

Exploring the Universe at the Highest Energies.

Astroparticle Physics at DESY

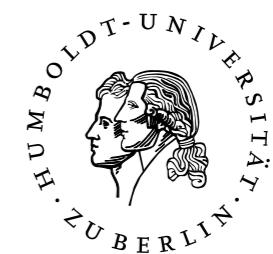
Gernot Maier, Alexander Kappes

DESY Astroparticle Forum

DESY-Hamburg/Zeuthen, 8./9. Nov. 2011



H U M B O L D T - U N I V E R S I T Ä T Z U B E R L I N



Outline

- Astroparticle physics at DESY – Introduction *A. Kappes*
 - Cosmic messengers and the high-energy universe
 - Astroparticle physics at DESY
- Exploring the universe with neutrinos *A. Kappes*
 - The IceCube neutrino observatory
 - Selected results
- Very high-energy gamma-ray astronomy *G. Maier*
 - Imaging Cherenkov telescopes: VERITAS and CTA
 - High-energy emission from the Crab pulsar

Astroparticle Physics at DESY – Introduction.

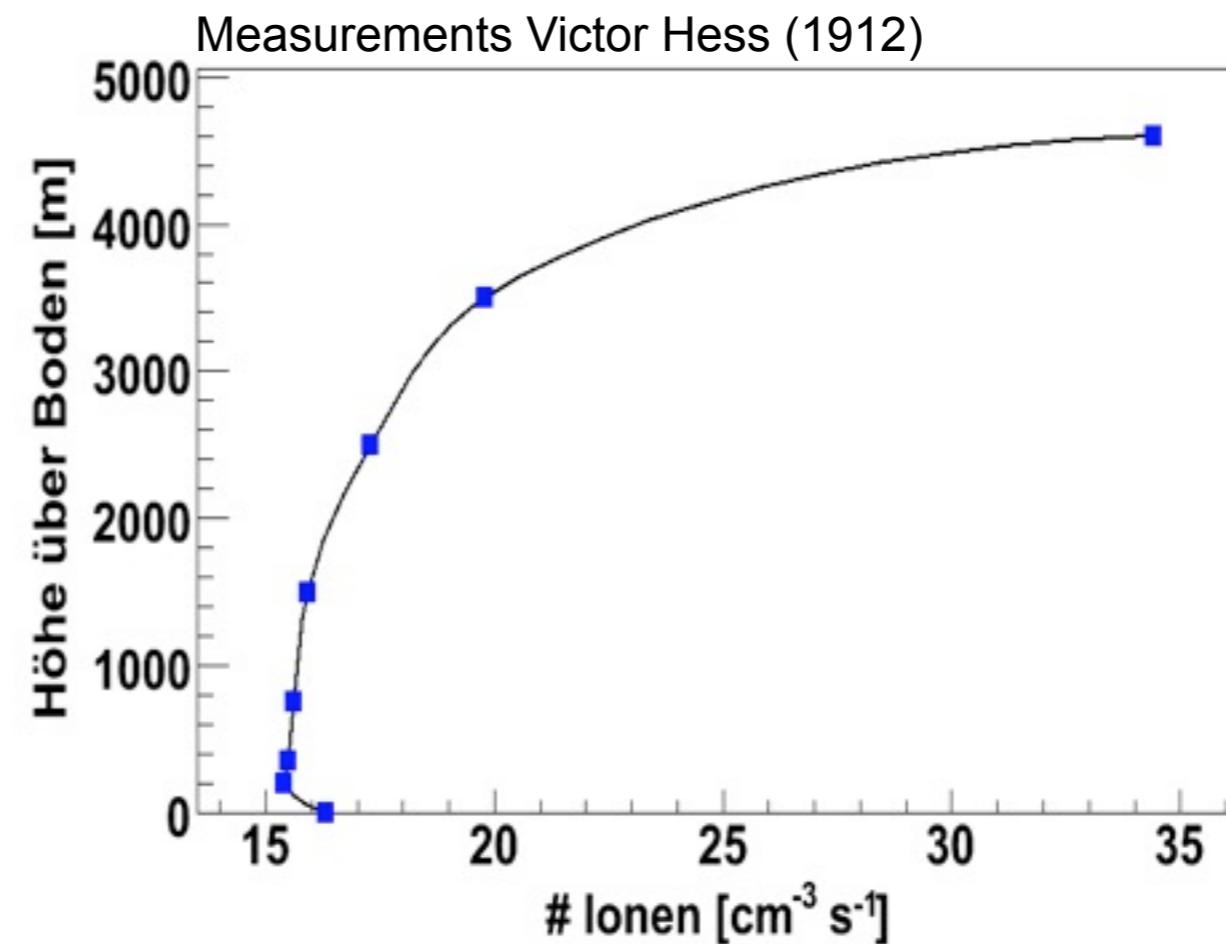


1912: Discovery of cosmic rays (Victor Hess)

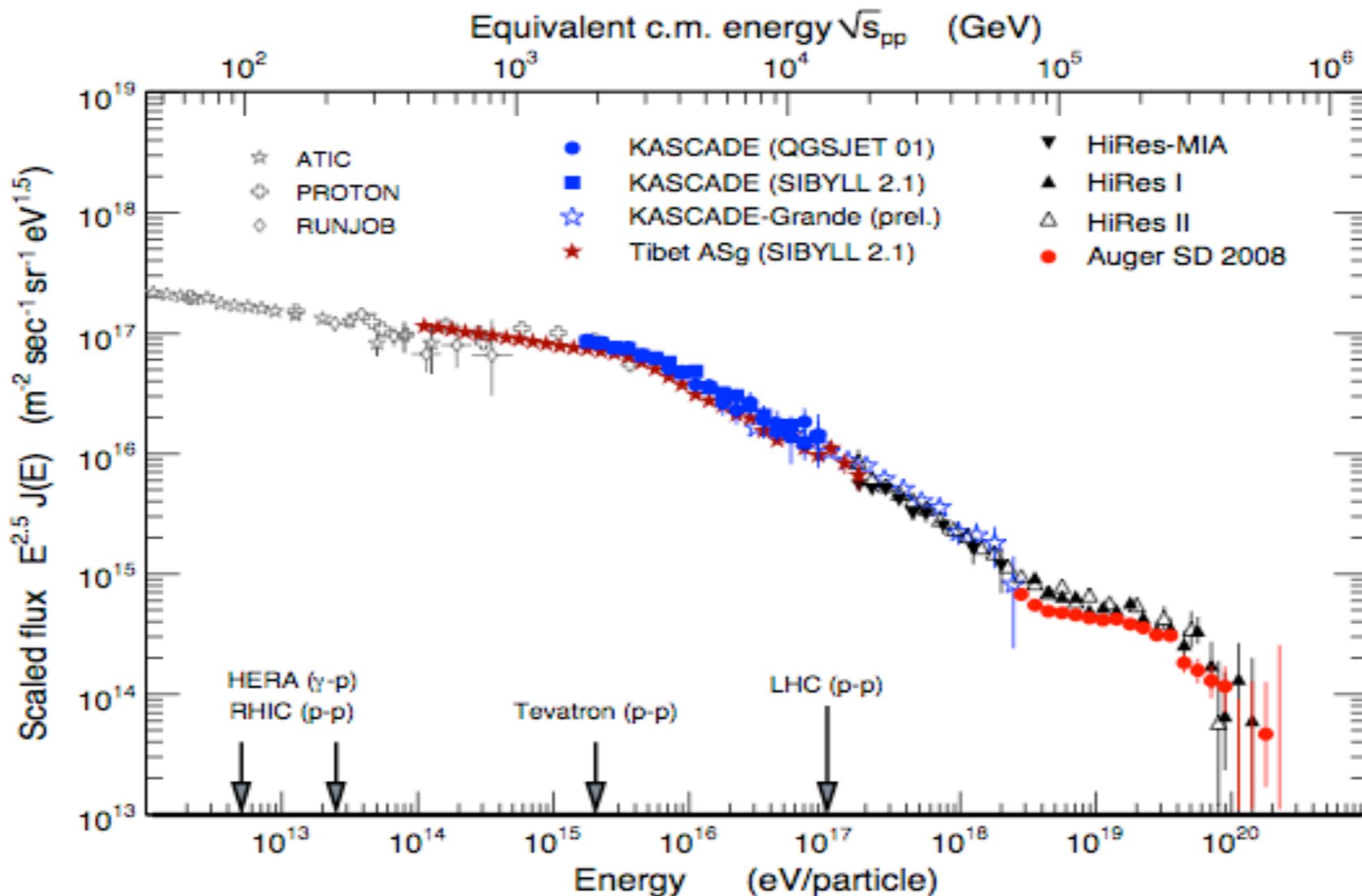
Balloon experiments (Hess, Kolhörster):



Victor Hess



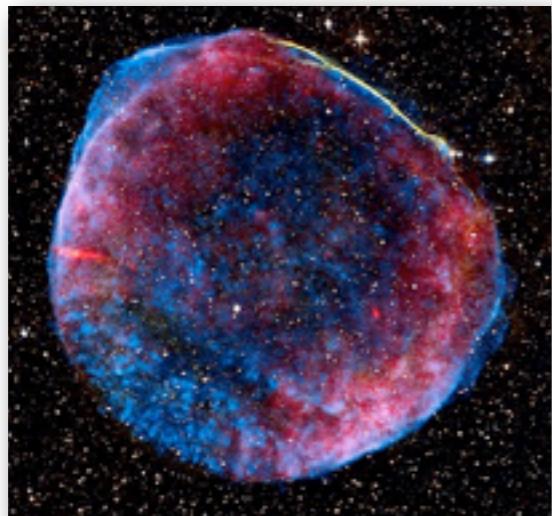
... 99 years later



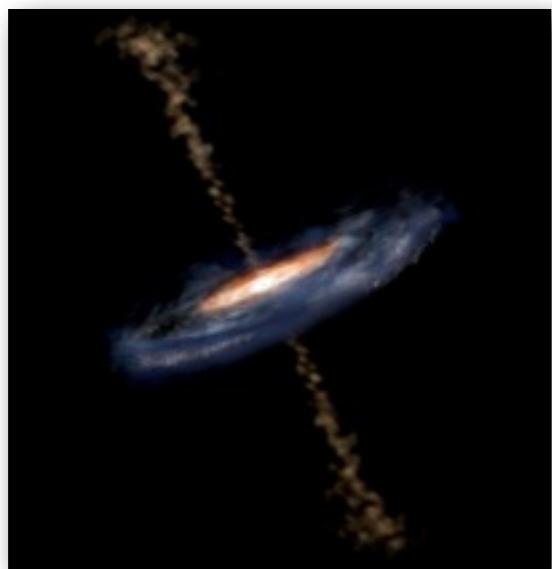
What and where are the accelerators ?

The high-energy universe

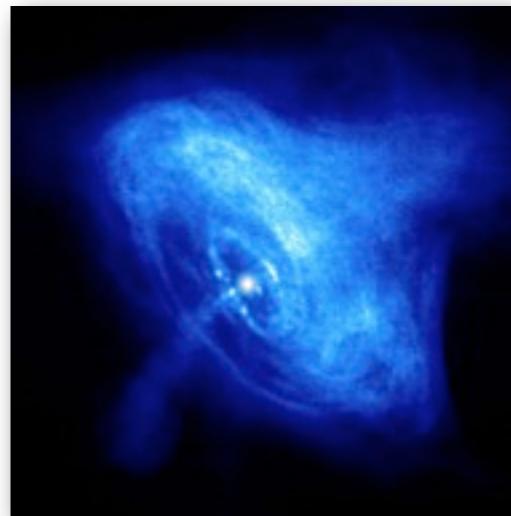
supernova remnants
(SN1006, optical, radio, X-ray)



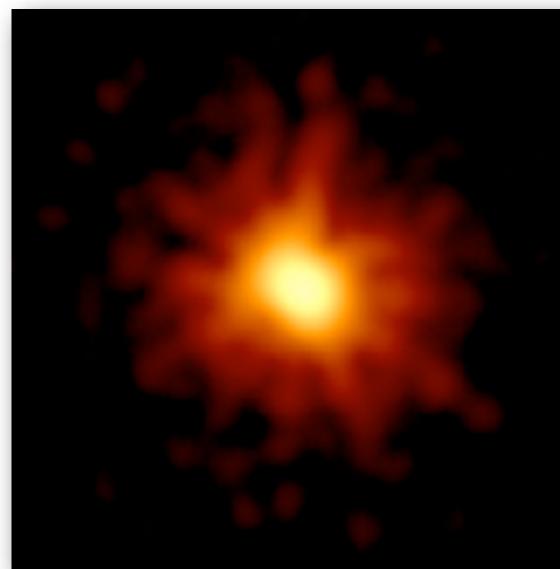
active galactic nuclei
(artist's view)



pulsars
(Crab, X-ray, Chandra)



