Cascade reconstruction and angular resolution in GVD

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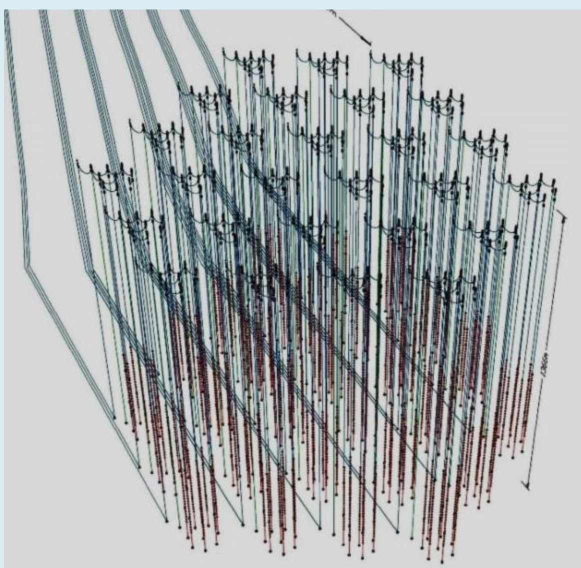
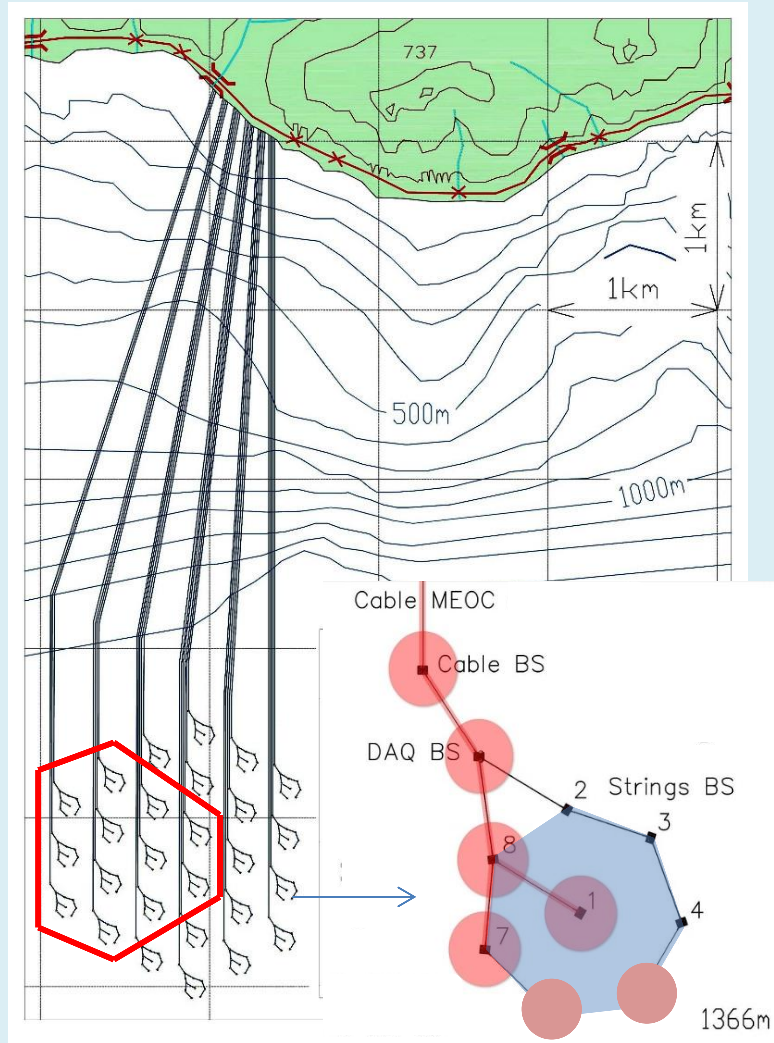
Gigaton Volume Detector (Lake Baikal)

