First evidence of Reactor $\overline{\nu}_e$ in water

一个灌水才能出来的成果

张洋　山东大学

2023. 09. 08

PHYSICAL REVIEW LETTERS

Evidence of Antineutrinos from Distant Reactors Using Pure Water at SNO+

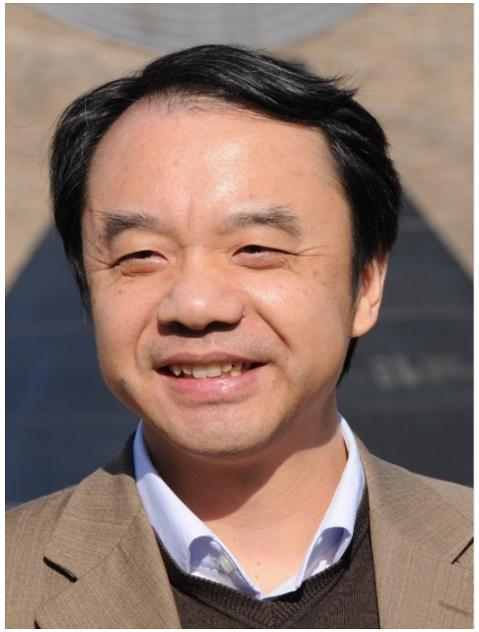
A. Allega *et al.* (The SNO+ Collaboration)
Phys. Rev. Lett. **130**, 091801 – Published 1 March 2023

Physics See synopsis: Reactor Neutrinos Detected by Water

PHYSICAL REVIEW LETTERS **130,** 091801 (2023)

The SNO+ Collaboration reports the first evidence of reactor antineutrinos in a Cherenkov detector. The nearest nuclear reactors are located 240 km away in Ontario, Canada. This analysis uses events with energies lower than in any previous analysis with a large water Cherenkov detector. Two analytical methods are used to distinguish reactor antineutrinos from background events in 190 days of data and yield consistent evidence for antineutrinos with a combined significance of 3.5σ.

“通过纯水的切伦科夫效应测量反应堆中微子是一个全新的成就，实验技术上极其困难。这种新方法和技术为未来中微子实验开辟了一条新的道路。祝贺山东大学张洋教授及其团队！”



中科院院士，高能所所长王贻芳院士

潘诺夫斯基实验粒子物理学奖-2014
基础物理学突破奖-2016
国家自然科学一等奖-2016
未来科学大奖“物质科学奖”-2019

美国《Physics》杂志

Reactor Neutrinos Detected by Water

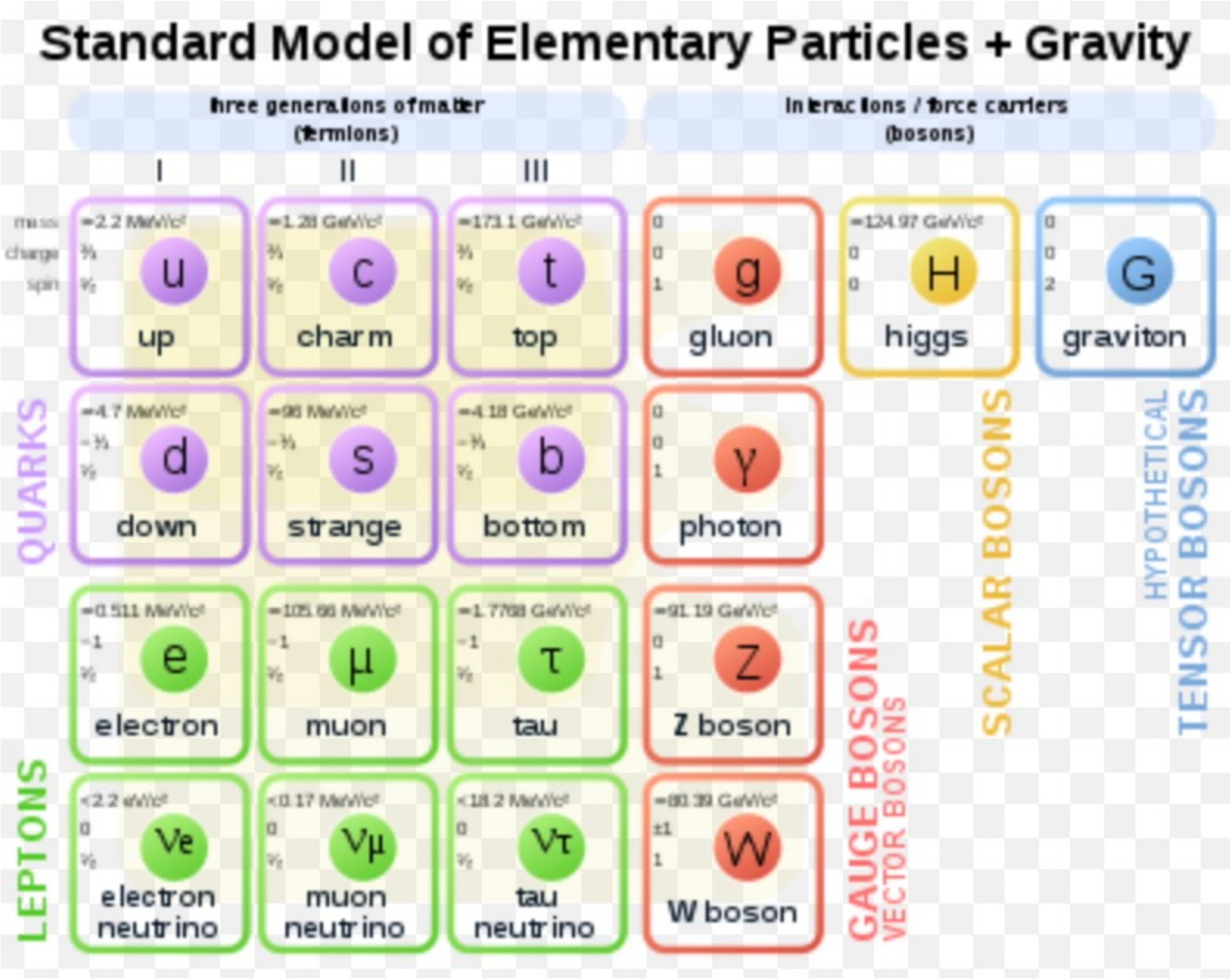
March 1, 2023 • *Physics* 16, s28

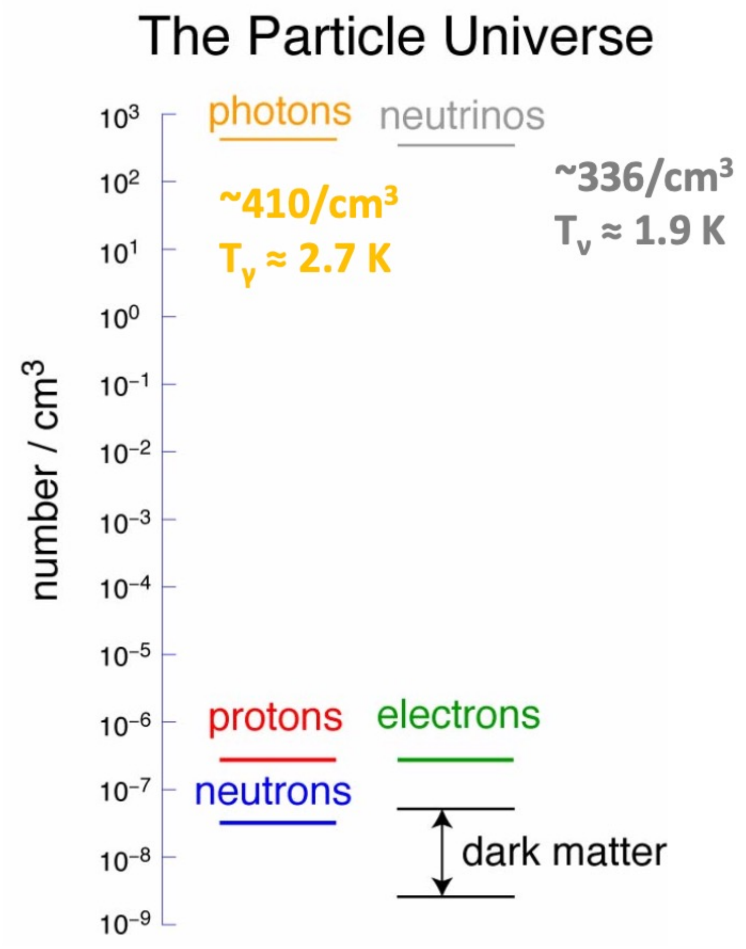
Researchers have captured the signal of neutrinos from a nuclear reactor using a water-filled neutrino detector, a first for such a device.

Viewpoint: Probing Majorana Neutrinos). But while SNO+ team members prepare for that search, they have made another breakthrough by capturing the interaction with water of antineutrinos from nuclear reactors [1]. The finding offers the possibility of making neutrino detectors from a nontoxic material that is easy to handle and inexpensive to obtain, key factors for use of the technology in auditing the world’s nuclear reactors (see **Feature: Neutrino Detectors for National Security**).

U.S. DEPARTMENT OF ENERGY
Science News

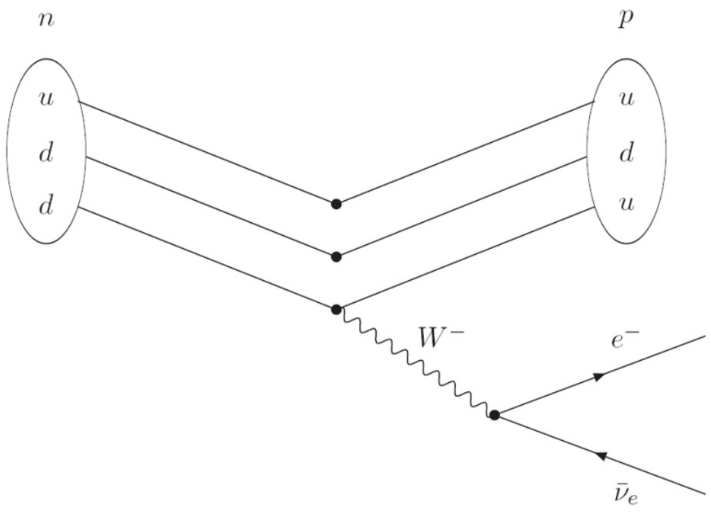
DOE Highlight


Standard Model of Elementary Particles + Gravity
three generations of matter (fermions)
interactions / force carriers (bosons)
I
II
III
u
up
c
charm
t
top
g
gluon
H
higgs
G
graviton
d
down
s
strange
b
bottom
γ
photon
e
electron
μ
muon
τ
tau
Z
Z boson
νe
electron neutrino
νμ
muon neutrino
ντ
tau neutrino
W
W boson
QUARKS
LEPTONS
GAUGE BOSONS
VECTOR BOSONS
SCALAR BOSONS
HYPOTHETICAL
TENSOR BOSONS


The Particle Universe
number / cm³
10³
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
photons
neutrinos
~410/cm³
Tγ ≈ 2.7 K
~336/cm³
Tν ≈ 1.9 K
protons
electrons
neutrons
dark matter

Pauli’s proposal

- **The neutrino was postulated first by Wolfgang Pauli in 1930 to conserve the energy, linear and angular momentum.**



Niels Bohr

量子过程中能量不守恒

Wolfgang Ernst Pauli

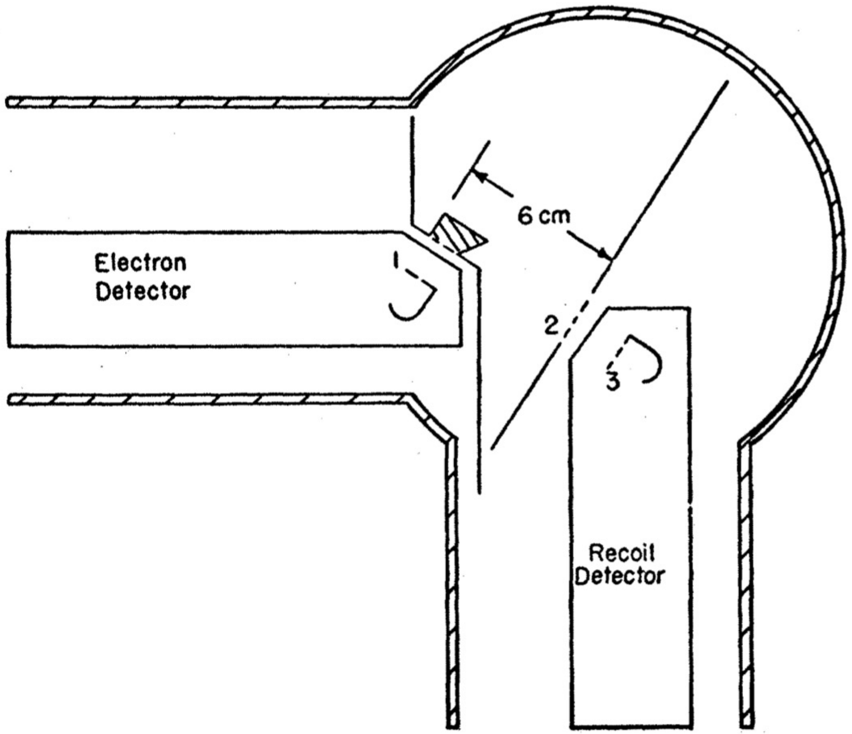
看不见的粒子，能量守恒。

1900-1958.

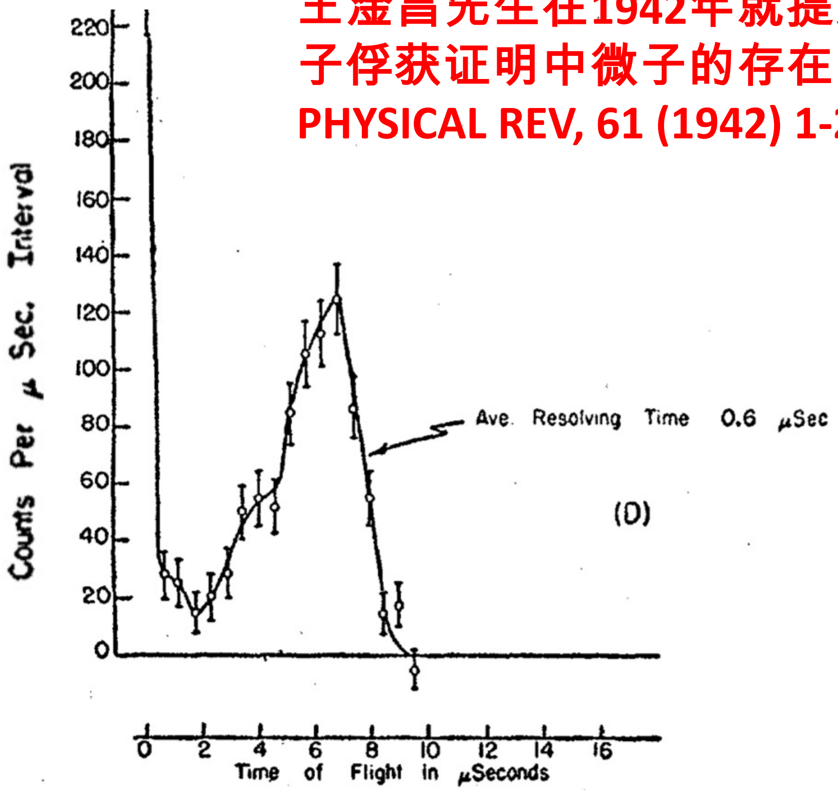
- **Pauli received the Nobel Prize for physics based on Pauli principle, not the hypothesis of neutrinos.**

中微子存在的间接证据

$^{37}Ar + e_{K,L} \rightarrow {^{37}Cl} + \nu + Q$



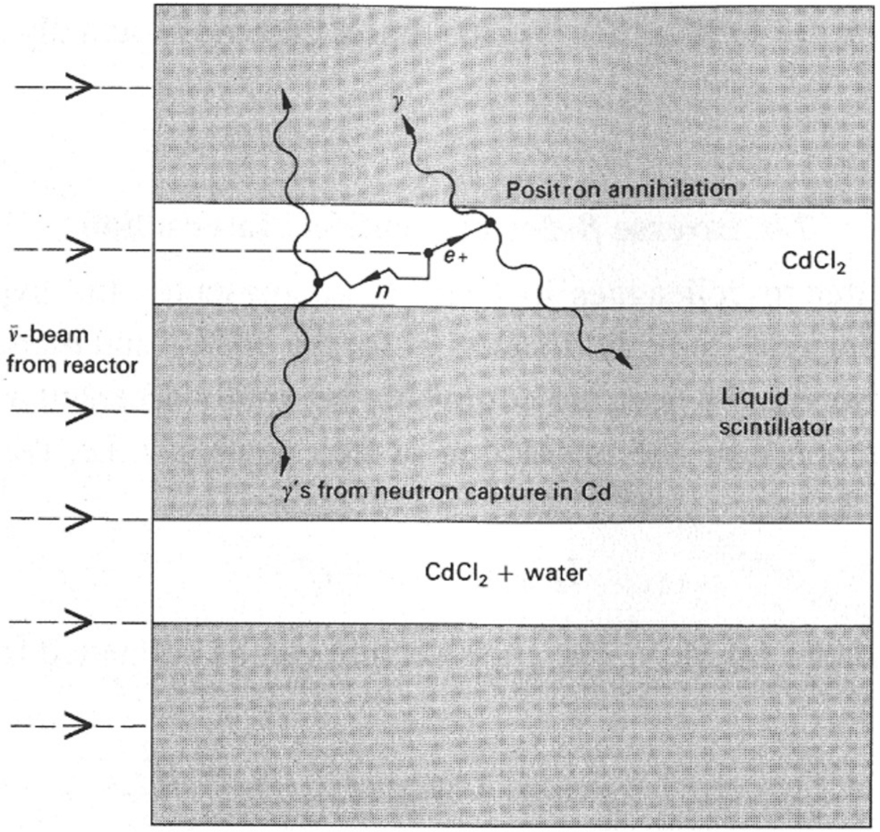
王淦昌先生在1942年就提到利用电子俘获证明中微子的存在
PHYSICAL REV, 61 (1942) 1-2, 97-97



Pointed out by H. R. Crane, Revs. Modern Phys. 20, 295 (1948)
Performed by G.W. Rodeback and J. S. Allen, PHYSICAL REV, 86, 4 (1952)

中微子存在的直接发现

Nobel lecture, 1995



So why did we want to detect the free neutrino? Because everybody said, you couldn't do it. Not very sensible, but we were attracted by the challenge.

As Bohr is reputed to have said, "A deep question is one where either a yes or no answer is interesting." So I guess this question of the existence of the "free" neutrino might be construed to be deep. Alright, what about the pro-

cross section with which you have to deal would be ~ 10^{-44} cm^2. To appreciate how minuscule this interaction is we note that the mean free path is ~ 1000 light years of liquid hydrogen. Pauli put his concern succinctly during a visit to Caltech when he remarked: "I have done a terrible thing. I have postulated a particle that cannot be detected." No wonder that Bethe and Peierls

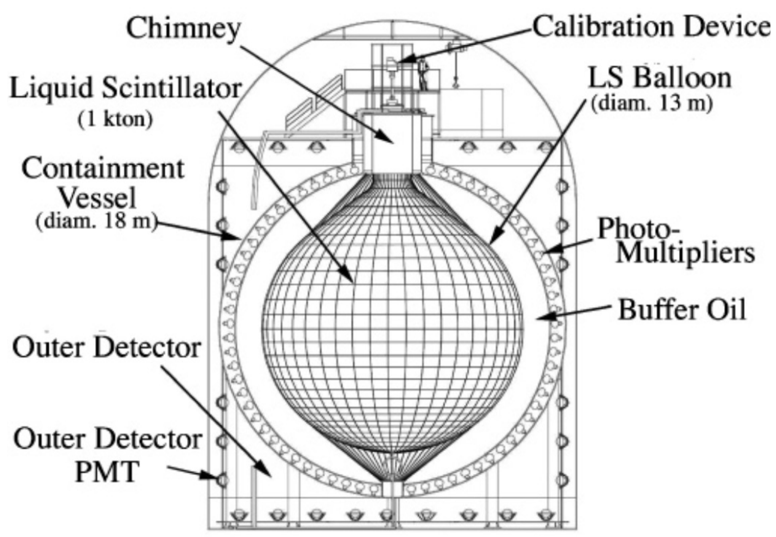
those around us. But of one thing I am certain: the open, free communication of our ideas was most stimulating to us and played a significant role in our eventual success. We were not inhibited in our communication by the concern that someone would scoop us. Neutrino detection was not a popular activity in 1952.

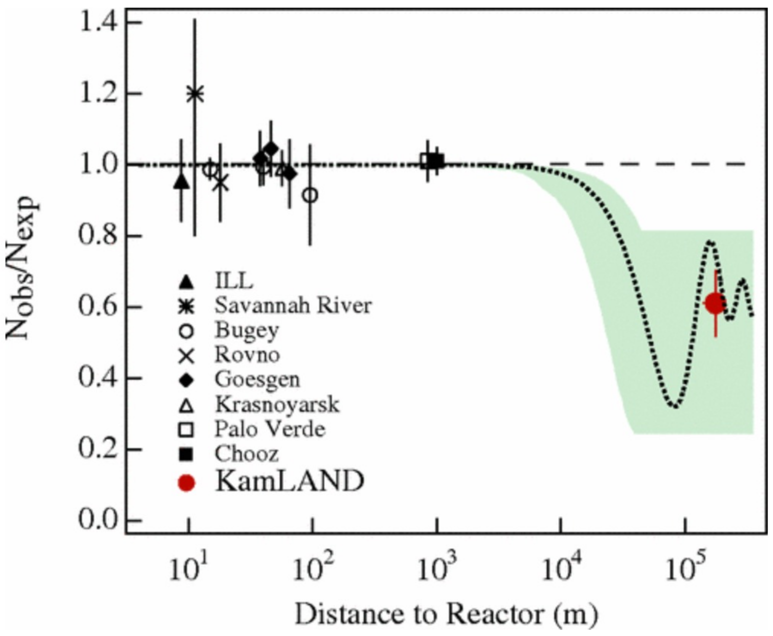
8 and says, "Thanks for the message. Everything comes to him who knows how to wait. Pauli"

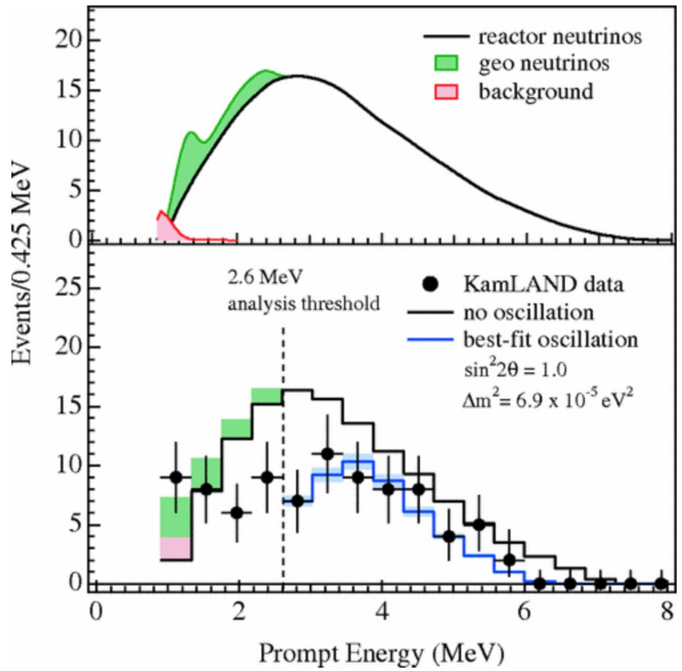
of many talented coworkers. One in particular I must mention - my very good friend and colleague Clyde Cowan, who was an equal partner in the experiments to discover the neutrino. I regret that he did not live long enough to share in this honor with me. I also wish to thank the personnel at

- **Reactor neutrinos was capitalized(1956).**
  - ✓ **IBD reaction; Enormous $\bar{\nu}_e$ flux.**
- **Reins receives the Nobel prize in 1995;**

