# Baikal GVD experiment

**R. Dvornicky**
**on behalf of the Baikal collaboration,**
**DLNP, JINR, Dubna & Comenius University, Bratislava,**
**AYSS annual conference, Alushta-2017**

# Collaboration: 9 institutions

1. Institute for Nuclear Research, Moscow, Russia.
2. Joint Institute for Nuclear Research, Dubna, Russia.
3. Irkutsk State University, Irkutsk, Russia.
4. Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia.
5. Nizhny Novgorod State Technical University, Russia.
6. St.Petersburg State Marine University, Russia.
7. Institute of Experimental and Applied Physics, Czech Technical University, Prague, Czech Republic.
8. Comenius University, Bratislava, Slovakia.
9. EvoLogics Gmbh., Berlin, Germany.

**Others approaching:**

- Krakow University, Poland
- University of Bucharest, Romania

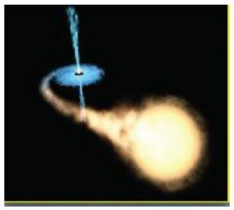
Outline:

- Introduction
- Site properties
- History
- Baikal – GVD
- Perspectives & conclusions

# • Cosmic Rays

✓ **Galactic: TeV – PeV – EeV?**

SNR



Microquasars

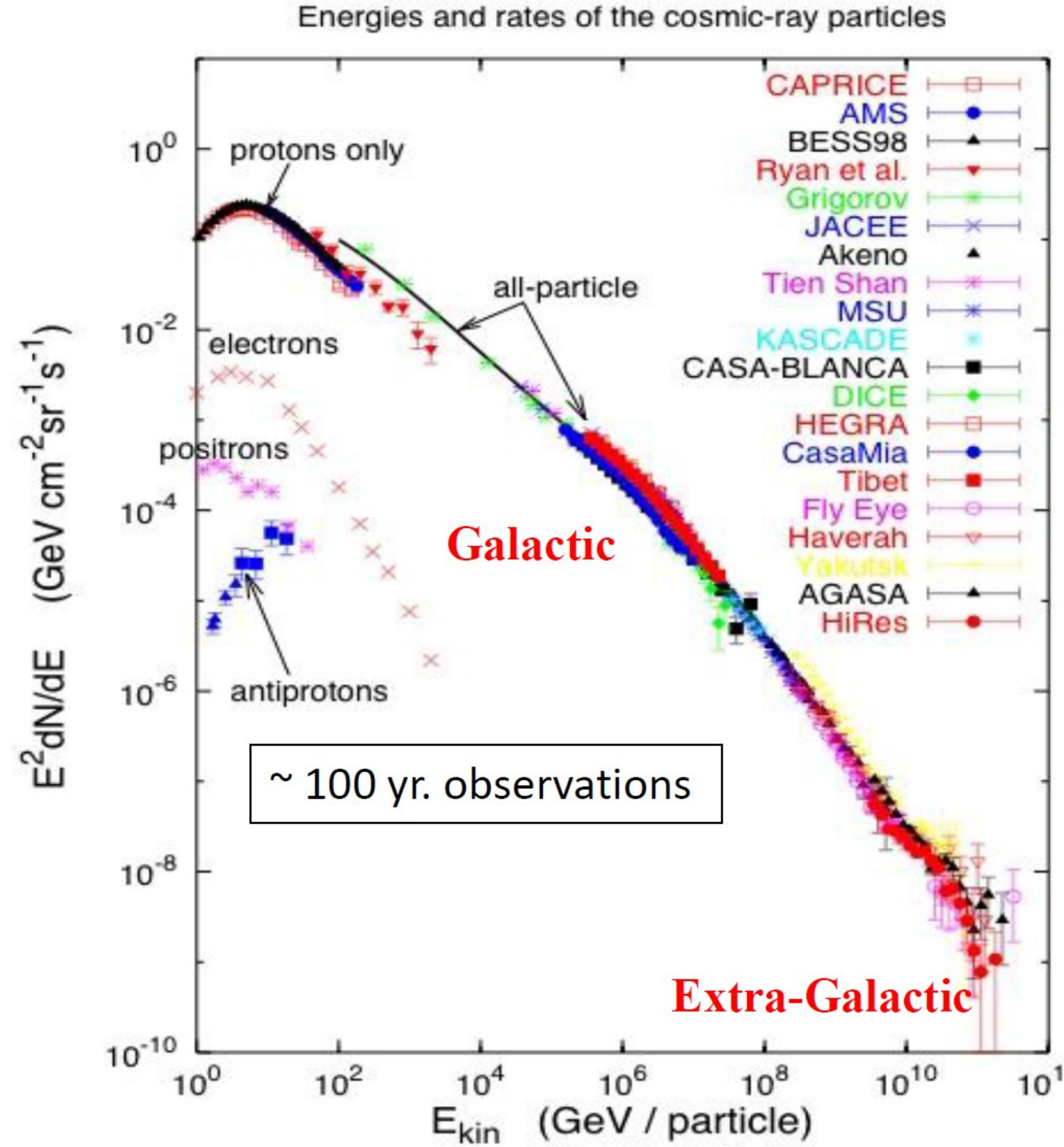
Pulsars

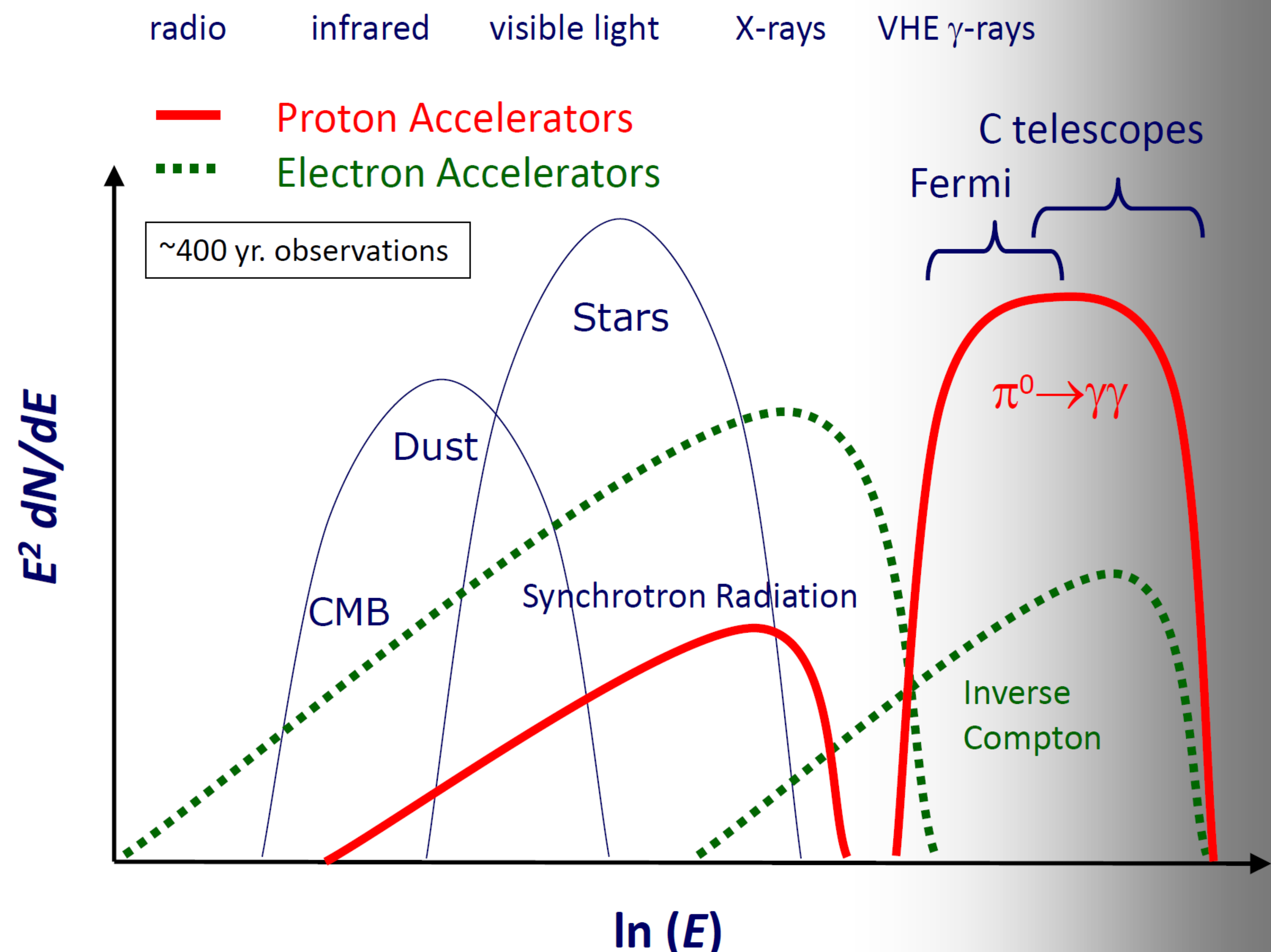
✓ **Extra-Galactic: PeV – EeV ->**

AGN

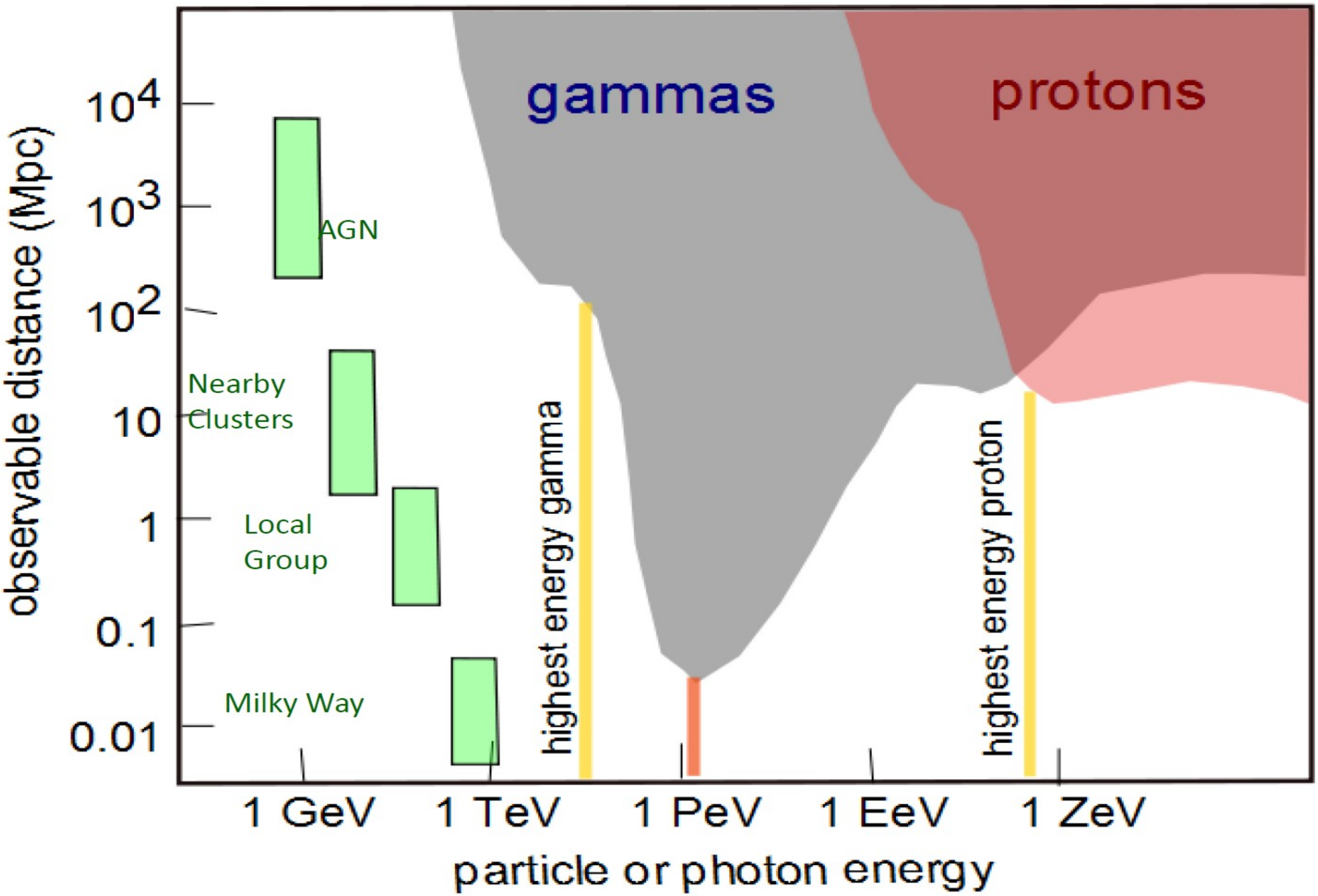
GRB

Energy spectrum !
Mass composition !
Sources location ?

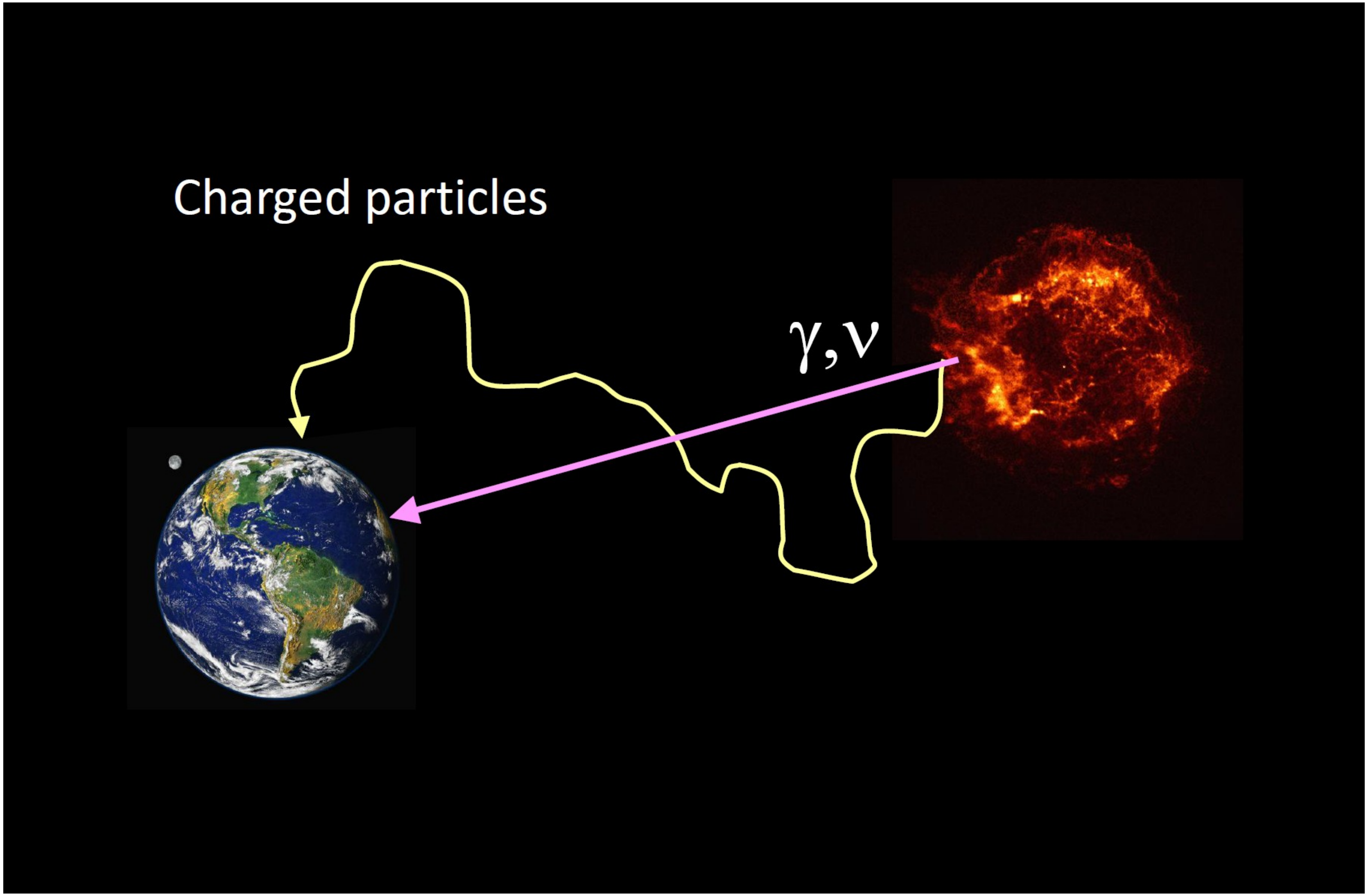



radio
infrared
visible light
X-rays
VHE γ-rays
Proton Accelerators
Electron Accelerators
C telescopes
Fermi
~400 yr. observations
Stars
Dust
$\pi^0 \rightarrow \gamma\gamma$
CMB
Synchrotron Radiation
Inverse Compton
$E^2\, dN/dE$
ln (*E*)

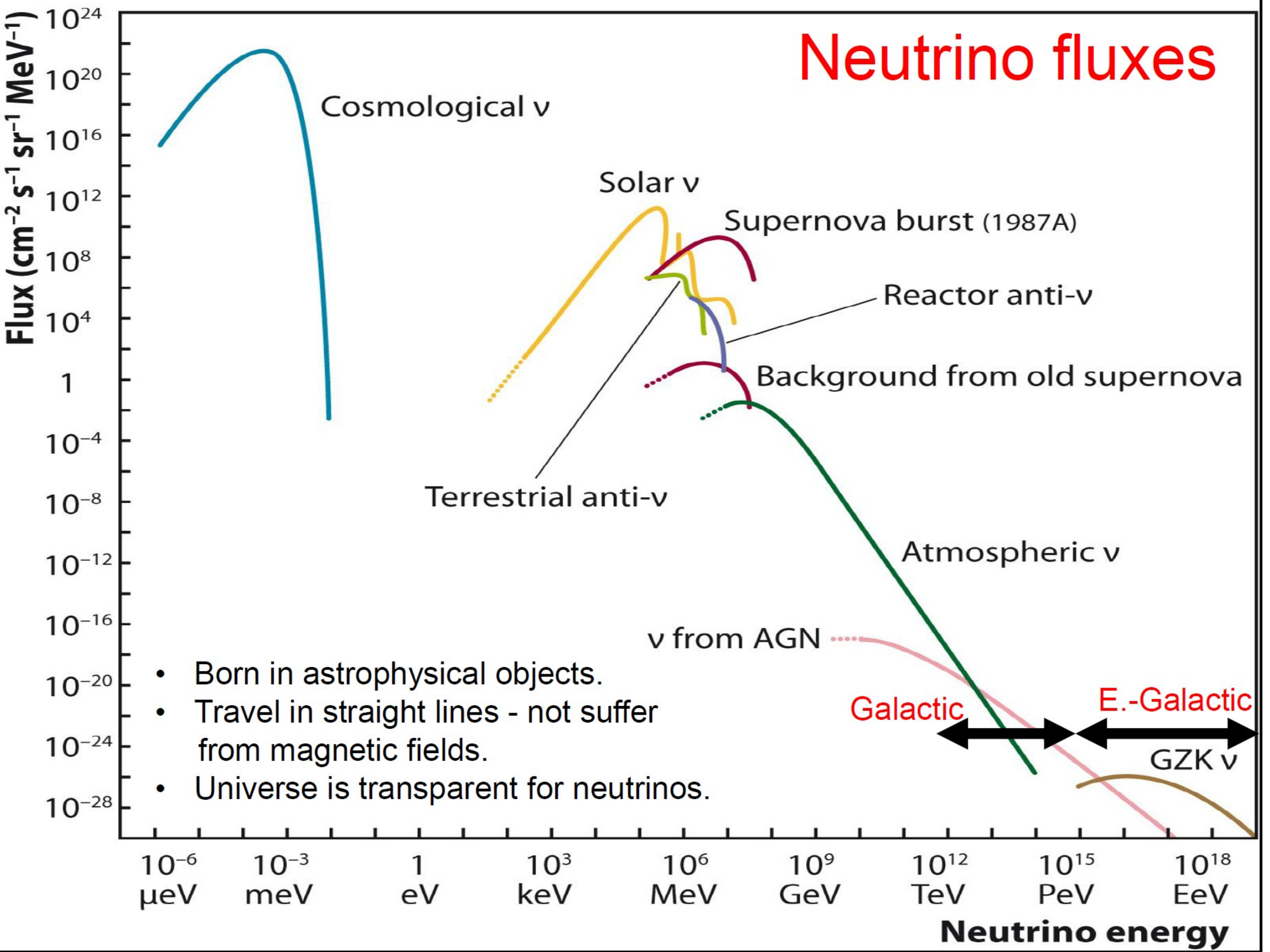
# The viewing range



# Charged cosmic rays vs. gamma rays vs. neutrinos



# Neutrino fluxes




- Born in astrophysical objects.
- Travel in straight lines - not suffer from magnetic fields.
- Universe is transparent for neutrinos.

M.Markov, **1960**:

„We propose to install detectors deep in a lake or in the sea and to determine the direction of charged particles with the help of Cherenkov radiation“ Proc. 1960 ICHEP, Rochester, p. 578.

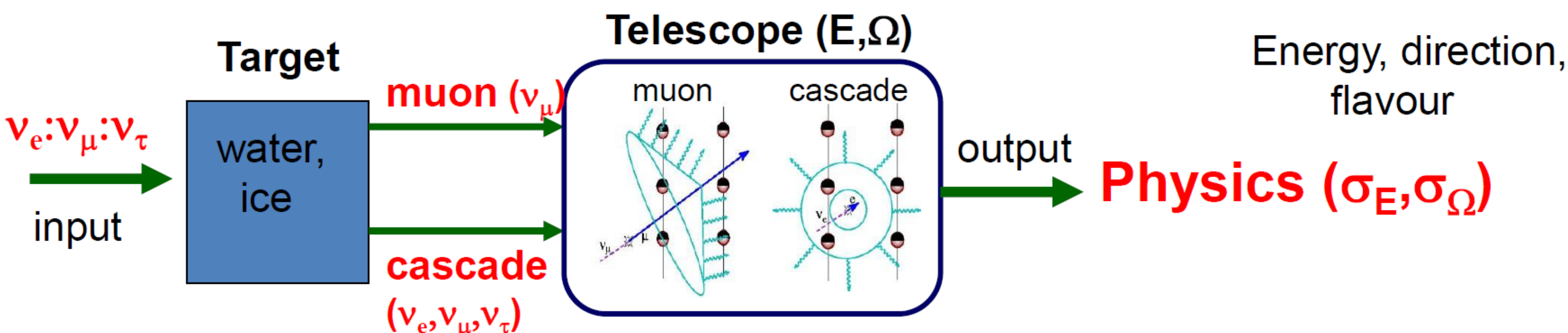
# Detection Principle – M. Markov 1960

**Flux**
From local sources, diffuse flux

**Detection modes**
muons, cascades

**Environment properties**
absorption, scattering, light background – $K^{40}$, bioluminescence

**Background**
downward going atm. muons, atm. neutrinos




Arrival times & amplitudes,
PMTs arrangement and orientation

# • Astrophysical Neutrino Fluxes

- Born in astrophysical objects → p + target → $\pi^+$ + .....
  (p, γ) → $\mu^+ + \nu_\mu$
  → $e^+ + \nu_e + \nu_\mu$

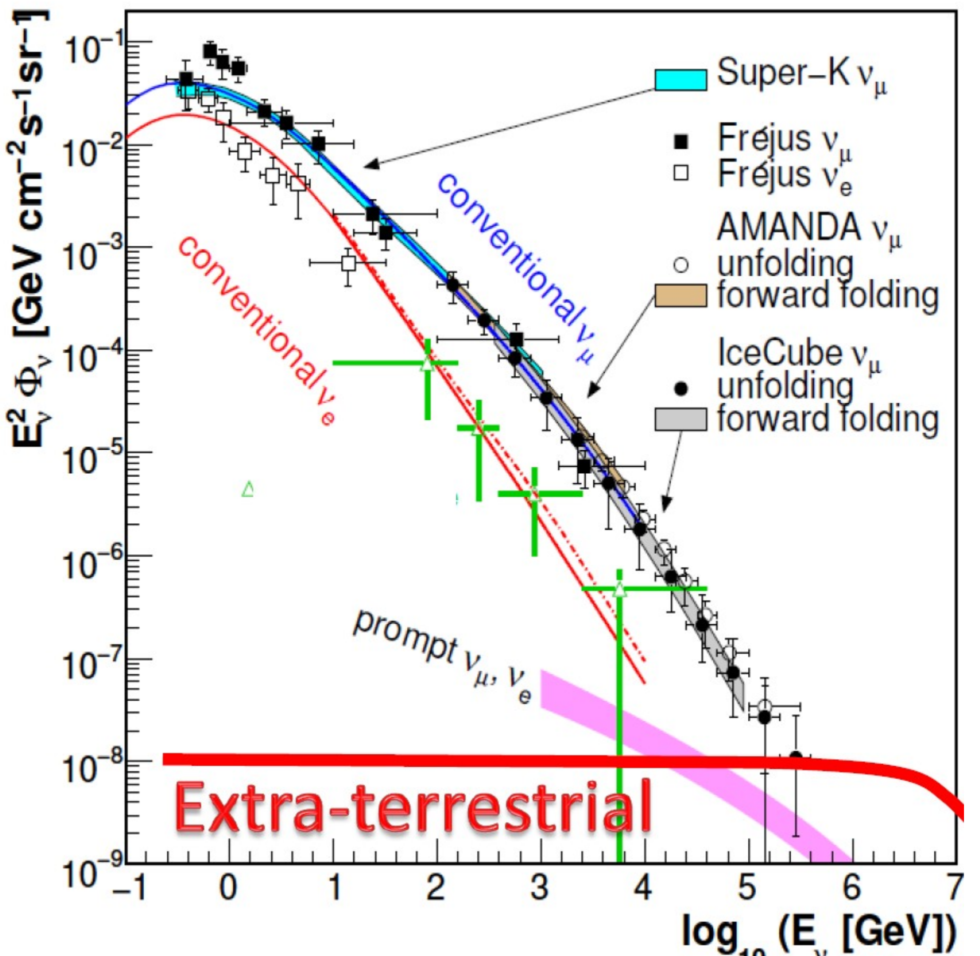
✓ **Generic spectrum:** ~$E^{-2}$

✓ **Direction:**
- from local objects
- diffuse (quasi)isotropic flux

✓ **Flavour content:**

1:2:0 in source

1:1:1 at Earth

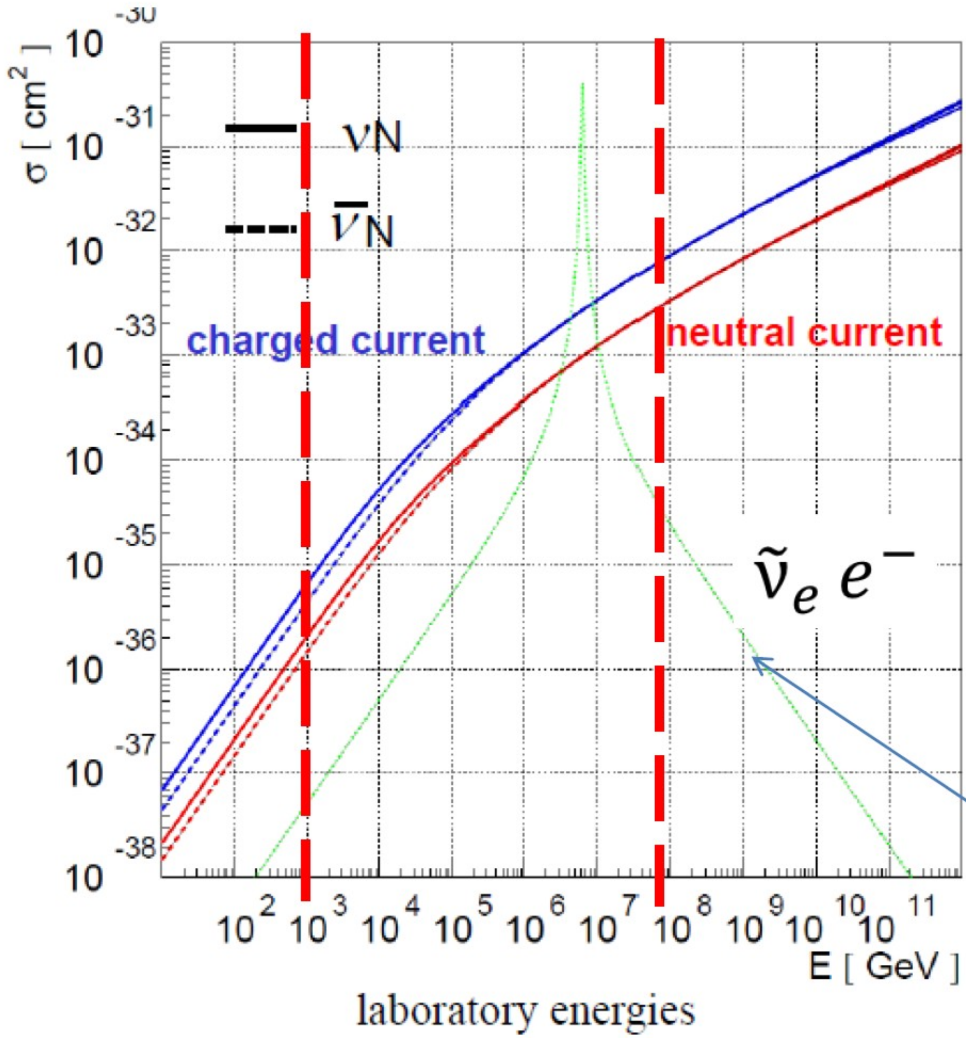


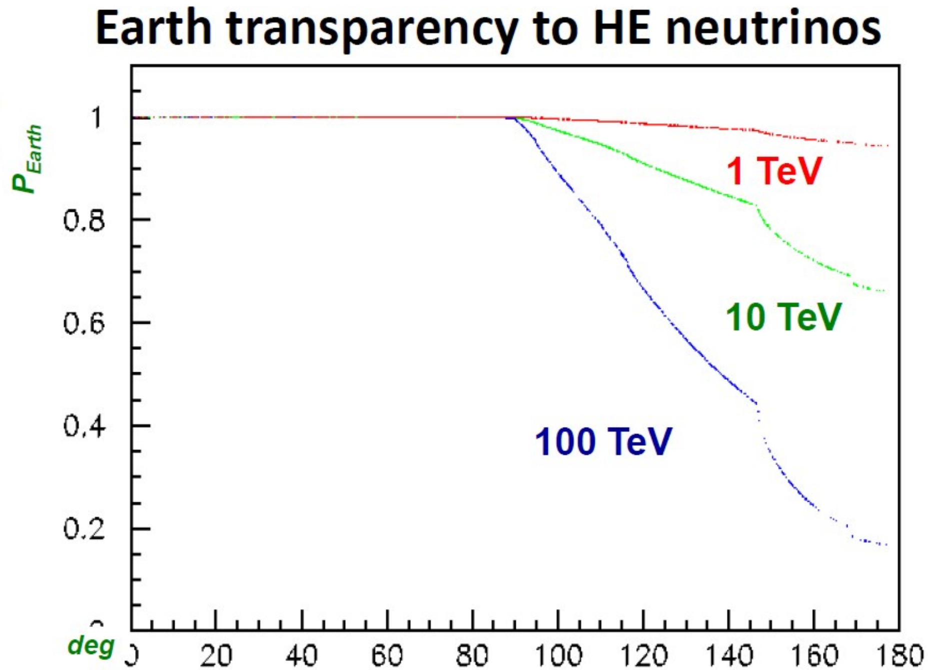

**IC: $E^2F \sim 1\cdot10^{-8}$ GeV cm$^{-2}$ c$^{-1}$ sr$^{-1}$**

**isotropic**
**1:1:1** } not contradict

**Detection threshold ~ 60 TeV**

# • Neutrino cross sections




"Glashow resonance"
neutrino energy: $6.3\cdot10^{15}$ eV,
resonance width: ±130 TeV,
peak cross section: $5\cdot10^{-31}$ cm $^{2}$