	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

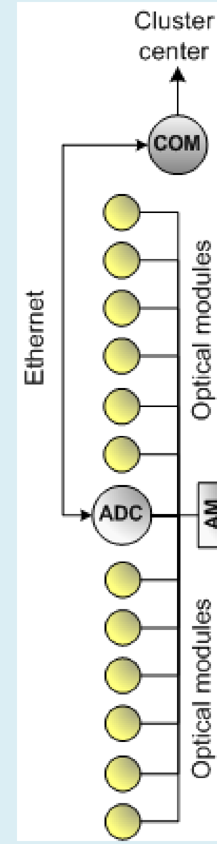




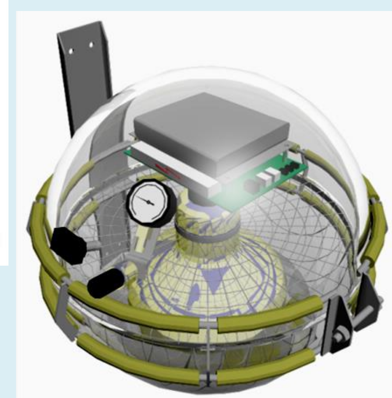
GVD array

1st GVD cluster: 8 strings

- Installed strings and cable stations



Section: basic detection unit



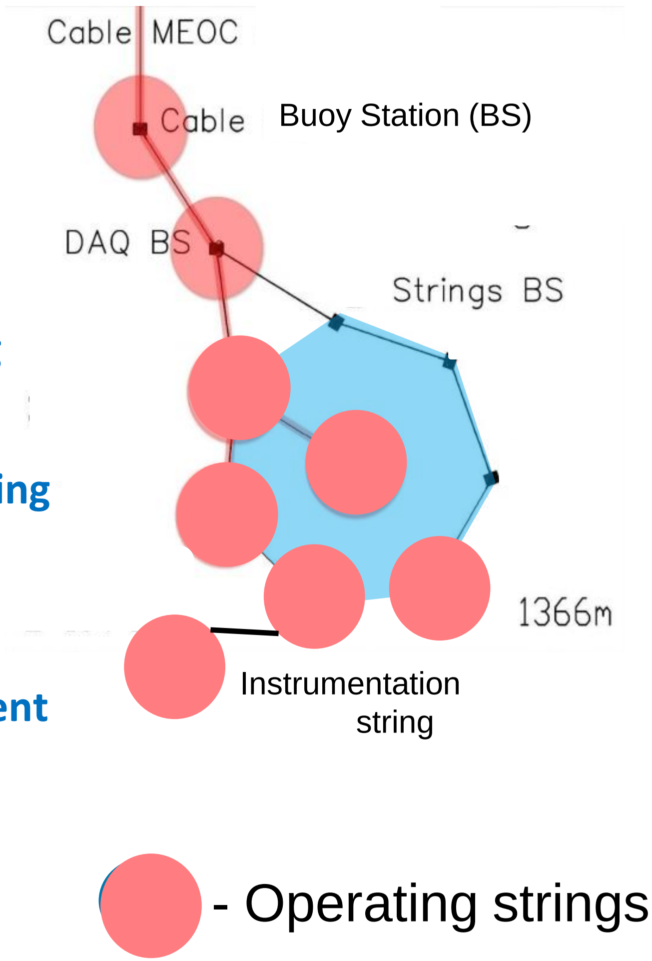
Optical module

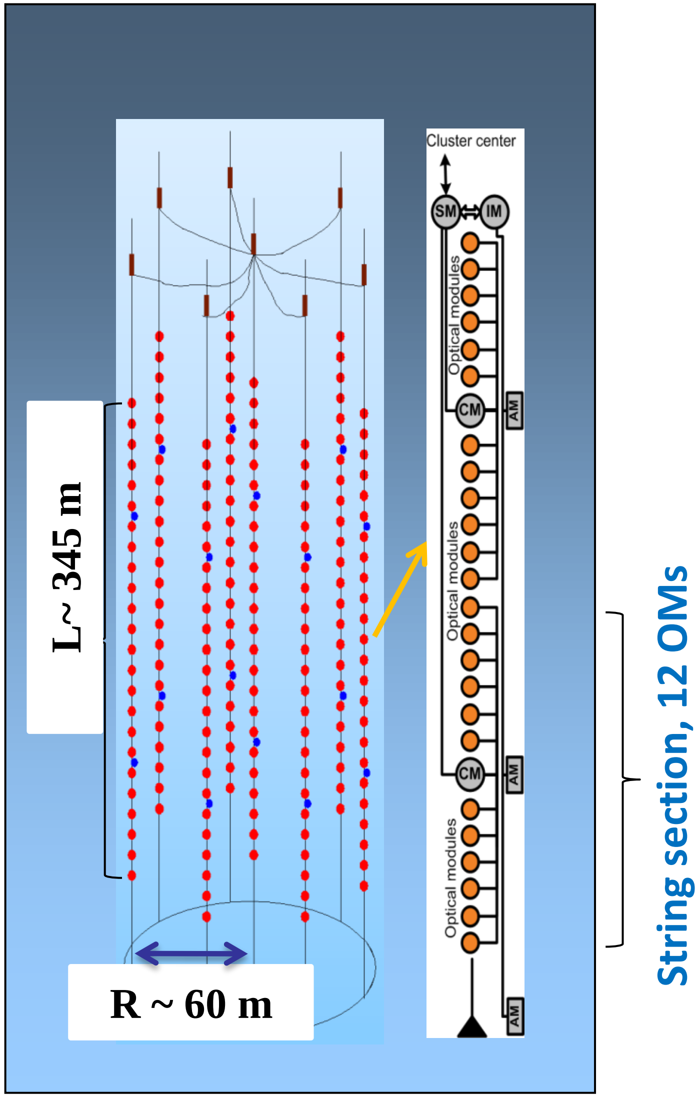
First Cluster-2015:

First cluster „DUBNA“

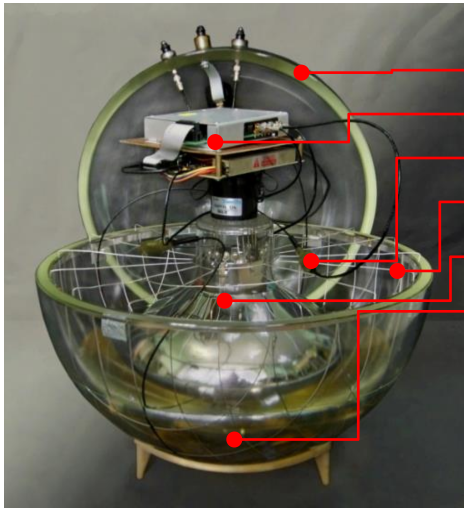
- 192 OMs at 8 Strings
  - 2 Sections per String
  - 12 OMs per Section
- DAQ-Center
- Cable to Shore
- Acoustic Positioning System
- Instrumentation String with detector calibration and environment monitoring equipment
- Active depth 950 – 1300 m

Layout - 2014



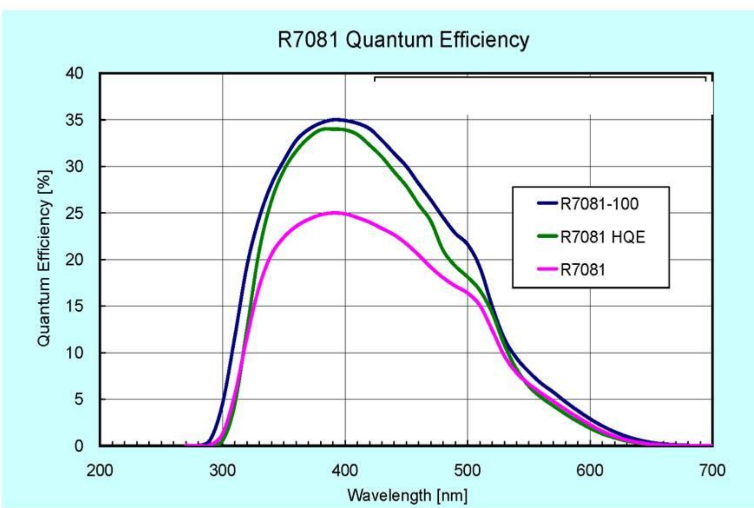


Optical module (OM)

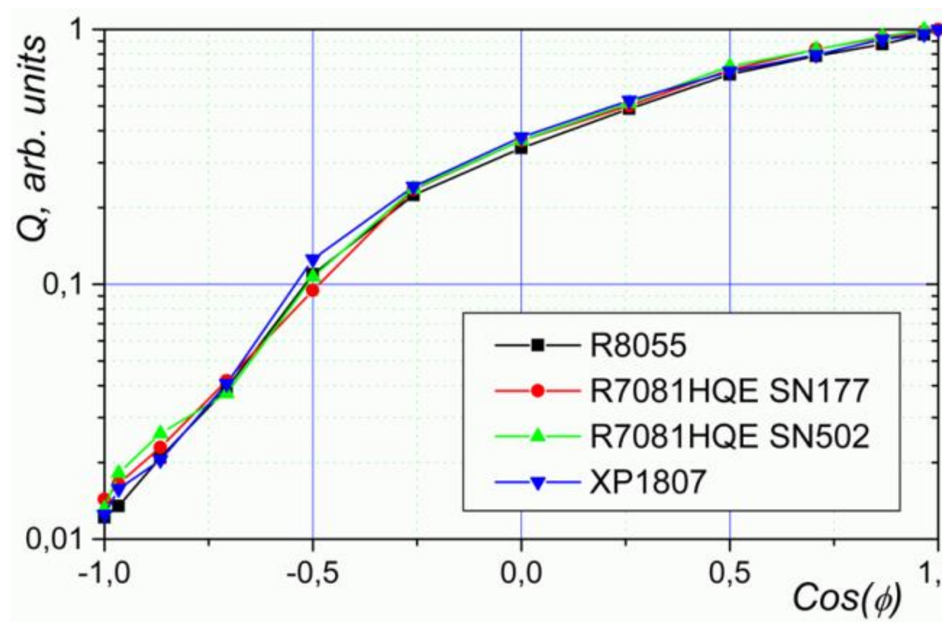


- Glass pressure-resistant sphere VITROVEX (17")
- OM electronics: amplifier, HV DC-DC, controller
- 2 on-board LED flashers: 1…10^8 pe., 430 nm, 5 ns
- Mu-metal cage
- **PMT R7081HQE : *D*=10", ~0.35QE**
- Elastic gel

