FERMILAB-Pub-00/173 August 2000

Searching for the Higgs at Hadron Colliders using the Missing Mass Method

Michael G. Albrow,[1] Andrey Rostovtsev[2]

[1] *Fermi National Accelerator Laboratory, Batavia, IL 60510*

[2] *Inst. Theor. Exp. Phys. (ITEP), Moscow, Russia*

Abstract

If the Higgs is produced with a large enough cross section in the *exclusive* reaction $p+\bar{p} \to p+H+\bar{p}$ it will give rise to a peak at M_H in the *missing mass* (MM) spectrum, measured from the kinematics $MM^2 = (p_{b1}+p_{b2}-p_3-p_4)^2$ where p_{bi} are the 4-momenta of the beam particles and p_j are the 4-momenta of the outgoing p and $\bar{p}$. The latter can be measured in precision silicon pixel detectors in roman pots placed beyond Tevatron dipoles. The resolution in MM can be approximately 250 MeV, independent of M_H from 100 GeV to 200 GeV. This high resolution makes a search feasible over nearly this full mass range at the Tevatron with 15 fb^{-1} as hoped for in Run II. Up to about 130-140 GeV the $b\bar{b}$ and $\tau^+\tau^-$ modes can be used, above 135 GeV the WW^* mode takes over and above 160 GeV the WW mode dominates. For the τ-pairs and using only the leptonic decay modes of the W-pair the signal is extremely clean because, unlike generic lepton pair production, there are no hadrons at the primary vertex. Thus a 160 GeV Higgs can appear as a final state with $p_3 + l_1^+ + l_2^- + \not{E}_T + p_4$ with no other particles on the $l_1 l_2$ vertex. Such events should be easily recognizable even with many interactions in a bunch crossing, using precision timing on the p and $\bar{p}$. At the high end of the

mass range the mass resolution becomes better than the width of the Higgs, which can then be measured. The ratio of events in the channels $b\bar{b}, \tau^+\tau^-$ and W^+W^- can demonstrate the coupling of the Higgs to mass. Production and decay angular distributions can demonstrate that it is a scalar. The visibility of this signal depends on the exclusive cross section $\sigma(p+\bar{p}\rightarrow p+H+\bar{p})$. Some theoretical calculations are very encouraging.
PACS numbers: 13.85.Qk, 12.38.Qk

Typeset using REVTeX

The predominant mode for Higgs production at hadron colliders is gg-fusion [1,2] through a virtual top quark loop. The dominant decay mode up to 135 GeV is to $b\bar{b}$, above which the WW^* mode becomes increasingly important until $M_H > 2M_W$ (160 GeV) when both W are real. By 200 GeV the ZZ mode has grown to 26%. The $\tau^+\tau^-$ mode decreases from 7.6% at 110 GeV to about 2% at 150 GeV. The intrinsic width of a Higgs over this mass region rises, from 5 MeV at $M_H = 130$ GeV, to 16 MeV at $M_H = 150$ GeV, to 650 MeV at $M_H = 180$ GeV [1], so mass resolution is crucial in increasing the signal:background $S : B$ ratio.

One has until now considered the observation of the Higgs in the intermediate mass region 110 GeV to 130 GeV in hadron collisions to be impossible because of the small $S : B$, *unless* one selects the relatively rare cases where it is produced in association with a massive particle (W, Z, t) or where it decays to $\gamma\gamma$ (branching fraction $\approx 2 \times 10^{-3}$), where much better mass resolution can be obtained than for any other final state. A high price has to be paid for these requirements; in 15 fb^{-1} we expect more than 10,000 120 GeV H to be produced; 70% of them decay to $b\bar{b}$. However the mass resolution in reconstructing a $b\bar{b}$ di-jet is about 10 GeV - 15 GeV, and the QCD background is indeed overwhelming when the signal is so spread out. Using the missing mass method that we propose, the resolution is improved to 250 MeV, increasing the $S : B$ by a factor $\approx$ 40 - 60. The method works not only for $b\bar{b}$ Higgs decays but also for $\tau^+\tau^-$, W^+W^- and ZZ decays, and the number of neutrinos in the final state is irrelevant for the mass resolution which is always about 250 MeV. In fact neutrinos are turned into an asset as they give missing E_T ($\not\!\!E_T$) which is a positive signature and can be used in a trigger.

