

ASTROPARTICLE PHYSICS

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# BELGIUM

Krijn De Vries, (for J. A. Aguilar)



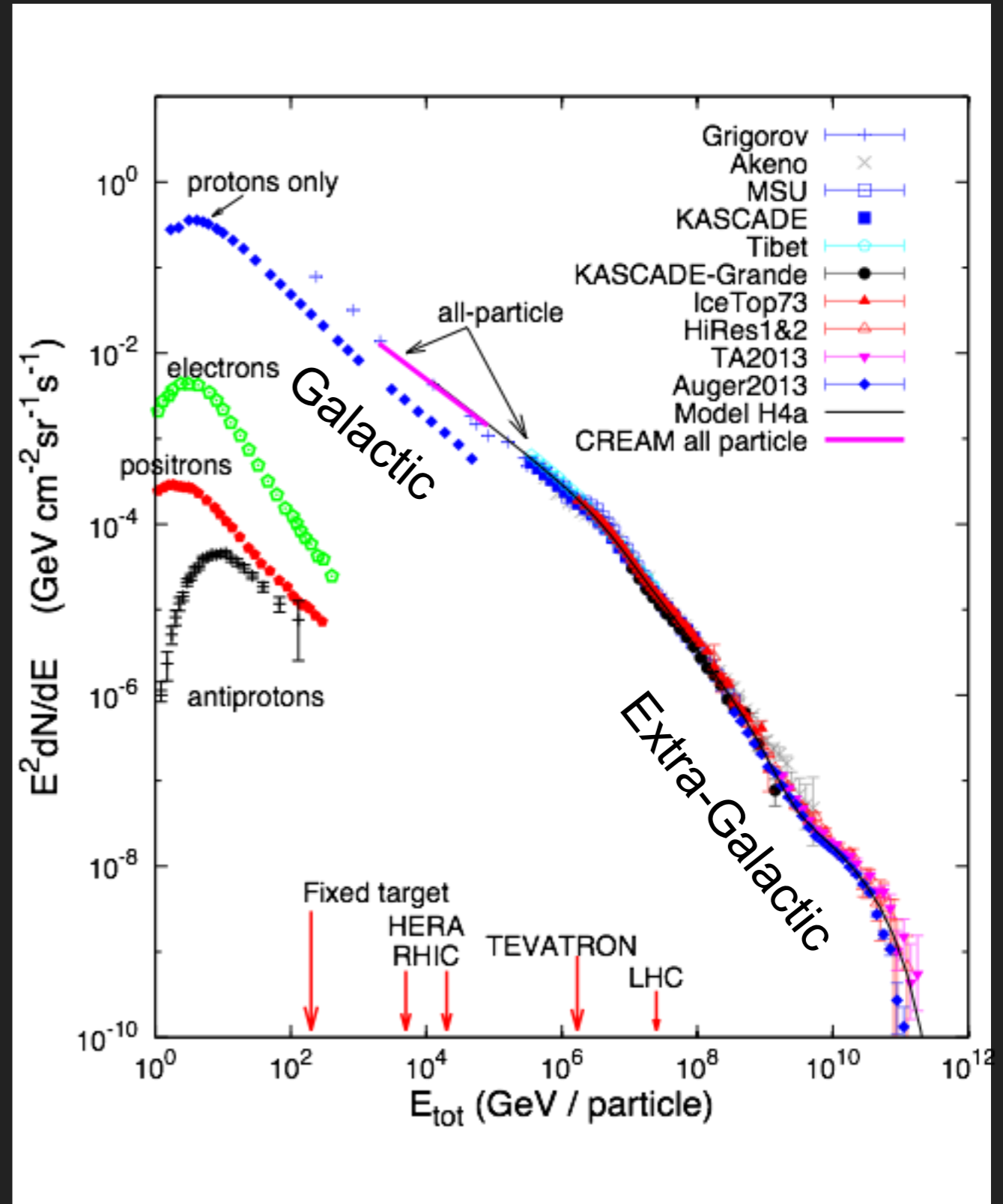
Photo: Ian Reese

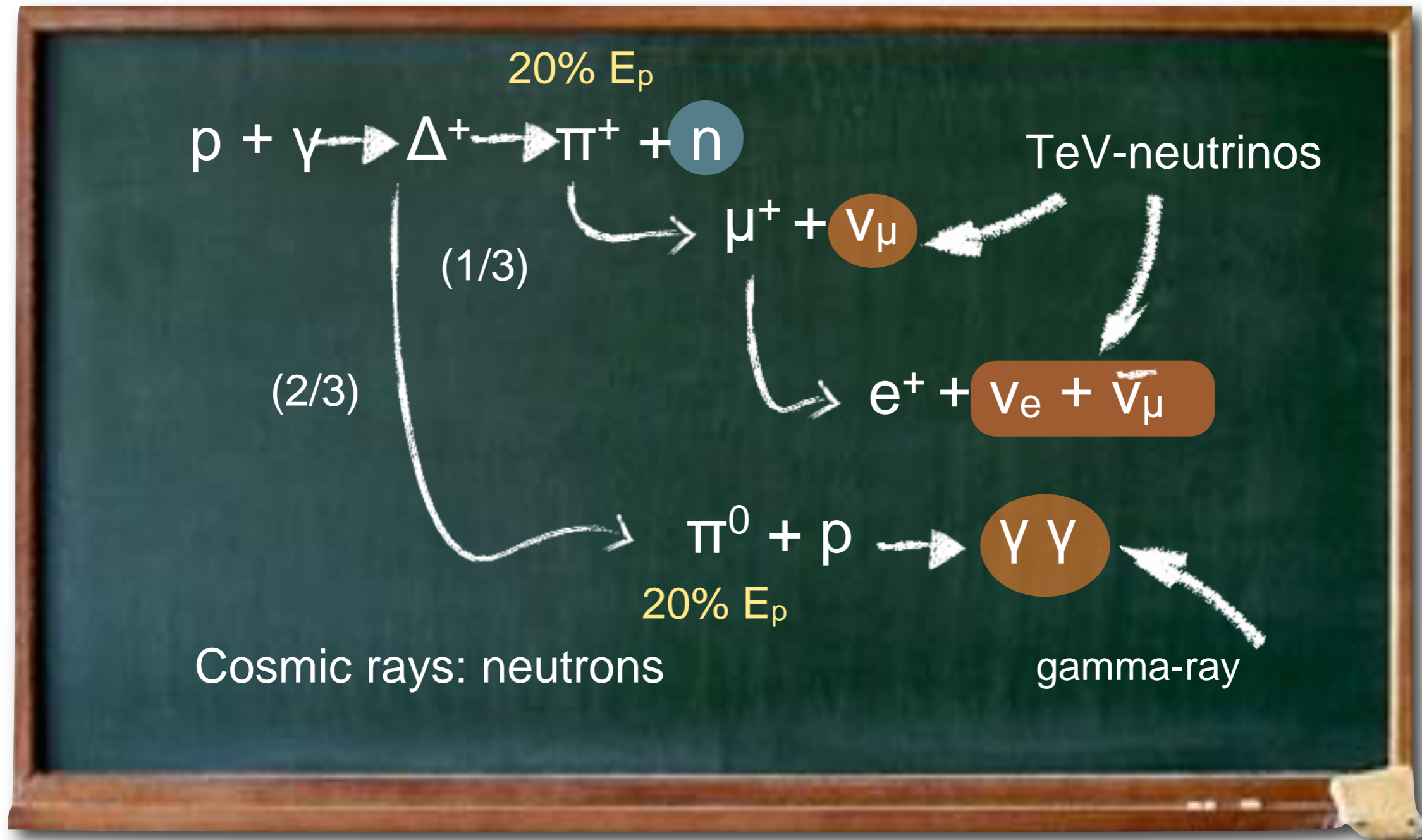
- ▶ The Cosmic Rays, Gamma-Ray and Neutrinos connection
- ▶ Neutrino Astronomy: The IceCube Neutrino Telescope
- ▶ Cosmic Rays: Auger and IceTop
- ▶ Conclusions

Disclaimer: This talk is heavily biased towards IceCube activities...

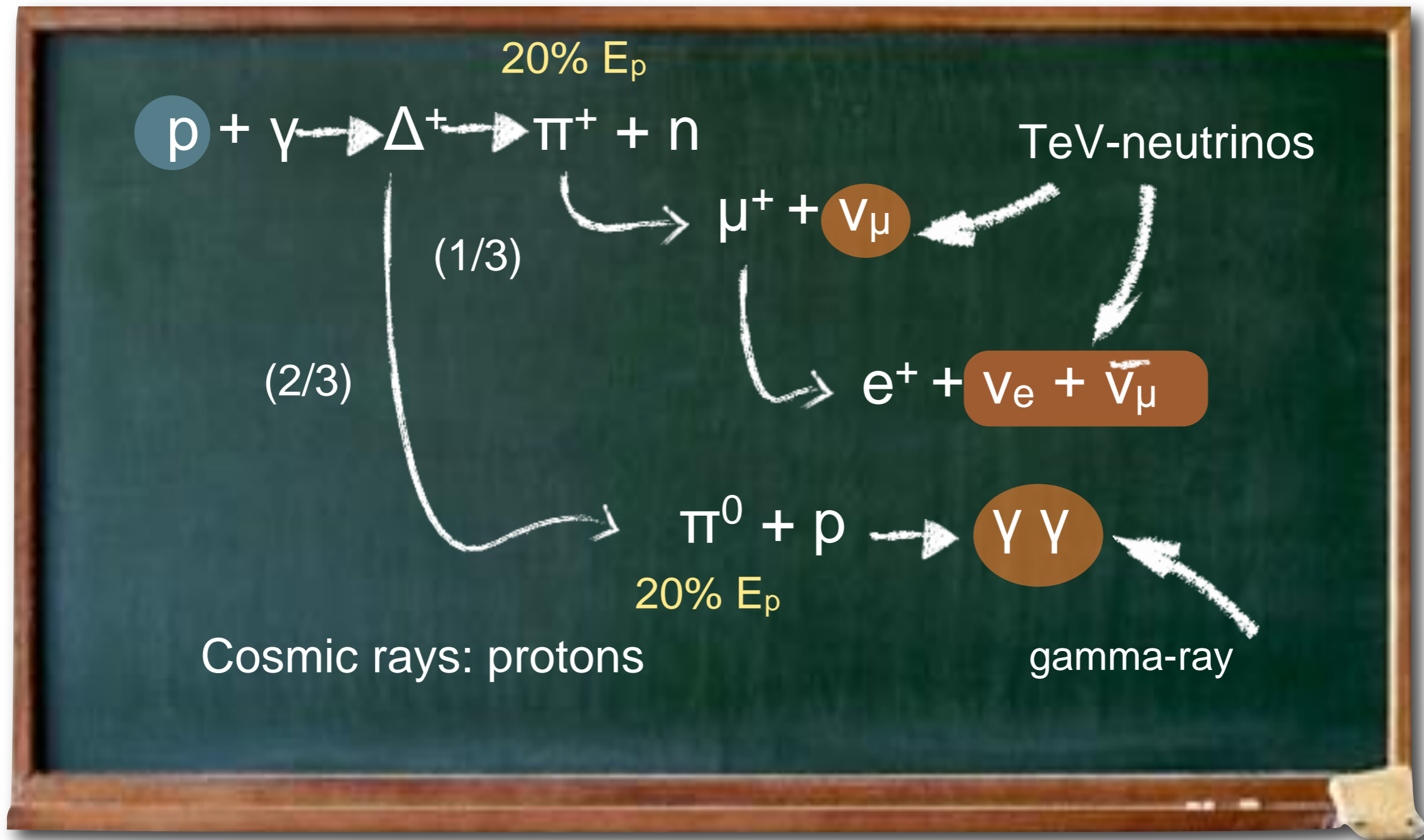
# THE COSMIC-RAY MYSTERY

- ▶ Cosmic Rays discovered by Victor Hess (and others) in 1912
- ▶ Cosmic Rays spectrum spans 10 decades of energy. Origin still unknown.
  - ▶ Galactic CRs: Supernova remnants?
  - ▶ Extra-Galactic CRs: AGNs, GRBs, magnetars?

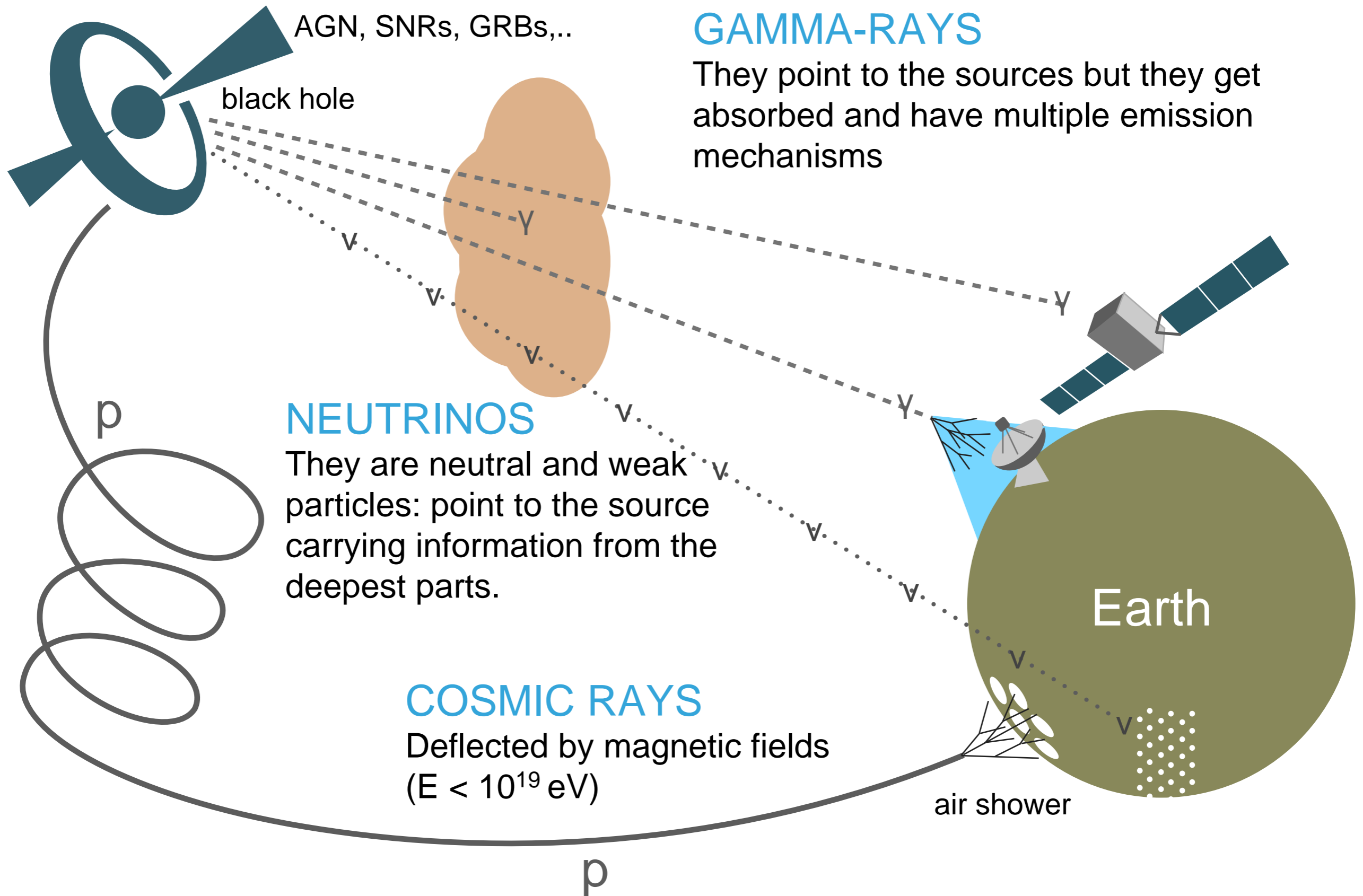




- ▶ Magnetic confinement (Rachel, Ahlers): Protons are trapped and neutrons escape decaying into CRs.



- ▶ Waxmann-Bahcall models: High-energy protons diffuse out of the shocks. The observed CR flux is a lower limit on the actual proton flux.



## GAMMA-RAYS

They point to the sources but they get absorbed and have multiple emission mechanisms

## NEUTRINOS

They are neutral and weak particles: point to the source carrying information from the deepest parts.

