IceCube Review

Our present status

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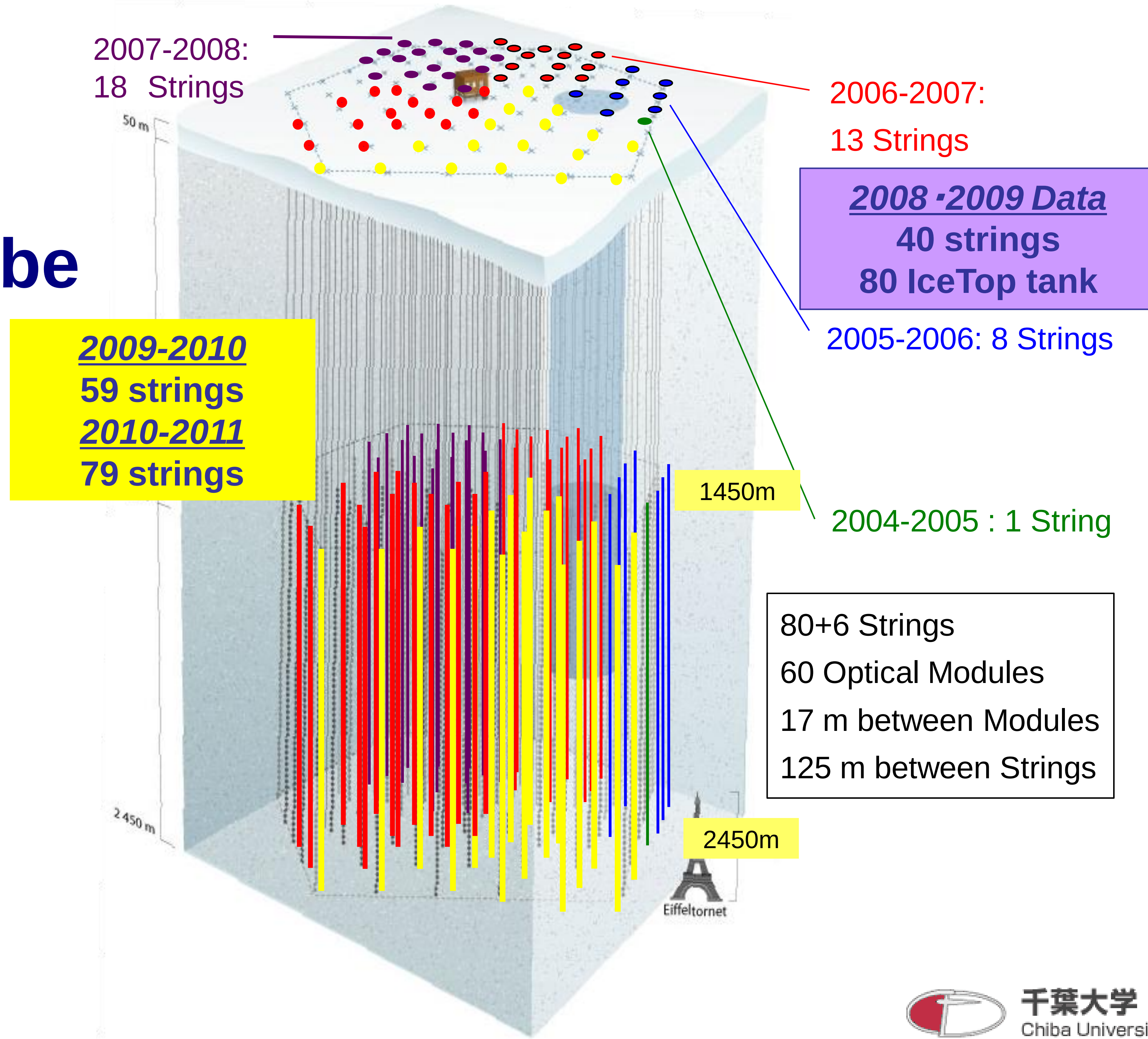
Chiba University

IceCube



千葉大学
Chiba University

IceCube

The IceCube Collaboration

USA:
Bartol Research Institute, Delaware
University of California, Berkeley
University of California, Irvine
Pennsylvania State University
Clark-Atlanta University
Ohio State University
Georgia Tech
University of Maryland
University of Alabama, Tuscaloosa
University of Wisconsin-Madison
University of Wisconsin-River Falls
Lawrence Berkeley National Lab.
University of Kansas
Southern University and A&M College, Baton Rouge
University of Alaska, Anchorage

Sweden:
Uppsala Universitet
Stockholm Universitet

UK:
Oxford University

Germany:
DESY-Zeuthen
Universität Mainz
Universität Dortmund
Universität Wuppertal
Humboldt Universität
MPI Heidelberg
RWTH Aachen
Ruhr-Universität Bochum

Switzerland:
EPFL

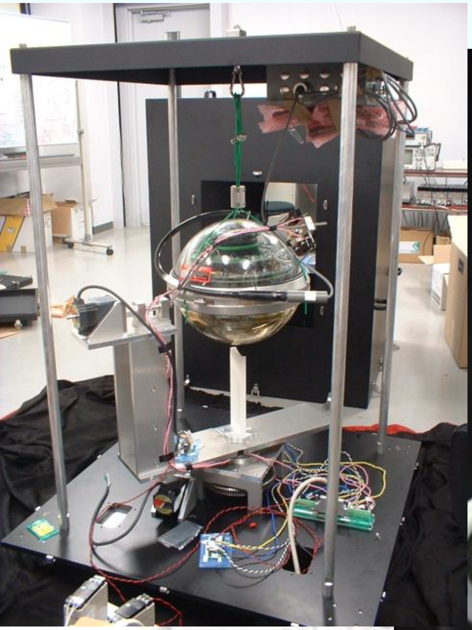
Belgium:
Université Libre de Bruxelles
Vrije Universiteit Brussel
Universiteit Gent
Université de Mons-Hainaut

