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The AMANDA neutrino telescope: Results from GRB and dark matter searches

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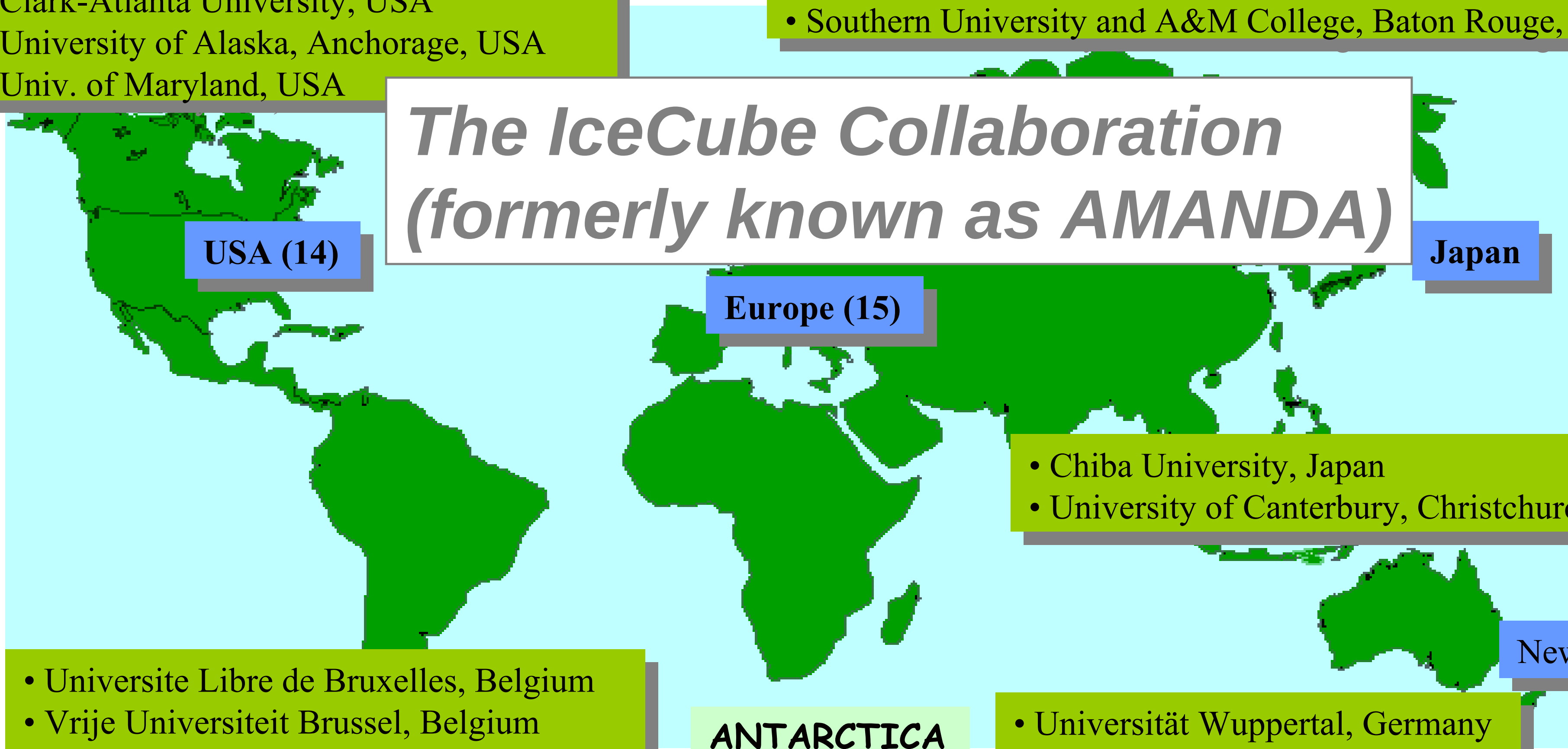
Content

- AMANDA/IceCube.
- AMANDA results on neutrinos from Dark Matter candidates
- AMANDA results on neutrinos from GRBs
- I'll keep it really simple …..

The IceCube Collaboration (formerly known as AMANDA)

- Alabama University, USA
- Bartol Research Institute, Delaware, USA
- Pennsylvania State University, USA
- UC Berkeley, USA
- UC Irvine, USA
- Clark-Atlanta University, USA
- University of Alaska, Anchorage, USA
- Univ. of Maryland, USA

- IAS, Princeton, USA
- University of Wisconsin-Madison, USA
- University of Wisconsin-River Falls, USA
- LBNL, Berkeley, USA
- University of Kansas, USA
- Southern University and A&M College, Baton Rouge, USA



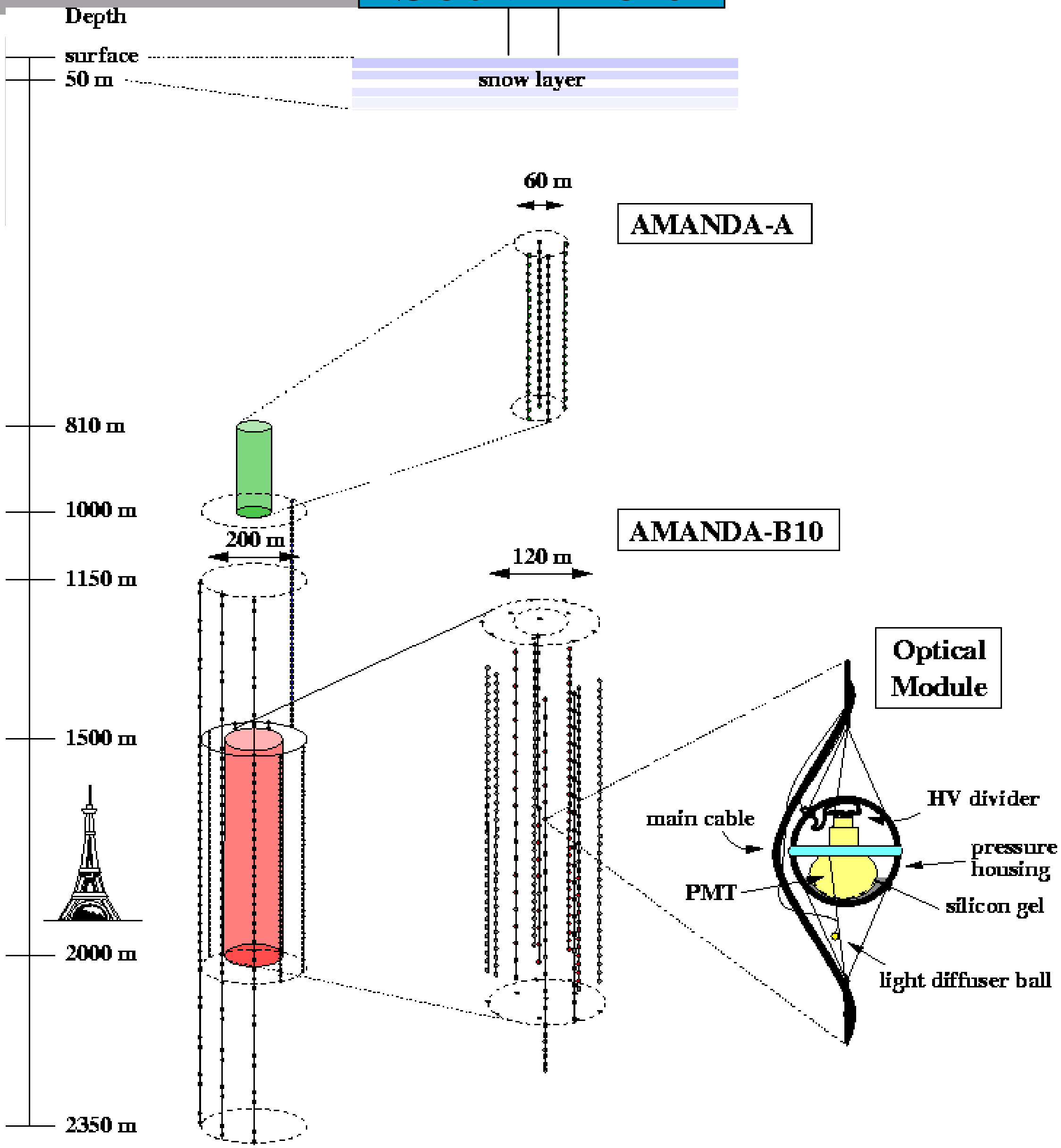
- Chiba University, Japan
- University of Canterbury, Christchurch, NZ

- Universite Libre de Bruxelles, Belgium
- Vrije Universiteit Brussel, Belgium
- Université de Mons-Hainaut, Belgium
- Universiteit Gent, Belgium
- Humboldt Universität, Germany
- Universität Mainz, Germany
- DESY Zeuthen, Germany
- Universität Dortmund, Germany

- Universität Wuppertal, Germany
- MPI Heidelberg, Germany
- Uppsala University, Sweden
- Stockholm University, Sweden
- Imperial College, London, UK
- Oxford University, UK
- Utrecht University, Netherlands

