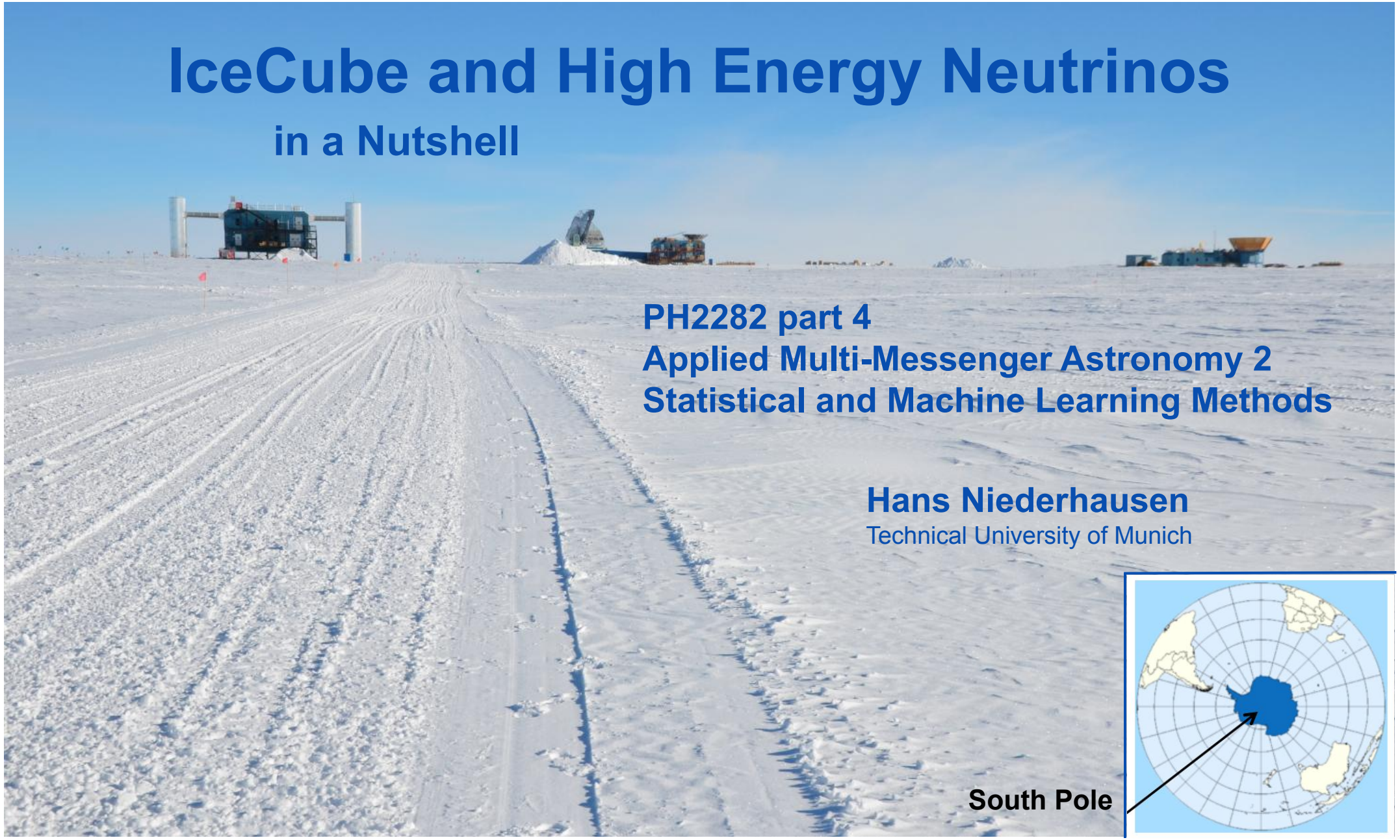
IceCube and High Energy Neutrinos

in a Nutshell



PH2282 part 4
Applied Multi-Messenger Astronomy 2
Statistical and Machine Learning Methods

