NEUTRINOS FROM SUPERNOVA REMNANTS AFTER THE FIRST H.E.S.S. OBSERVATIONS

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Abstract

We provide elements for a discussion of the expected $\nu$ signal from Supernova Remnants (SNR) in the Milky Way. After recalling why SNR are interesting and certain remarkable achievements of H.E.S.S., we describe a simple and straightforward method to evaluate the $\nu$ fluxes from $\gamma$-ray data. For an ideal detector, we get a flux of 5 thoroughgoing muons per km$^2$ per year from RX J1713.7-3946 in ANTARES location and above $E_{th} = 50$ GeV; similar calculations for Vela Jr show that the number of events, to be evaluated precisely after the next detailed observations of H.E.S.S., are larger. We comment on the role of neutrino oscillations.

1 The cosmic ray/SNR connection

Supernovae are suspected to be the cosmic ray (CR) accelerators since '34 (Baade & Zwicky [1]). 30 years later, Ginzburg & Syrovatsky [2] remarked that if 10 % or so of the SNR kinetic energy $\mathcal{E}_{SN} \approx 10^{51}$ erg (1 foe, also known as 1 bethe) goes in CR, the Milky Way losses are compensated:

$$\frac{V_{CR} \rho_{CR}}{\tau_{CR}} \approx 0.1 \times \frac{\mathcal{E}_{SN}}{\tau_{SN}}$$

where $V_{CR} = \pi R^2 H$ ($R = 15$ kpc, $H = 5$ kpc), $\tau_{CR} = 10^7$ yr and $\tau_{SN} = 30$ yr. The ‘diffusive shock wave acceleration’ mechanism based on Fermi ideas [3] is being developed to explain CR acceleration in SNR (lecture of
Blasi); CR accelerate in an expanding shock wave of size $R = u t$ ($u \sim 5,000$ km/s), mostly active in the first 1,000 yr, determined by $M_{\text{ejecta}} \sim 4\pi/3 R^3 n_{\text{ISM}}$.

Hillas selected a list of open (connected?) questions [4]:

- How to “inject” electrons? ($\text{diffusive shock accel. is incomplete? }$)
- Why isotropy? How $\Gamma = 2.1 \rightarrow 2.7$? ($\text{propagation/reacceleration? }$)
- $E_{\text{max}}$? ($R \sim D_{\text{Bohm}}/u$ limit, countered by Bell & Lucek [5])
- Too few point sources of VHE $\gamma$? ($\text{something lacking? }$)
- How to firmly exclude a leptonic origin? ($\text{TeV } \nu \text{ are needed? }$)

We will be mostly concerned with the last questions (the last one is not in Hillas’s list, but perhaps he would have included it, if giving this talk).

1.1 The landscape after the first H.E.S.S. results

For a few young shell-type SNR observed in VHE $\gamma$, the “hadronic” hypothesis seems plausible; more crucial tests will be possible with future observations by H.E.S.S. (VERITAS, MAGIC) and other instruments. The closest SNR’s, whose properties we recall here, are of particular interest:

| Name       | TeV $\gamma$ observ. | decl. $\delta$ | distance | size | age  |
|------------|-----------------------|----------------|----------|------|------|
| Vela Jr    | $< 10$ TeV (HESS)     | $-46^\circ 22'$ | 0.2 kpc  | 2°   | 680 yr |
| RXJ1713... | $< 40$ TeV (HESS)     | $-39^\circ 46'$ | 1 kpc    | 1°   | 1,600 yr |
| SN 1006    | no(t yet?)            | $-41^\circ 53'$ | 2 kpc    | 36°  | 1,000 yr |
| Cas A      | HEGRA (maybe)         | $58^\circ 08'$  | 3 kpc    | 6°   | 320 yr |

(note however that the “distance” and “age” are not reliably determined, see e.g. [6]). For the first two the velocity of expansion is as expected, for the other it is a bit larger. RX J1713.7-39346 and Vela Jr are the most intense shell-type SNR in the TeV $\gamma$ sky; thus, it is particularly important to discuss the expected neutrino fluxes from them.