## COSMIC RAYS

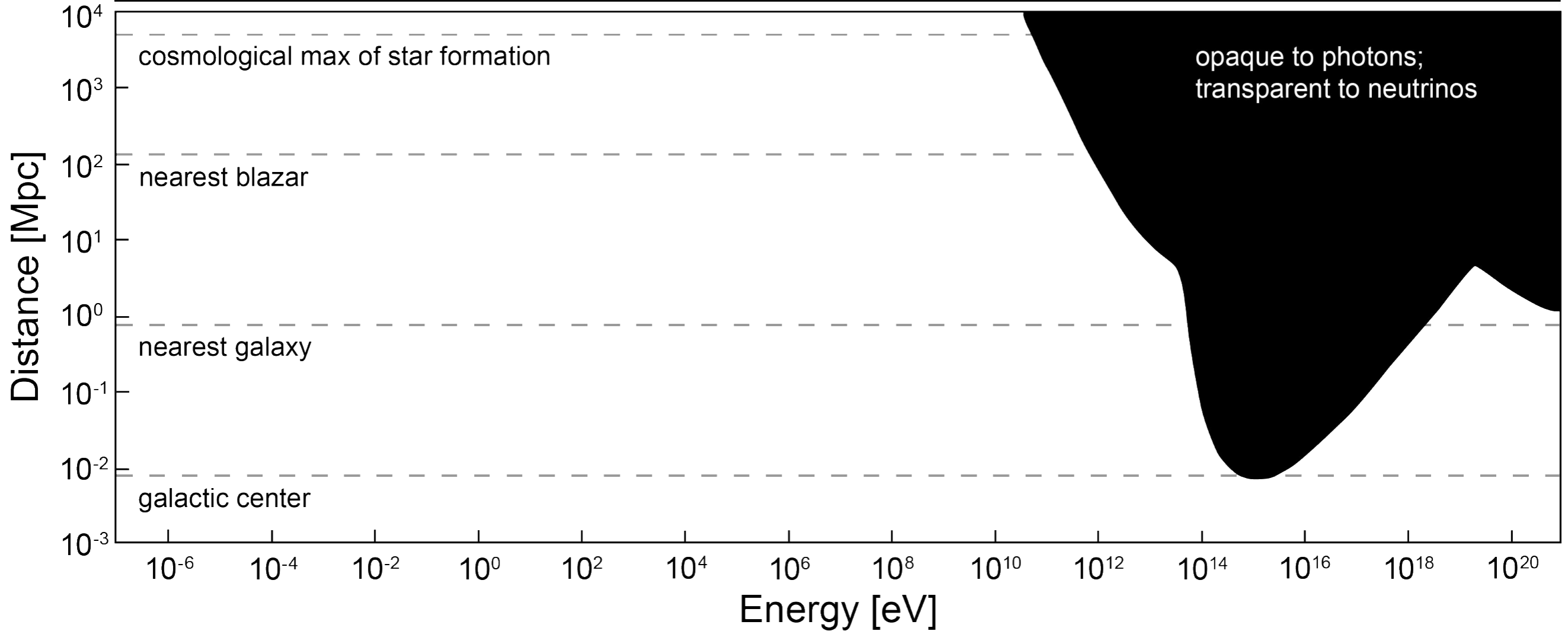
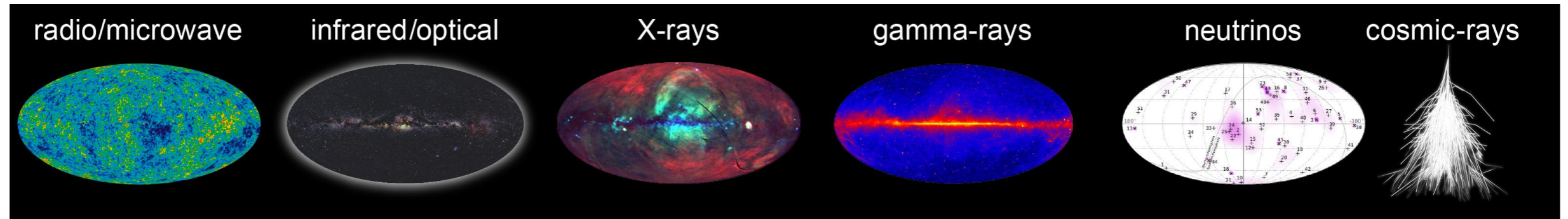
Deflected by magnetic fields ( $E < 10^{19}$  eV)

air shower

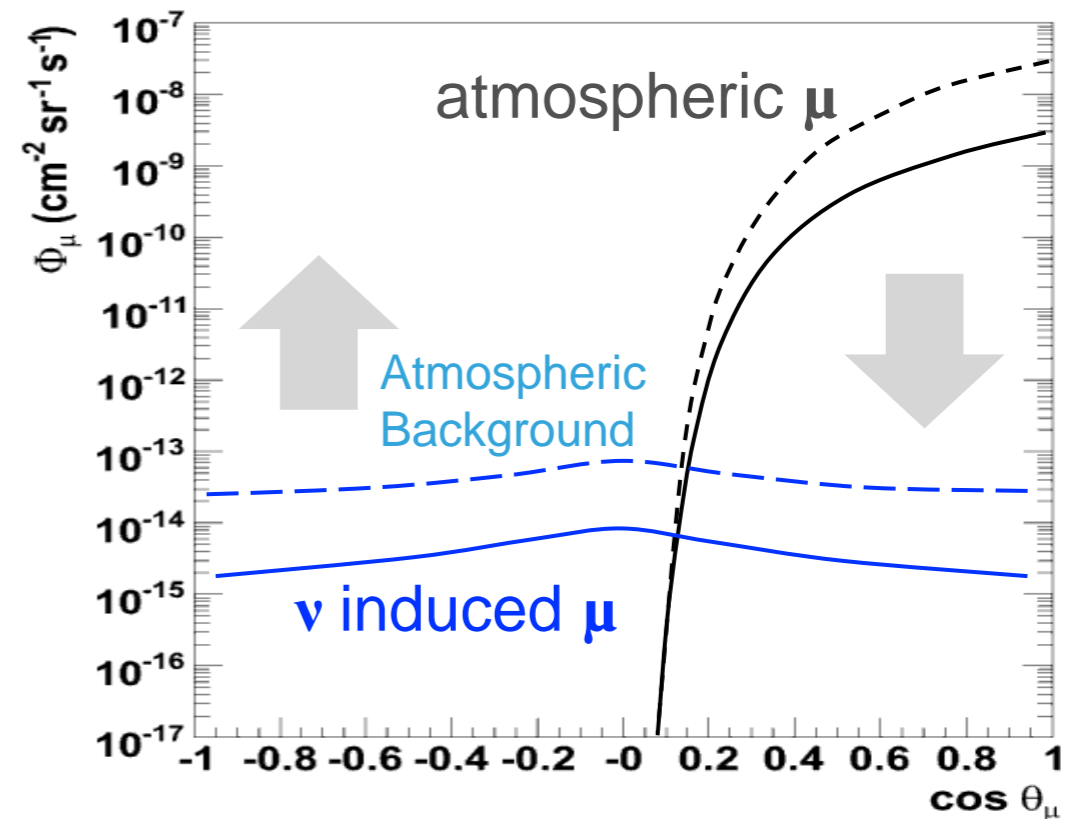
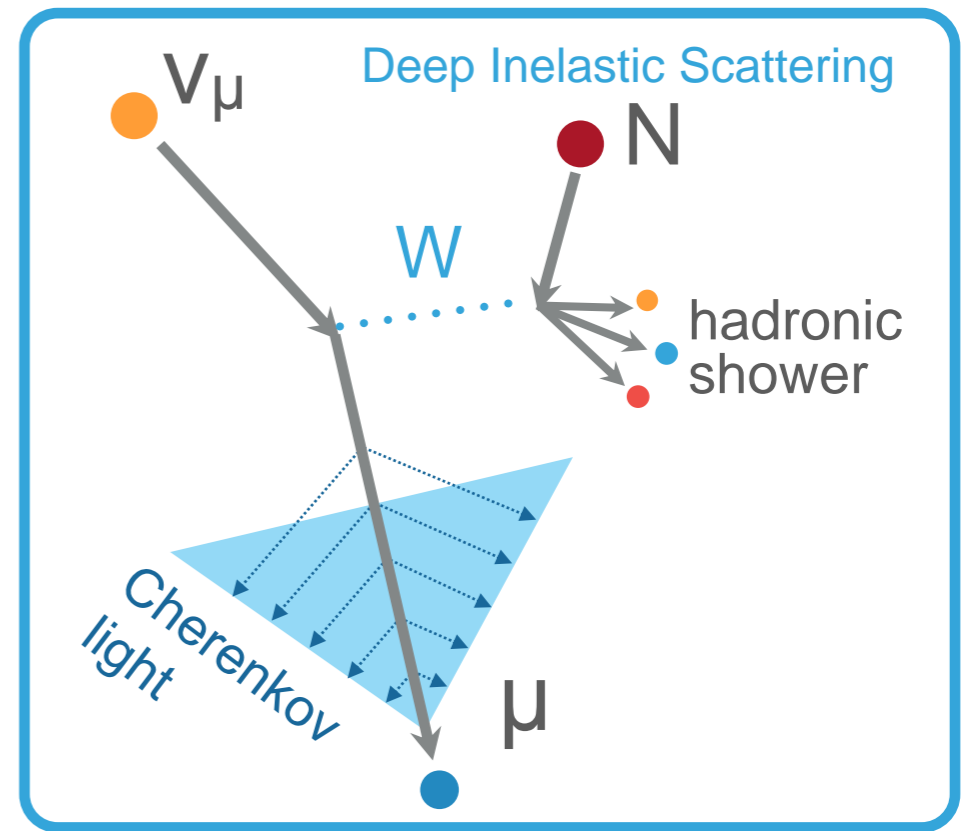
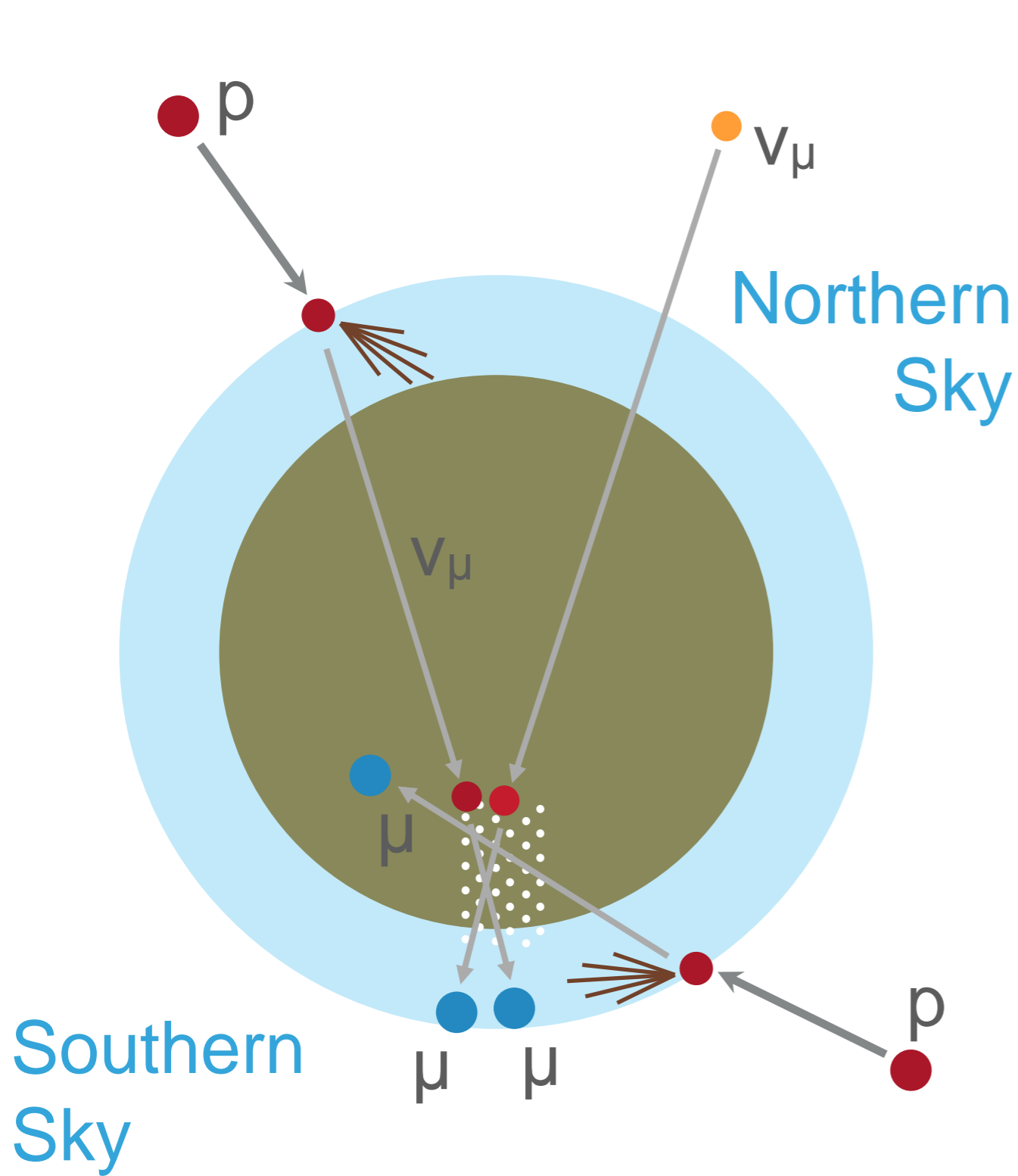
Earth

p

p

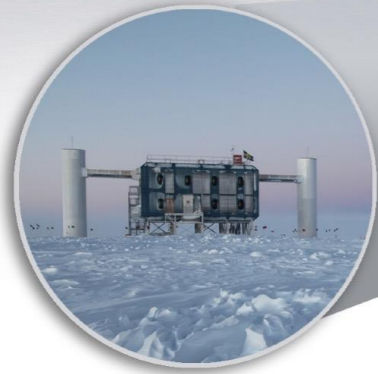


**Neutrino Astronomy is THE window  
to the extragalactic Universe above 100 TeV**





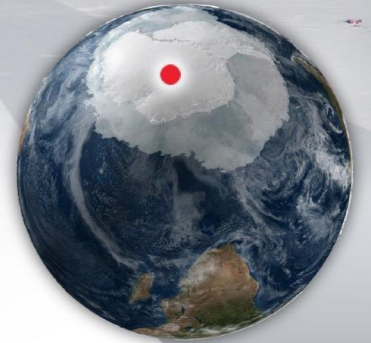
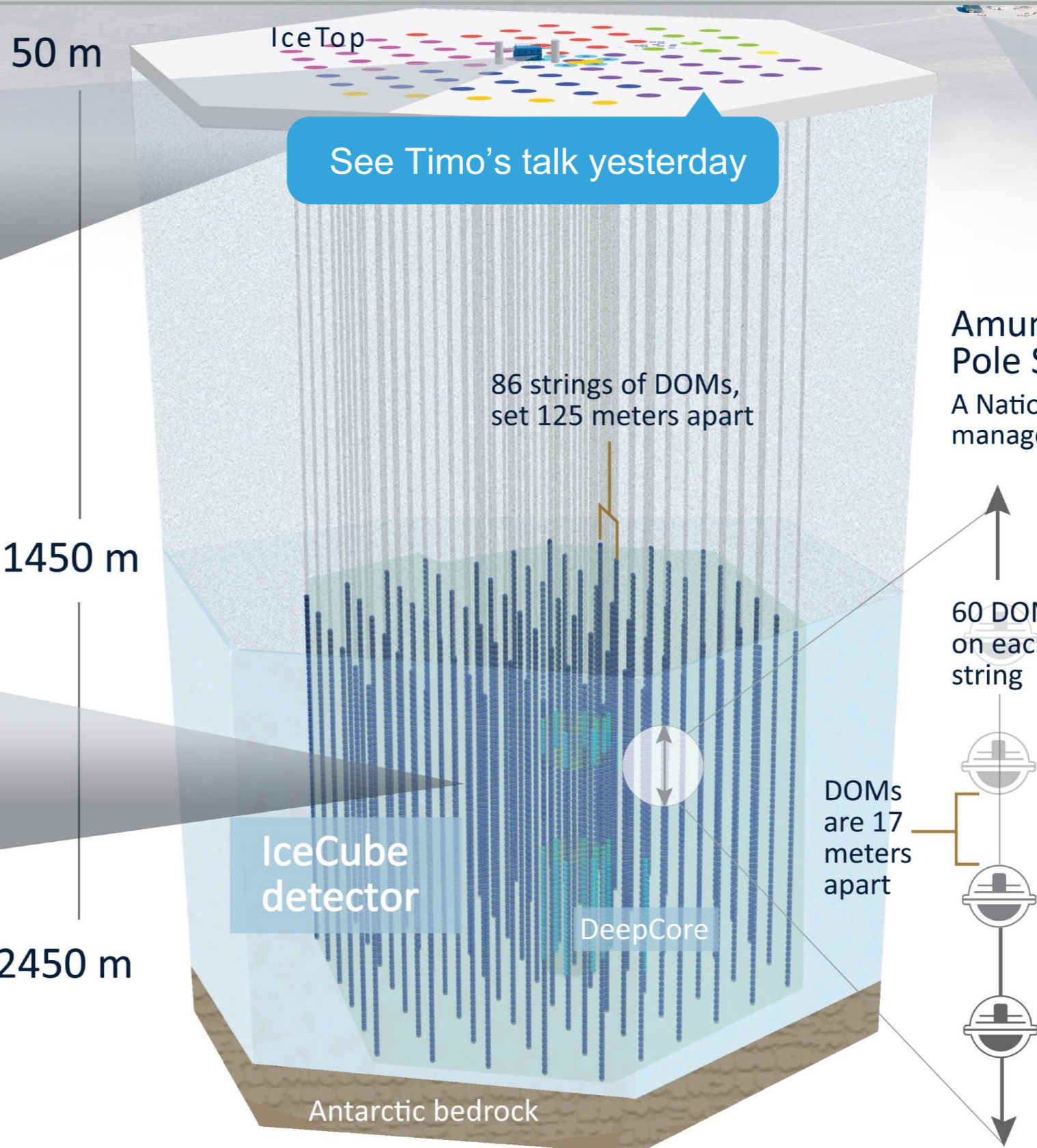
# THE ICECUBE NEUTRINO OBSERVATORY



