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Proposal to CDF for Run IIB: High Precision Very Forward Tracking Detectors.

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Abstract

The experiment we propose for CDF has possible sensitivity to Higgs, extra dimensions, glueballs, odderons, hybrids and new χ_c° and χ_b° decays. It will also do more orthodox QCD physics in unique ways, such as measuring the size (transversely and longitudinally) of color singlet gluon pairs at low x_{Bj}, producing millions of pure gluon jets, and millions/year clean high- $|t|$ elastic $p\bar{p}$ scattering events in a $|t|$-region where there is structure (not yet observed at the Tevatron). In addition to the searches for new physics we will make systematic precision measurements of Double Pomeron Exchange $D I\!\!P E$.

We propose to add, for Run IIB, high precision track detectors 55 m downstream on both (E & W) sides of CDF, to measure high Feynman-x protons and antiprotons in association with central states. The track detectors will be silicon strip telescopes ($\sigma \approx 5$ μm) backed up by high resolution (better than $\approx$ 30 ps) time-of-flight counters. We will have four spectrometer arms, each of dimensions about 60 mm (v) $\times$ 30 mm (h). The addition of these small detectors effectively converts the Tevatron into a gluon-gluon collider with $\sqrt{s}$ from 0 to $\approx$ 150 GeV.

Contents

I. INTRODUCTION

Two prominent areas of uncertainty in the Standard Model are the Higgs sector and non-perturbative QCD with the problem of confinement. Both of these are intimately related to properties of the vacuum, either electroweak or strong, and both are subjects of this proposal. Confinement is of course to do with how quarks and gluons end up, in *every collision* involving hadrons, in color singlet "clumps" i.e. hadrons. In the transition sometimes very massive color singlet clumps are formed, well separated from each other in rapidity space. The physics of rapidity gaps is closely related to diffraction; the largest gaps at the Tevatron being 15 units in elastic scattering.

It is possible that physics beyond the Standard Model is also accessible with the proposed experiment. We discuss non-SM Higgs bosons, light SUSY (LSP's), and large extra dimensions (LED's).

In Run I we made many important studies in CDF of diffraction and rapidity gaps. In Run IA small-$|t|$ ($|t| < 0.3$ GeV^2) elastic scattering [1] and single diffractive excitation (SDE) [2] and the total cross section [3] were measured. In Run IB we found rapidity gaps between high E_T jets [4], and using gaps we discovered diffractive production of W [5], J/ψ [6], and high E_T $b-$jets [7], and measured diffractive di-jet production [8]. In Run IC we used roman pots with scintillating fibre hodoscopes to measure high-x_F antiprotons and used jets to measure the diffractive structure function of the $\bar{p}$ [9], and we discovered double pomeron exchange ($DI\!PE$) production of high-E_T jets [10].

For Run IIA we are re-instrumenting (with new electronics) the previously used roman pots (which are only on the $\bar{p}$ side), we have installed new Beam Shower Counters (BSC) to tag forward rapidity gaps, and will install Miniplug calorimeters with high transverse granularity in the rapidity region $3.5 < |\eta| < 5.5$. The physics program is summarized in a CDF Note [11].

This is a proposal to supplement CDF in Run IIB with very forward tracking detectors to measure both p and $\bar{p}$ in events where they have fractional momentum loss $\xi = 1.0 - \frac{p_{out}}{p_{in}}$ in the range up to approximately 0.10. Elastic scattering events with large $|t|$ will be accepted, but we have special interest in the events where the p and

$\bar{p}$ have lost energy ($\xi > 0$). The energy they lose goes into creating a central state X, with mass up to about 200 GeV. We want to study the state X, hadrons from which will normally be separated by more than about 4 units in rapidity from the forward p and $\bar{p}$. This is the process known as Double Pomeron Exchange, $D\mathbb{P}E$, for the smaller values of ξ. Knowing the beam 4-momenta, p_{b1} and p_{b2}, and the outgoing 4-momenta p_3 and p_4, we can calculate the Missing Mass MM, from $MM^2 = (p_{b1}+p_{b2}-p_3-p_4)^2$. We aim for a resolution $\sigma_{MM} = 250$ MeV, independent of M_X.

The vacuum contains all possible virtual states that have vacuum quantum numbers, i.e. all conserved charges equal to zero and $I^G J^{PC} = 0^+0^{++}$. We will be able to see some of the known states, such as the χ_c° and χ_b°, in the central detector when the p and $\bar{p}$ have large (of order -1 GeV^2) t. We will be able to search for exclusively produced glueballs G and hybrids $Q\bar{Q}g$. Other $I = 0$ states with $J^{PC} = 1^{-+}, 2^{++}$ etc can also be formed in $D\mathbb{P}E$, but states with $C = -1$ can not.

The only Standard Model state with vacuum quantum numbers in the mass range 60 - 200 GeV where the acceptance is high (it then extends down to t_{min} corresponding to scattering angle $\theta = 0$) is the Higgs boson, H. According to some theoretical predictions [12–14] the Standard Model Higgs is produced with a large enough cross section in the *exclusive* channel $p\bar{p} \to pH\bar{p}$ to be observed in 15 fb^{-1} if $M_H < 180$ GeV. This is discussed in section III. We are also sensitive to some physics beyond the SM, as discussed in sections IV and V.

In $D\mathbb{P}E$ events with two high E_T jets, the jets are pure gluon jets, at the level $\approx 3000:1$ [15]. After removal of $b\bar{b}$ jets by tagging, the sample will be an order of magnitude more pure. We can collect millions of such jets. (To date the purest gluon jet sample is less than 500 events in OPAL of the type $e^+e^- \to Z \to b\bar{b}g$.)

II. APPARATUS

To carry out this physics program the outgoing p and $\bar{p}$ must be detected in roman pots, or microstations as are being proposed for ATLAS [16]. These enable one to move detectors very close (≈ 1 cm) to the circulating beams. In roman pots the detectors are in air; in the microstation concept the detectors are inside the vacuum itself. We will decide between these in early 2001. Roman pots have the advantage of accessibility to the detectors which can easily be replaced if necessary, and naturally good screening from electromagnetic pick-up from the beam bunch pulses. Microstations may enable the detectors to get a little closer to the beams. We will have two types of detectors: tracking based on silicon strips, and triggering and timing based on fast solid Cerenkov counters, either quartz or magnesium fluoride MF_2. One option for the Cerenkov light detection is to use microchannel plates which need to be in a vacuum, a point in favor of the microstation concept.

A. Tracking

The detectors must be after dipoles to give acceptance for Feynman x, $x_F > 0.90$ over as large a t, ϕ-coverage as possible, and to measure the p and $\bar{p}$ momenta. At present there is no warm space either at CDF or DØ where such detectors could go on the outgoing proton side. CDF already has roman pots on the outgoing antiproton side, and DØ will have them for Run IIA. DØ will also have quadrupole spectrometers on both sides with acceptance for $|t| >\approx 0.6$ GeV^2. The spectrometers we propose are superior to the DØ Run IIA set-up in at least four respects:

(1) Acceptance down to $|t| = |t_{min}| \approx 0$ for $0.03 < \xi < 0.08$ on both E and W sides.

(2) A factor $\times$ 20 better spatial resolution (Si strips vs fibers).

(3) Higher and more uniform magnetic fields (dipole vs quadrupole).

(4) Ability to take data at the highest luminosities (using precision timing).

We can make a warm space on the outgoing p side (see below). A lever arm of $\approx$ 1.8 m for detectors on the p side can be made, and up to 5 m on the outgoing $\bar{p}$ side, giving $\sigma_{x'} = \sigma_{y'} \approx 3(1) \times 10^{-6}$ with positioning accuracy of 5 μm. The Liverpool CDF group have obtained [17] 5 μm resolution with 25μm strips in an $r - \phi$ geometry. The p and $\bar{p}$ will have traversed 18.8 m of 4.34 Tesla dipoles before entering the detectors.

We have considered using pixel detectors, but strips appear to be simpler, cheaper and perfectly adequate. The Liverpool University group, some of whom are in CDF, are building silicon disc detectors with $r - \phi$ geometry of perhaps ideal dimensions for our arms [17]. These are discs (in two 180° half-moons) of outer radius = 40 mm and a circular cut-out for the beams with radius 8 mm. A larger central hole can be made if necessary. A rad-hard version with 25 μm circular strips and almost-radial strips has been built by Micron. If we use these we would probably use 4 doublets per arm, with the radial strips oriented to give small angle stereo when combining the two close doublets. This solution would give a system of 80,000 channels compared to 1.8M for the same coverage with pixels. The economics and availability weigh heavily in favor of this strip solution. Radiation hardness, signal:noise and pattern recognition, while inferior to a pixel solution, are probably adequate. The electronics is at the outer periphery where radiation is lower. The strip detectors are relatively cheap and could be easily replaced if necessary.

There will be a total of four "telescopes": on the inside (S) and outside (N) of the Tevatron and on the outgoing p (E) and $\bar{p}$ (W) sides. Each telescope has precise (we are aiming at ± 10 μm positioning reproducibility with ± 2 μm position readout) horizontal (N-S) motion to approach the beams. In the microstation concept the movement is linearly transmitted from motors through bellows by mechanics with ceramic parts. The motors can be mounted in a secondary vacuum chamber which simplifies the feedthrough design and thermally isolates the cooled regions. It may be possible to use a design which would be suitable both for the Tevatron and for the LHC. In the following we assume that we will use pots for simplicity. We would choose microstations if we find a major disadvantage in the pot solution.

1. Autosurvey

Although the detectors will be surveyed and will have as precise a position control and readout as practical, there are several ways in which the data themselves can be used as a check. The detectors in the front pot will be as widely separated in z as possible and rigidly mounted together so that they always move as a whole. If we know the position of this front detector unit, fitted tracks in it must point straight back to the detectors in the back pot, as there are no fields in between and the tracks are very stiff ($\approx$ 900 GeV). So the back detectors can be positioned *wrt* the front ones. Elastic scattering events, to be collected continuously at a rate $\approx$ 1 Hz, provide a check on the alignment of the East and West arms, as t_1 must equal t_2 and $\phi_1 = 180^\circ - \phi_2$. A check on the relative position of the N and S detector arms is also provided by elastic scattering, by choosing a t which has acceptance for all ϕ and checking that the ϕ distribution is flat across the N-S divide. If the N and S arms do not completely overlap there will be two narrow holes in this distribution, up and down. For any selected t, the ϕ-distribution of elastic scattering (which must be flat if acceptance $A = 100\%$) is a direct measure of the acceptance $A(t, \phi, \xi = 0)$. The N and S pots at the "same" location in z can be displaced in z by a pot diameter to reduce (perhaps to zero) any acceptance gap between them.

For low mass exclusive states such as $\pi^+\pi^-$ we know that $\sum p_x = \sum p_y = \sum p_z = 0$ and $\sum E = \sqrt{s}$. The first two constraints are especially powerful: plots of these quantities (summed over the $p, \bar{p}$ and the central charged particles) will show a narrow peak centered at 0 if the alignment is perfect. There will be events outside this peak due to cases where one or more particles have not been detected. The p_T resolution of the pot tracks is $\approx$ 20 MeV, and the resolution from the central trackers on $\sum p_T$ of a 2- or 4-particle state in the low mass ($\approx$ 1 GeV) region is similar.

For higher masses ($\xi \geq 0.03$) the $|t| = |t_{min}| = |2[m_p^2 - (E_{in}E_{out} - p_{in}p_{out})]|$ point falls inside the trackers. Plotting the data as a function of t for fixed ξ one can check the position of this sharp t_{min} edge. Another way of seeing the same thing is to plot the x, y distribution of hits in a detector for fixed ξ, and observe the position of the point of maximum density. When the alignment is satisfactory a plot of the ϕ distribution for fixed ξ and fixed t gives $A(\phi)$.

