



# Higgs boson photoproduction in Ultrapерipheral Collisions

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# Outline

- ▶ Motivation
- ▶ Predictions for the diffractive Higgs boson production
- ▶ Photoproduction approach
- ▶ Ultrapерipheral Collisions (UPC)
- ▶ UPC at the LHC
- ▶ Results
- ▶ Conclusions

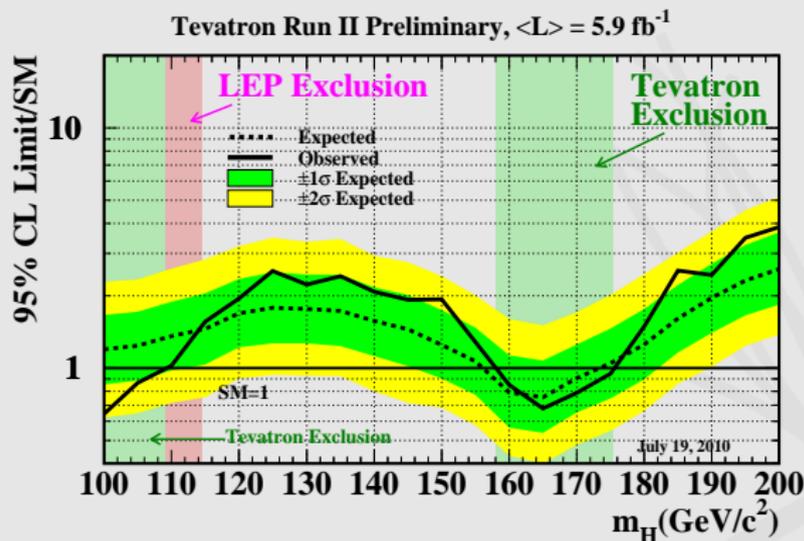
# Motivation

- ▶ LHC will allow to probe a new kinematical region:
  - ▶ CM energy:  $pp \rightarrow 7\text{-}14 \text{ TeV} :: pA/AA \rightarrow 5.5\text{-}9.9 \text{ TeV}/A$ ;
  - ▶  $pA$ : enhanced **photon flux**:  $\sigma_{tot} \propto Z^2$ .
  - ▶ Higgs physics: the low luminosity regime is favorable to the Higgs boson production in diffractive processes.
- ▶ The **Ultraperipheral Collisions (UPC)** are a new way to study the Higgs boson production in hadronic collisions;
  - ▶ The  $pA$  collisions have the best features to look for the Higgs boson at the LHC.
- ▶ 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  $M_H \sim 115 - 140 \text{ GeV}$ .
- ▶ New evidences: considering the excluded mass ranges, we may explore the window mass

$$115 \text{ GeV} < M_H \lesssim 158 \text{ GeV}$$

## New results from the Tevatron

- ▶ Excluded range\*:  $158 \text{ GeV} < M_H < 175 \text{ GeV}$
- ▶ Indirect constraints from EW data†:  $M_H > 185 \text{ GeV}$

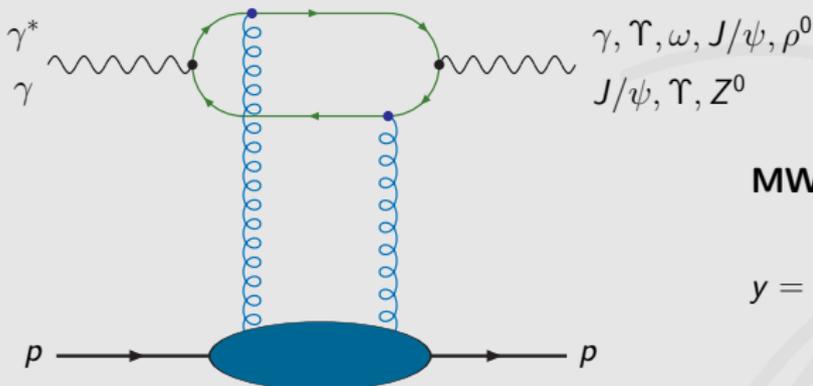


\* The TEVNPH Working Group, arXiv:1007.4587[hep-ex]

† LEP-Tevatron-SLD Electroweak Working Group, arXiv:0811.4682[hep-ex]

# Deeply Virtual Compton Scattering (DVCS)

- ▶ **1997:** Ji PRD **55** (1997) 7114
  - ▶  $\gamma^* p \rightarrow \gamma p$  by **Pomeron exchange** in  $ep$  collisions.
- ▶ **2001:** Munier, Staśto and Mueller NPB **603** (2001) 427
  - ▶ Vector meson production  $\gamma^* p \rightarrow Vp$  with **GBW model**.
- ▶ **2008:** Motyka and Watt PRD **78** (2008) 014023  
**2009:** Cisek, Schafer and Szczurek PRD **80** (2009) 074013
  - ▶ Vector particle production  $\gamma p \rightarrow Ep$  in **Ultraperipheral Collisions**.

