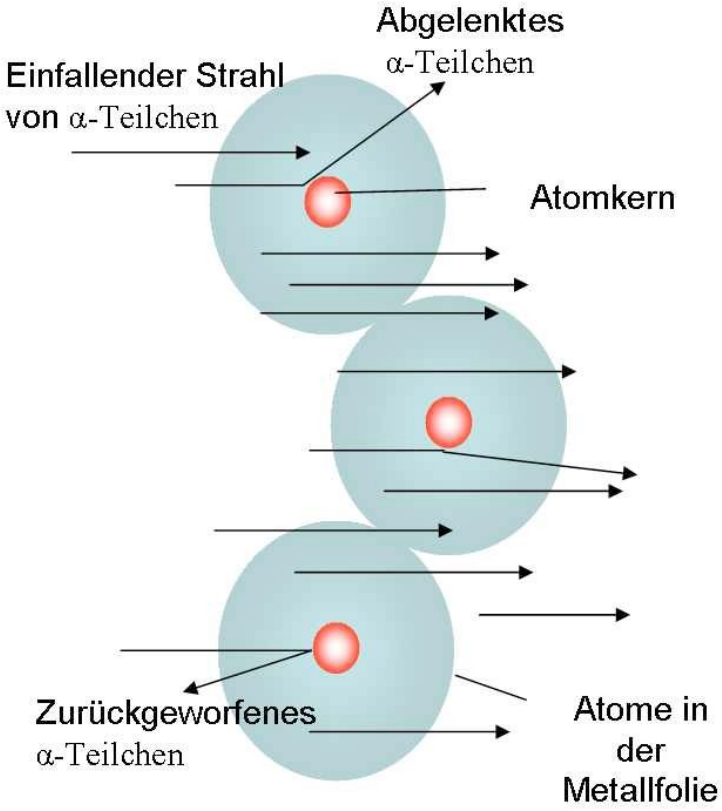
seit 2014

Streuexperimente

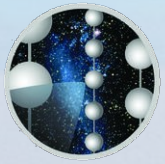


~1910





Ablenkung und Rückstoß von
α-Teilchen durch die Atomkerne einer
Metallfolie im Rutherford'schen Experiment



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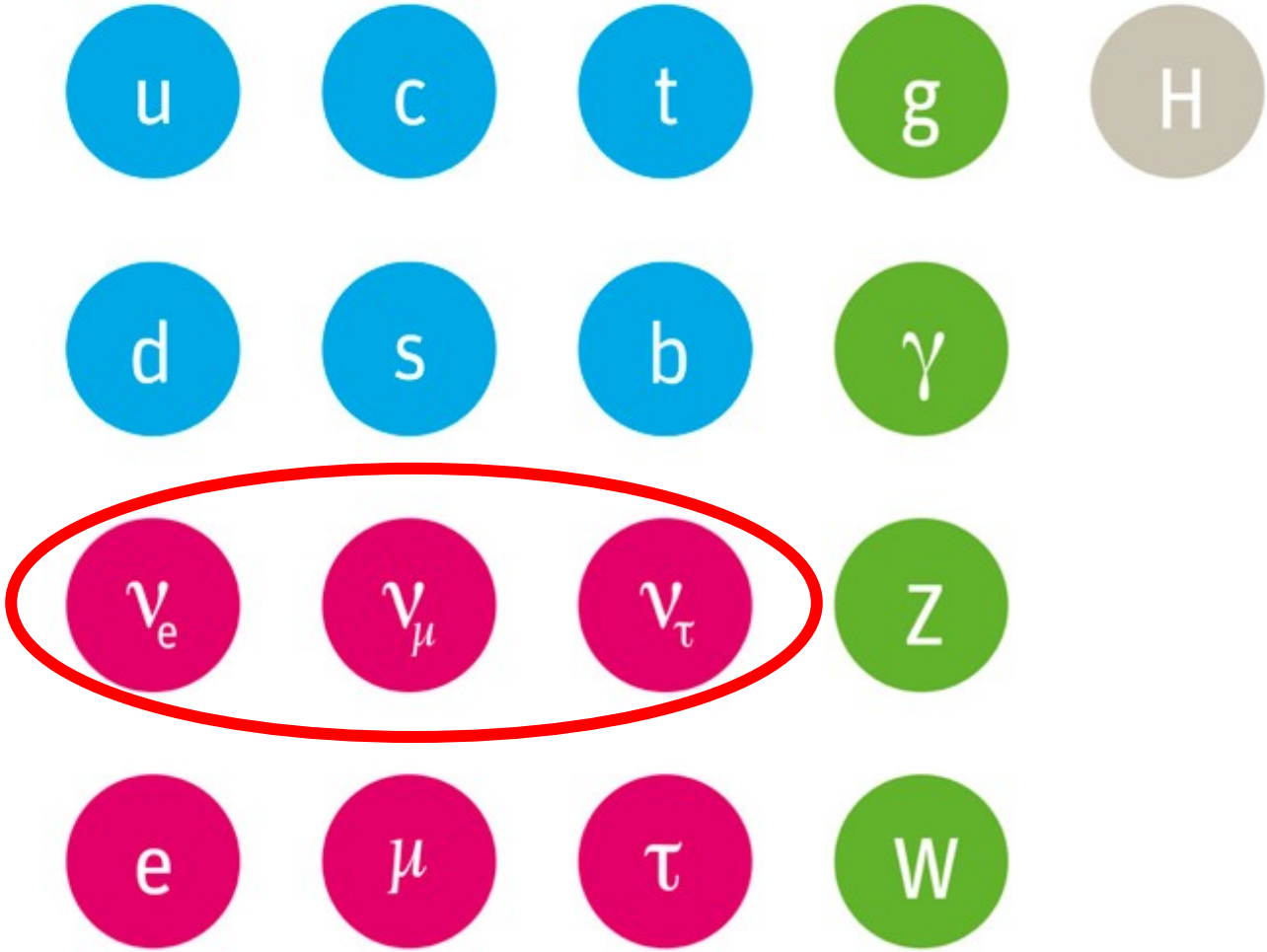
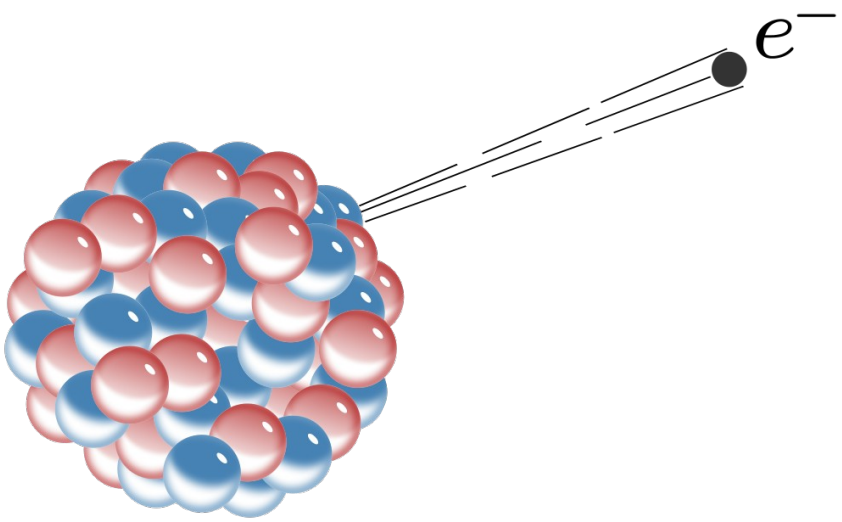
Das Standardmodel

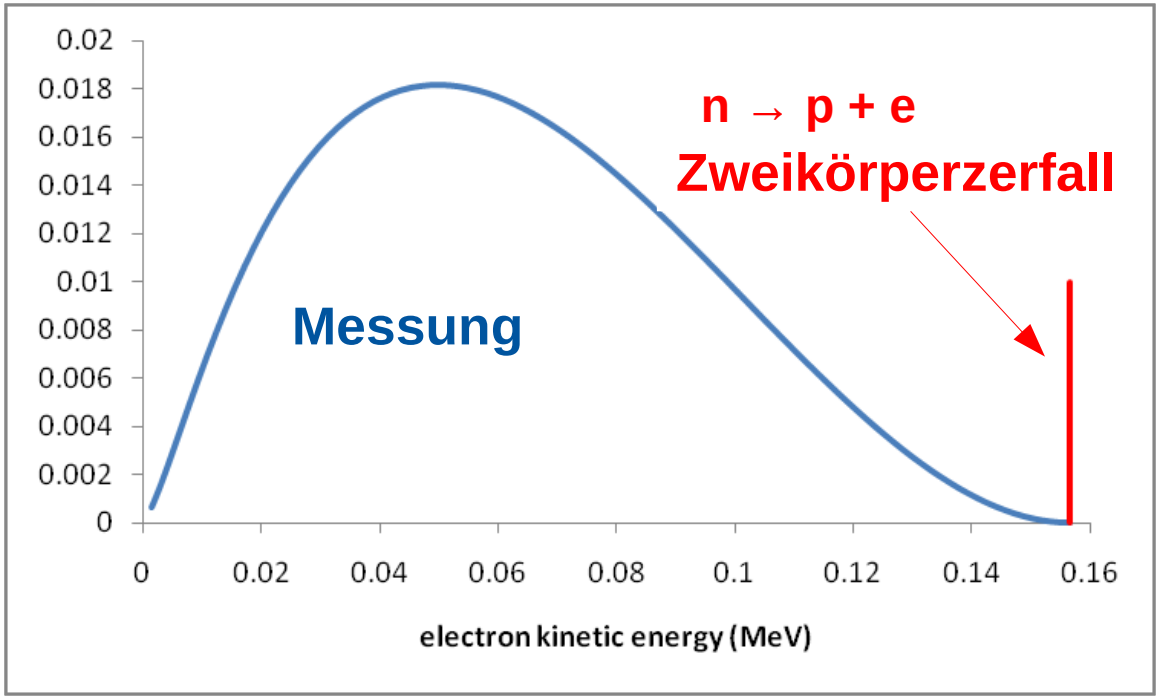
- Quarks
- Leptonen
- Kraftteilchen
- Higgs



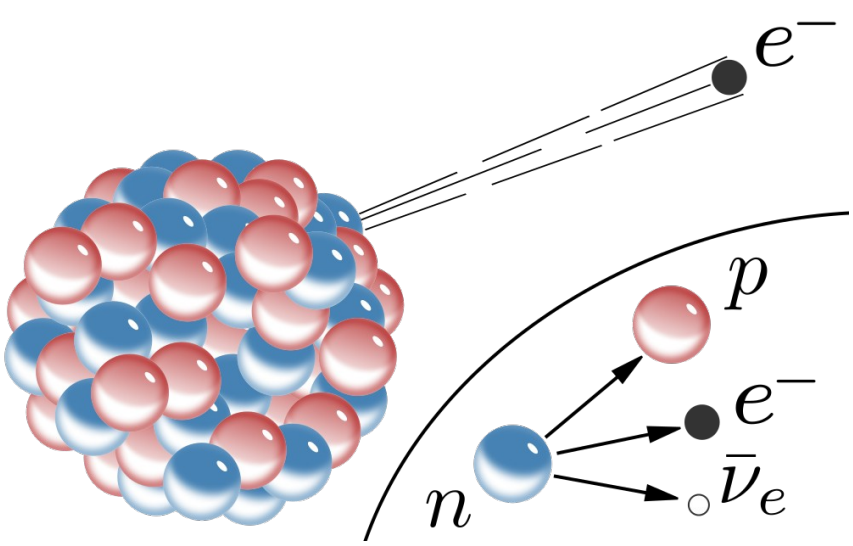
?

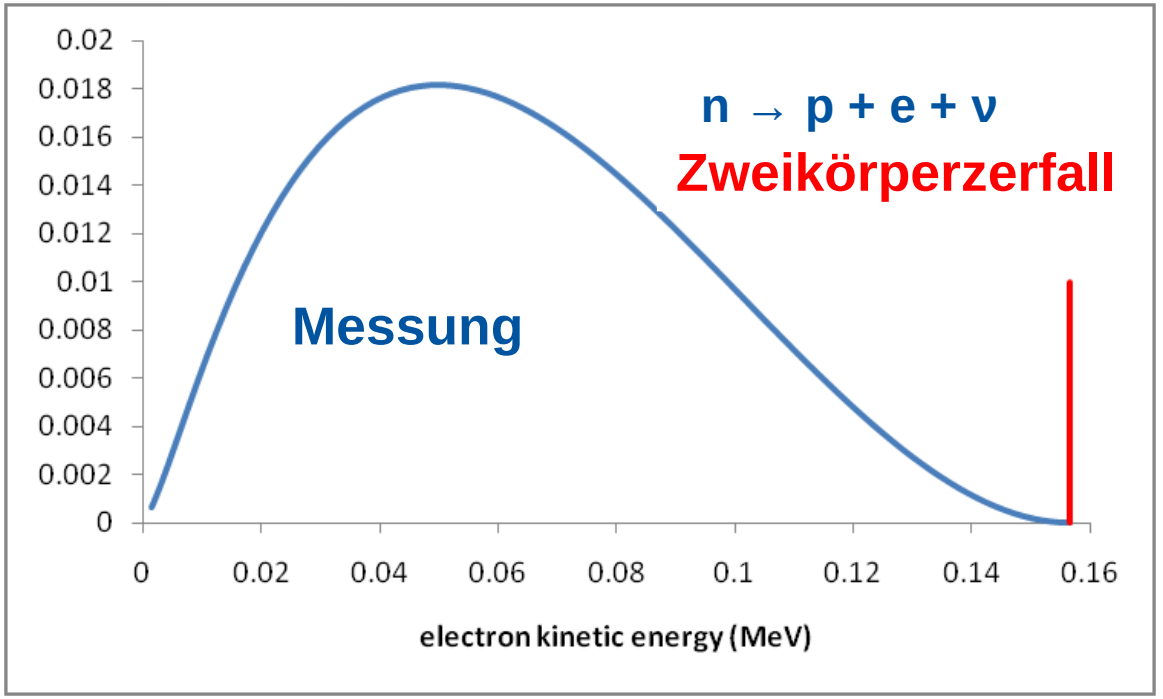
Der β-Zerfall





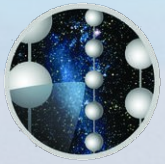
Der β-Zerfall





Wolfgang Pauli, 1930

„Heute habe ich etwas Schreckliches getan, etwas, was kein theoretischer Physiker jemals tun sollte. Ich habe etwas vorgeschlagen, was nie experimentell verifiziert werden kann."



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Neutrinos they are very small.

They have no charge and have no mass

And do not interact at all.

The earth is just a silly ball

To them, through which they simply pass,

Like dustmaids down a drafty hall

Or photons through a sheet of glass.

- John Updike

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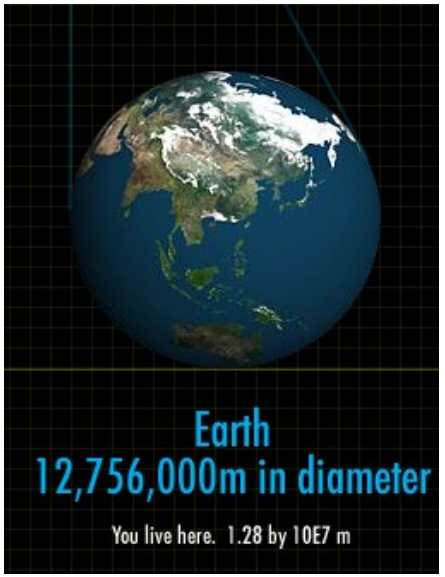
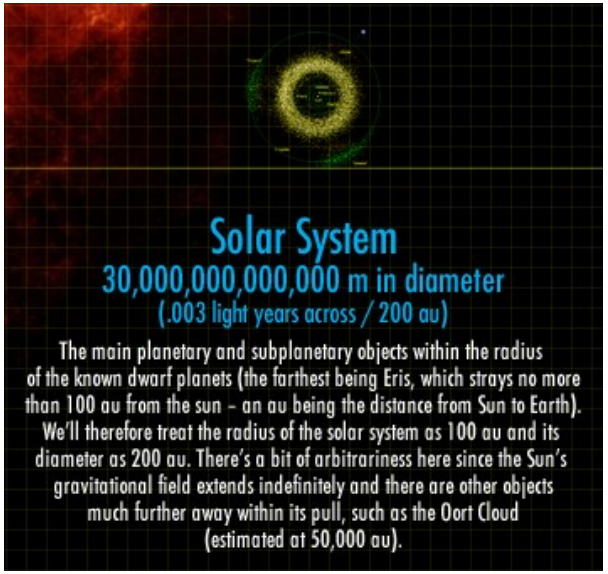
Astrophysik

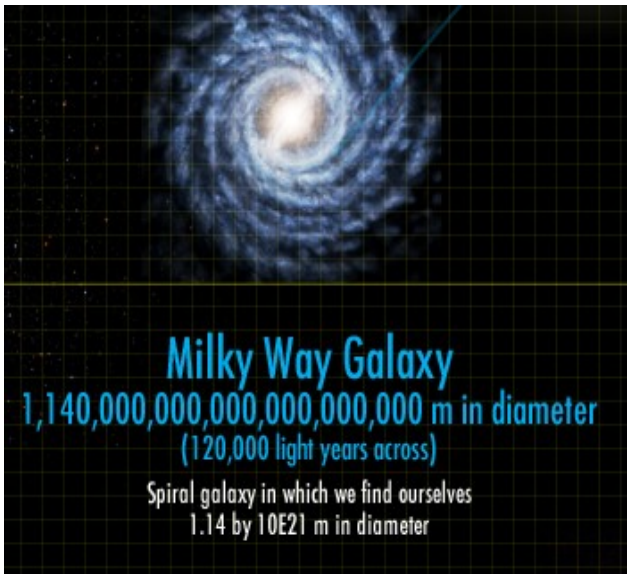
Kodiak Bear
3 m tall
Up to 10 ft = 3 by 10E0 m



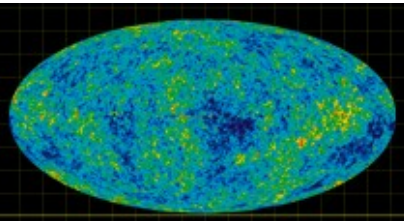
Earth
12,756,000m in diameter
You live here. 1.28 by 10E7 m



Solar System
30,000,000,000,000 m in diameter
(.003 light years across / 200 au)
The main planetary and subplanetary objects within the radius of the known dwarf planets (the farthest being Eris, which strays no more than 100 au from the sun – an au being the distance from Sun to Earth). We'll therefore treat the radius of the solar system as 100 au and its diameter as 200 au. There's a bit of arbitrariness here since the Sun's gravitational field extends indefinitely and there are other objects much further away within its pull, such as the Oort Cloud (estimated at 50,000 au).