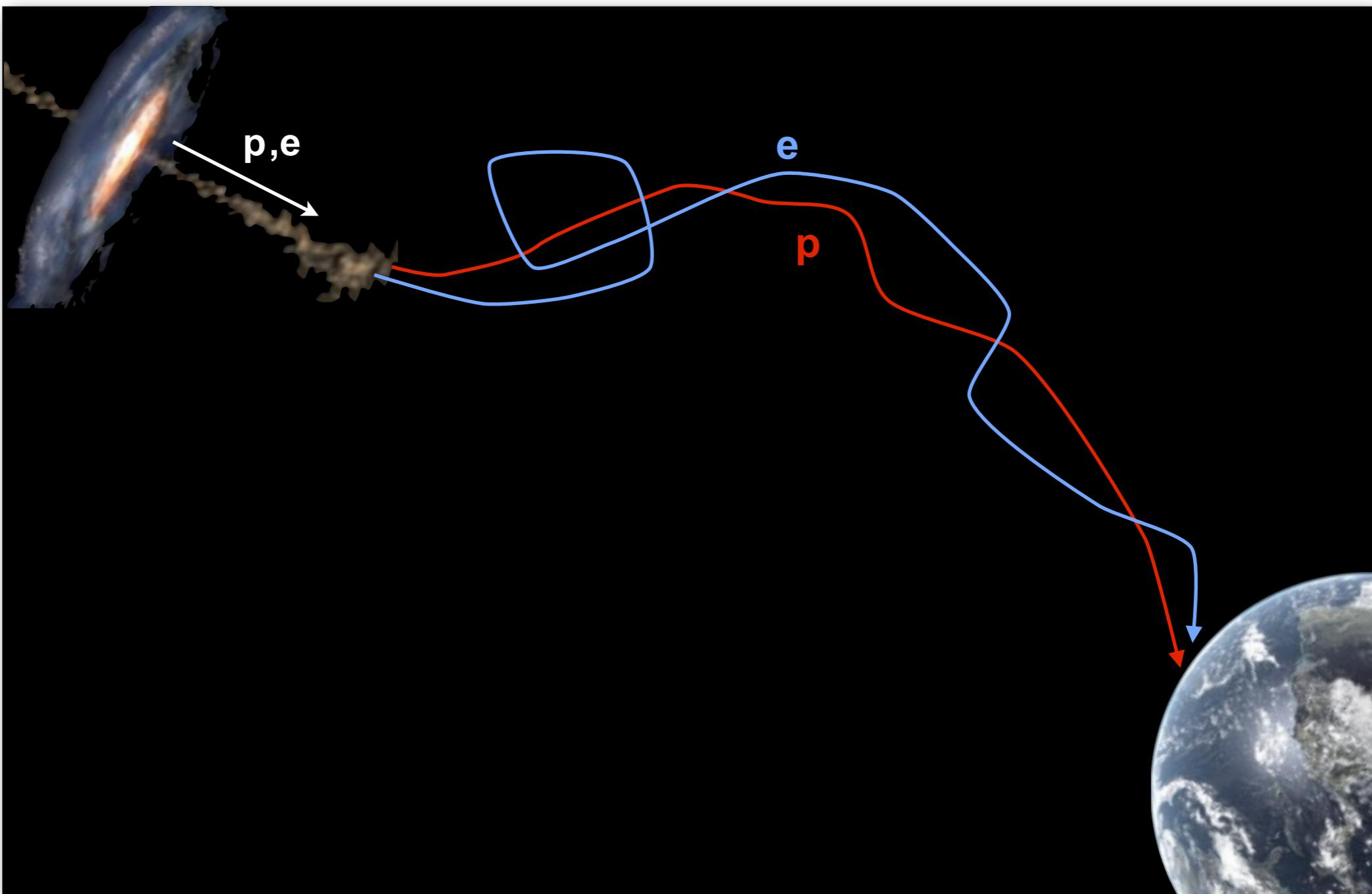
gamma-ray bursts
(GRB 080319B, X-ray, SWIFT)



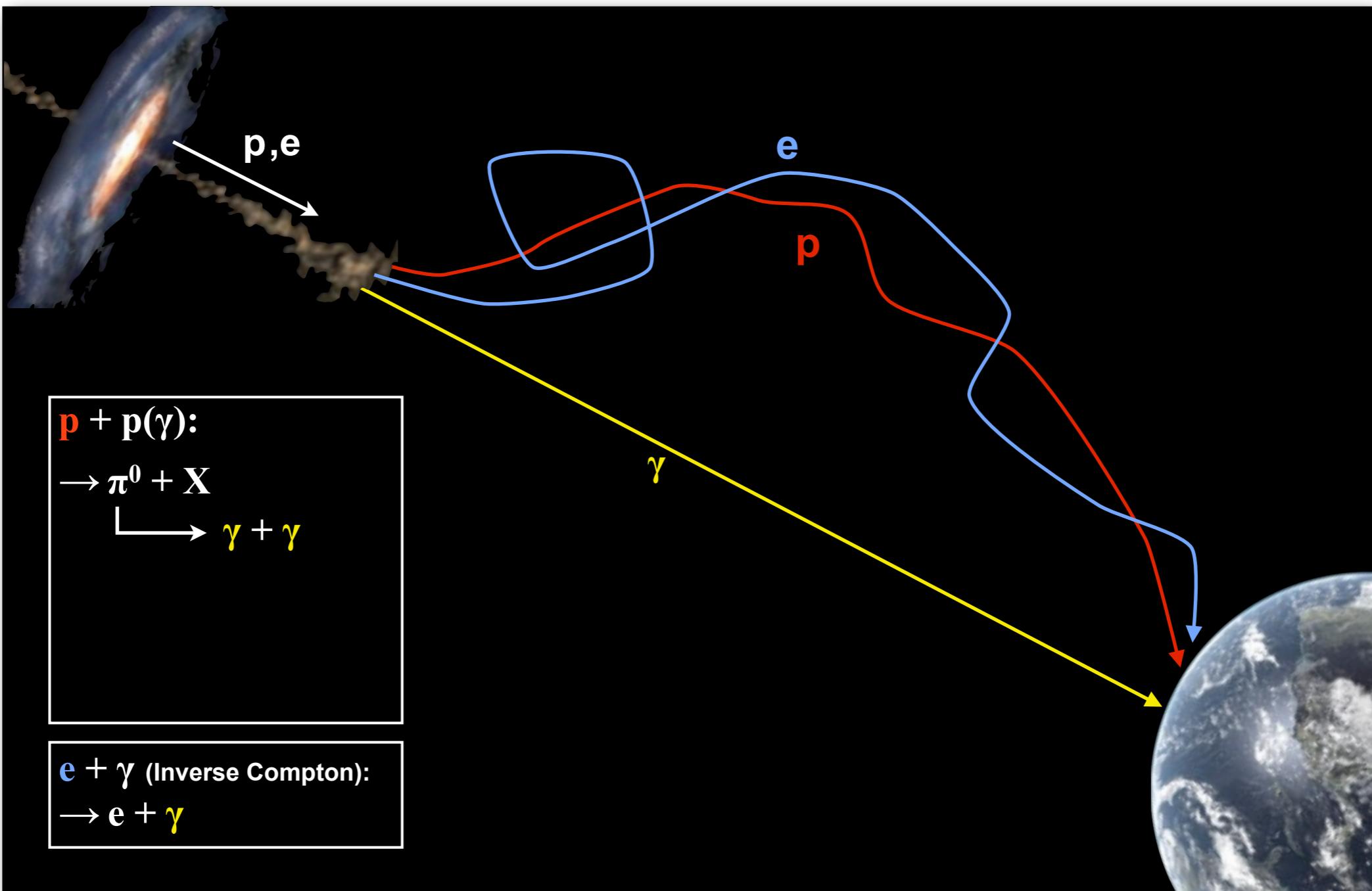
Messengers of the high-energy universe



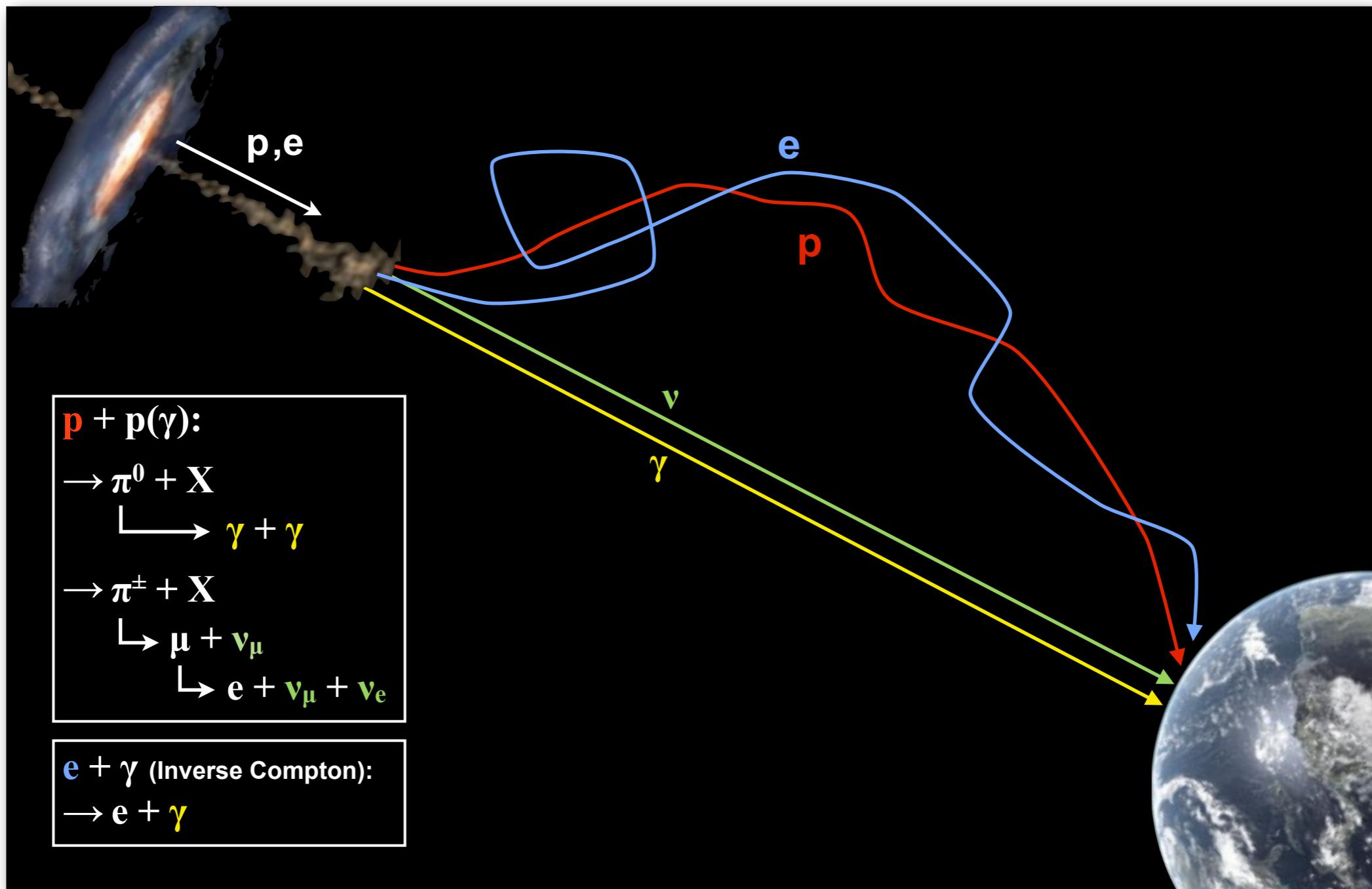
Messengers of the high-energy universe



Messengers of the high-energy universe



Messengers of the high-energy universe



The big questions are:

- what is the origin and composition of cosmic rays?
- what and where are the cosmic particle accelerators?
- what is the nature of dark matter?

Answering them requires:

- information from all messenger:
photons, neutrinos, cosmic rays
- models of sources and fluxes:
acceleration, environment, propagation

Astroparticle groups at DESY-HH

- Low-energy neutrino astrophysics
(C. Hagner)



- Axion-like particles
(A. Lindner, A. Ringwald, D. Horns)



- High-energy gamma-ray astronomy
(U-Hamburg, D. Horns)



- Theory
 - **A. Ringwald**,
Axions, axion-like particles, WISPs
 - **W. Buchmüller, T. Konstandin**
Inflation, baryogenesis, cosm. phase transitions, gravitino Dark Matter
 - **G. Sigl, A. Mirizzi, T. Bringmann (U-Hamburg)**
Cosmic rays, Dark Matter, axions

Astroparticle physics at DESY-Zeuthen

Gamma-ray telescopes (CTA, VERITAS, MAGIC, H.E.S.S., Fermi-LAT)

in cooperation with HU-Berlin (T. Lohse) and U-Potsdam (C. Stegmann)

- Staff 7
- Postdocs 5
- Students 17

Neutrino telescopes (IceCube)

in cooperation with HU-Berlin (substitute A. Kappes)

- Staff 5
- Postdocs 2
- Students 9

Theoretical astroparticle physics (Source modeling, Dark Matter)

in cooperation with U-Potsdam (M. Pohl)

- Staff 2
- Postdocs 3
- Students 4

total 54

Exploring the Universe with Neutrinos.



