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$\psi\psi$ PRODUCTION AND LIMITS ON BEAUTY MESON PRODUCTION FROM 400 GeV/c PROTONS

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ABSTRACT

From a study of multimuon events obtained in a high luminosity proton-platinum experiment at 400 GeV/c, we find 15 ± 4 $\psi\psi$ events, which correspond to a production cross section $\sigma(\psi\psi)$ = 27 ± 10 picobarns. The observed production is compared to the $\psi\psi$ events previously found in the same apparatus from incoming π^-; a comparison with QCD predictions is performed, giving a good agreement with expectations from gluon-gluon fusion. Finally, using like-sign dimuon, trimuon and quadrimuon events, we give model-dependent upper limits on beauty meson production: 2 nanobarns/nucleon for central models, 20 nb/nucleon for diffractive production.

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1. INTRODUCTION

In previous publications [1,2] the NA3 collaboration has given results on multimuon events produced in π^- nucleus collisions, from 150 to 280 GeV/c. These events allowed, in conjunction with like-sign high mass dimuons, to set model-dependent upper limits (of the order of 2 to 10 nanobarns) on the production of beauty mesons from 280 GeV/c π^-mesons [2]. From quadrimuon events, evidence was given for the simultaneous production of two J/ψ mesons with a cross-section around 30 picobarns per nucleon. This $\psi\psi$ production has been subsequently explained by several authors [3,4] in the framework of perturbative QCD, the production from π^- mesons being dominated by quark-antiquark graphs.

In the present publication we give results on $\psi\psi$ production, and on multimuon events from proton-nucleus interactions at 400 GeV/c.

2. THE EXPERIMENTAL SETUP

The NA3 experimental set-up [5] was adequately modified to take data with an intensity around 1.5 10^9 400 GeV/c protons per second; in particular the hadron filter was increased to 3.2 m in order to have a hadronic punch-through and a neutron background comparable to that obtained in previous data with much lower intensity. The trigger required at least one muon with P_{Tv} (vertical component of the transverse momentum) greater than 1 GeV/c both in the upper part and in the down part of the apparatus. A complete description of other modifications with respect to the previous set-up may be found in ref. [6].

The data presented here were taken using a 6 cm Platinum target and correspond to an integrated luminosity of (4.0 ± 0.6) 10^{39} cm^{-2}.

3. SELECTION OF EVENTS

We have followed the same analysis procedure as already described for the $\psi\psi$ selection in ref. [1] :

- Only muons with a good time signature (within ± 4 ns with respect to the absolute timing of the event, as described in detail in ref. [1]) are kept. This is mandatory in order to eliminate pile-up of tracks coming from different interactions. However, for ψ-ψ candidates, we allow (as in ref. [1]) one muon to be outside the acceptance of the timing signature device.

- A multitrack vertex finding procedure is performed in order to assign events either to the Platinum target, or to the beam dump. Only events assigned to the Platinum target are considered in the following.

- Due to the longer hadron filter, the mass resolution on dimuons is around 5.5% at the J/ψ mass. J/ψ candidates will be defined as + - dimuons with $2.6 < M_{\mu\mu} < 3.6$ GeV/c².

- We ask that the trigger requirements be fulfilled by one +- combination.

4. $\psi\psi$ EVENTS

Fig. 1a gives the distribution of the two mass combinations, m_1 and m_2, for quadrimuon events with (+-+-) topology. The $\psi\psi$ signal is present; it is evaluated from Fig. 1b where the events are plotted with respect to $d = \sqrt{(m_1-m_\psi)^2 + (m_2-m_\psi)^2}$. $\psi\psi$ candidates being defined by the condition $d < 0.5$ GeV/c², we find 21 candidates including 2 events from the background.

Other backgrounds must be subtracted from these candidates:

- Due to the very high beam intensity and interaction rate, the pile-up of two J/ψ issued from two different interactions within the 8 ns time window is not negligible and gives (4 ± 2) $\psi\psi$ events (assuming a random time distribution of beam interactions within the time window).

- Reinteraction of secondary hadrons in the platinum target gives a negligible background (< 0.15 events expected).

