What next ???

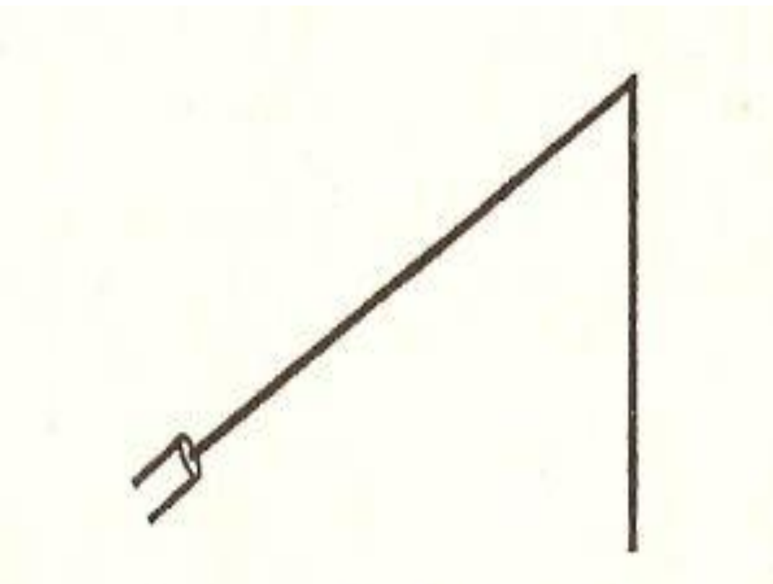
ANTARES... e oltre

Maurizio Spurio

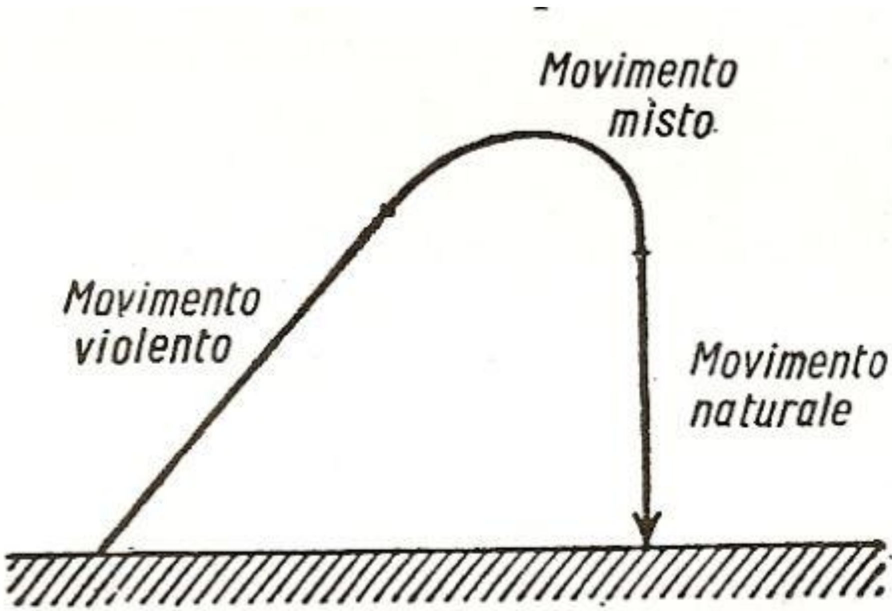
What Next – neutrini+ Raggi Cosmici

02/12/2014

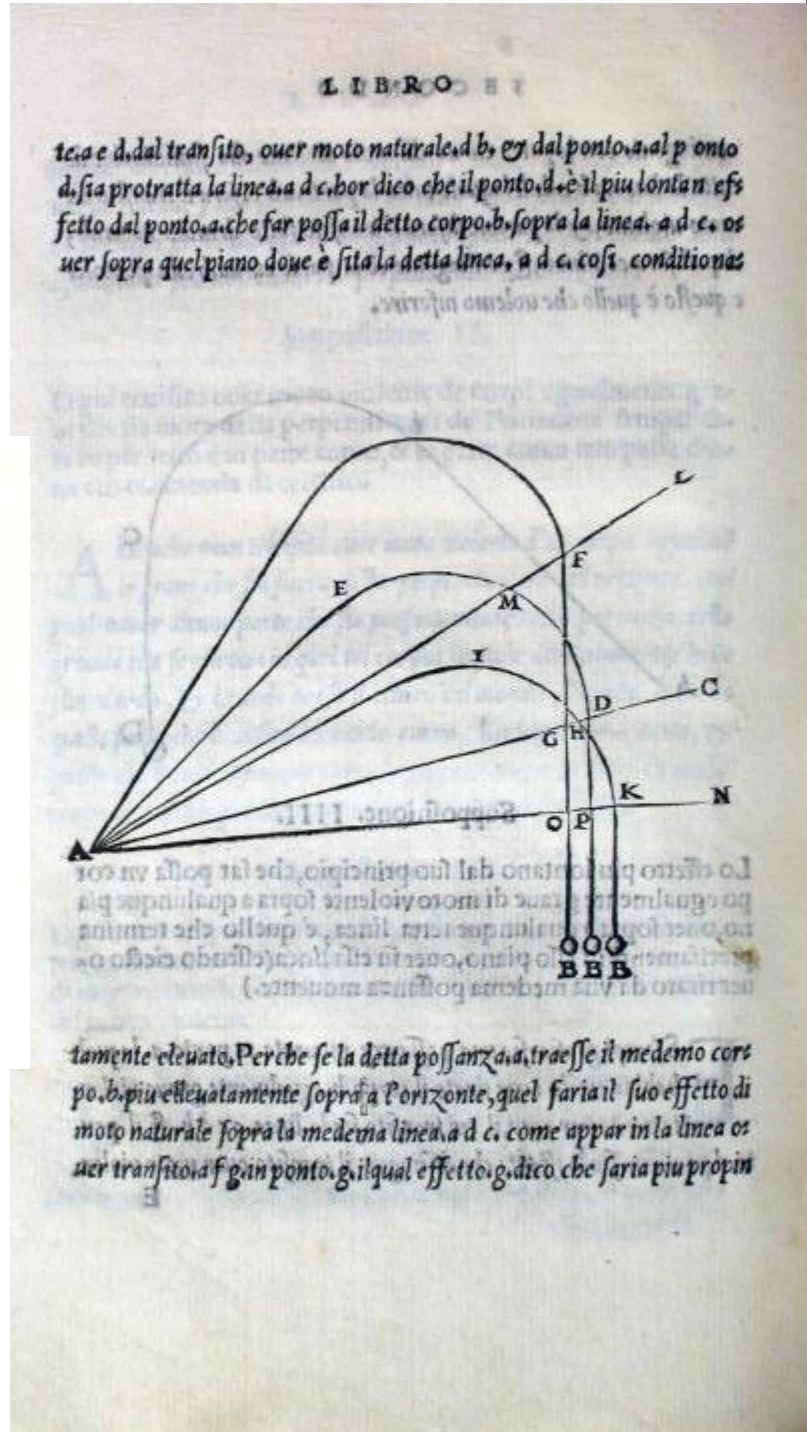
Balistica: conoscenze sperimentali



… sviluppi teorici



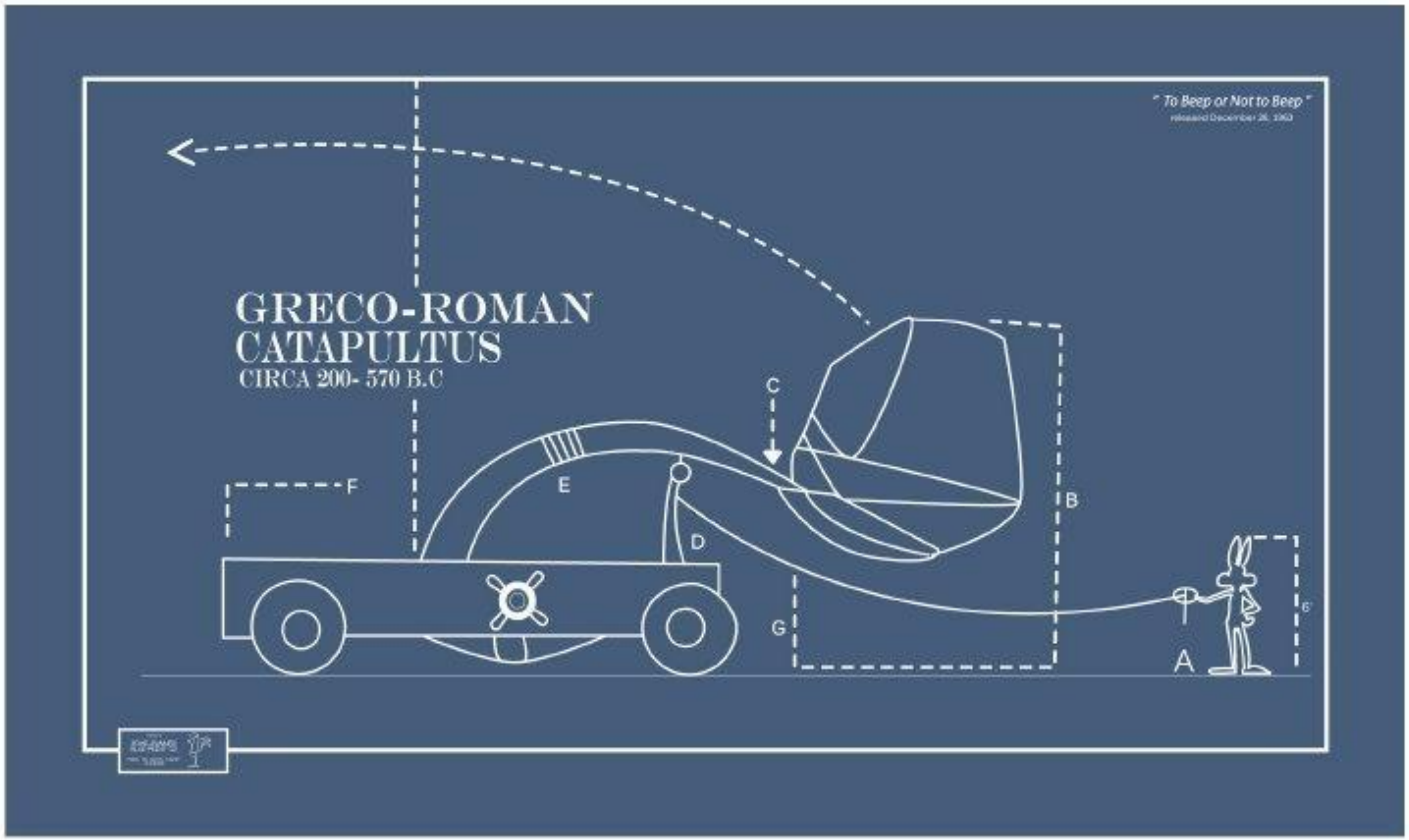
Curva Balistica di Tartaglia:
Delli quesiti et inventioni diverse, 1546

