НЕЙТРИННАЯ АСТРОФИЗИКА

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НИИЯФ МГУ, 16 декабря 2008г.,
Москва

Рождение нейтрино

Распад радиоактивных ядер (Земля)

$A(z) \Rightarrow A(Z+1) + e^- + \tilde{\nu}$ (E < 6 МэВ)

Реакции термоядерного синтеза (Солнце,…)

$p + p \Rightarrow D + e^+ + \nu$ (E < 10 МэВ)

……………………………………….

Процессы нейтронизации, $e^- e^+$ – аннигиляция (SN)

$e^- + p \Rightarrow n + \nu,\quad e^- + e^+ \Rightarrow \nu + \tilde{\nu}$ (E < 40МэВ)

Распад μ, π, K … -мезонов (Высокие энергии)

$p + A(Z) \Rightarrow \ldots + \pi\ (K,..)$ $\quad \pi \Rightarrow \mu + \nu$

Регистрация нейтрино

$\nu + A(Z) \Rightarrow A(Z+1) + e^-$

Радиохимический метод (Cl, Ga)

$\tilde{\nu} + p \Rightarrow n + e$

Жидкие сцинтилляторы

$\nu + e^- \Rightarrow \nu' + e^{-\prime}$

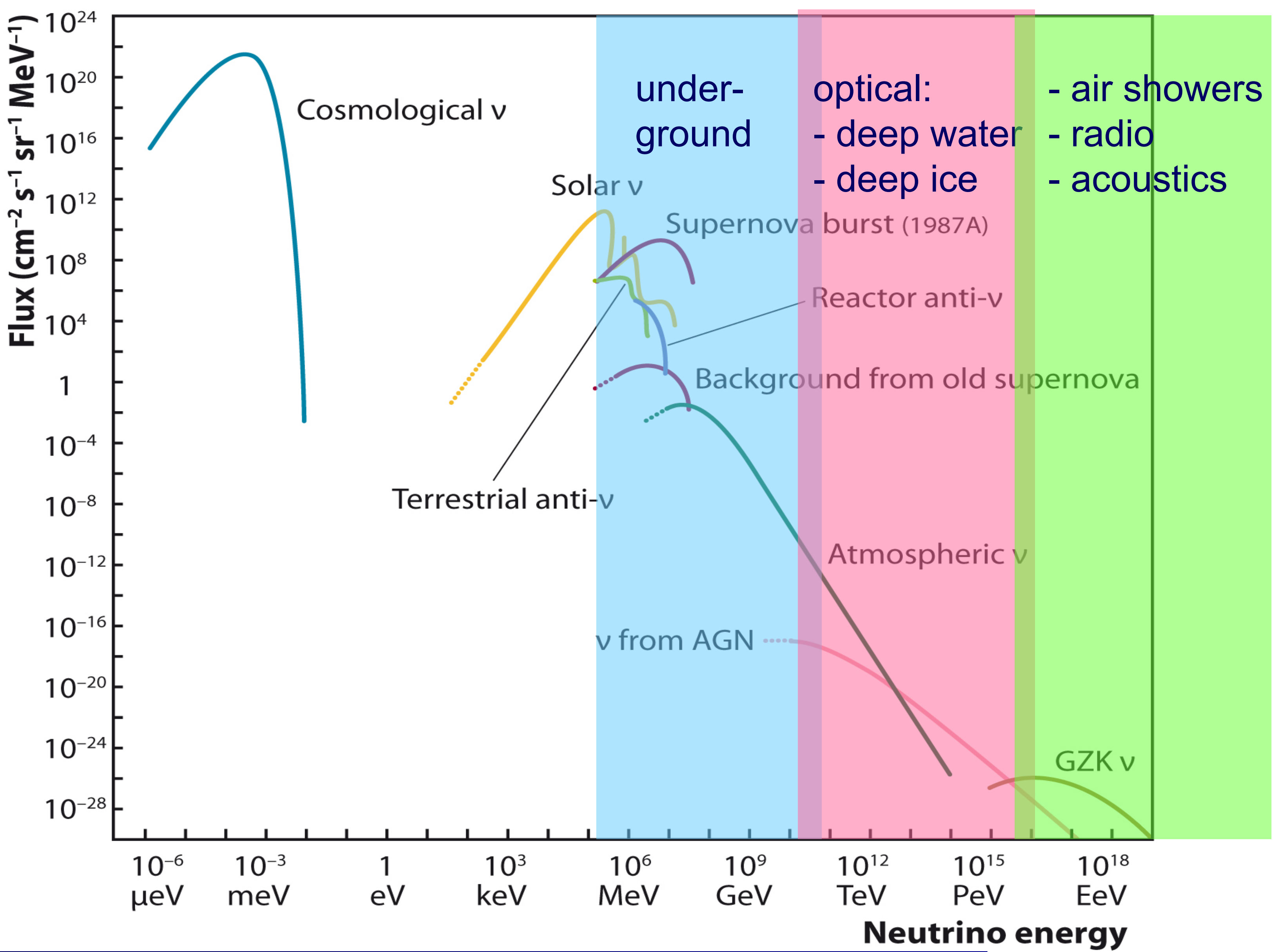
$\nu + A(Z) \Rightarrow \ldots + \mu(e, \nu')$

Черенковские детекторы

.

энергия нейтрино (эВ)	Источники нейтрино	Методы регистрации
10^{21}	Сверхмассивные частицы Грейзен-Зацепин-Кузьмин	Детекторы ШАЛ Радио ([redacted] Акустика (?)
10^{18} 10^{15} 10^{12}	Активные ядра галактик Сверхновые Центр нашей галактики Гамма всплески Объекты яркой фазы	Подводные: Черенковские
10^{9}	Темная материя Космические лучи	Подводные: Черенковские
10^{6} 10^{3}	Гравитационные коллапсы Солнце Земля	Подземные: Черенковские Радиохимические Сцинтилляционные
1		
10^{-3}	Реликтовое излучение	Нет

The unified spectrum of neutrinos



НЕЙТРИНО ОТ СОЛНЦА

Водородный цикл	E_ν (МэВ)	Поток ($см^{-2}с^{-1}$)
$p + p \Rightarrow D + e^+ + \nu$	0 – 0.42	$6\ 10^{10}$
$p + p + e^- \Rightarrow D + \nu$	1.44	$1.4\ 10^{8}$
$p + D \Rightarrow {}^3He + \gamma$		
${}^3He + {}^3He \Rightarrow {}^4He + p + p$		
${}^3He + {}^4He \Rightarrow {}^7Be + \gamma$		
$p + {}^7Be \Rightarrow {}^8B \Rightarrow {}^8Be^* + e + \nu$	0 – 15	$5.8\ 10^{6}$
$e^- + {}^7Be \Rightarrow {}^7Li + \nu$	0.83	$4.7\ 10^{9}$

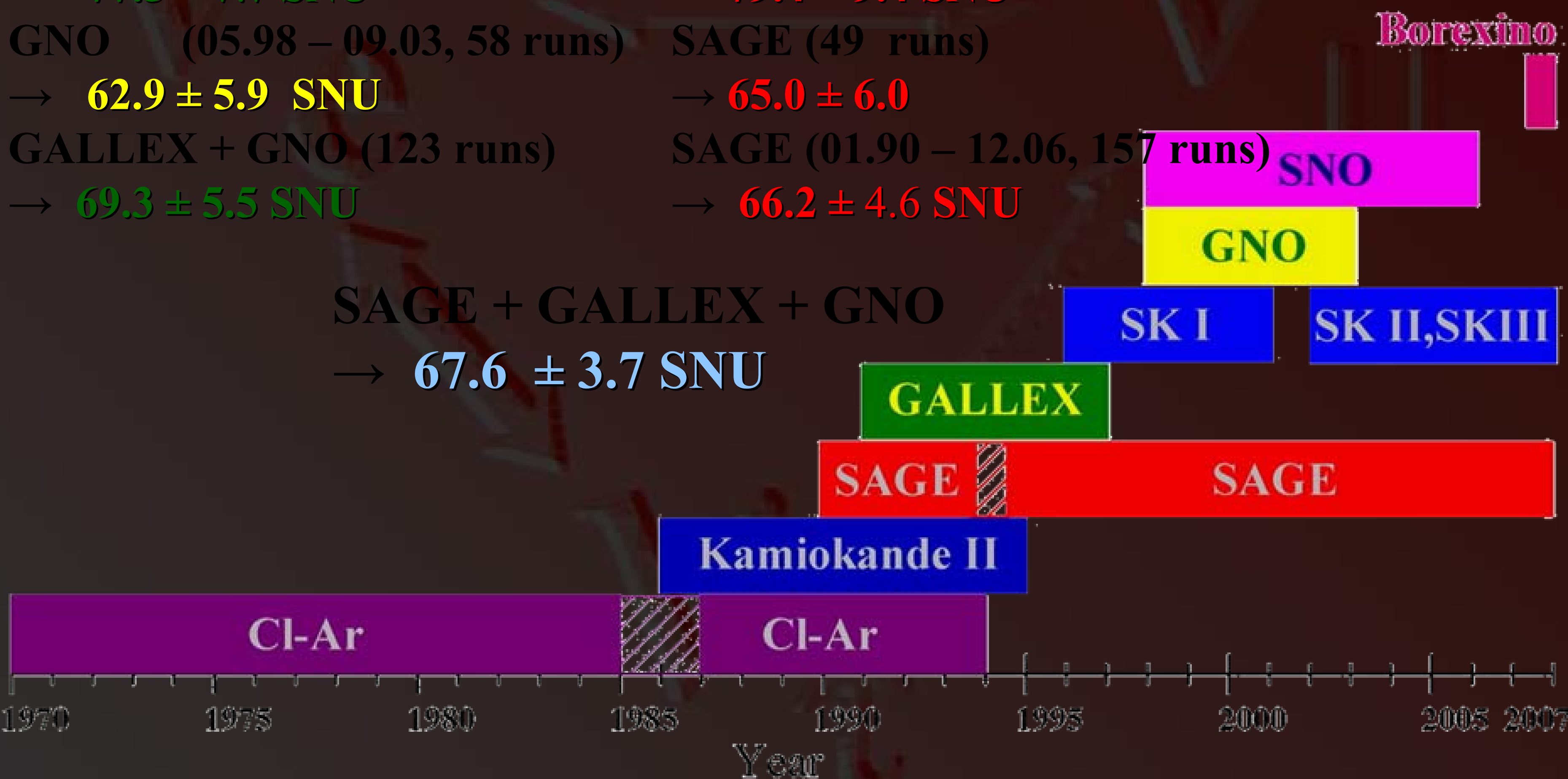
CNO цикл

$p + {}^{12}C \Rightarrow {}^{13}N + \gamma$		
${}^{13}N \Rightarrow {}^{13}C + e^+ + \nu$	0 – 1.199	$6\ 10^{8}$
$p + {}^{13}C \Rightarrow {}^{14}N + \gamma$, $p + {}^{14}N \Rightarrow {}^{15}O + \gamma$		
${}^{15}O \Rightarrow {}^{15}N + e^+ + \nu$	0 – 1.732	$5\ 10^{8}$
$p + {}^{15}N \Rightarrow {}^{12}C + {}^4He$		

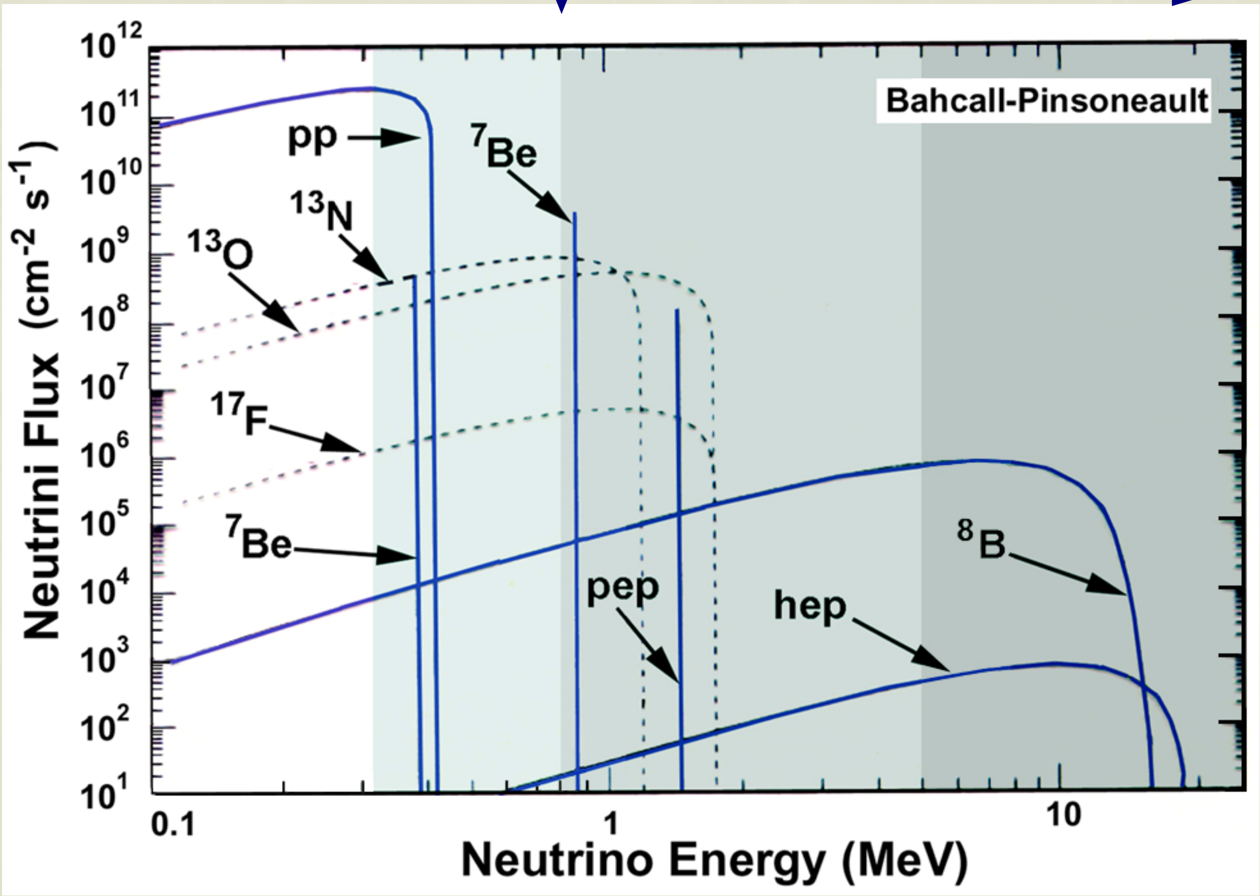
GALLEX (05.91-01.97, 65 runs)
→ 77.5 ± 7.7 SNU
GNO (05.98 – 09.03, 58 runs)
→ 62.9 ± 5.9 SNU
GALLEX + GNO (123 runs)
→ 69.3 ± 5.5 SNU

SAGE (45 runs)
→ 79.4 ± 9.4 SNU
SAGE (49 runs)
→ 65.0 ± 6.0
SAGE (01.90 – 12.06, 157 runs)
→ 66.2 ± 4.6 SNU

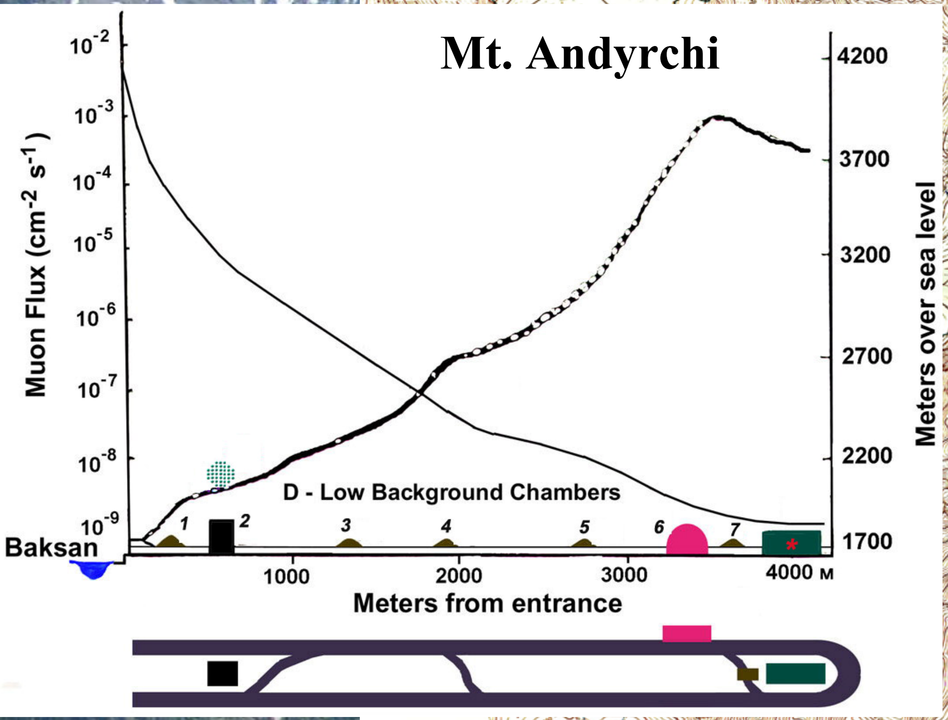
SAGE + GALLEX + GNO
→ 67.6 ± 3.7 SNU



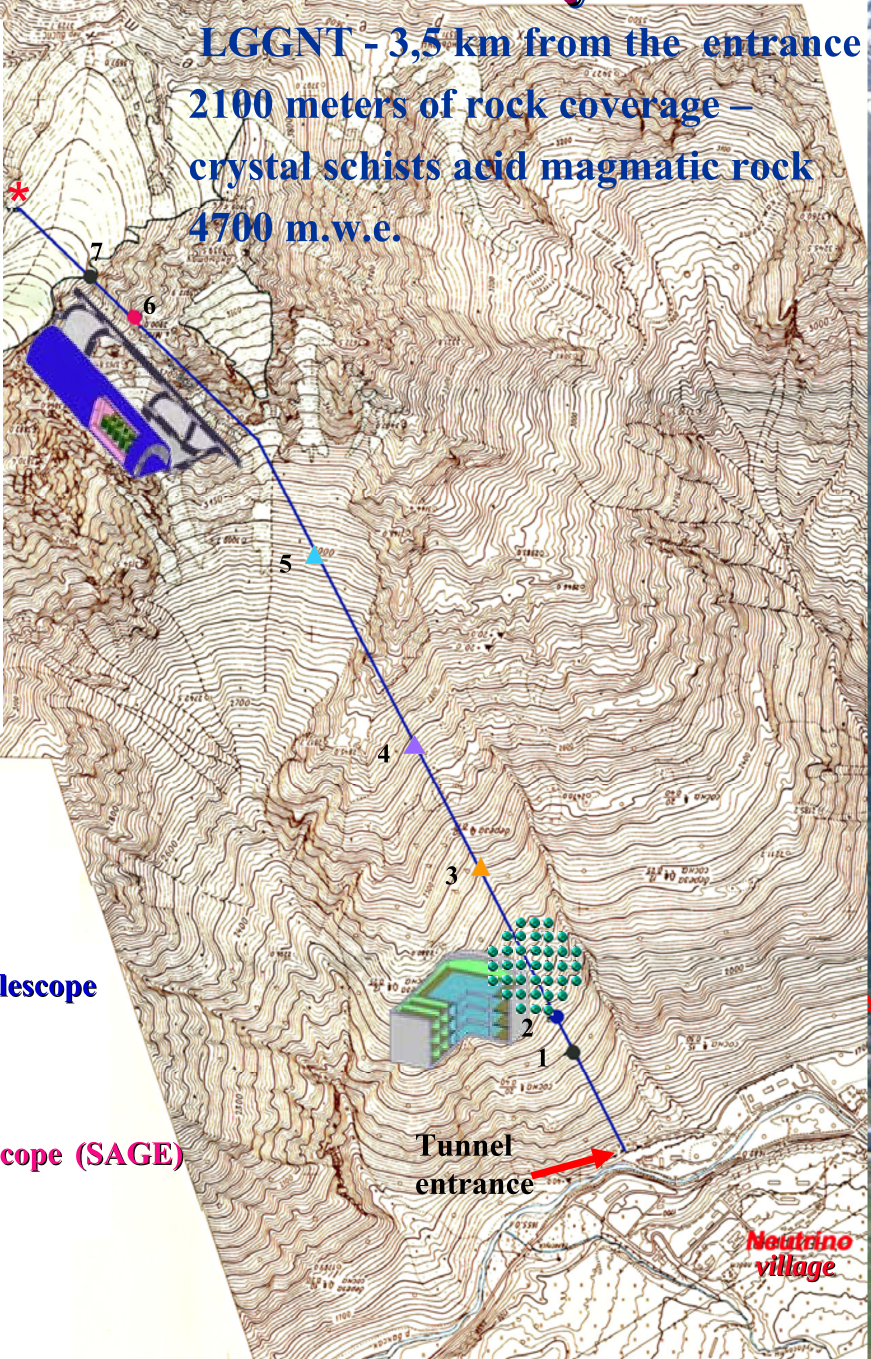
νe, CC, NC	SNO (5 MeV)	0,90 ± 0,08
νe	SuperK (5 MeV)	0,406 ± 0,04
$^{71}Ga + \nu_e \rightarrow {}^{71}Ge + e^-$	Ga-Ge (0,23 MeV)	0,52 ± 0,03
νe	Kamiokande II (7,5 MeV)	0,48 ± 0,08
$^{37}Cl + \nu_e \rightarrow {}^{37}Ar + e^-$	Cl-Ar (0,81 MeV)	0,30 ± 0,03



Baksan Neutrino Observatory



LGGNT - 3,5 km from the entrance
2100 meters of rock coverage –
crystal schists acid magmatic rock
4700 m.w.e.



1,7 - Low-background Chamber
2 - Baksan underground scintillation telescope
3 - Laser interferometer
4 - Acoustic gravitational antenna
5 - Geophysics laboratory
6 - Gallium-Germanium Neutrino Telescope (SAGE)
* - for the further projects
- EAS array “Andyrchy”

SAGE

Global intensity of muon
– $(3.03 \pm 0.19) \times 10^{-9}$ (cm^2/s)

Average energy of muon
– 381 GeV

Fast neutron flux (>3MeV)
– $(6.28 \pm 2.20) \times 10^{-8}$ (cm^{2}s)$^{-1}$

Ga_{met} ~ 50 tons

LGGNT
l = 60 m
w = 10 m
h = 12 m
Low background
concrete – 60 cm

SAGE

Measurement of the solar neutrino capture rate with gallium metal.

$^{71}Ga(\nu_e, e^-)^{71}Ge$, $E_{th} = 233$ keV

- **168 runs for 18 year period (Jan 1990 – Dec 2007) give the result : $65.4^{+4.0}_{-4.1}$ SNU**

  (1 SNU = 1 neutrino capture/sec in a target that contains 10^{36} atoms of the neutrino absorbing isotope.

  The weighted average of the results of all Ga experiments is now 66.1±3.1 SNU

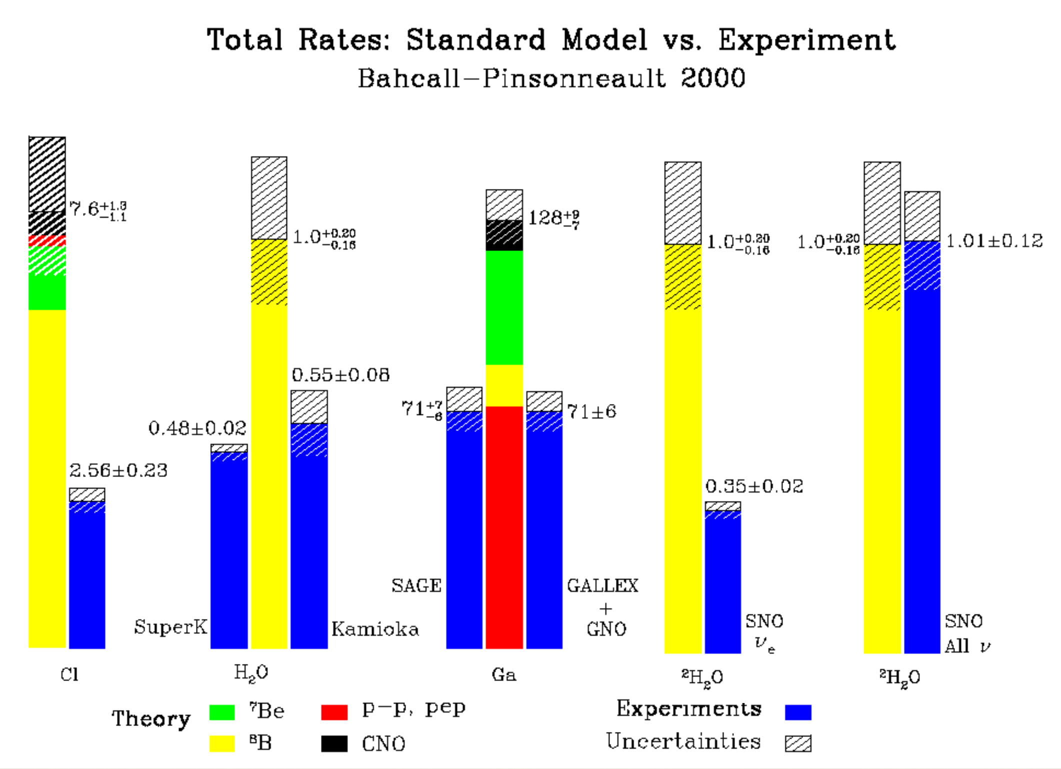
- **There is good agreement between SSM prediction including neutrino oscillations and Ga results.**

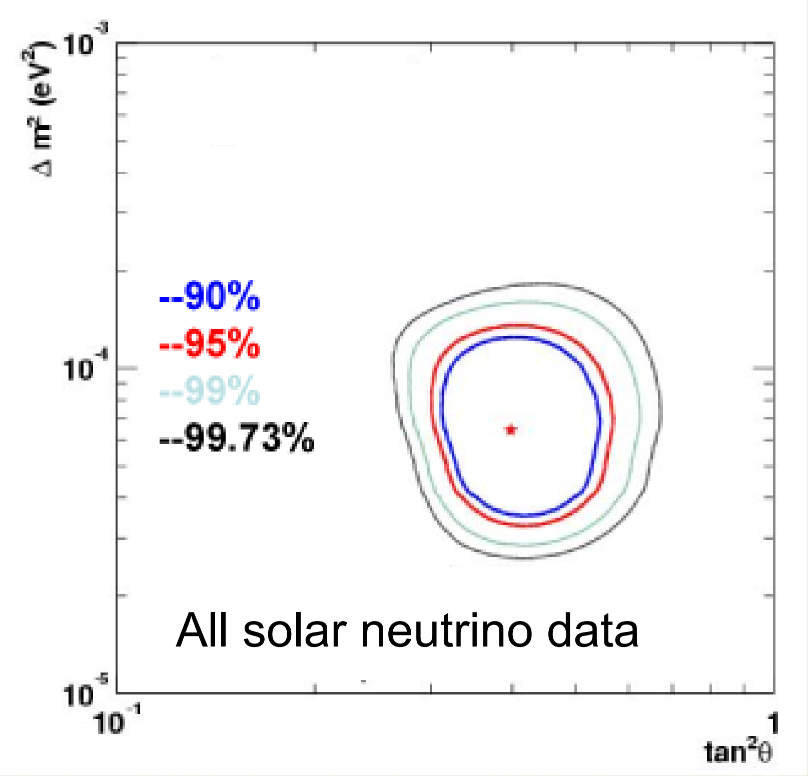
- **The recent test of SAGE with a reactor-produced ^{37}Ar neutrino source shown that SSM predicted rate may be overestimated.** (Although there are alternative explanations based on transitions to sterile neutrinos or on quantum decoherence in neutrino oscillations.)

- **A new test of SAGE is planed with a reactor-produced very intense neutrino source to shed light on this question.**

- **SAGE is currently the only operating solar neutrino experiment which provides the determination of the fundamental *pp* neutrino flux and a continuous monitoring of the low energy solar neutrino flux with increasing sensitivity over very long time period.**

Солнечные нейтрино





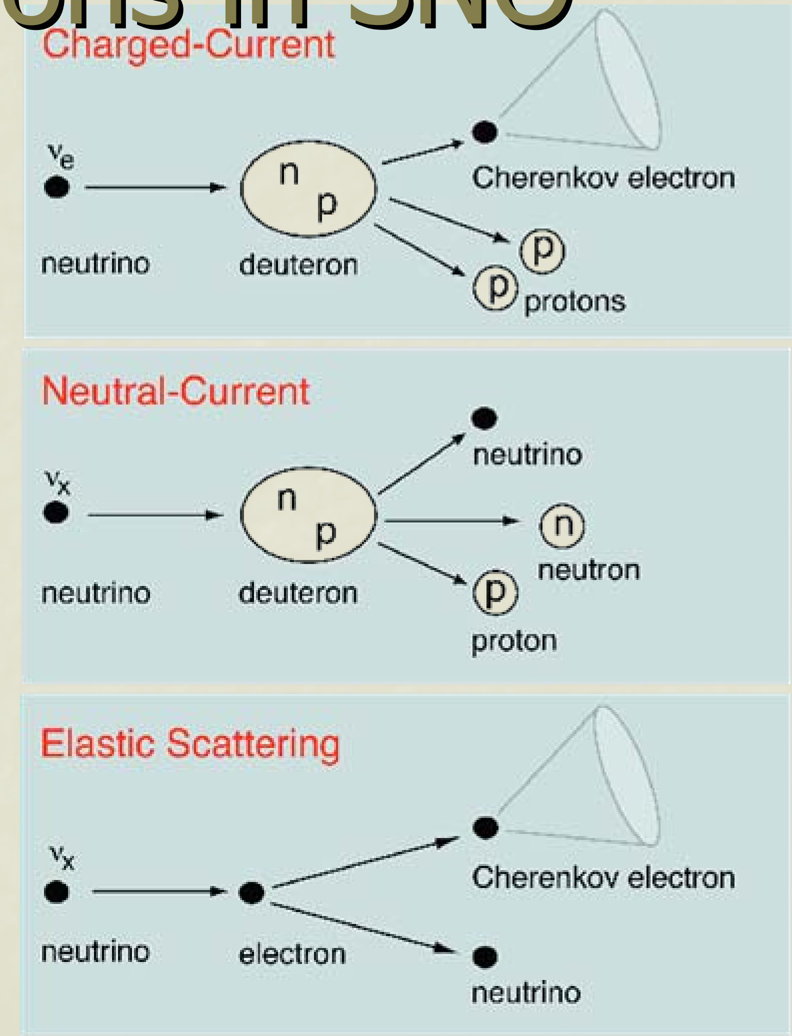
Neutrino Reactions in SNO

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

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

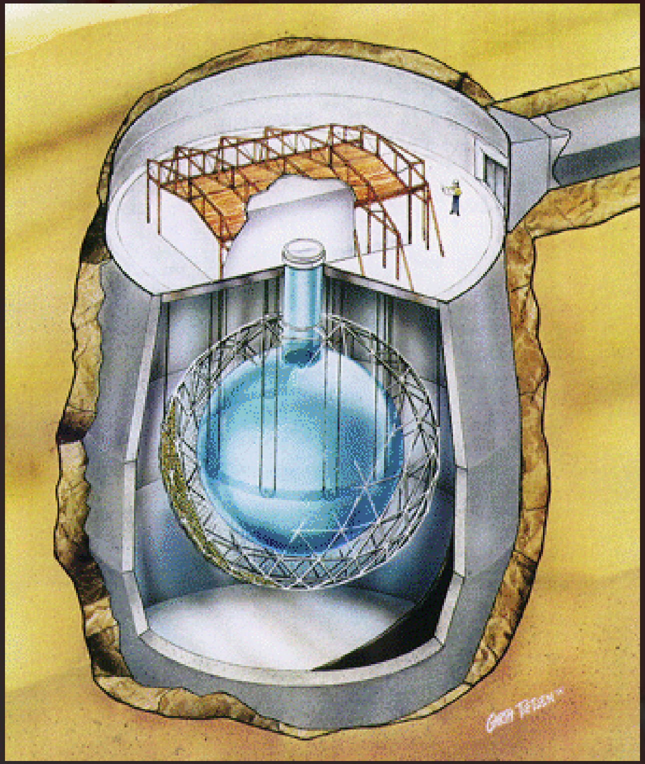
- measures total ^8B ν flux from the Sun
- equal cross section for all active ν flavors

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



Солнечные нейтрино

Детектор SNO



Тяжелая вода: 1000 тонн
Защита: 1700 + 5300 тонн H_2O
9500 ФЭУ

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

$$\Phi_{cc} = \Phi_e$$

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

$$\Phi_{nc} = \Phi_e + (\Phi_\mu + \Phi_\tau)$$

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

$$\Phi_{es} = \Phi_e + (\Phi\mu + \Phi\tau)/6$$

Borexino - 2008

- 8″ PMT – 2212
- Scintillator – 278.3 ton
- Energy region – (250 – 800) KeV
- SSM (osc.) – (49±4) counts/day 100ton

  without osc. – (75±4) counts/day 100ton

Exp. – (49 ± 3) cpd/100 tons

•Borexino is located under the Gran Sasso mountain which provides a shield against cosmic rays (4000 m water equivalent);

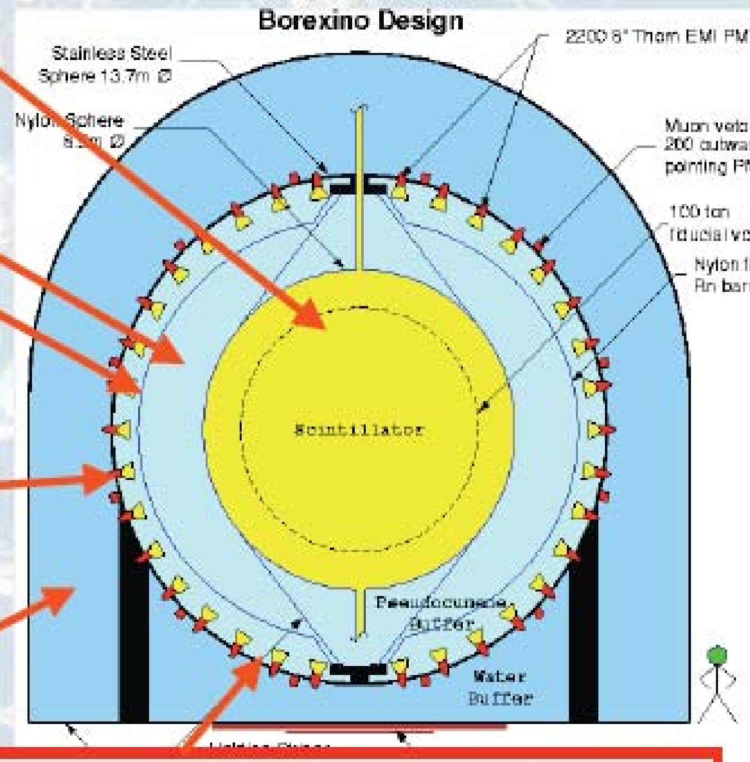
Core of the detector: 278 tons of liquid scintillator contained in a nylon vessel of 4.25 m radius (PC+PPO);

1st shield: 890 tons of ultra-pure buffer liquid (PC+quencher) contained in a stainless steel sphere of 6.75 m radius;

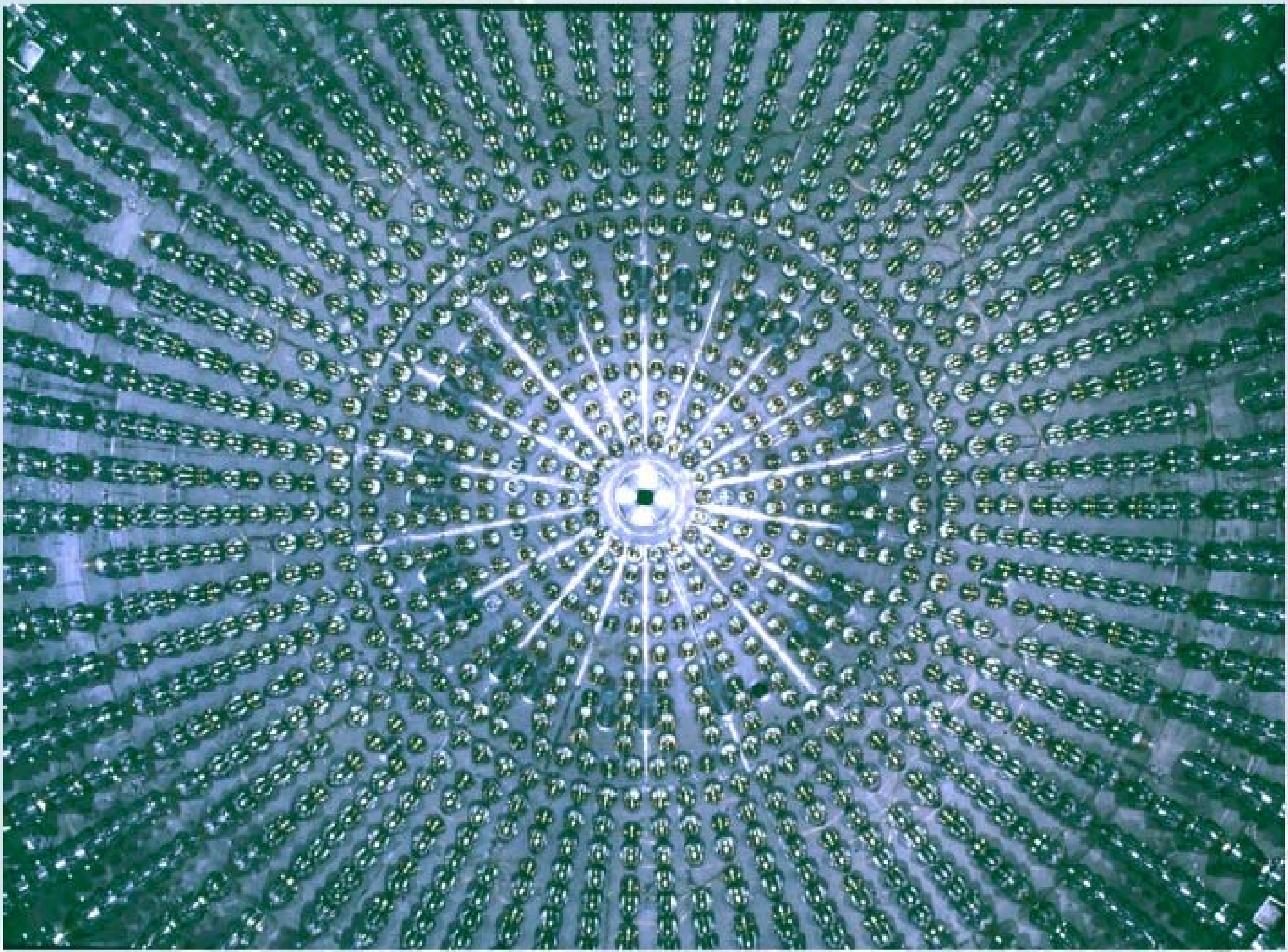
External nylon vessel; it is a barrier against Rn emitted by PMT and s.steel

2214 photomultipliers pointing towards the center to view the light emitted by the scintillator (1843 with opt. concentr.)