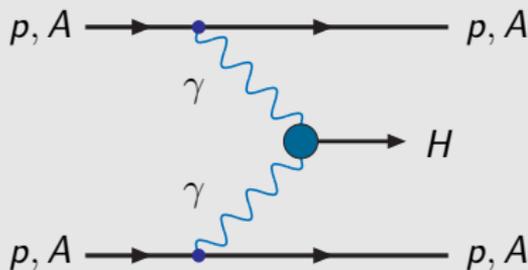


**MW:**  $Z^0$  boson production

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

# Electromagnetic Higgs boson production

- ▶ **1990:** Cahn and Jackson PRD **42** (1990) 3690  
Müller and Schramm PRD **42** (1990) 3699
  - ▶ Peripheral heavy-ion collision  $\rightarrow \gamma\gamma$  **annihilation**
  
- ▶ **2002:** Khoze, Martin and Ryskin EPJC **23** (2002) 311  
**2007:** Miller arXiv:0704.1985[hep-ph]  
**2008:** Levin and Miller arXiv:0801.3593[hep-ph]
  - ▶ Contribution from **Electroweak boson loops** to the  $\gamma\gamma \rightarrow H$ .
  
- ▶ **2010:** D'Enterria and Lansberg PRD **81** (2010) 014004
  - ▶ **Photon fluxes** and **Higgs effective Theory** in  $\gamma\gamma$  processes.



$$\begin{array}{l}
 M_H = 150 \text{ GeV} \\
 \sqrt{s} = 3.5 \text{ TeV}/A
 \end{array}
 \left\{ \begin{array}{l}
 \text{CJ: } \sigma_{\text{PbPb}} = 7.0 \text{ pb} \\
 \text{MS: } \sigma_{\text{AA}} \sim 100 \text{ pb}
 \end{array} \right.$$

$$\begin{array}{l}
 M_H = 120 \text{ GeV} \\
 \sqrt{s} = 14 \text{ TeV}
 \end{array}
 \left\{ \begin{array}{l}
 \text{KMR/M: } \sigma_{\text{pp}} = \mathbf{0.1 \text{ fb}/0.12 \text{ fb}} \\
 \text{LM: } \sigma_{\text{pAu(AuAu)}} = \mathbf{0.6 \text{ pb} (3.9 \text{ nb})} \\
 \text{DL: } \sigma_{\text{pp}} = \mathbf{0.18 \text{ fb}}
 \end{array} \right.$$

# Diffractive Higgs production in $pp$ and $AA$ collisions

- ▶ **1991**: Bialas and Landshoff

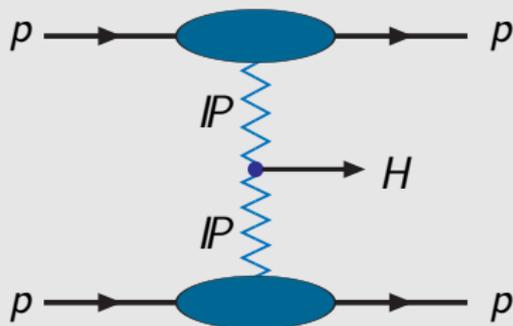
PLB **256** (1991) 540

- ▶ Regge Theory → **non-perturbative gluons**

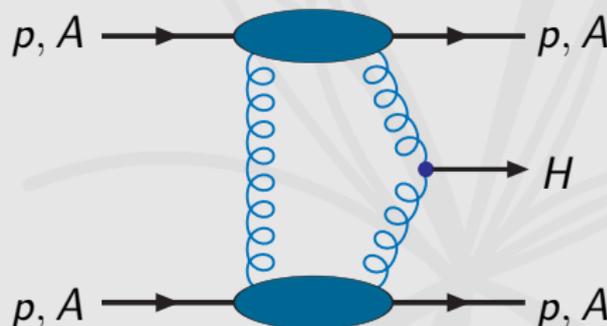
- ▶ **1997**: Khoze, Martin and Ryskin  
**2007**: Levin and Miller

