ν Astr

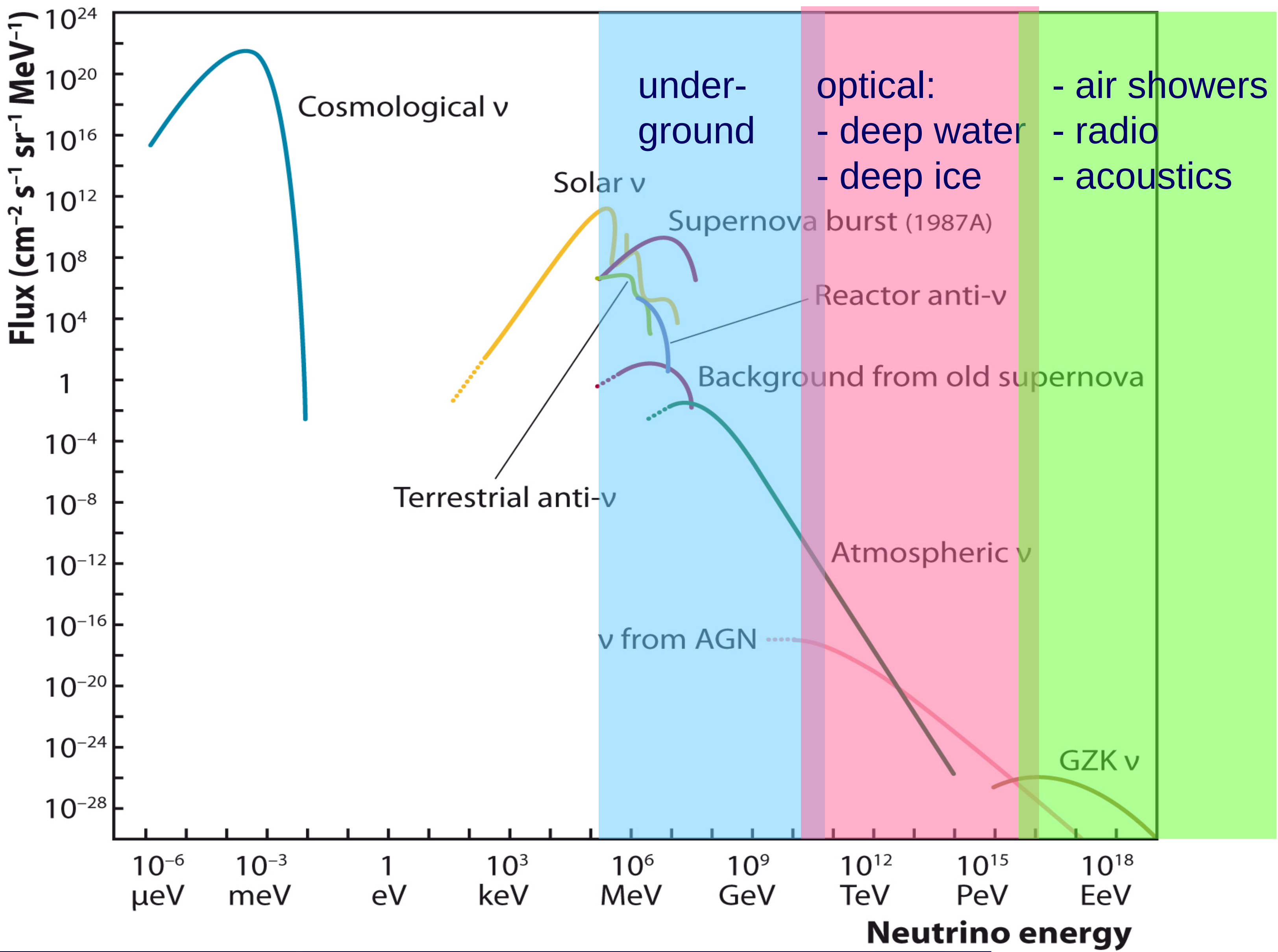
Neutrino Astronomy

Status and Perspectives

Christian Spiering
DESY

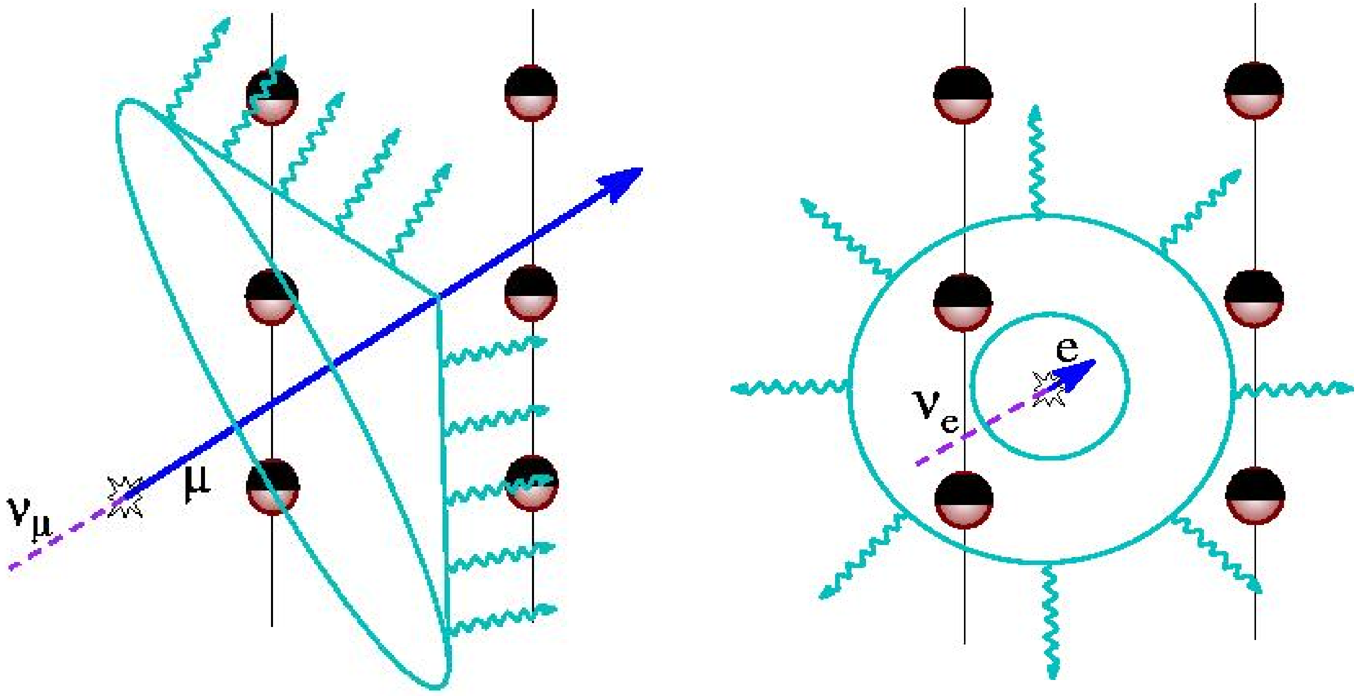
Gamma-2008, Heidelberg 2008

The unified spectrum of neutrinos



In this talk: only optical underwater/ice detection @ TeV/PeV

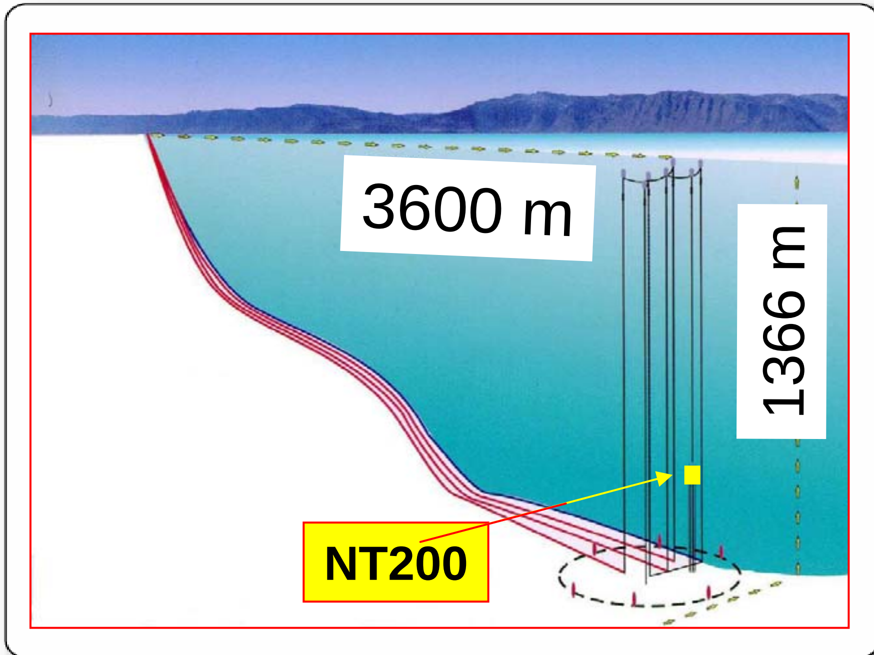
Underwater/Ice: optical telescopes



	muon tracks	cascades	
σ_{angle}	water < 0.3°	water 3-6°	(at 10 TeV)
	ice 0.5-1°	ice ~25°	(at 10 TeV)
σ_{energy}	0.3 in log E	30% in E	(at 10 TeV)

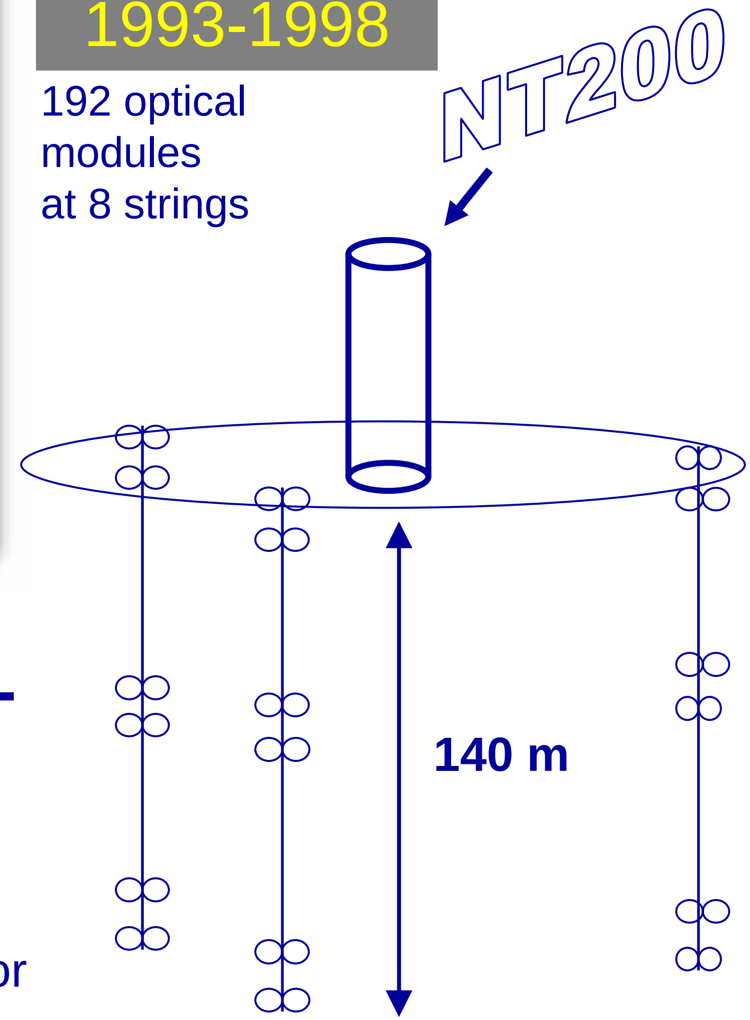
First Generation Telescopes

The Baikal Neutrino Telescope



construction
1993-1998

192 optical
modules
at 8 strings

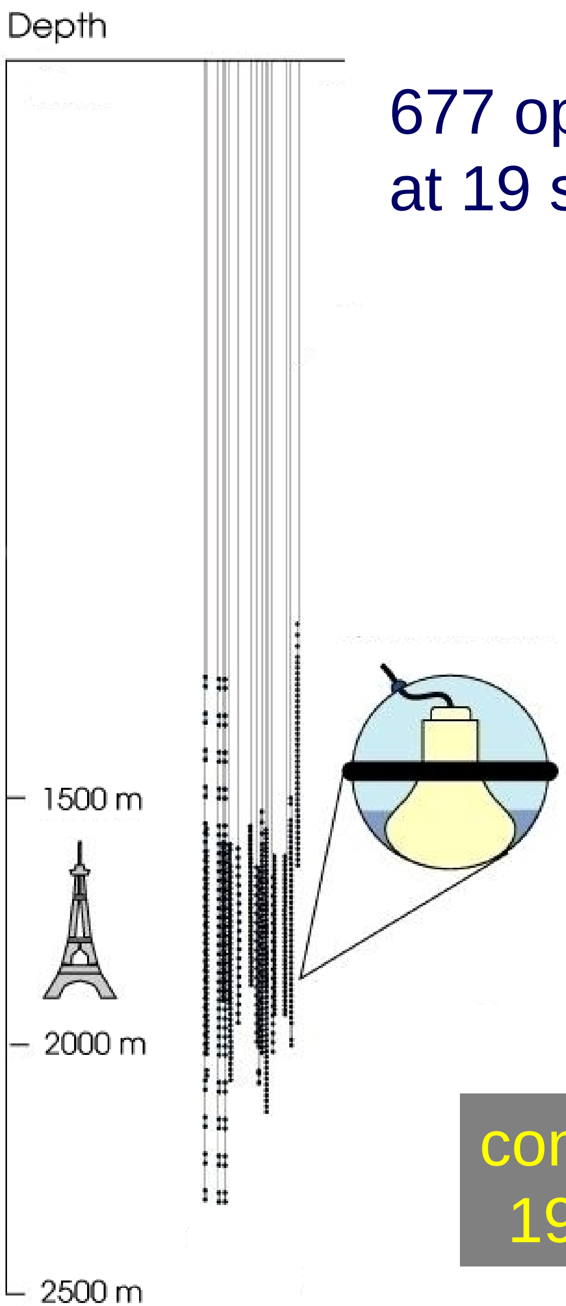


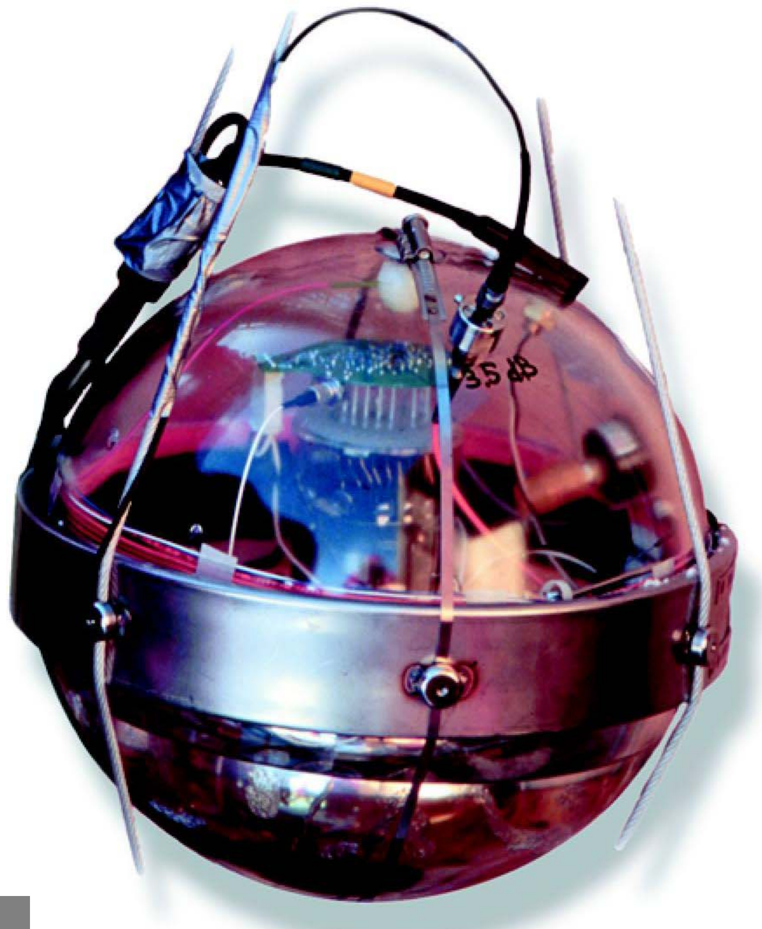
NT200+

- upgrade 2005/06
- 4 times better sensitivity than NT200 for PeV cascades
- basic cell for km3 scale detector

AMANDA

677 optical modules
at 19 strings





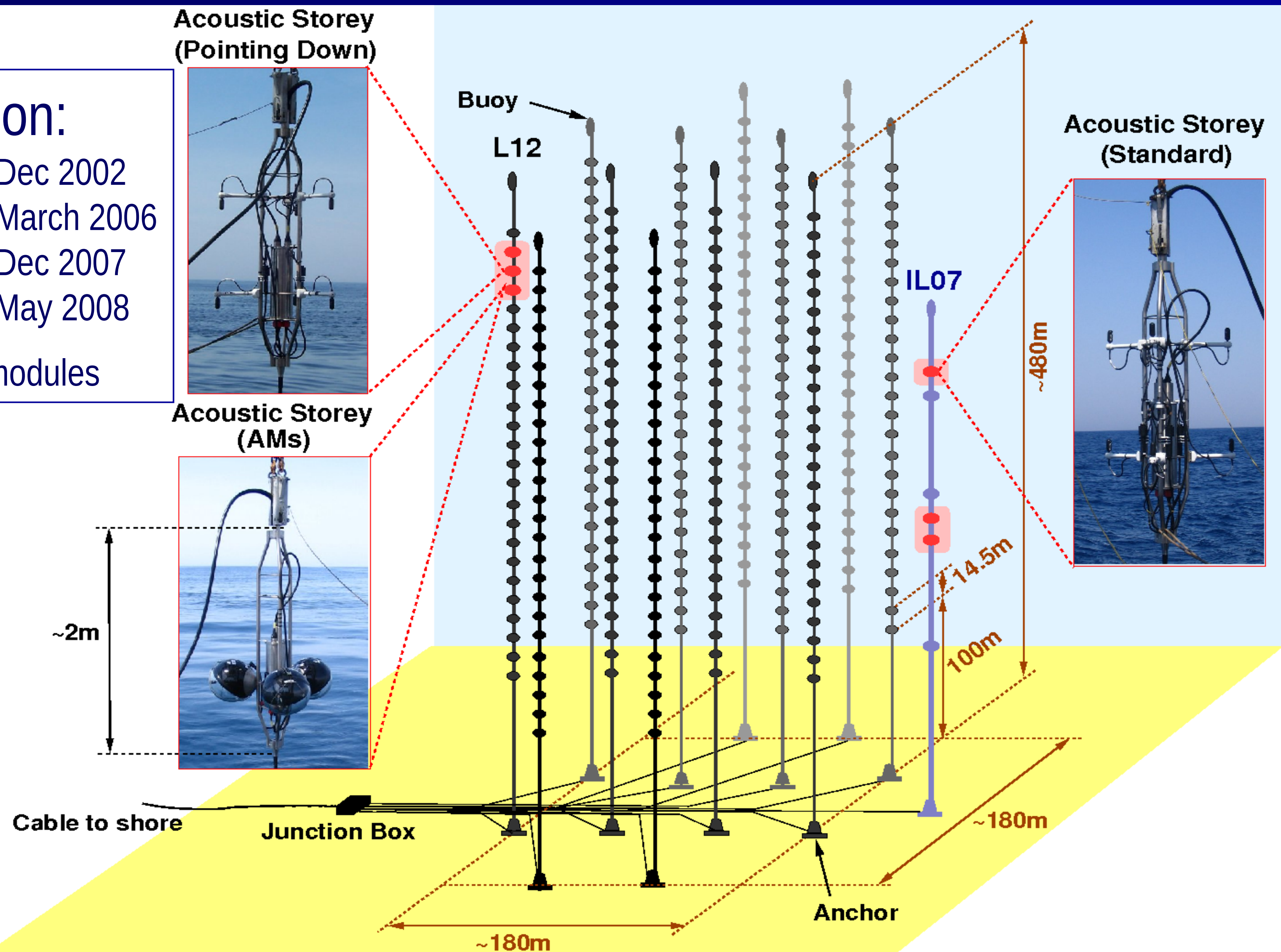
construction
1996-2000

ANTARES

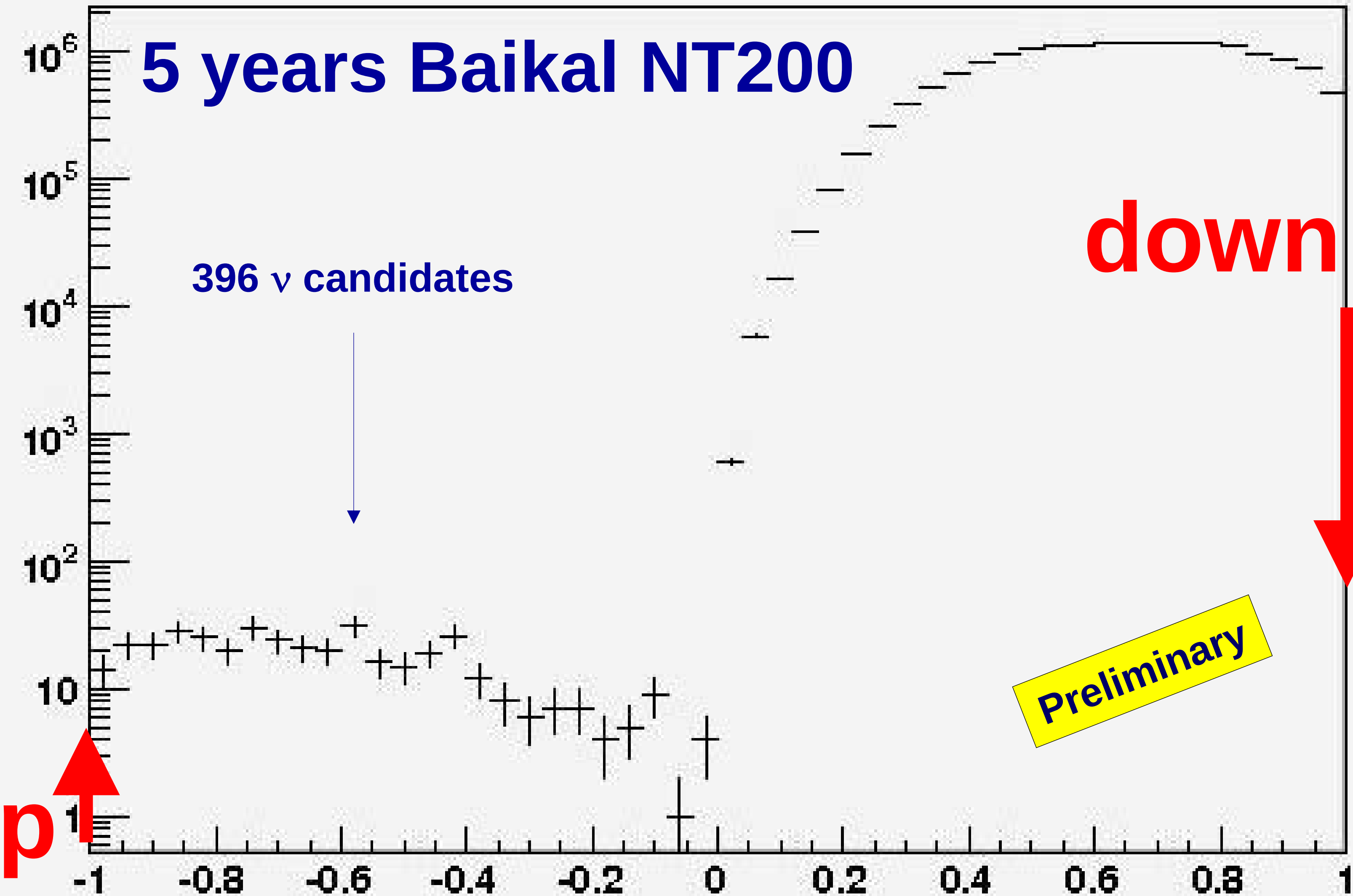
Installation:

Junct.Box - Dec 2002
Line 1 - March 2006
Line 5-10 - Dec 2007
Line 11-12 - May 2008

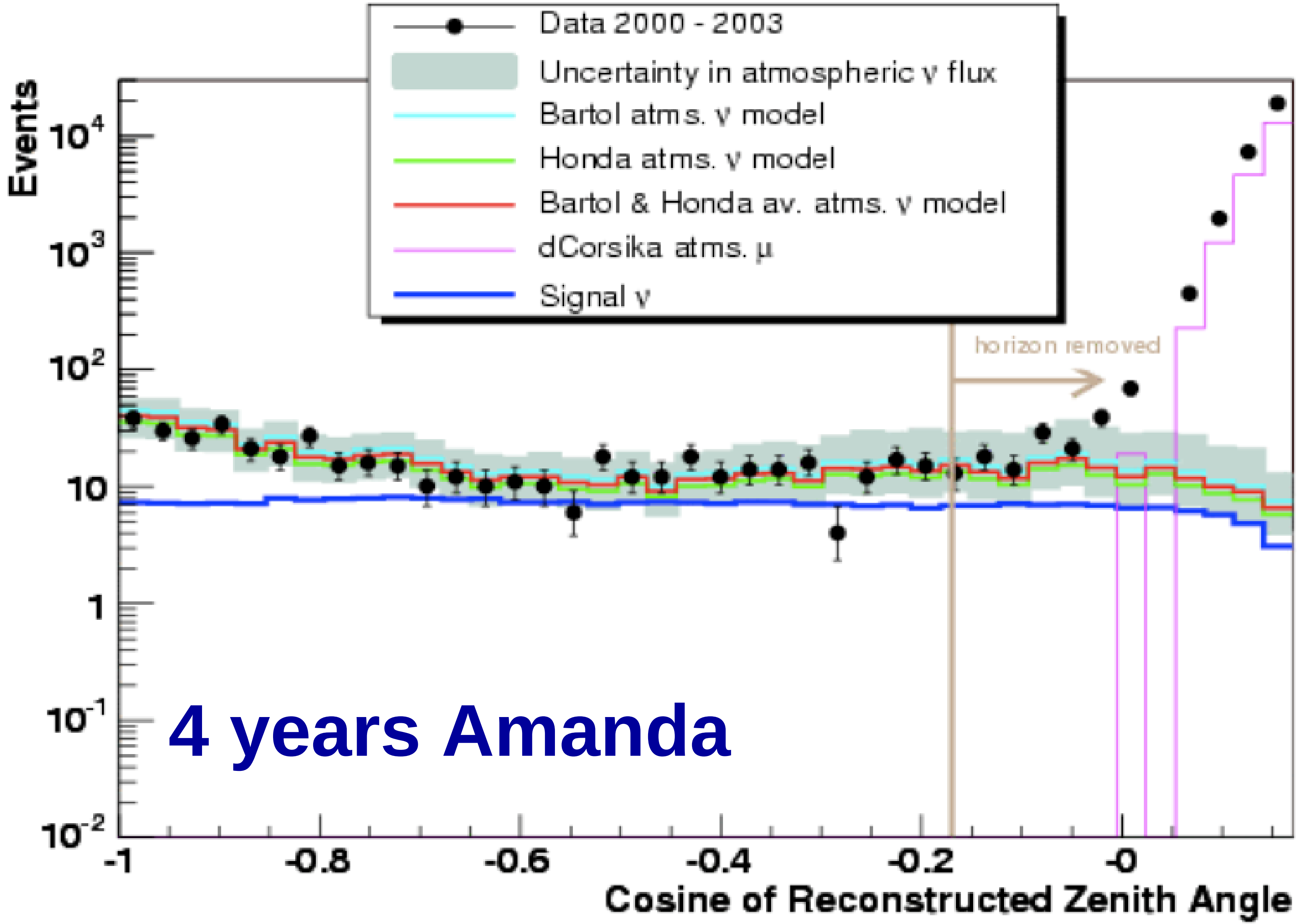
900 optical modules



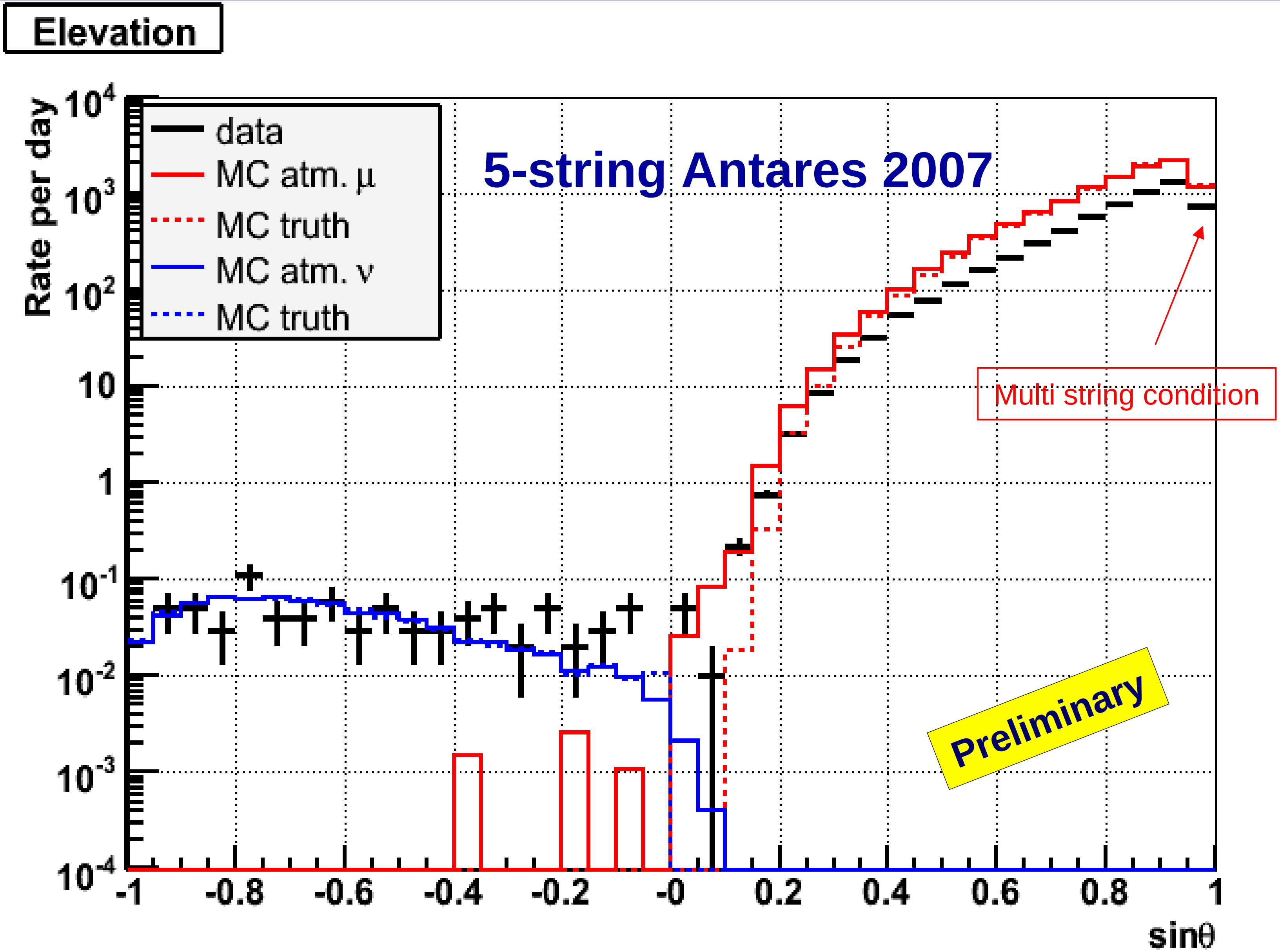
Atmospheric Neutrinos



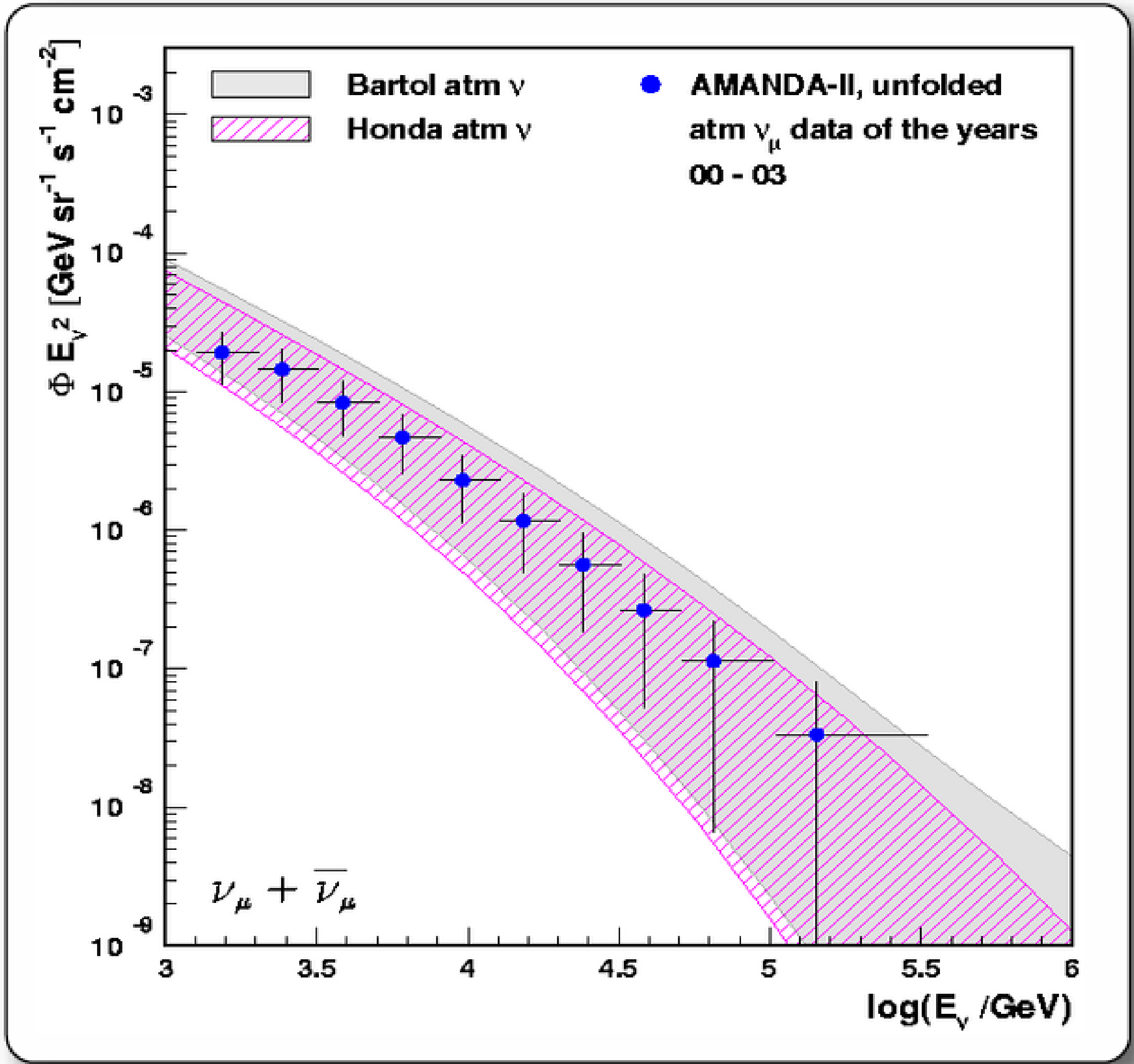
Atmospheric Neutrinos



Atmospheric Neutrinos

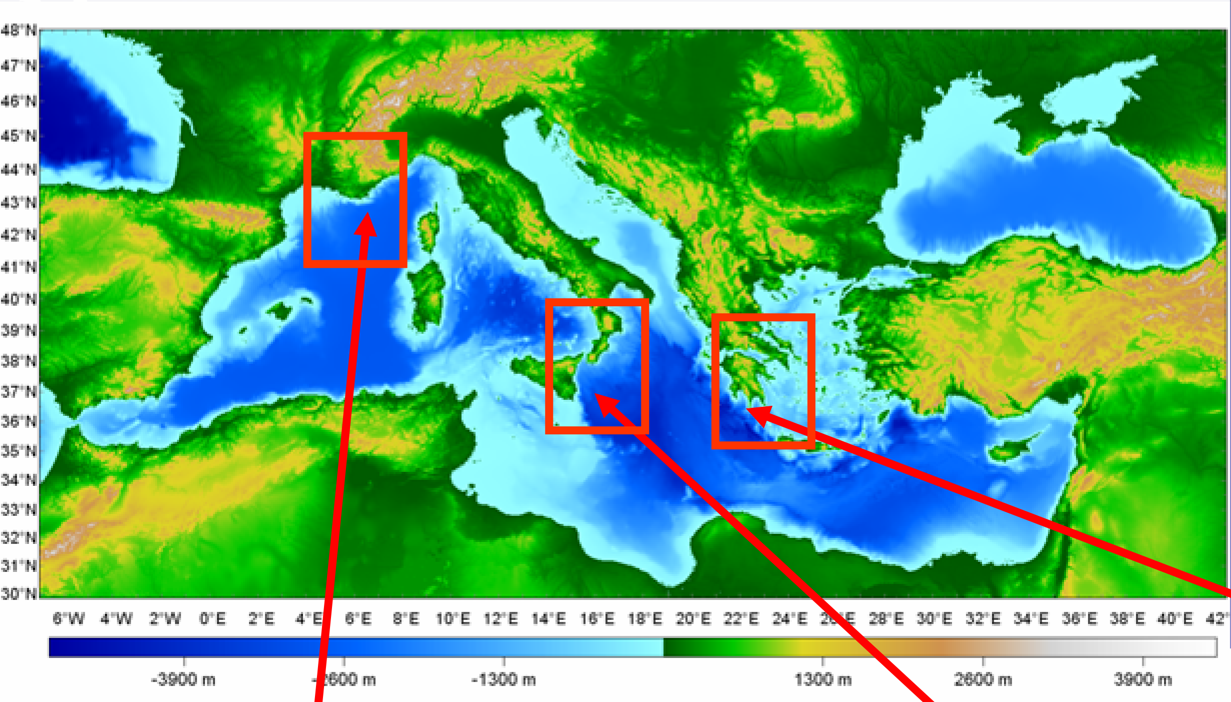


Amanda: energy spectrum of atmospheric neutrinos (4-year data)

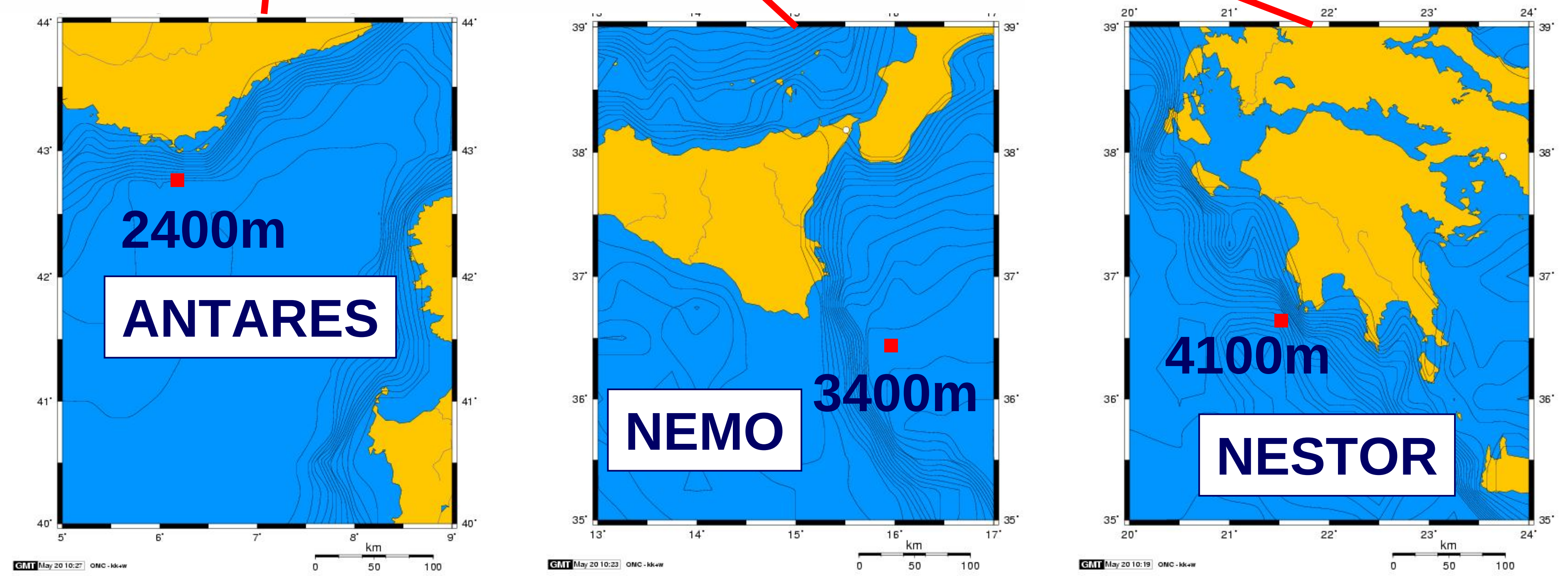


Spectrum up to >100 TeV !

NESTOR & NEMO



-3900 m
-2600 m
-1300 m
1300 m
2600 m
3900 m



2400m
ANTARES
NEMO
3400m
4100m
NESTOR
km
0
50
100

Second Generation Telescopes

- IceCube
- Baikal-GVD
- KM3NeT

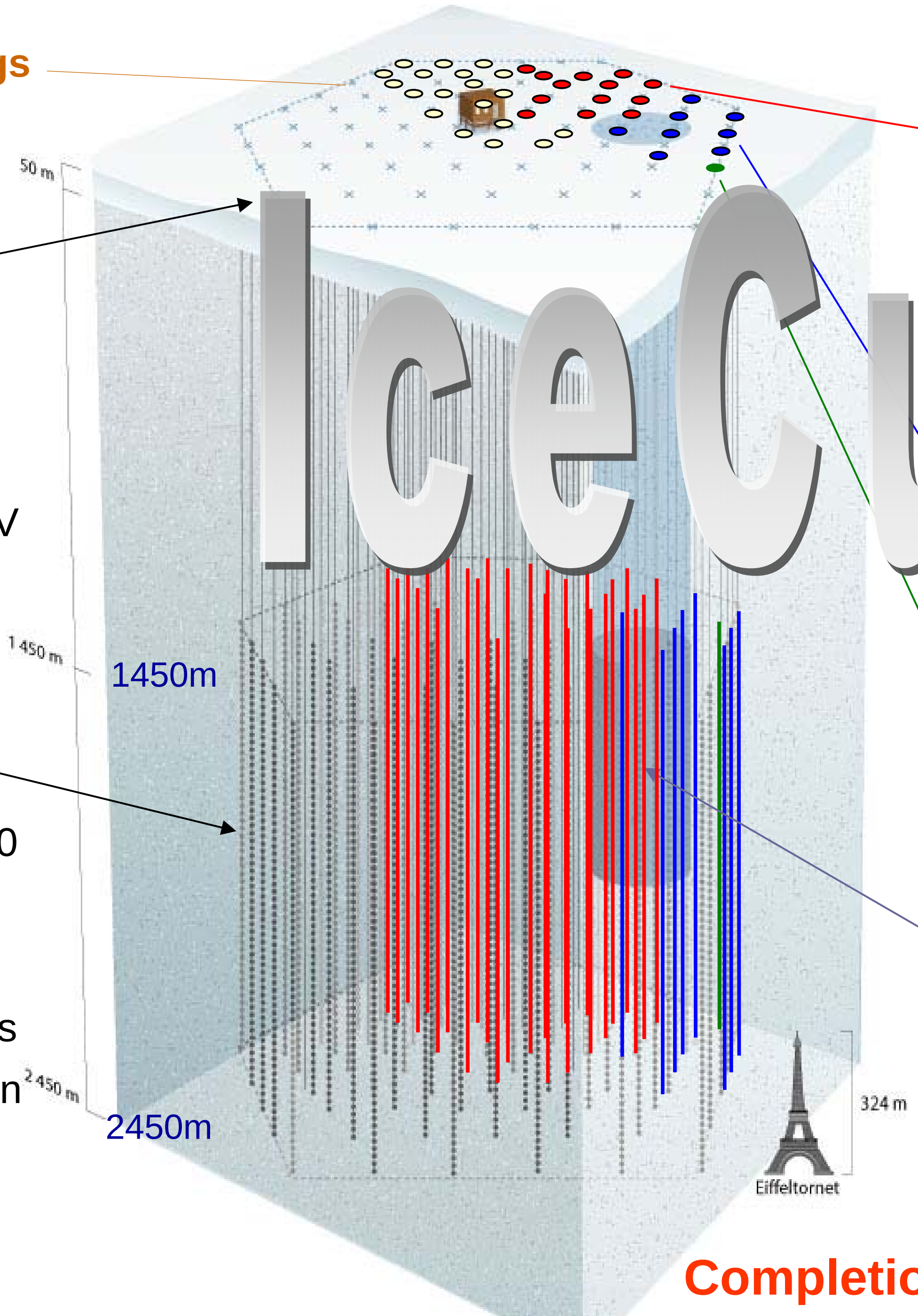
IceCube

2007-2008: 18 strings

2006-2007:
13 strings deployed

IceTop

Air shower detector
80 pairs of ice
Cherenkov tanks
Threshold ~ 300 TeV



2004-2005 : 1 string

IceCube

Goal of 80 strings of 60
optical modules each

17 m between modules
125 m string separation

AMANDA-II
19 strings
677 modules

Completion by 2011.