Quantum efficiency



Angular sensitivity

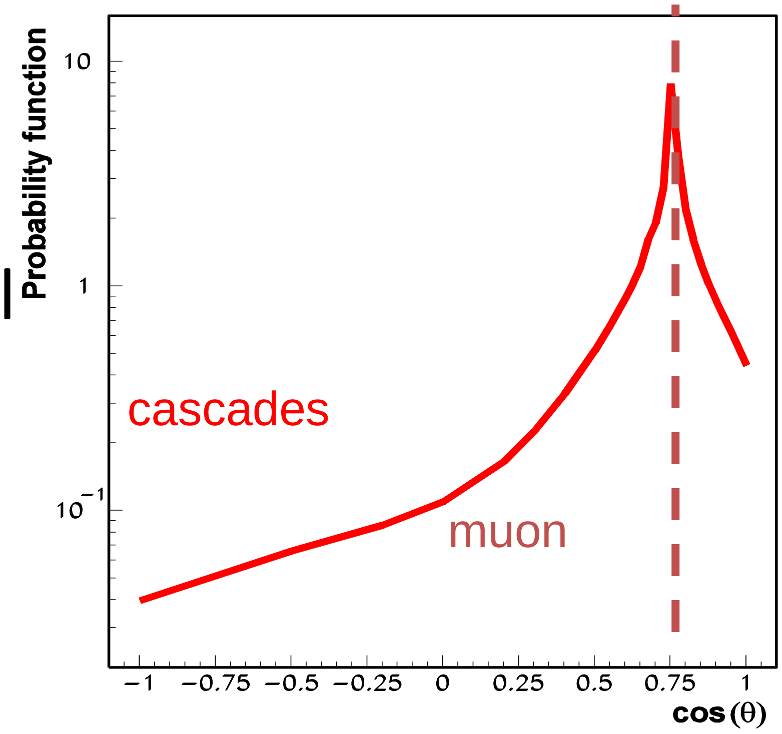


• Detection Mode

Cherenkov radiation

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

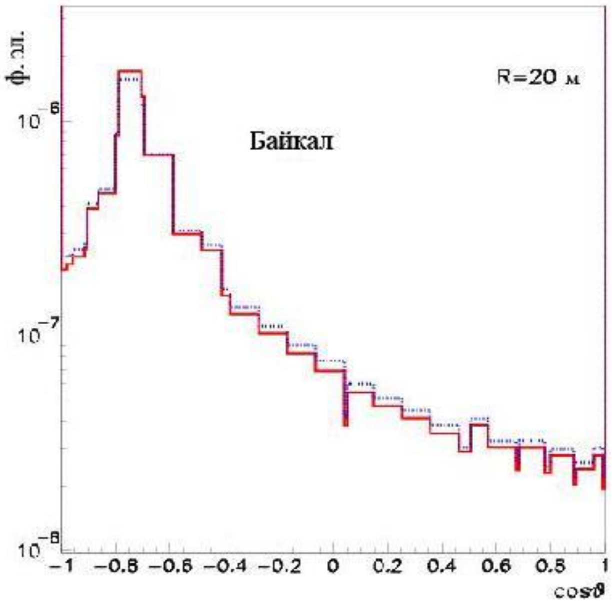
- Point-like, strongly anisotropic light-source - size proportional to lnE_{ν} (but LPM-effect for >20PeV!)
- Light intensity proportional to $E_{\nu} \cdot 10^8$ γ/TeV
- Detection efficiency strongly depend on environment properties (water/ice).

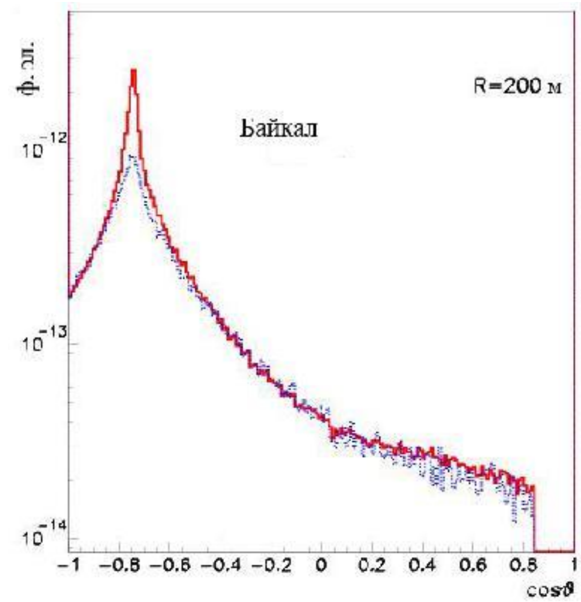


• Environment properties (Baikal)

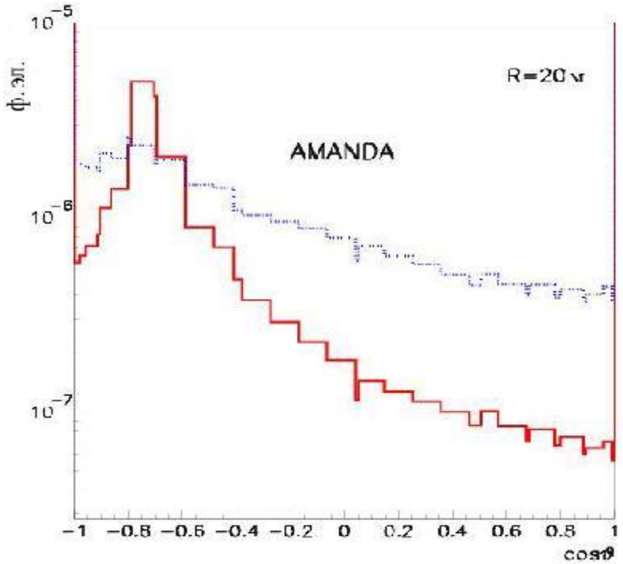
- ✓ Light absorption: L_{abs} ~ 20 – 25 m
- ✓ Light scattering: L_s ~ 30 – 50 m
- ✓ Dispersion of light velocity nigligible
- ✓ Light background: 15 - 40 kHz
- ✓ Scattering function: <cosθ> ~ 0.88

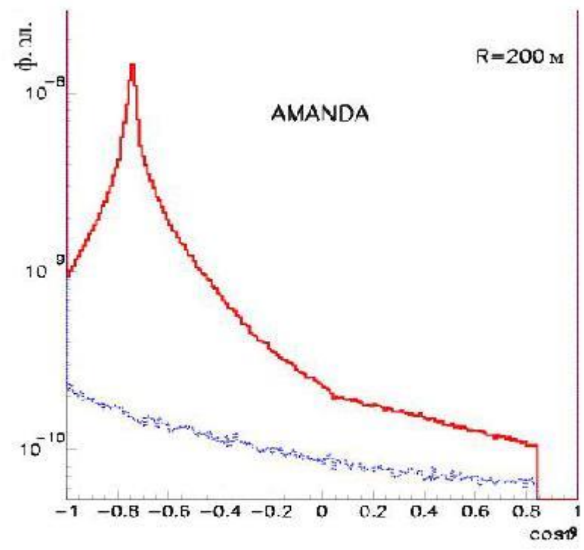
Water (Baikal): Light Scattering - 30 – 50 m





