Recent IceCube Results from GRB Neutrino Searches

Nathan Whitehorn
for the IceCube Collaboration

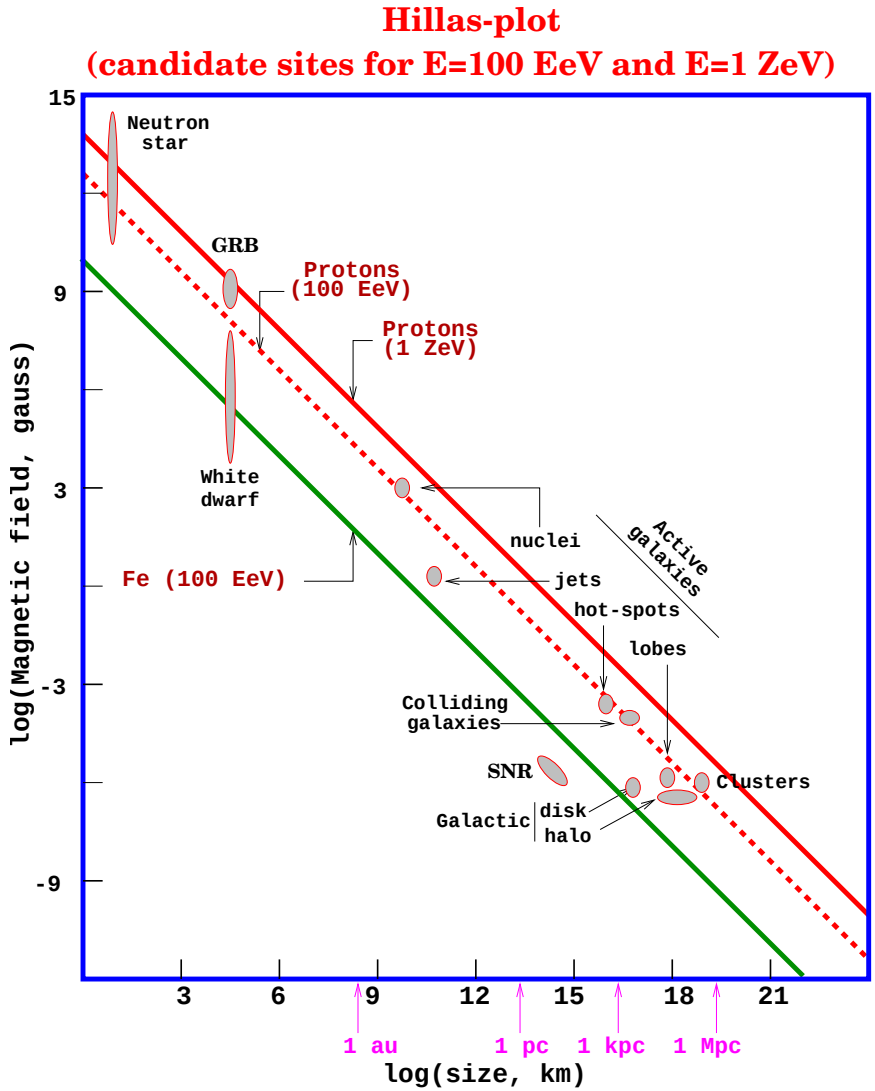
University of Wisconsin - Madison

June 7, 2012

The Problem

Limited number of possibilities to accelerate the highest energy cosmic rays

Which one is right?

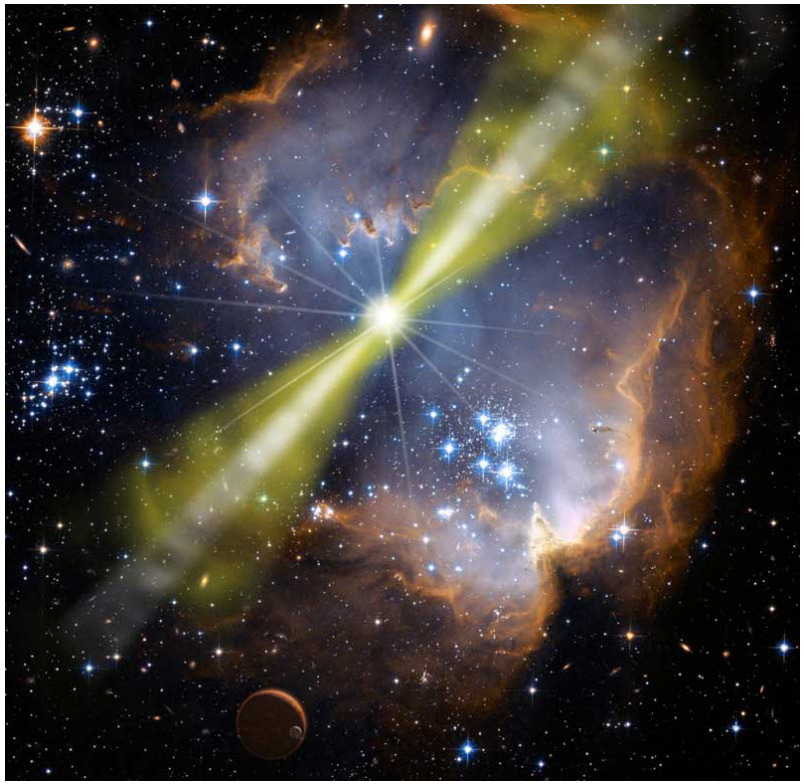


$E_{max} \sim ZBL$ (Fermi)

$E_{max} \sim ZBL\,\Gamma$ (Ultra-relativistic shocks-GRB)

The Solution?

- GRB Energy output: 10^{52} ergs in ≈ 1 second
- Similar to the energy density in ultra-high-energy cosmic rays
- Unknown progenitors
- Detected almost every day

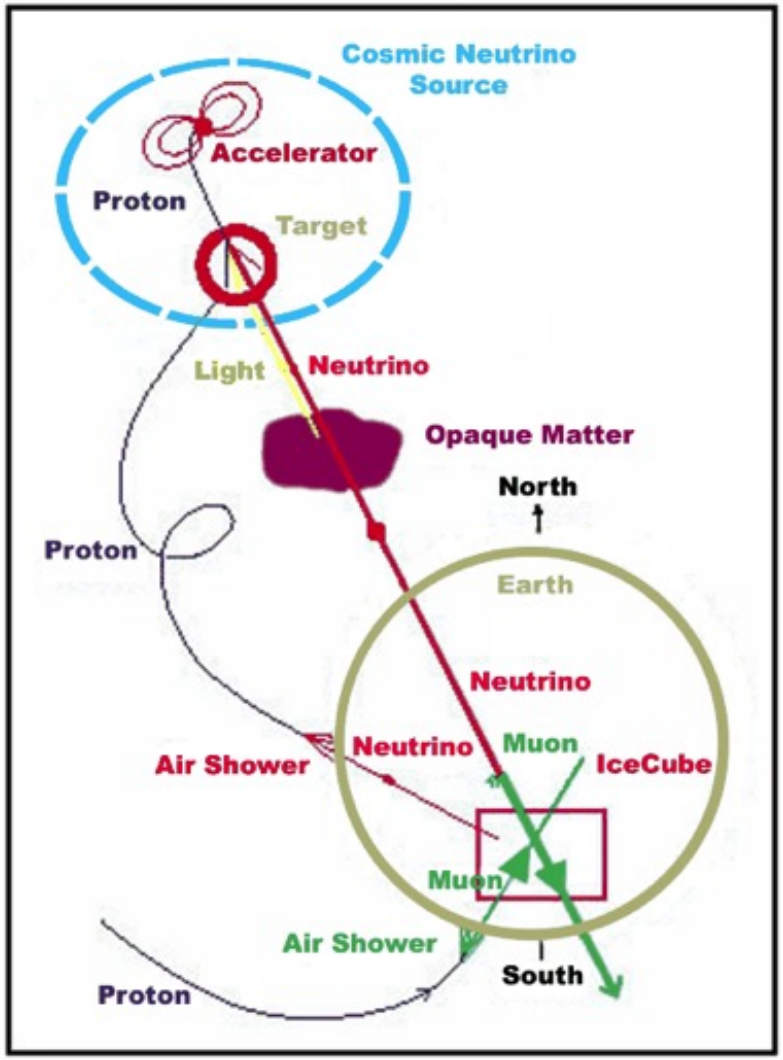


NASA/Swift

Mysteries

- Are GRBs the source of high energy cosmic rays?
- What causes GRBs?
- How and where are particles accelerated?

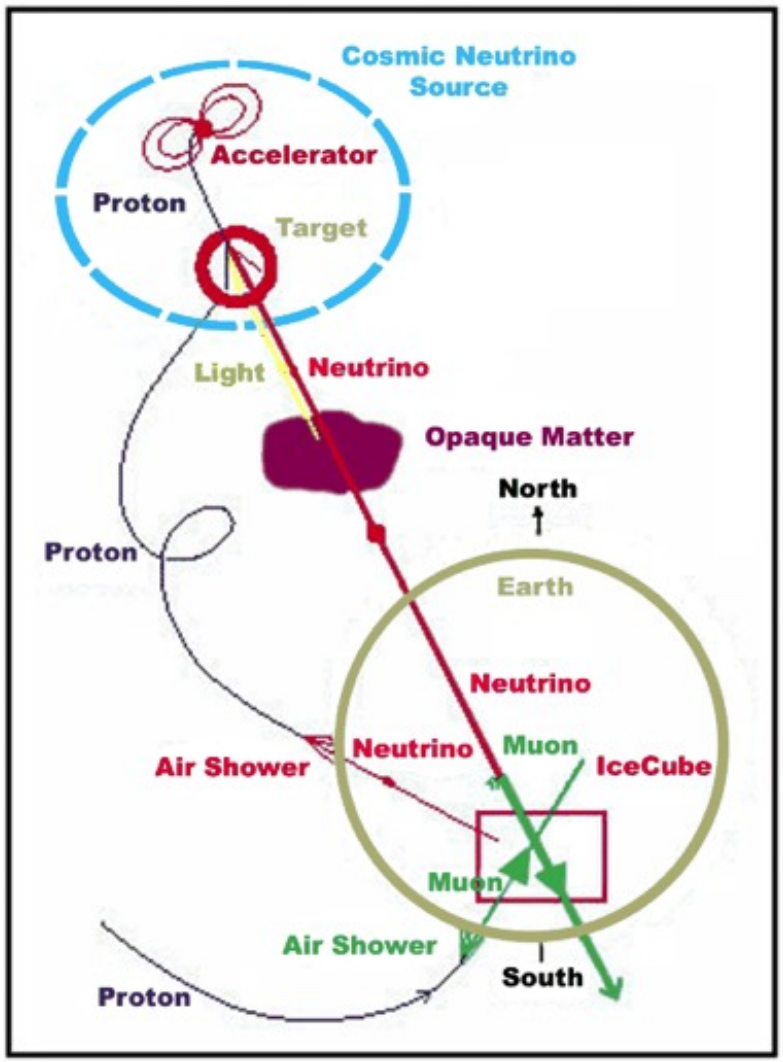
Testing the Theory



Gamma rays:

- Ambiguous

Testing the Theory



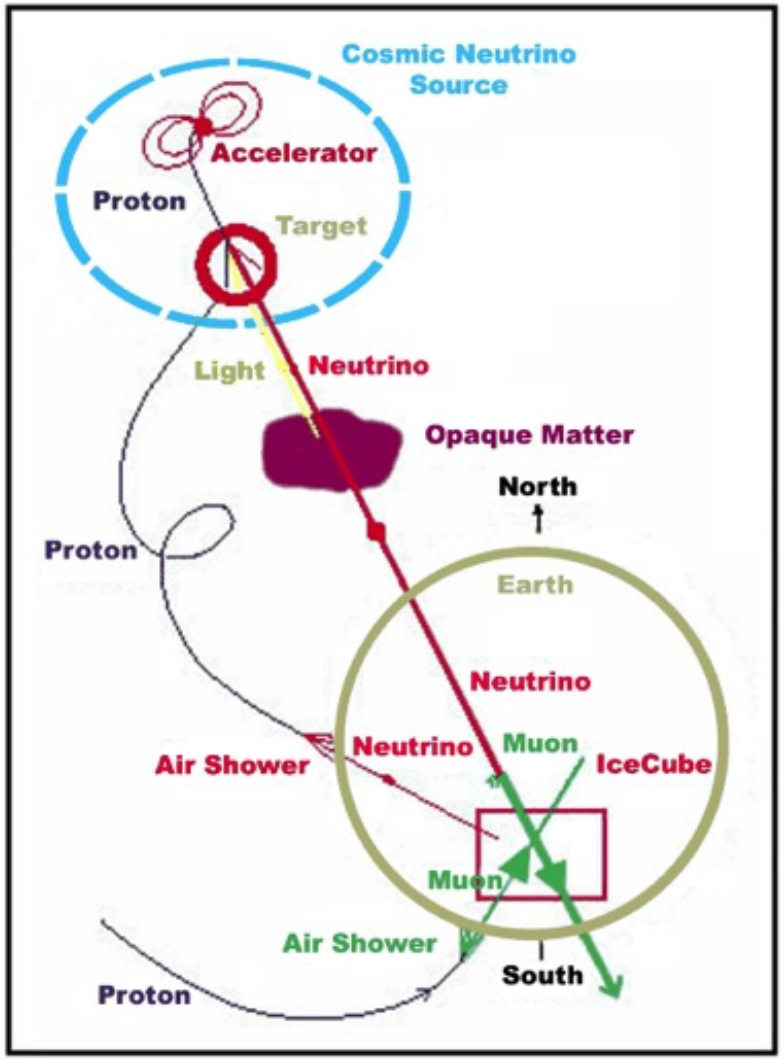
Gamma rays:

- Ambiguous

Protons:

- GZK horizon (50 Mpc)
- Follow curved paths
- Time dispersal

Testing the Theory



Gamma rays:

- Ambiguous

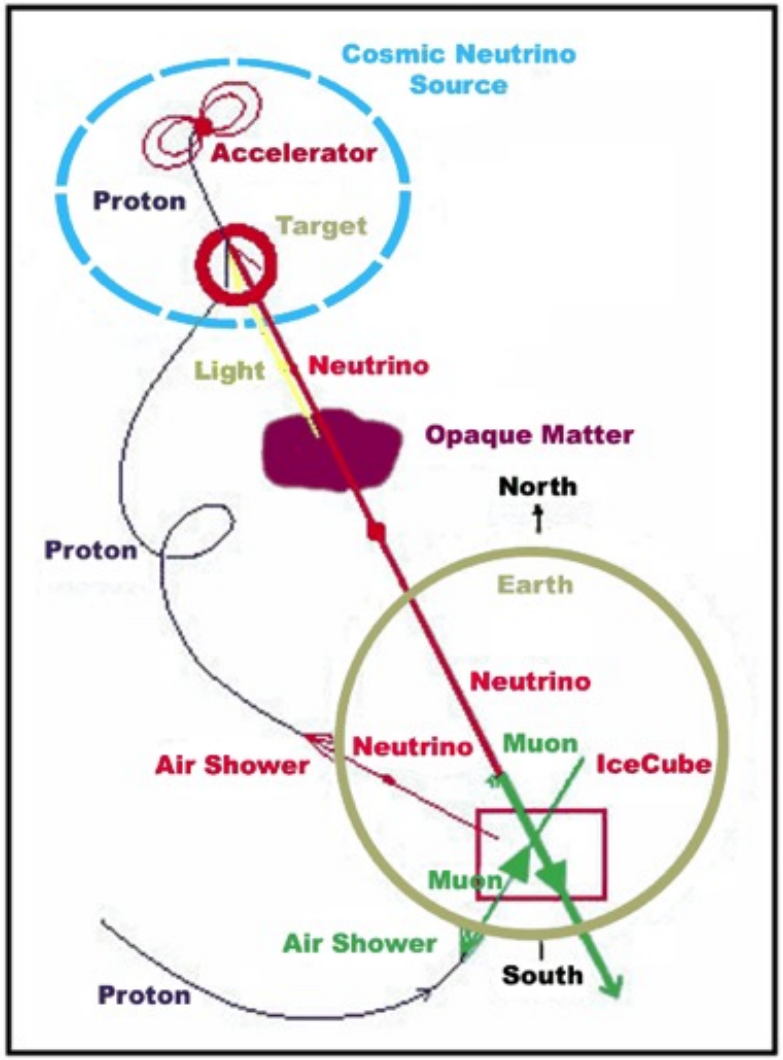
Protons:

- GZK horizon (50 Mpc)
- Follow curved paths
- Time dispersal

Neutrinos:

- Trace cosmic ray production
- Propagate freely – no GZK cutoff
- Follow straight paths

Testing the Theory



Gamma rays:

- Ambiguous

Protons:

- GZK horizon (50 Mpc)
- Follow curved paths
- Time dispersal

Neutrinos:

- Trace cosmic ray production
- Propagate freely – no GZK cutoff
- Follow straight paths
- ... hard to detect

IceCube


SOUTH POLE
INTERNATIONAL
PAX
TERMINAL
BL
58
U.S. AIR FORCE
NATIONAL SCIENCE FOUNDATION
BOMBARDIER
19607

Neutrino Telescopes

- Cherenkov light emitted by charged secondaries in neutrino interactions
- Light imaged by enormous arrays of photomultipliers
- Deep underground for background suppression

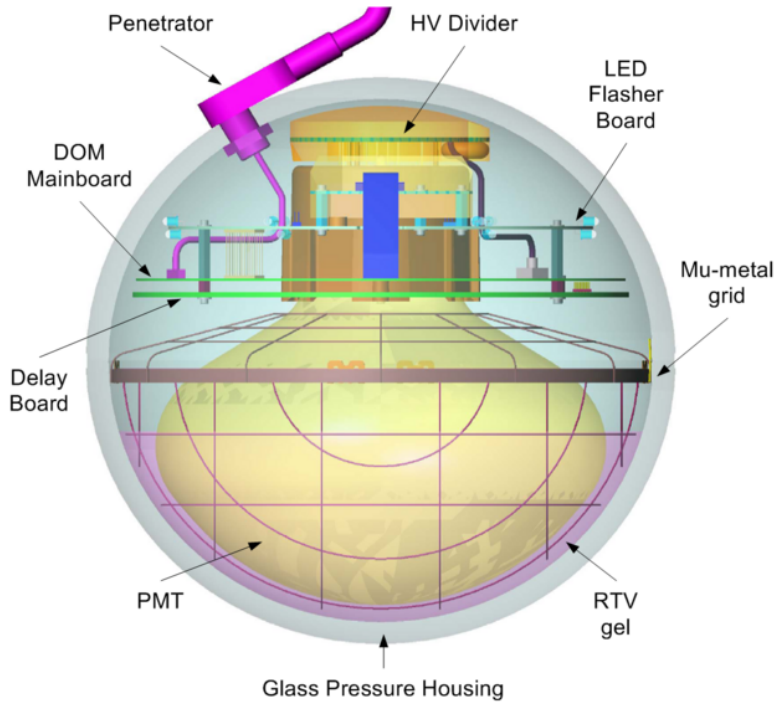
Neutrino Telescopes

- Cherenkov light emitted by charged secondaries in neutrino interactions
- Light imaged by enormous arrays of photomultipliers
- Deep underground for background suppression

- South Pole ice supplies a ready built detector!