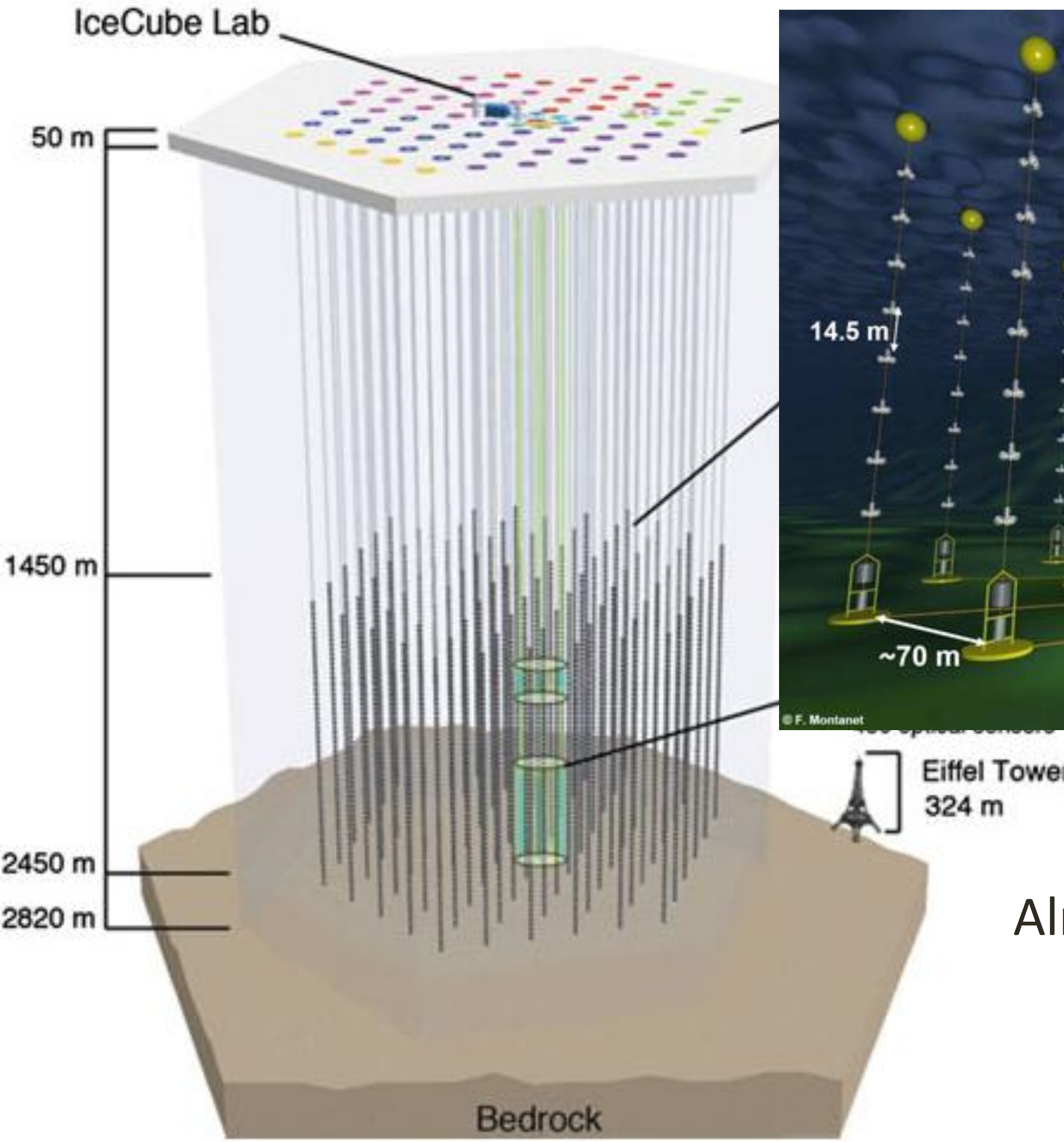

LIBRO

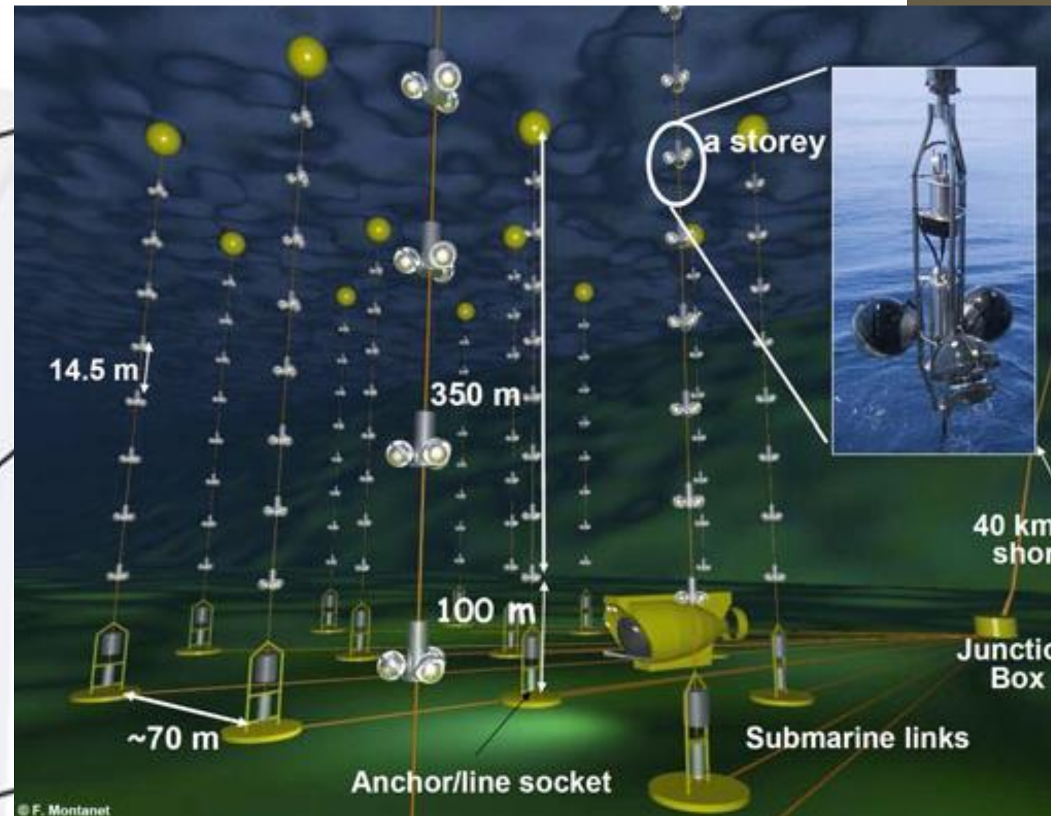
te.a e d.dal transito, ouer moto naturale.d b. & dal ponto.a.al ponto d.sia protratta la linea.a d c.hor dico che il ponto.d.è il piu lontan effetto dal ponto.a.che far possa il detto corpo.b.sopra la linea. a d c. ouer sopra quel piano doue è sita la detta linea. a d c. cosi conditiona

tamente eleuato.Perche se la detta possanza.a.traesse il medemo corpo.b.piu elleuatamente sopra a l'orizonte,quel faria il suo effetto di moto naturale sopra la medema linea.a d c. come appar in la linea ouer transito.a f g.in ponto.g.il qual effetto.g.dico che saria piu propin

… ma dove andremo a finire dipende dalle **condizioni iniziali**





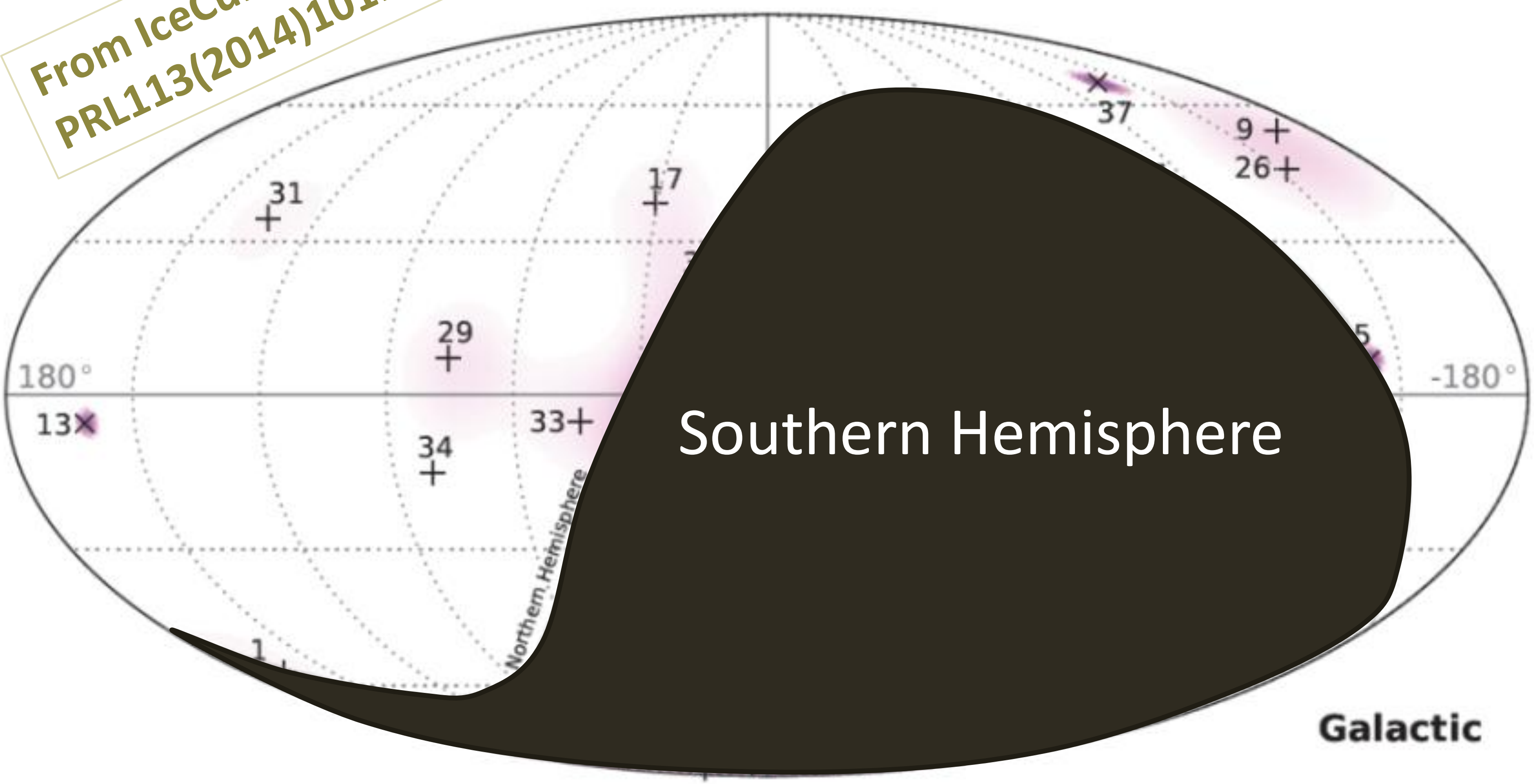


Almost in scale

ANTAR

The High Energy Starting Events (HESE) ν sky

From IceCube PRL113(2014)101101



$$
\begin{aligned}
E^2\Phi(E) &\equiv \Phi_0^{D,2.0} \\
&= (0.95 \pm 0.3) \times 10^{-8}\ \mathrm{GeV\ cm^{-2}s^{-1}sr^{-1}}