B. Timing and Trigger counters

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 $\sum p_z = 0$. However this "pile-up" can be further reduced by a factor $\approx$ 40 by backing up the silicon detectors with counters with excellent timing resolution. A conventional fast detector is a quartz (for radiation hardness) or MgF_2 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 [18] for Fast Timing Cerenkov Detectors ($FTCD$) using stacked microchannel plates which might even achieve a resolution of better than 10 ps. The sum of the p and $\bar{p}$ times referred with respect to the interaction time as measured by the central TOF barrel is a constant for genuine coincidences. Their difference Δt is a measure of $z_\circ$ of the interaction at the level of 1 cm (for Δt = 30 ps). CDF will have a Time-of-Flight barrel of 216 counters in $|\eta| < 0.75$ with resolution $\approx$ 100 ps per particle, or $<$ 50 ps on a b-jet. One can do a global timing fit between the p, the $\bar{p}$ and the central particles (if these are in the TOF barrel). We would need four of these $FTCD$, each about 70 mm (v) $\times$ 35 mm (h). If one uses microchannel plates the readout can be pixelated if desired.

C. Beam Position Monitors

The momenta p_3 and p_4 of the outgoing p and $\bar{p}$ are measured using the interaction vertex $x_\circ, y_\circ, z_\circ$ and the straight track in the forward detectors, with the knowledge of the magnetic and electric fields in between. It is valuable to know the centroid positions in x and y of the incoming and outgoing p and $\bar{p}$ bunches, to understand as well as possible the orbits and also to know the distances of the detector (or pot) edges from the beams. The beam positions can vary from bunch to bunch and from run to run. We will ask the Beams Division to mount Quadrupole Beam Position Monitors (BPM's) in the middle of our detector arms, between the front and back pots. These monitors have four curved pick-up electrodes (mounted like a cylinder with four slits at 45°, 135°, 225° and 315°). The transverse size of the beams at this location is $\sigma_x = \sigma_y \approx 0.8$ mm. The BPMs can measure the centroids bunch-by-bunch of both the incoming and outgoing p and $\bar{p}$ beams. The precision is about 5 μm. The beams are not at the same x, y. We would record this information (possibly for every event we could record e.g. the averages over the previous 1 s of the relevant bunch positions).

D. Modifications to the Tevatron

In order to create a warm space for the detectors on the outgoing p side, we have decided that the simplest solution is to remove the redundant Q1 quadrupoles on each side, and slide the first three dipoles (A48-3, A48-4, A48-5 and B11-2, B11-3, B11-4) closer to BØ . (An alternative of replacing these dipoles with higher field dipoles was considered, but this solution is much simpler and cheaper.) We are discussing this with Tevatron expert John Johnstone of the Beams Division who is doing some orbit calculations. It seems possible that we could either make a lever arm of order 1.8 m for tracking, or of about 1 m and use the extra space for orbit corrections. Without such a correction the lateral displacement of the beams will mean that the quadrupoles Q2 - Q4 and the electrostatic separators need a small sideways displacement. The CDF detector would also be positioned with a lateral shift of a few cm (we do not see a problem here, but it will need to be investigated). The Tevatron closed orbit grows by only 1.09 mm (with the transverse shifts). Calculations are being done. In the estimates of momentum and MM resolution we have assumed 1 m for tracking. If it becomes more, so much the better. We would like σ_{MM} to be limited by the spread in the beam momenta rather than by anything under our control.

On the outgoing $\bar{p}$ side, where we already have pots, we could have a warm straight section of $\approx$ 1.5 m + 3.5 m = 5 m (this assumes the existing pots are removed for Run IIB). New cryogenic bypasses would have to be made.

E. Running Conditions and Triggers

We shall not require any special running conditions; we use the normal low-β tune. (Of course we will need beam time to do commissioning tests.)

We would like to record the information in these detectors for every CDF event. Then one can look for forward protons in any physics process under study. However we will need forward triggers, requiring a forward track in both arms. The arm trigger is based on a signal from the Cerenkov counter, requiring also a coincidence with a majority of the silicon planes (each plane can provide an OR output if there was a mip anywhere in it).

We want the maximum luminosity for Run IIB and we aim to be able to take good data with the maximum luminosity the Tevatron can deliver. We discuss triggers more specifically after presenting the physics program.

III. EXCLUSIVE HIGGS BOSON PRODUCTION

If the Higgs is produced with a large enough cross section in the exclusive [1] reaction $p\bar{p} \to pH\bar{p}$ it will give rise to a peak at M_H in the missing mass spectrum. High resolution makes a Higgs search feasible over the full mass range 110-180 GeV (we now know from LEP that $M_H > 113.5$ GeV) 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 knowledge of $z_\circ$ from the precision timing. 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. Some theoretical calculations are very encouraging, while others claim that the cross section should be too low for the Tevatron, but perhaps not too low for the LHC. There are differences of more than a factor 100 in the predictions. The relevant diagrams are shown in Fig 1. The main problem in calculating these is the soft non-perturbative nature of the second gluon, for which we do not have a well accepted theory, and the difficulty in estimating the probability that no other particles will be emitted. If H is not seen in this proposed experiment that will rule out some models. If it *is* seen, that might not only be a discovery but it will provide the best way at hadron colliders of measuring M_H with an uncertainty of ≈ 250 MeV *per event*.

[1]Most of this section is based on reference [19].

FIGURES

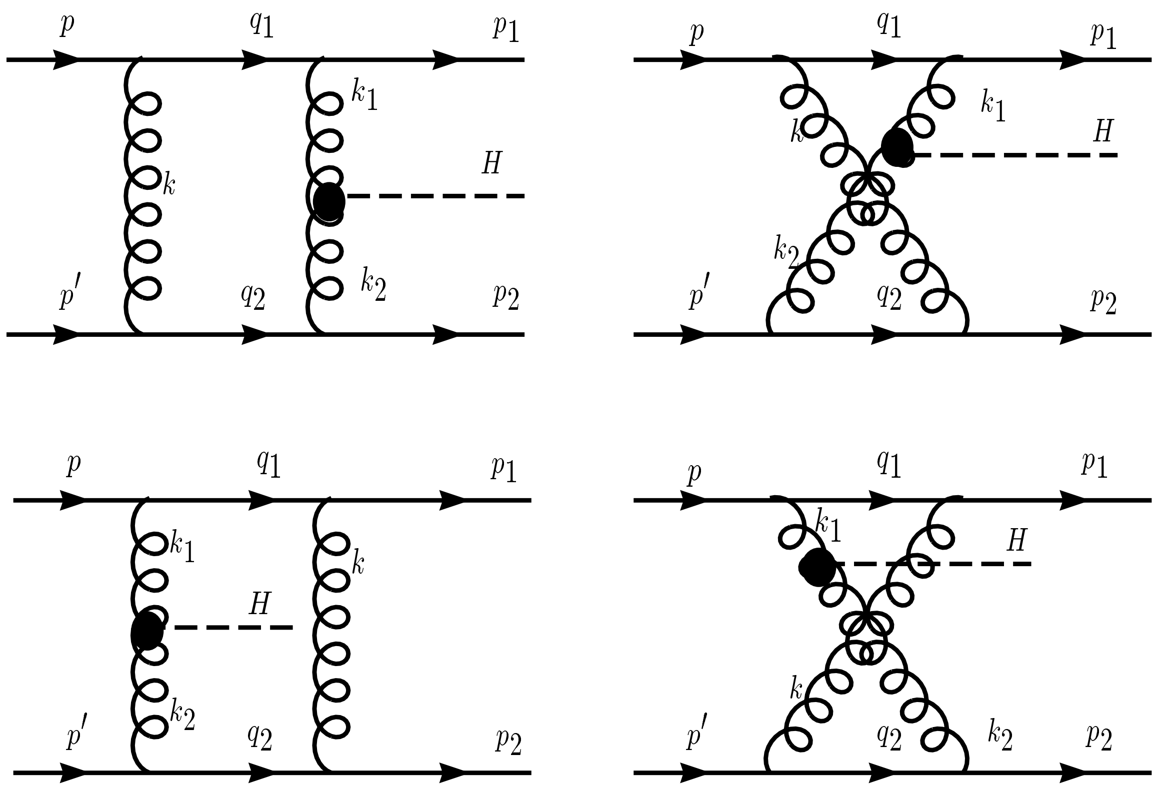

FIG. 1. Exclusive Higgs production diagrams (CH).

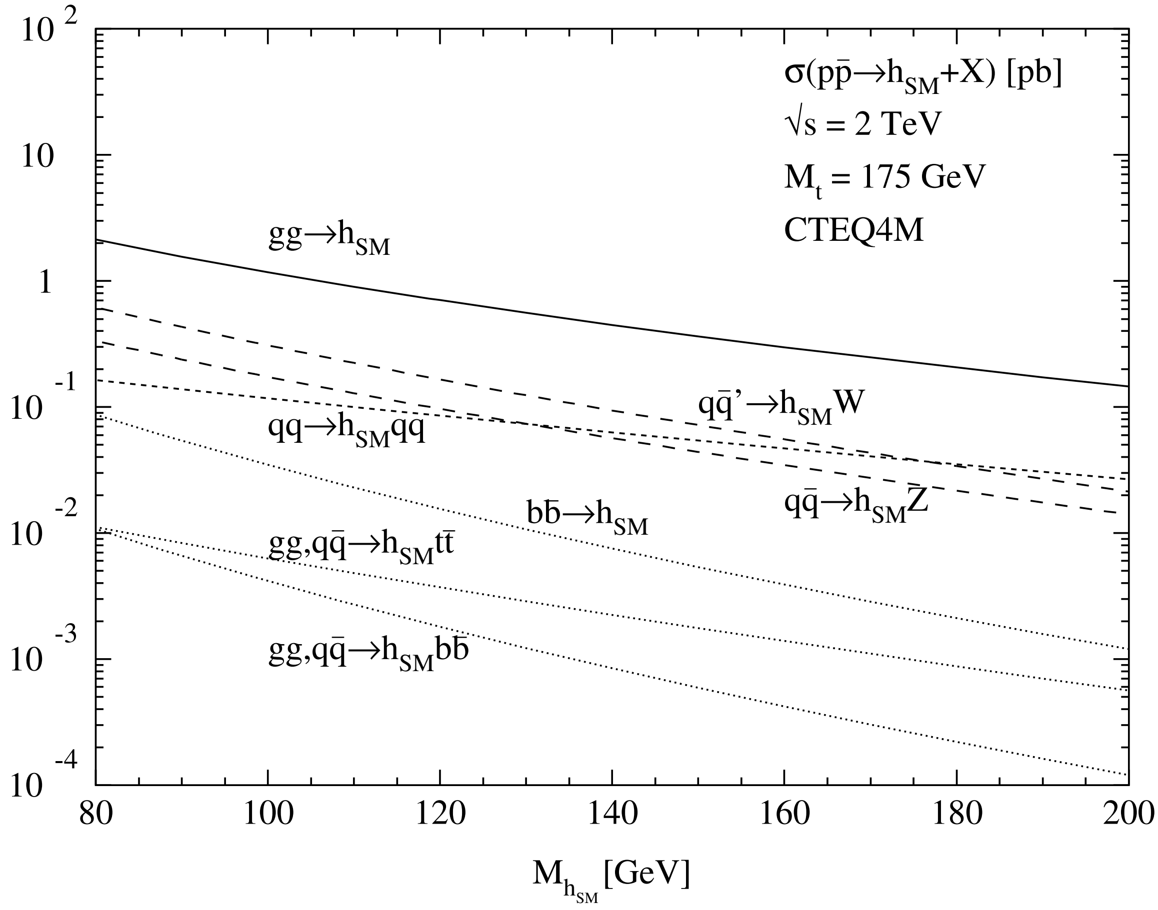

FIG. 2. Inclusive Higgs production cross sections vs M_H

The predominant mode for Higgs production at hadron colliders (see Fig.2) is gg-fusion [20,21] through a virtual top quark loop (in the 3-generation SM). The dominant decay mode up to 135 GeV is to $b\bar{b}$ (Fig.3), 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 only 5 MeV at $M_H = 130$ GeV, to 16 MeV at $M_H = 150$ GeV, to 650 MeV at $M_H = 180$ GeV (Fig.4) [20]. Mass resolution is therefore crucial in increasing the signal:background $S : B$ ratio.