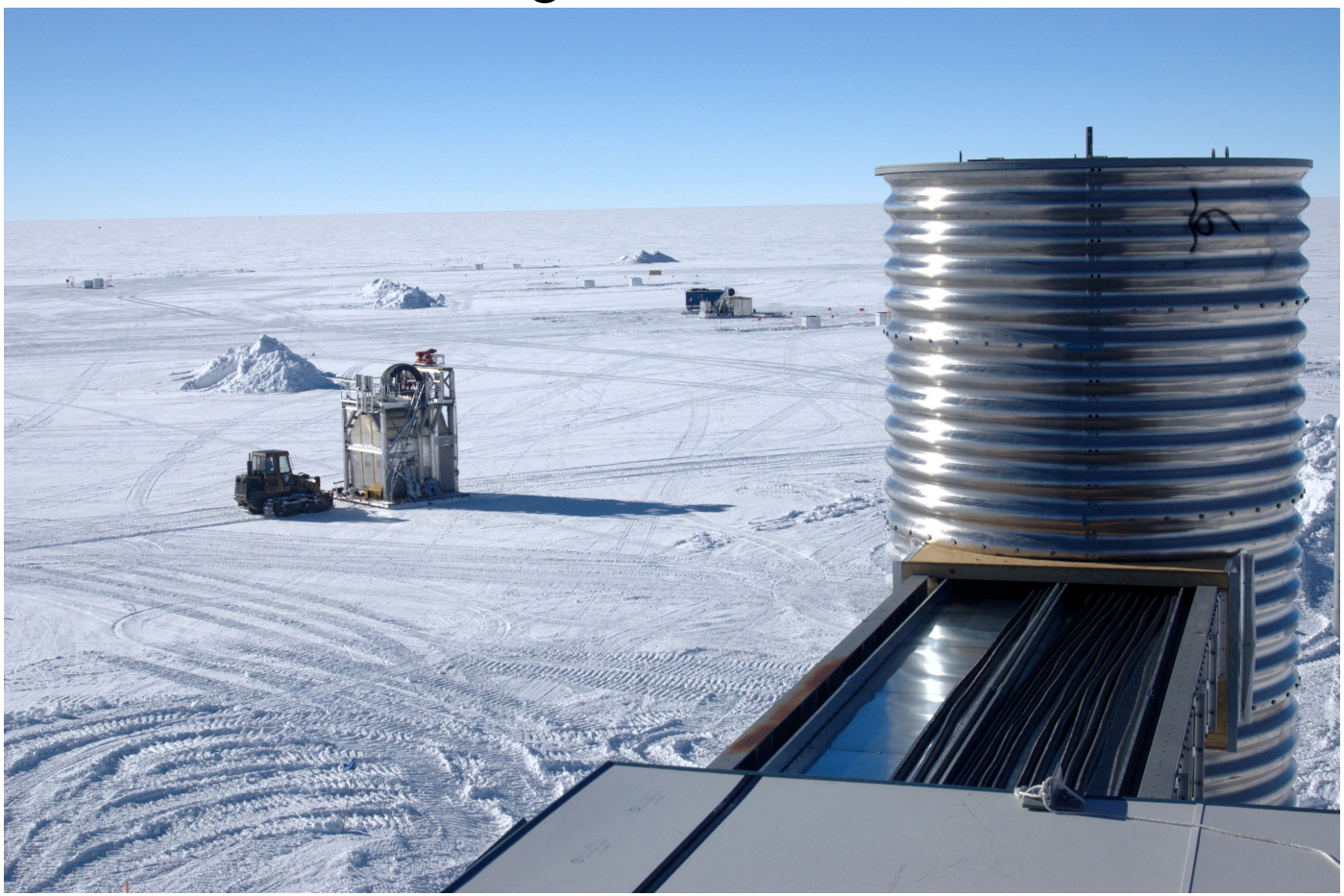
Digital Optical Modules

- 25 cm photomultiplier
- All-digitial readout: In-Situ Digitization
- Built-in calibration instruments



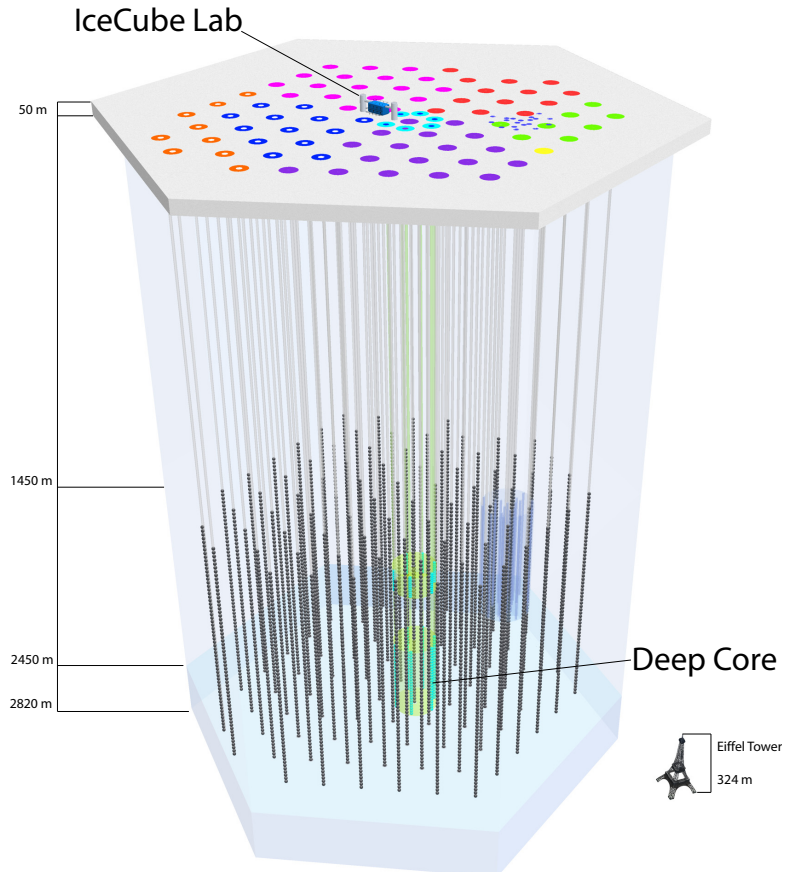
Construction

2.5 km boreholes using hot water



IceCube

- 5160 PMTs
- 1 km^3 volume
- 86 strings
- 17 m PMT-PMT spacing per string
- 120 m string spacing
- Angular resolution $\sim 1^o$
- Completed December 2010!

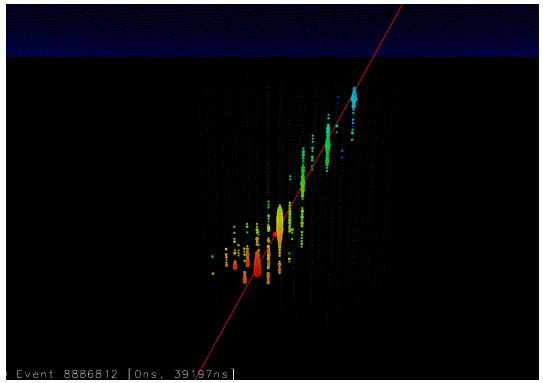


Challenges

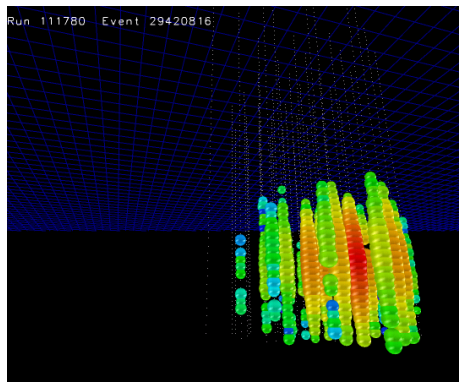
- Naturally occurring media $\rightarrow$ no spec sheet
- No known neutrino sources $\rightarrow$ no standard candle
- Electronics buried forever in the ice $\rightarrow$ no repairs
- Energies above the reach of accelerators $\rightarrow$ physics unknown

Neutrino Interactions

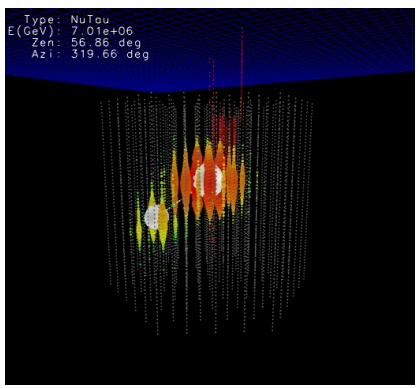
Muon Neutrino CC



Neutral Current or Electron Neutrino

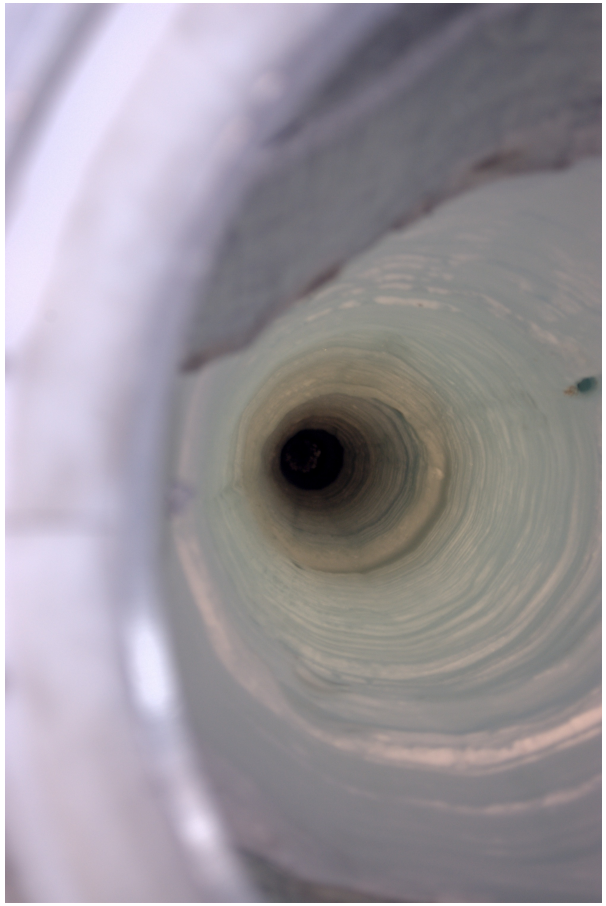


Tau Neutrino CC (simulation)



Physics Reach of IceCube

- Neutrino Point Source (AGN, GRBs)
- Measurement of Atmospheric Neutrino Spectrum (100k events/year)
- Indirect Dark Matter Searches
- Measurement of θ_{23}
- Direct Observation of ν_τ
- Cross-sections at ultra-high energies
- Cosmic Ray Measurements



IceCube Transient Analysis Programs

- **Offline full-sky flare searches** Bright neutrino flares on timescales of $\sim$ days (needs $\sim$ 10 events)
- **Offline GRB searches** Coincidence between satellite-triggered GRBs and neutrinos (needs $\sim$ 1 event, this talk)
- **Online Optical Followup** Triggers optical telescopes (ROTSE) on interesting neutrino candidates (coincident pairs)
- **Online X-Ray/Gamma Followup** Triggers SWIFT, MAGIC, and VERITAS on interesting neutrino candidates (coincident pairs)