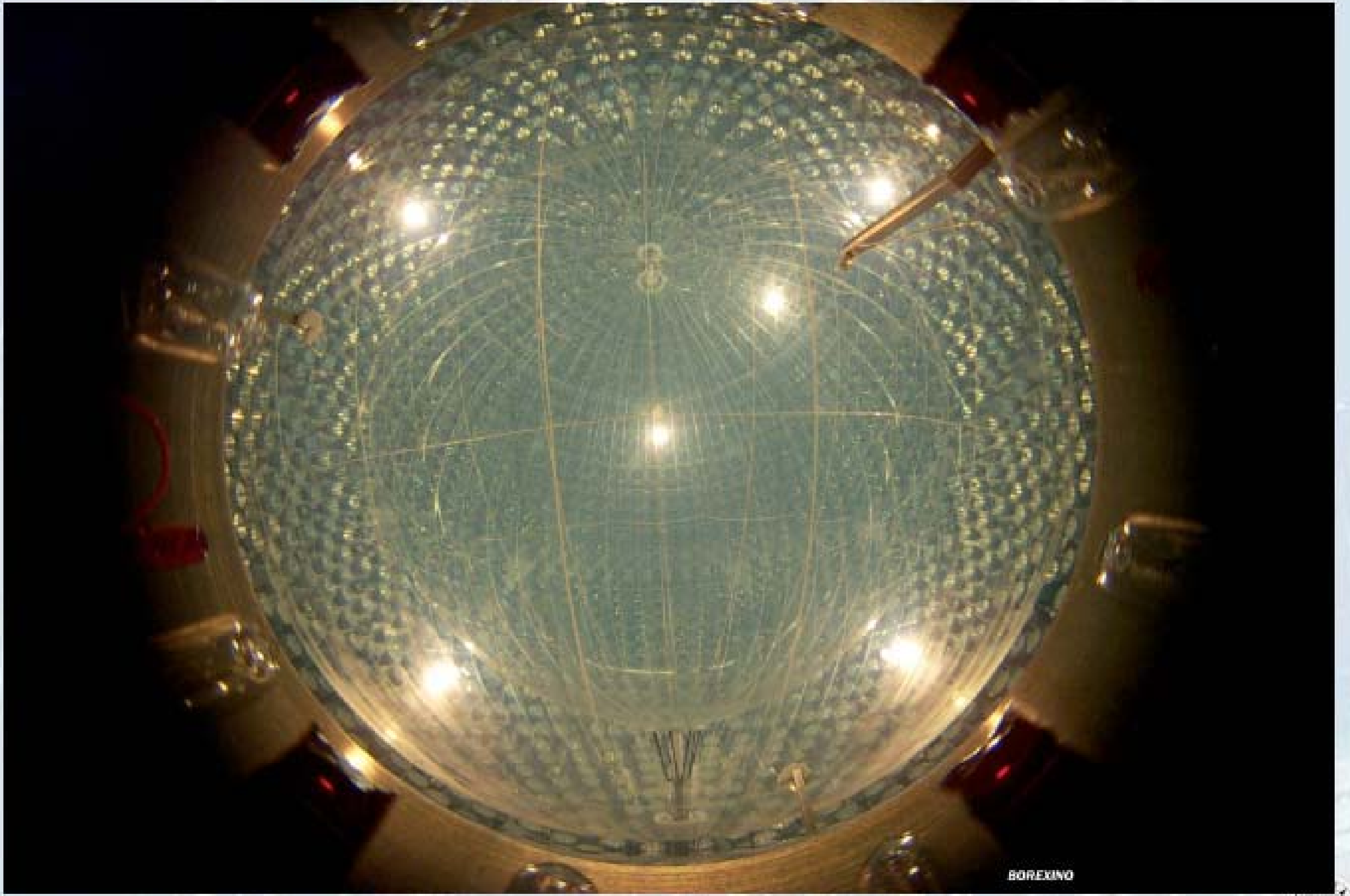
2nd shield: 2100 tons of ultra-pure water contained in a cylindrical dome;

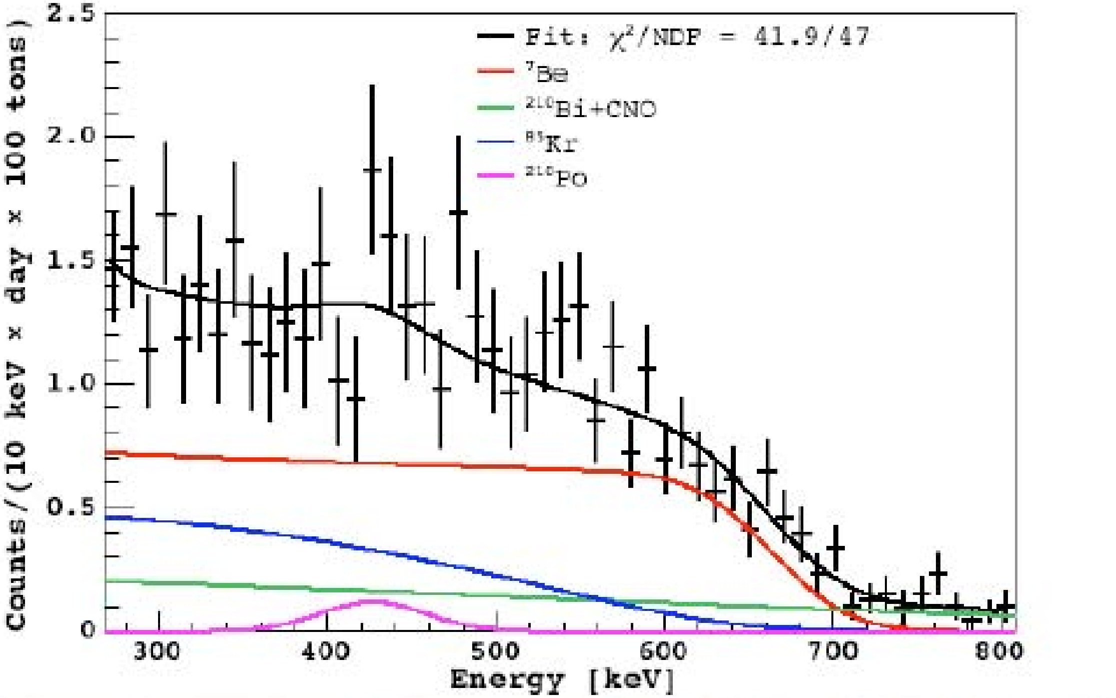


200 PMTs mounted on the SSS pointing outwards to detect light emitted in the water by muons crossing the detector;



PC filling completed





cpd / 100 tons

^{7}Be: 47 ± 7

^{85}Kr: 22 ± 7

^{210}Bi+CNO:15 ± 4

^{210}Po(res.): 0.9 ± 1.2

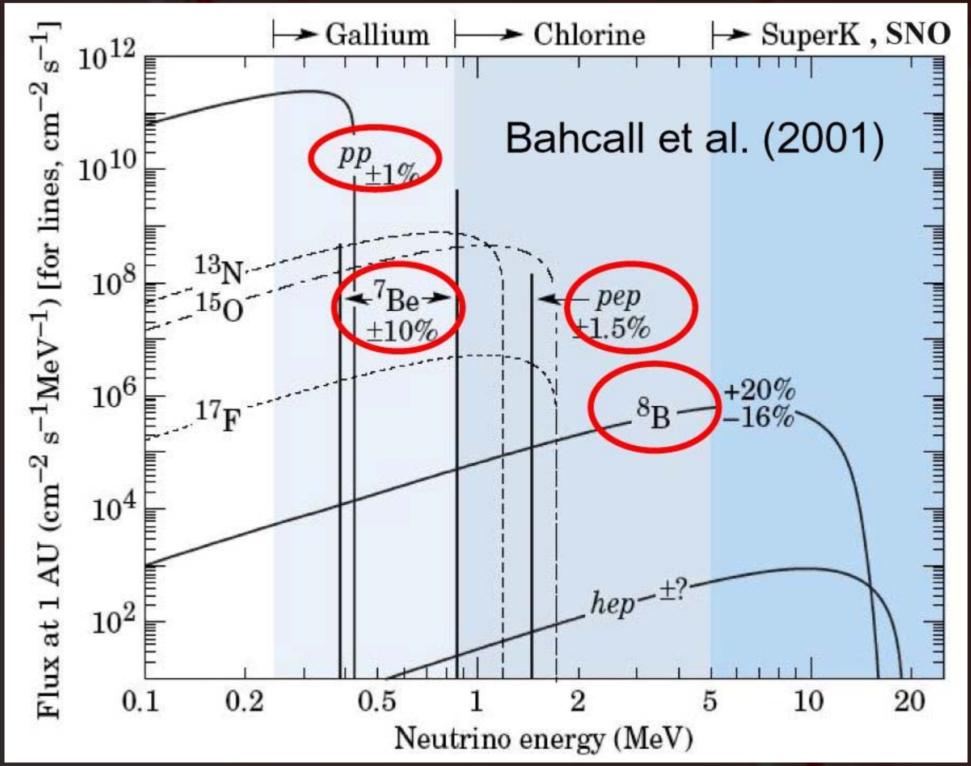
Syst error : 25%

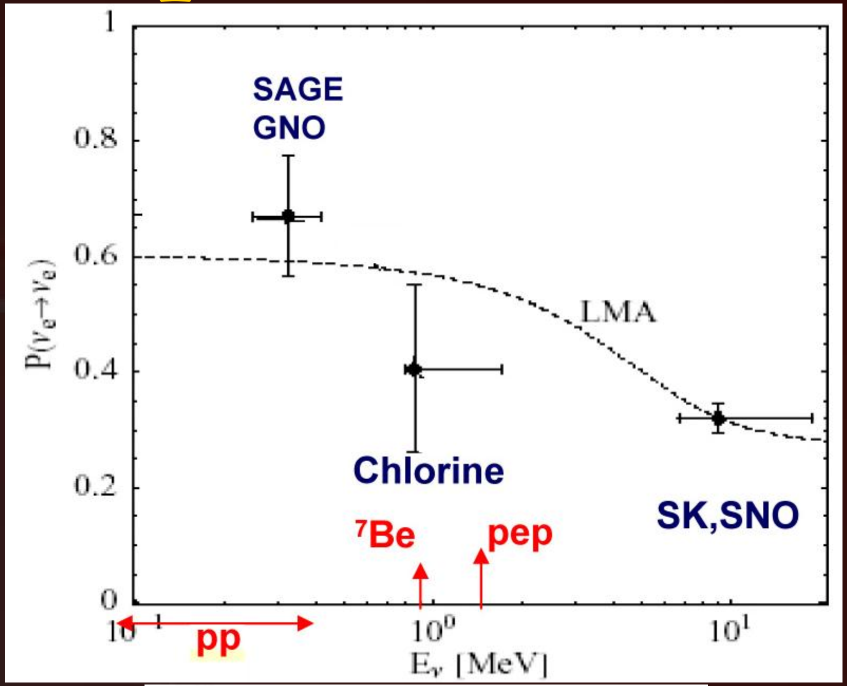
Fit in the En. Range: 240-800 keV

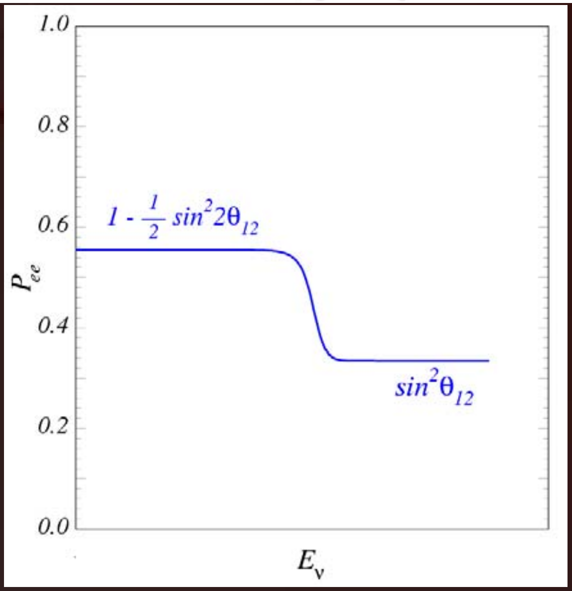
Free parameters: ^{7}Be, CNO+^{210}Bi, ^{85}Kr, ^{210}Po (residual)

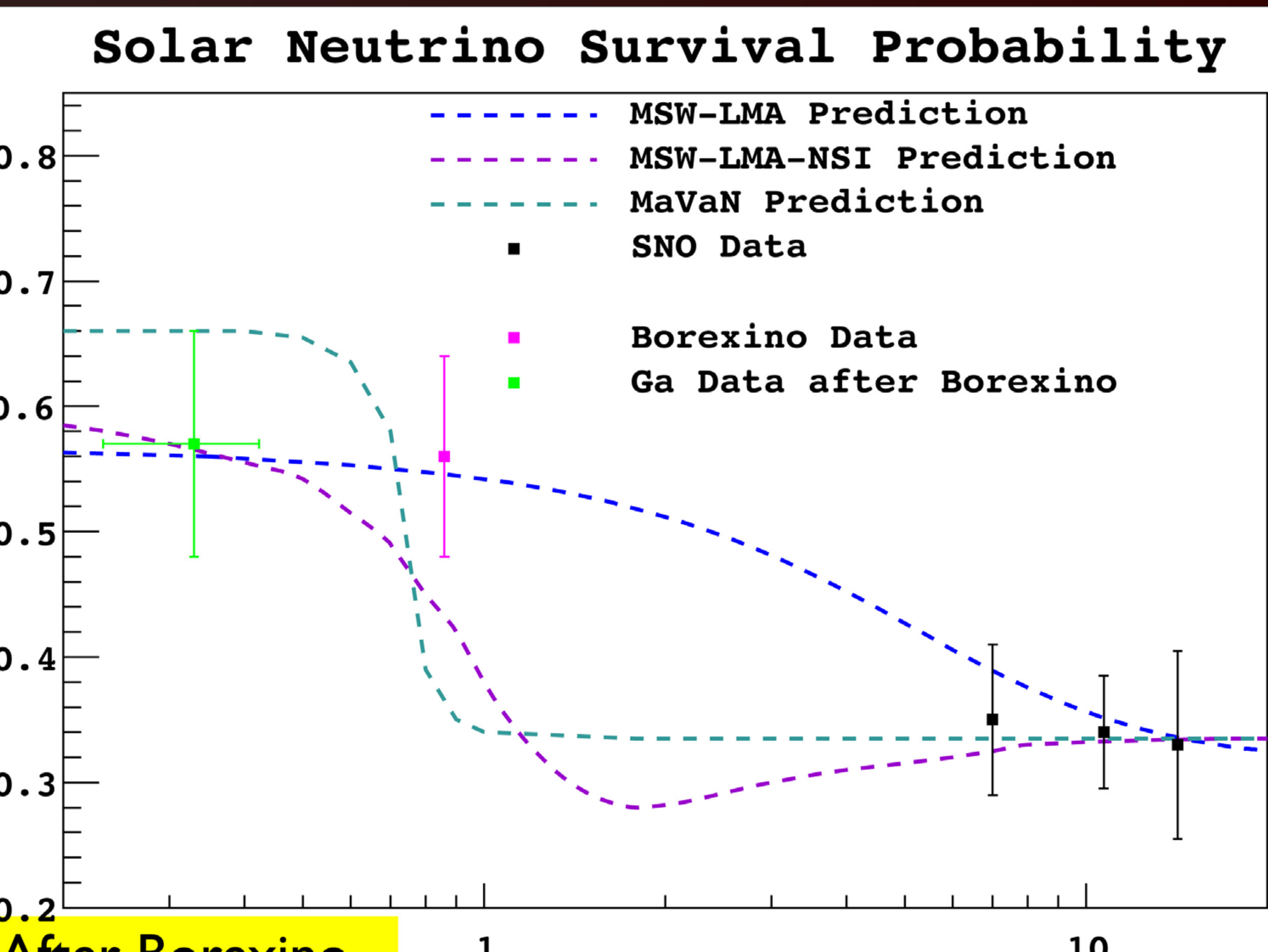
χ^2/NDF= 41.9 / 47

Солнечные нейтрино



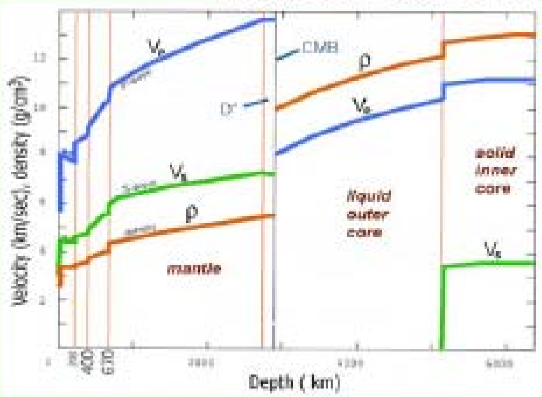





Solar Neutrino Survival Probability
MSW-LMA Prediction
MSW-LMA-NSI Prediction
MaVaN Prediction
SNO Data
Borexino Data
Ga Data after Borexino
0.8
0.7
0.6
0.5
0.4
0.3
0.2
1
10
After Borexino

Probes of the Earth's interior

- Deepest hole is about 12 km
- Samples from the crust (and the upper portion of mantle) are available for geochemical analysis.
- Seismology reconstructs density profile (not composition) throughout all Earth.



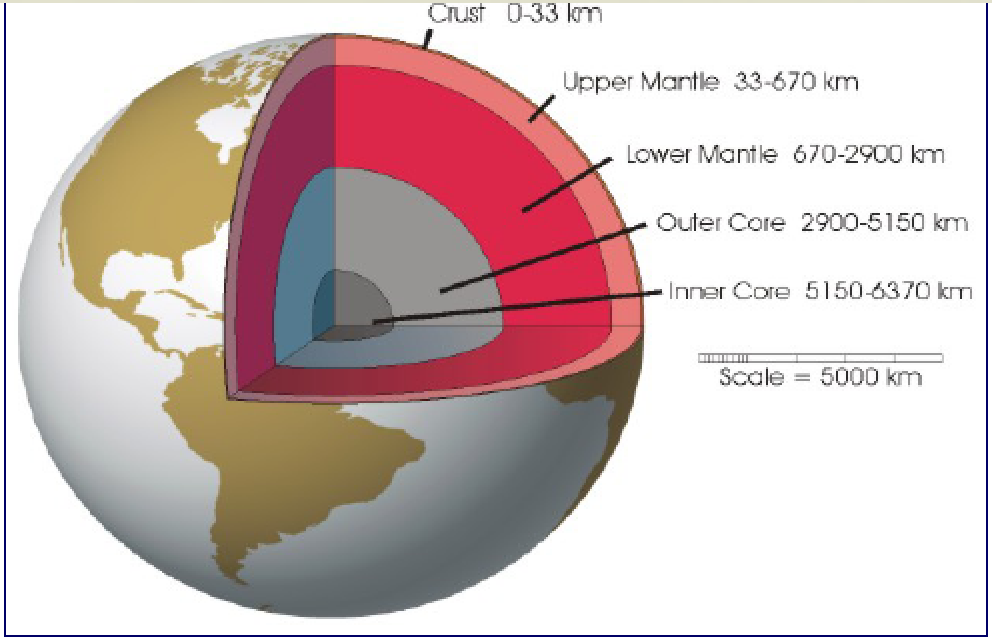
Geo-neutrinos: a new probe of Earth's interior

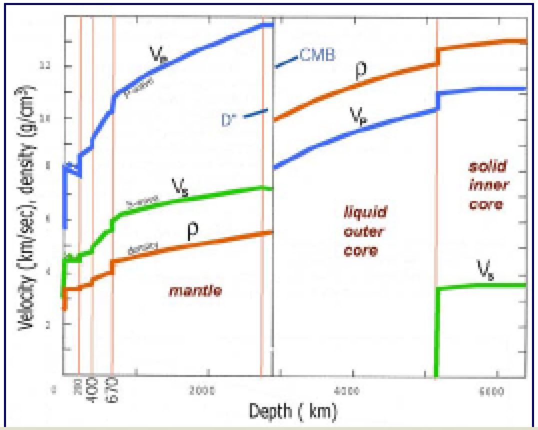
✓ They escape freely and instantaneously from Earth's interior.

✓ They bring to Earth's surface information about the chemical composition of the whole planet.

Probes of the Earth's interior

- Deepest hole is about 12 km.
- The crust (and the upper mantle only) are directly accessible to geochemical analysis.





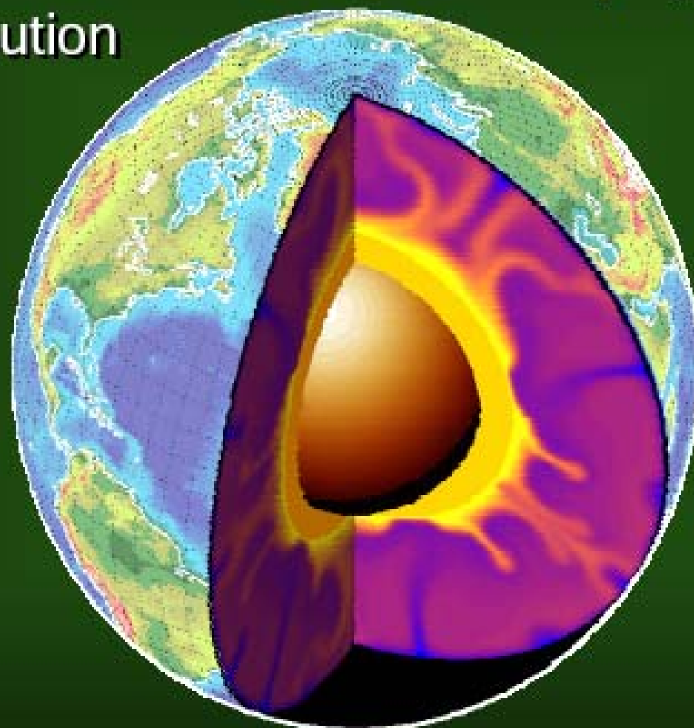
- Seismology reconstructs density profile (not composition) throughout all Earth.

Open questions about natural radioactivity in the Earth

1 - What is the radiogenic contribution to terrestrial heat production?

2 - How much U and Th in the crust?

3 - How much U and Th in the mantle?



4 - What is hidden in the Earth's core? (geo-reactor, ^{40}K, …)

5 - Is the standard geochemical model (BSE) consistent with geo-neutrino data?

Geoneutrinos: anti-neutrinos from the Earth

- Uranium, Thorium and Potassium in the Earth release heat together with anti-neutrinos, in a well fixed ratio:

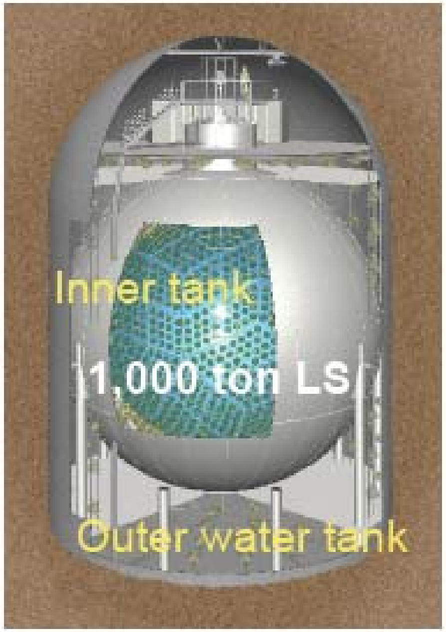
Decay	Q [MeV]	$\tau_{1/2}$ [10^9 yr]	E_{max} [MeV]	ε_H [W/kg]	$\varepsilon_{\bar{\nu}}$ [$kg^{-1}s^{-1}$]
$^{238}U \rightarrow {}^{206}Pb + 8\,{}^{4}He + 6e + 6\bar{\nu}$	51.7	4.47	3.26	$0.95 \cdot 10^{-4}$	$7.41 \cdot 10^{7}$
$^{232}Th \rightarrow {}^{208}Pb + 6\,{}^{4}He + 4e + 4\bar{\nu}$	42.8	14.0	2.25	$0.27 \cdot 10^{-4}$	$1.63 \cdot 10^{7}$
$^{40}K \rightarrow {}^{40}Ca + e + \bar{\nu}$	1.32	1.28	1.31	$0.36 \cdot 10^{-8}$	$2.69 \cdot 10^{4}$

- Earth emits (mainly) antineutrinos, Sun shines in neutrinos.
- Different components can be distinguished due to different energy spectra.
- Geoneutrinos from U and Th (not from K) are above treshold for inverse β on protons:

$$\bar{\nu} + p \rightarrow e^{+} + n - 1.8\,MeV$$

KamLAND

Kamioka Liquid Scintillator Anti-Neutrino Detector



34% photo-coverage with
1325 17" and 554 20" PMTs

2 flavor neutrino oscillation

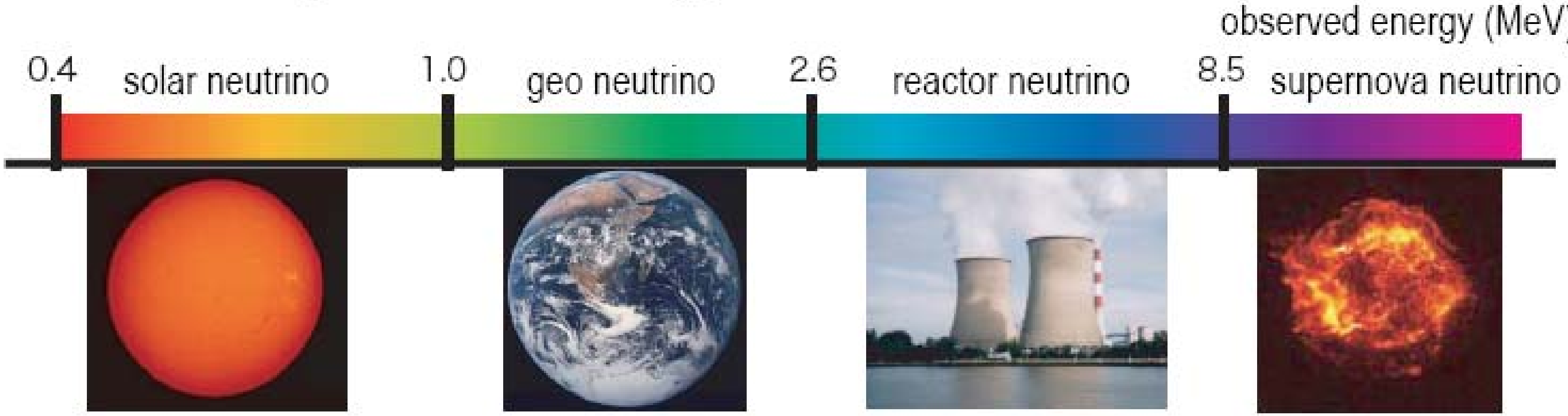
$$P(\nu_e \to \nu_e) = 1 - \sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2[\mathrm{eV}^2]l[m]}{E[\mathrm{MeV}]}\right)$$

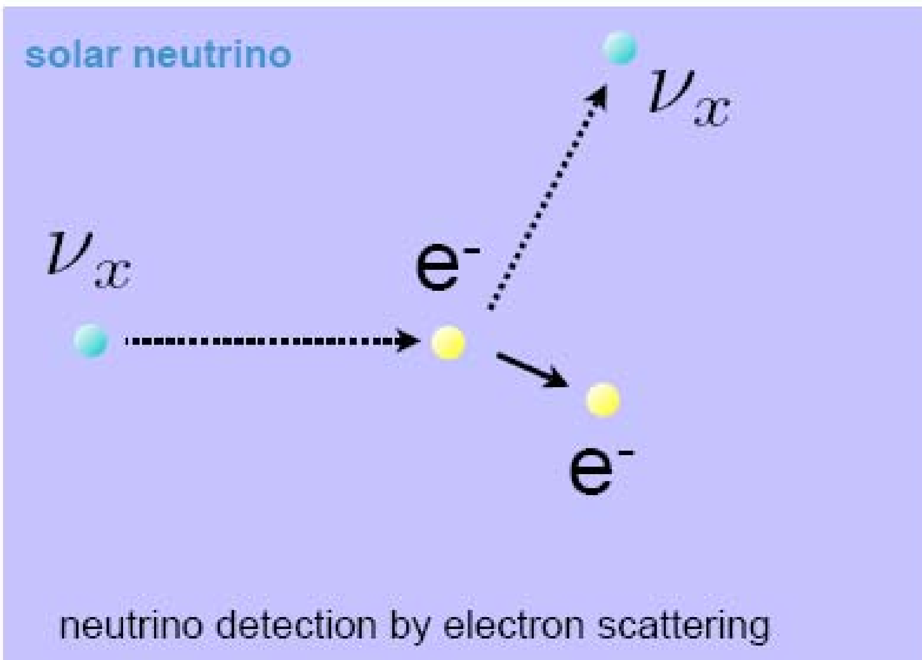
most sensitive region

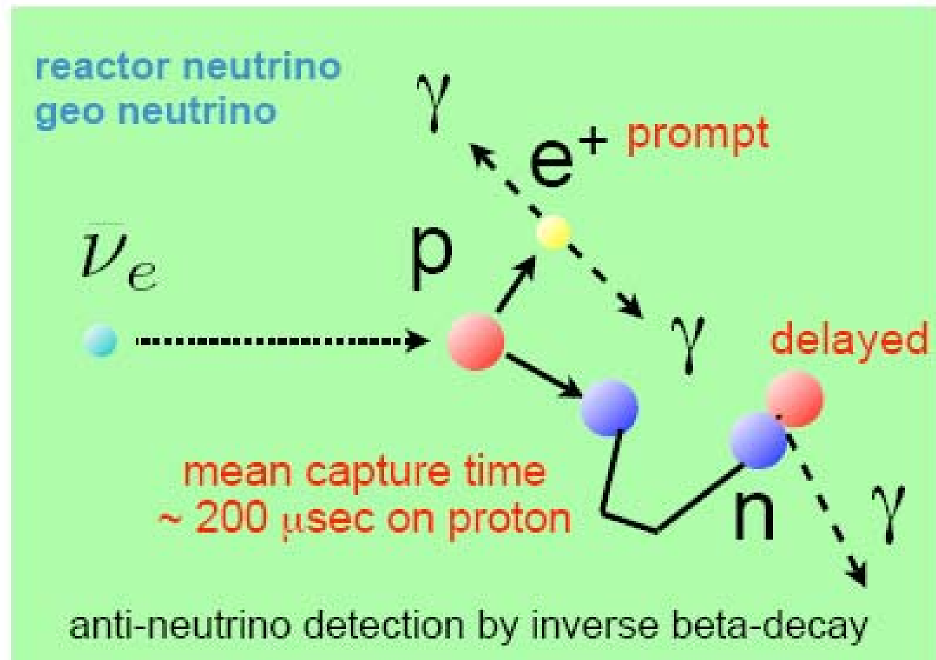
$$\Delta m^2 = (1/1.27)\cdot(E[\mathrm{MeV}]/L[m])\cdot(\pi/2)$$
$$\sim 3\times 10^{-5}\mathrm{eV}^2$$

reactor neutrino : sensitive to LMA solution

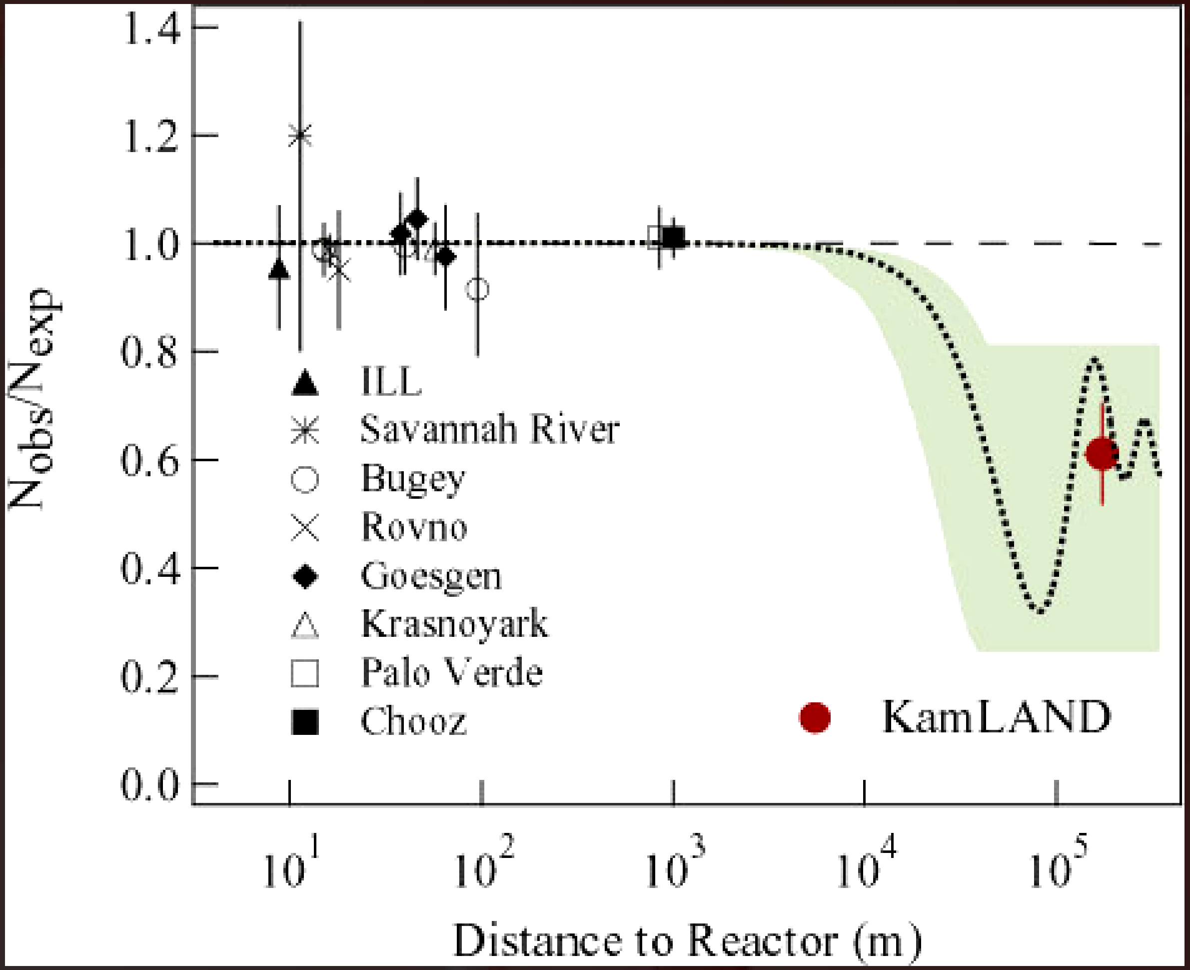
Physics Target in KamLAND



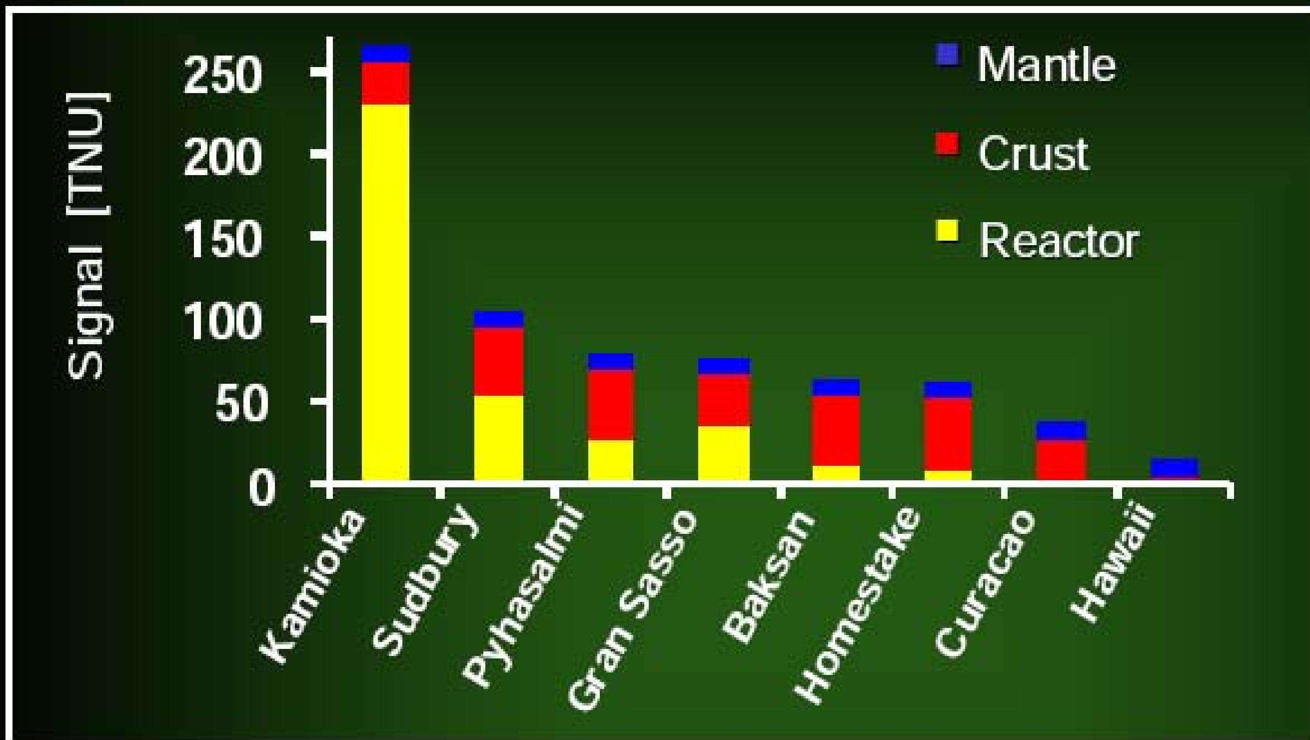


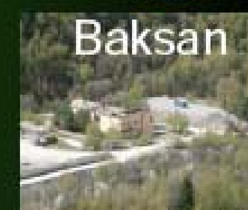


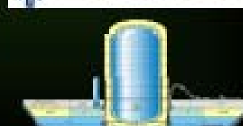
Эксперимент KamLAND



Running and planned experiments







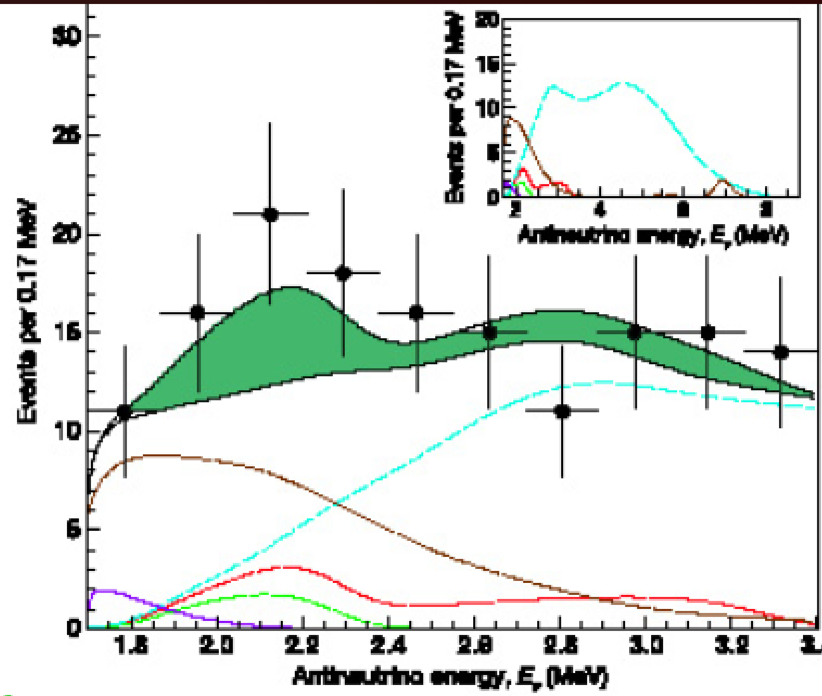
- Several experiments, either running or under construction or planned, have geo-ν among their goals.
- Figure shows the sensitivity to geo-neutrinos from crust and mantle together with reactor background.

