Higgs boson photoproduction at the LHC

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Outline

- Motivation
- Photoproduction approach
- Peripheral Collisions
- Photoproduction at the Tevatron and LHC
- Conclusions
Motivation

- LHC will allow to study a new kinematic region:
  - CM energy: \(14 \text{ TeV} \rightarrow 7\times \text{Tevatron energy}\)
  - Luminosity: \(10-100 \text{ fb}^{-1} \rightarrow \sim 10\times \text{Tevatron luminosity}\)
  - Higgs physics: low luminosity regime favorable to the Higgs boson production in diffractive processes.

- Some hadron-hadron collisions will occur with no strong interaction.
  - The Ultraperipheral Collisions (UPC) are a new way to study the Higgs boson production in hadronic collisions.

- Other processes of Higgs production are under study to allow its detection in hadron colliders.
  - DPE allows the Higgs boson production through the leading \(ggH\) vertex in the mass range \(M_H \sim 115 \sim 200 \text{ GeV}\).

- New evidences: considering the excluded mass ranges, we may explore the window mass

\[
115 \text{ GeV} < M_H < 160 \text{ GeV}
\]
New results from the Tevatron

► Excluded range: 


\[ 160 \text{ GeV} < M_H < 170 \text{ GeV} \]

► EW fits: 

\[ M_H = 116.3^{+15.6}_{-1.30} \text{ GeV} \]


![Graph showing 95% CL Limit/SM comparison between LEP Exclusion and Tevatron Exclusion, with SM curve and expected and observed limits marked.]
**Diffractive Higgs photoproduction**

- **Proposal:** $\gamma p$ process by DPE in $pp$ collision.

The loop is treated in **impact factor formalism** at $t = 0$. 

**Diagram:**
- **COLOR DIPOLE**
- **SCREENING GLUON**
- **EFFECTIVE VERTEX**
- **HIGGS VERTEX**
- **GLUON-GLUON FUSION**
- **NON-DIAGONAL PDF**
Scattering amplitude

► Partonic process: $\gamma q \rightarrow \gamma + H + q$

The scattering amplitude is obtained by the Cutkosky Rules

$$\text{Im } A = \frac{1}{2} \int d(PS)_3 \ A_{(\text{left})} A_{(\text{right})}$$
Applying the rules

- Performing the product of the two sides of the cut one gets

\[ \mathcal{A}_L \mathcal{A}_R = (4\pi)^3 \alpha_s^2 \alpha \left( \sum_q e_q^2 \right) \left( \frac{e_{\mu} e_{\nu}^*}{k^6} \right) \frac{V_{\sigma \eta}^{ba}}{N_c} (t^b t^a) \]

\[ \text{eikonal} \]

\[ \text{ggH} \]

\[ \text{4p}_\lambda p_\sigma \]

\[ \text{OTHER POSSIBILITIES} \]

- For a **not so heavy** Higgs \((M_H \lesssim 200\ \text{GeV})\), the \(ggH\) vertex reads

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

Plehn, 0910.4182[hep-ph]
The amplitude in parton level

- The imaginary part of the amplitude has the form

\[ \text{Im } A_s = - \frac{4}{9} \left( \frac{M_H^2 \alpha_s^2}{N_c \nu} \right) \left( \sum_q e_q^2 \right) \left( \frac{\alpha_s C_F}{\pi} \right) \int \frac{d k^2}{k^6} \chi(k^2, Q^2), \]

with

\[ \chi(k^2, Q^2) = \int_0^1 d \tau \int_0^1 d \rho \ \frac{k^2 [\tau^2 + (1 - \tau)^2] [\rho^2 + (1 - \rho)^2]}{Q^2 \rho(1 - \rho) + k^2 \tau(1 - \tau)}. \]

- First remark: dependence on \( k^{-6} \) due to the presence of the color dipole.

- Computing the event rate in central rapidity

\[ \left. \frac{d \sigma}{dy_H dp^2 dt} \right|_{y_H, t=0} = \frac{1}{2} \left( \frac{\alpha_s^2 \alpha M_H^2}{9 \pi^2 N_c \nu} \right) \left( \sum_q e_q^2 \right)^2 \left[ \frac{\alpha_s C_F}{\pi} \int \frac{d k^2}{k^6} \chi(k^2, Q^2) \right]^2. \]

- Quark → Proton: \( \alpha_s C_F / \pi \rightarrow f_g(x, k^2) = k \partial_{(\ln k^2)} x g(x, k^2) \).
Cross section for central rapidity
Gay Ducati and Silveira PRD 78 (2008) 113005

