# DIMUON PRODUCTION BY PROTONS IN TUNGSTEN*

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## ABSTRACT

The mass spectrum of dimuons produced by 400 GeV/c protons in Tungsten has been measured for masses greater than 7 GeV. A clear resonant signal of 2700 upsilons has been seen. The dependence of dimuon production on $x_F$ and $p_T$ has been determined for dimuon masses in the range 7.0 to 8.25 GeV as well as for masses in the upsilon region 8.25 to 9.75 GeV.

## INTRODUCTION

This is a report on an experiment currently running at the Fermi National Accelerator Laboratory. The experiment is primarily a search for high-mass ($\gtrsim$ 7 GeV) muon pairs. The experiment was designed to have very large acceptance (essentially the forward hemisphere in the center-of-mass system) yet be capable of operating at beam intensities in excess of $10^{11}$/sec. The design objectives were achieved at the expense of resolution. The mass resolution, $\sigma_m/m$, is 6% at the upsilon mass and worsens slowly as the mass increases.

Our large acceptance enables us to measure the dependence of muon pair production on $x_F$ and $p_T$. The acceptance extends over the range $-0.1 < x_F < 1$ and is essentially independent of $p_T$. Our large acceptance also allows us to look for events with more than two muons in the final state.

We report preliminary results based on data taken during a three week period in January 1978. Only results from the analysis of dimuon data are reported. We observed a clear signal for production of upsilons by 400 GeV/c protons incident upon a tungsten target. Our upsilon signal consists of $\sim$2700 events. We are able to accumulate upsilons at the rate of 100 events/hour under optimal conditions. We report results for the $x_F$ and $p_T$ dependence of dimuon production for masses in the range 7.0 to 8.25 GeV as well as for masses in the upsilon region 8.25 to 9.75 GeV.

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## EXPERIMENTAL APPARATUS

The experiment is set up in the M2 beam line of the Meson Laboratory at Fermilab. The high intensity 400 GeV/c diffracted proton beam is dumped in a 0.30-m-long tungsten target. Immediately downstream of the target, a muon spectrometer is formed by a series of three gapless steel magnets. The magnets are operated at the saturation field of 21 kgauss. The field is horizontal. The total length of the three magnets is 5.5 meters.

Downstream of the magnets are the particle detectors. The detectors are arranged to form two arms separated by a gap of 0.33 m. The sensitive area of each arm is 0.71 x 1.02 m. Each arm consists of 5 Cerenkov counter hodoscopes and 9 planes of multiwire chambers. A plan view of the experiment is shown in Fig. 1.

The Cerenkov hodoscopes form the basis for the trigger. The two planes of horizontal Cerenkov counters are used to require stiff trajectories in the muon spectrometer. The three planes of vertical counters are used to require trajectories which originate in the tungsten target. The back plane of vertical counters is wedge-shaped to avoid muons from the $\rho$ and $\psi$ background.

The multiwire chambers provide fine spatial information used to reconstruct the muon trajectories. The chambers were operated with a sensitive time of 200 nsec. At a beam intensity of $2 \times 10^{11}$/sec, 40,000 protons interact in the tungsten target within this sensitive time. Nevertheless, clean muon trajectories are observed in the chambers.

## ACCEPTANCE

The combined requirement of the horizontal and vertical Cerenkov hodoscopes sets a threshold for dimuon mass at $\sim$7 GeV. The mass acceptance in the threshold region as calculated by Monte Carlo technique is shown in Fig. 2. The mass acceptance remains high for indefinitely large masses.

The acceptance in the Feynman-x variable, $x_F$, as calculated for 9.5-GeV mass, 0.0-GeV/c $p_T$ dimuons is shown in Fig. 3. The $x_F$ acceptance is similar for all masses above our threshold and for all $p_T$ within reason.

While the $x_F$-acceptance is not flat, it is still large over a wide range. For $x_F$ = 0., well down from the peak, the acceptance is 1.7%.

## DIMUON RECONSTRUCTION

Events which satisfied the dimuon trigger requirement were reconstructed by the procedure:

1) Roads determined by the pattern in the Cerenkov hodoscopes were drawn through the multiwire chambers.

2) The roads were searched for wire hits. Straight line fits to the hit wires were made. At least 7 of the 9 chambers were re-

quired for a fit.

