

WG III Report on TeV Particle Astrophysics

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Abstract. This working group focused mainly on the complementarity among particle physics and astrophysics. The analysis of data from both fields will better constrain theoretical models. Much of the discussion focused on detecting dark matter and susy particles, and on the potential of neutrino and gamma-ray astrophysics for seeking or constraining new physics.

1. Introduction

Complementarity among particle physics and astrophysics was the tone of the discussions in this working group. Both theoretical and experimental aspects of this complementarity were discussed. There were eleven talks, three on detecting supersymmetric particles (more specifically Next to Lightest Supersymmetric Particles) in km³ neutrino telescopes, a talk on possibilities of finding new physics with ultra high energy neutrinos, two talks on a mechanism for generating TeV gamma-rays and neutrinos (photo-dissociation followed by nuclear de-excitation) largely ignored by the gamma-ray community, a talk on better constraining supersymmetric parameters when combining astrophysics with LHC data, two talks on dark matter, a talk on constraining spacetime foam with neutrinos, and a talk on a novel way to determine the Higgs field.

2. Detecting NLSPs with neutrino telescopes

Zackaria Chacko reported on his work [?], in which the possibility of detecting the Next to Lightest Supersymmetric Particle (NLSP) with neutrino telescopes was first suggested. Within susy scenarios in which the breaking scale is on the lighter side (below 10¹⁰ GeV), the lightest supersymmetric particle (LSP) is the gravitino. In most models within these scenarios the NLSP is a charged long lived slepton (typically the right handed $\tilde{\tau}$). The work reported here determines that NLSPs produced in high energy neutrino interactions inside the Earth can be detected in neutrino telescopes.

Although the NLSP production cross section is low (about three orders of magnitude lower than lepton production from the same interactions), the energy loss of these particles going through the Earth is also very small. This makes the NLSP range large, typically thousands of kilometers. The large range compensates for the low production cross section, making possible the NLSP detection. Moreover, the NLSPs will always be produced in pairs and go through the detector. As its energy loss is small it will look like a pair of low energy muons going

through the detector. The main background will be dimuon events originating from decay of charmed particles, themselves produced from neutrino interactions in the Earth. Although the dimuon background rate is slightly higher than the NLSP's, it can be effectively reduced by three cuts: track separation in the detector, a high energy cut, and a full track requirement [?]. The conclusion is that km^3 neutrino telescopes can detect NLSPs if the gravitino is the LSP. In this way it will probe the supersymmetry breaking scale in a fashion complementary to susy measurements at the LHC.

Markus Ahlers described his work on the same subject [?] and concluded that single $\tilde{\tau}$ events (occurring when one $\tilde{\tau}$ misses the detector) play a subdominant role when compared to muon events and will not affect the determination of the cosmic neutrino flux. He also discussed the possibility of stau trapping in the detector.

Mary Hall Reno presented her work on the $\tilde{\tau}$ energy loss. The radiative energy loss [?] was determined. It is slightly dependent on the energy. The main contribution is the loss due to photonuclear interactions. A comparison between the energy loss determined by the scaling of the lepton to the slepton mass to a direct calculation of each radiative process (pair production, bremsstrahlung and photonuclear) shows that the scaling calculation overestimates the energy loss by a factor of two. She also presented work on $\tilde{\tau}$ weak interactions [?]. The $\tilde{\tau}$ charge current interaction will remove the particle while the neutral current contributes to its energy loss. She showed that the neutral current weak interaction will always be subdominant when compared to the photonuclear energy loss. The charged current interaction may however be significant for $\tilde{\tau}$'s energies above 10^9 GeV, depending on the particular parameters of the model.

3. Ultra High Energy Neutrinos as a Window to New Physics

Ina Sarcevic pointed out the importance of ultra high energy neutrinos in revealing new physics. Since neutrinos are stable and neutral they point back to their sources without losing energy. This makes neutrino astronomy a unique window in looking deep into sources as well as looking to processes which occurred back in the past.

Probable sources of ultra high energy neutrinos are the same as the ones which produce ultra high energy cosmic rays ("cosmogenic" or "GZK" sources), Active Galactic Nuclei and Gamma Ray Bursts. Some more speculative sources such as topological defects and Z-bursts (at the level of the AGASA rate) seem to be incompatible with some data. One has to bare in mind that new physics might modify neutrinos interactions, and alter the SM conclusions. Also, there is a large uncertainty on the ultra high energy neutrino cross section. Neutrino signatures in various detectors such as neutrino or cosmic ray telescopes were discussed.

Specific examples of new physics to be probed by neutrinos were discussed. These were microscopic black holes as predicted by TeV scale gravity models; exchange of Kaluza-Klein gravitons; production of charged sleptons in neutrino interactions; and electroweak instanton-induced processes.