Milky Way Galaxy
1,140,000,000,000,000,000,000 m in diameter
(120,000 light years across)
Spiral galaxy in which we find ourselves
1.14 by 10E21 m in diameter



The Observed Universe
248,000,000,000,000,000,000,000,000 m in diameter
Gamma Ray Burst 090429B is 13.1 billion ly from Earth suggesting a radius for the observed universe of that distance and thus a diameter twice that distance; note that the universe is 13.7 billion years old, indicating that this gamma ray burst happened 600 million years after the Big Bang
2.48 by 10E26 m across

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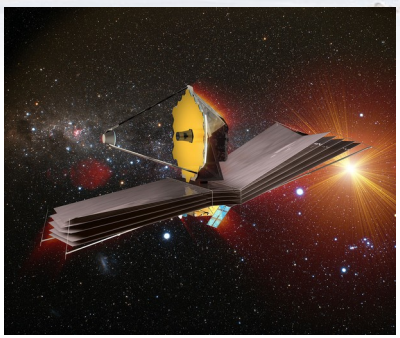
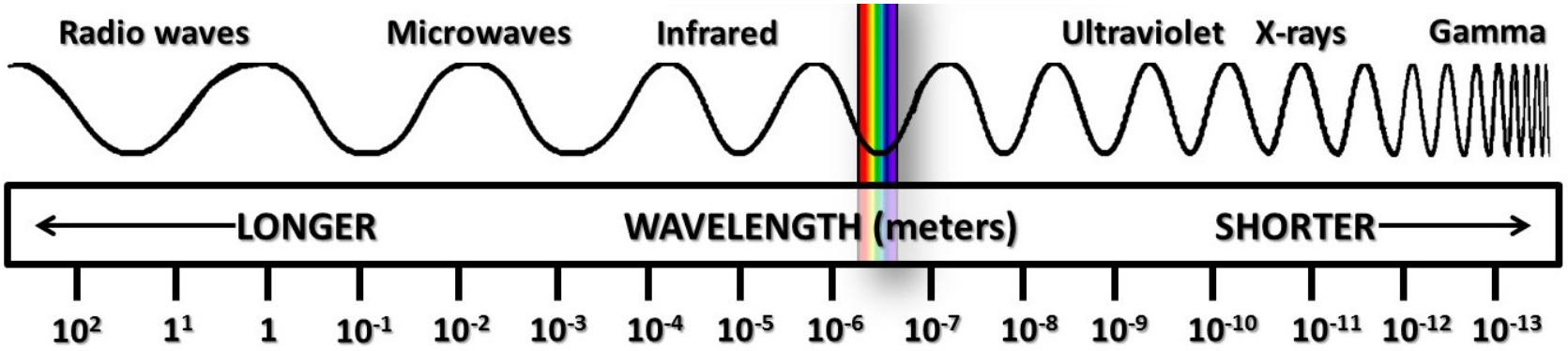
Licht-Astronomie





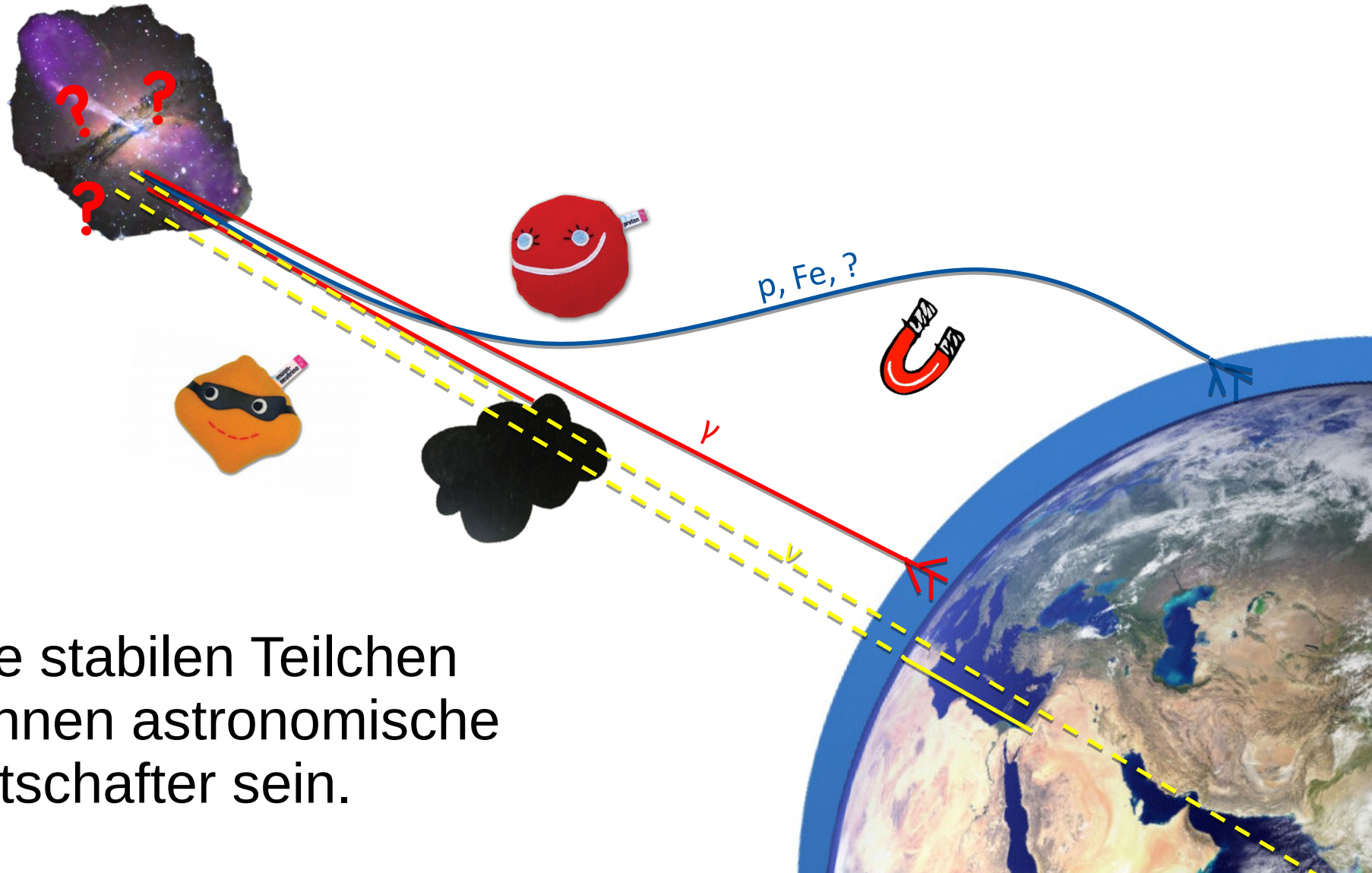

Radiocontinuum


MIR


Optical

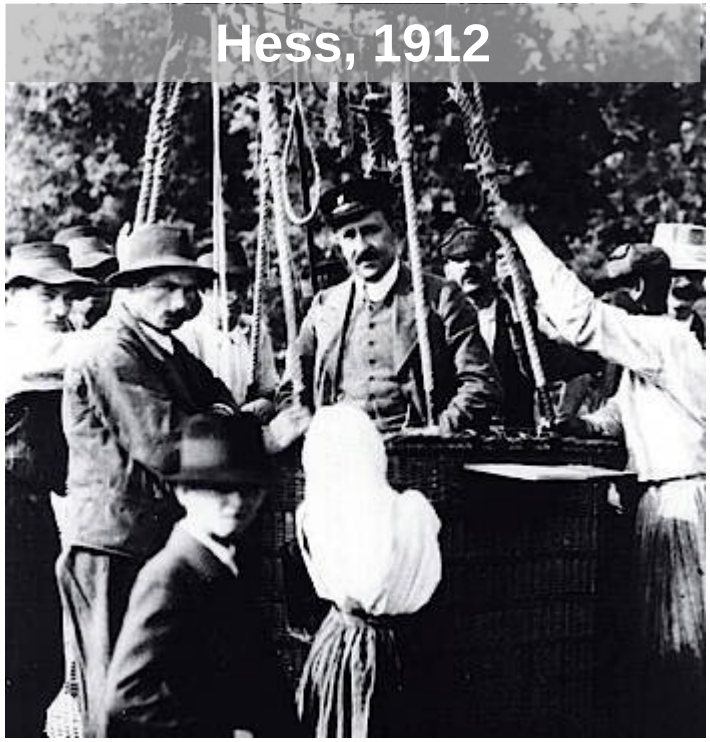

X ray

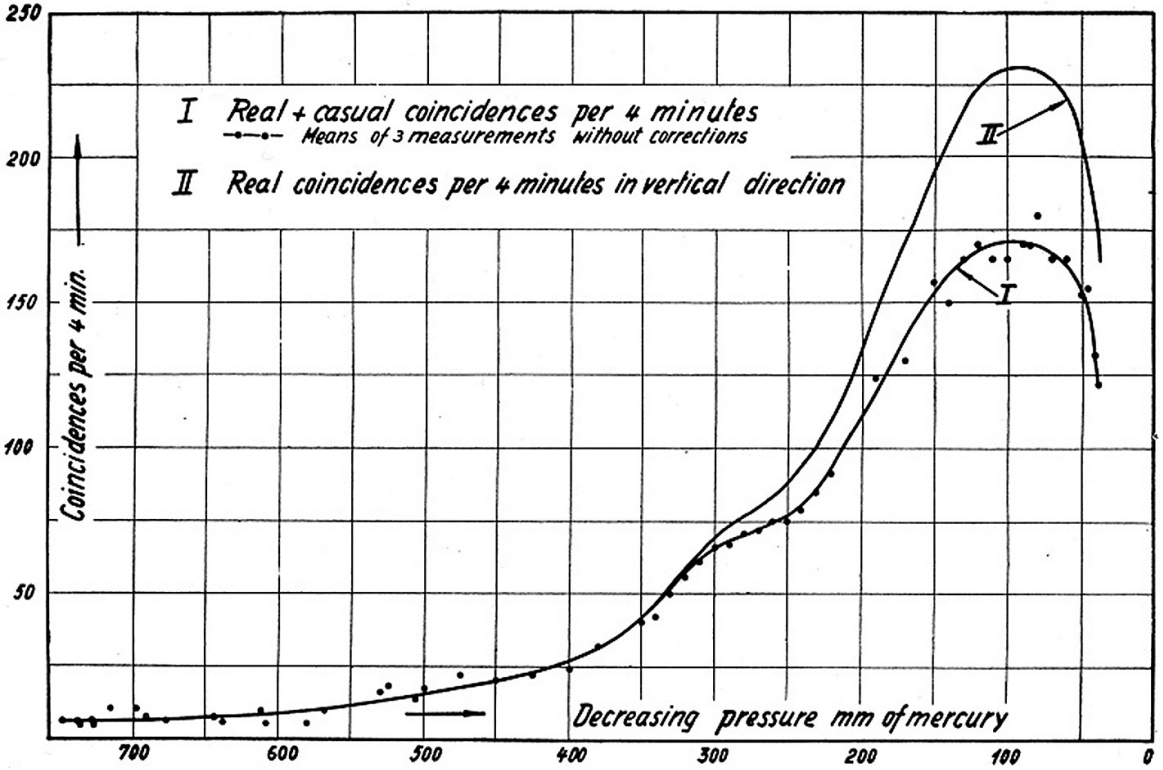
Was hat das mit Teilchenphysik zu tun?



Alle stabilen Teilchen können astronomische Botschafter sein.

Kosmische Höhenstrahlung





Die Radioaktivität nimmt mit der Höhe zu

→ die Erde wird aus dem Universum
von hochenergetischen, geladenen Teilchen bombardiert

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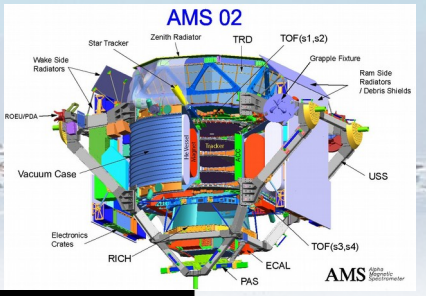
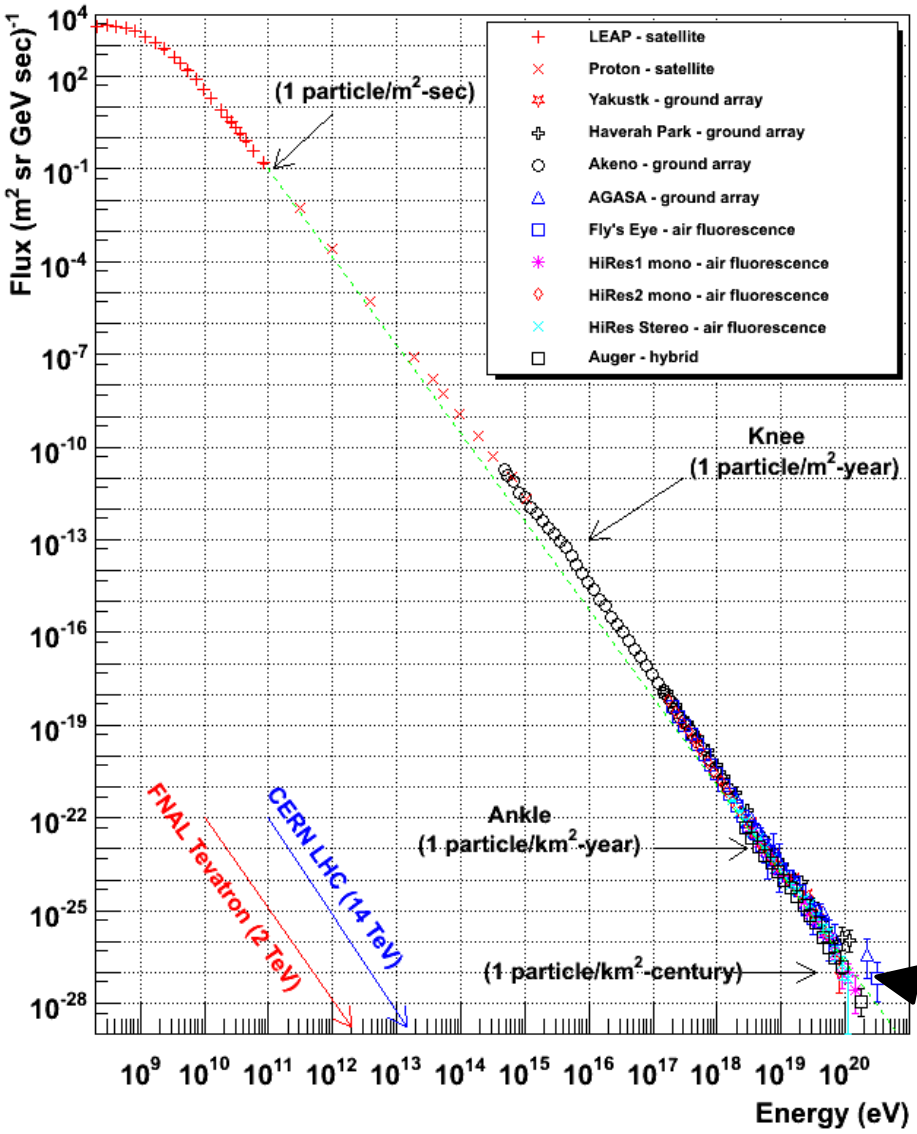
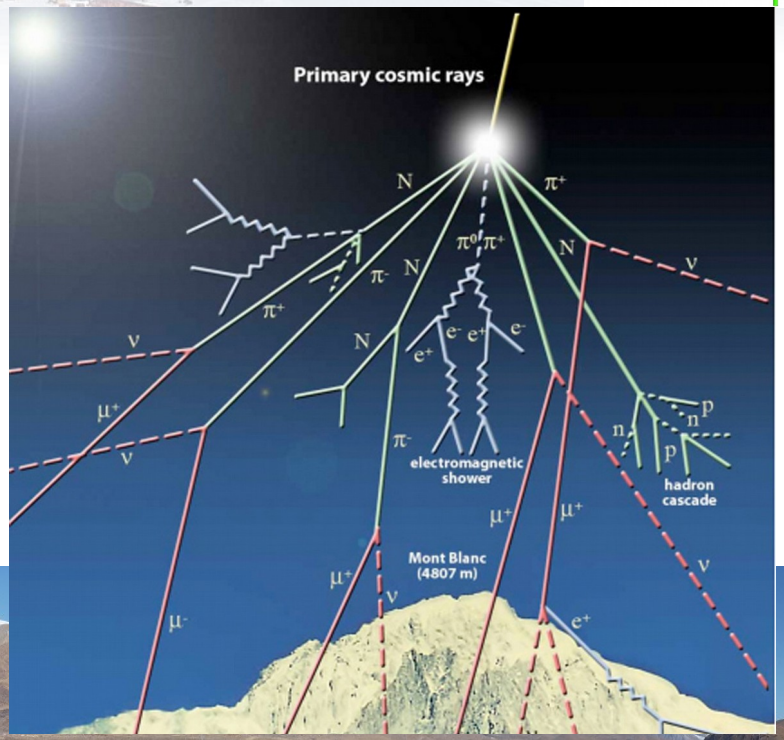
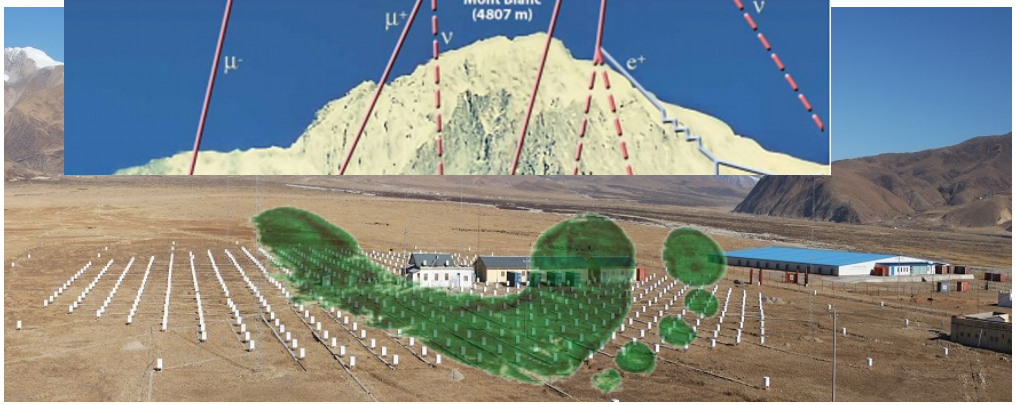
Energiespektrum







