WIN2015, Heidelberg, June 2015

Overview of Experimental Astroparticle Physics (and Particle Astrophysics)

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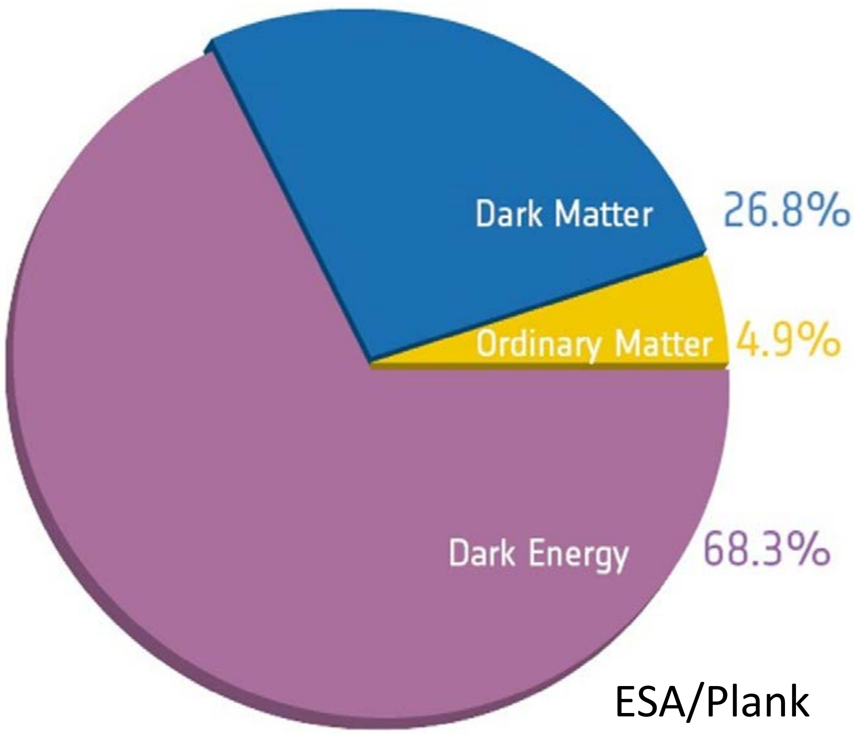
outline

- Dark Matter Searches: Direct Detection Experiments
- Dark Matter Searches: Indirect Experiments
- Cosmic Neutrinos
- Ultra High Energy Cosmic Rays
- Summary

Acknowledgements: S. Haino, S. Yoshida, S. Moriyama, H. Sagawa and many more people

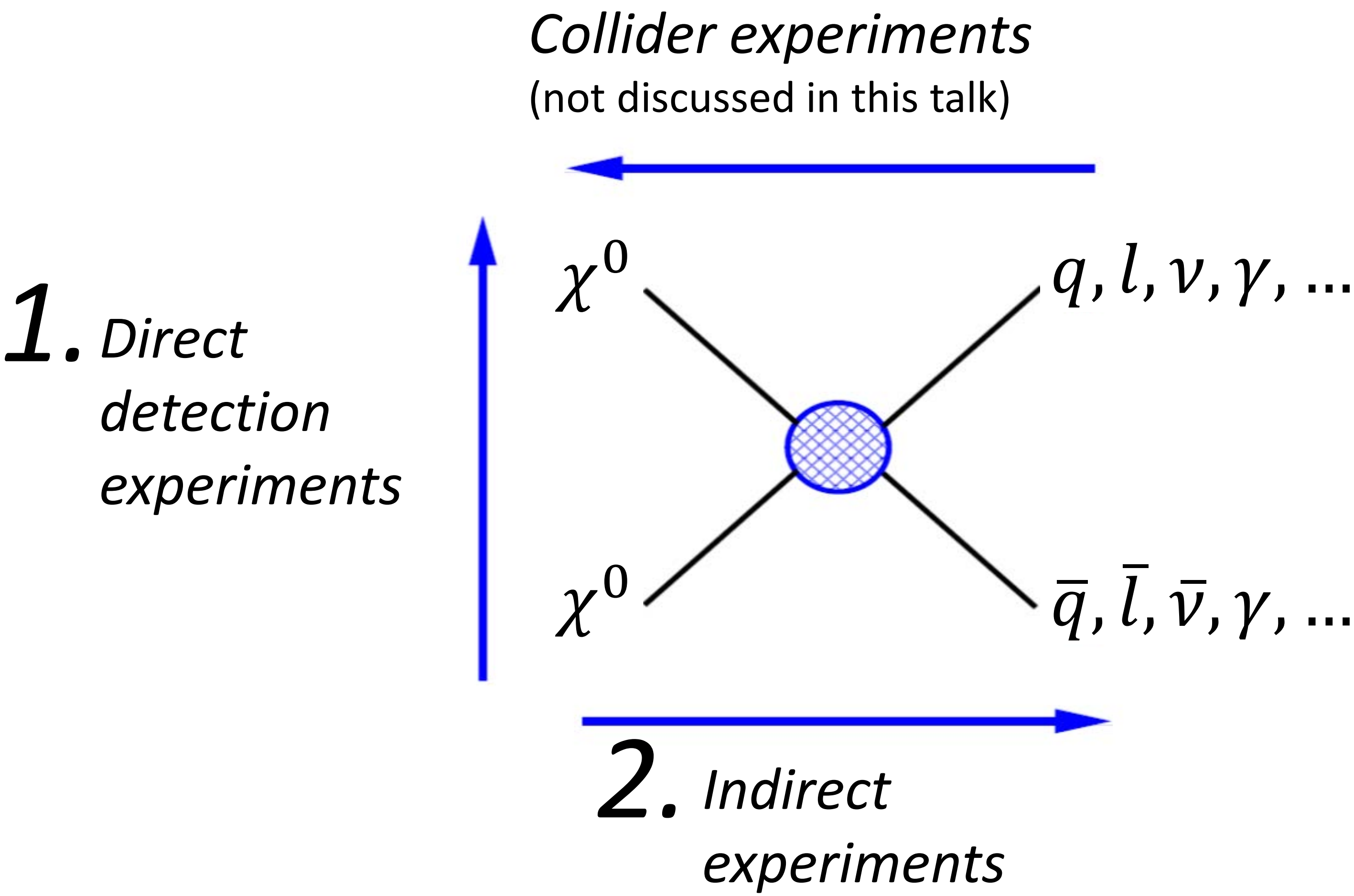
Dark Matter Searches

- We still do not know what are the dark matter particles.
- The detection and the identification of the dark matter are one of the most important subjects in astroparticle physics.
- In this talk, I will concentrate on the WIMPs detection experiments.



ESA/Plank

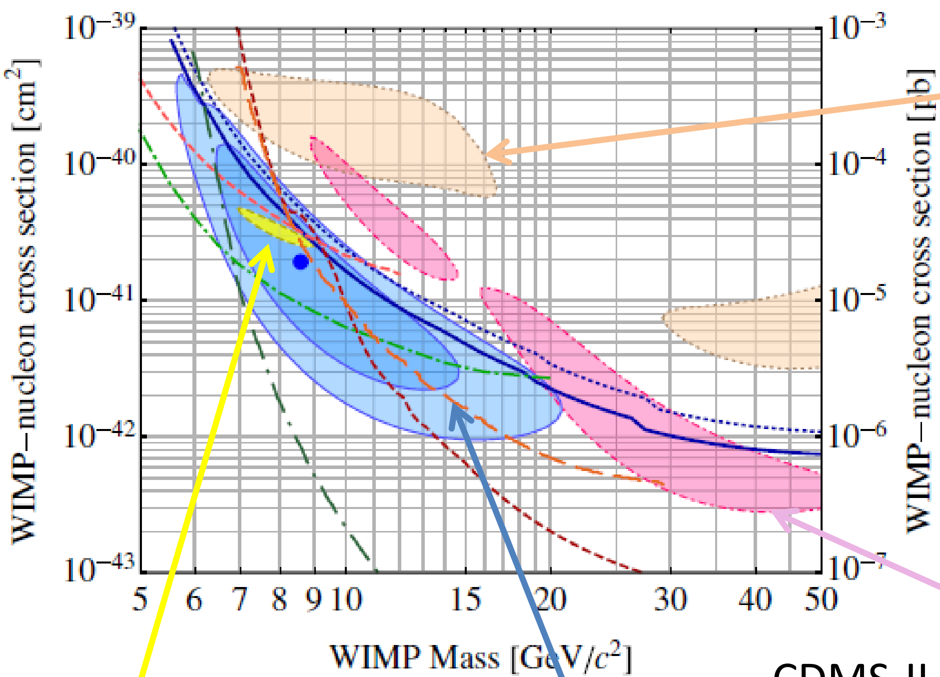
WIMPs detection

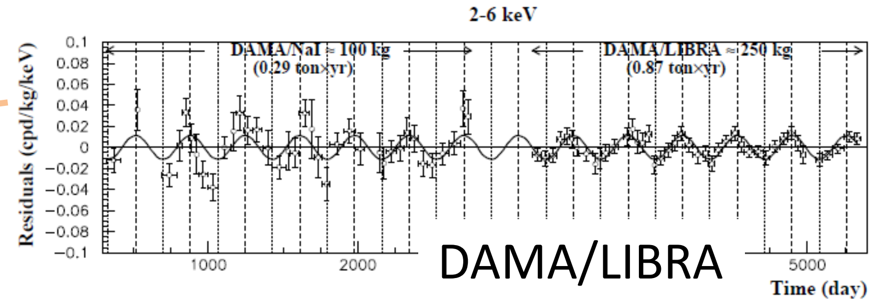


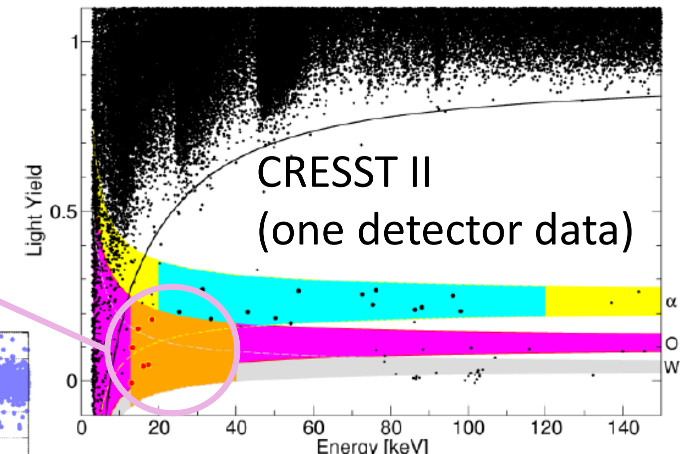
Direct detection experiments

Elena Aprile
NeuTel 2015

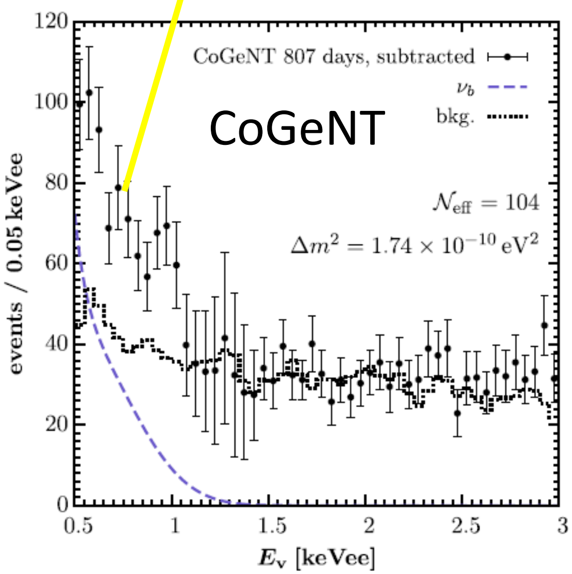
Low Mass WIMPs signals?



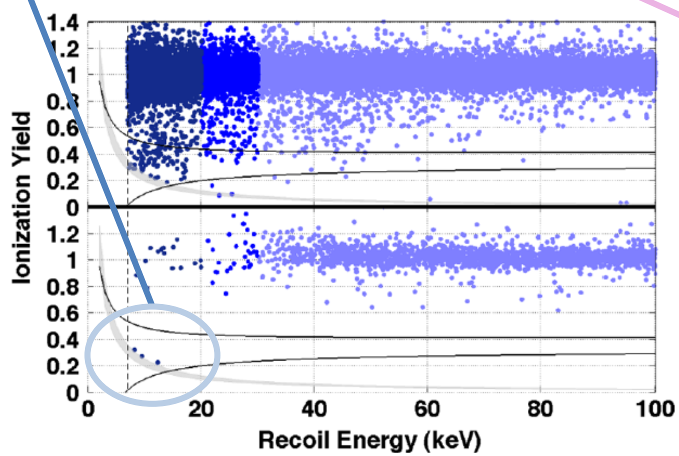




67 events (>4σ above BG)



CDMS-II Si



3 obs'd, BG =0.41 + <0.13 + < 0.08

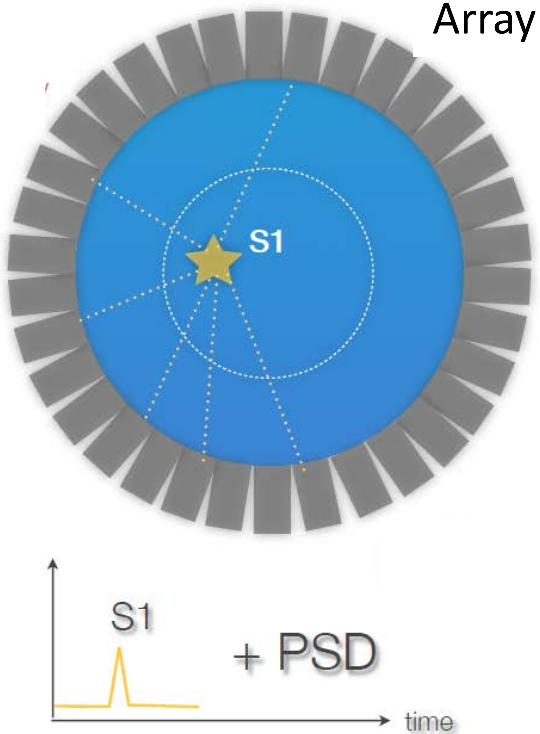
DAMA/LIBRA arXiv: 1301.6243
CoGeNT PRD 89, 055012 (2014)
CDMS II PRL 111, 251301 (2013)
CRESST II Eur. Phys. J C (2012) 72;1971

Experimental techniques

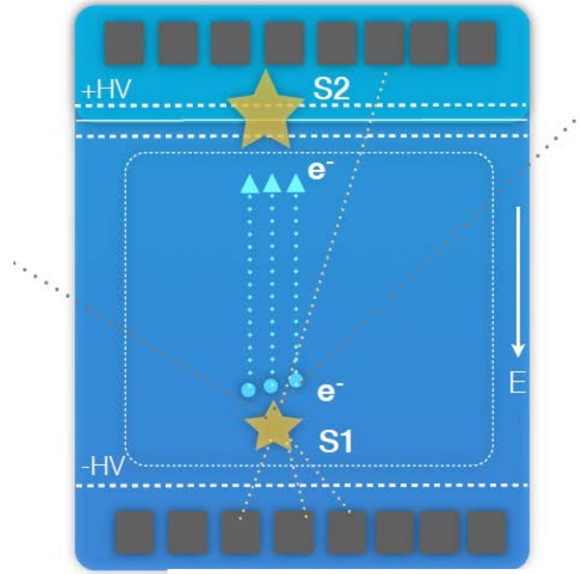
Liquid Xe or Ar

Single phase

PMT Array

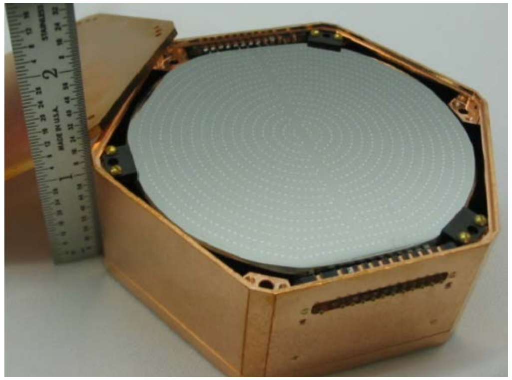


Double phase (TPC)



PMT Array

Solid



Cryogenic

NaI

and others..

