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HIGGS BOSON PRODUCTION IN P-$\overline{P}$ COLLISIONS AT COLLIDER ENERGIES

by

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ABSTRACT

We show that the contribution of gluon fusion to Higgs boson production in proton-antiproton collisions is much smaller than what has been predicted before for large Higgs masses.

The p-$\bar{p}$ colliders at CERN ($\sqrt{s}$ = 540 GeV) and at FERMILAB ($\sqrt{s}$ = 2 TeV) will open another possibility for the production of the Higgs boson, which is an essential ingredient of the Weinberg-Salam model(1).

The most important contribution for the Higgs boson production in p-$\bar{p}$ collisions comes from gluon fusion, via a quark loop (Fig. 1). This process was suggested by Georgi, Glashow, Machacek and Nanopoulos(2) in the study of proton-proton collisions. However, as we will show, their estimate is over optimistic, especially in the case of heavy Higgs bosons.

The rapidity distribution for the process of figure 1, in the framework of Drell-Yan mechanism(3), at $y=0$, is given by:

$$\left.\frac{d\sigma}{dy}\right|_{y=0} = \frac{\sqrt{2}\, G_F\, \alpha_s^2}{576\pi}\, N^2(\beta)\; \tau\; G^2(\sqrt{\tau}) \qquad (1)$$

where $G(x)$ is the gluon distribution function in the proton (antiproton), evaluated at $\sqrt{\tau} = M_H/\sqrt{s}$, and $N^2(\beta)$ is defined by:

$$N^2(\beta) \equiv \left|3 \sum_q I_q(\beta)\right|^2 = \left|3 \sum_q \int_0^1 dx \int_0^{1-x} dy\, \frac{(1-4xy)}{(1-\frac{xy}{\beta})}\right|^2 \qquad (2)$$

and β is the ratio:

$$\beta = \frac{m_q^2}{M_H^2} \qquad (3)$$

The summation in (2) is done over all flavors of quarks running in the fermion loop.

The integral that appears in (2) can be evaluated, and for $\beta < 1/4$ it has a real and an imaginary part:

$$I_q(\beta) = 2\beta - (1-4\beta)\beta \left[\int_0^{1/x_+} dx\, \frac{\ell n|1-x|}{x} + \int_0^{1/x_-} dx\, \frac{\ell n|1-x|}{x}\right] -$$

$$- i\pi(1-4\beta)\beta\ \ell n \left[\frac{1+\sqrt{1-4\beta}}{1-\sqrt{1-4\beta}}\right] \quad ; \quad \beta < 1/4 \qquad (4)$$

where $x_\pm$ are the roots of:

$$(1-x) = \frac{\beta}{x}$$

and the integrals involving logarithms must be calculated numerically.

Otherwise, for $\beta \geq 1/4$, $I_q(\beta)$ has only

a real part that can be expressed by the summation:

$$I_q(\beta) = 2\beta + (1-4\beta)\beta \sum_{n=1}^{\infty} \frac{[(n-1)!]^2}{(2n)!\,\beta^n} \quad ; \quad \beta \geq 1/4 \qquad (5)$$

Figure (2) shows the behavior of $\mathrm{Re}[I_q(\beta)]$, $-\mathrm{Im}[I_q(\beta)]$ and $|I_q(\beta)|$ as a function of β , and figure (3) gives $N^2(\beta)$ as a function of the Higgs boson mass (M_H).

We have used for the Higgs mass, values in the range:

$$6.5\ \text{GeV} < M_H < 300\ \text{GeV}$$

in agreement with lower and upper bounds that have been established by Weinberg(4) and Veltman(5). For the current-algebra masses of the quarks, we have assumed the following values(6):

m_u = 3.0 MeV	m_c = 1.3 GeV
m_d = 6.3 MeV	m_b = 5.0 GeV
m_s = 150 MeV	m_t = 18 GeV

The mass of the hypothetical top quark is quite arbitrary, but it does not alter our results in a significant way.

The graph of $|I_q(\beta)|$ (Fig. 2) exhibites a maximum at $\beta \cong 0.16$ and tends asymptoticaly to 1/3 as β tends to infinite. For $\beta \gtrsim 0.04$, $I_q(\beta)$ is always larger than 1/3. On the other hand, $N^2(\beta)$ (Fig. 3) has a maximum for all values of the Higgs boson mass satisfying: $M_H \cong 2.5\ m_q$ and decreases as M_H increases.

