

**UHE NEUTRINOS:
FROM CONVENTIONAL TO NEW PHYSICS**

V. Berezhinsky

INFN, Laboratori Nazionali del Gran Sasso, Italy

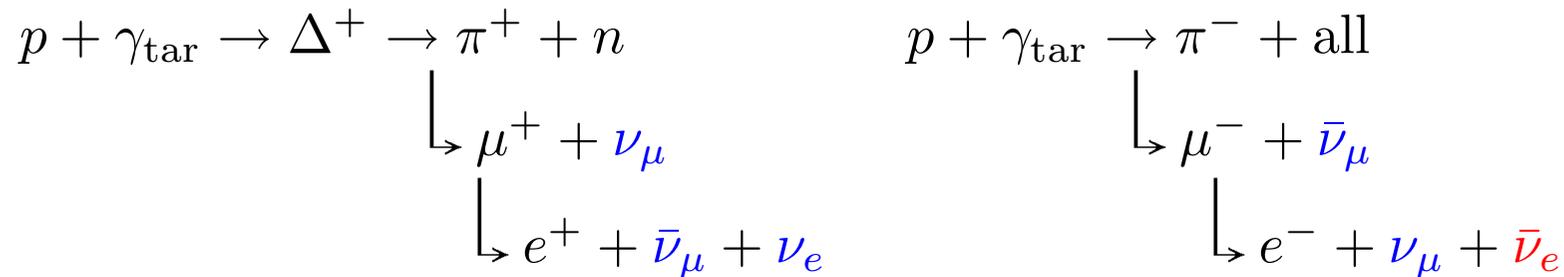
RAN, Institute for Nuclear Research, Moscow, Russia

UHE NEUTRINOS with $E > 10^{17}$ eV

Cosmogenic neutrinos

Reliable prediction guaranteed by observations of UHECR.

Production:

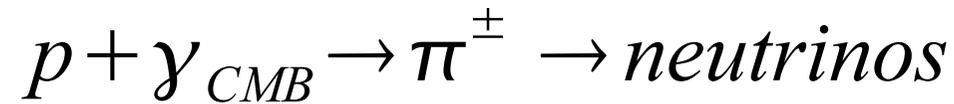


No τ -neutrinos and deficit of $\bar{\nu}_e$ neutrinos. They appear due to **oscillations**, with equipartition at observations $\nu_\mu : \nu_e : \nu_\tau = 1 : 1 : 1$ as approximation..

Neutrinos beyond SM

- Topological Defects
- Superheavy Dark Matter
- Mirror Matter

COSMOGENIC NEUTRINOS



$$J_{\nu}(E) = \frac{2}{3} 3 \left(\frac{E_{\nu}}{E_p} \right)^{\gamma_g - 1} \frac{1}{1 - \alpha^{\gamma_g - 1}} J_p^{umm}(E)$$

$$\frac{E_{\nu}}{E_p} \approx \frac{0.2}{4} = 0.05$$

Volume 28B, number 6 PHYSICS LETTERS 6 January 1969

COSMIC RAYS AT ULTRA HIGH ENERGIES (NEUTRINO?)

V. S. BERESINSKY and G. T. ZATSEPIN

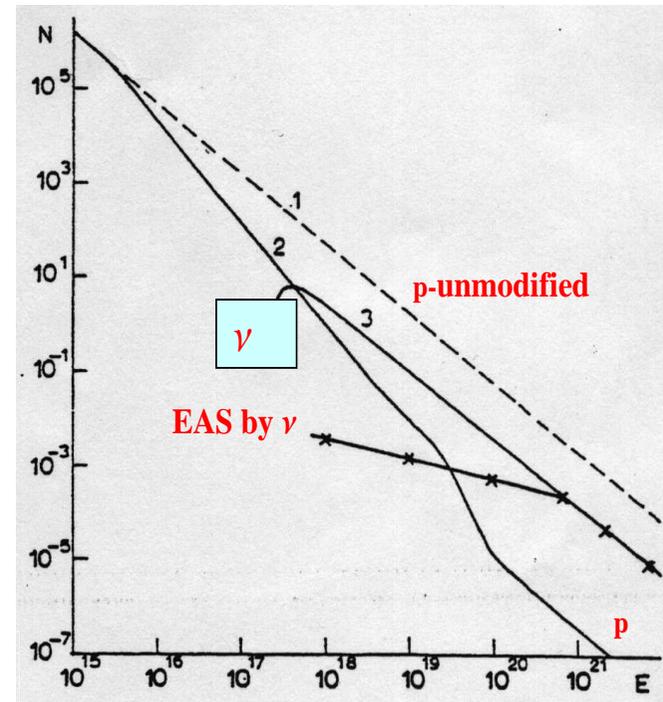
Academy of Sciences of the USSR. Physical Institute. Moscow

Received 8 November 1968

The neutrino spectrum produced by protons on microwave photons is calculated. A spectrum of extensive air shower primaries can have no cut-off at an energy $E > 3 \times 10^{19}$ eV. If the neutrino-nucleon total cross-section rises up to the geometrical one of a nucleon.

Greisen [1] and then Zatsepin and Kusmin [2] have predicted a rapid cut-off in the energy spectrum of cosmic ray protons near $E \sim 3 \times 10^{19}$ eV because of pion production on 2.7° black body radiation. Detailed calculations of the spectrum were made by Hillas [3]. Recently there were observed [4] three extremely energetic extensive air showers with an energy of primary particles exceeding 5×10^{19} eV. The flux of these particles turned out to be 10 times greater than according to Hillas' calculations.

In the light of this it seems to be of some interest to consider the possibilities of absence of rapid (or any) fall in the energy spectrum of shower producing particles. A hypothetical possibility we shall discuss* consists of neutrinos being the shower producing particles at $E > 3 \times 10^{19}$ eV due to which the energy spectrum of shower producing particles cannot only have any fall but even some flattening.



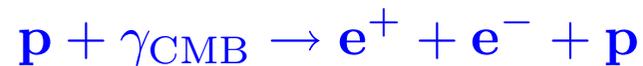
RECENT WORKS

- Engel, Seckel, Stanev 2001
- Kalashev, Kuzmin, Semikoz, Sigl 2002
- Fodor, Katz, Ringwald, Tu 2003
- VB, Gazizov, Grigorieva 2003
- Hooper et al. 2004
- Ave et al. 2005
- Seckel, Stanev 2005
- Allard et al. 2006
- Takami et al. 2009

COSMOGENIC NEUTRINOS IN THE DIP MODEL FOR UHECR

V.B. and Grigorieva 1988; V.B., Gazizov, Grigorieva 2005 - 2006.

