Higgs boson photoproduction at LHC

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work with G. G. Silveira [based on PRD **78** 113005 (2009)]

Outline

- Motivation
- Diffractive processes
  - Deeply Virtual Compton Scattering (DVCS)
  - Higgs boson production
    - $\gamma\gamma$ annihilation
    - Double Pomeron Exchange (DPE)
- Photoproduction approach: DPE in DVCS
- Ultraperipheral Collisions (UPC)
- Photoproduction at the Tevatron and LHC
- Summary

Motivation

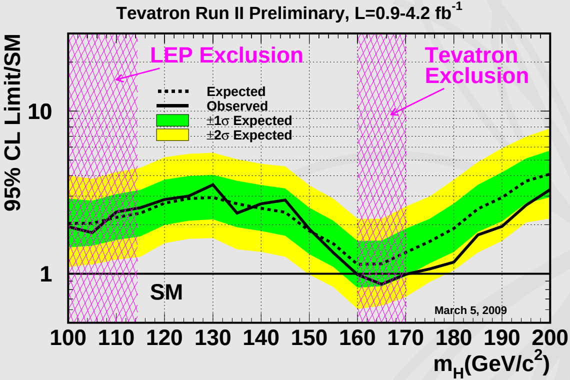
- LHC will allow to study a new kinematic region:
  - CM energy: 14 TeV → 7x Tevatron energy
  - Luminosity: 10-100 fb^{-1} → ∼10x Tevatron luminosity
  - Higgs physics: it is expected that the *pp* collisions will be able to produce the Higgs boson.
- Some hadron-hadron collisions will occur with **no** strong interaction.
  - The ultraperipheral collisions are a new way to study the Higgs boson production in *pp* and *pA* 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 mainly in the mass range $M_H \sim 115 - 200$ GeV.
- Evidences show another mass range **excluded** for Higgs boson production.

New results from the Tevatron

- Excluded range: The TEVNPH Working Group, arXiv:0903.4001[hep-ex]

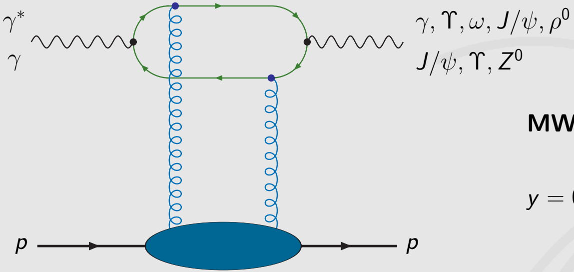
$$160 \text{ GeV} < M_H < 170 \text{ GeV}$$

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



Deeply Virtual Compton Scattering (DVCS)

- **1997**: Ji PRD **55** (1997) 7114
  - $\gamma^* p \to \gamma p$ by **Pomeron exchange** in *ep* collisions.
- **2001**: Munier, Staśto and Mueller NPB **603** (2001) 427
  - Vector meson production $\gamma^* p \to Vp$ with **GBW model**.
- **2008**: Motyka and Watt PRD **78** (2008) 014023
  - Vector particle production $\gamma p \to Ep$ in **Ultraperipheral Collisions**.

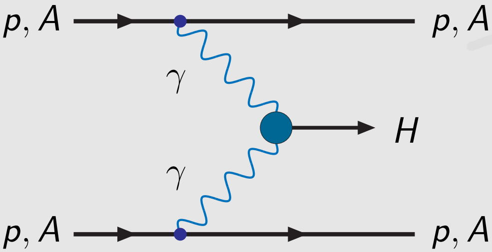


MW: Z^0 boson production

$$y = 0 \begin{cases} \sigma_{\gamma p} = \mathbf{4.2\ fb}\ , \text{Tevatron} \\ \sigma_{\gamma p} = \mathbf{37\ fb}\ , \text{LHC} \end{cases}$$

Electromagnetic Higgs production

- **1990**: Cahn and Jackson — PRD **42** (1990) 3690
  Müller and Schramm — PRD **42** (1990) 3699
  - Ultraperipheral heavy-ion collision $\rightarrow \gamma\gamma$ **annihilation**
- **2007**: Miller — arXiv:0704.1985[hep-ph]
  - Contribution from **Electroweak boson loops** to the $\gamma\gamma \rightarrow H$.
- **2009**: D'Enterria and Lansberg — PRD **81** 014004 (2010)
  - Effective Higgs boson vertex in $\gamma\gamma$ fusion.