Principle of neutrino detection

Turn a large volume of ice/water into a particle detector

Time & position of hits

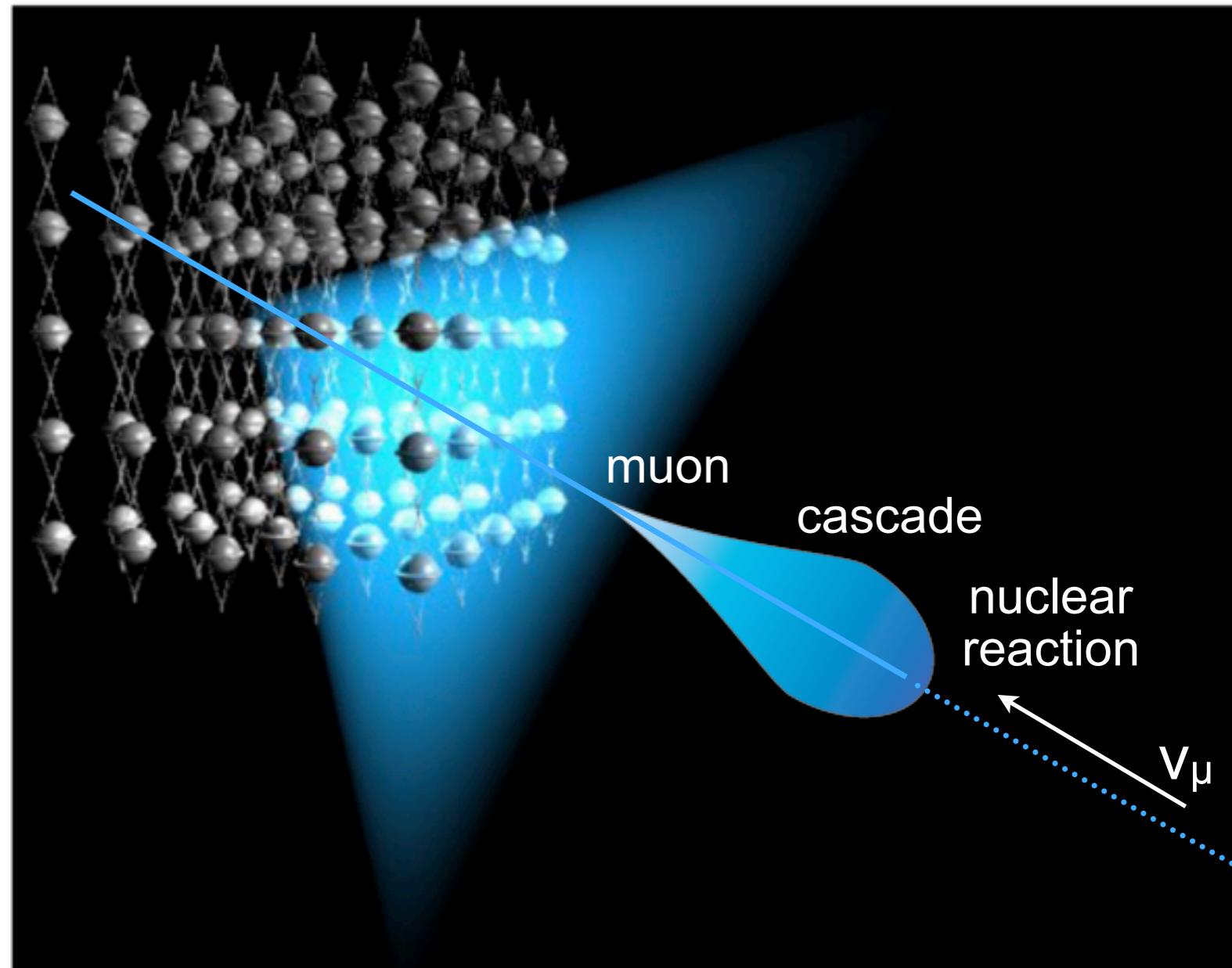


μ ($\sim \nu$) trajectory

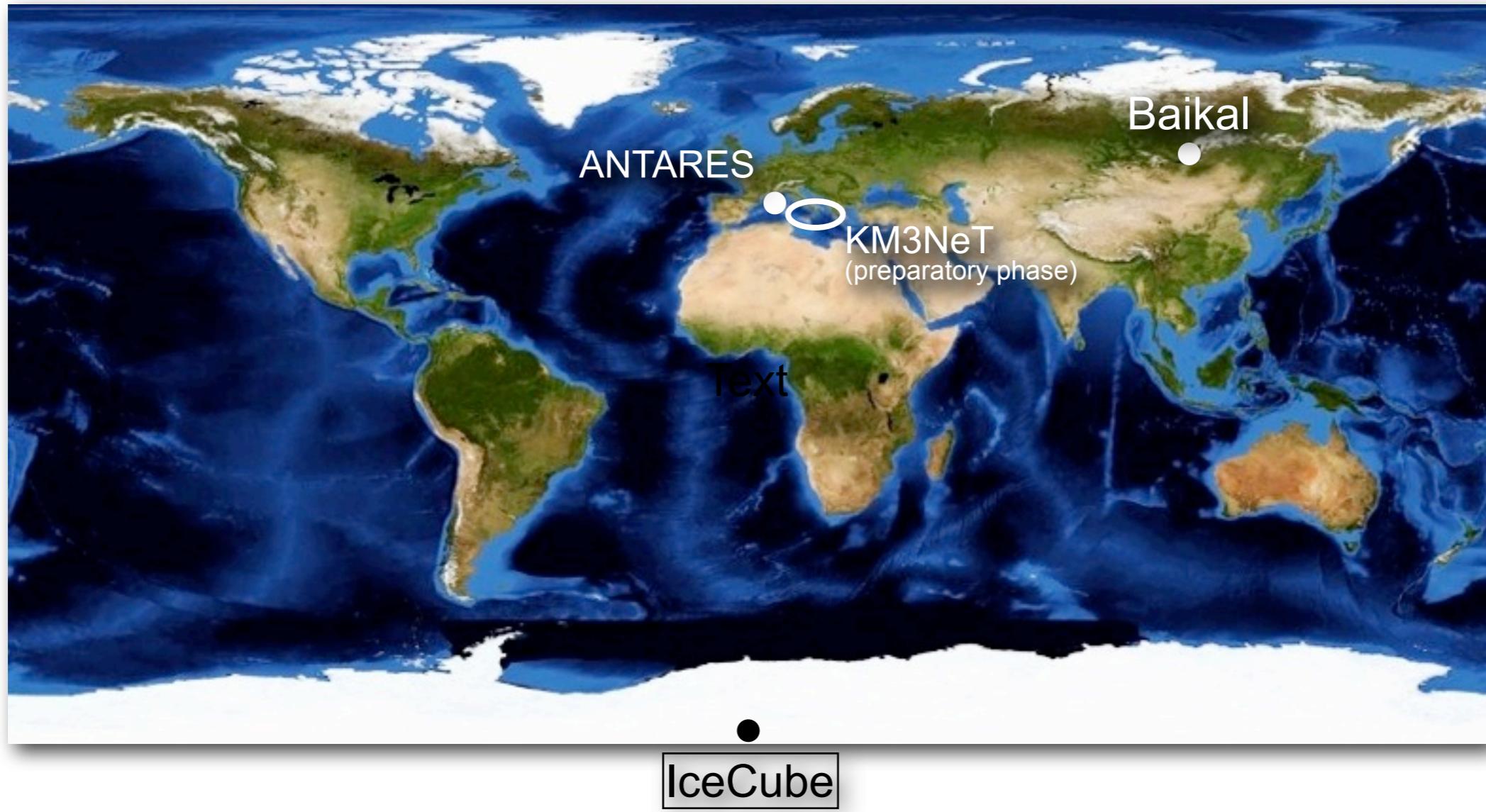
PMT amplitudes



Energy



Neutrino Telescope Projects



IceCube at the South Pole



Drilling and deploying



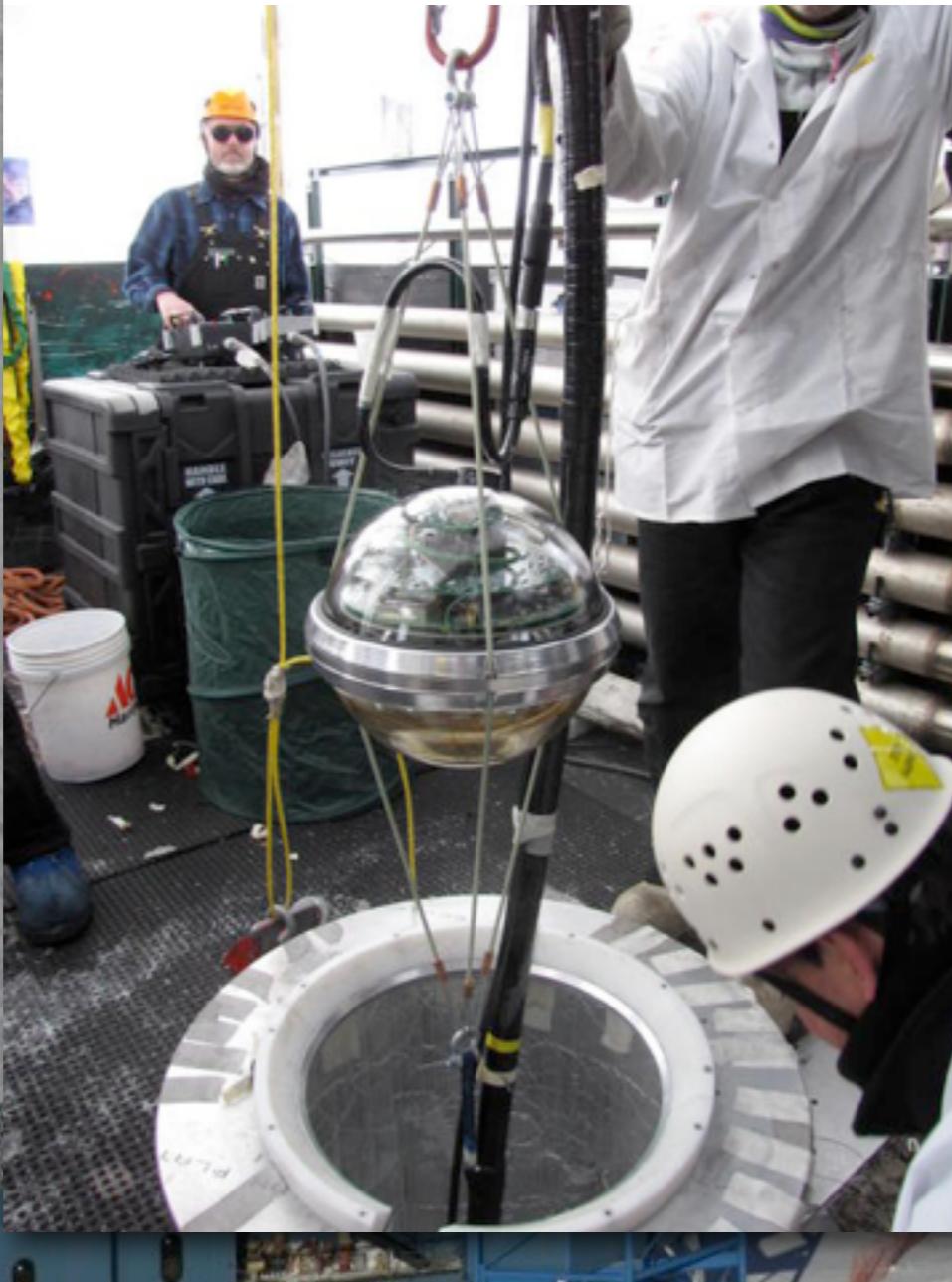
Nozzle delivers:

- 750 l per minute
- 90 degree C
- 70 bar

→ 4.8 MW heating plant

Drilling and deploying

to 2500 m in less than 2 days



Nozzle delivers:

- 750 l per minute
- 90 degree C
- 70 bar

→ 4.8 MW heating plant

The IceCube observatory

Completed since Dec. 2010

- **IceTop**

Air shower detector

- **InIce**

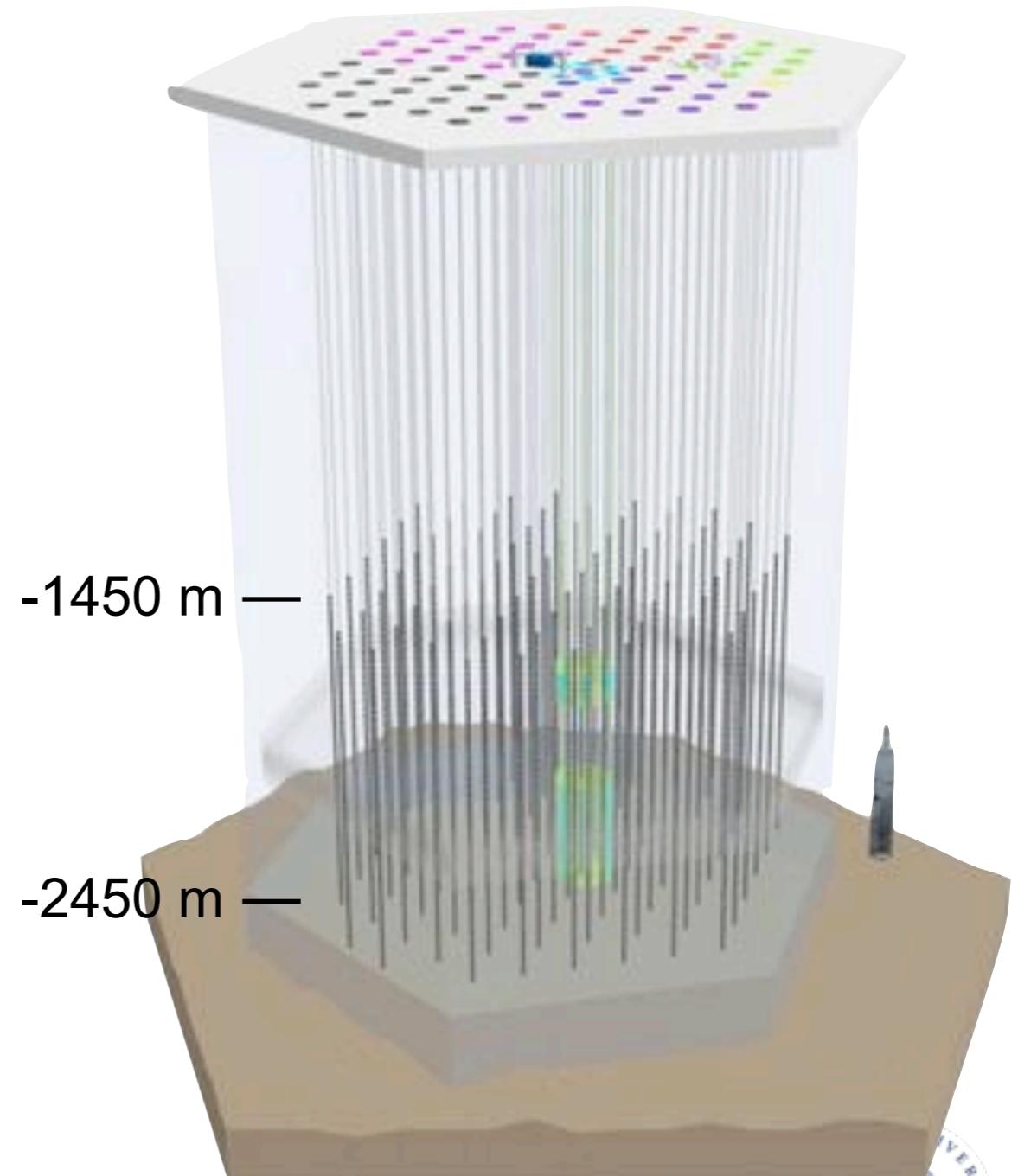
86 strings (5160 PMTs)

