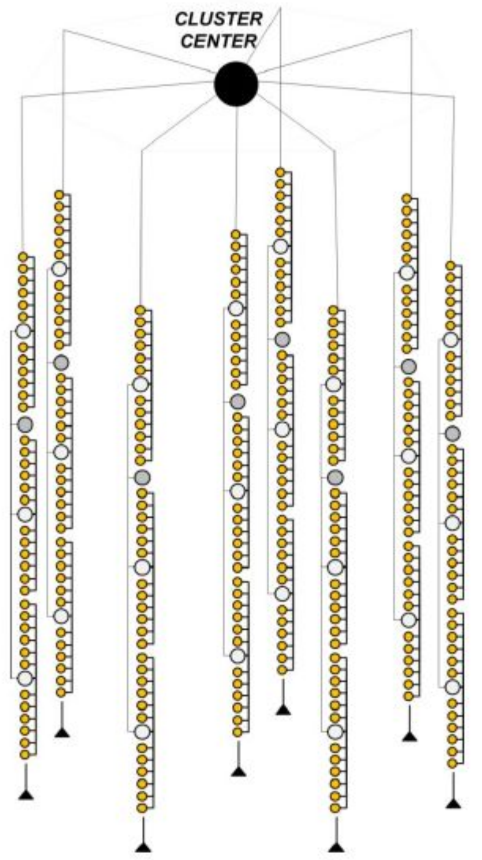
BAIKAL-GVD

Muon track reconstruction in BAIKAL-GVD

Grigory Safronov
JINR (Dubna), **ITEP** (Moscow)
on behalf of BAIKAL-GVD collaboration

VLVNT 2018, 2-4/10/2018, Dubna, Russia

Introduction



First full-scale cluster "Dubna" of BAIKL-GVD was commisioned and taking data in 2016

Charge and time calibrations were produced (talk by Mark Shelepov)

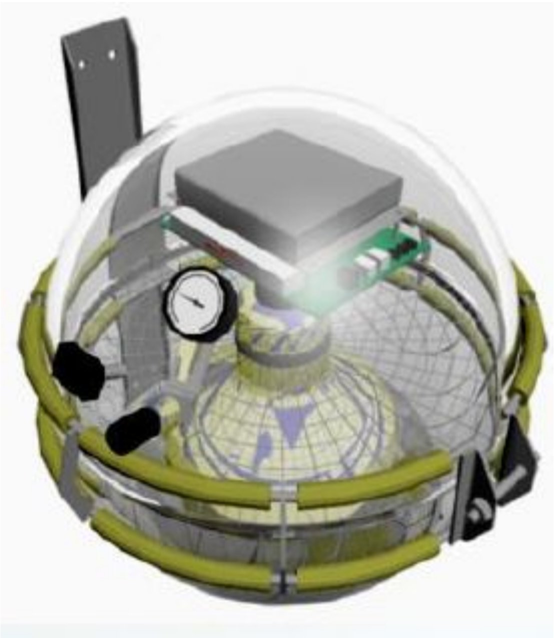
Cluster geometry is available via acoustic measurements (talk by Alexander Avrorin)

Lake and PMT noise were studied in detail (talk by Rostislav Dvornicky)

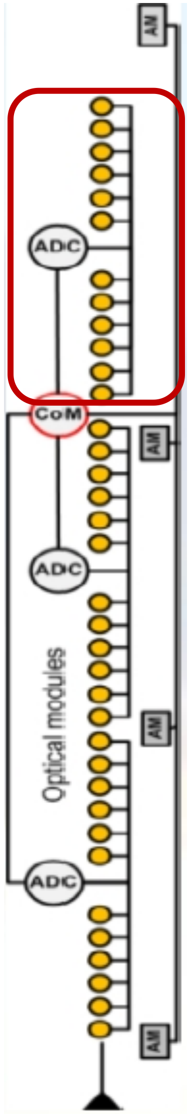
Data quality monitoring procedures were developed using 2016 data (talk by Evgeniy Khramov)

Muon track reconstruction analysis for 2016 cluster is discussed in this talk

"Dubna" cluster

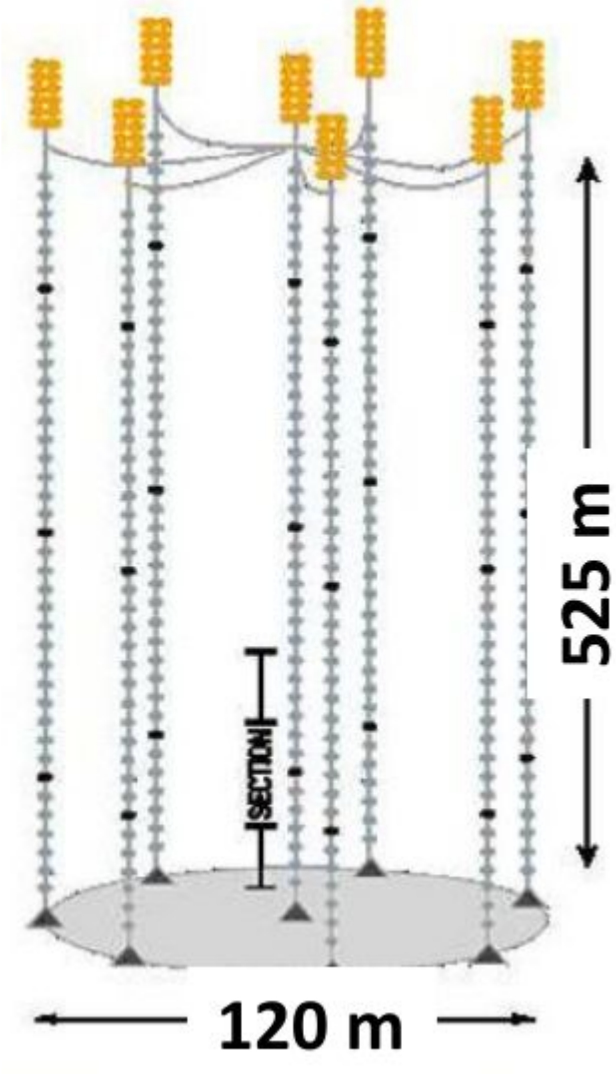


Optical module (OM)
PMT: Hamamatsu R7081-100



Section:
12 OMs

String:
3 sections,
36 OMs



Cluster:
8 strings, 288 OMs

depths:
750 -1275m

Track reconstruction procedure

At least 6 pulses at 3 string are required, simple χ^2 - like fit is is used so far

Track parametrisation: $$\vec{R(t)} = \vec{R_0} + c(t - t_0)\vec{V}$$

$\vec{V}$ is unit vector in polar coordinates, $\vec{R_0}$ and t_0 are taken in plane Z=0

Initial track approximation: $$\vec{V_{init}} = (1/|\sum_{t_i<t_j} \vec{R_{ij}}|) \sum_{t_i<t_j} \vec{R_{ij}}$$

where *i* and *j* are ordered in time and belong to different strings

Initial values for $\vec{R_0}$ and t_0 are obtained using hit with largest amplitude

