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Kaori Maeshima
for the CDF Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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Heavy Gauge Boson and Λ_b Baryon Searches at CDF

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Presented by Kaori Maeshima†
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

ABSTRACT

We have searched for new gauge bosons ($W' \to l\nu$, $Z' \to ll$) and b baryons ($\Lambda_b \to \psi\Lambda^0$) in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV from the 1988–89 run of the Collider Detector at Fermilab (CDF). We present 95% confidence level (C.L.) limits on the W' and Z' production cross section in leptonic decay modes. The nonobservation of these processes leads to limits of $M_{W'} > 520$ GeV/c^2 and $M_{Z'} > 412$ GeV/c^2 (95% C.L.), assuming Standard Model coupling strengths. We see no evidence for the signal ($\Lambda_b \to \psi\Lambda^0$) in our ψ sample ($\psi \to \mu\mu$) around the Λ_b mass region of 5600 MeV. We set an upper limit on $F(\Lambda_b)Br(\Lambda_b \to \psi\Lambda^0)$ of 0.55×10^{-3} (90% C.L.), assuming that b baryons and mesons are produced in the fragmentation process in similar ways. The CDF Λ_b search is also reported in the QCD session of this conference. This paper summarizes our result briefly; the details can be found in the other talk.

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* The CDF collaboration: ANL - Brandeis - UCLA - Univ. of Chicago - Duke - Fermilab - INFN (Frascati) - Harvard - Univ. of Illinois - Johns Hopkins - KEK - LBL - MIT - Univ. of Michigan - Univ. of New Mexico - Osaka City - Univ. di Padova - Univ. of Pennsylvania - INFN (Pisa) - Univ. of Pittsburgh - Purdue - Univ. of Rochester - Rockefeller - Rutgers - SSC Lab - Texas A&M - Univ. of Tsukuba - Tufts - Univ. of Wisconsin - Yale

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1. W' and Z' Search

1.1. Introduction

Heavy gauge bosons in addition to the W and Z are expected in certain extensions of the standard model (SM) such as Grand Unified Theories and left-right symmetric models. [1] These gauge bosons may be produced in $\bar{p}p$ collisions and observed via their decay to high transverse momentum (P_T) electrons and muons. Observation of such events would provide dramatic evidence for physics beyond the standard model. To date there is no experimental evidence for the existence of a new gauge boson. Previous direct searches for W' and Z' in $\bar{p}p$ collisions have set lower limits for the W' mass of 220 GeV/c^2 (90% C.L.) from UA1 [2] and 209 GeV/c^2 (90% C.L.) from UA2 [3] and for the Z' mass of 173 GeV/c^2 (90% C.L.) from UA1 [2] and 218 GeV/c^2 (95% C.L.) from UA2. [4] There are also limits from indirect searches. [6] Here, we report the CDF [5] search for the processes $W' \to \mu\nu$, [7] $W' \to e\nu$, [7] $Z' \to ee$ [8] and $Z' \to \mu\mu$, [9] for $M_{W'}$ and $M_{Z'}$ higher than 100 GeV/c^2. The mass limits quoted here are derived assuming the coupling strengths of the W' and Z' to quarks and leptons to be the same as those for the standard model gauge bosons. However, we also show that the limit on the Z' cross section times branching ratio to charged lepton pair ($\sigma(Z') \cdot \mathrm{B}_{ll}$) is quite insensitive to the choice of theoretical model, allowing mass limits to be extracted easily for many different models.

1.2. Event Selection, Acceptances, and Backgrounds

The events for this measurement are collected with inclusive lepton triggers. The efficiency for the electron trigger is measured to be $(97.3 \pm 0.5)\%$ in the transverse energy range $15 \leq E_T \leq 150$ GeV. The efficiency of the muon trigger is measured to be $(91 \pm 2)\%$ for $P_T > 20$ GeV.

From events passing the inclusive lepton triggers, we have selected electron and muon events with cuts designed to remain efficient for high-P_T leptons. Each of the four data sets, ee, $e\nu$, $\mu\mu$, and $\mu\nu$, consists of events selected by making tight cuts on one charged lepton and either a) less restrictive cuts on a second charged lepton, or b) a missing transverse energy ($\not\!\!E_T > 30$ GeV/c^2) requirement for the ν. E_T and P_T cuts on the "tight cut" leptons for these data samples are: $E_T > 30$ GeV/c^2 for the $W' \to e\nu$, $E_T > 15$ GeV/c^2 for the $Z' \to ee$, $P_T > 30$ GeV/c^2 for the $W' \to \mu\nu$, and $P_T > 20$ GeV/c^2 for the $Z' \to \mu\mu$ search samples.