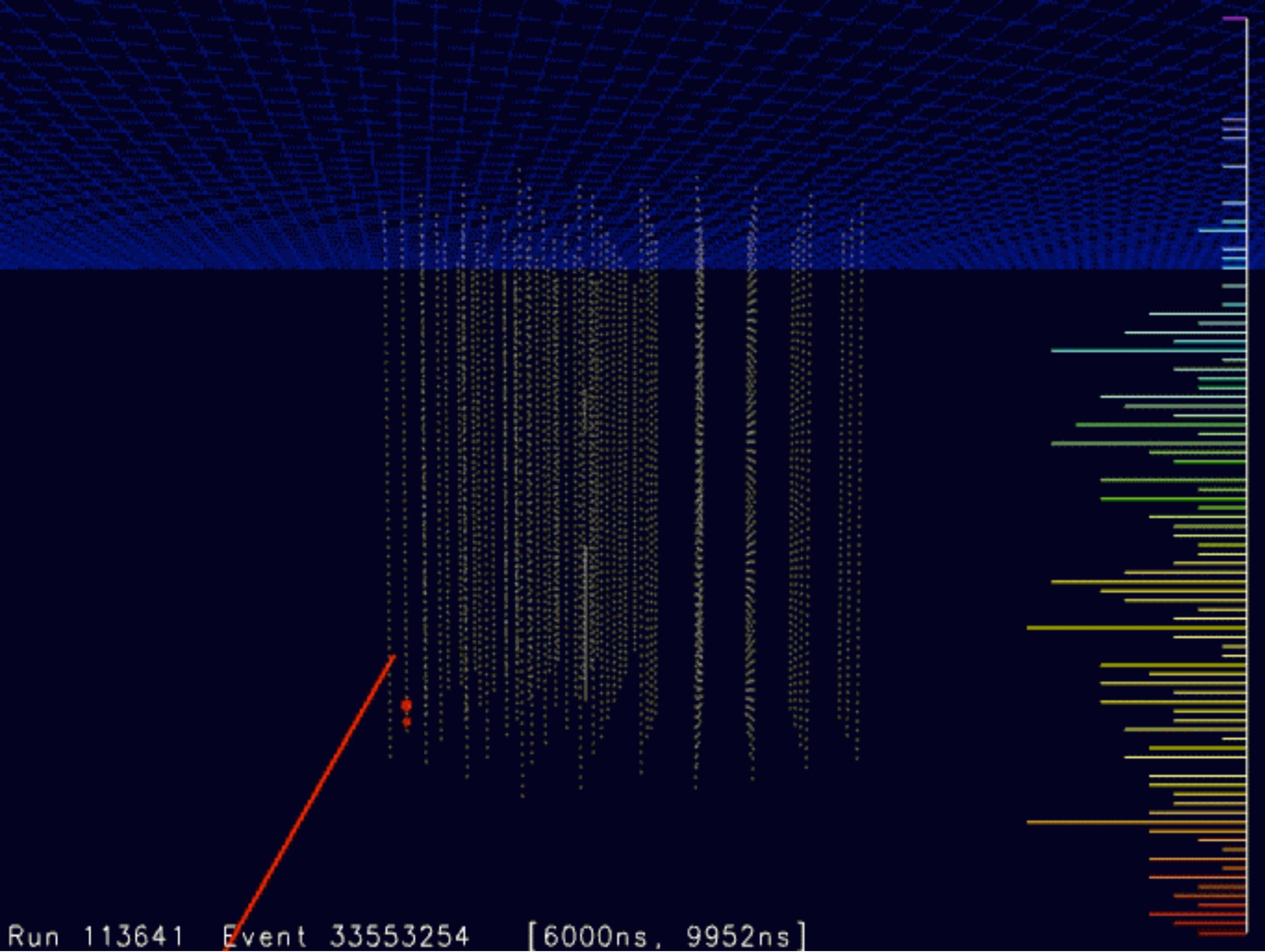
Instrumented volume: 1 km^3

- **Deep Core**

densely instrumented

central region (8 strings)





Run 113641 Event 33553254 [6000ns, 9952ns]

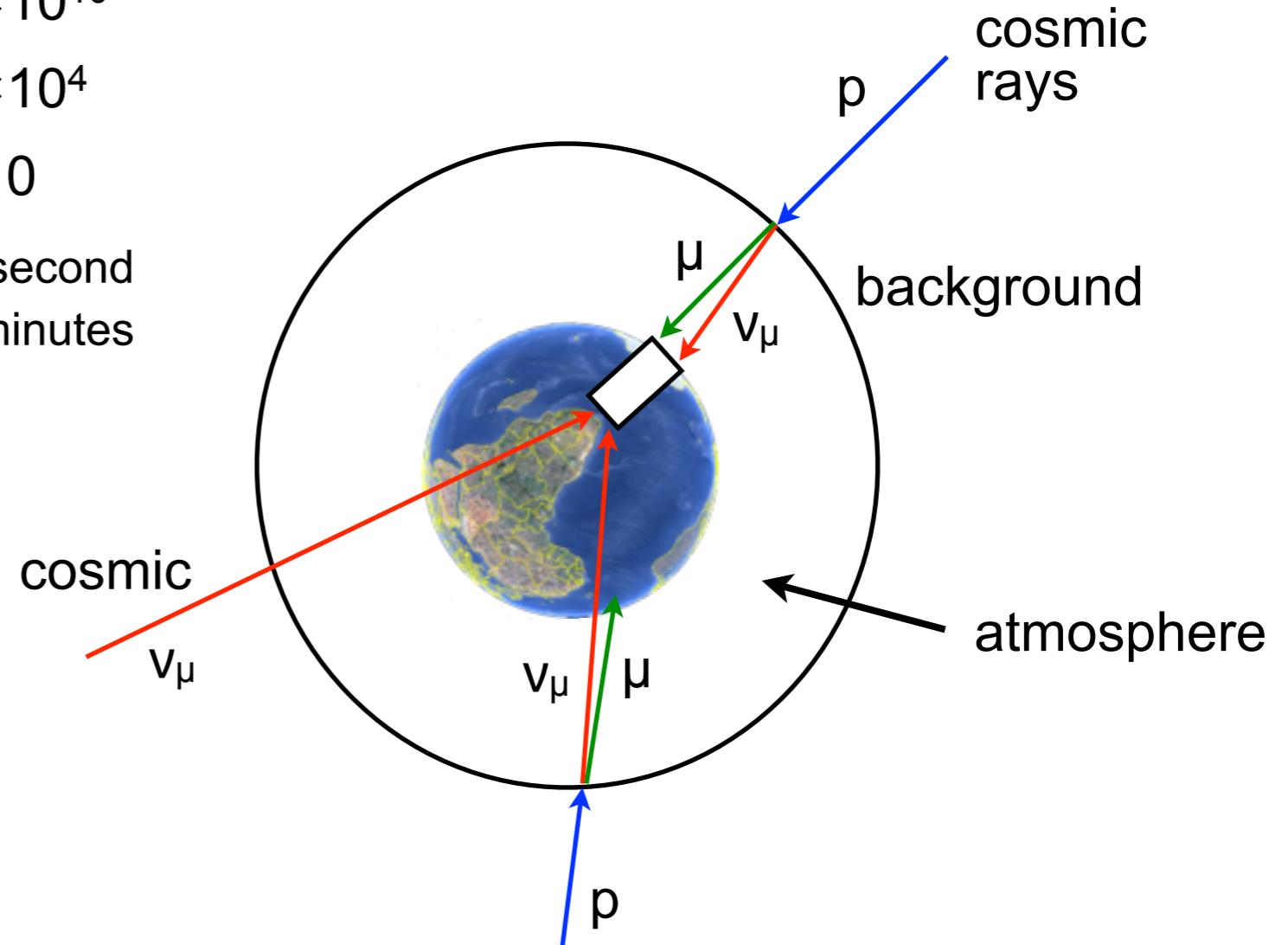
Backgrounds

Muons detected per year

- atmospheric* μ 7×10^{10}
- atmospheric** $\nu \rightarrow \mu$ 8×10^4
- cosmic $\nu \rightarrow \mu$ ~ 10

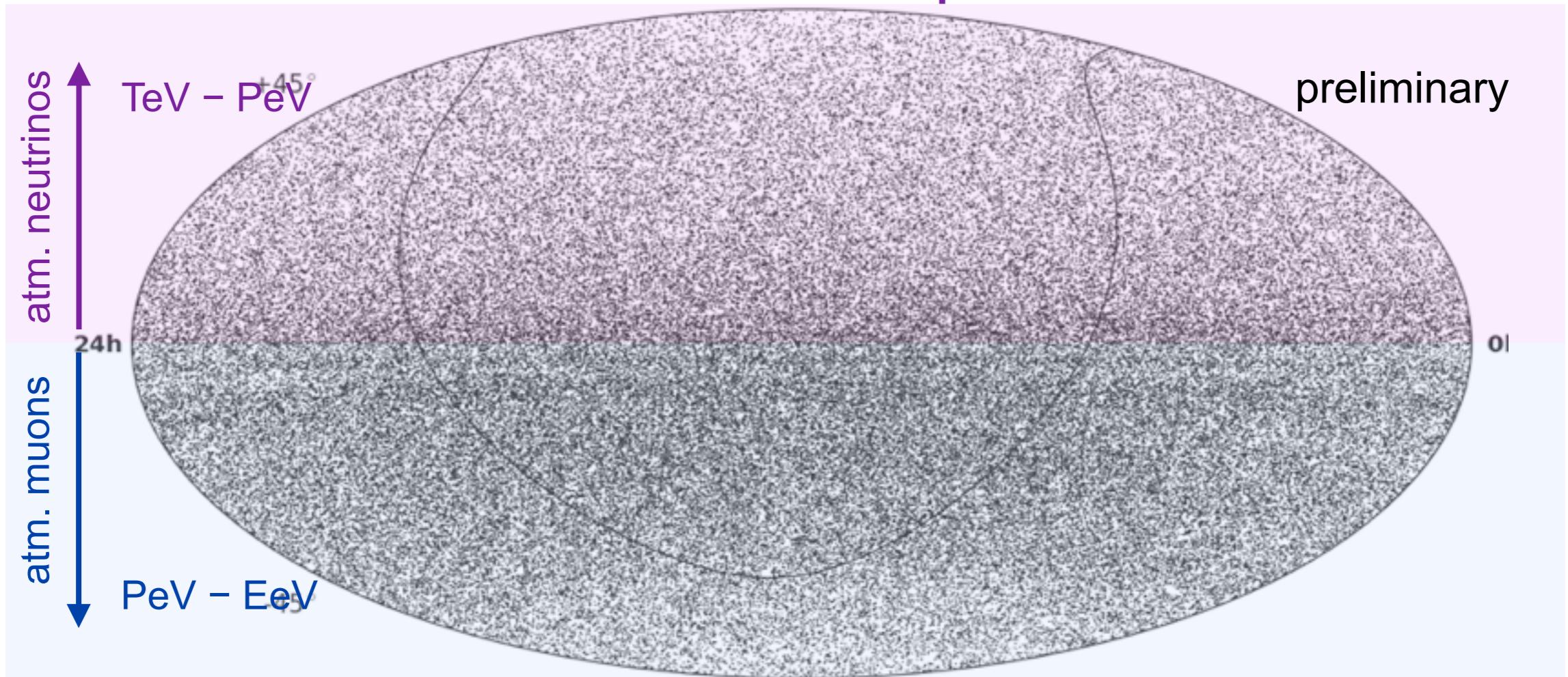
* 2000 per second

** 1 every 6 minutes



Skymap IceCube (IC40+59)

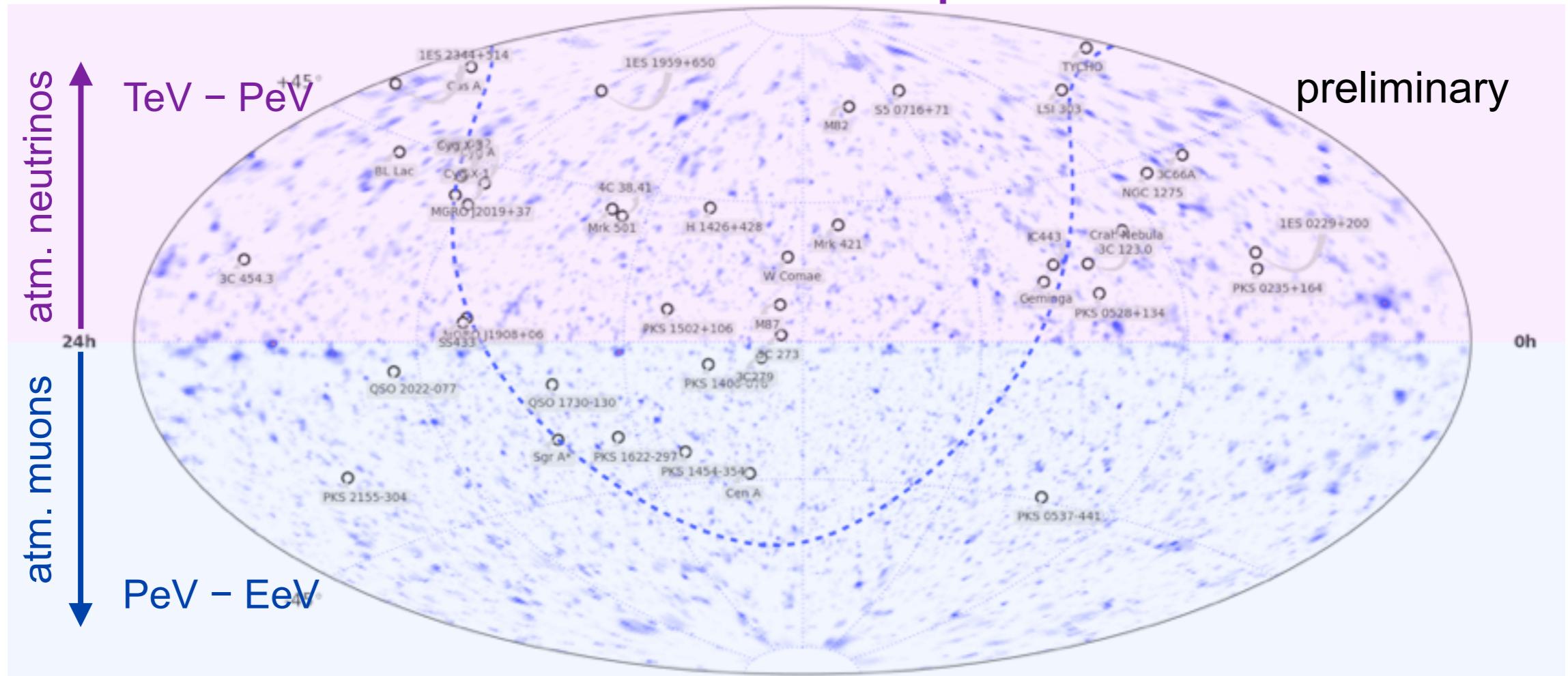
Northern hemisphere



- **107,569 events** (30% upgoing, livetime 723 d)
- **Source list:** 13 Galactic, 20 extragalactic

Skymap IceCube (IC40+59)