4. TeV Gamma Rays and Neutrinos from Nuclear Photo-dissociation/De-excitation

It is well known that TeV gamma-rays can originate in two different ways in astrophysical sources, either in electromagnetic (electron bremsstrahlung, inverse Compton scattering, synchrotron radiation) or hadronic processes (through π^0 production in pp or $p\gamma$ interactions). The talk by **Sergio Palomares-Ruiz** was devoted to a third mechanism: the photo-disintegration of nuclei at the source, followed by the de-excitation of the daughter nuclei. Although discussed some time ago [?], this mechanism has been largely ignored by the gamma-ray community.

The basic idea is as follows. A highly relativistic nucleus propagates in a photon background. If the boost factor of this nucleus is such that photo-excitation via the Giant Dipole Resonance

(GDR) is possible ($\epsilon_\gamma \sim 10 \text{ MeV} - 30 \text{ MeV}$ in the nucleus rest frame), then the emission of MeV gamma-rays from the excited daughter nucleus (in the rest frame of the nucleus) results. To get TeV gamma-rays in the lab from MeV GDR energies in the nuclear frame, the boost factor should be $\sim 10^6 - 10^7$. But this implies that in order to reach the GDR energy, the ambient photons must have energies in the far ultraviolet; such is expected from Lyman α emissions of hot stars. It was also shown that (i) this process effectively sets a lower limit on the resulting gamma-ray energy, with no counterpart at lower energies, (ii) that a low density interstellar medium is needed in order for this process to dominate over the π production and decay mode, and that (iii) concomitant stripped neutrons will β -decay to give rise to an associated flux of TeV antineutrinos (smaller than the flux of gamma-rays).

As a follow up of Palomares-Ruiz's talk on the nuclei photo-disintegration/de-excitation mechanism for TeV gamma-ray production, **Haim Goldberg** applied the mechanism to a particular TeV gamma-ray data set for which there is no compelling explanation. This is the HEGRA data [?] from the CygnusOB2 region. CygnusOB2 is a massive starburst association. This region is very rich in hot, young stars, and could provide the right ambient photon background for the mechanism sketched above. Goldberg showed three important features which arise from the characteristics of this region: (i) the dissociation time is larger than the diffusion time so that a single-dissociation calculation is valid, (ii) the observed gamma-ray flux is expected to have roughly the same power index as the source's nuclear flux, and (iii) there is a sharp cutoff predicted at $\sim 0.5 \text{ TeV}$, with no lower energy counterpart.

Goldberg concluded that the required nuclear density must arise from high efficiency acceleration of abundant nuclei trapped at much lower energies, and that all the energy requirements are satisfied by the CygnusOB2 region. Finally, he showed that the calculated CygnusOB2 neutrino signal from the concomitant neutron decay is not statistically significant in the forthcoming IceCube experiment.

5. Constraining Supersymmetry Parameters with Astro- Plus LHC Data

Dan Hooper reported on the complementarity of astrophysics data and the LHC. The LHC is aimed at discovering new physics including supersymmetric particles. Under the assumption that supersymmetry will stabilize the standard model in the TeV region, the LHC will be able to determine the LSP mass within 10%. Depending on the mass scale, it will be possible to determine sleptons, squark and heavier neutralino masses. However it will be hard to determine various supersymmetry parameters, including the bino/wino/higgsino composition of neutralinos.

Hooper showed that it is possible to determine the neutralino composition when combining astrophysical measurements with LHC data. This is possible because the neutralino's annihilation and elastic scattering cross sections are very sensitive to its composition. Dark matter direct detection will probe the correlation between the elastic scattering cross section, the neutralino composition, and the susy parameters $\tan \beta$, a and [?]. If the elastic scattering is spin dependent, the constraints from direct detection will remain very weak, and indirect detection via annihilation might contribute to the determination of the above parameters [?].

As gammas compose the neutralino annihilation products, they might also bring information on neutralino properties. Gamma ray observations might contribute to determine the fraction of various annihilation products, but will not help on determining the total cross section. Positron observations might contribute to pin down the total cross section. The positron flux generated in neutralino annihilation is dominated by our Galactic dark matter distribution.

Hooper also showed that the combination of these results with LHC measurements can not only help determine the composition of the neutralino, but can also break the degeneracies of the coannihilation/funnel/bulk parameter space, and can determine m_A for models in the A-funnel region of the parameter space.

6. Dark Matter

6.1. Bounds on Dark Matter Annihilation Cross Section

John Beacom reported on bounding the dark matter (DM) annihilation cross section using neutrino fluxes [?]. The size of the annihilation cross-section depends on the DM model. For example, if the DM is a thermal relic it will have a very different annihilation cross section than if it only appeared or grew mass in the late universe.

Previous work bounded the annihilation cross section from the visible annihilation products, especially the resulting diffuse photon flux. Beacom reported on an opposite approach, where the bound is determined from the “invisible” neutrino annihilation products. In assuming that all DM annihilates 100% into neutrinos, the bound which results closes a loophole, namely the possibility that DM annihilates into visible particles is negligible.

