Search for a diffuse cosmic neutrino flux using the ANTARES data from 2007 - 2012

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Latest diffuse flux searches with ANTARES

CC ν_μ **2008 – 2011 (855 / 903 days)**

Sensitivity: $\mathbf{4.7 \cdot 10^{-8}}$ GeV/(cm^2 sr s)
Upper limit: $\mathbf{5.1 \cdot 10^{-8}}$ GeV/(cm^2 sr s)
(quoted $4.8 \cdot 10^{-8}$ was without systematic errors)

I

Sensitivity: $\mathbf{4.2 \cdot 10^{-8}}$ GeV/(cm^2 sr s)
Upper limit: $\mathbf{7.7 \cdot 10^{-8}}$ GeV/(cm^2 sr s)
(quoted $7.0 \cdot 10^{-8}$ was without systematic errors)

II

showers **2007 – 2012 (1247 days)**

Sensitivity: $\mathbf{2.2 \cdot 10^{-8}}$ GeV/(cm^2 sr s) per flavour
Upper limit: $\mathbf{4.9 \cdot 10^{-8}}$ GeV/(cm^2 sr s) per flavour

combined **work is currently starting…**

ν_μ analyses (2008 - 2011)

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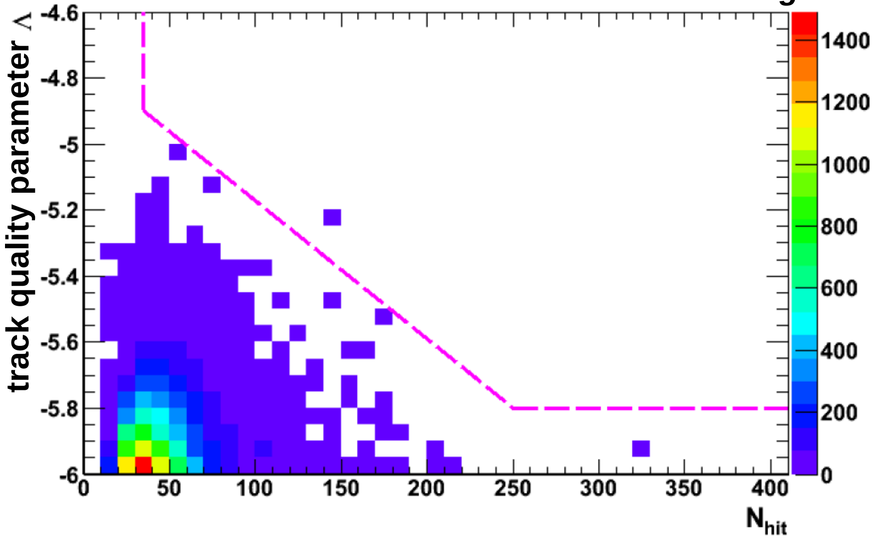
I

- Suppression of atm. muons:

J. Schnabel: TAUP13 Proceedings



- MRF optimization using a dE/dx energy estimator

Expected background events: 8.4
Measured events: 8
Upper limit: **5.1 · 10^{-8}** GeV/(cm^2 sr s)

II

- Include atmospheric muons in the MRF optimization
- Use a multivariate approach to
  - Reconstruct the energy of the muon / muon bundle
  - Optimize the MRF

Expected background events: 8.3
Measured events: 12
Upper limit: **7.7 · 10^{-8}** GeV/(cm^2 sr s)

Shower event reconstruction

- Two-step maximum likelihood fit

$$-\log LLH = \sum_{i=1}^{N_{\text{pulses}}} -\log pdf_i$$

- Shower vertex is reconstructed from the time and position information of the hits only (without the hit charge).
- Shower energy and direction are reconstructed from the charge and position information of the hits with the vertex kept fixed.
- Reconstruction is not restricted to contained events.

RECO-QUALITY	Median	Mean	10 / 90 % Quantiles
Vertex error :	4 meters	6 meters	3 / 6 meters
Logarithmic Energy error:	-0.16	-0.24	-0.02 / -0.61
Direction error :	6 deg	19 deg	2 / 66 deg

for showers @ 10 TeV shower energy after the muon filter (vertex llh < 7.9)

All flavour analysis using shower events (2007-2012)

Cut flow chart on reconstructed events

Muon filter (vllh < 7.9) → Hits on > 2 lines → Sparking event filter → Fitted zenith > 94° → Shower energy > 10 TeV

EVENT NUMBERS AFTER FINAL OPTIMIZED CUTS	Cosmic signal events	Atmospheric background events
Cosmic signal (test flux $1.2 * 10^{-8}$ per flav.)	**1.75**	
Conventional atmospheric neutrinos*	**-**	**2.32**
Prompt atmospheric neutrinos**	**-**	**0.56**
Tau neutrino estimation	**0.78**	**0.02** ***(prompt)***
Atmospheric muon extrapolation	**-**	**1.85**
Correction for missing vertex showers in CC muon simulations	**0.26**	**0.16**
High multiplicity muon bundles	**-**	**0.01**
TOTAL	**2.79**	**4.92**

Retrieved from full run-by-run simulations (first three rows)

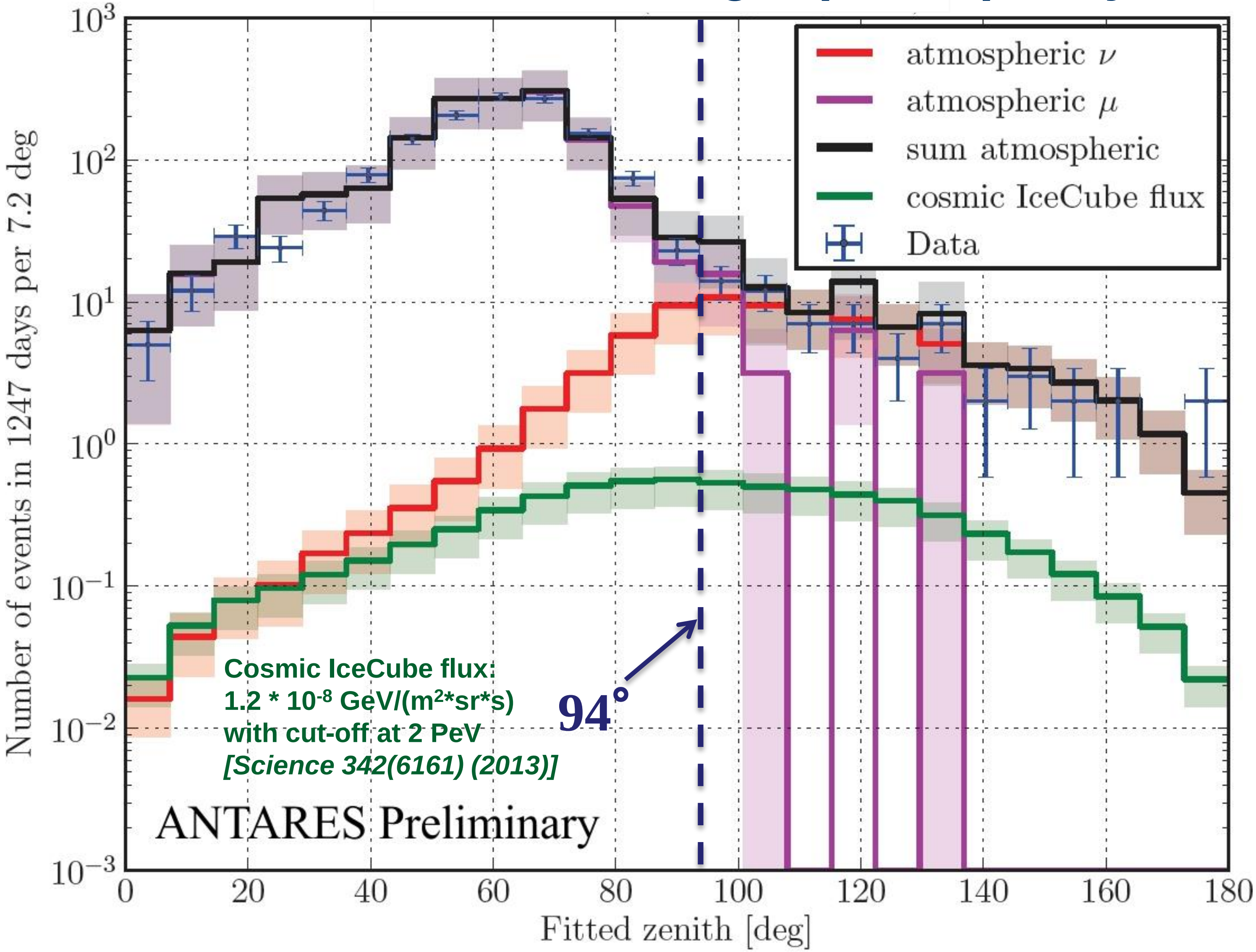
Additional estimations and extrapolations (last four rows before TOTAL)