KamLAND result*

- In two years 152 counts in the geo-neutrino energy range:
- Background is dominated by:

  -reactor events (80.4±7.2)

  -fake geo-neutrinos from $^{13}C(\alpha,n)$ (42± 11)

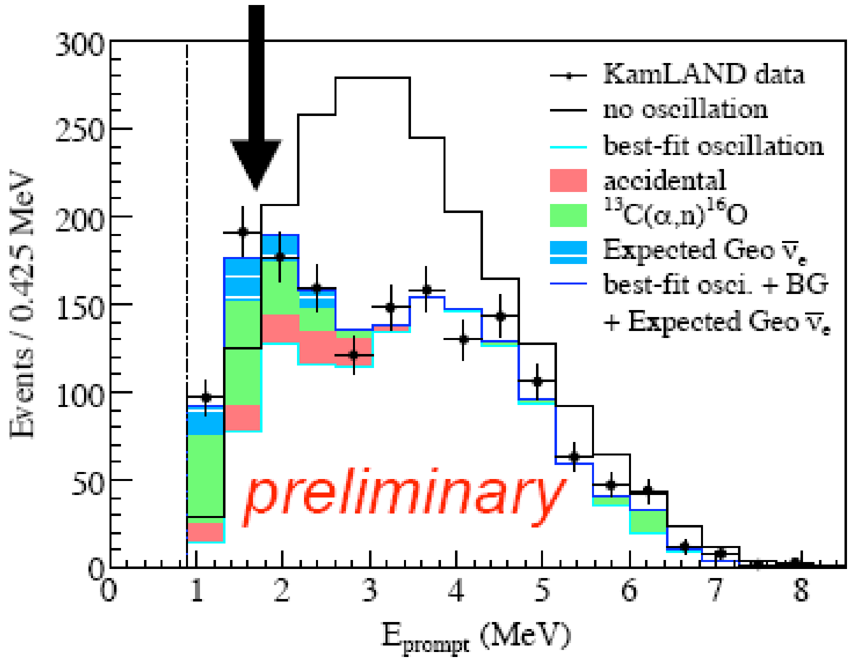


- The result** is $N(U+Th)=28_{-15}^{+16}$ geo-neutrino events from U+Th in the Earth (one event / month !)
- A pioneering experiment, showing that the technique for identifying geo-neutrinos is now available.

Geo Neutrino Estimation

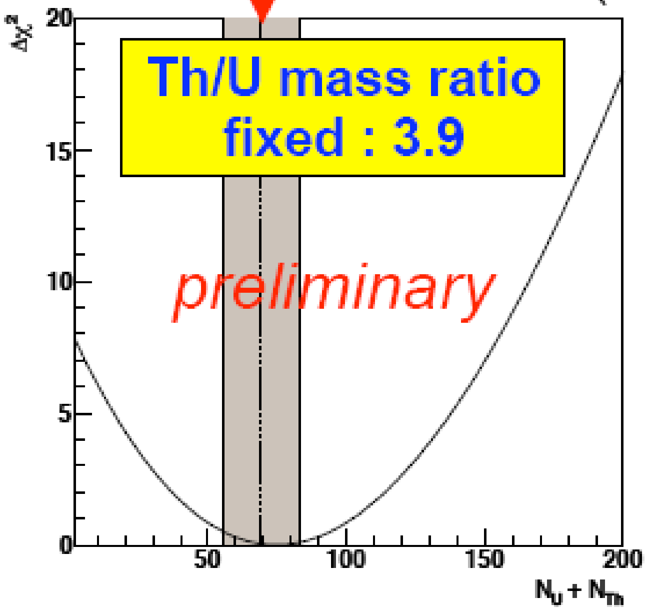
Analysis : KamLAND (rate + shape + time) + SNO

geo neutrinos (U, Th)



model expected

69.3 events (36.5 TNU)



Reference model (16 TW)

U : 56.2 event (28.9 TNU)

Th : 13.1 event (7.6 TNU)

U+Th = $74.9^{+27.3}_{-27.2}$ event

$39.4^{+14.4}_{-14.3}$ TNU

(previous result : $57.4^{+32.0}_{-30.0}$ TNU)

TNU (Terrestrial Neutrino Unit) = events/10^{32} target-proton/year

KamLAND result – 2007

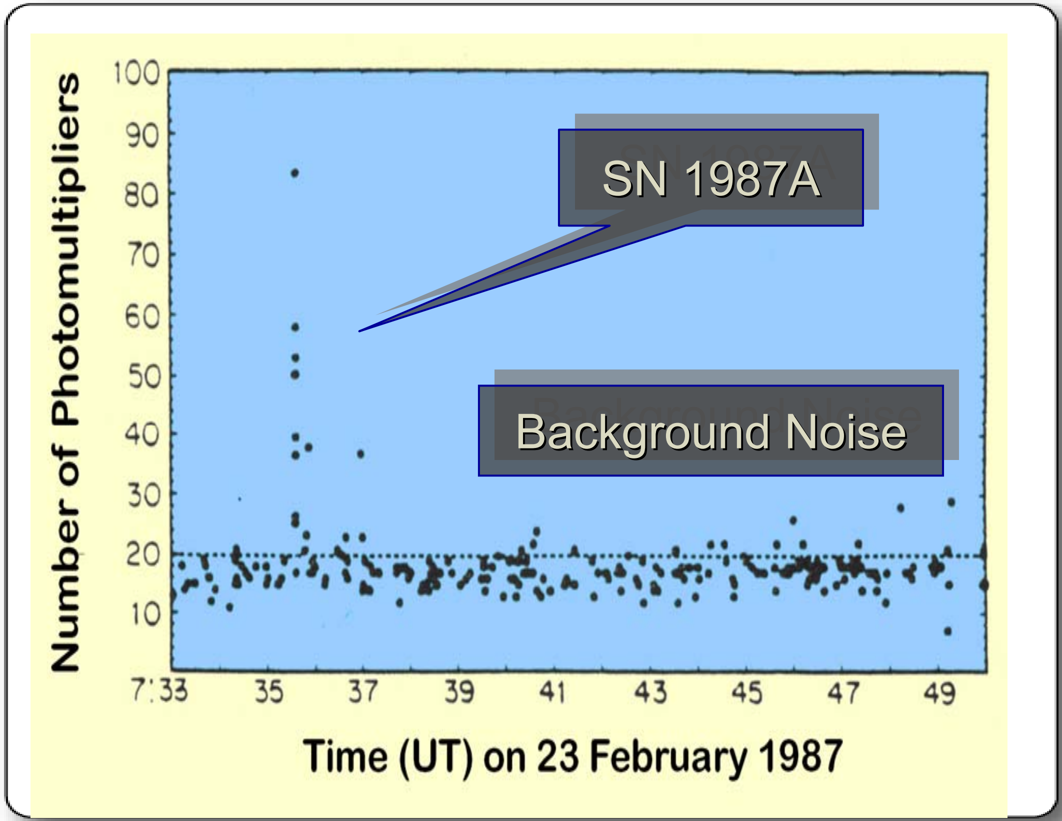
I.Shimizu, TAUP, 14 September, 2007

- Exposure – 2881 ton-year
- BSE model expectation – 69.3 events

(U: 56.2, Th: 13.1). H(U + Th) = 19 TW
H(Earth) = (30 – 44) TW

Experimental – 74.9 ±27.3 events

Detection of Supernova Bursts



12 neutrinos in KAMIOKANDE (figure)
8 in IMB, 3 in Baksan

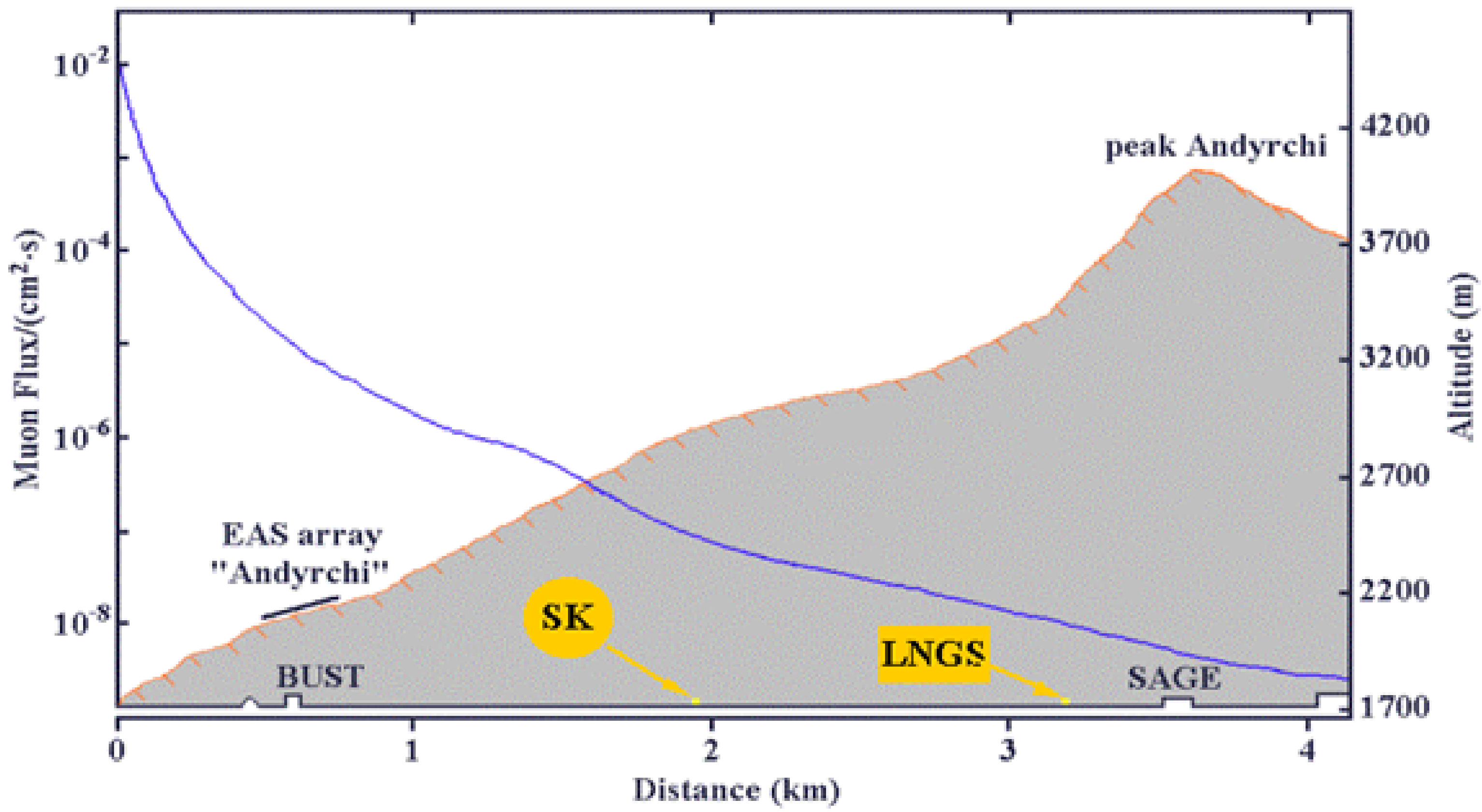
- **Remember SN-1987A**
- **Expect**
  - msec pulse from leptonization
  - Few-second-pulse from cooling

$$e^- + p \to n + \nu_e \quad (10ms)$$

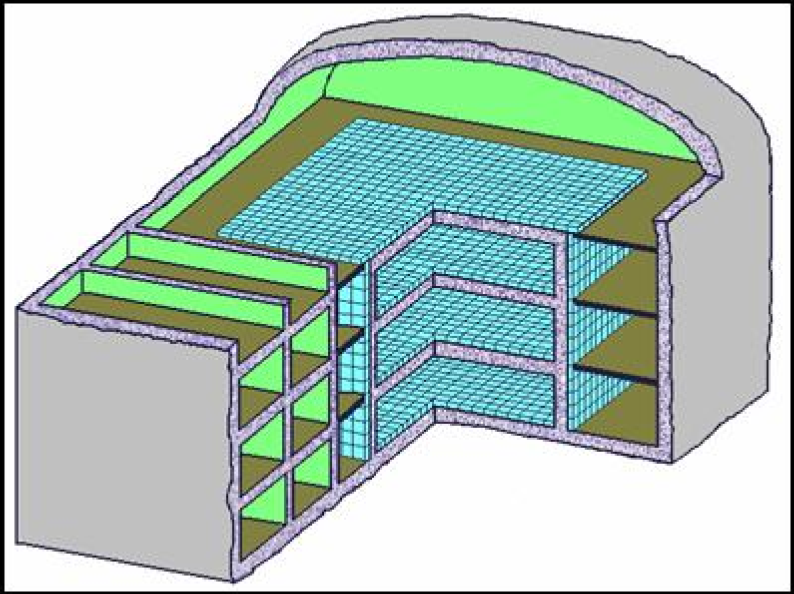
$$e^- + e^+ \to \nu_x + \nu_x \quad (10s)$$

- Av. energy a few MeV
- Threshold of ν telescope > 10MeV

Baksan Neutrino Observatory



- Depth: 850hg/cm^2
- Size: 17m$\times$17m$\times$11m
- Number of tanks: 3150
- Tank size: 70cm$\times$70cm´30cm
- Angular resolution: 2^o
- Time resolution: 5 ns
- Trigger: 10Mev in any plane
- Rate: 17 Hz
- upward/downward: 10^{-7}



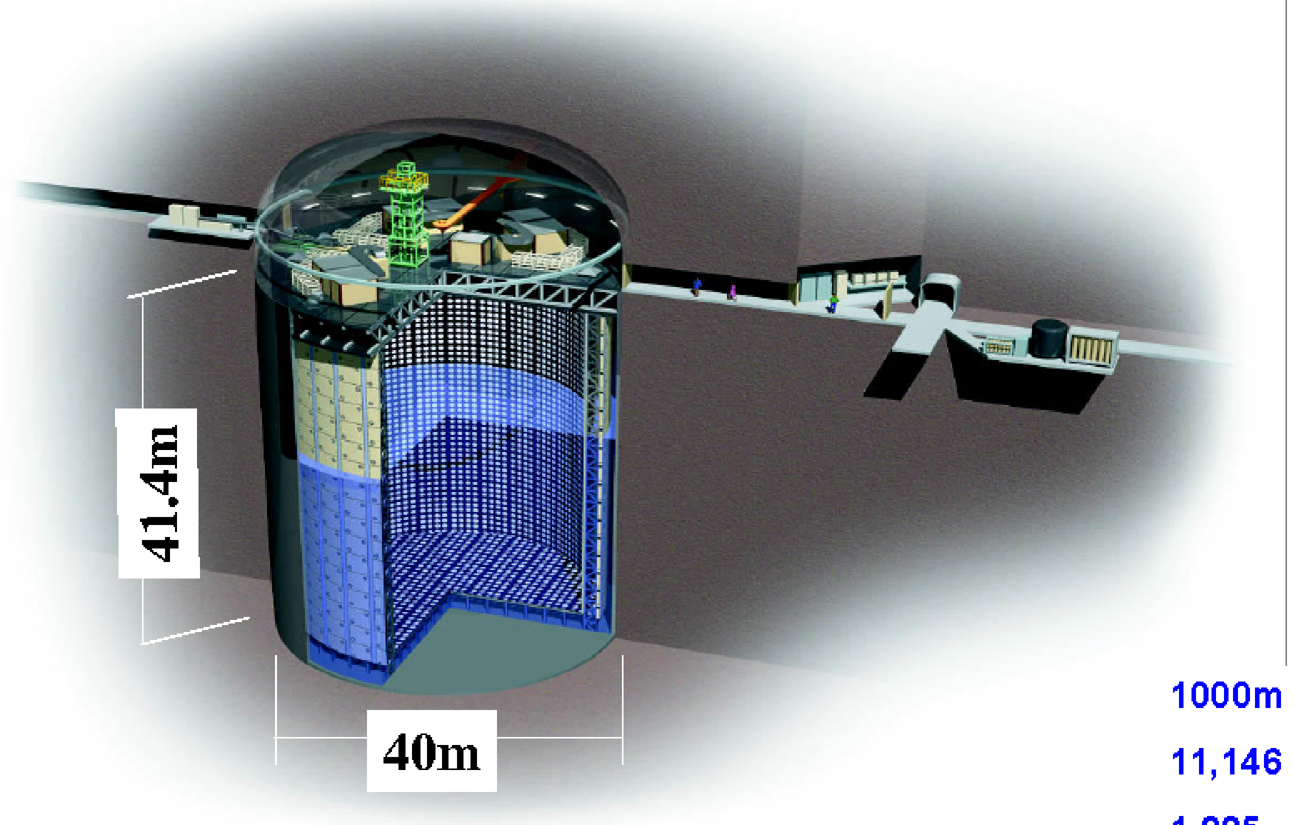
K.Nishikawa's talk

Атмосферные нейтрино

Super-Kamiokande

50,000 ton water Cherenkov detector (22.5 kton fiducial volume)

Optically separated INNER and OUTER detector

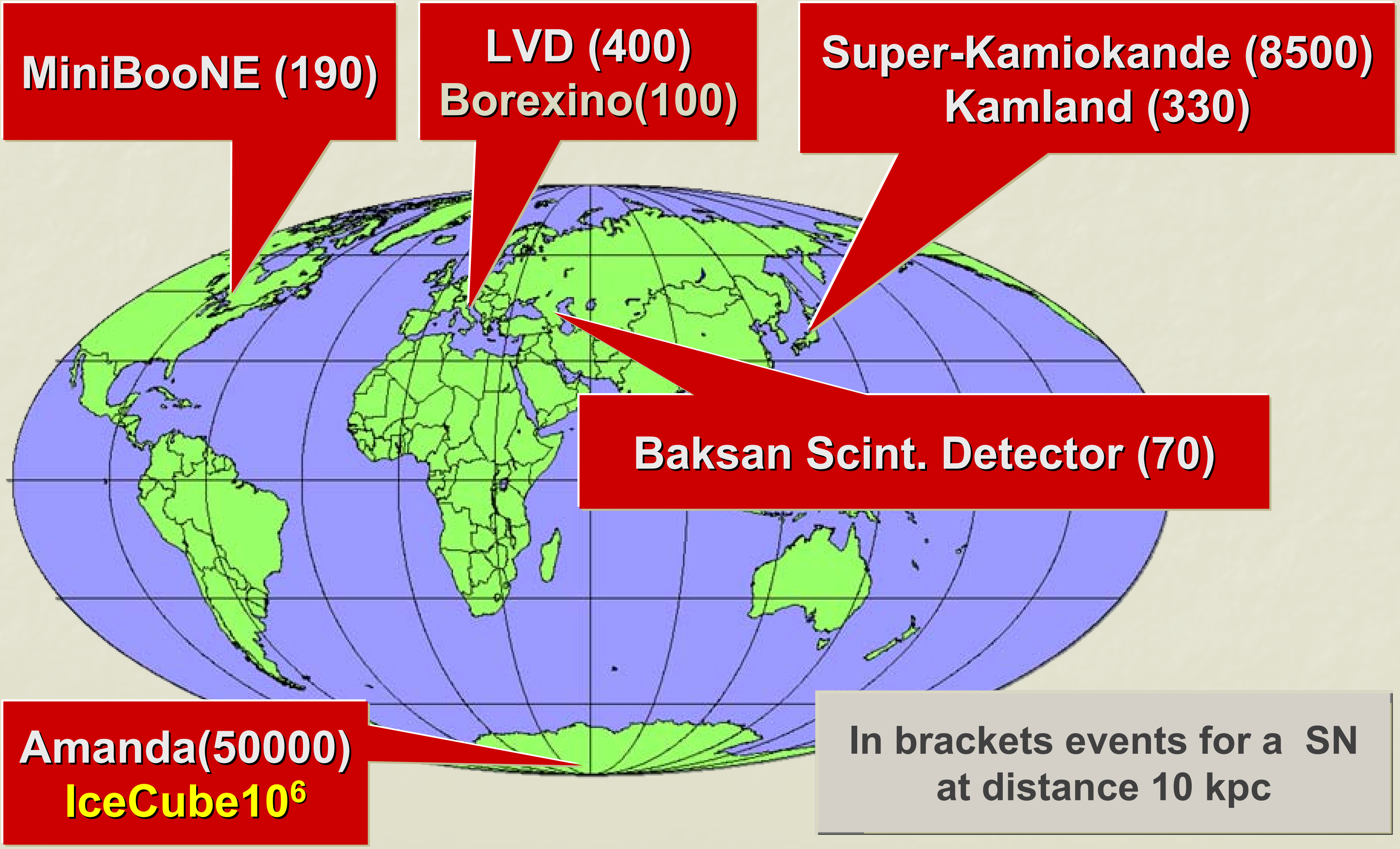


1000m underground (2700 m.w.e.)

11,146 20-inch PMTs for inner detector

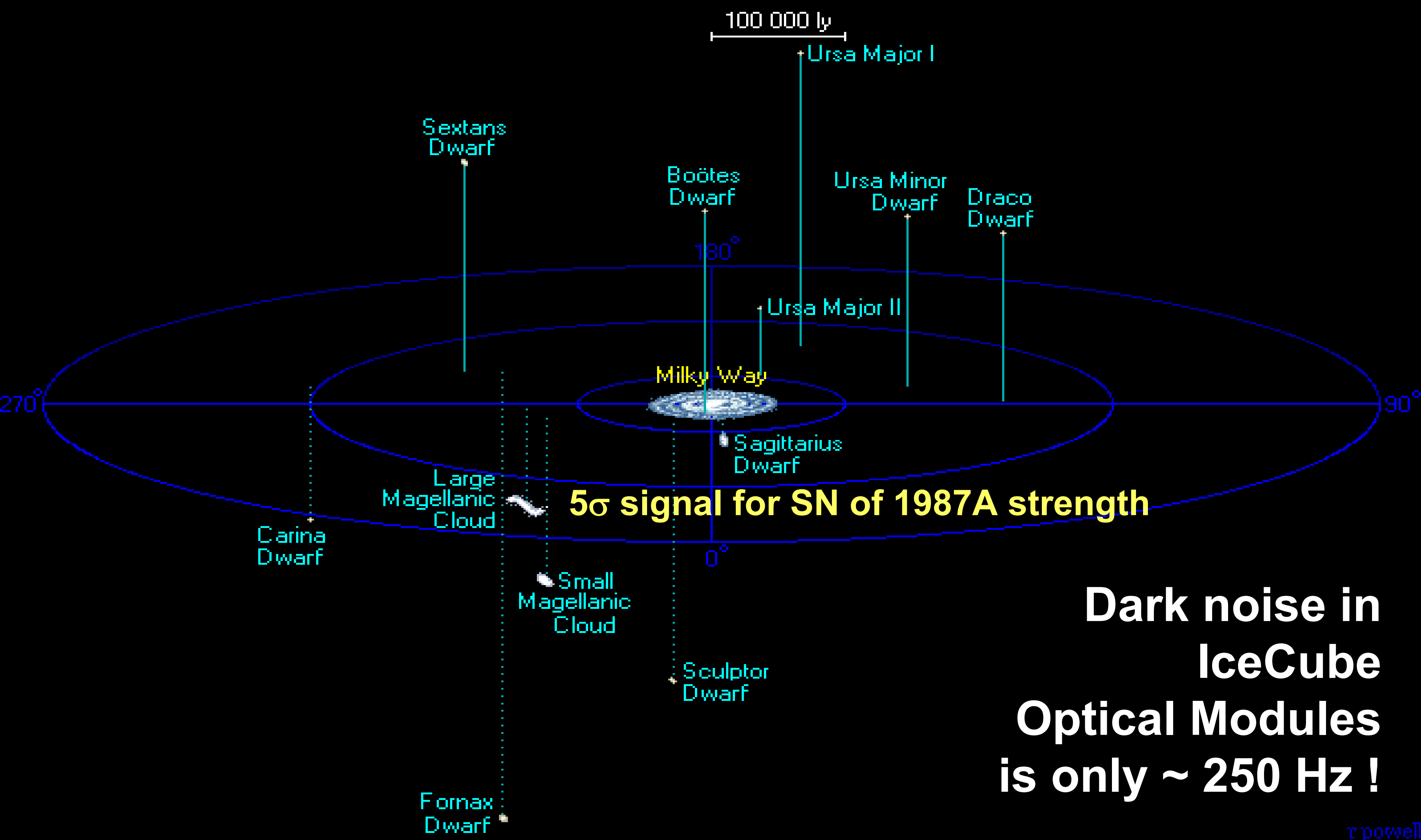
1,885 8-inch PMTs for outer detector

Large detectors for SN neutrinos



In brackets events for a SN at distance 10 kpc

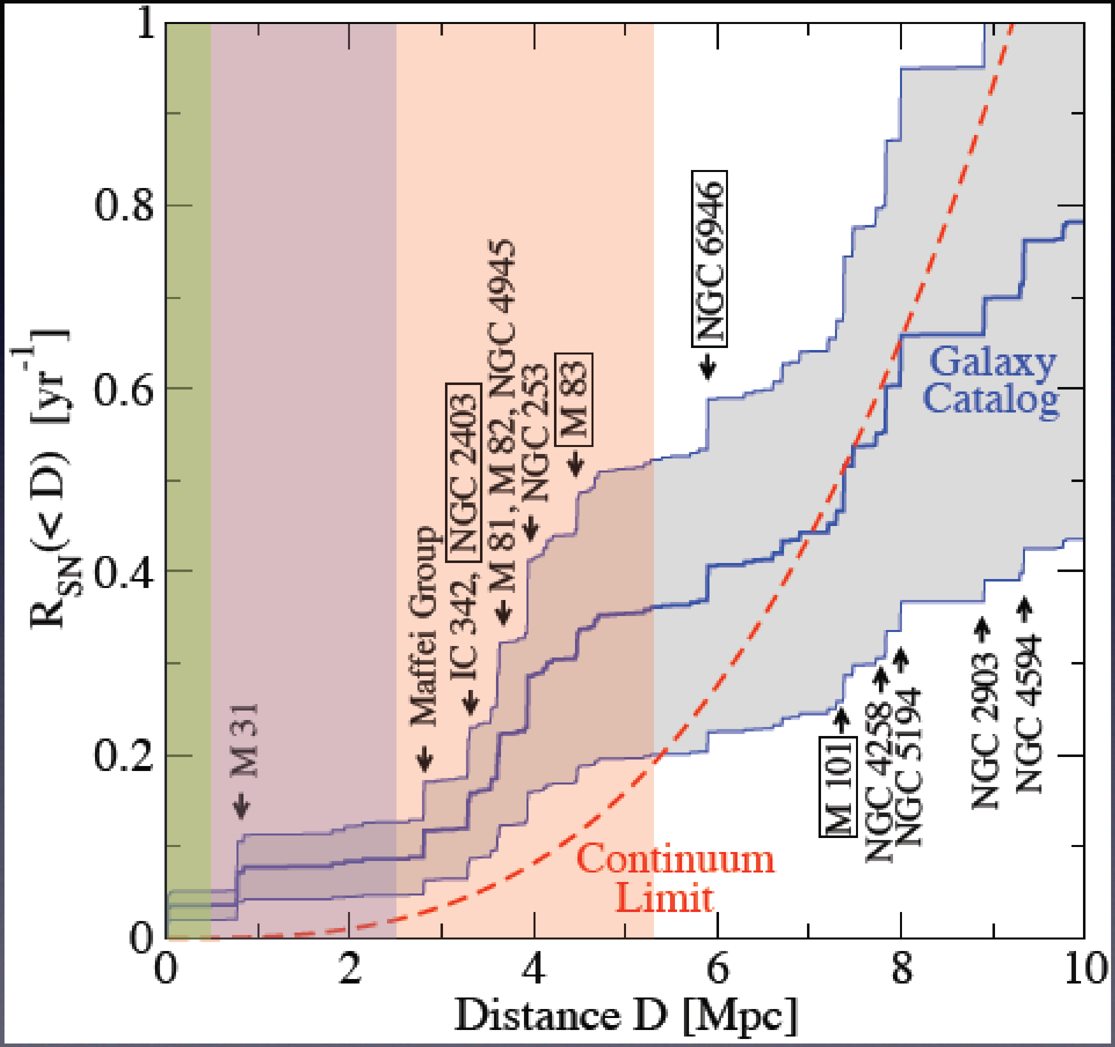
Supernova in IceCube



5σ signal for SN of 1987A strength

Dark noise in IceCube Optical Modules is only ~ 250 Hz !

4.4 Mton—A Magic Size



32 kton
1 Mton
4.4 Mton

- Reach of *burst mode* (≥ 5 events)
- Scaled by 10^4 events from a supernova at 10 kpc at 32 kton detector
- 4.4 Mton detector can take us beyond the "desert"

Based on work in preparation with J. F. Beacom and H. Yüksel

Summary of Neutrino Detection from Nearby Galaxies

- 1-Mton detectors allow us to collect SN neutrinos from nearby galaxies with a rate of ~ 1 / yr
- Burst mode reaches up to 4–5 Mpc with a 4.4-Mton detector (e.g., TITAND)
  - Within 4 Mpc, the SN rate is ~ 1 / yr
  - So, we can collect SN neutrinos at a rate of > 10 / yr
- We can learn time and energy distribution of SN neutrinos
- This also provides us precise information of the time of gravitational core collapse, invaluable for gravitational wave searches

SN rate

S.Ando, February 24, 2007, Hawaii

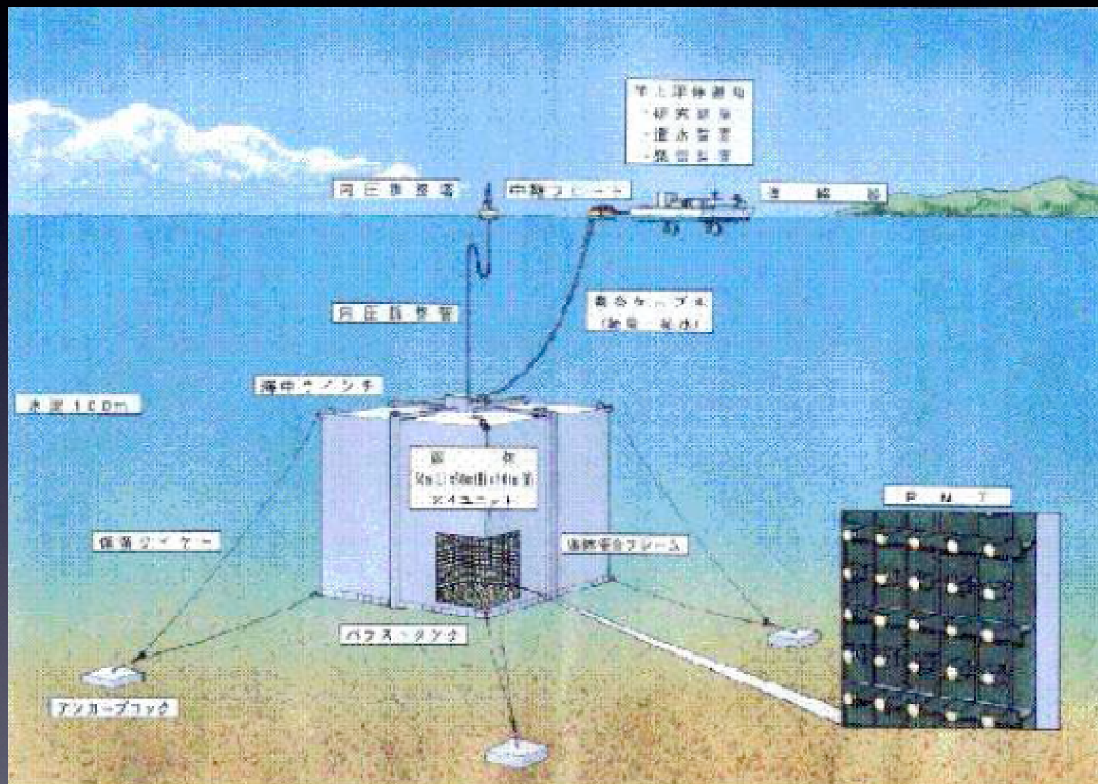
- Galactic SN rate is ~ a few/century
- Within 10 Mpc SNe occur with a rate of

  > 2 -3/year

N - Mton neutrino detector enable us to collect SN neutrinos at a rate of N/year

TITAND – 4.4 Mton ~ (3 – 5) Mpc

4.4-Mton Detector: TITAND



See talk by Y. Suzuki, or hep-ex/010005

DSNB Searches (Detection Upper Bounds)

- Super – K (Malek et al. 2002) : anti - ν_e

  $E_{e+} > 18$ MeV , $F_\nu < 1.2$ cm $^{-2}$ sec $^{-1}$ @ 90 %

- Mont Blanc (Aglietta et al. 1992) : ν_e

  F_ν (25 – 50 MeV) < 6800 cm $^{-2}$ sec $^{-1}$ @ 90 %

- Super – K (Lunardini 2006) : ν_e

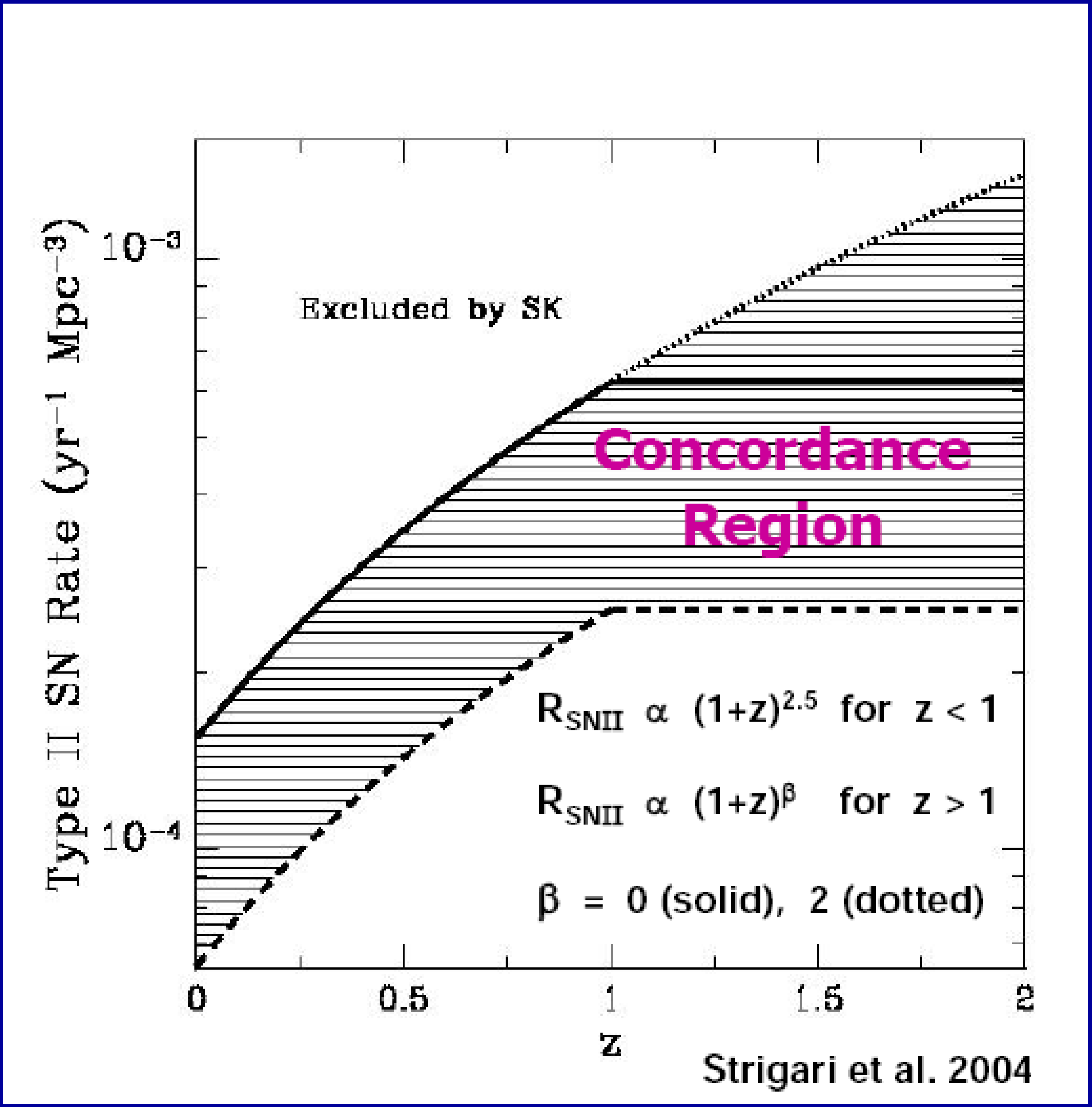
  $E_e > 18$ MeV , $F_\nu < 5.5$ cm $^{-2}$ sec $^{-1}$ @ 90 %

- SNO (ν_e + D $\rightarrow$ e + p + p) :

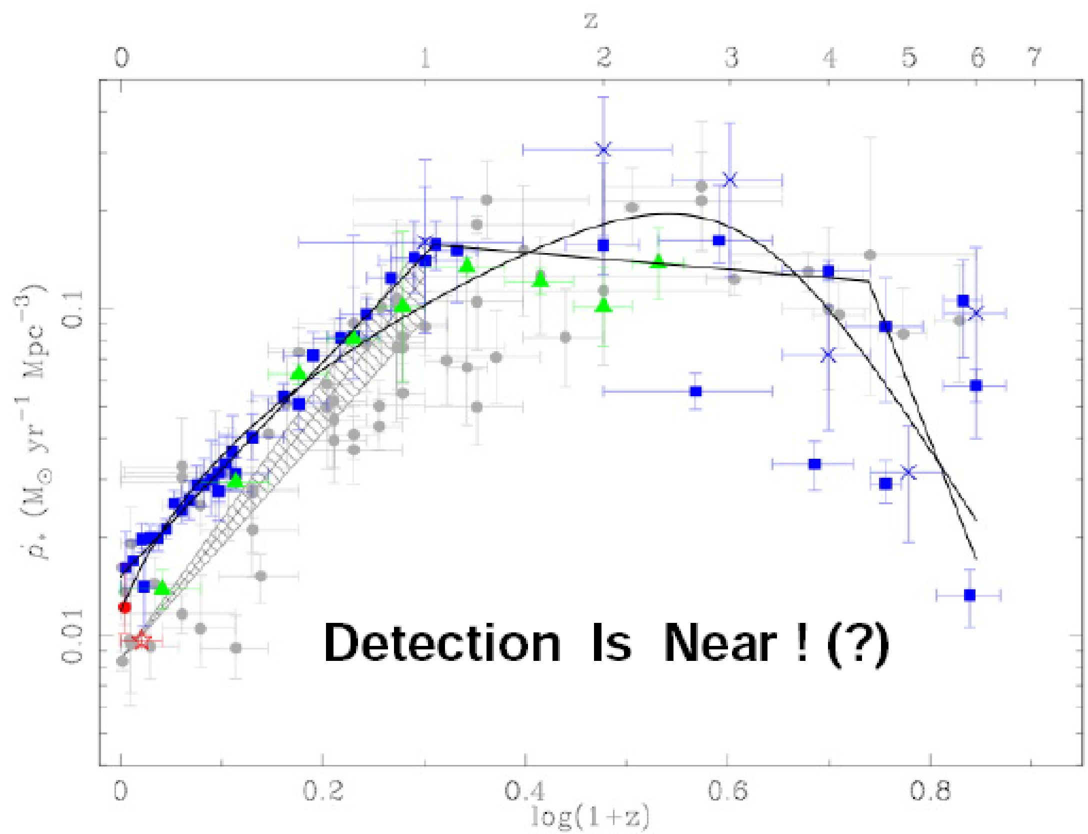
  Beacom & Strigari (2006) : $F_\nu < \sim 1$ cm $^{-2}$ sec $^{-1}$

  SNO (Aharmin et al. 2006) : $F_\nu < 70$ cm $^{-2}$ sec $^{-1}$ @ 90 %

UV & Optically (SDSS) Motivated SN Rates



Recent Data Favors The Upper End Of The Concordance Region



Hopkins & Beacom 2006

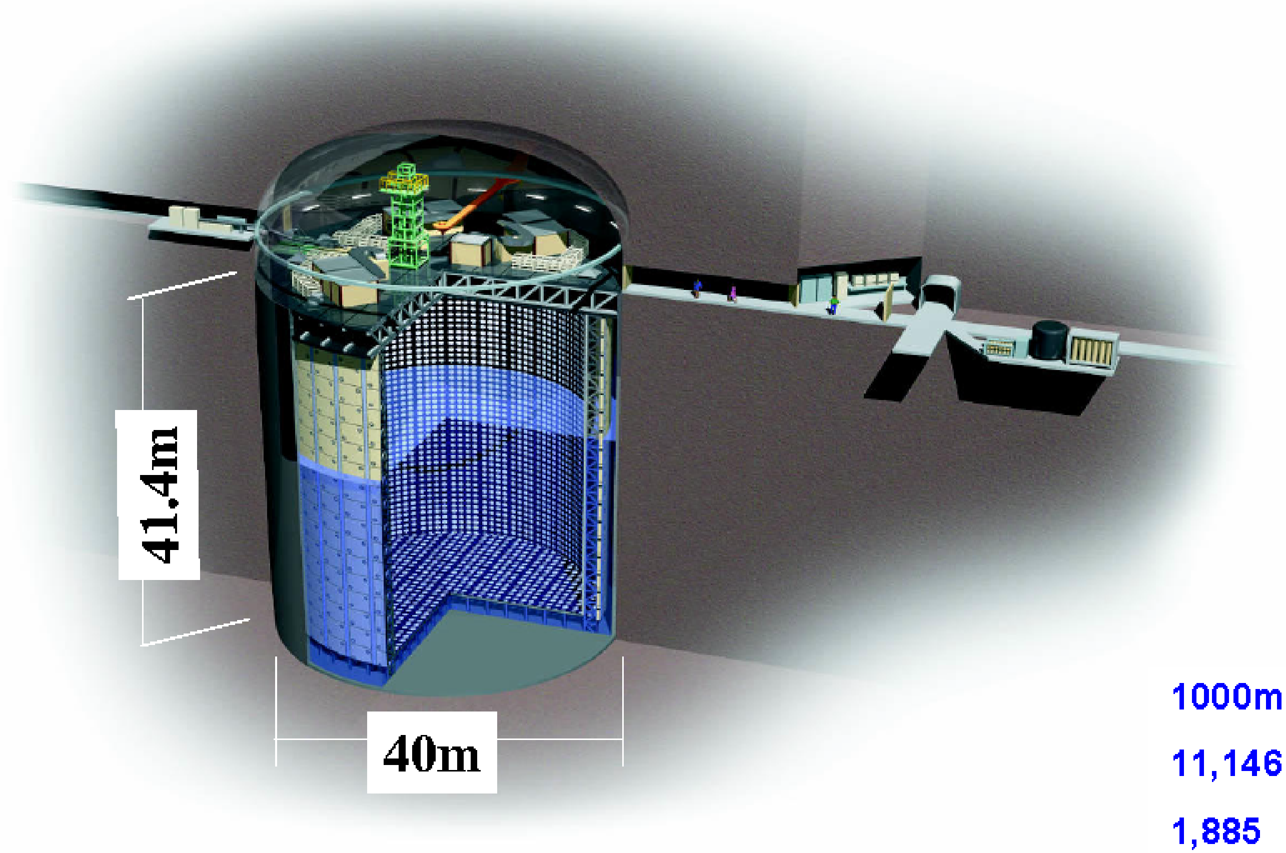
K.Nishikawa's talk

Атмосферные нейтрино

Super-Kamiokande

50,000 ton water Cherenkov detector (22.5 kton fiducial volume)

Optically separated INNER and OUTER detector



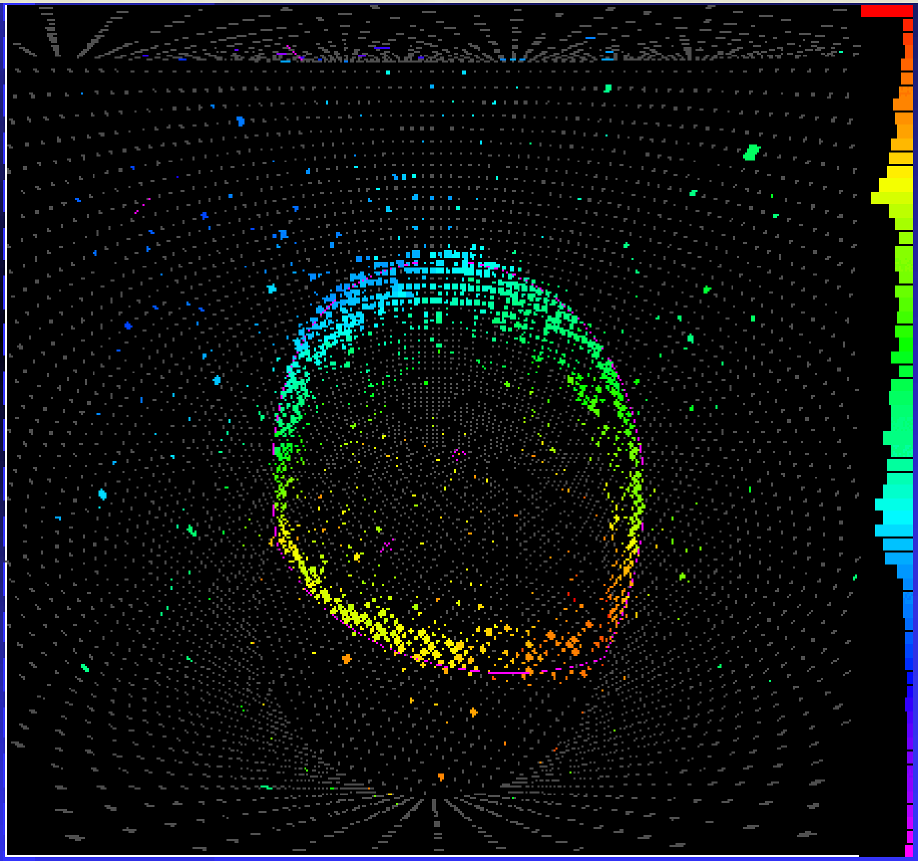
1000m underground (2700 m.w.e.)