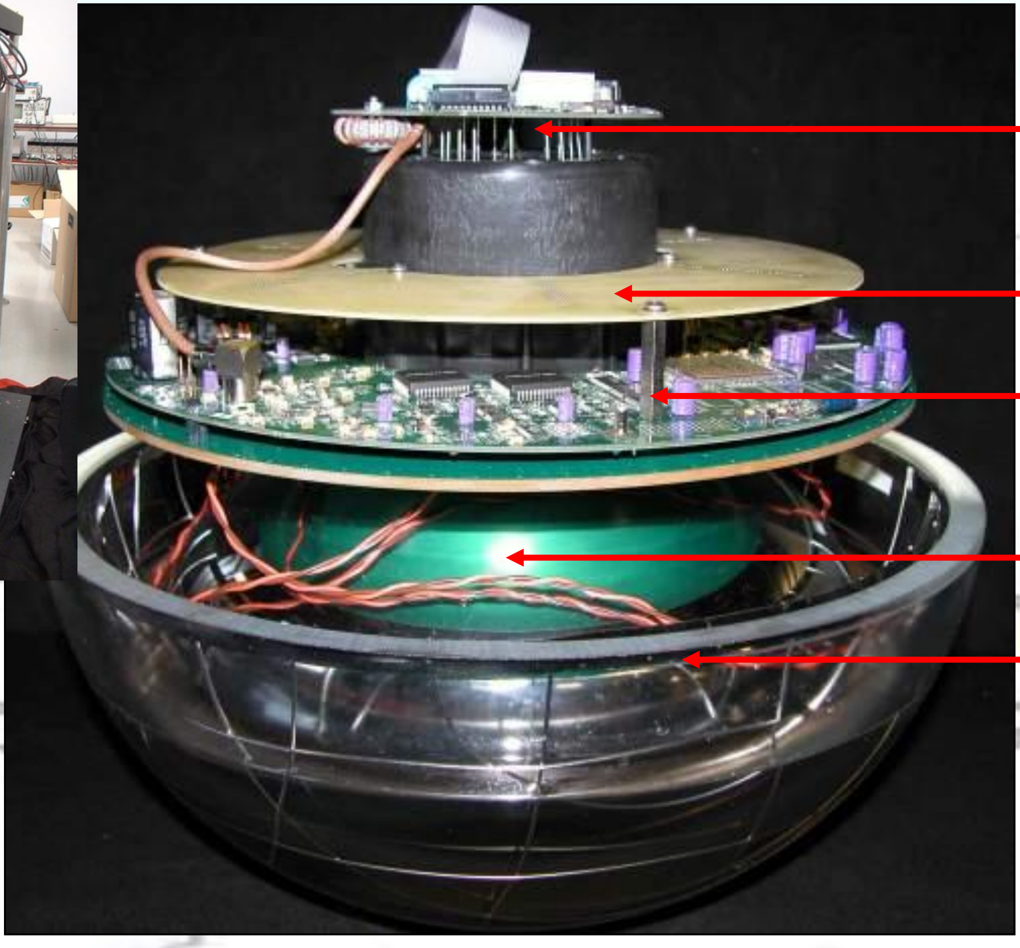
Japan:
Chiba University

New Zealand:
University of Canterbury

33 institutions, ~250 members
http://icecube.wisc.edu

DOM
Digital Optical Module



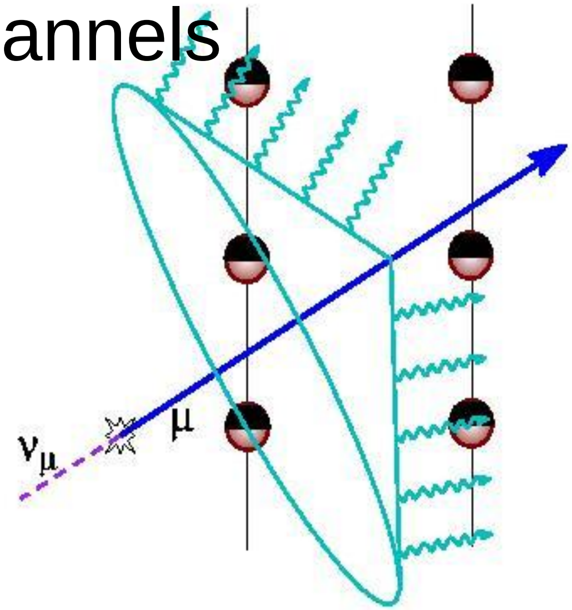


IceCube Event Topology

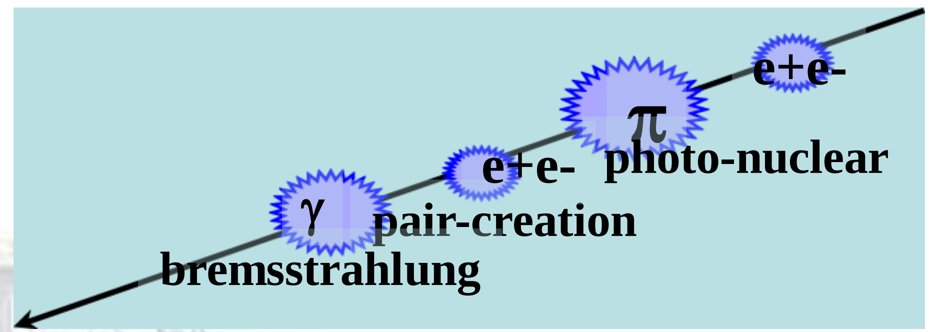
Main channels

sub-channels

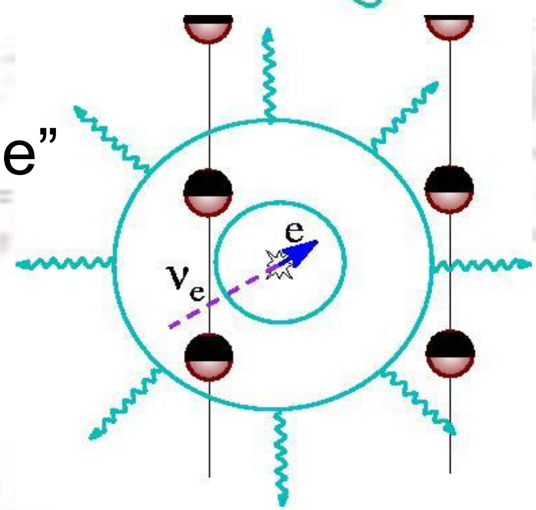
“Track”



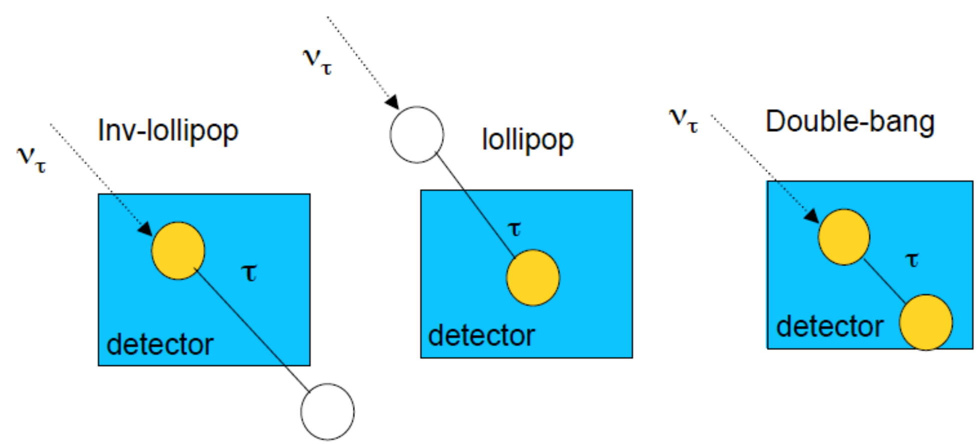
“Composite Bright Track”



“Cascade”



High E ν_τ: lollipops and double bangs



Data Filtering at South Pole

PY 2008 season

40 strings ~ a half of the completed IceCube

Simple Majority Trigger
8 folds with 5 μ sec

~ 950 Hz

Muon Filter
selects
“up-going” tracks

~20 Hz

EHE Filter
selects
“bright” events

~1.3 Hz

NPE > 630 p.e.

Cascade Filter
selects
“cascade”-like events

~17 Hz

Many others

- Min Bias
- Moon
- IceTop
- etc

To Northern Hemisphere

Point Source Search

Materials to cook

$\nu_\mu \rightarrow \mu$ base

μ filtered, EHE filtered and min-bias events

Require Quality cuts in multiple stages

Common aspects
In many other analysis

- to filter out vastly dominated down-going muons
- to realize reasonable agreement between MC and data

Point source specific →

- to create a sample of events with good angular resolution

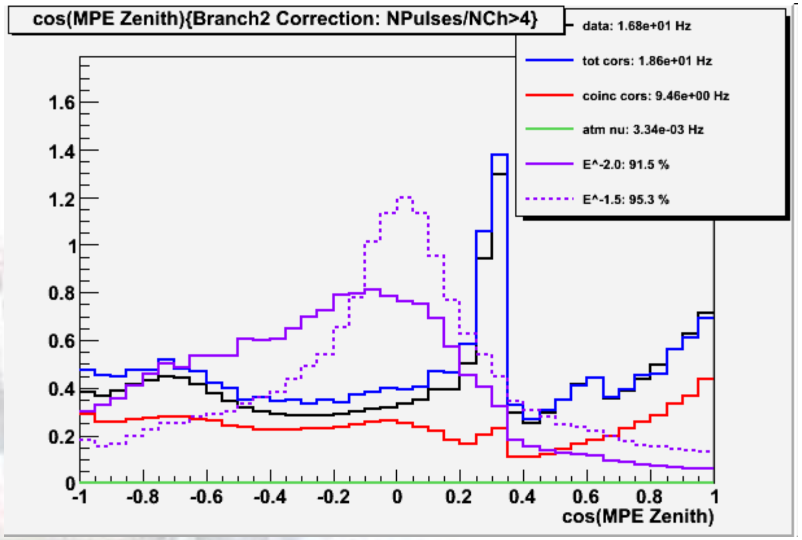
Point Source Search
Event Selection

Cut #1

$\theta > 90$ deg ("up-going" cut)

Attention: still atm μ dominates!!

Needs a series of further filtering to get us to **ν level**



Cut #2

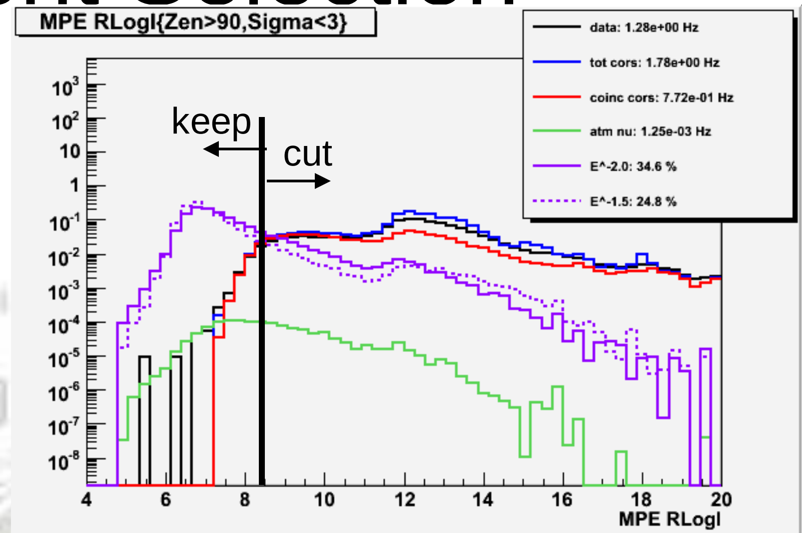
Paraboloid sigma cut $\sigma_{paraboloid} < 3$ deg

