Diffractive Higgs production in Peripheral Collisions

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work with M.B. Gay Ducati [PRD 78 (2008) 113005]
Motivations

- The Large Hadron Collider will allow to study a new kinematic regime never reached
  - CM energy: $E_{pp} = 14 \text{ TeV}$, $E_{pA} = 8.8 \text{ TeV}$, $E_{AA} = 5.5 \text{ TeV}$
  - Bjorken-$x$: $x \lesssim 10^{-4} - 10^{-5}$
  - Rapidity (CMS): $|\eta_{jets}| < 6.6$, $|\eta_{\gamma,e^\pm}| < 3$ and $|\eta_{\mu}| < 2.5$.
  - Higgs physics: the $pp$ collisions would be able to produce the Higgs boson at LHC.

- Collisions will occur with no strong interaction in LHC
  - The Peripheral Collisions are a new way to study the Higgs boson production in $pp$ and $AA$ collisions.

- DPE allows to study the diffractive Higgs production at low-$x$
  - DPE enables the Higgs boson production by the leading $ggH$ vertex mainly in the mass range $M_H = 100 - 200 \text{ GeV}$. 
Diffractive Higgs production in \( pp \) and \( AA \) collisions

- **1991**: Bialas and Landshoff
  - Regge Theory \(\rightarrow\) non-perturbative gluons
- **1997**: Khoze, Martin and Ryskin
  - Levin and Miller
- QCD Pomeron \(\rightarrow\) hard-gluon exchange

\[ \sqrt{s} = 16 \text{ TeV} \]

-**BL**: \( \sigma_{pp} = 0.1 \text{ pb} \)
-**KMR**: \( \sigma_{pp}^{\text{exc/inc}} \sim 1 \text{ fb}/300 \text{ fb} \)
-**LM**: \( \sigma_{pA(AA)} = 100 (3.9) \text{ pb} \)

-**H**: Higgs boson
-**IP**: Invariant Plane
Diffractive Higgs photoproduction

**Proposal:** Apply the DPE to the DVCS in $pp$ collision.

For a not too heavy Higgs ($M_H \lesssim 200$ GeV), the $ggH$ vertex reads

$$V_{\mu\nu}^{ab} \approx \frac{2}{3} \frac{M_H^2 \alpha_s}{4\pi V} \left( g_{\mu\nu} - \frac{k_{2\mu} k_{1\nu}}{k_1 \cdot k_2} \right) \delta^{ab}$$
Scattering amplitude

- **Partonic process**: $\gamma q \rightarrow \gamma + H + q$

\[
\begin{align*}
\gamma(q^{\mu}) & \rightarrow \gamma(q^{\mu}) \\
\bar{q}(q^{\mu} - \ell^{\mu}) & \rightarrow \bar{q}(q^{\mu} - \ell^{\mu}) \\
g(k^{\mu}) & \rightarrow g(k^{\mu}) \\
q(p^{\mu}) & \rightarrow q(p^{\mu})
\end{align*}
\]

- The scattering amplitude is obtained by the **Cutkosky rules**

\[
\text{Im } \mathcal{A} = \frac{1}{2} \int d(PS) \mathcal{A}_{(left)} \mathcal{A}_{(right)} = \frac{20M_H^2}{9} \frac{\alpha_s^2 \alpha_s}{N_c \nu} \sum_q e_q^2 \left( \frac{\alpha_s}{\pi} \right) \int \frac{d\vec{k}^2}{\vec{k}^6} \mathcal{X}(k^2, Q^2)
\]

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Cross section for central rapidity

The cross section is calculated for central production ($y_H = 0$)

$$\left. \frac{d\sigma}{dy_H dt} \right|_{y_H,t=0} = \frac{S_{\text{gap}}^2}{2\pi B} \left( \frac{\alpha_s^2 \alpha M_H^2}{3N_c \pi v} \right)^2 \left( \sum_q e_q^2 \right)^2 \left[ \int_{k_0^2}^\infty \frac{d k^2}{k^6} \right] e^{-S(k^2, M_H^2)} f_g(x, k^2) \chi(k^2, Q^2)$$

