Measurement of the atmospheric lepton energy spectra with AMANDA-II

presented by

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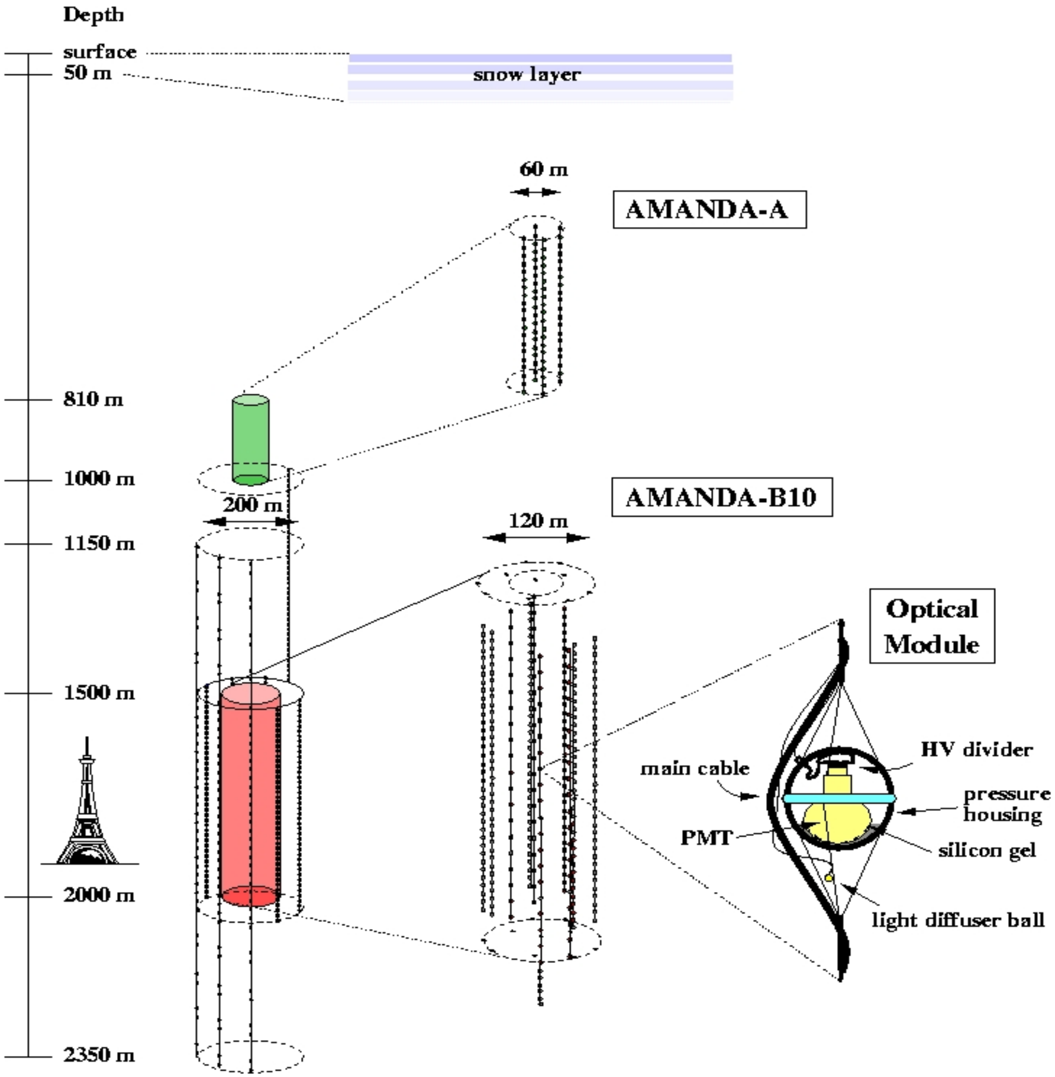
Overview

