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Study of Charmonium Production in Coincidence with Forward Rapidity Gaps in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV

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We present a preliminary study of J/ψ production in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV using the DØ detector at the Fermilab Tevatron. We focus on events with an absence of particles produced in the pseudo-rapidity regions $2.7 < |\eta| < 4.4$ referred to as rapidity gaps. Using a large sample of reconstructed $J/\psi \to \mu^+\mu^-$ decays, we isolate significant samples with a rapidity gap in either the positive or negative η region indicating single diffractive production of charmonium. We also find an excess of events with rapidity gaps in both the positive and negative η regions that may be an indication of charmonium production via double pomeron exchange.

INTRODUCTION

Diffractive events are inelastic collisions of color-singlet particles where neither color or flavor is exchanged between the particles in the collision. The momentum transfer in the collision is typically parameterized as the exchange of a pomeron. An example of diffraction in proton-antiproton collisions is the interaction $p + \bar{p} \to p + X$ where the proton remains intact throughout the process but sufficient momentum is transfered to disassociate the $\bar{p}$ into a multi-particle system. The daughters of the $\bar{p}$ follow the initial $\bar{p}$ direction leading to highly asymmetric events. Since the proton stayed intact, a large solid angle surrounding the proton is free of particles and is known as a rapidity gap. This rapidity gap is the experimental signature for diffractive events. Studies of various final state topologies such as inclusive jets, vector boson, and heavy flavor production in coincidence with rapidity gaps have been used to probe the nature of the pomeron and give insight on this interesting region of x that corresponds to a transition region between elastic and inelastic scattering.

Complementary to the effort to use diffractive processes to study low x inelastic collisions, an effort is underway to use diffractive events to greatly reduce the uncertainties involved with precision measurements at hadron colliders. While the beam momenta in a hadron collider are uniquely defined and controlled by the accelerator configuration, there is a large range in possible initial state energies due to the range in momentum fractions carried by the interacting hadron constituents. This ambiguity can be removed in diffractive processes such as $p + \bar{p} \to p + \bar{p} + X$ where the momentum transfer in this topology is typically parameterized as double pomeron exchange. If the final state momenta of the proton and antiproton can be determined using very forward detectors, $m(X)$ can be precisely determined allowing for the equivalent of beam energy constraints used successfully at lepton colliders in a hadronic environment. This may be particularly useful in determining the Higgs mass [1]. In terms of rapidity gaps, the experimental signature for double pomeron exchange is the presence of rapidity gaps in both the positive and negative η regions. The first step in quantifying the potential of double pomeron exchange is to observe this double gap phenomena in charmonium production and eventually reconstruct the mass of known charmonium states.

In this Note we report a study of charmonium production in coincidence with both single and double forward rapidity gaps. The charmonium state considered is the J/ψ decaying to the $\mu^+\mu^-$ final state. The study uses a 111.692 pb^{-1} data set of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV recorded by the DØ detector operating at the Fermilab Tevatron.

The DØ detector is a general purpose spectrometer and calorimeter [2]. Charged particles are reconstructed using a silicon vertex tracker and a scintillating fiber tracker located inside a superconducting solenoid coil that provides a 2 T magnetic field. Photons and electrons are reconstructed using the inner region of a liquid argon calorimeter optimized for electromagnetic shower detection. Jet reconstruction and electron identification are further augmented with the outer region of the calorimeter optimized for hadronic shower detection. Muons are reconstructed using a spectrometer consisting of magnetized iron toroids and three super layers of proportional tubes and plastic trigger scintillators located outside the calorimeter.

A suite of dimuon triggers are used for this study that rely on energy deposited in the muon scintillators and fast reconstruction of muon tracks in both the central tracker and muon spectrometer. In all triggers, at least one muon candidate is required to penetrate the muon system's toroid and the track reconstructed in the muon spectrometer must be consistent with a track reconstructed in the central tracking system. In some triggers, topological requirements are placed on the opening angle between the two muon candidates.