In the evaluation of Georgi, Glashow, Machacek and Nanopoulos, they took into account only quarks with masses satisfying the condition:

$$\beta \equiv \frac{m_q^2}{M_H^2} \gtrsim 1/25$$

and they assumed that the integral $I_q(\beta)$ contributes with approximately 1/3 for each heavy flavor (c, b, t) running in the loop, and accordingly $N^2 \equiv 9$, independently of the Higgs boson mass. However, this approximation is valid only if $M_H \leqslant 5\ m_c = 6.5$ GeV, which is the lower bound for the Higgs boson mass. Then, this procedure is not acceptable in the case of a heavy Higgs boson (or, small values of β), as we can see from figure 3. For example, when $M_H \cong 100$ GeV, we have $N^2(\beta) \cong 0.78$ which is more than an order of magnitude smaller than what

would be expected by the estimate of Georgi et al.. If we consider a Higgs boson as heavy as 300 GeV, the value of $N^2(\beta)$ falls to 3.8×10^{-2}, and the respective cross section is only 0.4% of what would be expected by them.

In order to verify the sensitivity of the cross section on possible parametrizations of the gluon distribution function[7], we consider, besides the standard distribution:

$$G_2(x) = 3.30\ \frac{(1-x)^5}{x} \qquad (6)$$

an alternative broad distribution:

$$G_1(x) = 1.10\ \frac{(1+9x)(1-4x)^4}{x} \qquad (7)$$

and a narrow one:

$$G_3(x) = 0.74\ \frac{(1-x)^5}{x^{3/2}} \qquad (8)$$

The rapidity distribution at $y=0$ for the process of gluon fusion versus M_H, at the energies of 540 and 2000 GeV are shown in figures 4 and 5, for each gluon distribution function.

If we consider the luminosity of the CERN and FERMILAB $p-\bar{p}$ colliders,

$$L \cong 10^{30} cm^{-2} sec^{-1} \cong 8.6 \times 10^{-2} pb^{-1} (day)^{-1}$$

we can see that if we want to have at least one event per day, only a Higgs boson with mass less than ~20 GeV may be observable in the case of the standard gluon distribution function (the other two distributions do not alter this value in a significant way).

If we take into consideration the poor signature of this process[8], besides the smallness of the cross section, we can therefore conclude that the possibilities of detection of the Higgs boson in the future generation of $p-\bar{p}$ colliders are very remote.

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REFERENCES

(1) S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967); A. Salam, in Elementary Particle Theory (Nobel Symposium 8) edited by N. Svartholm (Almquist and Wiksell, Stockholm, 1968), p. 367.

(2) H.M. Georgi, S.L. Glashow, M.E. Machacek and D.V. Nanopoulos, Phys. Rev. Lett. 40, 692 (1978).

(3) S.D. Drell and T.M. Yan, Phys. Rev. Lett. 25, 316 (1970) and Ann. of Phys. 66, 578 (1971).

(4) S. Weinberg, Phys. Rev. Lett. 36, 294 (1976).

(5) M. Veltman, Acta Phys. Pol. B8, 475 (1977) and Phys. Lett. 70B, 253 (1977).

(6) See for example: J. Gasser and H. Leutwyler, Phys. Rep. 87, 77 (1982).

(7) C.E. Carlson and P. Hoyer, Nucl. Phys. B193, 109 (1981).

(8) L.-L. Chau, W.-Y. Keung and S.C.C. Ting, Phys. Rev. D24, 2862 (1981).

FIGURE CAPTIONS

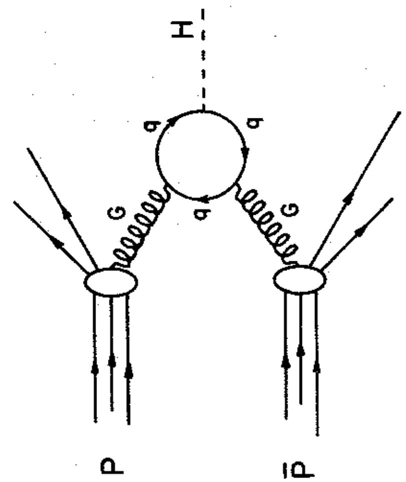
FIG. 1 - Dominant contribution to $p + \bar{p} \to H + x$.

