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Observations of track-like neutrino events with Baikal-GVD

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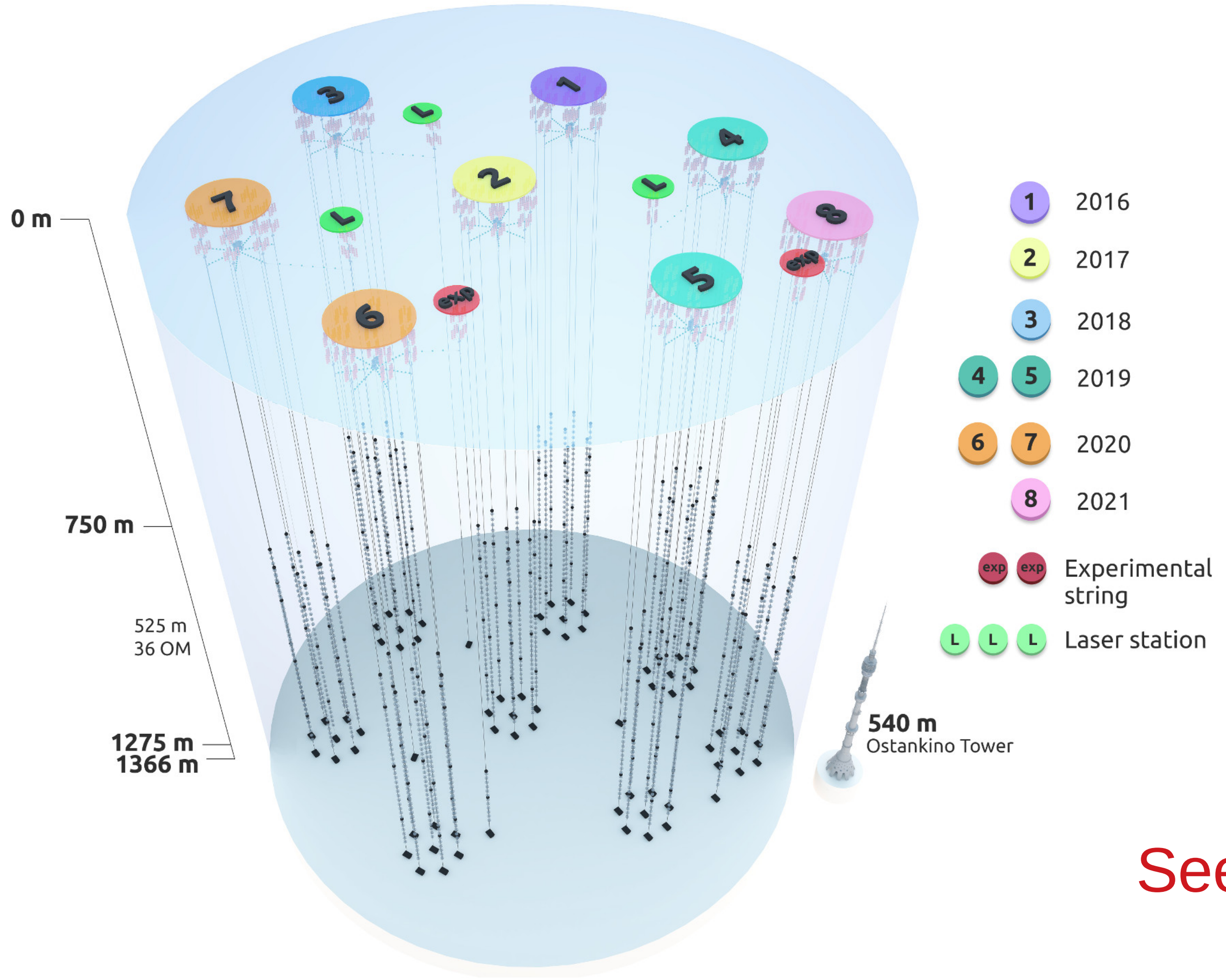
Baikal-GVD



- km³-scale neutrino detector under construction in Lake Baikal
- 8 strings per cluster
- 36 optical modules (OMs) per string
- One 10-inch PMT per OM

See talk by I. Belolaptikov

χ^2-like track reconstruction

See poster by G. Safronov

Initial hit selection

↓

Track prefit — Using vector sum

↓

Refined hit selection

↓

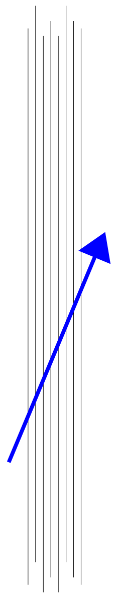
Main track fit — Minimize quality function

$$Q = \chi^2(t) + f(q, r)$$

$\chi^2(t)$: Time residuals

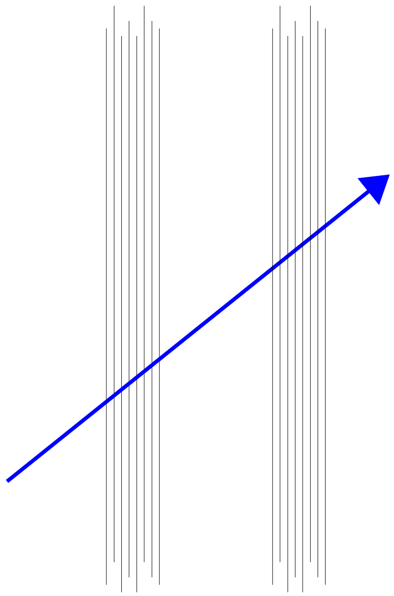
$f(q, r)$: Hit charge and distance

Two event types: single-cluster and multi-cluster



Single-cluster events:

- Low energy threshold
- Optimal sensitivity to nearly vertical tracks
- 90% of the recorded event sample



Multi-cluster events:

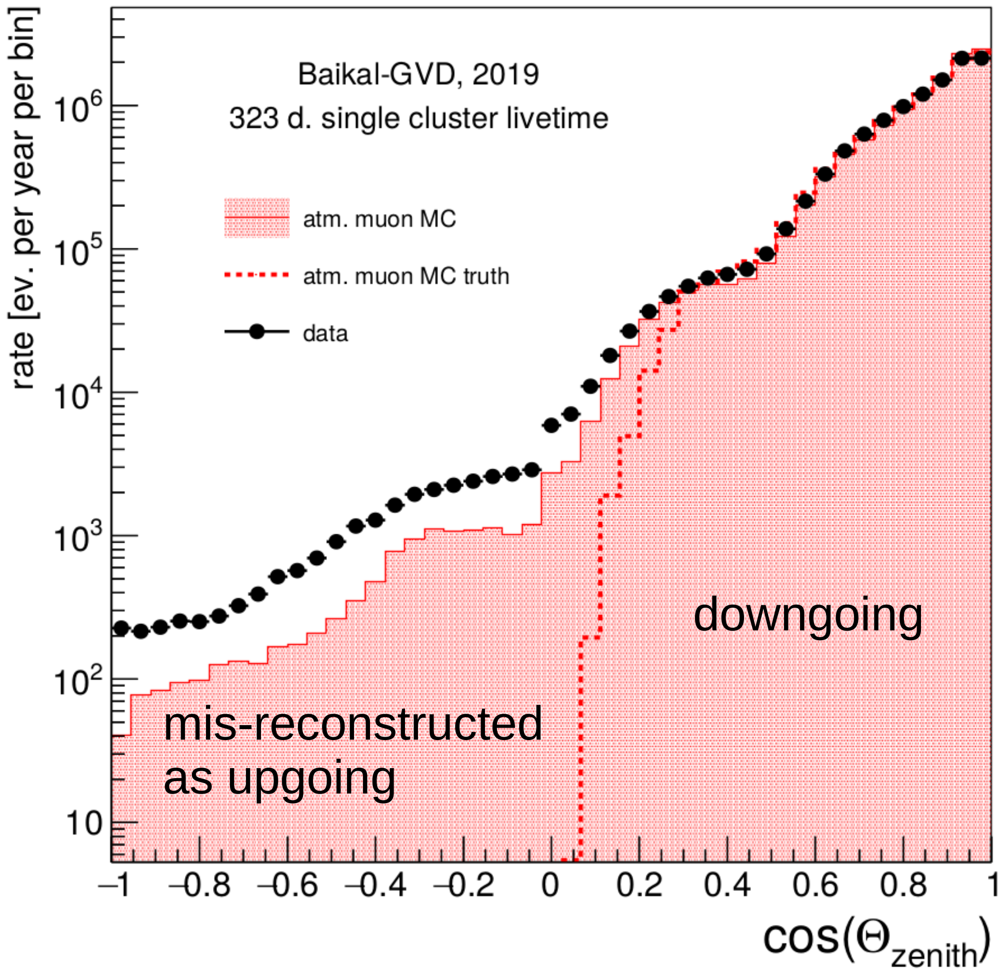
- Higher energy threshold
- Optimal sensitivity to inclined tracks
- 10% of the recorded event sample

Dataset used in this work

April 1 – June 30, 2019

GVD cluster	Number of active OMs	Dataset duration, days
1	270	68
2	273	72
3	288	74
4	288	61
5	288	47
1–5 combined single-cluster	1407	323

Single-cluster analysis: zenith distribution before quality cuts



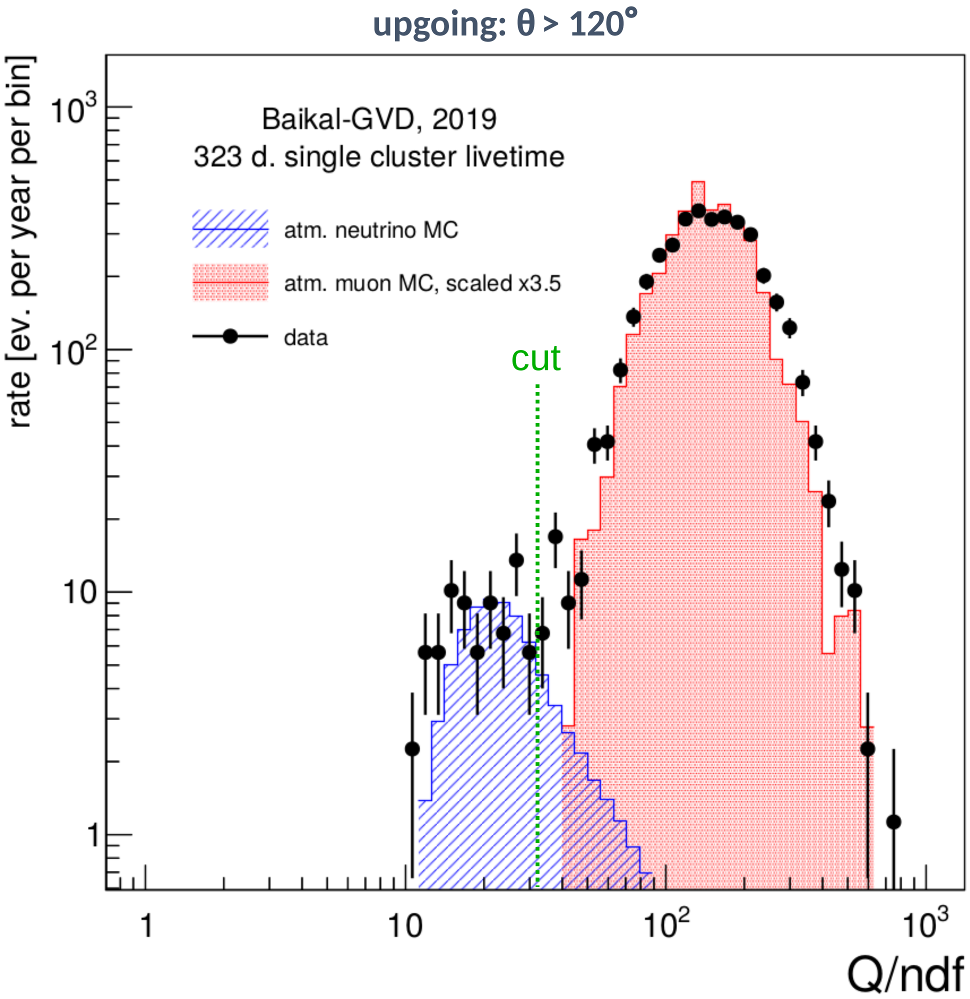
~ 9 800 000 events reconstructed with at least 8 hits on at least 2 strings