The **dip** is a feature in the spectrum of UHE protons propagating through CMB:

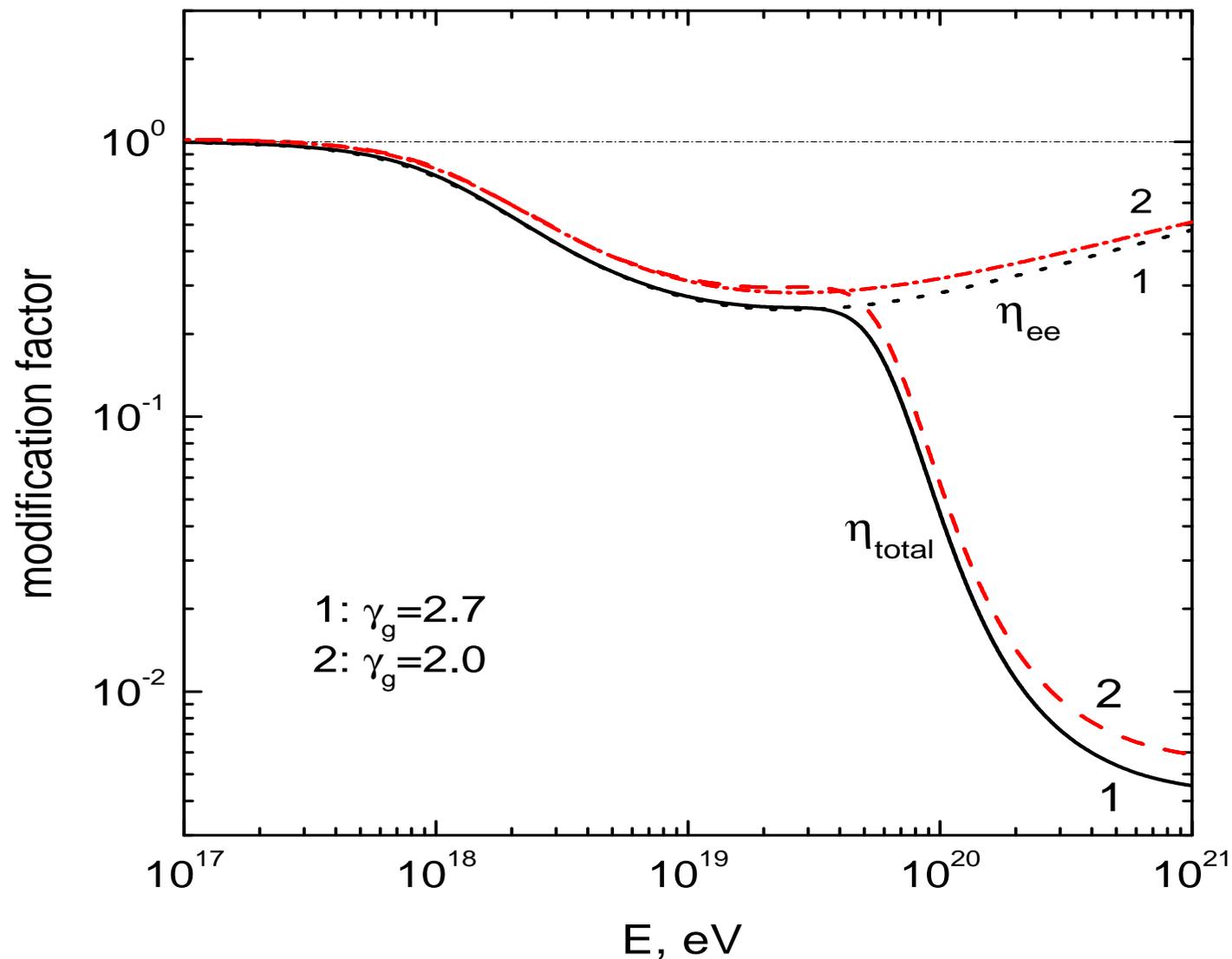


Calculated in the terms of **modification factor** $\eta(E)$ the dip is seen in all observational data.

$$\eta(\mathbf{E}) = \frac{\mathbf{J}_{\mathbf{p}}(\mathbf{E})}{\mathbf{J}_{\mathbf{p}}^{\text{unm}}(\mathbf{E})},$$

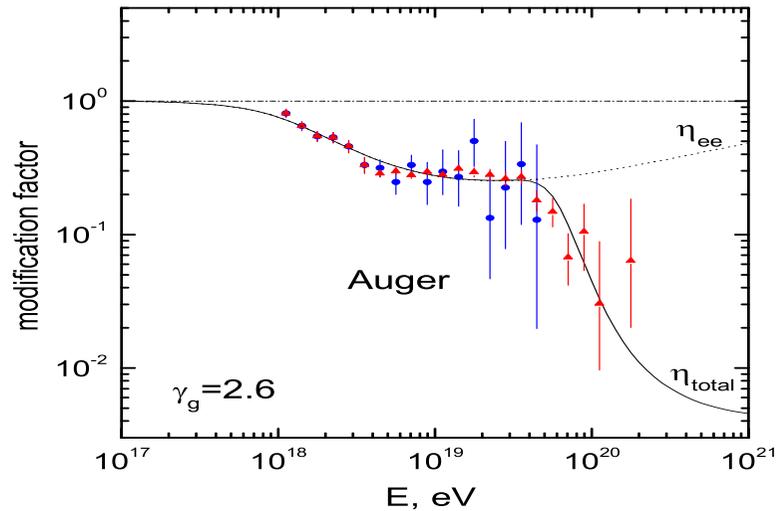
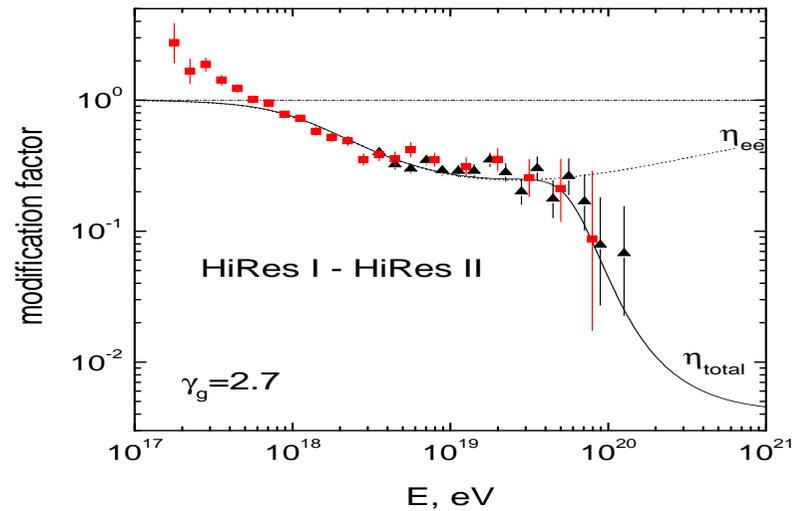
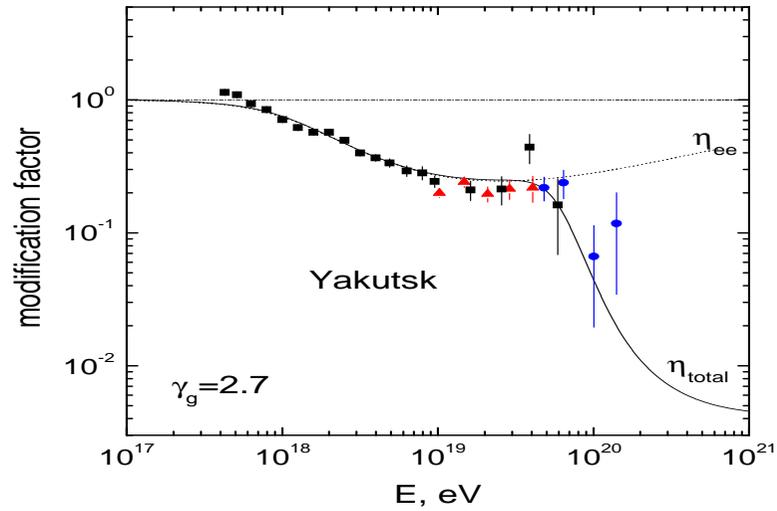
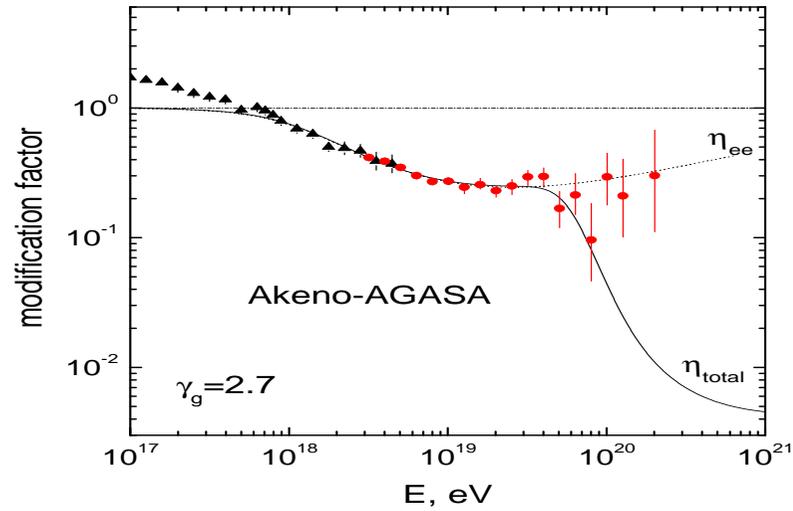
where $J_p^{\text{unm}}(E) = K E^{-\gamma_g}$ includes only adiabatic energy losses (redshift),
and $J_p(E)$ all energy losses.

