We present results from a deep VERITAS exposure of the distant ($z = 0.89$) flat-spectrum radio quasar (FSRQ) 4C +55.17. The high flux, hard index and steady emission found by Fermi LAT observations make this blazar a promising very-high-energy (VHE; $E \geq 100$ GeV) candidate, offering a possibility to clarify the location of FSRQ VHE emission. Non-detection supports the hypothesis that any VHE gamma-rays are produced within and absorbed by the broad-line region while VHE detection would support an emission region outside the broad line region and far from the base of the jet. This FSRQ additionally provides the possible means, by photon-photon pair production, to constrain the currently available extragalactic background light (EBL) models out to the groundbreaking redshift of $z=0.89$. The log-parabolic model that is fitted to the LAT photons allows an extrapolation of the fit up to VHE while accounting for the gamma-ray absorption by the EBL. The VERITAS upper limit derived from the deep exposure is compared to this extrapolated VHE flux.

1. VERITAS Instrument

VERITAS is an array of four 12-meter imaging atmospheric Cherenkov telescopes based near Tucson, Arizona. This instrument is sensitive to very-high-energy (VHE) gamma-ray photons of energy greater than 100 GeV and has a 3.5 degree field of view. Each telescope has 350 mirrors which reflect light onto a pixellated camera comprised of 499 photomultiplier tubes. The instrument has been operating in full array mode since 2007, and has so far detected 23 VHE blazars, having discovered VHE emission from 10 of them. See Holder et al. [2006] for further details regarding the operation of VERITAS.

2. The Extragalactic Background Light

Detection of VHE emitting blazars is made difficult by the pair production between VHE photons and lower energy extragalactic background light (EBL) photons [Nikishov 1962]. The EBL represents the entirety of starlight that has been emitted and reprocessed by dust throughout the history of the Universe. This interaction reduces the observed flux from extragalactic objects in a distant dependent manner, making the detection of higher redshift sources a challenge.

Measurements of the EBL offer integrated constraints on all of the processes that contribute, e.g. structure formation and galactic evolution [Hauser & Dwek 2001]. However, due to bright foregrounds in our solar system and Galaxy, direct measurements of the EBL are difficult. Moreover, a direct measurement would only reflect the current integrated state, which leaves the challenging task of unraveling the time history of the EBL. This challenge can be overcome when VHE gamma rays are used to probe the EBL through gamma-ray absorption. The absorption process deforms the intrinsic VHE gamma-ray spectra emitted by extragalactic objects such as blazars. This deformation can be used to estimate the spectral properties of the EBL out to the redshift of the source [Aharonian et al. 2006].

3. Fermi LAT Shows 4C +55.17 as a Candidate VHE Source

The flat-spectrum-radio-quasar (FSRQ) 4C +55.17 has been a steady, bright Fermi LAT source, as illustrated by the high energy gamma-ray light curve spanning four years (Figure 1) as well as by the various Fermi LAT catalog values reported in Table I. Data from the first eleven months of operation yielded acceptable fits to a power law, with a relatively bright 1-100 GeV integral flux and a hard index of $\Gamma \sim 2$. As additional statistics were collected, a log parabola was seen to provide an improved fit to the data. Additionally, this target continues to show a lack of gamma-ray flux variability, unlike other Fermi LAT detected FSRQs.

The steady, bright high-energy gamma-ray flux and hard index made this FSRQ a prime candidate for VHE emission. The relatively regular detections of associated photons with energy above 50 GeV (Table II) supports the VHE candidacy and the target was added to the VERITAS observing plan in the spring of 2010. The log-parabolic fit can be extrapolated into the VHE band to estimate expected flux values above 100 GeV, according to different EBL models as done in Figure 2 for the log-parabolic fit found using the first four years of Fermi LAT data.

4. VERITAS Observations of 4C +55.17

VERITAS observed the FSRQ 4C +55.17 for 45 hours of livetime between May 2010 and March 2012.
Table I  *Fermi* LAT observations of 4C +55.17 over four years. The 0FGL and 1FGL catalogs fit a differential power-law to the data of the form $dN/dE \propto E^{-\Gamma}$. Additional statistics collected after the first eleven months of operation provide an indication of spectral curvature, showing an improved fit for a log parabola of the form $dN/dE \propto E^{-a-b\log E}$ in the 2FGL catalog as well as in the analysis which includes the first four years of LAT data. The relatively high 1-100 GeV integral flux and hard spectrum show this FSRQ to be a promising candidate for VHE emission.

| Energy (GeV) | Time (MJD) | Separation (degree) | Probability |
|--------------|------------|---------------------|-------------|
| 141.2        | 55115      | 0.061               | 0.985       |
| 135.2        | 55999      | 0.486               | 0.528       |
| 80.5         | 54977      | 0.555               | 0.682       |
| 75.6         | 55550      | 0.076               | 0.994       |
| 68.7         | 55407      | 0.088               | 0.996       |
| 61.1         | 55339      | 0.018               | 0.997       |
| 52.4         | 54689      | 0.059               | 0.973       |

Table II Photons from the vicinity of 4C +55.17 above 50 GeV observed by the *Fermi* LAT instrument over the four year mission. These photons are noted along with the probability for association with the FSRQ.

Acknowledgments

This research was supported in part by NASA grant NNX10AP71G from the Fermi Guest Investigator program. The VERITAS collaboration is supported by grants from the US Department of Energy Office of Science, the US National Science Foundation, and the Smithsonian Institution, by NSERC in Canada, by Science Foundation Ireland, and by STFC in the UK. We acknowledge the excellent work of the technical support staff at the FLWO and at the collaborating institutions for the construction and operation of the instrument. The Fermi Collaboration acknowledges generous support from a number of agencies and institutes that have supported the development and the operation and scientific data analysis.

References

A. A. Abdo, et al. 2009, ApJS, 183, 46
A. A. Abdo, et al. 2010 ApJS, 188, 405
J. Finke et al. 2010, ApJ, 712, 238
A. Franceschini et al. 2008, A&A, 487, 837
J. Holder et al. 2006, Astropart. Phys., 25, 391
T. M. Kneiske et al. 2004, A&A, 413, 807
A. Nikishov 1962, Soviet Physics JETP, 14, 393
P. L. Nolan et al. 2012 ApJS, 199, 31
A. Roland et al. 2005, Nucl. Inst. Meth, 551, 493
T. Sbaratto et al. 2012, MNRAS, 421, 1764
Figure 1: A Fermi LAT two-week bin light curve of 4C +55.17 above 1 GeV. The source shows no variability with a \( \chi^2 \) of 89 with 103 degrees of freedom, consistent at 83% confidence level with steady state emission.

Figure 2: The spectrum and log-parabolic fit of 4C +55.17 above 100 MeV including four years of LAT data. This spectrum is shown with the VERITAS 95% confidence upper limit above 150 GeV, derived assuming an index of \( \Gamma = 5 \) for the differential power law \( dN/dE = (E/E_0)^{-\Gamma} \).