Cosmic Ray, Neutrino, Gamma-ray Physics

Scientific Highlights 2012-2016

Christopher van Eldik (ECAP)

FRIEDRICH-ALEXANDER
UNIVERSITÄT
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NATURWISSENSCHAFTLICHE
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ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS

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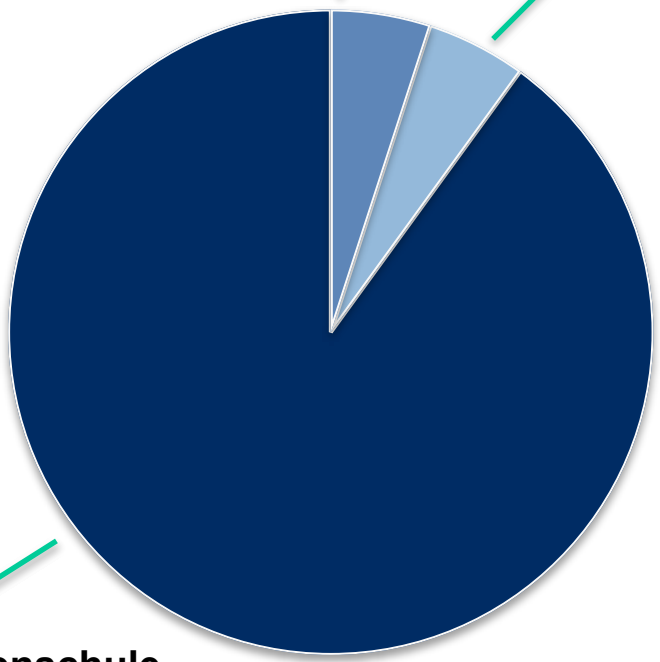
Personal Highlights 2012-2016

IceCube awarded
Break-through of the Year 2013

LIGO awarded
Special Break-through Prize
in Fundamental Physics 2016



ECAP Astroteilchenschule
now "School for Astroparticle Physics"
astroteilchenschule.nat.fau.de

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Scientific Objectives

- What are the detailed properties of the CR population?
- What are the sources of the CRs?
- How do cosmic particle accelerators work?
- How do CRs propagate from their sources to us?
- What impact do CRs have on the interstellar environment?
- …

Experimental Access

- Direct measurements of the local CR population
- Source imaging with gamma rays and neutrinos
- Multi-wavelength and multi-messenger studies

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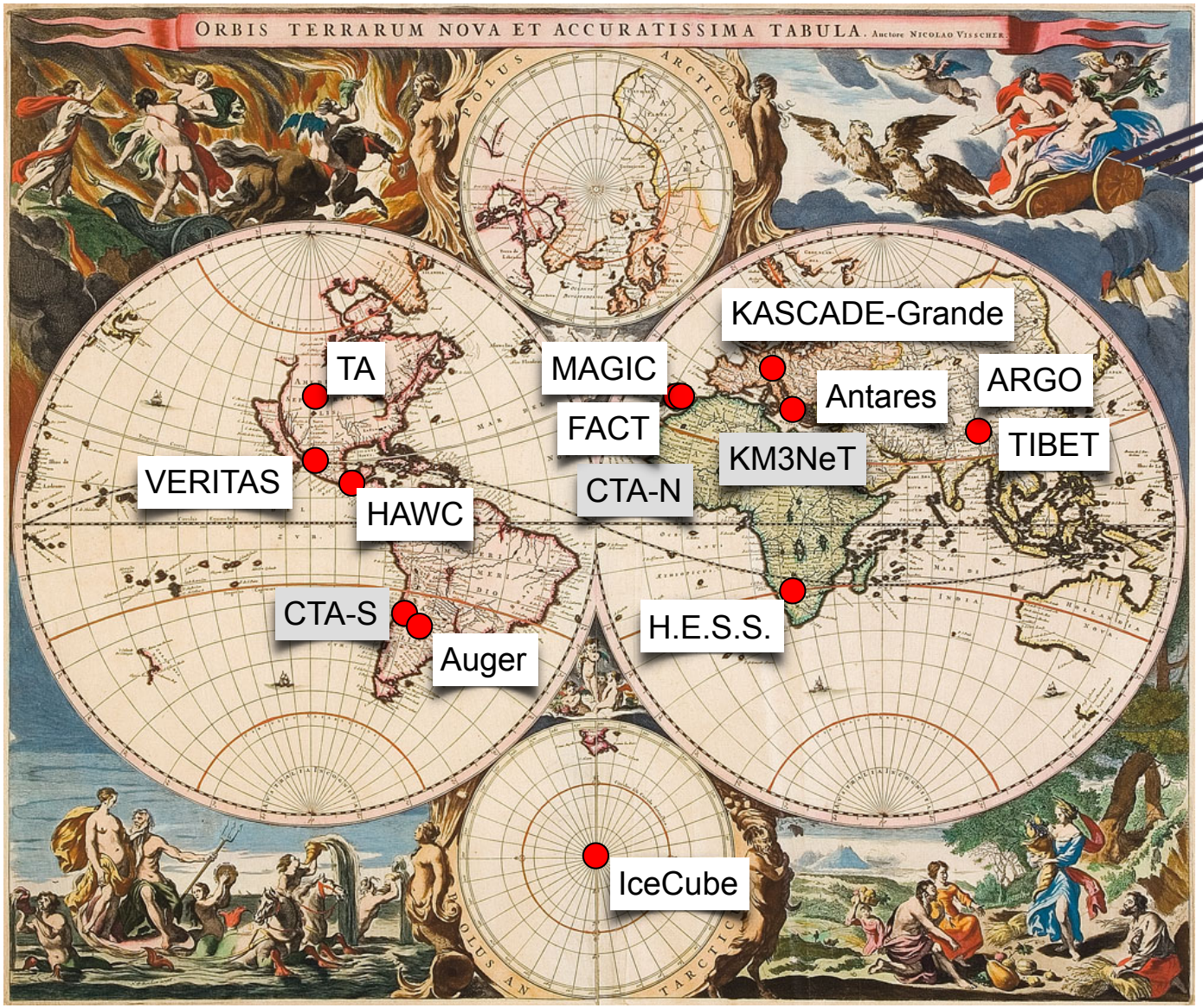
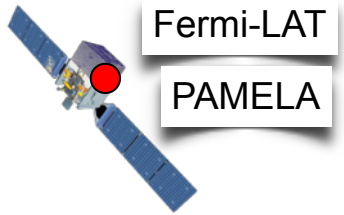
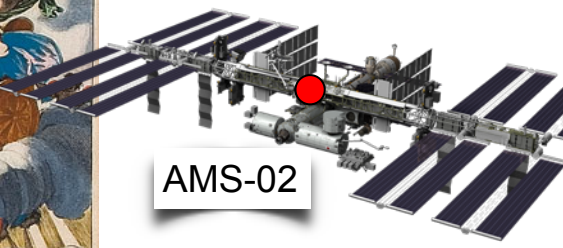
A selection of important instruments







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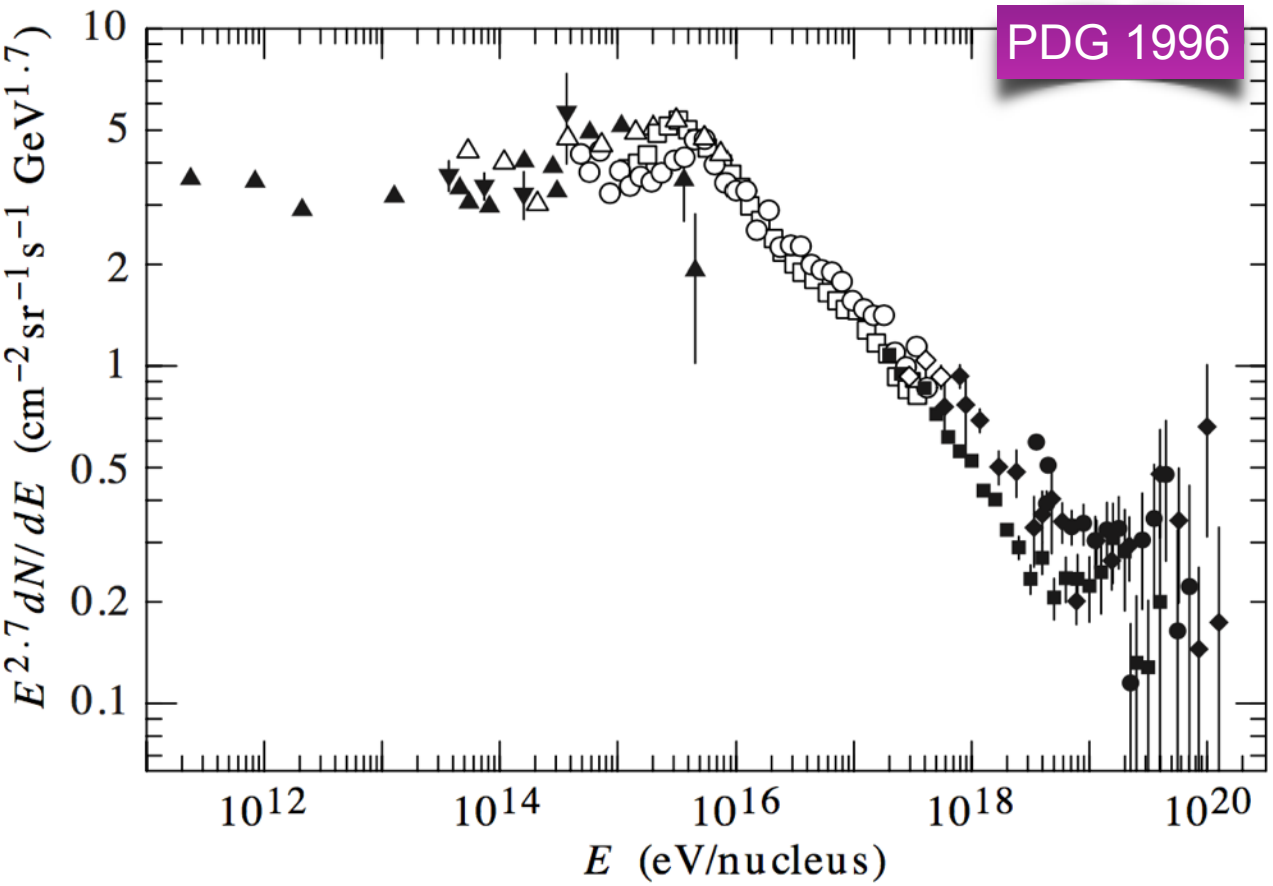
THE LOCAL CR POPULATION

All-particle spectrum: 1996 vs. 2011 vs. 2016



"…knee [and] ankle … are the subject of intense interest at the moment."

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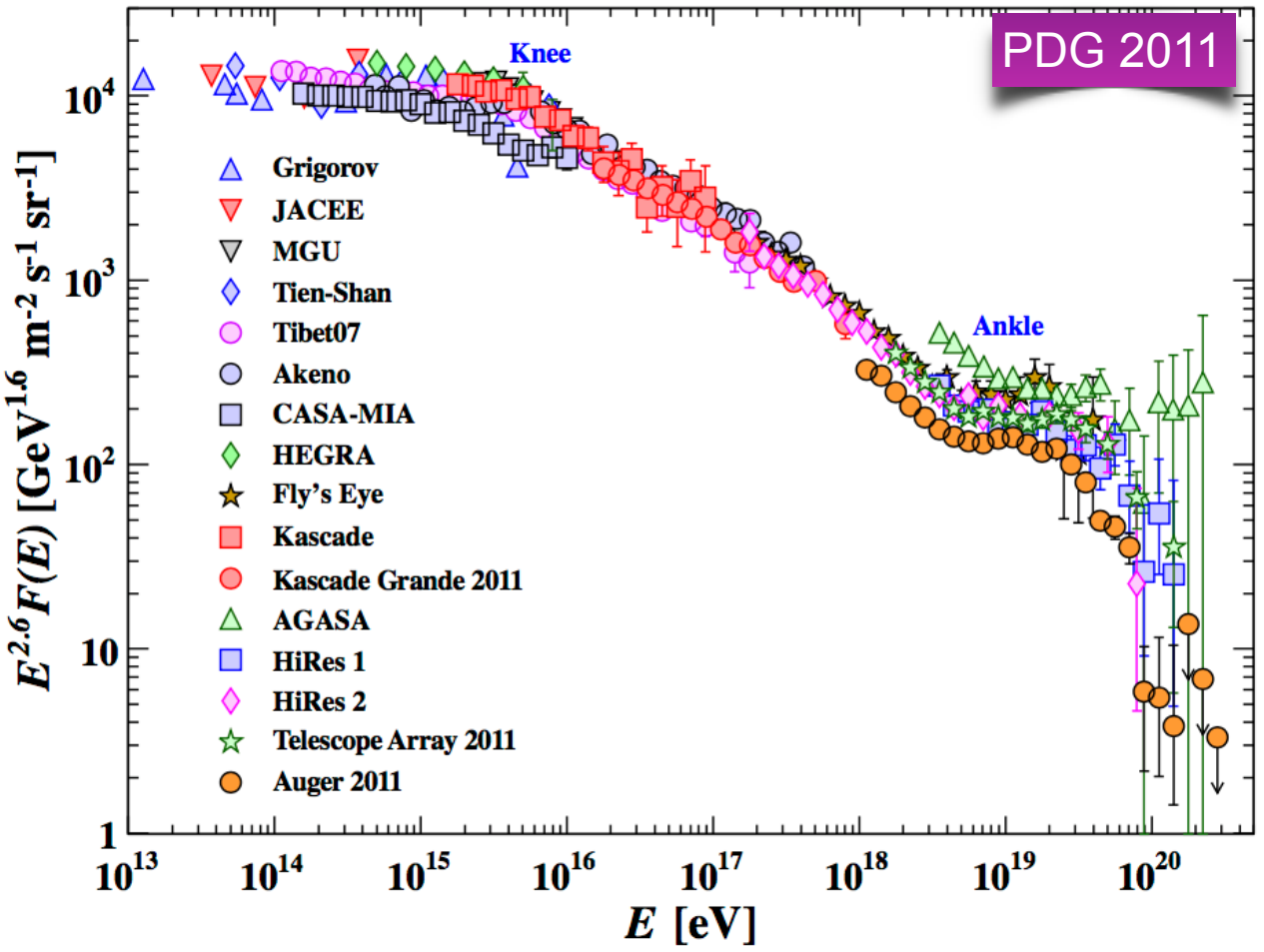
All-particle spectrum: 1996 vs. 2011 vs. 2016



GZK vs. continuation: (Auger+HiRes+TA) vs. AGASA

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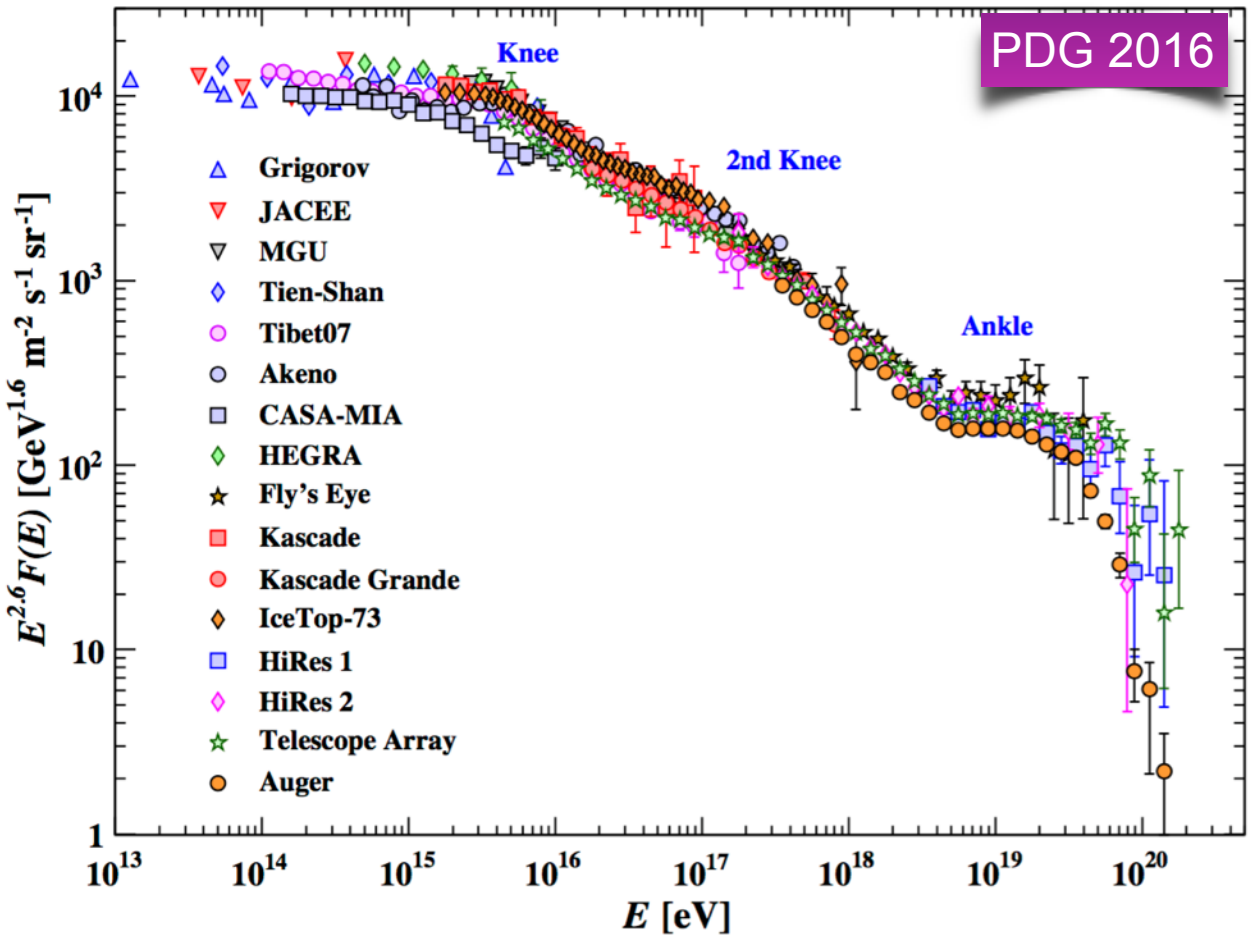
All-particle spectrum: 1996 vs. 2011 vs. 2016