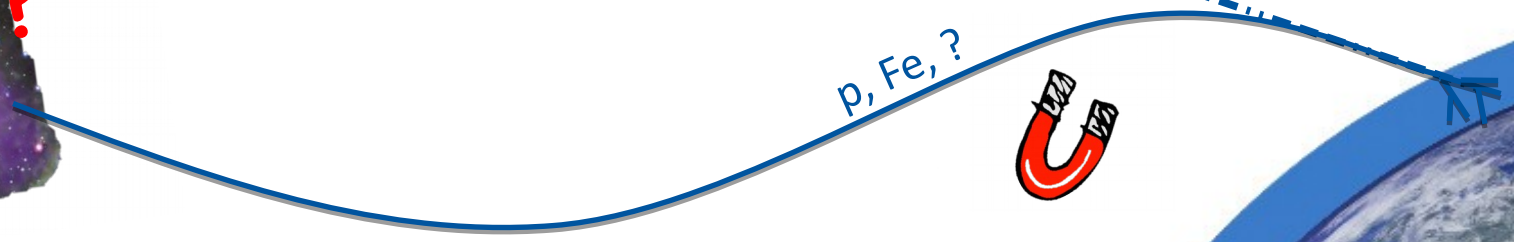


Genug Energie um einen Tennisball auf 270km/h zu beschleunigen.

Ankunftsrichtungen

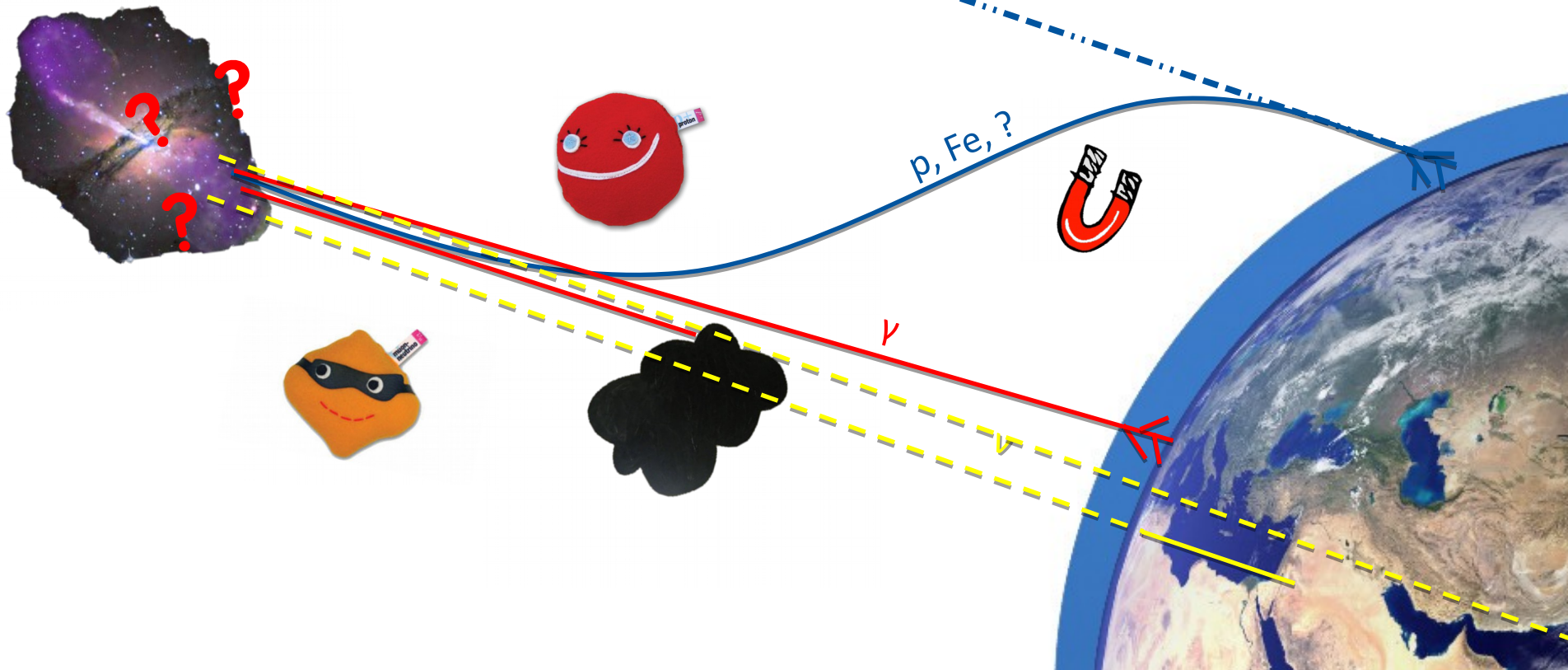
Geladene Teilchen werden in intergalaktischen Magnetfelden abgelenkt und zeigen nicht auf ihre Quelle zurück

→ **selbst nach Jahrzehnten an Forschung kennen wir die Quellen der kosmischen Strahlung nicht**



Neutrinoastronomie

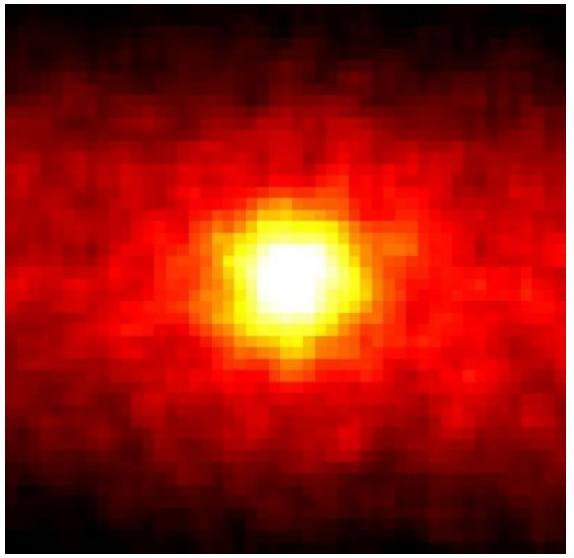
Neutrinos werden in den selben Orten wie die geladenen Teilchen produziert, aber sie werden nicht absorbiert oder abgelenkt
→ ideale Botschafter



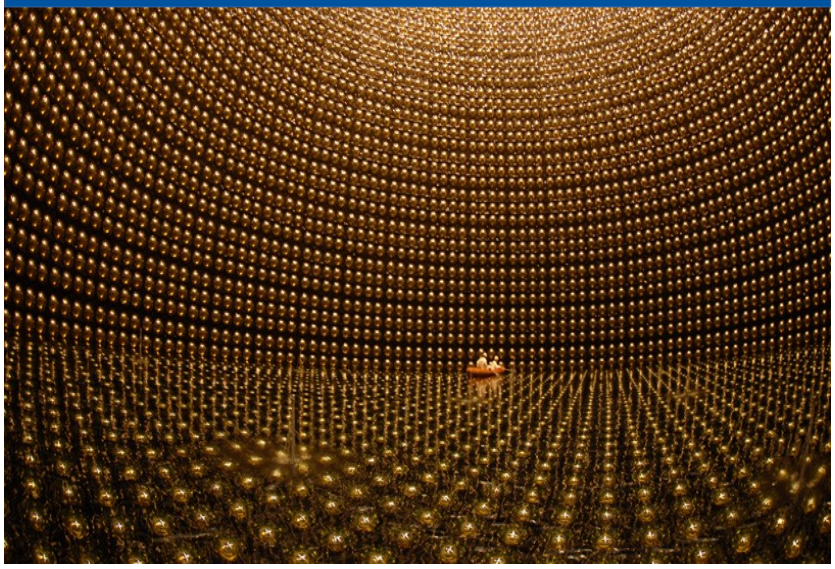
Neutrinoquellen

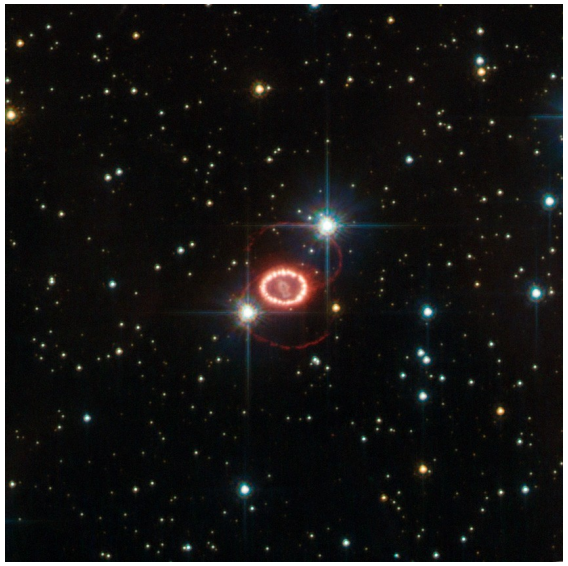
- Sonne ($7 \cdot 10^{10}$ pro cm^2 und Sekunde)
  ~5000 pro Jahr werden gemessen

- SN1987a (Supernova)
  24 gemessene Neutrinos



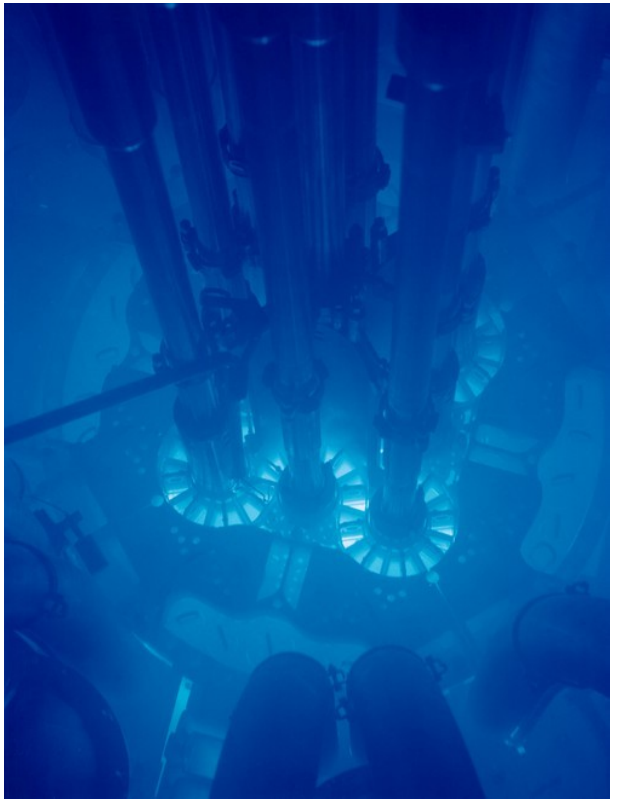
Detektor ~ 0,00003 km^3





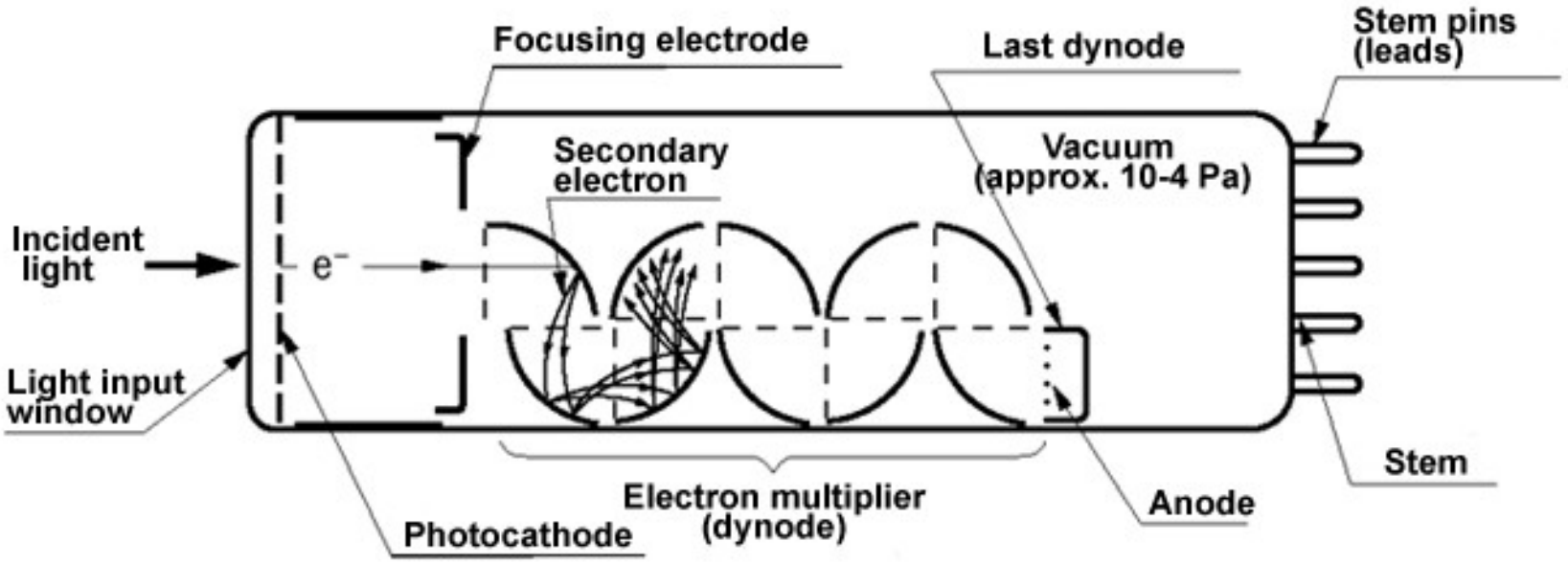
Cherenkov-Strahlung

- In Materie ist die Lichtgeschwindigkeit um den Brechungsindex reduziert
- Ein geladenes Teilchen, dass ein Medium oberhalb der Lichtgeschwindigkeit durchläuft, erzeugt eine „Schockwelle“ blauen Lichts
- Die Lichtmenge ist proportional zur Spurlänge und damit zur Energie



