# The $H \to \gamma\gamma$ background at NLO – whatelse?

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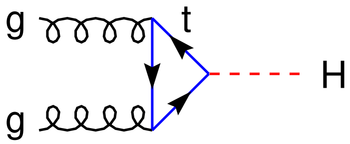
- Motivation
- Photon pair production in hadronic collisions at NLO
- Comparison of NLO results to experimental data
- NLO prediction for the background to $H \to \gamma\gamma$ at the LHC
- Whatelse has to be done?
- Summary

## Situation for the LHC

- The Tevatron might have a chance to discover a light Higgs boson $M_H < 125$ GeV
- Dominant process at the LHC: gluon fusion




- Promising signature for 80 GeV $< M_H <$ 140 GeV:

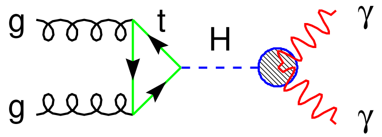
$$\boxed{gg \to H \to \gamma\gamma}$$

- The experimental studies do not include K factors!
  $L = 100\,\text{fb}^{-1} \Rightarrow S/B \sim 5\%,\ S \sim 1000,\ B \sim 20000$
- Corrections for the signal (NLO) of order 100% (!)
  NNLO corrections ($M_{Top} \to \infty$) are calculated, resummations to account for soft gluon effects are performed $\Rightarrow$ The signal is theoretically under control!

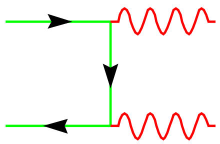
How big are the radiative corrections for the background?

# Photon pairs at the LHC

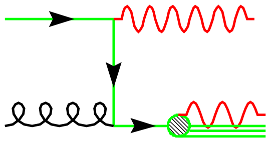
Apart from the signal:

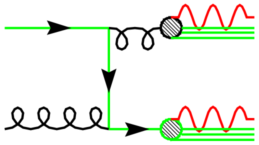



I Direct Photons: The photons are produced through point–like interactions

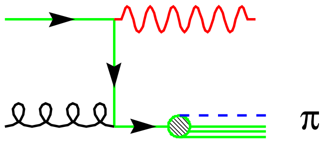


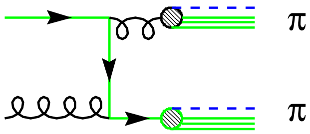
II Photons from fragmentation: At least one photon is produced in the hadronisation of partons





III Meson decay: $\pi^0, \eta, \ldots$ decay into photon paires. If $p_T(\pi^0)$ is big the two photons are misidentified as a single photon in the detector $\Rightarrow$ "Fake Photons"



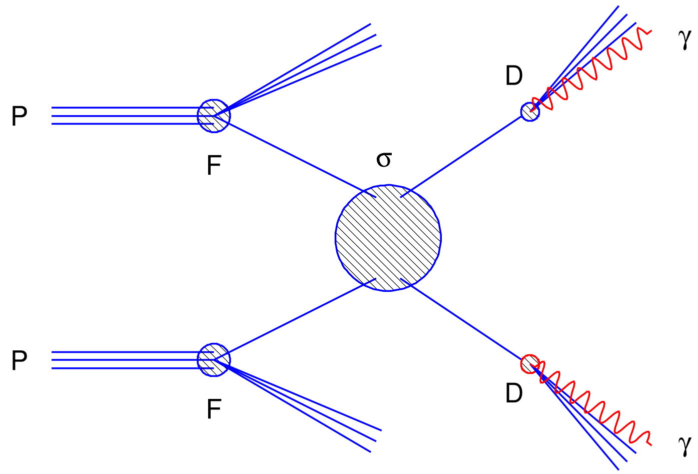




$\boxed{\text{Physics of } \gamma\text{'s} \Leftrightarrow \text{Physics of } \pi^0\text{'s}}$

# The parton model and collinear fragmentation

$$\sigma[PP \to \gamma\gamma] = \sum_{p_j} \int F_{p_1/P}(M) F_{p_2/P}(M)$$
$$\otimes \sigma[p_1 p_2 \to p_3 p_4](\mu) \otimes D_{\gamma/p_3}(M_f) D_{\gamma/p_4}(M_f)$$

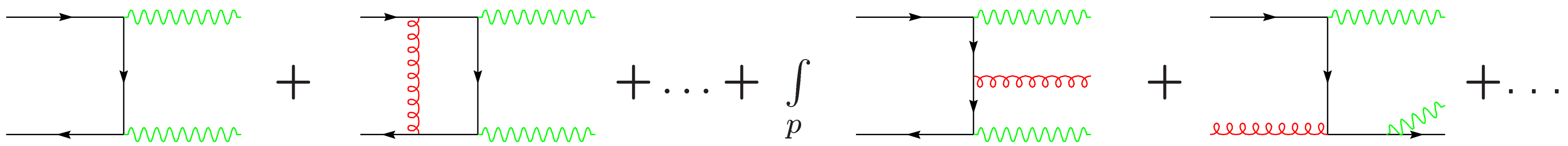
- Direct Photons $D_{\gamma/p_j} \leftrightarrow \delta(1-z)$
- Pion production $D_{\gamma/p_j} \leftrightarrow D_{\pi^0/p_j}$




$\Rightarrow$ at leading order predictions are very sensitive on variations of the scales $\mu, M, M_f$