Good agreement for cos(zenith) > 0.2

MC underpredicts the rate of misreconstructed events in the upgoing region by a factor of 3.5

NB: most of these events are muon bundles (average multiplicity ~ 10)

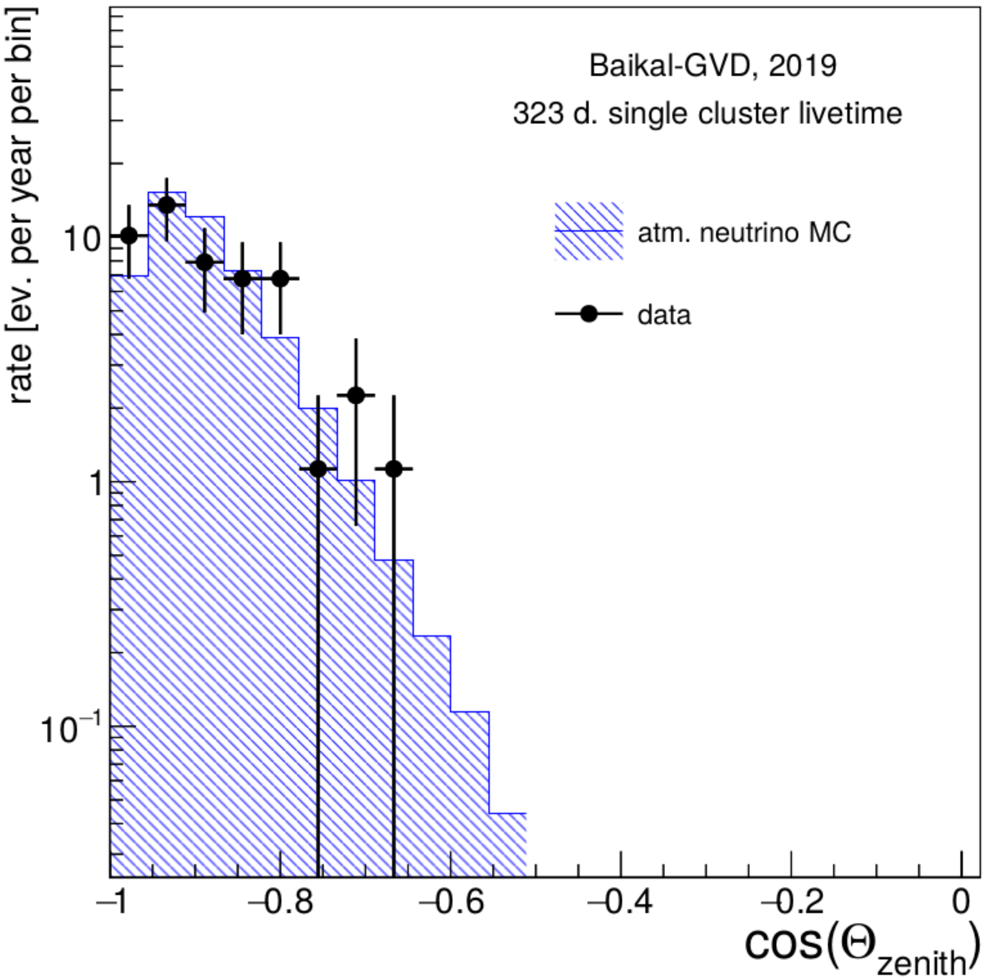
Single-cluster analysis: fit quality parameter



Shown is the fit quality distribution for events reconstructed as upgoing with cos(zenith) < -0.5

