Selection techniques of neutrino-induced cascades in the Baikal-GVD neutrino telescope

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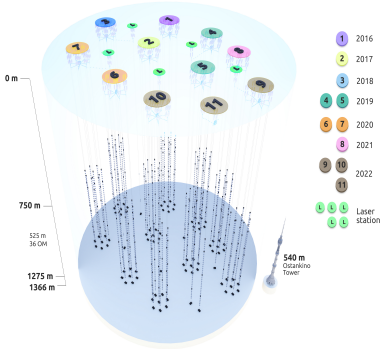
July 25, 2022

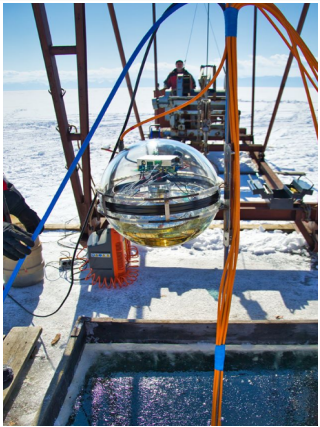
Baikal - GVD (Gigaton Volume Detector)

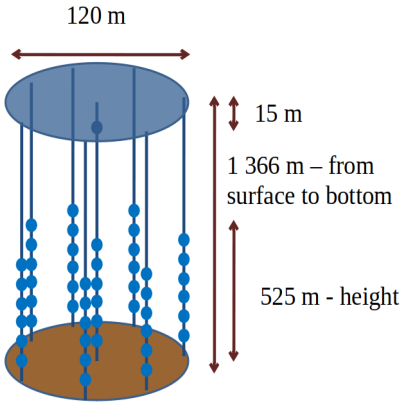
- Detector Baikal-GVD is located at the bottom of the deepest freshwater lake in the world, Lake Baikal.
- Very clean water provides low absorption ($\approx$ 24 m at 488 nm) and scattering ($\approx$ 480 m effective length at 475 nm)
- The lake freezes and ice layer allows for the construction of the detector without ships
- At the depths from 1275 - 750 m and 3.6 km from the shore



Detector Baikal-GVD

- Each cluster consists of 8 strings with 288 Optical Modules (OMs)
- Current state (year 2022) of the detector: 10 clusters $\rightarrow$ 2880 OMs



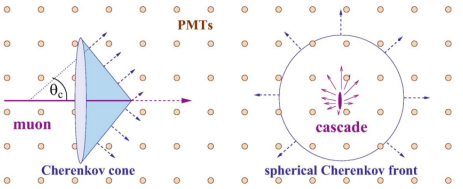


Principle of Detection

- Neutrinos can be indirectly detected through the weak current interactions:

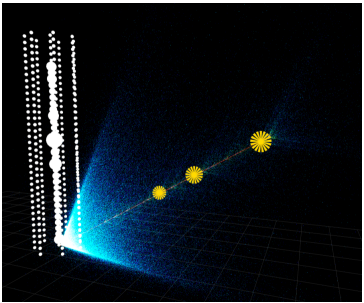
$$\nu_l\ (\bar{\nu}_l) + N \xrightarrow{Z^0} \nu_l\ (\bar{\nu}_l) + X, \qquad \nu_l\ (\bar{\nu}_l) + N \xrightarrow{W^\pm} l^-\ (l^+) + X$$

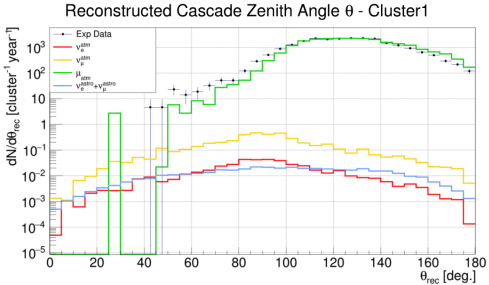
- $l = e, \mu, \tau$
- Secondary particles produced in the neutrino interactions with matter create Cherenkov light, which can be detected by the optical sensors
- The event topologies: Tracks and **Cascades** (ν_e CC, NC of all flavors, ν_τ CC)



Background Cascades

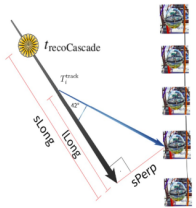
- Atmospheric muons and neutrinos are mainly produced in the decays:
- $\pi^+ \to \mu^+ + \nu_\mu, \quad \mu^+ \to e^+ + \nu_e + \bar{\nu_\mu}$
- **Background cascades** originate from discrete energy losses along muon tracks (bremsstrahlung, photonuclear processes, direct electron-positron pair production)
- Light signature $\Longrightarrow$ Cherenkov cone with stochastic energy losses
- To distinguish between signal and bkg cascades, we developed, optimized, and tested several techniques
- MC and experimental data in this work are used for early part of season 2019