DIP AND GZK CUTOFF IN TERMS OF MODIFICATION FACTOR

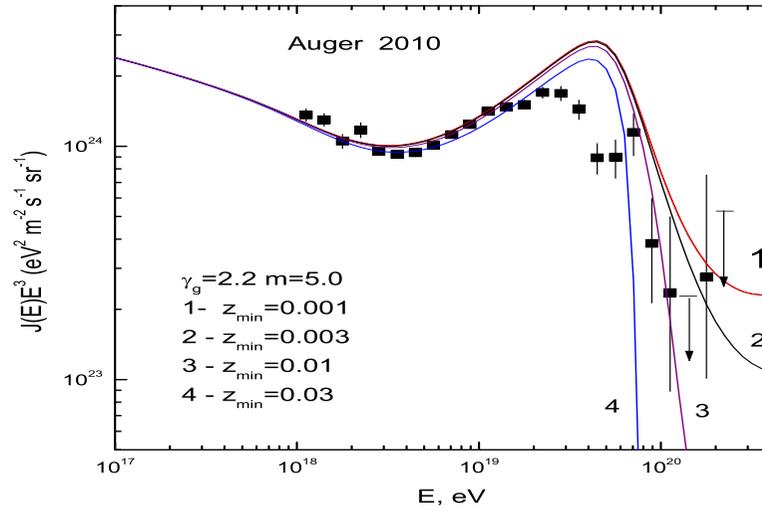
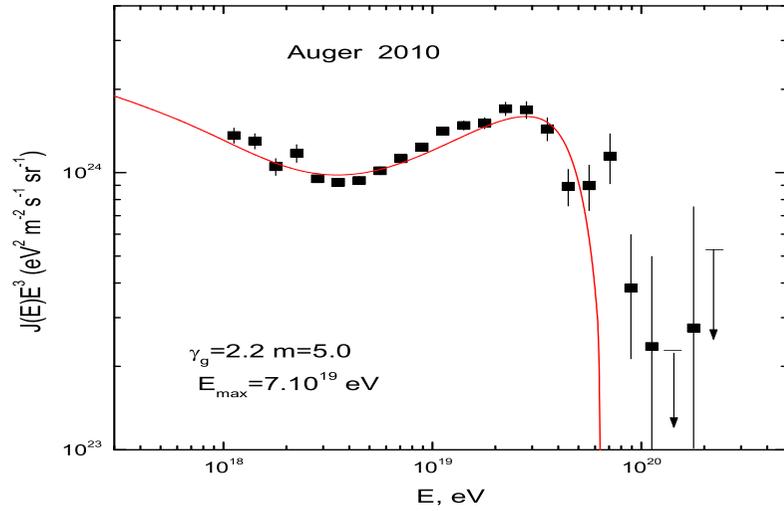
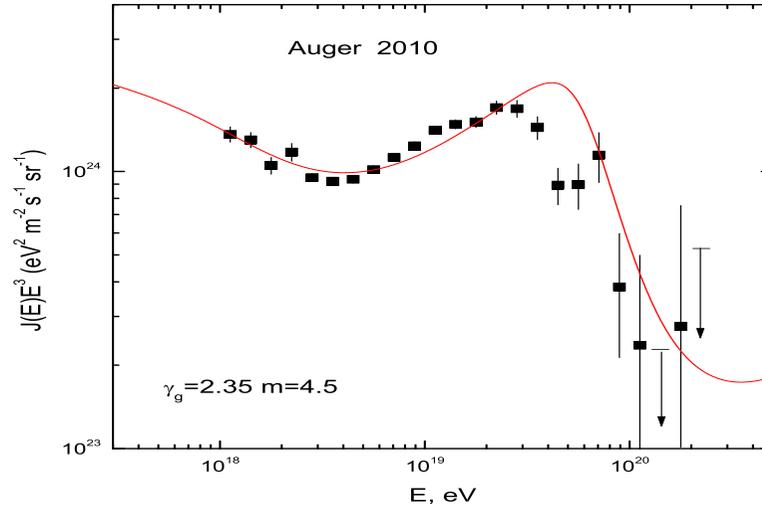
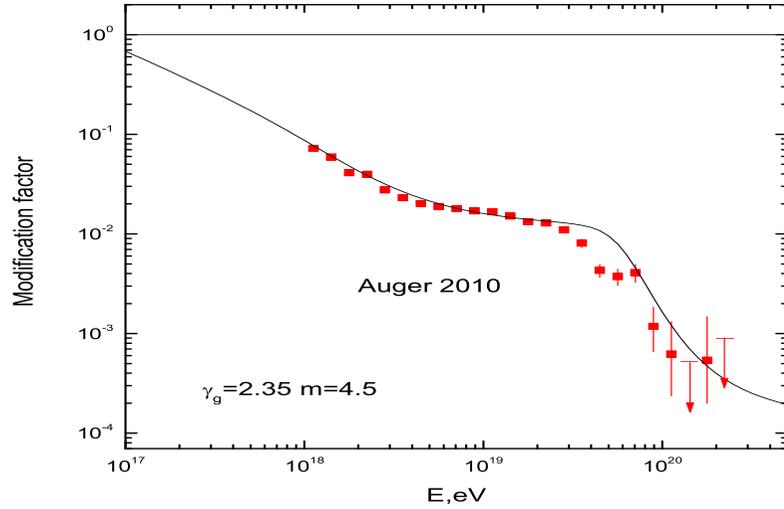


The dotted curve shows η_{ee} , when only adiabatic and pair-production energy losses are included. The solid and dashed curves include also the pion-production losses.