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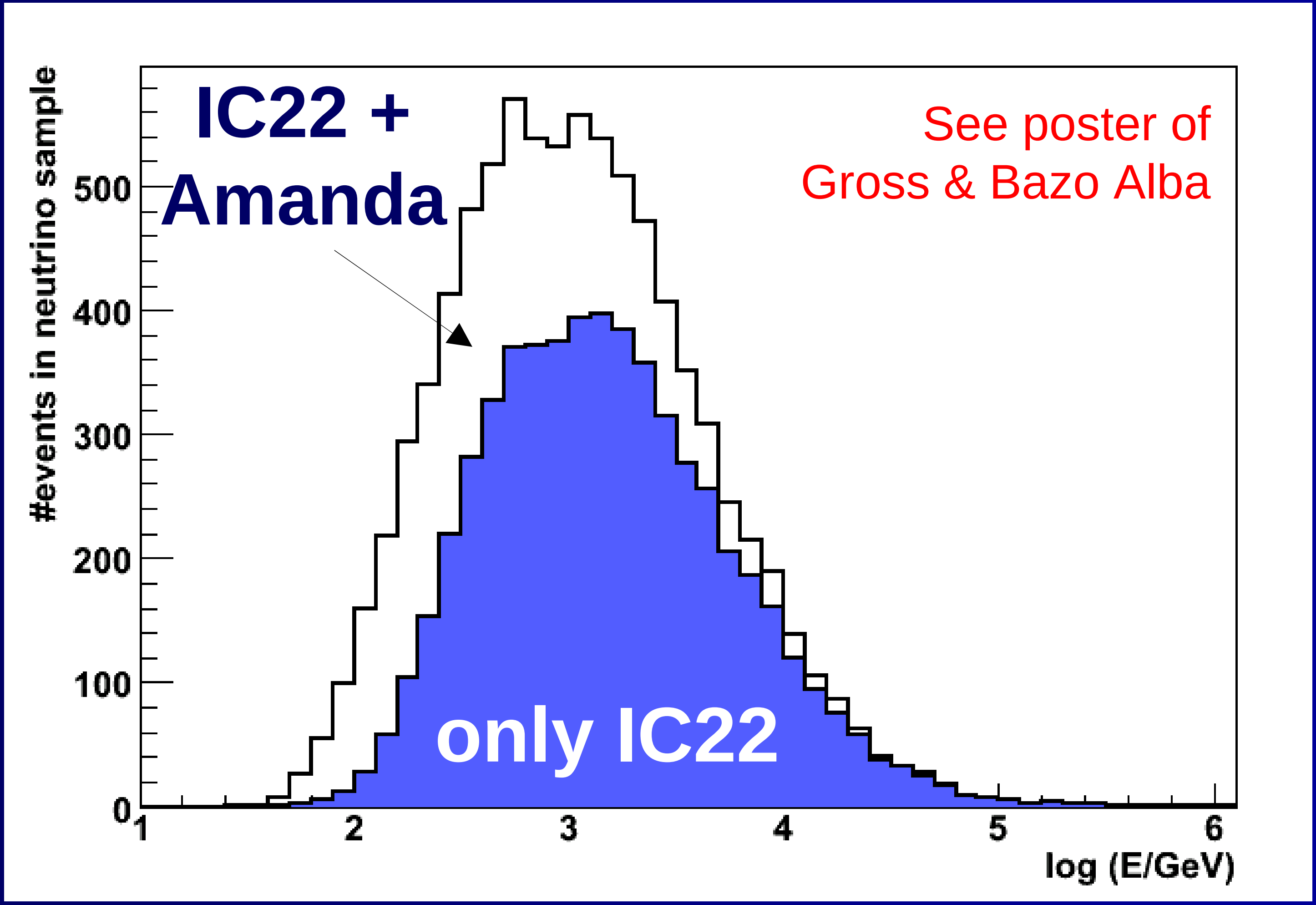
- IceCube 50% installed and taking data
- Will have 1 $km^3 \times$year by 2009
- Entering cubic kilometer era

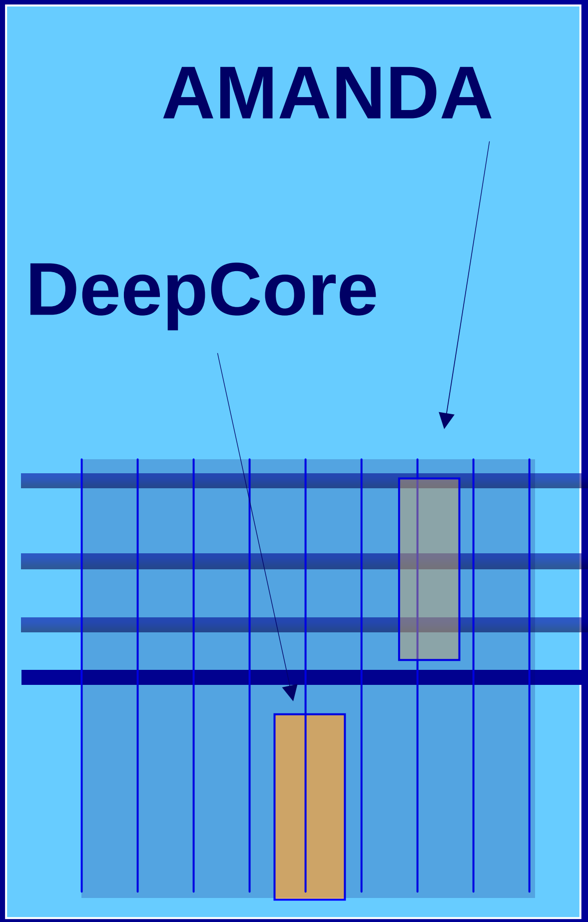
Amanda as a low-energy subdetector of IceCube



MC for livetime: IC22 281 days, 142 days together with AMANDA

DeepCore: a new low energy subdetector for IceCube

- 6 strings each with 60 PM, spaced by ~10 m
- better veto from top
- located in best ice (below 2100 m exceptionally clear!)
- uses IceCube technology
- considerably better performance at low energy
- **Can look upward !!**



See poster of O. Scholz

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Gigaton Volume Detector, GVD

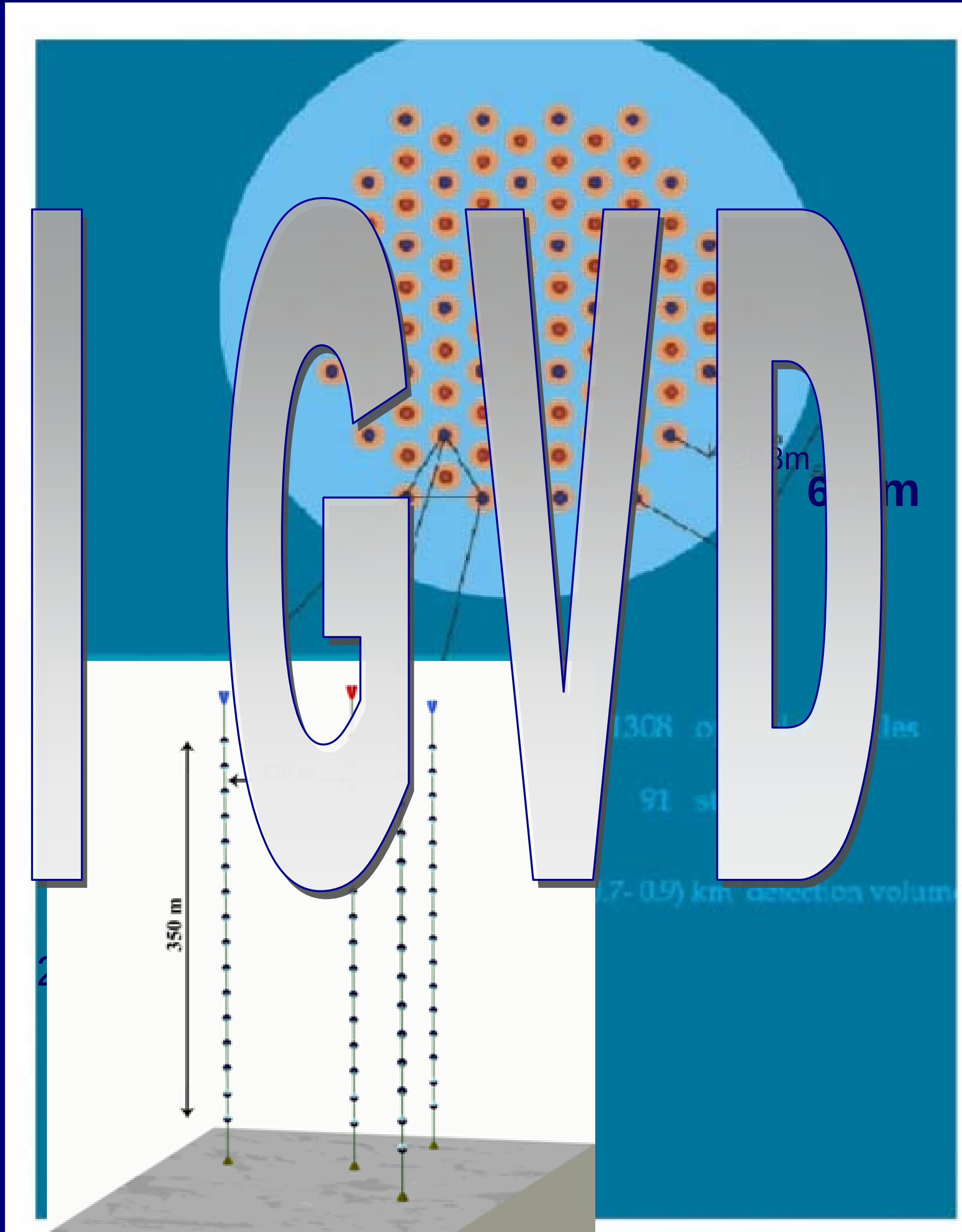
Sparse instrumentation:

91 – 100 strings with
12 – 16 OMs
(1300 – 1700 OMs)

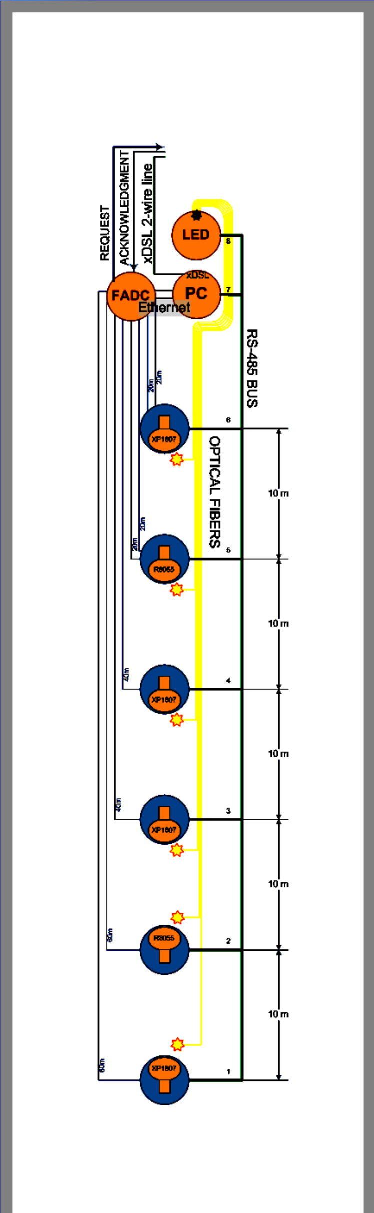
Effective volume for
100 TeV cascades:
~ 0.5 – 1.0 km^3

Muon threshold 10 – 30 TeV

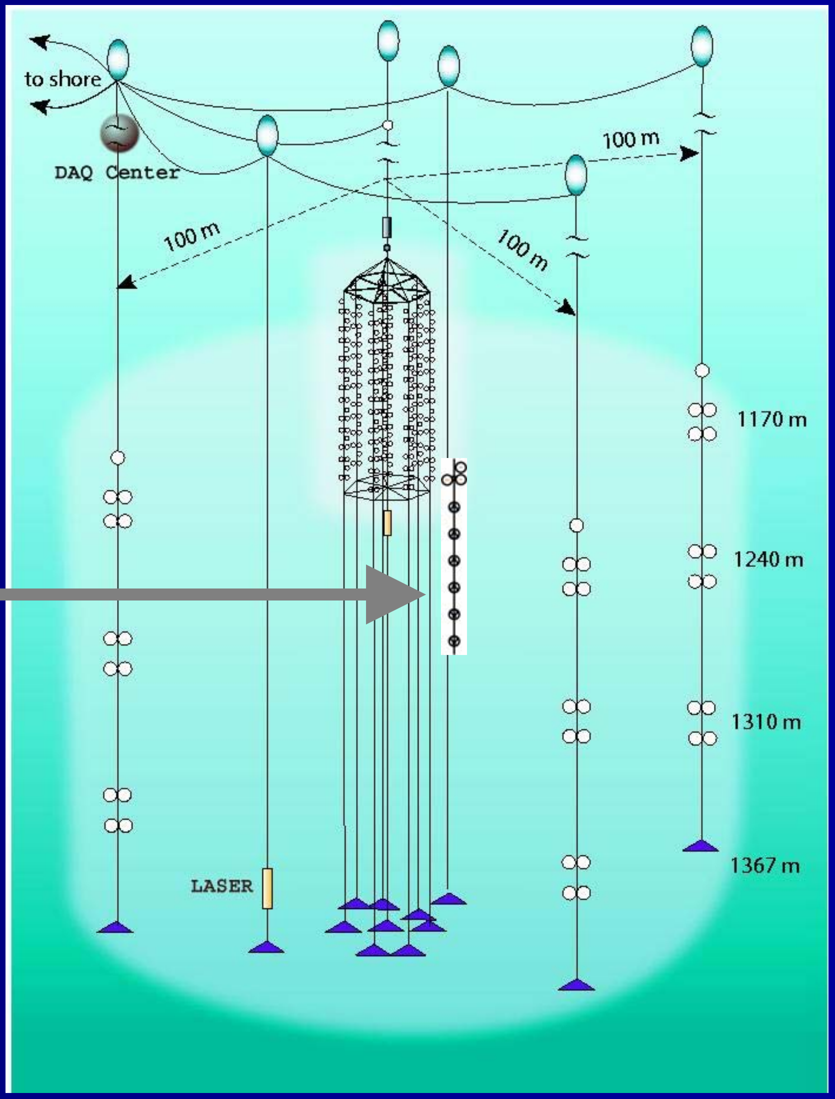
Baikal GVD



Gigaton Volume Detector, GVD



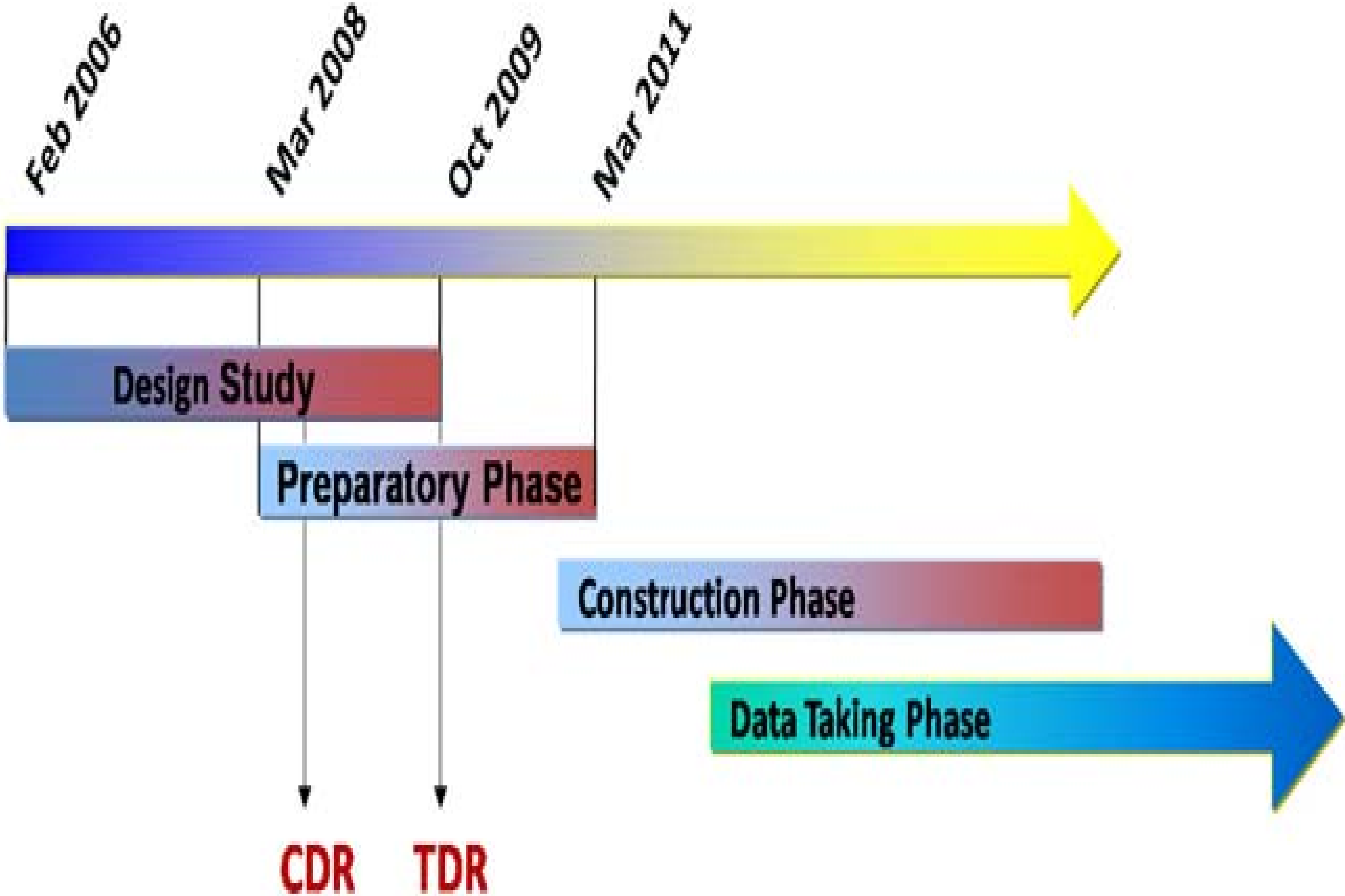
Presently under test: GVD prototype string

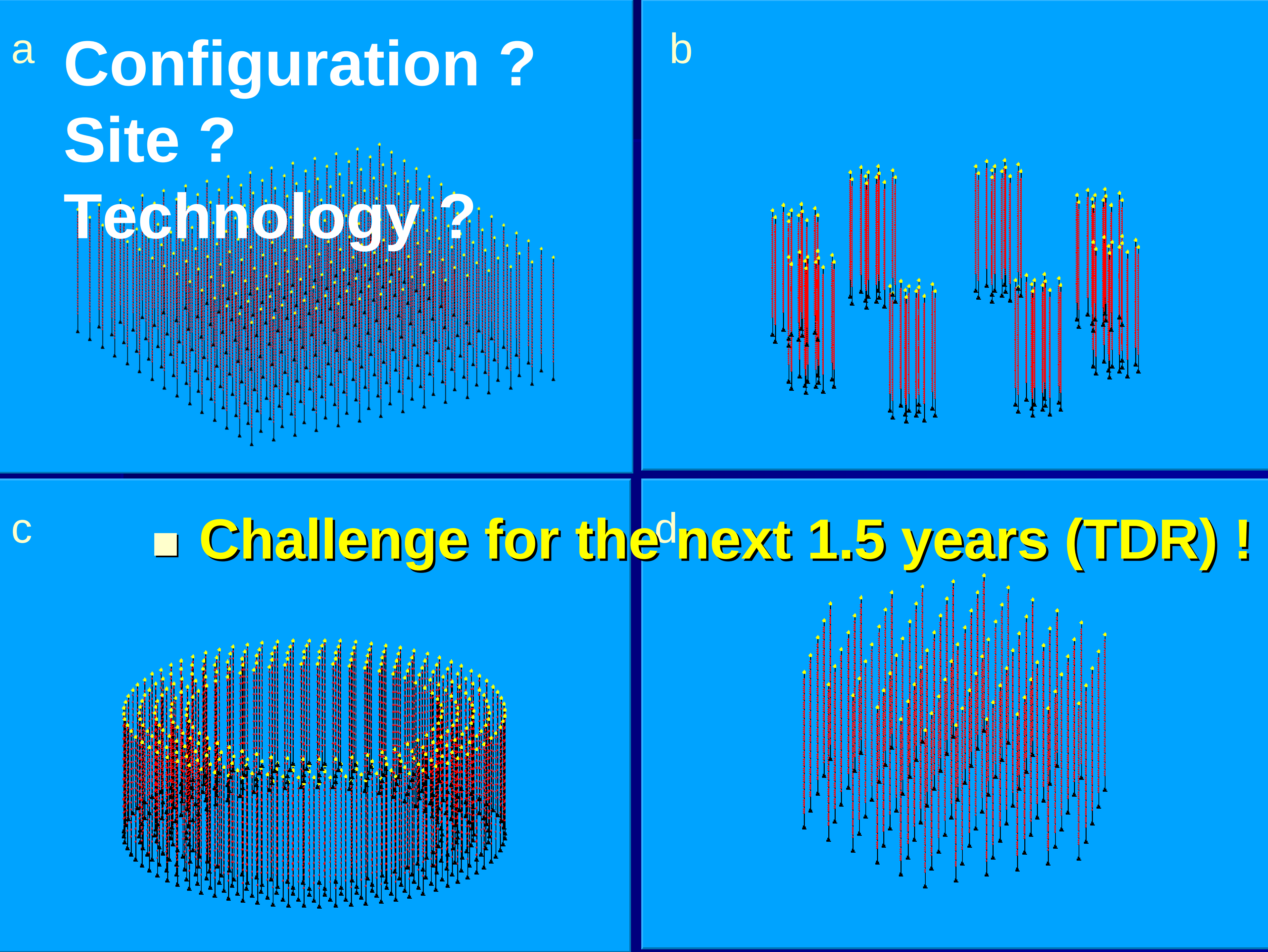


KM3NeT

- **European priority project of HE ν astronomy**
  - ESFRI list
  - FP6 design study
  - Recently started a FP7 Preparatory Phase
  - One of the priority entries in ASTRONET roadmap
- **Resources for a Mediterranean detector should be pooled in a single optimized design for a large research infrastructure.**
- **The sensitivity of KM3NeT must substantially exceed that of all existing neutrino detectors including IceCube.** This has to be achieved within the present budget estimate.

Time schedule




a
Configuration ?
Site ?
Technology ?
b
c
d
■ Challenge for the next 1.5 years (TDR) !