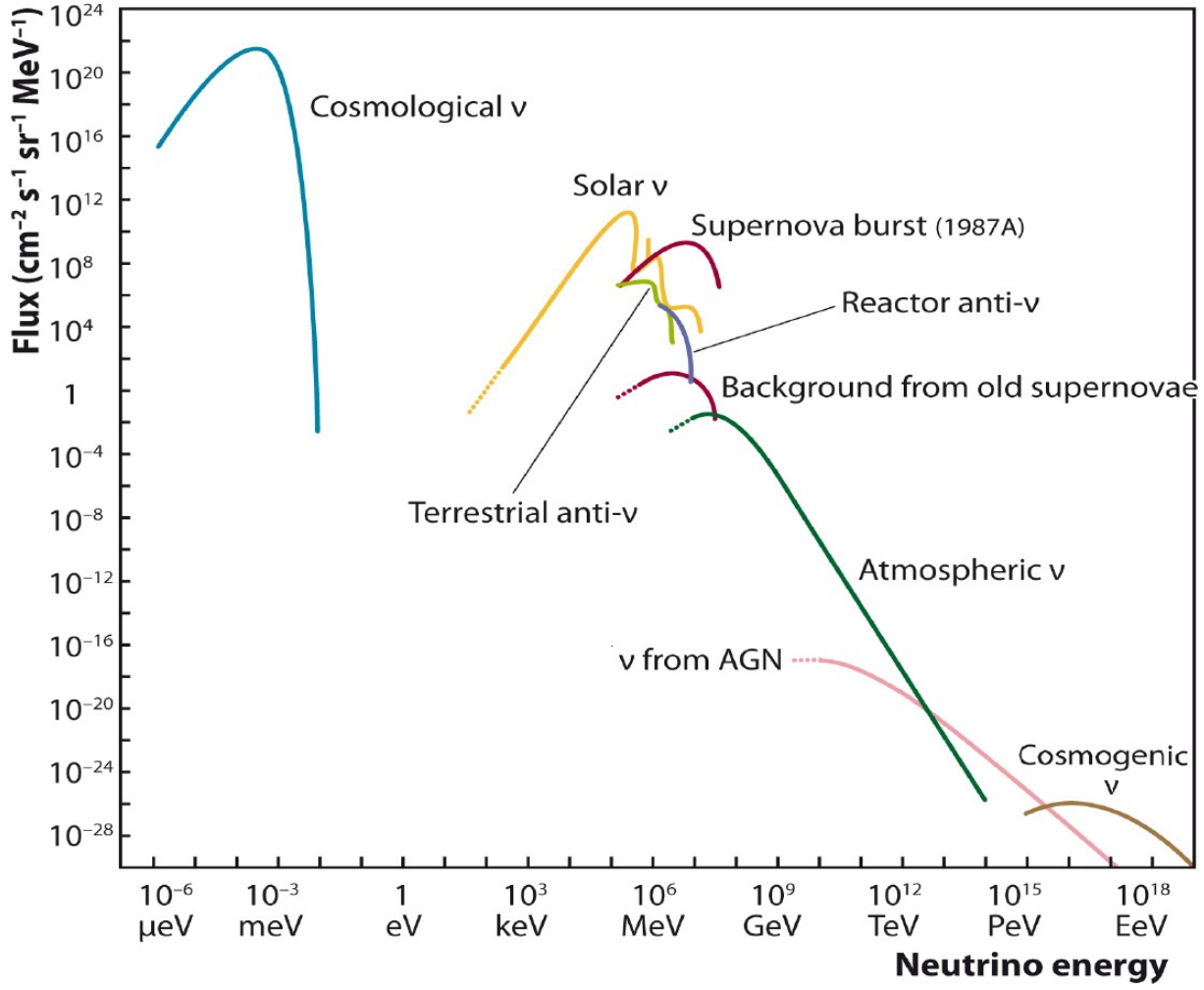
Photomultiplier

- Photoeffekt wandelt Photon in Elektron um
- Hochspannung verstärkt Ladung um ~10^7
- Strompuls gibt Zeit und Photonenanzahl an
- Effizienz ~25%



Die Herausforderung

- Es werden nur ein paar Ereignisse pro Jahr und km² erwartet → riesiger Detektor notwendig



Die IceCube Idee

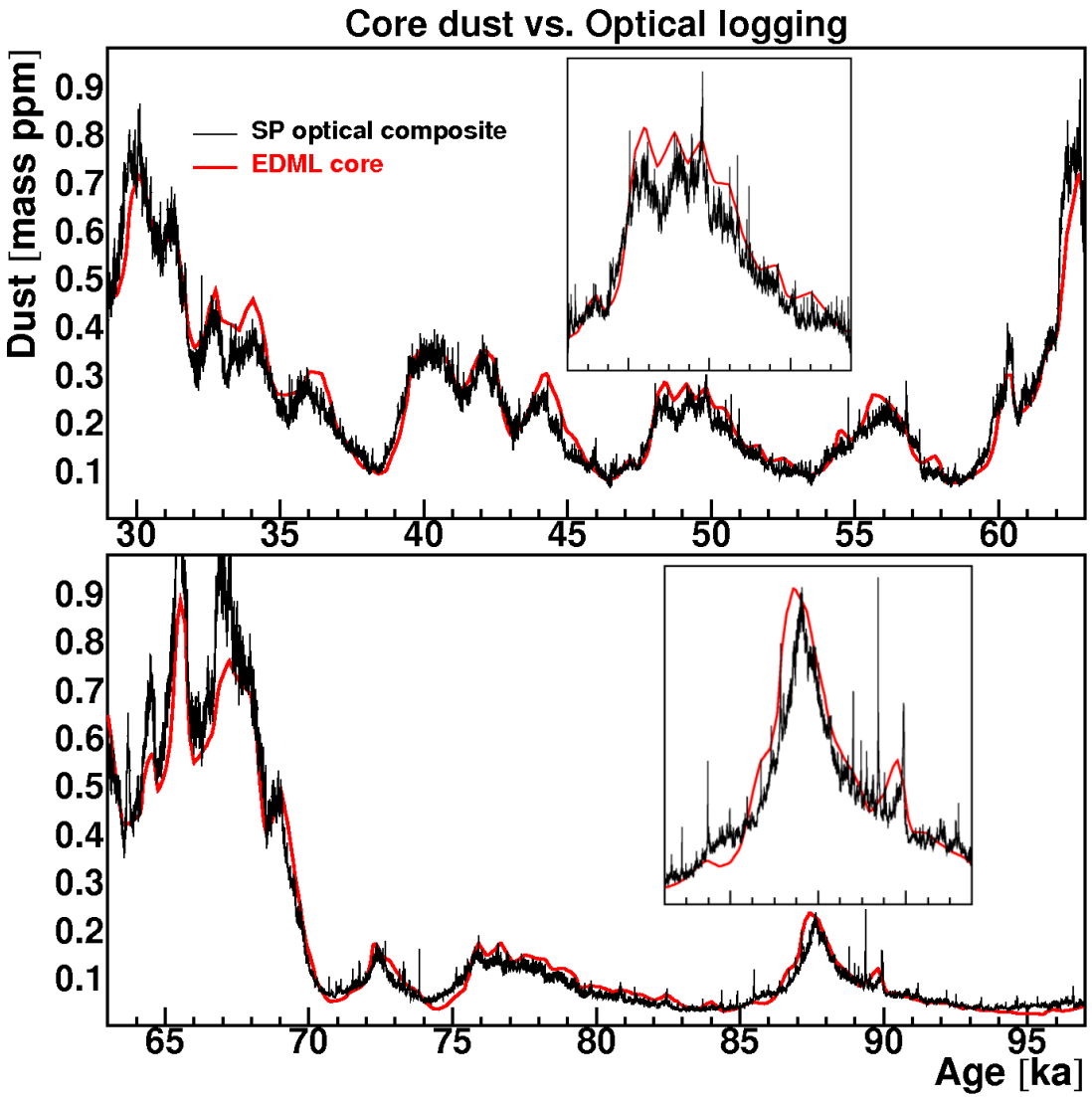
- Man suche sich eine großes (km^3) Volumen schweren, transparenten Material
- Man versenke eine große Zahl an Photomultipliern
- Hin und wieder interagiert ein Neutrino und produziert geladene Sekundärteilchen deren Licht man misst

Wasser ist nass, man kann nicht drauf laufen und Algen leuchten

IceCube
South Pole Neutrino Observatory

Der Südpol

Das Eis



- Hoher Druck im tiefen Eis garantiert gute Qualität
- Verunreinigungen durch vulkanische Asche

Absorptionslänge:

Leitungswasser: 2 m

Destilliertes Wasser: 8 m

Südpoleis: 125 m

Besser als die meisten optischen Gläser

IceCube
South Pole Neutrino Observatory

Die Station

Sommer (Tag)
~3 Monate

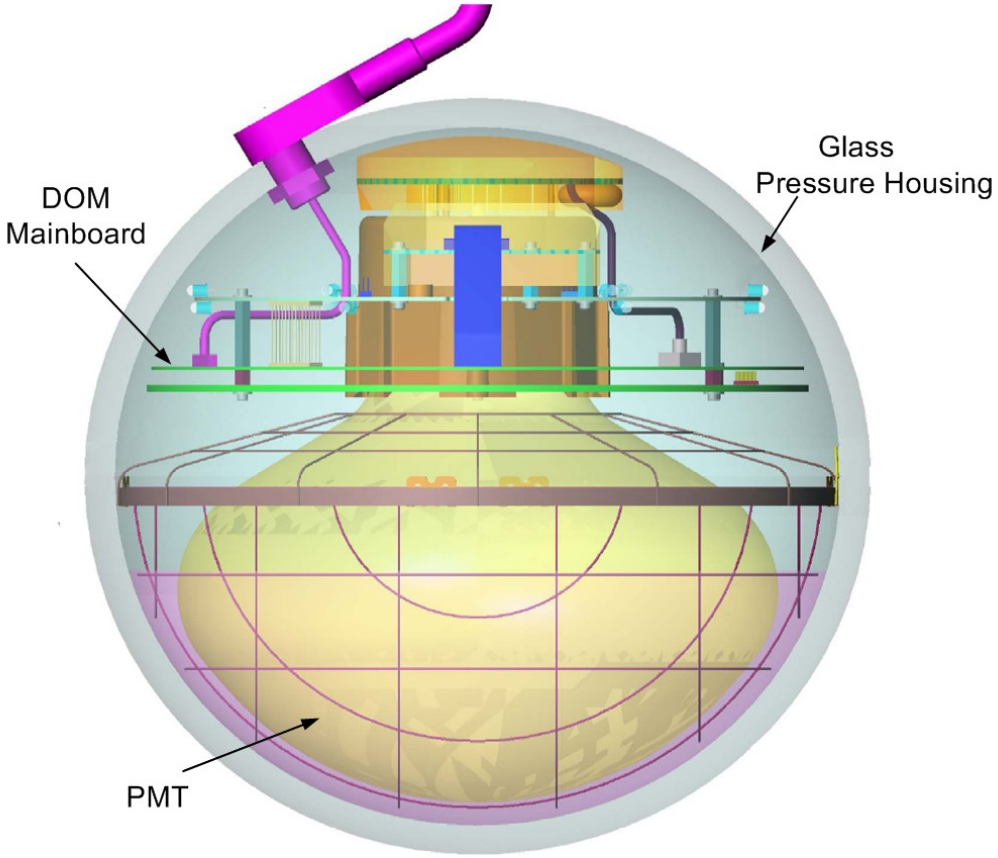
Winter (Nacht)
~9 Monate

- Bevölkerung ~300
- Tägliche Flüge
- ~ -20°C

- Bevölkerung ~30
- Kein Kontakt nach Außen
- ~ -70°C

Der DOM

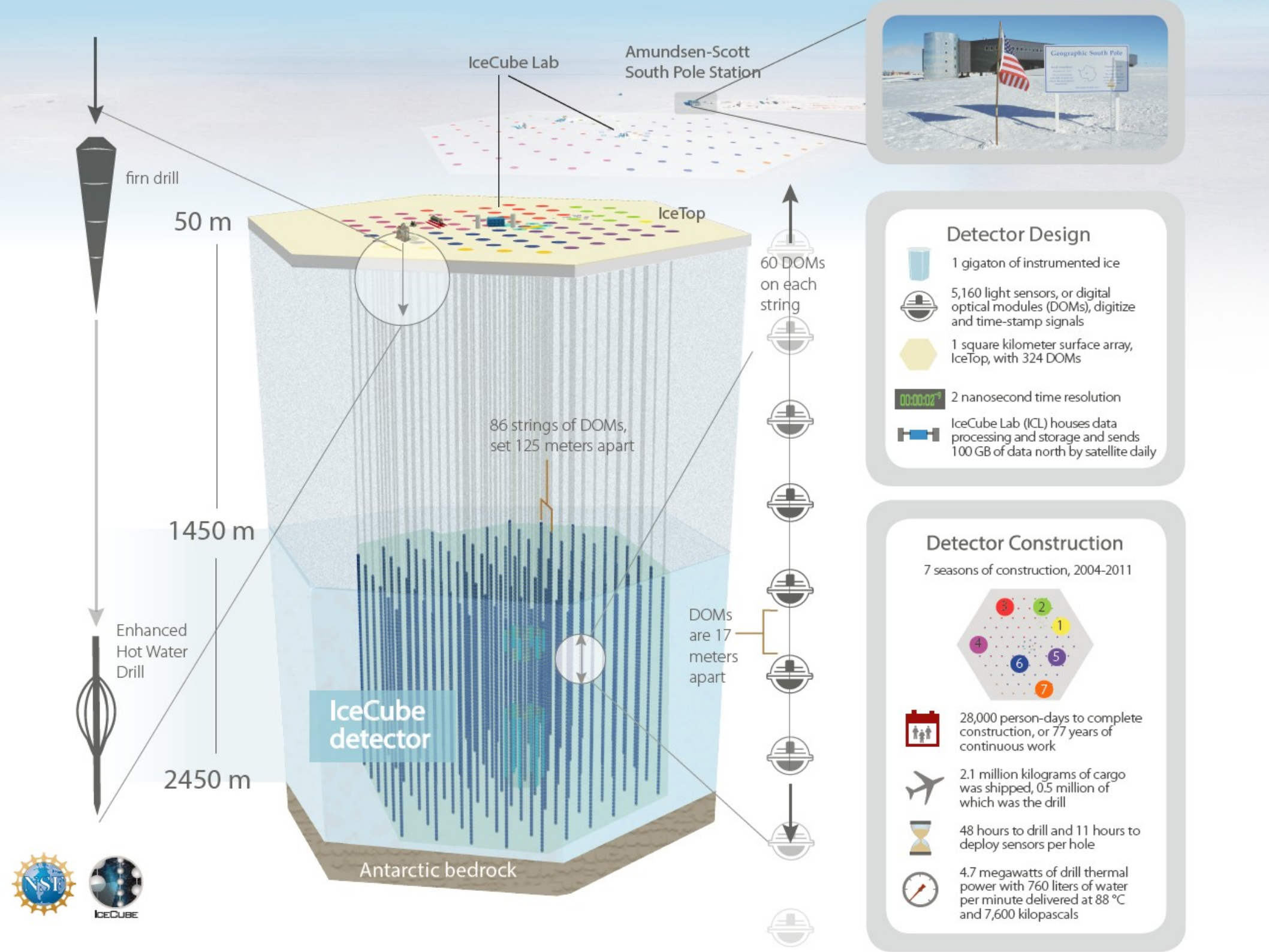
Digital **O**ptical **M**odule – Der IceCube Grundbaustein



- Photomultiplier
- Spannungsversorgung
- Digitalisierung, Triggerlogik und Zeitnahme (2ns)
- Kommunikation

- In einem Druckcontainer aus Glas

60cm ~ 2ns


IceCube Lab
Amundsen-Scott
South Pole Station
firn drill
50 m
IceTop
60 DOMs
on each
string
86 strings of DOMs,
set 125 meters apart
1450 m
Enhanced
Hot Water
Drill
DOMs
are 17
meters
apart
IceCube
detector
2450 m
Antarctic bedrock
Detector Design
1 gigaton of instrumented ice
5,160 light sensors, or digital optical modules (DOMs), digitize and time-stamp signals
1 square kilometer surface array, IceTop, with 324 DOMs
2 nanosecond time resolution
IceCube Lab (ICL) houses data processing and storage and sends 100 GB of data north by satellite daily
Detector Construction
7 seasons of construction, 2004-2011
28,000 person-days to complete construction, or 77 years of continuous work
2.1 million kilograms of cargo was shipped, 0.5 million of which was the drill
48 hours to drill and 11 hours to deploy sensors per hole
4.7 megawatts of drill thermal power with 760 liters of water per minute delivered at 88 °C and 7,600 kilopascals