South

South Pole



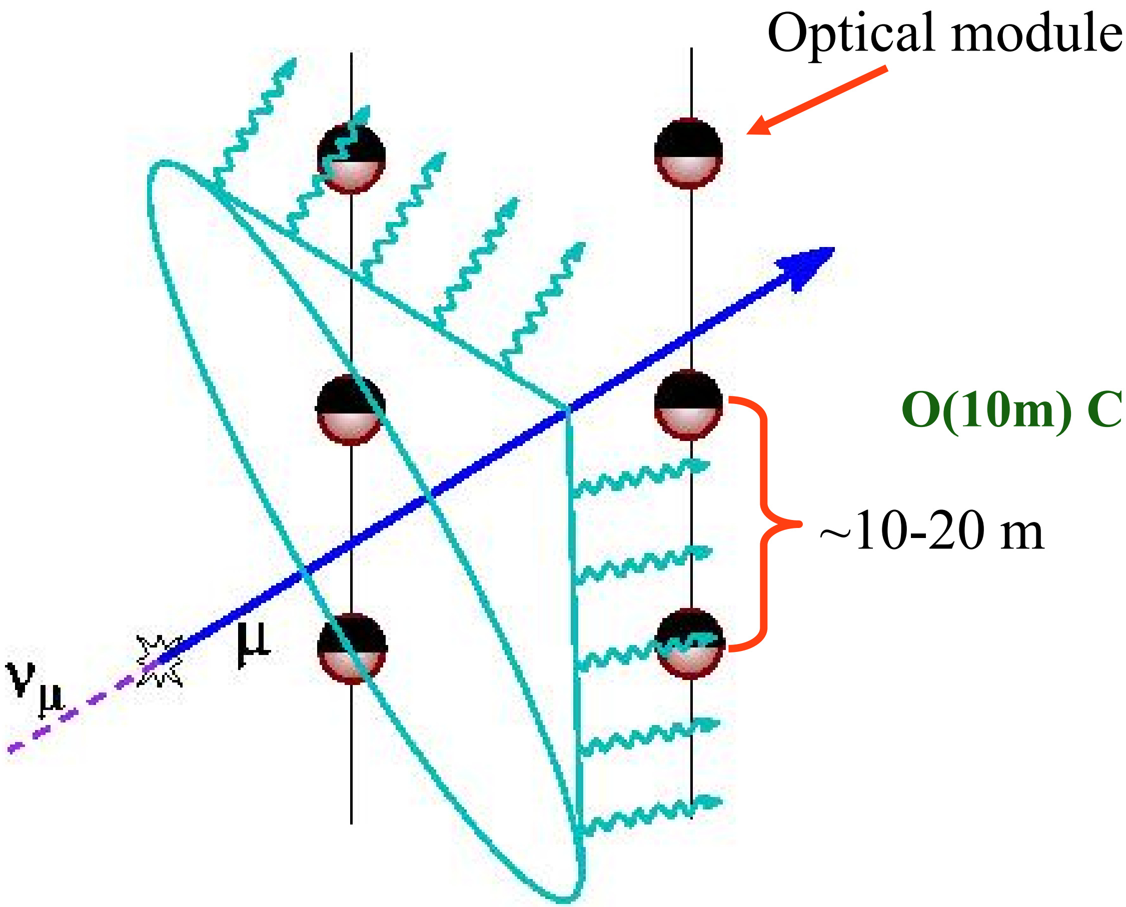
AMANDA as of 2000
Eiffel Tower as comparison
(true scaling)

zoomed in on
AMANDA-A (top)
AMANDA-B10 (bottom)

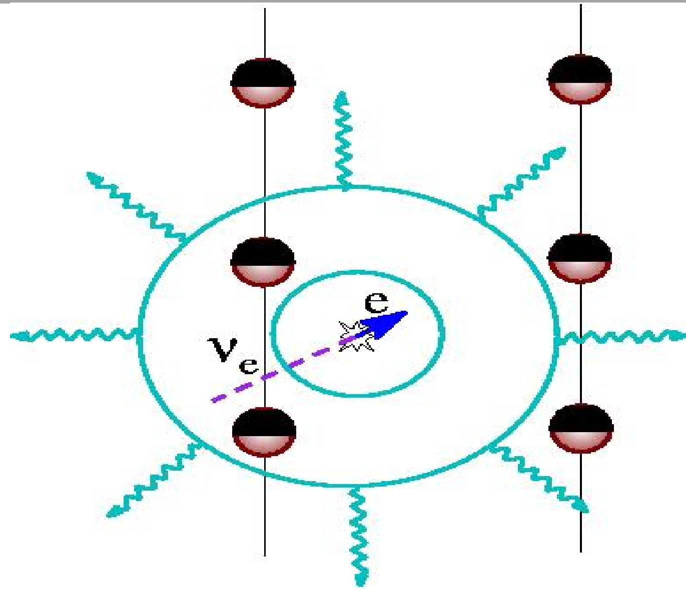
zoomed in on one
optical module (OM)

- AMANDA B-10:
  10 strings, 302 Optical Modules (1997-1999)
- AMANDA-II:
  19 Strings, 677 Optical Modules (2000-2004)
- Trigger rate: ~60 Hz
  (mostly downgoing muons)
- Angular resolution: $\delta\theta \sim 3°$
  (most probable for GRB search)

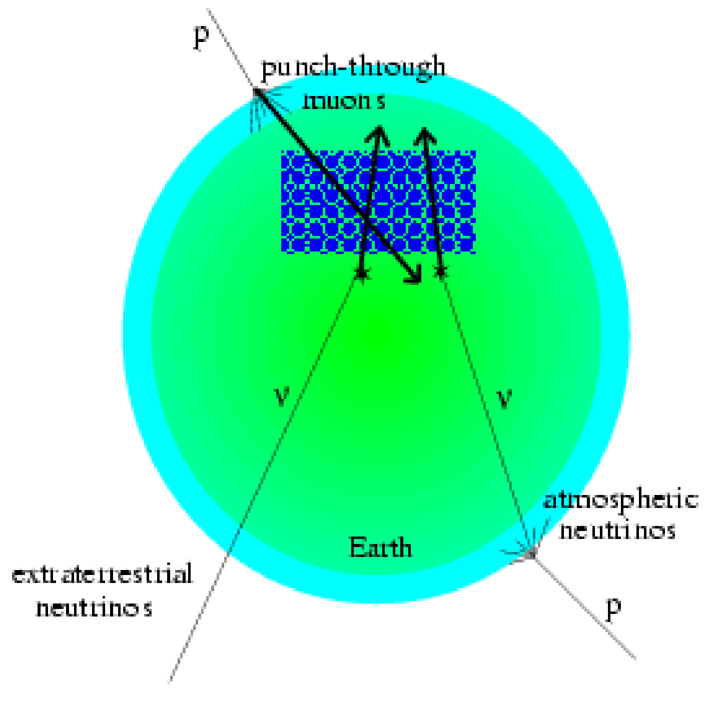
Detection principle



O(km) muons from ν_μ



O(10m) Cascades, ν_e , ν_τ and Neutral Current



IceCube Neutrino Observatory

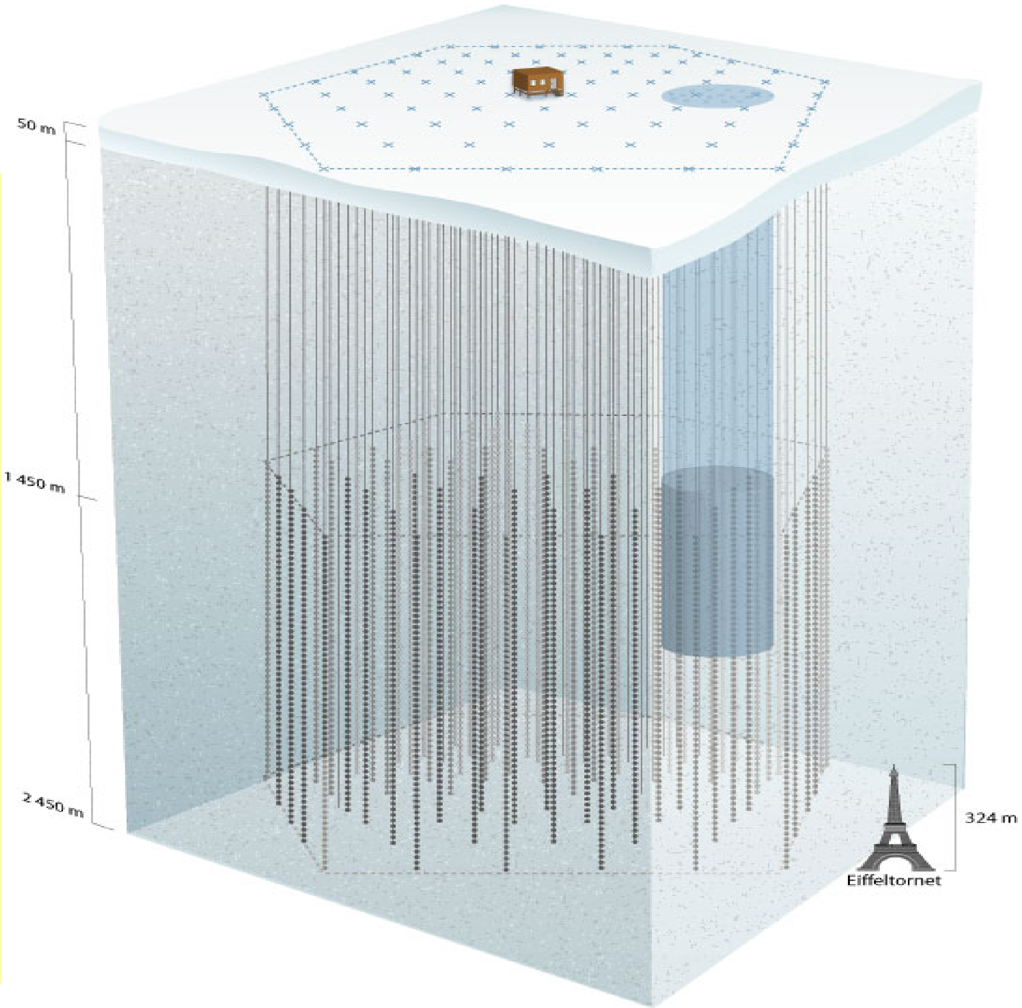
IceTop air shower array

80 pair of ice Cherenkov tanks

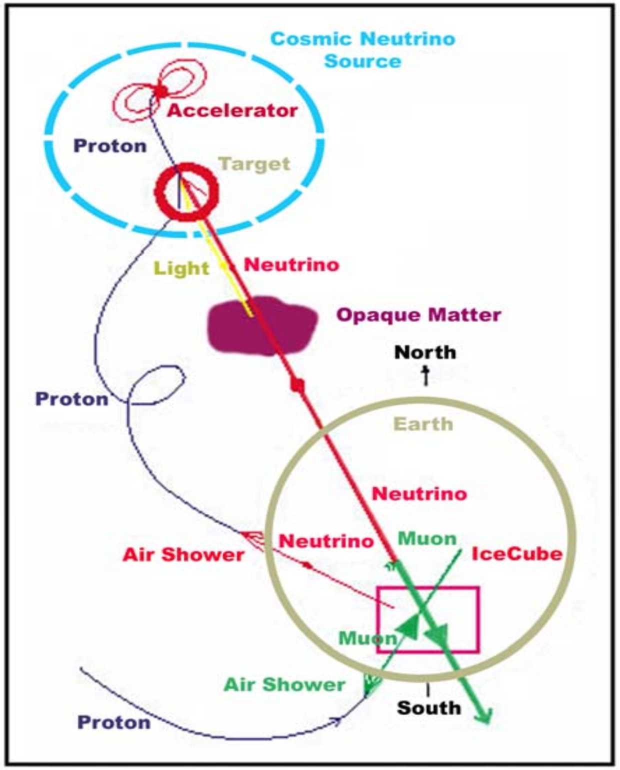
IceCube

80 strings with 60 optical modules
17 m between optical modules
125 m between strings
1 Gton detector!

Present status: 9 strings deployed !