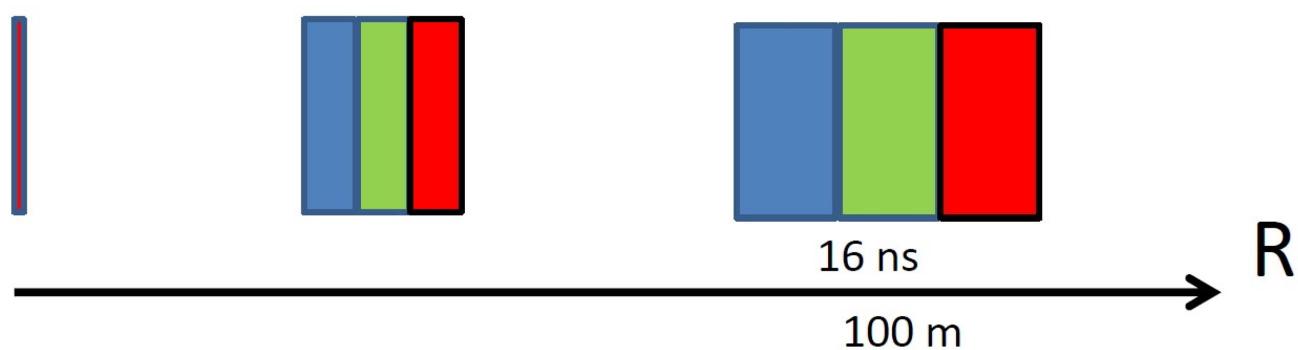
# • Cherenkov radiation

- ➢ Intensity: $$\frac{dN_c}{d\lambda} = 2\pi\alpha\left(1 - \frac{1}{\beta^2 n^2}\right)\frac{1}{\lambda^2},$$
  $N_c = 230\ \gamma/cm$ (350 – 600 nm, water)

- ➢ Cherenkov angle: $\cos\theta_c = 1/(\beta n)$, $\theta_c = 42^\circ\ water$

- ➢ Light velocity: $v_c = \frac{c}{n_g(\lambda)}$, $n_g(\lambda) = n(\lambda) - \lambda\frac{dn}{d\lambda}$
  $n(470nm) = 1.33 \rightarrow n_g(470nm) = 1.37$

Light velocity dispersion leads to time dispersion of signal

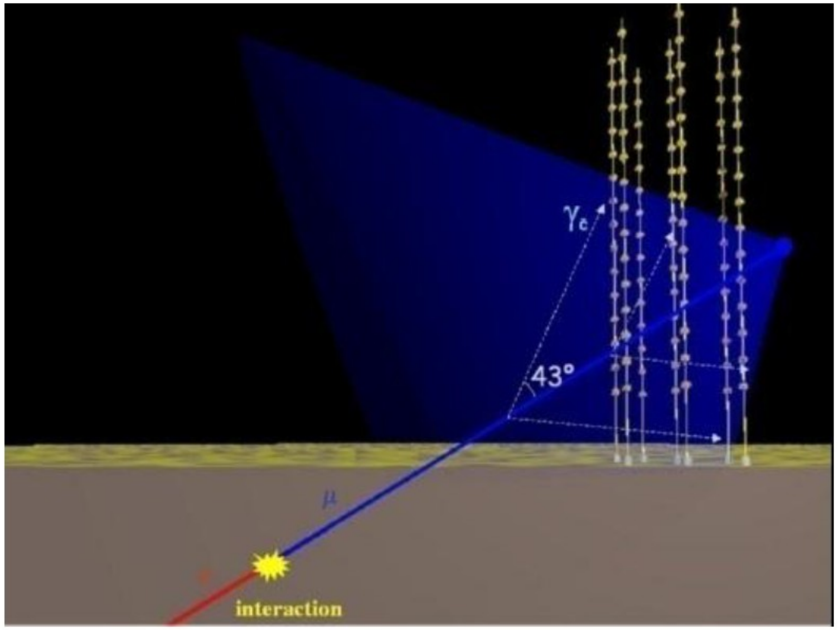


- **Detection Modes – cascads&muons**

$$\nu_l + N \xrightarrow{CC} \begin{cases} e^- + X \rightarrow cascades \\ \tau^- + X \rightarrow cascades \\ \mu^- + X \rightarrow track + cascade \end{cases}$$

$$\nu_l + N \xrightarrow{NC} \nu_l + cascade$$

μ/casc. ~ 1/3 for 1:1:1

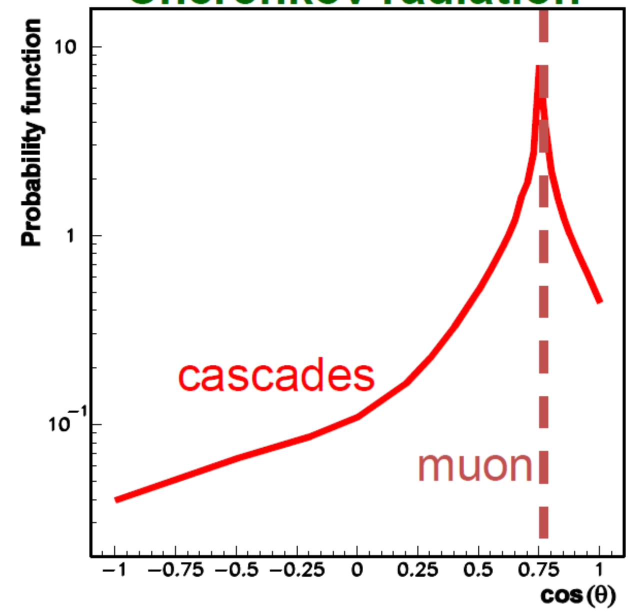


# • Cascades Detection Mode

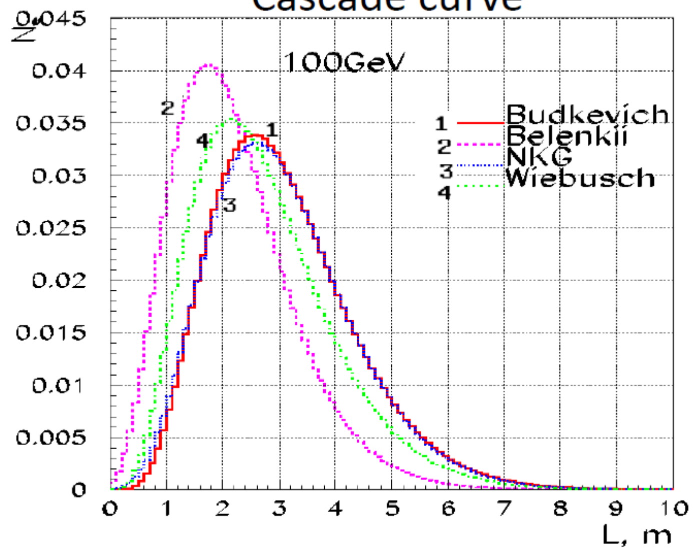
✓Cascades from $\nu_{e,\tau}$ & $\nu_\mu$(NC):

- Point-like, strongly anisotropic light-source
  - cascade size proportional to ~ln$E_\nu$ (but LPM-effect for >20PeV!)
- Light intensity proportional to neutrino energy ~ $E_\nu \cdot 10^8$ γ/TeV
- Detection efficiency strongly depend on environment properties (water/ice).
- Angular resolution ~3°- 15°
- High energy resolution ~10-20%

Cherenkov radiation




Cascade curve



# • Muon Detection Mode

## Muon energy loss

$$-\frac{dE}{dx} = a + bE$$

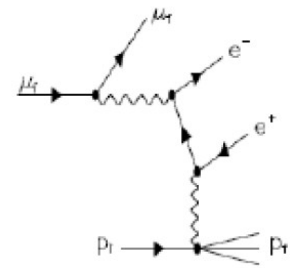
$$a = 0.002\left[\frac{GeV\,cm^2}{g}\right]$$

→ ionization

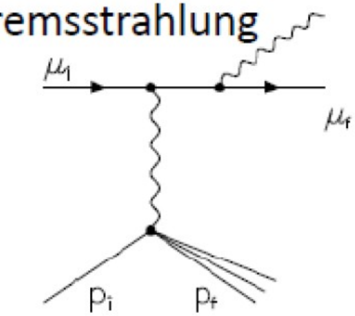
$$b = 3\cdot 10^{-6}\left[\frac{cm^2}{g}\right]$$

$$R_\mu = \frac{1}{b}\ln\left[1+\frac{b}{a}E\right]$$

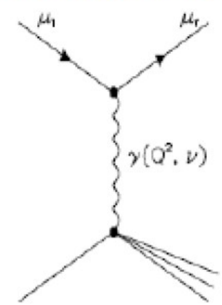
Pair creation

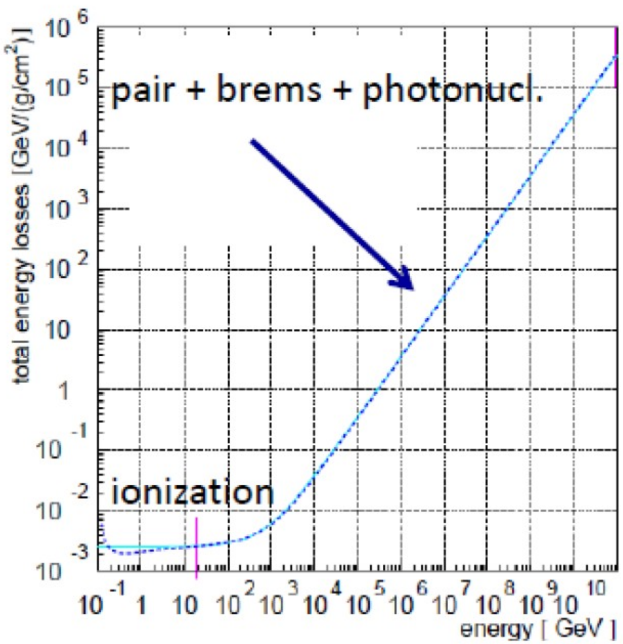



bremsstrahlung



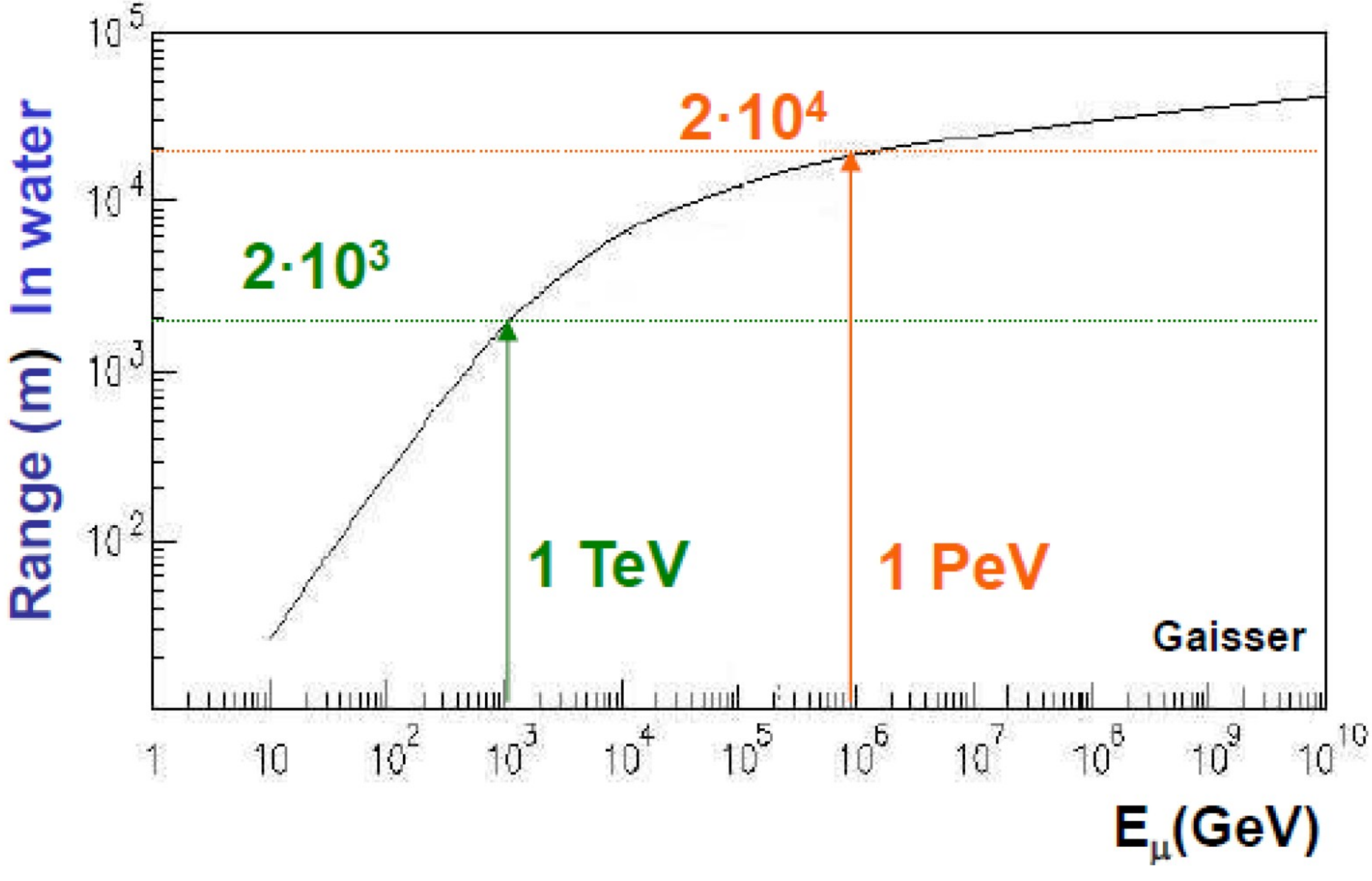

photonuclear reaction



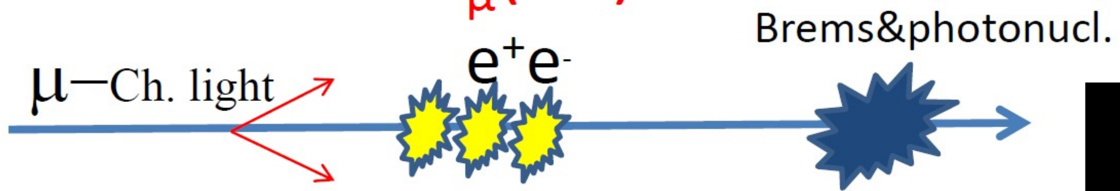

Pair creation: often, with small dE
Bremsstrahlung: rare, with larger dE
Photonuclear: very rare, very large dE

# Muon energy loss and range in water

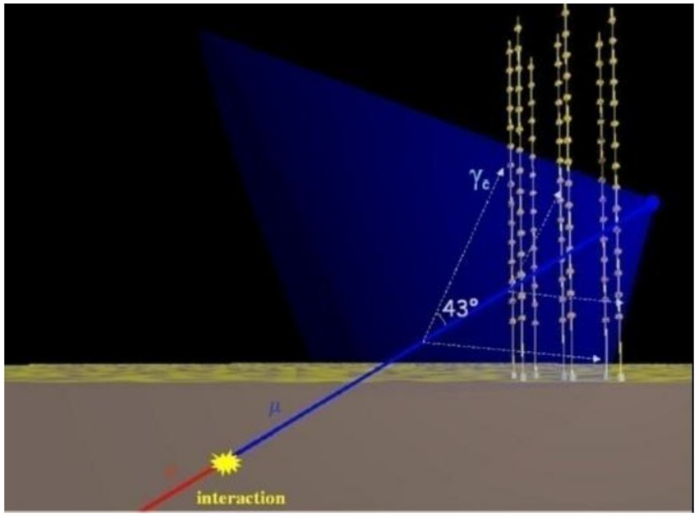


# • Muon Detection Mode

✓Muons from $\nu_\mu$(CC):




$$N_{ch} = n_\mu(1 + 0.6E(TeV))$$



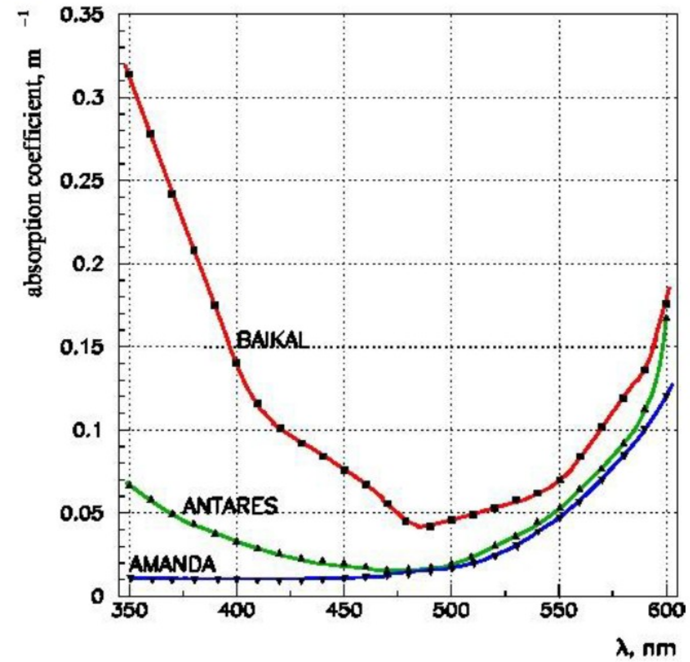

- High angular resolution ~0.1°- 1°
  (depends on visible track length)
- Enlarged effective volume
  (water/ice & bedrock for up-going $\nu_\mu$)
- Emits strongly in the Cherenkov angle

# • Environment properties

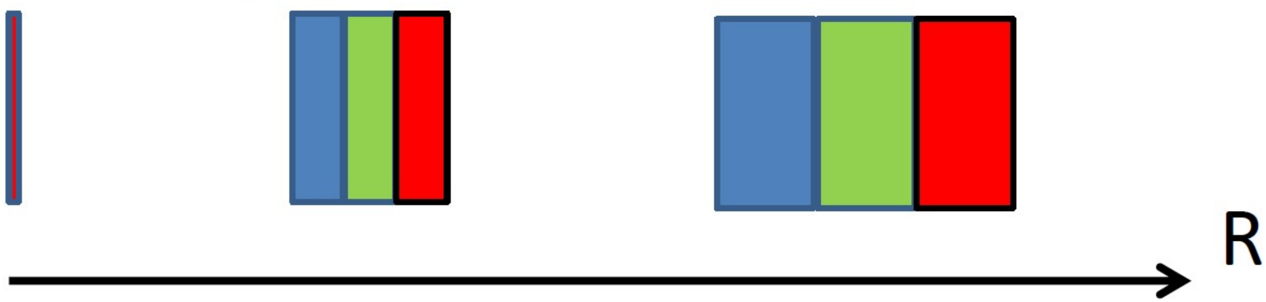
➢ Light absorption:

$L_{abs}$ ~ 20 – 100 m

$$N \sim \frac{exp\left(-\frac{r}{L_{abs}}\right)}{r^2}$$




- Density of light-sensor arrangement
- Keeps angular distribution of light flux
- Keeps time distribution of light flux, but filtering for case with deep minimum



# • Environment properties

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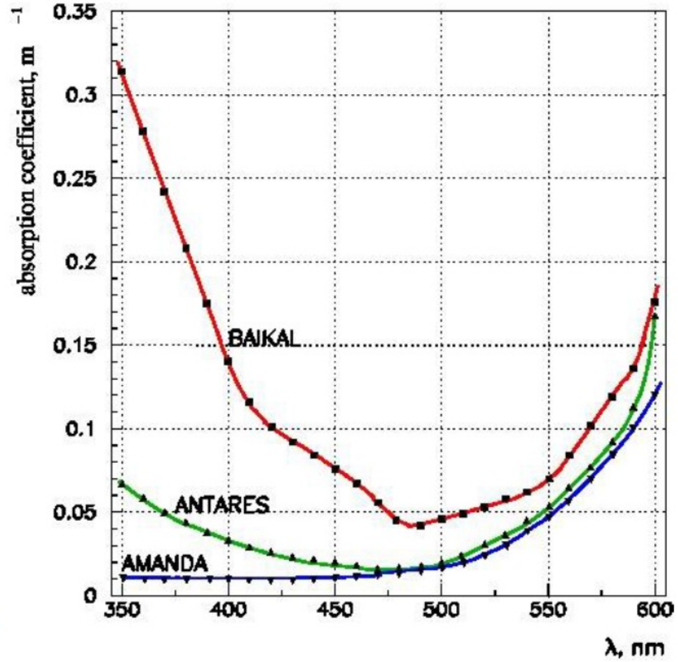



- Density of light-sensor arrangement
- Keeps angular distribution of light flux
- Keeps time distribution of light flux, but filtering for case with deep minimum

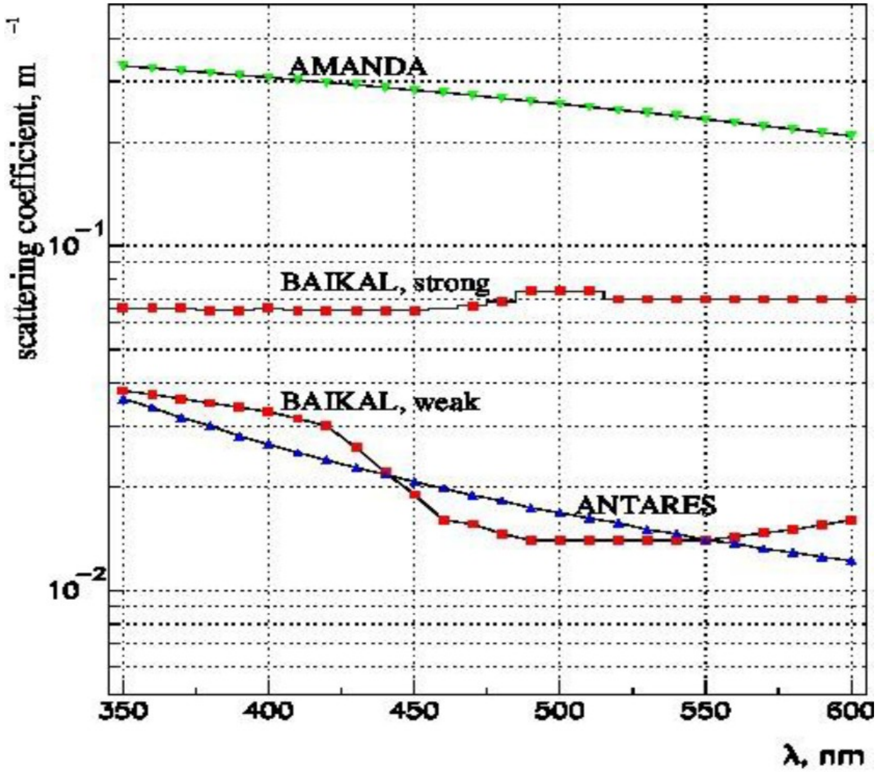
# • Environment properties

➢ Light scattering:

$L_s \sim 1 - 70$ m

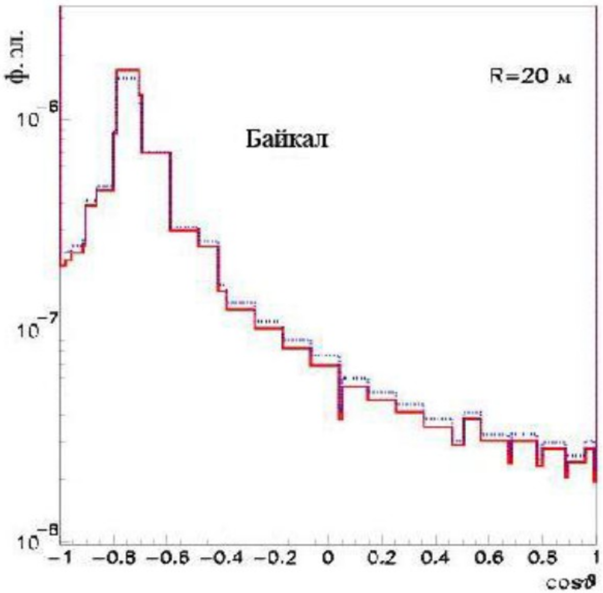
$$L_{ef} = \frac{L_s}{(1-\overline{\cos\theta})}, \quad L_{as} = \sqrt{\frac{L_a L_{ef}}{3}}$$

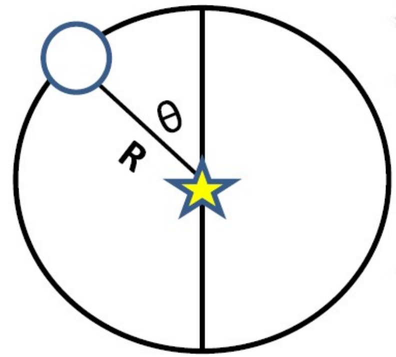
$$N \sim \frac{exp\left(-\frac{r}{L_{as}}\right)}{r}$$

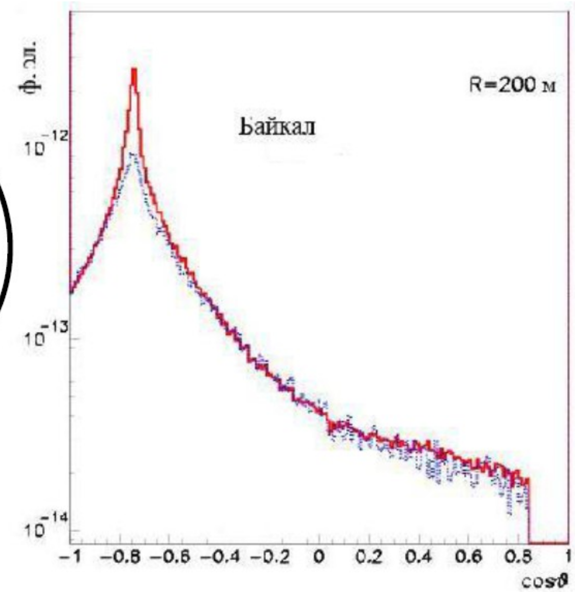



- Additional effective absorption
- Distortion of light arrival time distribution
- Distortion of angular distribution

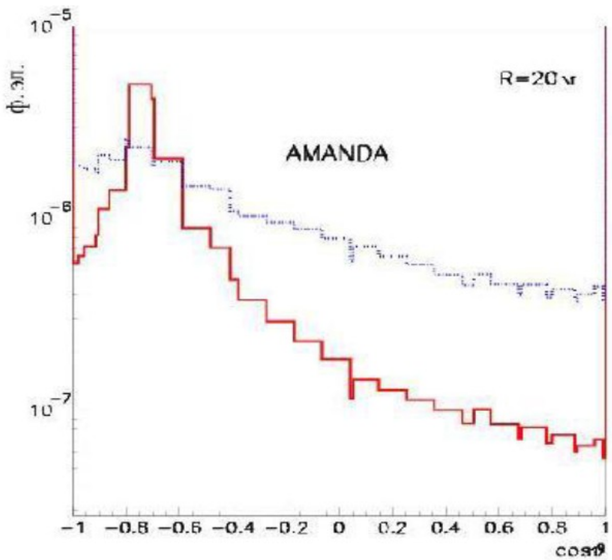
# Water (Baikal): Light Scattering - 30 – 50 m

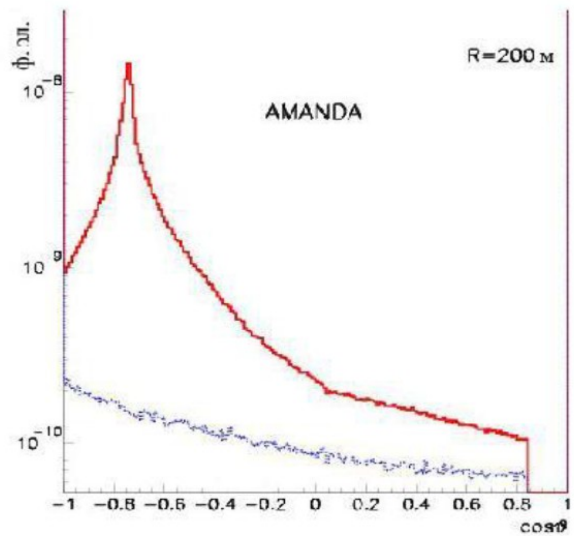



# Antarctic Ice: Light Scattering - 1 – 4 m



- **Environment properties**

  - Background:

    IceCube: ~500 Hz

    Baikal: 20 – 40 kHz

    KM3NeT: 50 – 100 kHz (1000 kHz)

