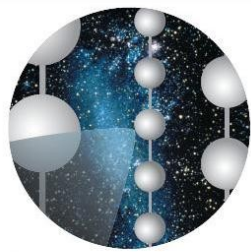




Vrije  
Universiteit  
Brussel



IceCube

# Catching Neutrinos with an IceCube



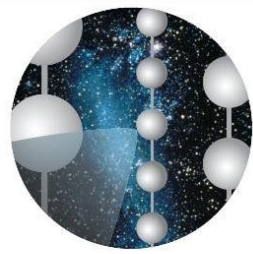
Mathieu Labare (for the IceCube Collaboration)

*Vrije Universiteit Brussel - IIHE*

[mlabare@icecube.wisc.edu](mailto:mlabare@icecube.wisc.edu)



# IceCube Collaboration



IceCube



University of Alberta



University of the West Indies



University of Alabama  
 University of Alaska, Anchorage  
 University of California, Berkeley  
 University of California, Irvine  
 Clark-Atlanta University  
 Bartol Research Institute, U.Delaware  
 Georgia Institute of Technology  
 University of Kansas  
 Lawrence Berkeley Natl. Laboratory  
 University of Maryland  
 Ohio State University  
 Pennsylvania State University  
 Southern University and A&M College  
 University of Wisconsin, Madison  
 University of Wisconsin, River Falls



Stockholms Universitet  
Uppsala Universitet



Oxford University



Vrije Universiteit Brussel  
Université Libre de Bruxelles  
Universiteit Gent  
Université de Mons



Chiba University



RWTH Aachen  
 Ruhr-Universität Bochum  
 Universität Bonn  
 DESY, Zeuthen  
 Universität Dortmund  
 MPIfK Heidelberg  
 Humboldt Universität, Berlin  
 Universität Mainz  
 BUGH Wuppertal



University of Canterbury

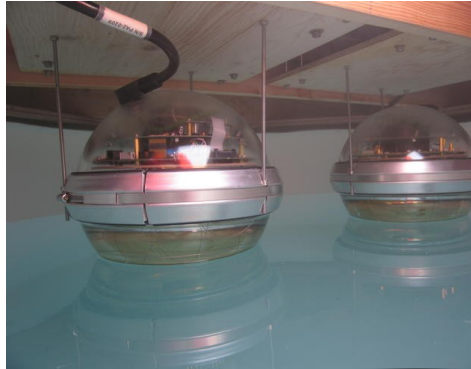


EPF Lausanne

**36 institutions**  
**~250 members**

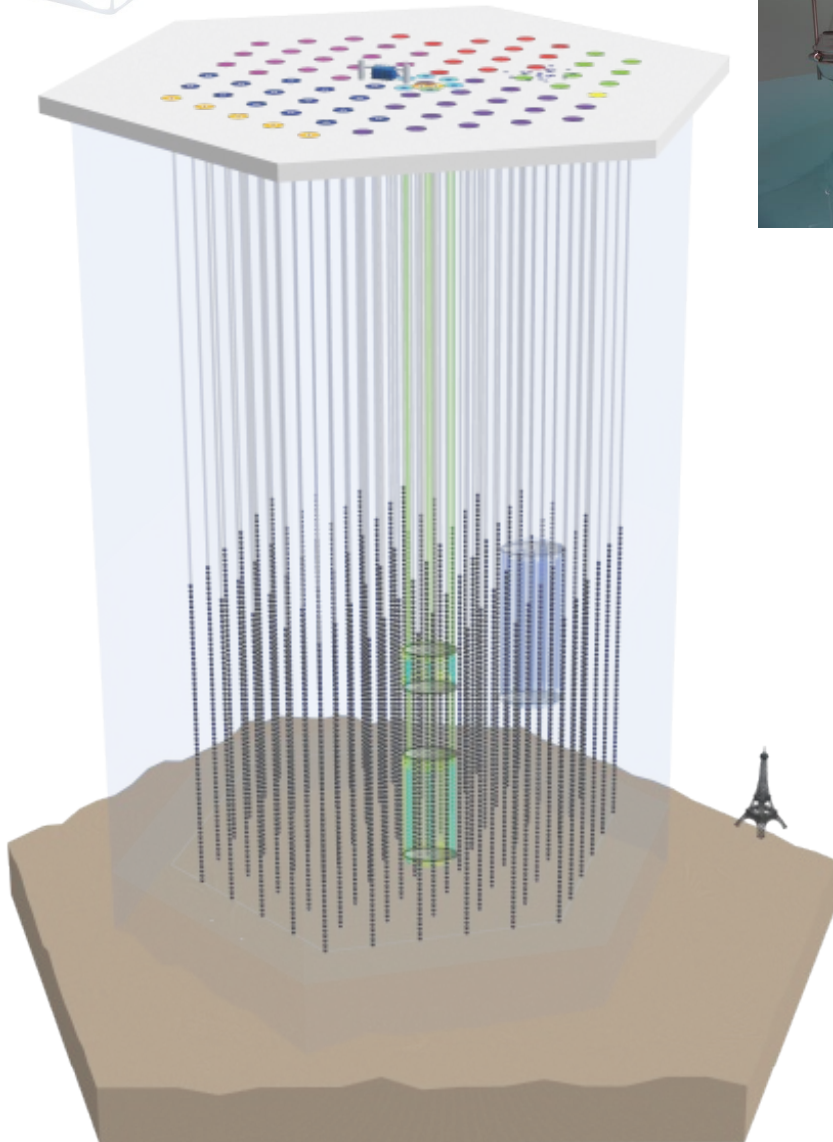


# IceCube Neutrino Observatory



## IceTop

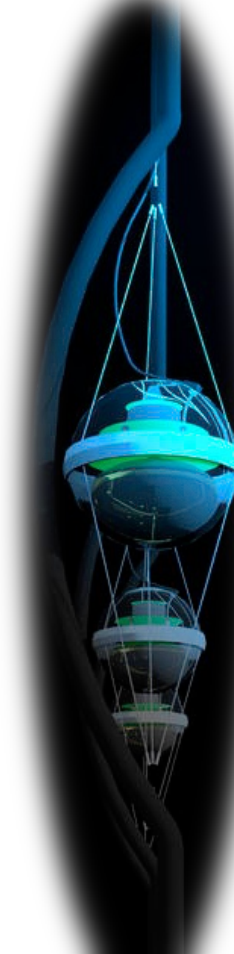
81 stations composed of 2 Cherenkov tanks with 2 DOMs sensors per tank.



## IceCube

86 strings of DOMs

Completed December 14<sup>th</sup> 2010 !



