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 TeV $\rightarrow$ 7x Tevatron energy
  - Luminosity: 10-100 fb^{-1} $\rightarrow$ $\sim$10x 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 $M_H \sim 115 - 140$ GeV.
- New evidences: considering the excluded mass ranges, we may explore the window mass

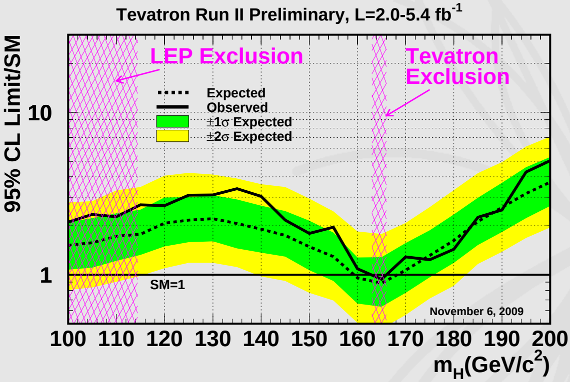
$$115 \text{ GeV} < M_H \lesssim 140 \text{ GeV}$$

New results from the Tevatron

- Excluded range: The TEVNPH Working Group, arXiv:0911.3930[hep-ex]

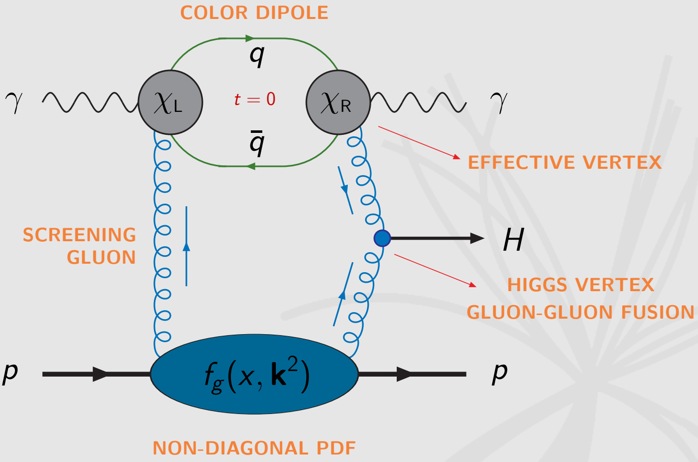
$$160\text{ GeV} \lesssim M_H \lesssim 170\text{ GeV}$$

- EW fits: $M_H = 116.3\,^{+15.6}_{-1.30}$ GeV   Goebel, arXiv:0905.2488[hep-ph]



Diffractive Higgs photoproduction

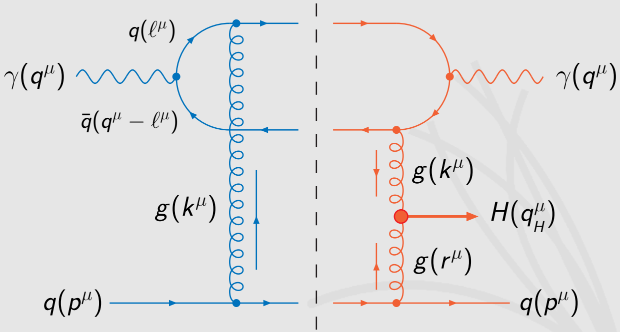
- **Proposal**: γp process by **DPE** in pp collision.



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

Scattering amplitude

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



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

$$\mathrm{Im}\,\mathcal{A} = \frac{1}{2}\int d(PS)_3\, \mathcal{A}_{(left)}\, \mathcal{A}_{(right)}$$

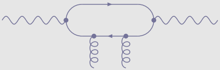
Applying the rules

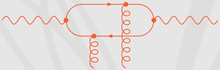
- Performing the product of the two sides of the cut one gets

$$\mathcal{A}_L\mathcal{A}_R = (4\pi)^3\alpha_s^2\,\alpha\left(\sum_q e_q^2\right)\left(\frac{\epsilon_\mu\epsilon_\nu^*}{k^6}\right)\frac{\overbrace{V^{ba}_{\sigma\eta}}^{\text{ggH}}}{N_c}\left(t^b t^a\right)\overbrace{4p_\lambda p^\sigma}^{\text{eikonal}}$$