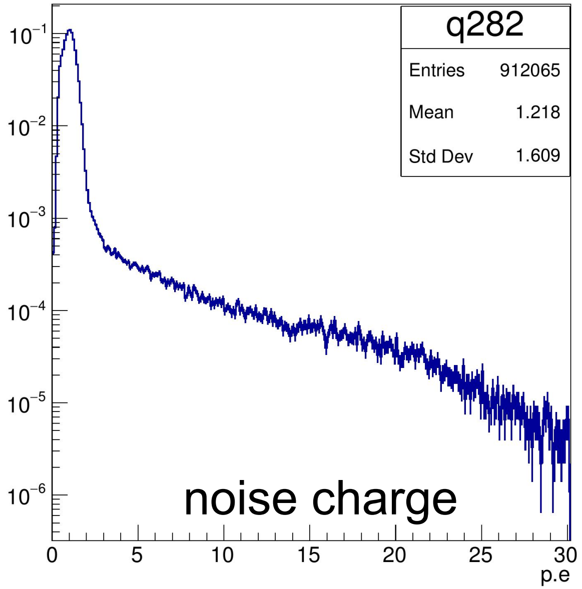
Minimisation function (quality): $$Q = \sum_{i=1}^{N_{hit}} \left[\frac{(t_i^{est} - t_i)^2}{\sigma_t^2} + \frac{A(a_i)D(d_i)}{d_0} \right]$$

inspired by ANTARES paper: https://arxiv.org/abs/1105.4116

Muon prompt Cerenkov radiation approximation is used for the time estimation

A and *D* are amplitude and distance functions

PMT signal jitter: σ_t = 3 ns

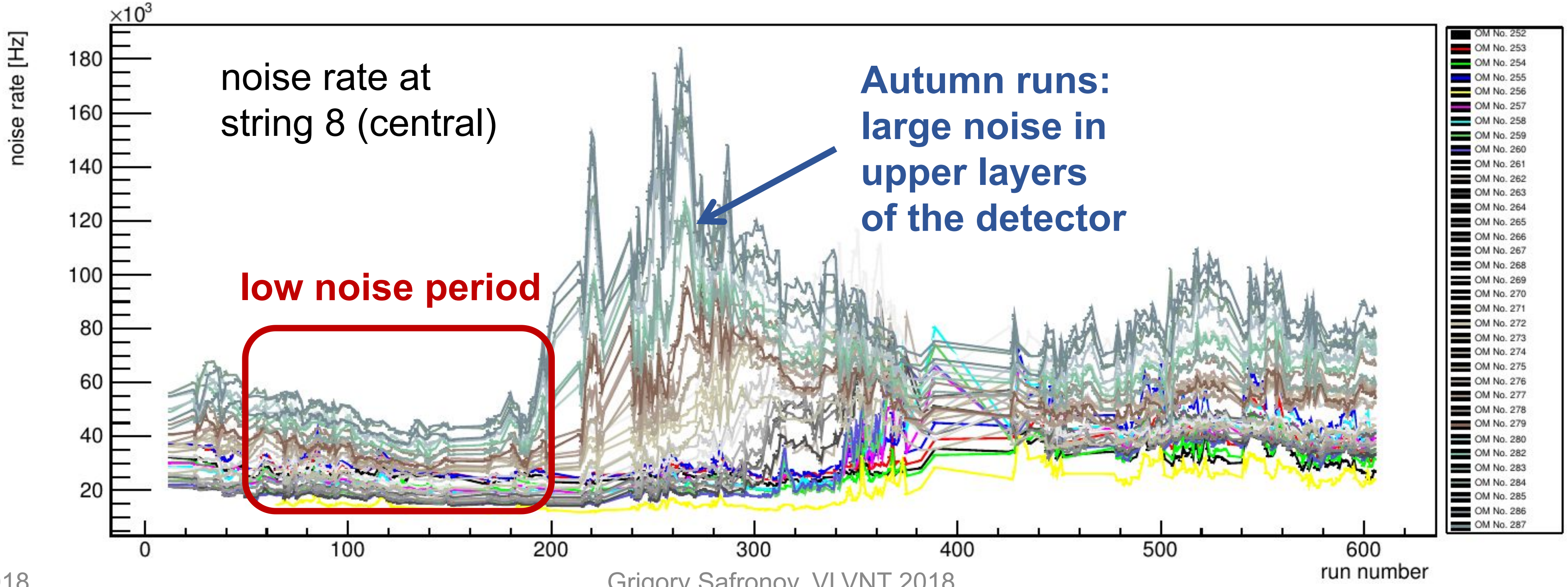


Lake and detector noise

OM pulses due to PMT dark current and lake fauna must be rejected before reconstruction

Noise rate 20-60 kHz for **"low noise period"**
Signal at photoelectron level

Event frame: 5 μs : ~60 noise pulses per event



Noise suppression

Pulses are clustered aroud "seed": **Q > 2.0 p.e.**

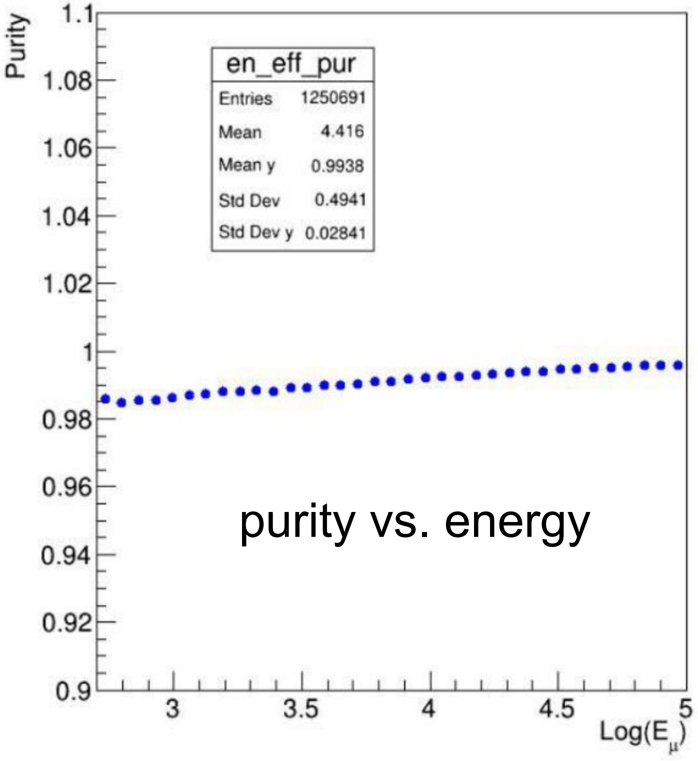
Each causally-connected pulse with **Q > 0.5 p.e.** is clustered

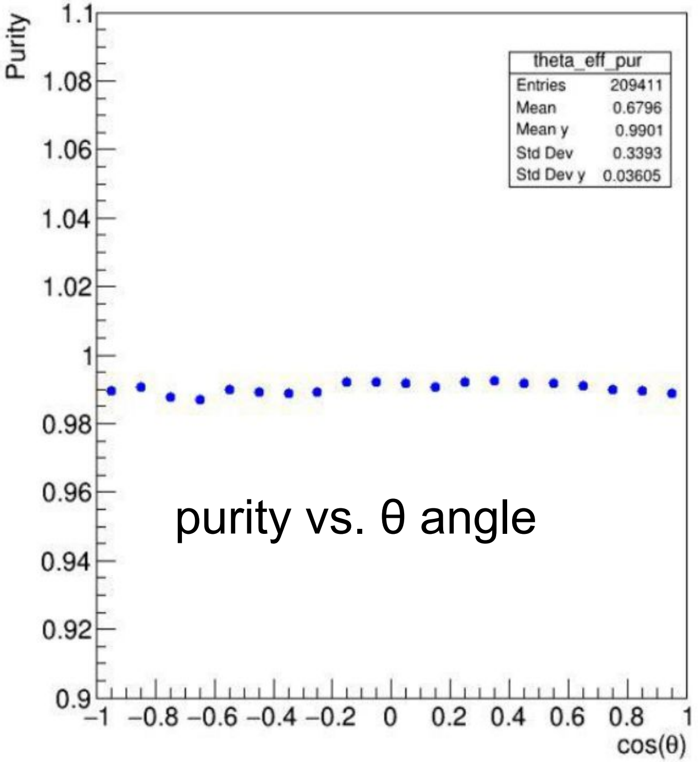
Causality:

$$|t_i - t_j| \leq \Delta R_{ij}/c_w + t_s, t_s = 10ns$$

Initial track approximation is calculated, ouliers are removed iteratively in tightening set of cuts