## AMANDA

Shutdown in March 2009

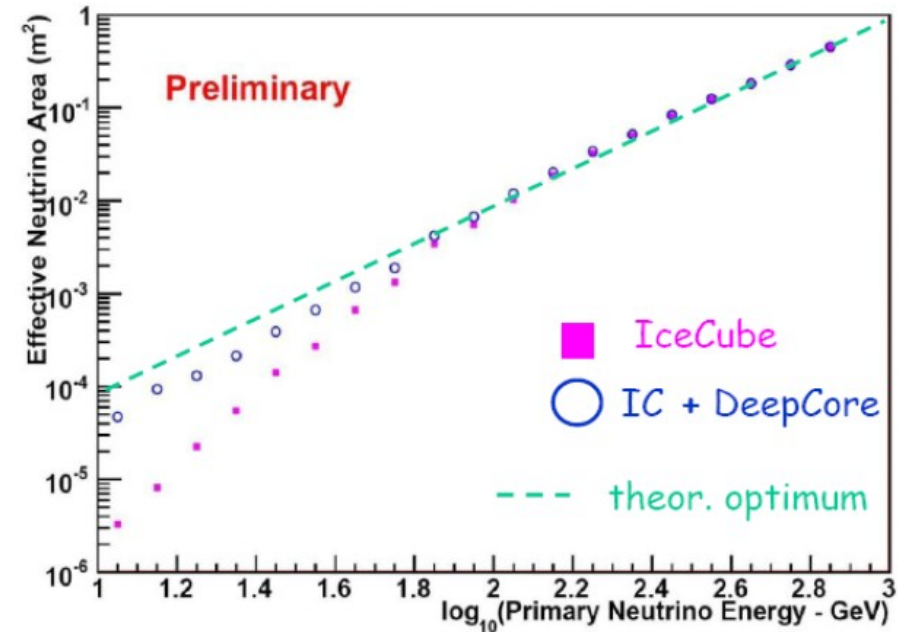
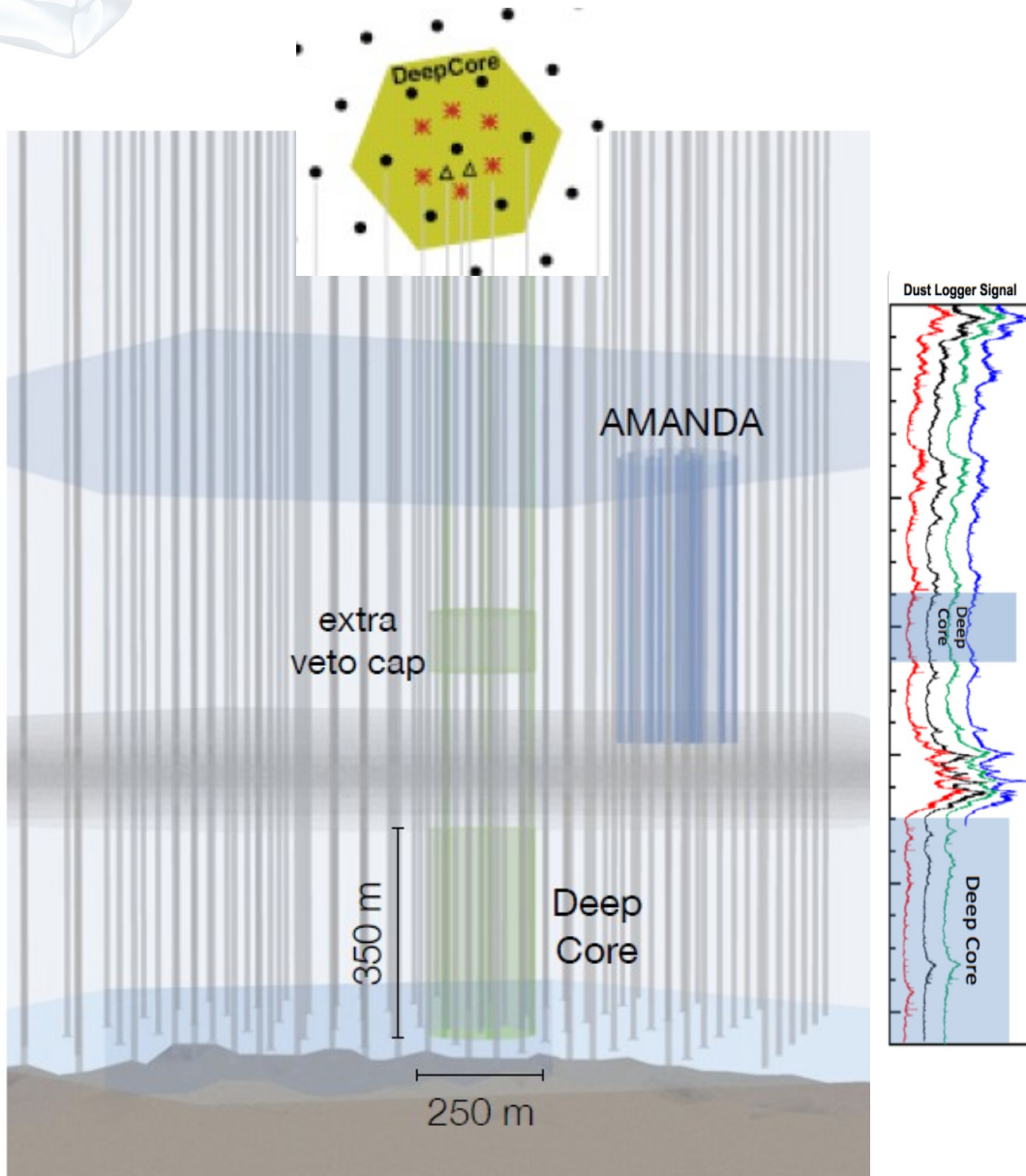
## DeepCore

8 strings of HQ-DOMs  
Low-Energy extension



# IceCube Neutrino Observatory

## The DeepCore extension



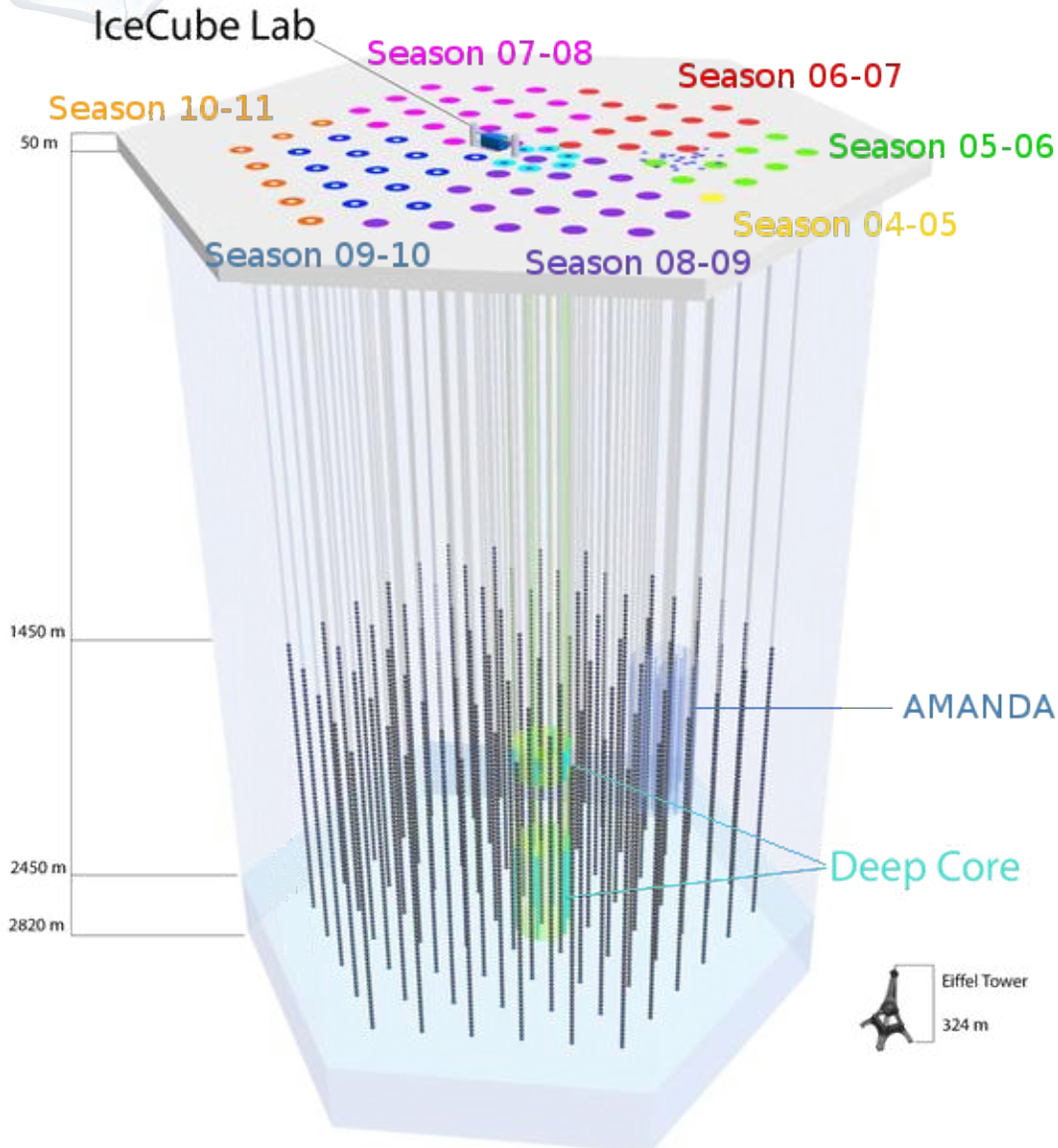
**DeepCore**  
8 strings of HQ-DOMs  
Low-Energy extension  
Completed in February 2010.





# IceCube Neutrino Observatory

## Successive configurations



### Season 04-05

First IceCube string deployed

### Season 05-06 : IC-9

### Season 06-07 : IC-22

- ▶ Cosmic Ray anisotropy
- ▶ Diffuse fluxes
- ▶ GRB observations

### Season 07-08 : IC-40

- ▶ Moon Shadow
- ▶ Point Source search
- ▶ Diffuses fluxes (Prel.)
- ▶ GRB observations

### Season 08-09 : IC-59

- ▶ GRB observations (Prel.)

### Season 09-10 : IC-79

### Season 10-11 : IC-86

IceCube is completed !



