CDFNOTE 8225

First Observation of Exclusive Electron Pairs in Hadron-Hadron Collisions

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URL http://www-cdf.fnal.gov
(Dated: April 21, 2006)

We present the observation of 16 exclusive e^+e^- production events on top of a background of estimate of $2.1^{+0.7}_{-0.3}$. Each event has an e^+e^- pair, both with $E_T > 5$ GeV and $|\eta| < 2$, and *nothing else* observable in the CDF detector. The measured cross section is $1.6\ ^{+0.5}_{-0.3}$(stat) ± 0.3(sys) pb, while the predicted cross section is 1.711 ± 0.008 pb. The events are consistent in cross section and properties with $p\bar{p} \rightarrow p + e^+e^- + \bar{p}$ through two photon exchange ($\gamma\gamma \rightarrow e^+e^-$). Two photon collisions have previously been studied elsewhere, but this is the first observation of *exclusive* two photon collisions in hadron-hadron collisions.

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I. INTRODUCTION

Exclusive two-photon collisions have not previously been observed in hadron-hadron collisions, having a very small cross section ($\sim$ pb) compared to the strong interaction cross section, $\sigma_{inel} \approx 60$ mb. The most promising channels are $\gamma\gamma \to e^+e^-$ and $\gamma\gamma \to \mu^+\mu^-$, with the p and $\bar{p}$ coherently scattered, thus $p\bar{p} \to p + e^+e^-(\mu^+\mu^-) + \bar{p}$. This is an *exclusive interaction*, meaning that the central system (e^+e^-) is fully reconstructed and the hadrons do not dissociate, see Figure 1.

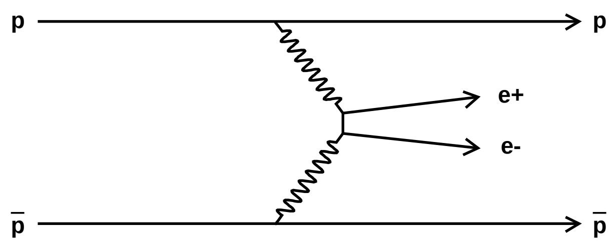

FIG. 1: Feynman diagram of exclusive e^+e^- via two photon exchange.

The two-photon process is (almost) pure QED. The only non-fundamental part is the electromagnetic form factor of the proton, which is well known (and in the limit $t \to 0$ becomes 1). Two-photon collisions have been much studied in e^+e^- collisions at PETRA [1], TRISTAN [2], and LEP [3–5]. Exclusive two-photon collisions have been studied in ep collisions at HERA [6]. Inclusive (meaning the hadrons dissociate) two-photon collisions have been studied in heavy ion collisions at RHIC [7].

The process in hadron collisions was first discussed in 1972 by Budnev, Ginsburg, Meledin and Serbo [8]. Other papers, mainly considering it as a process for luminosity calibration, are by Shamov and Telnov [9], Piotrzkowski [10], and Caron and Pinfold [11].

II. SIGNAL MC

The LPAIR program [12] is a matrix element Monte Carlo simulation of two photon production of fermion pairs for incoming beams of electrons, positrons, protons, and anti-protons. Three categories of two photon collisions from the incoming proton anti-proton beams of the Tevatron can be simulated with LPAIR. The elastic-elastic process is the generator configuration used to simulate the expected signal for this analysis. The elastic-inelastic and inelastic-inelastic configurations are used to help estimate the background.

1. elastic-elastic $p\overline{p} \to p + l^+l^- + \overline{p}$
2. elastic-inelastic $p\overline{p} \to p + l^+l^- + X$ and $p\overline{p} \to X + l^+l^- + \overline{p}$
3. inelastic-inelastic $p\overline{p} \to X + l^+l^- + X$

The cross section for elastic-elastic production of electron pairs with $E_T(e) > 5.0$ GeV, $|\eta| < 2.0$ at the Tevatron, $\sqrt{s} = 1960$ GeV, is predicted by LPAIR Monte Carlo to be $\sigma_{peep} = 1.711 \pm 0.008$ pb [12].