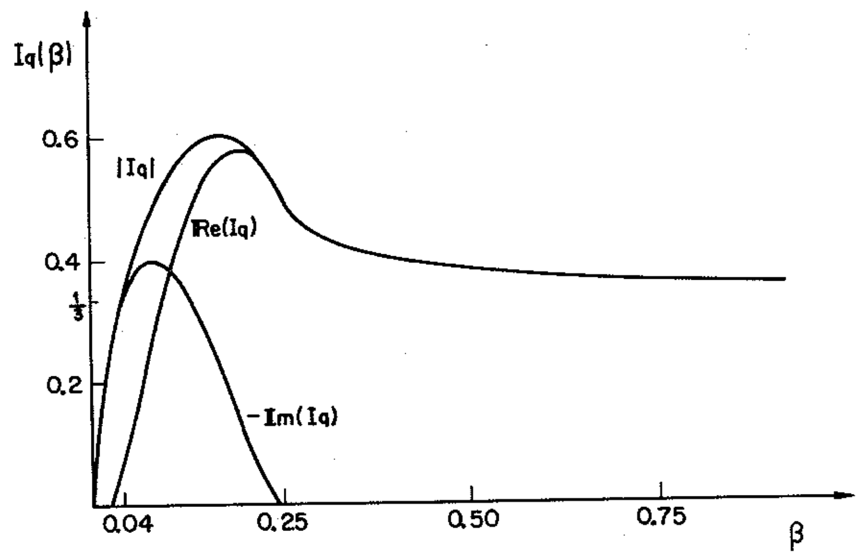
FIG. 2 - The real and imaginary part of the integral $I_q(\beta)$.

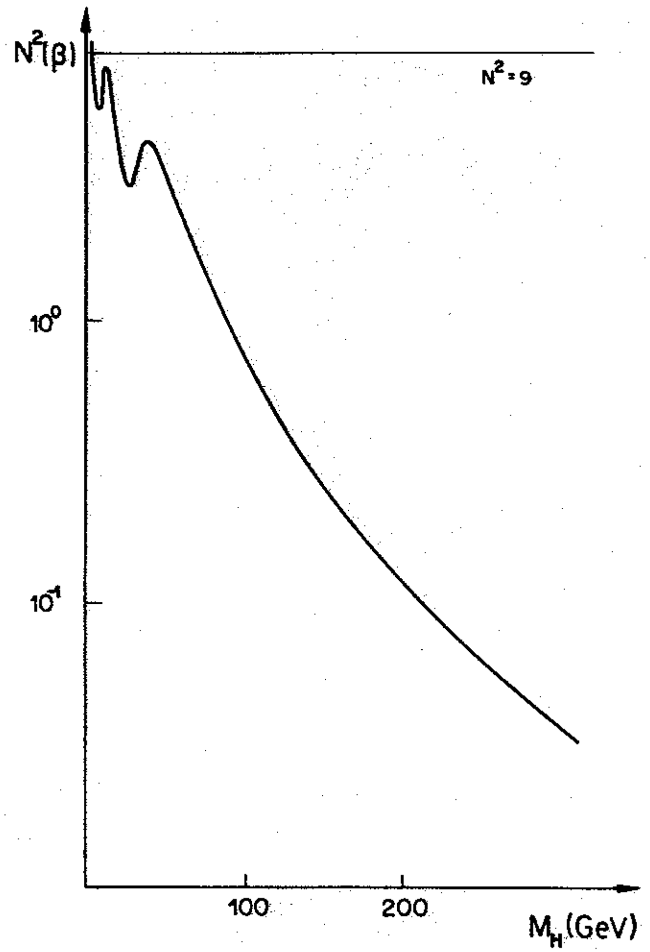
FIG. 3 - $N^2(\beta)$ as a function of the Higgs boson mass.

FIG. 4 - Cross section for gluon fusion at $\sqrt{s}$ = 540 GeV versus the Higgs boson mass. G_1, G_2 and G_3 are given by eq. (6), (7) and (8).

