

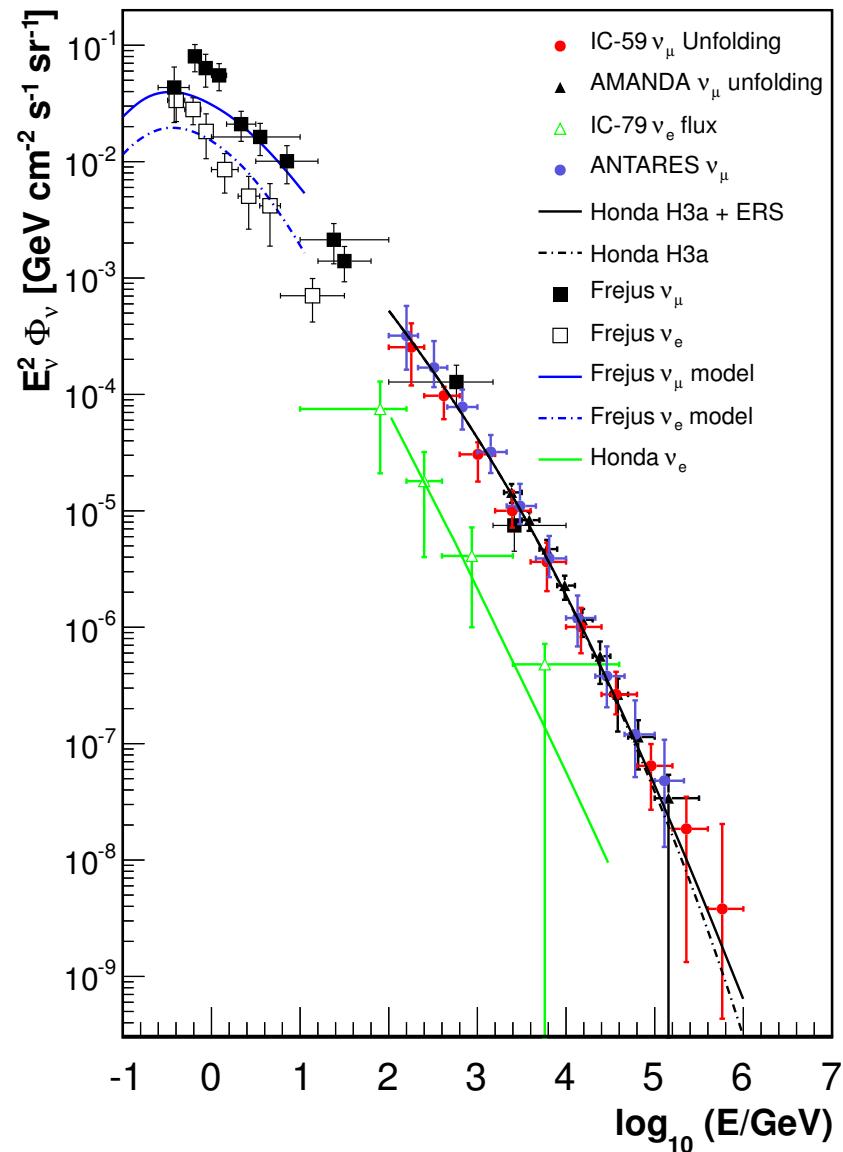
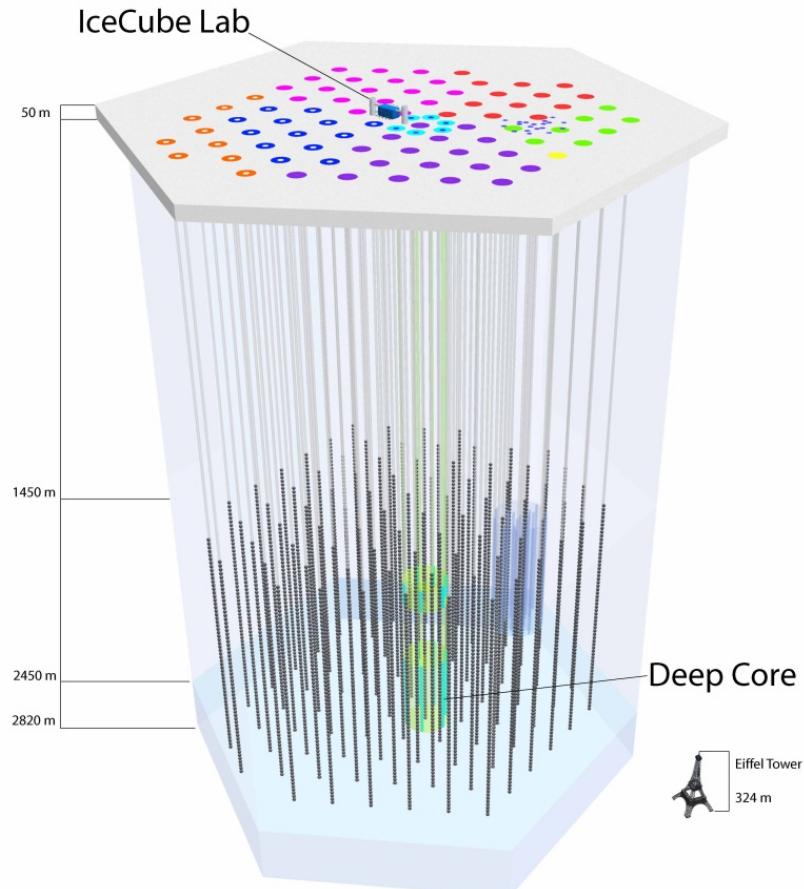
Measurement of the Atmospheric Muon Neutrino Energy Spectrum with IceCube in the 79- and 86-String Configuration

Tim Ruhe, Mathis Börner, Florian Scheriau, Martin Schmitz, TU Dortmund

Outline

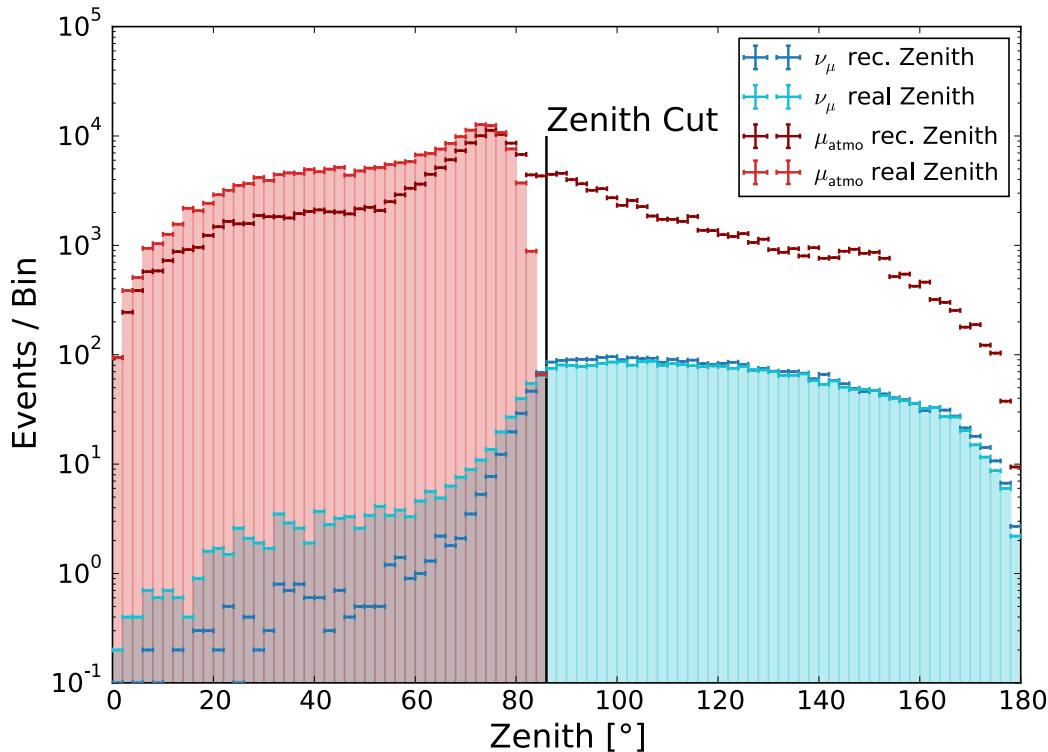
- IceCube and atmospheric neutrinos
- Event Selection
- Spectrum Unfolding
- Results
- Summary and Outlook

IceCube and atmospheric neutrinos



Data Preprocessing

Cut on zenith angle $> 86^\circ$



Additional cuts:

- Lepton velocity
- Empty Hits
- Truncated Energy (estimator)
- Track length

Reduction of the data volume,
BUT remaining background is
significantly harder to reject