The atmospheric muon MC has been re-scaled by a factor of 3.5

Single-cluster analysis: upgoing neutrino search



Neutrino selection based on

- zenith angle
- fit quality
- additional cuts

MC expected: 43.6

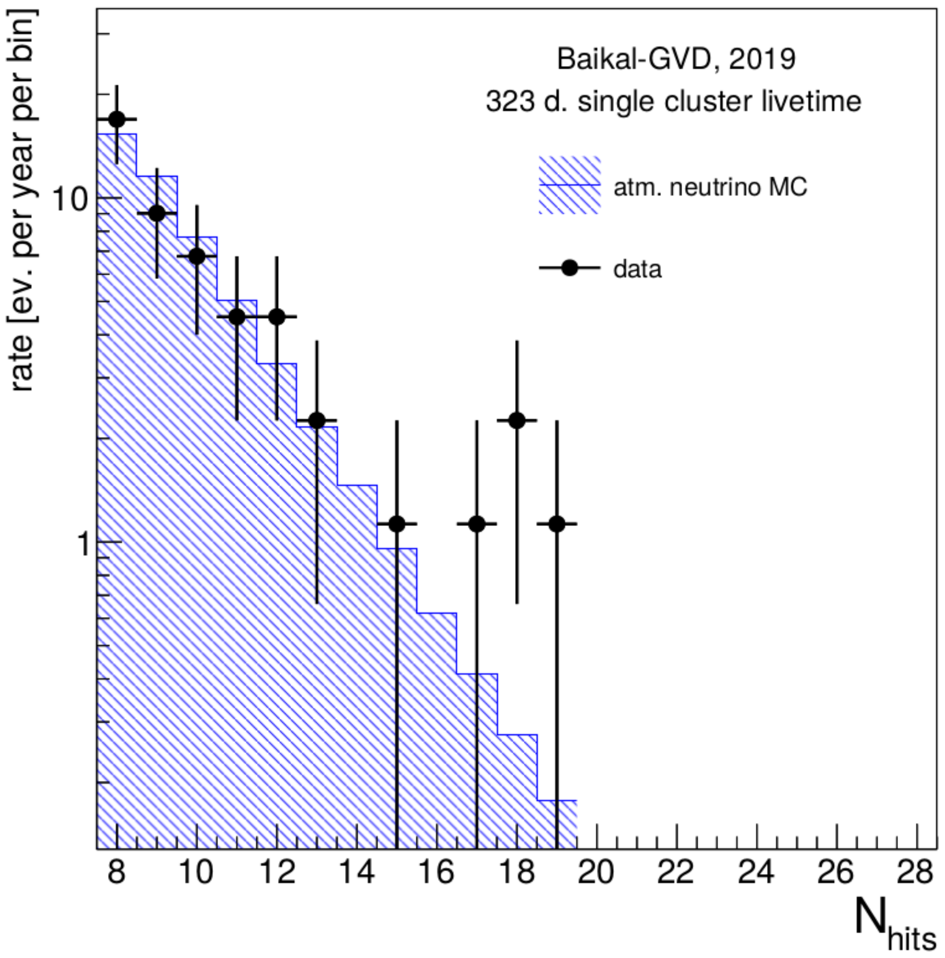
- atm. neutrino : 43.6
- atm. muons: < ~ 1

Observed events: 44

Good agreement with MC for atmospheric neutrino

Median energy of this sample ≈ 500 GeV

Single-cluster analysis: Nhit distribution

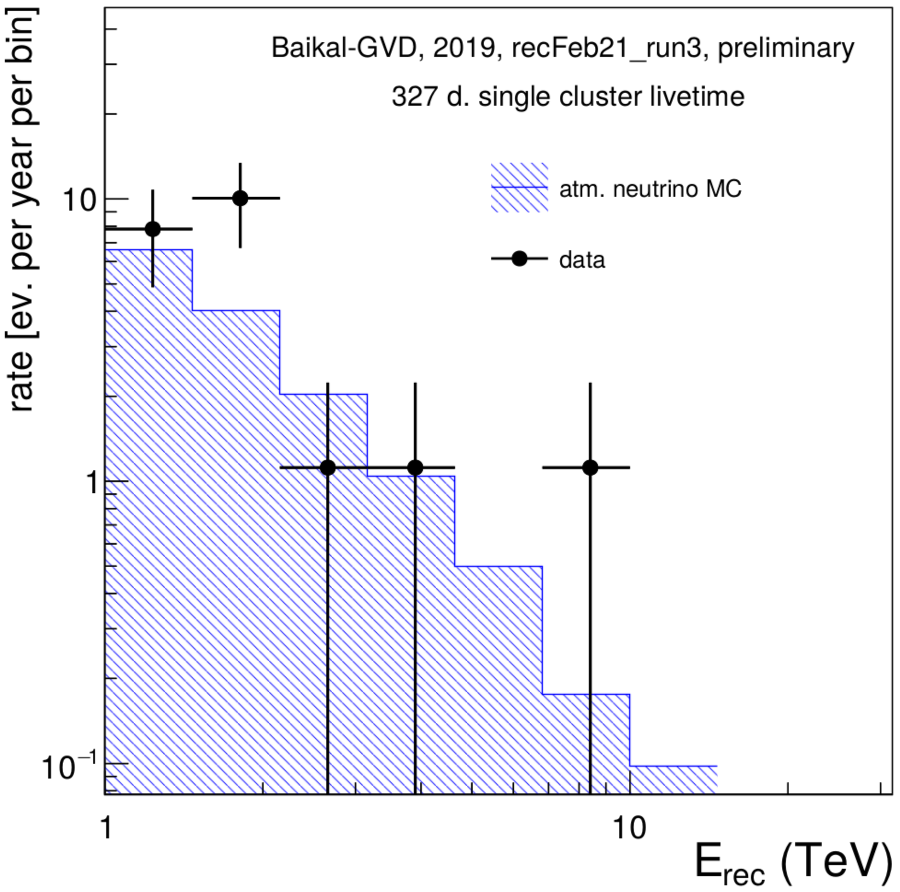


Good agreement between data and MC

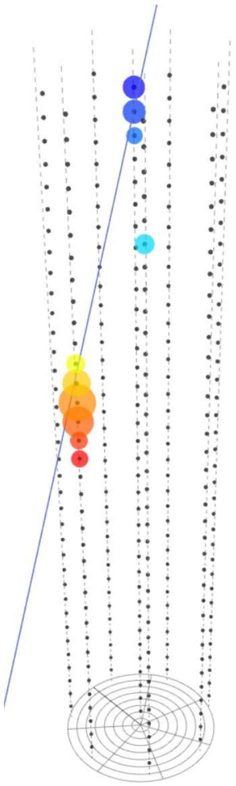
Apparent excess for N_{hits} = 17, 18 & 19 has a p-value ~ 0.05

