

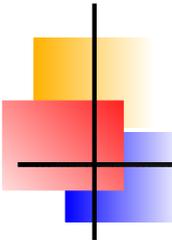
PHOTON PAIR PRODUCTION AT THE LHC HIGGS SIGNAL AND QCD BACKGROUNDS

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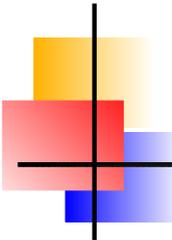
March 13, 2006

E. L. Berger and J.-W. Qiu, Phys. Rev. D 67, 034026 (2003)
C. Balazs, E. L. Berger, P. Nadolsky, C.-P. Yuan, hep-ph/0603037



Contents

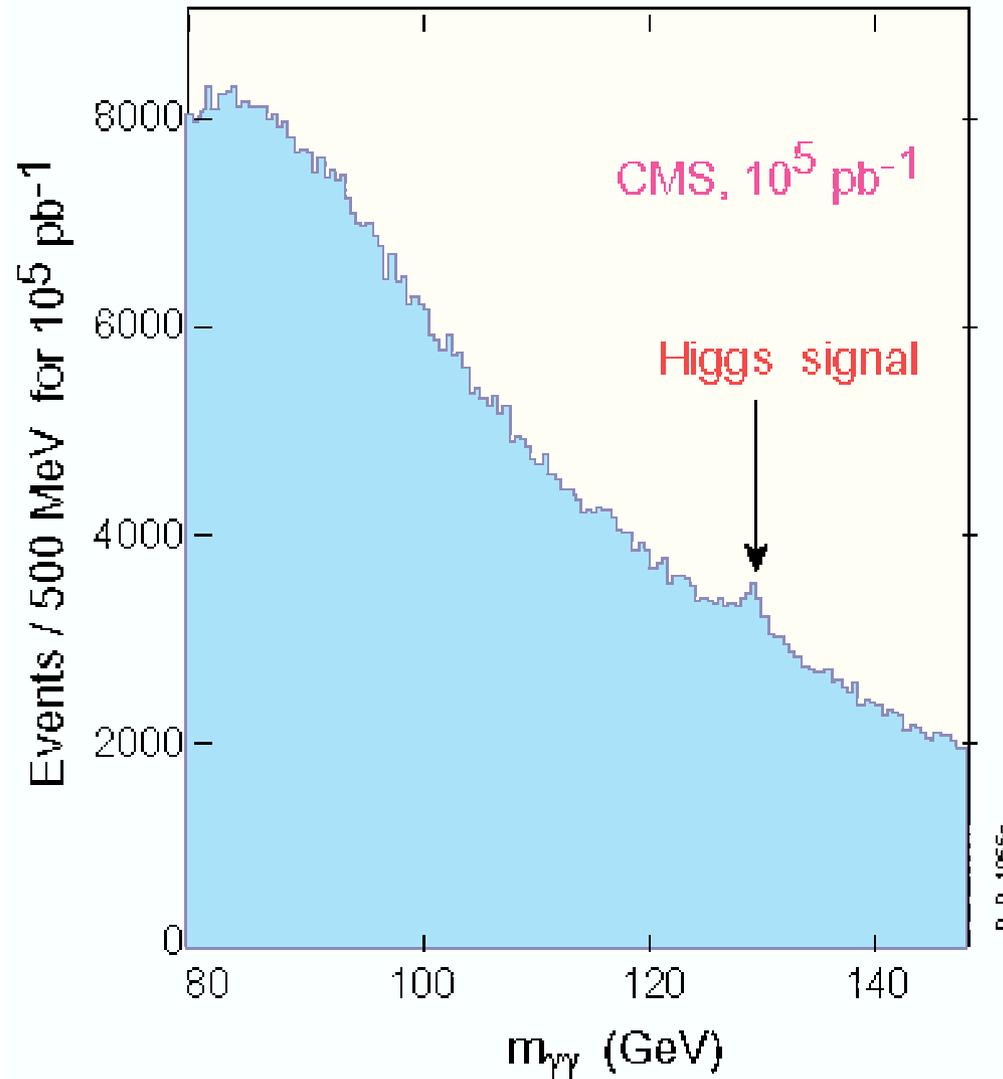
1. Higgs search at the LHC
2. Transverse momentum distribution
3. Necessity for all-orders soft gluon resummation
4. Calculations of the transverse momentum distributions of the Higgs boson and of $\gamma\gamma$ pairs in $p\bar{p} \rightarrow \gamma\gamma X$ at $\sqrt{S} = 1.96$ TeV, and comparison with data and $pp \rightarrow \gamma\gamma X$ at $\sqrt{S} = 14$ TeV
5. Summary and Discussion