**IceCube Laboratory**  
Data is collected here and sent by satellite to the data warehouse at UW-Madison



**Digital Optical Module (DOM)**  
5,160 DOMs deployed in the ice



**Amundsen-Scott South Pole Station, Antarctica**  
A National Science Foundation-managed research facility

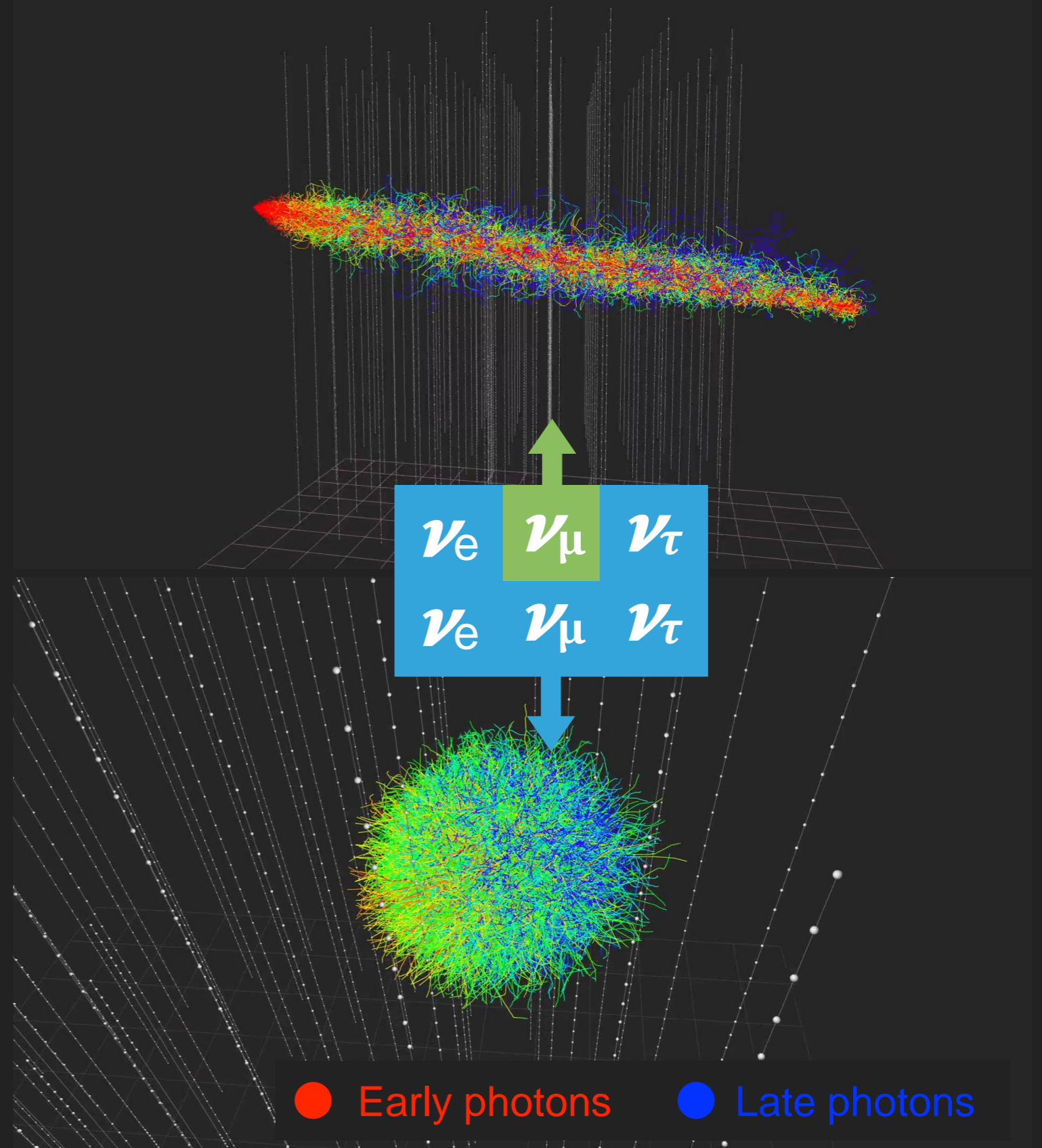


## Track topology

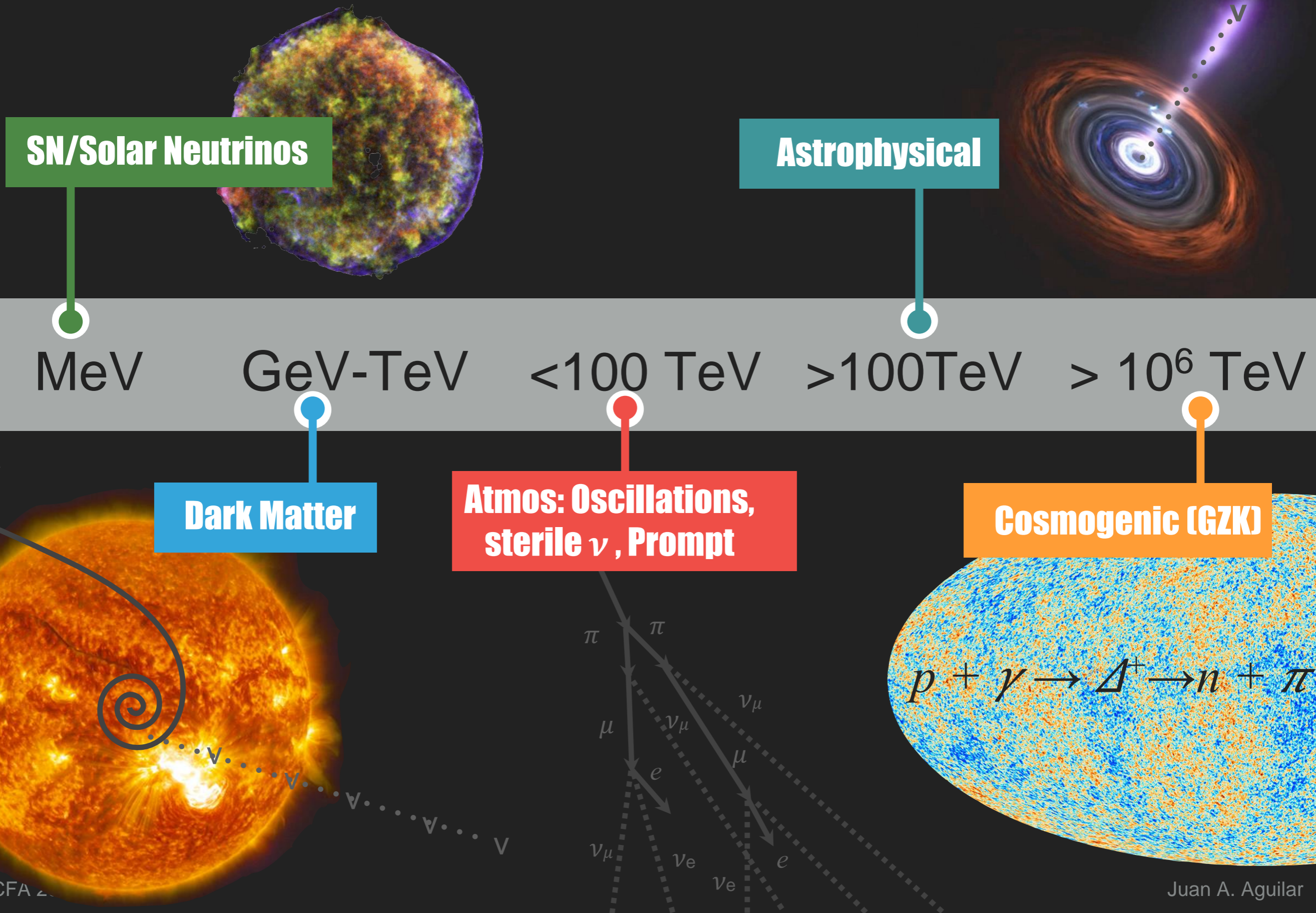
- ▶ Good angular resolution  $0.1^\circ - 1^\circ \rightarrow$  **Neutrino Astronomy**
- ▶ Vertex can be outside the detector  $\rightarrow$  **Increased effective volume**

## Cascade topology

- ▶ All flavors
- ▶ Fully active calorimeter  $\rightarrow$  **Good energy resolution  $\pm 15\%$  deposited energy**
- ▶ Angular reconstruction possible  $\rightarrow$   **$\sim 10^\circ > 100$  TeV**



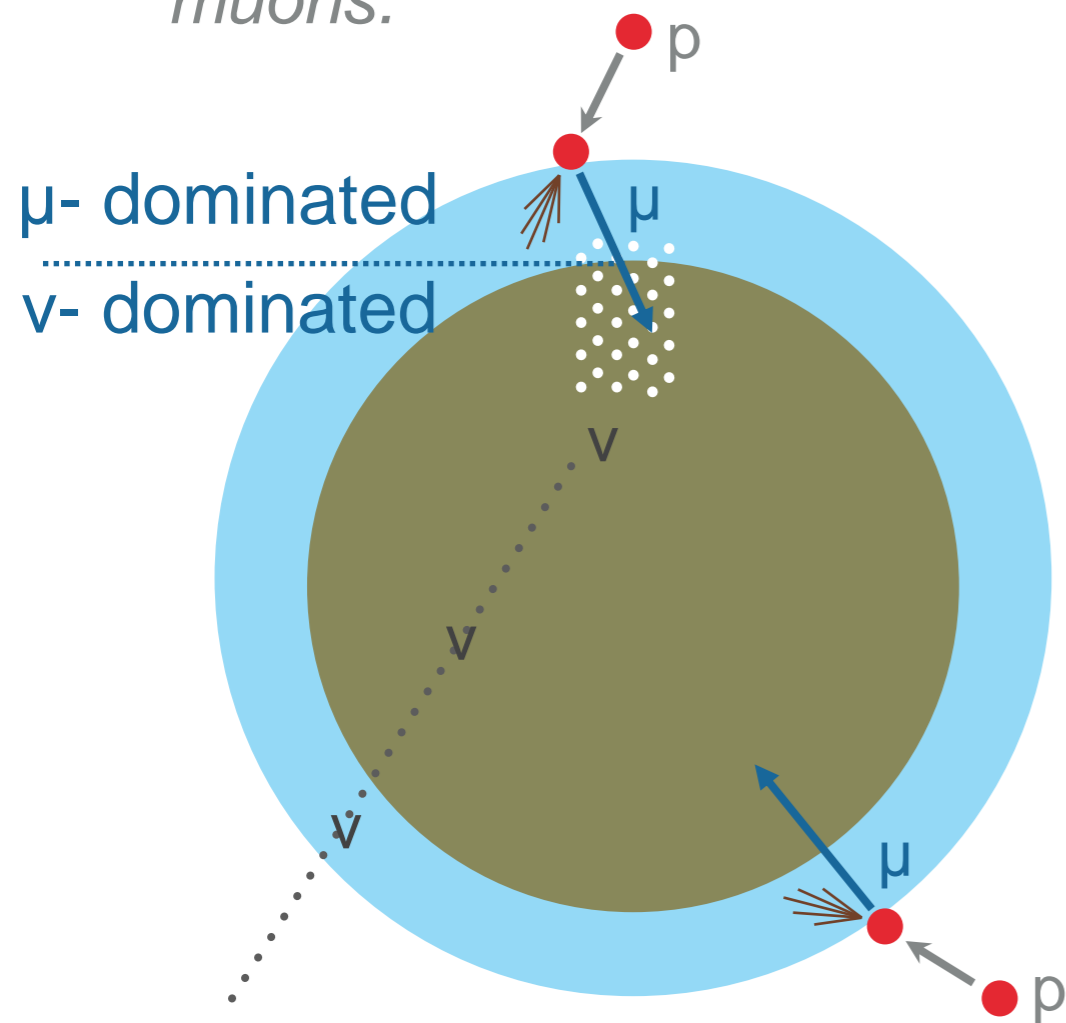
# ENERGY RANGE: SCIENTIFIC SCOPE



Sources may be numerous and faint, hard to resolve individually.

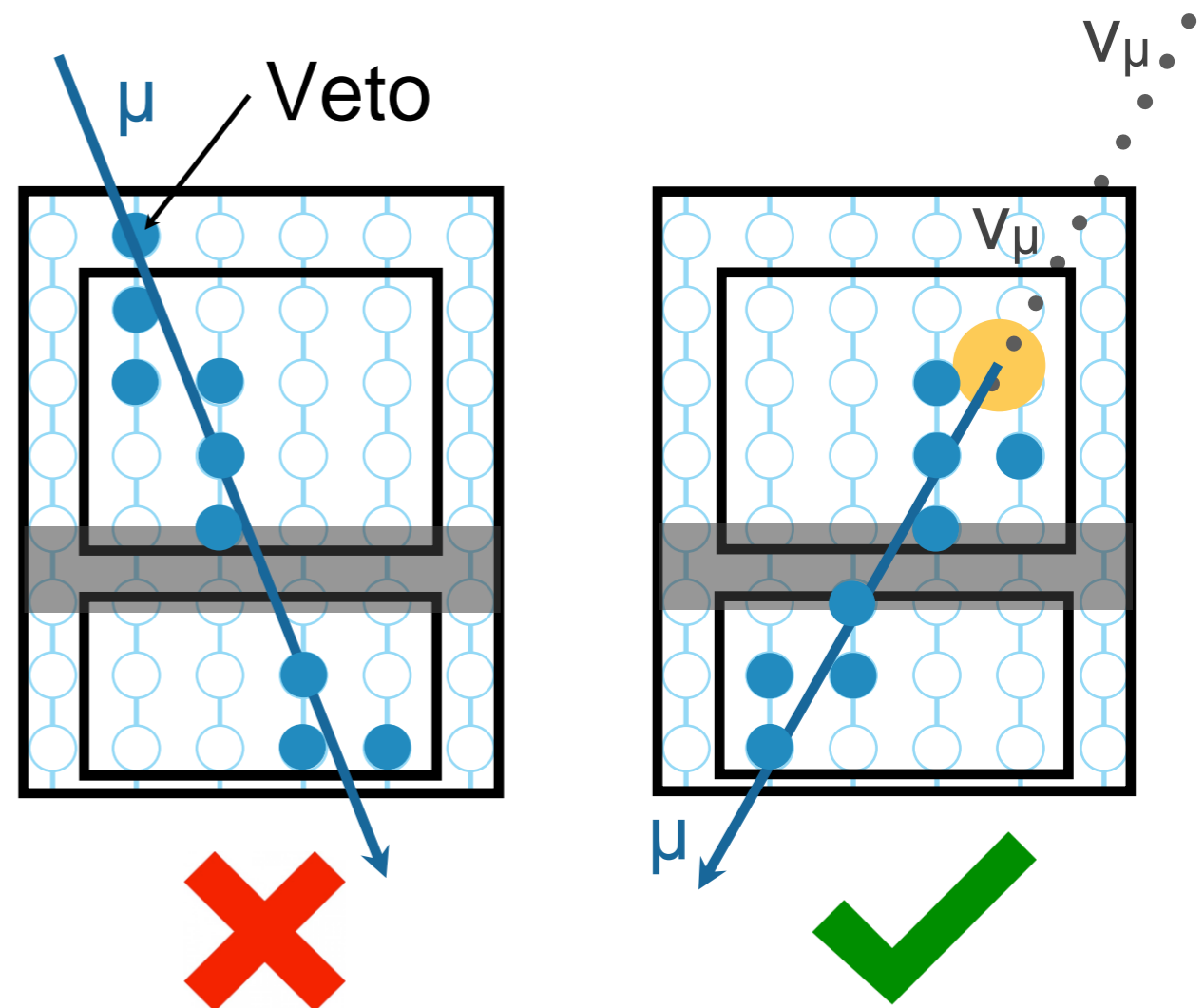
1

Using up-going through-going muon events using Earth as a shield against atmospheric muons.



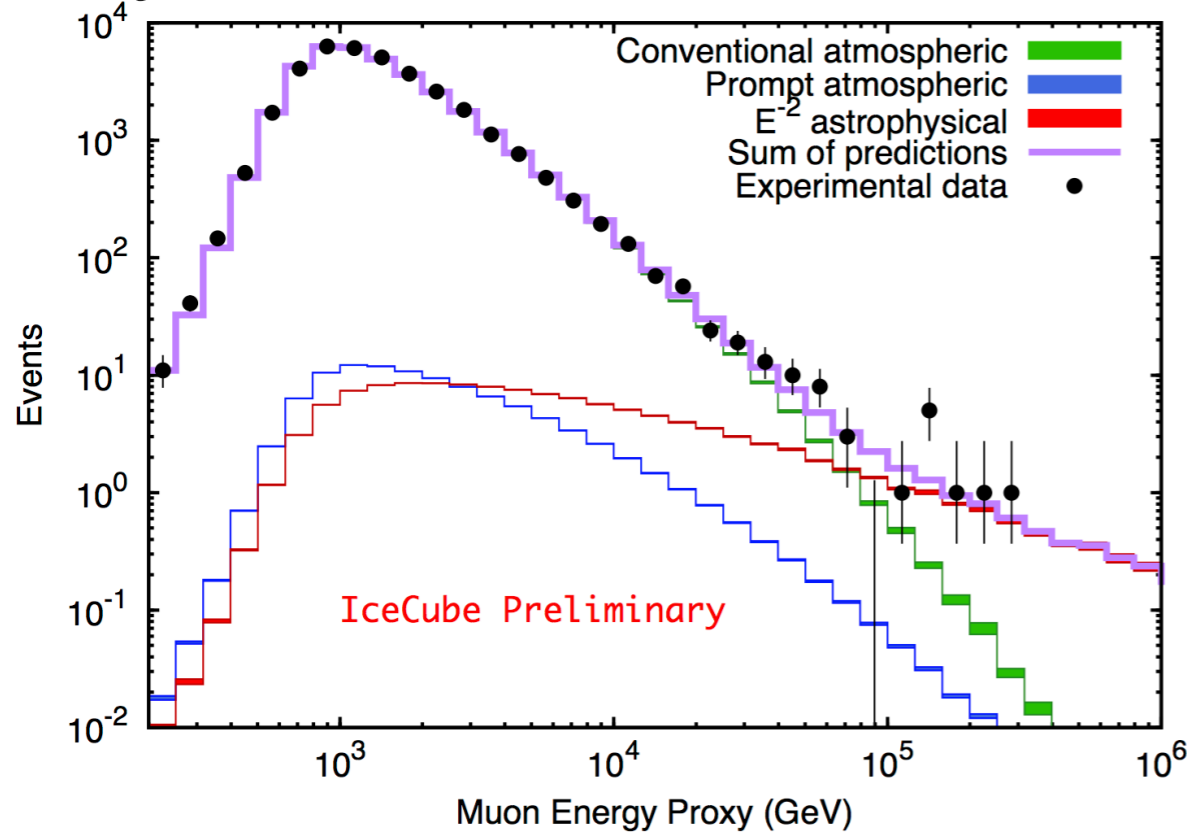
2

Using the outer layers as an active veto to select starting events.