Physics Motivations and Goals

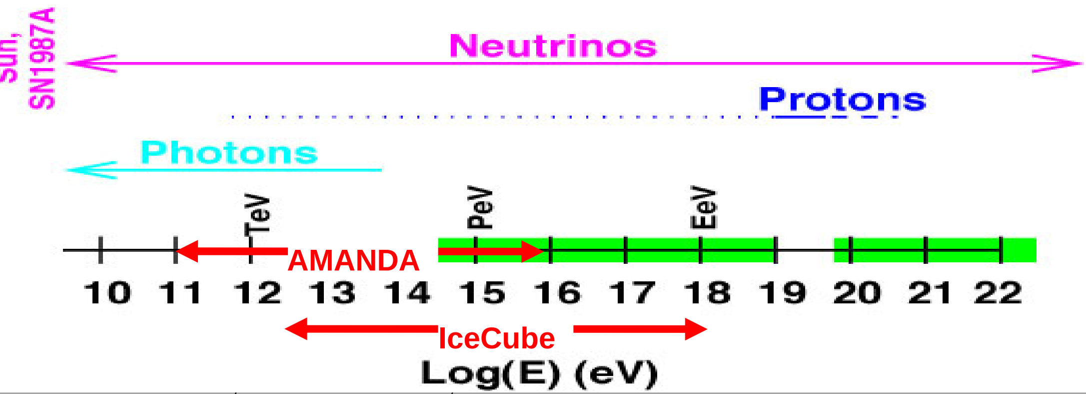


<u>Attractive astronomical messengers</u>:

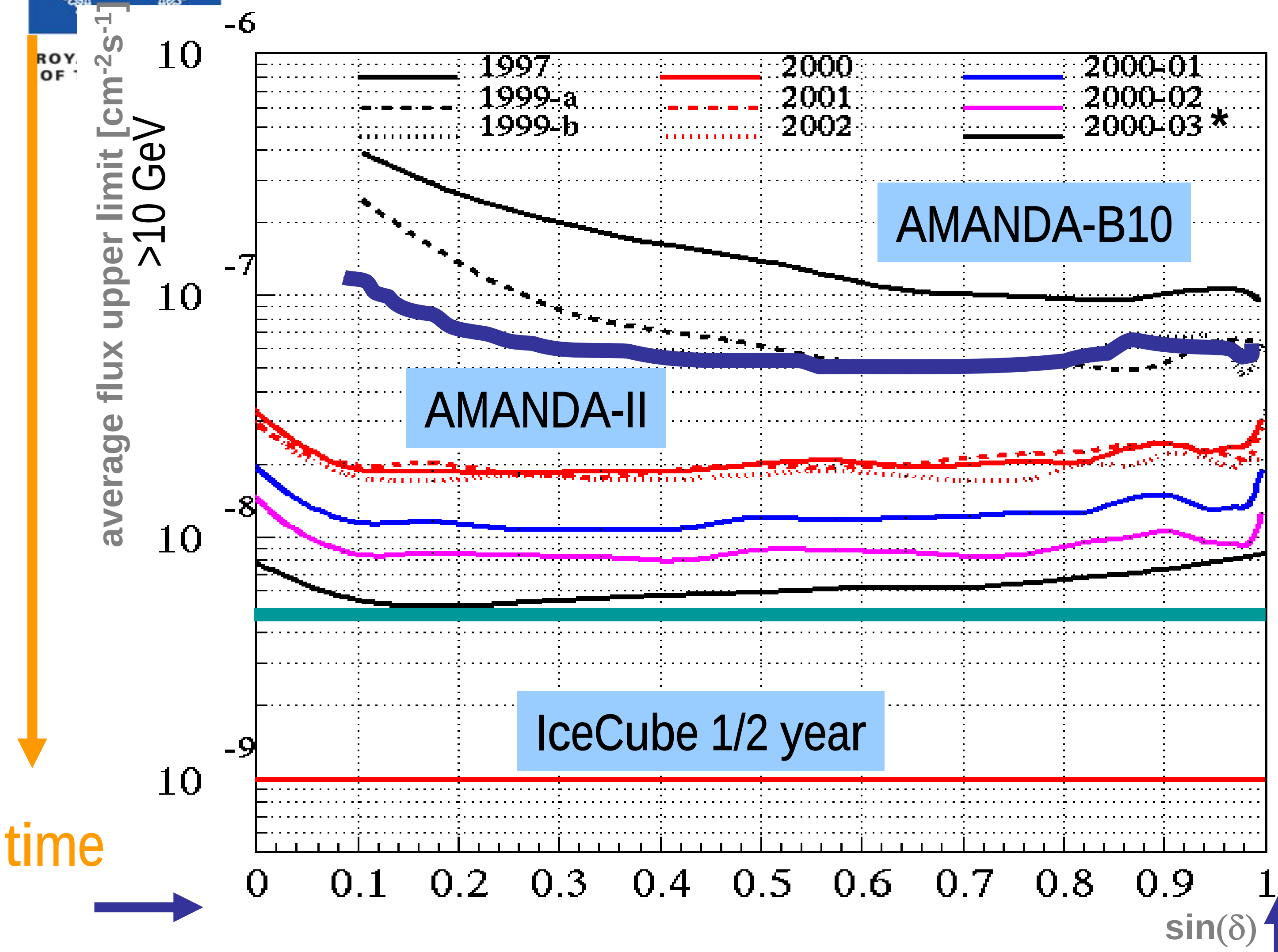
- Transparent Universe (≠γ)
- Travel in straight line (≠p)
- Produced in hadronic accelerators ?

<u>Study of:</u>

- Sources:
  AGNs, SNRs, GRBs...
- neutrino-physics:
  oscillations, cross-sections..
- “new” physics:
  WIMPS, monopoles...



Steady point source: progress in sensitivity (ego slide)



optimized for E^{-2}, (*) $E^{-2,\,3}$ signal

1999b: Jan's analysis

Jan's model, still not excluded ☺

Preliminary

$\Phi_\nu^{lim} \approx 0.68 \cdot 10^{-8}\ cm^{-2}s^{-1}$

Since I am among friends ..some words on 1ES 1955+650

- AMANDA II sees 5 neutrinos during a period of 4 years
- The expected background is 3.7
- It turns out 3 out of the 5 events are detected within a period of 66 days (which happens to be while 1ES1955 is in a flaring state)
- I calculate significance of: 3.2 σ (no trial factors)
- 66 days ?
- Would I bet on it ? Well, yes .....

Neutralino as dark matter candidate (in one minute)

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Cosmological observations

$$\left.\begin{aligned} \Omega_m &\sim 0.30 \\ \Omega_b &\sim 0.05 \end{aligned}\right\} \; . \exists \text{ dark, non-baryonic matter}$$

What is it ?

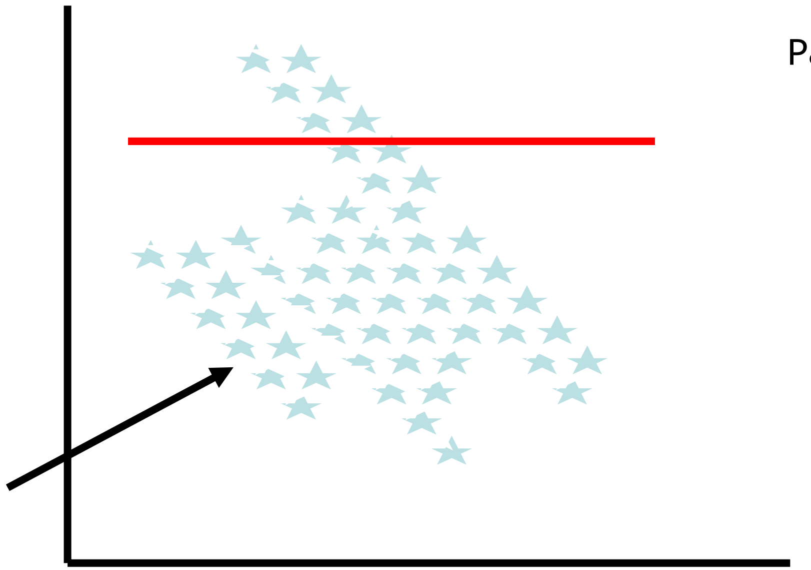
Minimal Supersymmetric Standard Model

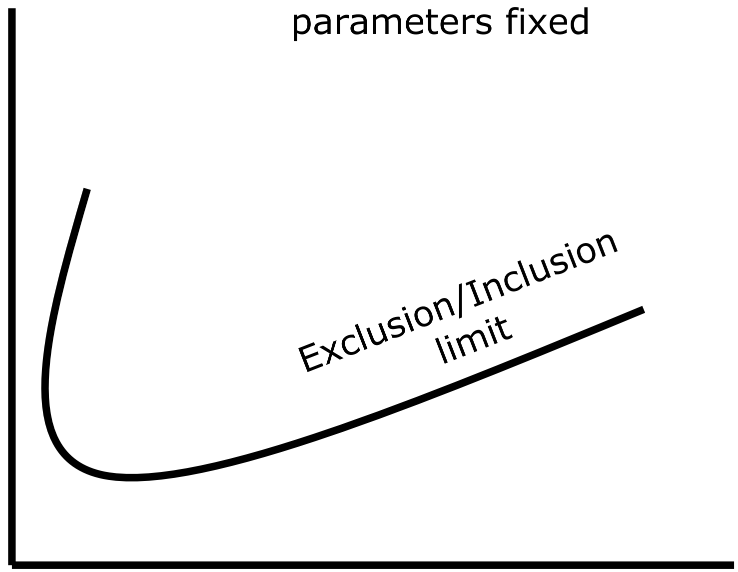
R- parity conserved → LSP stable = neutralino χ

$$\chi = \left\{\begin{array}{l} \text{interacts weakly} \\ \text{GeV-TeV mass} \\ \text{stable} \end{array}\right\} = \text{dark matter???}$$