Double-phase Xe and Ar TPCs (current generation)

XENON100 at LNGS:

161 kg LXe
(~50 kg fiducial)

242 1-inch PMTs
close to unblinding of new data set

LUX at SURF:

370 kg LXe
(100 kg fiducial)

122 2-inch PMTs
physics run and first results in 2013
new run in 2014

PandaX at CJPL:

125 kg LXe
(37 kg fiducial)

143 1-inch PMTs
37 3-inch PMTs
first results in August 2014

ArDM at Canfranc:

850 kg LAr
(100 kg fiducial)

28 3-inch PMTs
in commissioning
to run 2014

DarkSide at LNGS:

50 kg LAr (dep in ^{39}Ar)
(33 kg fiducial)

38 3-inch PMTs
first data with non-depl Ar in 2014

Single-phase Xe and Ar (current generation)

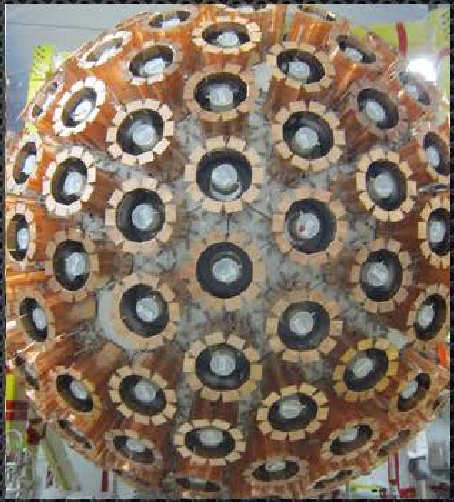
Laura Baudis COSMO 2014

XMASS at Kamioka:

835 kg LXe (100 kg fiducial),
single-phase, 642 PMTs
unexpected background found
detector refurbished
new run since Nov 2013

CLEAN at SNOLab:

500 kg LAr (150 kg fiducial)
single-phase open volume
under construction
to run in 2014

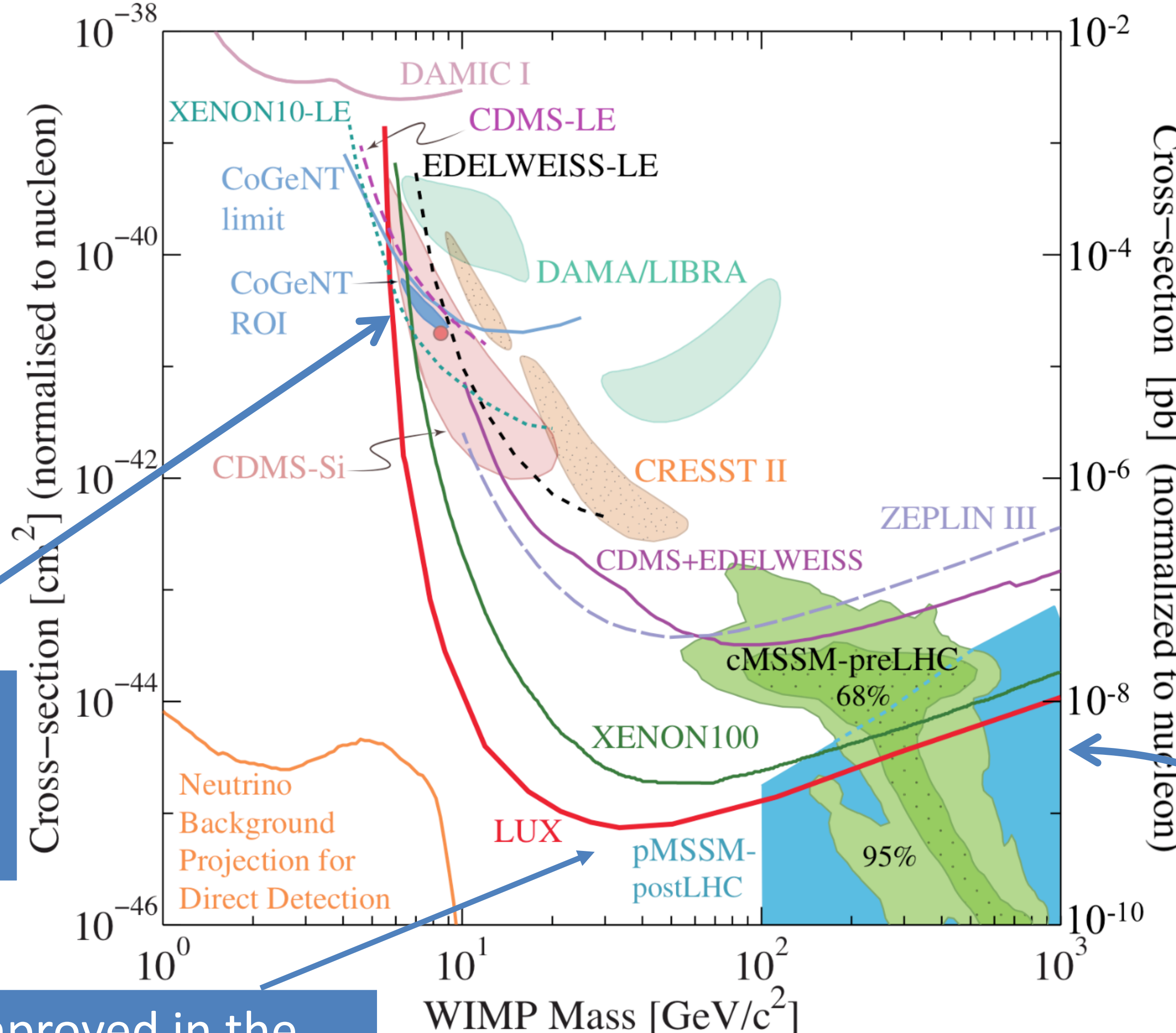


DEAP at SNOLab:

3600 kg LAr (1t fiducial)
single-phase detector
under construction
first data expected in fall 2014

Very active. Many experiments going on….

Present status



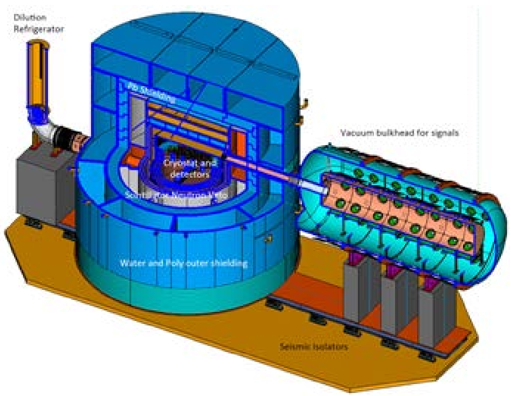
“signals” disfavored as DM

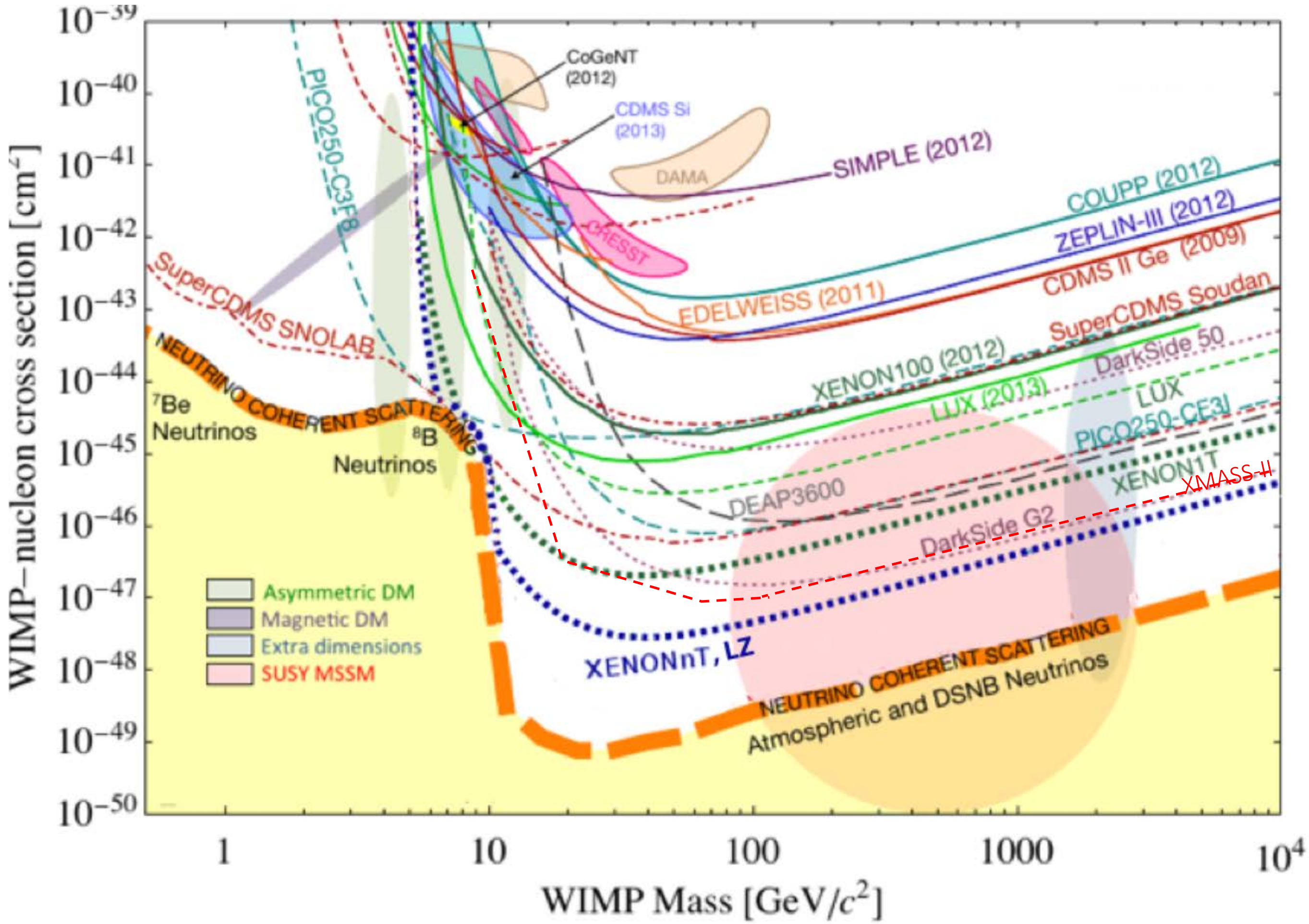
Much improved in the mid to high Mass region!

Region preferred by MSSM?

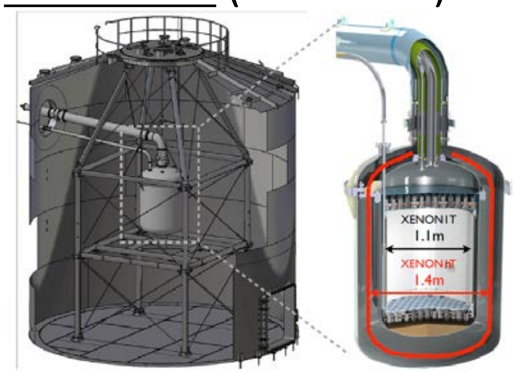
Future…

Super-CDMS
(50kg Ge, ~mK)

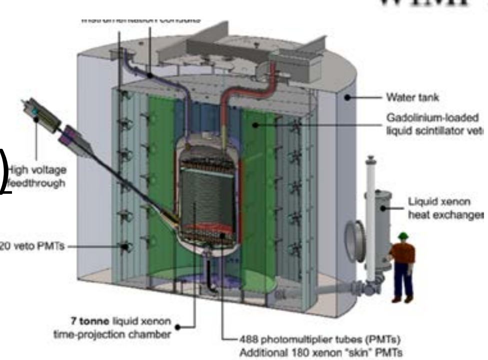


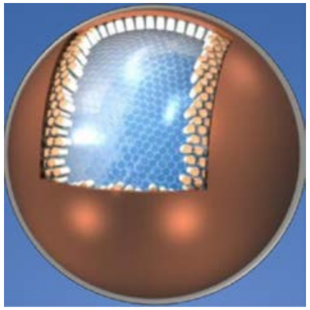


XENONnT (~7tons Xe)



LUX+ZEPLIN (LZ)
(~7ton Xe)





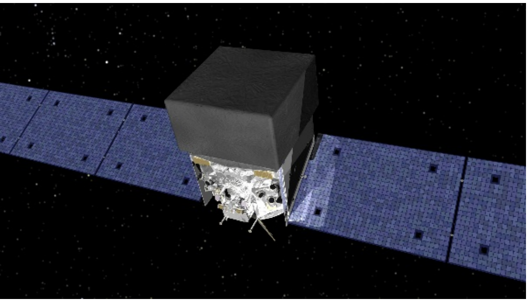
XMASS-II
(20ton, Xe)

And much more…

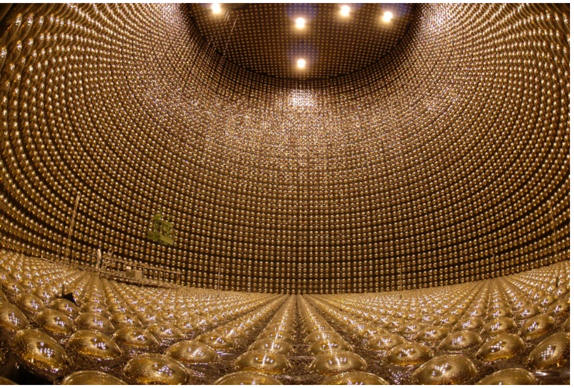
Elena Aprile NeuTel 2015
S. Moriyama

Indirect experiments

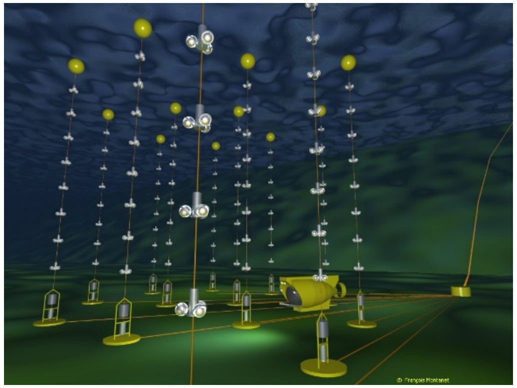
$e^+, \bar{p}, ..$

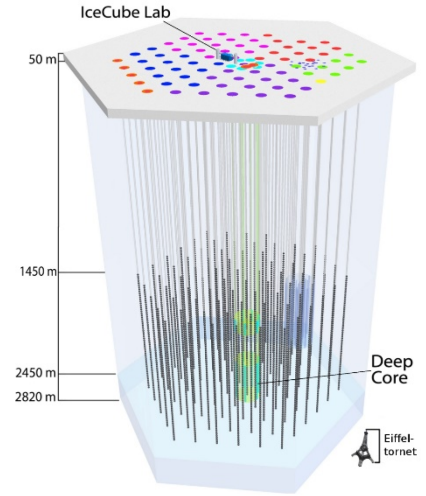


γ



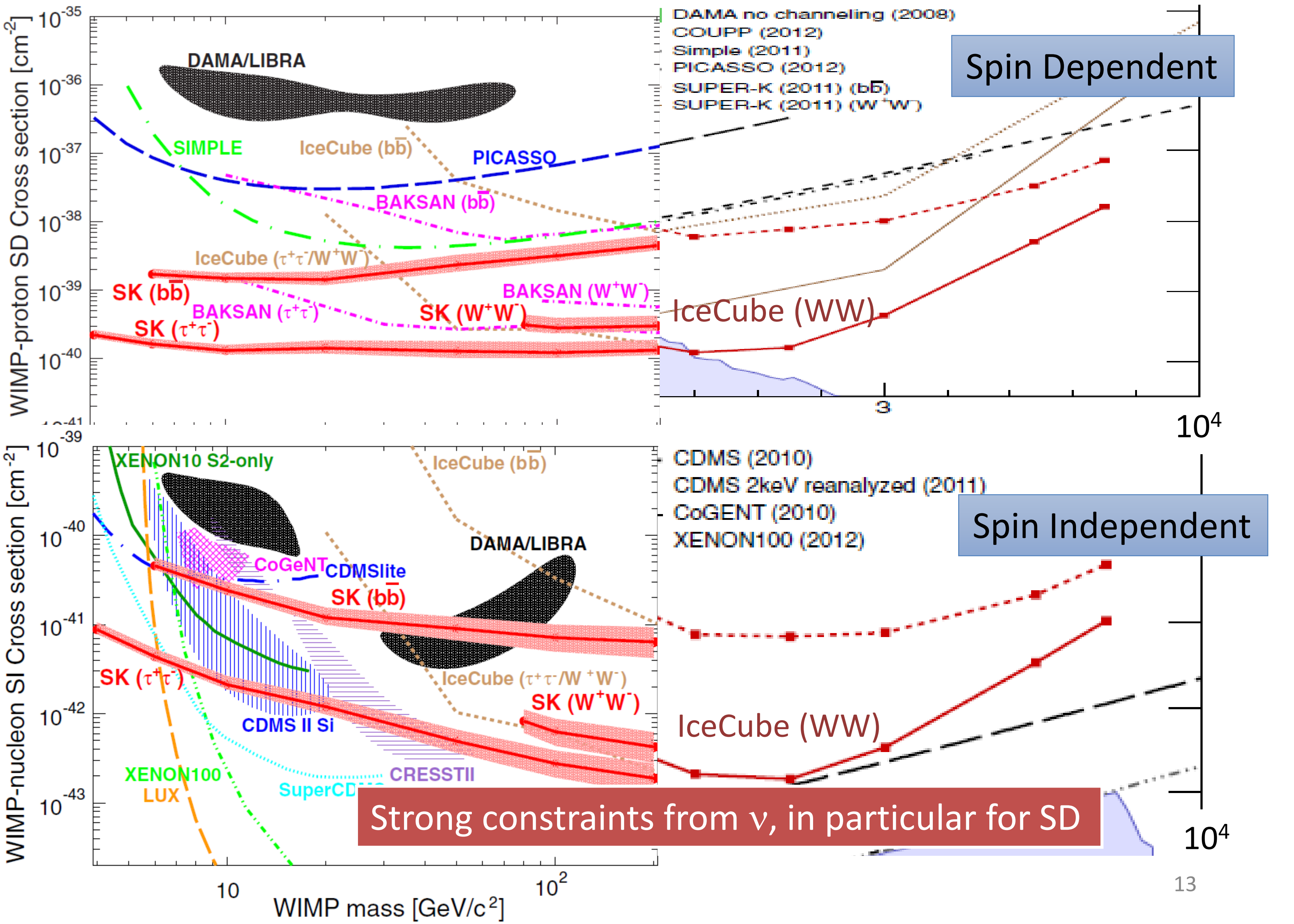
ν





HE ν from the Sun

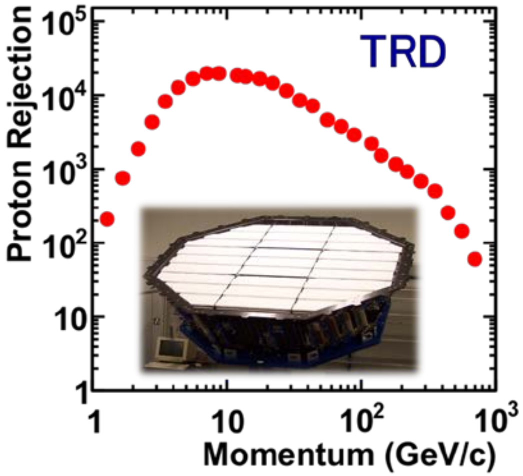
IceCube PRL 110, 131302 (2013)
ANTARES J.Cosmol. Astropart. Phys. 11 (2013) 032
M.M.Boliev et al., J.Cosmol. Astropart. Phys. 09 (2013) 019
SuperK PRL 114, 141301 (2015) and references therein