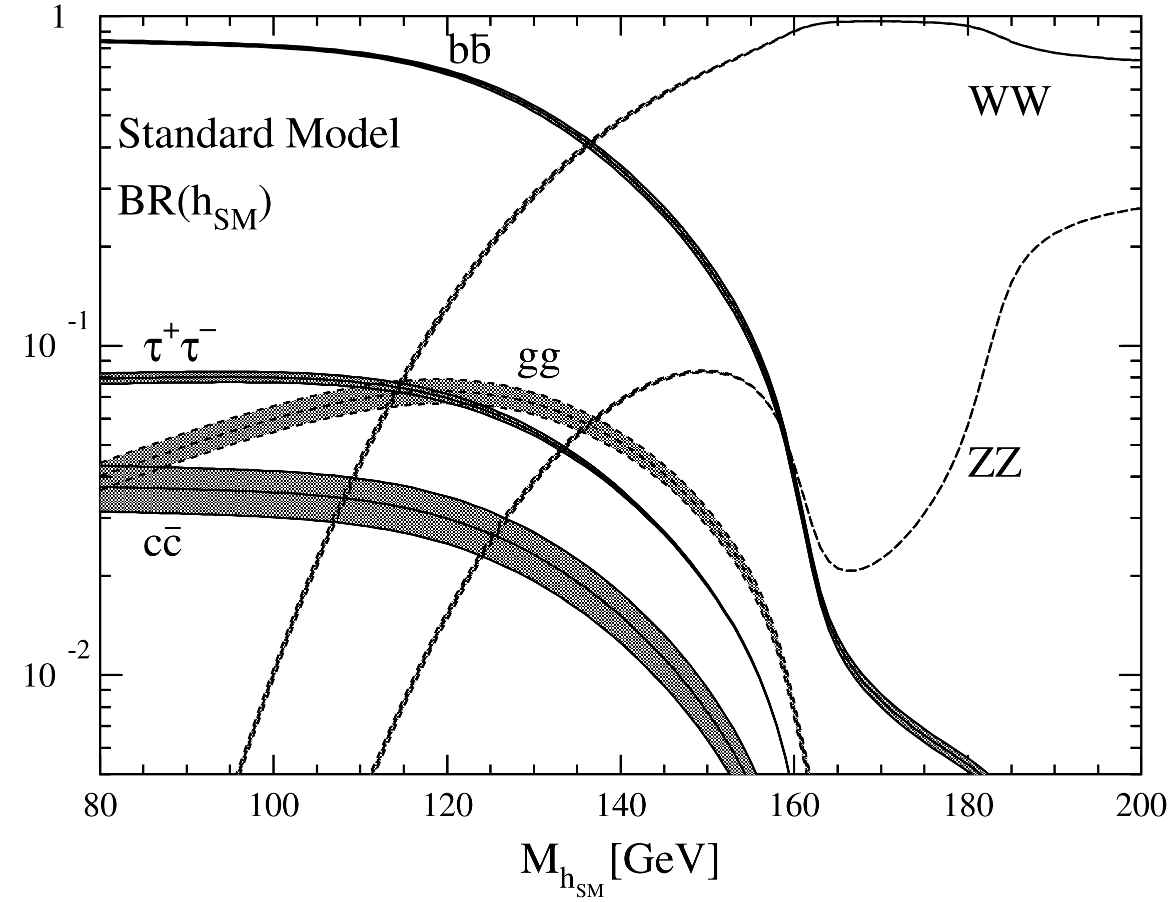

FIG. 3. SM Branching fractions as a function of M_H.

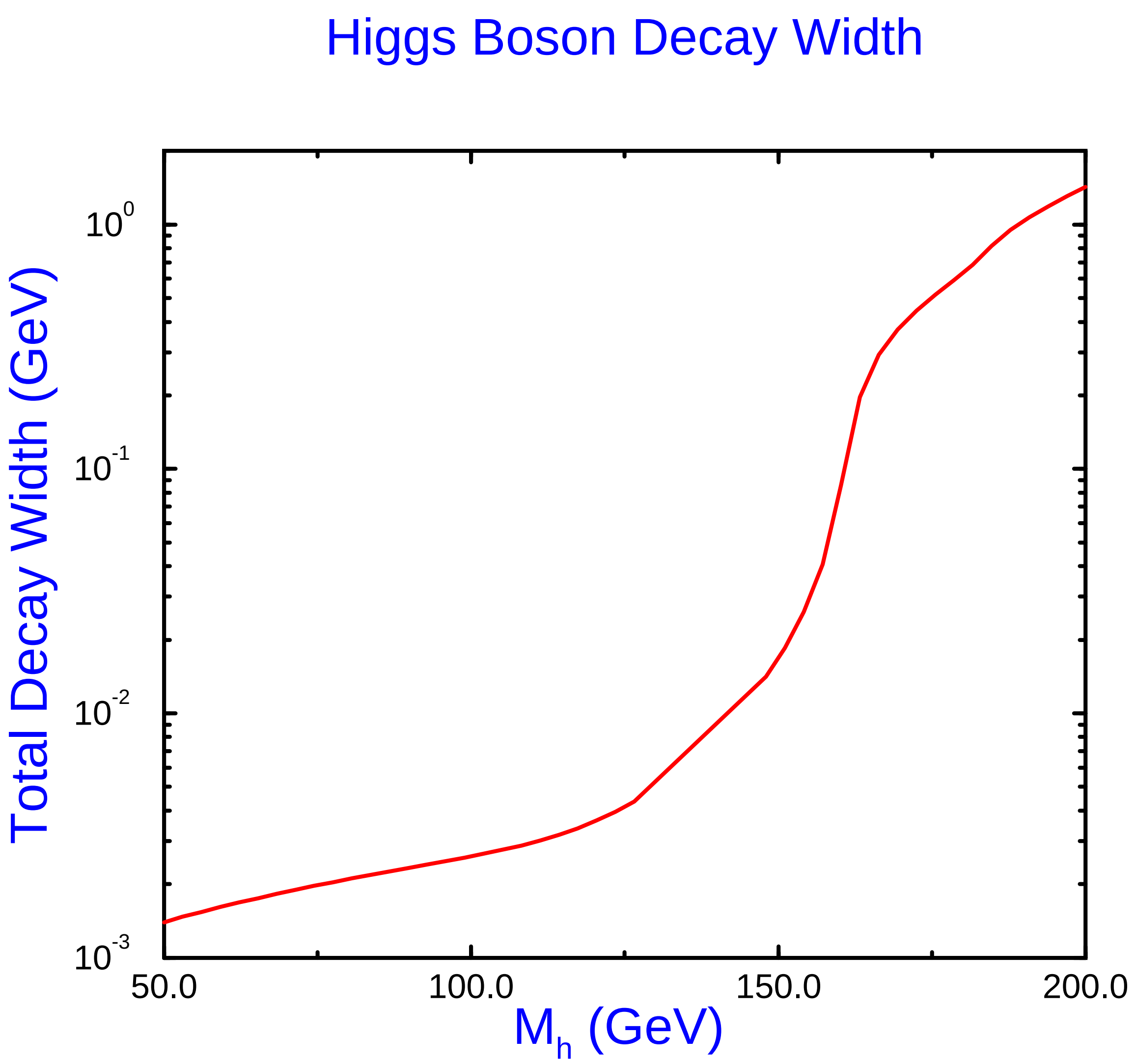

FIG. 4. SM Higgs width as a function of its mass.

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 and 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. 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.

The visibility of a signal will depend on the spread in the beam momenta $\frac{\delta p}{p}$ and the measurement error on p_3 and p_4. 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 [22] 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 $x_\circ, y_\circ, z_\circ$ will be reconstructed in the SVX with $\sigma \approx$4 μm, 4 μm and 10 μm respectively for central $b\bar{b}$ jets, and about a factor two worse [2] for l^+l^- final states. The outgoing p and $\bar{p}$ tracks will be measured using eight layers of crossed (and tilted?) silicon detectors giving $\sigma_x = \sigma_y \approx 5$ μm over $\approx$ 1.5 (5) m, thus $\sigma_{x'} = \sigma_{y'} \approx 3(1) \times 10^{-6}$. If $\sqrt{s}$ is the center of mass energy, 2 TeV (or 1.96 TeV) at the Tevatron in Run II, and the outgoing scattered beam particles have lost fractions ξ_1, ξ_2 of their incident momenta, 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 their divergence and the resolution of the "dipole spectrometers" which use the primary interaction point and the outgoing tracks. 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. Without being too specific for any objects except the Higgs boson, which is of course where most work has been done, we consider the present proposal to be motivated by a generic search for *any* objects which can be produced by $p\bar{p} \to pX\bar{p}$.

The visibility of the Higgs by this technique clearly depends on the size of the exclusive cross section. The mechanism $gg \to H$ normally leaves the p and $\bar{p}$ in color-

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

octet states and color strings fill rapidity with hadrons. However some fraction of the time one or more additional gluons can be exchanged which neutralize (in a color sense) the p and $\bar{p}$ and can even leave them in their ground state (see Fig.1). In Regge theory this is the double pomeron exchange ($DI\!PE$) process [3]. Several attempts have been made to calculate this cross section. In 1990 Schäfer, Nachtmann and Schöpf [24] considered 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 [25] made a calculation, also for nucleus-nucleus collisions, and concluded that the exclusive process is immeasurably small[4]. In 1991 Bialas and Landshoff [12] calculated from Regge theory that about 1% of all Higgs events may have the p and $\bar{p}$ in the $DI\!PE$ region of $x_F \approx 0.95$. In 1994 Lu and Milana [26] obtained an estimate "well below what is likely to be experimentally feasible". In 1995 Cudell and Hernandez [13] 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 (see Fig.5).

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[3]The two photon process can also give exclusive Higgs production, and this has been proposed [23] as a possibility for the LHC. The cross section is likely to be too small to be useful at the Tevatron. If point-like magnetic monopoles $\mathcal{M}$ which couple to the Higgs exist this conclusion might change. Then $p\bar{p} \to pH\bar{p}$ can proceed through an $\mathcal{M}$-loop (and the $H \to \gamma\gamma$ width will increase). One can distinguish this $\gamma\gamma \to \mathcal{M}\overline{\mathcal{M}} \to H$ case from $gg \to t\bar{t} \to H$ by the different $|t|$ distributions.

[4]Basically this is because they take a pomeron form factor and it is very difficult to "localize" pomerons to order M_H^{-1}. We have since learnt that this is unnecessary. A hard gg interaction has to be very localized, but the rest of the pomeron is extended.