- A last background source may come from false vertex assignation of events originating in the dump; from Monte Carlo simulation it may be estimated to $\sim$ 0.1 $\psi\psi$ events, and is therefore negligible.

Thus, subtracting these 6 ± 4 background events from the 21 candidates, we obtain 15 ± 4 $\psi\psi$ events in this sample of data.

b) <u>Kinematical properties of the events and $\psi\psi$ production mechanism</u> :

In order to determine the acceptance of the apparatus, we have used the explicit parametrizations of the $\psi\psi$ production cross-section given in ref. [3] and [4] for various production mechanisms : quark-antiquark fusion, gluon-gluon fusion, diffractive and central production with intermediate B-meson states. For the valence quark, sea quark and gluon structure functions in the proton we have taken the recent determination from neutrino deep inelastic scattering experiments [7], at $Q^2 = 4\ M_\psi{}^2$, for direct production and $Q^2 = 4\ M_B^2$ for production via B-meson states. The intrinsic transverse momentum distribution of the partons is assumed to be Gaussian-like, with a mean value $< k_T > = 0.7$ GeV/c.

We have displayed on Fig. 2 the experimental distributions, and some expected distributions from the models mentioned above, of $M_{\psi\psi}$ (invariant $\psi\psi$ mass), $\cos\theta_{\psi\psi}$ (production angle), $\varphi_{\psi\psi}$ (angle between the two outgoing ψ's in the transverse momentum plane).

The observed correlation in the $\varphi_{\psi\psi}$ distribution excludes that the events come from fortuitous pile-up of J/ψ mesons, within the 8ns time window defining the "good" events: the $\varphi_{\psi\psi}$ distribution should be flat in this case.

The acceptance is equal to: 2.4 ± 0.3%.
It is substancially lower than previously obtained with incident π^-; this fact is related to the much more restrictive trigger requirements; its value is not very sensitive to the production mechanism. This gives the following $\psi\psi$ production cross-section :

$$\sigma(\psi\psi) = 27 \pm 10 \text{ picobarns/nucleon}$$

assuming a linear A-dependence of the cross-section (A being the number of nucleons in the target).

This result is in very good agreement with the prediction obtained from ref. [3] using gluon fusion giving $\psi\psi$ events in p-p interactions : $\sigma(\psi\psi) \simeq 30$ picobarns at $\sqrt{s} = 28$ GeV. Therefore, as expected, the present results are compatible with $\psi\psi$ production via gluon fusion, whereas π^--induced events were compatible with $q\bar{q}$ fusion prediction.

The measured cross-section is displayed on Fig. 2d, where the total predicted cross-section has been scaled by a factor 4.25. This factor [3] accounts for next-to-leading QCD corrections (like the K-factor in Drell-Yan) and for J/ψ production through χ states.

c) Estimation of the effective transverse momentum of partons from $\psi\psi$ events :

It has been proposed [8] to use the transverse angular correlation between the two ψ's of a $\psi\psi$ event, to estimate the "effective" transverse momentum of the interacting partons $<K_T^2>_{eff} = <K_T^2>_{partons} + <K_T^2>_{QCD}$, where $<K_T^2>_{partons}$ concerns the primordial P_T of the partons, and $<K_T^2>_{QCD}$ accounts for the effects coming from the next-to-leading QCD corrections. For instance in [8] one finds $< k_T >_{eff} = 0.65 \pm 0.1$ GeV/c from π^- induced $\psi\psi$ events. Such estimations are quite model-independent and give results in agreement with other hard scattering processes (large P_T hadronic collisions, deep inelastic lepton scattering).

We give in Fig. 2c the distribution of the angle $\varphi_{\psi\psi}$ previously defined. In Fig. 3 we give the predicted mean value of $\varphi_{\psi\psi}$, as a function of $< k_T >_{eff}$. The experimental value obtained after background subtraction $< \varphi_{\psi\psi} > = (132 \pm 10)$ degrees gives $< k_T >_{eff} = 0.7 \pm 0.2$ GeV/c, and is in good agreement with that obtained from π^- induced $\psi\psi$ events or $D\bar{D}$ pairs.