Offline muon candidates are formed by matching charged particles reconstructed in the central trackers to hit segments reconstructed in the muon spectrometer. Alternatively, charged particles are matched to energy deposited along a series of hits in calorimeter cells that are consistent with the signature of a minimum ionizing particle originating at the interaction point. The charged particles must have hits in the fiber tracker. Candidate J/ψ mesons are formed using oppositely charged muons with 2.65 GeV$/c^2 < m(\mu^+\mu^-) <$ 4.0 GeV$/c^2$ and $p_T > 3$ GeV$/c$. At least one muon is required to have segments reconstructed in all three layers of the muon spectrometer and have $p_T > 1.5$ GeV$/c$. We require $p_T > 1.5$ GeV$/c$ for the second muon if it has segments in the muon spectrometer. If the second muon is reconstructed in the calorimeter, we require $p_T > 1$ GeV$/c$ and total momentum $p < 7$ GeV$/c$ and the p_T requirement is increased to 2.5 GeV$/c$ for the first muon and 4 GeV$/c$ for the J/ψ candidate. The $\mu^+\mu^-$ invariant mass distribution for J/ψ candidates passing the above criteria is shown in Fig. 1.

Rapidity gaps are identified using arrays of scintillators located at ± 140 cm from the interaction region covering pseudo-rapidity regions $2.7 < |\eta| < 4.4$ as shown in Fig 2. For each event, we record weather or not there was energy deposited in each array. Timing information is used to discriminate between hits from true inelastic collisions and hits from beam induced backgrounds.

In the DØ coordinate system, protons travel from negative to positive η. We define a *p gap* as an event that has

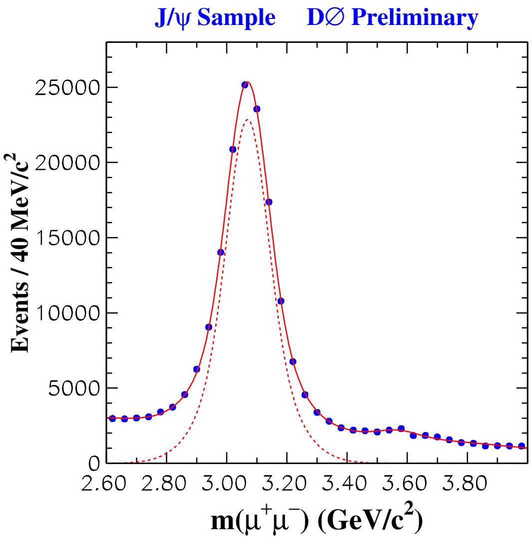

FIG. 1: All J/ψ candidates with the trigger requirements.

energy deposited in the $-\eta$ array and no energy in the $+\eta$ array consistent with the signature of the proton remaining intact throughout the collision. Conversely, a $\bar{p}$ *gap* event contains energy in the $+\eta$ array and no energy in the $-\eta$ array. Together, we refer to these topologies as *single gap* events. A *double gap* event has no energy in either array while a *no gap* event contains energy in both arrays. The fake gap fraction where energy was deposited but not recorded in an array has been determine to be small in an independent analysis of inclusive inelastic events [3].