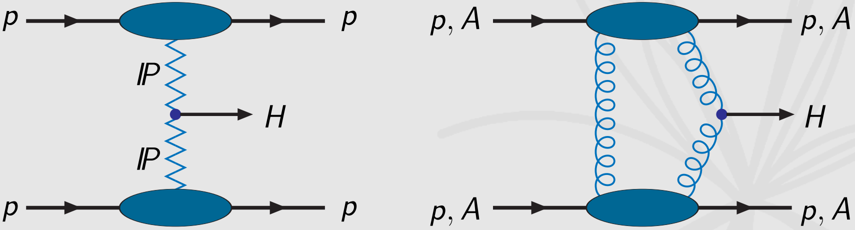


$M_H = 150$ GeV, $\sqrt{s} = 3.5$ TeV/A:
- **CJ**: $\sigma_{\rm PbPb} = 7.0$ pb
- **MS**: $\sigma_{\rm AA} \sim 100$ pb

$M_H = 120$ GeV, $\sqrt{s} = 14$ TeV:
- **M**: $\sigma_{\rm pp} =$ **0.12 fb**
- **DL**: $\sigma_{\rm pp} =$ **0.18 fb**

Diffractive Higgs production in *pp* and *AA* collisions

- **1991**: Bialas and Landshoff — PLB **256** (1991) 540
  - Regge Theory → **non-perturbative gluons**
- **1997**: Khoze, Martin and Ryskin — PLB **401** (1997) 330
  2007: Levin and Miller — arXiv:0801.3593[hep-ph]
  - QCD Pomeron → **hard-gluon exchange**

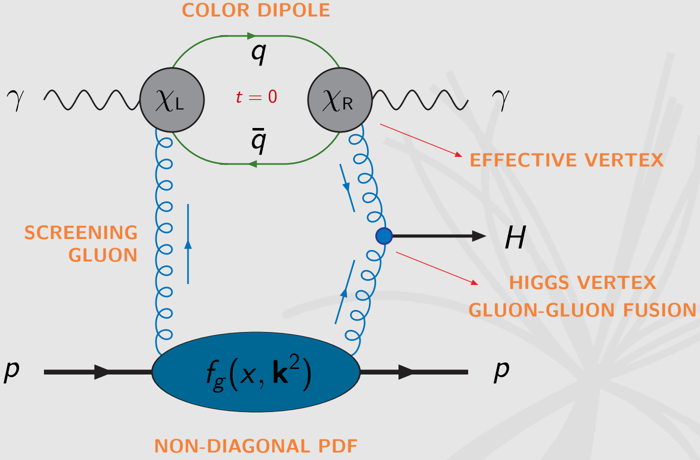


$M_H = 150$ GeV, $\sqrt{s} = 16$ TeV $\left\{ \textbf{BL} : \sigma_{\rm pp} = 0.1 \text{ pb} \right.$

$M_H = 120$ GeV, $\sqrt{s} = 14$ / 8.8 (5.5) TeV/A $\left\{ \begin{array}{l} \textbf{KMR} : \sigma_{\rm pp}^{\rm exc/inc} \sim \textbf{1 fb}/300 \text{ fb} \\ \textbf{LM} : \sigma_{\rm pA(AA)} = 0.64 \text{ pb (3.9 nb)} \end{array} \right.$