Ensure good angular resolution

Point Source Search Event Selection

Cut #3

cuts with μ track likelihood



Cut #4

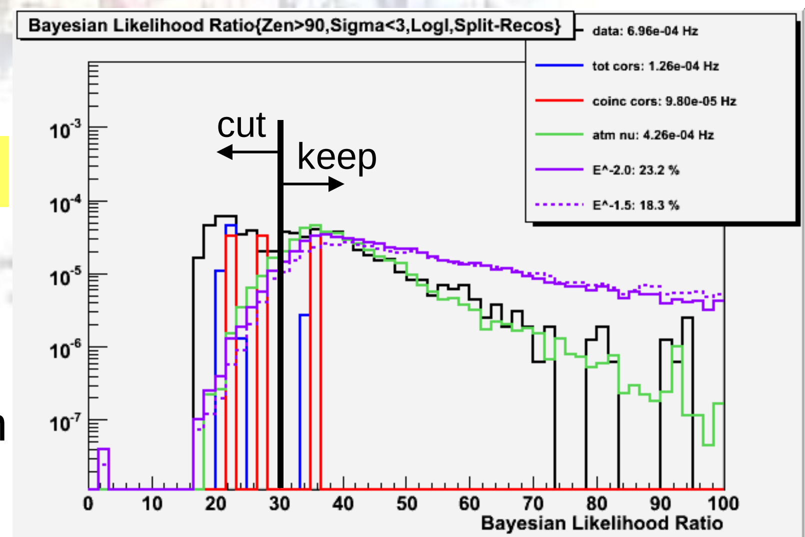
split zeniths > 80 deg

Cut #5

Bayesian likelihood ratio

Test of down-going hypothesis

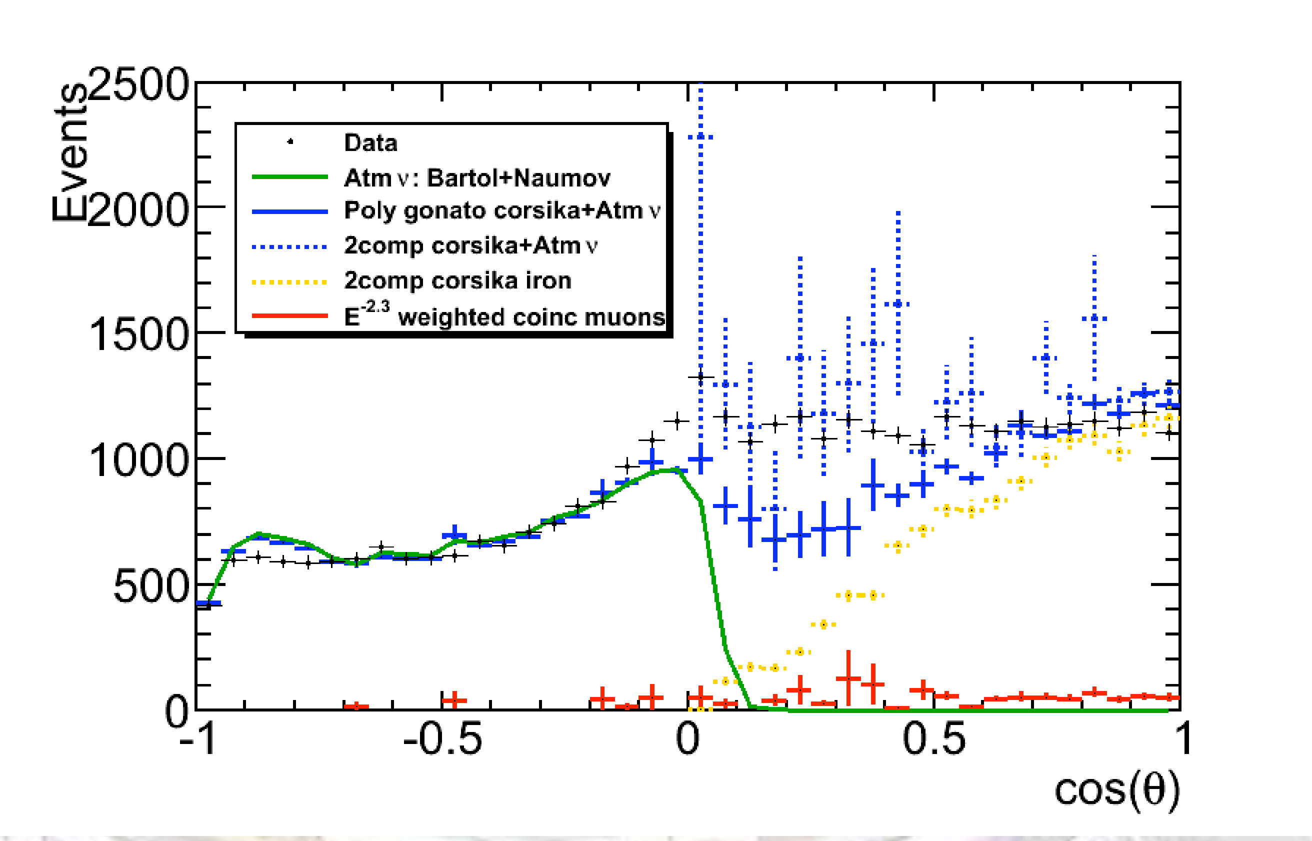
Now on **ν level**



Cut #6

cuts on track length and Nch

Zenith Angle Distribution in the final sample



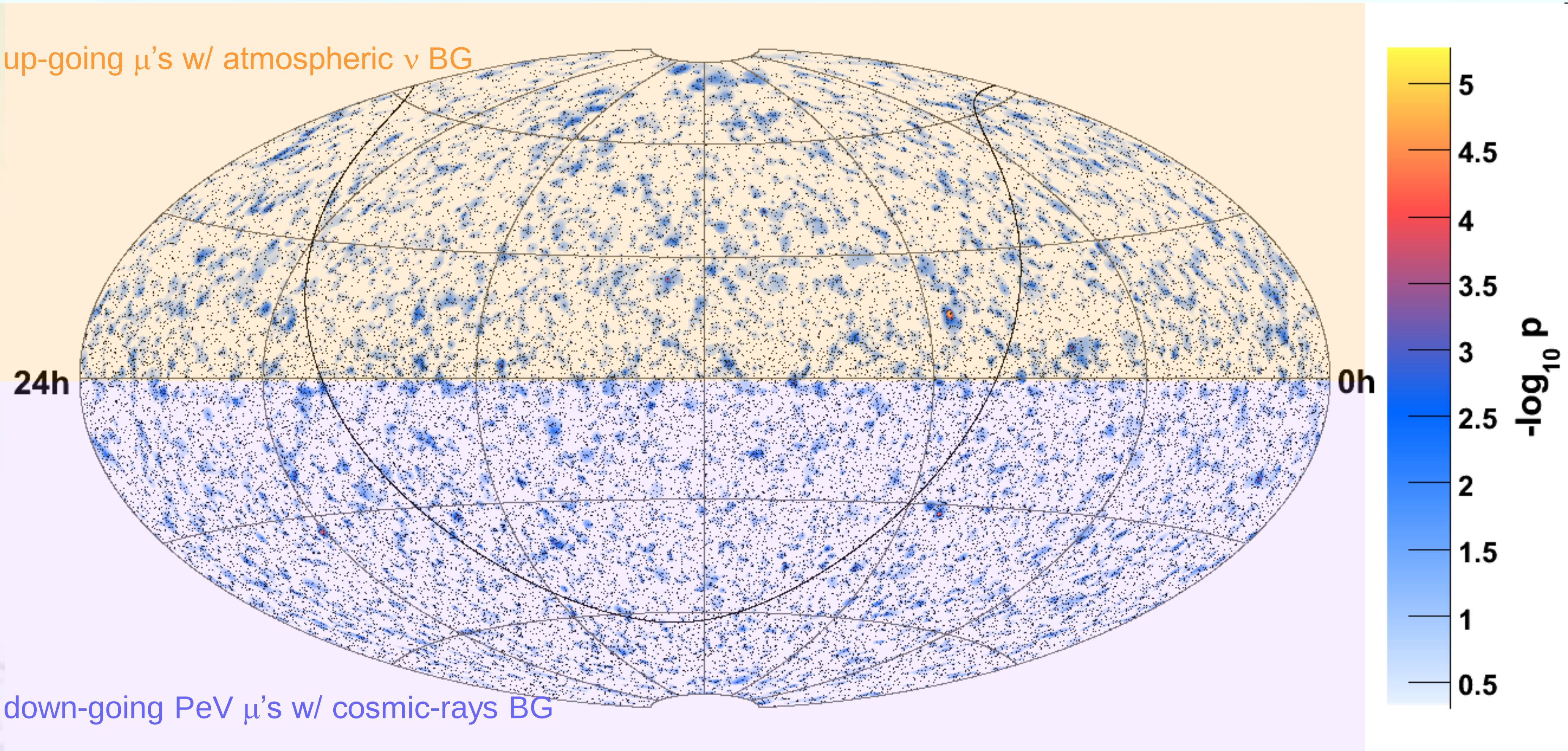
* Introduced hard “down-going” cuts for extension to Northern sky

(retains only O(PeV) down-going events)

Jon Dumm (UW-Madison)

千葉大学 Chiba University

ν skymap



All sky search: post-trial p-value 18%

Hottest spot: RA 113.75 Dec 15.15 -log(p)=5.28

Jon Dumm (UW-Madison)

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Source List Results

IceCube Preliminary

	p-value
Crab	---
BL Lac	0.226
Mrk 501	0.421
Mrk 421	0.142
M87	---
CygA	0.439
PKS 1622-297	0.048

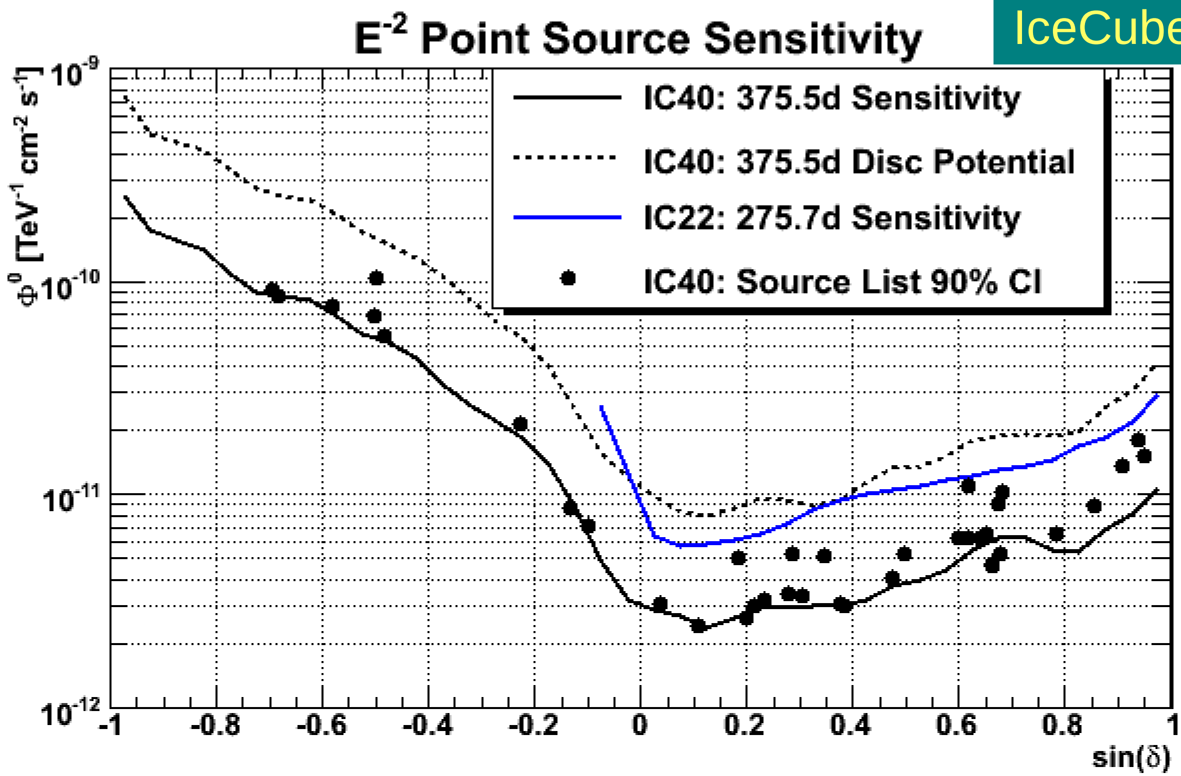
← The highest significance from list of the 39 IceCube sources