- **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



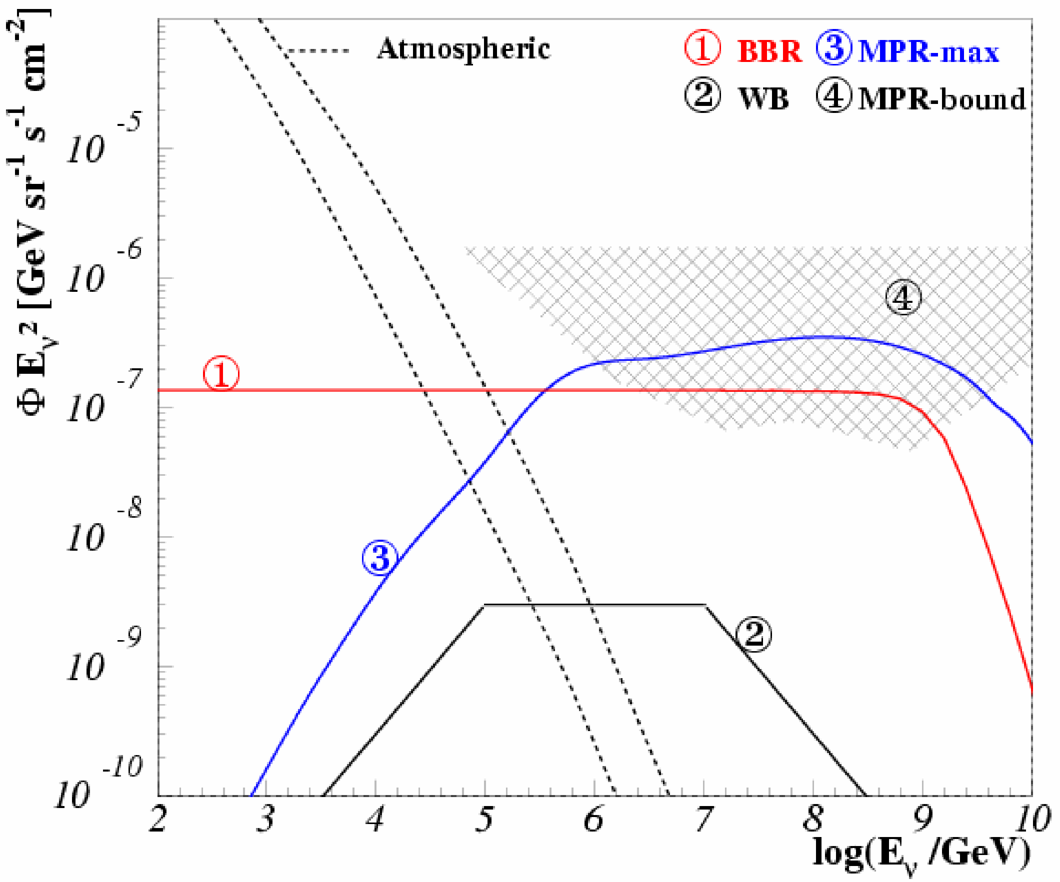
AMANDA as of 2000
Eiffel Tower as comparison
(true scaling)

zoomed in on
AMANDA-A (top)
AMANDA-B10 (bottom)

zoomed in on one
optical module (OM)

- High energy ν experiment
- Located at the geographical southpole
- detection medium: ice
- 19 strings
- 677 optical modules

Isotropic analysis



- Search for an isotropic signal: use complete northern hemisphere
- The flux of conventional (π 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

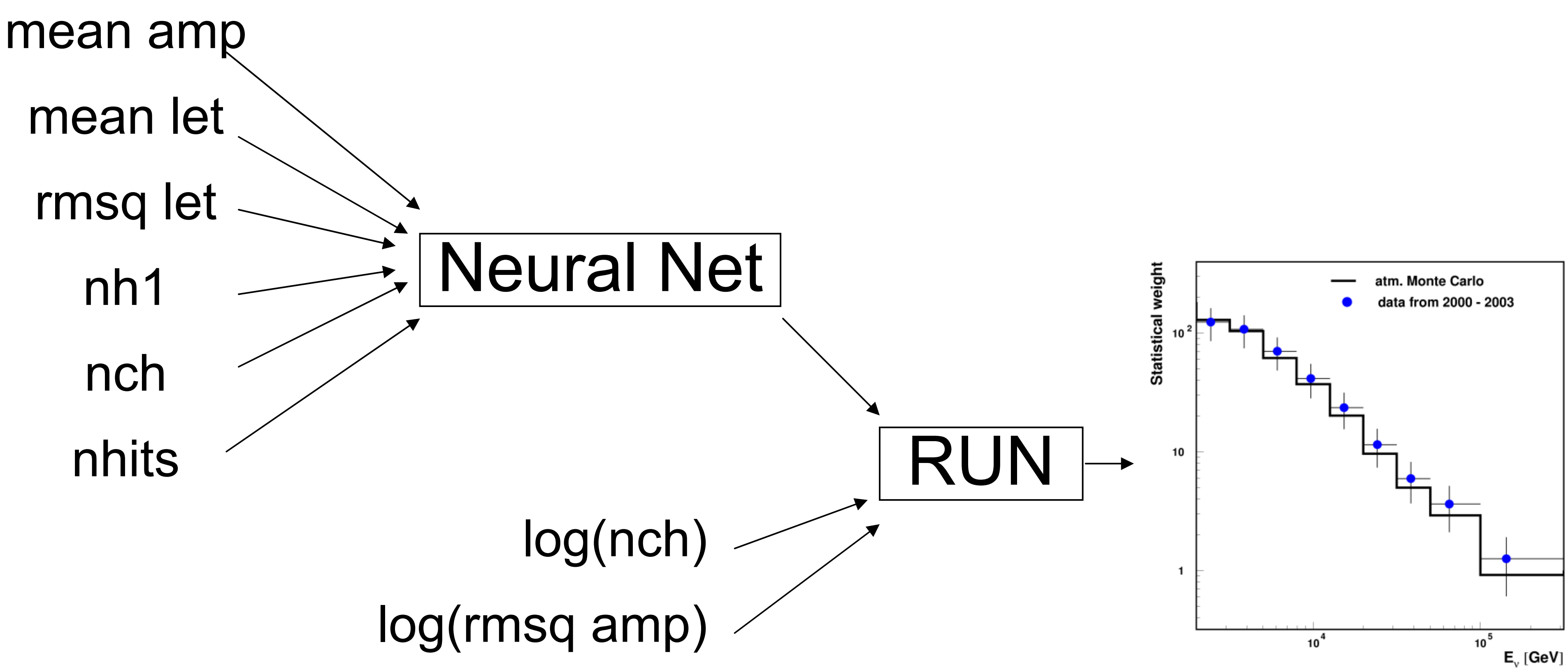
- General case:
  - measured distr. → unfolding → true distr.