Cluster of pulses with the best quality is selected



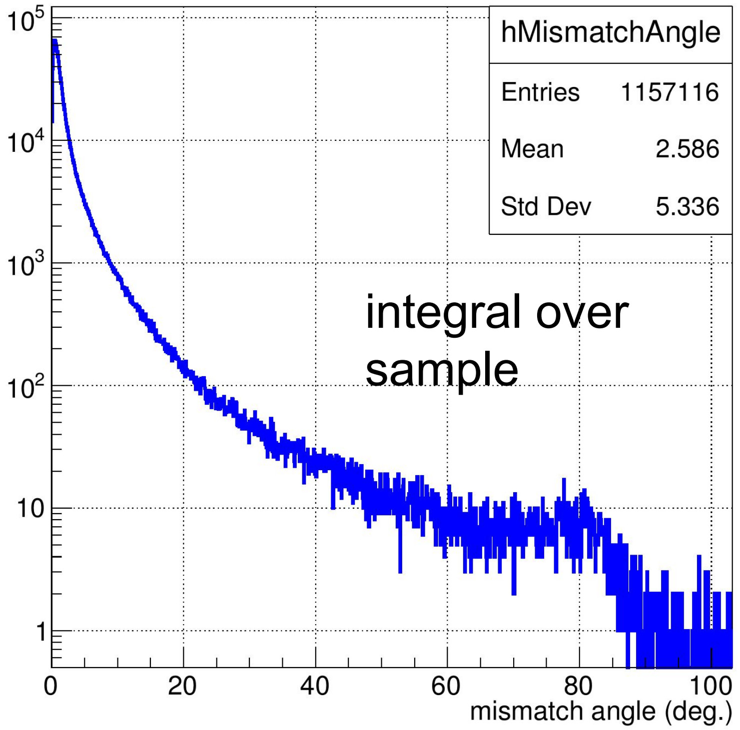


Purity of selected group of pulses ~99%,
weakly depends on muon incident angle and energy

Reconstruction performance

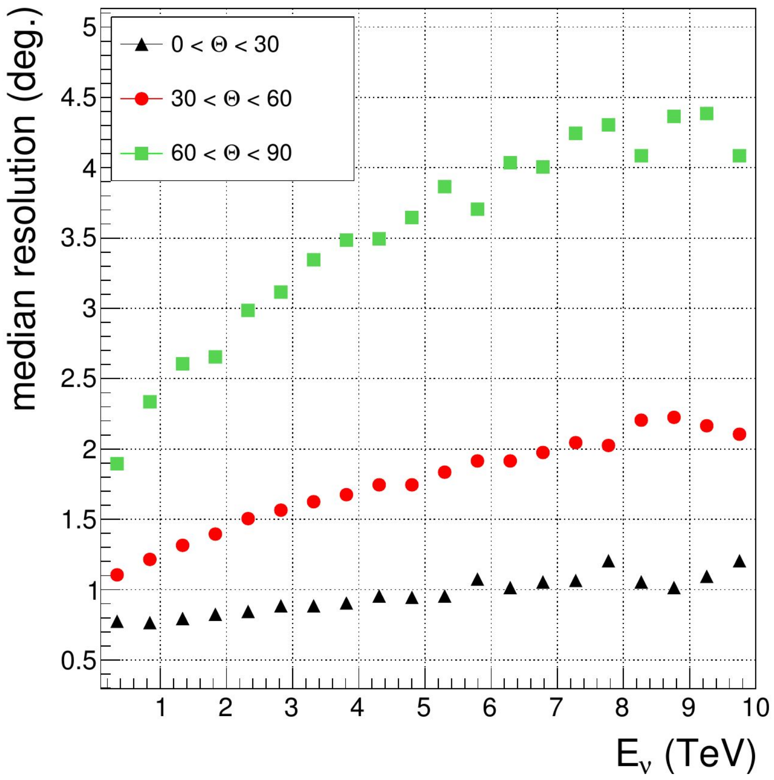
Reconstruction performance is evaluated on atmospheric neutrino sample, E > 100GeV

MC truth mismatch angle



median ~1.2 deg.
tail > 10 deg. : 4.4%
tail > 20 deg. : 1.4%

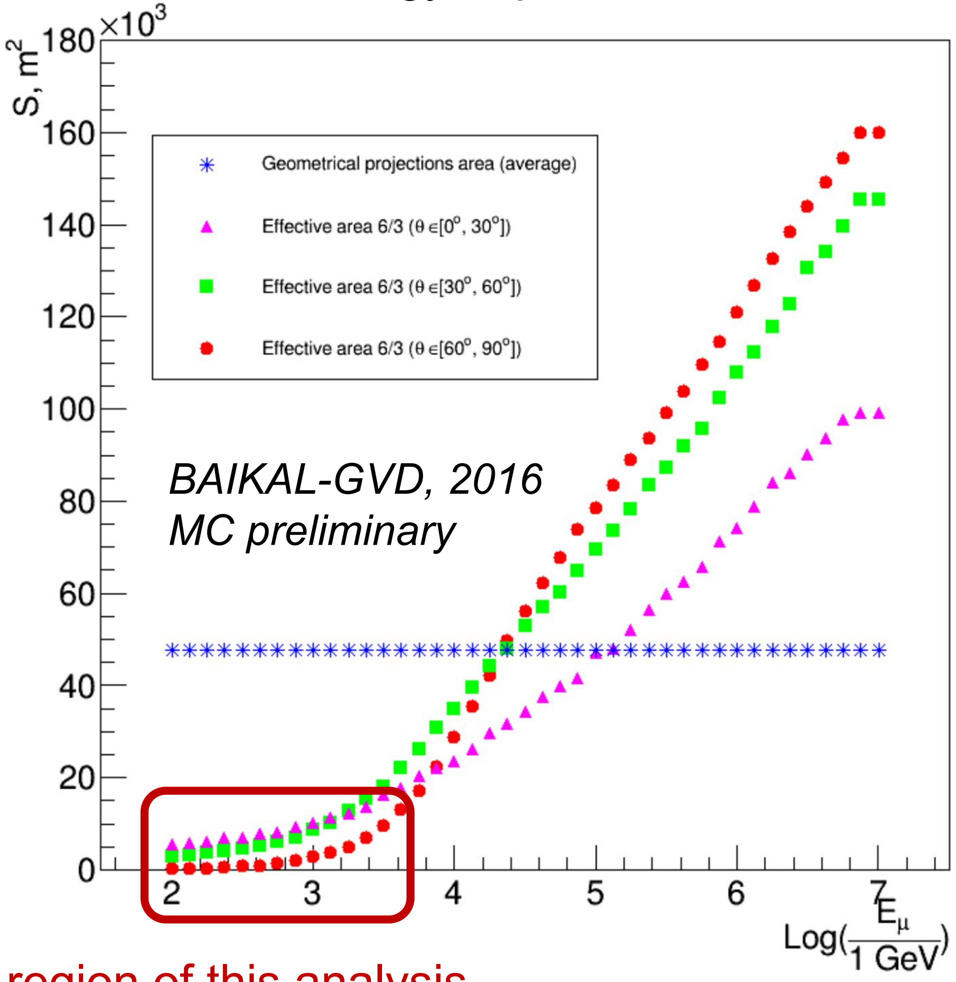
resolution energy dependence



Degrades with energy (more accompanying showers)
Worse for horisontal events (short trajectory)

