THE STATUS OF CFS

(the Columbia-Fermilab-Stony Brook Collaboration)

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Abstract:

Some aspects of the final published E-288 data set are examined. Some extrapolations and systematics which plague current phenomenology are emphasized. A description of a planned follow-on experiment, Fermilab E-605, is given.

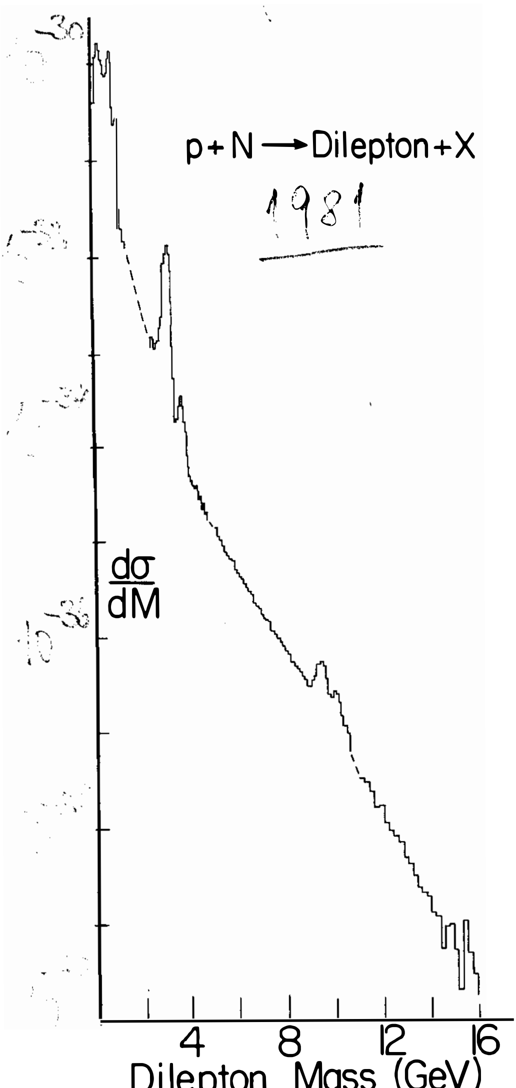
It is now two years since we took the last dimuon data with the CFS apparatus and one year since we finished the final analysis of all the data. The special calibration runs have been combined with extensive Monte Carlo checks to complete the full analysis of the data. Complete tables of the data, listed in separate bins in the transverse, longitudinal and mass variables (P_t, y, m) are included in the final publication.[1]

In the data we have seen presented to this conference, there are usually correlations between these kinematic quantities which are often forgotten when spectra are integrated over one variable to give better statistics in some other variable. I urge phenomenologists who want to critically examine the ensemble of lepton-pair production data now available to carefully watch for and consider these correlations.

In my short review of our CFS results today I would like to remind the audience of one such complication which makes it difficult to extract a "K-factor" from our data. I would then like to examine our P_t spectra in the manner that Altarelli and Scott have suggested in preceding talks with the object of giving some guidance in designing our future experiment, E-605. Finally I will show the present design plans for E-605.

Contrary to Vannucci's introductory talk at this conference, I do not think of the Drell-Yan effect as a QCD diagram, but rather as a real physical effect. Figure 1 schematically shows the yield of dimuon pairs in proton-nucleus collisions at Fermilab. The vector meson resonances sit on a monotonically falling continuum of massive dilepton states. We now believe that we can understand this yield of virtual photons, over most of the ten decades of cross-section shown, in terms of a simple quark-antiquark annihilation.[2] Indeed, the predictions that follow from this simple explanation: A-dependance, angular distribution of the decay, scaling, dimuon-dielectron equality, universality of the structure functions thus determined, have been investigated and qualitatively confirmed in the many experiments you have heard from this week. In proceeding in the future with further testing of QCD we are now faced with two choices.

Fig. 1. Schematic yield of dilepton pairs in 400 GeV proton-nucleus collisions (from CFS and Chicago-Princeton data at FNAL).