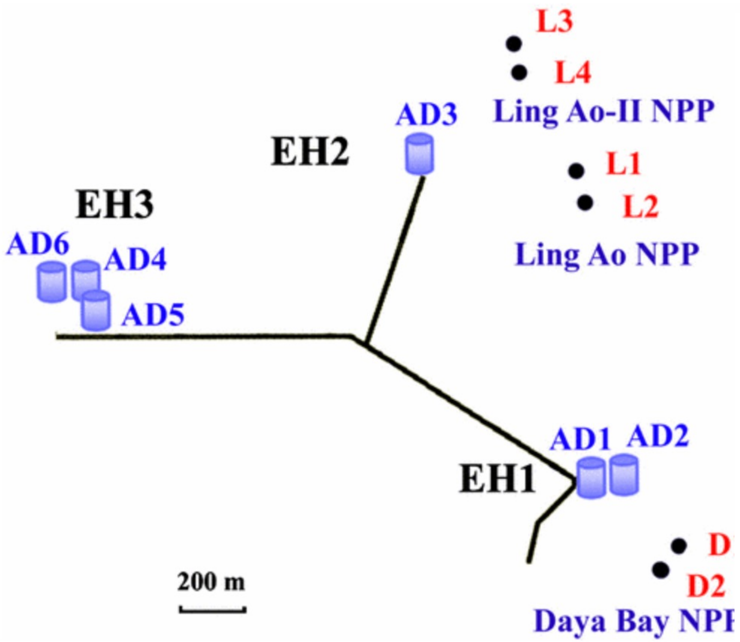
Roles of reactor neutrinos-KamLAND

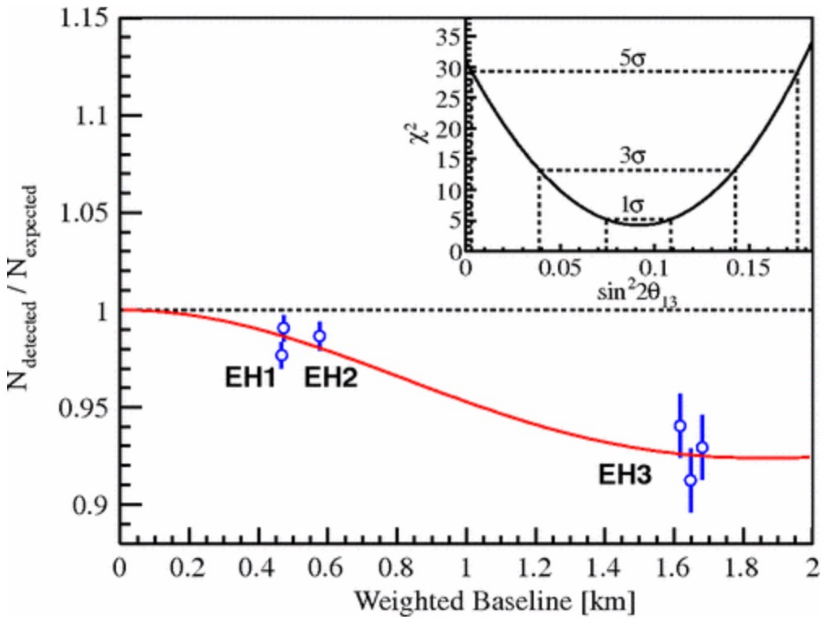


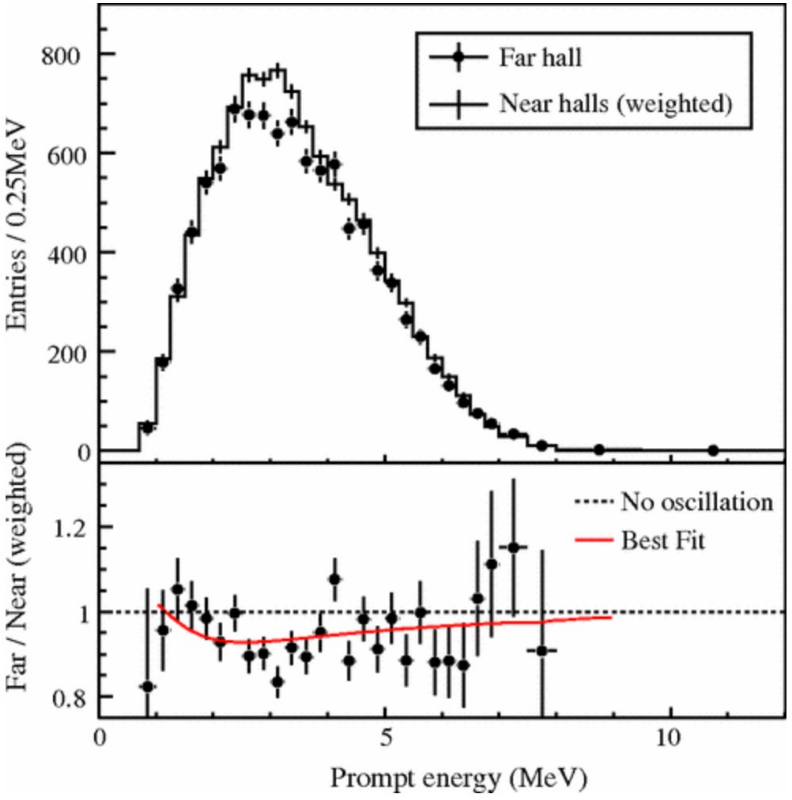




Roles of reactor neutrinos-Daya Bay



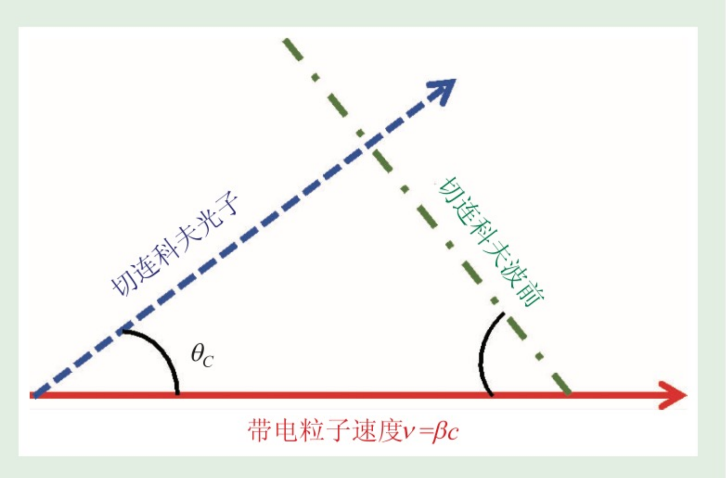


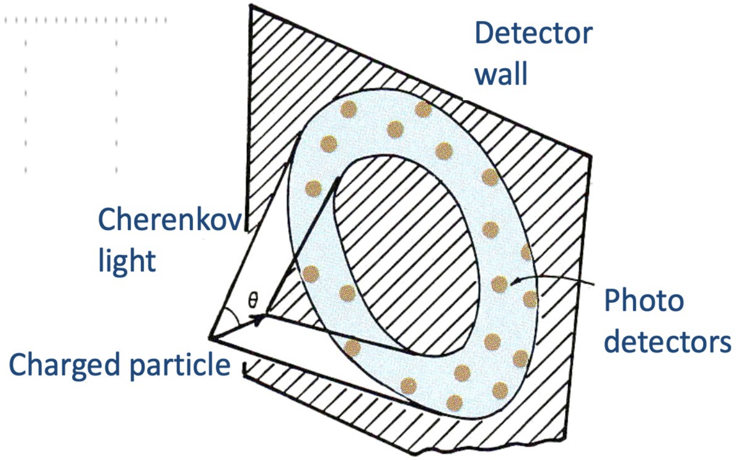


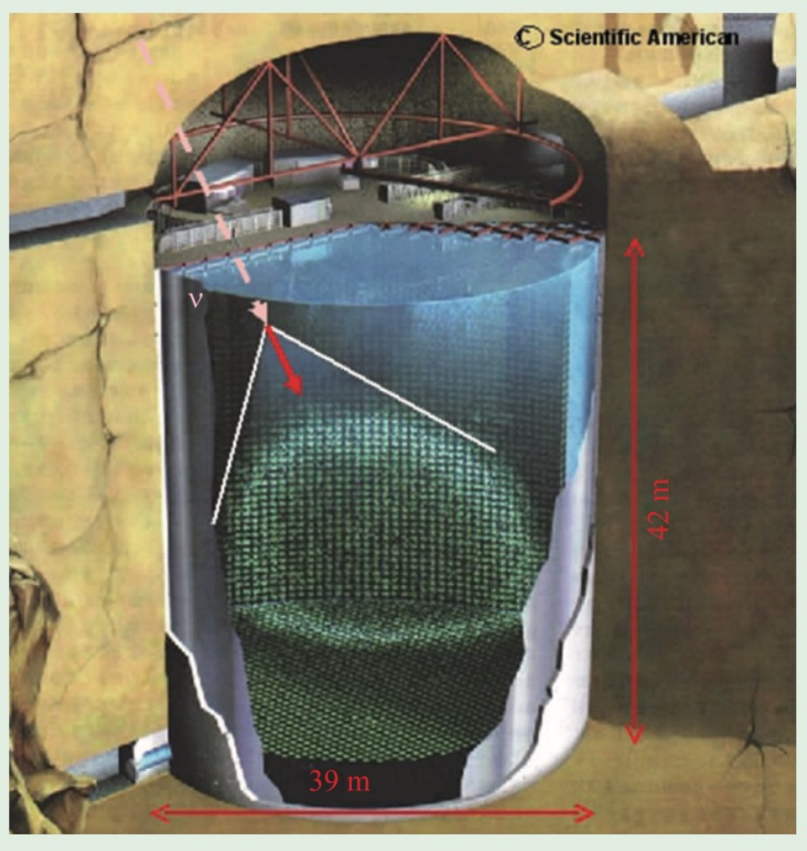
基础物理突破奖-2016

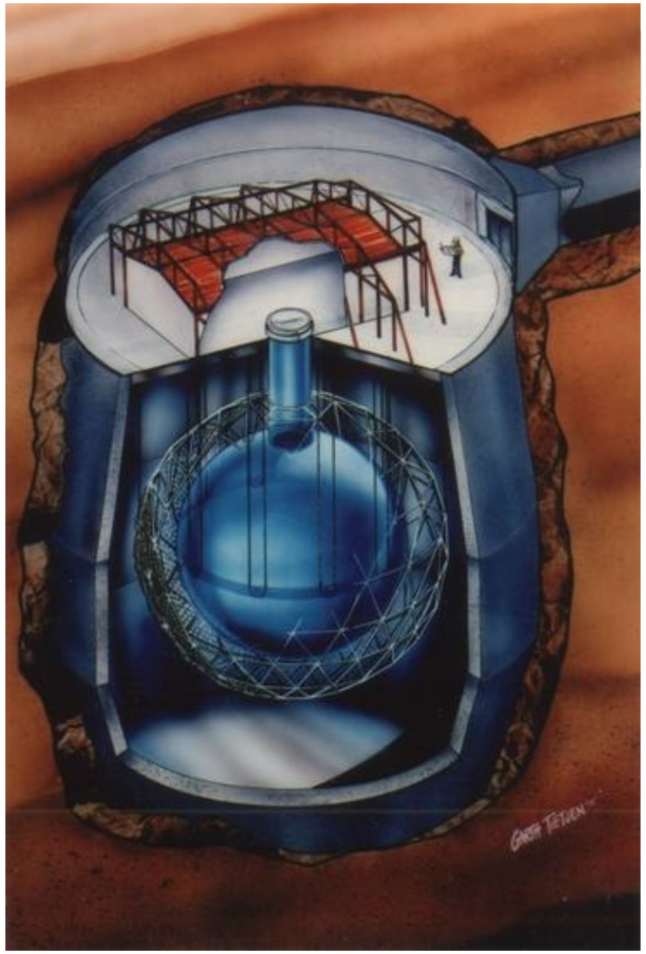
- **KamLand and Daya Bay etc. win the 2016 fundamental physics breakthrough prize.**

水契伦科夫技术





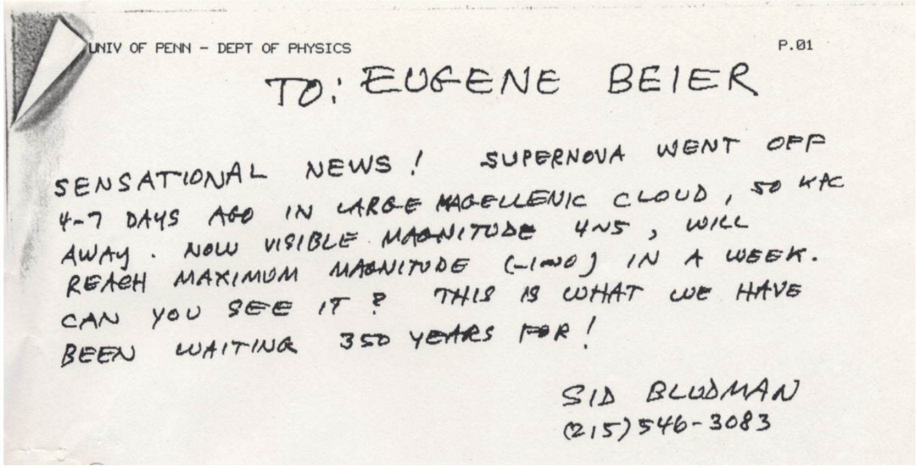




Courtesy: Kajita's nobel lecture，《物理》

昂贵的重水：~20万美元/吨
(Atomic Energy of Canada Limited (AECL)**)**

水契伦科夫技术-Kamiokande

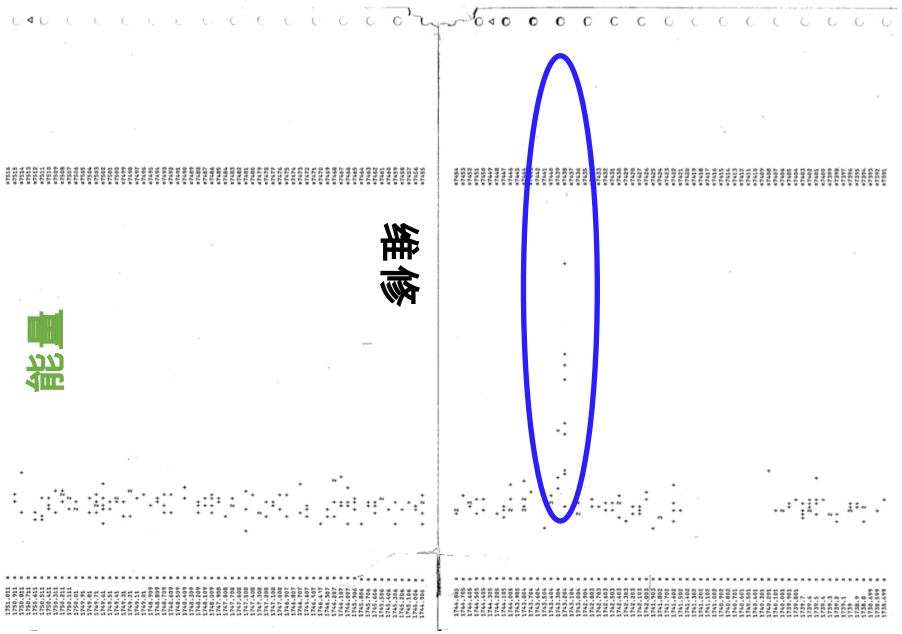


UNIV OF PENN - DEPT OF PHYSICS P.01

TO: EUGENE BEIER

SENSATIONAL NEWS ! SUPERNOVA WENT OFF
4-7 DAYS AGO IN LARGE MAGELLENIC CLOUD, 50 KPC
AWAY. NOW VISIBLE MAGNITUDE 4~5, WILL
REACH MAXIMUM MAGNITUDE (~1~0) IN A WEEK.
CAN YOU SEE IT ? THIS IS WHAT WE HAVE
BEEN WAITING 350 YEARS FOR !

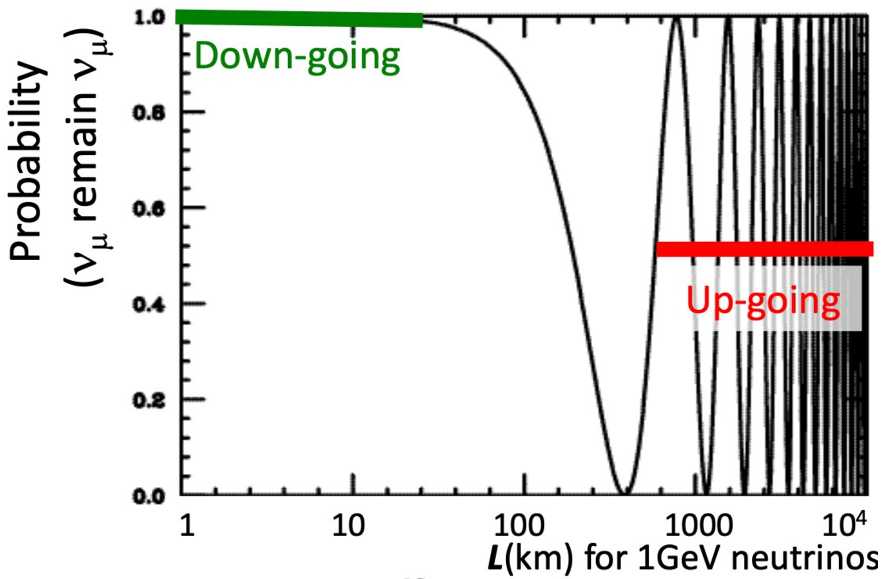
SID BLUDMAN
(215)546-3083

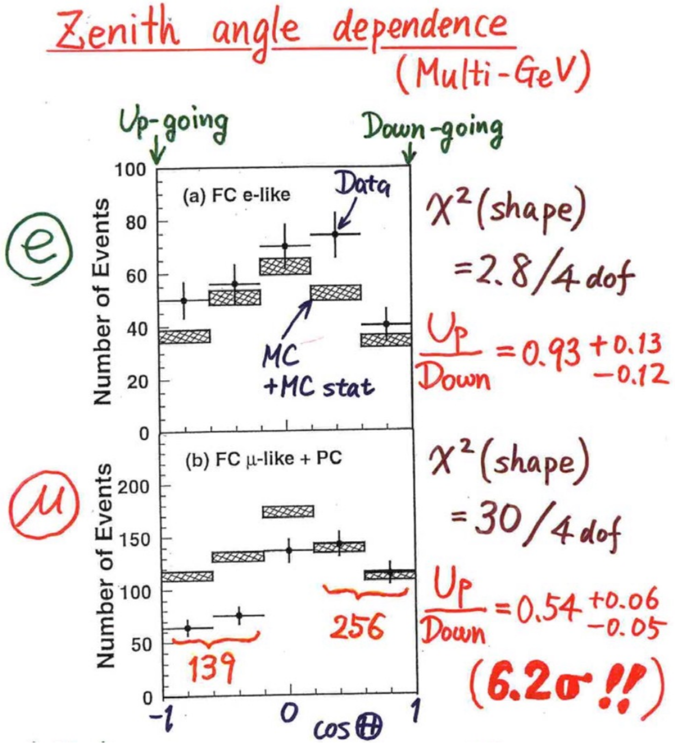


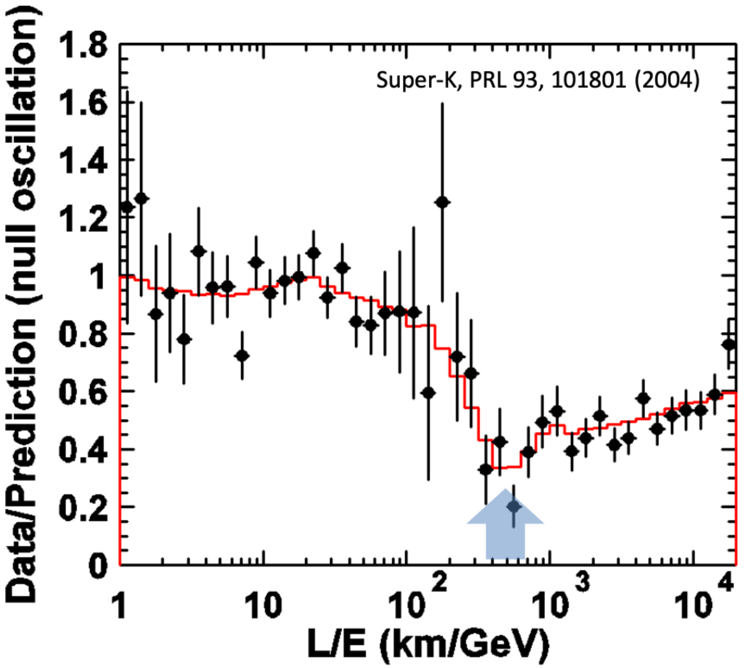
小柴昌俊
诺贝尔2002

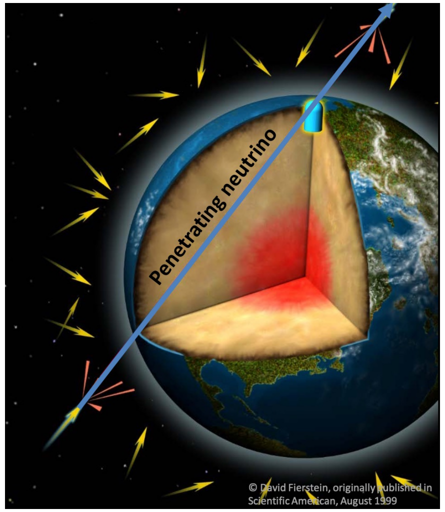
中微子天文学的开启!

