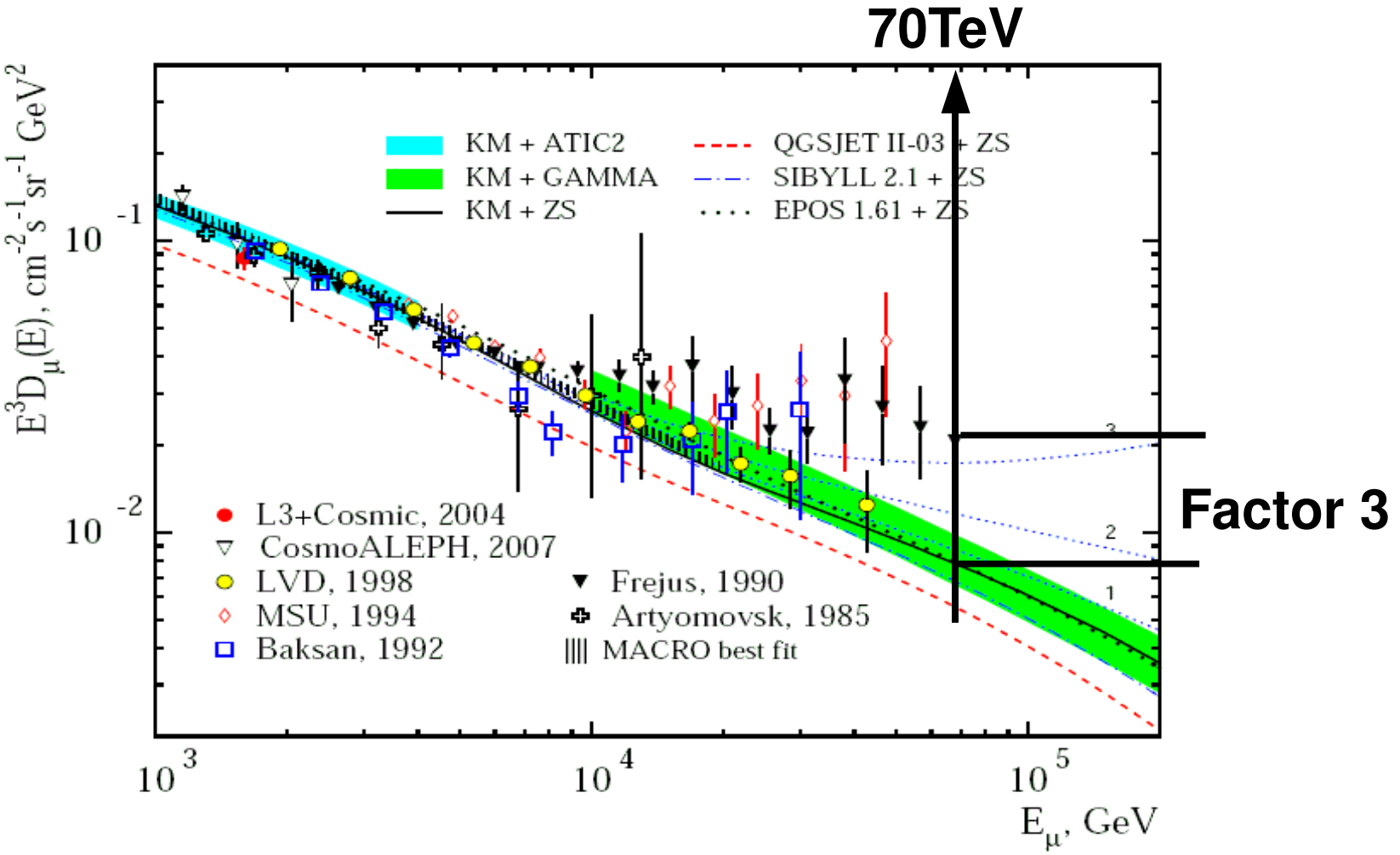
Why IceCube Is Not Doomed To Fail

Seminar

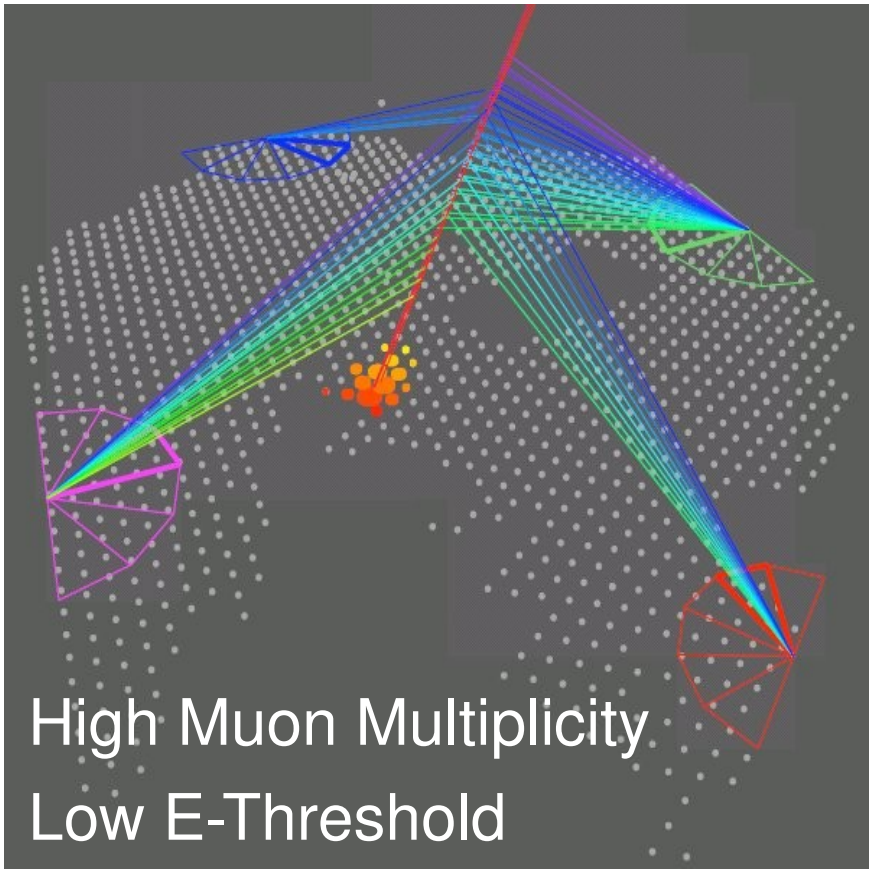
PB

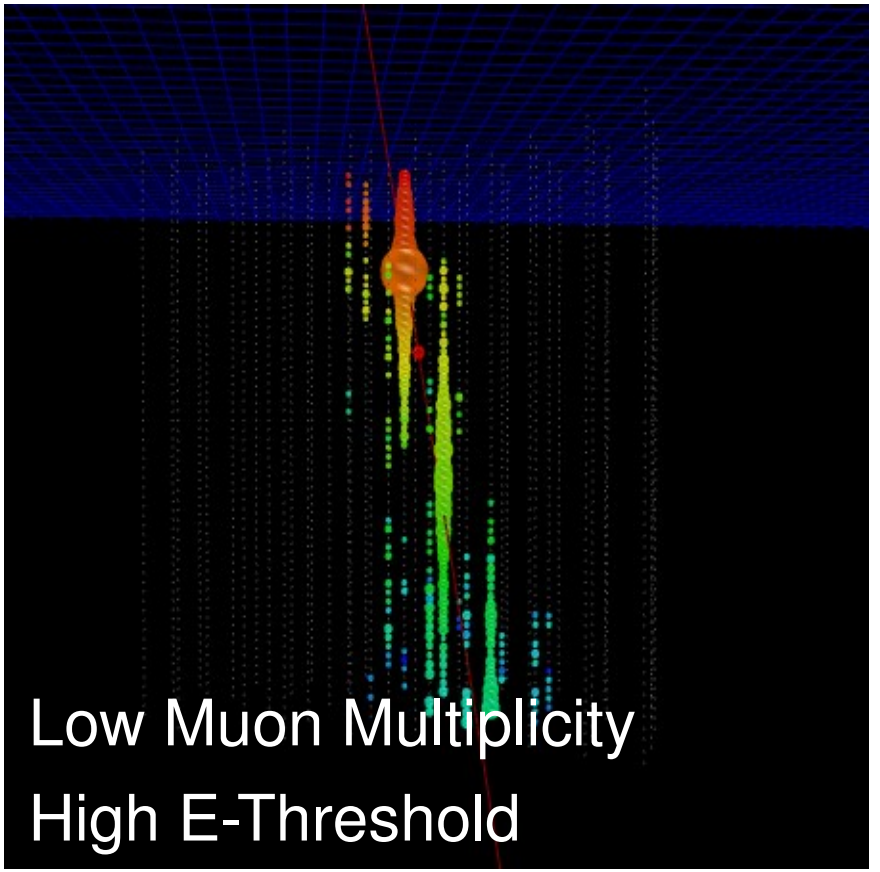
Muon Spectrum



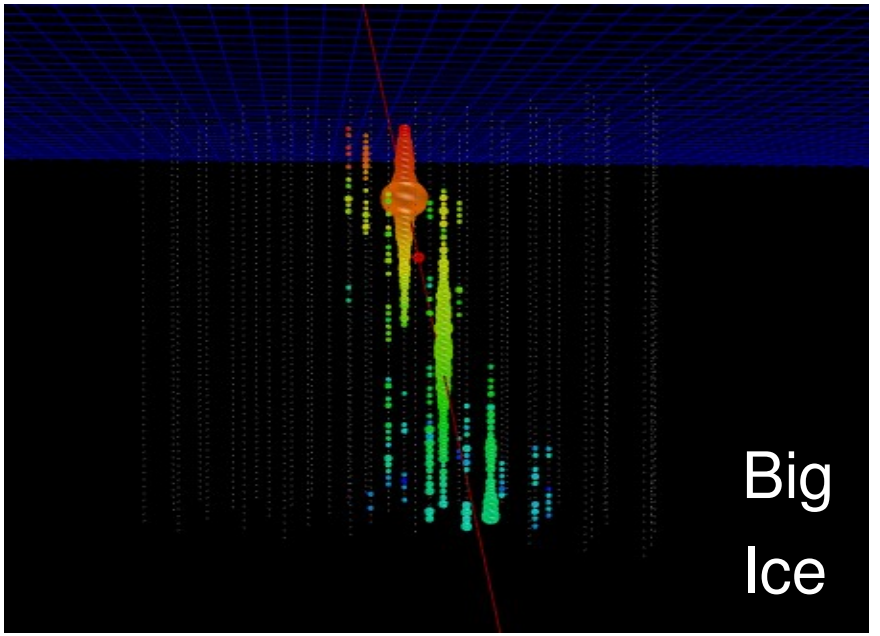
Kochanov, Sinegovsky and -aya 0803.2943

Auger vs. IceCube

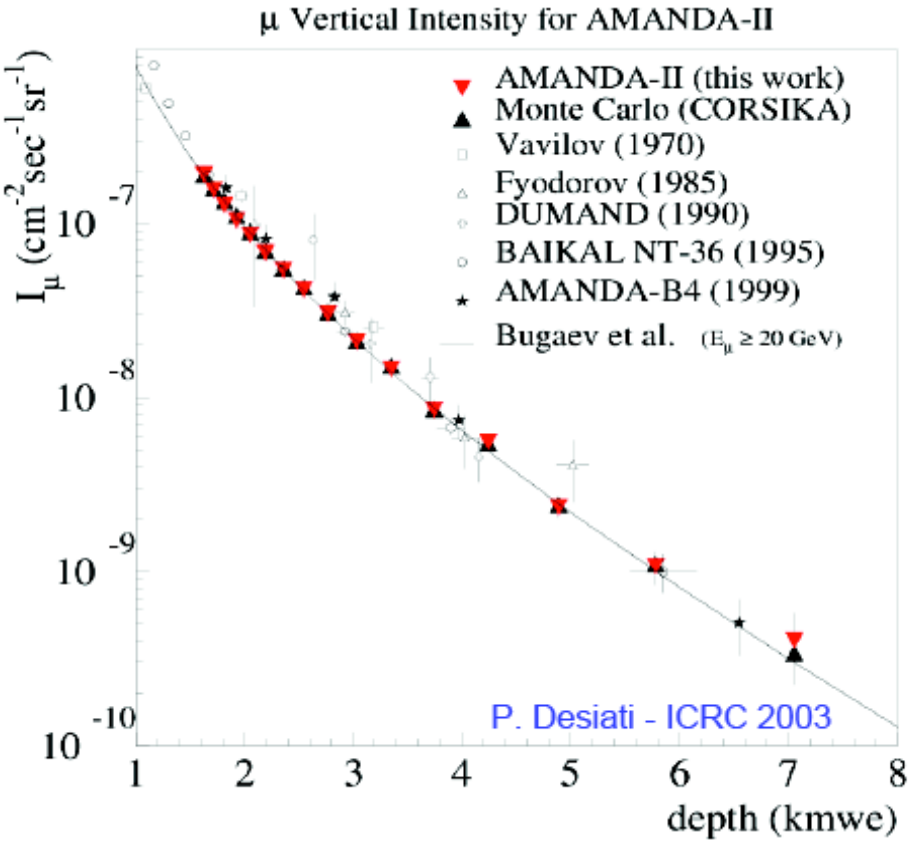




Macro vs. IceCube



AMANDA Muons



Φ_μ(depth)

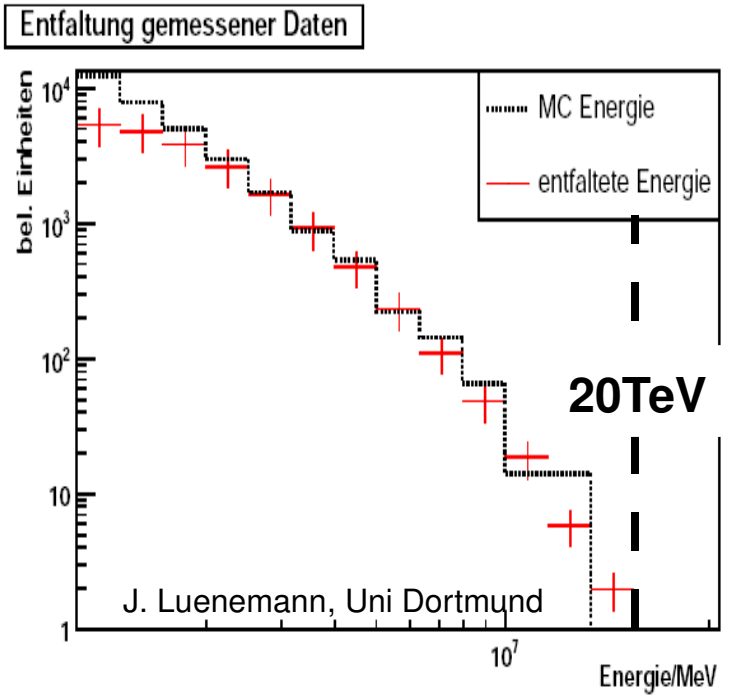
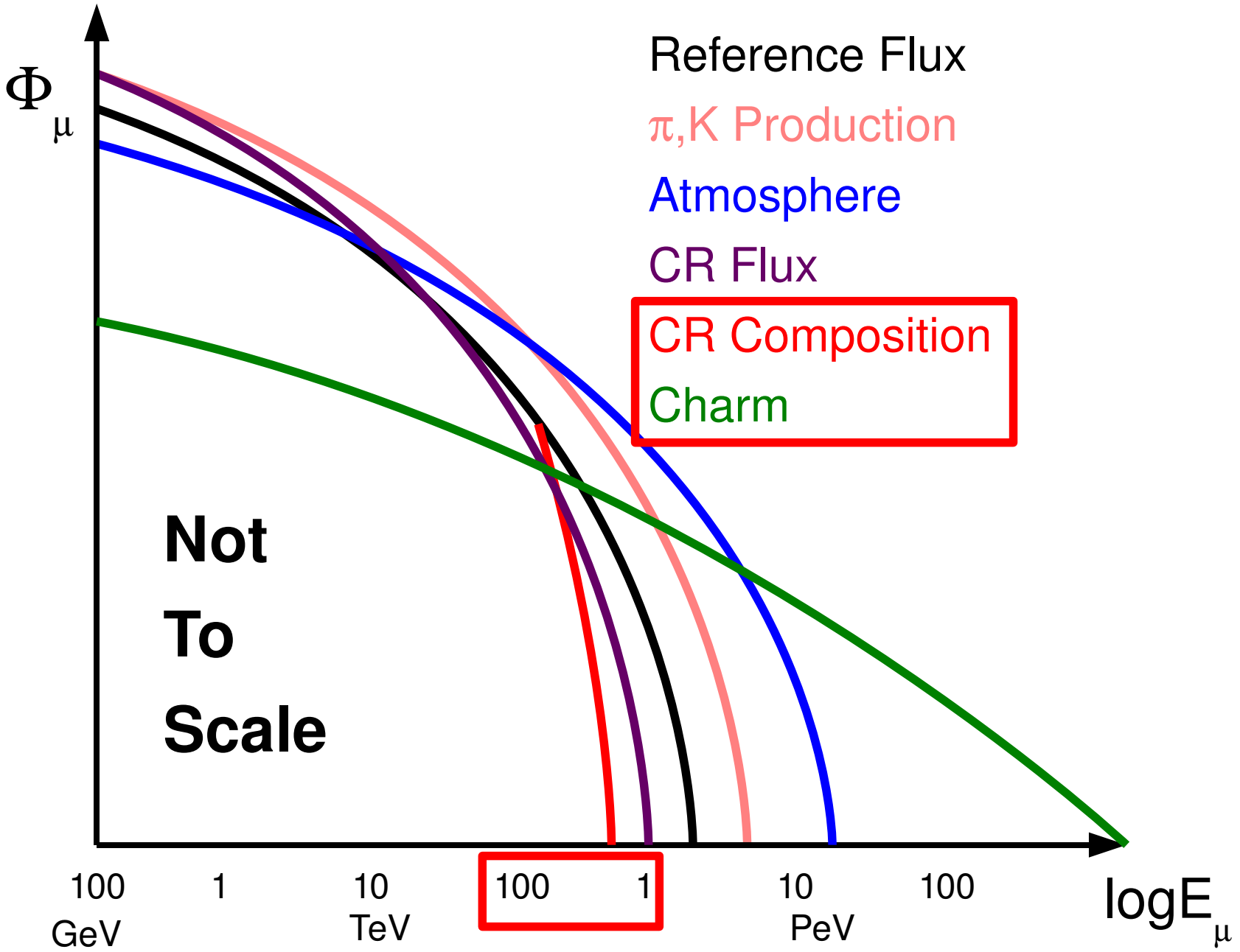


Abbildung 7.13: Entfaltung von gemessenen Daten aus dem Jahr 2000, verglichen mit simulierten Ereignissen (gestricheltes Histogramm)

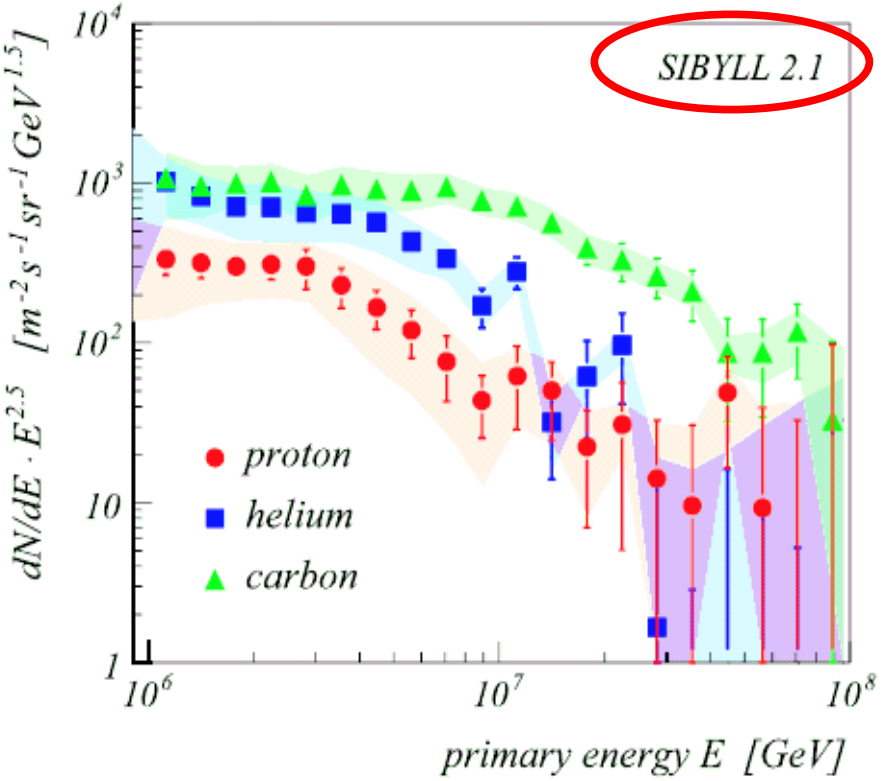
Das Energieünföldingen

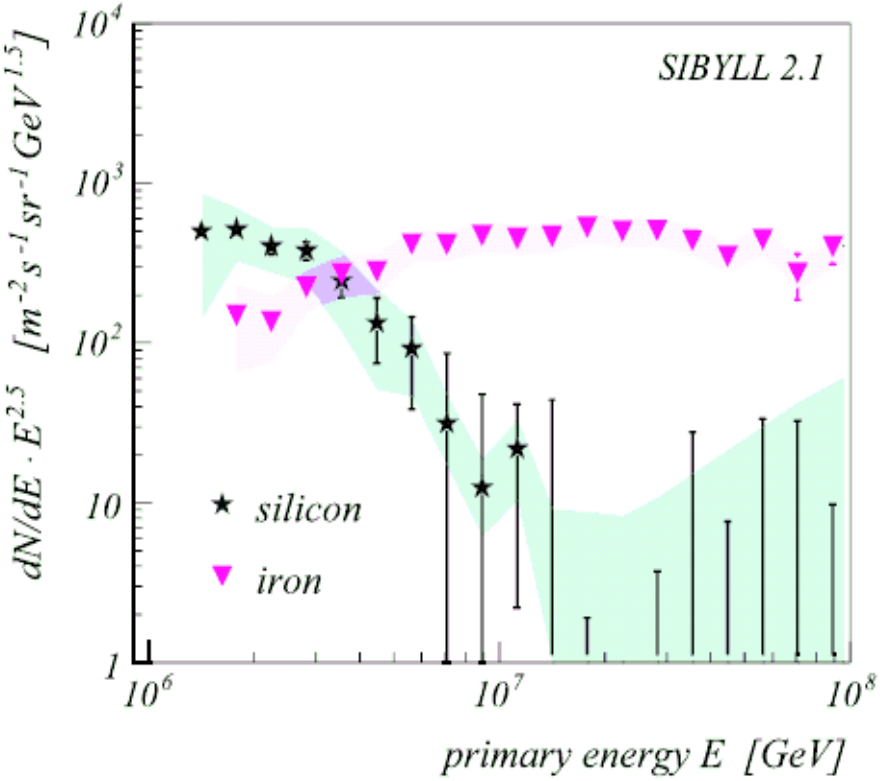
Physics with Muons


Φμ
Reference Flux
π,K Production
Atmosphere
CR Flux
CR Composition
Charm
Not
To
Scale
100
GeV
1
10
TeV
100
1
10
PeV
100
logEμ

KASCADE Composition

model-dependent

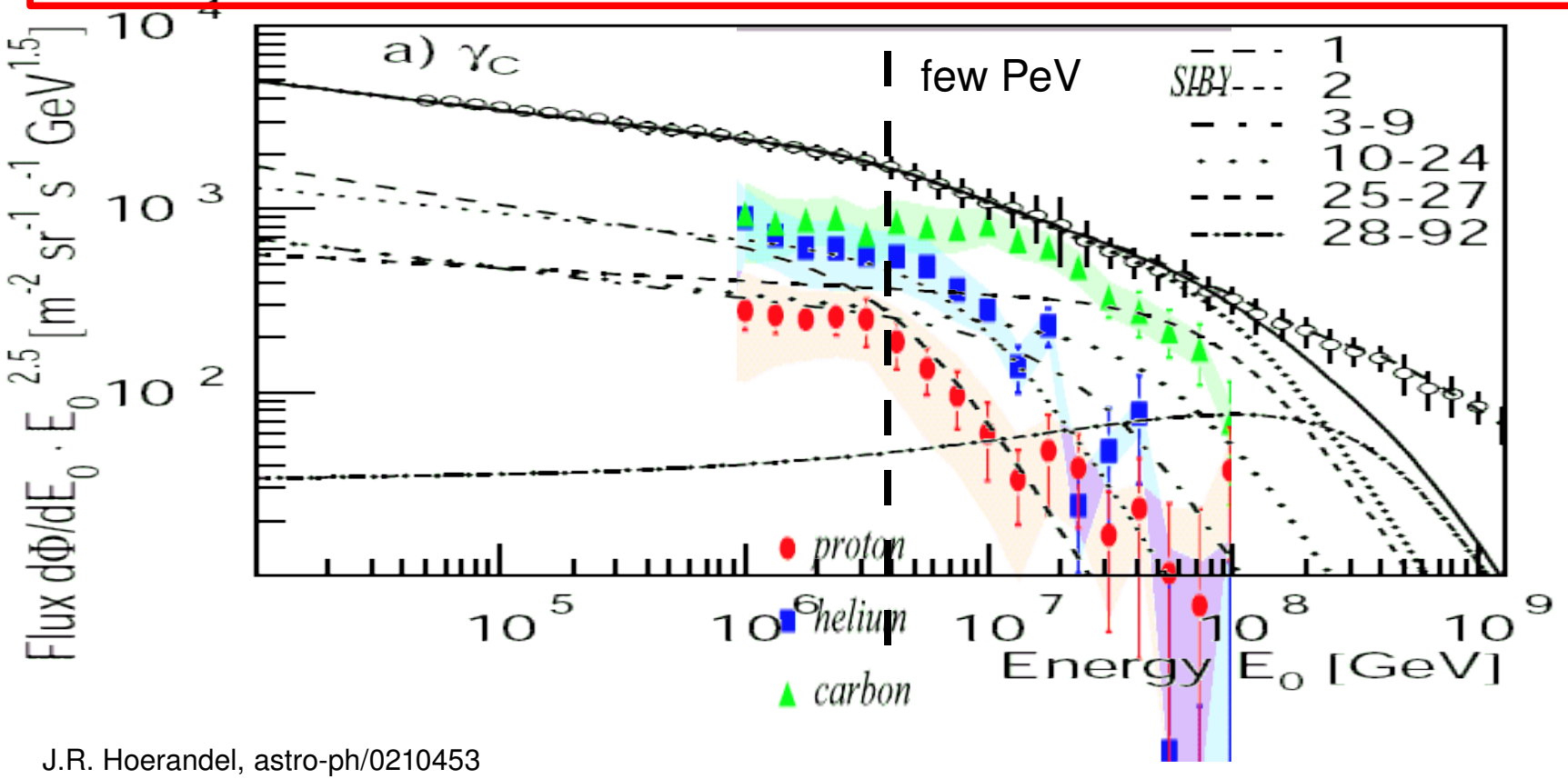




astro-ph/0505413

“Poly-Gonato” Model

Steepening of Muon/Neutrino Spectrum above 100TeV

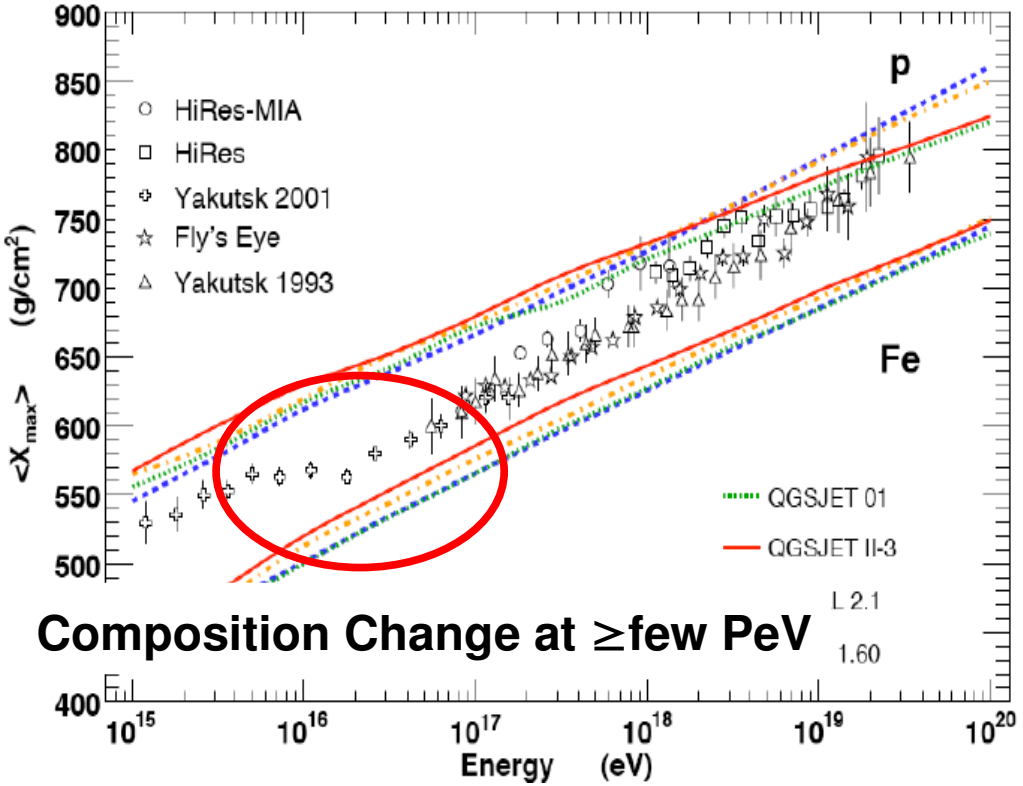


J.R. Hoerandel, astro-ph/0210453

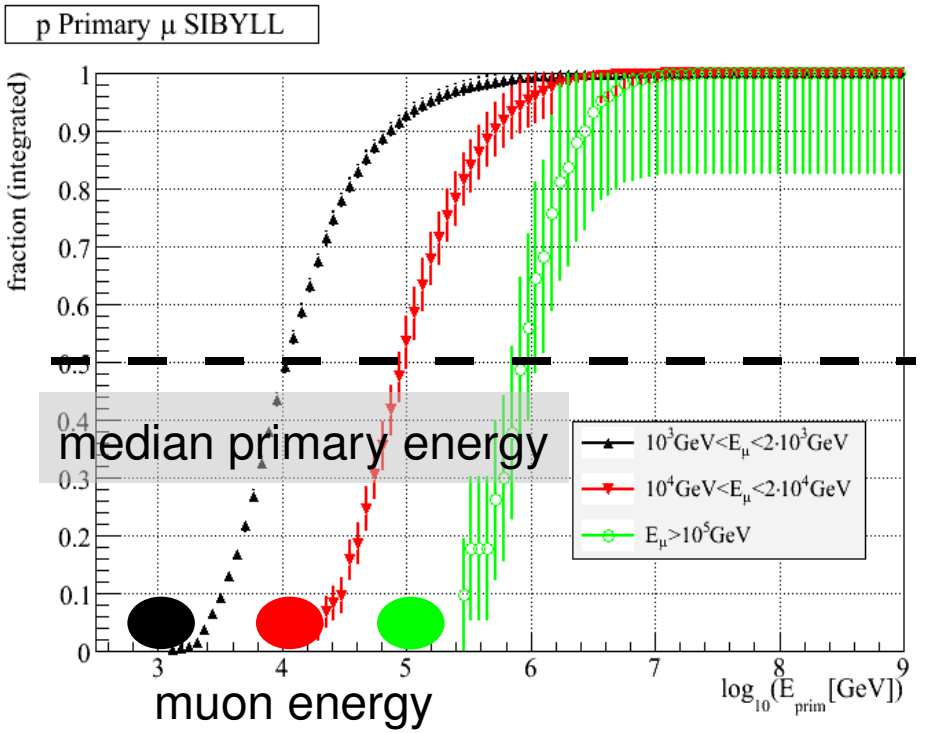
CR Composition

$\overline{E}_{prim,nucleon}$! $/E_{\mu} \leq 10$

(T.K.Gaisser, "CR&Part.Phys.")



