

Hadronic-Origin orphan TeV flare from the 1ES 1959+650

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Abstract

The 1ES 1959+650 is a high-peaked BL Lacertae object. On 4th of June, 2002, it exhibited a strong TeV flare without any low energy counterpart, providing for the first time an example of an *orphan* flare from a blazar. Observation of this orphan flare is in striking disagreement with the predictions of the leptonic models thus challenging the conventional synchrotron self-Compton (SSC) interpretation of the TeV emission. Here we propose that, the low energy tail of the SSC photons in the blazar jet serve as the target for the Fermi-accelerated high energy protons of energy $\lesssim 100$ TeV, within the jet to produce the TeV photons through the decay of neutral pions from the delta resonance. Our model explains very nicely the observed TeV flux from this orphan flare and we also estimate the high energy neutrino flux from this flaring event.

PACS numbers: 98.54.Cm; 98.70.Rz; 98.70.Sa

I. INTRODUCTION

Blazars are a subclass of active galactic nuclei (AGNs) which include flat-spectrum radio quasars (FSRQs) and BL Lacertae (BL Lac) objects. Both FSRQs and BL Lac are characterized by strong and rapid flux variability across the entire electromagnetic spectrum which are predominantly nonthermal. The emission extends all the way from radio to γ -ray and is believed to be produced in a highly relativistic plasma jet pointing along the line of sight to the observer. Due to the small viewing angle of the jet, it is possible to observe the strong relativistic effects, such as the boosting of the emitted power and a shortening of the characteristic time scales, as short as minutes[1, 2]. Thus these objects are important to study the energy extraction mechanisms from the central super-massive black holes, physical properties of the astrophysical jets, the acceleration mechanisms of the charged particles in the jet and production of ultra high energy cosmic rays. The spectral energy distribution (SED) of blazars is characterized by two nonthermal bumps [3, 4] and depending on the location of the first peak of the SED, these are often sub-classified into low energy peaked blazars (LBLs) and high energy peaked blazars (HBLs)[5]. In LBLs, the first peak is in the near-infrared/optical energy range and for HBLs it is in the UV or X-rays range, while the second peak is around GeV energy range for LBLs and for HBLs it is in the TeV energy range.

There is a general consensus that the low energy peak is produced due to the synchrotron emission from accelerated electrons and positrons in the emitting region. Although, the origin of the high energy peak remains inconclusive, the leading interpretation is the SSC model, where the high energy emission is from a population of relativistic electrons up scattering their self-produced synchrotron photons[6] or by external photons. This model is found very successful in explaining the multi-wavelength emission from BL Lac objects and FR I galaxies such as NGC 1275 and M87 [4, 6] and also Centaurus A[7, 8]. The inevitable outcome of the leptonic models is that, flaring at TeV energy should be accompanied by a simultaneous flaring in the synchrotron peak. Alternatively, in the hadronic models, the high energy peak is produced due to proton synchrotron emission or decay of neutral pions formed in cascades from the interaction of high energy proton beam with the radiation or gas clouds surrounding the source [9]. In this scenario, a strong correlation between the gamma-ray and the neutrino fluxes is expected [10–12].

The AGN 1ES 1959+650 was first detected in the Einstein IPC Slew Survey[13] and classified as a HBL subclass, based on its X-ray to radio flux ratio[14]. It has a redshift of $z = 0.047$ [15] with a luminosity distance of $d_L = 210$ Mpc and the mass of the central black hole is estimated to be $\sim 1.5 \times 10^8 M_\odot$. Because of the HBL subclass and low redshift, it had long been considered a potential candidate for TeV γ -ray source. The first very high energy (VHE) gamma-ray from 1ES 1959+650 was observed in 1998 by the Seven Telescope Array in Utah, with a 3.9σ significance[16] and later on other observations were also reported but the observed flux was weak in both gamma-rays and in X-rays. The HEGRA collaboration reported only a marginal signal during its observations from 2000 until early 2002. In May 2002, 1ES 1959+650 underwent a strong TeV outburst which was observed by Whipple[17] and HEGRA experiments[18] as well as in the X-ray range by RXTE experiments. The X-ray flux smoothly declined throughout the following month. However, during this smooth decline period, a second TeV flare was observed after few days (on 4th of June) of the initial one without a X-ray counterpart[19]. On the other hand, In July 2006, the BL Lac PKS 2155-304 had a giant TeV flare recorded by HESS[2] which was accompanied by an increase in X-ray flux and can be explained through SSC model. So the observation of the “orphan” flare in 1ES 1959+650 is in striking disagreement with the predictions of the leptonic models thus challenging the SSC interpretation of the TeV emission. Non observation of a significant X-ray activity could naturally be interpreted by the suppression of electron acceleration and inverse Compton scattering as production mechanism for very high energy (VHE) gamma rays in favor of hadronic models. Motivated by the above argument, a hadronic synchrotron mirror model was proposed by Böttcher[20] to explain this orphan TeV flare and also the neutrino flux is estimated during the flaring[10]. In this model, the flare is explained through the decay of neutral pions to gamma rays when the former are produced due to the interaction of high energy cosmic ray (HECR) protons with the primary synchrotron photons that have been reflected off clouds located at a few pc above the accretion disk. These photons are blue shifted in the jet frame so that there will be substantial decrease in the HECR proton energy to overcome the threshold for delta resonance and, at the same time, it is an alternative to the standard scenario where HECR protons interact with the synchrotron photons, where one needs HECR protons to be Fermi accelerated to high energy. But the idea of the reflection of synchrotron photons off-cloud at a few pc above the accretion disk demands a special geometry of the jet+cloud system,