- much better statistics across whole spectrum
- new contributor: IceTop
- cut-off at 10^{20} eV clearly established

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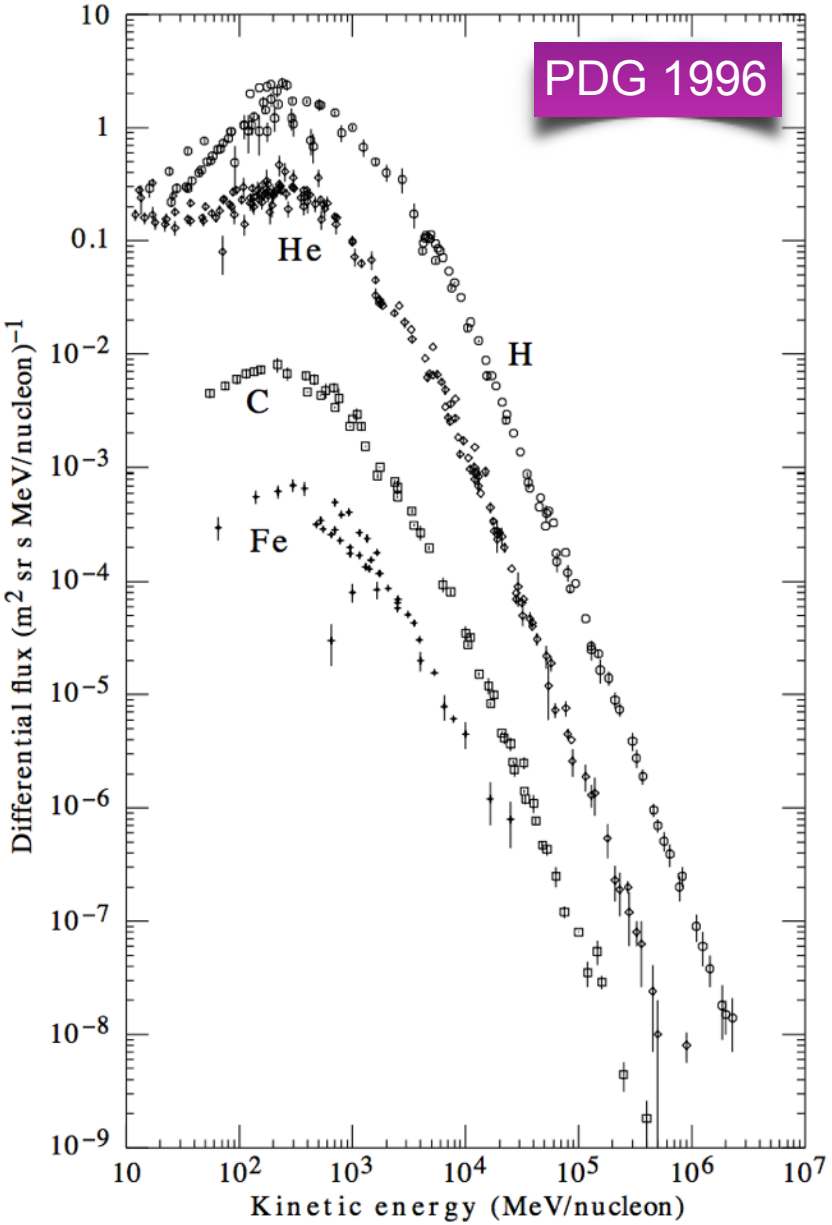
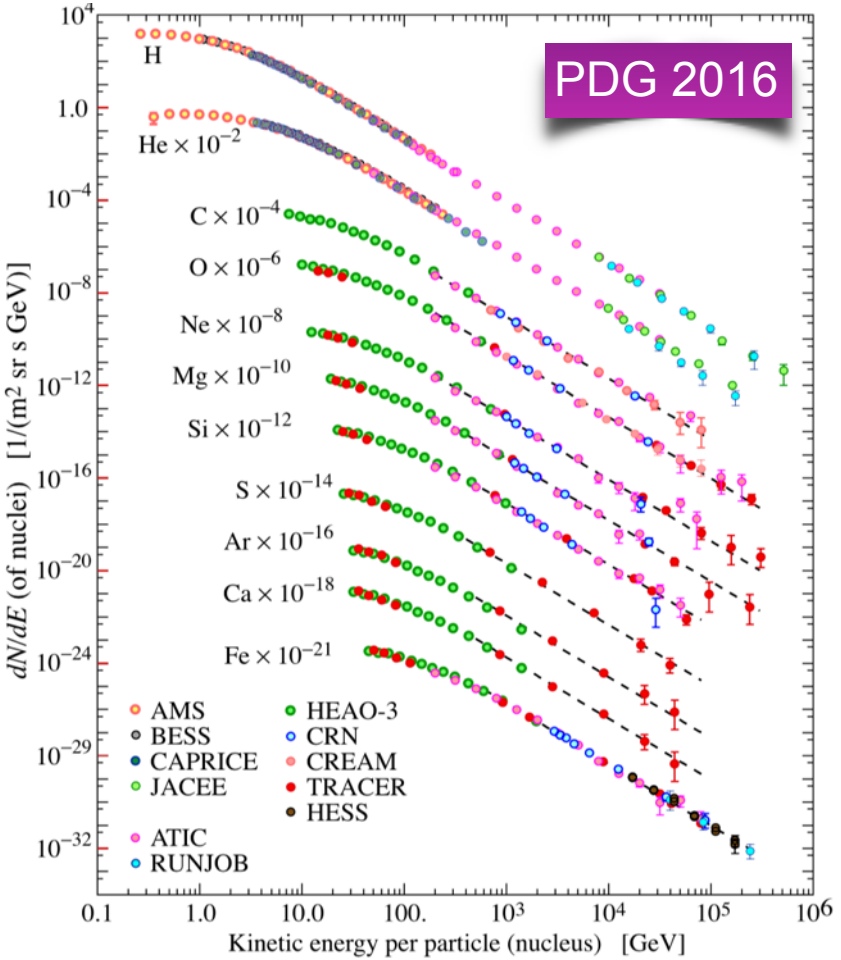
Composition at low energies: 1996 vs. 2016





- element-wise resolution
- extension to higher energies

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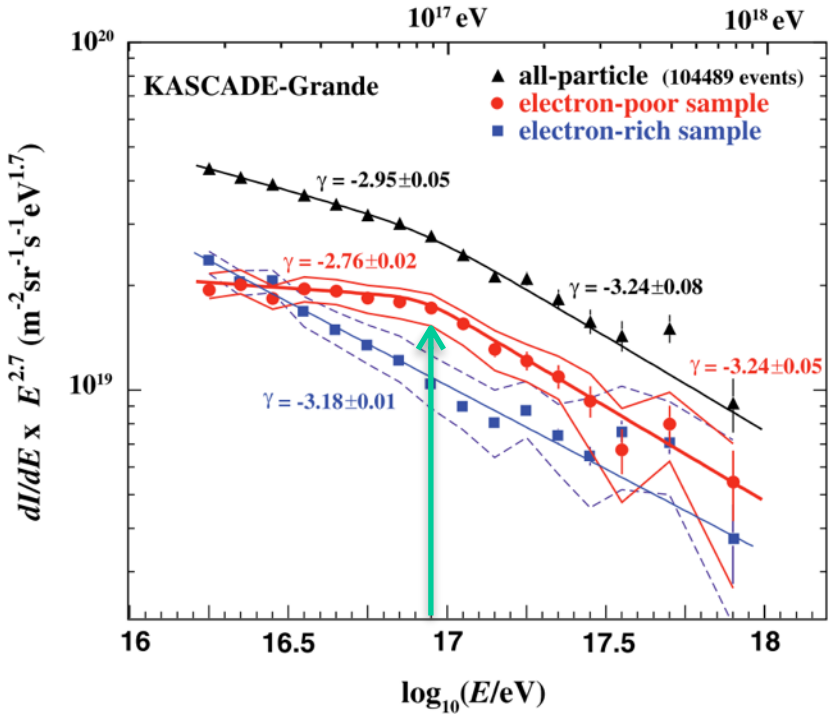
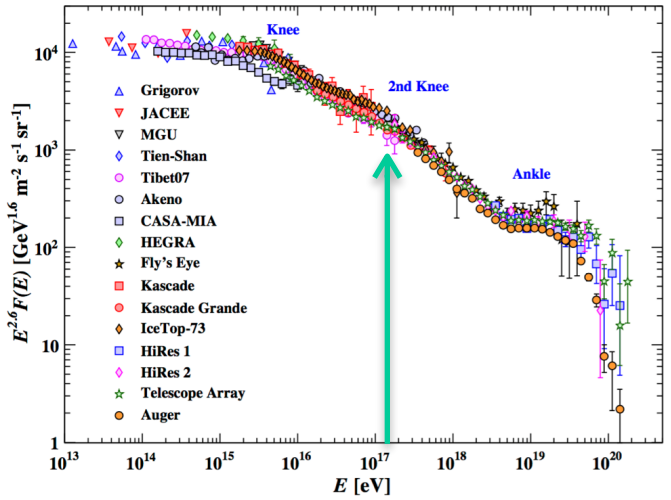
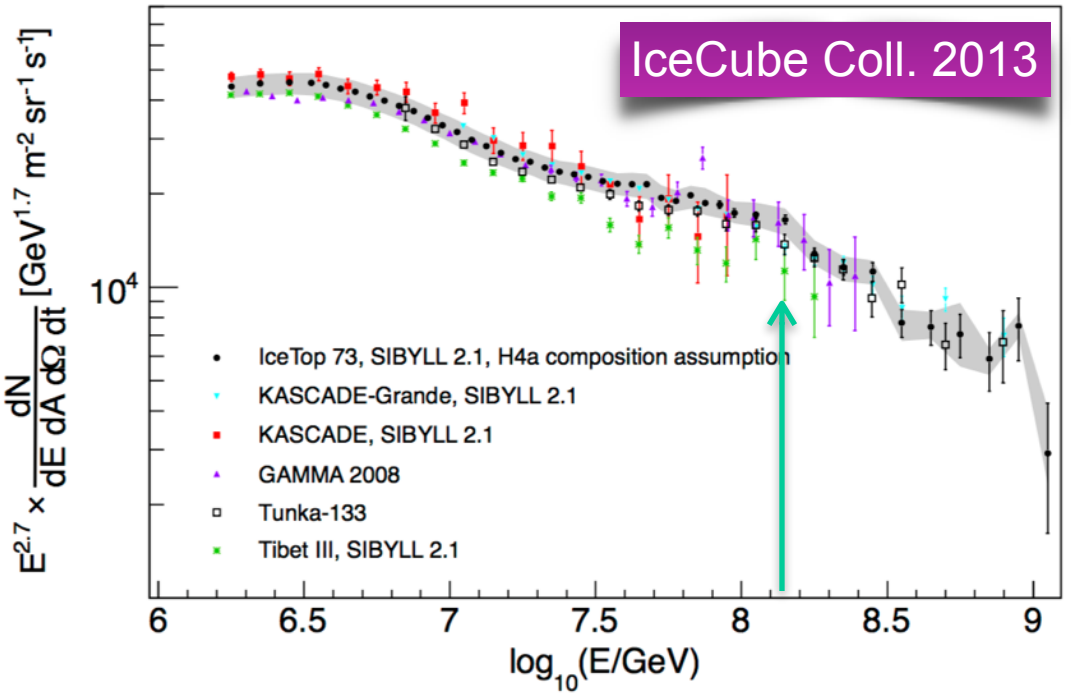
The second knee



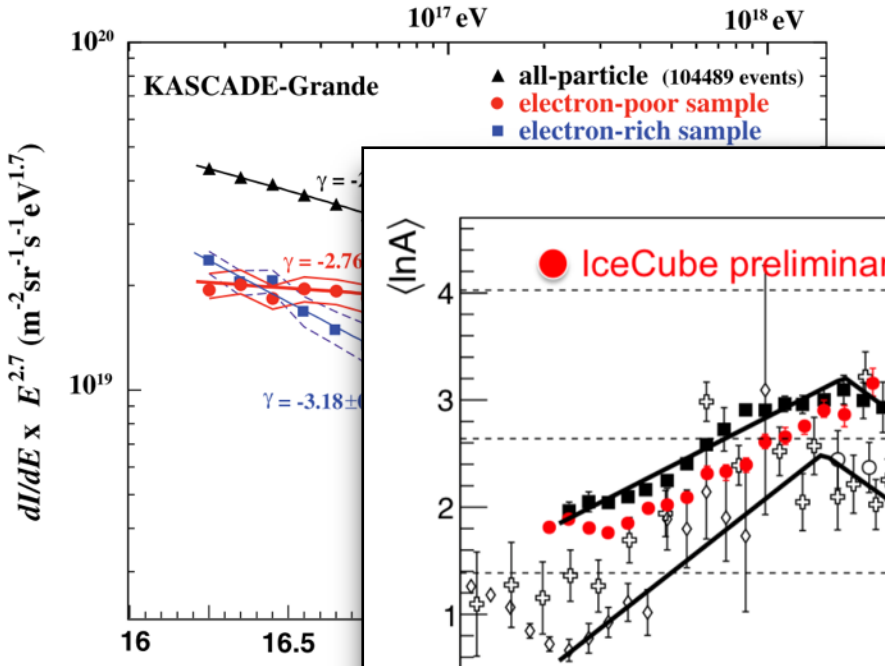
KASCADE-Grande Coll. 2011

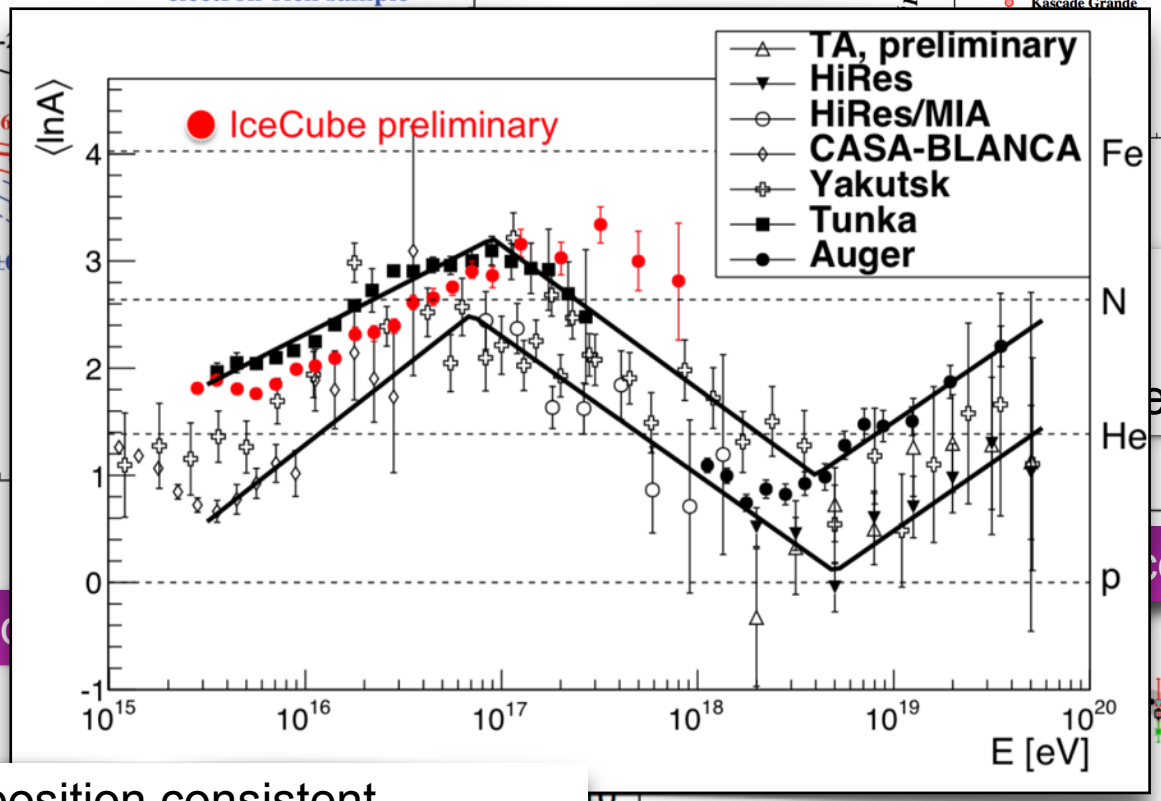


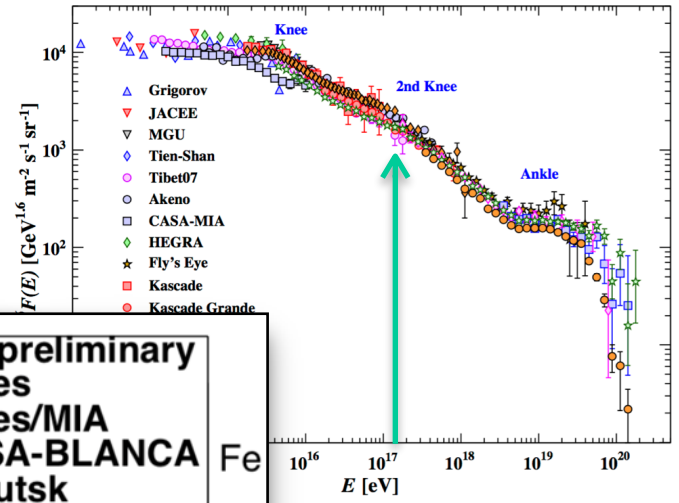
- solid measurement of spectral turnover at ~100 PeV
  → cut-off of iron component of the GCRs