COMPARISON OF DIP WITH OBSERVATIONS



AUGER DATA 2010



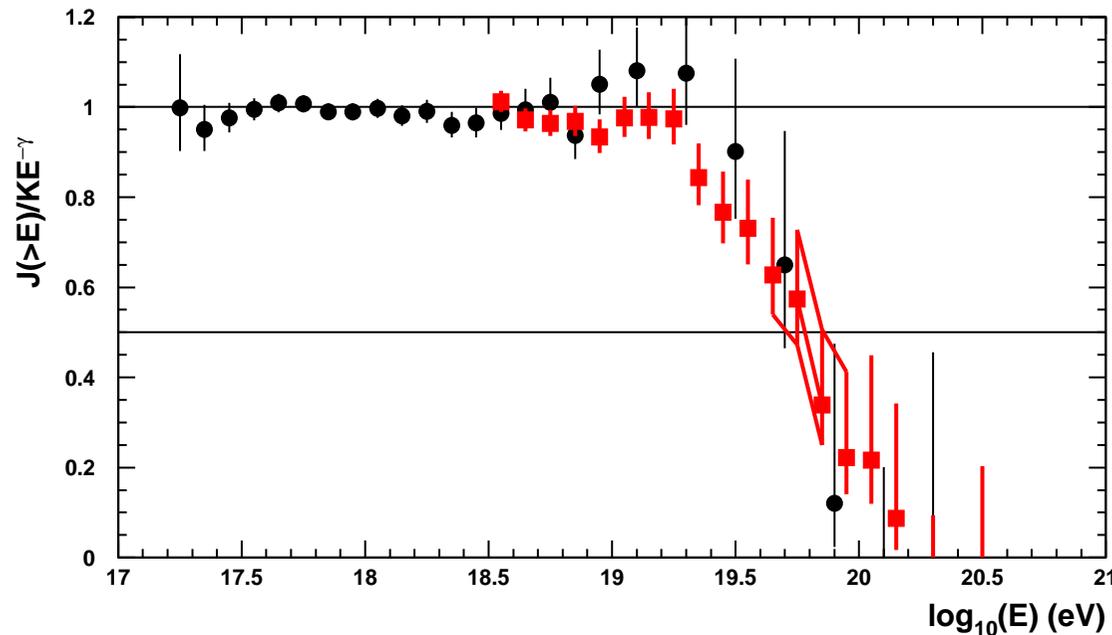
GZK CUTOFF IN HiRes DATA

In the **integral** spectrum GZK cutoff is numerically characterized by energy $E_{1/2}$ where the calculated spectrum $J(> E)$ becomes half of power-law extrapolation spectrum $KE^{-\gamma}$ at low energies. As calculations (V.B.&Grigorieva 1988) show

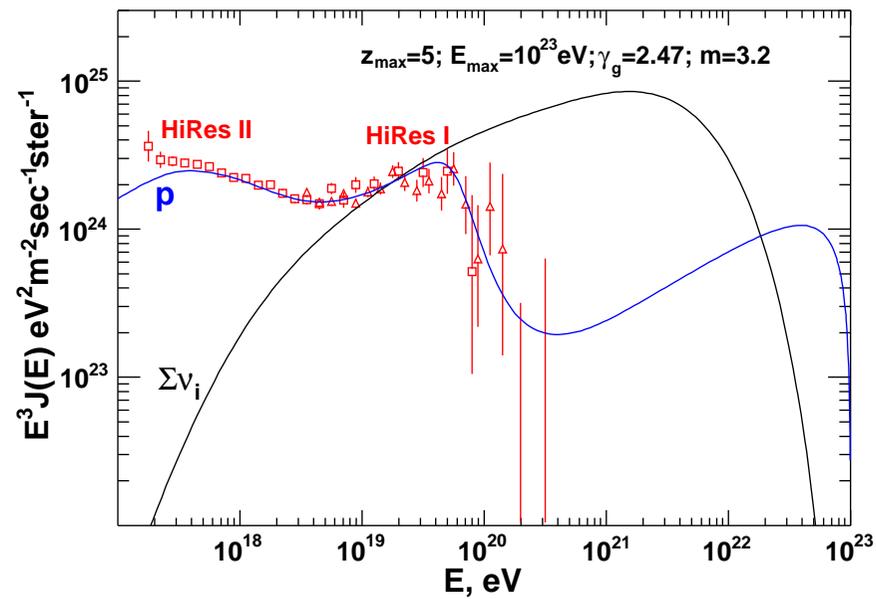
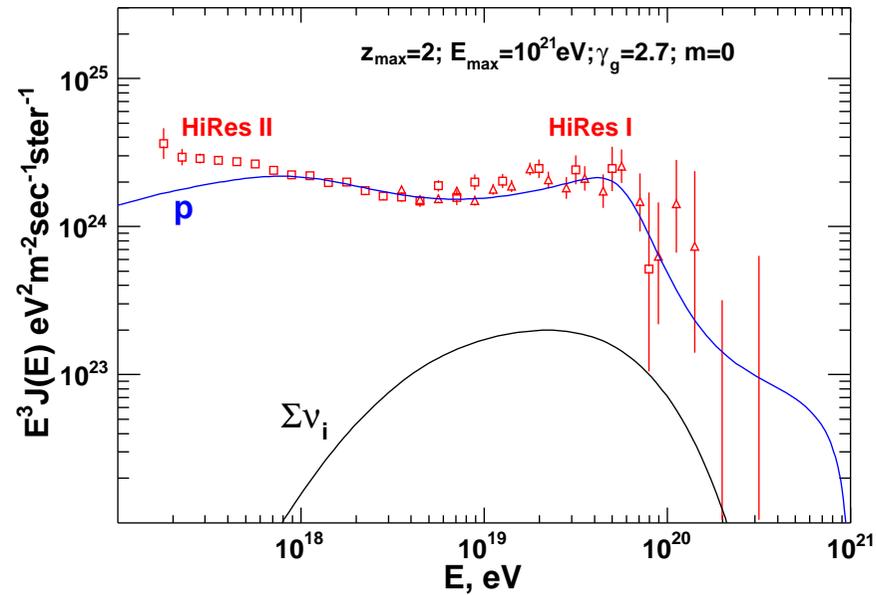
$$E_{1/2} = 10^{19.72} \text{ eV}$$

valid for a wide range of generation indices from 2.1 to 2.8. **HiRes obtained:**