III. DATA SAMPLE & EVENT SELECTION

This analysis uses an integrated luminosity of 532 ± 32 pb^{-1} of data collected with the CDF detector [13] between December 7 2004 and November 9 2005. It uses a trigger designed for this analysis. The trigger requires two electromagnetic clusters in $0 < |\eta| < 3.6$ with online $E_T > 4$ GeV and a veto on activity in the first Beam Shower Counter (BSC-1, $5.4 < |\eta| < 5.9$). Offline event selection can be broken into three categories; 1) electron identification, 2) cosmic rejection, 3) exclusivity

A. Electron Identification

Events containing two electrons with offline $E_T > 5$ GeV and $0 < |\eta| < 2.0$ are selected from the triggered data. Electron identification is done using the Had/EM energy ratio of the cluster as well as the shower maximum shape. The electron is also required to have a track with $p_T > 1$ GeV pointing to the calorimeter cluster. Isolation is not applied in the electron identification stage of the selection because the exclusivity cuts are equivalent to very tight isolation cuts. The efficiency for triggering, reconstructing, identifying, and track matching a signal event is $\varepsilon_{ee} = 0.26 \pm 0.03$.

B. Cosmic Rejection

Cosmic rays are rejected from the data sample using the timing of the electromagnetic calorimeter cluster (EMTime). The EMTime of each electron candidate is required to be less than 10 ns, and the difference between the EMTime of the two electron candidates is required to be less than 10 ns. The efficiency for this cut is $\varepsilon_{cosmic} = 0.93 \pm 0.03$.

C. Exclusivity

In order to determine that there was no other activity in the CDF detector each calorimeter region was analyzed to determine its noise thresholds. Noise thresholds were chosen in 18 different regions of the calorimeter. A calorimeter tower that is not part of an electron cluster that is above its noise threshold is called an *additional* tower. Only events with zero additional towers are included in the candidate sample. The 16 events that pass into the candidate sample are discussed in Section IV.

The efficiency of the exclusivity cuts, ε_{exc}, must be calculated as a function of the bunch luminosity[15]. The ε_{exc} can be defined as the probability that the CDF detector is in a state that is capable of observing an exclusive interaction. This means that the detector must pass all of the exclusivity cuts, meaning that there can be no second $p\bar{p}$ interaction in the crossing. The value of ε_{exc} as a function of bunch luminosity is calculated from zerobias data (triggered solely on the bunch crossing time) as the number of zerobias events that pass the exclusivity cuts divided by the total number of zerobias events. Figure 2 shows ε_{exc} (points with scale on right) as well as the weighted bunch luminosity distribution of the data sample. From this plot, the overall ε_{exc} for the data sample is determined as the integral of the filled histogram divided by the integral of the empty (line) histogram to be $\varepsilon_{exc} = 0.0856$.

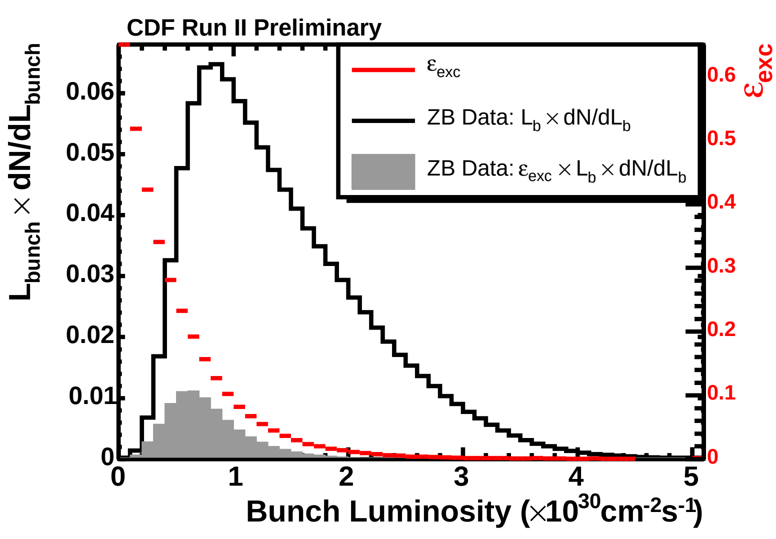

FIG. 2: Bunch luminosity distribution for all zerobias data (open histogram with scale on left), ε_{exc} (points with scale on right), and weighted bunch luminosity (filled histogram with scale on left).