Pretrial 4.8 % →post-trial 62 % for the source list

* Shown here is only a part of the IceCube pre-determined source list

Point Source Sensitivity

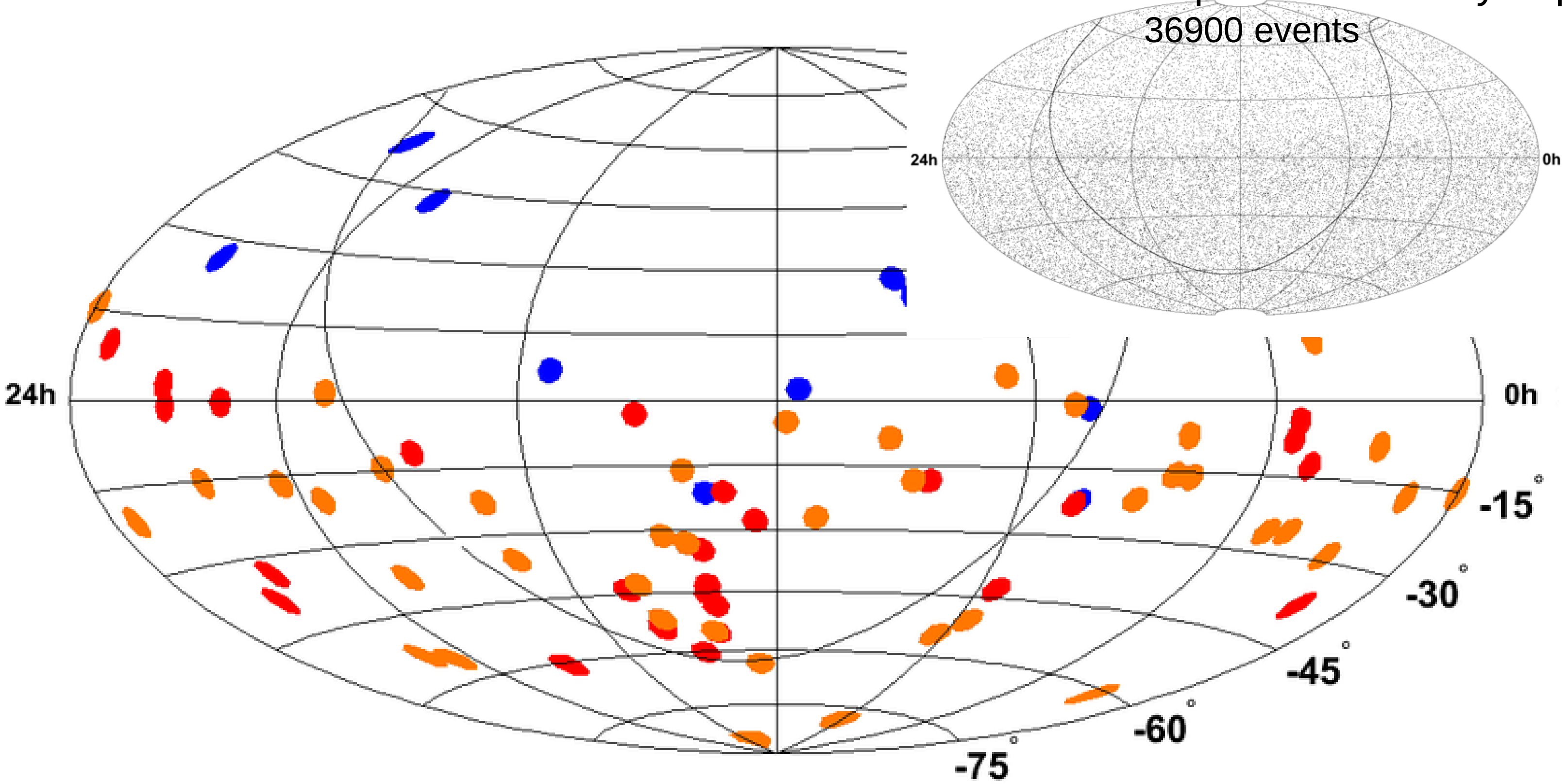
IceCube Preliminary



Jon Dumm (UW-Madison)

UHECR correlation analysis

IceCube 2008 point-source skymap
36900 events



- 27 events from PAO in the 2007 publication. Energy > 57 EeV
- 42 events released from PAO 2010. Energy > 57 EeV
- 13 stereo events from HiRes. Energy > 56 EeV

Robert Lauer (DESY)

UHECR correlation analysis

Correlation search optimized for
hypotheses of magnetic deflection of cosmic rays by 3 degree

J. Abraham et al (Pierre Auger collaboration) Astropart. Phys. **29** 188-204 (2008).

Unbinned Likelihood search with σ = 3 degree

IceCube Preliminary

-2(log L(signal) – log L(bg)) = 0 i.e., consistent with the background-only hypotheses

Binned search with 3 degree radius

298 IceCube events found in 82 bins of 3 deg radius

274 events expected from the background-only hypothesis

1.48 σ (p-value 0.069)

Note: ν emission is assumed here from O(TeV) extending to O(EeV) (typically with E^{-2})

i.e., not like the GZK ν emission where main energy range is above PeV

Robert Lauer (DESY)

GRB model-dependent Search

Materials to cook

$\nu_\mu \rightarrow \mu$ base

μ filtered and EHE filtered

Require Quality cuts in multiple stages

Common aspects
In many other analysis

- to filter out vastly dominated down-going muons **Zenith > 85 deg.**
- to realize reasonable agreement between MC and data

GRB specific → use “off-time” data as the BG sample to train the BDT

Building of the PDFs

Unbinned Maximum Likelihood

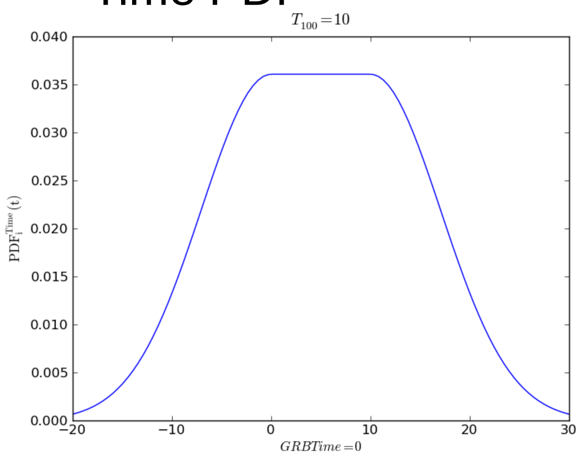
PDF

$$S_i^{tot}(\vec{x}, t, E) = PDF_i^{space}(\vec{x}) * PDF_i^{time}(t) * PDF_i^{Energy}(E)$$

Total PDF

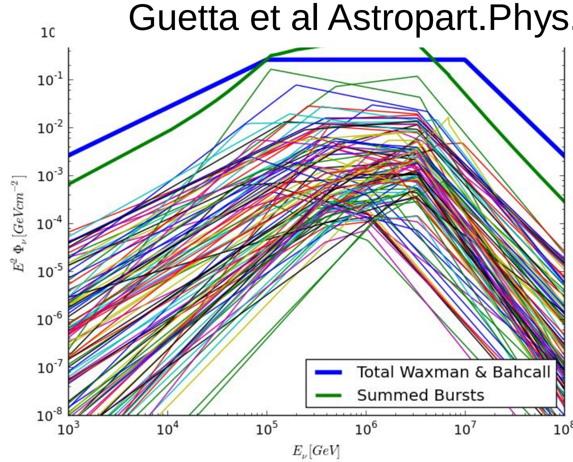
$$P_i(|\mathbf{x}_i - \mathbf{x}_s|, E_i, \gamma, n_s) = \frac{n_s}{n_{\rm tot}} S_i(|\mathbf{x}_i - \mathbf{x}_s|, E_i, \gamma) + \left(1 - \frac{n_s}{n_{\rm tot}}\right) B(\mathbf{x}_i, E_i)$$

Time PDF



Predicted ν spectra

Guetta et al Astropart.Phys. 20 (2004) 429



Optimize BTD score
to maximize the discovery
potential

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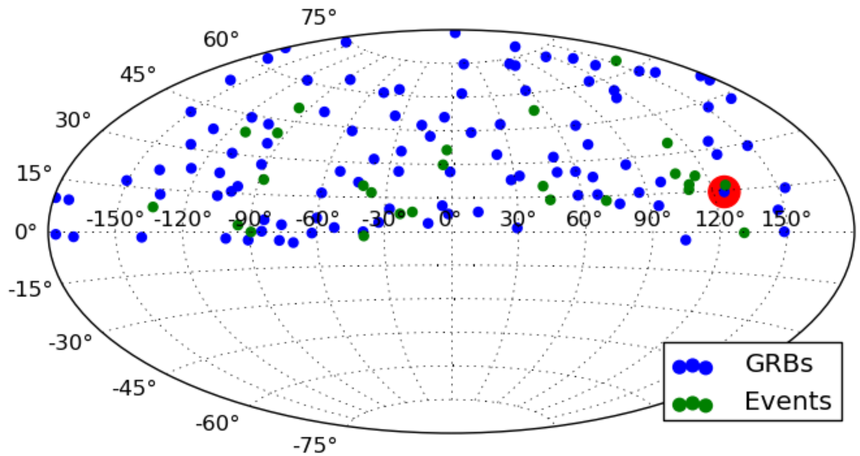
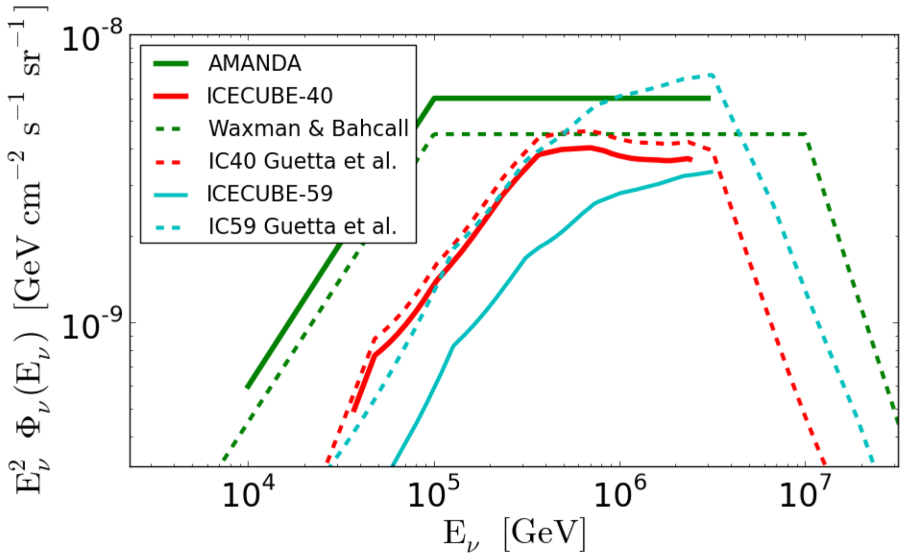
No association of ν's with GRB..