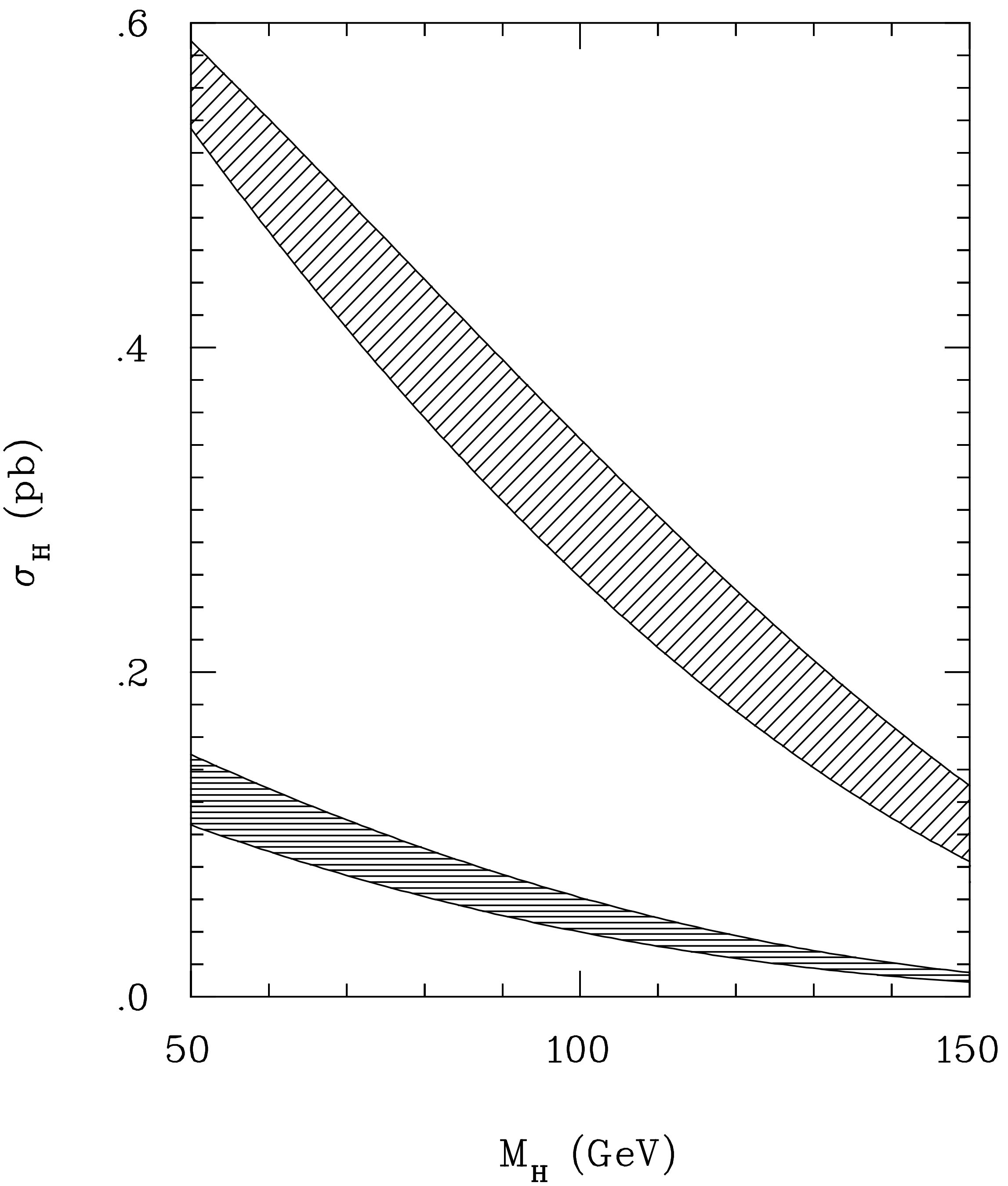

FIG. 5. *CH* exclusive cross-section $p\bar{p} \to pH\bar{p}$ (lower band). The upper band is when the p and/or $\bar{p}$ are allowed to diffractively dissociate.

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(1.5) fb at 170(200) GeV (all within a factor two). The total Higgs production cross section by the dominant gg-fusion mechanism is [21] 900 fb, 364 fb, 247 (145) fb respectively so the exclusive fraction decreases from 5% to about 1% over this mass range, even higher than the Bialas and Landshoff estimate. However there are issues of "rapidity gap survival probability", "pomeron flux renormalization" [27], shadowing effects, initial and final state interactions etc. These 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 recent calculations. Khoze, Martin and Ryskin [28] find $\sigma(pp \rightarrow pHp)$ = 0.06 fb for M_H = 120 GeV at $\sqrt{s}$ = 2 TeV if the probability S^2_{spect} not to have extra rescattering in the interaction is S^2_{spect} = 0.1. Kharzeev and Levin [14] find much higher values of 19 - 140 fb for M_H = 100 GeV at the Tevatron, but they do not present the M_H-dependence. The main difference from Ref [28] is associated with final state bremsstrahlung. For the channels $H \rightarrow \tau^+\tau^-$ and $H \rightarrow WW^{(*)}$ with both W decaying leptonically, we can allow additional hadrons with 4-momenta p_i as long as they are measured in the central detectors. Then:

$$MM^2 = (p_1 + p_2 - p_3 - p_4 - \Sigma p_i)^2$$

This will increase the cross section significantly. In a recent review [29] Landshoff reiterates his view that the exclusive production cross section should be large. Although there are large differences in the theoretical predictions, we shall show that the higher predictions allow a Higgs discovery at the Tevatron in Run II over the full mass range from 110 GeV to 180 GeV. We do not believe that the 2-gap survival probability in the central Higgs case should necessarily 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 much later than the formation time of all the other hadrons in the event. If it is heavy ($M_H > \approx 150$ GeV) it decays faster, on hadronization time scales, but we look at dilepton final states which do not couple to gluons. The $t\bar{t}$-loop is too small to interact with soft gluons. One should perhaps rather think of the "non-interacting" Higgs as being produced in the middle of one long (15 units) rapidity gap. The situation is reminiscent of rapidity gap survival in ep collisions, where the electron and the virtual photon do not interact with soft gluons, and in this case the gap probability ($\approx$ 10 %) is a factor $\approx$ 10 higher than in hard $p\bar{p}$ collisions. In our case we may also have a 2-gap probability $\approx (10\ \%)^2$

$= 1\ \%$, rather than $(1\ \%)^2 = 10^{-4}$ which is the approximate level of $DI\!PE$ in the $gg \to b\bar{b}$ background.

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 (or 1.96 TeV) and noting that the CH estimate has a factor ≈ 2 uncertainty. The CH predictions for the Standard Model Higgs are neither the most "optimistic" nor the most "pessimistic" and we take them as an example. We consider signals and backgrounds, first for $b\bar{b}$, then for $\tau^+\tau^-$ and then for $WW^{(*)}$ using only the leptonic decays $l_1^+ l_2^- \nu\bar{\nu}$. We also consider W^+W^- decaying to $l^{\pm}\nu jj$. 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	< 37.5
		$\tau^+\tau^-$	0.076	3.4	26	< 0.1
130	25	$b\bar{b}$	0.525	13.1	96	< 7.5
		$\tau^+\tau^-$	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	$\ll 1$
170	6.0	$W(l\nu)W(jj)$	0.996	2.49	18.5	$\ll 1$
180	3.5	$W(l\nu)W(jj)$	0.935	1.47	11.1	$\ll 1$

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, or, for the last two rows, one W decaying leptonically and one hadronically. A factor 0.5 has been applied to events and background for acceptance/efficiency.

A. $H \to b\bar{b}$

For the $b\bar{b}$ dijet background we take CDF's published cross section [30] $\frac{d\sigma}{dM_{JJ}}$ for two b-tagged jets, which starts at 150 GeV (see Fig.6), 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 $|\eta| < 2.0, |cos(\theta^*)| < 2/3$).

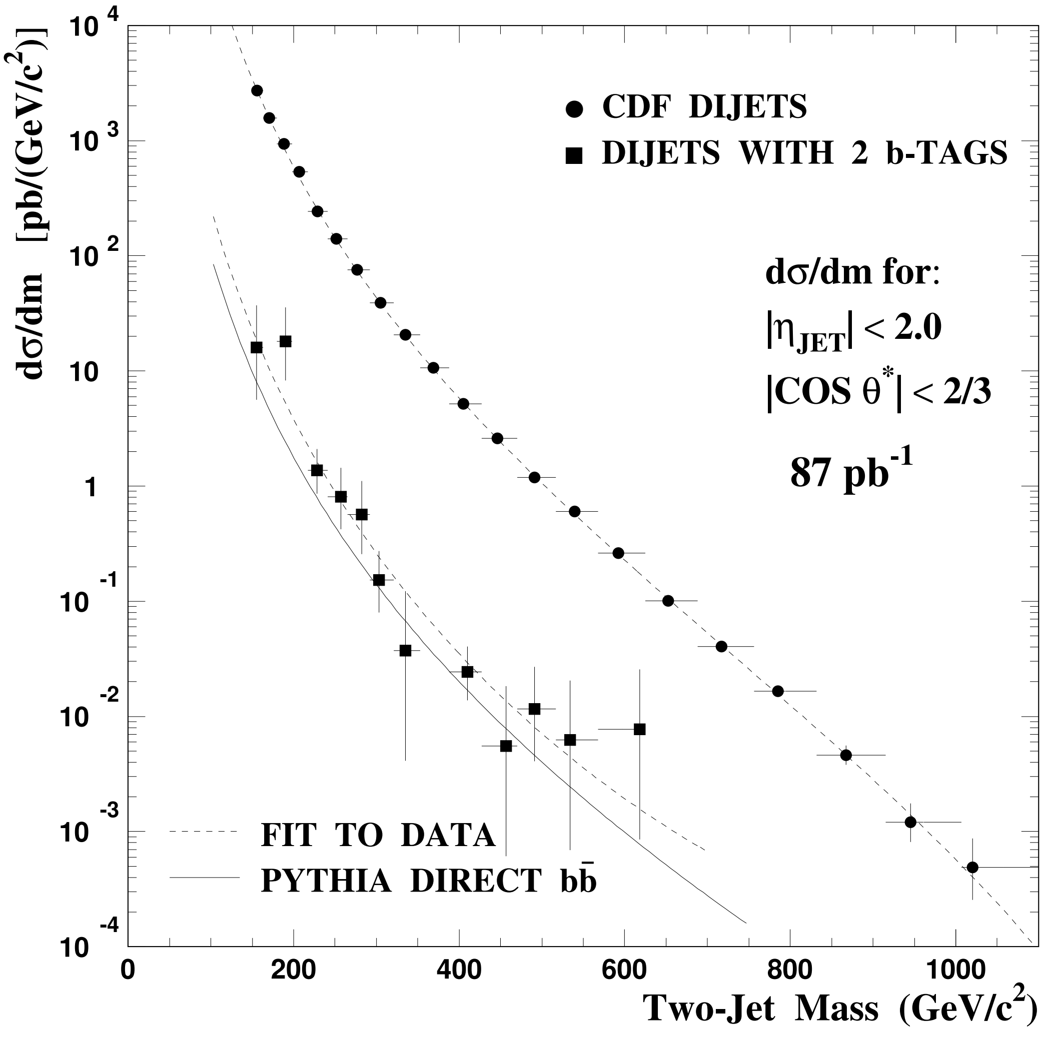

FIG. 6. Dijet and $b\bar{b}$ dijet cross section vs M_{JJ} (CDF).

From our other $DI\!PE$ studies, of lower mass dijets [10], we expect that less than 10^{-4} of these are $DI\!PE$ ($p\bar{p} \to p + b\bar{b} + \bar{p}$), where $+$ 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 5(1) fb per 250 MeV bin, to be compared with a signal of around 45(25) fb [13]. 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 37.5(7.5). Even if the CH predictions are too high by an order of magnitude these signals are 4.2(3.5)σ. 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); 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. (In practice we would probably cut on some combination like the product $B_1 B_2$ where B_i is the probability of jet i being a b-jet.) We have put in an acceptance of 50% for the signal and background, assuming the $|t|$-distribution is as expected for high mass $DI\!PE$, $\approx e^{b(t_1)+b(t_2)}$ with $b \approx 4$. The H has small p_T ($<\approx 2$ GeV) and being heavy is mostly produced with small rapidity. When the difference in p_z of the forward p and $\bar{p}$ is < 50 GeV, as it must be for our acceptance, $y_H < 0.41$ (0.28) for $M_H = 120$ (180) GeV. Of course it decays isotropically.