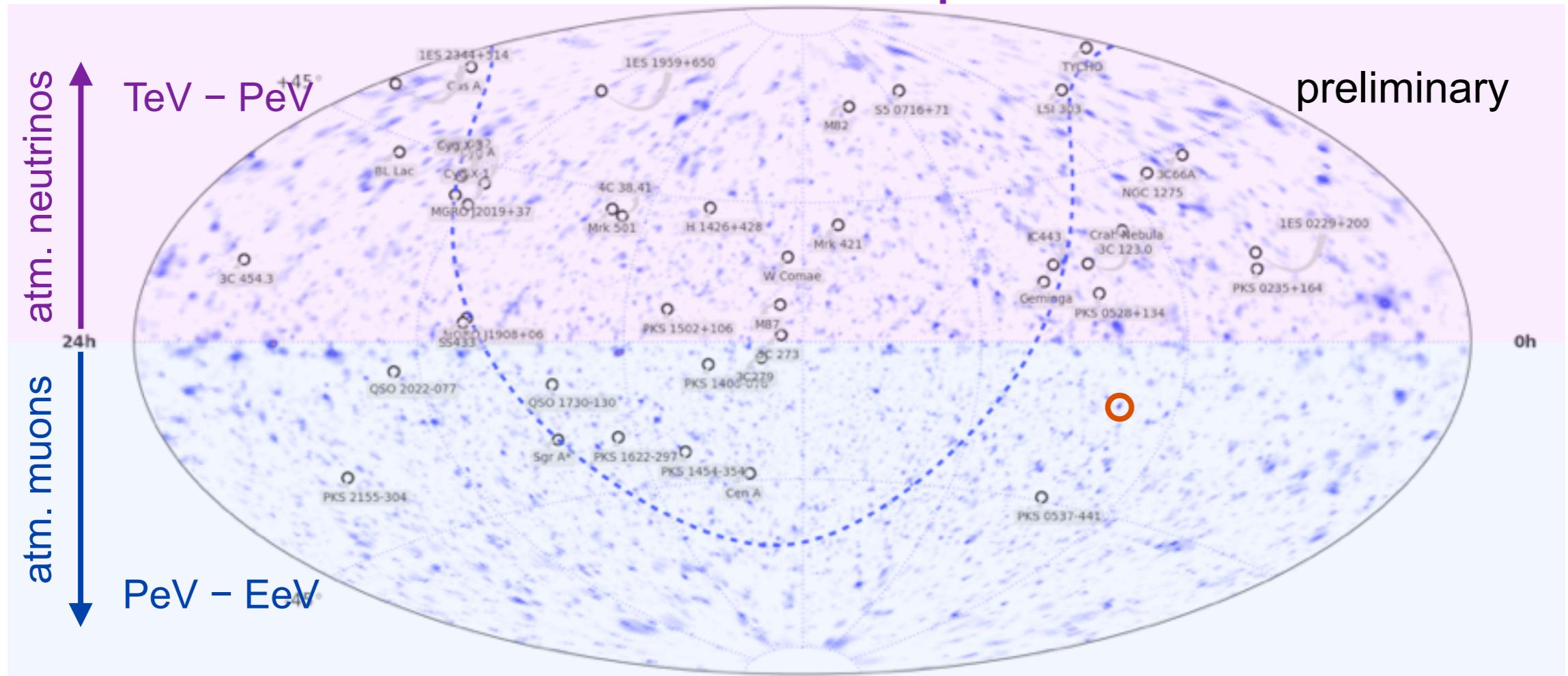
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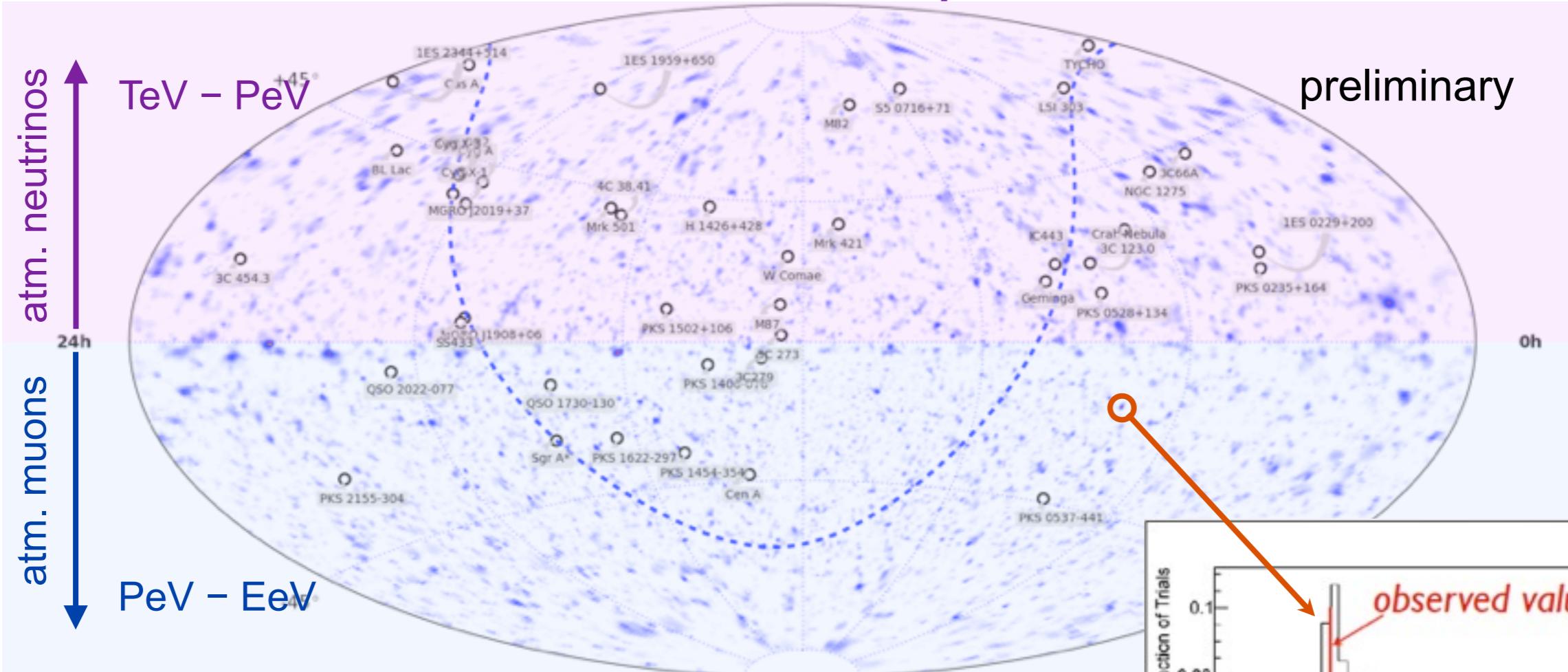
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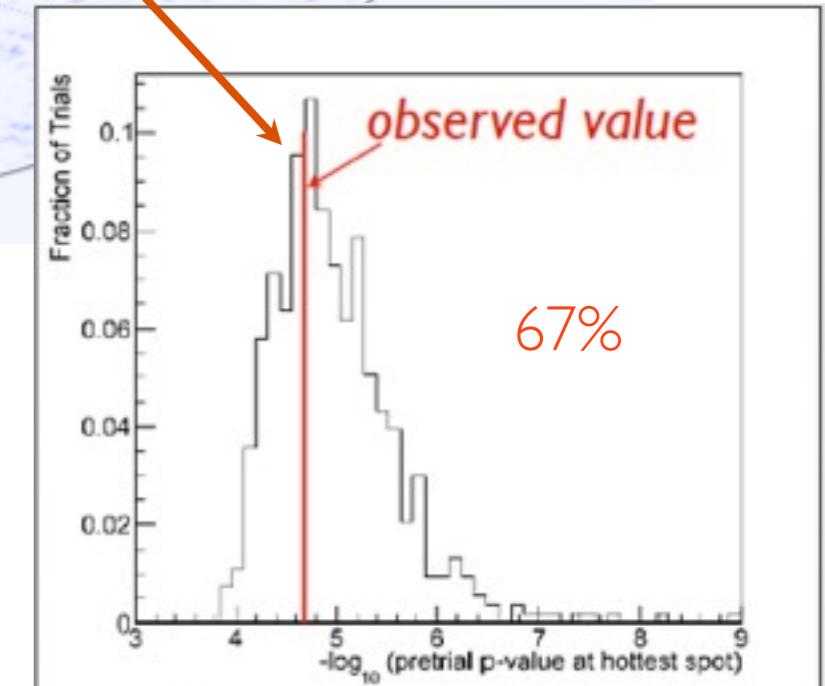
Skymap IceCube (IC40+59)

