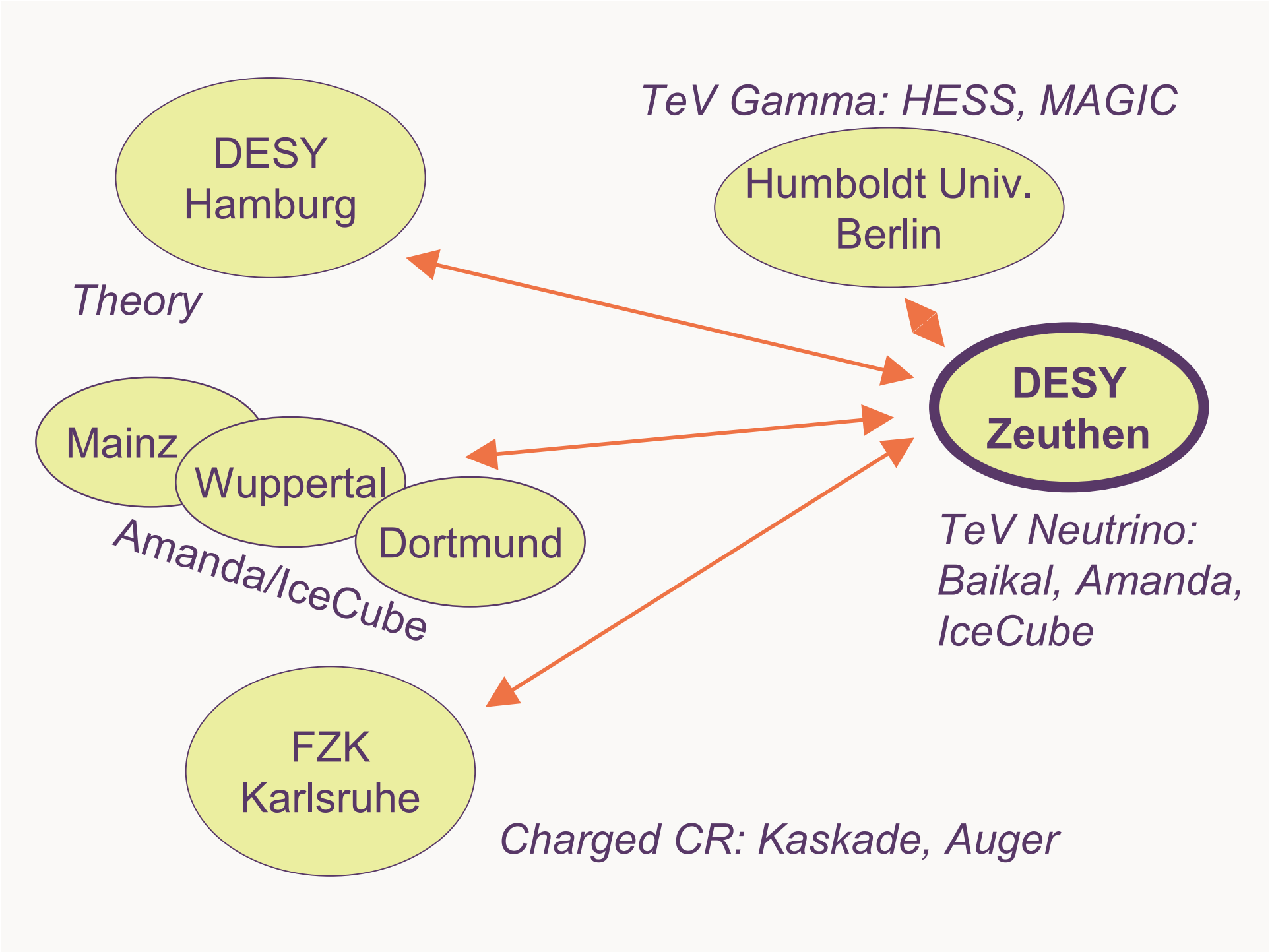
Experimental Astroparticle Physics in DESY

Baikal Amanda IceCube

The Future

Christian Spiering, DESY Theory Workshop, September 2004


TeV Gamma: HESS, MAGIC
DESY
Hamburg
Humboldt Univ.
Berlin
Theory
DESY
Zeuthen
Mainz
Wuppertal
Dortmund
Amanda/IceCube
TeV Neutrino:
Baikal, Amanda,
IceCube
FZK
Karlsruhe
Charged CR: Kaskade, Auger

The Detectors

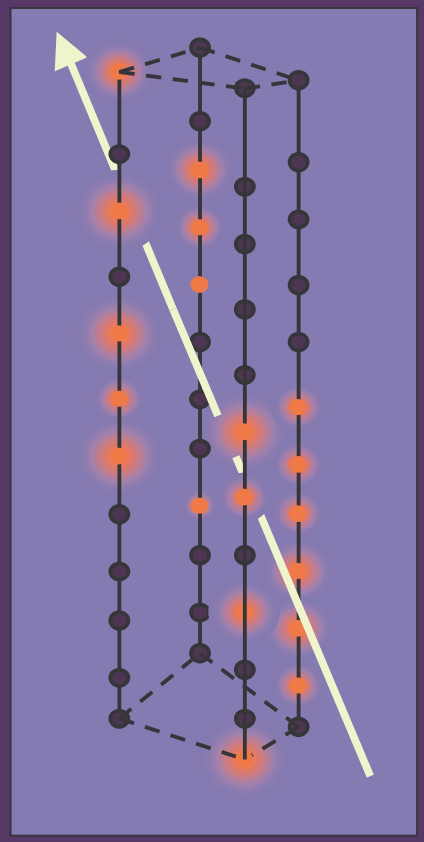
NT-200

Lake Baikal

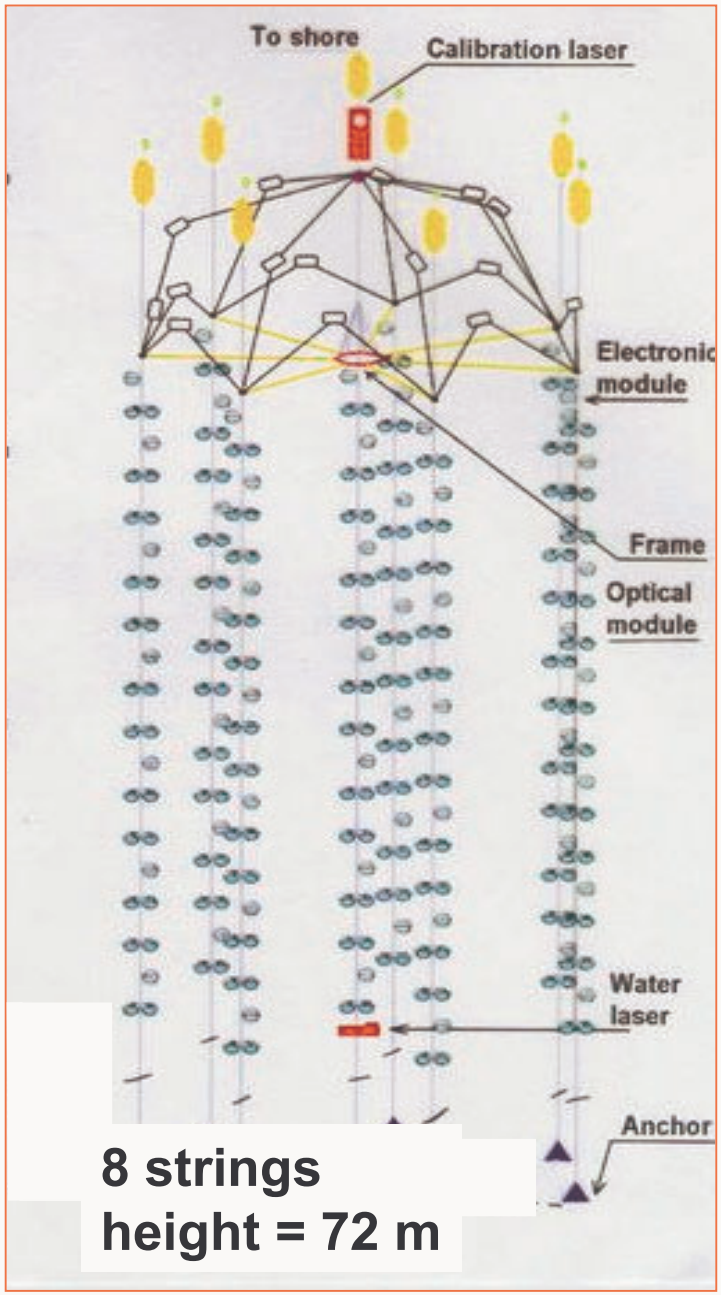
1981 first site explorations
1984 first stationary string
1993 first neutrino detector NT-36
1994 first atm. neutrino separated
1998 NT-200 finished

~ 2x Super-K for 1 TeV muons

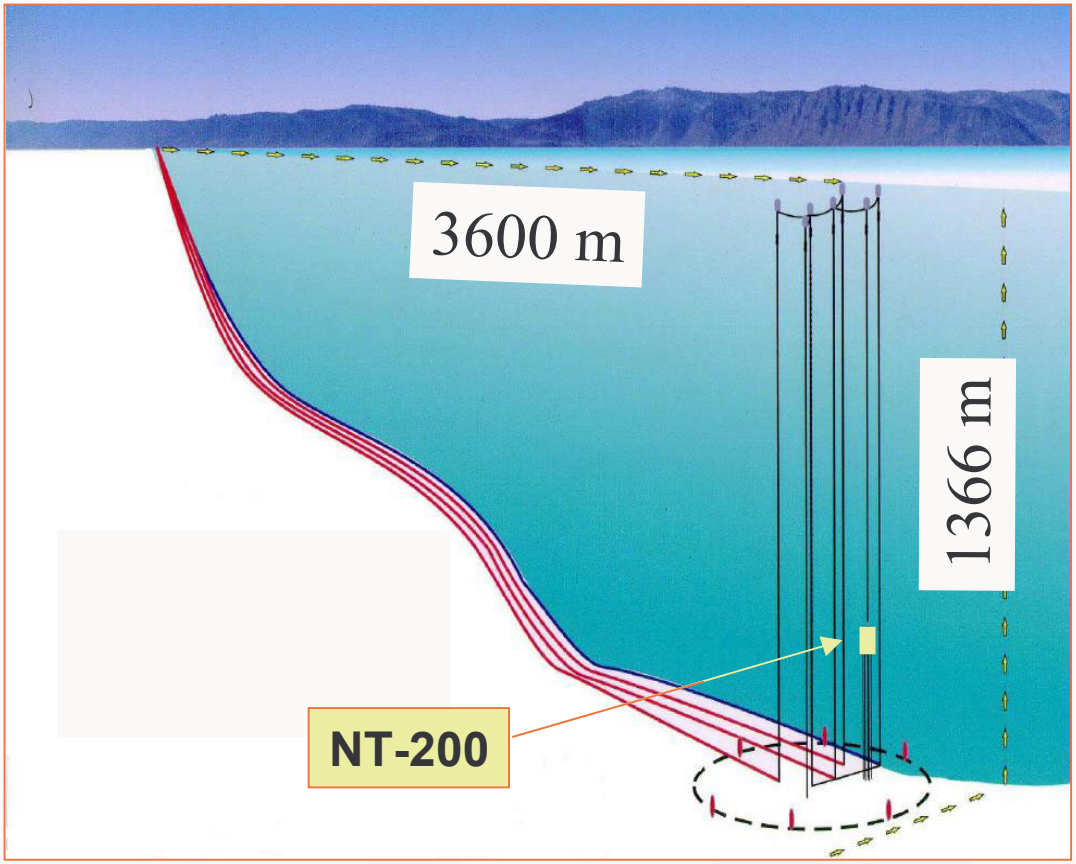
Zeuthen group since 1988



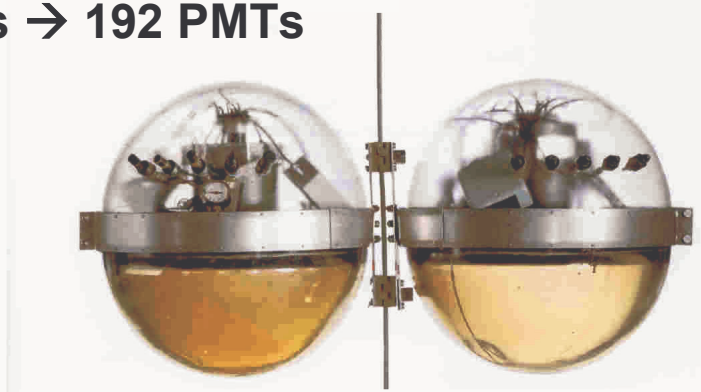
Gold-plated neutrino event from 4-string stage (1996)

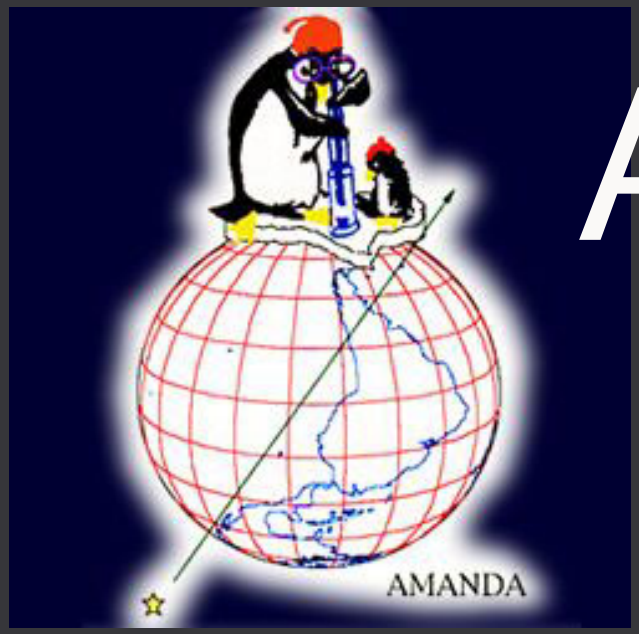


8 strings
height = 72 m



96 pairs → 192 PMTs



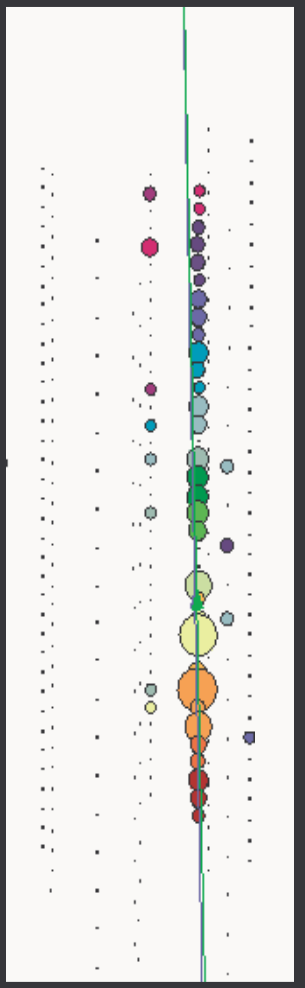


AMANDA

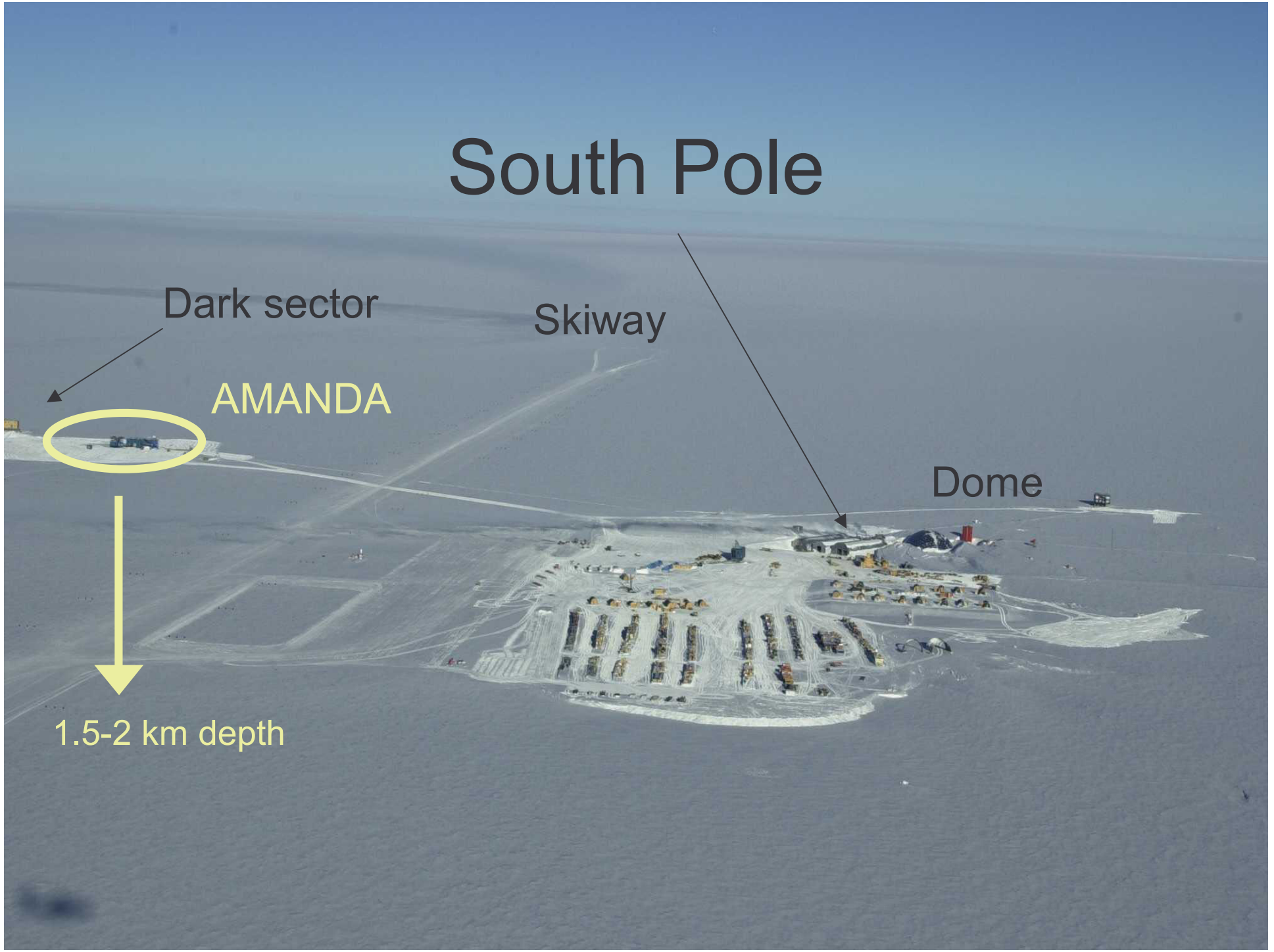
South Pole

first site studies at South Pole	~	1990
shallow detector in bubbly ice		1993/4
10 strings (Amanda-B10)		1997
19 strings (Amanda-II)		2000