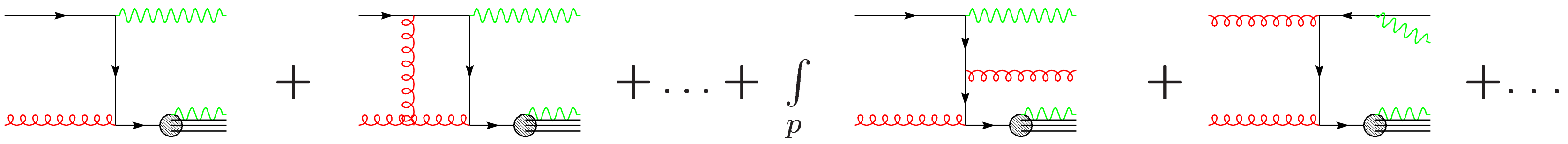
## $\gamma\gamma$ production beyond the leading order

Contribution direct/direct:

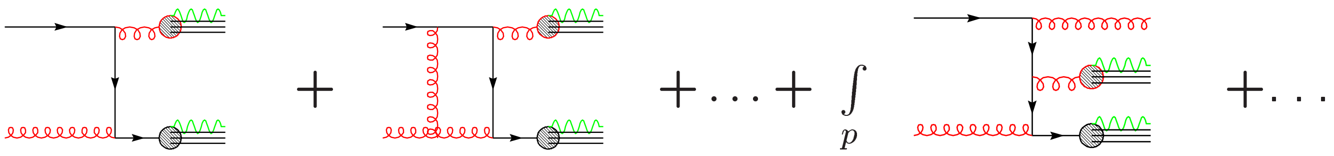


LO NLO virtual NLO real

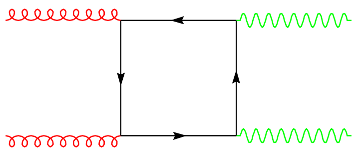
Contribution direct/fragmentation:



Contribution fragmentation/fragmentation:



The box contribution:



## The program DIPHOX

- All contributions are calculated and included in a flexible FORTRAN code: DIPHOX

  [T.B., J.P. Guillet, E. Pilon, M. Werlen, EPJ C16 (2000)]

- Describes the production of photon pairs, photon+hadron and hadron pairs in hadronic collisions at NLO

- Allows to study effects due to experimental cuts

- Allows to compare existing data with NLO QCD

- Allows to make predictions for photon pair rates at the LHC

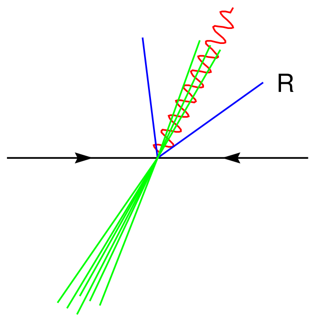
## Comparison with Tevatron data

Tevatron: $P\bar{P}$ collider at Fermilab, Run I: $\sqrt{s} = 1.8$ TeV

Experimental cuts:

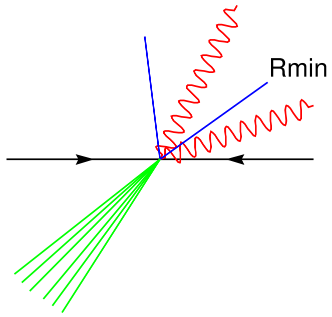
- Cut on transverse momenta and rapidity:

$$p_T(\gamma_1) > 14.9 \text{ GeV}$$
$$p_T(\gamma_2) > 13.9 \text{ GeV}$$
$$|y(\gamma_{1,2})| < 1$$




- Isolation cut:

$$E_{T\,hadronic} < E_{T\,max} = 2 \text{ GeV}$$
$$R = \sqrt{(y - y_\gamma)^2 + (\phi - \phi_\gamma)^2} < 0.4$$