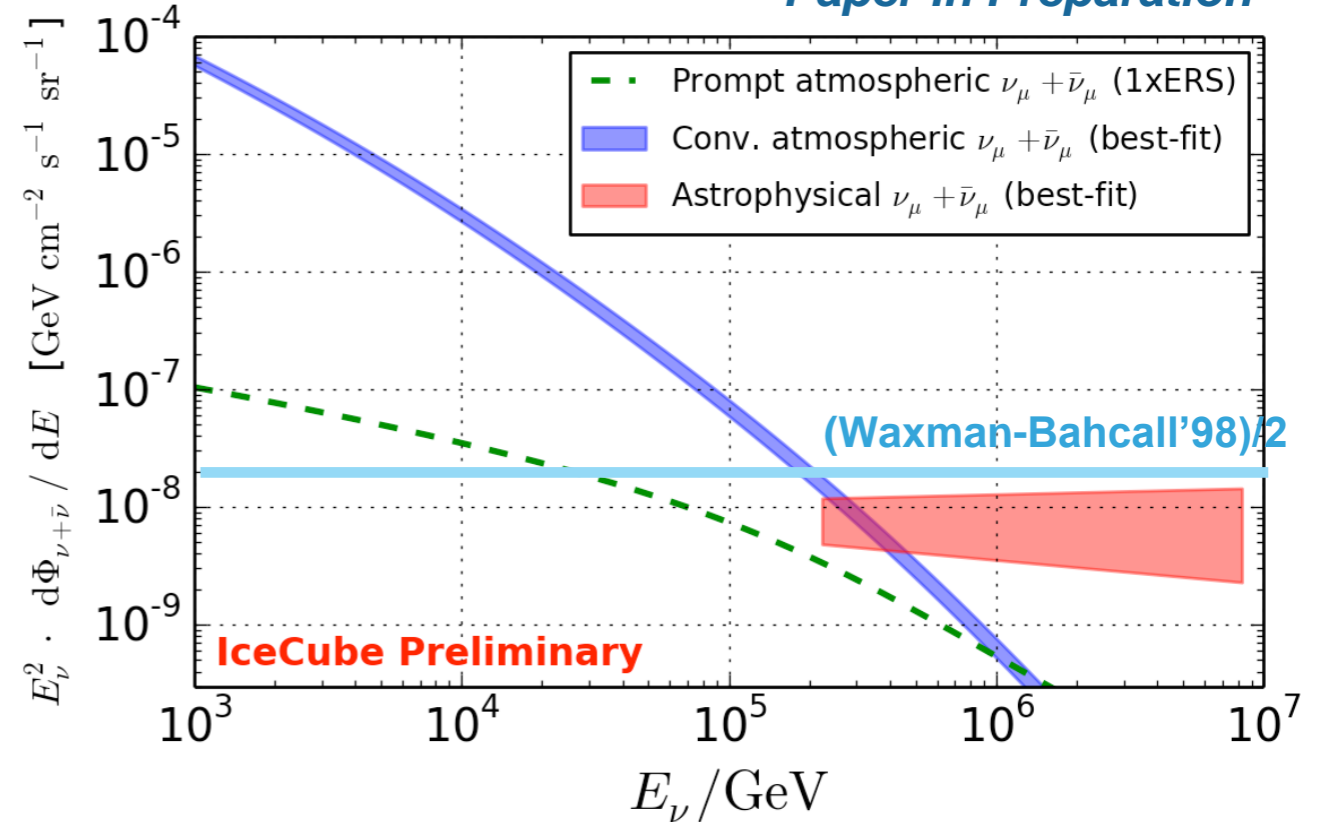
2 years

*PRL 115, 081102 (2015)*



6 years

*TeVPA 2015, Tokyo. Paper In Preparation*



- ▶ First evidence ( $3.7\sigma$ ) of an extra  $\nu_\mu$ -based astrophysical component already seen with **2 years** of data.
- ▶ Latest results ( $5.9\sigma$ ) with **6 years**.

Measured flux:

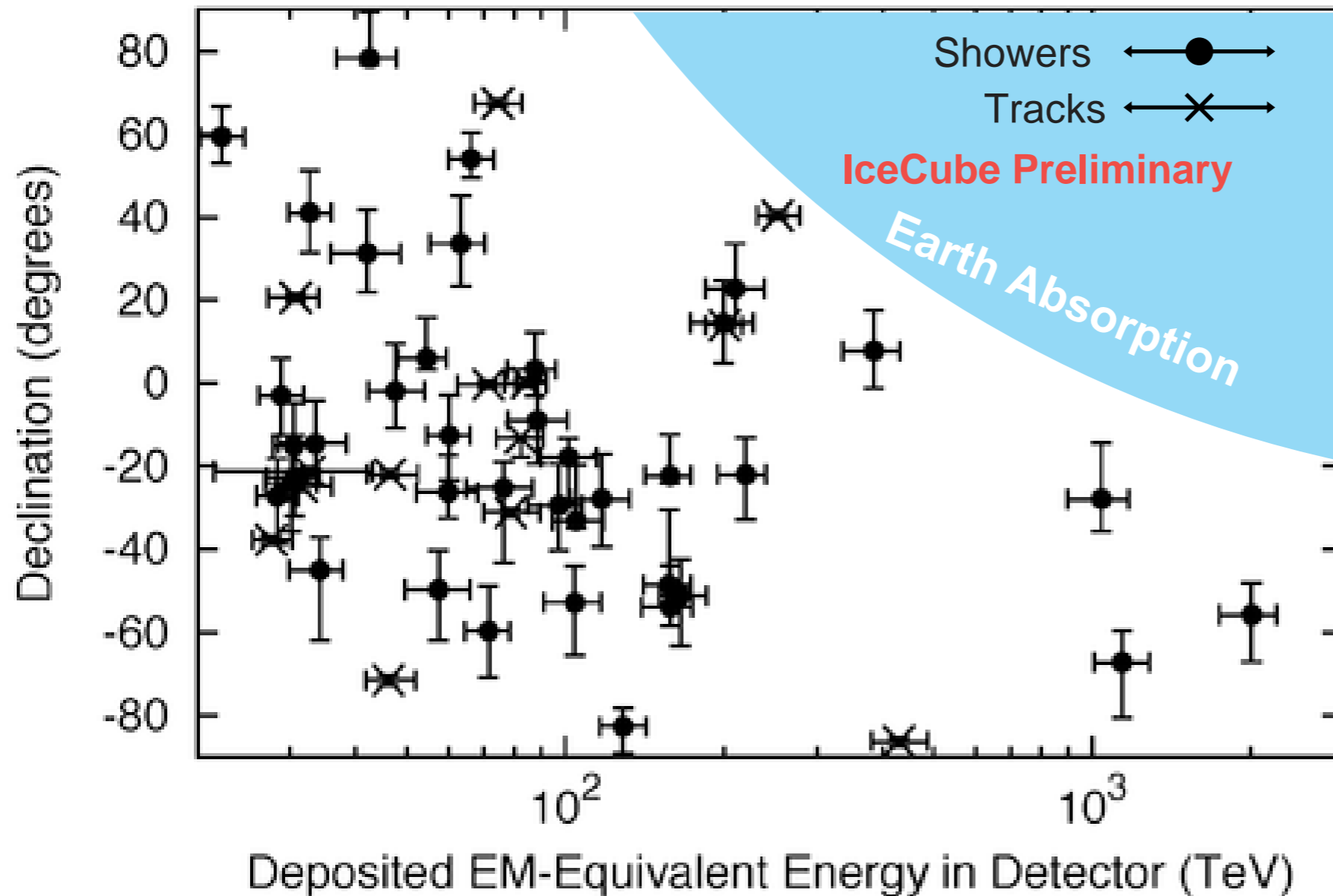
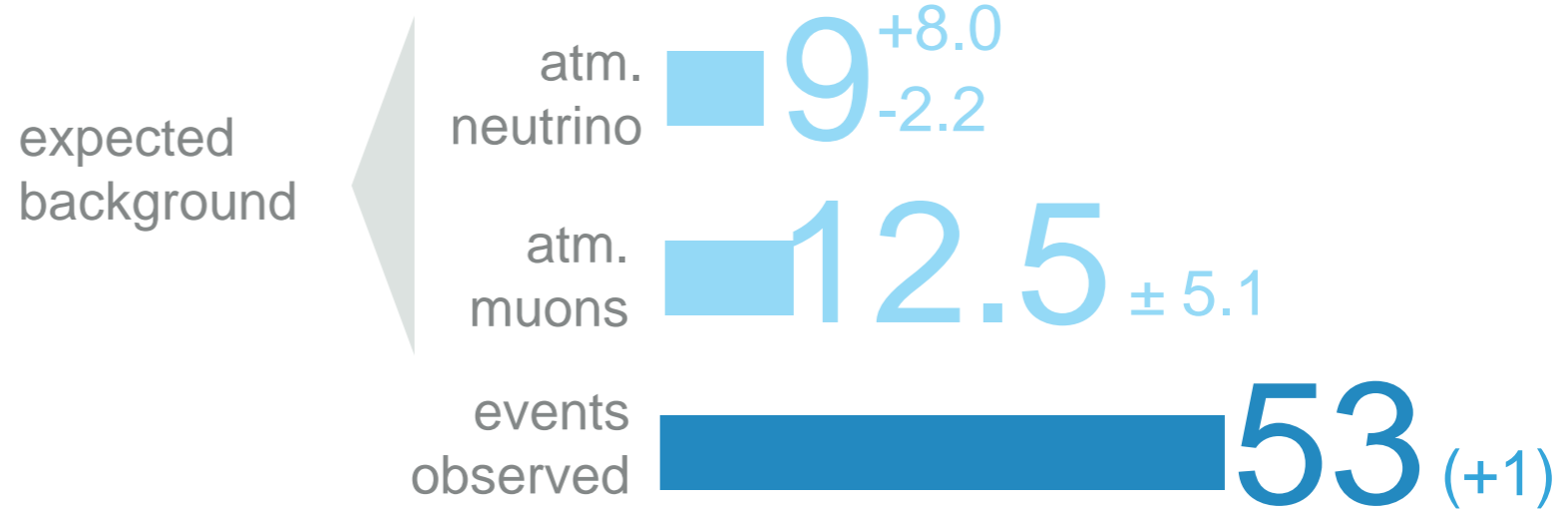
$$\Phi(E_\nu) = 0.82_{-0.26}^{+0.30} \times 10^{-18} \text{GeV}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{s}^{-1} (E_\nu / 100 \text{ TeV})^{(-2.08 \pm 0.13)}$$

hard spectrum



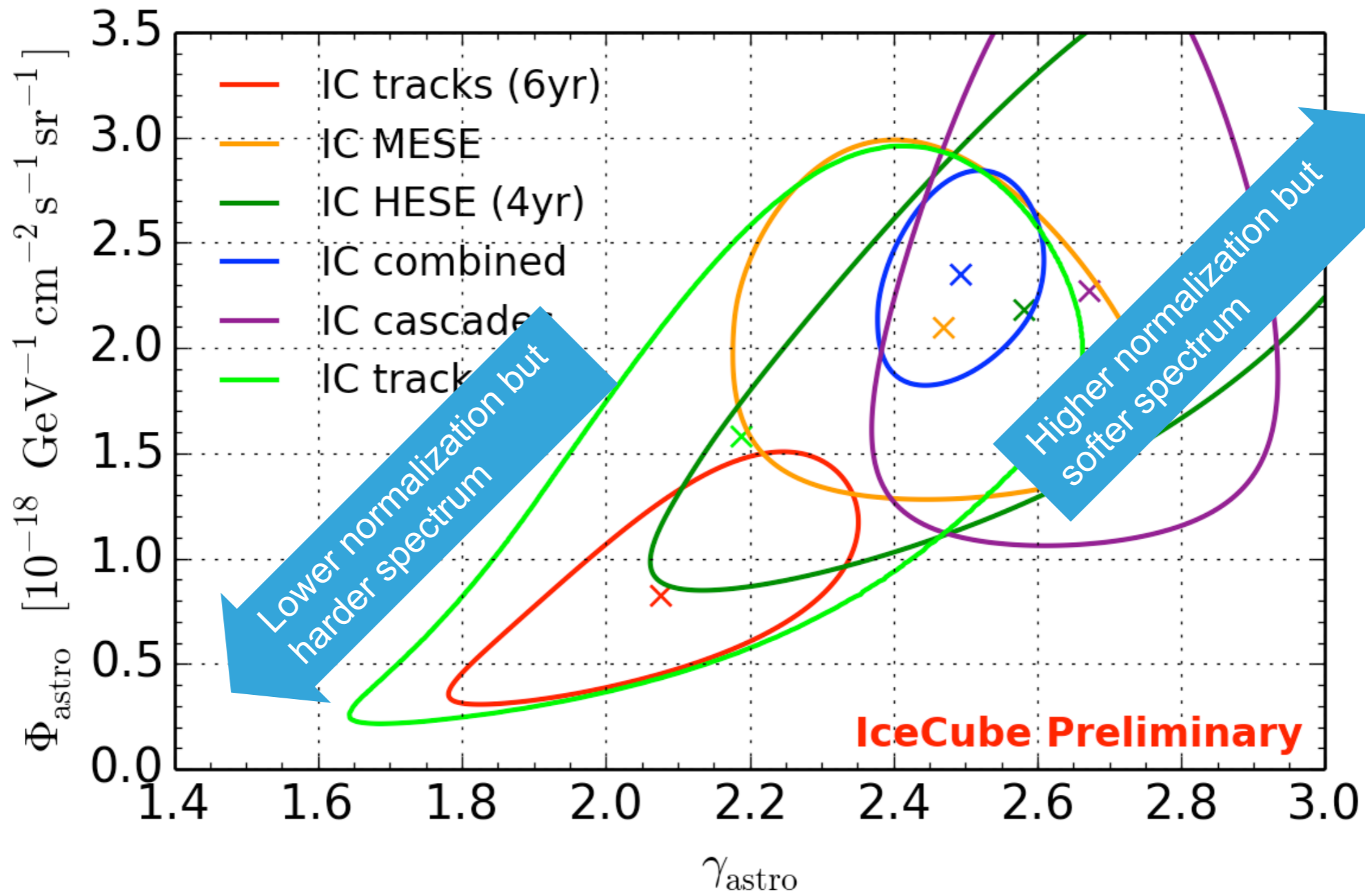
# 2 DIFFUSE: STARTING EVENTS

- ▶ Results from 4 years of data.
- ▶ Analysis is sensitive to track and cascade topologies.
- ▶ Lower energy threshold



**6.5σ**  
for 53(+1) events

*arXiv:1510.05223*  
*PoS(ICRC2015)1081*

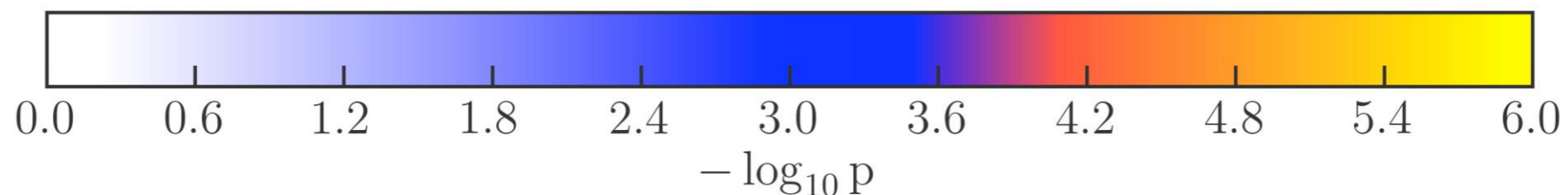
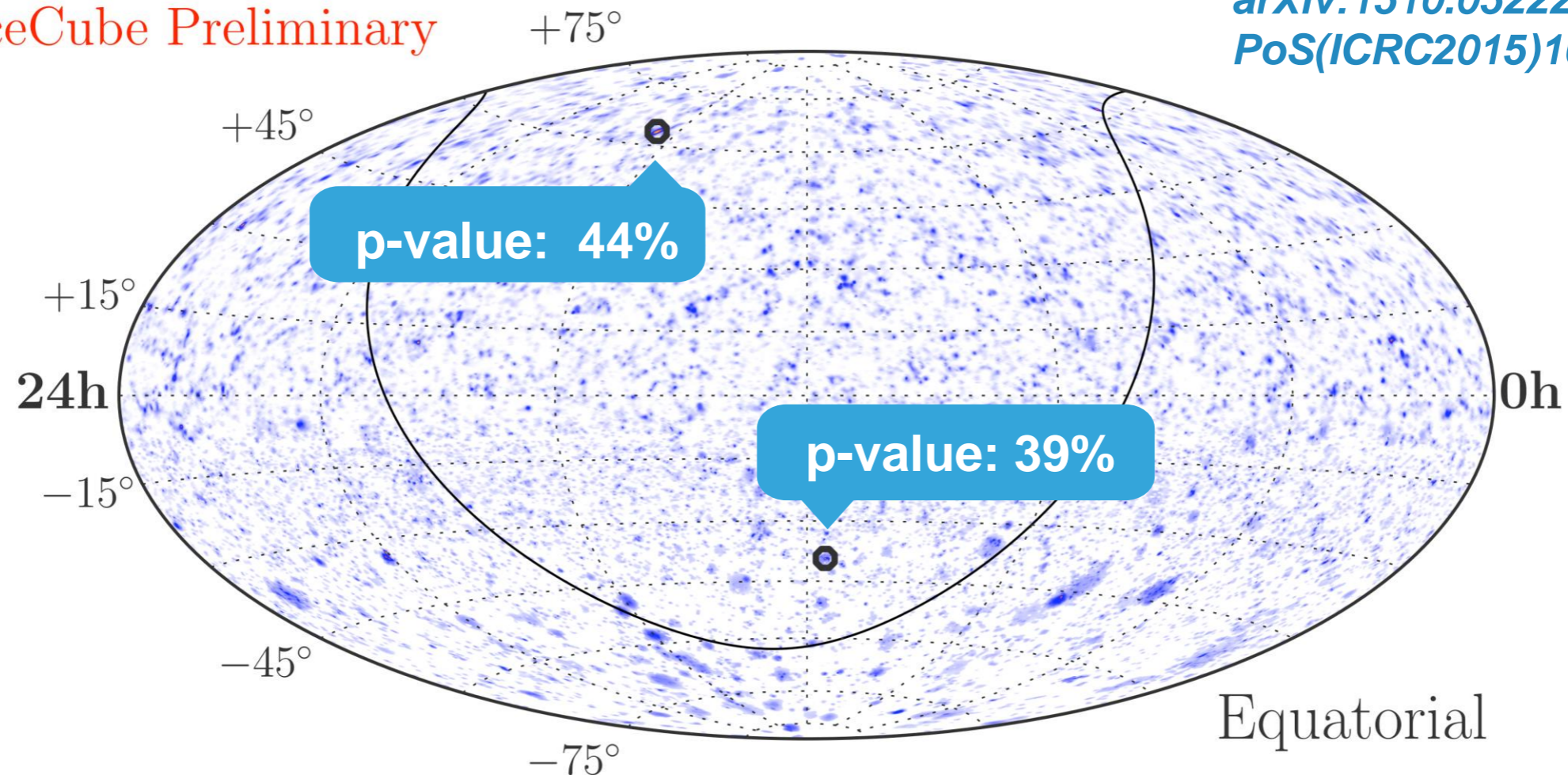


- ▶ Departing from the single unbroken power-law hypothesis  $E^{-\gamma}$ ?