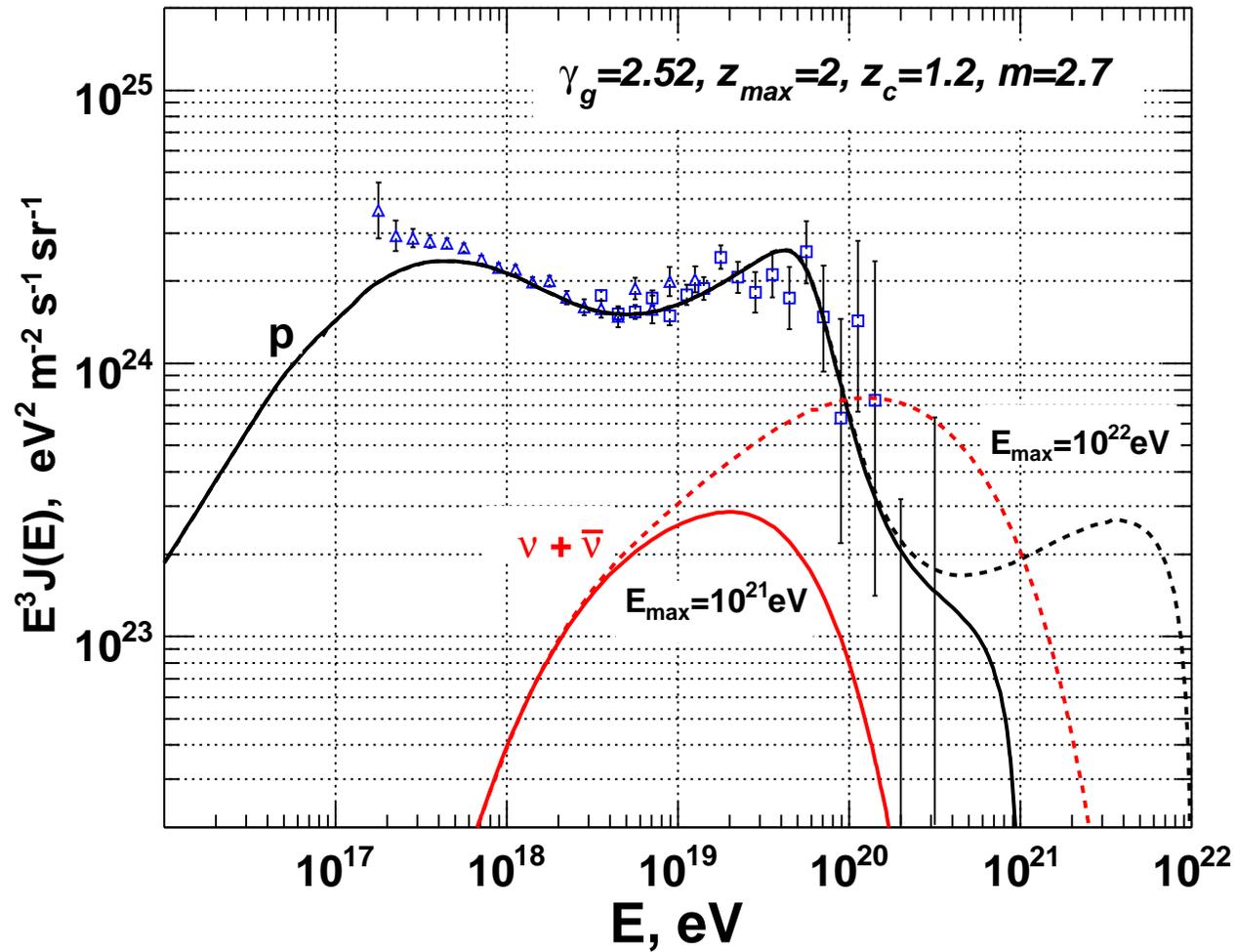
$$E_{1/2} = 10^{19.73 \pm 0.07} \text{ eV}$$



COSMOGENIC NEUTRINO FLUXES IN THE DIP MODEL

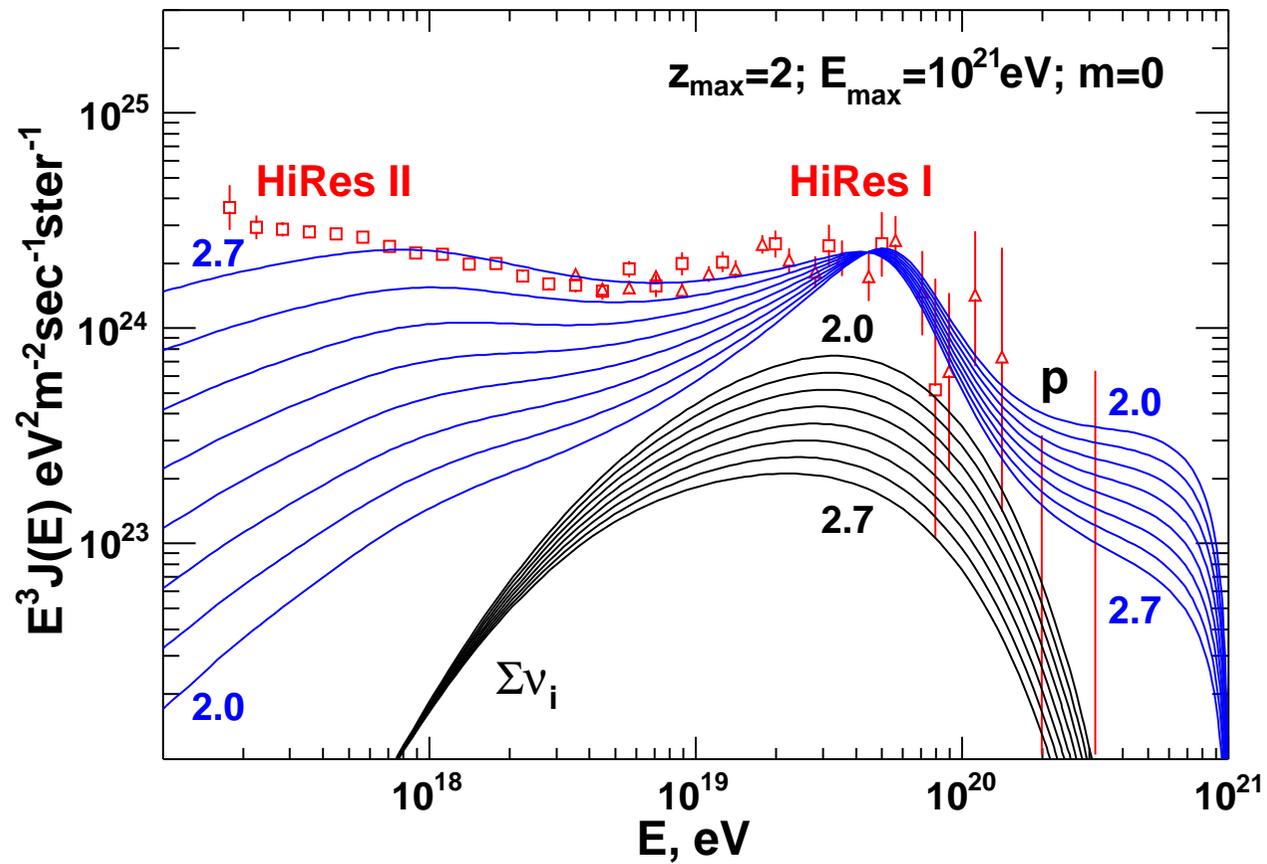


COSMOGENIC NEUTRINO FLUXES FROM AGN



LOWER LIMIT ON NEUTRINO FLUXES IN THE PROTON MODELS

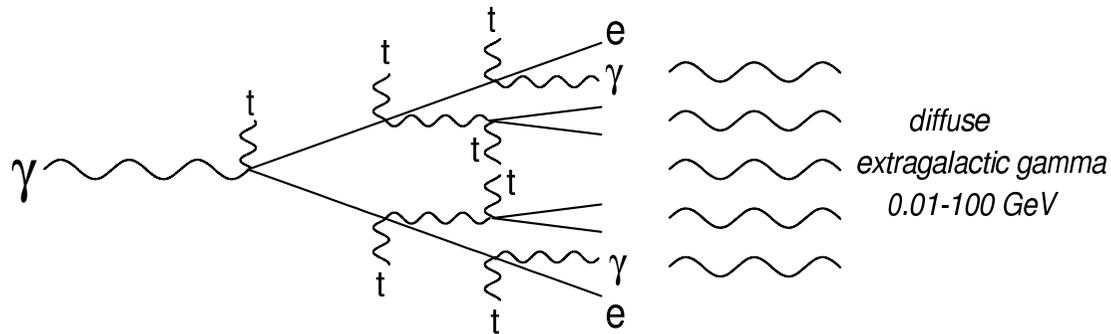
V.B. and A. Gazizov 2009



CASCADE UPPER LIMIT

V.B. and A.Smirnov 1975

e – m cascade on target photons : $\begin{cases} \gamma + \gamma_{\text{tar}} \rightarrow e^+ + e^- \\ e + \gamma_{\text{tar}} \rightarrow e' + \gamma' \end{cases}$



Spectrum of cascade photons

$$J_{\gamma}^{\text{cas}}(E) = \begin{cases} K(E/\varepsilon_X)^{-3/2} & \text{for } E \leq \varepsilon_X, \\ K(E/\varepsilon_X)^{-2} & \text{for } \varepsilon_X \leq E \leq \varepsilon_a, \end{cases} \quad (1)$$

with a steepening at $E > \varepsilon_a$, and $\varepsilon_X = 1/3 (\varepsilon_a/m_e)^2 \varepsilon_{\text{cmb}}$.