We can try to test the basic Drell-Yan prediction with much higher statistics experiments or we can try to find regions of phase space where terms other than the Born term dominant the cross-section.

Let me first address the question of high-precision tests of Drell-Yan by considering our CFS scaling data shown in Figure 2. The agreement with scaling appears to be better than the quoted ±20% systematic error and shows almost no sign of log Q^2 scale-breaking effects. Figure 3 indicates the magnitude of scale-breaking expected from structure function evolution calculations.[3] Clearly, investigation of any log Q^2 predictions of QCD is going to require large excursions in center-of-mass energy to avoid systematic error problems inherent in any experiment.

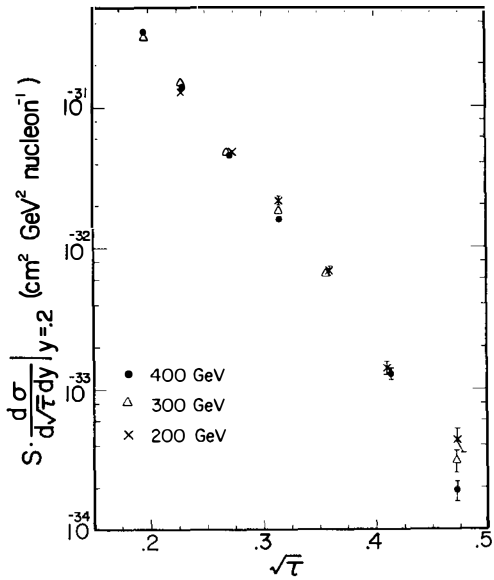


Fig. 2. Scaling form of the cross section for 200, 300, and 400 GeV data.

Figure 4 shows such an attempt to confront scaling over a larger range in energies by comparing our data to ISR data.[4] Since the comparison involves both an extrapolation to smaller values of $\sqrt{\tau}$ and a different reaction, proton-proton instead of proton-nucleus, the comparison must be made to a curve calculated from the structure functions derived from the CFS data. Although the agreement is impressive, the combination of the meager ISR statistics and the extrapolation preclude any stringent test of log Q^2 effects.

Next, one might try to accurately determine the absolute normalization of the dilepton data. The ratio of the measured cross-section to that predicted using structure functions determined in deep inelastic lepton scattering experiments (DIES), the so-called "K-factor", is believed to be a sensitive test of higher order QCD effects. We choose to make the comparison in figure 5 using the combined ocean structure function $\bar{q}(x) = \bar{u}(x) + \bar{d}(x) + \bar{s}(x)$ derived from a fit to our data.

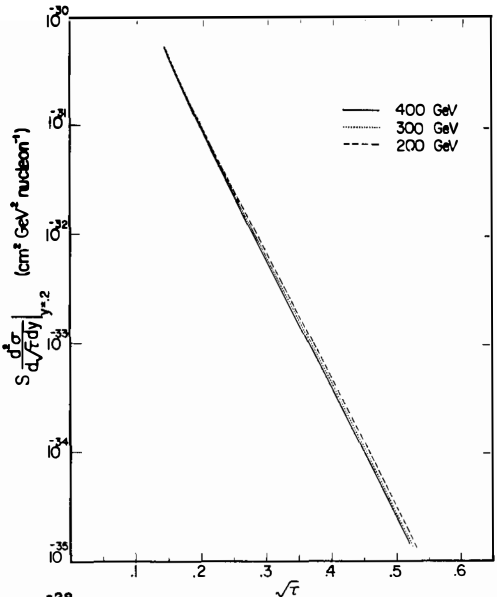


Fig. 3. Cross section at the three different beam energies as predicted by a QCD calculation of Owens and Reya (Ref. 3).

