Atmospheric muon studies with ORCA

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Outline

- Quick reminder of results presented last year:
  - Atmospheric muon rejection feasible with a combination of reconstruction parameters.
- Updates on the atmospheric muon rejection:
  - Improvements using multivariate technique approach.
- Future goals.

Production chain

Muon generation: **MUPAGE v3r5** – muon bundles at the can

- $1 < E_{\mu} < 10^5$ GeV
- $0° < \theta < 85°$
- Multiplicity < 200

Muon propagation and light production: **km3 v4r4**

Optical background: **modk40**

Reconstruction: **recoLNSlowE20** (track reco algorithm – Jannik's talk)

Reference detector:

- 50 strings, 20 m spacing;
- 20 OMs per string, 6 m spacing;
- 31 3” PMT per OM.

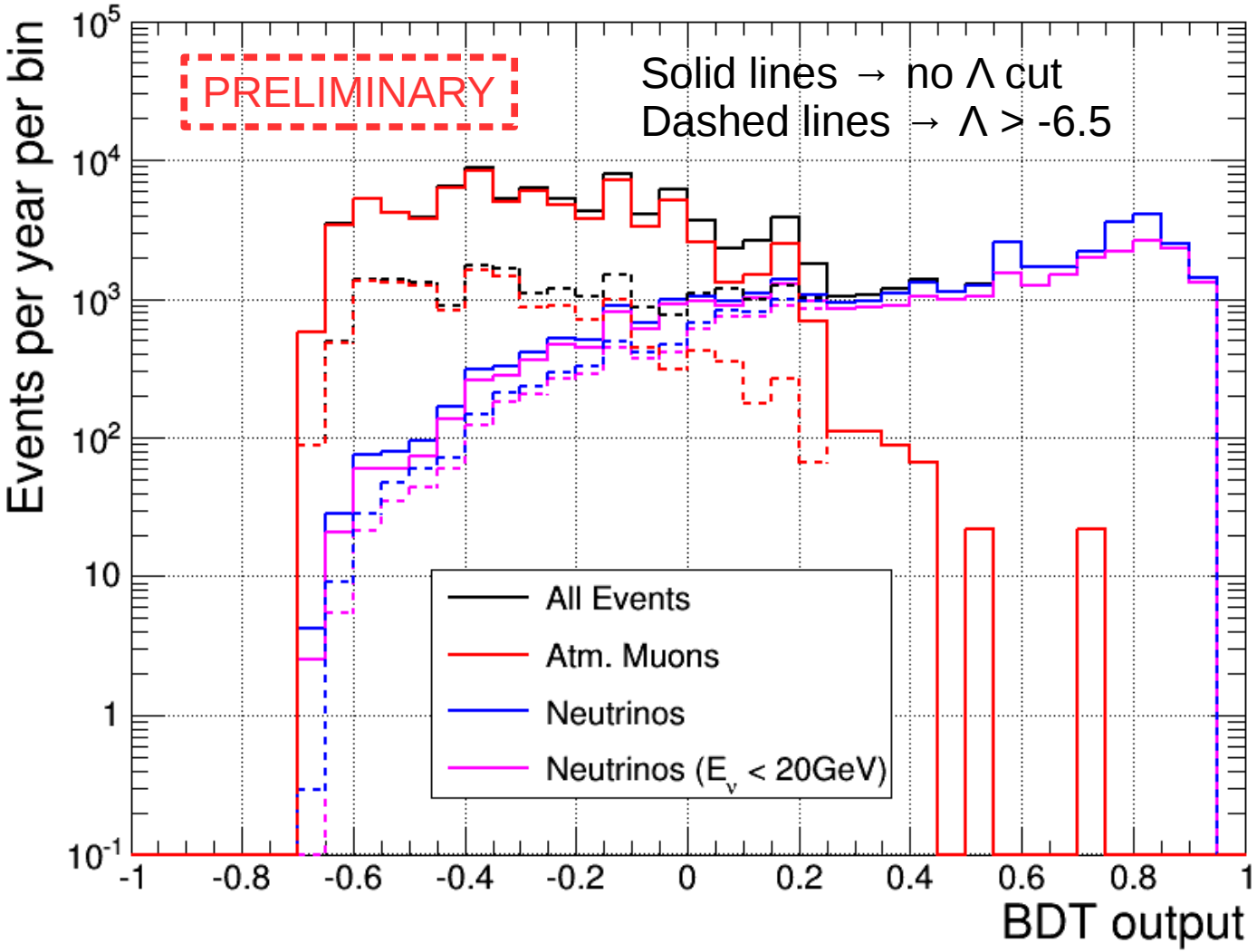
Reminder

- What did we find?
  - Rejection of wrongly reconstructed atmospheric muons feasible with $\Lambda+\beta$ cut and R_{ν} containment
    - Λ is the log-likelihood per d.o.f. from the track reconstruction, β is the angular error estimation: really upgoing track are better reconstructed