Composition Change at ≥few PeV

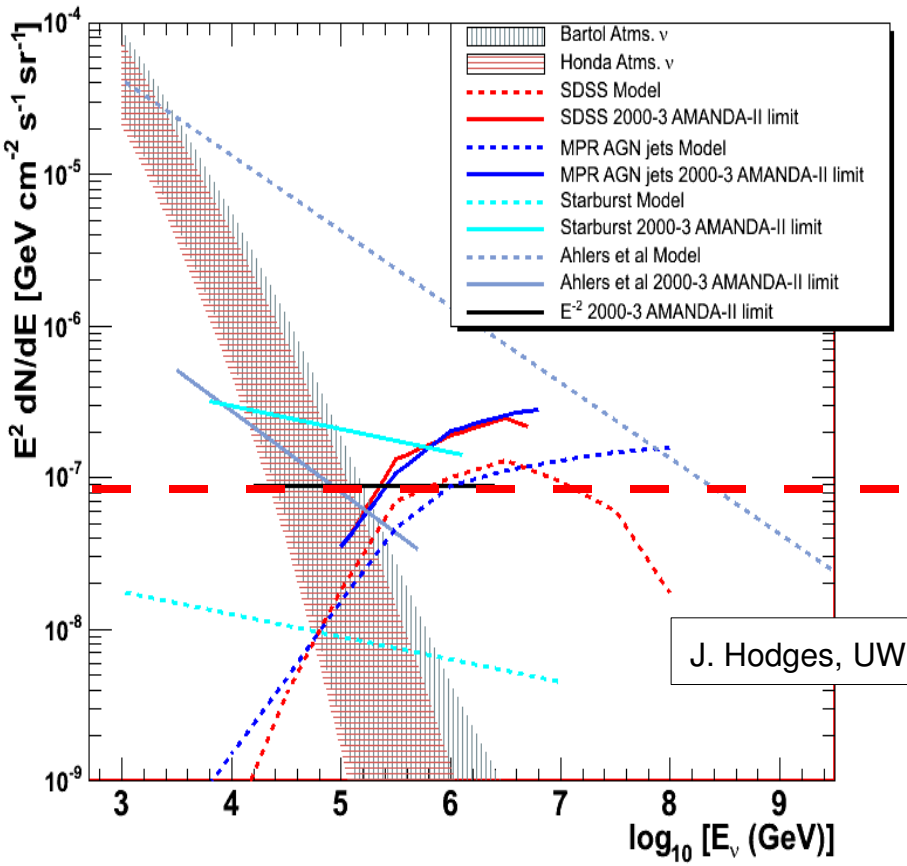


median primary energy

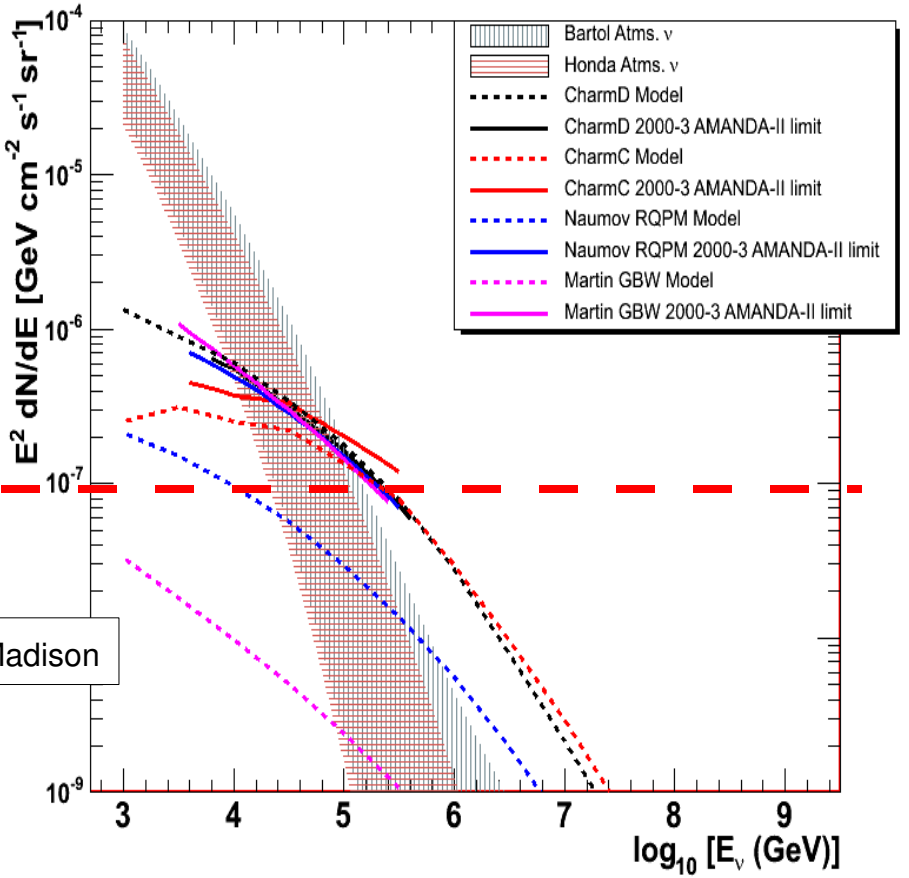
muon energy

Prompt Flux

Diffuse ν

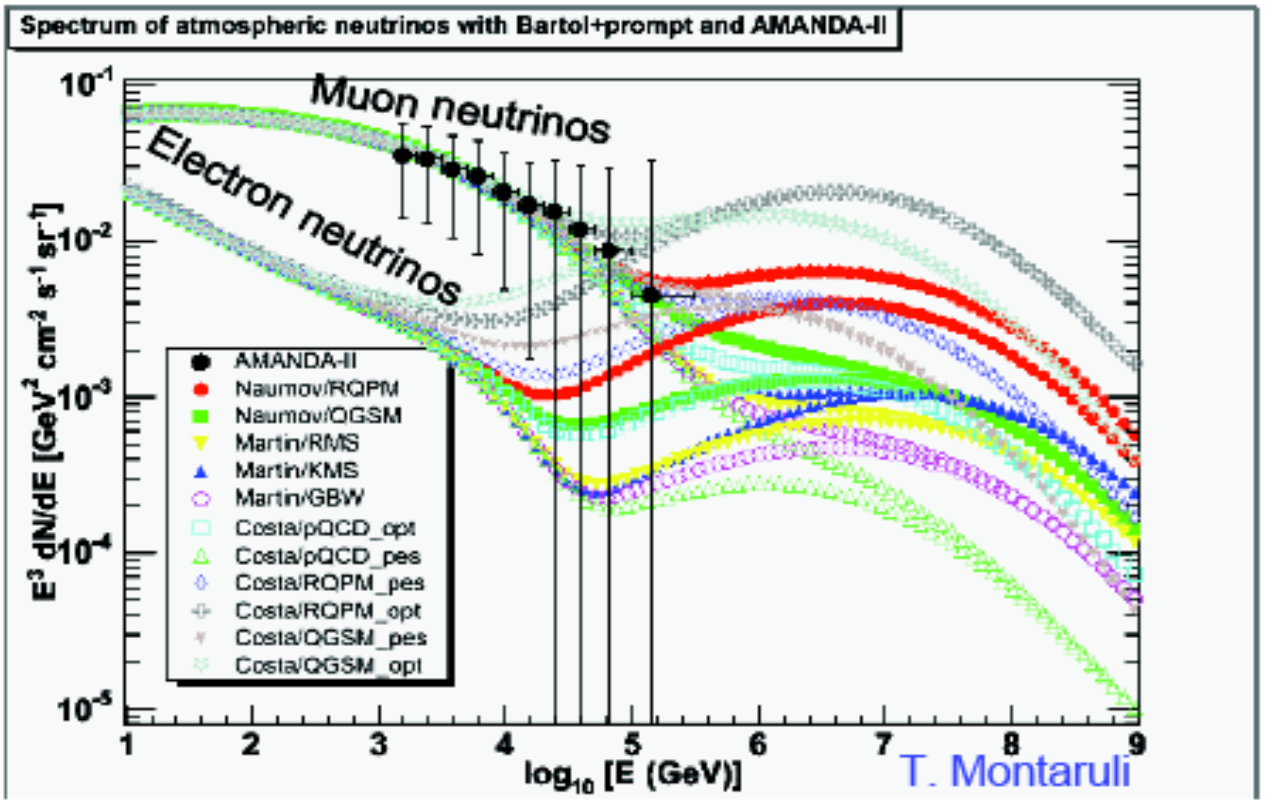


Atmospheric ν

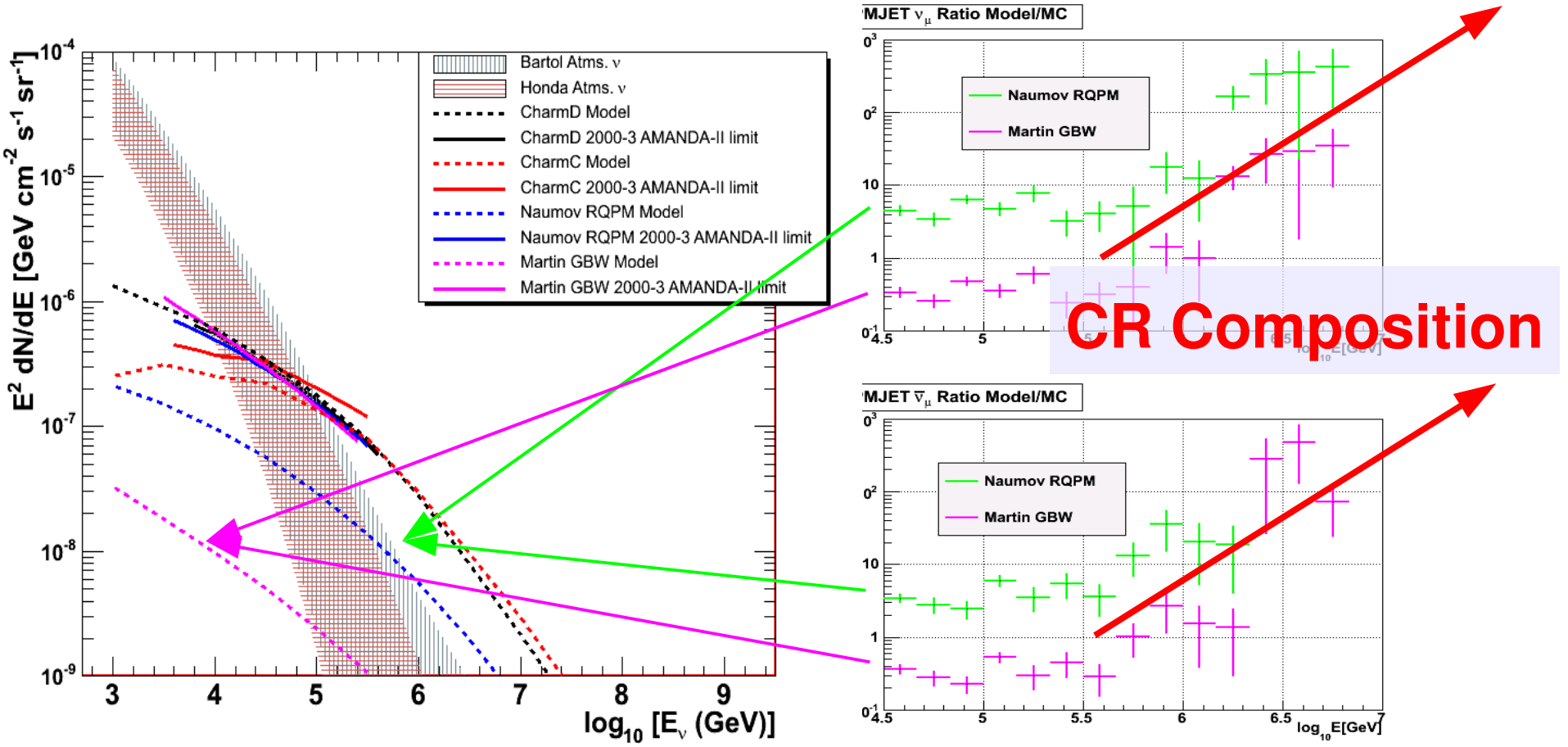


J. Hodges, UW Madison

Prompt Neutrino Models

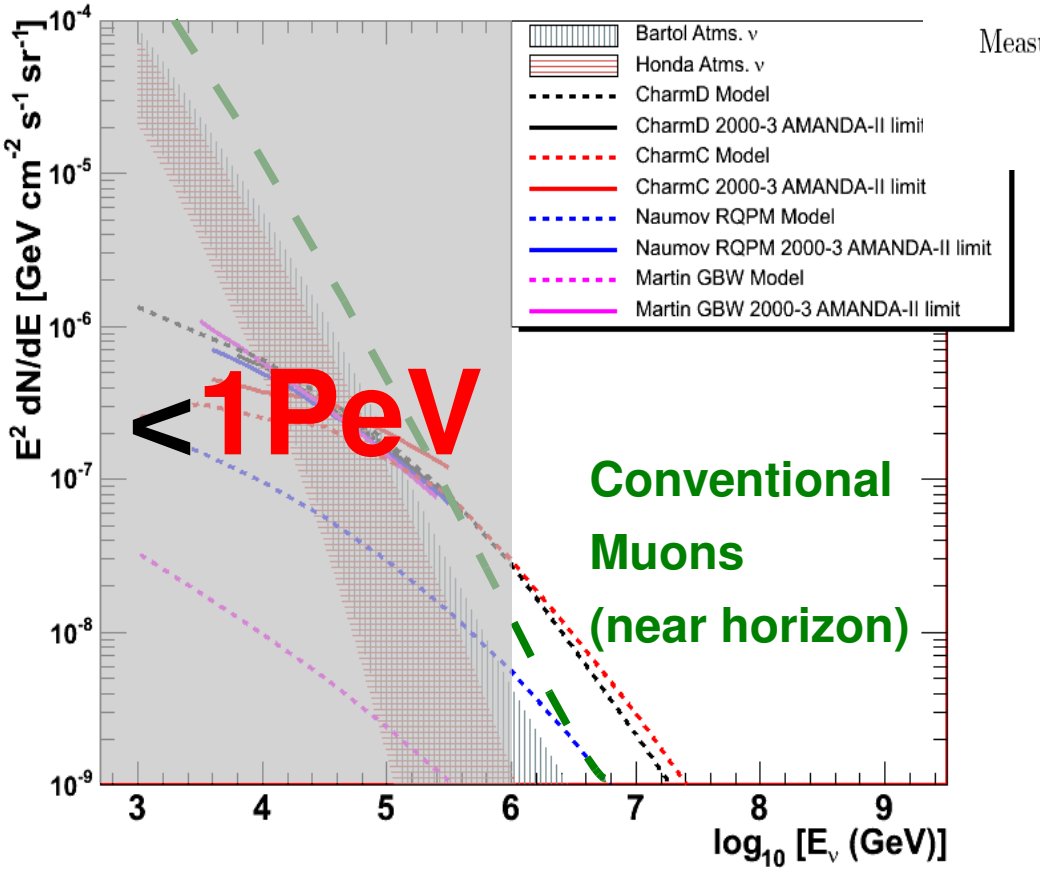


Prompt Neutrinos



CR Composition

Prompt Muons



UCLA/02/TEP/23, CWRU-P13-02, NSF-ITP-02-97

Measuring the prompt atmospheric neutrino flux with down-going muons in neutrino telescopes

Graciela Gelmini[1], Paolo Gondolo[2], and Gabriele Varieschi[3]

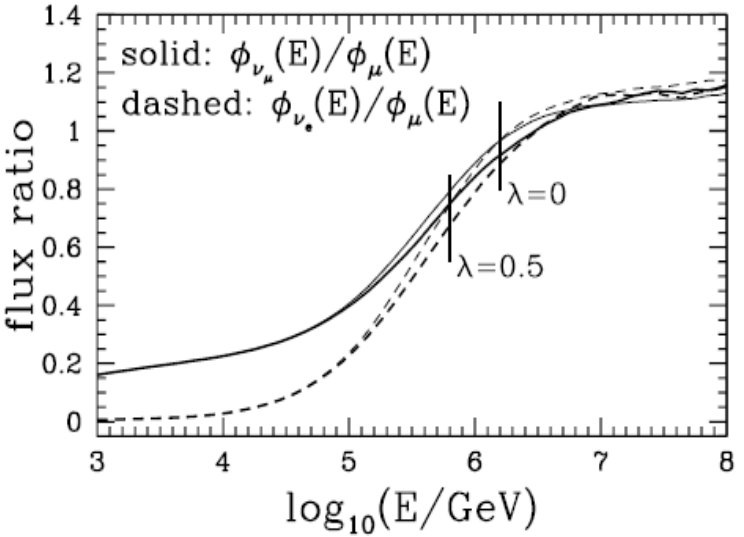


FIG. 4. Total neutrino-over-muon ratio as a function of lepton energy. Vertical marks denote the crossing energy from conventional to prompt muons.

High-Energy Light Mesons

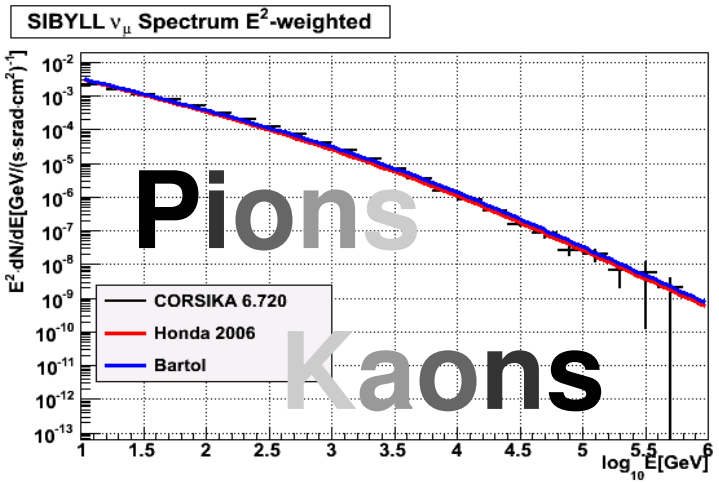
SIBYLL

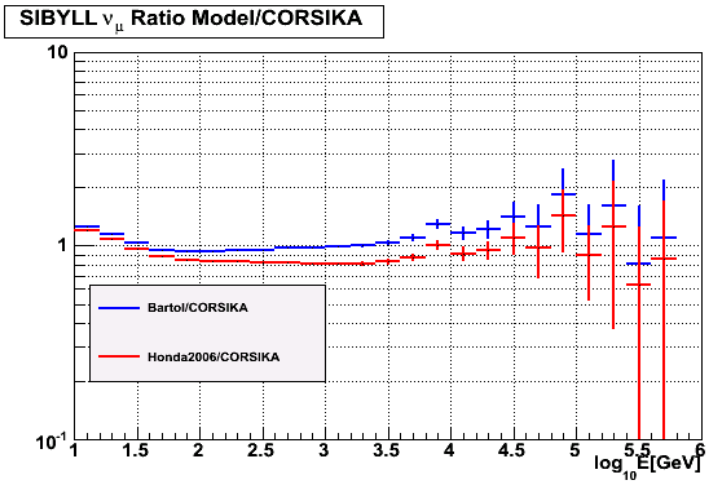
≈

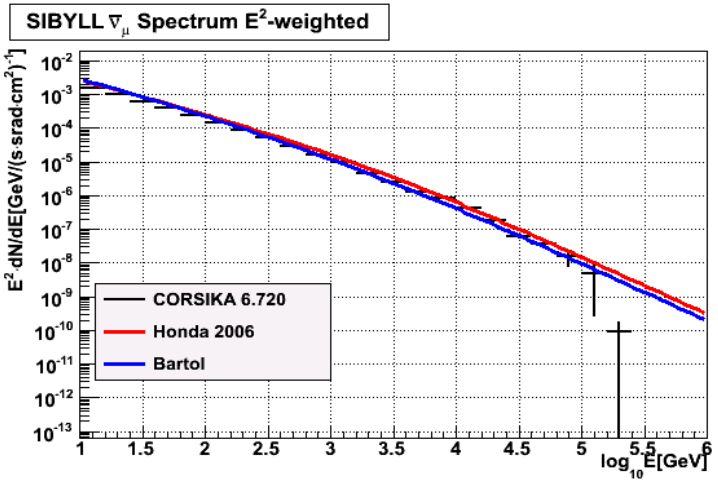
Bartol

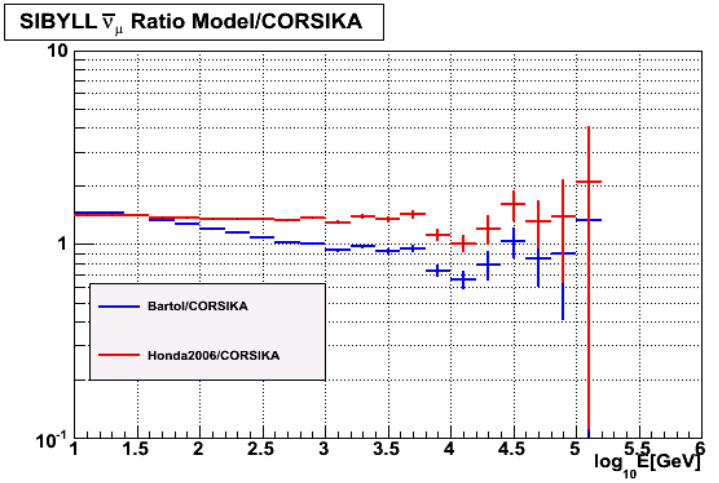
≈

Honda '06





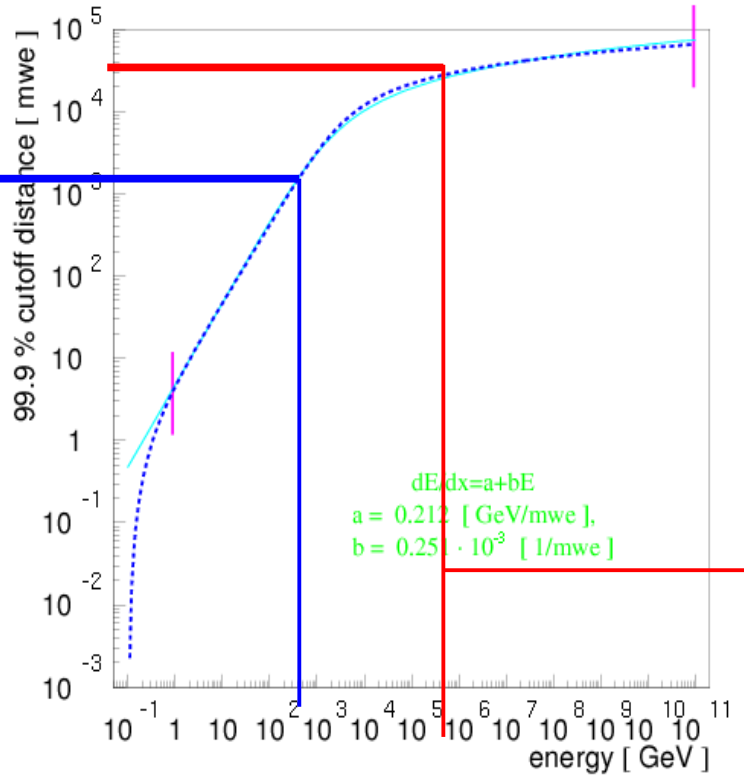




Threshold Energy

Vertical

≃400GeV



Bottom (85°)