\end{aligned}
$$

Hypotheses on the HESE origin

(non-exhaustive list)

- **Extragalactic**
  - E. Waxman. The Beginning of Extra-Galactic Neutrino Astronomy. Physics 7 (2014) 88
  - F.W. Stecker. Phys. Rev. D 88 (2013) 047301;
  - P. Padovani and E. Resconi. arXiv:1406.0376
  - …
- **Dark Matter**
  - A. Esmaili and P. D. Serpico, JCAP 1311, 054 (2013)
  - J. Zavala. arXiv:1404.2932
  - …
- **Unidentified**
  - D. B. Fox, K. Kashiyama, P. Meszaros. ApJ, 774, 74;
  - ….
- Galactic
  - J. Joshi, W. Winter, N. Gupta. MNRAS 439 (2014) 3414
  - Y. Bai, R. Lu, and J. Salvado, (2013); arXiv:1311.5864
  - L. A. Anchordoqui et al., Phys.Rev. D89 (2014) 083003;
  - M. Kachelriess, S. Ostapchenko. arXiv:1405.3797
  - M. Ahlers, K. Murase. Phys. Rev. D 90, (2014) 023010;
  - S. Razzaque. Phys. Rev. D 88 (2013) 081302;
  - A. D. Supanitsky. Phys. Rev. D 89 (2014) 023501;
  - A.Neronov, D.V.Semikoz, C.Tchernin. PRD89(2014) 103002
  - L. Bay et al. Neutrino Lighthouse at Sagittarius A* PrD 90, 063012 (2014)