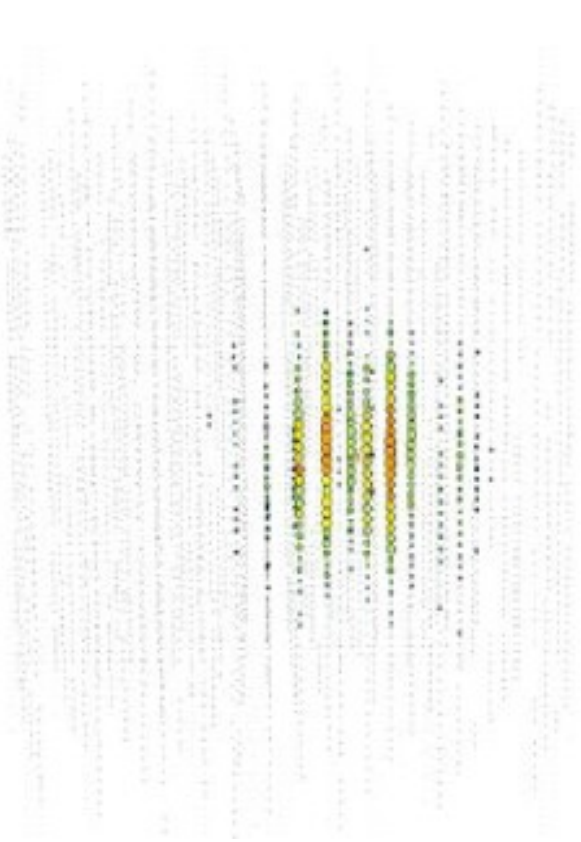
# Signal in IceCube

**Cherenkov radiation detected by optical sensors**

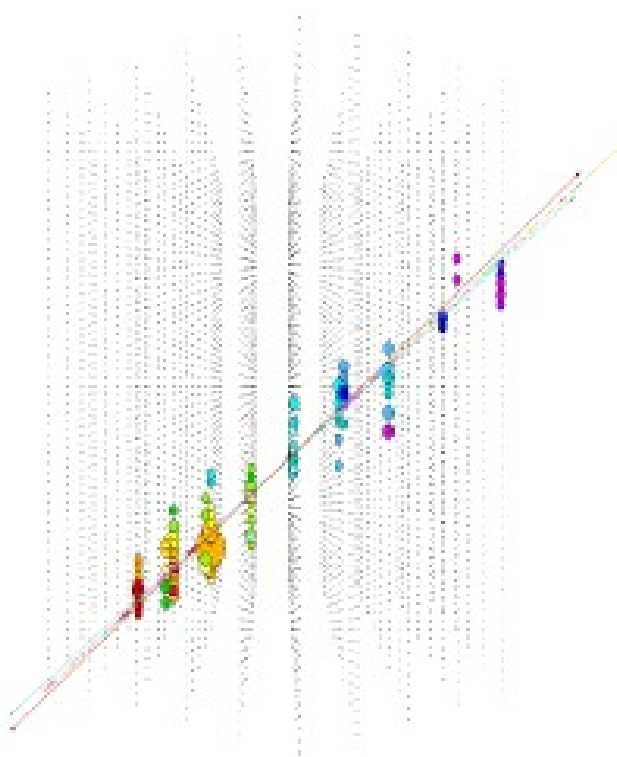
Information : Time – Intensity – Position