* *Bartol [Phys.Rev.D 70:023006 (2004)]*
** *Enberg [Phys.Rev.D 78:043005 (2008)]*

Sensitivity per neutrino flavour:

$$E^2 \cdot \bar{\Phi}_{90\,\%} = 2.2^{+0.9}_{-0.7} \cdot 10^{-8}\,\mathrm{GeV/cm^2 \cdot sr \cdot s}$$

Fitted neutrino zenith angle (after quality cuts)



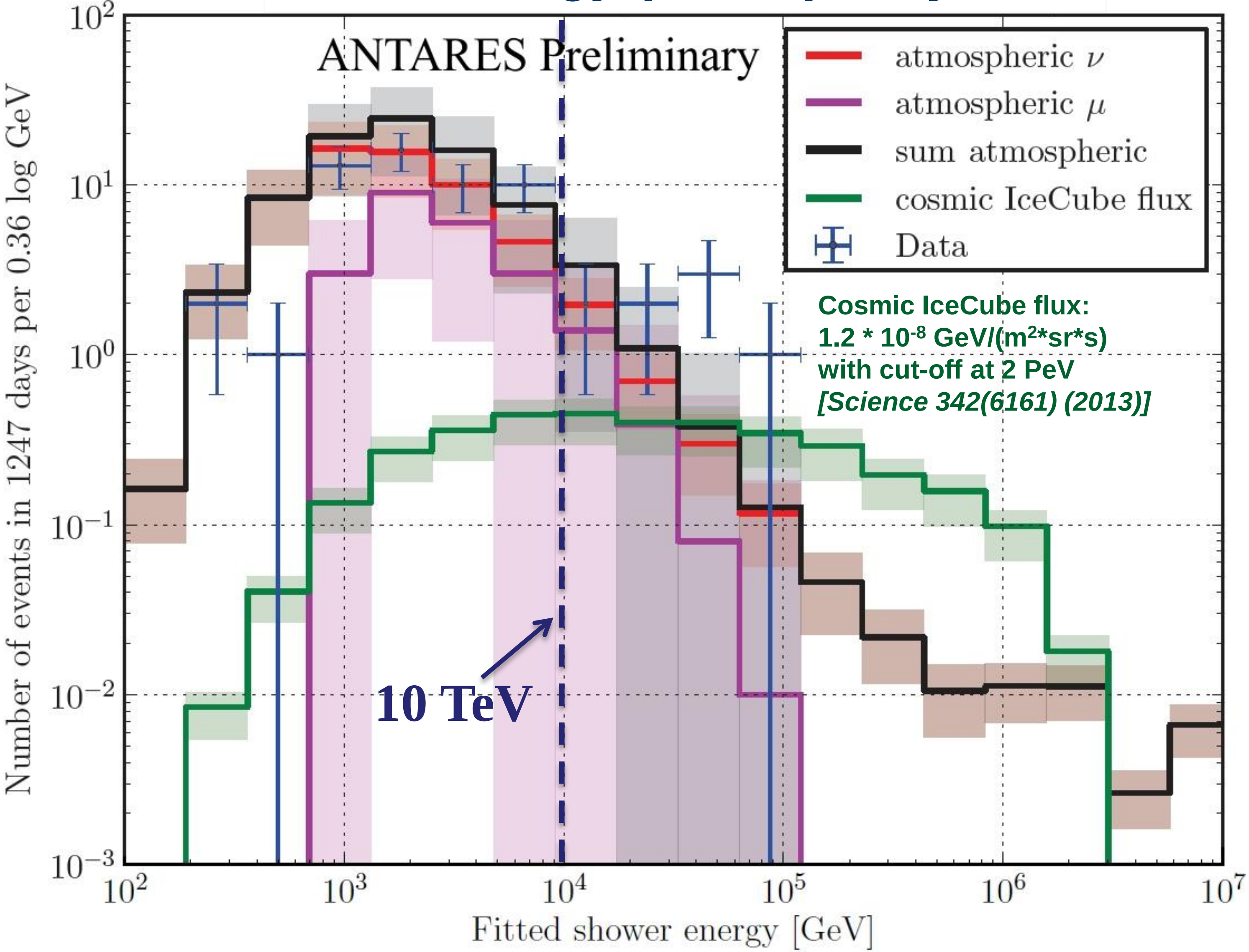
Data set after

- Muon filter (vertex llh < 7.9)
- Lines > 2
- Sparking filter (OMDist > 15m)

Error bends on Monte-Carlo contain systematic and statistical errors

Error bars on data points indicate Poisson statistical errors.

Fitted shower energy (after quality and zenith cuts)



Data set after

- Muon filter (vertex llh < 7.9)
- Lines > 2
- Sparking filter (OMDist > 15m)
- Zenith > 94°

Error bends on Monte-Carlo contain systematic and statistical errors

Error bars on data points indicate Poisson statistical errors.

The result of the shower analysis (1247 days)

- After the zenith cut **60 data events** are measured, where **$81.7^{+40.0}_{-39.6}$** are expected from **background only**.

- After the very final cut **8 data events** remain, where the **background only** expectation is **$4.92^{+2.84}_{-2.95}$**.

- Following **Feldman-Cousins*** the 90% confidence upper limit on the diffuse flux is (no systematic uncertainties included)

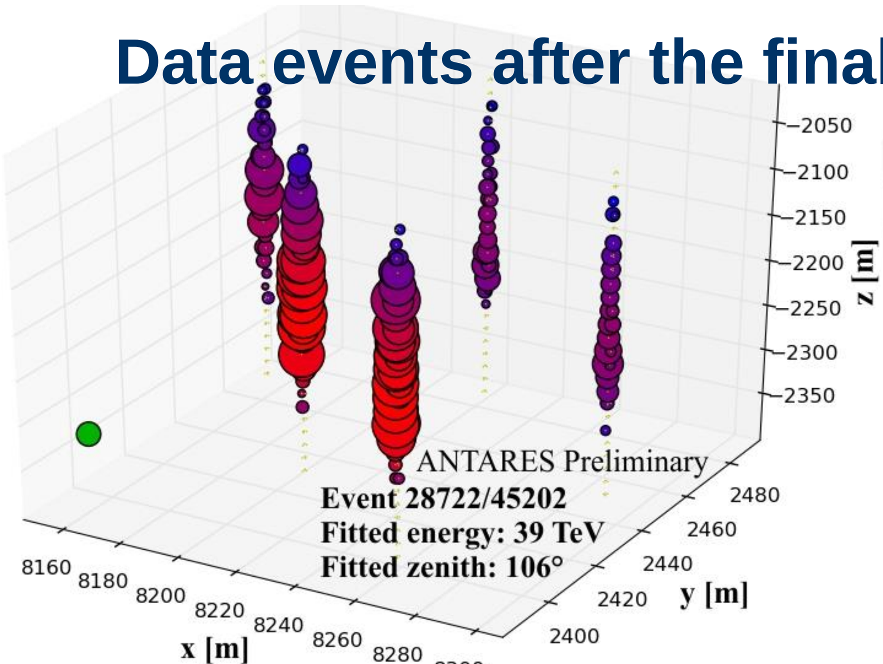
$$E^2 \cdot \Phi_{90\,\%} = 3.9 \cdot 10^{-8}\,\mathrm{GeV}/\mathrm{cm}^2 \cdot \mathrm{sr} \cdot \mathrm{s}$$