A galactic component in HESE

- A correlation with the Galactic plane/center is quoted statistically non-significant in the IceCube paper;

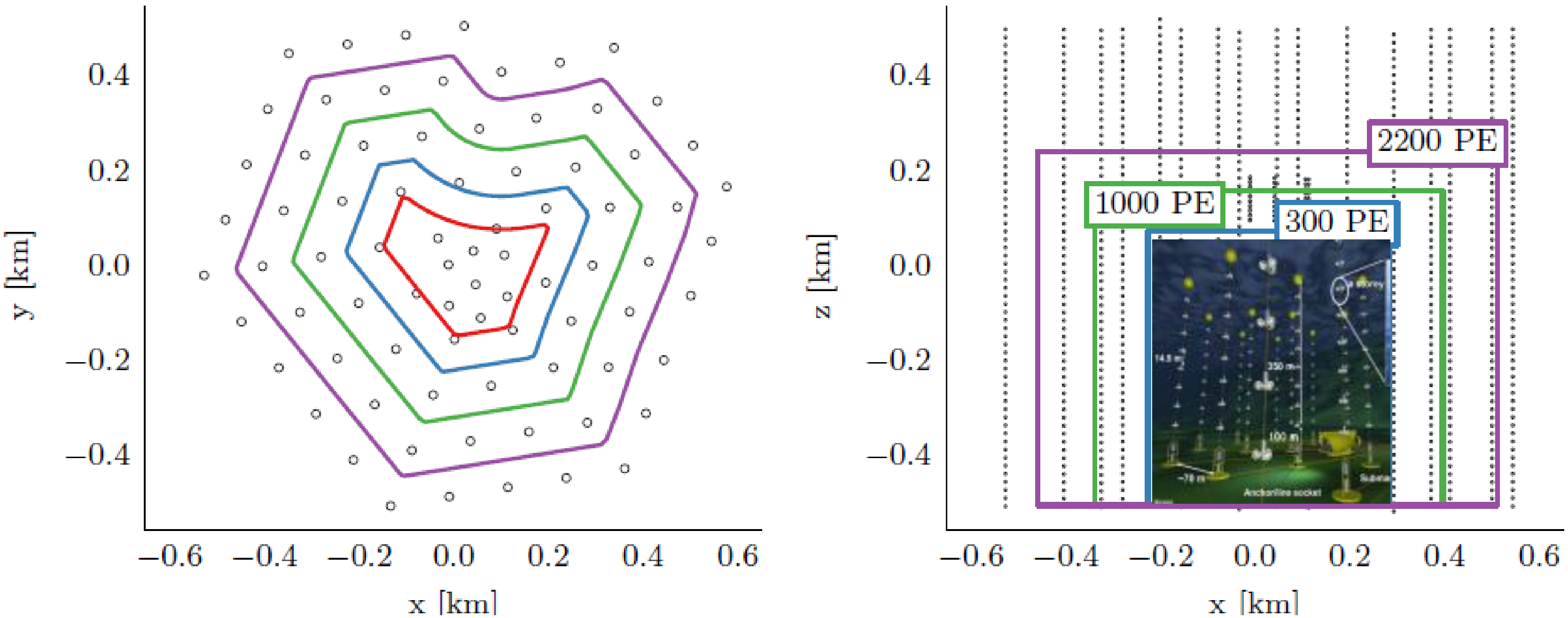
E>60 TeV	Data	Bck	Data-Bck	Best Fit
All events	20	2.7	17.3	18.2
Up (North)	5	1.4	3.6	6.7
Down (South)	15	1.3	13.7	11.5

- The measured signal from the Northern hemisphere =3.6 evts (~purely extragalactic) is ~ 50% expected;
- Assuming: 3.6 from North + symmetric extragalactic flux →expected 6.2 HESE events of extragalactic origin from South
- **Galactic contribution**=13.7 - 6.2 ≅ **7.5 events**
- This holds for any source energy spectrum $E^{-\Gamma}$.

News! arXiv:1410.1749

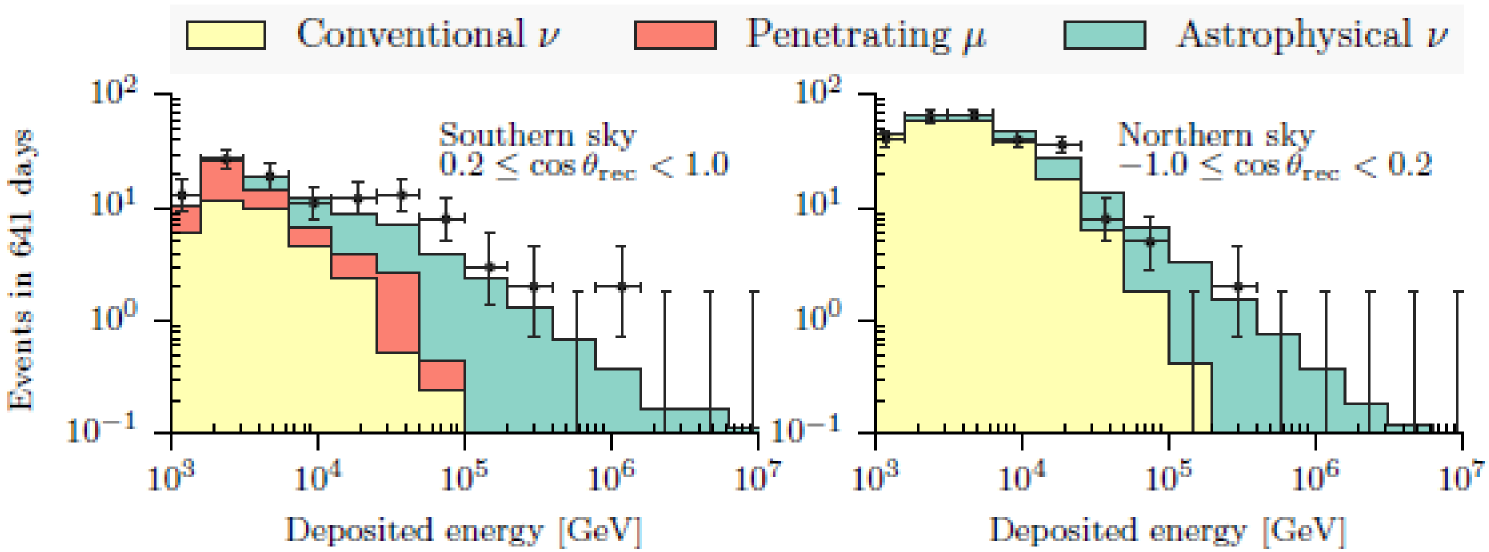
Atmospheric and Astrophysical Neutrinos above 1 TeV Interacting in IceCube