In the exclusive process $p + \bar{p} \rightarrow p + H + \bar{p}$, with no other particles in the final state (we talk in this note in Tevatron terms although all the arguments clearly refer also to the LHC), we use the known 4-momenta of the incoming and outgoing p and $\bar{p}$ to calculate the missing mass from $MM^2 = (p_{b1} + p_{b2} - p_3 - p_4)^2$. The visibility of a signal will depend on the spread in these quantities; any overall scale factor such as would come e.g. from uncertainty in the magnetic fields in the Tevatron only affects the central value, i.e. M_H if a signal is seen. The momentum spread of the incoming beams [3] is 1.0 $\times 10^{-4}$ at the beginning of a store and rises to about 1.6 $\times 10^{-4}$ after 20 hours of collisions. The position of the interaction point x_o, y_o, z_o can be reconstructed with $\sigma \approx 4\mu$m, 4μm and 10μm respectively for central $b\bar{b}$ jets, and about a factor two worse [1] for l^+l^- final states. The outgoing p and $\bar{p}$ tracks can be measured after 18.8m of 4.34 Tesla dipoles using several layers of crossed and tilted silicon pixel detectors giving $\sigma_x = \sigma_y \approx 2.5\mu$m over $\approx$ 1.0m, thus $\sigma_{x'} = \sigma_{y'} = 2.5 \times 10^{-6}$. If $\sqrt{s}$ is the center of mass energy, 2 TeV at the Tevatron in Run II, and the outgoing scattered beam particles have lost fractions ξ_1, ξ_2 of their incident momenta ($\xi = 1 - x_F$ where x_F is Feynman-x), we have approximately $MM^2 = \xi_1 \xi_2 s$. The spread in the reconstructed missing mass, δ_{MM} is a combination of the relative spread $\frac{\delta p_b}{p_b}$ in the beam particles' momenta p_b and the resolution of the "dipole spectrometers" which use the primary interaction point and the outgoing track. With the above parameters this is $\approx$ 250 MeV, independent of MM.

We note that this method is not limited to Higgs searches but would be sensitive to any relatively narrow massive objects with vacuum quantum numbers, for example $\tilde{g}\tilde{g}$ bound states, heavy particles on the pomeron P (or P' ?) trajectory, etc.

The visibility of the Higgs by this technique clearly depends on the size of the cross section for the process where the Higgs is produced (in the central region) completely exclusively, i.e. the p and $\bar{p}$ go down the beam pipes each having lost about $\frac{M_H}{2}$ in longitudinal momentum and no other particles are produced. The mechanism is as usual $gg \rightarrow H$ through intermediate loops of heavy particles (predominantly a top loop); this normally leaves the p and $\bar{p}$ in color-octet states and gives rise to color strings filling rapidity with hadrons. However some fraction of the time one or more other gluons can be exchanged which neutralize (in a color sense) the p and $\bar{p}$ and can even leave them in their ground state. In Regge theory this is the double pomeron exchange (DPE) process. Several attempts have been made to calculate this cross section. In 1990 Schäfer, Nachtmann and Schöpf [4] consid-

[1]We assume both leptons are tracked in the silicon vertex detectors.