Diffractive Higgs photoproduction

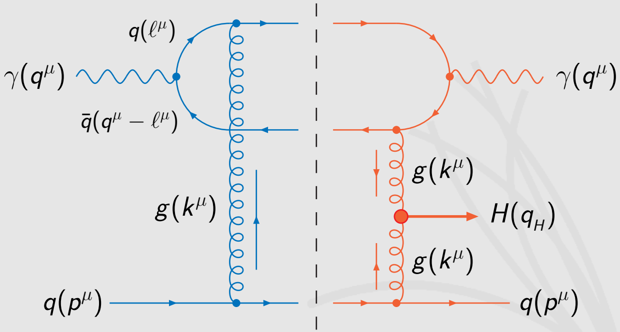
- **Proposal**: γp process by **DPE** in pp collision.



- 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**

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

Photon impact factor

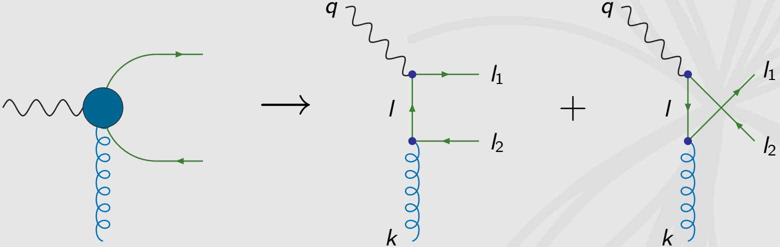
- The color dipole is composed of two effective vertices to the γg coupling

$$\chi_L^{\mu\nu} = -ig_s\, ee_q\, t^a \left\{ \gamma^\mu \left[\frac{\not{l}_1 - \not{q}}{(l_1 - q)^2} \right] \gamma^\nu - \gamma^\nu \left[\frac{\not{l}_1 - \not{k}}{(l_1 - k)^2} \right] \gamma^\mu \right\}$$

$$\chi_R^{\lambda\eta} = -ig_s\, ee_q\, t^b \left\{ \gamma^\lambda \left[\frac{\not{k} - \not{l}_2}{(k - l_2)^2} \right] \gamma^\eta - \gamma^\eta \left[\frac{\not{q} - \not{l}_2}{(q - l_2)^2} \right] \gamma^\lambda \right\}$$

- Photon polarization vectors for $t = 0$:

$$\epsilon_\mu^L \epsilon_\nu^L = \frac{4Q^2}{s} \frac{p_\mu p_\nu}{s} \quad \text{and} \quad \sum \epsilon_\mu^T \epsilon_\nu^{T*} = -g_{\mu\nu} + \frac{4Q^2}{s} \frac{p_\mu p_\nu}{s}$$



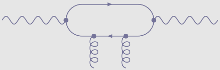
Applying the rules

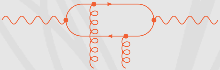
- Performing the product of the two sides of the cut one gets

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

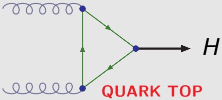
$$\times\ 2\left\{\frac{\mathrm{Tr}\left[(\not{q}-\not{l})\gamma^\mu\not{l}\gamma^\nu(\not{k}+\not{l})\gamma^\eta\not{l}\gamma^\lambda\right]}{l^4}+\frac{\mathrm{Tr}\left[(\not{q}-\not{l})\gamma^\nu(\not{k}+\not{l}-\not{q})\gamma^\mu(\not{k}+\not{l})\gamma^\eta\not{l}\gamma^\lambda\right]}{l^2(k+l+q)^2}\right\}$$