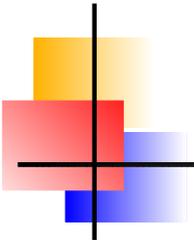
Higgs Boson Search at the LHC

- Discover/understand the mechanism for electroweak symmetry breaking: a clear goal of hadron collider experiments during the next decade
- ATLAS and CMS plans:
 - Thorough search for Higgs bosons
 - Measure their properties and determine their couplings
- Help guide the search with theoretical predictions for the signal and backgrounds
- Focus in this talk on the $\gamma\gamma$ final state:
 - Signal $h \rightarrow \gamma\gamma$ and background from all QCD subprocesses

What do we expect to see in the $\gamma\gamma$ mass spectrum?



- Try to improve the signal to background by selecting events with 'large' Q_T



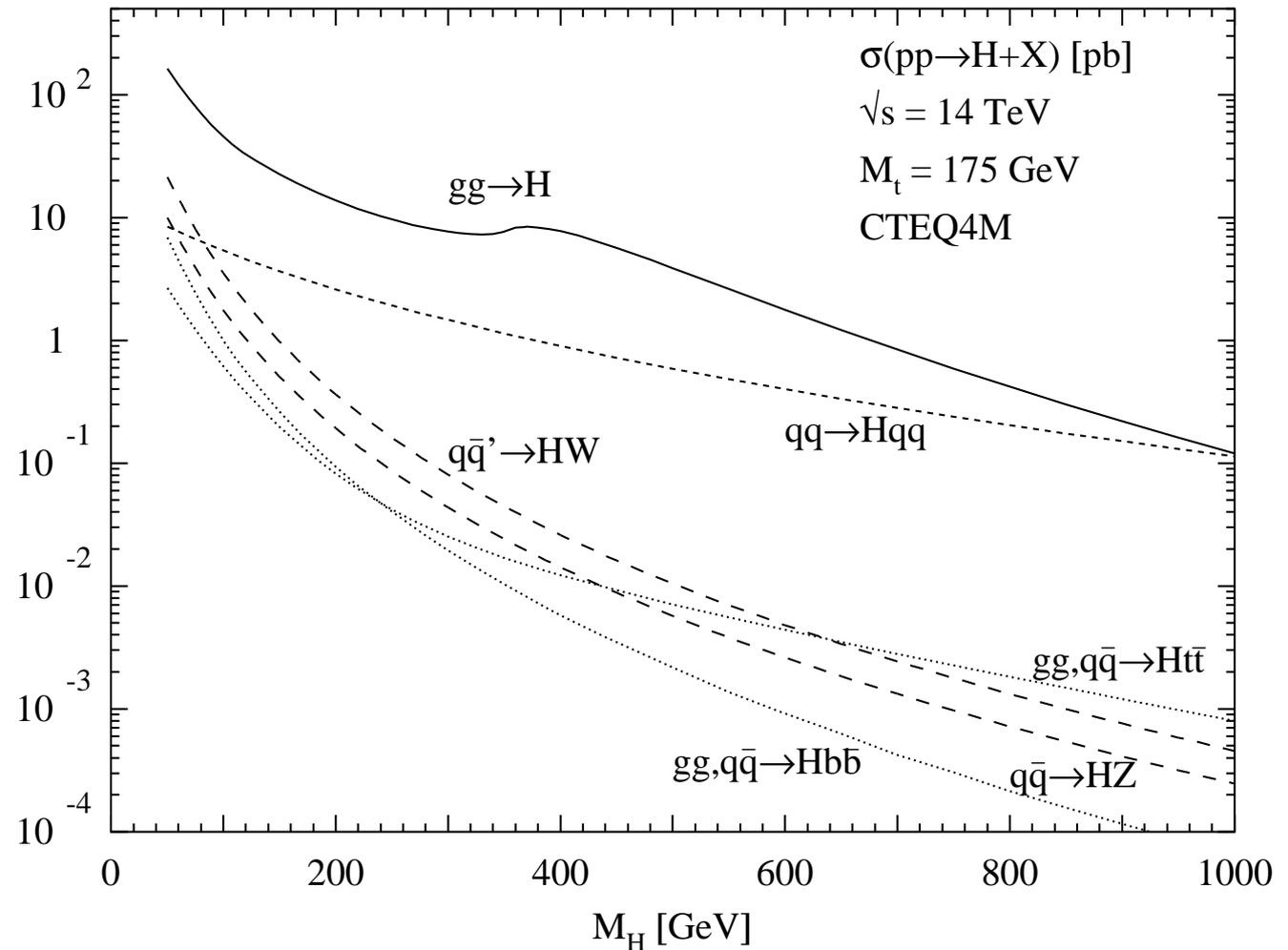
Transverse momentum Q_T distribution

- Event modeling, kinematical acceptance, and efficiencies all depend on Q_T
- Expected shape of $d\sigma/dQ_T$ can affect experimental triggering and analysis strategies