- ▶ Energy and/or direction reconstruction

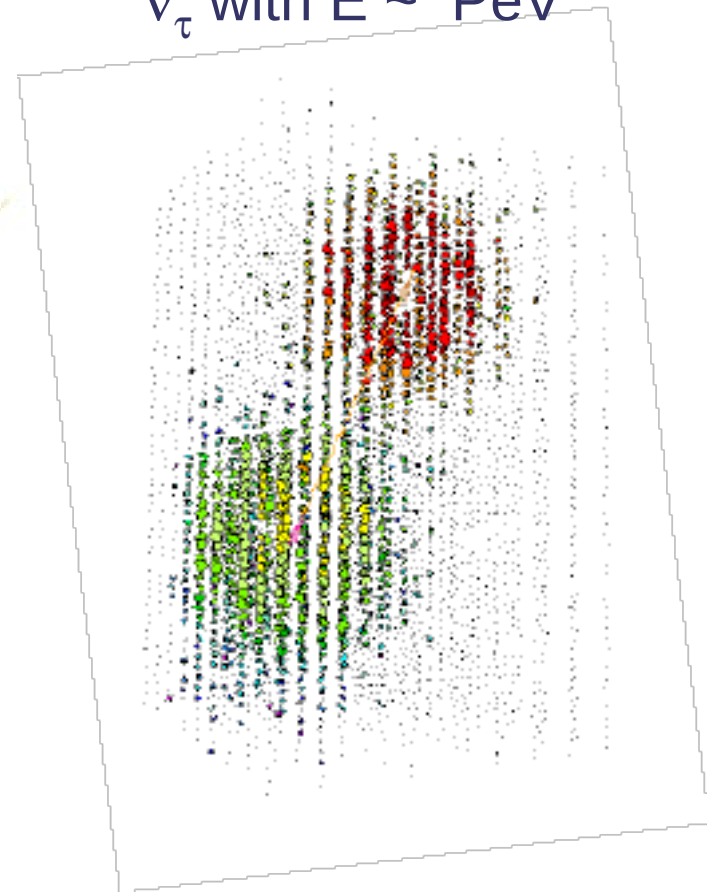
$\nu_e$  with  $E = 375$  TeV



$\nu_\mu$  with  $E = 6$  TeV



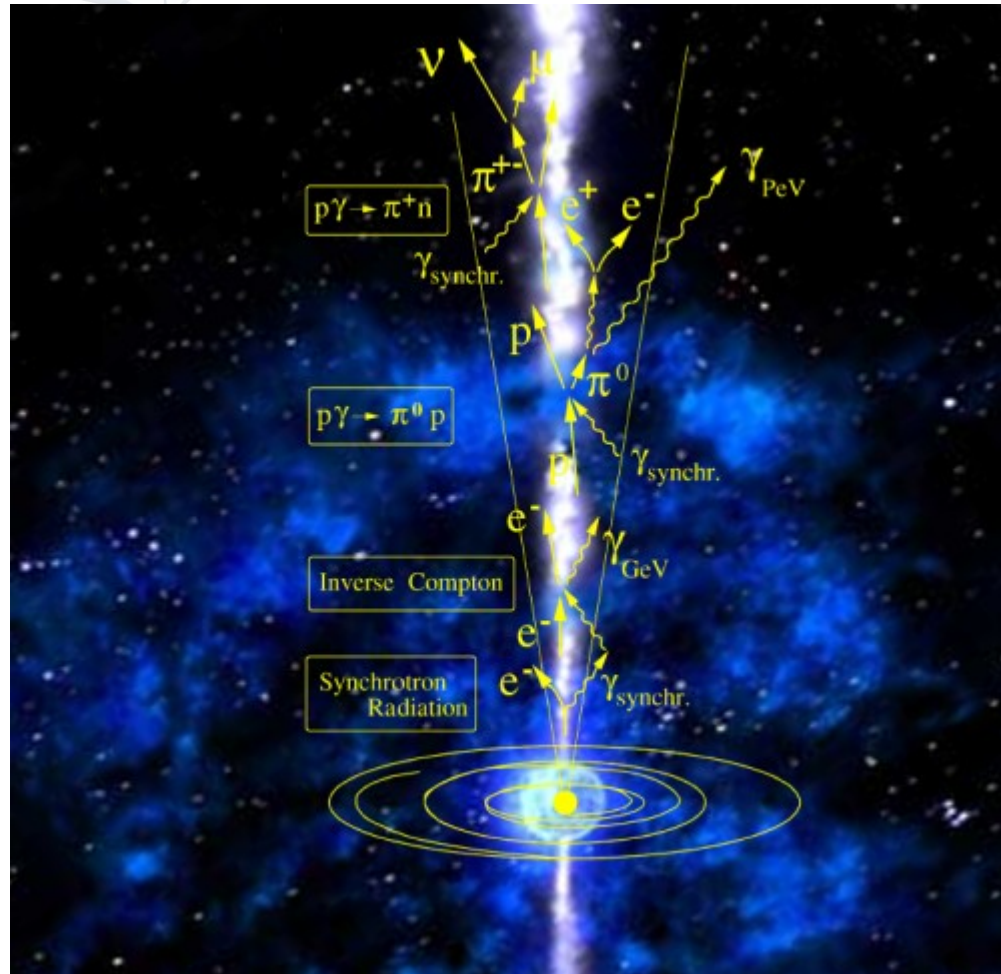
$\nu_\tau$  with  $E \sim$  PeV





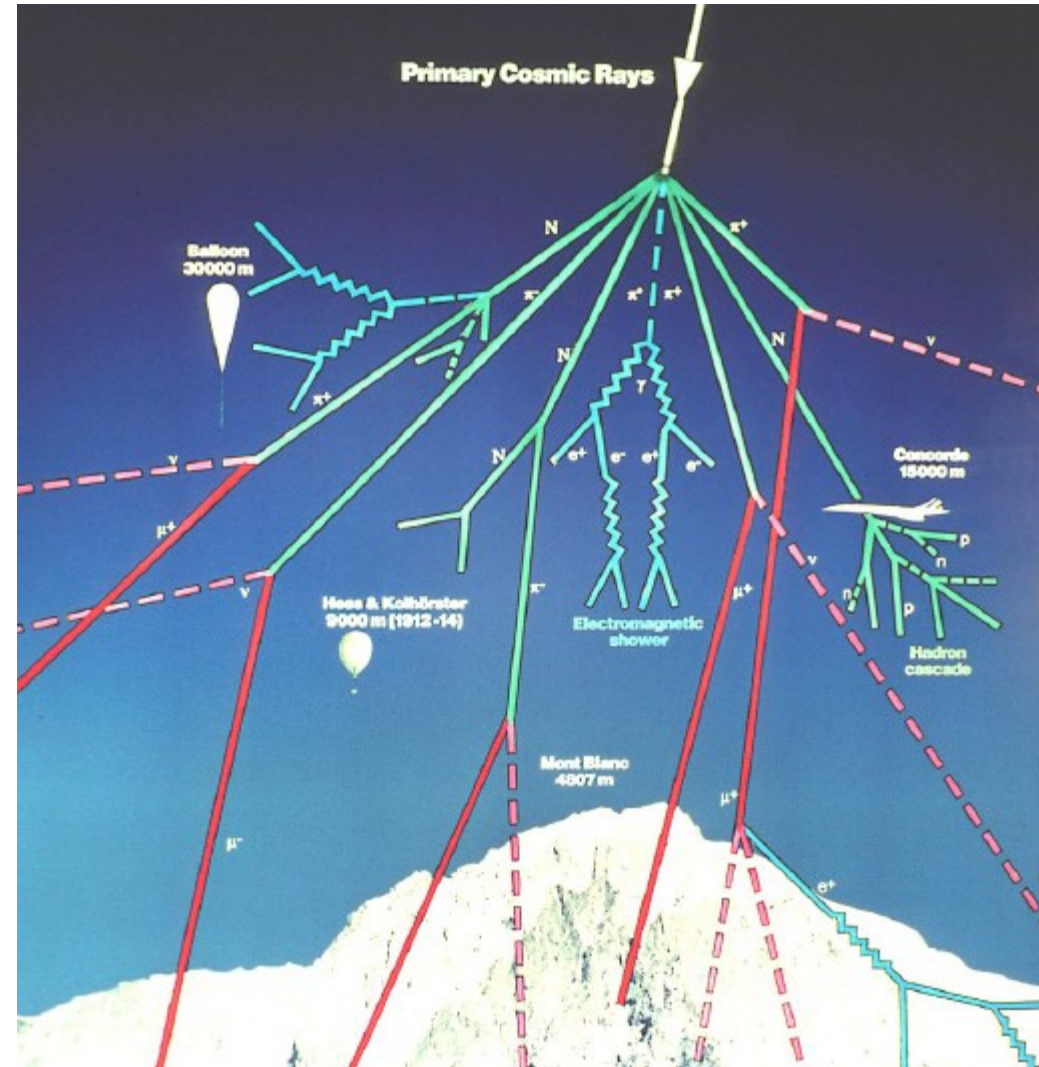
# Signal in IceCube

Cosmic



$$\sim E^{-2}$$

Atmospheric



$$\sim E^{-3.7}$$





# IC-40 The Moon Shadow

## Verification of the IceCube pointing accuracy

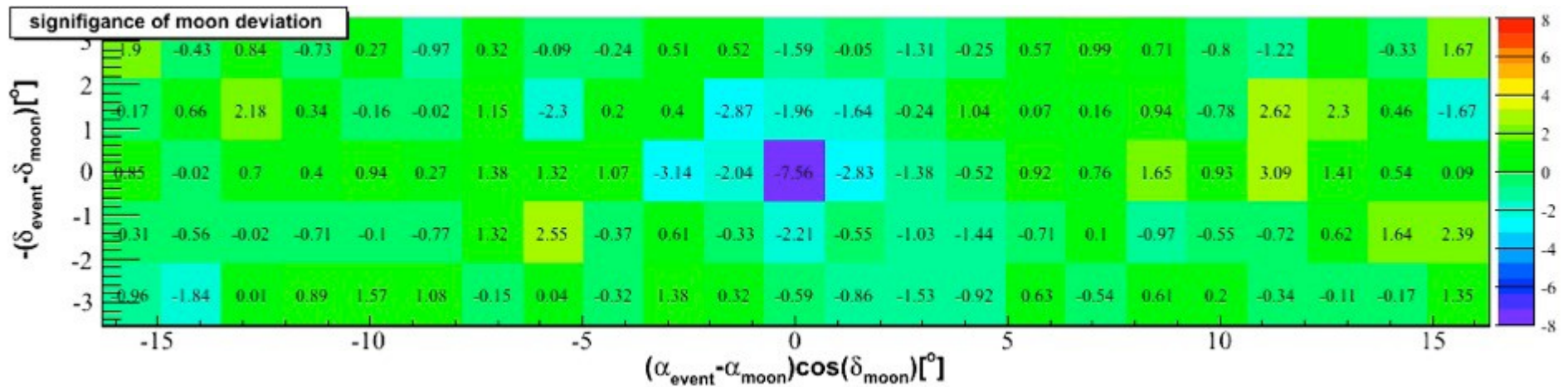
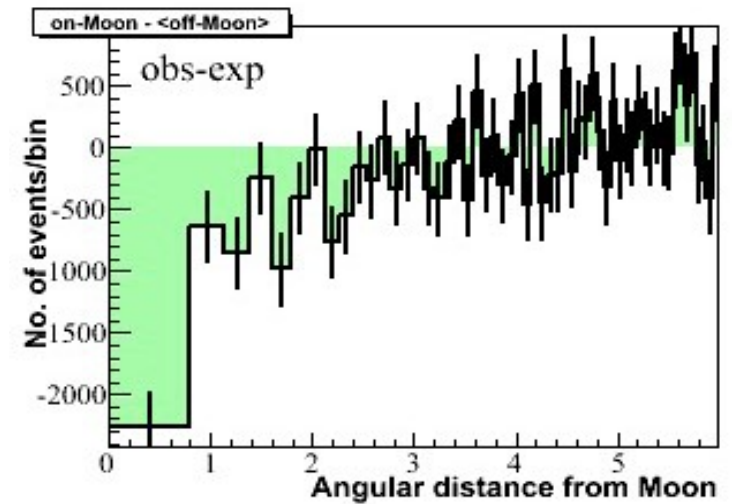
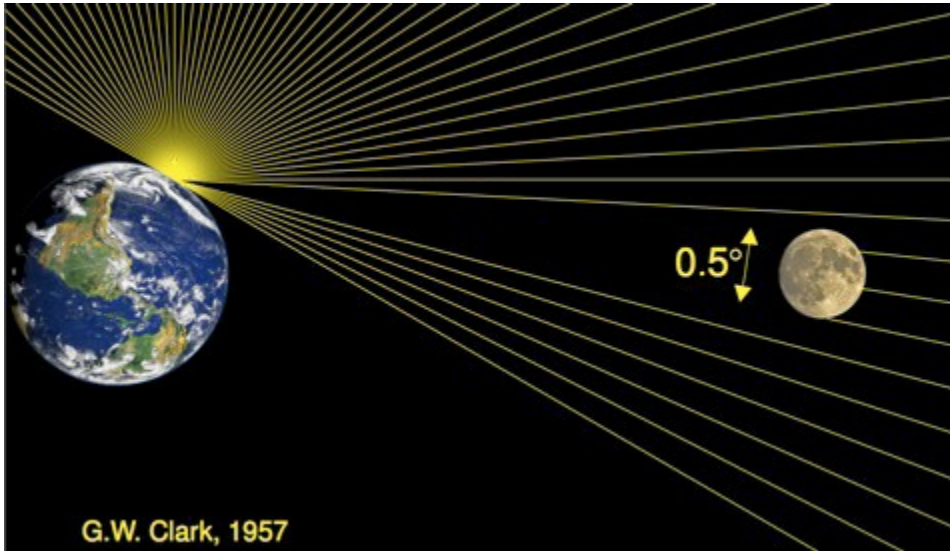
observed:  $7.173 \times 10^4$  events