* Quark contribution\(^1\): $\frac{\alpha_s \, C_F}{\pi} \rightarrow f_g(x, k^2) = \mathcal{K} \partial_{(\ell n \, k^2)} xg(x, k^2)$

* Gap Survival Probability\(^2\): $S_{\text{gap}}^2 \rightarrow 3\% \ (5\%)$ for LHC (Tevatron)

* Gluon radiation suppression\(^3\): Sudakov factor $S(k^2, M_H^2) \sim \ell n^2 \left(\frac{M_H^2}{4k^2}\right)$

* Cutoff $k_0^2$: In order to avoid infrared divergencies :: $k_0^2 = 1 \text{ GeV}^2$

* Electroweak vacuum expectation value: $v = 246 \text{ GeV}$

* Slope of the gluon-proton form factor: $B = 5.5 \text{ GeV}^{-2}$

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\(^1\)Khoze, Martin, Ryskin, EJPC 14 (2000) 525

\(^2\)Khoze, Martin, Ryskin, EJPC 18 (2000) 167

\(^3\)Forshaw, hep-ph/0508274
Results: \( pp \) vs. \( \gamma p \) process

- **Higher** rate in the mass region expected for Higgs detection.
Results: Gluon distribution functions

- **Tevatron**: Distinct behaviors for the LO and NLO distributions;
  - Leading contribution \( \begin{cases} \text{NLO} & \rightarrow M_H \lesssim 200 \text{ GeV} \\ \text{LO} & \rightarrow M_H \gtrsim 400 \text{ GeV} \end{cases} \)

- **LHC**: NLO distributions show a higher contribution than the LO ones.
Results: $Q^2$-dependence

- Peripheral Collisions: photon limit of $Q^2 = 0.04$ GeV$^2$
- **Divergent region**: highest cross section for Higgs production
- Perturbative region: $Q^2 \sim 1$ GeV$^2$
- **Smaller event rate**: range expected to its detection $\sigma_{\text{exc}} \sim 3$ fb.

![Graph showing $d\sigma/dy_H dt$ vs $Q^2$]

- $E_{\text{LHC}} = 14$ TeV
- $k_0^2 = 1.0$ GeV$^2$
- $M_H = 140$ GeV
The photoproduction in Peripheral Collisions

- The $\gamma p$ process is a subprocess of **Peripheral pp Collisions**

- **Large impact parameter** $|\vec{b}| \gtrsim 2R_p$

  NO STRONG INTERACTION OCCURS!

- The hadronic cross section is given by

  $$\sigma^{pp} = 2 \int dk \frac{dn}{dk} \sigma^{\gamma p}$$

  and the **photon flux** in Peripheral $pp$ Collisions reads

  $$\frac{dn}{dk} = \frac{\alpha_{em}}{2\pi k} \left[ 1 + \left( 1 - \frac{2k}{\sqrt{s}} \right)^2 \right] \left( \ln A - \frac{11}{6} + \frac{3}{A} - \frac{3}{2A^2} + \frac{1}{3A^2} \right)$$

  where $A = 1 + (0.71 \text{ GeV}^2)/Q_{min}^2$ and $Q_{min}^2 \simeq k^2/\gamma_L^2$. 
Results: \textit{pp} cross section

$\sigma_{\gamma p} \propto$ Higgs mass $M_H$ (GeV)

$\frac{d\sigma}{dy} = \frac{d\sigma}{dt} = 0$

$E_{\text{LHC}} = 14$ TeV

$\frac{d\sigma}{dt} = 1.0$ GeV$^2$

\textbf{pp collisions}: The results have the \textbf{same} shape as the $\gamma p$ ones.
Summary

- We compute the event rate for Higgs boson production in $\gamma p$ and $pp$ processes in Peripheral Collisions at LHC.

- In the LHC kinematical regime, the results with NLO distributions are 15% higher than the LO ones.

  - It assigns the importance of the gluon recombination effects (if the non-perturbative effects are small).

- These results are three times less sensitive to the integration cuts if compared to the KMR approach.

  - The next step is to produce a comprehensive phenomenological analysis of the $pp$ collision.

- The $pp$ results show the robustness of this approach, which predicts an enhanced signal for the Higgs detection in LHC.