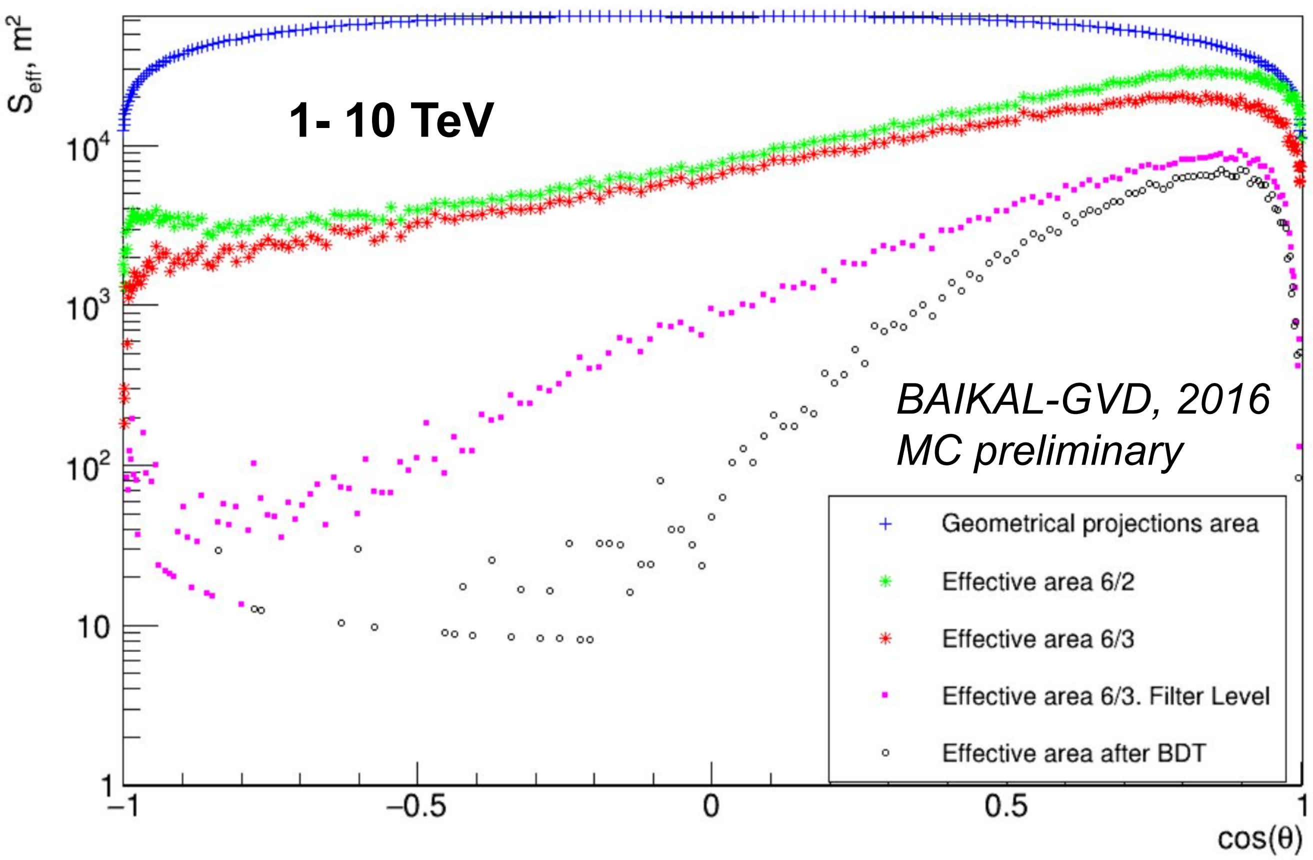
Detector effective areas

energy dependence



region of this analysis

eff. area angular dependence



Atmospheric muon flux

Large tail of misreconstructed as upgoing events (~3%)

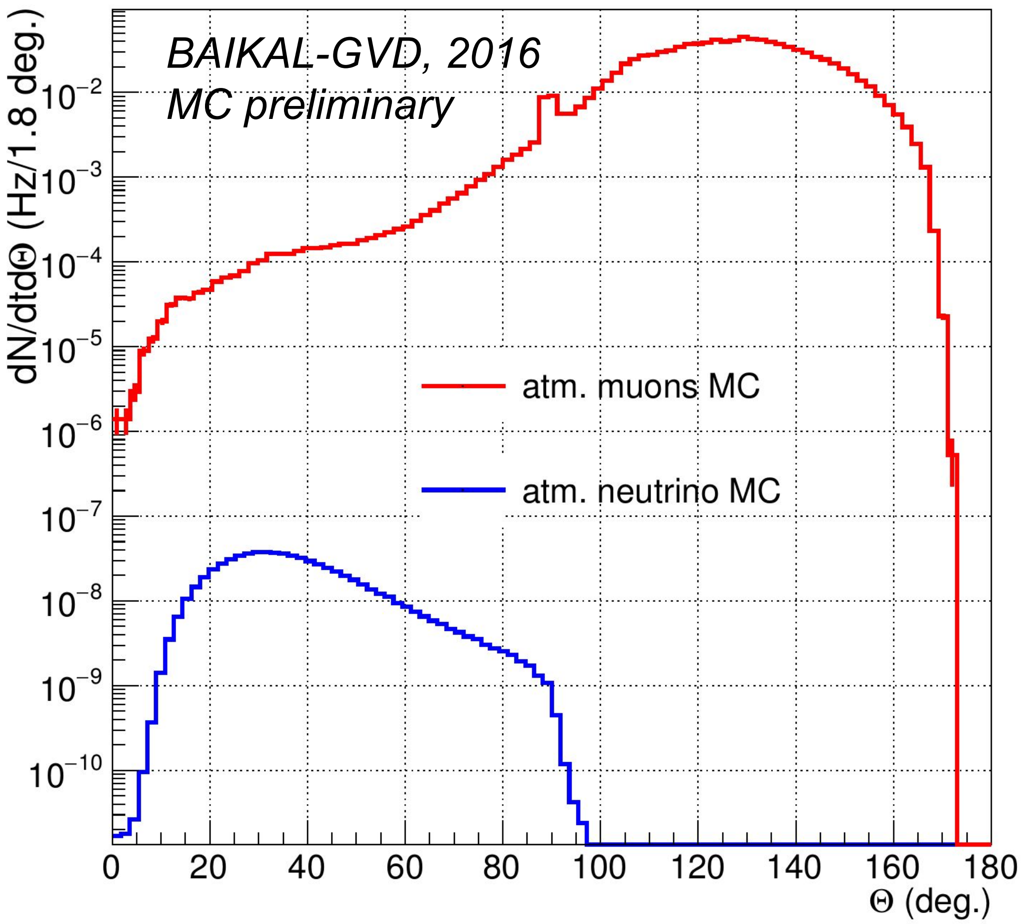
~ 4-5 orders of magnitude larger than expected upgoing neutrino flux

Technique to reject misreconstructed muon groups is needed

Simplest: track quality variable cuts, but rejects a lot of signal

Boosted decision trees: acceptable signal efficiency

muon groups as reconstructed in MC



Selection of upgoing tracks

TMVA framework from ROOT package was used to train the BDT

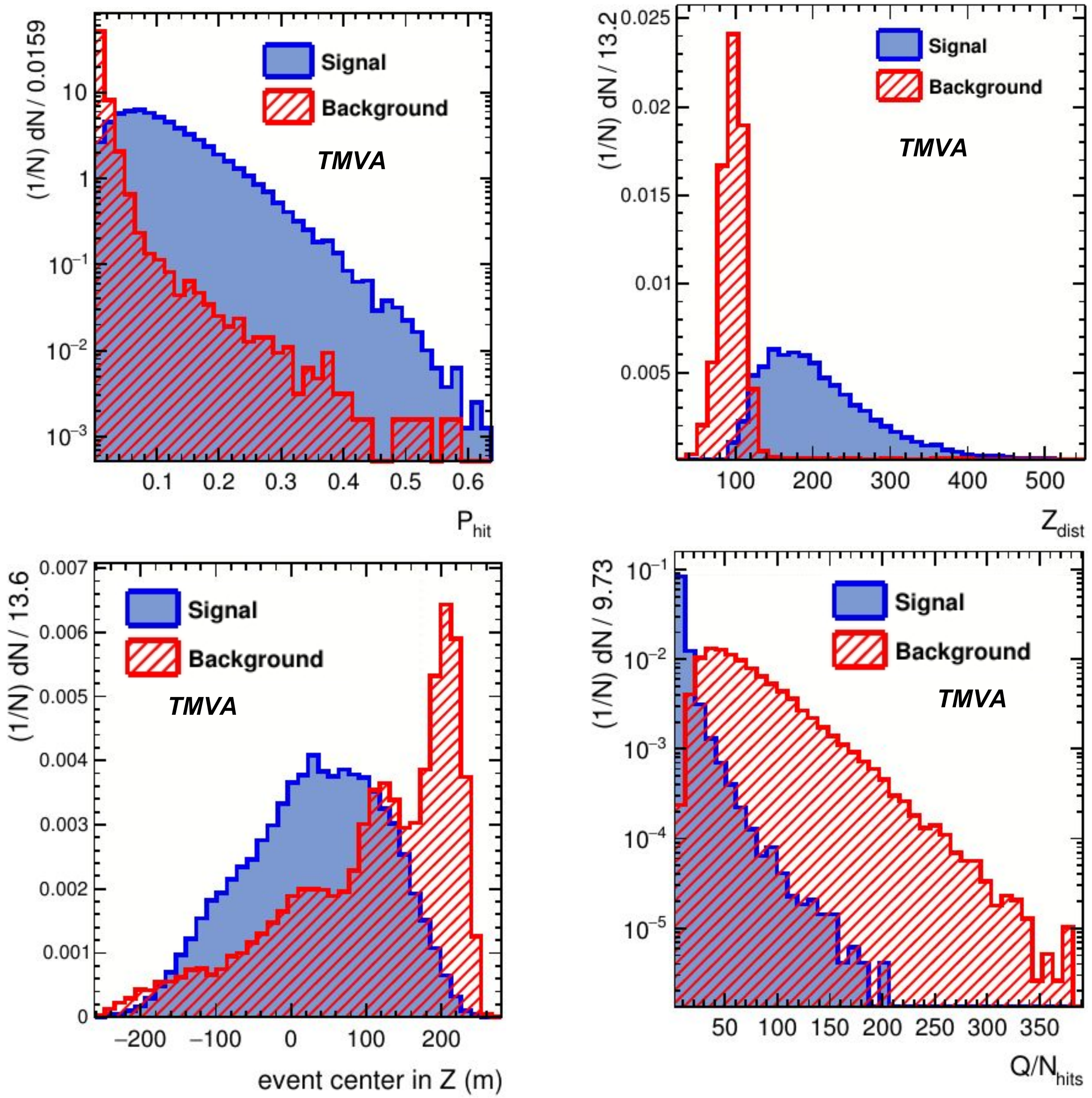
A set of 15 quality variables was used at input