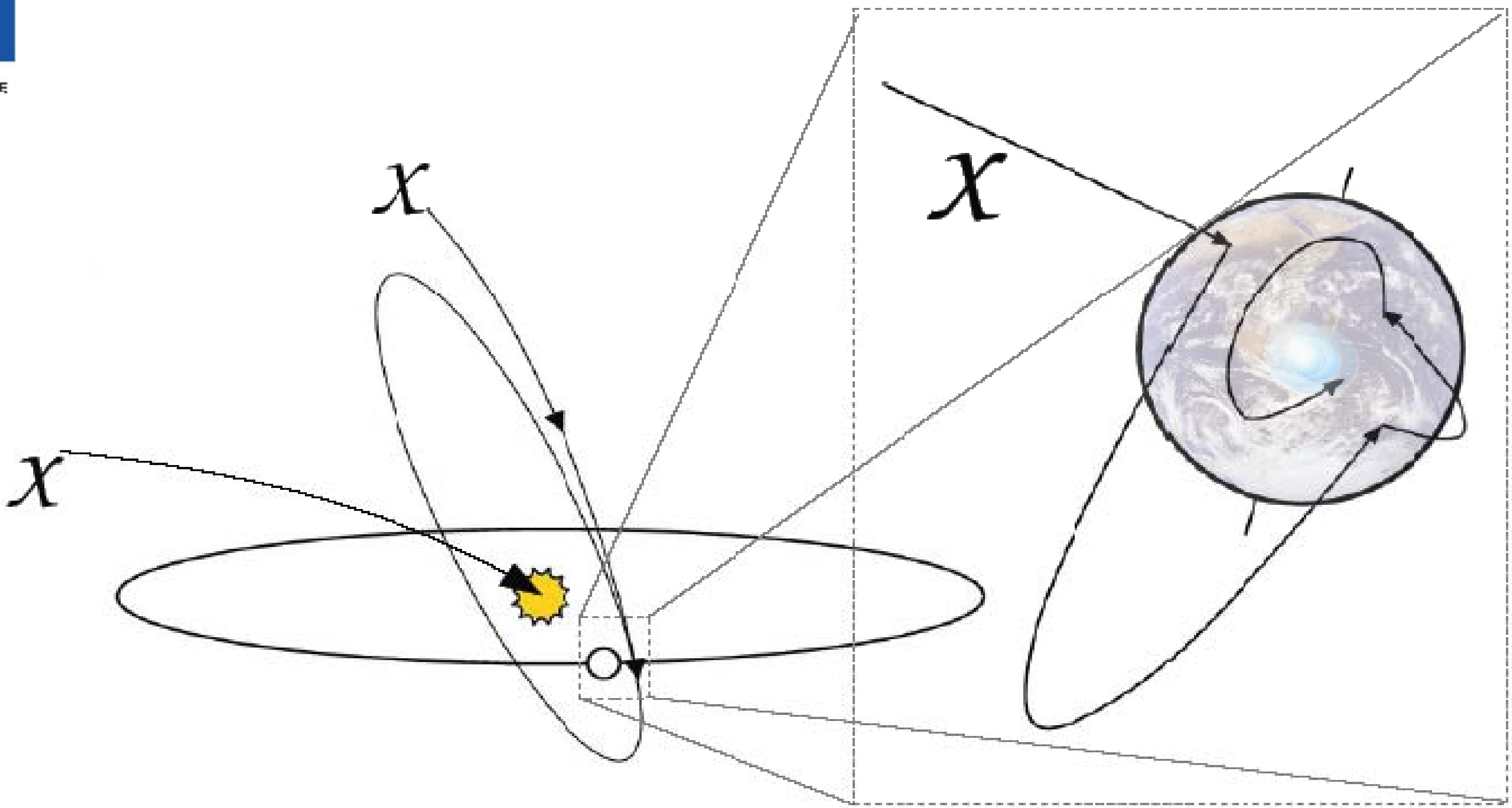
MSSM: presentation

- Bosons ←→ Fermions (~double the particle content, and introduce many new couplings) → 106 free parameters





Neutralino capture

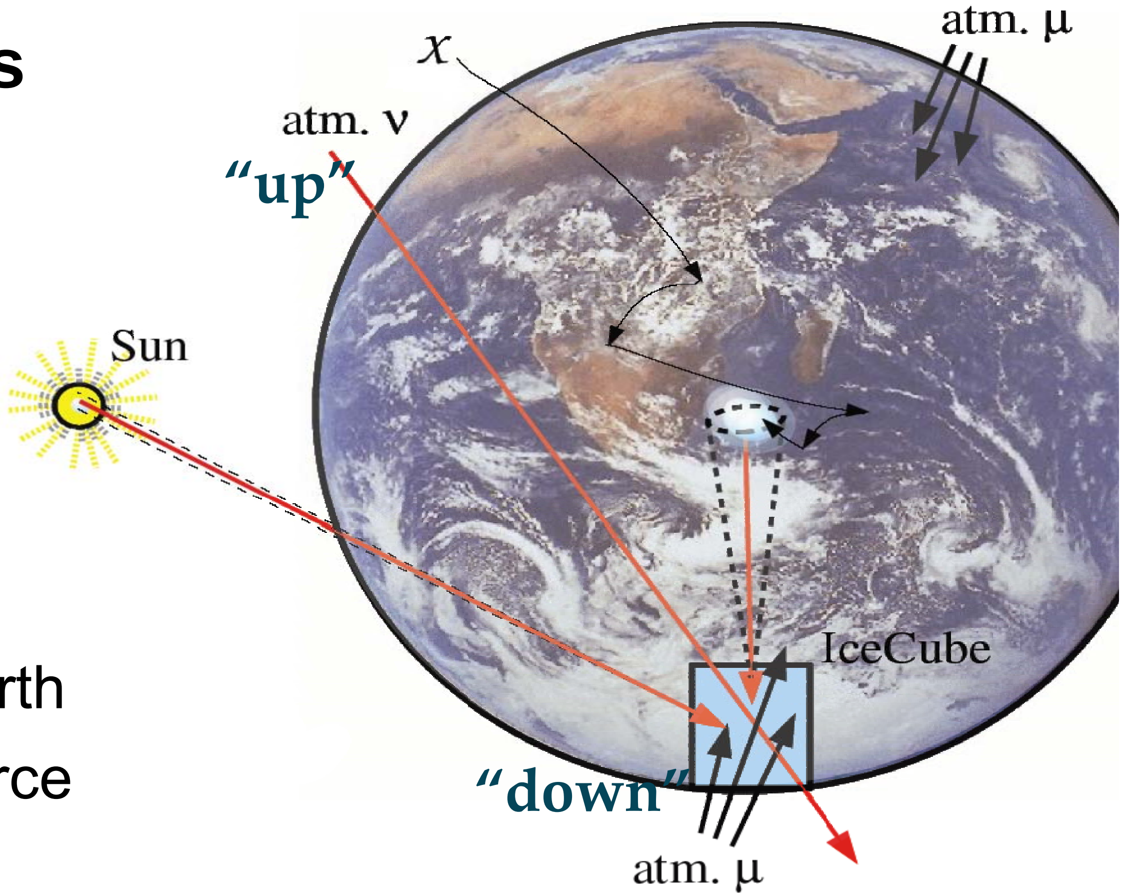


Higher density → appreciable rates

Neutralino signals

Neutralino-induced neutrinos

$$\chi\chi \rightarrow \left\{ \begin{array}{c} q\bar{q} \\ l^{+}l^{-} \\ W, Z, H \end{array} \right\} \rightarrow \nu$$



