Search for GeV neutrinos associated with solar flares with IceCube
I am about to tell you:

- How we can use the IceCube neutrino observatory as a GeV neutrino detector

- Why solar flares are ideal candidates for this event selection
Extracting GeV neutrinos

• Selecting neutrinos with $E < 5\text{GeV}$

• Searching for an enhancement in the event rate during an astrophysical transient event
Extracting GeV neutrinos

- Select the filters
- Remove HE events
- Try to remove noise
IceCube
IceCube

DeepCore
Extracting GeV neutrinos

- After filter selection

<table>
<thead>
<tr>
<th>Data</th>
<th>16 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Noise</td>
<td>7 Hz</td>
</tr>
</tbody>
</table>

| Signal*    | 99.8 % |

* = Neutrinos < 5GeV with $E^{-2}$ spectrum
Extracting GeV neutrinos

- Select the filters
- Remove HE events
- Try to remove noise
What is the difference?
How many Hard Local Coincidences?
Are they causally connected?
Extracting GeV neutrinos

✓ Select the filters

- Remove HE events

\[
N_{\text{HLC-DOMS}} \text{ in IceCube strings} \leq 6
\]

\[
N_{\text{HLC-DOMS}} \text{ in DeepCore strings} \leq 7
\]

\[
N_{\text{DOMS}} \text{ causally connected} \leq 10
\]
Extracting GeV neutrinos

- Select the filters
- After removing HE events

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Pure Noise</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>6.79 Hz</td>
<td>6.49 Hz</td>
<td>99.0 %</td>
</tr>
</tbody>
</table>
Uncorrelated thermal noise

Uncorrelated radioactive noise

Correlated scintillation noise
Causality between hits
(time window, threshold, velocity)
## Extracting GeV neutrinos

- Select the filters
- Remove HE events
- Try to remove noise

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<th>Signal</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>0.22 Hz</td>
<td>0.11 Hz</td>
<td>57.0 %</td>
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</tbody>
</table>
Extracting GeV neutrinos

- Select the filters
- Remove HE events
- Try to remove noise

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<tr>
<th>Data</th>
<th>0.22 Hz</th>
<th>Sensitive to SF!</th>
</tr>
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<td></td>
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</tbody>
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Solar flare $\nu$, what?

$p + p_{\odot \text{ atm}} \rightarrow \nu, \gamma$

hadron acceleration (up to several GeV)

$p, \alpha... = \text{Solar Energetic Particles}$

$\pi^+ \rightarrow \mu^+ + \nu_\mu$

$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$

$\pi^0 \rightarrow 2\gamma$

$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$

$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$
Solar Energetic Particles

hadron acceleration (up to several GeV)

\( p \rightarrow p_{\text{atm}} \)

\( p + p_{\text{atm}} \rightarrow \pi^0 + \bar{\nu}_\mu + \bar{\nu}_e + \nu_e + \nu_\mu \)

Solar flare? what?
Solar flare $\nu$, how?
Solar flare $\nu$, how?

Fermi light curve for March 7\textsuperscript{th}, 2012
Solar flare ν, how?

Fermi light curve for March 7\textsuperscript{th}, 2012
Solar flare $\nu$, why?

If detection:

Confirmation of hadronic acceleration in solar flares

If no detection:

Strongest limit on $S\nu$ flux

In any case:

Constraint on the proton acceleration
Beam of protons:

$$F(E) = A \ E^{-\delta} \ H(E_{max} - E)$$

A and $\delta$ derived from observations

Fixed $\delta = 3.2$

Average $\nu$ yield per injected proton vs. Neutrino energy (GeV)

- $E_{max} = 7\text{GeV}$
- $E_{max} = 3\text{GeV}$
Solar flare $\nu$, why?

Fixed $\delta = 3.2$


- March 7$^{th}$, 2012
- Impulsive phase
- 20 minutes
- 0.22Hz of data
Take-home messages

• IceCube is sensitive to GeV neutrinos from transient sources

• We can constrain solar flare physics

Thanks!
Extracting GeV neutrinos

- Select the filters

DeepCore

- AOF*
  - CascadeFilter
  - MuonFilter
  - VEF
  - ...

Low-Up

Full Sky Starting

* AOF = Any Other Filter
Extracting GeV neutrinos

Causality between hits

3 parameters:

- time window (ns)
- velocity (m/ns)
- threshold (#of pairs)
• beam of protons of

\[ F(E) = A \, E^{-\delta} \, H(E_{\text{max}} - E) \]

A and \( \delta \) derived from observations
beam of protons of

\[ F(E) = A E^{-\delta} H(E_{\text{max}} - E) \]

A and \( \delta \) derived from observations

Coupling with Fermi observations: \((\delta, E_{\text{max}})\)