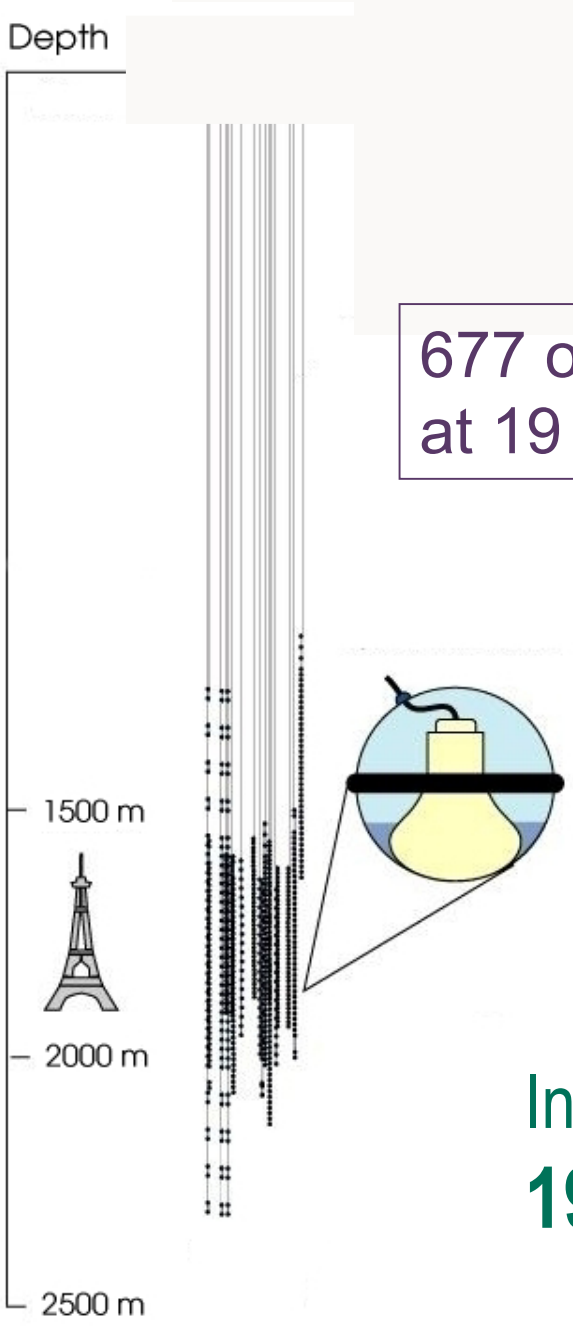
Zeuthen group since 1994



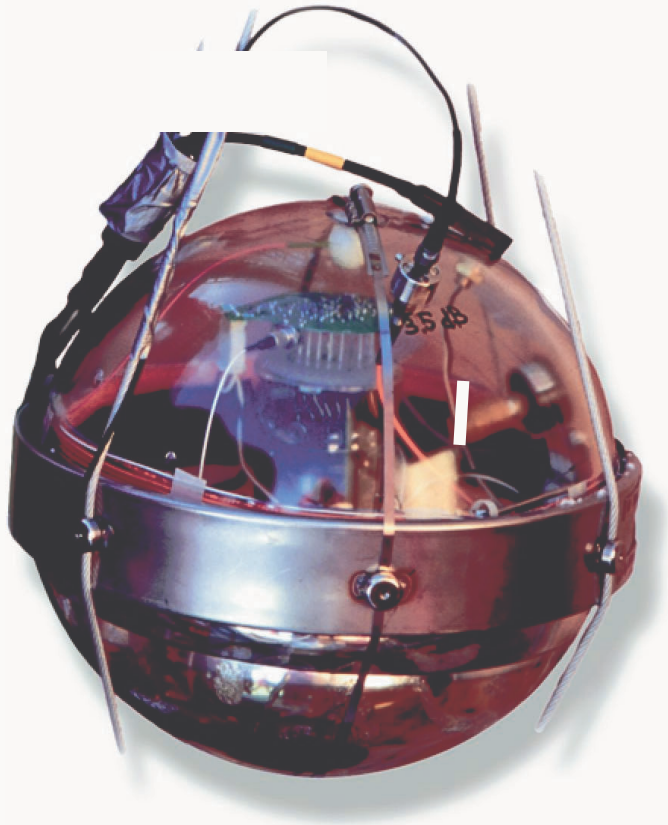
Gold-plated neutrino event,
Amanda-B10


South Pole
Dark sector
Skiway
AMANDA
Dome
1.5-2 km depth

AMANDA-II



677 optical modules
at 19 strings

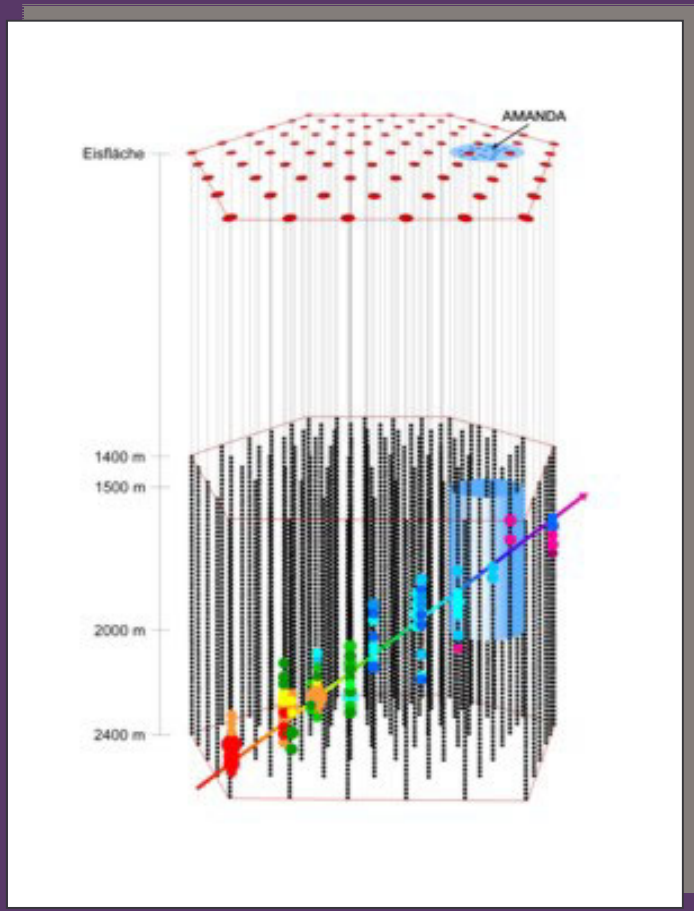


Installation
1996-2000

The km3 scale at South Pole

IceCube

- 80 Strings
- 4800 PMTs
- Instrumented Volume: 1 km^3
- Installation: 2005-2010



Revised baseline since April 2004 (70 strings)

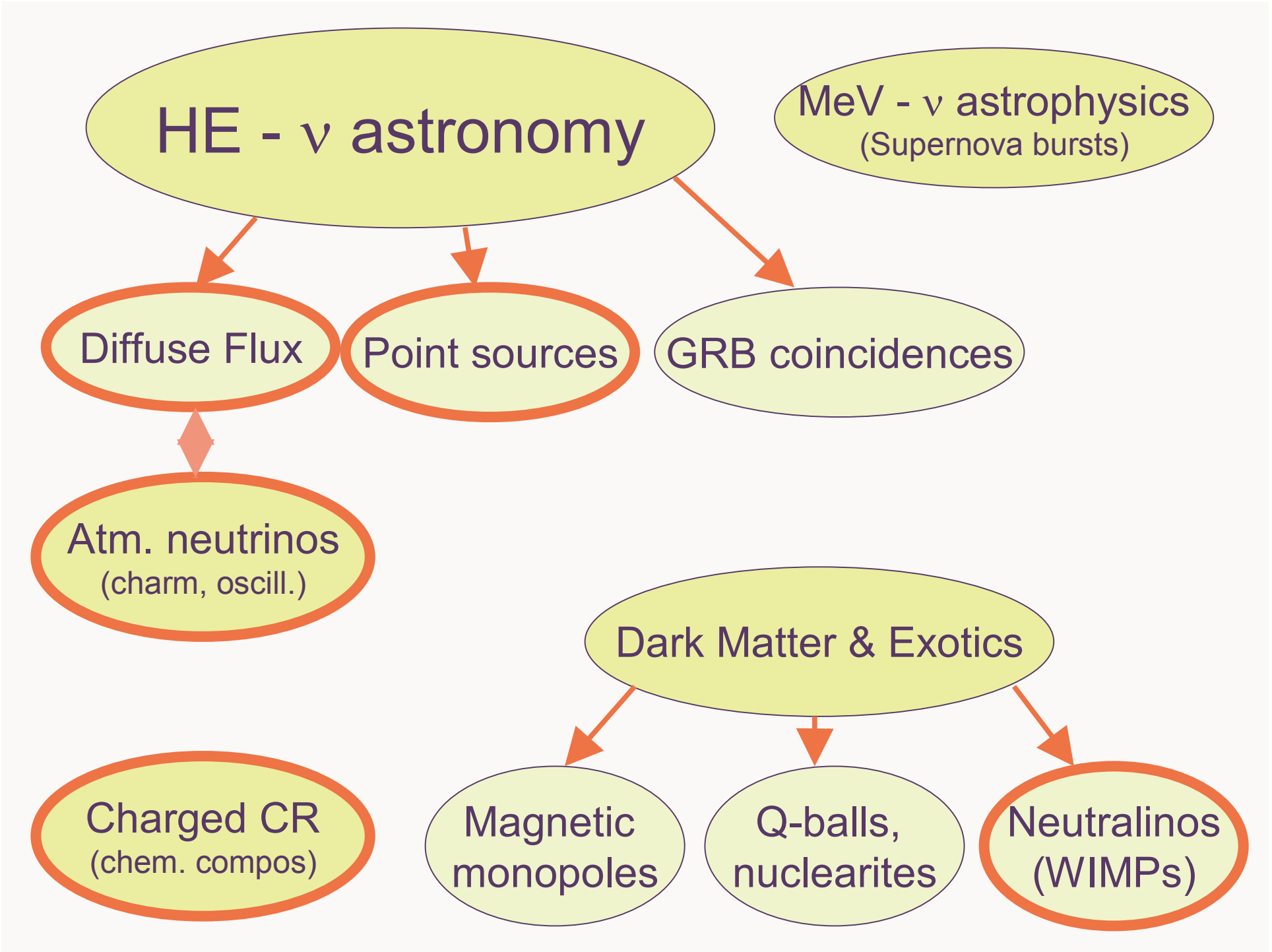
string *71-80* in contingency

IceCube strings	**IceTop tanks**	
up to 4	up to 8	Jan 2005
16	32	Jan 2006
32	64	Jan 2007
50	100	Jan 2008
68	136	Jan 2009
70+n	140+n	Jan 2010

DESY:

- 1300 Optical Modules
- software/data processing
- part of electronics
- analysis

Physics Goals

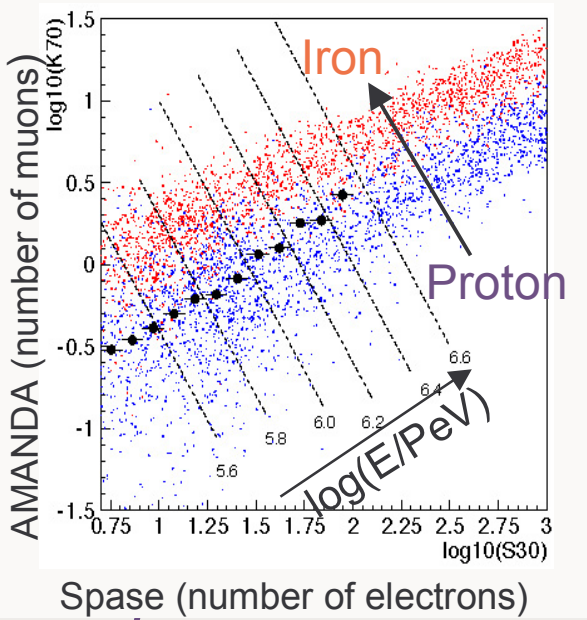

HE - ν astronomy
MeV - ν astrophysics
(Supernova bursts)
Diffuse Flux
Point sources
GRB coincidences
Atm. neutrinos
(charm, oscill.)
Dark Matter & Exotics
Charged CR
(chem. compos)
Magnetic
monopoles
Q-balls,
nuclearites
Neutralinos
(WIMPs)