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

- Using regularized unfolding (RUN):
  - measured distr. A (E)
  - measured distr. B (E) → RUN → energy distribution
  - measured distr. C (E)

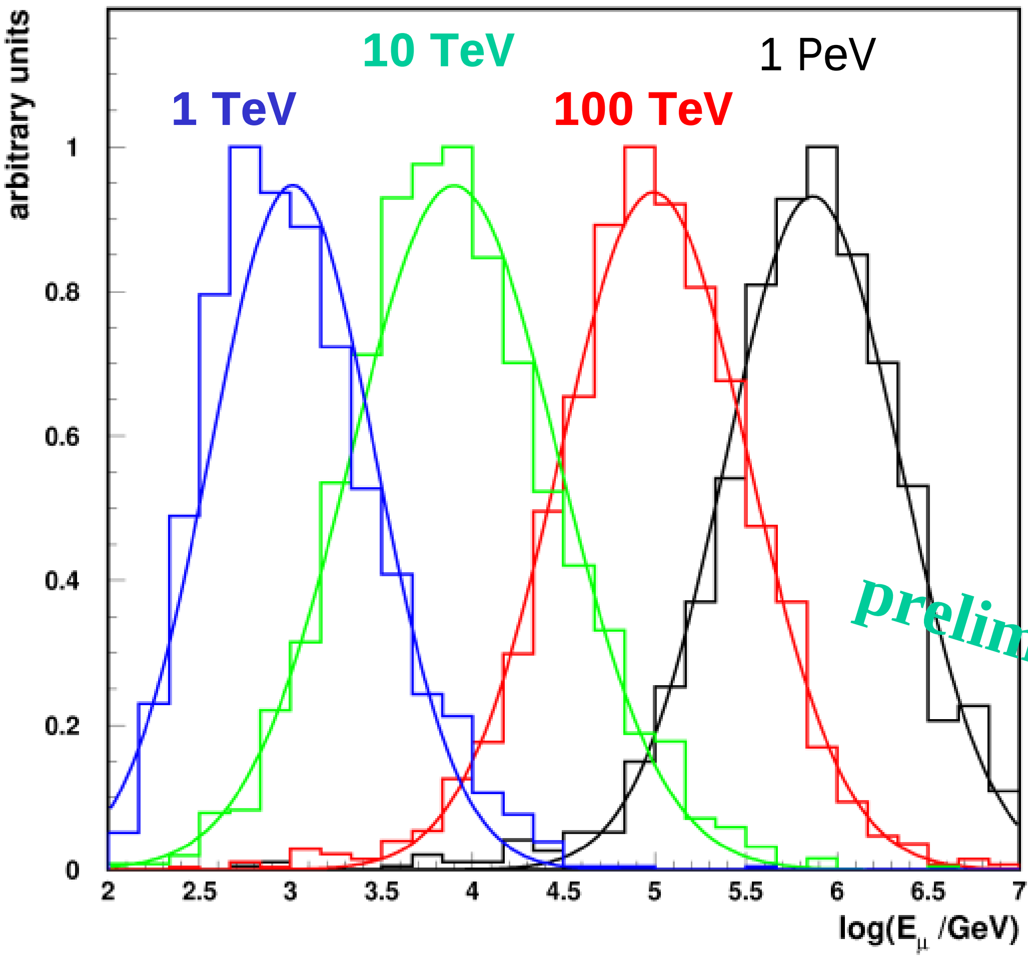
Isotropic energy spectrum

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



Neural network performance

2000 - 2003



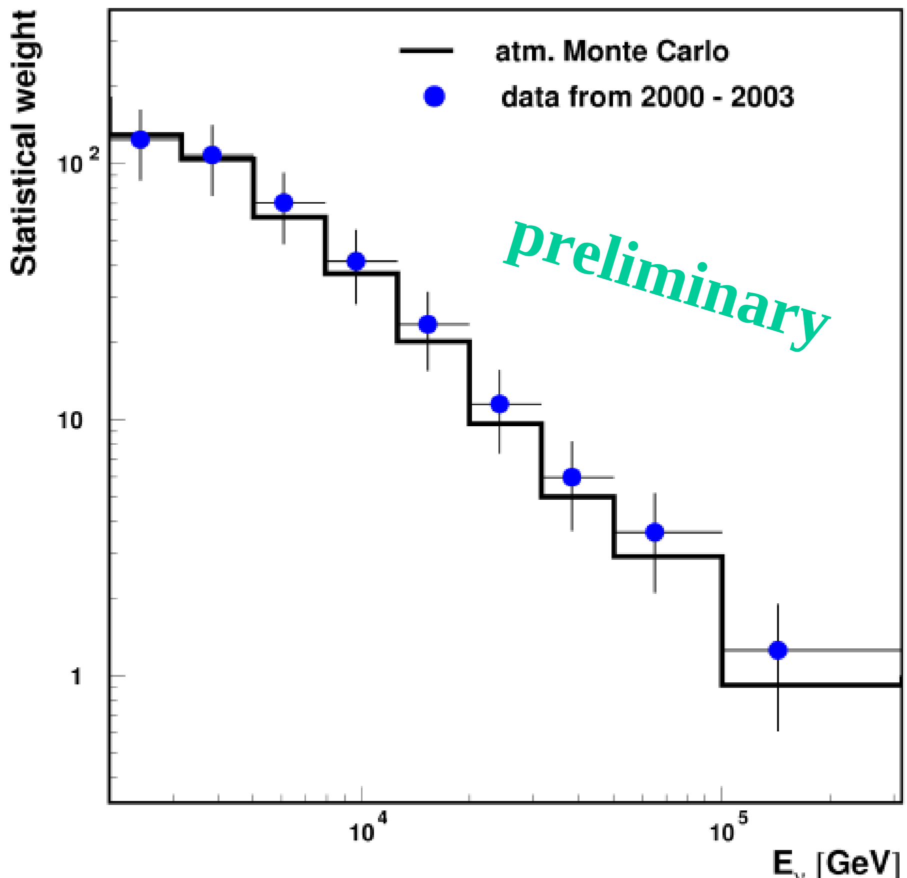
Performance tested with mono energetic muons