expected:  $7.4 \times 10^4$  events

deficit: -2262 events

error: 285 events

significance:  $-7.9\sigma$







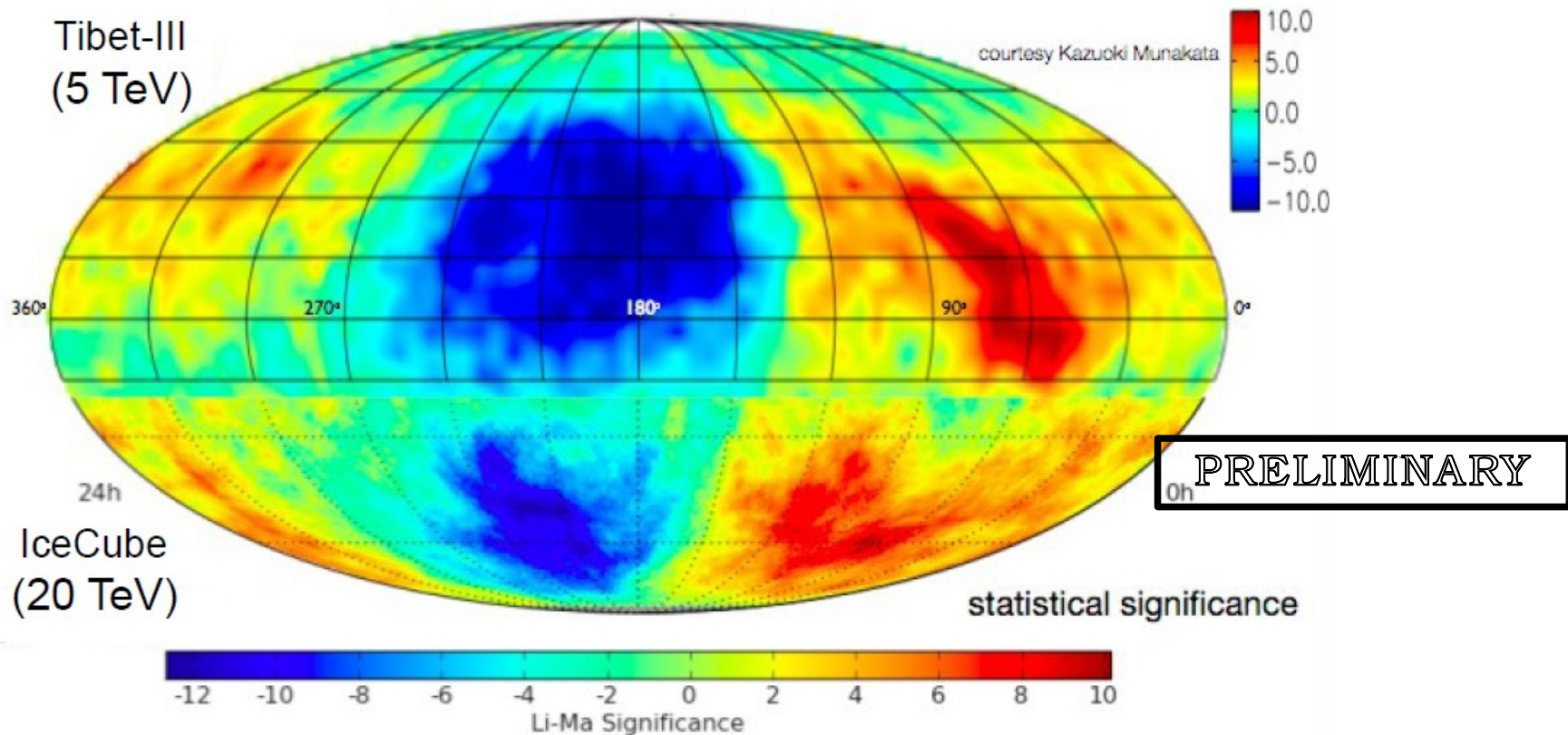
# IC-22 Cosmic Ray Anisotropy

*ApJ Letters*, 718 (2010) L194

June, 2007 - March, 2008  
4.3  $10^9$  atm.  $\mu$        $\langle E \rangle = 14$  TeV

## Very first measurement for Southern Hemisphere

- ▶ Anisotropy up to 100 TeV
- ▶ Energy dependence







# IC-40 All sky Point Source Search

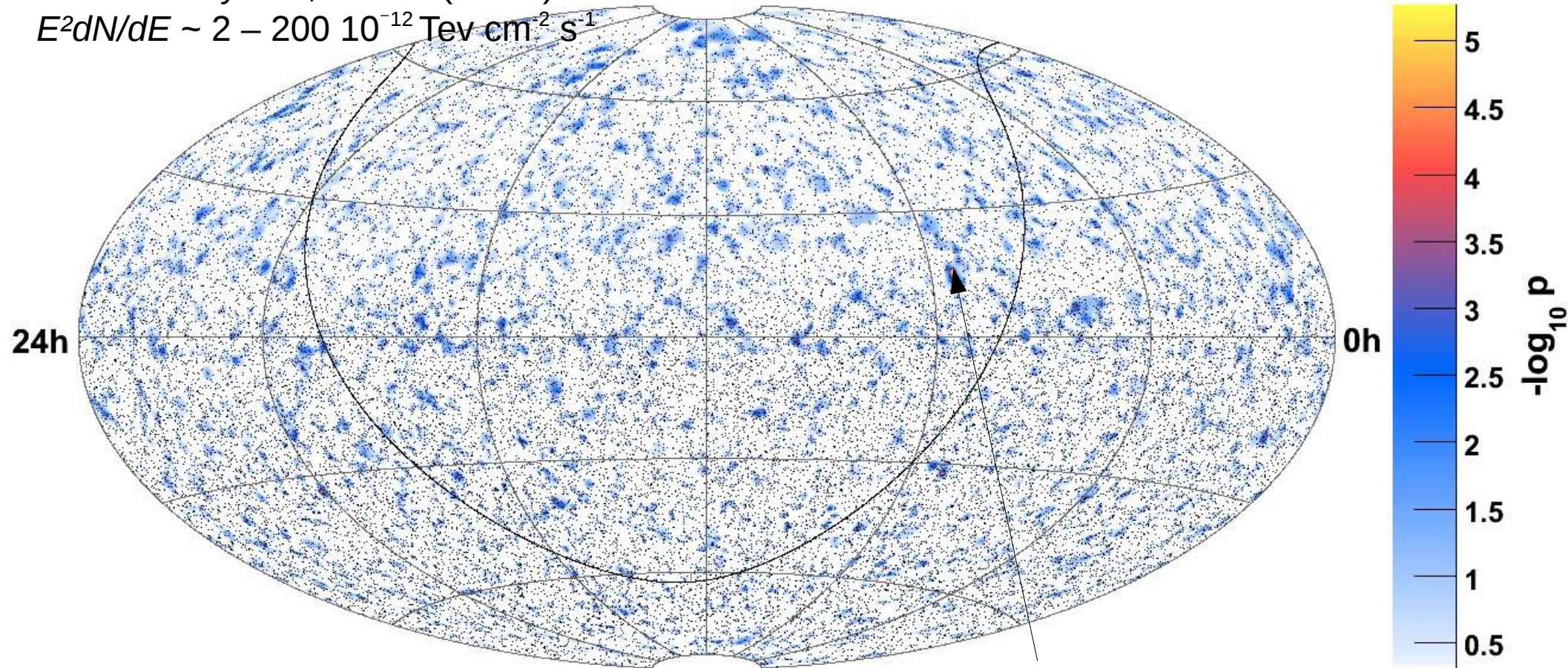
ArXiv:1012.2137 (To be published in ApJ.)

375.5 days livetime

$3 \cdot 10^{10}$  ev. → 36,900 events

Northern sky : 14,121 ev. (atm- $\nu$ )

$E^2 dN/dE \sim 2 - 200 \cdot 10^{-12} \text{ Tev cm}^{-2} \text{ s}^{-1}$



Southern sky : 22,779 ev. (atm  $\mu$ )

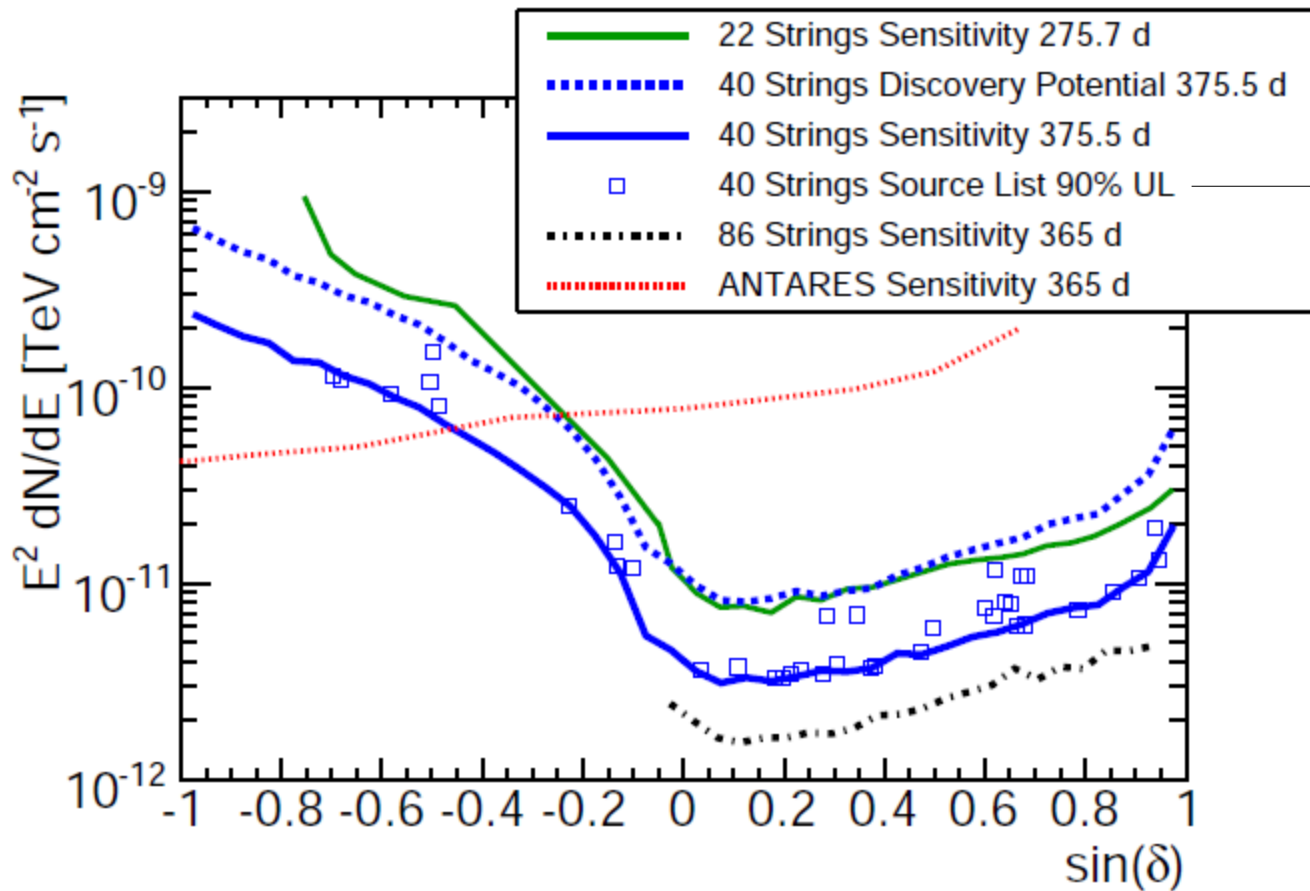
$E^2 dN/dE \sim 3 - 700 \cdot 10^{-12} \text{ Tev cm}^{-2} \text{ s}^{-1}$

113.75°ra , 15.15°dec  
Post-trial proba : 18%



# IC-40 All sky Point Source Search

ArXiv:1012.2137 (To be published in ApJ.)