ered diffractive Higgs production at the LHC and SSC, concluding that the cross sections for the exclusive process could not be reliably predicted. Müller and Schramm [5] made a calculation, also for nucleus-nucleus collisions, and concluded that the exclusive process is immeasurably small[2]. In 1991 Bialas and Landshoff [6] calculated from Regge theory that about 1% of all Higgs events may have the p and $\bar{p}$ in the DPE region of $x_F \approx 0.95$, but they did not estimate the *fully exclusive* cross section. In 1994 Lu and Milana [7] obtained an estimate "well below what is likely to be experimentally feasible". In 1995 Cudell and Hernandez [8] made a lowest order QCD calculation with the non-perturbative form factors of the proton tuned to reproduce elastic and soft diffractive cross section measurements. They presented the exclusive production cross section as a function of M_H up to 150 GeV at $\sqrt{s} = 1.8$ TeV. They found a cross section decreasing slowly with M_H from 45 fb at 110 GeV, 13.5 fb at 150 GeV and, by extrapolation, 6.0 fb at 170 GeV (all within a factor two). The total Higgs production cross section by the dominant gg-fusion mechanism is [2] 900 fb, 364 fb and 247 fb respectively so the exclusive fraction decreases from 5% to about 2.4% over this mass range, even higher than the Bialas and Landshoff estimate. However there are issues of "rapidity gap survival probability", "pomeron flux renormalization" [9], shadowing effects, initial and final state interactions etc. These not-fully-understood effects are (not necessarily different) ways of explaining why diffractive cross sections in hadron-hadron (but not ep) collisions are about an order of magnitude lower at high $\sqrt{s}$ than naïve Regge expectations. There are two very recent calculations. Khoze, Martin and Ryskin [10] find $\sigma(p+p \rightarrow p+H+p) = 0.06$ fb for $M_H = 120$ GeV at $\sqrt{s} = 2$ TeV if the probability S^2 of both gaps surviving is $S^2 = 0.1$. It is not clear to us whether the 2-gap survival probability in the central Higgs case should be the square of the 1-gap survival probability, because the Higgs is colorless and its decay products (if it is light, with $\Gamma_H < 10$ MeV say) emerge

[2]Basically this is because they take a pomeron form factor and it is very difficult to "localize" pomerons to order M_H^{-1}.

much later than the formation time of all the other hadrons in the event. One should rather think of the "non-interacting" Higgs as being produced in the middle of one long (15 units) rapidity gap. Kharzeev and Levin [11] find much more optimistically 19 - 140 fb for $M_H =$ 100 GeV at the Tevatron, but do not present the M_H-dependence. It is clear that there is much uncertainty in the theoretical predictions, but we shall show that the more optimistic predictions allow a Higgs discovery at the Tevatron in Run II over the full mass range from 110 GeV to 180 GeV. We take the Cudell and Hernandez (CH) prediction as our benchmark, ignoring any gain from the $\sqrt{s}$ increase from 1.8 TeV to 2.0 TeV and noting that the CH estimate has a factor ≈ 2 uncertainty. It will be seen that even if the true exclusive cross section is lower by an order of magnitude a discovery is still possible over most of this mass range.

We now consider signals and backgrounds, first for $b\bar{b}$, then for $\tau^+\tau^-$ and lastly for $WW^{(*)}$. Table 1 shows a compilation of results.

TABLES

M_H (GeV)	$\sigma(CH)$ (fb)	Mode	BR	σ.BR.BR (fb)	Events $15fb^{-1}$	Background /250 MeV
110	45	$b\bar{b}$	0.770	34.6	260	3.75
		$\tau^+\tau^-$	0.076	3.4	26	< 0.1
130	25	$b\bar{b}$	0.525	13.1	96	0.75
		$\tau^+\tau^-$	0.054	1.35	10.0	< 0.1
		WW^*	0.289	0.72	5.4	$\ll 1$
150	13.5	WW^*	0.685	0.93	7.0	$\ll 1$
170	6.0	W^+W^-	0.996	0.58	4.3	$\ll 1$
180	3.5	W^+W^-	0.935	0.34	2.5	$\ll 1$

TABLE I. For various Higgs masses, the exclusive production cross section according to Cudell and Hernandez at 1.8 TeV. Column 5 shows the cross section $\times$ branching fractions either to two b-jets or to two charged leptons. A factor 0.5 has been applied to events and background for acceptance/efficiency.