Reconstructed energy

Example plot for a set of neutrino candidate events

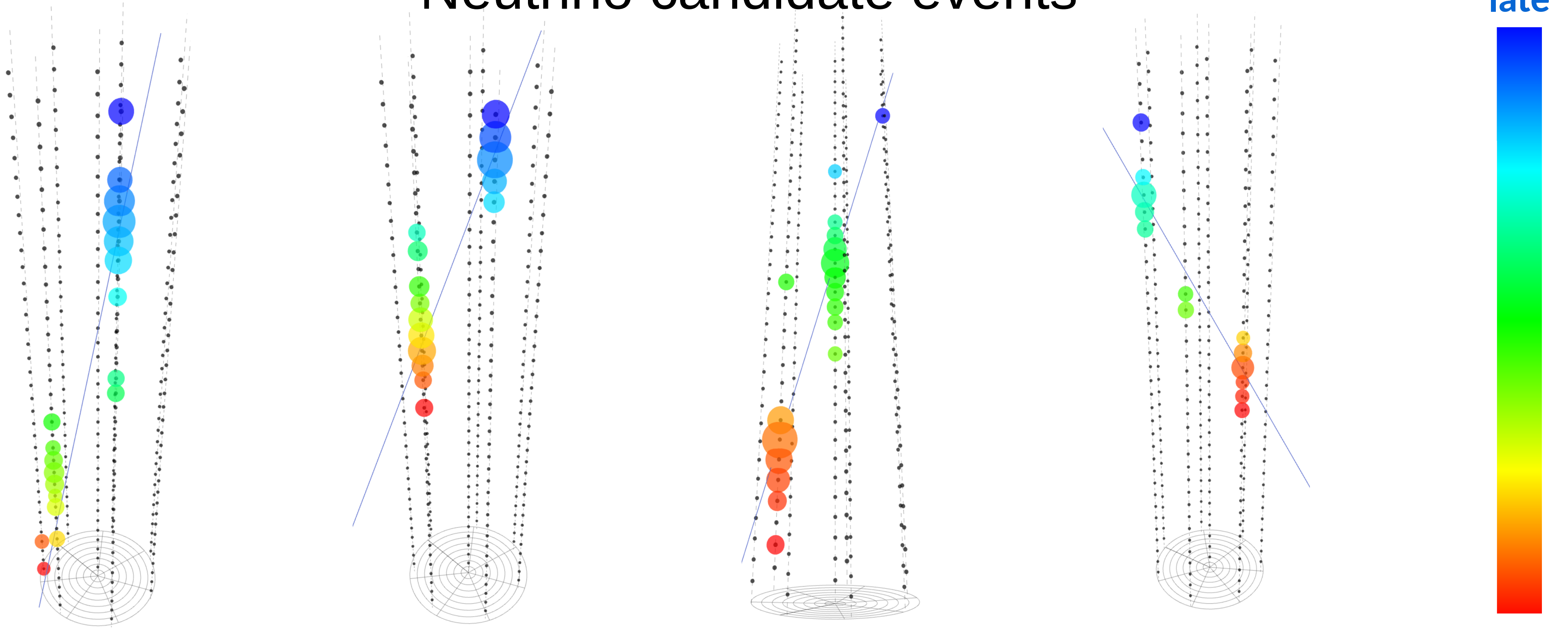


- dE/dx energy estimator - see poster by G. Safronov
- Works for E > 1 TeV
- Largest measured energy in cut-based low-energy neutrino candidate sample: 9.3 TeV



cluster 1, run 84
evt. 473478
θ = 165.5°
$N_{strings}$ = 3
N_{hits} = 10

Neutrino candidate events



cluster 3, run 122
evt. 1549343
θ_{zenith} = 169.78°
$N_{strings}$ = 3
N_{hits} = 19

cluster 1, run 157
evt. 1414137
θ_{zenith} = 161.78°
$N_{strings}$ = 2
N_{hits} = 15

cluster 4, run 99
evt. 438088
θ_{zenith} = 162.22°
$N_{strings}$ = 3
N_{hits} = 18