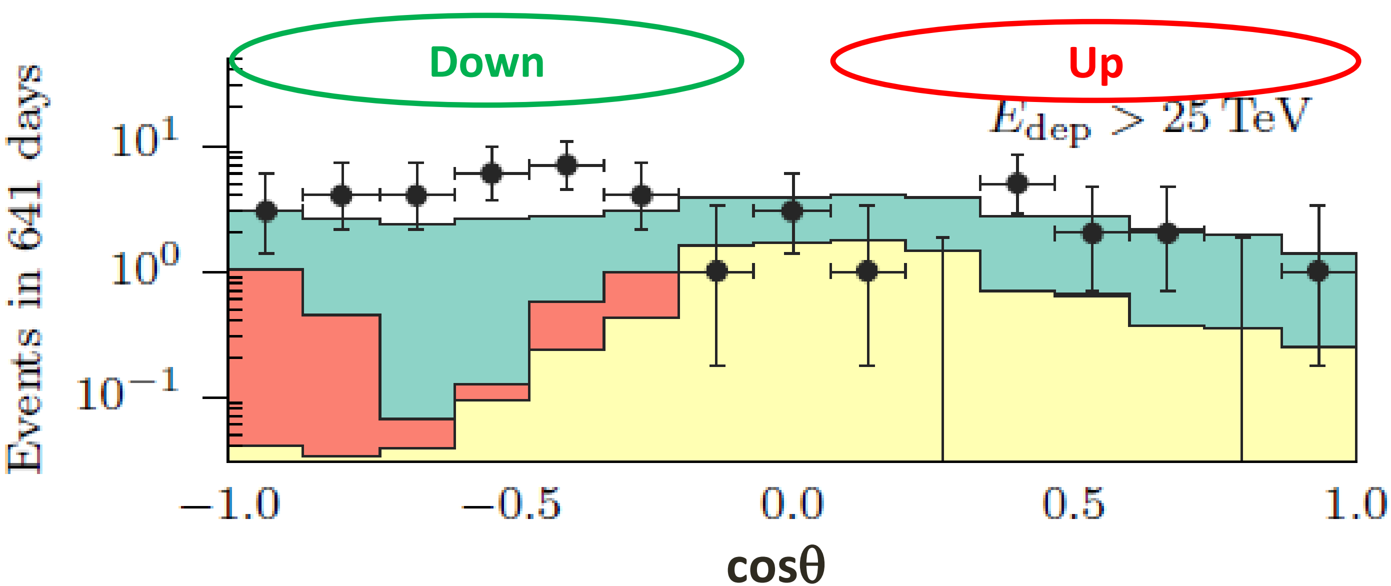
M. G. Aartsen,[2] M. Ackermann,[47] J. Adams,[15] J. A. Aguilar,[23] M. Ahlers,[28] M. Ahrens,[38] D. Altmann,[22] T. Anderson,[44] C. Arguelles,[28] T. C. Arlen,[44] J. Auffenberg,[1] X. Bai,[36] S. W. Barwick,[25] V. Baum,[29] J. J. Beatty,[17,18] J. Becker Tjus,[10] K.-H. Becker,[46] S. BenZvi,[28] P. Berghaus,[47] D. Berley,[16] E. Bernardini,[47] A. Bernhard,[32] D. Z. Besson,[26] G. Binder,[8,7] D. Bindig,[46] M. Bissok,[1] E. Blaufuss,[16] J. Blumenthal,[1]



Almost in scale

Northern and Southern sky





E>60 TeV	Data	Bck	Data-Bck	Best Fit
All events	20	2.7	17.3	18.2
Up (North)	5	1.4	3.6	6.7
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HESE

New sample

E>25 TeV	Data	Bck	Data-Bck	Best Fit
All events	43	11.7	31.3	29.1
Up ($\sin\delta > 0.06$)	11	5.3	5.7	12.1
Down($\sin\delta < -0.06$)	29	4.8	24.2	15.0

- **Best fit**= 1:1:1 and isotropy. Small dependence on Γ
- Much larger asymmetry between the North and South hemispheres in the new data set than in HESE
- Event map not present in the arXiv

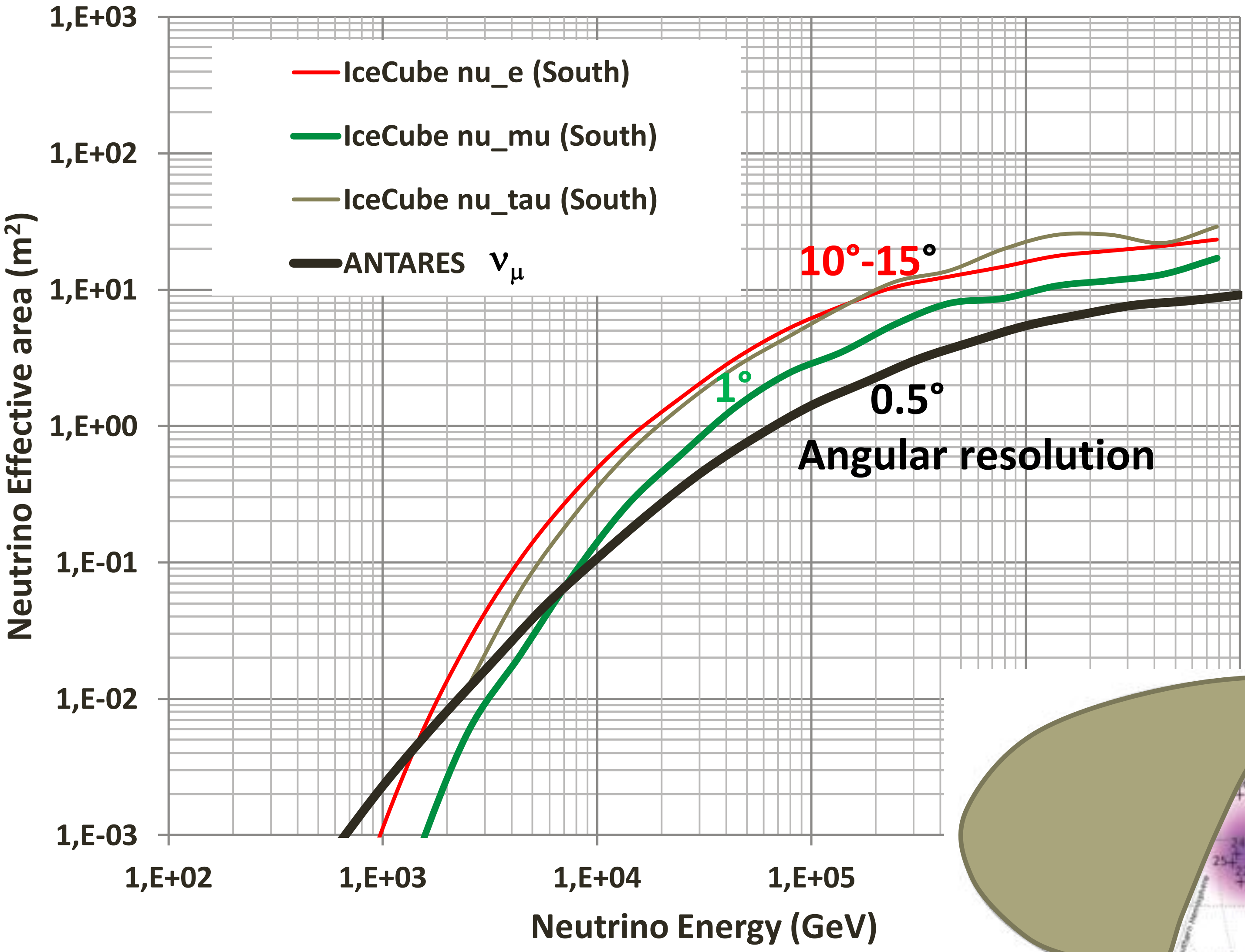
Parametro di qualità di un νT

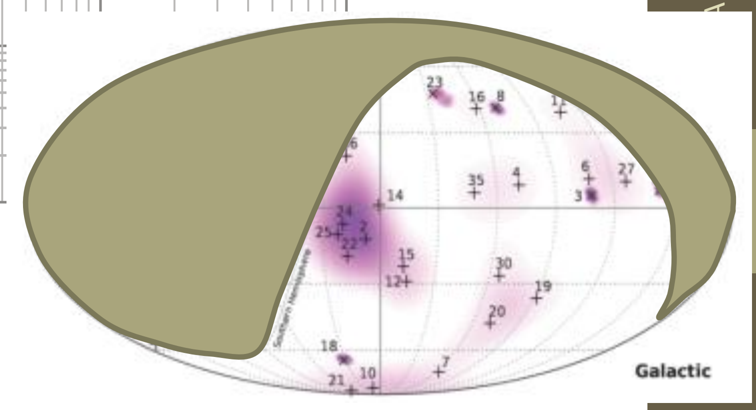
- Area Effettiva: contiene la funzione di risposta del rivelatore al flusso di neutrini di dato sapore ed energia E
- Dipende dai tagli di analisi
- Dipende dalle richieste di fisica.
- Dato un flusso astrofisico (esempio: $\Phi(E) = \Phi^0 E^{-\Gamma}$)
- Il numero di eventi misurati in un tempo T è dato da

$$N = T \int A_{eff} \cdot \Phi(E) \cdot dE$$

- **Neutrino telescopio** ≡ se permette di **individuare le sorgenti.** Solo per eventi con risoluzione angolare inferiore al 1° (ν_μ)