3) Events with two good tracks were analyzed assuming both tracks originated at a point along the beam line and one absorption length (10.3 cm) into the tungsten target. The muon momentum and vertical projection of the production angle were determined from the vertical projection of each track. The single parameter, the vertical projection of the muon momentum, was varied until the track could be traced back through the spectrometer to pass through the assumed production point.

4) The horizontal projection of each track was extrapolated back to the region of the assumed production point. The horizontal deviation was required to be less than 3.5 times the expected deviation. The calculation of the expected deviation was based on the spatial resolution of the chambers and the multiple Coulomb scattering at the measured momentum.

## RESOLUTION

Our resolution is primarily limited by the multiple Coulomb scattering the muons suffer in passing through the 5.5 meters of steel in the muon spectrometer. The rms projected $p_T$ so acquired is 0.26 GeV/c. The maximum $p_T$ which can be transferred in any single collision with the nuclear Coulomb field is only $\sim$0.04 GeV/c. Consequently we expect the errors in projected $p_T$ to be Gaussian-distributed to an excellent approximation. The magnetic field of 21 kgauss acting for 5.5 meters transfers 3.5 GeV/c of momentum to the muon.

Detailed analysis shows that our mass resolution is maximized for symmetric pairs in which each muon bends back toward the beam line. In our treatment of the data, we enhance our mass resolution by requiring that the momentum ratio of the muons be less than 4 and that each muon bend back to the beam-line. Since our acceptance is largest for bend-back pairs, the bend-back cut results in only a mild (25%) reduction of our data sample. The present momentum ratio cut excludes virtually none of our data.

The results of a Monte Carlo calculation of the dimuon mass, $x_F$ and $p_T$ resolutions are shown in Table I. The expected error in $p_T$ is approximately proportional to the dimuon mass.

## RESULTS

The distribution of reconstructed $\mu^+\mu^-$ mass is shown in Fig. 4. The distribution has been corrected for our acceptance. A clear resonant signal of $\sim$2700 upsilons is seen. At 9.5 GeV, the ratio of apparent resonant production to non-resonant production is 0.41. The ratio of the total $\Upsilon \rightarrow \mu^+\mu^-$ signal to the continuum signal at 9.5 GeV is 0.82 GeV. Our resolution is insufficient to discern the individual members of the upsilon family.

A subsample, 16%, of our January 1978 data was analyzed to determine the $x_F$ and $p_T$ dependence of $\mu^+\mu^-$ pair production in two mass regions: 7.0 to 8.25 GeV and 8.25 - 9.75 GeV. The upsilon region contained $\sim$20% upsilons.

The observed distributions in $p_T^2$ for the two regions are shown in Figs. 5 and 6. The fall-off with $p_T^2$ is strikingly different for the two regions. The fits shown in Figs. 5 and 6 were determined by eye. The fit shows that the average $p_T^2$ for the continuum region, 7.0 - 8.25 GeV, is 1.5 $(GeV/c)^2$. The average value of $p_T^2$ for the upsilon region is 2.2 $(GeV/c)^2$. These fits were inserted into the Monte Carlo program. The Monte Carlo-calculated distributions reproduced the data, verifying that apparent slopes in $p_T^2$ are very close to true slopes.

It is not possible to fit the $p_T^2$ distribution in the upsilon region with a two-component model which maintains the continuum slope at its value in the 7.0-to-8.25 GeV mass region. It seems that the continuum slope must be changing with mass. Thus, with our present analyzed data sample, we are unable to unravel the upsilon and continuum production. With our complete data sample, we expect to measure the slope in $p_T^2$ for continuum production above the upsilon region as well. We should then be able to draw conclusions about different production mechanisms.

Our data sample peaks in both mass regions at $x_F \simeq 0.25$. We assumed production cross sections of the form

$$\frac{d\sigma}{dx dp_T^2} = (1 - |x_F|)^N \; e^{-p_T^2/A}$$

and varied the parameter N in the Monte Carlo program until the observed $x_F$ distributions were reproduced. In both mass regions, good fits were obtained for N = 3.0.