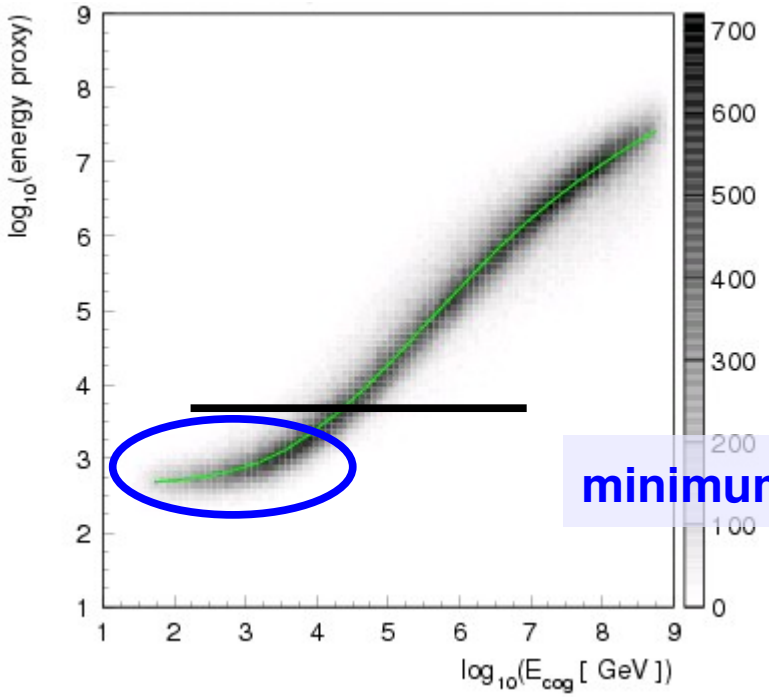
≃1PeV

D. Chirkin, W. Rhode
hep-ph/0407075

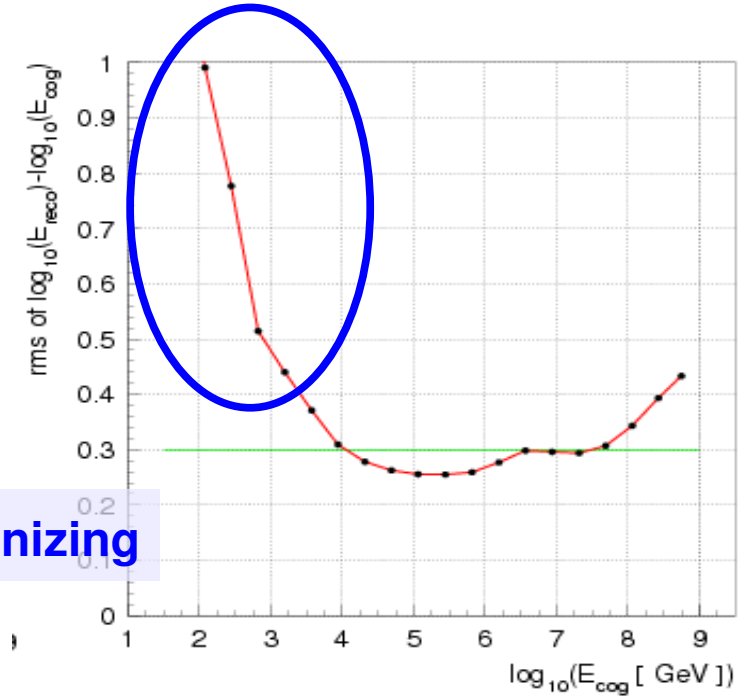
Fig. 29. Fit to the $E_{cut}(x)$

Energy Resolution

μ tracks, IC22



minimum ionizing



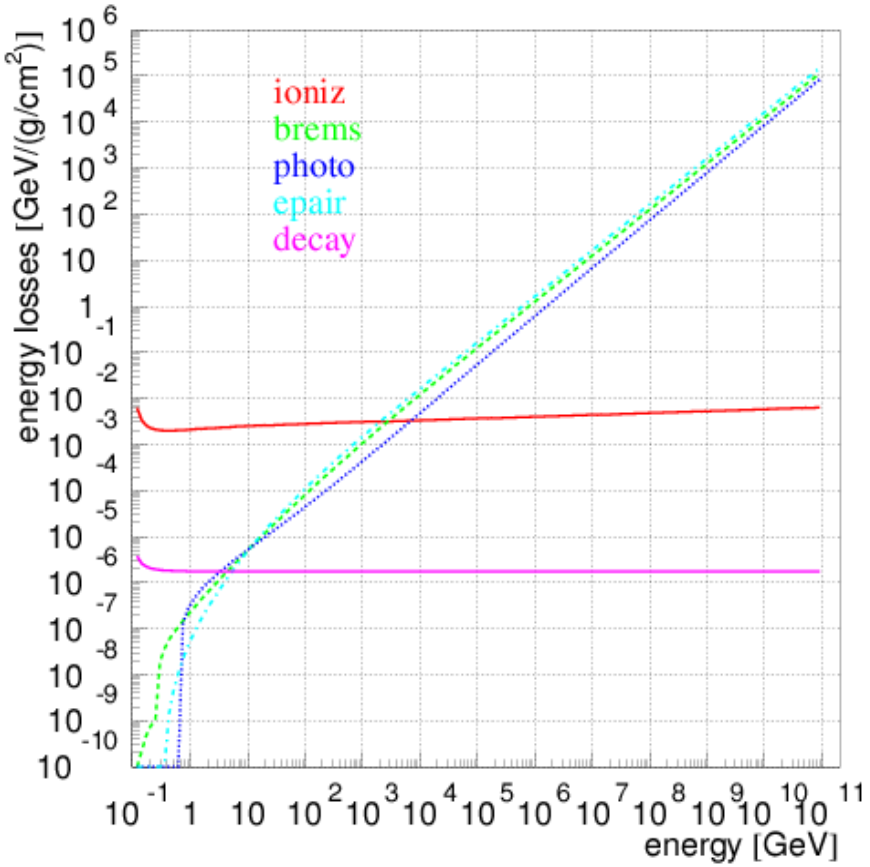
Energy Resolution
$\sigma(\log_{10}E) \sim 0.3$

Source: D. Chirkin, UW

Muon Monte Carlo: a high-precision tool for muon propagation through matter

hep-ph/0407075

Dmitry Chirkin[1], **Wolfgang Rhode**[2]
chirkin@physics.berkeley.edu
rhode@uni-wuppertal.de



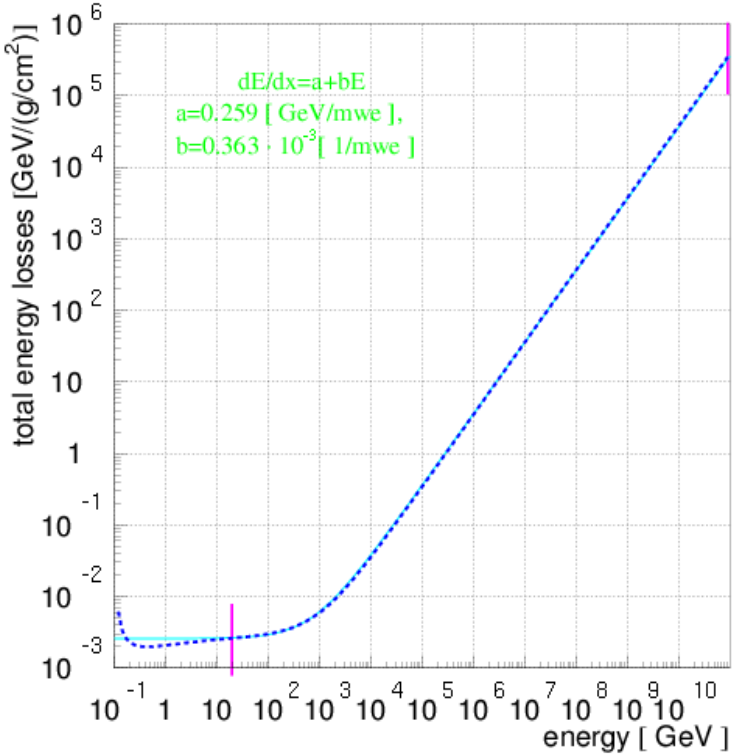
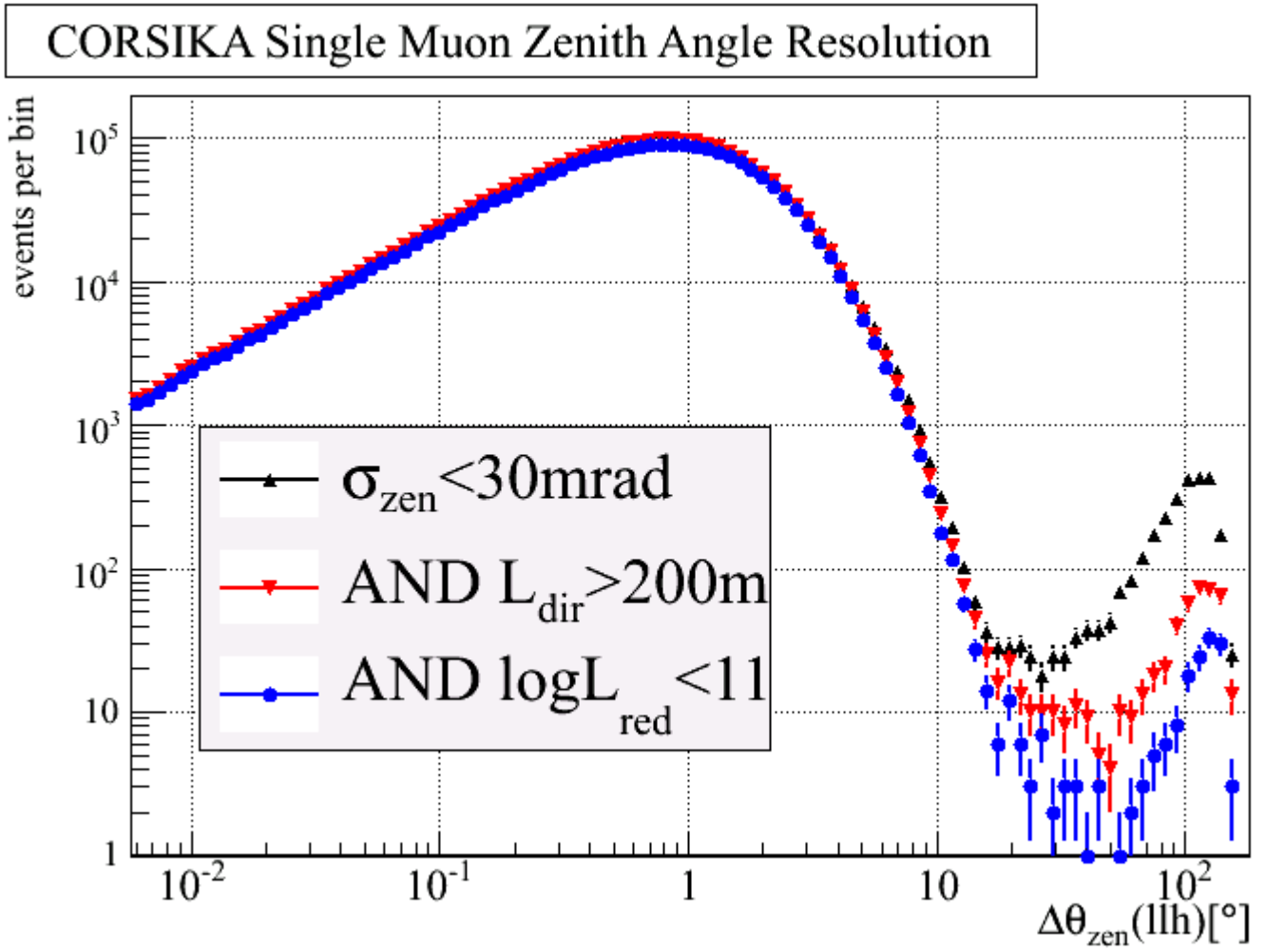


Fig. 21. Fit to the energy losses in ice

Stochasticity

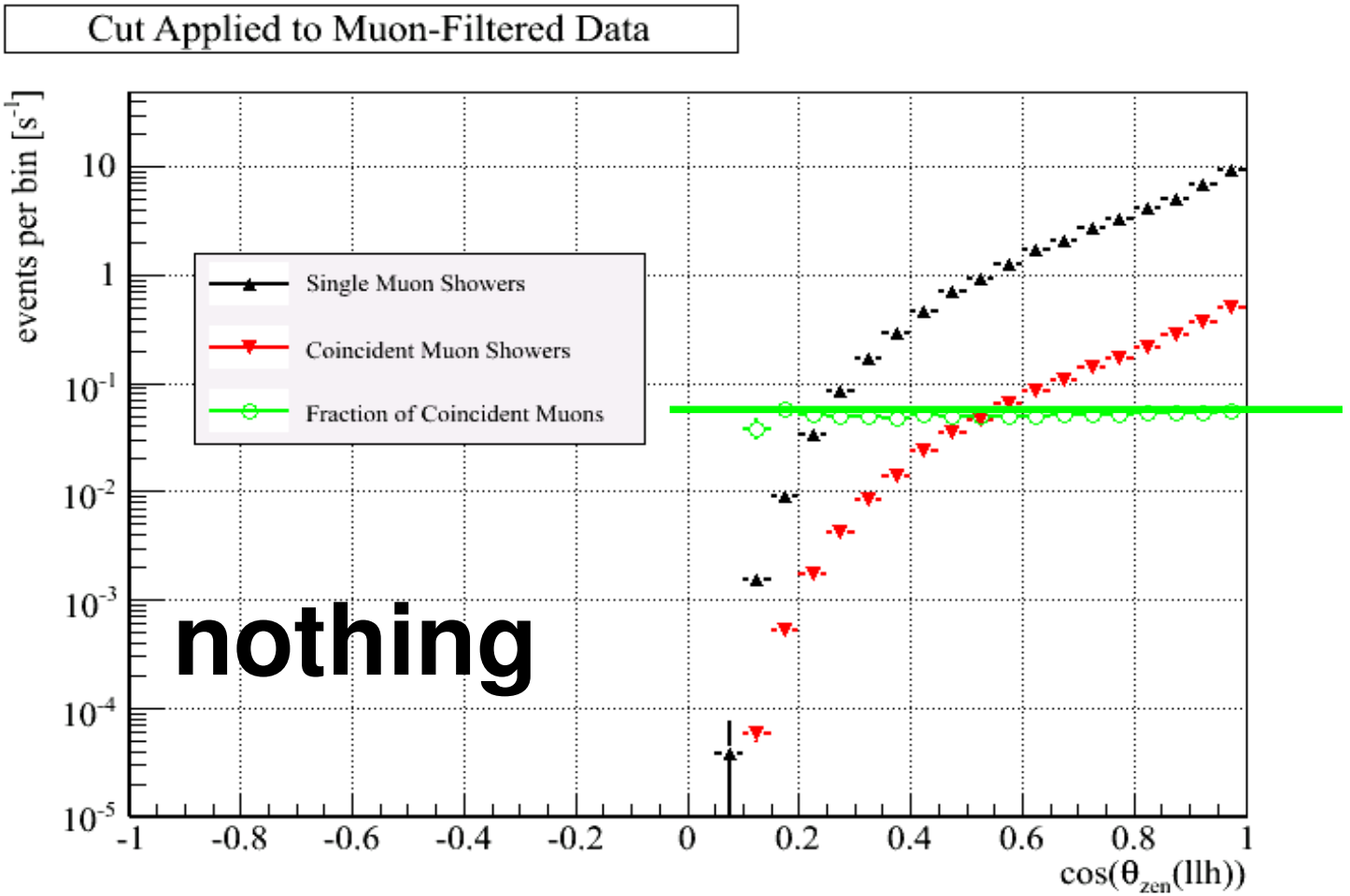
IceCube Muons

Misreconstructed Tracks/“Soft Cut”



Reduction

Final Cut Level/“Hard Cut”