Antarctic Ice: Light Scattering - 1 – 4 m





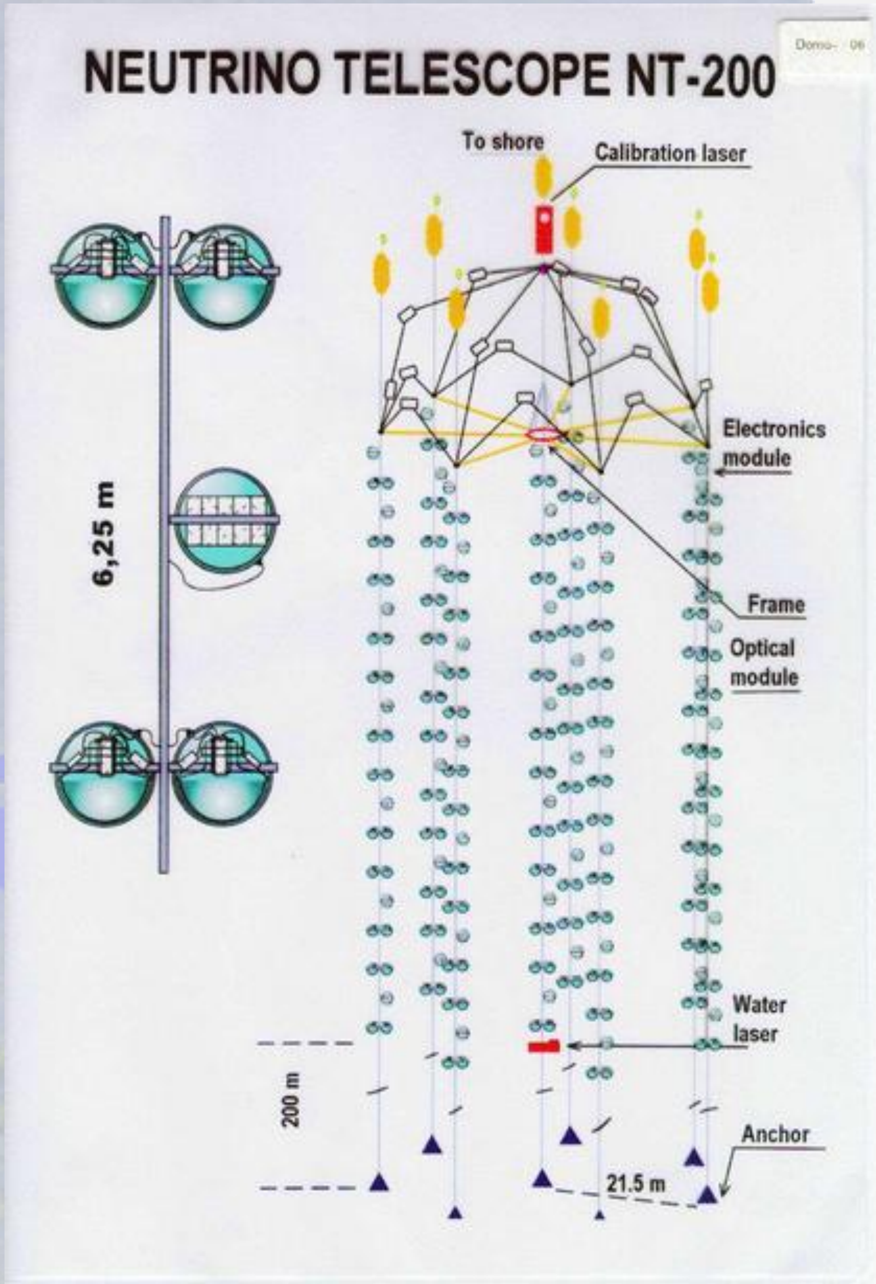
- **Background**

  - Cascades from atm, muons

  - Atm. electron neutrinos ($\sim E_\nu^{-3.7}$) ($\nu_e/\nu_\mu \sim 1/20$)

History of Cascade detection in Baikal

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



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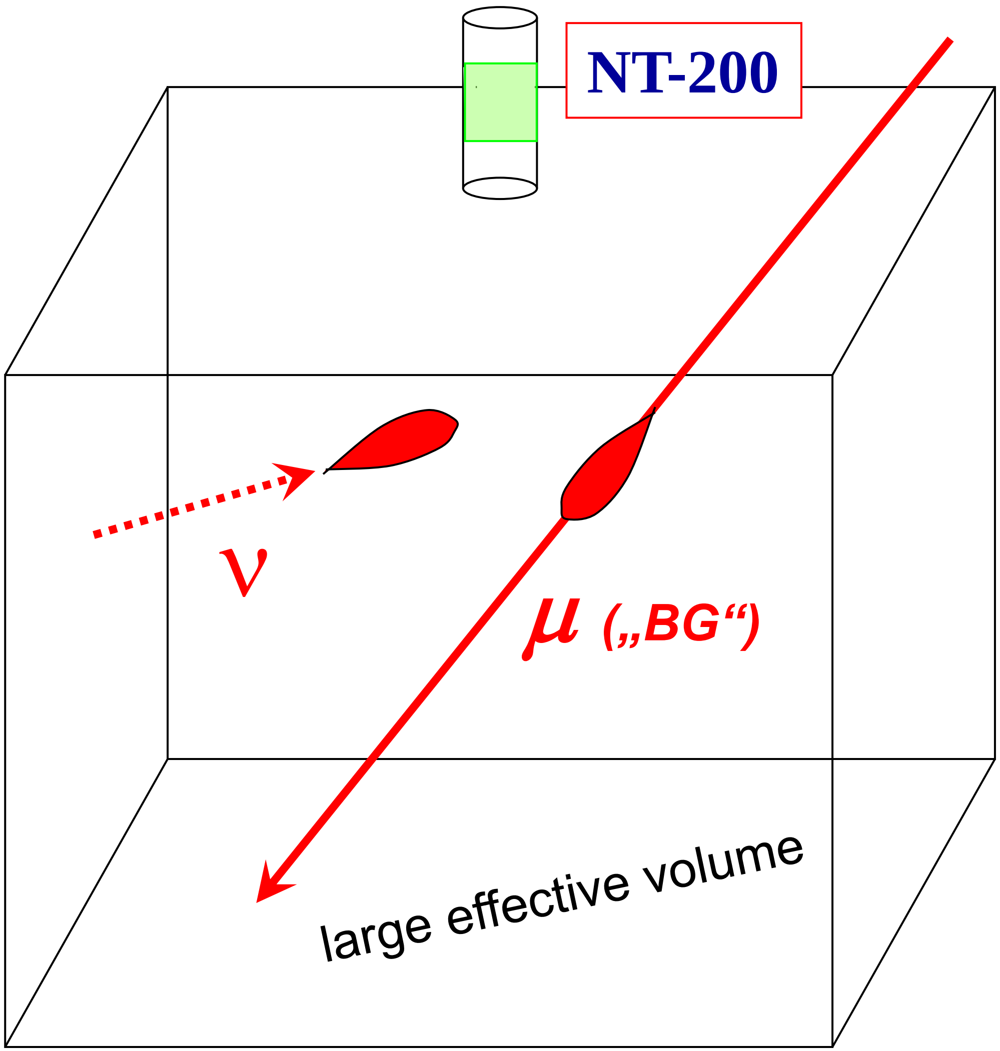
Search for High-Energy Cascades With NT200



Cascades produced below NT200:

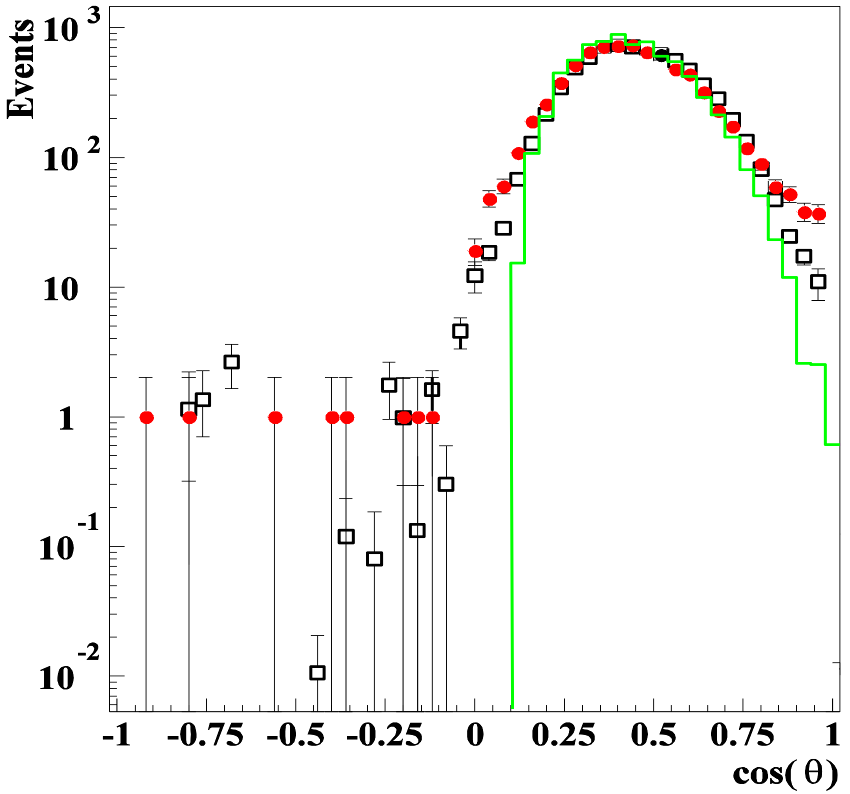
- **Arrival times were used for vertex reconstruction:**
  $\Delta r/r \sim 7\%$