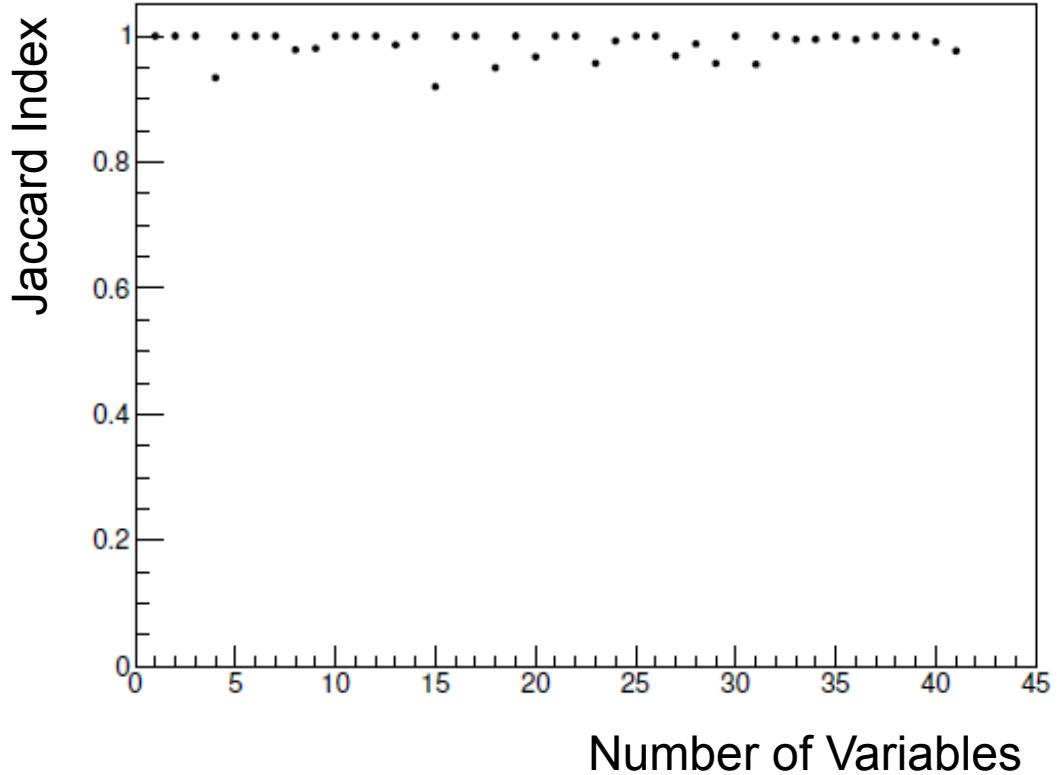
Feature Selection Stability

Jaccard:

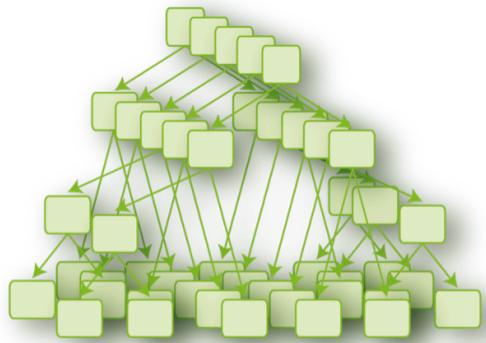
$$J = \frac{|A \cap B|}{|A \cup B|}$$

Average over many sets of
variables:

$$\bar{J} = \frac{2}{l^2 - l} \sum_{i=1}^l \sum_{j=1}^l J(F_i, F_j)$$



Training and Validation of a Random Forest



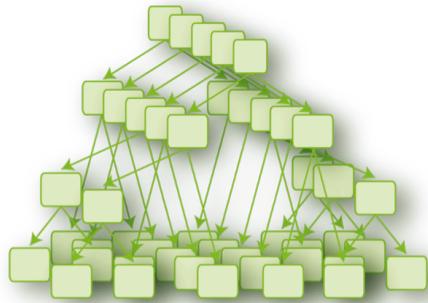
$$S = \frac{1}{n_{trees}} \sum_{i=0}^{n_{trees}} S_i$$

$$S_i = \{0,1\}$$

- use an ensemble of simple decision trees
- Obtain final classification as an average over all trees

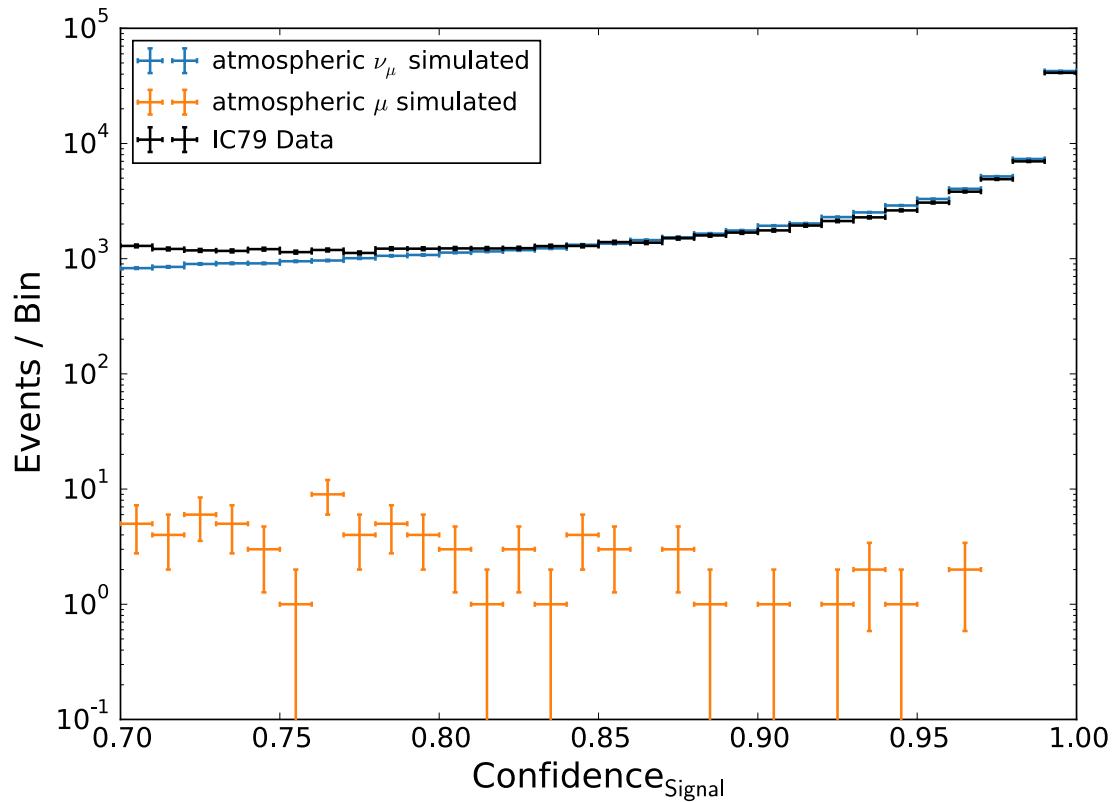


Random Forest Output

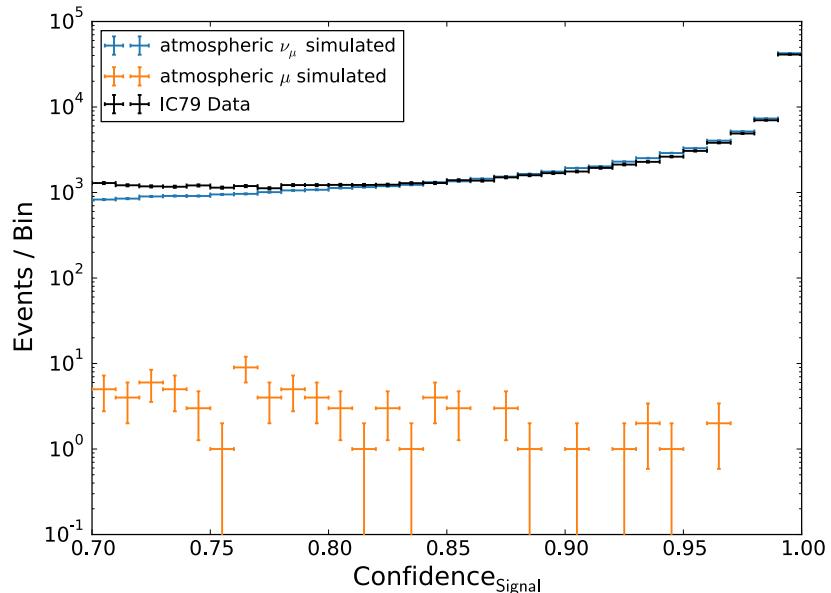


Forest Settings:

- 200 trees
- 5 Random Features per node
- 120,000 signal events
- 30,000 background events



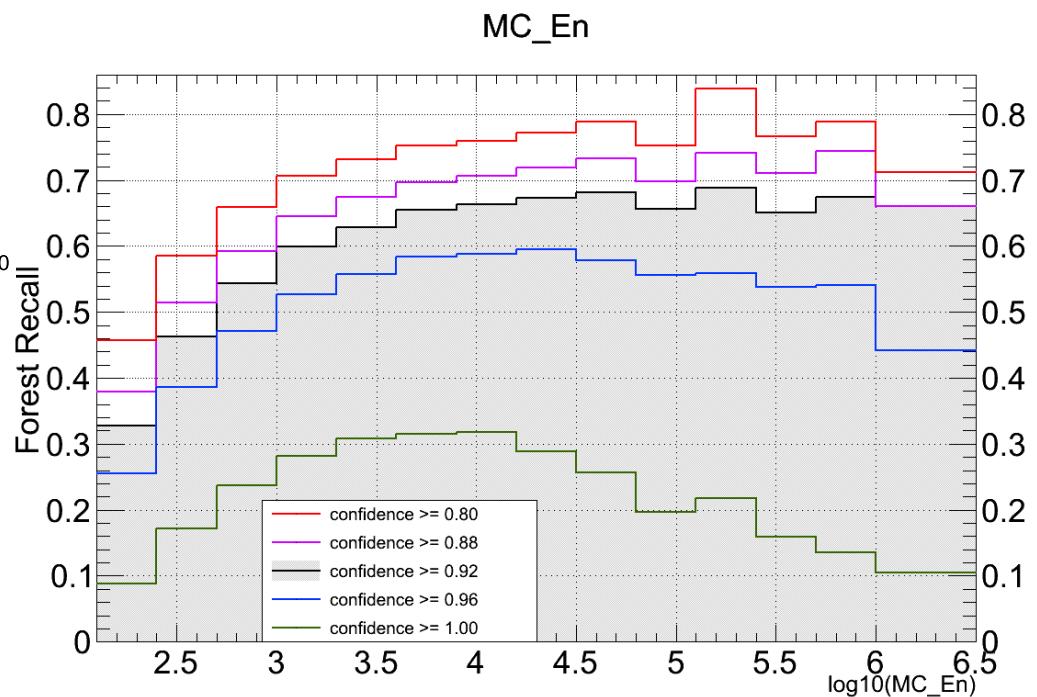
Random Forest Output (IC79)