11,146 20-inch PMTs for inner detector

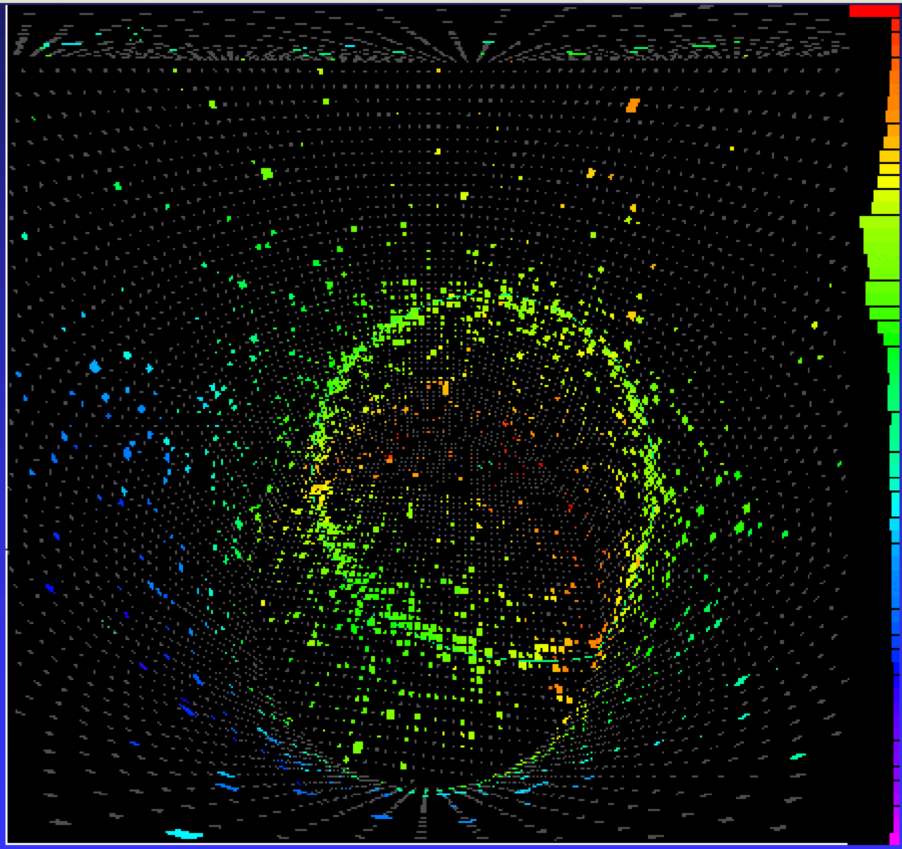
1,885 8-inch PMTs for outer detector

Атмосферные нейтрино

Super-Kamiokande



μ–like ring



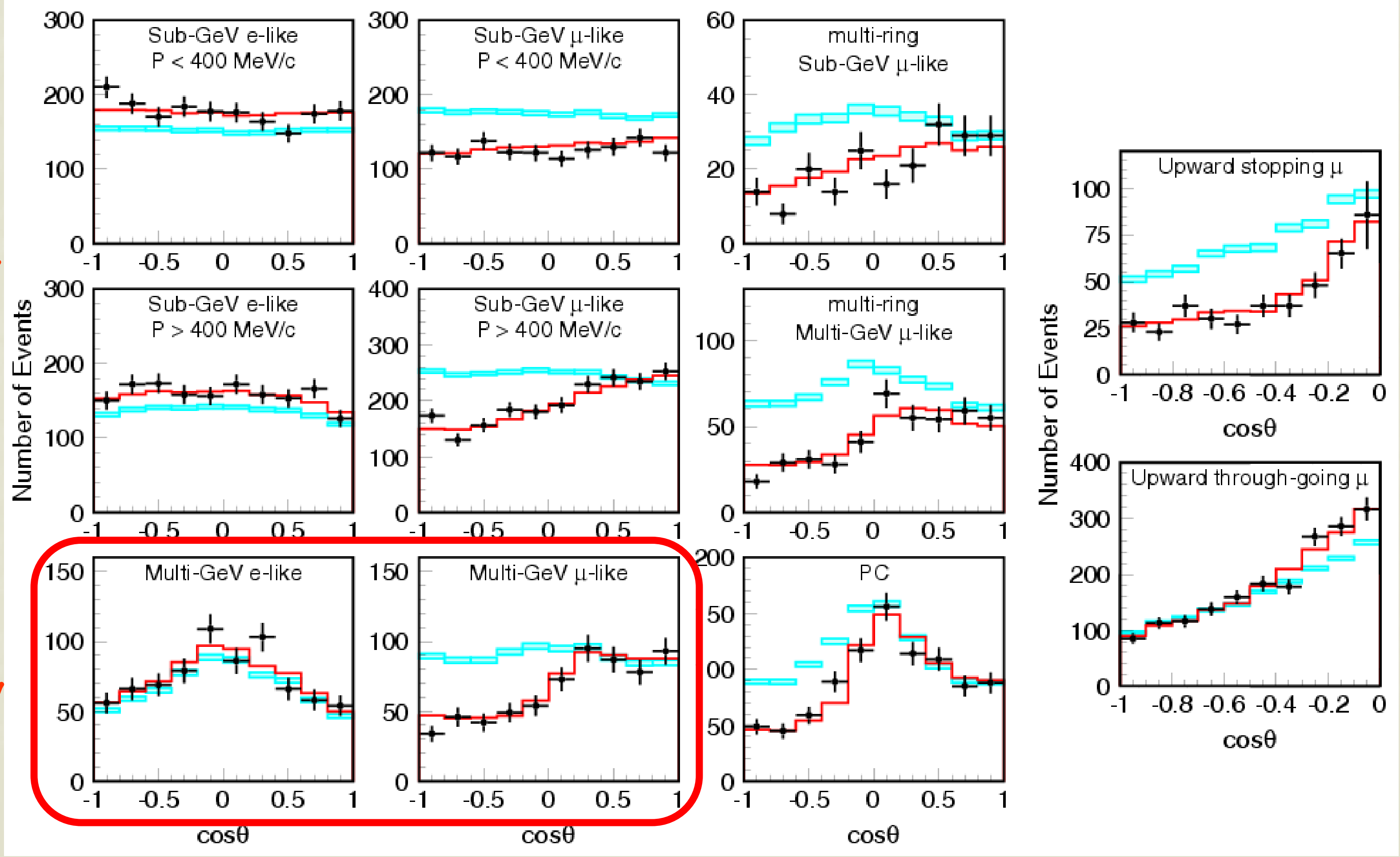
e-like ring

Атмосферные нейтрино

Угловое распределение

Sub-GeV
E_{vis} < 1.3 GeV

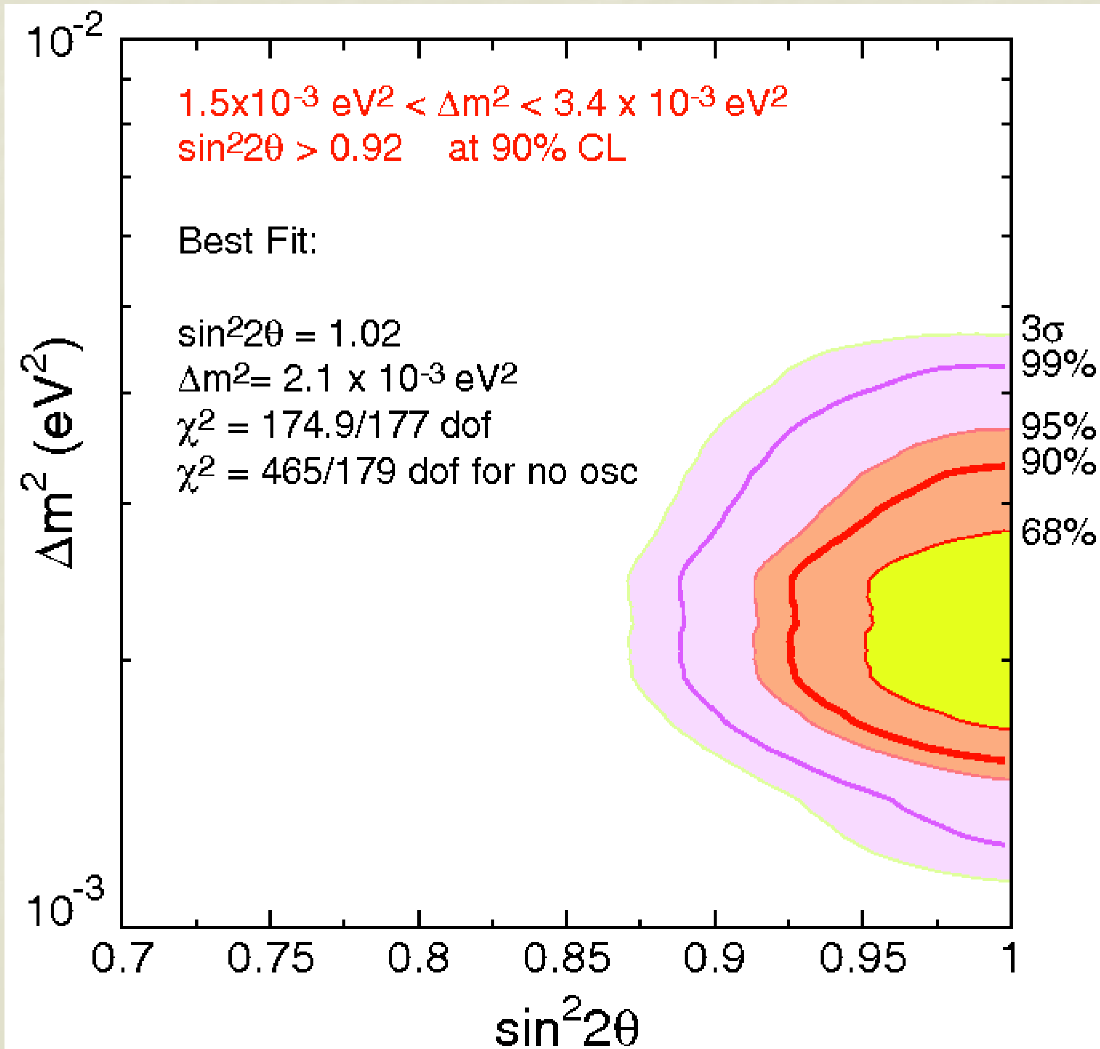
Multi-GeV
E_{vis} > 1.3 GeV



Ed Kearns for the SK Collaboration
Neutrino2004, June 15, Paris

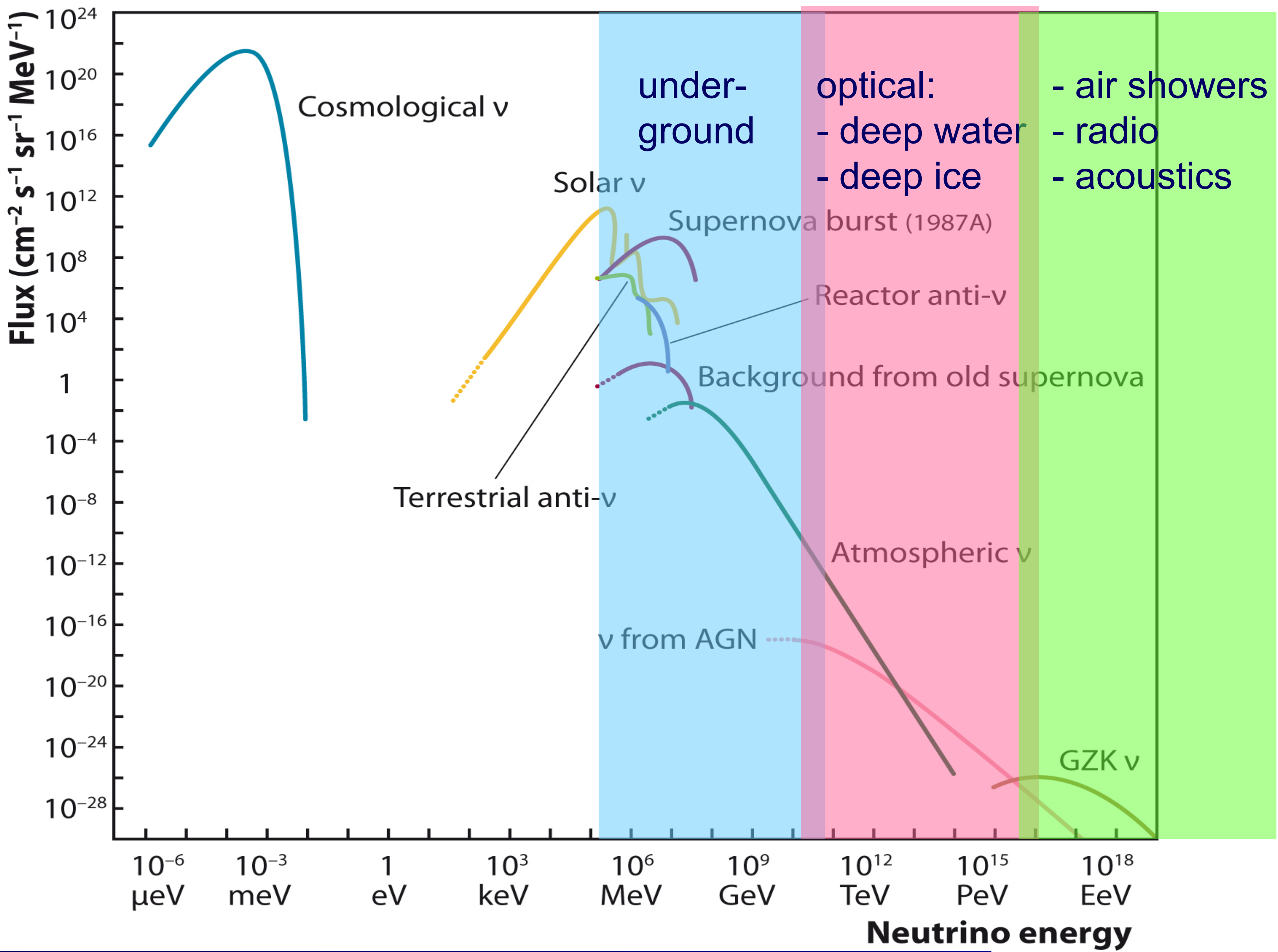
Атмосферные нейтрино

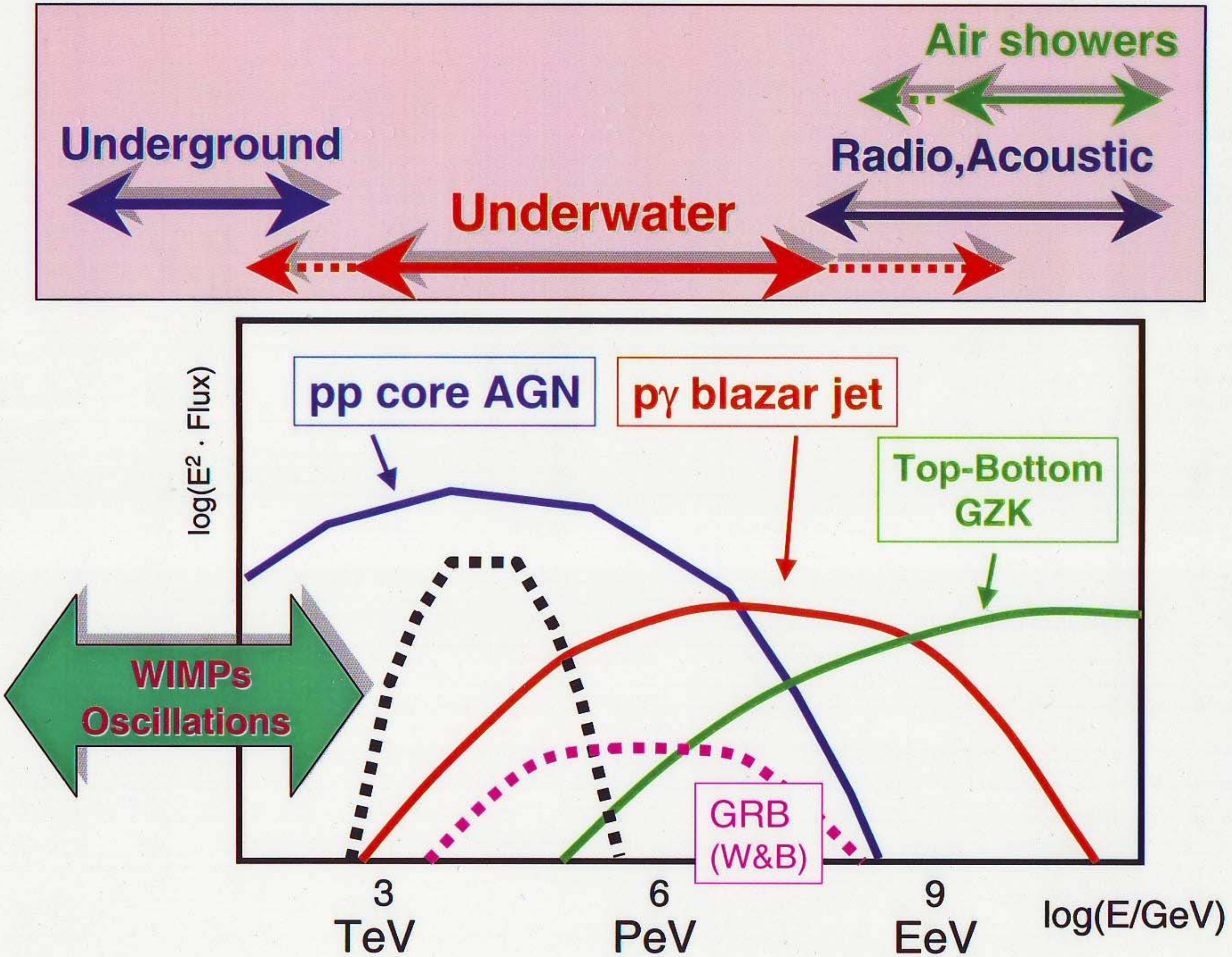
$\nu_\mu \leftrightarrow \nu_\tau$ осцилляции



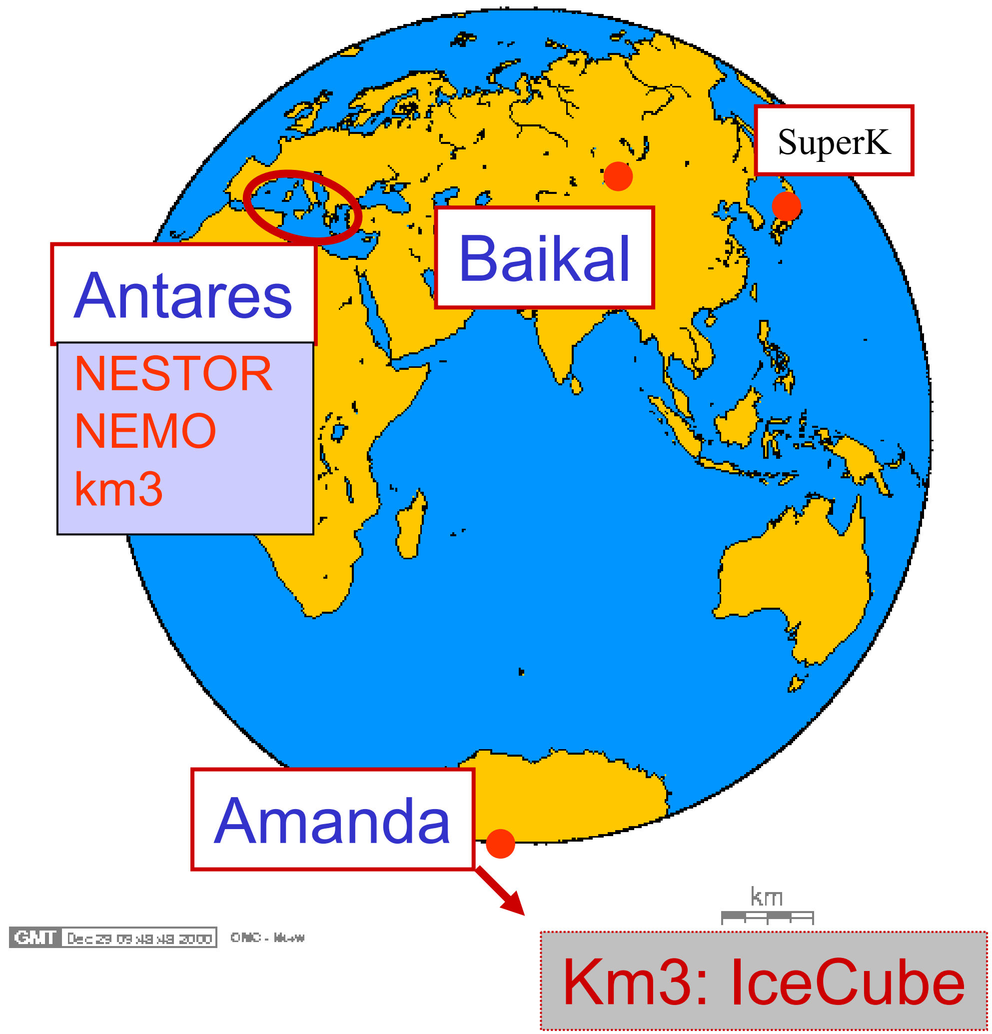
Ed Kearns for the SK Collaboration
Neutrino2004, June 15, Paris

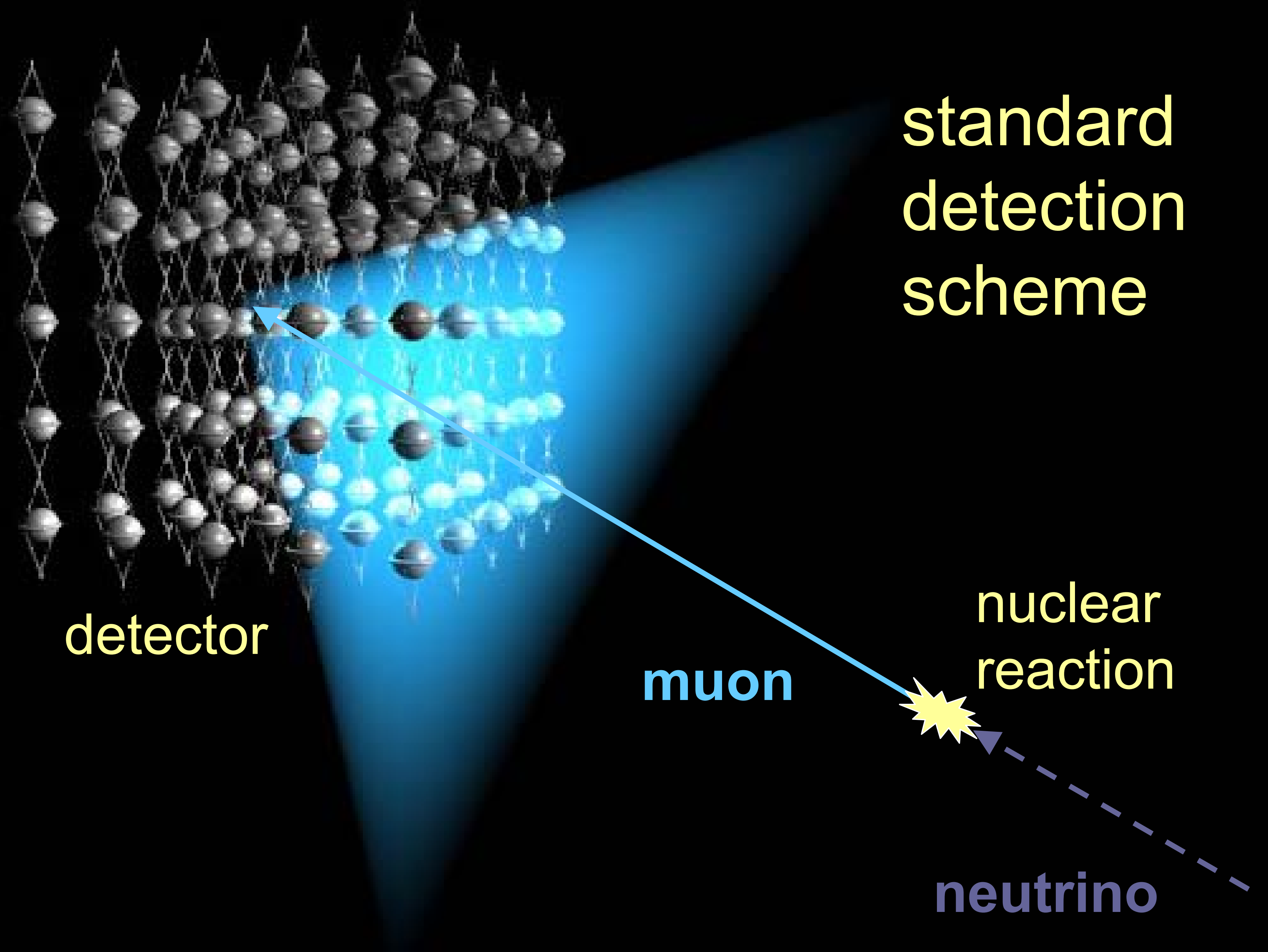
The unified spectrum of neutrinos

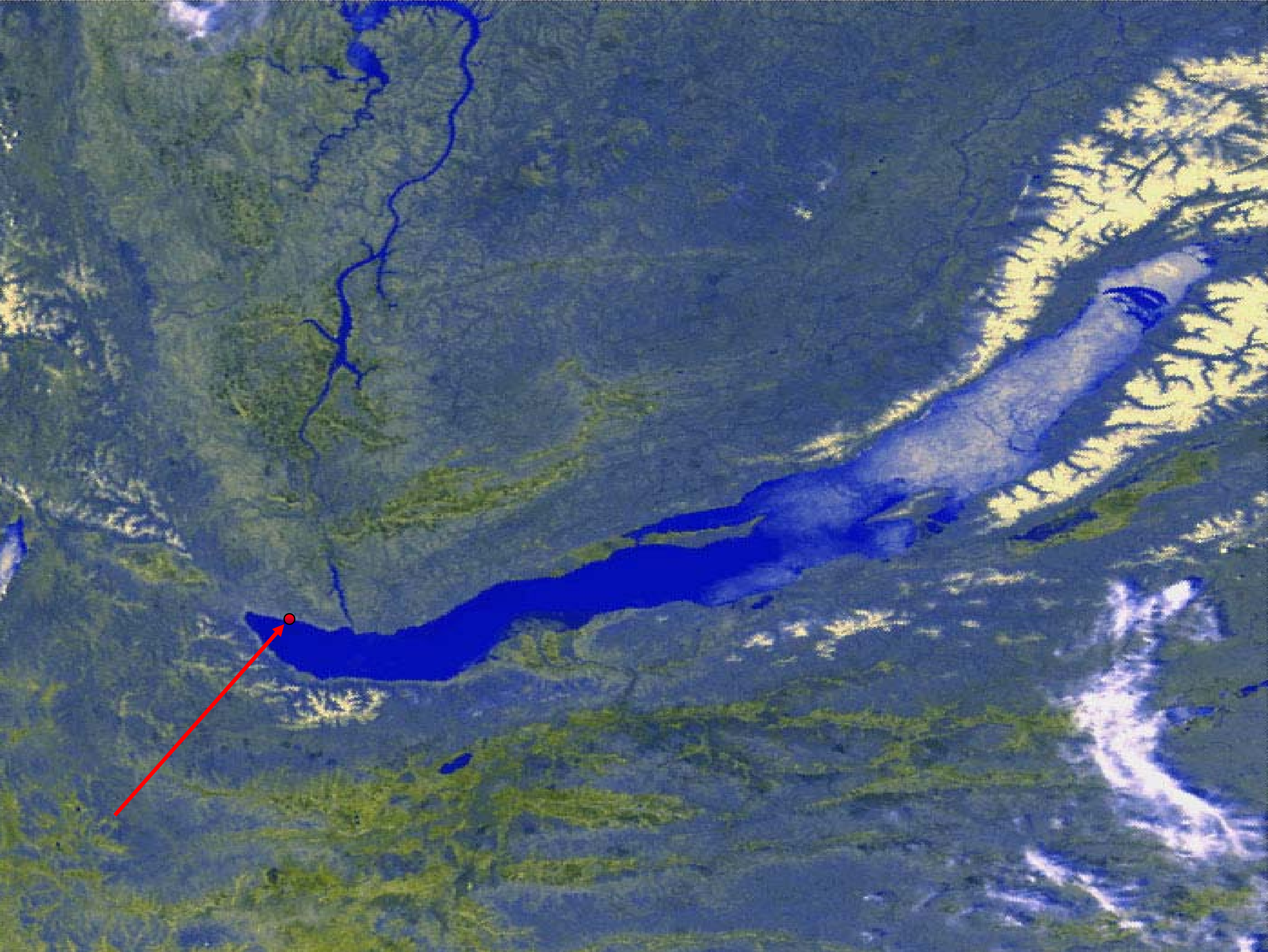




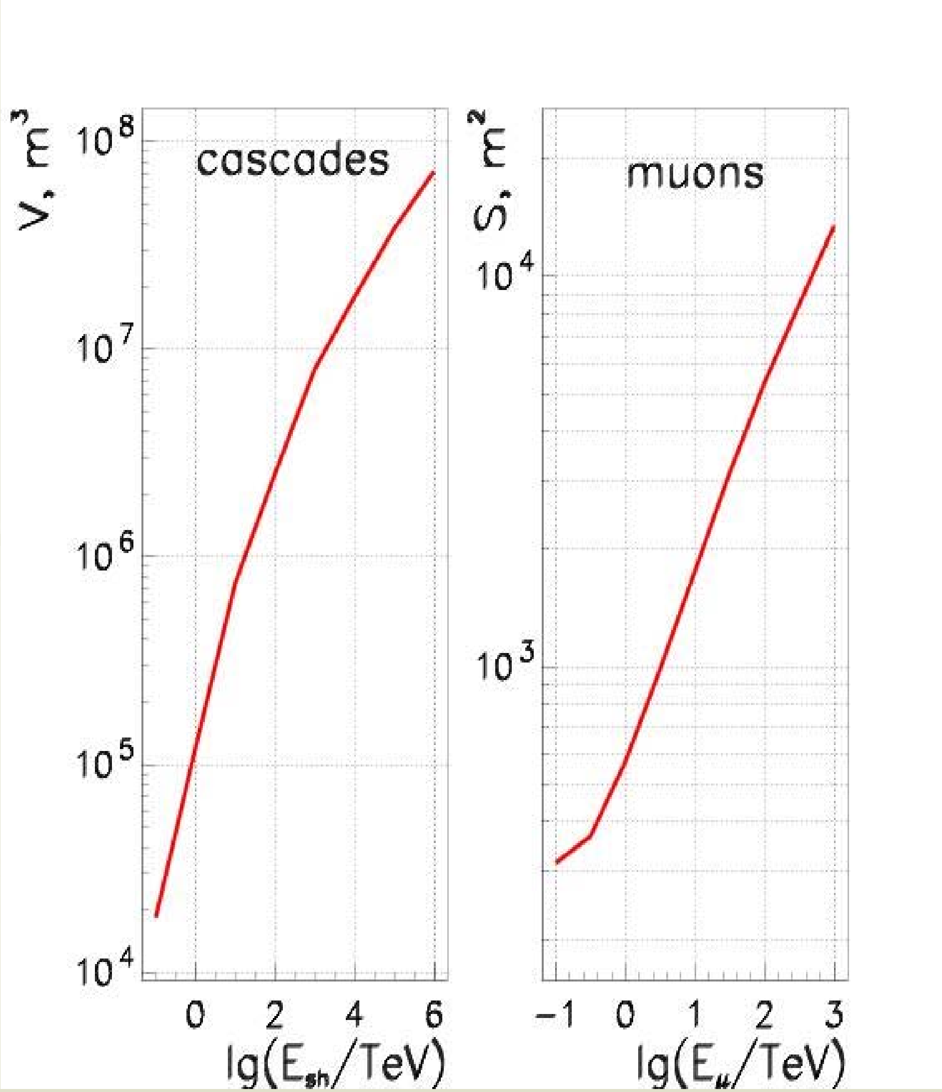
Air showers
Underground
Radio,Acoustic
Underwater
pp core AGN
pγ blazar jet
Top-Bottom
GZK
log(E² · Flux)
WIMPs
Oscillations
GRB
(W&B)
3
TeV
6
PeV
9
EeV
log(E/GeV)