PLB **401** (1997) 330  
arXiv:0801.3593[hep-ph]

- ▶ QCD Pomeron → **hard-gluon exchange**



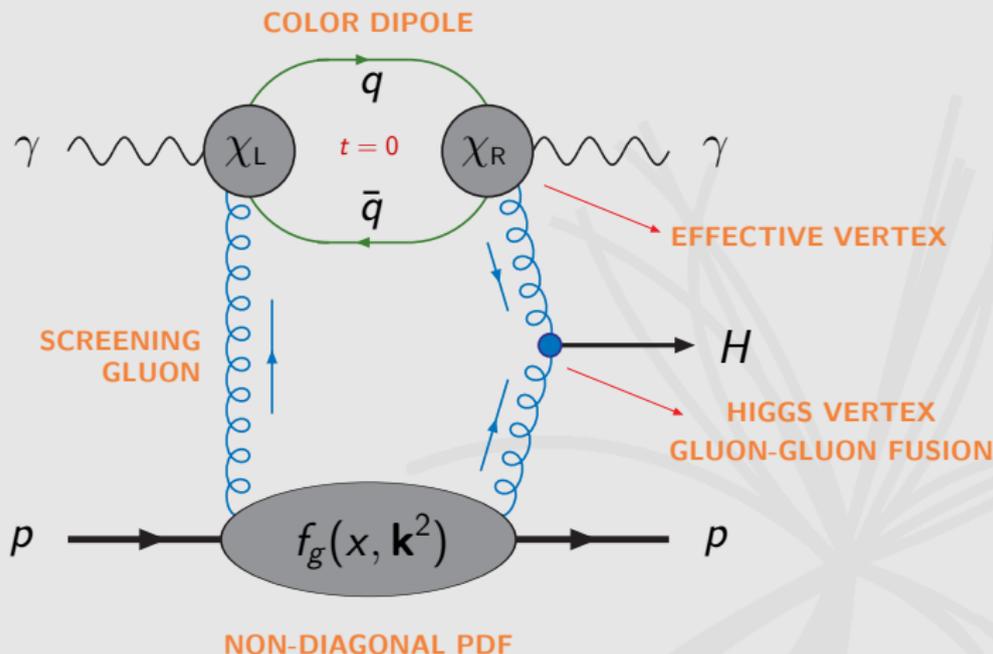
$$M_H = 150 \text{ GeV} \quad \left\{ \begin{array}{l} \text{BL} : \sigma_{pp} = 0.1 \text{ pb} \\ \sqrt{s} = 16 \text{ TeV} \end{array} \right.$$



$$M_H = 120 \text{ GeV} \quad \left\{ \begin{array}{l} \text{KMR} : \sigma_{pp}^{\text{exc/inc}} \sim 3 \text{ fb} / 300 \text{ fb} \\ \sqrt{s} = 14 / 8.8 (5.5) \text{ TeV/A} \\ \text{LM} : \sigma_{pA(AA)} = 0.1 \text{ pb} (3.9 \text{ pb}) \end{array} \right.$$

# Diffractive Higgs photoproduction

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

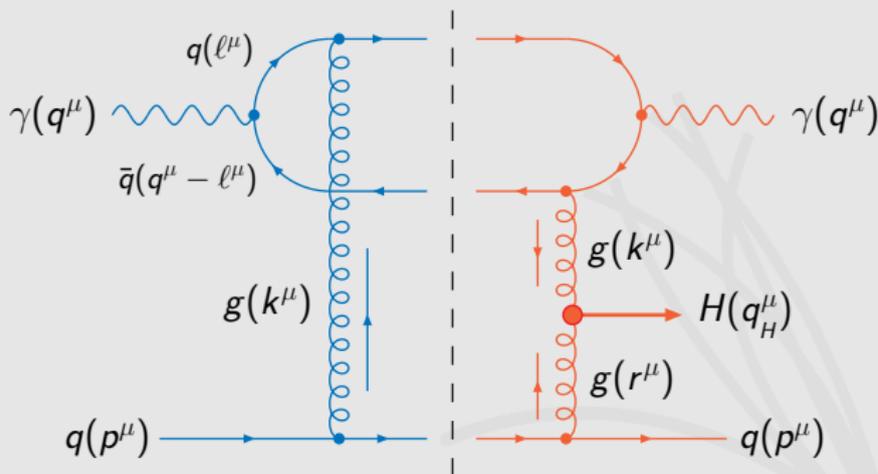


- A good test would be compute the  $J/\psi$  or  $\chi_c$  production.