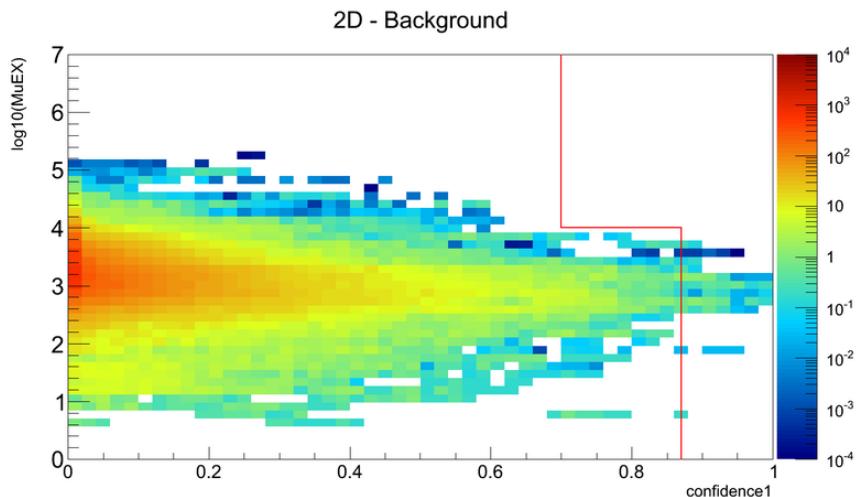
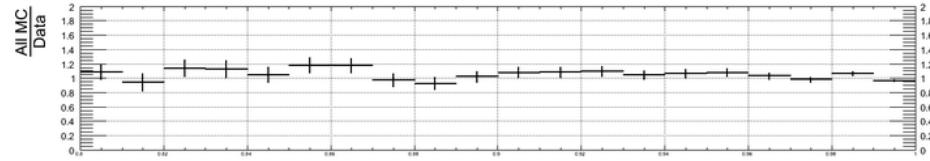
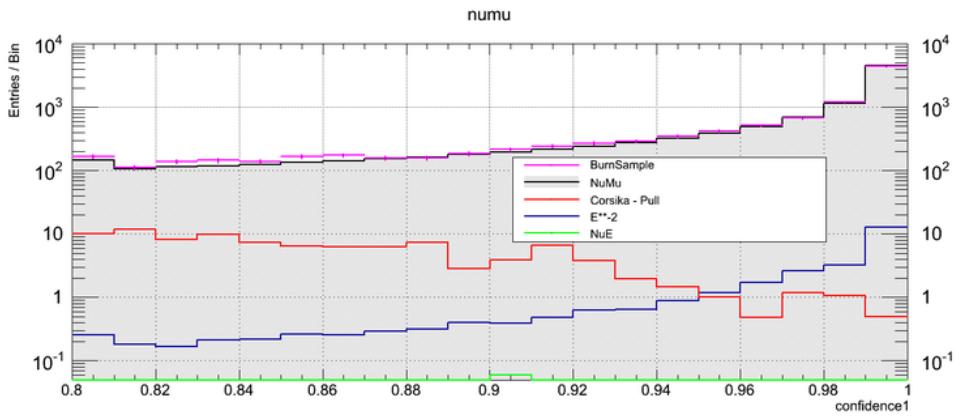
- 212 neutrino candidates per day
- 66885 neutrino candidates in total
- 330 ± 200 background muons

Find a trade-off between background rejection and signal efficiency

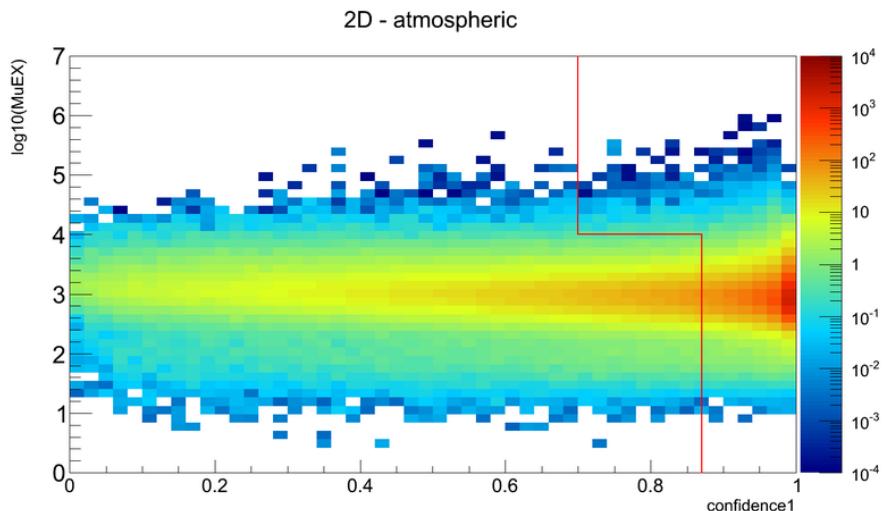
Place a cut at confidence ≥ 0.92



Random Forest Output (IC86)



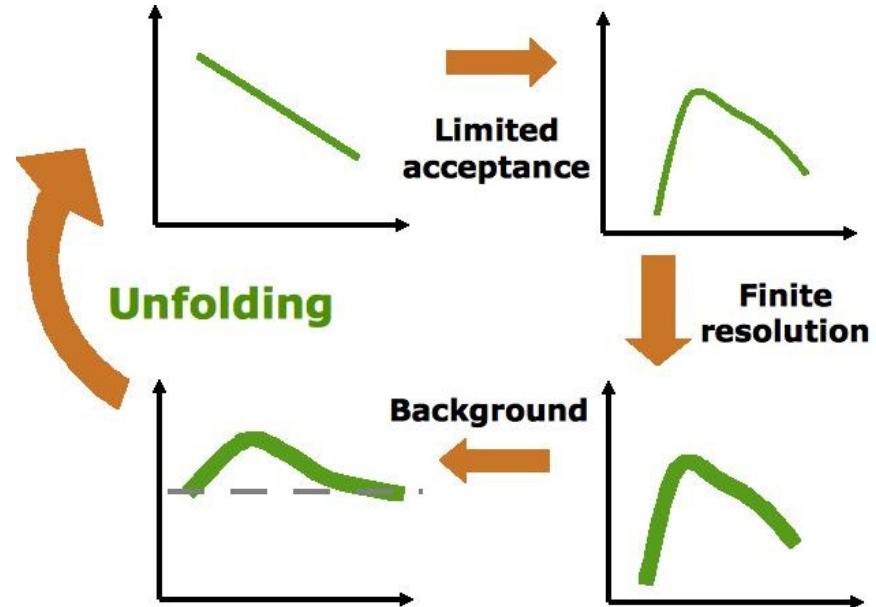
2-dimensional cut



- 289 neutrino candidates per day
- 92060 neutrino candidates in total
- 410 ± 220 background muons

Why unfold?

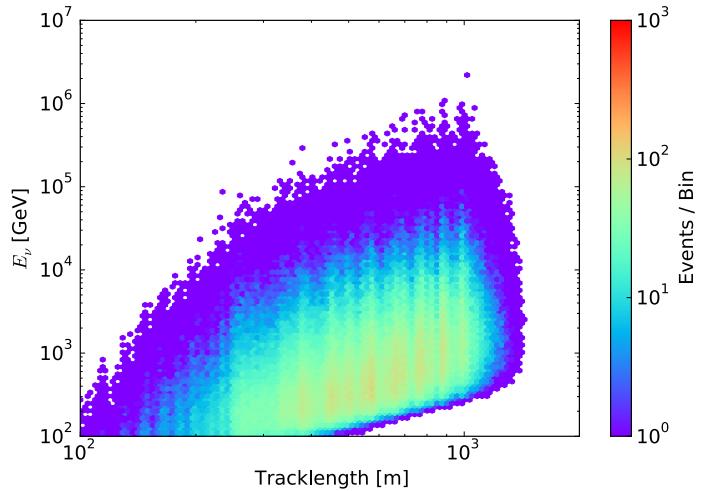
- Muon production governed by stochastical processes
- Energy losses on the way towards the detector
- Finite resolution
- Limited acceptance of the detector