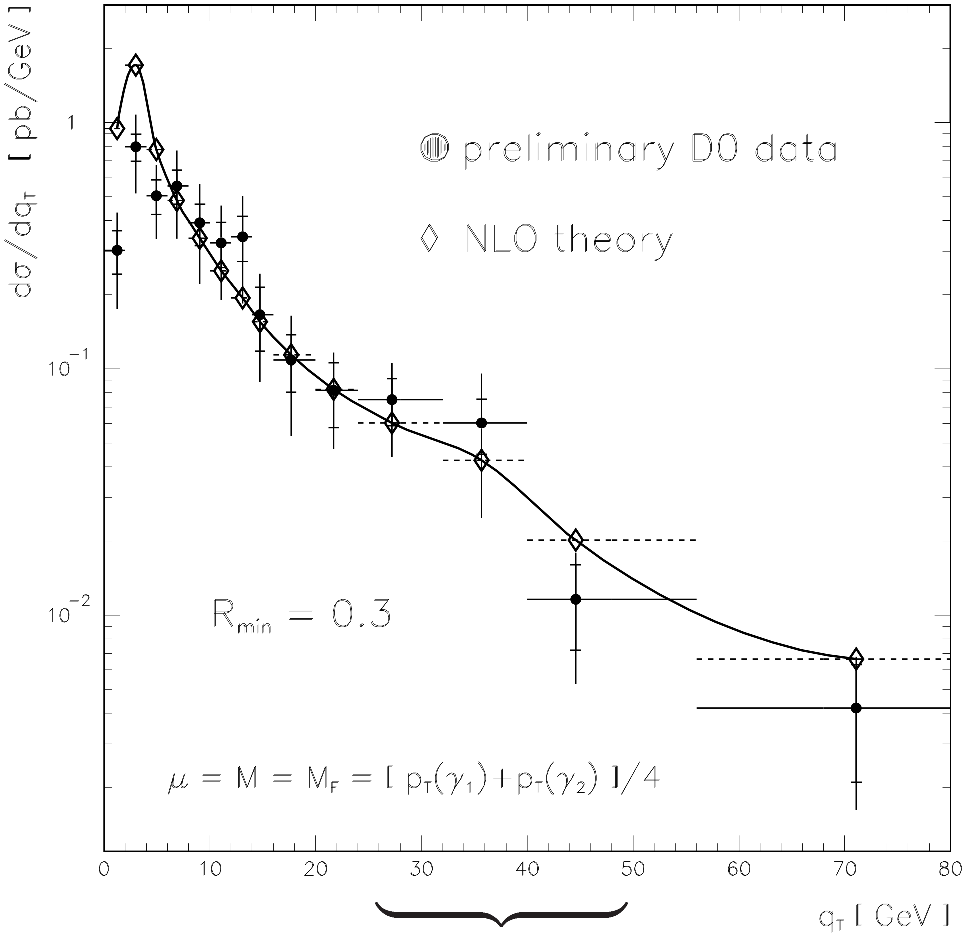

- Separation cut for the photons:

$$R_{min} = \sqrt{(y_{\gamma_1} - y_{\gamma_2})^2 + (\phi_{\gamma_1} - \phi_{\gamma_2})^2} > 0.3$$

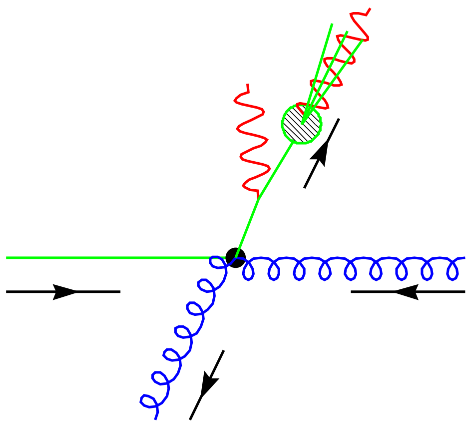
## The $q_T$ distribution at the Tevatron

[T.B., J.P. Guillet, E. Pilon, M. Werlen, Phys. Rev. D63 (2001)]

higher orders important $\rightarrow$ resummation !!!



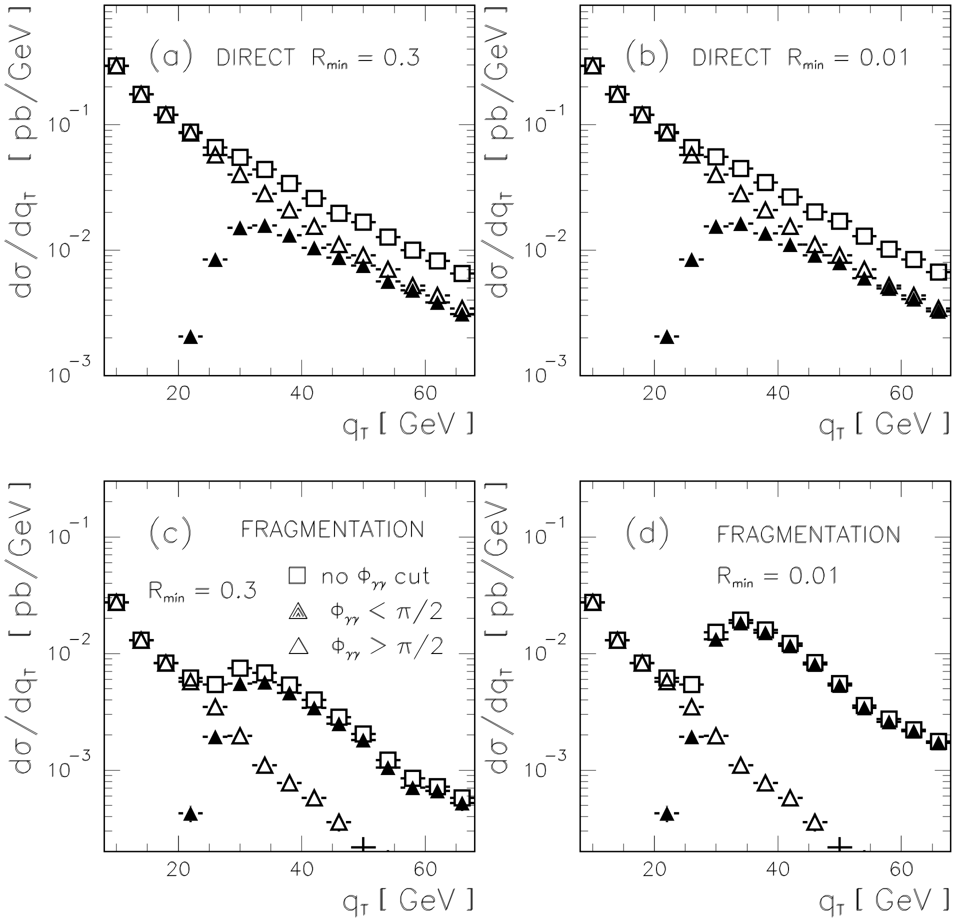

$$q_T = |\vec{p}_T(\gamma_1) + \vec{p}_T(\gamma_2)|$$

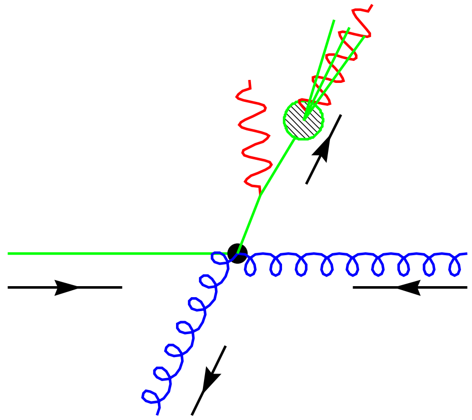


small shoulder visible $\Rightarrow$ collinear effect in the final state

$\Rightarrow$ NLO effect in the fragmentation part !!!