- **PMT amplitudes were used for energy and derection reconstruction:**
  $\delta \lg E \sim 20\%$, $\psi_{med} \sim 4.5°$

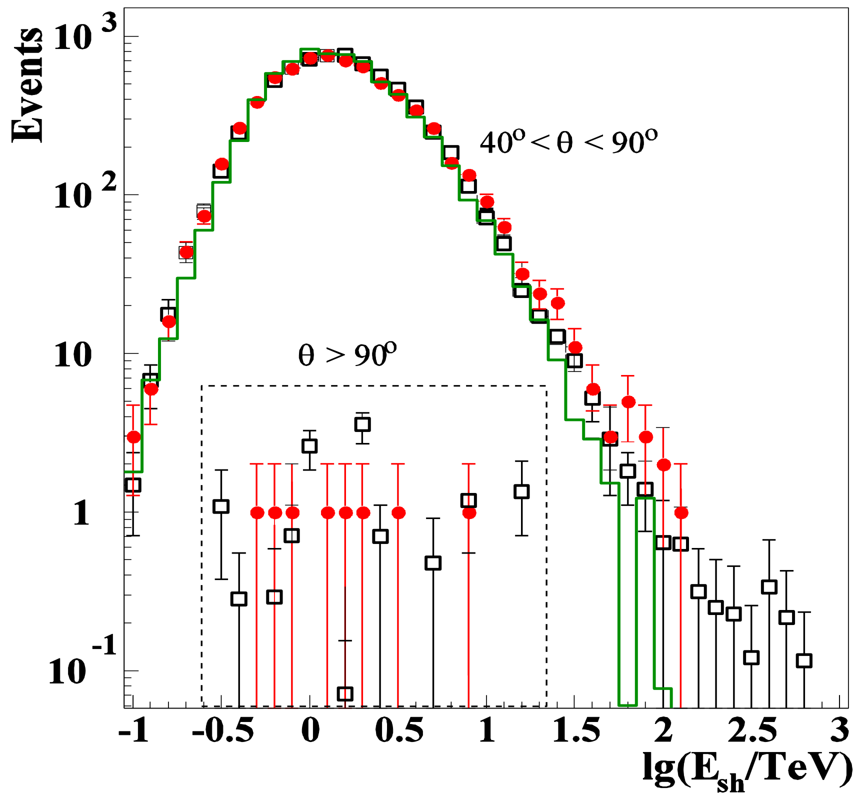
Results of laser light source position and intensity reconstruction prove an efficiancy of used methods.

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)

Generation procedure:

- Cascade vertex r(x,y,z) within ~0.3 km^3 volume and direction Ω

- Neutrino ($\nu_{e,}$ $\nu_{\mu,}$ ν_{τ}):
  - Energy selection – uniform logE distribution
  - passing through Earth to vertex point (CC, NC)
    – survival probability (due to CC), final energy (due to NC)
  - Interaction in r and cascade energy E_{sh} generation

- Light propagation in water and OM-response
  - OM-response table n(μ,ψ,t,ρ,r) on point-like cascade
  - Integration along cascade length

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

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 $\bar{n}_{pe}(\rho, z, \theta, \varphi, \tau)$

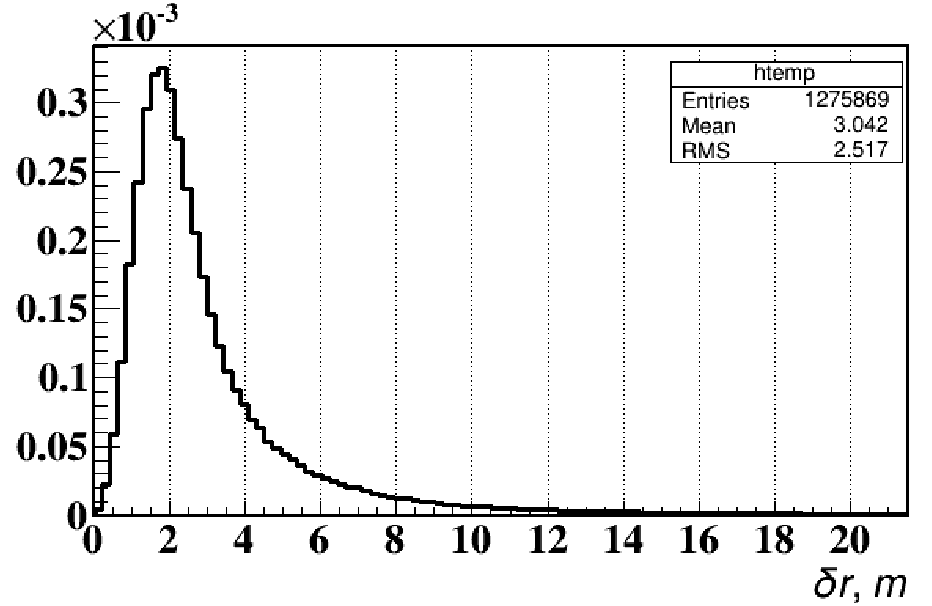
Reconstruction of a cascade vertex in GVD-Cluster

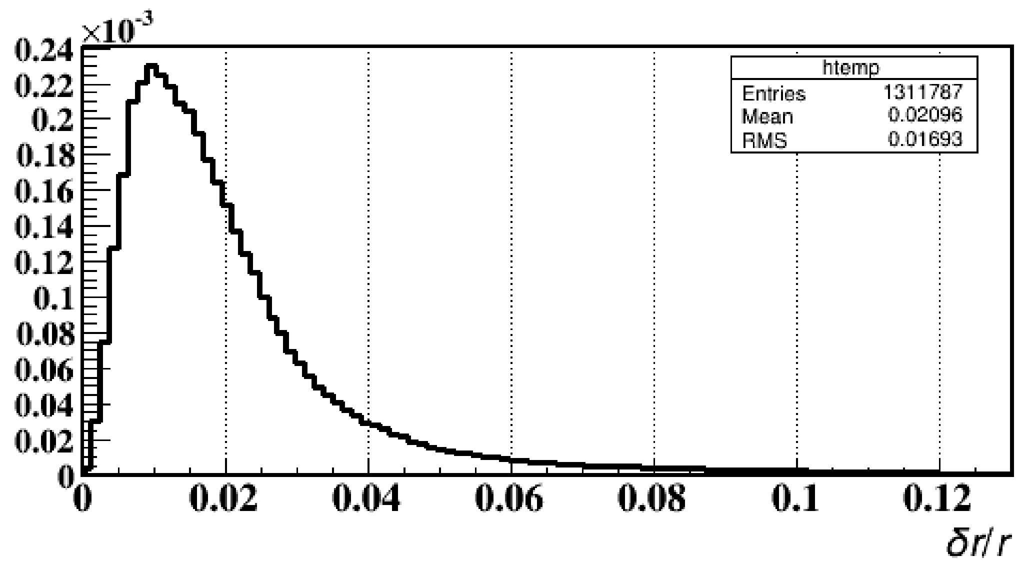
Iterative procedure- OMs with residual $\delta t > 15$ ns are excluded and final N_{hit} is obtained for for following analysis