which plays a vital role. Also how efficiently these photons will be reflected from the cloud is rather unclear.

II. THE HADRONIC MODEL

In a recent paper Sahu and Zhang[21] have shown that the multi-TeV emission from the AGN, Centaurus A, detected by HESS during 2004 to 2008 can be well interpreted as the decay of neutral pions from the Δ -resonance of $p\gamma$ interactions of Fermi-accelerated high energy protons in the jet with the seed photons around the second SED peak at ~ 170 keV. It is also shown that this same model is consistent with the detection of two ultra-high energy cosmic ray events by Pierre Auger Observatory from the Centaurus A direction. After the success of the hadronic model to explain the multi-TeV photon flux from Centaurus A[21], we would like to apply it to the orphan TeV flare of 1ES1959+650. Here we assume the standard interpretation of the leptonic model to explain both, low and high energy peaks, by synchrotron and SSC photons respectively as in the case of Centaurus A. Thereafter, we propose that the low energy tail of the SSC photons in the jet serve as the target for the Fermi-accelerated high energy protons to produce the pions through delta resonance and their subsequent decay to high energy photons. In this scenario the condition of Böttcher[20] is automatically satisfied without the need of a special geometry.

The SED of the 1ES1959+650 is fitted quite well with the leptonic one-zone synchrotron and SSC model[22, 23]. In this model, the emitting region is a blob with comoving radius R'_b moving with a velocity β_c corresponding to a bulk Lorentz factor Γ and seen at an angle θ_{ob} by an observer which results with a Doppler factor $\mathcal{D} = \Gamma^{-1}(1 - \beta_c \cos \theta_{ob})^{-1}$. The emitting region is filled with an isotropic electron population and a randomly oriented magnetic field B' . The electrons have a power-law spectrum given as $dN/dE \propto E^{-\alpha}$ with the power index $\alpha \geq 2$.

The energy spectrum of the Fermi-accelerated protons in the blazar jet is also assumed to be of power-law. Due to high radiative losses, electron acceleration is limited. On the other hand, protons and heavy nuclei can reach UHE through the same acceleration mechanism.

The pion production in $p\gamma$ collision through Δ -resonance is

$$p + \gamma \rightarrow \Delta^+ \rightarrow \begin{cases} p \pi^0, & \text{fraction } 2/3 \\ n \pi^+ \rightarrow n e^+ \nu_e \nu_\mu \bar{\nu}_\mu, & \text{fraction } 1/3 \end{cases}, \quad (1)$$

which has a cross section $\sigma_{\Delta} \sim 5 \times 10^{-28} \text{ cm}^2$. The charged π 's subsequently decay to charged leptons and neutrinos, while neutral π 's decay to GeV-TeV photons. For the above process to take place, the center-of-mass energy of the interaction has to exceed the Δ -mass 1.232 GeV which corresponds to the kinematical condition

$$E'_p = \frac{(m_{\Delta}^2 - m_p^2)}{2\epsilon'_{\gamma}(1 - \beta_p \cos \theta)} \simeq \frac{0.32 \text{ GeV}^2}{\epsilon'_{\gamma}}, \quad (2)$$

where E'_p and ϵ'_{γ} are the proton and the background photon energies in the comoving frame of the jet, respectively (quantities with a prime are in the comoving frame and without prime are in the observer frame). Also for high energy protons we take $\beta_p \simeq 1$. Since in the comoving frame the protons collide with the SSC photons from all directions, in our calculation we consider an average value $(1 - \cos \theta) \sim 1$ (θ in the range of 0 and π). In the observer frame, one can re-write the matching condition as

$$E_p \epsilon_{\gamma} \simeq 0.32 \frac{\Gamma \mathcal{D}}{(1+z)^2} \text{ GeV}^2. \quad (3)$$