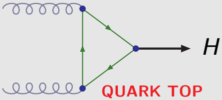
$$\times\ 2\left\{\frac{\mathrm{Tr}\left[(\not q-\not l)\gamma^\mu\not l\gamma^\lambda(\not k+\not l)\gamma^\eta\not l\gamma^\nu\right]}{l^4}+\frac{\mathrm{Tr}\left[(\not q-\not l)\gamma^\lambda(\not k+\not l-\not q)\gamma^\mu(\not k+\not l)\gamma^\eta\not l\gamma^\nu\right]}{l^2(k+l+q)^2}\right\}$$

OTHER POSSIBILITIES





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



QUARK TOP LOOP

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

Plehn, 0910.4182[hep-ph]

The amplitude in parton level

- The imaginary part of the amplitude has the form

$$\frac{\mathrm{Im}\,\mathcal{A}}{s} = -\frac{4}{9}\left(\frac{M_H^2\alpha_s^2\alpha}{N_c v}\right)\left(\sum_q e_q^2\right)\left(\frac{\alpha_s C_F}{\pi}\right)\int\frac{d\mathbf{k}^2}{\mathbf{k}^6}\,\mathcal{X}(\mathbf{k}^2,Q^2)\,,$$

with

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

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

- Computing the event rate in central rapidity

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

- **Quark → Proton**: $\alpha_s C_F/\pi \;\rightarrow\; f_g(x,\mathbf{k}^2) = \mathcal{K}\,\partial_{(\ell n\,\mathbf{k}^2)}\,xg(x,\mathbf{k}^2)$.

Cross section for central rapidity Gay Ducati and Silveira PRD **78** (2008) 113005

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

$$\left.\frac{d\sigma}{dy_H\,dt}\right|_{y_H,t=0} = \frac{S^2_{gap}}{2\pi B}\left(\frac{\alpha_s^2\alpha M_H^2}{3N_c\pi v}\right)^2\left(\sum_q e_q^2\right)^2\left[\int_{\mathbf{k}_0^2}^{\infty}\frac{d\mathbf{k}^2}{\mathbf{k}^6}\,e^{-S(\mathbf{k}^2,M_H^2)}\,f_g(x,\mathbf{k}^2)\,\mathcal{X}(\mathbf{k}^2,Q^2)\right]^2$$

- Proton content[1]: $\alpha_s C_F/\pi \;\; \rightarrow \;\; f_g(x,\mathbf{k}^2) = \mathcal{K}\,\partial_{(\ell n\,\mathbf{k}^2)}\,xg(x,\mathbf{k}^2)$
- Gap Survival Probability[2]: $S^2_{gap} \rightarrow$ 3% (5%) for LHC (Tevatron)
- Gluon radiation suppression[3]: Sudakov factor $S(\mathbf{k}^2, M_H^2) \sim \ell n^2\,(M_H^2/4\mathbf{k}^2)$
- Cutoff $\mathbf{k}_0^2$: Necessary to avoid infrared divergencies :: $\mathbf{k}_0^2 = 0.3$ GeV^2.
- Electroweak vacuum expectation value: $v = 246$ GeV
- Gluon-proton form factor: $B = 5.5$ GeV^{-2}

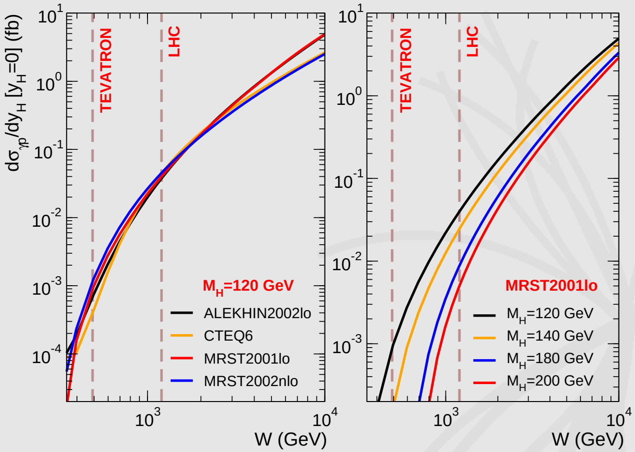
[1] Khoze, Martin, Ryskin, EPJC **14** (2000) 525

[2] Khoze, Martin, Ryskin, EPJC **18** (2000) 167

[3] Forshaw, hep-ph/0508274

Results: predictions for the γp process

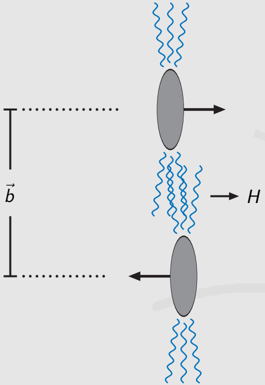
- The predictions for different PDF's are close in LHC
- **Tevatron**: restricted to $M_H < 140$ GeV (reason: $x > 0.01$)