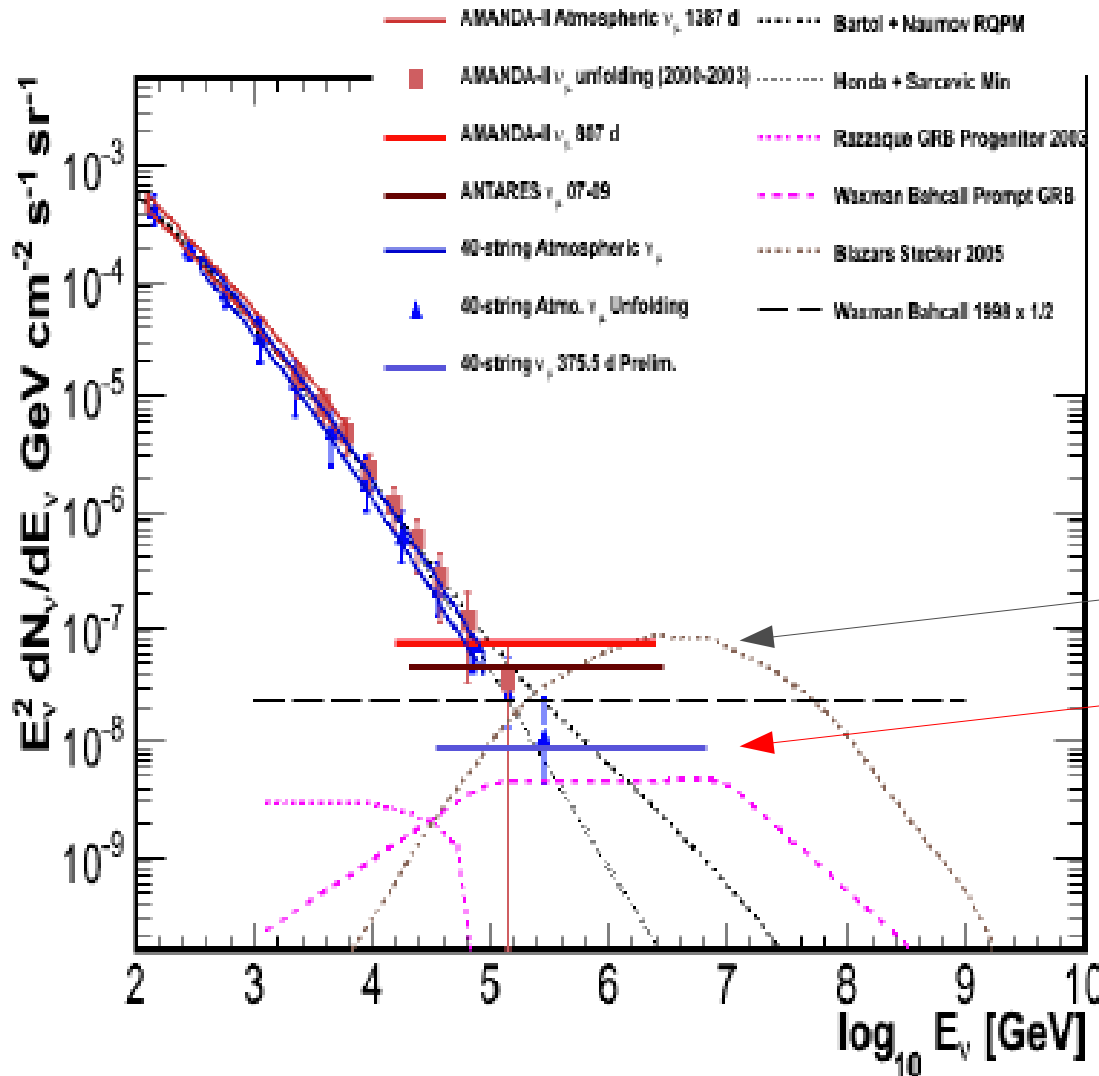
	$\Phi_{\nu_\mu}^{90}$	$\Phi_{\nu_\mu+\nu_\tau}^{90}$	p-value
Cyg OB2	6.04	10.54	–
MGRO J2019+37	7.50	13.3	0.44
MGRO J1908+06	3.73	6.82	0.43
Cas A	9.04	15.92	–
IC443	3.80	6.62	–
Geminga	3.91	6.66	0.48
Crab Nebula	3.70	6.58	–
1ES 1959+650	10.74	19.18	–
1ES 2344+514	7.24	12.96	–
3C66A	10.89	19.70	0.24
H 1426+428	6.14	10.94	–
BL Lac	10.80	18.70	0.25
Mrk 501	8.11	14.14	0.41
Mrk 421	11.71	20.14	0.15
W Comae	4.46	8.06	–
1ES 0229+200	6.89	12.06	0.19
M87	3.42	5.98	–
S5 0716+71	13.28	23.56	–
M82	19.14	32.84	0.4
3C 123.0	5.59	10.66	0.44
3C 454.3	3.42	5.92	–
4C 38.41	6.77	11.86	0.48
PKS 0235+164	6.77	11.62	0.15
PKS 0528+134	3.63	6.72	–
PKS 1502+106	3.26	5.78	–
3C 273	3.61	6.54	–
NGC 1275	6.04	10.54	–
Cyg A	7.84	13.44	0.46
IC-22 maximum	3.26	5.86	–
Sgr A*	80.56	139.26	0.41
PKS 0537-441	113.90	201.82	–
Cen A	109.51	191.56	–
PKS 1454-354	92.56	156.74	–
PKS 2155-304	105.41	182.90	0.28
PKS 1622-297	152.28	263.86	0.048
QSO 1730-130	24.83	43.30	–
PKS 1406-076	16.04	28.72	0.42
QSO 2022-077	12.18	21.78	–
3C279	11.94	21.36	0.33





# IC-40 Astroph. $\nu$ diffuse fluxe (TeV-PeV)

IC-40 : 375.5 days livetime



## Atmosph. $\nu$

- ▶ unfolding method  
*ArXiv : 1010.3980*
- ▶ forward method  
*ArXiv : 1005.4962*

AGN model excluded @  $5 \sigma$

**IC-40 : under the WB limit !**

- ▶ constraints on n prod. models in AGNs  
*ArXiv : 1008.1396*



# IC-22 (IC-40) Astroph. $\nu$ diffuse fluxe (PeV-EeV)

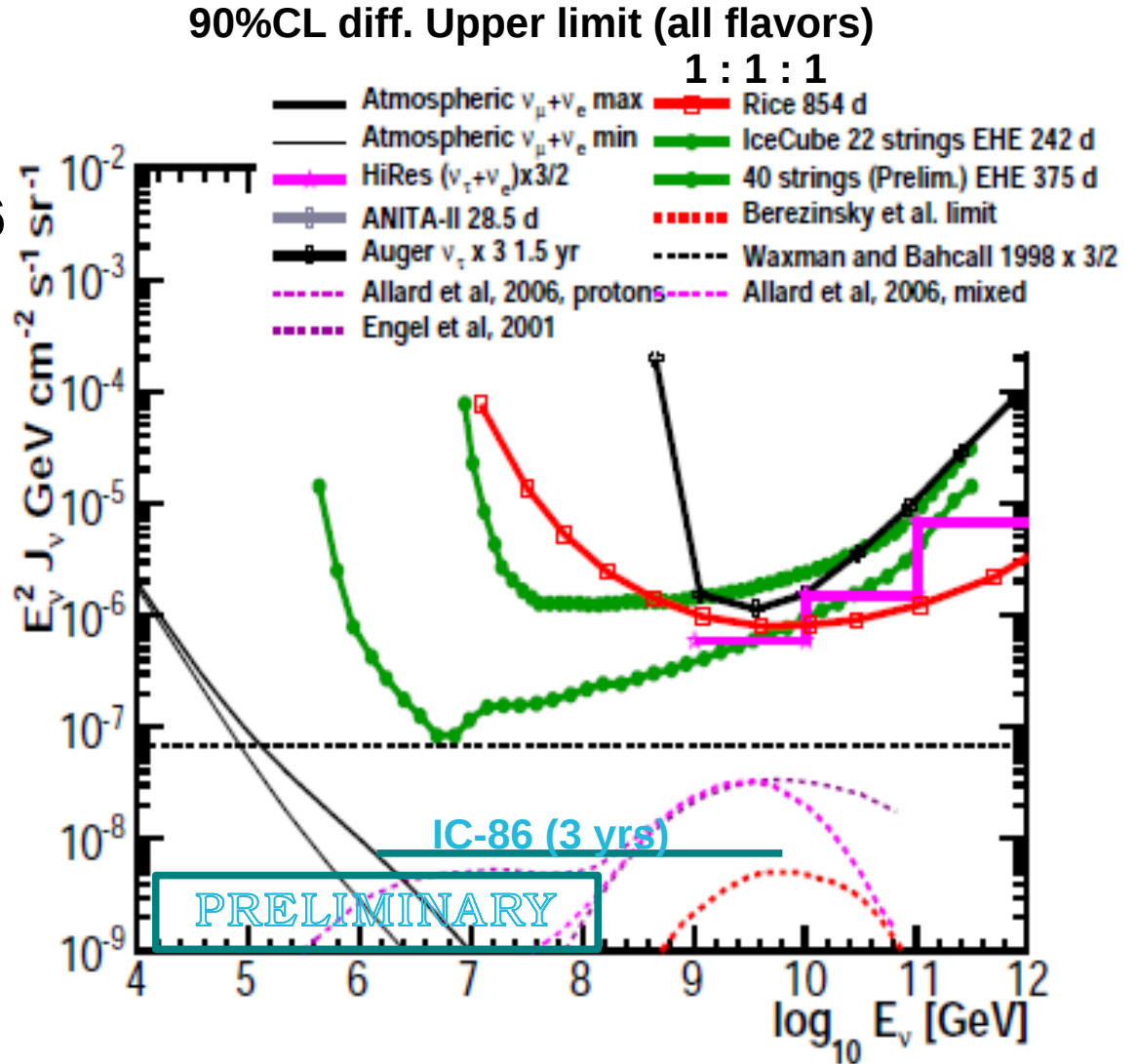
IC-22 : 333,3 days lifetime

IC-40 : 375.5 days livetime

Between 2 and 24.5  $\nu$  ev.  
Expected in 3 years with IC-86

## Challenging analyses

- ▶ Based on MC prediction of expected fluxes
- ▶ Excellent description of ice properties vs. depth