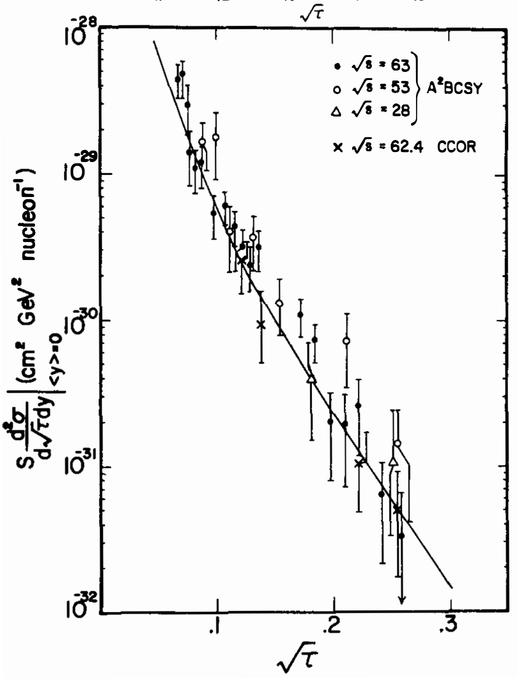


Fig. 4. CERN ISR dilepton data. The solid line is a Drell-Yan model fit to the CFS data extrapolated to the CERN regime.

Unfortunately both the DIES data and the dilepton data have a bad correlation of x and Q^2 as indicated in the figure 5 caption. The overlap in Q^2 occurs at about x = .15, below the CFS data. Thus the determination of the "K-factor" involves an extrapolation (with an unknown functional shape) to lower x for the CFS data, an extrapolation in Q^2, and a neutrino-antineutrino subtraction measurement with its inherent systematic problems. The data are consistent with a K-factor of about 2 but no more accurate statement than this can honestly be made. I urge you to remember this in other determinations of the K-factor; the simple ratio of two large data sets is usually completely dominated by hidden extrapolations and systematics.

I believe one aspect of our data does confront QCD calculations and can lead to more fruitful research in the future. Figure 6 shows our data on the yield of dilepton pairs as a function of the P_t of the pair. The data shows a complicated behavior; for P_t<1 GeV/c the curves look quadratic, i.e. a behavior like $e^{-aP_t^2}$.

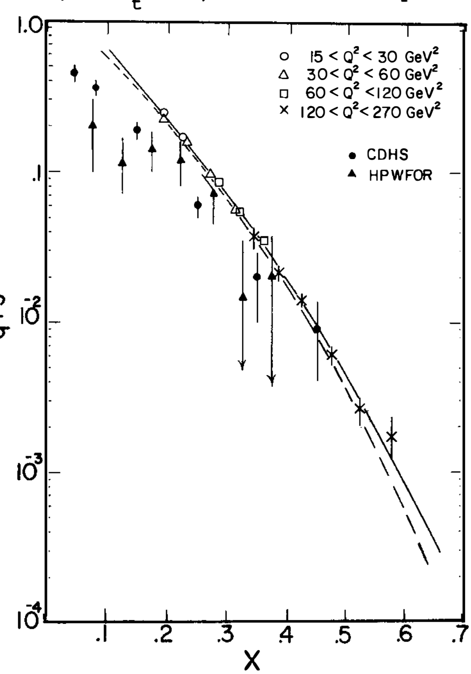


Fig. 5. Sea distribution for this experiment compared with neutrino results. In the dilepton data there is a correlation $\langle Q^2 \rangle$ 2πmx^{2}E and in the neutrino data the correlation is $\langle Q^2 \rangle$ 2πmxyE. See Reference 1 for details of the comparison and fitted curves.

For P_t>2 GeV/c the curves flatten off and become slightly concave indicating a P_t dependance slower than exponential, a possible sign of power-law dependance. Clearly, quoting an average value of $\langle P_t \rangle$ or $\langle P_t^2 \rangle$ does not do justice this data; the cross section may be reflecting different sub-processes in the low and high P_t region.