Northern hemisphere

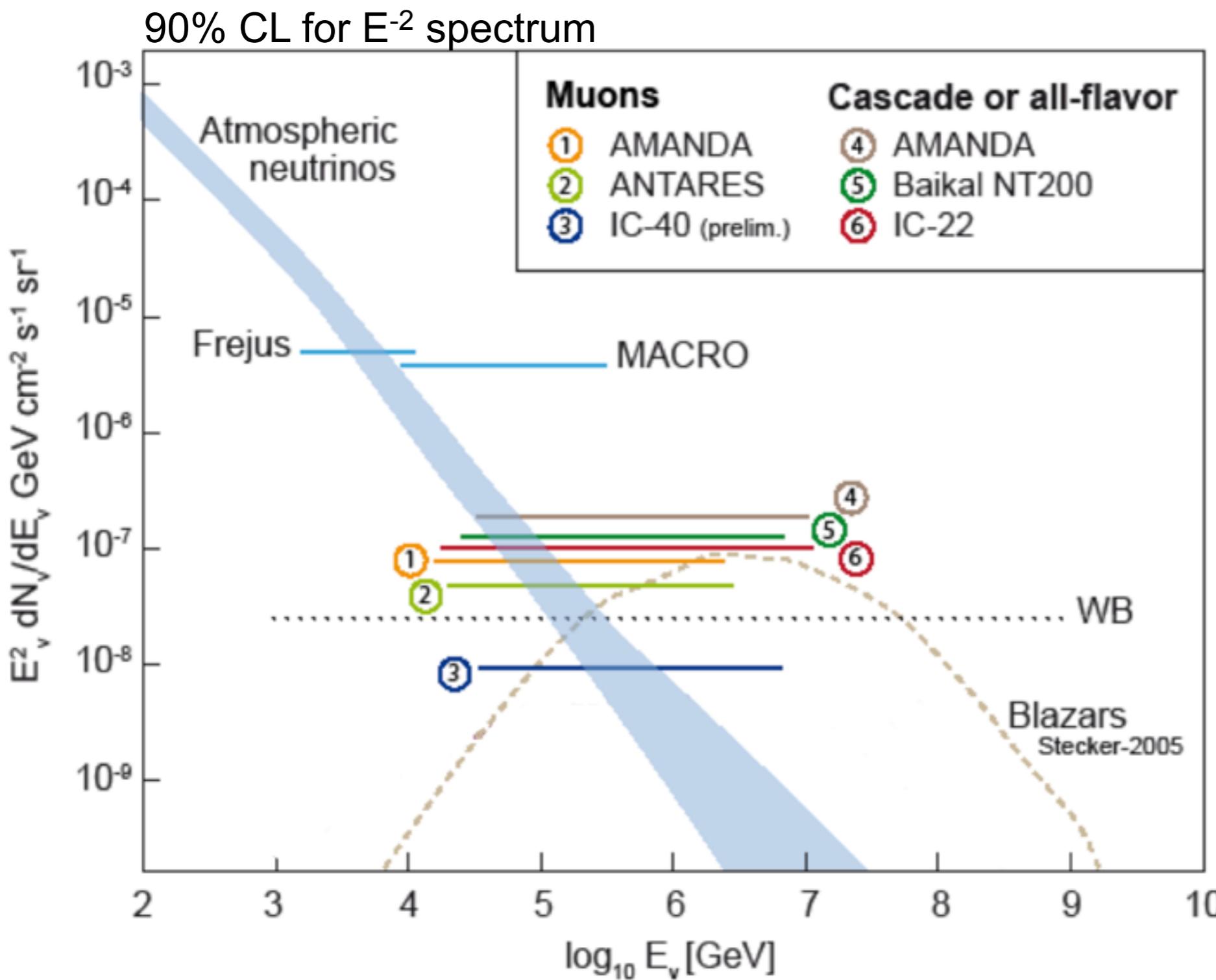


Southern hemisphere

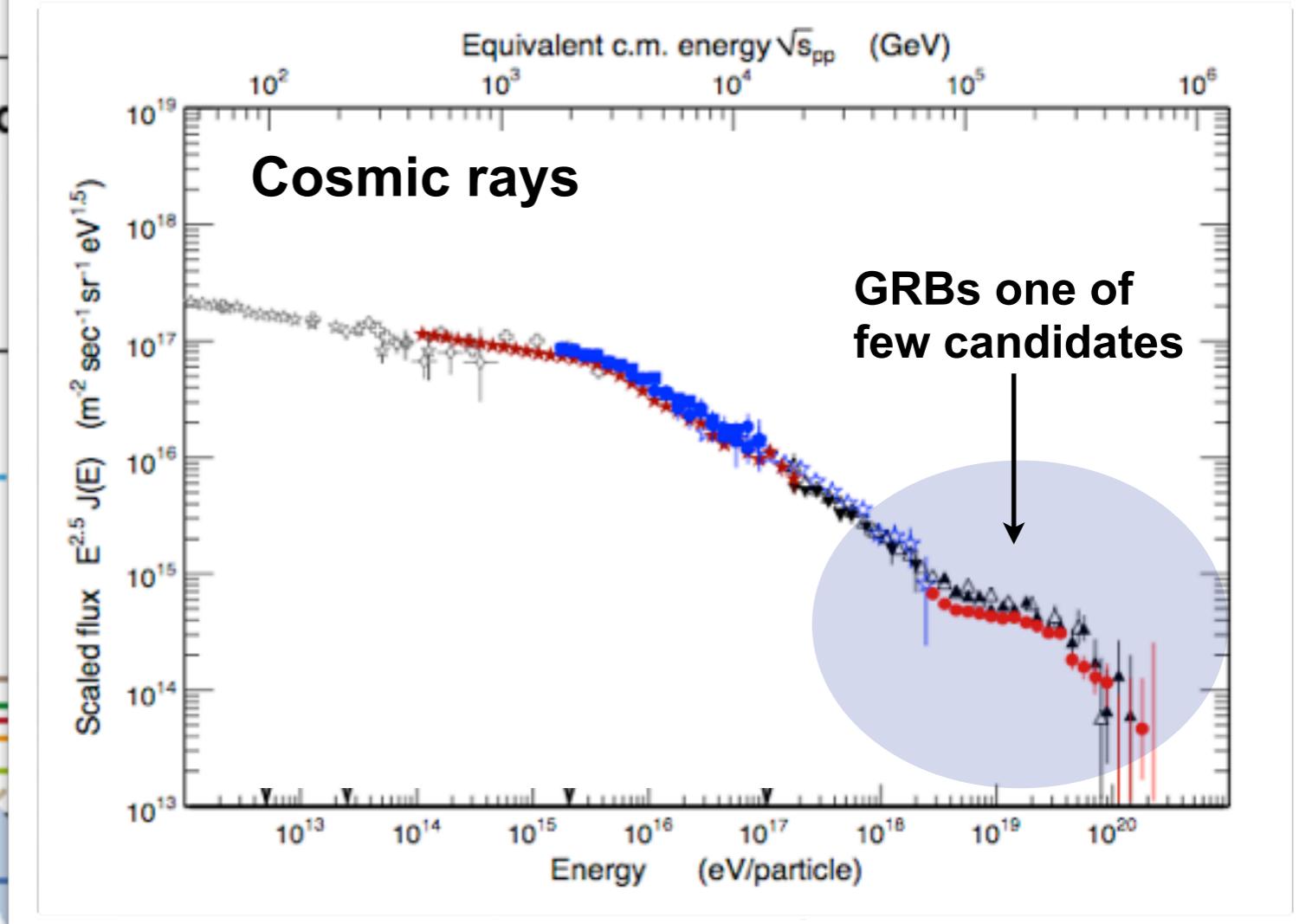
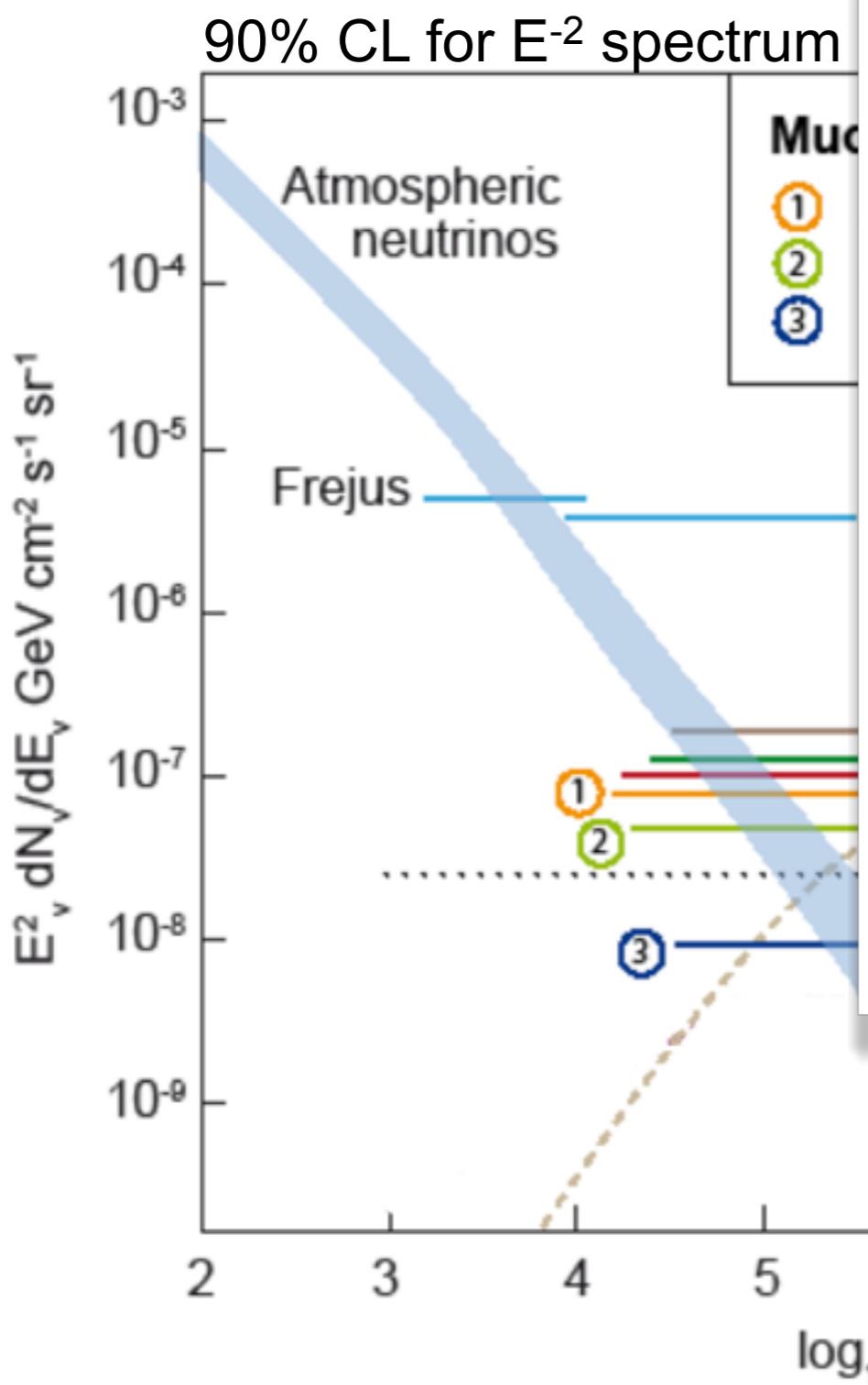
- **107,569 events** (30% upgoing, livetime 723 d)
- **Source list:** 13 Galactic, 20 extragalactic
- **No significant excess**



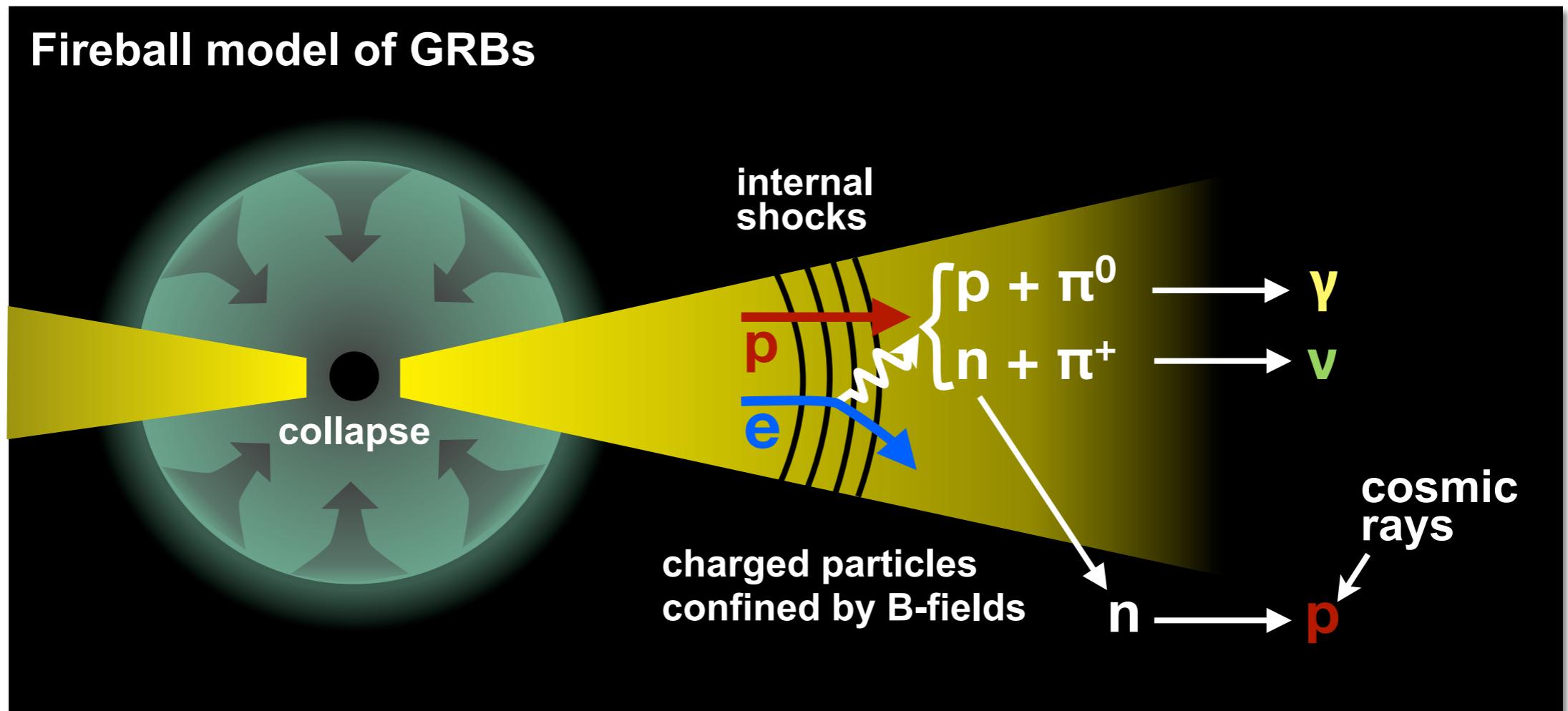
Upper limits on diffuse neutrino fluxes



Upper limits on diffuse neutrino fluxes

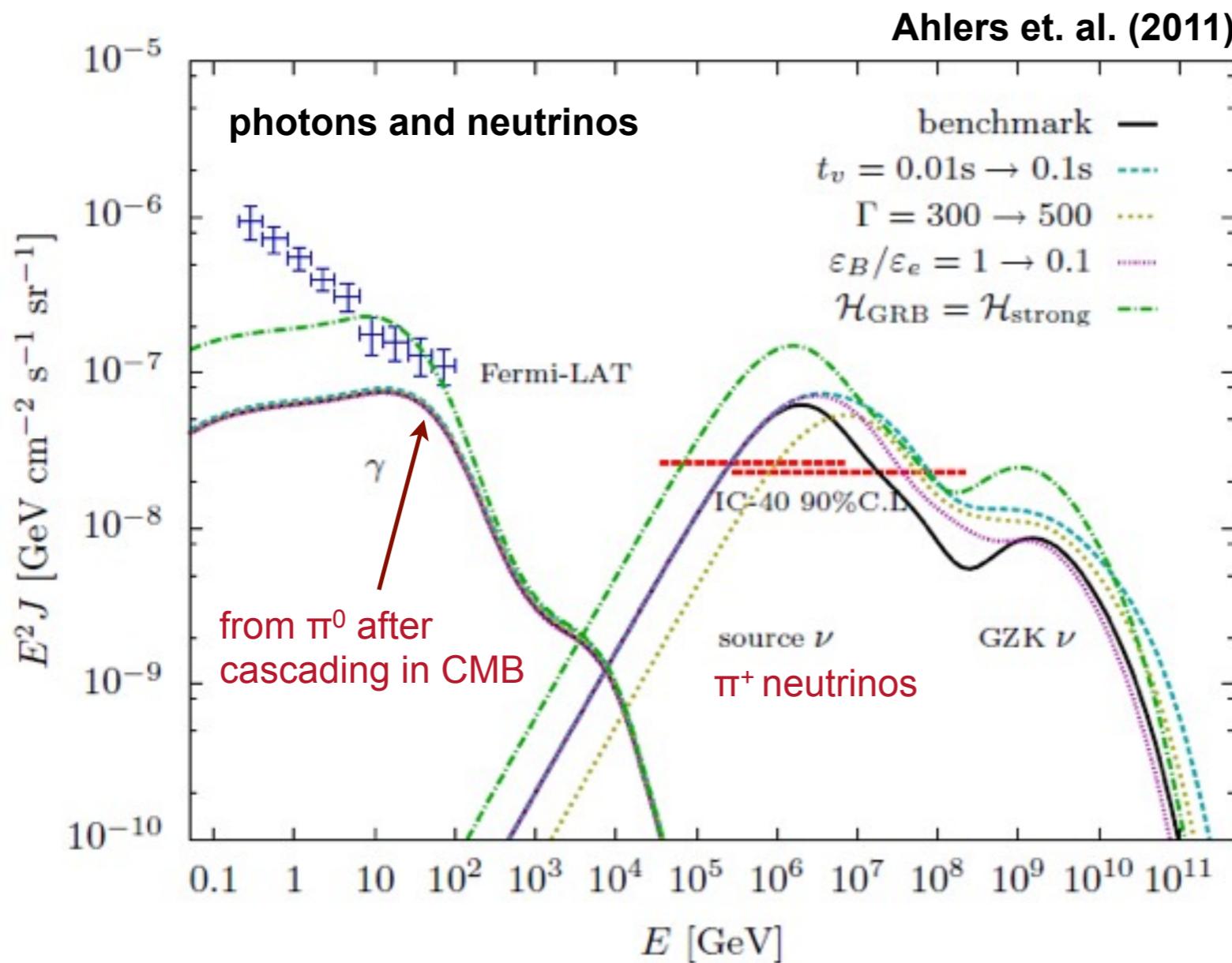


Fireball model of GRBs



Fireball model of GRBs

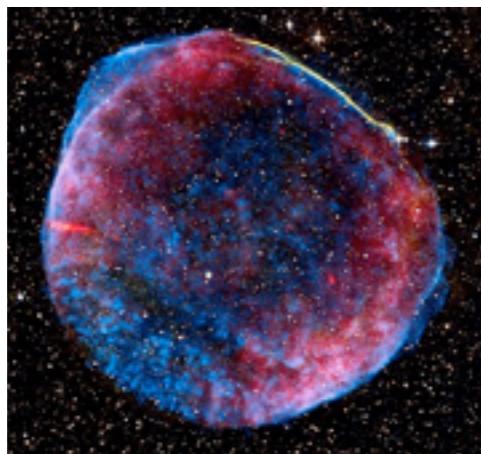
- Protons from n-decay fitted to cosmic-ray spectrum
- Photons from π^0 -decay cascade down in CMB



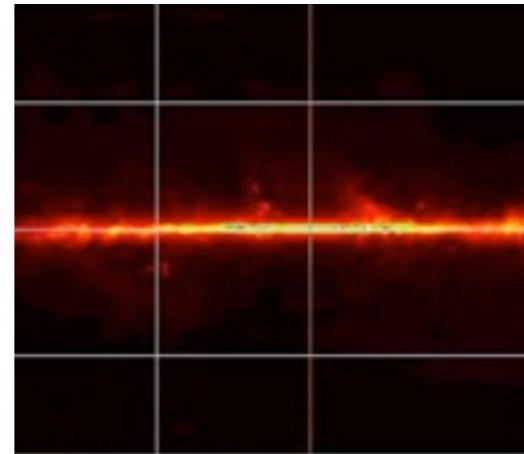
IceCube starts to challenge GRBs as major sources of UHECR cosmic rays