Higgs production in UPC

- The γp process is a subprocess in Ultraperipheral *pp* collisions

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



- **Impact parameter**: $|\vec{b}| > 2R \rightarrow$ **NO STRONG INTERACTION!**
- Only EM force acts in the second proton $\rightarrow$ **REAL PHOTONS**

Hadronic cross section

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

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

where the photon flux is given by

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

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 $h = 2R_A\omega/\gamma_L$.

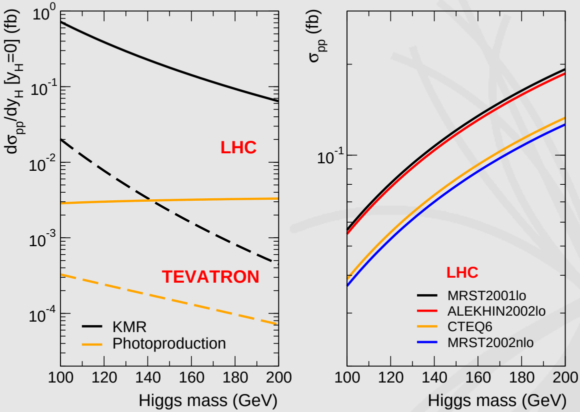
- The photon virtuality can be written in terms of the ω and $\mathbf{q}_\perp$

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

with $\gamma_L = (1 - \beta_L^2)^{-1/2} = \sqrt{s}/2m_N$.

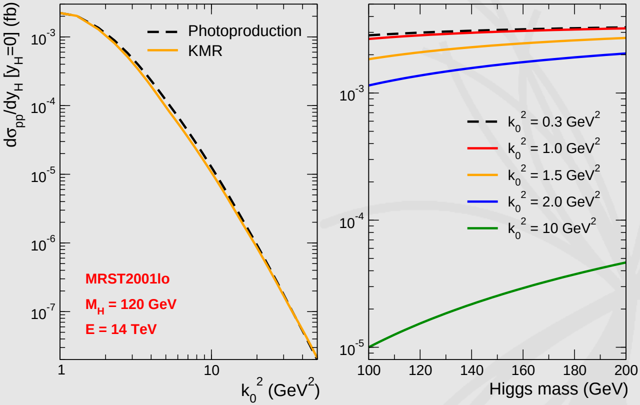
Results: Higgs boson in Ultraperipheral *pp* collisions

- Results similar to those from $\gamma\gamma$ process (0.1 fb).
- Gap between the predictions for LHC with distinct parametrizations.



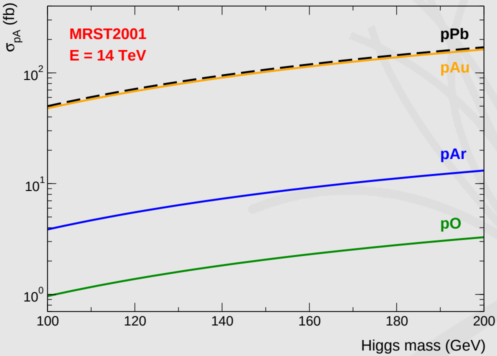
Results: Cutoff sensitivity

- The main contribution comes from the range $\mathbf{k}_0^2 < 30$ 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;
- σ_{pAu}: **8x** lower than $\gamma\gamma$ process with **all bosons loops**[4];
- σ_{pPb}: **50%** lower than $\gamma\gamma$ process by the **Higgs Effective Field Theory**[5].



[4] Levin & Miller, arXiv:0801.3593 [hep-ph]

[5] D'Enterria & Lansberg, arXiv:0909.3047 [hep-ph]

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 γp process (3% like KMR).

Subprocess	GSP (%)	σ_{pp} (fb)
$I\!P I\!P$	2.3	2.7
$I\!P I\!P$	0.4	0.47
$\gamma\gamma$	100	0.1
γp	3.0	**0.08**

- We expect that the GSP could be higher than 3% for the γp 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:

$$\sigma_{\rm pp} \sim 0.1 \text{ fb} \qquad \sigma_{\rm pA} \sim 100 \text{ fb}$$

- 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**.