We propose a novel mechanism for exclusive diffractive Higgs production $pp \rightarrow Hpp$, in which the Higgs carries a significant fraction of the projectile proton’s momentum. This mechanism will then provide a clear experimental signal for Higgs production, due to the small background in this kinematic region. The key assumption underlying our analysis is the presence of intrinsic charm (IC) and intrinsic bottom (IB) fluctuations in the proton bound state, whose existence, at high light-cone momentum fraction $x$, has a substantial and growing experimental and theoretical support.

1. Introduction

A central goal of the Large Hadron Collider (LHC) being built at CERN is the discovery of the Higgs boson, a key component of the Standard Model, and whose discovery would also constitute the first observation of an elementary scalar field. A number of theoretical analyses suggest the existence of a light Higgs boson with a mass $M_H \lesssim 130$ GeV. Perhaps the most novel production process for the Higgs is the exclusive exclusive diffractive reaction, $pp \rightarrow p + H + p$, where the + sign stands for a large rapidity gap (LRG) between the produced particles. If both protons are detected, the mass and momentum distribution of the Higgs can be determined.

The TOTEM detector proposed for the LHC will have the capability to detect exclusive diffractive channels.

The detection of the Higgs via the exclusive diffractive process $pp \rightarrow p + H + p$, has the advantage that it does not depend on a specific decay mechanism for the Higgs. The branching ratios for the decay modes of the Higgs can then be individually determined by combining the measurement of $\sigma(pp \rightarrow p + H + p)$ with the rate for a specific exclusive diffractive final states $B_f \sigma(pp \rightarrow p + H_{\rightarrow f} + p)$. This is in contrast to the standard inclusive measurement where one can only determine the product of the cross section and branching ratios $B_f \sigma(pp \rightarrow H_{\rightarrow f}X)$.

The existing theoretical estimates for exclusive diffractive Higgs production are based on the gluon-gluon fusion subprocess, where two hard gluons couple to the Higgs ($gg \rightarrow H$). A third gluon is also exchanged in order that both projectiles
remain color singlets. Perturbative QCD then predicts \( \sigma(pp \rightarrow p + H + p) \approx 3 \text{ fb} \) for the production of a Higgs boson of mass 120 GeV at LHC energies, with a factor of 2 uncertainty. Since the annihilating gluons each carry a small fraction of the momentum of the proton, the Higgs is primarily produced in the central rapidity region.

In a recent work, we proposed a novel mechanism for exclusive diffractive Higgs production in which the Higgs is produced with a significant fraction of the projectile’s momentum. The key assumption underlying our analysis is the presence of intrinsic charm (IC) and intrinsic bottom (IB) fluctuations in the proton bound state, whose existence at high \( x \) has a substantial and growing experimental and theoretical support. The virtual Fock state \(|uudQ\bar{Q}\rangle\) of one of the incident protons has a long lifetime at high energies and can be materialized in the collision by the exchange of gluons. The heavy quark and antiquark from the same projectile then coalesce to produce the Higgs boson at large \( x_F \).

It was originally suggested in Ref. [4,5] that there is a \( \sim 1\% \) probability of IC Fock states in the nucleon; more recently, the operator product expansion has been used to show that the probability for Fock states in light hadron to have an extra heavy quark pair of mass \( M_Q \) decreases only as \( \Lambda_{QCD}^2/M_Q^2 \) in a non-Abelian gauge theory. In the case of Abelian QED, the probability of an intrinsic heavy lepton pair in a light-atom such as positronium is suppressed by \( \mu_{\text{bohr}}/M_\ell^4 \) where \( \mu_{\text{bohr}} \) is the Bohr momentum. The quartic QED scaling corresponds to the dimension-8 Euler-Heisenberg effective Hamiltonian \( F^4/M_\ell^4 \) for light-by light scattering mediated by heavy leptons. Here \( F_{\mu\nu} \) is the electromagnetic field strength. In contrast, the corresponding effective Hamiltonian in QCD \( G^3/M_Q^2 \) has dimension 6. The maximal probability for an intrinsic heavy quark Fock state occurs for minimal off-shellness; i.e., at minimum invariant mass squared \( M^2 = \sum_{i=3}^{n}(m_i^2 + k_{i,\perp}^2)/x_i \). Thus the dominant Fock state configuration is \( x_i \propto m_{\perp i} \) where \( m_{\perp i}^2 = m_i^2 + k_{i,\perp}^2 \); i.e., at equal rapidity. Since all of the quarks tend to travel coherently at same rapidity in the \(|uudQ\bar{Q}\rangle \) intrinsic heavy quark Fock state, the heaviest constituents carry the most momentum.