Physics with IceCube

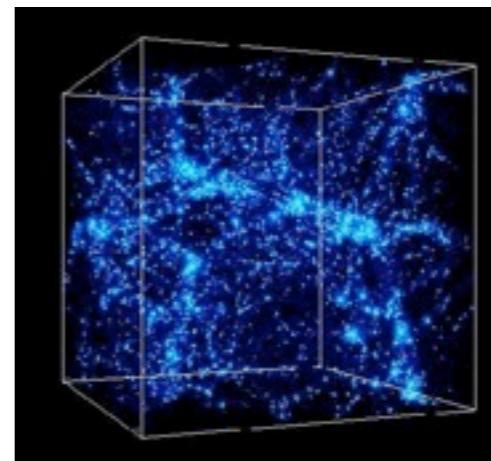
Cosmic accelerators



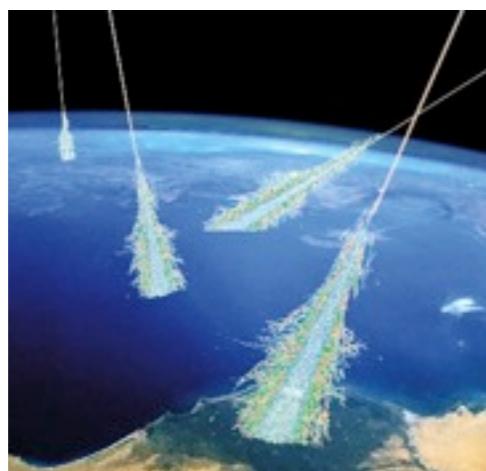
Diffuse fluxes



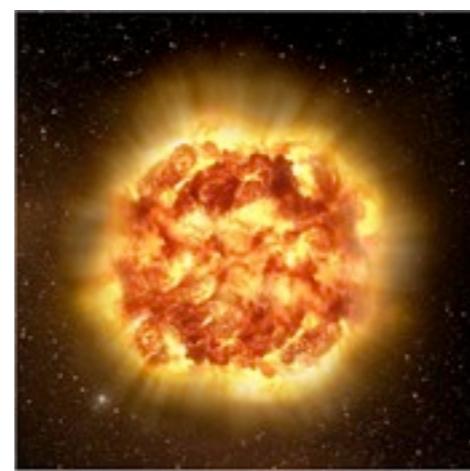
Dark Matter & Exotic Physics



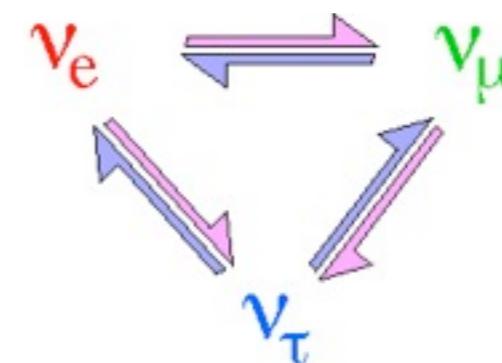
Cosmic rays



Supernovae



Neutrino Properties & Particle Physics



Physics with IceCube

*worked on at DESY

Cosmic accelerators

- ★ *Point-like sources (SNRs, Binaries ...)
- ★ Extended sources
- ★ *Transients (GRBs, AGN flares ...)

Diffuse fluxes

- ★ *All-sky fluxes (e.g. cosmogenic)
- ★ Galactic plane
- ★ Extended structures (e.g. Fermi-Bubbles)

Dark Matter & Exotic Physics

- ★ Indirect DM search (Sun, Galactic halo)
- ★ *Magnetic monopoles, Q-balls
- ★ Lorentz invariance violation

Cosmic rays

- ★ *Spectrum around “knee” (10^{15} – 10^{17} eV)
- ★ *Composition
- ★ Anisotropy

Supernovae

- ★ Galactic/LMC SNe
- ★ Phases
- ★ Neutrino hierarchy

Neutrino Properties & Particle Physics

- ★ *Neutrino oscillations
- ★ Charm in showers
- ★ K/ π ratio in showers
- ★ Cross sections at very high energies

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Cosmic-ray anisotropy

Desiati, Nusky 2011

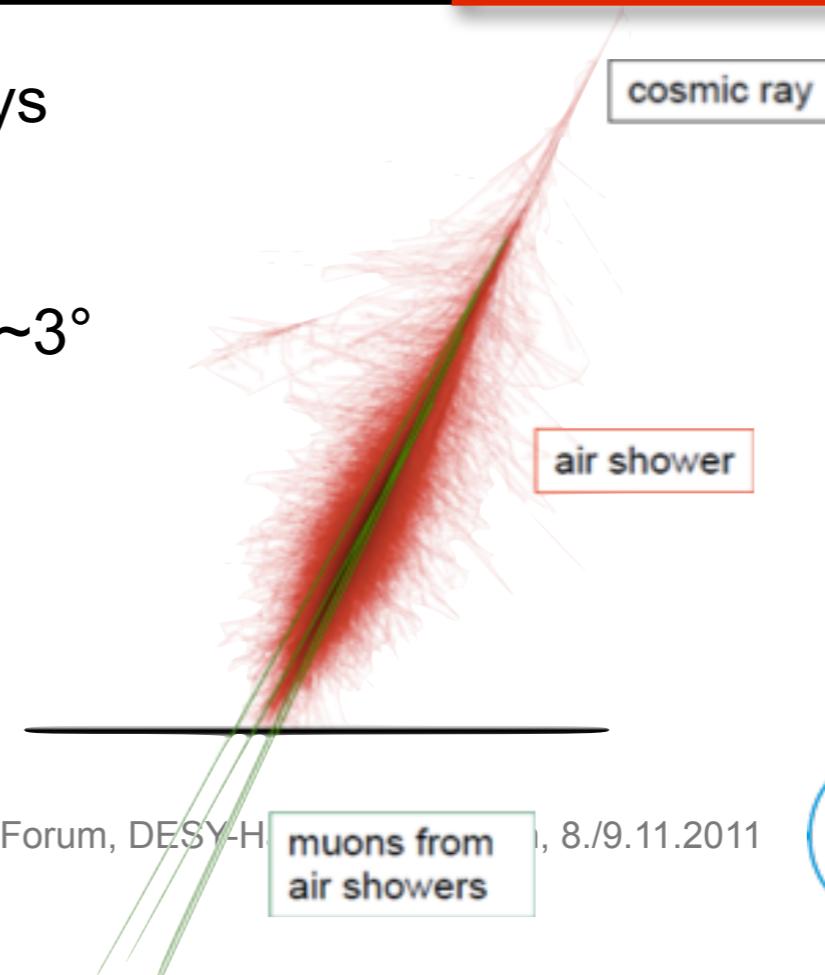
detector	trigger rate (Hz)	actual time (d)	livetime (d)	number of events (*)
IceCube-22	500	300	226	5.4×10^9
IceCube-40	1,100	358	324	19×10^9
IceCube-59	1,700	367	334.5	34×10^9
IceCube-79	2,000	365	337	40×10^9
IceCube-86	2,500	365	365	50×10^9

(*) number of events with LLH reconstruction from online-filter collected by DST

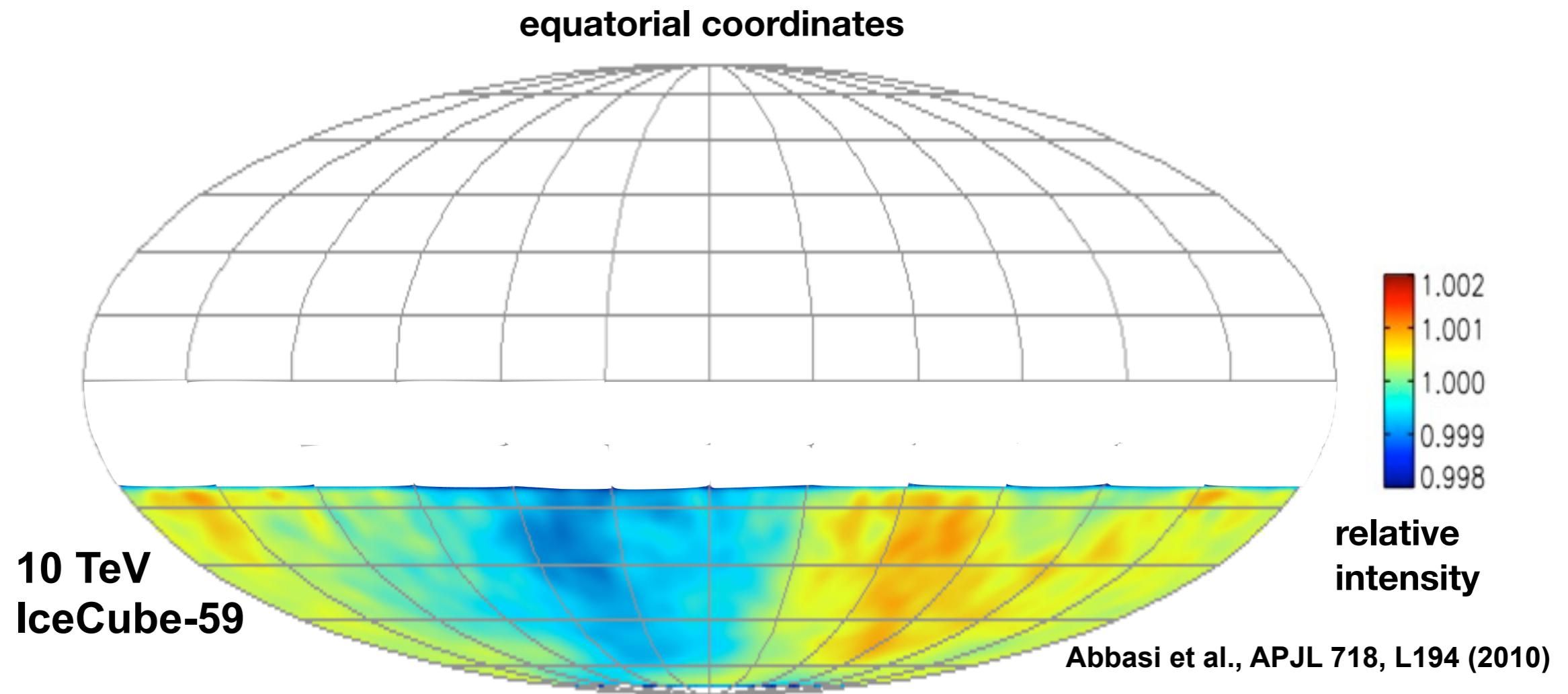
Mapping of highest Galactic cosmic rays

Muon (bundle) reconstruction:

- primary direction: median resolution $\sim 3^\circ$
- mean primary energy ~ 20 TeV