Electron and muon identification efficiencies are measured from W and Z events. In the ee event sample, the efficiency is measured to be $(88 \pm 4)\%$ for the first electron, and $(96 \pm 1)\%$ for the second electron which has less stringent requirements. At very high E_T, these efficiencies degrade due to bremsstrahlung and shower leakage. The former effect is calculated using a radiative Monte Carlo (MC), while the later is extrapolated from measurements of test beam electrons. The efficiency degrades by 15% at 250 GeV. The tight cut muon identification efficiency is measured to be $(82 \pm 7)\%$ for $P_T > 20$ GeV. The acceptance for Drell-Yan events rises at larger dilepton masses as the events are more centrally produced. The acceptance is calculated by MC as a function of the transverse mass (M_T) for the $e\nu$ and $\mu\nu$ samples and the dilepton invariant mass (M_{ll}) for the ee and $\mu\mu$ samples. These four data sets are summarized in Table 1.

The primary backgrounds to directly-produced high P_T leptons arise from jets which can either fake leptons or produce indirect leptons from conversions (electrons), K, π decays-in-flight (muons), and heavy flavor decays. These backgrounds are characterized

Data Sample	Number of Events	Integrated Luminosity (pb^{-1})	Efficiency (including Acceptance)
$W' \to e\nu$	1796	4.15	20% at M_W rising to 41% at higher masses
$W' \to \mu\nu$	783	3.54	10% at M_W rising to 26% at higher masses
$Z' \to ee$	406	4.05	36% at M_Z rising to 51% at higher masses
$Z' \to \mu\mu$	148	3.54	16% at M_Z rising to 30% at higher masses

Table 1: Summary of data samples for the heavy vector boson search.

by their lack of isolation and can be measured in the data. Additional isolated backgrounds for W events ($W \to \tau\nu$,Z) and for Z events ($Z \to \tau\tau$) are calculated from MC. For the dimuon sample, residual cosmic ray background is estimated to be less than one event. All of these backgrounds peak at low M_T and M_{ll} and are negligible above $M_T = M_W$ and $M_{ll} = M_Z$.

1.3. M_T distributions and W' Limit

The M_T distributions for the $e\nu$ and $\mu\nu$ samples are shown in Fig. 1a) together with a MC prediction. The M_T distribution is well modeled by a simple MC incorporating the W' P_T distribution [11] and a model of the missing E_T resolution based on a full detector simulation. The highest transverse mass events are at 185 GeV/c^2 in the electron channel and 205 GeV/c^2 in the muon channel. To search for the W', a maximum likelihood fit of the data to the W plus W' transverse mass distributions is made. The 95 % C.L. limit on σB as a function of transverse mass is shown in Fig. 1b). The limit includes systematic uncertainties ($\sim$ 9%) due to M_T shape (W' P_T), and rate (luminosity, efficiency, and acceptance). Also shown is σB for a W' with standard model couplings. We find, for a W' with standard model couplings, $M_{W'} > 490$ (electrons), 435 (muons) and 520 GeV/c^2 (combined) at 95% C.L. The limit on σB applies to a right-handed W to the extent that the right-handed neutrino accompanying the observed lepton is light ($\lesssim$ 15 GeV/c^2) and stable, and that the right-handed CKM matrix, like the left-handed one, is essentially diagonal.