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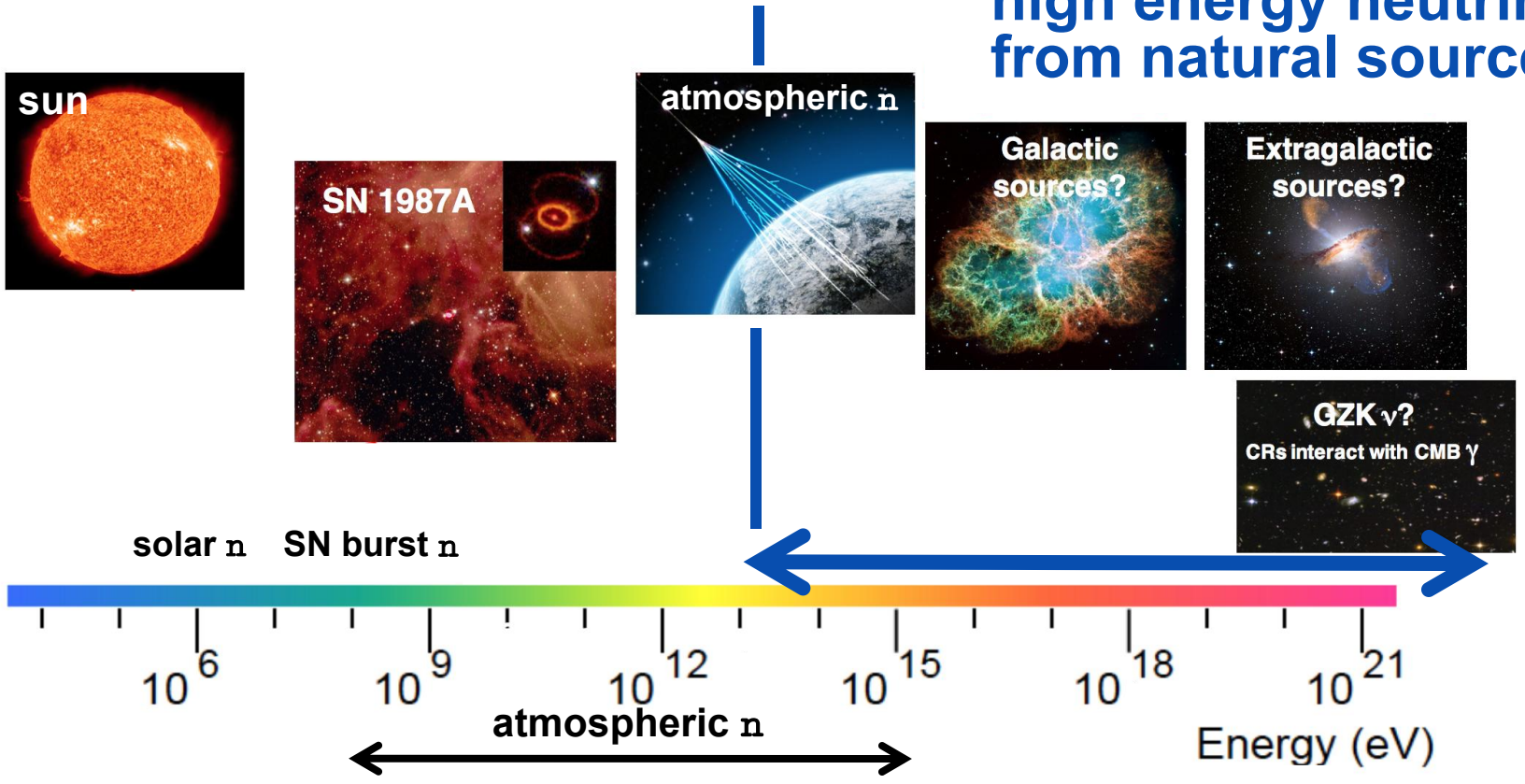
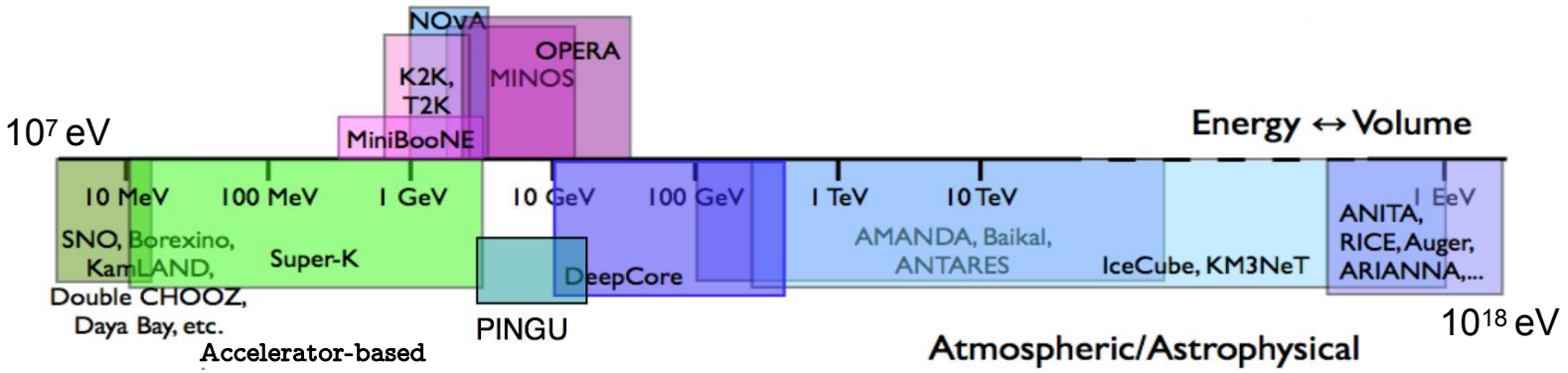
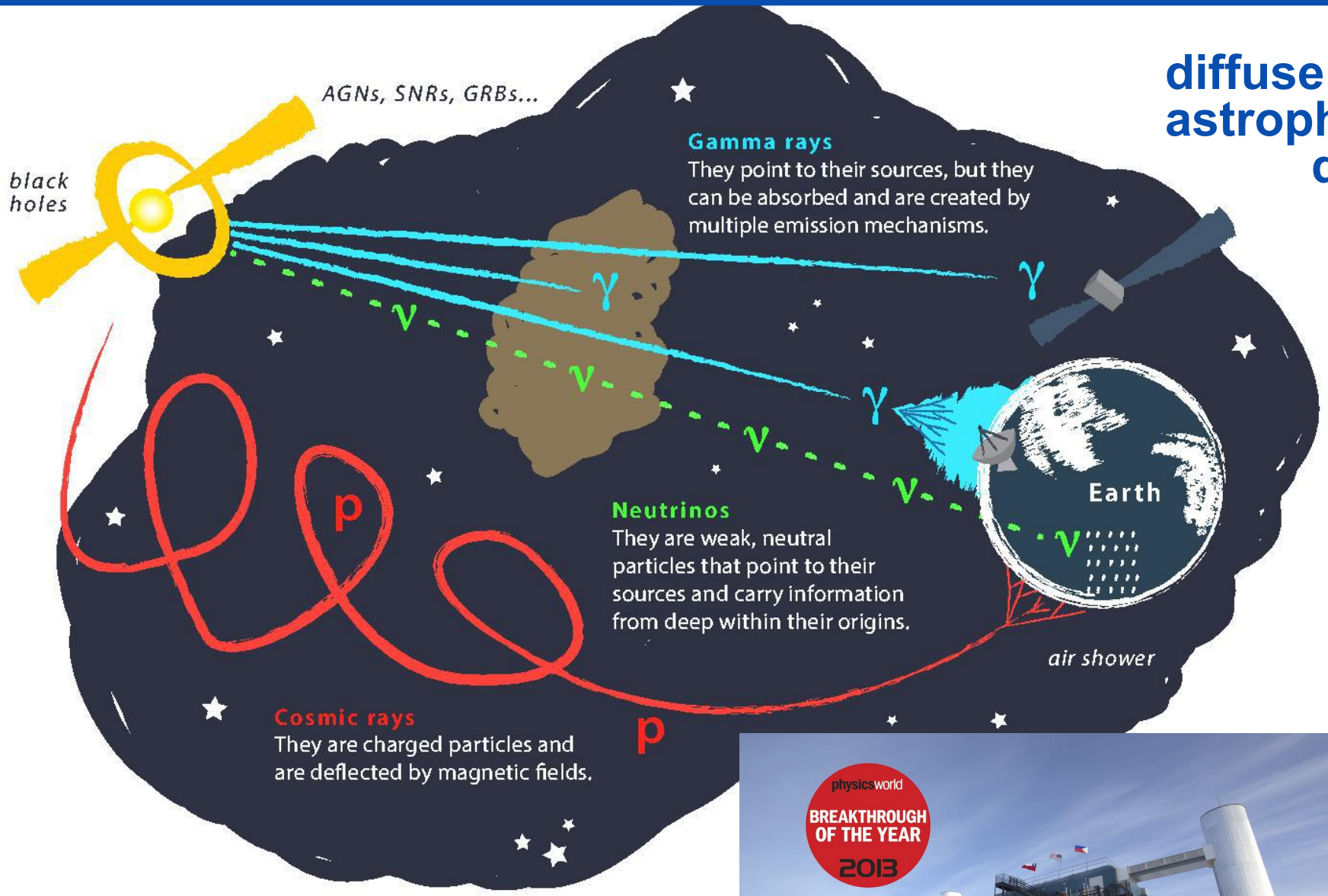
Technical University of Munich