水契伦科夫技术-SK









A dip is seen around L/E = 500 km/GeV.
➔ *Really oscillations (2004) !!*

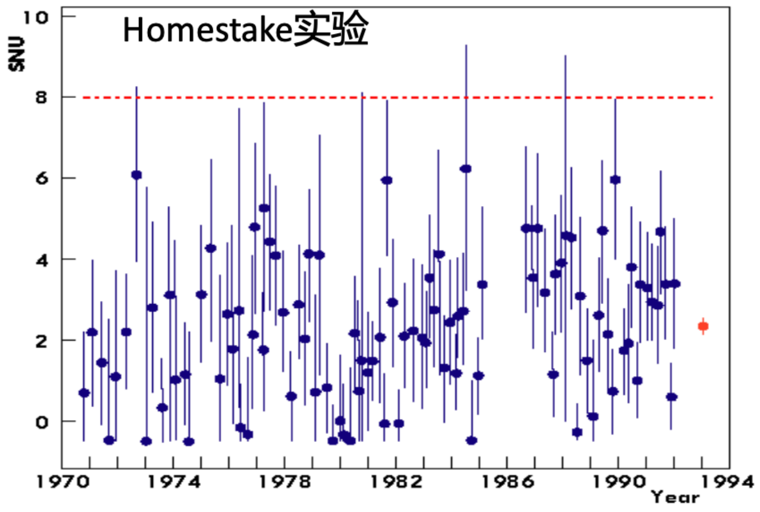
PHYSICAL REVIEW LETTERS

Featured in Physics | Milestone | Free to Read

水契伦科夫技术-SNO

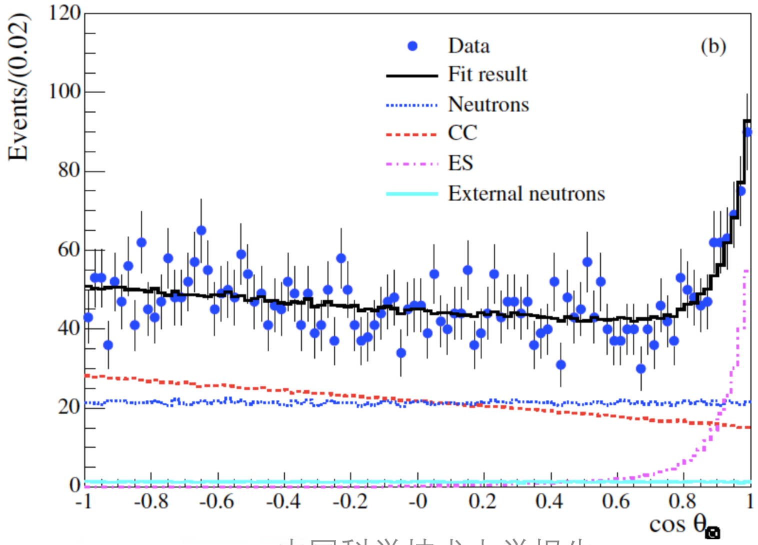
Herbert H. Chen（陈华森）
(1942 - 1987)

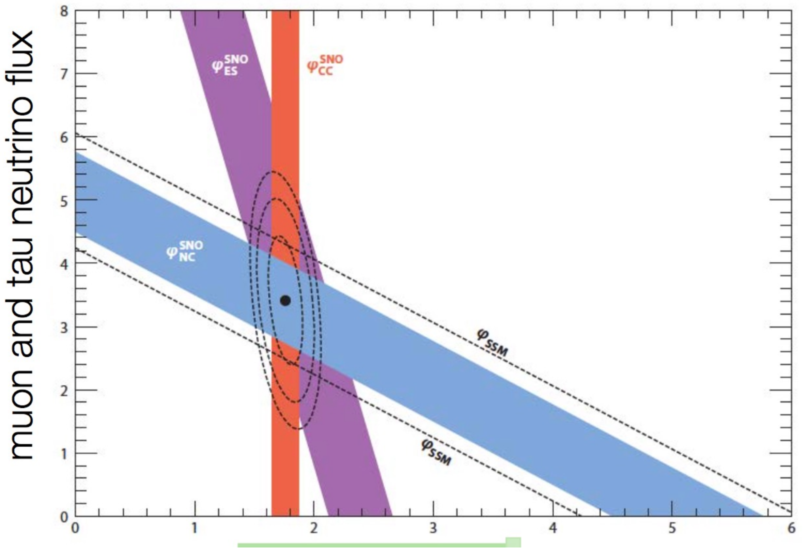
$$\nu_e + {}^{37}Cl \rightarrow {}^{37}Ar + e^-$$



首次观测到太阳中微子，但与预期不符！

$$\text{CC}: \nu_e + d \rightarrow p + p + e^- - 1.442\,\text{MeV}$$
$$\text{NC}: \nu_x + d \rightarrow p + n + \nu_x - 2.224\,\text{MeV}$$
$$\text{ES}: \nu_x + e^- \rightarrow \nu_x + e^-$$





Nobel physics prize 2015

© Nobel Media AB. Photo: A. Mahmoud

Takaaki Kajita

© Nobel Media AB. Photo: A. Mahmoud

Arthur B. McDonald

Discovery of atmospheric neutrino oscillation at SK

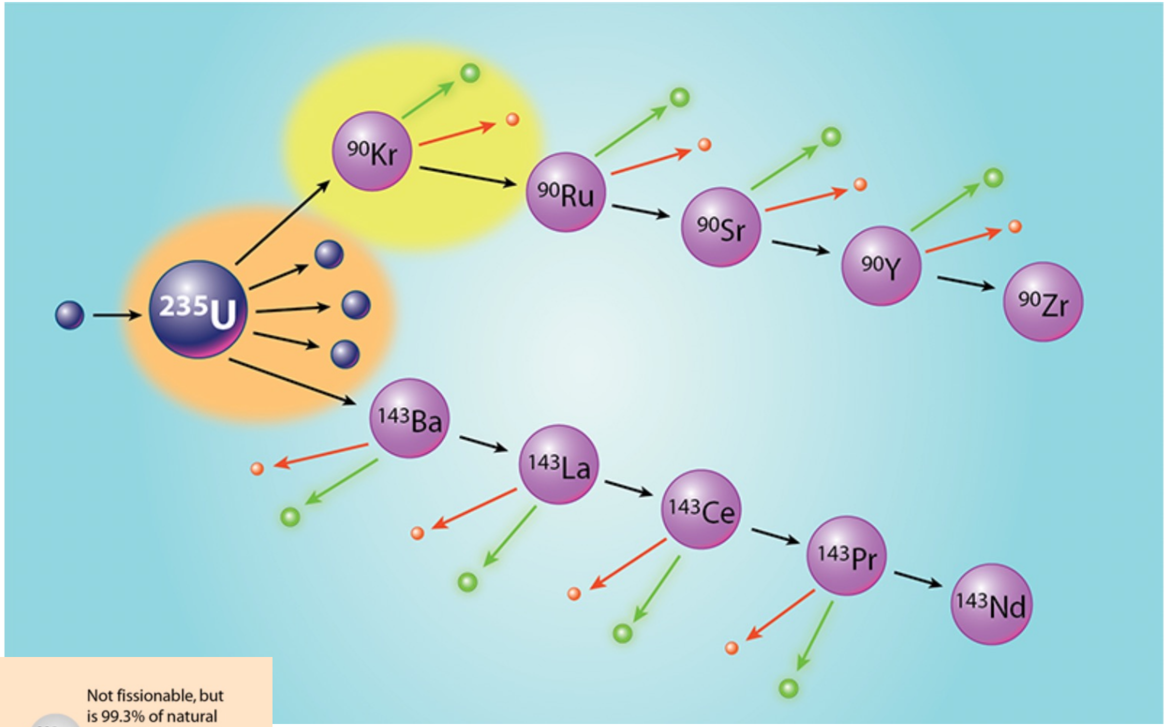
&

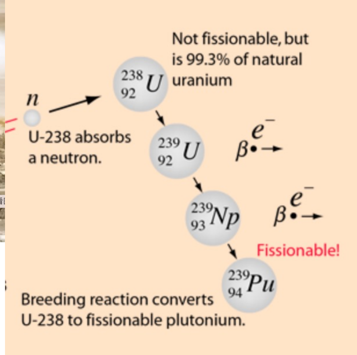
Discovery of solar neutrino oscillation at SNO

The Nobel Prize in Physics 2015 was awarded jointly to Takaaki Kajita and Arthur B. McDonald "for the discovery of neutrino oscillations, which shows that neutrinos have mass."

可否用纯水来测量反应堆中微子？(Yes or No)

中微子探测和国家安全、世界和平





https://physics.aps.org/articles/v13/36

FEATURE

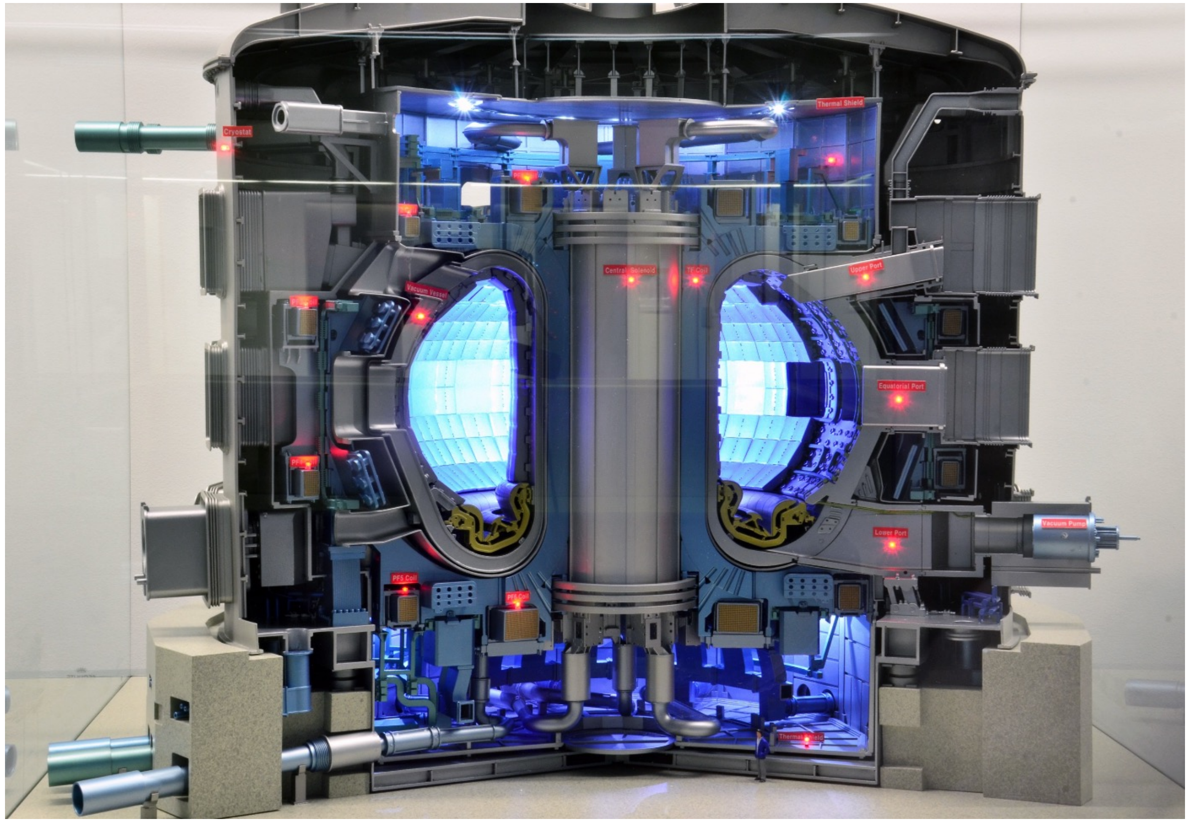
Neutrino Detectors for National Security

March 12, 2020 • *Physics* 13, 36

Detecting neutrinos offers a new way to monitor the potential bomb materials inside a nuclear reactor, but the technology's practicality remains uncertain.

The cost of these detectors also presents a significant implementation barrier, since building and operating even one detector could potentially require a large fraction of the annual nuclear verification budget (about $170 million) of the International Atomic Energy Agency (IAEA), the organization that audits nuclear reactors. So the IAEA has no immediate plans to use the technology. But researchers are still hopeful that the technology will find use. "This kind of monitoring is eminently feasible. We have already done it and could do it at other reactors fairly easily," says Bryce Littlejohn, a nuclear physicist at the Illinois Institute of Technology in Chicago.

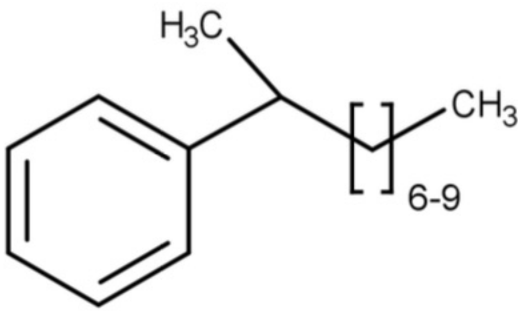
核反应堆的实时无接触式监测

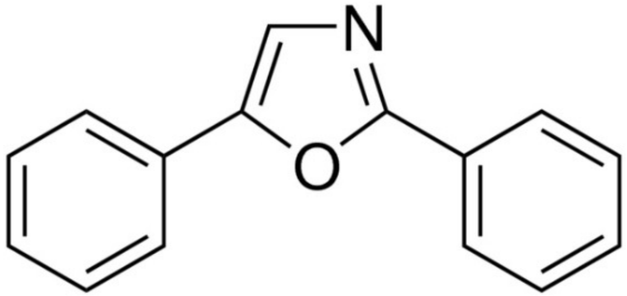


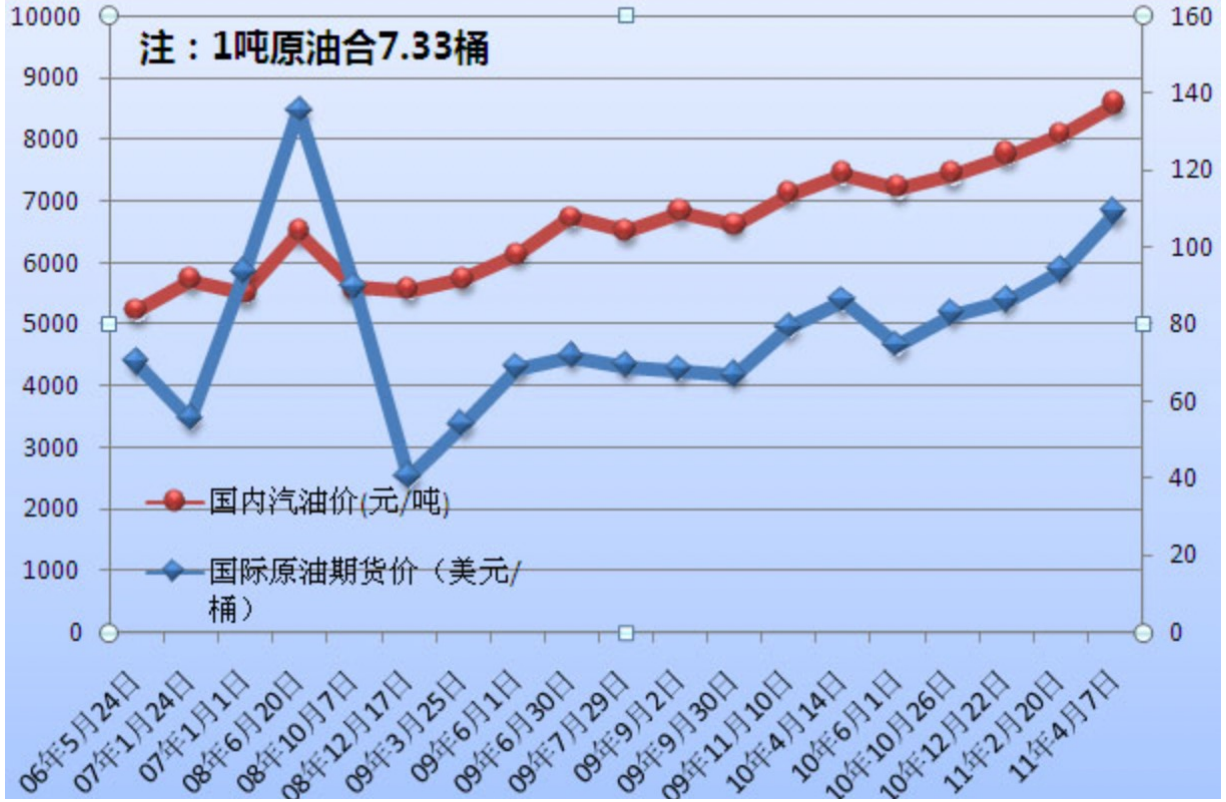
$\sim 10^{20}\ \overline{\nu}_e/\mathrm{GW_{th}},\ \propto \frac{1}{R^2}$，概率 $\sim 1/10^{19}$.

- 中微子探测器需要大的靶质量

探测器材料-价格

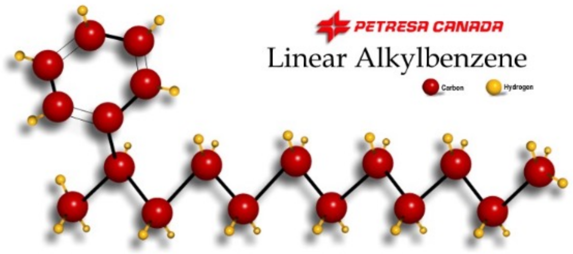






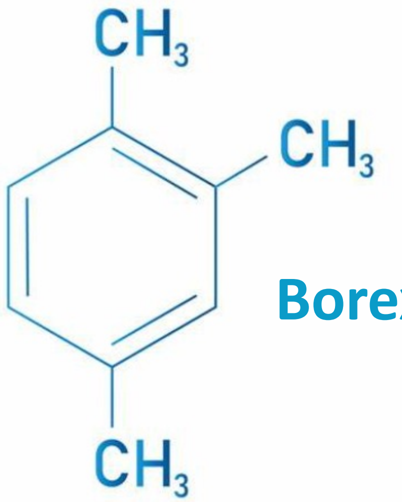
- 光产额是水契伦科夫探测器的50倍，但是贵！
  - 千吨级的探测器：~$5 million/千吨。还在涨！水的价格忽略不计。
  - 需要多个探测器：价格成倍增长；~450 个反应堆分布在~30个国家。

探测器材料-安全性

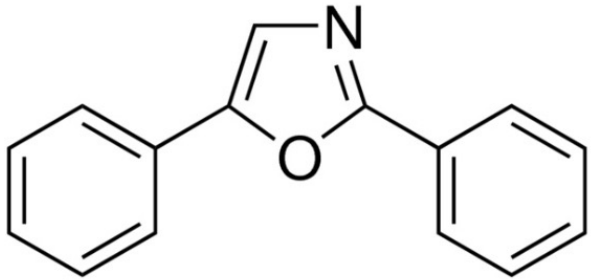


LAB (solvent)

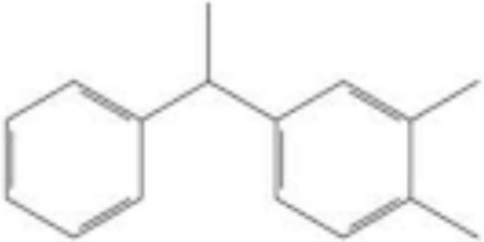
PC

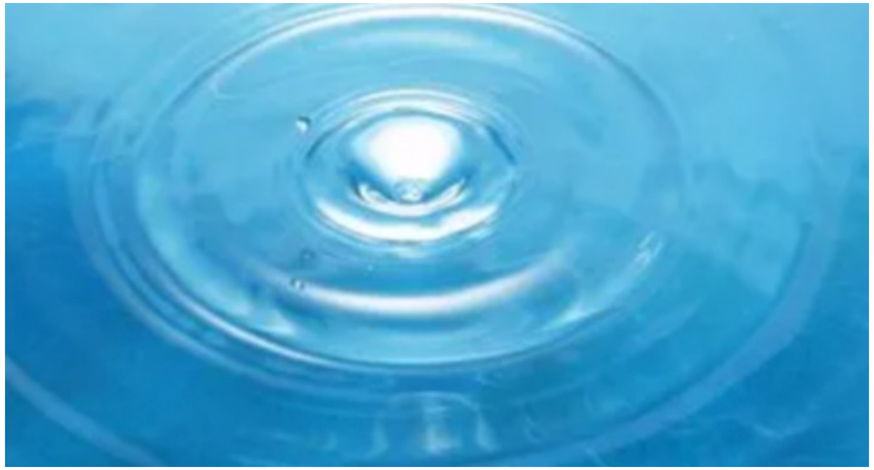


Borexino



PXE



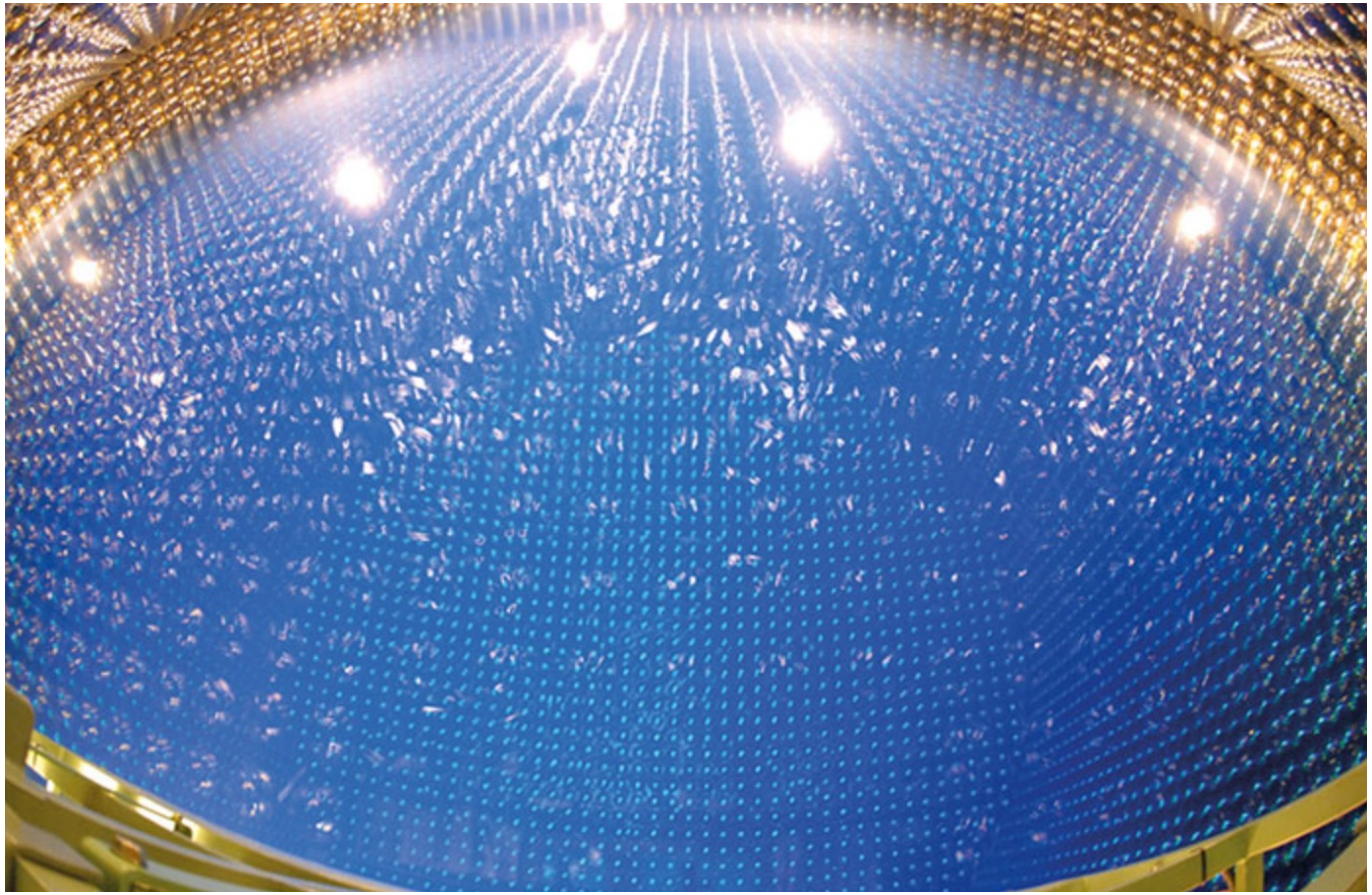


挥发性、毒性和易燃等缺点

e.g. 意大利Borexino实验 shut down 2021.10

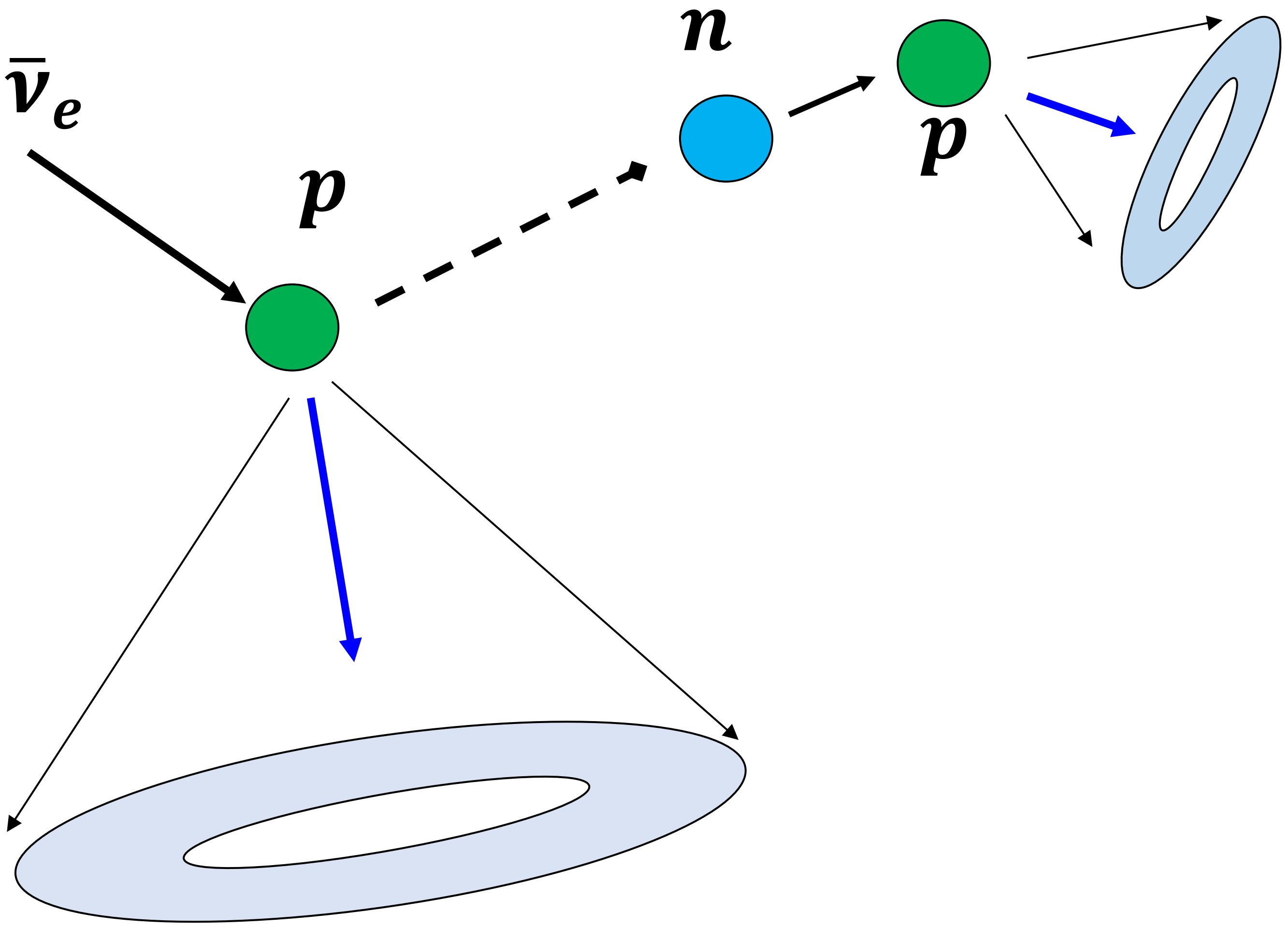
纯天然，最安全

探测器透明度-靶质量



液体闪烁体：~20 米
水：>100 米 。 因此探测器可以做的很大，譬如百万吨级别。

反应堆中微子在水中的测量



关键是中子的高效率测量

中子测量在纯水中可行吗(Yes or No)