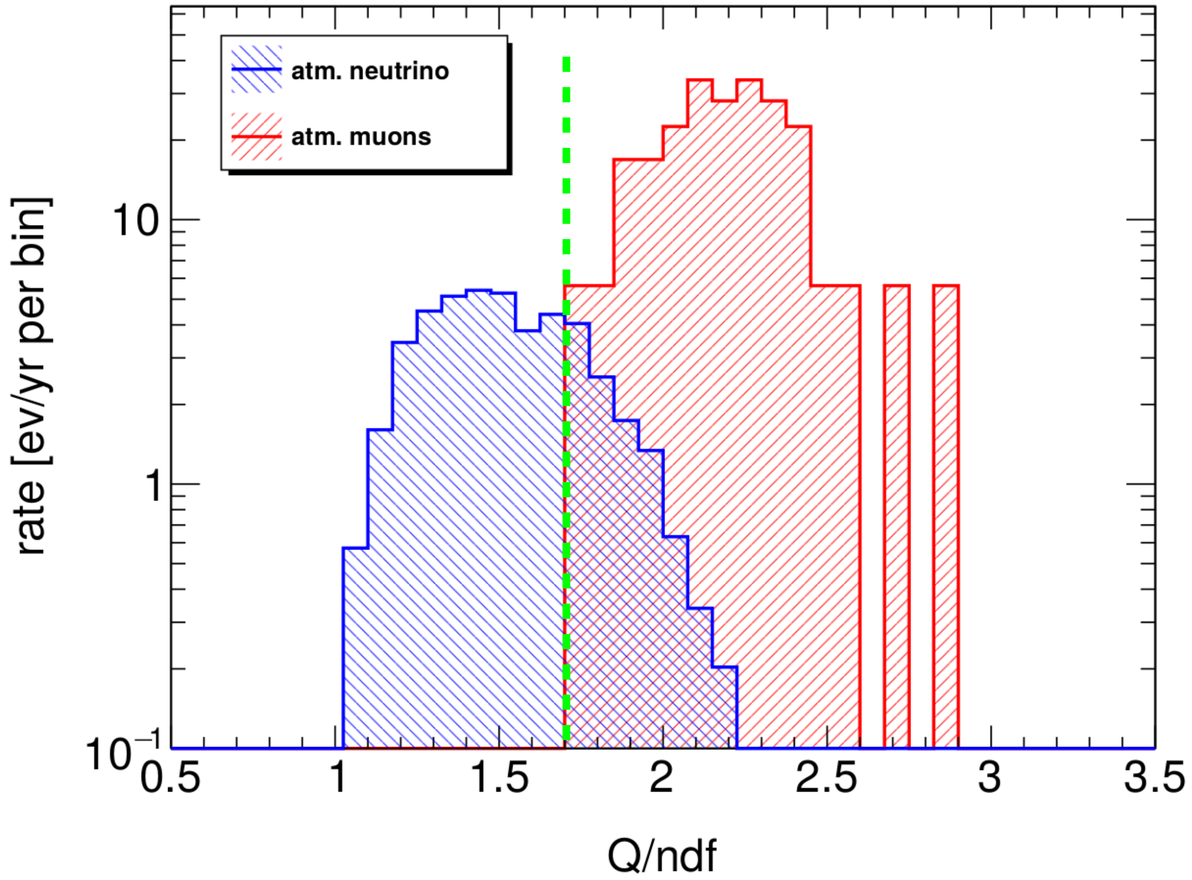
cluster 5, run 162
evt. 1939721
θ_{zenith} = 148.07°
$N_{strings}$ = 3
N_{hits} = 13

Notes

- The reconstruction and analysis were optimized for low-energy atmospheric neutrinos (~ 1 TeV)
- Sub-optimal neutrino efficiency due to conservative cuts
- A factor 2 improvement in analysis efficiency is possible (see poster by G. Safronov)

Multi-cluster analysis : MC expectations

Fit quality distribution after zenith angle cut



- In the 5-cluster detector, after cuts on the fit quality and other variables, we **expect 29.4 multi-cluster events per year** due to atmospheric neutrinos
- Median energy ~ 4 TeV
- The analysis will be applied to real data as soon as is the multi-cluster calibration is fully validated