OTHER POSSIBILITIES





- For a **non-heavy Higgs** ($M_H \lesssim 200$ GeV), the *ggH* vertex reads



QUARK TOP LOOP

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

Forshaw, hep-ph/0508274

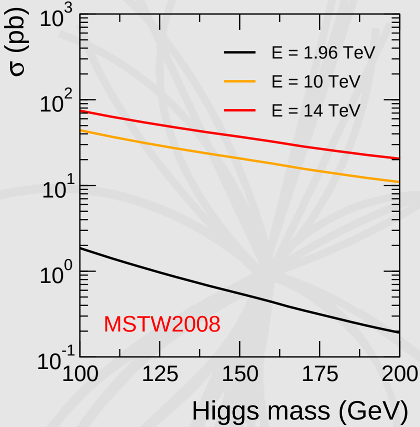
Updates on $gg \to H$ cross section

De Florian and Grazzini
PLB **674** (2009) 291

- Most recent advances taken into account:
  - NNLL soft-gluon resummation;
  - NLO bottom-quark contribution;
  - 2-loop EW effects.
- Significant improvements in LHC.

TEVATRON $\begin{cases} +9\% \to M_H = 115 \text{ GeV} \\ -9\% \to M_H = 200 \text{ GeV} \end{cases}$

LHC $\begin{cases} +30\% \to M_H = 115 \text{ GeV} \\ +9\% \to M_H = 300 \text{ GeV} \end{cases}$



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

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

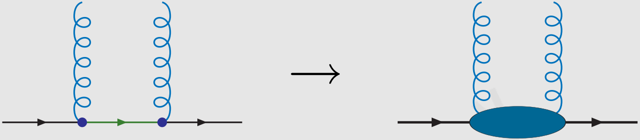
- **First remark**: dependence on $\mathbf{k}^{-6}$ due to the presence of the color dipole.

- Computing the event rate in central rapidity

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

- Only the **quark contribution** → extension to the hadron coupling.

Parton → Hadron



- The hadron coupling is represented by a **non-diagonal** PDF

$$\frac{\alpha_s C_F}{\pi} \longrightarrow f_g(x,\mathbf{k}^2) = \mathcal{K}\left(\frac{\partial[xg(x,\mathbf{k}^2)]}{\partial \ell n\,\mathbf{k}^2}\right)$$

Khoze, Martin and Ryskin PLB **401** (1997) 330

- The non-diagonality is approximated by a multiplicative factor

$$\mathcal{K} = (1.2)\exp(-B\mathbf{p}^2/2)$$

Shuvaev *et al* PRD **60** (1999) 014015

where $B = 5.5\ \text{GeV}^{-2}$ is the slope of the gluon-proton form factor.

- To correctly compute the pomeron coupling to the proton: $x \sim 0.01$.

Phenomenology inside

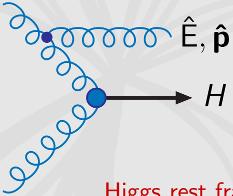
Gluon Radiation

Forshaw, hep-ph/0508274

- The real gluon emission from the ggH vertex needs to be **suppressed**.
  - Sum the virtual graphs that include terms like $\ell n\left(M_H/\mathbf{k}^2\right)$.
- The emission probability of 1-gluon is computed by **Sudakov form factors**

$$S(\mathbf{k}^2, M_H^2) = \frac{N_c}{\pi}\int_{\mathbf{k}^2}^{M_H^2/4} \frac{\alpha_s(\hat{\mathbf{p}}^2)}{\hat{\mathbf{p}}^2}\, d\hat{\mathbf{p}}^2 \int_{p_T}^{M_H/2} \frac{d\hat{\mathrm{E}}}{\hat{\mathrm{E}}} = \frac{3\alpha_s}{4\pi}\, \ell n^2\left(\frac{M_H^2}{4\mathbf{k}^2}\right)$$

- Real emissions are **not suppressed** if the gluon color neutralization **fails**.
- Suppressing many gluons emission:
  - It is included a factor e^{-S} to the cross section.
    - Emissions below $\mathbf{k}^2$ are **forbidden**.
  - As $\mathbf{k}^2 \to 0$ the non-emission probability goes to zero **faster** than any power of $\mathbf{k}$, like $\mathbf{k}^{-6}$.