Energy log(E/MeV)	Mean	Sigma
3	3.03	0.42
4	3.92	0.58
5	4.99	0.51
6	5.86	0.48

NN output fitted with Gaussian distributions

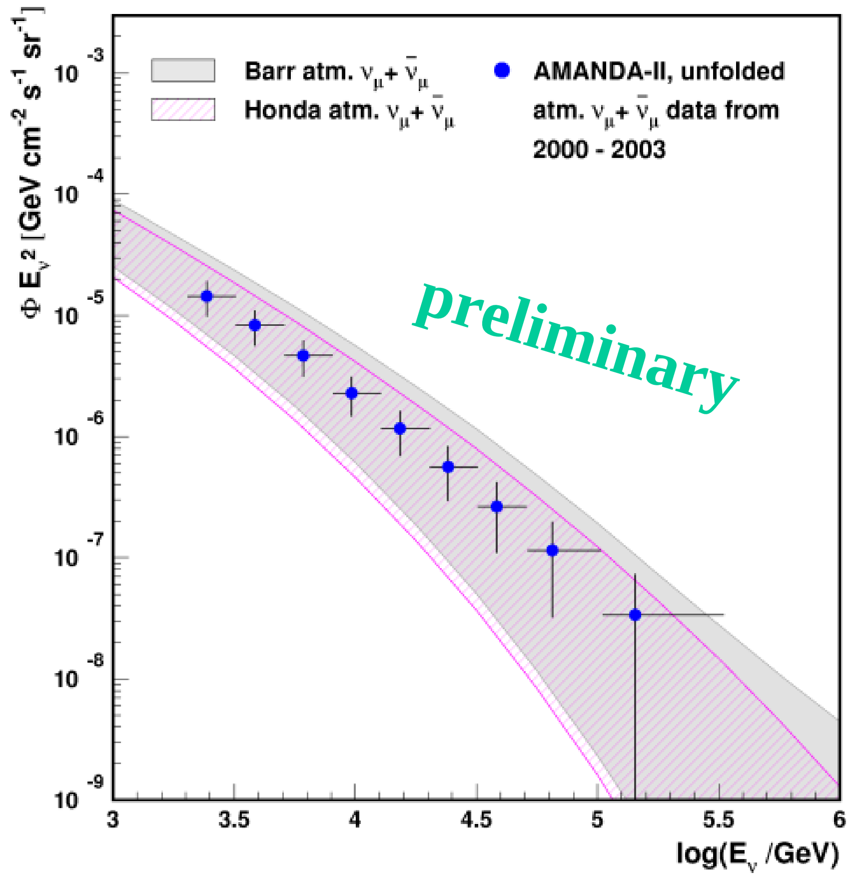
Isotropic energy spectrum

Statistical weight



the statistical weight corresponds to the weighted number of events

Energy spectrum



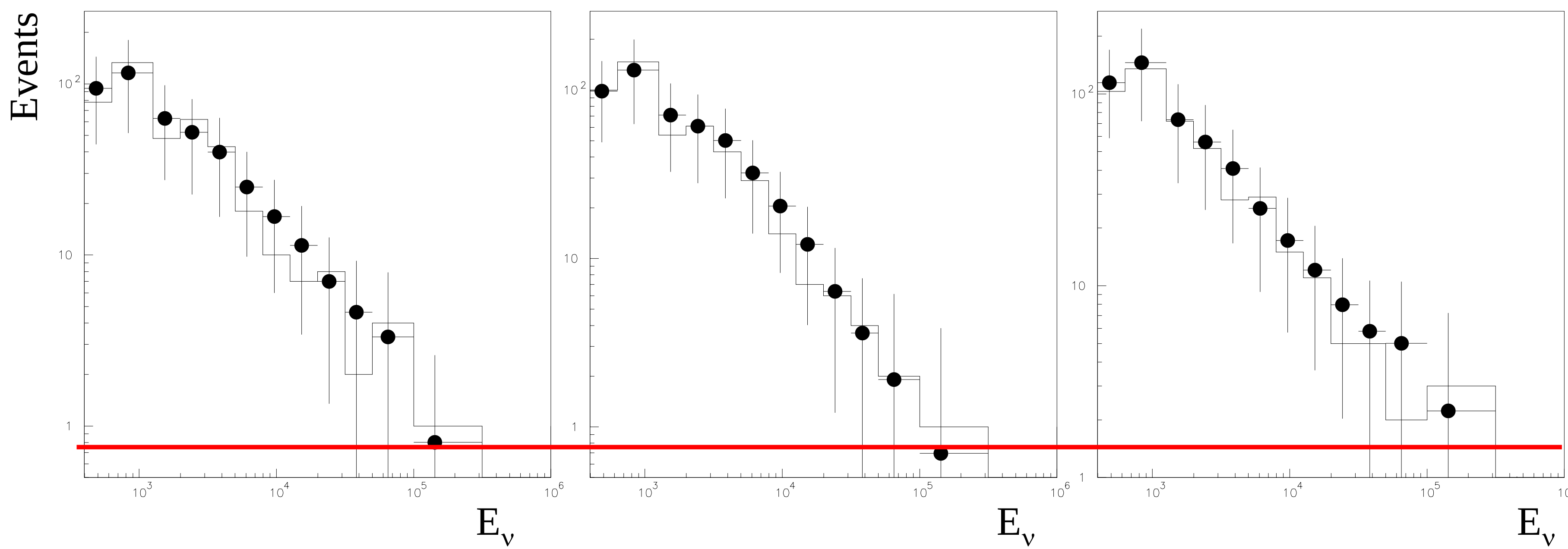
<u>atmospheric prediction:</u>

horizontal flux (upper border)

vertical flux (lower border)