IceCube footprint

IceCube Bau

~20 2,5km tiefe Löcher pro Jahr,
mit ja 60 DOMs + Verkablung

Detector Construction

7 seasons of construction, 2004-2011

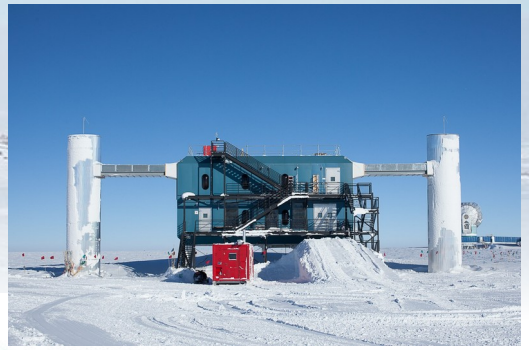
28,000 person-days to complete construction, or 77 years of continuous work

4.7 million pounds of cargo shipped, 1.2 million of which was the drill

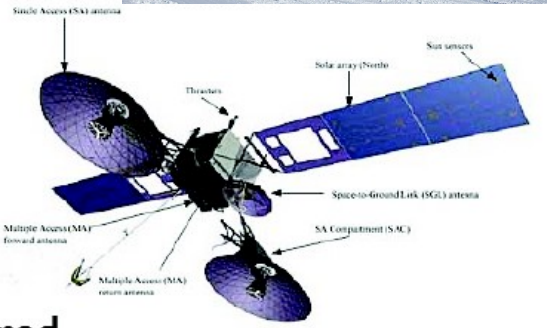
48 hours to drill and 11 hours to deploy sensors per hole

4.7 megawatts of drill thermal power with 200 gallons of water per minute delivered at 88 °C and1,000 psi

IceCube Betrieb



South Pole System (SPS)



South Pole Archival and Data Exchange

Rate ~ 3000Hz

data acquisition

processing & filtering

filtered

DAQ

PnF

SPADE / JADE

trigger

filter

DOMs

data warehouse

~11 000 CPUs

~500 GPUs

~4000 TB

IceCube
South Pole Neutrino Observatory

Winterover

Benjamin Eberhardt (DE)

Kathrin Mallot (USA)

The IceCube Collaboration

Canada
University of Alberta–Edmonton
University of Toronto

USA
Clark Atlanta University
Drexel University
Georgia Institute of Technology
Lawrence Berkeley National Laboratory
Michigan State University
Ohio State University
Pennsylvania State University
South Dakota School of Mines & Technology
Southern University and A&M College
Stony Brook University
University of Alabama
University of Alaska Anchorage
University of California, Berkeley
University of California, Irvine
University of Delaware
University of Kansas
University of Maryland
University of Wisconsin–Madison
University of Wisconsin–River Falls
Yale University

Niels Bohr Institutet, **Denmark**

Sweden
Stockholms universitet
Uppsala universitet

Chiba University, **Japan**

Sungkyunkwan University, **Korea**

University of Oxford, **UK**

Belgium
Université Libre de Bruxelles
Université de Mons
Universiteit Gent
Vrije Universiteit Brussel

Germany
Deutsches Elektronen-Synchrotron
Friedrich-Alexander-Universität Erlangen-Nürnberg
Humboldt-Universität zu Berlin
Ruhr-Universität Bochum
RWTH Aachen
Technische Universität München
Technische Universität Dortmund
Universität Mainz
Universität Wuppertal

Université de Genève, **Switzerland**

University of Adelaide, **Australia**

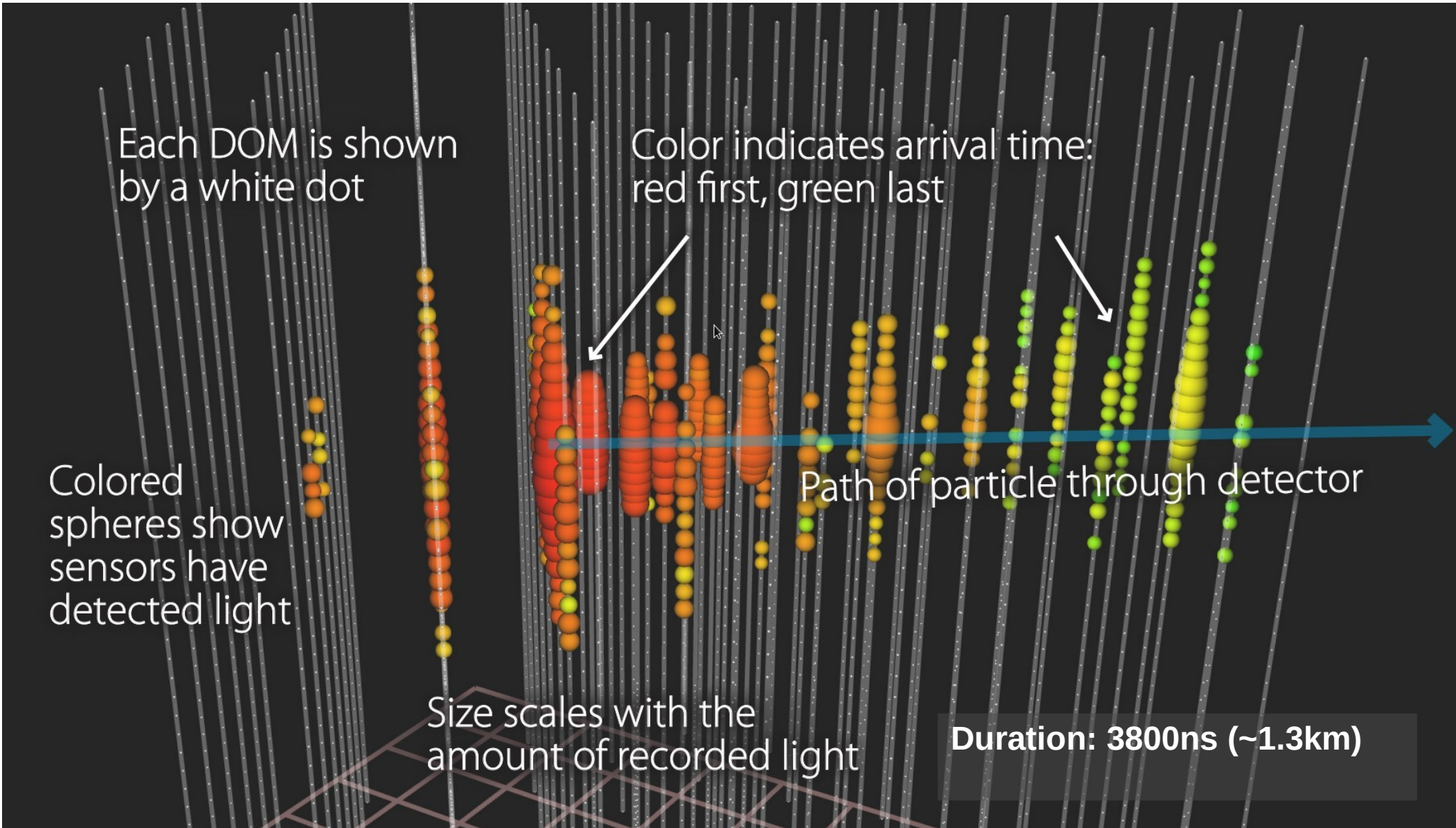
University of Canterbury, **New Zealand**

Funding Agencies

Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
Federal Ministry of Education & Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)
Japan Society for the Promotion of Science (JSPS)
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

IceCube
South Pole Neutrino Observatory

Event display

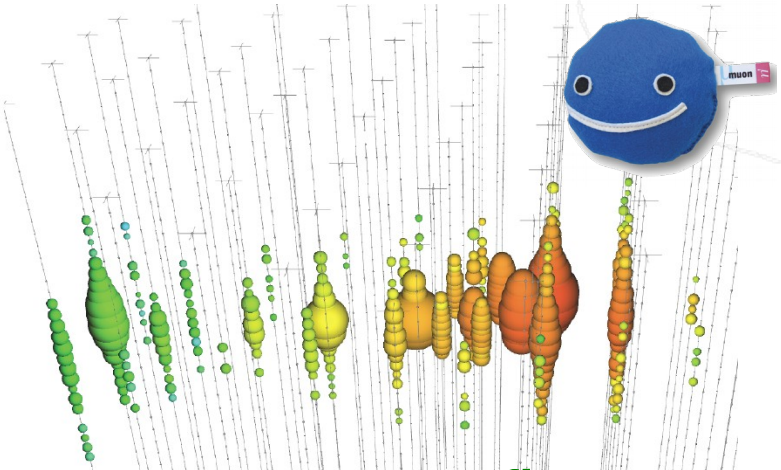


Das Signal

Spuren:

Das Neutrino „stößt“ durch eine $W^{+/-}$-Wechselwirkung ein Muon an

$$\nu_\mu + N \rightarrow \mu + X$$

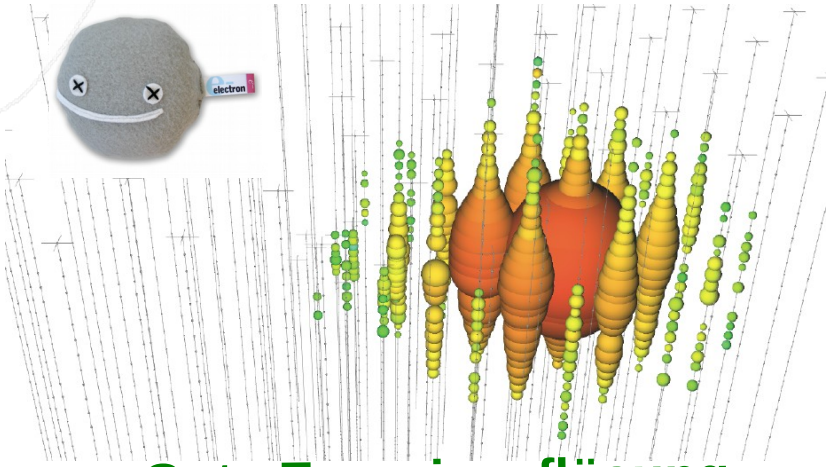


Gute Richtungsauflösung,
schlechte Energieauflösung

Kaskaden:

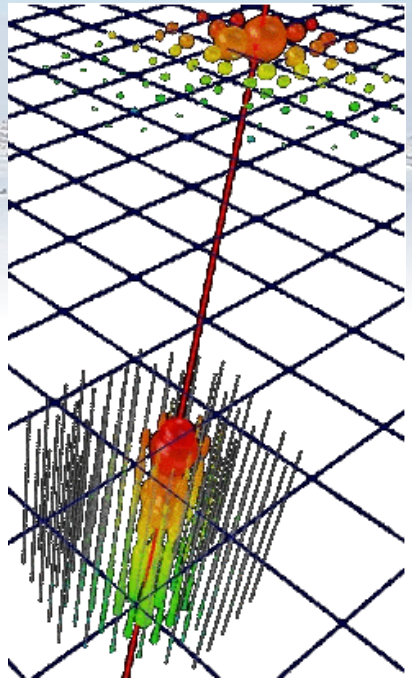
Das Neutrino „stößt“ durch eine Z^0-Wechselwirkung einen Atomkern an

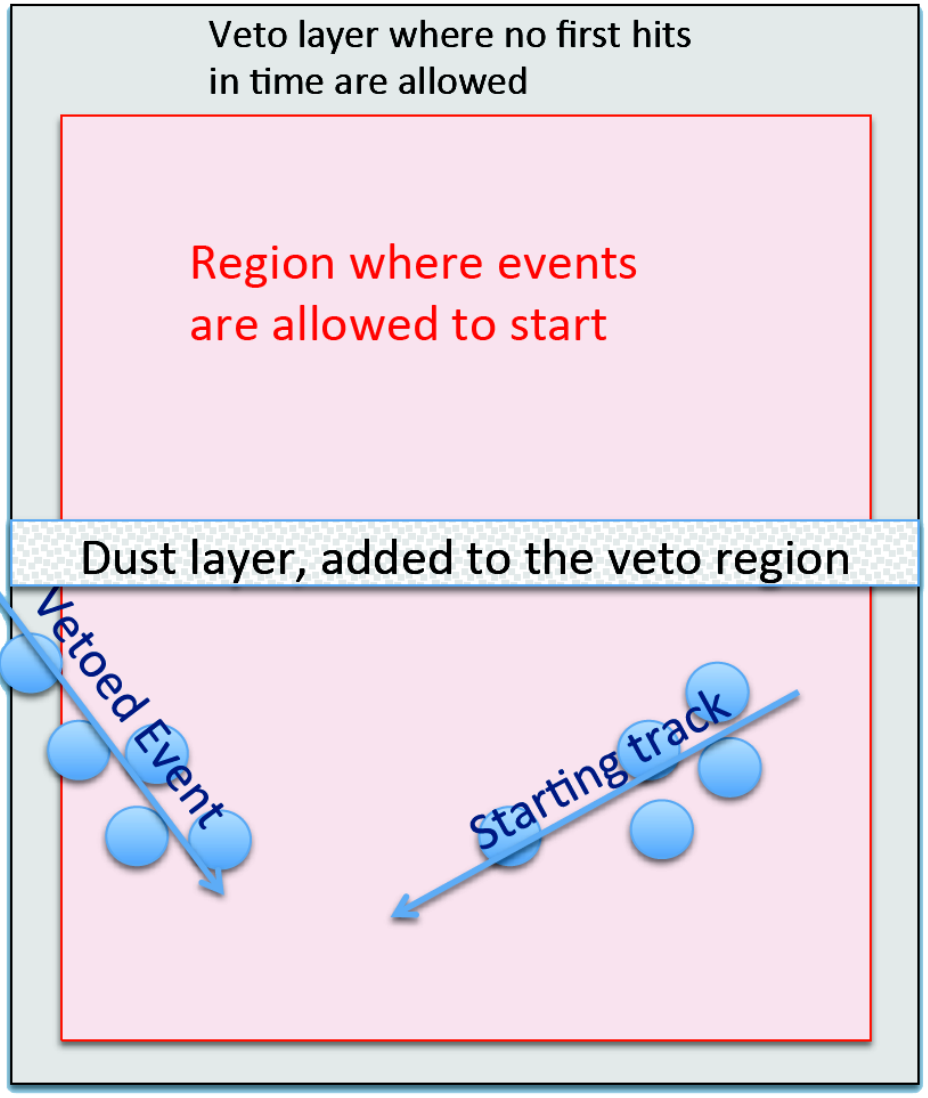
$$\nu_e + N \rightarrow e + X$$
$$\nu_x + N \rightarrow \nu_x + X$$



Gute Energieauflösung,
schlechte Richungsauflösung

HESE Ansatz





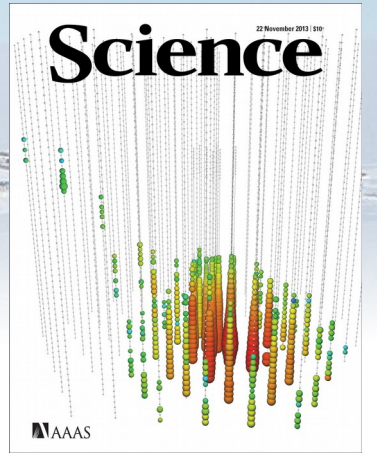
Bedingung:
Das Ereignis muss im Detektor starten

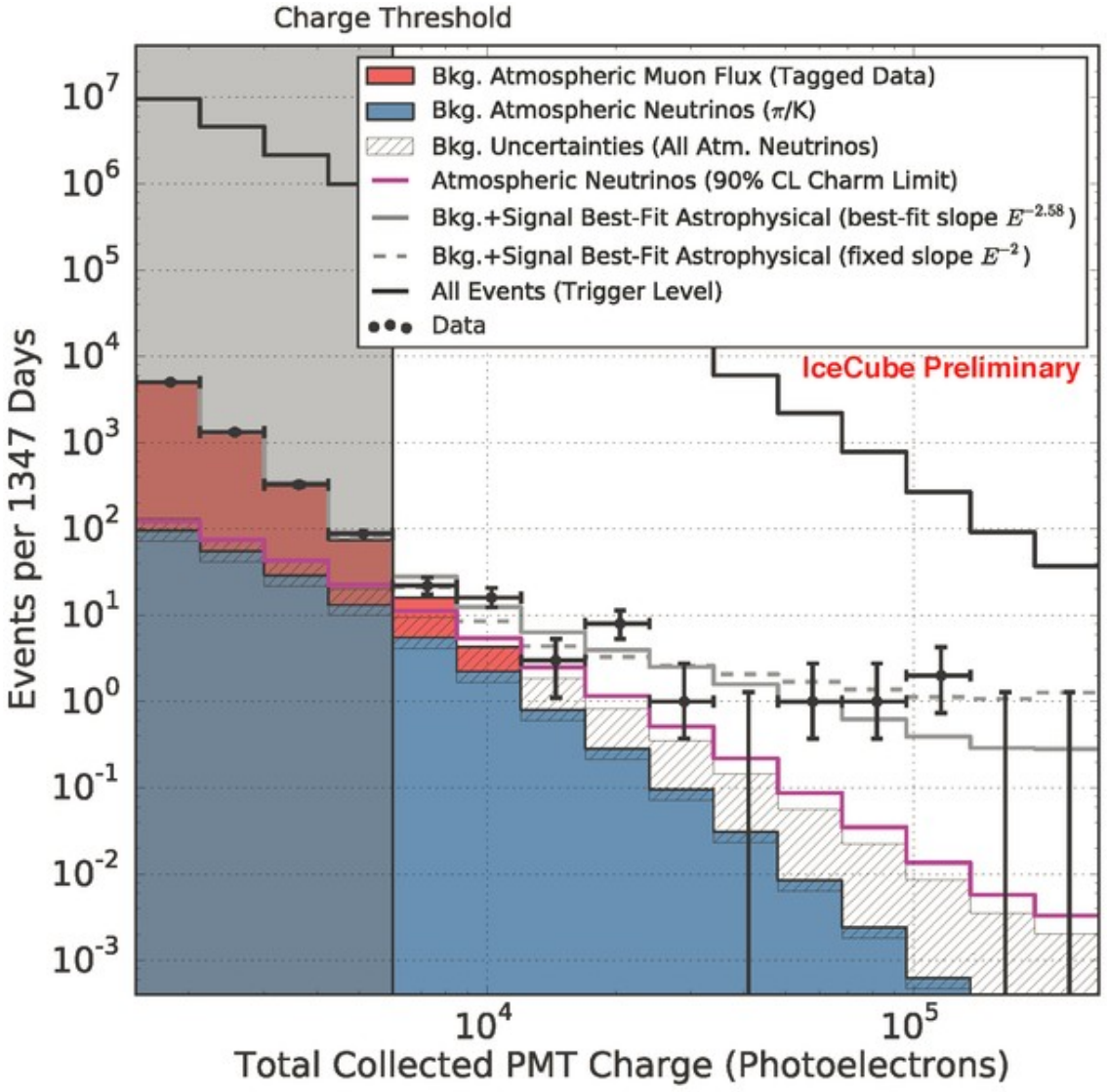
Oder genauer:
Die Vetoregion darf höchstens 3 der ersten 250 PE enthalten

Ergebnis:
Muonen aus der Höhenstrahlung werden verworfen, wohingegen (alle) Neutrinos überleben

Was machen wir mit atmosphärischen Neutrinos?