  - Decrease an event selection efficiency

# • Background

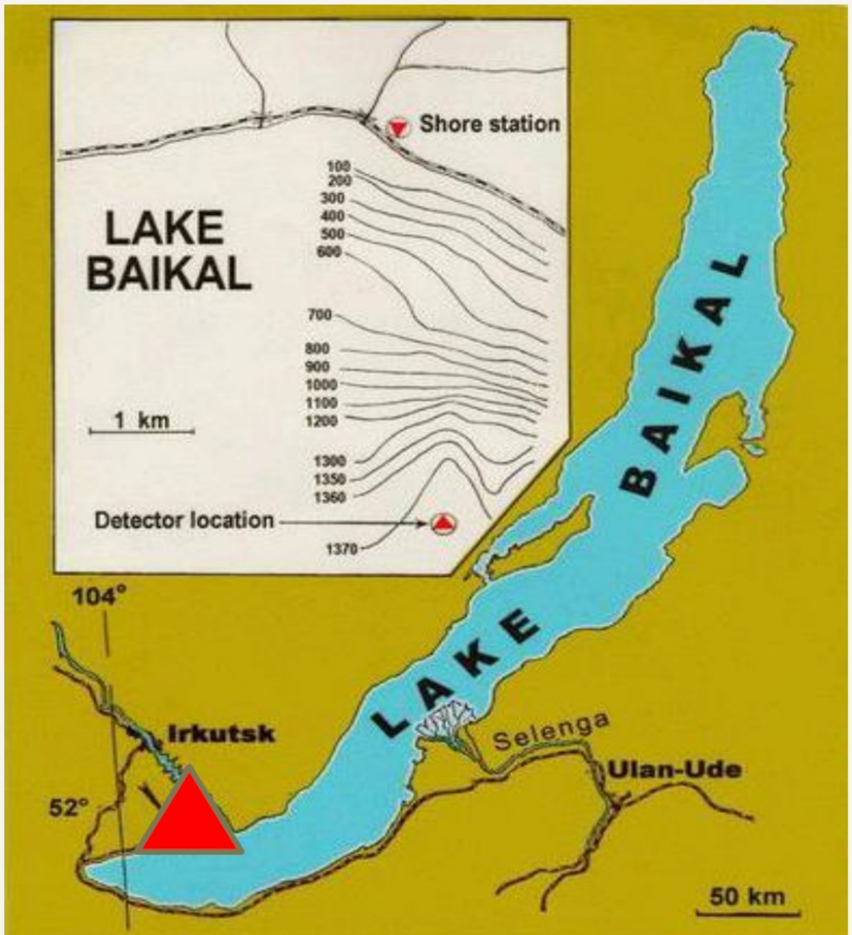
- ✓ Through-going muons
  - Atm. muons ($\sim E_\mu^{-3.7}$) reduces aperture to $2\pi$ for E<PeV
  - Atm. muon neutrinos ($\sim E_\nu^{-3.7}$)
- ✓ Cascades
  - Cascades from atm. muons
  - Atm. electron neutrinos ($\nu_e/\nu_\mu \sim 1/20$)

Search strategy – looking for upward going muons

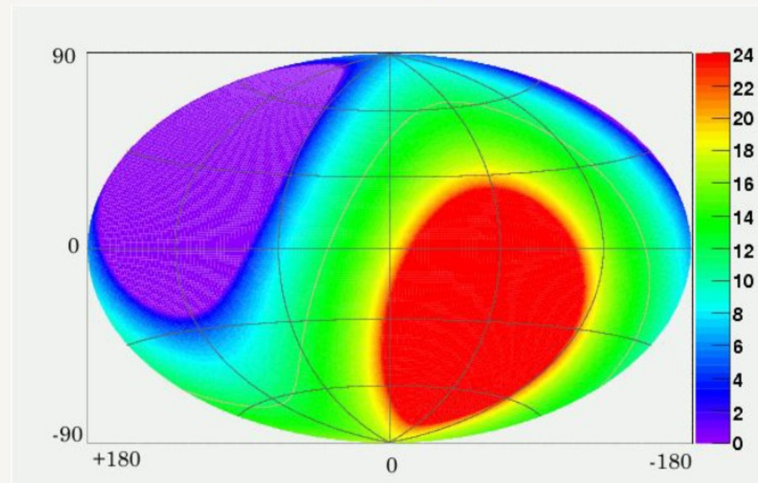
# Site properties

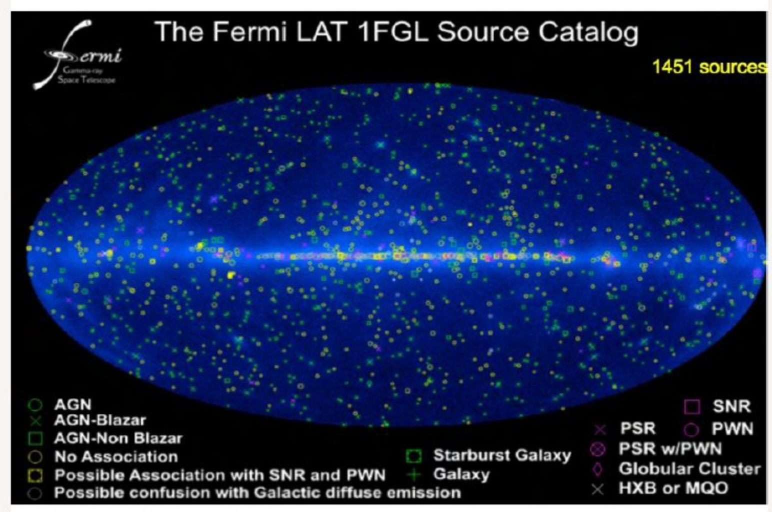
# • Location: 104°25′ E; 51°46′ N

**Northern hemisphere– GC (~18h/day) and Galactic plane survey**




The GVD sky view



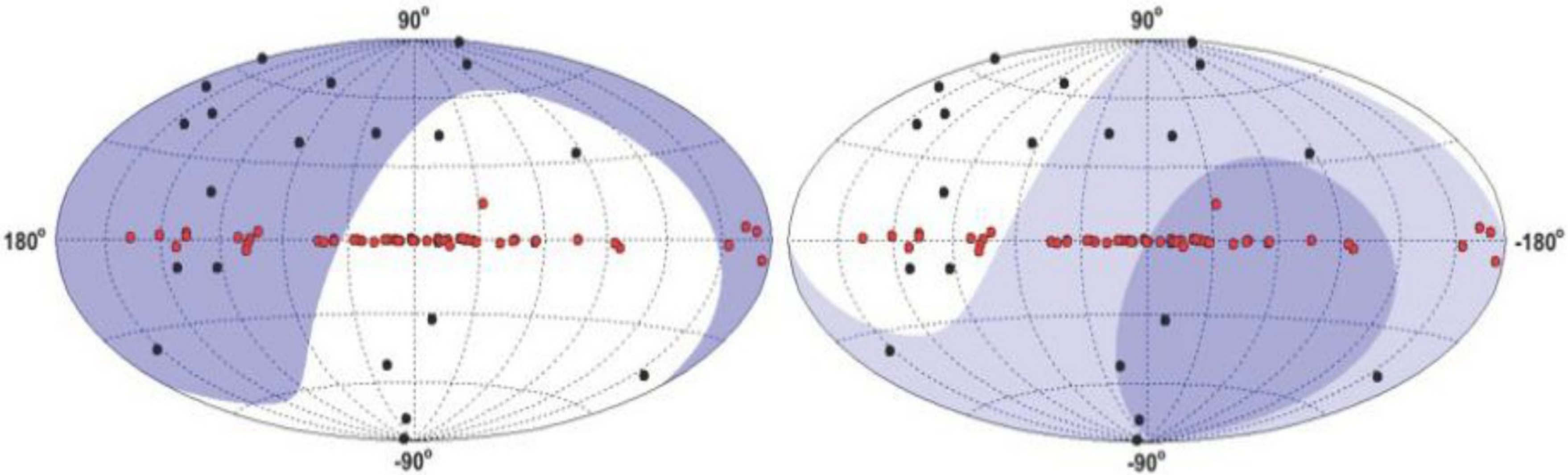
# Sky coverage

Visibility South Pole (IceCube)

- 100%
- 0%

Lake Baikal

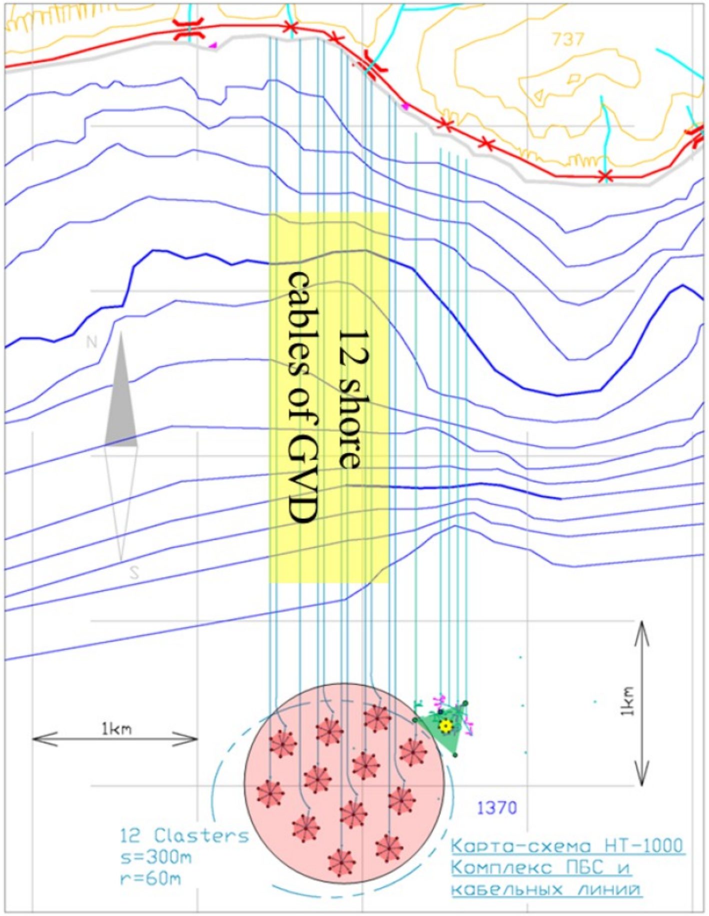
- > 75%
- 25% – 75%
- < 25%

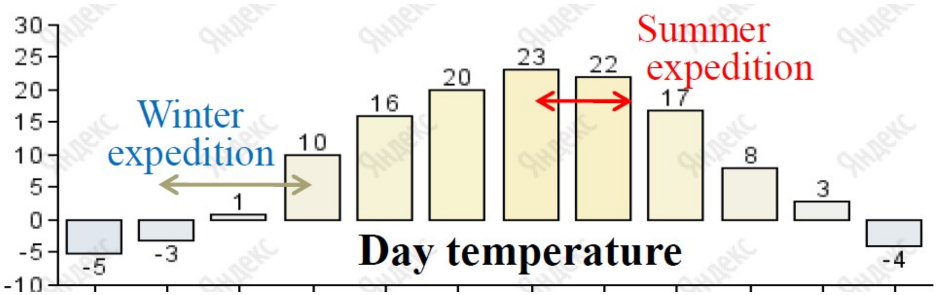


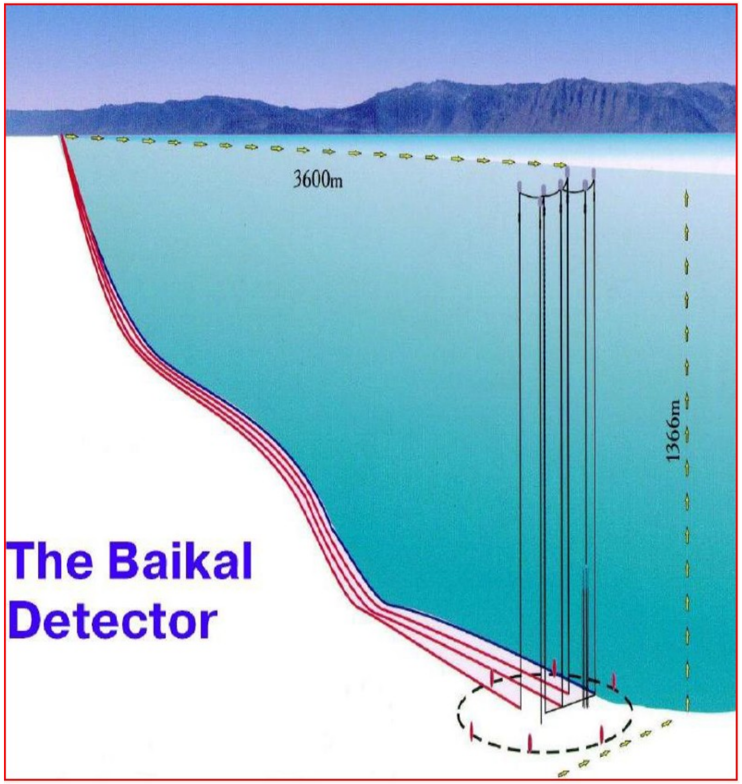

TeV gamma-ray sources

- Galactic
- extragalactic

- **Site properties**

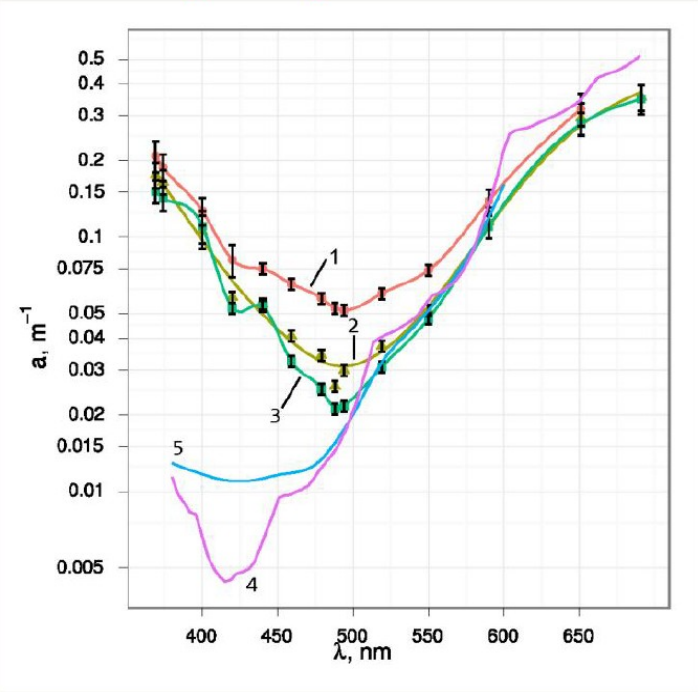


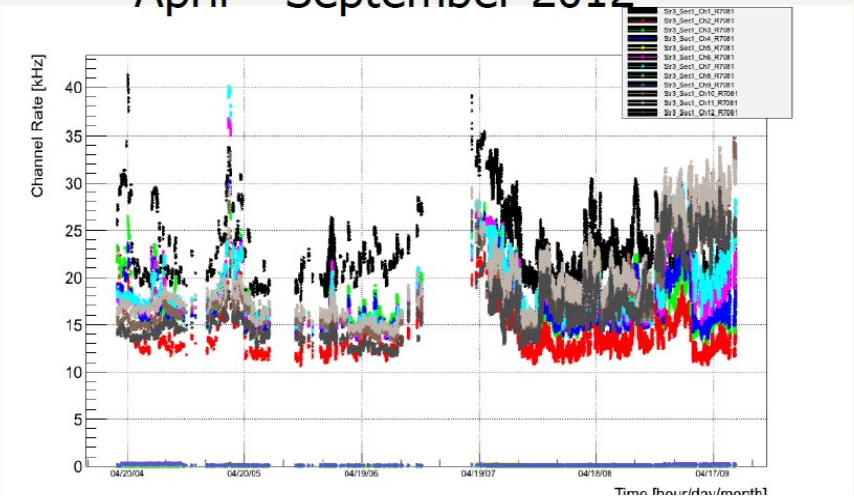

**Depth – 1360 m; Flat the lake bed at >3 km from the shore – allows > 250 km3 Instrumented Water Volume!**

# Water properties

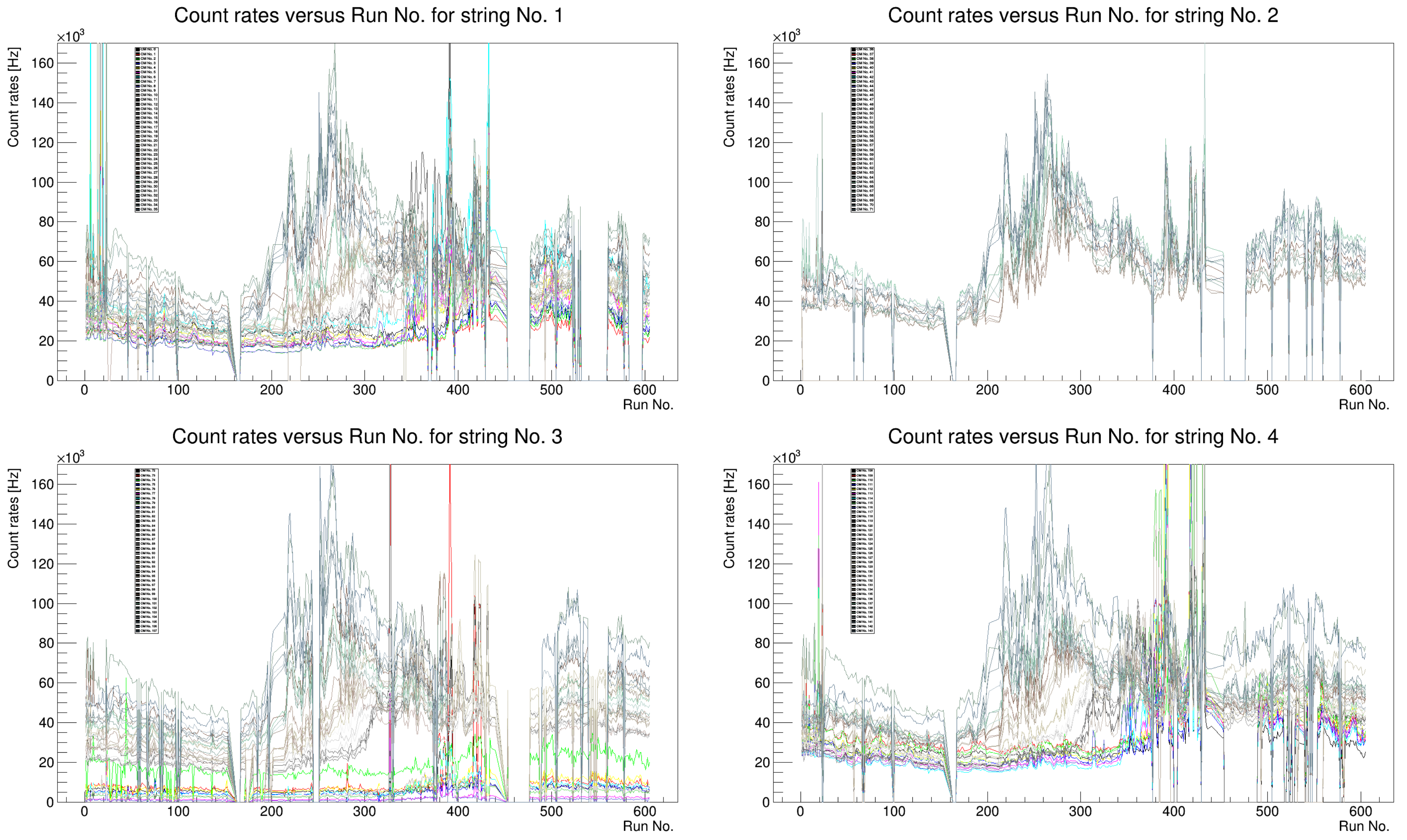



- **Absorption length: ~ 22-24 m**
- **Scattering length: $L_s$ ~ 30-50 m**
  **$L_{eff} = L_s /(1- <\cos\theta>)$ ~ 300-500 m**
- **Strongly anisotropic phase function: $<\cos\theta>$ ~ 0.9**

PMTs Counting rates
April – September 2012




- **Moderately low background in fresh water: 15 – 40 kHz (R7081HQE)**
  absence of high luminosity bursts from biology and $K^{40}$ background.

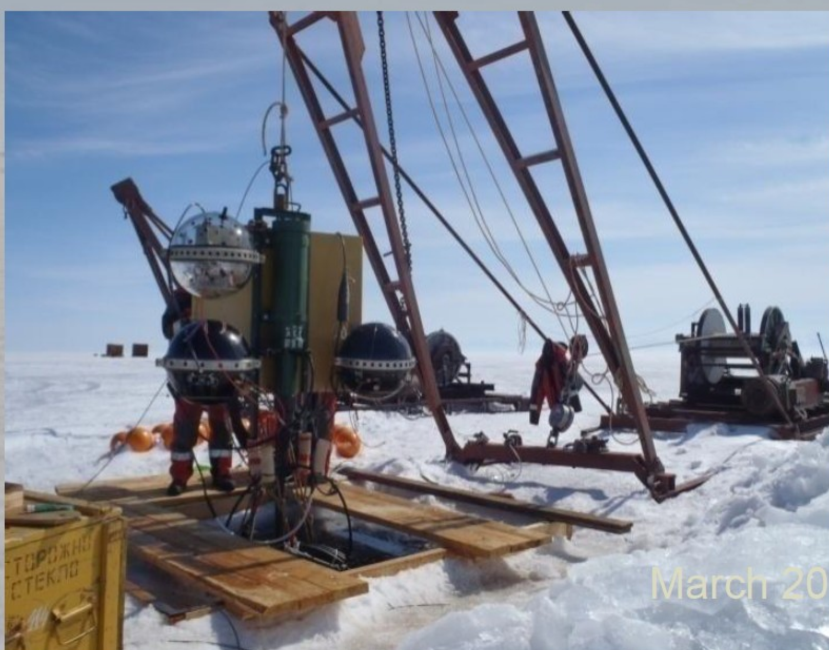



# Counting rates for the year 2016

## • Strong ice cover during ~2 months:

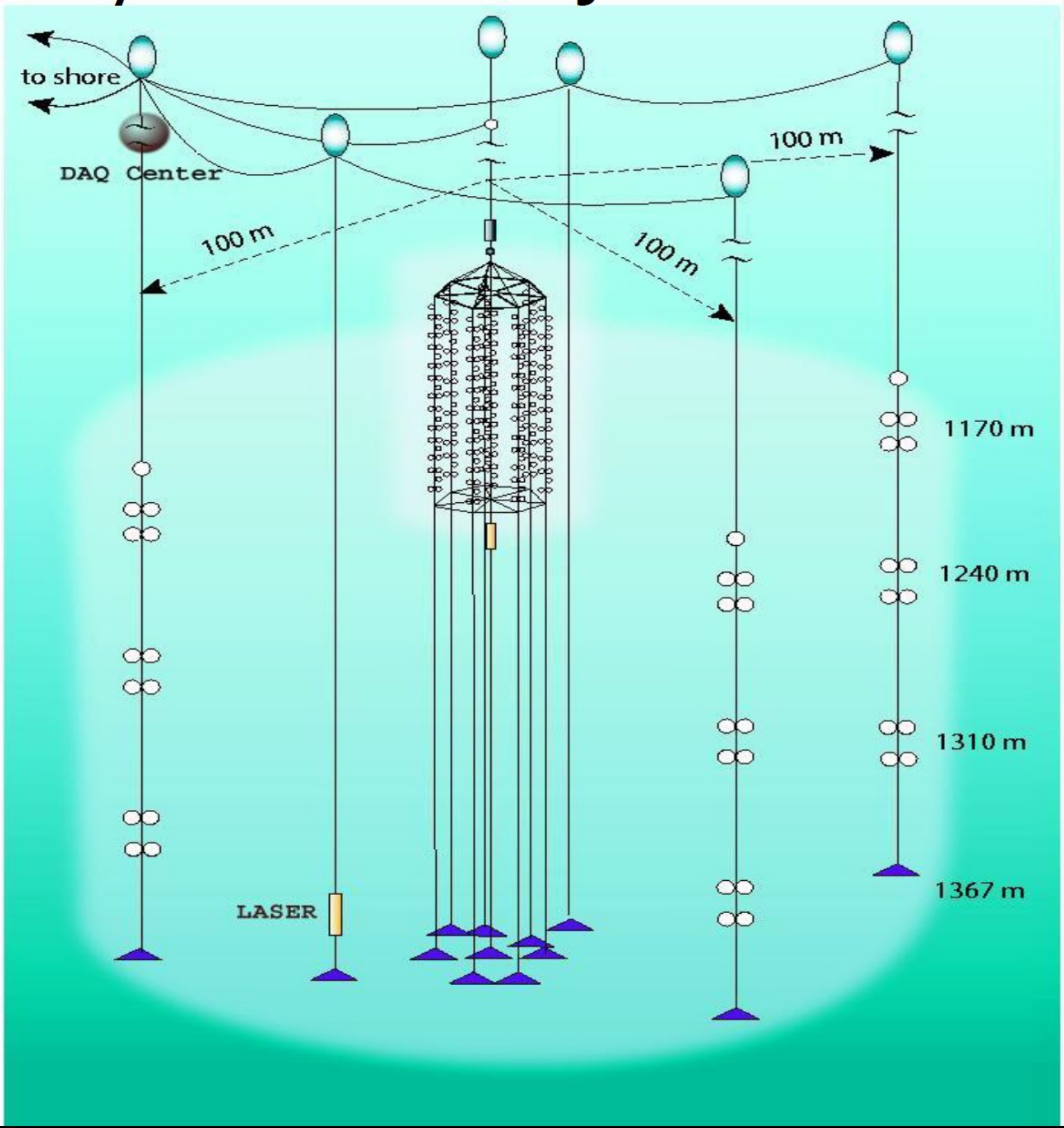
- Telescope deployment, maintenance, upgrade and rearrangement
- Installation & test of a new equipment
- All connections are done on dry
- Fast shore cable installation (3-4 days)
- Simultaneous deployment of strings

*Dry mating*



# All connections on dry without bed junction boxes

Underwater DAQ Center
at shallow depth ~30 m



# Distance is shorter during the winter period


• Infrastructure
Living quarters
Shore station
Lab

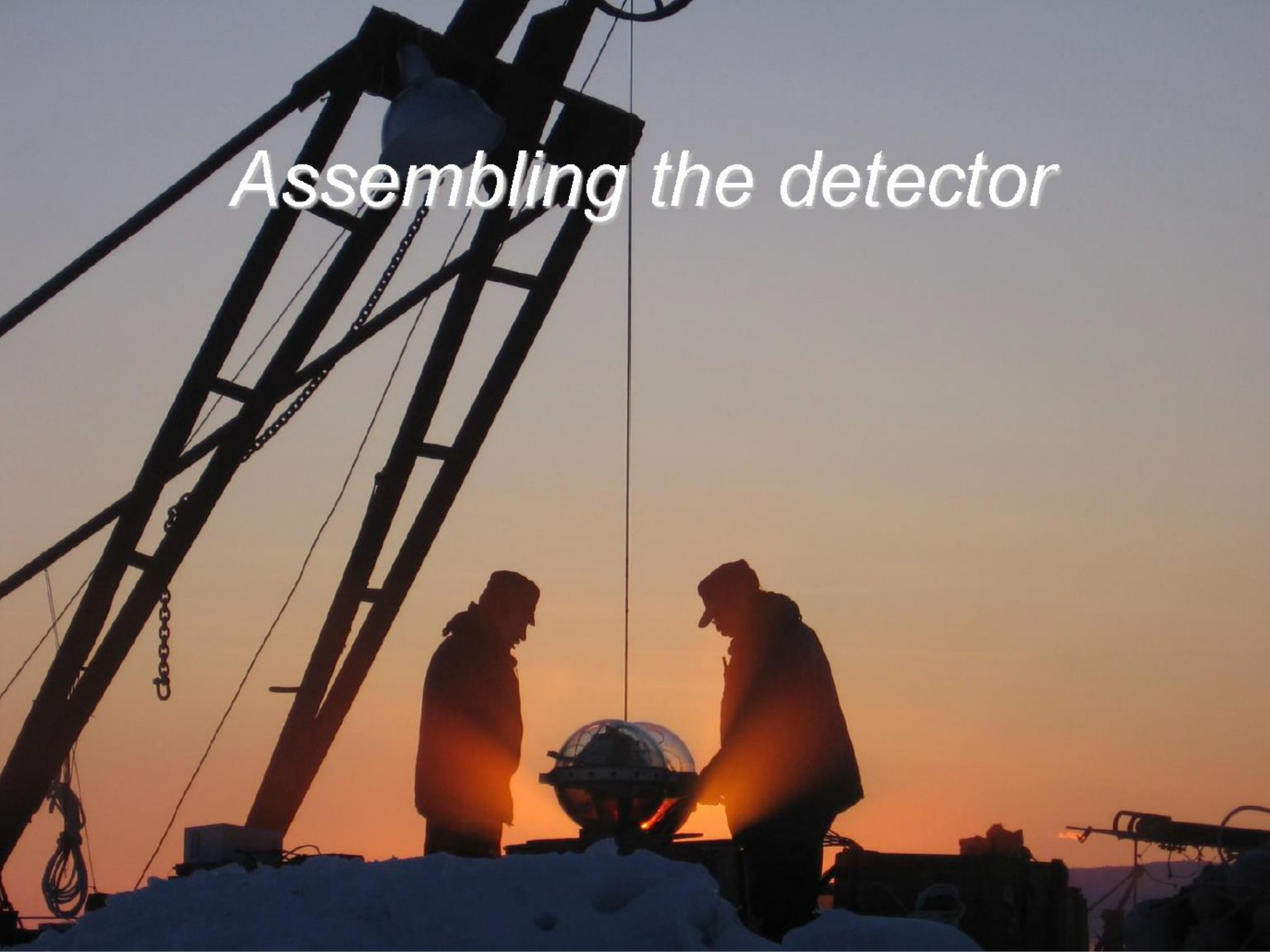
# • Infrastructure


107 km: living quarters, dining room

Baikal'sk:

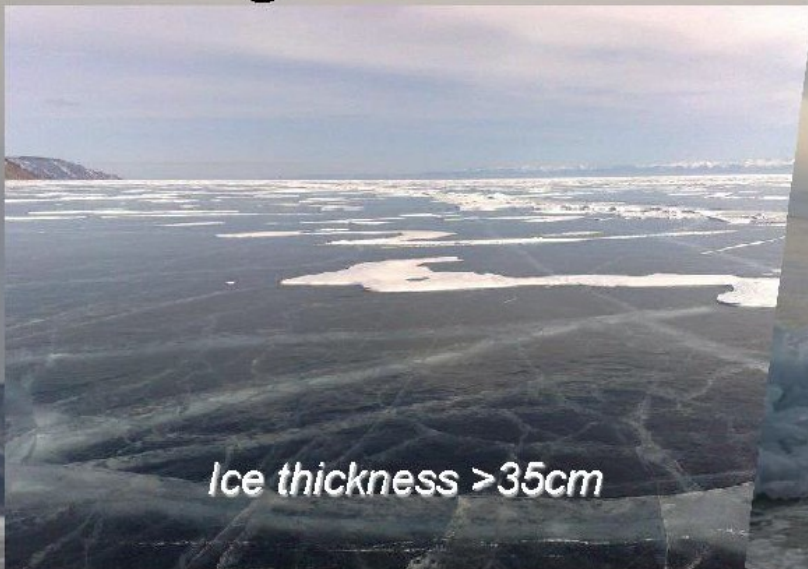
Garage,
Workshop,
Storage
facilities

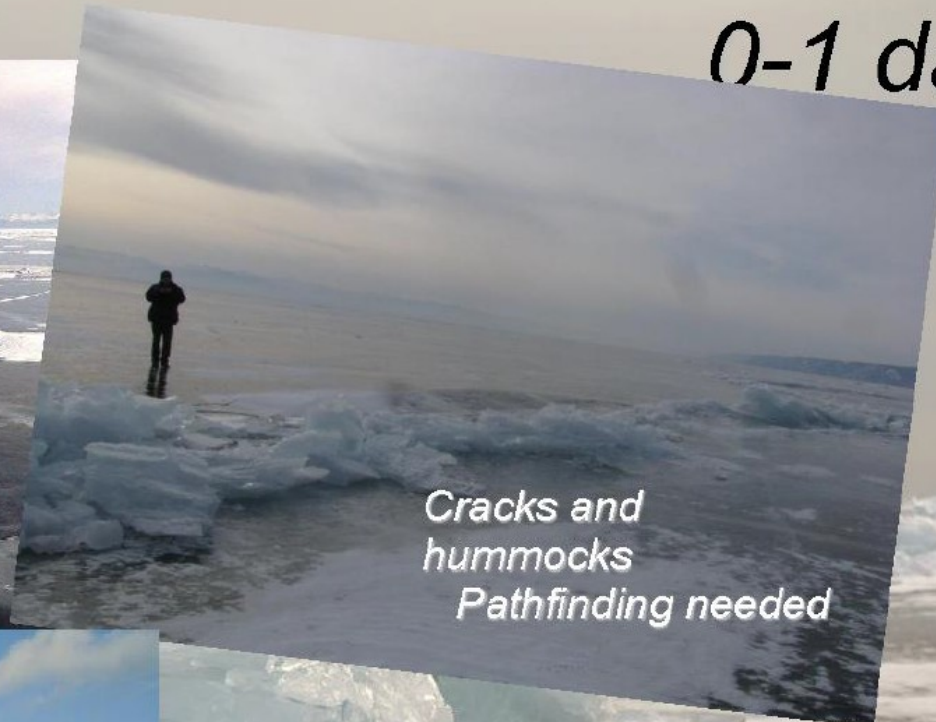

# Upgrade: control center in a new cabin



Assembling the detector

# Stage 0

# Timeline: 0-1 days





# *Vehicles*


Making ice-holes
Stage 1
Timeline:
1-2 days

## Stage 1

**Timeline: 1-2 days**

# > 20 units need to transport to Ice-camp

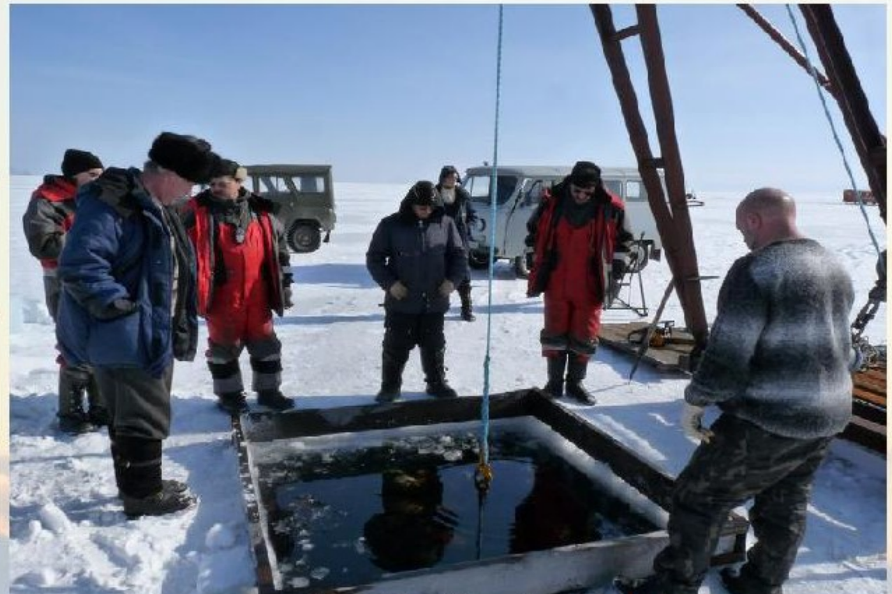
...and even more in the next days


Stage 1
Divers
Timeline:
3-5 days
attach the rope to the top of the string
get rid of fishing nets
Using echo-sounding device

# *Stage 2*

- 15-20 men working in groups

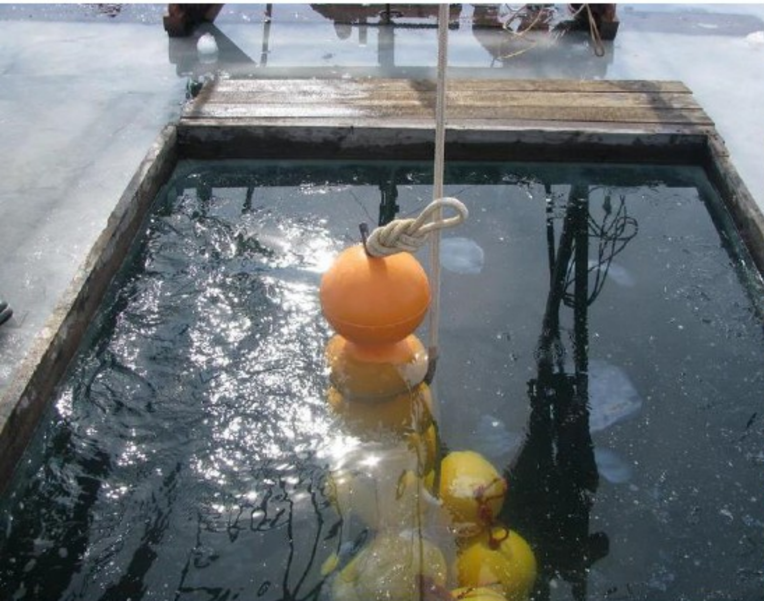
# Stage 2



**Timeline: 5-45 days**


Stage 2
mounting new string
Timeline:
5-40 days
5 days for a group (4-5 men) to fully
assemble and install new string from
a finished parts

# *mounting new string: technical features*



# cabling to the shore

Screw-propelled vehicle

ice-cutter

Cable layer & winch

# cabling to the shore

*need one cable for each two clusters*
*task parallel to other work*
*takes 3 week to prepare and only 2 days to complete*

# History

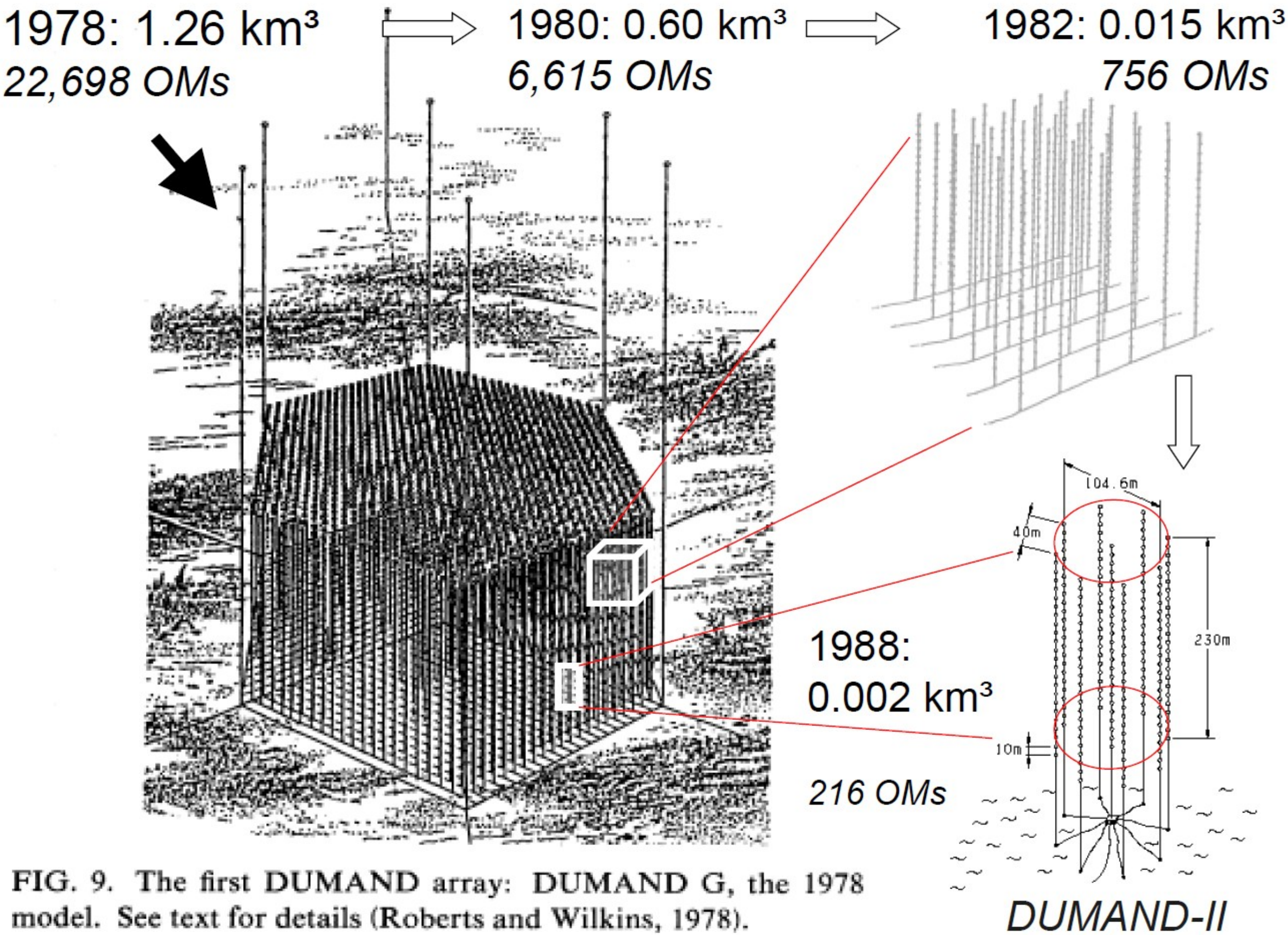
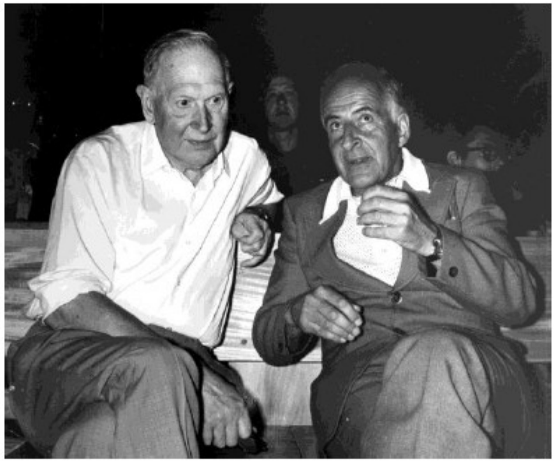



FIG. 9. The first DUMAND array: DUMAND G, the 1978 model. See text for details (Roberts and Wilkins, 1978).

1960 M.Markov – Deep underwater detection method



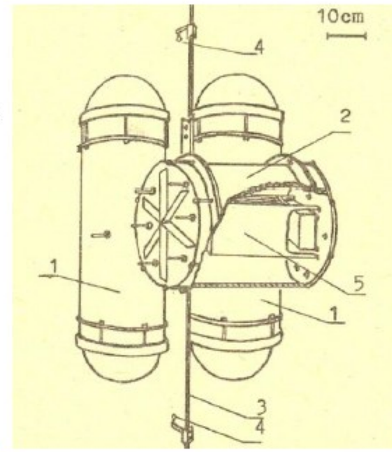
1977 V.Berezinsky and G.Zatsepin – Scientific program for neutrino telescopes

1978 A.Chudakov – NT in Lake Baikal

1981 – Start of Baikal Neutrino Experiment

# • 1981-1993

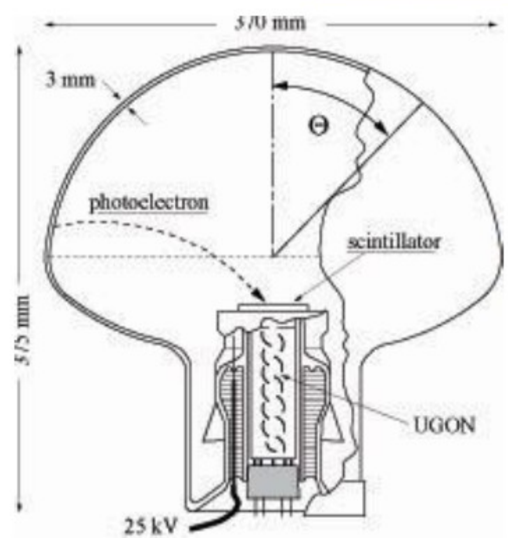
- 1984: first stationary string
  - Muon flux measurement




- 1986: second stationary string (Girlyanda 86)

  Limits on GUT magnetic monopoles

- Development of a Russian smart phototube (Quasar)
- Deployment of first shore cables
- 1990: design of the NT200

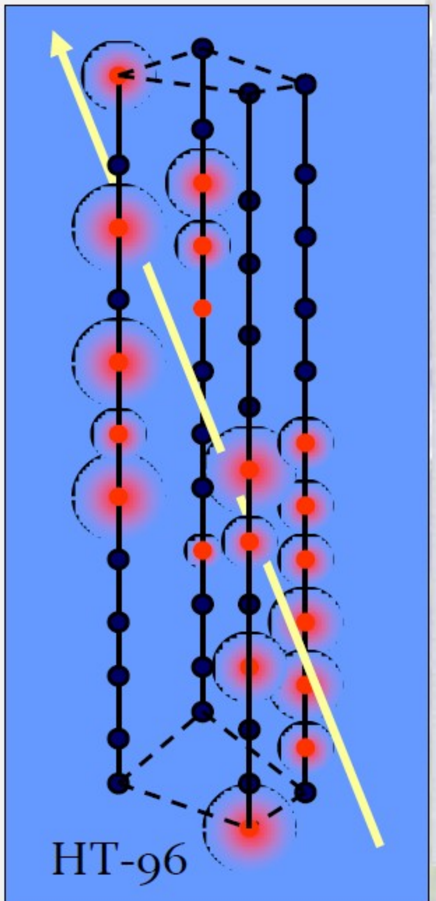


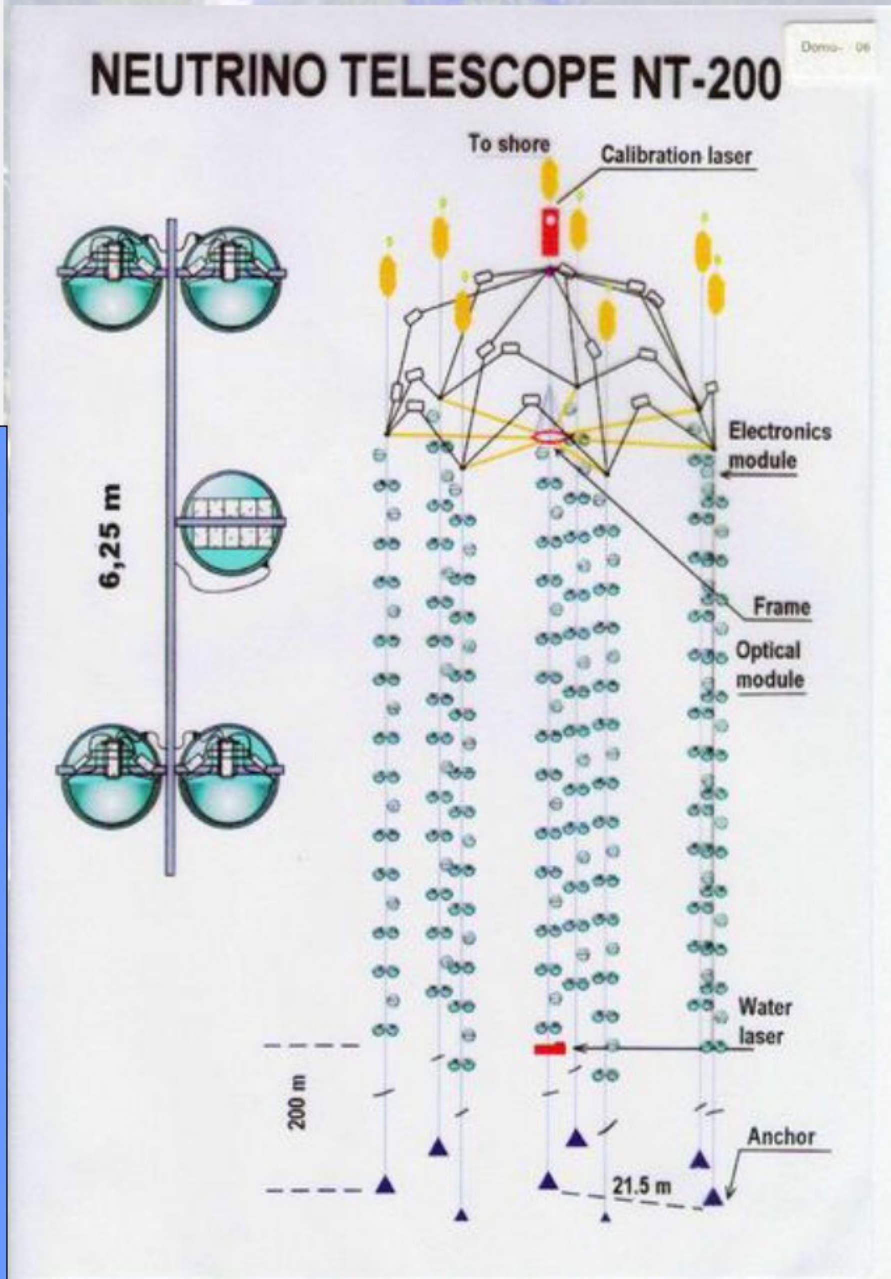
- 1993-1998

  - ✓ Deployment of the first underwater neutrino telescope NT200

  - ✓ First results with different stages of NT200
    - Selection of first neutrino events
    - Search for WIMP neutrinos from Earth
    - Search for diffuse HE-neutrino flux

Fully reconstructed neutrino event (1996)

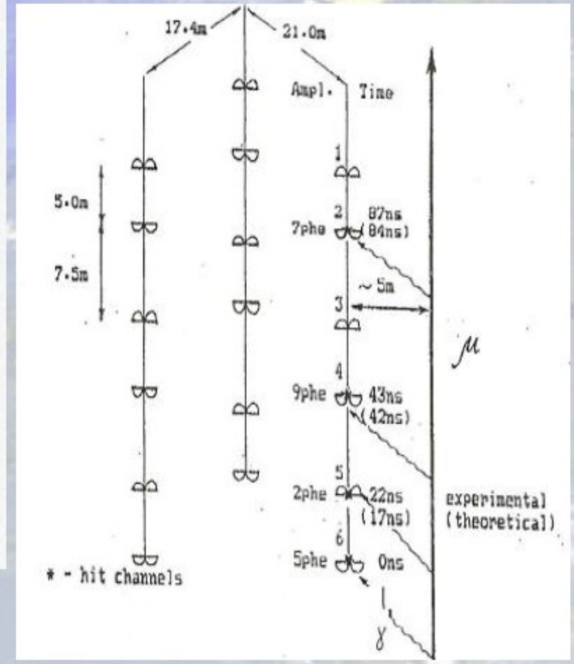



~ 3.6 km to shore, 1070 m depth

NT200: 8 strings (192 OMs)
Height x ∅ = 70m x 40m,
$V_{inst}=10^5 m^3$
Effective area: 1 TeV~2000m²
Eff. shower volume:
100 TeV~ 1.0 Mton

2 first neutrino events with NT-36 (1993-1994)

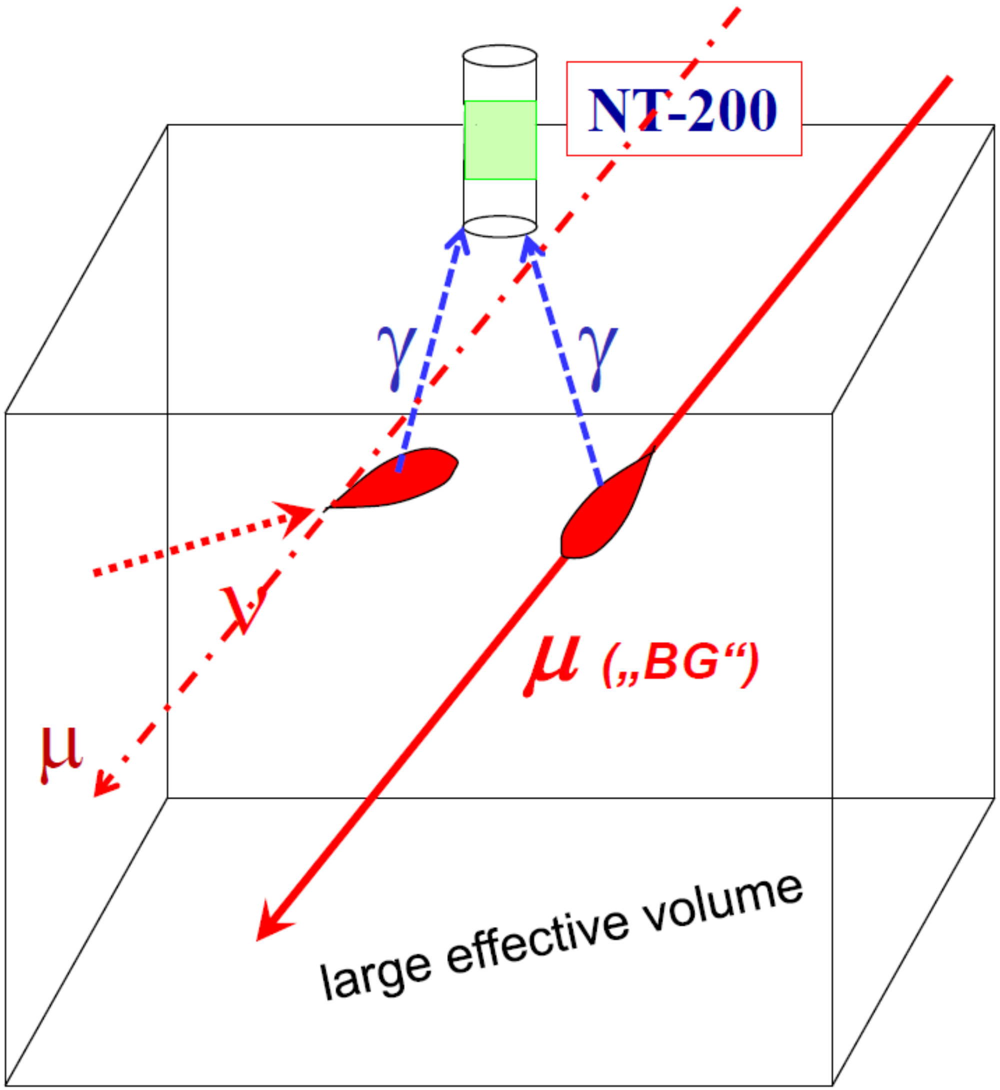


- 1998-2003

NT200 operation in full scale.
1038 days of livetime data were collected and used for search for:

- ✓ Atmospheric neutrinos
- ✓ Neutrinos from WIMP annihilation in the Sun and Earth
- ✓ Neutrinos from point-like sources
- ✓ Neutrinos from GRB
- ✓ Magnetic monopoles
- ✓ Diffuse flux of HE-neutrinos

# Search for High-Energy Cascades With NT200




**Cascades produced below NT200:**

- **Arrival times were used for vertex reconstruction:**

  $\Delta r/r \sim 7\%$

- **PMT amplitudes were used for energy and derection reconstruction:**

  $\delta \lg E \sim 20\%, \ \psi_{med} \sim 4.5°$

**Results of laser light source position and intensity reconstruction prove an efficiancy of used methods.**

# Reconstruction technique

## Reconstruction of cascade position

$$\chi_t^2 = \frac{1}{(N_{hit}-4)} \sum_{i=1}^{N_{hit}} \frac{(T_i(\vec{r}_{sh}, t_0) - t_i)^2}{\sigma_{ti}^2},$$

where $T_i(\vec{r}_{sh}, t_0)$ time of flight of unscattered photons

**Iterative procedure - OMs with residual $\delta t > 15$ ns are excluded and reconstruction is repeated**

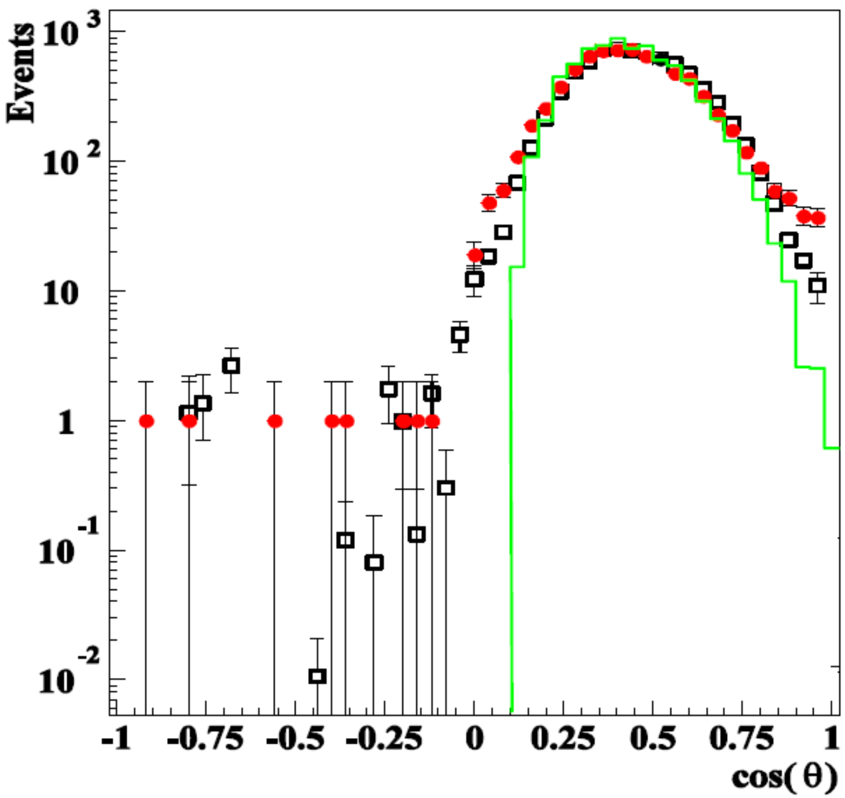
## Reconstruction of cascade direction and energy

$$L_A = -\sum_{i=1}^{N_{hit}} \ln P_i(A_i, E_{sh}, \vec{\Omega}_{sh}(\theta, \varphi)),$$

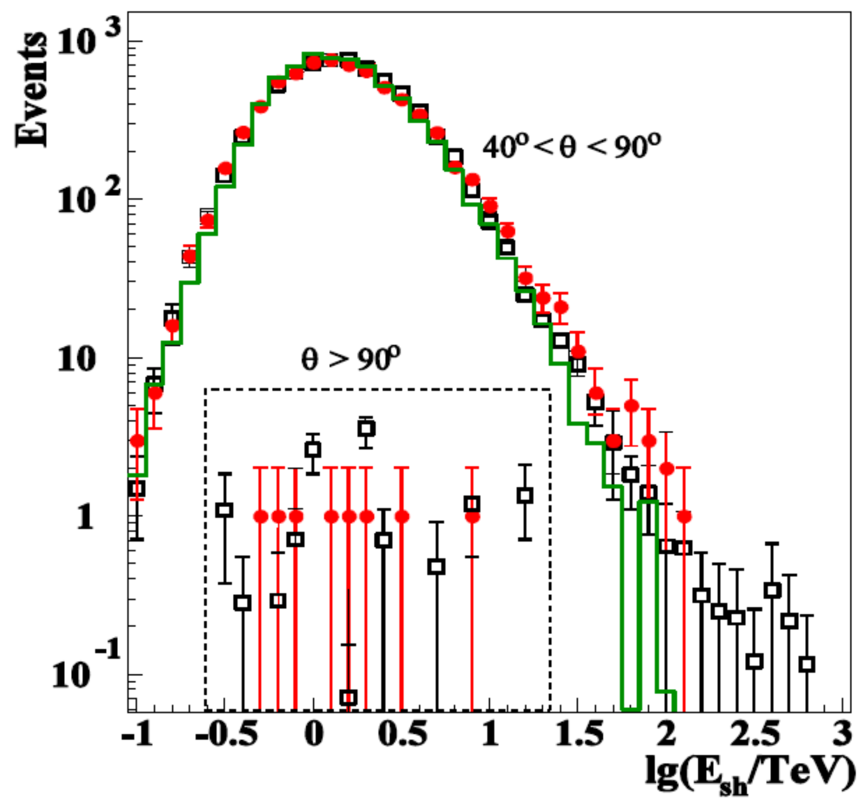
where $P_i$ calculates in respect of tabulated $N_{pe}(\mu, \varphi, z, \rho)$