\* Gay Ducati and Silveira, Phys. Rev. **D78** (2008) 113005

# Scattering amplitude

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



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

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

## The amplitude in parton level

- ▶ The imaginary part of the amplitude has the form

$$\text{Im } \mathcal{A} = -\frac{s}{6} \frac{M_H^2}{\pi v} \frac{\alpha_s}{N_c} \left( \frac{\alpha_s C_F}{\pi} \right) \int \Phi_{\gamma\gamma}^T(\mathbf{k}^2, Q^2) \frac{d\mathbf{k}^2}{\mathbf{k}^6}$$

with the  $\gamma\gamma$  impact factor given by

$$\Phi_{\gamma\gamma}^T(\mathbf{k}^2, Q^2) = 4\pi\alpha_s\alpha \sum_q e_q^2 \int_0^1 d\tau d\rho \frac{\mathbf{k}^2 [\tau^2 + (1-\tau)^2] [\rho^2 + (1-\rho)^2]}{Q^2\rho(1-\rho) + \mathbf{k}^2\tau(1-\tau)}.$$

- ▶ **First remark:** dependence on  $\mathbf{k}^{-6}$  due to the presence of the color dipole.
- ▶ Computing the event rate in central rapidity

$$\frac{d\sigma}{dy_H d\mathbf{q}^2} = \frac{\alpha_s^4 K_{NLO}}{288\pi^5 B} \left( \frac{M_H^2}{N_c v} \right)^2 \left[ \int \frac{\alpha_s C_F}{\pi} \Phi_{\gamma\gamma}^T(\mathbf{k}^2, Q^2) \frac{d\mathbf{k}^2}{\mathbf{k}^6} \right]^2.$$

- ▶  $\gamma p$ : replace the quark contribution to the parton content into the proton.

Parton  $\rightarrow$  Hadron

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

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

- ▶ The non-diagonality is approximated by a multiplicative factor<sup>†</sup>

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

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:  $x \sim 0.01$ .

\* Khoze, Martin and Ryskin, Phys. Lett. **B401** (1997) 330

<sup>†</sup> Shuvaev et al., Phys. Rev. **D60** (1999) 014015

# Phenomenology inside

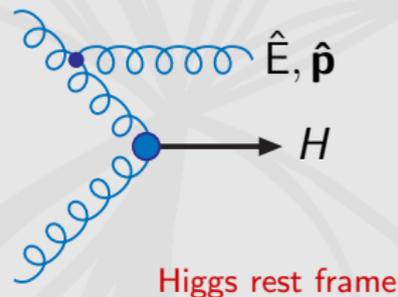
## Gluon Radiation at DLLA

Khoze, Martin and Ryskin, PLB **650** (2007) 41

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

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

- ▶ 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  $\mathbf{k}^2 \rightarrow 0$  the non-emission probability goes to zero **faster** than any power of  $\mathbf{k}$ , like  $\mathbf{k}^{-6}$ .



# Phenomenology inside

## Gluon Radiation at LLA

Khoze, Martin and Ryskin, PLB **650** (2007) 41

- ▶ Possibility of **quark** emissions from the production vertex.

- ▶ There will be contributions of single logarithms.

- ▶ The **Sudakov form factors** are rewritten as

$$T(\mathbf{k}^2, \mu^2) = \int_{\mathbf{k}^2}^{\mu^2} \frac{\alpha_s(\hat{\mathbf{p}}^2)}{2\pi} \frac{d\hat{\mathbf{p}}^2}{\hat{\mathbf{p}}^2} \int_0^{1-\Delta} \left[ z P_{gg}(z) + \sum_q P_{qg}(z) \right] dz$$

- ▶ The  $P_{ij}$  are the DGLAP splitting functions;
  - ▶ In this work,  $\mu = M_H/2$ .
- ▶ In order to correctly include these contributions to the amplitude, the unintegrated distribution is written as\*

$$\tilde{f}(x, \mathbf{k}^2, \mu^2) = \mathcal{K} \frac{\partial}{\partial \ln \mathbf{k}^2} \left[ \sqrt{T(\mathbf{k}^2, \mu^2)} x g(x, \mathbf{k}^2) \right]$$