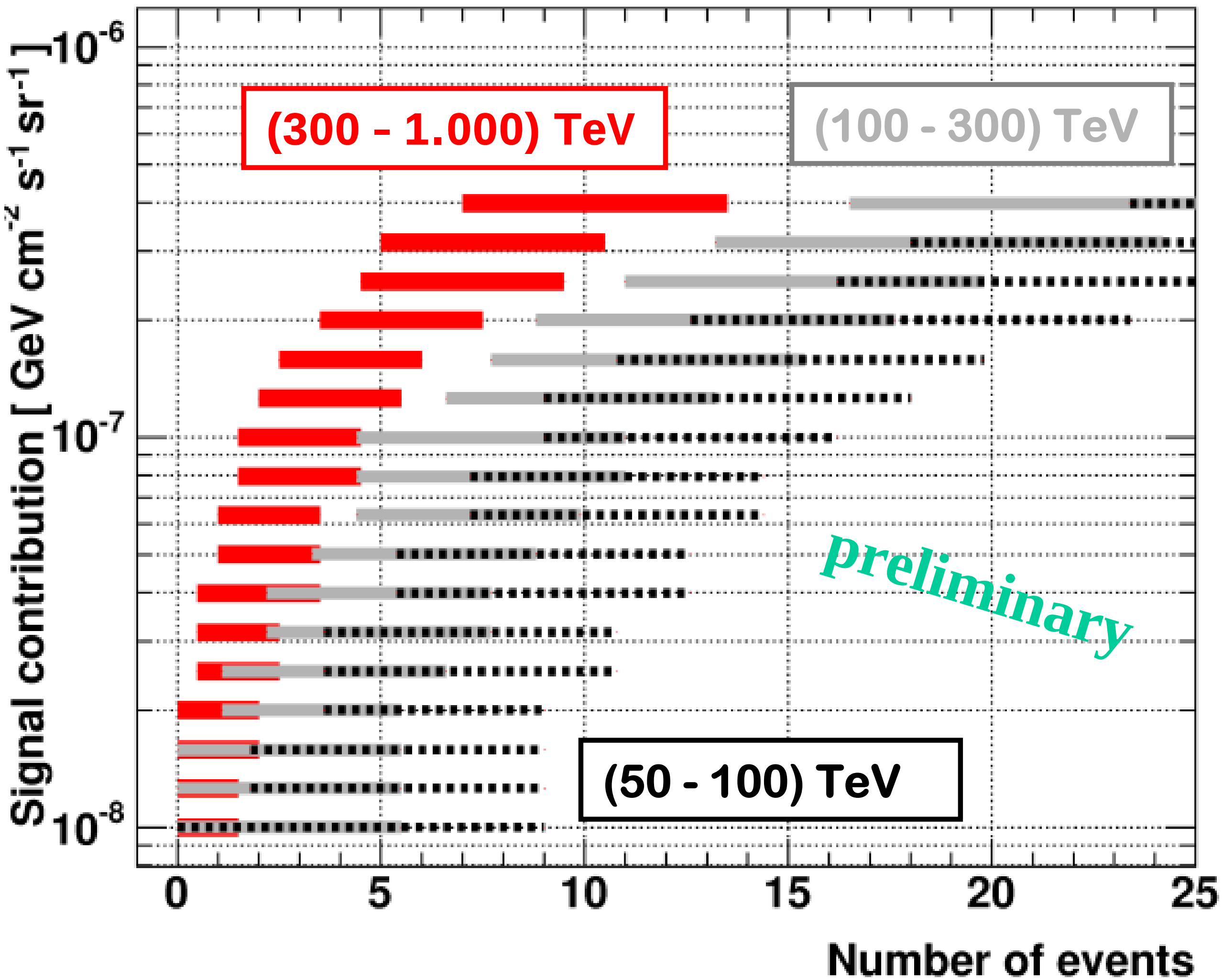
Effect of the unfolding

1. Study the effect of the unfolding procedure with MC



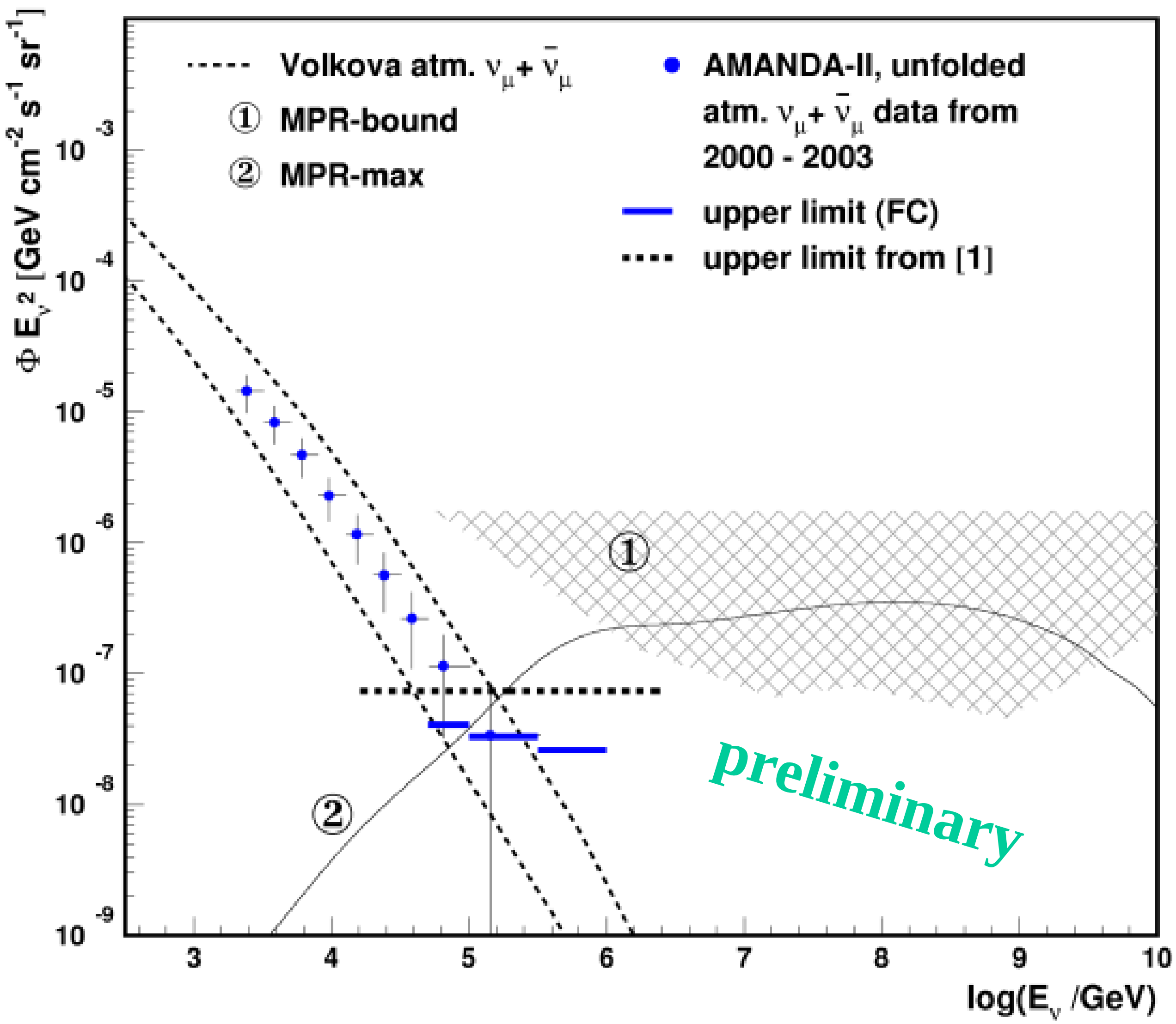
2. Generate individual probability density functions – pdf P(x|y)
3. Use P(x|y) with the Feldman Cousins procedure