Higgs rest frame

Phenomenology inside

Rapidity Gaps KMR, EPJC **18** (2000) 167; Gotsman, Levin, Maor, arXiv:0708.1506[hep-ph]

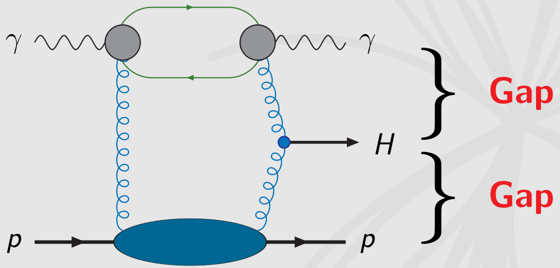
- The **Rapidity Gap Survival Probability** is calculated by

$$S^2_{\text{gap}} = \frac{\int |\mathcal{A}(s,b)|^2 \, e^{-\Omega(b)} \, d^2\mathbf{b}}{\int |\mathcal{A}(s,b)|^2 \, N \, d^2\mathbf{b}} = \begin{cases} 5\% & \text{Tevatron} \\ 2.7\% - 3\% & \text{LHC} \end{cases}$$

where $N = e^{-\Omega_0}$ is the relevant opacity at $\Omega = 0$.

- Pomeron loops: Higgs boson production with $S^2_{gap} = 0.4\%$

Miller
EPJC **56** (2008) 39
arXiv:0908.3450[hep-ph]



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 :: $\mathbf{k}_0^2 = 1$ GeV^2.
- Electroweak vacuum expectation value: $v = 246$ GeV
- Gluon-proton form factor: $B = 5.5$ GeV^{-2}

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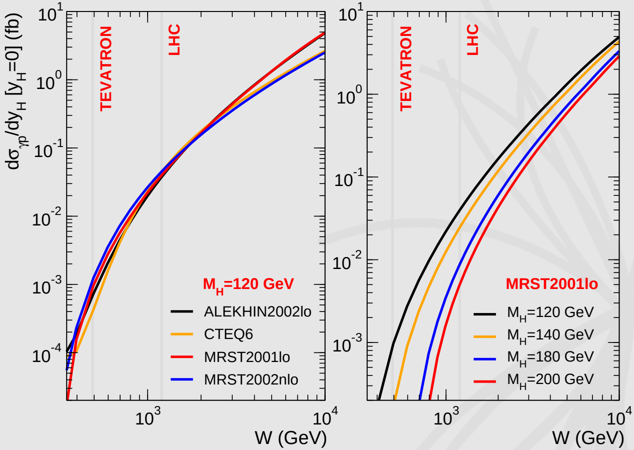
[1] Khoze, Martin, Ryskin, EJPC **14** (2000) 525
[2] Khoze, Martin, Ryskin, EJPC **18** (2000) 167
[3] Forshaw, hep-ph/0508274

Results: predictions for the γp process

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



Results: gluon PDF parametrizations

- All parametrizations start the distribution evolution from

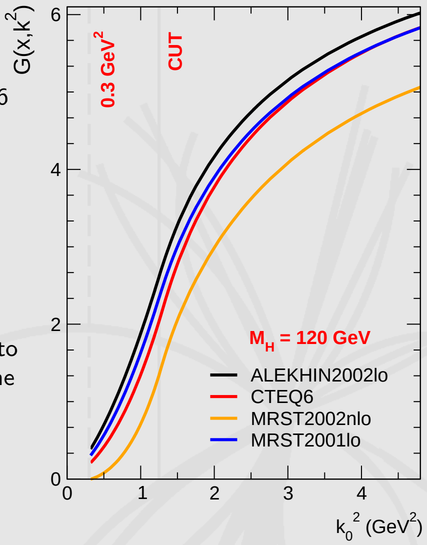
$$\mathbf{k}_0^2 = \begin{cases} 1.25\ \text{GeV}^2,\ \text{MRST and CTEQ6} \\ 1.31\ \text{GeV}^2,\ \text{ALEKHIN} \end{cases}$$

- One can extrapolate the distribution for $\mathbf{k}^2 \to 0$

$$k^2_{\leftarrow} \sim k^{4+2(\gamma+2)\mathbf{k}^2}$$

- For each parametrization one needs to compute the parameters to match the **function** and its **derivative** in the correct value.