SuperK
Baikal
Antares
NESTOR
NEMO
km3
Amanda
km
Km3: IceCube


standard
detection
scheme
detector
muon
nuclear
reaction
neutrino

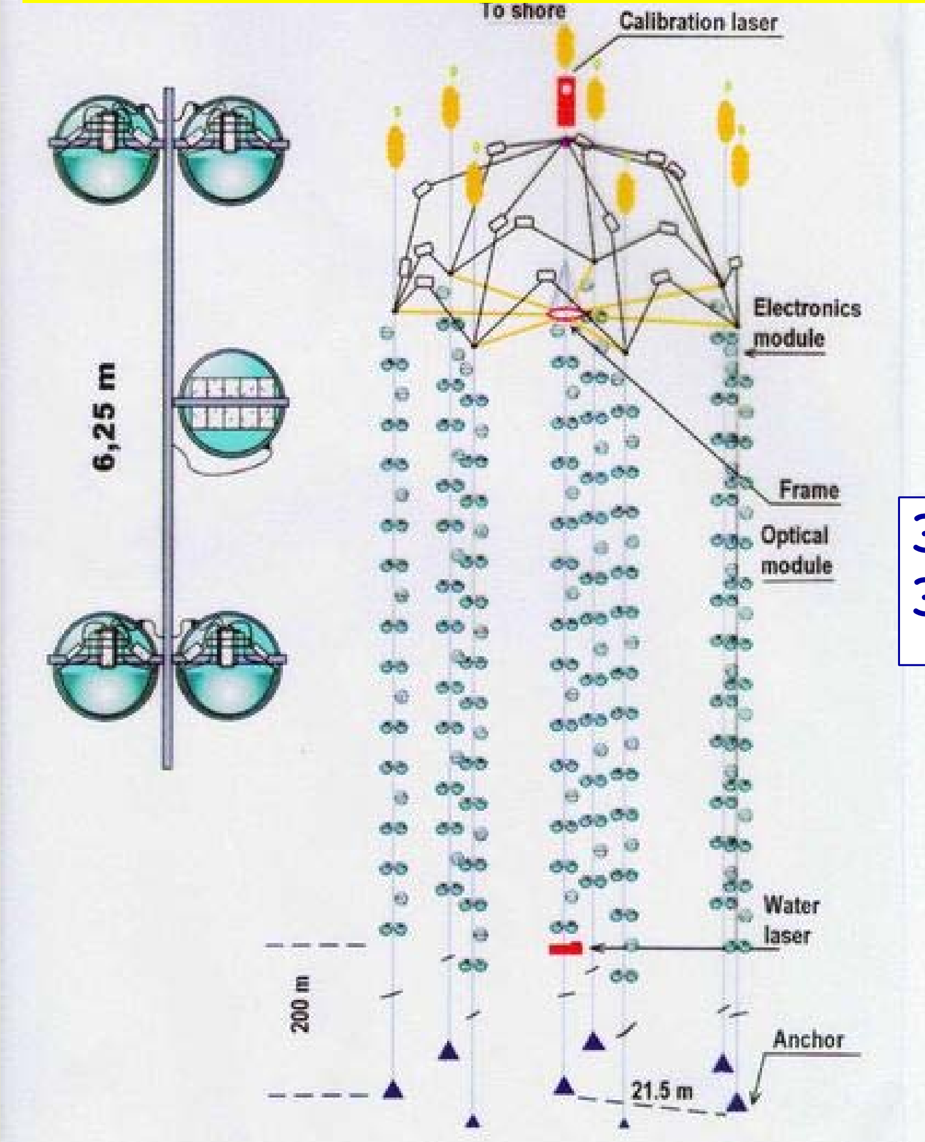


Чувствительность оптического фотоприемника




Береговой центр
4км от берега
Глубина: 1366 м


Нейтринный телескоп НТ-200



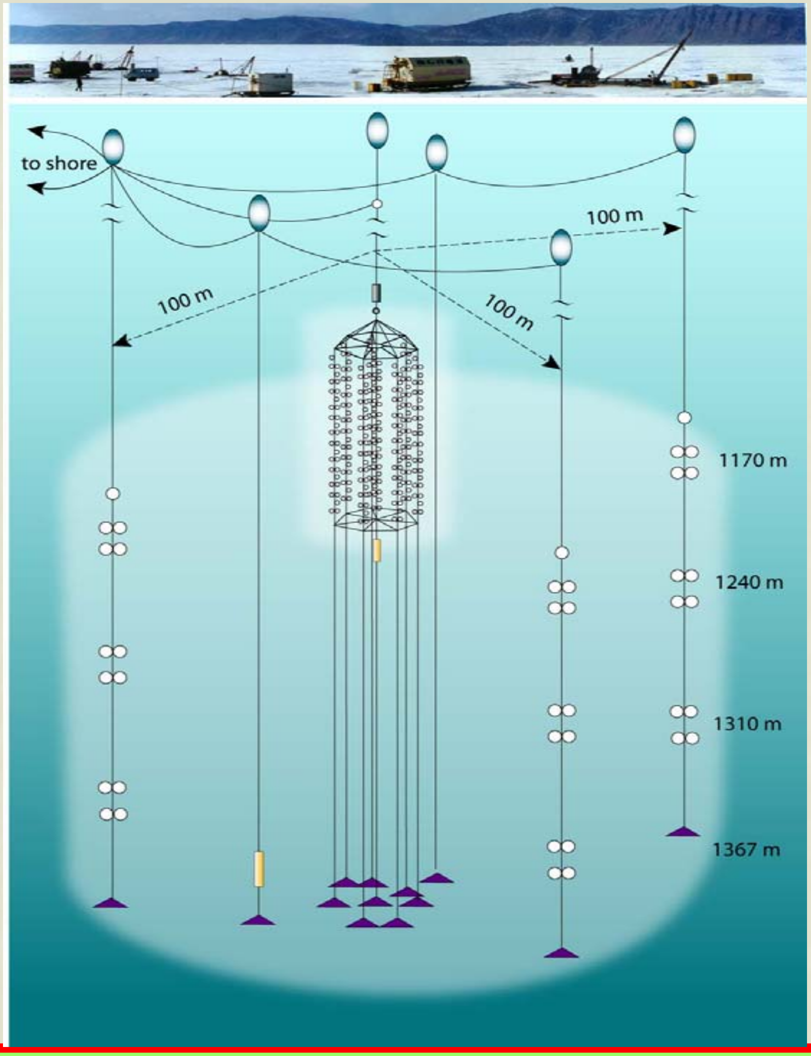
Высота x диаметр = 70м x 40м, V=10^5м^3

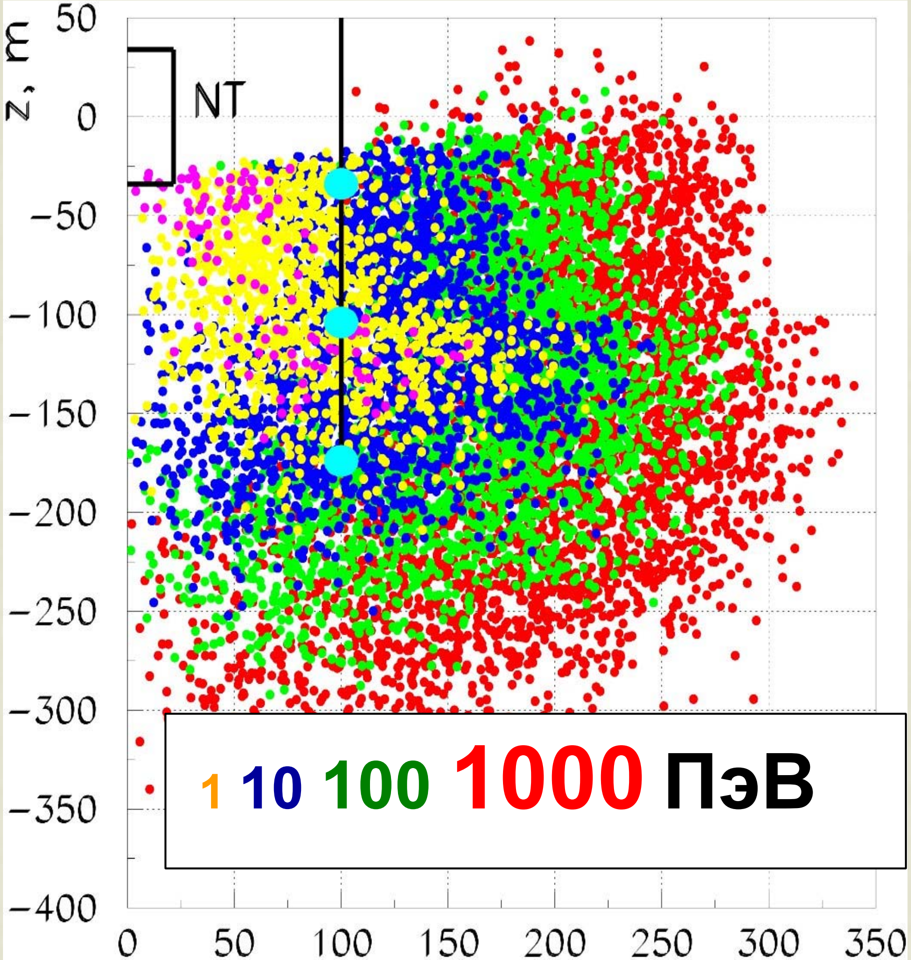
-8 гирлянд ОМ: 72m
- 192 оптических модуля
- 96 измерительных каналов
- калибровка - N-лазеры
- временная точность ~ 1 нс
- Дин. диапазон ~ 1000 ф.эл.

Эфф. площадь : 1 TeV ~2000 м^2
Эфф. объем (каскады): 10TeV ~0.2Мт

Квазар: d = 37cm

Детектор НТ-200+





1 10 100 **1000** ПэВ

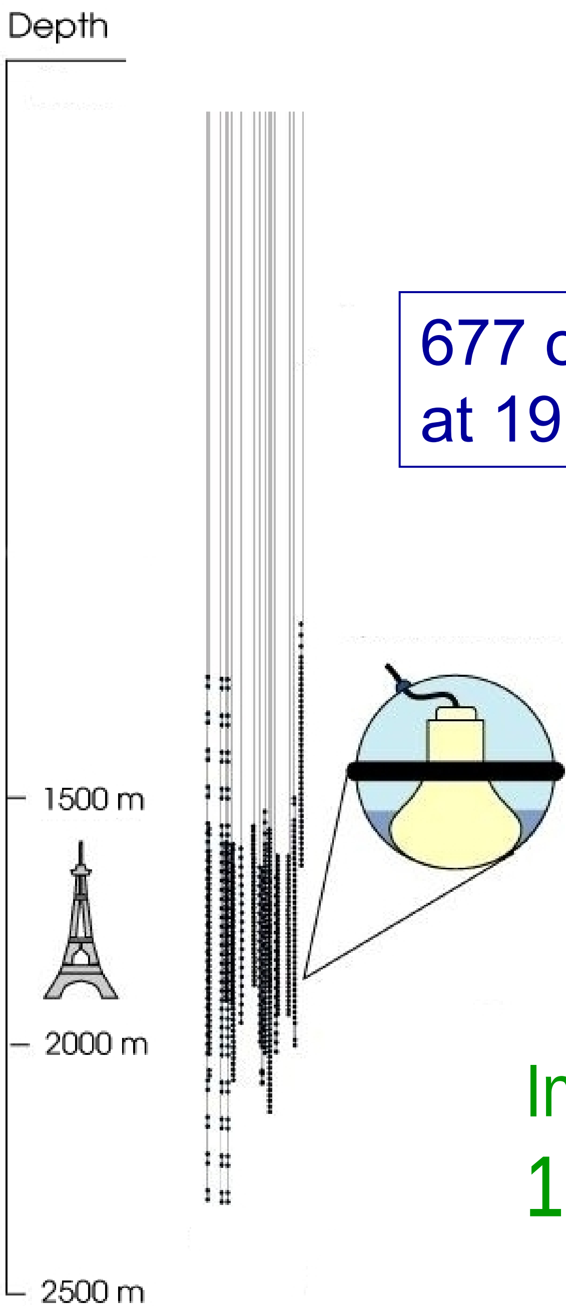
4 15 23 **40** Мт

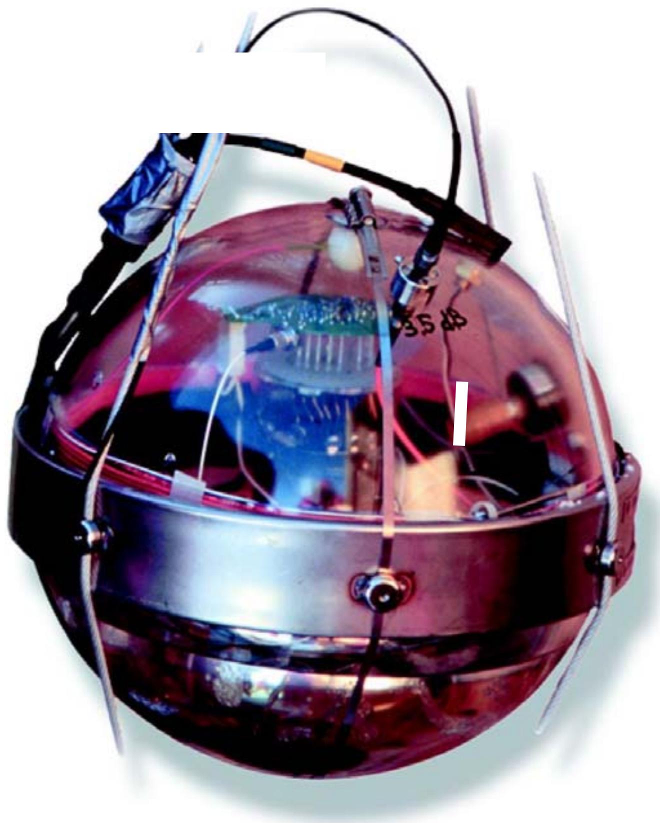
36 дополнительных ОМ на трех удаленных гирляндах


ОСТОРОЖНО СТЕКЛО

AMANDA-II

677 optical modules
at 19 strings





Installation
1996-2000

Hot water drilling

2 MW power

3-4 days / 2 km

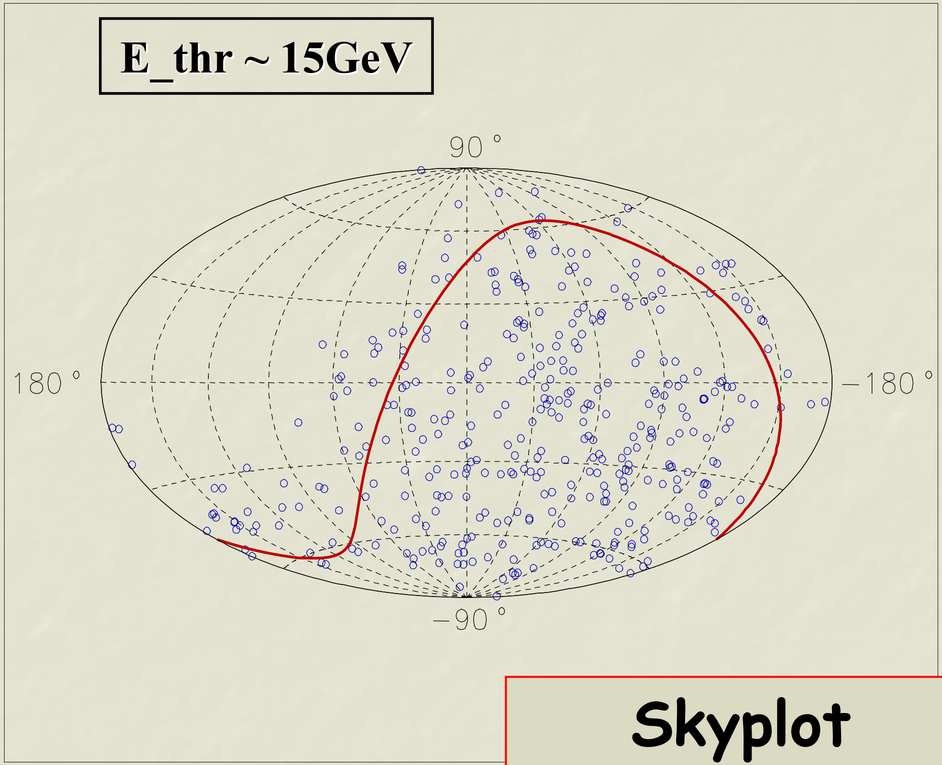
60 cm hole

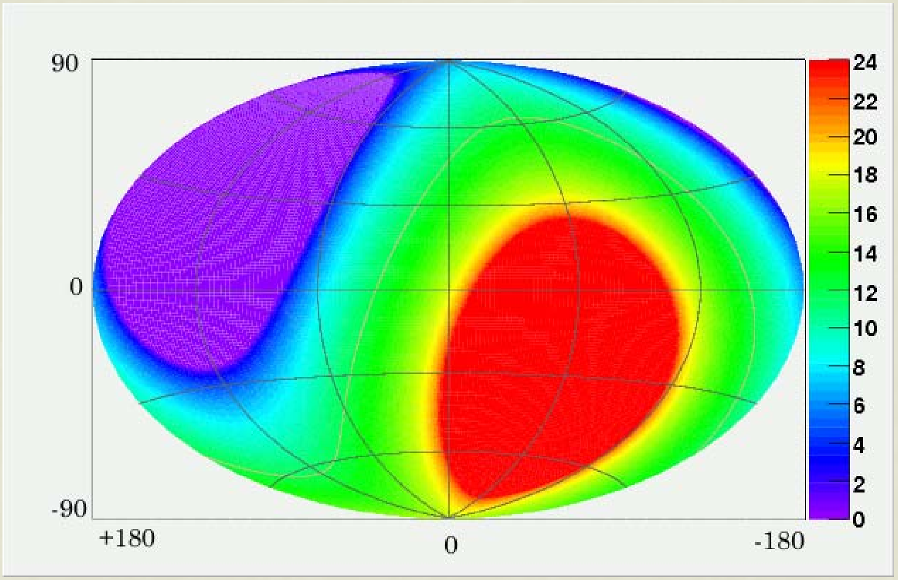

South Pole
Dark sector
Skiway
AMANDA
Dome
IceCube

Объекты (направления) исследования

- Природные потоки нейтрино высоких (E > 15 ГэВ) энергий (поиск локальных источников нейтрино).
- Частицы темной материи (поиск массивных слабовзаимодействующих частиц - WIMP).
- Магнитные монополи.
- Диффузный поток нейтрино сверхвысоких (E>10 ТэВ) энергий.

Atmospheric Muon-Neutrinos

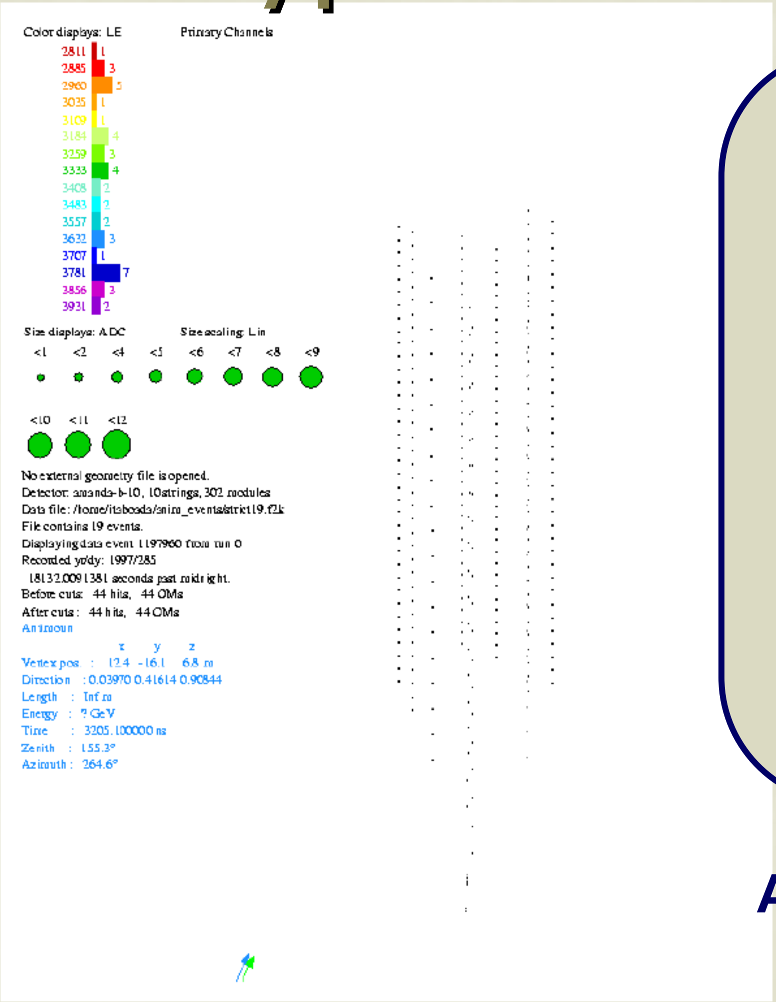


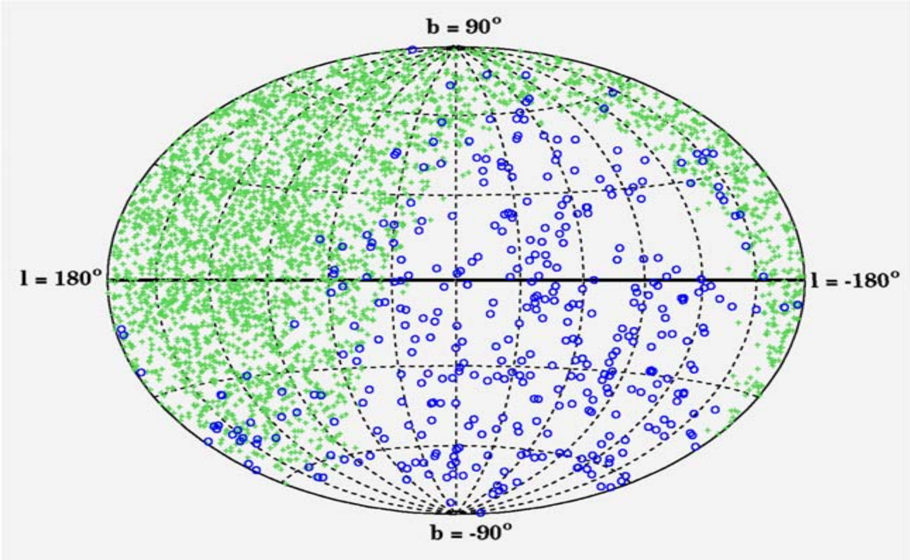


Skyplot
(galactic coordinates)

- With looser cuts, 1998-2002: 372 events. $N_{\mu}(>15GeV)/N_{\mu}(>1GeV) \sim 1/7$
  → A higher statistics neutrino sample
  for Point-Source Search.
- MC: 385 ev. Expected (15%BG).

Skyplot AMANDA and Baikal

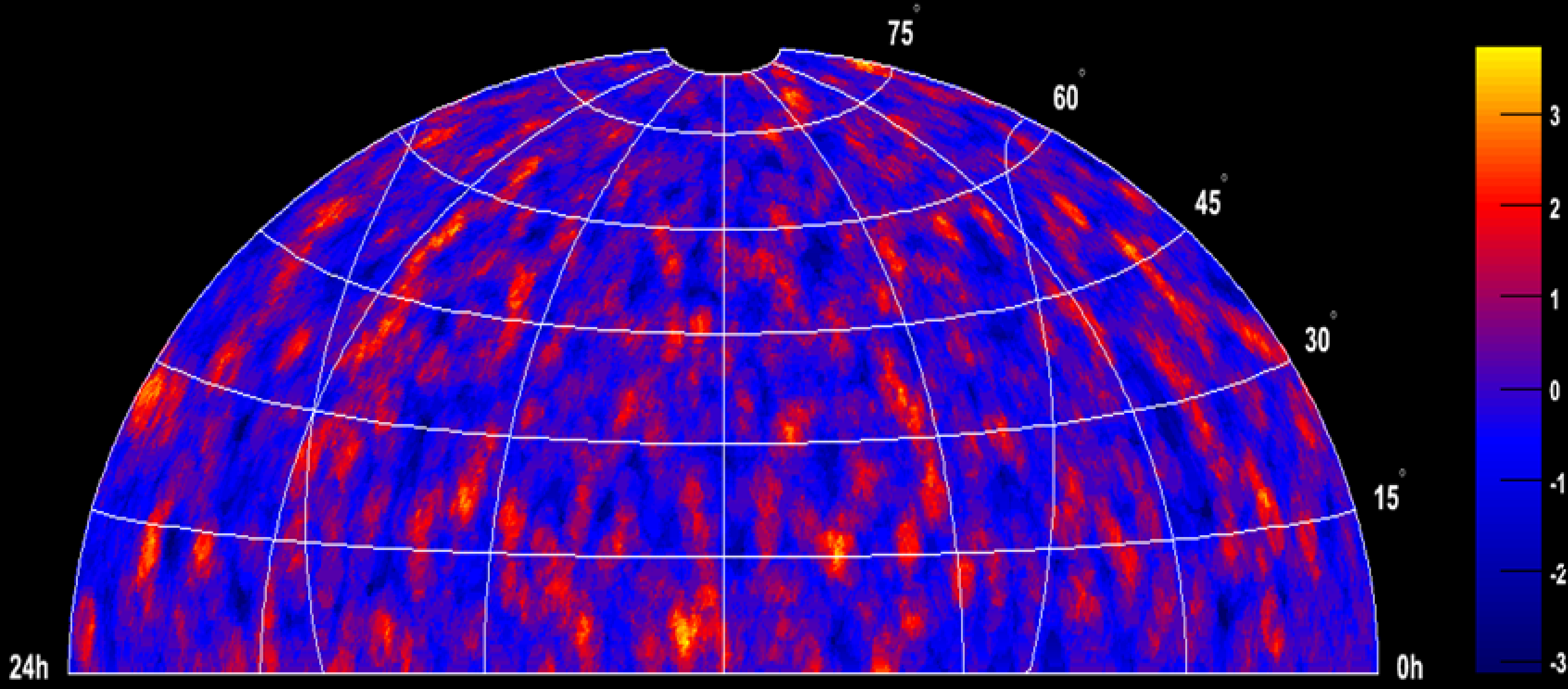




AMANDA:2000-2003, Baikal: 1998-2002
galactic coordinates

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

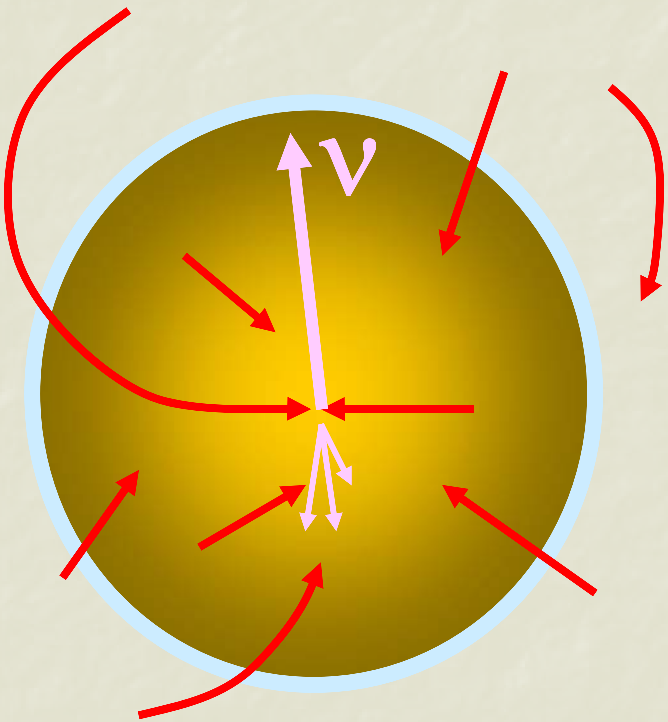
Search for steady point source



AMANDA-II: 2000-2004 (1001 live days) 4282 ν from Northern hemisphere

No significant excess found

Поиск дополнительного потока мюонов, обусловленного нейтрино от аннигиляции частиц невидимого вещества в центре Земли

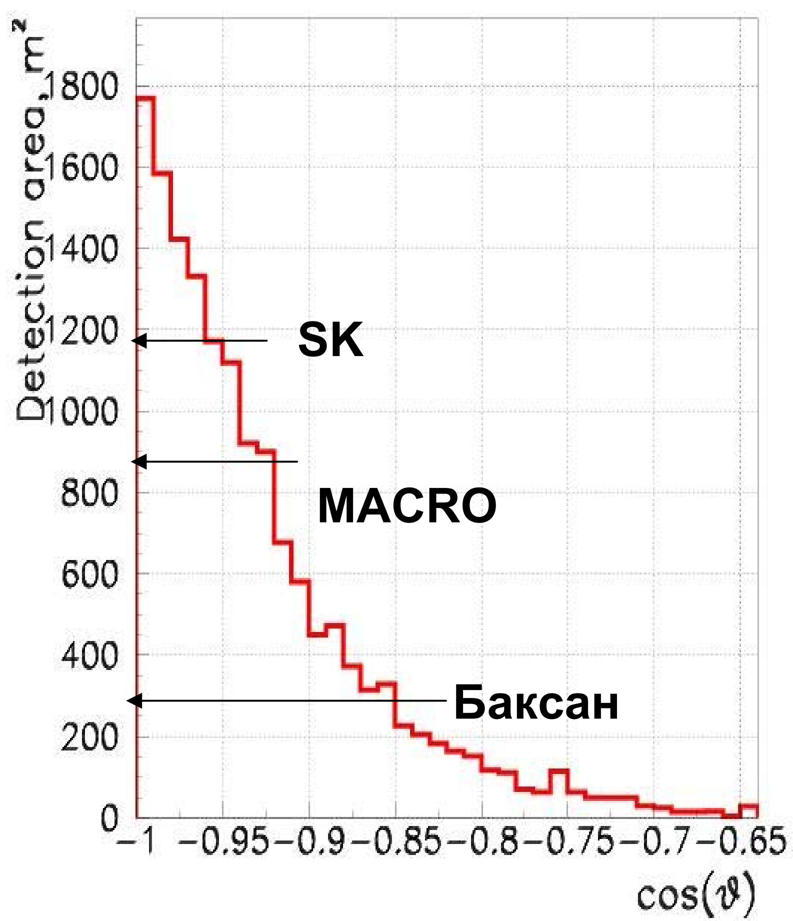


$$\chi + \chi \to b + b$$

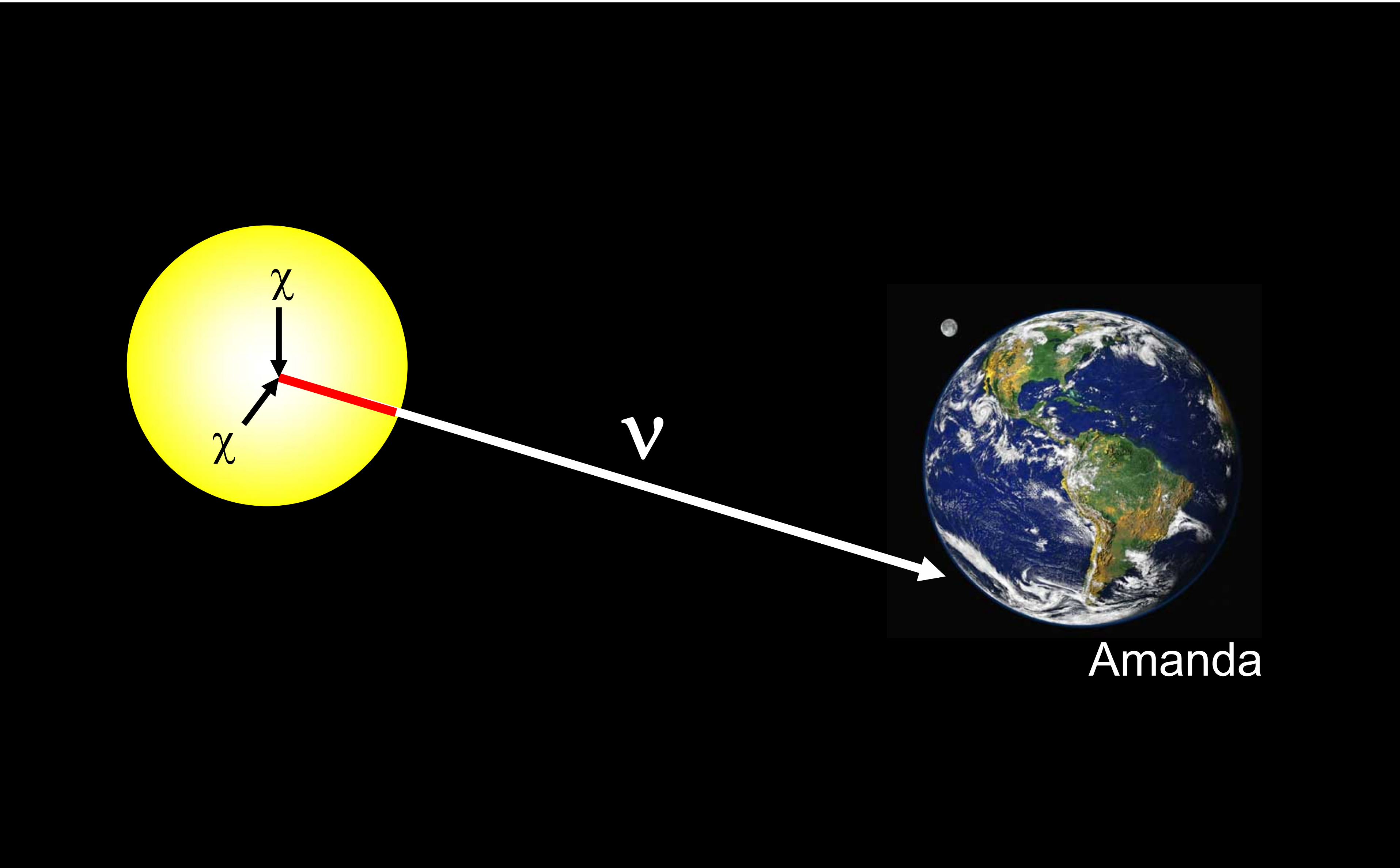
$$\searrow c + \mu + \nu_\mu$$

$$\to W^+ + W^-$$

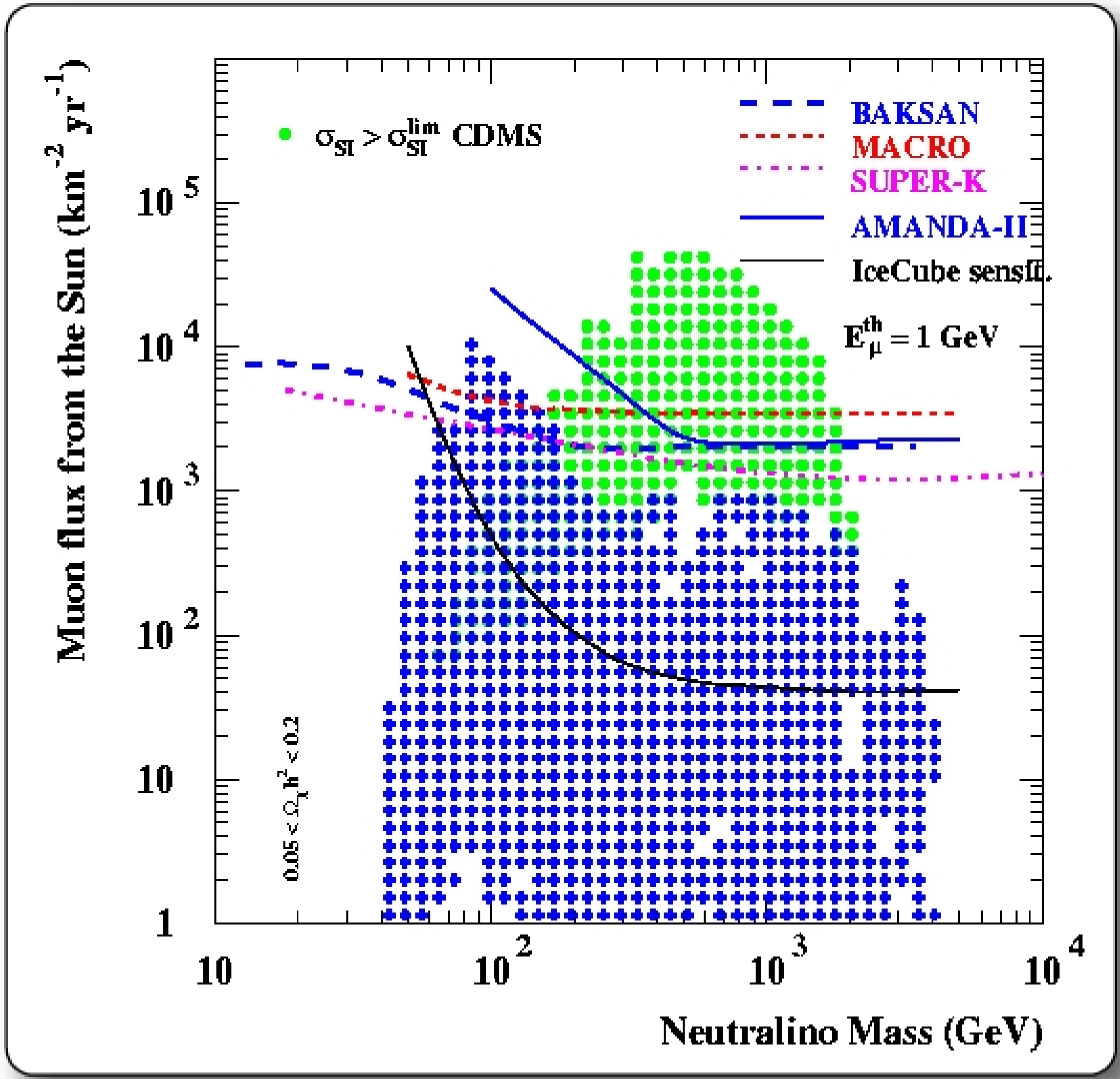
Эффективная площадь регистрации околовертикальных мюонов снизу нейтринным телескопом НТ-200



WIMPs: neutrinos from Sun



WIMPs: neutrinos from Sun



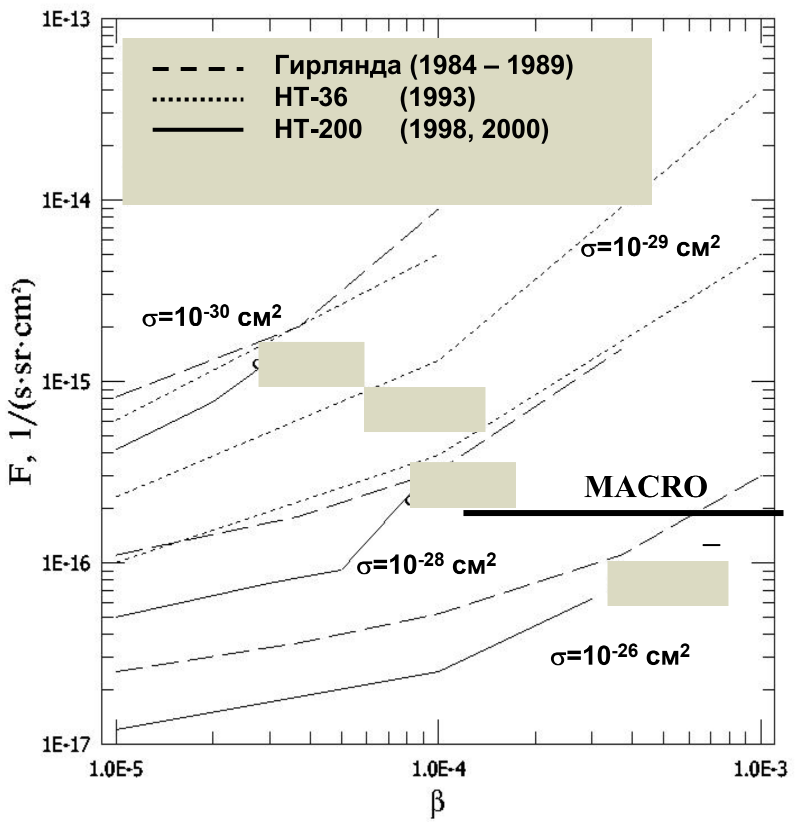
Ограничения на потоки медленных ($10^{-5}<\beta<10^{-3}$) и релятивистских монополей $\beta>0.8$

NT-200 – поиск ярких объектов (GUT-monopoles, nuclearites, Q-balls …)