- The behavior of $d\sigma/dQ_T$ affects the precision of the determination of the event vertex from which the Higgs boson ($\gamma\gamma$ peak) emerges. Greater Q_T activity associated with Higgs boson production allows a more precise determination of the vertex especially in the case of multiple events per beam crossing
- Selections on Q_T can be used to enhance the signal/background ratio

Cross sections for Higgs Boson Production

M. Spira

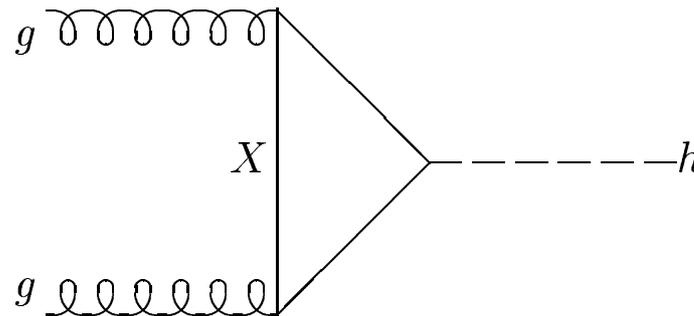
- The fully inclusive gluon-gluon fusion subprocess $gg \rightarrow hX$ is the dominant production mechanism for Higgs bosons



glue glue fusion for Higgs production

- lowest order triangle graph

$$X = t, b, \tilde{q}$$



- In the SM, the top quark t contribution dominates
- Take the limit $m_t \rightarrow \infty$. The triangle collapses to a point. The predicted cross section agrees within 5% with the triangle cross section for