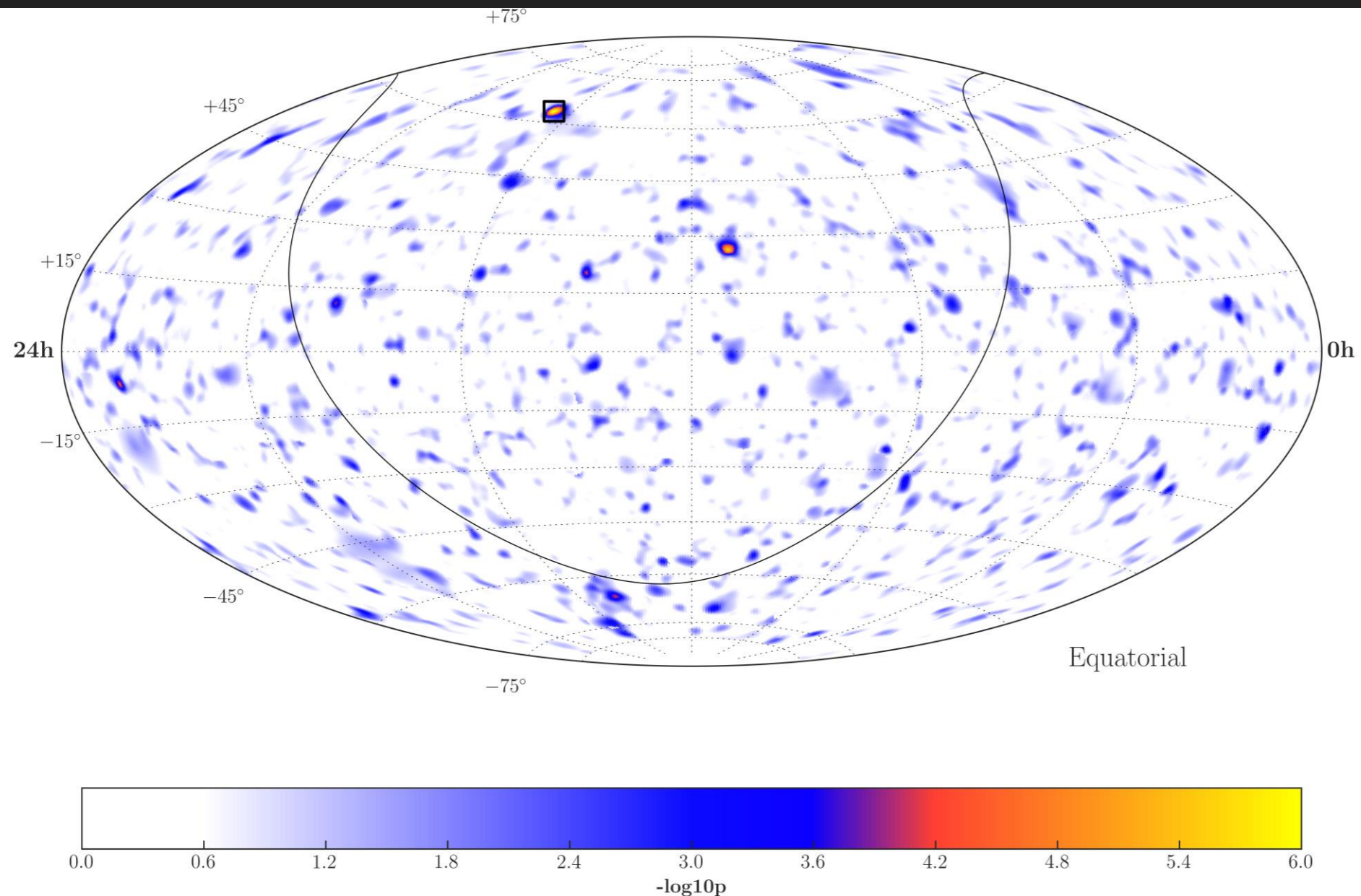
- ▶ Using **6 years** through-going sample, best sample for point-source searches.
- ▶ No significant excess found.

*arXiv:1510.05222*  
*PoS(ICRC2015)1047*

IceCube Preliminary

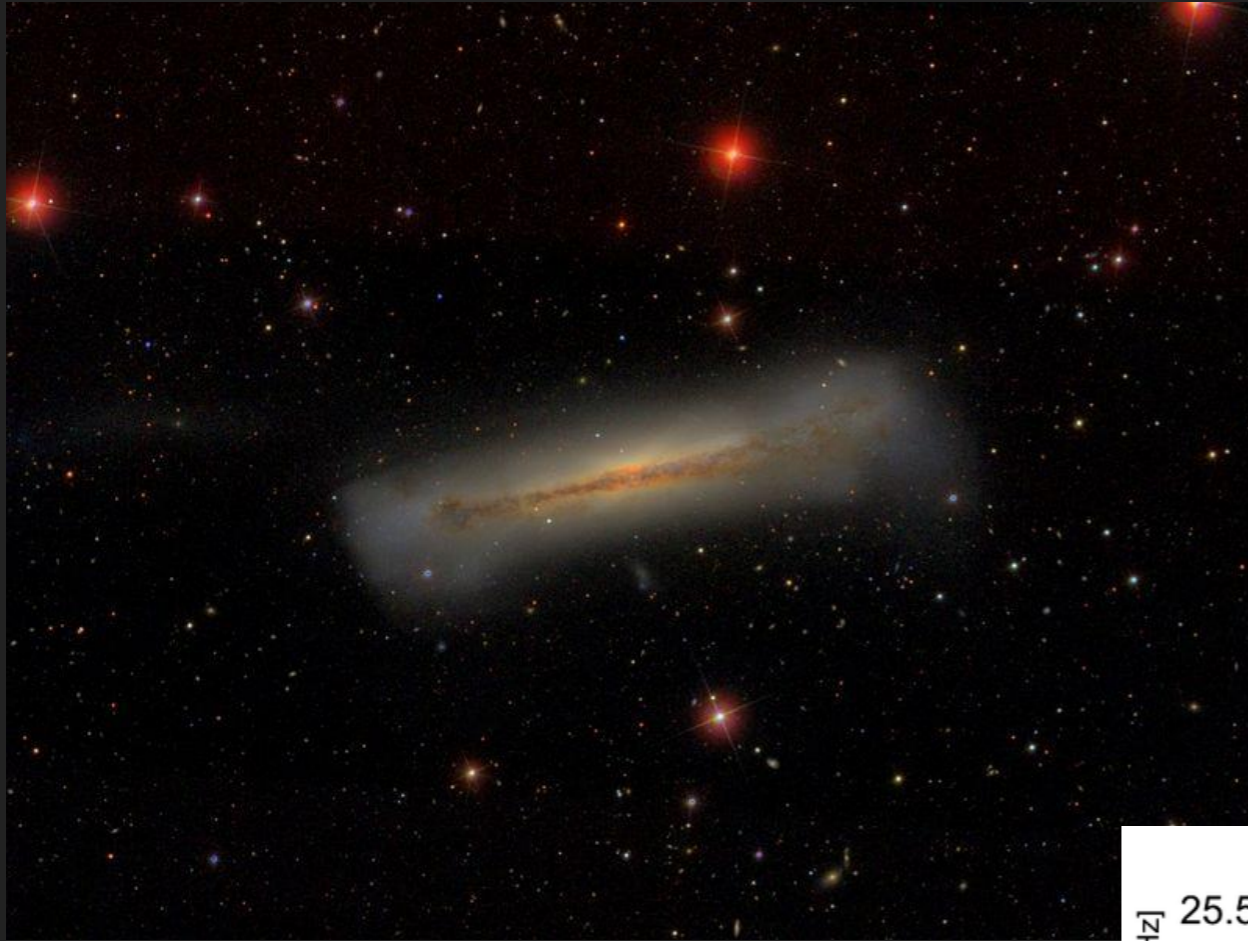






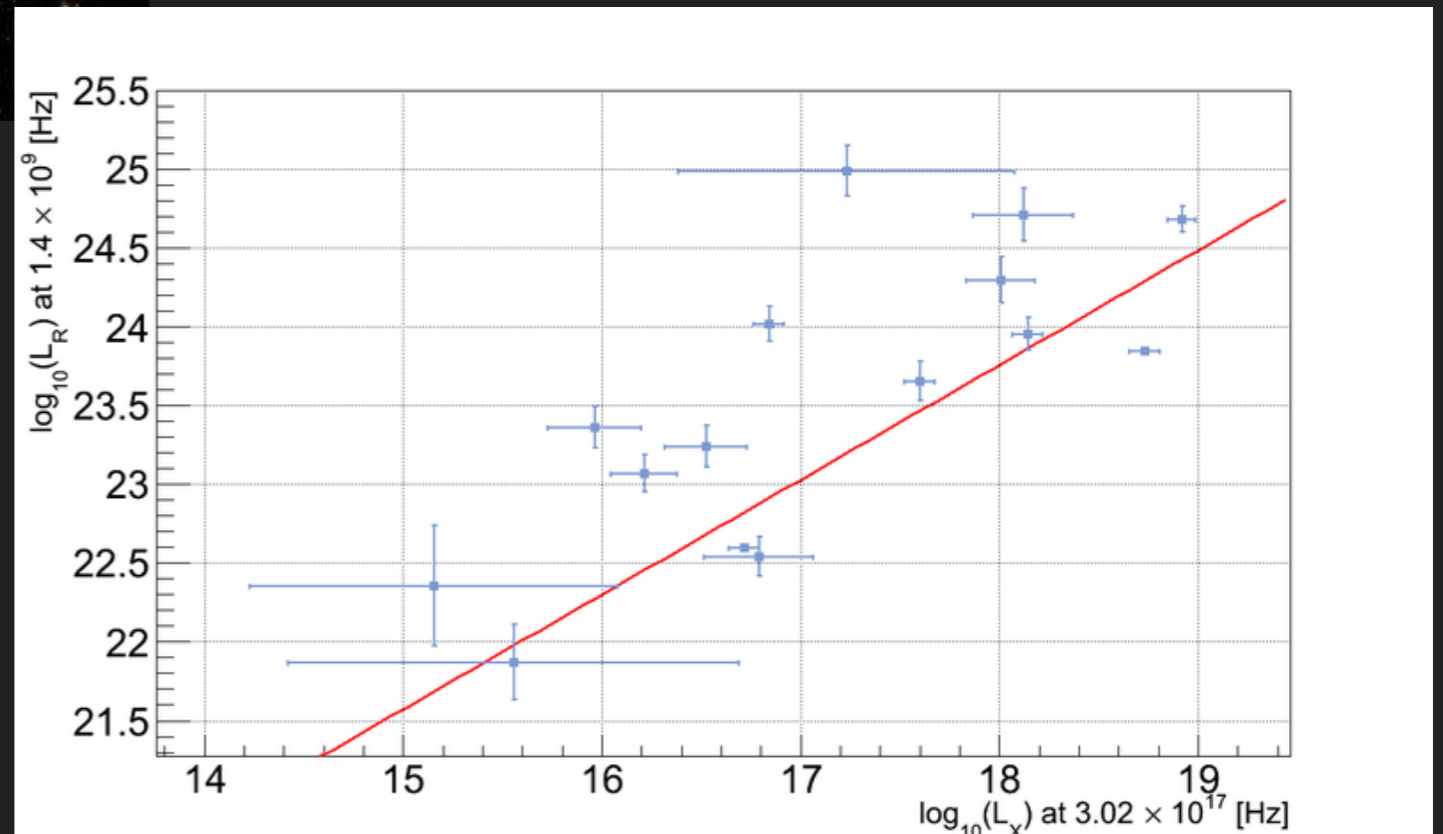
- ▶ Similar analysis but assuming sources are extended.
- ▶ Scans of 1 - 5 degrees.
- ▶ No significant excess found on any skymap

work at ULB



- ▶ Dust obscured radio AGNs can offer the perfect calorimetric environment (beam dump) for neutrino production.
- ▶ These sources will appear in high luminosity in IR but low in gamma-rays.