109 GRBs detected by Fermi, Swift, Konus, and WAM
in the IceCube FOV (2009 June – 2010 May)

Peter Redl (UMD)

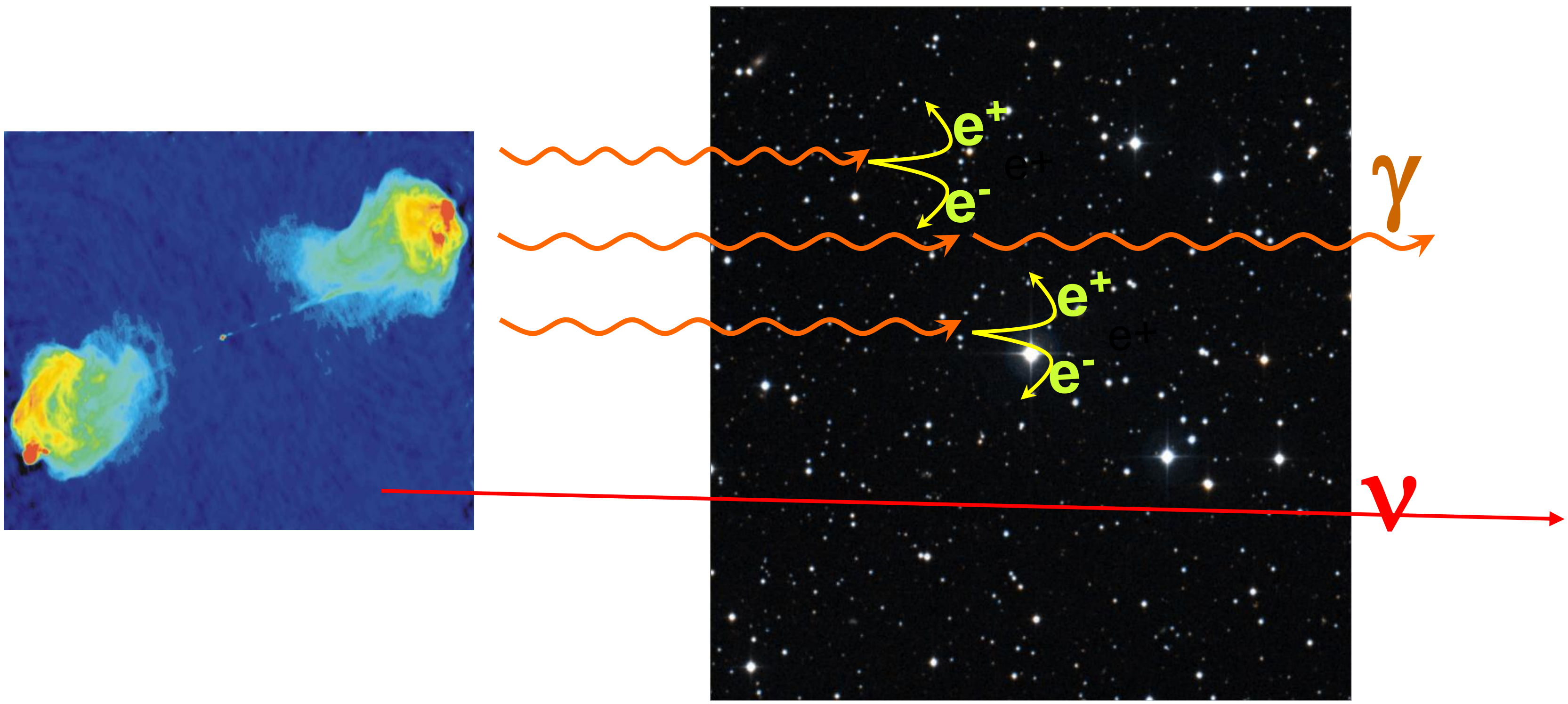




We are on the way to indicate GRBs are unlikely to be a major UHECR origin.

Astronomical Diffuse Neutrinos

Neutrino can travel very long, carrying the fossil record of the Universe's emission activities.



Diffuse ν Search

O(100 TeV) ~ 10 PeV

Materials to cook

μ filtered, EHE filtered events

$\nu_\mu \rightarrow \mu$ base

Require Quality cuts in multiple stages

Common aspects
In many other analysis

- to filter out vastly dominated down-going muons
- to realize reasonable agreement between MC and data