Basic parameters of the detectors

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Effective ν area @ 100 TeV:

- ~ 4 m^2 Amanda/Antares class
- ~100 m^2 km^2 class

Angular resolution:

- ~ 4° Baikal NT200
- ~ 2° Amanda
- < 1° IceCube
- ~ 0.3° Antares (KM3NeT)

Point source sensitivity (5σ):

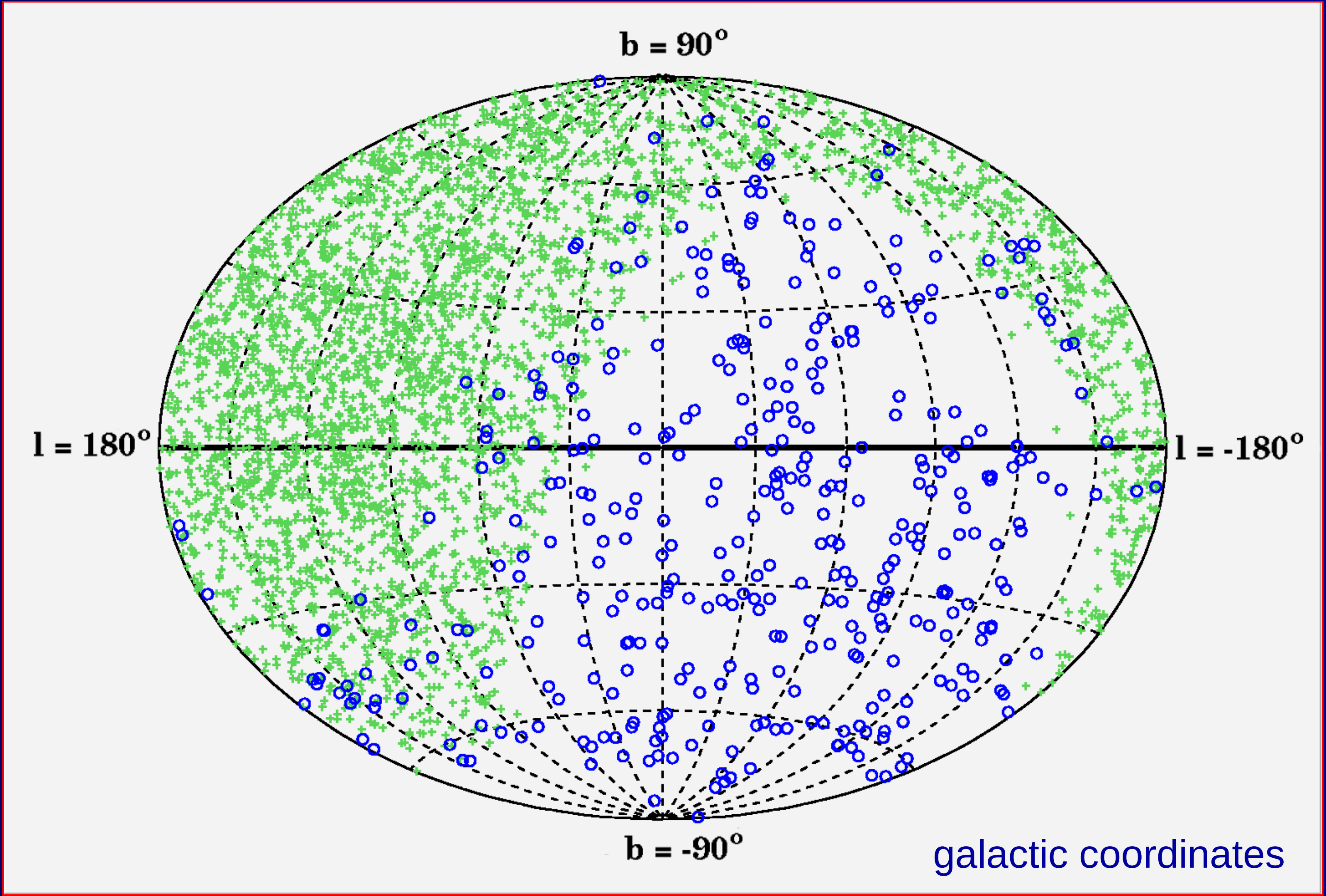
- AMANDA, ANTARES: ~ $3 \cdot 10^{-10}$ ν / (cm^2 s) above 1 TeV
- IceCube, KM3NeT < 10^{-11} ν / (cm^2 s) above 1 TeV

Results and Expectations

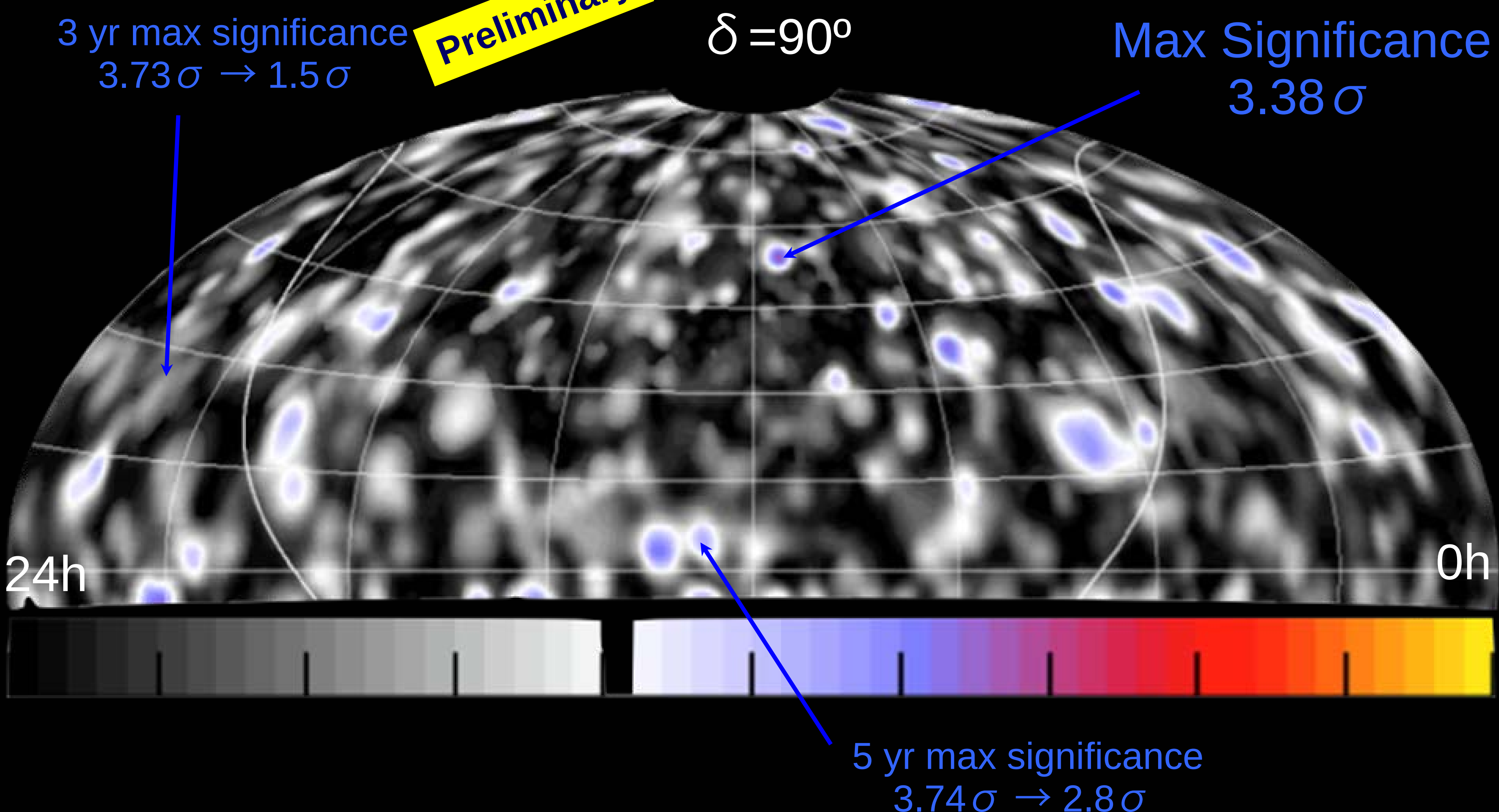
- High energy astrophysical sources
- (Supernova burst)

- *Nothing on particle physics, dark matter, charged cosmic rays, …*

Skymap AMANDA and Baikal



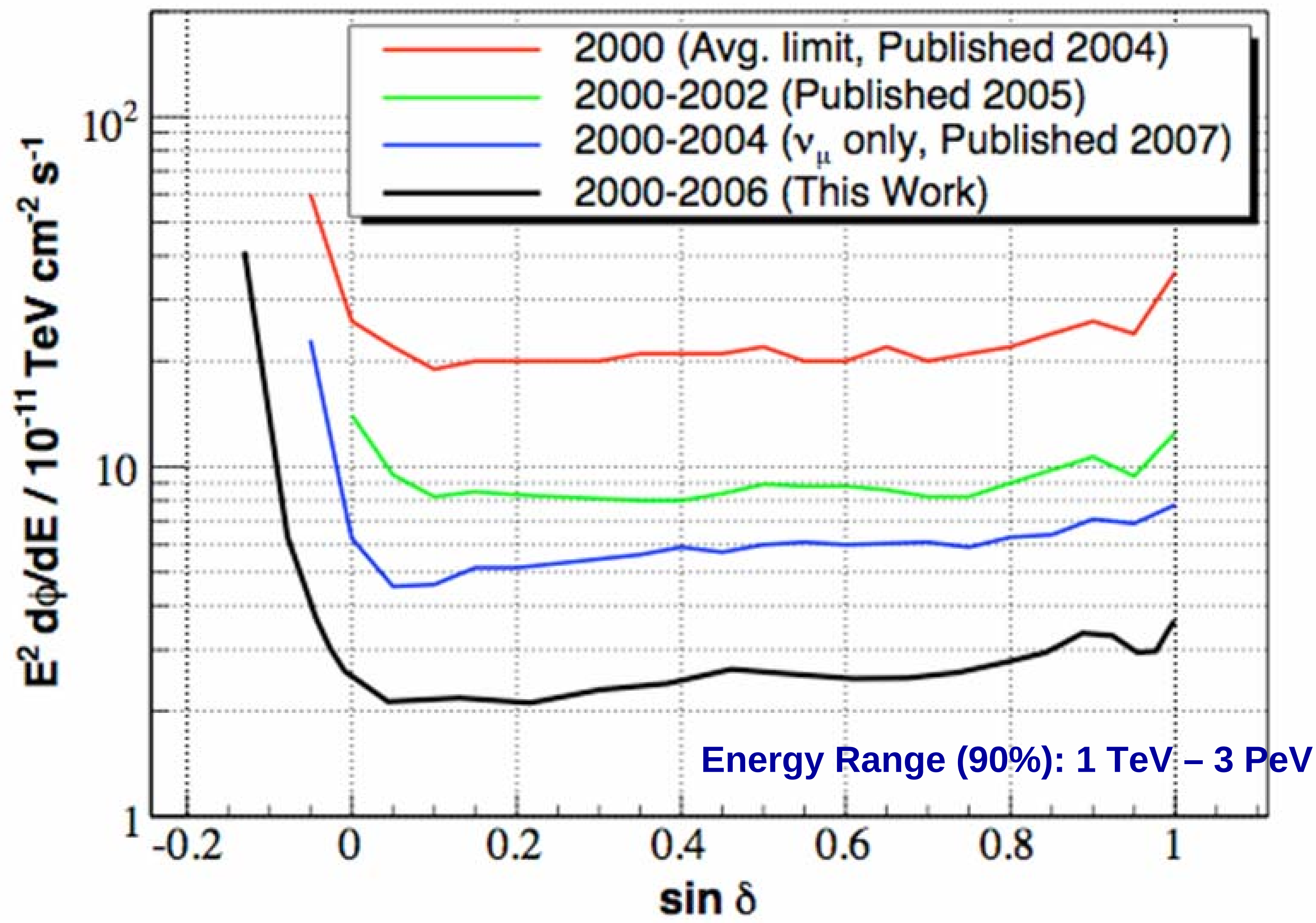
7 years Amanda (6595 events)



No significant excess

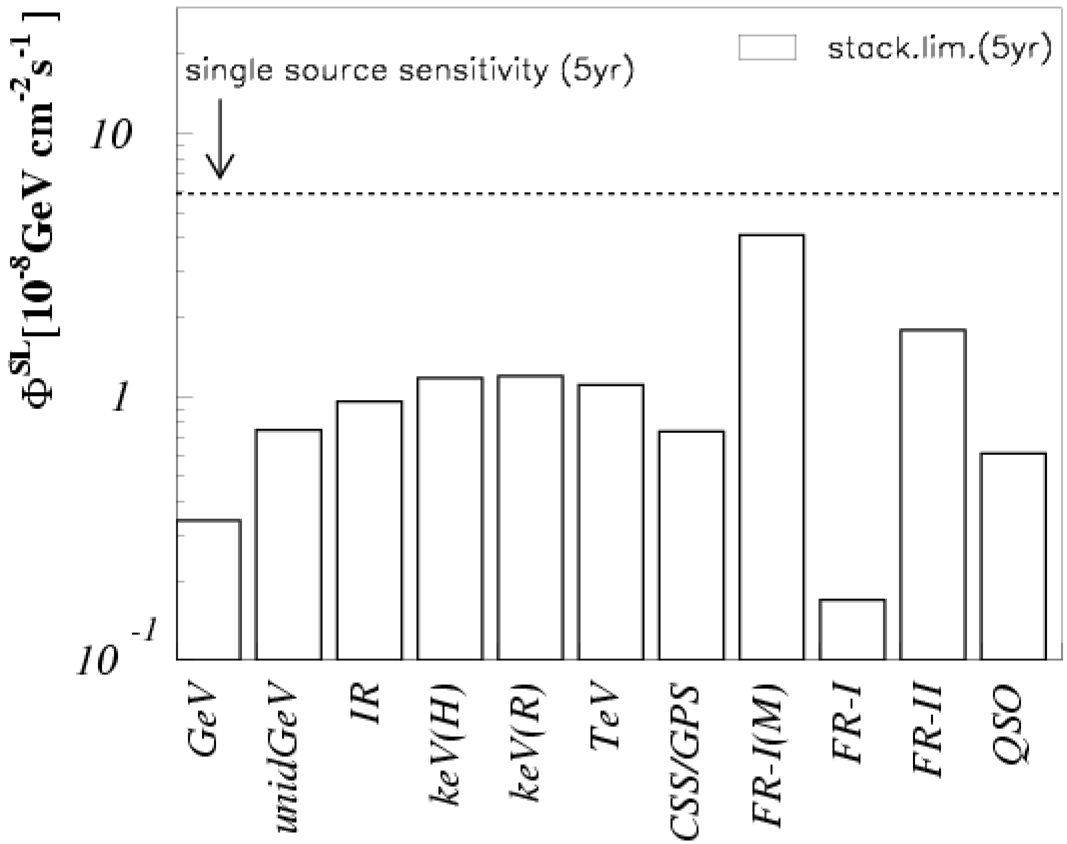
Amanda Flux Limits for E^{-2} Point sources

Preliminary



Spiering
Gamma-08

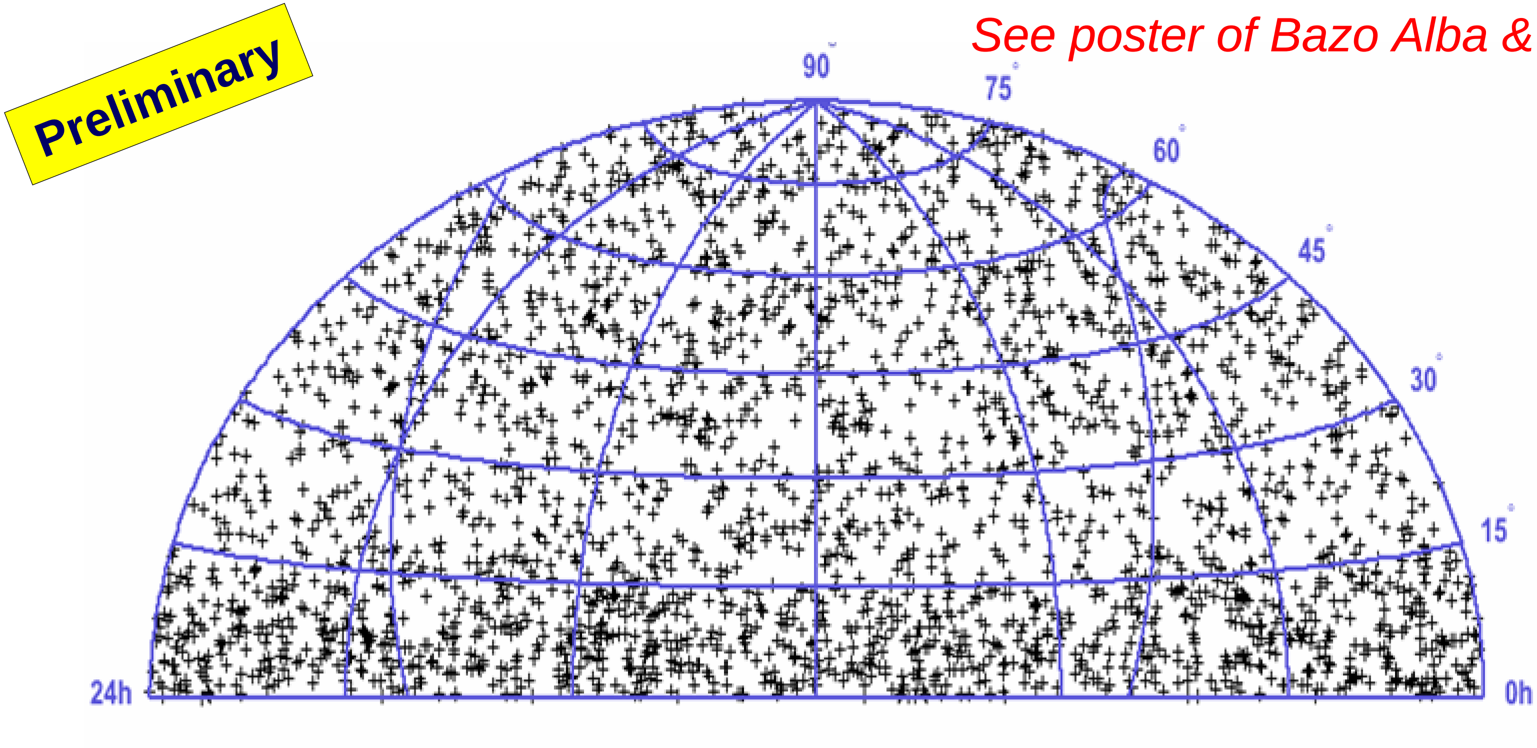
Stacking of AGN (Amanda)



Assumes „identical“ objects with a given class

IceCube 22 strings, 2007

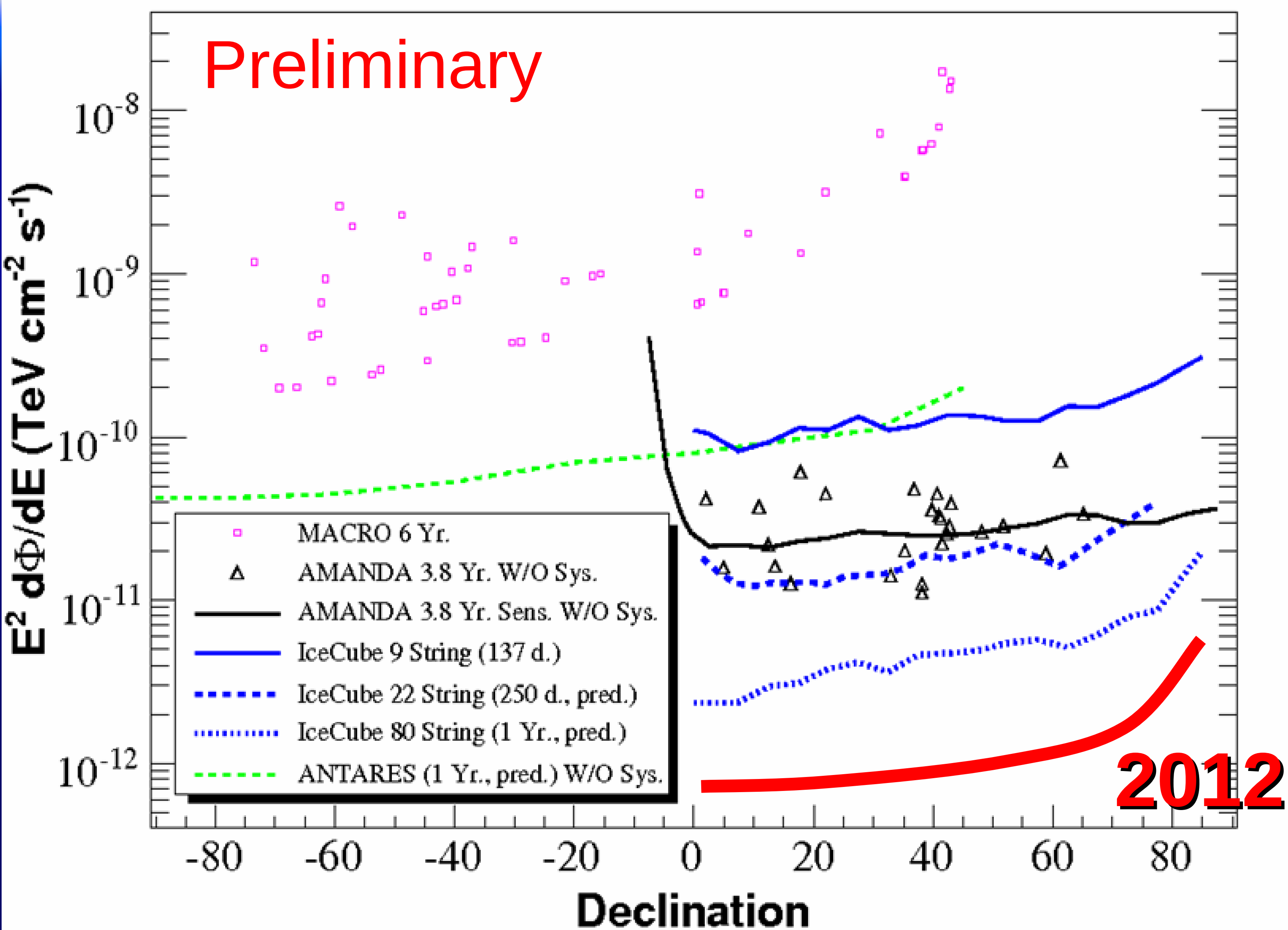
See poster of Bazo Alba & Gross



Equatorial sky map (scrambled in RA!) for 281 days of IC22, from a binned analysis optimized for $E^{-2} – E^{-3}$.

Note: there are 2 analyses, 1 binned, 1 unbinned. Limits/fluxes will be published for the more sensitive one. Unblinding soon.