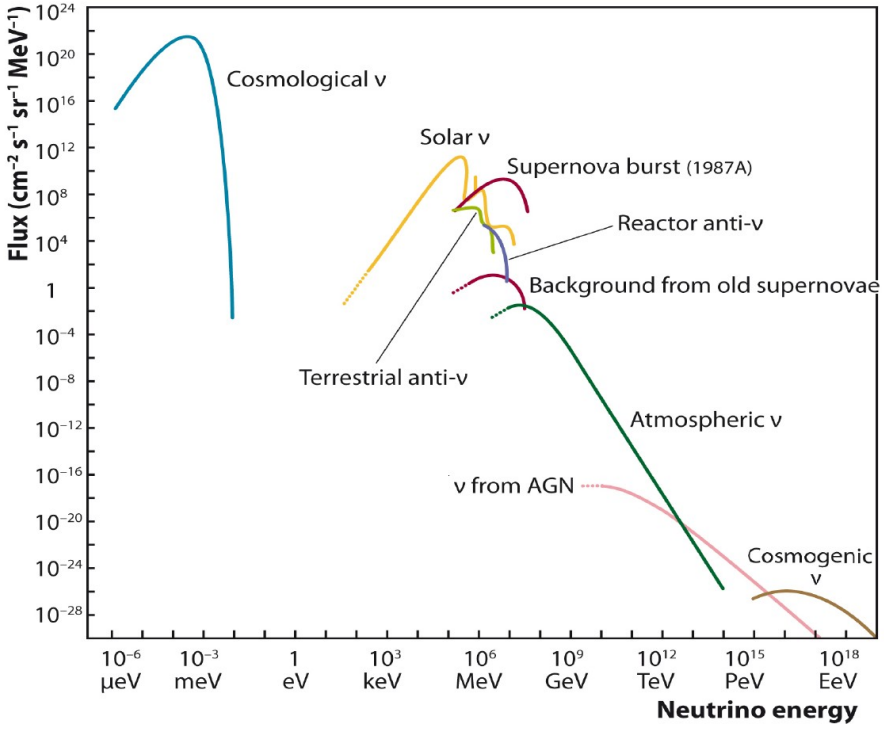
HESE Spektrum





Atmosphärische Neutrinos haben ein „weicheres“ Spektrum als astrophysikalische Neutrinos

→ Das Spektrum separiert bei hohen Energien



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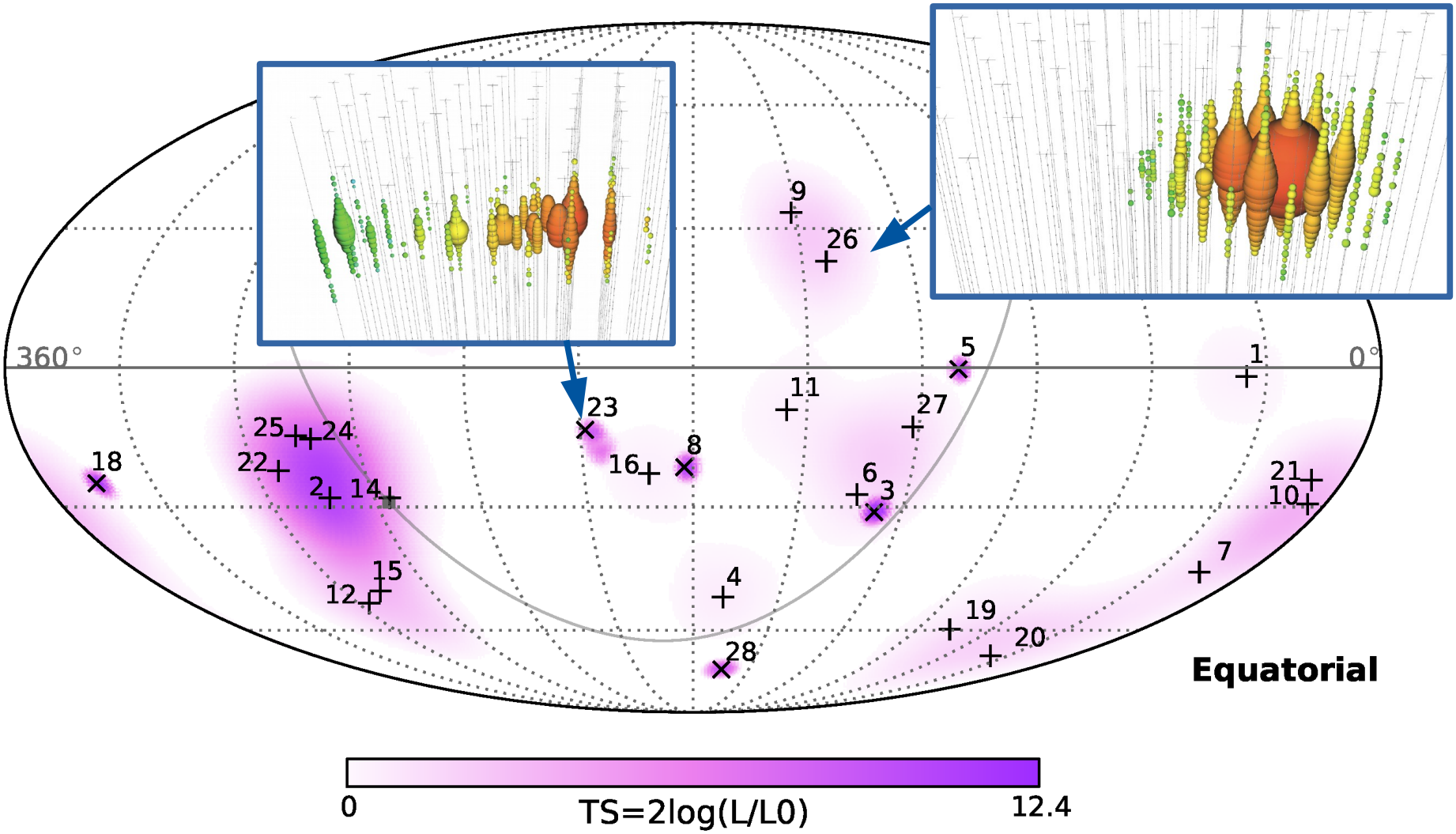
Unsere Himmelskarte



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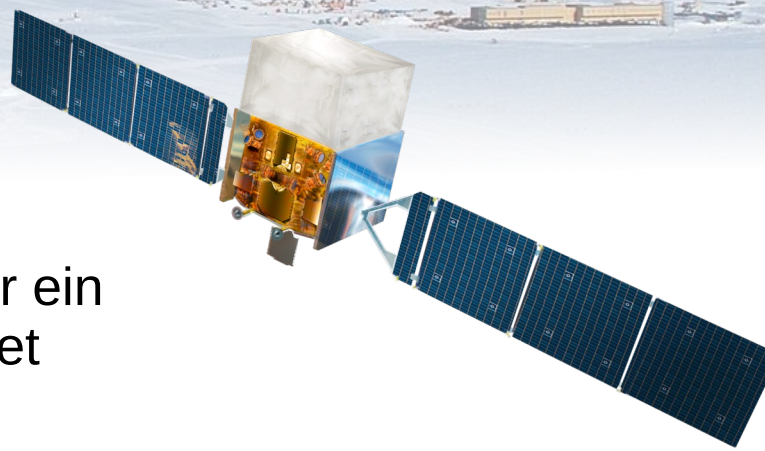
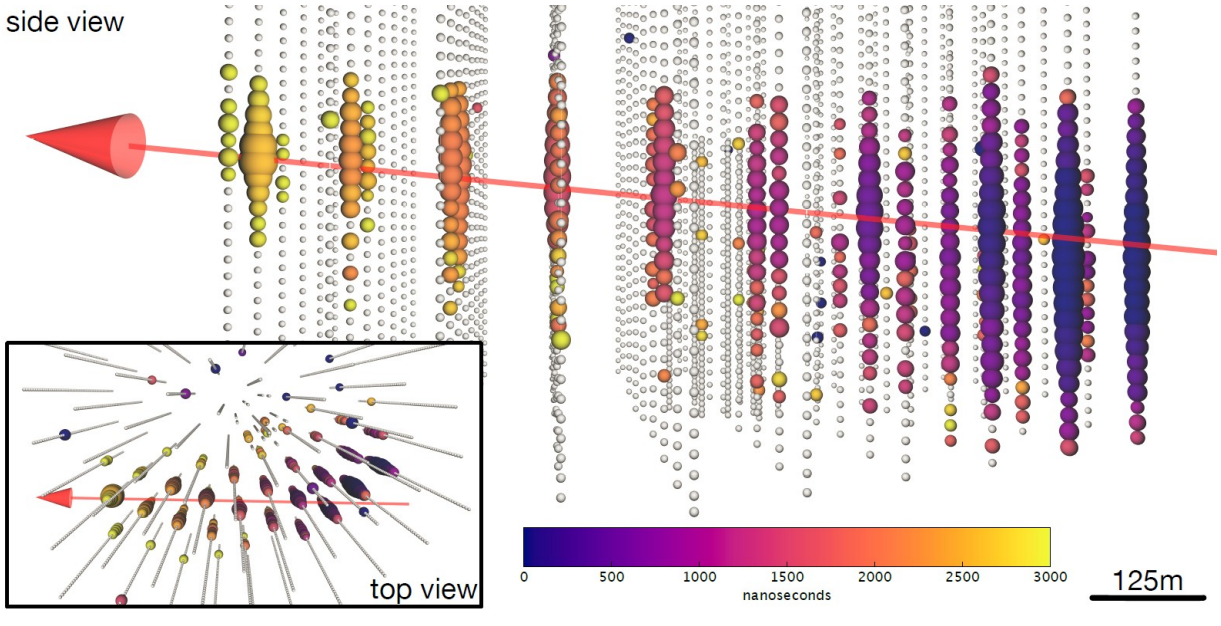
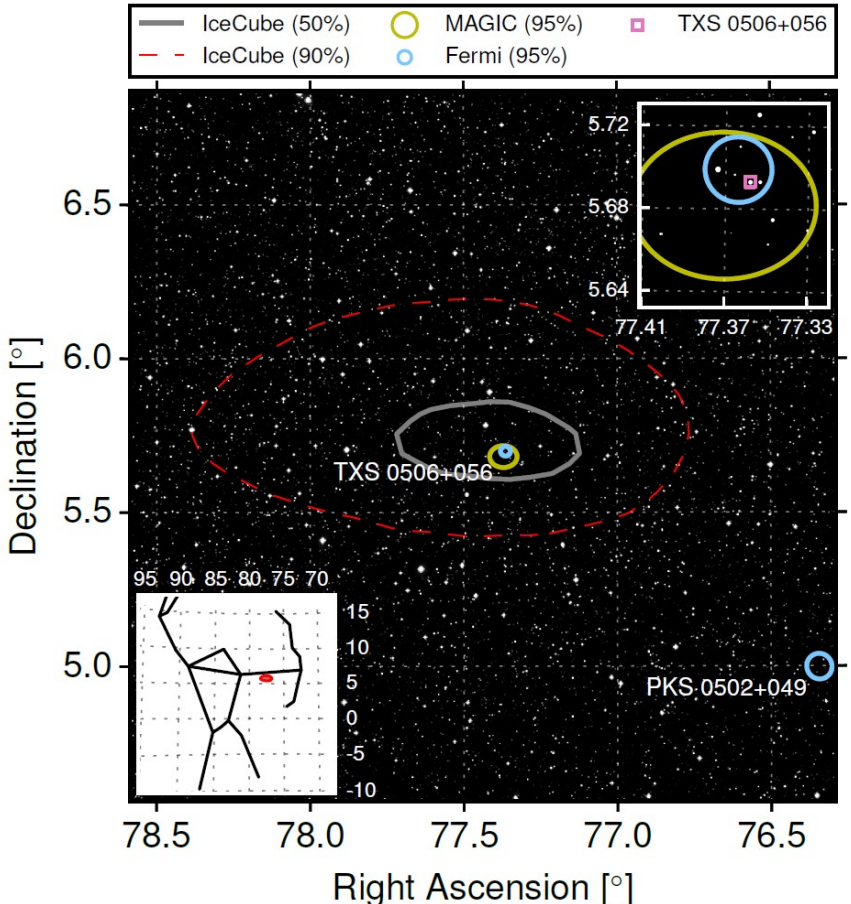
TXS 0506+056

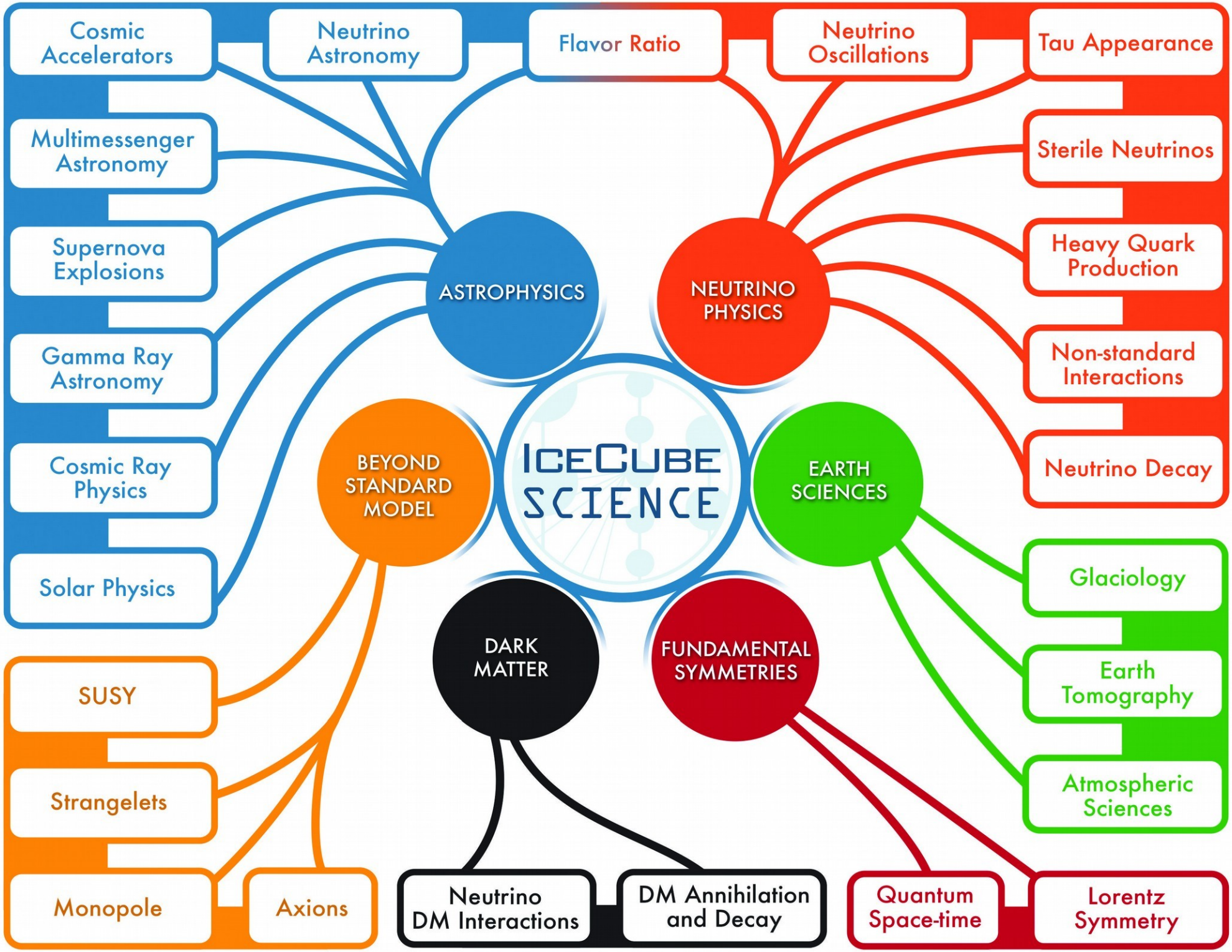


- Am 22. September 2017 hat IceCube einen Alarm über ein Hochenergieneutrino an alle Partnerteleskope gesendet
- In der selben Richtung hat FERMI (Gamma-Rays) einen aufleuchtenden Blazar gefunden
- In Archivdaten wurden weitere Neutrinos aus der selben Richtung identifiziert

→ die erste Quelle??