\* Dokshitzer, Diakonov and Troian, Phys. Rept. **58** (1980) 269

# Phenomenology inside

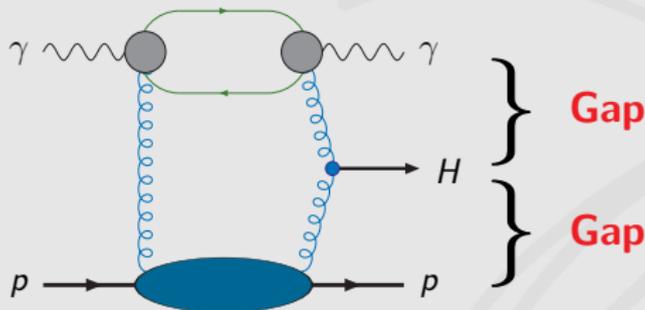
**Rapidity Gaps** KMR, EPJC **18** (2000) 167; Gotsman, Levin, Maor, PRD **60** (1999) 094011

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

$$S_{\text{gap}}^2 = \frac{\int |\mathcal{A}(s, b)|^2 e^{-\Omega(b)} d^2\mathbf{b}}{\int |\mathcal{A}(s, b)|^2 N d^2\mathbf{b}} = 2.7\% - 3\% \text{ for LHC}$$

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

- ▶ Pomeron loops: Higgs boson production with  $S_{\text{gap}}^2 = 0.4\%$   
Miller, EPJC **56** (2008) 39
- ▶ Central dijet production at HERA: diffractive ratio of **10%**.  
Kaidalov, Khoze, Martin, and Ryskin, PLB **567** (2003) 61



## Cross section for central rapidity

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

$$\left. \frac{d\sigma}{dy_H dt} \right|_{y_H, t=0} = S_{gap}^2 \frac{K_{NLO}}{288\pi^5 B} \alpha_s^4 \left( \frac{M_H^2}{N_c v} \right)^2 \left[ \int_{k_0^2}^{\mu^2} \frac{dk^2}{k^6} \tilde{f}_g(x, \mathbf{k}^2, \mu^2) \Phi_{\gamma\gamma}^T(\mathbf{k}^2, Q^2) \right]^2$$

- ▶ Proton content\*:  $\alpha_s C_F / \pi \rightarrow f_g(x, \mathbf{k}^2) = \mathcal{K} \partial_{(\ln k^2)} \left[ \sqrt{T} x g(x, \mathbf{k}^2) \right]$
- ▶ Sudakov form factor†:  $T(\mathbf{k}^2, \mu^2) = [\alpha_s(\mathbf{k}^2) / \alpha_s(\mu^2)] e^{-S}$ ,  $S \sim \ln^2(\mu^2 / \mathbf{k}^2)$ ‡
- ▶ Gap Survival Probability:  $S_{gap}^2 \rightarrow 3\%$ § and 10% for LHC
- ▶ Cutoff  $k_0^2$  to regulate the infrared divergences:  $k_0^2 = 0.3 \text{ GeV}^2$ .
- ▶ Electroweak vacuum expectation value:  $v = 246 \text{ GeV}$
- ▶ Gluon-proton form factor:  $B = 5.5 \text{ GeV}^{-2}$

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\* Khoze, Martin and Ryskin, EPJC **14** (2000) 525

† Forshaw, hep-ph/0508274 (2005)

‡ Gay Ducati and Silveira, PRD **78** (2008) 113005

§ Khoze, Martin and Ryskin, EPJC **18** (2000) 167



## Hadronic cross section

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

$$\sigma_{\text{tot}} = 2 \int_{\omega_{\min}}^{\omega_{\max}} d\omega \frac{dn_i}{d\omega} \sigma_{\gamma p}(\omega, M_H),$$

with  $\omega_{\min} = M_H^2/2X\sqrt{SN}$  and  $\omega_{\max} = \sqrt{Q^2\gamma_L^2\beta_L^2}$ . The **photon flux** is