    - Atmospheric muon events reconstructed as upgoing have their pseudo-vertex outside the instrumented volume
  - Muon rejection possible: different cuts, from 50% down to 1% muon contamination in the resulting sample
    - Results already shown last year at MANTS
  - Drawbacks:
    - Lowering of the neutrino efficiency at low energies ($E_{\nu} < 10$ GeV, i.e. in the most interesting region for ORCA);
    - The β cut is the main responsible for this.
  - Developments needed: multivariate analysis of the problem.

Boosted Decision Tree

- Use a combination of reconstruction parameters
  - Events with reconstructed vertex inside the instrumented volume
  - Simply, again, Λ, β and R_v, as we yet know that they are effective
  - Can be improved with further studies/more complicated things
- Optimize for signal (neutrinos below 20 GeV) efficiency and background (atmospheric muons) rejection
  - Train the algorithm for signal identification with an atmospheric muon background
- Only track events here (as in the old studies).

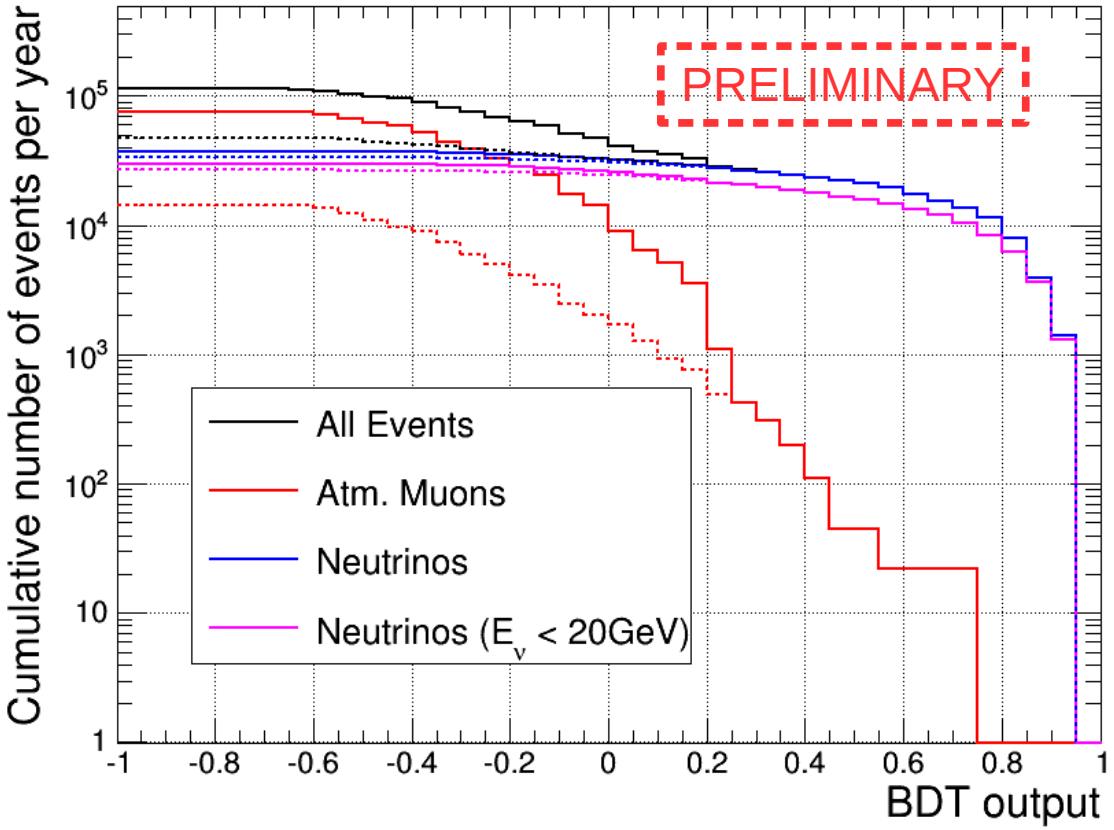
BDT output distribution



Positive values:
more neutrino-like (i.e. really upgoing event)