r_{gen} – generated
r_{rec} – reconstructed

$\delta r = |r_{rec} – r_{gen}| \sim 2$ m

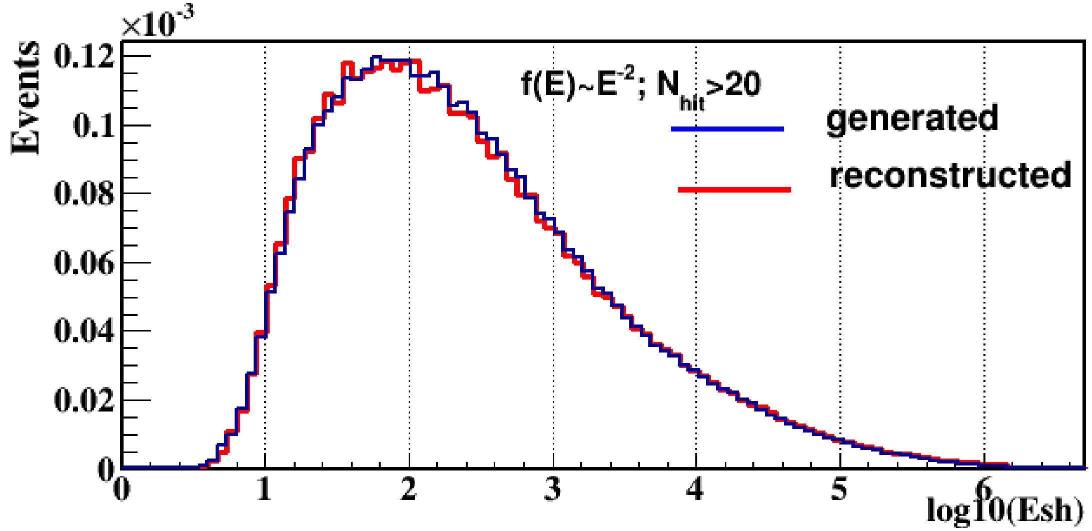
$\delta r/r = |r_{rec} – r_{gen}| \sim 0.01$



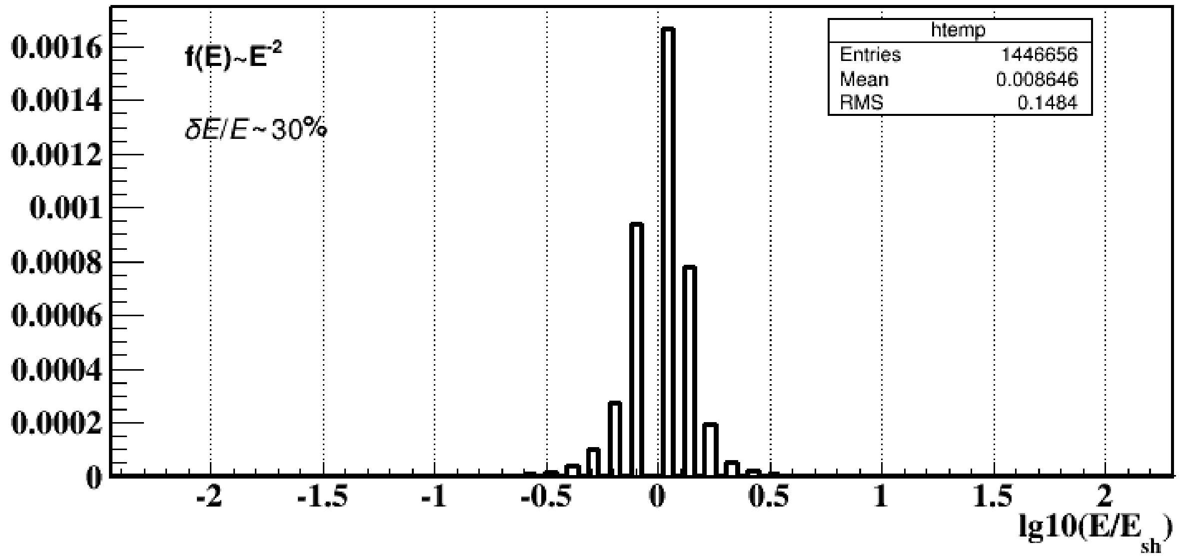


Reconstruction of a cascade energy in GVD-Cluster

Generated and reconstructed energy distributions of cascades from electron neutrino flux ~E^{-2}

