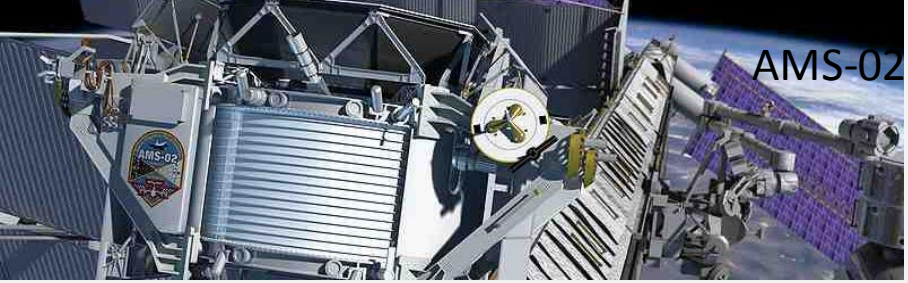
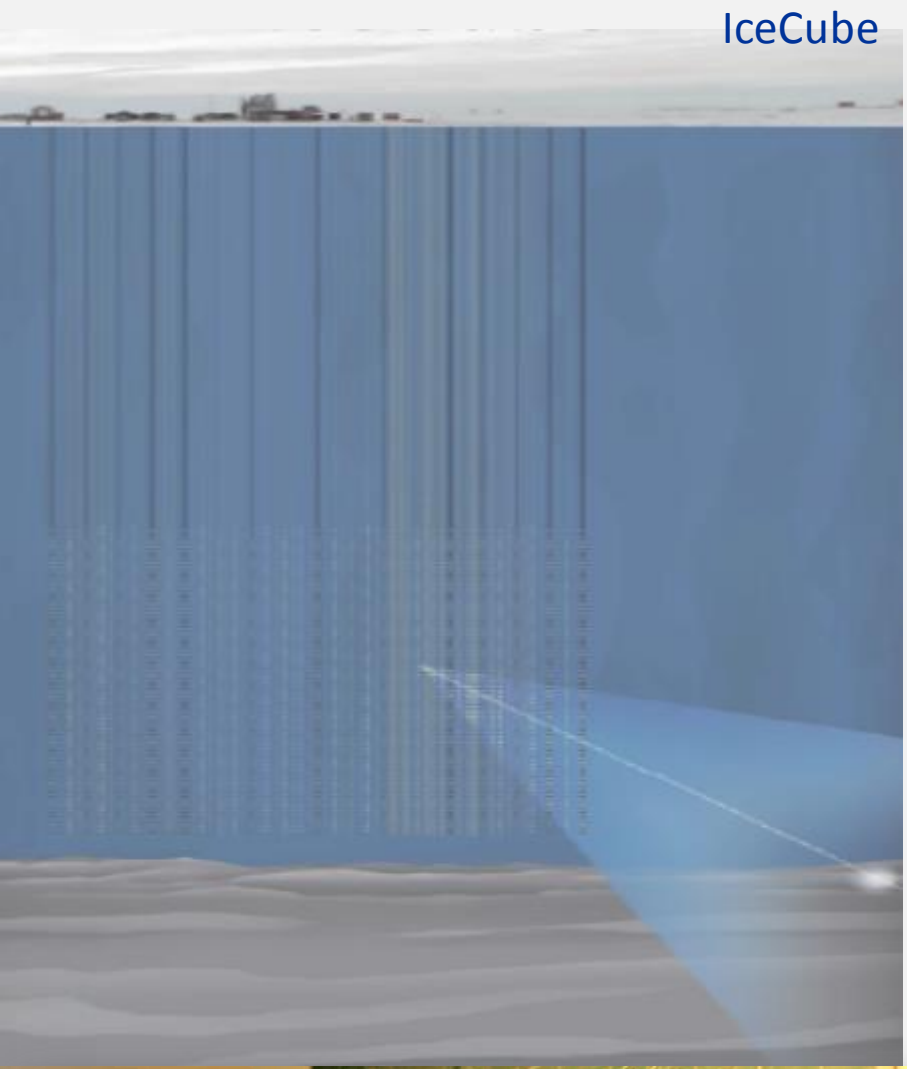
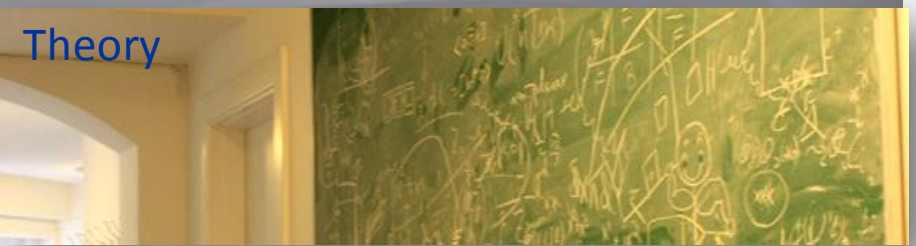






Experimental and Phenomenological

Astroparticle Physics

Subir Sarkar
University of Oxford

Associate of 'Discovery Center'
and NBI Visiting Professor 2012-13

(Niels Bohr Professor @ NBIA, 2013-18)