D. Final State Radiation

A consequence of the exclusivity cuts is that an electron that emits enough Bremsstrahlung radiation could be excluded from the signal sample. This inefficiency is accounted for by passing LPAIR MC generated signal events through the exclusivity cuts. The efficiency works out to be $\varepsilon_{fsr} = 0.79 \pm 0.05$.

IV. SIGNAL SAMPLE

The signal sample of 16 events is compared to the LPAIR Monte Carlo in Figures 3 to 7. They show that there is agreement between the data and MC within the statistics of the sample. Figures 8 shows an event display of a typical signal event; run 195762, event 3788.

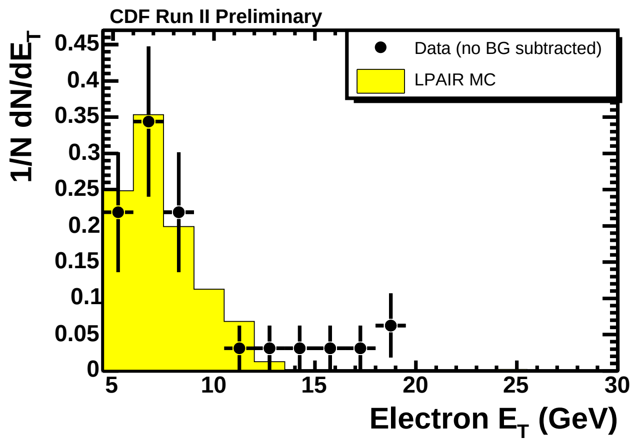

FIG. 3: E_T of electrons in signal sample (points) compared to LPAIR MC (line)

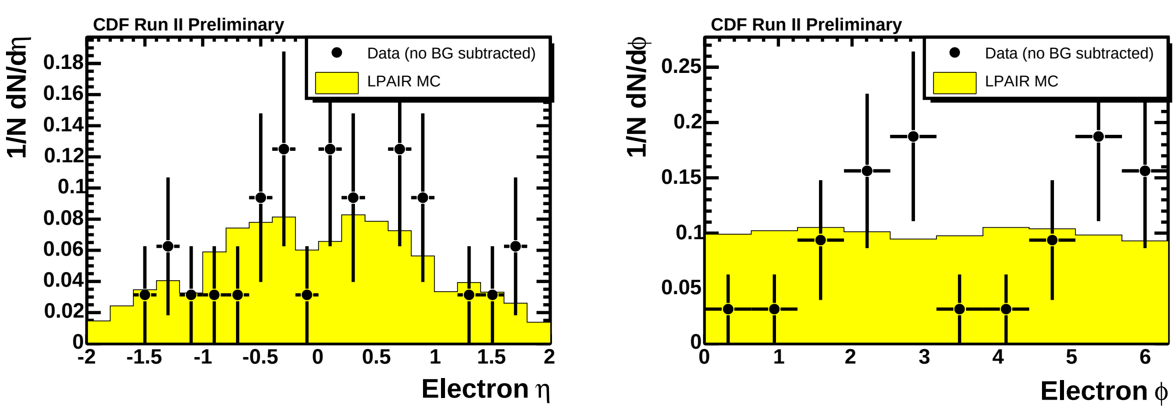

FIG. 4: eta (left) and phi (right) of electrons in signal sample (points) compared to LPAIR MC (line)