Chemical Composition of charged CR

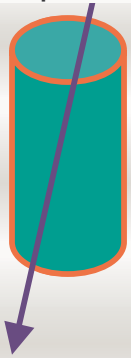
Chemical Composition

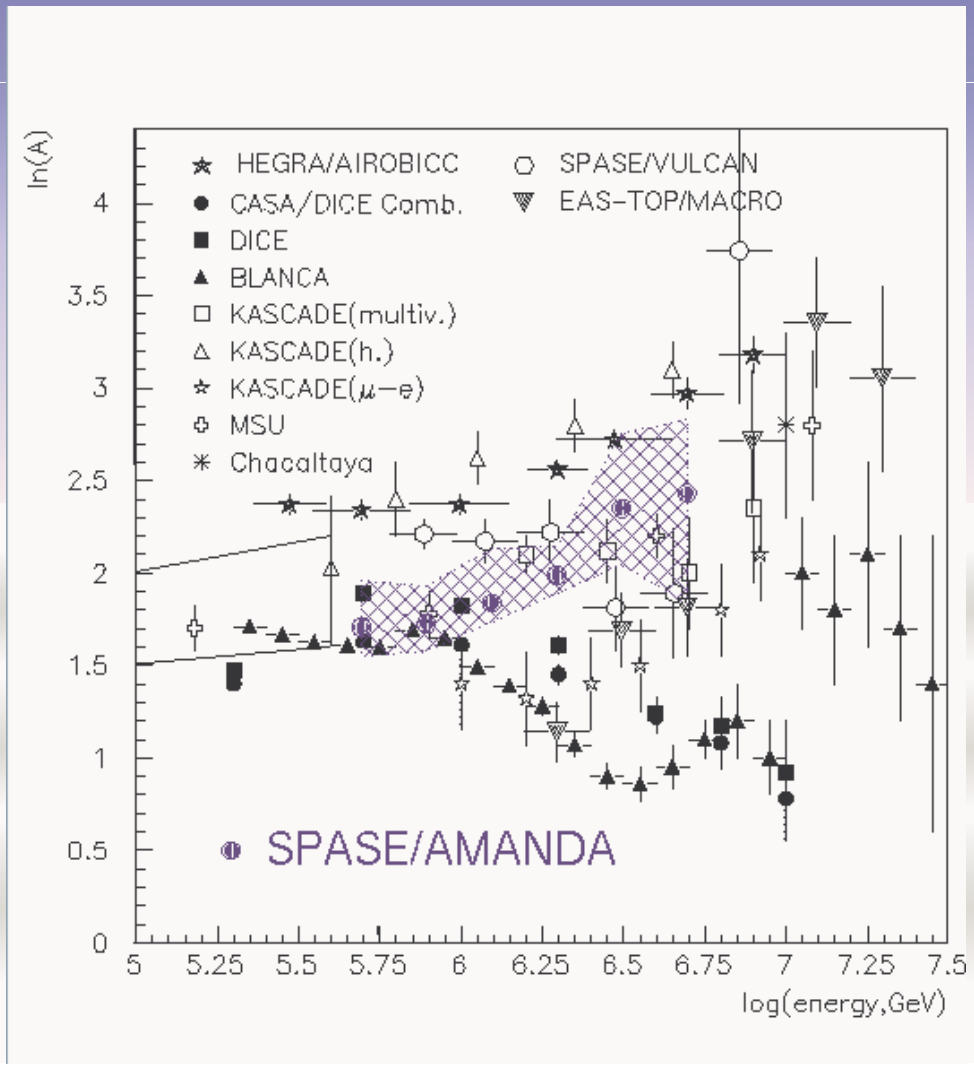
1 km

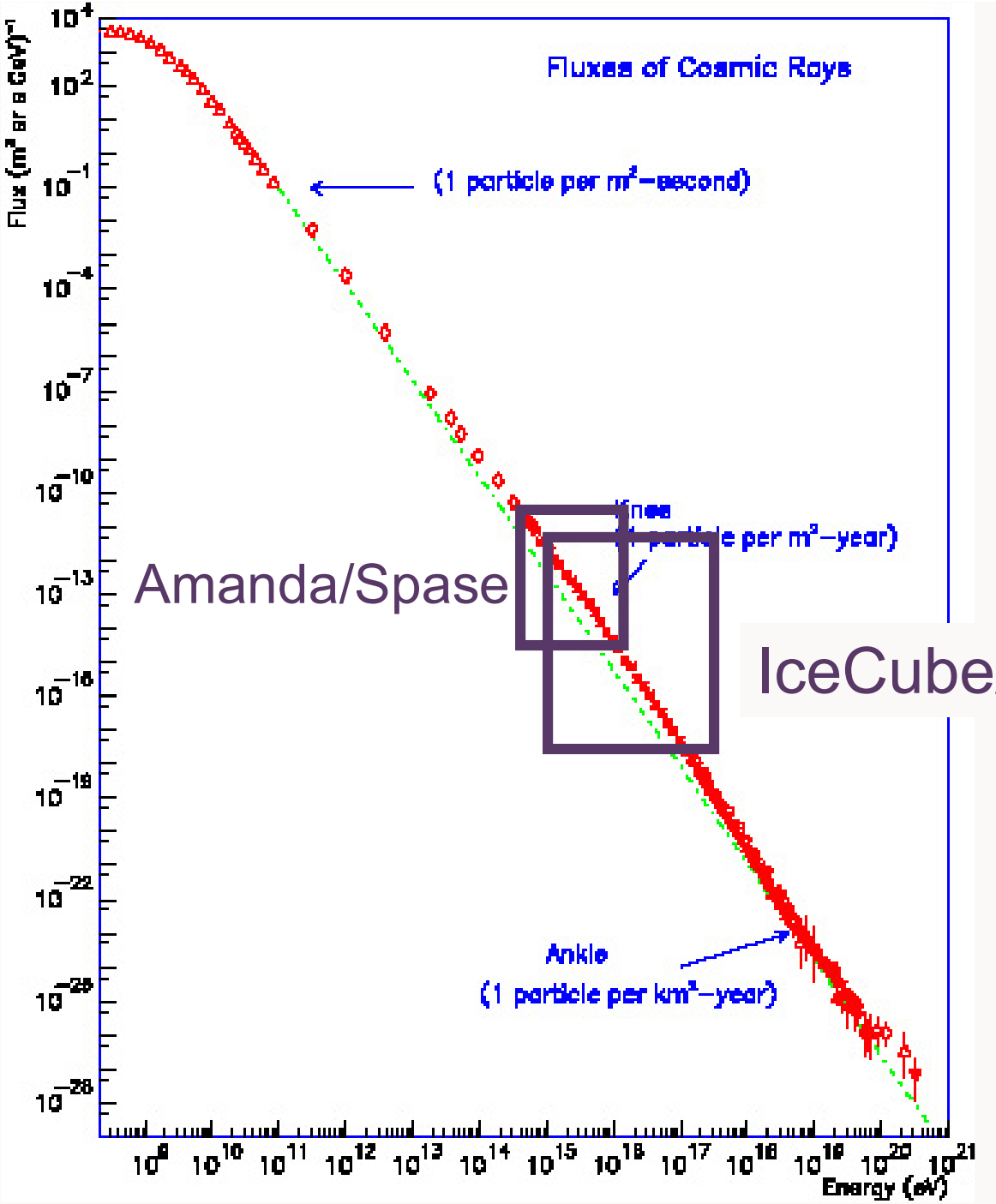
2 km



Spase (number of electrons)





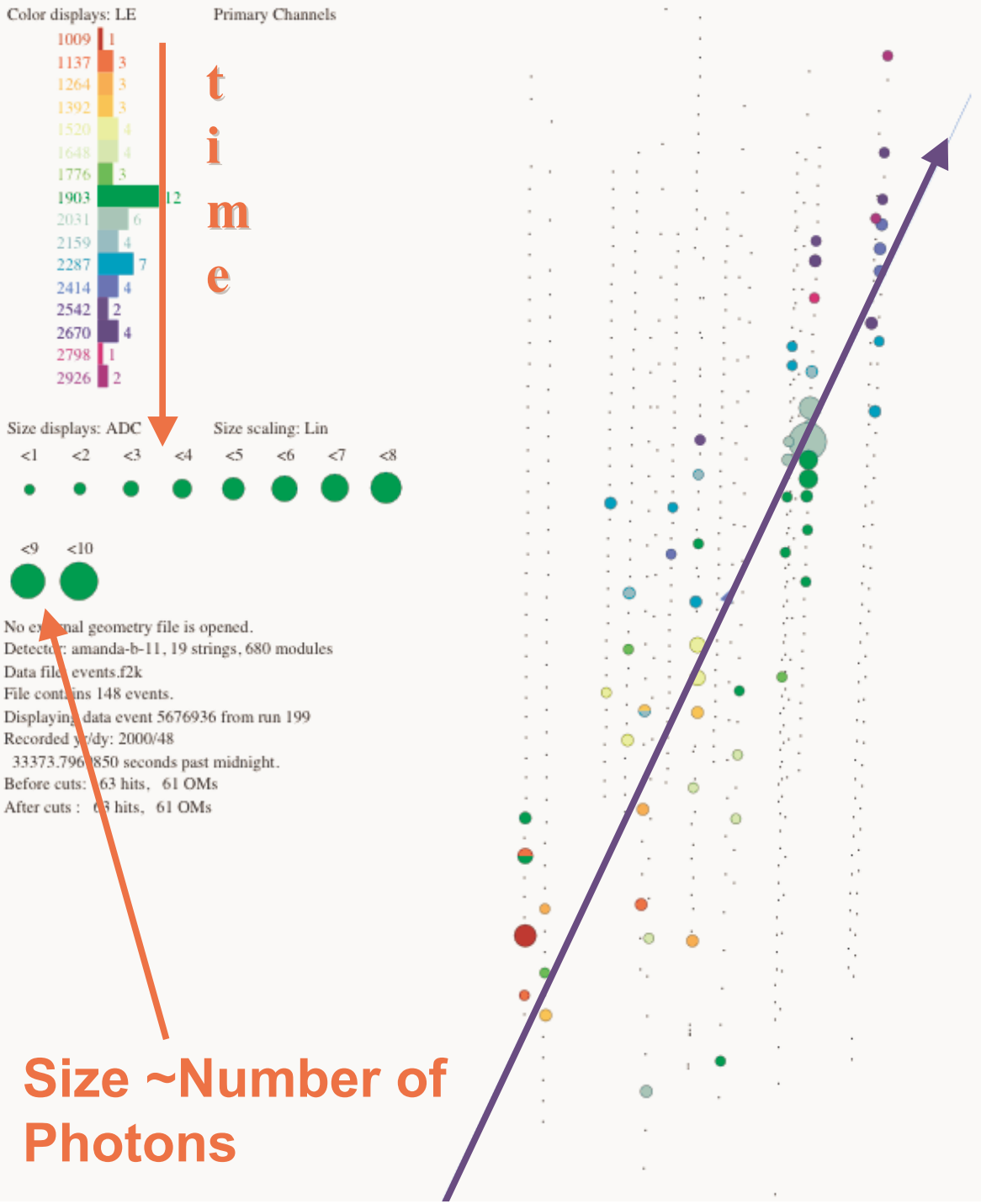


... investigates transition to extra-galactic CR

Atmospheric Neutrinos

AMANDA II

- up-going muon
- 61 modules hit



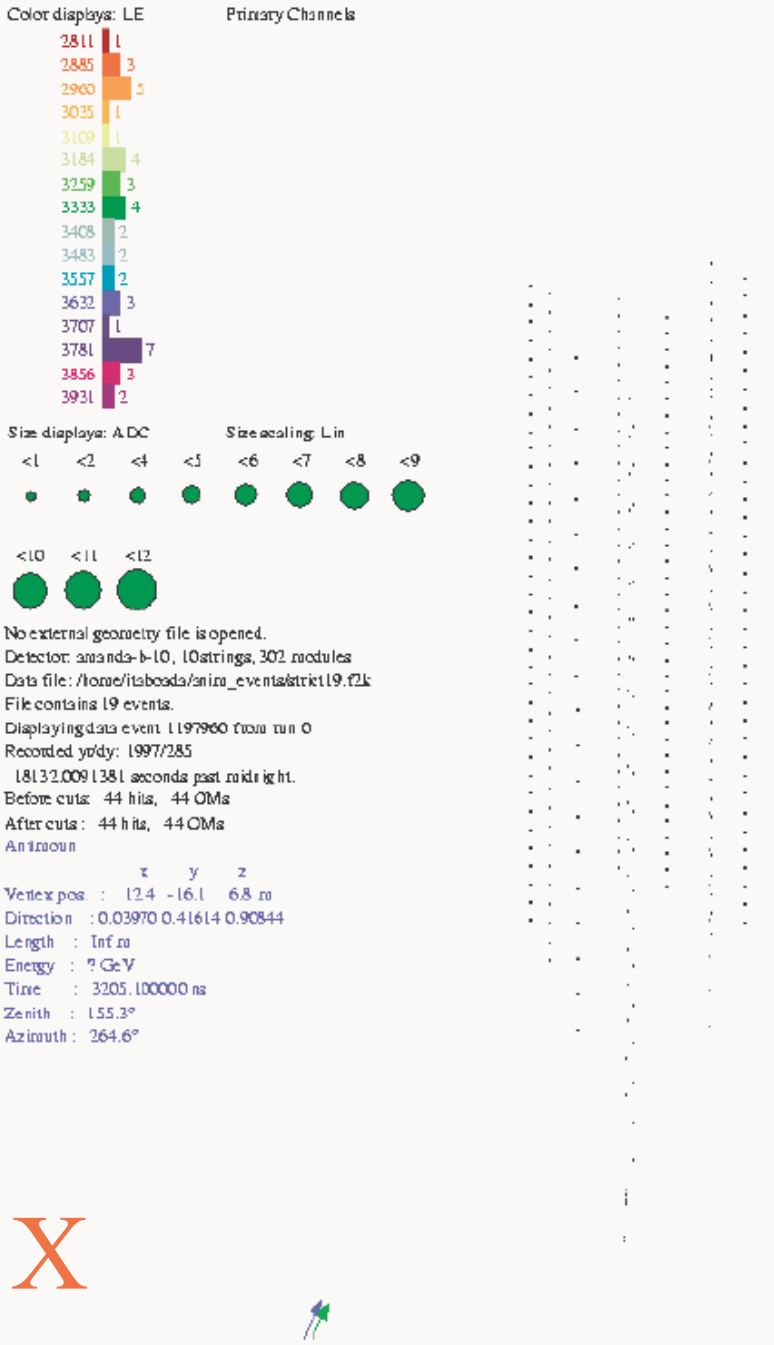
> 4 neutrinos/day

AMANDA Event Signatures: Muons

CC muon neutrino interaction

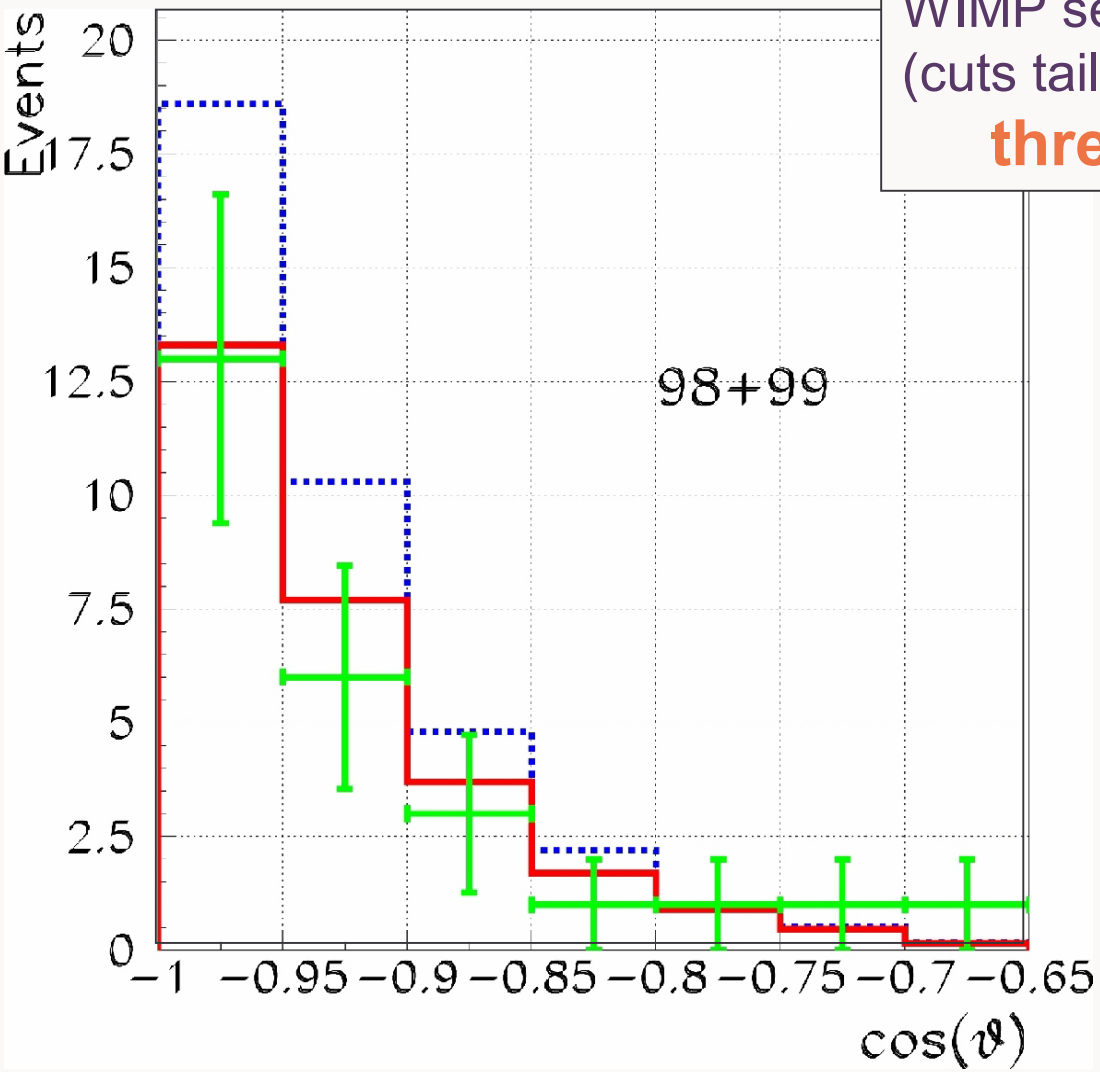
→ **track**

$$\nu_\mu + N \rightarrow \mu + X$$



Baikal NT-200

WIMP search analysis
(cuts tailored to WIMP detection)
threshold ~ 10 GeV



Green:
Experiment

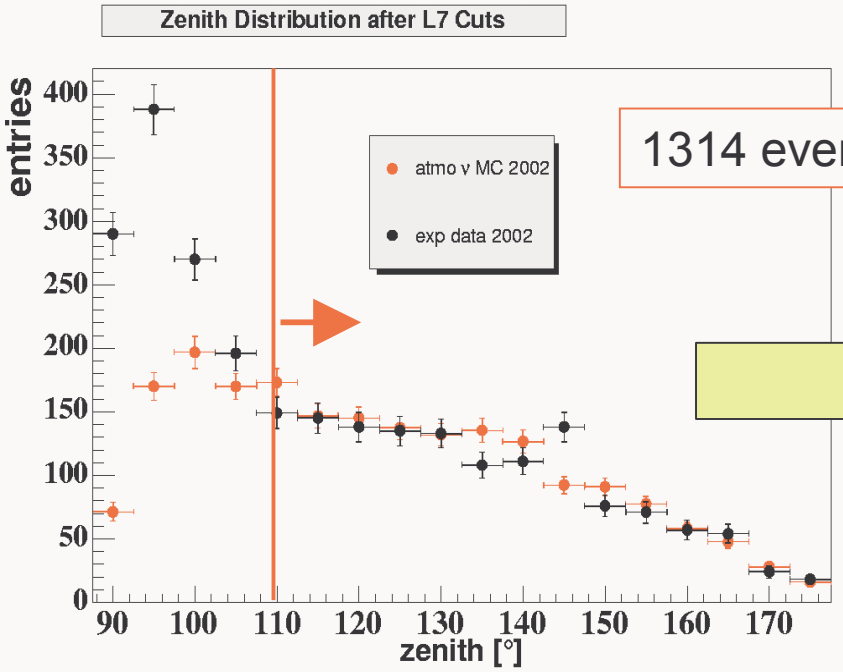
Blue:
MC atm. ν, no oscill. (Bartol-96)