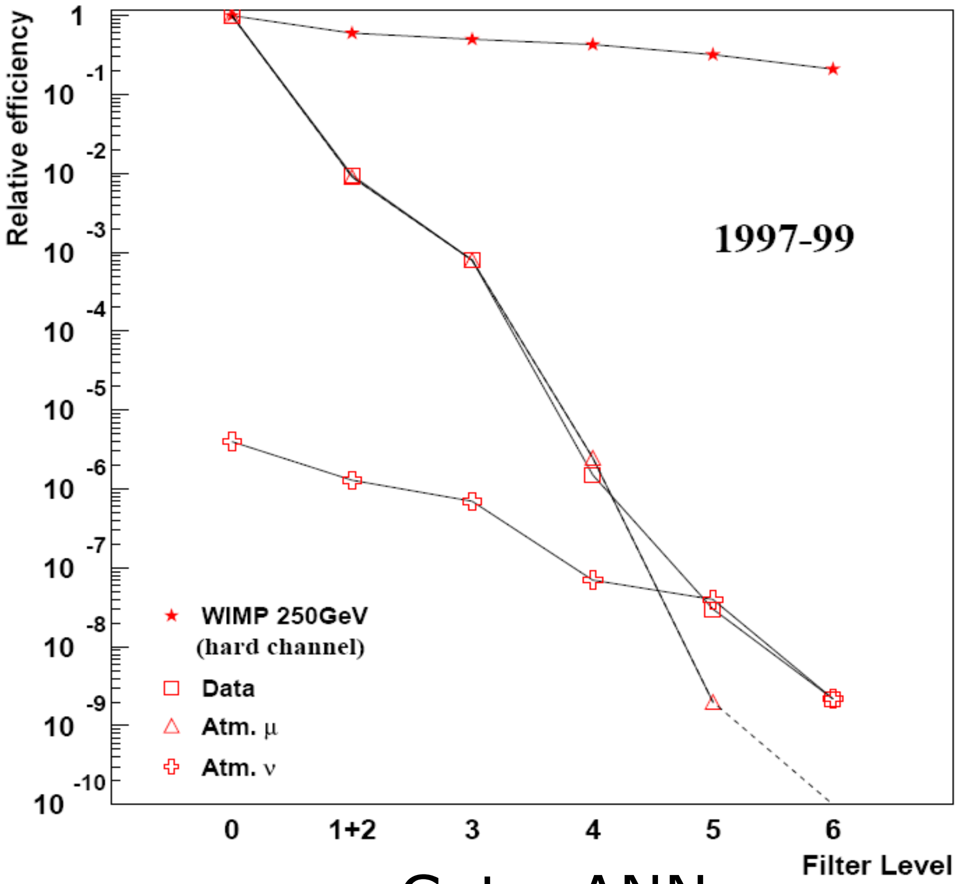
Atmospheric background

- atm. μ: absorbed by the Earth
- atm. ν: compare on/off source angular regions

Analysis

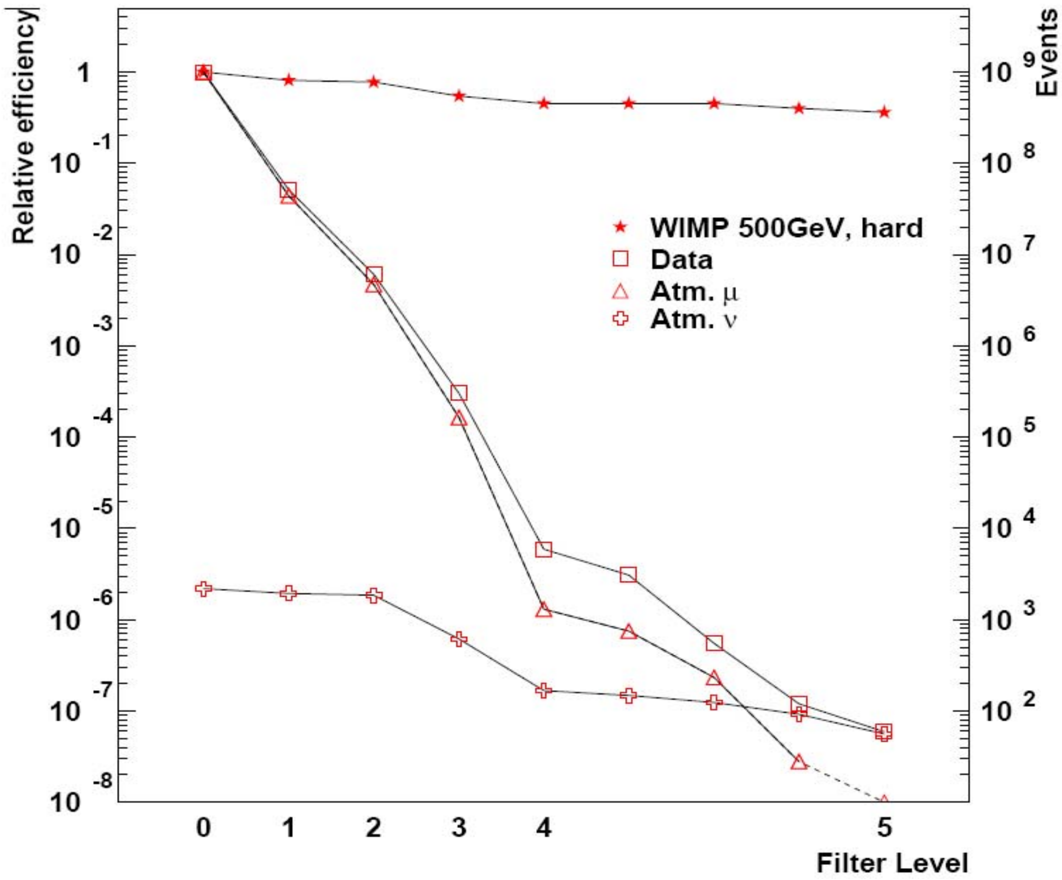
Earth 1997-1999

(paper in preparation)



Cuts, ANN

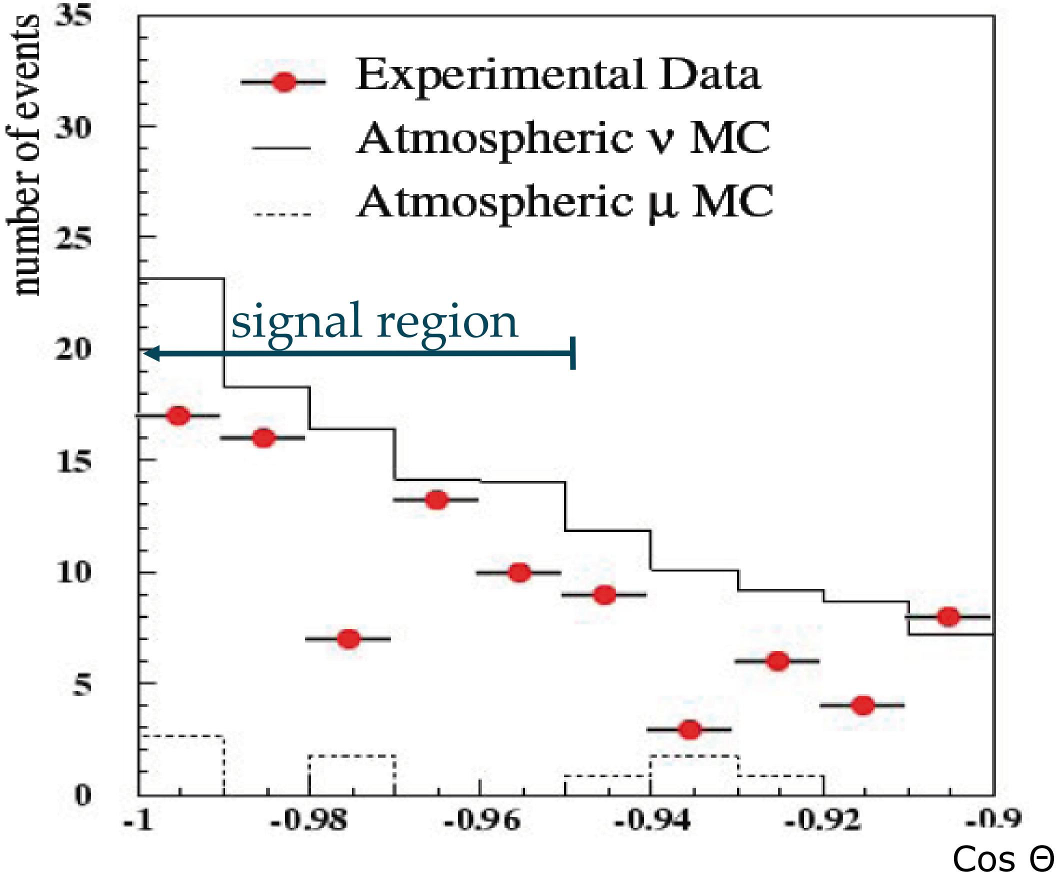
Sun 2001 **(submitted to Astrop. Phys.)**



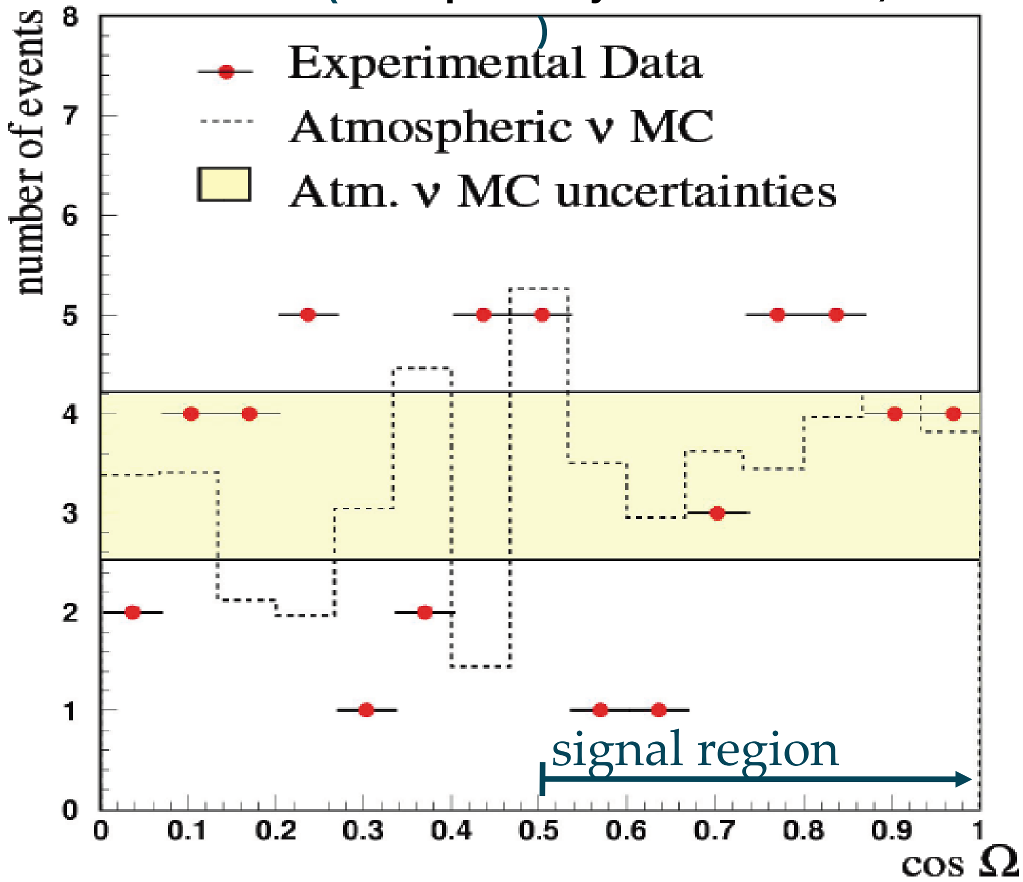
Cuts, ANN

Results

Earth 1997-1999 **(paper in preparation)**



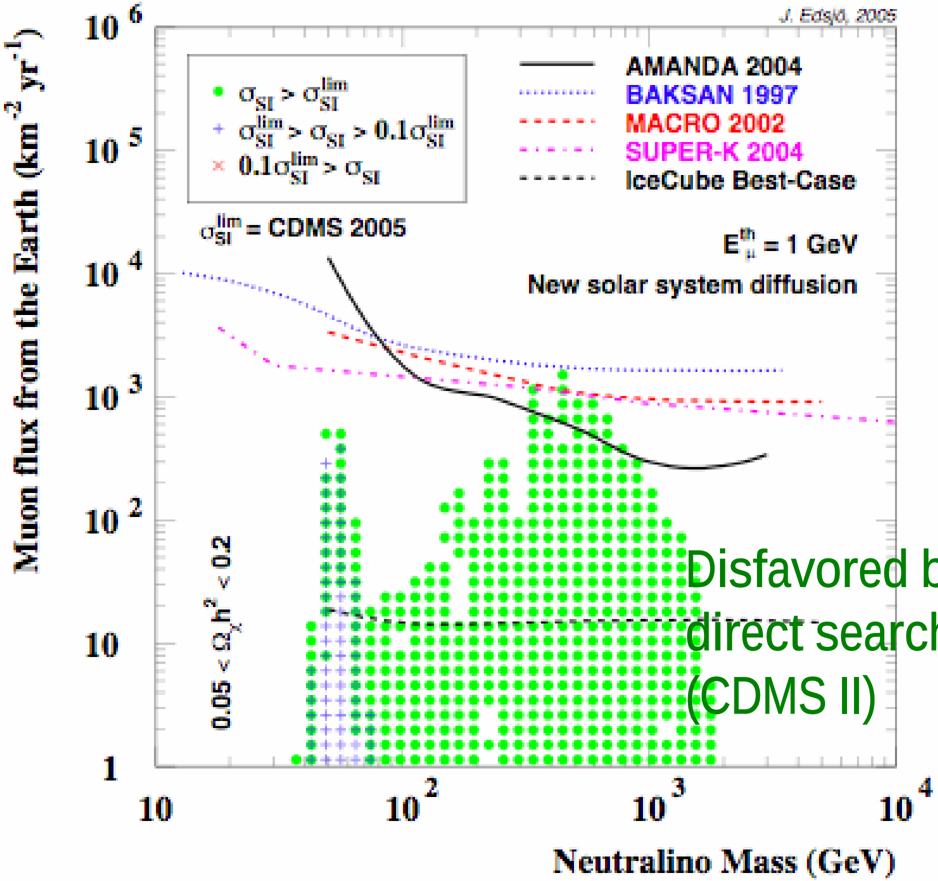
Sun 2001 **(Astropart.Phys.24:459-466,2006)**