Most significant ones:

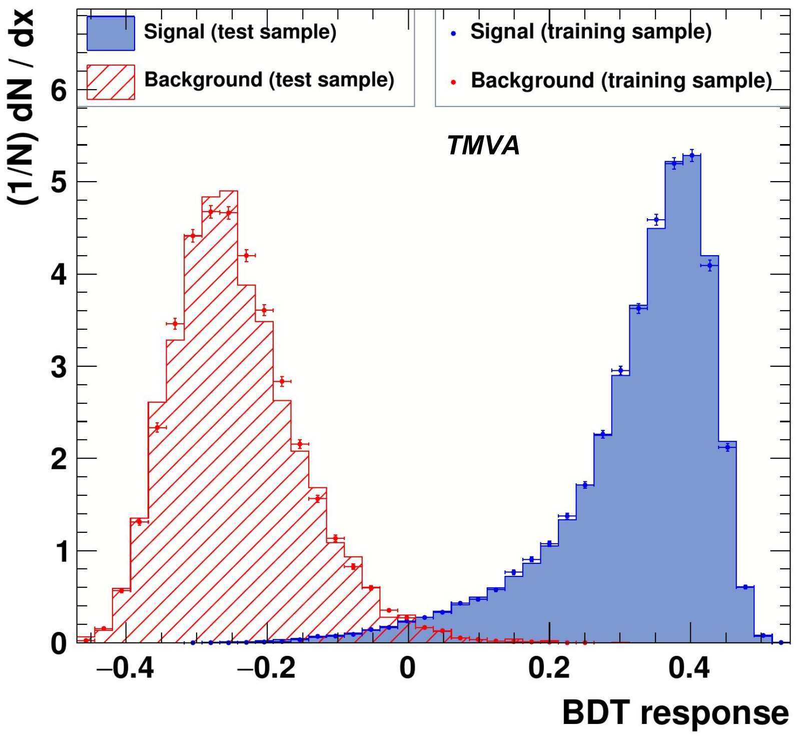
- Quality/N_{hits}
- P_{hit} : probability of given hit collection from the track
- Z_{dist} : max distance between OM projections on the track
- Event center in Z, weighted with pulse charge

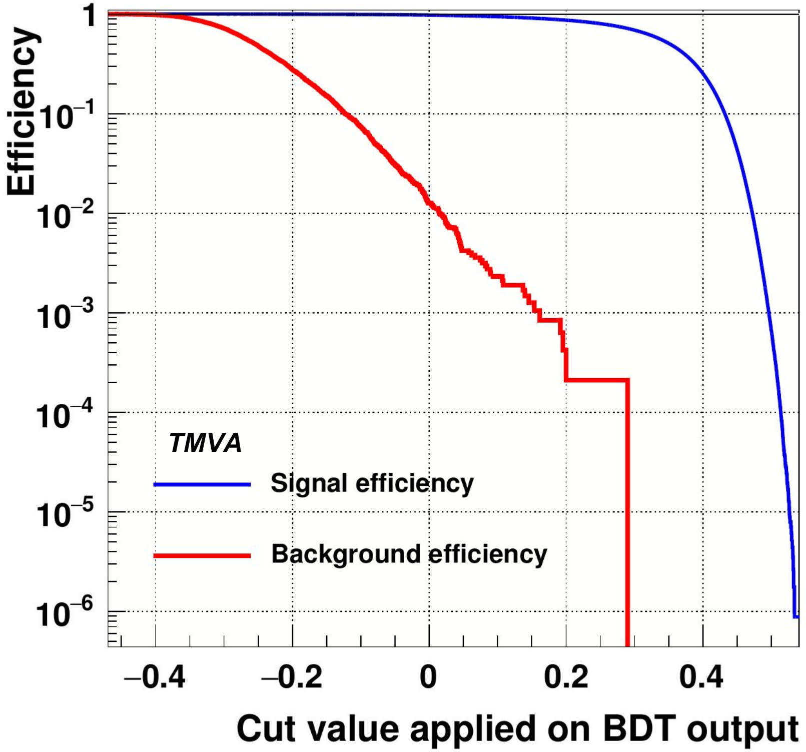
Signal sample: upgoing neutrino E>100GeV

Background sample: misreconstructed downgoing muon groups, θ_{rec} < 80 deg.



BDT performance





cut	signal eff. (%)
0.25	80
0.3	70
0.35	50
0.4	25

Background is suppressed at the level of 10^4-10^5, maintaining signal efficiency at the level of ~80% (cut 0.25)

Data analysis

2016 - is the first year of full-scale cluster operation and the data quality is not perfect

- Sections missing in readout
- Active calibration LED's in some runs
- Noisy OMs

Automatized data certification based on monitoring

- Subset of events with particular section configuration may be selected
- Events with active LEDs or noisy OMs may be rejected

Features present in data are implemented in MC

- Lake and PMT noise with OM-wise rate and amplitude distribution
- OM assembly sensitivity
- Realistic string positions
- Realistic configuration of working sections

DATA/MC comparisons

"Good dataset" (15 days of exposition):

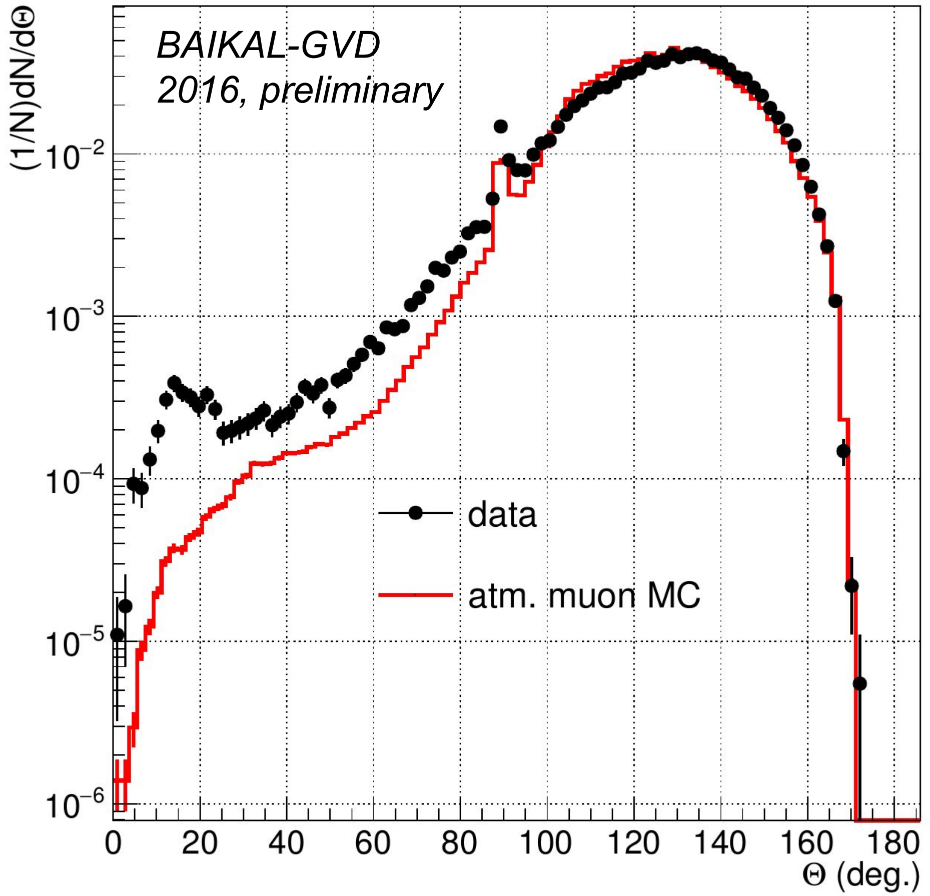
- "Low noise period": runs 90 - 200
- Fixed configuration: 3 sections are off (12.5% of the cluster off)
- Events with active LED's are rejected