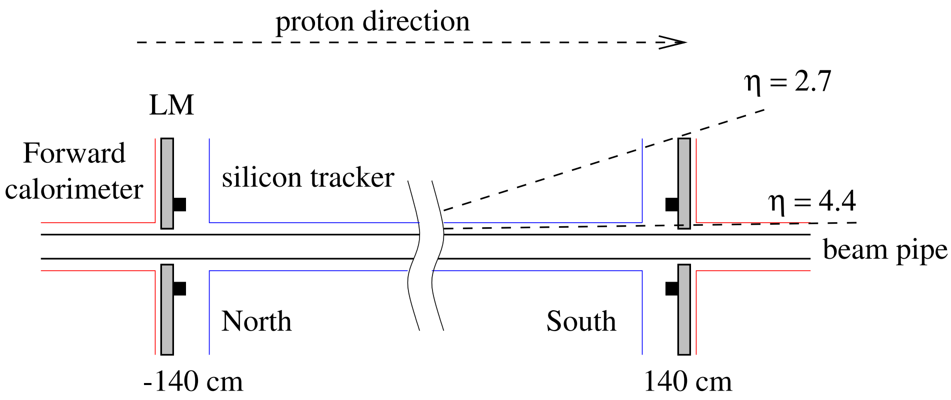

FIG. 2: Figure of the luminosity monitor

The $\mu^+\mu^-$ invariant mass distributions for the for the no gap, p gap and $\bar{p}$ gap samples are shown in Figs. 3- 5. The ratio of the single gap to no gap samples as a function of η is plotted in Fig 6 and clearly shows the asymmetry expected from single diffractive events. While the fake gap fraction has been determined to be small, at this preliminary stage of the analysis we choose to set upper limits on the gap fractions assuming all events are background. Using the larger sample we arrive at a single gap fraction of

$$F_{SG}(J/\psi) < (1.91)\% \quad @90\% \;\; \text{C.L.}$$

which has been corrected for pile up effects due to multiple interactions.

The $\mu^+\mu^-$ invariant mass distributions for the for the double gap sample is shown in Fig. 7. The J/ψ yield of $16 \pm xx$ events is significantly above the combinatoric background and well above current expectations for the double fake rate. However at this preliminary stage we again choose to set an upper limit on the double gap fraction of

$$F_{DG}(J/\psi) < (0.07)\% \quad @90\% \;\; \text{C.L.}$$

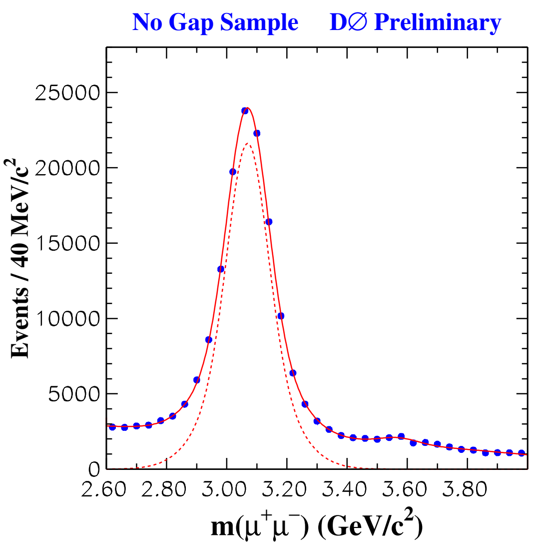

FIG. 3: no gap sample

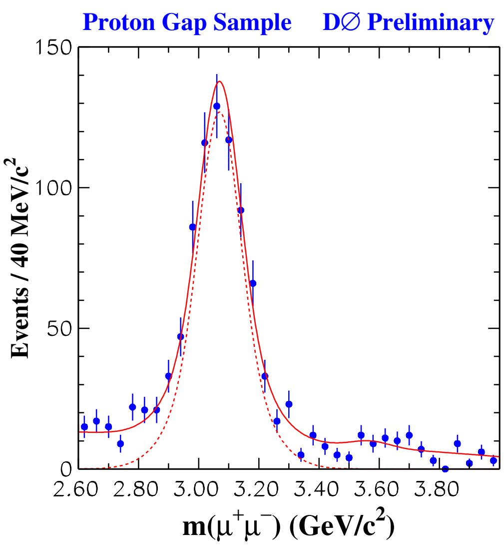

FIG. 4: p gap sample

which has been corrected for pile up effects due to multiple interactions.