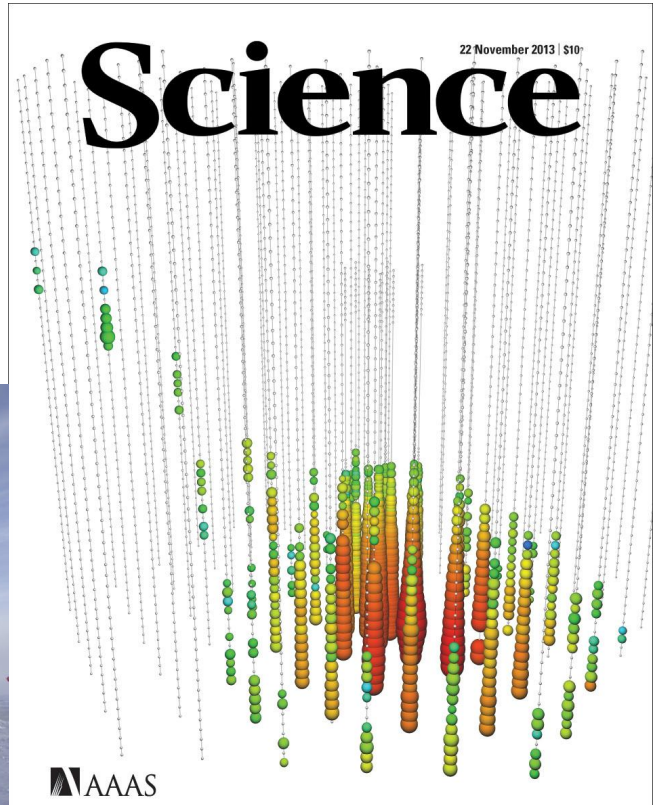
high energy neutrinos from natural sources

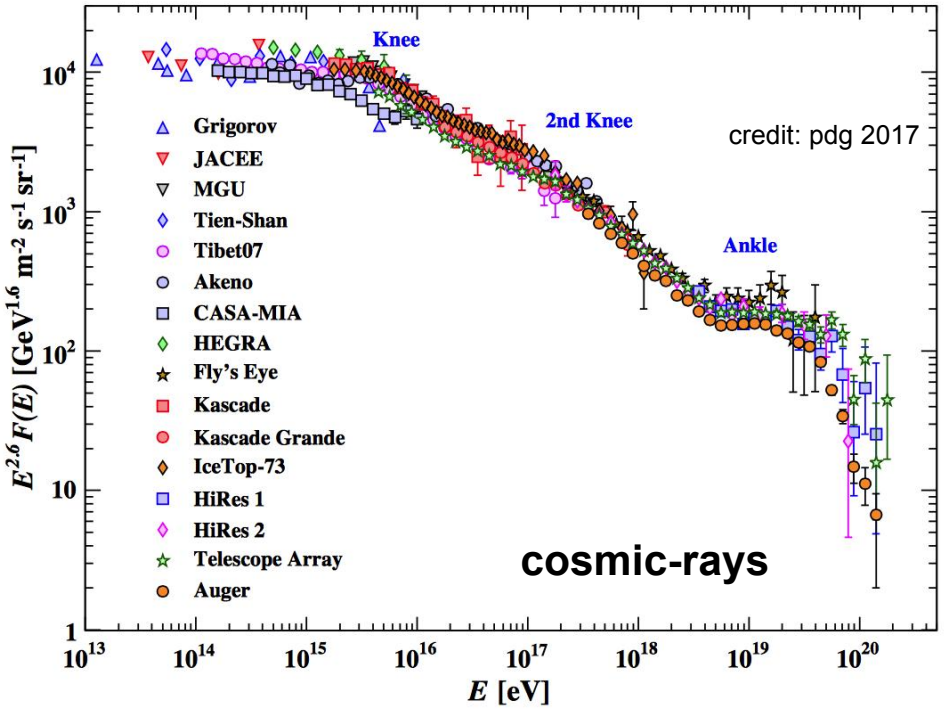




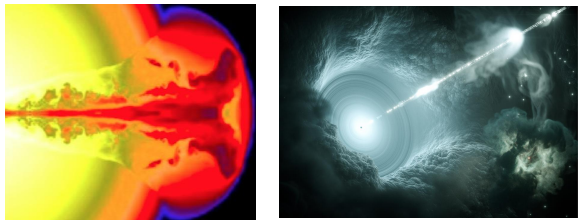
diffuse flux of high energy astrophysical neutrinos discovered in 2013







at high energies:



AGNs?

"The Cosmic Ray Connection"

production of astrophysical neutrinos

TeV – PeV neutrinos from decays of charged mesons (pions)

$$p + p \rightarrow N\left[\pi^0 + \pi^+ + \pi^-\right] + X$$

$$p + \gamma \rightarrow \Delta^+ \rightarrow \begin{cases} n + \pi^+ & \frac{1}{3}\ of\ all\ cases \\ p + \pi^0 & \frac{2}{3}\ of\ all\ cases \end{cases}$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \rightarrow \left(e^+ + \nu_e + \bar{\nu}_\mu\right) + \nu_\mu$$

two guaranteed contributions

neutrino-production at high energy sources

neutrino-production during cosmic ray propagation

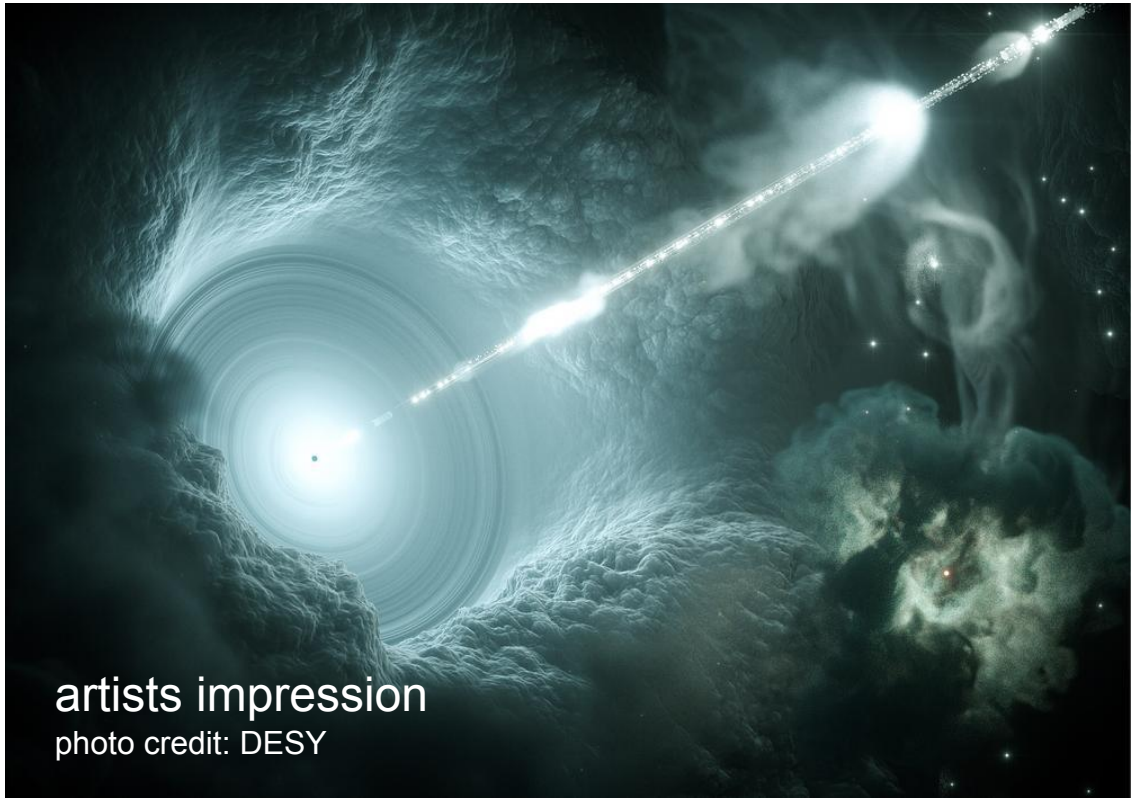
(more exotic scenarios possible)