Total 6/3 muon rate in data: 0.22 Hz

Rate in MC is 32% lower

Some discrepancies in misreconstructed background description

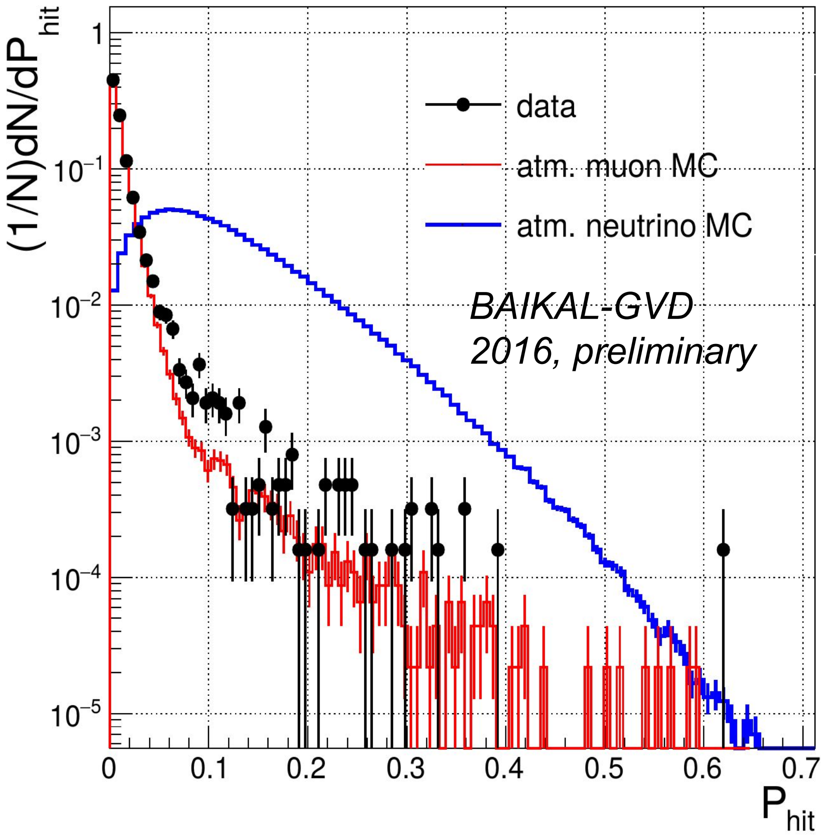
- Normalisation shift: MC correction factor is used in the following
- Feature close to θ_{rec} ~10 deg. in data

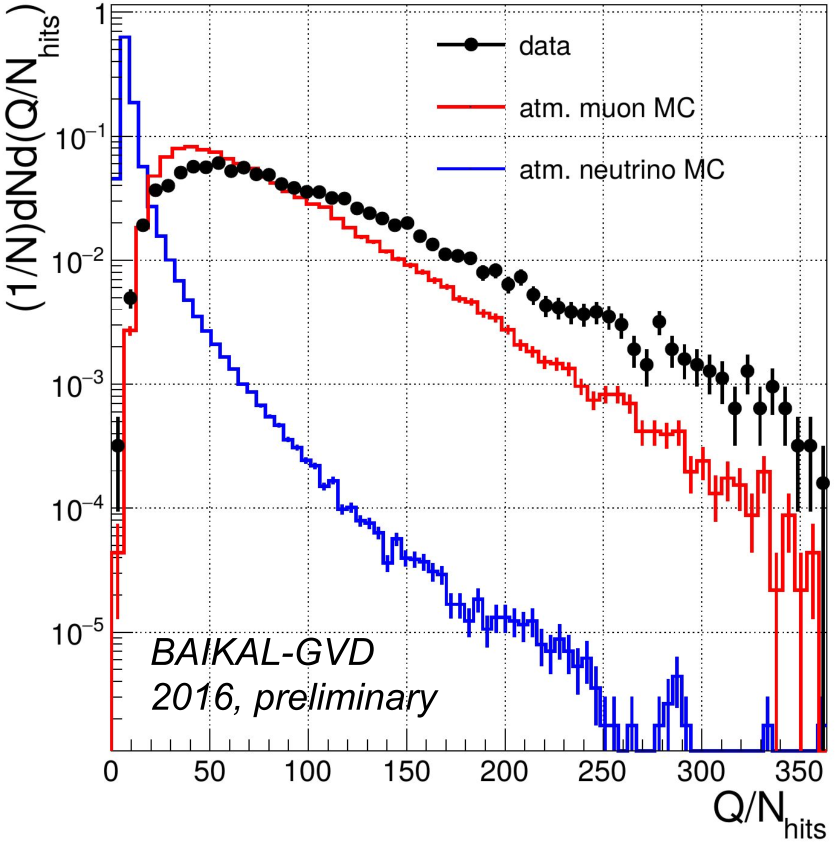


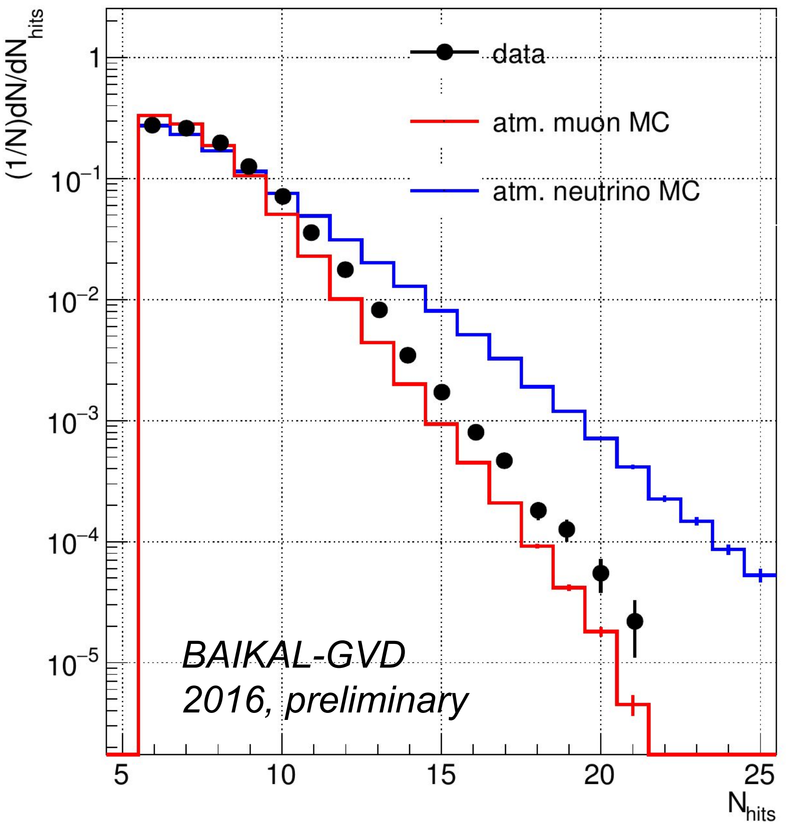
DATA/MC comparisons

Description of the data in the θ_{rec} < 80 deg. region:

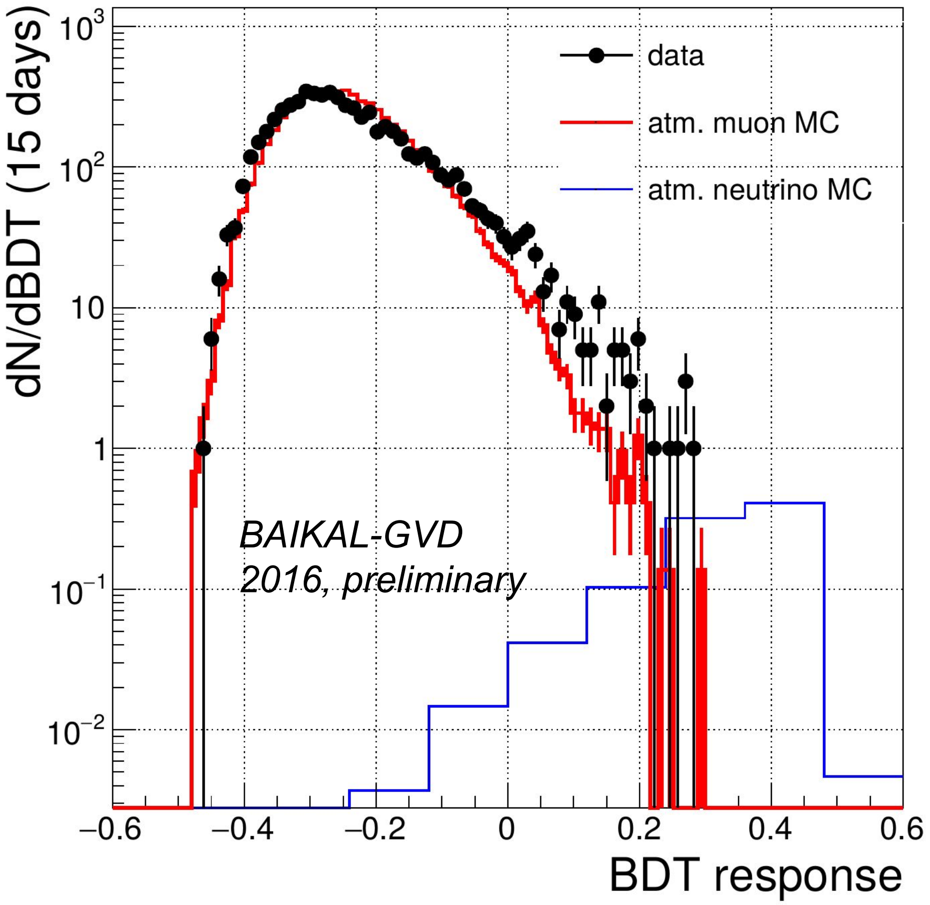
Some discrepancy in the Q/N_{hits} variable is observed







Results



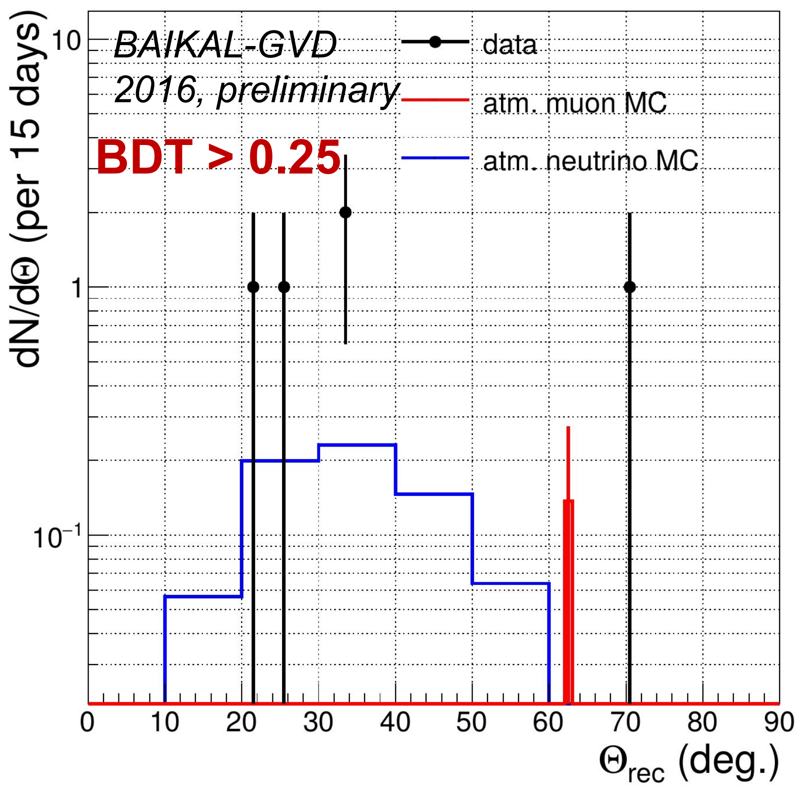
BDT for "good dataset":