As DM traces density square, the determination of the neutrino flux requires an integration over the DM halo radial density profile, the distribution of halo masses and their evolution with redshift. This is dealt with by adapting the prior calculation of the photon bound [?]. The resulting neutrino signal has a sharp feature, which can be compared to the atmospheric neutrino background published by AMANDA, Frejus and Super-Kamiokande. This comparison allows the determination of an upper bound on the DM annihilation cross section. By closing the loophole mentioned above, the bound rules out the KKT [?] model of structure formation, which proposed DM self annihilation to soften halo cusps. Although the new bound does not reach the natural scale of thermal relics, it can be improved as new data appears from Super-Kamiokande and IceCube.

6.2. Squishing Dark Matter with Black Holes

Gianfranco Bertone reported on enhancement of dark matter (DM) annihilation due to Black Holes. The idea is that DM mini-halos will react to the formation or adiabatic growth of Intermediate Black Holes (IBH) annihilating into mini-spikes. He showed that the adiabatic growth of a massive object at the center of a DM distribution will induce redistribution of matter. If the DM density profile follows a power law with spectral index γ , the DM will be redistributed into a new power law with index $(9 - 2\gamma)/(4 - \gamma)$. Near $r = 0$ a DM mini-spike will occur.

DM annihilation at the mini-spikes will produce bright gamma-rays [?]. Each IBH spike can be as bright as the whole galaxy. This radiation can be detected by Air Cherenkov Telescopes such as Cangaroo, Hess, Magic and Veritas, if they extend their observations to higher energies. Better is a full sky survey, such as will happen with GLAST. However, GLAST is not sensitive to energies above 300 GeV and so might miss the DM detection if the DM mass is heavy. Bertone showed the expected flux as a function of the number of black holes for Glast and EGRET [?].

Another possibility for finding DM mini-spikes is with neutrino telescopes. It was argued that mini-spikes can also be bright sources of neutrinos. The rates expected for ANTARES and IceCube are encouraging [?], with ANTARES being better located since it can see the Galactic center.

7. Spacetime Foam

Luis Anchordoqui reported on a study using the flavor ratios of incoming cosmic neutrinos at IceCube to improve bounds on the scale of quantum gravity, M_{QG} . It is often stated that the quantum effects of gravity may never be experimentally accessible because they would be manifest only at the Planck scale, $M_{Pl} \equiv \sqrt{\frac{\hbar c}{G_N}} \simeq 1.2 \times 10^{19}$ GeV. However, being a non-renormalizable interaction, gravity may leave a distinctive imprint at energies much lower than the Planck scale, akin to observable parity violation in β -decay at energies far below the $G_F^{-1/2}$ scale of the weak interaction. For example, if quantum space-time has a ‘foamy’ structure in

which Planck length size black holes form and evaporate on the Planck time scale, then there may be a loss of quantum information across their event horizons which induces decoherence of a pure state. The particle most sensitive to such effects would appear to be the pure neutrino state which gives rise to neutrino flavor oscillations.

A heuristic view of decoherence induced by neutrino interactions with the virtual black holes is that flavor is randomized by these interactions, since black holes are believed not to conserve global quantum numbers. The visible effect of quantum decoherence, then, would be to alter the neutrino flavor ratios $\nu_e : \nu_\mu : \nu_\tau$ to $\simeq 1 : 1 : 1$, regardless of the initial flavor content. Since the decoherence effects grow with the distance traveled by the (anti) neutrinos, observation of a cosmic ν -flux with flavor ratios $\neq 1 : 1 : 1$ could place strong constraints on the energy scale of quantum decoherence. It has recently been suggested [?] that antineutrinos originating in the decay of neutrons from photo-dissociated cosmic ray sources in the Galaxy [?] can provide a very sensitive probe of foam dynamics. Present limits are $M_{\text{QG}} > 10^{16}$ GeV from pp -annihilation into a BH, and $M_{\text{QG}} > 10^{28/(n-1)}$ GeV from SuperKamiokande flavor measurements, where n is the power of the decoherence parameterization $\sim M_{\text{QG}} (E/M_{\text{QG}})^n$ [?]. Anchordoqui claimed that IceCube will dramatically improve the sensitivity to decoherence effects [?]. With future data, perhaps from Galactic neutron $\rightarrow \bar{\nu}_e$ sources, IceCube can reach $M_{\text{QG}} > 10^{46/(n-1)}$ GeV.

8. Higgs Field

Stephen Reucroft proposed a novel way [?] to detect the Higgs sector. His idea is to look for the Higgs field instead of looking for the Higgs particle. His argument is that at short range, such as exists in momentarily is pair production, the Higgs Yukawa potential alters the effective masses of the pair particles. He proposes to look for an effect in the threshold cross section of massive pair production. The reaction $e^+e^- \rightarrow W^+W^-$ provides an optimized laboratory.

In the group discussion that followed his report, it was argued that this effect is small, and debated whether radiative corrections already include this effect.

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