Here

$$\epsilon_{\gamma} = \frac{\mathcal{D} \epsilon'_{\gamma}}{(1+z)}, \quad (4)$$

is the observed background photon energy, while

$$E_p = \frac{\Gamma E'_p}{(1+z)}, \quad (5)$$

is the energy of the proton as measured by the observer on Earth, if it could escape the source and reach earth without energy loss.

In the comoving frame, each pion carries ~ 0.2 of the proton energy. Considering that each π^0 decays into two γ -rays, the π^0 -decay γ -ray energy in the observer frame (E_{γ}) can be written as

$$E_{\gamma} = \frac{1}{10} \frac{\mathcal{D}}{(1+z)} E'_p = \frac{\mathcal{D}}{10\Gamma} E_p. \quad (6)$$

The matching condition between the π^0 -decay photon energy E_{γ} and the target photon energy ϵ_{γ} is therefore

$$E_{\gamma} \epsilon_{\gamma} \simeq 0.032 \frac{\mathcal{D}^2}{(1+z)^2} \text{ GeV}^2. \quad (7)$$

With the leptonic one-zone synchrotron and SSC interpretation, different models use different parameters[22, 23] to fit the SED of 1ES 1959+650. In all these models, although the blob size differ by about 1 to 2 orders of magnitudes ($1.4 \times 10^{14} \text{ cm} \leq R'_b \leq 1.4 \times 10^{16} \text{ cm}$),

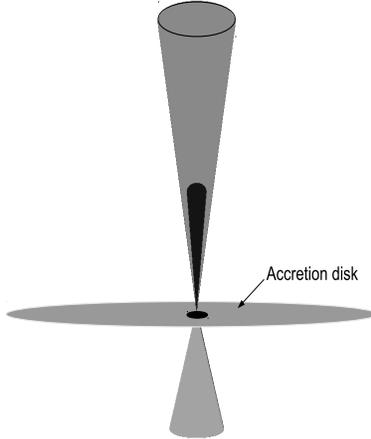


FIG. 1: Geometry of the orphan flaring of blazar 1ES 1959+650: the interior compact cone (jet) is responsible for the orphan flaring and the exterior cone corresponds to the normal jet.

the bulk Lorentz factor Γ and \mathcal{D} are almost the same ($18 \leq \Gamma \simeq \mathcal{D} \leq 20$) and the comoving magnetic field B' lies in the range 0.04 G to 0.25 G. The multiwavelength observation of the SED of 1ES 1959+650 was performed in 2006 May and fitted with the above one-zone model by Tagliaferri et. al [22] (their FIG: 8), where the parameters used for the jet are $\Gamma \simeq \mathcal{D} = 18$, $R'_b = 7.3 \times 10^{15}$ cm and $B' = 0.25$ G.

The time averaged TeV energy spectrum (above 1.4 TeV) of the flaring state of the 1ES 1959+650 was well fitted with pure power-law by the HEGRA collaboration and the power-law spectral index is $\alpha = 2.83 \pm 0.14_{\text{stat}} \pm 0.08_{\text{sys}}$ or by a power-law with an exponential cut-off at $E_c = (4.2^{+0.8}_{-0.6\text{stat}} \pm 0.9_{\text{sys}})$ TeV and a spectral index of $1.83 \pm 0.15_{\text{stat}} \pm 0.08_{\text{sys}}$ [18, 24]