# 1038 days (April 1998 – February 2003)

Zenith angle distribution




Energy spectrum



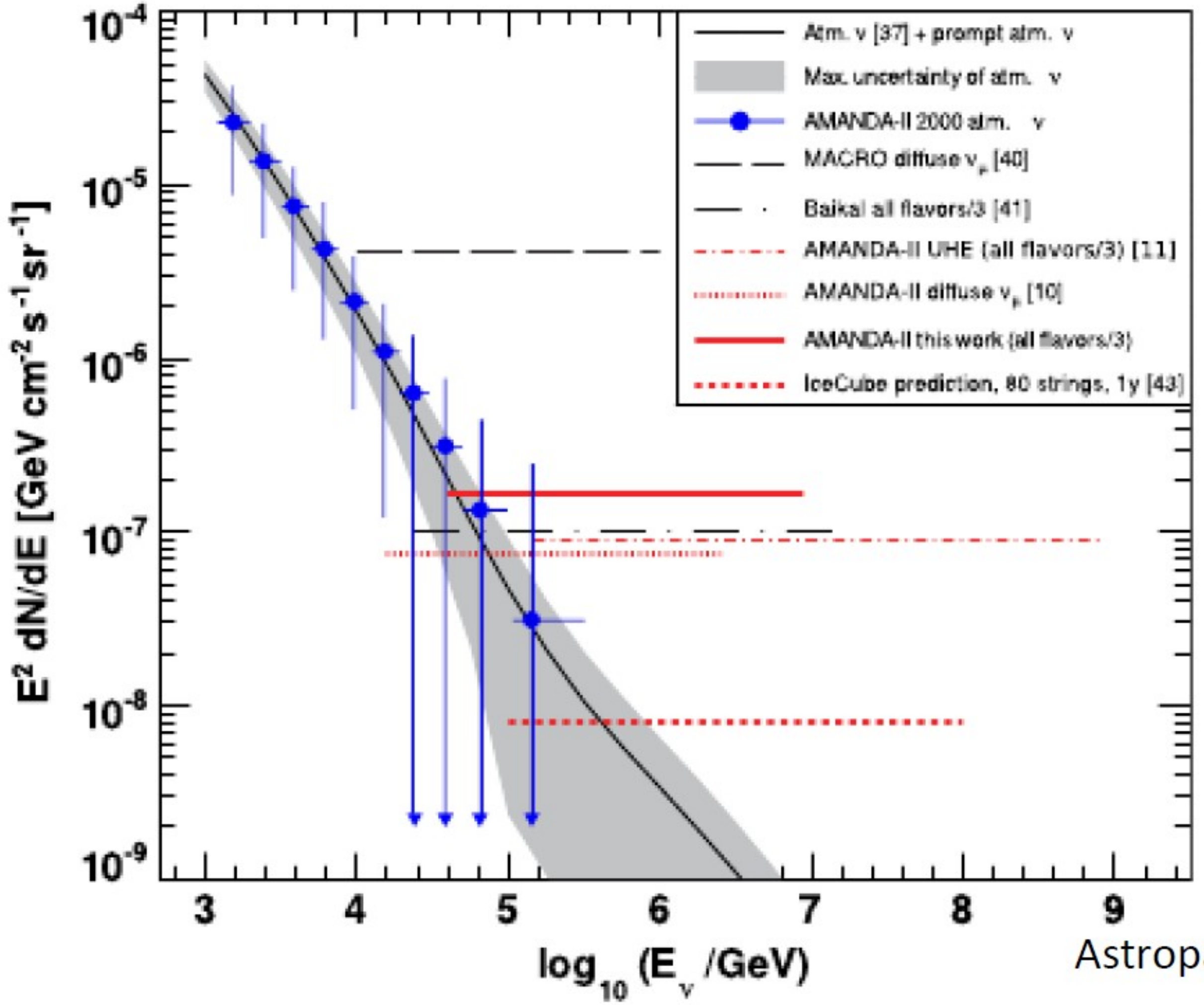

Extra cuts for ν events separation:

Esh > 130 TeV (40 < θ < 180) & Esh > 10 TeV (θ > 90)

# Limits on all-flavour flux of neutrinos assuming F ~ $E^{-2}$, flavour ratio 1:1:1

AMANDA: 1001 livedays  $5.0 \cdot 10^{-7}$ Gev cm $^{-2}$ s$^{-1}$ sr$^{-1}$

NT200: 1038 livedays  $2.9 \cdot 10^{-7}$ Gev cm $^{-2}$ s$^{-1}$ sr$^{-1}$

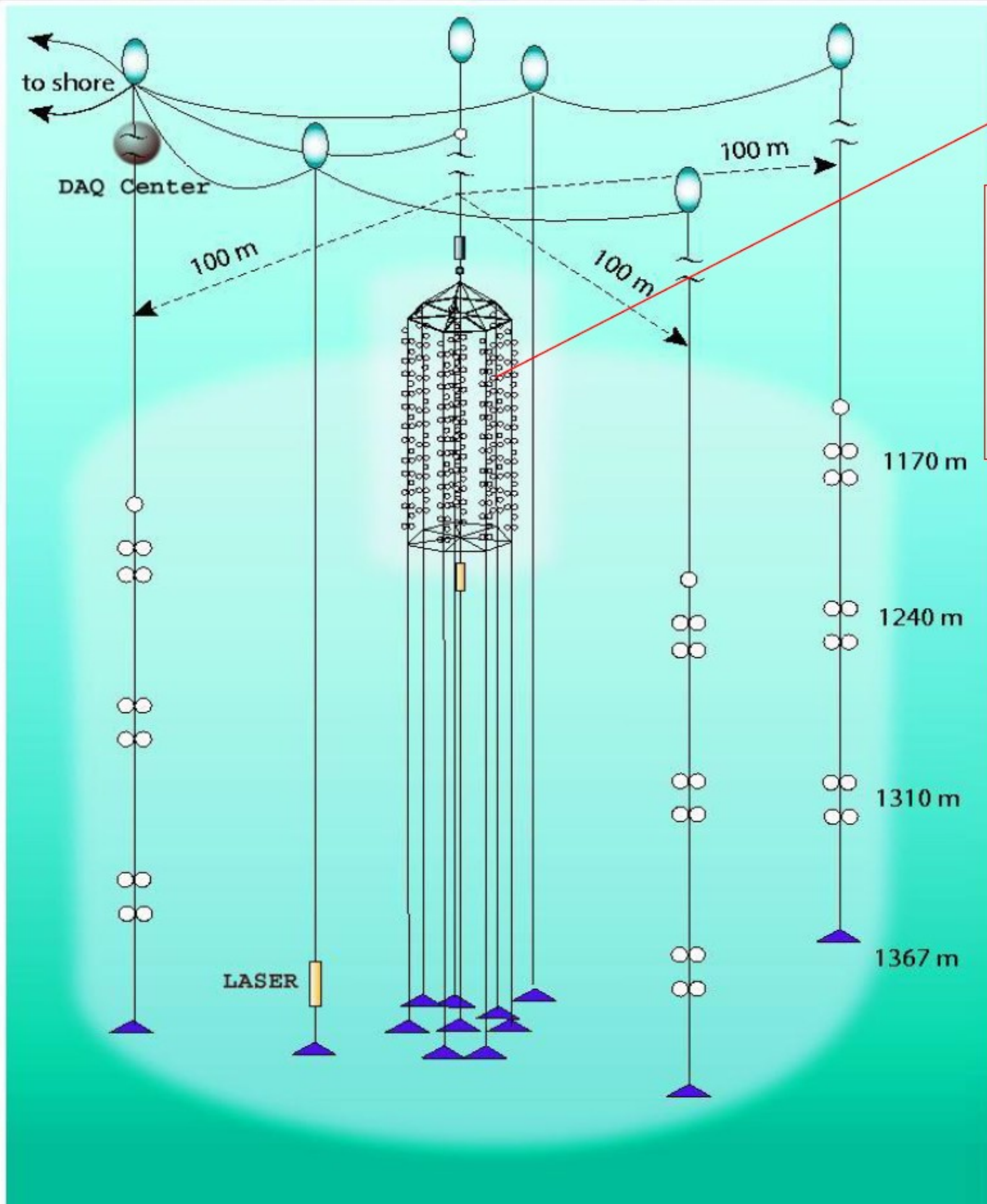



Astropart. Phys. 34 (2011) 420

- 2003-2006
  - NT200+ - upgrade of Baikal Neutrino telescope
    - ✓ Design of NT200+
    - ✓ Deployment of 3 new strings
    - ✓ First step towards km3-scale NT in Baikal

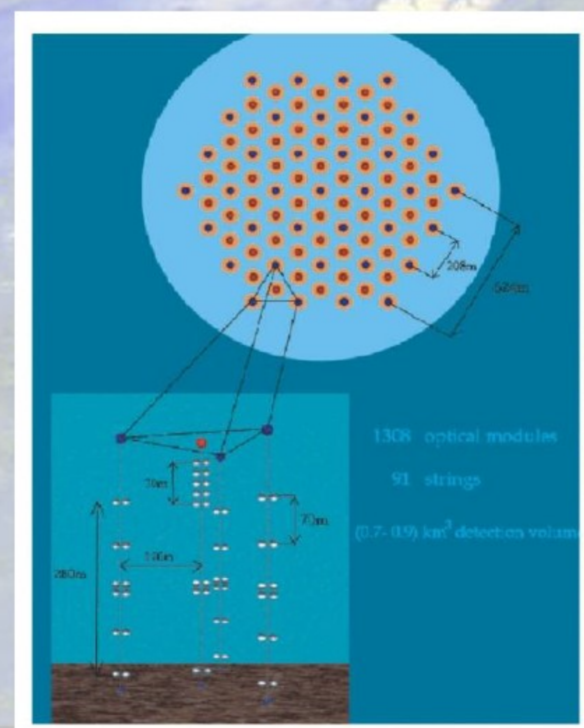
# 1998 - NT200

# 2005 - NT200+




NT200+ = NT200 + 3 outer strings
(192+36 OMs)
Height x ∅ = 210m x 200m,
$V_{inst}$ = $5\times10^6 m^3$
Eff. shower volume: $10^4$ TeV ~ 10 Mton

Project of km3 scale array



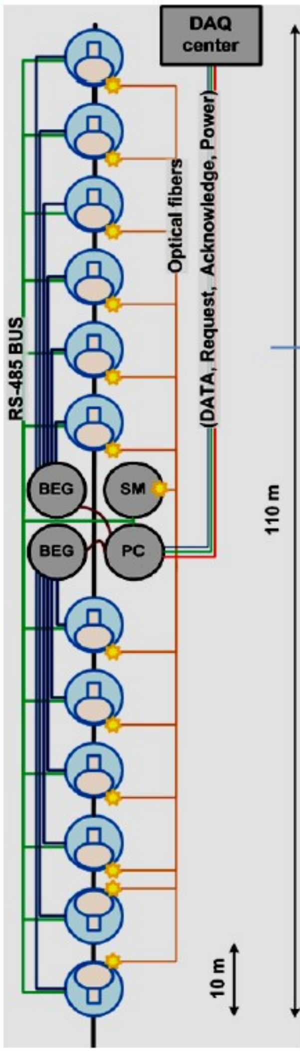
# R&D and component prototype tests: 2008 – 2010

Design, production and long-term in-situ tests
of key elements and systems of GVD integrated in NT200+

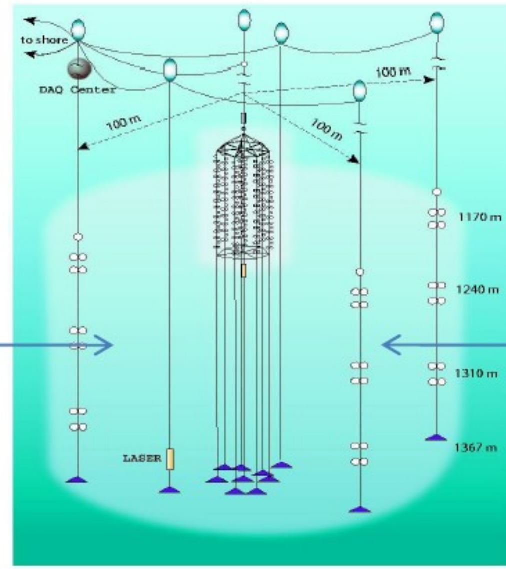

2008-2009 2008-2010 2010

# GVD prototype strings 2009 - 2010

**Prototype string 2009**




**PMT:**
**Photonis XP1807**
**6 OM**
**Hamamatsu R8055**
**6 OM**

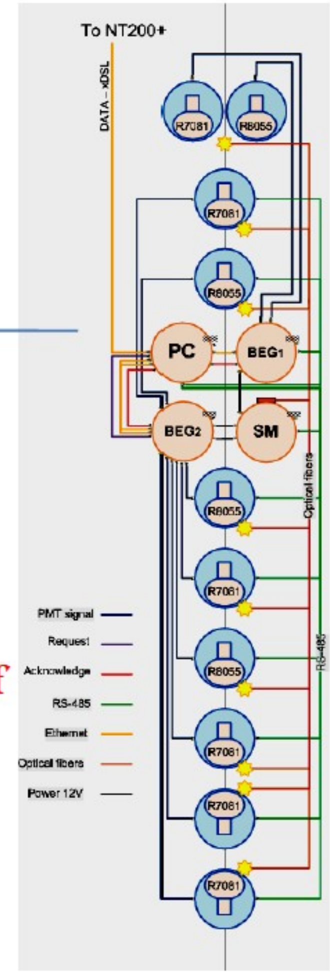



NT200+

**In-situ tests of basic elements of GVD with prototypes strings (2009…2010)**

**Investigation and tests of new optical modules, DAQ system, cabling system, triggering approaches**

**Prototype string 2010**




**PMT:**
**Hamamatsu R7081HQE**
**7 OM**
**Hamamatsu R8055**
**3 OM**

# Baikal - GVD

# Gigaton Volume Detector (GVD) in Lake Baikal

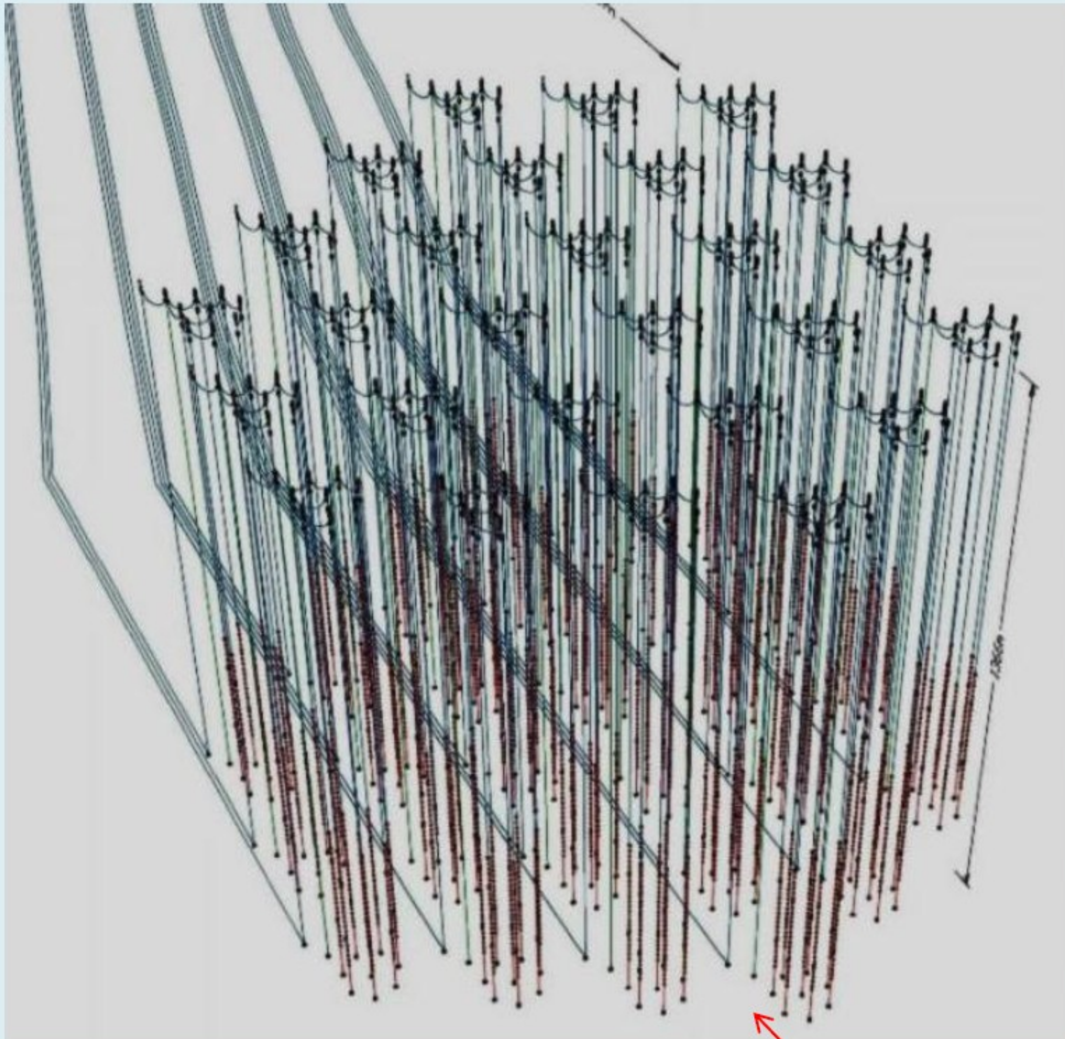
## Objectives:

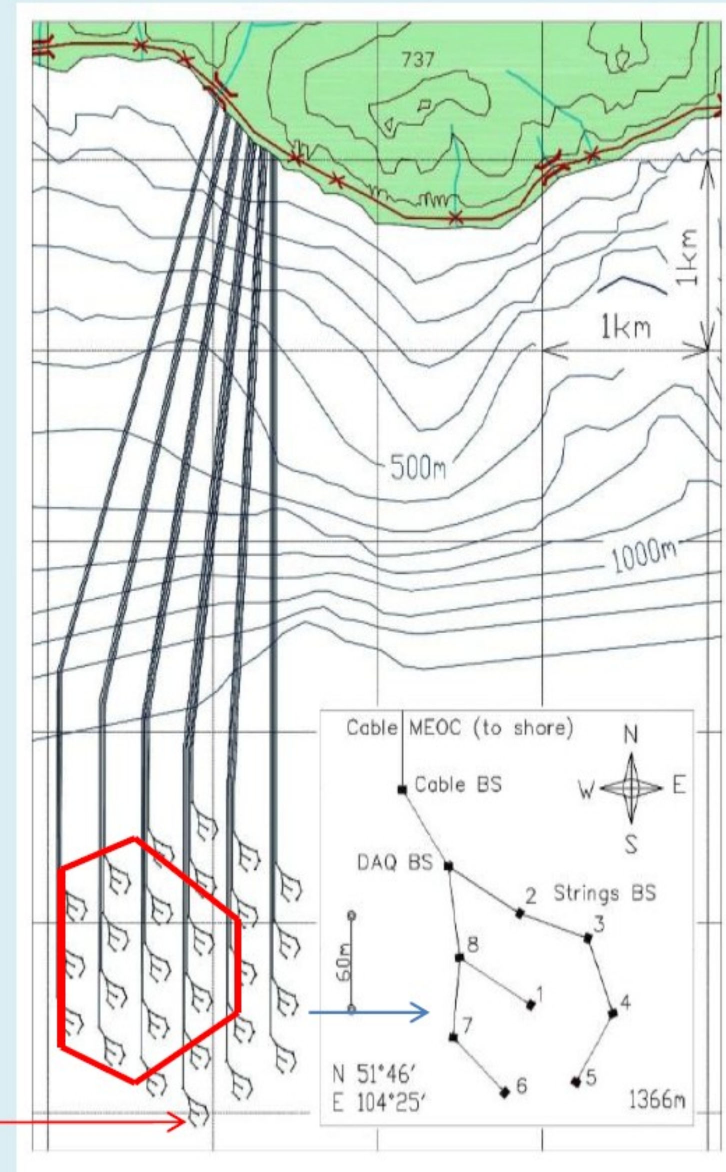
- km3-scale 3D-array of photo sensors
- flexible structure allowing an upgrade and/or a rearrangement of the main building blocks (clusters)
- high sensitivity and resolution of neutrino energy, direction and flavor content

## Central Physics Goals:

- Investigate Galactic and extragalactic neutrino "point sources" in energy range > TeV
- Diffuse neutrino flux – energy spectrum, local and global anisotropy, flavor content
- Transient sources (GRB, …)
- Dark matter – indirect search
- Exotic particles – monopoles, Q-balls, nuclearites, …

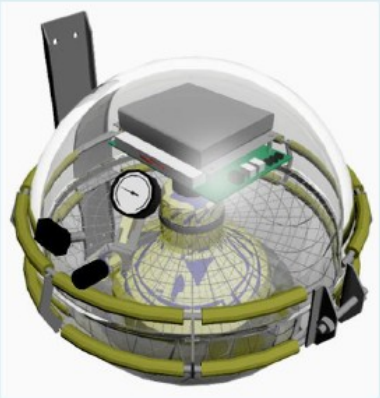
# Gigaton Volume Detector (Lake Baikal)





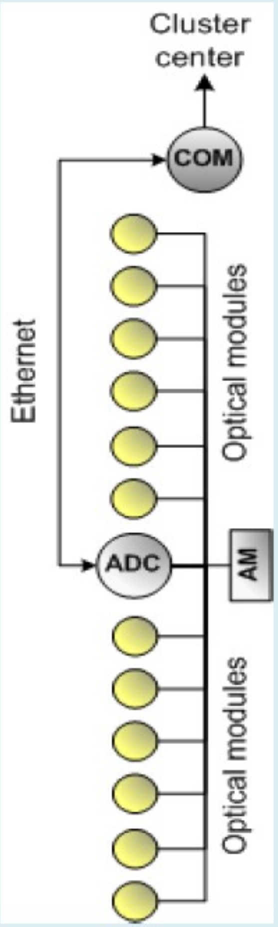

Cluster

# Gigaton Volume Detector (Lake Baikal)

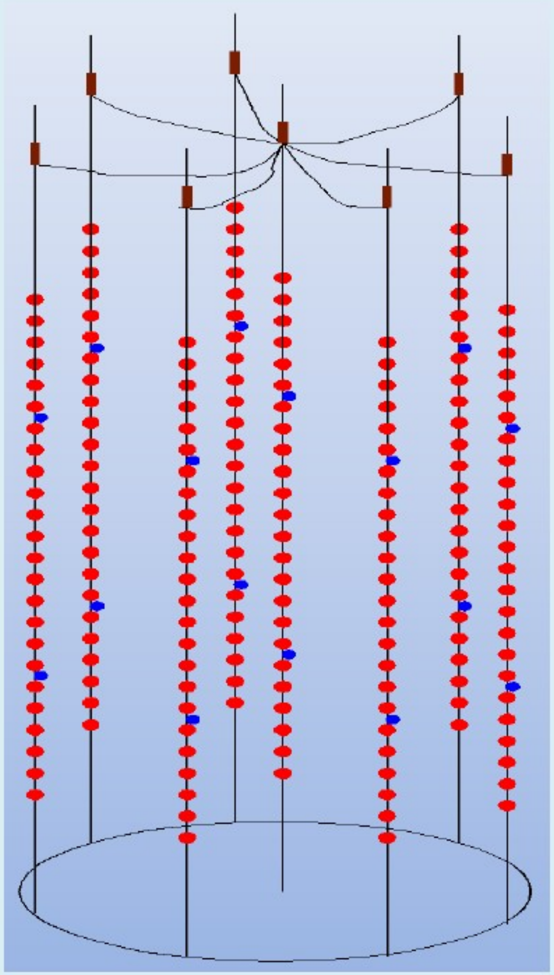


**Optical module**

| | GVD | 4*GVD |
|---|---|---|
| OMs | 2302 | 10368 |
| Clusters (8 Strings) | 12 | 27 |
| Sections (12 OMs) | 2/Str. | 4/Str. |
| Depths, m | 950 – 1300 | 600 – 1300 |
| Instr. volume | 0.4 km$^3$ | 1.5 km$^3$ |




**Section – detection unit**

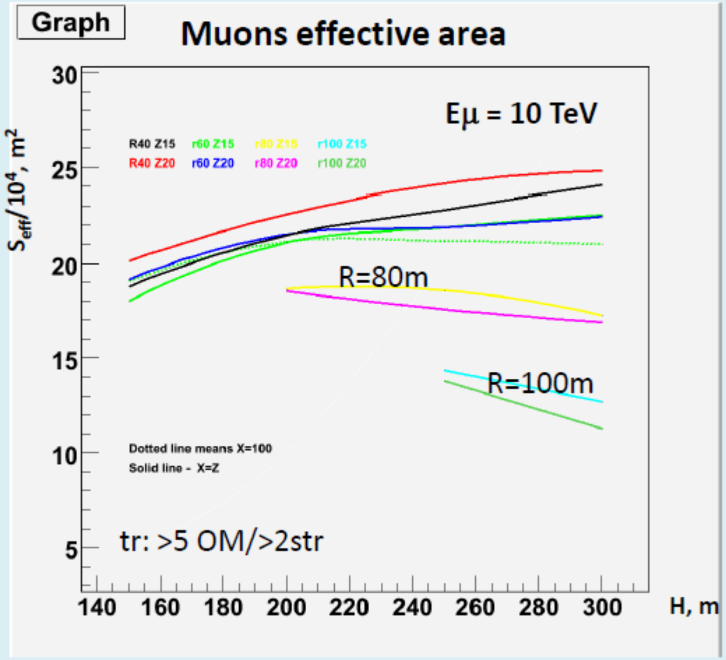


**Cluster (8 strings)**

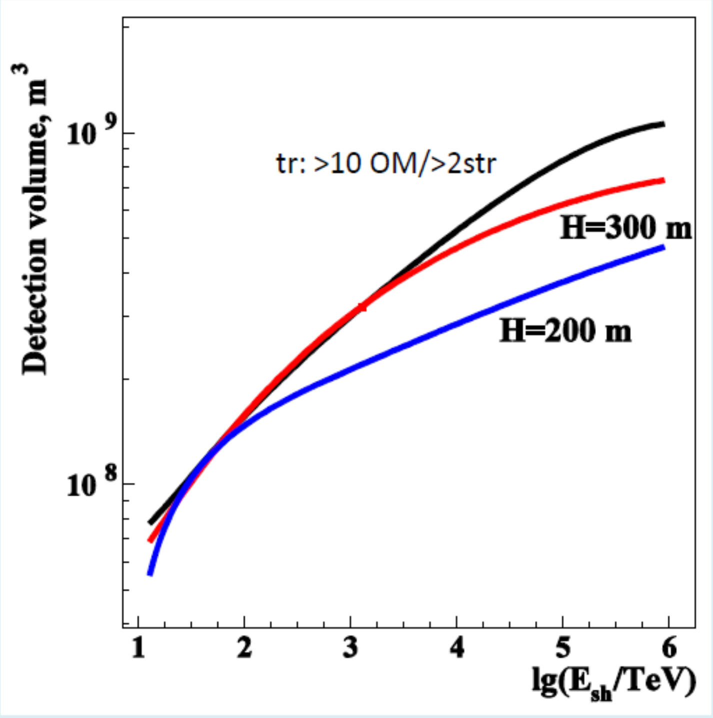
# Optimisation of GVD configuration

**Results of optimization:**

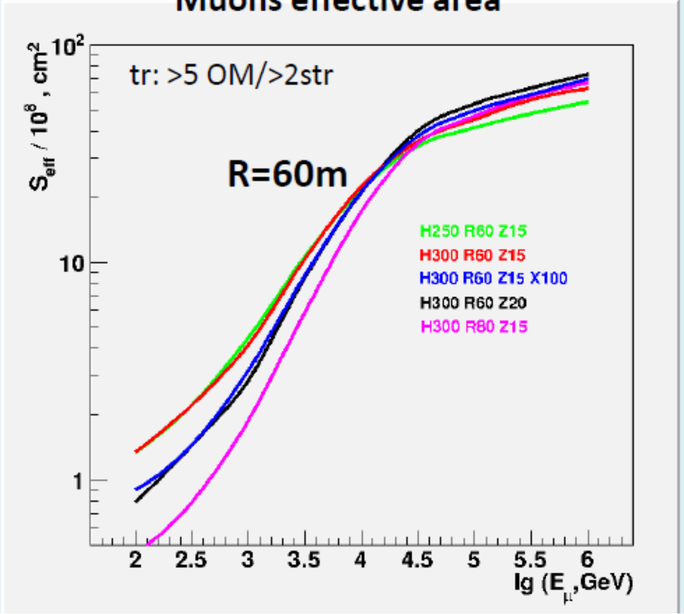
OMs spacing on string Z = 15 m
Radius of cluster R = 60 m
Clusters spacing H = 300 m