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

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

- Proton content\(^1\): $\alpha_s C_F / \pi \rightarrow f_g(x, k^2) = K \partial_{\ln k^2} xg(x, k^2)$
- Gap Survival Probability\(^2\): $S_{\text{gap}}^2 \rightarrow 3\% (5\%)$ for LHC (Tevatron)
- Gluon radiation suppression\(^3\): Sudakov factor $S(k^2, M_H^2) \sim \ln^2 \left( M_H^2 / 4k^2 \right)$
- Cutoff $k_0^2$: Necessary to avoid infrared divergencies :: $k_0^2 = 0.3 \text{ GeV}^2$
- Electroweak vacuum expectation value: $v = 246 \text{ GeV}$
- Gluon-proton form factor: $B = 5.5 \text{ GeV}^{-2}$

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\(^1\) Khoze, Martin, Ryskin, EPJC 14 (2000) 525
\(^2\) Khoze, Martin, Ryskin, EPJC 18 (2000) 167
\(^3\) Forshaw, hep-ph/0508274
Results: predictions for the $\gamma p$ process

- The predictions for different PDF’s are close in LHC
- **Tevatron**: restricted to $M_H < 140$ GeV (reason: $x > 0.01$)
Higgs production in UPC

- The $\gamma p$ process is a subprocess in Ultraperipheral $pp$ collisions

Hencken et al
Phys. Rept. 458 (2008) 1

- Impact parameter: $|\vec{b}| > 2R \rightarrow \text{NO STRONG INTERACTION!}$

- Only EM force acts in the second proton $\rightarrow \text{REAL PHOTONS}$
Hadronic cross section

- For $pp$ collisions, $\sigma_{\gamma p}$ is convoluted with the photon flux

$$\sigma(pp \rightarrow p + H + p) = 2 \int_{\omega_0}^{\infty} d\omega \frac{dn}{d\omega} \sigma_{\gamma p}(\omega, M_H),$$

where the photon flux is given by

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

for protons with $A \simeq 1 + (0.71 \text{ GeV}^{-2})\sqrt{s}/2\omega^2$, and

$$\frac{dn}{d\omega} = \frac{2Z^2\alpha_{em}}{\pi\omega} \left[ hK_0(h)K_1(h) - \frac{h^2}{2}[K_1^2(h) - K_0^2(h)] \right].$$

for nuclei with $h = 2R_A\omega/\gamma_L$.

- The photon virtuality can be written in terms of the $\omega$ and $q_\perp$

$$Q^2 = -\omega^2/(\gamma_L^2\beta_L^2) - q_\perp^2$$

with $\gamma_L = (1 - \beta_L^2)^{-1/2} = \sqrt{s}/2m_N$. 
Results: Higgs boson in Ultraperipheral $pp$ collisions

- Results similar to those from $\gamma\gamma$ process ($10^{-1}$ fb).

- Gap between the predictions for LHC with distinct parametrizations.

![Graph showing Higgs boson production in different processes.]

- $d\sigma_{pp}/dy_H|_{y_H=0}$ (fb)
- $\sigma_{pp}$ (fb)
- Higgs mass (GeV)

Legend:
- KMR
- Photoproduction
- MRST2001lo
- ALEKHIN2002lo
- CTEQ6
- MRST2002nlo
Results: Cutoff sensitivity

- The main contribution comes from the range $k_0^2 < 30 \text{ GeV}^2$.

- **Sensitivity**: almost the same behavior than the direct $pp$ process.
Results: $pA$ collisions

- $\sigma_{pAu} \sim 100$ fb: competitive with the Pomeron-Pomeron process;
- $\sigma_{pAu}$: 8x lower than $\gamma\gamma$ process with all bosons loops\(^4\);
- $\sigma_{pPb}$: 50% lower than $\gamma\gamma$ process by the Higgs Effective Field Theory\(^5\).

Gap Survival Probability

- The predicted cross section is lower than the direct $pp$ process;
- The Rapidity Gap Survival Probability (GSP) is not appropriated to the $\gamma p$ process (3% like KMR).

<table>
<thead>
<tr>
<th>Subprocess</th>
<th>GSP (%)</th>
<th>$\sigma_{pp}$ (fb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma\gamma$</td>
<td>100</td>
<td>0.1</td>
</tr>
<tr>
<td>$\gamma p$</td>
<td>3.0</td>
<td>$0.08$</td>
</tr>
<tr>
<td>$\gamma p$</td>
<td>0.4</td>
<td>0.47</td>
</tr>
<tr>
<td>$\gamma p$</td>
<td>2.3</td>
<td>2.7</td>
</tr>
</tbody>
</table>

- We expect that the GSP could be higher than 3% for the $\gamma p$ process;
- The next step is compute this probability in order to perform a reliable prediction of the cross section.
Conclusions

- We compute the event rate for **Higgs boson production** in UPC at LHC:
  \[ \sigma_{pp} \sim 0.1 \text{ fb} \quad \sigma_{pA} \sim 100 \text{ fb} \]

- This approach allows a comprehensive study in UPC (even with AA collisions, but more work);

- Low sensitivity to the input parameter: infrared region under control;

- Even predicting a lower cross section than other processes, a correct GSP can improve it, being competitive with those processes;

- The photoproduction results may be more prominent than direct **pp** results in the data from **non-central events**.