"diffuse neutrino-flux = sum neutrino-flux from all sources"

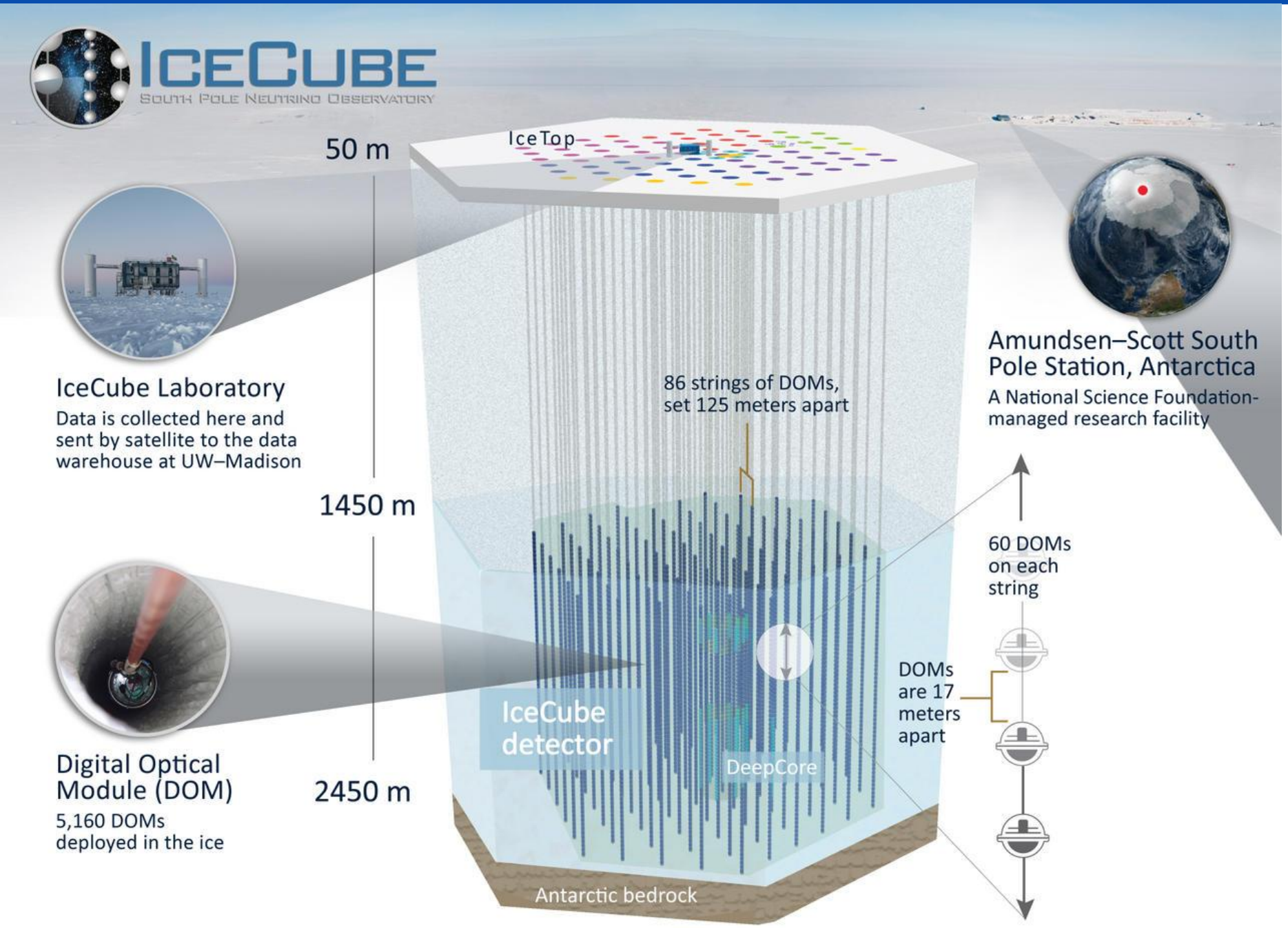
many sources, large extra-galactic distances

diffuse neutrino-flux approximately isotropic

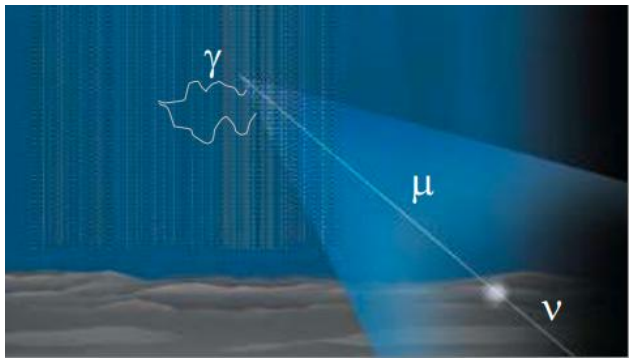
equal contributions from all neutrino-flavors



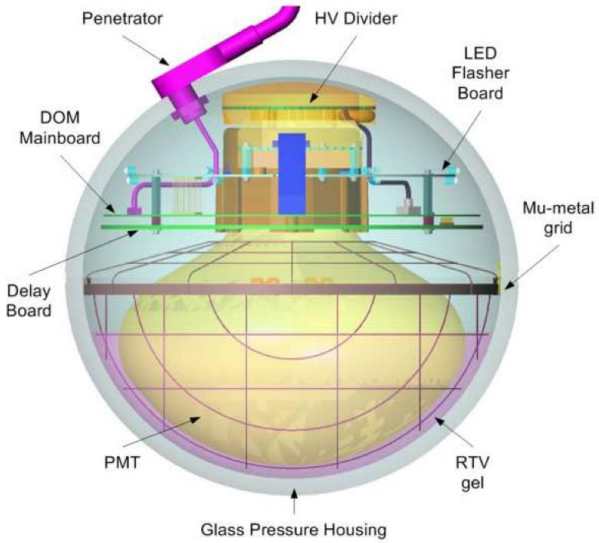
- neutrino production during acceleration of protons
- diffusive shock acceleration (Fermi)
- naively predicts powerlaw spectrum
- spectral index of ~2