Y. Suzuki: 2016年基础物理突破奖获得者
J. Beacom: 著名天体物理理论学家

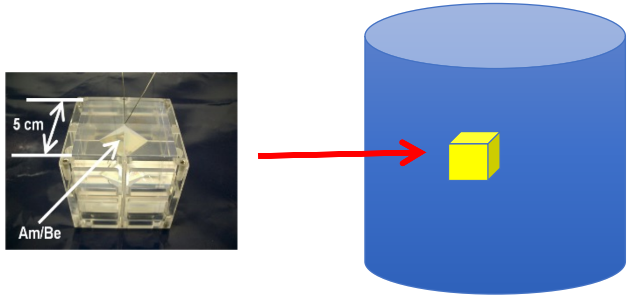
曾认为中子测量在纯水中无法实现！

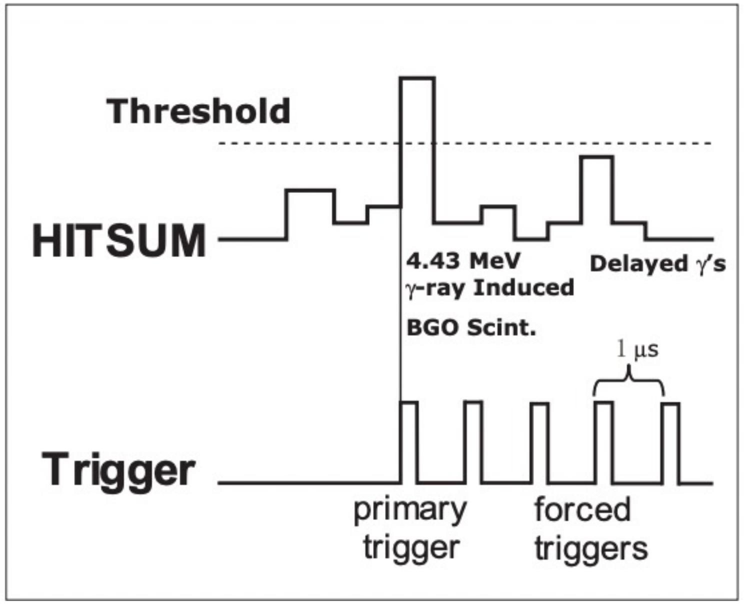
中子测量在水中的首次实现

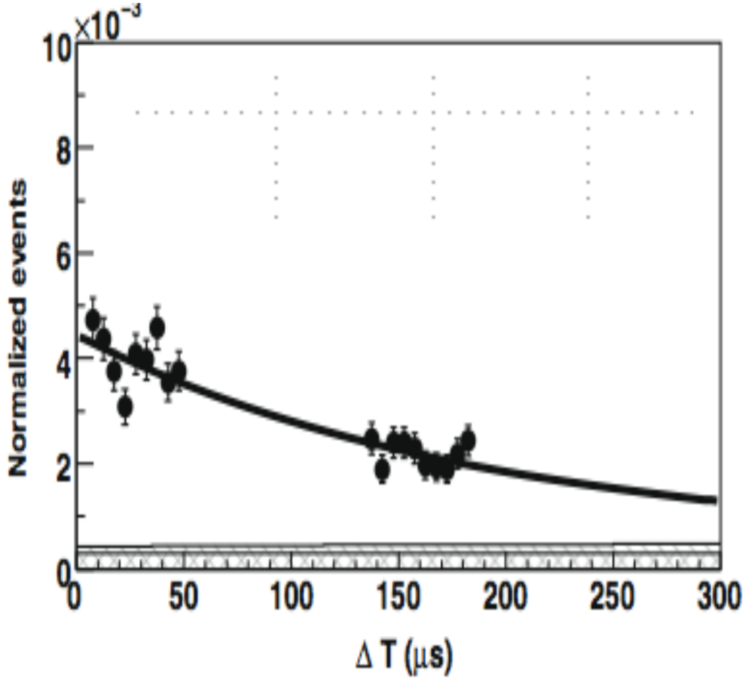
$\alpha + {}^{9}\mathrm{Be} \rightarrow {}^{12}\mathrm{C}^{*} \square n$

${}^{12}\mathrm{C}^{*} \rightarrow {}^{12}\mathrm{C} \square \gamma$ (prompt)

$n \square p \rightarrow d \square \gamma$ (delayed)







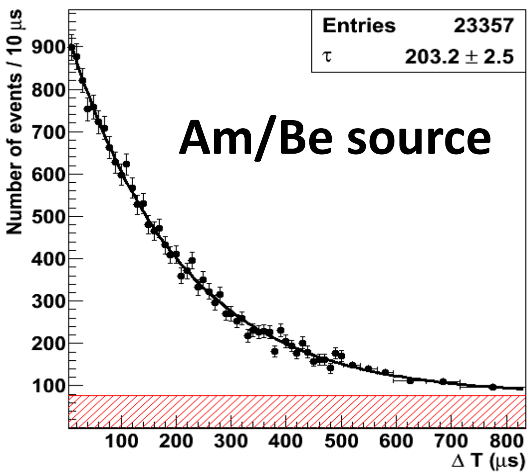
Astropart.Phys. 31 (2009) 320-328

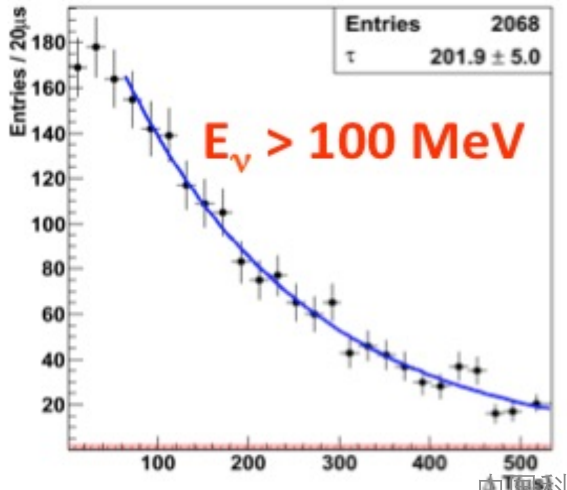
中子在纯水中的测量首次由清华大学工物系在超级神冈实现

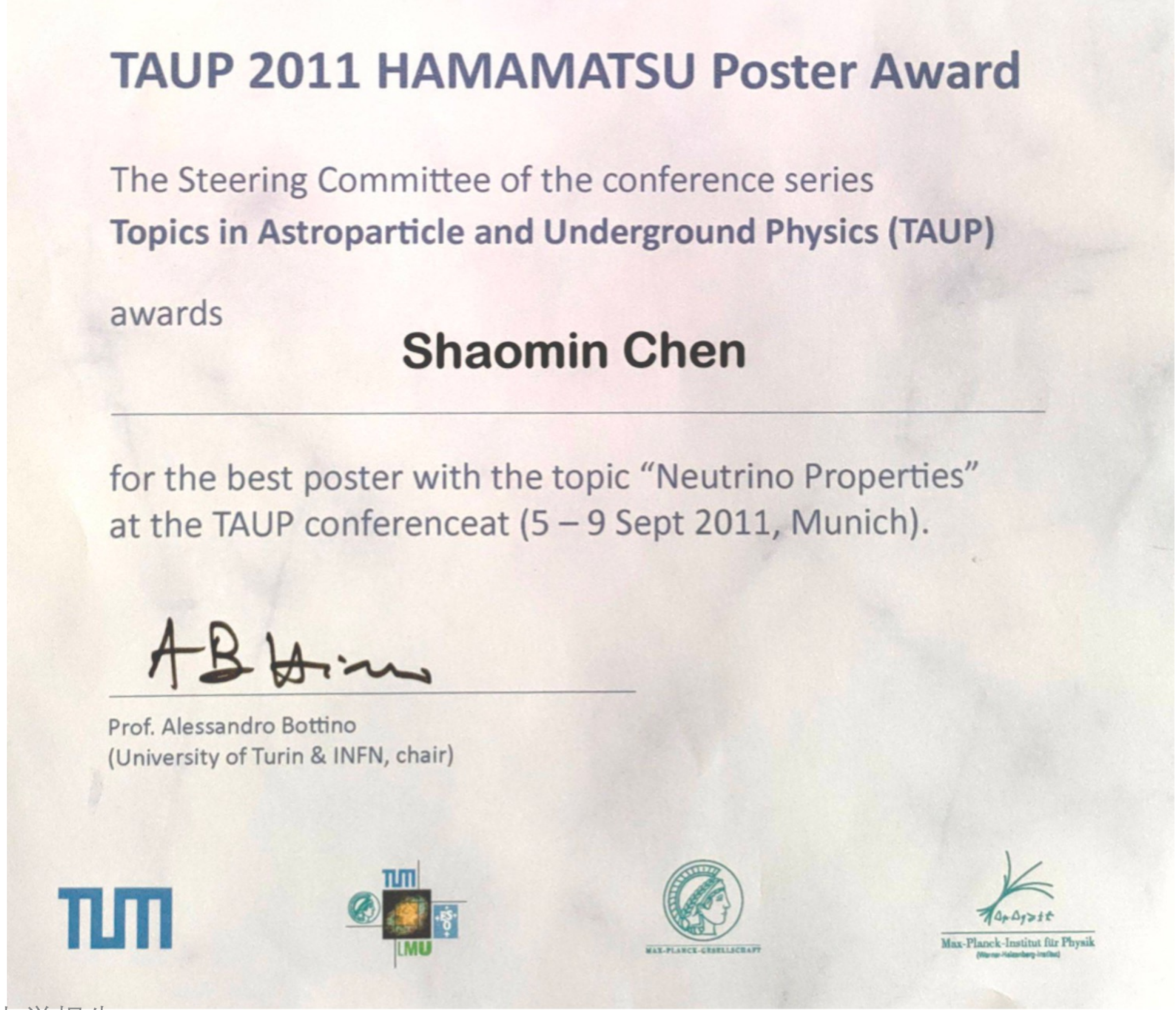
中子测量系统在SK-IV中的安装

- **Implement a correlated trigger online**

Primary trigger 40 μs Forced trigger 500 μ s







TAUP 2011 HAMAMATSU Poster Award

The Steering Committee of the conference series
Topics in Astroparticle and Underground Physics (TAUP)

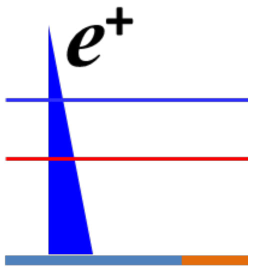
awards

Shaomin Chen

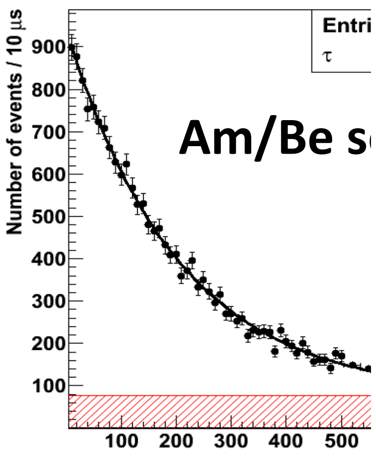
for the best poster with the topic "Neutrino Properties"
at the TAUP conferenceat (5 – 9 Sept 2011, Munich).

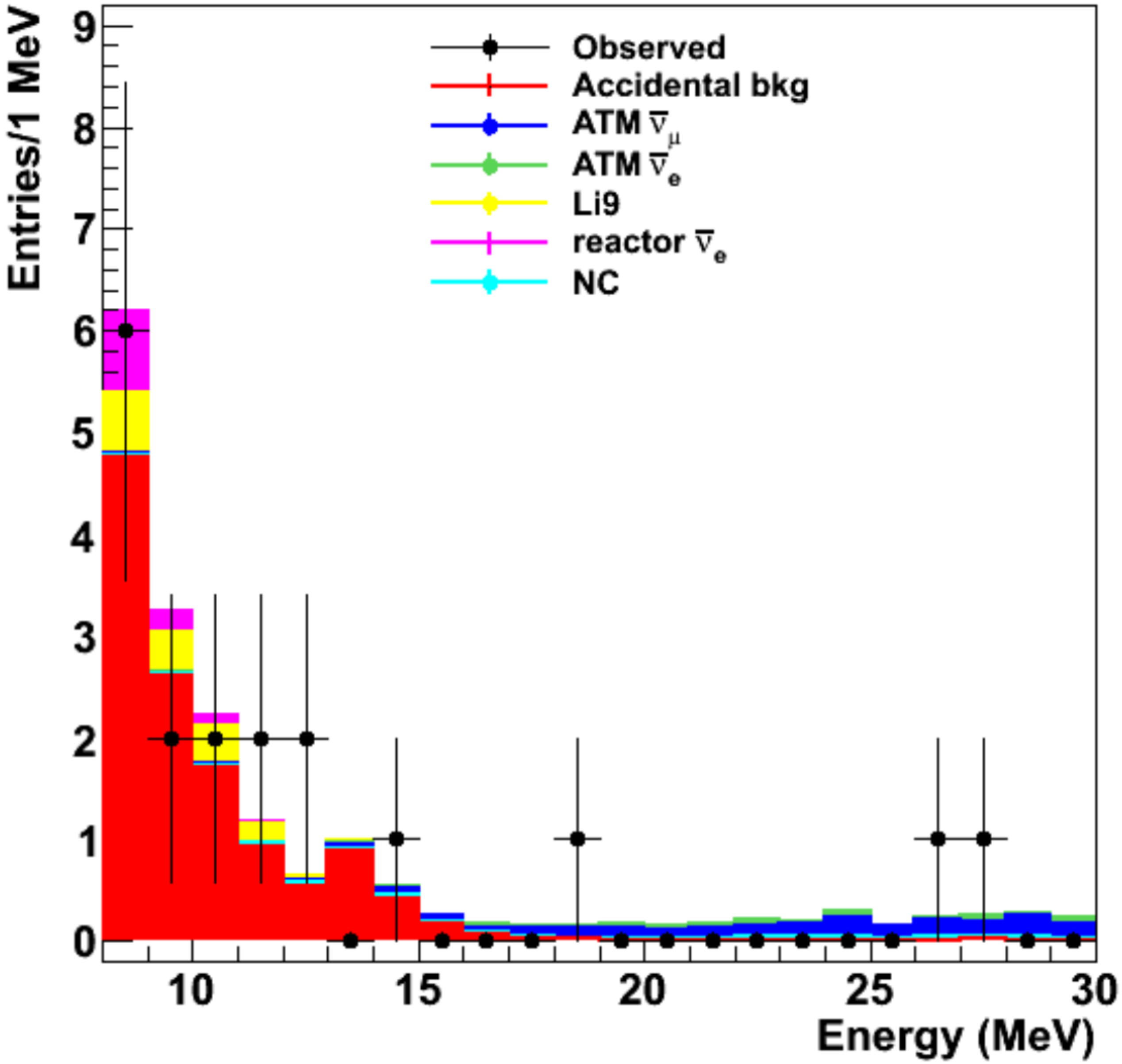
Prof. Alessandro Bottino
(University of Turin & INFN, chair)

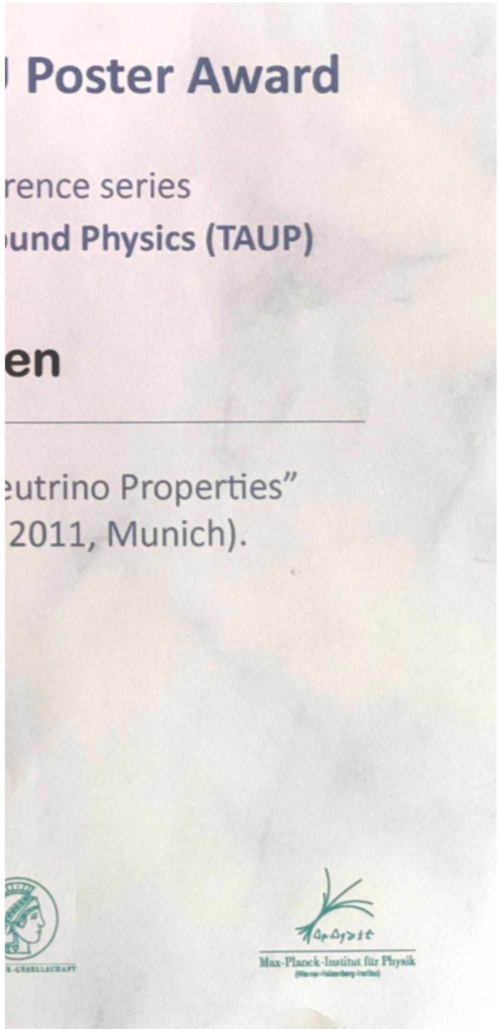
- **Implen**



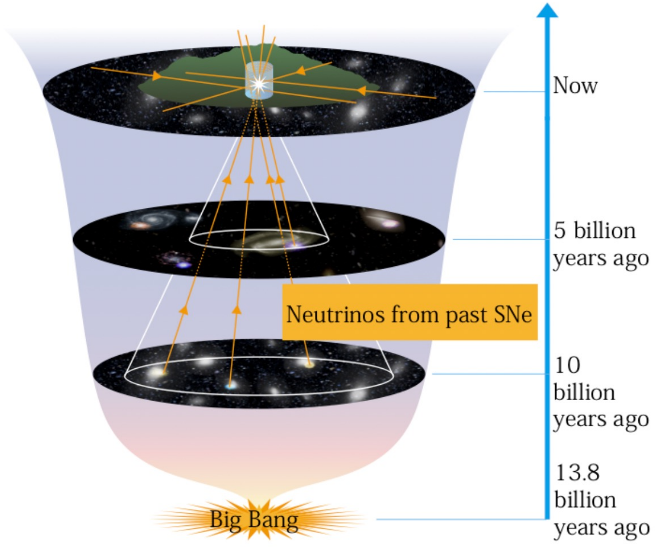
Primary trig

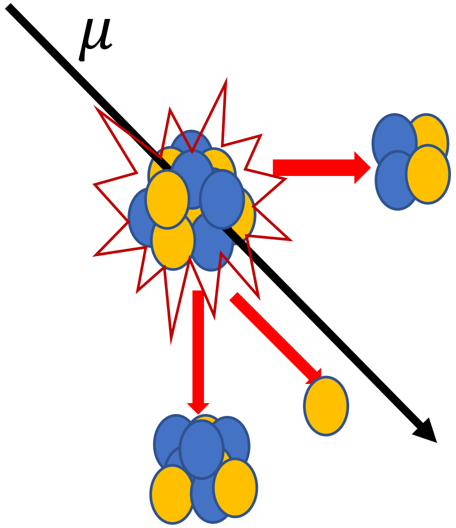


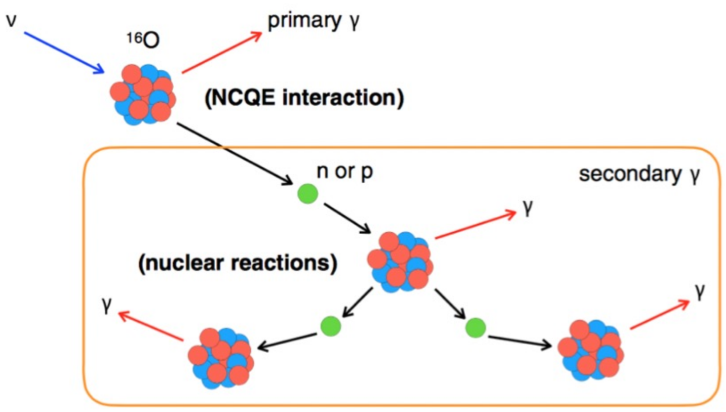




中子测量在物理研究中取得的成就







Supernova Relic Neutrino Search with Neutron Tagging at Super-Kamiokande-IV

Super-Kamiokande Collaboration • H. Zhang (Tsinghua U., Beijing) Show All(120)
Nov 15, 2013

6 pages
Published in: *Astropart.Phys.* 60 (2015) 41-46
Published: Jan, 2015
e-Print: 1311.3738 [hep-ex]
DOI: 10.1016/j.astropartphys.2014.05.004
Experiments: SUPER-KAMIOKANDE
View in: OSTI Information Bridge Server, ADS Abstract Service

pdf cite claim reference search 139 citations

First measurement of radioactive isotope production through cosmic-ray muon spallation in Super-Kamiokande IV

Super-Kamiokande Collaboration • Y. Zhang (Tsinghua U., Beijing, Dept. Eng. Phys.) Show All(129)
Sep 27, 2015

12 pages
Published in: *Phys.Rev.D* 93 (2016) 1, 012004
Published: Jan 15, 2016
e-Print: 1509.08168 [hep-ex]
DOI: 10.1103/PhysRevD.93.012004
Experiments: SUPER-KAMIOKANDE
View in: OSTI Information Bridge Server, ADS Abstract Service

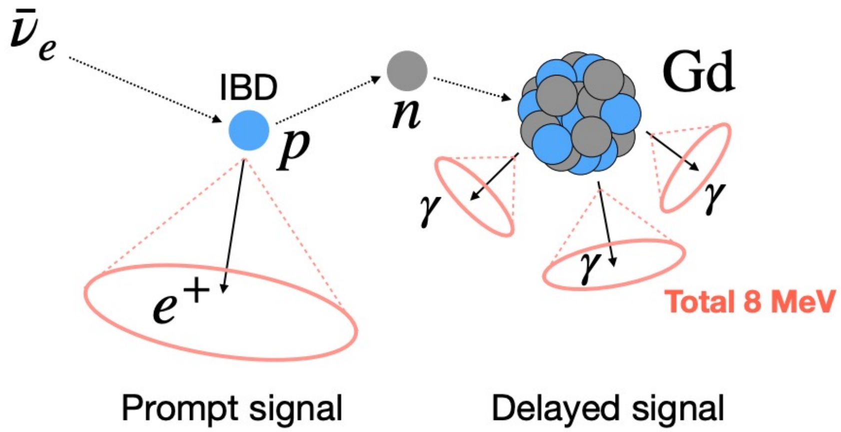
pdf cite claim reference search 59 citations

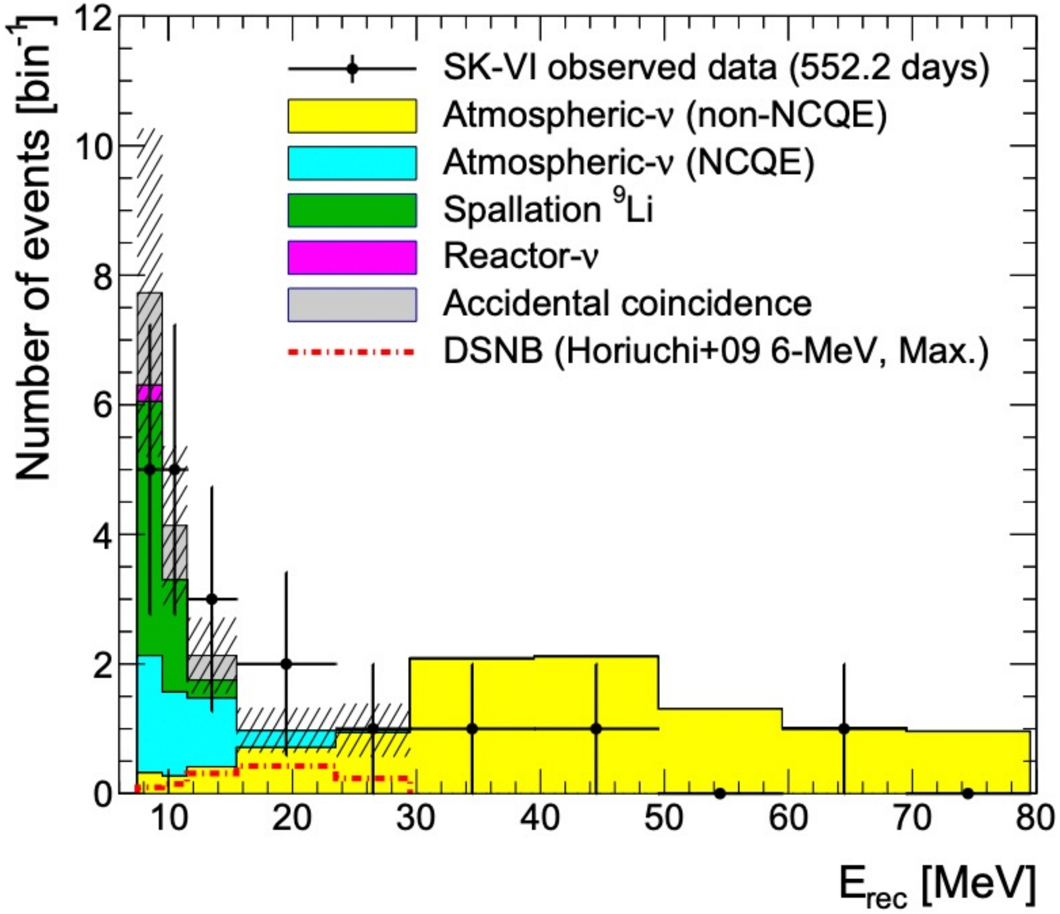
Measurement of the neutrino-oxygen neutral-current quasielastic cross section using atmospheric neutrinos at Super-Kamiokande