Diffuse analysis specific

Stronger cuts (than PS search) required for enhancing purity of ν sample

Diffuse ν search

Quality cuts : stronger than those for the point-source search

Level 1
$\theta > 90$ deg

Level 2
cuts with μ track likelihood

Level 3
$\sigma_{paraboloid} < 3$ deg

Level 4
Bayesian likelihood ratio

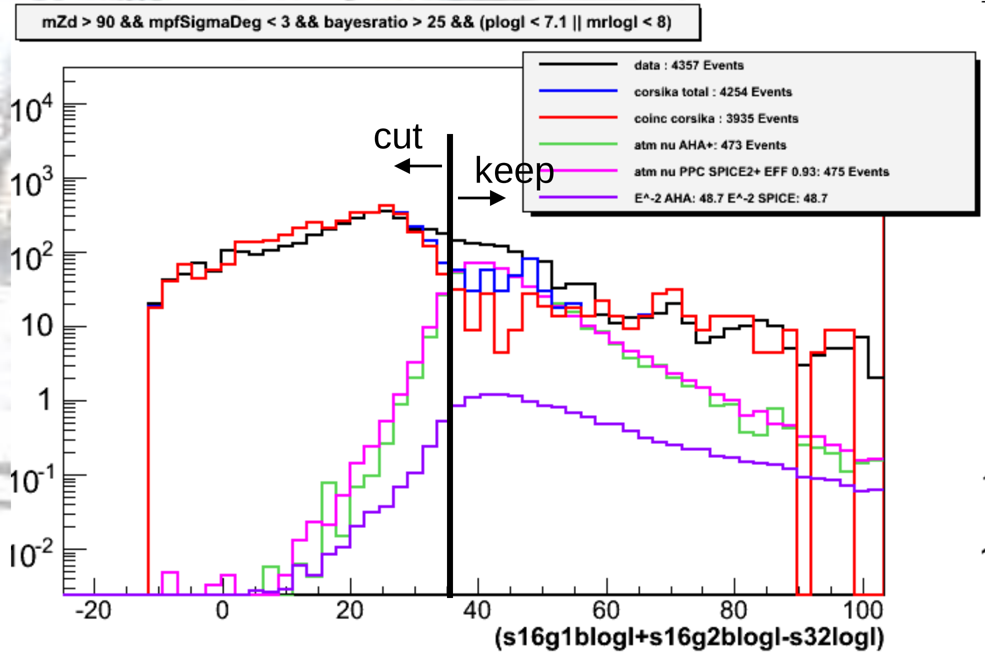
Level 5
Split Bayesian likelihood ratio

Test of down-going coincidence μ hypothesis

→ Get into *almost* **ν level**

Level 6
split zeniths > 80 deg

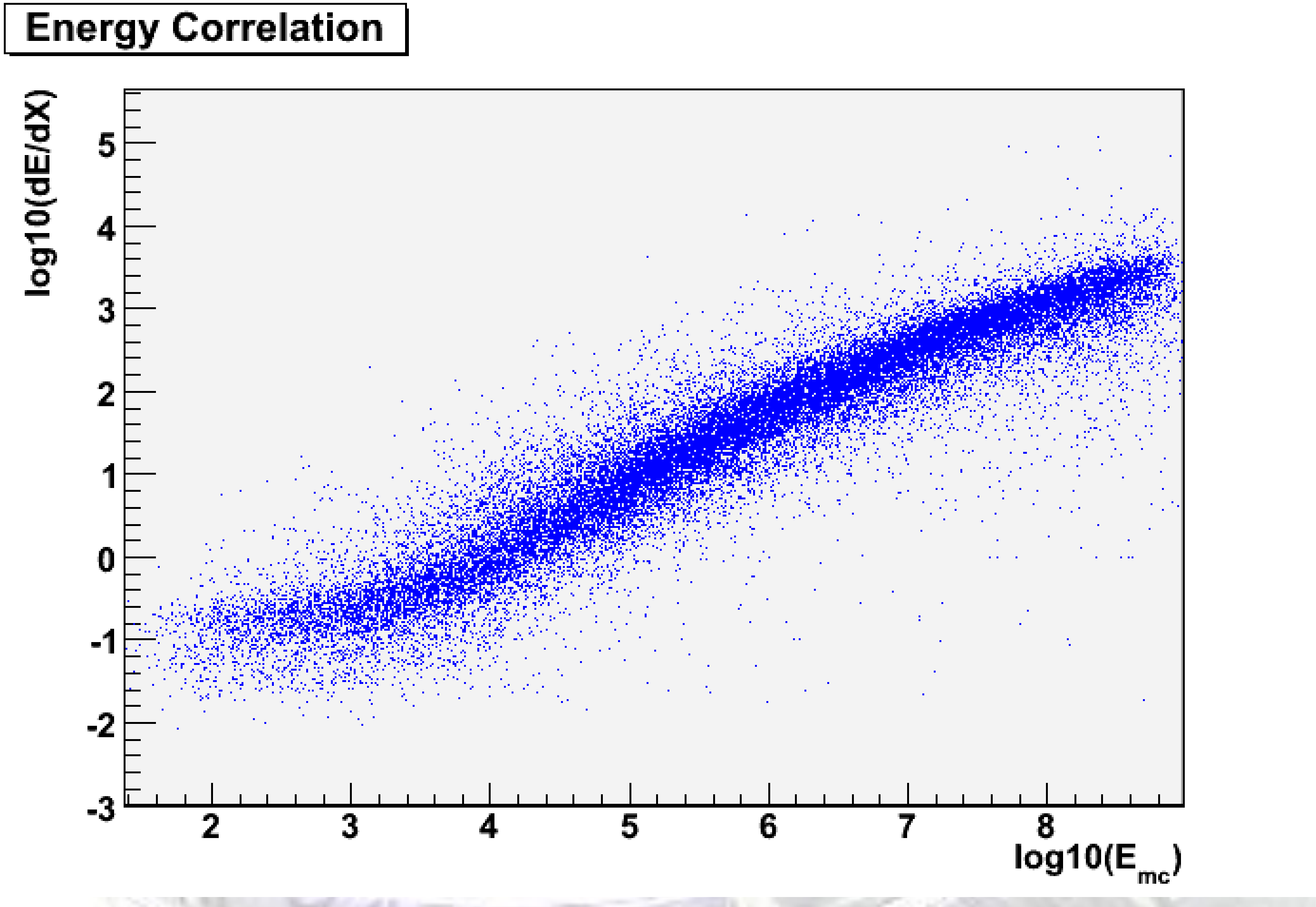
Level 7
cuts on track length and Nch



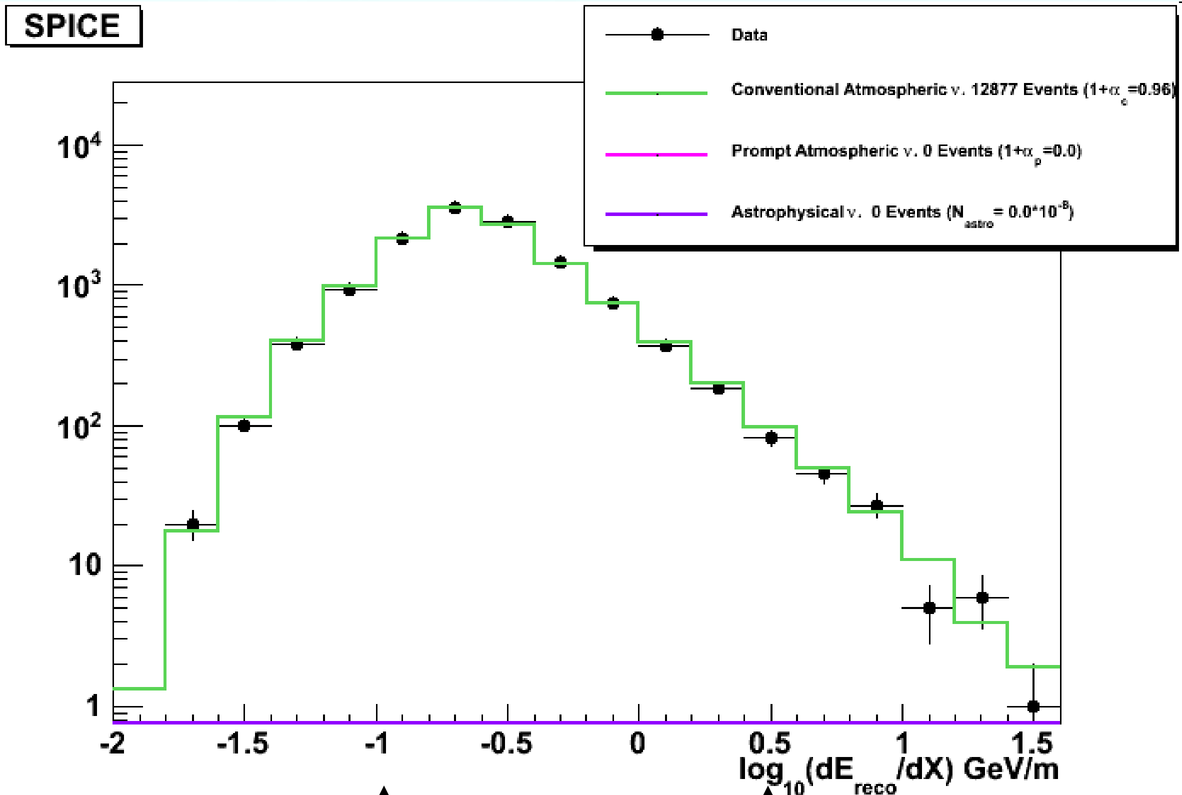
Sean Grullon (UW-Madison)

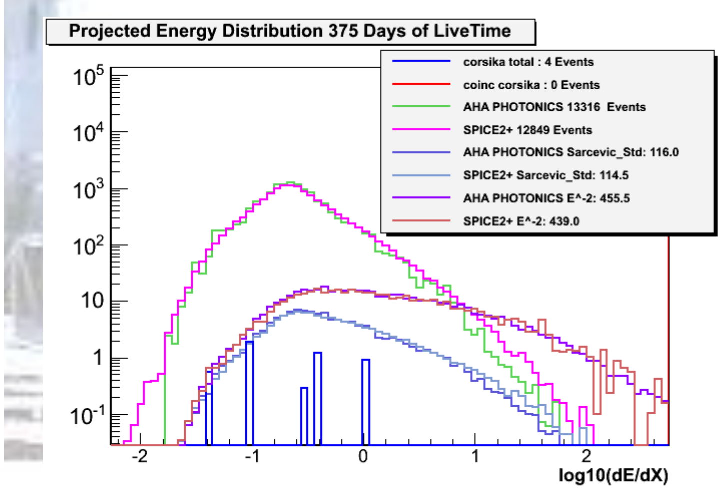
Now look at "energy" distribution

Calculates μ's energy loss (dE/dX) from the Cherenkov γ profile



Final "Energy" distribution





O(100GeV~TeV)

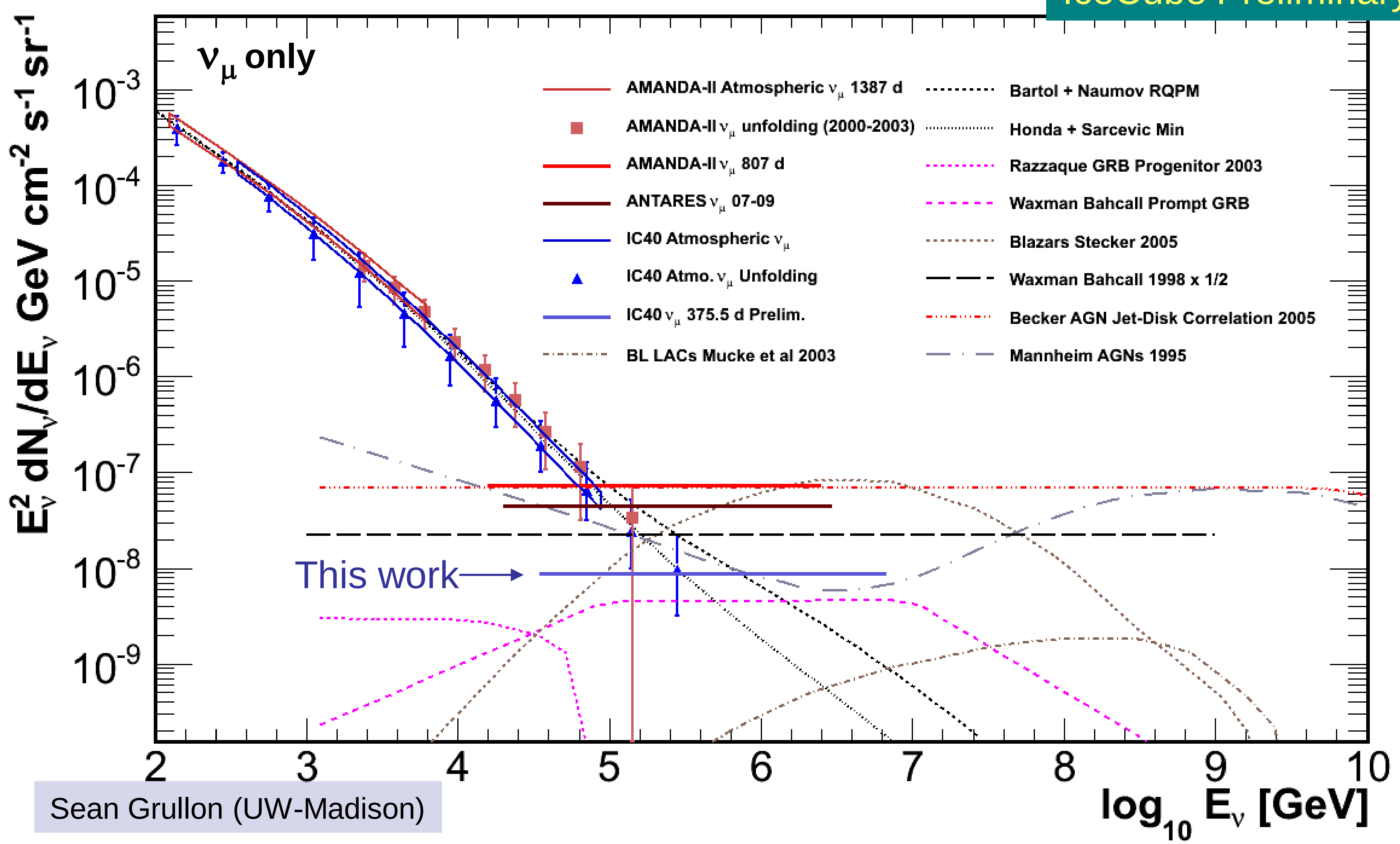
O(10TeV~100TeV)

Sean Grullon (UW-Madison)

Diffuse ν limit

Now below the Waxman-Bahcall limit

IceCube Preliminary



Sean Grullon (UW-Madison)