5. UPPER LIMITS ON BEAUTY MESON PRODUCTION

a) The events

Beauty mesons have been discovered and studied in e^+e^- annihilations around the Υ_{4s} (10575) resonance. They remain to be detected in hadronic interactions. In a previous paper [2] we have given model-dependant upper limits (from 2 to 10 nanobarns/nucleon) on beauty production from 280 GeV/c pions.

The present 400 GeV/c proton interactions are analyzed in the same way. Five different final states are considered: like-sign dimuons, trimuons events with or without one J/ψ, quadrimuons events with or without one J/ψ ($\psi\psi$ events are excluded). All selected events must come from the Platinum target, and all muons in the event must have a good timing signature. Other cuts are performed, in particular on transverse momentum of individual muons or of muon pairs. These cuts are summarized in Table 1; their values have been choosen from simulated events to enrich the samples in B meson candidates. Fig. 4 gives the experimental p_T distribution for the muon with the highest p_T in like-sign dimuons; it is compared to the distributions predicted from refs. 3 and 4.

b) Acceptance

We have generated B meson pairs according to the models described in ref. [3 and 4]. The momentum distributions of the decay products of B mesons (muons and D mesons) have been taken from Cornell results [9], as well as the most recent values of the B meson branching ratios :

$R(B \to \mu + X) = (11.15 \pm 0.5)\%$ [9]

$R(B \to D, D^* + X) = 95\%$ [9]

$R(B \to \psi + X) = (1.0 \pm 0.4)\%$ [10]

The results are summarized in Table II, where we give 90% C.L. upper limits on $B\bar{B}$ production, assuming no nuclear effect. We have verified that these limits are quite insensitive to the cuts described in Table 1. The most sensitive channel (like-sign dimuons) gives upper limits around 2nb/nucleon for central $B\bar{B}$ production, 20 nb/nucleon for diffractive production. These limits are more than one order of magnitude lower than previous results at the same energy [11]; they are consistent with the limits obtained from π^- interactions at 190 and 280 GeV/c [2,12].

Finally, one can notice that even with $\sigma(B\bar{B}) \simeq 20$ nb, only 1 $\psi\psi$ event could be attributed, in our data, to $B\bar{B}$ production.

6. CONCLUSION

We have given evidence for production of $\psi\psi$ events from 400 GeV/c protons, with a cross-section compatible with QCD predictions from gluon-gluon fusion mechanism. From like-sign dimuons, and from events with 3 or 4 prompt muons we obtain upper limits on beauty meson production around some nanobarns for central models in the most sensitive channel.

7. ACKNOWLEDGEMENTS

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TABLE CAPTIONS

Table 1 Statistics on like-sign dimuon and multimuon events, cuts applied to select B-meson decay products, and 90% C.L. upper limits on $B\bar{B}$ production cross-sections. "Central production" refers to the model $gg \rightarrow B\bar{B}$ of refs. 3 and 4. "Diffractive production" refers to the model $q\bar{q} \rightarrow Br\bar{B}r$ of refs. 3 and 4. Muons are labelled 1,2,3,4 according to decreasing p_T value.

$M(i,j)$: invariant mass of particles i and j (in GeV/c²).

$\Phi_T(i,j)$: angle between particles i and j in the plane perpendicular to the beam axis (in degrees).