Cut on the BDT output to separate νs and μs

BDT output distribution



Solid lines → no Λ cut
Dashed lines → Λ > -6.5

An example solution:

- BDT > 0 and Λ > -6.5
- Contained reco vertex

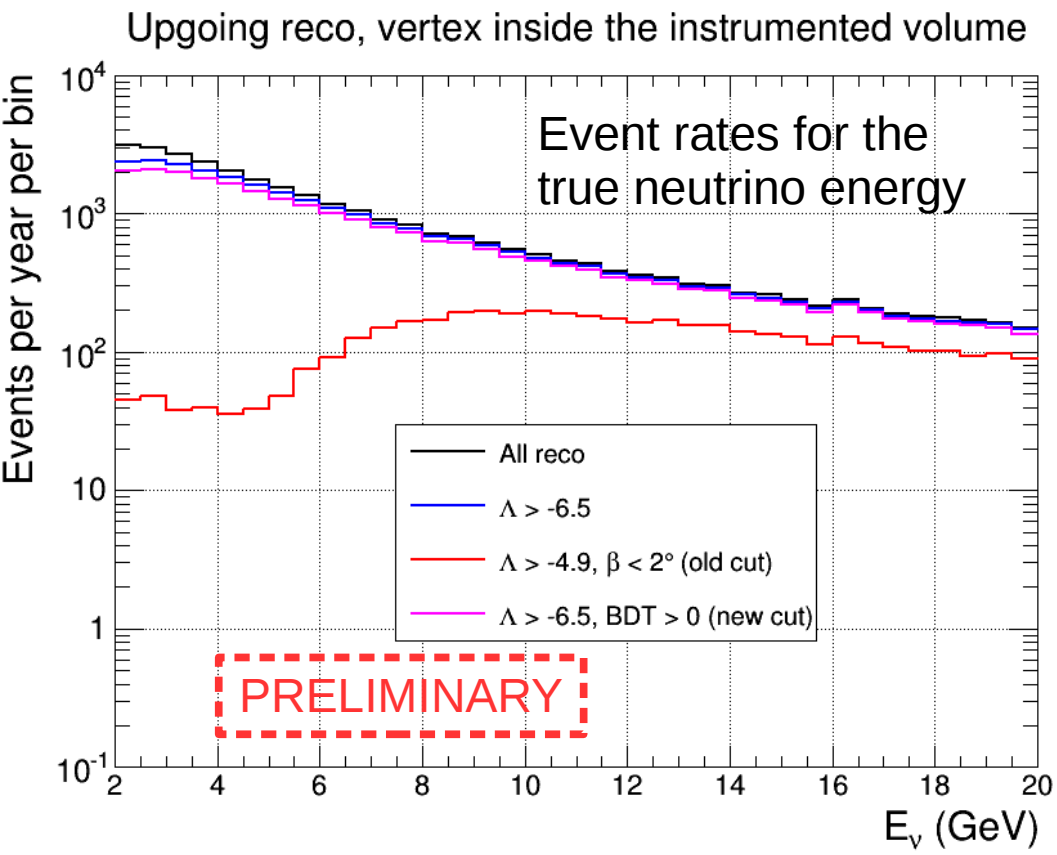
Muon contamination < 10%

	Old cut	New cut
#ν/yr	~15k	~30k
#ν_{20}/yr	**~5k**	**~25k**
#μ/yr	~1k	~2k

Factor 5 gain in “signal” region.