The best known $\gamma$ spectrum is the one of RX J1713.7-3946. H.E.S.S. [7] showed that the spectrum of RX J1713.7-3946 deviates from a power law distribution above $\sim 10$ TeV. Assuming that the $\gamma$-rays come from CR interactions with the environment (are of hadronic origin), the cut in the CR (proton) spectrum should be around 150 TeV, in agreement with naive expectations from diffusive shock acceleration models. Specific models of this SNR have been proposed: Malkov, Diamond, Sagdeev ’05 [8] suggest that the nearby molecular cloud has a main role for CR interactions whereas Berezhko & Völk ’06 [9] fit H.E.S.S. observations starting from the opposite view; in both models the hadronic contribution is sizable or dominant. In short, H.E.S.S. observations renewed the interest in the CR/SNR connection and perhaps, figured out the most intense sources of VHE $\gamma$ rays.
Two web links that can help to keep information updated are:
⋆ H.E.S.S. Source Catal., www.mpi-hd.mpg.de/hfm/HESS/ [W. Hofmann];
⋆ Catalogue of SNR, www.mrao.cam.ac.uk/surveys/snrs/ [D. Green].
See also the review of H.J. Völk [10] and the lecture of Wei Cui.

2 TeV neutrinos from SNR

Motivated by the (shell-type, young) SNR / CR connection and by the existing plans for large neutrino telescopes, we calculate the flux of TeV neutrinos from the SNR with known VHE $\gamma$-ray spectrum. Indeed, during CR acceleration the SNR are transparent to their $\gamma$ radiation. Thus, we can convert the measured $\gamma$ ray flux (from $\pi^0$ and $\eta$) into an expectation for the neutrino flux (from $\pi^\pm$ and $K^\pm$) under the hypothesis that the radiation is of hadronic origin. We begin by discussing flavor oscillations, describe the $\gamma/\nu$ connection and estimate the rate of events in (km$^2$ class, ideal) neutrino telescopes.

2.1 Oscillations

The flux of neutrinos–from meson decays–are modified by the oscillations:

$$F_{\nu_\mu} = F_{\nu_\mu}^0 P_{\mu\mu} + F_{\nu_e}^0 P_{e\mu}$$

The oscillation probabilities take the simplest form, Gribov-Pontecorvo’s [11] (namely, the one that applies for low energy solar neutrinos):

$$P_{\ell\ell'} = \sum_{i=1}^{3} |U_{\ell i}|^2 |U_{\ell' i}|^2$$

with $\ell, \ell' = e, \mu, \tau$

There is no MSW effect [12], for matter term is negligible close to the SNR and too large in the Earth. With central values of the mixing elements $U_{\ell i}$ we get $P_{\mu\mu} \sim 0.4$ and $P_{e\mu} \sim 0.2$; that is, 1/2 of the original $\nu_{\mu}$ and $\bar{\nu}_{\mu}$ fluxes reach the detector.

We performed also a detailed (or sophisticated) analysis

$$L(P_{\mu\mu}) \propto \max \left[ e^{-\frac{(P_{\mu\mu} - P_{\mu\mu}(\theta))^2}{2\sigma^2}} \times L_{osc}(\theta) \right] \quad \text{with } \sigma \to 0$$

where $\theta$ are the measured parameters taken from [13] that we marginalize away by maximizing the result. We get $P_{\mu\mu} = 0.39 \pm 0.05$ and $P_{e\mu} = 0.22 \pm 0.05$ where most of the error (0.04) is due to $\theta_{23}$. 
To understand the uncertainty budget one can use an expansion in the small parameters [14]:

\[ P_{\mu\mu} \simeq \frac{1}{2} - \frac{x}{8} - y \text{ and } P_{e\mu} \simeq \frac{x}{4} + y, \]

where \[ \left\{ \begin{array}{l}
x = \sin^2 2\theta_{12}, \\
y = \cos 2\theta_{23} \frac{x}{4} \cos \theta_{13} \cos \delta_{\text{CP}} \sqrt{x(1-x)}/2.
\end{array} \right. \]