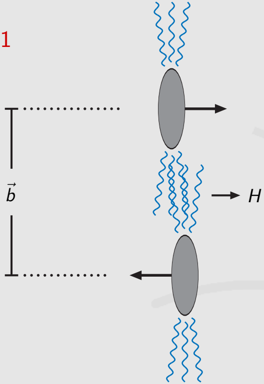
MRST2001lo $\to \gamma = 1.987455222$



Higgs production in Ultraperipheral Collisions

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

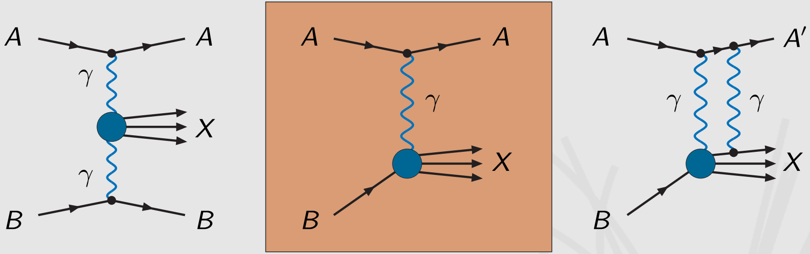
Hencken *et al*
Phys. Rept. **458** (2008) 1



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

Peripheral photons

Baur, Hencken and Trautman
J. Phys. **G24** (1998) 1657



- The **photon virtuality** is related to the nucleus radius: coherent action of the charged particles

$$Q^2 \lesssim 1/R^2$$

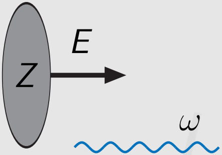
COHERENCE CONDITION

  - In the **proton case**: $Q^2 \lesssim 10^{-2}\ \text{GeV}^2$.

- **Uncertainty principle**: upper limit to the photon transverse momentum

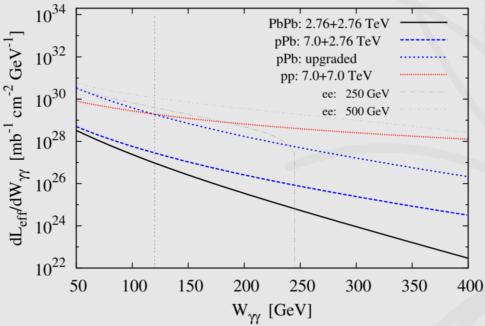
$$\mathbf{Q} \lesssim \frac{1}{R} \approx \begin{cases} 28\ \text{MeV, Pb beam} \\ 330\ \text{MeV, proton beam} \end{cases}$$

Photon spectra



- The energy fraction of the photon related to the incident nucleus obey the **coherence condition**

$$x_\gamma = \frac{\text{photon energy}}{\text{beam energy}} = \frac{\omega}{E} \begin{cases} x_\gamma \lesssim 10^{-3}, \text{Ca} \\ x_\gamma \lesssim 10^{-4}, \text{Pb} \end{cases}$$



d'Enterria and Lansberg arXiv:0909.3047[hep-ph]

- The photon distribution is **strongly** suppressed at high energies.

Hadronic cross section

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

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

  where the photon flux is given by

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

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

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

  where $\mu = \omega b_{min}/\gamma_L$, and $b_{min} = r_p + R_A$.