RECFA Meeting, Carlsberg Academy, Copenhagen, 3-4 May 2013


Frandsen


Kouvaris


Sannino

CP³ - Origins
Particle Physics & Cosmology

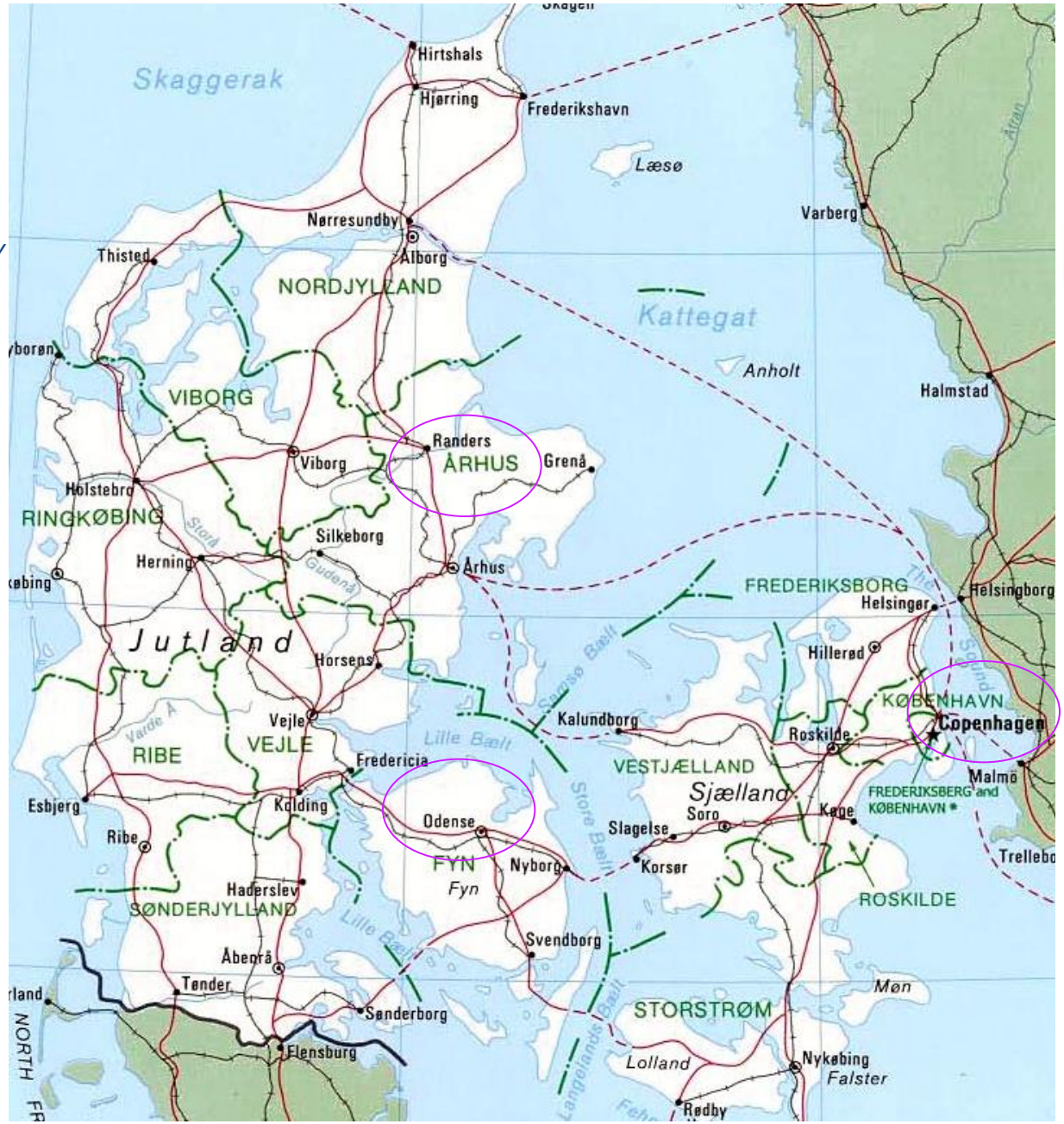
SYDDANSK UNIVERSITET

AARHUS UNIVERSITY


Fynbo


Hannestad


Madsen



Dark Cosmology Centre


Hansen

centre for particle physics
Discovery


Koskinen


Peterson


Naselsky

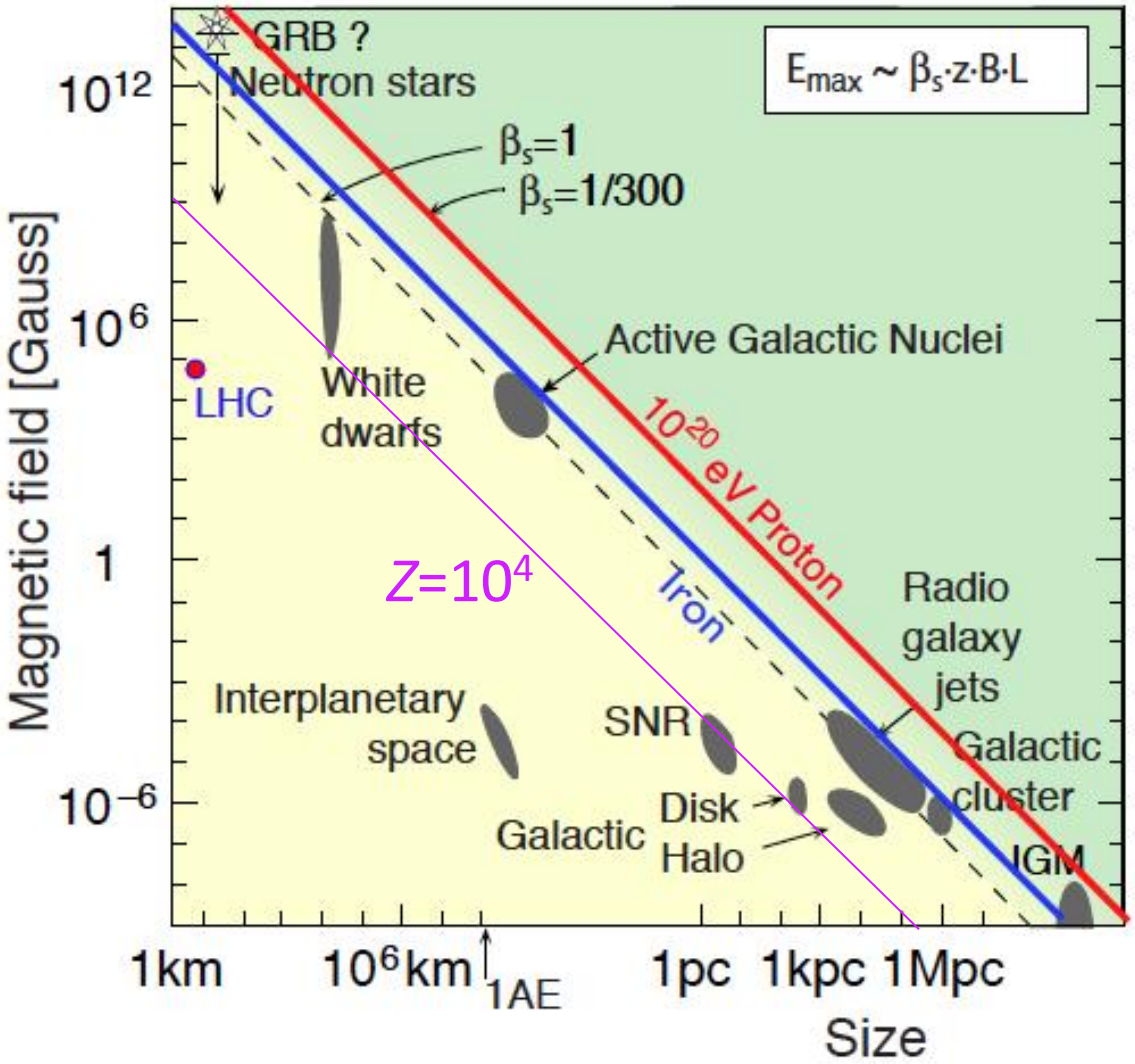

Sarkar

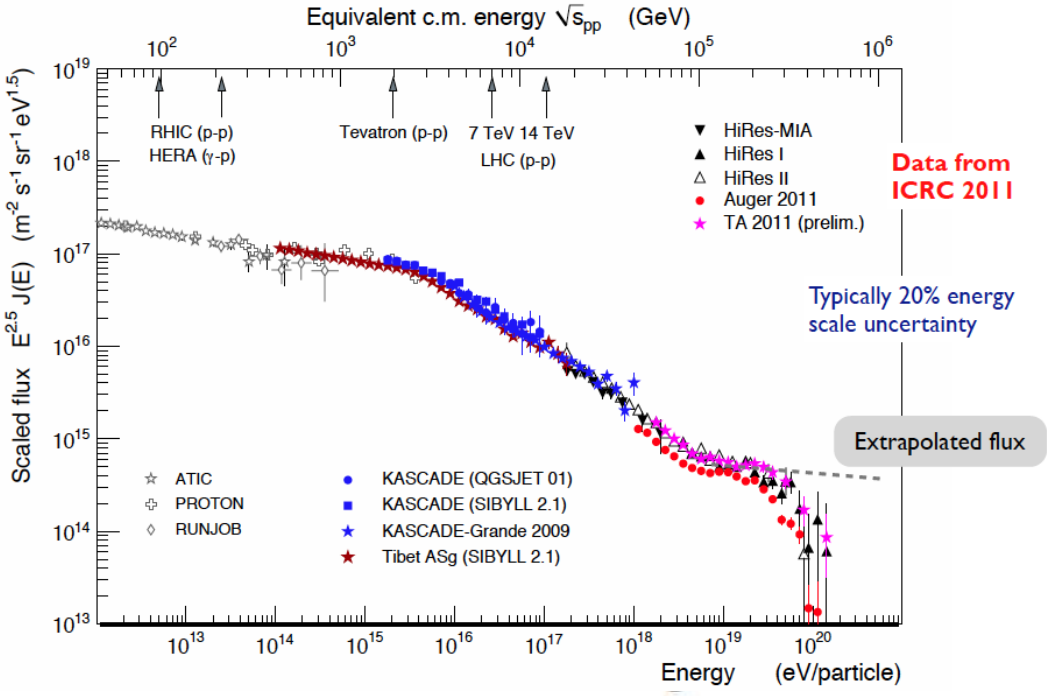
How does Nature manage to accelerate particles to ~ZeV energies?