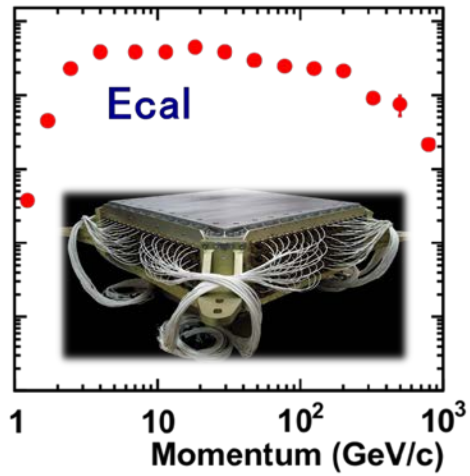


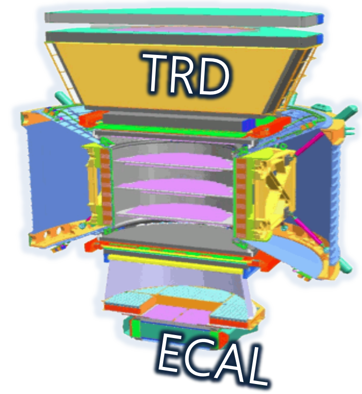
Strong constraints from ν, in particular for SD

Positron(e^+) fraction

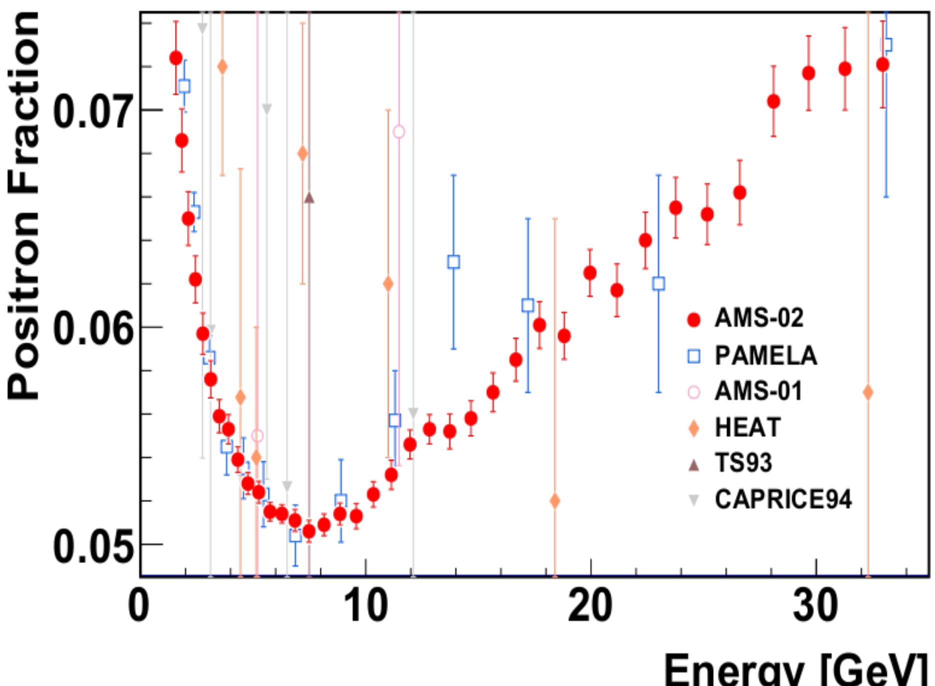
AMS PRL 113, 121101 (2014)

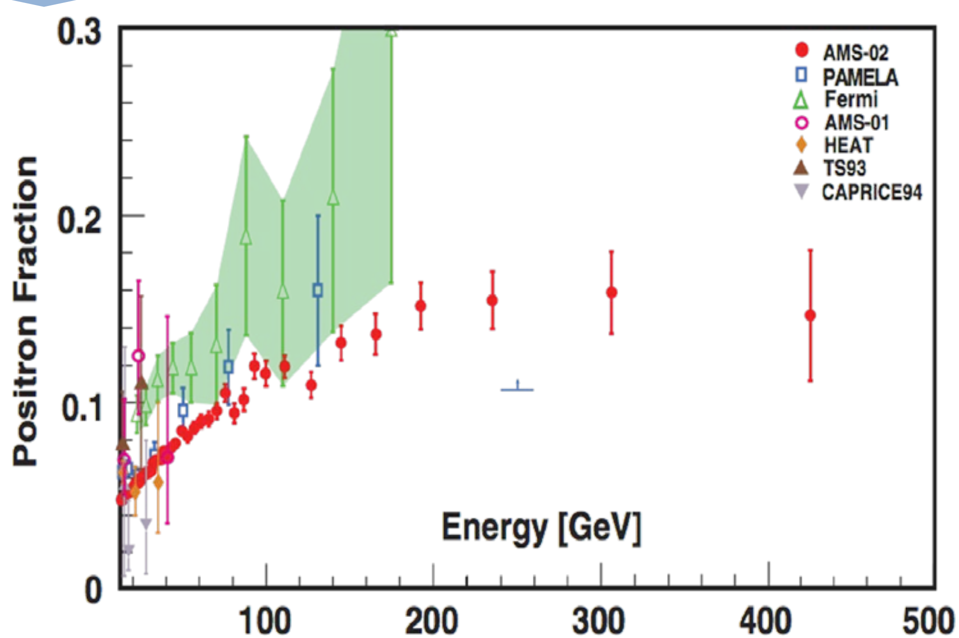






Very high proton rejection power

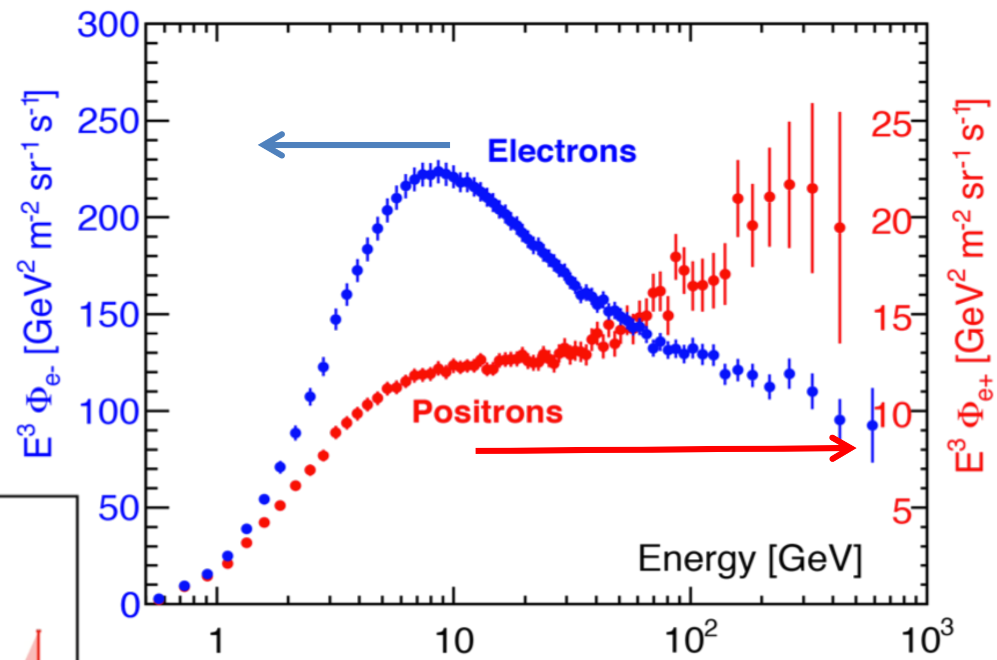




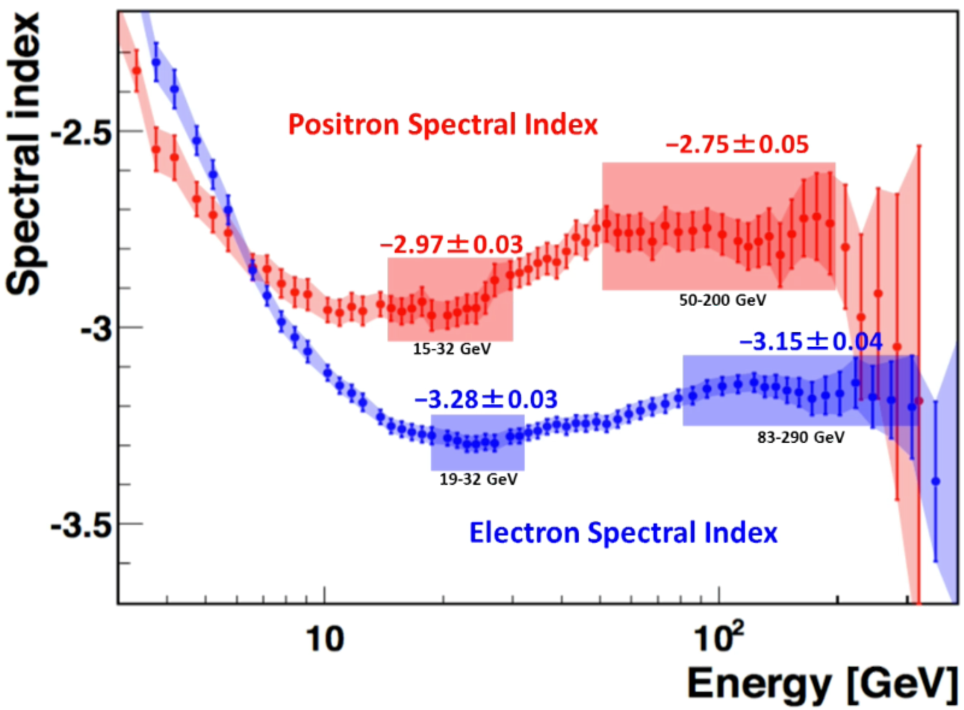
Electron and Positron flux measurements

AMS PRL 113, 121101 (2014)