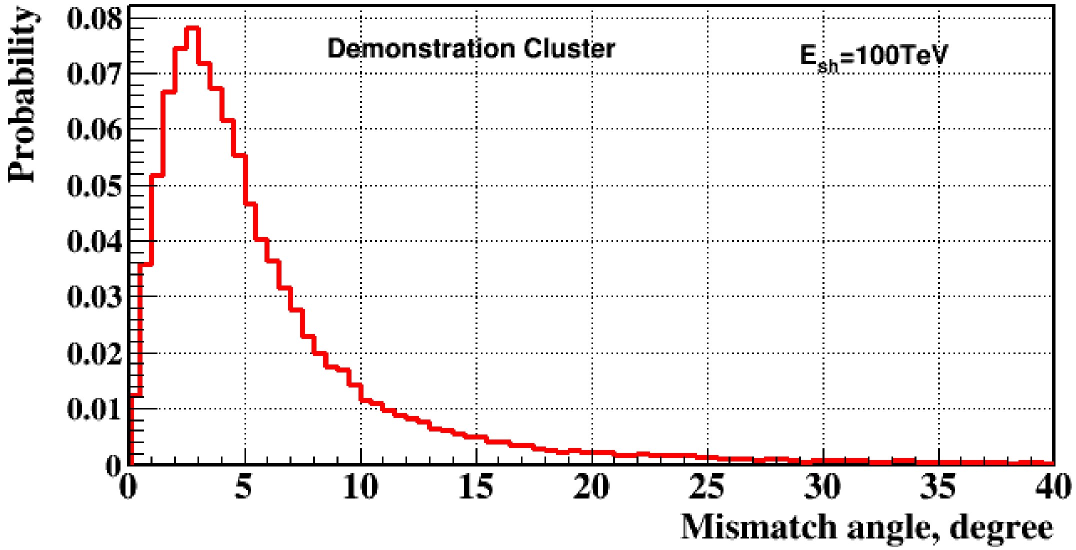


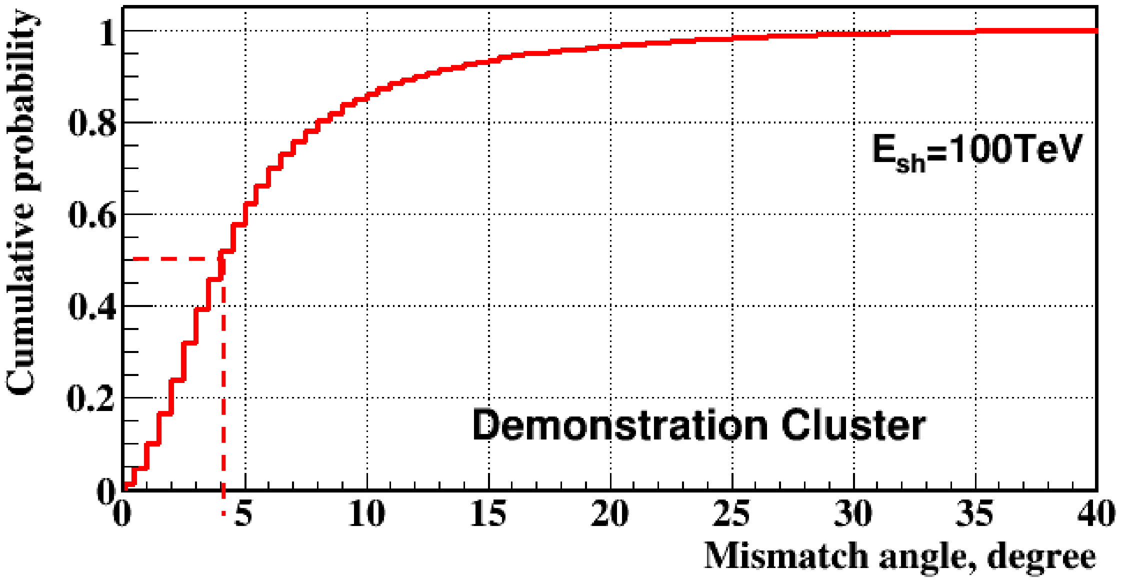
δE/E ~ 30%



Directional Resolution for Showers

Cascade angular resolution ~ 4°





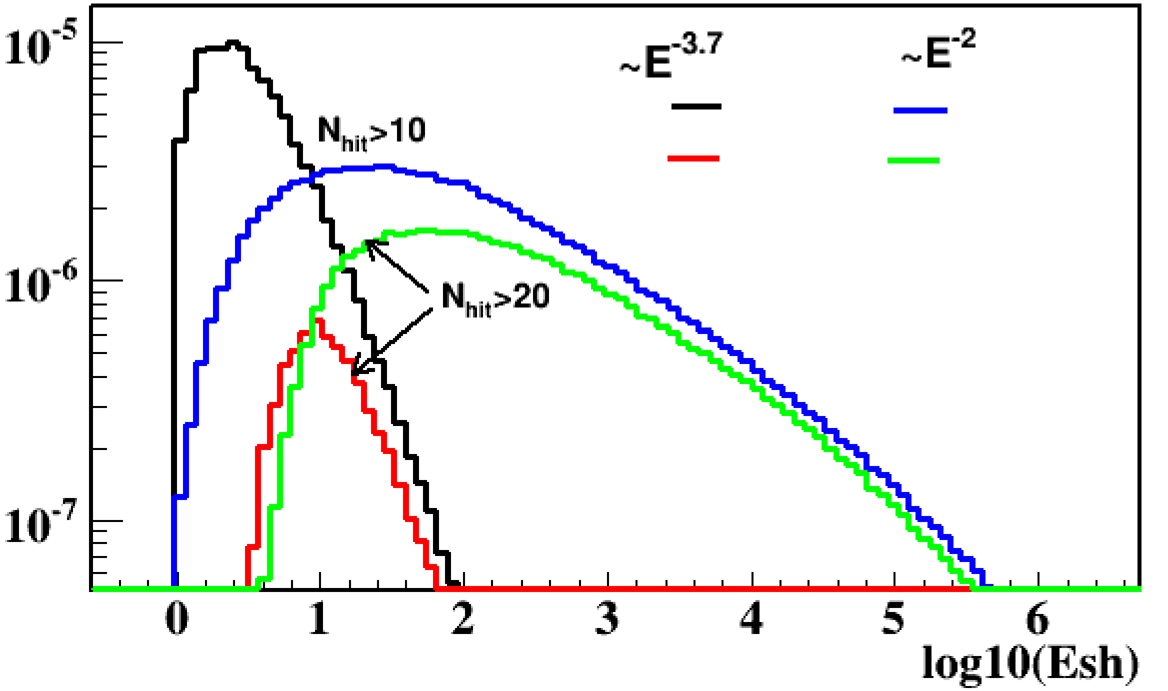
Selection criteria based on hit multiplicity

Flux ~E $^{-2}$:
$F(N_{hit}>20)/F(>10) = 0.51$

Flux ~E $^{-2.3}$:
$F(N_{hit}>20)/F(>10) = 0.36$

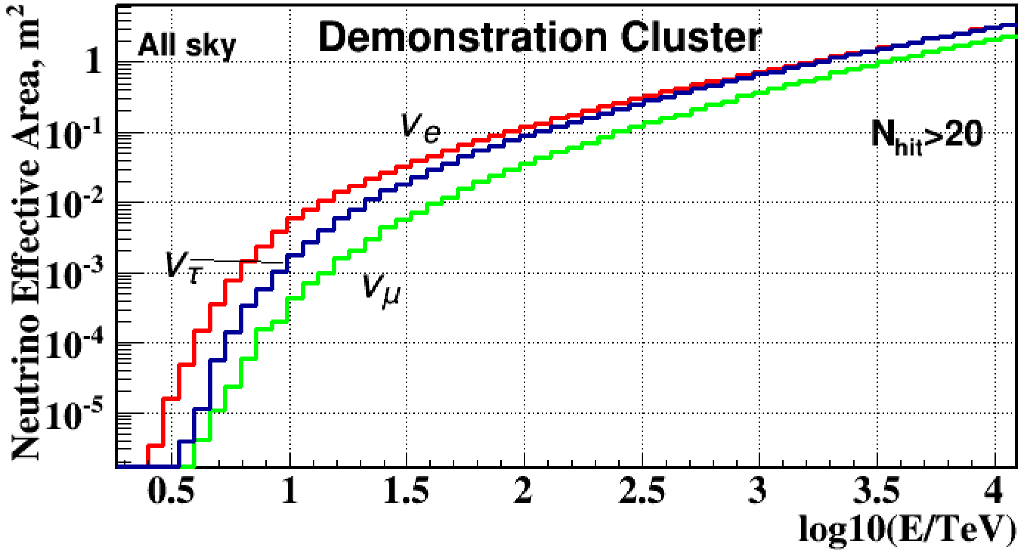
Flux ~E $^{-3.7}$:
$F(N_{hit}>20)/F(>10) = 0.06$

Cascade energy distributions

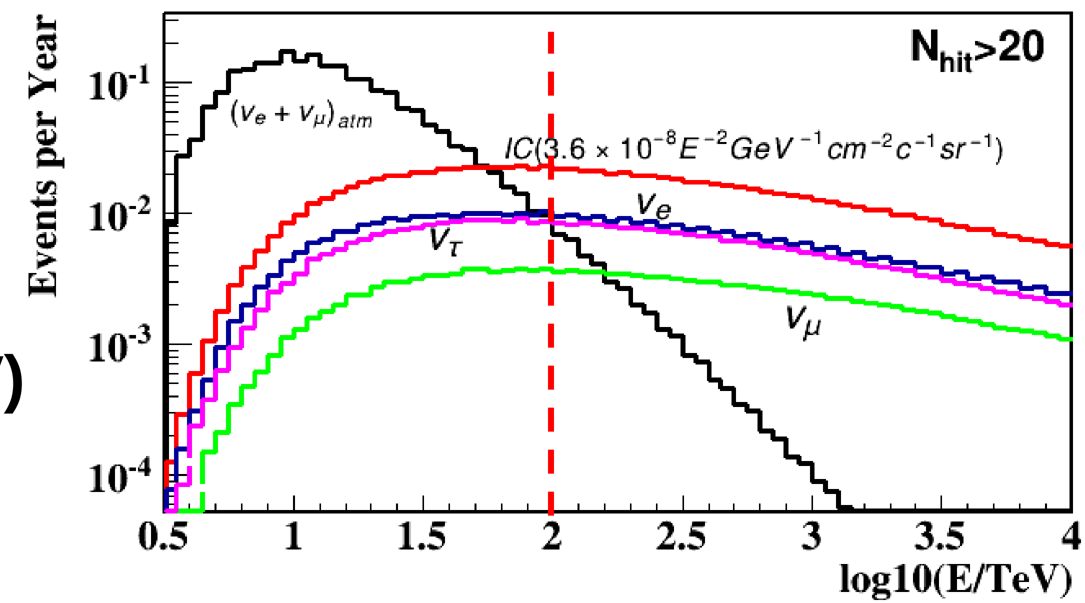


GVD-Cluster:

Neutrino Effective Area



Events per Year from IC-flux (E^2F_{IC}=3.6·10^{-8} GeV cm^{-2}s^{-1}sr^{-1})