TABLE I. RESOLUTION

DIMUON MASS RESOLUTION
(For $x_F$=.2 and $p_T$=0.)

| m(GeV) | $\sigma_m/m$ |
|---|---|
| 9.5 | .059 |
| 18 | .077 |

DIMUON $x_F$ AND $p_T$ RESOLUTION
(For m=9.5 GeV and $p_T$=0.)

| $x_F$ | $\sigma_{x_F}$ | $\sigma_{p_T}$(GeV/c) |
|---|---|---|
| .2 | .03 | .62 |
| .6 | .06 | .76 |

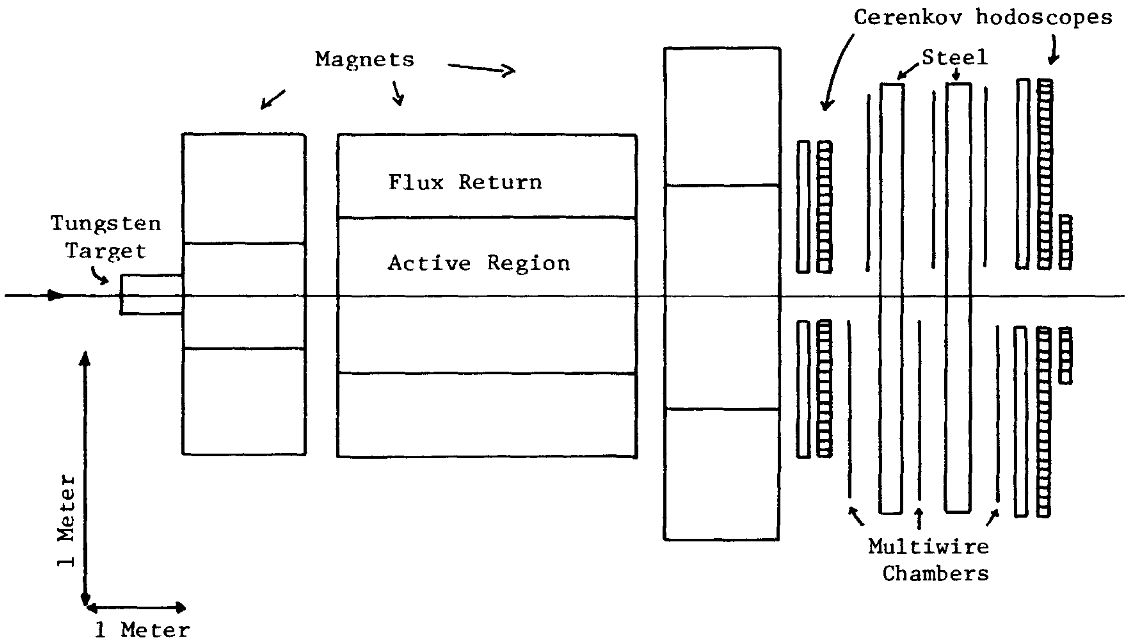


Figure 1. Plan view of the experiment.

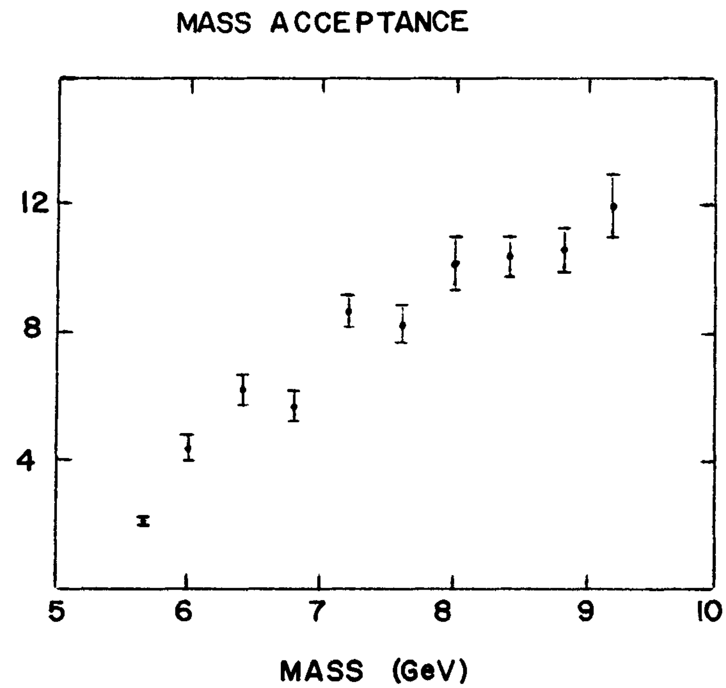


Figure 2. Mass acceptance as calculated by Monte Carlo program. The generated $x_F$ and $p_T$ distribution was $(1 - |x|)^2\ e^{-p_T^2/1.8}$.