The second knee



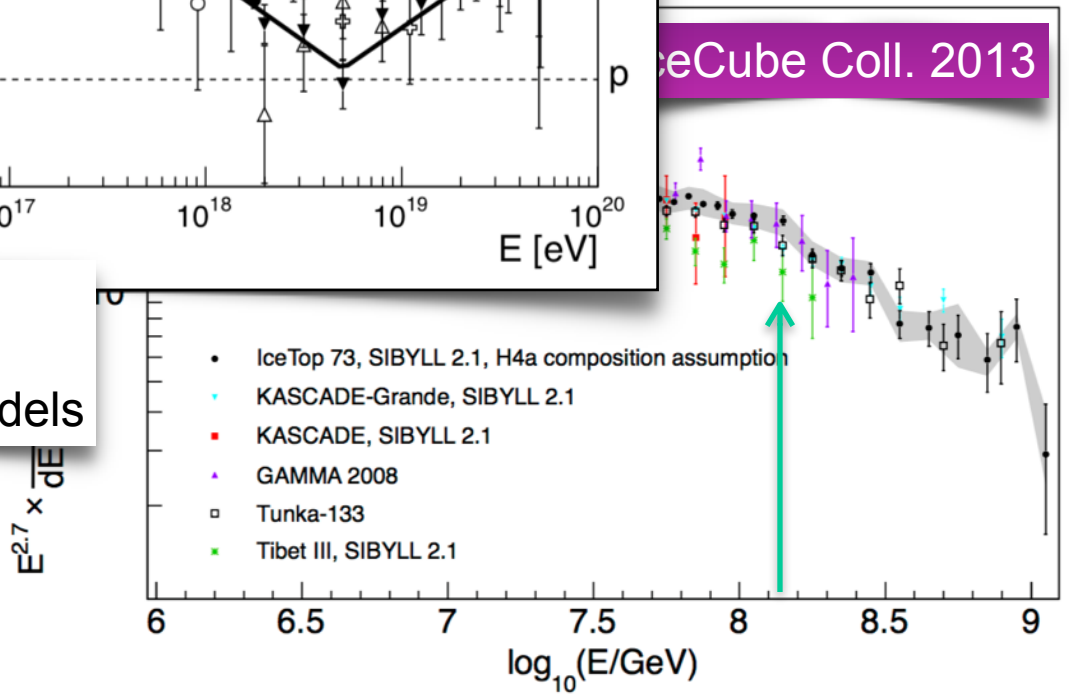




PeV
ent of the GCRs

KASCADE-Gran

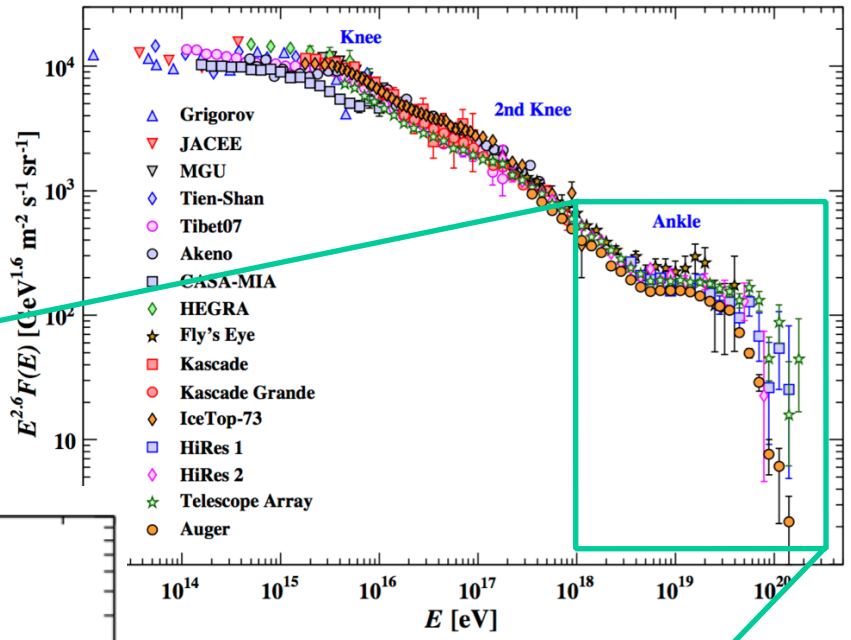
eCube Coll. 2013

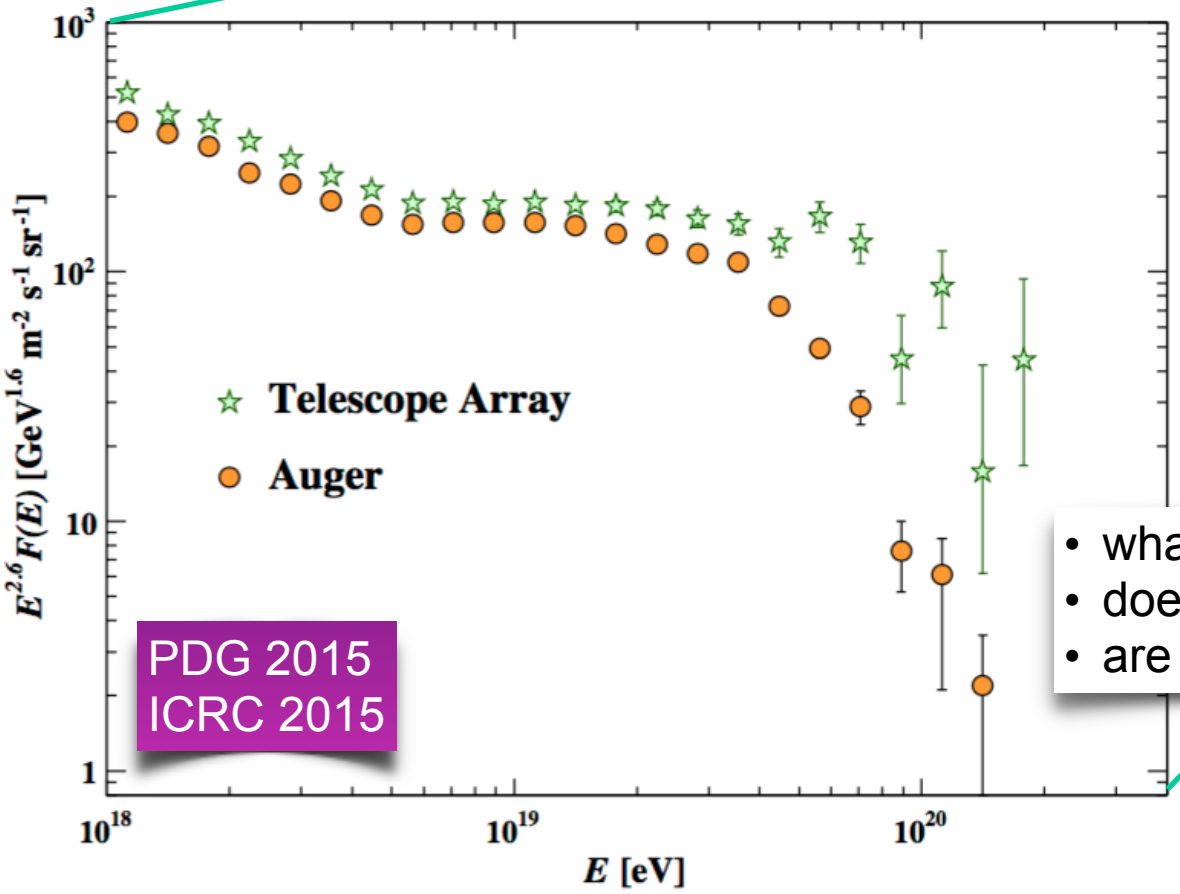


- mass composition consistent between various experiments
- strong dependence on shower models

Gaisser 2016
Kampert & Unger 2012

The ankle region





PDG 2015
ICRC 2015

- what is the explanation of the ankle?
- does the GZK cutoff exist?
- are the data consistent > 10^{19} eV?

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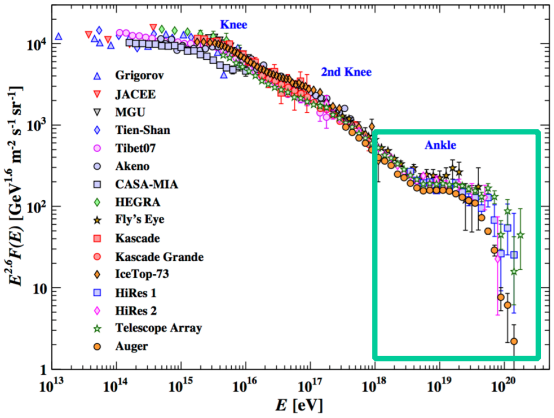
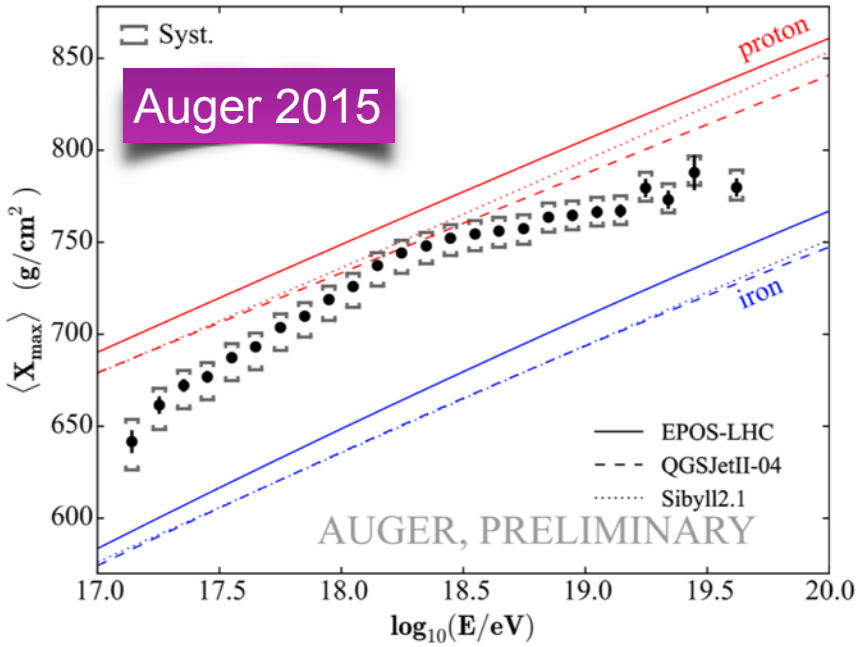
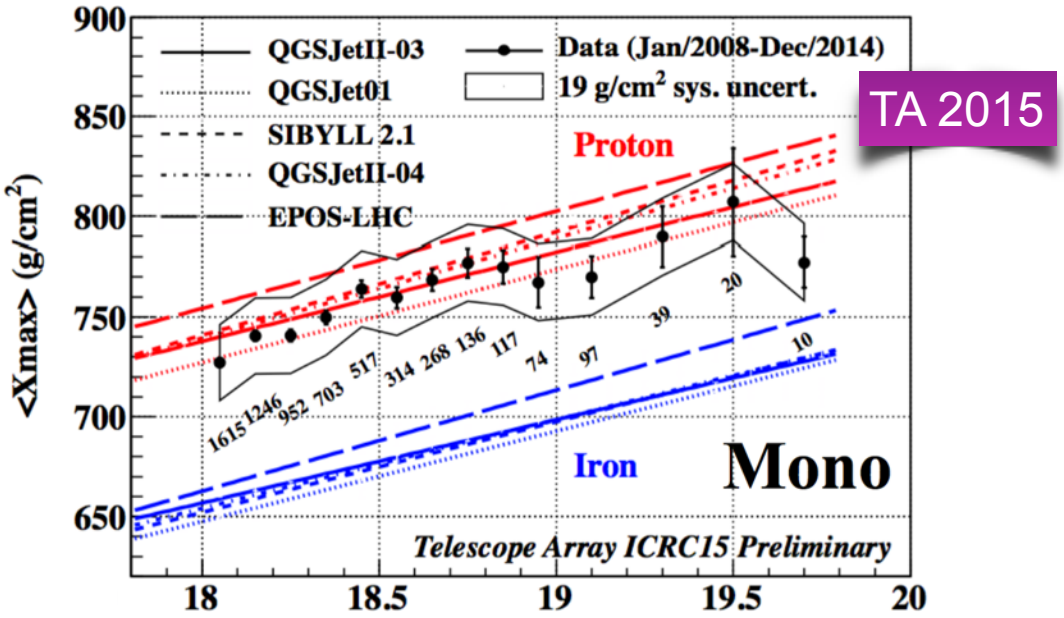
The ankle region: mass composition







heavy - light - heavy?

light-only?

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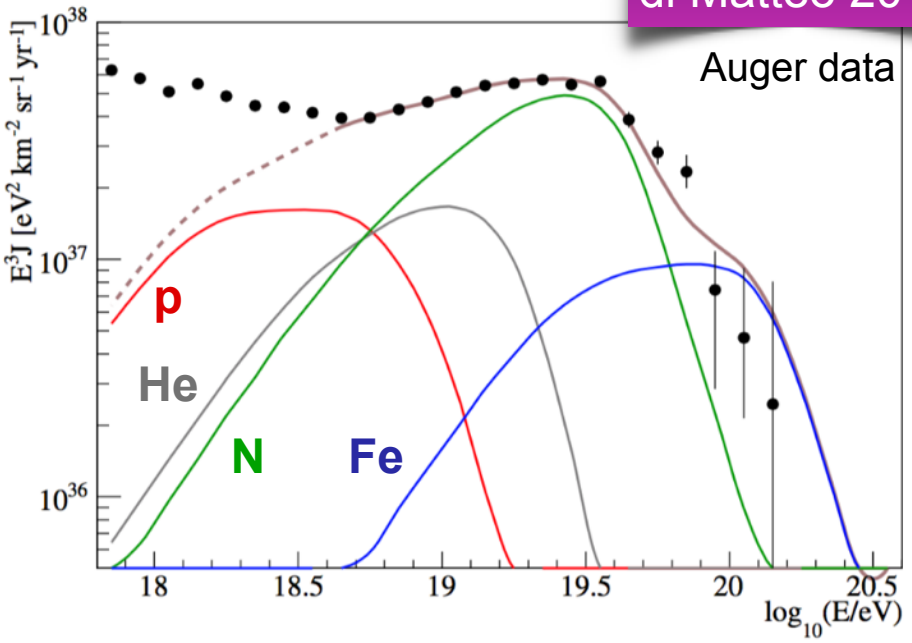
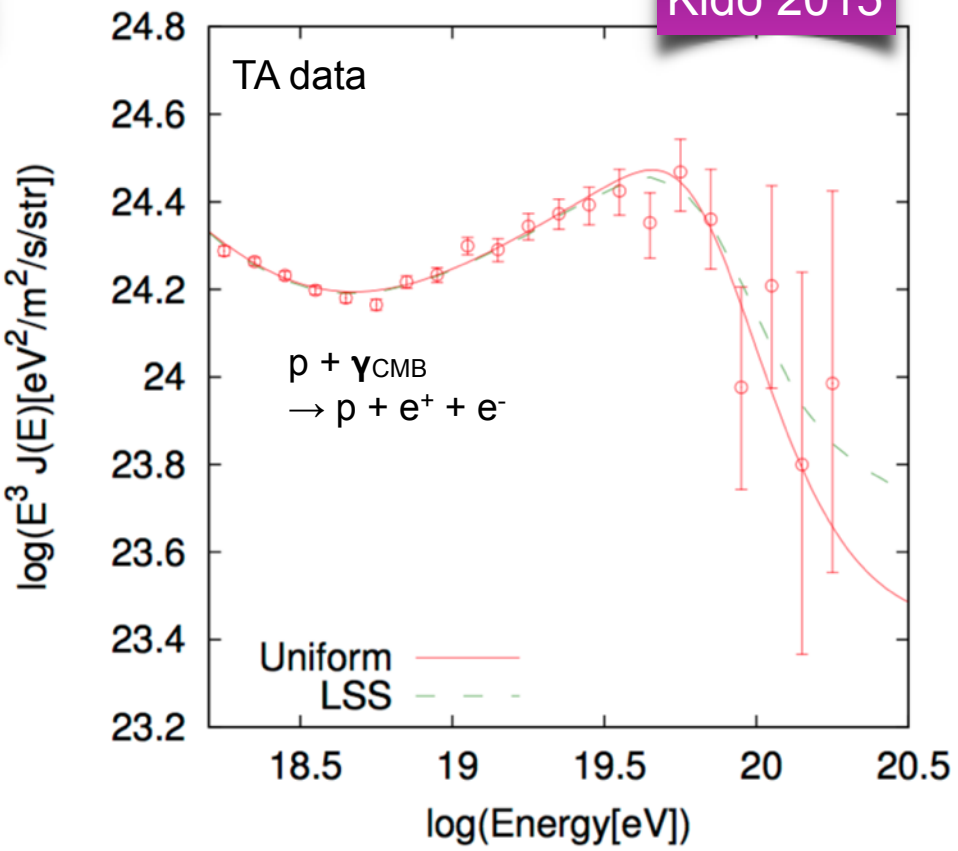
The ankle: mixed composition vs. proton-only

di Matteo 2015



mixed composition w/ rigidity-dependent cutoffs?

Kido 2015



purely protons suffering energy losses on CMB?