Cascades effective volume



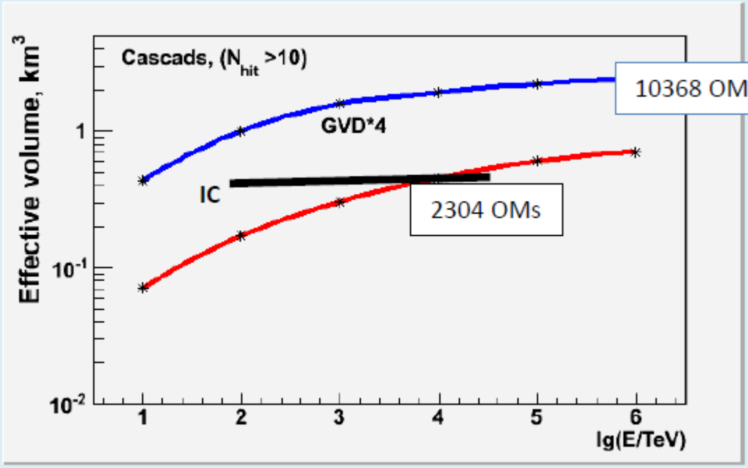

Muons effective area



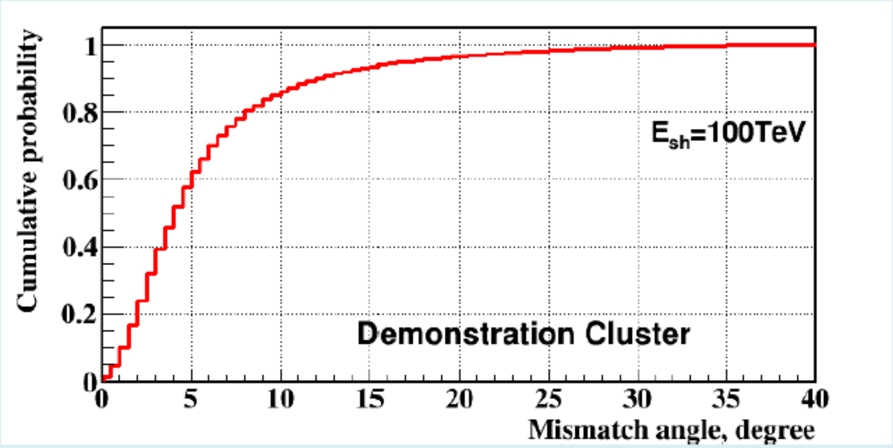
# GVD Performance

## Cascades:

$V_{eff}$ ~0.4–2.4 km$^3$

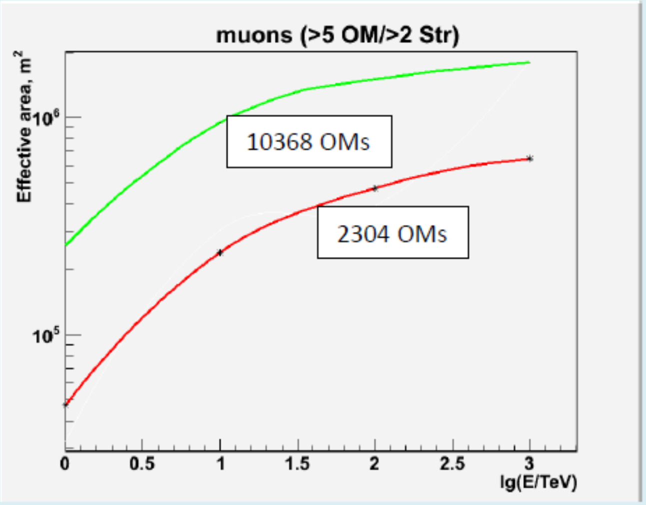



Directional resolution: 3.5° - 5.5°

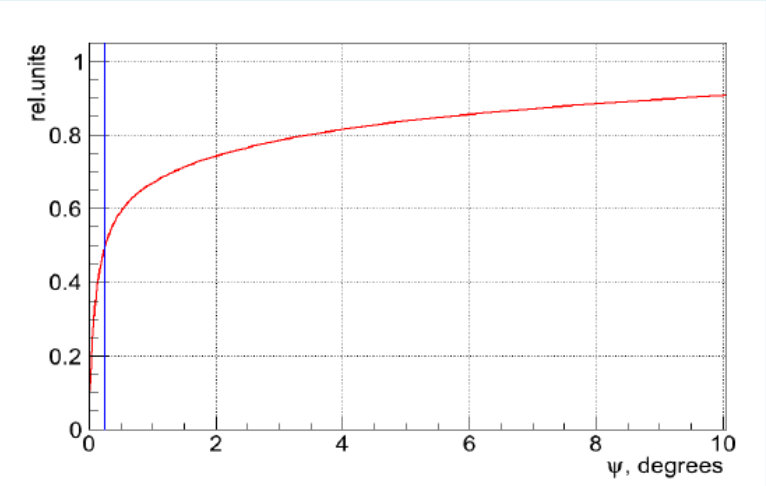



## Muons:

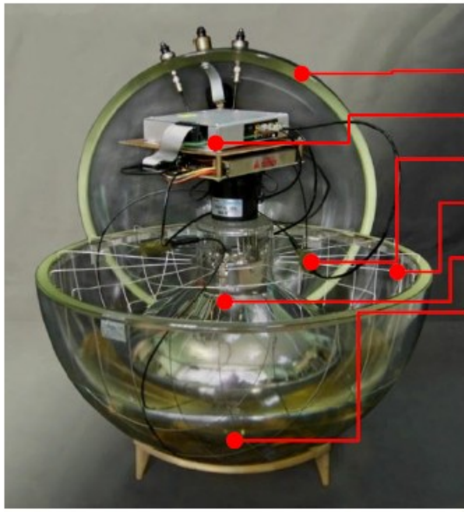
$S_{eff}$ ~ 0.3–1.8 km$^2$




Directional resolution - 0.25°

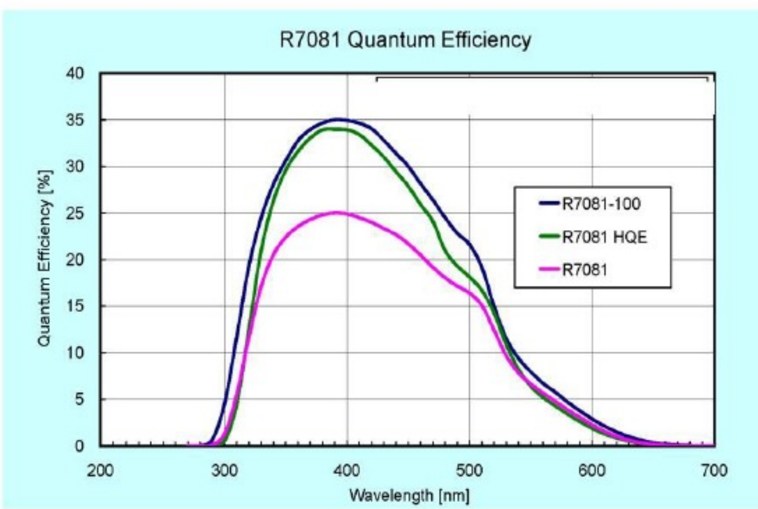


# Optical module (OM)

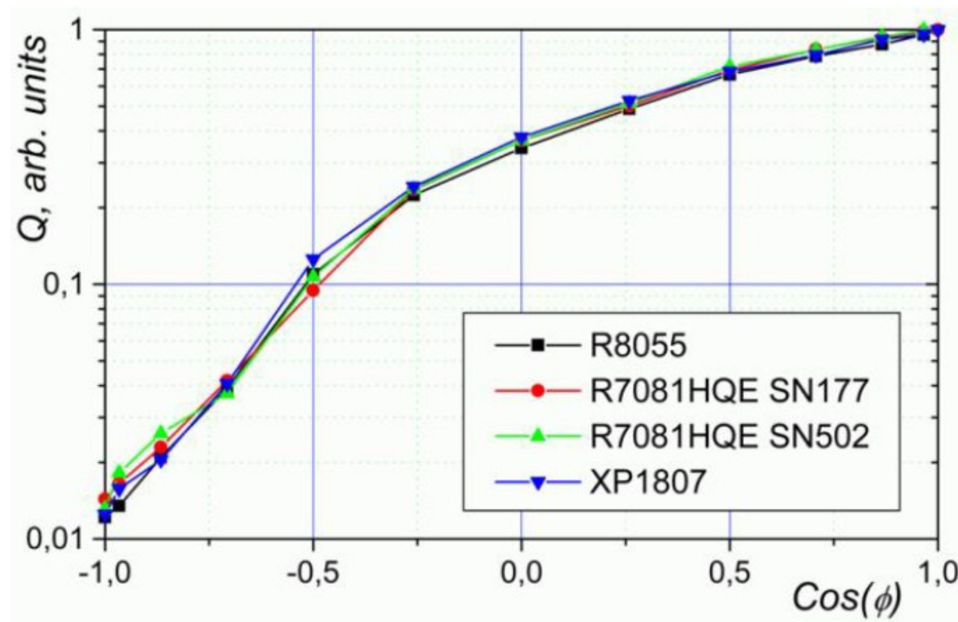


- Glass pressure-resistant sphere VITROVEX (17")
- OM electronics: amplifier, HV DC-DC, controller
- 2 on-board LED flashers: 1…$10^8$ pe., 470 nm, 5 ns
- Mu-metal cage
- **PMT R7081HQE : *D*=10", ~0.35QE**
- Elastic gel

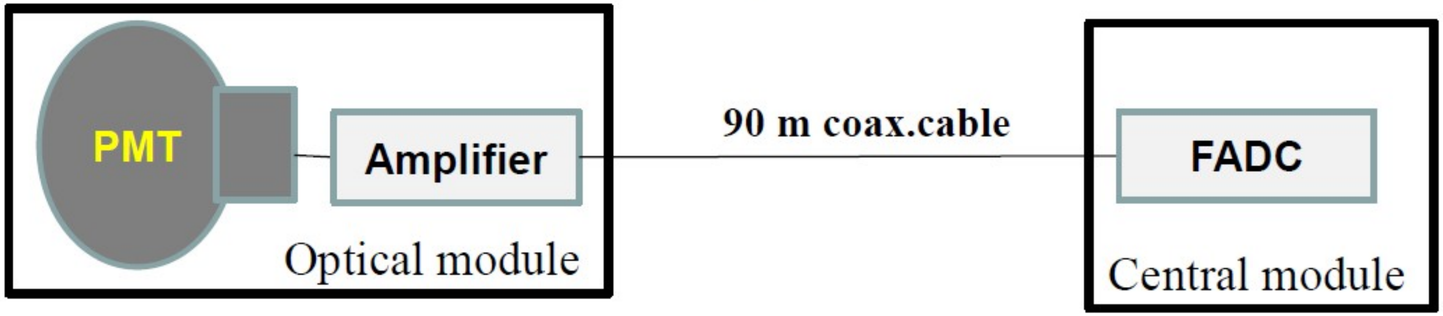
## Quantum efficiency

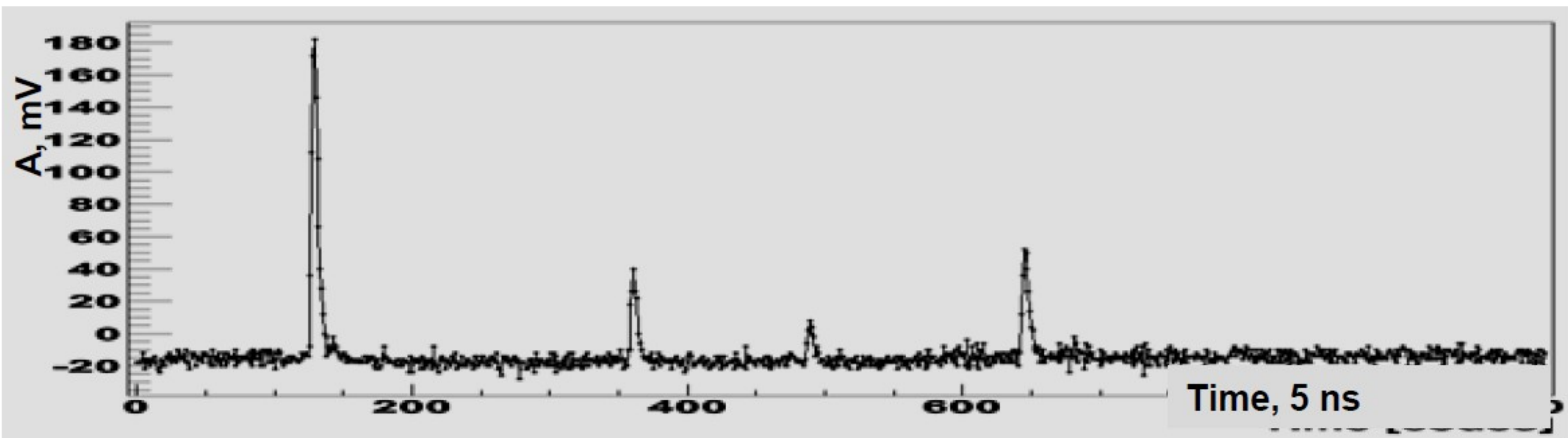



## Angular sensitivity



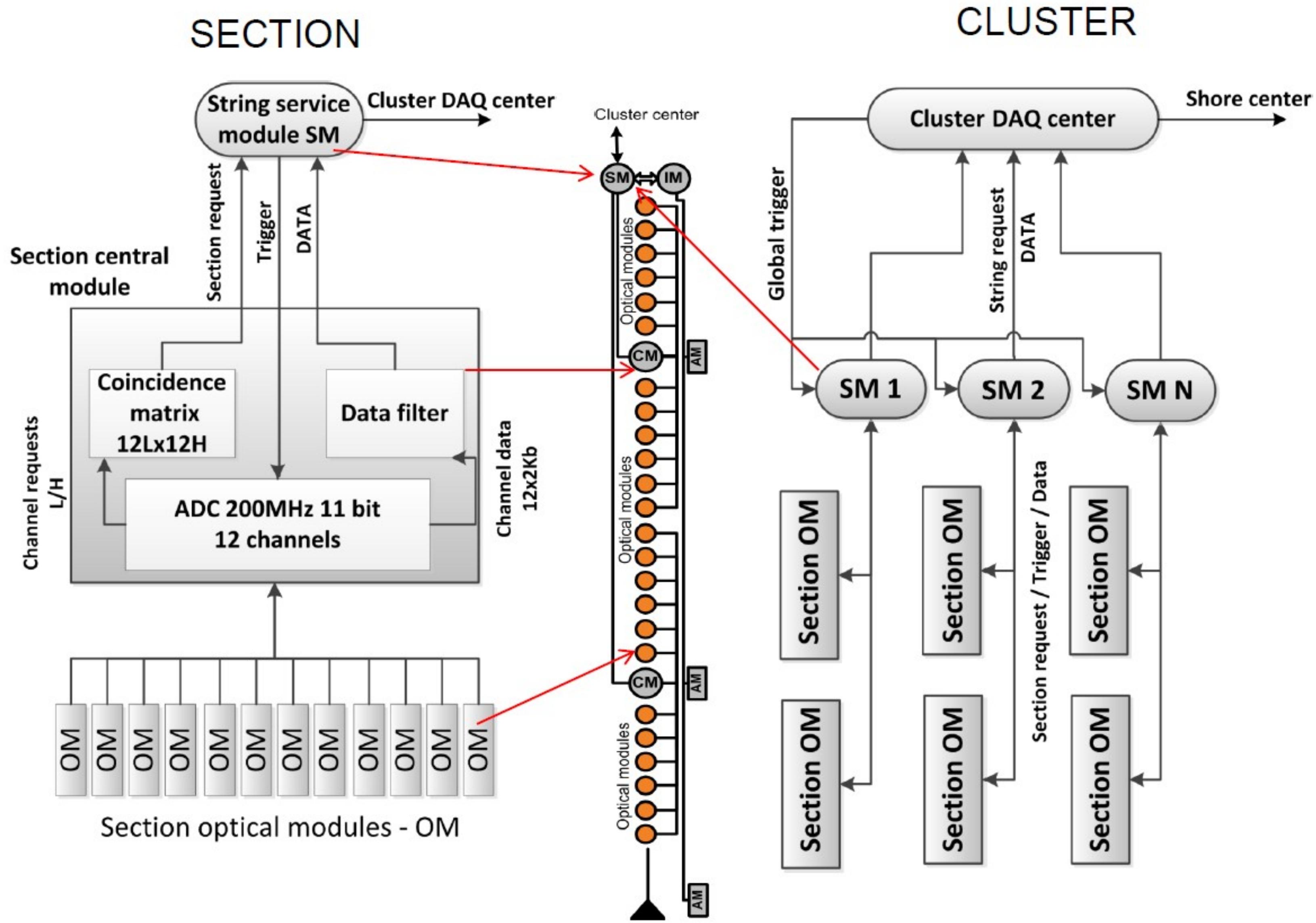
# Measuring channel



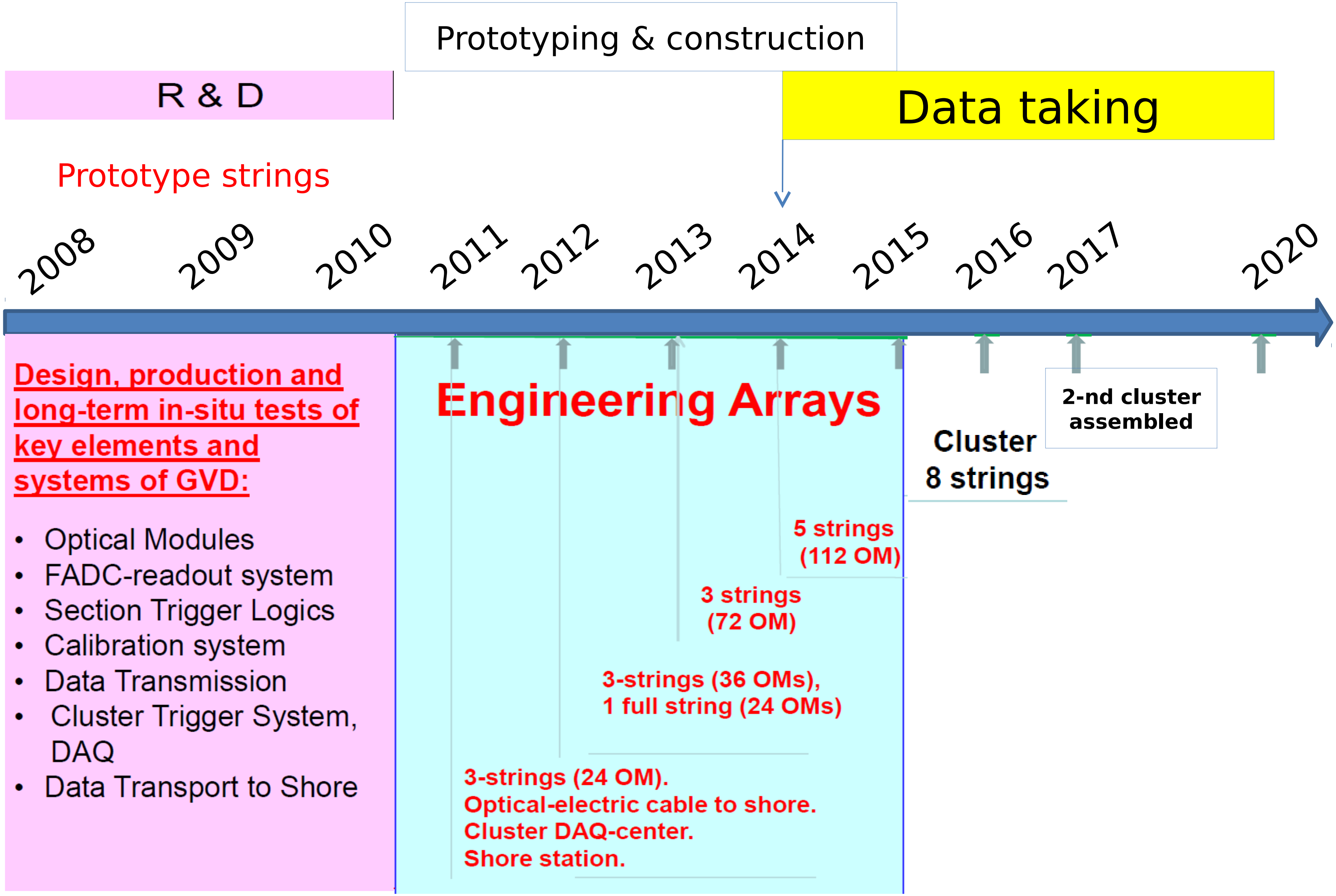




- Nominal PMT gain $1\times10^7$ (PMT voltage 1250 – 1650 V)
- Amplifier, $k_{amp}$=10;
- Pulse width ~20 ns
- ADC: 12 bit 200 MHz FADC (5 ns time bin);
- Waveform information is recorded in a programmable interval (up to 30 mks)
- Linearity range: 1 — 100 p.e.;

# Triggering and Data Transmission



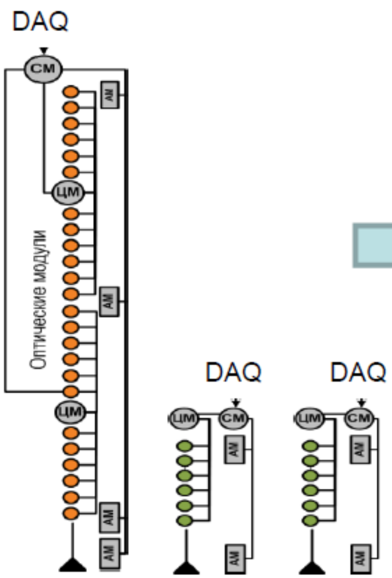
# ***Project time-line***



# Engineering arrays (2012-2015)

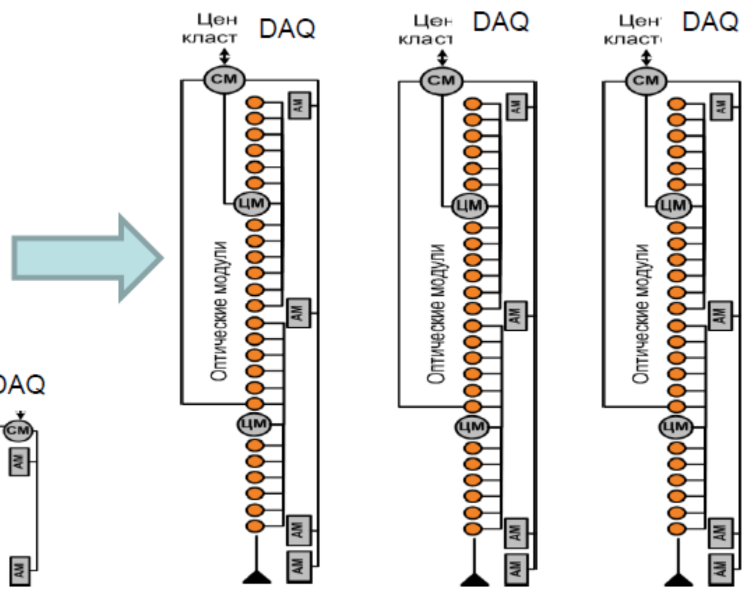
## 2012

3 strings, first full-scale GVD string (24 OMs)
Data taking from April 2012 yr.



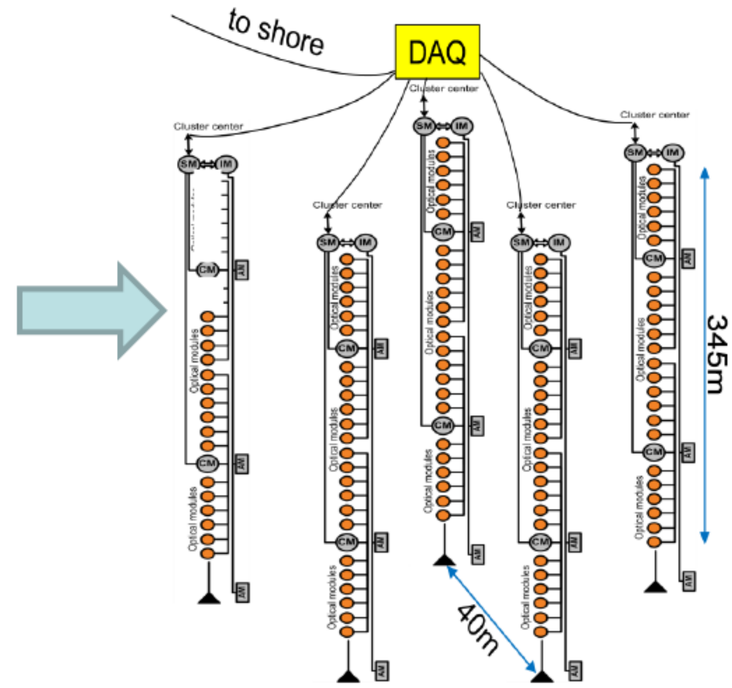

## 2013

3 full-scale strings (72 OMs), update of section electronics
Data taking from April 2013 yr.




## 2014

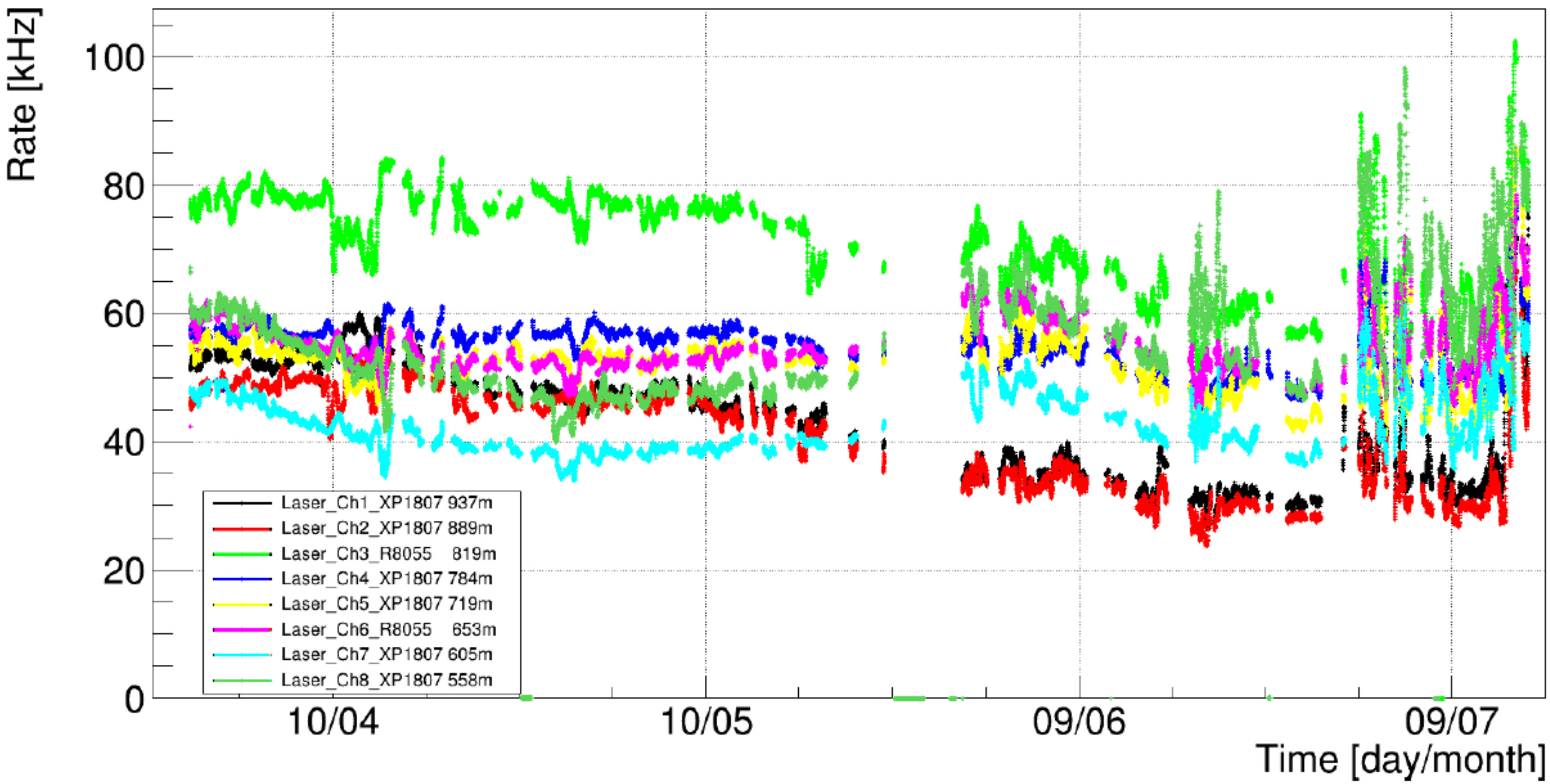
5 strings (120 OMs)
Data taking from April 2014 yr.