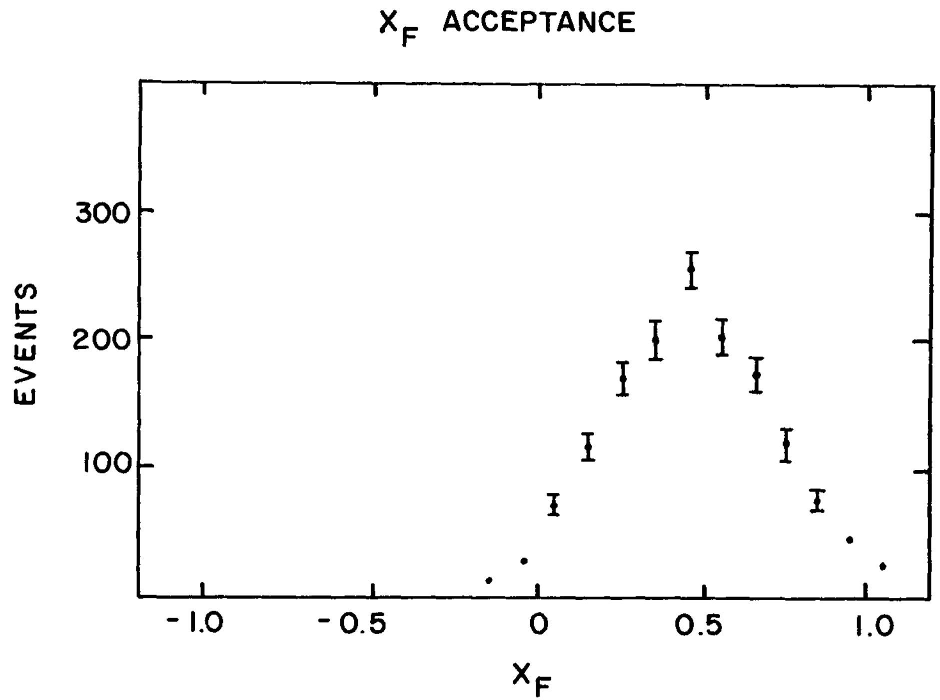


Figure 3. Acceptance in Feynman-x. Dimuons were generated with m = 9.5 GeV, $p_T$ = 0. and a flat $x_F$ distribution. Reconstructed value of $x_F$ is plotted.