Detecting strangelets with AMS-02
Research › Working paper

A. Chikanian
E. Finch
J. Madsen
R. Majka
J. Sandweiss

stopped in 2013

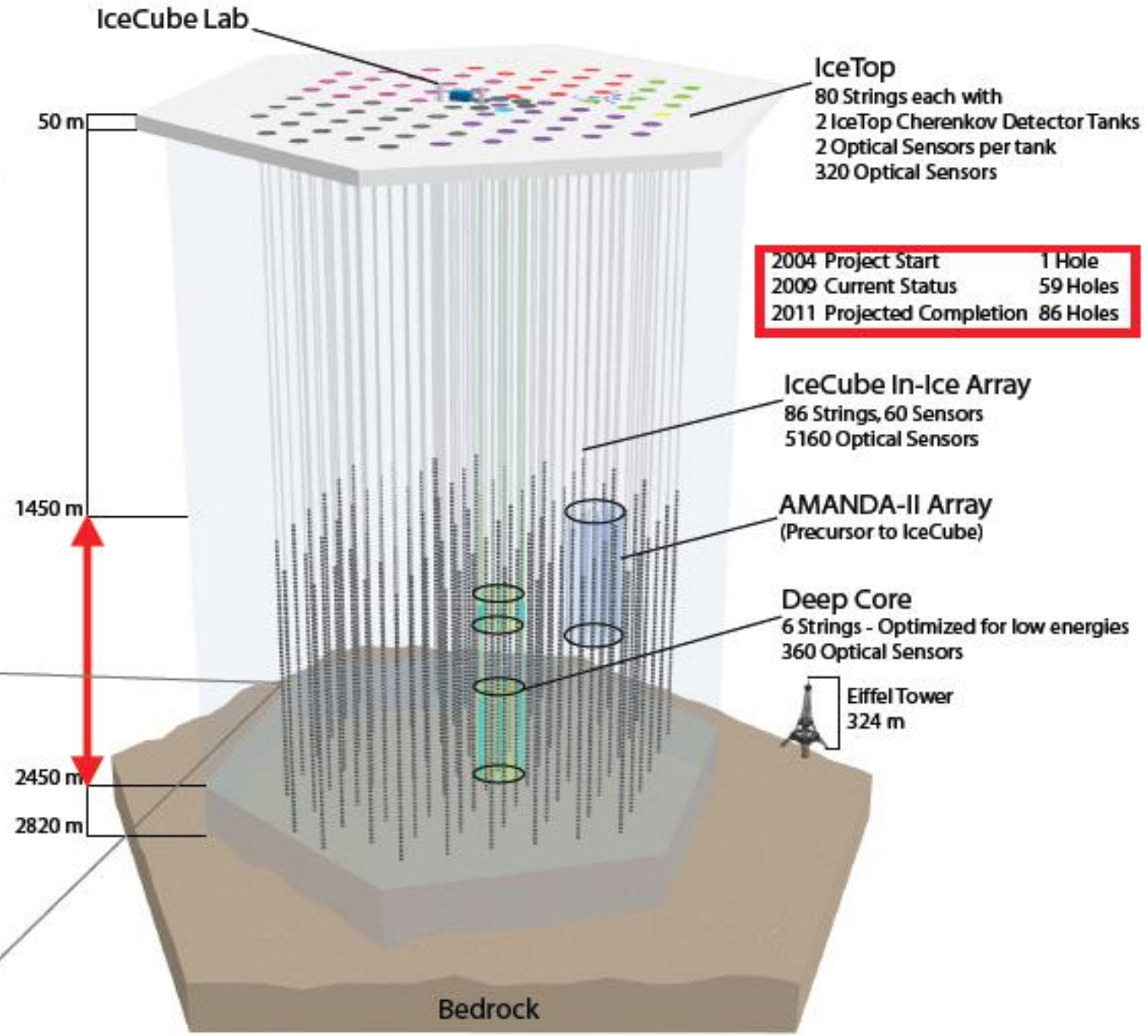




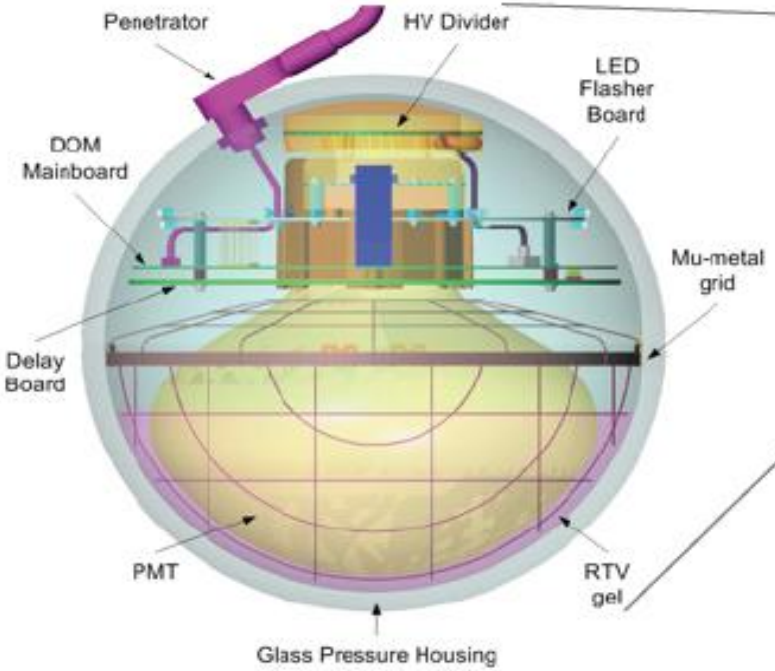
If the ultrahigh energy cosmic rays are **strangelets**, they can be accelerated *locally*

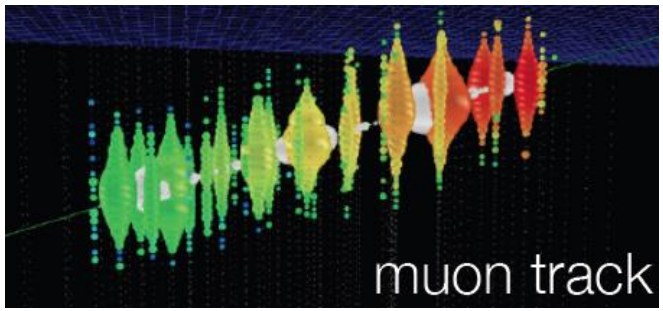
IceCube Observatory

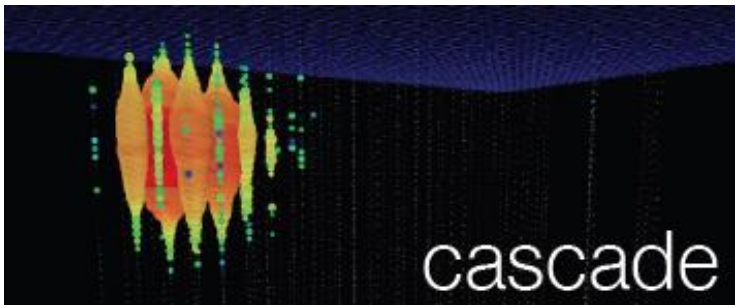
- 86 strings
- 5160 DOMs
- 17 m vertical spacing
- 125 m between strings



Digital Optical Module - DOM







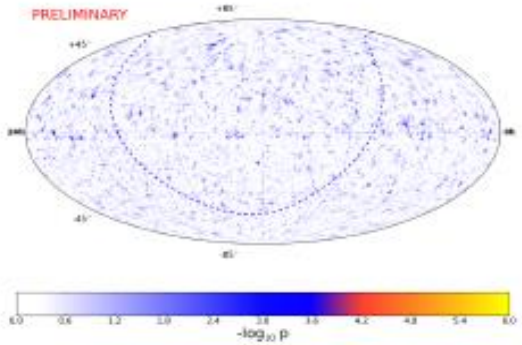
The IceCube Collaboration

39 Institutions ~ 250 Members

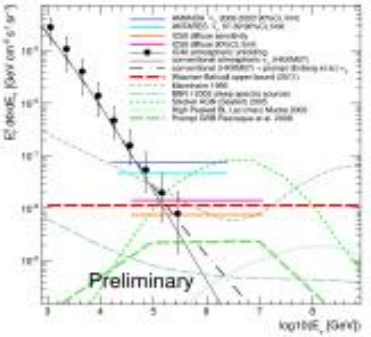
International Funding Agencies

Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
Federal Ministry of Education & Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

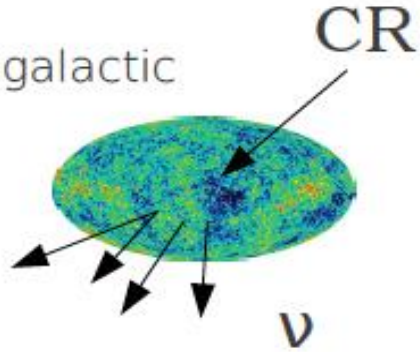
The IceCube physics program



Diffuse/ atmospheric



Search for an extragalactic neutrino signal



GZK neutrinos

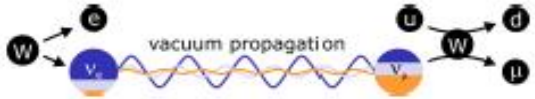
Point source

Search for point-like sources
→ galactic (e.g. SNR)
→ extragalactic (e.g. AGN)