Триггер $N_{hit}>4$ в интервале dt=500µsec

Критерии отбора - $N_{ch}>1$ с $N_{hit}>14$

$\sigma_{cat}=0.17\sigma_0/\beta^2$,

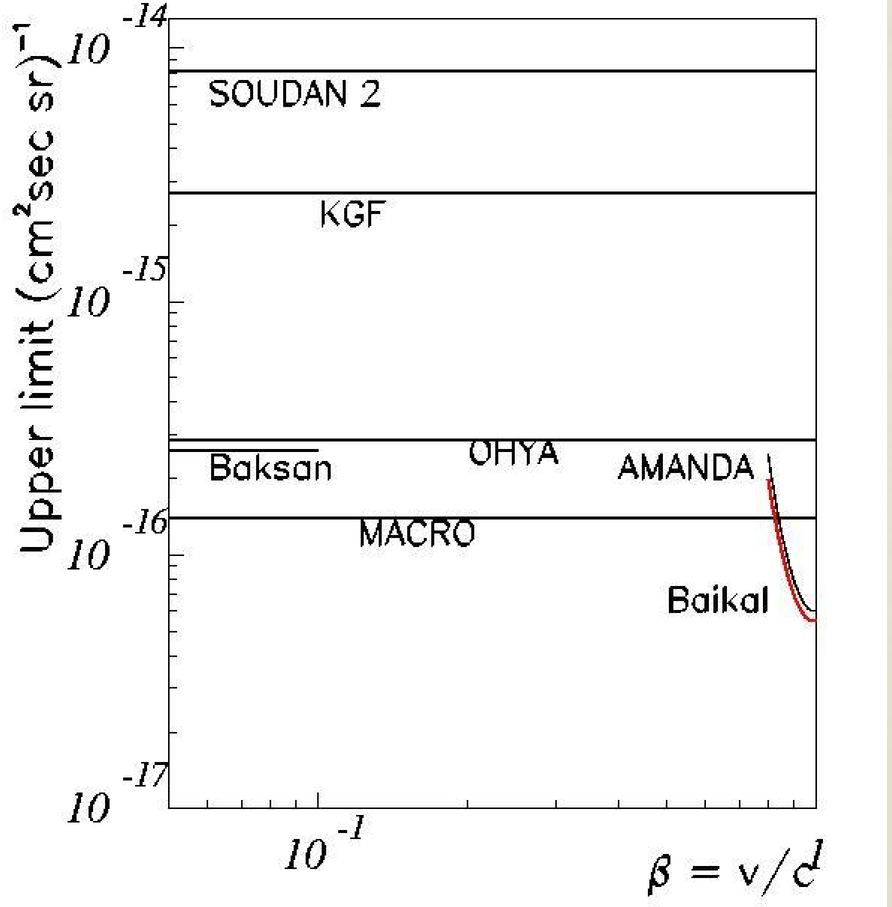


$N_\gamma(\lambda) = n^2 (g/e)^2 N_{\gamma\mu}(\lambda) = 8300\, N_{\gamma\mu}(\lambda)$

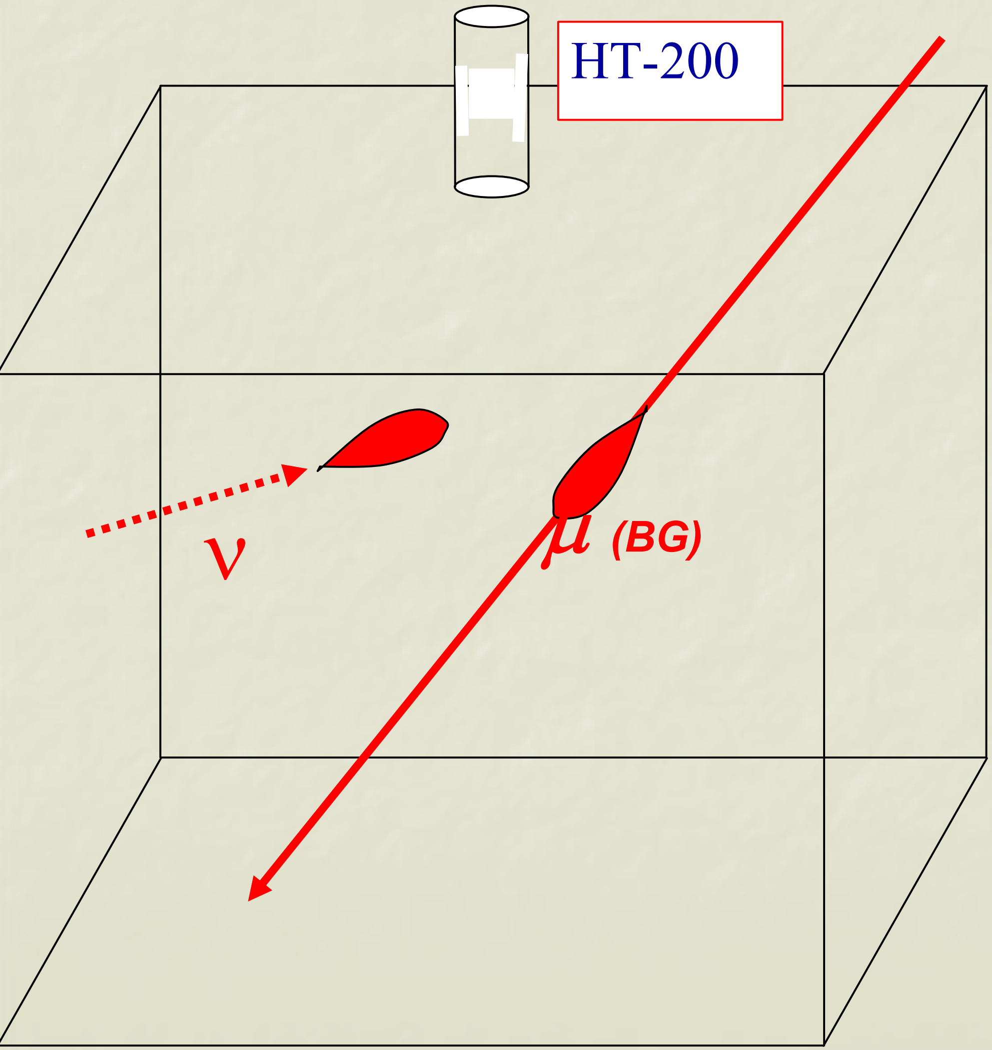
$g = 137/2,\ n = 1.33$

Критерии отбора $N_{hi\,t}>35$ ch, свет снизу

$\Sigma(z_i-z)(t_i-t)/(\sigma_t\sigma_z) > 0.45$ & $\theta > 100^o$

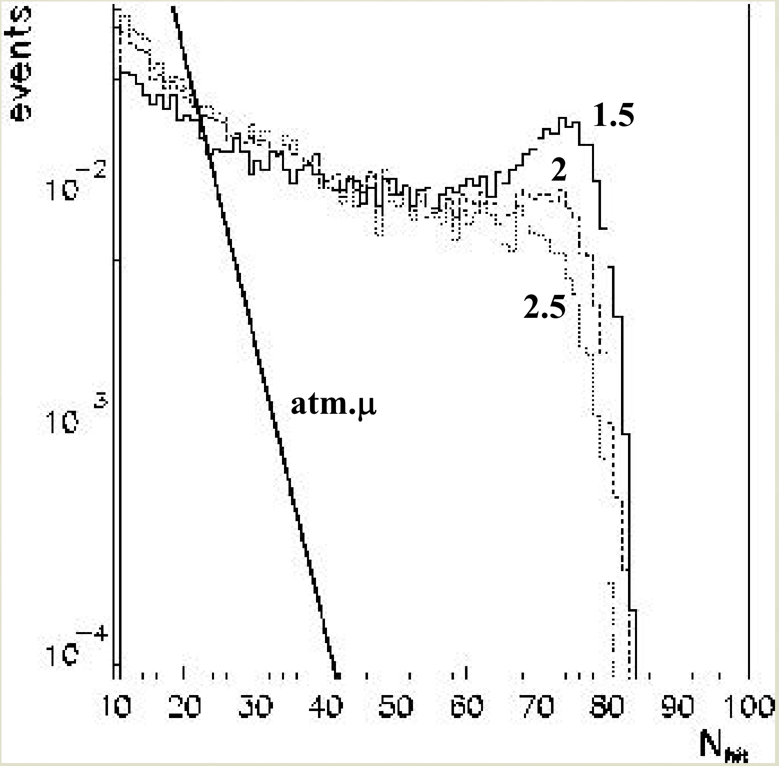


Стратегия поиска событий от нейтрино высоких энергий

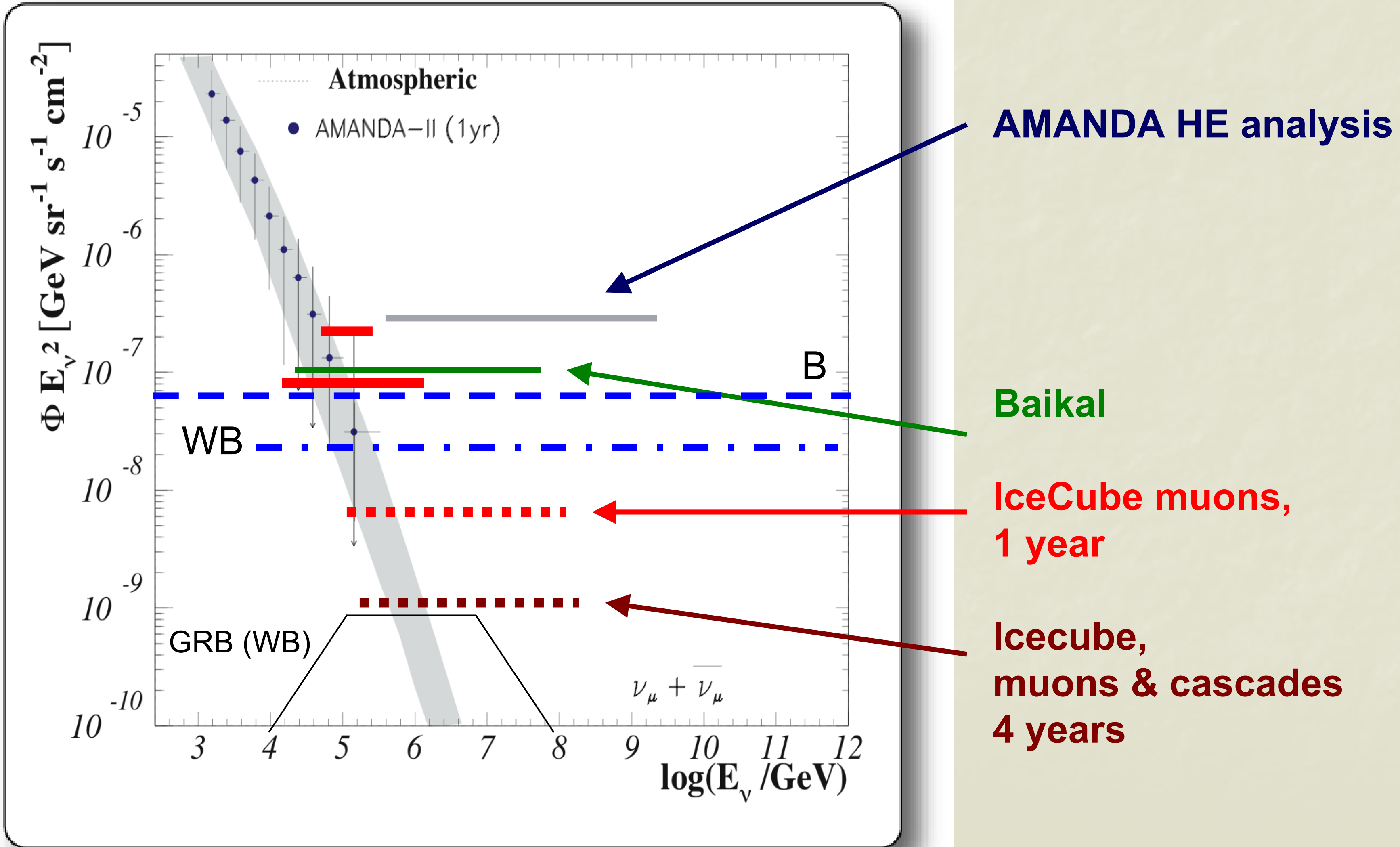


$\Phi_\nu = AE^{-\gamma}$

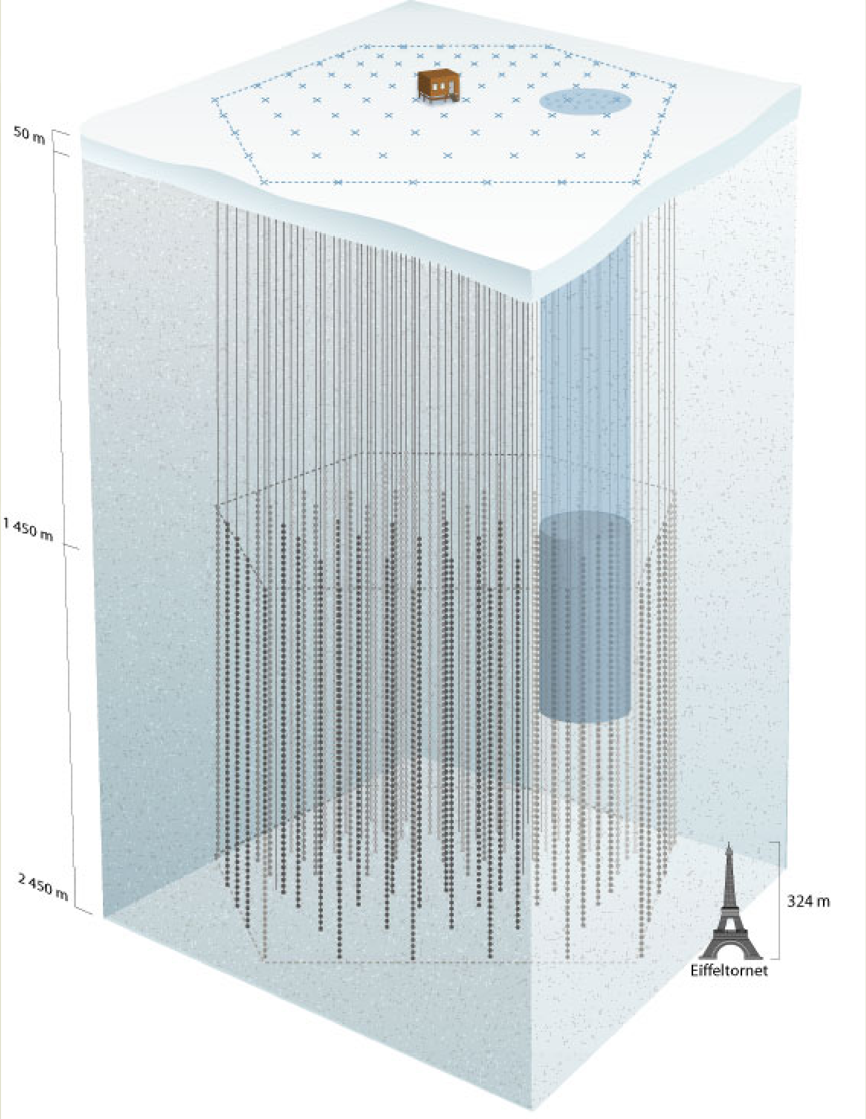
множественность числа сра-ботавших каналов в событии



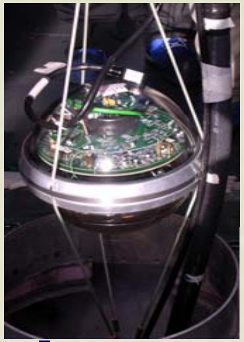
Limit on diffuse extraterrestrial fluxes



IceCube



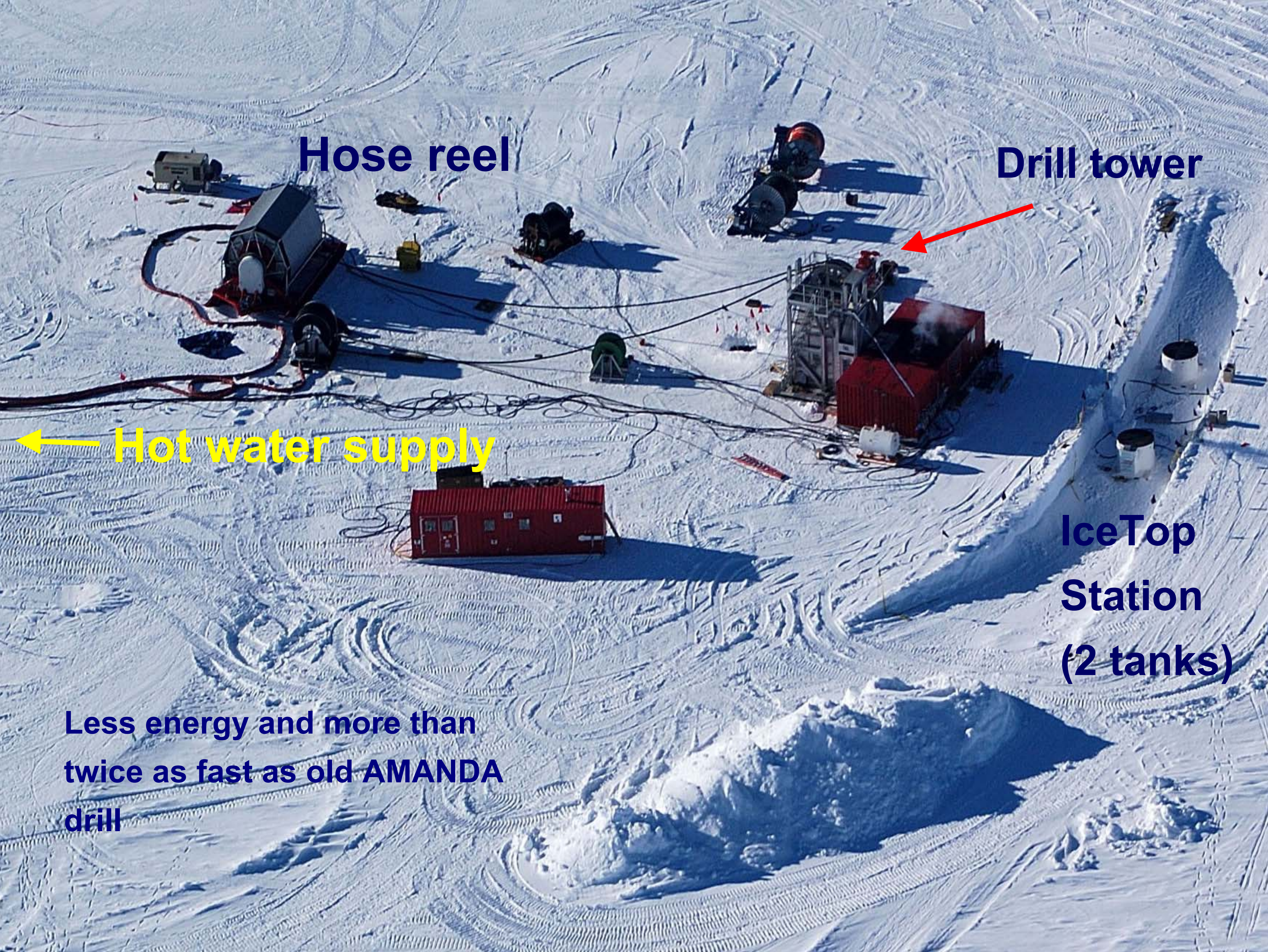
- **4800 Digital Optical Modules on 80 strings**

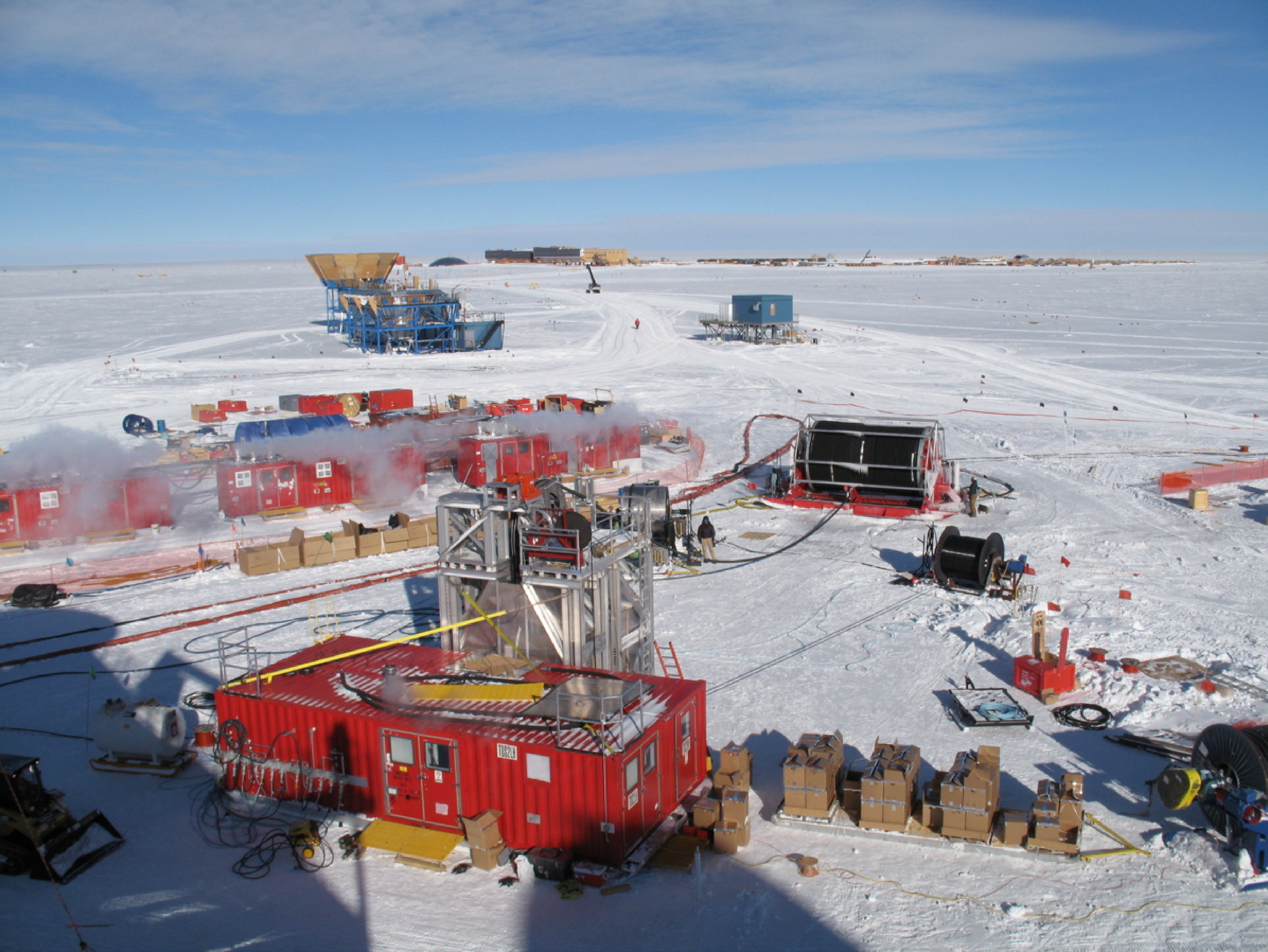


- **160 Ice-Cherenkov tank surface array (IceTop)**
- **1 km^3 of instrumented Ice**
- **Surrounding existing AMANDA detector**

IceCube

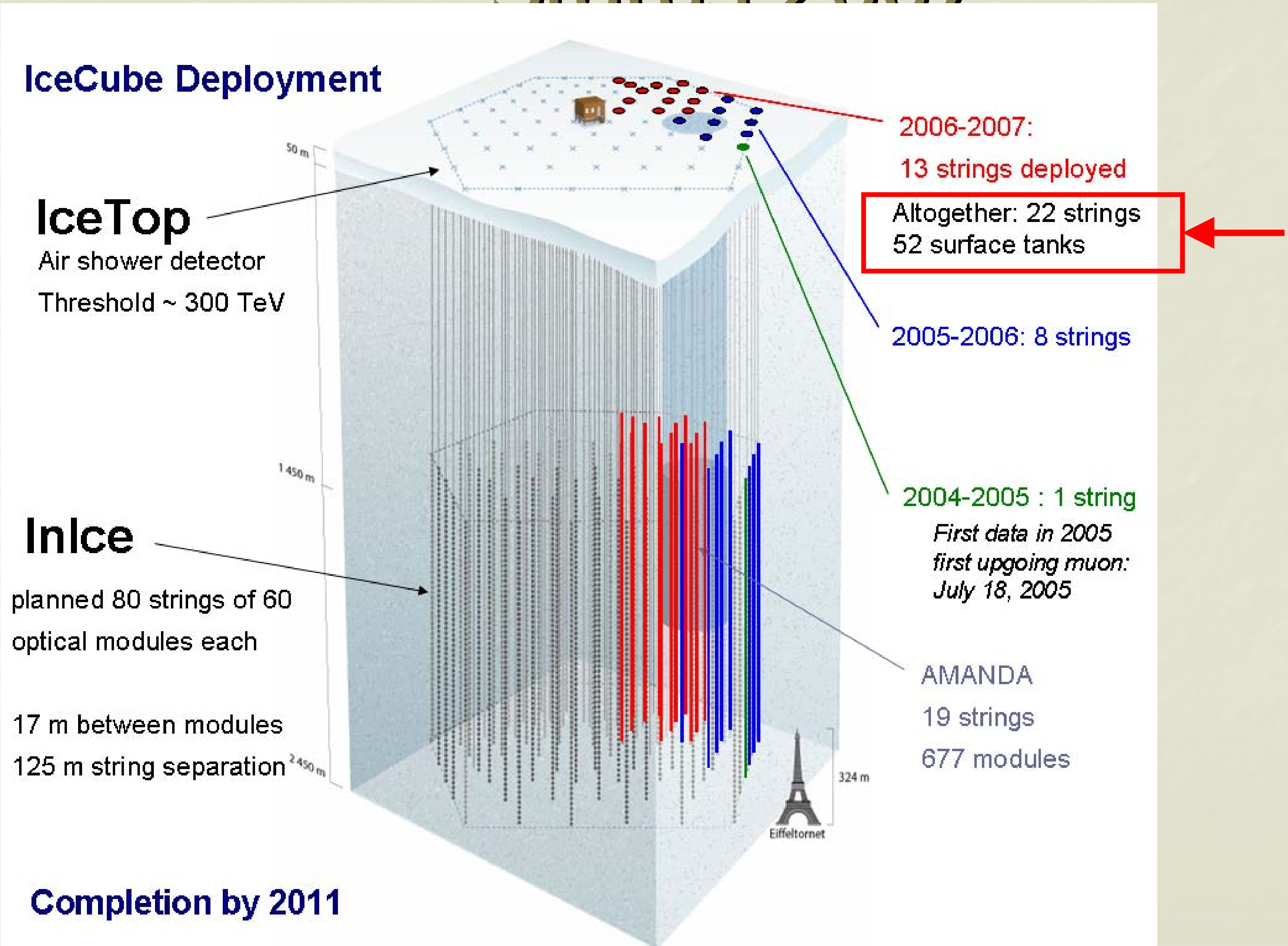

IceCube
South Pole Station
AMANDA
Skiway
Geographic South Pole
Dark sector


Hose reel
Drill tower
Hot water supply
IceTop
Station
(2 tanks)
Less energy and more than
twice as fast as old AMANDA
drill



IceCube Laboratory and Data Center

Status 2007



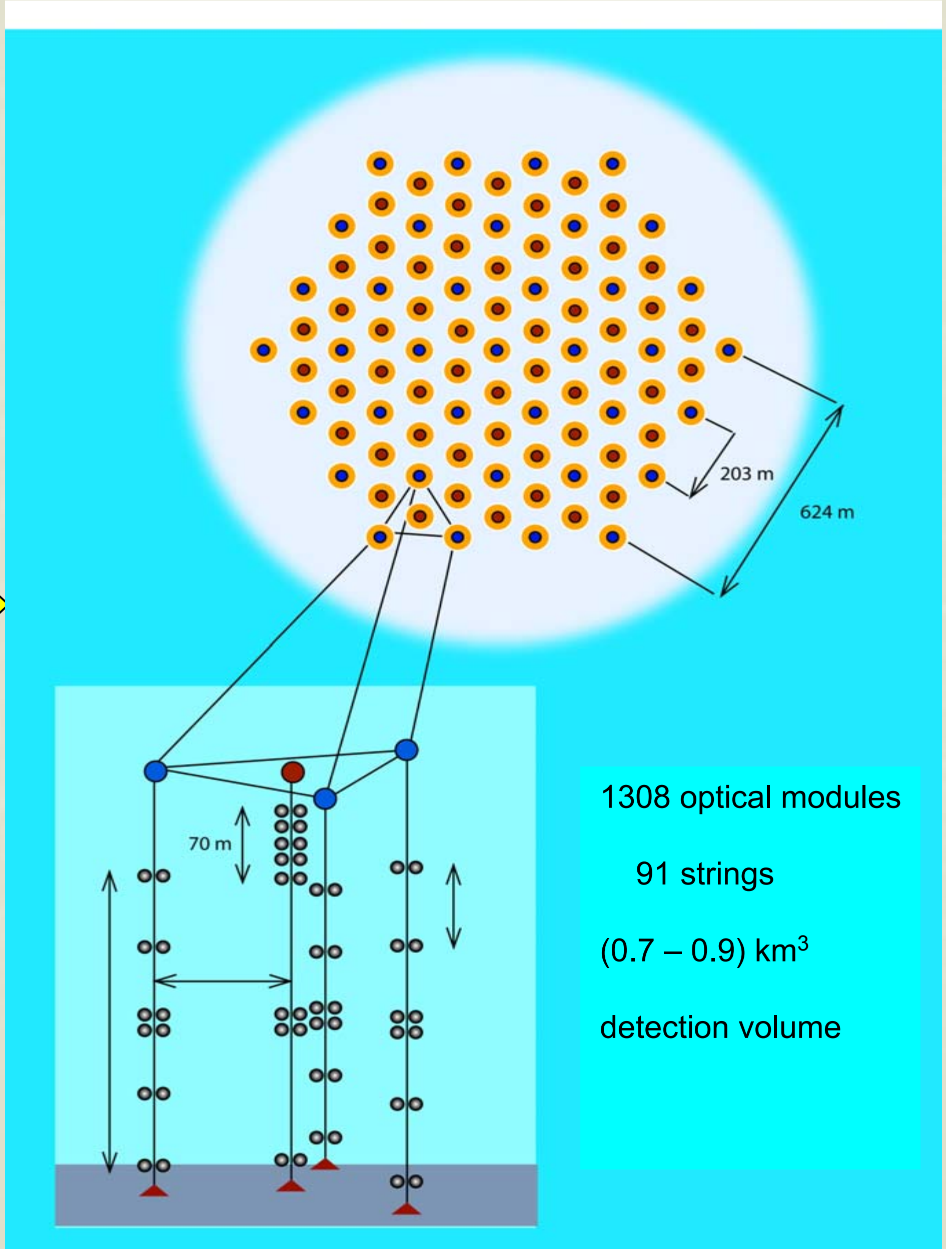
IceCube Deployment
IceTop
Air shower detector
Threshold ~ 300 TeV
InIce
planned 80 strings of 60
optical modules each
17 m between modules
125 m string separation
Completion by 2011
50 m
1 450 m
2 450 m
324 m
Eiffeltornet
2006-2007:
13 strings deployed
Altogether: 22 strings
52 surface tanks
2005-2006: 8 strings
2004-2005 : 1 string
First data in 2005
first upgoing muon:
July 18, 2005
AMANDA
19 strings
677 modules

Гигатонный (км^3) Водный Детектор на оз.Байкал

91 гирлянда (12 ОМ)
= 1308 ОМ

→ эффективный объем для регистрации каскадов (E>100 TeV) ~ 0.5 -1.0 км^3!

→ порог регистрации мюонов 10 - 100 ТэВ



План (стратегический)

2008 - 2009 – завершение работы над проектом детектора HT1000 (BAIKAL-GVD).

2009 - 2014 - изготовление и приобретение комплектующих элементов

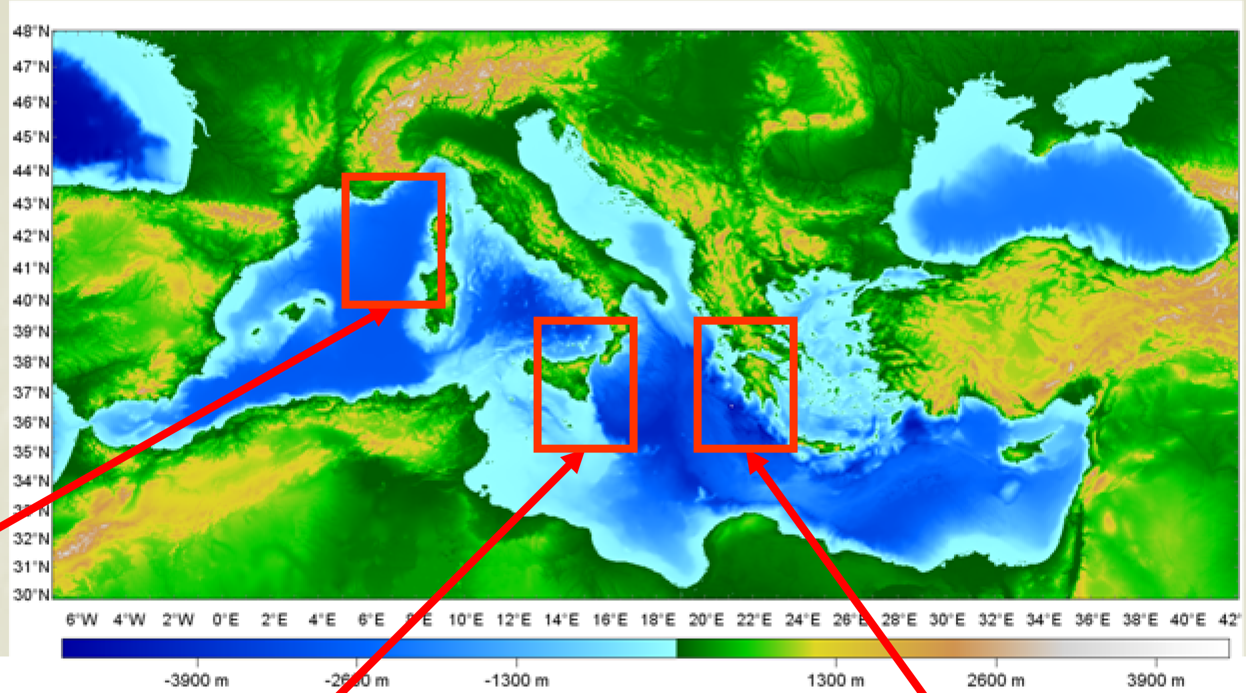
2010 – 2012 – развертывание первой очереди (0.1 – 0.3) куб км

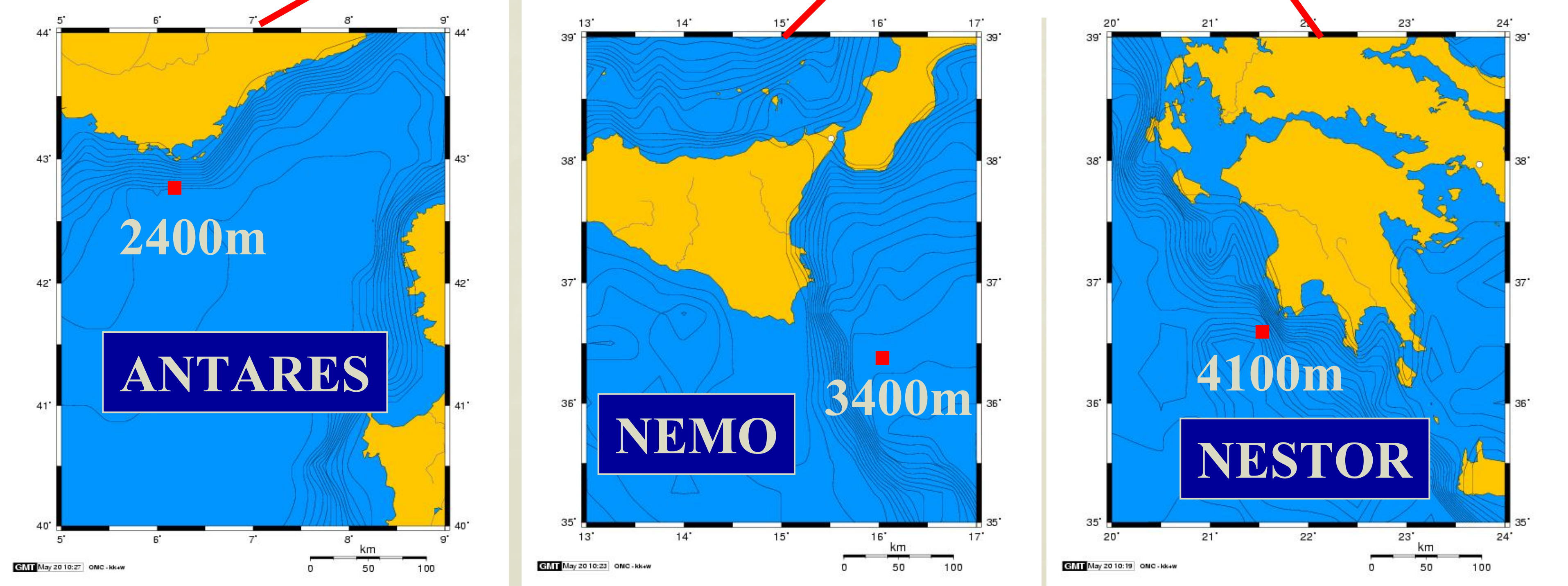
2014 – вторая очередь (0.3 – 0.6) куб км

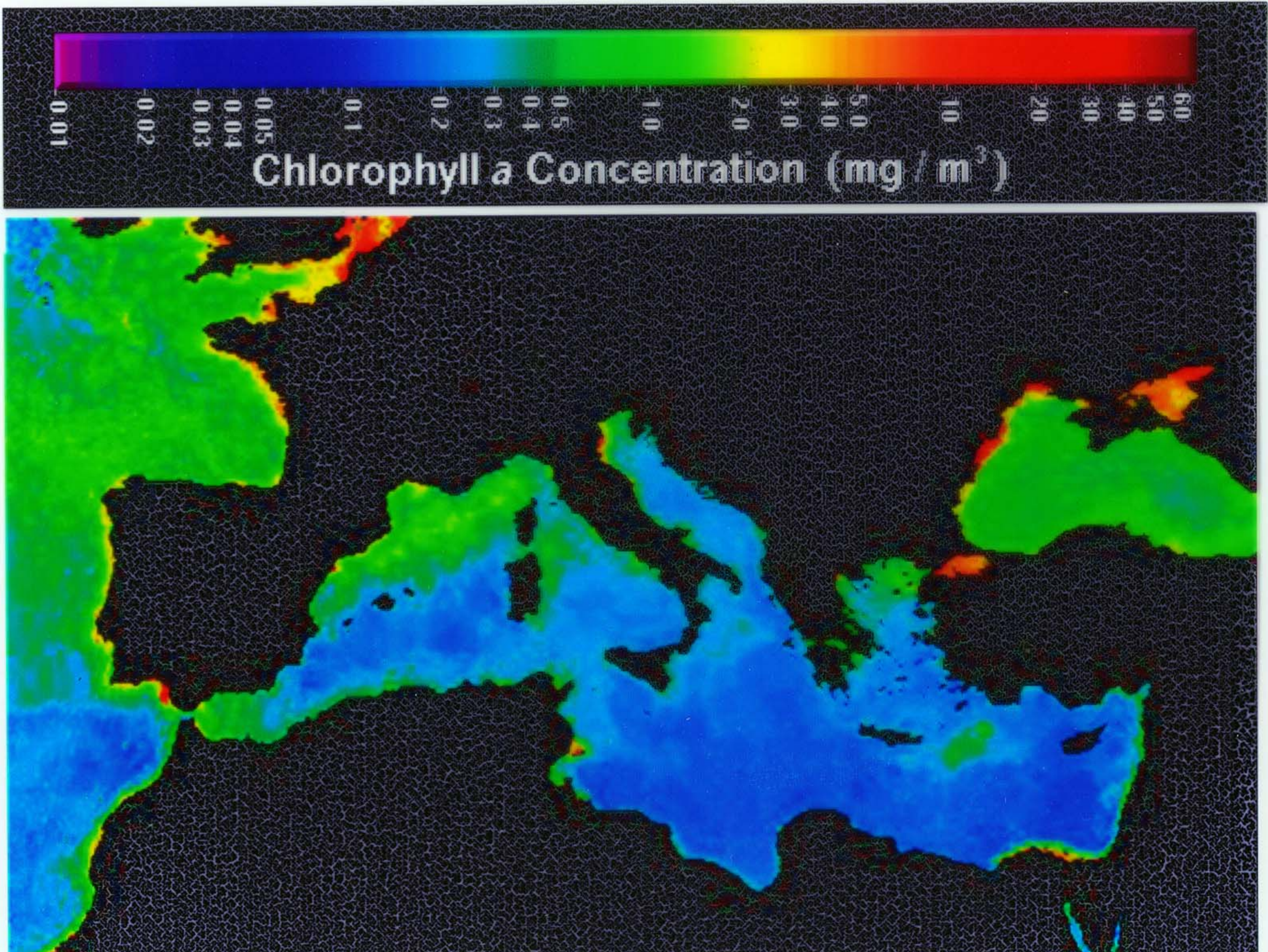
2016 – третья очередь (0.6 – 0.9) куб км