TABLE 1

FINAL STATE →	$\mu_1^+\mu_2^-$ or $\mu_1^-\mu_2^-$	$\psi\mu$	$\mu_1^+\mu_2^-\mu_3^\pm$	$\psi\mu_1^\pm\mu_2^\mp$	$\mu_1^+\mu_2^-\mu_3^+\mu_4^-$
Number of events in targets (with good timing)	1490	12208	12850	145	212
Cuts on transverse momentum (GeV/c)	$P_T(\mu_1)>2$ $P_T(\mu_2)>1$	$P_T(\psi)>1$ $P_T(\mu)>2$	$P_T(\mu_1)>1$ $P_T(\mu_2)>1$ $P_T(\mu_3)>0.6$	$P_T(\psi)>1.5$ $P_T(\mu_1)>1.5$ $P_T(\mu_2)>0.6$	$P_T(\mu_1)>1.5$ $P_T(\mu_2)>1$ $P_T(\mu_3)>1$
Other Cuts	$\Phi_T>135°$ $M(\mu_1\mu_2)>4$ $X_F(\mu_1\mu_2)>0$	$\Phi_T(\psi,\mu)$ $>90°$	$M(\mu_1\mu_2)>4$ $M(\mu^\pm\mu_3)>2.5$	$\Phi_T(\psi,\mu\mu)>90°$ $M(\mu_1\mu_2)\neq M_\psi$	$M(\mu_1\mu_2)\neq M_\psi$ $M(\mu_3\mu_4)\neq M_\psi$
Number of events after cuts	18±5	24±5	19±5	10±4	6±3
Acceptance (central production)	$1.2\ 10^{-4}$	$3.5\ 10^{-3}$	$3\ 10^{-4}$	$9\ 10^{-3}$	$4\ 10^{-4}$
90% CL limit on $\sigma(B\bar{B})$ (central production)	2nb	14nb	20nb	20nb	40nb
90% CL limit on $\sigma(B\bar{B})$ (diffractive production)	20nb	75nb	200nb	40nb	300nb

FIGURE CAPTIONS

Fig. 1a) Distribution of the two mass combinations m_1 and m_2 in $\mu^+\mu^-\mu^+\mu^-$ events.

1b) Distribution of events with respect to the variable d described in the text.

Fig. 2 Experimental properties of $\psi\psi$ events and comparison with QCD predictions

a) $M_{\psi\psi}$ (invariant ψ-ψ mass)

b) $\cos \theta^*_{\psi\psi}$ (production angle of the $\psi\psi$ system).

c) $\varphi_{\psi\psi}$ (angle between the two ψ's in the transverse momentum plane).

d) Total cross-section.
The curves in a)b)c) are normalized to the data and derived from the models described in Refs. 3 and 4.

Fig. 3 Prediction of $\langle\varphi_{\psi\psi}\rangle$ as a function $\langle K_T\rangle_{eff}$.
Full-line: Fermi-like distribution of the effective transverse momentum; dashed line: Gaussian-like distribution.

Fig. 4 Momentum distribution of the muon with highest transverse momentum, in like-sign dimuons.
The curves are predictions derived from the models of Refs. 3 and 4, normalized to the data.