# The origin of the $q_T$ shoulder



collinear enhancement in fragmentation part for $\phi_{\gamma\gamma} \to 0$

$\Rightarrow$ $q_T$ shoulder is visible effect stemming from higher order corrections to the fragmentation component !!!

$\Rightarrow$ Effect depends on experimental cuts

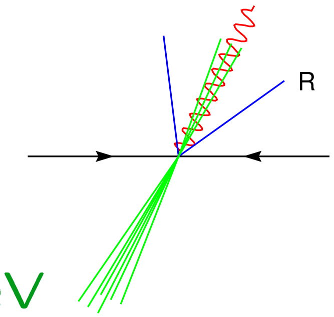
## Predictions for the LHC

[T.B., J.P. Guillet, E. Pilon, M. Werlen, EPJdirect C7 (2002)]

LHC: $PP$ collider at CERN: $\sqrt{s} = 14$ TeV, start $2007 + x$

- Cuts on transverse momenta, rapidity and invariant mass:

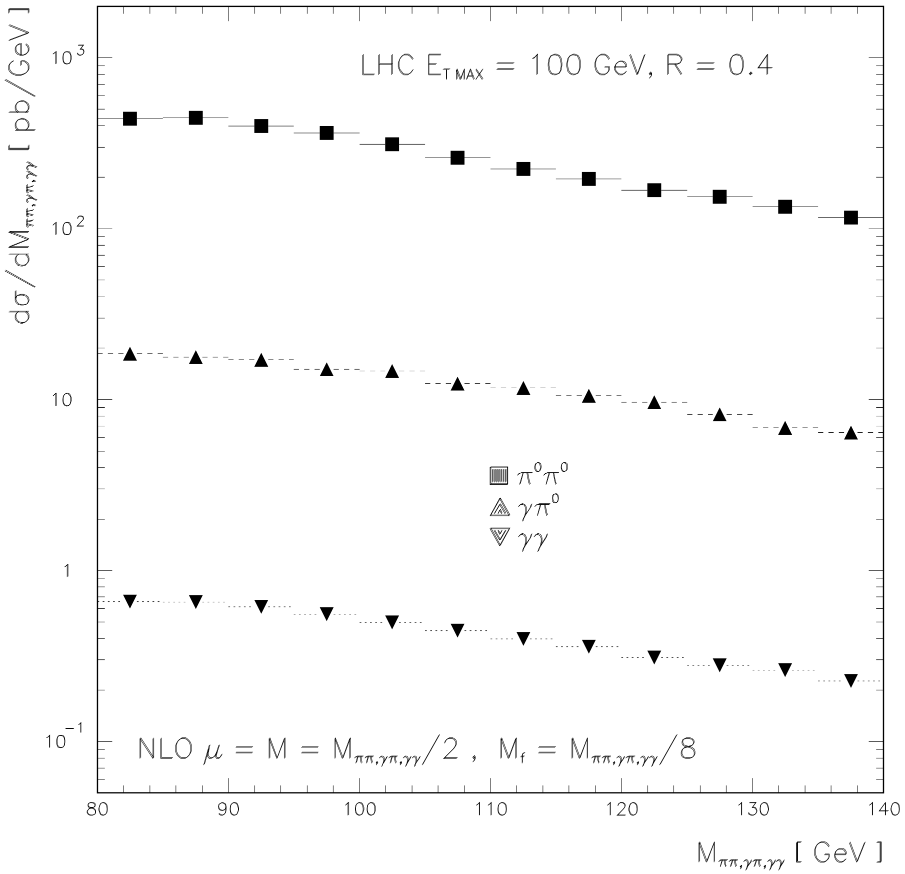
$$p_T(\gamma_1, \pi_1) > 40 \text{ GeV}$$
$$p_T(\gamma_2, \pi_2) > 25 \text{ GeV}$$
$$|y(\gamma_{1,2}, \pi_{1,2})| < 2.5$$
$$80 \text{ GeV} < M_{\gamma\gamma,\gamma\pi,\pi\pi} < 140 \text{ GeV}$$