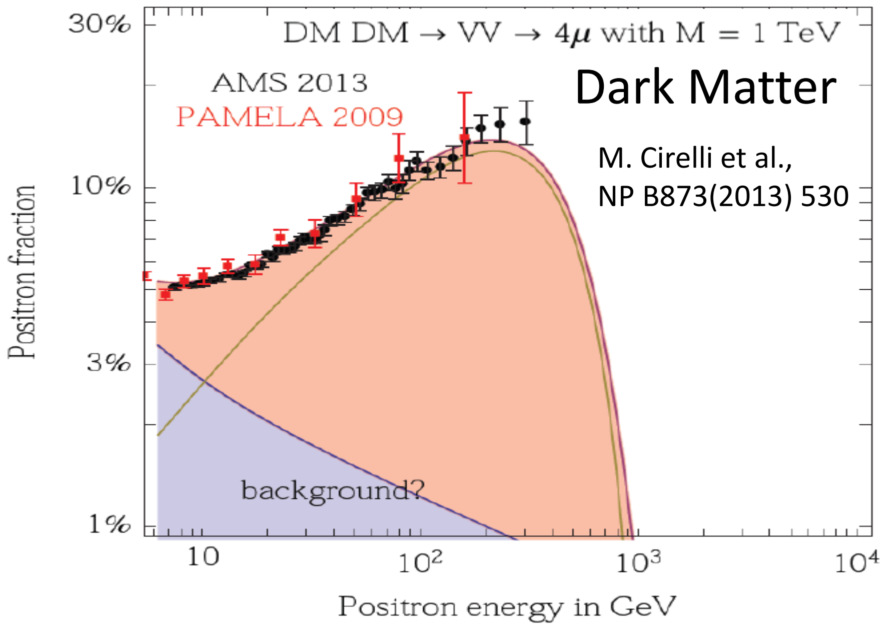
Fluxes

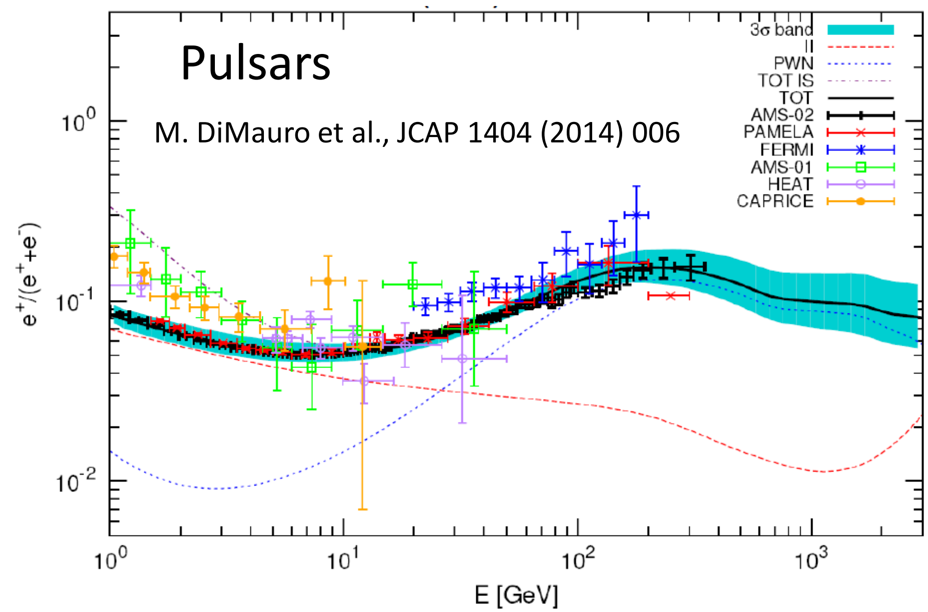


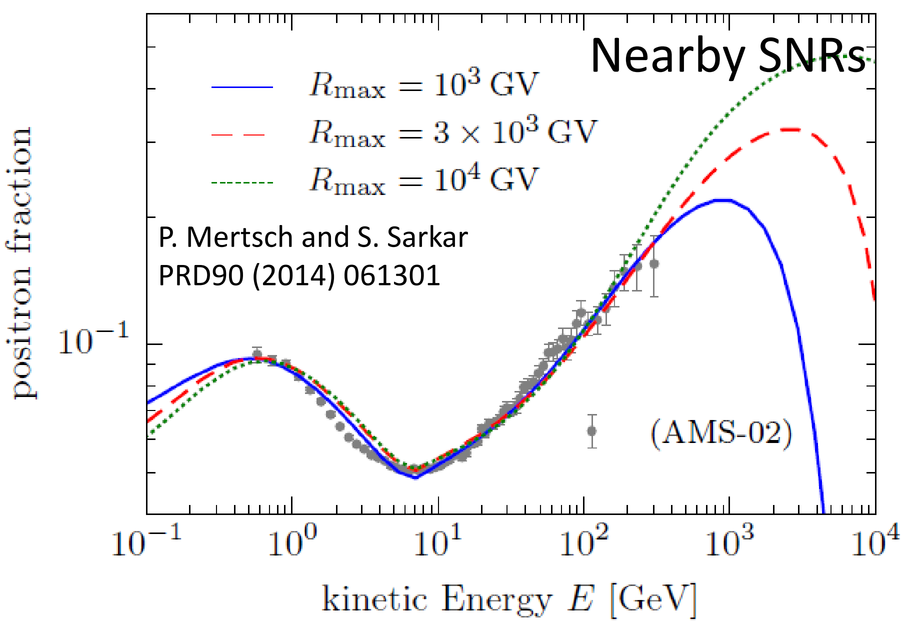
Spectral indices

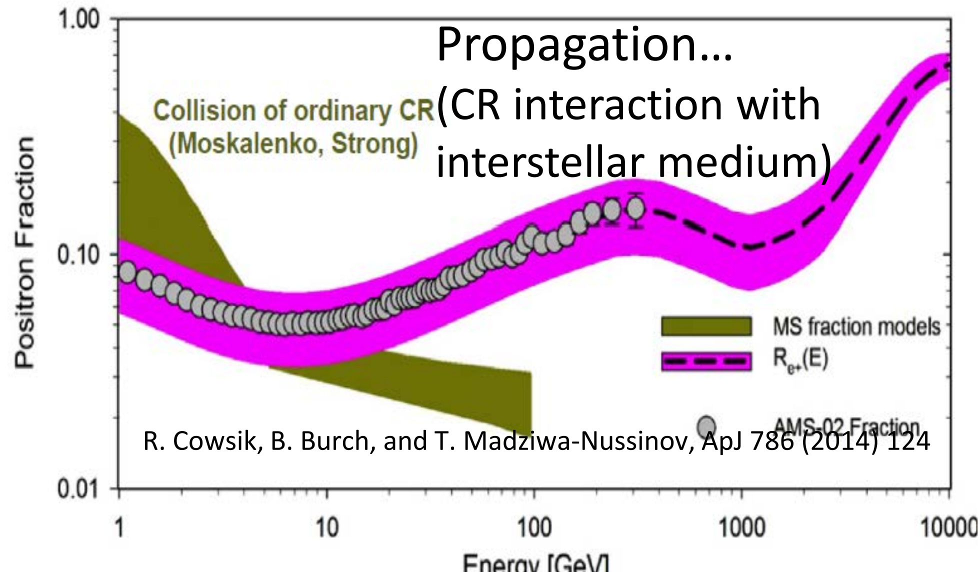


Dark Matter or…



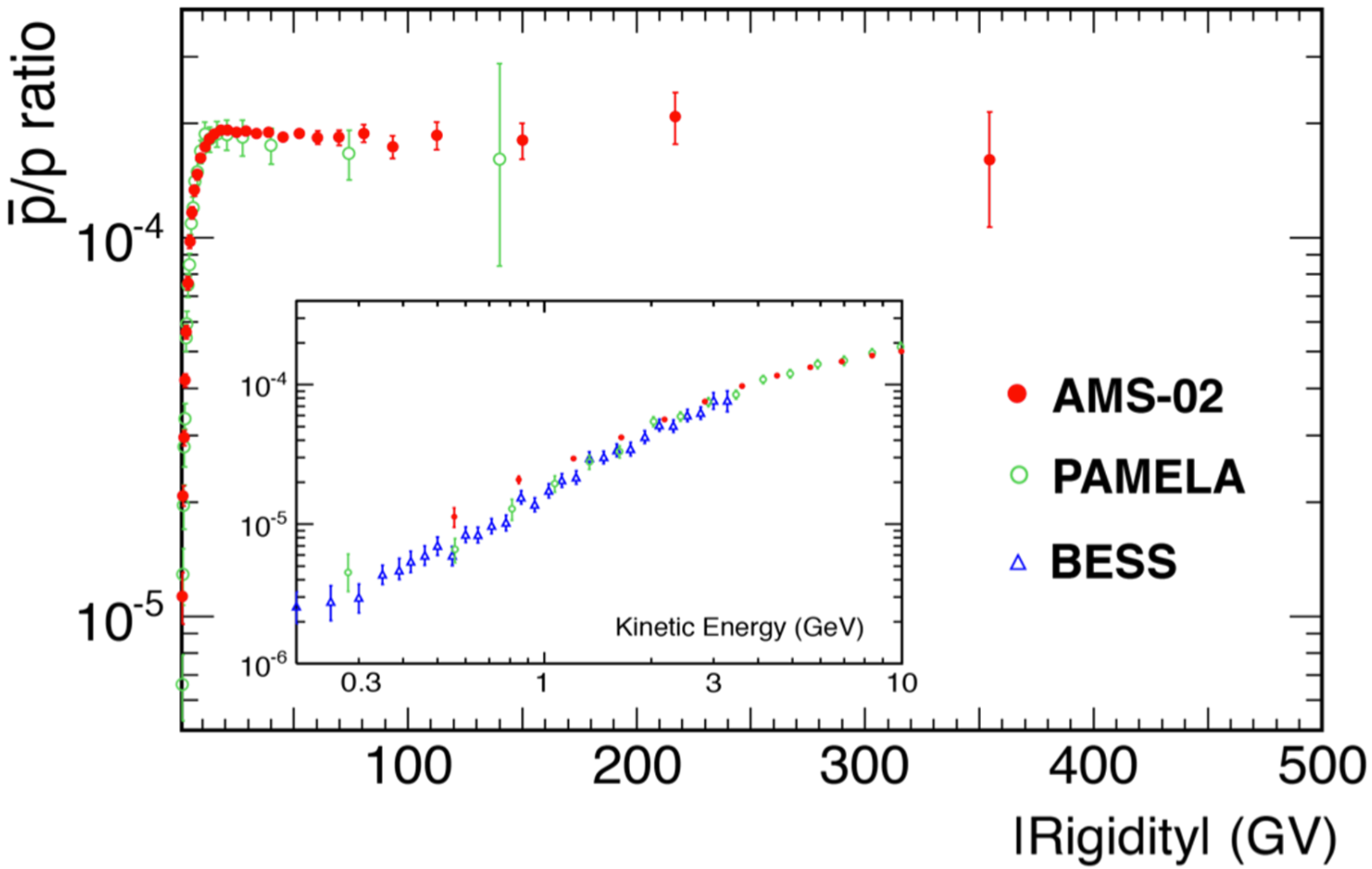






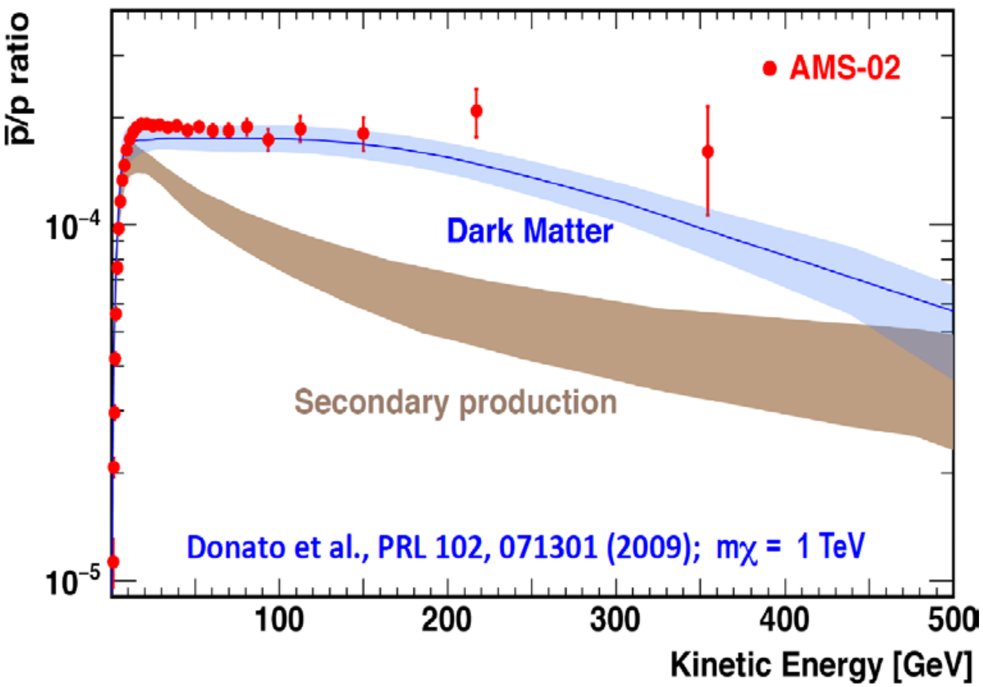
Anti-proton ($\bar{p}$)

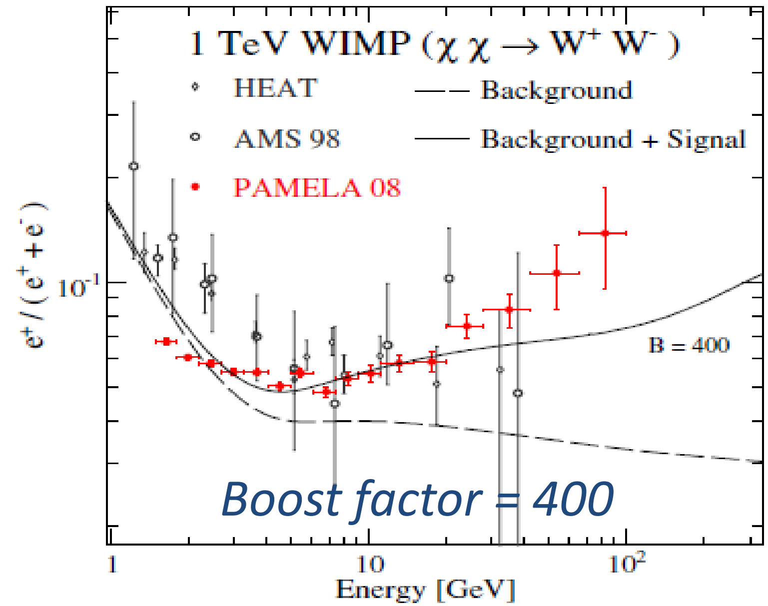
A. Kounine, AMS Days at CERN (April 15, 2015)

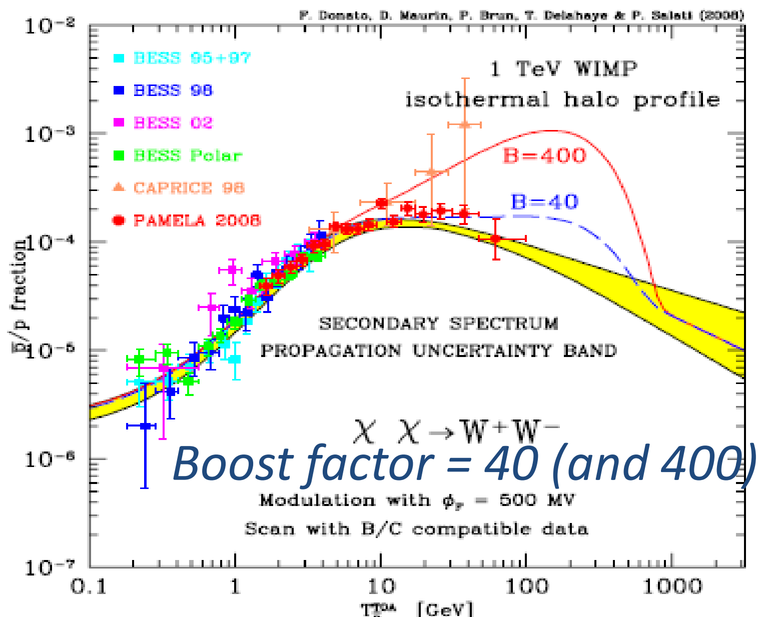


Anti-proton and DM?

A. Kounine, AMS Days at CERN (April 15, 2015)





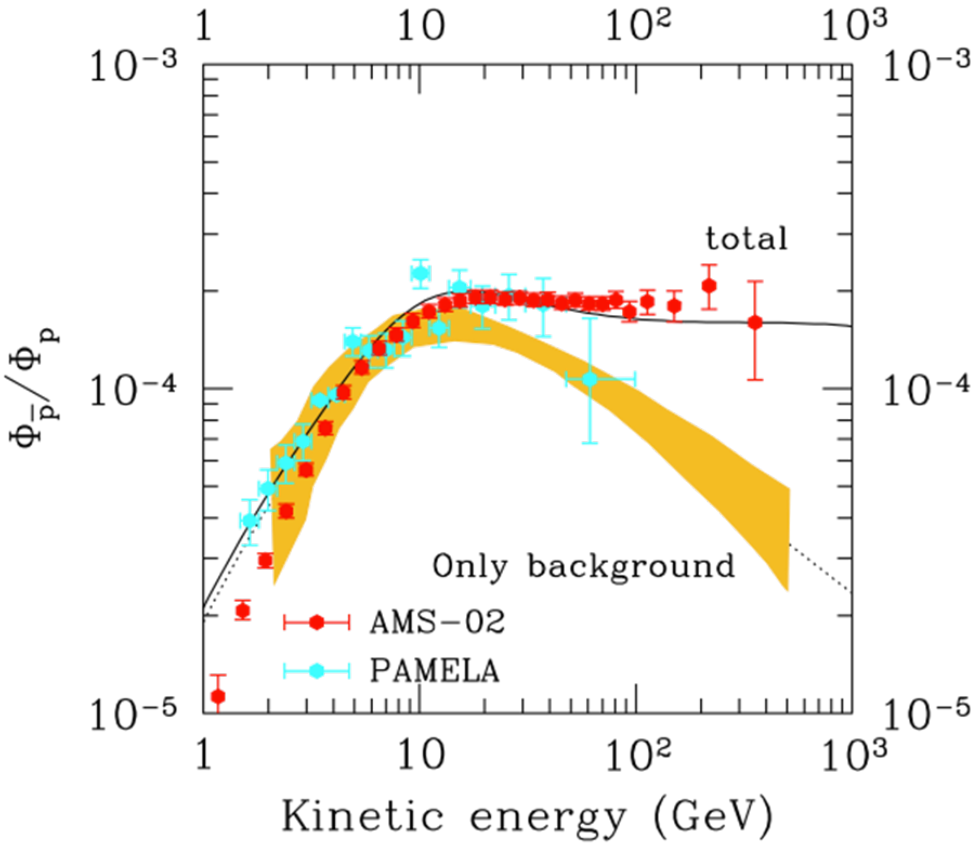


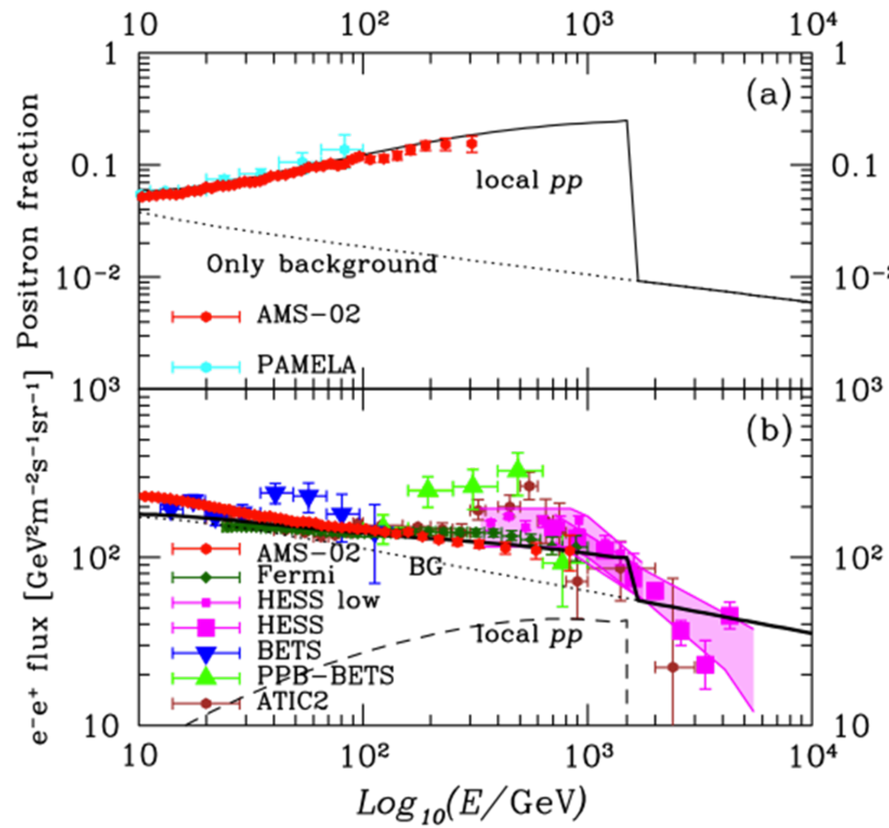
Donato et al., PRL 102, 071301 (2009)

Interpreting positron and anti-proton data...

K. Kohri et al., arXiv: 1505.01236

Astrophysical model: Recent (10^5-10^6 years) Supernova explosion in a dense gas cloud (*pp* collisions) near the Earth (~200pc).

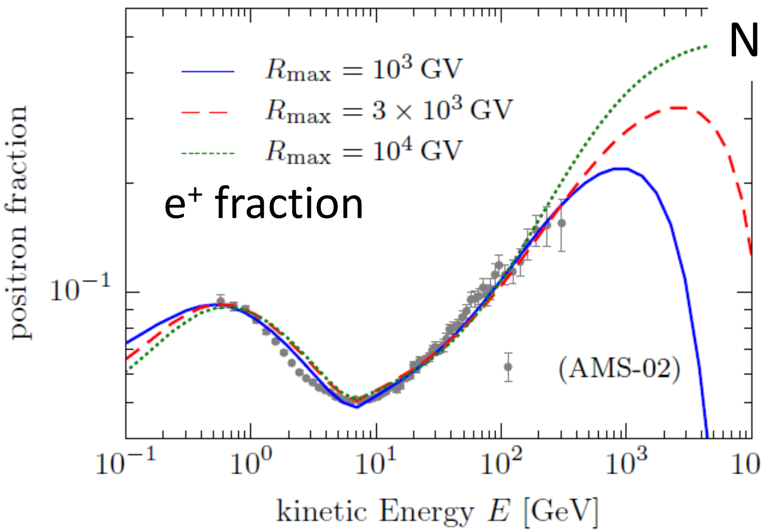


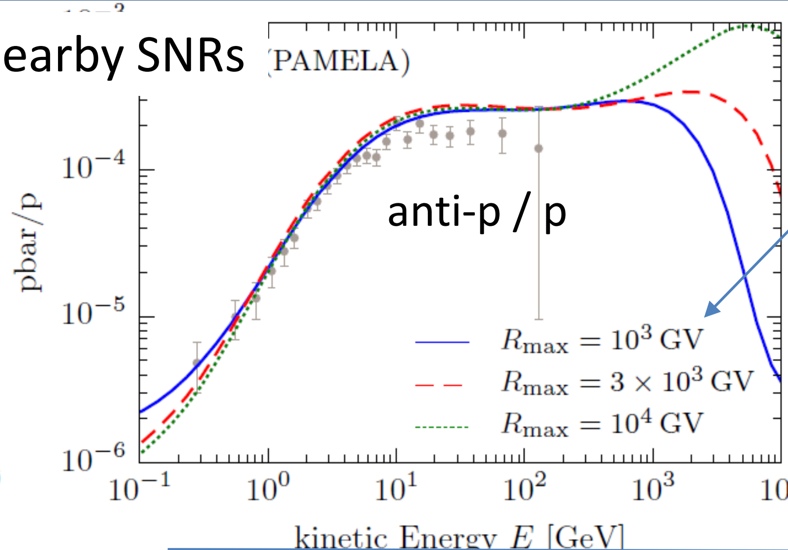


Interpreting positron and anti-proton data…

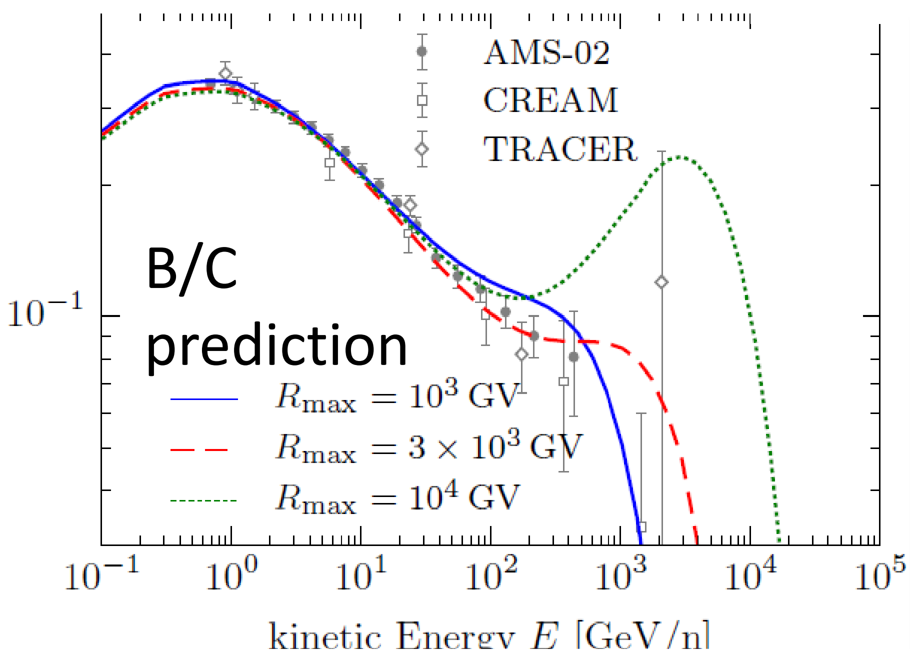
P. Mertsch and S. Sarkar
PRD90 (2014) 061301