Super-Kamiokande Collaboration • L. Wan (Tsinghua U., Beijing, Dept. Eng. Phys.) Show All(166)
Jan 16, 2019

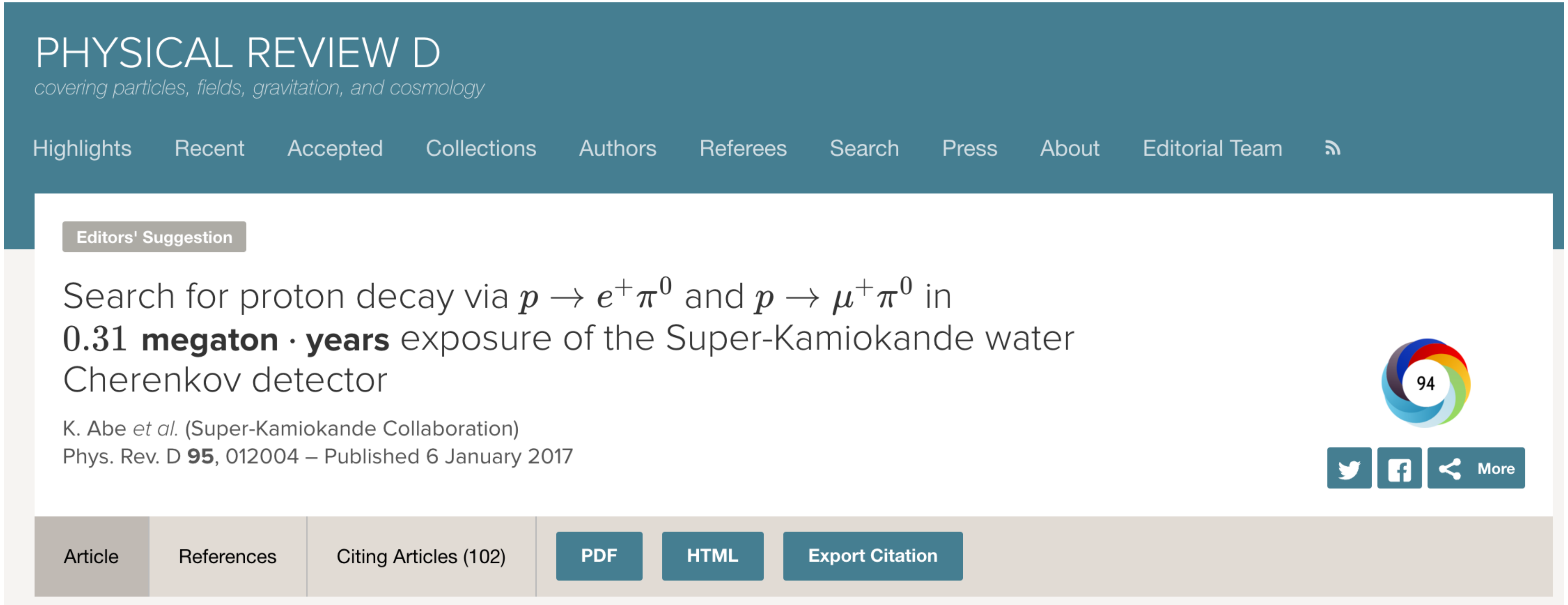
11 pages
Published in: *Phys.Rev.D* 99 (2019) 3, 032005
Published: Feb 16, 2019
e-Print: 1901.05281 [hep-ex]
DOI: 10.1103/PhysRevD.99.032005 (publication)
Experiments: SUPER-KAMIOKANDE
View in: HAL Science Ouverte, ADS Abstract Service

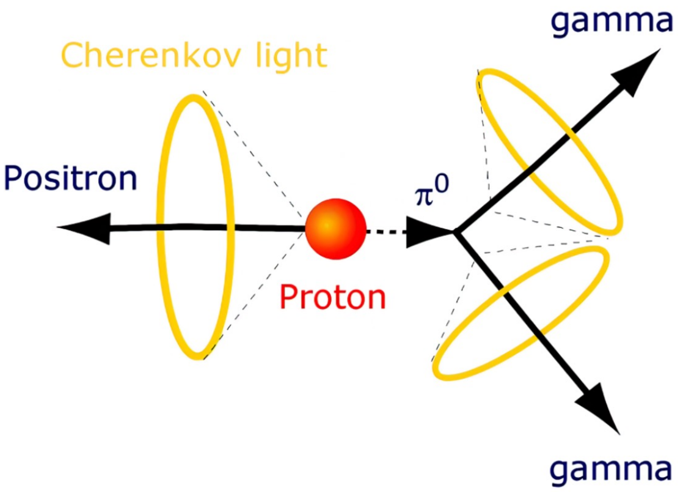
pdf cite claim reference search 20 citations



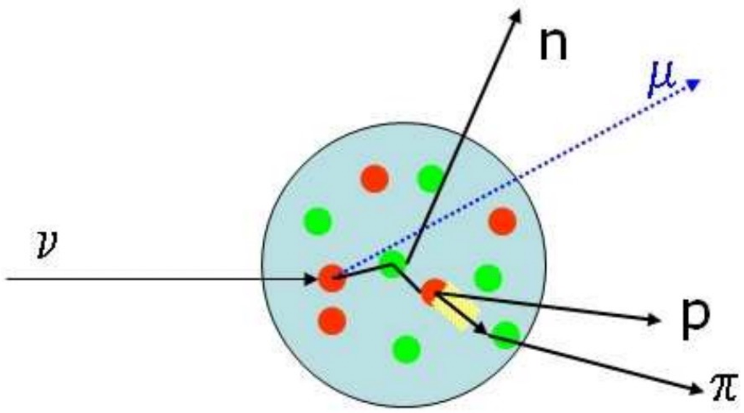


0.01% Gd, 552 days



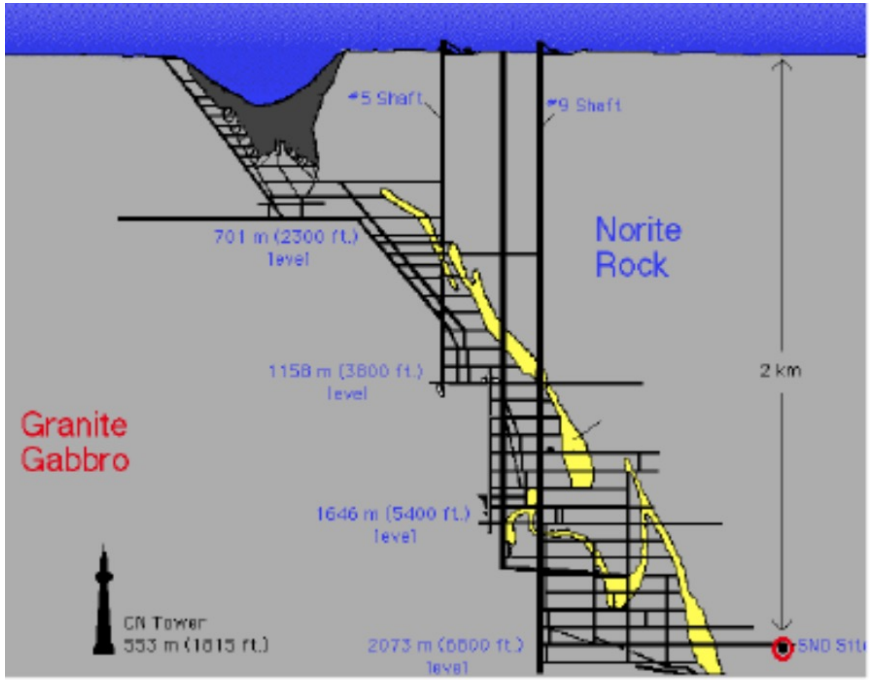


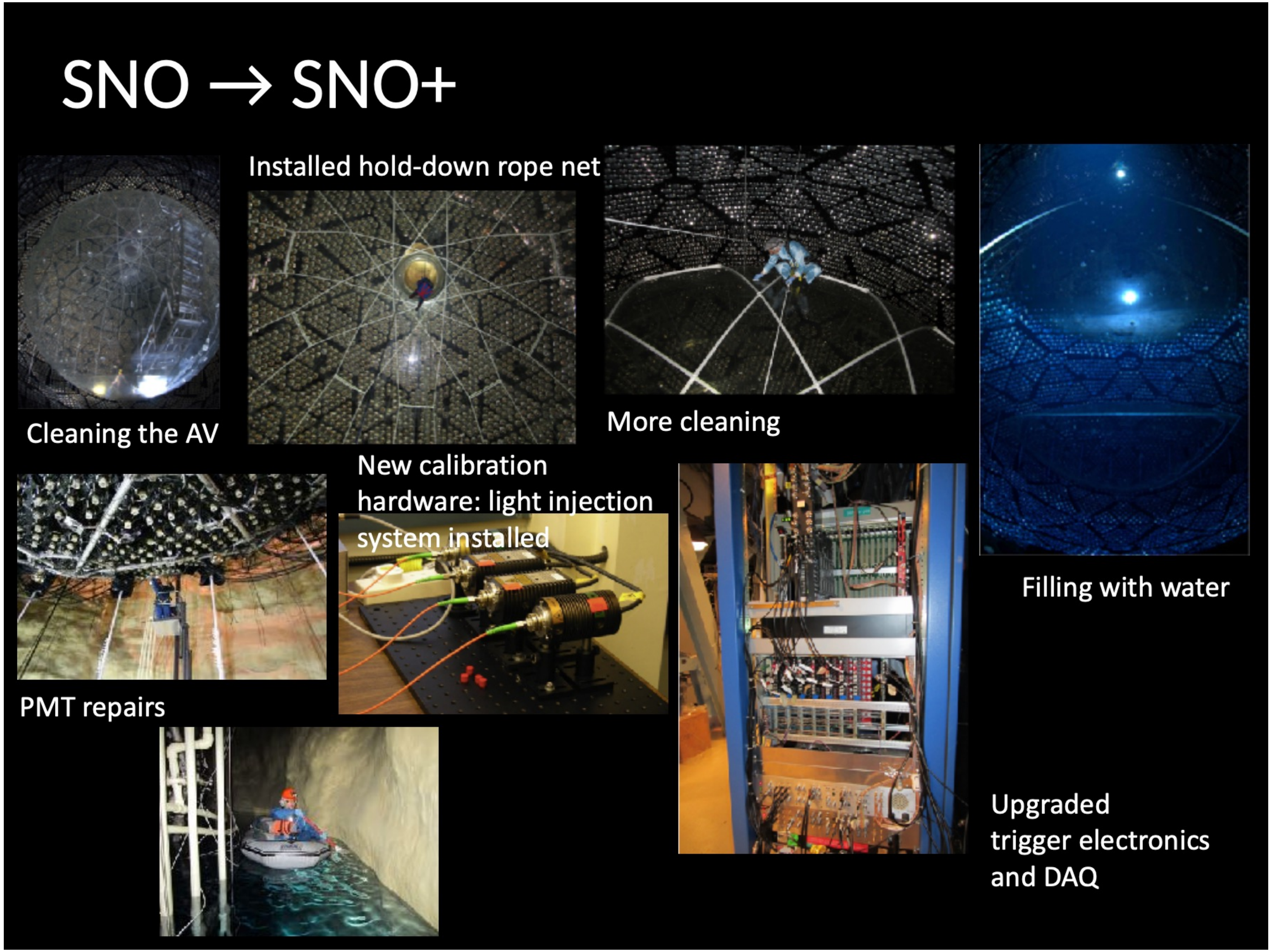
ACTA PHYSICA POLONICA B, 40, 9, 2009




Greater | Grand
Sudbury
Welcome
Bienvenue
Aanii

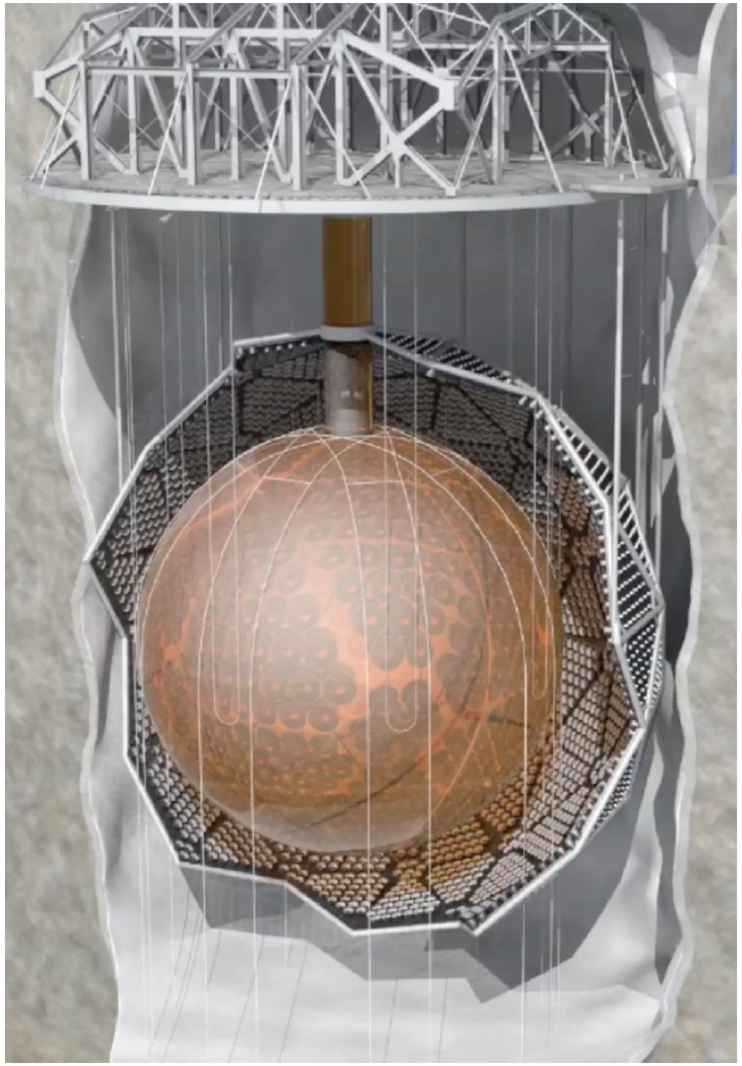

CANADA
5 CENTS
NICKEL
1751-1951

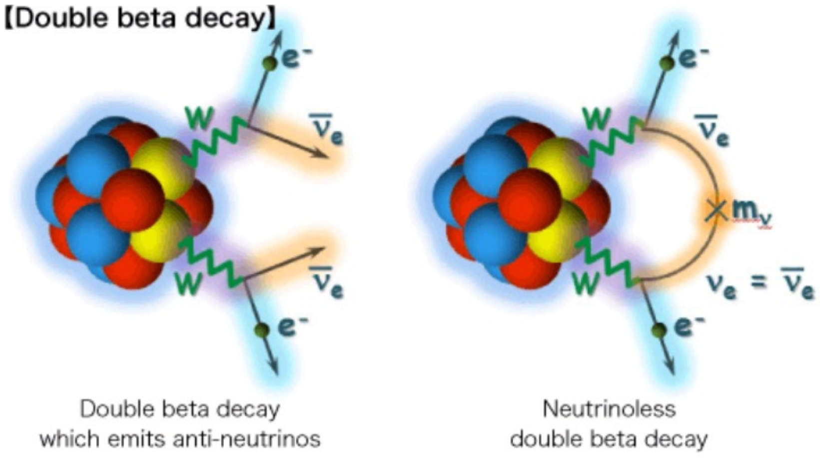

#5 Shaft
#9 Shaft
701 m (2300 ft.)
level
Norite
Rock
1158 m (3800 ft.)
level
2 km
Granite
Gabbro
1646 m (5400 ft.)
level
CN Tower
553 m (1815 ft.)
2073 m (6800 ft.)
level



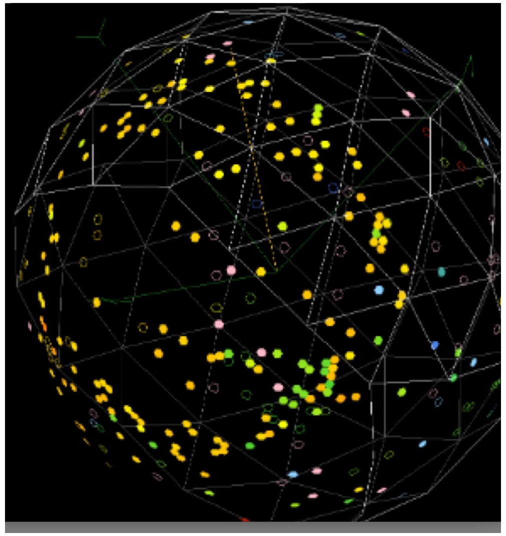
Courtesy: Mark Chen @清华

SNO+ experiment





Te-loaded LS



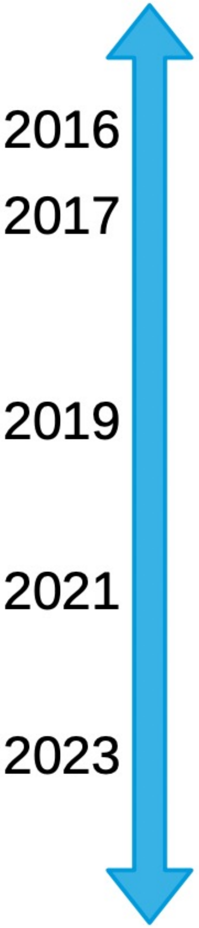
水数据: 刻度探测器性能

1.2017.05-2017.09 ： Nhits=15

2.2017.09-2018.09: Nhits~7

3.2018. 09-2019.07: N_2 gas above

SNO+ timeline

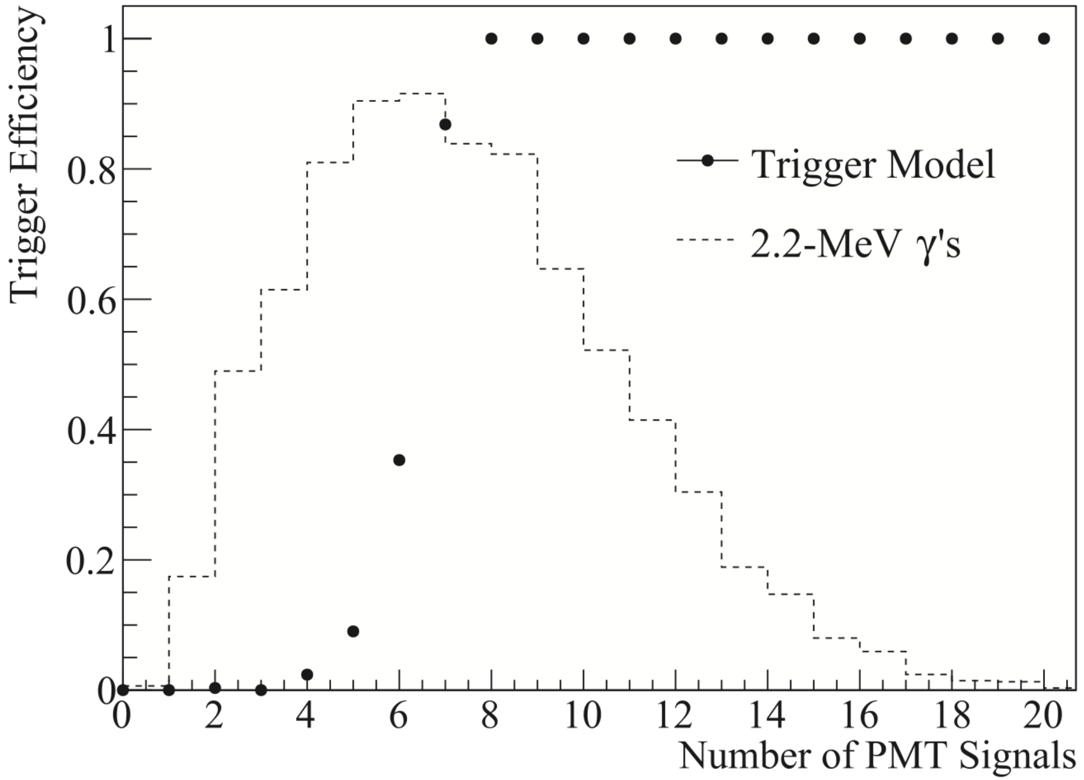


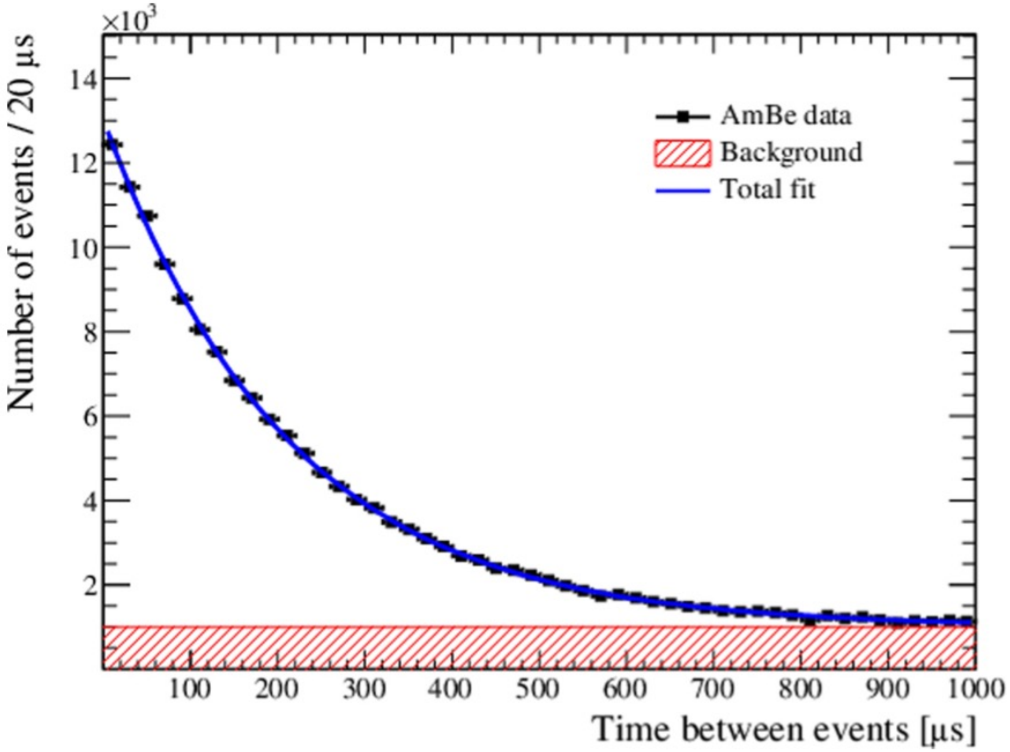
- Dec 2016: start commissioning with water
- May 2017: start of water phase

^{8}B Solar neutrino flux: PRD 99 (2019) 012012
Invisible nucleon decay modes: PRD 99 (2019) 032008, PRD 105 (2022) 112012
Neutron-proton capture: PRC 102 (2020) 014002
Reactor neutrinos: PRL 130 (2023) 9