IceCube Science
Astrophysics
Cosmic Accelerators
Neutrino Astronomy
Multimessenger Astronomy
Supernova Explosions
Gamma Ray Astronomy
Cosmic Ray Physics
Solar Physics
Neutrino Physics
Flavor Ratio
Neutrino Oscillations
Tau Appearance
Sterile Neutrinos
Heavy Quark Production
Non-standard Interactions
Neutrino Decay
Beyond Standard Model
SUSY
Strangelets
Monopole
Axions
Dark Matter
Neutrino DM Interactions
DM Annihilation and Decay
Fundamental Symmetries
Quantum Space-time
Lorentz Symmetry
Earth Sciences
Glaciology
Earth Tomography
Atmospheric Sciences

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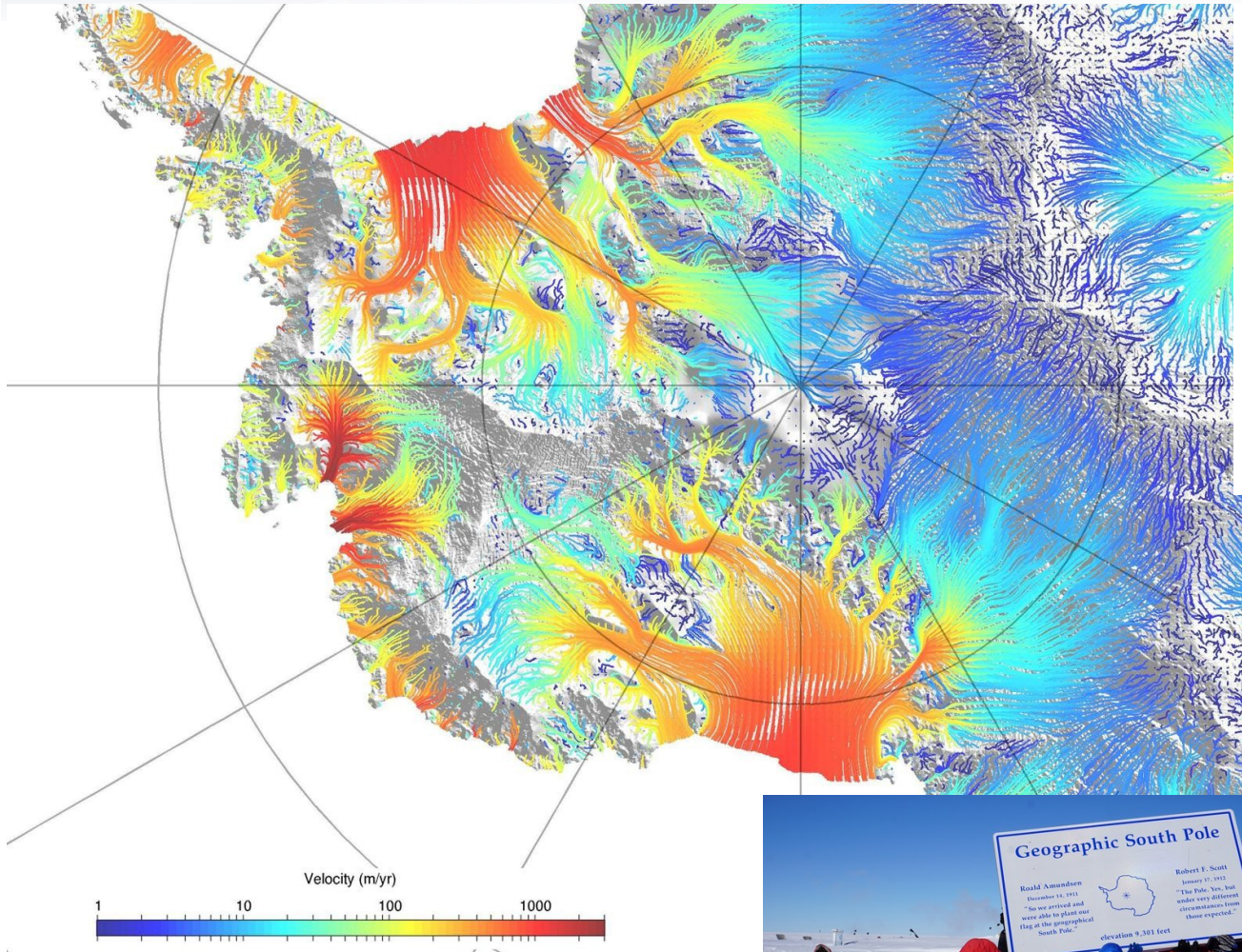
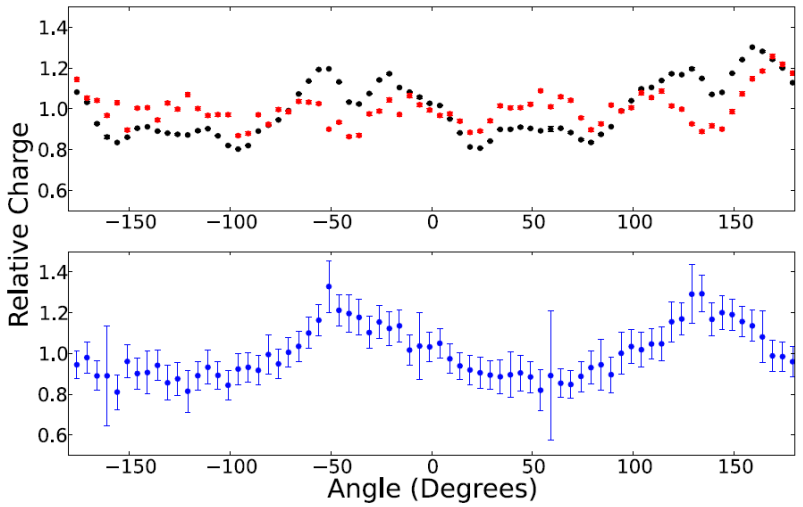
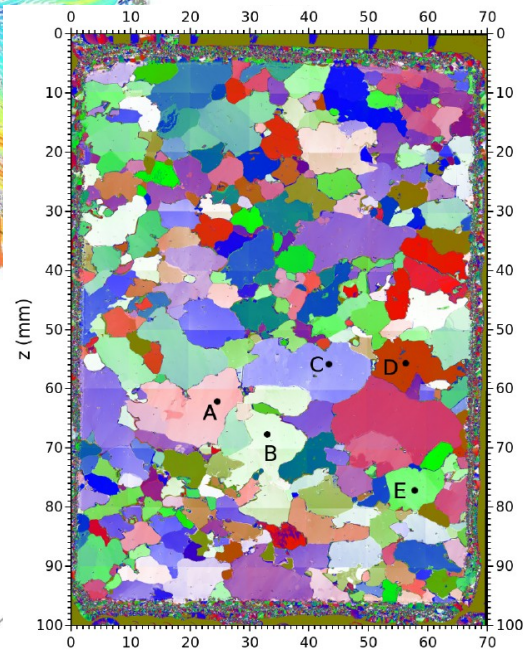
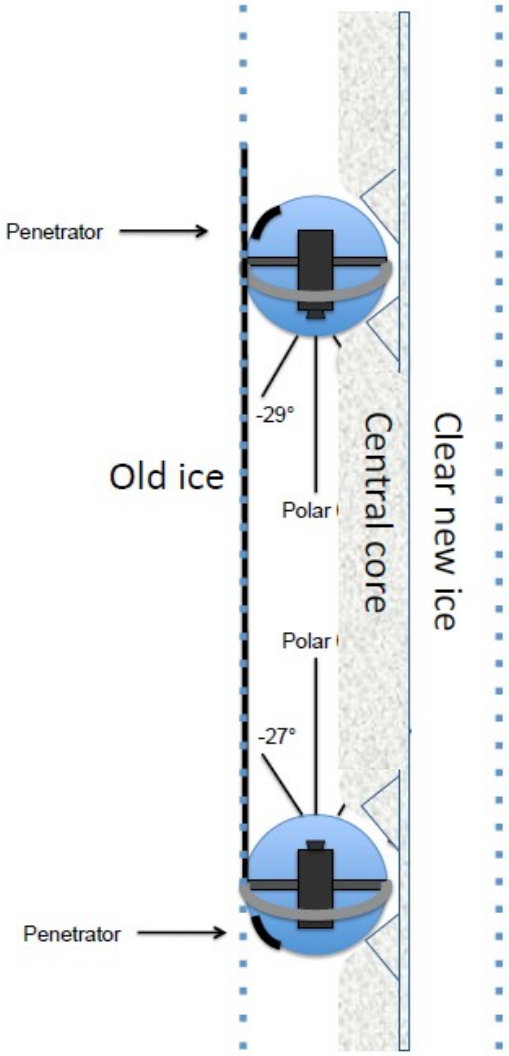
Die optische Anisotropie