For the $b\bar{b}$ dijet background we take CDF's published cross section [12] $\frac{d\sigma}{dM_{JJ}}$ for two b-tagged jets, which starts at 150 GeV, and extrapolate the fit to the data (which is a factor 2-3 higher than the PYTHIA prediction) down to 110(130) GeV finding 200(40) pb/GeV (in $|\eta| < 2.0, |cos(\theta^*)| < 2/3$). From our other DPE studies, of lower mass dijets [13], we expect that about 10^{-5} of these are DPE ($p+\bar{p} \rightarrow p+G+b+\bar{b}+G+\bar{p}$), where G represents a rapidity gap exceeding about 3 units, assuming this fraction is not E_T-dependent. If the fraction is smaller, so much the better. That gives 0.5(0.1) fb per 250 MeV bin, to be compared with a signal of around 45(25) fb [8]. With 15 fb^{-1} and assuming 50% acceptance for both signal and background we have 260(96) events (see Table 1) on a background of 3.75(0.75). Even if the CH predictions are optimistic by an order of magnitude these signals exceed 10σ. We have not put in a factor for b-tagging efficiency (which affects the signal and the background the same way apart from differences in the angular distributions); in CDF it was about 35% per jet in Run I at $M_{JJ} = 200$ GeV. It will be higher in Run II with more silicon coverage and at smaller masses; also we only have to tag one jet, so this is probably a very modest reduction in both signal and background. We have put in an acceptance of 50% for the forward p and $\bar{p}$ for the signal and background, assuming the $|t|$-distribution is as expected for high mass DPE. The $S : B$ ratio rises with M_H in this mass region 110-130 GeV. The Higgs production cross section falls less steeply than the QCD backgrounds because the top loop becomes more real and the Higgs couples to mass. As M_H increases beyond 120 GeV the branching fraction for $H \rightarrow b\bar{b}$ drops more rapidly.

The Higgs branching fraction to $\tau^+\tau^-$ drops from 7.6% at 110 GeV to 5.4% at 130 GeV, as the WW^* mode grows in competition. Backgrounds to the proposed search could come from normal Drell-Yan $(DY)/Z$ production together with 0,1, or 2 associated high-x_F tracks; in the first two cases leading (anti-)protons come from different events (pile-up); we discuss ways of minimizing this later. In the third case the events look like continuum DPE production of DY pairs, together with associated particles. CDF found [14] single diffractive (SD) production of W at the level of $(1.15 \pm 0.55)\%$ of non-diffractive (ND)

production. A recent CDF study [13] of jet production at low E_T has found a breakdown of factorization for jet production in the sense that $\frac{\sigma_{DPE}}{\sigma_{SD}} \approx 5 \times \frac{\sigma_{SD}}{\sigma_{ND}}$. Let us assume this fraction is the same for high-mass DY, and then assume (conservatively) factorization break-down by the same factor 5 for high mass DY. Then DPE production of high mass DY is at the relative level of 5.10^{-4}. From a CDF study [15] of high mass e^+e^- and $\mu^+\mu^-$ we infer that $\frac{d\sigma}{dM}$ for the region 110-130 GeV is 100 ± 40 fb GeV^{-1}. Therefore the cross section for $p\bar{p} \to pG\mu^+\mu^-XG\bar{p}$, where X represents additional associated hadrons, n_{ass} of which are charged tracks, is expected to be about 100 fb GeV^{-1} $\times$ 5.10^{-4} = 0.05 fb.GeV^{-1} or 0.2 events in 15 fb^{-1} in a 250 MeV bin. Note however that for the exclusive Higgs production process $n_{ass} = 0$, while for generic DY/Z production $< n_{ass} > \approx 16$ [16] for $p_T \geq 0.2$ GeV, $|\eta| \leq 1$. We claim that the observation of lepton pairs with no associated tracks, $n_{ass} =$ 0, would already be good evidence for exclusive Higgs production [3]. The CH cross section $\sigma(p + \bar{p} \to p + H + \bar{p}) \times$ branching fraction $H \to \tau^+\tau^-$ of 3.4 (1.3) fb at 110 (130) GeV gives 26 (10) events on a background of less than 1 event if we include a 50% acceptance/efficiency factor. High p_T τ are easily recognized: one-prong decays are 85% and three-prong are 15%. A high p_T 3-prong τ decay is quite distinct from a QCD hadronic jet because it is tightly collimated, with $M_{eff} < M_\tau = 1.78$ GeV.

The Higgs branching fraction to $WW^{(*)}$ rises from 29% at 130 GeV to 69% (97%) at 150 (170) GeV (see Table 1). Beyond 180 GeV it falls because of competition from the $ZZ^{(*)}$ mode. We will only consider the leptonic decay modes of the W because of the spectacular cleanliness [4] of the event vertices: either $ee, e\mu, \mu\mu, e\tau, \mu\tau$ or $\tau\tau$ and no other charged particle tracks ($n_{ass} = 0$), together with large $\not{E}_T$ and the forward p and $\bar{p}$.