Transient sources
→ GRB, flaring objects

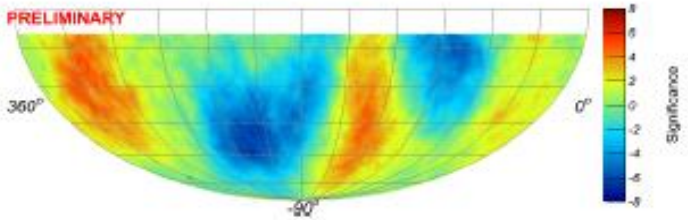
Optical follow-up programs

Prompt atms. neutrinos



Neutrino oscillations

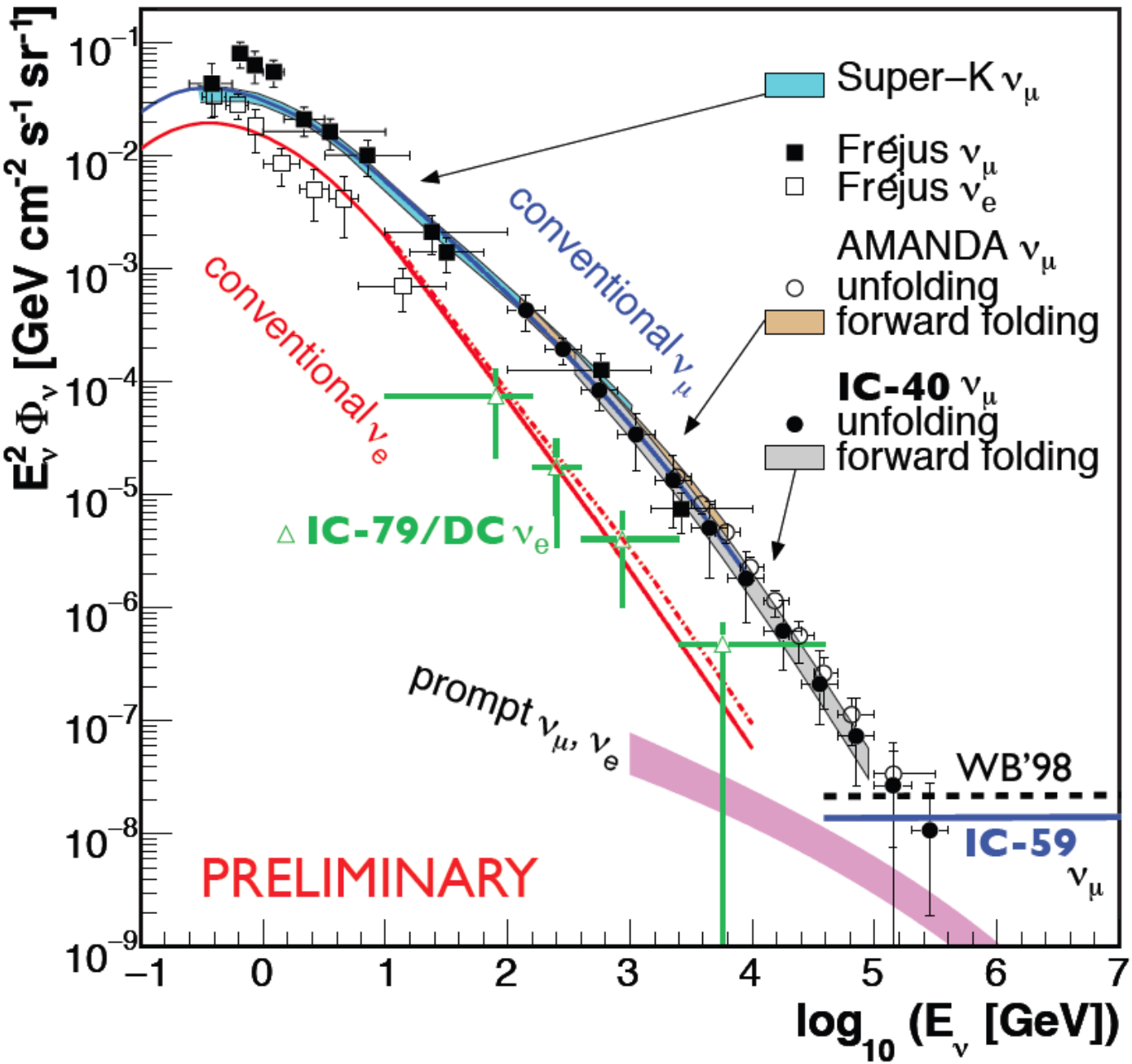
Cosmic ray physics



Dark Matter

Exotic particles

Measured atmospheric ν_μ spectrum constrains likely cosmic sources



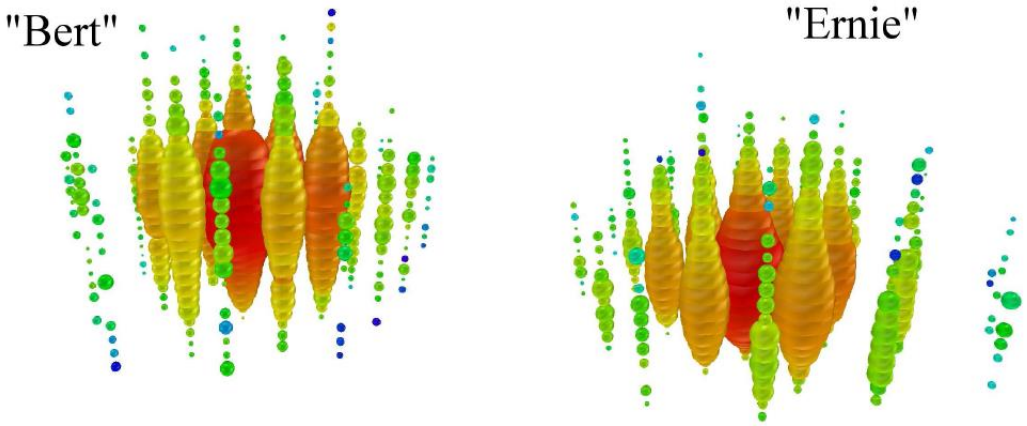
… e.g. IceCube rules out the 'Waxman-Bahcall' model for GRBs (Nature, 484:351, 2012) and is beginning to constrain the 'prompt' atmospheric neutrino flux (sensitive to low-*x* physics)

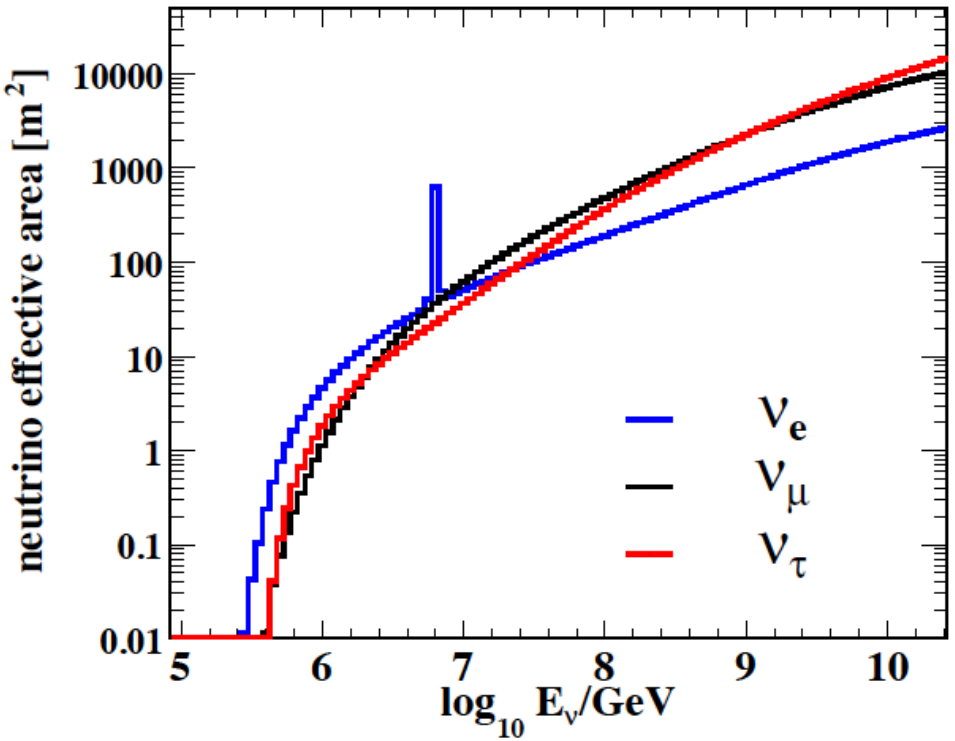
First observation of PeV-energy neutrinos with IceCube