Satellite Detection

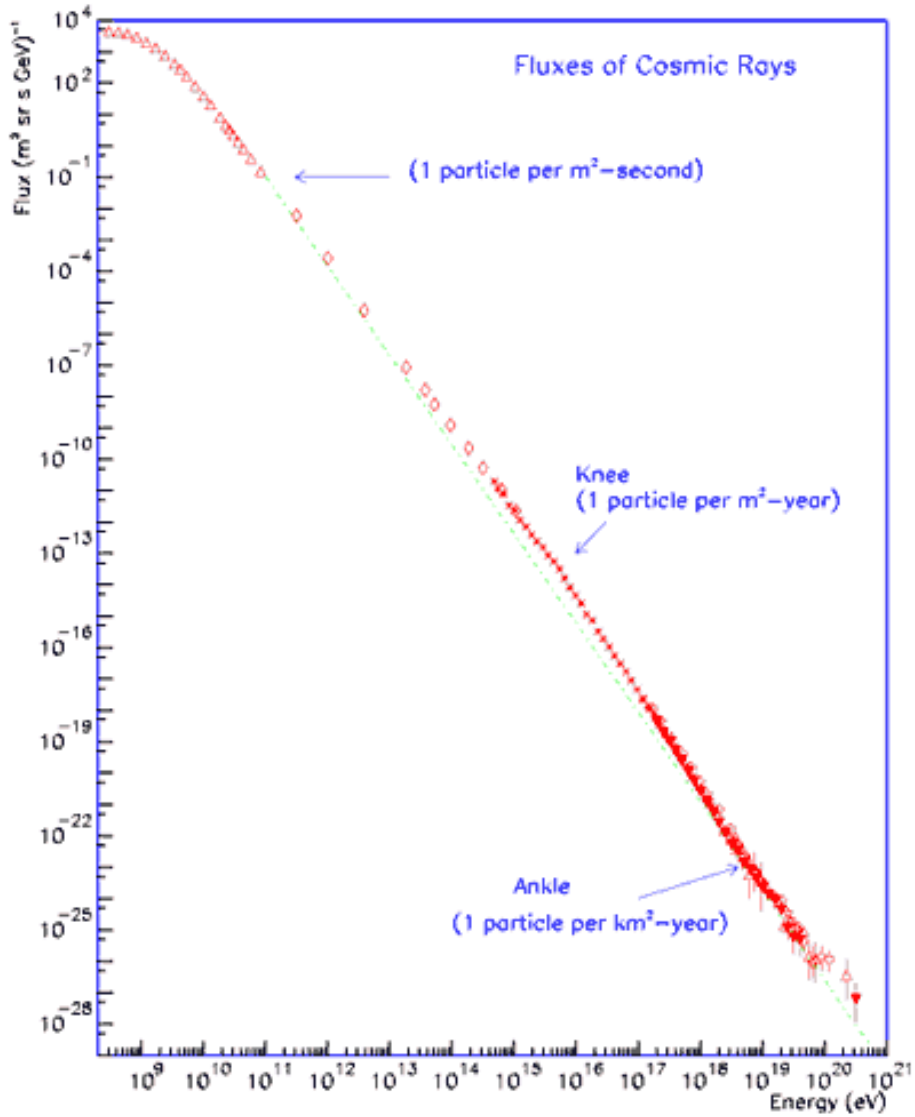
- FERMI GBM (2008-)
  - Wide Acceptance, Low Angular Resolution
- SWIFT (2004-)
  - Narrower Acceptance, Repointing, High Resolution
- Interplanetary Network
  - Array of spacecraft around the Solar System
  - Low trigger efficiency
  - Strange point spread function

In all, $\approx$ 300 events per year collected by GCN network used in IceCube analysis.

Neutrinos from Cosmic Rays

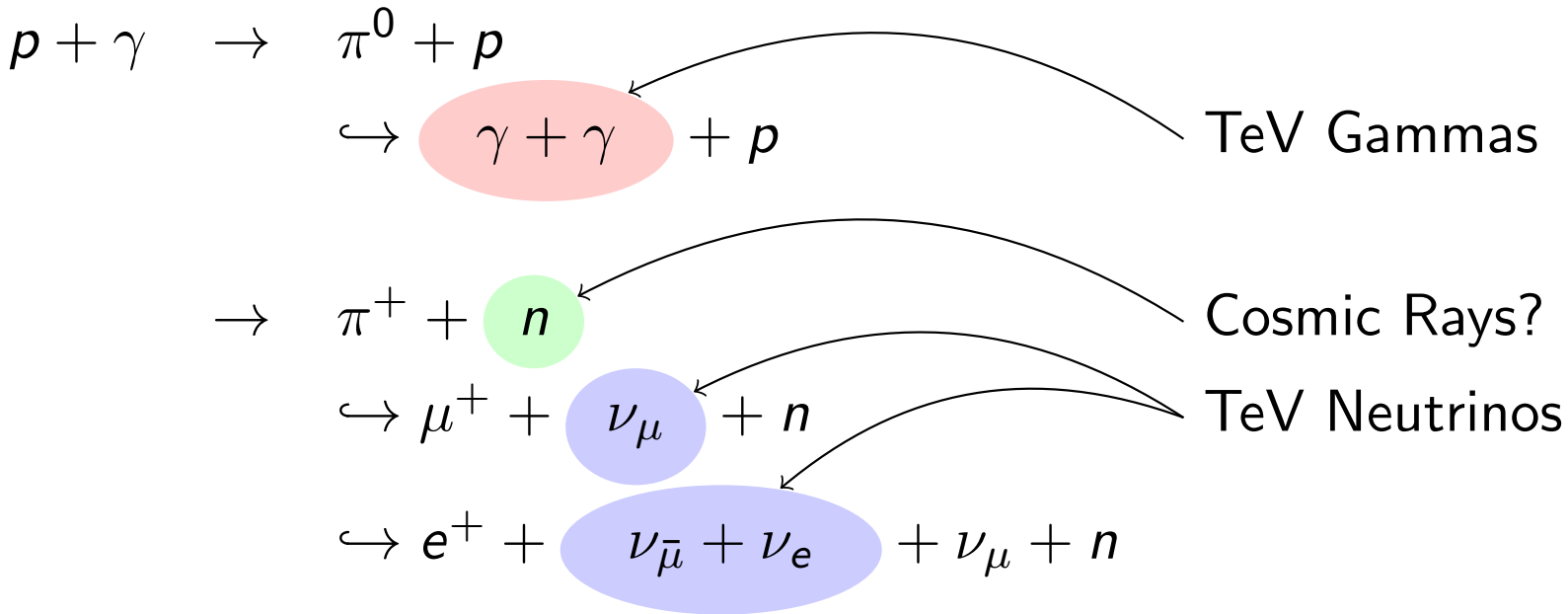
Usual Model:

- GRBs responsible for entire extragalatic CR flux
- GRB proton flux dominant at the ankle ($\sim 10^{18}$ eV)
- 500-1000 bursts per year total
- Neutrinos produced in $p\gamma$ interactions in expanding fireball



S. Swordy, U. Chicago

Neutrino Production



This implies a neutrino spectrum with $E \gtrapprox 100$ TeV (set by bulk Lorentz factor Γ)

Model Flavors

- **Waxman-Bahcall** All extragalactic cosmic rays from GRBs. Protons diffuse out of shocks at high energies.

Model Flavors

- **Waxman-Bahcall** All extragalactic cosmic rays from GRBs. Protons diffuse out of shocks at high energies.
- **Magnetic Confinement Models** All extragalactic cosmic rays from GRBs. Protons trapped by magnetic fields – escape as neutrons (Rachen et al. 1998, Ahlers et al. 2011).

Model Flavors

- **Waxman-Bahcall** All extragalactic cosmic rays from GRBs. Protons diffuse out of shocks at high energies.
- **Magnetic Confinement Models** All extragalactic cosmic rays from GRBs. Protons trapped by magnetic fields – escape as neutrons (Rachen et al. 1998, Ahlers et al. 2011).
- **Non-Cosmic Ray Models** Fixed fraction of GRB energies in protons, which do not necessarily escape (Guetta et al. 2004, Hümmer et al. 2012).

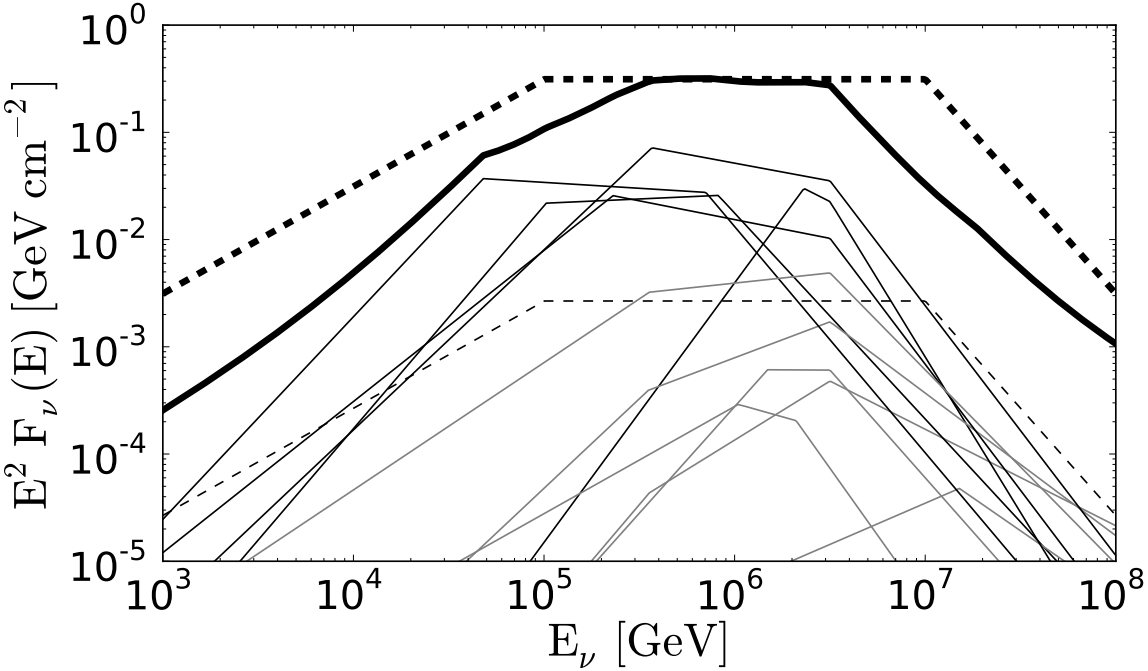
Searching for Neutrinos from GRBs

Signal:

- Neutrino events with source at the GRB position
- Neutrino events coincident in time with GRBs

Background:

- Misreconstructed cosmic ray muons
- Atmospheric neutrinos (10^{-7} s^{-1} deg^{-2})



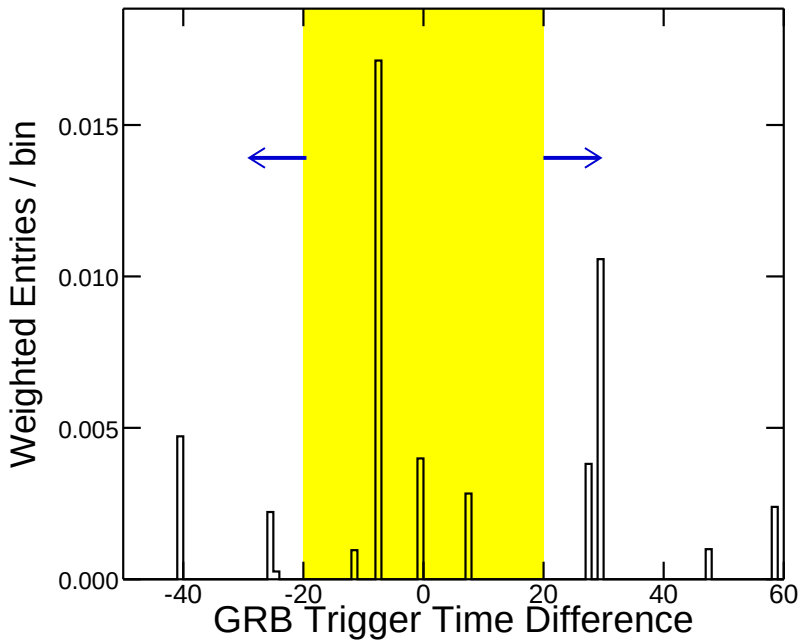
Analysis Details

Model-Dependent Analysis:

- Search for neutrinos with per-burst spectra from γ observations
- Live during window of maximum gamma emission ($T_{90} \approx 30$ s)

Model-Independent Analysis:

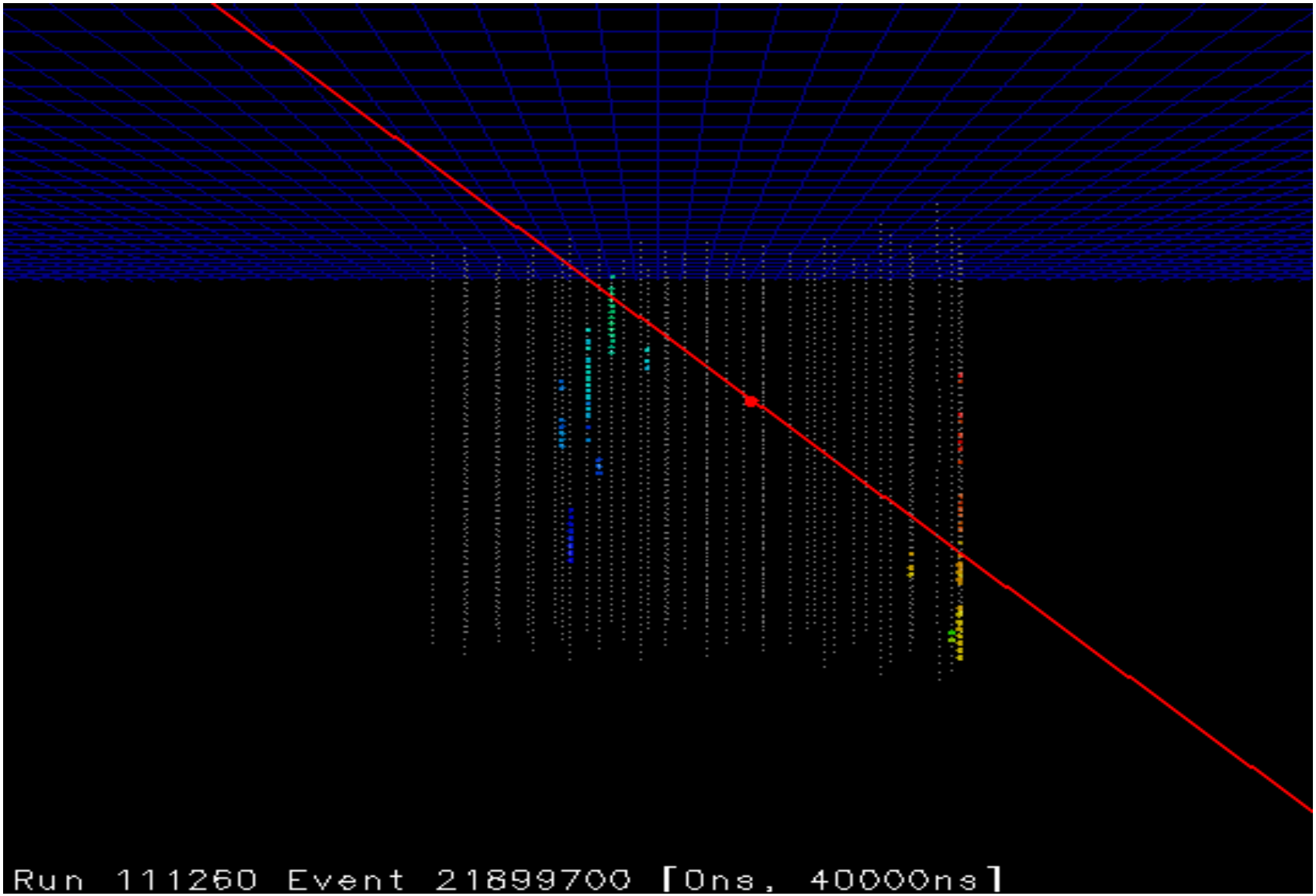
- Search for neutrinos at all triggering energies
- Expanding time window from ± 10 s to ± 1 day



Backgrounds

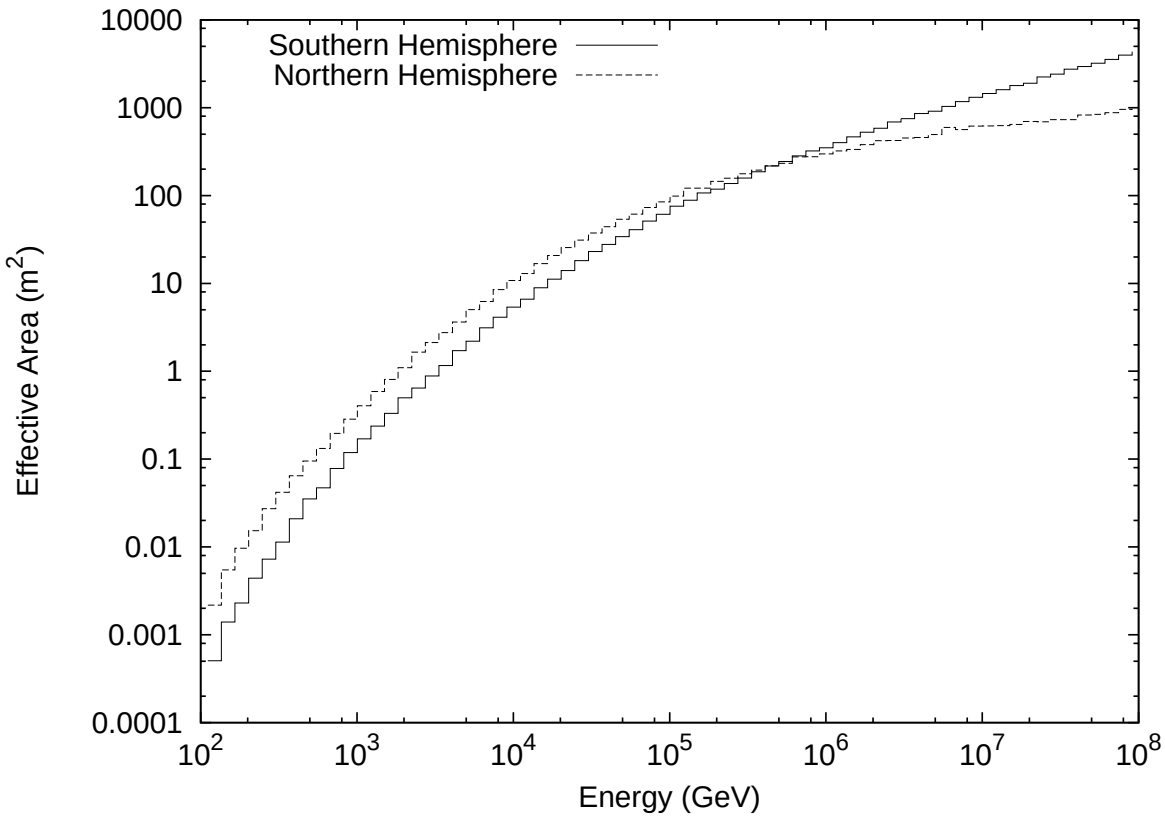
Atmospheric neutrinos controlled by space/time coincidence.