Red:
MC atm.ν, incl.oscill. ($\delta m^2 = 2.5 \cdot 10^{-3}$ eV^2)

AMANDA-II

2002 data

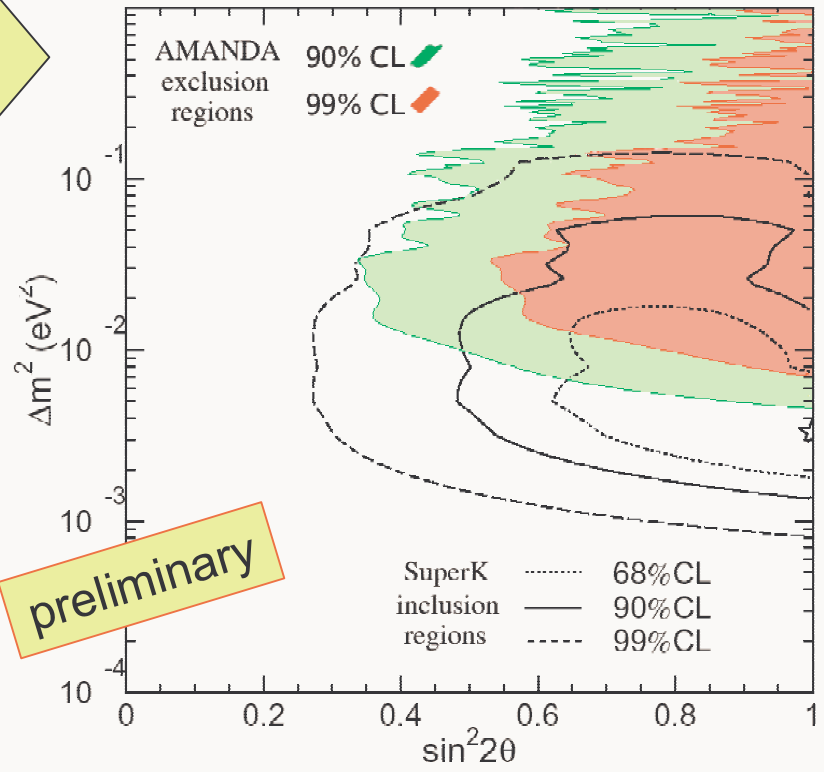
atmospheric neutrino optimization



1314 events > 110°

threshold ~ 60 GeV

Exclusion regions



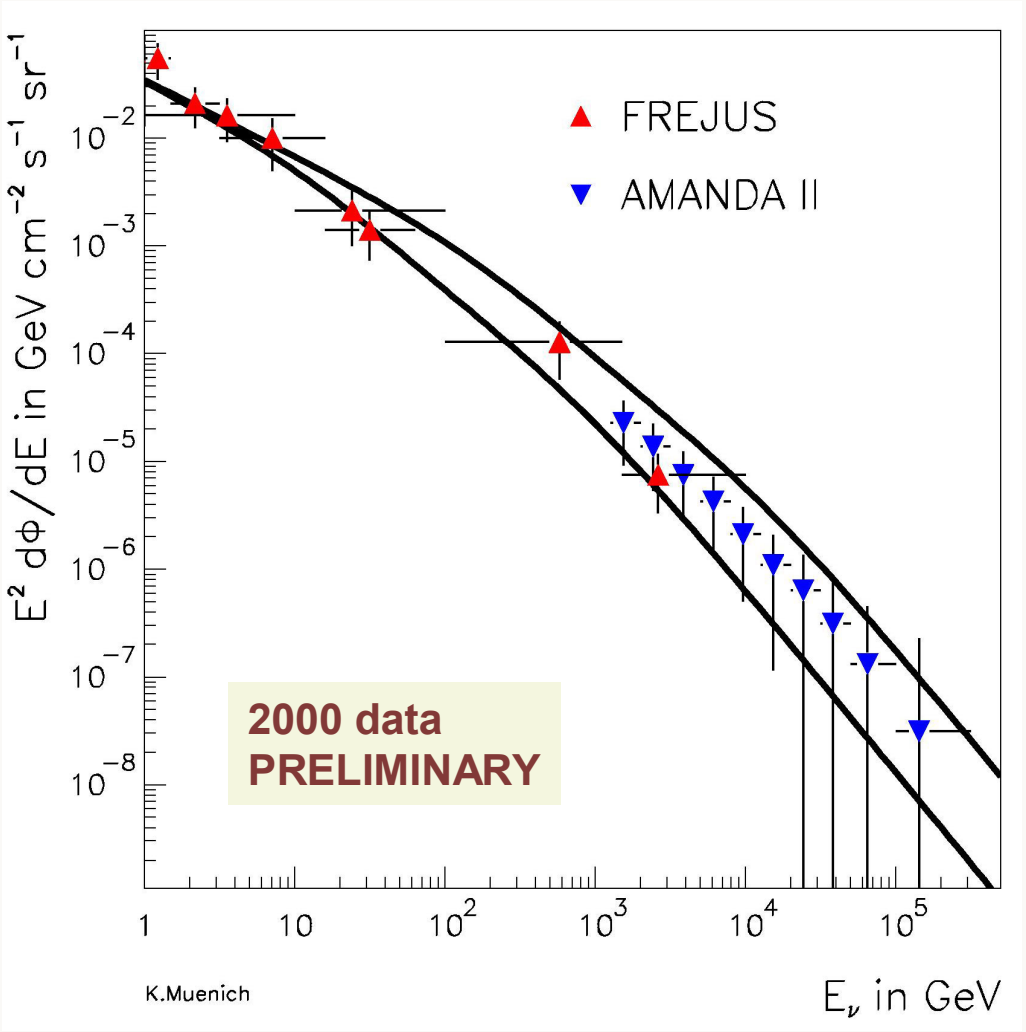
AMANDA-II

2000 data

First spectrum > 3 TeV:

- up to 100 TeV

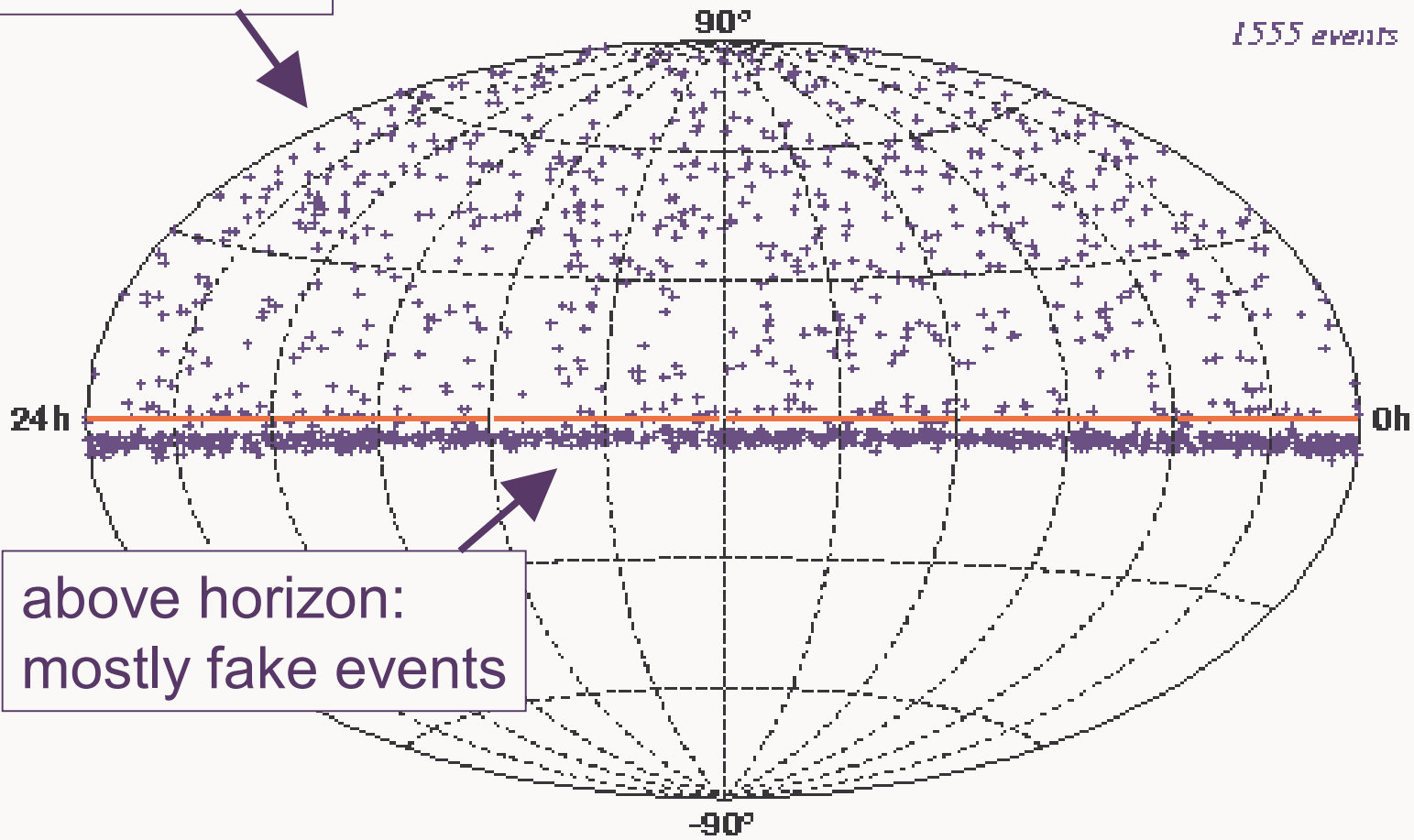
- matches lower-energy Frejus data



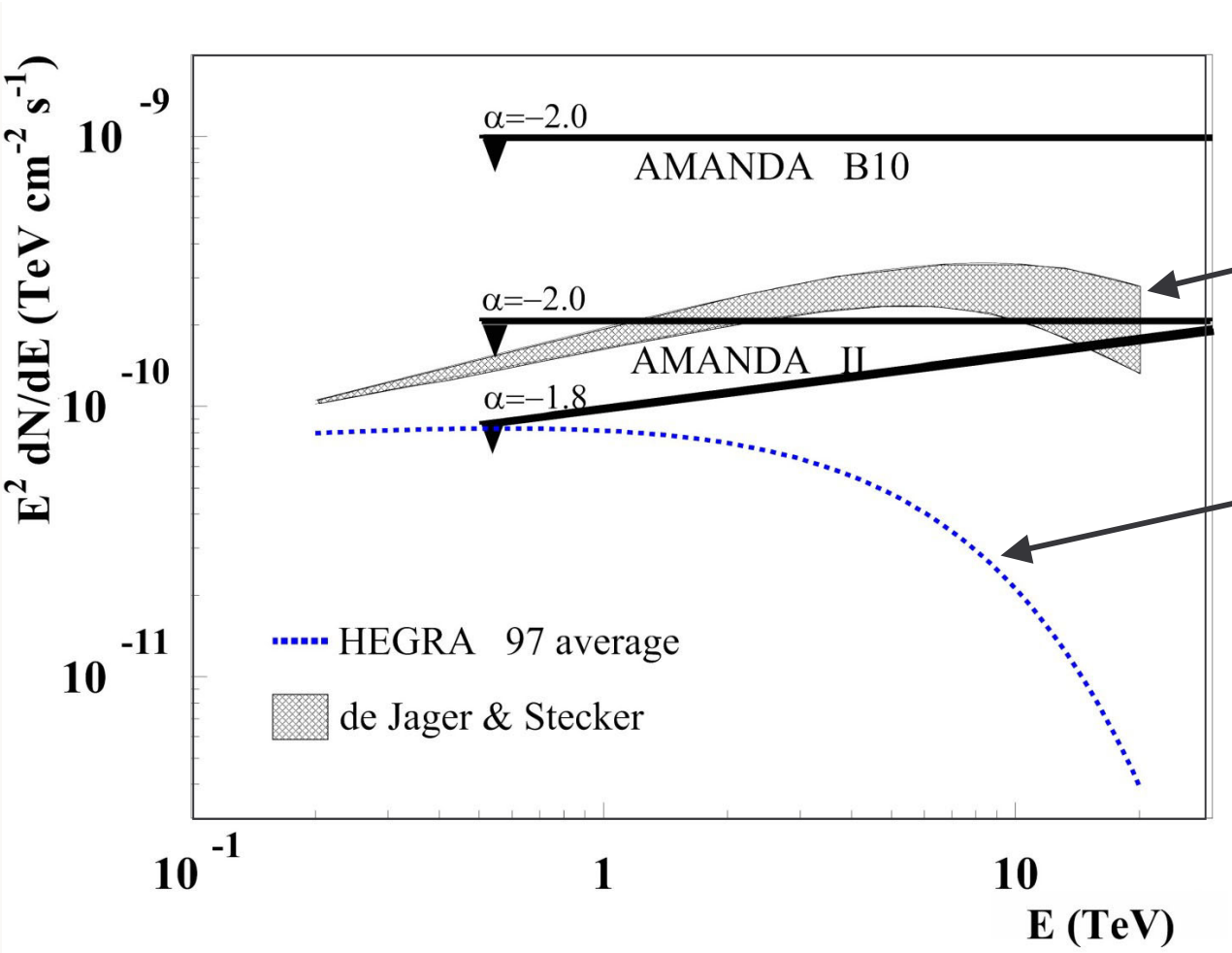
Search for Point Sources

Skyplot Amanda-II, 2000

697 events
below horizon



above horizon:
mostly fake events



Intrinsic source γ spectrum (corrected for IR absorption)

