Measurement of the atmospheric lepton energy spectra with AMANDA-II

presented by

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Overview

- **Introduction:**
  - AMANDA-II

- **Isotropic analysis:**
  - search for extraterrestrial neutrinos
  - analysis strategy
  - diffuse energy spectrum measurement
  - setting an upper limit:
    - applying the Feldman & Cousins algorithm to the unfolding problem
AMANDA-II

- High energy $\nu$ experiment
- Located at the geographical southpole
- Detection medium: ice
- 19 strings
- 677 optical modules
Isotopic analysis

- Search for an isotropic signal: use complete northern hemisphere
- The flux of conventional ($\pi$ and $K$) neutrinos steepens asymptotically to an power law of $E_\nu^{-3.7}$
- Main goal: Search for extra-galactic contribution

AGN (1) (Becker/Biermann/Rhode)
AGN (3 and 4) (Mannheim/Protheroe/Rachen)
GRBs (2) (Waxman/Bahcall)
Isotropic energy spectrum

- General case:
  - measured distr. \( \rightarrow \) unfolding \( \rightarrow \) true distr.

\[
g(y) = \int A(y, x) f(x) dx
\]

- Using regularized unfolding (RUN):
  - measured distr. A (E)
  - measured distr. B (E) \( \rightarrow \) RUN \( \rightarrow \) energy distribution
  - measured distr. C (E)
Isotropic energy spectrum

- More than three measured distributions (E):
  - combine N-2 observables to a new variable
  - using a neural network for combining

mean amp
mean let
rmsq let
nh1
nch
nhits

Neural Net

log(nch)
log(rmsq amp)

RUN

Statistical weight

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Neural network performance

2000 - 2003

Performance tested with mono energetic muons

<table>
<thead>
<tr>
<th>Energy log(E/MeV)</th>
<th>Mean</th>
<th>Sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3.03</td>
<td>0.42</td>
</tr>
<tr>
<td>4</td>
<td>3.92</td>
<td>0.58</td>
</tr>
<tr>
<td>5</td>
<td>4.99</td>
<td>0.51</td>
</tr>
<tr>
<td>6</td>
<td>5.86</td>
<td>0.48</td>
</tr>
</tbody>
</table>

NN output fitted with Gaussian distributions

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Isotopic energy spectrum

Statistical weight

- atm. Monte Carlo
- data from 2000 - 2003

Energy spectrum

- Barr atm. $\nu_\mu + \bar{\nu}_\mu$
- Honda atm. $\nu_\mu + \bar{\nu}_\mu$
- AMANDA-II, unfolded atm. $\nu_\mu + \bar{\nu}_\mu$

the statistical weight corresponds to the weighted number of events

atmospheric prediction:
horizontal flux (upper border)
vertical flux (lower border)
1. Study the effect of the unfolding procedure with MC

2. Generate individual probability density functions – pdf $P(x|y)$

3. Use $P(x|y)$ with the Feldman Cousins procedure
Confidence belts

90 % confidence belts for different energy cuts

(300 - 1,000) TeV
(100 - 300) TeV
(50 - 100) TeV

preliminary
Limits

Summary

- Isotopic analysis with the data taken with AMANDA-II in 2000-2003
- Isotropic neutrino flux measured:
  - combination of neural network and unfolding
  - spectrum up to 100 TeV
  - spectrum follows the atm. neutrino flux prediction
- Analyses show so far no signal above atm. flux
- Confidence interval construction applied to an unfolding problem
- upper limit on extraterrestrial (E^{-2}) contribution

$$\phi \cdot E^2 = 2.6 \cdot 10^{-8} \text{GeV cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$$
Backup slides
Isotropic energy spectrum

comparison: result 2000 with 2000-2003

atm. prediction: horizontal flux (upper border), vertical flux (lower border)
RUN

• **Fredholm equation:** \( g(y) = \int A(y, x) f(x) \, dx \)
  - measured
  - true

• **Discretise:** \( f(x) = \sum a_i B_i(x) \)
  - \( B_i(x) = \text{B-Splines} \)
  - \( g(y) = \sum a_i \int A(x, y) B_i(x) \, dx = \sum a_i A_i(y) \)

• **Minimise:** \(-2 \ln L(f) + \frac{1}{2} \tau \cdot R(f)\) using the total curvature
  - \( R = \int |f''(x)|^2 \, dx = a^T C a \)
CB: Feldman & Cousins

Building a confidence belt according to Feldman & Cousins:

- Using a new ranking procedure to build the CB
- Ranking: particular choice of ordering based on likelihood ratios

\[
R(x) = \frac{P(x|\mu)}{P(x|\mu_{best})} = \frac{P(x|\mu)}{P_{\mu-\text{max}}(x)}
\]

\[\mu_{\text{best}} = \text{physically allowed value of } \mu \text{ for which } P(x|\mu) \text{ is maximum}\]

- \(R\) determines the order in which values of \(x\) are added to the acceptance region at a particular value of \(\mu\)
- \(\to\) no unphysical or empty confidence intervals
Constructing the PDFs

- For each **fixed** signal contribution $\mu_i$
- Plot the **energy distribution** for each of the 1000 one-year MC experiments
- Place an **energy cut** ($100 \text{ TeV} < E < 300 \text{ TeV}$) and count the event rate
- **Histogram** the event rate
- **Normalise** the histogram

\[ \mu = 2 \times 10^{-7} \text{ GeV cm}^{-2} \text{s}^{-1} \text{ sr}^{-1} \]
Constructing a Limit

1. Constructing a probability table by using the individual PDFs.

2. Estimate $P_{\mu-\text{max}}(n)$ for each counting rate $n$ by using the probability table.

3. Calculate the ranking factor (likelihood-ratio) $R(n|\mu) = P(n|\mu)/P_{\mu-\text{max}}(n)$.

4. Rank the entries $n$ for each signal contribution (highest first).

5. Include for each fixed $\mu$ all counts $n$ until the wanted degree of belief is reached.

6. Plot the acceptance slice for the fixed $\mu$. 