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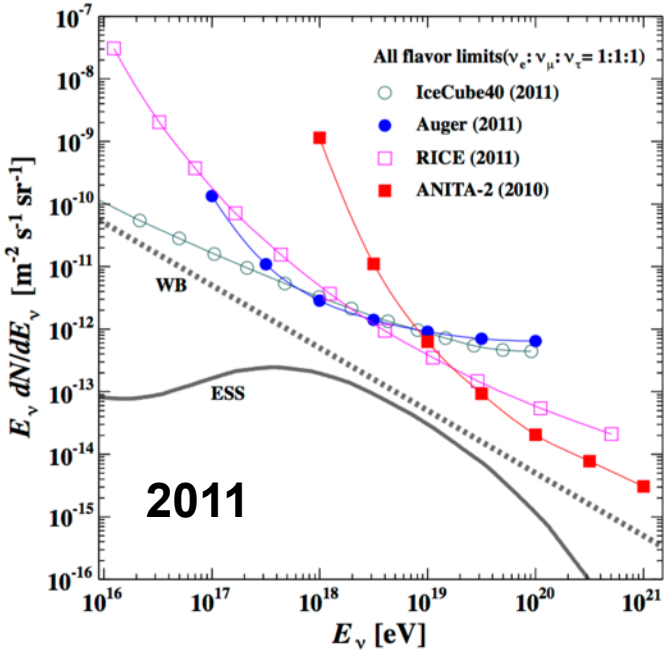
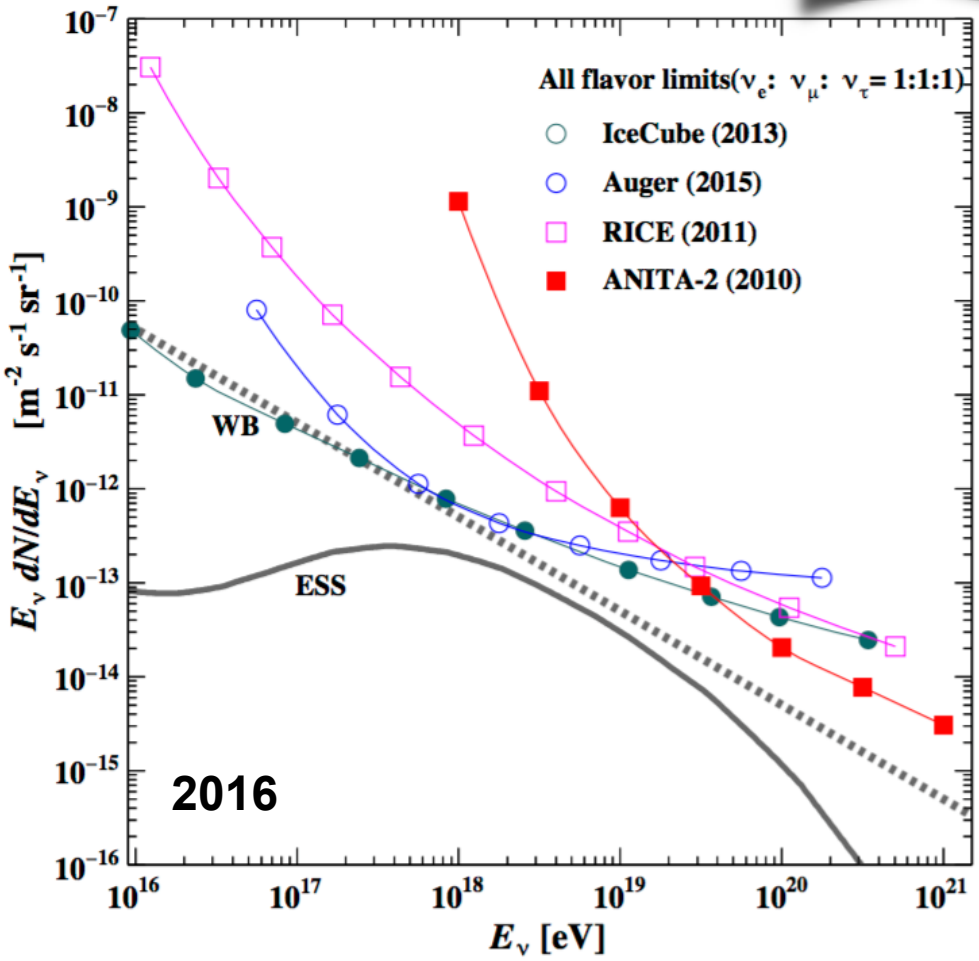
The GZK cutoff: cosmogenic neutrinos



limits approaching
- Waxman-Bahcall limit
- estimated level of cosmogenic flux

PDG 2016



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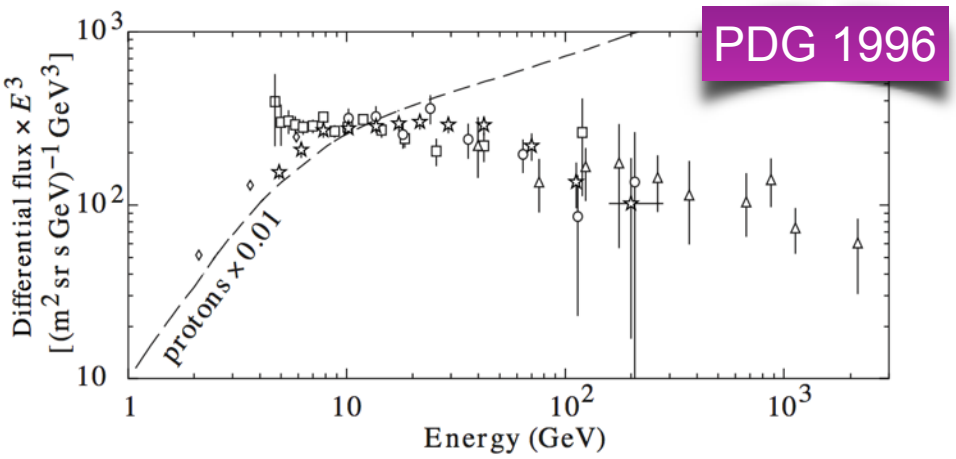
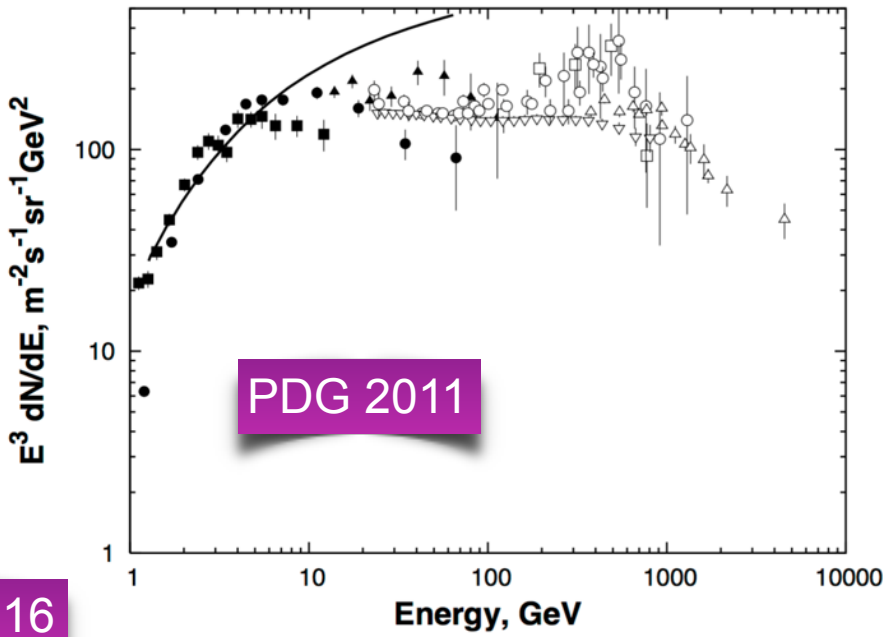
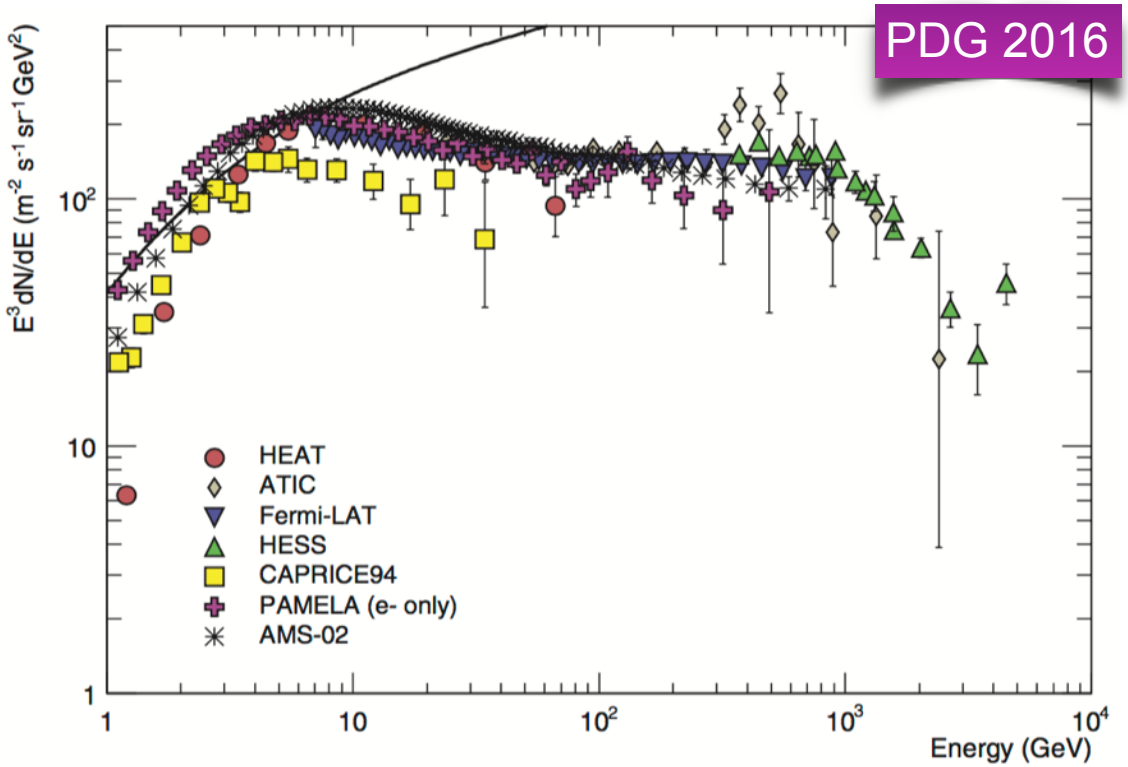
Electrons + Positrons







- new contributor: AMS-02
- "ATIC-Peak" finally ruled out: spectrum flat at 100 GeV - 1 TeV → implications for DM
- all in line with standard astrophysical production
- multi-TeV region largely unexplored (local sources)

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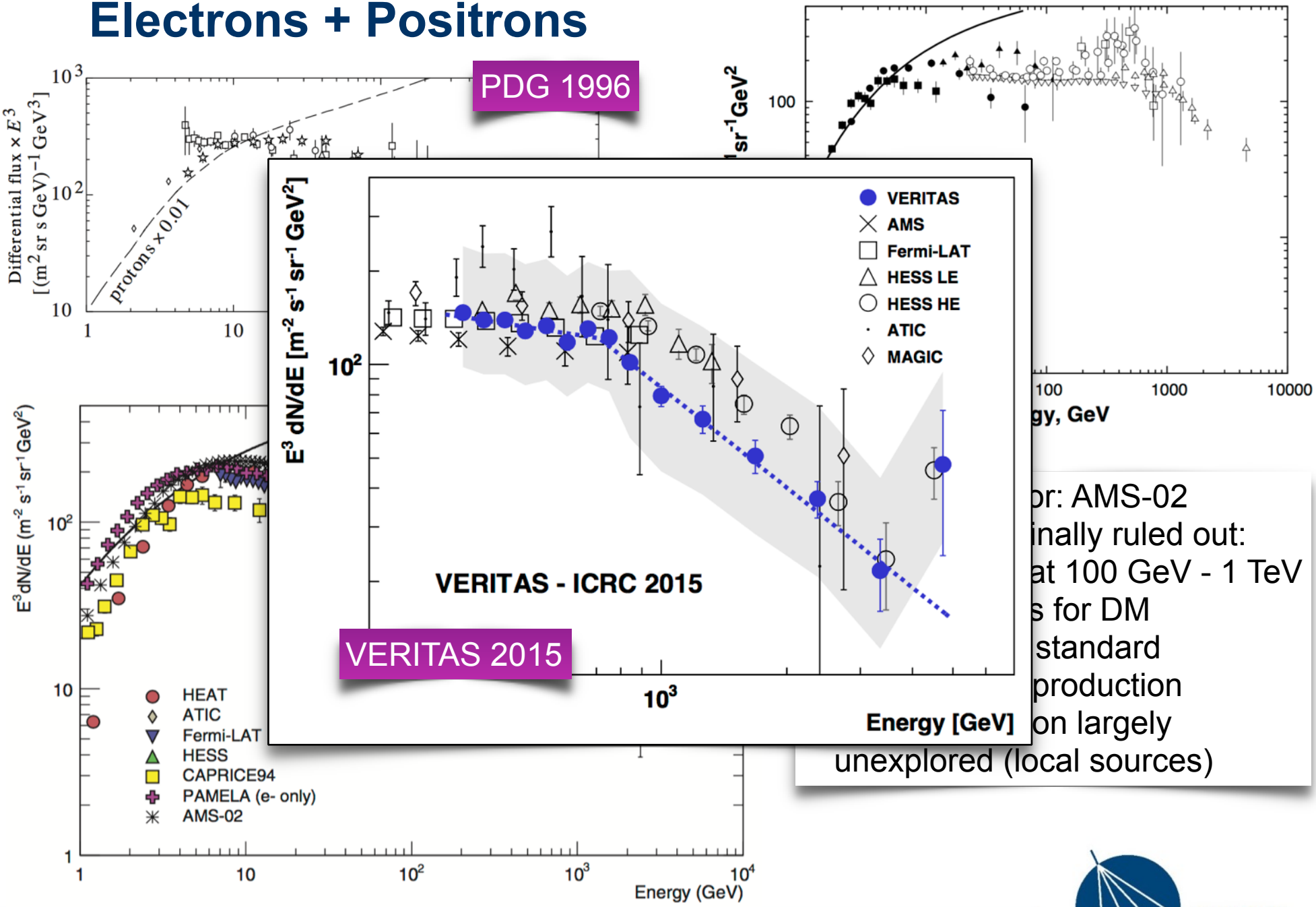
Electrons + Positrons



or: AMS-02
inally ruled out:
at 100 GeV - 1 TeV
s for DM
standard
production
on largely
unexplored (local sources)

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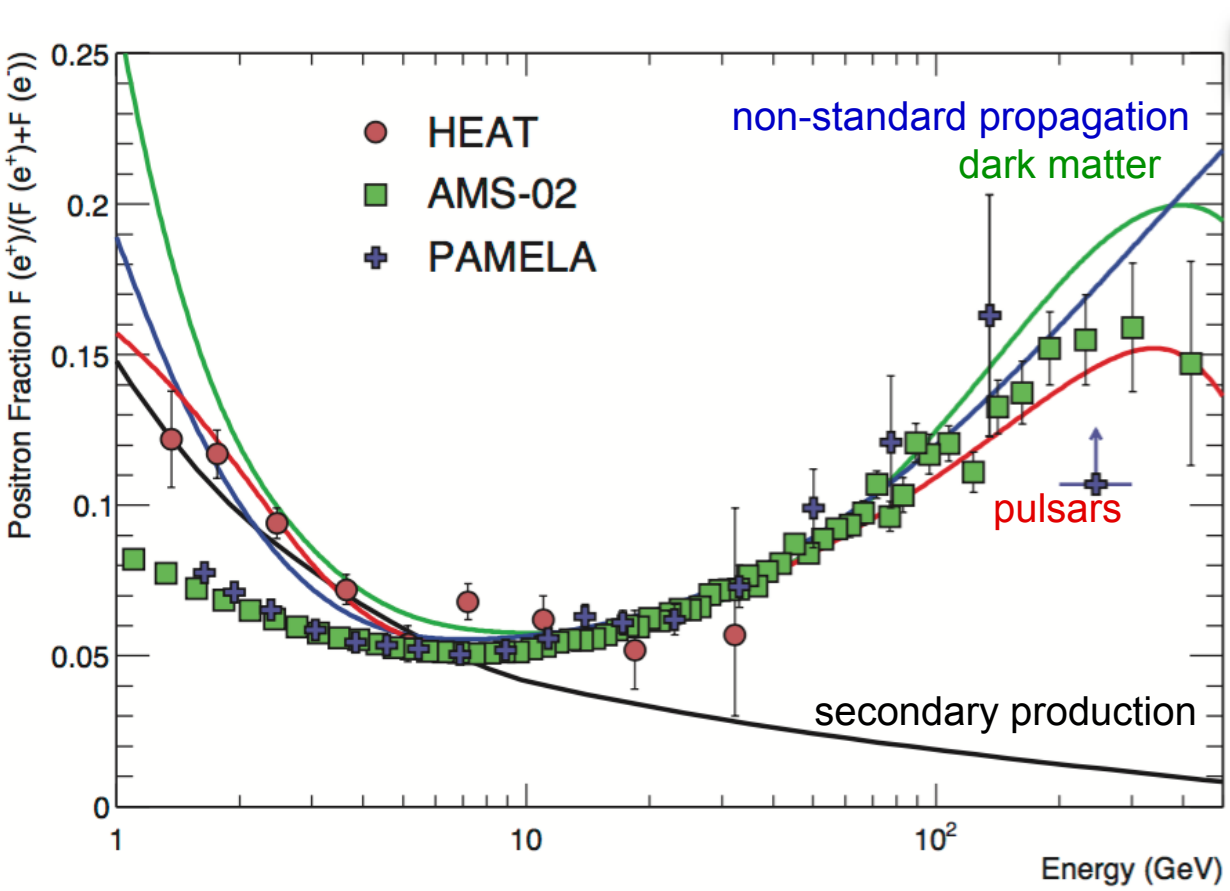
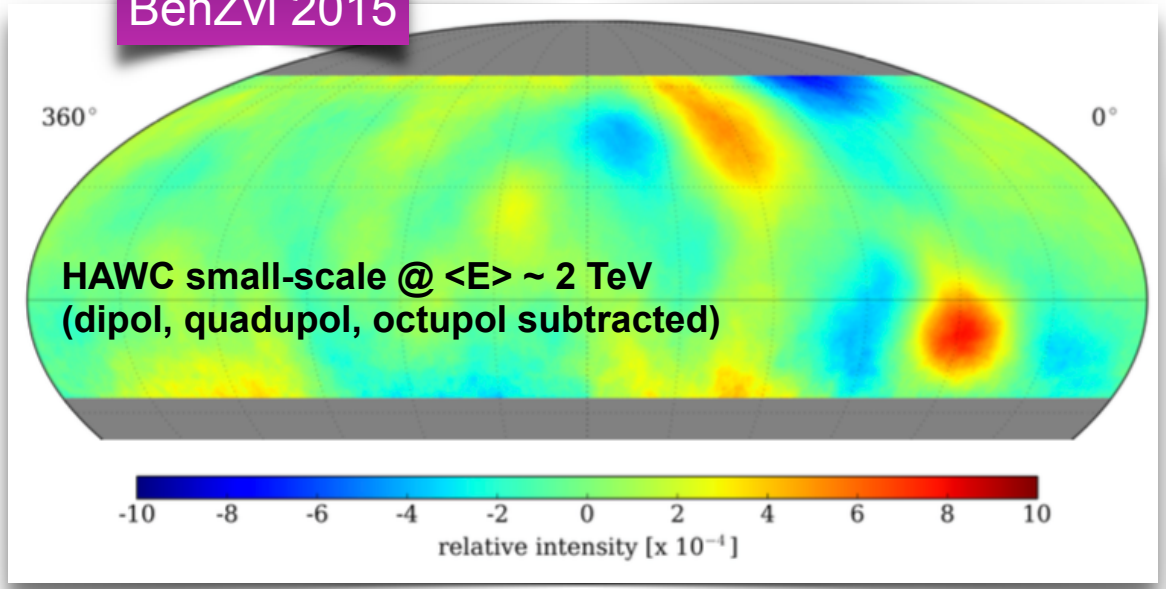
Positron fraction



