A new IceCube starting track event selection and realtime event stream

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IceCube and Atmospheric Neutrino Self-Veto

IceCube trigger dominated by cosmic ray muons

Use energy and zenith angle to distinguish atmospheric and astrophysical neutrinos

Can find **neutrinos in southern sky** by looking for **starting muon tracks** using a veto region

**Reject atmospheric neutrinos** by light from their sibling muons created in the same air shower
Enhanced Starting Track Event Selection (ESTES)

Selection Goal: Observe starting tracks
- High astrophysical muon neutrino purity in southern sky
- Good pointing resolution

Starting track selection defines a unique veto region for each event

Can use starting track events for:
- Diffuse astrophysical spectrum fit
- Point source searches
- Realtime event stream

(Existing) Starting Event Selections
Use predefined veto regions to find starting events
- Restrict detector volume
- Optimized for cascades

(New) ESTES

"Bert"

"Ernie"
Veto region selection

Assume an infinite track hypothesis

Predict light yield at optical modules (DOMs)

Find earliest hit consistent with track hypothesis

Define **muon region** and **veto region**

Calculate the probability, $p_{\text{miss}}$, of DOMs in veto region missing light from track

- Product of poisson probability that DOMs in veto region saw no hits

Use $p_{\text{miss}}$ as main parameter in determining if starting track
## Full starting track selection

<table>
<thead>
<tr>
<th></th>
<th>Atmo $\mu$ (per year)</th>
<th>Atmo $\nu$ (per year)</th>
<th>Astro $\nu$ (per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South pole filters and total charge cut</td>
<td>$9.0 \times 10^8$</td>
<td>$1.7 \times 10^4$</td>
<td>$1.2 \times 10^3$</td>
</tr>
<tr>
<td>Starting track veto (cuts on $p_{\text{miss}}$)</td>
<td>$5.6 \times 10^6$</td>
<td>$3.4 \times 10^3$</td>
<td>150</td>
</tr>
<tr>
<td>Sneaking track grid search with starting track veto</td>
<td>$1.6 \times 10^4$</td>
<td>910</td>
<td>50</td>
</tr>
<tr>
<td>Up-going ($\theta &gt; 80^\circ$)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Straight cuts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Down-going ($\theta &lt; 80^\circ$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straight cuts + BDT</td>
<td>$&lt;1$</td>
<td>160</td>
<td>14</td>
</tr>
</tbody>
</table>

### Final Level

Numbers for all sky

Astrophysical flux assumed throughout this talk ([PRD 91 (2015)](https)):  

$$\phi = 2.06 \times 10^{-18} \left( \frac{E}{10^5 \text{GeV}} \right)^{-2.46} \text{GeV}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{s}^{-1}$$
Effective area and per year event expectations

Average angular error around **1.7 degrees** for full sample

Angular error has little dependence on energy

Starting tracks use **hadronic shower** and **muon energy loss** to reconstruct energy

**Neutrino energy resolution** around 0.25 in log(Energy) across all energies
Results from preliminary data

10% of 4 years of data
Will perform diffuse fit on data
Point sources and astrophysical purity in the southern sky

High astrophysical purity in southern sky

Only need a few events to be sensitive to source

10 Years of starting tracks in southern sky:

- 68 background events
- 66 astrophysical events
- Events needed for 5σ point source: 3

Point source sensitivities

Starting track selection sensitive to southern sky

Competitive sensitivities especially when spectrum softer or energy cutoffs applied

IC 7 Year: arXiv:1609.04981
IC (40+59+79) + Antares: arXiv:1511.02149v1
ESTReS: ESTES near realtime event stream

Modified veto selection run in realtime at South Pole
- Higher energy
- Longer track length

<table>
<thead>
<tr>
<th>Atmospheric $\mu$</th>
<th>Atmospheric $\nu$</th>
<th>Astrophysical $\nu$ (Total/Total at 50% purity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1300 per year</td>
<td>7.5 per year</td>
<td>2.8/2.4 per year</td>
</tr>
</tbody>
</table>

Events sent north to have whole ESTES selection run on them in ~5 minutes
In the future, if event passes full selection, send out an alert
Conclusion and next steps

ESTES provides a sample of muon neutrinos with high astrophysical purity in the southern sky

ESTES events have good energy and angular resolution

We have a competitive sensitivity in the southern sky for point source searches

Soon will start ESTReS alert system and send out alerts for southern sky events
Backup Slides
Veto and $p_{\text{miss}}$ definition in detail

Each DOM has a poisson probability of observing photons elections (PE)

$$p(\lambda, k) = \frac{\lambda^k e^{-\lambda}}{k!}$$

$\lambda$ is expected number of PE

$K$ is observed number of PE

$p_{\text{miss}}$ is the product of probabilities that DOMs in the veto region saw no charge

$$p_{\text{miss}} = \prod_{i}^{\text{veto region DOMs}} p(\lambda_i, k = 0)$$

where

$$\lambda_i = a \lambda_{e_i} + \lambda_{n_i}$$

The scale factor, $a$, is calculated for each event with a maximum log likelihood fit using DOMs in the muon region
BDT Efficiency

Use BDT in southern sky

Efficient at removing cosmic ray muon background
Diffuse astrophysical flux measurement outlook

Starting track selection fits to simulation of previous measurements

Up-going muon distinguishable from cascade dominated fluxes

HESE: 4 Year (cascade dominated)
- [https://pos.sissa.it/archive/conferences/236/1081/ICRC2015_1081.pdf](https://pos.sissa.it/archive/conferences/236/1081/ICRC2015_1081.pdf)

MESE: 2 Year (cascade dominated)

Up-going muon neutrinos

Measure flux properties for southern sky muon neutrinos