Dilepton Production and Scaling

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ABSTRACT

The 1968 BNL dimuon data are reanalyzed in the light of new data in the production of resonances, on the Feynman x behavior of dilepton continua and on the A -dependence of dilepton production. The results show a very high degree of consistency with scaling in the BNL energy domain $s = 45-60 \text{ GeV}^2$. Comparison with Fermilab data at $s = 750$ confirms the agreement and indicates that $m^3 d\sigma/dm = F(m^2/s)$.

The availability of high mass dilepton data at FNAL¹ has stimulated a reanalysis of the 1968 dimuon experiment at BNL² in order to address the crucial question of scaling. This is a prediction of many of the currently used models for dilepton production in hadron collisions but also follows from dimensional arguments and predicts:

$$m^3 \frac{d\sigma}{dm} = F(m^2/s) \quad (1)$$

at sufficiently high m , s , but finite $\tau = m^2/s$.

The reanalysis involves subtracting³ the resonance induced "shoulder" and refitting the data to a smooth m -dependence. The data must also be corrected for the $P_{||}$ cut induced by the apparatus. We have been guided by popular models,⁴ by the observed BNL $P_{||}$ distribution,² and by continuum and resonance data^{5,6} up to the J/ψ . We have also studied excursions of the model to understand the sensitivity of the corrections to the details of the model. Finally, we note that recent measurements of the A dependence

of the continuum^{1,5} and of the resonances suggest a dependence of the power of Λ on mass which increases from 0.67 at the rho to 0.93 at the J/ψ . The BNL experiment assumed $(\sigma_{\mu\mu}/\sigma_T)_{\text{uranium}} = (\sigma_{\mu\mu}/\sigma_T)_{\text{hydrogen}}$ and so this assumption is corrected here.⁷

The corrections are applied to three sets of data taken with incident protons of 22, 25, and 29.5 GeV. A fourth set at 28.5 GeV is in very good agreement with the 29.5 GeV data. The corrections are made to each mass bin in each of the energies to form

$$\frac{d\sigma}{dm} = \int_{-x_m}^{+x_m} \frac{d^2\sigma}{dm dx} \cdot dx \quad (2)$$

where $|x_m|$ is the kinematic limit of $x \equiv 2P_{||}^*/\sqrt{s}$. This limit varies with mass. The results are presented in Fig. 1 as $m^3 \frac{d\sigma}{dm}$ vs. $\tau \equiv m^2/s$. We note a remarkable consistency of these three data sets over the range of BNL energies studied. This is in contrast to the earlier conclusions² that the s -dependence "seemed" steeper than the Drell-Yan predictions. The new feature emerges from the greater confidence and presumed correctness of the aperture corrections. In Fig. 1, we also present the recent Fermilab results on dimuons from 400 GeV protons incident on copper.¹ These data are corrected from $d^2\sigma/dm dy|_{y=0}$ to $m^3 d\sigma/dm$ by the same model corrections used for the BNL data. We conclude that the indications of a scaling regime, i.e. Eq. (1), are again remarkably confirmed over a range of s from 45 to

750 GeV². The residual differences (factor of 1.5 to 2.5) are well within the normalization and systematic uncertainties of the different experiments. We note that the departure of the BNL scaling curve from the FNAL fit¹ above $\tau = 0.15$ could be due to Fermi motion which has the net effect of increasing the value of s . At $\tau \approx 0.4$, this could easily represent a downward correction by a factor of 2, as noted by Farrar.⁷

In Figs. 2 and 3, we present some other features of the BNL data: Figure 2 shows the x -distribution contrasted with the model we used for the corrections. Figure 3 shows the $P_{\perp}$ behavior compared to recent higher energy studies in the same mass region.⁶ This indicates that $\langle P_{\perp} \rangle$ is not a function of m^2/s in this domain.⁸

Finally, we are encouraged to use these results to make some predictions based upon simple analytic fits to the BNL data, e.g.:

$$F(\tau) \approx 2 \times 10^{-36} (1-\tau)/(0.02+\tau)^3.$$

These predictions are relevant to experiments currently underway at ISR ($\sqrt{s} = 53,61$) and anticipated for proposed higher energy storage rings.^{9,10} Some are given in Table I. If these predictions are confirmed, and the knowledge of $F(\tau)$ improved, one can go on to predict the production of all esoteric particles which may be pair produced by the virtual photon "flux" available in pp collisions e.g. heavy leptons, unconfined quarks, monopoles, etc.¹⁰

We are aware of other attempts to establish scaling using these and other data.¹¹ The virtue of this analysis is the internal self-consistency and intimate appreciation of aperture problems.

The authors would like to thank the members of the Fermilab collaboration (Columbia-Fermilab-Stony Brook) and the CERN collaboration (CERN-Columbia-Oxford-Rockefeller) for information and discussions. We are also grateful to Dr. L.L. Wang for her calculations and compilations.

TABLE I

Predictions of Cross Sections from Scaling

$M(\text{GeV})$	$\sqrt{s} \text{ GeV}$				
	27	53	400 a)	600 a)	
10 $l\bar{l}$	5×10^{-37}	7×10^{-36}			cm^2/GeV
15 $l\bar{l}$	1×10^{-38}	5×10^{-37}			cm^2/GeV
50 W^+			4×10^{-33}	2×10^{-32}	cm^2
100 W^+			3×10^{-34}	2×10^{-33}	cm^2

a) $\sigma_W \geq 0.09 M_W^3 \left(\frac{d\sigma}{dm}\right)_{M_W}$: See Ref. 9.

* Research supported in part by the National Science Foundation.

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- Fig. 1   Scaling behavior of BNL and FNAL data. The dashed lines represent the limits uncertainties in the corrections given by plausible variations in the model.
- Fig. 2   Behavior of dilepton production with x in the Drell-Yan model from Ref. 4. The analytical fit is $[1-(x/x_m)^2]^n$ and the power was varied from 2 to 4 to provide model dependence limits shown in Fig. 1.
- Fig. 3   The $P_{\perp}$ dependence at $\sqrt{s} = 59$. The mean $P_{\perp}$ is plotted on the inset with the data of Ref. 6. The dashed line is a fit to: $\exp(-2.3 P_{\perp}^2)$ which implies $\langle P_{\perp} \rangle = 0.74 \text{ GeV}/c$.