[3] One should see a peak at $n_{ass} = 0$ in this multiplicity distribution.

[4] Although in this note we have only considered fully exclusive production, sometimes the H will be acccompanied by a few hadrons, central enough to have well measured four-momenta $p_5 ... p_k$. Then one can still use $MM^2 = (p_{b1} + p_{b2} - p_3 - ... - p_k)$.

Precision timing ($\approx$ 30 ps) on the p and $\bar{p}$ will not only check that they came from the same interaction but can pin down the vertex z_{vtx} to about 1 cm, to be related to the dilepton vertex known to $\sigma_z < 100\mu$m. This cleanliness means that the search is insensitive to the number of collisions in a bunch crossing, at least up to the envisaged luminosities for Run II at the Tevatron. Using the missing mass method the Higgs mass can be measured with $\sigma_M \approx 250$ MeV *per event* despite the two undetected neutrinos! To estimate the signal we extrapolate the Cudell and Hernandez (1.8 TeV) exclusive cross sections from 150 GeV (11 - 16 fb) to 180 GeV (2.5 - 5 fb). Putting in $BR(H \rightarrow WW^{(*)})$, a 10% probability that both W decay leptonically, and assuming that, by using lower than usual trigger thresholds on the central leptons and $\not{E}_T$, we can keep the efficiency at 50%, we find in 15 fb^{-1} 7 events for $M_H = 150$ GeV falling to 2.5 events at $M_H = 180$ GeV. To estimate the background we refer to the observation of five W^+W^- events by CDF [17] [5] which gave $\sigma(p + \bar{p} \rightarrow W^+W^-X)$ = 10.2 $\pm$ 6.5 pb which we assume to be roughly uniform over $160 < M_{WW} < 180$ GeV so $d\sigma/dM \approx 0.5$ pb GeV^{-1}. Below 160 GeV the cross section for WW^* will be smaller. The observed W^+W^- cross sections are consistent with Standard Model NLO expectations, ignoring the Higgs, of $\sigma(p + \bar{p} \rightarrow W^+W^-X) = 10$ pb at 1.8 TeV. We multiply by the 10% probability that *both* W decay leptonicaly and apply a 50% "efficiency" for detecting the $p, \bar{p}$ and both leptons and recognizing the event as $l^+l^-\not{E}_T$. This is high compared with the efficiency in ref [19], which was 5.4% - 8.9%, because due to the lack of background we can surely lower the selection cuts on $\not{E}_T, p_T(e), p_T(\mu)$ and $p_T(\tau)$ significantly. We assume as before that about 5×10^{-4} of these are from DPE, giving $\approx 3 \times 10^{-3}$ fb/250 MeV. For any non-diffractive background we can asssume that the associated charged multiplicity on the WW vertex is Poisson-distributed with a mean of about 16, which is what CDF observes [16] for Z events. This non-diffractive background then has a completely negligible tail at $n_{ass} = 0$. Thus the backgrounds in all the dilepton channels with $n_{ass} = 0$ are negligible,

[5] DØ earlier found one e^+e^- event [18] in 14 pb^{-1}.

and even 3 or 4 events at the same MM would constitute a discovery.

In order not to be limited by the number of interactions in a bunch crossing one should not use a method requiring rapidity gaps (as normally measured in counters or calorimeters). This is where the strength of using only leptonic decays of the W^+W^- enters. Tracking back the l^+ and l^- to their common vertex (which can be done using the SVX detectors in CDF to a precision $\sigma_x = \sigma_y \approx 10\mu$m and $\sigma_z < 20\mu$m) there will, for the exclusive process, be *no other particles* coming from the same vertex, $n_{ass} = 0$. All "normal" production of W-pairs will on the contrary have a highly active vertex with many associated hadrons. (Even in the absence of dipole spectrometers one can plot n_{ass} and look for a peak at $n_{ass} = 0$. This would be "evidence" for exclusive Higgs production. Enough events of this kind would enable one to make fits of kinematic quantities as a function of M_H.) One can then plot the missing mass MM for these superclean events with two and only two oppositely charged leptons on a vertex, with and without $\not{E}_T$. A Higgs signal will be a cluster of events at the same MM within the resolution (≈ 250 MeV).