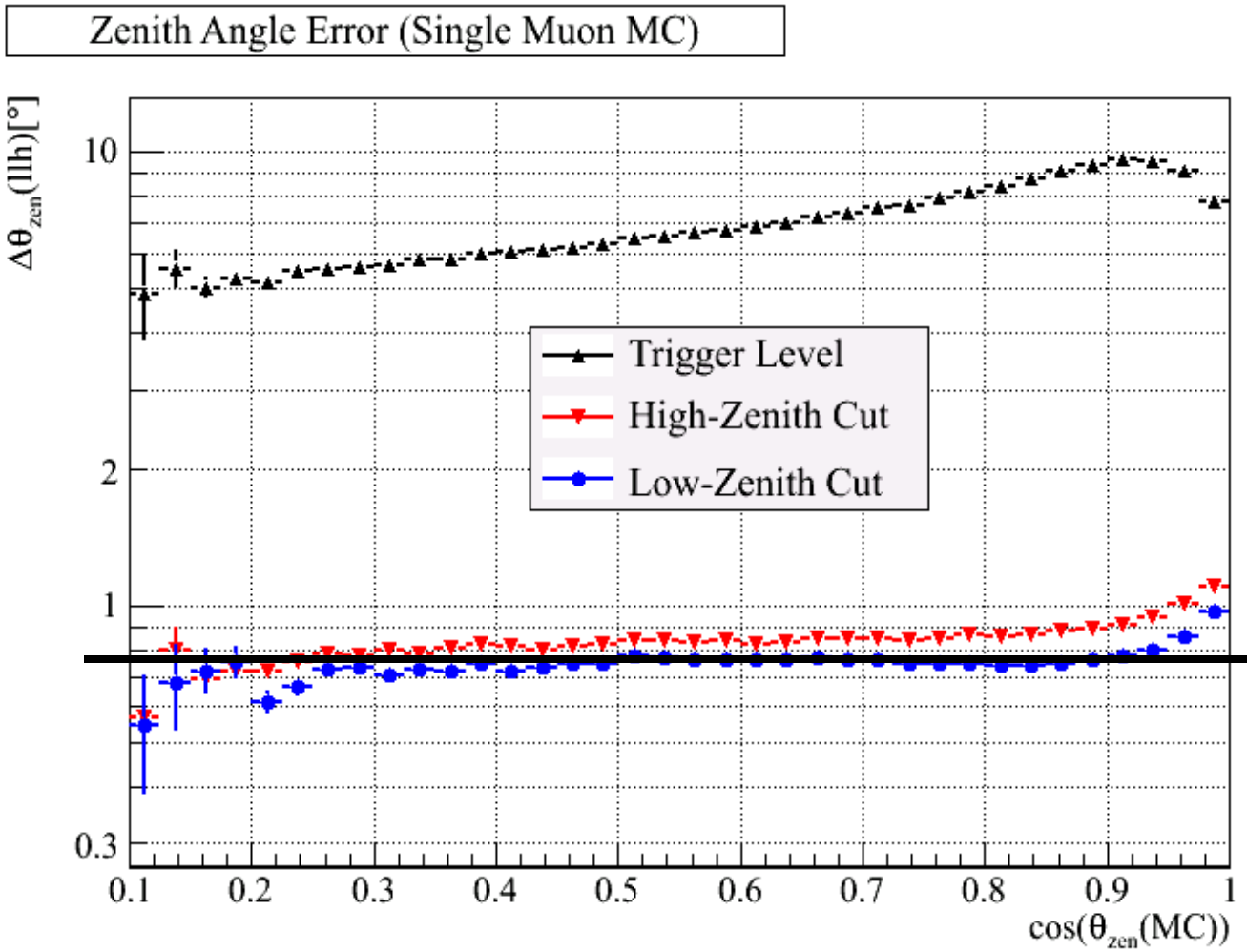


Coincident

=

Single

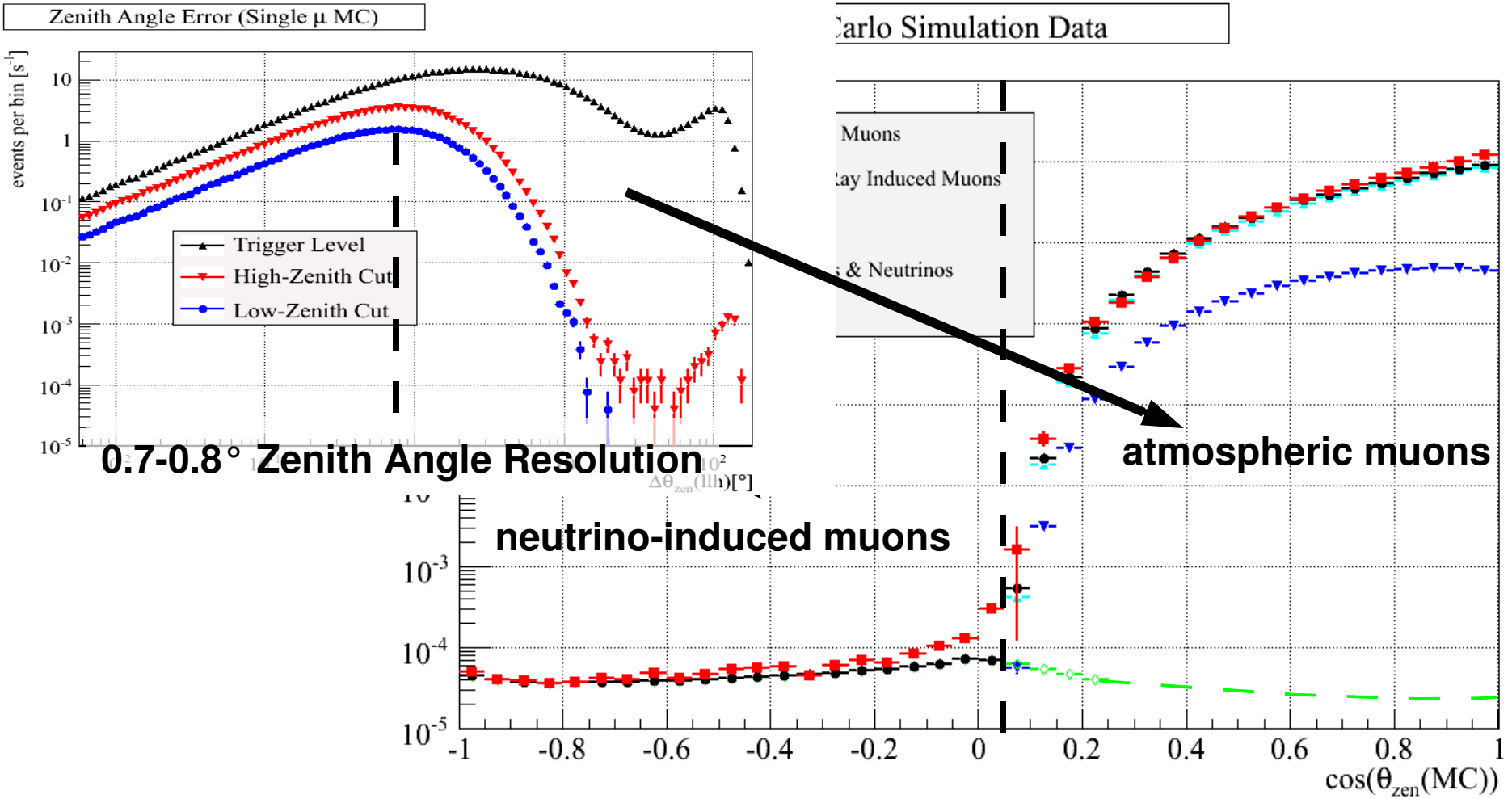
Zenith Angle Resolution



0.7-0.8°

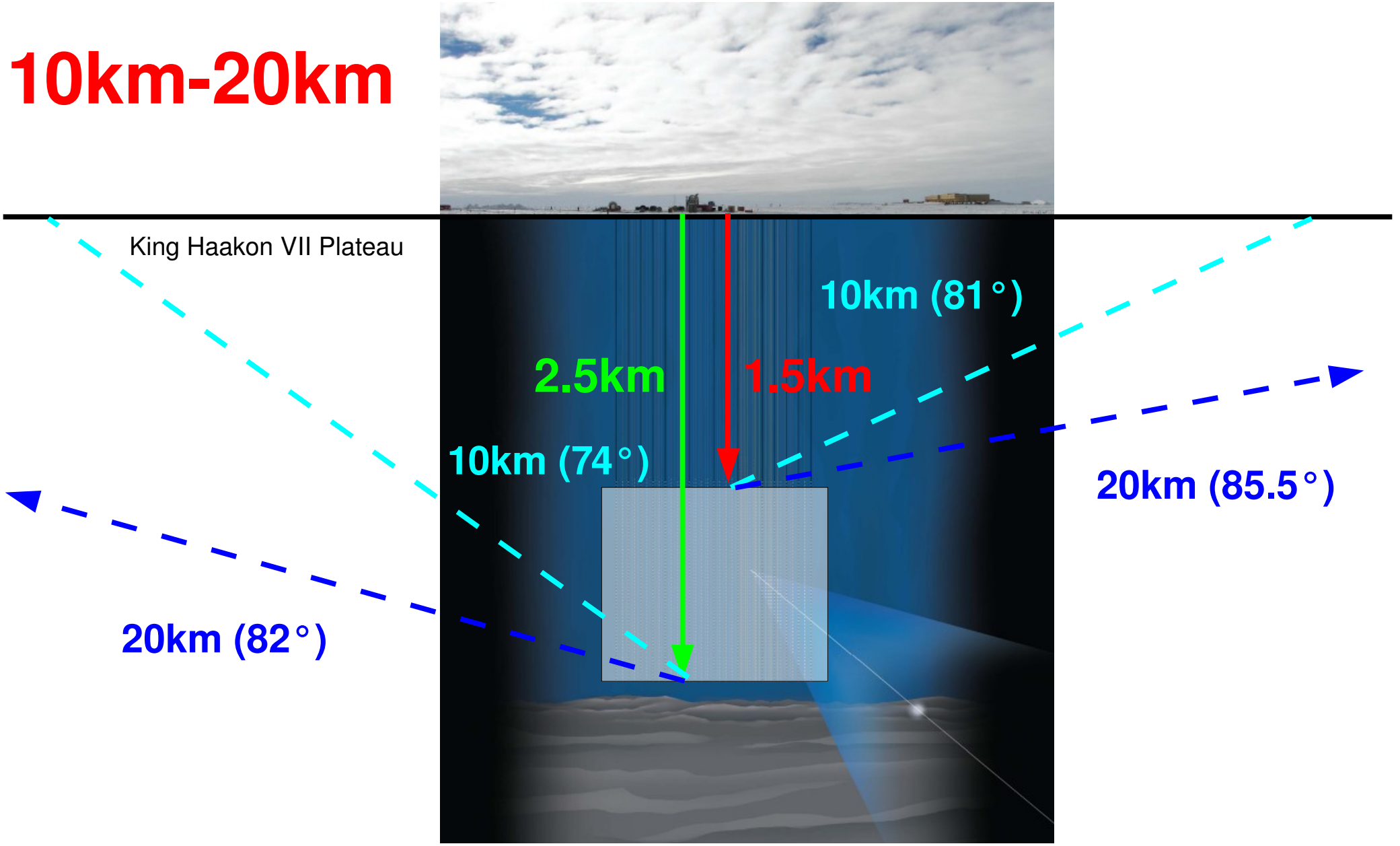
IceCube Muons

≃300 days IC22

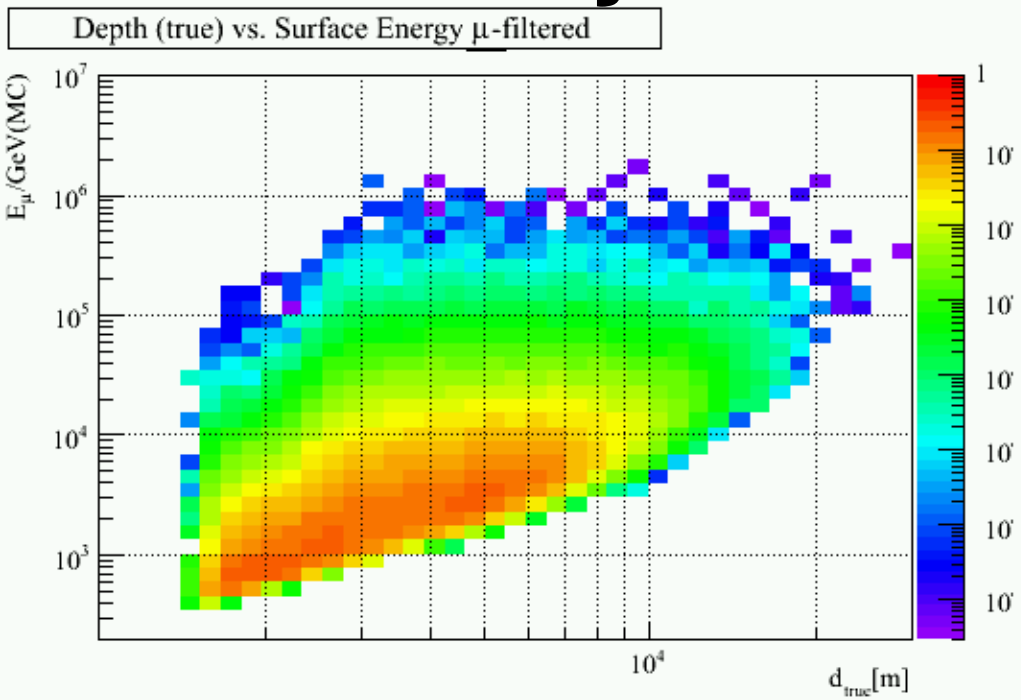


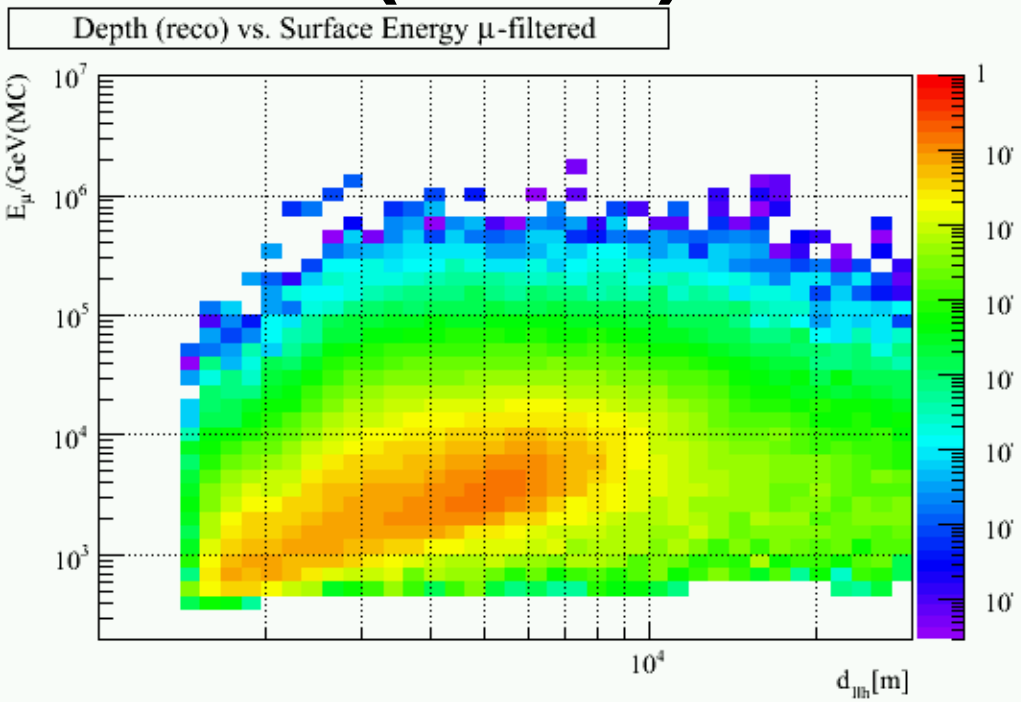
New Information

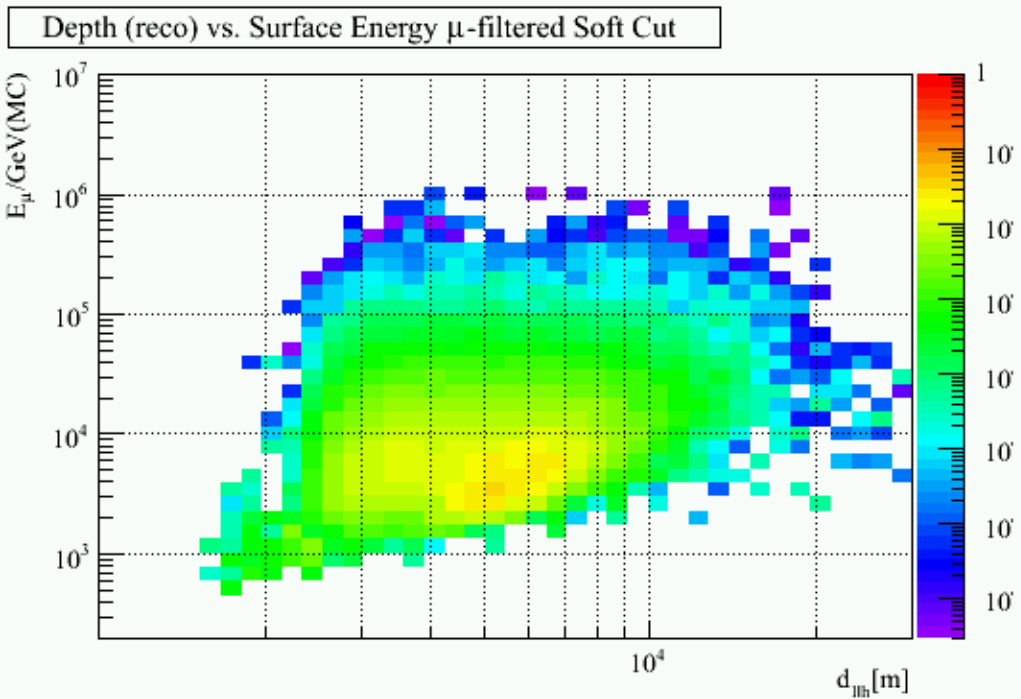
10km-20km

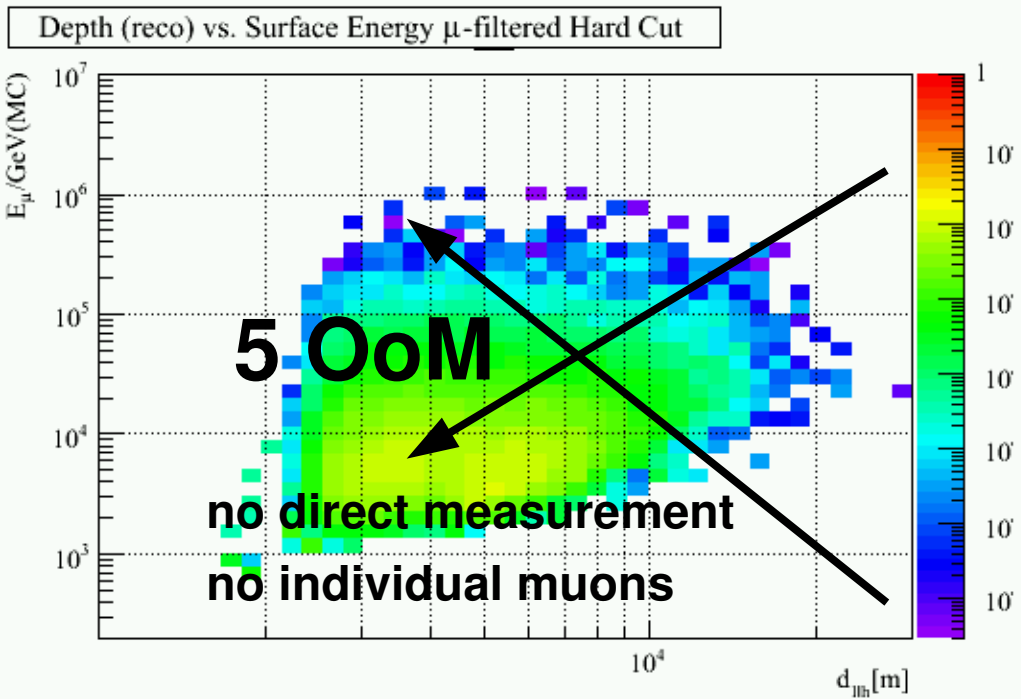

King Haakon VII Plateau
10km (81°)
2.5km
1.5km
10km (74°)
20km (85.5°)
20km (82°)

Why Not All Muons (Newt)?

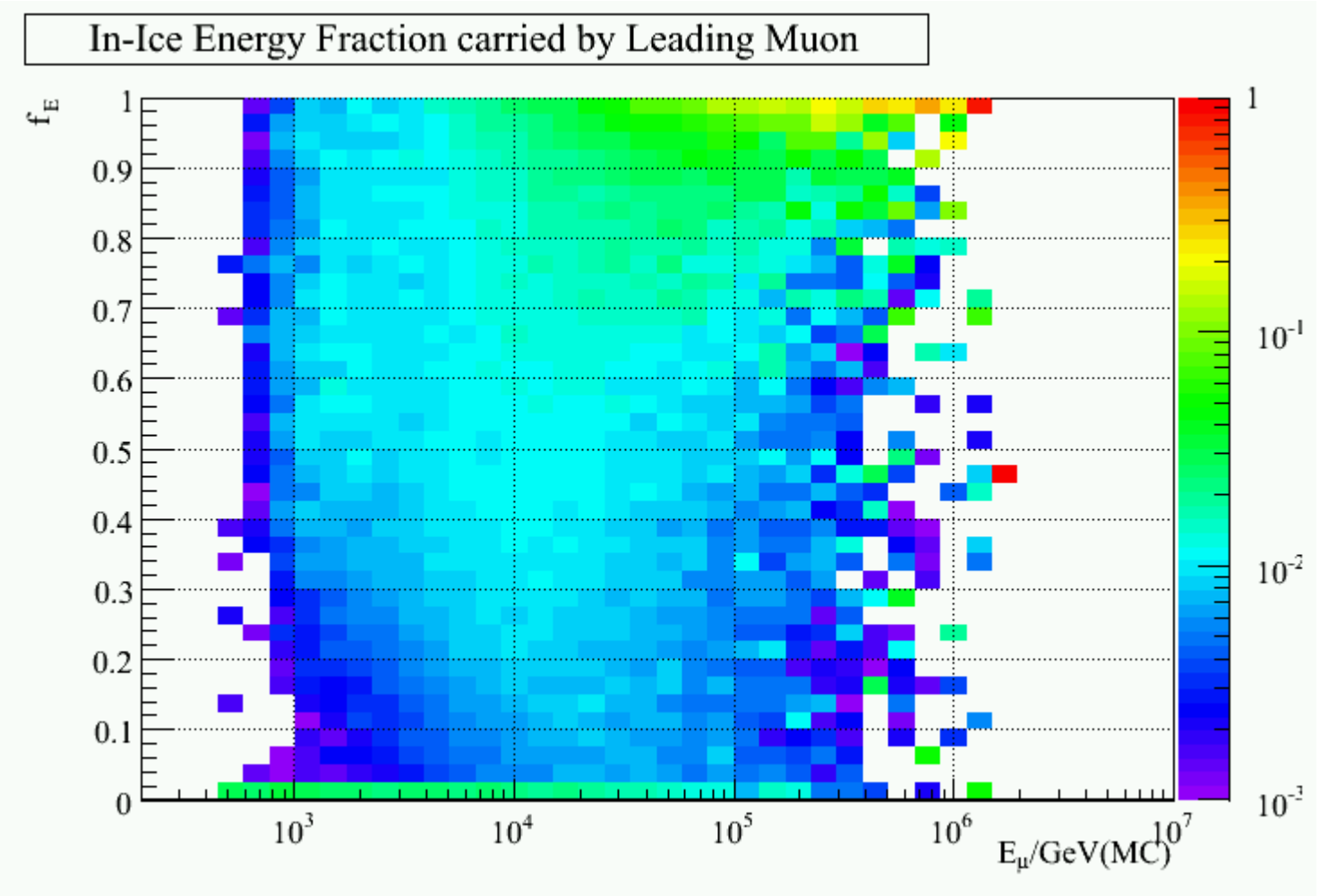




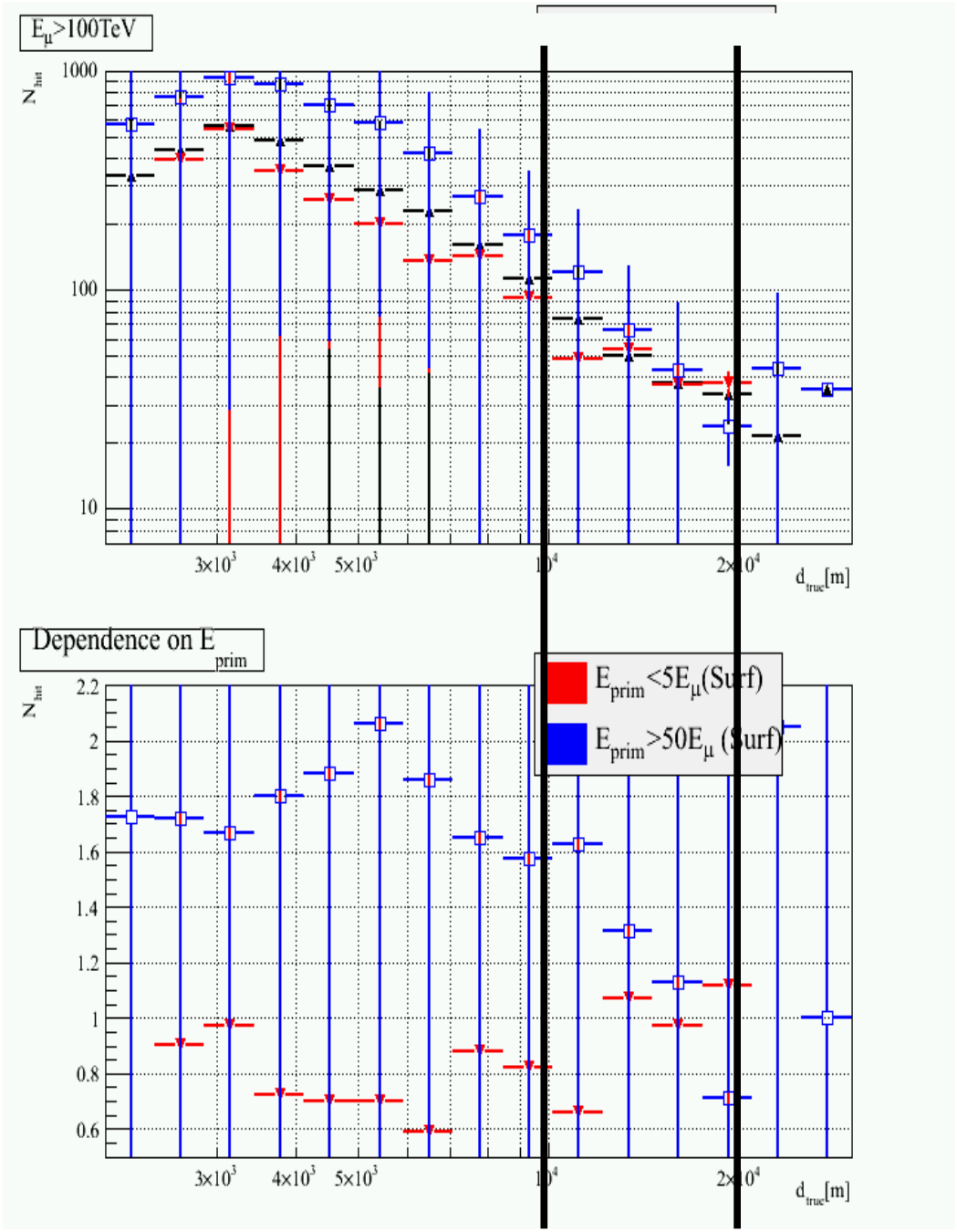




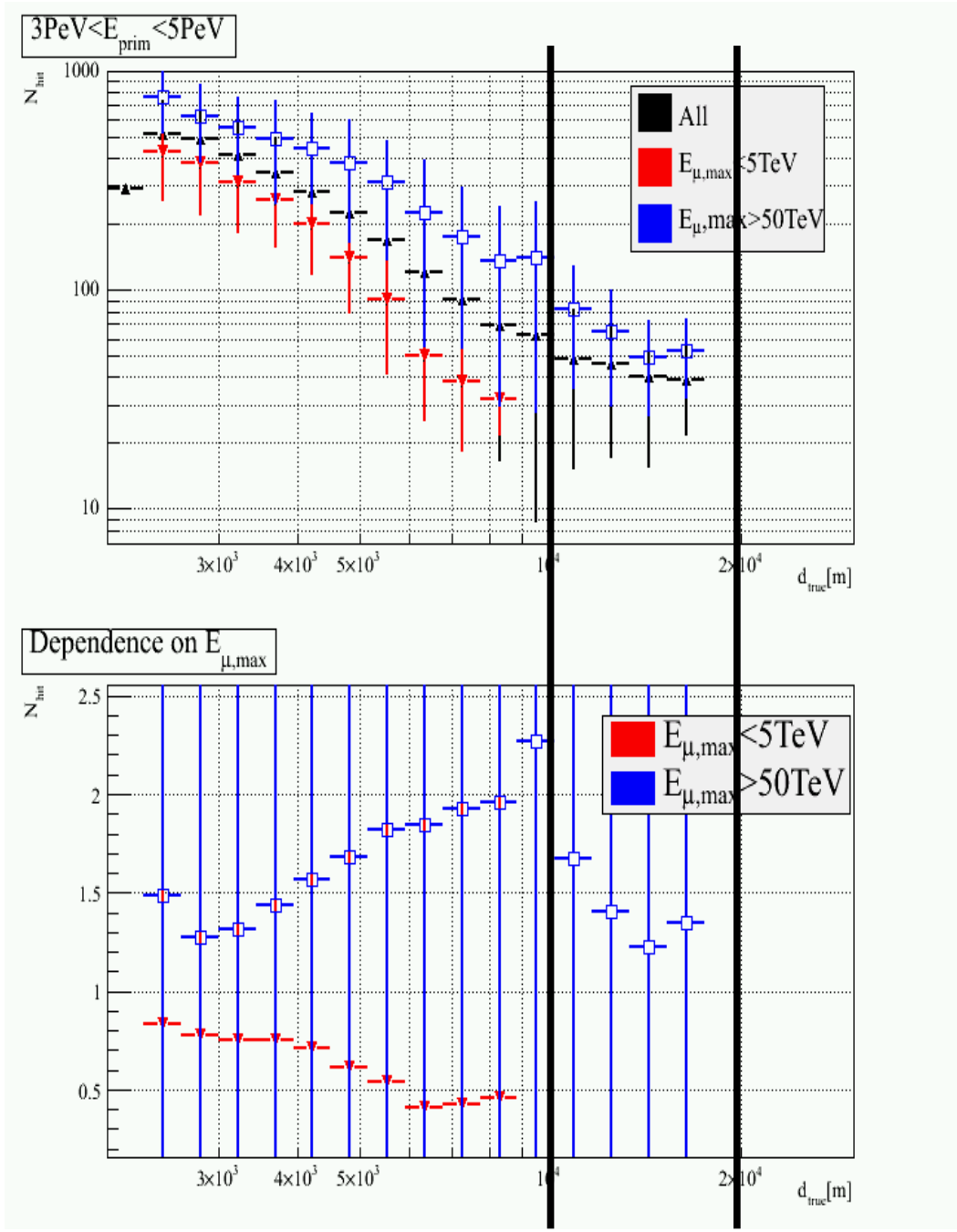
Direct Measurement!