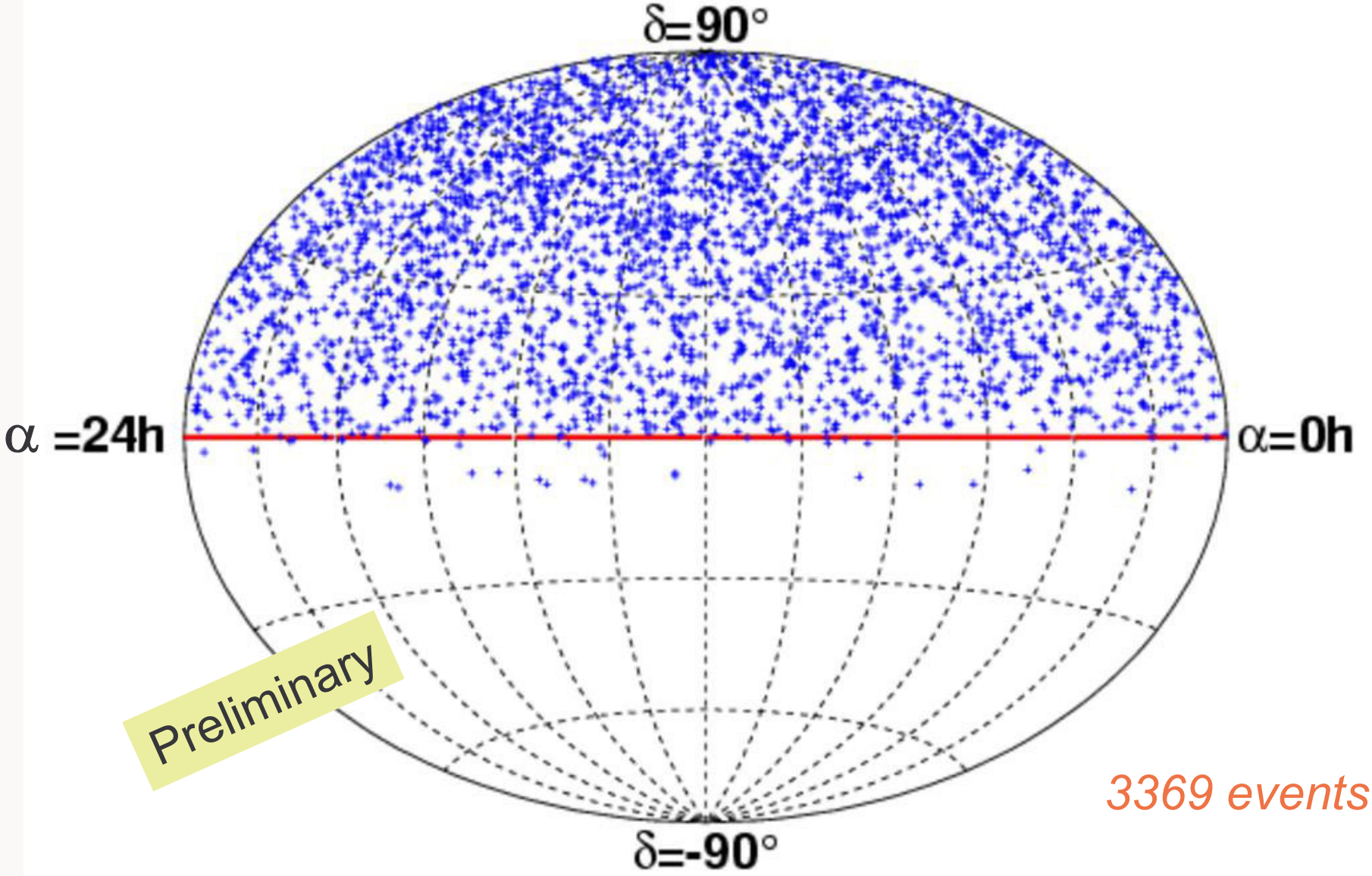
Measured γ spectrum

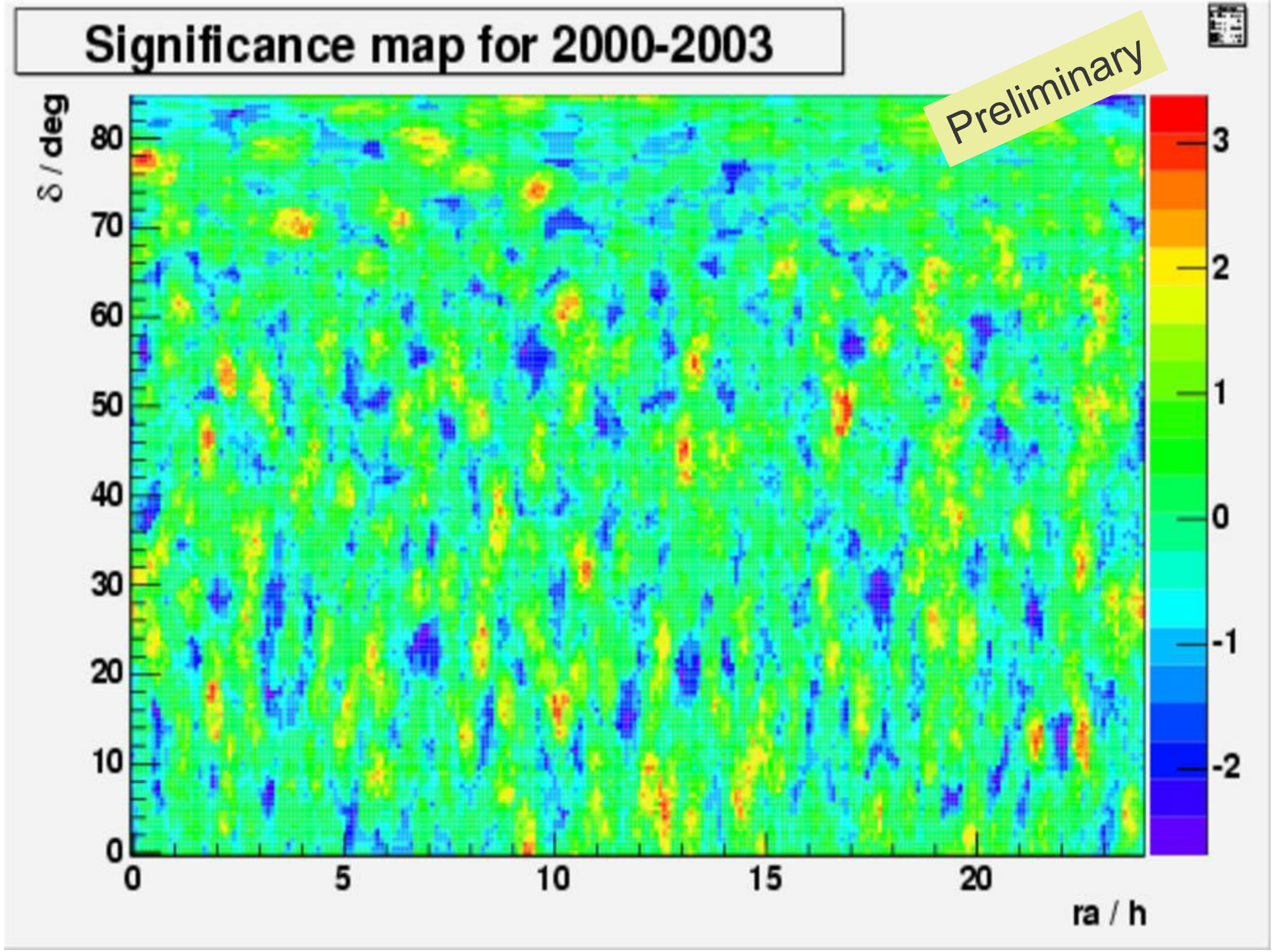
AMANDA average flux limit for two assumed spectral indices α, compared to the average gamma flux of **Markarian 501** as observed in 1997 by HEGRA.

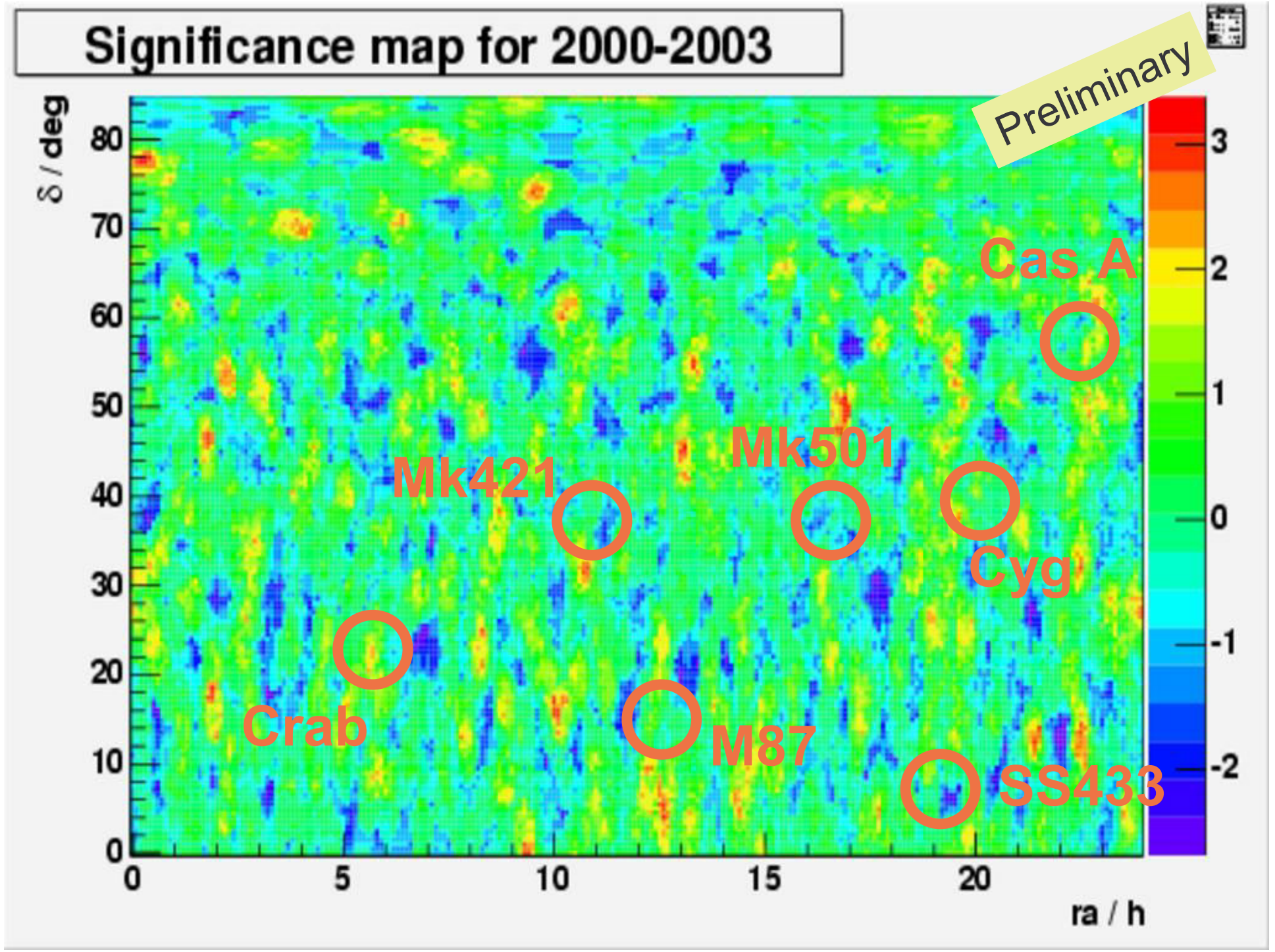
AMANDA-II has reached the sensitivity needed to search from neutrino fluxes from TeV gamma sources of similar strength to the instrinsic gamma flux.

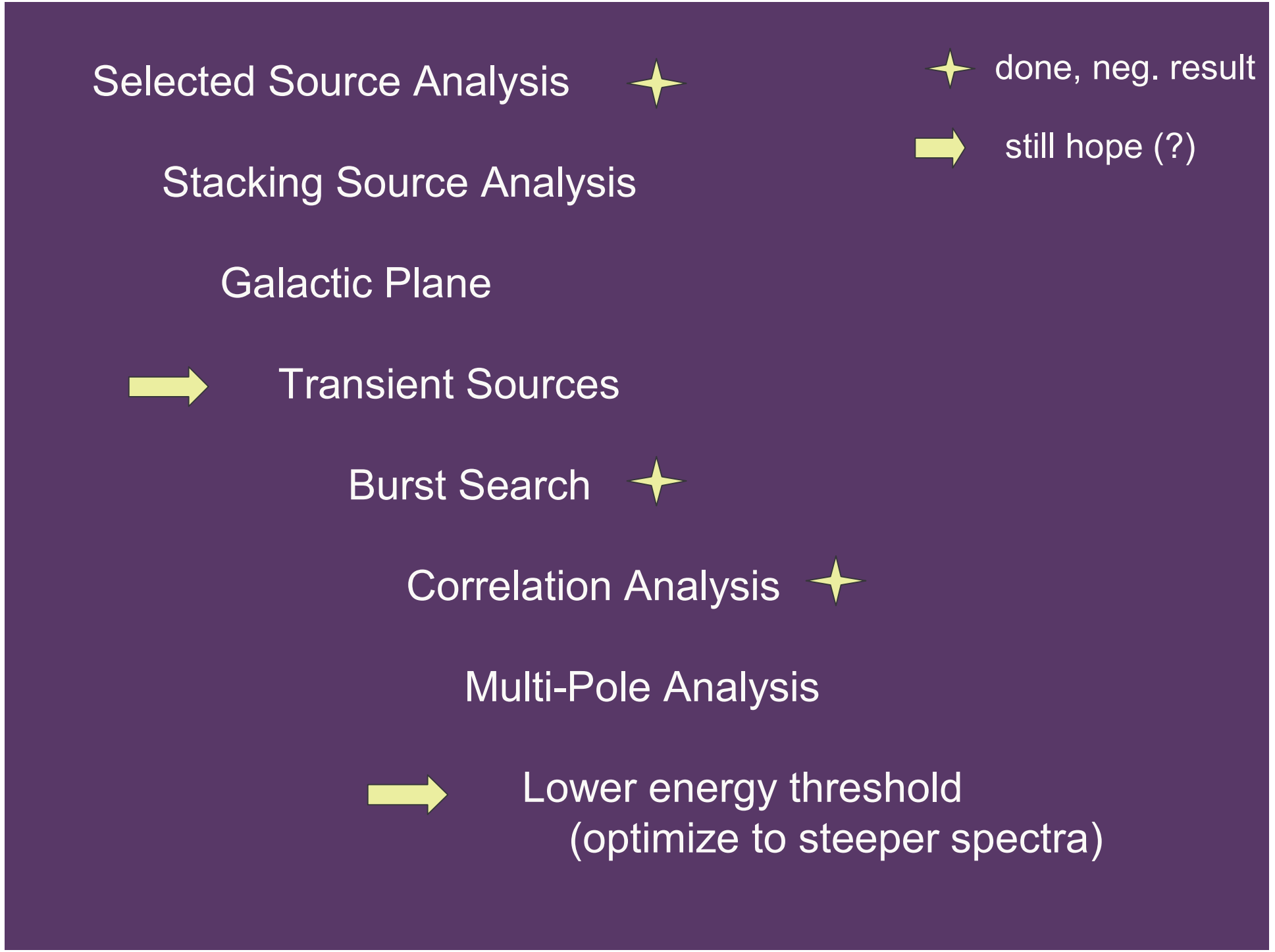
AMANDA skyplot 2000-2003

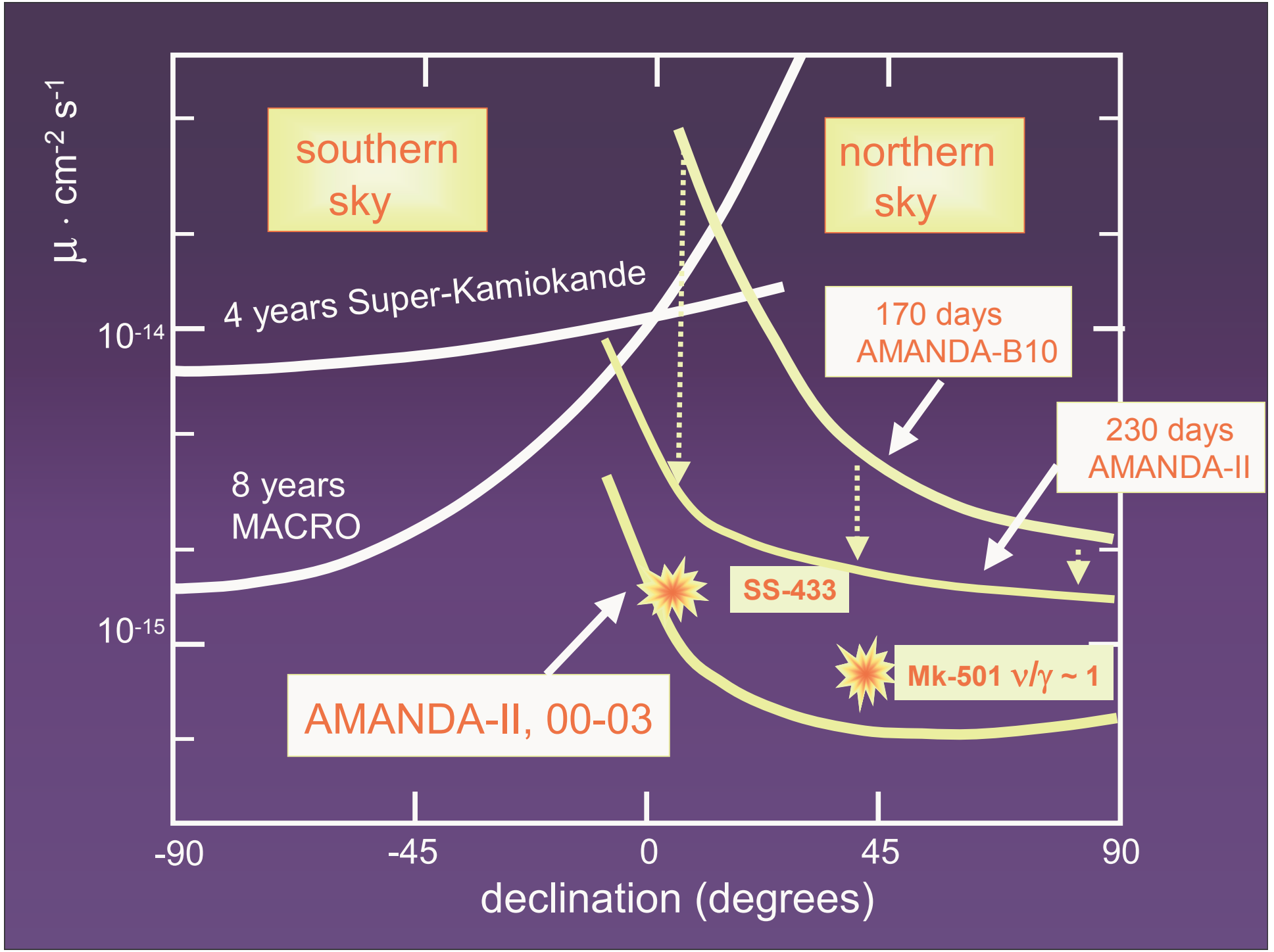
optimized for best sensitivity to E^{-3} – E^{-2} sources