In this work we assume that the flaring occurs within a compact and confined volume of radius R'_f inside the blob of radius R'_b ($R'_f < R'_b$). The geometrical description of the jet structure in the orphan flare is shown in FIG. 1. This double jet structure may be applicable to all orphan flares. In this scenario the internal and the external jets are moving with the same bulk Lorentz factor Γ and the Doppler factor \mathcal{D} as the blob. Within the confined volume, the injected spectrum of the Fermi accelerated charged particles have a power-law with an exponential cut-off, and for the protons with energy E_p it is given as as

$$\frac{dN_p}{dE_p} \propto E_p^{-\alpha} e^{-E_p/E_{p,c}}, \quad (8)$$

where the high energy proton has the cut-off energy $E_{p,c}$ and the spectral index $\alpha > 2$. Also

in this small volume, the comoving photon number density $n'_{\gamma,f}$ (flaring) is much higher than rest of the blob n'_γ (non-flaring), which can be due to the copious annihilation of electron positron pairs, splitting of photons in the magnetic field, enhance IC photons in this region and Poynting flux dominated flow which can form, from the magnetic reconnection in the strongly magnetized plasma around the base of the jet[25, 26]. This can be expressed as $n'_{\gamma,f}(\epsilon_\gamma) = \lambda n'_\gamma(\epsilon_\gamma)$, where $\lambda \gg 1$. So the ratio of photon densities at two different background energies ϵ_{γ_1} and ϵ_{γ_2} in flaring and non-flaring states remains the same, that is

$$\frac{n'_{\gamma,f}(\epsilon_{\gamma_1})}{n'_{\gamma,f}(\epsilon_{\gamma_2})} = \frac{n'_\gamma(\epsilon_{\gamma_1})}{n'_\gamma(\epsilon_{\gamma_2})}. \quad (9)$$

The high energy protons will collide with the low-energy tail of the SSC photons within the confined volume of radius R'_f in the energy range ~ 1 MeV to 8 MeV ($\sim 2.0 \times 10^{20}$ Hz to $\sim 2.0 \times 10^{21}$ Hz) to produce Δ -resonance. It can be observed from Eqs. (6) and (7) that, in the hadronic model, high energy γ -rays are produced when very high energy protons collide with low-energy SSC photons and vice versa and the optical depth of the Δ -resonance process is given as

$$\tau_{p\gamma} = n'_{\gamma,f} \sigma_\Delta \mathcal{R}'_f. \quad (10)$$

The comoving photon number density within the confined volume can be given in terms of the luminosity L_γ as

$$n'_{\gamma,f} = \eta \frac{L_\gamma (1+z)}{\mathcal{D}^{2+\kappa} 4\pi \mathcal{R}'_f{}^2 \epsilon_\gamma}, \quad (11)$$

with $\kappa \sim (0 - 1)$ (depending on whether the jet is continuous or discrete) and $\eta \sim 1$. In the flaring region, the number of π^0 -decay photons at a given energy depend on the number of high energy protons and the optical depth, i.e. $N(E_\gamma) \propto N(E_p)/\tau_{p\gamma} \propto N(E_p)n'_{\gamma,f}(\epsilon_\gamma)$, where E_γ , E_p and ϵ_γ satisfy the Δ -resonance matching conditions given in Eqs.(3) and (7) and the γ -ray flux from π^0 decay will be

$$\begin{aligned} F_\gamma(E_\gamma) &\equiv E_\gamma^2 \frac{dN(E_\gamma)}{dE_\gamma} \\ &\propto E_p^2 \frac{dN(E_p)}{dE_p} n'_{\gamma,f}(\epsilon_\gamma). \end{aligned} \quad (12)$$

So the high energy observed photon flux from π^0 -decay at two different observed photon

energies $E_{\gamma,1}$ and $E_{\gamma,2}$ will scale as

$$\begin{aligned} \frac{F_\gamma(E_{\gamma_1})}{F_\gamma(E_{\gamma_2})} &= \frac{n'_{\gamma,f}(\epsilon_{\gamma_1})}{n'_{\gamma,f}(\epsilon_{\gamma_2})} \left(\frac{E_{\gamma_1}}{E_{\gamma_2}} \right)^{-\alpha+2} e^{-(E_{\gamma_1}-E_{\gamma_2})/E_c} \\ &= \frac{n'_\gamma(\epsilon_{\gamma_1})}{n'_\gamma(\epsilon_{\gamma_2})} \left(\frac{E_{\gamma_1}}{E_{\gamma_2}} \right)^{-\alpha+2} e^{-(E_{\gamma_1}-E_{\gamma_2})/E_c}, \end{aligned} \quad (13)$$

where $E_{\gamma_{1,2}}$ correspond to the proton energy $E_{p_{1,2}}$ and we have used the relations $E_{p_1}/E_{p_2} = E_{\gamma_1}/E_{\gamma_2}$, and $E_{p_{1,2}}/E_{p,c} = E_{\gamma_{1,2}}/E_c$. By using the known flux at a particular energy in the flaring state, we can calculate the flux at other energies using Eq.(13).