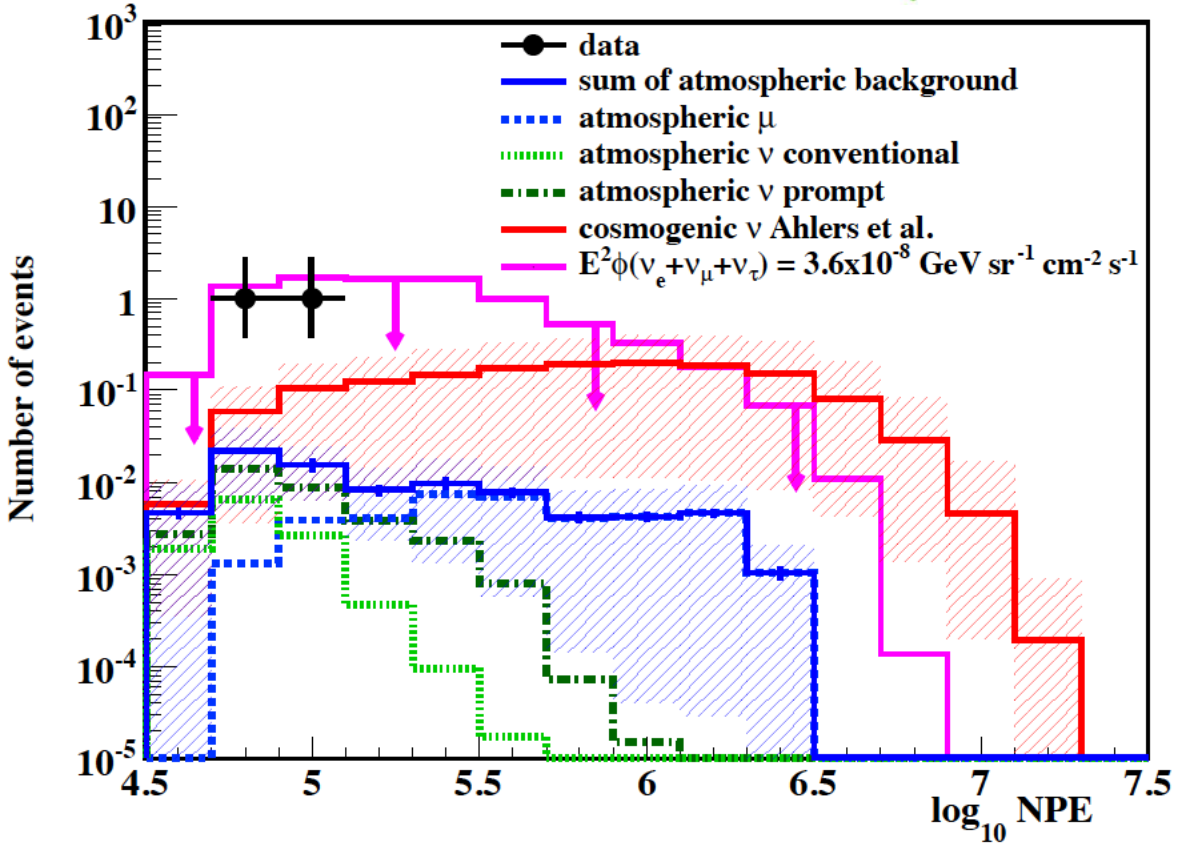
arXiv:1304.5356

Very *unlikely* to be from charm (produced in cosmic ray interactions in atmosphere) and the energies are below the 'Glashow resonance' … so are they cosmic in origin?

events	"Bert"	"Ernie"
date (GMT)	August 8, 2011	January 3, 2012
NPE	7.0×10^4	9.6×10^4
number of recorded DOMs	312	354
reconstructed deposited energy (PeV)	1.04 ± 0.16	1.14 ± 0.17
reconstructed z vertex (m)	122 ± 5	25 ± 5