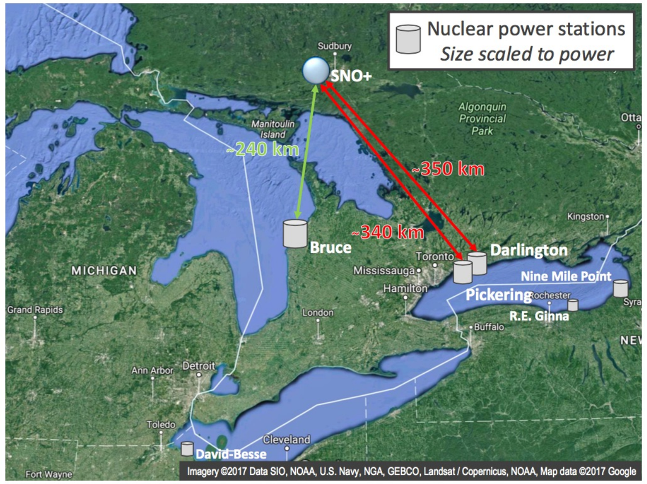
- July 2019: start filling with scintillator (LAB+PPO fluor)
  - "Partial fill" phase due to pandemic: 365T LS, 0.6g/L PPO
- April 2022 : start of scintillator phase
  - 780T LS, 2.2g/L PPO
- 2023: preparation for Te loading for 0νββ phase

Courtesy: Jeff Tseng @LNGS

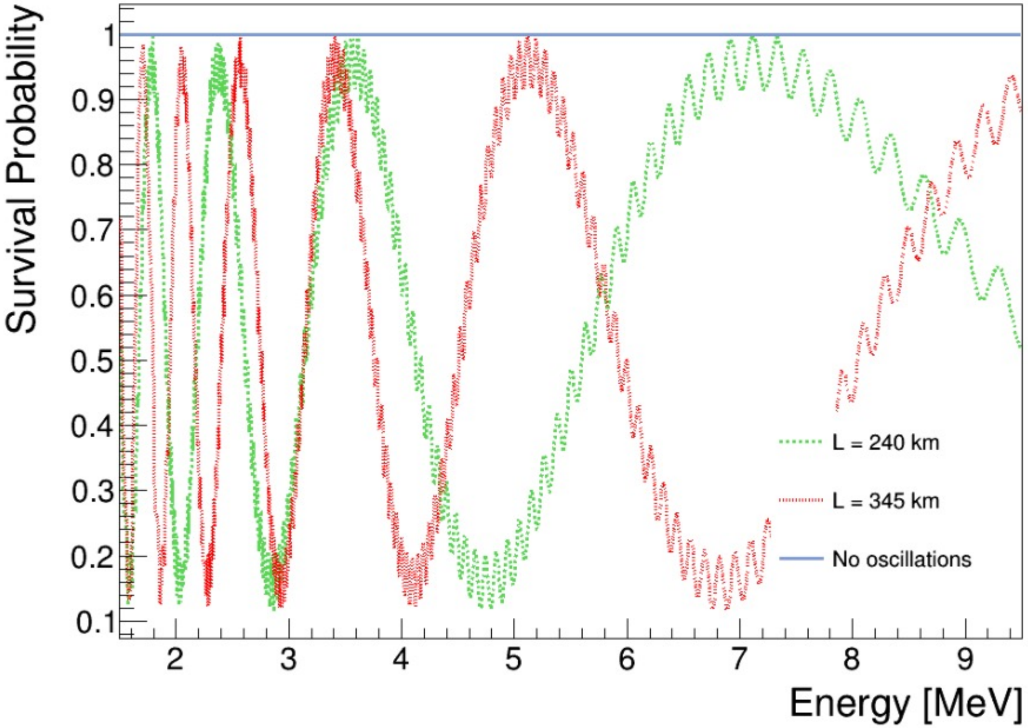


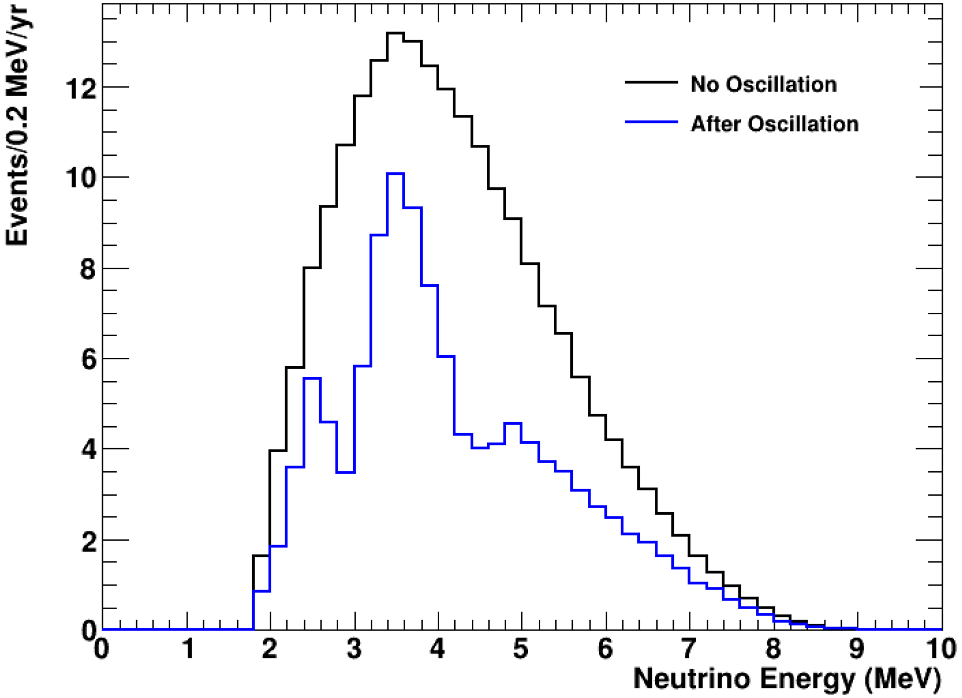


Phys.Rev.C 102 (2020) 1, 014002



- $P_{ee} = 1 - S^2 2\theta_{12} C^4_{13} S^2 1.27 \Delta m^2_{21} [eV^2] \frac{L[km]}{E[GeV]} - S^2 2\theta_{13} S^2 1.27 \Delta m^2_{31} [eV^2] \frac{L[km]}{E[GeV]}$





Can we see it?

不能完成的任务？(Yes or No)

Electron Antineutrinos in the Water Phase of the SNO+ Experiment

by

Pawel Mekarski

A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Physics
University of Alberta

数据: 2.2017.09-2018.01: 65 days

指数增长 ↑

本底预期

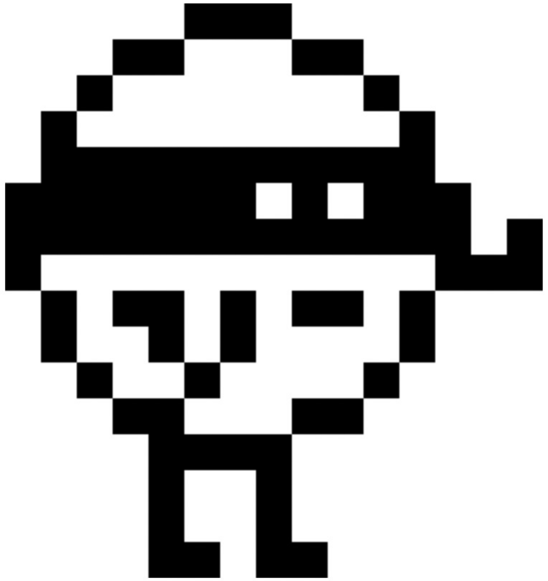
Minimum e^+ nHit	Expected	Measured
25	19.53	15
26	12.46	11
27	7.94	7
28	5.06	5
29	2.94	5
30	1.75	5
31	1.00	2
32	0.52	1
33	0.25	0

Signal: 0.07 /65天

"We've done it. We cannot see it."

重拾信心

2018.05： 加入SNO+



6月就开展实际研究工作

Study of IBD ($\bar{\nu} + p \rightarrow e^{+} + n$) events @SNO+

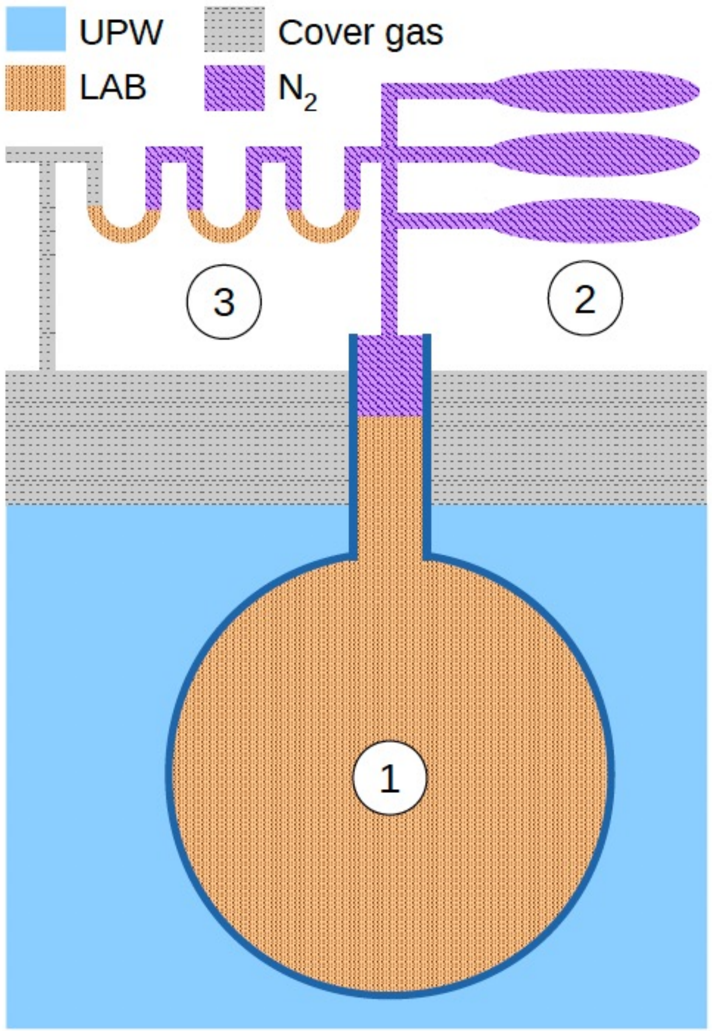
Yang ZHANG
PDF @University of Alberta
Supervising member: Aksel Hallin

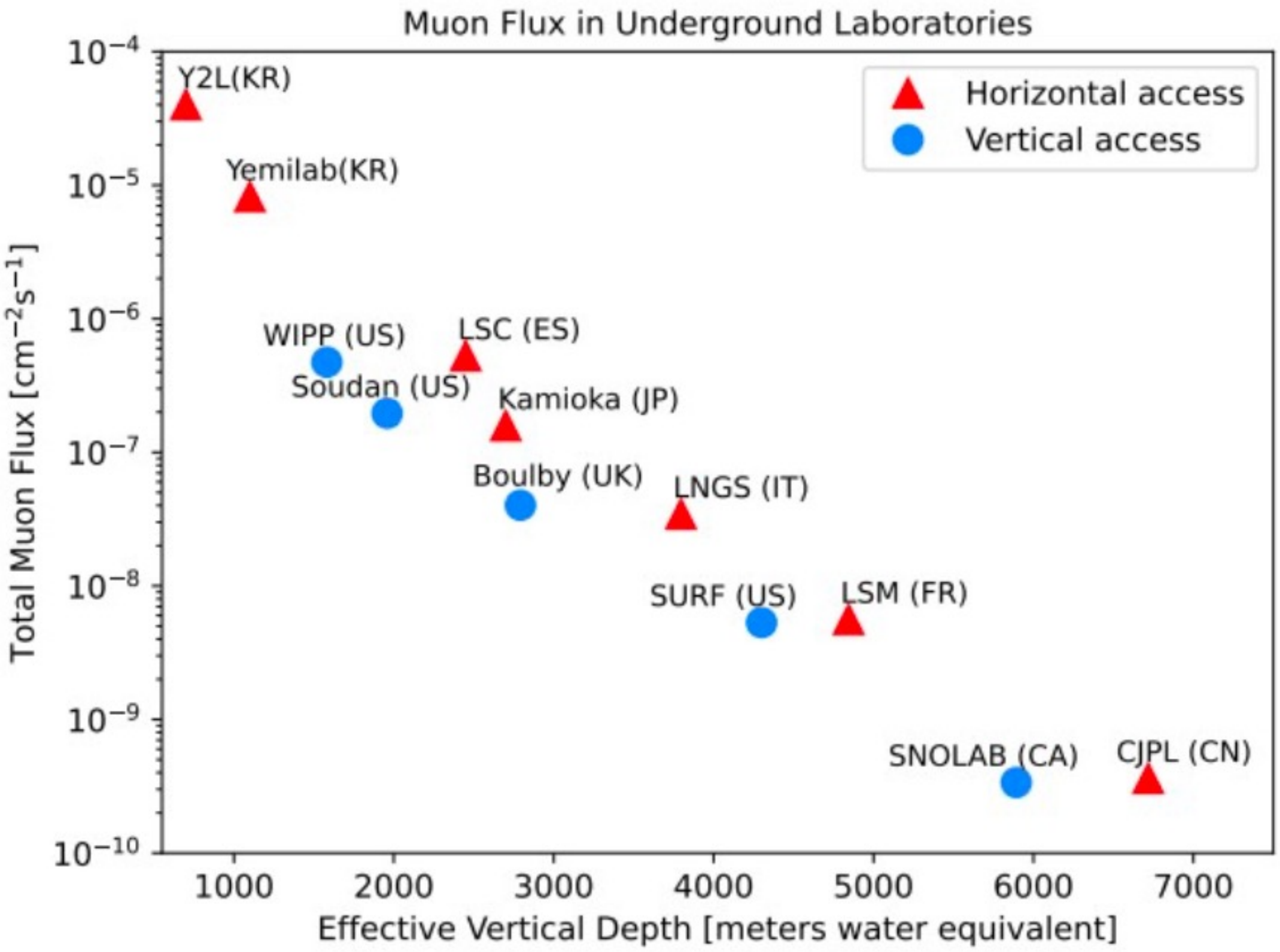
June. 11th, 2018

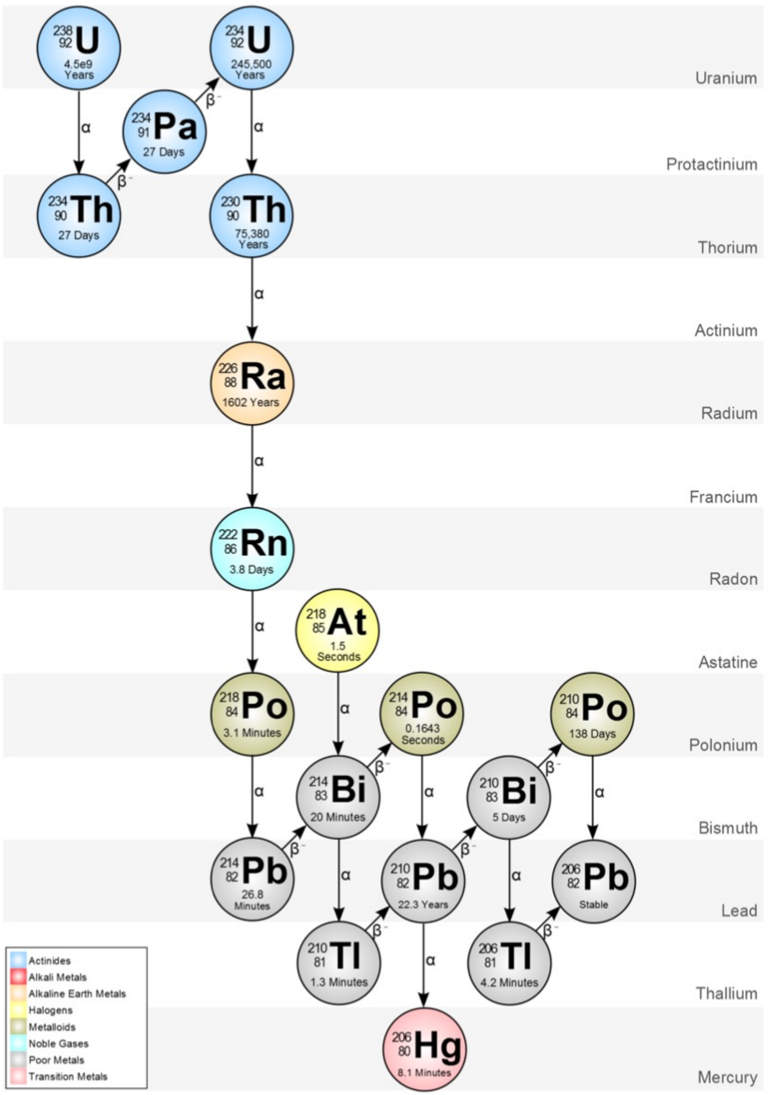
Summary

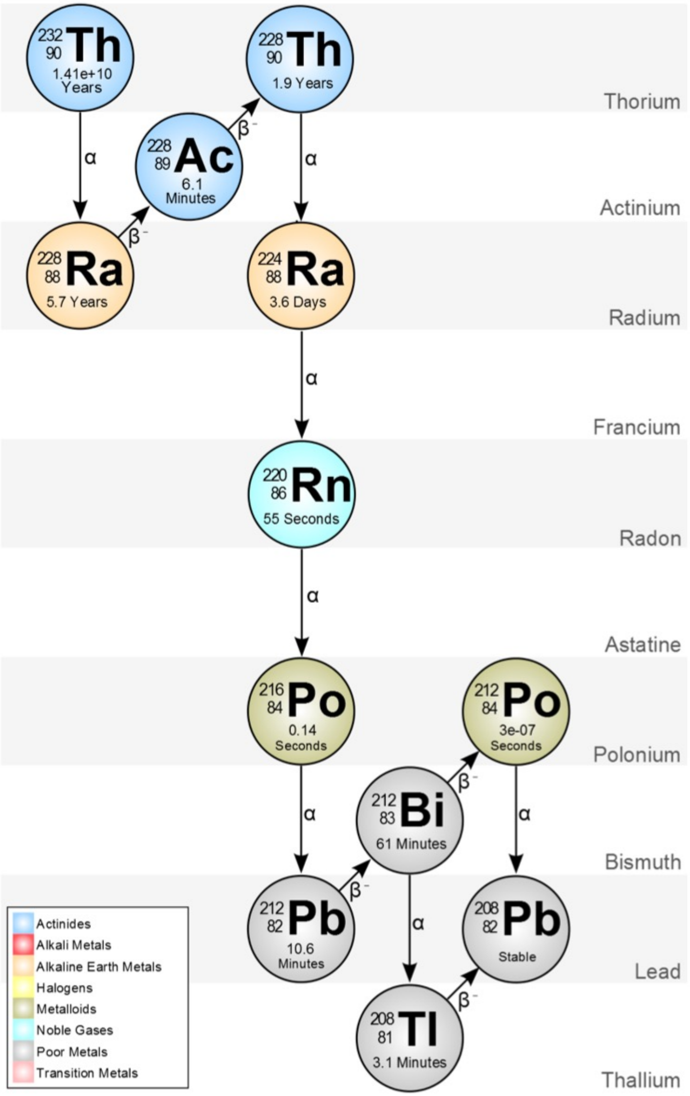
- Roughly speaking, we would expect ~0.4 signal events v.s. ~0.8 bkg. events (Nhits>=29) per year at signal efficiency of ~10% and bkg. level of 0.01%. (assuming other settings are same as Pawel's).
  - Notice accidental bkg level is suppressed by a factor of ~20.
  - This could be achieved.

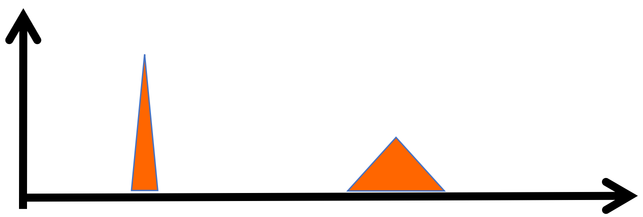
Expectation: ~1 IBD, ~1 bkg for ~140-day data
Observed: 1 evt

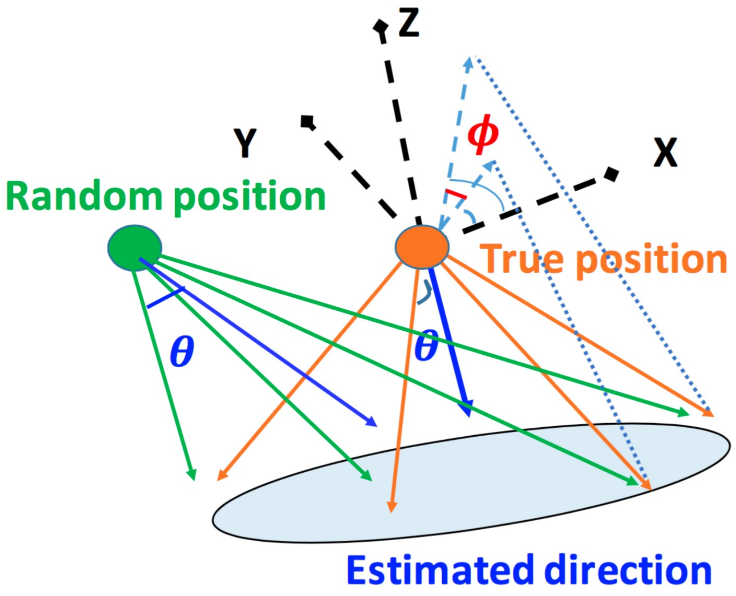

UPW
Cover gas
LAB
N2
3
2
1

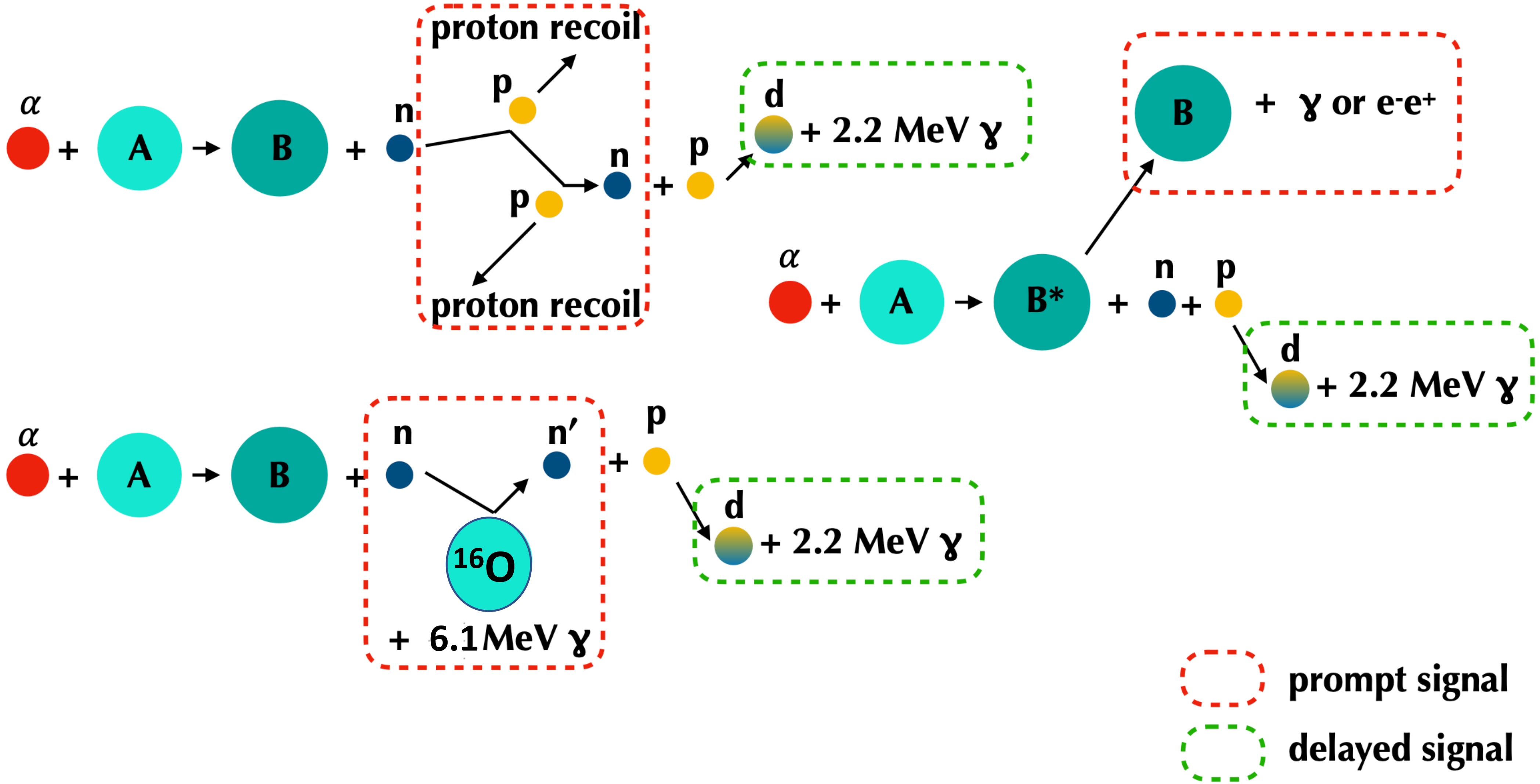

Muon Flux in Underground Laboratories
Total Muon Flux [cm⁻²s⁻¹]
Effective Vertical Depth [meters water equivalent]
Horizontal access
Vertical access
Y2L(KR)
Yemilab(KR)
WIPP (US)
LSC (ES)
Soudan (US)
Kamioka (JP)
Boulby (UK)
LNGS (IT)
SURF (US)
LSM (FR)
SNOLAB (CA)
CJPL (CN)
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
1000
2000
3000
4000
5000
6000
7000