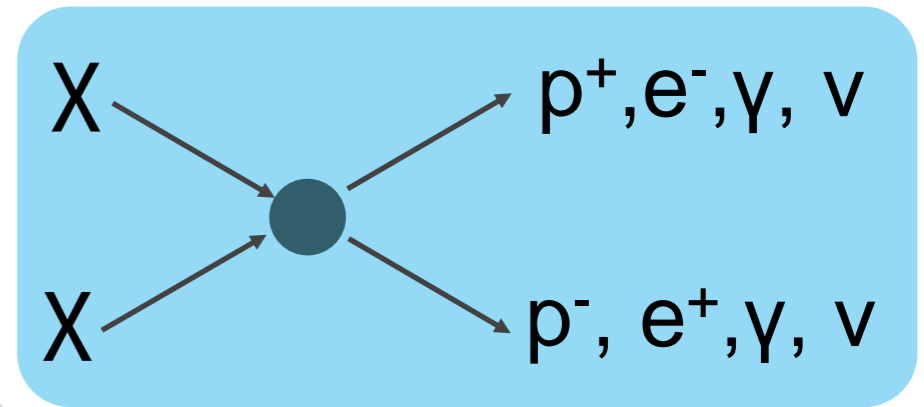
- ▶ Analysis being done at VUB



# INDIRECT SEARCH OF DARK MATTERS: RESERVOIRS <sup>19</sup>

Dwarf spheroidal  
Galaxies  
Cluster of Galaxies

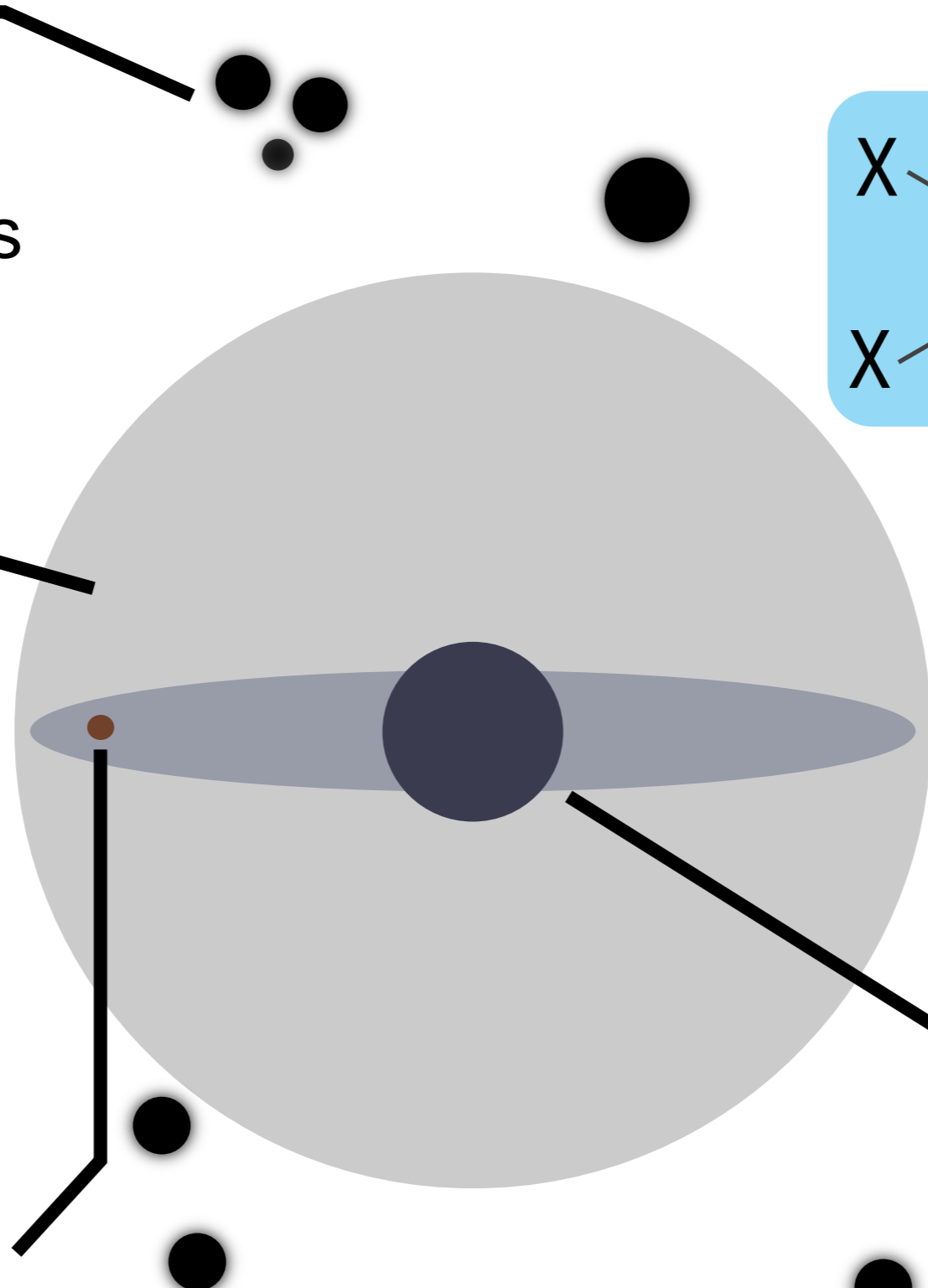
Indirect searches

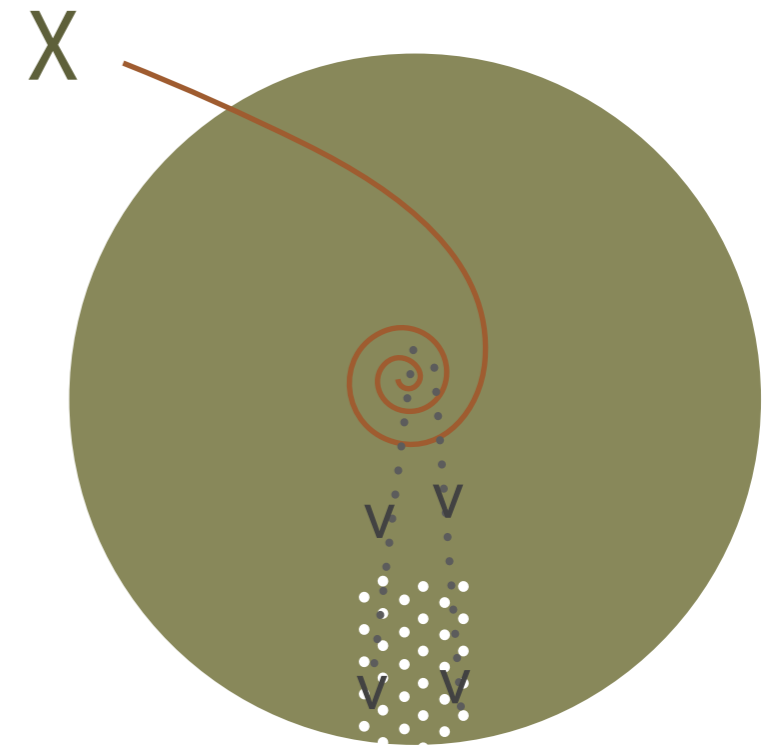
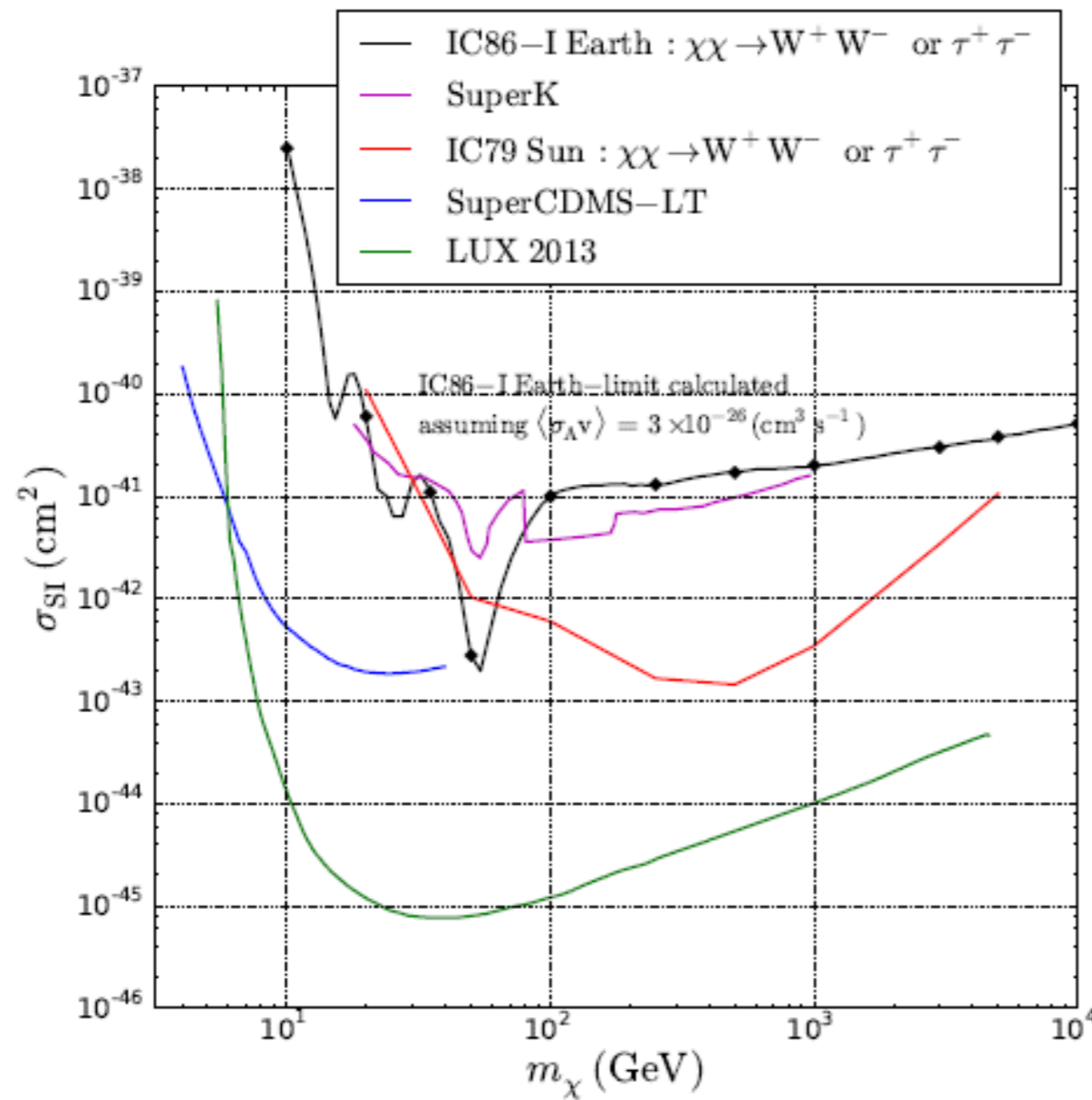


Galactic Halo

Galactic Center

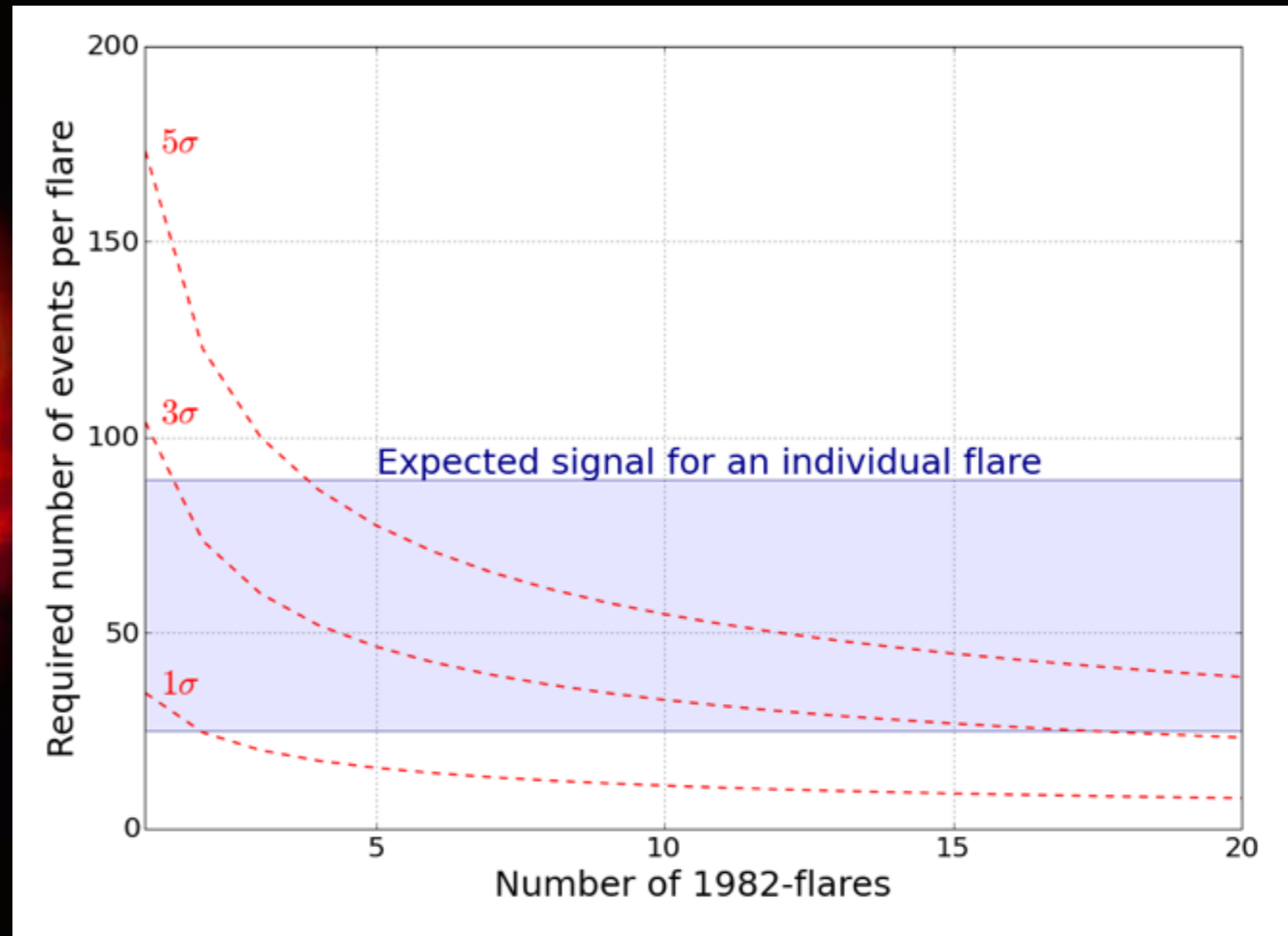
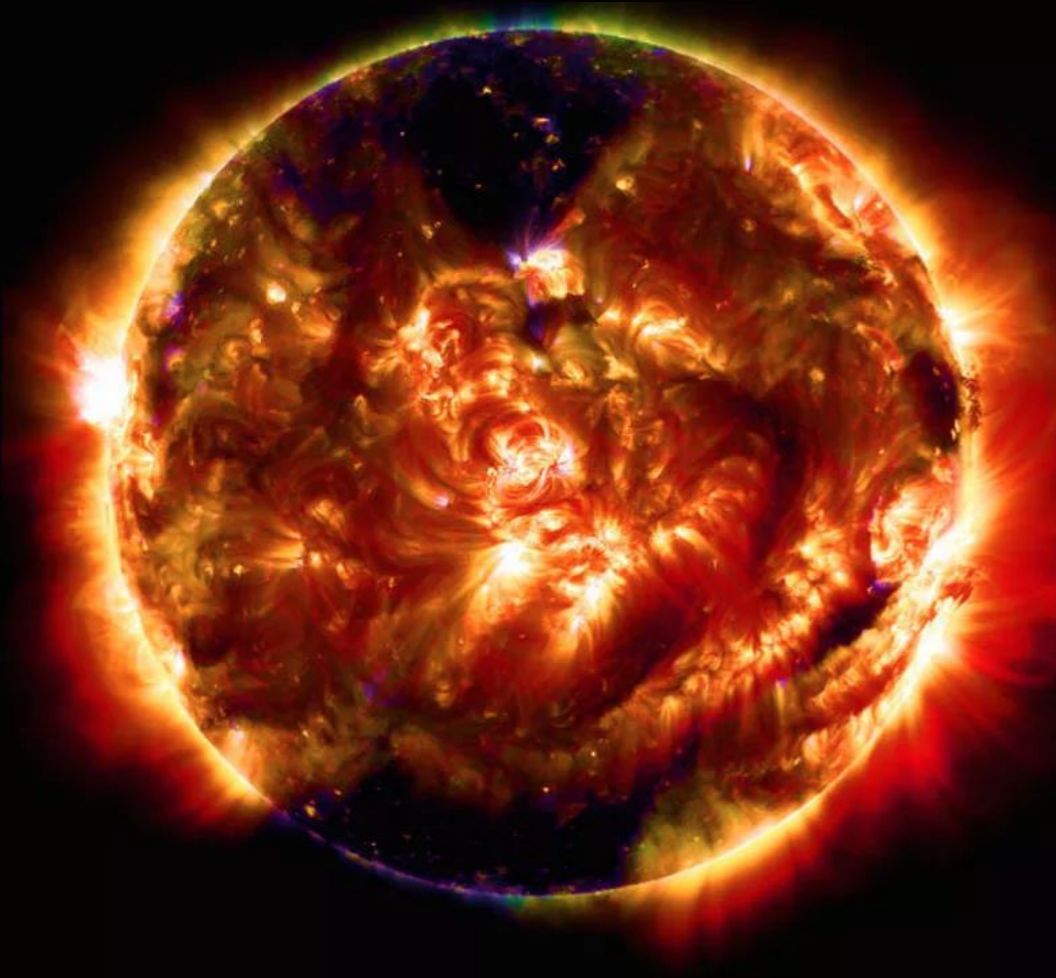
Local Sources (Sun, Earth)



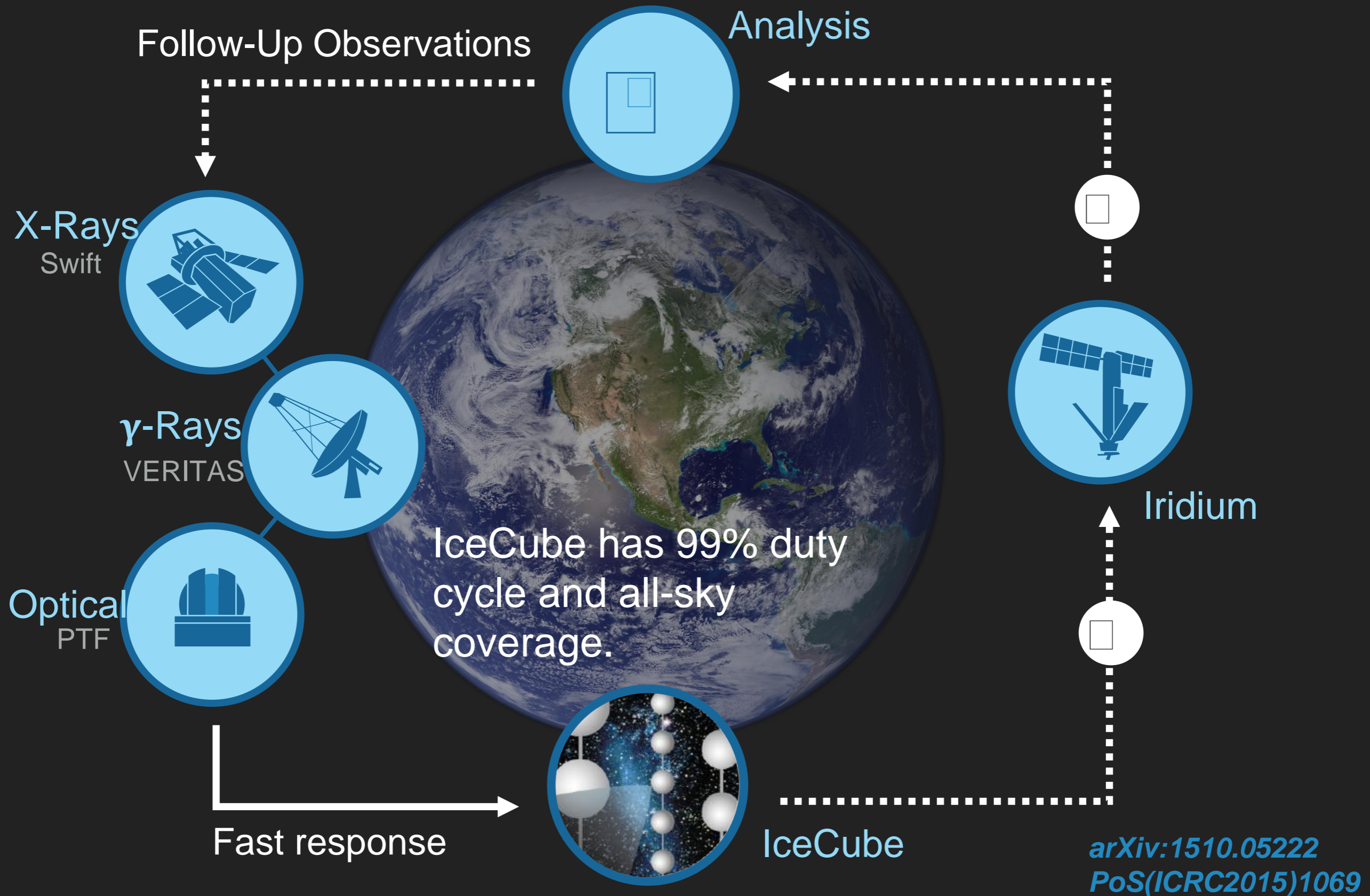


- ▶ First analysis since AMANDA.
- ▶ Work performed at VUB
- ▶ Continuation at ULB

Eur. Phys. J. C (2017) 77: 82. doi:10.1140/epjc/s10052-016-4582-y

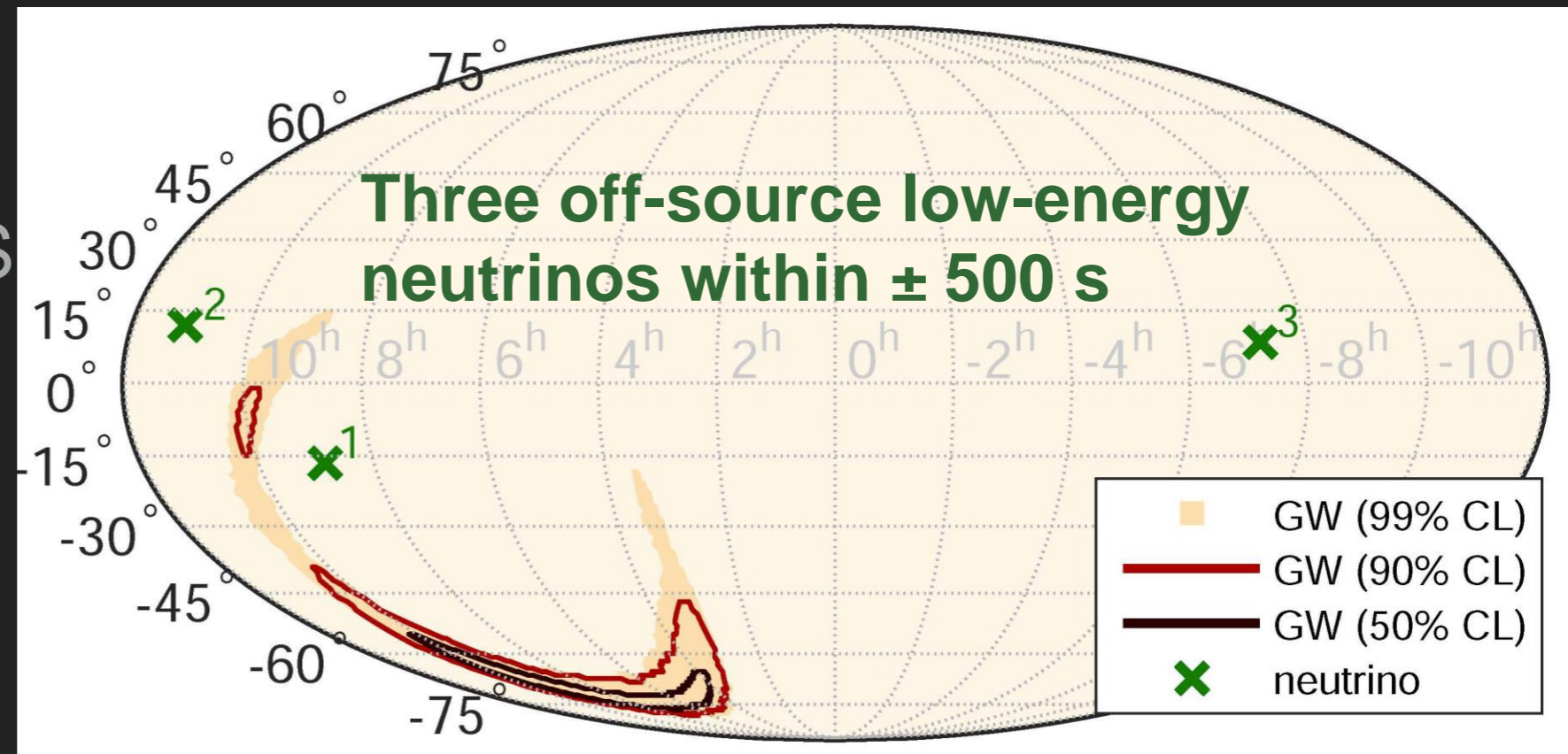


- ▶ Solar flares can produce  $\sim 100$  MeV neutrinos if gamma-rays are coming from  $\pi^0$  decays.
- ▶ Work done at the VUB



- ▶ LIGO discovered **gravitational waves!**
- ▶ IceCube/ANTARES did a follow-up of LIGO GW150914

*ANTARES Collaboration, IceCube Collaboration, LIGO Scientific Collaboration, Virgo Collaboration [arXiv:1602.05411]*



- ▶ No neutrino association found (expected from BH mergers)
- ▶ A **fast-response analysis** is being put in place at the ULB to respond quickly to this kind of astronomical events.