Kajantie and Raitio[5]; Altarelli, Parisi and Petronzio[6]; Berger[7]; and other theorists spotted these trends in our data and attempted to calculate second order lepton-production contributions. Briefly, their work involved including contributions due to the gluon bremstrahlung and gluon Compton scattering diagrams shown in Figure 7b and 7c respectively. The Compton scattering diagram especially was found to contribute importantly at high P_t if one assumed that the constituent quarks in a nucleon had a limited intrinsic transverse momentum.

Unfortunately the simple calculation of these second order diagrams diverges at low P_t. Some way must be found to "regularize" the low P_t behavior. A simple procedure involves folding all the calculations with a simple gaussian intrinsic transverse momentum, $e^{-aK_t^2}$. A straightforward procedure can then be followed to fit the data to the sum of the five terms shown in Figure 7.

In order to fit our data, we have assumed a univeral shape for the distribution of gluons in a nucleon, $B(1-x)^m$; a form for the anti-quark distributions in a proton, $d= A(1-x)^n$ and $u= A(1-x)^{n+\beta}$; and a Gaussian intrinsic transverse momentum spectrum for the constituents, $e^{-aK_t^2}$. The valence structure functions u(x) and d(x) are taken from existing deep inelastic scattering data.[8] Since the second order diagrams involve a gluon-quark vertex, the strong coupling constant α_s is also a parameter in the fit.

The convergence of the fit was slow due to a large correlation between the number of gluons, coefficient B, and the strength of their coupling, α_s. In the final fit the integral of the fractional momentum carried by the gluons (i.e. the coefficient B) was fixed at 50%, as seen in deep inelastic scattering. The data were binned in incident energy (200 GeV, 300 GeV, 400 GeV), dilepton mass (excluding the upsilon region), dilepton P_t, and dilepton rapidity y.

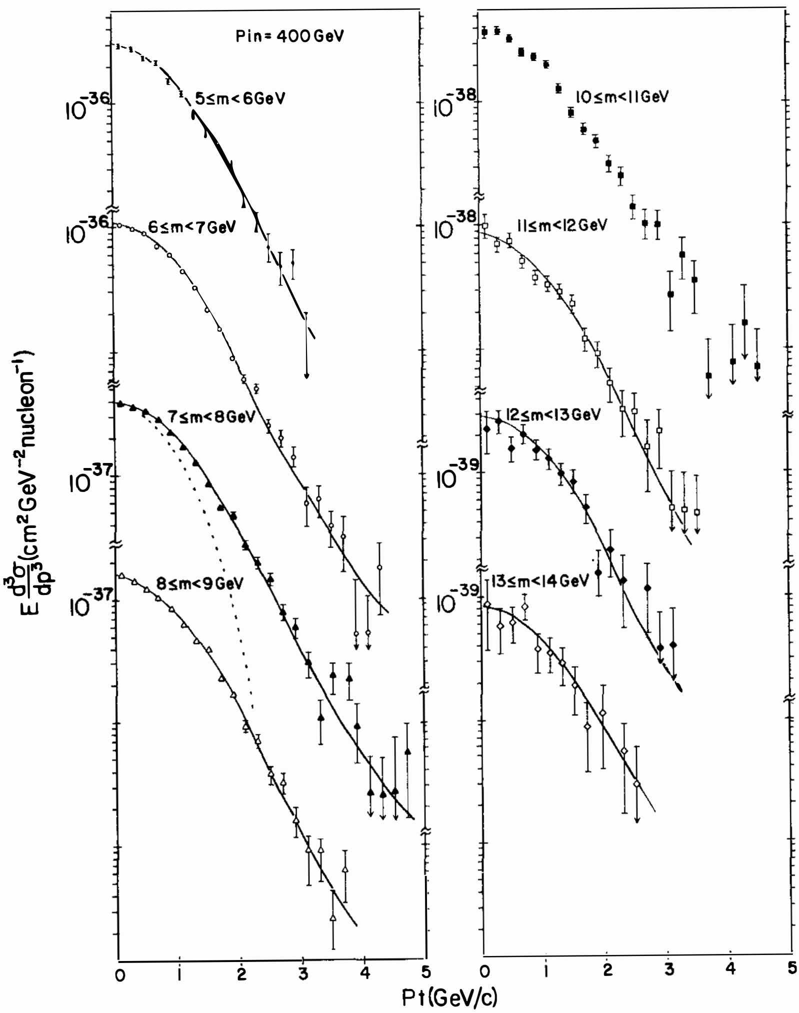
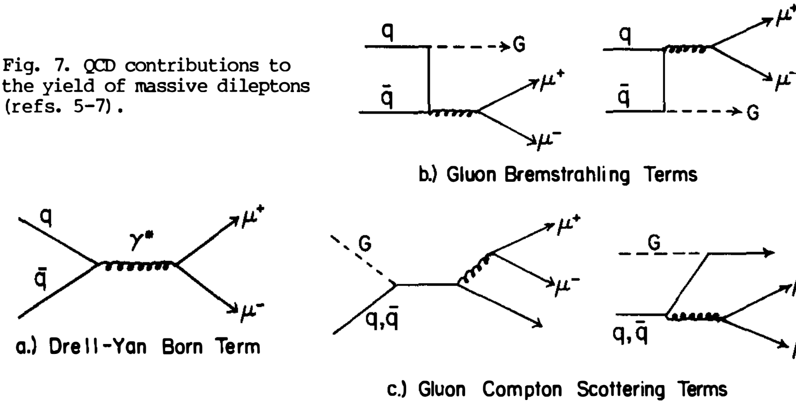