These are more of a problem:



Sensitivity

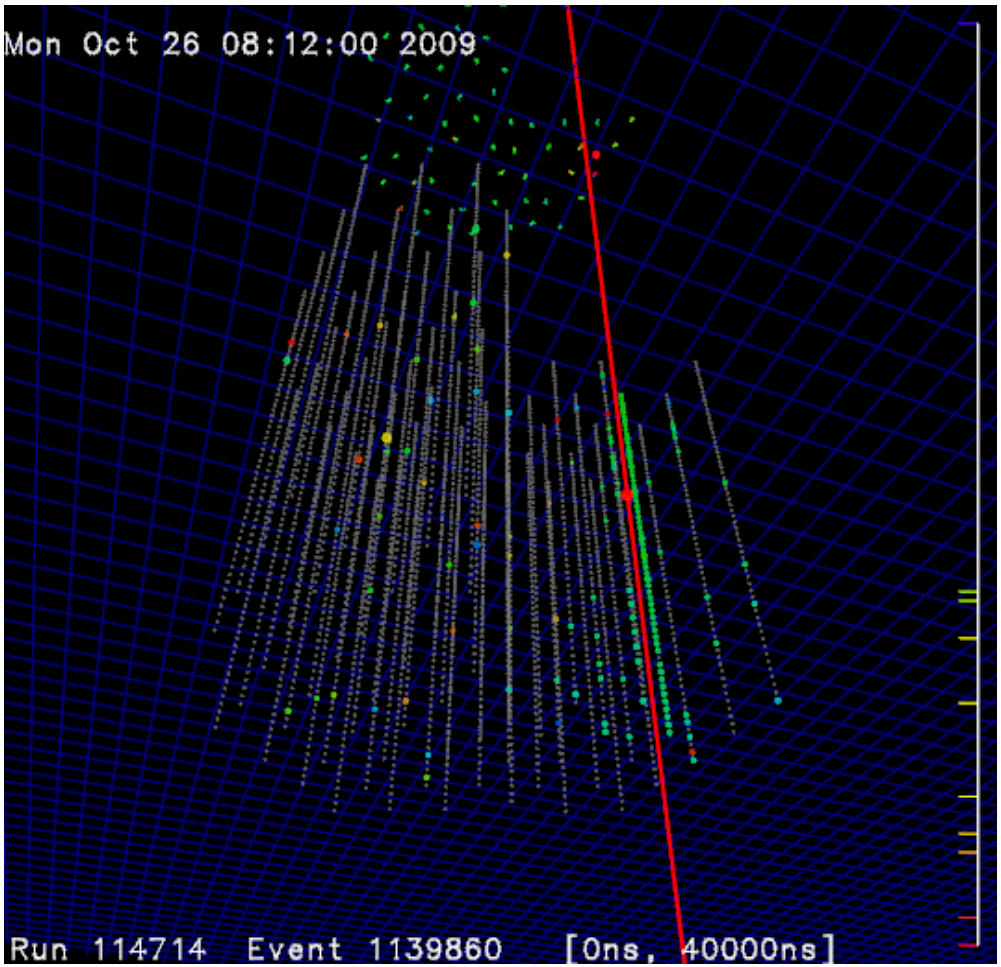
- Optical telescope-sized effective area in region of interest ($\sim$ 100 TeV)
- Northern Hemisphere can filter out cosmic rays
- Southern Hemisphere (new!) more sensitive at high energies due to Earth absorption



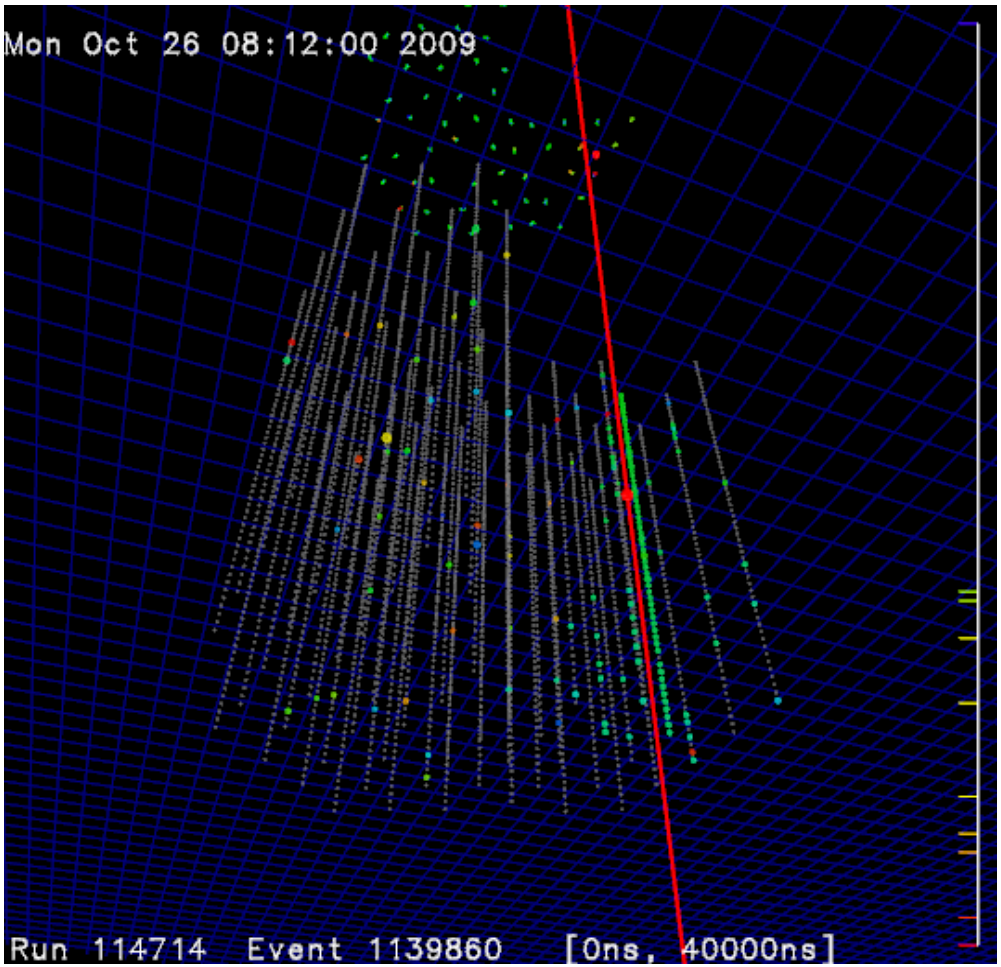
Data on Hand

- Detector completion in December 2010
- Data from 2008-2010 analyzed
- 2010-2012 available soon