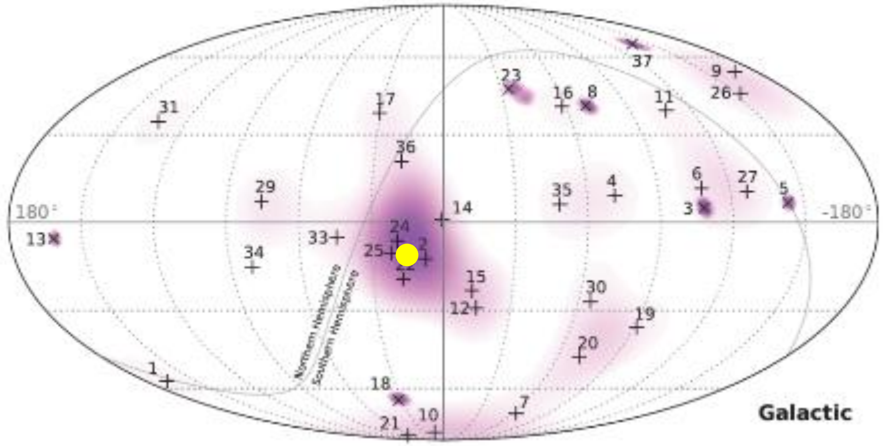
IC-1410.1749 vs. ANTARES A_{eff}





I) A point-like Galactic source

- n_p = from a point-like source
- N_{IC} =total IC-HESE sample
- The Galactic component can have a generic $E^{-\Gamma}$ spectrum:



$$E^{\Gamma}\Phi^{p,\Gamma}(E) = \boxed{\Phi_0^{p,\Gamma}} \quad \text{units: GeV cm}^{-2}s^{-1}$$

- The normalization factor can be derived with the use of the A_{eff} (E)
- $\Phi_0^{p,\Gamma}$ depends on the diffuse flux normalization factor

$$\Phi_0^{p,\Gamma} = 4\pi \cdot \left(\frac{n_p}{N_{IC}}\right) \cdot \Phi_0^{D,\Gamma}$$

Same formula as in:

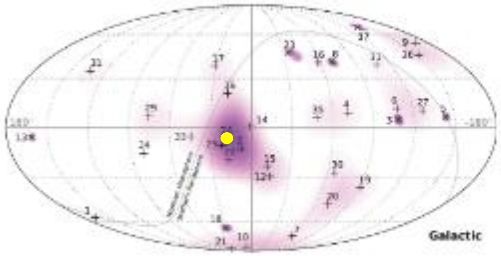
S. Razzaque. Phys. Rev. D 88 (2013) 081302;

Luis A. Anchordoqui et al. JHEAp (2013)

M.C. Gonzalez-Garcia, F. Halzen, V. Niro. Astropart.Phys. 57-58 (2014) 39-48; arXiv:1310.7194

Predictions

$$\Phi_0^{p,\Gamma} = 4\pi \cdot \left(\frac{n_p}{N_{IC}}\right) \cdot \Phi_0^{D,\Gamma}$$



$\Gamma =$	IceCube $\Phi_0^{p,\Gamma}$ (GeV cm^{-2} s^{-1}) $n_p = 1$	$n_p = 2$	$n_p = 3$	$n_p = 4$	$n_p = 5$	ANTARES 90% C.L. upper limit
2.0	$6.9\ 10^{-9}$	$1.4\ 10^{-8}$	$2.1\ 10^{-8}$	$2.8\ 10^{-8}$	$3.5\ 10^{-8}$	$4.0\ 10^{-8}$
2.1	$2.6\ 10^{-8}$	$5.1\ 10^{-8}$	$7.7\ 10^{-8}$	$1.0\ 10^{-7}$	$\underline{1.3\ 10^{-7}}$	$1.2\ 10^{-7}$
2.2	$9.0\ 10^{-8}$	$1.8\ 10^{-7}$	$2.7\ 10^{-7}$	$\underline{3.6\ 10^{-7}}$	-	$3.2\ 10^{-7}$
2.3	$3.3\ 10^{-7}$	$6.6\ 10^{-7}$	$\underline{9.9\ 10^{-7}}$	-	-	$8.4\ 10^{-7}$
2.4	$1.2\ 10^{-6}$	$\underline{2.3\ 10^{-6}}$	-	-	-	$2.2\ 10^{-6}$
2.5	$3.9\ 10^{-6}$	$\underline{7.9\ 10^{-6}}$	-	-	-	$5.5\ 10^{-6}$

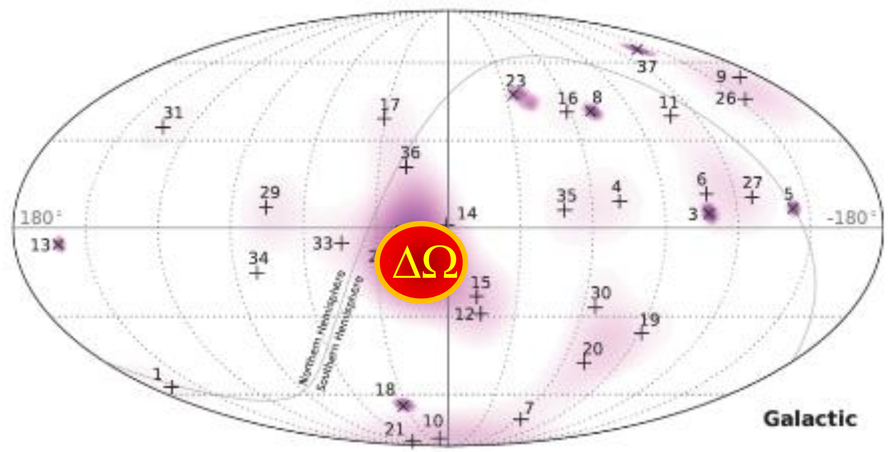
THE ASTROPHYSICAL JOURNAL LETTERS, 786:L5 (5pp), 2014 May 1

ANTARES upper bounds

- The ANTARES 90% C.L. upper limit excludes that a single point-like source produces n_p>5 HESE, assuming Γ=2.0.
- A single point-like source yielding n_p>2 is excluded for Γ=2.3
- A clusters made of $n_p \geq$ 2 is excluded for Γ> 2.3.