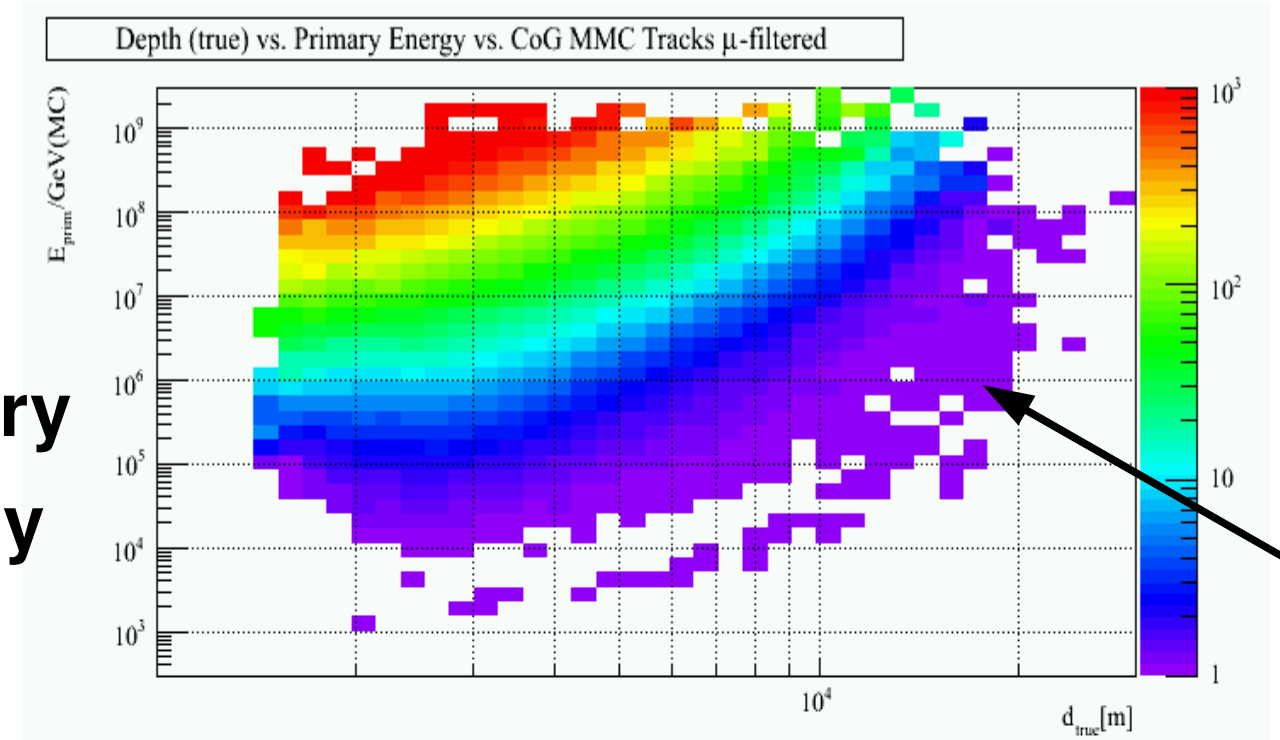
Same Muon Energy



Same Primary Energy

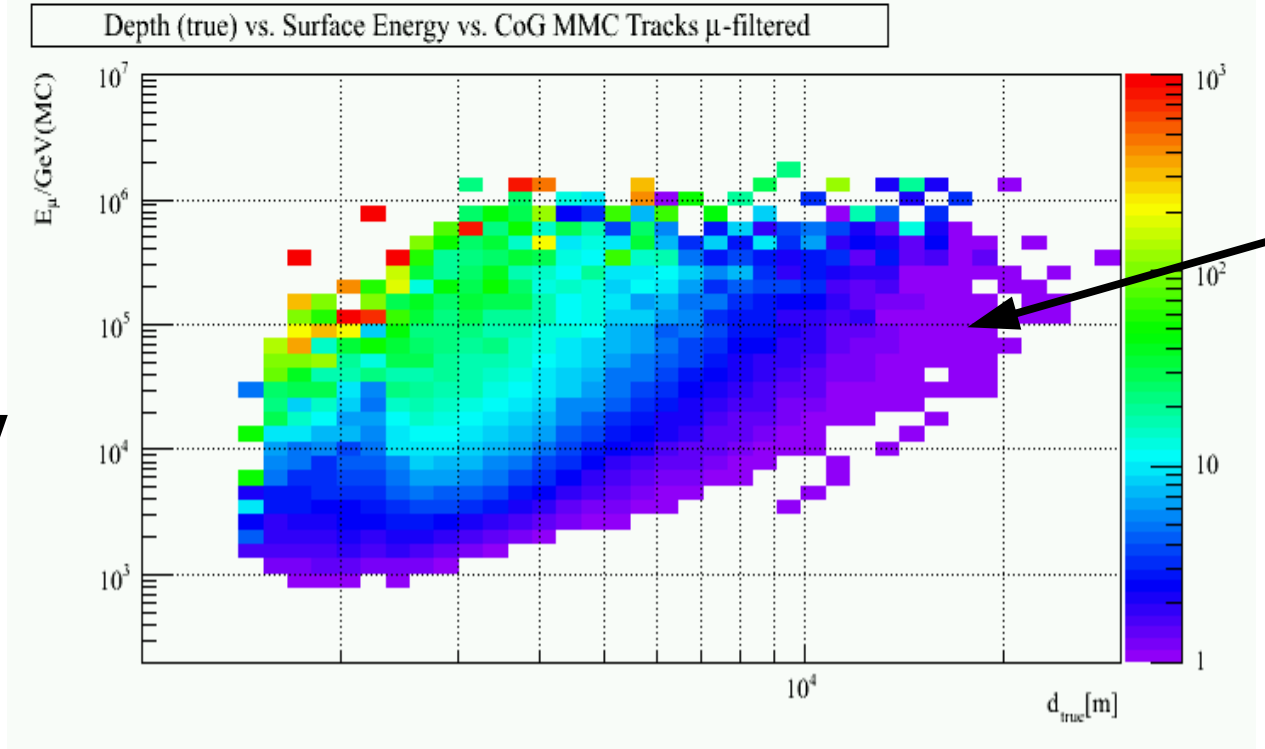


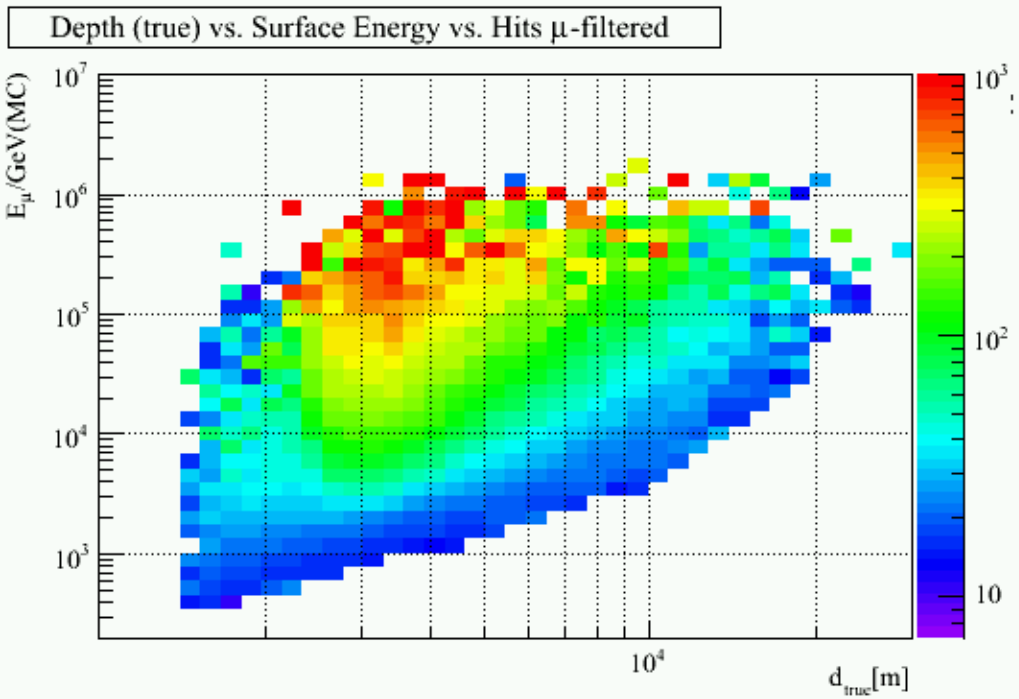
Primary Energy

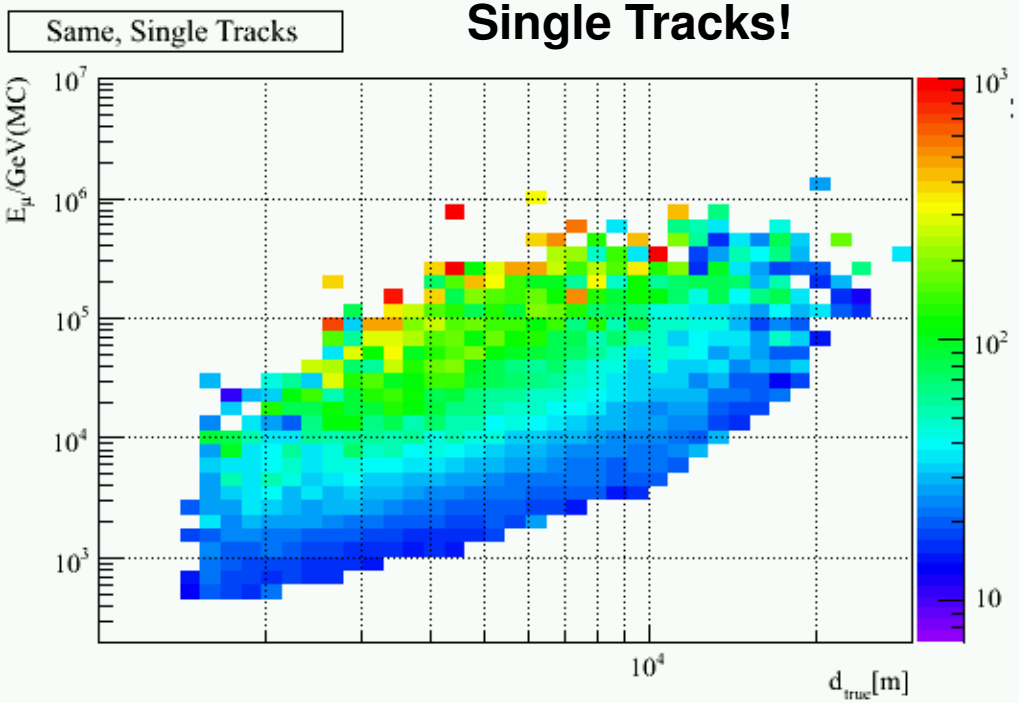


Very Few Tracks

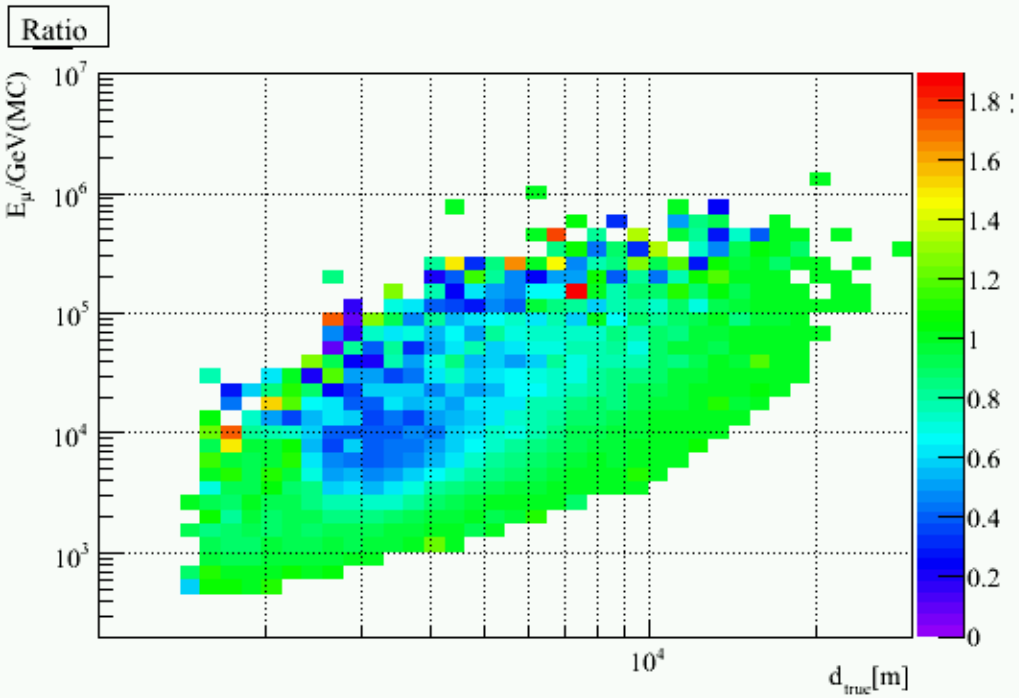
Muon Energy

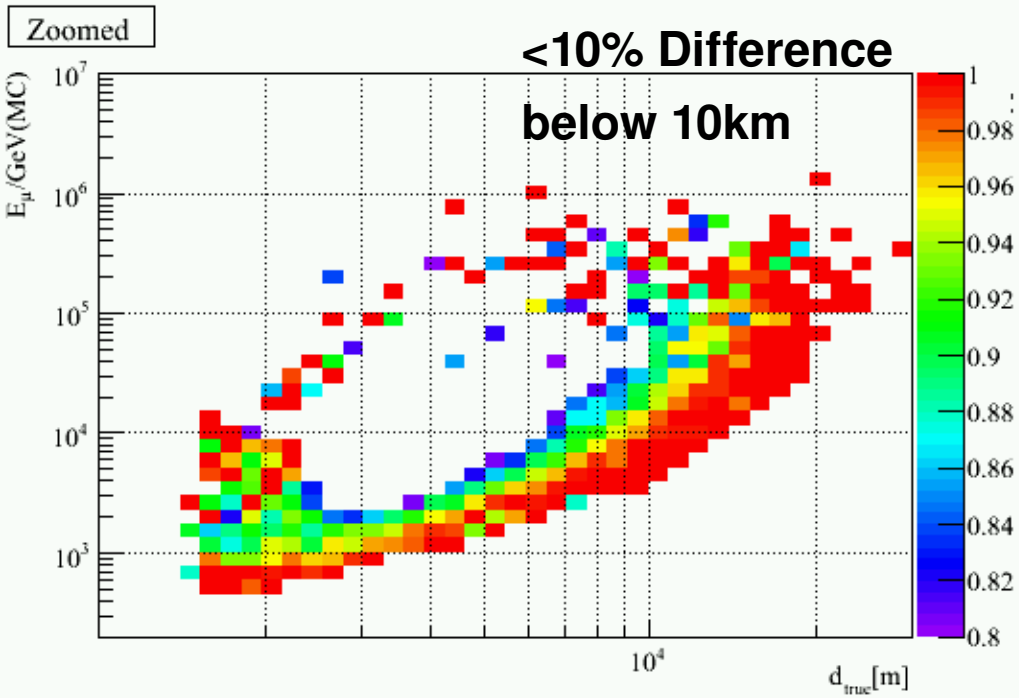




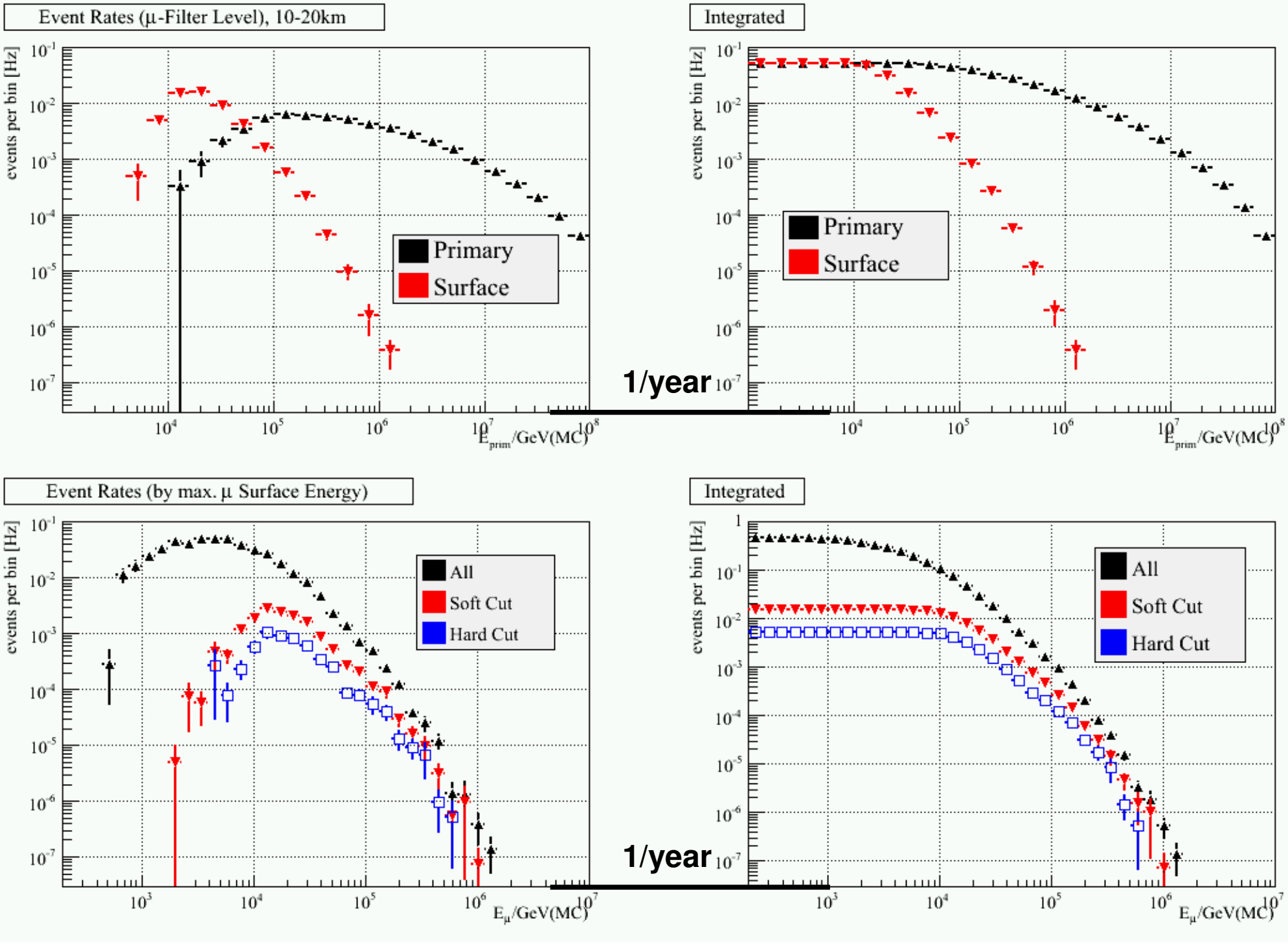


Single Tracks!

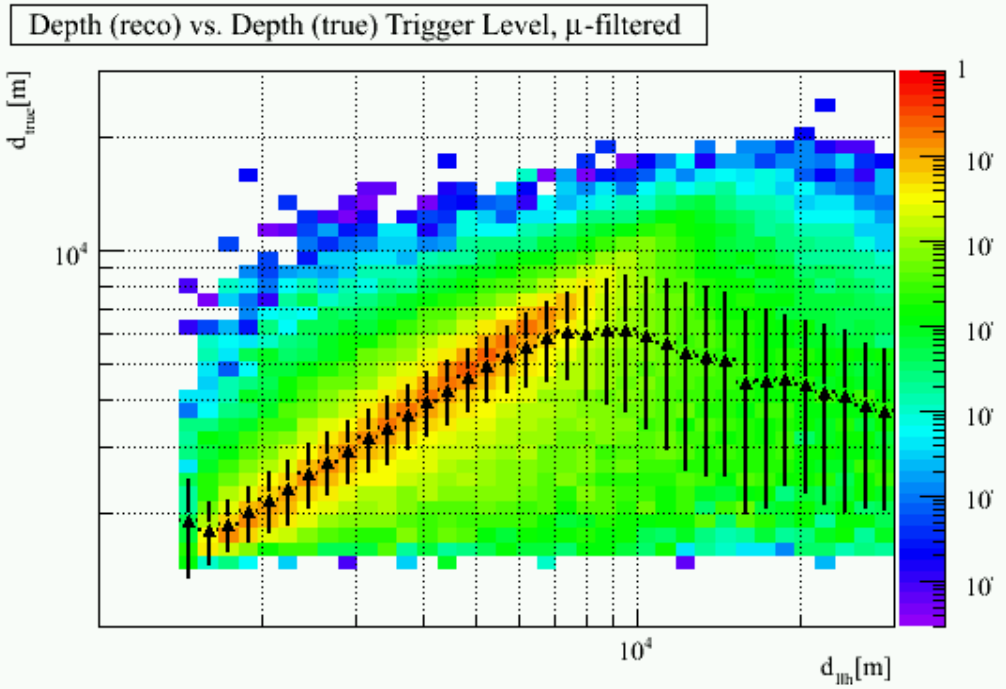


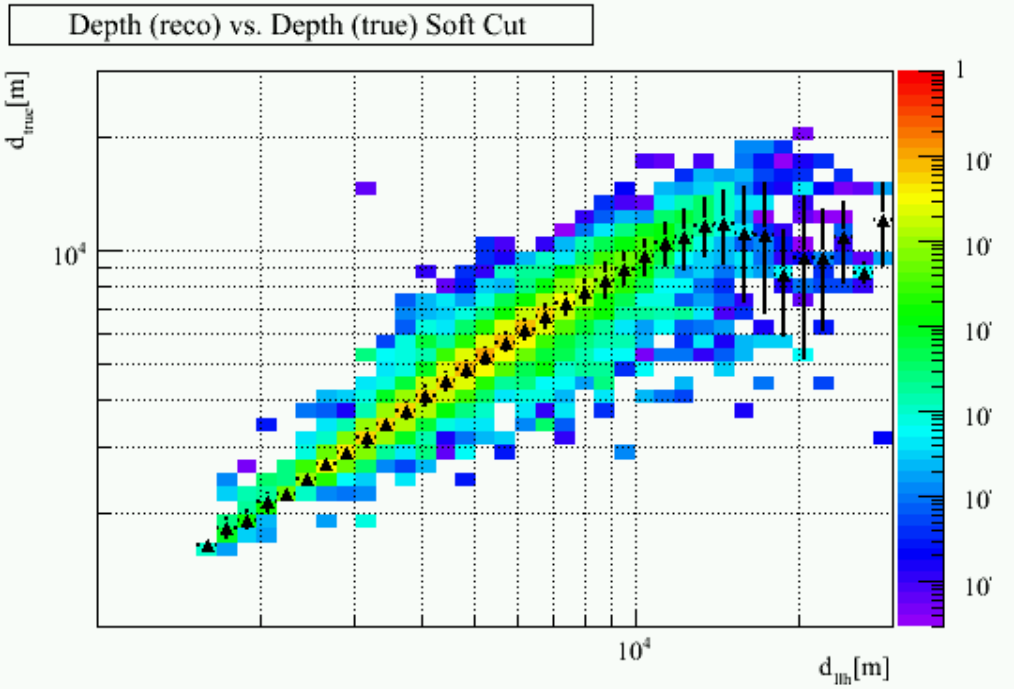


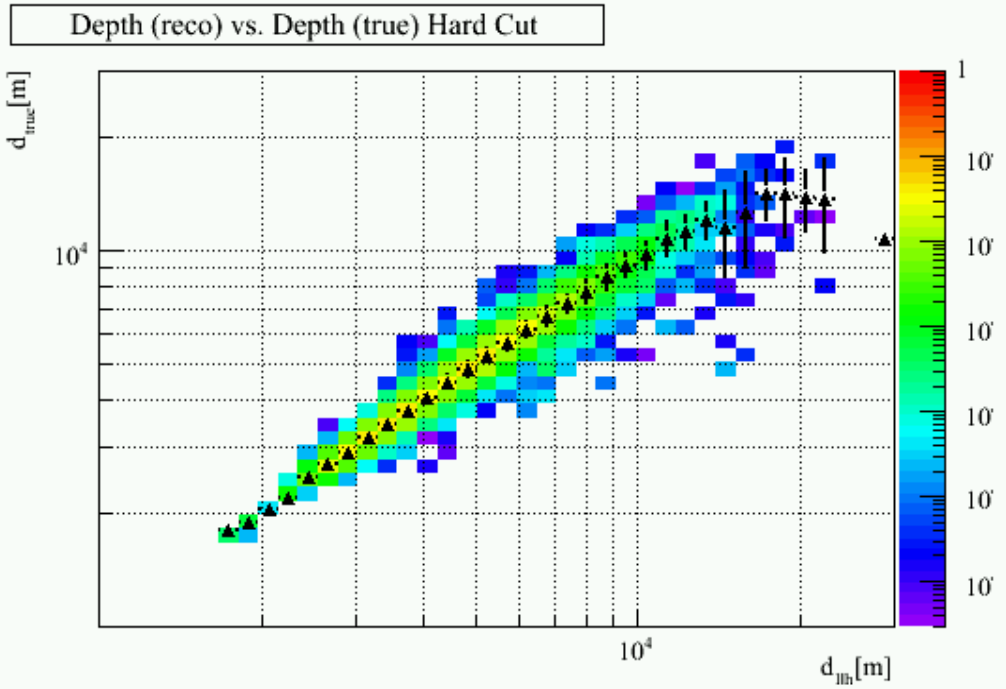
<10% Difference below 10km

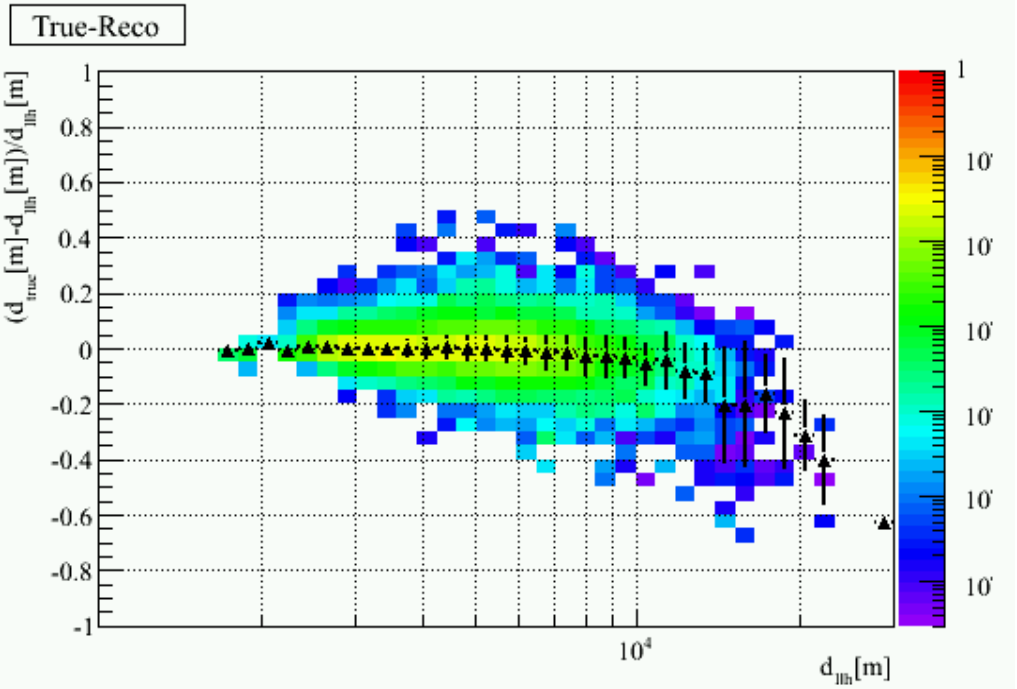

Event Rates (μ-Filter Level), 10-20km
events per bin [Hz]
Primary
Surface
E_{prim}/GeV(MC)
Integrated
1/year
Event Rates (by max. μ Surface Energy)
All
Soft Cut
Hard Cut
E_{μ}/GeV(MC)