t + 30 seconds

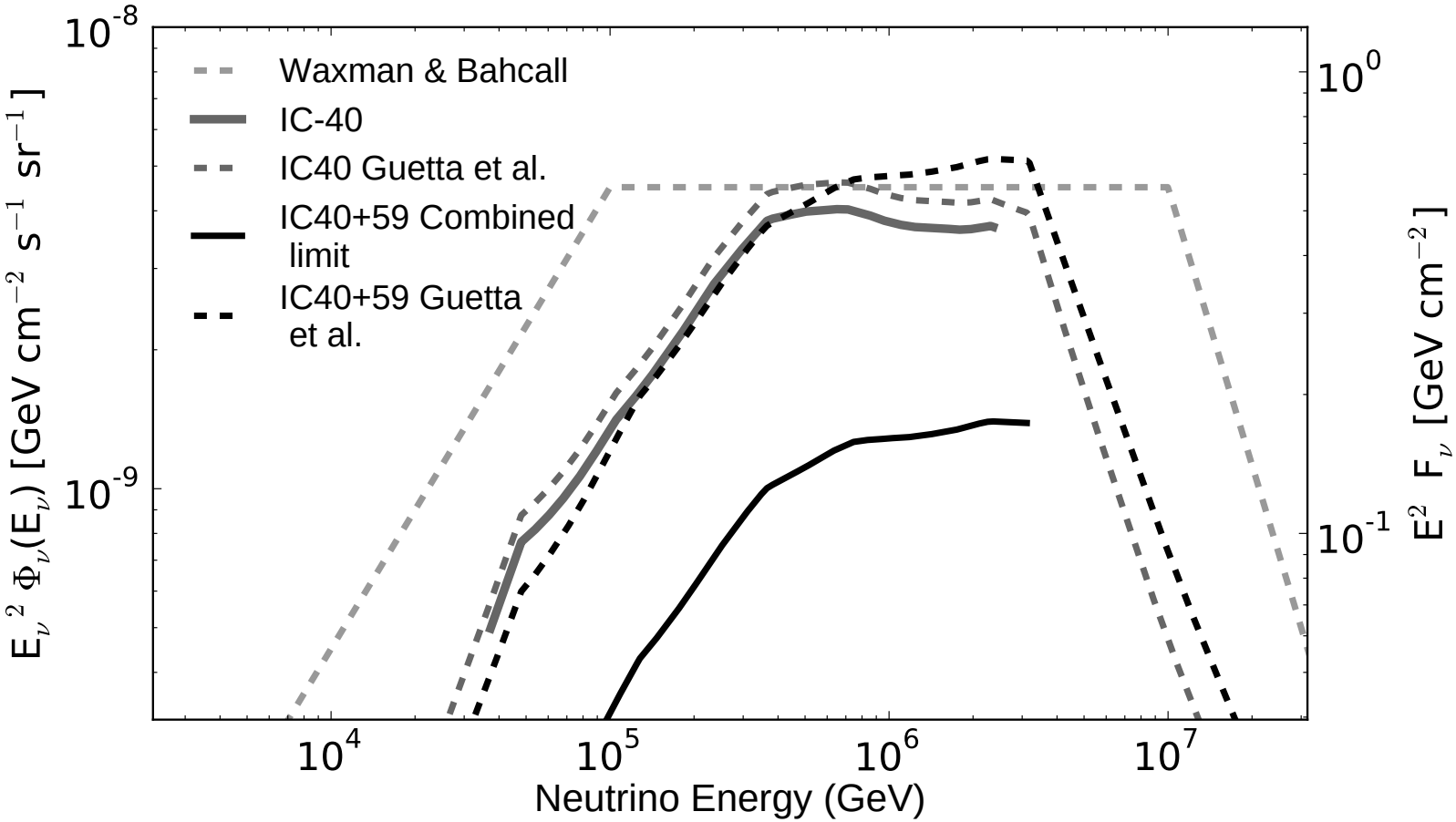


~~t + 30 seconds~~ Not a Neutrino

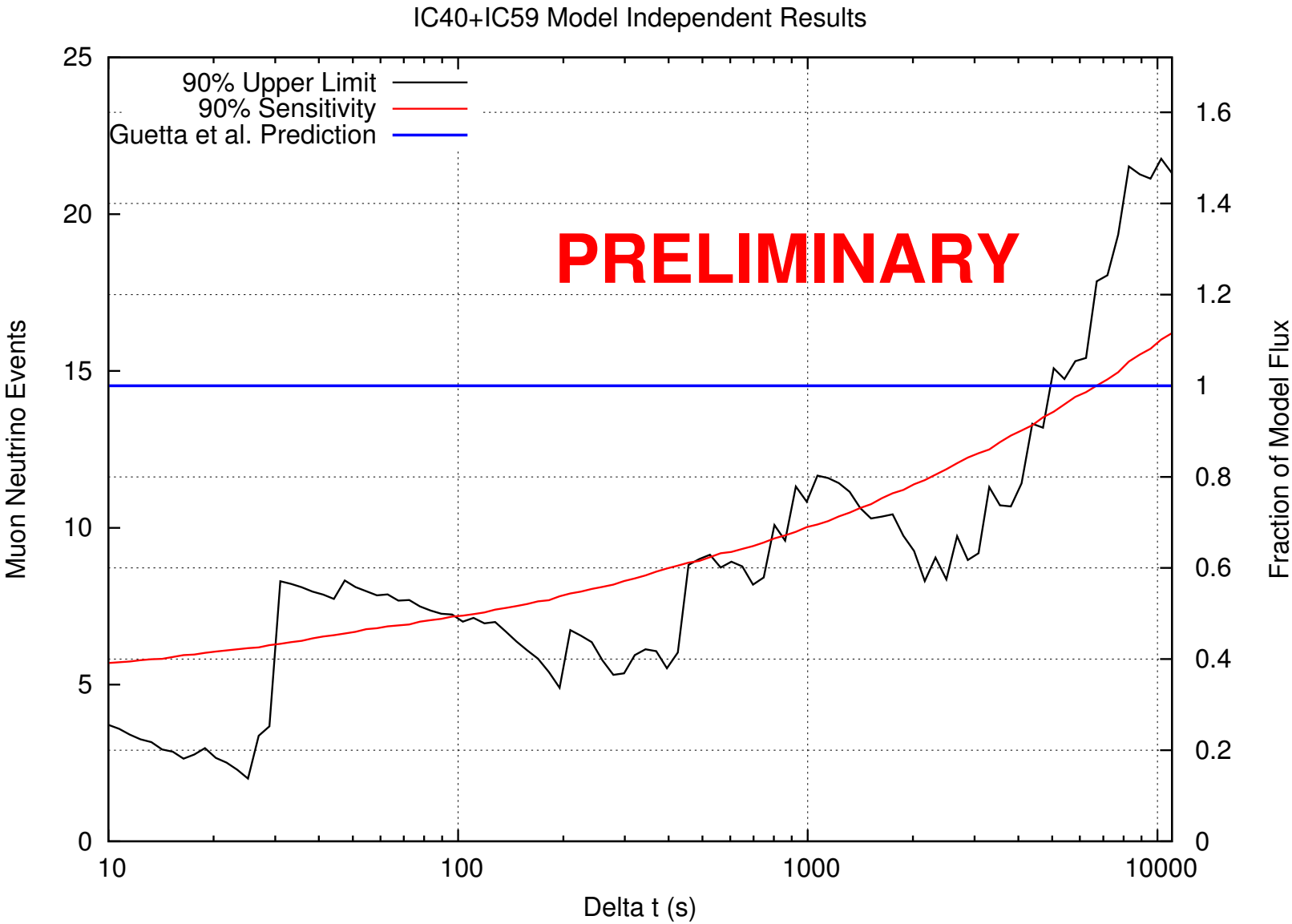


But a near miss – this event triggered the IceTop surface array and is part of a cosmic ray air shower.

IC40+IC59 Limit



Time-dependent Limits



Model-dependent results

Magnetic Confinement (e.g. Ahlers *et al.* 2011)

Default params excluded at 12σ (factor of 20).

Model-dependent results

Magnetic Confinement (e.g. Ahlers *et al.* 2011)

Default params excluded at 12σ (factor of 20).

Waxman-Bahcall

For Waxman-Bahcall, weaken these limits by a factor of 3.2 (≈ 10 with new figures from Waxman), which is still excluded at $> 7(3)\,\sigma$.

Model-dependent results

Magnetic Confinement (e.g. Ahlers *et al.* 2011)

Default params excluded at 12σ (factor of 20).

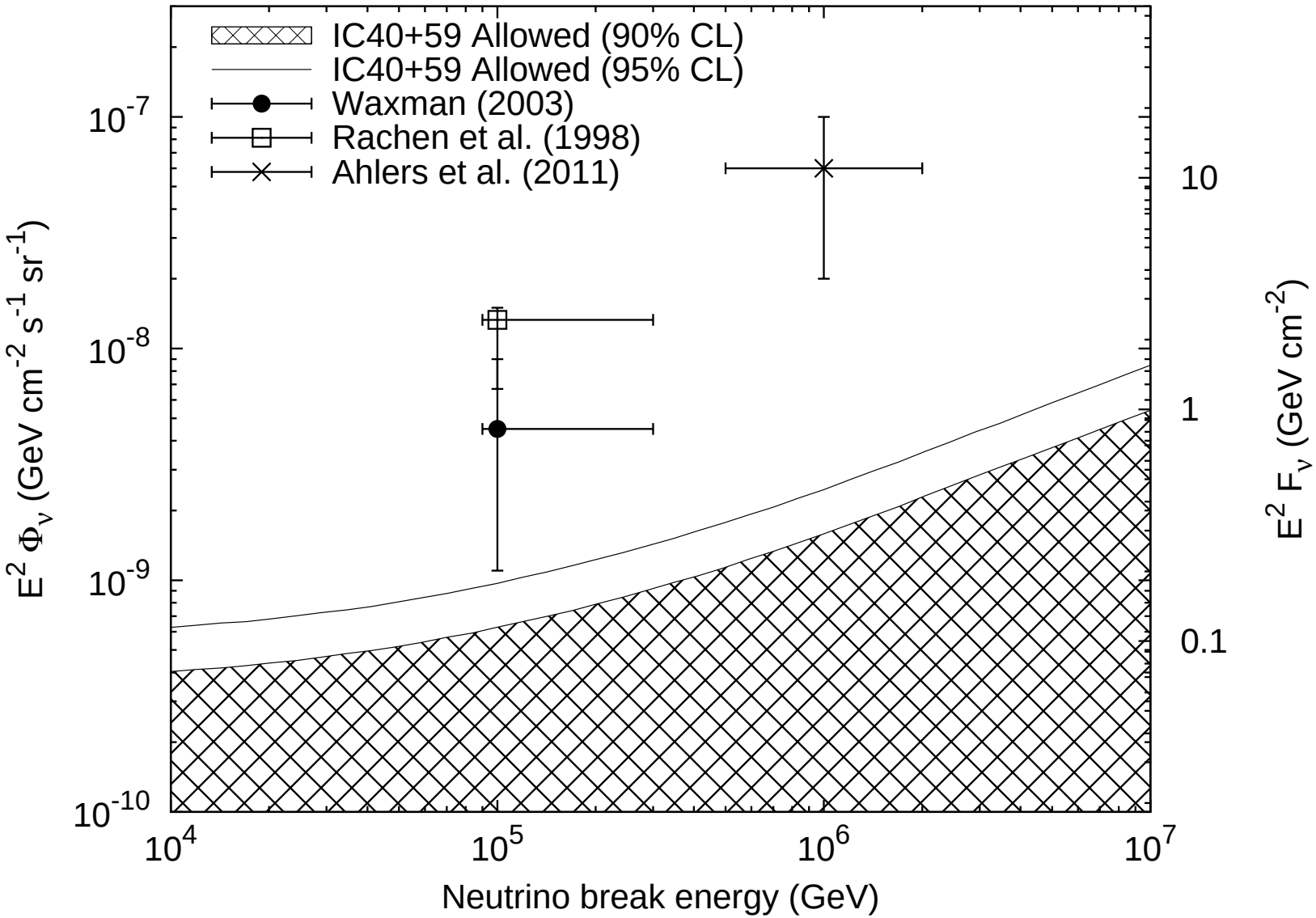
Waxman-Bahcall

For Waxman-Bahcall, weaken these limits by a factor of 3.2 (≈ 10 with new figures from Waxman), which is still excluded at $> 7(3)\,\sigma$.

Guetta et al.

Similar high-gamma/low-proton fraction scenario with Guetta ($\Gamma > 500$). Default parameters excluded at $> 3\sigma$.

Allowed Parameters



Accomodating the limits

What things need to change in the predictions?

- GRBs not responsible for entire extragalatic CR flux? (normalization)

Accomodating the limits

What things need to change in the predictions?

- GRBs not responsible for entire extragalatic CR flux? (normalization)
- GRB neutrino flux moves to high energies (threshold/Γ)

Accomodating the limits

What things need to change in the predictions?

- GRBs not responsible for entire extragalatic CR flux? (normalization)
- GRB neutrino flux moves to high energies (threshold/Γ)
- GRB proton flux moves to high energies (ankle models)

Accomodating the limits

What things need to change in the predictions?

