Ups and Downs

Of Soudan 2 data

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for the
Soudan 2 Collaboration
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Partially Contained Events - the Soudan 2 Saga Continues:

*Up to now:*

PCE required to have
- either 3 or more prongs, or
- 2 prongs, with non-muon prong having more than 4 hits

*Are the rest of PCEs incoming or outgoing?*

**Uptracks:**
- Straight, lightly ionizing track at edge of detector.
- Multiple scattering and/or heavy ionization toward interior end of track.
- Associated hits near the interior end compatible with a decay shower.
- May have > 1 associated Active Shield hit.

**InDowns:**
- Straight, lightly ionizing track at interior end.
- May but need not to exhibit ranging toward edge of detector.
- Associated hits near interior end compatible with a p or \( \bar{p} \) prong.
- At most 1 associated Active Shield hit.

**Ambiguous:**
- Cannot tell.
Average number of hits per track:
  \[= 90 \text{ for Uptracks}\]
  \[= 80 \text{ for InDowns}\]
Simulation:

InDowns:
- Part of the FC/PC processing chain.

Uptracks:
- Separate effort.
- Define rock fiducial volume increasing with \( E_n \)
- 4 \( E_n \) bins: 0-10, 10-20, 20-40, 40-70 GeV
- NEUGEN neutrino event generator
- GEANT to propagate through the rock.
- Soudan 2 full detector simulation.
- Same software filter as FC/PC.
- Checkscan all event types.
- Simplification: \( m \) CC only.
- Scanning:
  - single prong
  - up/down/ambiguous
  - no hadronic characteristics
  - length > 100 cm
- Reconstruction
- Cuts:
  \[
  \cos \theta < +0.05 \\
  \text{range} > 260 \text{ g/cm}^2 \text{ (2 \( l_p \))}
  \]

Note: All MC event rates shown here are normalized to data exposure of 5.9 kty.
Event tally:

<table>
<thead>
<tr>
<th>Scanned as</th>
<th>No-osc. MC Truth</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Indown</td>
<td>Uptrk</td>
</tr>
<tr>
<td>InDown</td>
<td>16.3±1.6</td>
<td>0.8±0.2</td>
</tr>
<tr>
<td>Uptrk</td>
<td>0.8±0.3</td>
<td>66.4±2.1</td>
</tr>
<tr>
<td>Ambig</td>
<td>1.1±0.2</td>
<td>6.6±0.4</td>
</tr>
</tbody>
</table>
No-osc. MC matches data in shape & rate

\[ \cos(\theta_2) > +0.1 \]

No oscillations in Soudan 2 InDowns
No-osc. MC does not match data

see oscillations in Soudan 2 Uptracks

Mitigate against background:

1. **Downgoing muon “sliders”**: veto shield, modest \( \cos \theta_z \) cut

2. **Hadrons (from downgoing muons)**: veto shield, range cut > 2 cm

**Hic sunt (leones)**

Matter Effects
Uptracks vs. oscillations

MC with □ oscillations, \( \sin^2 2\theta = 1 \), but no matter effects

□ Uptracks prefer lowish □\( \Delta m^2 \)
Uptracks:  $\cos \theta_z < -0.1$

InDowns:  $\cos \theta_z > +0.1$
Conclusion:

Soudan 2 Uptracks and InDowns bracket

\[ 2.5 \times 10^{-4} < \Delta m^2 < 10^{-2} \text{ eV}^2 \]

with slight preference for lower values.

Plans:

- Investigate backgrounds;
- Implement matter effects in MC;
- Incorporate into the overall Soudan 2 likelihood fit.