$$m_h < 2m_t$$

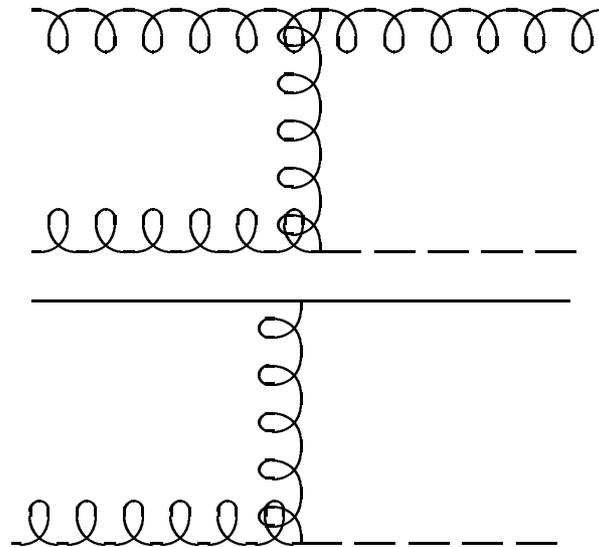
- NLO and NNLO contributions to the inclusive rate are large

Spira, Djouadi, Graudenz, and Zerwas; Dawson and Kauffman; Harlander and Kilgore;

Anastasiou and Melnikov

Cross section at finite transverse momentum Q_T

- At zero-th order, the triangle diagram produces a $\delta^2(\vec{Q}_T)$ -function transverse momentum distribution
- Finite Higgs boson transverse momentum is provided at order α_s by gg , qg , and $q\bar{q}$ subprocesses