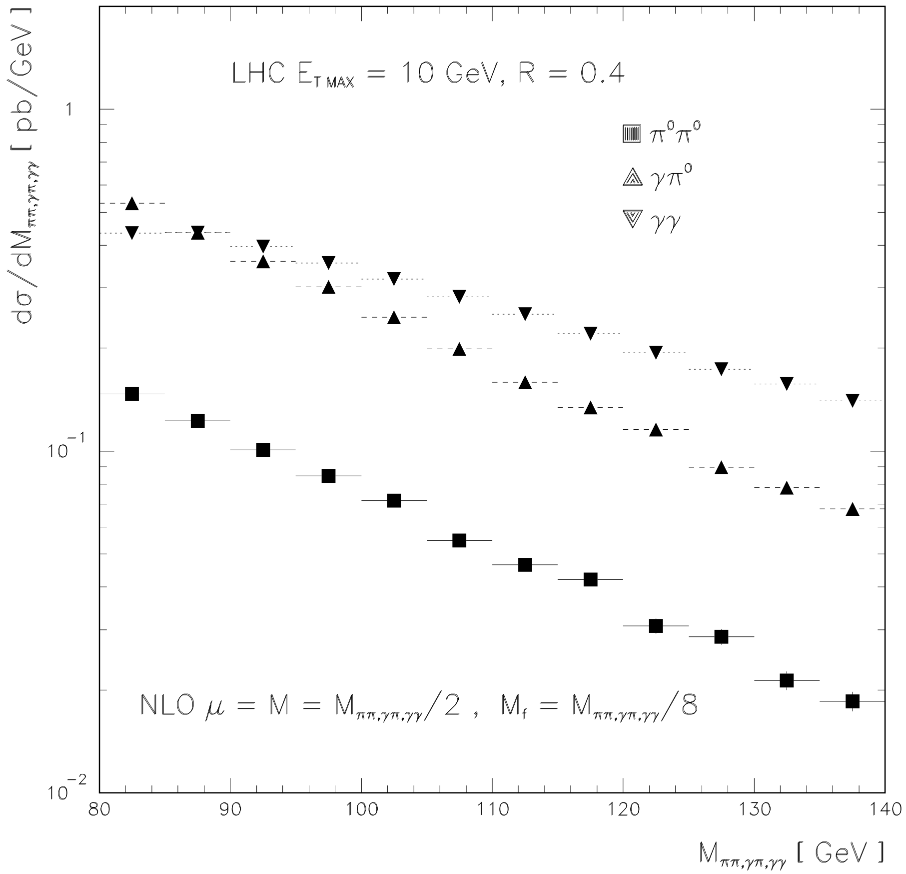



- Isolation cuts:

$$E_{T\,hadronic} < E_{T\,max} = 5, \ldots, 15 \text{ GeV}$$
$$R = \sqrt{(y - y_\gamma)^2 + (\phi - \phi_\gamma)^2} < 0.4$$