In view of astrophysical uncertainties and small counting rates we believe that the uncertainties in the oscillation parameters do not have an important role for the discussion of SNR \( \nu \) and presumably even for other cosmic sources.\footnote{We comment on a proposal [15] to study \( \theta_{13} \) and \( \delta_{\text{CP}} \) with a source of \( \bar{\nu}_e \) [16, 17] using the \( \bar{\nu} \) flux ratio \( F_{\bar{\nu}}/(F_\tau + F_\nu) = P_{\bar{\nu}\mu}/(1 - P_{\bar{\nu}\mu}) \). Since the shift due to \( \delta_{\text{CP}} \) and \( P_{\bar{\nu}\mu} \) around \( 0^\circ \) is \( \delta \bar{\nu}/b = 0.02 \), first we should know the impact of \( \theta_{23} \). If this were negligible, the number of \( e + \tau \) signal events \( N \) should obey \( \delta N/N \leq 10\% \). This needs 60 years of an ideal detector and a small systematic \( \delta b/b \leq 1\% \), if we use the event rates per year in a km\(^2\) area of [15] \( s = 16 \) (signal) and \( b = 145 \) (background): 10\(^5\) signal events over 10\(^4\) events. We get instead \( s = s_e + s_\tau = 1.3 \) \( s_e = N_t \int_{0}^{\infty} \sigma(E) F_\nu(E) dE; \) targets: \( N_t = 4.5 \times 10^{38} \) nucleons; flux from [16], fig.1: \( 7 \times 10^{26} (E/\text{TeV})^{-3.1} \text{ 1/TeV yr km}^2 \) with \( P_{e\tau} \approx 0.6 \); cross section: \( 4 \times 10^{-36}(E/\text{TeV})^{0.87} \text{ cm}^2 \). Even assuming the source is real, with \( s = 1.3 \) the question is whether a signal can be seen.}

2.2 The connection between \( \gamma \) and \( \nu \)

For RX J1713.7-3946 there are various calculations in the literature:

1. Alvarez-Muniz & Halzen '02 [18] inspired by CANGAROO first observations use \( F_\gamma \propto E^{-2} \) and obtain \( F_\mu = F_{\nu\mu} \propto F_\gamma \) by

\[ \int_{E_{\gamma}^{\text{max}}}^{E_{\gamma}^{\text{min}}} dE_\gamma E_\gamma F_\gamma(E_\gamma) = \int_{E_{\nu}^{\text{min}}}^{E_{\nu}^{\text{max}}} dE_\nu E_\nu F_\nu(E_\nu) \]

2. Costantini & V '04 [14] use \( F_\gamma \propto E^{-2.2} \) as extrapolated from early H.E.S.S. below 10 TeV results and adopt standard techniques (see e.g., [19, 20])

\[ F_\gamma = \frac{\Delta X}{X_p} \frac{2Z_{\text{proj}}}{\Gamma} F_p \text{ and similarly for } F_\nu \]

Both methods, however, are tailored for power law spectra; and we know from the only detailed observation that we have (RX J1713.7-3946) that this is not a good approximation. Thus we are lead to recalculate the neutrino
fluxes. In principle, one could de-convolute the CR flux from the \( \gamma \)-ray flux and then obtain the neutrino flux, as described in the lecture of K.-H. Kampert. In our case, when the atmosphere (the target for CR) is much thinner—it is transparent—a much simpler and direct approach \[21\] is possible based on the classical techniques of Lipari '88 \[22\]. In fact, from the integral expression for VHE \( \gamma \)-rays

\[
F_{\gamma}(E) = \int_{E}^{\infty} \frac{dE'}{2} F_{\pi^0}(E')/E'
\]

we find immediately:

\[
F_{\pi^0}(E) = -\frac{E}{2} \frac{dF_{\gamma}}{dE}
\]  

(1)

Due to the approximate isospin-invariant distribution of pions, \( F_\pi \equiv F_{\pi^0} \approx F_{\pi^+} \approx F_{\pi^-} \), we find for the neutrinos from \( \pi^+ \rightarrow \mu^+\nu_\mu \):

\[
F_{\nu_\mu}(E) = \int_{E/(1-r)}^{\infty} \frac{dE'}{1-r} \frac{F_\pi(E')}{E'} = \frac{F_\gamma(E/(1-r))}{2(1-r)}
\]  

(2)

where \( r = (m_\mu/m_\pi)^2 \). The neutrinos \( \nu = \bar{\nu}_\mu, \nu_e \) from \( \mu^+ \) decay are:

\[
F_{\nu}(E_{\nu}) = \int_{0}^{1} \frac{dy}{y} F_\mu(E_\mu) \left[ g_0(y) - \bar{P}_\mu(E_\mu) g_1(y) \right] \text{ where } E_\mu = \frac{E_{\nu}}{y}
\]  