Confidence belts



90 % confidence belts for different energy cuts

Limits



[1] Achterberg et al., astro-ph/0705.1315

Summary

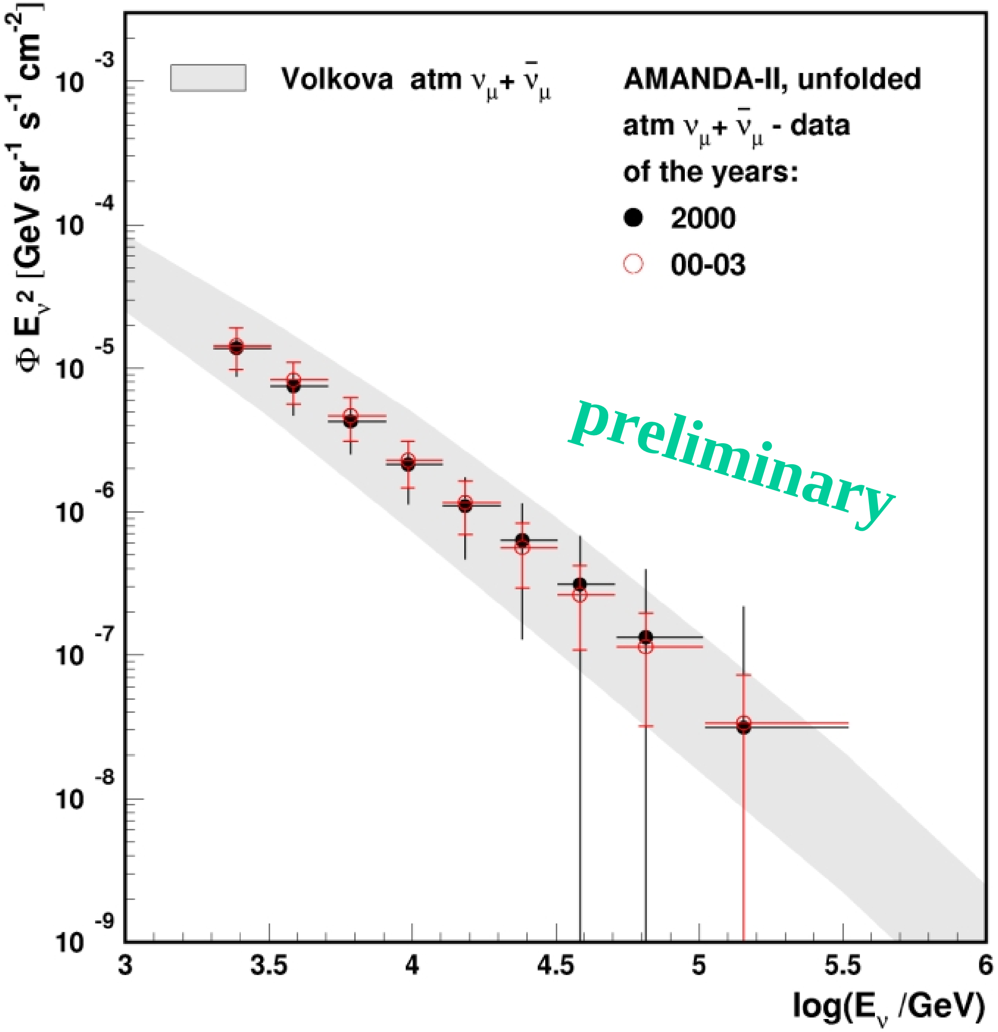
- Isotropic analysis with the data taken with AMANDA-II in **2000-2003**
- Isotropic neutrino flux measured:
  - combination of **neural network** and **unfolding**
  - spectrum up to **100 TeV**
  - spectrum follows the atm. neutrino flux prediction
- Analyses show so far **no signal** above atm. flux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