Results cont'd

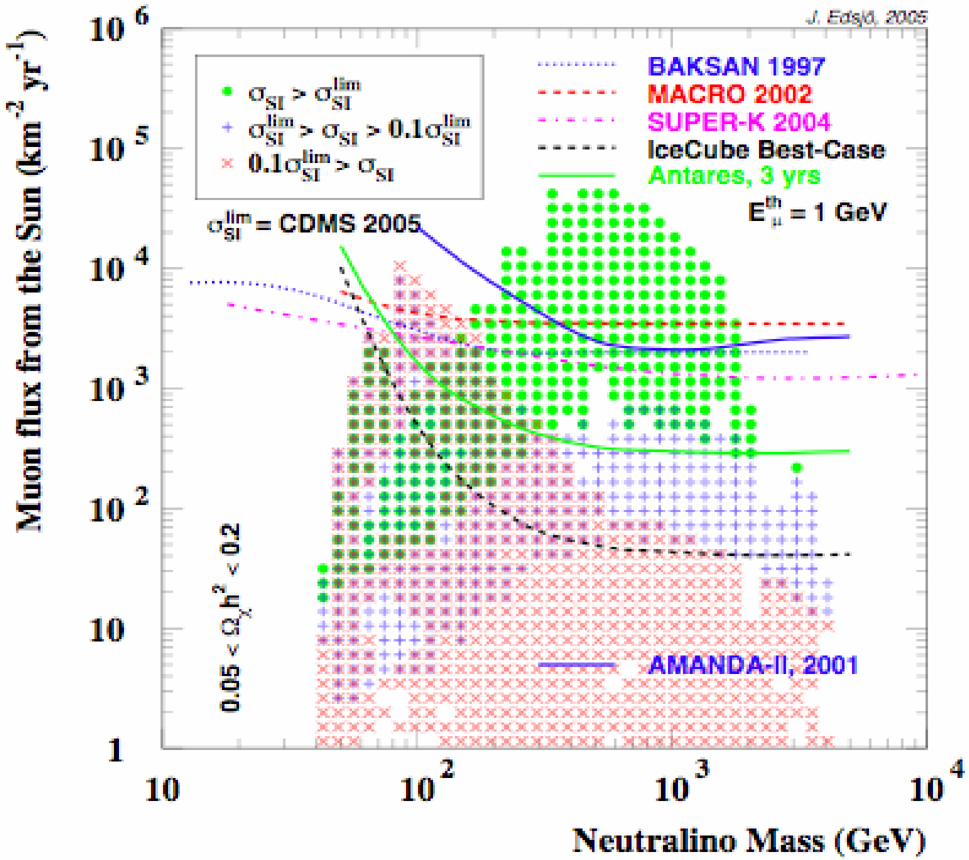
Submitted for publication

Limits on muon flux from Earth center



Published in Astrpart. Phys.

Limits on muon flux from Sun



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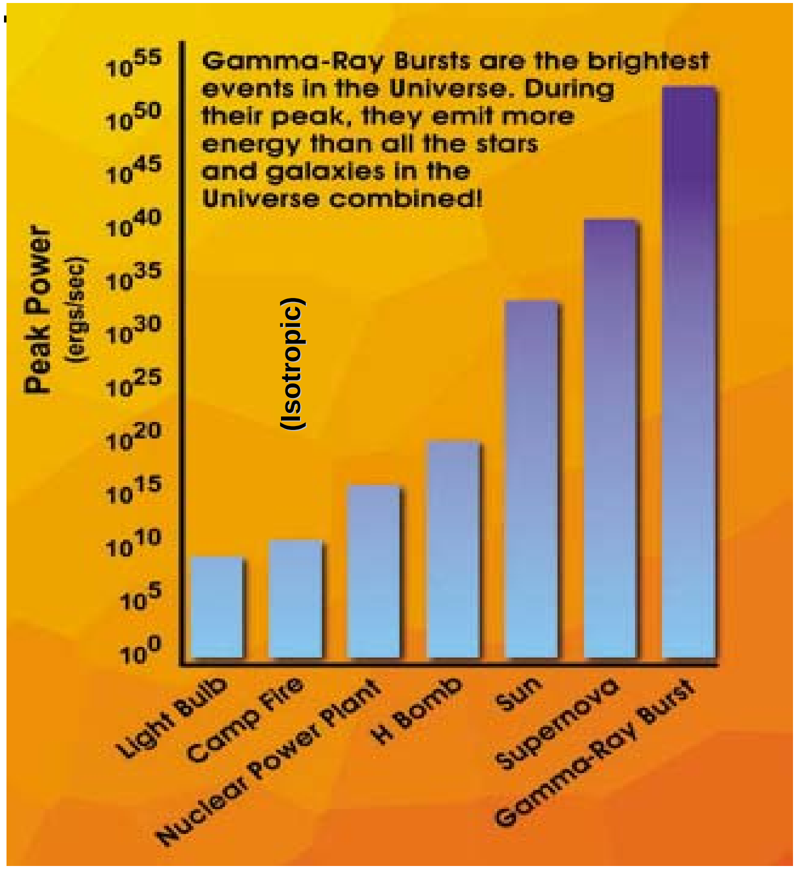
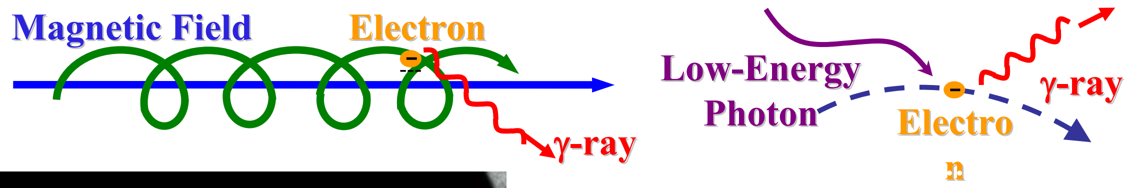
And now to something else....

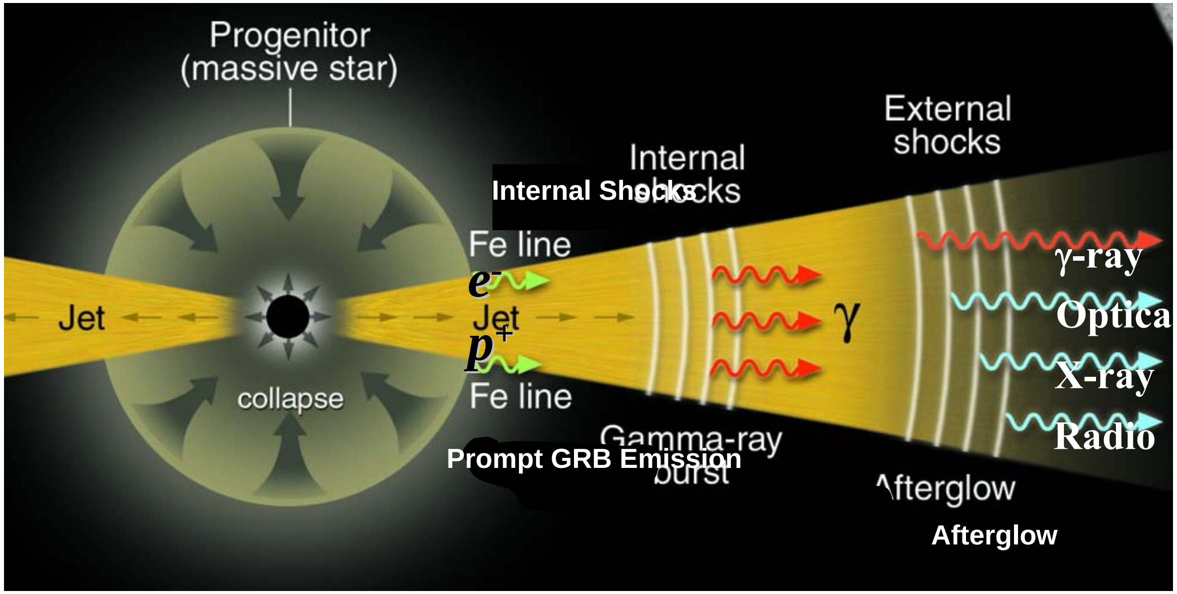
GRBs in a minute

- GRBs are unique, varying from burst to burst and class to class (short, long, X-ray strong).
- Durations: .1-100s, 0.1-1Mev gammas
- relativistic expansion from a compact object $R \leq 2\Gamma 2cDt$ (compact explains rapid variability, relativistic expansions lets high energy gammas escape)
- Observations indicate: synchrotron radiation or inverse compton as source of prompt emission