Out of $\tau_{p\gamma}^{-1}$ many protons, one interact with the SSC background to produce photons and neutrinos as shown in Eq.(1). So the fluxes of the TeV photons and the Fermi accelerated high energy protons F_p , are related through

$$F_p(E_p) = 5 \times \frac{3}{2} \frac{1}{\tau_{p\gamma}(E_p)} F_\gamma(E_\gamma), \quad (14)$$

where the factor 5 corresponds to 20% of the proton energy taken by each π^0 and 3/2 is due to the 2/3 probability of Δ -resonance decaying to $p\pi^0$. Like photons, the proton fluxes at different energies $E_{p,1}$ and $E_{p,2}$, scale as

$$\frac{F_p(E_{p_1})}{F_p(E_{p_2})} = \left(\frac{E_{p_1}}{E_{p_2}} \right)^{-\alpha+2} e^{-(E_{p_1}-E_{p_2})/E_{p,c}}. \quad (15)$$

The fluxes of π^+ and π^0 are related, because each pion carries 20% of the proton energy, while each neutrino and each e^+ carries 1/4 of the π^+ energy, from the π^0 decay the photon carries 1/2 of the π^0 energy. The neutrino and e^+ , each has energy $E_\nu = E_{e^+} = E_\gamma/2$ and the neutrino flux can be calculated from the GeV-TeV photon flux, through

$$F_\nu = \frac{3}{8} F_\gamma, \quad (16)$$

where we assume that the TeV photon flux in the flaring state is solely due to the hadronic process.

III. RESULTS

During the flaring event, the high energy γ -rays flux was observed in the energy range 1.26 TeV(3.05×10^{26} Hz) $\lesssim E_\gamma \lesssim 9.4$ TeV(2.3×10^{27} Hz) by HEGRA and Whipple experiments. In the context of the hadronic model that we consider here, the corresponding proton

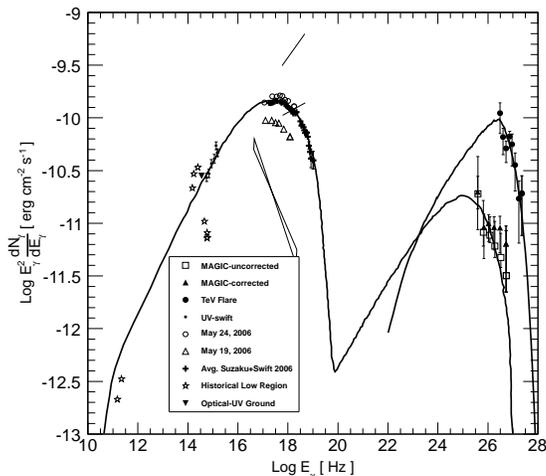


FIG. 2: The observed SED $E_\gamma^2 \frac{dN_\gamma}{dE_\gamma}$ (or F_γ) from radio to γ -ray of the blazar 1ES 1959+650 as measured at the end of 2006 May with other historical data from Ref. [22]. Different symbols are observations with different sources marked within the box, and the curves are model fits: The continuous curve (from low energy to high energy) is synchrotron + SSC fit from Tagliaferri et. al. [22], while the second continuous curve (extreme right) is the hadronic model fit to TeV flux from π^0 -decay. The X-ray spectra are the single-power-law fit taken from Ref. [19].

energy will lie in the range $12 \text{ TeV} \lesssim E_p \lesssim 94 \text{ TeV}$ which will collide with the background photons in the energy range $7.5 \text{ MeV} (1.8 \times 10^{21} \text{ Hz}) \gtrsim \epsilon_\gamma \gtrsim 1 \text{ MeV} (2.4 \times 10^{20} \text{ Hz})$ and these ϵ_γ lie exactly in the low energy tail of the SSC photons as shown in FIG: 2, calculated using the one-zone leptonic model. Due to our ignorance of $n'_{\gamma,f}$, we can use the n'_γ from the one-zone SSC fit to non-flaring state and use it in Eq.(13) to calculate the flaring flux.