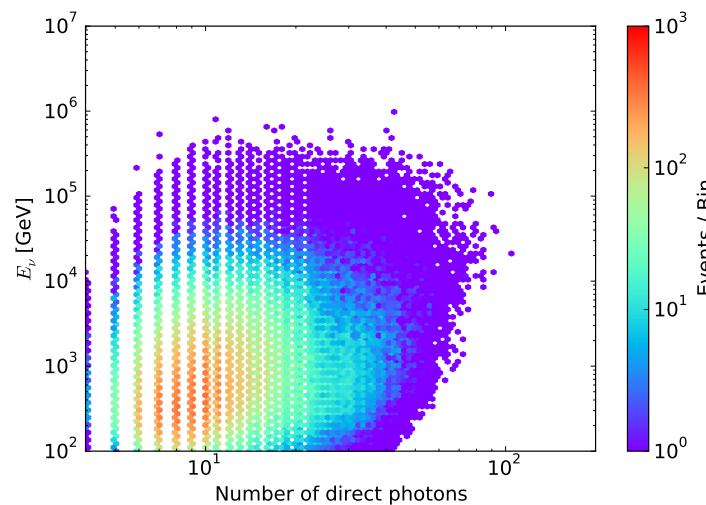
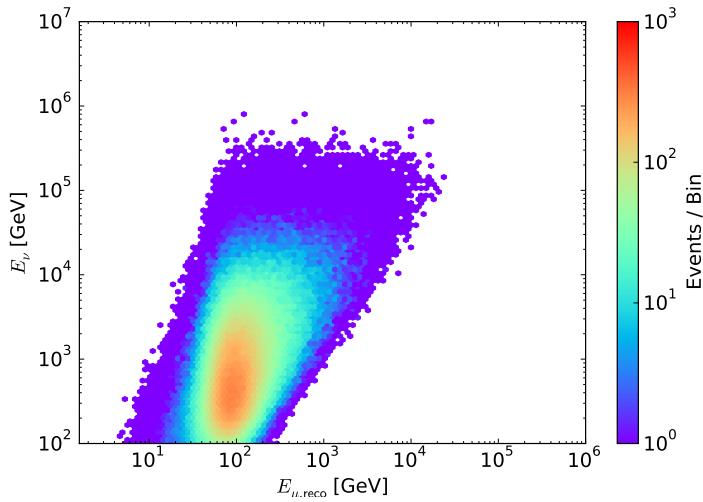
$$g(y) = \int_{E_{\min}}^{E_{\max}} A(E, y) f(E) dE$$

Inverse Problem, to be solved
with TRUEE.

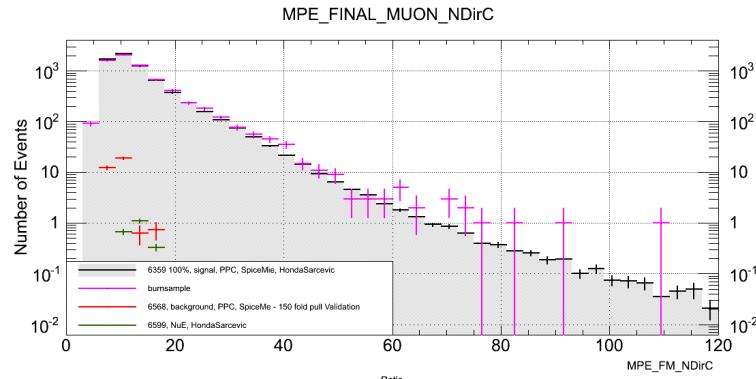
Unfolding Input (1): Energy Correlation



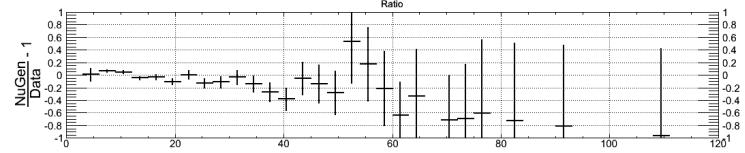
Input variables show good correlation with energy



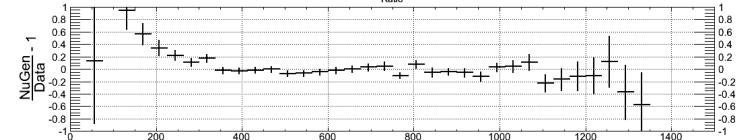
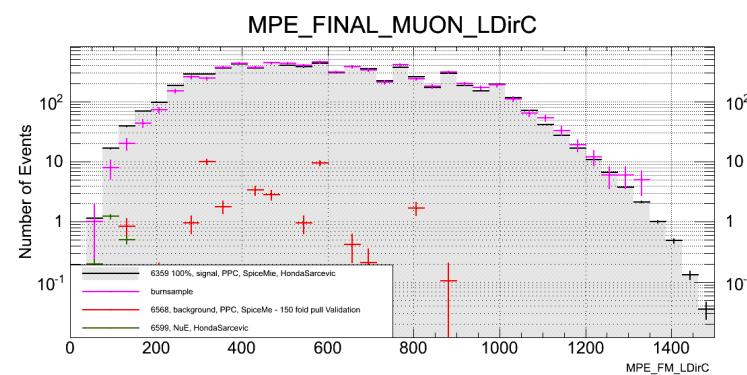
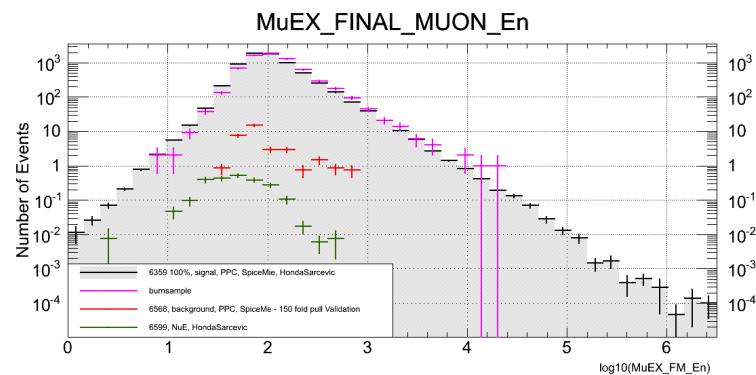
Unfolding Input (2): Background Distributions for IC79



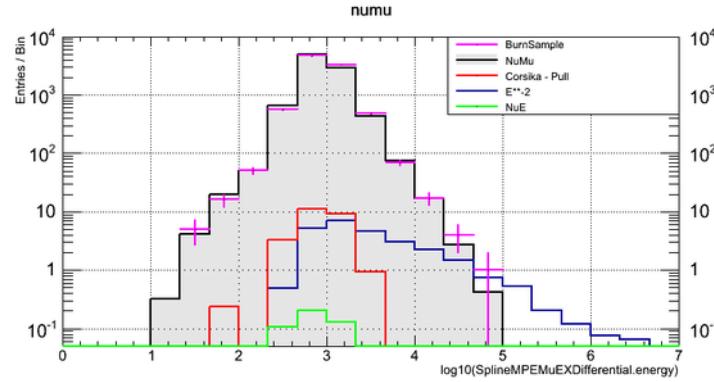
Background events are located at lower energies



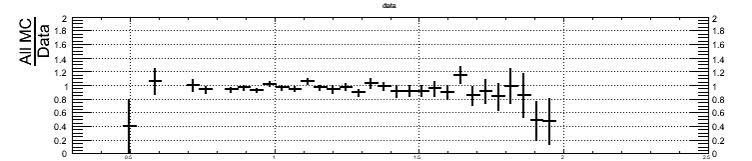
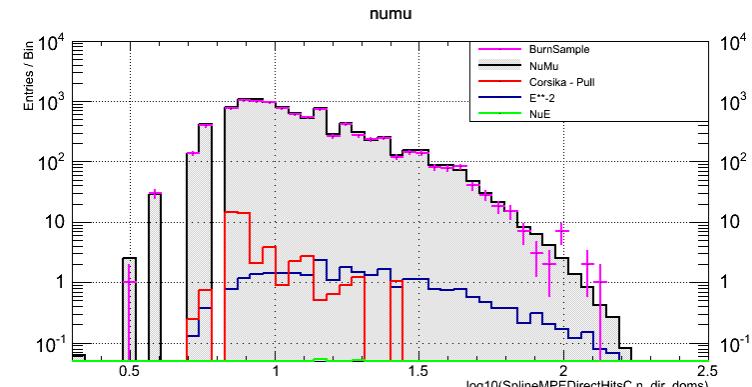
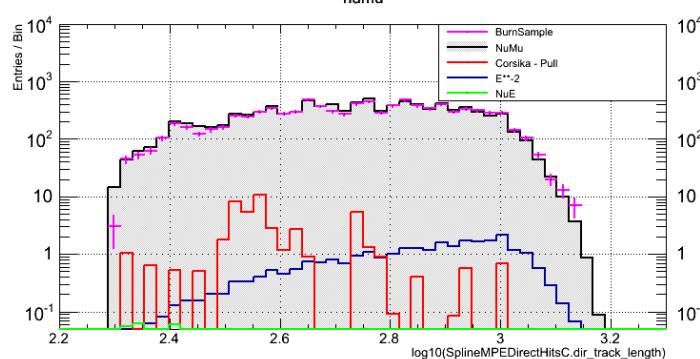
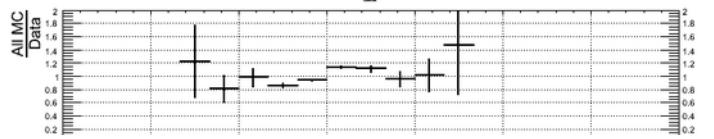
Therefore, they do not affect the highest energy bins