Significance map for 2000-2003
Preliminary
δ / deg
80
70
60
50
40
30
20
10
0
0
5
10
15
20
ra / h
3
2
1
0
-1
-2

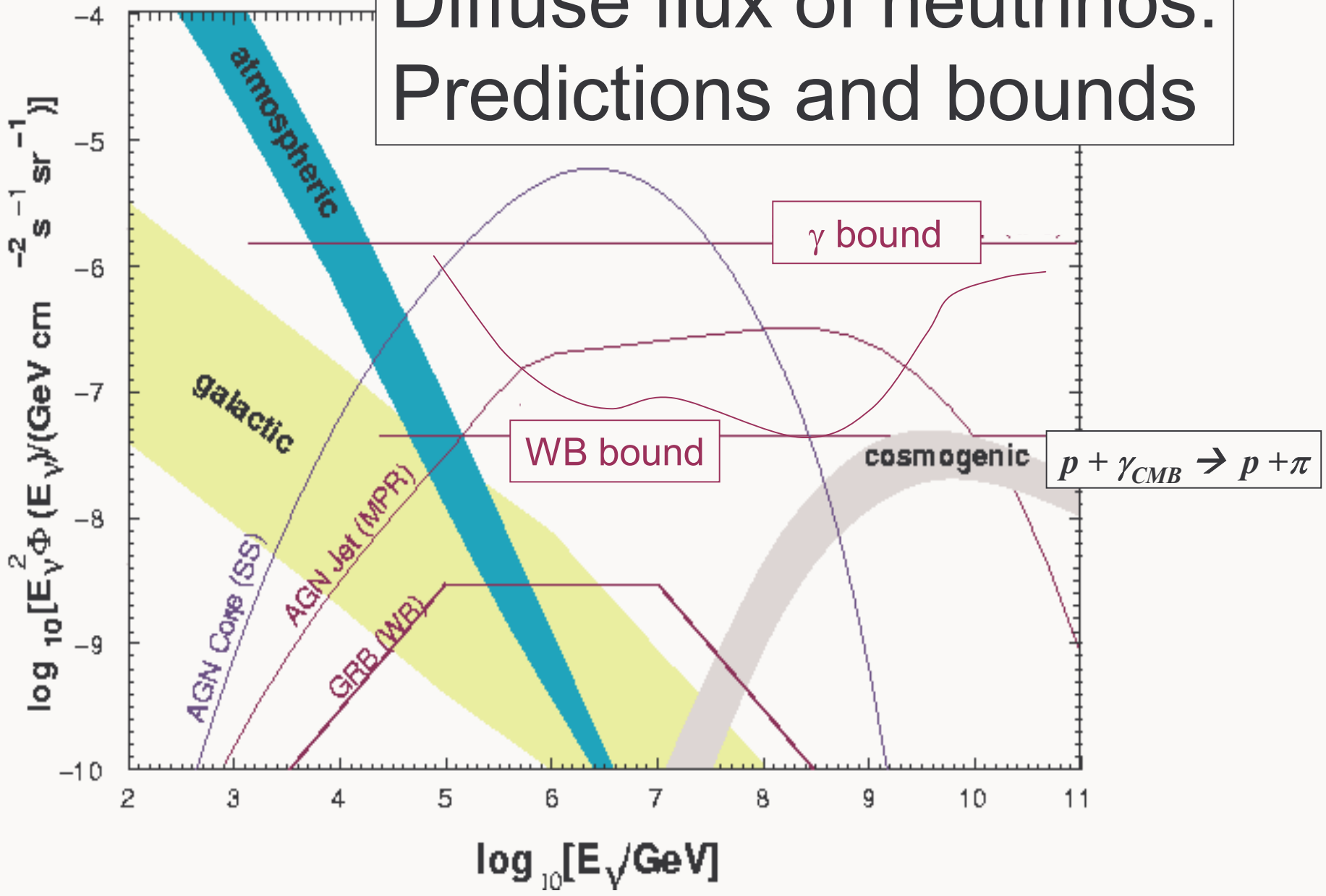

Significance map for 2000-2003
Preliminary
δ / deg
ra / h
Cas A
Mk421
Mk501
Cyg
Crab
M87
SS433
0
10
20
30
40
50
60
70
80
0
5
10
15
20
3
2
1
0
-1
-2


Selected Source Analysis
done, neg. result
still hope (?)
Stacking Source Analysis
Galactic Plane
Transient Sources
Burst Search
Correlation Analysis
Multi-Pole Analysis
Lower energy threshold
(optimize to steeper spectra)

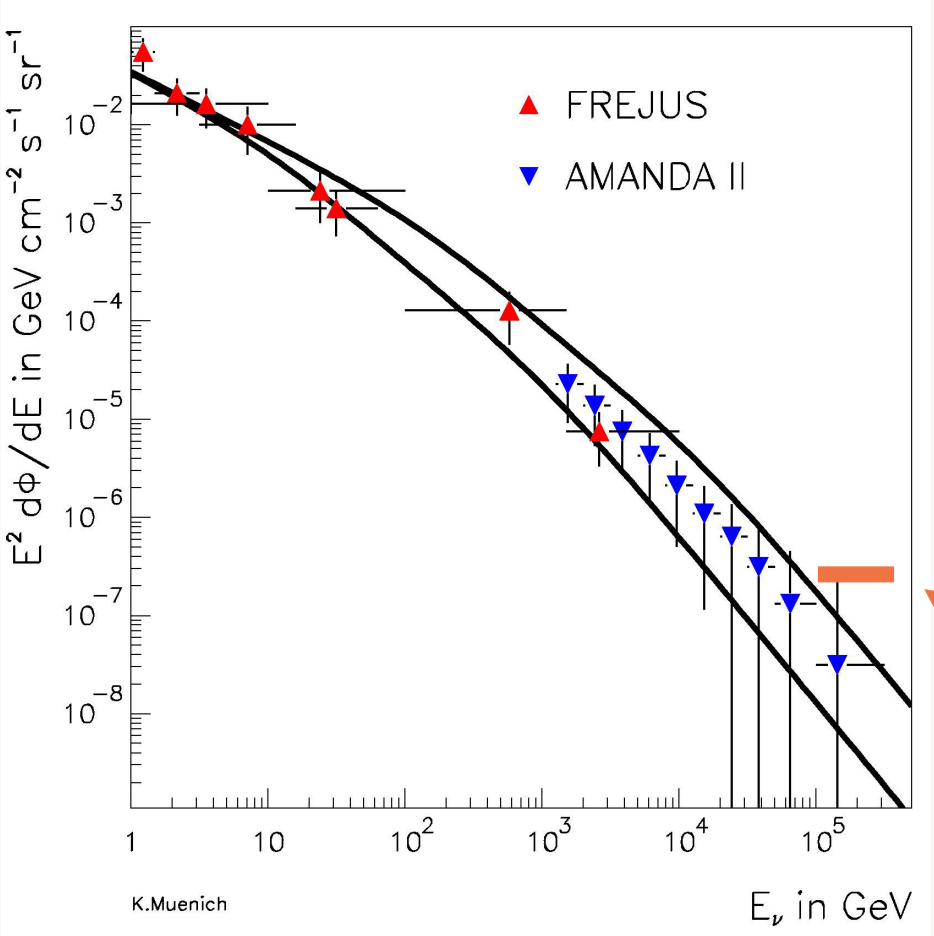

μ · cm-2 s-1
10-14
10-15
southern sky
northern sky
4 years Super-Kamiokande
8 years MACRO
170 days AMANDA-B10
230 days AMANDA-II
SS-433
Mk-501 ν/γ ~ 1
AMANDA-II, 00-03
-90
-45
0
45
90
declination (degrees)

Search for a Diffuse Extraterrestrial Flux

Diffuse flux of neutrinos: Predictions and bounds



Muon neutrinos, energy < 1 PeV



AMANDA-II, 2000 data

How much E^{-2} extraterr. Signal allowed within uncertainty ?

differential limit
100-300 TeV

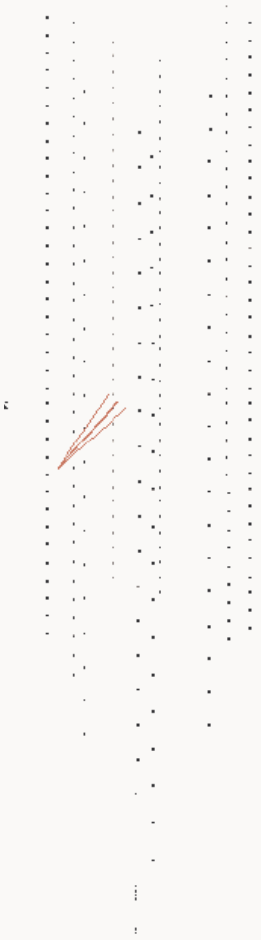
$E^2\, \Phi(\nu_\mu)$
$< 2.9 \cdot 10^{-7}$ GeV^{-1} cm^{-2} s^{-1} sr^{-1}

Cascades inside detector

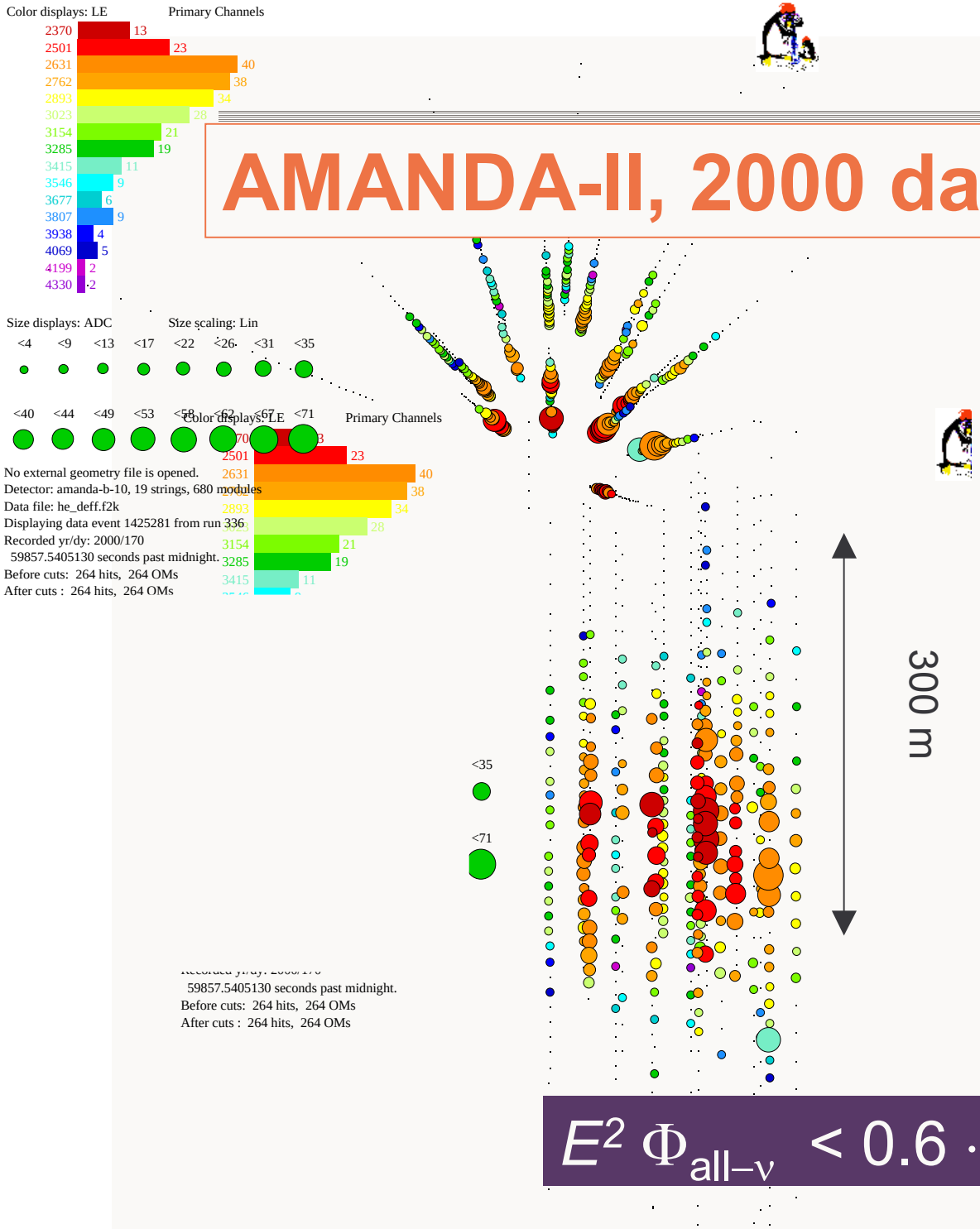
Sensitive to all 3 flavors

- CC electron and tau neutrino interaction:
- $\nu_{(e,\tau,)} + N \rightarrow$ **(e, τ) + X**
- NC neutrino interaction:

  $\nu_x + N \rightarrow \nu_x +$ **X**



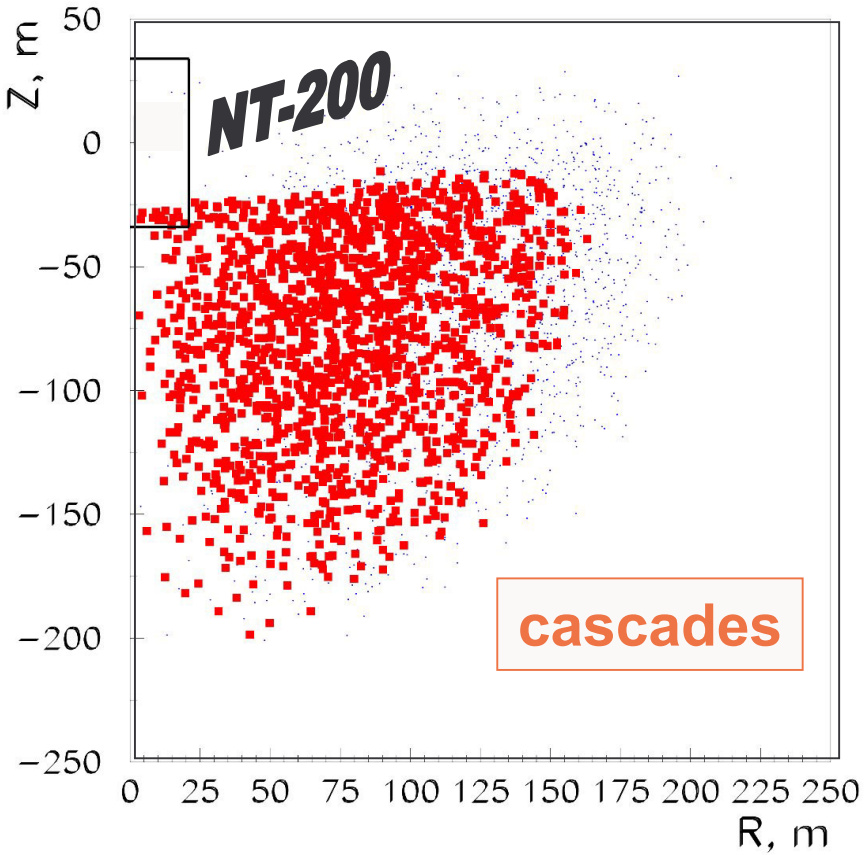
AMANDA-II, 2000 data

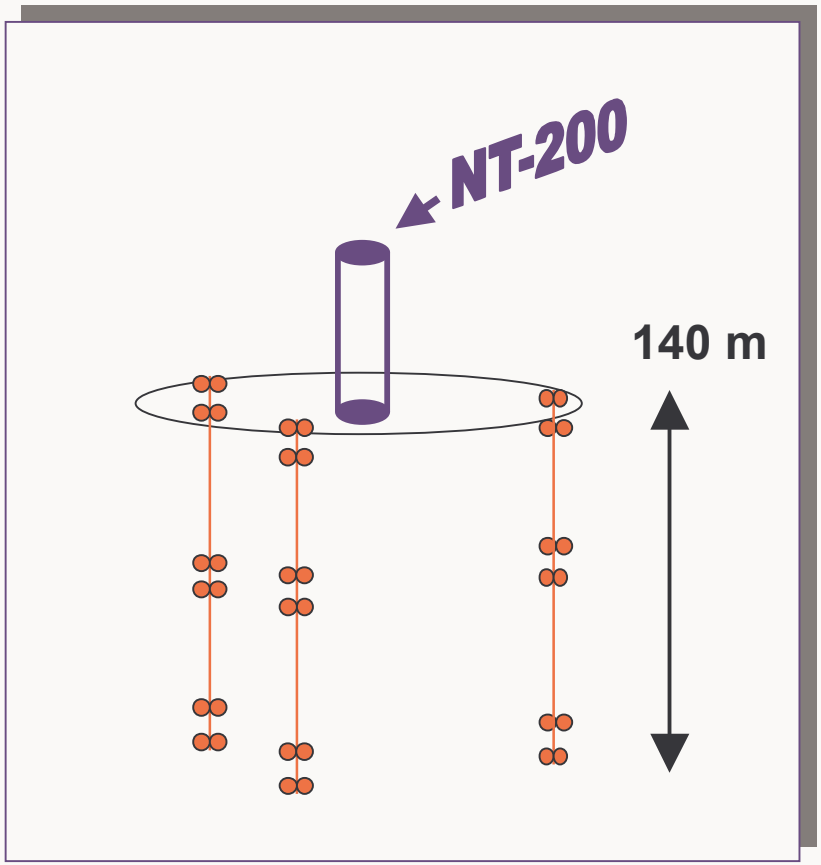


The highest energy cascade-like event (~ 200 TeV)

$$E^2 \Phi_{\text{all}-\nu} < 0.6 \cdot 10^{-6}\ \text{GeV}^{-1}\ \text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}$$

Baikal NT-200



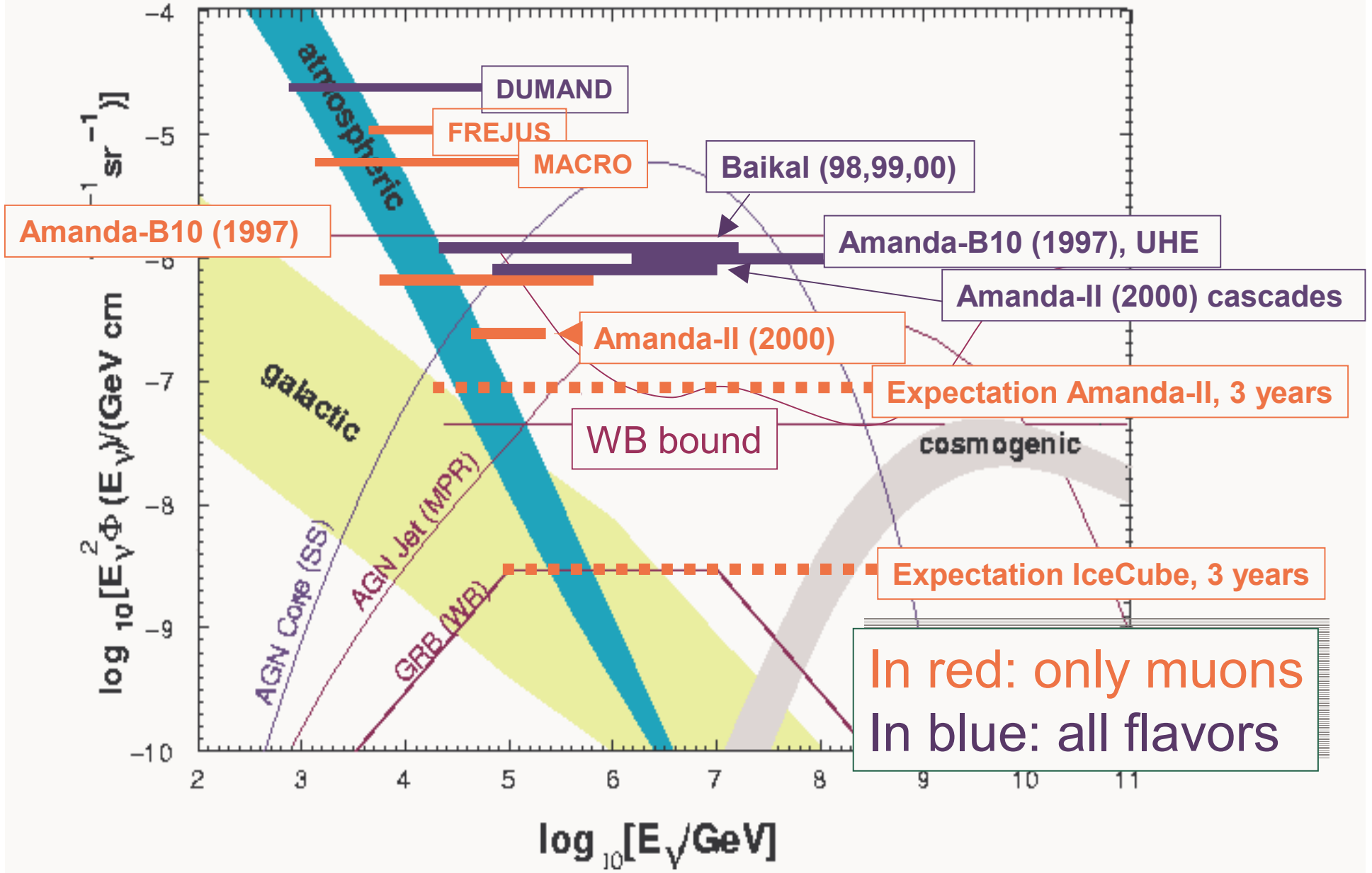


1998/1999/2000

$E^2 \Phi_{all-\nu} < 1.02 \cdot 10^{-6}$ GeV^{-1} cm^{-2} s^{-1} sr^{-1}

36 additional PMTs →
4 times better sensitivity !

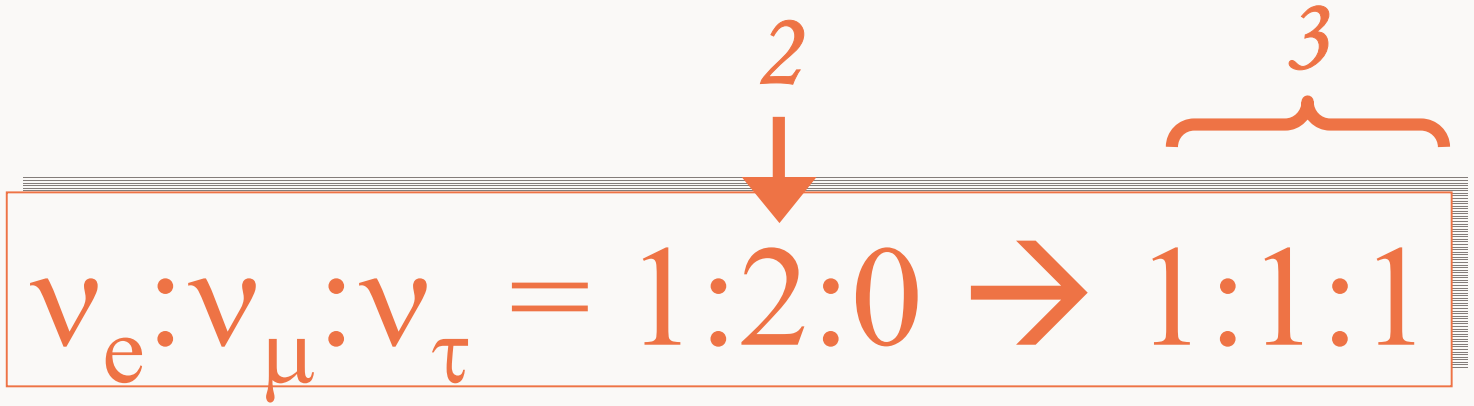
Experimental Limits



Models and bounds are shown for ν_μ , and without taking into account oscillations

$$\nu_e:\nu_\mu:\nu_\tau = 1:2:0$$

Taking into account oscillations ($\nu_e:\nu_\mu:\nu_\tau = 1:1:1$) and refering to **all 3 flavors**, we multiply by factor **1.5**:



On the following slide, exp.limits which have been obtained for ν_μ alone, are multiplied by a **factor 3**.

shown in red

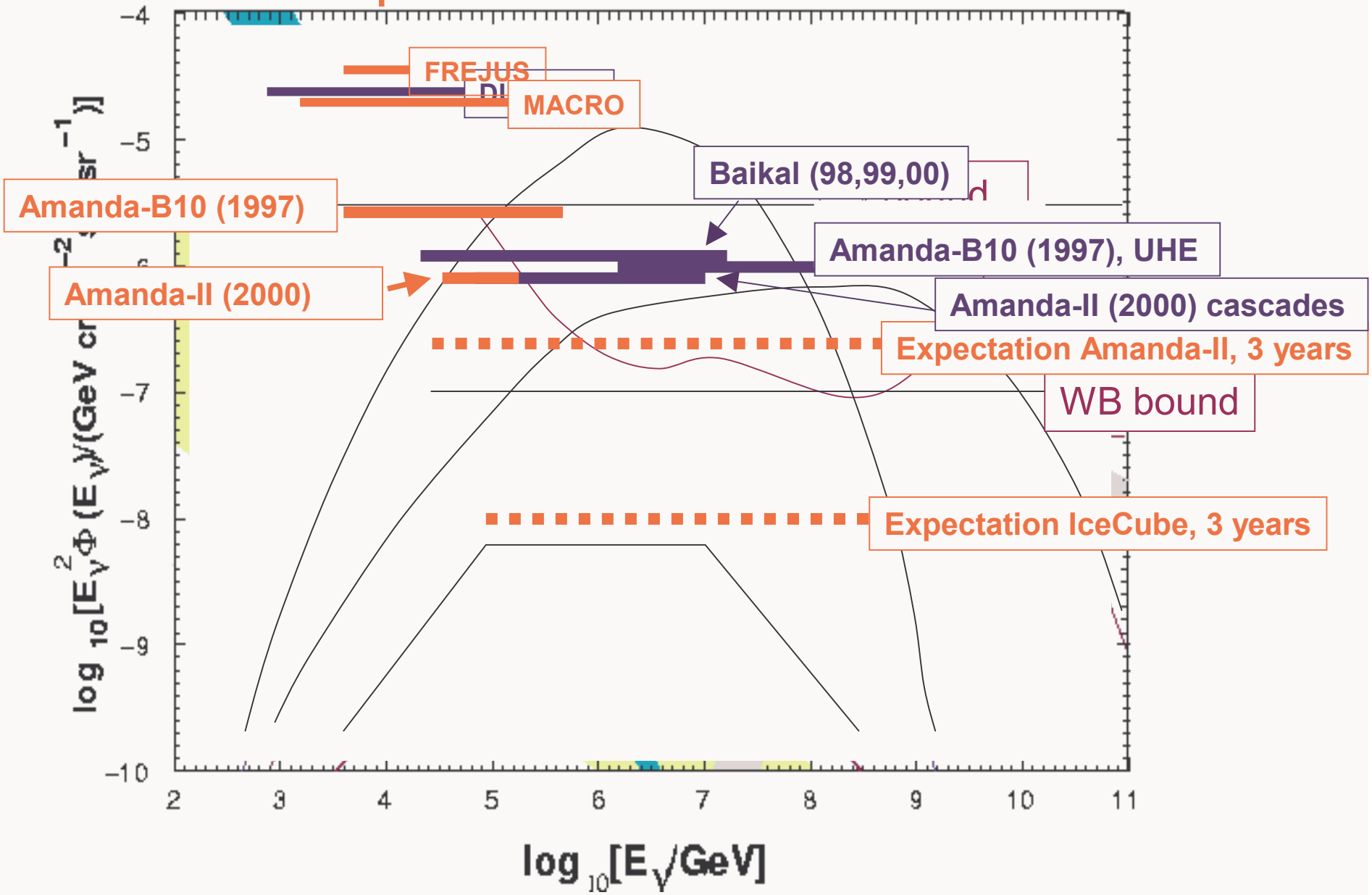
assuming $\Phi_{all} = 1/3 \cdot \Phi_{\nu_e} + 1/3 \cdot \Phi_{\nu_\mu} + 1/3 \cdot \Phi_{\nu_\tau}$

... in contrast to limits, which have been obtained in analyses sensitive to all flavors

shown in blue

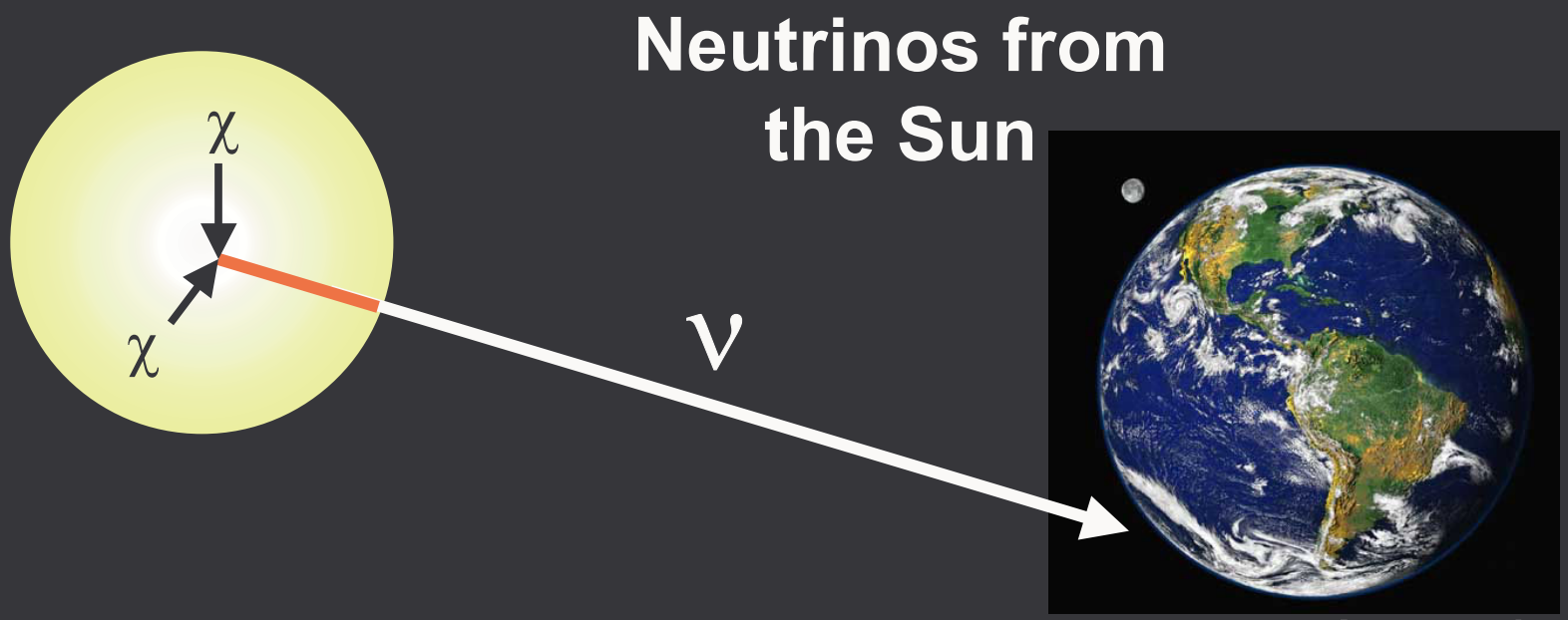
Lines for integral limits extend over the energy range which includes 90% of the events of a hypothetical E^{-2} flux (5% below and 5% above)