For $1 \text{ MeV} \lesssim \epsilon_\gamma \lesssim 7.5 \text{ MeV}$, the corresponding photon density in the blob is $300 \text{ cm}^{-3} \gtrsim n'_\gamma (= n'_{\gamma,f}/\lambda) \gtrsim 88 \text{ cm}^{-3}$. Protons with energy $E_p < 12 \text{ TeV}$ will collide with photons having energy $\epsilon_\gamma > 7.5 \text{ MeV}$ and $n'_{\gamma,f}/\lambda < 88 \text{ cm}^{-3}$, to produce $E_\gamma < 1.2 \text{ TeV}$. Similarly, high energy protons ($E_p > 94 \text{ TeV}$) will collide with the low energy photons ($\epsilon_\gamma < 1 \text{ MeV}$ with $n'_{\gamma,f}/\lambda > 300 \text{ cm}^{-3}$) to produce $E_\gamma > 9.4 \text{ TeV}$. Here we use $\kappa = 0$ and for discrete jet, $n'_{\gamma,f}$ will be reduced by a factor of \mathcal{D}^{-1} .

For the calculation of the TeV flux, first we take into account one of the observed flaring fluxes with its corresponding energy for normalization e.g. $F_\gamma(E_{\gamma_2} = 1.26 \text{ TeV}) \simeq$

$10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$) and $n'_\gamma(\epsilon_{\gamma_2} = 7.5 \text{ MeV})/\lambda \simeq 88 \text{ cm}^{-3}$ and using it calculate the flux for other energies with the Eq.(13). This we have done for different observed fluxes for a better fit. The spectral index α and the cut-off energy E_c are the free parameters in the model and the best fit is obtained for $\alpha = 2.83$ and $E_c = 5.0 \text{ TeV}$ [18]. The γ -ray cut-off energy of 5 TeV corresponds to $E_{p,c} = 50 \text{ TeV}$ and above the cut-off energy the flux decreases rapidly.

The Eddington luminosity of the blazar with the central black hole mass $\sim 1.5 \times 10^8 M_\odot$ is $L_{\text{Edd}} \sim 2 \times 10^{46} \text{ erg s}^{-1} (M/10^{8.3} M_\odot)$ having the corresponding flux $F_\gamma \sim 3.8 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$. In the flaring state, the proton luminosity $L_p(E_p = 94 \text{ TeV})$ has to be smaller than L_{Edd} , which gives $\tau_{p\gamma} \gtrsim 0.02$. By considering $R'_f \sim 10^{14} \text{ cm}$, it gives $n'_{\gamma,f} \gtrsim 4 \times 10^{11} \text{ cm}^{-3}$. So the photon density has to be very high within the compact region.

The high energy protons will be accompanied by electrons in the same energy range ($12 \text{ TeV} \lesssim E_e \lesssim 94 \text{ TeV}$). These electrons will radiate synchrotron photons in the jet magnetic field, in the range $1.9 \text{ MeV} (4.5 \times 10^{20} \text{ Hz}) \lesssim E_\gamma \lesssim 115.4 \text{ MeV} (2.8 \times 10^{22} \text{ Hz})$ which lies just in the lower part of the SSC spectrum where the photon flux is quite low, as shown in FIG: 2. So even if the flux in this region increases by an order of magnitude due to electron synchrotron emission, there will still be a dip in the spectrum which is unobserved.

During the flaring the high energy γ -rays were in the range $1.26 \text{ TeV} \lesssim E_\gamma \lesssim 9.4 \text{ TeV}$. If these photons were to interact with the photons in the jet background to have e^+e^- pair creation, then each electron/positron will have an energy $E_\gamma/2$. The e^+ produced during the π^+ decay as shown in Eq.(1) will also carry same amount of energy as the individual e^- and e^+ in the pair creation process. Within the jet, these electrons and positrons may undergo synchrotron emission where the magnetic field is about 0.25 G as discussed earlier. We found that the synchrotron photons will be in the range $1.3 \times 10^{18} \text{ Hz} (0.005 \text{ MeV})$ to $7 \times 10^{19} \text{ Hz} (0.29 \text{ MeV})$, which lies in the high-energy edge of the synchrotron spectrum as shown in FIG. 2. However the mean free path $\lambda_{\gamma\gamma} = (n'_\gamma \sigma_{\gamma\gamma})^{-1}$ for the pair creation in the jet background is several orders of magnitude larger than blob radius R'_b . Even if we replace n'_γ by the photon density in the flaring region i.e. $n'_{\gamma,f}$, the photon mean free path is still much larger than the blob radius. This implies that TeV photons will not be degraded by pair creation and therefore no synchrotron emission will take place for the above e^+e^- pairs. But the e^+ created due to pion decay will emit synchrotron radiation in the frequency band $1.3 \times 10^{18} \text{ Hz}$ to $7 \times 10^{19} \text{ Hz}$, and its flux will be much smaller than $F_\gamma(E_\gamma = 1.26 \text{ TeV})/8$ i.e. $F_{e^+, \text{syn}} \ll 1.25 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$. This is much below the observed synchrotron flux