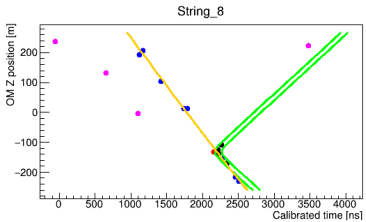


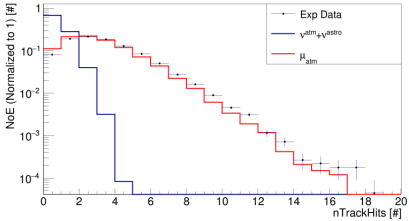


Selection Techniques

- Selection techniques have been optimized with MC simulations for season 2019 of signal and background cascades
- Experimental data used from season 2019
- Variable *nTrackHits*: $T_i^{\text{track}} = t_{\text{recoCascade}} + (\text{sLong} - \text{lLong}) \cdot \frac{1}{c} + \sqrt{\text{sPerp}^2 + \text{lLong}^2} \cdot \frac{1}{c_w}$
- noise hits, muon track hits, **cascade hits**, reconstructed cascade, expected cascade hits time, expected track hits time

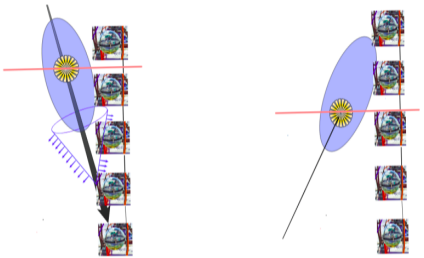


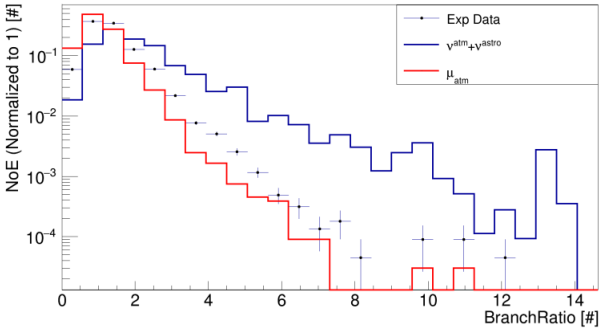




Selection Techniques

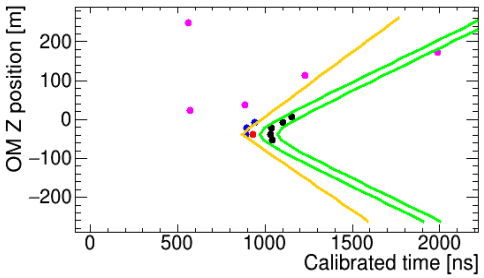
- *BranchRatio* - ratio of hit OMs that lie in the upper half-plane versus the ones in the lower
- The plane intersection is determined by the position of the reconstructed cascade
- $BranchRatio = \frac{nOMs_{upper}}{nOMs_{lower}}$

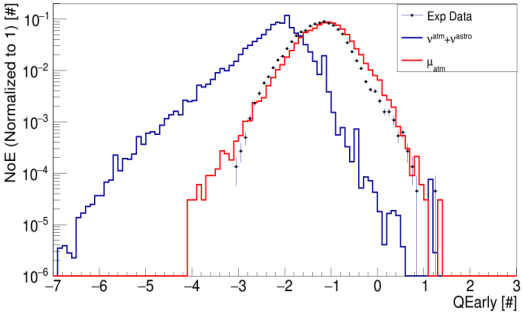




Selection Techniques

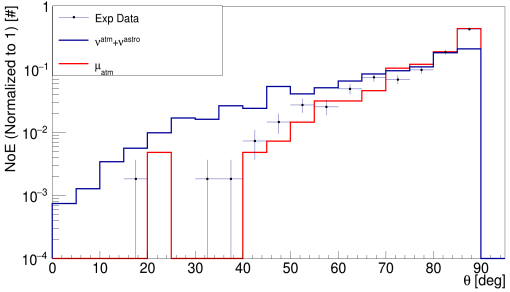
- *QEarly* was inspired by ANTARES collaboration (Astron. J. 154, 275. 2017)
- Compares the total charge of track hits and the total charge of cascade hits (green band)
- $QEarly = \log_{10}\left(\frac{(Q_{\mathrm{trackHits}}+a)}{Q_{\mathrm{cascadeHits}}}\right)$