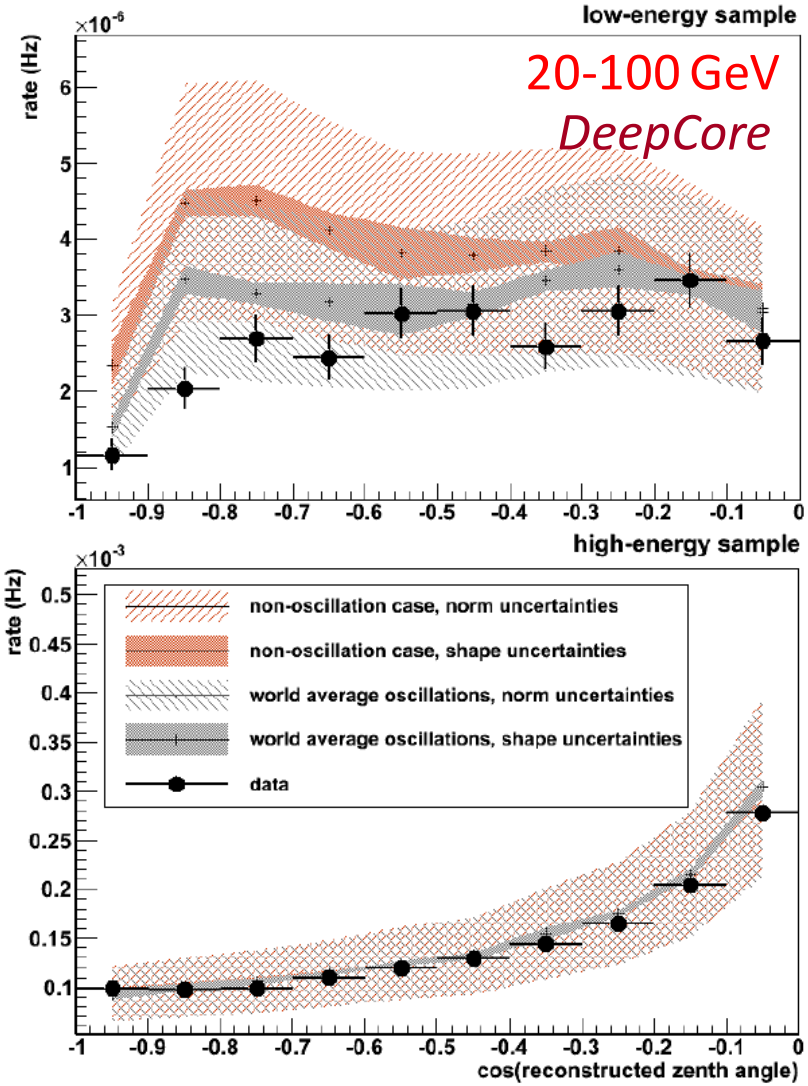


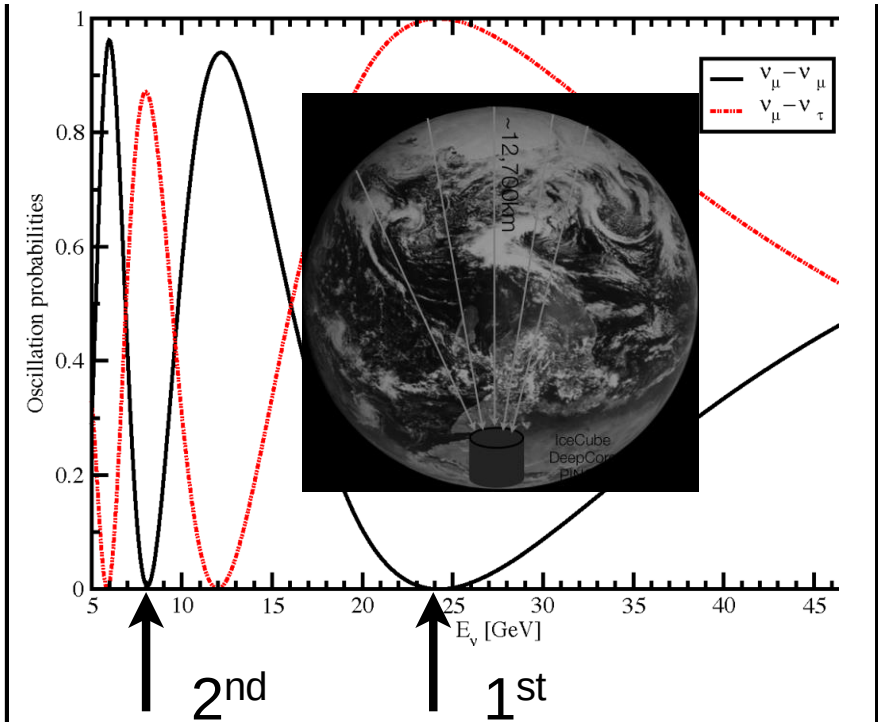


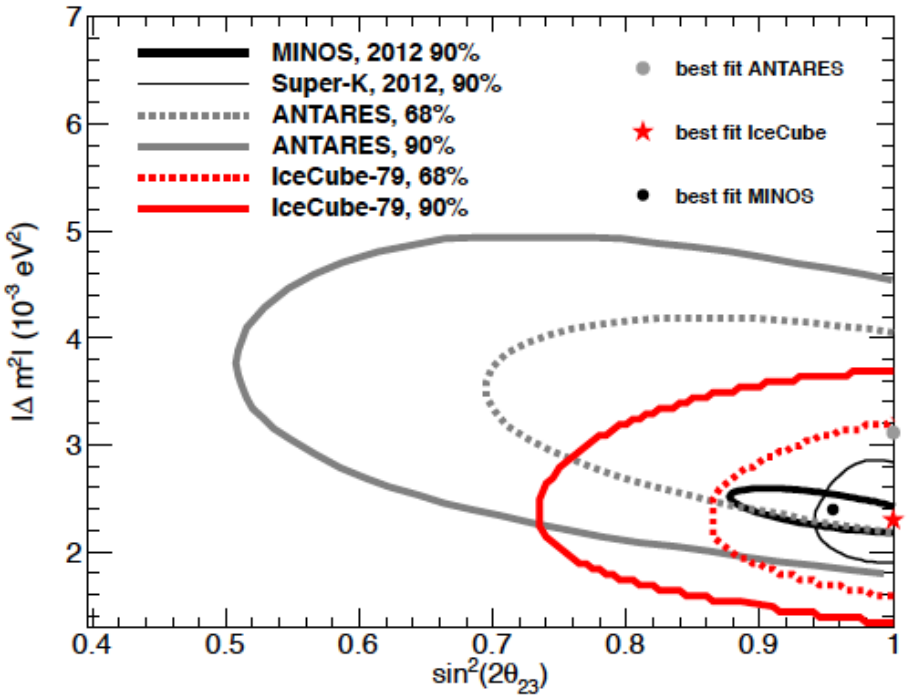
Measurement of Atmospheric Neutrino Oscillations with IceCube

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2(2\theta_{23}) \sin^2(1.27 \Delta m^2_{23} L/E)$$

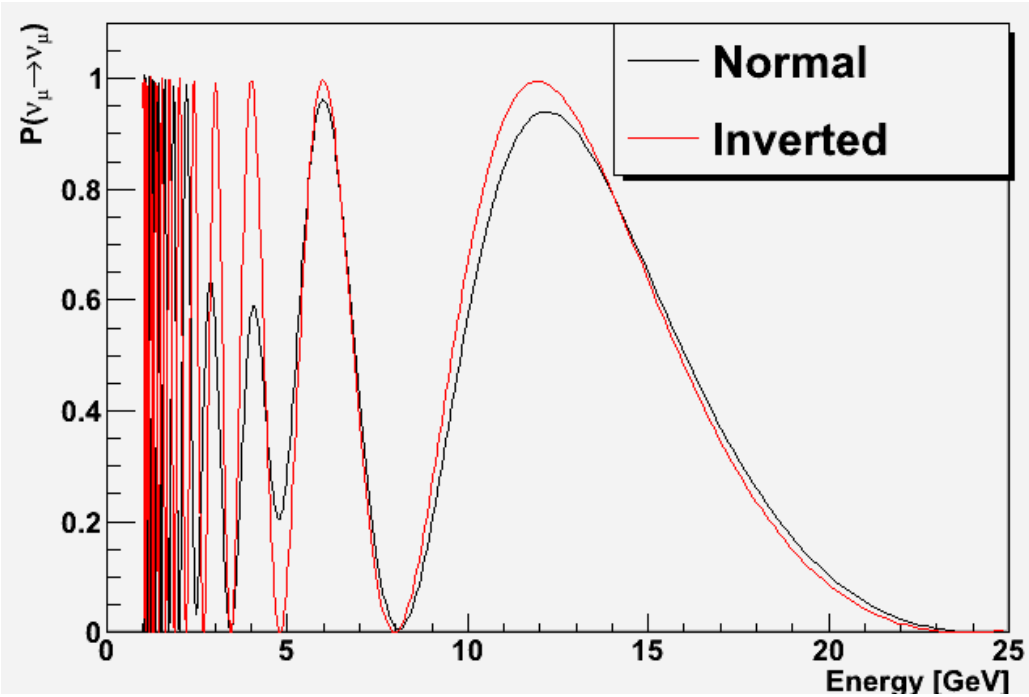
Atmospheric ν_μ from Northern hemisphere oscillating over the Earth's diameter have the oscillation minimum at ~25 GeV (detect with DeepCore infill array of IceCube)
⇒ distorted zenith angle distribution wrt no oscillations