Unfolding Input (3): Background Distributions for IC86

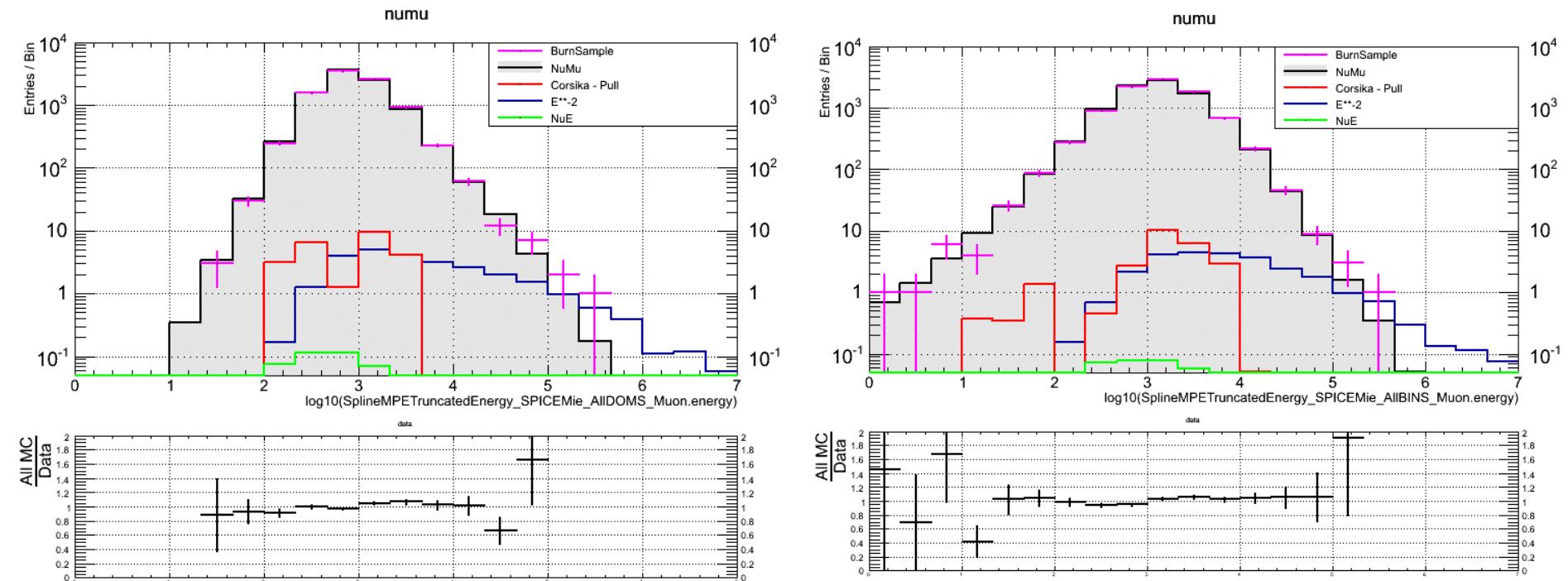


Background events are located at lower energies

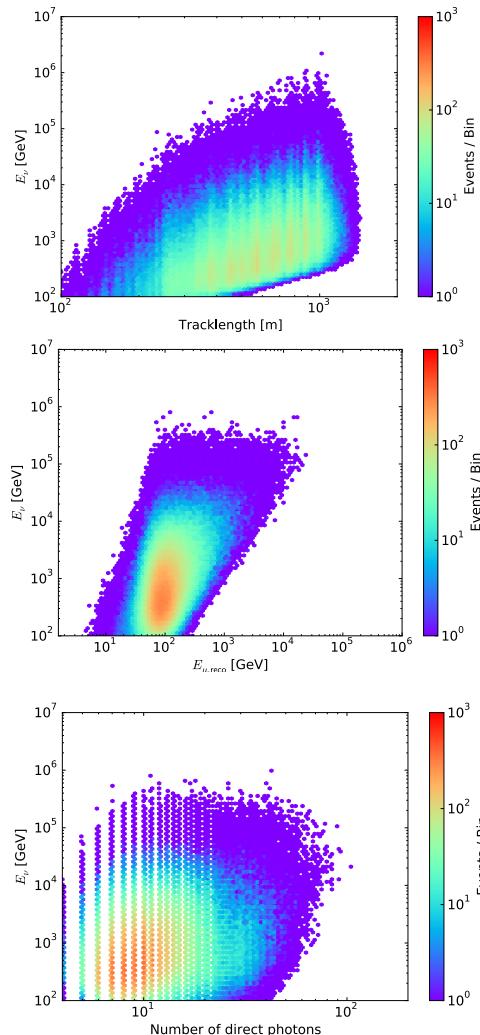


Therefore, they do not affect
the highest energy bins

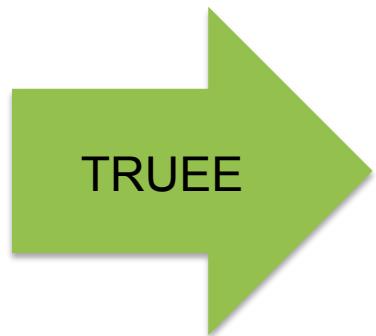
Unfolding Input (3): Background Distributions for IC86



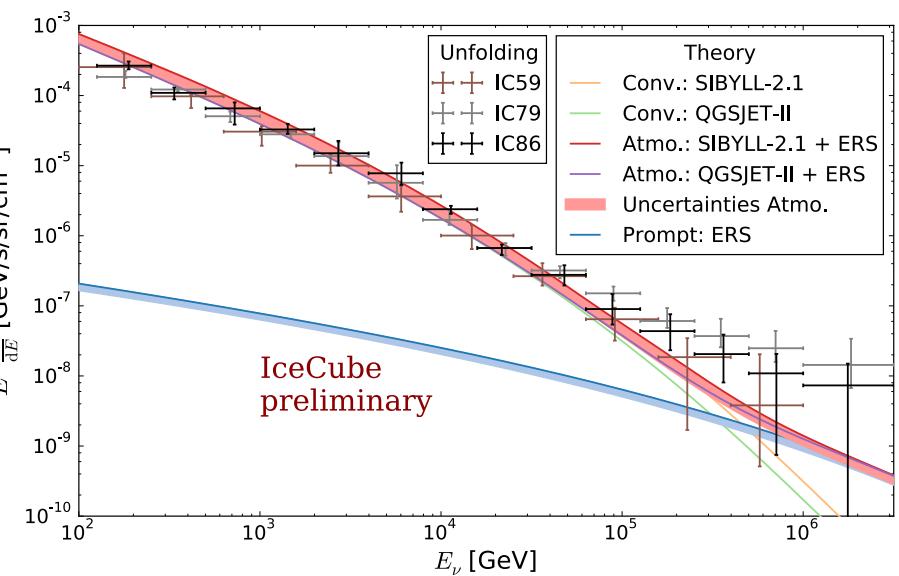
Unfolding the spectrum



3 energy dependent
input variables

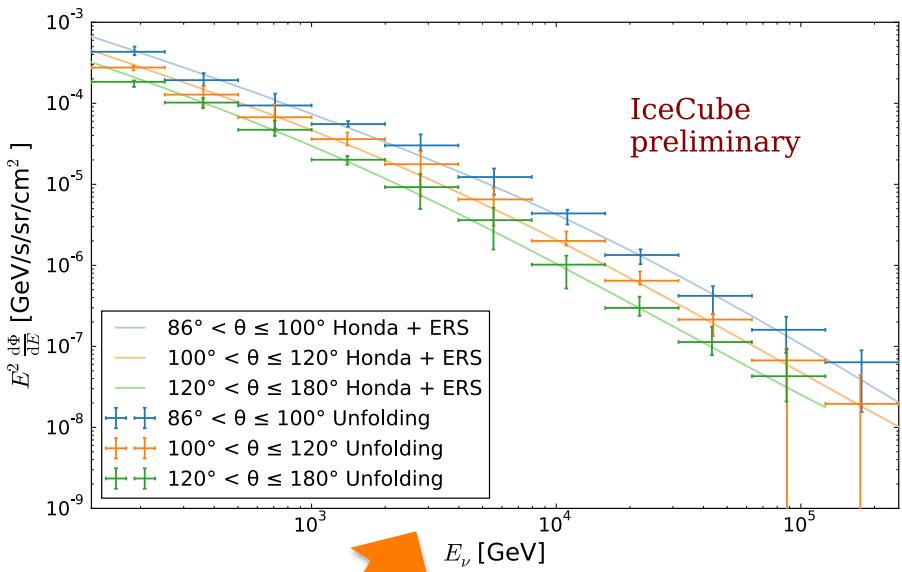
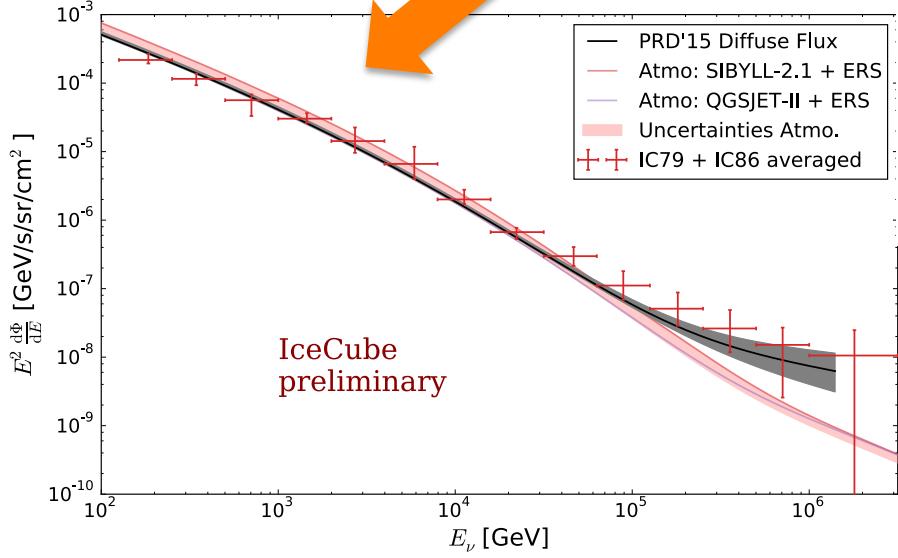