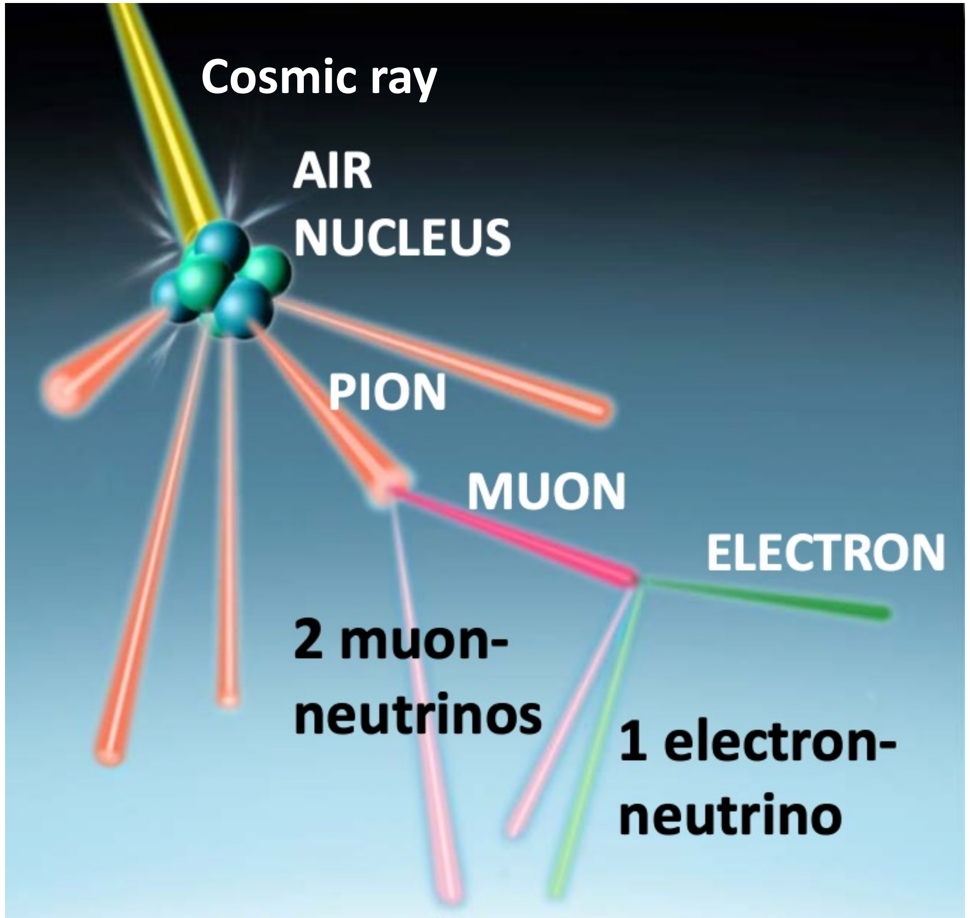

238 92 U 4.5e9 Years
234 92 U 245,500 Years
234 91 Pa 27 Days
234 90 Th 27 Days
230 90 Th 75,380 Years
226 88 Ra 1602 Years
222 86 Rn 3.8 Days
218 85 At 1.5 Seconds
218 84 Po 3.1 Minutes
214 84 Po 0.1643 Seconds
210 84 Po 138 Days
214 83 Bi 20 Minutes
210 83 Bi 5 Days
214 82 Pb 26.8 Minutes
210 82 Pb 22.3 Years
206 82 Pb Stable
210 81 Tl 1.3 Minutes
206 81 Tl 4.2 Minutes
206 80 Hg 8.1 Minutes
α
β⁻
Uranium
Protactinium
Thorium
Actinium
Radium
Francium
Radon
Astatine
Polonium
Bismuth
Lead
Thallium
Mercury
Actinides
Alkali Metals
Alkaline Earth Metals
Halogens
Metalloids
Noble Gases
Poor Metals
Transition Metals


232 90 Th 1.41e+10 Years
228 90 Th 1.9 Years
228 89 Ac 6.1 Minutes
228 88 Ra 5.7 Years
224 88 Ra 3.6 Days
220 86 Rn 55 Seconds
216 84 Po 0.14 Seconds
212 84 Po 3e-07 Seconds
212 83 Bi 61 Minutes
212 82 Pb 10.6 Minutes
208 82 Pb Stable
208 81 Tl 3.1 Minutes
α
β⁻
Thorium
Actinium
Radium
Francium
Radon
Astatine
Polonium
Bismuth
Lead
Thallium
Actinides
Alkali Metals
Alkaline Earth Metals
Halogens
Metalloids
Noble Gases
Poor Metals
Transition Metals



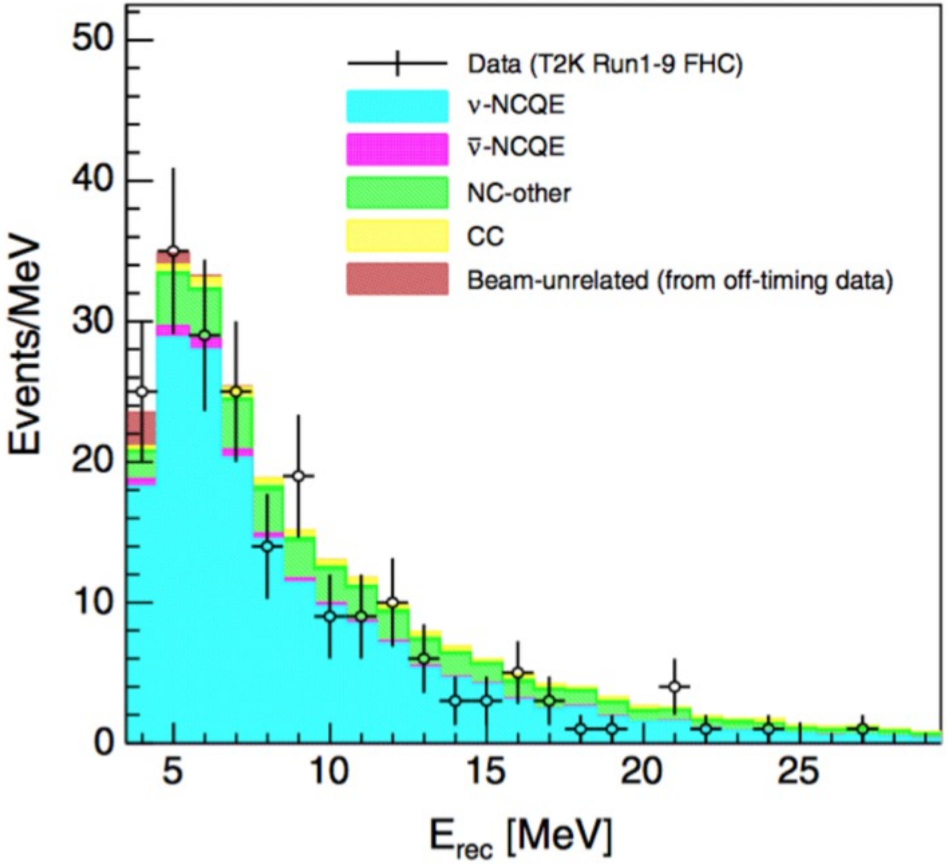

Z
Y
X
ϕ
Random position
True position
θ
θ
Estimated direction


α
+
A
B
+
n
proton recoil
p
n
p
proton recoil
+
p
d
+ 2.2 MeV γ
B
+ γ or e-e+
α
+
A
B*
+
n
+
p
d
+ 2.2 MeV γ
α
+
A
B
+
n
n′
16O
+ 6.1MeV γ
+
p
d
+ 2.2 MeV γ
prompt signal
delayed signal



Courtesy: Kajita’s nobel lecture

PRD 100, 112009 (2019) .



盲分析-Sideband 研究本底

偶然符合

1、即时事例和延时事例随机配对，进行无偏估计。
2、用0.5-1 ms时间窗口进行本底验证

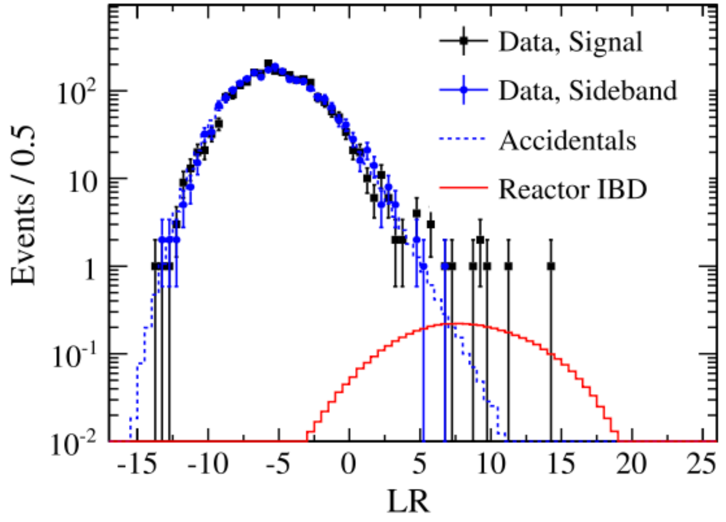
（ α,n ）本底

1、Si- α 计数器测量 ^{210}Po活度 over acrylic in-situ, 2.4±0.8 Bq/m^2
2、Bench-top measurement of leaching rate。
3、亚克力附近（ α,n ）事例测量来验证

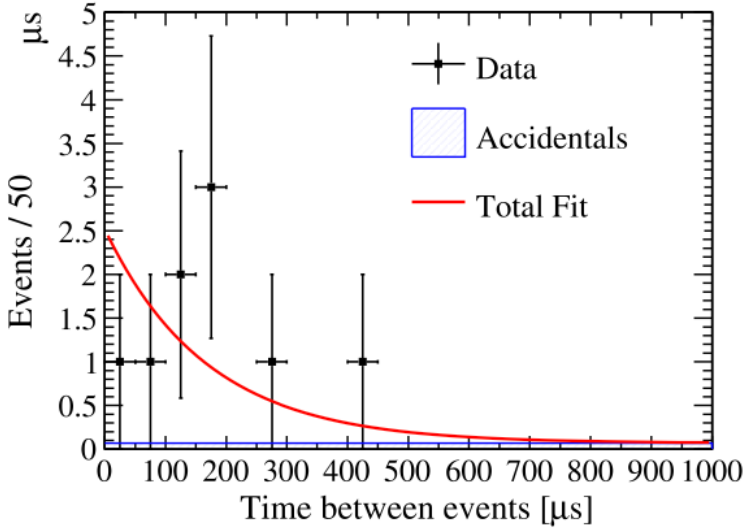
中性流

1、2.5-25 MeV, 中子重复度>=2。

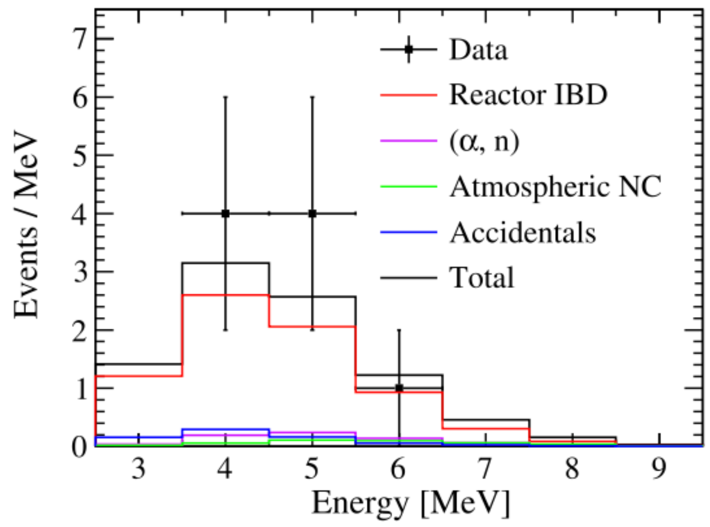
2、9.5-25 MeV, 中子重复度为1。


Data, Signal
Data, Sideband
Accidentals
Reactor IBD
Events / 0.5
LR

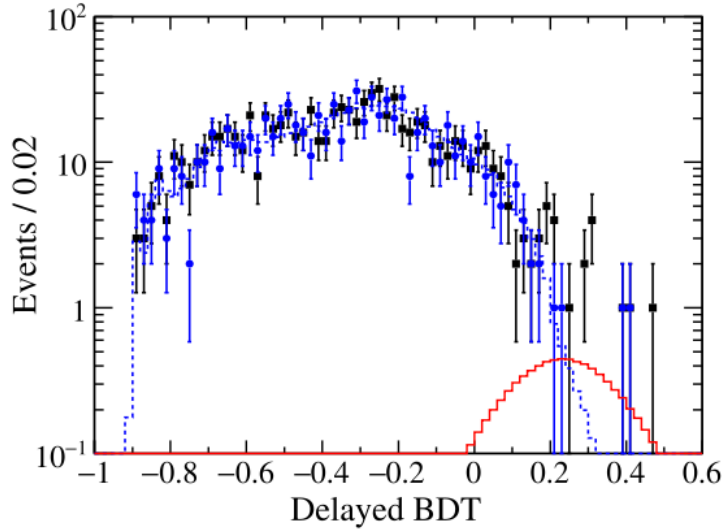
(a)


Data
Accidentals
Total Fit
Events / 50 µs
Time between events [µs]

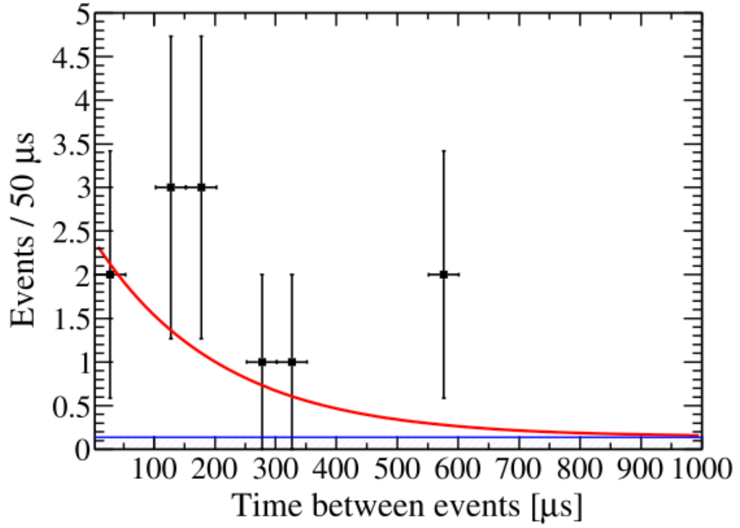
(b)


Data
Reactor IBD
(α, n)
Atmospheric NC
Accidentals
Total
Events / MeV
Energy [MeV]

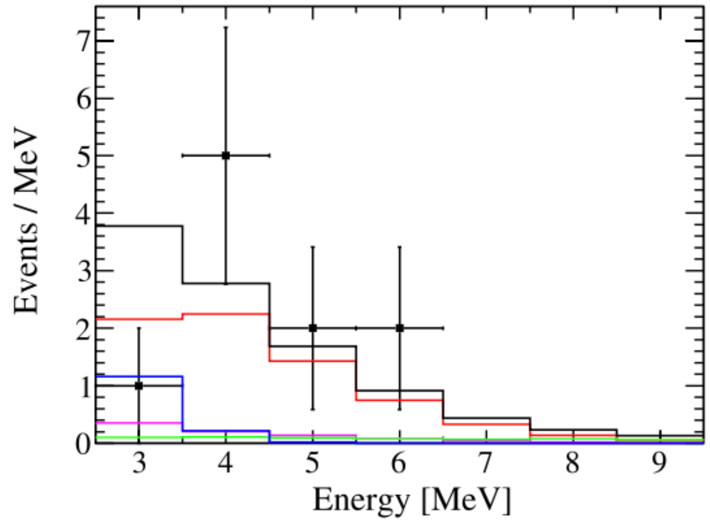
(c)


Events / 0.02
Delayed BDT

(d)


Events / 50 µs
Time between events [µs]

(e)


Events / MeV
Energy [MeV]

(f)

Altmetric

Evidence of Antineutrinos from Distant Reactors Using Pure Water at SNO+

Overview of attention for article published in Physical Review Letters, March 2023

- **35** news outlets
- **6** blogs
- **62** tweeters
- **1** Facebook page
- **3** Redditors
- **1** Dimensions
- **4** Mendeley

SUMMARY | News | Blogs | More...

So far, Altmetric has seen **37** news stories from **35** outlets.

In the top 5% of all research outputs scored by Altmetric

High Attention Score compared to outputs of the same age (99th percentile)

High Attention Score compared to outputs of the same age and source (99th percentile)

სუფთა წყალში ატომური ელექტროსადგურის მოჩვენებითი ნათება დააფიქსირეს
Marketer.ge, 12 Apr 2023
ეს ამბავი ონტარიოში მოხდა და მნიშვნელოვანი იმითაა, რომ პირველი შემთხვევაა, როცა წყალი ანტინეიტრინოს ნაწილაკის გამოსავლენად გამოიყ...

格鲁吉亚语

The Ghostly Glow of a Nuclear Power Station Detected in Pure Water 150 Miles Away
Science Alert, 12 Apr 2023
Buried under kilometers of rock in Ontario, Canada, a tank of the purest water flashed as barely detectable particle slammed...

The SNO+ collaboration gathers the first evidence of antineutrinos in a water Cherenkov detector
Phys.org, 11 Apr 2023
Antineutrinos, the antimatter counterpart of neutrinos, have an almost non-existent mass and charge, and almost never interact...

2100 méterrel a felszín alatt kapcsolták be az érzékelőt, bejelzett a 240 km-re lévő atomerőmű miatt
hvg.hu, 19 Apr 2023
tudomány + Kanadai kutatók korábban úgy gondolták, egy olyan kis detektor, mint amit ők használnak egy földalatti bányában, nem...

匈牙利语

Pure Water Breakthrough in Neutrino Detection
Today Headline, 04 Apr 2023
A view inside the SNO detector when filled with water. In the background, there are 9,000 photomultiplier tubes that detect...

Pure Water Breakthrough in Neutrino Detection
Scitech Daily, 04 Apr 2023
A view inside the SNO detector when filled with water. In the background, there are 9,000 photomultiplier tubes that detect...

Une équipe a trouvé un moyen de détecter les neutrinos à l'aide d'eau
Nouvelles du monde, 03 Apr 2023
Dans une expérience collaborative connue sous le nom d'observation des neutrinos de Sudbury (SNO+), une équipe internationale...

法语

Ground-breaking 'antineutrino' detector requires pure water only
Interesting Engineering, 29 Mar 2023
A significant breakthrough in detecting subatomic particles known as antineutrinos has been achieved, according to recent...

Reactor antineutrinos detected in pure water in an experimental first Physics World
physicsworld.com, 28 Mar 2023
For the first time, pure water has been used to detect low-energy antineutrinos produced by nuclear reactors.

New neutrino detection method using water
Phys.org, 28 Mar 2023
Research published in the journal Physical Review Letters conducted by an international team of scientists including Joshua...

AskByGeeks | Five things to know: The latest breakthrough in neutrino detection
AskByGeeks, 27 Mar 2023
research published in journals Physical Review Letters The study, conducted by an international team of scientists including...

Ydinvoimalan säteily havaittiin 240 kilometrin päästä suoraan peruskallion läpi
Tekniika & Talous , 17 Mar 2023
Ydinvoimalan neutriinosäteily on onnistuttu mittaamaan 240 kilometrin päästä suoraan peruskallion läpi kanadalais-yhdysvaltalaise...

芬兰语

Neutrinodetector meet actieve kerncentrales honderden kilometers verderop
New Scientist.nl, 14 Mar 2023
Het Canadese deeltjesexperiment SNO+ heeft neutrino's gevangen die zijn ontstaan in kerncentrales honderden kilometers verderop.

荷兰语

Sudbury SNOLAB makes scientific breakthrough in monitoring nuclear power
CTV News, 06 Mar 2023
A surprise result during an experiment at SNOLAB in Sudbury revealed a scientific breakthrough in the astroparticle physics...

SNOLAB captures first reactor neutrinos detected by water
The Sudbury Star, 06 Mar 2023
Even before it's completed, the SNO+ experiment at Sudbury's SNOLAB has made a breakthrough, one that can assist in monitoring...

ASKBY GEEKS

Science

Five things to know: The latest breakthrough in neutrino detection

could be very expensive," Klein said. "So, our work shows that it's possible to build very large detectors and do it with just water."

abides by its commitments in the nuclear weapons treaty; it is the handle to ensure nuclear non-proliferation.

Joshua Klein is the Edmund J. and Louise W. Kahn Professor and Chair of Graduate Studies in the Department of Physics and Astronomy in the College of Arts and Sciences.

INTERESTING ENGINEERING

Ground-breaking 'antineutrino' detector requires pure water only

A team of scientists has devised a new technique to detect antineutrinos from a distance using little more than pure water.

A significant breakthrough in detecting subatomic particles known as antineutrinos has been achieved, according to recent research published in *APS*.

Today Headline SciTechDaily

Pure Water Breakthrough in Neutrino Detection

An international team of scientists has made a breakthrough in detecting neutrinos using pure water instead of the expensive liquid scintillator that was previously used. The Sudbury Neutrino Observation (SNO+) experiment, located in a mine in Sudbury, Ontario, detected subatomic particles, known as antineutrinos, using pure water. Neutrinos and antineutrinos are tiny subatomic particles that are considered fundamental building blocks of matter and have practical applications such as monitoring nuclear reactors and detecting nuclear activities. The researchers hope that an array of large and inexpensive reactors could be built to ensure that countries are adhering to nuclear weapons treaties.

physicsworld

Reactor antineutrinos detected in pure water in an experimental first

For the first time, pure water has been used to detect low-energy antineutrinos produced by nuclear reactors. The work was done by the international SNO+ collaboration and could lead to safe and affordable new ways to monitor nuclear reactors from a distance.

The result could have implications for the development of techniques used to monitor nuclear reactors. Recent proposals have suggested that antineutrino detection thresholds could be lowered by doping pure water with elements like chlorine or gadolinium – but now, the results from SNO+ show that these costly, potentially dangerous materials may not be necessary to achieve the same quality of results.

-Mark Chen

DOE SCIENCE NEWS SOURCE

U.S. DEPARTMENT OF ENERGY

Science News

Detecting Neutrinos from Nuclear Reactors with Water

The SNO+ experiment has for the first time shown that neutrinos from a nuclear reactor over 240 km away can be detected with plain water.

The Impact

The SNO+ measurement shows that distant nuclear reactors can be observed and monitored with something as simple and inexpensive as water. Reactors cannot shield the neutrinos they produce. This means SNO+'s measurement is a proof of the idea that such water detectors could play a role in ensuring nuclear non-proliferation. Like SNO+, such detectors would still need to be very clean of any radioactivity, large (SNO+ contains 1,000 tons of water), and able to detect the tiny amount of light that the neutrinos produce. The use of water, however, means that very large detectors are possible and a real option for "seeing" even very distant reactors.