Atmospheric ν spectrum

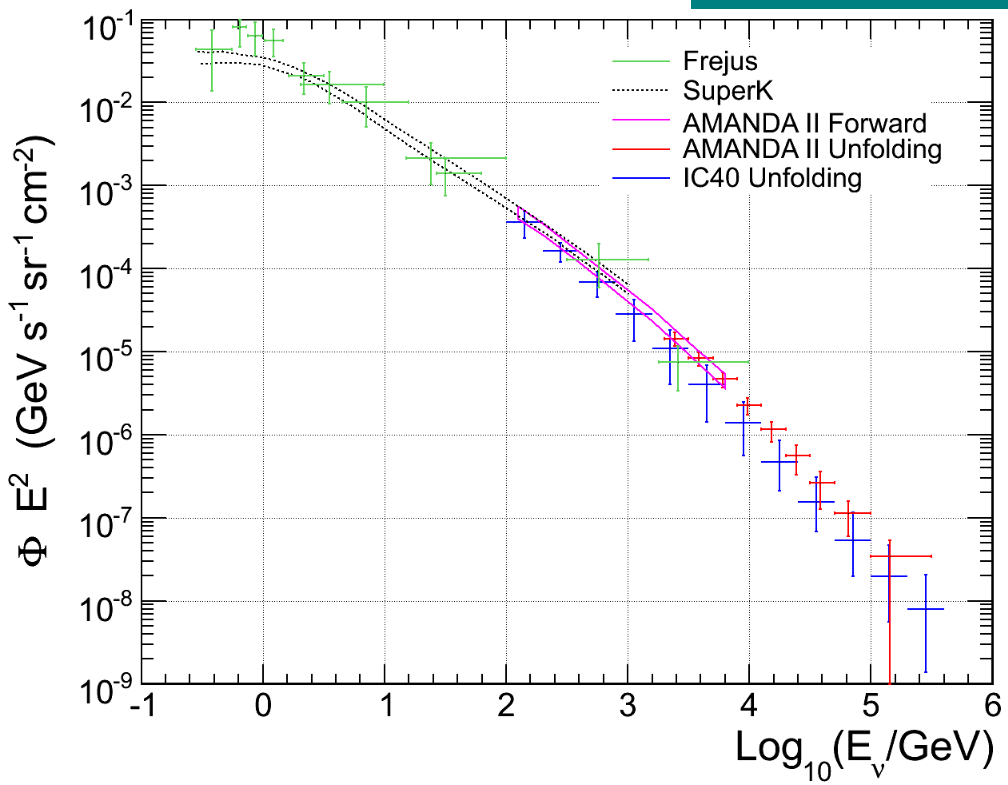
The quality cuts by the similar philosophy
but with **the BDT training method**

An independent analysis with slightly different event selections

IceCube Preliminary

dE/dX → Eν

Spectrum Unfolding
by SVD method
NIM A 372 (1996) 469



Warren Whuelsnitz (UMD)

No indication of prompt ν and new physics (e.g. quantum gravity)

GZK ν Search

O(PeV) ~ 10 EeV

Materials to cook

EHE filtered events

All ν flavor base

No strong quality cuts necessary because..

Unique features
in this particular analysis

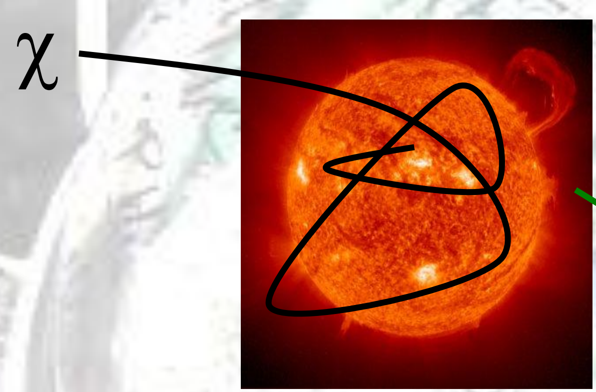
these ν's are more energetic than atmospheric μ BG

Just increase energy threshold in analysis leads to better S/N

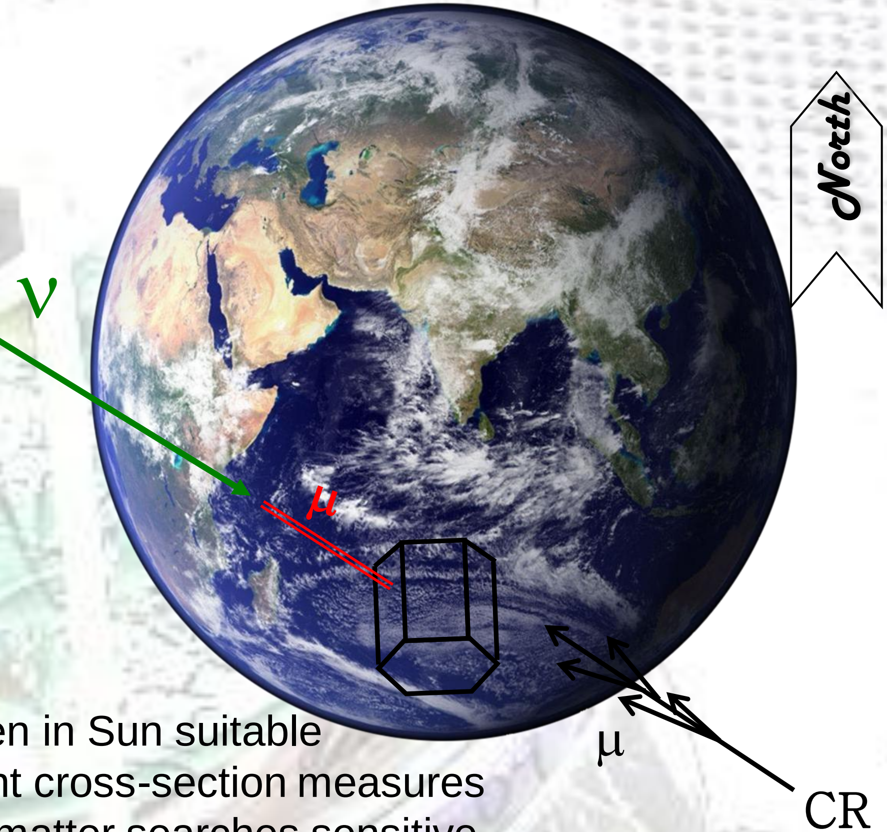
GZK analysis specific issues

- Earth filters out signal ν as well

MSSM Neutralino Dark Matter



$$\chi\chi \rightarrow b\bar{b}, \tau^{+}\tau^{-}, W^{+}W^{-}, \ldots \rightarrow \nu s$$



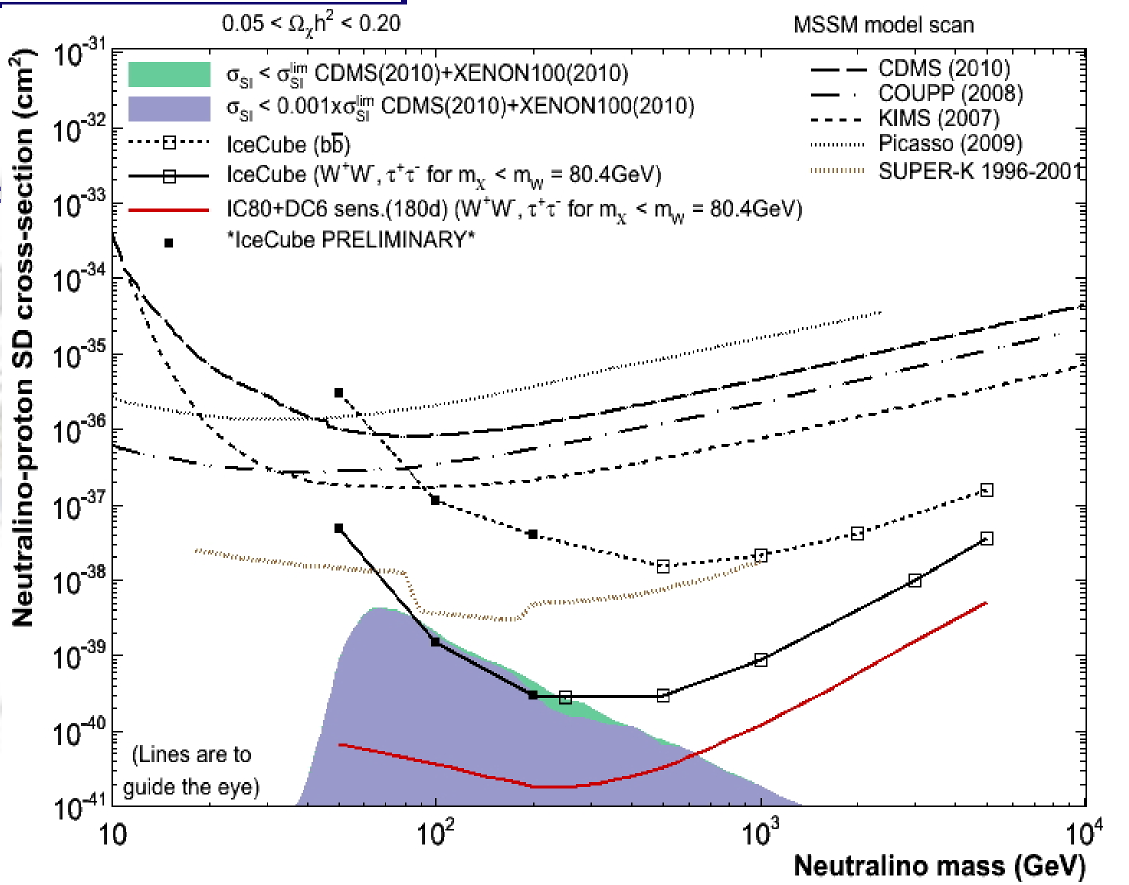
Spin Dependent cross-section: Abundant hydrogen in Sun suitable for spin dependent cross-section measures

Spin Independent cross-section: Many direct dark matter searches sensitive

Dark matter searches: Solar WIMPs

$$\chi\chi \rightarrow b\bar{b}(soft), W^+W^-(hard), \ldots \rightarrow \nu s$$

- Determine the muon flux from the direction of the Sun
  - A few to 10^3 events per year
  - GeV to TeV energies
- Limit the neutrino-induced muons from WIMP annihilation
- A strong limit on SD cross-section and good potential