Clear deviation from an atmospheric
only prediction



More results

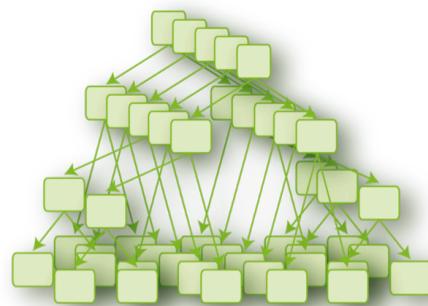
Combining the spectra



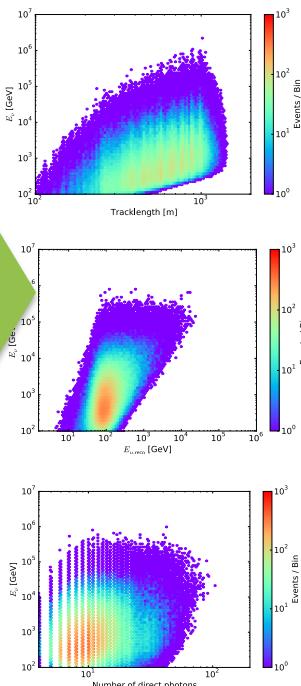
Unfolding different zenith bands

Summary and Outlook

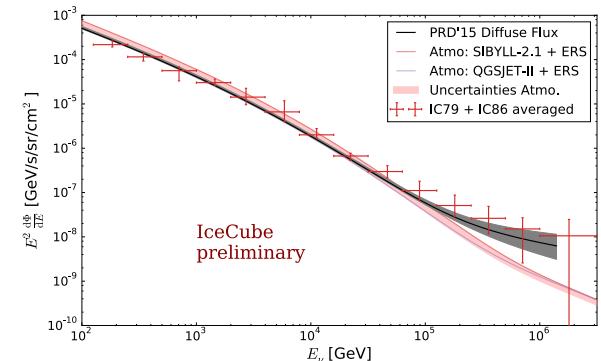
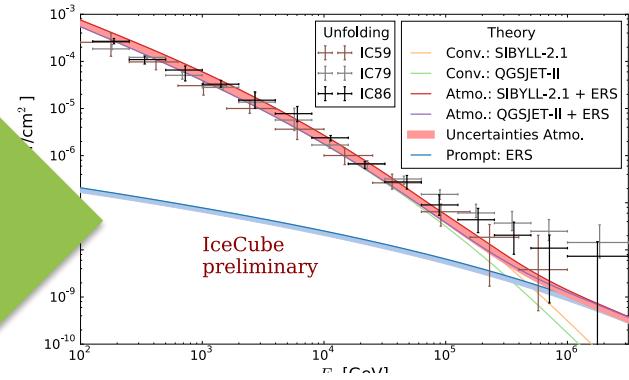
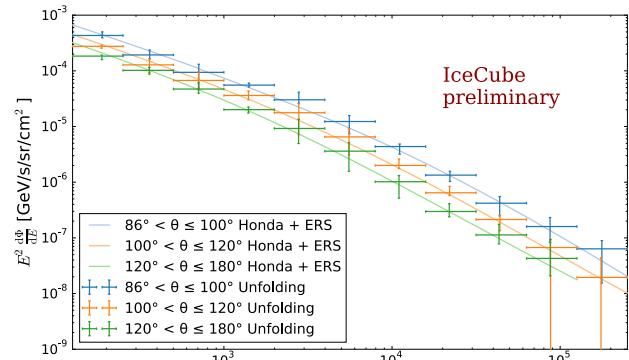
Random Forest &
MRMR



$$g(y) = \int_{E_{\min}}^{E_{\max}} A(E, y) f(E) dE$$

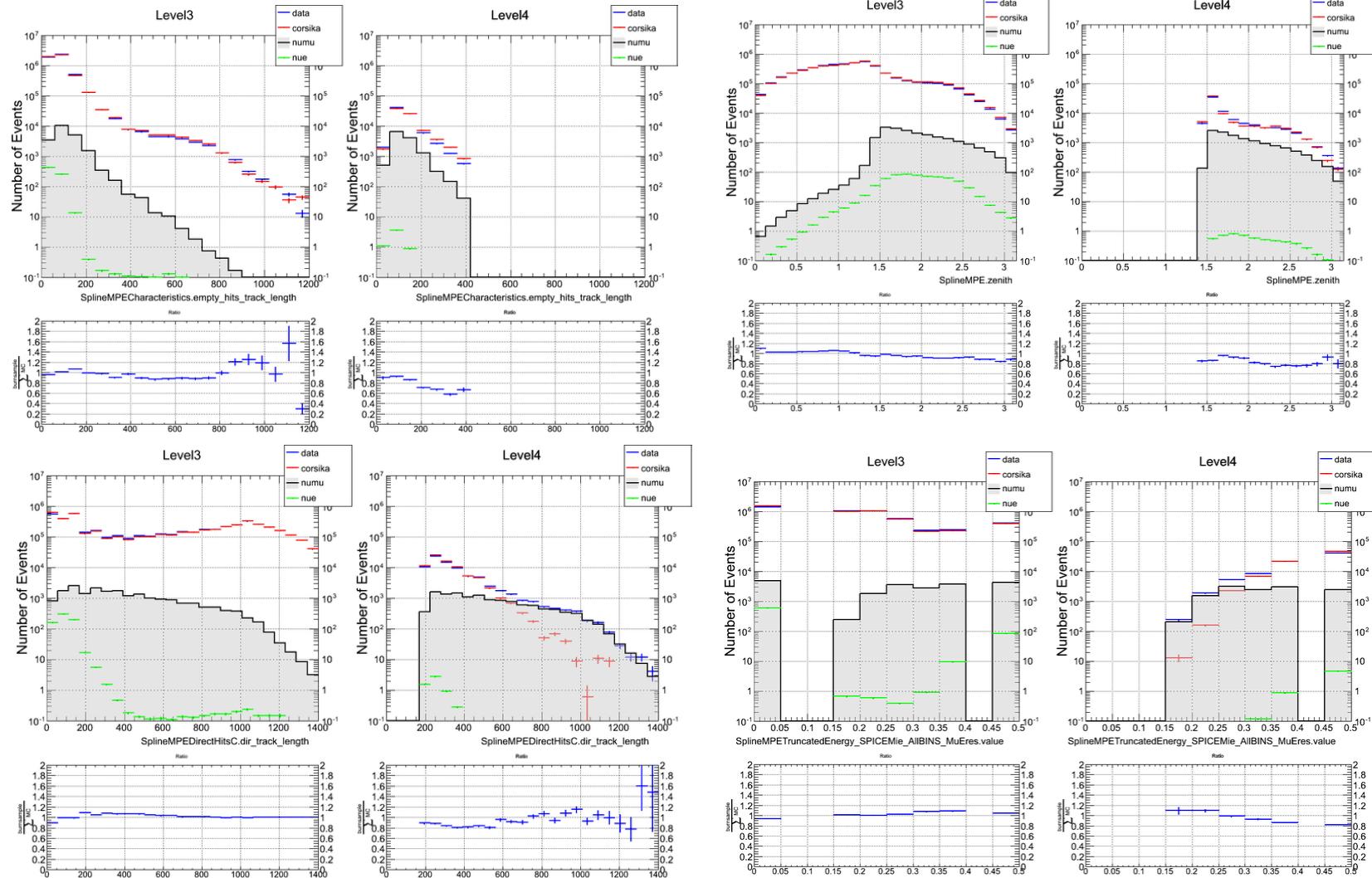


TRUEE

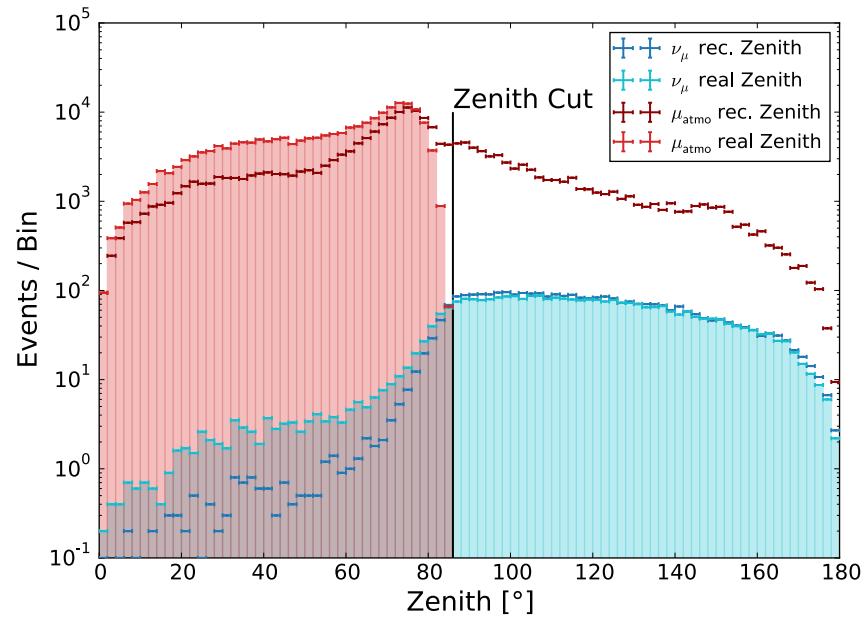
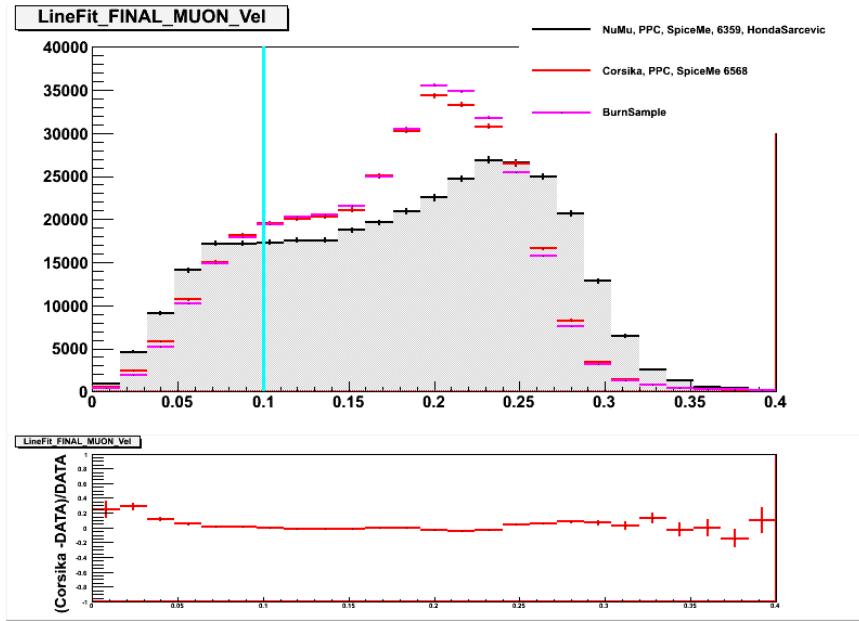