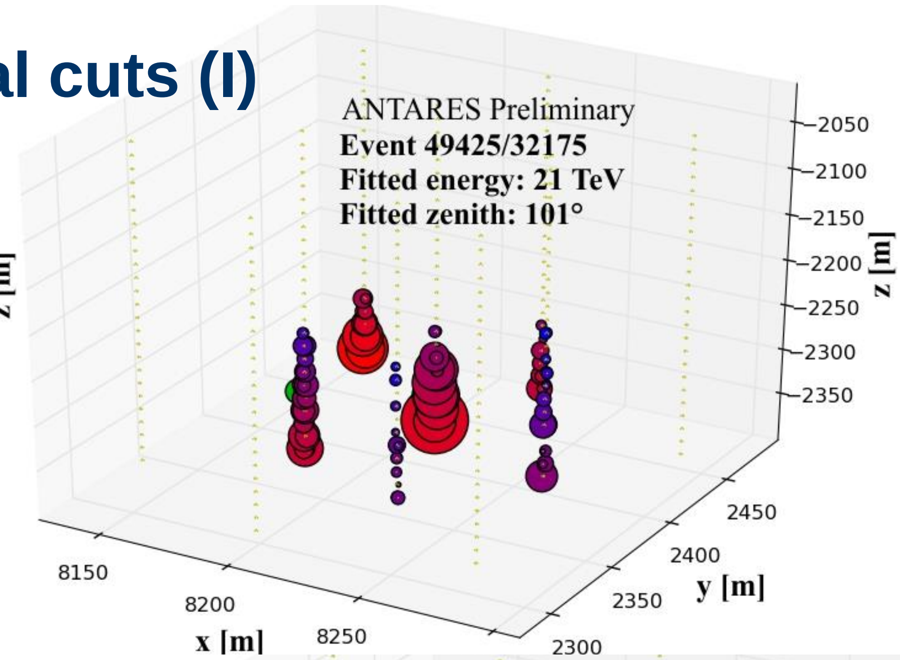
- Taking into account systematic uncertainties using **Pole 1.0**** (relative background uncertainty: 0.42, rel. signal uncert.: 0.29) the upper limit is:

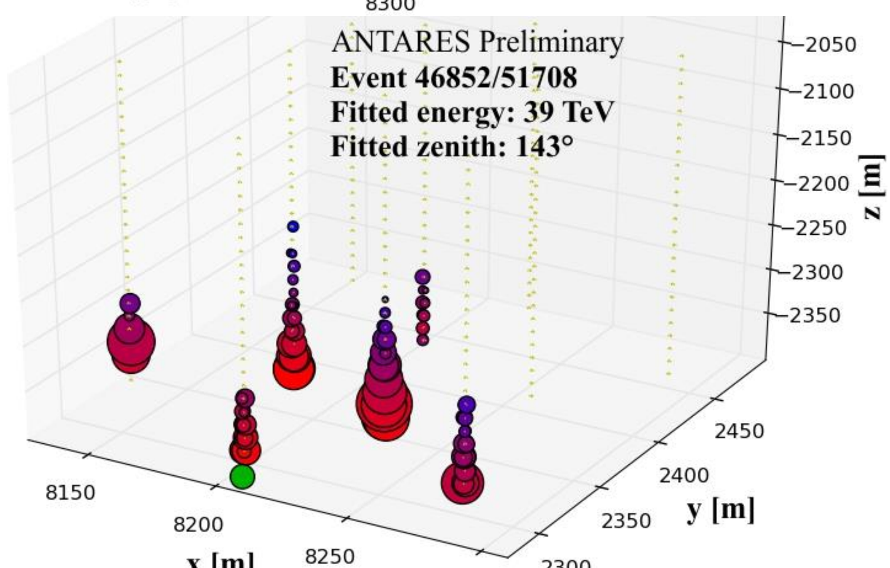
$$E^2 \cdot \Phi_{90\,\%} = 4.9 \cdot 10^{-8}\,\mathrm{GeV}/\mathrm{cm}^2 \cdot \mathrm{sr} \cdot \mathrm{s}$$

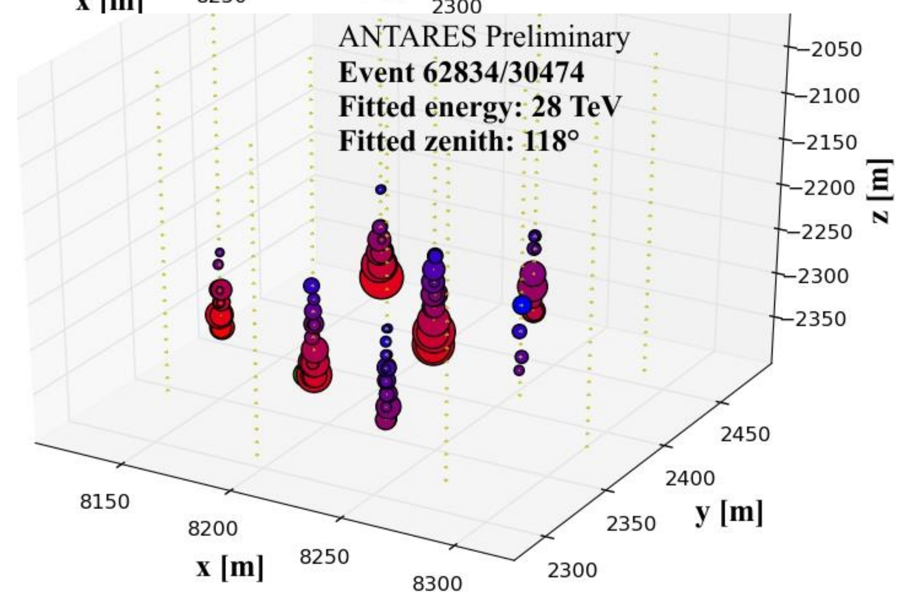
**   [Phys.Rev.D 57:3873-3889 (1998)] [Astropart.Phys. 19(3):393-402 (2003)]*
*** [Comp.Phys.Comm. 158(2):117-123 (2004)]*

Data events after the final cuts (I)