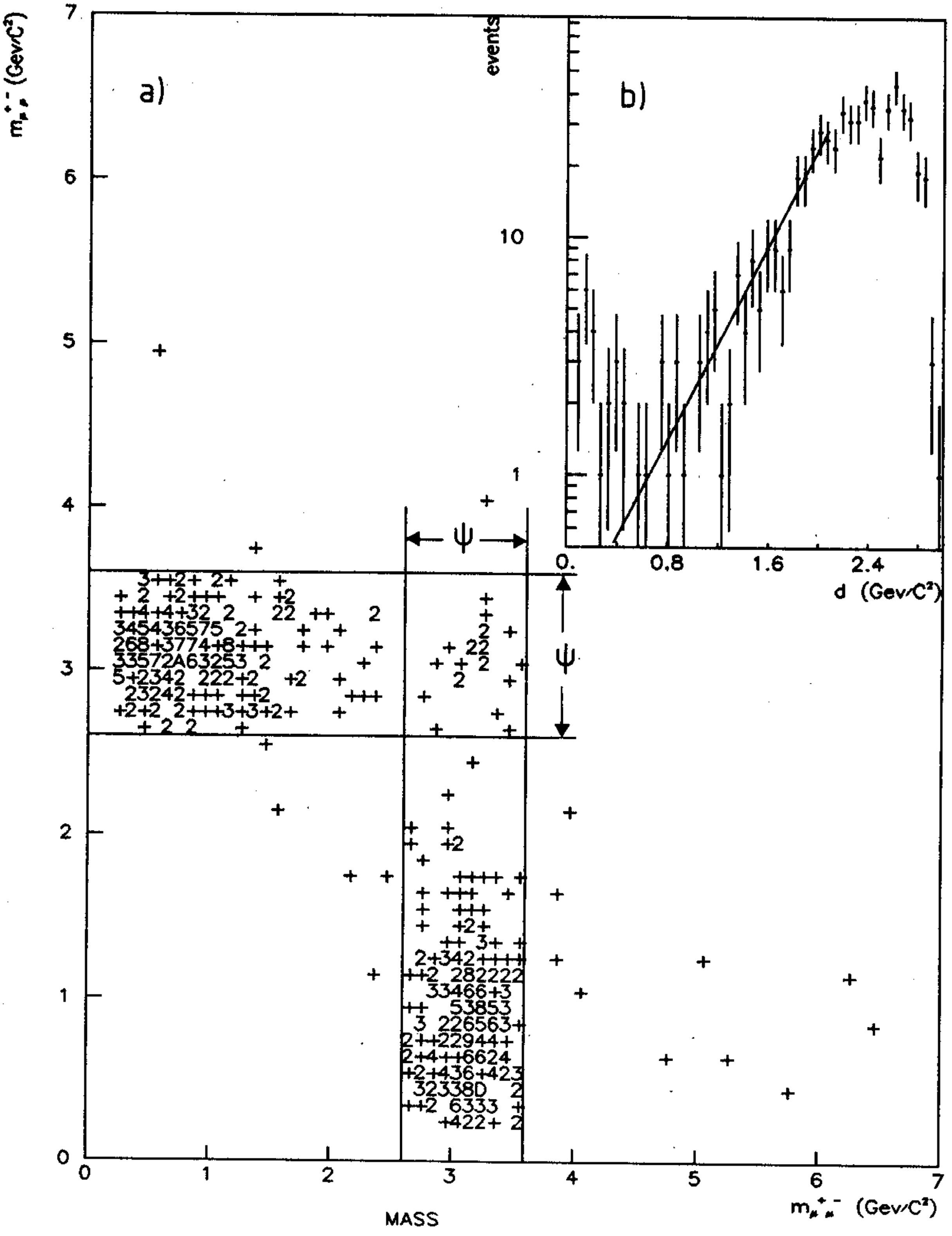


FIG 1

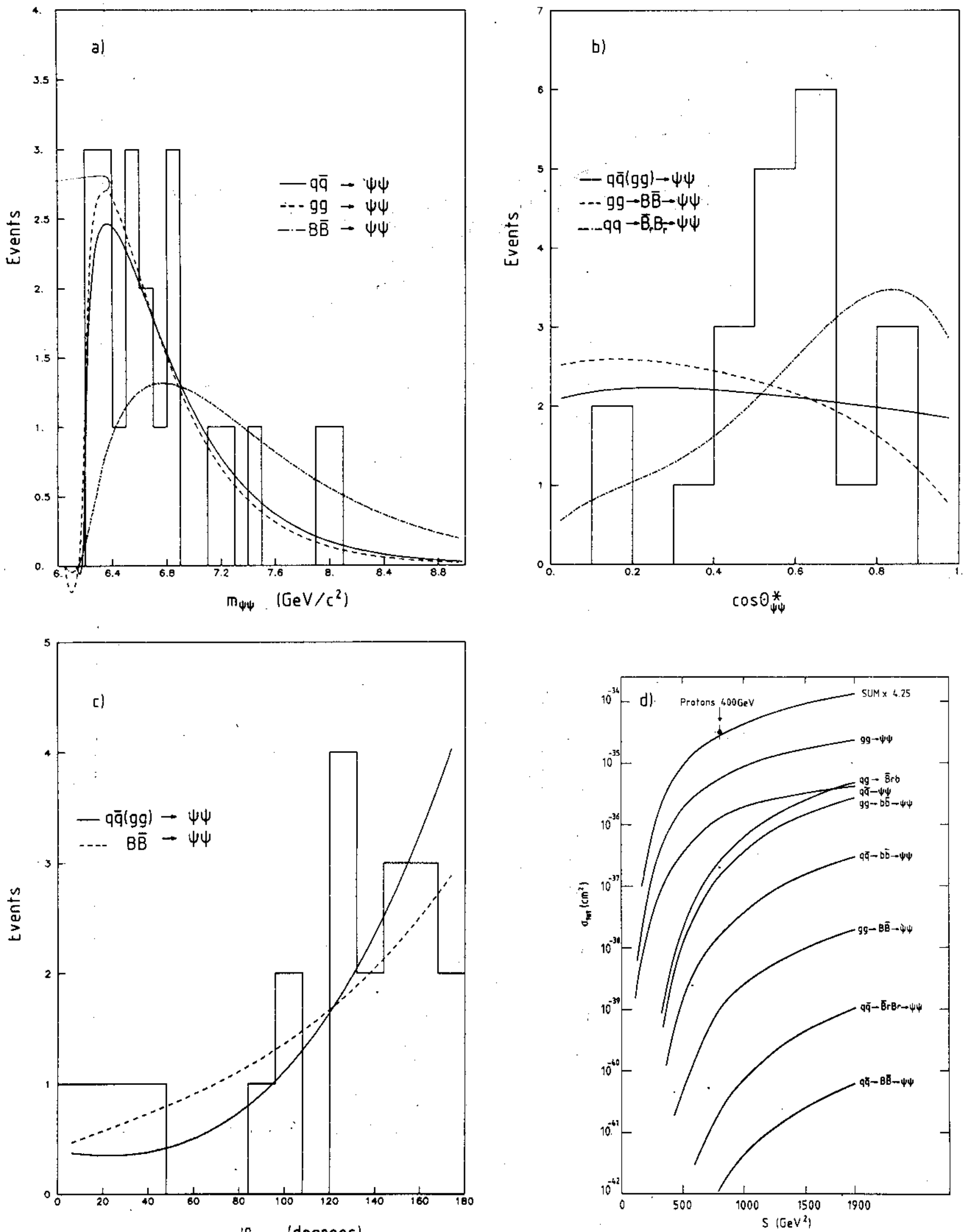
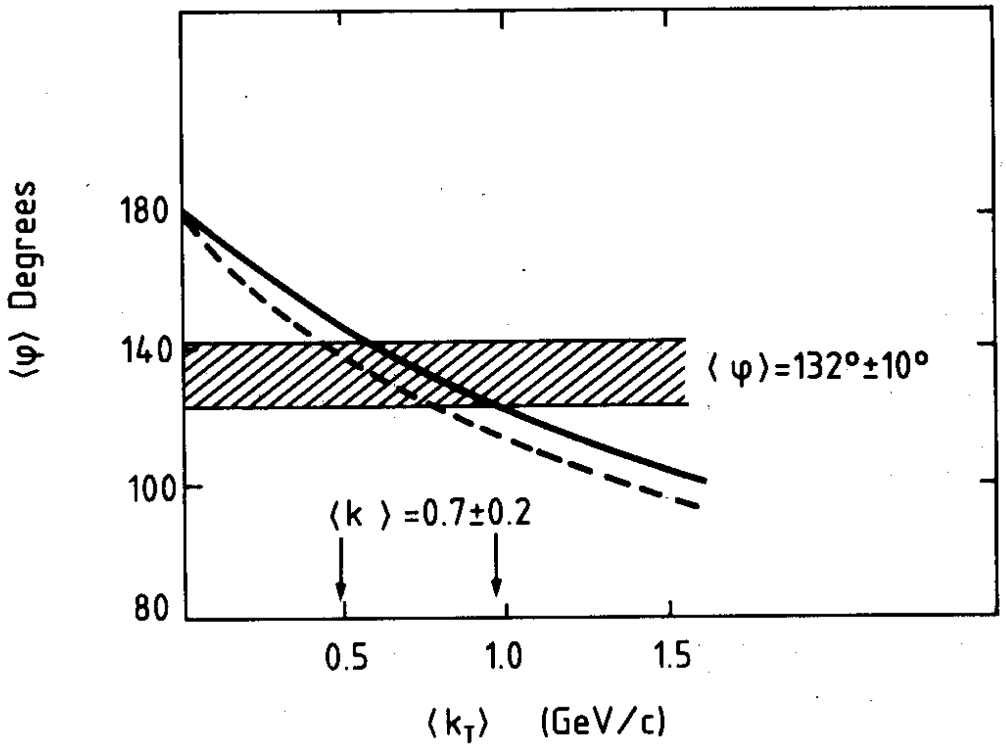
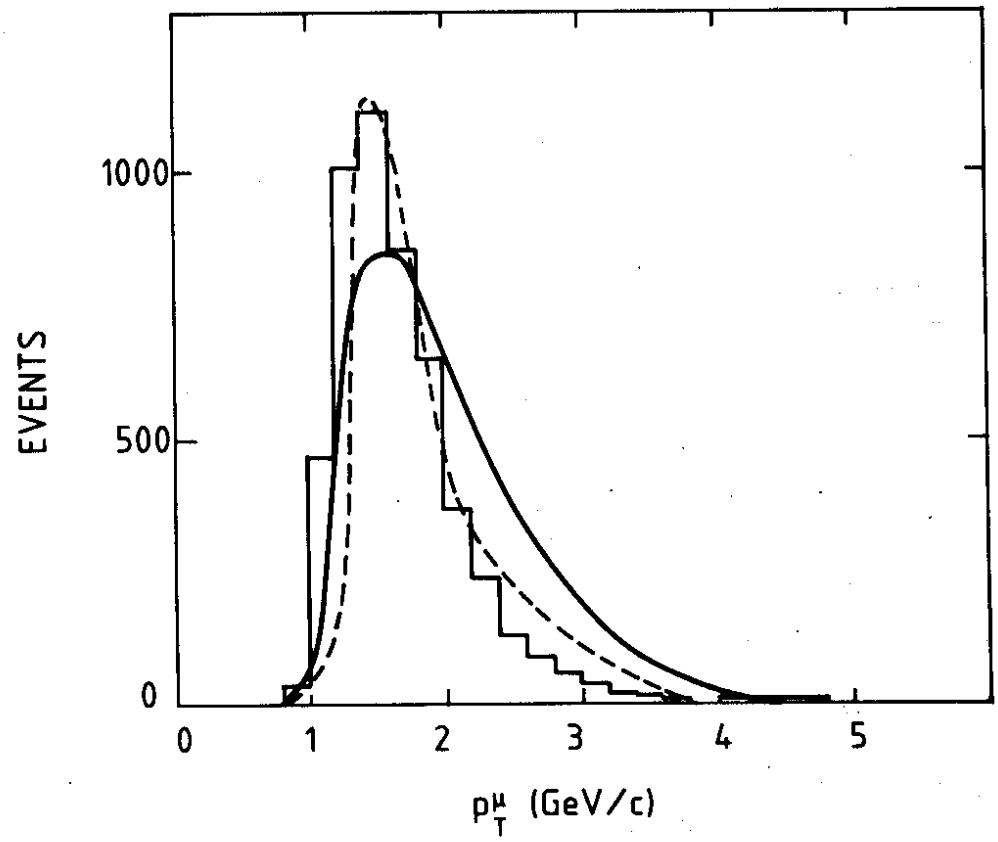

a)
qq̄ → ψψ
gg → ψψ
BB̄ → ψψ
Events
m_ψψ (GeV/c²)
b)
qq̄(gg)→ψψ
gg→BB̄→ψψ
qq→B̄rBr→ψψ
Events
cosθ*_ψψ
c)
qq̄(gg) → ψψ
BB̄ → ψψ
Events
φ_ψψ (degrees)
d)
Protons 400GeV
SUM x 4.25
gg→ψψ
qg→ B̄rb
qq̄→ψψ
gg→bb̄→ψψ
qq̄→bb̄→ψψ
gg→BB̄→ψψ
qq̄→B̄rBr→ψψ
qq̄→BB̄→ψψ
σ_ψψ (cm²)
S (GeV²)

FIG 2



⟨φ⟩ Degrees
180
140
100
80
⟨φ⟩=132°±10°
⟨k ⟩ =0.7±0.2
0.5
1.0
1.5
⟨k_T⟩ (GeV/c)

FIG 3



EVENTS
1000
500
0
0
1
2
3
4
5
p^μ_T (GeV/c)

FIG 4.