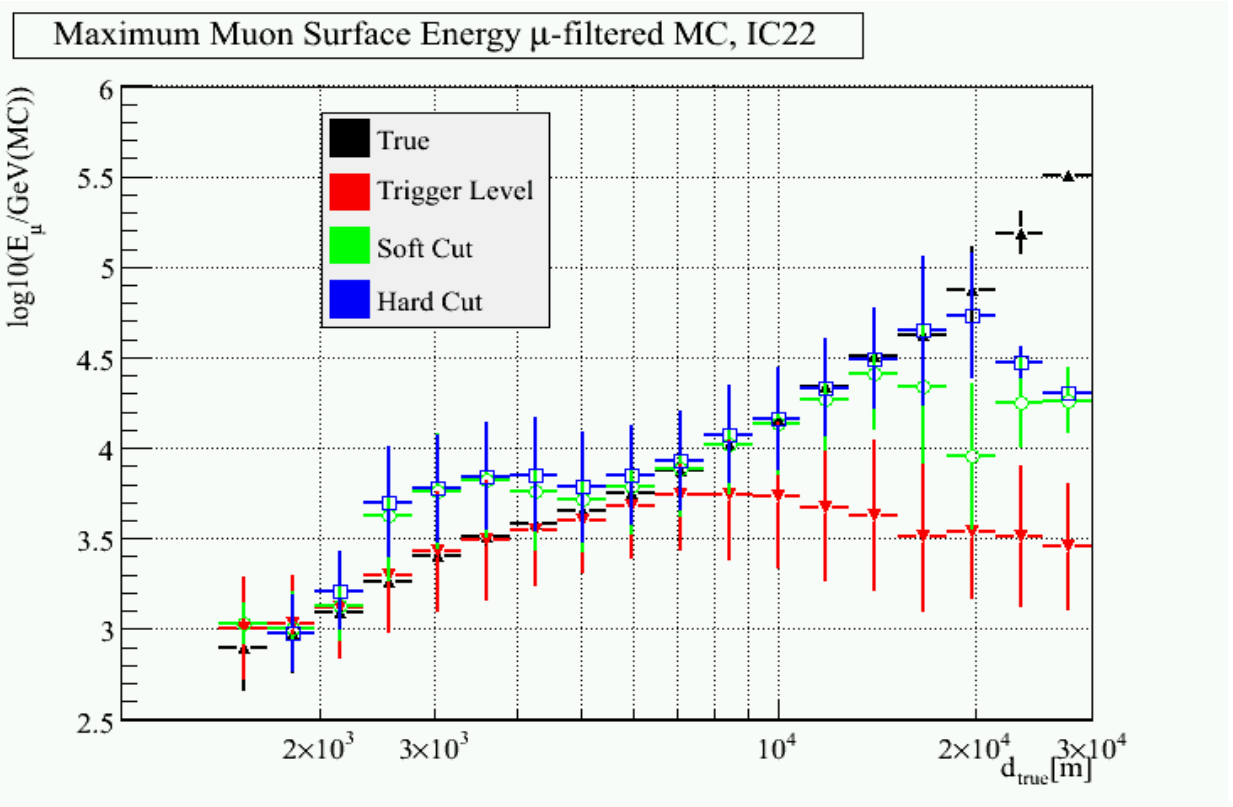
Depth Measurement Accuracy





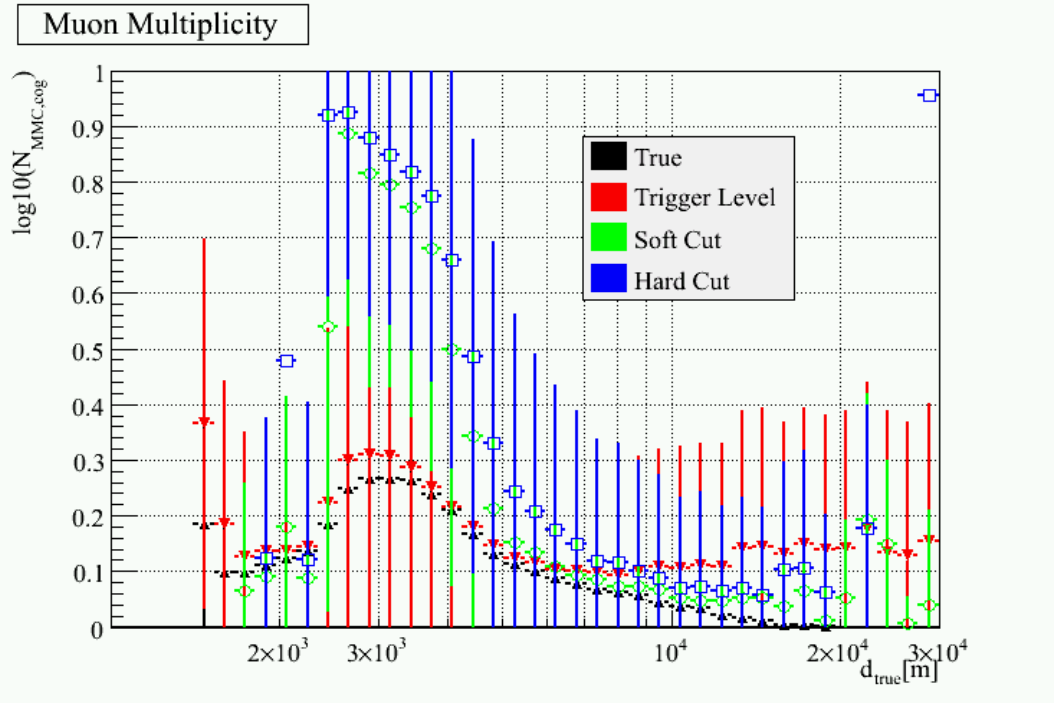


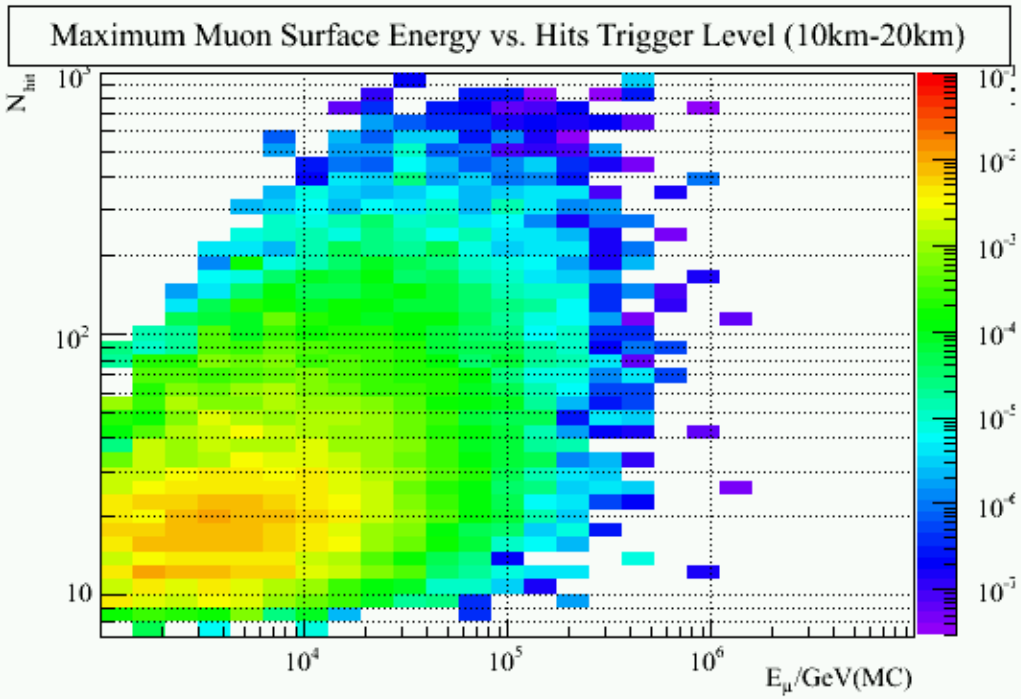


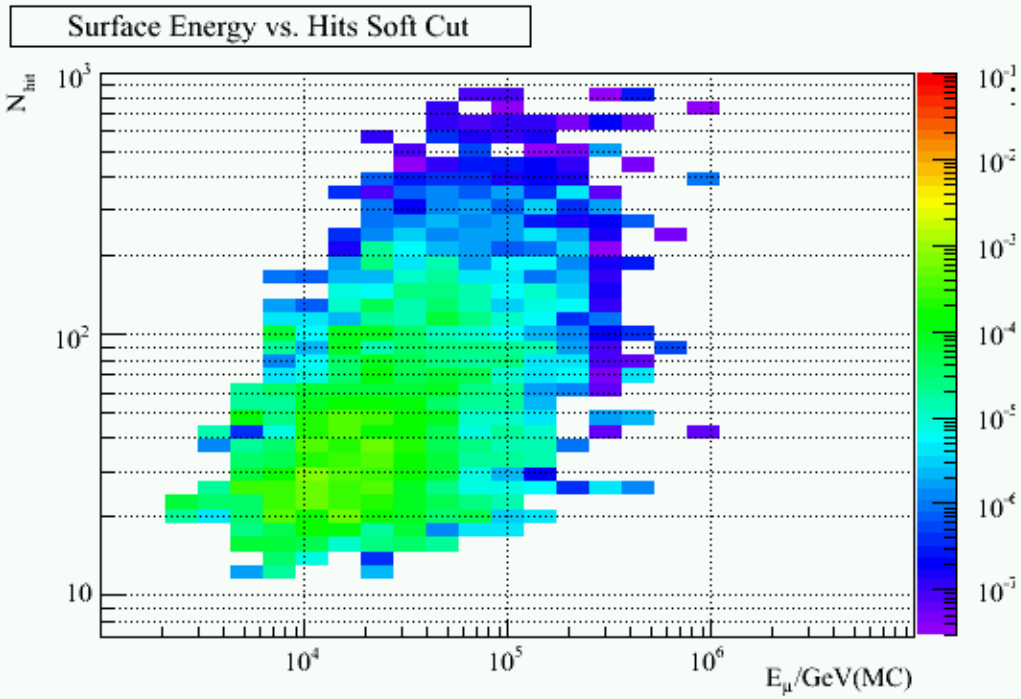


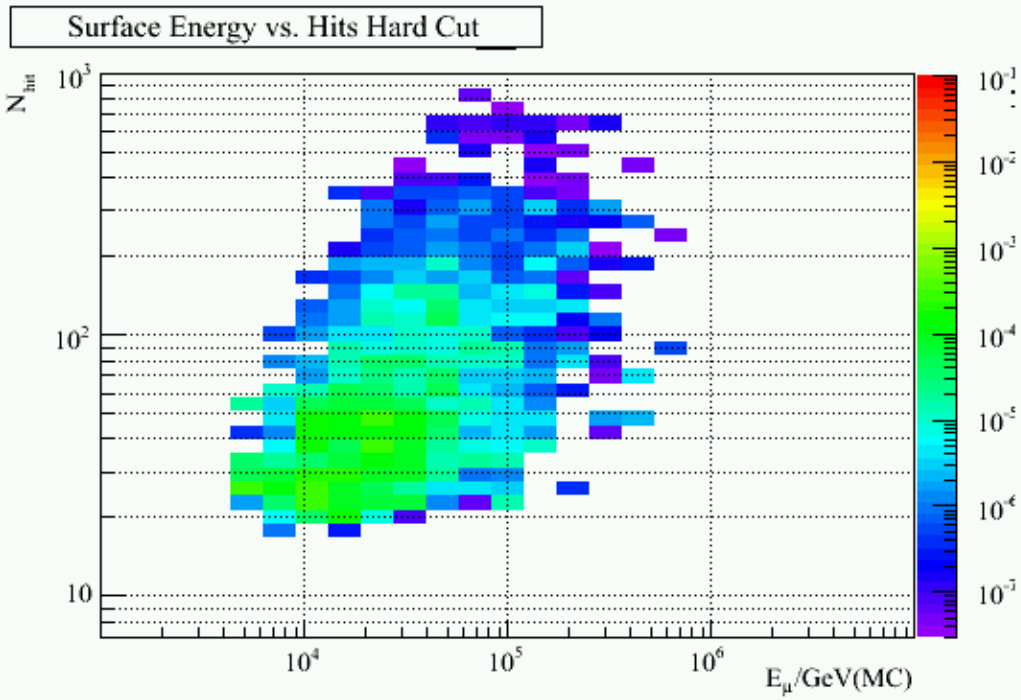
Energy

Multiplicity



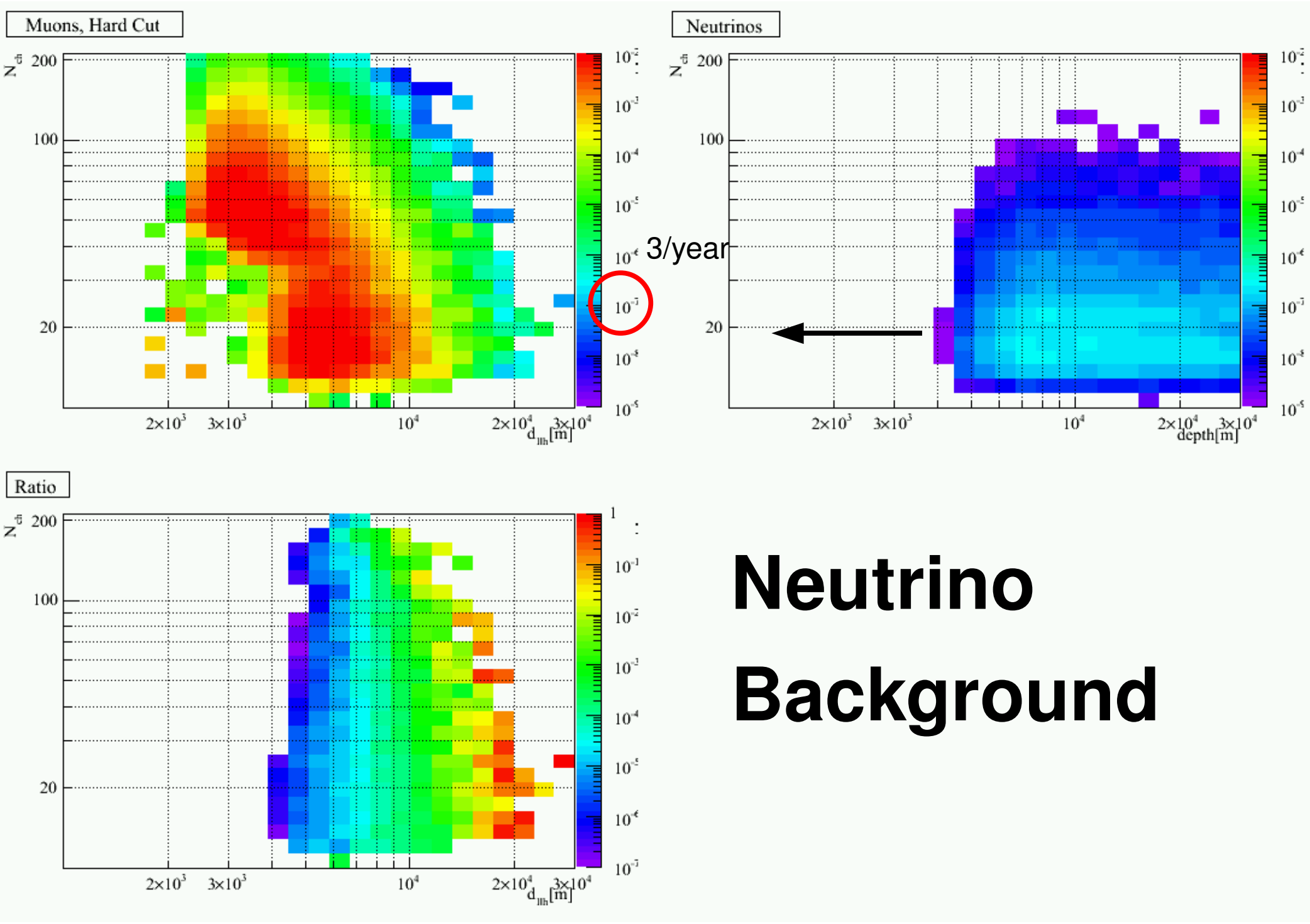




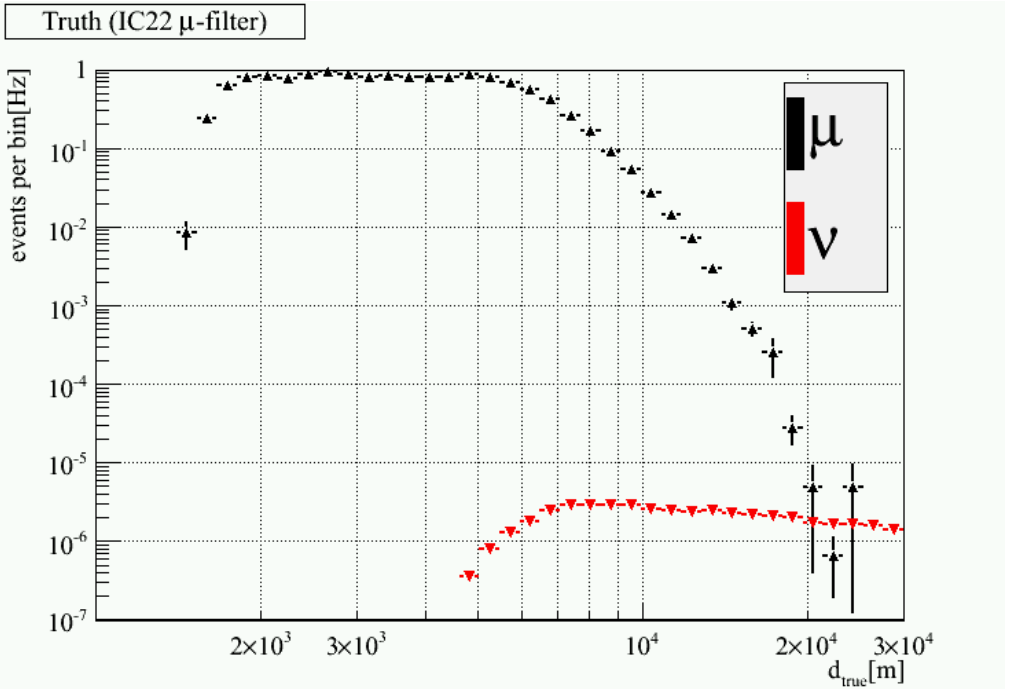


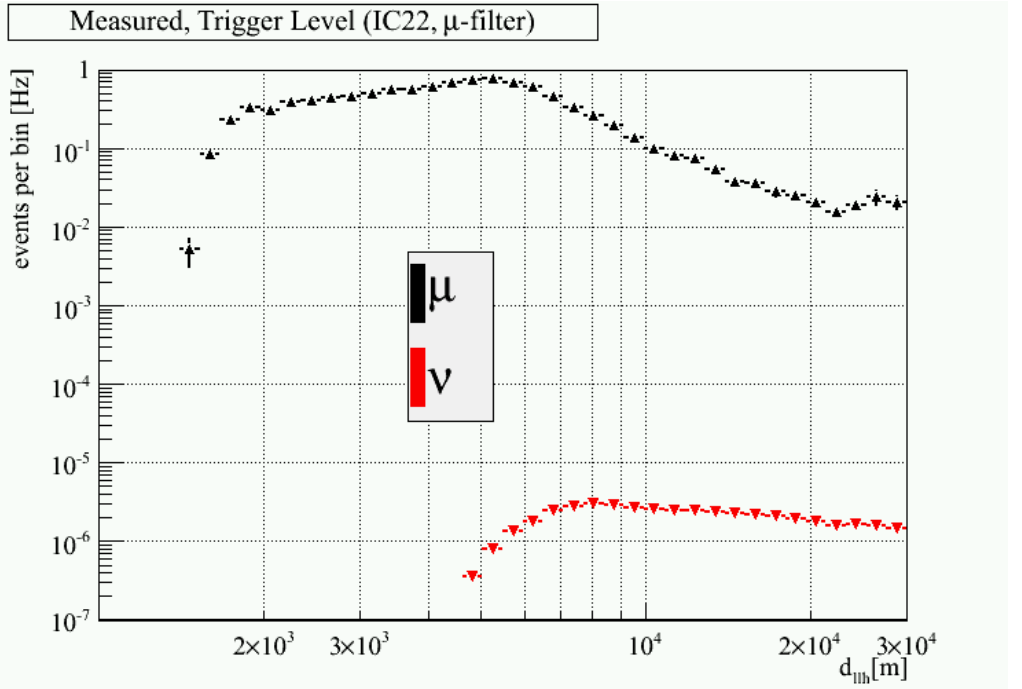
Energy and Energy Estimator

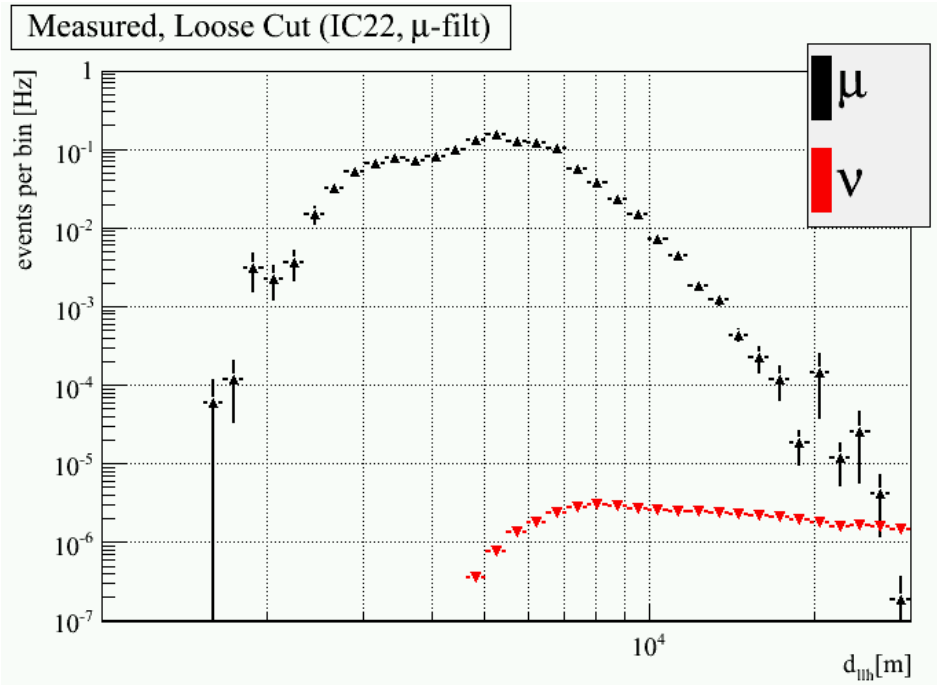
Indirect Measurement!

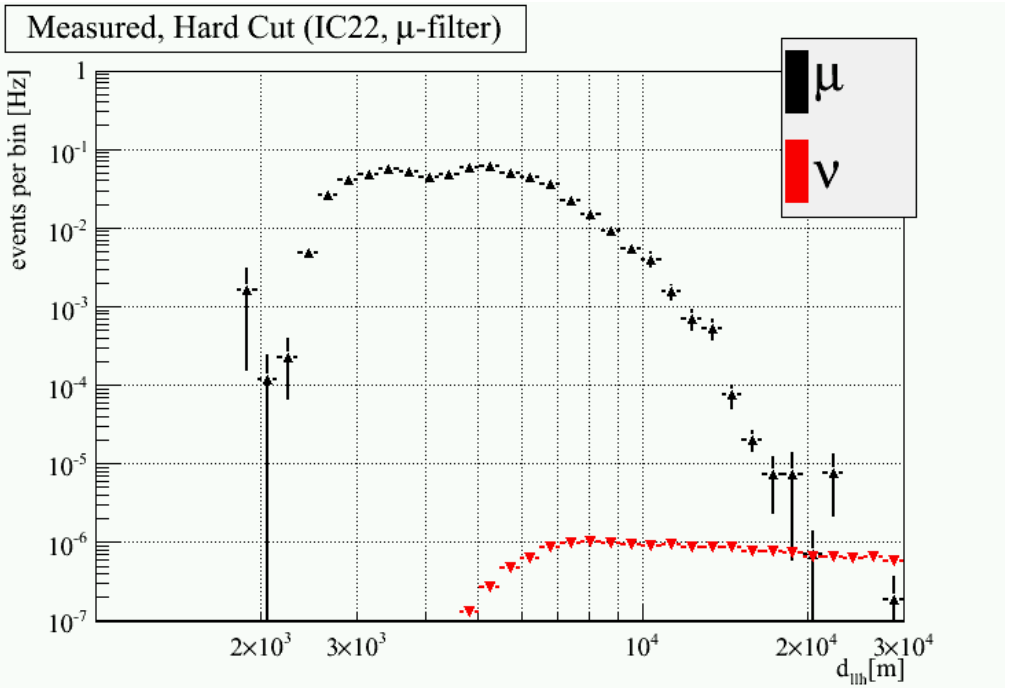


Neutrino Background

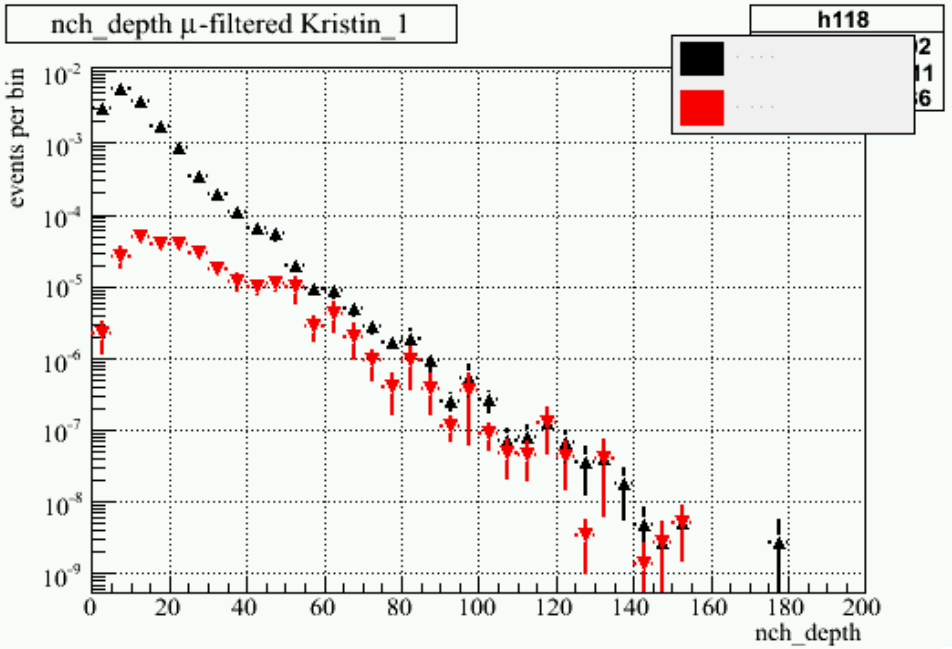

Truth (IC22 μ-filter)
events per bin[Hz]
μ
ν
d_true[m]

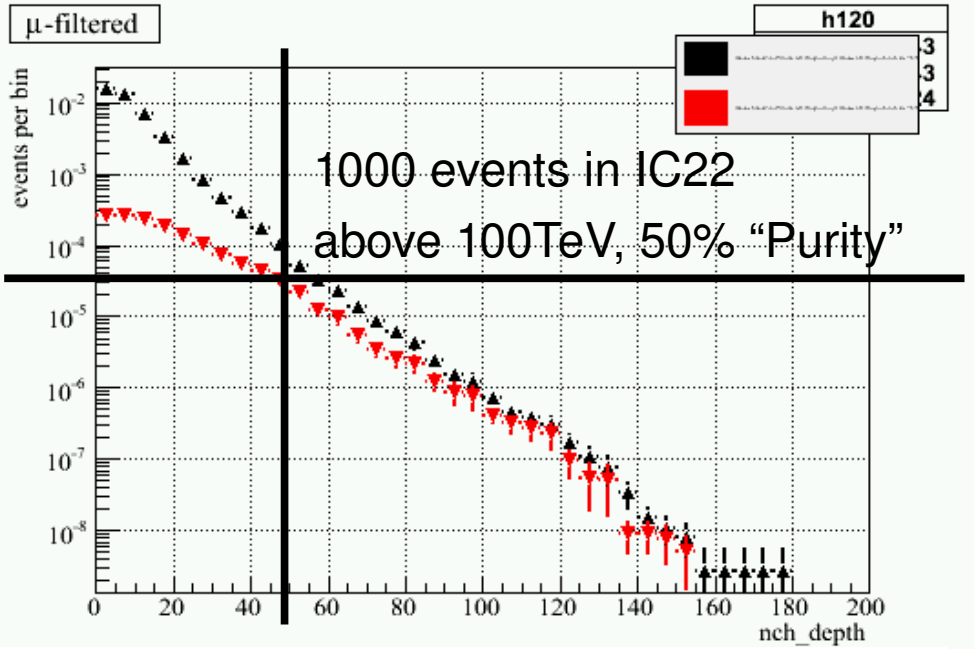

Measured, Trigger Level (IC22, μ-filter)
events per bin [Hz]
μ
ν
d_llh[m]

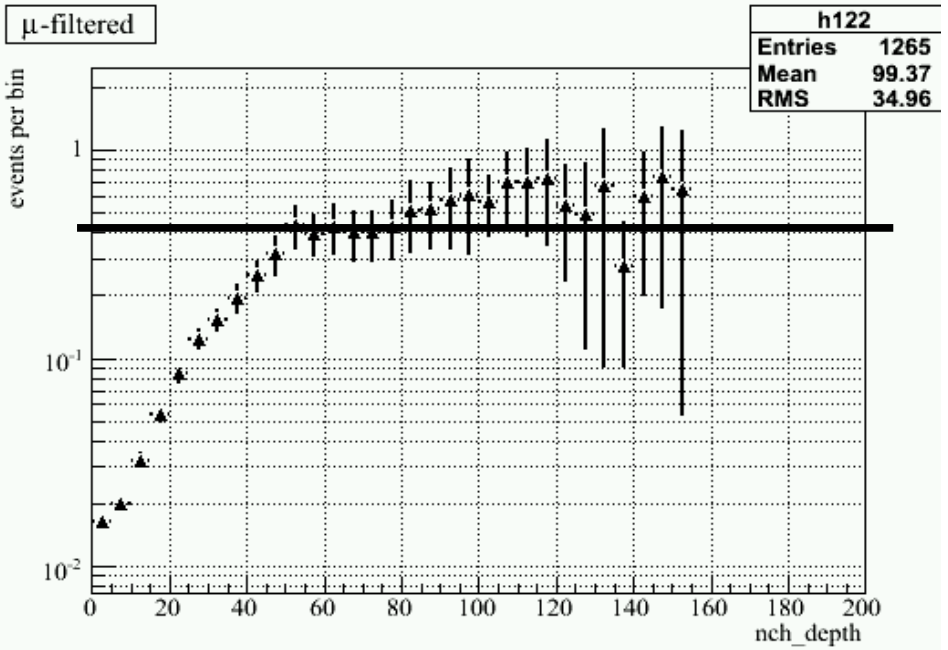

Measured, Loose Cut (IC22, μ-filt)
events per bin [Hz]
μ
ν
d_llh[m]

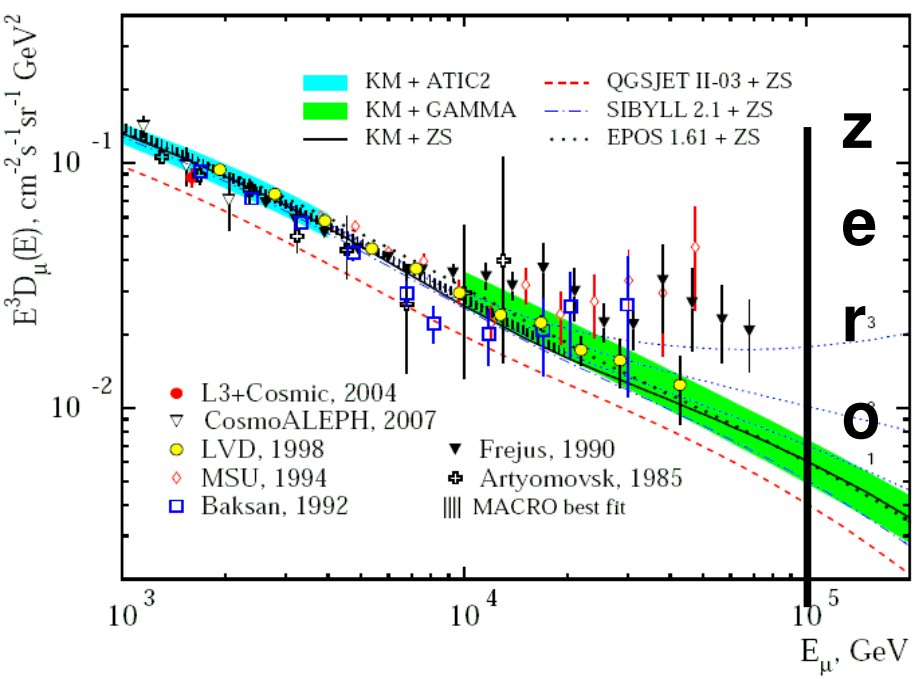

Measured, Hard Cut (IC22, μ-filter)
events per bin [Hz]
μ
ν
d_llh[m]

Example: Very Crude Cut









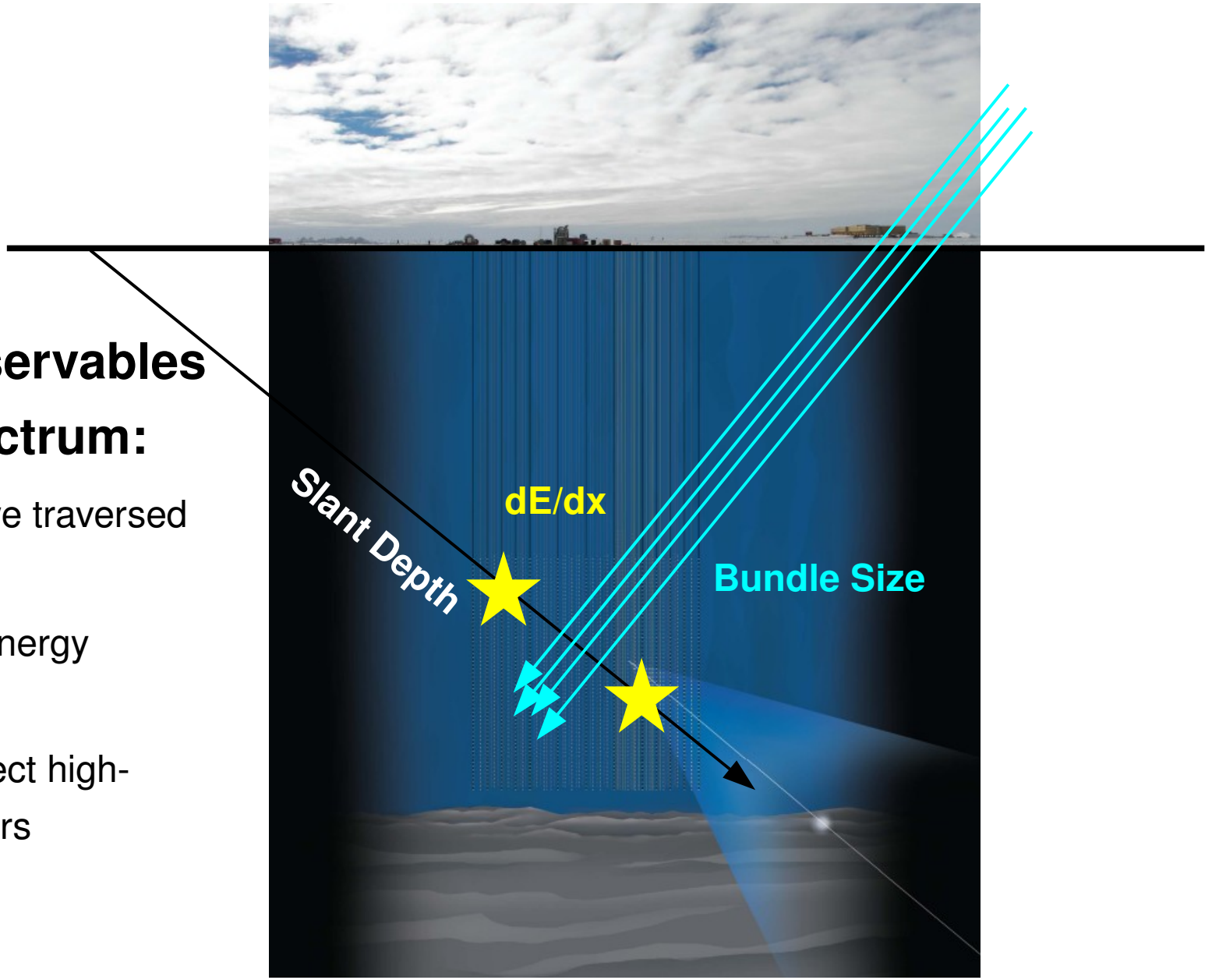
Technical Issues

Essential Observables for Muon Spectrum:

Slant Depth: mwe traversed

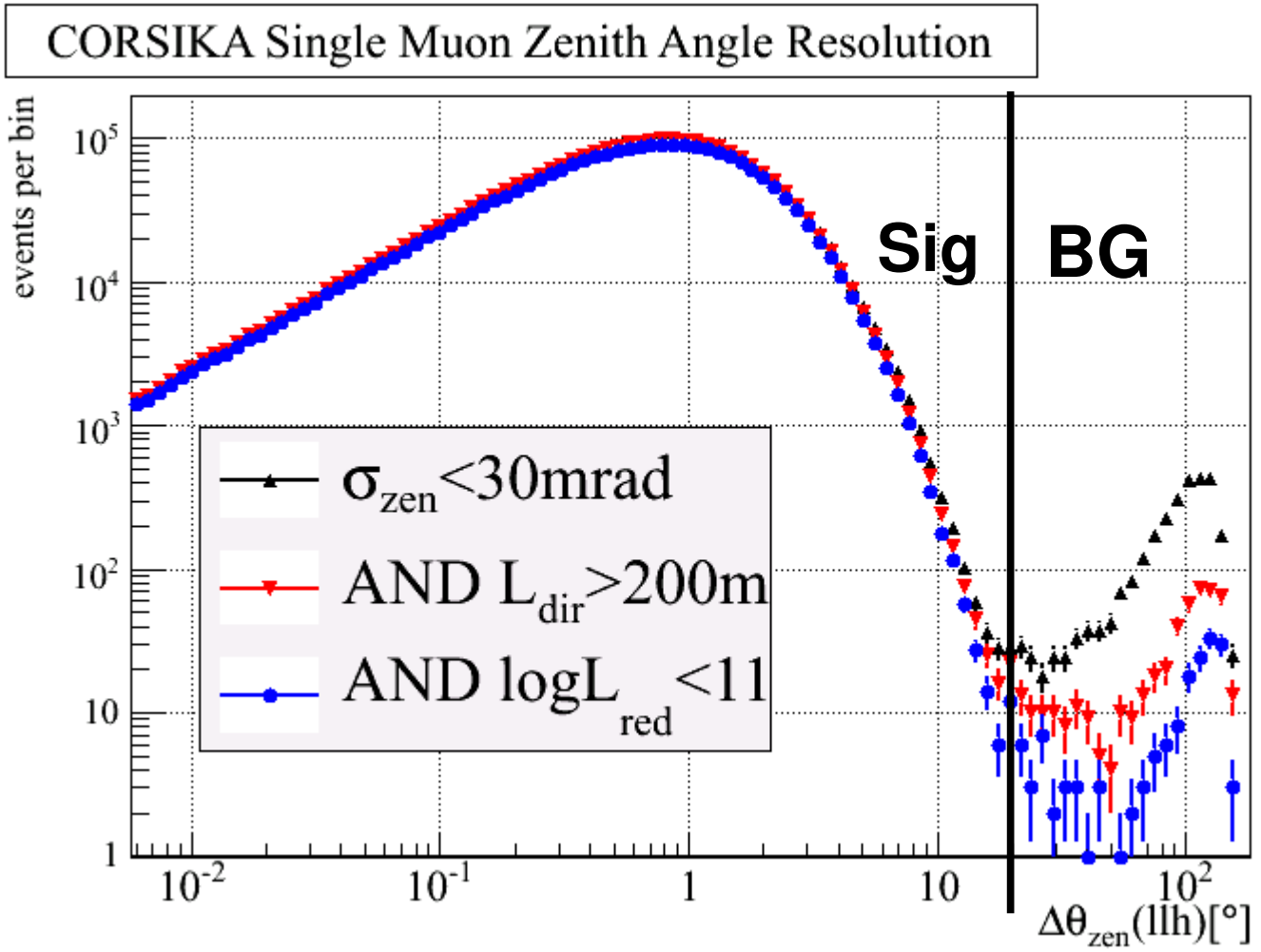
dE/dx: shower energy

Bundle Size: reject high-multiplicity showers



Track Reconstruction (Depth)