2. Experimental Evidence for Intrinsic Charm

The most direct test of intrinsic charm is the measurement of the charm quark distribution \( c(x, Q^2) \) in deep inelastic scattering \( \ell p \rightarrow \ell' cX \). The only experiment which has looked for a charm signal at large \( x_{bj} \) is the European Muon Collaboration (EMC) experiment, which used prompt muon decay in deep inelastic muon-proton scattering to tag the produced charm quark. The EMC data show a distinct excess of events in the charm quark distribution at \( x_{bj} > 0.3 \), at a rate at least an order of magnitude beyond lowest predictions based on gluon splitting and DGLAP evolution. More recent next-to-leading order (NLO) analyses show that an intrinsic charm component, with probability of order 1%, is needed to fit the EMC data in the large \( x_{bj} \) region.
The existence of the rare double IC Fock state such as $|uud\bar{c}\bar{c}\rangle$ leads to the production of two $J/\psi$'s or a double-charm baryon state at large $x_F$ and small $p_T$. Double $J/\psi$ events at a high combined $x_F \geq 0.8$ were in fact observed by NA3 [10]. The observation of the doubly-charmed baryon $\Xi_{cc}^+(3520)$ has been confirmed recently by SELEX at FNAL [11]; the presence of two charm quarks at large $x_F$ has, indeed, a natural IC interpretation.

3. Higgs Production

We will now explain, using Fig. 1, how the exclusive diffractive production arises with the required color structure in the final state. As noted above, the IC Fock state of the projectile (upper) proton has a 1% probability to fluctuate to the state with the color structure $|uud\bar{c}\bar{c}\rangle$. It has a long coherence length in a high energy collision $\propto s/M^2m_p$, where $M$ is the total invariant final mass, which is much larger than the initial mass. In a $pp$ collision, two soft gluons must be exchanged in order to keep the target (lower) proton intact and to create a rapidity gap. The two gluons will couple from the target to the large color dipole moment of the projectile IC Fock state. For example, as shown in Fig. 1, one gluon can be attached to the $d$ valence quark spectator in $|uud\bar{c}\bar{c}\rangle$, changing its color, and the other one can be attached to the $\bar{c}$, changing also its color. The net effect of this color rearrangement is the same as a single gluon exchange between the two color-octet clusters. The $\bar{c}$ and the $uud$ thus can emerge as color singlet because of the gluonic exchange. The $[\bar{c}c]_{1c}$ now can couple to the $J/\psi$ color singlet, or to a $Z$ or to a $H$. Meanwhile the color-singlet $uud$ gives rise to the scattered proton, and we have the two required rapidity gaps in the final state. Notice that the $x_F$ distribution of the produced particle is approximately the same as the distribution of the $[\bar{c}c]$ inside the

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*Additional relevant experimental facts are listed in Ref. [3]
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proton. Unfortunately the coupling of the gluon to all the different quarks brings in a form factor which vanishes at zero momentum transfer, and which therefore gives an important suppression factor.

The cross section of exclusive diffractive production of the Higgs, \( pp \to ppH \), can be estimate in two-gluon approximation in accordance with the Feynman graph shown in Fig. 1. Here we assume the presence in the proton of an intrinsic charm (IC) component, a \( \bar{c}c \) pair which is predominantly in a color-octet state, and which has a nonperturbative origin and mixes in the proton with the 3\( q \) valence quark component. Correspondingly, like in charmonium, the mean \( \bar{c}c \) separation should be much larger than the size \( 1/m_c \) of perturbative \( \bar{c}c \) fluctuations. In Fig. 1, \( \Psi \) denotes the light-cone wave function of the IC component of the initial proton, properly normalized, \( H \) is the wave function of the color singlet \([\bar{c}c]_{1C}\) in the produced Higgs and \( \Phi \) stands for the wave function of the final proton \( p_1 \). The details and different aspects (energy dependence, absorbive corrections, etc. . .) of the calculation will be reported in Ref. [3], but we anticipate that the final result will turn out to be rather small. Various possibilities to get a larger cross section will be also discussed, in particular, heavy flavors contribution or nuclear enhancement.

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References

1. A. De Roeck, V. A. Khoze, A. D. Martin, R. Orava and M. G. Ryskin, Eur. Phys. J. C25, 391 (2002), and references therein.
2. TOTEM Collaboration, M. Diele, arXiv:hep-ex/0410084.
3. S. J. Brodsky, B. Kopeliovich, I. Schmidt and J. Soffer, in preparation.
4. S. J. Brodsky, C. Peterson and N. Sakai, Phys. Rev. D23, 2745 (1981).
5. S. J. Brodsky, P. Hoyer, C. Peterson and N. Sakai, Phys. Lett. B93, 451 (1980).
6. M. Franz, M. V. Polyakov and K. Goeke, Phys. Rev. D62, 074024 (2000) [arXiv:hep-ph/0002240]. See also: S. J. Brodsky, J. C. Collins, S. D. Ellis, J. F. Gunion and A. H. Mueller, DOE/ER/40048-21 P4 Submitted to Proc. of 1984 Summer Study on the SSC, Snowmass, CO, Jun 23 - Jul 13, 1984.
7. European Muon Collaboration, J. J. Aubert et al., Nucl. Phys. B213, 31 (1983).
8. B. W. Harris, J. Smith and R. Vogt, Nucl. Phys. B461, 181 (1996).
9. R. Vogt and S.J. Brodsky, Phys. Lett. B349, 569 (1995).
10. NA3 Collaboration, J. Badier et al., Phys. Lett. B114, 457 (1982).
11. SELEX Collaboration, A. Ocherashvili et al., arXiv:hep-ex/0406033.