The $S : B$ ratio rises with M_H in this mass region 110-130 GeV, because the Higgs production cross section falls less steeply than the QCD backgrounds as the top loop becomes more real and the Higgs couples to mass. As M_H increases beyond 130 GeV the branching fraction for $H \rightarrow b\bar{b}$ drops rapidly.

B. $H \rightarrow \tau^+\tau^-$

The Higgs branching fraction to $\tau^+\tau^-$ decreases 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 discussed ways of minimizing this in section IIB. In the third case the events look like continuum $DI\!PE$ production of DY pairs, together with associated particles. Recent CDF studies [9,10] of diffractive jet production at low E_T have found a breakdown of factorization for jet production in the sense that

$\frac{\sigma_{DIPE}}{\sigma_{SD}} \approx 5 \times \frac{\sigma_{SD}}{\sigma_{ND}}$. Let us assume this fraction is the same for high-mass DY, and then assume factorization break-down by the same factor 5 for high mass DY. Then $DIPE$ production of high mass DY is at the relative level of 5.10^{-4}. From a CDF study [31] 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 $p\bar{p} \to p + \mu^+\mu^- X + \bar{p}$, 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 $< n_{ass} > \approx 16$ [32] for $p_T \geq 0.2$ GeV, $|\eta| \leq 1$. The observation of lepton pairs with ***no*** associated tracks, $n_{ass} = 0$, would already be good evidence for exclusive Higgs production [5]. The CH cross section $\sigma(p\bar{p} \to pH\bar{p})$ $\times$ 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. From the two neutrinos we will have central mass $M_X < MM$. For any non-diffractive background we can assume that the associated charged multiplicity on the l^+l^- vertex is Poisson-distributed with a mean of about 16, which is what CDF observes [32] for Z events [6]. 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, and even 3 or 4 events at the same MM would constitute a discovery. Although we only considered fully exclusive production in the above discussion, sometimes the H will be accompanied by some hadrons, central enough to have well measured four-momenta $p_5 ... p_k$. Then one can still use $MM^2 = (p_{b1} + p_{b2} - p_3 - ... - p_k)^2$. Being able to use these "nearly exclusive" events will increase the rate significantly. This technique can only be used with the

[5] One should see a peak at $n_{ass} = 0$ in this multiplicity distribution. This is a study that can be started in Run IIA.

[6] We realize that $< n_{ass} >$ will decrease when events have a large x_F p and $\bar{p}$, as the energy available for particle production will be less than normal.

leptonic H decays to $\tau^+\tau^-$ and $l^+l^-\nu\bar{\nu}$.

C. $H \to WW^{(*)}$

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 consider first the leptonic decay modes of the W because of the spectacular cleanliness 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 $\bar{p}$.

Precision timing $\approx$ 30 (10) ps on the p and $\bar{p}$ will not only check that they came from the same interaction but can pin down the vertex $z_\circ$ to about 1 cm (a few mm), to be related to the dilepton vertex known to $\sigma_z \approx 20\ \mu$m. This cleanliness means that the search is insensitive to the number of collisions in a bunch crossing. 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 $WW^{(*)}$ 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 $BR(H \to WW^{(*)})$, 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. The estimates are for $\sqrt{s} = 1.8$ TeV; for $\sqrt{s} = 1.96$ TeV the production cross section will be ($\approx$ 25%) higher. To estimate the background we refer to the observation of five W^+W^- events by CDF [33] [7] which gave $\sigma(p\bar{p} \to W^+W^-X) = 10.2 \pm 6.5$ 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 $\sigma(p\bar{p} \to W^+W^-X) = 10$ 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

[7] DØ earlier found one event [34] in 14 pb^{-1}.

both leptons and recognizing the event as $l^+l^-\not{E}_T$. This is high compared with the efficiency in ref [5], which was 5.4% - 8.9%, because due to the lack of background we can lower the selection cuts on $\not{E}_T, p_T(e), p_T(\mu)$ and $p_T(\tau)$ significantly. We assume that about 5×10^{-4} of these are from $DI\!PE$, giving $\approx 3 \times 10^{-3}$ fb/250 MeV.

It is also possible to use the exclusive W^+W^- events where one W has decayed hadronically giving $l\nu jj$ with $M_{jj} \approx M_W$. Improvements to our jet algorithms, as being worked on by S. Kuhlman and others [35] will be valuable. The number of these events is a factor 4.3 more than the number of $l^+l^-\nu\bar{\nu}$ events, and the continuum background is still very small. With the CH estimate this gives 11 events even for M_H = 180 GeV, at $\sqrt{s}$ = 1.8 TeV, as shown in Table I.

In order not to be limited by the number of interactions in a bunch crossing we will 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 to a precision $\sigma_x = \sigma_y \approx 10$ μm and $\sigma_z \approx 20$ μm) 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. One can plot the missing mass MM for the 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. However as stated above we will also search in $WW \to l\nu jj$ events.

If the exclusive cross section is indeed big enough to provide events in the data, but continuum background were to be an issue, one has further recourse to angular distributions [36]. 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) from a Higgs must 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. No matter what the decay mode(s), we can measure M_H with $\sigma_M \approx \frac{250MeV}{\sqrt{n}}$ (statistical). The systematic uncertainty will be determined by how well we can calibrate the MM scale using elastic (section VA) and low mass exclusive inelastic events (section VB).

D. $H \to ZZ$

Looking for $H \to ZZ$ at the highest masses 190(200) GeV where its SM branching fraction is 0.219(0.261) presents special challenges. The (CH) exclusive production cross section is about 1.5(0.5) fb (based on an extrapolation), about 1%(0.3%) of the inclusive $gg \to H$ production. Putting in the branching fraction to ZZ we find only about 5(2) events in 15 fb^{-1}. On the other hand we can perhaps use *all* decays including $\nu\bar{\nu}\nu\bar{\nu}$ ($MM \approx 200$ GeV with *nothing* on the primary vertex! But this is only 4% of the decays.) We can perhaps pick up some cross section by allowing a few measured hadrons on the primary vertex. The cases where one Z decays to $\nu\bar{\nu}$ and the other decays visibly (32%) are interesting in that the invisible missing mass $(p_1 + p_2 - p_3 - p_4 - p_{Z-visible})$ should be equal to M_Z. In the 42% of the cases where only one Z decays to jets we can apply the $M_{JJ} = M_Z$ constraint. While the ZZ channel is very marginal with 15 fb^{-1} it could become interesting with higher luminosity.

IV. BEYOND THE STANDARD MODEL

A. Extra generations

If there exist more massive strongly interacting fermions than the top quark the $gg \to H$ cross section will be enhanced as the additional loops come into play. One intriguing possibility, that there exists a 4th generation of very massive and nearly degenerate quarks and leptons, has been recently proposed by S. Sultansoy [37]. The LEP generation-counting experiment would not have been sensitive to this because the "neutrino" is too massive. Sultansoy's expectation is that $m_4 \approx 8m_W$, in which case the Higgs production cross section is enhanced by a factor of approximately 8. (This affects the gg-fusion process of interest to this proposal, but not the more orthodox $W^* \to WH$ associated production process.)

B. Extended Higgs models, CP-odd scalars

In extended Higgs models [38], a Higgs boson h° may have quite different decay modes from the SM modes considered in the previous section. One possibility is for the h° to decay to a pair of light neutral CP-odd scalars A° which have a supressed coupling to fermions. This could be the dominant decay mode, rather than the $b\bar{b}$ mode for the lighter Higgs masses. The A° may be even lighter than 0.5 GeV and will then decay with nearly 100% branching ratio to $\gamma\gamma$ which would not be resolved, so the event would look like two high-E_T direct photons. Higher mass A° can give similar signatures, e.g. $h^\circ \rightarrow A^\circ A^\circ \rightarrow 3\pi^\circ + 3\pi^\circ$. Even though there may be no associated hadrons on the primary vertex we can still find z_o from the timing on the p and $\bar{p}$.

C. Top-Higgs

Another example of accessible Higgs physics beyond the standard model is the idea of the top-Higgs, h_t, in which a $< t\bar{t} >$ condensate is responsible for the large top quark mass. In the Topcolor Assisted Technicolor (TATC) scenario proposed by Hill [39], the top-Higgs is a $t\bar{t}$ bound state which could be as light as 200 GeV. As $t\bar{t}$ decays are kinematically forbidden the predominant decay is to $t\bar{c}$ or $\bar{t}c$ [40]. The production cross section via gluon-gluon fusion could be nearly 1 pb at the Tevatron with $\sqrt{s} = 2$ TeV. If 10^{-3} of these h_t are produced exclusively then 15 fb^{-1} would produce 15 events of the type $p\bar{p} \rightarrow p + t\bar{c} + \bar{p}$. The h_t width is expected to be < 7 GeV.

D. Lightest SUSY particle, χ_1°

There are light mass windows where a χ_1° is not excluded. If R-parity is conserved then χ_1° would be long-lived or stable and only weakly interacting. This state can be produced in pairs, or with a χ_2°, in gg interactions via a $q\tilde{q}$ box diagram. Normally one concentrates on the $\chi_1^\circ\chi_2^\circ$ associated production, because the (much more massive) χ_2° can be detected through its decays, while $p\bar{p} \rightarrow \chi_1^\circ\chi_1^\circ + X$ does not have a distinctive final state, both χ_1° being invisible. However our MM technique provides a possibility. We select events with a measured p and $\bar{p}$ and plot the MM spectrum for events where there are no particles on the primary vertex ($z_\circ$ coming from the timing). We exclude elastic scattering by cutting on Δt and $\Delta\phi$. We have to exclude additional interactions by requiring no tracks, and only noise in all the CDF calorimeters (including the BSCs). We then search the MM spectrum for a localized threshold effect (a step). The main background is from interactions like $p\bar{p} \rightarrow p\pi^\circ\pi^\circ\bar{p}$ or $pn\bar{n}\bar{p}$ or $pK_L^\circ K_L^\circ\bar{p}$, where the central hadrons are too soft to distinguish from noise, or which go in detector cracks. The effective luminosity for this search will be lower because of the single interaction requirement. The *optimum* luminosity for this is about 10^{32} cm^{-2} s^{-1} when the average number of interactions per crossing is 1.0.

V. LARGE EXTRA DIMENSIONS

If there exist "large" extra dimensions in which (Kaluza-Klein) gravitons can propagate, while the known particles are confined to the 3-dimensional "3-brane", one can explain the relative weakness of gravity. Gravitons $\mathcal{G}$ can be created in $p\bar{p}$ collisions either singly through $gg \rightarrow \mathcal{G}$ (with or ... in our case ... without a recoiling gluon) or with much lower cross section in pairs $gg \rightarrow \mathcal{G}\mathcal{G}$. Gravitons probably exist as a large (or infinite) number of states of different mass: a "graviton tower". Gravitons emitted into "the bulk", out of our 3-D world, will be invisible except in so far as they will give rise to an *apparent* violation of 4-momentum conservation. This is how neutrinos were first "seen". Our proposed experiment is ideally suited to search for the emission of such states [41]. We select non-elastic (by cutting on $\Delta|t|, \Delta\phi$) events where there are no central tracks and all the CDF detectors (except our pots!) are consistent with being empty as in the search for $\chi_1^\circ\chi_1^\circ$. This clearly restricts us to single interactions/crossing, but even at $L = 2.10^{32}$ cm^{-2} s^{-1} with 132 ns between crossings we have $\approx 10^6$ s^{-1}. The MM spectrum might have five components:

(1) The KK graviton tower production signature would be a rising then a falling distribution starting at $MM =$ (essentially) 0. Individual levels of the tower will not be resolved. The cross section $\sigma(gg \rightarrow \mathcal{G})$ rises with the "effective $M_\mathcal{G}$", because the $\mathcal{G}$ couples to the gluons via their stress-energy tensor. The distribution falls after the

initial rise because the gg luminosity falls with increasing $\sqrt{\hat{s}(gg)}$. The cross section can be calculated [42] and (extrapolating down in E_T) is expected to be about 10 pb, giving 10,000 events in 1 fb^{-1}. Only a fraction ($\approx 1\%$?) of these will be exclusive. It remains to be seen whether we can use the "nearly exclusive" events.