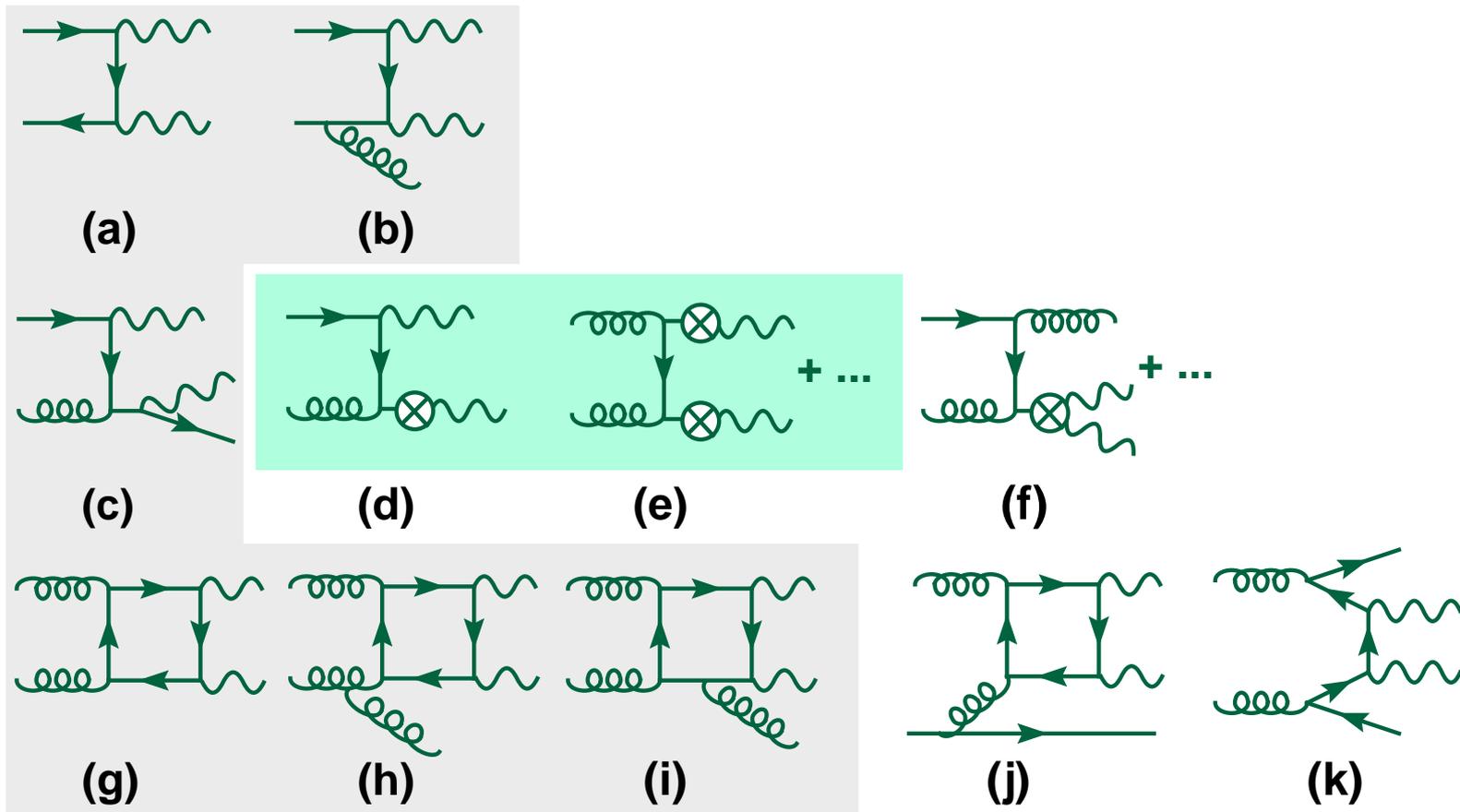


- Also $gg \rightarrow g^* \rightarrow gh$ and $q\bar{q} \rightarrow g^* \rightarrow gh$
- Differential cross section at fixed-order, NNLO, exists

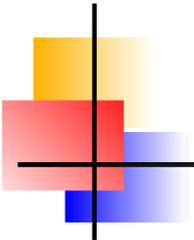
Anastasiou, Melnikov, Petriello

QCD Production of Photon Pairs

- QCD 'background' subprocesses initiated by $q\bar{q}$, qg and gg subprocesses



- Run 2 data from CDF at FNAL permit test of calculations
- Interesting QCD in its own right



Differential cross section; fixed-order in α_s

- At fixed-order in α_s , the transverse momentum distribution behaves as

$$\frac{\alpha_s}{Q_T^2} [a + b \log(m_{\gamma\gamma}^2/Q_T^2)] \rightarrow \infty \text{ as } Q_T^2 \rightarrow 0$$

- $1/Q_T^2$ divergence is related to the light parton propagators
- The logarithmic term $\log(m_{\gamma\gamma}^2/Q_T^2)$ remains after the usual cancellation of infra-red divergences and the absorption of collinear divergences into the renormalized parton densities

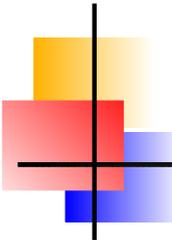
- In addition

$$\frac{\sigma^{\text{NLO}}}{\sigma^{\text{LO}}} = \mathcal{O}(\alpha_s \log^2(m_{\gamma\gamma}^2/Q_T^2)) \text{ is not small } (\alpha_s(\mu)/\pi) \ln^2(m_h^2/Q_T^2) \sim 0.7$$

if $\mu = m_h = 125 \text{ GeV}$ and $Q_T = 14 \text{ GeV}$

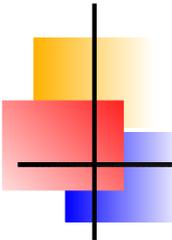
- The large logarithmic terms spoil conventional factorization in QCD perturbation theory
- The physical cross section peaks below $Q_T \sim m_{\gamma\gamma}/3$.