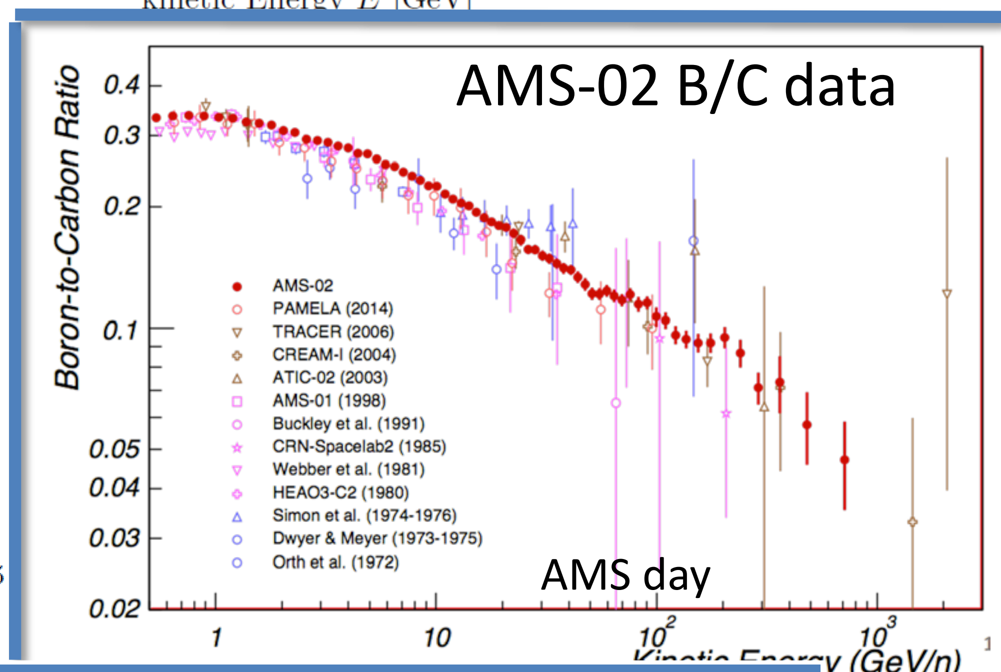
Nearby SNRs





Rmax:
maximum
rigidity of
accelerated
secondaries

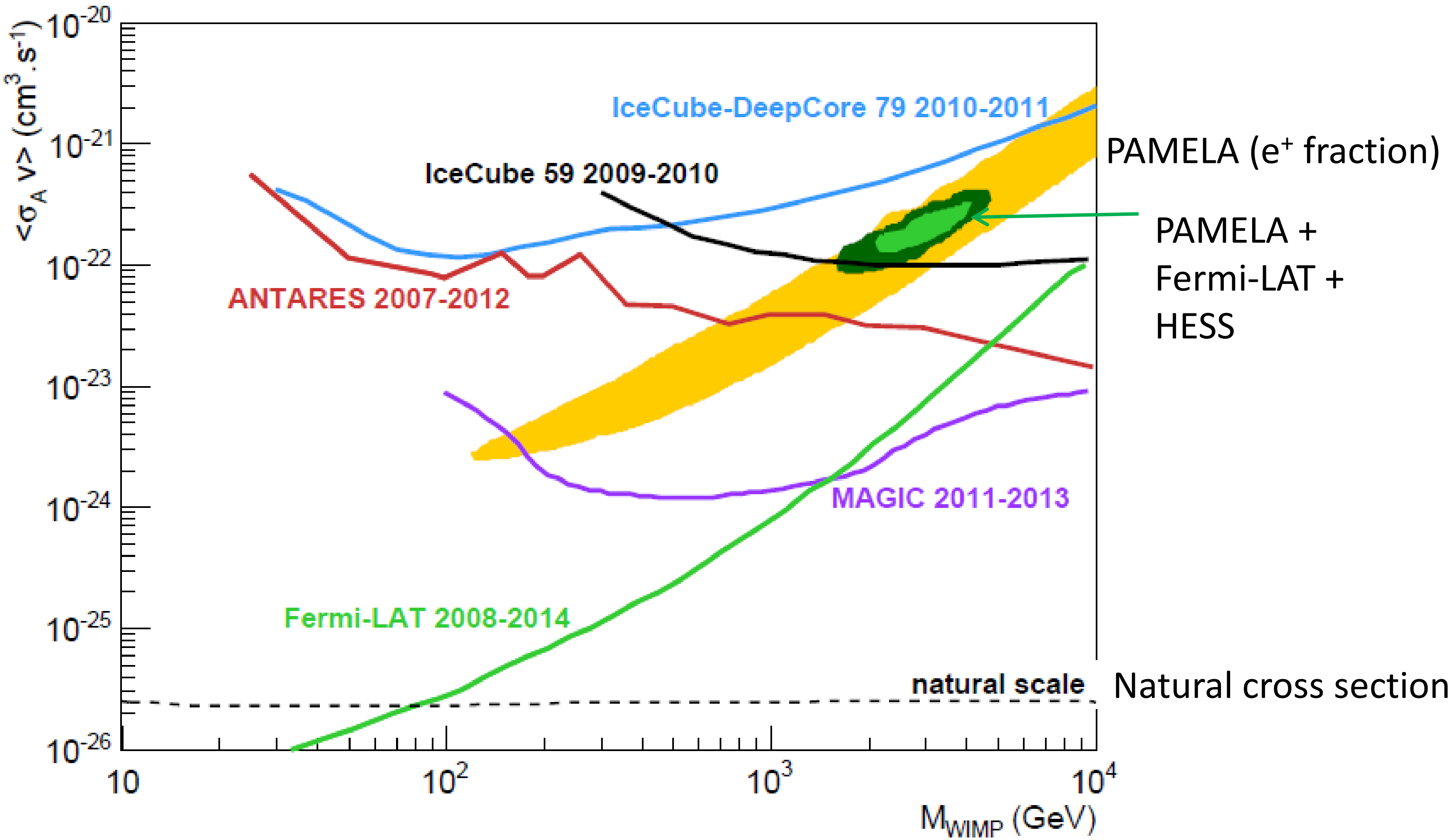




Precise CR data are very important to understand the e+ and anti-p data.

Neutrinos and Gammas from DM annihilation at GC?

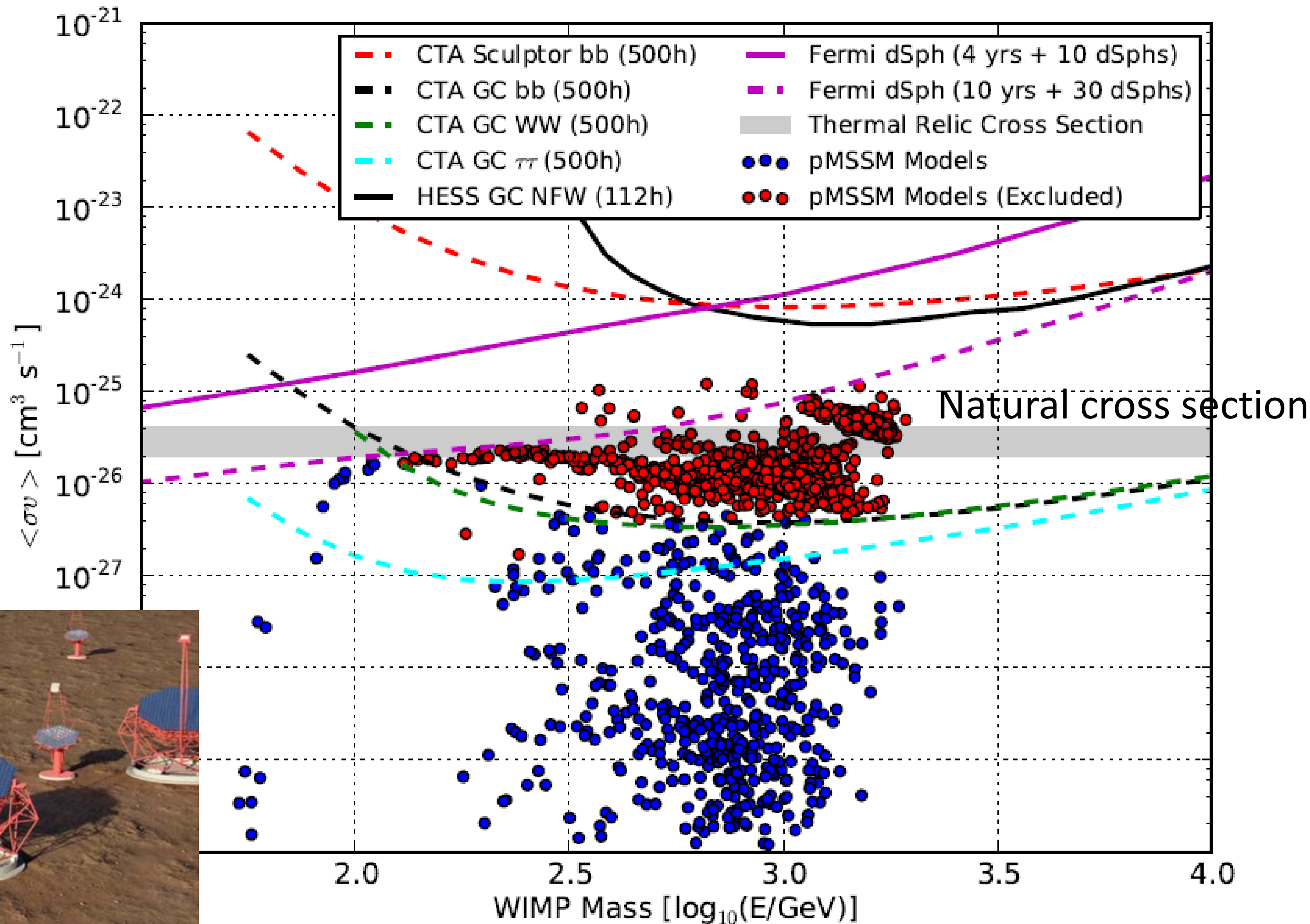
ANTARES arXiv: 1505.04866
(and refences therein)

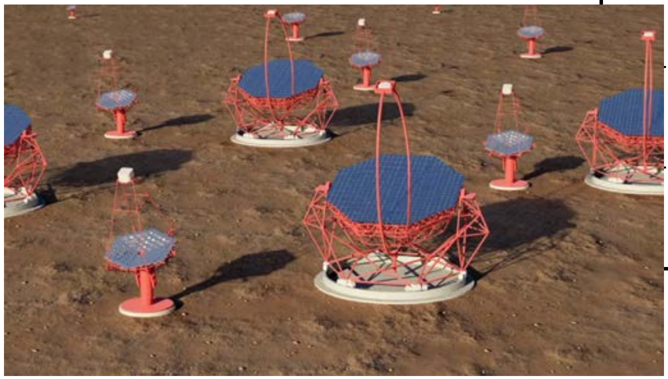


DM interpretation of e^+ and e^- data is disfavored.

Indirect detection: future

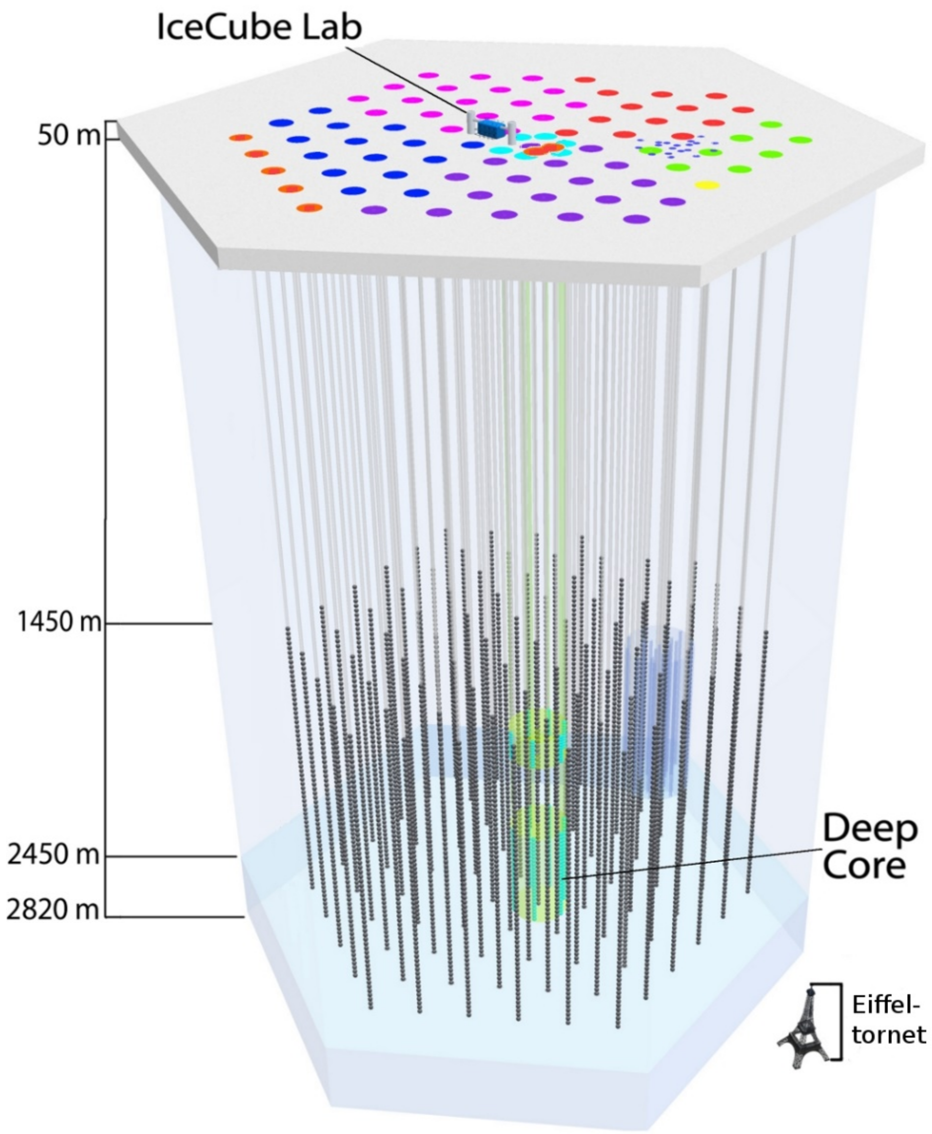
B. Dasgupta and R. Laha, PRD 86, 093001 (2012)