(2) Lightest SUSY particle (χ_1°) pair production, giving a threshold rise at 2 $M_{\chi_1^\circ}$. We would not complain if this was our background!

(3) Elastic scattering where the p and $\bar{p}$ came from different events, their partner $\bar{p}$ and p having been missed. This will have to be Monte-Carlo'd but with 360° forward track coverage it should be very small, and will probably give $MM \approx 0$ (or somewhat negative) as both p and $\bar{p}$ have the beam momentum but are not colinear.

(4) Low mass $DI\!PE$ where the central state is missed, perhaps being $n\bar{n}$ or $K_L^\circ K_L^\circ$, although these should be detected in the calorimeters, especially the $\bar{n}$ which deposits a 2 GeV annihilation signal. Unfortunately there are calorimeter cracks so a purely neutral final state can fake an empty event. This will need to be studied by simulations.

(5) Double beam halo events. We can measure this by combining p_{halo} tracks with $\bar{p}_{halo}$ tracks. 10^n events of each type give 10^{2n} $p_{halo}\bar{p}_{halo}$ combinations. Even if the beam halo conditions fluctuate from run to run, we can use halo tracks found in coincidence with elastic scattering events. Thus the halo-halo fakes are monitored continuously. One can even do this bunch-by-bunch (and the information might be useful for Tevatron diagnostics).

Tachyons $\mathcal{T}$ are hypothetical states which *always* have speeds in excess of c, so $|p| > E$ and $M_{\mathcal{T}}^2$ is negative. Zero energy tachyons have infinite speed. As $E_{\mathcal{T}}$ increases the speed tends to c *from above.* If there are extra *time* dimensions then KK towers of tachyons could exist [43], giving rise to a continuum in the MM^2 spectrum for negative MM^2 ! To us confined to a 3-brane we see the p and $\bar{p}$ coming out of the collision with more energy than they had initially! This is bound to be more interesting than cold fusion!

VI. OTHER PHYSICS

Although the processes $p\bar{p} \rightarrow pX\bar{p}$ for high M_X or with X "invisible" are our main motivations, there is much other physics that can be done "parasitically":

A. Elastic scattering at high-t.

The detectors will have acceptance for particles with $p = p_{beam}$ $(MM = 0)$ for $|t|$ values of order 0.8 GeV^2 - 4.0 GeV^2 depending on the closeness of approach to the beams and the geometry of the detectors. As the detectors on the p and $\bar{p}$ sides have acceptance for $\Delta\phi = 180°$ we will accept elastic scattering events. Elastic scattering in this $|t|$ region has not been measured at Tevatron energies. At the CERN $S\bar{p}pS$ collider, $\sqrt{s} = 540$ GeV, there is structure

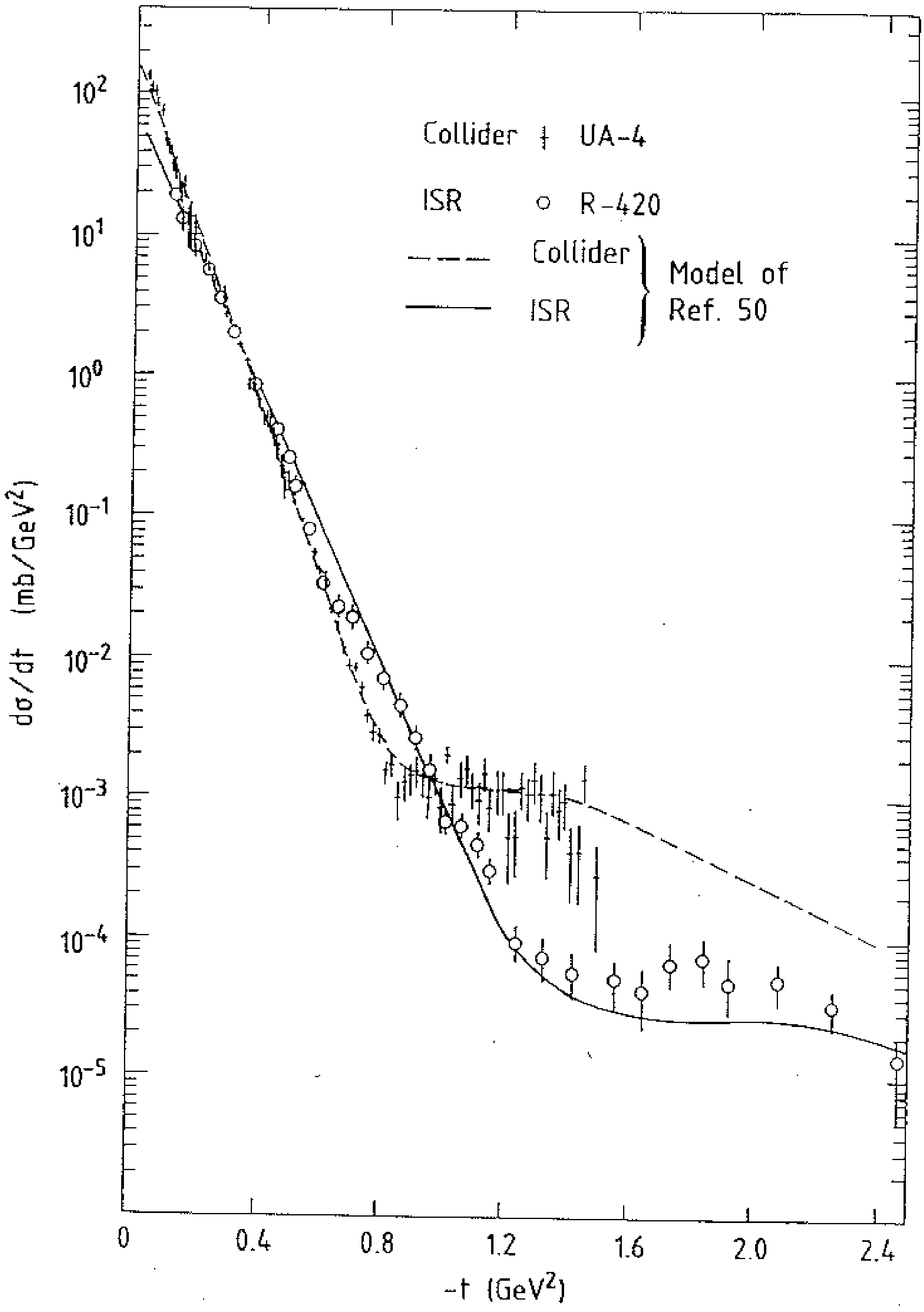

FIG. 7. $p\bar{p}$ elastic scattering at 52.7 and 546 GeV.

around 1.2 - 1.6 GeV^2 which was seen at the ISR ($\sqrt{s}$ = 53 GeV) at lower $|t|$ [44](Fig.7). It would be interesting to measure this at the Tevatron. Donnachie and Landshoff [45] have considered large-$|t|$ elastic scattering in terms of triple gluon exchange (one between each quark pair). At $|t| > \approx 3.5$ GeV^2 the cross section through the ISR energy range ($27.4 < \sqrt{s} < 62.1$ GeV^2) is approximately independent of $\sqrt{s}$. They predict that the cross section may even rise at higher energies, but whether the $|t|$ of our proposal is large enough to see this effect is not yet known. The differential cross section should be about $\frac{d\sigma}{dt} \approx 10^{-5}$ mb.GeV^{-2}, and the rate therefore about $A\times 1$ s^{-1} where A is the acceptance, at $L = 10^{32}$ cm^{-2}s^{-1}. Millions of events can be collected with a trigger on the p and $\bar{p}$ with $MM = 0, t_1 = t_2, \Delta\phi = 180^\circ$. The $|t|$-resolution will be $\approx 10^{-2}$ GeV^2 and the background should be very small. The elastic scattering events can provide one check on the calibration and MM, t and ϕ resolutions of the experiment, although the x, y position of the vertex is not known better than the convoluted transverse beam size ($\sigma_x = \sigma_y \approx 25\mu$m). The longitudinal interaction position $z_\circ$ is known from the FTCD-TOF. The DØ forward proton detector proposal also mentions large $|t|$ elastic scattering as an "other accessible physics topic". The present proposal will extend those measurements to higher integrated luminosity with better resolution in ξ, t and ϕ.

B. Low Mass Exclusive Central Production

In this section we consider exclusive $p\bar{p} \rightarrow p + X + \bar{p}$ where X is a *low mass* state near rapidity $y = 0$ and $+$ represents a rapidity gap $\Delta y > \approx 5.5$. These reactions provide much information about QCD at the non-perturbative frontier. We must learn how to calculate these processes before we can claim to have a good understanding of the strong interaction. As for elastic scattering there will only be acceptance for large $|t|$. It will be interesting to see whether the mass spectra and flavor composition are the same as when $|t|$ is small (as can be measured in Run IIA without forward detectors [46] from $+X+$ events). See Appendix I for some Run IIA physics of special relevance to this proposal. We are expecting to do a lot of this physics in Run IIA using the Miniplugs and BSC in veto and triggering on a few central charged particles in the TOF barrel. At this time it is not possible to say whether we will want to continue this physics with the forward p and $\bar{p}$ tagged in Run IIB. Even though the rates will be orders of magnitude smaller (the cross section is not known at these large $|t|$) the tagging allows some new physics.

1. Glueballs

The central state is a good place to look for glueballs G (produced exclusively, $p\bar{p} \to p+G+\bar{p}$) and hybrids e.g. $c\bar{c}g$, $b\bar{b}g$. Some papers can be found in the proceedings of the workshop on QCD and Weak Boson Physics in Run II [47]. Interesting central states are $\pi\pi, KK, KK\pi\pi, \phi\phi, p\bar{p}$, $\Lambda\bar{\Lambda}$ etc. Structures are sure to exist in some of these mass spectra, as they have been observed at lower $\sqrt{s}$ [48,49] and backgrounds from $I\!R$-exchange will have decreased to a negligible level at our $\sqrt{s}$.

If glueballs exist and lie on Regge trajectories, like other hadrons, it is commonly believed that they will lie on the $I\!P$ trajectory ($\alpha(t) \approx 1.08 + 0.2t$) so $M = \sqrt{\frac{J-1.08}{0.2}}$. The first such state would be $I^G J^{PC} = 0^+ 2^{++}$ with $M_G \approx 2.1$ GeV. However the lightest glueball is surely a scalar $J^{PC} = 0^{++}$. This cannot lie on the $I\!P$ trajectory but must lie on a (parallel?) daughter. If this is the candidate $f_\circ(1500)$ ... close to a lattice QCD prediction in the pure-gauge theory of 1600 ± 100 MeV [50] ... then its first recurrence will be a 2^{++} around 3.5 GeV. Clarification of the glueball spectrum (and there are *many* states) should provide a powerful reality check on Lattice Gauge Theory in the pure glue sector. If LGT can correctly calculate the glueball spectra it may find that they lie on $I\!R$egge trajectories with the slope of the $I\!P$omeron !