Fig. 6. Invariant yield of dimuons at 400 GeV as a function of the transverse momentum P_t of the muon pair. The solid curves result from the simultaneous fit to all the CFS data as described in the text, the dashed curve indicates the contribution of the Born term alone at 7.5 GeV mass.

Fig. 7. QCD contributions to the yield of massive dileptons (refs. 5-7).



The 876 separate data points were fit very well (χ^2 per degree of freedom ~ 1) with the parameters shown in Table I.

The solid curves on Figure 6 are a plot of the calculated fit. The dotted curve shows the contribution of the Drell-Yan Born term for one mass bin. At high P_t the fit describes the data very well and is completely dominated by the second order terms. The fit values of the strong coupling constant $\alpha_s = .27$, the intrinsic transverse momentum $\langle K_t \rangle = 580$ MeV, and the gluon structure function shape m = 4.1 appear very reasonable.

Table I

Explicit QCD Fit Parameters

			A	=	0.56 ± 0.01
$\bar{d}$	=	$A(1-x)^N$	N	=	8.1 ± 0.1
$\bar{u}$	=	$A(1-x)^{N+\beta}$	β	=	2.6 ± 0.3
$\bar{s}$	=	$(\bar{u} + \bar{d})/4$	B	=	2.55 (fixed by $\int g(x)dx = 0.5$)
g	=	$B(1-x)^m$	m	=	4.1 ± 0.2
f	=	$e^{-ak_T^2}$	α_s	=	0.27 ± 0.01
			a	=	1.14 ± 0.02 GeV^{-2}
			χ^2/DF	=	805/876

I would not claim that we have in any way determined the values of these second order contributions. Instead, I claim that the fit qualitatively shows that we are probing different physics at high P_t. Instead of studying the log Q^2 behavior of the Born term at low P_t, a more definitive test of QCD might involve studying in more detail, i.e. as a function of both production and decay variables, the behavior of this high P_t dilepton yield. This is indeed one of the goals of our next experiment, E-605.

Two years ago when we began planning for an experiment to follow E-288 we set down a number of design goals:

a.) The apparatus should have a physical aperture stop for all particles with P_T<6 GeV.

b.) It is important to positively identify all particle species: $e^{\pm}, \mu^{\pm}, \pi^{\pm}$, $k^{\pm}$ and $p^{\pm}$.

c.) The apparatus should be compatible with intensities of 3 x 10^{12} protons per pulse at 1 TeV incident energy.

d.) The acceptance for high P_t pairs should be increased.

e.) The resolution should be better than E-288.