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

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

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

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

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

$$Q^2 = -\omega^2/(\gamma_L^2\beta_L^2) - q_\perp^2 \leq \frac{1}{R^2}$$

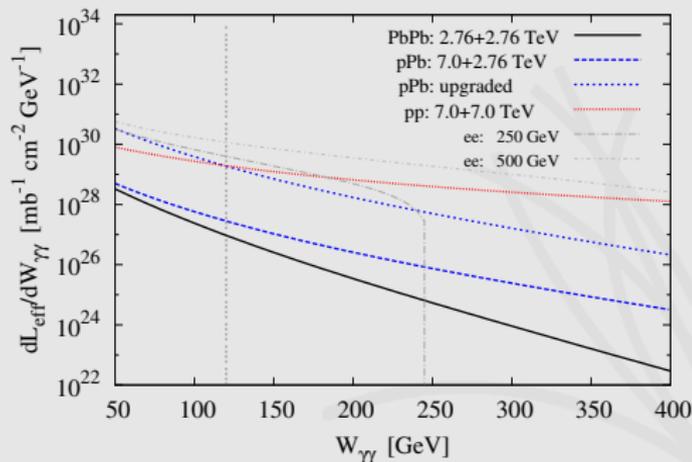
with  $\gamma_L = (1 - \beta_L^2)^{-1/2} = \sqrt{s}/2m_N$ .

\* Drees and Zeppenfeld, Phys. Rev. **D39** (1989) 2536

† Klein and Nystrand, Phys. Rev. **C60** (1999) 014903

## UPC at the LHC

- ▶ The photon flux **increases** with  $Z$  but the photon luminosity **decreases** from  $pp$  to nuclei collisions.

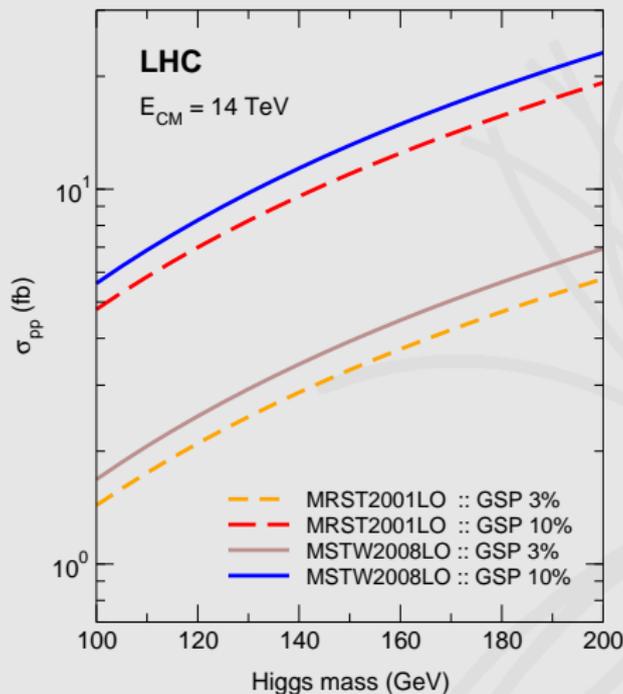


- ▶ The  $pA$  collisions may provide the **best experimental conditions** to look for the Higgs boson\*.
- ▶ We apply our approach to  $pp$  and  $pA$  collisions: gluon shadowing suppresses the AA predictions.

\* D'Enterria and Lansberg, Phys. Rev. **D81** (2010) 014004

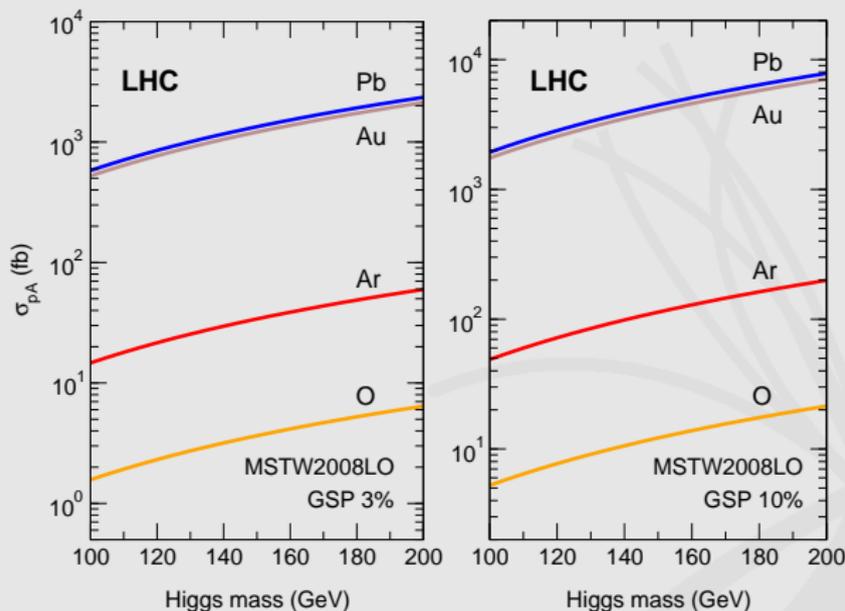
## Results: Higgs boson in Ultraperipheral $pp$ collisions