Another useful channel for glueball G_i production is through $I\!PI\!P \to G_i G_j$ with $\hat{t}$-channel $I\!P$ exchange. One can play games like dividing the central event into two hemispheres, e.g. Forward:Backward *wrt* the t-channel axis or *wrt* the sphericity axis (which may be equal ... something to be studied), and plotting M_F vs M_B. We will calculate the hadrons' rapidity *wrt* the t-channel axis, $y_t = \frac{1}{2} ln \frac{E+p_t}{E-p_t}$ where p_t is the momentum component along the t-channel axis. Then one can select the events that have a y_t gap between the F and B clusters, to select $\hat{t}$-channel $I\!P$ exchange. If $G_i = G_j$ we will have a peak on the diagonal, otherwise we may have horizontal and vertical bands with off-diagonal peaks.

2. Hybrids

To search for hybrid states we will reconstruct effective masses of combinations like $\Upsilon\pi^+\pi^-$. Note that these events, unlike elastic scattering, have a well-measured central vertex, and often a well measured central mass M_X, and therefore provide an excellent calibration of the missing mass scale and resolution.

It is exciting to observe and study heavy (exotic) hybrids. Much can be learnt about QCD and confinement from these heavy hybrids, because the Born-Oppenheimer approximation holds [51]. Several of them may lie below the $D^{**}\overline{D}$, $B^{**}\overline{B}$ threshold. Those hybrids are predicted to be narrow ($\approx$ 10 MeV) [52] because of selection rules that suppress their open charm/beauty channels [53]. Their dominant decay modes would then be into hidden charm/beauty, and into light hadrons [52]. Lattice gauge calculations predict the exotic charmed hybrid $1^{\mp}0^{\pm}$ at 4.3 ± 0.2 GeV [54]. Thus even an exotic charmed hybrid could be narrow. This is an important field for non-perturbative QCD, including understanding how to calculate QCD on the Lattice.

3. χ_Q states

States such as χ_c° (3415 MeV, $\Gamma \approx 10$ MeV) and χ_b° (9860 MeV, width unknown) have the quantum numbers $I^G J^{PC} = 0^+0^{++}$ (like the vacuum) and hence can be produced in $DI\!PE$. Little is known about these states apart from their masses from their production in radiative $\psi(2S)$ and $\Upsilon(2S)$ decays. Most of their decay modes are unknown. In particular for χ_b° the 2000 PDG only gives $\gamma\Upsilon(1S) < 6\%$. We can trigger on $MM = 9860 \pm 300$ MeV and study the mass spectra of selected likely final states for signs of the χ_b°, and we can measure its width. States to investigate include $K^+K^-\pi^+\pi^-$ and $K_S^{\circ}K_S^{\circ}\pi^+\pi^-$. Being scalars these states must decay isotropically. Background can therefore be reduced by projecting out the S-wave, by studying the moments of the angular distributions in the t-channel (i.e. *wrt* the $I\!PI\!P$ axis).

4. Odderon search

It will be particularly interesting to look for states with negative C like the vector mesons $\omega(782)$, $\phi, J/\psi$ and Υ. These states, with $I^G J^{PC} = 0^- 1^{--}$, cannot be produced in double pomeron exchange. They can, however be produced in $I\!\!P - \gamma$ exchange, but the t-distribution at the $pp\gamma$ vertex is very steep (Coulomb) and we will not get such events with $t_{min} \approx -0.8$ GeV^2. (We might find them in Run IIA as $p\bar{p} \to +J/\psi+$ where $+$ means a rapidity gap $\Delta y \geq 6$ units.) If we do see such events, it will therefore be rather conclusive evidence for the existence of the *odderon* $O\!\!\!/$. The odderon [55–57] is a firm prediction of QCD but its existence has not been established. It is similar to the pomeron except it has $C = -1$ (like the photon) and it must have a minimum of three gluons (*cf* two for the pomeron). It is associated with a Regge trajectory with $t = 0$ intercept near 1.0 (but not the same as that of the pomeron). The slope α' is unknown. The trajectory could be measured from the t-dependence at more than one $\sqrt{s}$-value. Seeing these vector mesons in lepton pairs would be quite special also in the sense that there should be *no continuum background*, as the only way for $I\!\!P I\!\!P$ or $I\!\!P O\!\!\!/$ interactions to give an exclusive lepton pair is through a resonance. (Exclusive lepton pairs could come from $\gamma\gamma$ collisions, but with our acceptance in t at these masses that will be negligible.)

Apart from the expectation in QCD for odderon exchange as a regge trajectory, there could also exist hadron states with real mass lying on that trajectory, just as one expects C = +1 glueballs on the pomeron trajectory. These *Real Odderons* must have a minimum of three valence gluons (no valence $q, \bar{q}$) and have C = -1. They can decay e.g. to S-wave $K^\circ_S K^\circ_L$ or $K^\circ_S K^\circ_L \pi^+\pi^-$ and might show up in the spectra of such C = -1 particle combinations. Real Odderons can of course also be produced in pairs in $DI\!\!PE$.

If one could find $I\!\!P \to GO\!\!\!/$ this would be strong C- and P-violation. However it is not obvious that one could separate that process from the more likely $I\!\!P O\!\!\!/ \to GO\!\!\!/$ process, without the large statistics at different $\sqrt{s}$ values needed to map out the trajectories $\alpha(t)$. Apart from the $O\!\!\!/$ state which (in the string picture) has two 3-string junctions $\mathbf{Y}$, there might also exist quarkless states with *any* even number of such junctions [58]. The search technique is to study the MM spectrum for central states that have an unusually large p and $\bar{p}$ (or Λ and $\bar{\Lambda}$ content, as determined from $\frac{dE}{dx}$ and TOF. We call these states *Junction Boxes* (four junctions gives the topology of a tetrahedron, eight of a cube, etc.).

C. Inclusive $D\mathbb{P}E$

1. The Pomeron "Size"

In gluon language by pomeron "size" we mean the transverse spatial distribution of the ≥ 2 gluons that form the color singlets that are removed from the p and $\bar{p}$. It is interesting not only to measure this but to determine whether it shrinks as $|t|$ increases, as one might expect. (It is supposed that in large-$|t|$ elastic pp scattering the 3 valence quarks have fluctuated into an unusually close-together configuration.) There are three possible ways (that we are aware of) for measuring the size of the pomeron in $D\mathbb{P}E$.

(a) Measure the total cross section $\sigma_{\mathbb{P}\mathbb{P}}(M_X, t_1, t_2)$ where M_X is the c.m. energy of the $\mathbb{P}\mathbb{P}$ interaction. Because we do not know from first principles the "flux" of the colliding pomeron "beams", this cannot be done without some assumptions. The simplest is to assume soft factorization, in the sense that the $pp\mathbb{P}$ coupling $g_{pp\mathbb{P}}(t)$ is the same in elastic and inelastic processes, at least for the $|t|$-region of our measurements. This may well be true even though we have shown that factorization breaks down for hard diffractive processes. Incidentally $\sigma_{\mathbb{P}\mathbb{P}}(M_X, t_1, t_2)$ is also interesting because it is related through the optical theorem to elastic $\mathbb{P}\mathbb{P}$ scattering at $t = 0$. There is only one allowed t-channel exchange in elastic $\mathbb{P}\mathbb{P}$ scattering and that is the pomeron itself. Therefore we would expect, since the intercept $\alpha_{\mathbb{P}}(t = 0) > 1.0$, $\sigma_{\mathbb{P}\mathbb{P}}(M_X, t)$ to rise with M_X already from low values, unlike hadron-hadron scattering which proceeds at low energies through $\pi_{\mathbb{R}}$, $\rho_{\mathbb{R}}$ etc exchanges (subscript $\mathbb{R}$ means reggeized). I = 1 or C = -1 exchanges are forbidden here. The relevant diagram is "double-triple-pomeron", and we can measure the triple-pomeron coupling $g_{\mathbb{P}\mathbb{P}\mathbb{P}}(t_1, t_2, 0)$. This is an important parameter in the physics of the vacuum.

(b) Double parton scattering, DPS. These are two $2 \rightarrow 2$ parton scatters in the same interaction, producing (in LO) four jets. The other 4-jet process is double bremsstrahlung, DBS. They can be distinguished statistically by the pairwise balance of the E_T-vectors in the DPS case. This was observed first [59] at the ISR at $\sqrt{s}$ = 63 GeV (not an untypical value of M_X in our case) and later at the Tevatron by CDF [60]. The cross section for DPS depends on the size of the interacting objects (through $\sigma_{DPS} \equiv \frac{\sigma_A \sigma_B}{\sigma_{eff}}$ where $\sigma_{A(B)}$ is the cross section for $2 \rightarrow 2$ processes A and B, and σ_{eff} is an effective area of the overlap of the interacting objects). This measures the transverse spatial extent of color-singlet $\geq$ 2-gluon clusters (pomerons). Given statistics, one can determine whether σ_{eff} decreases as $|t|$ increases as one might expect.

One can use DPS to measure *skewed gluon distributions* in the proton (or in the pomeron). By this is meant the function $g_2(x_{Bj}(1), x_{Bj}(2))$ where g_2 is the 2-gluon density. Having found events with four pairwise balancing jets, for each pair one constructs $x^{\pm}_{Bj} = \frac{1}{\sqrt{s}} \sum_{i=1}^{2} E^i_T e^{\pm \eta_i}$

(c) Bose-Einstein correlations. Studying correlations at small effective masses between identical bosons, like $\pi^+\pi^+, K^+K^+$ [61] or $K^\circ_S K^\circ_S$ can tell us about the dimension of the region at which the hadrons emerge. This can be done distinguishing between the direction parallel to the $I\!PI\!P$ axis ($|t|$-channel axis) and the transverse direction [62]. Again, t and M_X dependences should be studied.

2. Direct Photons

One can search for direct photons in $DI\!PE$ events. If the $I\!P$ is purely gluonic the leading order diagram is a box diagram $gg \rightarrow q\bar{q} \rightarrow \gamma g$. This may be a good test for the presence of $q, \bar{q}$ in the $I\!P$ which would allow the much higher cross section process $gq \rightarrow q\gamma$. Note that in one case the recoil jet is a gluon and in the other case a quark. The ability to identify jets as $g, u+d, s$ or c would allow one to measure separately the $u+d, s$ and c components of $q/I\!P$ vs β, Q^2 and t. This is ambitious, but with enough events in the range say 20 GeV $< M_X <$ 100 GeV it will be possible. At the ISR, $\sqrt{s}$ = 63 GeV, $\frac{\gamma}{\pi^\circ}$ rises with p_T to $\approx$ 10 % at p_T = 5 GeV. The Shower Maximum detectors will be used to separate direct photons from π°, η etc.

3. Inclusive Two Proton Spectra

We leave to last in this section (although maybe it should have come first) measurements of the double inclusive cross section $d\sigma_{p\bar{p}\to pX\bar{p}}/dt_1 d\xi_1 dt_2 d\xi_2 d\phi$, ideally at three $\sqrt{s}$ values[8] One can test this against the quintuple-regge phenomenolgy (this is a generalization of the more familiar triple-regge diagram applicable to single diffractive dissociation). Although this is an *inclusive* measurement, one can do the same analysis when one has a pair of high E_T jets in the final state, and study the Q^2-dependence of the extracted $\alpha(t)$ values.

4. General Comments

It is interesting to determine whether the central spectra depend on $|t|$. Run IIA studies can give the spectra without seeing the p and $\bar{p}$ so these will be dominated by low $|t|$ (see Appendix I). In Run IIB we can vary $|t|$ between about 0.8 and 4.0 GeV^2. Another interesting study, given good ϕ-coverage for both arms, is to determine whether the spectra of selected central states depend on $\Delta\phi$. At much lower $\sqrt{s}$-values (SPS fixed target $\sqrt{s} = 30$ GeV^2) they do, and resonances come and go as one varies $\Delta\phi$. It has been argued [63] that small $\Delta\phi$ (the opposite situation to elastic scattering) should enhance glueballs relative to $q\bar{q}$ states. The $\Delta\phi$ distribution has been used to show that the pomeron transforms as a non-conserved vector current. This requires further study.