Experimental all-flavor limits



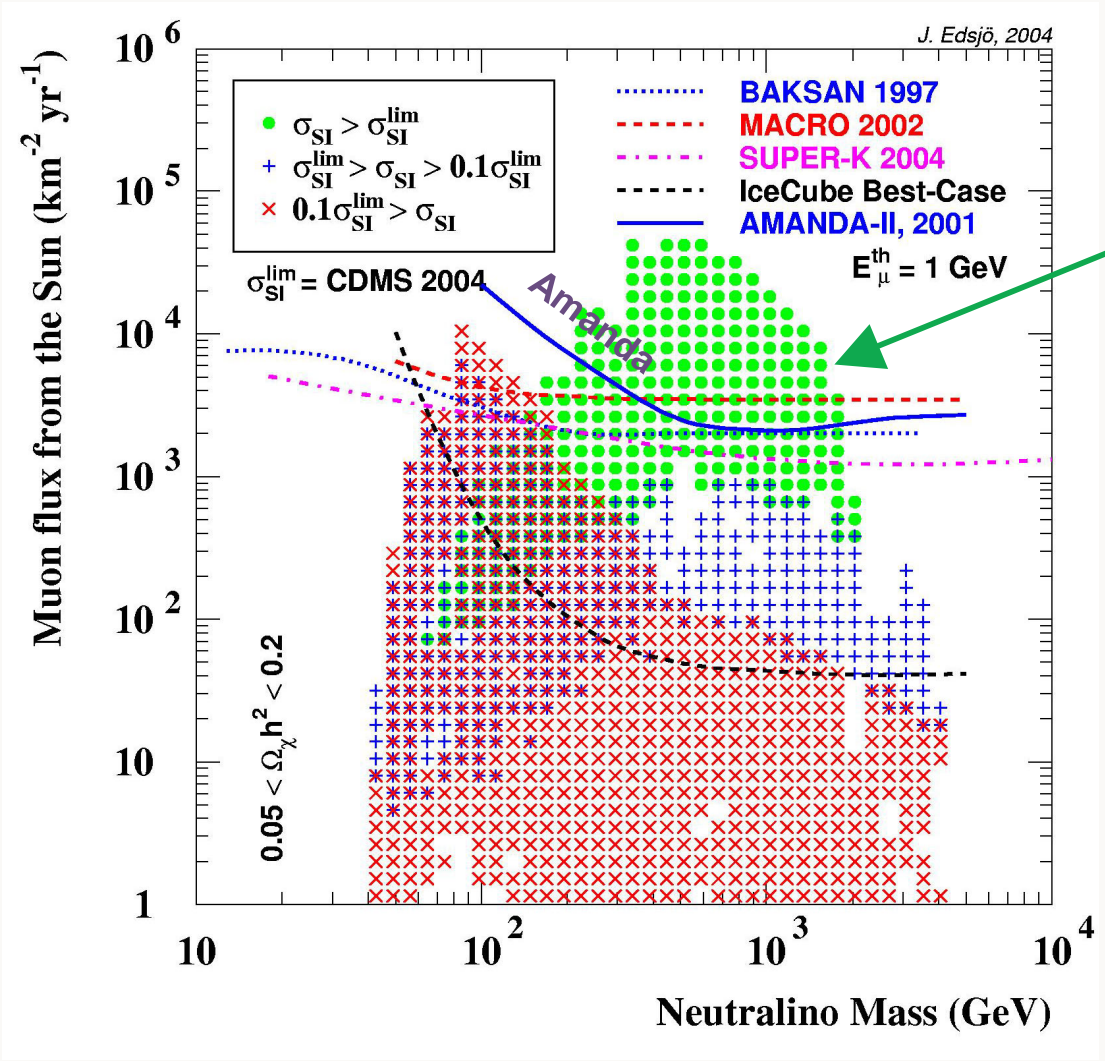
Search for exotic particles

Indirect Search for WIMPs



At South Pole the Sun sinks maximally 23° below horizon. Therefore only Amanda-II with its dramatically improved reconstruction capabilities for horizontial tracks (compared to Amanda-B10) can be used for solar WIMP search.

Present upper limits and expected IceCube sensitivity on muon flux from neutralino annihilations in center of Sun

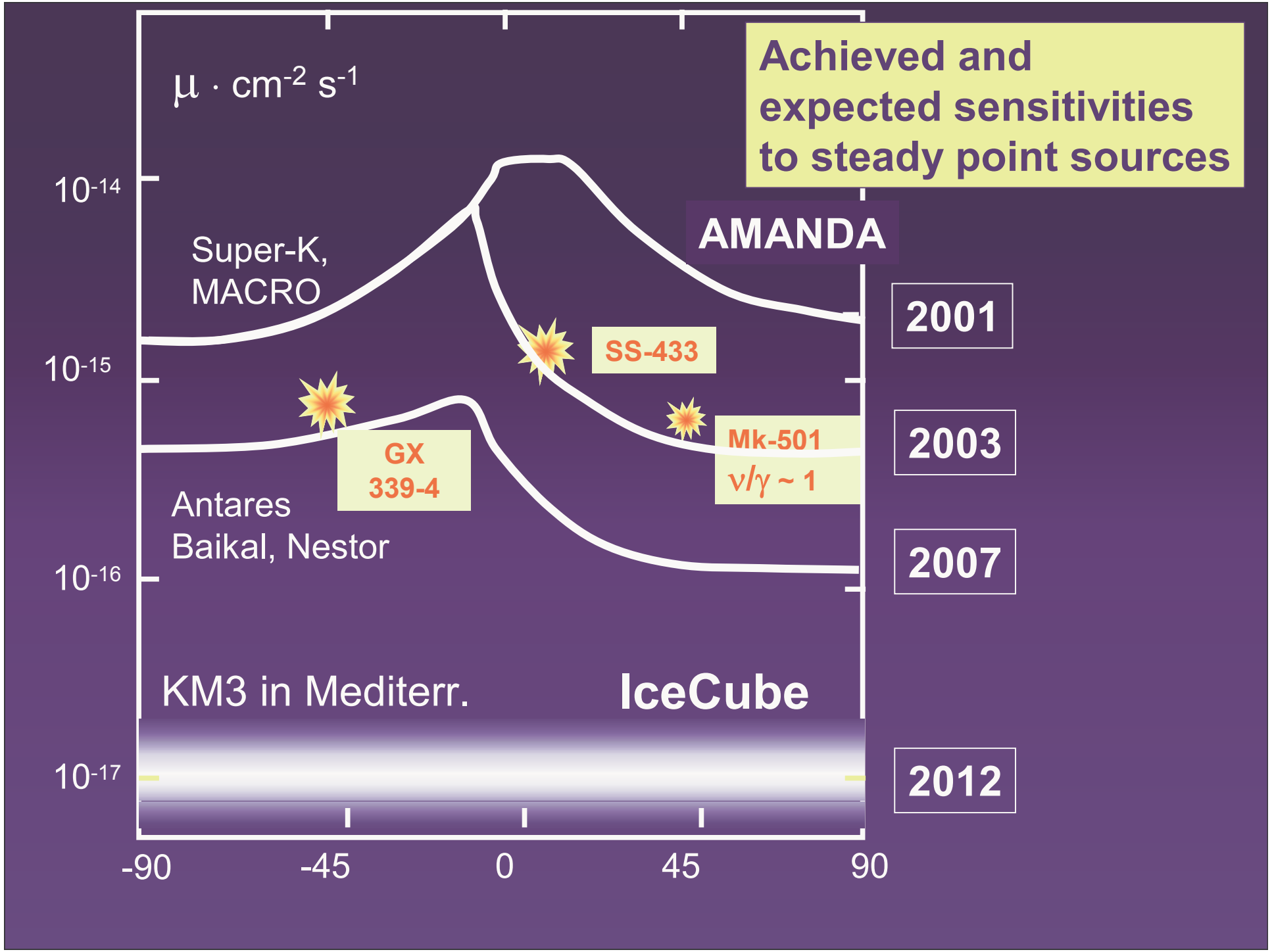


• Disfavoured by direct search (CDMS-II)

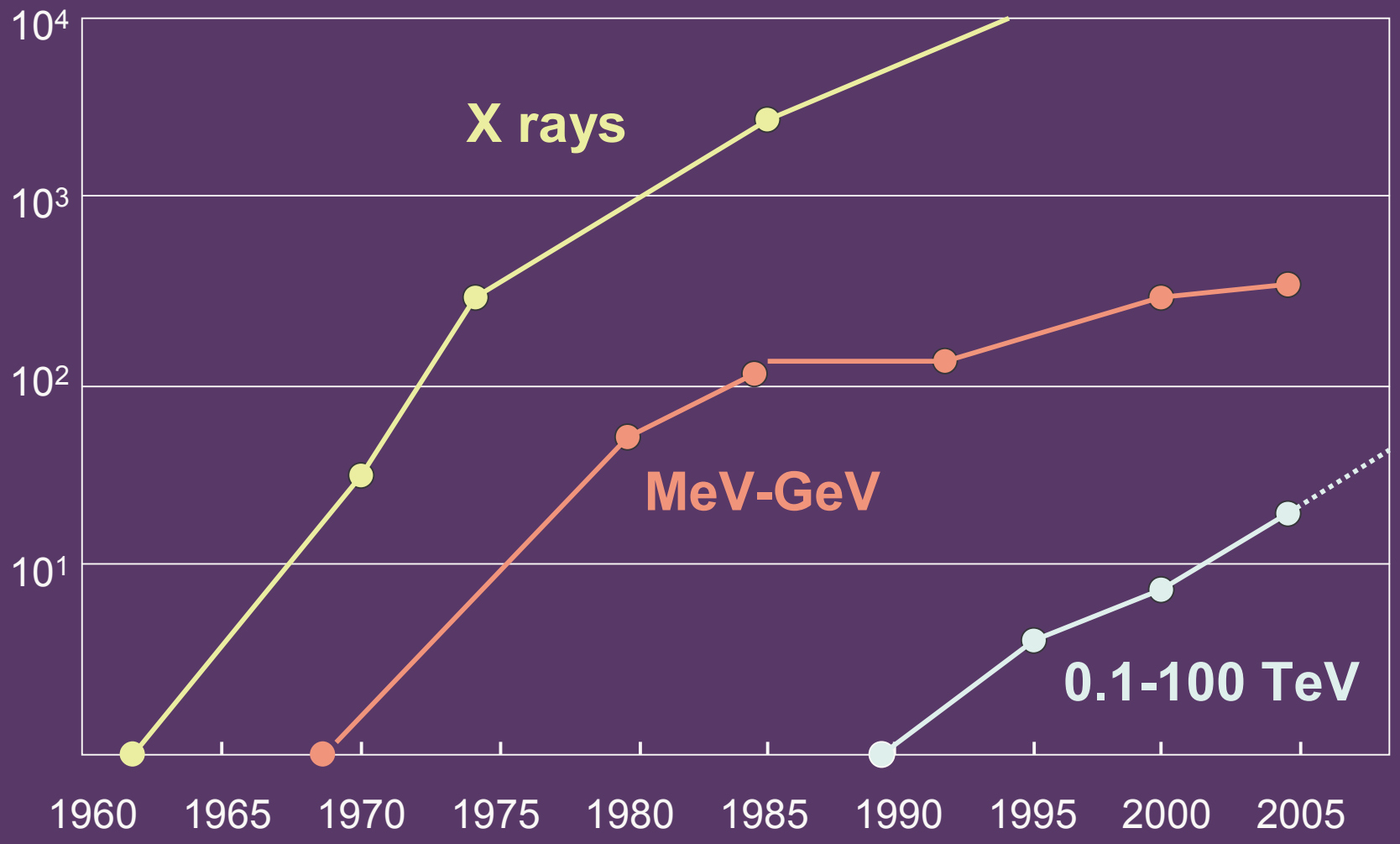
Green dots: Excluded by present direct searches

Blue crosses: can be excluded by 10 times more sensitive direct searches

Perspectives

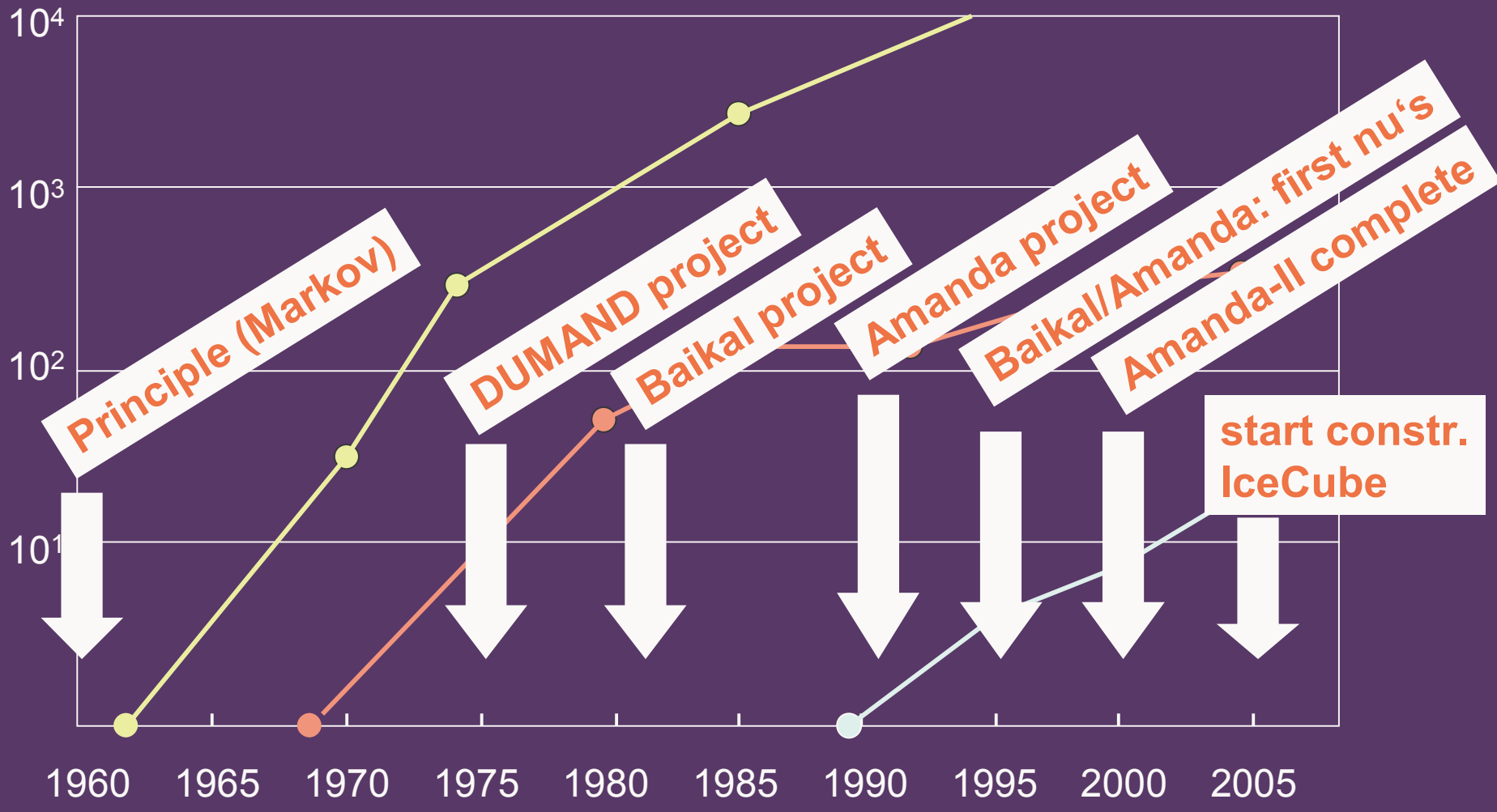

Achieved and
expected sensitivities
to steady point sources
μ · cm-2 s-1
10-14
10-15
10-16
10-17
Super-K,
MACRO
AMANDA
2001
SS-433
Mk-501
ν/γ ~ 1
2003
GX
339-4
Antares
Baikal, Nestor
2007
KM3 in Mediterr.
IceCube
2012
-90
-45
0
45
90

High Energy Photon Sky: Source Count vs. Year



(modified from M. De Naurois, astro-ph/0409361)

High Energy Photon Sky: Source Count vs. Year



(modified from M. De Naurois, astro-ph/0409361)

Achieved and expected sensitivities to diffuse fluxes