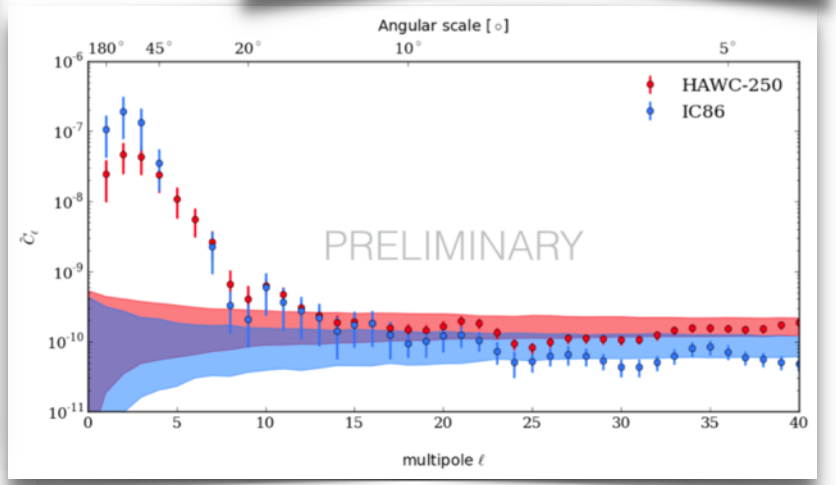
- precise measurement also at few 100 GeV
- shape not explained by secondary production
- nearby pulsars?

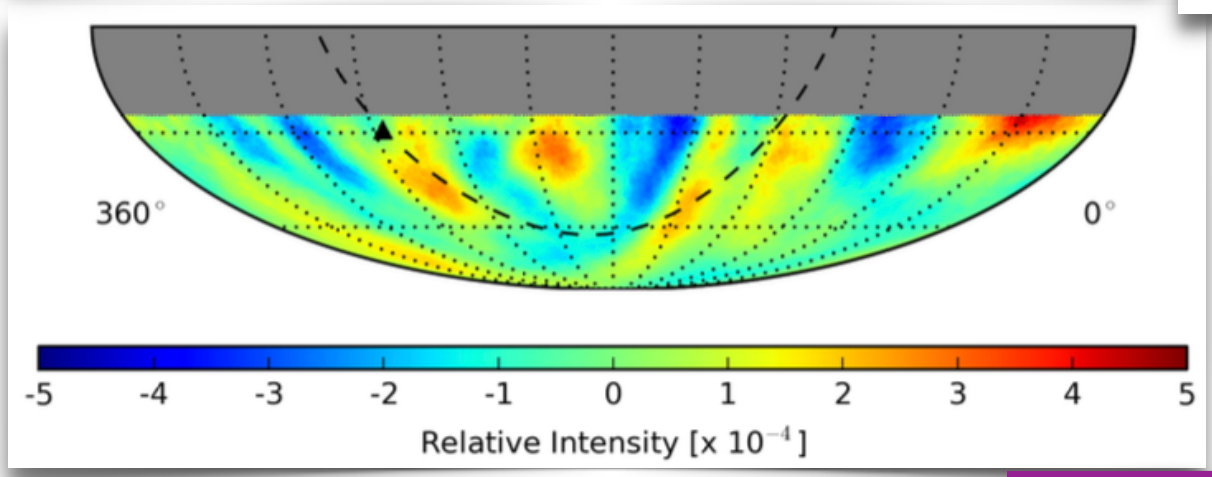
Arrival direction: CR anisotropy of TeV/PeV CRs

BenZvi 2015



HAWC/IceCube Coll. 2015





IceCube small-scale @ <E> ~ 20 TeV
(dipol, quadrupol, subtracted)

IceCube Coll. 2016

- large scales: source distribution?
- small scales: field turbulence?
- strongly energy-dependent

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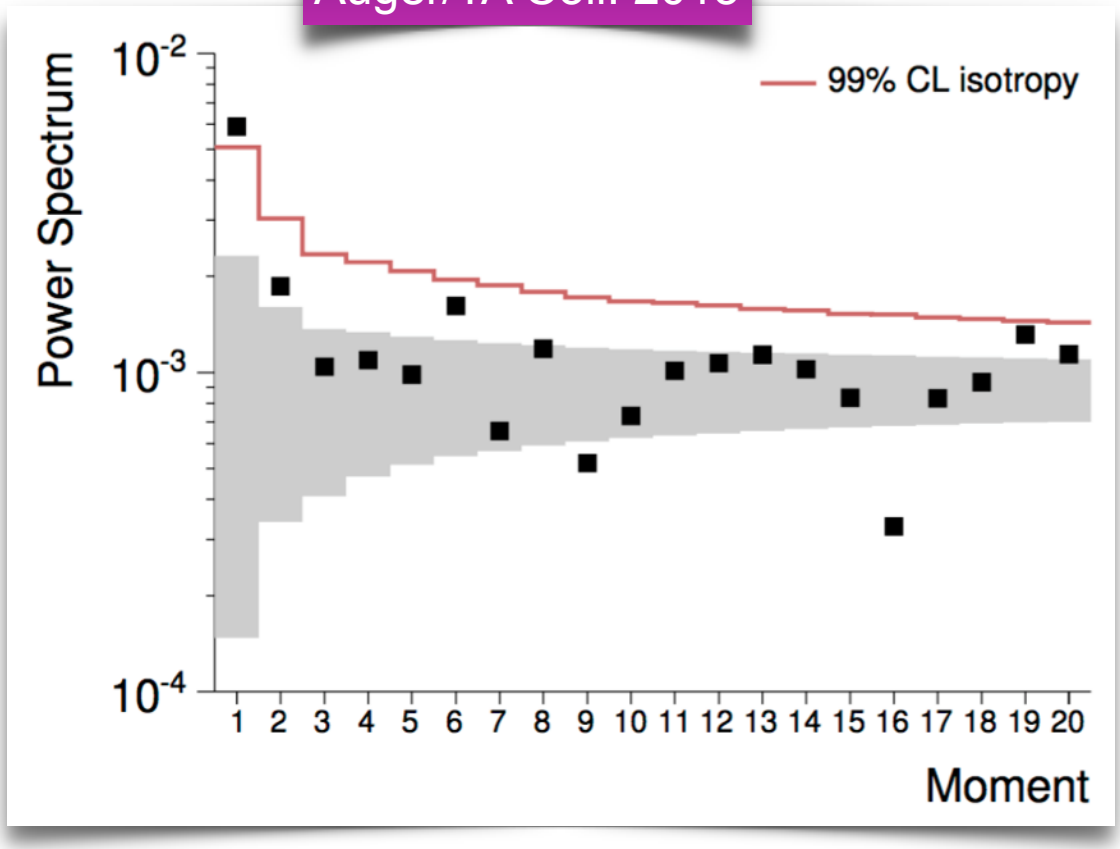
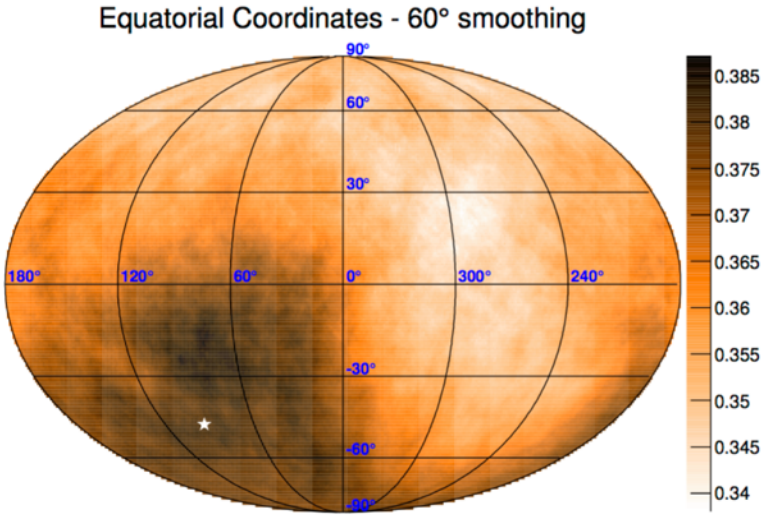
Arrival direction: CR anisotropy of UHECRs

Auger/TA Coll. 2015





- $E > 10^{19}$ eV
- only dipole term significant
- nearby (extragalactic) sources?
  but: no short-scale structure,
  no clustering w.r.t. extragal. sources

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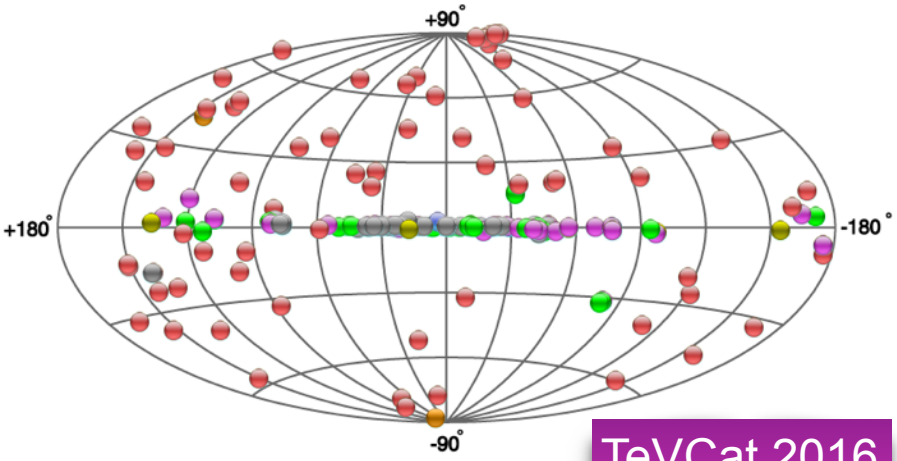
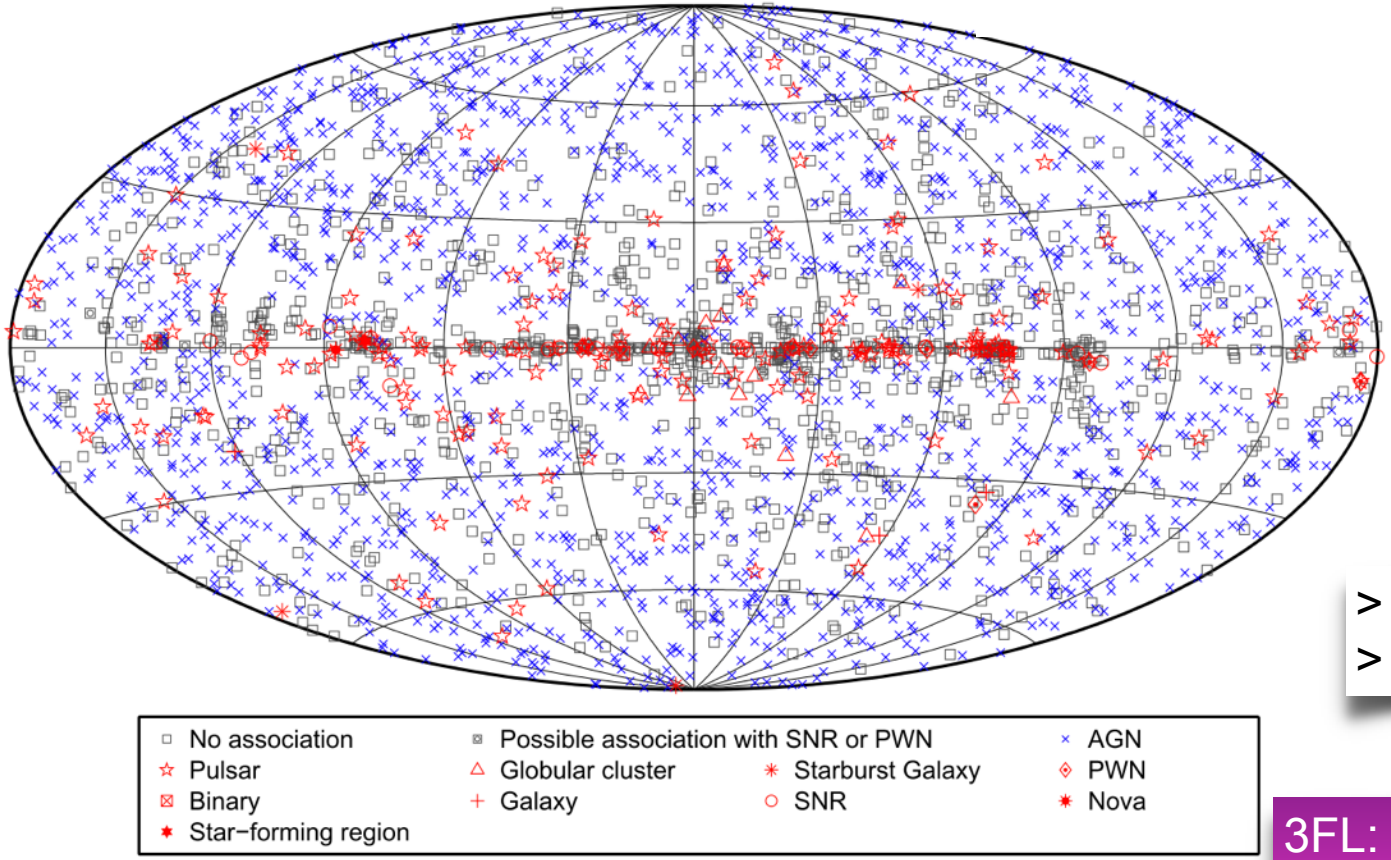
CR SOURCES

GeV/TeV catalogues



TeVCat 2016



> 3000 GeV sources
> 170 TeV sources

3FL: Fermi-LAT Coll. 2015

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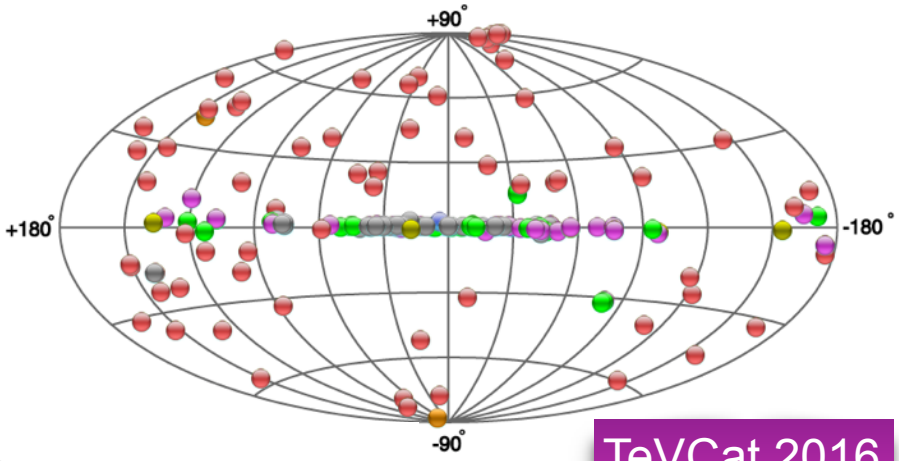
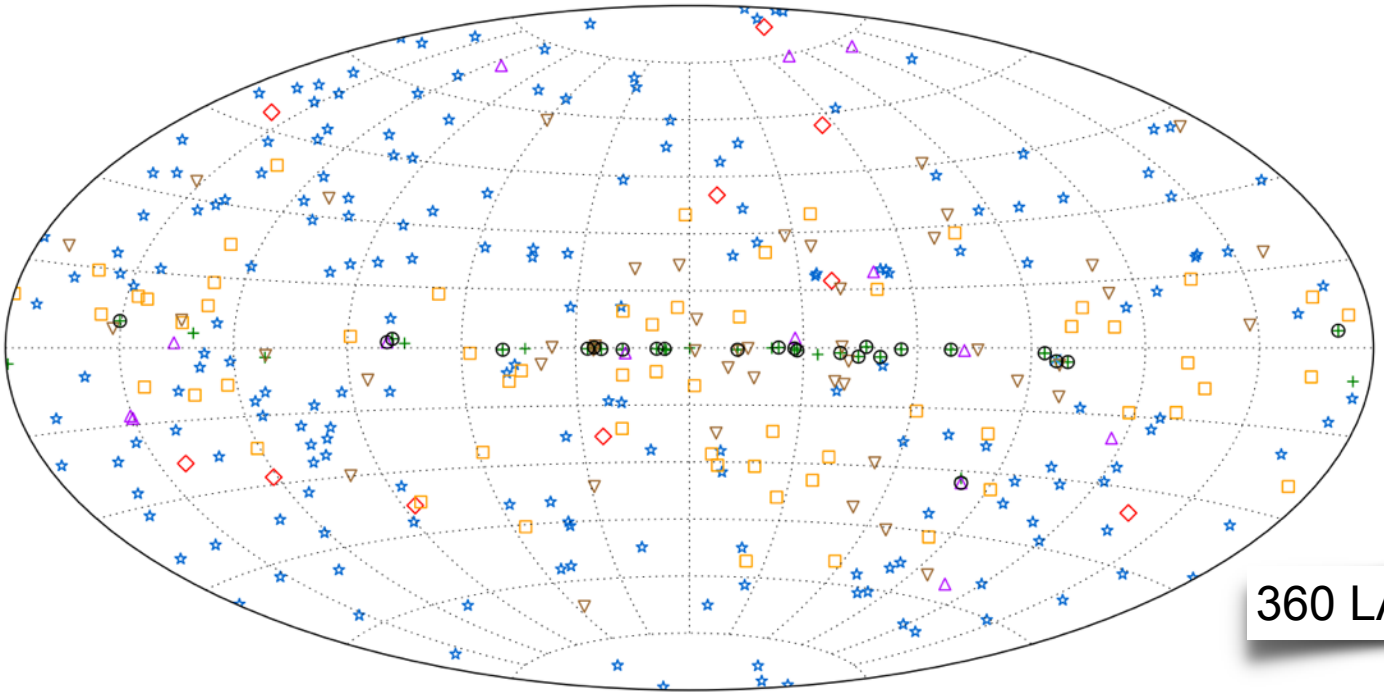
GeV/TeV catalogues