□ Phys. Rev. Lett. 102 201302 arXiv:0902.2460

■ IceCube Preliminary

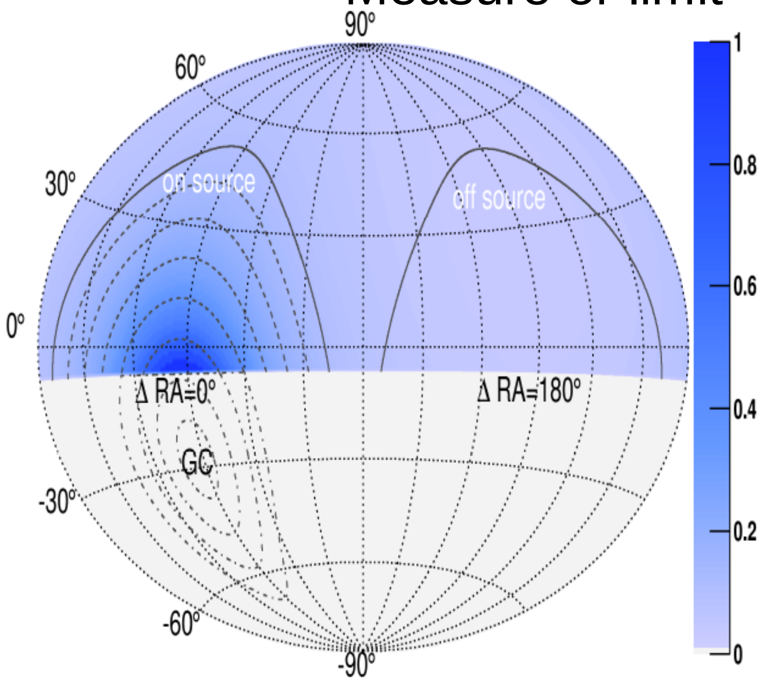
Dark Matter from the Galactic Halo

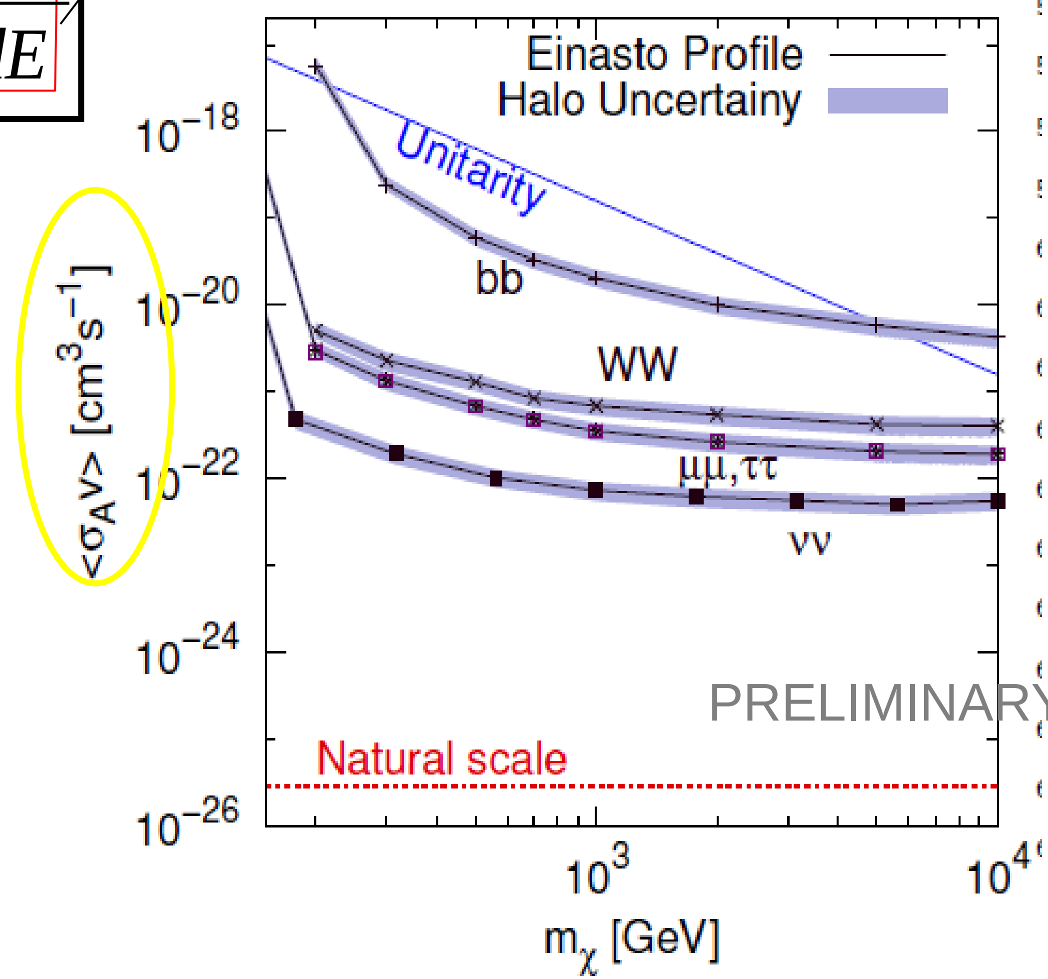
$$\frac{d\Phi_\nu}{dE} = \frac{<\sigma_A \upsilon>}{2} J(\psi) \frac{R_{sc}\rho_{sc}^2}{4\pi m_\chi^2} \frac{dN_\nu}{dE}$$

Dark matter density profile

Dark matter model

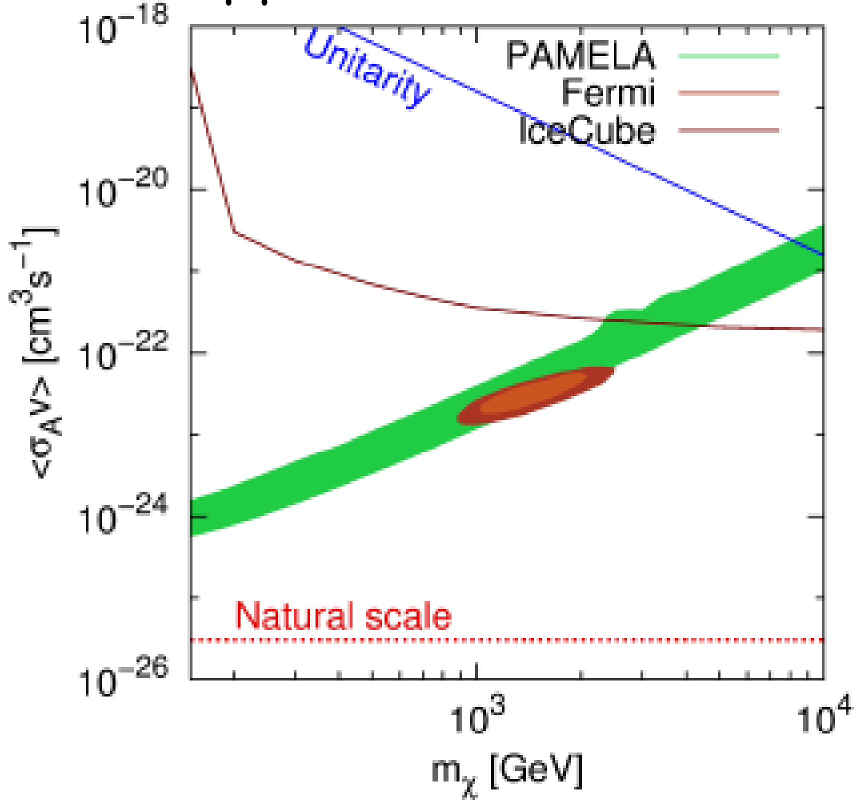
Measure or limit



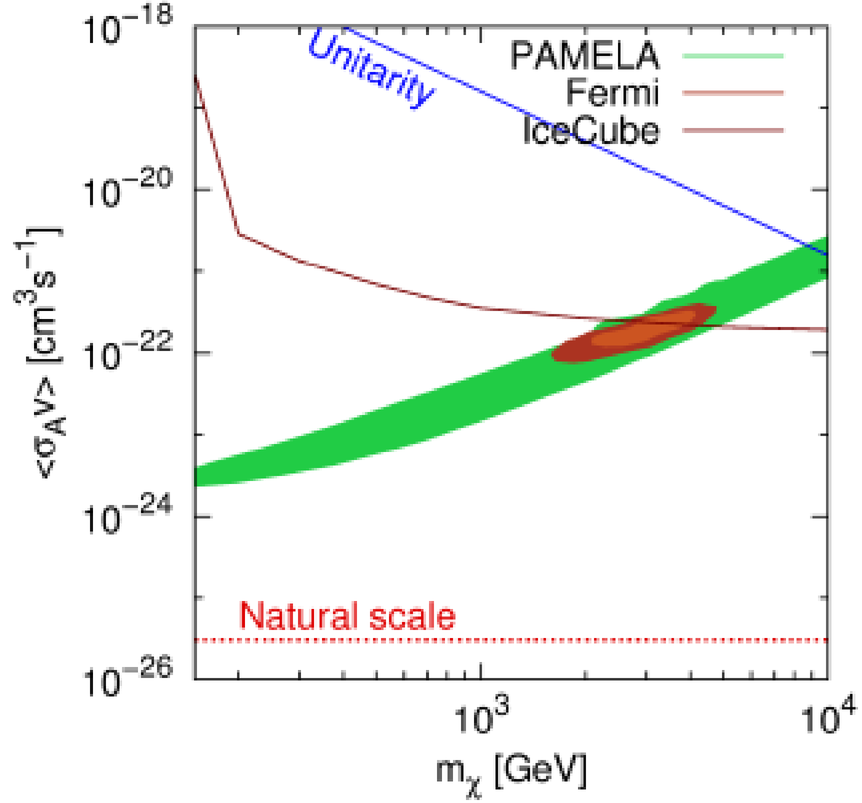


Dark Matter from the Galactic Halo

μμ



ττ



(My) Outlook

- Point Source 感度は既に 1/√T 領域に入った。GRB もかなり制限がついたが、あと3年程度は transient 現象では何か起こっても不思議でない。
- Diffuse ν (GZK 含む)探索はまだ 1/T で感度がどんどん向上。Stay tuned!

  new 2009-2010 data + published 2008-2009 data →2倍の向上

  2012 年5月までの data combined → published results の5倍以上

  (full IceCube 3 years equivalent)

- Deep Core physics 未開拓 特に

  100 GeV - TeVν astronomy