(3)

g_i \text{ are polynomials, } F_\mu \text{ and } \bar{P}_\mu \text{ (polarization averaged over } \pi \text{ distribution) are also known. The contributions of semileptonic } K^\pm \text{ decays to the } \nu'\text{s and the one of } \eta \rightarrow \gamma\gamma \text{ to } \gamma\text{-rays can be described with a contribution proportional to the pionic one; these two correct the formulae in opposite directions so that effectively one should just add a contribution of kaons of the order of 10 percent. For details, see \[21\].}

2.3 **A case study: RX J1713.7-3946**

The neutrino flux, evaluated as described above, is shown in figure 1 and table 1. For the purpose of illustration, we use it to calculate the number of muon events \( N_\mu + N_{\bar{\mu}} \) for an *ideal detector*\(^2\) using:

\[
N_\mu = A \cdot T \cdot f_{liiv} \cdot \int_{E_{th}}^{\infty} dE_{\nu} F_{\nu_\mu}(E_{\nu}) \left[ Y_{\nu}(E_{\nu}, E_{th}) (1 - P_{\nu_\mu}(E_{\nu})) \right]
\]

where \( E_{\nu} \) is the neutrino energy before the interaction point and the various quantities in the previous formula are defined as follows:

\(^2\text{By definition, ‘ideal detector’ means that all muons above threshold are detected: } \epsilon(E_\mu) = 1 \text{ for } E_\mu > E_{th}. \text{ Of course in a real detector (where the geometrical area } A \text{ changes with the time of observation } t \text{ and, above all, the efficiency } \epsilon \text{ increases with the energy) the impact of the cut in the spectrum is expected to be much more important.}
Figure 1: $\nu_\mu$ spectra, corresponding to two fits of the H.E.S.S. VHE $\gamma$-rays from RX J1713.7-3946 [7]: a broken power law and a power law with exponential cutoff; the third fit—a curved power law—is incompatible with a hadronic origin, for it increases before 40 GeV. The $\bar{\nu}_\mu$ flux is the same in our approximation.

- $A = 1$ km$^2$ and $T = 1$ solar year.
- The source is below ANTARES horizon (=visible) for $f_{\text{liv}} = 78 \%$.
- The threshold for muon detection is $E_{\text{th}} = 50$ GeV (as low as possible).
- The muon range (that goes in the yield $Y_\mu$) is calculated for water.
- The neutrino absorption coefficient $a_{\nu_\mu}$, averaged over the daily location of the source, is calculated for standard rock.

We find that the total number of events does not depend crucially on the extrapolation:

$$N_\mu + N_{\bar{\mu}} = \begin{cases} \text{4.8 per km}^2 \text{ per year} & \text{[exponential cutoff]} \\ \text{5.4 per km}^2 \text{ per year} & \text{[broken power law]} \end{cases}$$

This can be compared with the 9 events in [14] (power law extending till 1 PeV) and the 40 events in [18] (oscillations, livetime and absorption ignored).

| $E$  | 0.1  | 0.2  | 0.4  | 0.6  | 0.8  | 1    | 2    | 4    | 6   |
|------|------|------|------|------|------|------|------|------|-----|
| exp. | 5.1e2| 1.3e2| 3.1e1| 1.4e1| 7.4e1| 4.6e1| 1.0e0| 1.9e-1| 6.1e-2|
| brok.| 5.9e2| 1.4e2| 3.4e1| 1.4e1| 7.9e0| 5.0e0| 1.1e0| 1.9e-1| 6.1e-2|

| $E$  | 8    | 10   | 20   | 40   | 60   | 80   | 100  | 200  | 300 |
|------|------|------|------|------|------|------|------|------|-----|
| exp. | 2.6e-2| 1.3e-2| 8.7e-4| 2.4e-5| 1.4e-6| 1.2e-7| 1.3e-8| 4.4e-13| 3.0e-17|
| brok.| 2.6e-2| 1.3e-2| 1.4e-3| 1.4e-4| 3.7e-5| 1.4e-5| 6.9e-6| 7.0e-7| 1.8e-7|

Table 1: Differential $\nu_\mu$ flux from RX J1713.7-3946 for selected energies (1st and 4th lines). Units: TeV for the energy, 1e-12/TeV s cm$^2$ for the flux.
3 Summary and perspectives