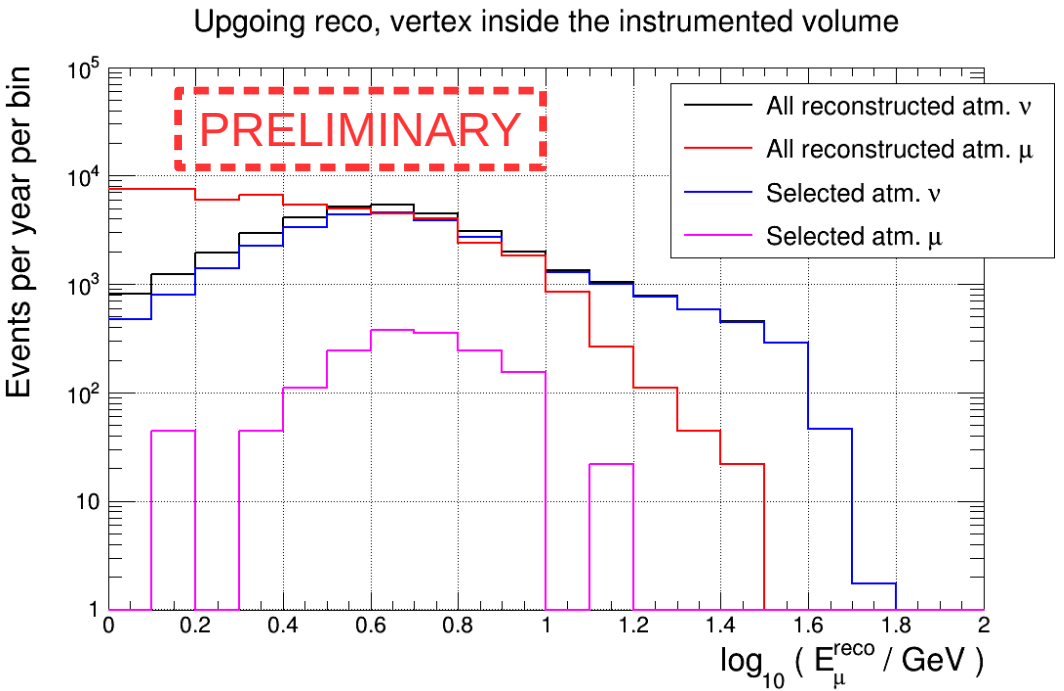
Further rejection possible – complete study ongoing

What about low energies?



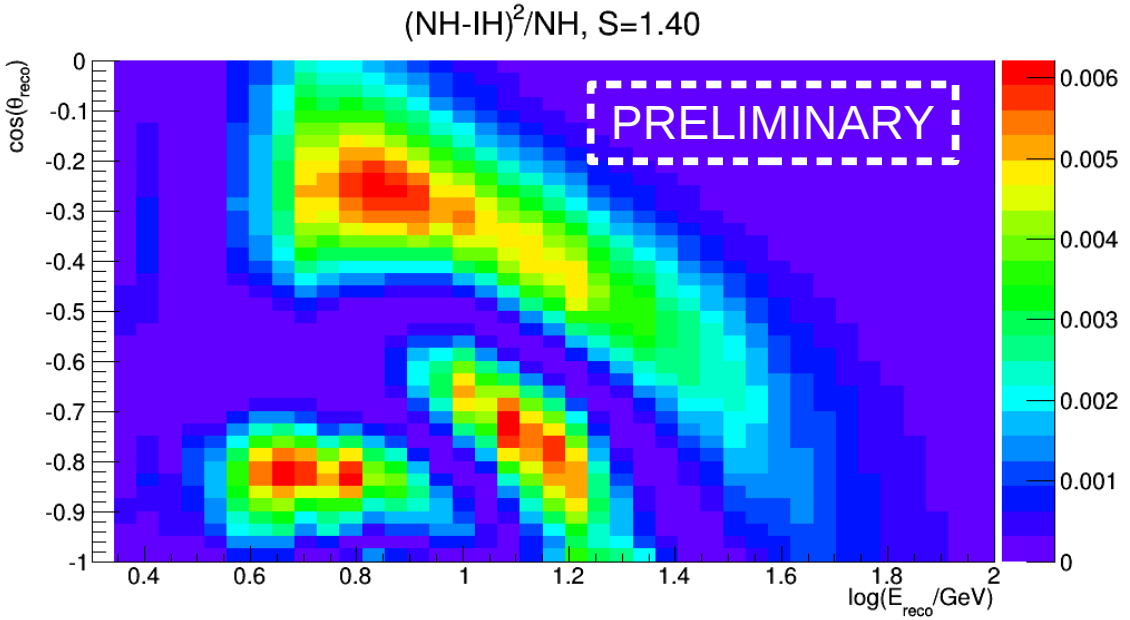
Getting much closer to the expected event rates with a looser Λ and no β cut.