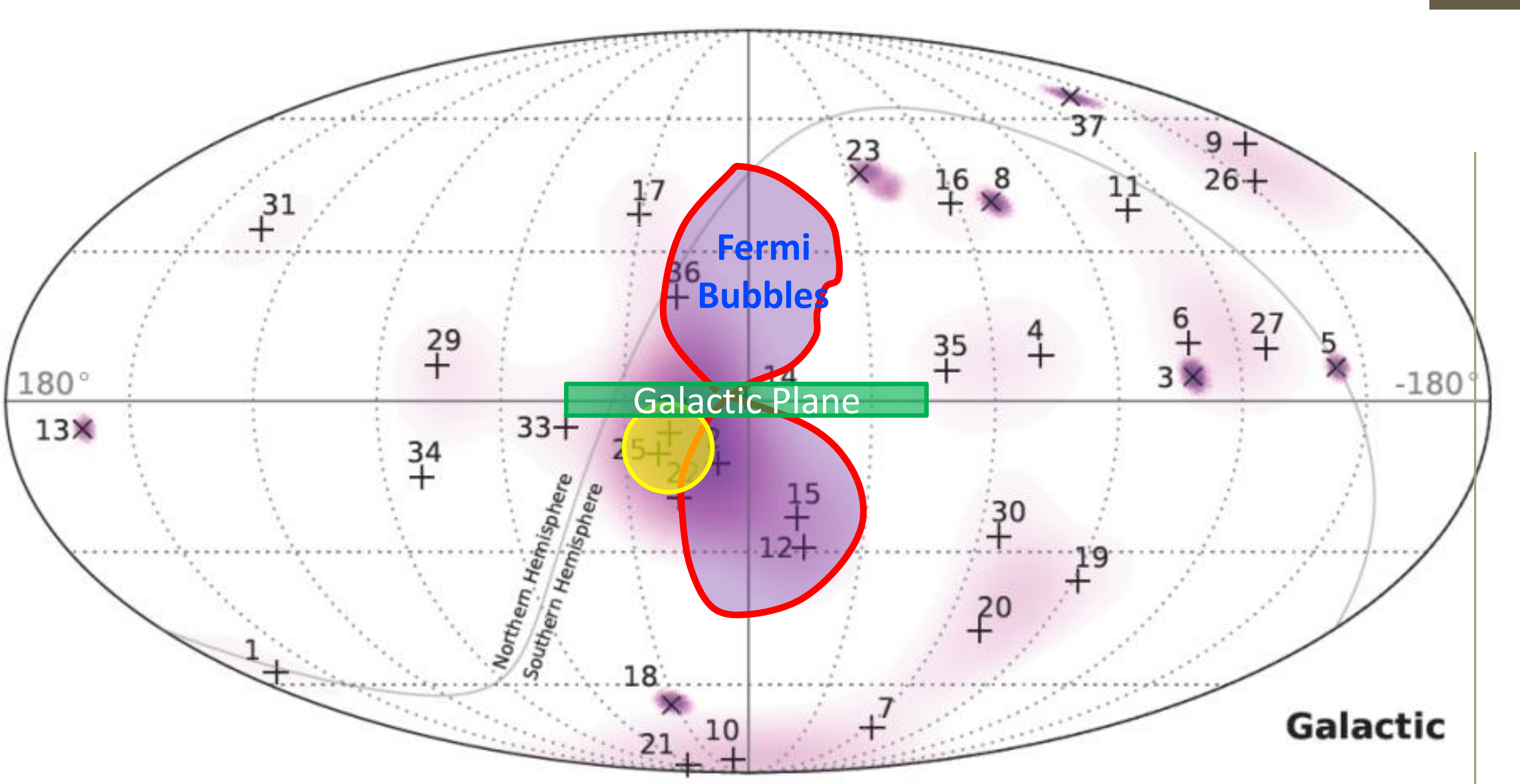
II) Enhanced diffuse Galactic flux

- Signal generated in an **extended region**, comparable with the IC-HESE angular resolution (~15°);
- Size $\Delta\Omega$ much larger than the ANTARES angular resolution;
- $n_{\Delta\Omega}$ events out N_{IC} are due to this source, with energy spectrum:



$(\mathrm{GeV\ cm^{-2}\ s^{-1}\ sr^{-1}})$

$$\Phi_0^{D',\Gamma} = \left(\frac{n_{\Delta\Omega}}{N_{IC}}\right) \cdot \left(\frac{4\pi}{\Delta\Omega}\right) \cdot \Phi_0^{D,\Gamma}$$



- **IC hot spot**. Best fit Γ=2.2-2.4
- **Fermi- Bubble region**. ANTARES study optimized for Γ=2.0 and using 3y of data. Eur. Phys. Jour. C74 (2014) 2701
- **Galactic Center region**. ANTARES study optimized for Γ=2.6-2.7 and using 5y of data.

Predictions for an enhanced flux vs. $(n_{\Delta\Omega}, \Delta\Omega)$ and Γ

units: $(\mathrm{GeV\ cm^{-2}\ s^{-1}\ sr^{-1}})$

$$\Phi_0^{D',\Gamma} = \left(\frac{n_{\Delta\Omega}}{N_{IC}}\right) \cdot \left(\frac{4\pi}{\Delta\Omega}\right) \cdot \Phi_0^{D,\Gamma}$$

$\Delta\Omega$ (sr)	$\Gamma =$	$n_{\Delta\Omega} = 3$	$n_{\Delta\Omega} = 4$	$n_{\Delta\Omega} = 5$	$n_{\Delta\Omega} = 6$	ANTARES sensitivity
0.06	2.0	$3.5\ 10^{-7}$	$4.6\ 10^{-7}$	$5.8\ 10^{-7}$	$7.0\ 10^{-7}$	$3.1\ 10^{-7}$
8°	2.2	$4.5\ 10^{-6}$	$6.0\ 10^{-6}$	$7.5\ 10^{-6}$	$9.0\ 10^{-6}$	$3.6\ 10^{-6}$
	2.3	$1.7\ 10^{-5}$	$2.2\ 10^{-5}$	$2.8\ 10^{-5}$	$3.3\ 10^{-5}$	$1.1\ 10^{-5}$
	2.4	$5.9\ 10^{-5}$	$7.8\ 10^{-5}$	$9.8\ 10^{-5}$	$1.2\ 10^{-4}$	$3.4\ 10^{-5}$
0.38	2.0	$5.4\ 10^{-8}$	$7.3\ 10^{-8}$	$9.1\ 10^{-8}$	$1.1\ 10^{-7}$	$3.1\ 10^{-7}$
20°	2.2	$7.1\ 10^{-7}$	$9.4\ 10^{-7}$	$1.2\ 10^{-6}$	$1.4\ 10^{-6}$	$3.6\ 10^{-6}$
	2.3	$2.6\ 10^{-6}$	$3.6\ 10^{-6}$	$4.4\ 10^{-6}$	$5.2\ 10^{-6}$	$1.1\ 10^{-5}$
	2.4	$9.3\ 10^{-6}$	$1.2\ 10^{-5}$	$1.5\ 10^{-5}$	$1.9\ 10^{-5}$	$3.4\ 10^{-5}$

- Esercizio per Gamma astronomia: visibili con IACTs, HAWC ?

Condizioni iniziali (t_0=12/2014)

- Il rate di conteggi di eventi classificati come neutrini cosmici in diverse analisi di IC sembra differente per i due emisferi N/S
- Attualmente, nessun claim di anisotropia. Flusso cosmico interpretato come diffuso e con flavor ratio 1:1:1
- Segnale con spettro di energia $E^{-\Gamma}$ (preferito: $\Gamma \cong$ 2.2-2.3)
- L'eccesso di eventi dal cielo Sud può essere interpretato come dovuto ad una sottostima del fondo, fluttuazione, o presenza di una componente (presumibilmente) galattica.
- Asimmetria N/S possibile per oggetti Galattici (Vissani et al Astropart.Phys. 34 (2011) 778-783)
- ANTARES ha un'area effettiva per ν_μ comparabile con IC per l'emisfero Sud, e con migliore risoluzione angolare.

Condizioni iniziali (t_0=12/2014)

- Un eventuale claim di asimmetria (=presenza di sorgenti puntiformi/diffuse nel cielo Sud) favorirebbe ANTARES
- Indipendentemente da ciò, ANTARES ha sufficiente sensibilità per escludere modelli di **sorgente puntiforme** con $E^{-\Gamma}$, Γ>2.2.
- Work in progress per **sorgenti estese .** Presenza/assenza di segnale in regioni di estenzione $\sim 10^o$ può essere studiata.
- La balistica sorvola adesso KM3NeT → Rosa
- Ma…

- Fase 1 ha $t \cong t_0$, quasi condizioni iniziali
- 24 stringhe + 8 torri; logistica migliore di ANTARES
- Area efficace almeno x 3 ANTARES
- Strumento per fare FISICA !!

KM3NeT Strategy Document

KM3NeT is a large research infrastructure, that will consist of a network of deep-sea neutrino telescopes in the Mediterranean Sea with user ports for Earth and Sea sciences. The main objectives of KM3NeT are the discovery and subsequent observation of high-energy neutrino sources in the Universe and the determination of the mass hierarchy of neutrinos. A cost effective technology for (very) large water Cherenkov detectors has been developed based on a new generation of low price 3-inch photo-multiplier tubes. Following the successful deployment and operation of two prototypes, the construction of the KM3NeT research infrastructure has started. The prospects of the different phases of the implementation of KM3NeT are summarised.