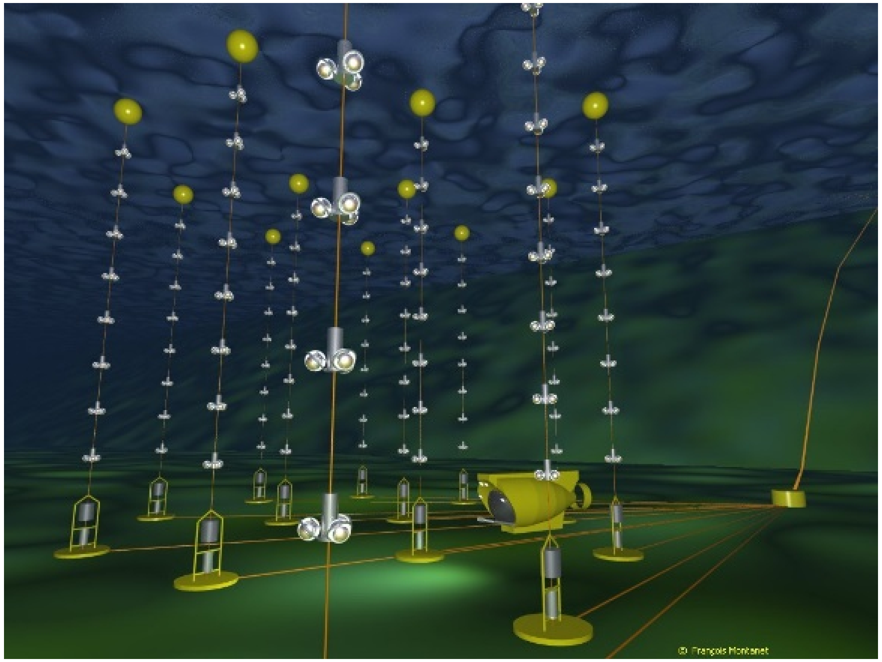




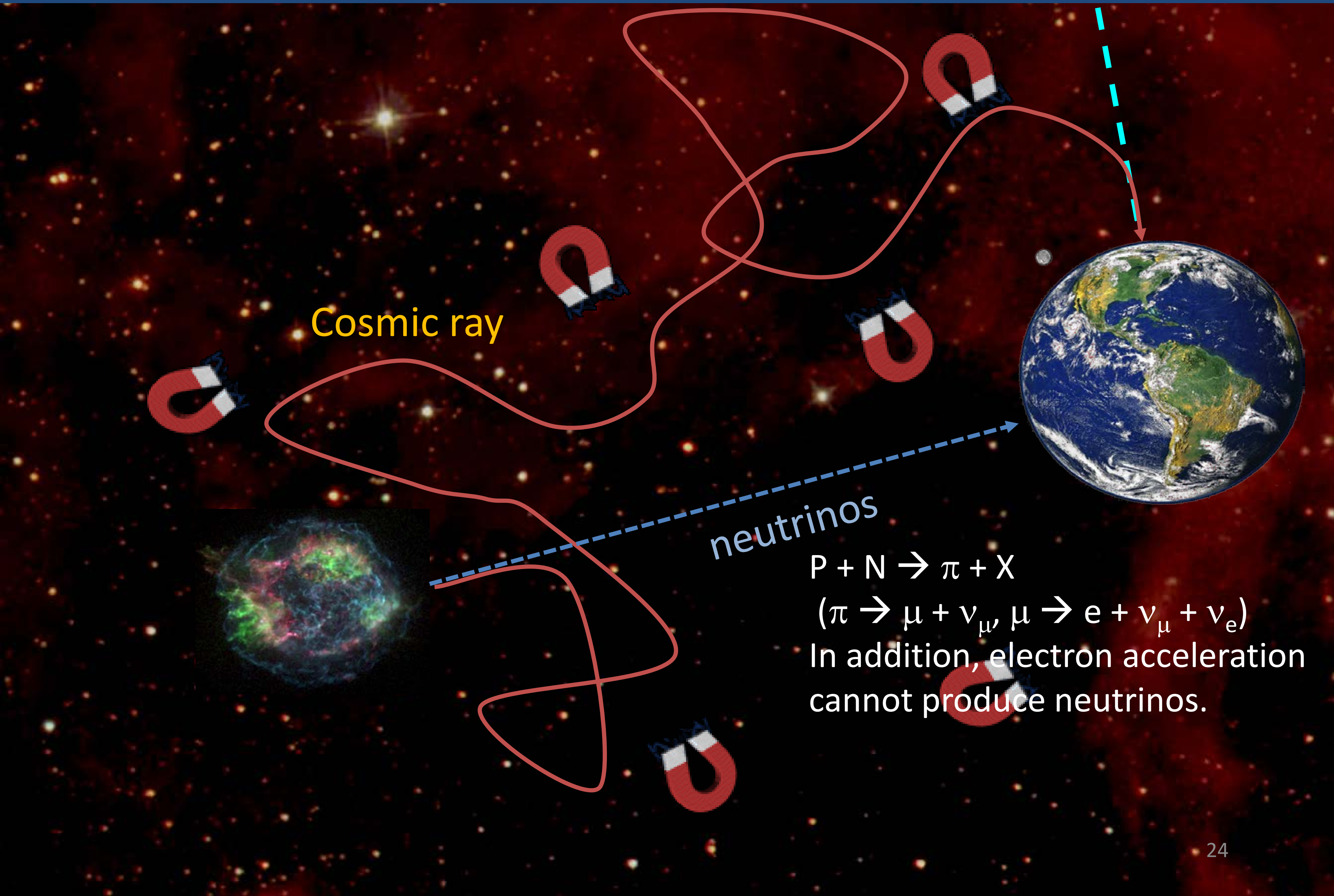
CTA

Cosmic Neutrinos





Origin of cosmic rays



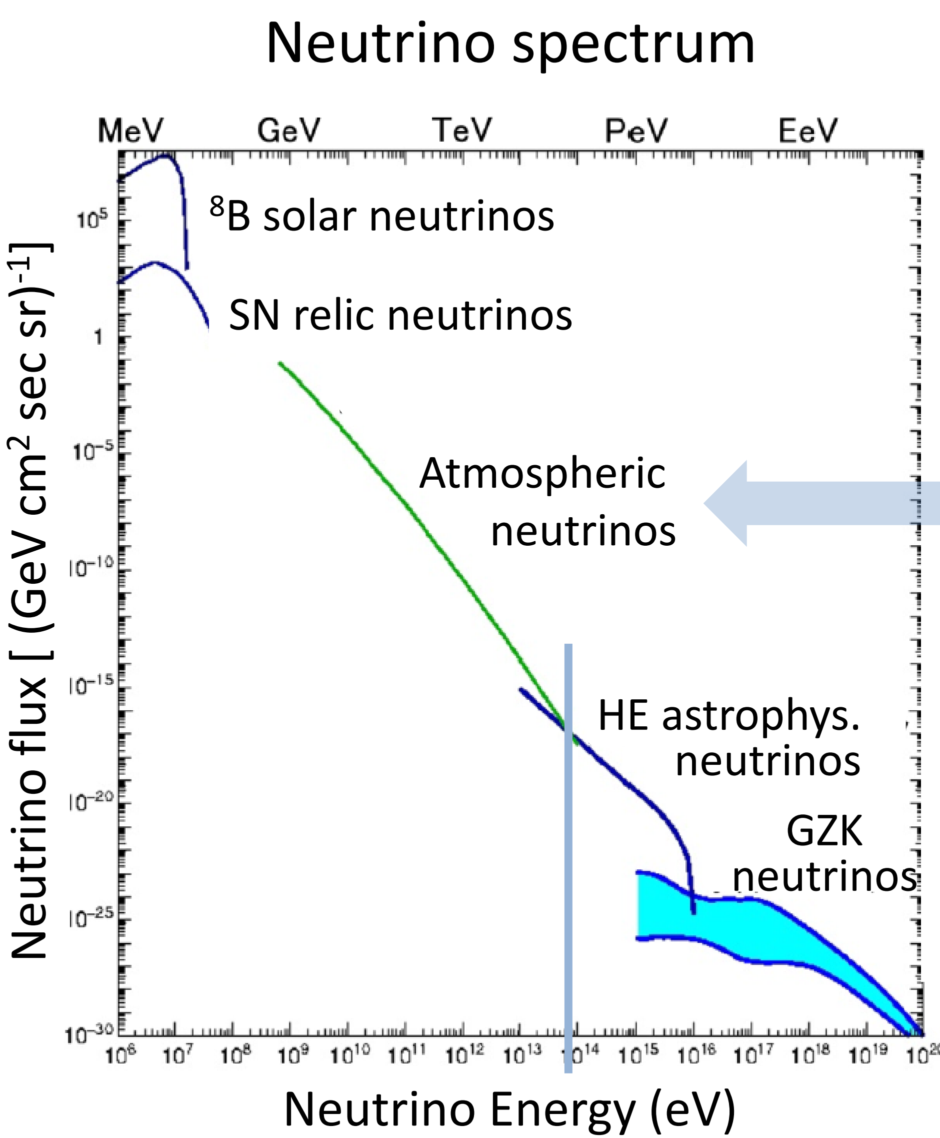
$P + N \rightarrow \pi + X$

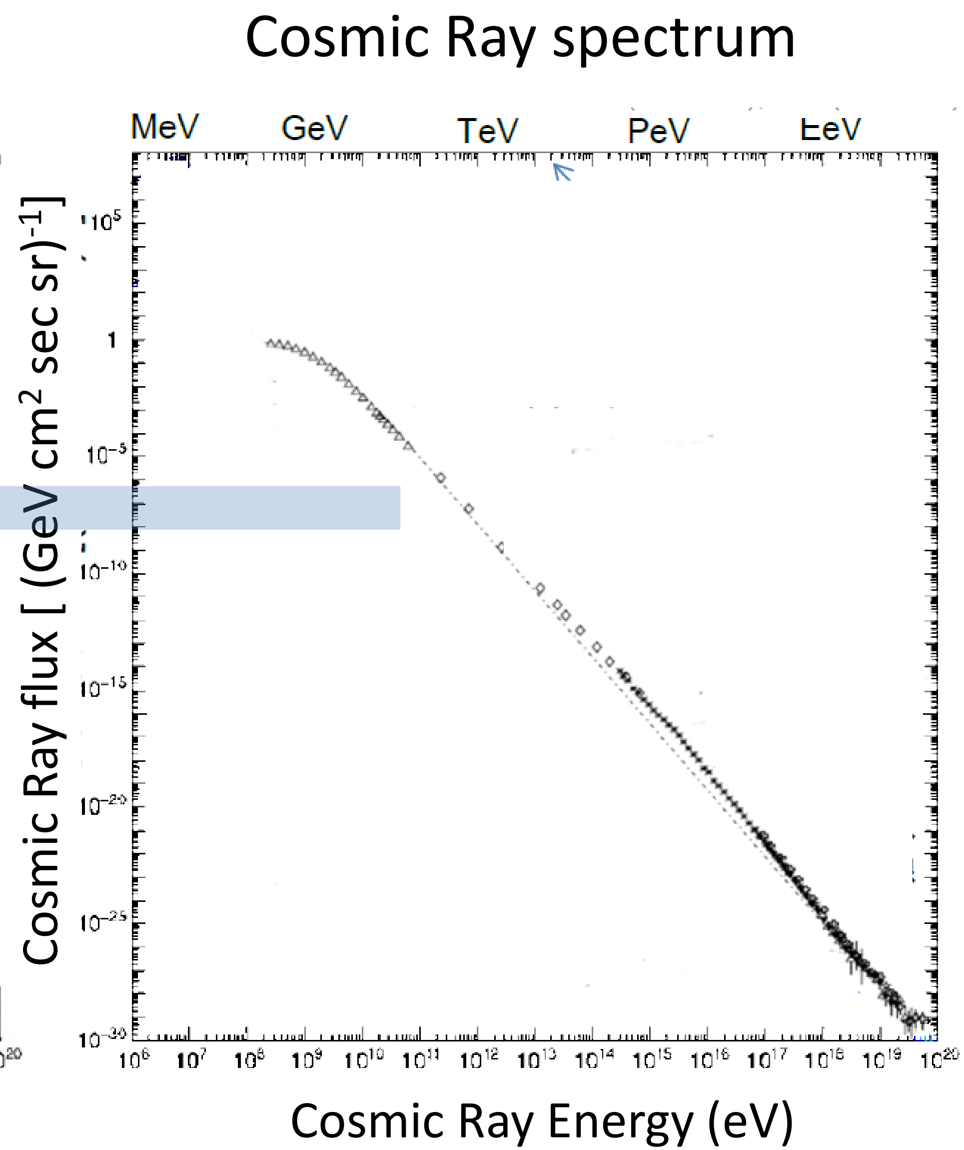
$(\pi \rightarrow \mu + \nu_\mu,\ \mu \rightarrow e + \nu_\mu + \nu_e)$

In addition, electron acceleration cannot produce neutrinos.

Cosmic neutrino flux

A. Ishihara JPS meeting, March 2015

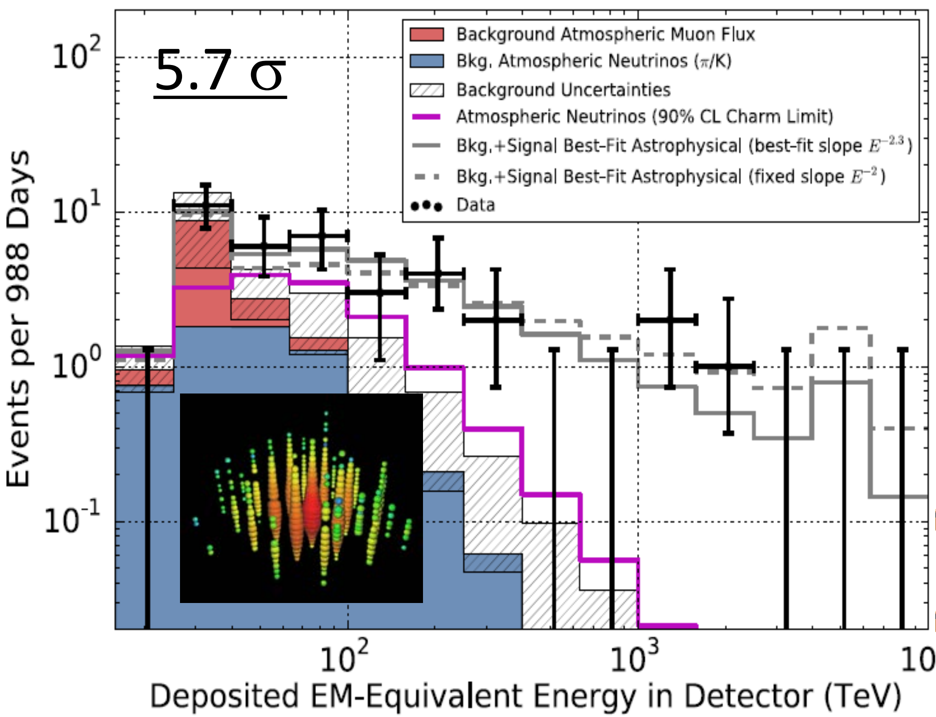




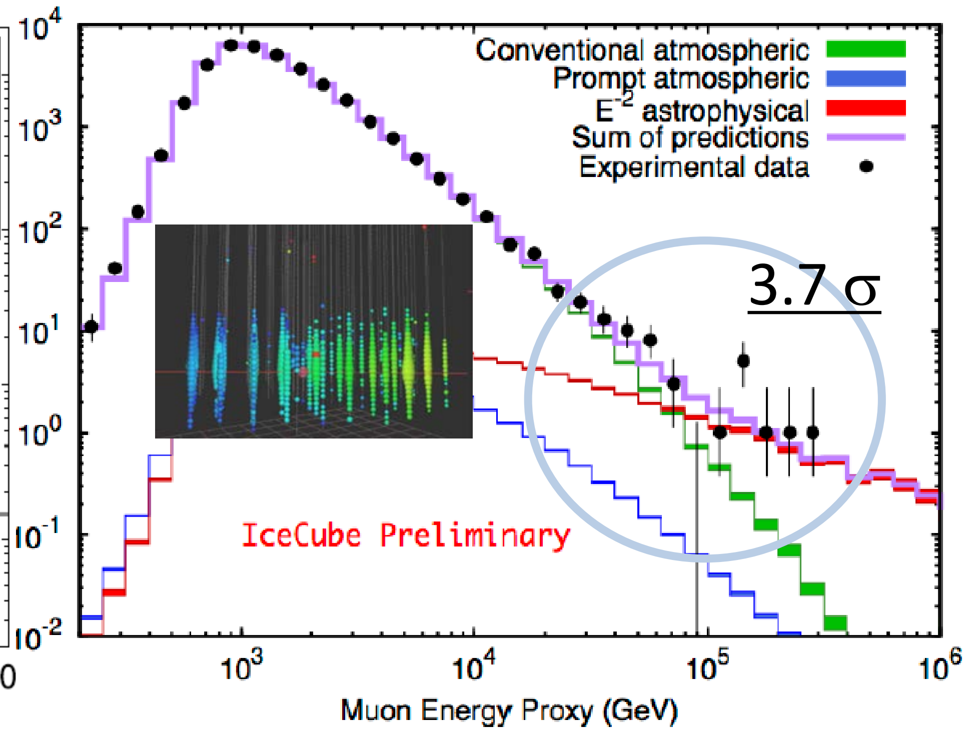
Astrophysical neutrinos

IceCube PRL 113, 101101 (2014)
F. Halzen AMS day, April 2015

Neutrinos interacting inside IceCube



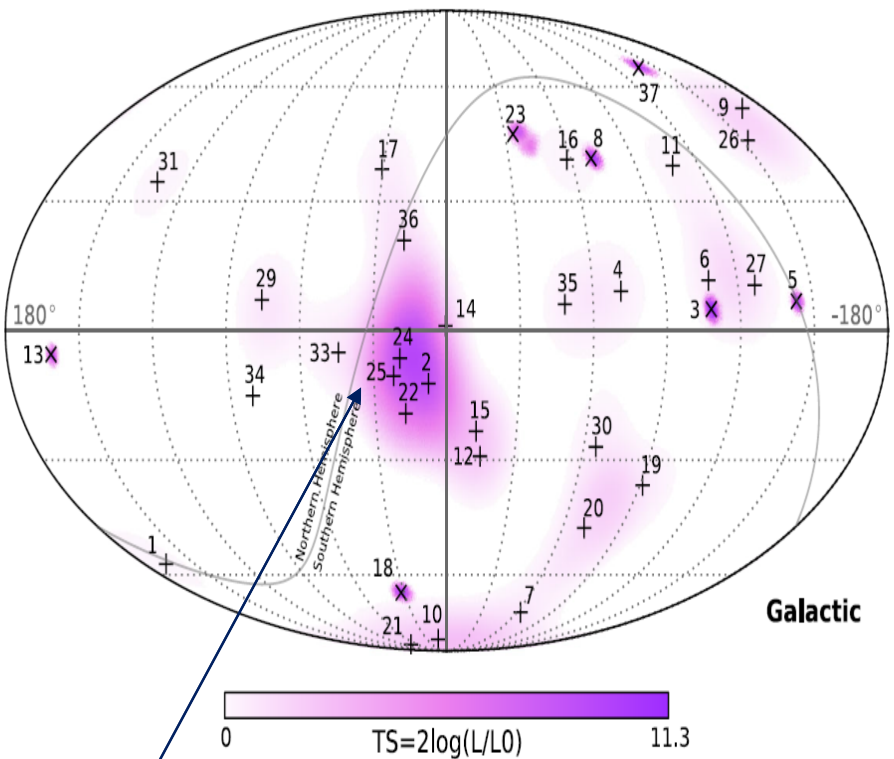
Muon neutrinos (penetrating muons)