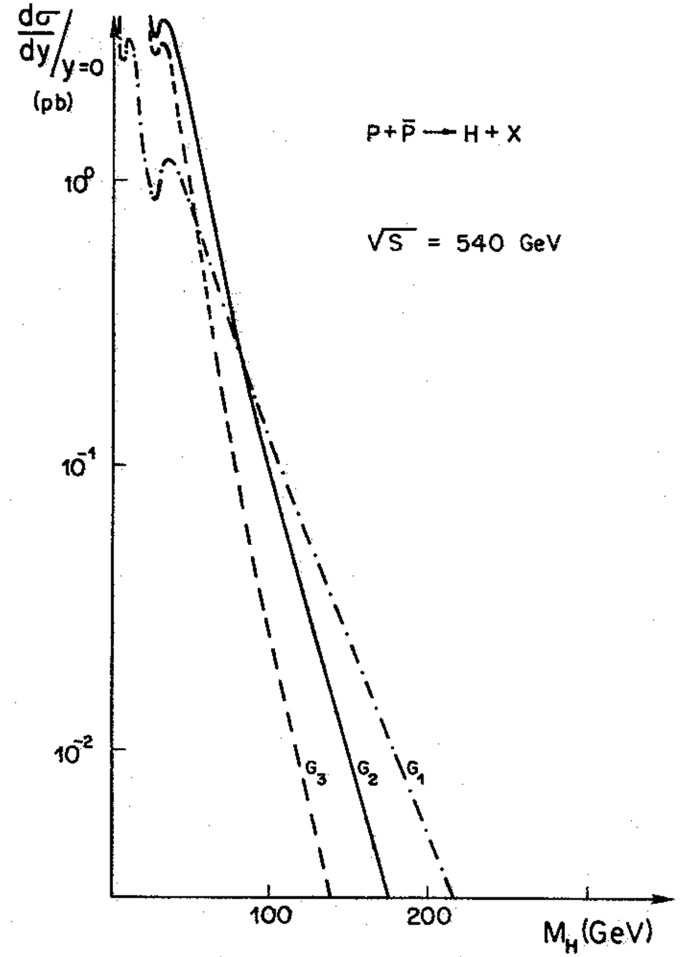
FIG. 5 - Cross section for gluon fusion at $\sqrt{s}$ = 2000 GeV versus the Higgs boson mass. G_1, G_2 and G_3 are given by eq. (6), (7) and (8).



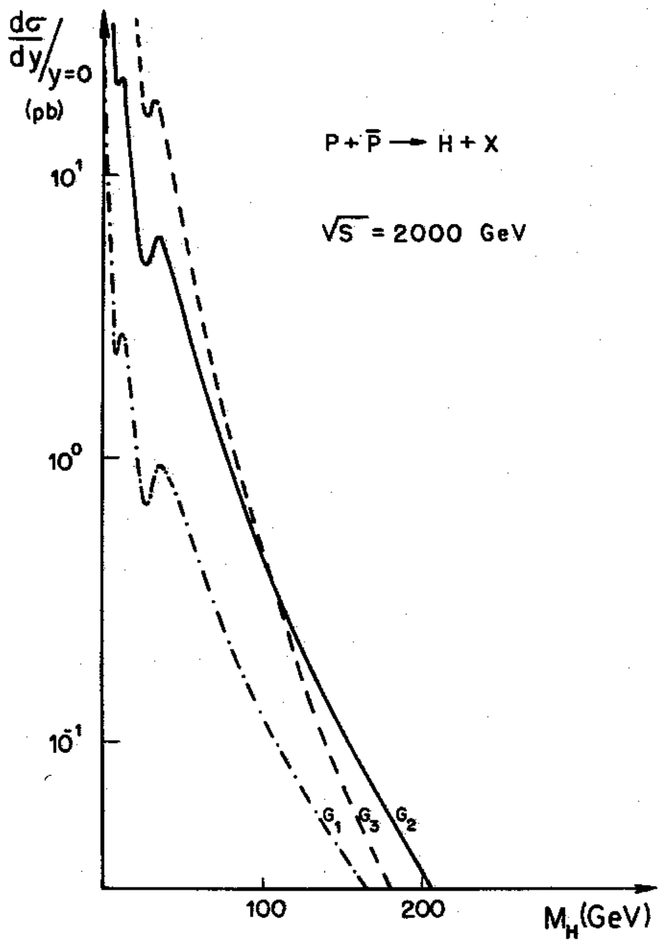




N²(β)
N² = 9
10⁰
10⁻¹
100
200
M_H (GeV)



dσ/dy |y=0 (pb)
P + P̄ → H + X
√S = 540 GeV
10⁰
10⁻¹
10⁻²
G3
G2
G1
100
200
M_H (GeV)



dσ/dy |y=0
(pb)
10¹
10⁰
10⁻¹
P + P̄ → H + X
√S = 2000 GeV
G1
G3
G2
100
200
M_H (GeV)