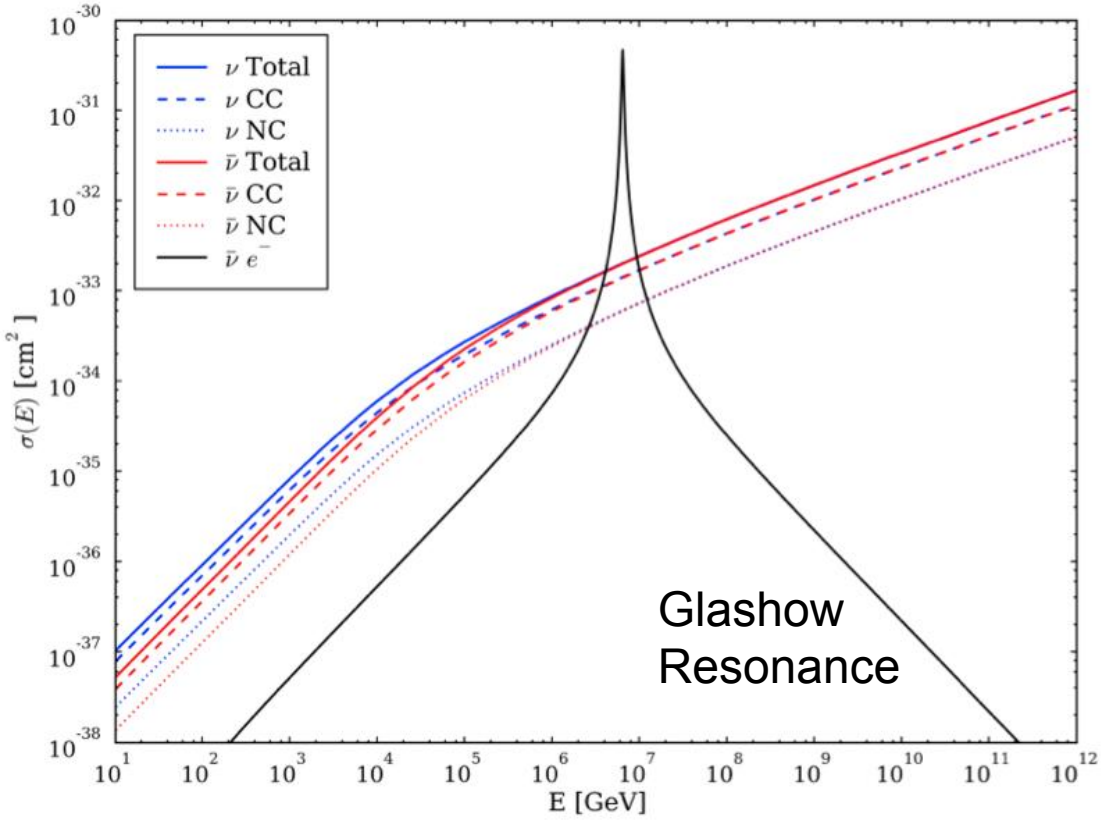
Designed to detect **Cherenkov Light**

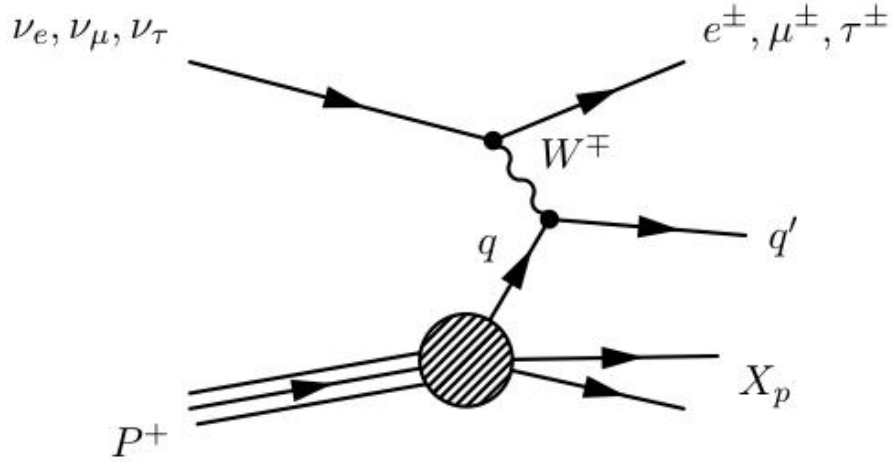


Infer neutrino properties from photon **arrival time distributions** in each optical module (DOM)

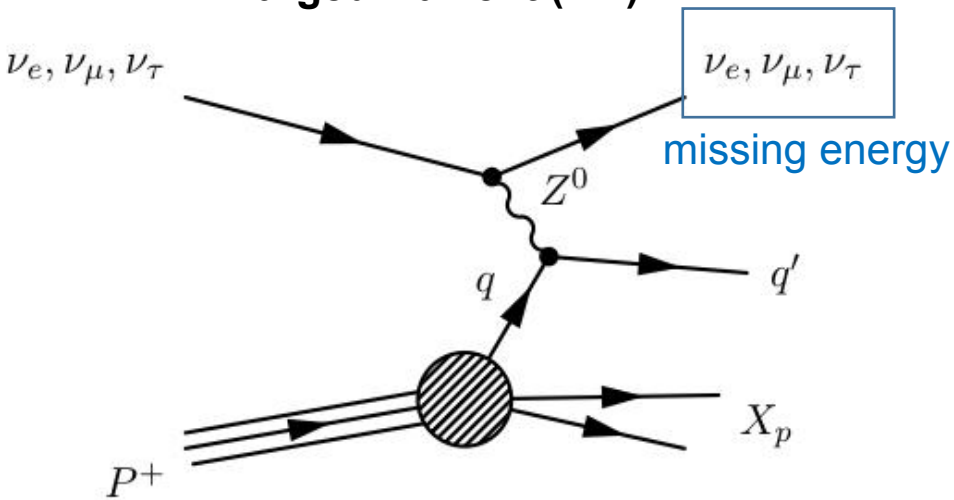


Dominant Neutrino Interaction in IceCube:
Deep Inelastic Neutrino – Nucleon Scattering (DIS)