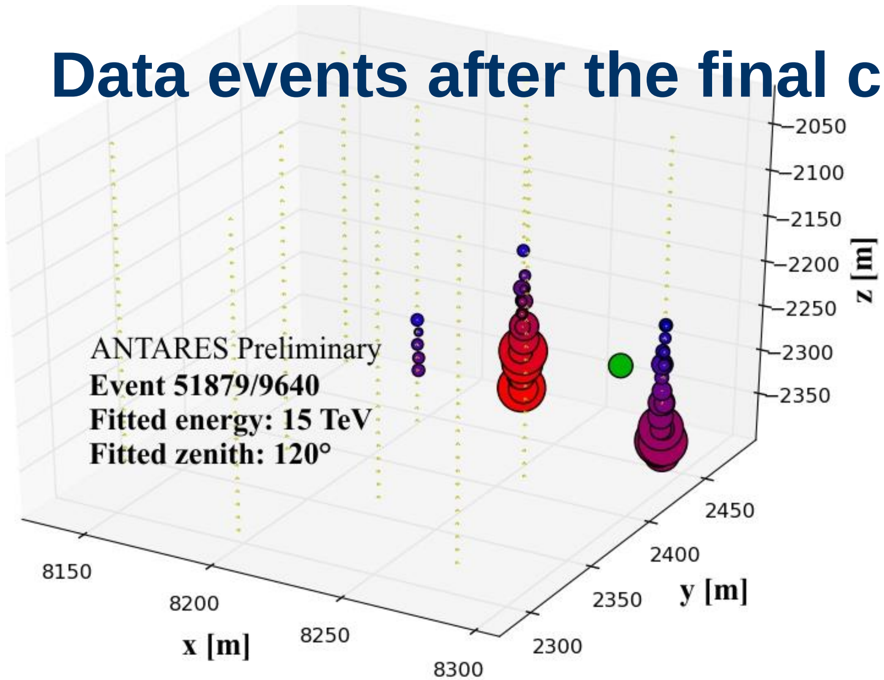


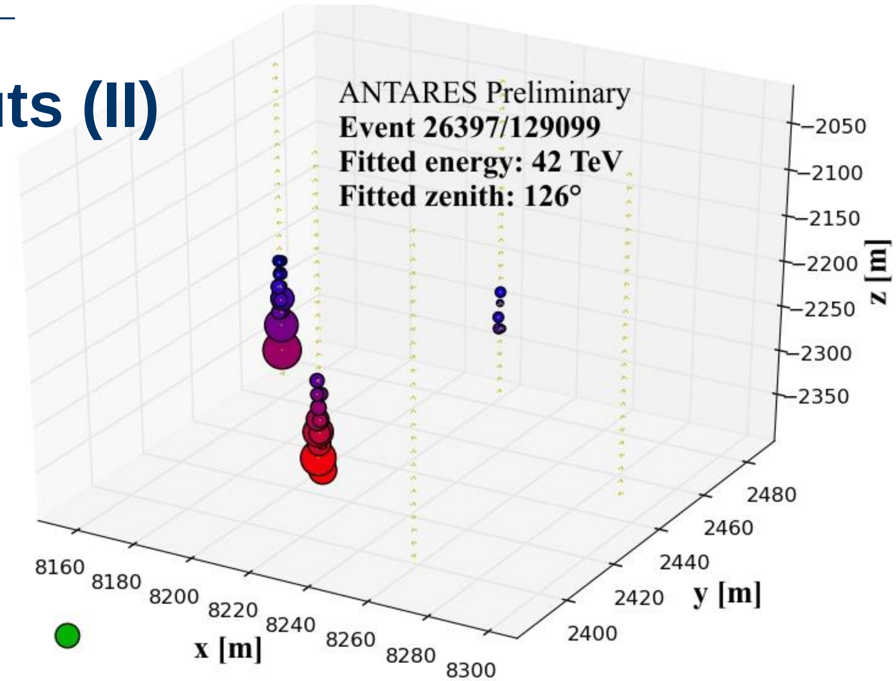


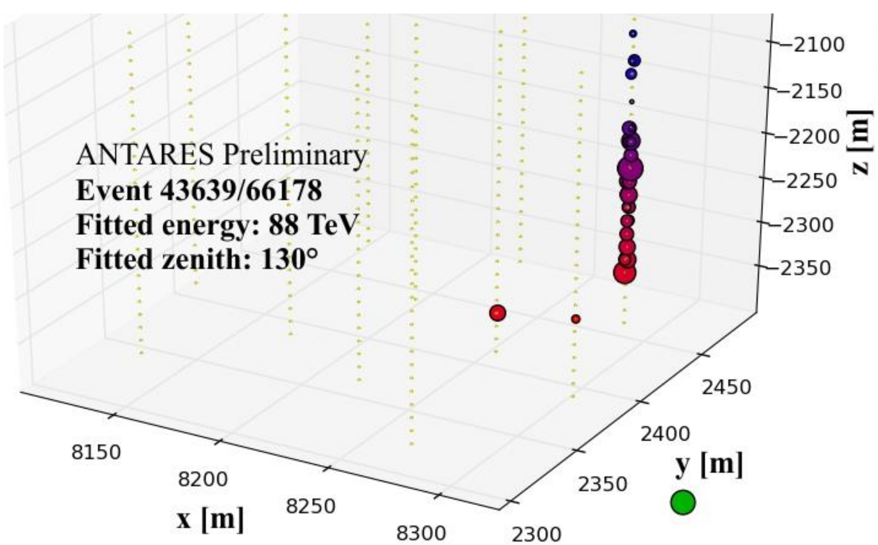


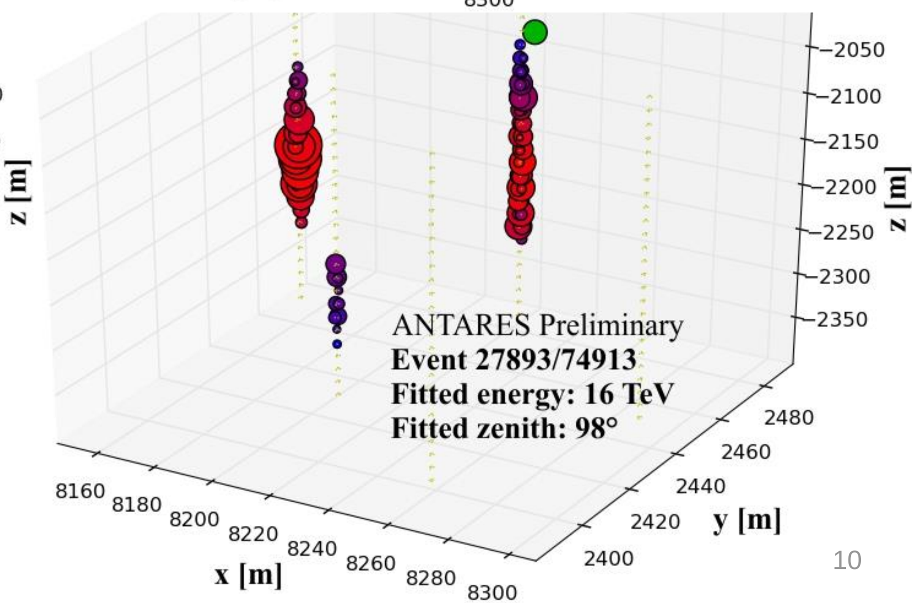


Data events after the final cuts (II)