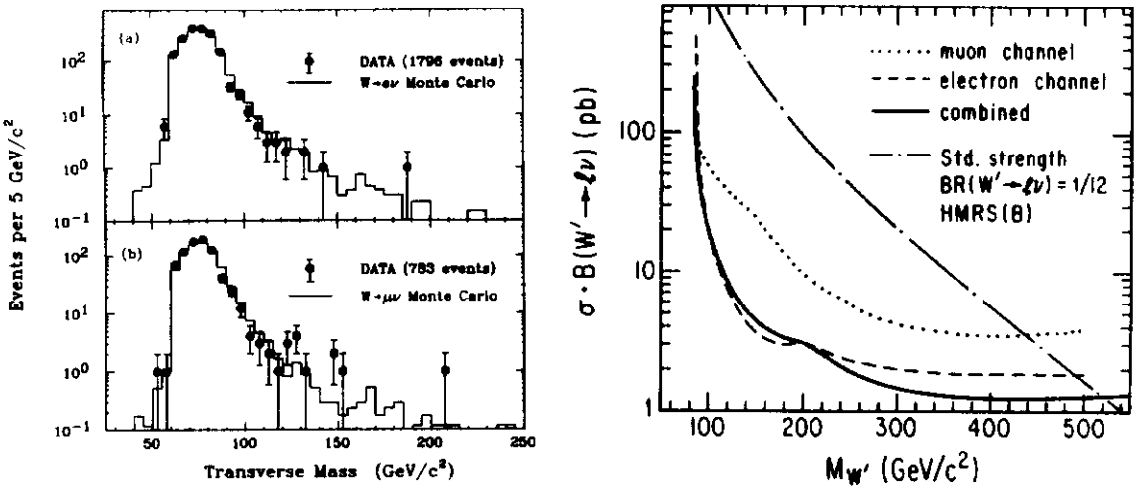

Figure 1: **a)** Observed transverse mass distributions for the electron and muon samples with the MC prediction for W boson decay. **b)** The 95% confidence level limits on the σB for $W' \to e\nu$ (dots), $W' \to \mu\nu$ (dashes) and combined (solid) processes. The dot-dashed line is the predicted value of σB, assuming the SM couplings.

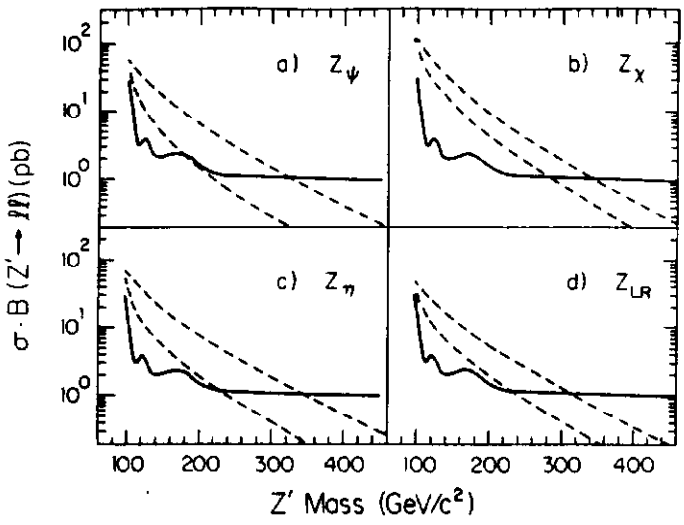

Figure 3: The 95% C.L. lower mass limits for four different Z' models from the E_6 symmetry group. In each plot the solid curve is the combined $\sigma(Z') \cdot B_{ll}$ limit, which is independent of the choice of these models. The dashed curves in Figs. a) through d) are $\sigma(Z') \cdot B$ calculated for four commonly discussed Z' models, namely Z_ψ, Z_χ, Z_η, and Z_{LR}. [12] The bands represent the theoretical range allowed by assuming Z' decay to known fermions only (upper bound) and all allowed fermions and supersymmetric fermions (lower bound). The intersections of the solid and dashed curves set the lower mass limit for the each case.

$\sigma(Z') \cdot B$ limit using SM-couplings can be compared with the $\sigma(Z') \cdot B$ prediction from any theoretical model, as long as the width of the predicted Z' is less than $2\Gamma^{SM}_{Z'}$ for $M_{Z'} > 120$ GeV/c^2. Figure 3 shows our combined $\sigma(Z') \cdot B_{ll}$ limit (solid line) together with predictions from four popular E_6 models (dashed lines). [12] In each plot the upper dashed curve corresponds to the model's prediction for a Z' decaying only to SM fermions; the lower dashed curve is the expectation for Z' decaying to all fermions in the model. For these calculations we assume the masses of the t-quark, supersymmetric fermions, and exotic fermions to be 140, 150, and 45.5 GeV/c^2, respectively. The intersections of the dashed curves with the $\sigma(Z') \cdot B_{ll}$ limit set the lower mass limits (95% C.L.) for each model.

2. Λ_b Baryon Search

The CDF Λ_b search is also reported in the QCD session of this conference. Here, we summarize the result, and refer the interested reader to the latter presentation. [14] Recently, the UA1 collaboration reported the observation of the Λ_b baryon in $\bar{p}p$ collision. [13] Based on 16 ± 5 $\Lambda_b \rightarrow \psi\Lambda^0$ events, UA1 measures the fraction of Λ_b produced by b quarks times the $\Lambda_b \rightarrow \psi\Lambda^0$ branching fraction to be $F(\Lambda_b)Br(\Lambda_b \rightarrow \psi\Lambda^0) = (1.8 \pm 1.0) \times 10^{-3}$. CDF has two times as many ψ events, comparable Λ^0 reconstruction efficiency, and better mass resolution. We observe no events with small background. Using the b quark cross section measured at CDF we put an upper limit on $F(\Lambda_b)Br(\Lambda_b \rightarrow \psi\Lambda^0)$ of 0.55×10^{-3} at 90% confidence level. UA1 detector has better sensitivity to lower momentum Λ^0's. To determine our Λ^0 reconstruction efficiency, we have assumed that the fragmentation of the Λ_b baryon is similar to that of b mesons. If this is not the case, and the Λ^0 from Λ_b decay has a much softer P_T spectrum than we have assumed, this could explain the disagreement.