EGRET: agreement with spectrum (1) and $\omega_{\gamma}^{\text{obs}} \sim 3 \times 10^{-6} \text{eV/cm}^3$.

UPPER LIMIT ON NEUTRINO FLUX

$$\omega_{\text{cas}} > \frac{4\pi}{c} \int_E^\infty E J_\nu(E) dE > \frac{4\pi}{c} E \int_E^\infty J_\nu(E) dE \equiv \frac{4\pi}{c} E J_\nu(> E)$$

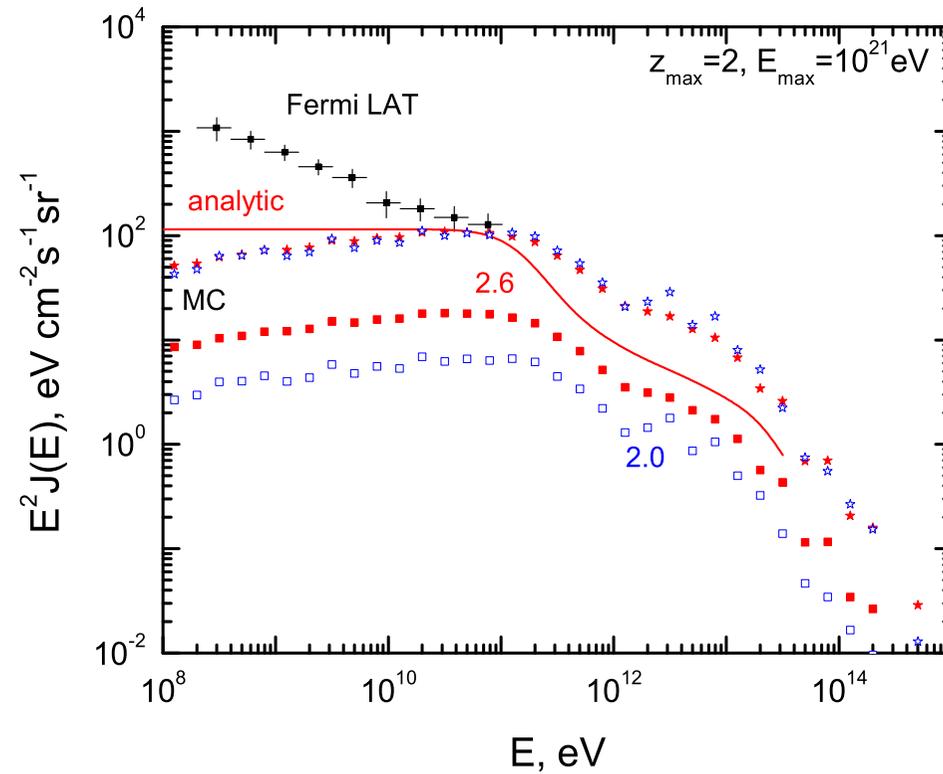
$$E^2 I_\nu(E) < \frac{c}{4\pi} \omega_{\text{cas}}.$$

E^{-2} -generation spectrum:

$$E^2 J_\nu(E) < \frac{c}{4\pi} \frac{\omega_{\text{cas}}}{\ln E_{\text{max}}/E_{\text{min}}}.$$

CASCADE UPPER LIMIT FROM FERMI LAT

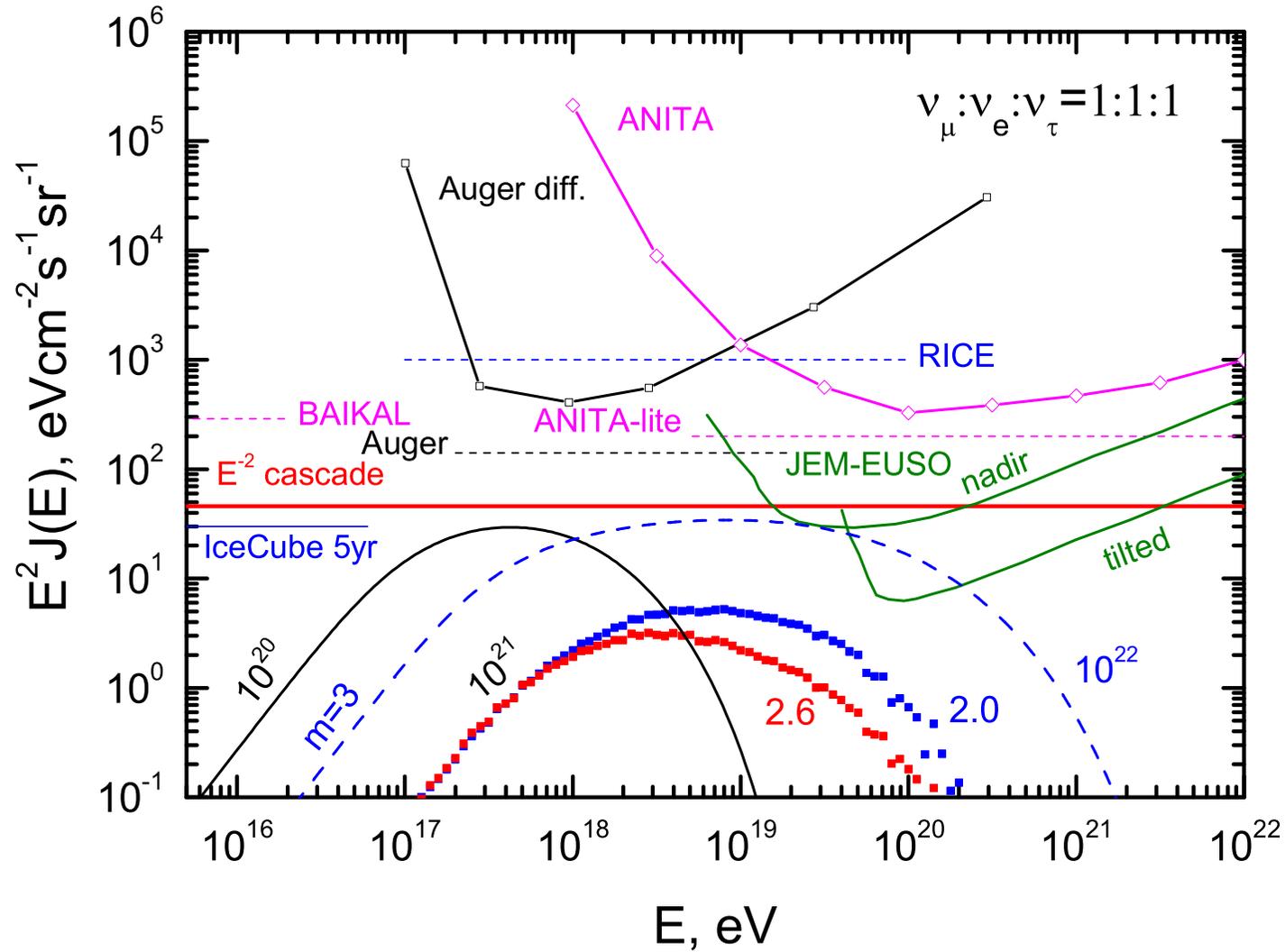
V.B., Gazizov, Kachelriess, Ostapchenko 2010.



$$\omega_{\text{cas}}^{\text{max}} = 5.8 \times 10^{-7} \text{ eV cm}^{-3}$$

OBSERVATIONAL AND THEORETICAL UPPER LIMITS

V.B., Gazizov, Kachelriess, Ostapchenko 2010.