We discussed the expected neutrino flux from $\gamma$-transparent accelerators of cosmic rays, and emphasized the case of young SNR. We showed that for RX J1713.7-3946 (the best known SNR in TeV sky, thanks to H.E.S.S.) the expectations are stable: $\sim 5$ events per km$^2$ per year in an ideal detector. The median neutrino energy is 3 TeV. Since the detected $\mu$ are softer than the $\mu$ in the production point (that in turn is softer than the impinging $\nu$) several events will fall in an energy region where the atmospheric background and the role of imperfect detection efficiency are important: see the lectures of Lipari and Lucarelli. Thus, we believe that it would be desirable to have a detailed discussion of the characteristics of a detector that aims to see a $\nu$ signal from RX J1713.7-3946.

Sometimes soon H.E.S.S. should tell us more on another intense VHE $\gamma$-ray source, RX J0852.0-4652 (Vela Jr). This SNR has $F_\gamma = 6.5$ million $\gamma$-rays $E^{-2.1}/$(TeV km$^2$ yr) below 10 TeV. If the exponential cutoff is at $E_{\gamma\text{cut}} = 50$ (150) TeV (and again, if these $\gamma$ rays are of hadronic origin) we get $N_\mu + N_{\bar{\mu}} = 10$ (14)/(km$^2$ yr) in an ideal detector, with a significantly higher energy \[21\].

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A Details of signal evaluation

Following \[14\] and \[21\], we describe here two specific elements used for the evaluation of the signal and comment on them.

A.1 Muon background

It should be possible to increase the acceptance by designing an angular cut that depends on the energy and on the time of the event. Yet, here we follow the simplest prescription to exclude cosmic muon contamination: accept only the events below the horizon of the detector. The angle $\theta$ between an
astronomical object and the vertical of the detector is

$$\cos \theta(t) = (\cos \delta, 0, \sin \delta) \cdot (\cos \phi \cos(\pi t/\tau), \cos \phi \sin(\pi t/\tau), \sin \phi)$$

where 1) $\delta$ is the declination of the object (for the two sources discussed in the text: RX J1713.7-3946 = $-39^\circ46'$, RX J0852.0-4652 / Vela Jr = $-46^\circ52'$); 2) $\phi$ is the latitude of the detector (for the detectors in the Northern hemisphere: Baikal = $51^\circ50'$, ANTARES = $42^\circ50'$, NEMO = $36^\circ30'$, NESTOR = $37^\circ33'$); 3) $2 \times \tau = 23^h56^m4^s$ is the duration of the sidereal day; 4) $t$ is the time measured from the point when the object is at the apex. If $\cos \theta(t = 0) < 0$, the object remains always below the horizon; if the converse happens, but $\cos \theta(t = \tau) < 0$, the object is observable for a fraction of the time $1 - \tau_0/\tau$, determined by the condition $\cos \theta(\tau_0) = 0$.

### A.2 Earth absorption

The Earth absorption of the neutrino depends on the time $t$ through the average column density in the Earth and it is mostly due to CC interactions. NC interactions are $\sim 1/3$ smaller and, furthermore, cannot remove a neutrino, but only degrade its energy. A detailed evaluation of this effect is numerically demanding [23], however it supports the expectations from a simple heuristic argument inspired to the formalism of ‘scaling’ (proper of strong interaction): NC interactions increase the absorption, but only by few %. Thus in a first approximation NC effect can be neglected.

### A.3 Comments

In the light of the new H.E.S.S. results, it is useful to note that:

1. Accepting events from a few degree above the horizon (that is, setting the cut to a certain value $\cos \theta_0 > 0$) can lead to significant increase of the events, especially for RX J1713.7-3946 [24]. E.g., for ANTARES the fraction of time becomes $f_{\text{live}} = 88\%$ just adding 5 degrees above the horizon.

2. The absorption coefficient obtained by the approximate procedure mentioned in sect. A.2 using a power law distribution $E^{-2.2}$ and averaged over the fraction of the time when $\cos \theta(t) < 0$ is very similar for RX J1713.7-3946 and for Vela Jr (slightly weaker in the second case).