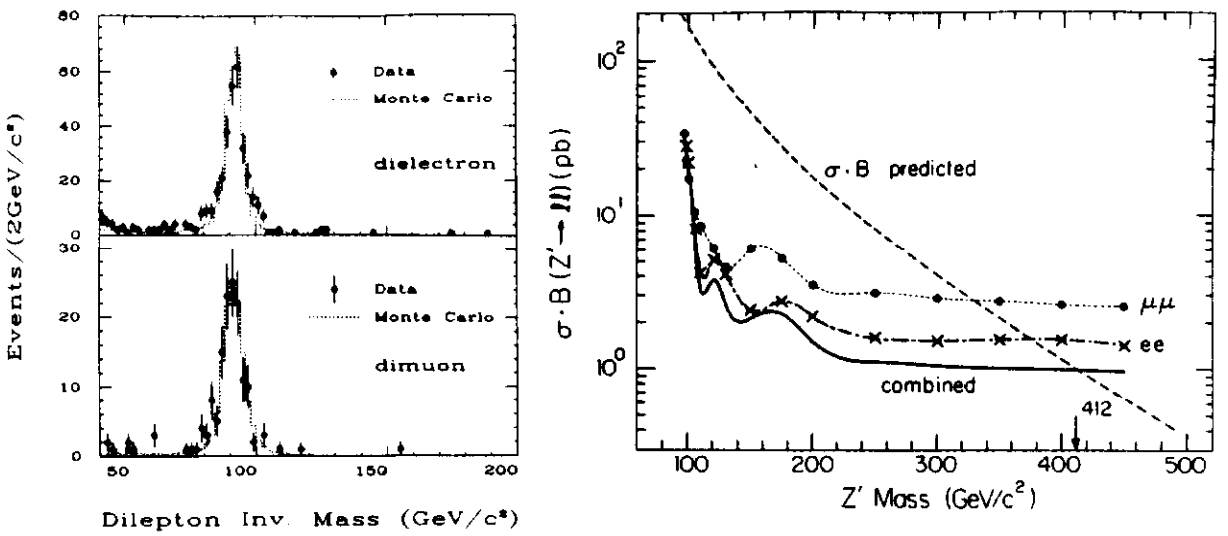

Figure 2: **a)** Observed invariant mass distributions for the dielectron and dimuon samples, together with the MC predictions. **b)** The 95% confidence level limits on the σB for $Z' \to ee$ (dot-dash), $Z' \to \mu\mu$ (dot) and combined (solid) processes. The dashed line is the predicted value of σB, assuming the SM couplings.

1.4. M_{ll} distributions and Z' Limit

The invariant mass distributions for the ee and $\mu\mu$ samples are shown in Fig. 2a) along with a MC prediction. In the mass range above the Z, 9 electron and 2 muon events are observed corresponding to an integrated cross section for $M_{ll} > 110$ GeV/c^2 of 4 ± 1 pb, which is consistent with the Drell-Yan expectation of 4 pb. The highest mass events are 189 GeV/c^2 (electron) and 155 GeV/c^2 (muon). The 95 % C.L. limit on $\sigma(Z') \cdot \mathrm{B}_{ll}$ limit as a function of mass is shown in figure 2 b). The limit includes systematic uncertainties ($\sim$ 10%) due to luminosity, efficiency, acceptance, and QCD corrections. Also shown is $\sigma(Z') \cdot \mathrm{B}_{ll}$ limit for a Z' with standard model couplings. We find, for a Z' with standard model couplings, $M_{Z'} > 387$ (electrons), 327 GeV/c^2 (muons). By combining the electron and muon data we obtain a lower limit on the Z' mass of 412 GeV/c^2 (95% C.L.).