TeVCat 2016



360 LAT sources > 50 GeV

+ SNRs and PWNe	☆ BL Lacs	□ Unc. Blazars	▽ Unassociated
× Pulsars	◇ FSRQs	△ Others	○ Extended

2FHL: Fermi-LAT Coll. 2016

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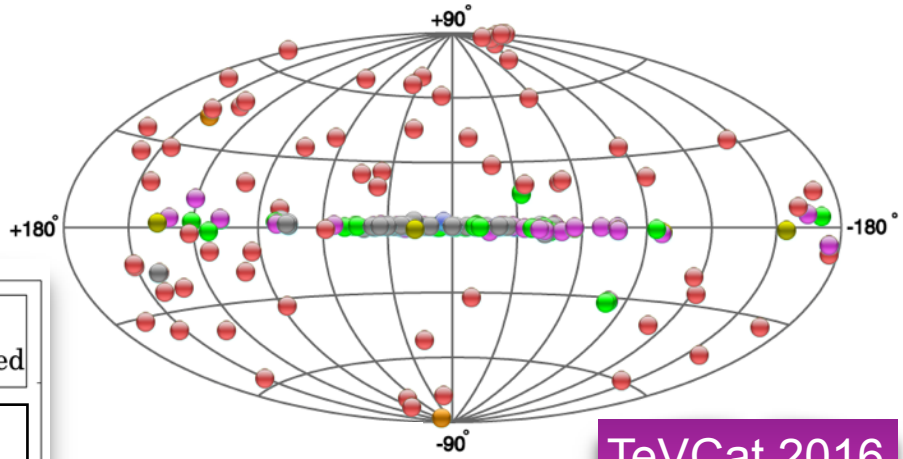
GeV/TeV catalogues



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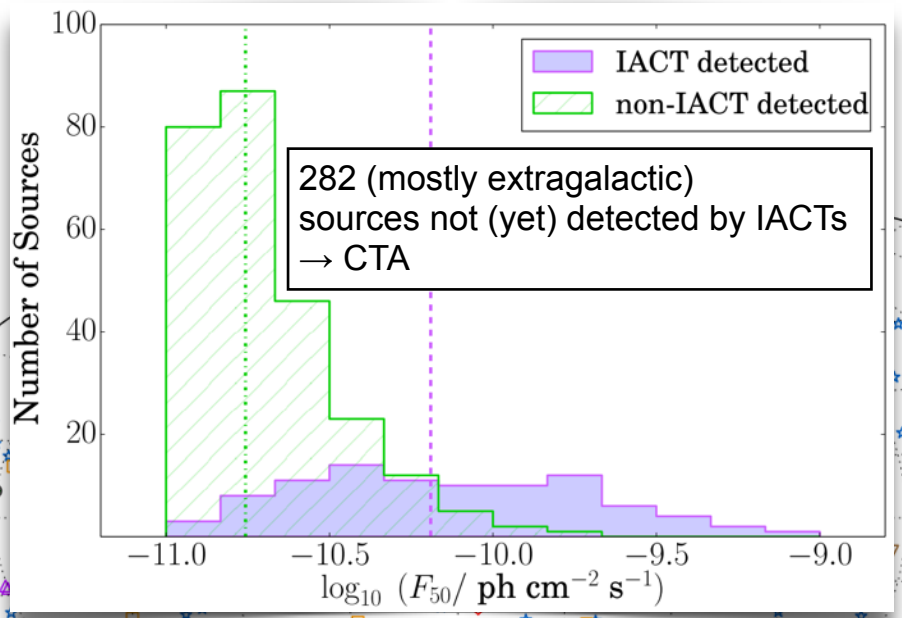
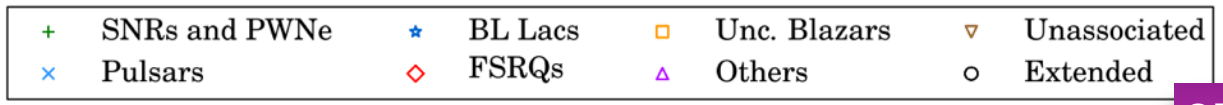


360 LAT sources > 50 GeV



2FHL: Fermi-LAT Coll. 2016

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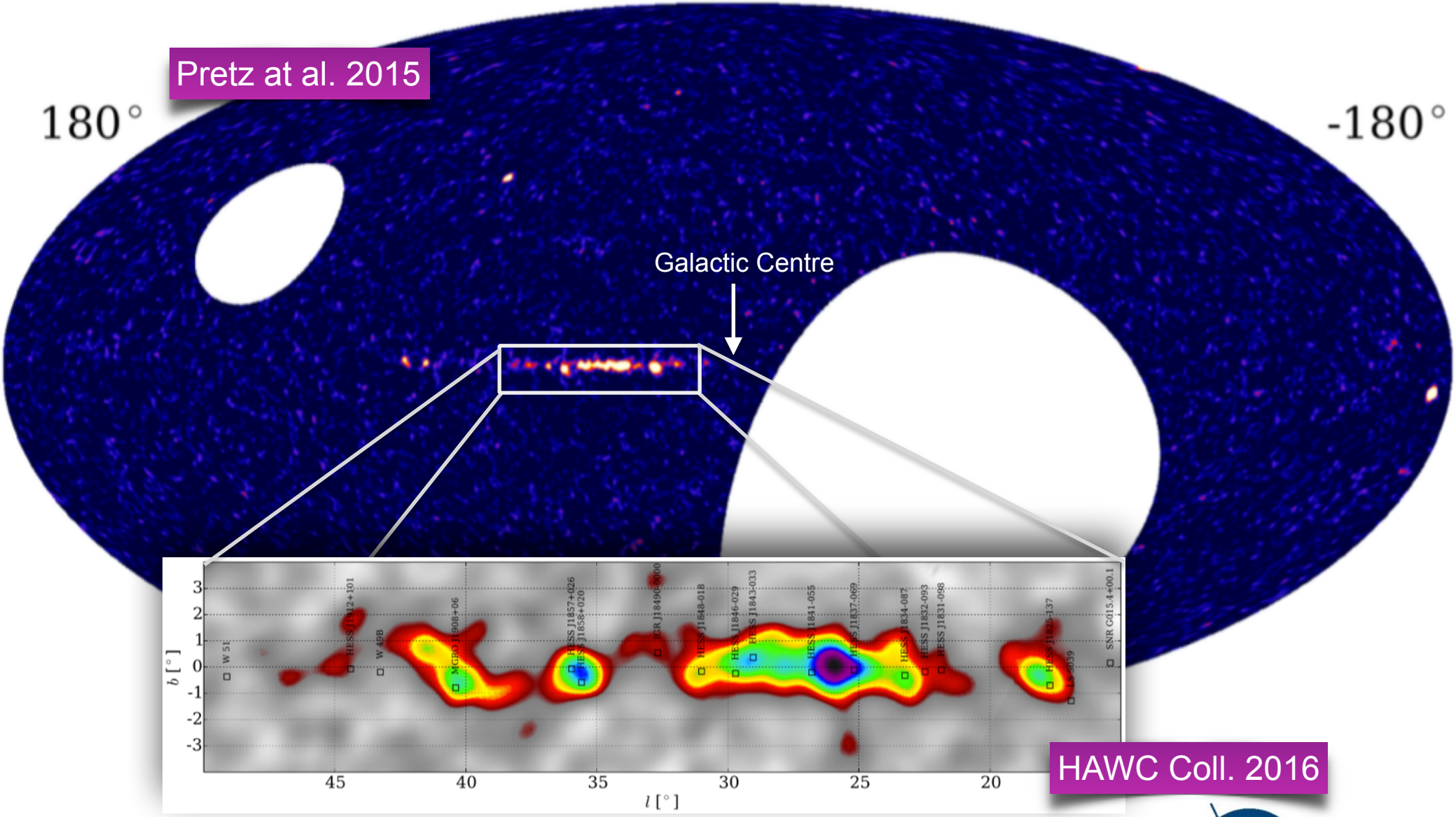
The HAWC's view: mapping the TeV sky



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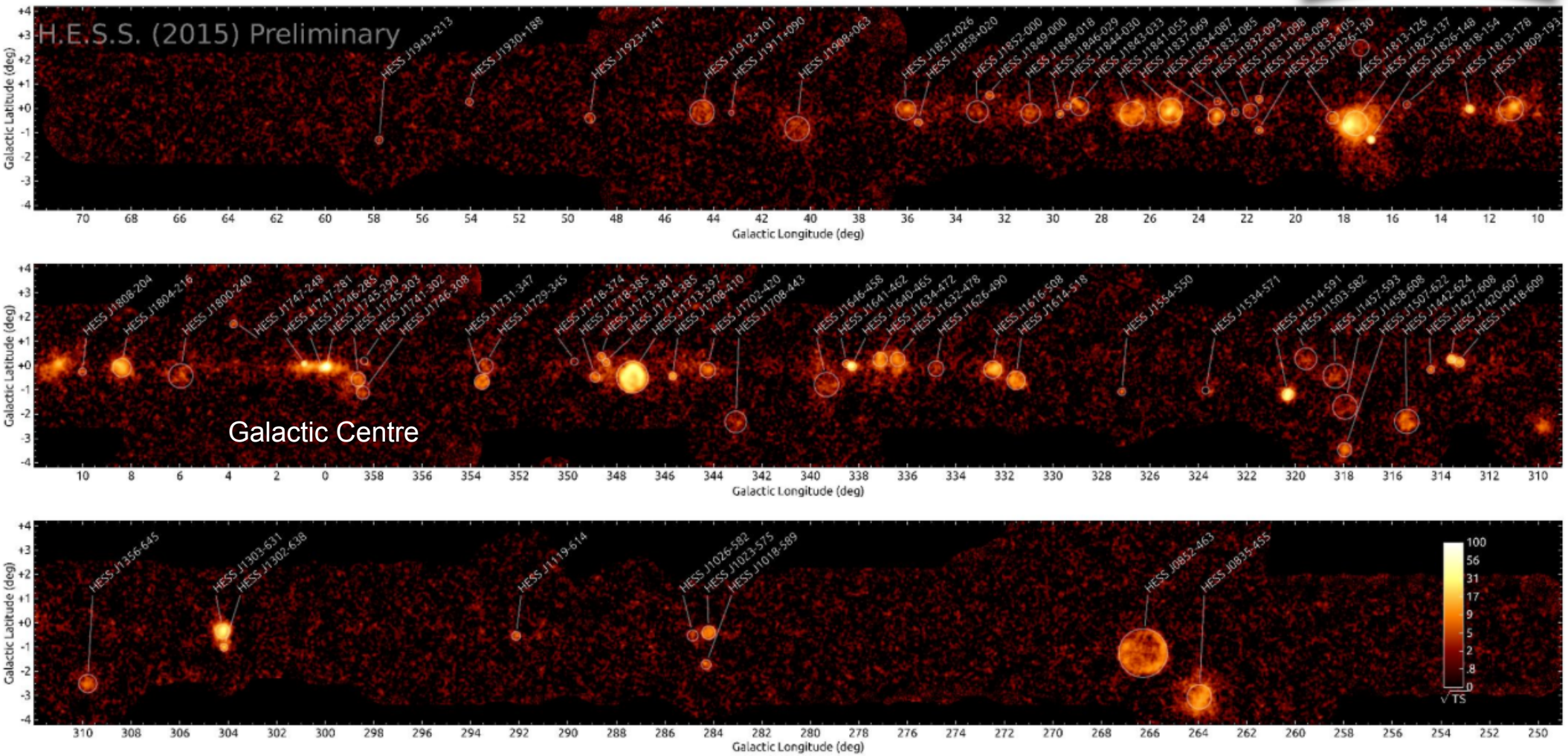
The H.E.S.S. Inner Galaxy Survey

Deil et al. 2015



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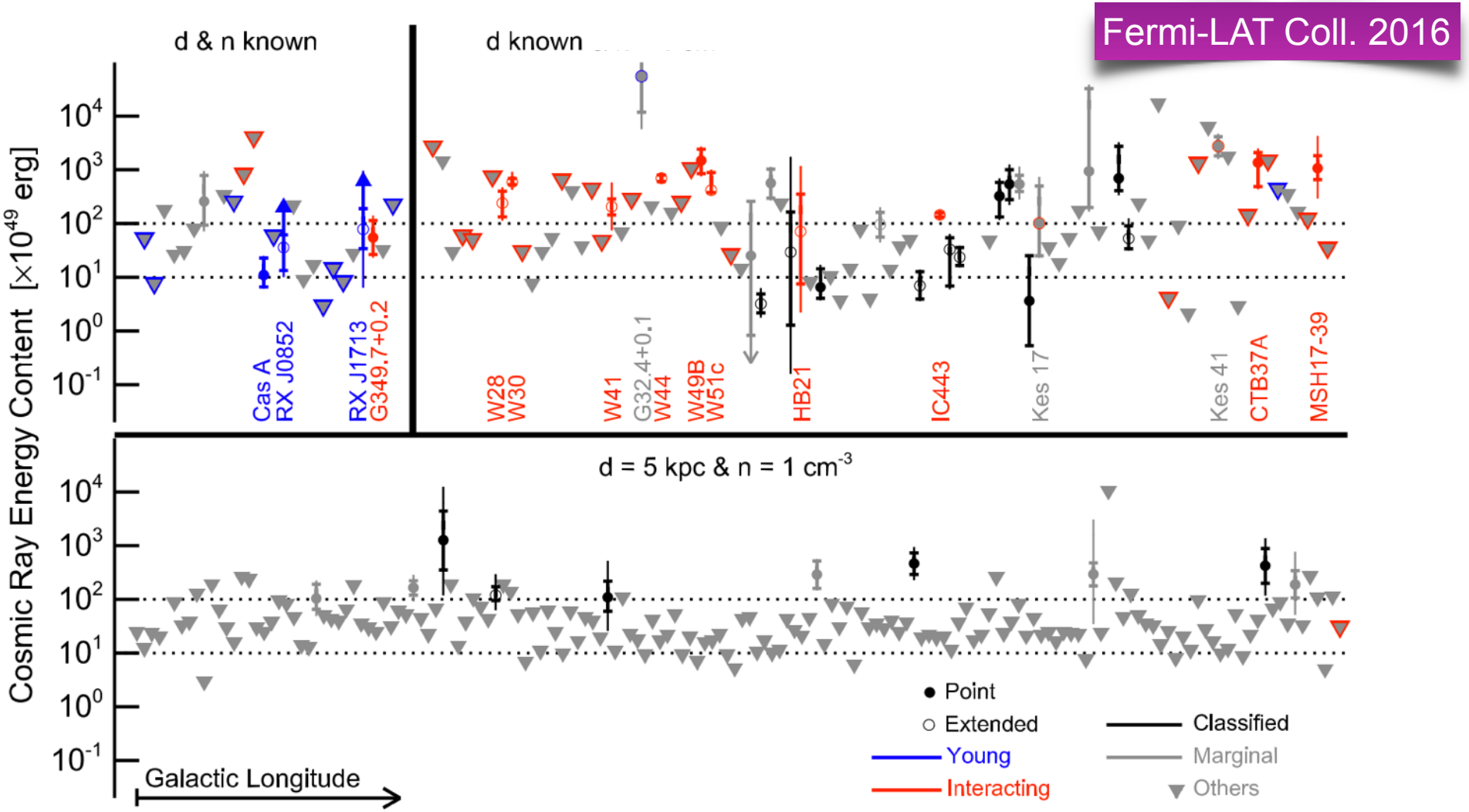
Fermi-LAT SNRs: limits on CR efficiency