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$^3$For a cosmic muon that reaches the depth of 1 km under the surface, $5^\circ$ means more than 12 km of water but recall that a muon can change its direction by scattering.
3. If the neutrinos are confined to be of relatively low energy, as it is the case of RX J1713.7-3946, the effect of Earth absorption is small.

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Discussion

AURELIO GRILLO: 1) How reliable is the $\gamma$-transparency hypothesis? 2) What is the relative weight of oscillations and correct spectrum?

FRANCESCO VISSANI: 1) For a SNR as RX J1713.7-3946 it is possible to check that the matter is very diffuse either distributing several solar masses in the wide volume, or more directly using X-ray data, so that the absorption of $\gamma$-rays is negligible. E.g., for the molecular cloud: $100 \, M_\odot$ at 1 kpc and a size of 15' means a column density of about $2 \times 10^{20}$ protons/cm$^2$ (10 protons per cm$^3$). For other sources as $\mu$QSO (namely, stellar black holes or neutron stars with jets) this does not apply and a relatively weak $\gamma$-radiation could be compatible with intense $\nu$ fluxes \cite{note:25}.

2) Again for RX J1713.7-3946, each of the two effects reduce the signal in an ideal detector by a factor of $1/2$. However oscillations are universal whereas deviations from power-law depend on the individual object. We hope this is less pronounced for Vela Jr, and wait for the response of H.E.S.S.

GIANNI NAVARRA: Is it possible to “extrapolate” these calculations in order to obtain a neutrino luminosity from the galactic disk, in the hypothesis that all CR are produced by SNR?

FRANCESCO VISSANI: Strictly speaking the results in eqs.\cite{note:1,note:2,note:3} are just a tool to assess an upper bound to $\nu$ from $\gamma$-transparent sources (or if you like it more, a lower bound to $\nu$ from VHE $\gamma$ ray sources of hadronic origin) and I can only hope that they will be useful for tasks as the one you

\footnote{It was suggested that $\mu^\pm$ (but not $\pi^\pm$) are absorbed in $\mu$QSO. This leads to a peculiar flavor neutrino ratio, as for $\bar{\nu}$ from hypothetical neutron sources (see footnote\cite{note:1}). Of course, before testing flavor ratios we should be sure that we can at least observe muon neutrinos above TeV and the most cautious attitude would suggest to perform all possible tests with conventional means first.}
propose. One ingredient for the calculation seems to be the following: if we have a new SN each 30 years and if they are mostly active for some thousand years, we have 40-80 SNR that inject CR effectively in each moment. These are most likely located in the spiral arms of the Milky Way, but we can get a rough idea of their distribution assuming that their density is $r \exp(-r/r_0)$, with $r_0 \sim 3$ kpc [26]. In this way we can find the expected distance of the closest one, their average distance, etc. These results could/should be cross-checked with SNR databases. An obstruction could arise in the description of an ‘average’ SNR: at different ages the intensity and the distribution of $\gamma$-rays could change. In fact, I suspect that the SNR that we are beginning in the $\gamma$-rays sky are peculiar objects, as those associated with molecular clouds, and/or the brightest/closest ones.

BERND ASCHENBACH: Just a comment: Even if it should turn out that the TeV spectrum in RX J1713.7-3946 is dominated by hadronic processes, it is also very useful to compute the contribution of leptonic processes, since it should be there if adiabatic diffusive acceleration (involving protons and electrons) at the SNR shock front is universal. The question is at which level.

FRANCESCO VISSANI: Certainly this task is of paramount importance. Despite the difficulties, it should profit from the accumulation of new observations, it can be approached in concrete models of CR acceleration (such as [8] and [9]) and it is presented in a moderately optimistic perspective in a recent authoritative review work [32].

But I would like to use this occasion to recall that, beside the contribution from leptons to $\gamma$ rays spectrum, there is also a hadronic contribution to the spectrum of hard X-rays. This originates from the non-thermal population of electrons produced in muon decays [33] (incidentally, no new formula is needed to describe the flux of electrons or positrons for this is just the same as the one of $\bar{\nu}_e$ or $\nu_e$, see eq. [3] that could provide us with a further handle to disentangle the components of leptonic and hadronic origin.

\footnote{Just after Vulcano 2006 several papers appeared addressing this type of problem [27, 28, 29], mostly using assumptions on the CR flux at least for intermediate steps. More information and discussion in two subsequent conferences [30] and [31].}