Science

Technology

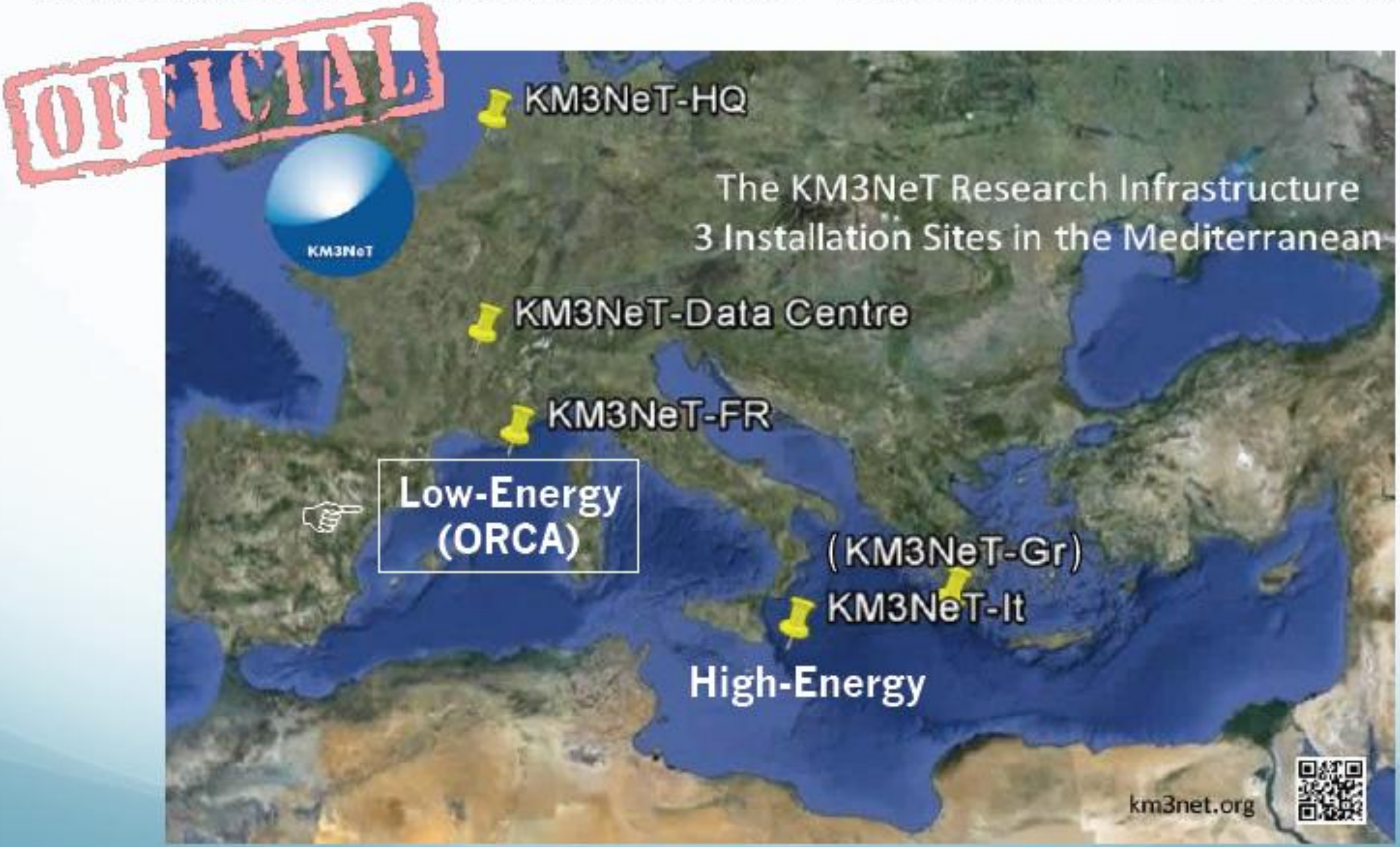
Phase	Additional costs [M€]	Blocks	Primary deliverables
1	0	0.2	Proof of feasibility and first science results.
1.5	50-60	2	Measurement of the neutrino signal reported by IceCube.
ORCA	40	1	Determination of the neutrino mass hierarchy.
2	130-170	6	Neutrino astronomy including Galactic sources.

Table 1: Summary of the phased implementation of the KM3NeT research infrastructure. The costs for Phase-1 are fully covered. When both Phase-1.5 and ORCA are pursued, about 10 M€ additional costs are needed to accommodate both detectors.

Forewords

KM3NeT is a distributed research infrastructure with 2 main physics topics:

Low-Energy studies of atmospheric neutrinos – High-Energy search for cosmic neutrinos



Many unofficial preliminary material shown today

Details: arXiv 1409.4552
Phys.Rev. D90 (2014) 10, 103004

PHYSICAL REVIEW D **90**, 103004 (2014)

Constraints to a Galactic component of the Ice Cube cosmic neutrino flux from ANTARES

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The IceCube evidence for cosmic neutrinos in the high-energy starting events (HESE) sample has inspired a large number of hypotheses on their origin, mainly due to the poor precision on the measurement of the direction of showering events. The fact that most HESE are downward going suggests a possible Galactic component. This could be originated either by a single pointlike source or to a directional excess from an extended Galactic region. These hypotheses are reviewed and constrained, using the present available upper limits from the ANTARES neutrino telescope. ANTARES detects ν_μ from sources in the Southern sky with an effective area larger than that providing the IceCube HESE for $E_\nu < 60$ TeV and a factor of about two smaller at 1 PeV. The use of the ν_μ signal enables an accurate measurement of the incoming neutrino direction. The Galactic signal allowed by the IceCube HESE and the corresponding ANTARES limits are studied in terms of a power law flux $E^{-\Gamma}$, with spectral index Γ ranging from 2.0 to 2.5 to cover most astrophysical models.

DOI: 10.1103/PhysRevD.90.103004 PACS numbers: 95.85.Ry, 95.55.Vj

I. INTRODUCTION

The IceCube Collaboration announced in [1] evidence for the first detection of extraterrestrial high-energy neutrinos using two years of data with the full detector, recently updated with a third year [2]. The estimated energies of events in the IceCube sample (high-energy starting events, HESE) range from 30 TeV to 2 PeV. In the IceCube papers the hypothesis of a neutrino flux with flavor ratios $\nu_e:\nu_\mu:\nu_\tau = 1:1:1$ is considered. This flux is exactly that expected from charged pion decays in cosmic ray (CR) accelerators and neutrino oscillation on their way to the Earth. The nonobservation of events beyond 2 PeV suggests a break or an exponential cutoff in the neutrino flux for a power law $\Phi(E) \propto E^{-\Gamma}$ and a hard spectral index, as for instance $\Gamma \simeq 2.0$. An unbroken power law is also

upper bound up to $\sim 10^{15}$ eV [3]. If active Galactic nuclei or γ-ray bursts were sources of ultrahigh energy cosmic rays, then they should produce neutrinos with energies up to $E \sim 10^{19}$ eV [4]. The same holds for the cosmogenic neutrino flux which peaks around 10^{18} eV for proton primaries [5].

The observed HESE energy spectrum requires strong energy loss processes of protons up to 50 PeV that are not expected to take place within γ-ray bursts or AGN sources. A possible explanation [6] is that protons produce pions not within the sources, but in the environment surrounding them, as in starburst galaxies. These galaxies act as calorimeters: protons with energies < 100 PeV lose all their energy into pions after escaping the source that produced them but before escaping the galaxy. This mechanism could also explain the suppression of HESE above 2 PeV, as protons of

Quello che conosco io della balistica:

- http://www.springer.com/astronomy/astrophysics+and+astroparticles/book/978-3-319-08050-5