Постоянно – поддержание работоспособности, набор и анализ данных HT200+………HT1000

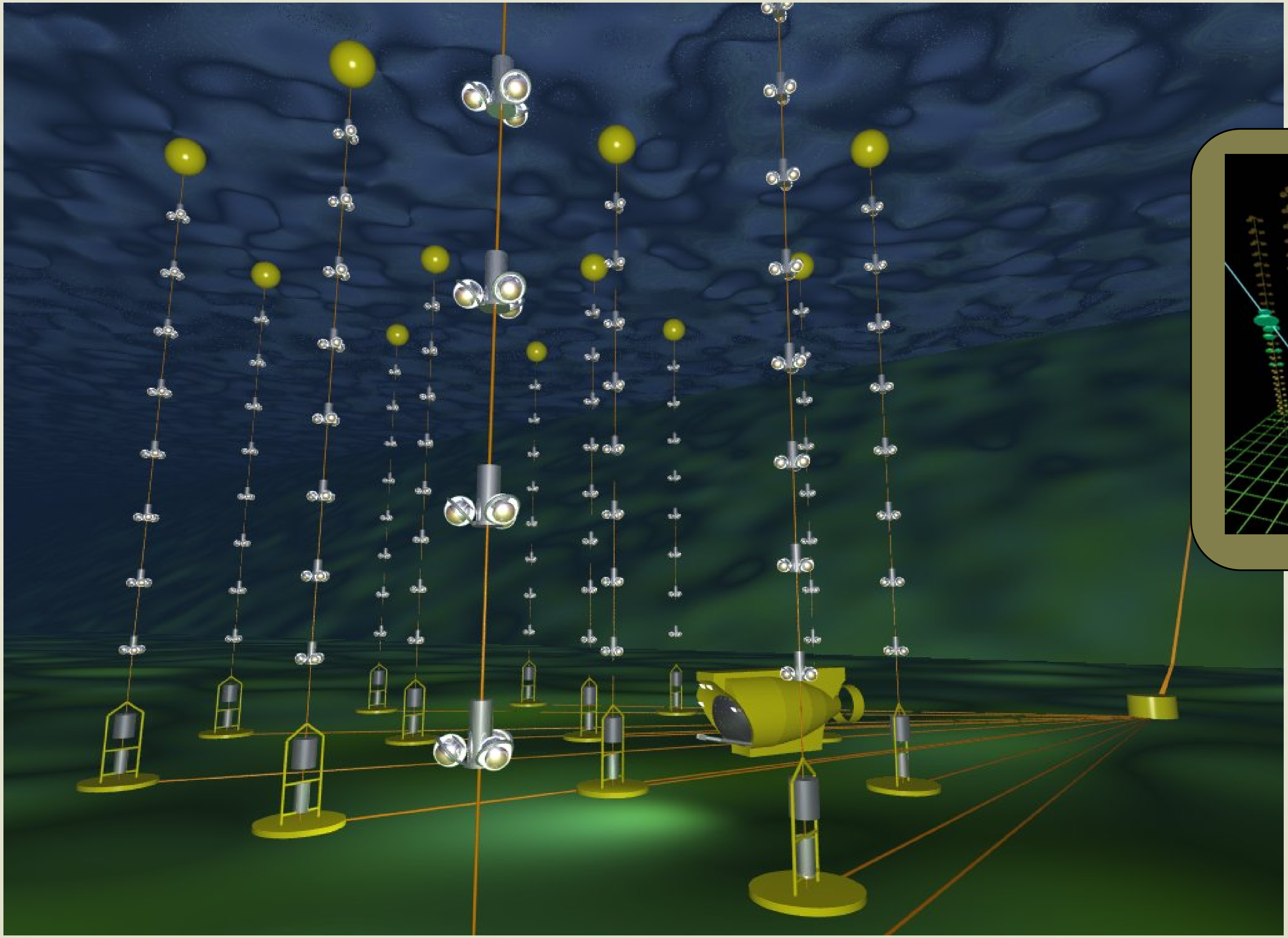
The Mediterranean approach

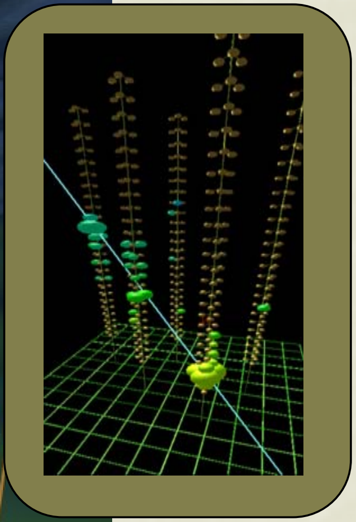





0.01
0.02
0.03
0.04
0.05
0.1
0.2
0.3
0.4
0.5
1.0
2.0
3.0
4.0
5.0
10
20
30
40
50
60
Chlorophyll a Concentration (mg / m3)

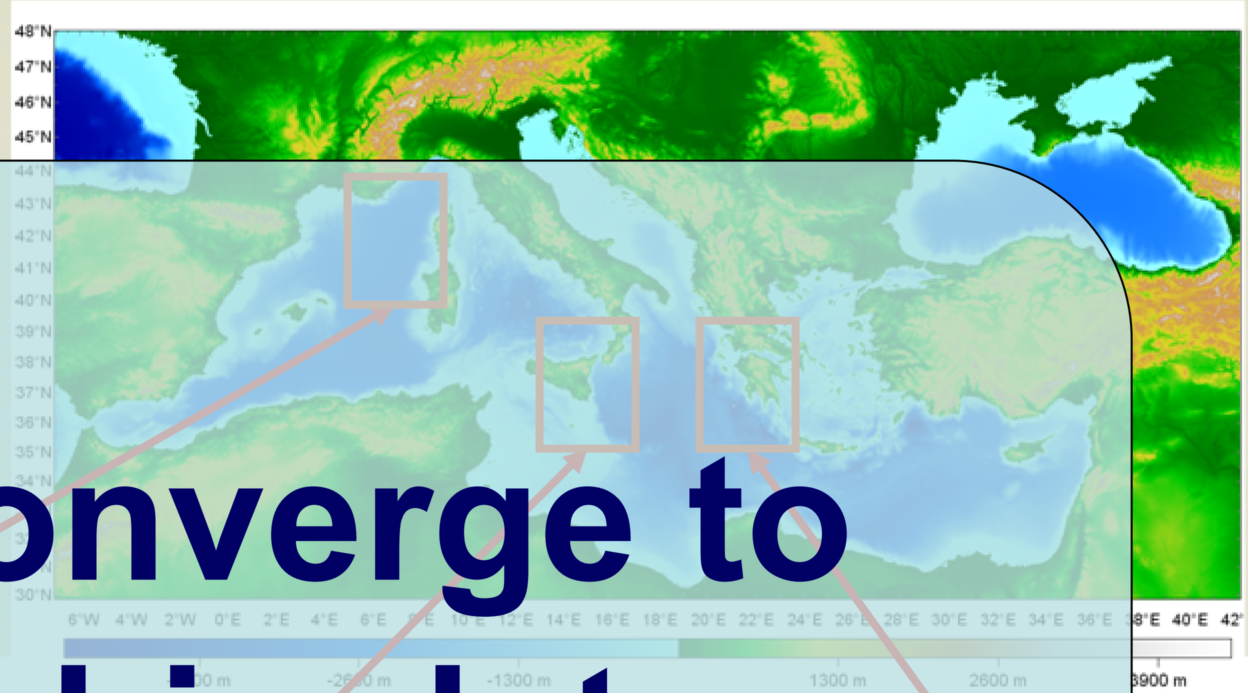
ANTARES

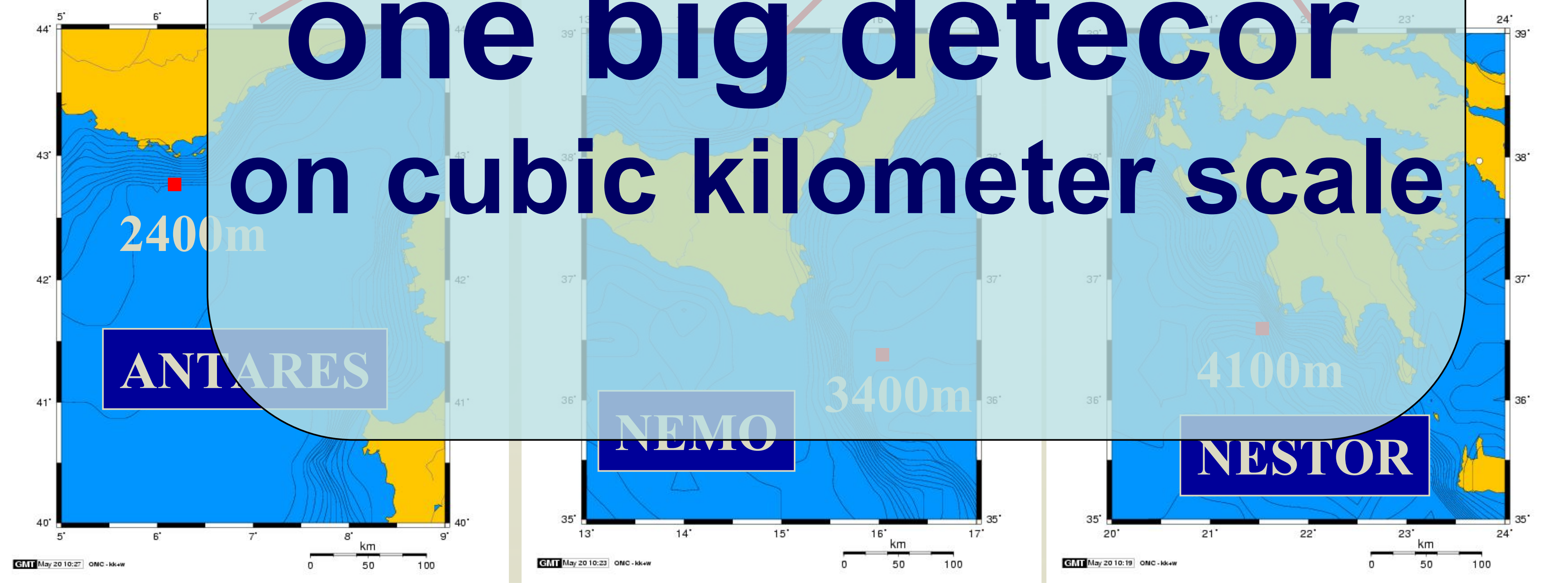




Neutrino candidate from 5-string detector

The Mediterranean approach

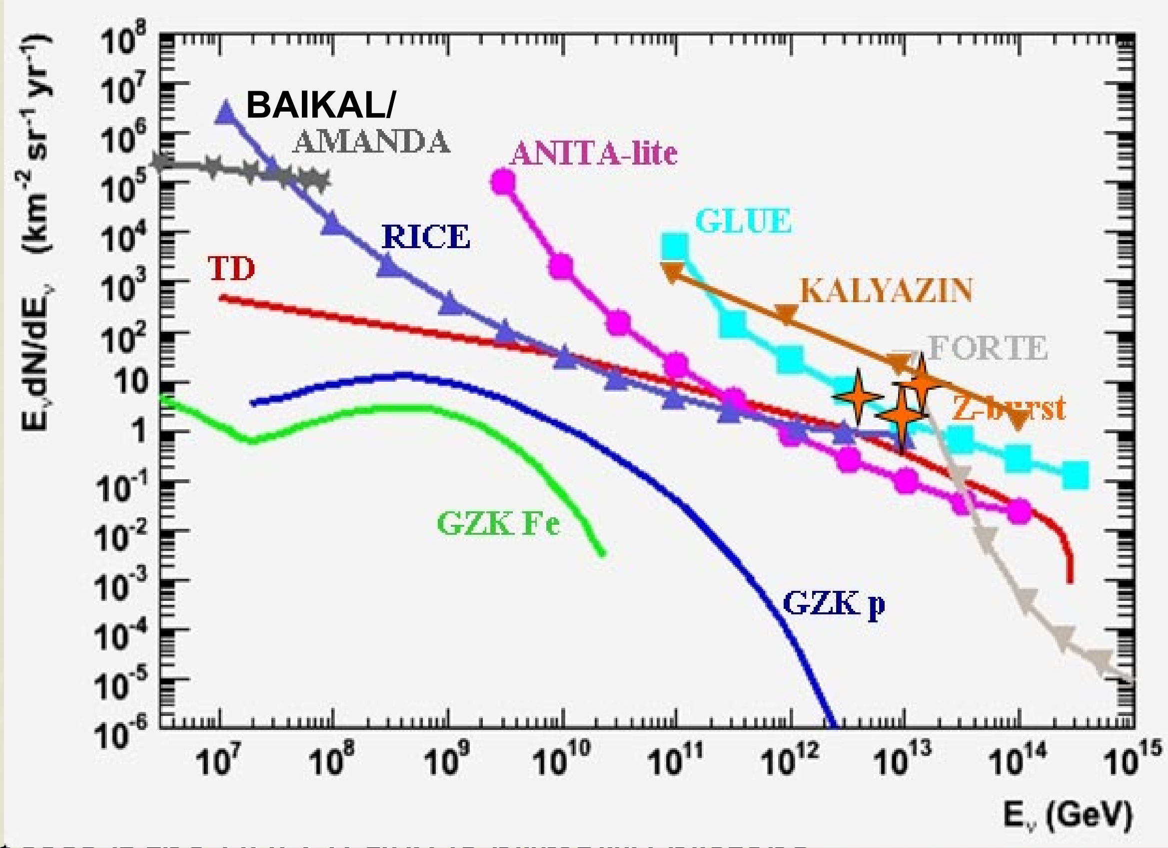


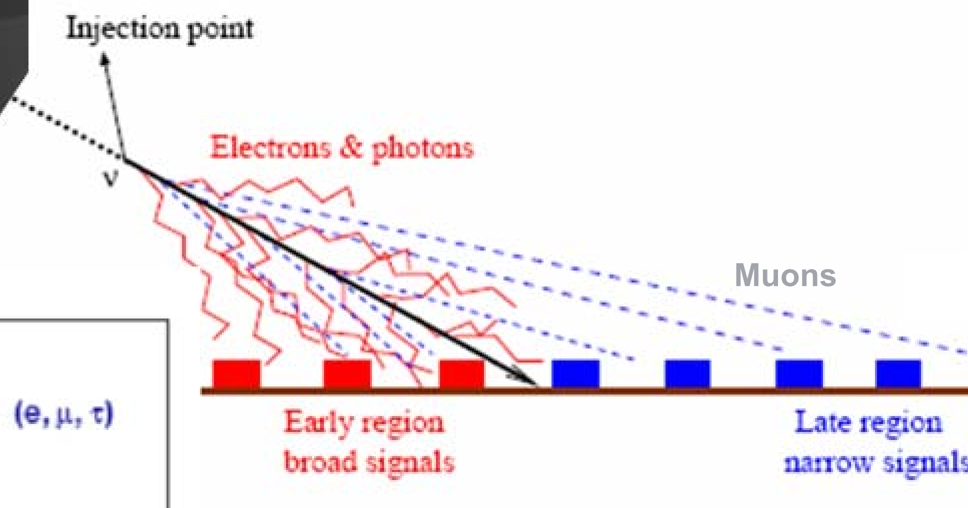


Converge to one big detecor on cubic kilometer scale

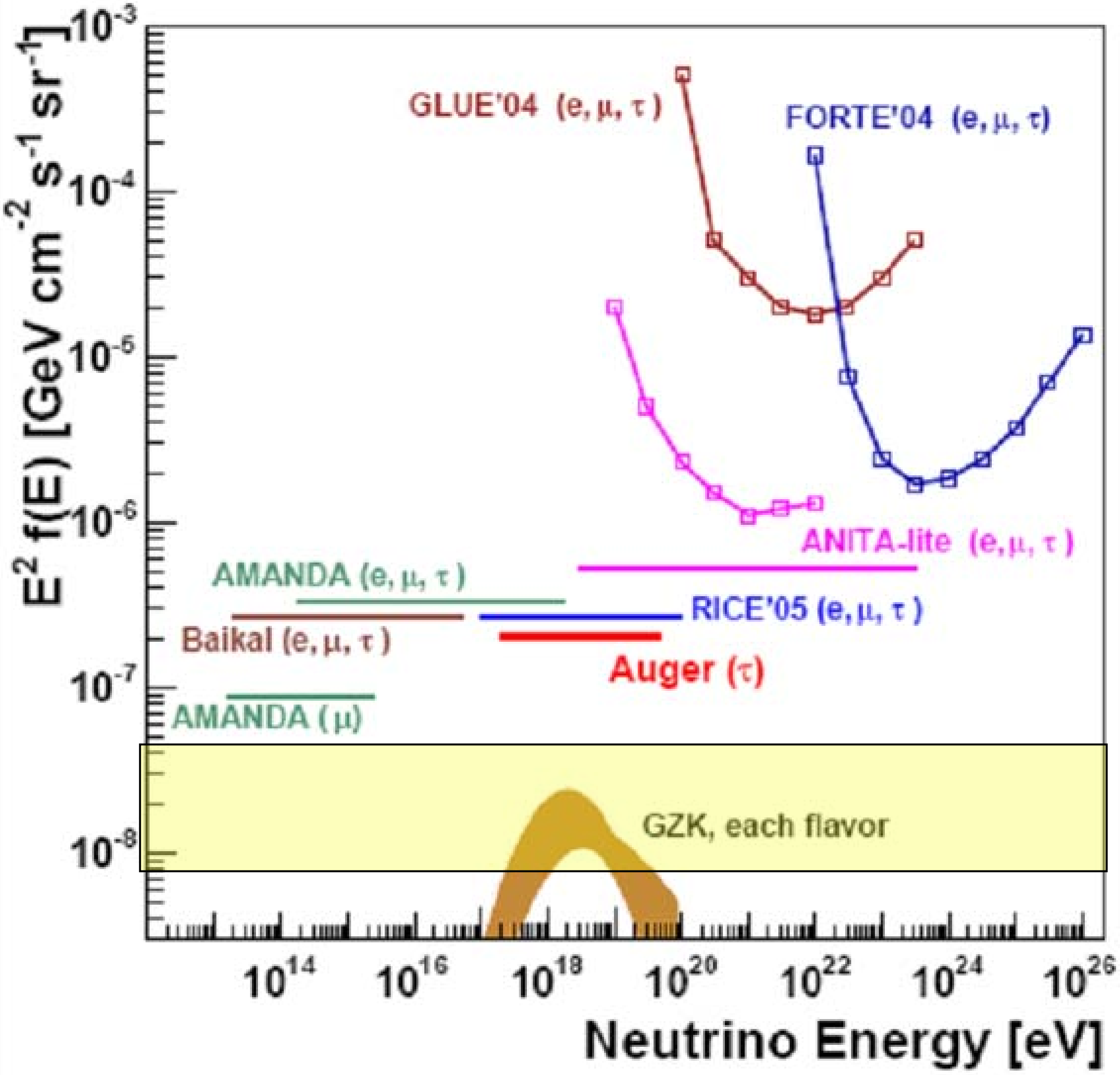
Flux of Ultra-High Energy Neutrinos

- AMANDA: Optical Cherenkov in South Pole ice
- RICE: Radio Cherenkov in South Pole Ice
- GLUE and
- KALYAZIN-RAMHAND: Earthbound search for Radio Cherenkov in Lunar Regolith (RAMHAND - Radio Astronomical Method of Hadron And Neutrino Detection, 1989; KALYAZIN – Radio Telescope near Moscow)
- FORTE: Satellite search for radio Cherenkov in Greenland ice
- ANITA-lite: prototype search in 2003
- Theory:
  - GZK p: Neutrinos from GZK process if the UHECR flux is primarily protons
  - GZK Fe: Neutrinos from GZK process if the UHECR flux is primarily iron
  - TD: Neutrinos from a top down theory of UHECR origin (cosmic string loops or monopolonium)
  - Z-burst: UHECRs originate from interactions of UHE neutrinos



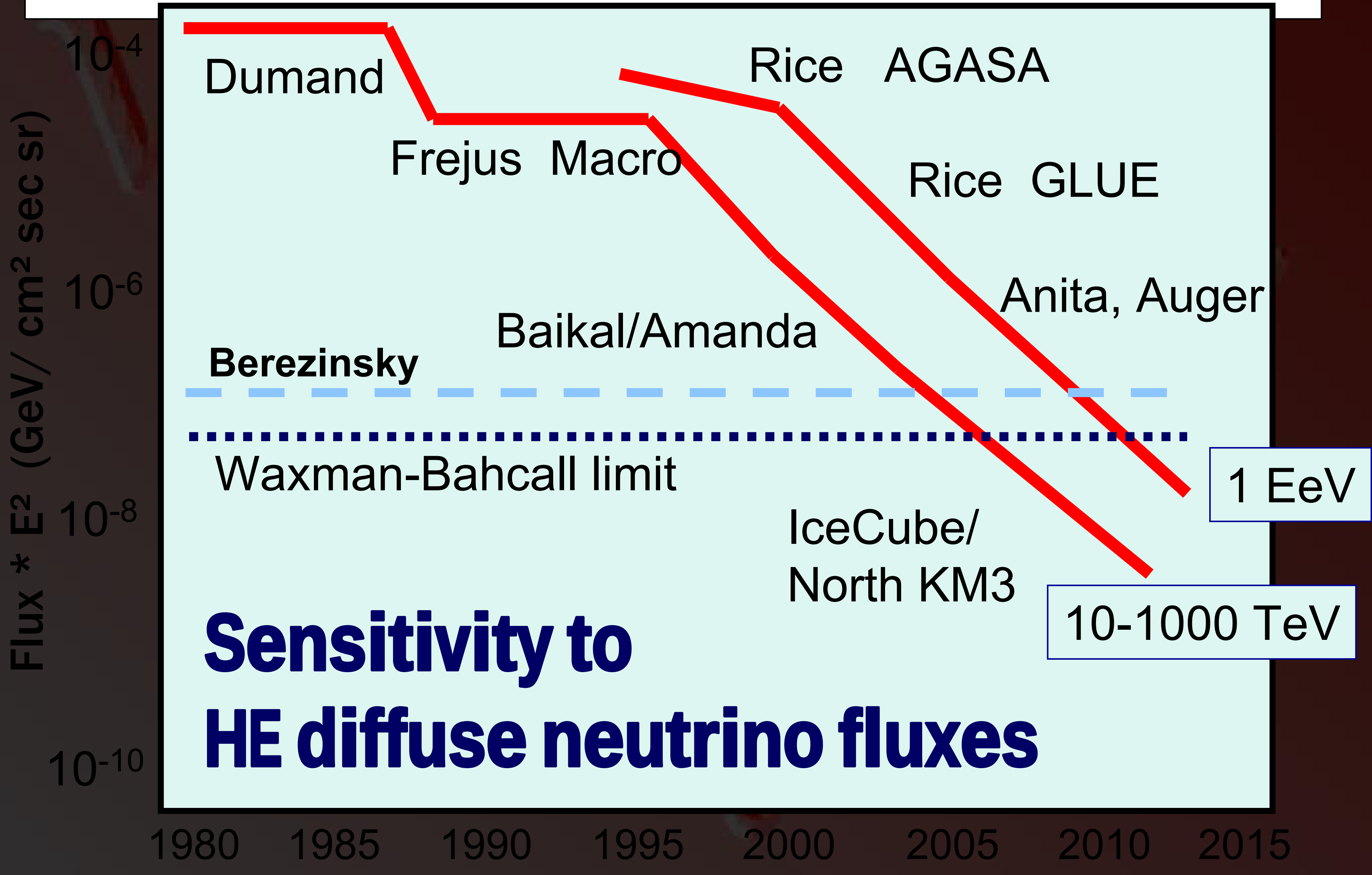


Injection point
ν
Electrons & photons
Muons
Early region
broad signals
Late region
narrow signals

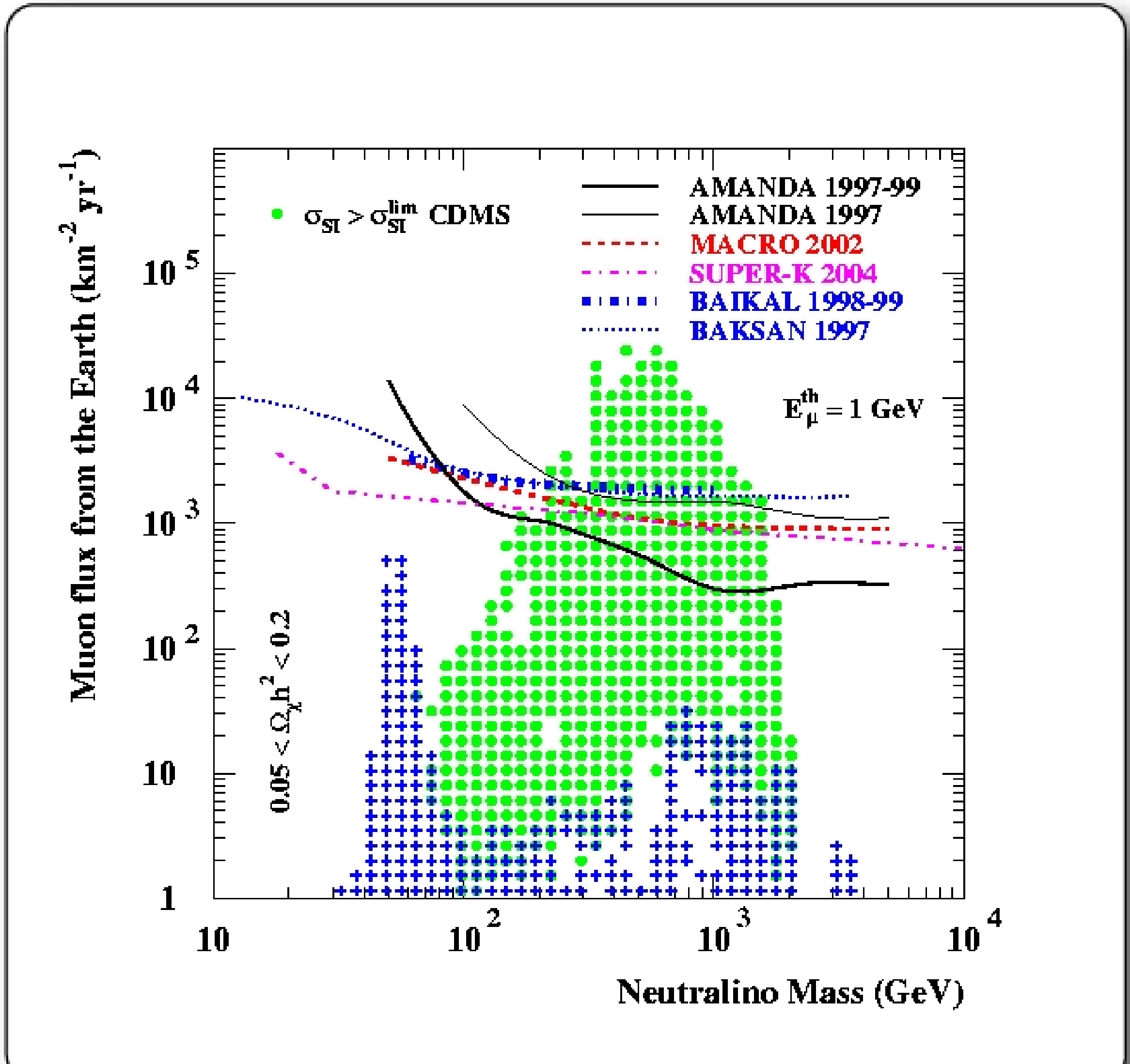


E^2 f(E) [GeV cm^{-2} s^{-1} sr^{-1}]
GLUE'04 (e, μ, τ)
FORTE'04 (e, μ, τ)
ANITA-lite (e, μ, τ)
AMANDA (e, μ, τ)
RICE'05 (e, μ, τ)
Baikal (e, μ, τ)
Auger (τ)
AMANDA (μ)
GZK, each flavor
Neutrino Energy [eV]

The big picture



WIMPs: neutrinos from center of Earth

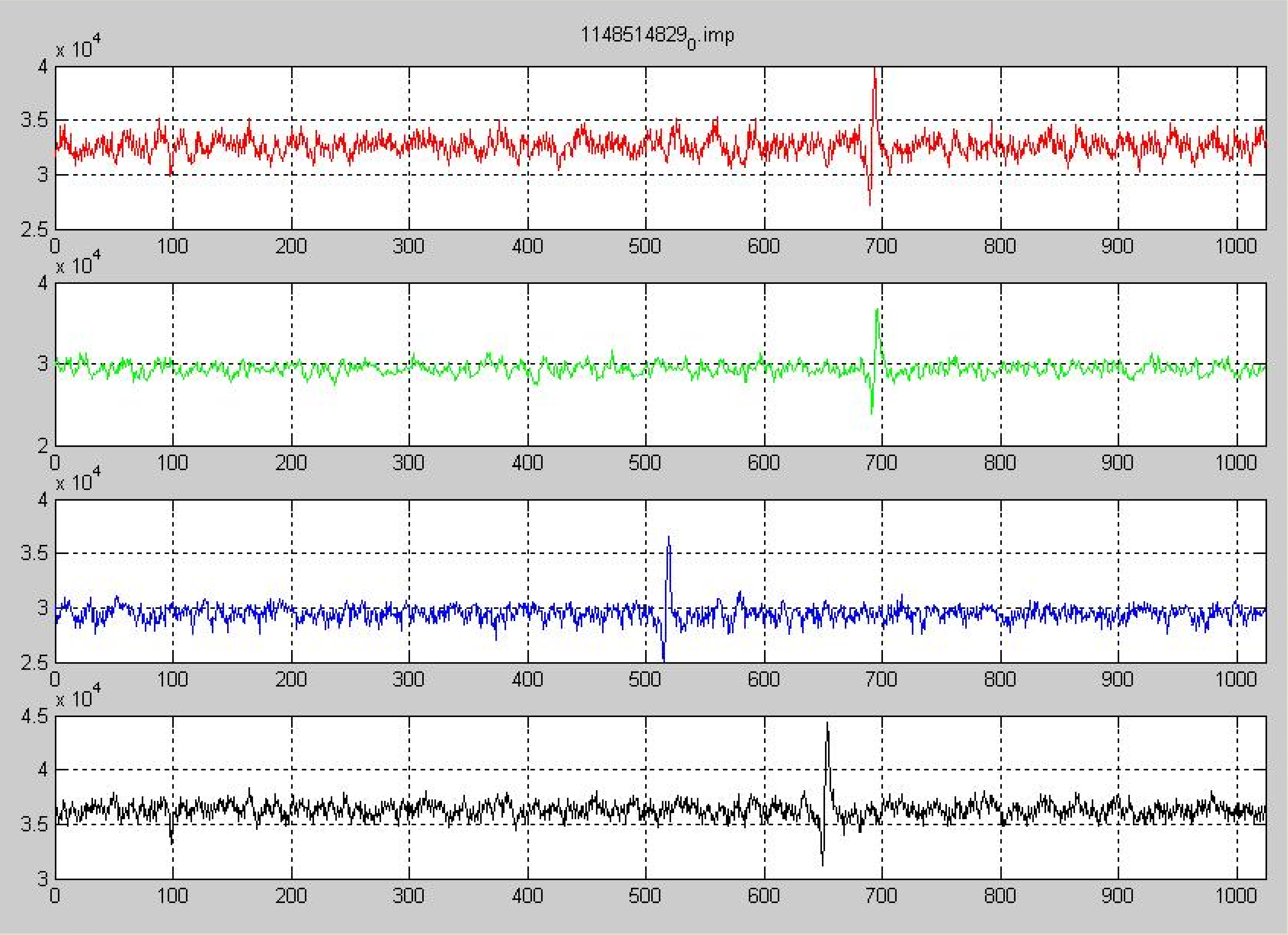


Baikal – GVD
Schedule Milestones

- 06-07 R&D, Testing NT200+
- 08 Technical Design
- 08-14 Fabrication (OMs, cables, connectors, electronics)
- 10-12 Deployment (0.1 – 0.3) km3
- 13-14 Deployment (0.3 – 0.6) km3
- 15-16 Deployment (0.6 – 0.9) km3

Overall cost with logistics ~ 20 MEuro

Detector ~ 16 MEuro Logistics, including infrastructure ~ 4 MEuro



11485148290.imp
x 10^4
4
3.5
3
2.5
0
100
200
300
400
500
600
700
800
900
1000
x 10^4
4
3
2
x 10^4
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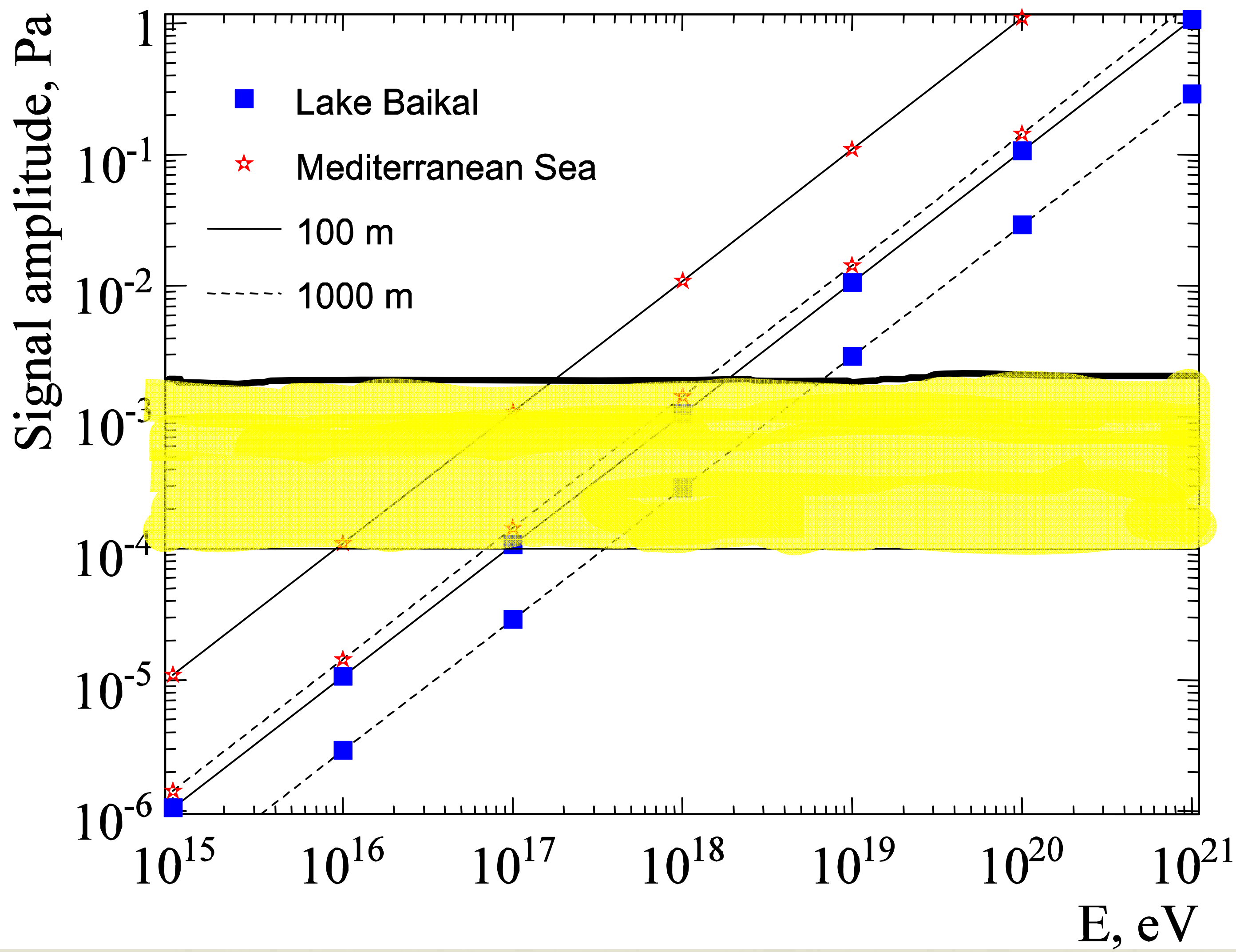
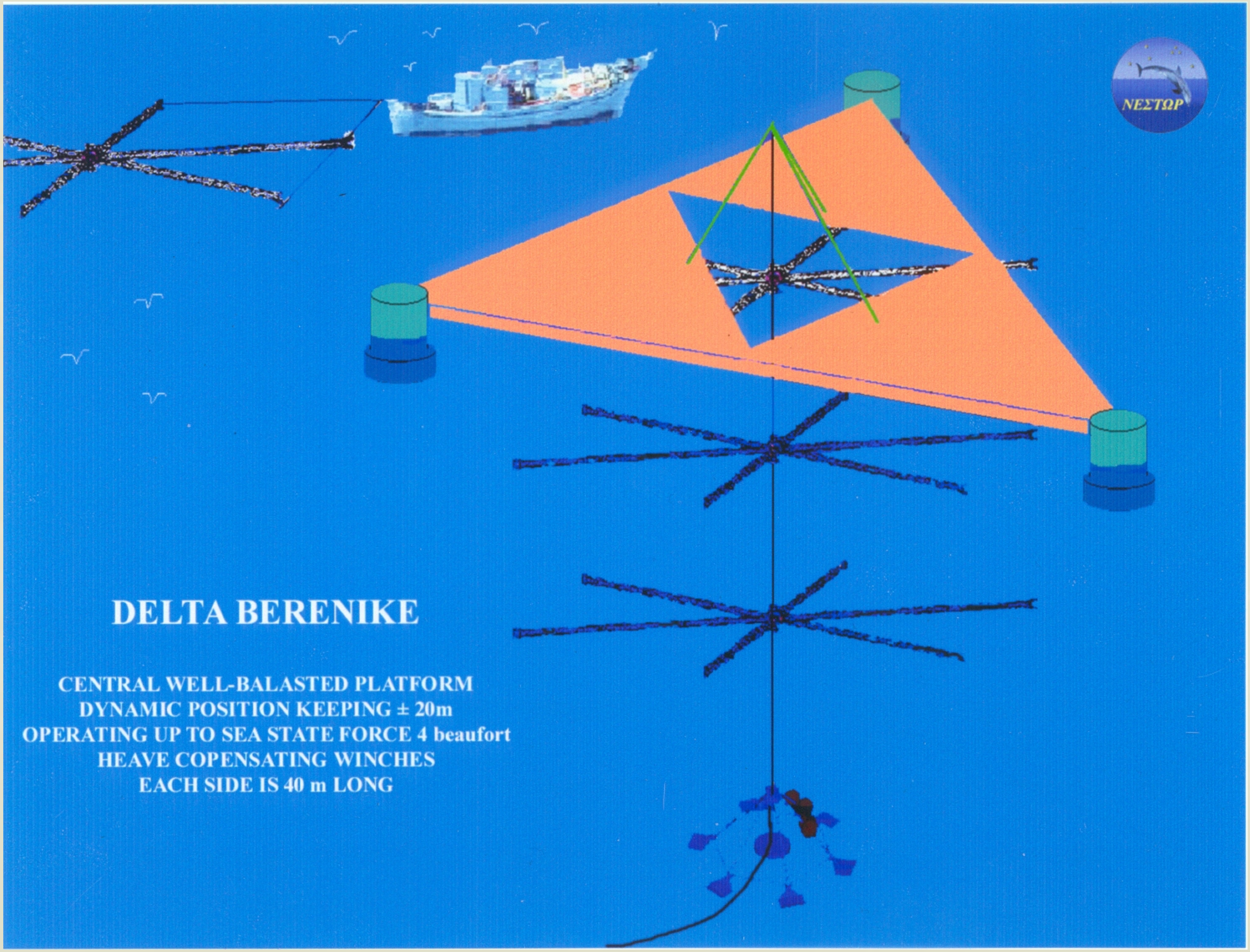
3
2.5
x 10^4
4.5
4
3.5
3