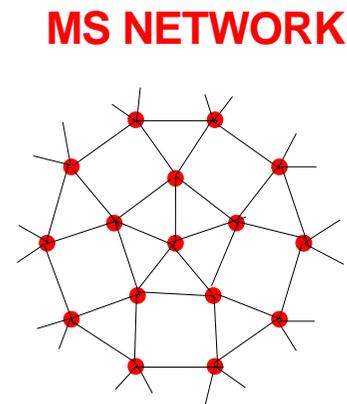
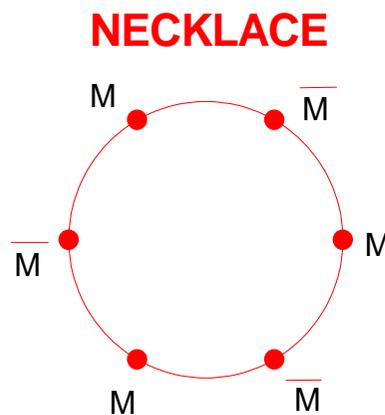


UHE NEUTRINOS FROM TOPOLOGICAL DEFECTS

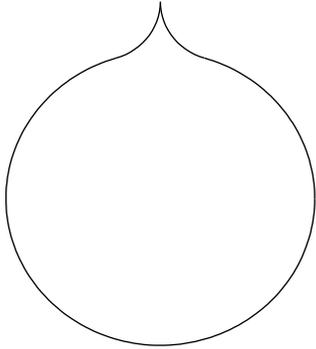
Symmetry breaking in early universe results in **phase transitions**, which are accompanied by Topological Defects.

TDs OF INTEREST FOR UHE NEUTRINOS.

- **Monopoles:** $G \rightarrow H \times U(1)$
- **Ordinary strings:** $U(1)$ breaking
- **Superconducting strings:** $U(1)$ breaking
- **Monopoles connected by strings:** $G \rightarrow H \times U(1) \rightarrow H \times Z_n$
e.g. **necklaces** $Z_n = Z_2$.



ORDINARY and SUPERCONDUCTING STRINGS



Ordinary strings are produced at $U(1)$ symmetry breaking, i.e. by the Higgs mechanism: $\mathcal{L} = \lambda(\phi^+ \phi - \eta^2)^2$.

They are produced as **long strings** and **closed loops**.

The fundamental property of a loop is **oscillation** with periodically produced **cusp**, where $v \rightarrow c$.

In a wide class of particle physics strings are **superconducting** (Witten 1985)

$$dJ/dt \propto e^2 E$$

If a string moves through magnetic field the electric current is induced

$$J \sim e^2 v B t$$

The charge carriers X are massless inside the string, and massive outside.

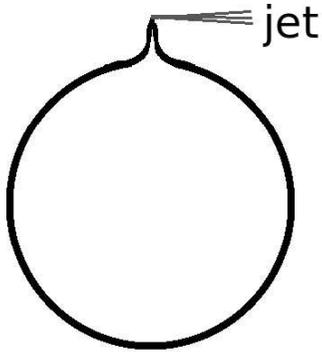
When current exceeds the critical value $J_c \sim em_X$, the charge carriers X can escape.

Energy of released particles is $E_X \sim \gamma_c m_X$, they are emitted in a cone $\theta \sim 1/\gamma_c$.

In ordinary strings the neutral particles, e.g. Higgses, can escape through a cusp, too.

UHE neutrino jets from superconducting strings

V.B., K.Olum, E.Sabancilar and A.Vilenkin 2009



Basic parameter: symmetry breaking scale $\eta \gtrsim 1 \times 10^9$ GeV.

Lorentz factor of cusp $\gamma_c \sim 1 \times 10^{12} i_c \eta_{10}^{-1} B_{\mu G}^{-1}$, $i_c \lesssim 1$.

Electric current is generated in magnetic fields (B, f_B).

Clusters of galaxies dominate.

$$J \sim e^2 B l, \quad J_{\text{cusp}} \sim \gamma_c J, \quad J_{\text{cusp}}^{\text{max}} \sim i_c e \eta.$$

Particles are ejected with energies $E_X \sim i_c \gamma_c \eta \sim 10^{22}$ GeV.

Diffuse neutrino flux :

$$E^2 J_\nu(E) = 2 \times 10^{-8} i_c B_{-6} f_{-3} \text{ GeV cm}^{-2} \text{ s}^{-1}$$

does not depend on η in a range $\eta > 1 \times 10^9$ GeV.

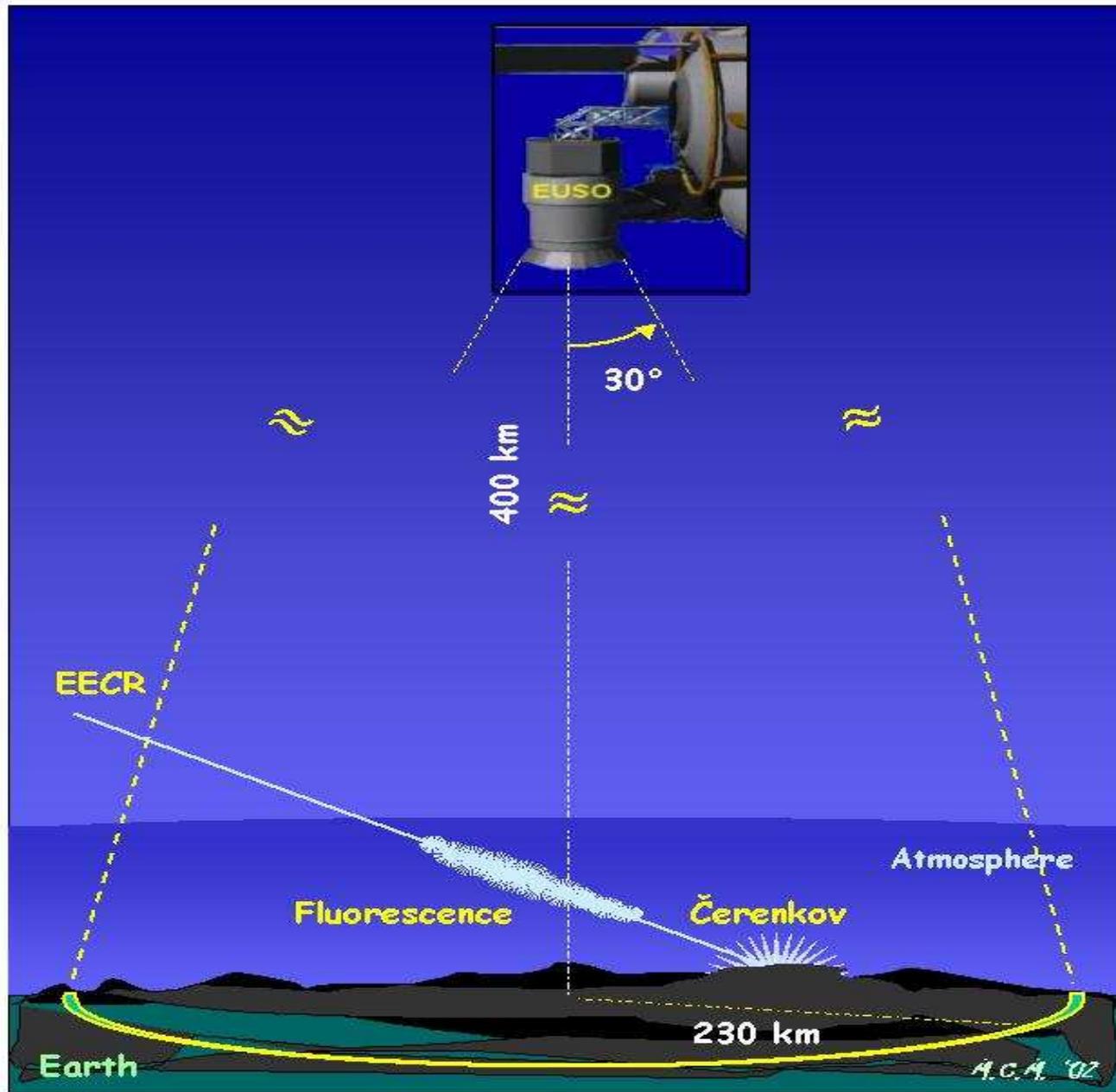
Signatures:

- Correlation of neutrino flux with clusters of galaxies.
- Detectable flux of 10 TeV gamma ray flux from Virgo cluster.
- Multiple simultaneous neutrino induced EAS in field of view of JEM-EUSO.

CONCLUSIONS

- UHE neutrino astronomy has a balanced program of observations of reliably existing **cosmogenic** neutrinos, and top-down neutrinos predicted by the models beyond **SM** (e.g. topological defects or SHDM).
- Fluxes of cosmogenic neutrinos are strongly bounded by **the cascade upper limit** with the new extragalactic gamma-ray background radiation measured by Fermi-LAT. With this upper limit detectability of neutrino flux depends on **maximum acceleration energy** E_{\max} . Acceleration to $E_p^{\max} \sim 1 \times 10^{22}$ eV is a problem in astrophysics. With this E_p^{\max} cosmogenic neutrinos can be detected only marginally by JEM-EUSO. Fluxes of cosmogenic neutrinos are further lowered if **heavy-nuclei** make the substantial contribution to primary radiation. and are undetectable in case heavy nuclei are dominant component.
- Energies of **cosmogenic neutrinos** are expected below $E_\nu \sim 10^{21}$ eV, while energies of neutrinos in top-down scenarios should be much higher. Thus neutrinos with $E_\nu > 10^{21} - 10^{22}$ eV are a signal for a new physics.

PRINCIPLES OF EUSO OBSERVATIONS

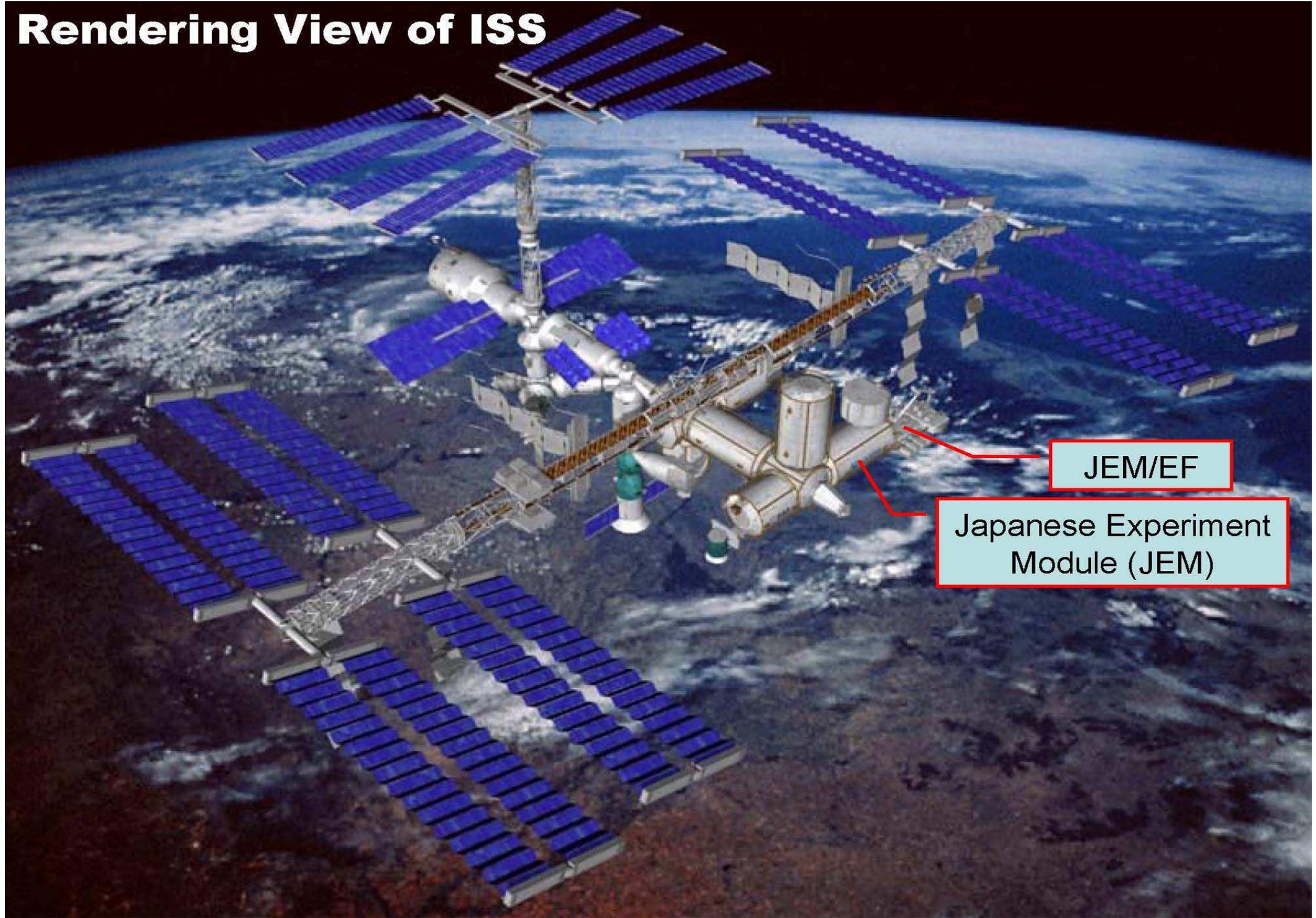


Field of View of EUSO

EUSO ~ 300 x AGASA ~ 10 x Auger
EUSO (Instantaneous) ~ 3000 x AGASA
~ 100 x Auger



Rendering View of ISS



JEM/EF

Japanese Experiment
Module (JEM)

H-IIA Launch Vehicle



Nov. 29, 2003

**Accident happened
for the H-IIA Launch Vehicle No 6**

Feb. 26, 2005

**The H-IIA Launch Vehicle No. 7 with
MTSAT-1R was launched
successfully.**

Jan. 24, 2006

**The H-IIA Launch Vehicle No. 8 with
the Advanced Land Observing
Satellite "Daichi" (ALOS) was
launched successfully.**

Feb. 18, 2006

**The H-IIA Launch Vehicle No. 9
with the Multi-functional Transport
Satellite 2 (MTSAT-2) was launched
successfully.**