We believe the apparatus shown in Figure 8 more than meets these goals. The large target and dump magnet has a field integral of 30 Tesla-m. A forward particle must have a momentum greater than 70 GeV/c to reach the MWPC detector station 1. The momentum remeasurement in the second magnet and the positive particle identification in the ring-imaging Cerenkov, the electron and hadron calorimeters, and behind the muon wall assure sensitive background rejection. The mass resolution of the apparatus is designed to be .3% FWHM for hadron or lepton pairs in the 10 to 20 GeV mass range.

The calculated acceptance of the apparatus for one sign of the charge (the upper half of the aperture) is shown in Figure 9. The acceptance boundaries shown are determined by the physical location of the magnet coils and the beam dump in the magnet. A trigger processor being built at Columbia University will be used to reject background particles including muons from the dump and hadrons rescattered off the various aperture boundaries.

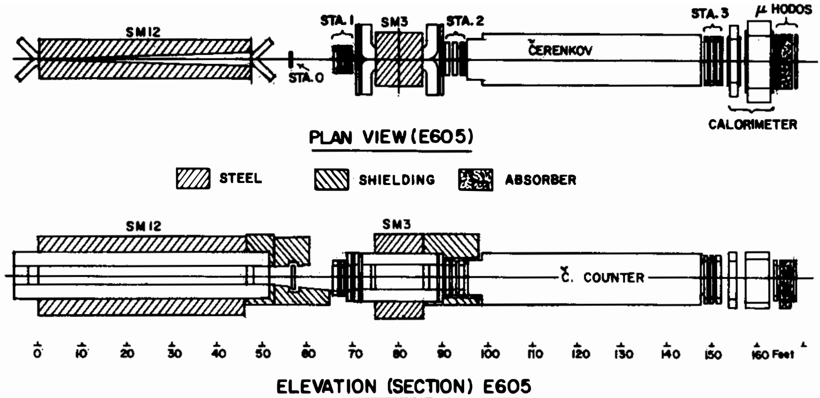


Fig. 8. Schematic of Fermilab Experiment 605, a Columbia, Fermilab, Stony Brook, Univ. of Washington, KEK, Kyoto, Saclay and CERN collaboration. This experiment is currently under construction in the Meson Detector Building at Fermilab.

Note that we are sensitive to a large fraction of the kinematic domain $X_t > .5$. In this unique domain the particle detected, whether it is a lepton or hadron, must be the leading particle. In a constituent scattering picture one would expect an increasing probability of observing an accompanying particle on the other side. This has been observed in our previous experiments[9] for $X_t < .5$. We hope that by studying the kinematic domain $X_t > .5$ in detail we can make sharp tests of QCD constituent scattering predictions.

The experiment is currently under construction and will be set up in the M1 beam line at Fermilab this summer. Hopefully by this time next year we will be getting our first glimpse of very high P_t hadrons and leptons.

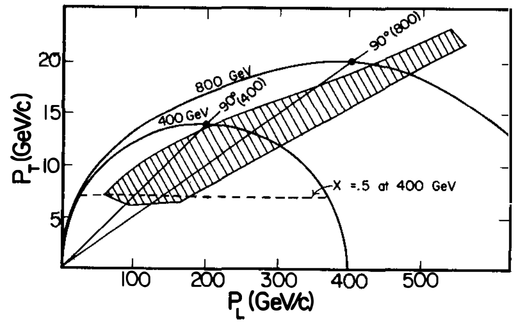


Fig. 9. E-605 acceptance plot. The magnetic field, magnet coils, and absorber placement determine the acceptance (shaded area) for positive particles and for negative particles (passing above and below the dump respectively). The semi-circles indicate the kinematic limit at 400 and 800 GeV incident proton energy.

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