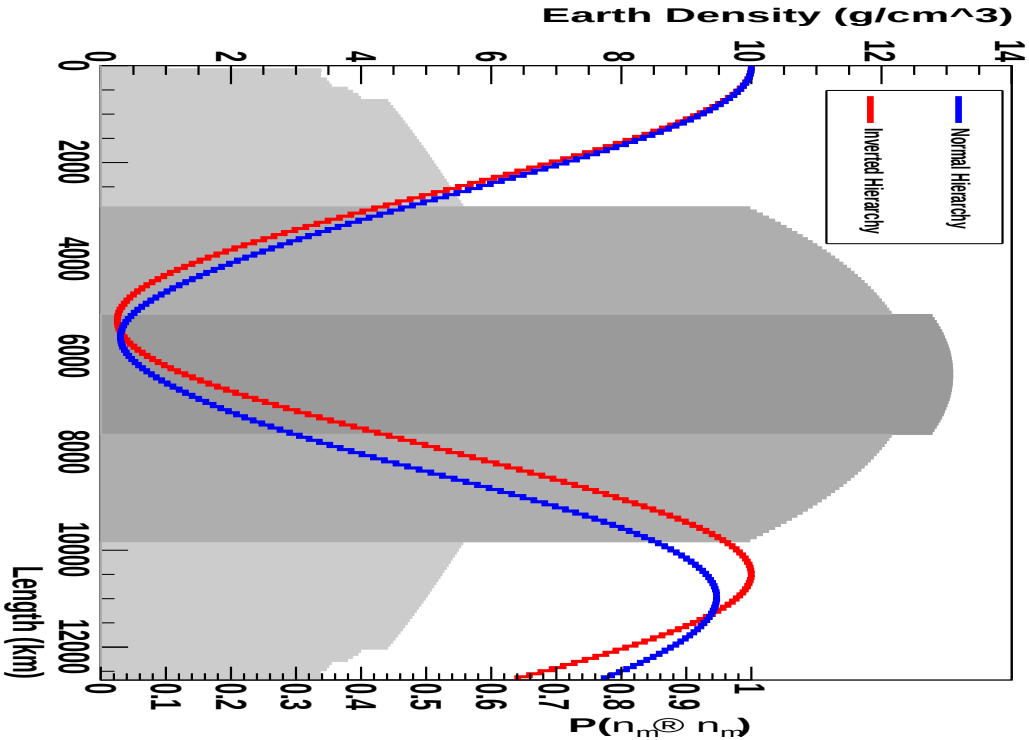


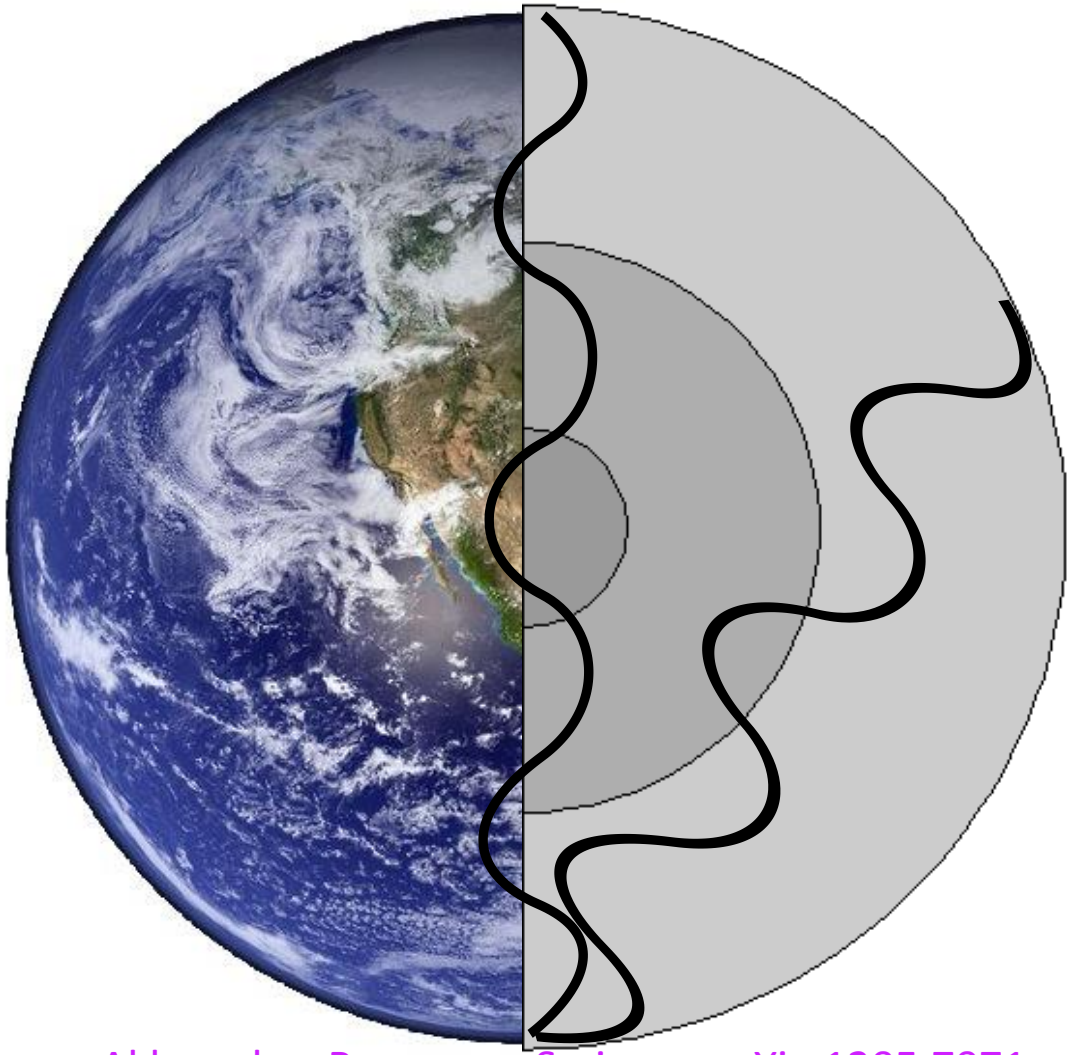


Lower energy threshold to ~few GeV in **Precision IceCube Next Generation Upgrade**



Inverted/Normal hierarchy has up to ~20% difference in ν_μ oscillation probability for specific energies and zenith angles (baselines), so can determine hierarchy *without* δ_{CP} dependence, exploiting huge statistical power afforded by a megaton scale detector





Akhmedov, Razzaque, Smirnov, arXiv:1205.7071

BBC NEWS

SCIENCE & ENVIRONMENT

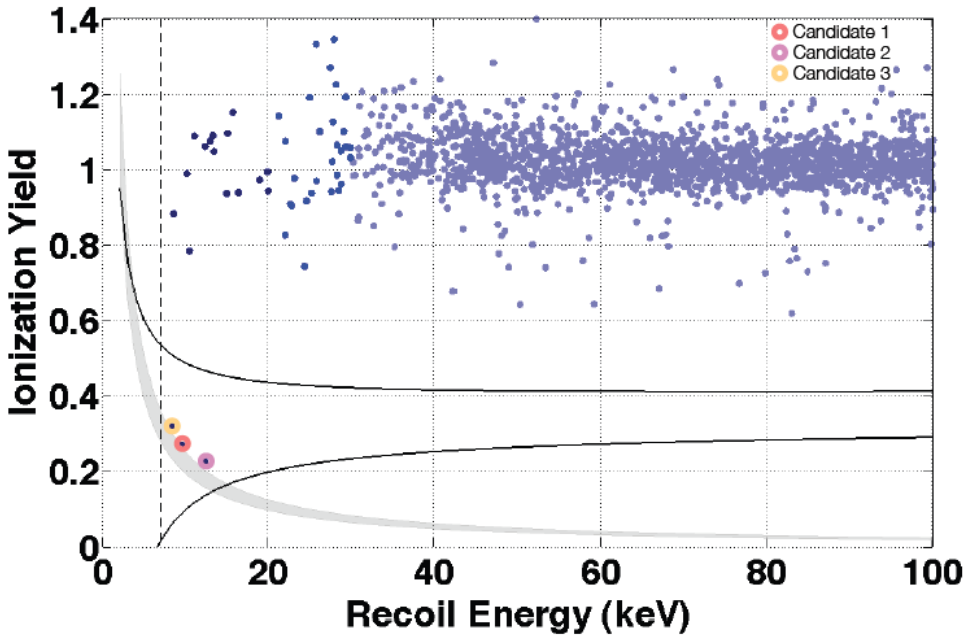
15 April 2013 Last updated at 21:08

Dark matter experiment CDMS sees three tentative clues

A major question for BSM theorists is the nature of the **dark matter** … while interest has mainly been focussed on *O*(100) GeV mass neutralinos in SUSY extensions of the SM, an alternative interesting possibility is that dark matter is *asymmetric* (just like baryons) and has a mass of *O*(5) GeV - perhaps arising from new strong dynamics in a hidden sector

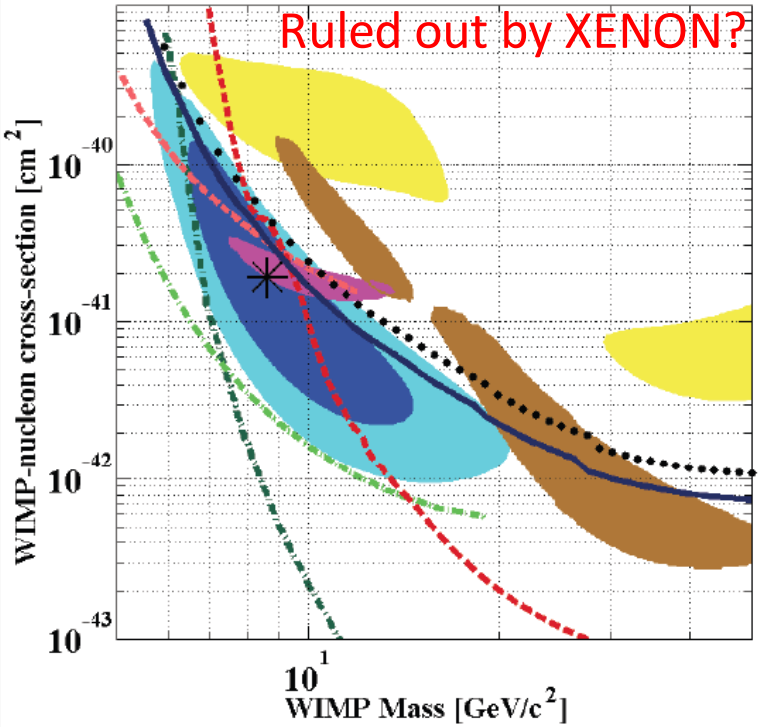
(Frandsen, Kouvaris, Sarkar, Sannino, Zwicky *et al*)

Unblinding Results - after timing cut



There have been hints of such particles from DAMA, CoGeNT, CRESST, … and now CDMS!

Profile Likelihood Confidence Intervals



- A profile likelihood analysis favors a WIMP+background hypothesis over the known background estimate as the source of our signal at the 99.81% confidence level (~3σ, p-value: 0.19%).
- We do not believe this result rises to the level of a discovery, but does call for further investigation.
- The maximum likelihood occurs at a WIMP mass of 8.6 GeV/c^2 and WIMP-nucleon cross section of 1.9x10^{-41}cm^2.