Neutrinos from GRBS

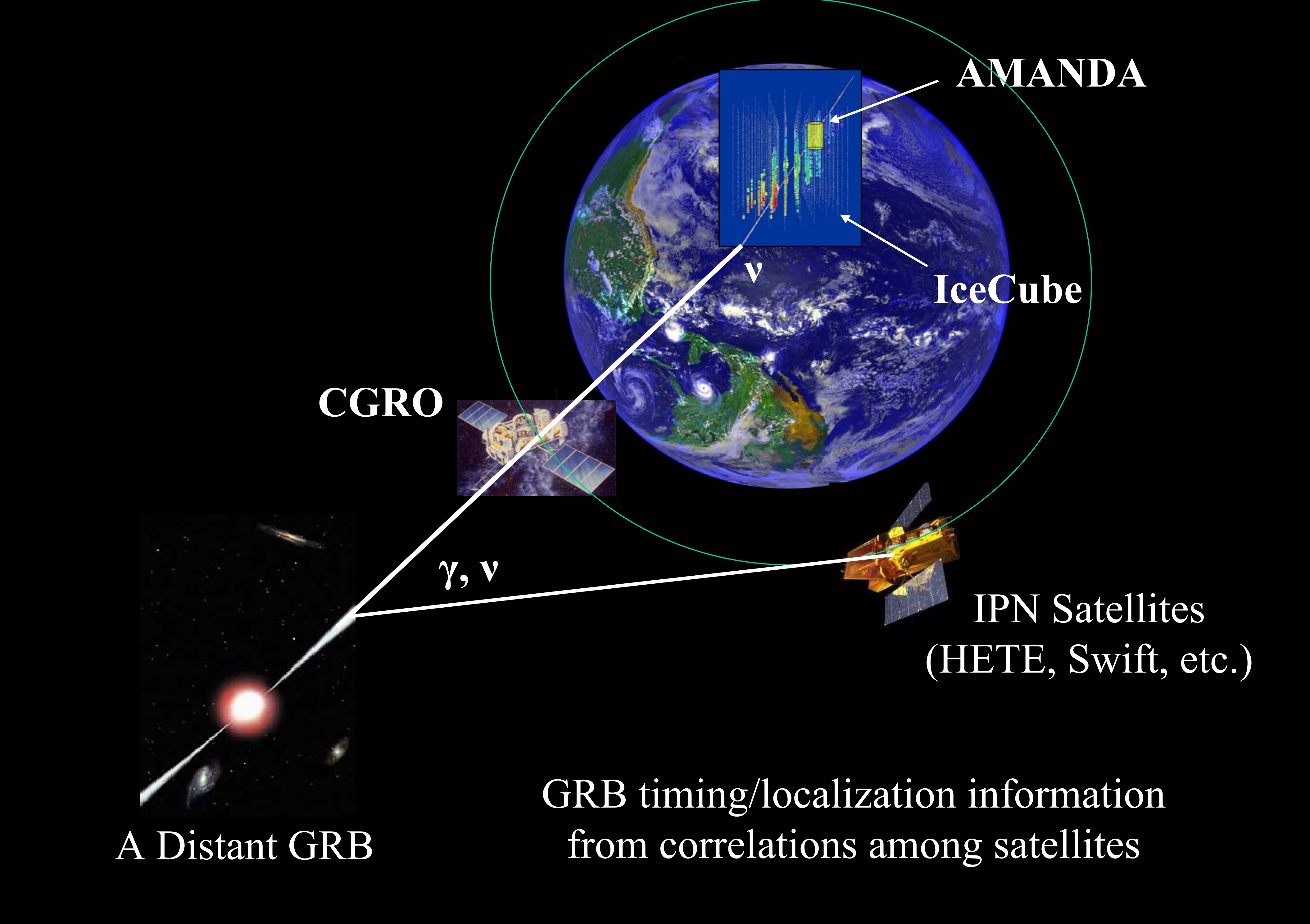




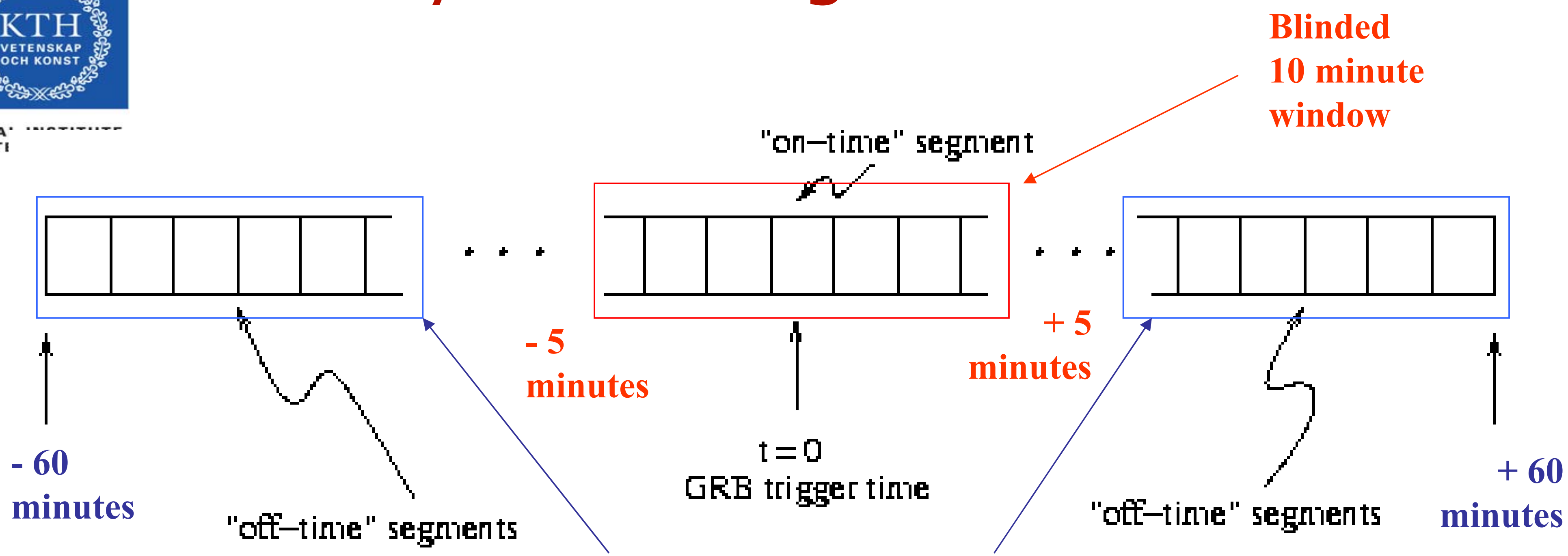
$E^{p\gamma}_{cm} \equiv$ pγ center of mass energy & $E^{Th}_{\Delta^+} \equiv \Delta^+$ threshold energy.

$$\text{If } E^{p\gamma}_{cm} > E^{Th}_{\Delta^+} \Rightarrow p^+ + \gamma \to \Delta^+ \to (n) + \pi^+ \to \nu_\mu + \mu^+ \to \nu_\mu + e^+ + \nu_e + \bar{\nu}_\mu$$

Hadron Acceleration ?! -→ COSMIC RAYS ?


AMANDA
IceCube
ν
CGRO
γ, ν
IPN Satellites
(HETE, Swift, etc.)
A Distant GRB
GRB timing/localization information
from correlations among satellites

Analysis strategies



~110 (120-10) minute background used to set cuts and check for data quality & stability

- Background region is approximately ±60 minutes surrounding each GRB (determined by BATSE/IPN)
- Omit ±5 minutes surrounding GRB trigger time
- Analyse large number of BATSE GRBs assuming average neutrino spectrum ("mass search") OR look at individual GRB: model neutrino spectrum from e.-m. observations ("individual search")

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Event quality selection

Cuts based on:

- *event time relative to BATSE trigger*
- *reconstructed track direction* relative to burst position
- *uniformity* of hits along reconstructed track
- *event-wise angular resolution* of reconstructed track

→ Optimize with respect to figure of merit

Results: Mass search

Year	N_{Bursts}	B_{Exp}	N_{Obs}	U.L.
2000	88	1.02	0	2.05
2001	15	0.05	0	2.19
2002	17	0.08	0	2.01
2003	19	0.10	0	1.61
00-03	139 (All)	1.25	0	1.47

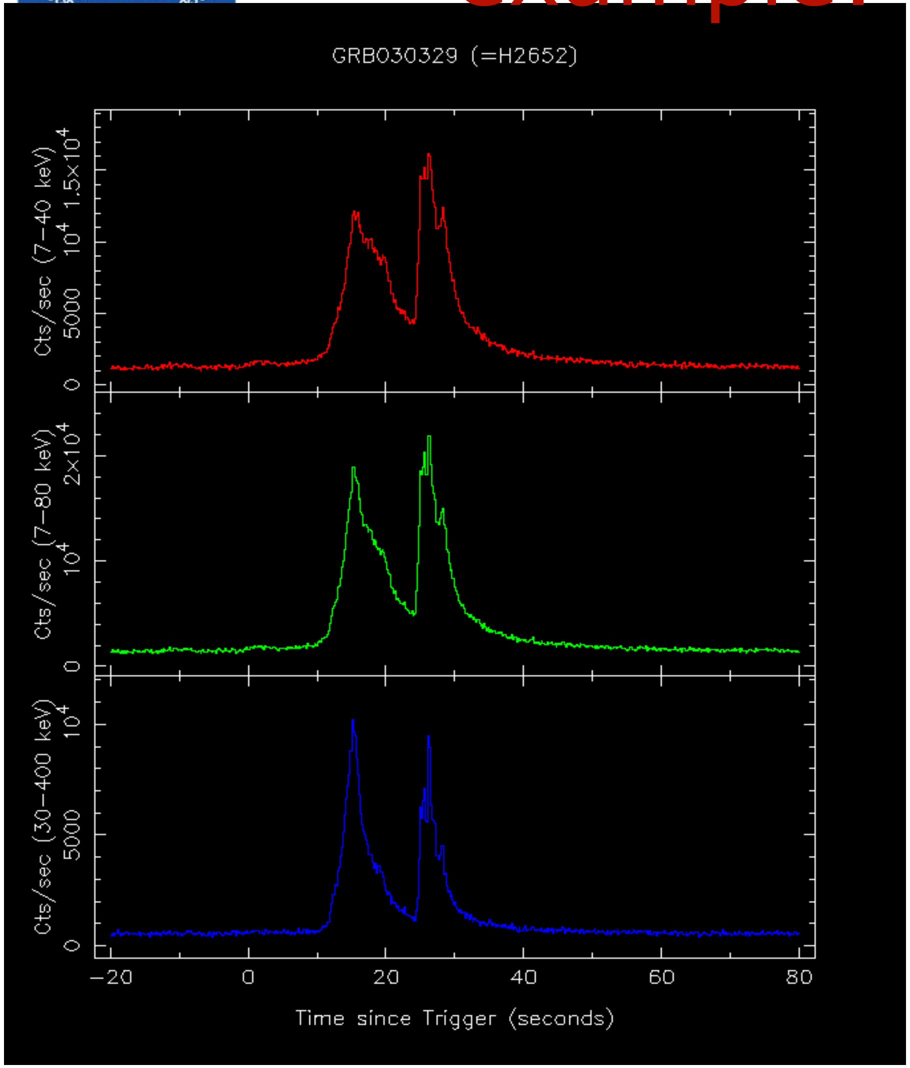
Assuming prediction from Waxman&Bahcall

Phys.Rev.D59:023002,1999

$$E_\nu^2 \Phi_\nu < 4\text{x}10^{-8}\ \text{GeV cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}$$

Note: O(10) times the WB bound

Results: individual search, example: GRB030329



Close: z ~ 0.17

Among top 0.2 % of the 2700 BATSE GRBS (Fluence)

Peak flux 100 x Crab

[Razzaque *et al.*, PRD **69** 023001 (2004)]