Summary

Water detectors have several advantages. They are inexpensive and can be very large, making them useful for monitoring reactors across international borders. Improvements to

Scientists long thought that the tiny signals (just 10-20 photons) created by reactor neutrinos in a water detector would make it impossible to detect those neutrinos, particularly when the detector was far away from the reactor and the rate of these signals was very low. By ensuring that the detector was clean from even trace amounts of

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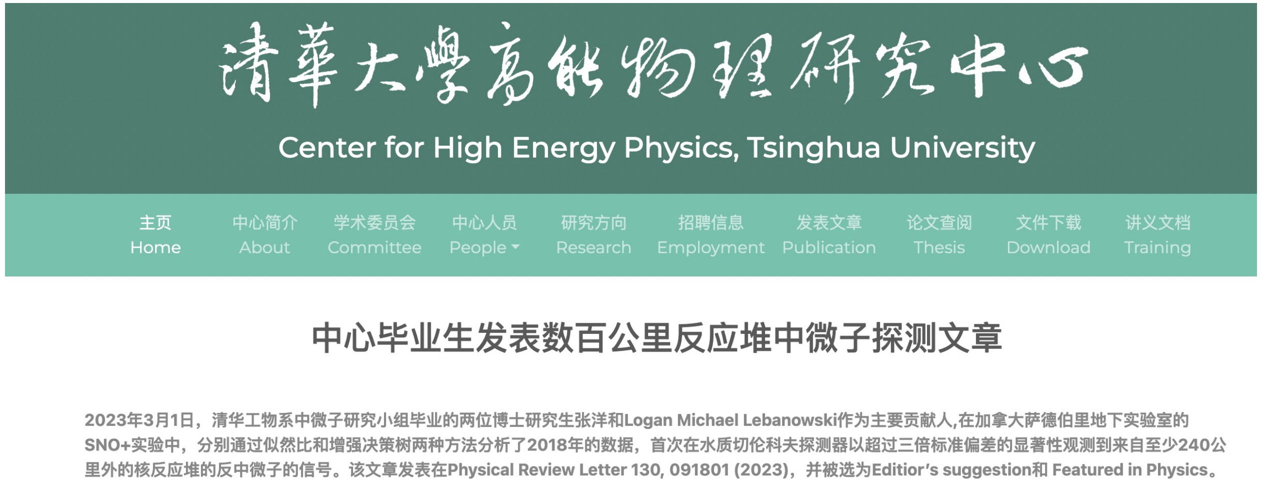
SNO+合作组在国际上首次实现利用纯水测量反应堆中微子，山大团队作出重要贡献

发布日期：2023年03月03日 08:37 点击次数：1020



清華大學高能物理研究中心

Center for High Energy Physics, Tsinghua University

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中心毕业生发表数百公里反应堆中微子探测文章

2023年3月1日，清华工物系中微子研究小组毕业的两位博士研究生张洋和Logan Michael Lebanowski作为主要贡献人,在加拿大萨德伯里地下实验室的SNO+实验中，分别通过似然比和增强决策树两种方法分析了2018年的数据，首次在水质切伦科夫探测器以超过三倍标准偏差的显著性观测到来自至少240公里外的核反应堆的反中微子的信号。该文章发表在Physical Review Letter 130, 091801 (2023)，并被选为Editior's suggestion和 Featured in Physics。

首次实现利用纯水测量反应堆中微子，山大团队做出重要贡献

Original 山大中微子团队 现代物理知识杂志 2023-03-31 18:42 Posted on 北京

近期，SNO+（Sudbury Neutrino Observatory +）合作组在国际上首次实现利用水契伦科夫技术测量反应堆中微子，基线长度大于240公里，统计显著度为3.5倍标准偏差。实验结果于3月1日在线发表在《物理评论快报》（Phys.Rev.Lett. 130, 091801,(2023)）。论文同时被选为编辑推荐（Editors'suggestion）和物理特写（Featured in physics）【1】。山东大学前沿交叉科学青岛研究院的张洋教授是该研究结果的主要完成人之一，独立完成了论文所述两种并行方法的其中一种。目前，张洋教授担任SNO+国际合作组的中方代表。

中国物理学会高能物理分会

HIGH ENERGY PHYSICS BRANCH OF CPS

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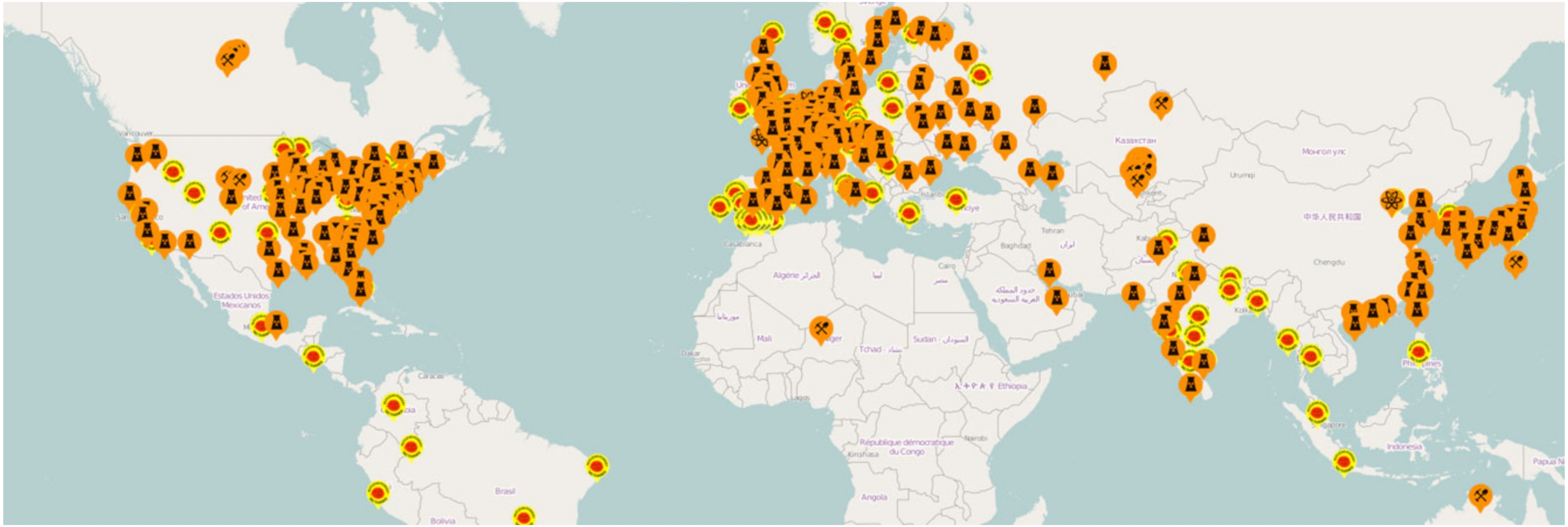
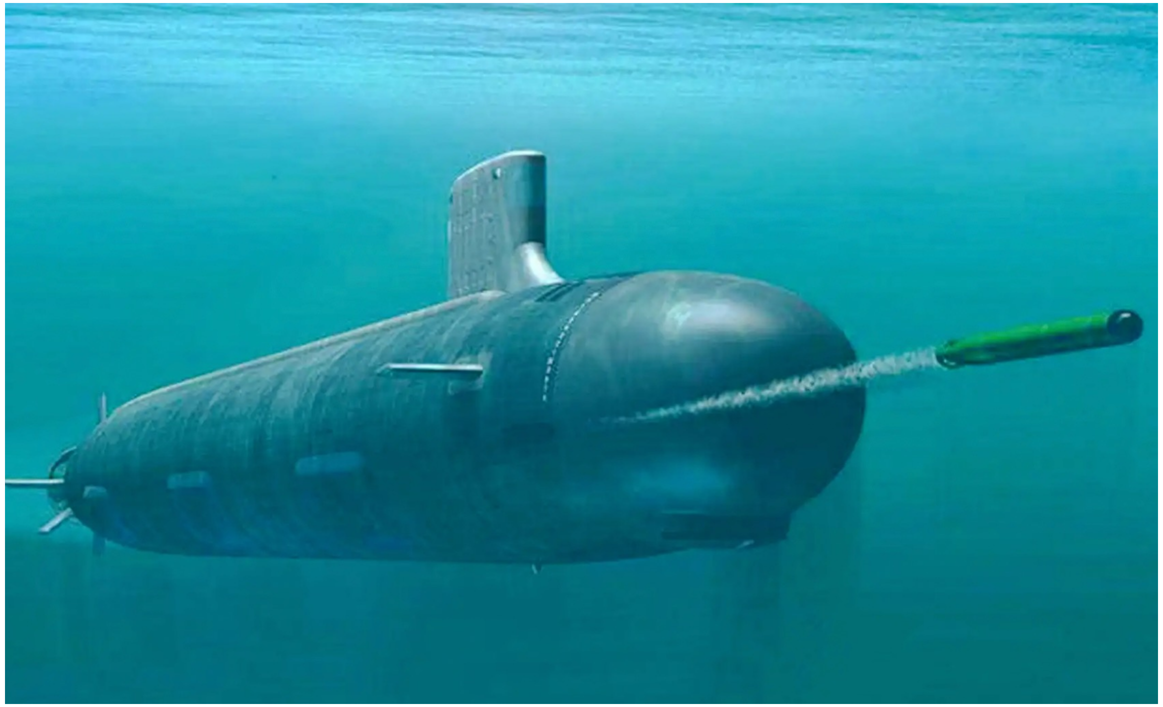
Towards future



把$\frac{1}{10}$SNO+探测器放在~500 m处，信号增强~10^4倍！O(10^2)/天！

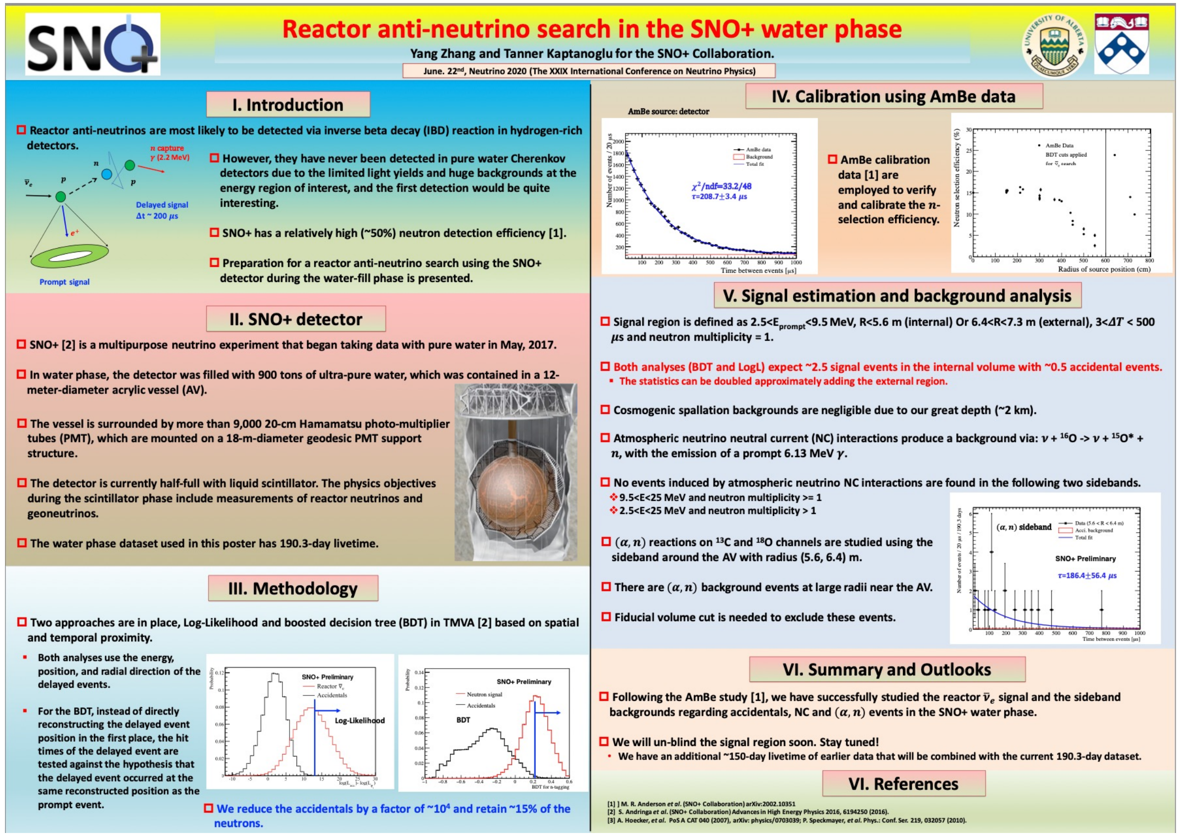
中微子：从科学走向技术



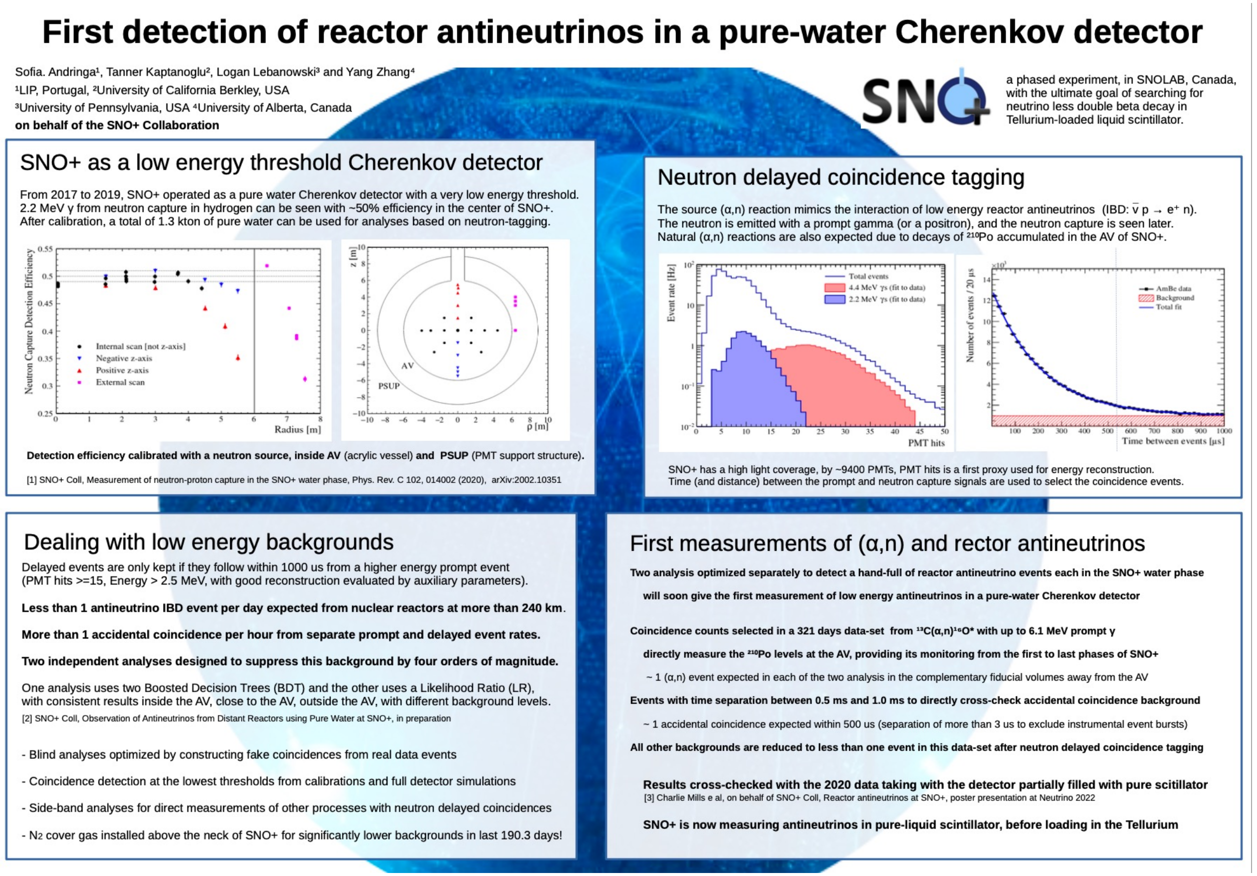
走过长夜，走过坎坷，走进曙色

山大是国内唯一合作单位！

Neutrino 2020

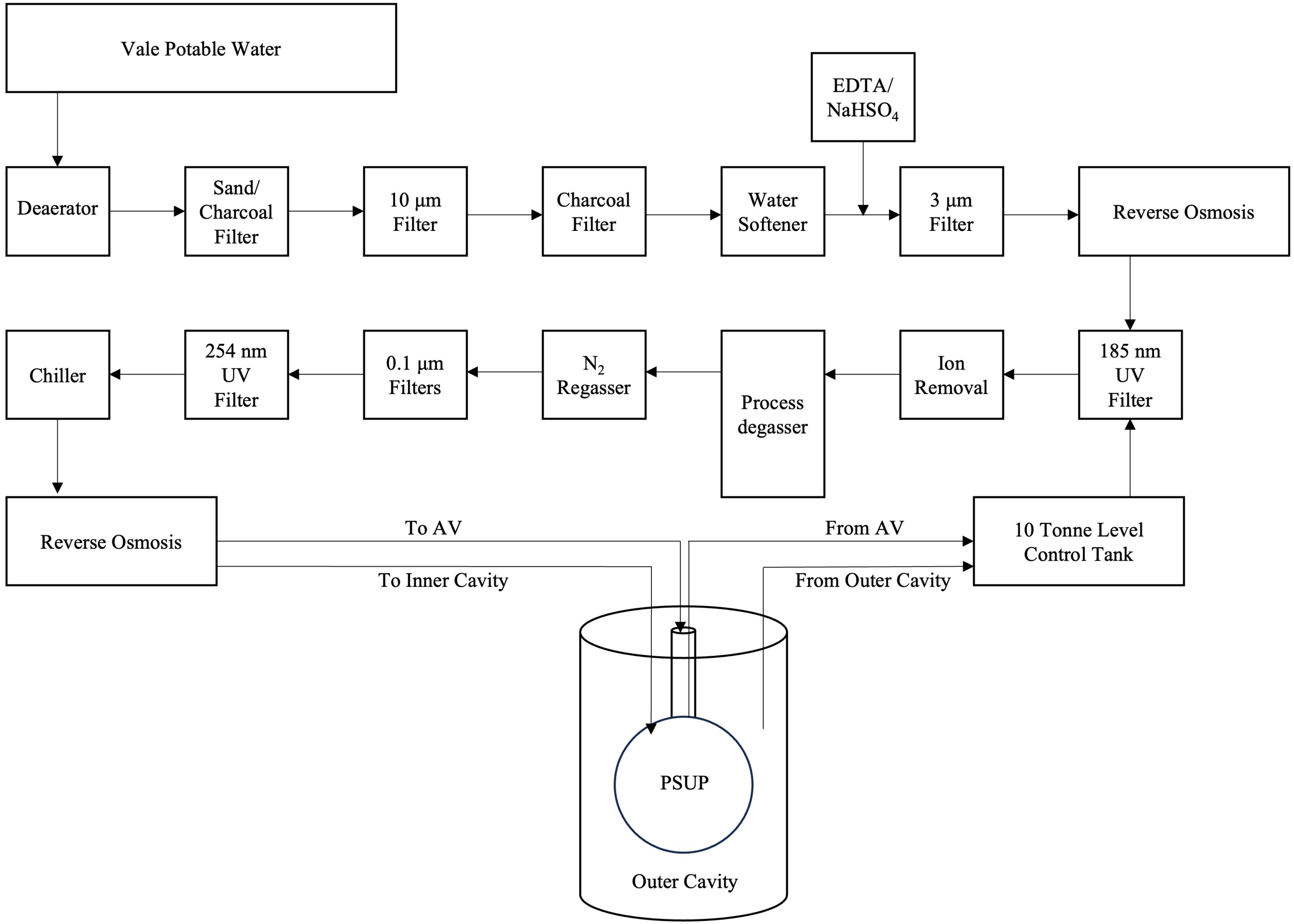


Neutrino 2022

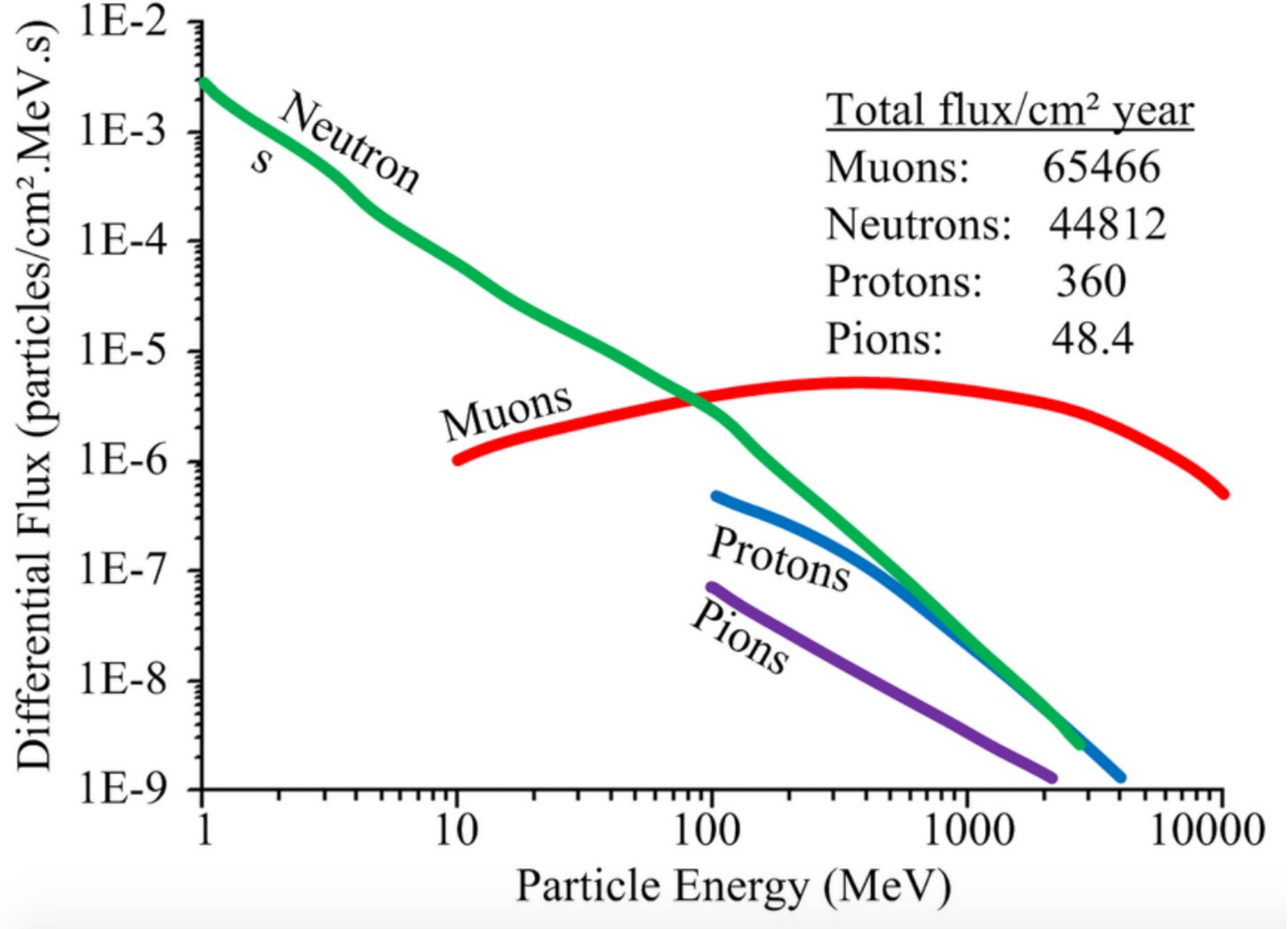


BACKUP

- Po-210 is measured using Si-alpha counters
- Measurements are done over acrylic *in situ*
- *Also* two pipes from inside AV were measured
- Distance from detector to acrylic 1-2 mm of air
- Po-210 spectral line at 5.3 MeV is counted
- Efficiency estimated with Am-241 source



Vale Potable Water
Deaerator
Sand/ Charcoal Filter
10 μm Filter
Charcoal Filter
Water Softener
EDTA/ NaHSO4
3 μm Filter
Reverse Osmosis
185 nm UV Filter
Ion Removal
Process degasser
N2 Regasser
0.1 μm Filters
254 nm UV Filter
Chiller
Reverse Osmosis
To AV
To Inner Cavity
From AV
From Outer Cavity
10 Tonne Level Control Tank
PSUP
Outer Cavity


Differential Flux (particles/cm².MeV.s)
1E-2
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
1
10
100
1000
10000
Particle Energy (MeV)
Neutrons
Muons
Protons
Pions
Total flux/cm² year
Muons: 65466
Neutrons: 44812
Protons: 360
Pions: 48.4