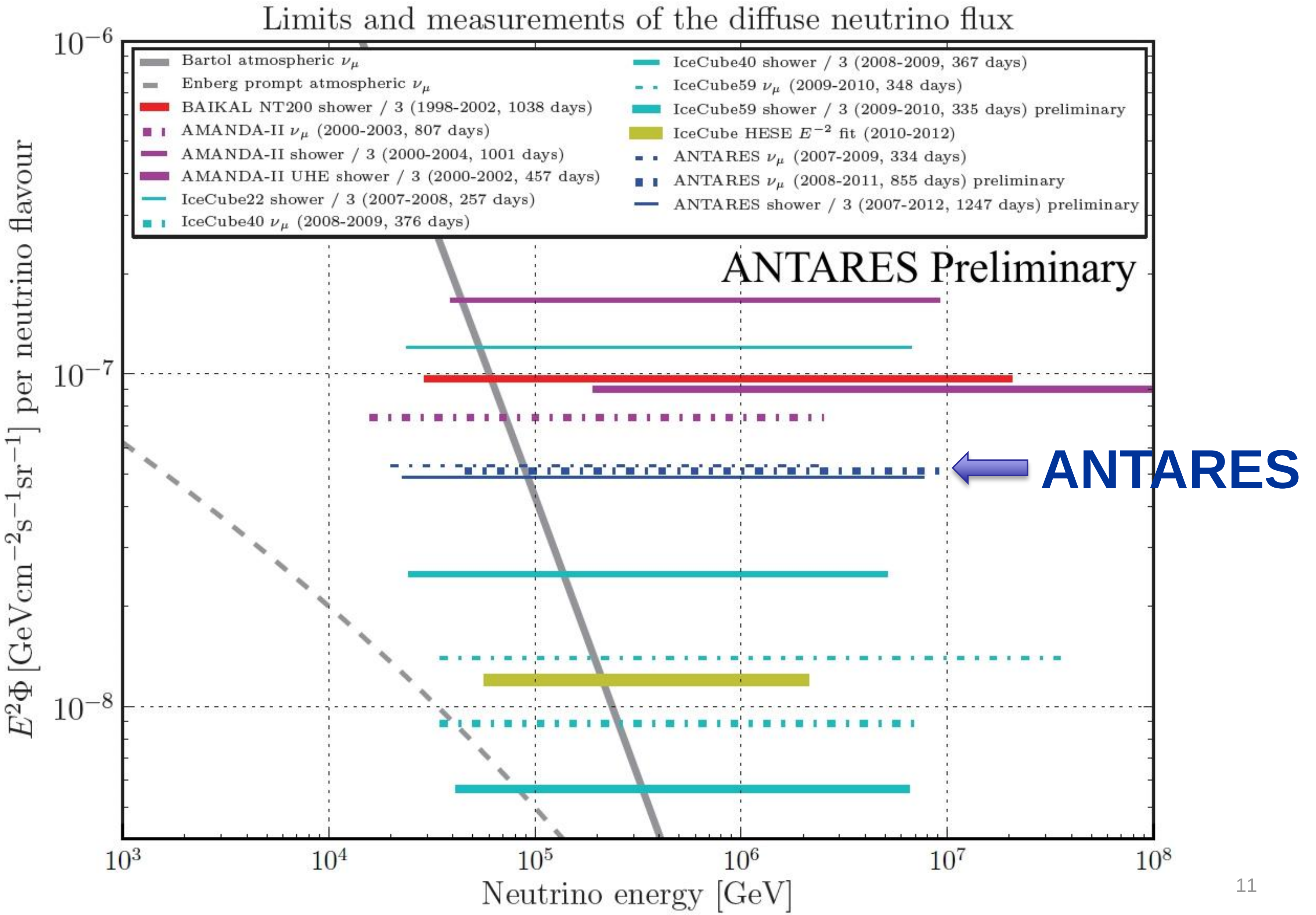








Diffuse flux limits



Summary

- The latest search for a diffuse cosmic neutrino flux with ANTARES was performed using shower events in the data from 2007-2012 (**1247** days)

- **8** events have been observed after the final cuts where $\mathbf{4.9^{+2.8}_{-3.0}}$ are expected from atmospheric background.

- Within the systematic and statistical uncertainties the measurement is compatible with the atmospheric background.

- An upper limit per neutrino flavour on the diffuse cosmic neutrino flux in the energy range from **23 TeV** to **7.8 PeV** was evaluated to:
$$E^2 \cdot \Phi_{90\,\%} = 4.9 \cdot 10^{-8}\,\mathrm{GeV/cm^2 \cdot sr \cdot s}$$

- The result agrees well with previous analyses in the ν_μ CC channel.

Backup slides

The 8 remaining data events

Run ID	Fitted energy [TeV]	Fitted zenith [°]	# hits / strings	Total charge [pe]	Containment	Run burst fraction	Run mean rate [kHz]	Quality basic
26397	42.1	125.9	42/3	169	29*	0.41	91	1
27893	16.3	98.2	75/3	321	61*	0.05	63	4
28722	39.1	106.1	286/5	1373	23*	0.04	63	4
43639	87.5	129.7	36/3	74	84*	0.09	90	4
46852	39.3	143.3	91/6	603	84*	0.13	87	1
49425	21.4	100.9	88/6	562	22*	0.36	235	1
51879	15.0	119.6	50/3	318	40*	0.16	100	4
62834	28.1	118.5	99/7	456	69*	0.16	66	4

* Distance in meters to detector edge.

- All remaining events have a fitted vertex outside the instrumented volume

Limits for other flux assumptions

	Unbroken cosmic signal flux	Cosmic signal flux with a cut-off at 2 PeV
Normal Enberg[1] prompt atmospheric flux	Signal events: **2.79** Backgr. events: **4.92** Sensitivity[2]: **$2.2 \cdot 10^{-8}$** POLE UPPER LIMIT[2]: **$4.9 \cdot 10^{-8}$**	Signal events: **2.14** Backgr. events: **4.92** Sensitivity[2]: **$2.9 \cdot 10^{-8}$** POLE UPPER LIMIT[2]: **$6.4 \cdot 10^{-8}$**
3.8 * Enberg[1] prompt atmospheric flux	Signal events: **2.79** Backgr. events: **6.63** Sensitivity[2]: **$2.5 \cdot 10^{-8}$** POLE UPPER LIMIT[2]: **$4.1 \cdot 10^{-8}$**	Signal events: **2.14** Backgr. events: **6.63** Sensitivity[2]: **$3.2 \cdot 10^{-8}$** POLE UPPER LIMIT[2]: **$5.3 \cdot 10^{-8}$**

Unblinding result

[1] Phys.Rev.D 78:043005 (2008)

[2] In units **GeV / ($cm^2 \cdot sr \cdot s$)**

Systematic errors

- The uncertainty of the **conventional atmospheric flux** was assumed to be **+/- 30 %**
- The uncertainty on the **prompt flux** is implemented in the Enberg parametrization in neutrinoflux and is about **+ 27 / - 41 %**
- The systematic error from varying **absorption length, scattering length and PMT efficiency** by 10% yields on average
  - **+ 36 / - 24 %** for shower events
  - **+ 11 / - 16 %** for muon track events
- **Differences from the RBR v2 to km3 v4r5** have been taken into account by adding an additional systematic error of **- 31 %**

Shower reconstruction scheme

Hit selection

- *Evaluate a rough vertex estimation from the distribution of coincident and big hits*
- *Apply a cut on the time residual respective this vertex*

Shower reconstruction

- *2-step Gulliver maximum-likelihood fit where the likelihood is calculated from Monte-Carlo based pdf values (idea firstly introduced by R. Auer)*

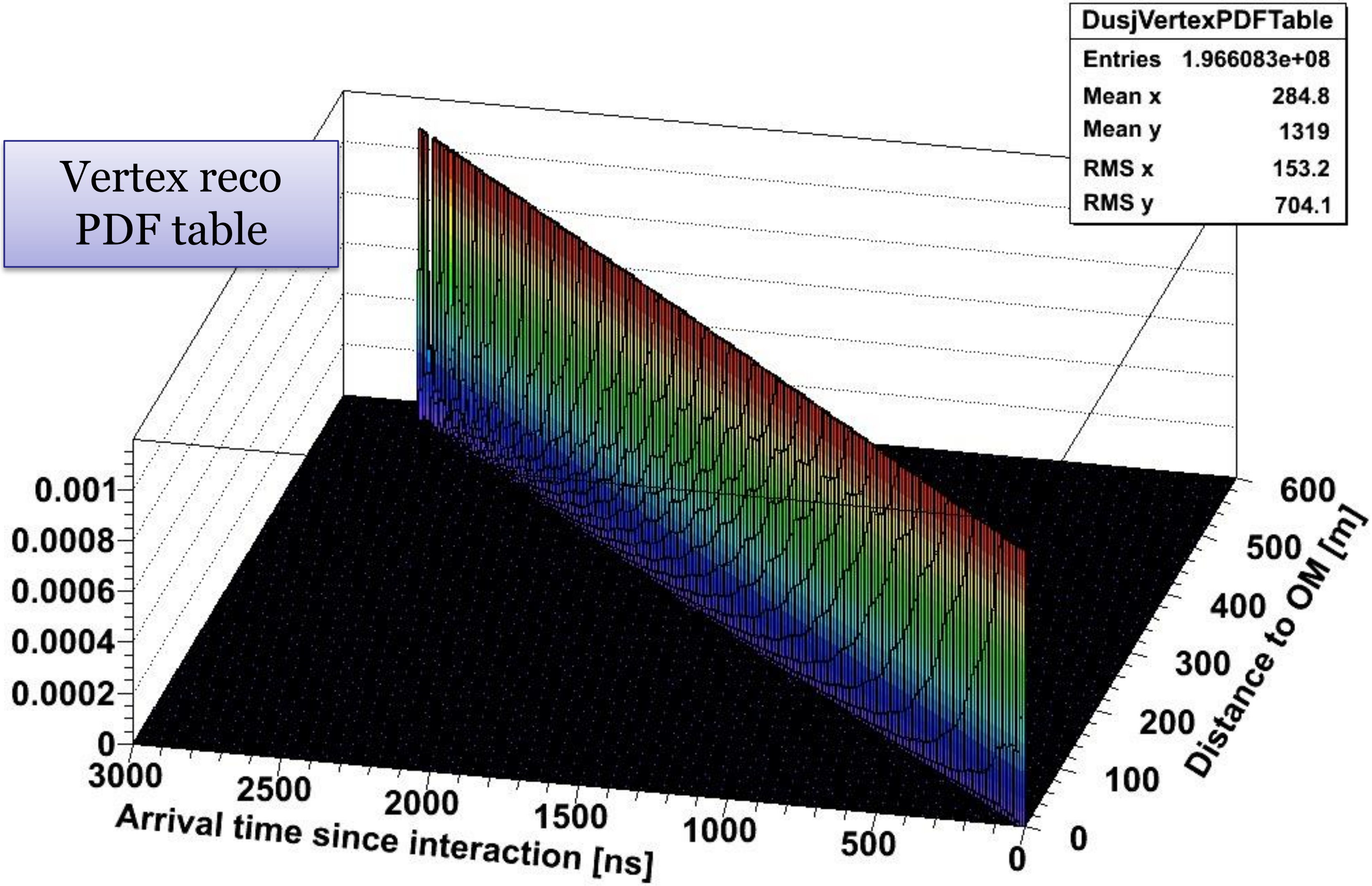
$$-\log LLH = \sum_{i=1}^{N_{\text{pulses}}} -\log pdf_i$$

probability that the whole event has been caused by a certain shower assumption (refers to $-\log LLH$)

probability that one single hit has been caused by a certain shower assumption (stored in tables that were filled from Monte-Carlo simulations) (refers to $-\log pdf_i$)