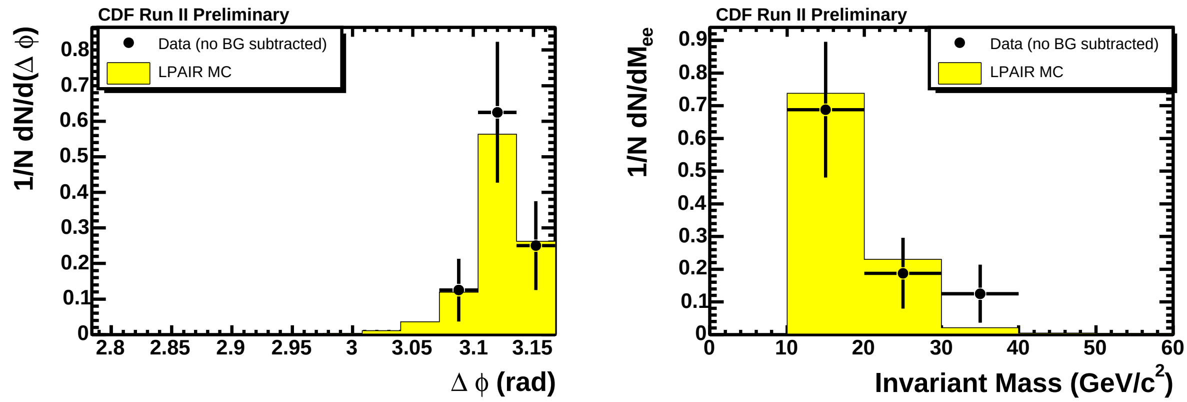

FIG. 5: Delta ϕ (left) and invariant mass (right) of ee pairs in signal sample (points) compared to LPAIR MC (line)

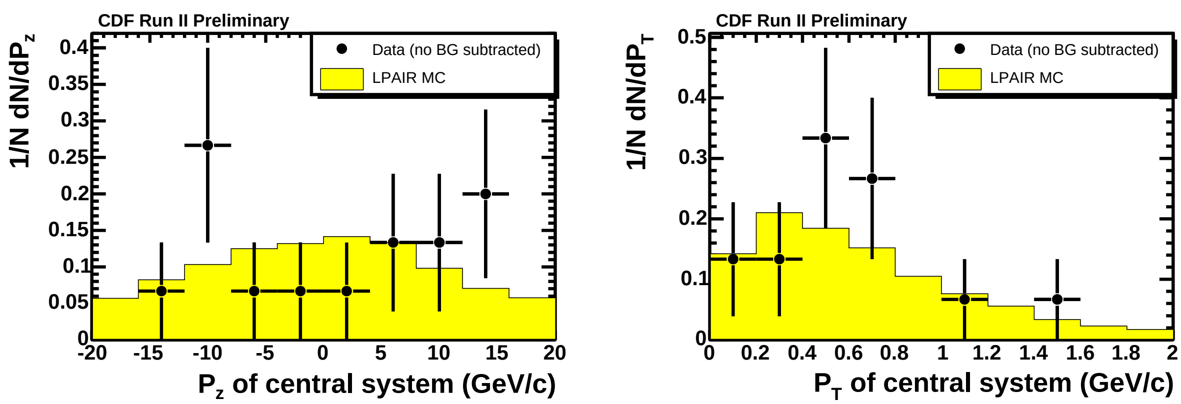

FIG. 6: p_z and p_T of ee pairs in signal sample (points) compared to LPAIR MC (line)