If the exclusive cross section is indeed big enough to provide a few events in the data, but continuum background were to be an issue, one has further recourse to angular distributions [20]. The H is a scalar and decays isotropically, while generic W^+W^- production is not isotropic with respect to the beam axis; also the W's (like the τ's) will have opposite polarizations. This is not generally true for the backgrounds, so one can plot quantities sensitive to these kinematic features as a function of MM to look for localised structure.

To carry out this search for the Higgs using the missing mass method, both the outgoing p and $\bar{p}$ must be detected in roman pots (these enable one to move detectors very close to the circulating beams). The pots must be after dipoles to give acceptance for $x_F \approx 0.925 \pm 0.025$ over as large a t, ϕ-coverage as possible, including $|t|_{min}$ (polar angle $\theta = 0$). At present there is no warm space either at CDF or DØ where such pots could go on the outgoing proton side. (CDF already has such pots on the outgoing antiproton side, and DØ will have them.) The simplest way to make such a space is to remove the "Q1" quadrupoles which are redundant in Run II [6] and to move the dipoles closer to the interaction point. A lever arm of $\approx$ 1m for pot detectors can be made, giving $\sigma_{x'} = \sigma_{y'} \approx 2.5 \times 10^{-6}$ with positioning accuracy of 2.5μm. The RHVD group [21] have achieved 5 μm, by tilting pixel planes, and one can improve this by a factor 2 by using 4 layers.

With multiple interactions in a bunch crossing a background could come from two single diffractive collisions, one producing the p and the other the $\bar{p}$. One way of reducing this is to require longitudinal momentum balance. However "pile-up" can be reduced by one to two orders of magnitude by backing up the silicon detectors in the pots by counters with excellent timing resolution. A conventional fast detector would be a quartz (for radiation hardness) block producing Cerenkov light viewed by a fast photomultiplier. One can achieve 30 ps timing resolution on the p and $\bar{p}$, much better than the ($\approx$ 1 ns) spread between random concidences. There are ideas [22] for Fast Timing Cerenkov Detectors ($FTCD$) using microchannel plates which might achieve a resolution of a few ps. The sum of the p and $\bar{p}$ times is a constant for genuine coincidences, and their difference Δt is a measure of z_{vtx} at the level of 1 cm (for $\Delta t = 30$ ps). CDF will have a Time-of-Flight (TOF) barrel of 216 counters in $|\eta| < 0.75$ with resolution $\approx$ 100 ps per particle, or about 50 ps on a b-jet. One can do a global timing fit between the p, the $\bar{p}$ and the two b-jets or leptons (if the latter are in the TOF barrel).

There are various studies that can be done already in Run IIA, before both dipole spectrometers are installed, to learn more about the feasibility of this proposed Higgs search. Both CDF and DØ will have one dipole spectrometer arm. DØ has calorimetry out to $|\eta| \approx 4.5$ and CDF will have new calorimetry (MiniPlug) to $|\eta| \approx 5.5$ and "Beam Shower Counters" (BSC) covering approximately $5.5 < |\eta| < 7.5$. DØ will have quadrupole pot spectrometers on both arms, but their acceptance is limited to $|t| > 0.5$ GeV^2 which reduces the rate for two-arm physics.

[6]They have already been removed in DØ to mount quadrupole spectrometers.

1) Measure the $b\bar{b}$ dijet mass spectrum, $M_{b\bar{b}}$, over the mass range up to 150 GeV to complement the earlier CDF measurement [12]. Using the existing pot spectrometers and the rapidity gap technique measure what fraction of these dijets are from single diffraction and what fraction are from DPE, as a function of $M_{b\bar{b}}$. What is the angular distribution of the b-jets in the DPE case? This studies the background in the $b\bar{b}$ search; but note that the fraction of Higgs that are produced exclusively may be much higher than the the fraction of exclusive $b\bar{b}$ dijets.