MC background is scaled by the factor 3.58 to match the data normalisation

BDT > 0.25 cut is used for neutrino selection

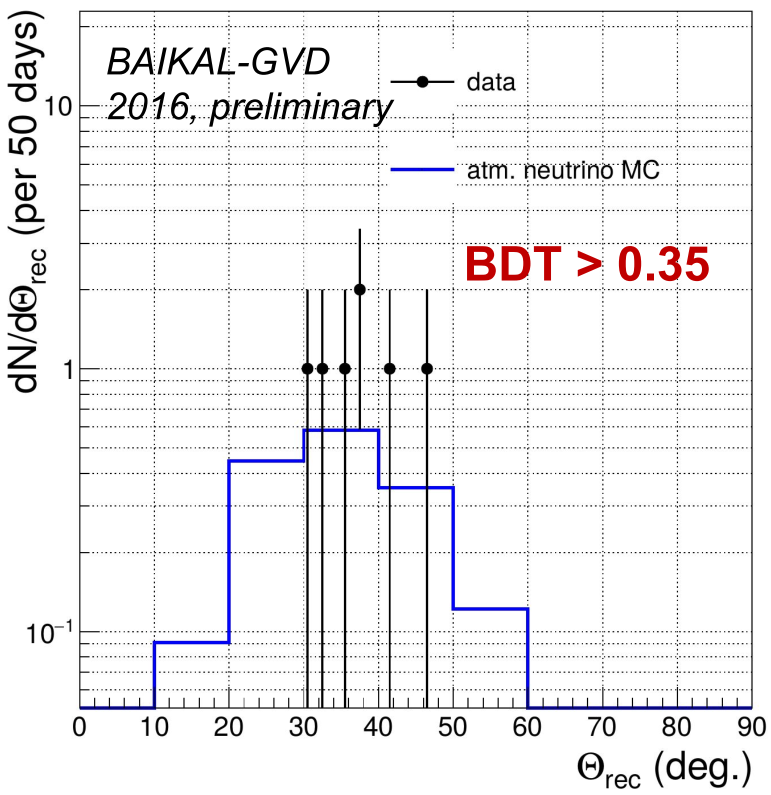
Results

Good dataset (15 days of exposition)
fixed configuration



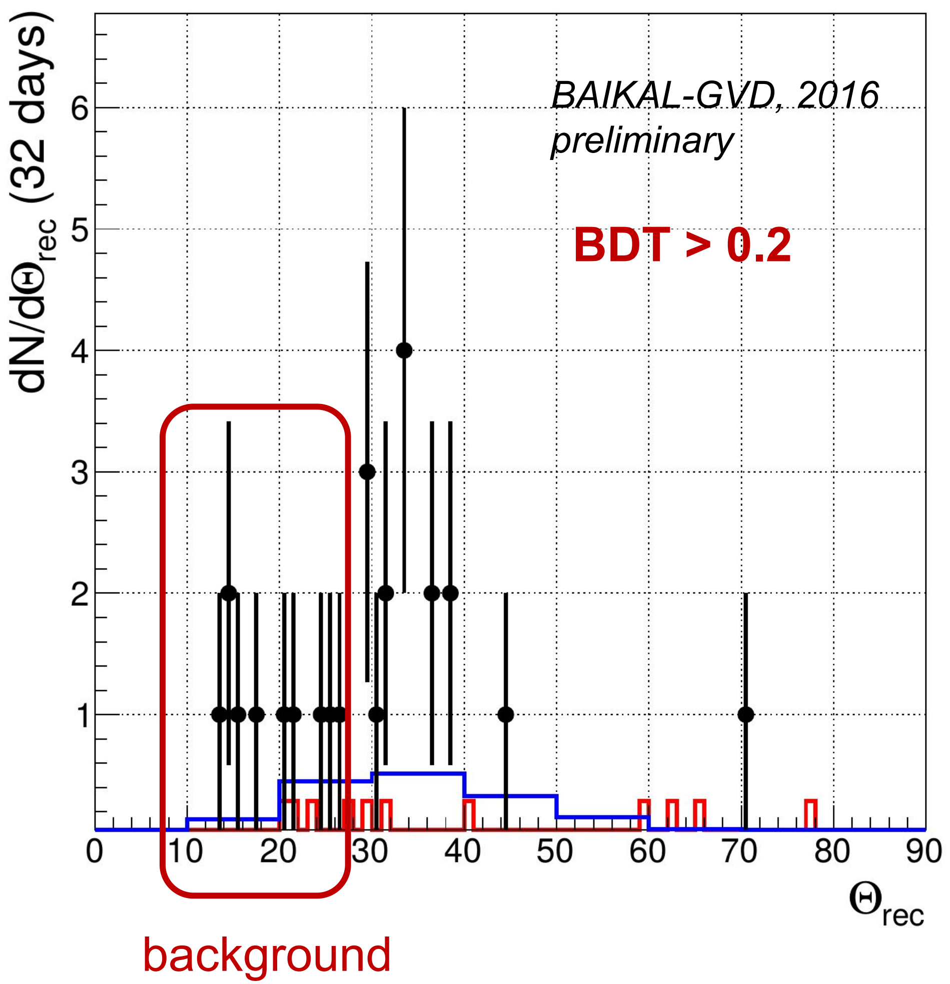
background exp.	0.14
signal exp.	0.72
data	5

50 days of exposition
all configurations, noisy runs → hard BDT cut



background exp.	--
signal exp.	1.6
data	7

Results



- "Low noise period", all configurations, 32 days of exposition
- Softer BDT cut: BDT > 0.2
- Affected by background on the left (not reproduced in MC)

background exp.	3.3
signal exp.	1.7
data	~16

Conservative summary for 3 datasets and selections:

1 neutrino candidate per ~3 days

Available atmospheric neutrino MC predicts lower flux

Event displays

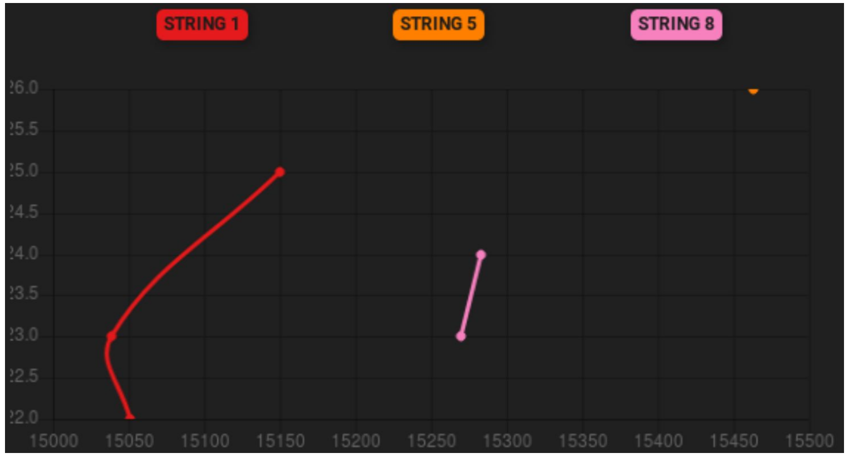
Size: Log(charge)

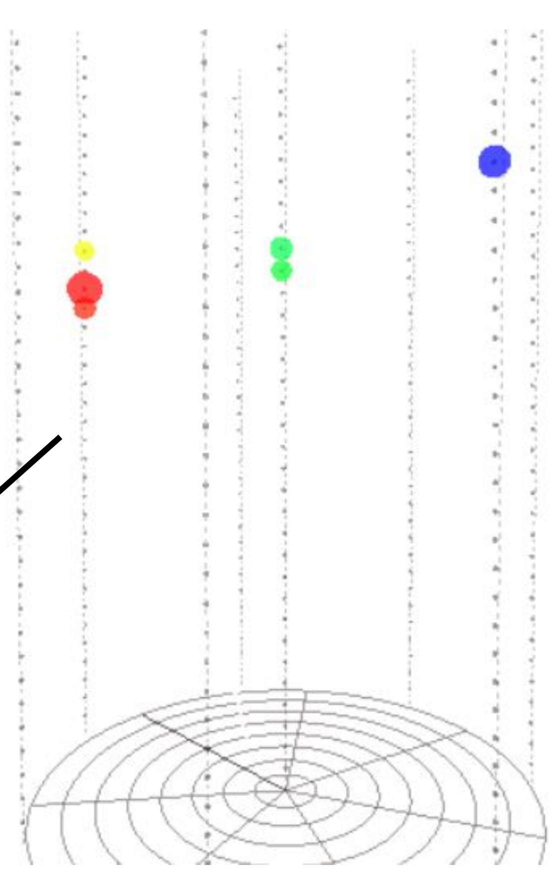
Color: time

red → early

blue → late

Z vs time

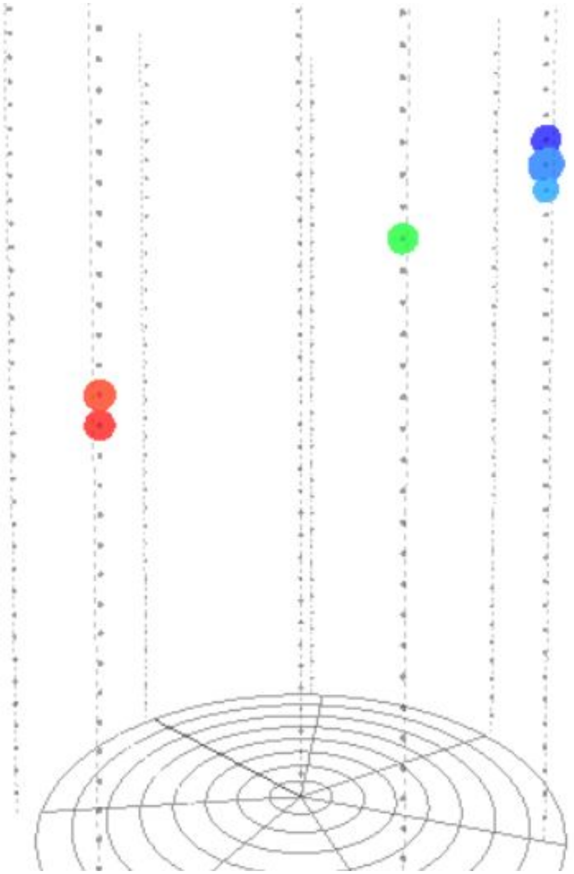




run 189, event 1900873

θ_{rec} = 72 deg.

BDT=0.27



run 241, event 104612

θ_{rec} = 35.5 deg.

BDT=0.40

Summary

BAIKAL-GVD

Detector properties for 2016 cluster have been studied

We continue to improve MC to match with detector conditions

Procedures to certify good data are being developed

Track reconstruction software has been developed

- Simple χ^2 -like fit, no likelyhood is used so far

Atmospheric background rejection procedure has been developed

- Background rejection at the level of 10^4-10^5

Preliminary results on atmospheric neutrino flux are available

- 1 neutrino candidate per ~3 days