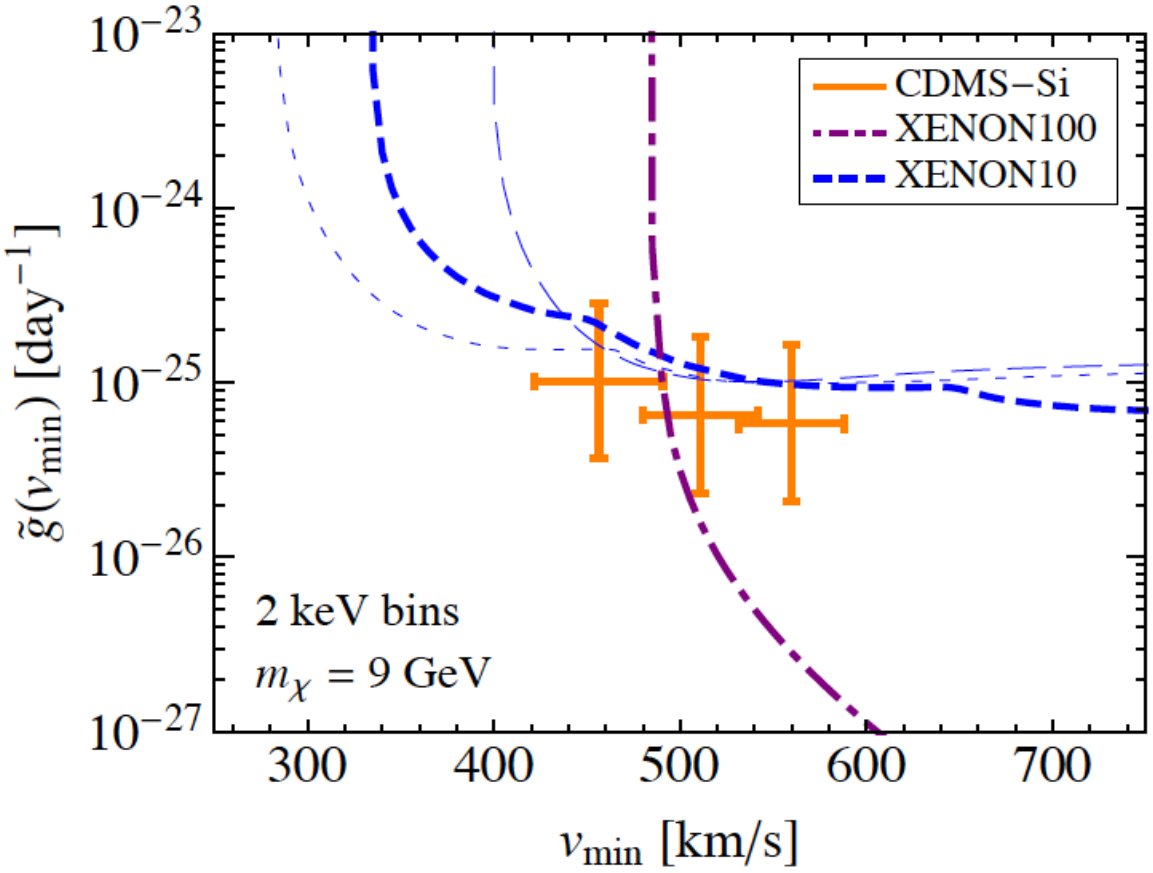
COGENT (2012)
CRESST-II final
DAMA (2008)
XENON100 (2012)
XENON10 S2 (2011)
CDMSII Ge low-E
CDMSII Ge (2010)
90% Upper limit, this data
90% Upper limit,CDMSII c34+c58 Si
68% C.L., this data
90% C.L., this data
Best fit, this data

The unbearable lightness of being: CDMS versus XENON

We find from a careful evaluation of the data that there is in fact consistency @ 90% CL

$$\frac{\mathrm{d}R}{\mathrm{d}E_R}(E_R,t) = M_{\mathrm{tar}}\frac{\rho_\chi}{2m_\chi\mu^2}\frac{(f_pZ+f_n(A-Z))^2}{f_n^2}\sigma_n F^2(E_R)\int_{v_{\mathrm{min}}}^{\infty}\mathrm{d}^3v\,\frac{f_{\mathrm{local}}(\vec{v},t)}{v}$$

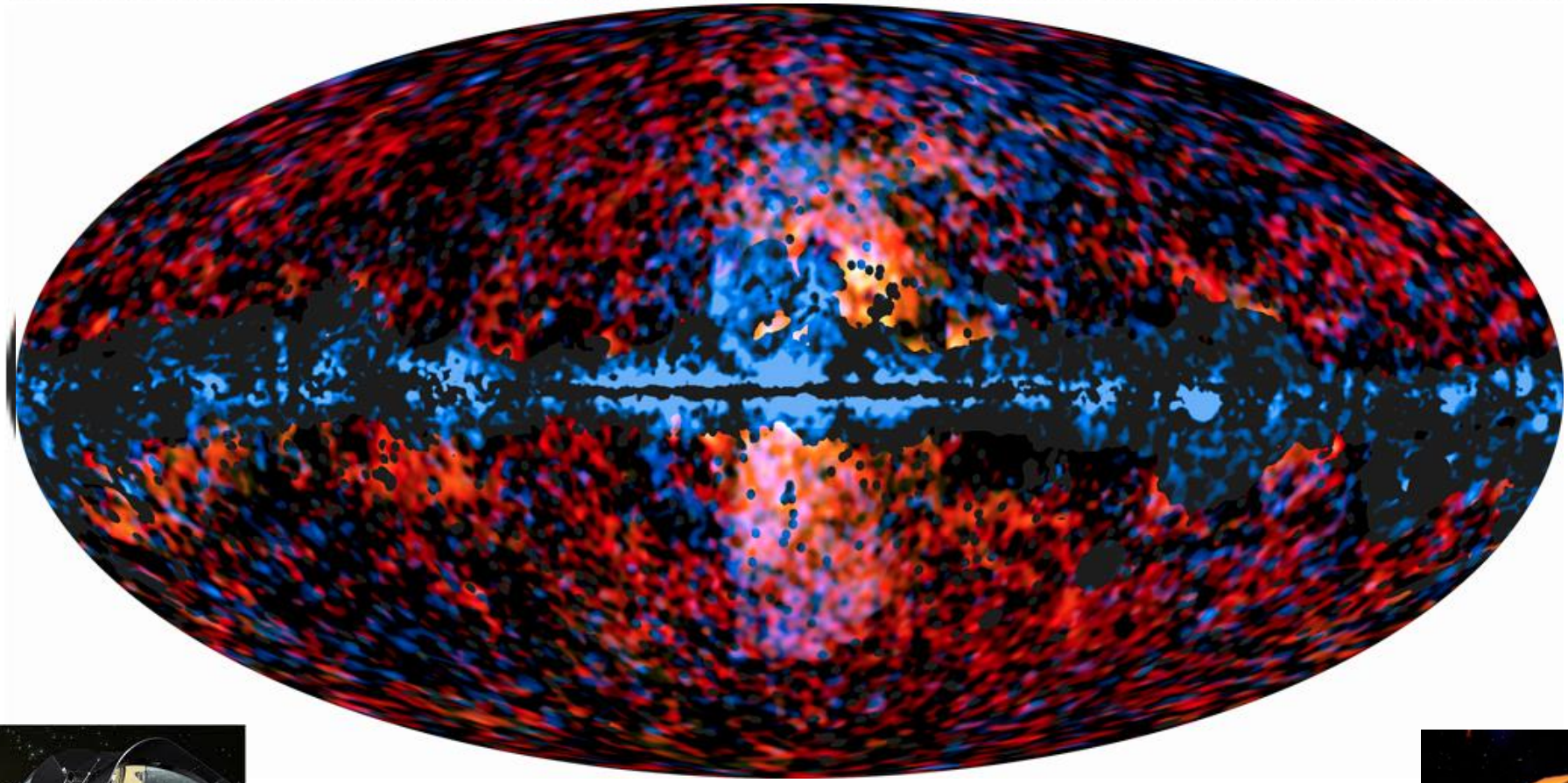
Particle physics — Nuclear physics — astrophysics



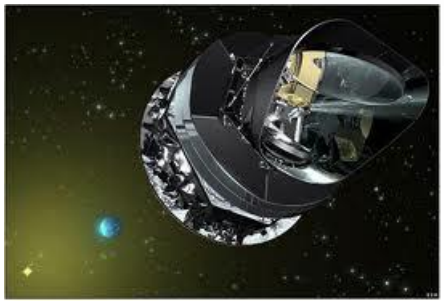
Frandsen *et al*, arXiv:1304.6066

Modification of the DM couplings, e.g. setting f_n/f_p = -0.7, can desensitise Xenon wrt Silicon

The mysterious Galactic Haze seen by Planck



Planck Collaboration, arXiv:1208.5483



Planck sky at 33 and 44 GHz, superimposed on Fermi sky at 10-100 GeV, revealing giant 'bubbles' in centre of Galaxy … has been attributed to **dark matter** annihilation

But need better understanding of astrophysical particle acceleration & foregrounds

Summary

The ***non-thermal universe*** revealed by high energy cosmic radiation provides new probes of fundamental physics and cosmology

Radio, X-ray, and γ-ray astronomy have yielded dramatic discoveries of many new phenomena … and neutrino astronomy is about to open up

The *dark universe* presents another challenge, to unravel which needs progress in both experiment/observation and BSM theory

This is an opportune time for Denmark to become involved in the world's biggest neutrino observatory (➥ **IceCube)** which addresses both astronomy and particle physics

"The real voyage of discovery consists not in seeking new landscapes but in having new eyes"

Marcel Proust