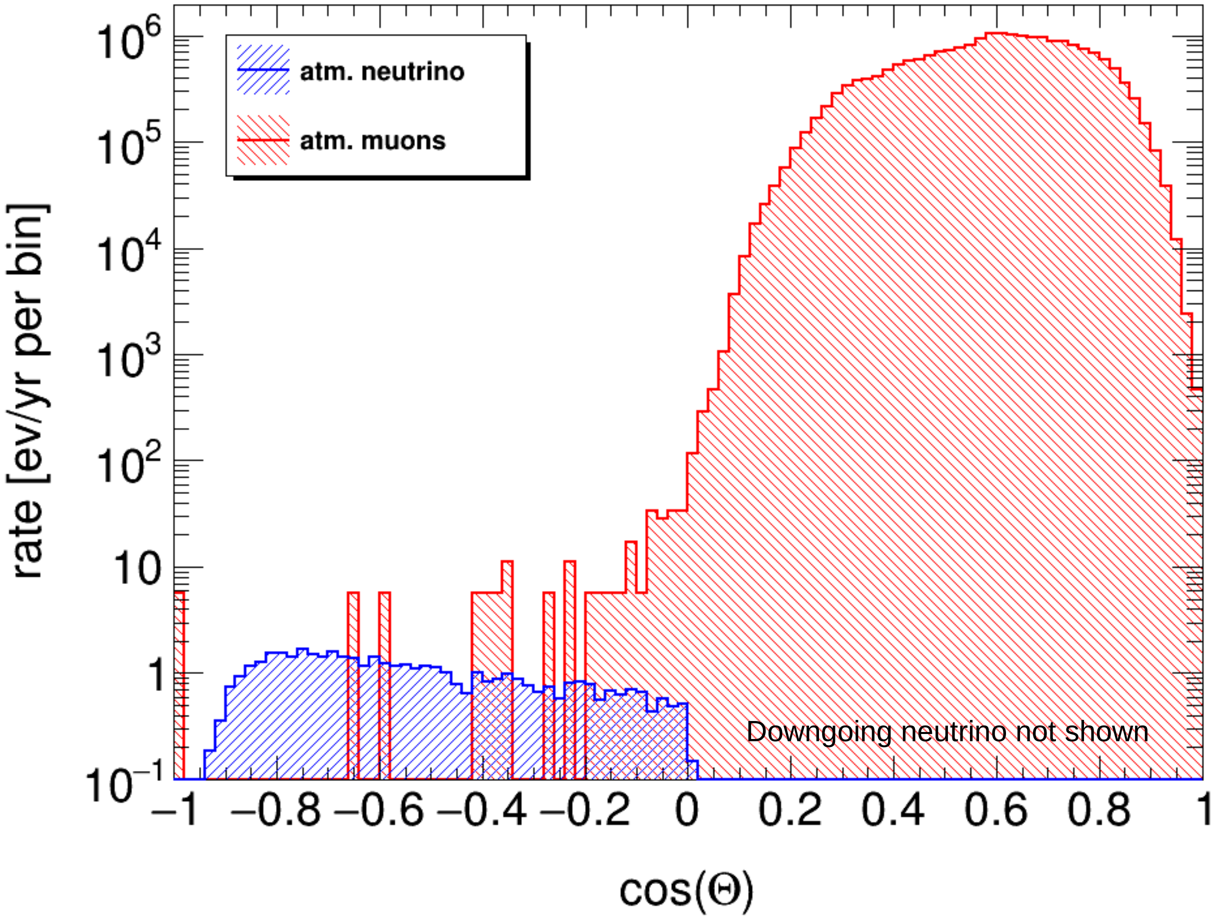
Conclusion

- Using a simple χ^2-based track reconstruction algorithm, we observe atmospheric neutrinos
- The observed rate, zenith distribution and energy distribution are in good agreement with MC predictions
- Shown here is only a small fraction of the collected data; further data analysis is imminent

Backup slides

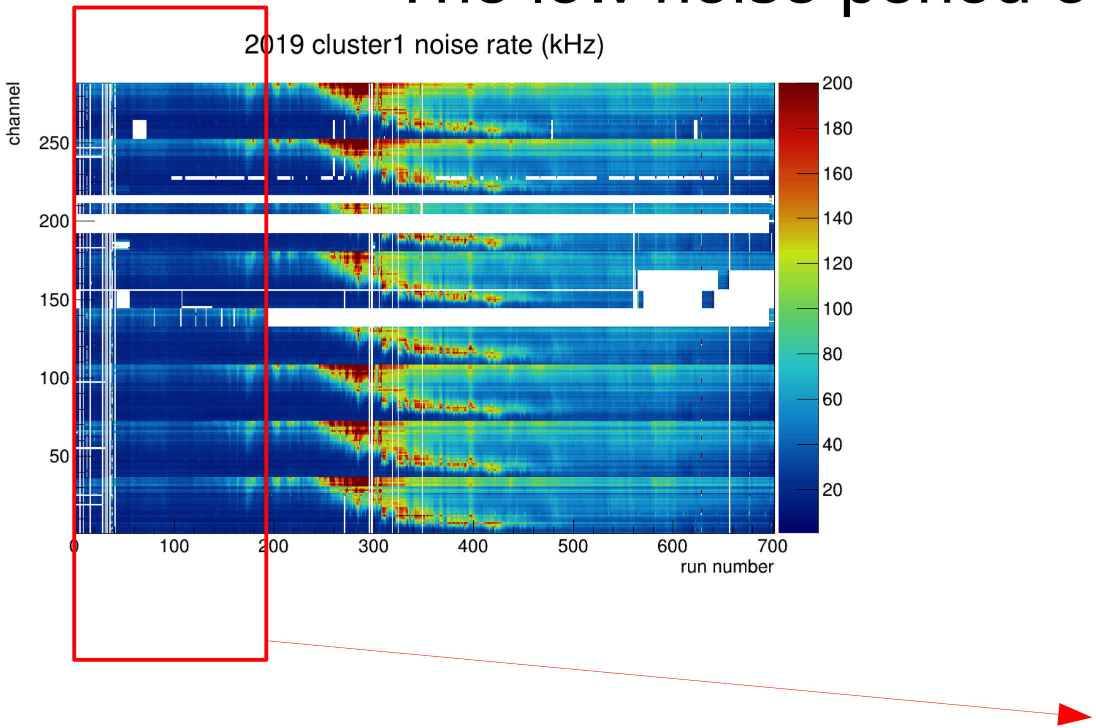
Multi-cluster analysis: reconstructed zenith angle distribution

after cut on reconstructed track length

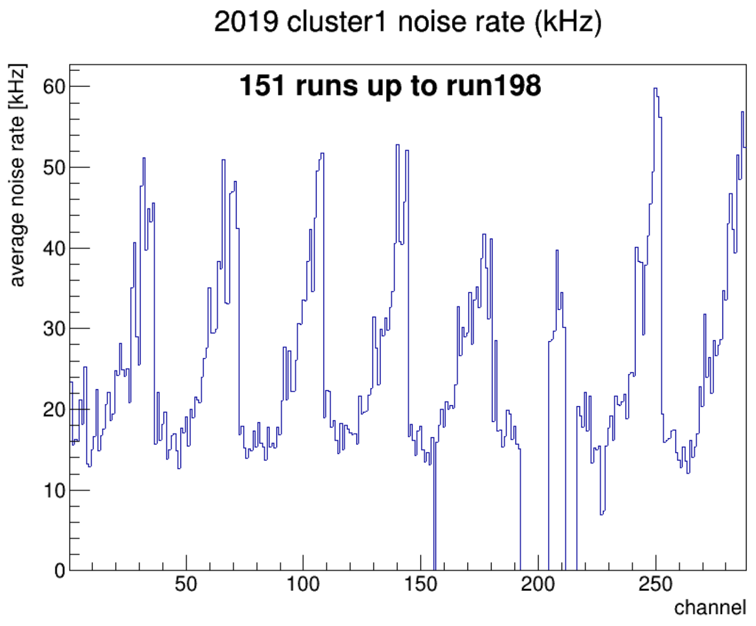


- The mutli-cluster event selection and the track length cut are very effective at suppressing misreconstructed atmospheric muon events