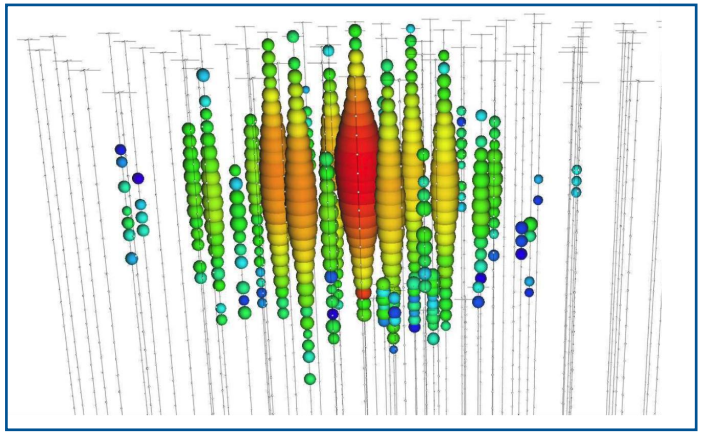




Charged Current (CC)



Neutral Current (NC)



cascades

CC: $\nu_e(\nu_t)$ + N --> e(t) + hadrons

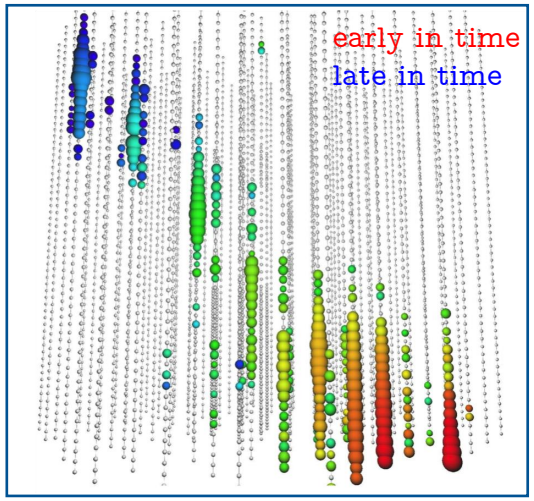
NC: $\nu_e(\nu_m, \nu_t)$ + N --> $\nu_e(\nu_m, \nu_t)$ + hadrons

point-like light emission

angular resolution >10°

good energy resolution

~15% if contained



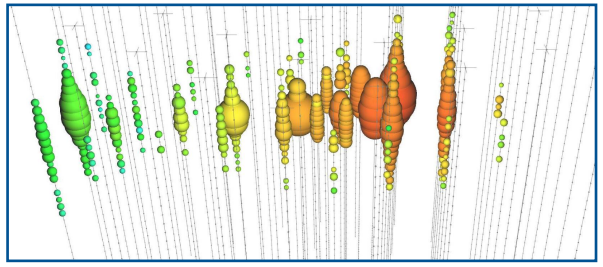
through-going tracks

ν_m + N - -> m + hadrons (CC)

pointing resolution <1°

m energy resolution

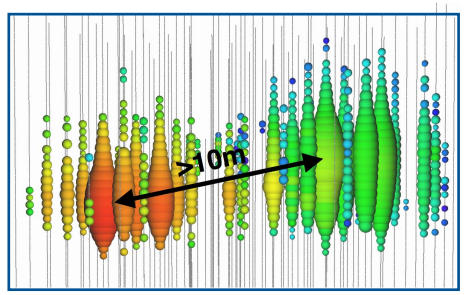
~ factor of 2



starting tracks

(cascade + track)

ν_m + N --> m + hadrons (CC)

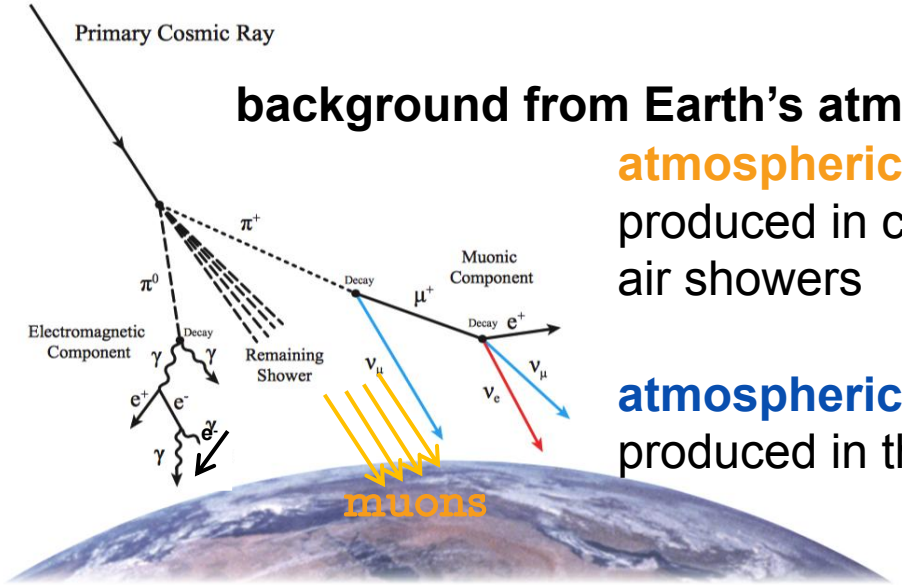


double cascades/bangs

ν_t + N --> t + hadrons (CC)

ν_t + hadrons

(and more …)