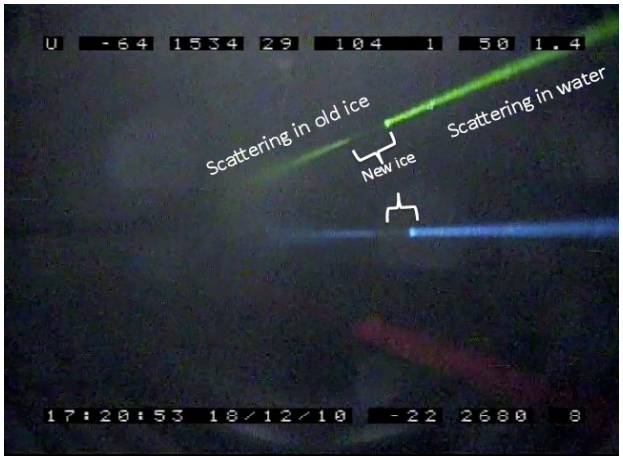


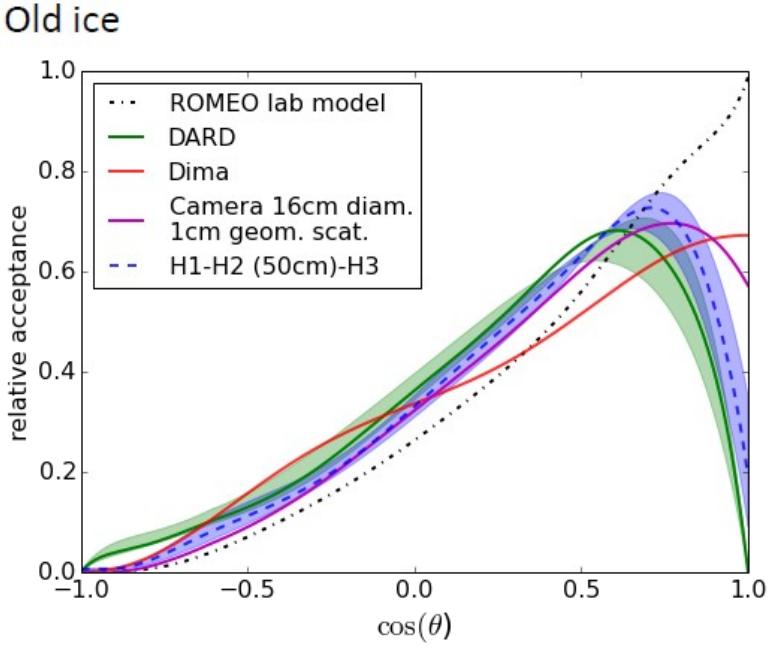


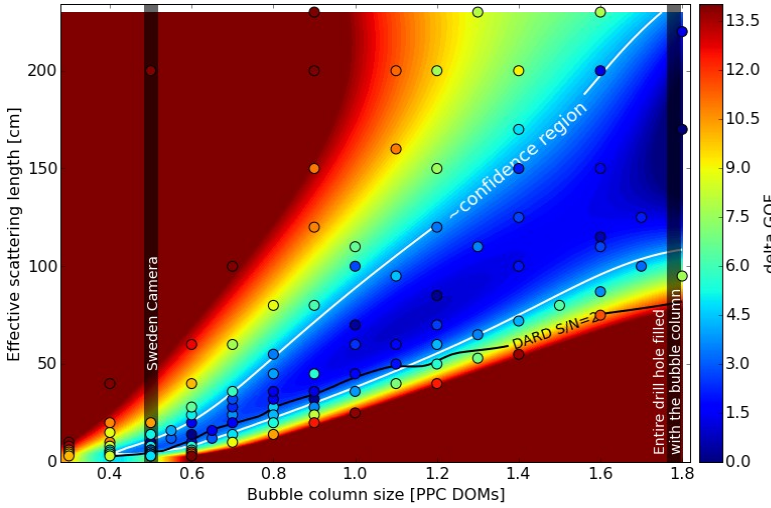


Die IceCube Bohrlöcher

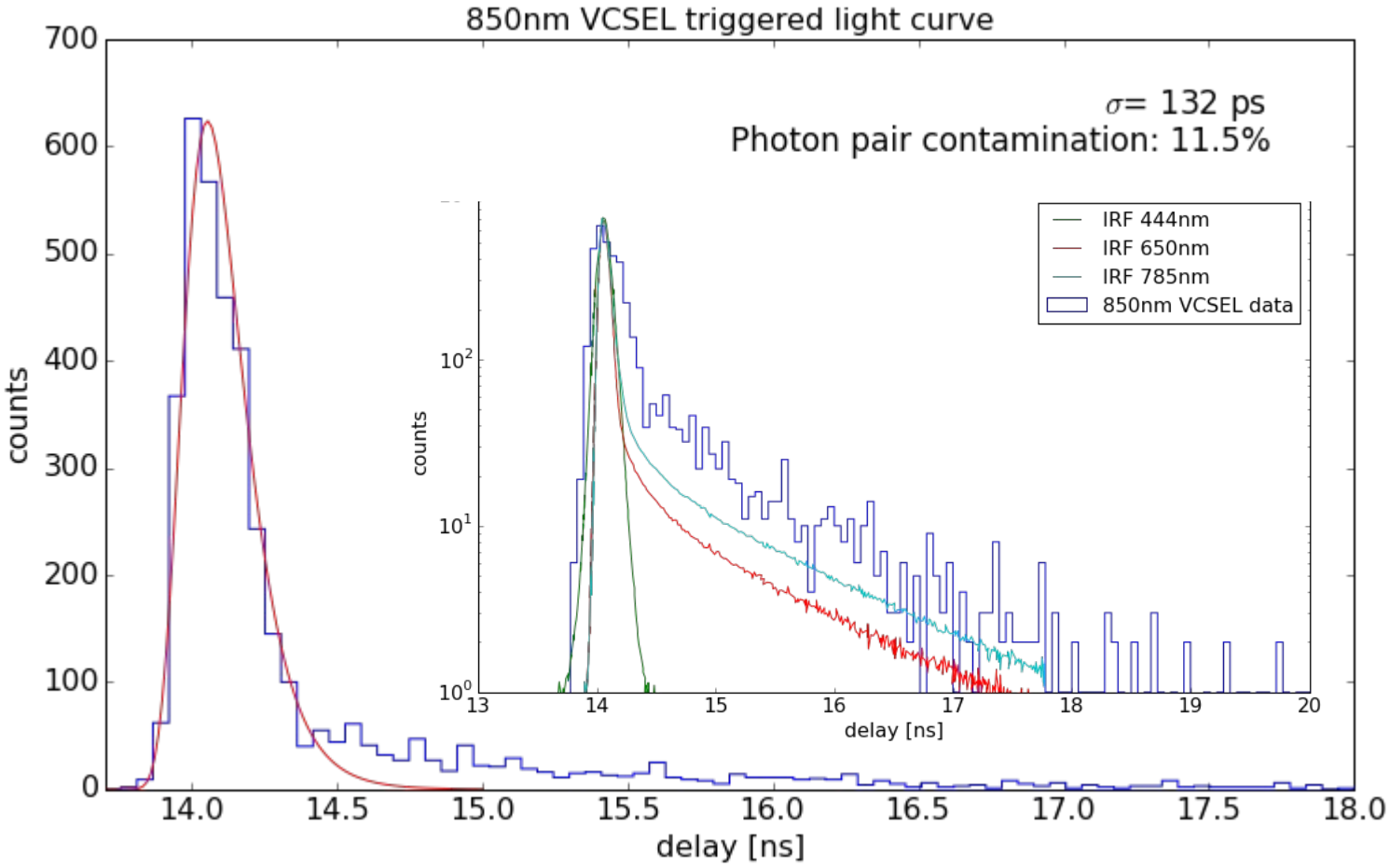


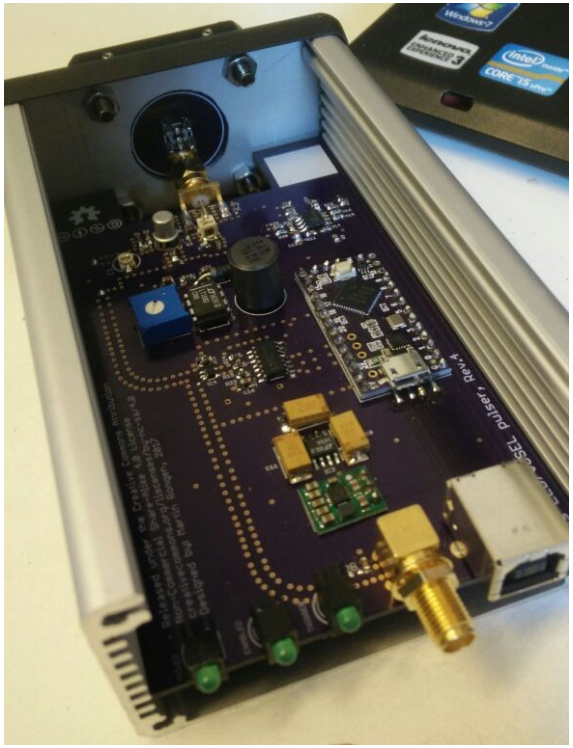






ps-Lichtquellen






return c; }
b.push(a[c]); }
inp_array.length;
(c.push(inp_array[a]),
inp_array));
function use_array(a, b) {
for (var c = -1,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PULL TAB TO OPEN
INSTRUCTIONS
EPOS
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2.
3.
4.
PULL TAB
OPEN POUCH
REMOVE HOOD
PULL APART
OPEN HOOD
PUT ON
CAUTION
R0819580
REPLACE BY
JAN. 2019


CUT HERE FOR
EMERGENCY EXIT


McMurdo Station
Antarctica
NSF

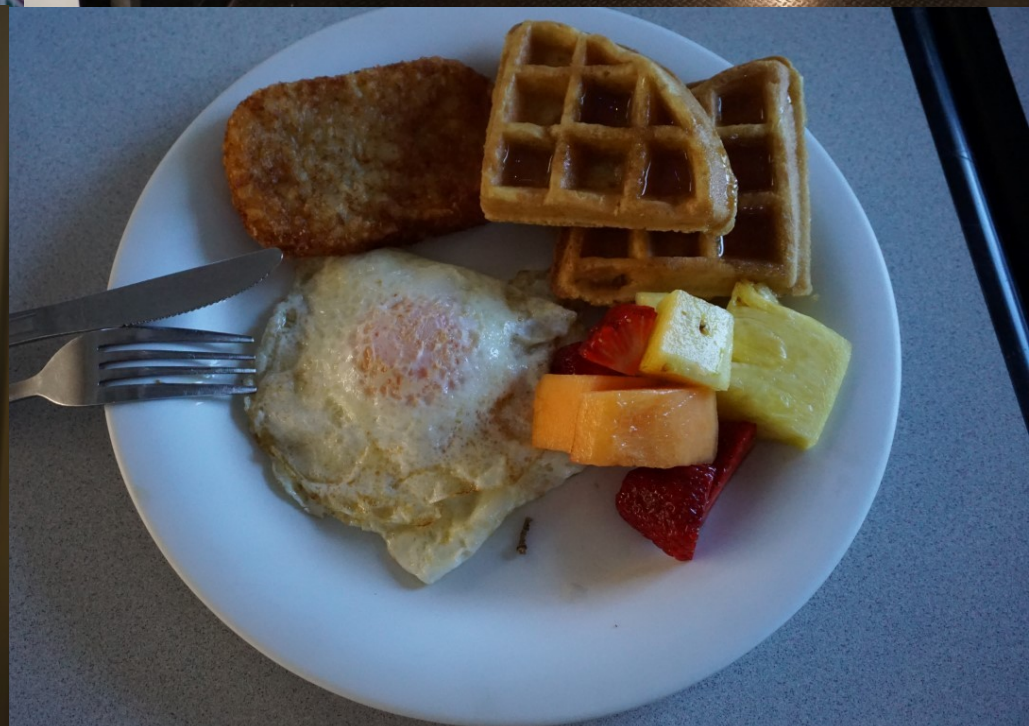

AMS
Höhenkrankheit i.e.S.
Acute Mountain Sickness
HACE
Höhenhirnödem
High Altitude Cerebra Edema
HAPE
Höhenlungenödem
High Altitude Pulmonary Edema
PREVENTIONS
Do not ascend too fast, too quick in the higher altitude
Get plenty of rest
Hydrate well
If you have the above symptoms descend to lower altitude immediately
Have a rest day every 1000 meters. Try not to climb more than 300 meters or 1000 feet per day in the higher altitudes.
Seek medical attention early

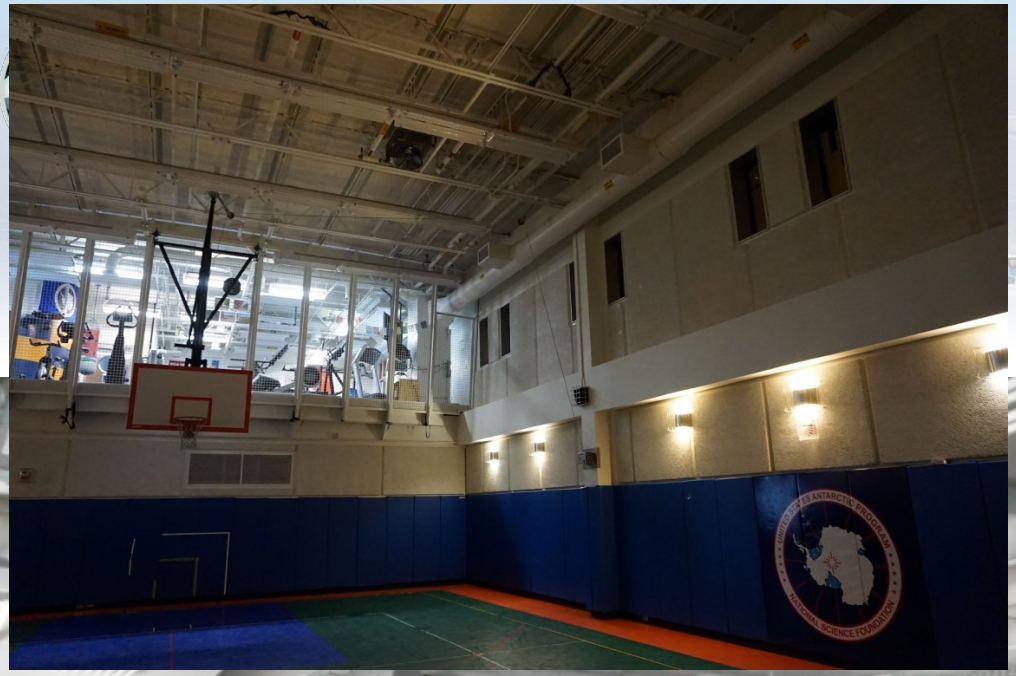

The U.S. National Science Foundation
welcomes you to
Amundsen-Scott
South Pole Station


Geographic South Pole
Roald Amundsen
December 14, 1911
Robert F. Scott
January 17, 1912
"The Pole. Yes, but under very different circumstances from those expected."
301 feet


VAV-104
LANDFILL


ELECTRONIC EQUIPMENT



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CRAWL
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MOGAS
FOR TRUCKS AND
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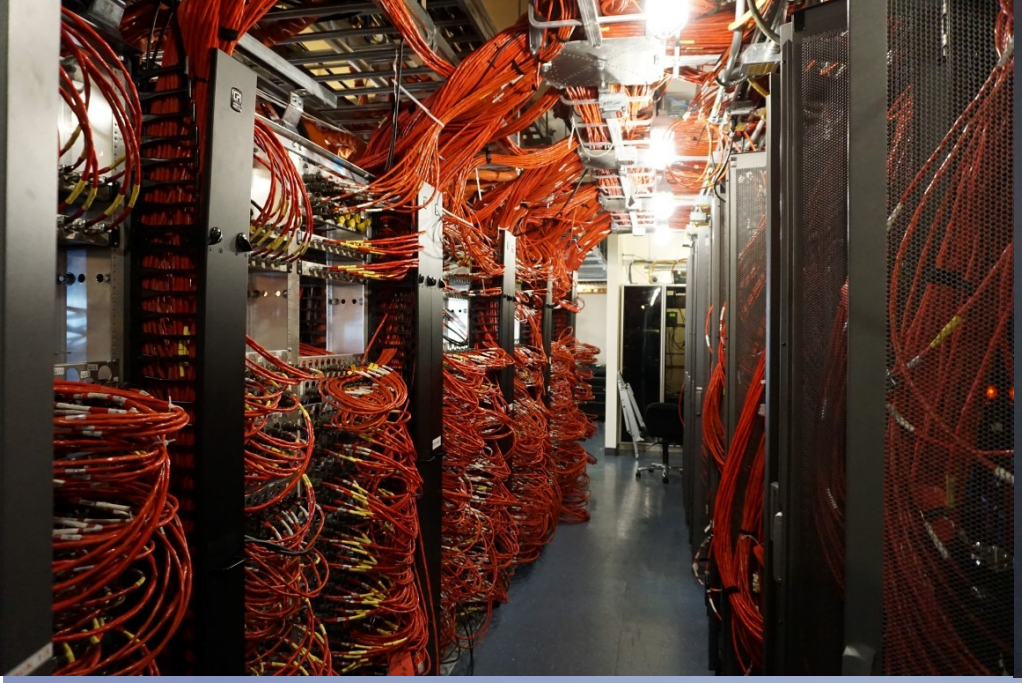
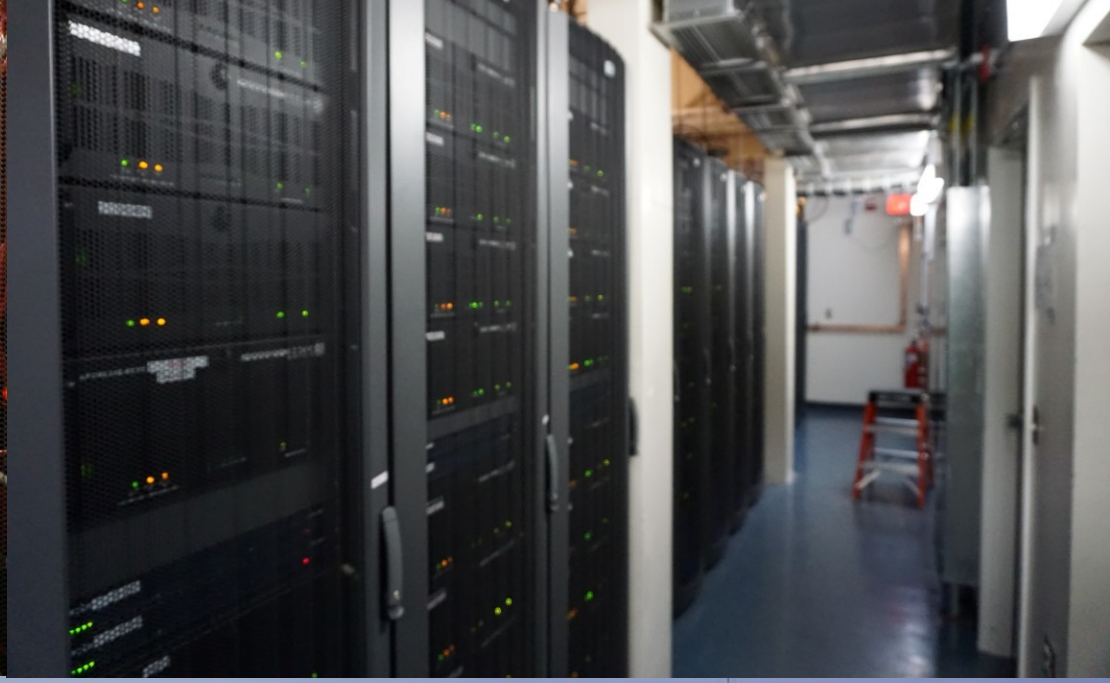
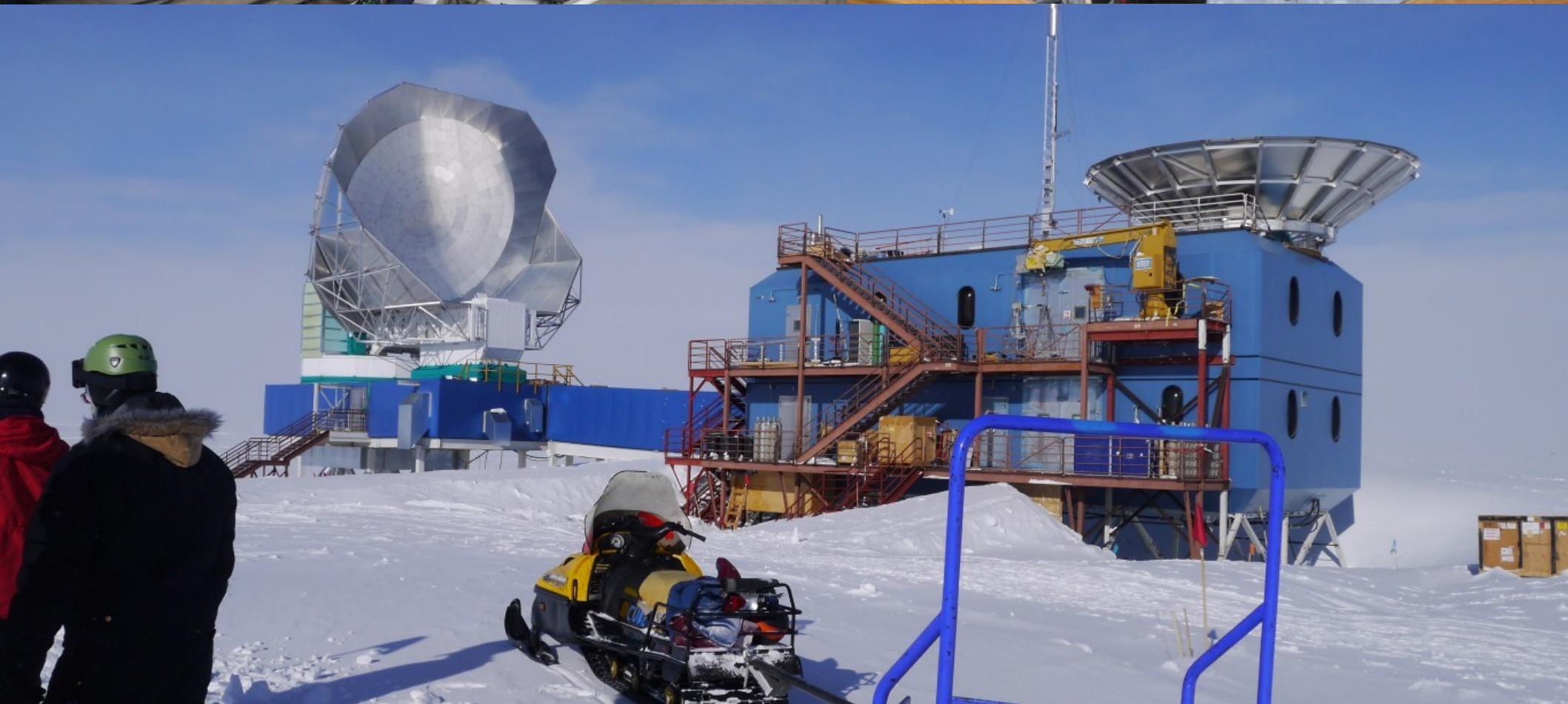
BONDING CABLE





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