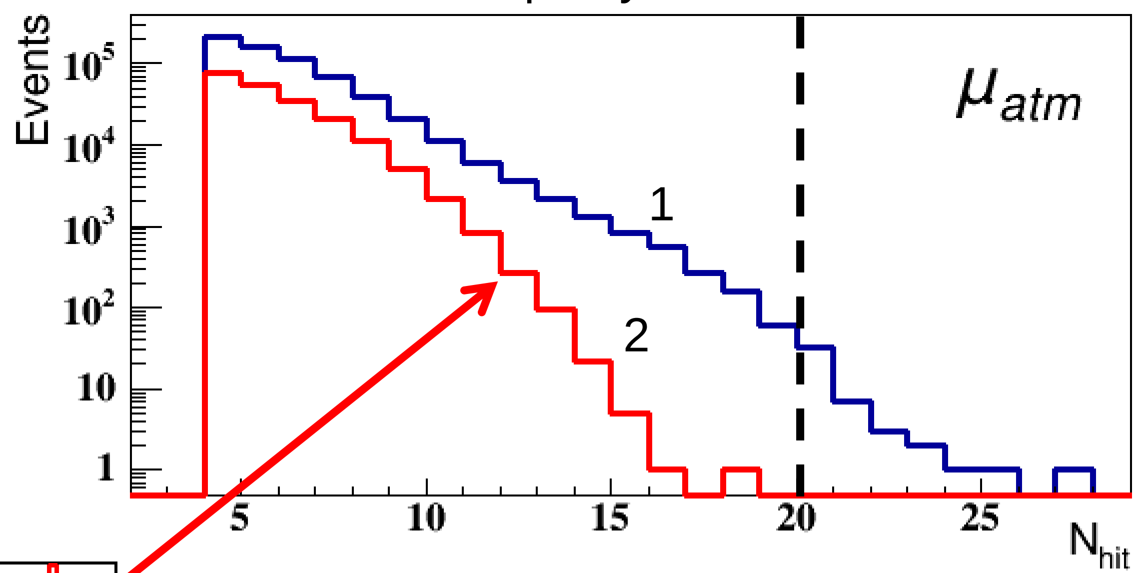
~1 Event/Year (>100 TeV)

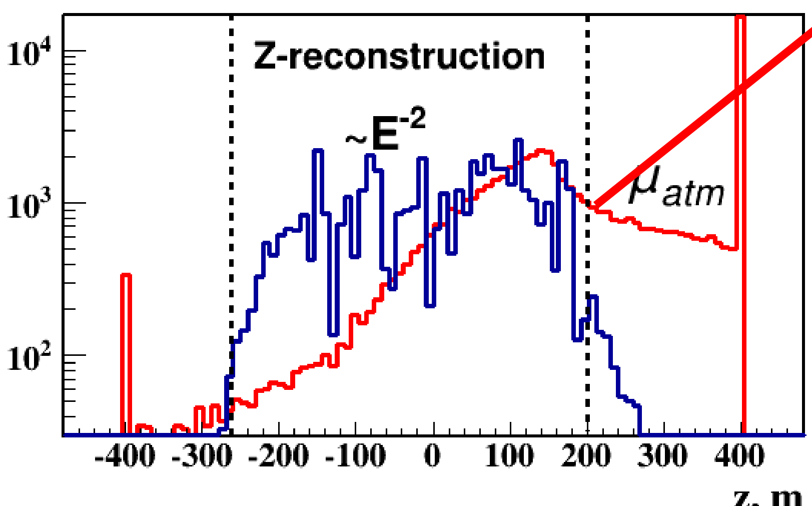
Atmospheric muons MC-sample corresponding to 341 life days

1 – after vertex reconstruction

2 – after vertex reconstruction quality cuts

Hit channel multiplicity distributions





Conclusion

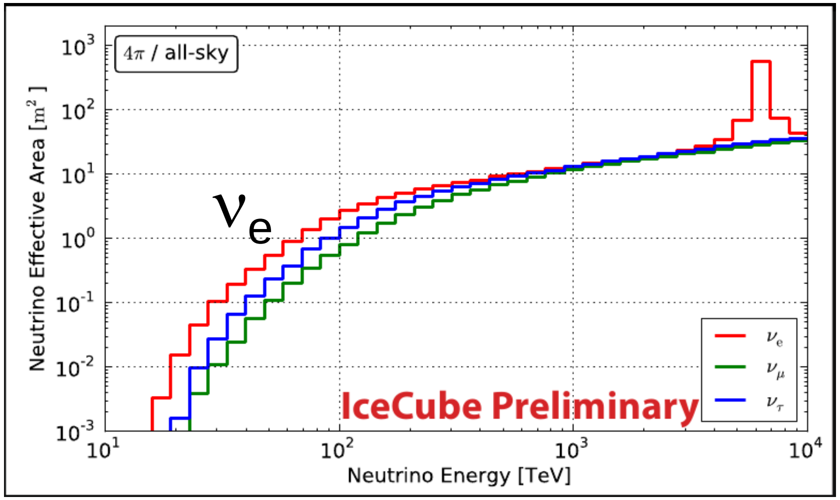
- First GVD-Cluster will be deployed in 2015

- It will have ~ 30% energy resolution and ~ 4° angular resolution

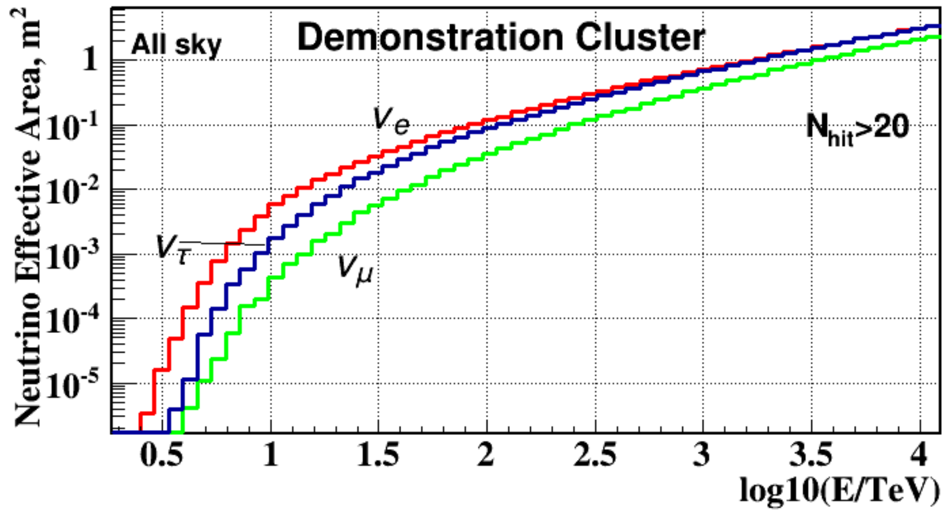
- About 1 IC astrophysical neutrino event is expected in 1 year data sample

Neutrino Effective Area

IceCube

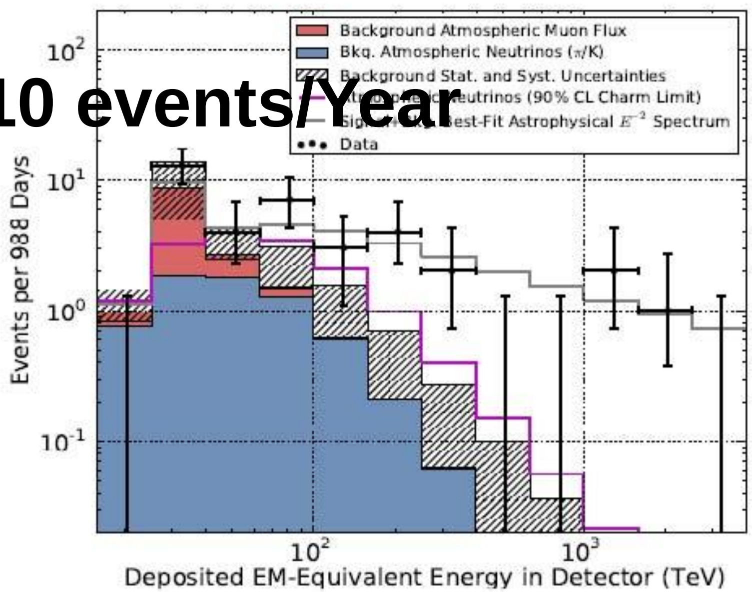


GVD-Cluster



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

~ 10 events/Year



~1 Event/Year (>100 TeV)