background from Earth's atmosphere

atmospheric muons
produced in cosmic ray air showers

1/10⁶

atmospheric neutrinos
produced in the same showers

conventional n
decay of p/K mesons

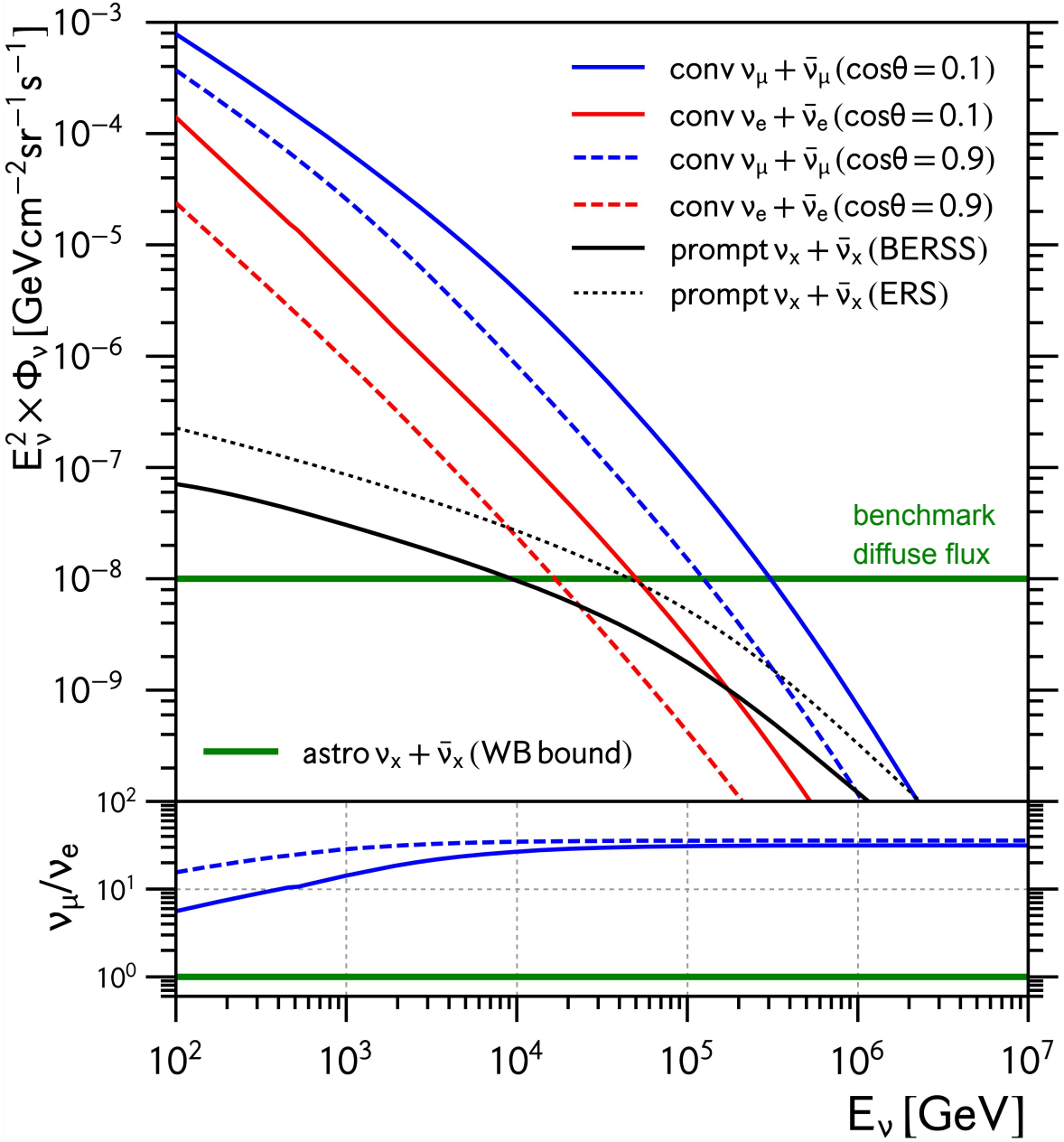
n_m dominates
n_e suppressed

behaves as ~$E^{-3.7}$
flux largest at horizon

prompt n
decay of heavier mesons (charm)
(not identified yet)

$n_m : n_e \sim$ (1:1)

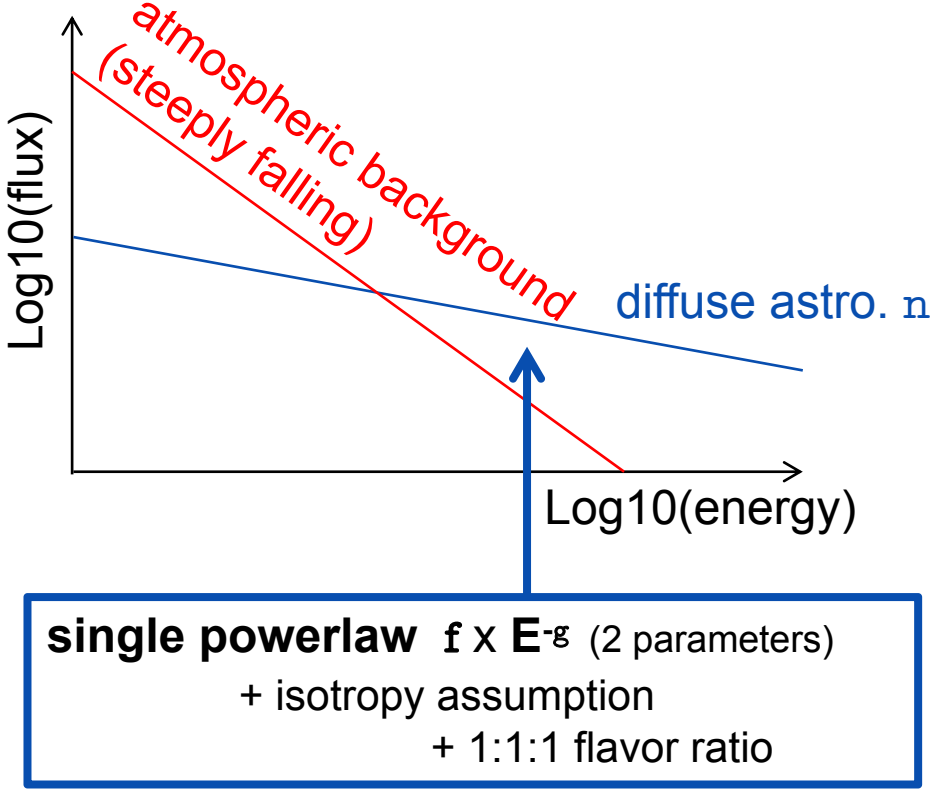
behaves as ~$E^{-2.7}$
flux isotropic



analysis method

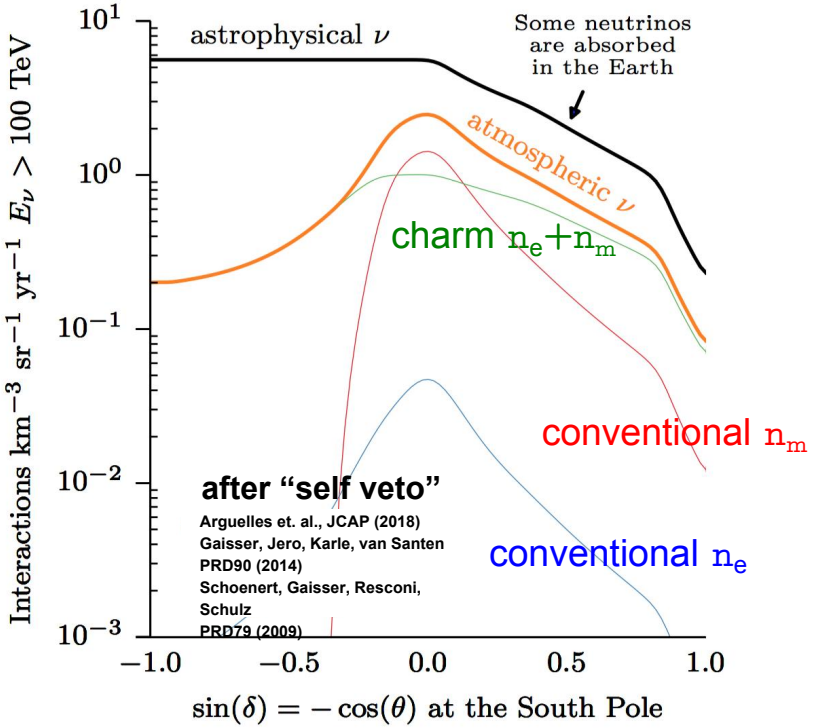
study **excess of high energy events** over atmospheric expectation