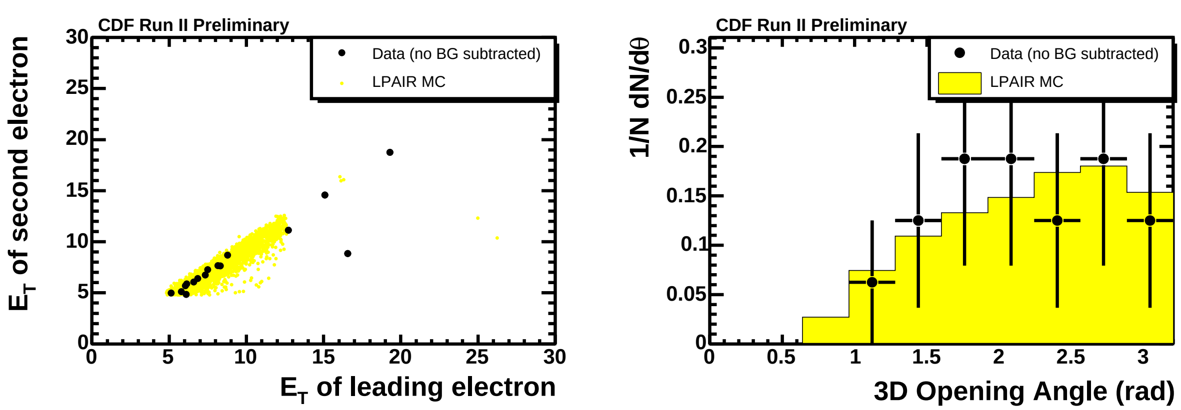

FIG. 7: E_T of leading electron vs E_T of second electron (left) and 3-D opening angle of ee pairs in signal sample (points) compared to LPAIR MC (line) (right)

V. BACKGROUNDS

There are four backgrounds to consider; jet fakes, cosmics, exclusivity, and dissociation. Each are discussed in the following sections.