$$\phi \cdot E^2 = 2.6 \cdot 10^{-8} GeV cm^{-2} s^{-1} sr^{-1}$$

BACKUP

Isotropic energy spectrum

comparison: result 2000 with 2000-2003



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

RUN

- Fredholm equation: $g(y) = \int A(y,x) f(x) dx$

  ($g(y)$ ↑ measured; $f(x)$ ↑ true)

- Discretise: $f(x) = \sum a_i B_i(x)$ $\quad B_i(x) = \text{B-Splines}$

$$g(y) = \sum a_i \int A(x,y) B_i(x) dx = \sum a_i A_i(y)$$

- 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

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

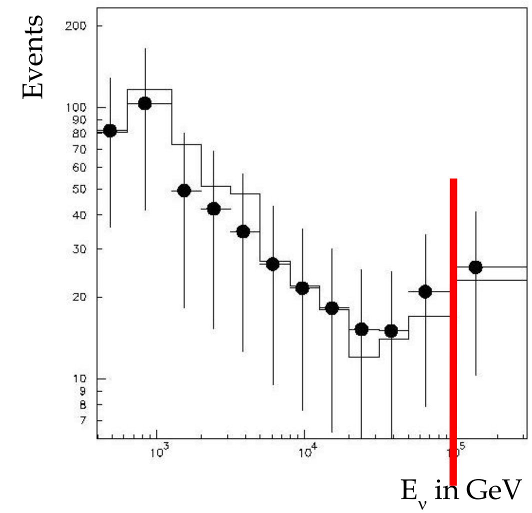
$\mu_{best} =$ physically allowed value of μ for which P(x|μ) is maximum

- R determines the order in which values of x are added to the acceptance region at a particular value of μ
- $\rightarrow$ no unphysical or empty confidence intervals

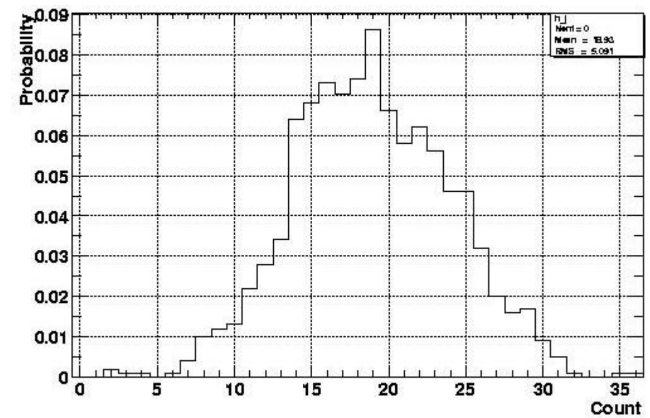
Constructing the PDFs

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

e.g. $\mu = 2 * 10^{-7}$ GeV $cm^{-2} s^{-1} sr^{-1}$



1000 times



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 μ all counts n until the wanted degree of belief is reached
6. Plot the acceptance slice for the fixed μ