## The rates for $\gamma\gamma$, $\gamma\pi^0$, $\pi^0\pi^0$ at the LHC

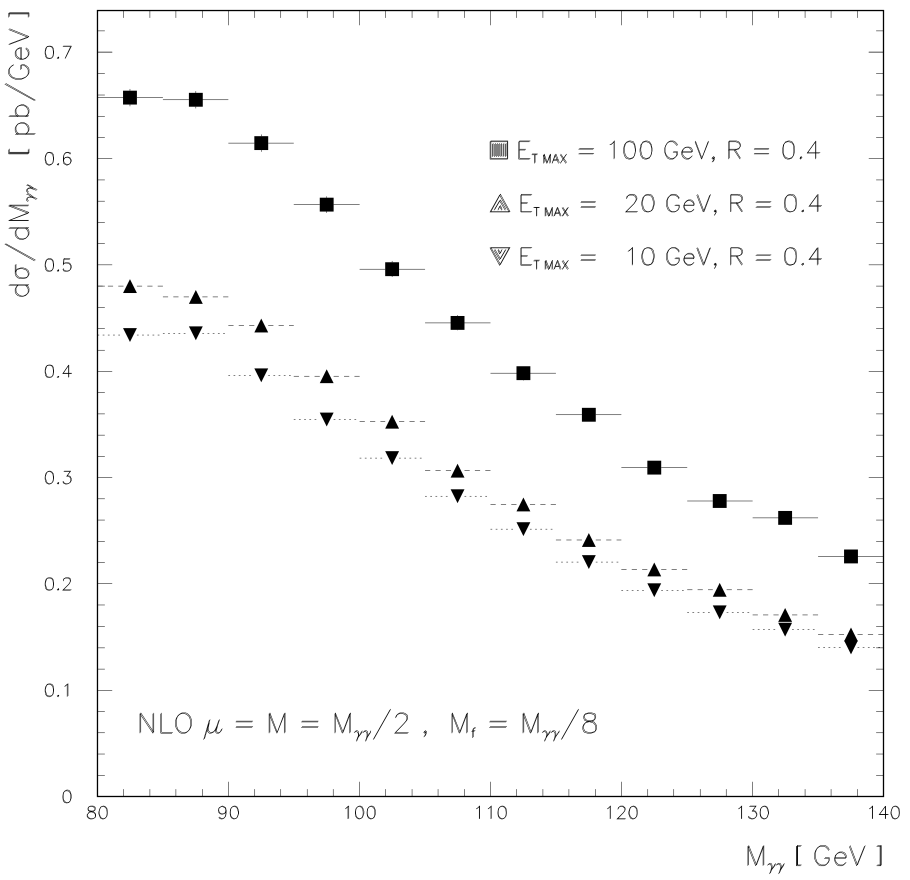


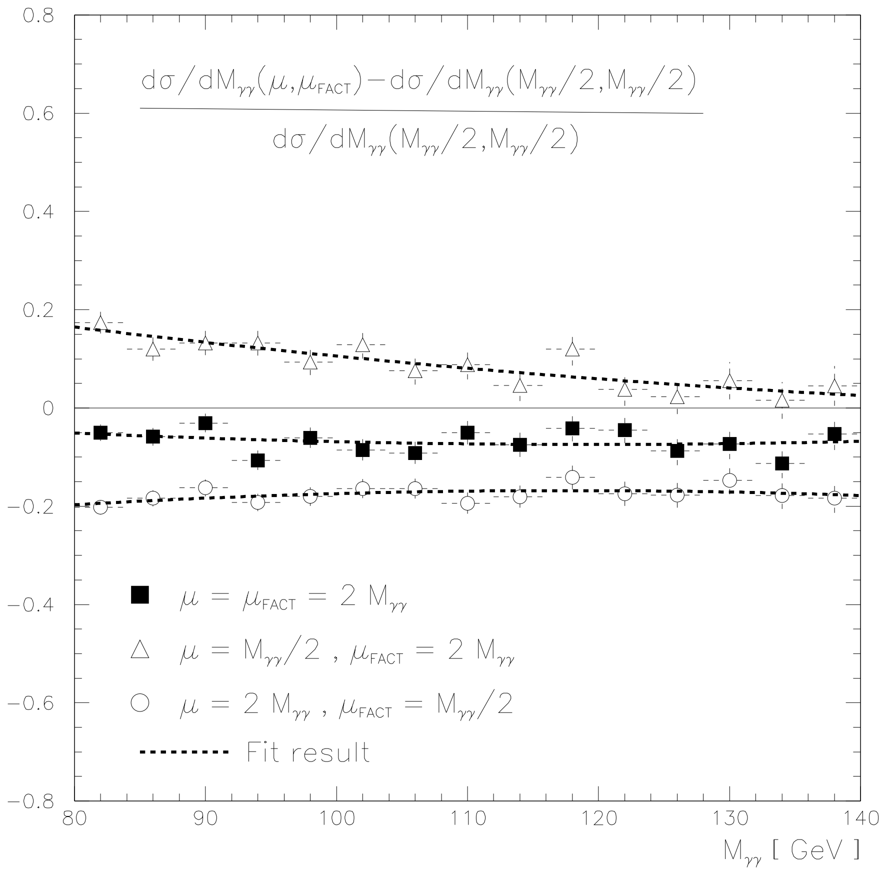




To suppress the pions ($\rightarrow$ "fake photons") and the photons of the fragmentation part severe isolation cuts have to be applied

!!! reduction factors of order $\mathcal{O}(1000)$ !!!

# Uncertainty for the $\gamma\gamma$ rate




uncertainty due to higher orders $\sim \pm 10 - 20\%$

contribution of the fragmentation component $\sim 10\%$

$[E_{T\,max} = 10$ GeV, $R = 0.4]$

## Problems due to strict isolation cuts

severe isolation cuts $\Rightarrow$

$$z = \frac{E_T(\pi^0)}{E_T(Had) + E_T(\pi^0)} \;,\; E_T(Had) = \frac{1-z}{z} E_T(\pi^0)$$

$$\Rightarrow \quad 1 \geq z \geq z_{min} = \frac{p_{T\,min}}{p_{T\,min} + E_{T\,max}}$$

$$E_T(\pi^0) > p_{T\,min} = 25 \text{ GeV}$$

$$E_T(Had) < E_T(max) \sim 10 \text{ GeV}$$

$$\Rightarrow \qquad z > z_{min} \sim 0.7$$

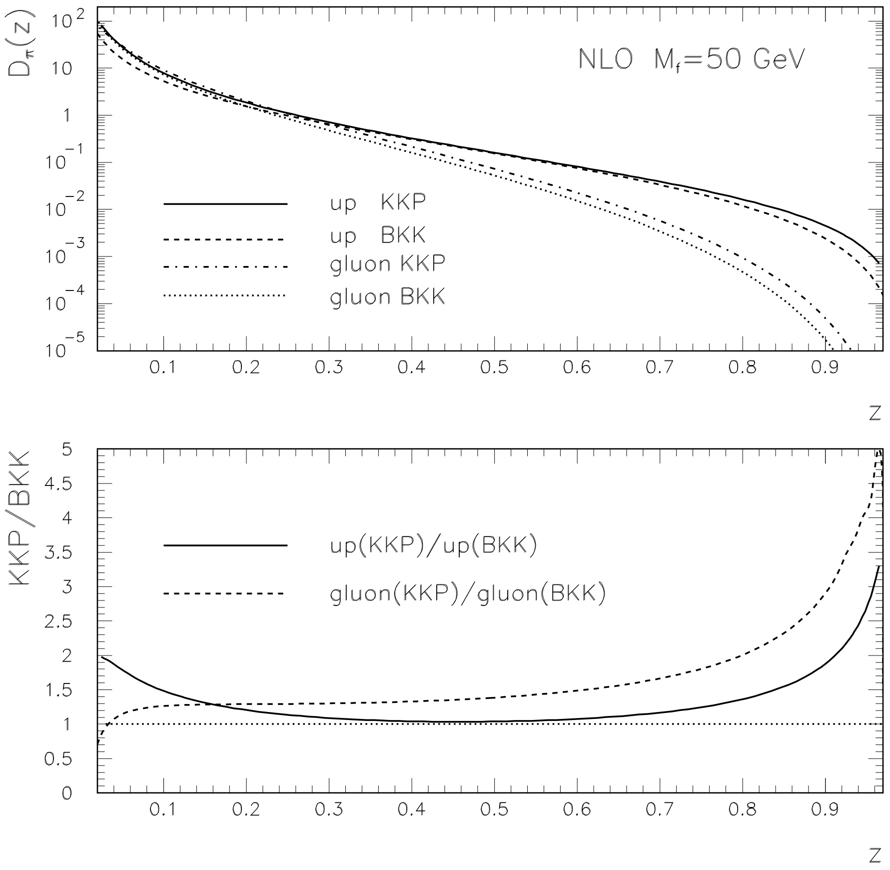
$\boxed{\text{Fragmentation models are tested at high } z,\ z \sim 1}$