Likelihood Ratio ("Naïve Bayesian")



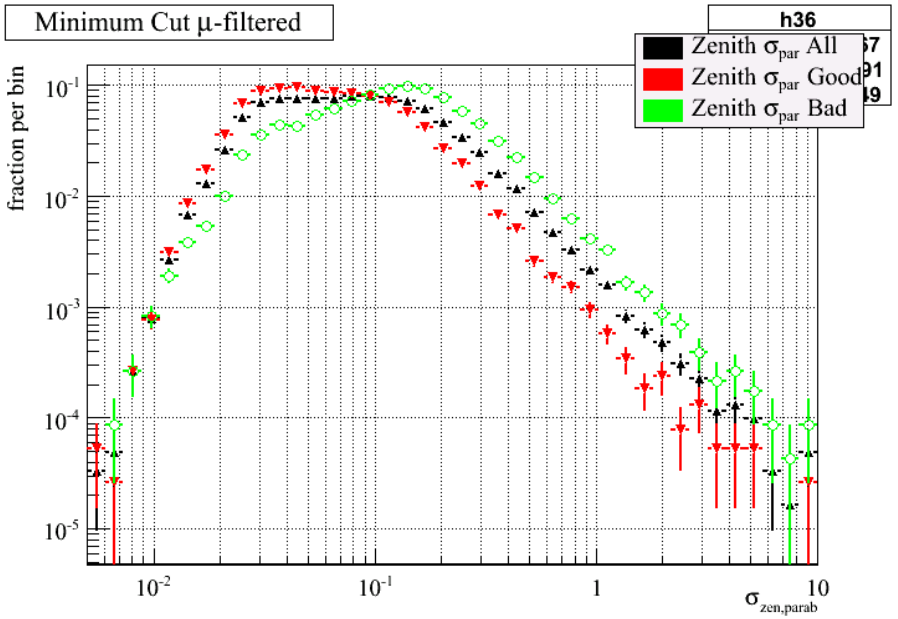
LR Advantages

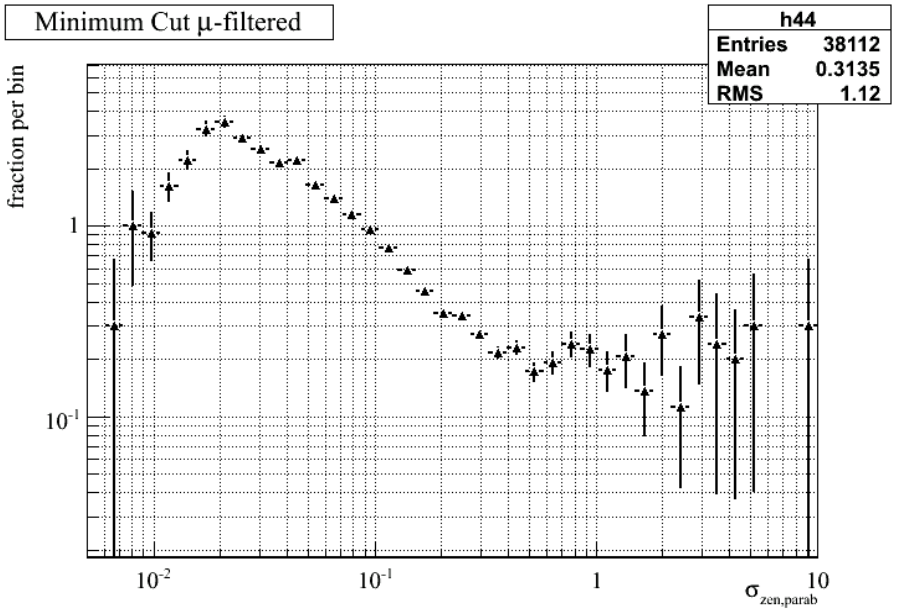
Single Cut Parameter

- Simple Cut
- Convergence

Simpler than SBM

Proven to Work (B10PS, HD, WIMPs)





Candidate Variables:

sigma (zen)

N_{dir}

llh_{red}

v_{lf}

L_{dir}

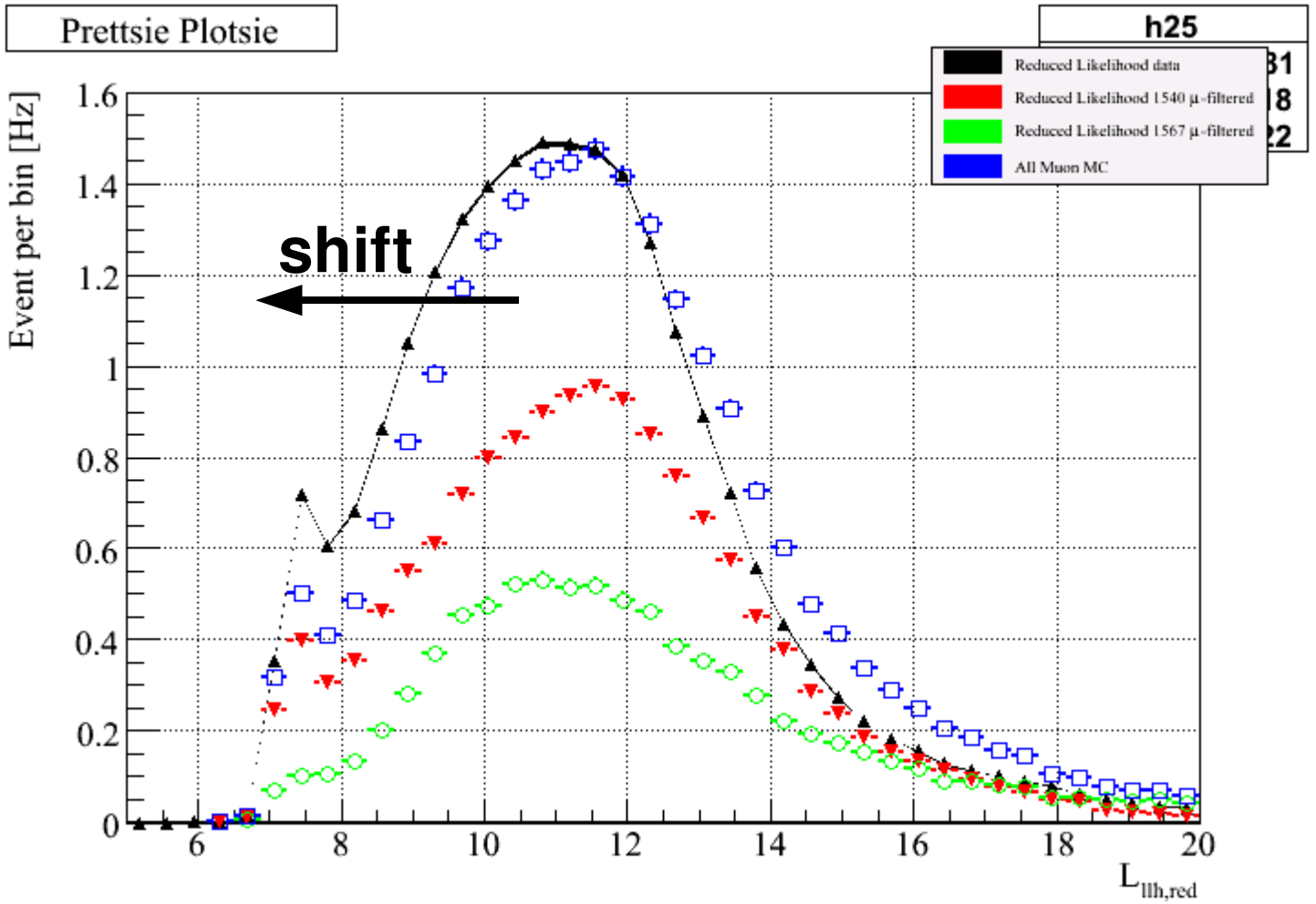
umbrella delta llh

smoothness

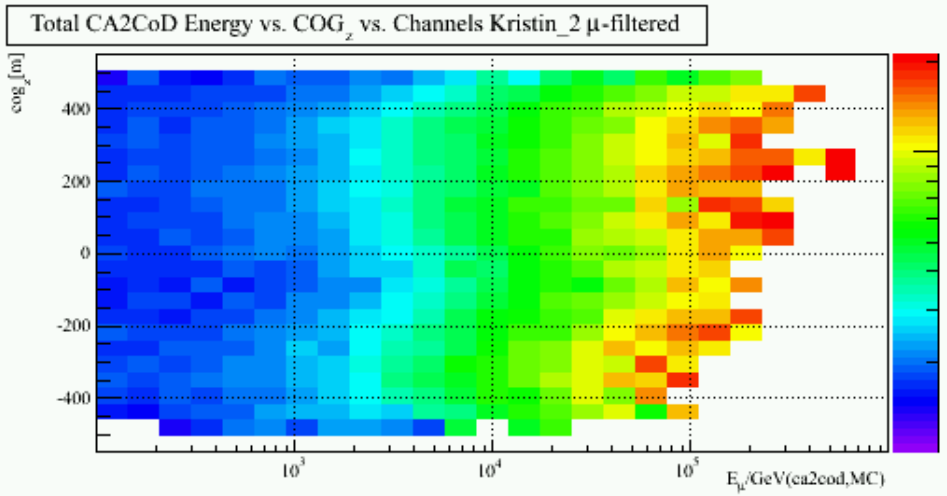
Blue: Affected by N_{ch}

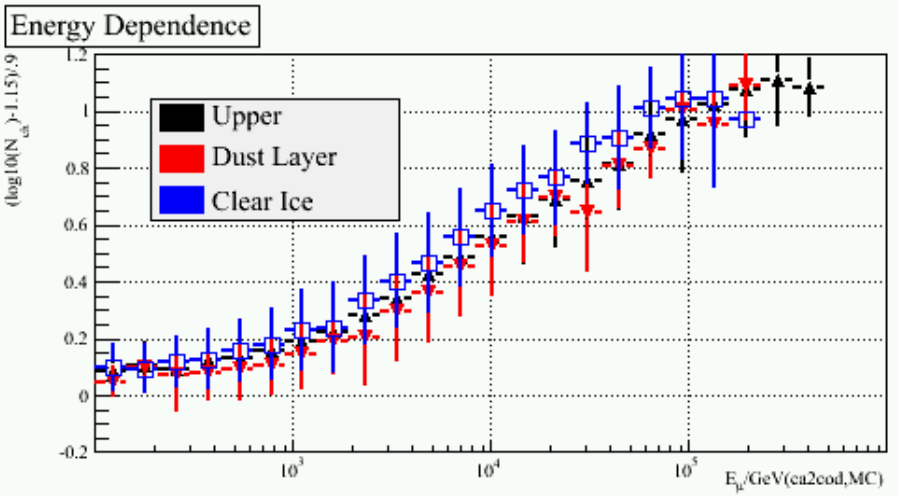
Red: Affected by SPE (in IC22)

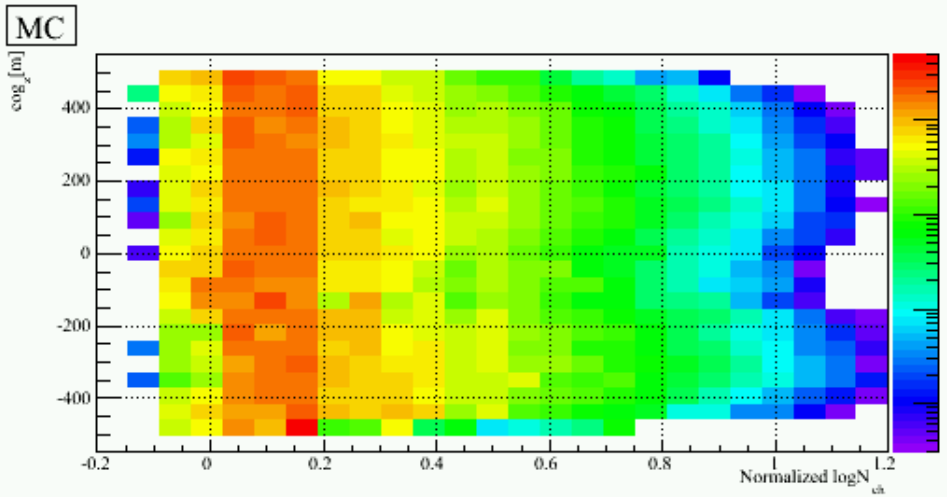
N_{ch} Correction

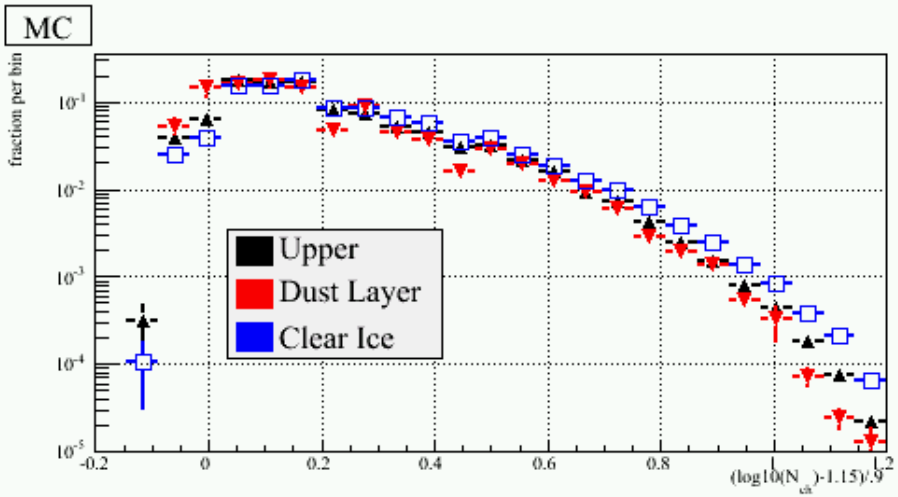


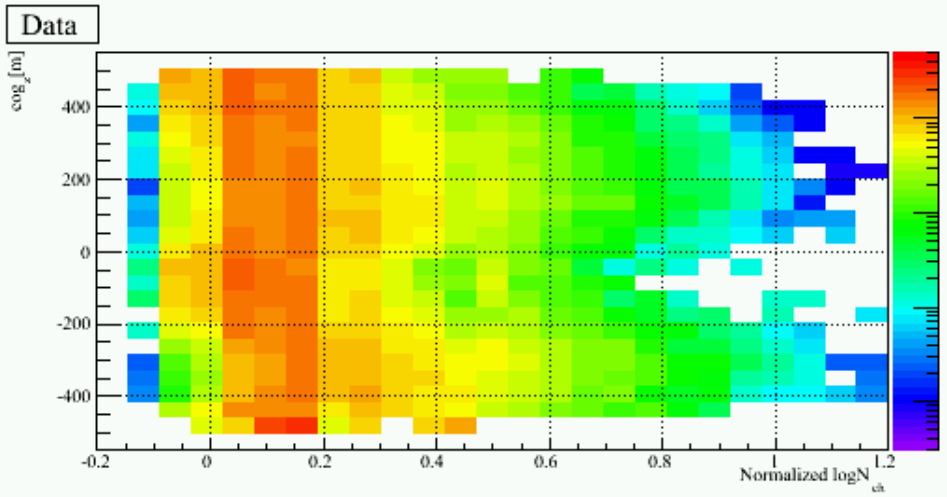
Energy Estimator

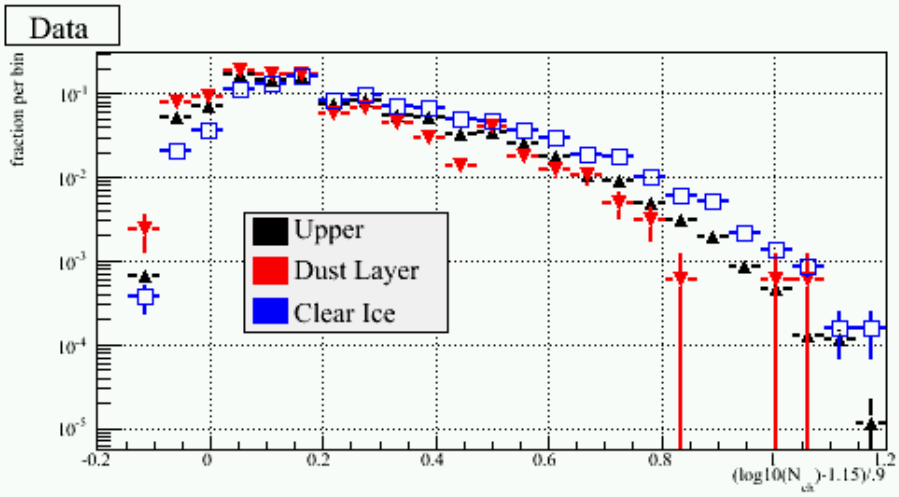

Total CA2CoD Energy vs. COG$_z$ vs. Channels Kristin_2 μ-filtered
cog$_z$ [m]
E$_\mu$/GeV(ca2cod,MC)

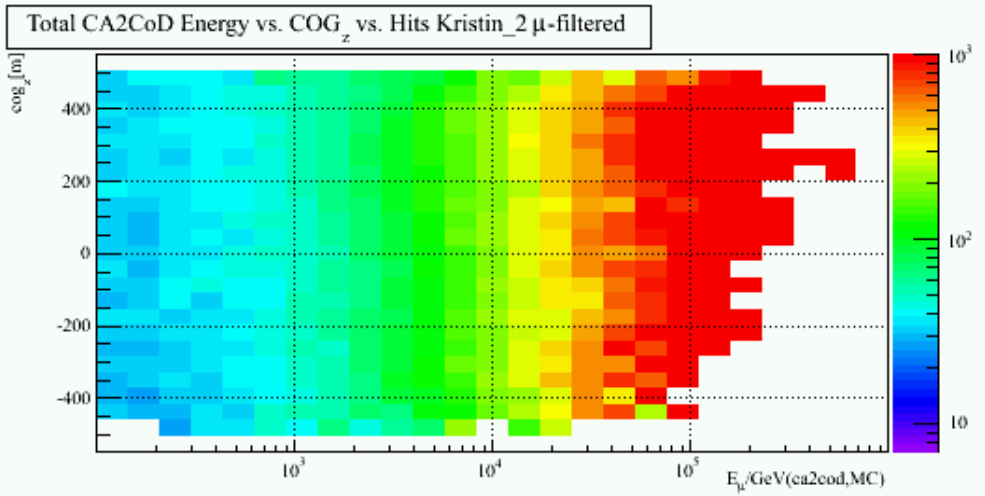

Energy Dependence
Upper
Dust Layer
Clear Ice
(log10(N$_{ch}$)-1.15)/.9
E$_\mu$/GeV(ca2cod,MC)

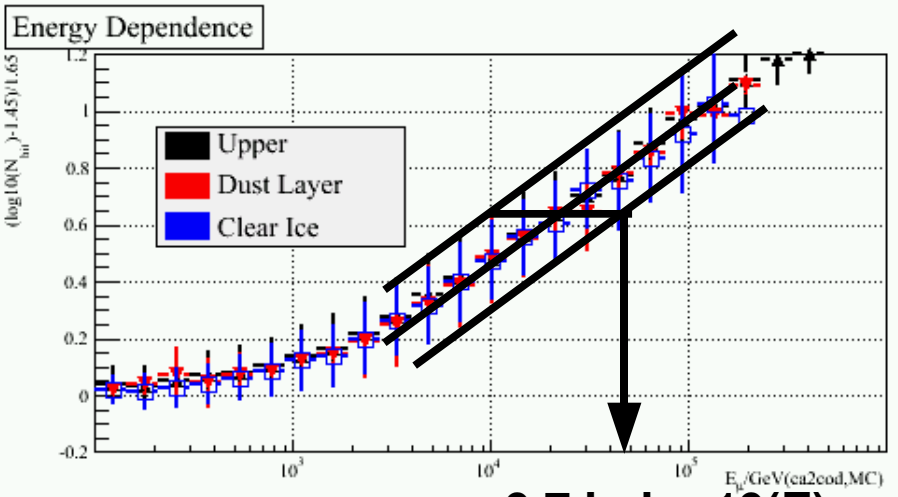

MC
cog$_z$ [m]
Normalized logN$_{ch}$


MC
fraction per bin
Upper
Dust Layer
Clear Ice
(log10(N$_{ch}$)-1.15)/.9

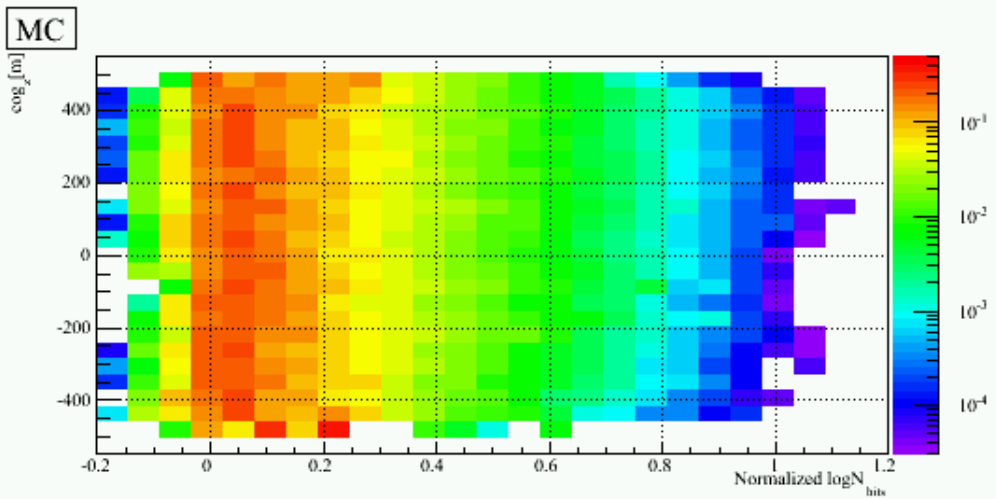

Data
cog$_z$ [m]
Normalized logN$_{ch}$

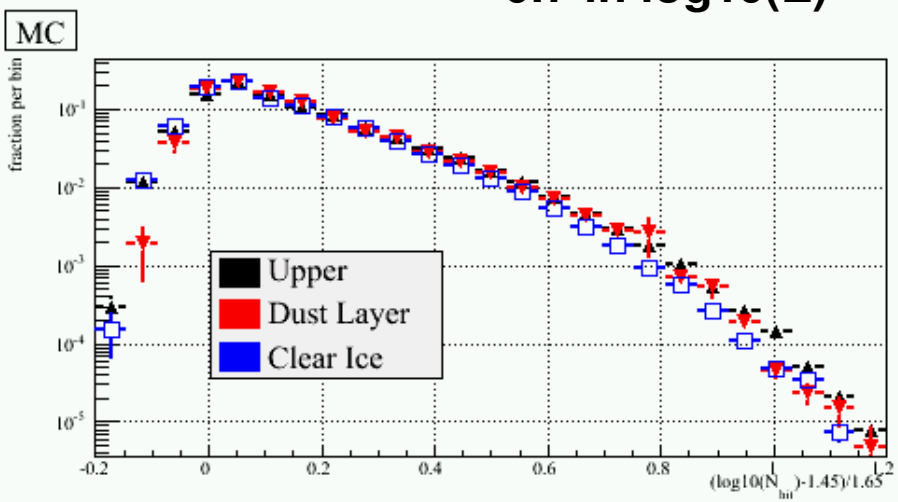

Data
fraction per bin
Upper
Dust Layer
Clear Ice
(log10(N$_{ch}$)-1.15)/.9

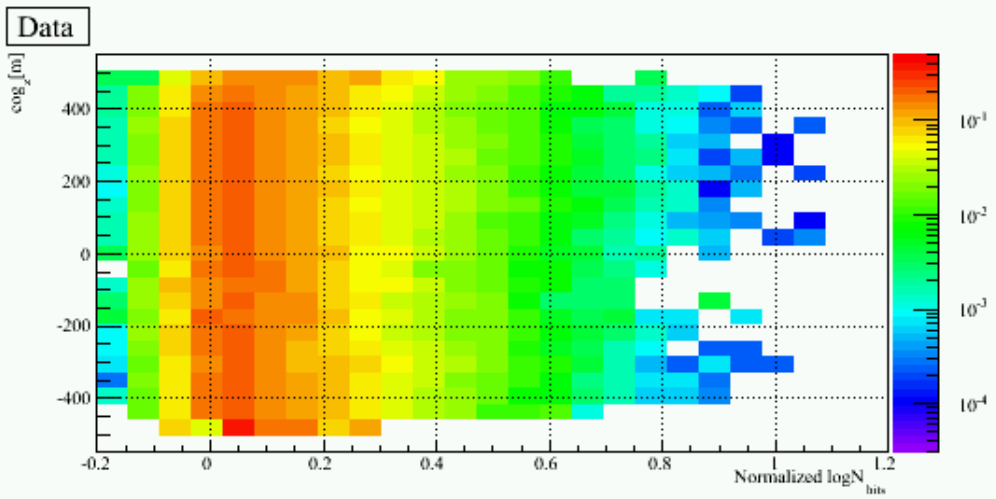

Total CA2CoD Energy vs. COG_z vs. Hits Kristin_2 μ-filtered
cog_z [m]
E_μ/GeV(ca2cod,MC)

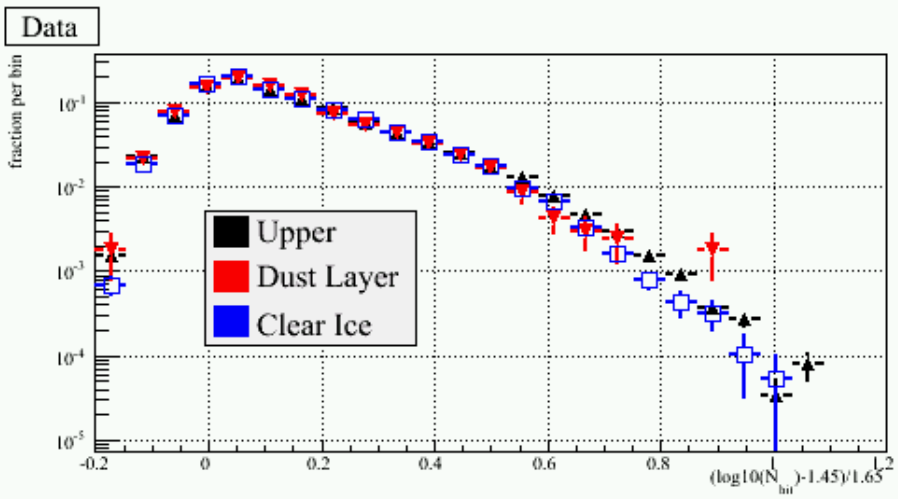

Energy Dependence
Upper
Dust Layer
Clear Ice
E_μ/GeV(ca2cod,MC)