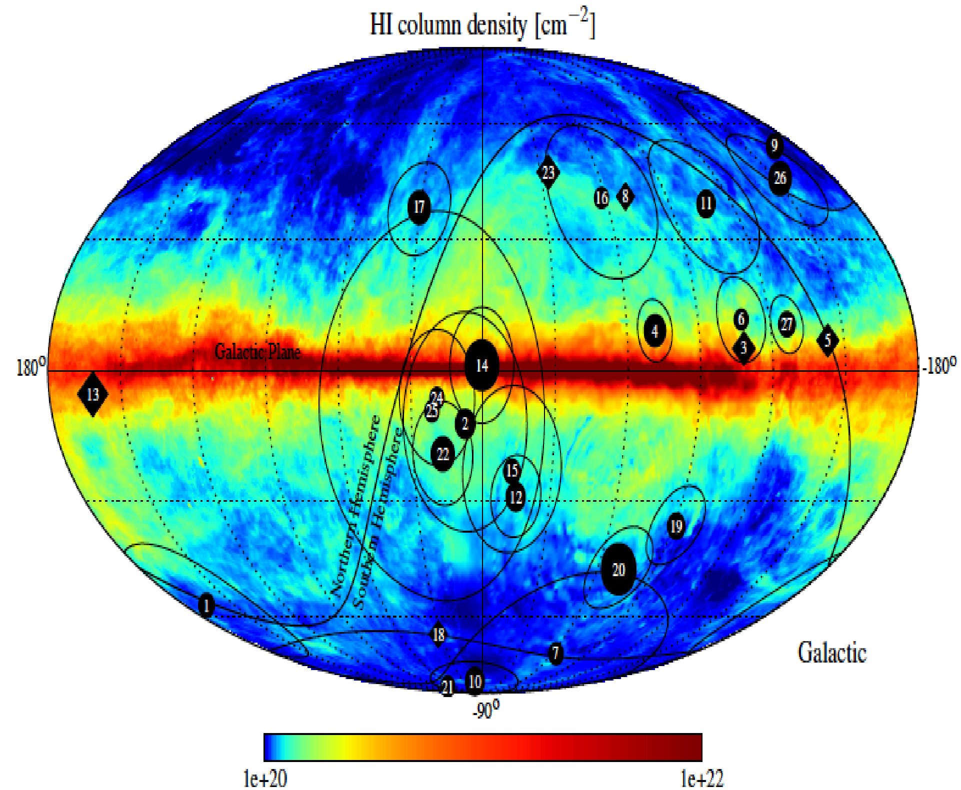


Signals observed in 2 different modes.
Consistent with equal fluxes of all neutrino flavors

Astrophysical neutrinos: Arrival directions

IceCube PRL 113, 101101 (2014)
F. Halzen AMS day, April 2015





7.2%

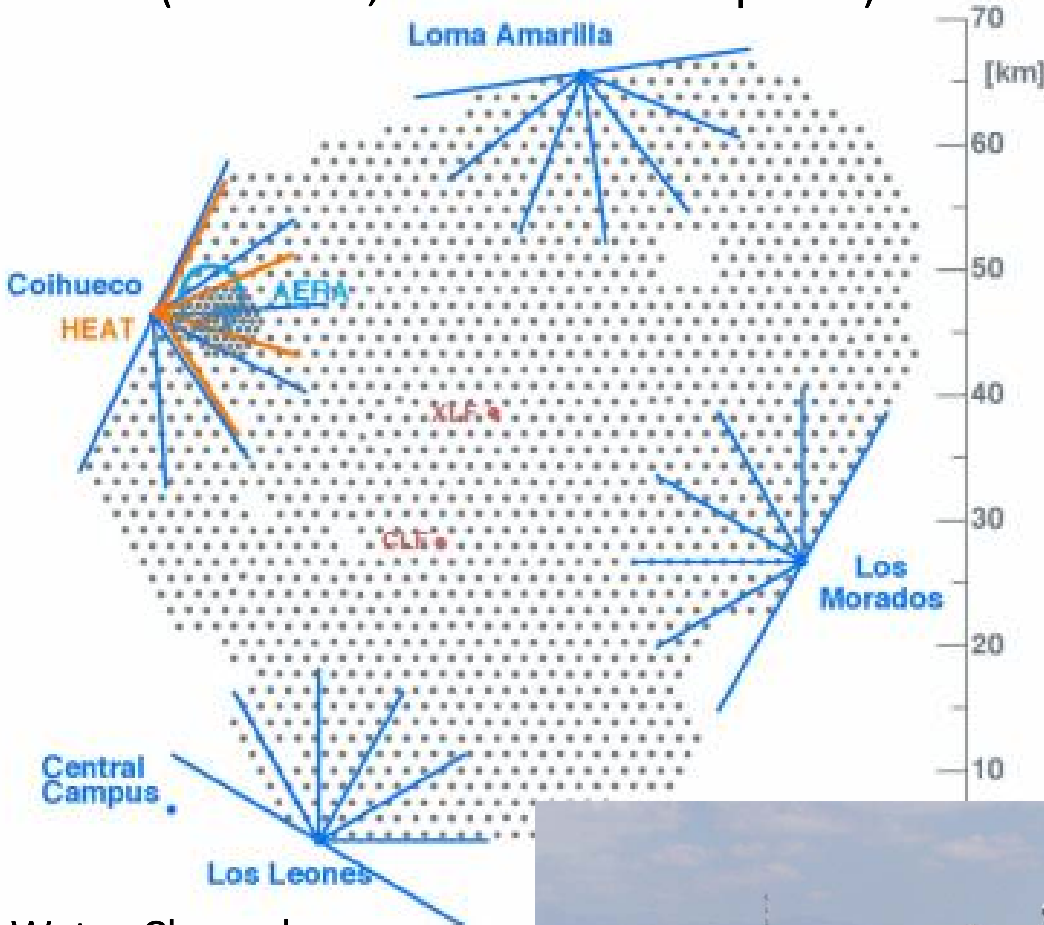
Correlation with Galactic plane: 2.8% probability for a width of 7.5 deg

More data needed to discuss the source….
(➔ next generation detectors needed.)

(F. Halzen for more details)

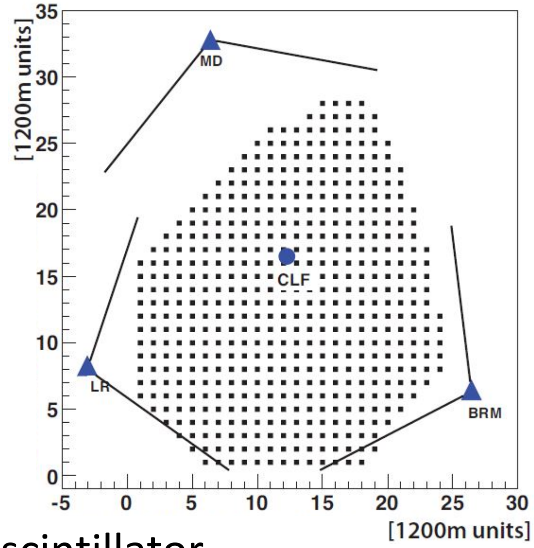
Ultra High Energy Cosmic Rays

Pierre Auger Observatory
(3000km^2, Southern hemisphere)



Water Cherenkov detectors
+ fluorescence telescopes

Telescope Array Experiment
(700km^2, Northern hemisphere)



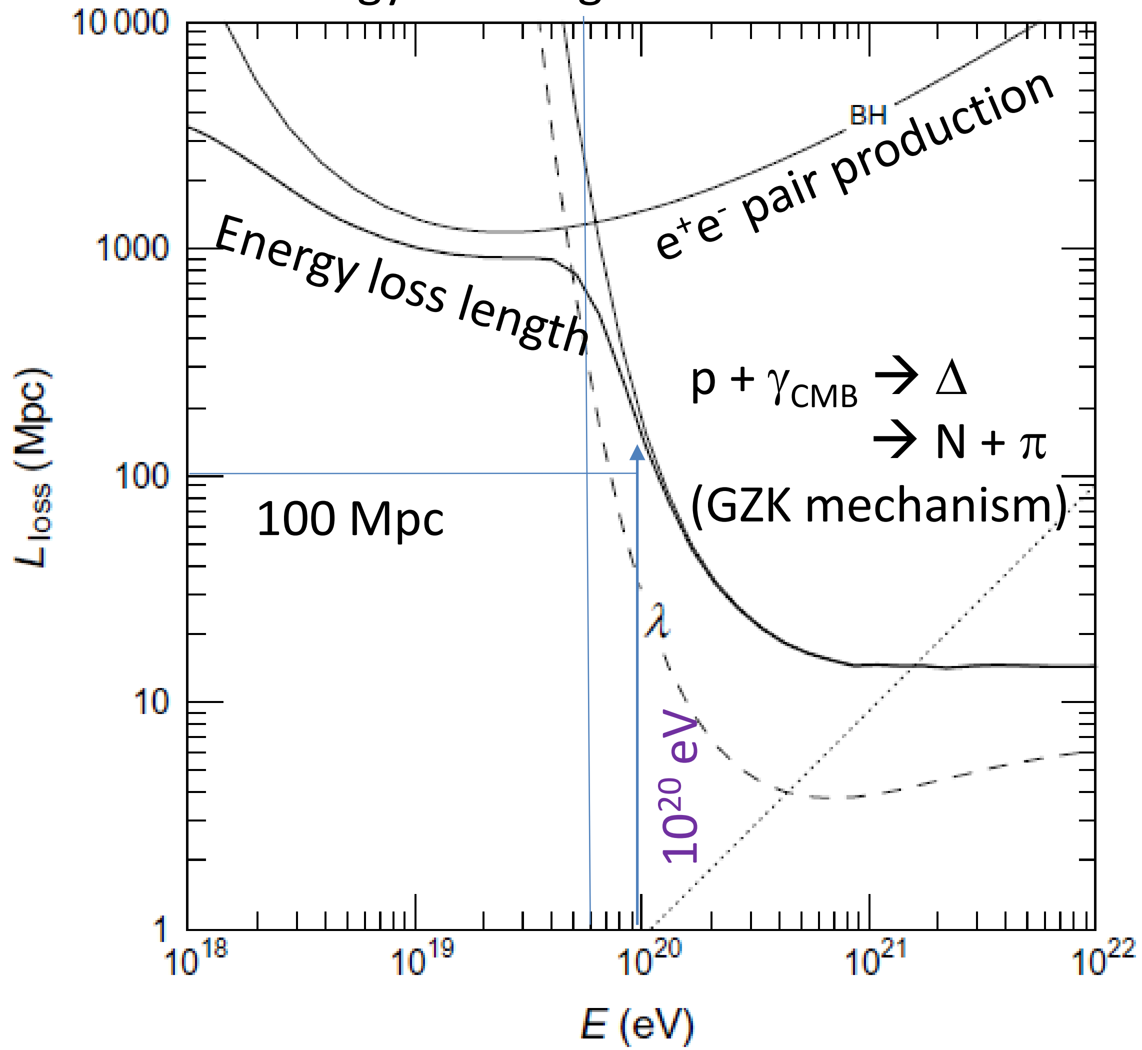
Plastic scintillator detectors
+ fluorescence telescopes

Ultra High Energy Cosmic Rays (UHECR): Questions

T. Stanev NJP 11 (2009) 065013

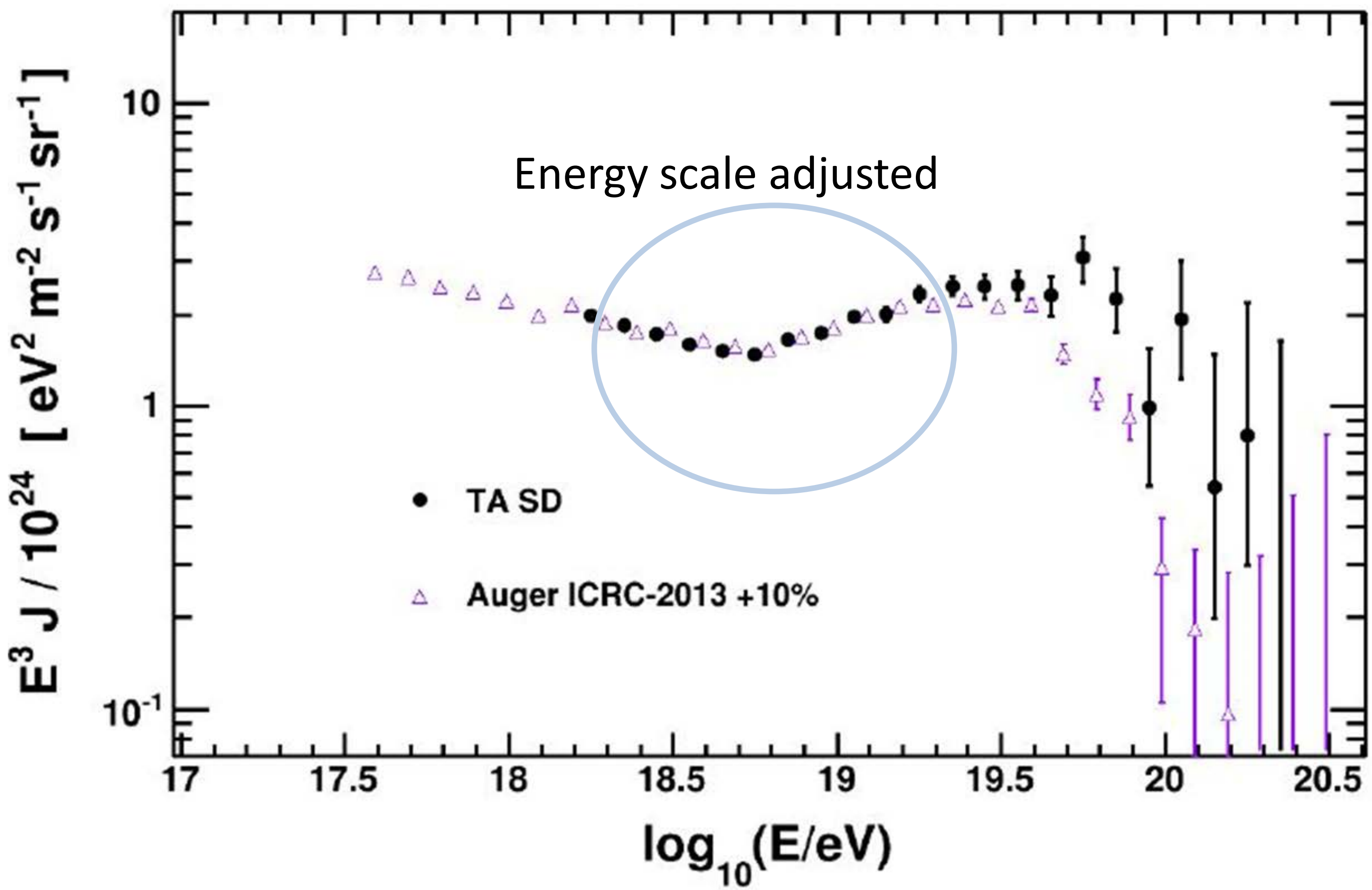
- What is the origin of ultra high energy cosmic rays?
- Do they propagate long distances?
- Are they protons or other nuclei(Fe)?

Energy less length for Protons



Energy spectrum

J.N. Matthews,
Qui Nhon 2014
M. Fukushima
AMS day 2015



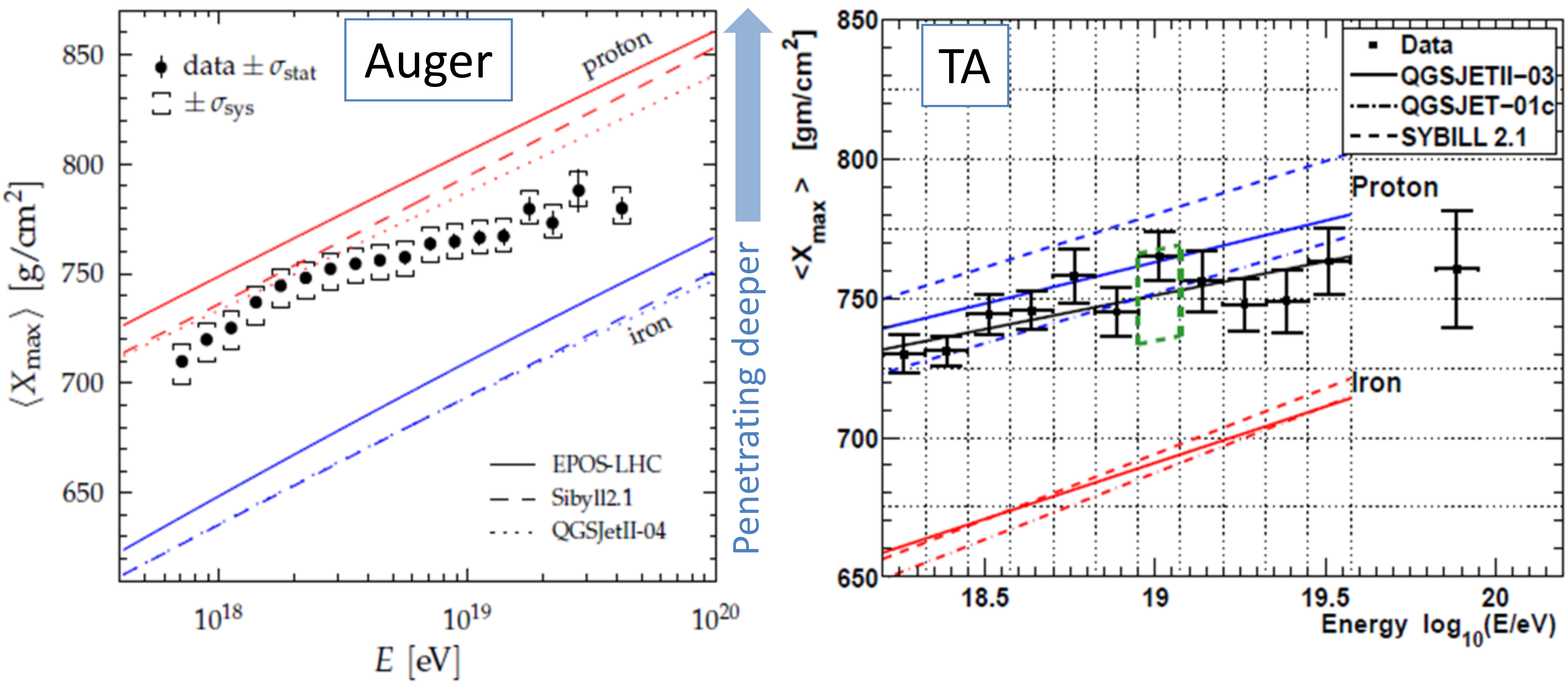
Cutoff (> $10^{19.6\text{-}19.8}$ eV) observed in both experiments.