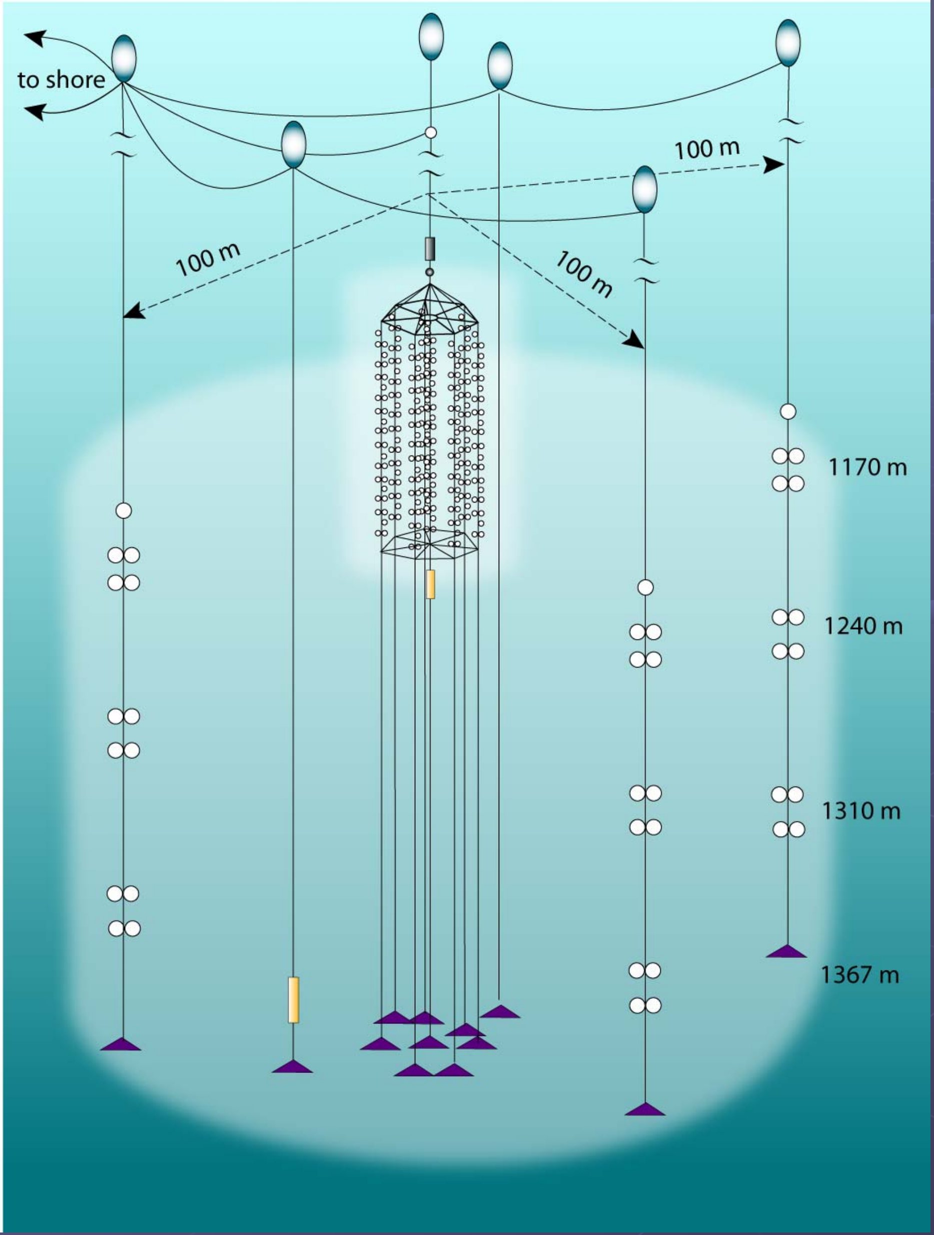
Very preliminary

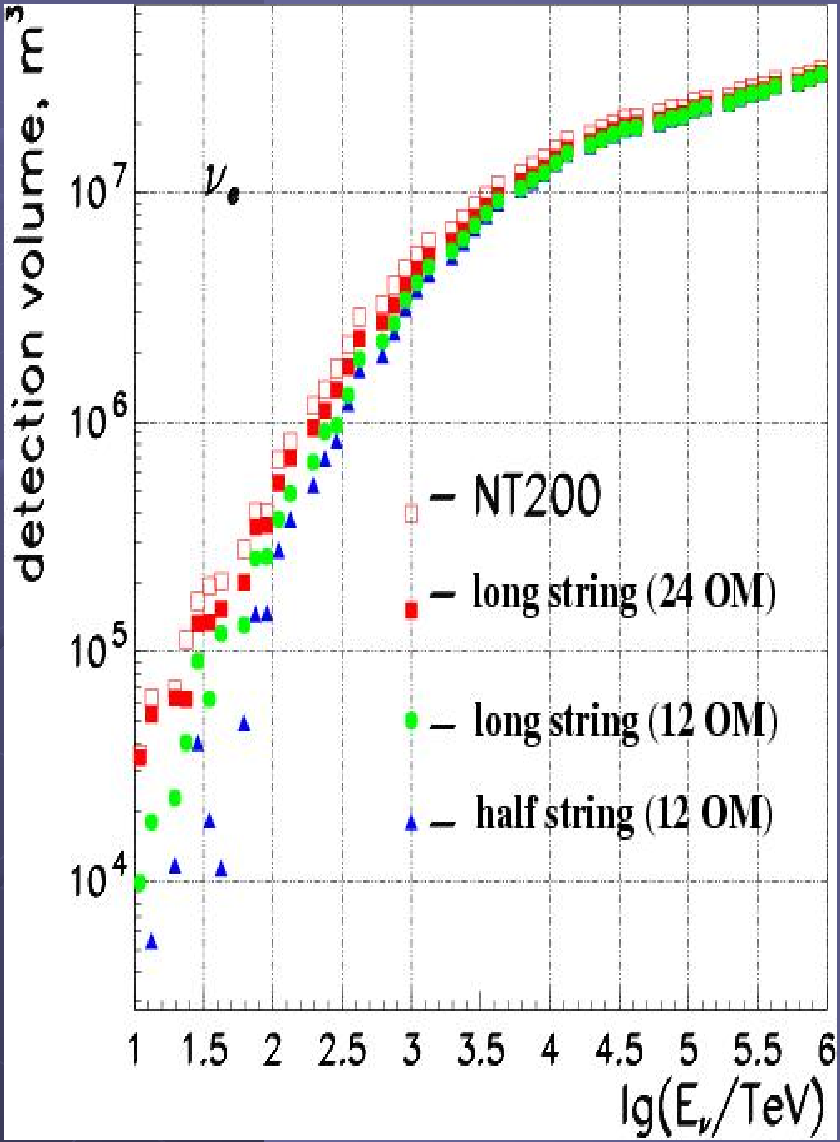


Under Construction: will be operational at Pylos the summer of 2007

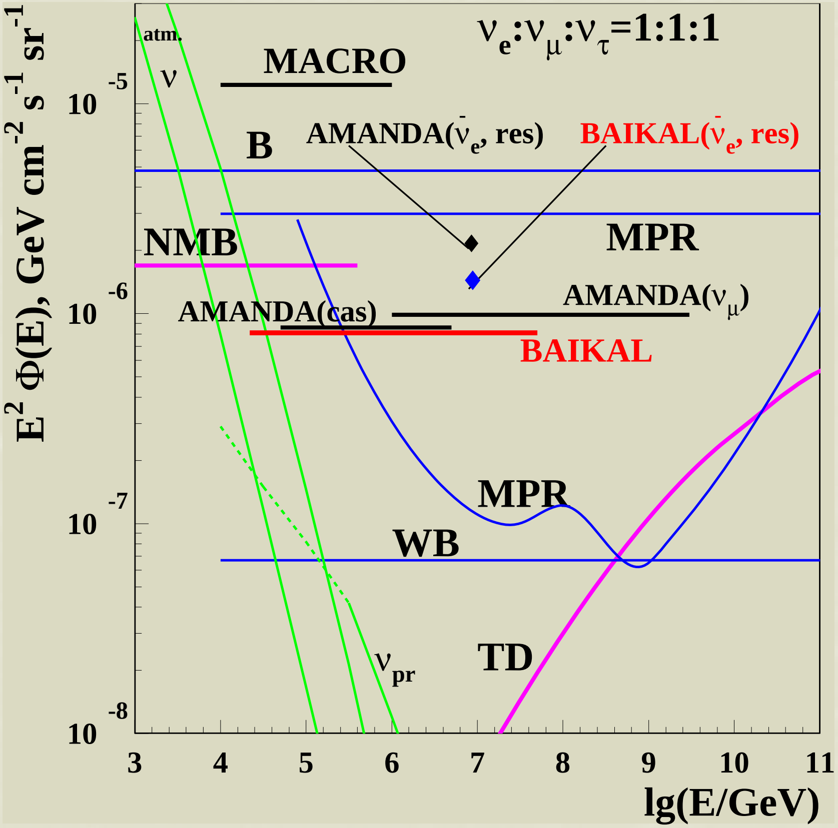


НТ-200+ в качестве модуля гигатонного детектора

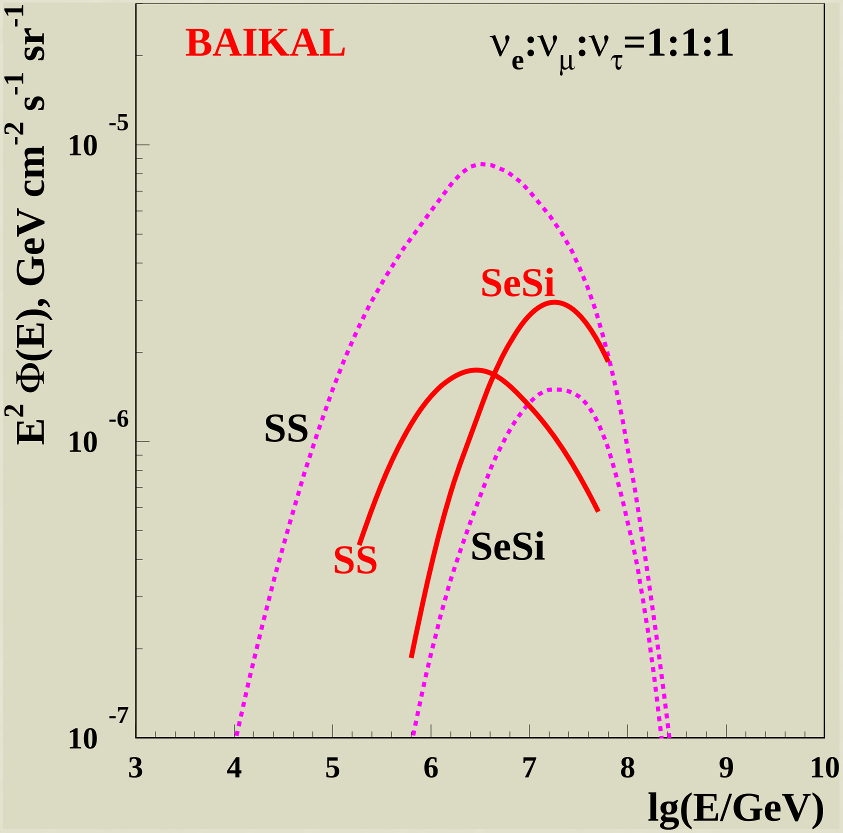




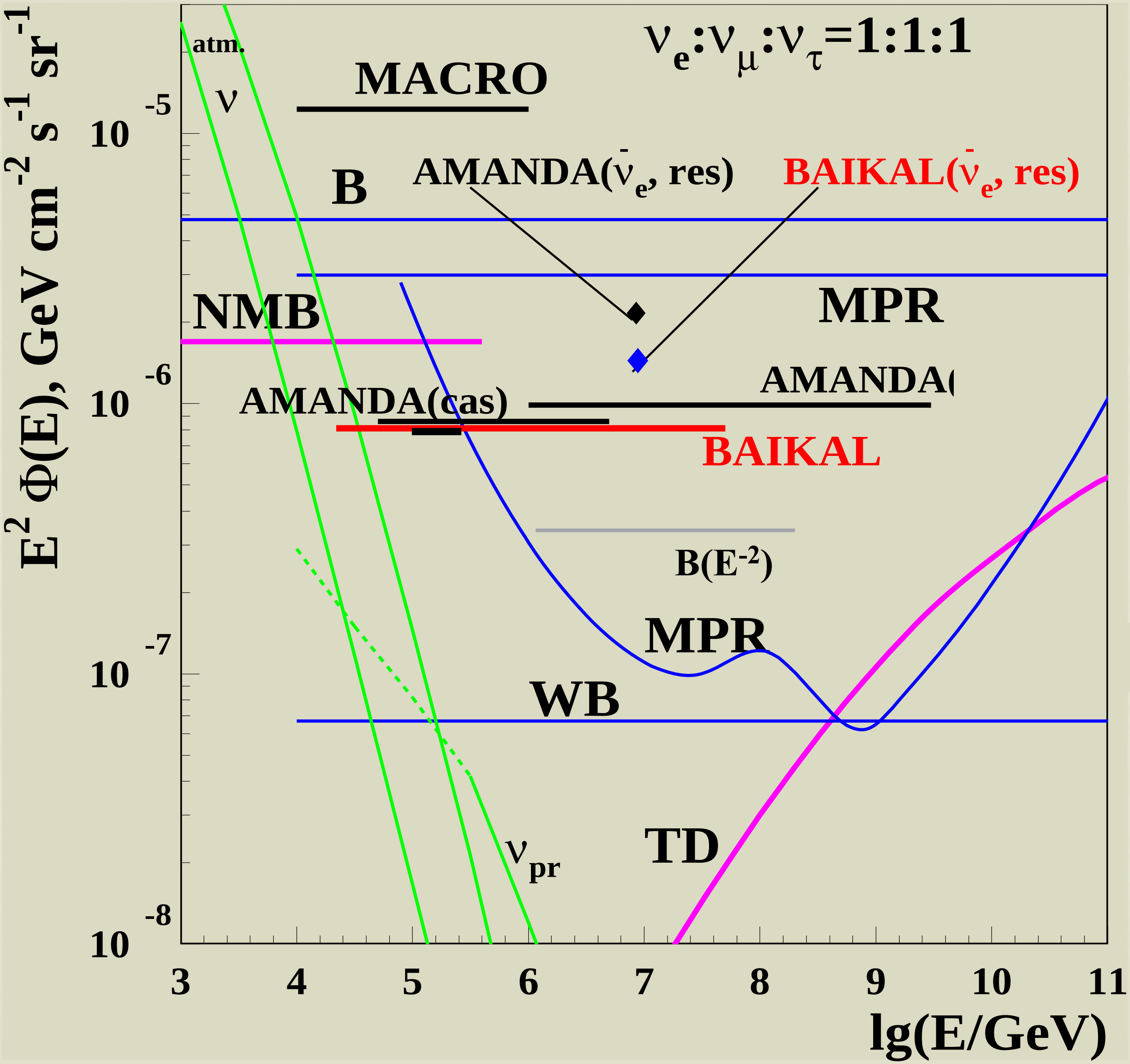
Теоретические ограничения на величину диффузного потока нейтрино высоких энергий и экспериментальные верхние пределы на величину потока с формой спектра ~E^{-2}

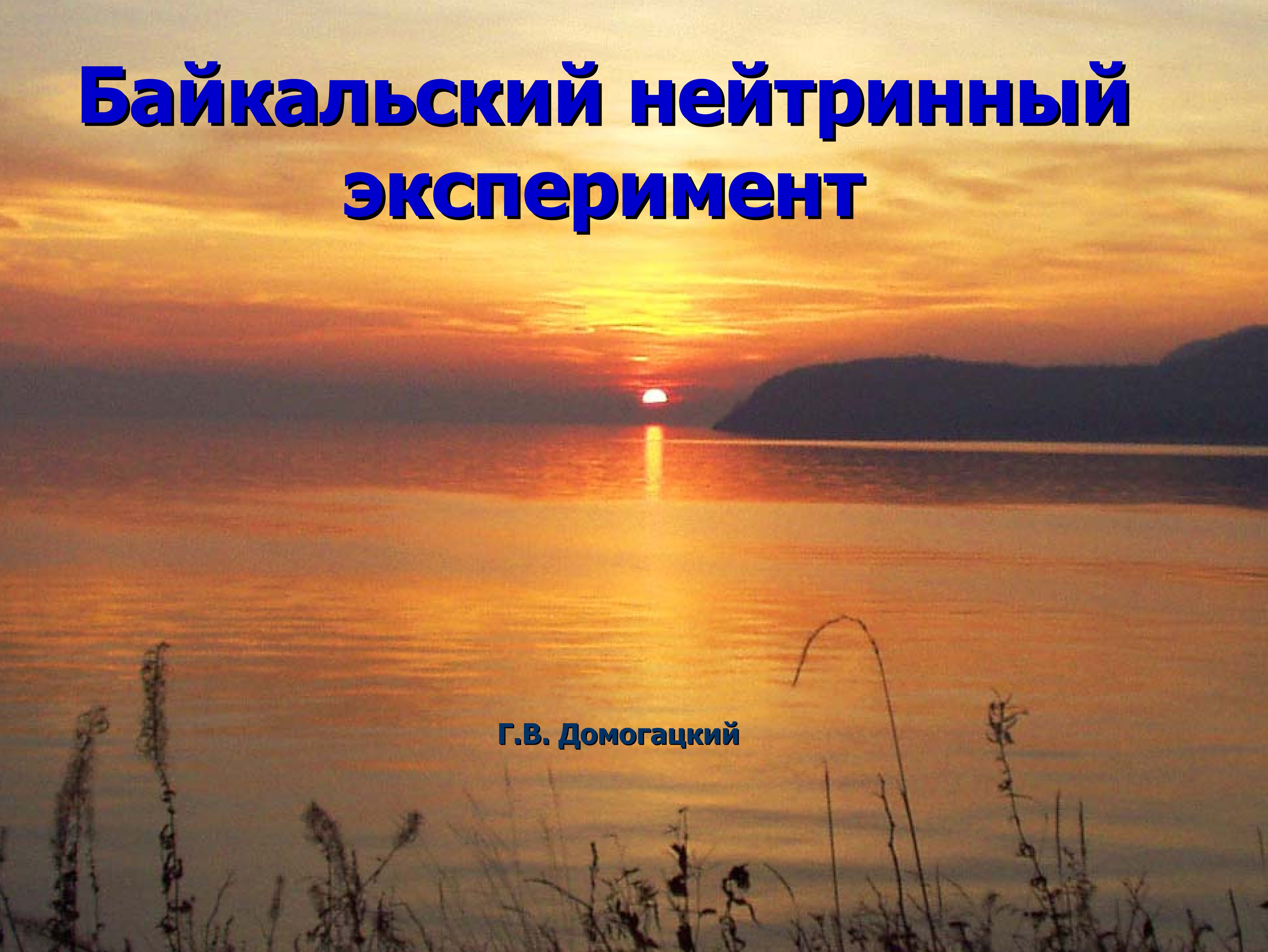


Верхние пределы на величину диффузного потока нейтрино от Квазаров (модель SS) и от Блазаров (модель SeSi)



Diffuse Flux Limits

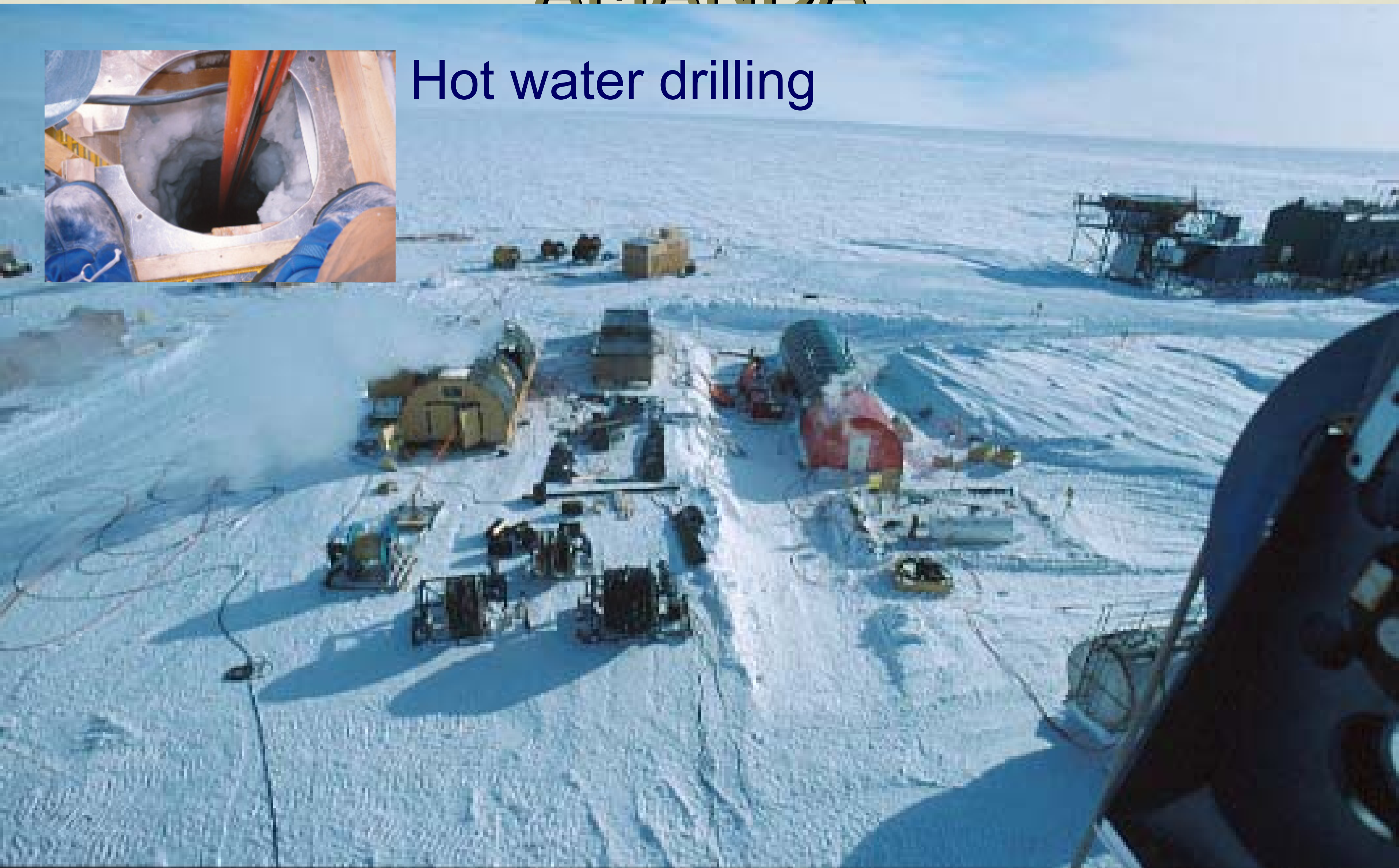




Байкальский нейтринный эксперимент

Г.В. Домогацкий

AMANDA



Hot water drilling

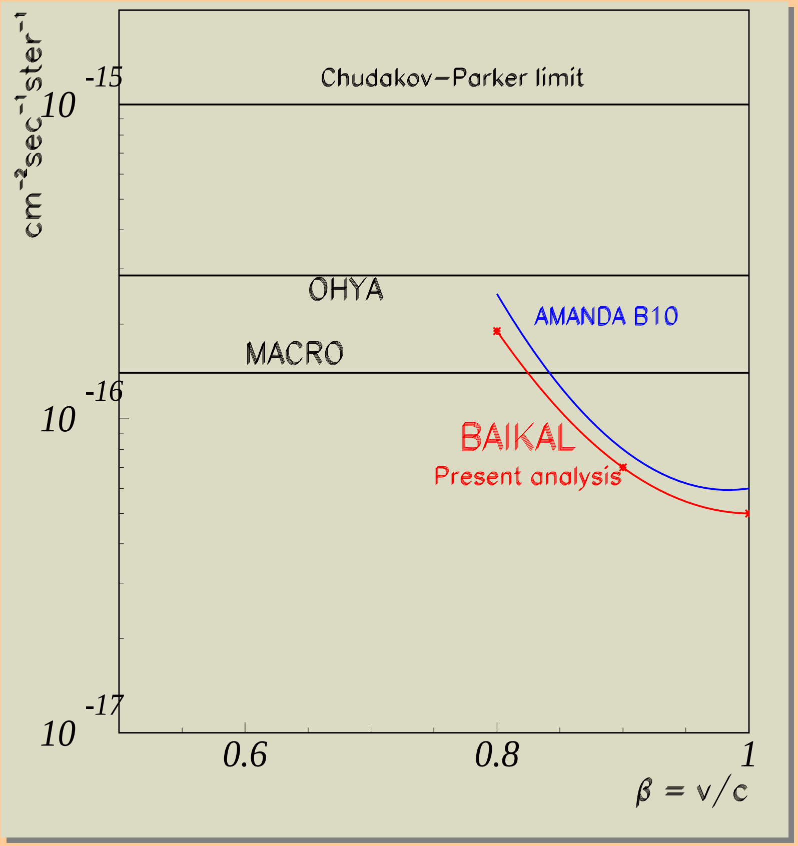
Search for fast monopoles ($\beta > 0.8$)

$$N_\gamma(\lambda) = n^2 (g/e)^2 N_{\gamma\mu}(\lambda) =$$
$$= 8300\, N_{\gamma\mu}(\lambda)$$
$$g = 137/2, \quad n = 1.33$$
$$\sim E_\mu = 10^7 \text{ GeV}$$

Event selection criteria:

hit channel multiplicity - $N_{hit} > 35$ ch,
upward-going monopole -
$\Sigma(z_i - z)(t_i - t)/(\sigma_t \sigma_z) > 0.45$ & $\theta > 100^o$

Background - atmospheric muons

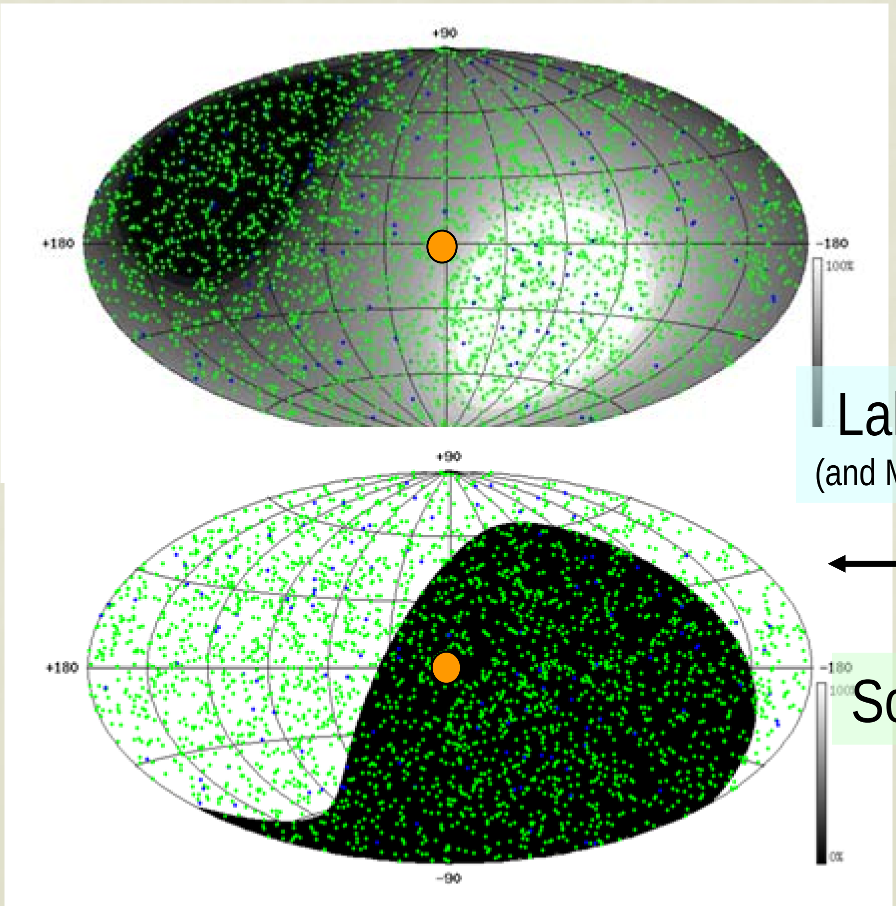


90% C.L. upper limit on the flux of fast monopole (994 livedays)

The case for >1 Uw/Ice - Telescopes

(1) Complete sky cove

Sky coverage in Gal.Coordinates



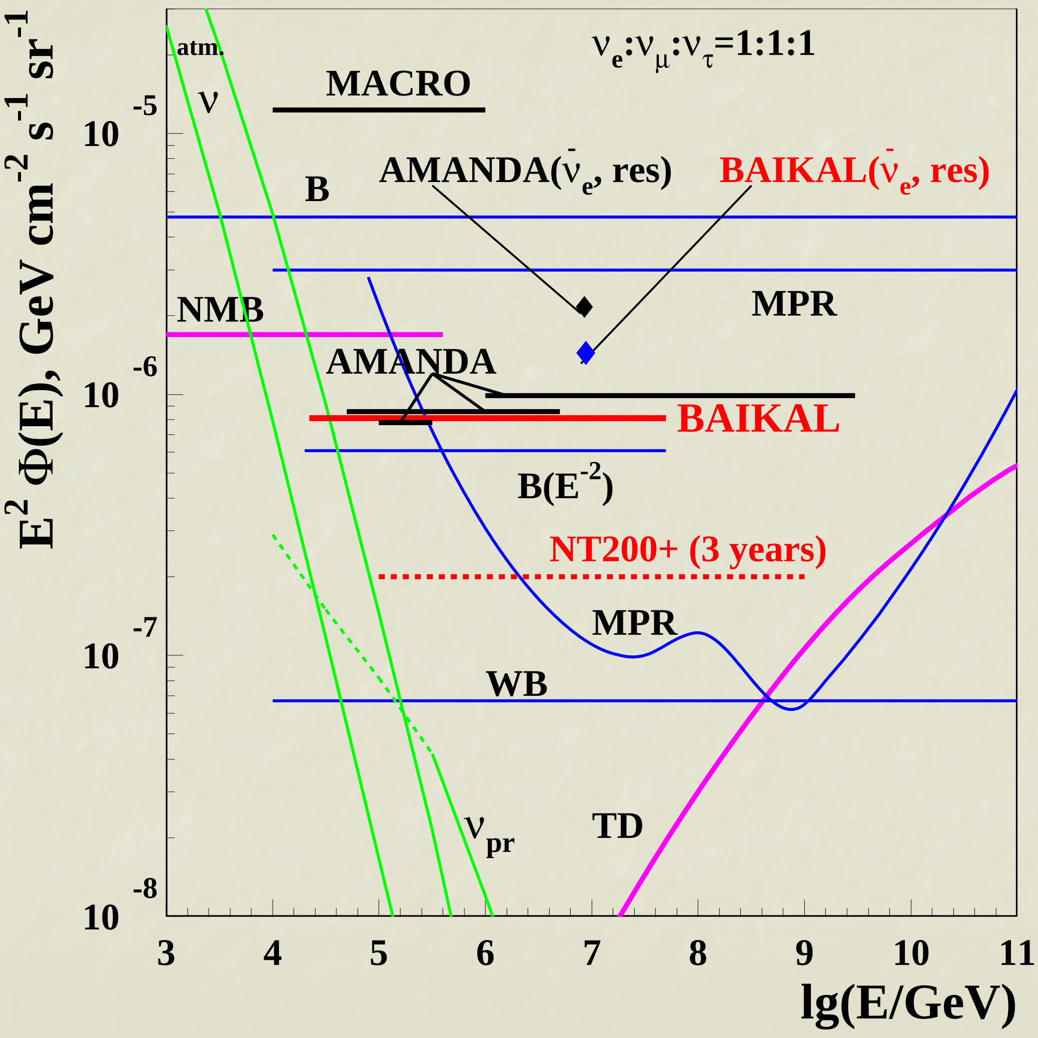
Lake Baikal
(and Mediterranean...)

Visibility: below local horizon
- white = 100% visibility
- black = „blind region“

South Pole (AMANDA)

= galactic center

Ограничения на диффузные потоки нейтрино



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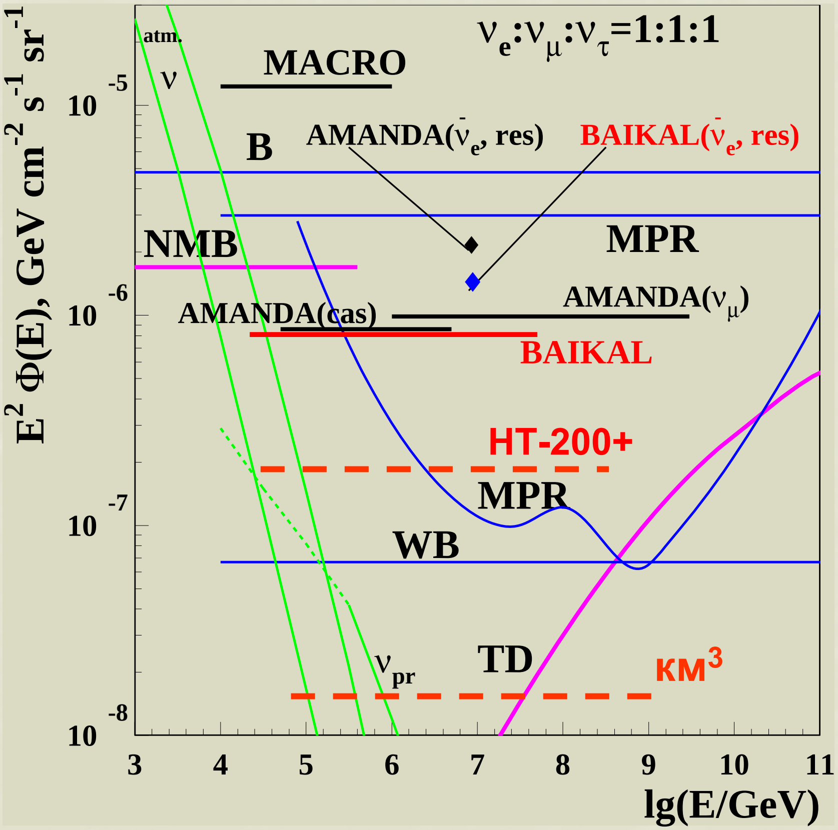

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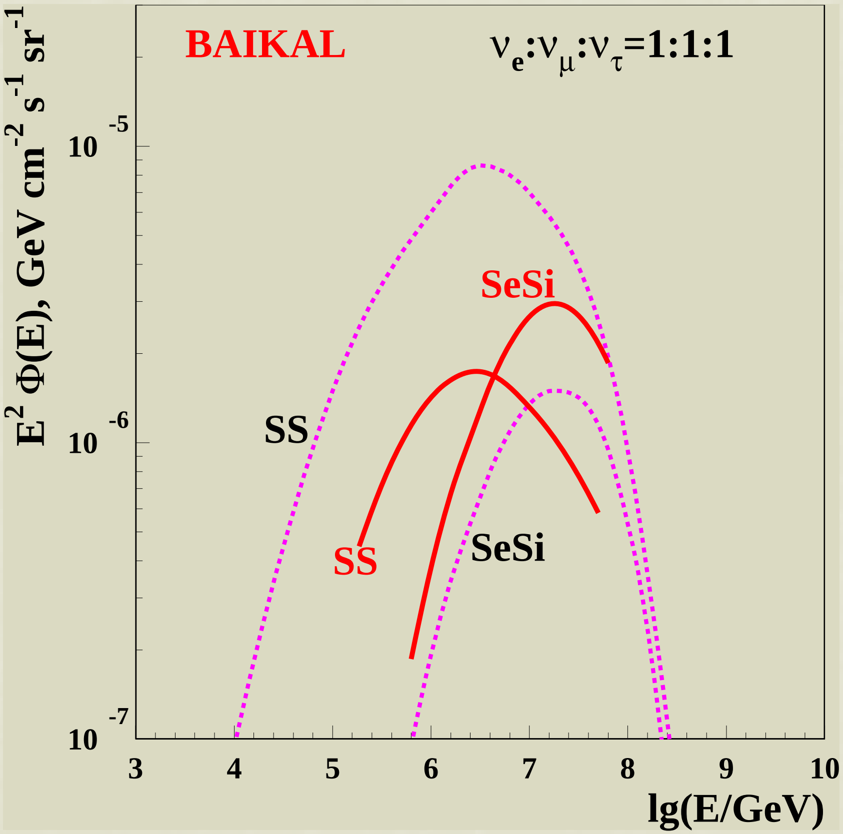


NT-200+ - intermediate stage to

Gigaton Volume Detector (km3 scale)

Energy spectrum of all flavor extraterrestrial HE-neutrinos:

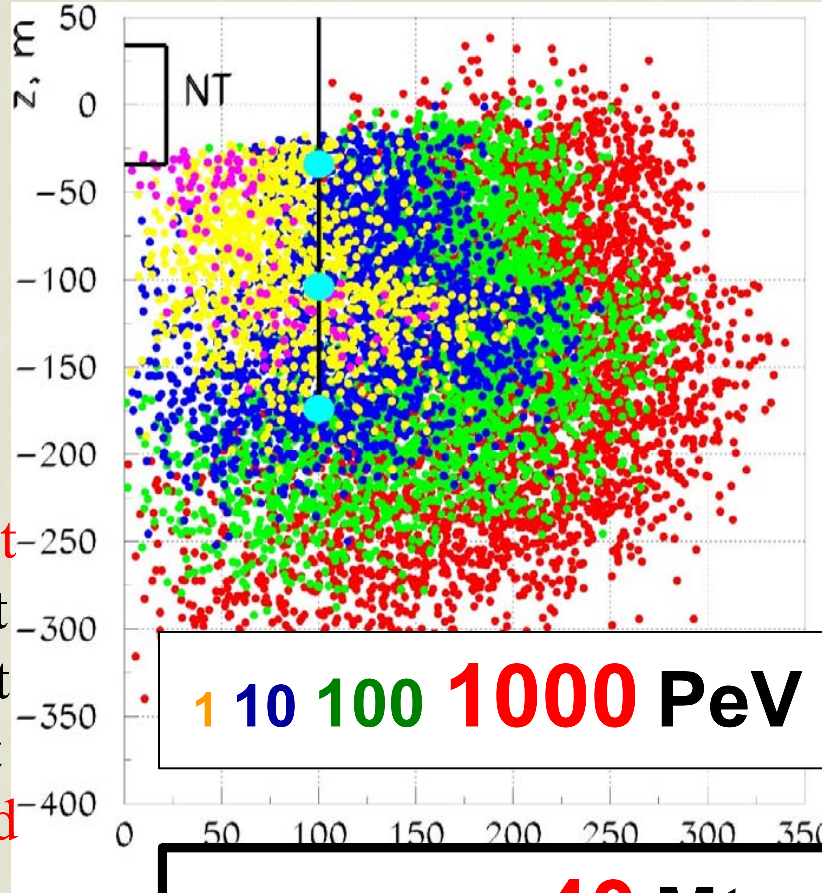
- enclosed volume 5 Mt, V(E) > 10 Mt

AMANDA II – 10 Mt

ANTARES - 10 Mt

NESTOR (7 towers) - 30 Mt

- high resolution of cascade vertex and energy → neutrino energy



4 15 23 40 Mton

CONCLUSIONS

>> Borexino just started the study of the various solar neutrino sources below 2 MeV, with a real time detection (pp,^{7}Be, pep, CNO)

>> The program includes also the study of the antineutrinos (from Sun, Earth, Reactors)

>> Borexino in also a useful observatory for the Supernova

>>A study of the neutrino magnetic moment with an artificial source is also considered