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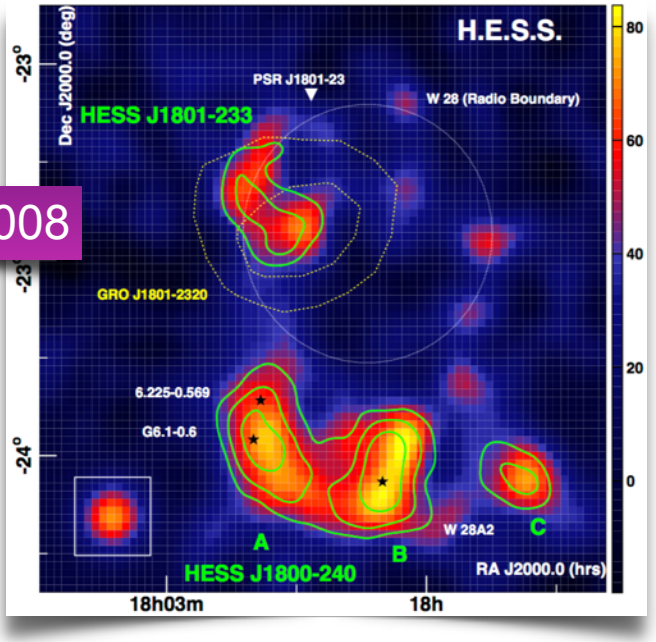
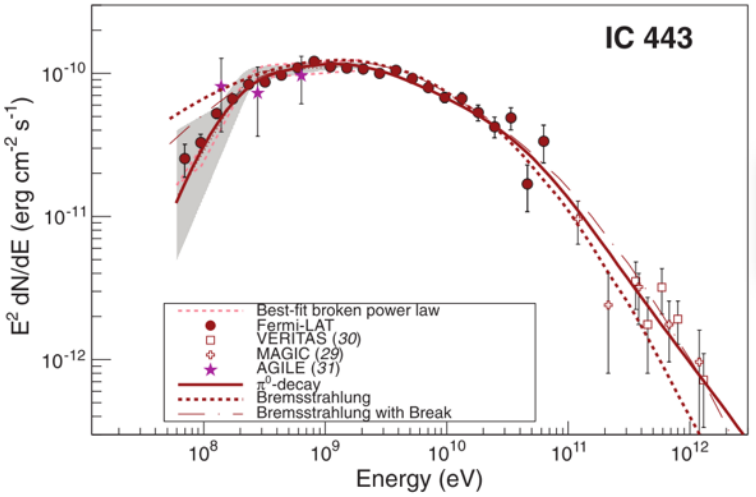
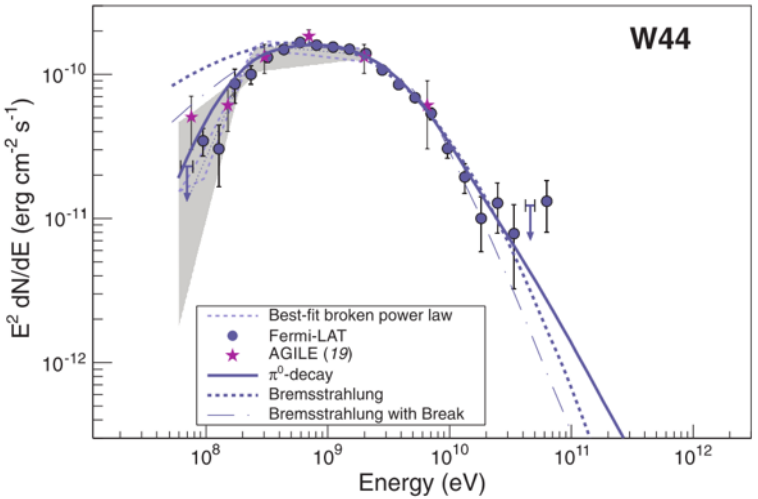
Some SNRs accelerate protons…

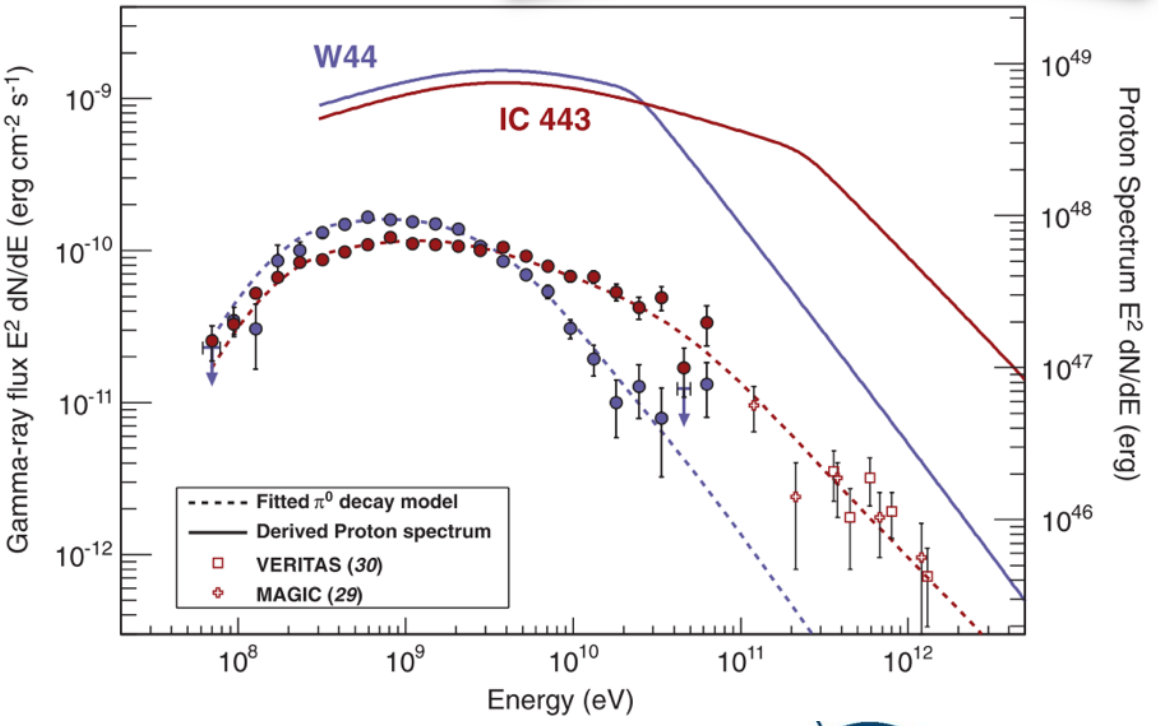
H.E.S.S. Coll. 2008



- cloud interaction
- pion decay signature







Fermi-LAT Coll. 2013

… but are too old to be PeVatrons.

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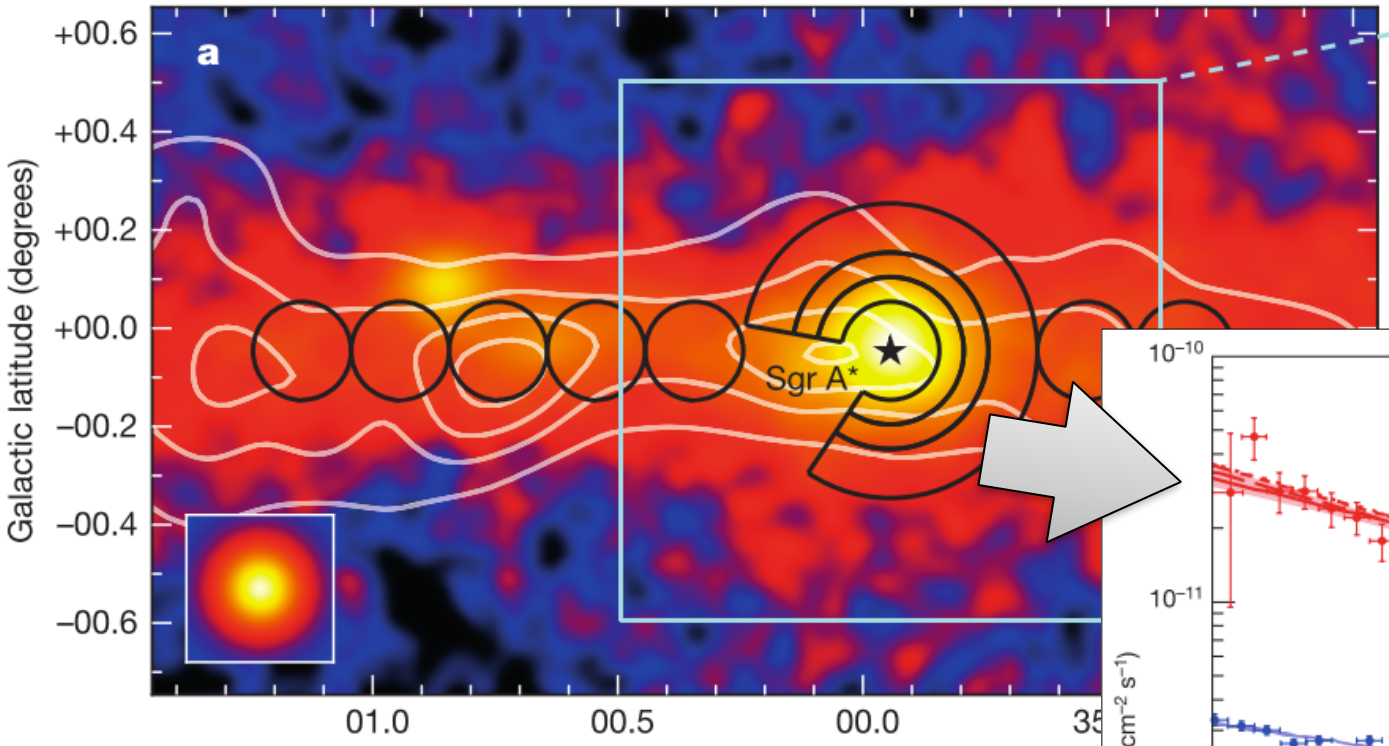
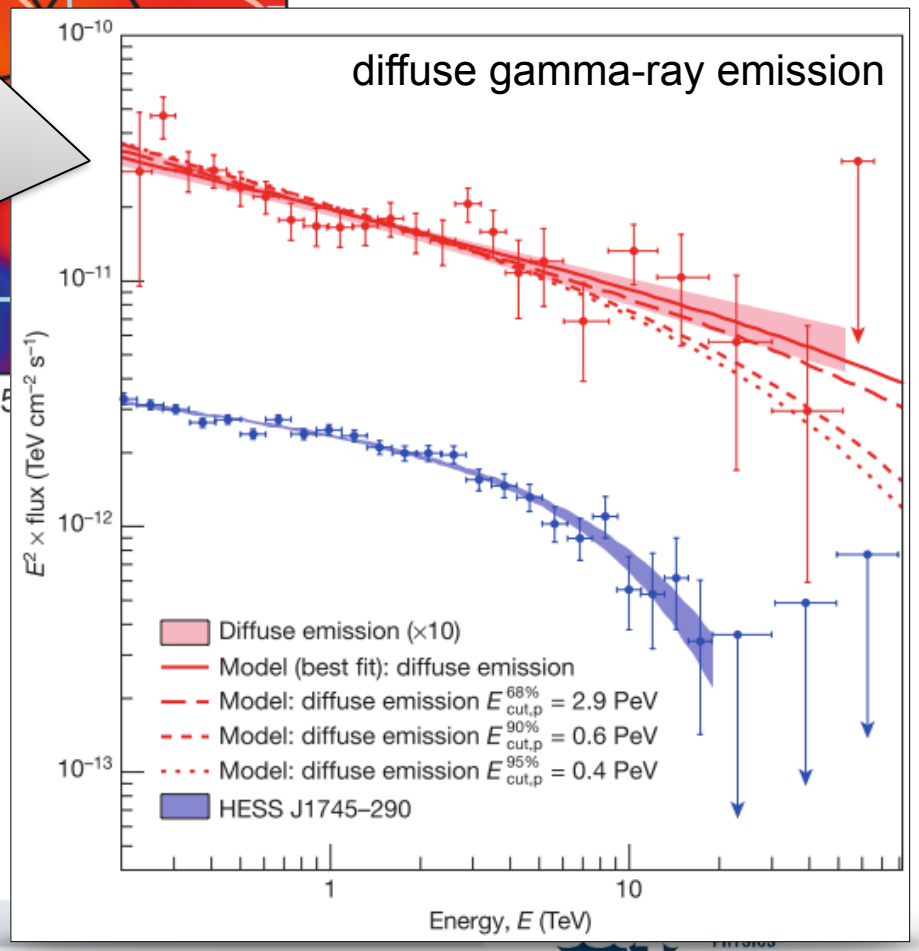
The Galactic Centre: a PeVatron!



H.E.S.S. Coll. 2016



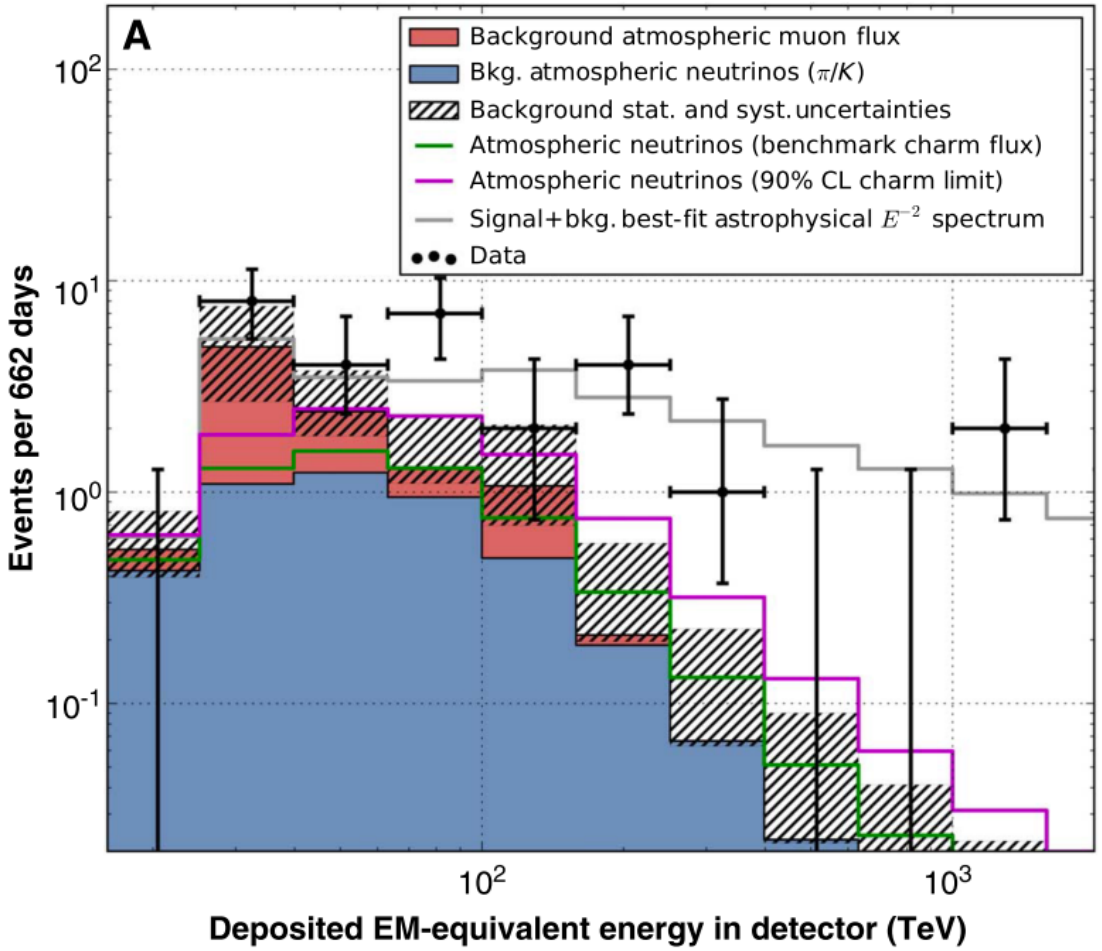
- strong correlation with molecular clouds
- gamma rays with E>50 TeV, no cutoff

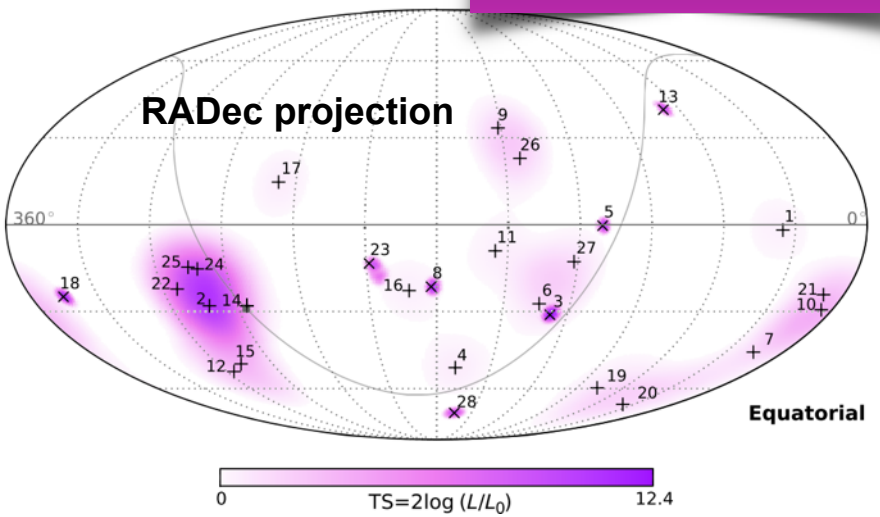
  → proton acceleration up to the CR knee!

- actual accelerator? Less clear.