~$10^6$ м$^3$ instrumented volume

# Instrumentation string

Depth – 588m – 937 m




Temporal behaviour of light background

- noise level increases on factor ~2 with depth decreasing from 1100 m to 600 m

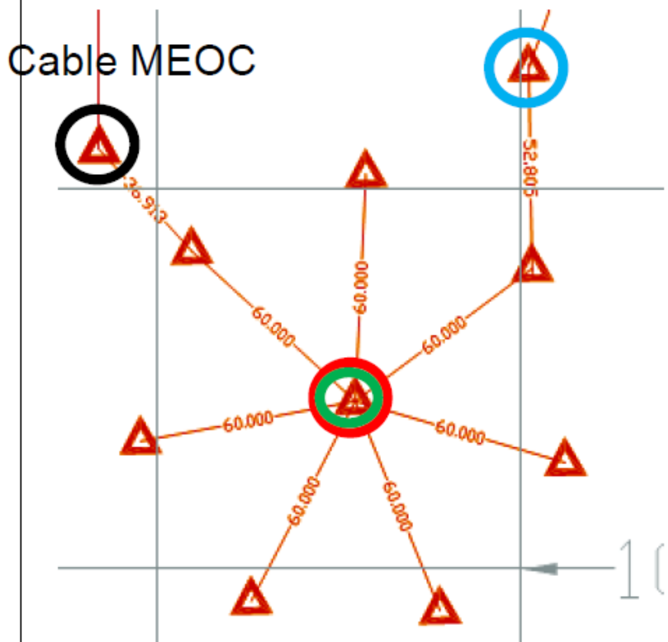
# First Demonstration Cluster “DUBNA” (April 2015)

- 192 OMs at 8 Strings
  2 Sections per String
  12 OMs per Section
- DAQ-Center
- Cable to Shore
- Acoustic Positioning System
- Instrumentation String with detector calibration and environment monitoring equipment
- Two LED beacons for interstring calibration

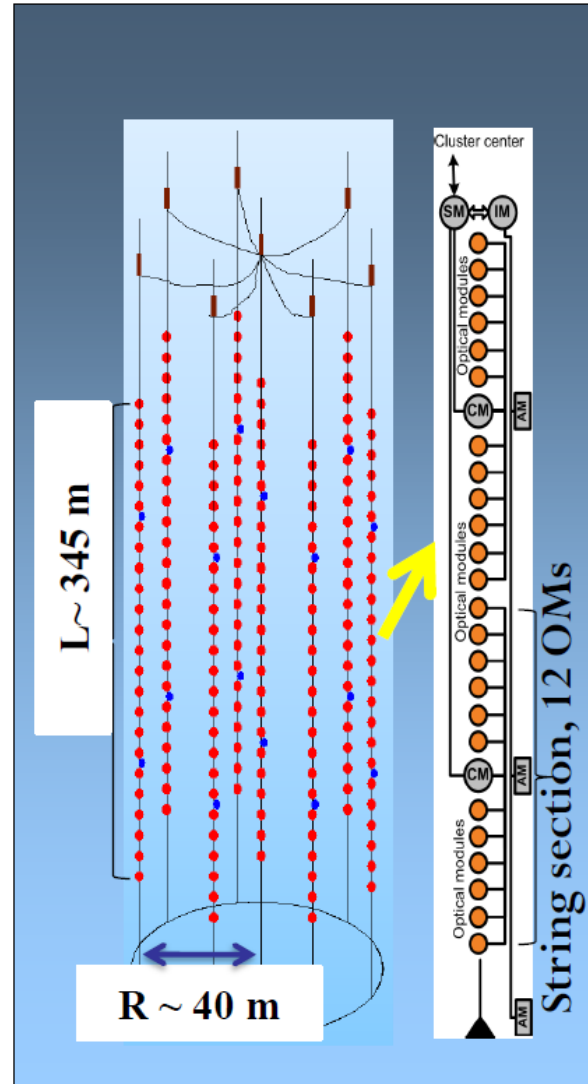
Active depth 950 – 1300 m

Instrumented volume 1.7 Mt

## Final Layout



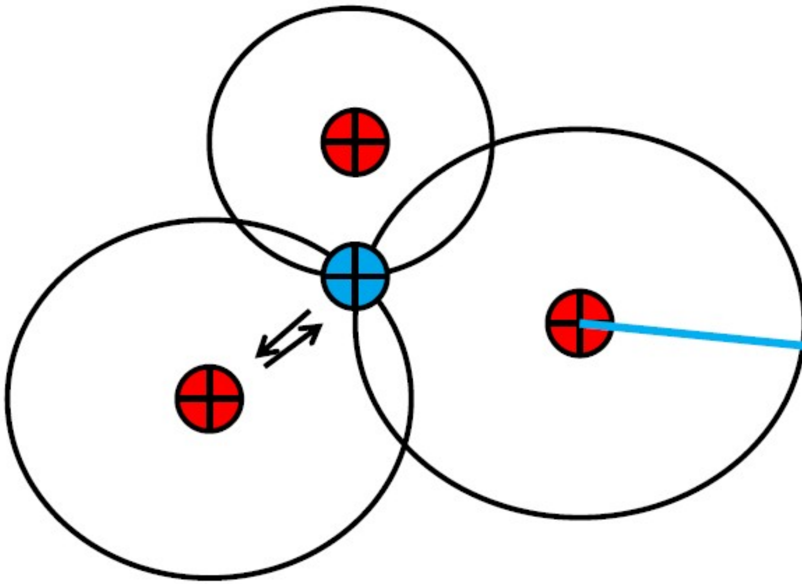

- DAQ center
- Instrumentation string
- OE Cable Buoy Station



# Operation - 2015

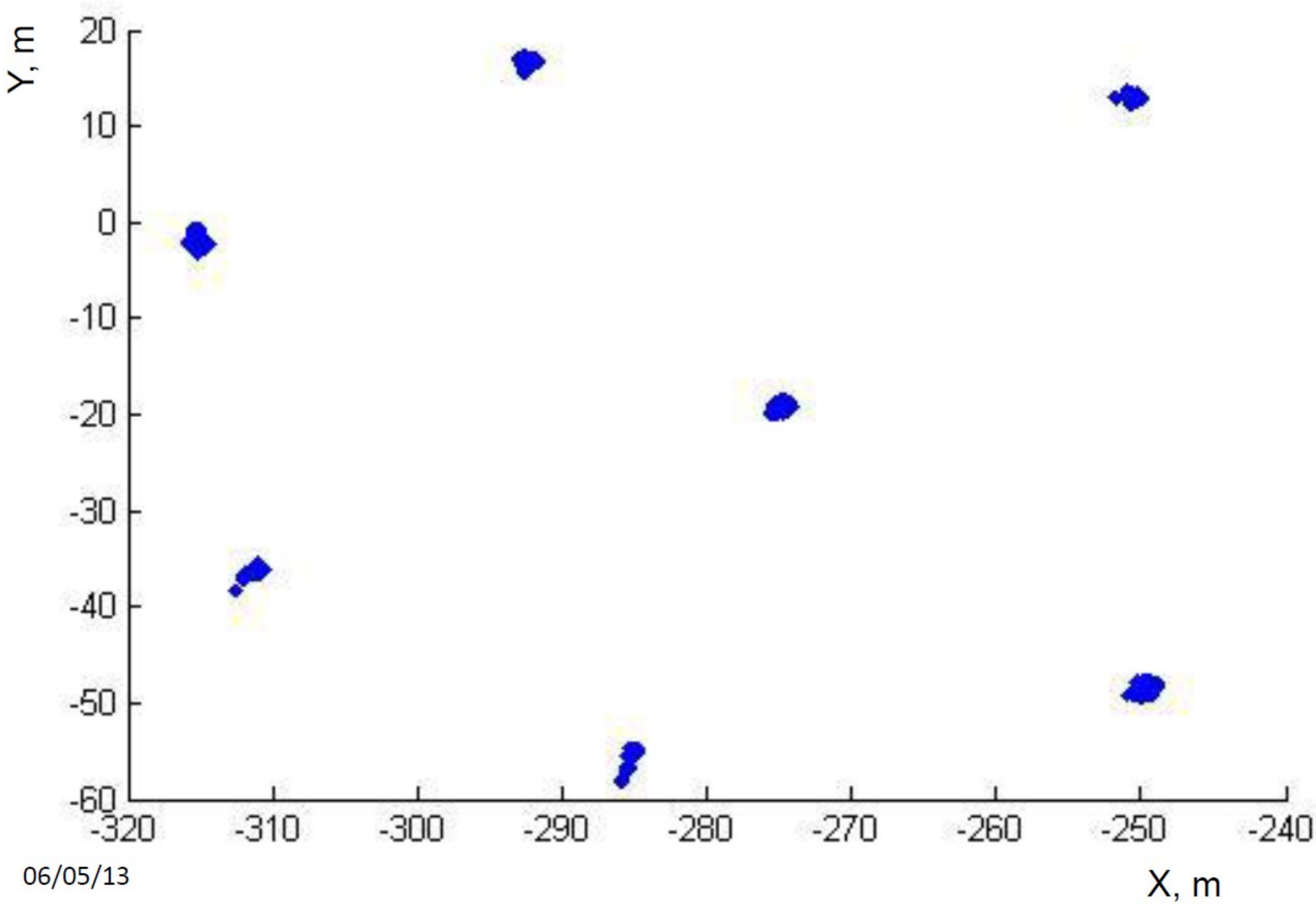
Performance of acoustic positioning system:

- data every 30 seconds
- high resolution ~ 3-5 cm

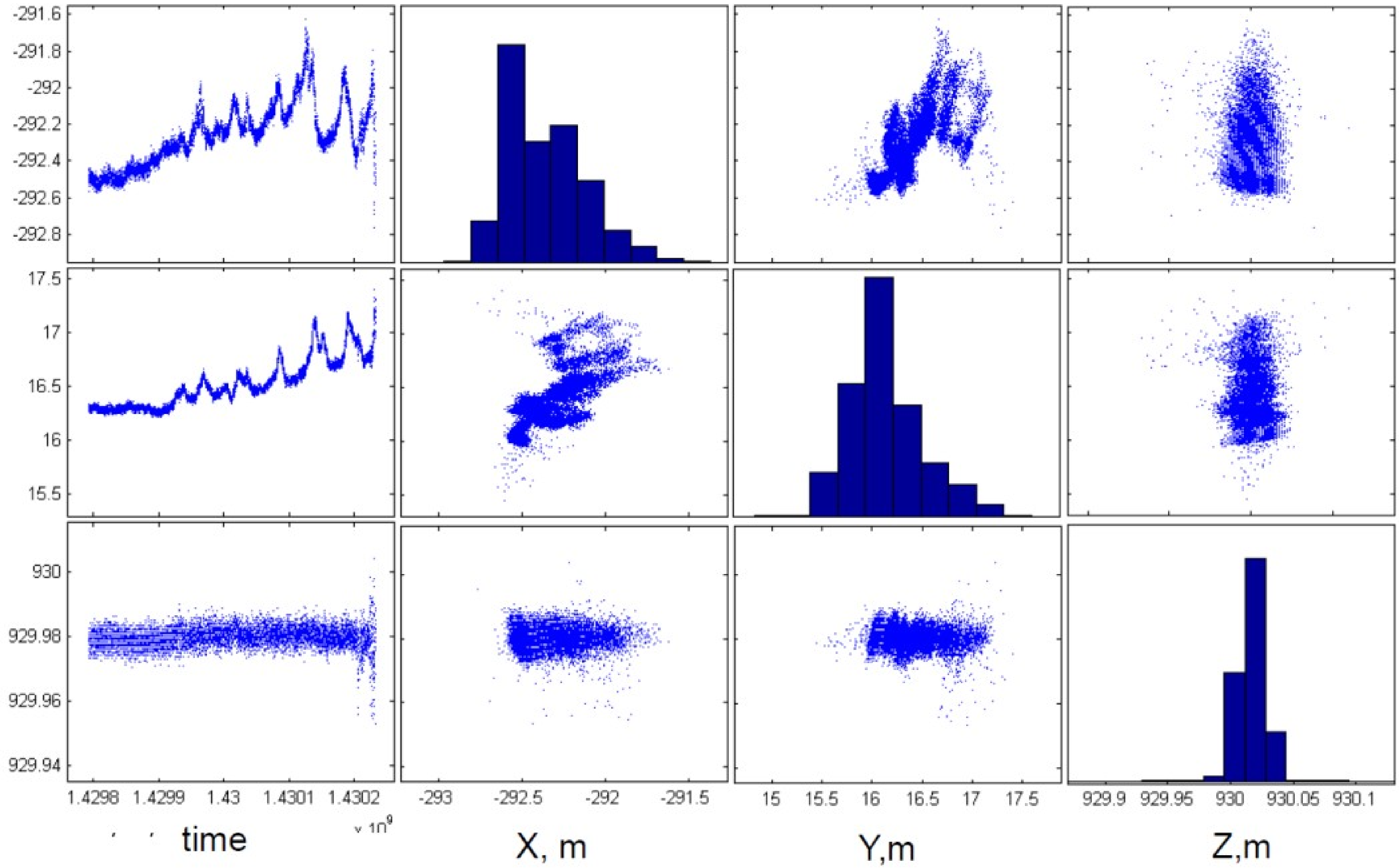


L = c·t/2, c ~ 1500 m/s

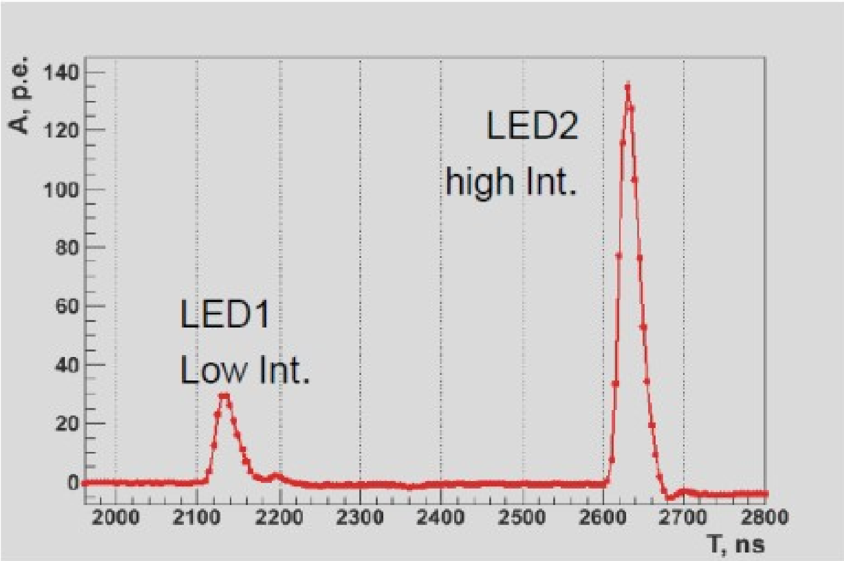
# X,Y – coordinates of positioning system modems

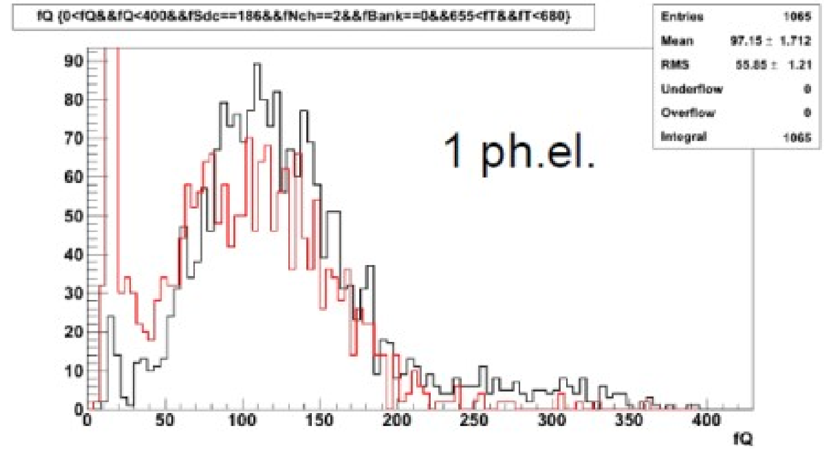


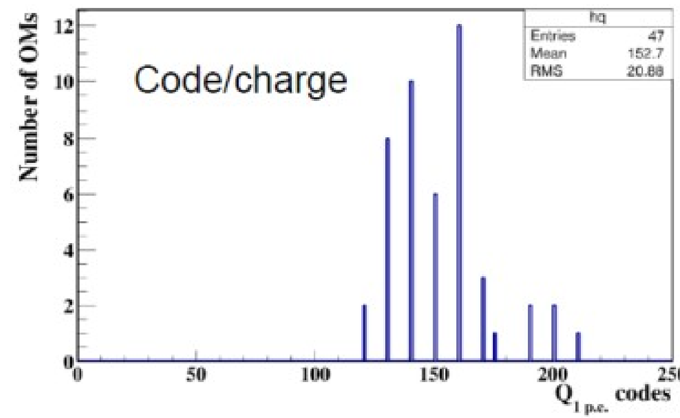
# Coordinates of transponder: May-2015

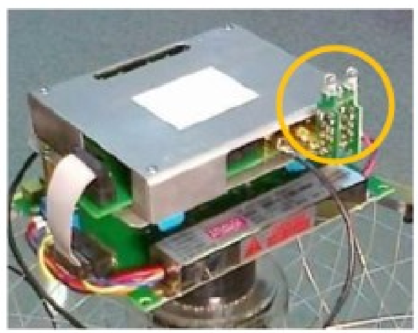


# Amplitude calibration



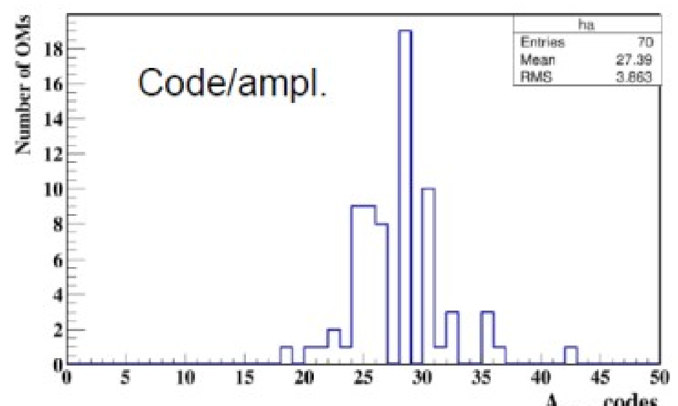



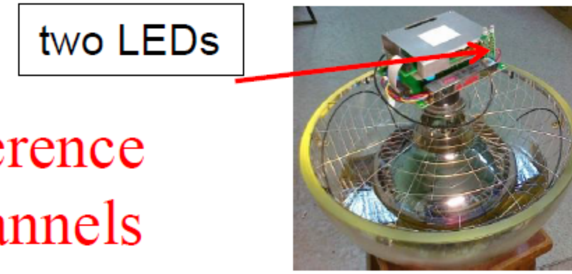
Calibration methods:

1 – two LEDs with high and low (~10% OM detection probability) intensities

2 – analysis of noise pulses

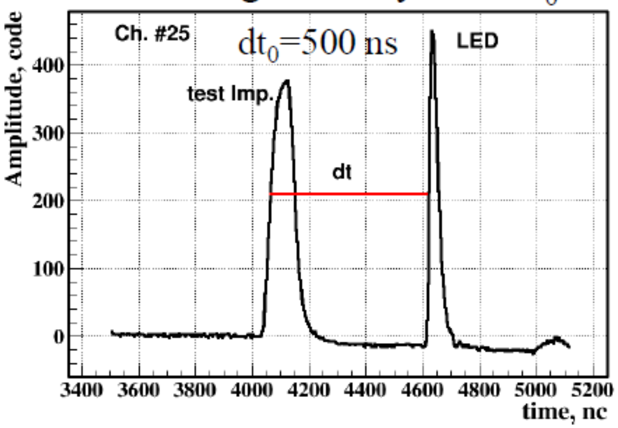


# Time calibration – two methods

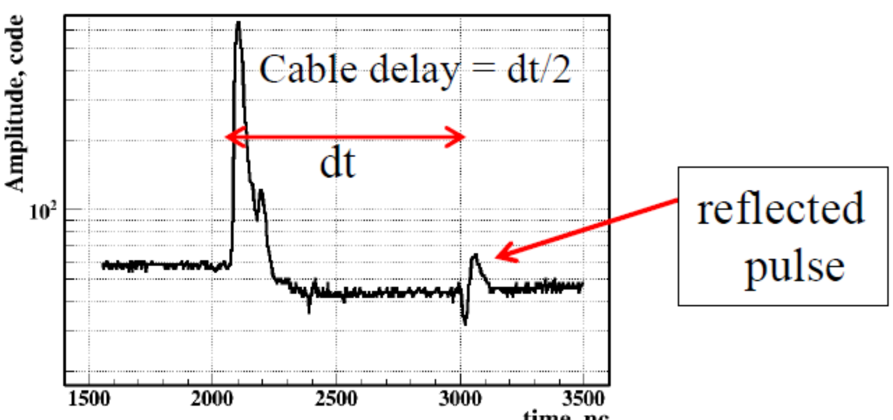



## Measurement of signal delay of each channel

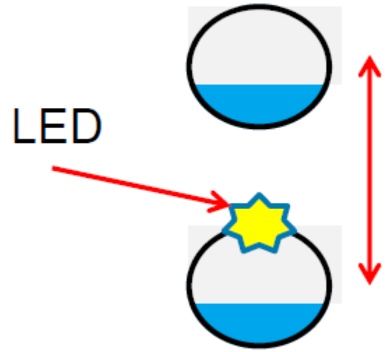
PMT signal delay = dt-dt$_0$




Signal delay in cable (~90 m) is measured in lab.

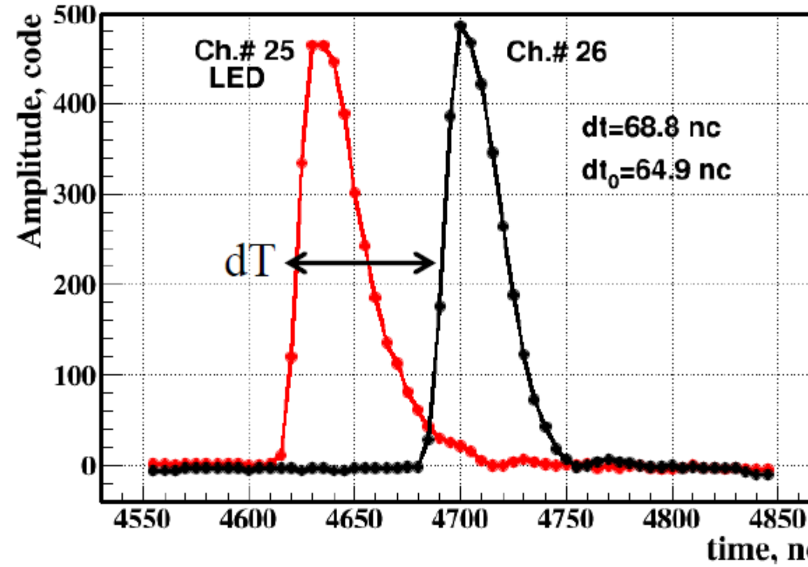



## Time difference of two channels




15 m- distance between OMs

$dT_0$ = 64.9 ns – expected time difference



# Operation - 2014

Laser based light-source

**External calibration laser:**

- 480 nm light pulses

- Five fixed intensities:
  $\sim 10^{12} - 6 \times 10^{13}\, \gamma\, / pulse$
  **(~10 PeV – 600 PeV shower energy)**

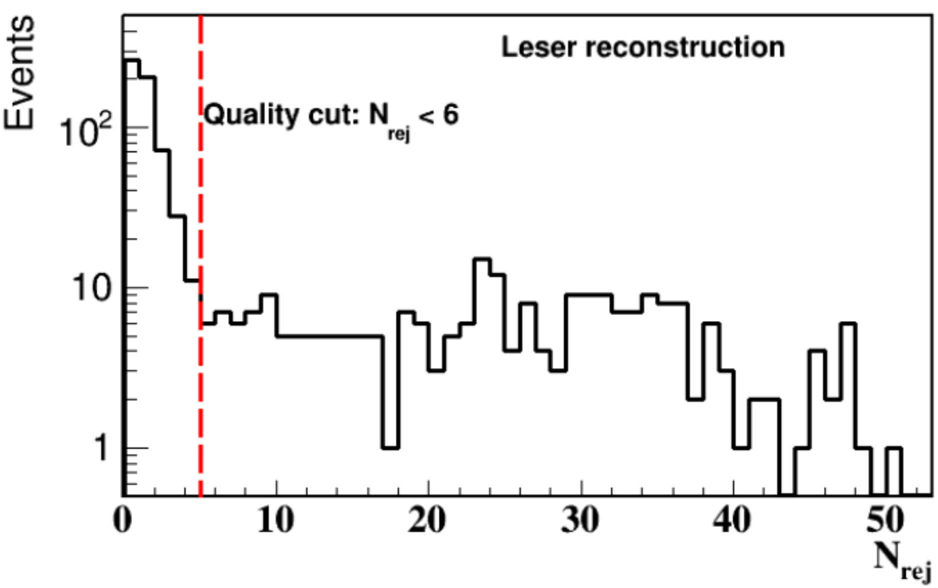
- Distances: 50 – 250 m.

# Reconstruction of laser-light source position

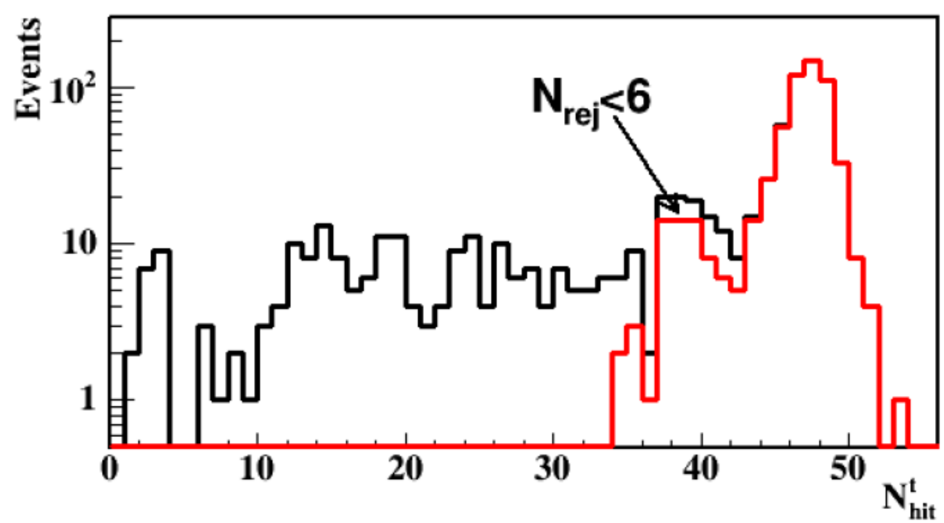
- Laser and OMs coordinates from data of acoustic positioning system
- Time offsets of OMs from LED calibration
- Iterative reconstruction procedure – OMs with residual δt > 15 ns are excluded from analysis

$$\chi_t^2 = \frac{1}{(N_{hit} - 4)} \sum_{i=1}^{N_{hit}} \frac{(T_i(x, y, z, t_0) - t_i)^2}{\sigma_{ti}^2},$$

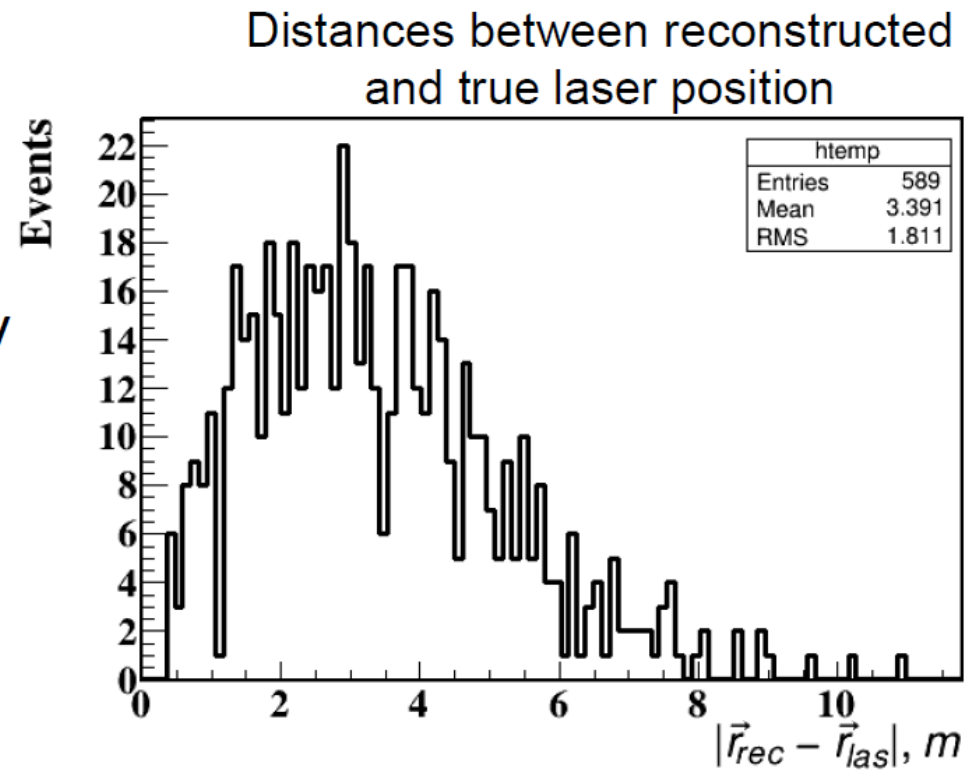
Multiplicity of rejected OMs



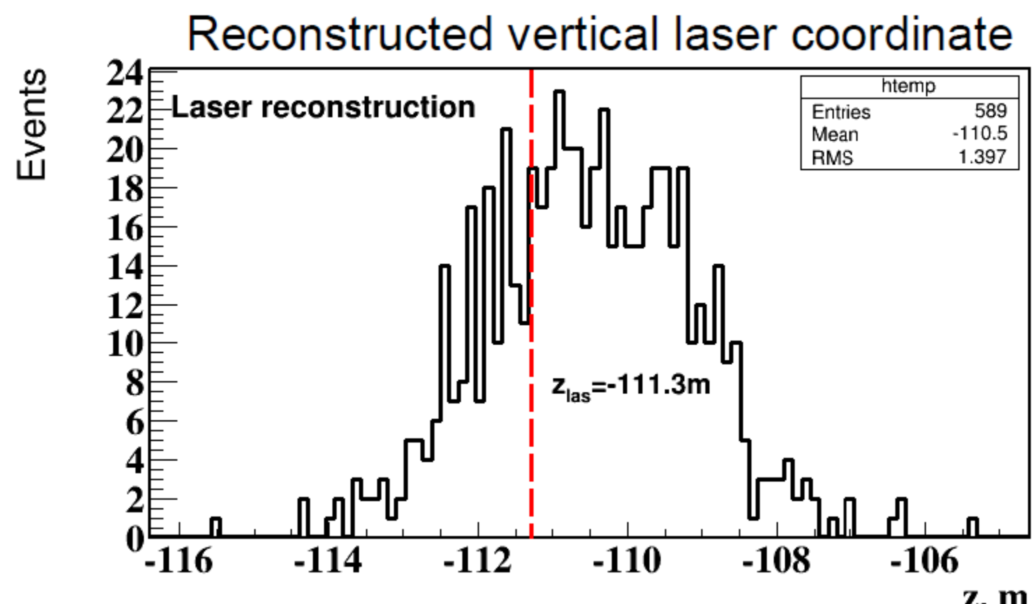

Multiplicity of hit OMs after reconstruction



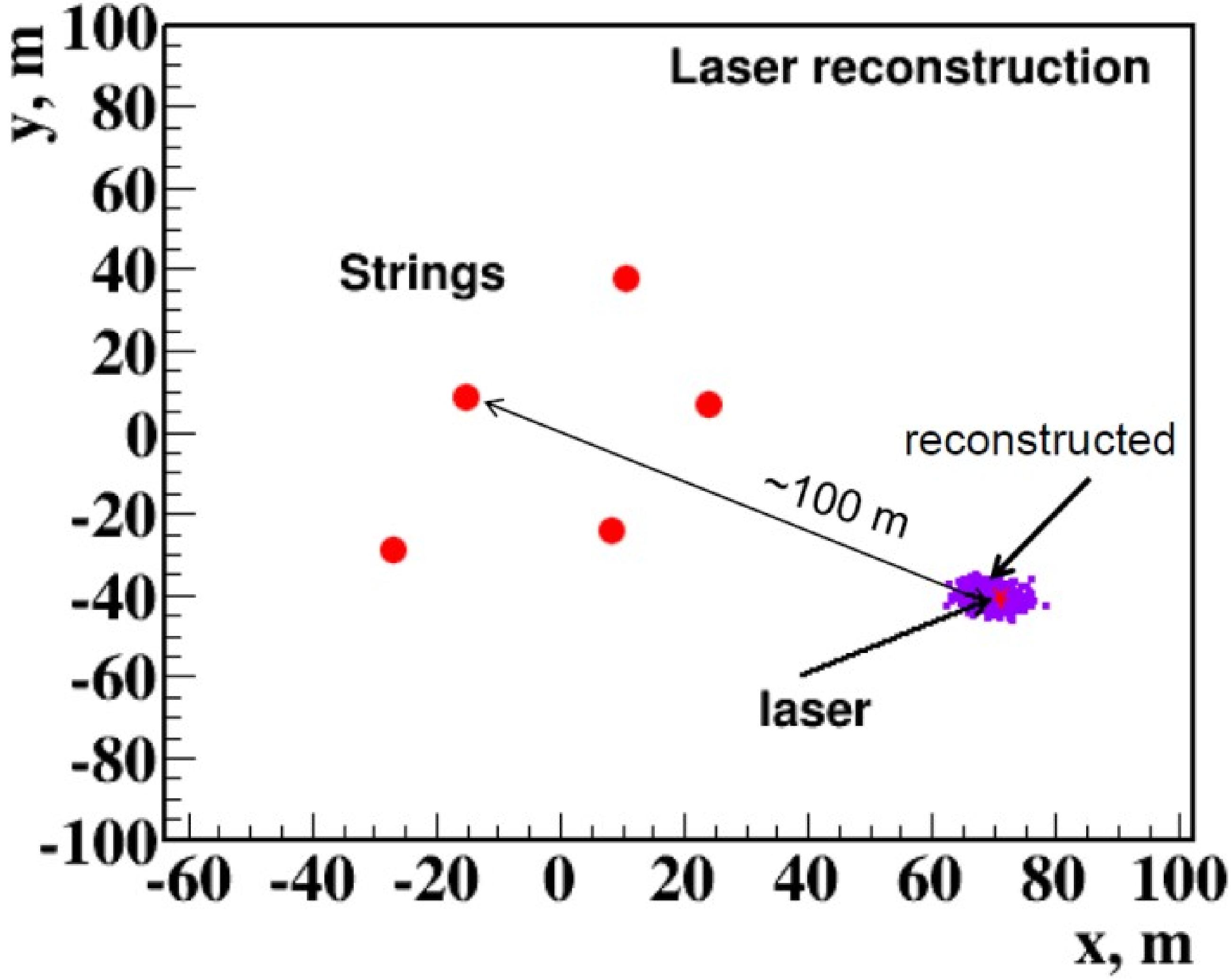
✓ Reconstruction accuracy (median value) of laser position ~3 m




✓ Accuracy of vertical coordinate about of 1.5 m

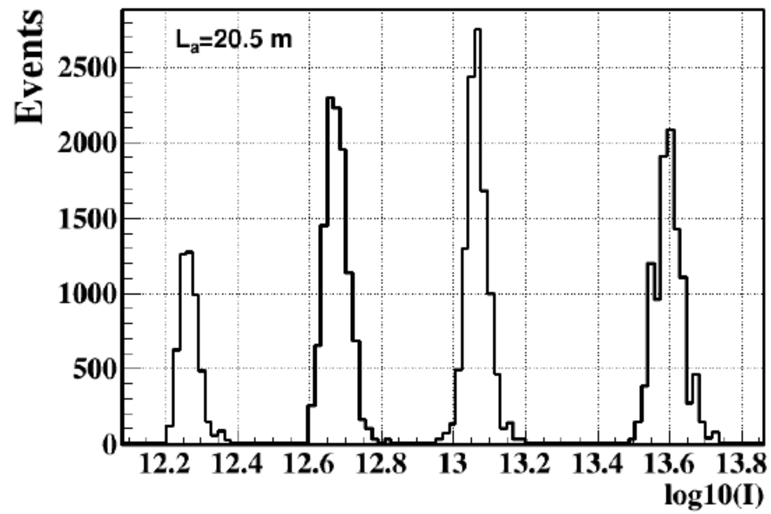


# Reconstruction of laser-light source position



# Laser intensity reconstruction

Distributions of reconstructed laser intensities



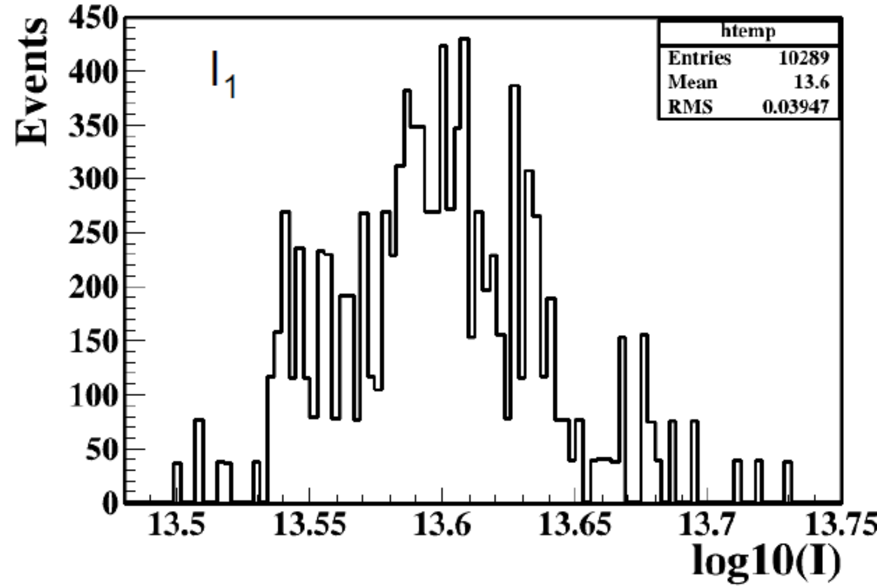

**External calibration laser:**

- 480 nm light pulses;
- Five fixed intensities: $\sim 10^{12} - 6\times10^{13}\ \gamma\ /\ pulse$
  **(~10 PeV – 600 PeV shower energy)**
- Distances: 130 – 250 m.