Event rates for the reco muon energy



Caveat

- Limited statistics for simulations (~16.5 days) but the BDT works well – using only reconstructed event-by-event quantities.
- These cuts are a tentative solutions to the problem:
  - To be put inside the sensitivity calculations



Significance in the ν_μ channel, no atmospheric μ background included. Need to understand its changes.

- Minimize the loss of events in the high significance regions
- Minimize the muon background in the same regions

Now ongoing

- Studying the behavior of the 115 strings detector.

- Reconstruction(s) to be applied and muon contribution to neutrinos to be studied with this detector
  - Same strategy as for the reference detector
  - Larger volume, different r-z shape – effects on the radius expected
  - Further studies also in the shower channel

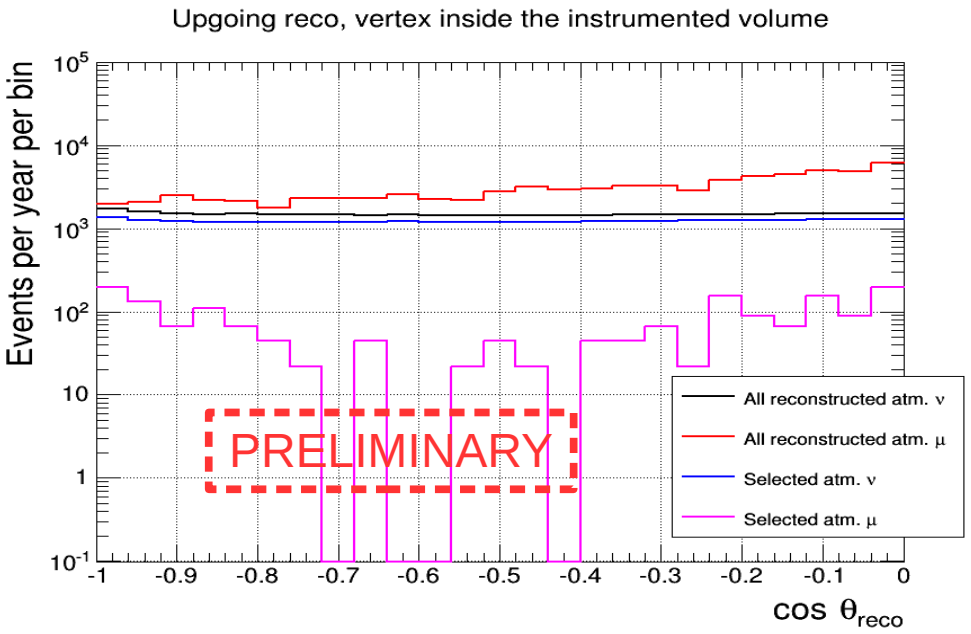
Conclusions and outlook

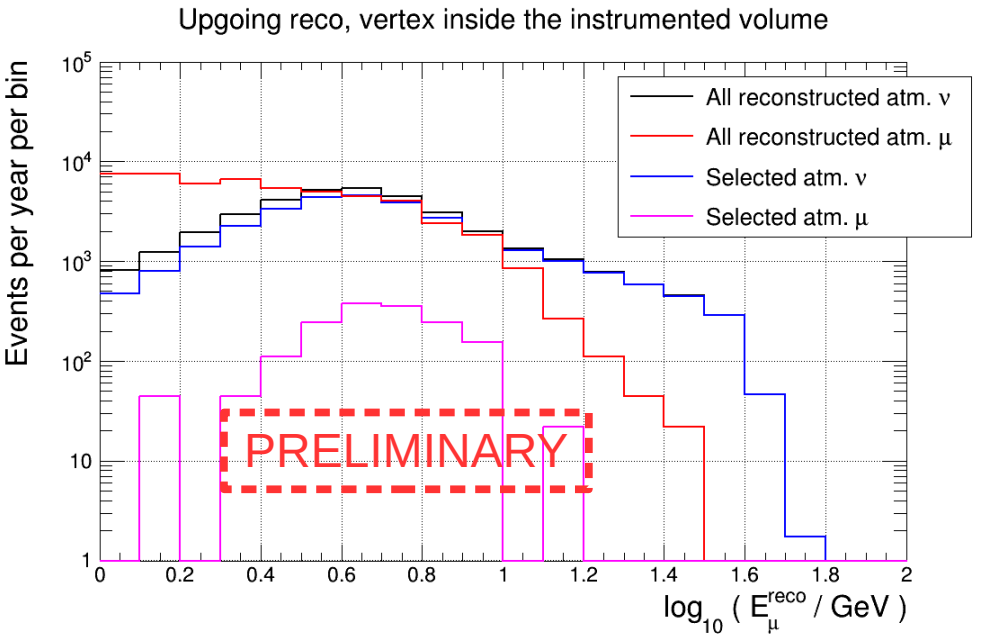
- Strong improvement using the BDT technique:
  - Dealing with a combination of Λ, β and R_v, but properly treated to optimize low energies;
  - Preliminary, but encouraging results; ~$10^{4\div5}$ rejection factor on the cumulative number of mis-reconstructed events.
  - Need to put it into the actual sensitivity calculations to have a complete insight in the muon contamination problem.