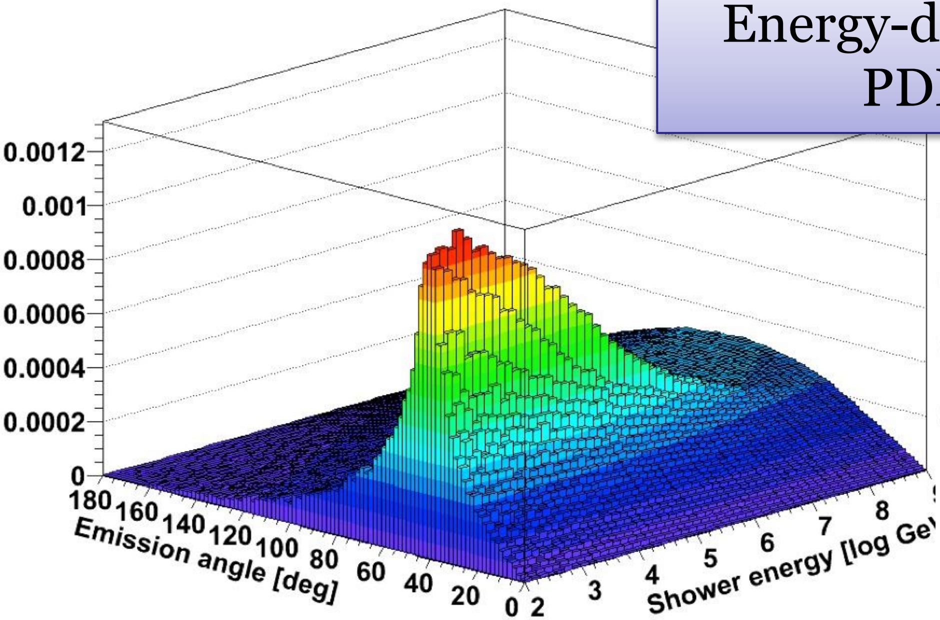
Shower vertex reconstruction

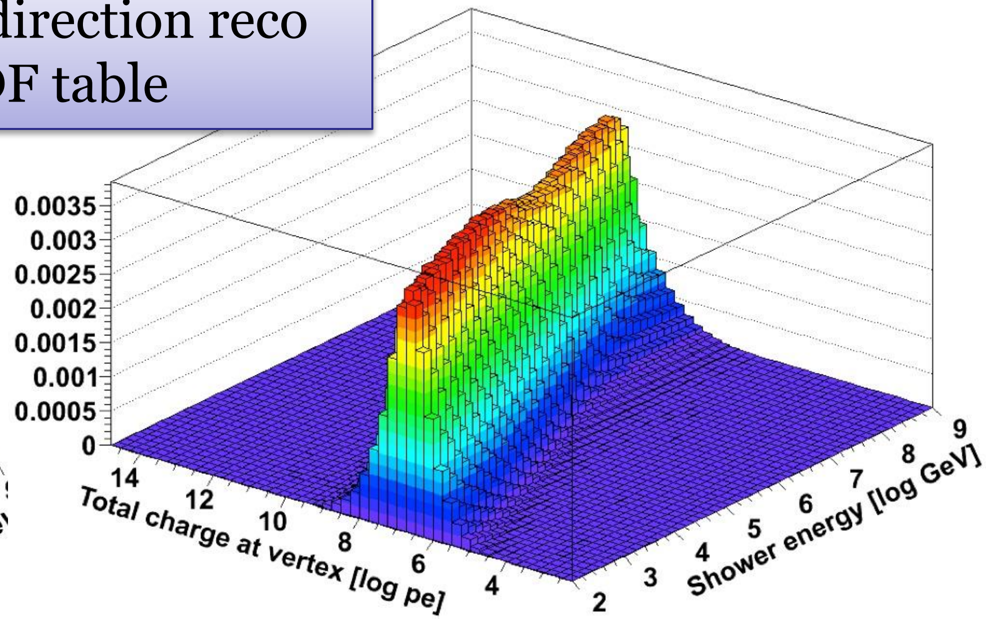
Vertex reco
PDF table



Shower energy and neutrino direction reconstruction

Energy-direction reco
PDF table



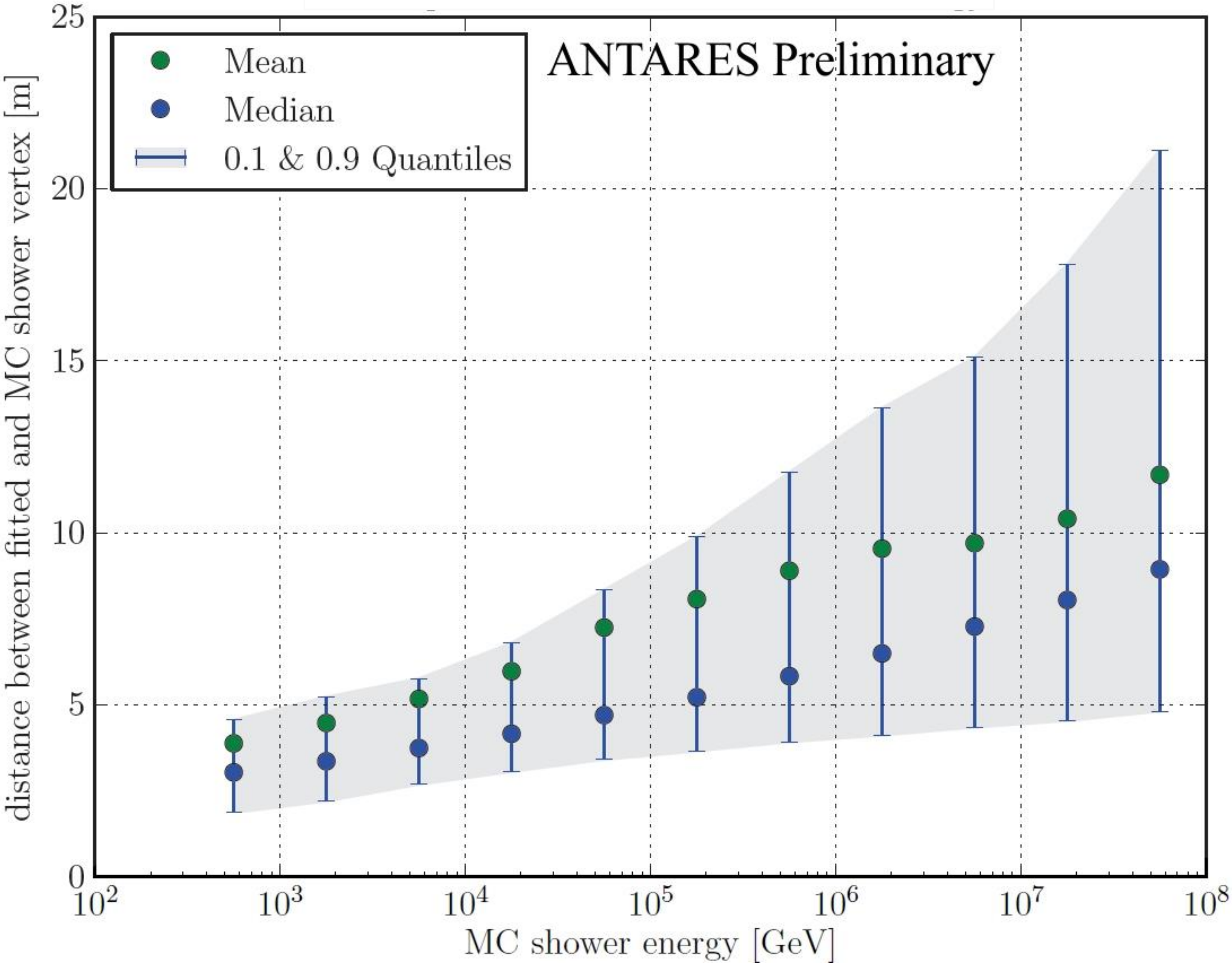


3-dimensional table relating for each hit:

- *Energy of the shower*
- *Photon emission angle with respect to neutrino track*
- *Total expected charge at the vertex*

$$c_{\text{vertex}} = c_{\text{pulse}} \cdot e^{\frac{d}{\lambda_w}} \cdot \frac{1}{\alpha} \cdot \frac{4\pi d^2}{A_{\text{OM}}^2}$$

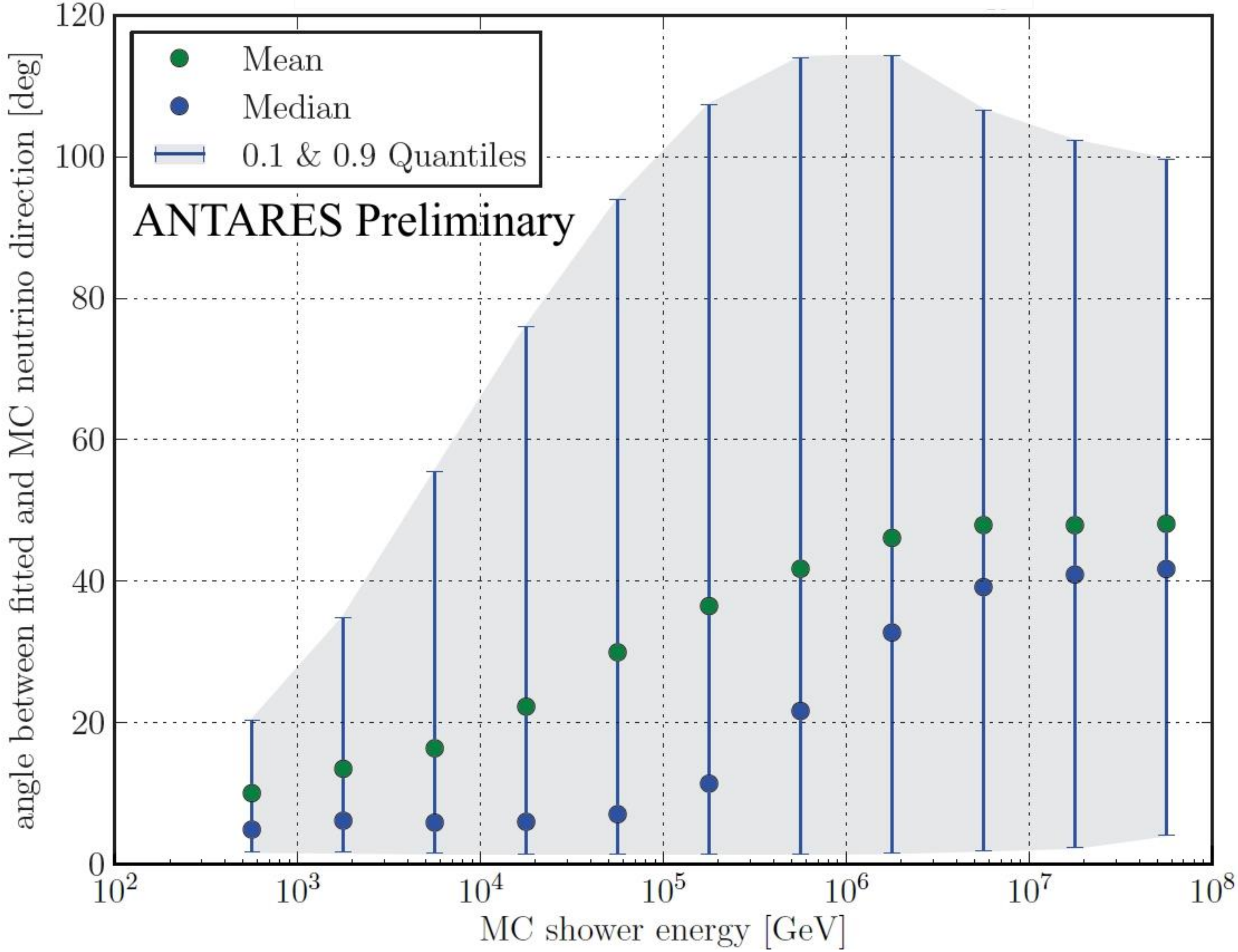
Vertex reconstruction quality



Evaluated from ν_e & ν_μ NC and ν_e CC shower events in the run-by-run based simulation.

After the muon filter (the cut on the reduced vertex log-likelihood at 7.9)