It is our intention to make a first level trigger (see section VII) on missing mass MM together with other conditions. Thus we could for example select $8 < MM < 11$ GeV for a study of $b\bar{b}g$ hybrids and χ_b°, in parallel with other MM regions for other physics.

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[8]Of course we do not want to spend much time away from the highest $\sqrt{s}$. But about two weeks at each of 630 GeV and 1200 GeV would be very useful for many QCD studies.

D. Gluon Jet Factory

It has been pointed out by Khoze, Martin and Ryskin [15] that dijets produced by $D\mathbb{P}E$ are almost entirely gluon jets. We quote: "...for the exclusive process the initial gg state obeys special selection rules. Besides being a colour-singlet, for forward outgoing protons the projection of the total angular momentum is $J_z = 0$ along the beam axis. This follows from $P-$ and $T-$invariance and fermion helicity conservation. ... Thus, if we were to neglect the $b-$quark mass, then at leading order we would have no QCD $b\bar{b}$-dijet background (to H) at all." Even without b-jet identification the ratio $gg : b\bar{b}$ dijets is expected to be about 3.10^3. Identifying the b-jets in the SVX can increase this ratio by an order of magnitude. The light $q\bar{q}$ jets are negligible [64]. We have measured the cross section for $D\mathbb{P}E$ production of dijets with jet $E_T > 10$ GeV to be a few nb. That corresponds to a million events (times the acceptance) in 1 fb^{-1}. In contrast, at present the highest purity g-jet sample is 439 jets from $Z \to b\bar{b}g$ in 5 years of running at LEP1 [65].

With this large sample of essentially pure $gg \to gg$ events we can test the QCD predictions of the dependence on $\hat{s}, \hat{t}$. Referred to the t-channel ($\mathbb{P}\mathbb{P}$) axis in the $\mathbb{P}\mathbb{P}$ rest frame we can extract the $\beta = \frac{p_g}{p_{\mathbb{P}}}$ of the scattering gluons from the dijet kinematics[9]. As a parenthetic comment, when these dijet events have empty BSC's, the MM should be equal to the total central calorimetric mass (apart from any escaping neutrinos). This can provide a valuable calibration of the central (including the Plugs and Miniplugs if they are not empty) energy scale, including the gluon jet E_T-scale.

E. Another Glueball Search

We have already mentioned the power of this proposal for glueball searches through $p\bar{p} \to p + G + \bar{p}$ and $p\bar{p} \to p + G_i G_j + \bar{p}$. The large samples of pure gluon jets obtainable (see above) suggest another way of searching for glueballs. A jet initiated

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[9] $\beta_{L,R} = \frac{1}{\sqrt{M_X}} \sum_{i=1}^{2} E_T^i e^{\pm\eta^i}$ with E_T and η referred to the t-channel axis.

by a gluon can fragment with a gluonium state as the leading hadron. The color octet string behind the leading gluon can break with another gluon as the second-leading parton. In the string model the gluon jet can be initially described as a hairpin configuration, and the tip of the hairpin can break off as a closed loop (glueball). To do the search one constructs the rapidity of the jet hadrons *wrt* the jet axis, $y_J = \frac{1}{2} ln \frac{E+p_j}{E-p_j}$ where p_j is the component of the hadron momentum along the jet axis and E is its energy. Select jets where the leading (largest y_J) two (or four) hadrons have $\Sigma Q = 0$ and where they are followed by a rapidity gap in y_J exceeding 2 or 3 units. Study the effective mass spectra. We have to assume they are pions, unless we have identified e.g. K^o_S or ϕ.

F. Single Diffractive Dissociation (SDE)

In Run IIA we have the roman pots on the $\bar{p}$ arm (with $\sigma_x \approx \sigma_y \approx 100\mu$m) together with the Beam Shower Counters (BSC) and Miniplugs, and we will learn much about high mass SDE with them. We cannot now predict what will be the interesting questions in 2004, and we cannot claim that the better resolution of the proposed spectrometers will be important. There are however some small cross section processes where we will most probably want more data (using the ability to use bunch crossings with several interactions). Diffractive $W^{\pm}$ and Z° production, the cross sections of which are about 1% of the total production, is an example. Per fb^{-1} about 50,000 $W^{\pm} \rightarrow e\nu$ and $\mu\nu$ events and 5000 $Z \rightarrow e^+e^-$ and $\mu^+\mu^-$ should be produced diffractively, and the acceptance of the combination of forward spectrometer and CDF central detector will be large.

VII. TRIGGERS

This is a very rich physics program and we would like a powerful trigger system to make optimum use of the luminosity with minimum impact on the rest of the CDF program. To do this we propose a fast trigger processor working at Level 1.

Prompt signals come from the solid Cerenkov counters and from the silicon strip detectors (a fast OR from each layer). An "arm" trigger will be a coincidence between the Cerenkov and a majority ($\geq$6/8) of the strip detectors. This ensures a track passed through the front and back detectors, but allows for inefficiencies.

The next stage of the trigger, still at Level 1, is to compute the tracks : $x_1, y_1, \frac{dx}{dz}, \frac{dy}{dz}$. We have four arms : NE, SE, NW, SW. The OR of these will provide the one arm trigger for SDE studies, put in coincidence at Level 1 with central requirements, and also simply prescaled without other requisites. The 2-arm trigger will be based on (NE + SE) * (NW + SW). A trigger processor will calculate the missing mass MM using $x_1, y_1, \frac{dx}{dz}, \frac{dy}{dz}$ on each arm and the vertex z_o from $(t_E - t_W)$. Different ranges of MM will be separately prescalable, and put in combination with other requirements at Levels 2 and 3. Central requirements will be a combination of jets (including hadronic τ decay), e's and μ's, γ's, $\not\!\!E_T$, and also *nothing* $\emptyset$ visible on the interaction point (from FTCD-TOF). In the latter case elastic scattering will be separated out using Δt and $\Delta\phi$ cuts. Inelastic events $p\bar{p} \rightarrow p\emptyset\ \bar{p}$ will be especially interesting, in combination with no significant signals in all the calorimetry and the CLC and BSC. We do not yet have rate estimates for all the various triggers that we propose. We can live within a specified bandwidth by prescaling, but will not compromise on the 110 - 180 GeV^2 Higgs search. We suggest that an incremental data rate (to tape) of *at least* 5 s^{-1} should be allowed for this program. (Incremental, because some of the events will be triggered on anyway, and we will read out our detectors for *every* CDF event.) Note that the elastic and low mass events will be very small.

VIII. TIMESCALE

At present, assuming a few month shut-down starting in late 2003, we foresee the following schedule:

• December 15th 2000: This proposal to CDF.

• Jan - Mar 2001 Choice of technique and geometry (roman pots (detectors in air) or microstations (detectors in vacuum)), size and shape of detectors. Definition of modifications to Tevatron.

• March 15th 2001: We would like approval by CDF.

• March 20th 2001: Proposal to PAC for April 20th Meeting.

• Jan - Oct 2001: Technical design of detectors and vacuum vessels. Tracking, acceptance and resolution calculations. Monte Carlo study of acceptances with different final states.

• November 2001: Final approval by PAC if not given earlier.

• 2002 - mid 2003 Construction of detectors and all hardware (including mechanics for vacuum system, BPM's, electronics for DAQ and trigger).

• Second half 2003: Beam tests of final detectors, alignment.

• End 2003, or whenever "6-month" shutdown between Runs IIA and IIB occurs, removal of Q1 quadrupoles, displacement of dipoles to create warm bypass. Installation of detectors in Tevatron.

• 2004, beginning of Run IIB, beam commissioning, trigger tests, and data.

• Note that, like all Tevatron Higgs and SUSY searches, we want the maximum integrated luminosity before the LHC becomes more sensitive than the Tevatron. We note that there are plans for a Proton Driver to increase the proton intensities at Fermilab, but that there is a risk of this being too late to be useful for the Tevatron. We believe [66] that it might be available by 2005 given the right funding profile and priority. We ask that a speeding up of this project be given serious and urgent consideration.

IX. COSTS

At this stage we do not give cost estimates, but we believe that the total for the project should be less than $ 0.8 M. A cost estimate will be given for the April PAC meeting.

• Modifications to the Tevatron : removal of Q1 quadrupoles, translation of A48-3, A48-4, A48-5, and B11-2, B11-3, B11-4 dipoles, new warm sections on remote (from BØ) side of A48-3 and B11-4 for placement of detectors. Lateral adjustment of Q2, Q3, Q4 and ES separators as necessary. It is expected that CDF will need to be displaced radially outwards (i.e away from the center of the Tevatron) by a few cm with respect to its Run IIA position.

• Silicon detectors : sensors, preamps, electronics/DAQ. Four telescopes of eight planes each, (+ four spare planes) area about 60 mm $\times$ 30 mm. Number of channels

$\approx$ 80,000.

- Four Time of Flight/trigger counters (quartz or MF_2 Cerenkov counters) (+ one spare) about 60 mm $\times$ 30 mm.
- Cables from detector stations to BØ .
- Trigger electronics, with special Level 1 MM processor.
- Detector stations, including motors, position sensors, slow controls, precision position read out. These could be built at Fermilab (BD), Helsinki or by a collaboration between both.
- Two quadrupole beam position monitors. We will ask the Beams Division to provide these. The beam diagnostics they provide will also be useful for Tevatron operations.

X. PEOPLE

A few of the people who have signed this proposal are not yet members (or not full members) of CDF. Those who are Fermilab but not full members of CDF should be on all physics publications resulting from this proposal (as was the case for C. Moore for the Run IC roman pot physics). R. Orava and the Helsinki Group will put in a bid to join CDF, with contributions to this project to satisfy entrance requirements. They are proposing similar forward detectors for ATLAS. The Liverpool CDF group have expertise and capabilities in $r-\phi$ silicon strip detectors for LHCB, which appear to be very suitable. They also have a Monte Carlo Array Processor MAP Farm [67] of 300 400MHz PC's operating under LINUX which can do large volumes of Monte Carlo programming and eventually data analysis. This project will be an integral part of CDF and we will welcome additional participation.

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Appendix : Run IIA Studies

There are many relevant studies that will be done already in Run IIA [11]. CDF will have one dipole spectrometer arm, new calorimetry (Miniplug) to $|\eta| \approx 5.5$ and "Beam Shower Counters" (BSC) covering approximately $5.5 < |\eta| < 7.5$.

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 [30]. Using the existing pot spectrometer and the rapidity gap technique we can measure what fraction of these dijets are from single diffraction and what fraction are from $D\mathbb{P}E$, as a function of $M_{b\bar{b}}$. What is the angular distribution of the b-jets in the $D\mathbb{P}E$ case? This studies the background in the $H \rightarrow b\bar{b}$ search; but note that the fraction of Higgs bosons that are produced exclusively may be higher than the fraction of all QCD $b\bar{b}$ dijets. Is the ratio $\frac{b-jet}{jet} \approx 3.10^{-4}$ in $D\mathbb{P}E$ as predicted?

2) Measure the l^+l^- ($l = e, \mu, \tau$) mass spectrum in the region of $M_{l^+l^-}$ 20-180 GeV, with and without $\not{E}_T$, 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 Drell-Yan, Z, W^+W^- and generic (non-$D\mathbb{P}E$) Higgs production with leptonic decay? The exclusive $D\mathbb{P}E$ 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 $D\mathbb{P}E$ 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 exclusive low mass systems X using the double rapidity gap technique $p\bar{p} \rightarrow +X+$. This can be done using a multiplicity count in the TOF barrel in the Level 1 trigger, together with a beam crossing and forward vetos. A separate CDFNOTE is in preparation [68] describing the $+X+$ proposal for Run IIA.

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