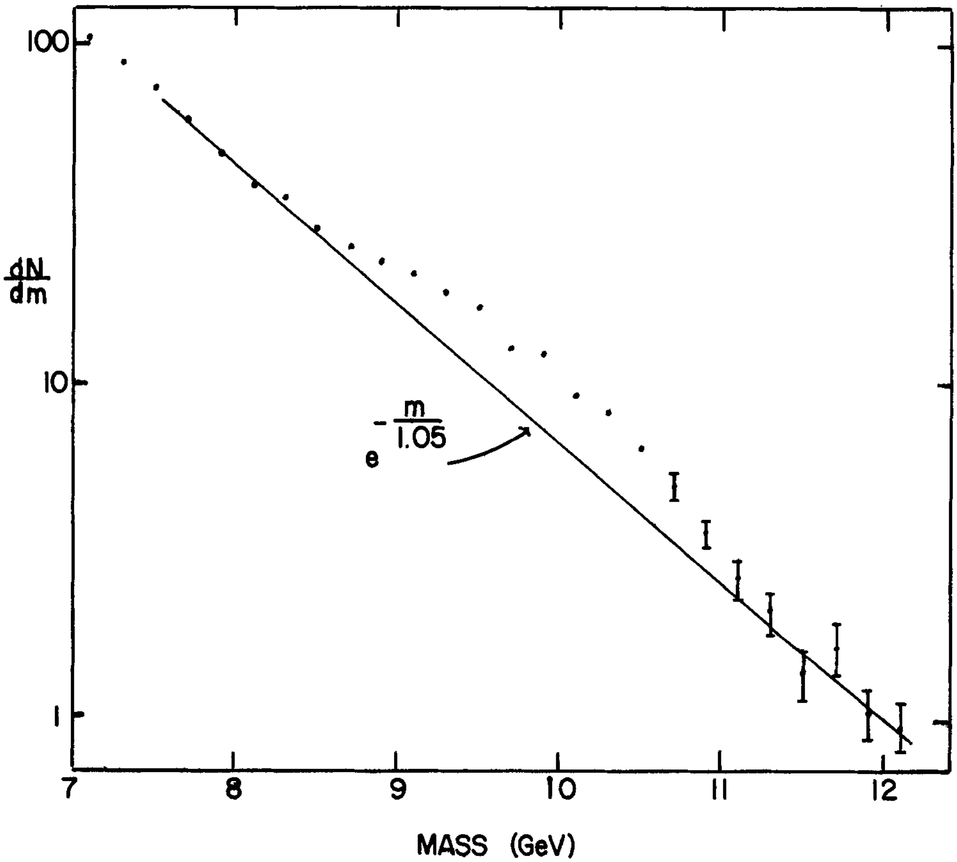


Figure 4. Dimuon mass spectrum after correction for acceptance. There are ∿2700 events in the upsilon peak.