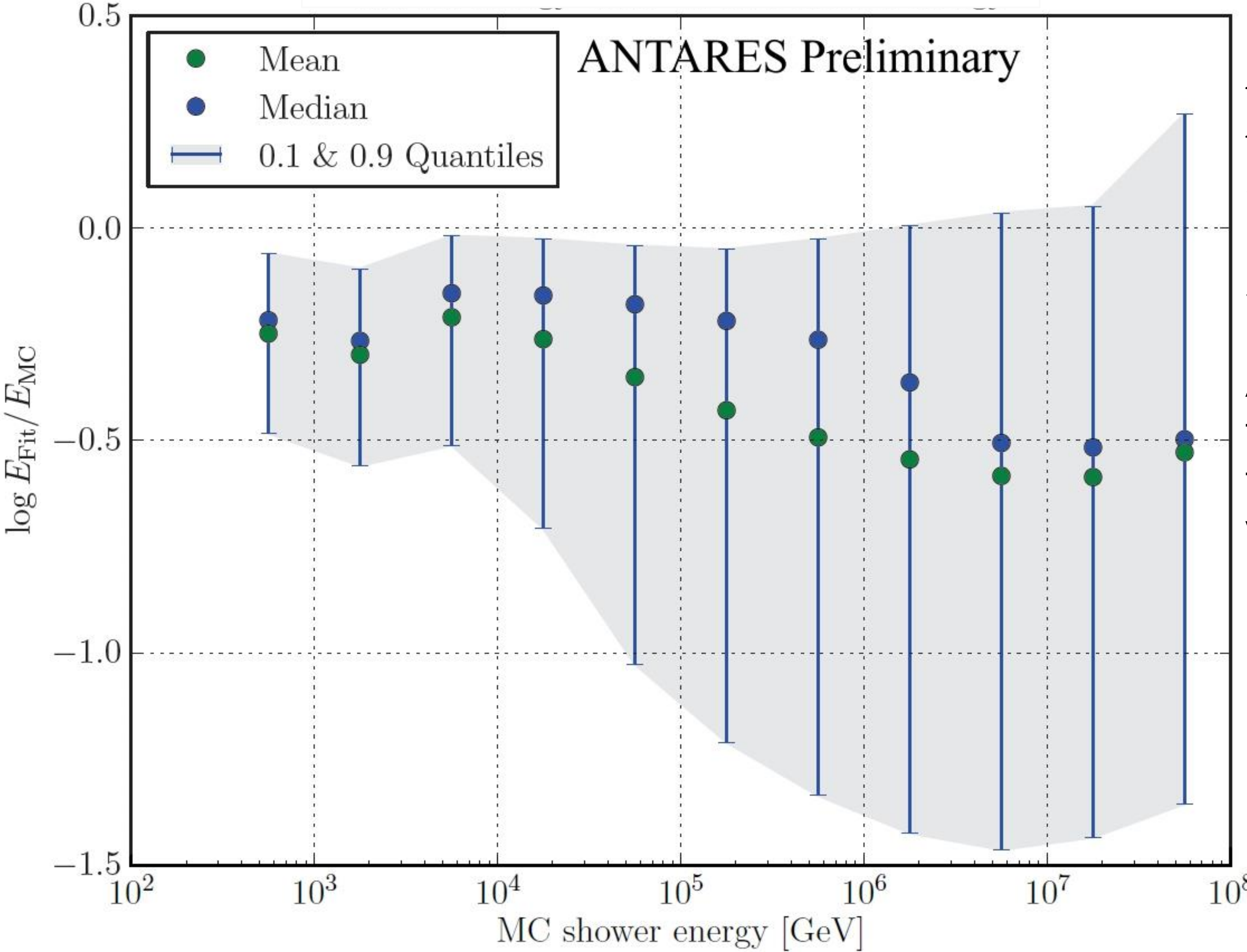
Direction reconstruction quality



Evaluated from ν_e & ν_μ NC and ν_e CC shower events in the run-by-run based simulation.

After the muon filter (the cut on the reduced vertex log-likelihood at 7.9)

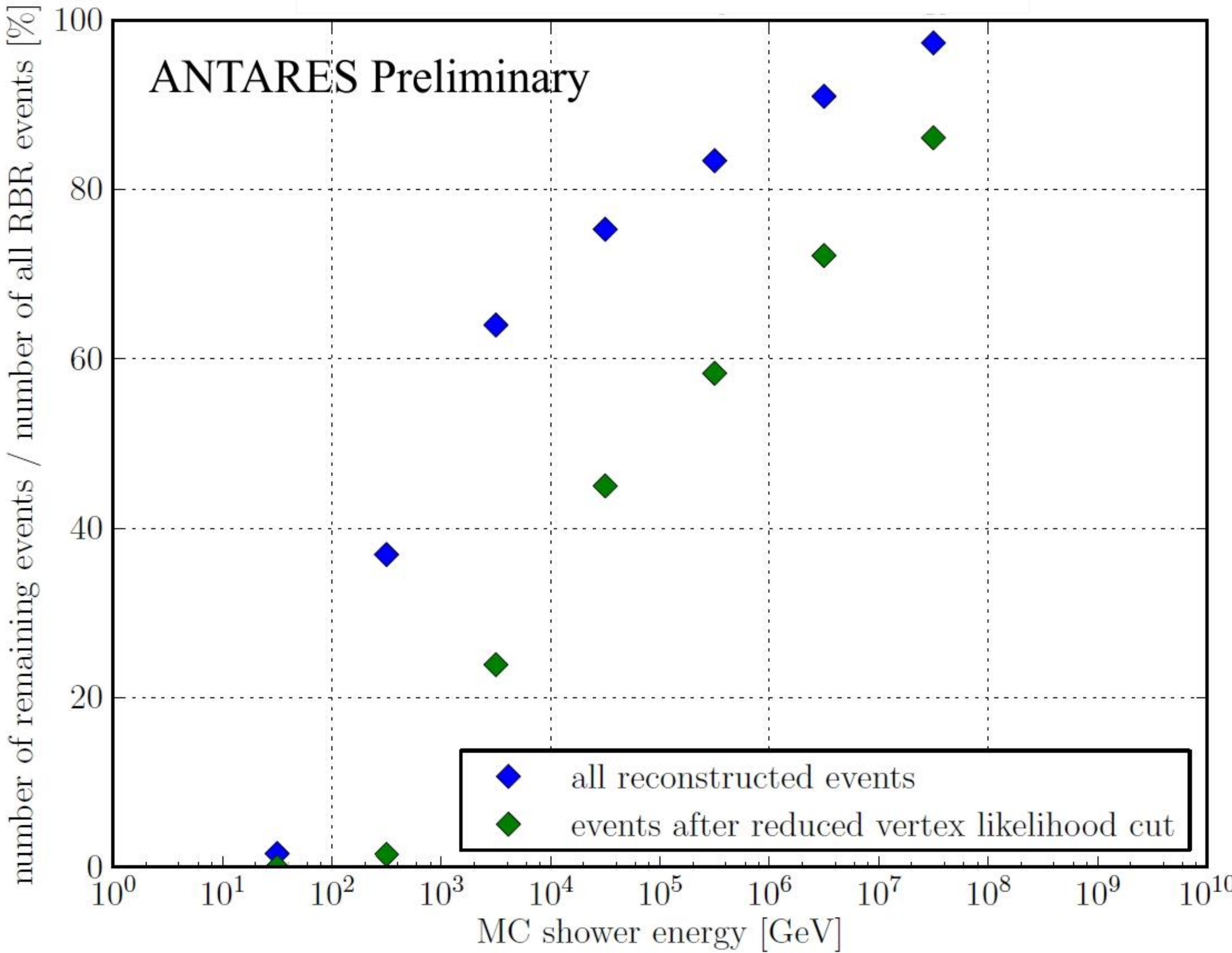
Shower energy reconstruction quality



Evaluated from ν_e & ν_μ NC and ν_e CC shower events in the run-by-run based simulation.

After the muon filter (the cut on the reduced vertex log-likelihood at 7.9)

Shower reconstruction efficiency



Evaluated from ν_e & ν_μ NC and ν_e CC shower events in the run-by-run based simulation.

After the muon filter (the cut on the reduced vertex log-likelihood at 7.9)

Detailed number of events in final full sample

Event type	Conventional atmospheric events	Prompt atmospheric events	Cosmic events
ν_e NC	$0.02^{+0.01}_{-0.01}$	$0.02^{+0.01}_{-0.01}$	$0.32^{+0.05}_{-0.10}$
$\bar{\nu}_e$ NC	$0.01^{+0.004}_{-0.004}$	$0.02^{+0.01}_{-0.01}$	$0.28^{+0.05}_{-0.09}$
ν_e CC	$0.42^{+0.26}_{-0.23}$	$0.23^{+0.07}_{-0.12}$	$2.08^{+0.35}_{-0.69}$
$\bar{\nu}_e$ CC	$0.15^{+0.10}_{-0.09}$	$0.20^{+0.06}_{-0.11}$	$2.89^{+0.49}_{-0.95}$
ν_μ NC	$0.51^{+0.32}_{-0.29}$	$0.02^{+0.01}_{-0.01}$	$0.32^{+0.05}_{-0.10}$
$\bar{\nu}_\mu$ NC	$0.10^{+0.06}_{-0.06}$	$0.02^{+0.01}_{-0.01}$	$0.28^{+0.05}_{-0.09}$
ν_μ CC	$1.05^{+0.33}_{-0.38}$	$0.04^{+0.01}_{-0.01}$	$0.78^{+0.07}_{-0.06}$
$\bar{\nu}_\mu$ CC	$0.19^{+0.06}_{-0.07}$	$0.03^{+0.01}_{-0.01}$	$0.60^{+0.06}_{-0.05}$
ν_τ NC	0	$0.001^{+0.000}_{-0.001}$	$0.32^{+0.05}_{-0.10}$
$\bar{\nu}_\tau$ NC	0	$0.001^{+0.000}_{-0.000}$	$0.28^{+0.05}_{-0.09}$
ν_τ CC	0	$0.010^{+0.005}_{-0.007}$	$1.22^{+0.55}_{-0.65}$
$\bar{\nu}_\tau$ CC	0	$0.008^{+0.003}_{-0.005}$	$1.10^{+0.55}_{-0.63}$
atm. muons	$1.86^{+1.53}_{-1.53}$	0	0
Total	$4.31^{+2.67}_{-2.68}$	$0.61^{+0.19}_{-0.30}$	$10.45^{+2.37}_{-3.61}$
	Bartol 2004 [Phys.Rev.D 70:023006]	Enberg 2008 [Phys.Rev.D 78:043005]	

Cosmic events refer to a test flux of 4.5 * 10-8 per flavour!