The low noise period of the 2019 season

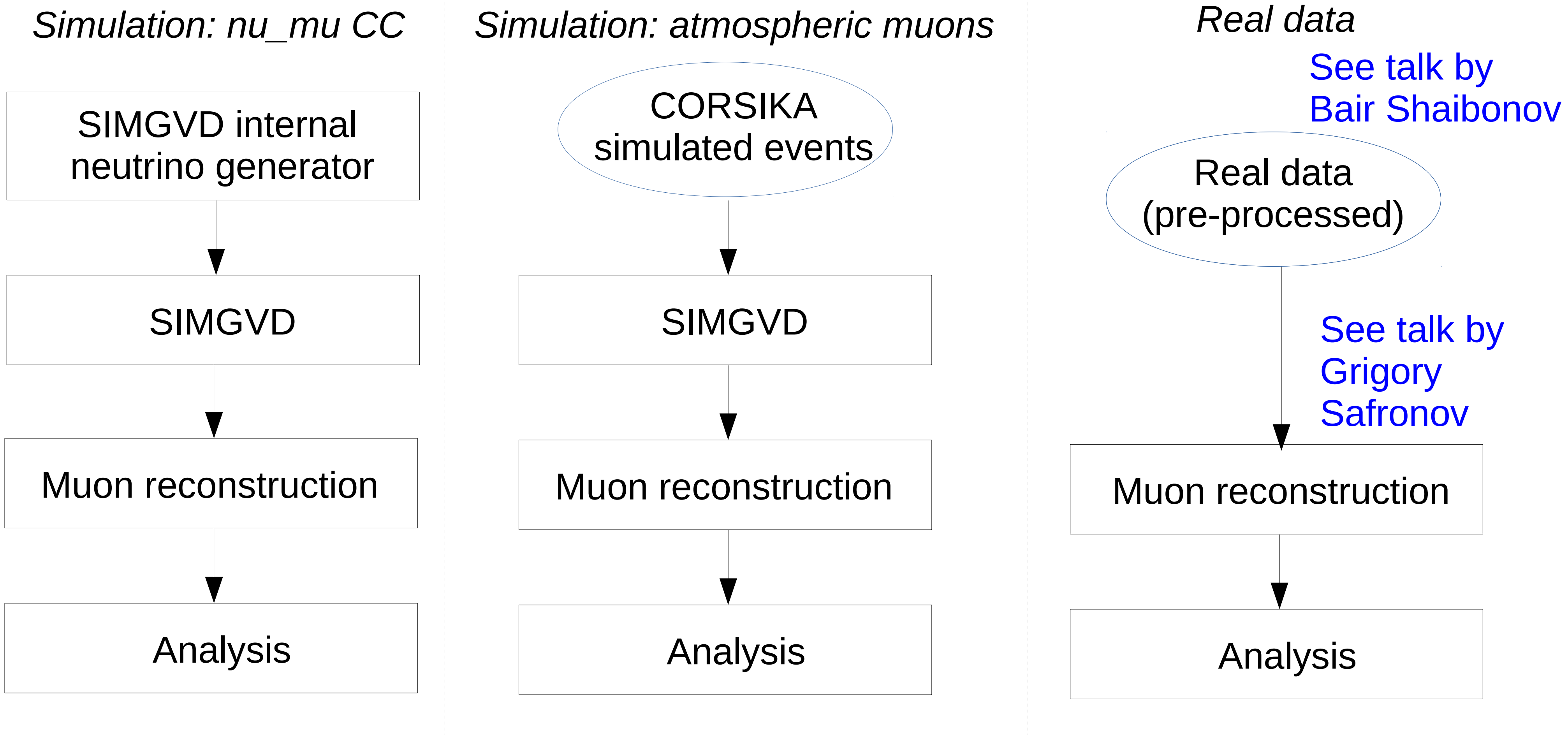


April 1 – June 30, 2019



Similar for clusters 2-5

The processing chain(s)



Simulations

- Atmospheric muons
  - CORSIKA 5.7 + QGSJET
  - 1 yr effective livetime
- Atmospheric neutrinos
  - ν_μ CC and $\bar{\nu}_\mu$ CC only
  - Bartol flux (Phys. Rev. D53 (1996) 1314)
  - Neutrino oscillations ignored
- Detector simulations
  - Muons propagated with MUM
  - Simplistic parameterized shower model

Additional cuts for neutrino selection

- Sum of hit amplitudes (> 18 p.e.)
- Visible track length (> 75 m)
- Hit density along the track length (> 1/42 m^{-1})
- Combined hit likelihood ($P_{hit} > 0.05$)
- Combined likelihood for non-hit OMs ($P_{nonhit} > 0.1$)
- Effective width of time residual distribution
- Zenith angle error estimate (< 2°)
- Average track – hit distance (< 18 m; this acts as a containment cut; may suppress high energy neutrinos)