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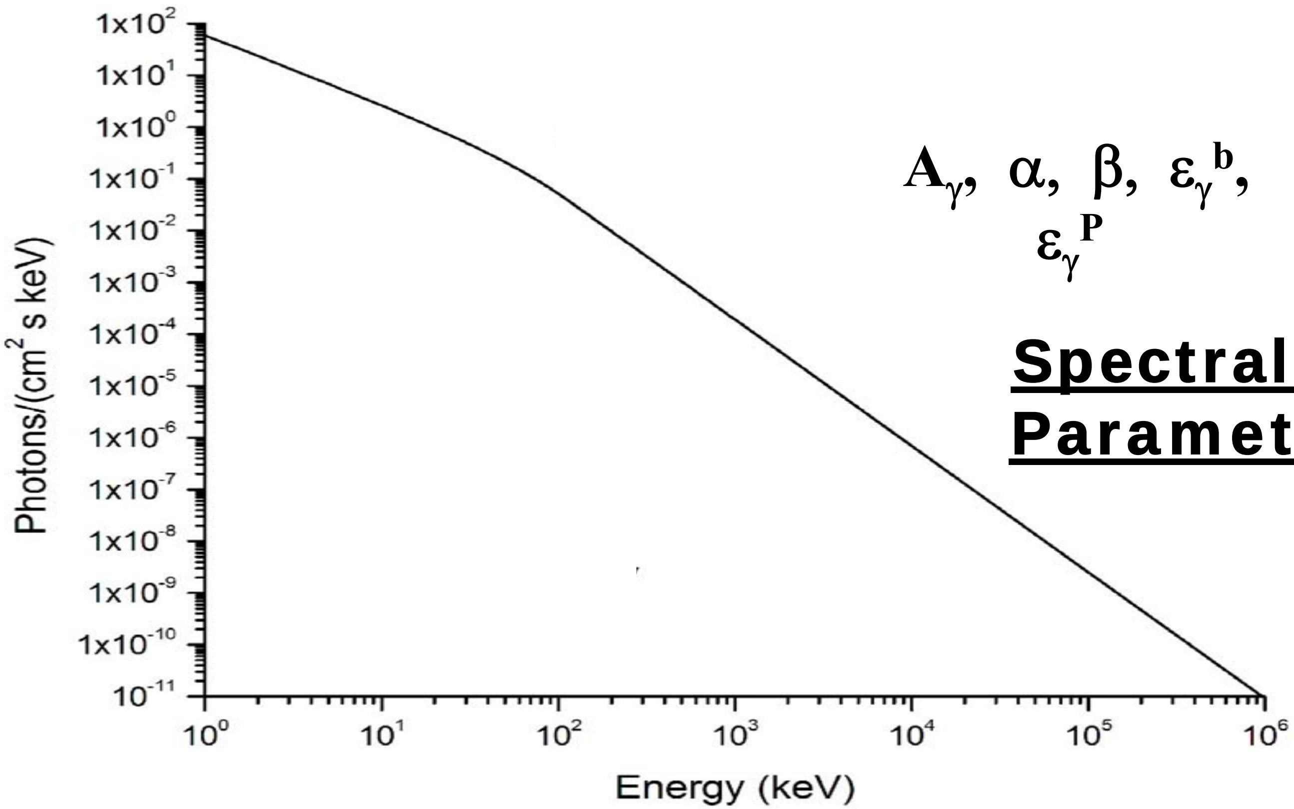
General strategy

- Fit photon-spectrum with empirical ”Band function”
- get redshift from observations of optical afterglow
- calculate expected neutrino spectrum from photon spectrum under certain assumptions
  - For example: Photon meson production (protons accelerated in the shock, photons are synchrotron photons in the jet)

See Guetta et a,l Astropart.Phys.20:429-455,2004

Band spectrum



A_γ, α, β, $\varepsilon_\gamma^{\,b}$, $\varepsilon_\gamma^{\,P}$

Spectral Fit Parameters

Neutrino spectrum

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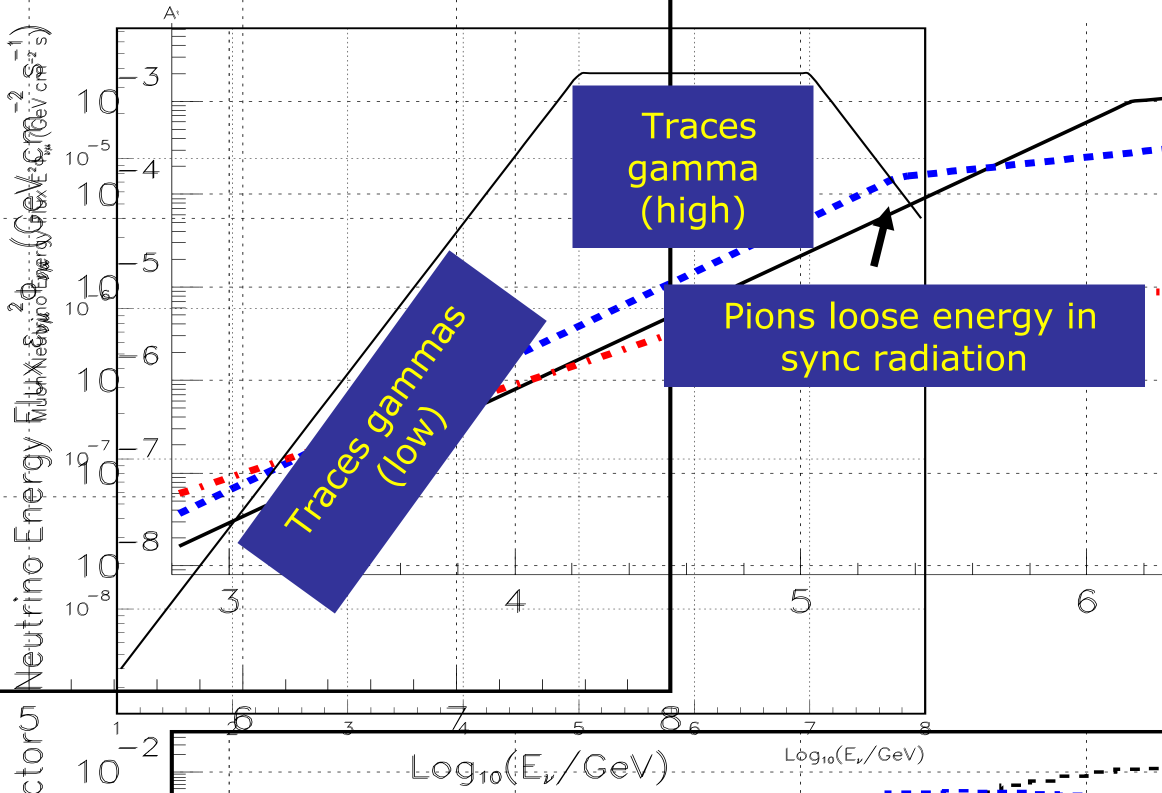
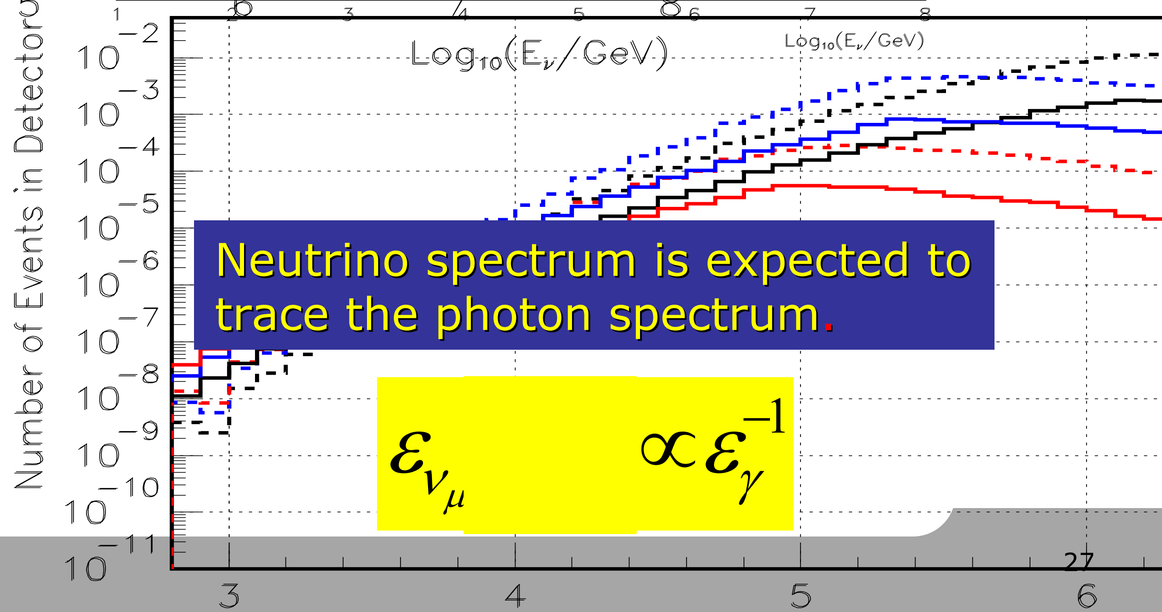
$$\varepsilon_{\nu_\mu}^2 \Phi_{\nu_\mu} \approx A_{\nu_\mu} \times \begin{cases} \left(\dfrac{\varepsilon_{\nu_\mu}}{\varepsilon_\nu^b}\right)^{-\beta-1} & \left(\varepsilon_{\nu_\mu} < \varepsilon_\nu^b\right) \\ \left(\dfrac{\varepsilon_{\nu_\mu}}{\varepsilon_\nu^b}\right)^{-\alpha-1} & \left(\varepsilon_\nu^b < \varepsilon_{\nu_\mu} < \varepsilon_\pi^b\right) \\ \left(\dfrac{\varepsilon_{\nu_\mu}}{\varepsilon_\nu^b}\right)^{-\alpha-1}\left(\dfrac{\varepsilon_{\nu_\mu}}{\varepsilon_\pi^b}\right)^{-2} & \left(\varepsilon_{\nu_\mu} \geq \varepsilon_\pi^b\right) \end{cases}$$

Is function of :

fluence, T90, redshift, gamma luminosity





Neutrino spectrum is expected to trace the photon spectrum.

$$\varepsilon_{\nu_\mu} \propto \varepsilon_\gamma^{-1}$$

Individual vs. Average (GRB 030329)

Flux model	Search bin Size (deg)	Expected background	Expected number of signal events	Observed number of events
Isotropic individual	11.3	0.23	**0.02**	0
Isotropic average	11.3	0.17	**0.001**	0

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Conclusions

- Dark matter search:
  - no dark matter found,
  - ICECUBE might be sensitive to class of models which are not allerady excluded by CDMS, looking at the sun
- GRBs:
  - no neutrinos from GRBs found
  - IceCube will have order of magnitude larger effective area
  - Detection likely to come from one exceptional (high fluence) burst, rather than average burst

KTH VETENSKAP OCH KONST

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References

- http://icecube.wisc.edu/

- Wimps in AMANDA:
  - D. Hubert, talk given at DM 2006 (Marina del Rey)
  - AMANDA collab: Astropart.Phys.24:459-466,2006 (solar)
  - AMANDA collab: Phys.Rev.D66:032006,2002 (terrestrial)

- GRBs in AMANDA:
  - M.Stamatikos : to appear in SWIFT symposium
  - IceCube collab: M. Stamatikos: ICRC 2005, Puna, India
  - Guetta et. al: Astropart.Phys.20:429-455,2004
  - E. Waxman & J. Bahcall: Phys.Rev.D59:023002,1999
  - IceCube collab: K. Kuehn: ICRC 2005, Puna, India