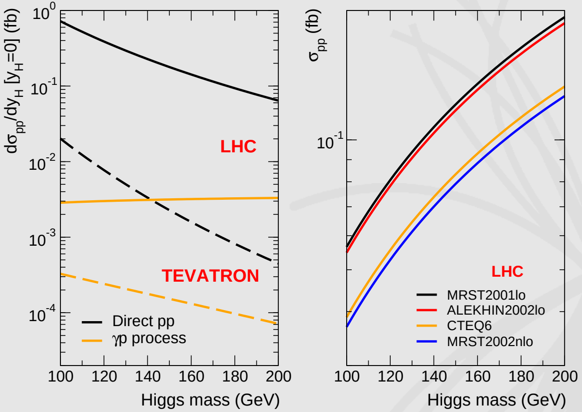
- The parametrization allows one to write the virtuality as

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

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

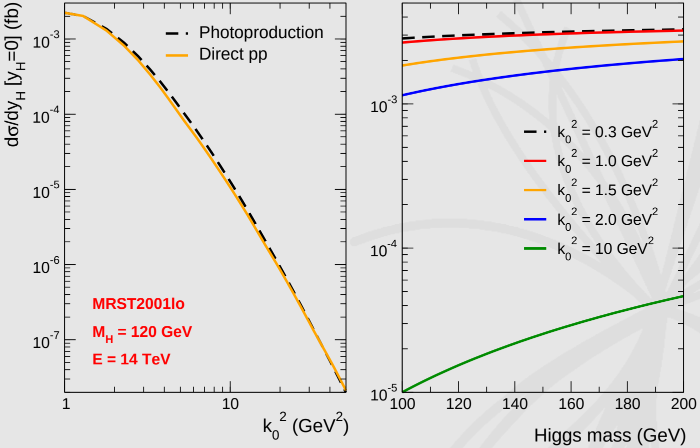
Results: Higgs boson in UPCs

- Similar to those from $\gamma\gamma$ process (10^{-1} fb).
- Clear distinction among the predictions in LHC for different PDF's.
- The event rate is obtained from the relation $\frac{d\sigma_{pp}}{dy_H} = 2\int_{\omega_0}^{\sqrt{s}/2} \frac{dn}{d\omega} \frac{d\sigma_{\gamma p}}{dy_H}\, d\omega$.



Results: Cutoff sensitivity

- The main contribution comes from the range $\mathbf{k}_0^2 < 30\ \text{GeV}^2$.
- Sensitivity: almost the same behavior than the direct *pp* process.

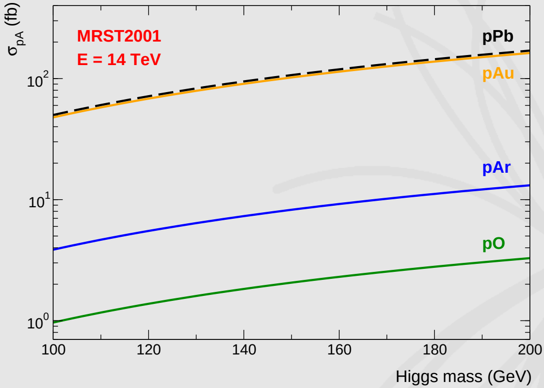


Results: *pA* collisions

- Some species are inspected for the Higgs boson photoproduction:

$$Pb, \quad Au, \quad Ar, \quad O$$

- The photon flux is improved by a factor of Z^2;



Summary

- We compute the event rate for **Higgs boson production** in Ultraperipheral Collisions at LHC:

$$\sigma_{pp} \sim 0.1 \text{ fb} \qquad \sigma_{pPb} \sim 80 \text{ fb}$$

- The computed total cross section is lower than the direct *pp* process, however,
  - The Rapidity Gap Survival Probability (GSP) is not appropriated to the γp process (3%).
  - **We must compute the GSP for the γp collsions.**

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**

- The predictions can be analysed with the data for **non-central collisions**.
  - It will be less competitive than direct *pp* processes if analysed separetely.