Flux limits for point sources



Signal predictions: galactic sources

- Predictions on firmer ground than for extragalactic sources
  - Shell-type SNR
  - Pulsar Wind Nebula
  - Micro-quasars
  - Compact Binary Systems
- Many papers in the last 2 years, e.g.:
  - Vissani 2006
  - DiStefano 2006
  - Lipari 2006
  - Kappes, Hinton, Stegmann, Aharonian 2007
  - Gabici, Aharonian 2007
  - Torres, Halzen 2007
  - Halzen, Kappes, Murchadha 2008
  - Taylor et al., 2008
- Conclusion: ***Cubic kilometer detectors will likely just scrape the detection region***

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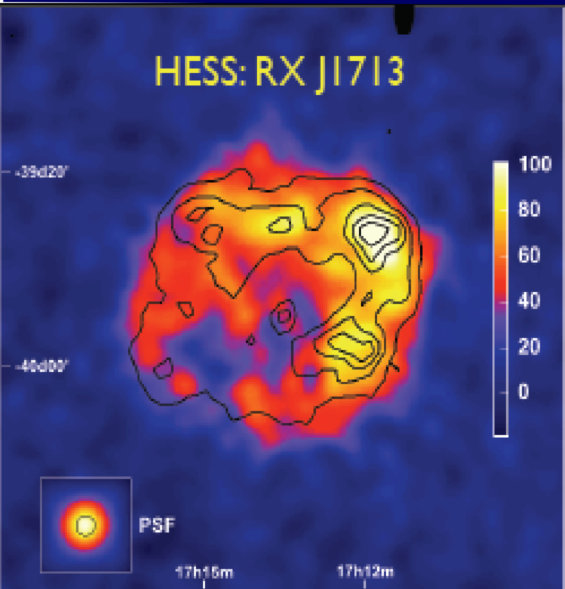
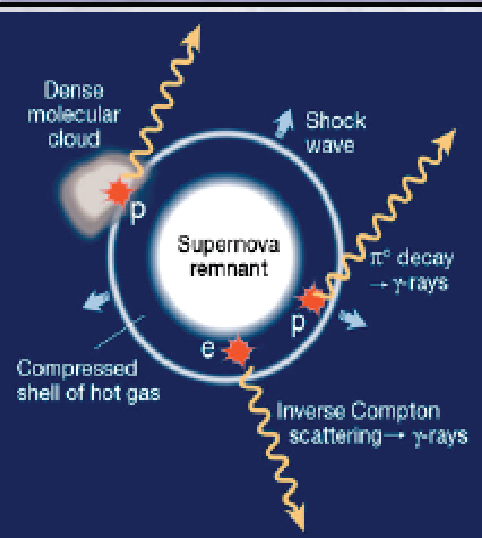
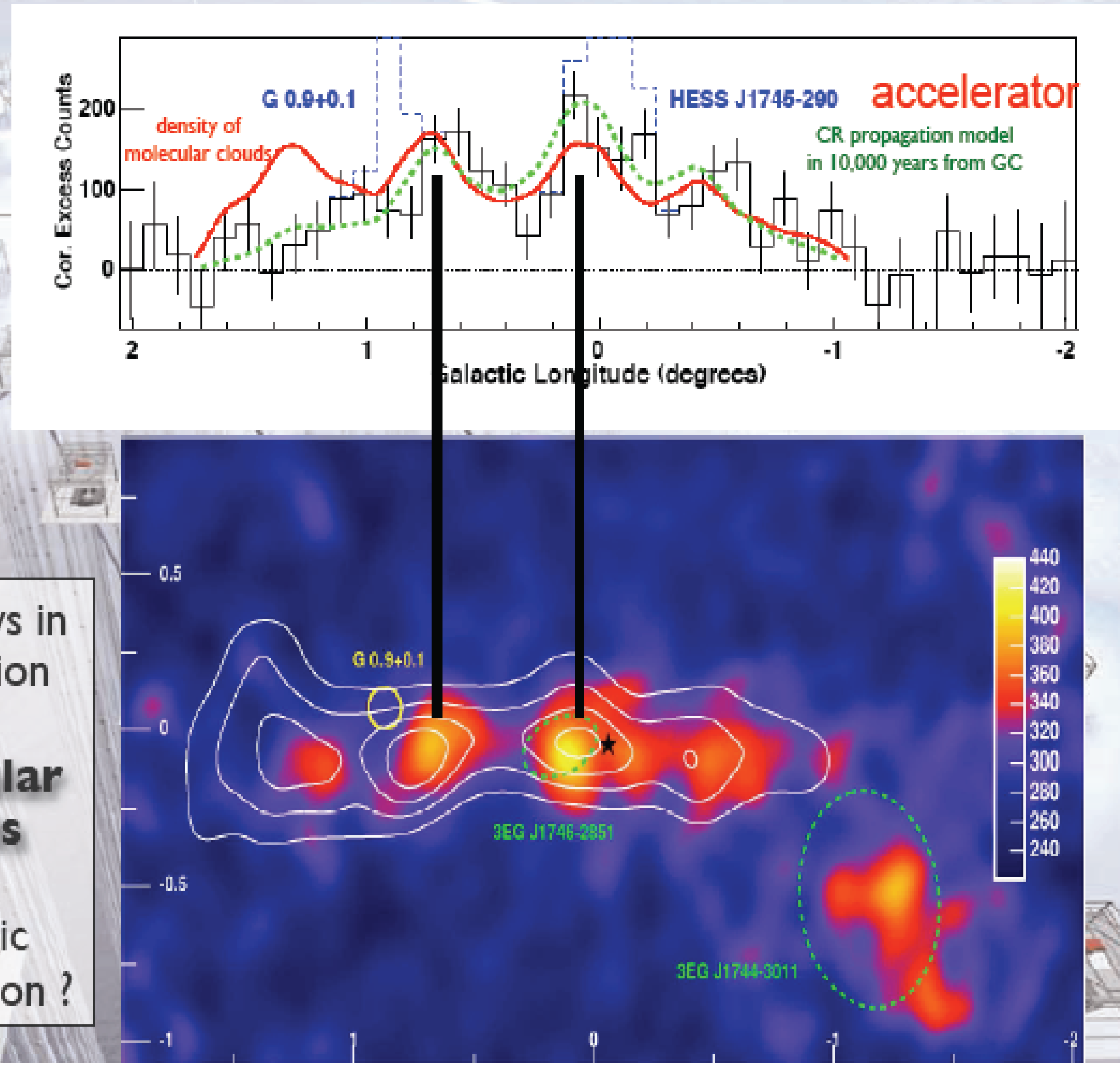
γ from molecular Clouds: smoking gun for hadronic acceleration ?





TeV γ rays in correlation with **molecular clouds**

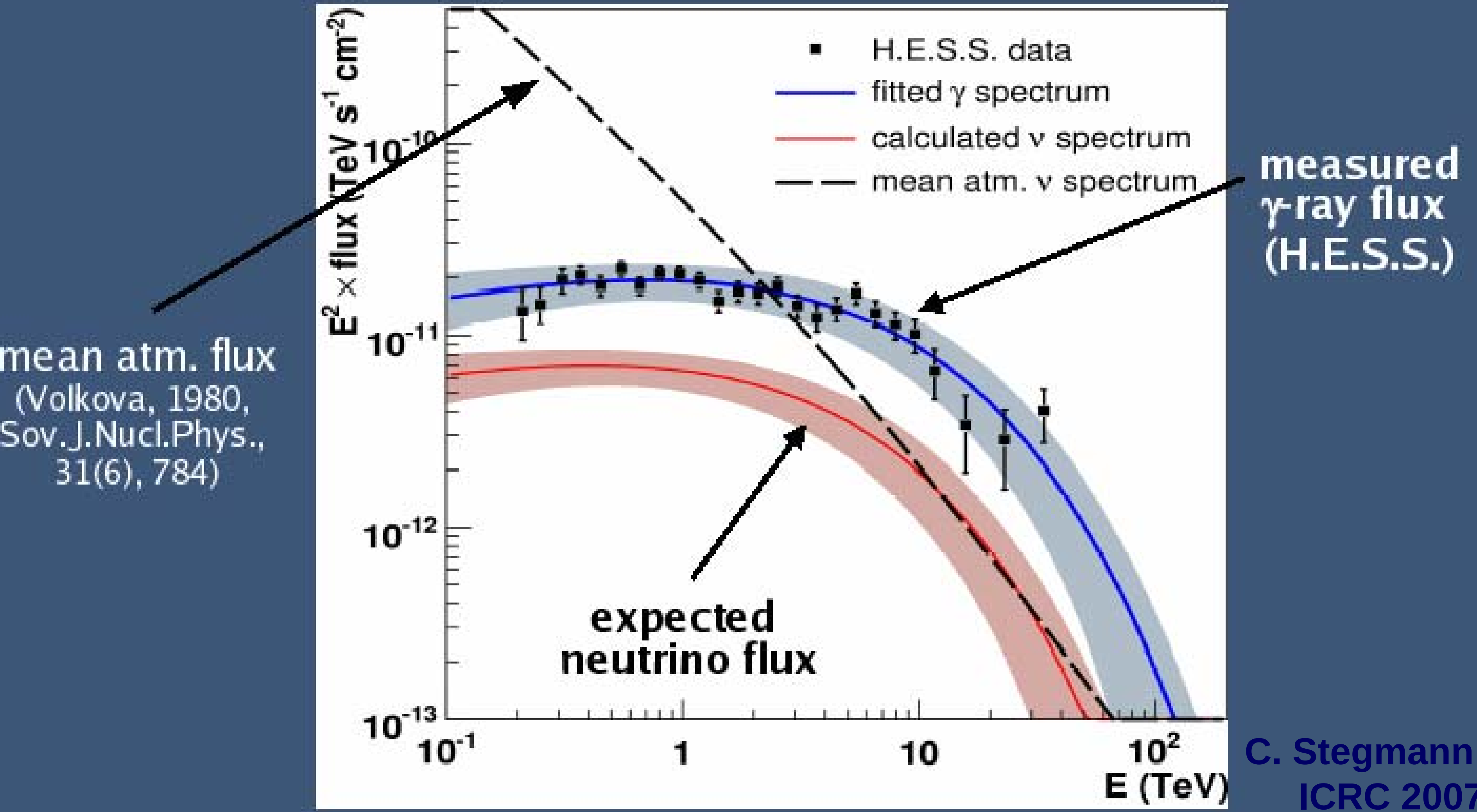
hadronic acceleration ?



Aharonian et al., Nature 439 (2006), 695

Expected ν flux from galactic point sources, example: RXJ 1713-3946

Assume $\pi^0 \rightarrow \gamma$ and calculate related $\pi^\pm \rightarrow \nu$



C. Stegmann ICRC 2007

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Neutrino Event Rates (II)

- γ-ray sources with observed cut-off (KM3NeT, 5 years)

	Type	Dia. [º]	E > 1TeV src	bck	E > 5TeV src	bck
- Vela X	PWN	0.8	9 – 23	23	5 – 15	4.6
- RX J1713.7-3946	SNR	1.3	7 – 14	21	2.6 – 6.7	8.2
- RX J0852.0-4622	SNR	2.0	7 – 15	104	1.9 – 6.5	21
- HESS J1825–137	PWN	0.3	5 – 10	9.3	2.2 – 5.2	1.8
- Crab Nebula	PWN	<0.1	4.0 – 7.6	5.2	1.1 – 2.7	1.1
- HESS J1303–631	NCP	0.3	0.8 – 2.3	11	0.1 – 0.5	2.1
- LS 5039* (INFC)	Binary	<0.1	0.3 – 0.7	2.5	0.1 – 0.3	0.5

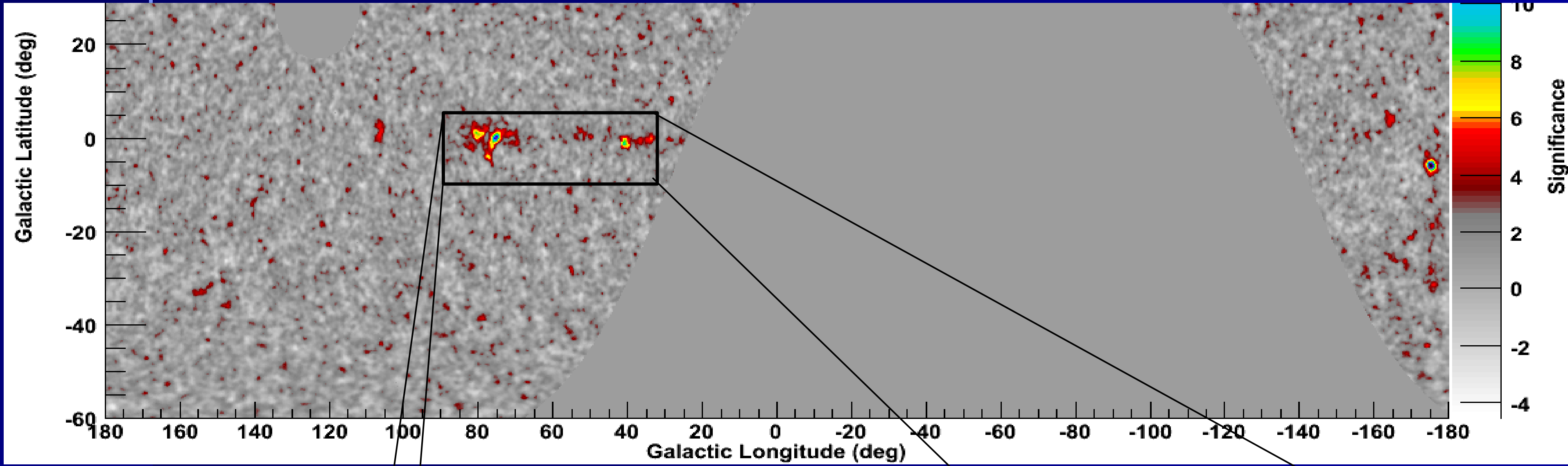
NCP: no counterparts at other wavelength

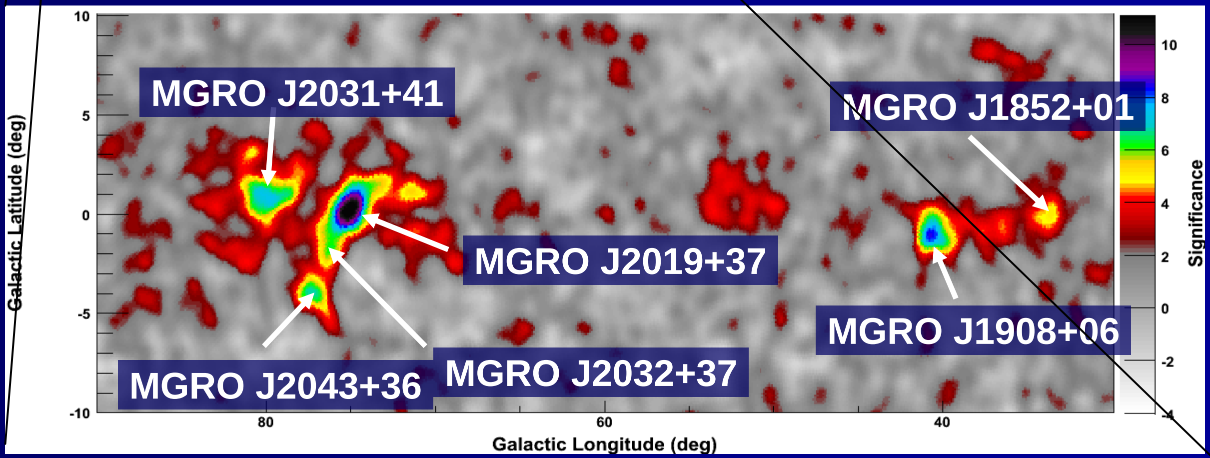
* no γ-ray absorption

- 23 further γ-ray sources investigated:
  - All γ-ray spectra show no cut-offs (but limited statistics)
  - Event numbers mostly below 1 – 2 in 5 years

Christian Stegmann, Galactic Neutrinos, ICRC 2007

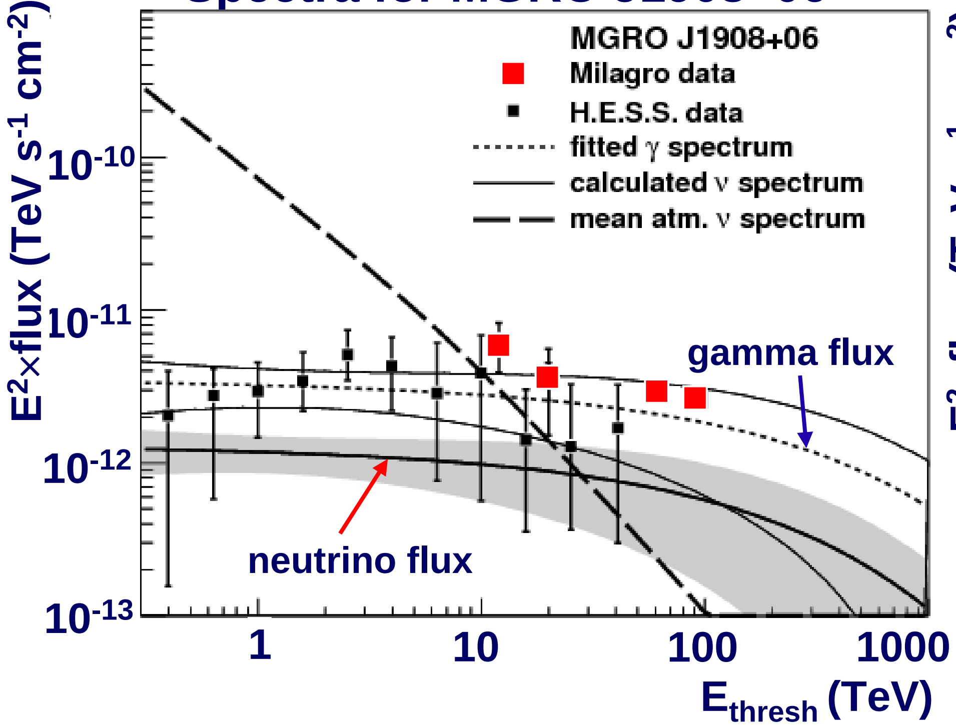
Milagro, Galactic plane



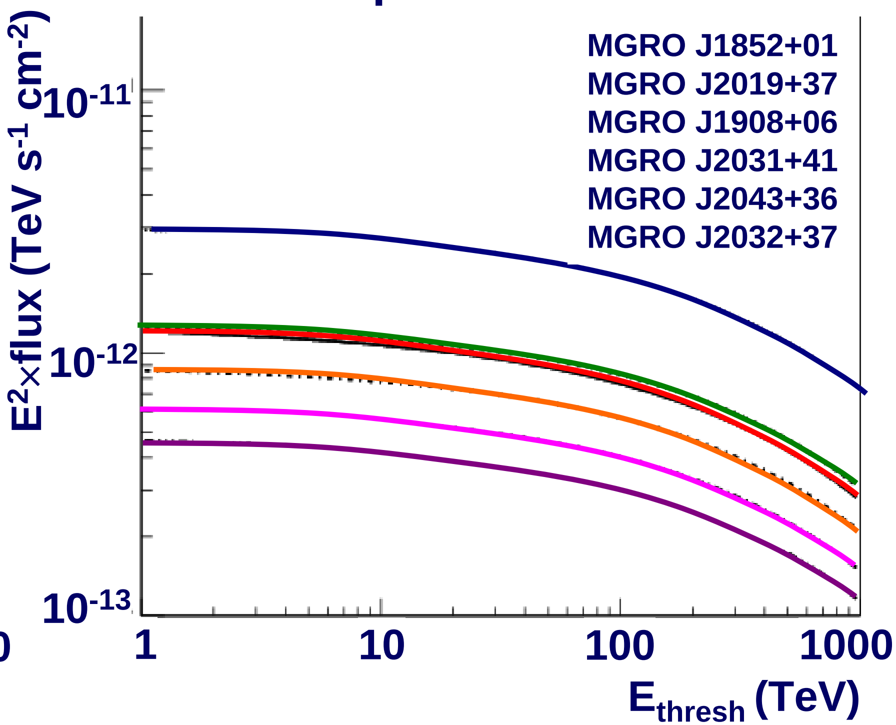


MGRO J1908+06: the first Pevatron ?

Spectra for MGRO J1908+06



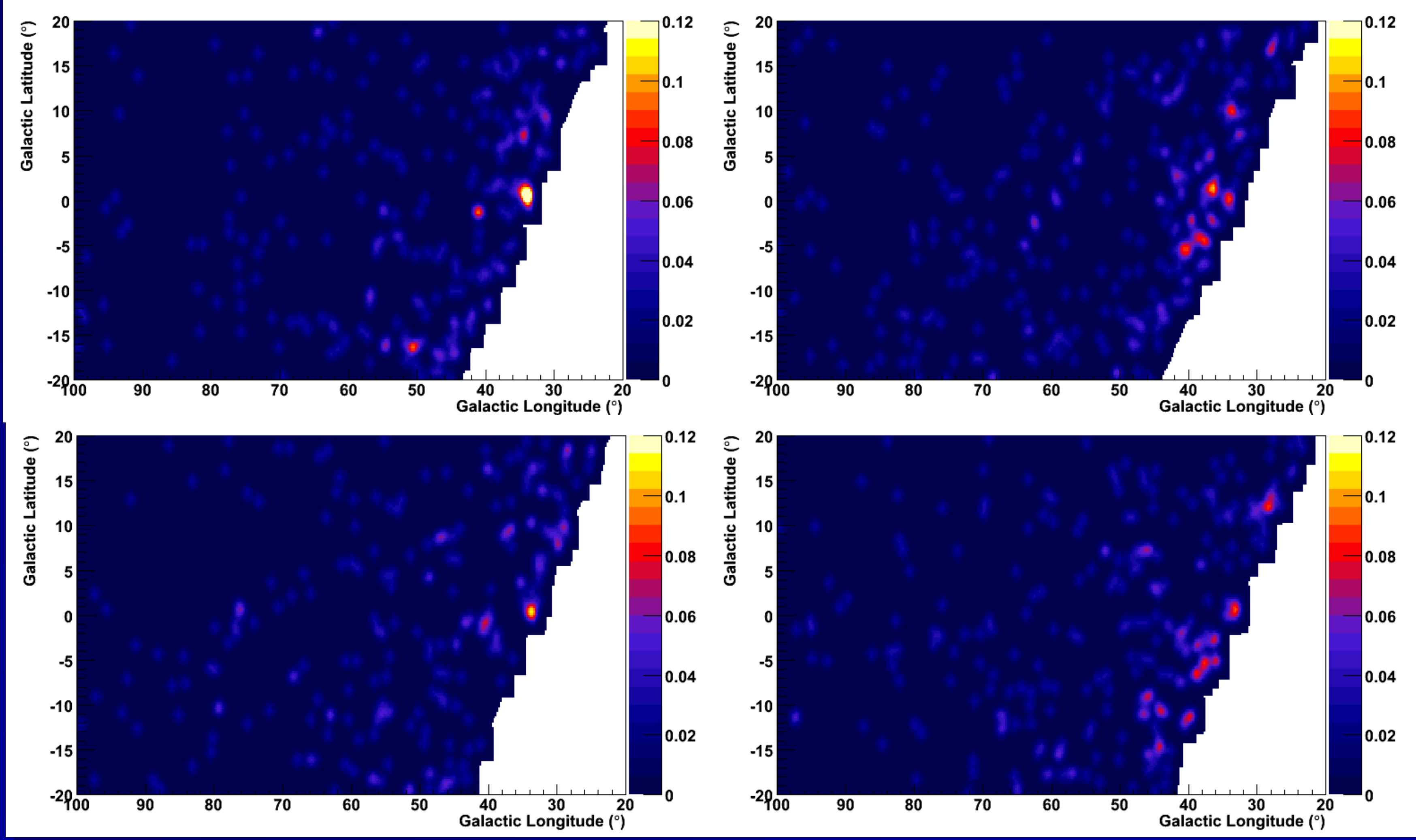
Neutrino spectra for all sources



- Assumed E^{-2} with Milagro normalization (MGRO J1908+06 index= 2.1)
- ν spectrum cutoff @ 300 TeV