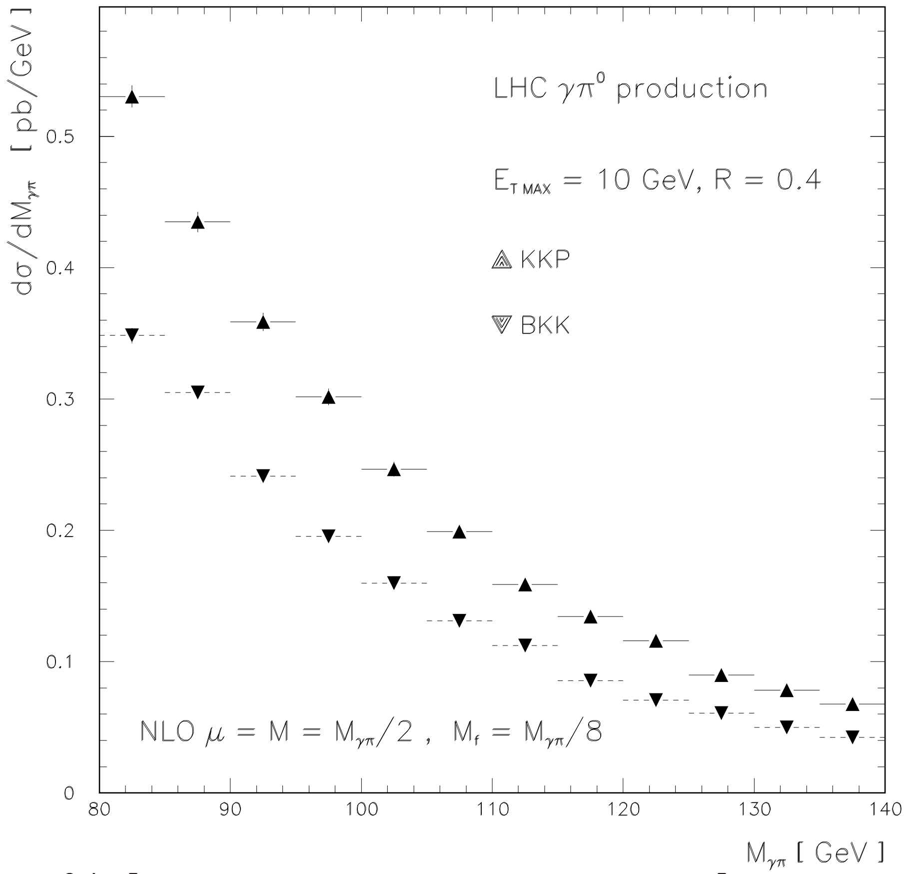
$D_{\pi/q,g}(z)$ is only constrainte for $0.1 < z < 0.7$ !!!

$\boxed{\text{Danger of large logarithms } \log(1-z)}$

$\sigma \sim A \log^2(1 - z_{min}) + B \log(1 - z_{min}) + \ldots \rightarrow$ resummation !!!

# Uncertainty for $\gamma\pi^0$ due to fragmentation functions



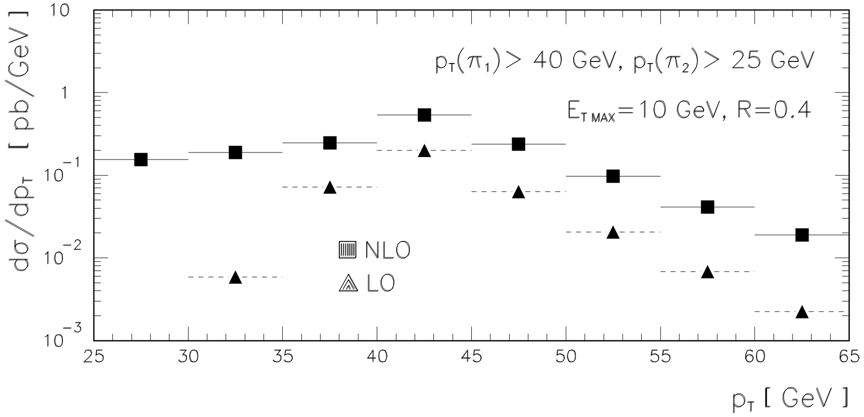

Contribution of the fragmentation part $\sim 10\%$ $[E_{T\,max} = 10$ GeV, $R = 0.4]$

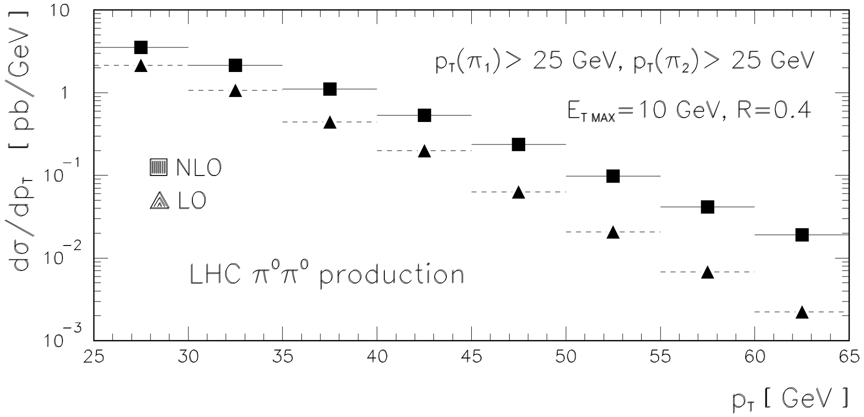
Uncertainties due to higher order effects $\sim \pm 40 - 50\%$

Uncertainty due to fragmentation functions $\sim \pm 50\%$ (???)