Backup

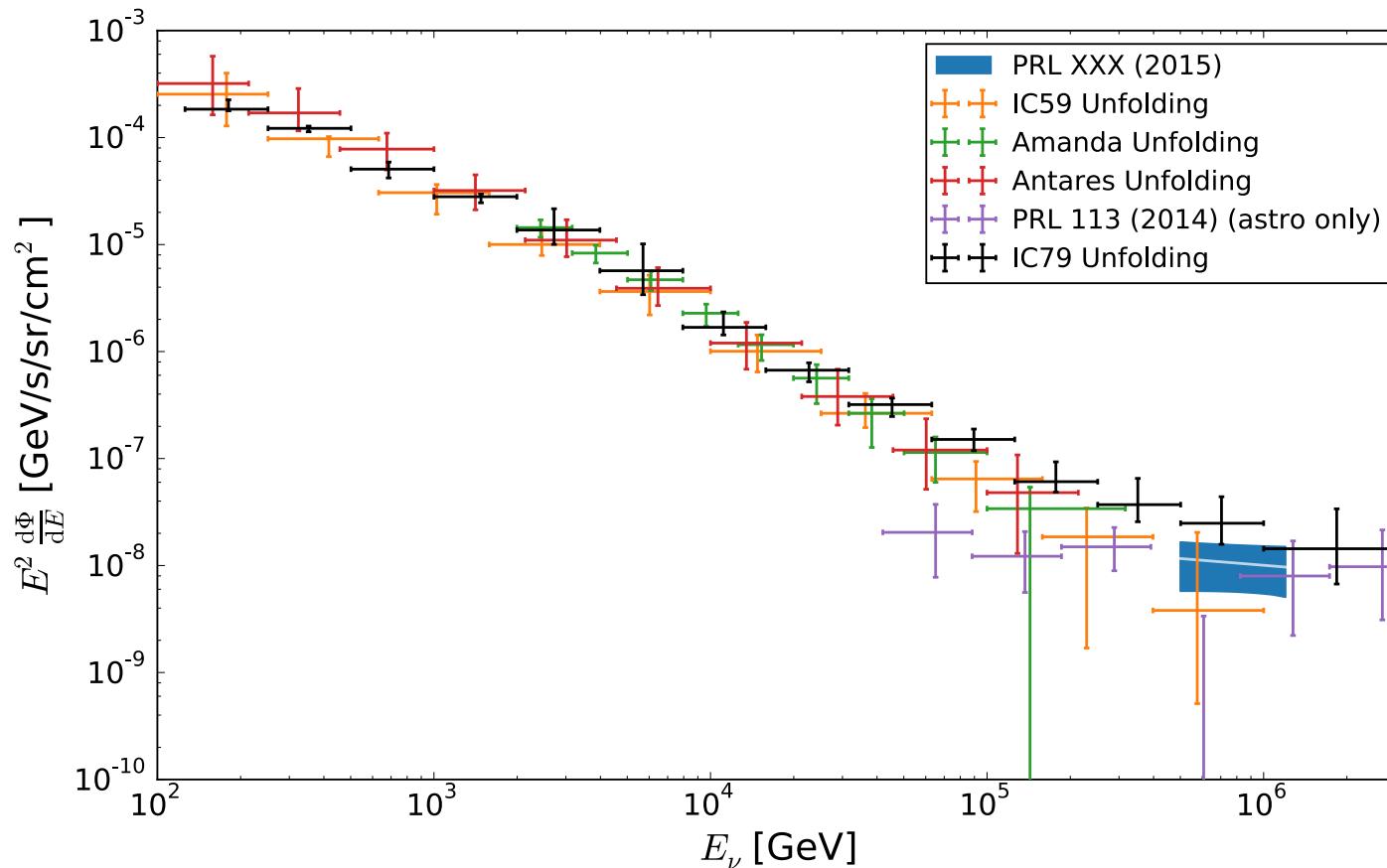
IC86 Precuts



IC79 Precuts



Comparison to other measurements



Relevance vs. Redundancy: MRMR (continuous case)

Relevance:

$$\max V_F$$

$$V_F = \frac{1}{|S|} \sum_{i \in S} F(i, h)$$

Redundancy:

$$\min W_c$$

$$W_c = \frac{1}{|S|^2} \sum_{i,j} |c(i, j)|$$

MRMR:

$$\max Q$$

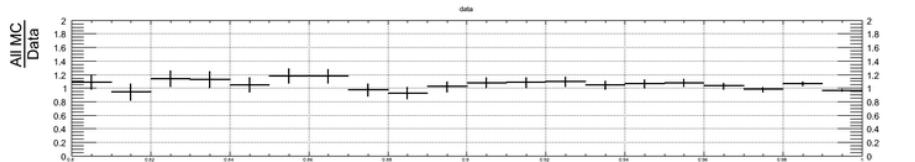
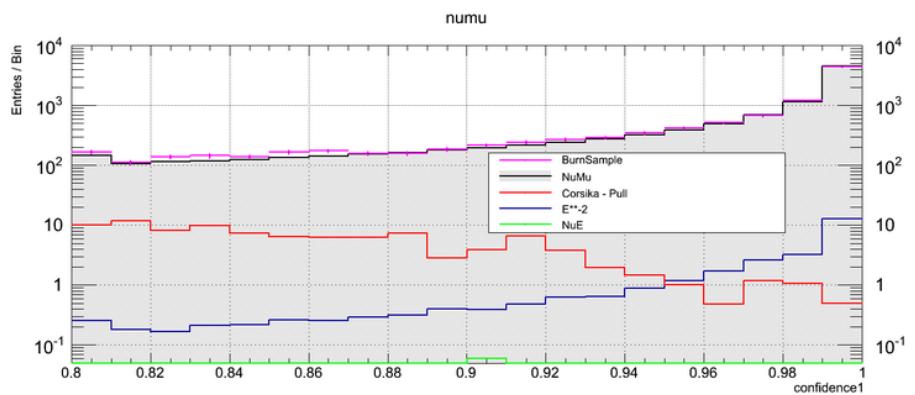
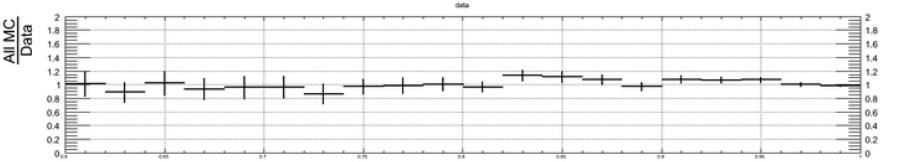
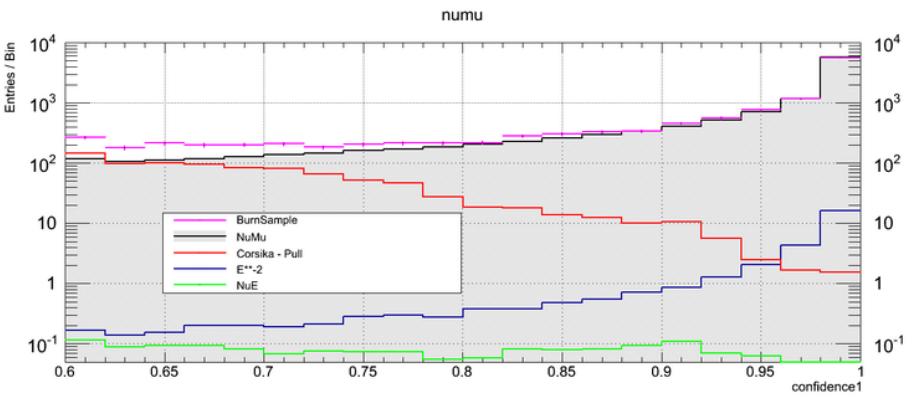
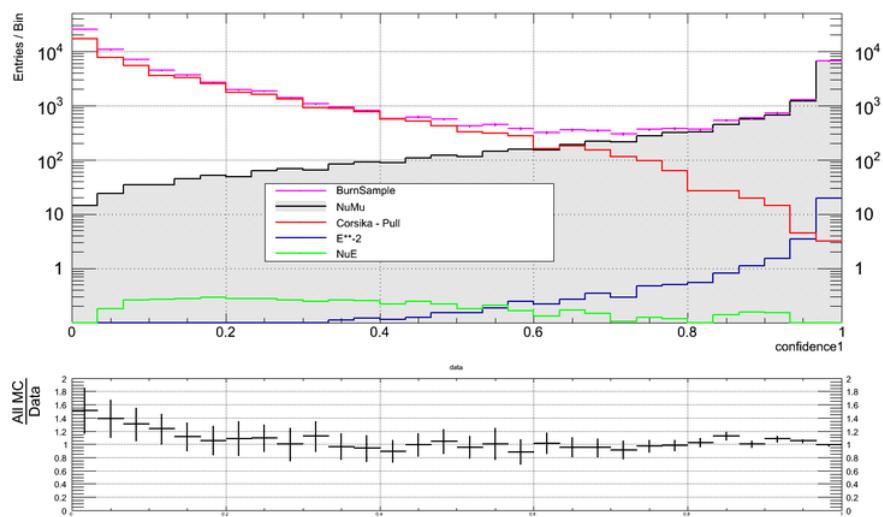
$$Q = \frac{V_F}{W_C}$$