## PINGU

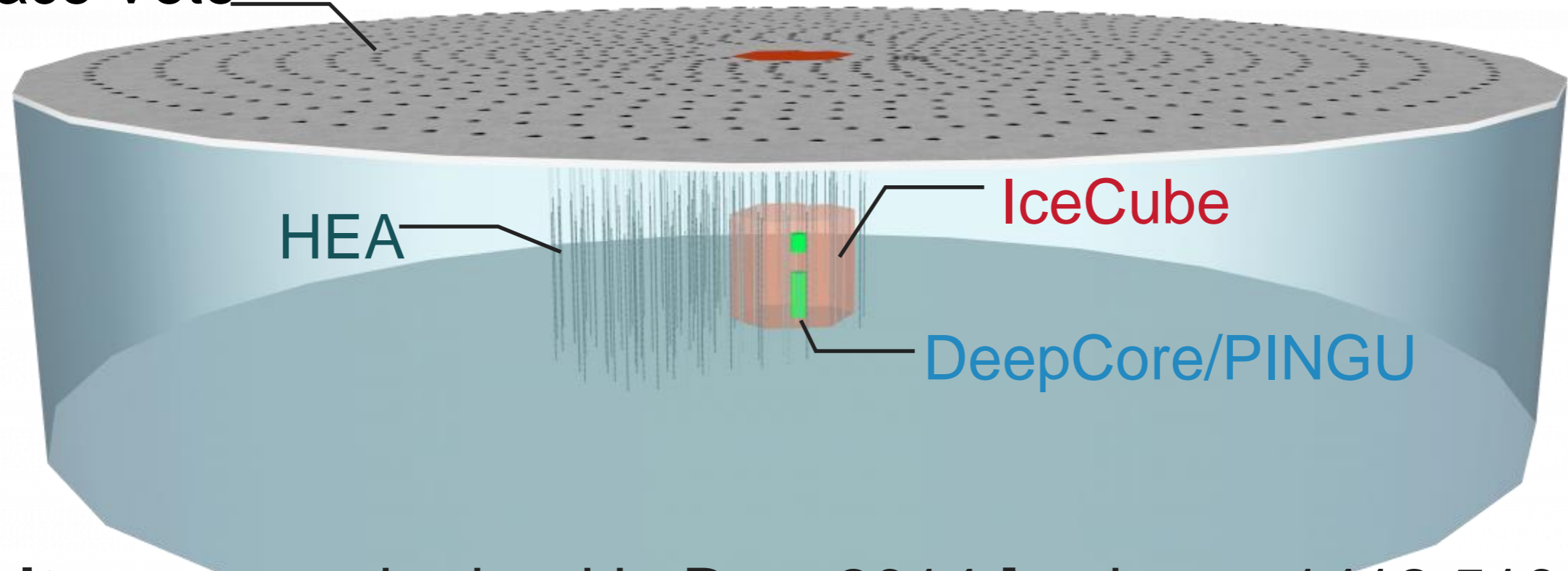
Further in-fill  
 Lower the energy threshold few GeV  
 Neutrino Mass Hierarchy  
 Dark Matter + Solar Flares

## High Energy Array (HEA)

Extension of IceCube array  
 Look for high-energy events  
 GZK and astrophysical neutrinos

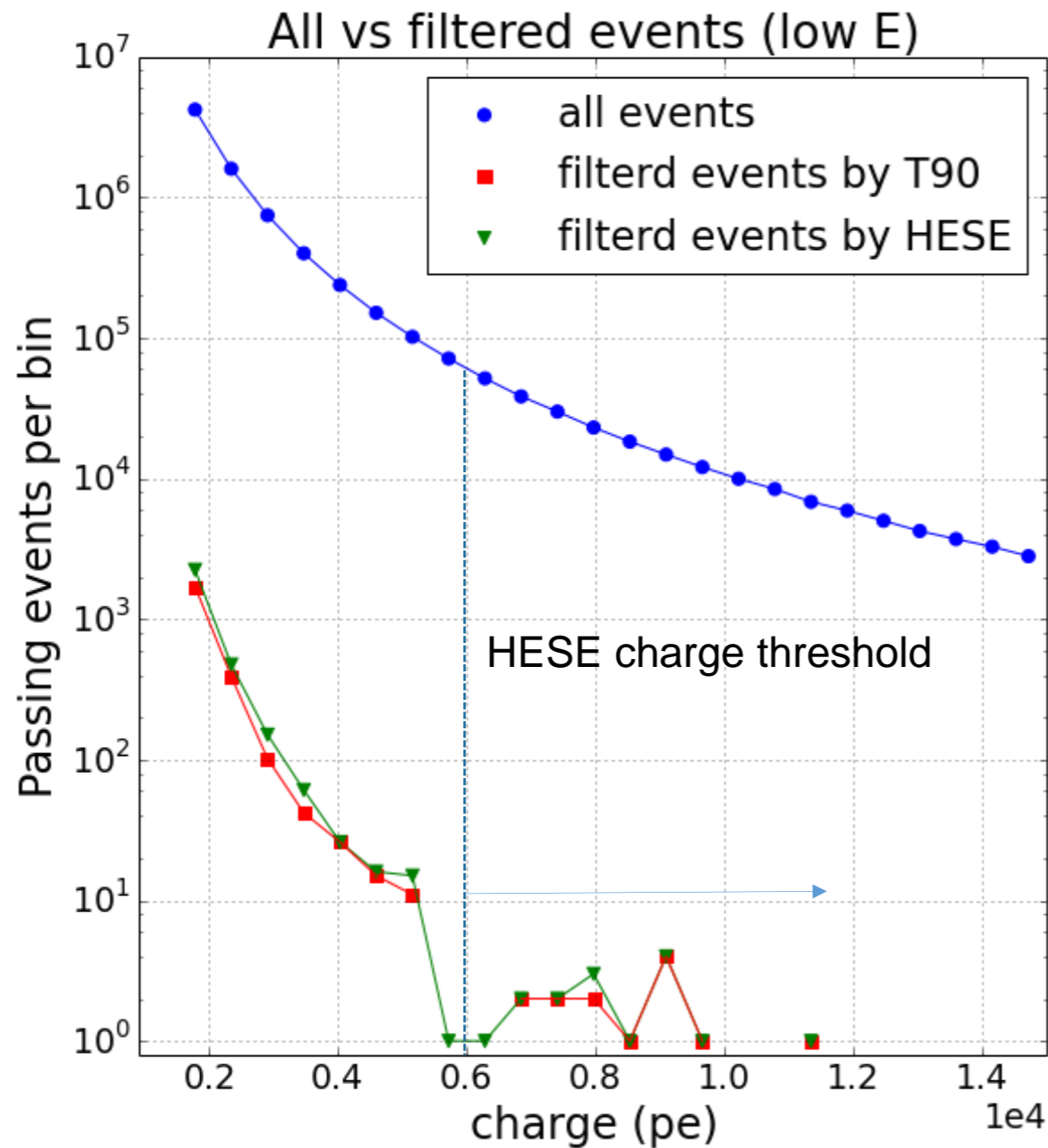
- + Radio Array: 100-300 km<sup>2</sup> for extremely high energies ( $\geq 10^{18}$  eV)
- Surface Veto: Air shower detector with 75 km<sup>2</sup> / 100 TeV threshold

Surface Veto



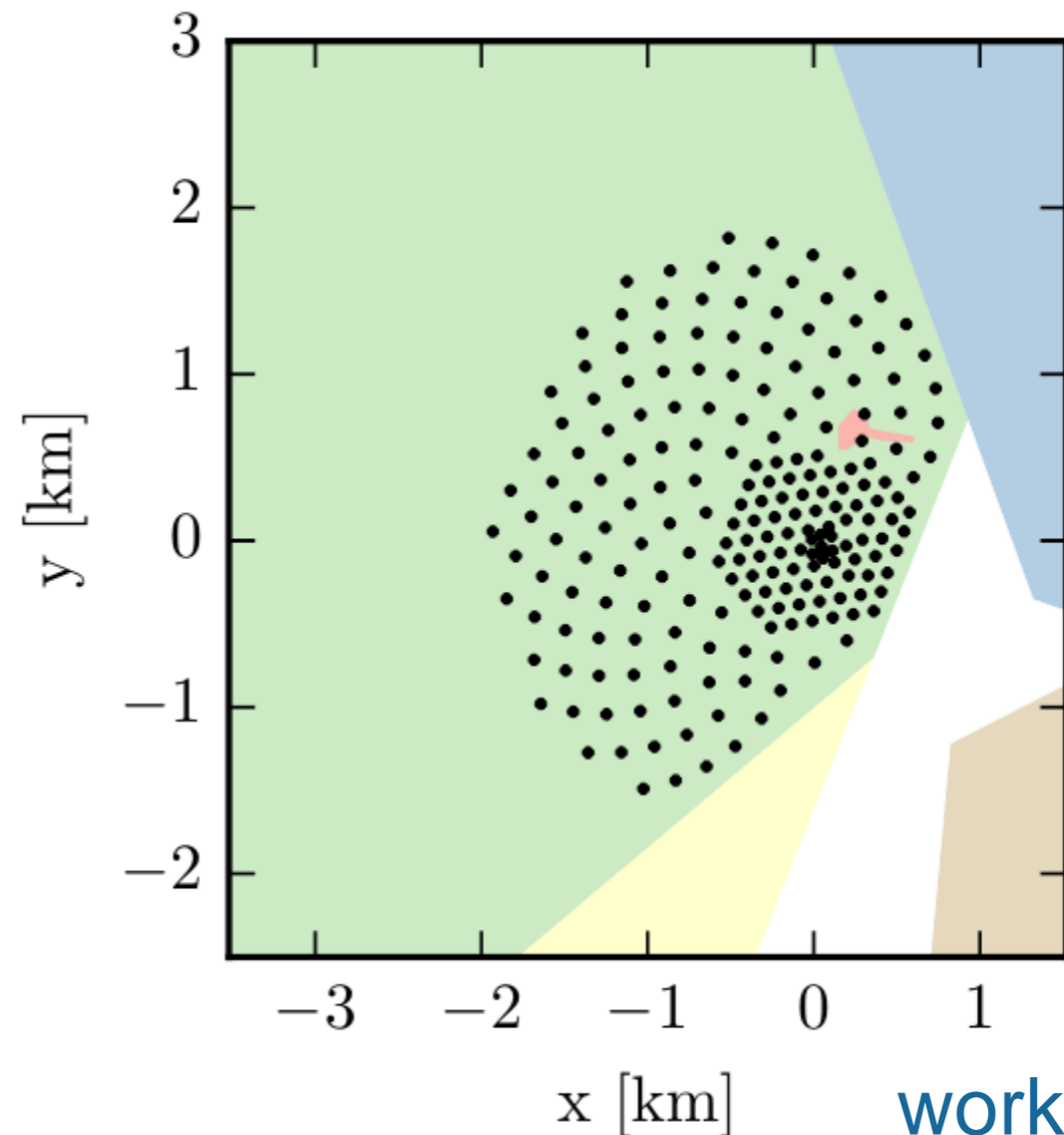
**White paper:** submitted in Dec. 2014 [[arxiv.org:1412.5106](https://arxiv.org/abs/1412.5106) ]





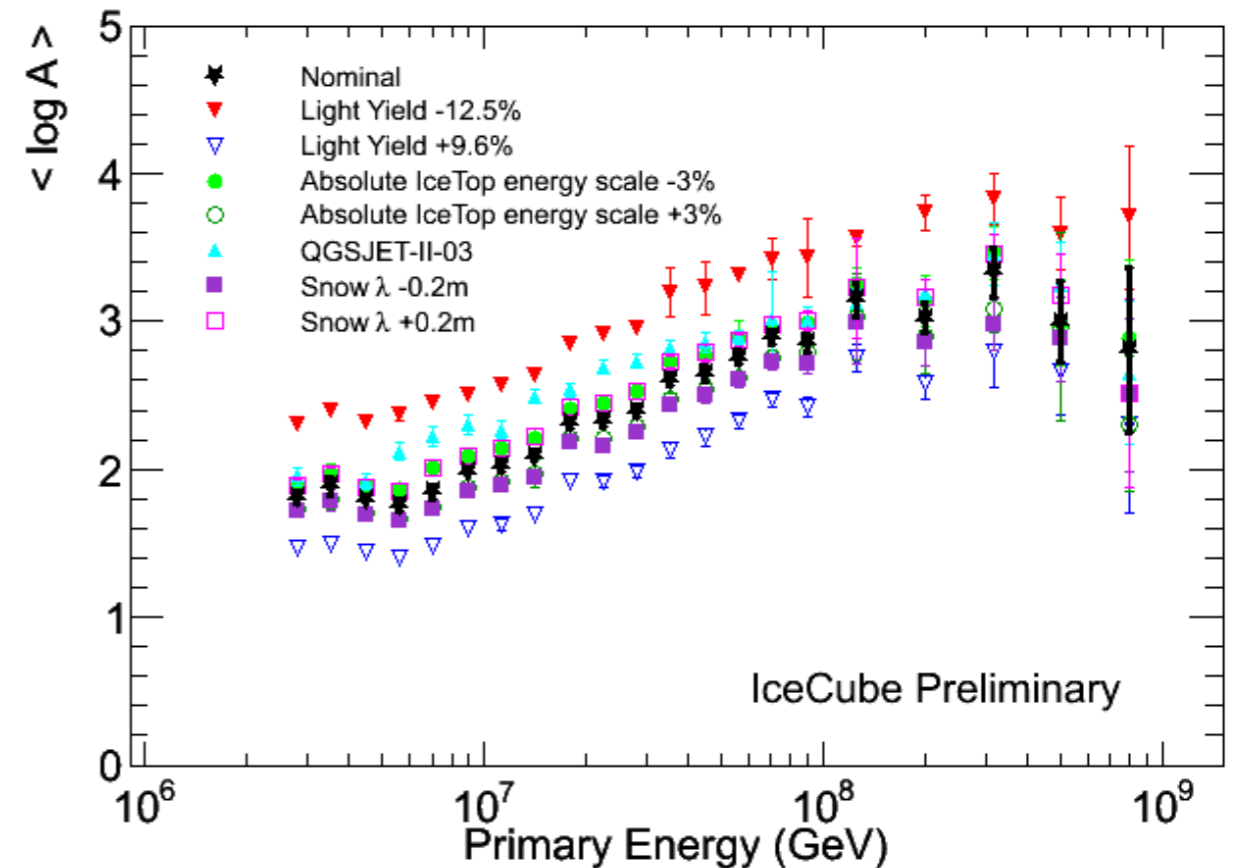
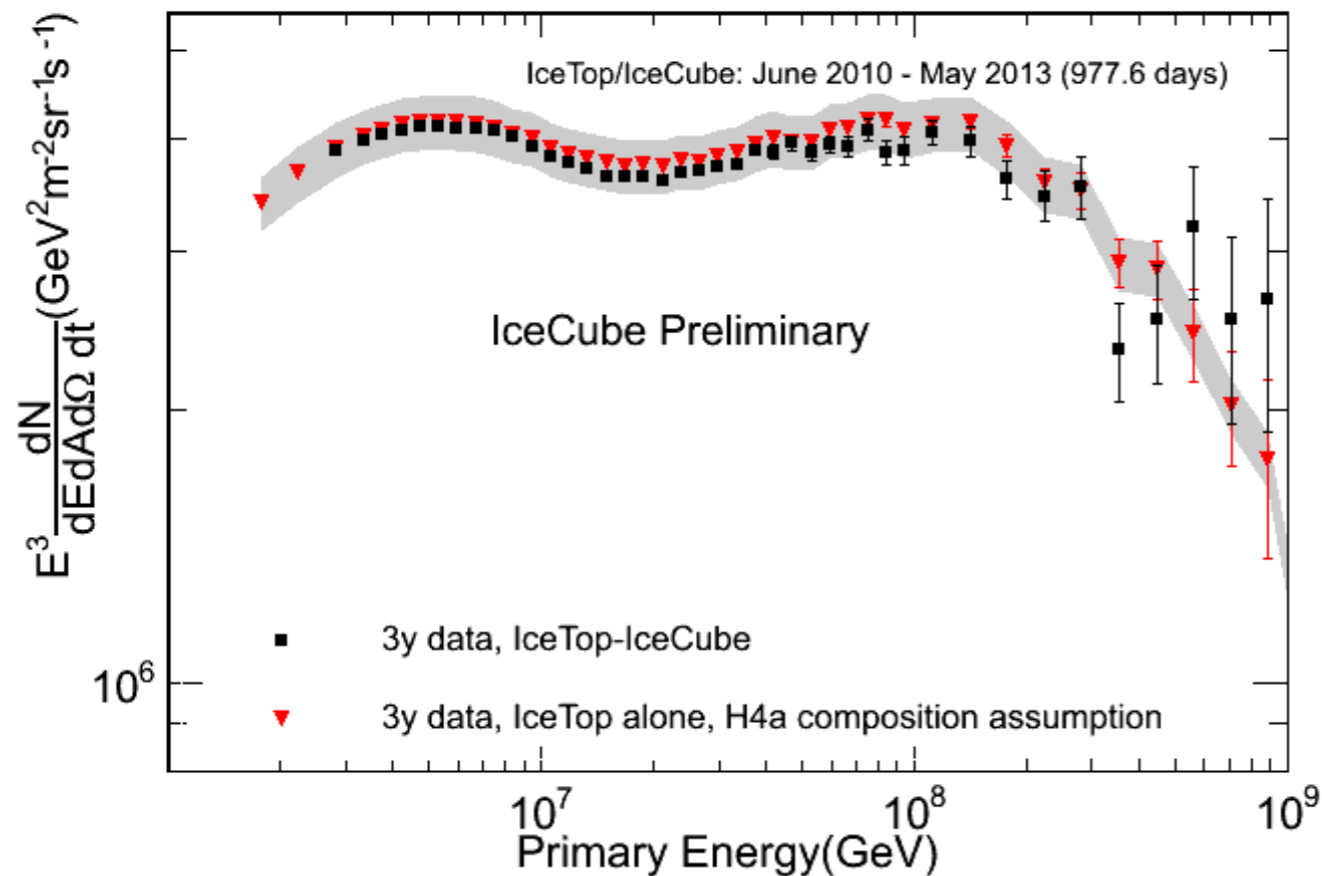
Background event  
wrongfully accepted by  
HESE filter