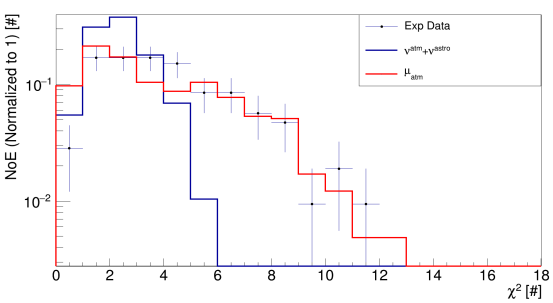




Multivariate Analysis

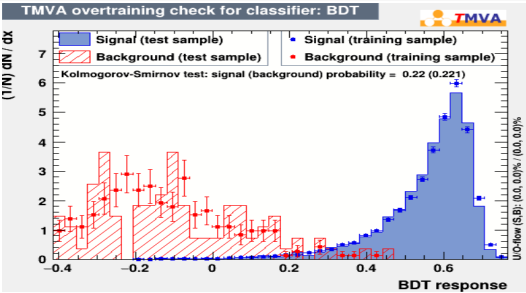
- Multivariate event classifier Boosted Decision Tree (BDT) in ROOT package
- 5 variables used for training and testing BDTs with signal and background cascades
- nTrackHits, BranchRatio, QEarly, Zenith angle θ, χ^2
- To find potential neutrino cascade we used only **contained upgoing** events ($\theta < 90\,\text{deg}$)
- Downgoing muons from the air showers misreconstructed as upgoing

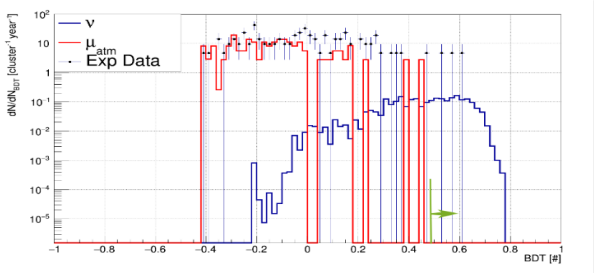




Multivariate Analysis

- BDT output value distribution for signal (blue) and background (red)
- The event rates of neutrino cascades are scaled down according to realistic neutrino fluxes
- To find potential neutrino cascade we used only contained upgoing events ($\theta < 90\,\text{deg}$)
- Maximum value of significance $S/\sqrt{S+B} \implies$ cut on the BDT value (0.48)
- Strong suppression of bkg and $\sim 50\%$ signal efficiency

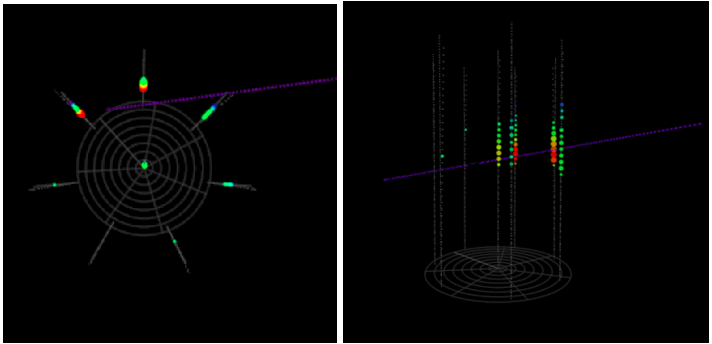




Search for Interesting Events

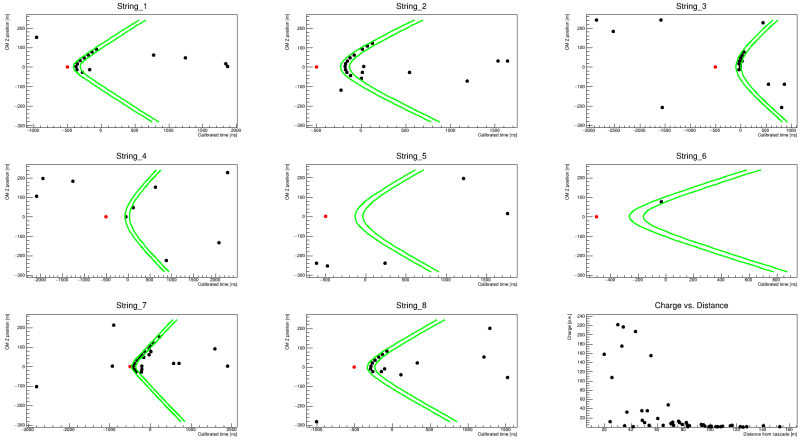
- Find interesting events in experimental data (2019) with BDTvalue > 0.48 and $E_{reco} > 50$ TeV
- Interesting upgoing contained well-reconstructed event found
- Season 2019, Run 114, EventID 773569, Cluster1

Cluster	**BDT** [#]	**E [TeV]**	θ [°]	ϕ [°]	Q [p.e.]	nHits	nRecoHits	nTrackHits
1	**0.6**	**83.3**	70.9	4.96	1665	106	44	1



Upgoing Event - ID 773569

- Dependence of Z coordinates of OMs on hits detection times



Conclusion

Summary

- We developed and optimized methods (MC) to distinguish between signal and bkg cascades
- We took the advantage of Multi-variate analysis - trained and tested BDTs
- Application to experimental data 2019
- Scan for interesting events -> one candidate for upgoing neutrino event found with E = 83.3 TeV
- It is not final result $\rightarrow$**analysis is in progress**

Thank you for your attention!

Upgoing Event - ID 773569

- Direction and Energy scan of interesting upgoing event