In conclusion, we have presented a preliminary study of charmonium production in coincidence with rapidity gaps. The data contain indications for heavy flavor production via both single diffractive interactions and double pomeron exchange although further studies and larger data samples will be necessary to make more conclusive statements. With the analysis of larger data samples already collected we will also have the ability to try and isolate the production of particular charmonium states such as the $\chi_c(0)$, possibly in coincidence with signals from forward detectors now commissioned that are designed to directly measure the momentum of the outgoing proton and antiproton in the interaction.

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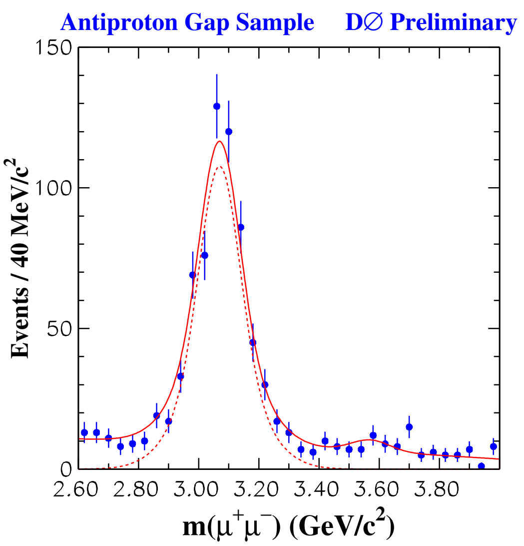

FIG. 5: pbar gap sample

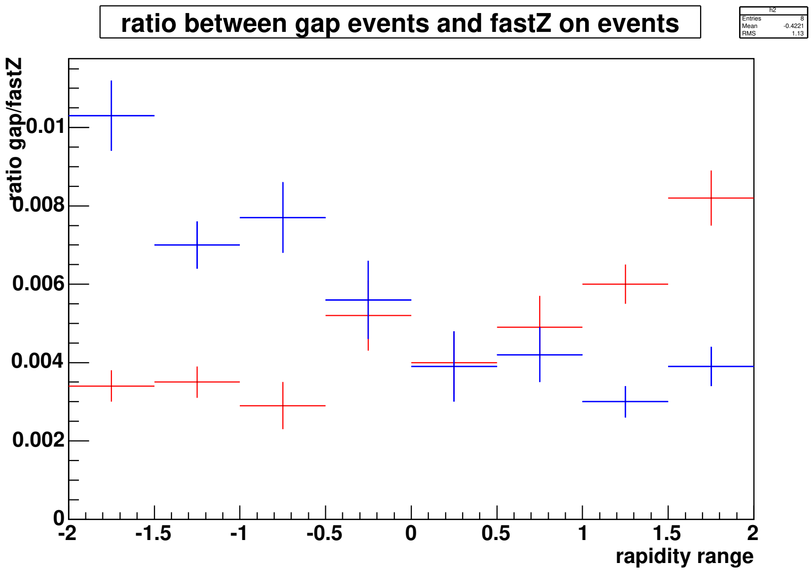

FIG. 6: gaps versus eta

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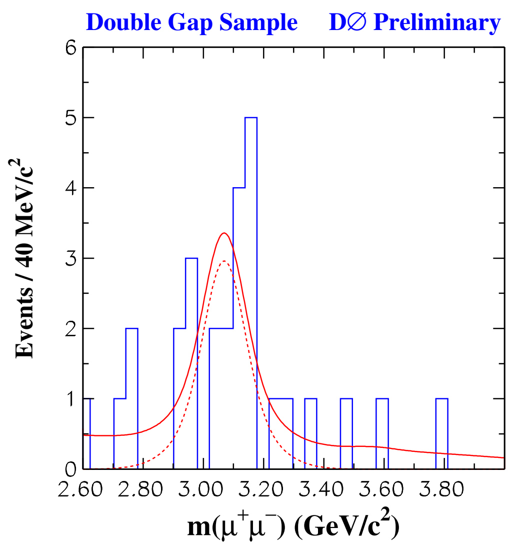

FIG. 7: double gap sample