**Average values of reconstructed intensities for four light source output series**

| $I, 10^{12}\gamma/pulse$ | $I_1$ | $I_2$ | $I_3$ | $I_4$ |
|---|---|---|---|---|
| Cluster | **40** | **12** | **4.7** | **1.8** |

Reconstruction accuracy ~ 10 %



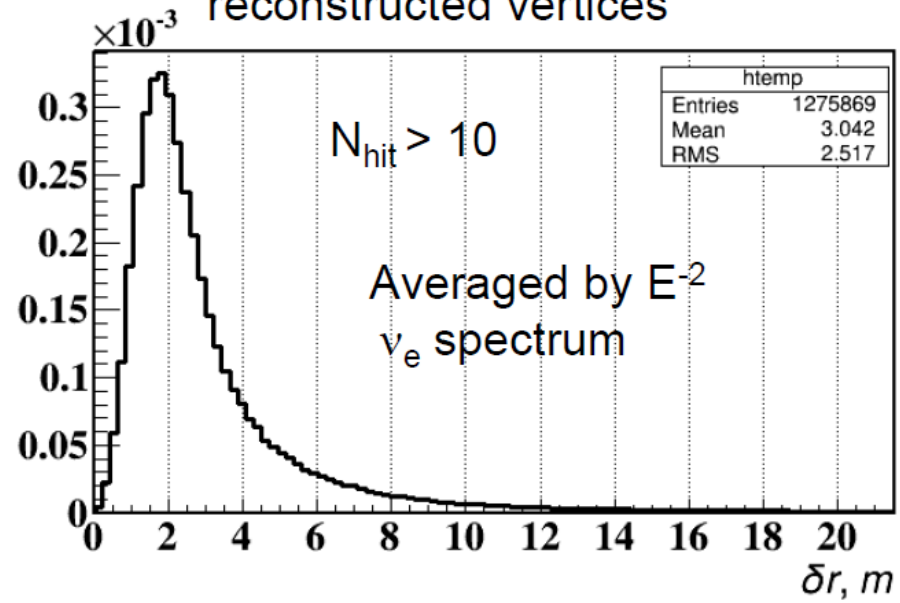
# Cluster performance for cascades detection

- **Reconstruction of a cascade vertex:**

  **Iterative procedure- OMs with residual $\delta t > 15$ ns are excluded and final $N_{hit}$ is obtained for following analysis.**

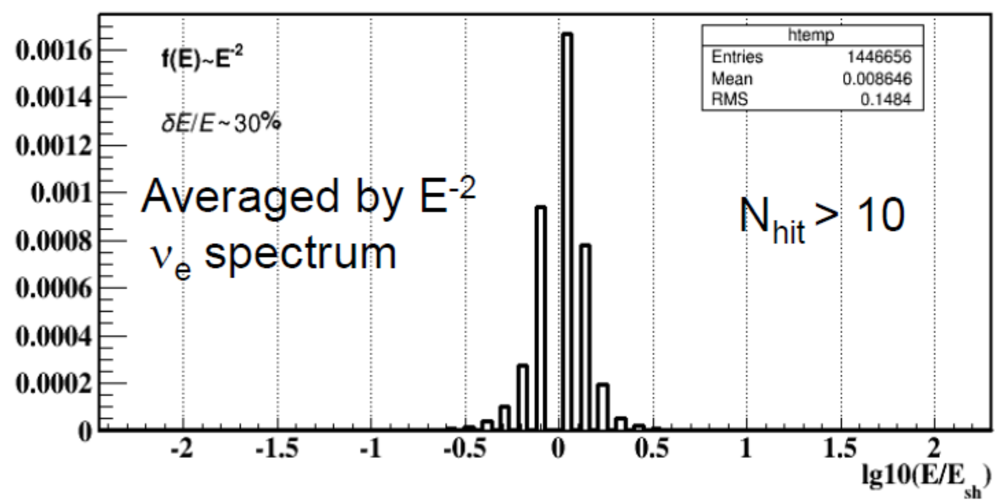
  **$\delta r = |\mathbf{r}_{rec} - \mathbf{r}_{gen}| \sim 2$ m (median value)**

Distance between generated and reconstructed vertices




- **Energy resolution for cascades:**

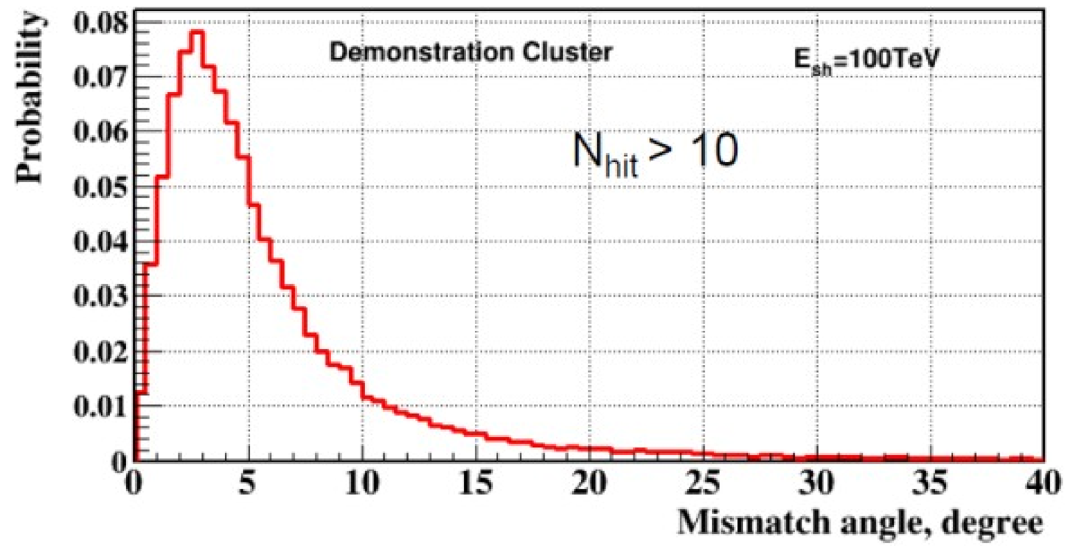
  $\delta E/E$ **~ 30%** , averaged by $E^{-2}$ $\nu_e$ spectrum



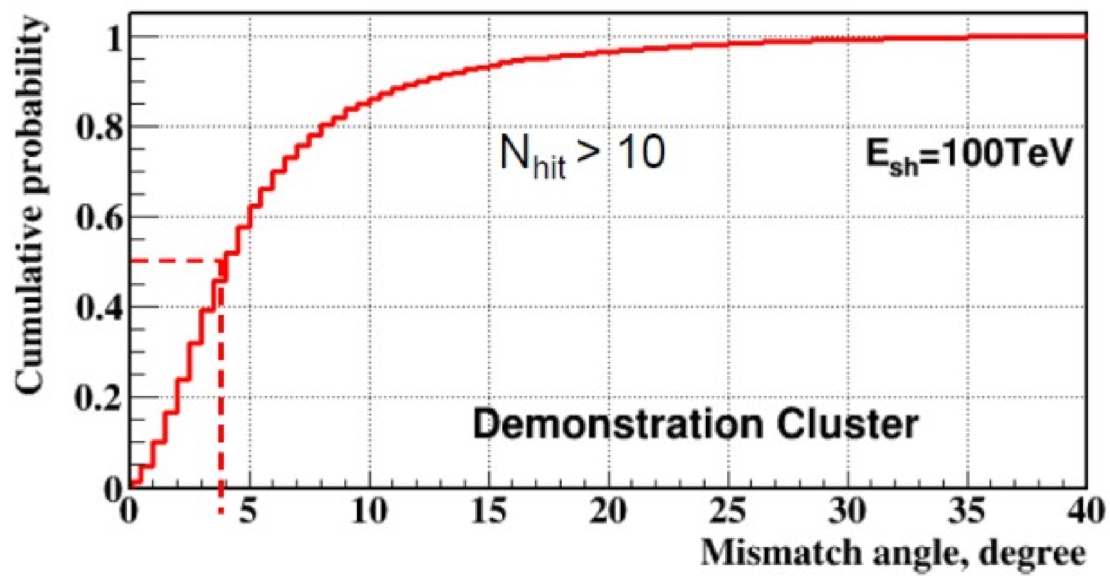
**Directional resolution for cascades:**

**Median value of mismatch angles ~ 3°- 4° depending on energy and cuts**

Distribution of mismatch angles



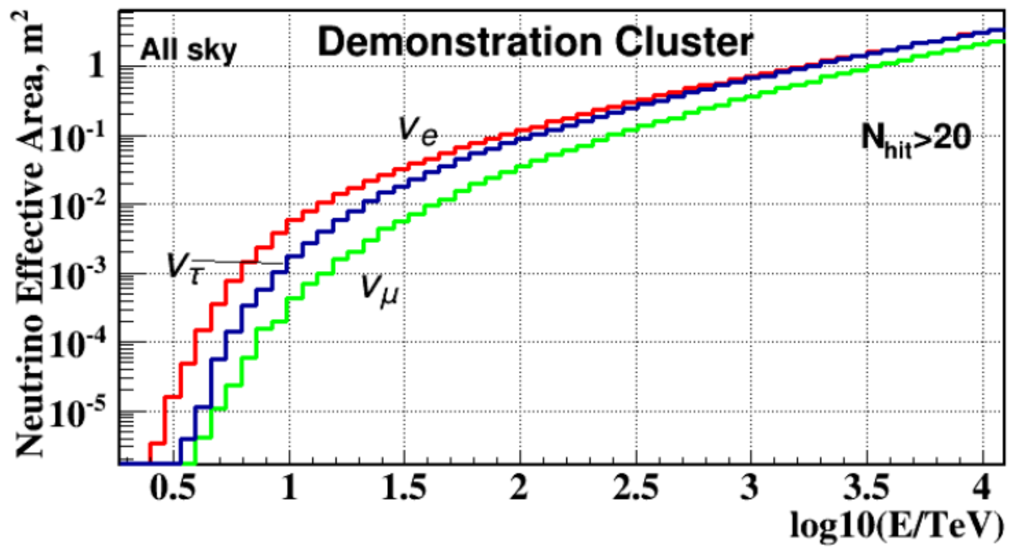

Cumulative distribution



# GVD-Cluster:

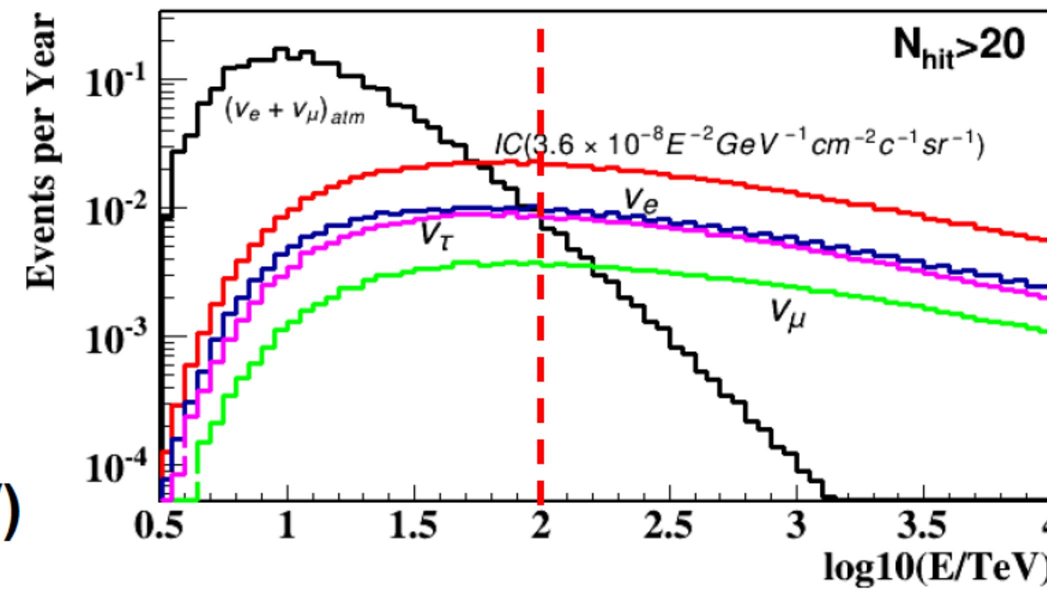
## Neutrino Effective Area

Cut on number of hit OMs after vertex reconstruction significantly suppresses background atm. neutrinos




## Events per Year from IC-flux ($E^2F_{IC}=3.6\cdot10^{-8}$ GeV cm$^{-2}$s$^{-1}$sr$^{-1}$)

Applied cuts:
$N_{hit} > 20$;
$E_{rec} > 100$ TeV

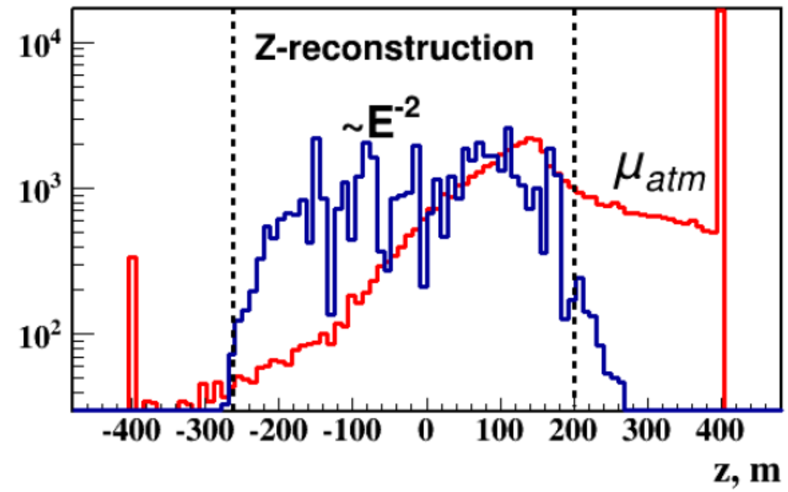



**~1 Event/Year (>100 TeV)**

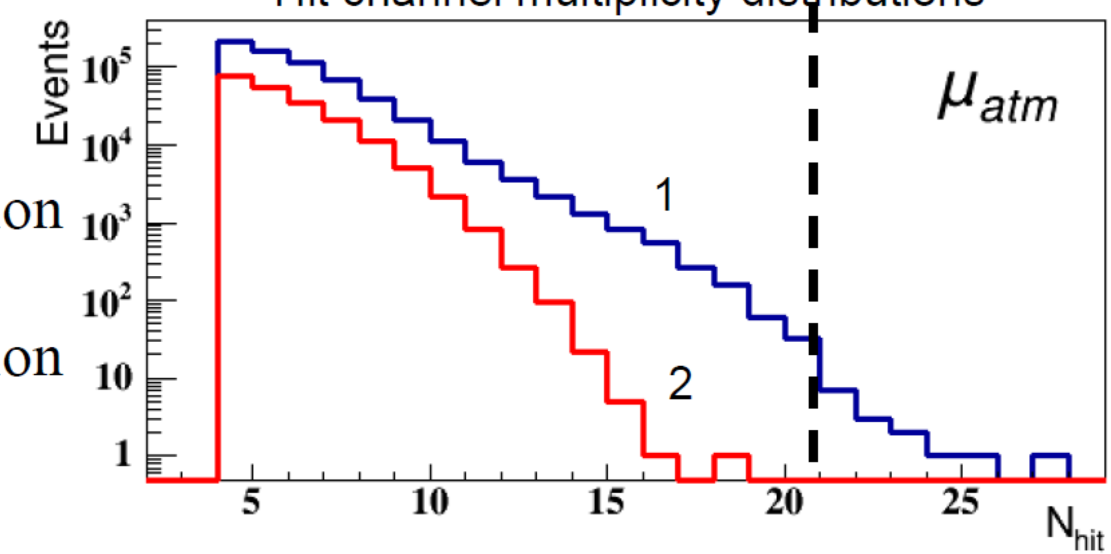
# Atmospheric muons MC-sample corresponding to 341 life days

✓ Vertex reconstruction filter:
$-270 < z_{rec} < 200$ m,

(OMs location: -172.5 ÷ +172.5 m)




Hit channel multiplicity distributions




1 – after vertex reconstruction

2 – after vertex reconstruction quality cuts

# Cluster performance for cascades detection

**Applied cuts:**

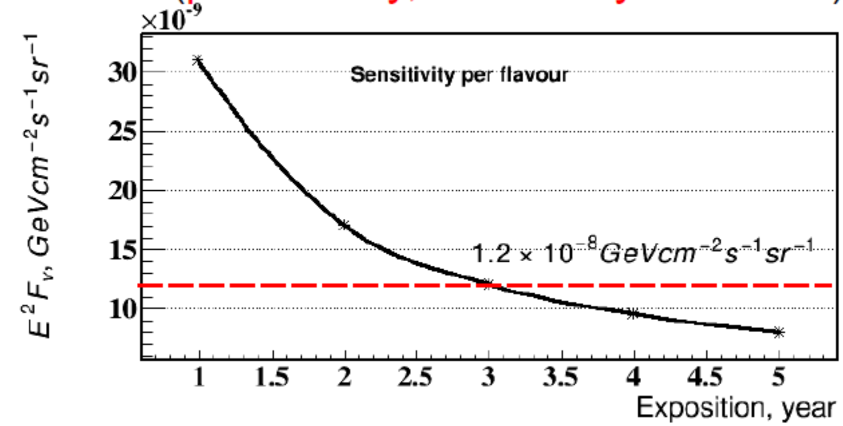
- $N_{hit}$ > 20 (after vertex reconstruction)
- Vertex reconstruction filter:
  -270< $z_{rec}$<200 m
  (OMs location: -172.5 ÷ +172.5 m)
- $E_{rec}$ > 100 TeV

Expected number of events for 1 year exposition:

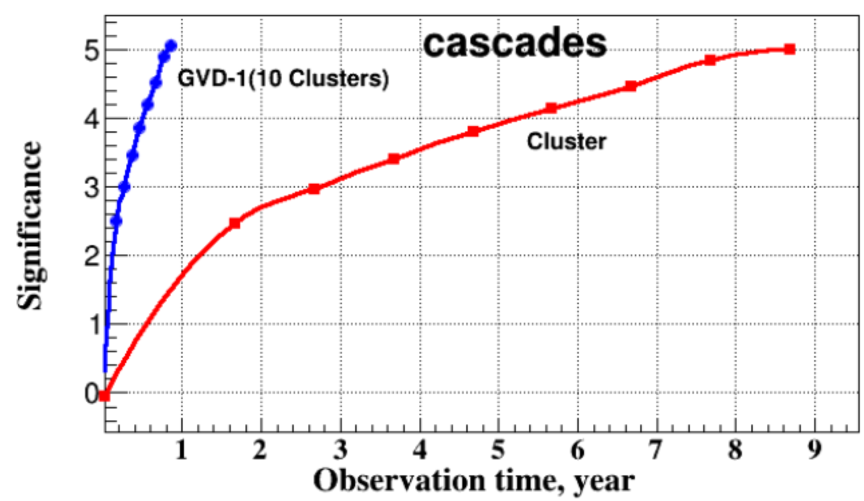
Signal:
1 ev. from astrophysical IC flux
($3.6x10^{-8}$ GeV $cm^{-2}$ $s^{-1}$ $sr^{-1}$)

Background:
0.05 ev – atm. ν;
0.05 ev. – atm. μ

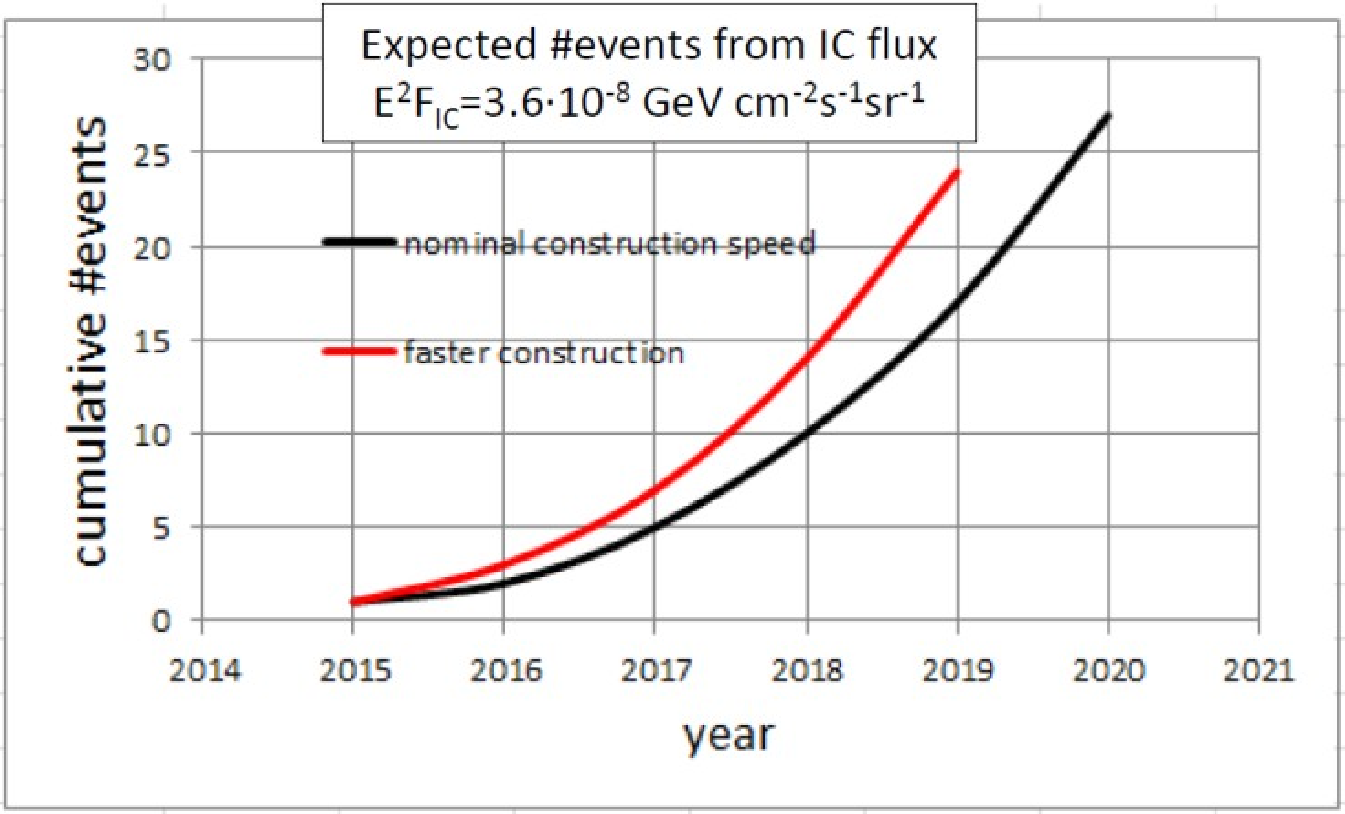
Sensitivity on one flavor $E^{-2}$ flux
(preliminary, without systematics)




5 σ discovery potential for IC neutrino flux with $E^{-2}$ spectrum

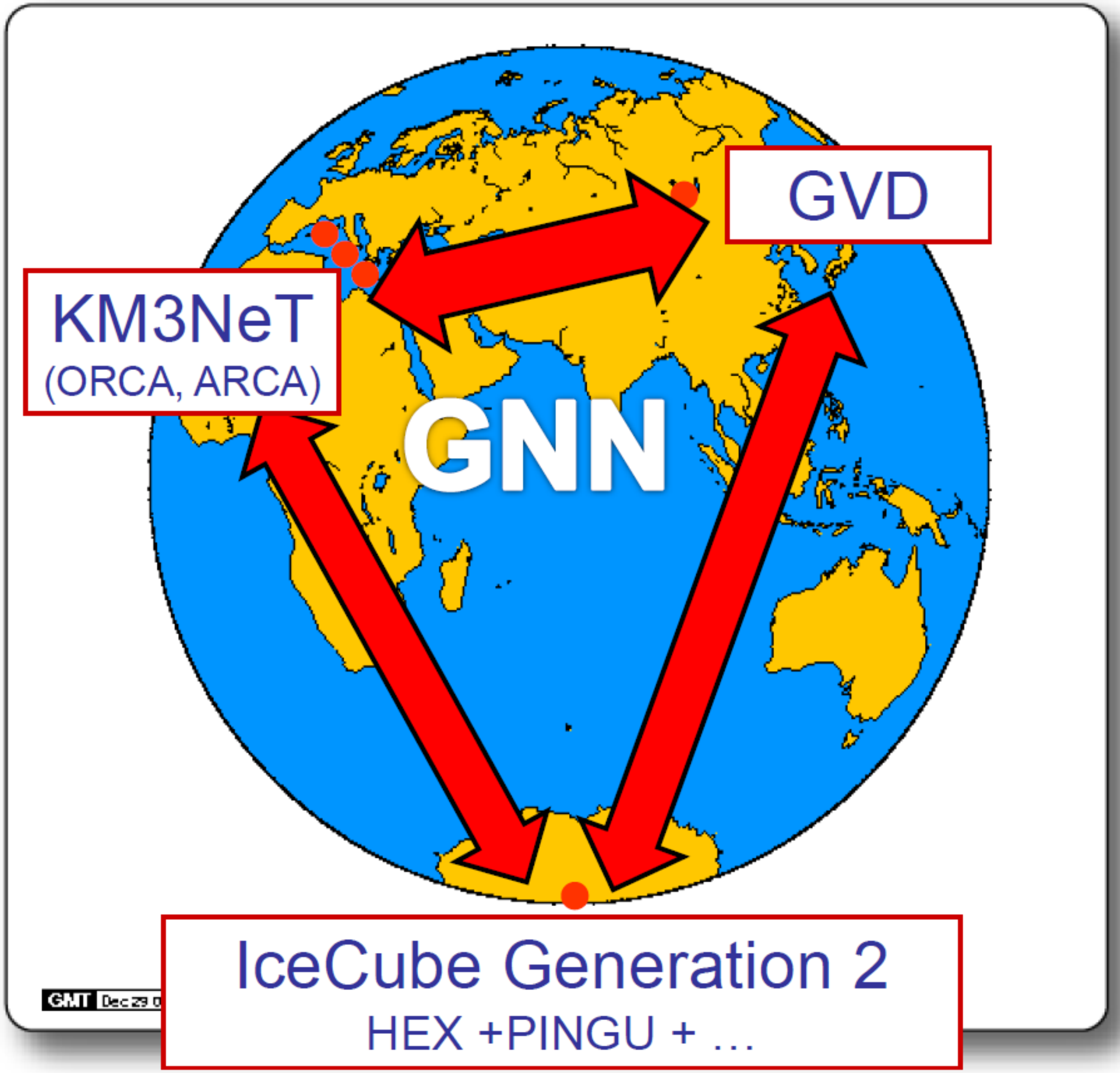


# Baikal-GVD: performance




E > 100 TeV: ~1 event/cluster/year

# Baikal, Mediterranean Sea, South Pole



# Thank You for your attention