- ▶  $\sigma_{pp}$ : one order higher than the results from  $\gamma\gamma$  processes (0.1-0.18 fb).
- ▶ An optimistic approach for the GSP provides a cross section of **6 fb**.



## Results: $pA$ collisions

- ▶  $\sigma_{pAu} \sim 800$  fb: competitive with the  $\gamma\gamma$  process\*;
- ▶  $\sigma_{pPb}$ : **4x** higher than the approach with an **Effective Field Theory**†.



\* Levin and Miller, arXiv:0801.3593 [hep-ph] (2008)

† D'Enterria and Lansberg, Phys. Rev. **D81** (2010) 014004

## Gap Survival Probability

- ▶ The predicted cross section is competitive with other approaches;
- ▶ The Rapidity Gap Survival Probability (GSP) **is not** computed for the Higgs boson production in  $\gamma p$  processes;
  - ▶ Based on previous evidences from HERA:  $S_{gap}^2 = 10\%$ .

Subprocess	GSP (%)	$\sigma_{pp}$ (fb)
<i>IPIP</i>	2.6*	3.0 <sup>†</sup>
<i>IPIP</i>	0.4 <sup>‡</sup>	0.47
$\gamma\gamma$	100	0.10-0.18
$\gamma p$	3.0	<b>1.77</b>
$\gamma p$	10.	<b>5.92</b>

- ▶ The  $\gamma p$  process may provide a good way to look for the Higgs boson in  $pp$  and  $pA$  collisions at the LHC.

\* Khoze, Martin, Ryskin, JHEP **05** (2006) 36

<sup>†</sup> Khoze, Martin, Ryskin, Eur. Phys. J. **C23** (2002) 311

<sup>‡</sup> Miller, Eur. Phys. J. **C56** (2008) 39

## Event rates

- ▶ Taking the Branching ratio for  $BR(H \rightarrow b\bar{b}) = 72\%$ , the event rate for the Higgs boson production can be predicted for LHC\*.
- ▶ Little chance to observe  $b\bar{b}$  decay in LHC:  $\gamma\gamma$  and  $\tau^+\tau^-$  expected<sup>†</sup>.

	$\sigma$ (fb)	$BR \times \sigma$	$\mathcal{L}$ (fb <sup>-1</sup> )	events/yr
$pp$	1.77	1.27	1(30)	<b>1 (30)</b>
$pp$	5.92	4.26	1(30)	<b>6 (180)</b>
$pPb$	617	444	0.035	<b>21</b>
$pPb$	2056	1480	0.035	<b>72</b>

- ▶ There is an one-month run scheduled to Nov./2010 of AA collisions.
- ▶ New data from nuclei collisions may be available in 2011.

\* Ahrens, Becher, Neubert and Yang, arXiv:1008.3162 (2010)

<sup>†</sup> CMS, Physics Technical Design Report (2007)

## Conclusions

- ▶ We have computed the production cross section for the **Higgs boson** in UPC at the LHC:

$$\sigma_{pp} \sim 2 - 6 \text{ fb} \quad \sigma_{pA} \sim 0.8 - 2 \text{ pb}$$

- ▶ The  $pA$  collisions provide a clean process to discover the Higgs boson at the LHC:
  - ▶ The luminosity and pile-up in such processes will be favorable for the Higgs boson detection;
  - ▶ A reasonably event rate predicted for future  $pA$  runs.
- ▶ Low sensitivity to the input parameter: infrared region under control;
- ▶ Taking the specific GSP for the photoproduction processes, the predictions may be **higher** than the ones from other approaches;
- ▶ The photoproduction approach allows a data analysis for the Higgs boson production in **non-central events**.