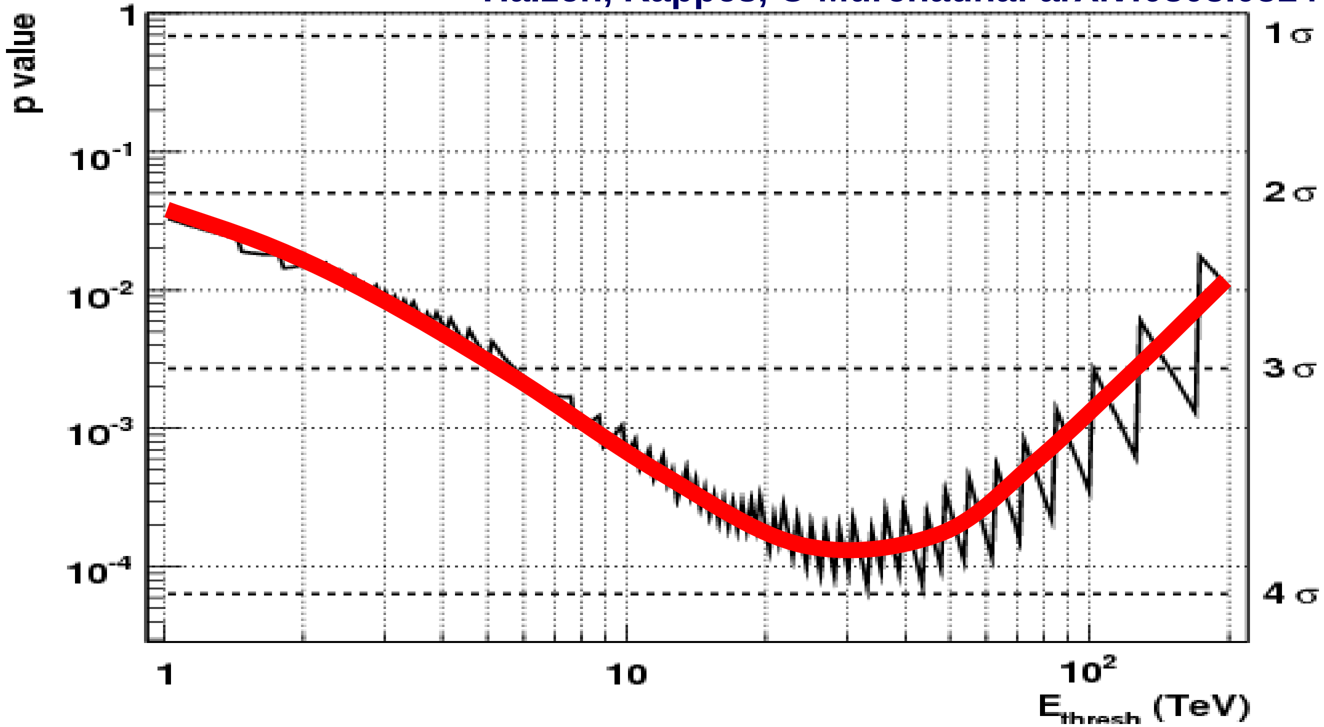
Halzen, Kappes, O'Murchadha: arXiv:0803.0314

Simulated Neutrino Skymaps IC80 (5 years)



Stacking all 6 Milagro sources, 5 years

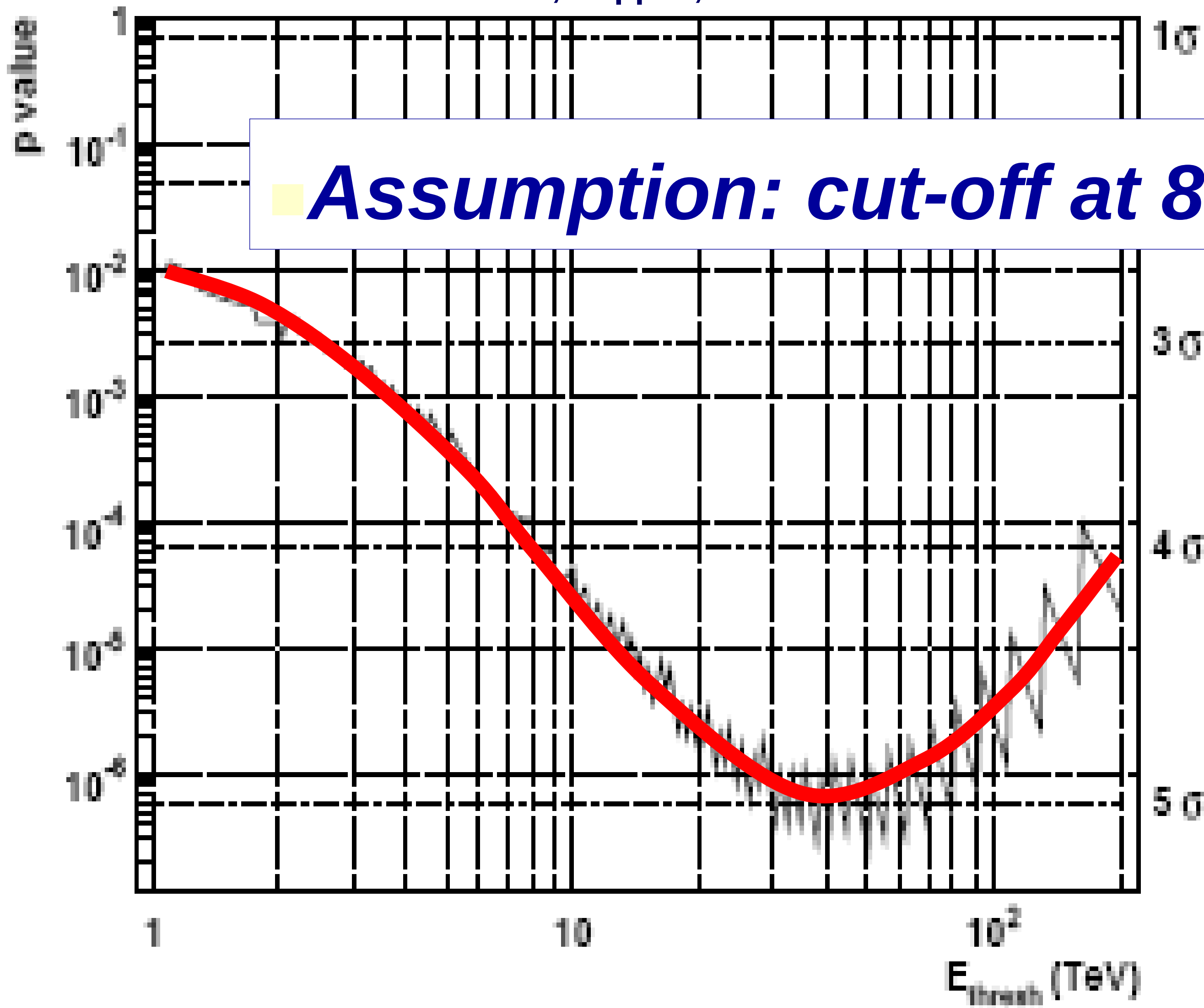
Halzen, Kappes, O'Murchadha: arXiv:0803.0314



- Assumption: cut-off at 300 TeV
- p-value close to 10^{-4} after 5 years
- Optimal threshold @ 30 TeV (determined by loss of signal events)

Stacking all 6 Milagro sources, 5 years

Halzen, Kappes, O'Murchadha: arXiv:0803.0314



- ***Assumption: cut-off at 800 TeV***

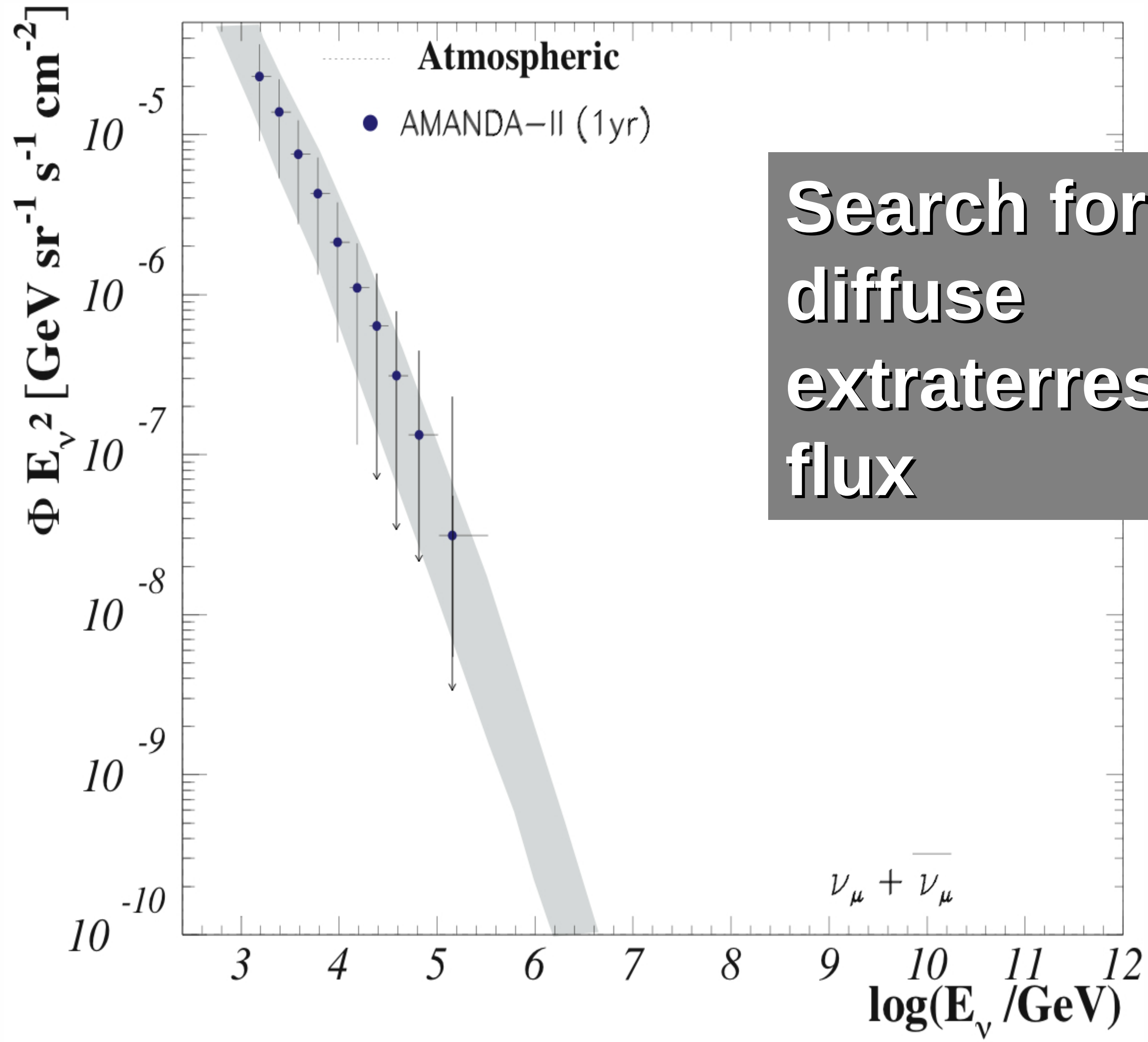
5σ

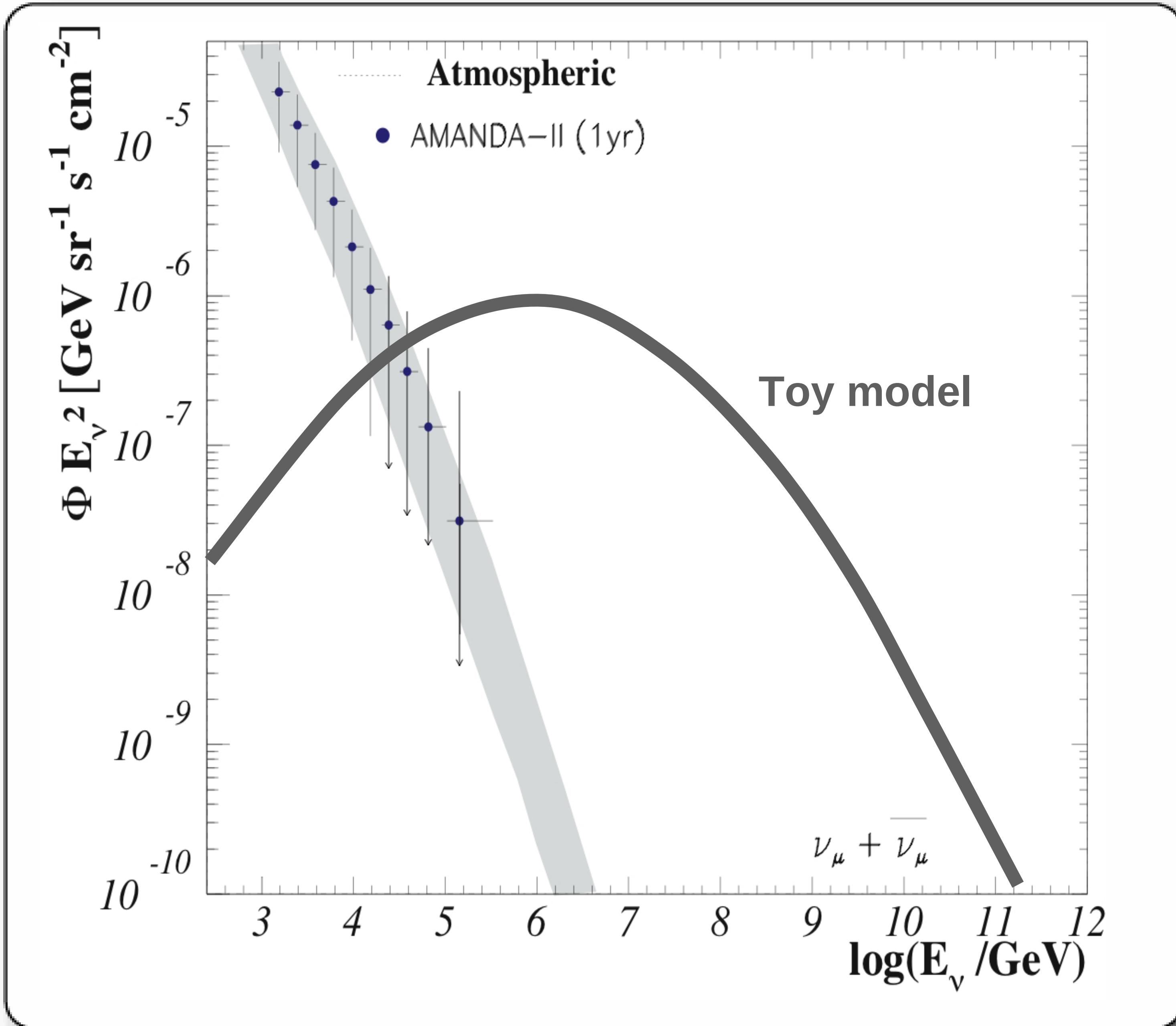
Conclusions for galactic sources

- Optimum threshold for typical analyses with a km³ detector 5-30 TeV
- Desirable sensitivity > 5 $\times$ IceCube
- But: don‘t forget SN shells in first months after explosion !
- Always to the rescue: hidden sources

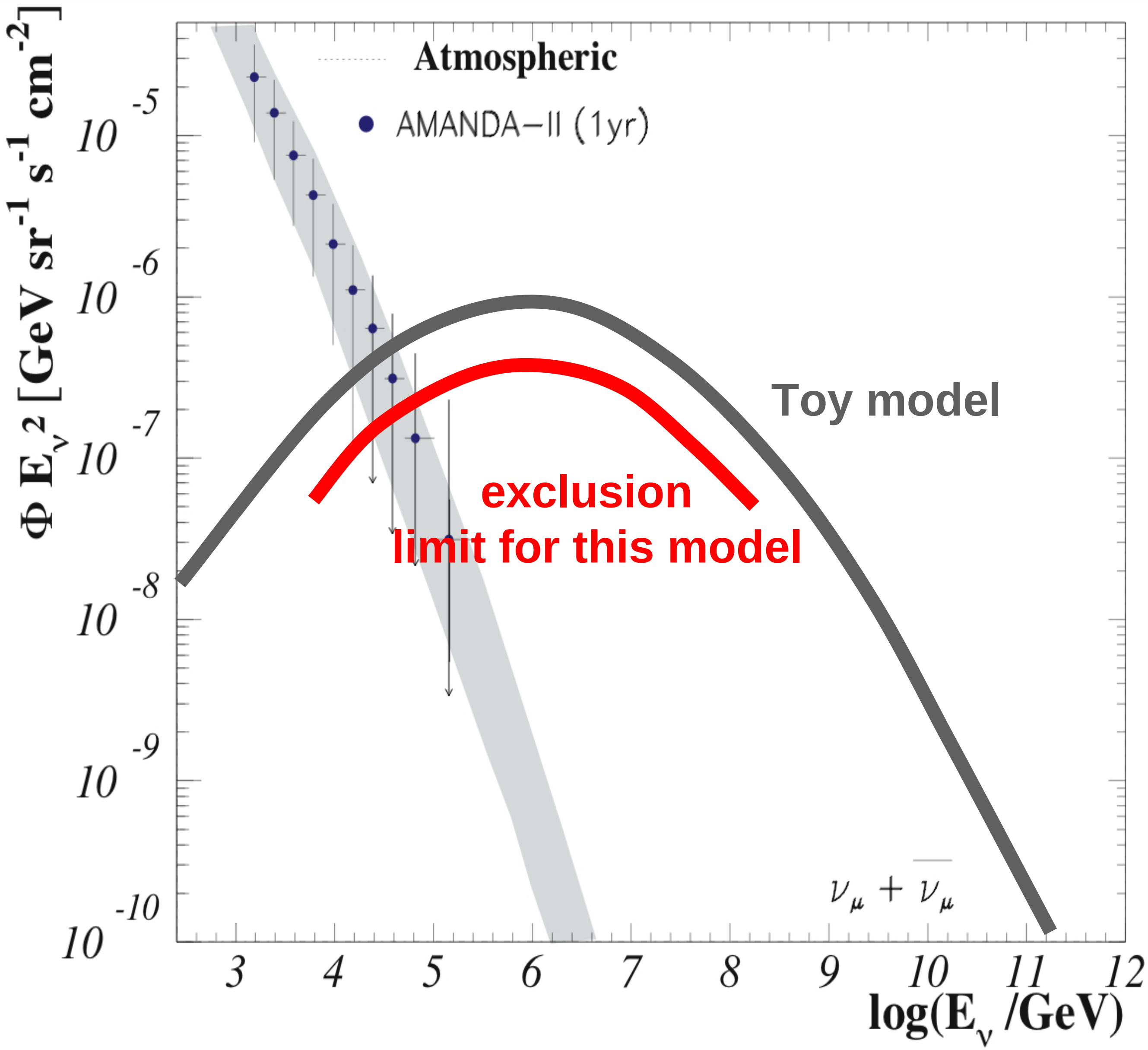
  (but they also eventually should be visible at low photon energies !)

Search for diffuse extraterrestrial flux

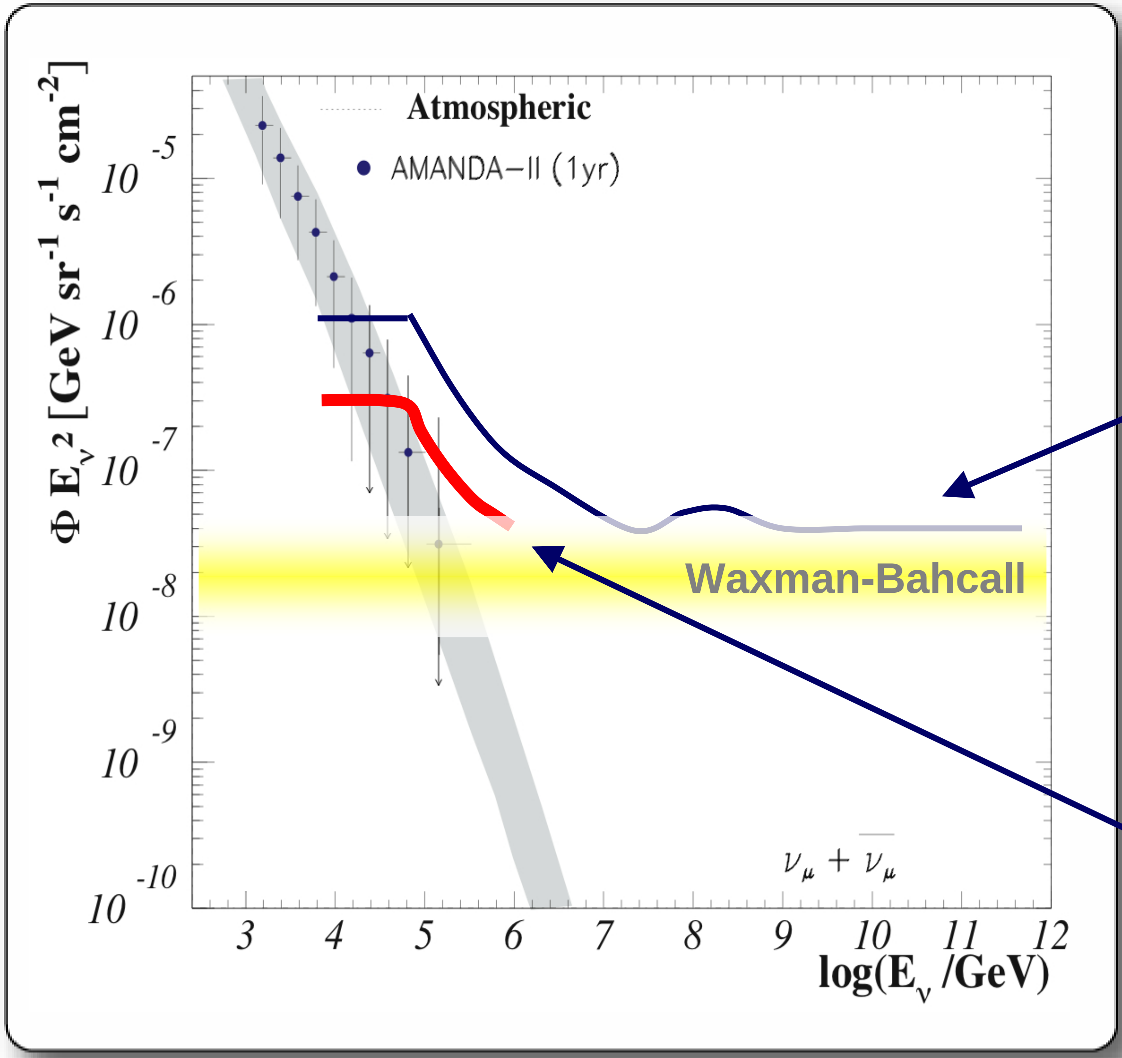




Atmospheric
AMANDA−II (1yr)
Toy model
$\nu_\mu + \bar{\nu}_\mu$
ΦE_ν^2 [GeV sr^{-1} s^{-1} cm^{-2}]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
3 4 5 6 7 8 9 10 11 12
log(E_ν /GeV)