1.5. Comments on Model Dependencies on Z' Limit and Mass Limits from some E_6 models

Model differences that may affect the $\sigma(Z') \cdot \mathrm{B}_{ll}$ limit are the Z' width ($\Gamma_{Z'}$) and the coupling strengths to u- and d-quarks. To derive mass limits on a Z' predicted by various models, a representative range of $\Gamma_{Z'}$ values is taken to be 0.15 to 2.0 times $\Gamma_{Z'}^{\mathrm{SM}}$ based on some models from the E_6 symmetry group. [12] We obtain limits of $\sigma(Z') \cdot \mathrm{B}_{ll}$ using the range of $\Gamma_{Z'}$, and find that the $\sigma(Z') \cdot \mathrm{B}_{ll}$ limit is insensitive to these changes of $\Gamma_{Z'}$ for Z' masses above about 120 GeV/c^2. Variations in the coupling strengths to u- and d-quarks can cause changes in the acceptance because of differences in the u and d parton distribution functions. We consider two limiting cases: i) a Z' that couples to d-quarks but not to u-quarks, and ii) a Z' that couples to u-quarks but not to d-quarks. We find that the limit extracted using SM couplings is a conservative estimate of the limit for case i), while the limit with SM couplings is almost identical to that for case ii) down to a dilepton invariant mass of 100 GeV/c^2. Hence, the experimentally obtained

References

1. J. Pati and A. Salam, *Phys. Rev. D.* **10** (1974) 275; R. E. Marshak and R. N. Mohapatra, *Phys. Lett.* **91B** (1980) 222; P. Langacker, R.W. Robinett, and J.L. Rosner, *Phy. Rev D.* **30** (1984) 1470; D. London and J.L. Rosner, *Phys. Rev. D.* **34** (1986) 1530; S.L. Glashow and U. Sarid, *Phys. Rev. Lett.* **64** (1990) 725; R. Foot, O. F. Hernandez and T. G. Rizzo *Phys. Rev. D* **41** (1990) 2283; F. del Aguila et al., *Nuclear Phy.* **B287** (1987) 419.
2. UA1 Collab., C. Albajar et.al., *Z. Phys. C.* **44** (1989) 15.
3. UA2 Collab., R. Ansari et.al., *Phys. Lett.* **B195** (1987) 613.
4. S. Grunendahl, in *Proceedings of the Vancouver Meeting, Particles and Fields '91*, August 18-22, 1991, Vancouver, B.C., Canada, edited by D. Axen, D. Bryman and M. Comyn. (World Scientific Publishing Co. Pte. Ltd.)
5. CDF Collab., F. Abe *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **271**, 387 (1988).
6. J. Carr et. al., *Phys. Rev. Lett.* **51** (1983) 627; A. E. Jodidio et. al., *Phys. Rev. D.* **34** (1984) 1967; **37** (1988) 237(E); B. Balke et. al., *Phys. Rev. D.* **37** (1988) 587; Amaldi et. al., *Phys. Rev. D.* **36** (1987) 1385; G. Costa et. al., *Nucl. Phys.* **B297** (1988) 244; W. Marciano and J. L. Rosner, *Phys. Rev. Lett.* **65** (1990) 2963; J. A. Grifols, E. Masso and T. G. Rizzo, *Phys. Rev. D.* **42** (1990) 3293; VENUS Collab., K. Abe et.al.,*Phys. Lett.* **B246** (1990) 297; F. del Aguila, J. M. Moreno and M. Quiros, Phys. Lett. B. **254**, 497 (1991).
7. CDF Collab., F. Abe *et al.*, Phys. Rev. Lett. **67**, 2609 (1991).
8. CDF Collab., F. Abe *et al.*, Phys. Rev. Lett. **67**, 2418 (1991).
9. CDF Collab., F. Abe *et al.*, Phys. Rev. Lett. **68**, 1463 (1992).
10. CDF Collab., F. Abe *et al.*, Phys. Rev. D **44**, 1 (1991); The CDF results on σB for muons is reported by H. Plothow-Besch in Lepton-photon Conference, Geneva 1991.
11. CDF has measured the W P_T distribution and found it to be in excellent agreement with next-to-leading order QCD. CDF Collab., Abe et al., *Phys. Rev. Lett.* **66** (1991) 2951.
12. F. del Aguila, M. Quiros, and F. Zwirner, Nucl. Phys. **B287**, 457 (1987); D. London and J. L. Rosner, Phys. Rev. D **34**, 1530 (1986); F. del Aguila, J. M. Moreno and M. Quiros, Phys. Rev. D **41**. 134 (1990), and references therein.
13. UA1 Collab., C.Albajar et al.Phys.Lett.B273,540(1991)
14. Alain Gauthier (CDF Collab.) in these proceedings.