- ▶ New veto strategies for sparse geometries.
- ▶ Improved performance over standard veto



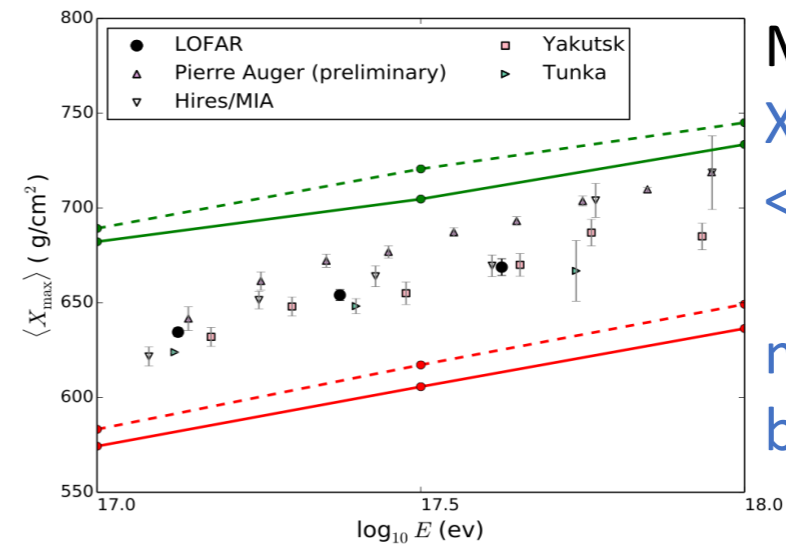
work at VUB

- Concentrate on energy spectrum, mass composition



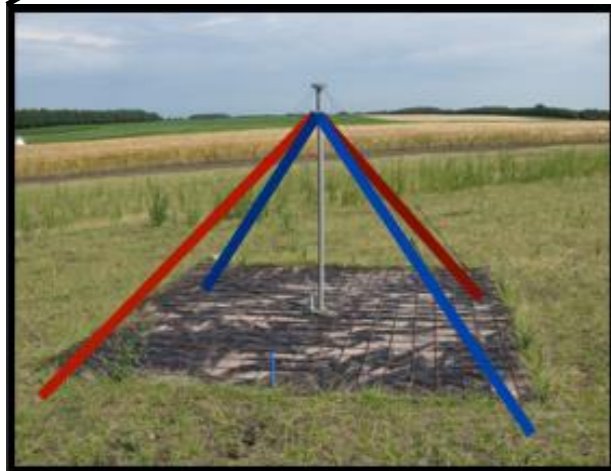
- Present activity: combined observables (muon content of shower): mass composition + hadronic interaction

work at UGent



Mass Composition:  
 $X_{max}$  measured with  
<math>< 20 \text{ g/cm}^2</math> precision

mass measurements  
below the CR ankle



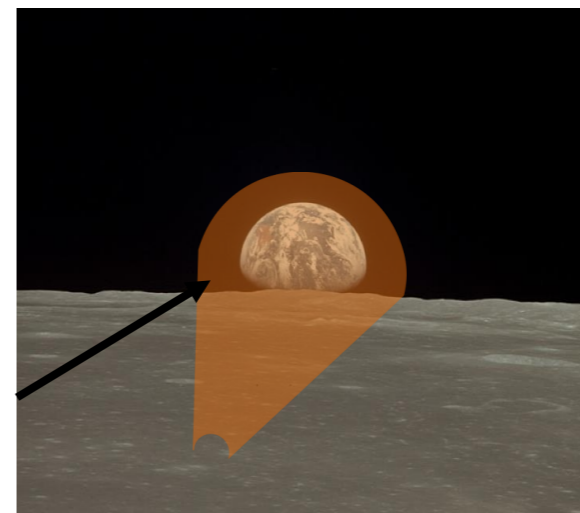
**High Precision:**  
radio footprints of air  
shower detected with  
100s of dipole antennas

Validation of radiation  
simulation codes

**Air Showers in  
Thunderstorms:**  
remotely probing  
electric fields  
cosmic rays & lightning  
initiation  
3D discharge mapping

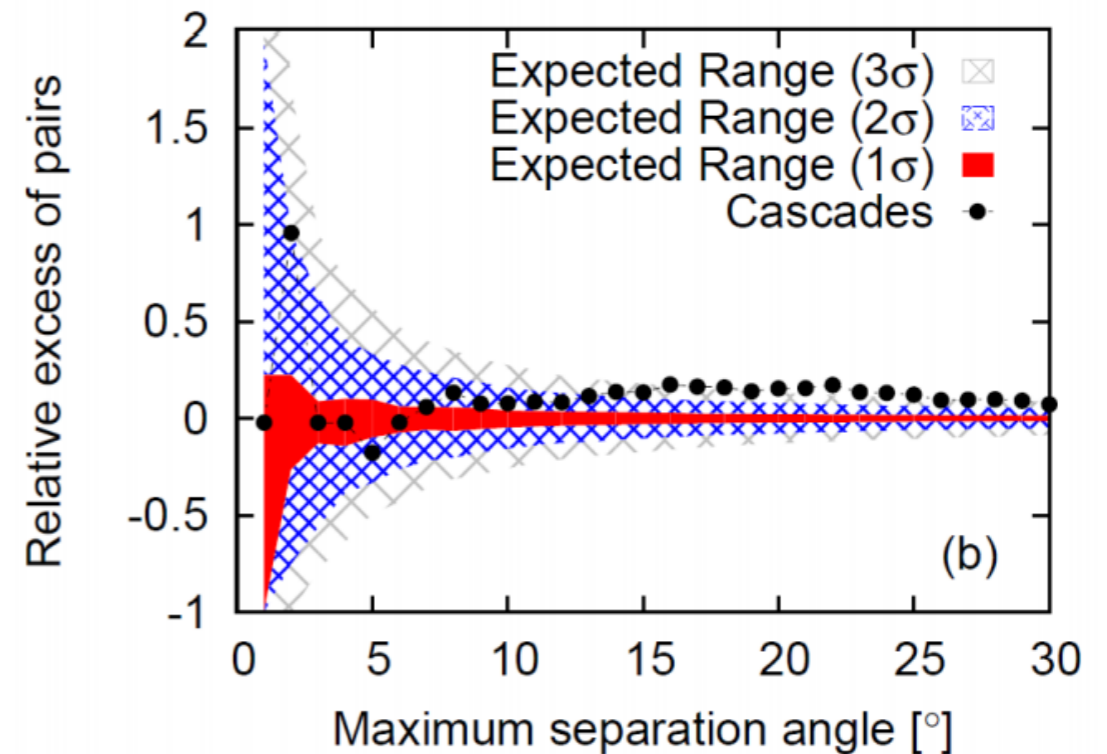
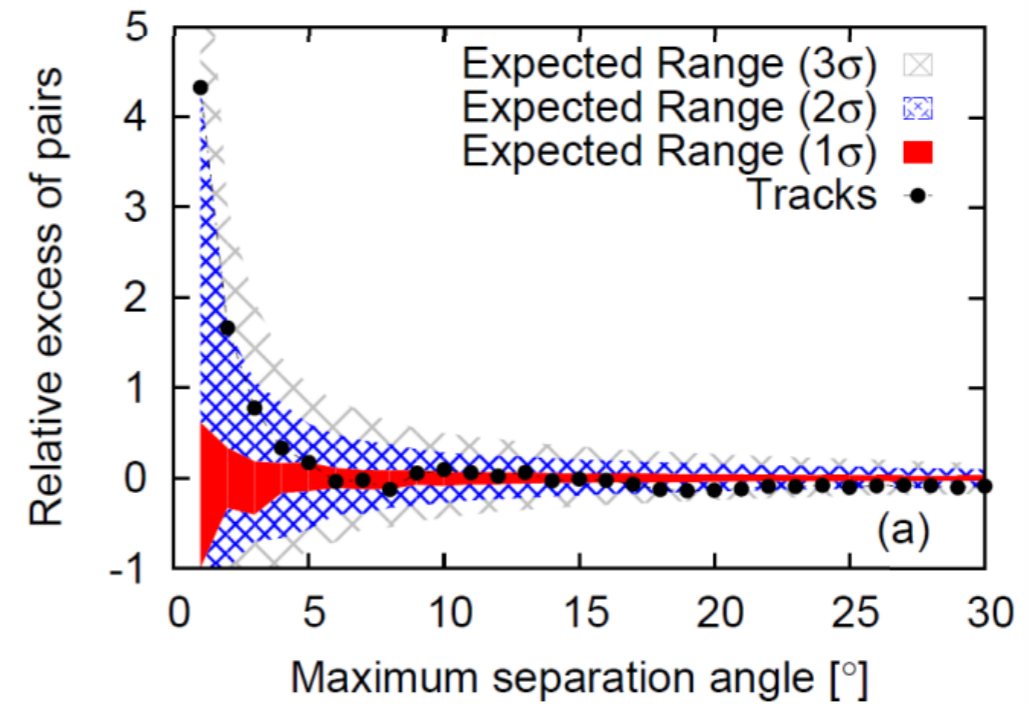


work at VUB



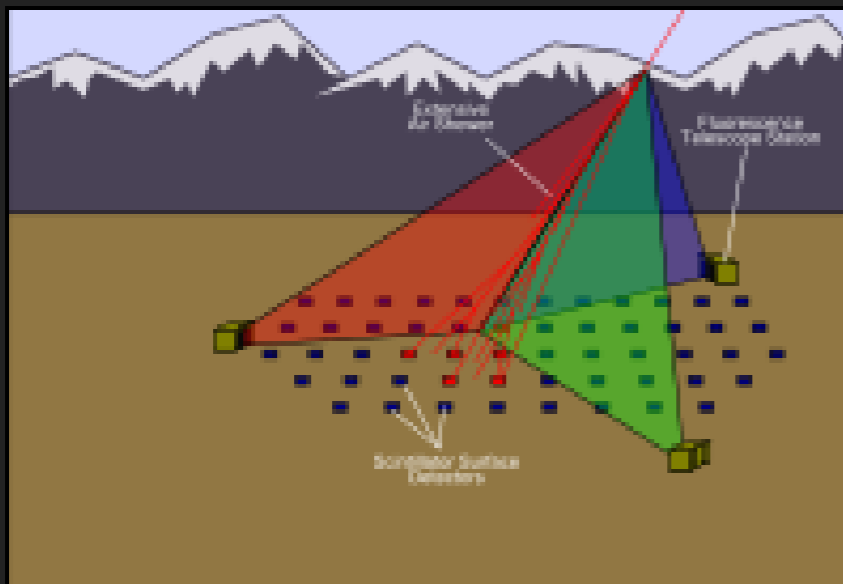
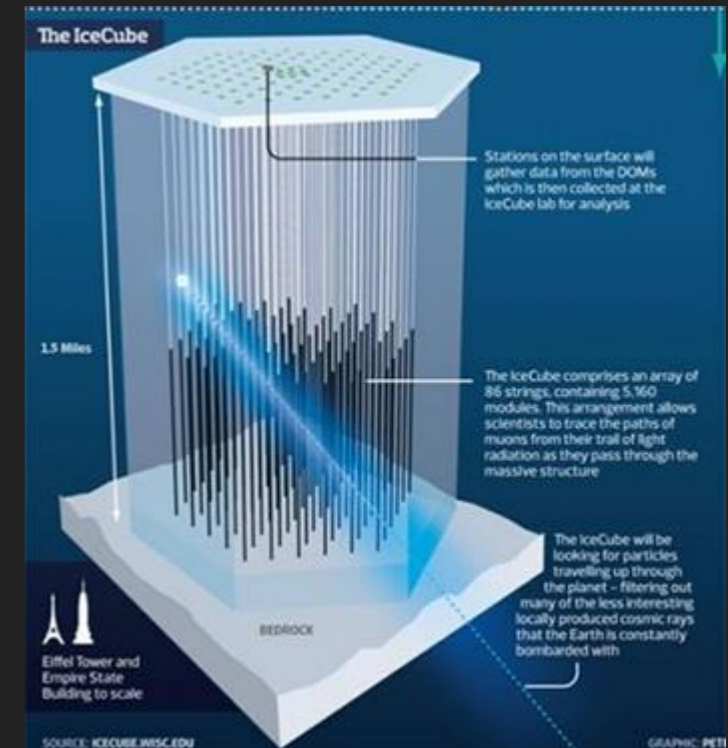
**Energy Frontier:**  
best sensitivity to >  
 $10^{21}$  eV  
particles hitting  
Moon

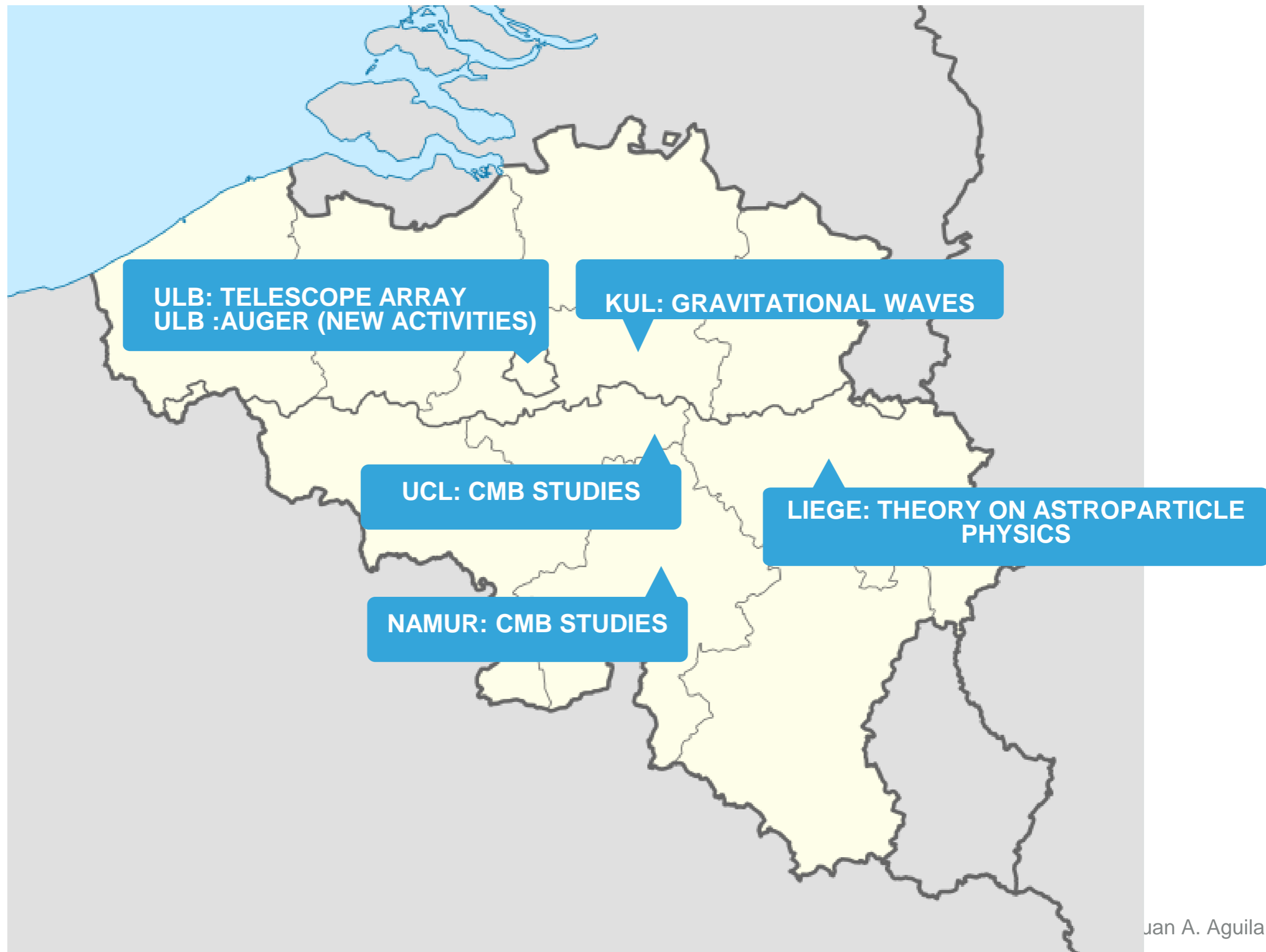
- ▶ Work done at ULB (TA, IceCube), and VUB (IceCube).
  - ▶ 10 years of Auger data (231 UHECR)
  - ▶ 6 years of TA data (87 UHECR)
  - ▶ IceCube cosmic  $\nu$  candidates (39 cascades, 16 tracks)
- ▶ Most significant deviations
  - ▶ Tracks :  $2^\circ$  P-value=0.34
  - ▶ Cascades :  $22^\circ$  P-value= $5 \cdot 10^{-4}$



- ▶ The CosPa network aims at federating the various Belgian groups working on cosmoparticle physics and at increasing the visibility of cosmoparticle physics, regionally, and nationally.
- ▶ [Seventh CosPa meeting](#) March 8th 2017, KUL, "Gravitational Waves"
- ▶ This network is funded by FWO and FNRS

- ▶ IceCube Neutrino Observatory: (ULB,VUB) : IIHE(~20), UGent(~10), UMons(2)
- ▶ LOFAR: VUB (5)
- ▶ Pierre Auger: ULB (1), VUB (2)
- ▶ Telescope Array: ULB (1)





- ▶ Belgium has expanded the astroparticle program.
- ▶ New staff positions initiating novel activities (Auger, LOFAR,...)
- ▶ In 2013 IceCube discovered the astrophysical neutrinos and it continues the characterization. Many searches to identify the neutrino sources led by Belgian groups.
- ▶ IceCube-Gen2 is the vision for the future neutrino astronomy.