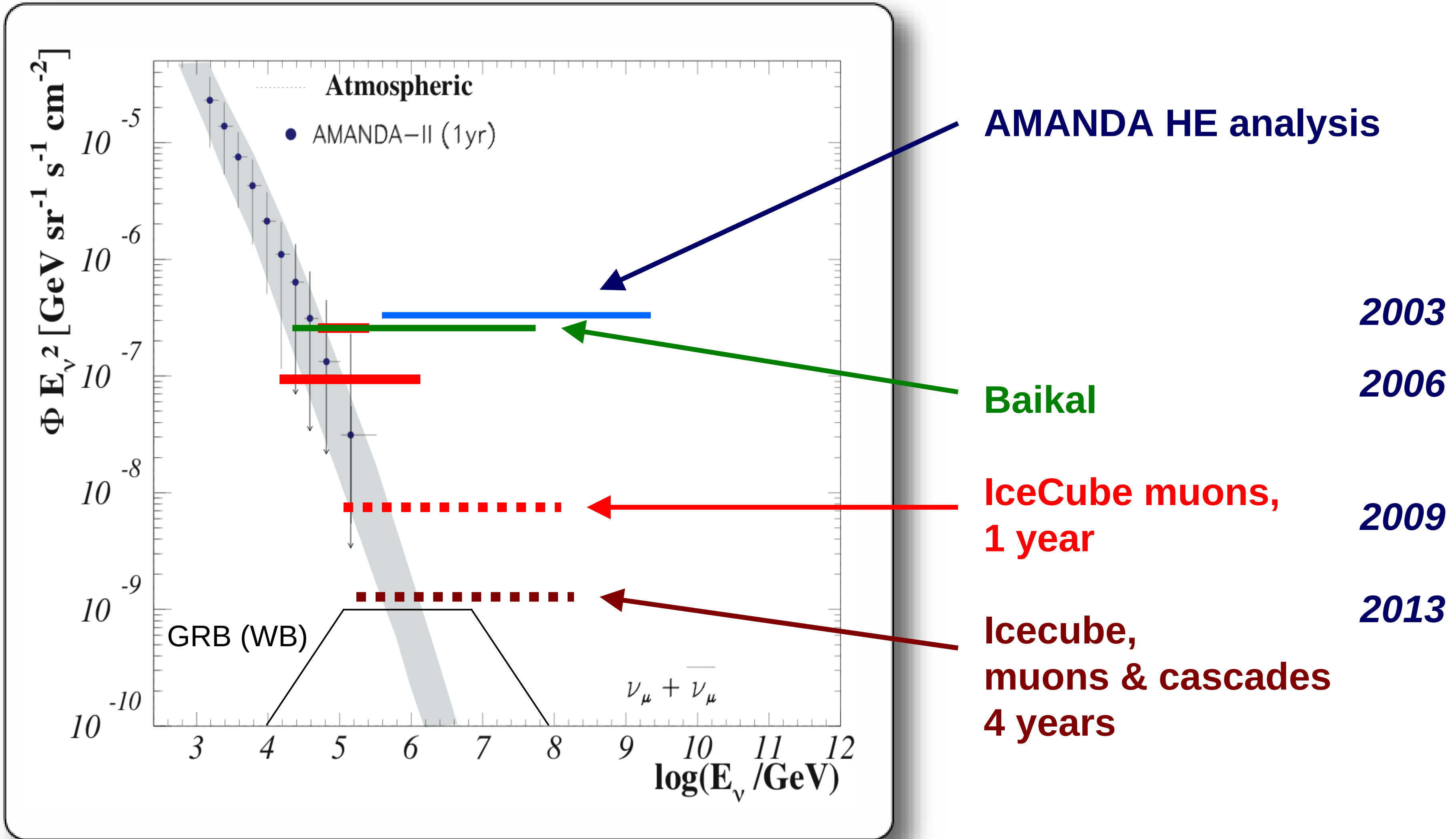

Atmospheric
AMANDA−II (1yr)
Toy model
exclusion
limit for this model
$\nu_\mu + \overline{\nu_\mu}$
ΦE_ν^2 [GeV sr^{-1} s^{-1} cm^{-2}]
log(E$_\nu$ /GeV)
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
3 4 5 6 7 8 9 10 11 12

MPR and WB bound



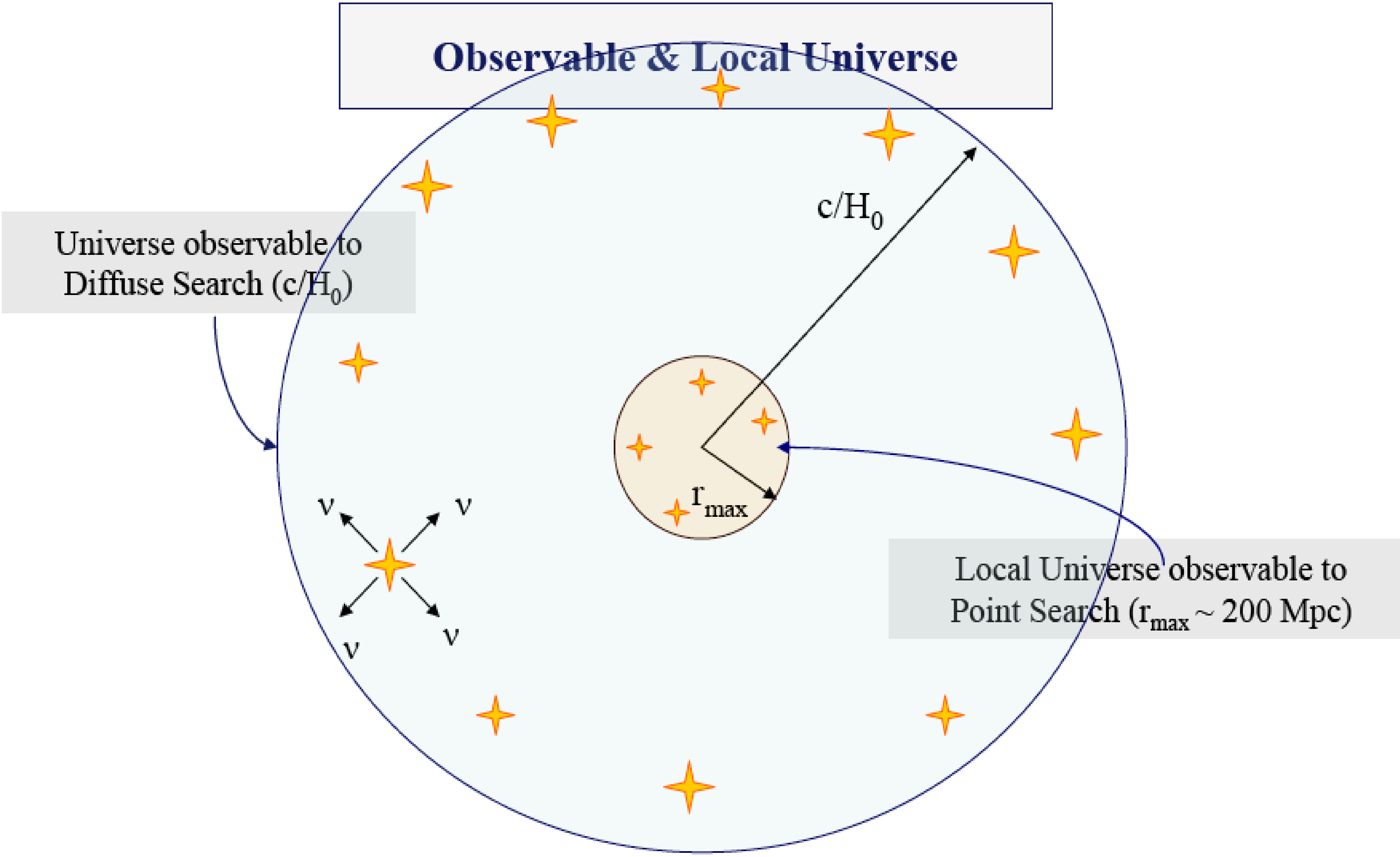
- MPR bound, neutrons escape (CR bound)
- Factor 4 below MPR bound for sources transparent to neutrons

Limit on diffuse extraterrestrial fluxes



Connecting diffuse and point source fluxes

[based on Lipari, Nucl. Instrum. Meth. A **567**, 405 (2006)]



A. Silvestri, thesis, 2007

Connecting diffuse and point source fluxes

Number of observable point sources

Limit on diffuse flux

Typical source luminosity

$$N_s \sim \frac{K_{diffuse} \cdot \sqrt{L_{source}}}{C_{point}^{3/2}}$$

Flux sensitivity for point sources

Assumptions:

- Isotropically distributed sources
- Similar ν luminosity for all sources
- *dN/dE ~ E*$^{-2}$ for all sources and cut-off only at >100 Tev
- Euclidian Universe, uniform source density

Connecting diffuse and point source fluxes

Number of observable point sources

Limit on diffuse flux

Typical source luminosity

$$N_s \sim \frac{K_{diffuse} \cdot \sqrt{L_{source}}}{C_{point}^{3/2}}$$

Flux sensitivity for point sources

Amanda present

Amanda

$N_s < 0.01 - 0.1$

Connecting diffuse and point source fluxes

Number of observable point sources

Limit on diffuse flux

Typical source luminosity

$$N_s \sim \frac{K_{diffuse} \cdot \sqrt{L_{source}}}{C_{point}^{3/2}}$$

Flux sensitivity for point sources

Amanda present

IceCube

$N_s < 1 - 10$

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- Simple arguments suggest that 1 km³ has a fair – but not too large! – discovery chance for single sources.

- Increase point source sensitivity
  - by area > 1 km²
  - by better pointing
  - by reducing the BG of atmospheric neutrinos

- Not excluded that first a **diffuse excess** will be discovered.

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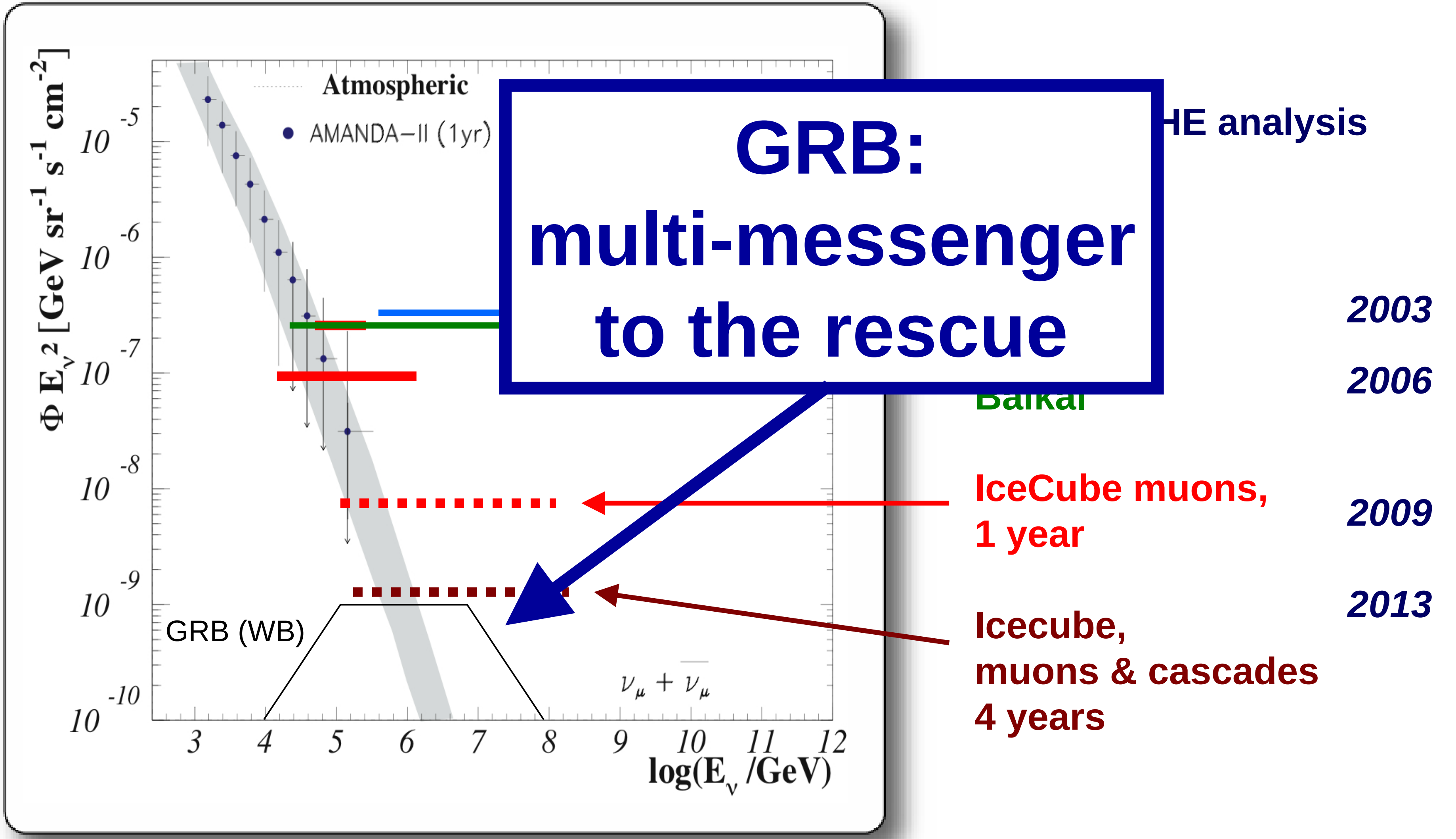
Multi-Messenger Approaches

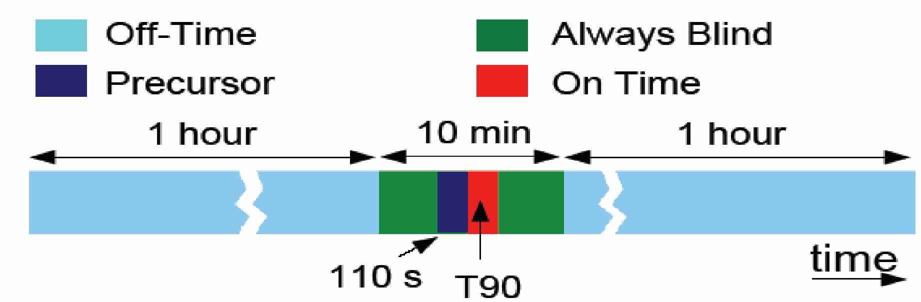
Multi-Messenger Analyses

- **Steady sources**
  – Reducing trial factors by source selection based on X-ray/gamma information
- **Transient sources**
  – Being triggered by GRB satellite data
  – Optical follow-up of neutrinos doublets
  – Target of Opportunity programs (like AMANDA/MAGIC)
  – Compile continuous gamma time series
  – Identify flare states
  – SN burst trigger to optical astronomers

Limit on diffuse extraterrestrial fluxes

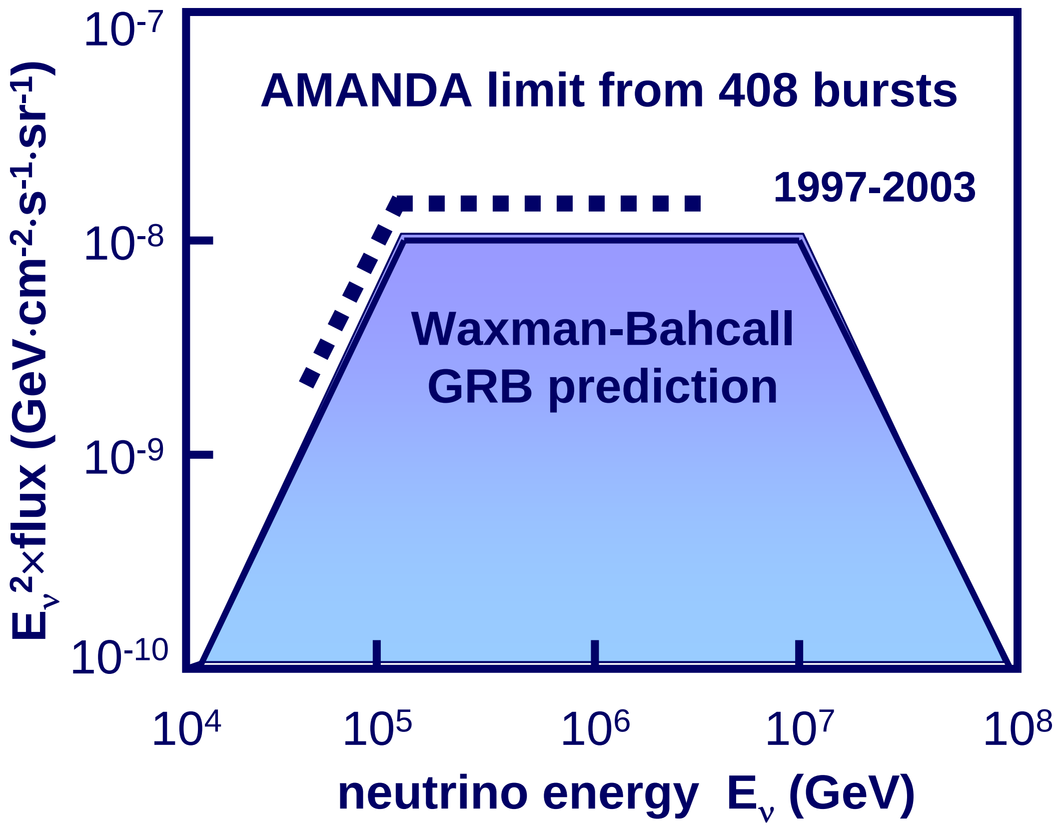


Coincidences with GRB



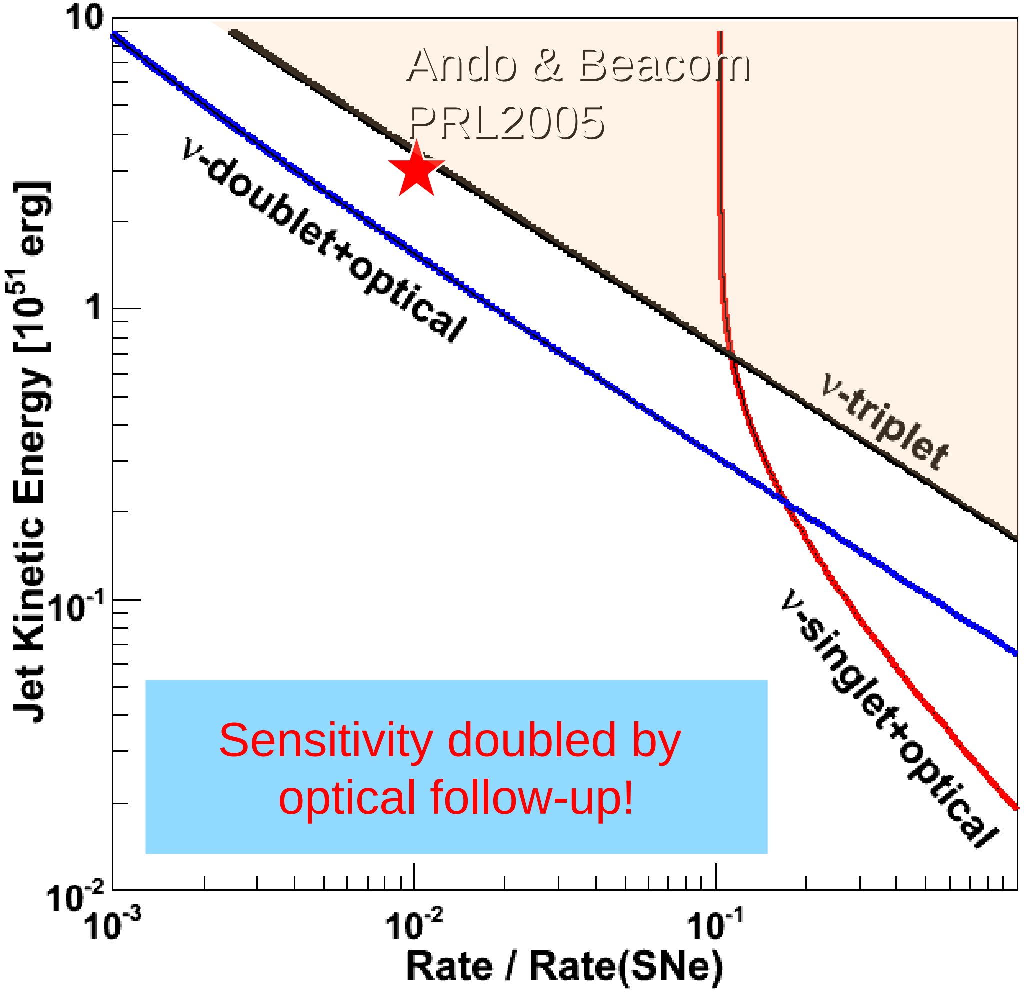
Check for coincidences with
BATSE, IPN, SWIFT

- **close to WB within < factor 2**
- **with IceCube: test WB within a few months**



Optical follow-up for GRB/SN

M.Kowalski, A. Mohr, astro-ph/0701618



Principle:
turn robotic optical telescopes to directions of doublets in nu-telescopes.