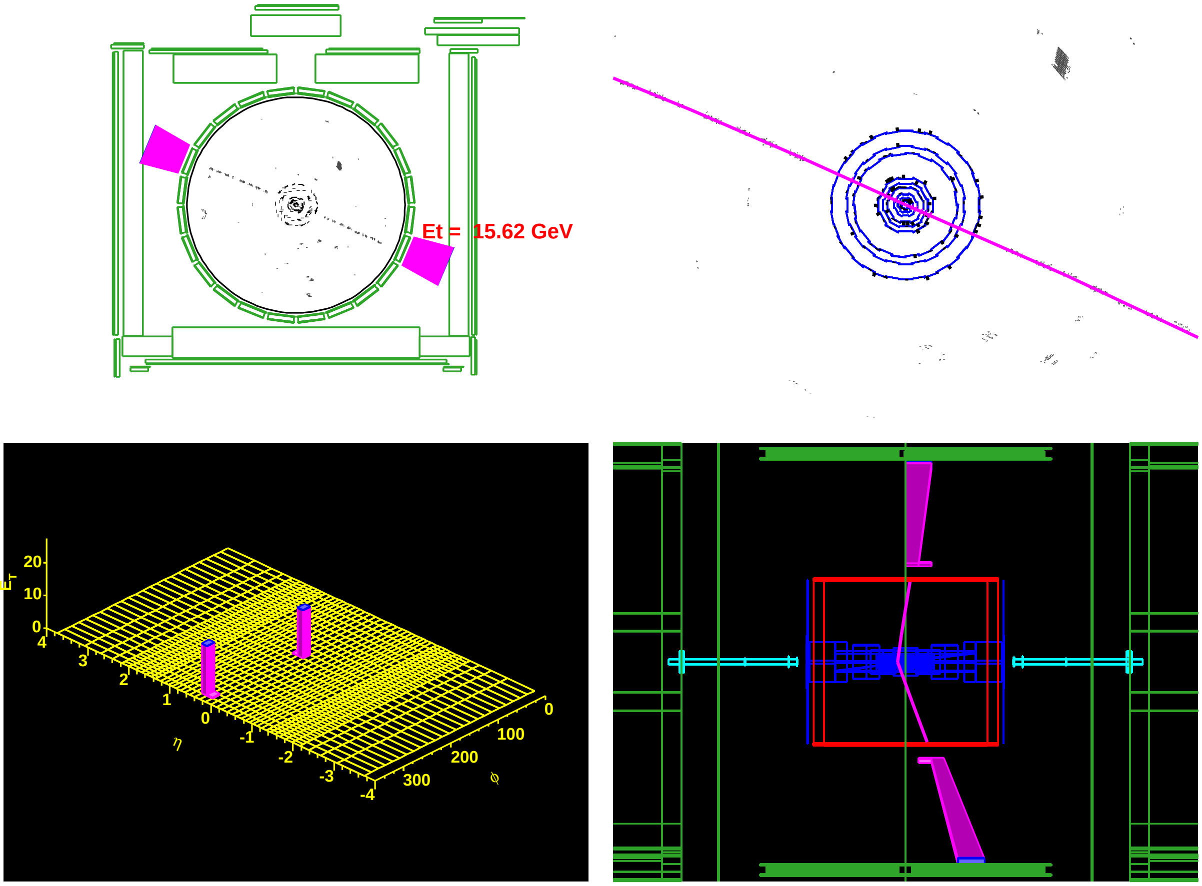

FIG. 8: Event display of run 195762 event 3788. Note that there is no activity in the calorimeter or tracking systems other than the two electrons.

A. 'Jet' Fake Background

The jet fake background is the probability that some exclusive hadronic state, like $\pi^+\pi^-$, fakes the exclusive electron signal when both hadrons are reconstructed in the detector as electrons. By examining the probability that a calorimeter cluster passes the electron cuts and then determining an upper limit on the number of events with two exclusive calorimeter clusters (no electron cuts), the upper limit on the jet fake background is determined to be 0.1. Therefore the jet fake background is $0.0^{+0.1}_{-0.0}$.

B. Cosmic Background

By examining the distribution of EM Timing in cosmic ray events, the probability that a candidate event comes from a cosmic ray is 2.3×10^{-4}. This corresponds to a negligible background in the 16 event candidate sample.

C. Exclusivity Background

The exclusivity background accounts for non-exclusive events where some particle(s) passed through the cracks of the calorimeter coverage or below the noise thresholds, causing them to appear exclusive. Z boson events provide an ideal sample to test the ability of the calorimeters to observe exclusive events because Z can not be produced exclusively[16]. Events from the two candidate sample are compared to Z events as a function of the number of additional clusters in Figure 9. An additional cluster is defined as a cluster of additional towers.

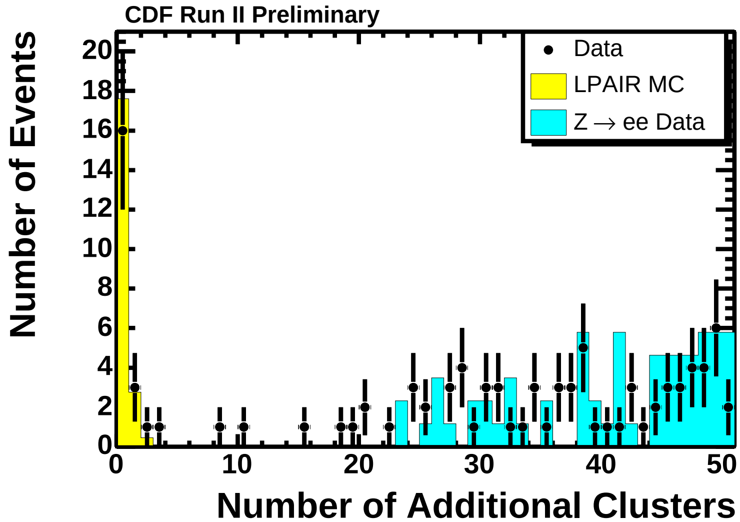

FIG. 9: Number of additional clusters for LPAIR MC, Z→ee data, and the electron sample (with no BSC cuts applied). LPAIR MC is normalized to events below 5 clusters, Z→ee data is normalized to the events above 5 clusters.