Astrophysical neutrinos

IceCube Coll. 2013





- 28 non-terrestrial neutrinos > 30 TeV, 2 above 1 PeV
- flux consistent with E^{-2} spectrum and equal-flavour composition
- no significant event clustering (yet)

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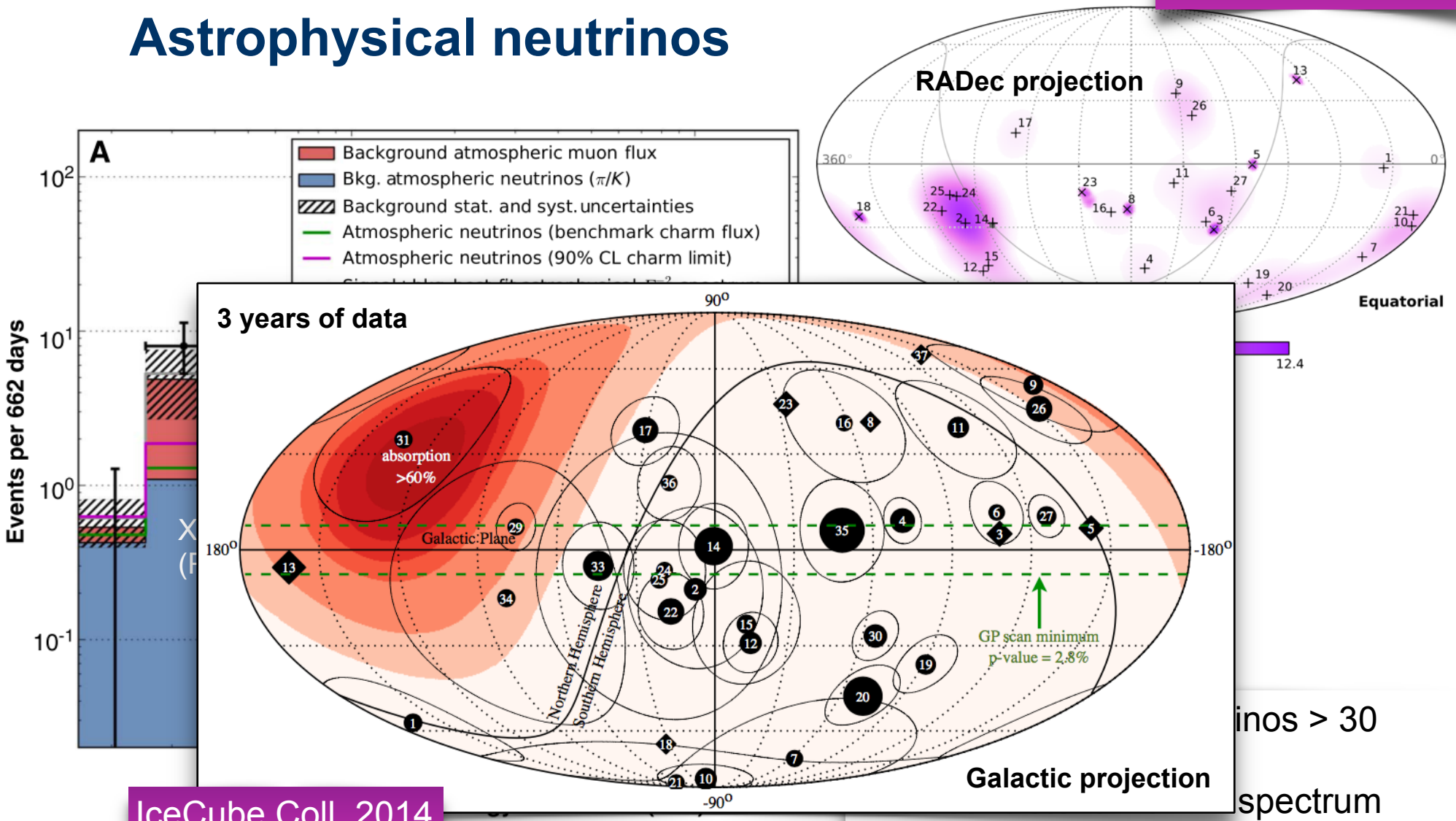
Astrophysical neutrinos

IceCube Coll. 2013



IceCube Coll. 2014

Ahlers 2015

inos > 30

spectrum

and equal-flavour composition

- no significant event clustering (yet)

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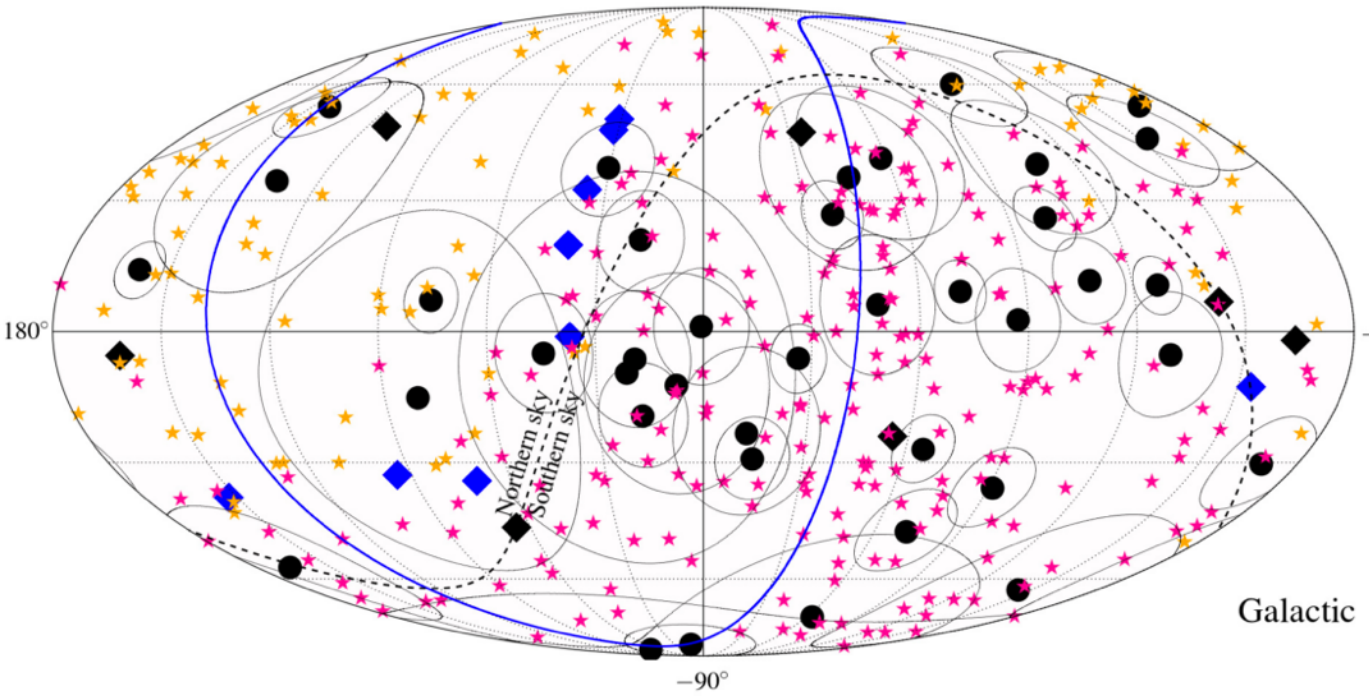
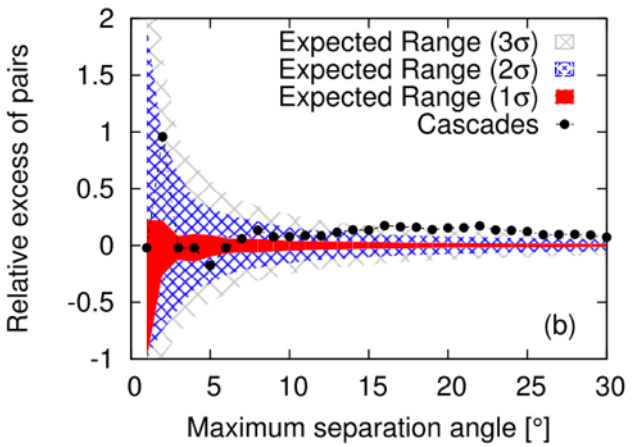
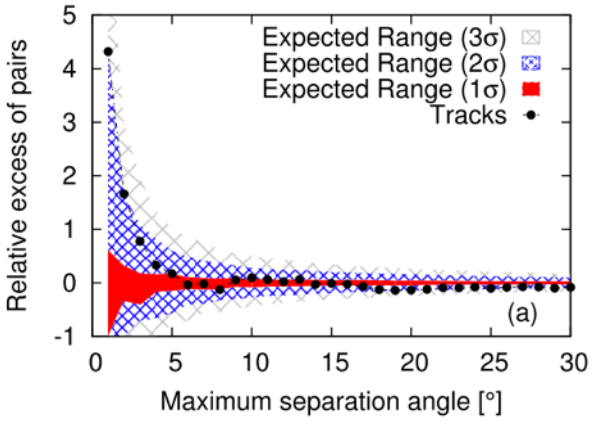
Astrophysical neutrinos: correlation with UHECRs?







Auger Coll, TA Coll., IceCube Coll. 2016

- no indication of correlation between IceCube > 30 TeV neutrinos and > 5×10^{19} eV UHECRs
- nearby UHECR vs. far-away neutrino sources?
- PeV neutrino sources not UHECR sources?
- deflection time delays?

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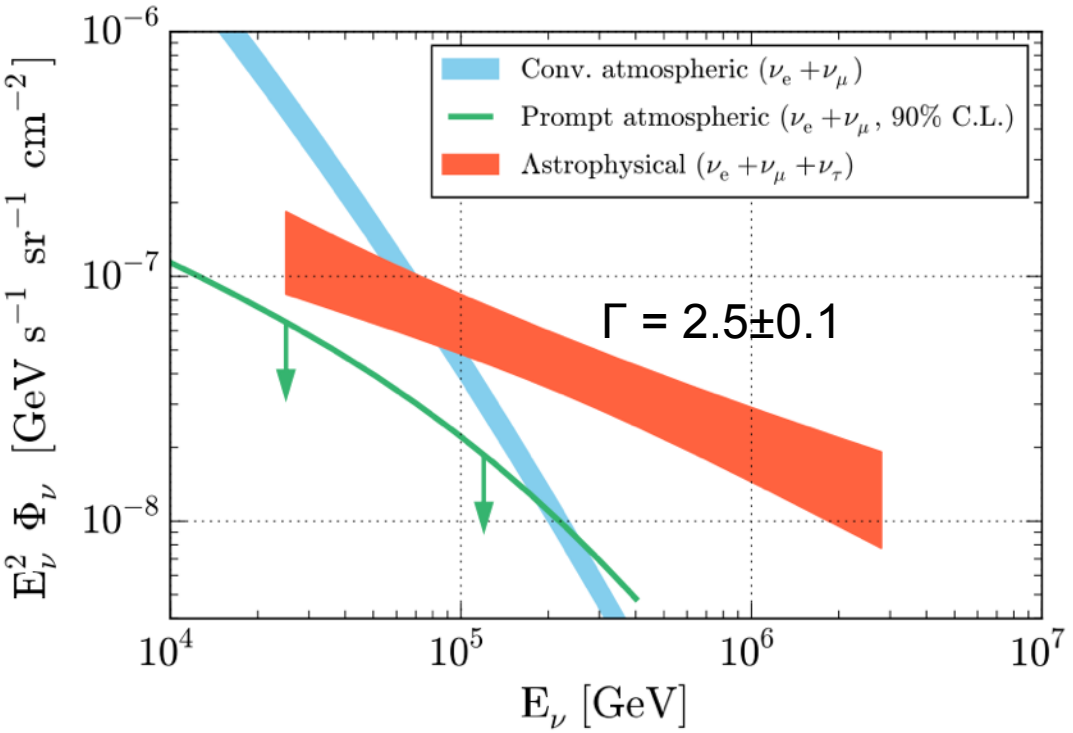
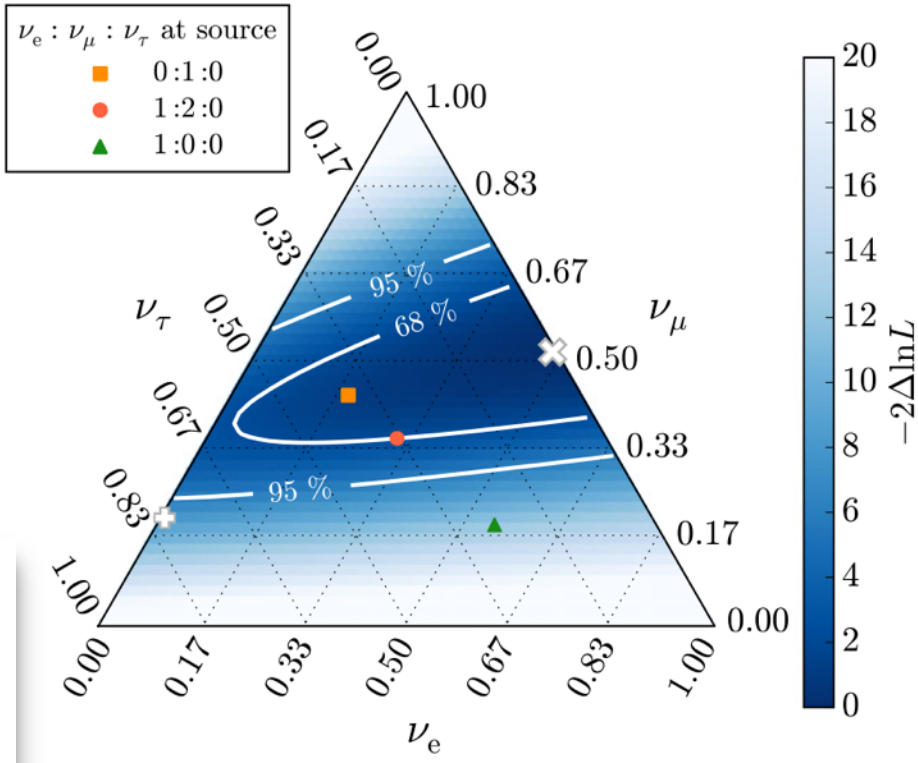
Astrophysical neutrinos: spectrum and composition

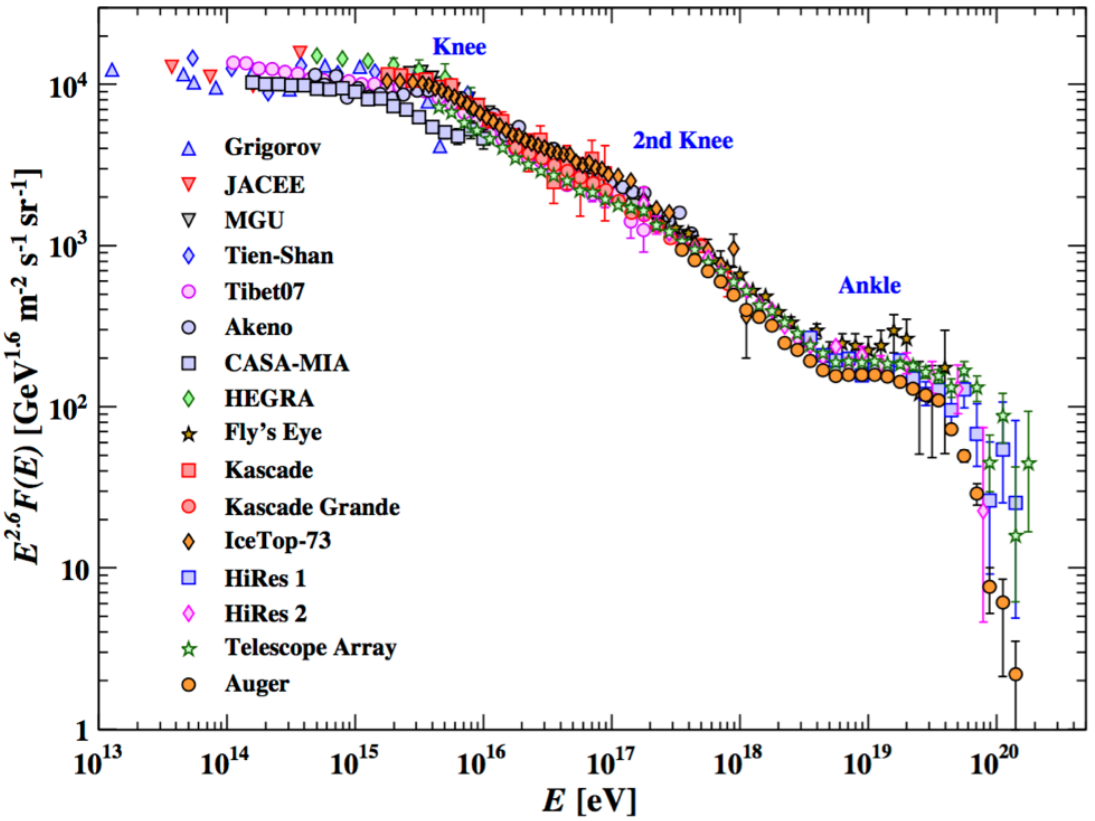


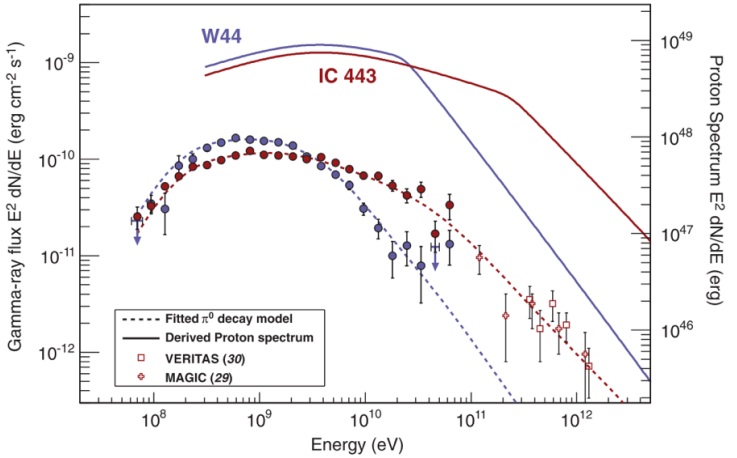
IceCube Coll. 2015

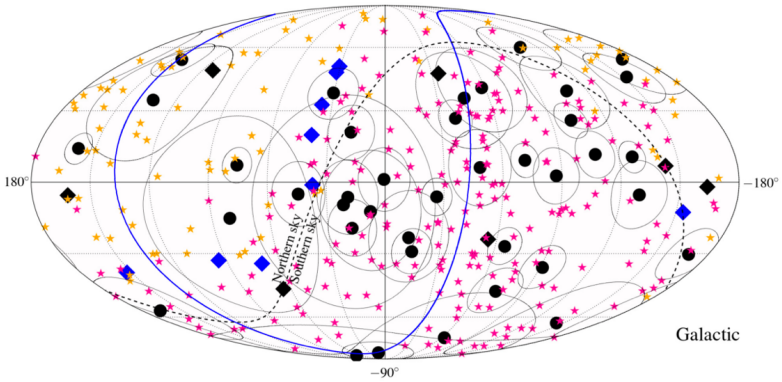


- most-precise measurement of astrophysical neutrino spectrum
- conventional E^{-2} spectrum ruled out
- index of single power law spectrum at odds with extragalactic gamma-ray flux?
- best-fit at-earth composition in agreement with standard pion decay scenario

Summary on achievements







- Cosmic rays do indeed exist.
- Knee, ankle and a few other details
  are the subject of intense interest at the moment.
- Have opened up new observational windows to the universe.
- More detailed measurements, more sensitive instruments to come.

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