- To be applied on the new 115 strings detector.

Backup

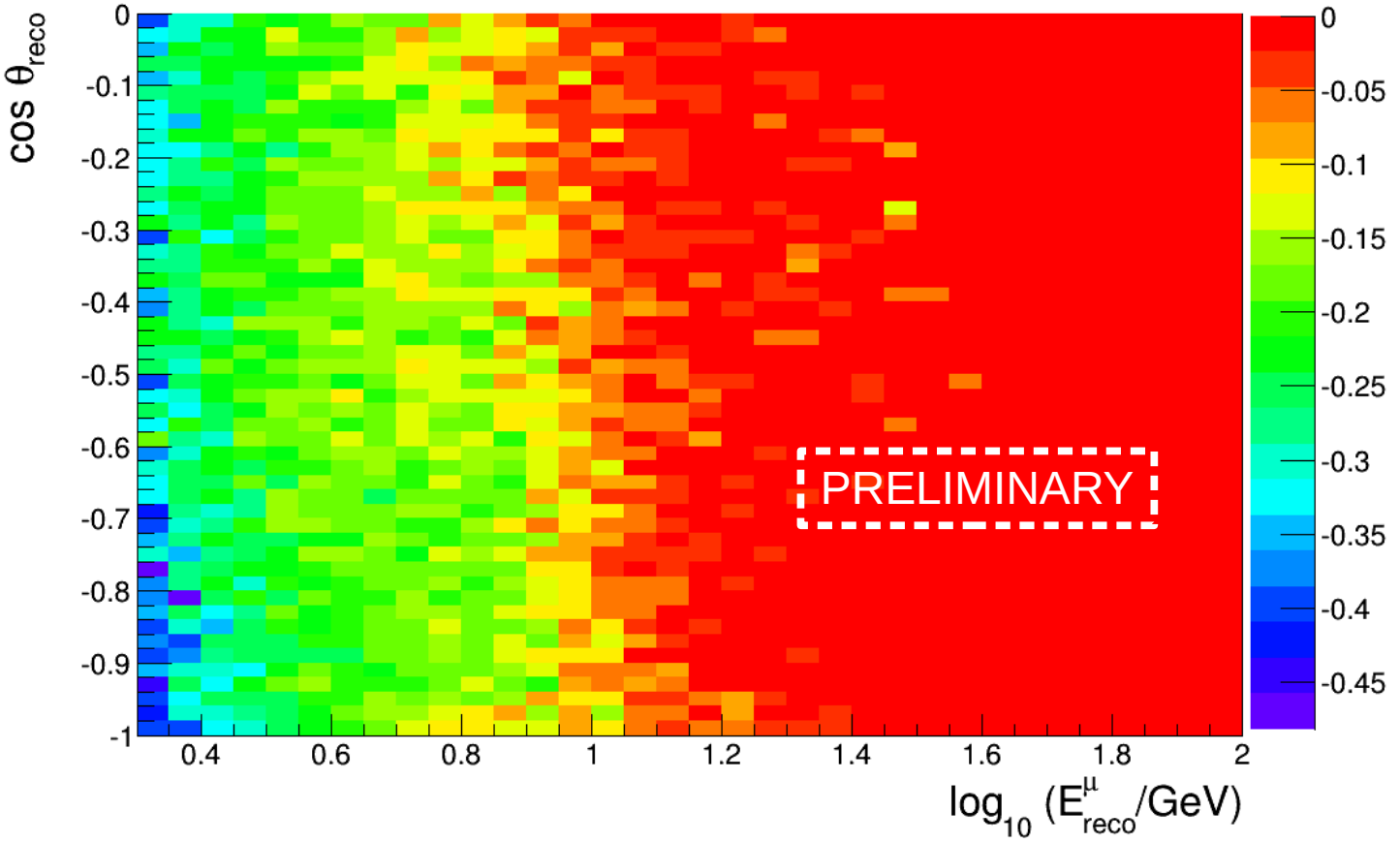
Cut effects in energy and zenith





Zenith (left) and reco energy (right) before and after cuts

Cut efficiency in energy vs zenith



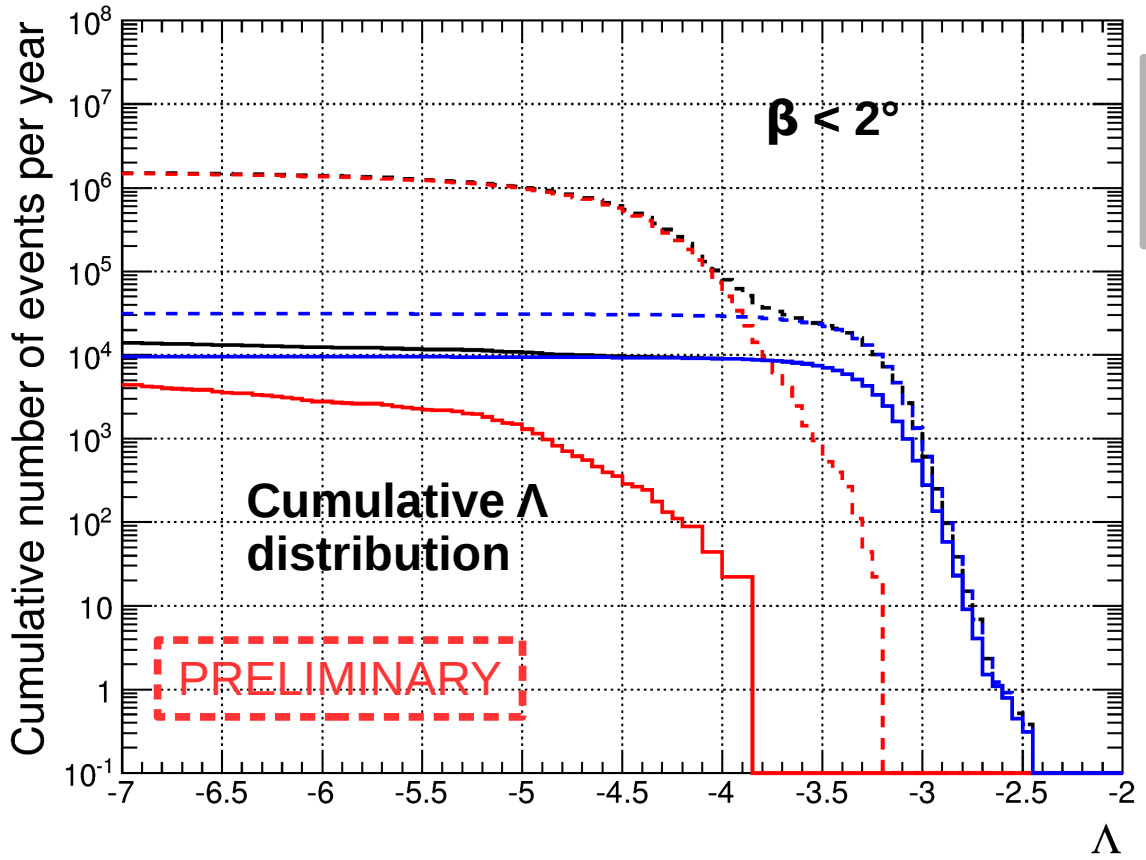
Relative loss in neutrino event rate with respect to all reconstructed events.

Shown 1 year ago @ MANTS

Using the track starting point

Cμ 10%
Λ > -4.8

A combination of **Λ, β** and R_ν is effective in the rejection of upgoing reconstructed atmospheric muons



Solid: R_ν < 70m
Dashed: no R cut