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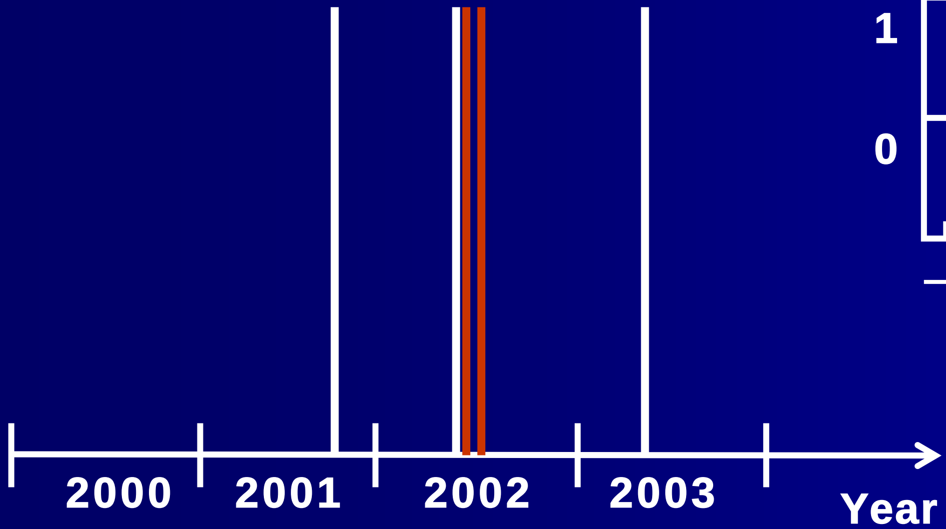
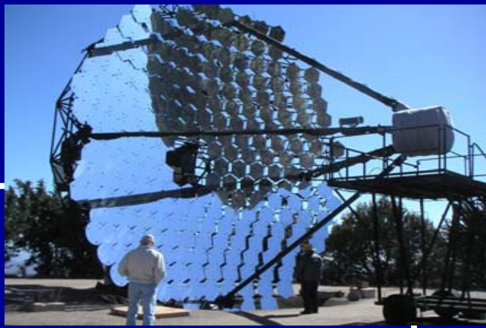
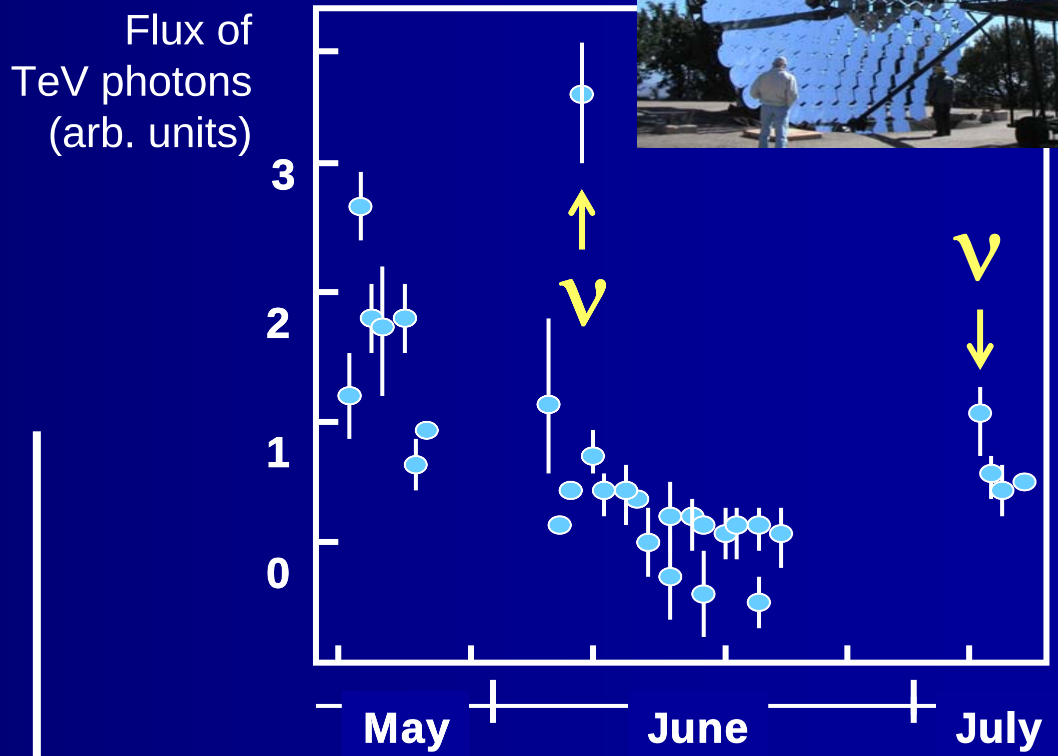
Flares of AGN: ES 1959+650 ?

Arrival time of neutrinos from the direction of the AGN ES1959+650



WHIPPLE

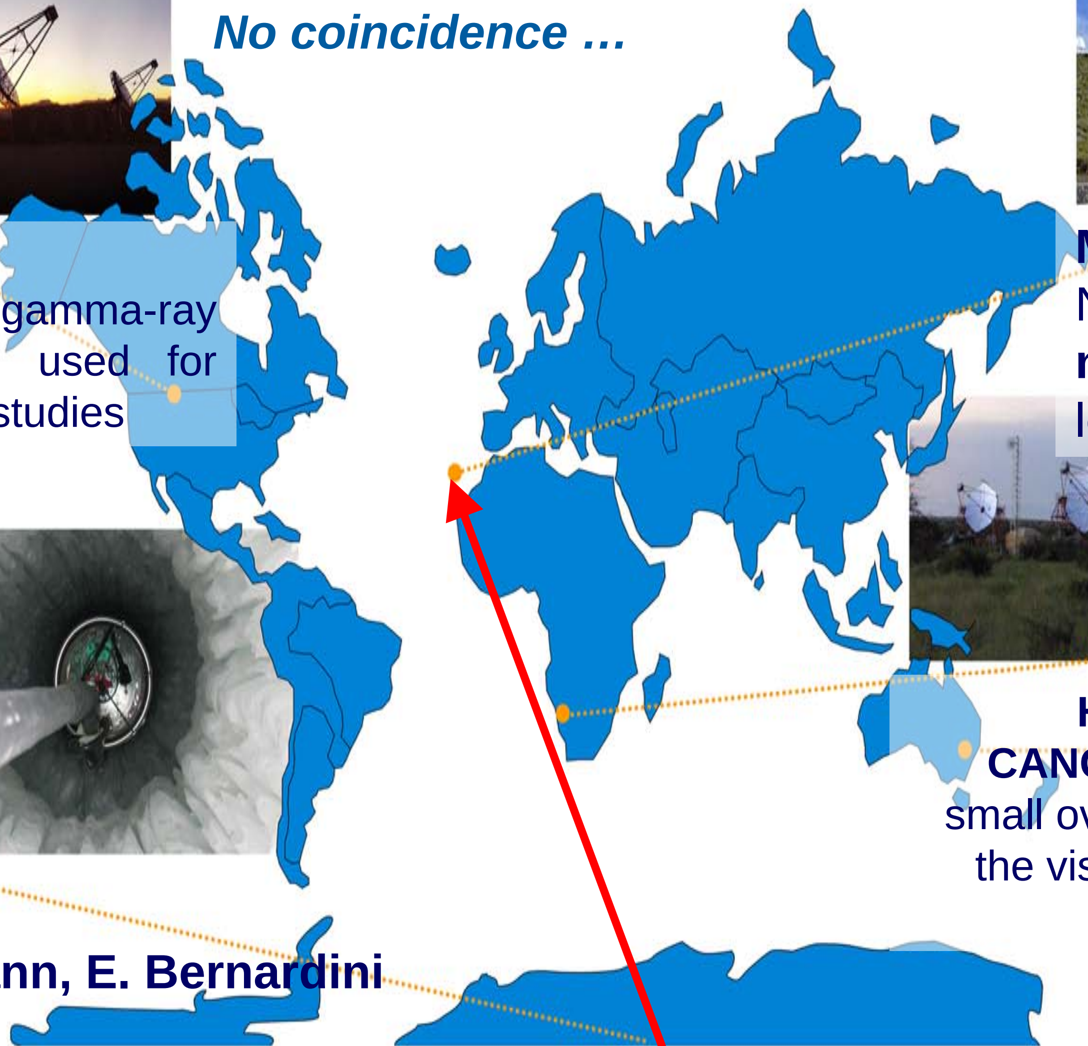




Neutrino Target of Opportunity (NToO)*

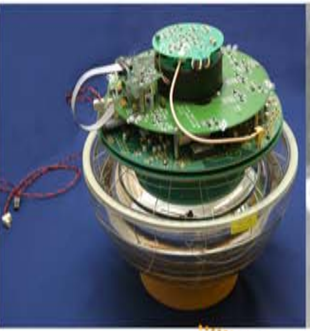
27th September to 27th November 2006
Five alerts sent

Result: 3 observations
No coincidence …



VERITAS
Long-term gamma-ray observations used for light-curves studies

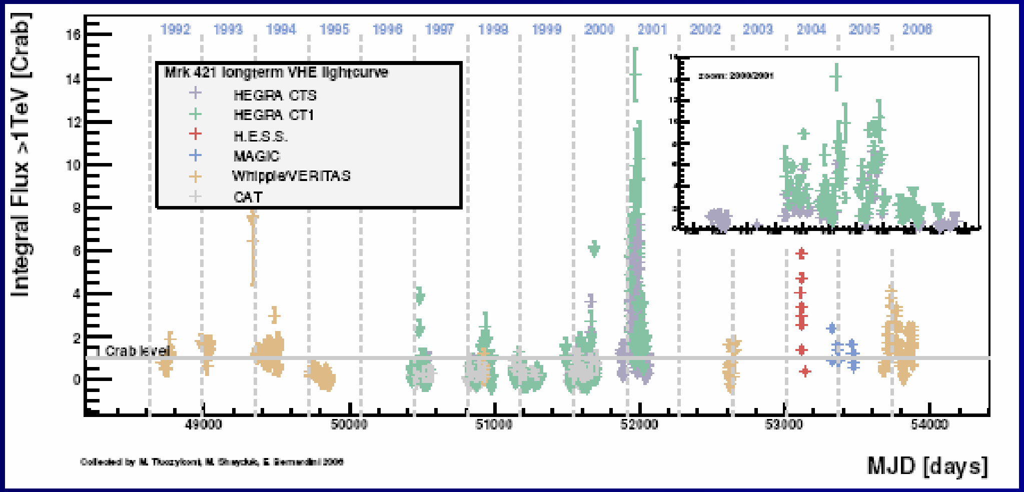
MAGIC
NToO – follow-up **neutrino** alerts plus long term γ observ.



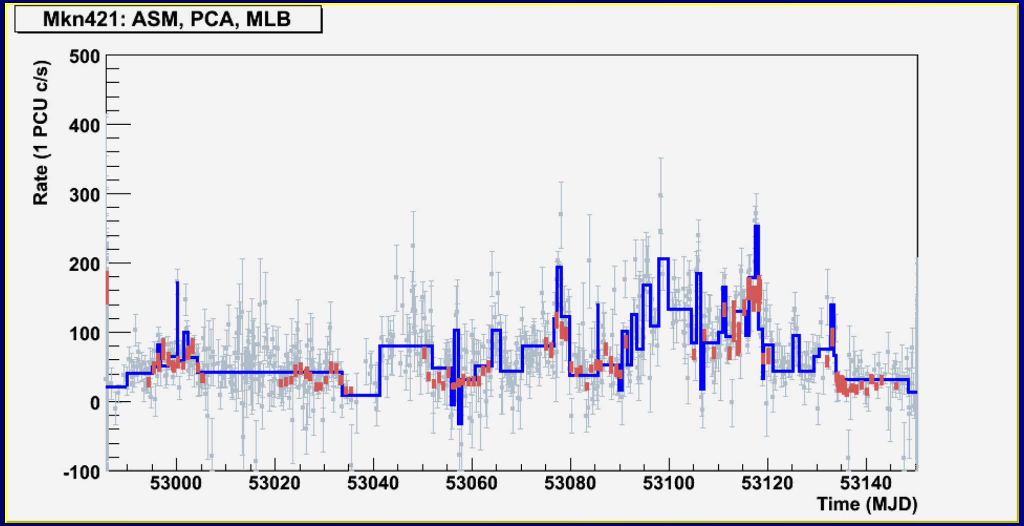
H.E.S.S.
CANGAROO
small overlap in the visible sky

*** M. Ackermann, E. Bernardini**

Understanding transient gamma signals



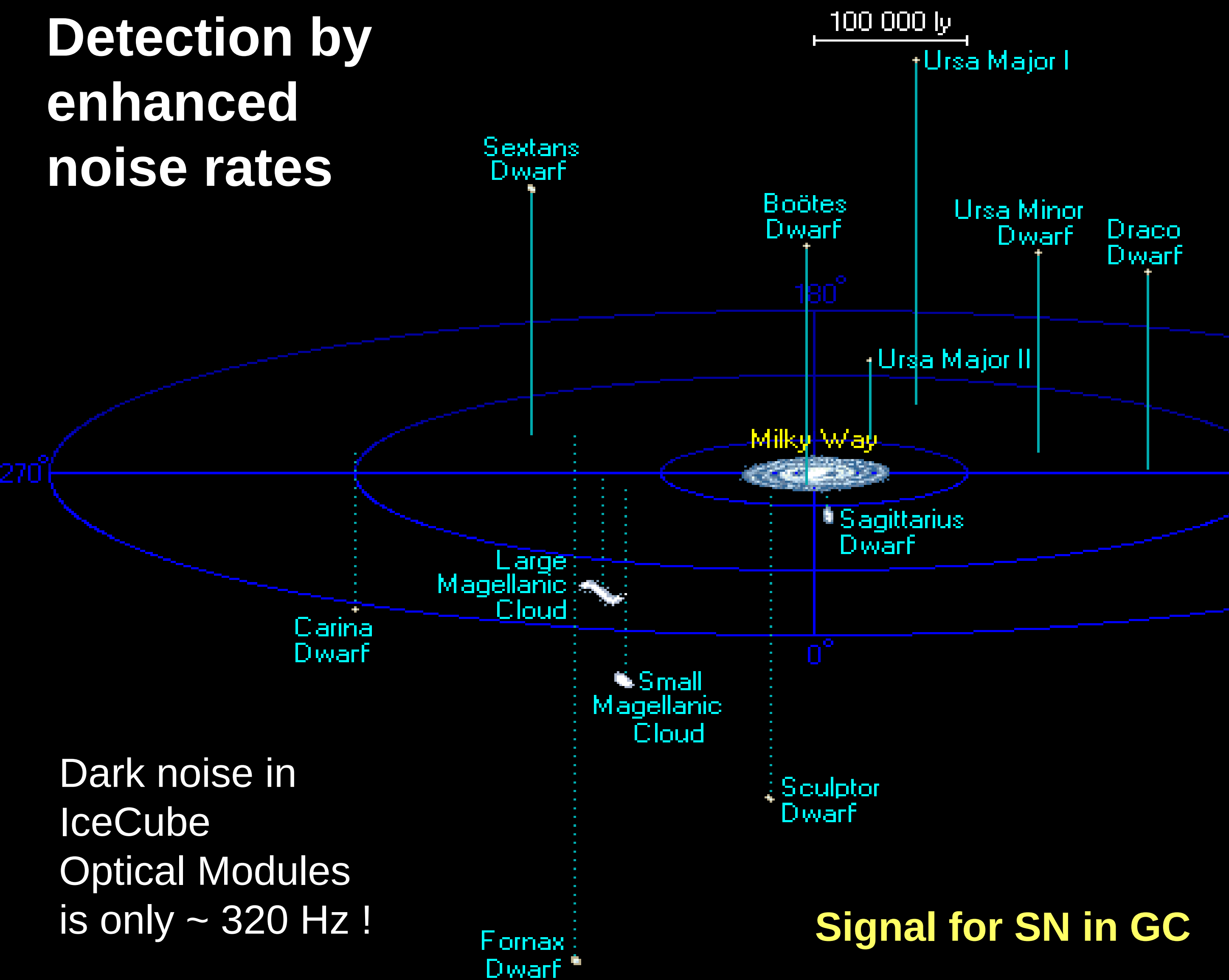
Compiling gamma time series, e.g. M. Tluczykont et al., JoP 60 (2007) 318



Defining flare periods e.g. E.Resconi et al., JoP 60 (2007) 223

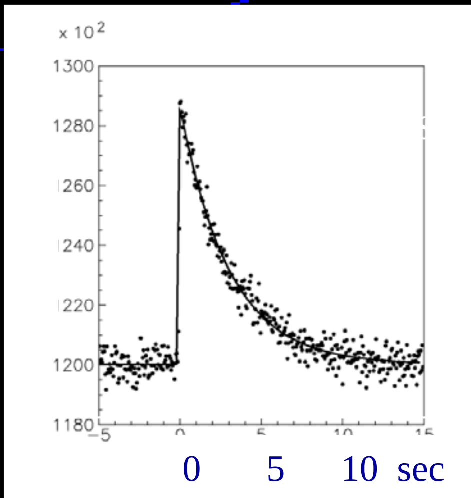
Supernova in IceCube

Detection by enhanced noise rates



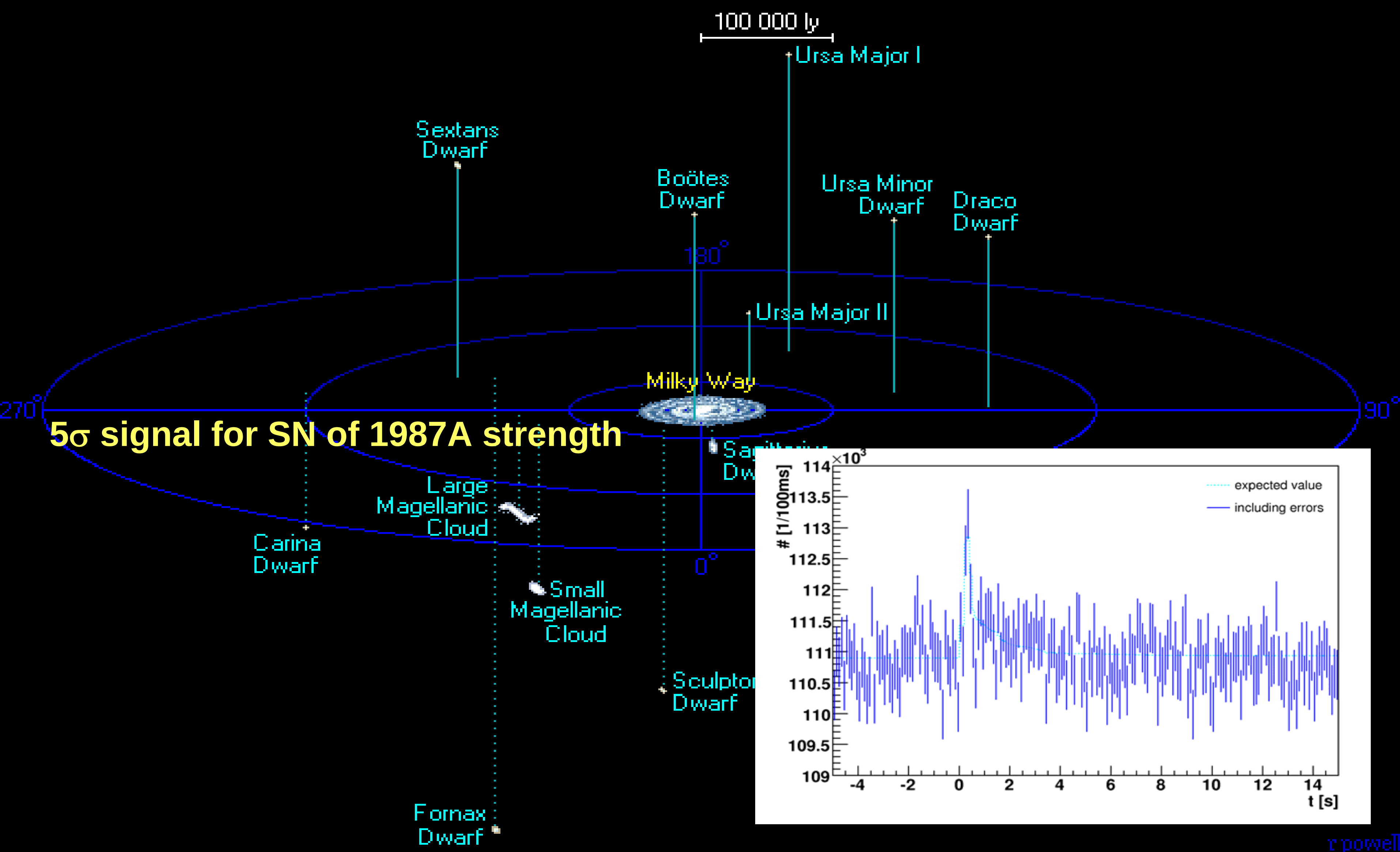
Dark noise in IceCube Optical Modules is only ~ 320 Hz !

Signal for SN in GC



Supernova in IceCube

5σ signal for SN of 1987A strength



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Summary

- tremendous technological progress over last decade
- no positive detection yet, but already testing (optimistic) bounds
- IceCube reaches 1 $km^3 \times$ year by early 2009
- entering region with fair discovery potential. **Most interesting period 2009-2013 !**
- KM3NeT should be substantially more sensitive than IceCube
- IceCube is ready for the next Supernova

Discovery potential for neutrino point sources

ν Astr

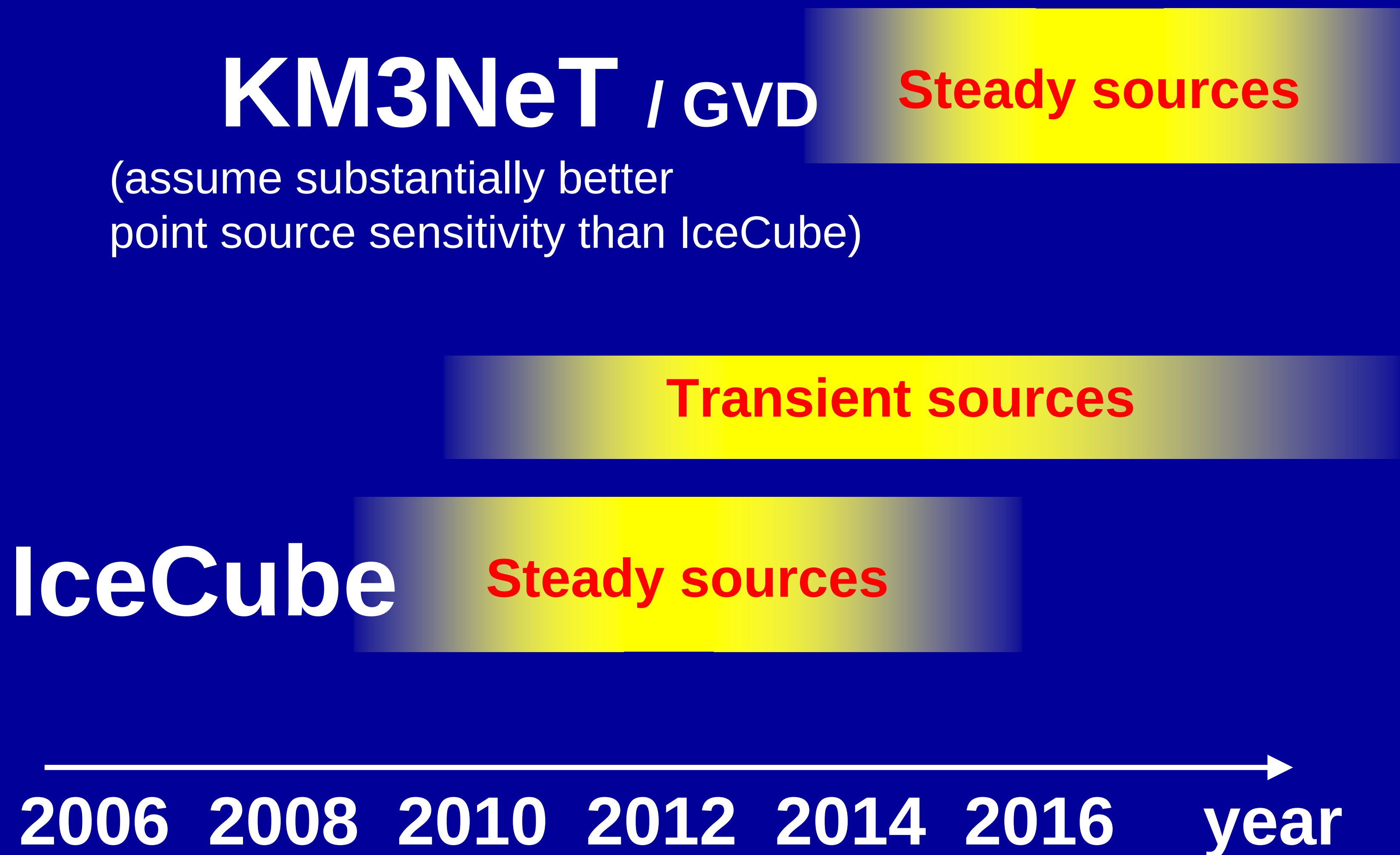
IceCube

Transie

Stead ources

2006 2008 2010 2012 2014 2016 year

Discovery potential neutrino point sources



END