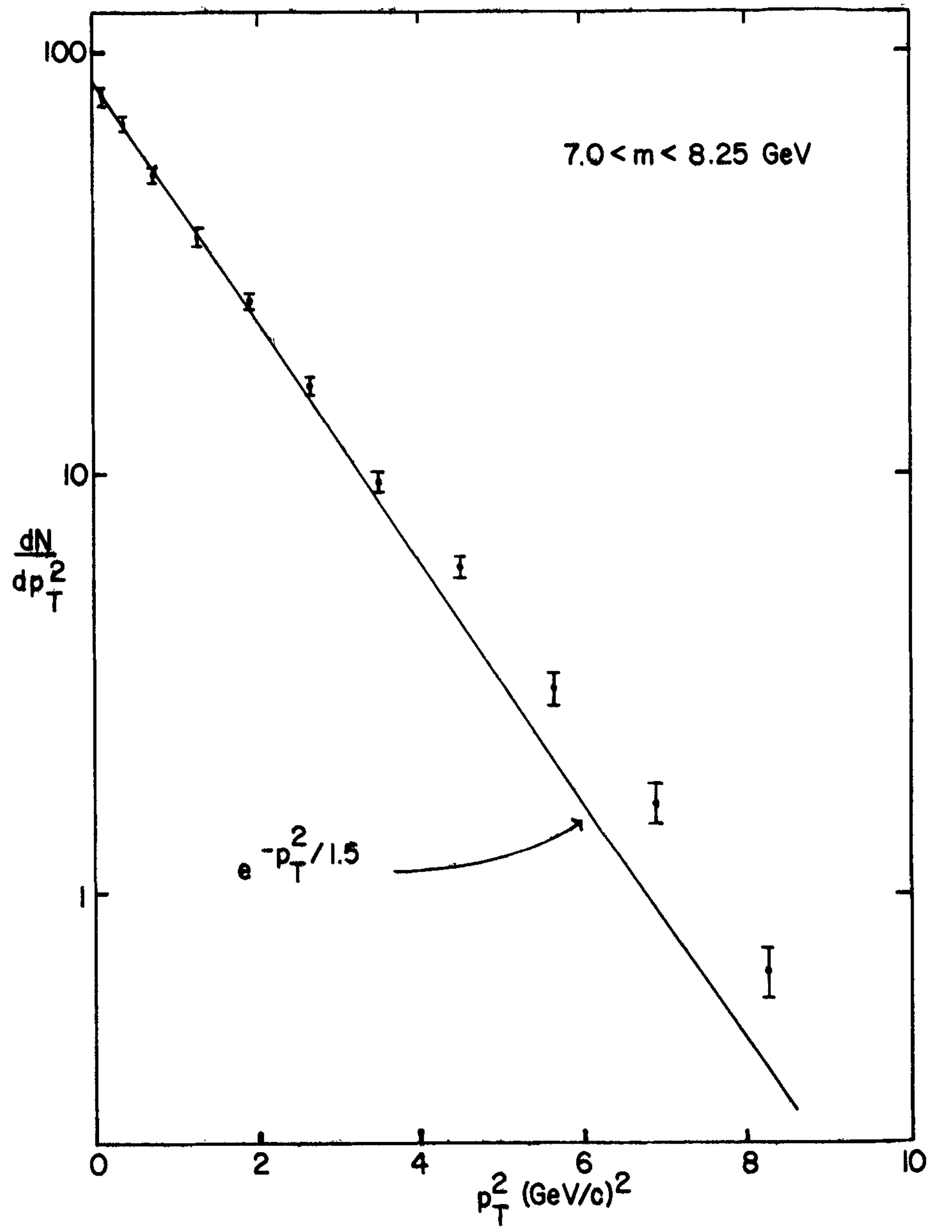


Figure 5. Dimuon $p_T^2$ spectrum for masses in the region 7.0 to 8.25 GeV. The average $x_F$ is 0.25.

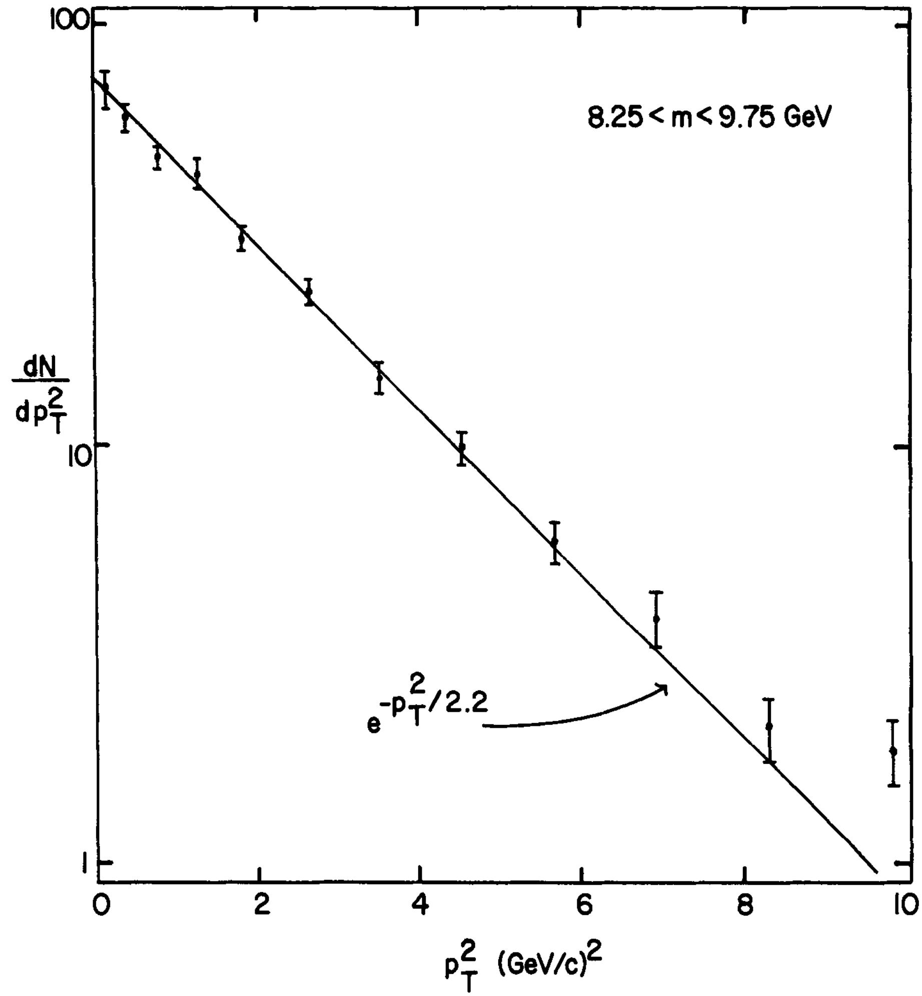


Figure 6. Dimuon $p_T^2$ spectrum for masses in the upsilon region 8.25 to 9.75 GeV. The average $x_F$ is 0.25.