2) Measure the l^+l^- mass spectrum in the region of $M_{l^+l^-}$ 80-180 GeV, carefully studying the associated charged multiplicity n_{ass} on the primary l^+l^- vertex for different mass ranges. How do the results compare with Monte Carlo full event generators of D-Y/Z, W^+W^- and generic (non-DPE) Higgs production with leptonic decay? The exclusive DPE Higgs events have $n_{ass} = 0$, and one may observe an excess of events in that bin (or an excess at low n_{ass}), which would be *evidence for* DPE production of a Higgs. The only other process we are aware of which could give such events is the two-photon exchange process, but (a) the cross section is much lower (b) this could not produce dilepton events with different flavor, as $H \rightarrow W^+W^-$ could (c) the $H \rightarrow W^+W^-$ events have a large $\not{E}_T$.

3) Measure the production of exclusive χ_c^o and χ_b^o states. Note that some of these states have the same quantum numbers [7], $I^G J^{PC} = 0^+0^{++}$, as the vacuum and the Higgs. We are especially interested in the cross sections, and the ratios of exclusive to inclusive production. For the χ_c^o(3415 MeV) the $2(\pi^+\pi^-)$ and the $\pi^+\pi^-K^+K^-$ decays account for 4%. Exclusive $\chi_b^o \rightarrow \Upsilon\gamma \rightarrow \mu^+\mu^-\gamma$ can be triggered on by two central muons, together with forward rapidity gaps. We want to compare the exclusive $\chi_{c,b}^o$ production to inclusive production, and check whether theorists make a successful prediction for this ratio. However the exclusive:inclusive ratio for H may be much higher for reasons mentioned above.

This work was supported by the U.S. Department of Energy and the Institute for The-

[7] Allowed quantum numbers for exclusive states in DPE are $I^C = 0^+$ but any J^P [23].

oretical and Experimental Physics (ITEP),Russia. We thank P.Bagley and C. Moore for information on the Tevatron, and V.Kim, D.Kharzeev and E.Levin for discussions on exclusive Higgs production.

REFERENCES

[1] See for example S.Dawson in Perspectives on Higgs Physics vol.2 (G.Kane, ed) 1997, and the Report of the Higgs Working Group for Physics in Run II, Eds: M.Carena, J.Conway, H.Haber, J.Hobbs (2000) http://fnth37.fnal.gov/susy.html

[2] M.Spira, hep-ph/9810289, DESY 98-159.

[3] P.Bagley, Private Communication.

[4] A.Schäfer, O.Nachtmann and R.Schöpf, Phys. Lett. B **249**, 331 (1990).

[5] B.Müller and A.J.Schramm, Nucl.Phys. **A523** 677 (1991).

[6] A.Bialas and P.V.Landshoff, Phys. Lett. B **256**, 540 (1991).

[7] H.J.Lu and J.Milana, Phys.Rev. **D51** 6107 (1995).

[8] J-R.Cudell and O.F.Hernandez, Nucl.Phys **B471**,471 (1996); hep-ph/9511252.

[9] K.Goulianos, Phys.Lett. **B358**,379 (1995); **B363**,268 (1995).

[10] V.A.Khoze, A.D.Martin and M.G.Ryskin, Eur.Phys.J.**C14**, 525 (2000); Also hep-ph/0006005.

[11] D.Kharzeev and E.Levin, hep-ph/0005311, FERMILAB-PUB-00/035-T, BNL-NT-00/14.

[12] F.Abe et al.(CDF), Phys.Rev.Lett. **82**, 2038 (1999).

[13] T.Affolder et al.(CDF), Dijet Production by Double Pomeron Exchange at the Fermilab Tevatron, Submitted to Phys.Rev.Lett. (May,2000)

[14] F.Abe et al.(CDF), Phys.Rev.Lett. **78**, 2698 (1997).

[15] F.Abe et al.(CDF), Phys.Rev.Lett. **79**, 2192 (1997).

[16] CDF Paper in preparation (2000).

[17] F.Abe et al.(CDF), Phys.Rev.Lett. **78**, 4536 (1997).

[18] S.Abachi et al. (DØ) Phys.Rev.Lett. **75**,1023 (1995).

[19] F.Abe et al. (CDF) Phys.Rev.Lett. **78**,4536 (1997).

[20] M.Dittmar and H.Dreiner, hep-ph/9703401

[21] J.Appel et al. Rad Hard Vertex Detector R&D group.

[22] A.Bross, Private communication.

[23] J.Pumplin, Electroweak and QCD in Run II Workshop (1999).