GZK mechanism observed? (cannot conclude yet --- next page)

What does the difference in the cutoff energy mean?

Composition of UHE cosmic rays?

Method: proton shower should be penetrating deeper than that due to heavy ions.



Indication of changing the composition from light to heavy (Auger)?

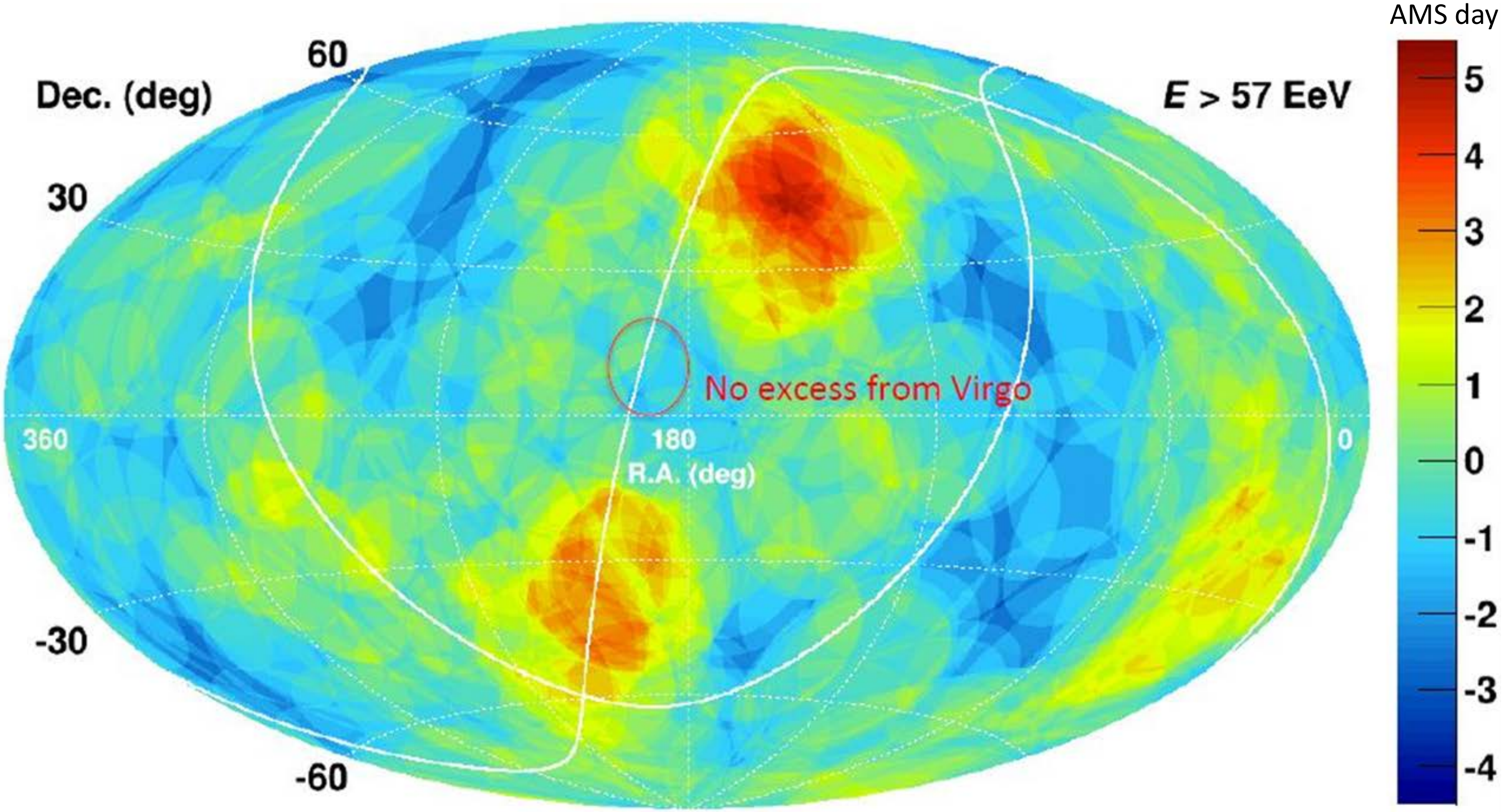
Not confirmed by TA…

“GZK suppression” at $10^{19.6\text{-}19.8}$ eV needs protons… ➔ Cannot conclude..

Source of UHE cosmic rays?

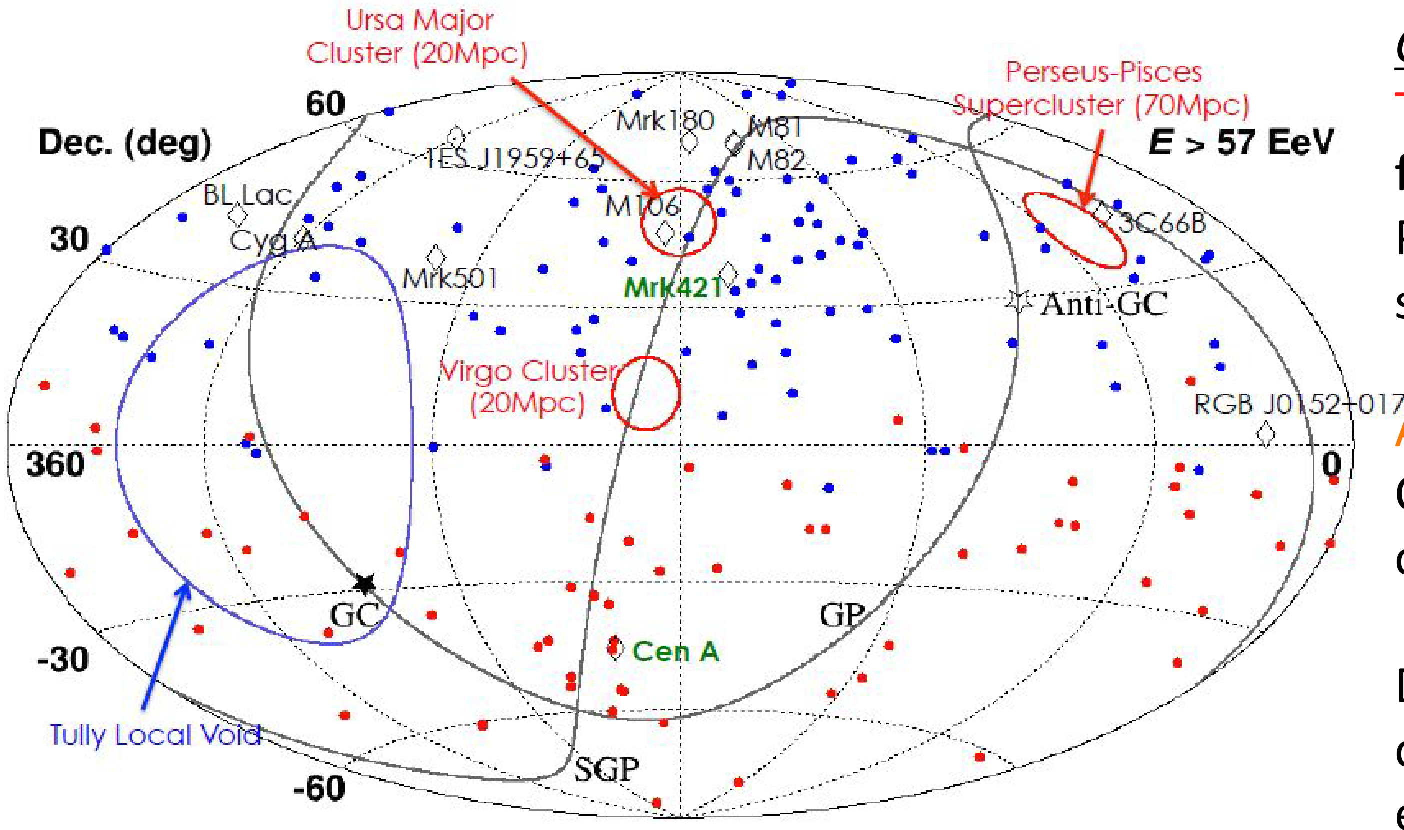
Anisotropy for E > $5.7*10^{19}$ eV (Auger + TA)

Auger APJ 804:15 (2015)
M. Fukushima
AMS day



North: $S_{MAX} = 5.19\sigma$, (R.A, Dec.) = (148.4°, 44.5°)
South: $S_{MAX} = 3.57\sigma$, (R.A, Dec.) = (210.9°, -48.2°)

Source of UHE cosmic rays?



TA : 2008 May – 2014 May (6.0 years) 87 events
Auger : 2004 May – 2009 Nov (5.5 years) 62 events

Beginning of UHECR astronomy !! ?

→ Next generation detectors needed. (News that TA extension (TAX4) has been (partially?) funded.

<u>*Comments:*</u>

TA hotspot: 19º off from Super Galactic Plane. No obvious source candidate.

Auger warm-spot: Cen A as a source candidate.

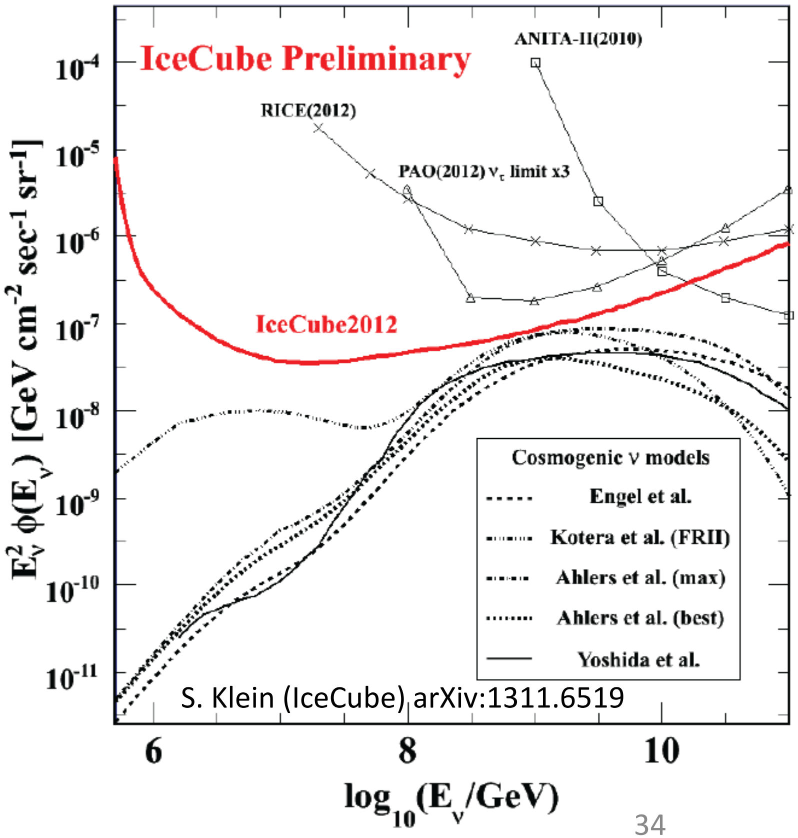
Do these results consistent with the expected magnetic deflection, which depends on the chemical composition?

Toward the consistent picture of UHECR

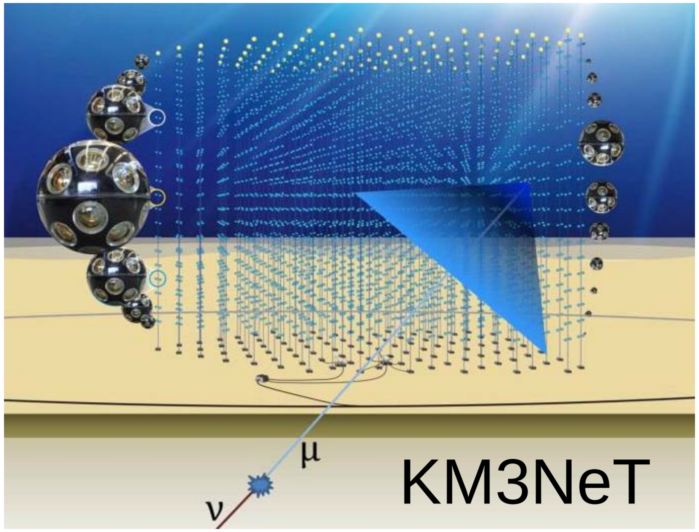
- It seems one of the key issue is the chemical composition.
  - ◆If iron – the cutoff in the spectrum might be due to the maximum acceleration energy, the hot/warm spots be a statistical fluctuation ? or..?
  - ◆If proton – might be GZK cutoff… (might be the maximum acceleration energy)
- Auger and TA are working hard to understand the chemical composition.
- Any independent ways?

➔ *GZK neutrinos !*

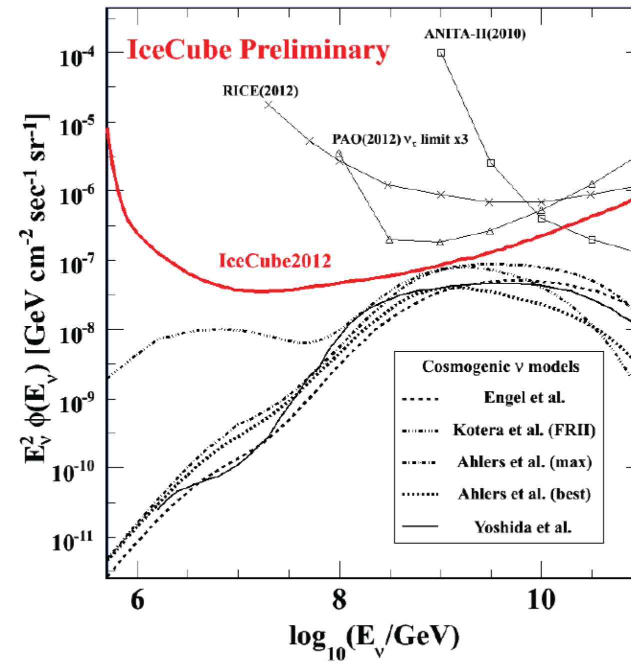
$$p + \gamma_{CMB} \rightarrow \Delta \rightarrow N + \pi$$
$$\pi^{+/-} \rightarrow \mu + \nu_\mu$$
$$\mu \rightarrow e + \nu_\mu + \nu_e$$

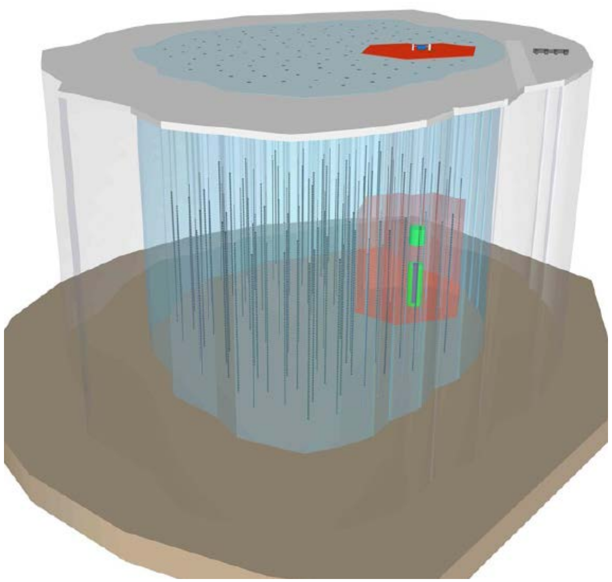


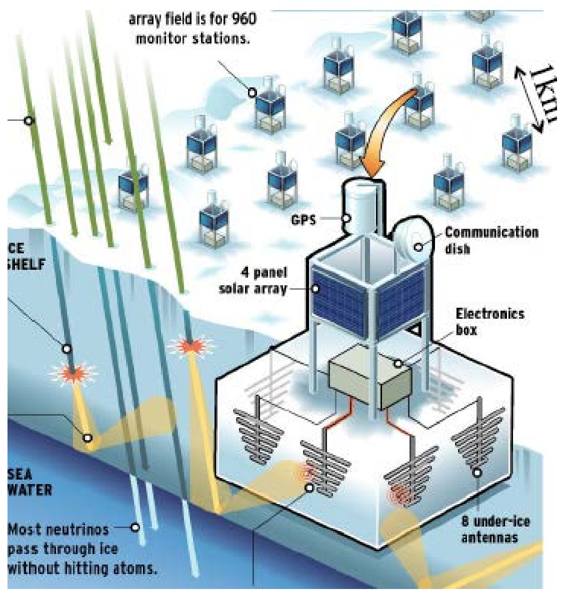
Next generation neutrino detectors needed



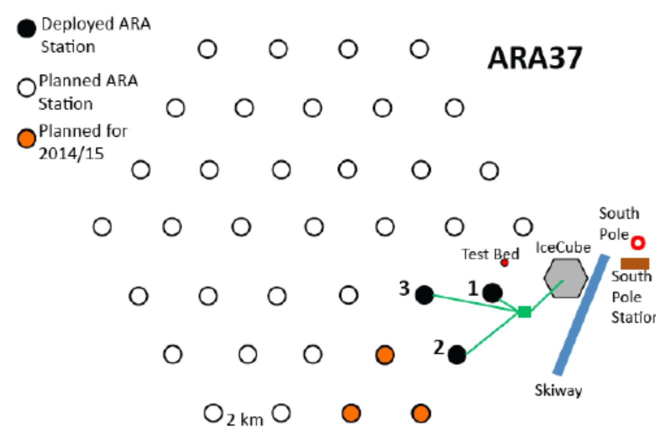
S. Klein (IceCube) arXiv:1311.6519







ARIANNA



Summary

- Lots of really exciting results!
- Various WIMPs dark matter experiments produce impressive results. In particular, the positron and anti-proton excess are interesting.
- High energy astrophysical neutrinos have been observed. ➔ *Neutrino astronomy!*
- Much improved data in ultra high energy cosmic rays. In particular, the hot and warm spots in UHECR. ➔ *UHECR astronomy!*
- Much more expected!

Much more in highlight and parallel session talks