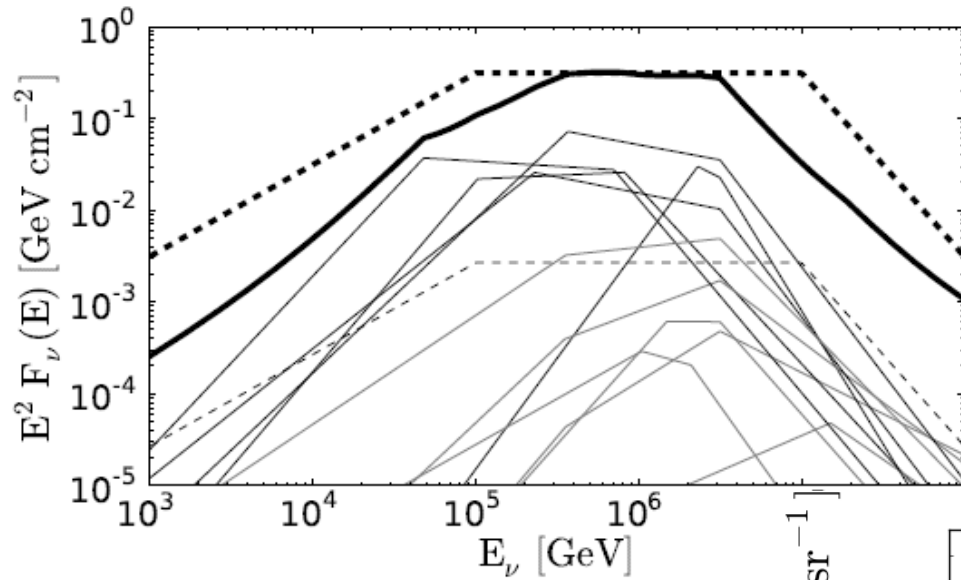
# IC-40(IC-59) : Search for GRB $\nu$ signal

ArXiv:1101,1448v2

From April 5, 2008 till May 20, 2009

129 GRBs (GCN)  $\rightarrow$  117 GRBs

**Model-dependent : Unbinned LLH**  
 Direction – arrival time – muon energy  
 No event observed (2.99 expected)

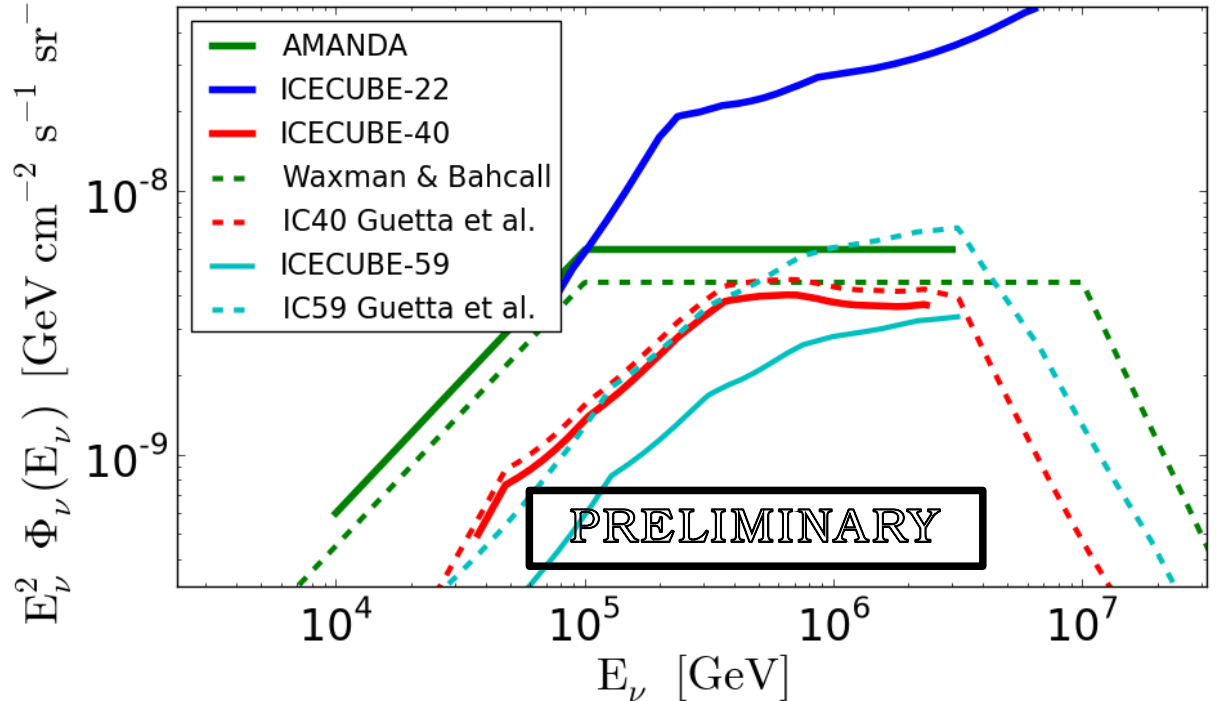


**Model-independent :  
 time window search**

[-10s ; +10 s]

$\rightarrow$  [-1 day ; +1 day]

No candidate event in  $\pm 2248s$   
 (4.2 expected)

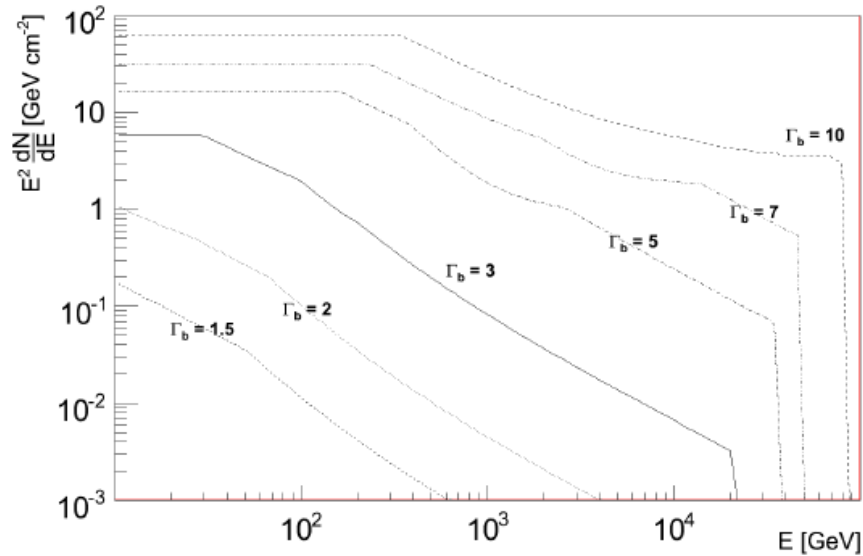






# IC-22 : Constraint on HE $\nu$ from SN2008D

A&A, n.15770



January, 9 2008

SWIFT X-Ray flash detection

09h09m30.70s ra ; 33°09'19,1" decl.