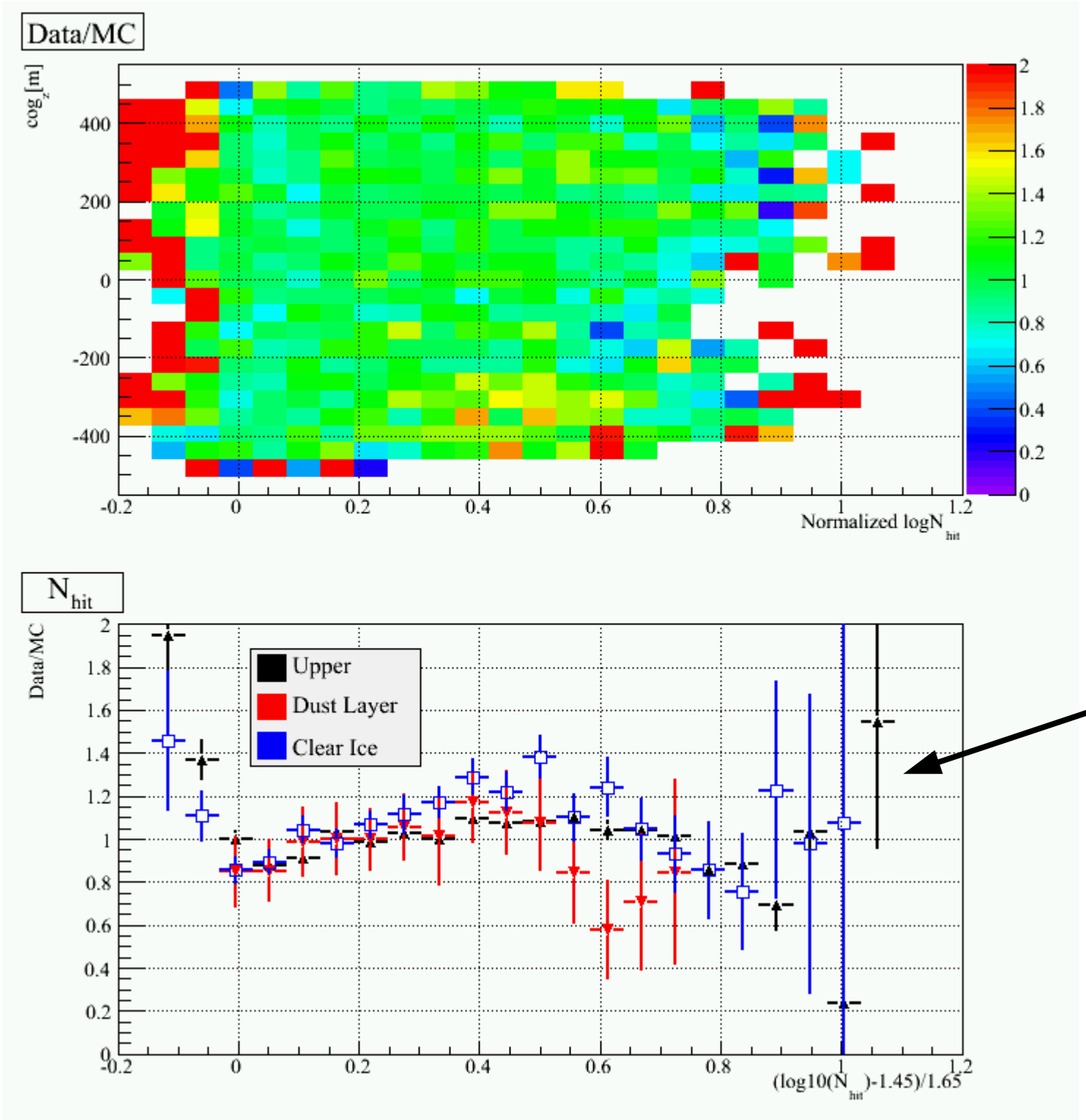
≈0.7 in log10(E)


MC
cog_z [m]
Normalized logN_hits

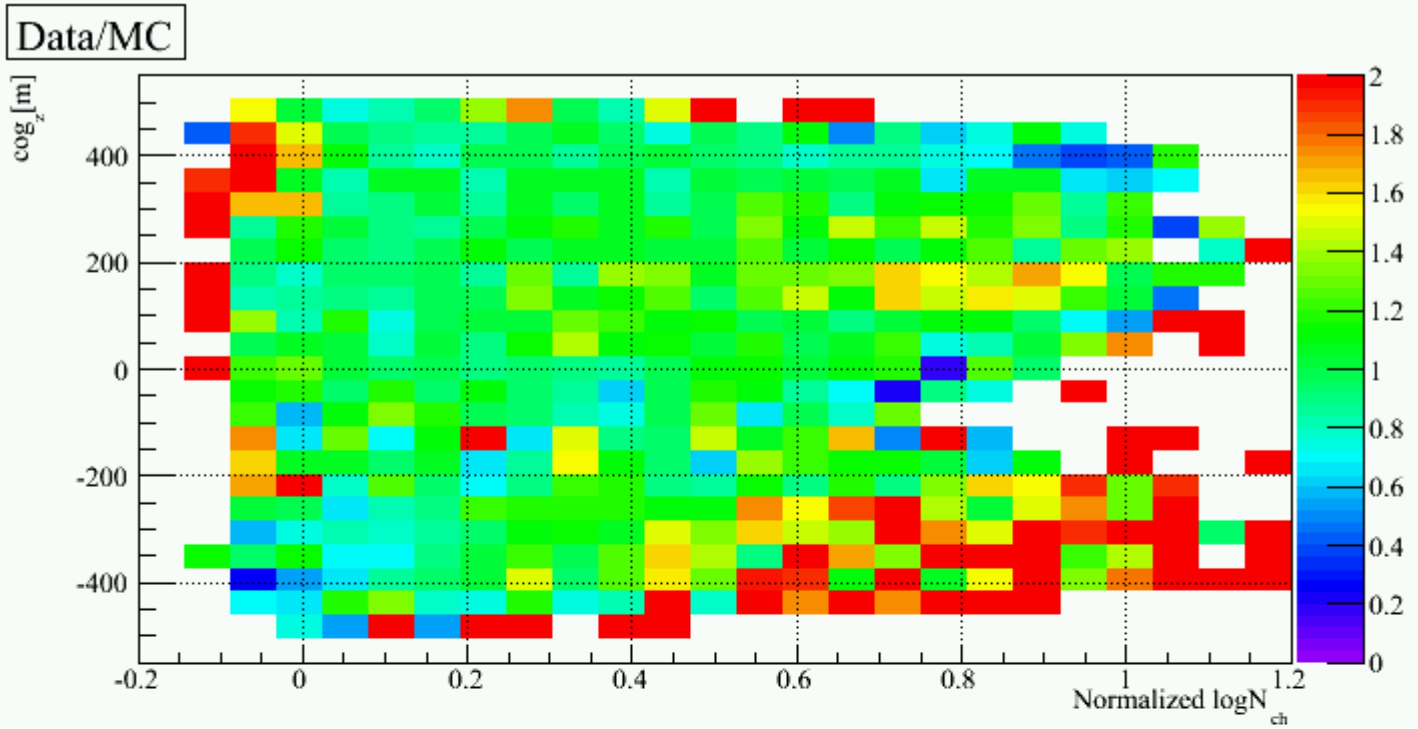

MC
fraction per bin
Upper
Dust Layer
Clear Ice

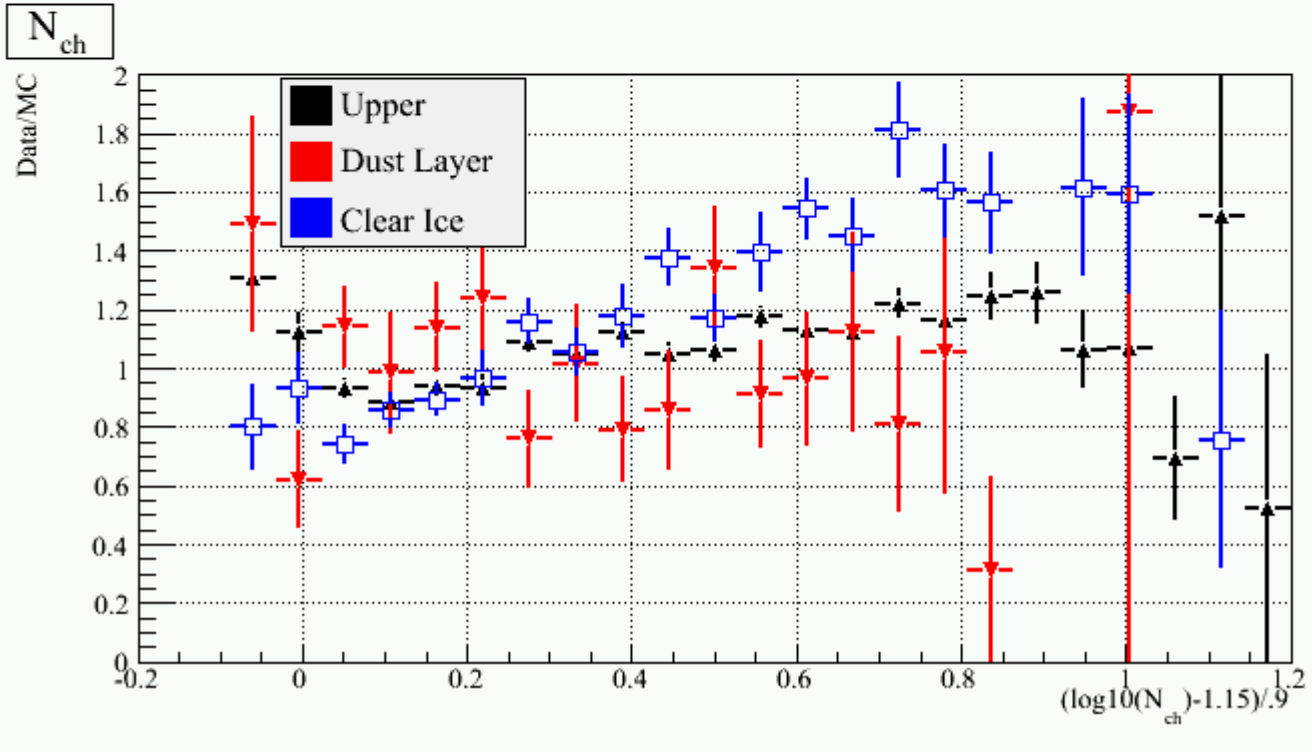

Data
cog_z [m]
Normalized logN_hits


Data
fraction per bin
Upper
Dust Layer
Clear Ice



Global Correction Possible (?)

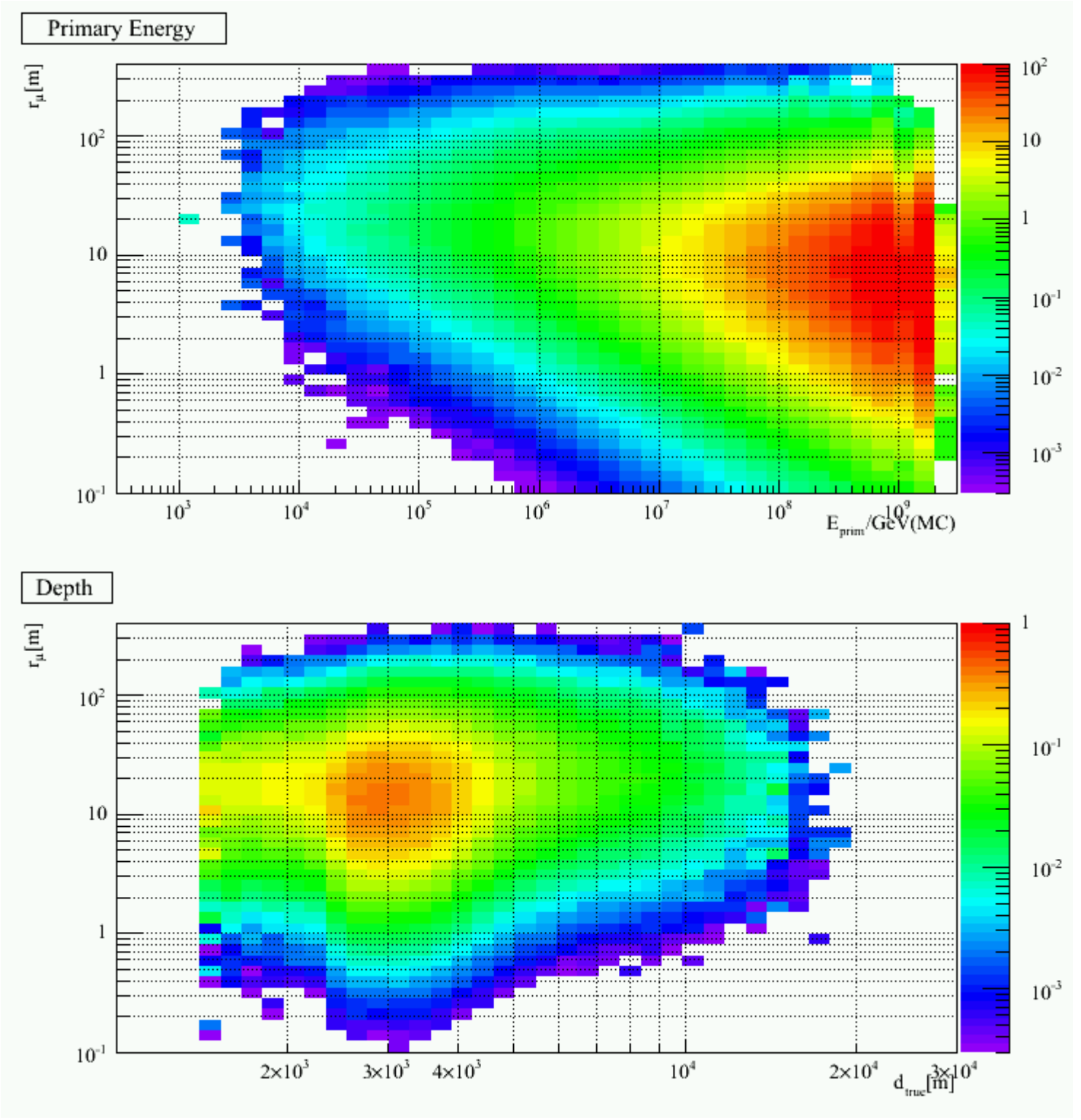

Data/MC
cog_z [m]
400
200
0
-200
-400
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
Normalized logN_ch
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0


N_ch
Data/MC
Upper
Dust Layer
Clear Ice
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
(log10(N_ch)-1.15)/.9

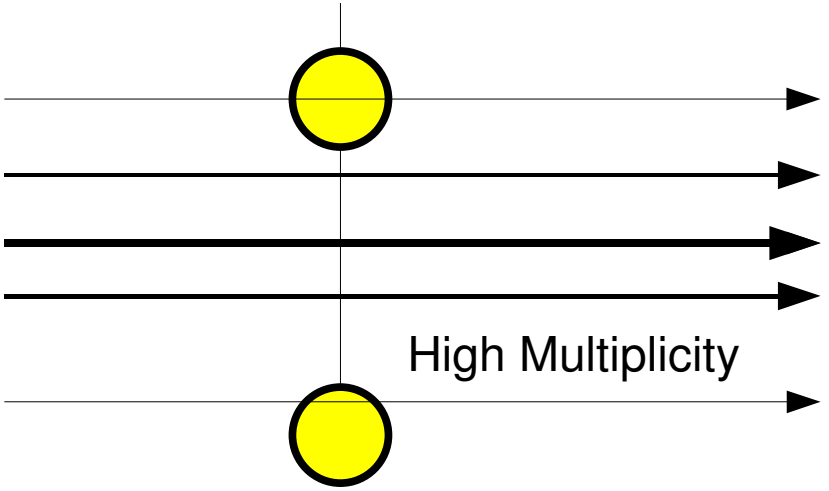
Back to N_{ch}

Multiplicity

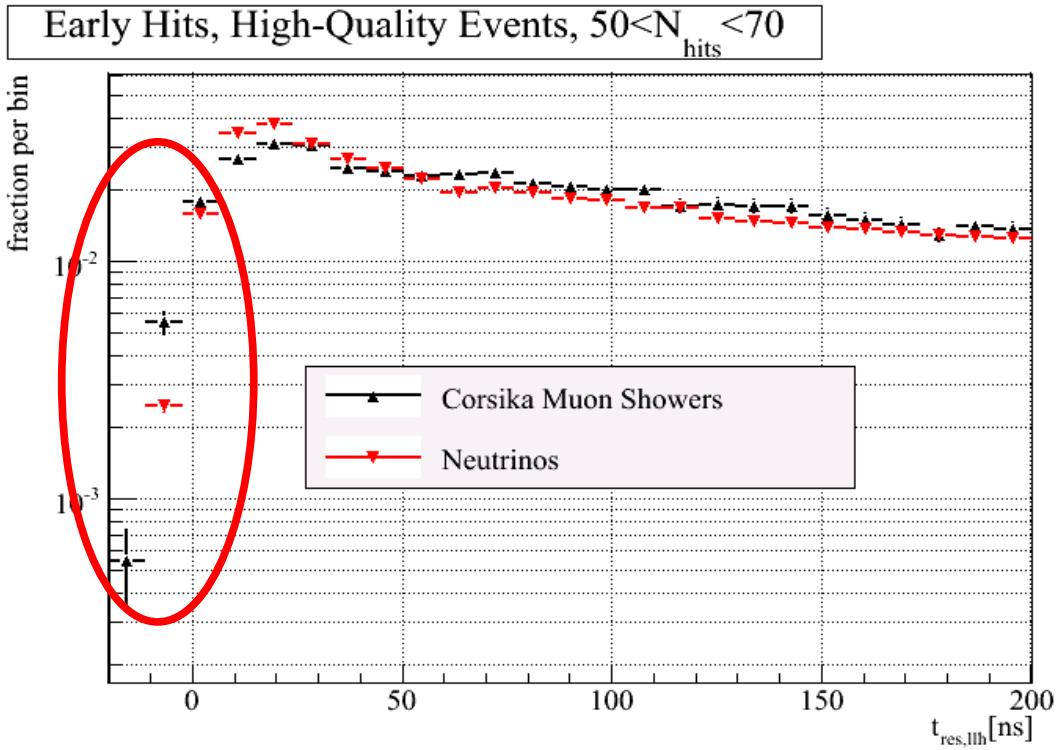
Shower Radius



Background Suppression: Early Hits



Showers produce more early hits!



Strategy

IC22

HE Muon Filter

L3 (MPE, MuE...)

or

IC40

wait...

?

Non-Hoerandel MC (->IceTop)

HE Muon MC (generic $E^{-2.7}$ prompt)

LR Cuts

Energy Estimator Systematics

Result: Unfolding, Fit?

Summary

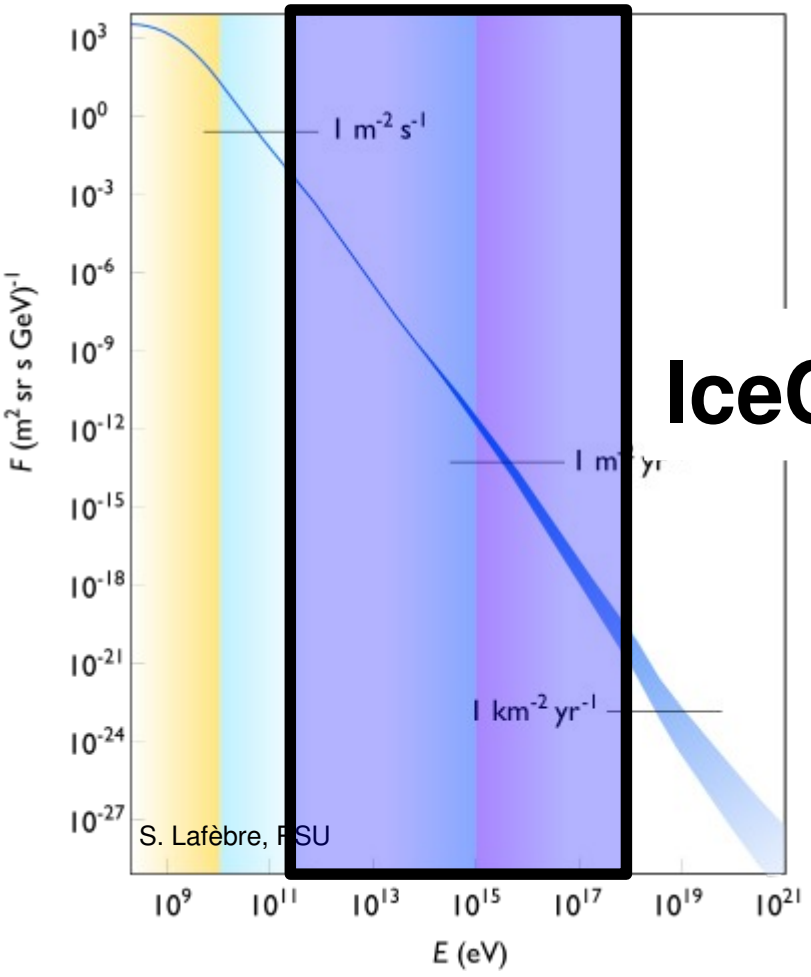
Direct Muon Spectrum Measurement Possible

Interesting Physics

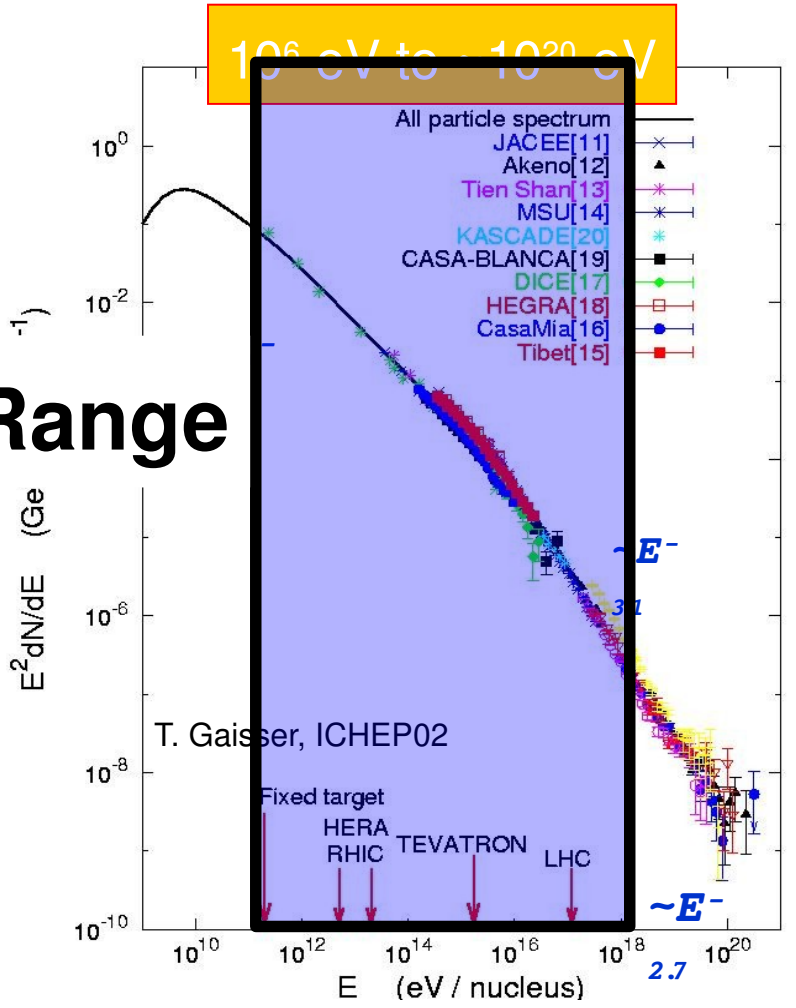
Also Helps with Diffuse Neutrinos

Backup Slides

Cosmic Rays

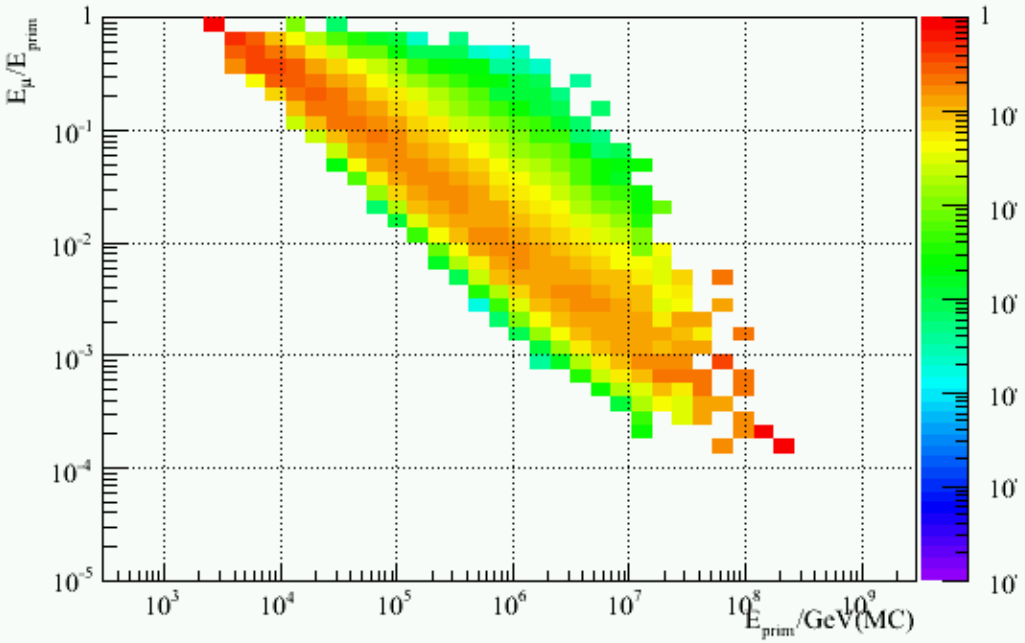


IceCube Range

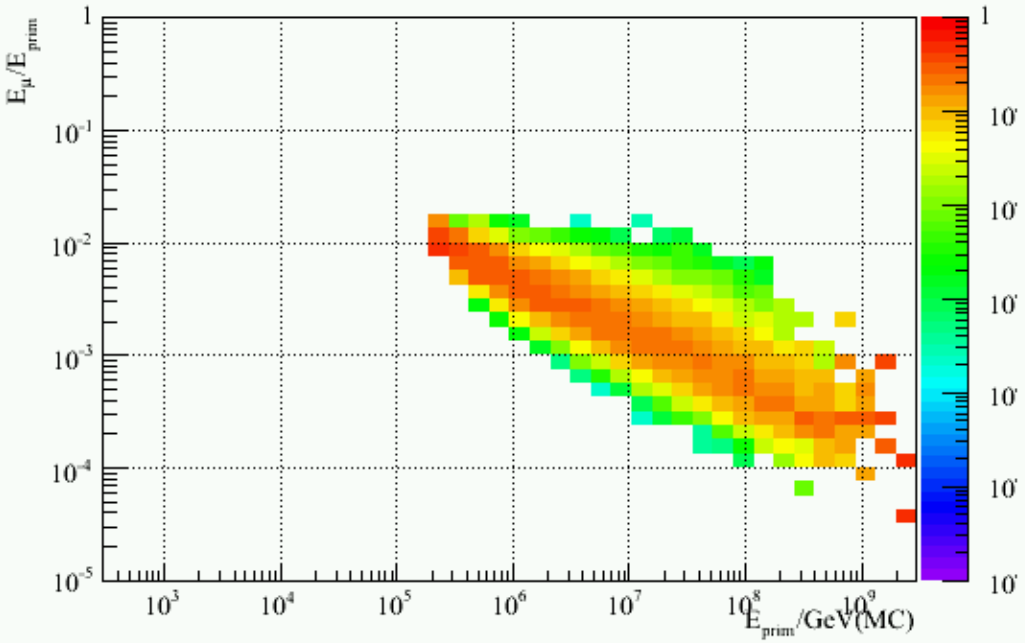


[GeV]

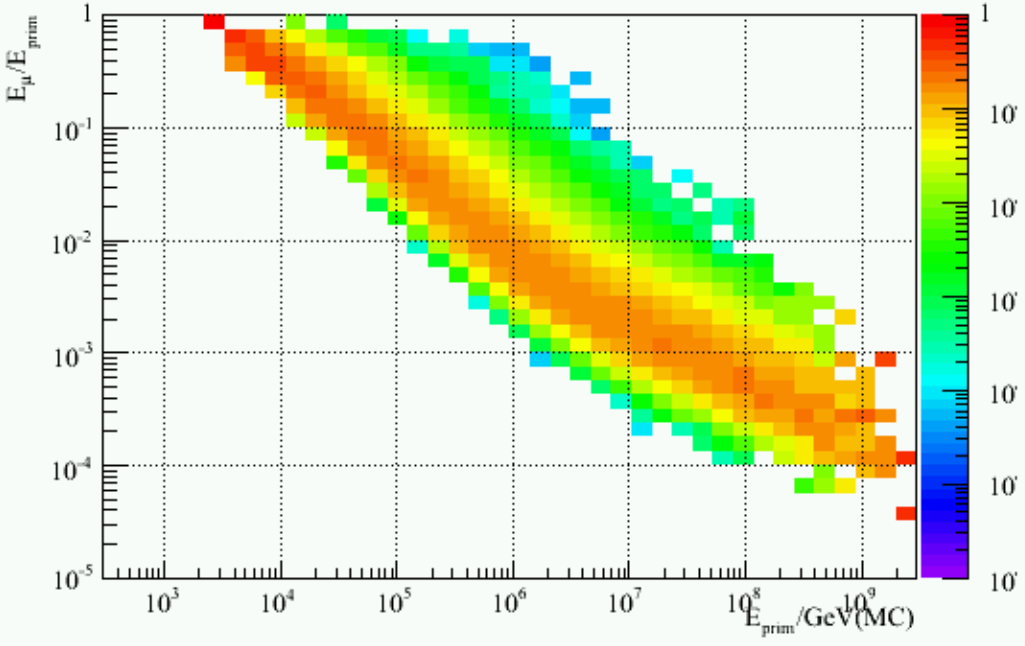
Protons



Iron



All




Allergen Filtration • 100% Dust Mites • 99.98% Ragweed Pollen