**!!! Measurement of high $p_T$ pions at Tevatron necessary !!!**

# Uncertainty for the $\pi^0\pi^0$ prediction




Asymmetric cuts worsen the problems:

$\rightarrow$ K factors much bigger

$\rightarrow$ scale variations much bigger

$\rightarrow$ uncertainties of fragm. functions bigger: 3–4 !

symmetric cuts preferable!

uncertainties of $\sim 10$ !!!

By analysing the forme of electromagnetic showers one can identify about 2 of 3 “fake photons” as a pion

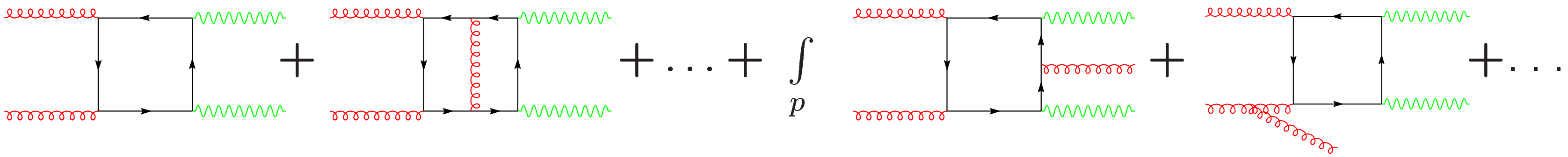
$\Rightarrow$ reduction factor $\sim 10$ for $\pi^0\pi^0$ !!! (uff)

## to improve DIPHOX ...

- ... include resummation for observables which are infrared sensitive
  - Clear for logarithms in $q_T$ in the direct part
  - Less clear for th elarge logarithms which are due to severe experimental cuts

  in the fragmentation part, for example $\log(1 - z_{min})$.

- ... include NLO corrections for the box contribution



[Bern, Dixon, de Freitas, JHEP 0203 (2002); Bern, Dixon, Schmidt, Phys. Rev. D66 (2002)]

- ... promote DIPHOX to NNLO (?)

## Other backgrounds for Higgs boson search

To make a reliable estimate of backgrounds for the relevant signal signatures

– $PP \to H$ by Gluon Fusion (NNLO), $H \to \gamma\gamma$, $H \to WW^{(*)}$

– $PP \to Hj$ (NLO $m_{Top} \to \infty$)

– $PP \to Hjj$ by Weak Boson Fusion (NLO), $H \to \tau^+\tau^-$, $H \to WW^{(*)}$, $H \to \gamma\gamma$

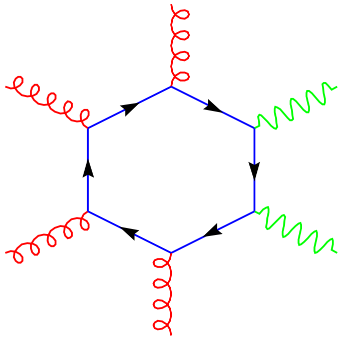
the following NLO computations are needed:

– $PP \to \gamma\gamma + 0, 1, 2\,\text{jets}$

– $PP \to WW^* + 0, 1, 2\,\text{jets}$

– $PP \to t\bar{t} + 0, 1, 2\,\text{jets}$

– $PP \to \tau^+\tau^- + 0, 1, 2\,\text{jets}$



Computation needs a GOLEM: General One-Loop Evaluator of Matrix Elements

...combination of EW and QCD methods
...isolation of IR poles (→subtractions)
...(maybe) development of numeric routines for finite reminders
...optimal amplitude representations (→numerically stable)

# Summary:

- Signal and background for $H \to \gamma\gamma$ known beyond LO
  - $\Rightarrow$ DIPHOX: full $\gamma\gamma$, $\gamma\pi^0$, $\pi^0\pi^0$ background at NLO
  - $\Rightarrow$ DIPHOX describes all available data
  - $\Rightarrow$ main uncertainty from $D_{\pi/q}(z)$ for $z > 0.7$ (measureable at Tevatron!)
  - $\Rightarrow$ NLO corrections increase Higgs discovery potential
  - $\Rightarrow$ DIPHOX available: http://wwwlapp.in2p3.fr/lapth/PHOX_FAMILY/diphox.html

- Backgrounds for Higgs searches in WBF only at tree level
  - $\Rightarrow$ NLO calculations for many $2 \to 3$, $2 \to 4$ processes on the wish-lists
  - $\Rightarrow$ Needed: automatization of multi-particle NLO calculations "GOLEM"
  - $\Rightarrow$ NLO amplitudes as input for MC@NLO $\to$ reliable S+B predictions

Only a profound knowledge of the Standard Model will allow us to understand new and unexpected phenomena !!!