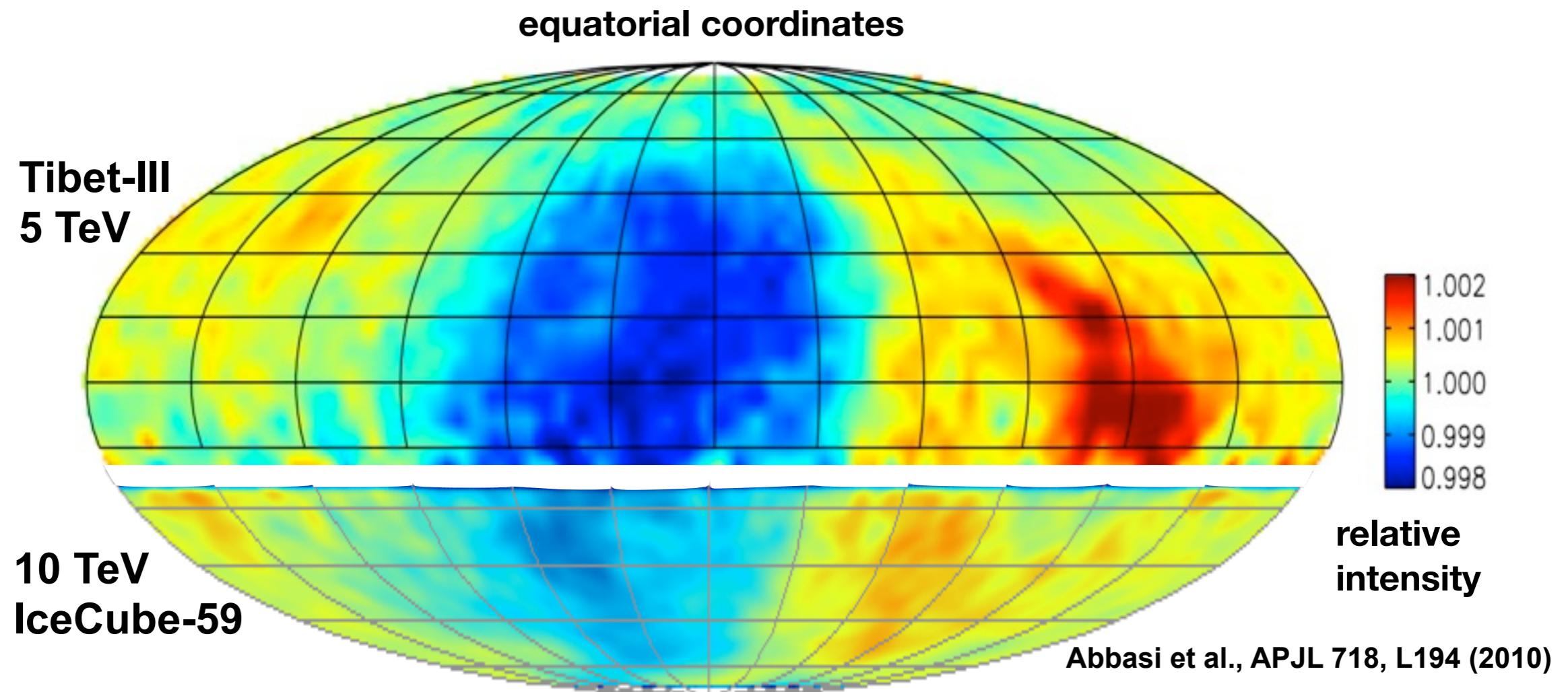


Cosmic-ray anisotropy



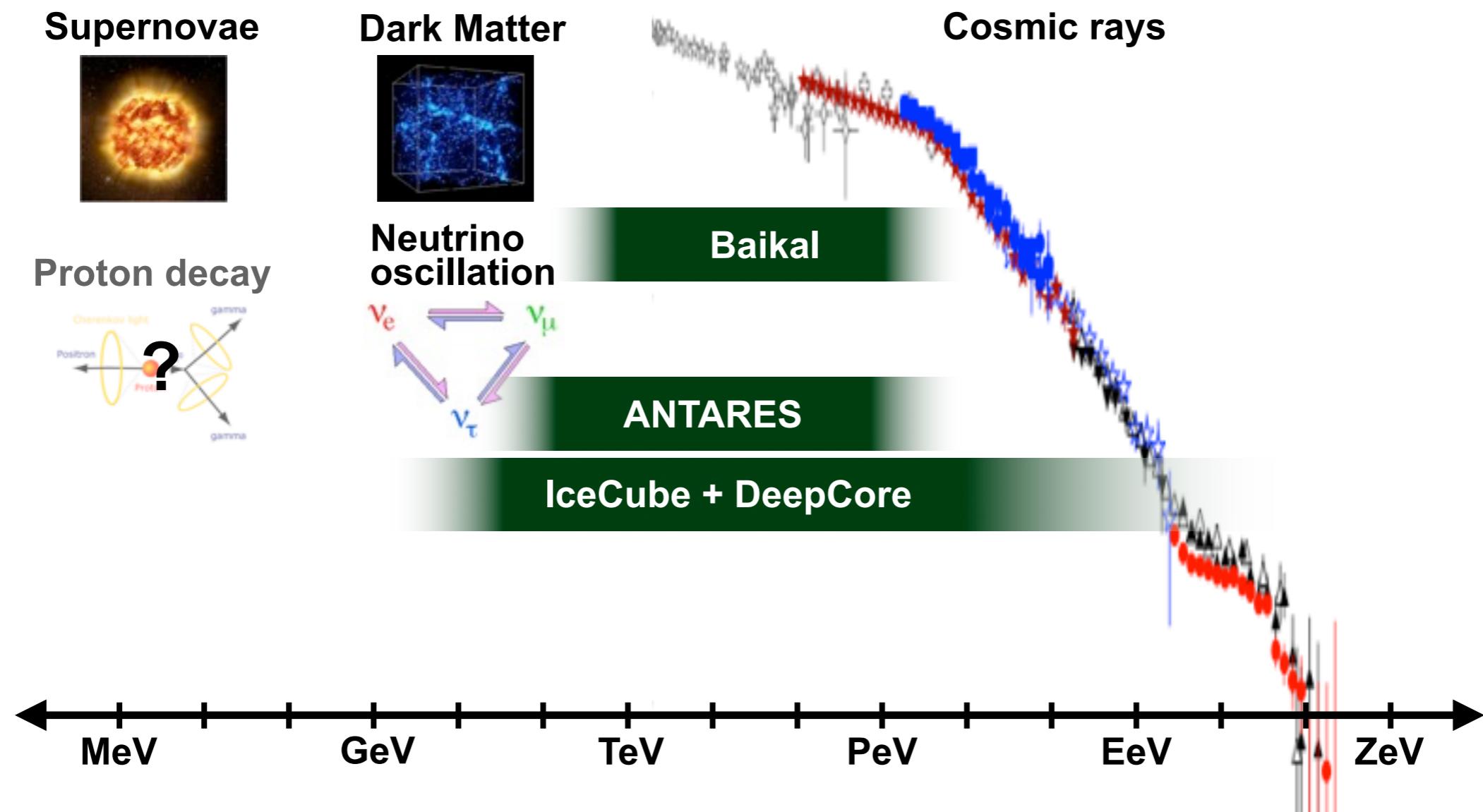
- Gyro radius < 1 pc in μG Galactic B-field
- Closest sources \sim 100 pc
→ cosmic rays should not point !

Cosmic-ray anisotropy

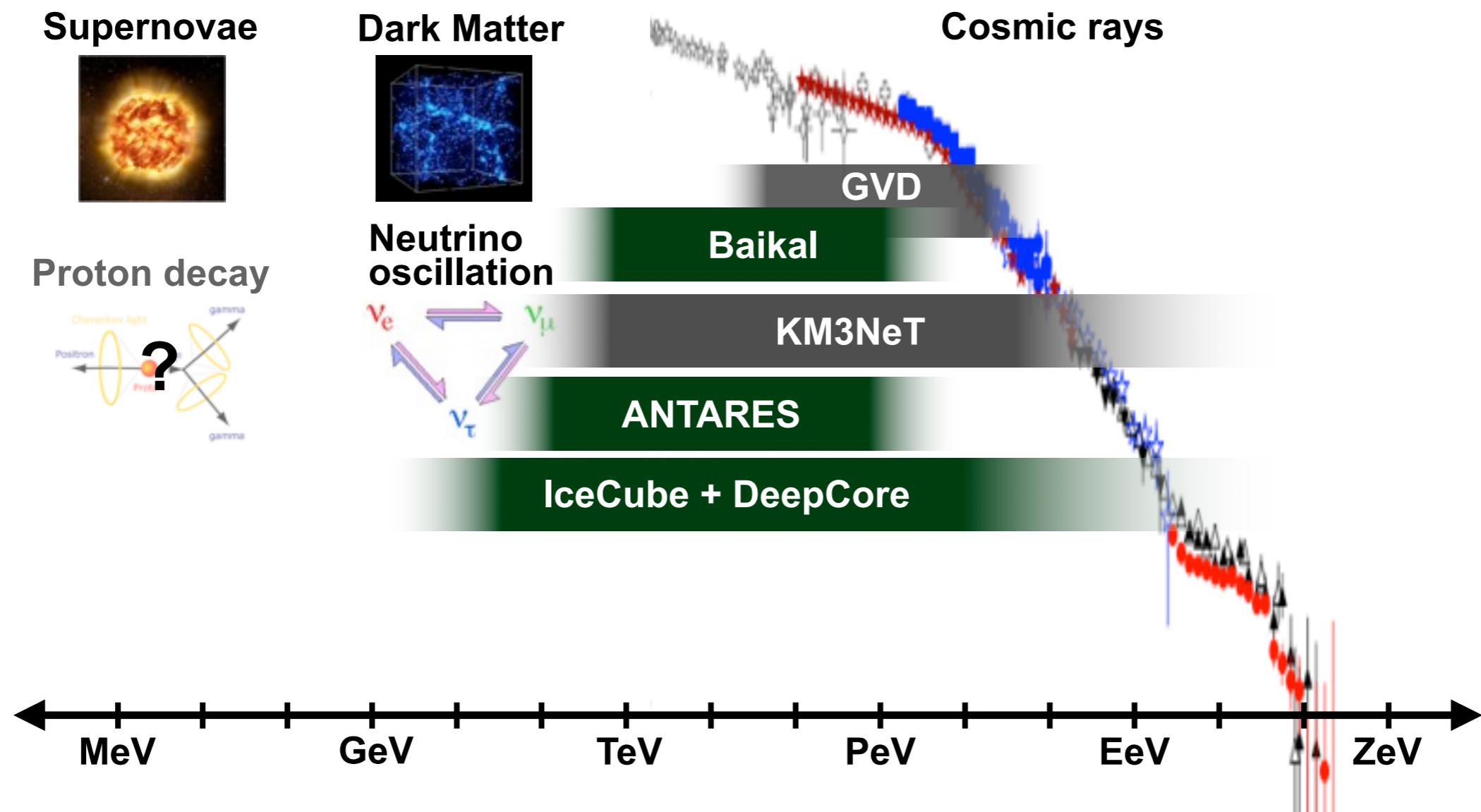


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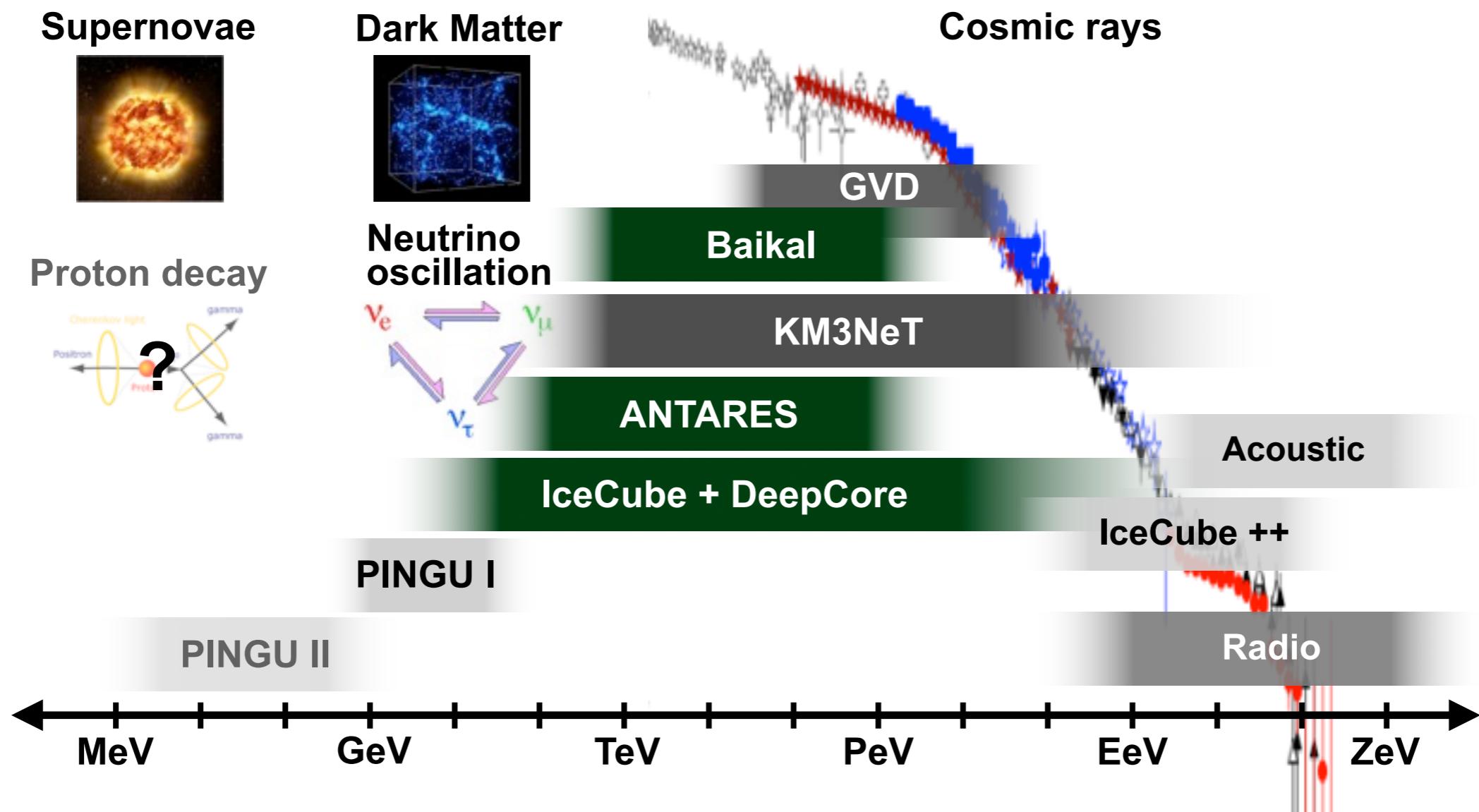
Going to lower and higher energies



Going to lower and higher energies



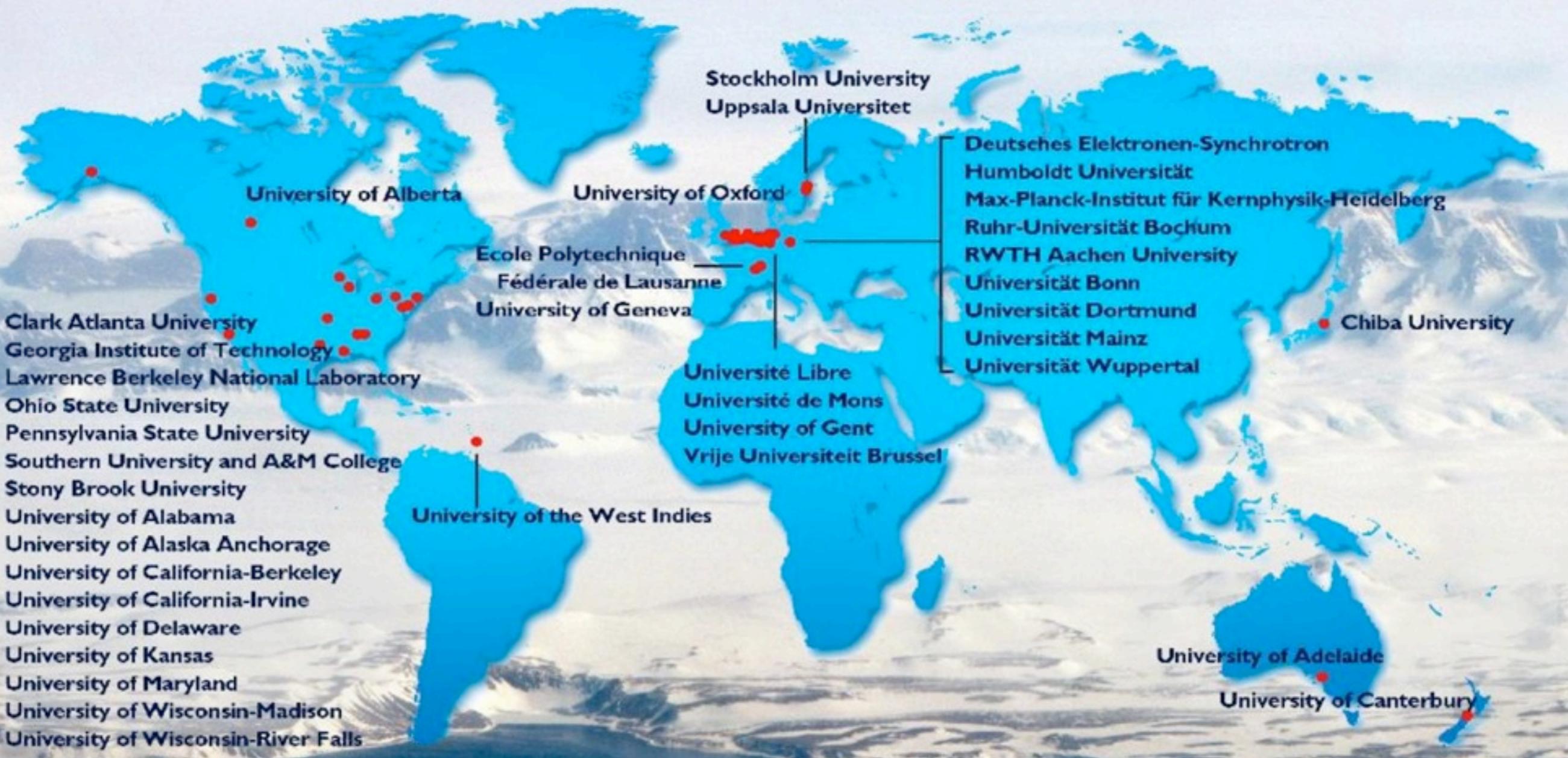
Going to lower and higher energies



Summary

- A multitude of highly interesting astro- and particle physics topics for neutrino telescopes
- **IceCube completed since Dec. 2010 (equiv. ~1 yr of data analyzed)**
 - Factor 1000 improvement in sensitivity over 10 years
 - Searches for cosmic neutrinos so far with negative results
 - Neutrino limits start to challenge GRBs as major sources of extragalactic cosmic rays
- **IceCube observes anisotropy in Galactic cosmic rays**
→ origin unknown up to now
- **Several projects to extend coverage to higher/lower energies and to include southern hemisphere in high-sensitivity coverage**

The IceCube Collaboration



IceCube Collaboration

11 countries
40 institutions
~260 collaborators