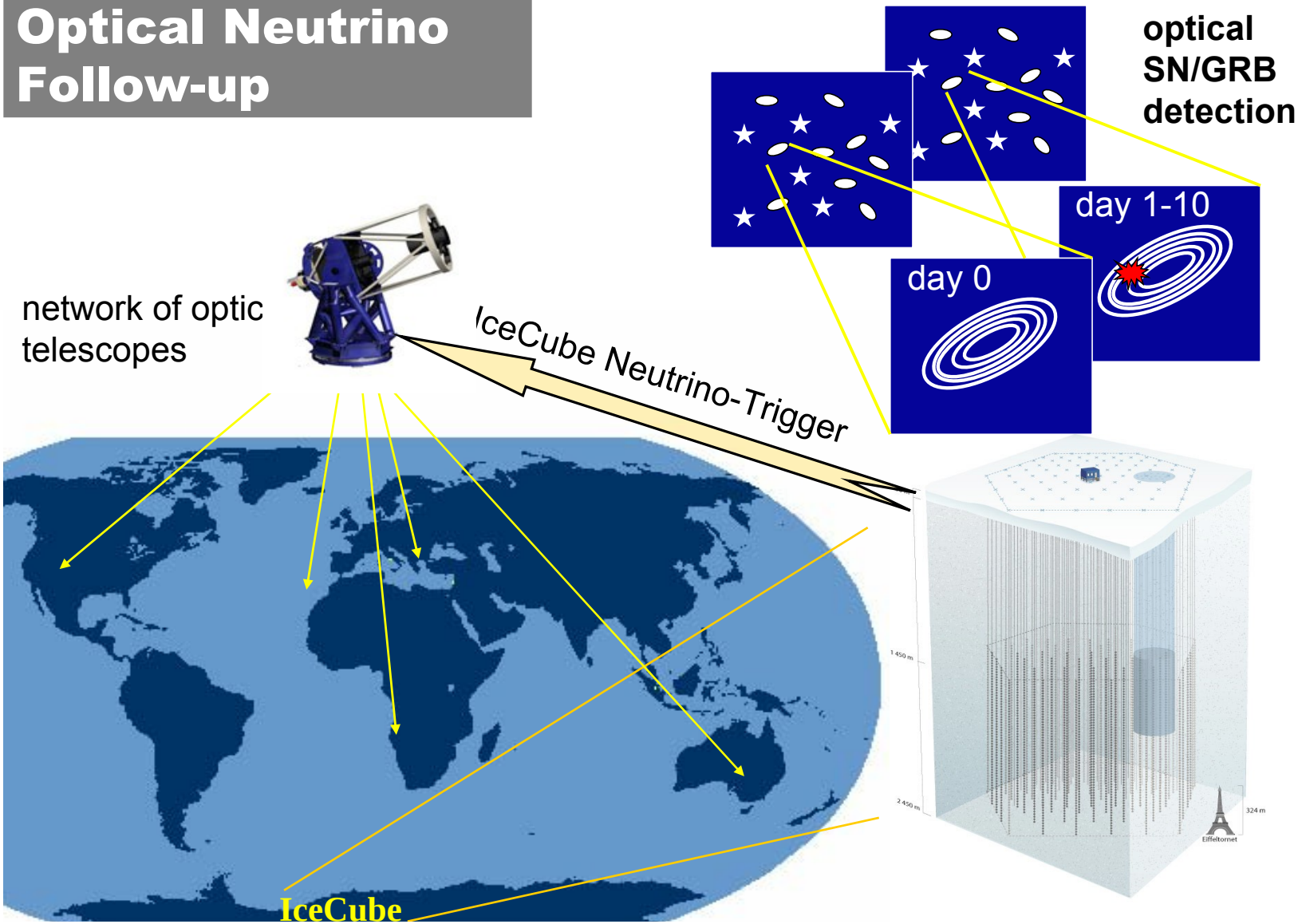
- GRBs not responsible for entire extragalatic CR flux? (normalization)
- GRB neutrino flux moves to high energies (threshold/Γ)
- GRB proton flux moves to high energies (ankle models)
- Other physics in the predictions?

Accomodating the limits

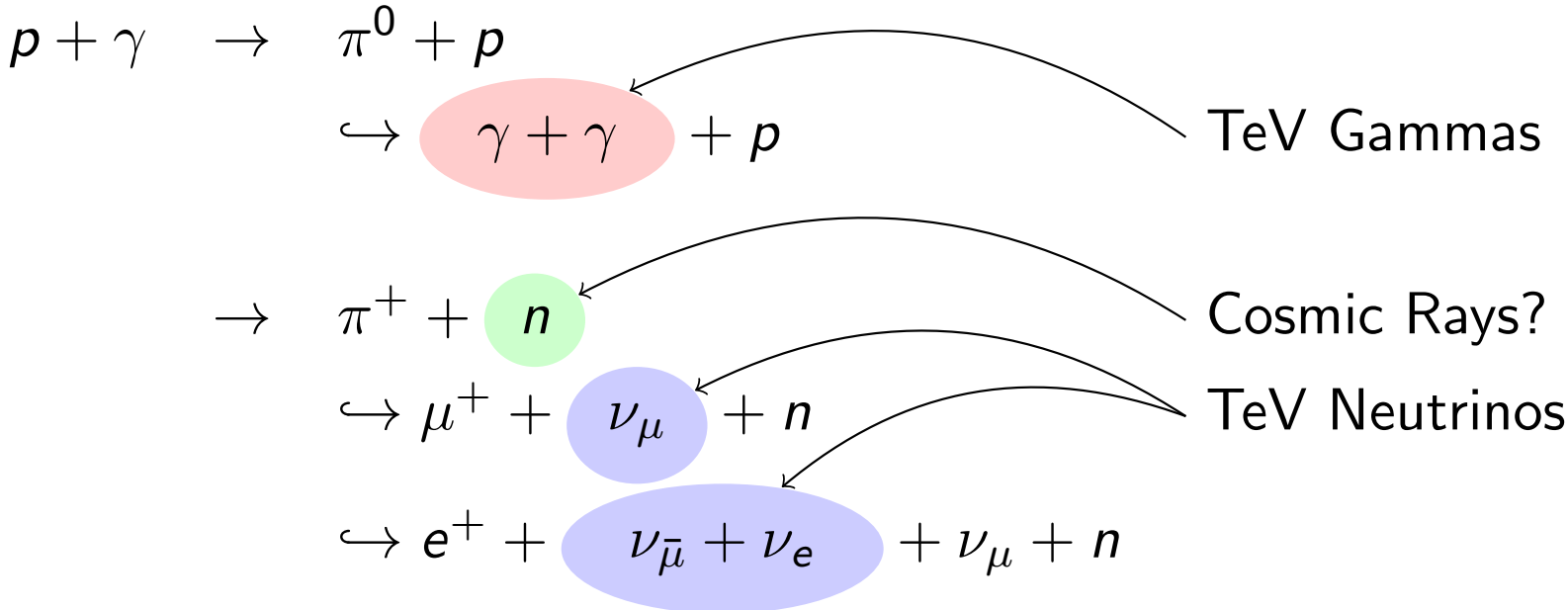
What things need to change in the predictions?

- GRBs not responsible for entire extragalatic CR flux? (normalization)
- GRB neutrino flux moves to high energies (threshold/Γ)
- GRB proton flux moves to high energies (ankle models)
- Other physics in the predictions?
- Global GRB rate

Optical Neutrino Follow-up

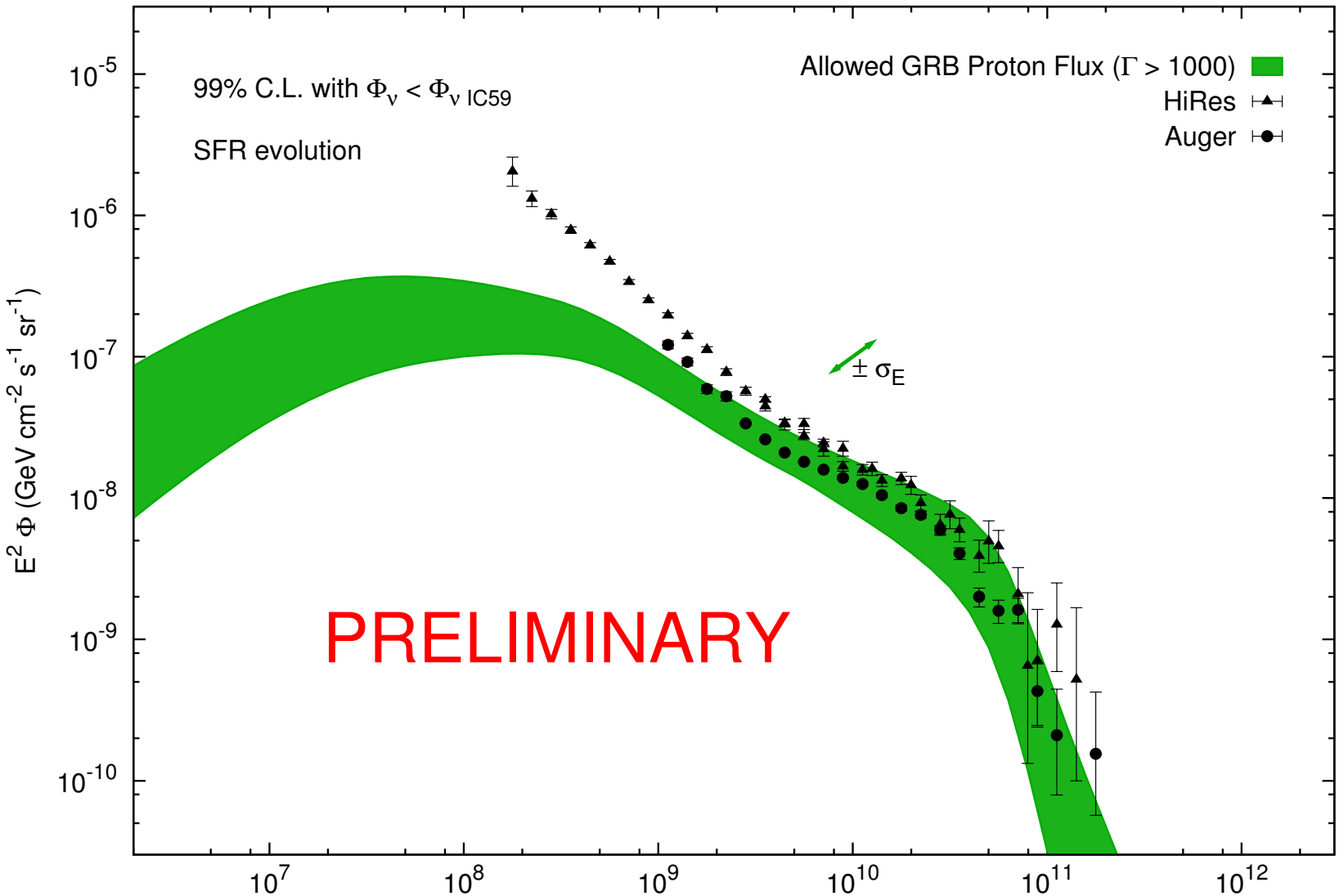


Neutrino Production



Note on magnetic confinement models

Magnetic confinement models directly link neutrinos and cosmic rays – very few degrees of freedom. All changes to the neutrino flux reflected in cosmic rays. Need $\langle \Gamma \rangle > 1000$ for this to still work.



Outlook

- IC79/IC86-I data collection complete – results soon
- GRB analyses still exposure-limited – sensitivity $\propto t$
- New programs (semi-realtime analysis) likely coming soon
- Neutrinos hopefully on the way