## Soft jet model

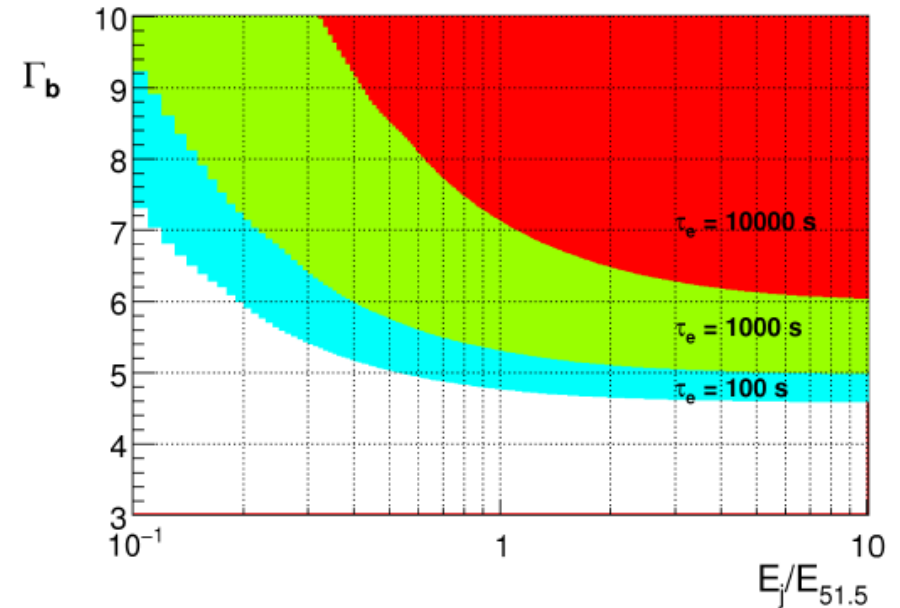
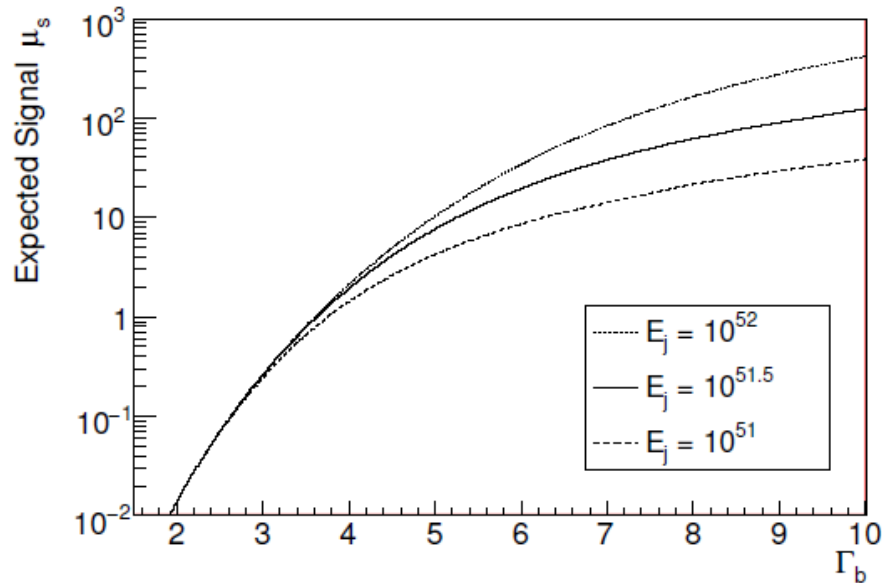
massive star collapse  $\rightarrow$  neutron star or B.H.

$\Gamma_b \sim 1 - 10$      $\theta_j \sim 5^\circ - 50^\circ$      $E_j \sim 3 - 6 \cdot 10^{51}$  erg

**IC-22 : 275.72 days**

Time range : [-9.5h ; +1.8h]

Bg rate : 0.03 Hz    0.26 signal ev. expected





# Summary

## IceCube is completed after 7 years of deployment!

- ▶ 86 strings with 5160 sensors for the biggest neutrino telescope in full activity.
- ▶ **IceTop** surface array
- ▶ **DeepCore** extension : 8 densely instrumented region lowering the energy threshold @ 10 GeV

## Data has been taken during construction phase

- ▶ 1<sup>st</sup> observation of CR anisotropy in the Southern Sky (IC-22)
- ▶ Limits for Point Source (IC-40)
  - NS :  $\sim 2 - 200 \text{ } 10^{-12} \text{ Tev cm}^{-2} \text{ s}^{-1}$
  - SS :  $\sim 3 - 700 \text{ } 10^{-12} \text{ Tev cm}^{-2} \text{ s}^{-1}$
- ▶ Limits for Atm. Neutrino diffuse flux (IC-22/IC-40)
  - We're under the WB limit !!
- ▶ Search for GRB/SN signal (IC-22/IC-40/IC-59)
  - No event observed
  - Constraints on soft jet models
  - Multi-WL Follow-up with SWIFT, Fermi, ROTSE,...



# Summary

## Additional topics :

- ▶ DarkMatter
- ▶ Exotic particles
- ▶ Electronic cascades
- ▶ Tau  $\nu$  physics

## Additional detectors for new channels :

- ▶ South Pole Accoustic Test Setup (SPATS)
- ▶ Askaryan Radio Array (ARA) will start soon.

**Analyses with partialy built detector  
have been successful**

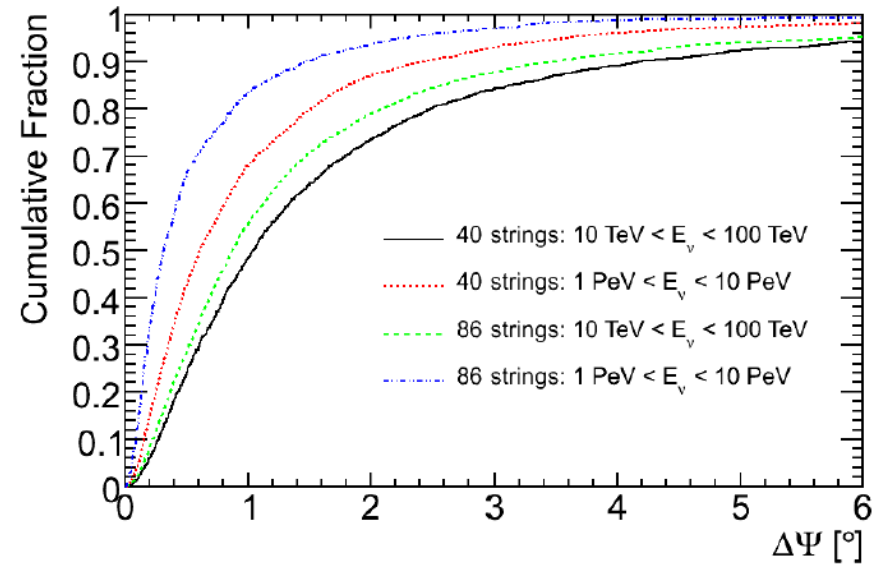
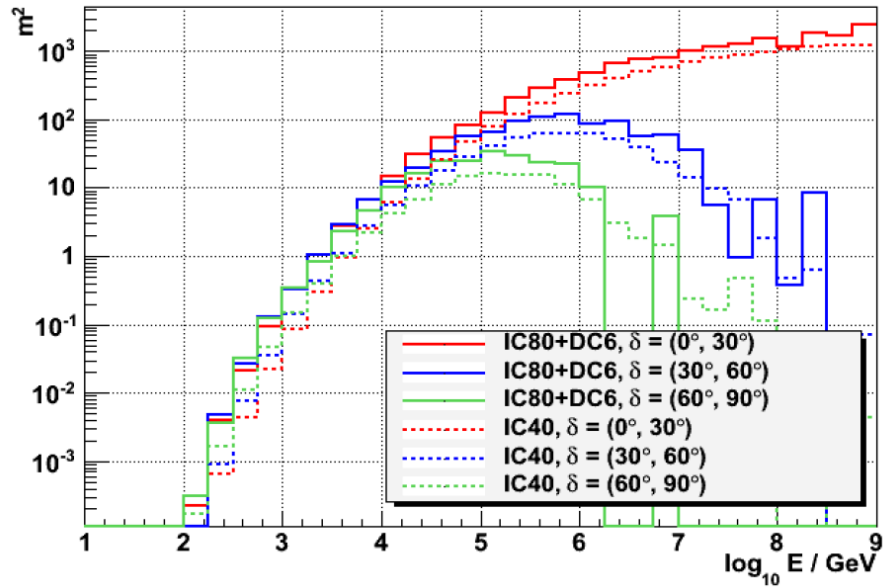
**The full km<sup>3</sup>-sized detector will provide  
an important increase in sensitivity for future analyses**

**NEW DISCOVERIES ?**





# Detector characteristics (Back-up)

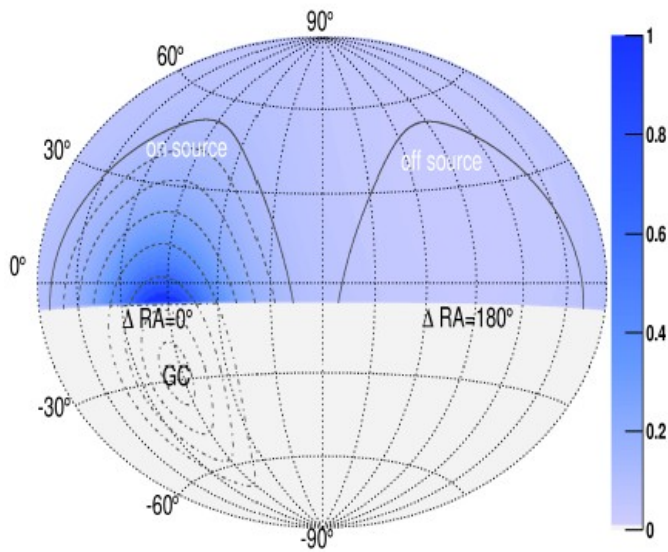




# Searches for Dark Matter (Back-up)

## Indirect detection of $\nu$ from DM annihilation

*Phys.Rev.Lett.* **102**, 201302 (2009)



## Galactic Halo observation

*ArXiv* : 1101.3349v1