in the normal case as can be seen from FIG. 2 and can't be observed during the flaring event. The non-observation of e^+ synchrotron flux during the flaring is also explicitly shown by Böttcher which makes the flare genuinely orphan[20]. It is true that the synchrotron radiation of the positrons from the π^+ decay and the electrons which accompany the Fermi accelerated protons will make the dip shallower which will be $\ll 1.25 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ in the range $\sim 10^{18} \text{ Hz}$ to $\sim 10^{22} \text{ Hz}$. This is the frequency range which falls in the falling edge of the synchrotron spectrum and the tail of the IC spectrum. It is important to note that the marginal enhancement in the photon flux in the above frequency range is only during the flaring event and not in the normal circumstances when leptonic process is the sole contributor to the SED.

The TeV flux from 1ES 1959+650 can in principle be reduced due to the absorption of TeV photons by the diffuse extragalactic background radiation through $\gamma_{\text{TeV}} + \gamma_{\text{b}} \rightarrow e^+ e^-$ process. But the energy range of our interest $\sim 1 \text{ TeV}$ to several TeV, the spectral shape remains nearly unchanged due to the almost constant optical depth for most of the extragalactic background radiation[18].

Our result is shown in FIG. 2, which fits very well with the observed flaring flux. Also it is observed that the flux increases for $E_\gamma < 1.2 \text{ TeV}$ due to the high proton flux in this energy range. However, in order not to violate the Eddington luminosity, the proton energy spectrum must break to a harder index (e. g. $\alpha \sim 2.3$) below 12 TeV. Here we have introduced a break at $E_{p,b} \sim 12 \text{ TeV}$ below which $\alpha = 2.3$ and above this energy $\alpha = 2.83$. The spectral energy distribution F_γ falls below $E_{p,b} \sim 12 \text{ TeV}$ as shown in FIG. 2. It may also so happen that $\epsilon_\gamma > 7.5 \text{ MeV}$ are very much suppressed within the compact region implying n'_γ to be too low for Δ -resonance to occur hence $E_\gamma < 1.2 \text{ TeV}$ production is negligible. The flux decreases rapidly for $E_\gamma > 9.4 \text{ TeV}$ because of the exponential cut-off. This corresponds to a proton flux above 94 TeV which will also fall exponentially as shown in Eq.(8).

We have also estimated the neutrino flux from decay of the charged pions during the intense flare, where the neutrino flux will be $4.5 \times 10^{-9} \text{ GeV cm}^{-2} \text{ s}^{-1} \lesssim F_\nu \lesssim 2.6 \times 10^{-8} \text{ GeV cm}^{-2} \text{ s}^{-1}$ corresponding to neutrino energy in the range $4.7 \text{ TeV} \gtrsim E_\nu \gtrsim 0.6 \text{ TeV}$.

IV. CONCLUSIONS

We have employed the hadronic model to interpret the TeV emission from the orphan flaring event of June 2002, from the blazar 1ES 1959+650. In this picture, Fermi-accelerated protons of energy $\lesssim 100$ TeV interact with the low energy $\sim (1 - 8)$ MeV tail of the SSC photons in a very compact and confined region of the jet to produce Δ -resonance and its subsequent decay to photons through neutral pion decay. The TeV photons thus obtained are proportional to both, high energy proton spectrum which is a power-law with an exponential cut-off and the low energy SSC photon density in the blazar jet. Our result fits very well with the observed flux from the flaring event. We have also estimated the neutrino flux from this event.

We are thankful to Bing Zhang for useful discussions. S.S. is thankful to Departamento de Fisica de Universidad de los Andes, Bogota, Colombia, for their kind hospitality during his several visits. This work is partially supported by DGAPA-UNAM (Mexico) Project No. IN103812 and IN105211.

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