Figure 9 shows a very clear peak above a very small background. In order to estimate the amount of background in the zero bin (the signal region), the number of events in the 5 to 20 bins are averaged over all 15 bins. 5 events in 15 bins, comes out to 0.3 events per bin. Because there is no real evidence the exclusive background actually results in any background events, this estimate is taken as an upper limit, making the exclusivity background $0.0^{+0.3}_{-0.0}$. Note that the $Z \to ee$ sample is not used to determine the background, it simply guides the sideband limit and shows that one does not expect some detector effect to create an excess in the zero bin.

D. Dissociation Background

The dissociation background accounts for events that are mediated by two-photon exchange, but instead of being truly exclusive, one or both of the protons is excited into a low mass state and then dissociates. It is possible for these dissociations to be contained inside the beam pipe, and hence they would not be observable in the CDF detector. The inelastic running mode of LPAIR MC is used to estimate this background.

Unfortunately, LPAIR MC only provides the kinematics of the dissociating proton, it does not actually dissociate the system. To dissociate the system, a function called 'fragment_cluster' from Minimum Bias Rockefeller (MBR) MC [14] is used. This function fragments a cluster into pions, and then boosts the system back into the lab frame.

The kinematics of the dissociated system from LPAIR is input into the fragment cluster routine. Then the ratio of the elastic-elastic, elastic-inelastic, and inelastic-inelastic cross sections is taken from LPAIR, and the number of background events from proton dissociations that were not observable in the CDF detector is estimated to be 2.1±0.3.

E. Background Summary

A summary of the backgrounds is listed in Table I.

VI. CONCLUSION

Using the numbers in Table II the cross section for exclusive ee (E_T >5 GeV, $|\eta| < 2$) is measured to be:

$$\sigma_{exc,ee}^{E_t>5\ GeV,|\eta|<2} = \frac{N_{sig} - N_{bkgd}}{\varepsilon_{cos} \cdot \varepsilon_{fsr} \cdot \varepsilon_{ee} \cdot \varepsilon_{exc} \cdot \mathscr{L}} = 1.6^{+0.5}_{-0.3}(stat) \ \pm 0.3(sys)pb \tag{1}$$

Background	Value	Systematic
jet fake	0.0	$^{+0.1}_{-0.0}$
cosmic	negligible	negligible
exclusive	0.0	$^{+0.3}_{-0.0}$
dissociation	2.1	0.3
total	2.1	$^{+0.7}_{-0.3}$

TABLE I: Summary of background numbers put into the cross section calculation.

Quantity	Value	Uncertainty
N_{sig}	16	$^{+5.1}_{-3.2}$ (stat)
N_{bkgd}	2.1	$^{+0.6}_{-0.3}$ (sys)
$\mathscr{L}$	532	32 (sys)
ε_{exc}	0.0856	n/a
ε_{cos}	0.93	0.03 (sys)
ε_{fsr}	0.79	0.05 (sys)
ε_{ee}	0.26	0.03 (sys)

TABLE II: Summary of numbers put into the cross section calculation.

This agrees with the theoretical cross section from LPAIR of 1.711±0.008 pb. We have observed 16 exclusive electron pair events in CDF, within $|\eta_e| < 2.0$ and $E_T > 5$ GeV/c with a background estimate of 2.1 $^{+0.7}_{-0.3}$ events. The events are consistent in both their cross section and kinematic distributions with $pp \rightarrow p+e^+e^-+p$ through two photon exchange ($\gamma\gamma \rightarrow e^+e^-$). There is a 5.0×10^{-8} probability that a background of 2.8 events fluctuates to 16, corresponding to a 5.4σ observation. This is the first time the two-photon process has been observed in hadron-hadron collisions.

Acknowledgments

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium fuer Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Comision Interministerial de Ciencia y Tecnologia, Spain; and in part by the European Community's Human Potential Programme under contract HPRN-CT-20002, Probe for New Physics.

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[15] Bunch luminosity is the instantaneous luminosity of the bunch crossing
[16] The Z boson can not be produced exclusively via two-photon nor gluon exchange.