or

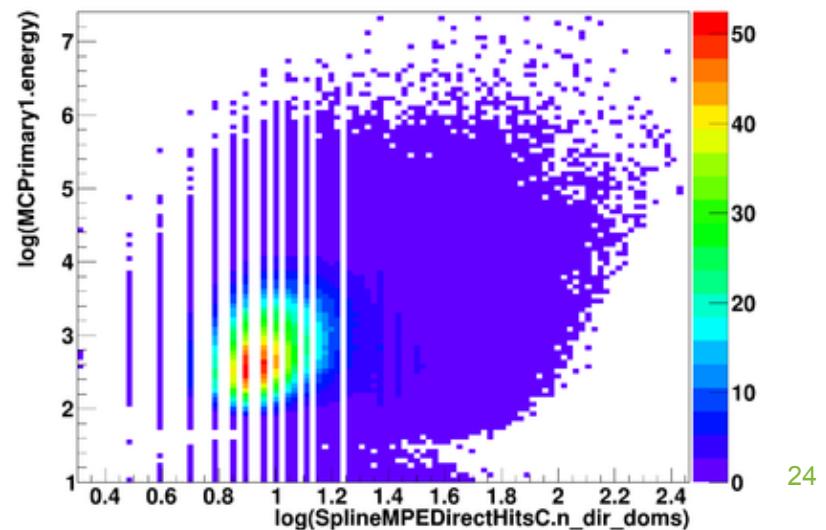
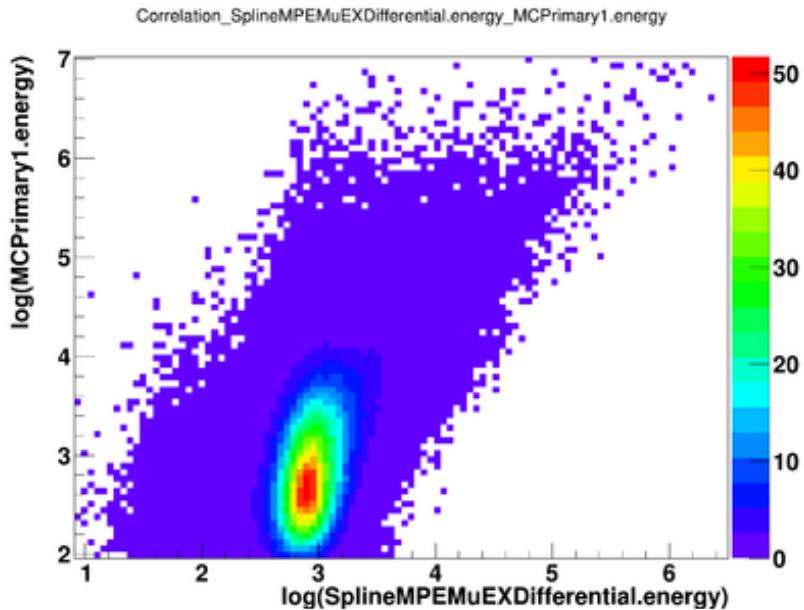
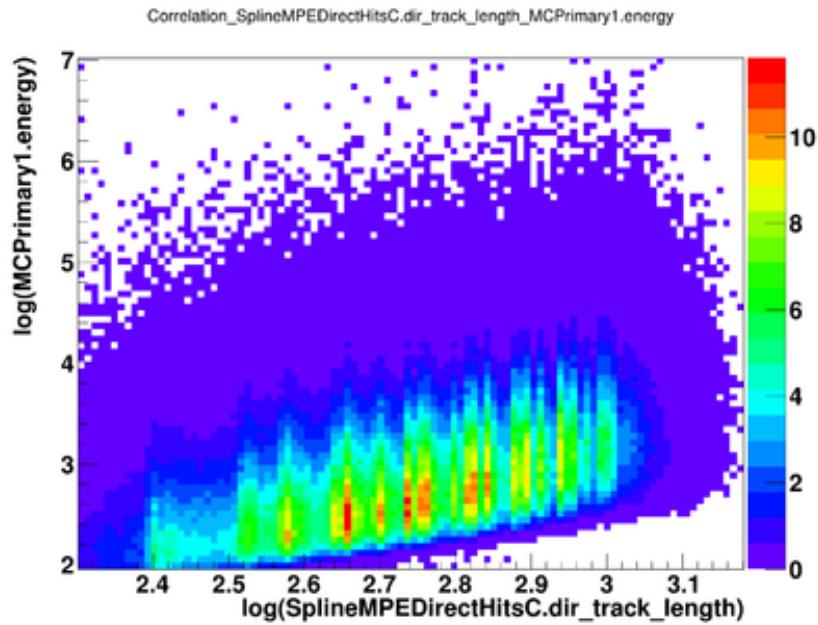
$$\max D$$

$$D = V_F - W_c$$

IC86 Confidence Distributions

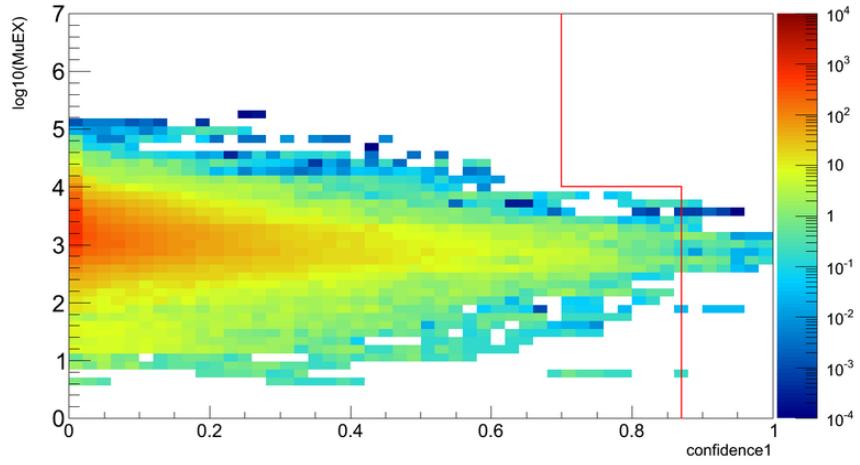


Unfolding Input for IC86

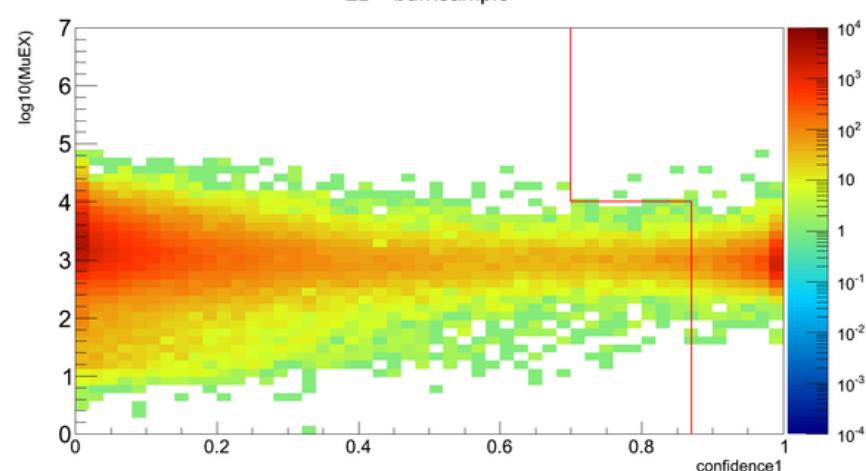


IC86 2D Cut

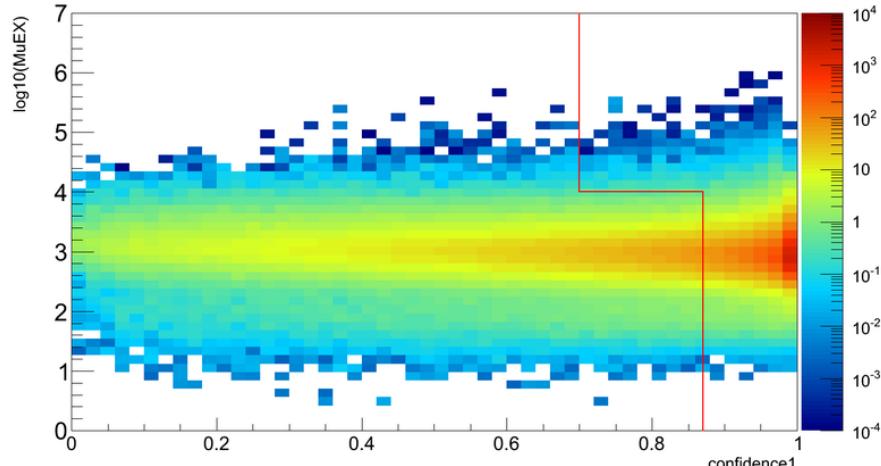
2D - Background



2D - burnsample



2D - atmospheric



2D - E^{**2} flux