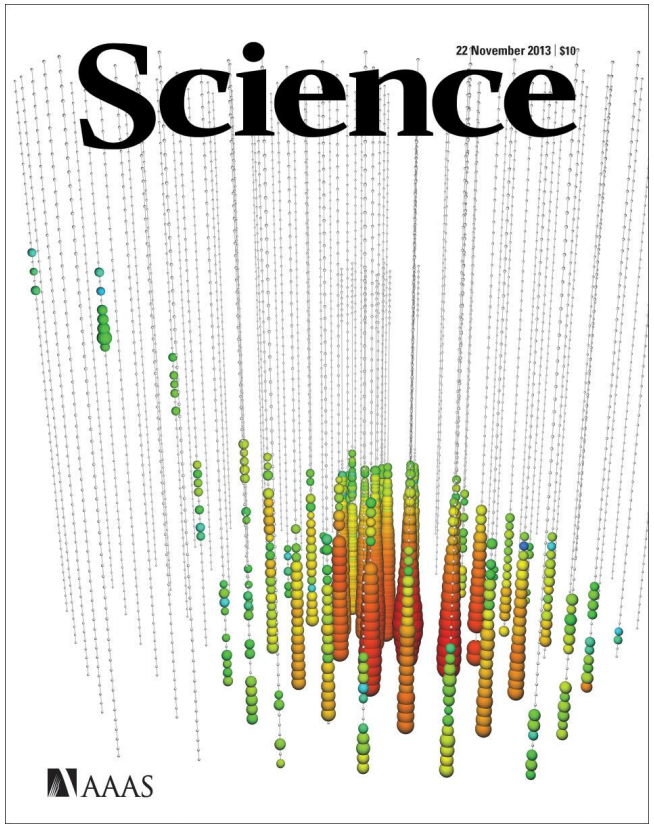
harder spectrum + **different angular distribution**

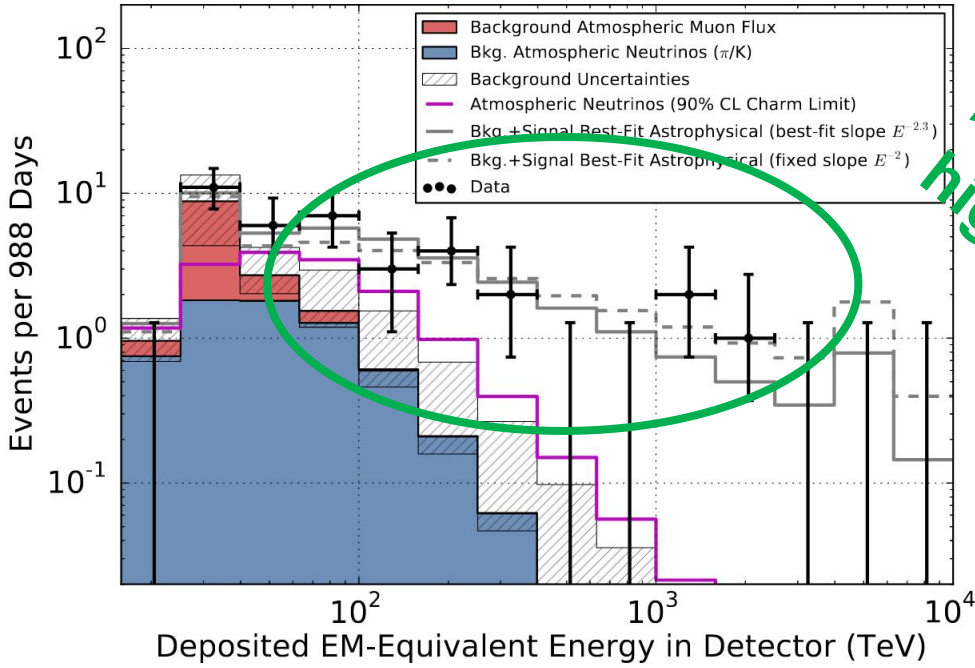


suppression of atmospheric n in southern sky

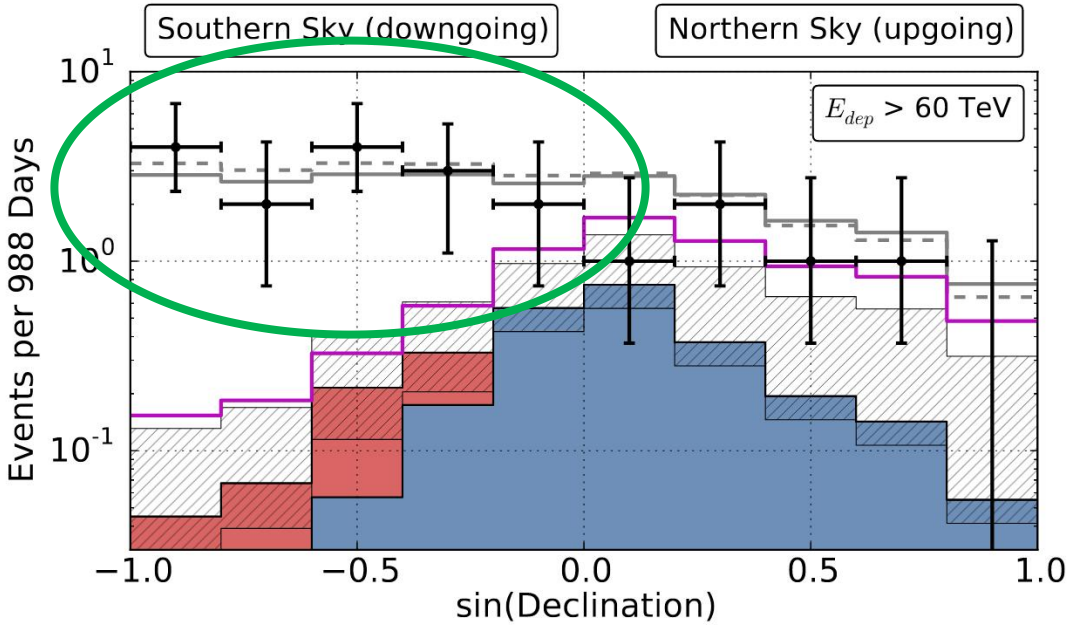
as by-product of muon rejection (starting events)







> 5 sigma excess in high energy tail



this analysis used standard maximum likelihood methods

modeling of IceCube observables non-trivial

requires extensive Monte Carlo simulations of the detector response to neutrino interactions

plan for today

- **understand this type of analysis**
- **use a simplified MC generation code to predict observables (discussed next)**
- **implement a MC based maximum likelihood analysis**
- **“discover” the tail of high energy neutrinos in a pseudo dataset**