A reliable QCD calculation for small and intermediate Q_T requires that we resum the large logarithmic terms to all orders in α_s



Restructure the perturbative expansion

- In terms of $\alpha_s \ln^2(Q/Q_T)$, instead of α_s , with ($L = \ln(Q/Q_T)$)
- $d\sigma/dQ_T^2 =$
$$Q_T^{-2} \{ \alpha_s ({}_1v'_1 L + {}_1v'_0) + \alpha_s^2 ({}_2v'_3 L^3 + {}_2v'_2 L^2) + \alpha_s^3 ({}_3v'_5 L^5 + {}_3v'_4 L^4) + \dots \}$$
$$+ \alpha_s^2 ({}_2v'_1 L + {}_2v'_0 L^0) + \alpha_s^3 ({}_3v'_3 L^3 + {}_3v'_2 L^2) +$$
$$+ \alpha_s^3 (\dots$$
- In a fixed order calculation (column by column), convergence at small Q_T is compromised by higher order uncalculated logarithmic terms
- In a resummed calculation (line by line), convergence is preserved in each “order” (each line), and higher order corrections are included systematically
- Expand the predictive power of QCD perturbation theory by (re)summing the large logarithmic contributions in an improved calculational scheme

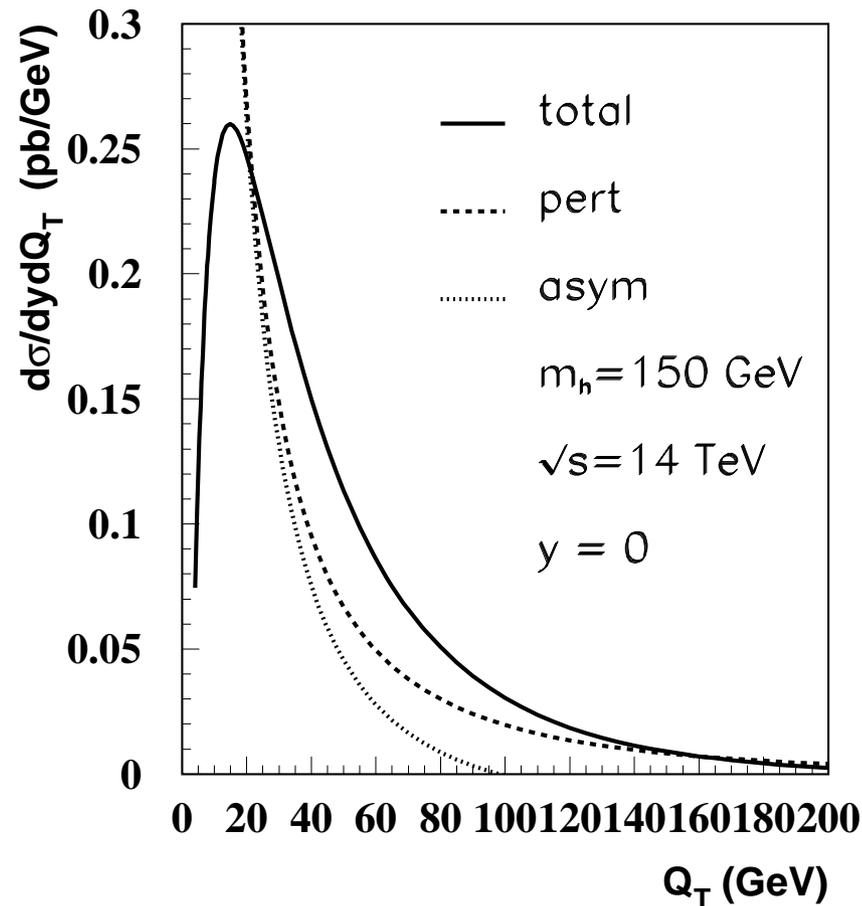


All Orders Soft Gluon Resummation

- Resummation in impact parameter b -space
 - \vec{b} -space = Fourier conjugate of \vec{Q}_T -space
 - Fourier transform $\frac{d\sigma}{dydQ_T^2}$ to b -space
 - Sum multiple gluon emission to all orders in α_s
 - Transverse momentum conservation preserved
 - Fourier transform back to Q_T -space
 - Resummation produces a Q_T distribution that is finite as $Q_T \rightarrow 0$

Higgs boson differential cross section at LHC

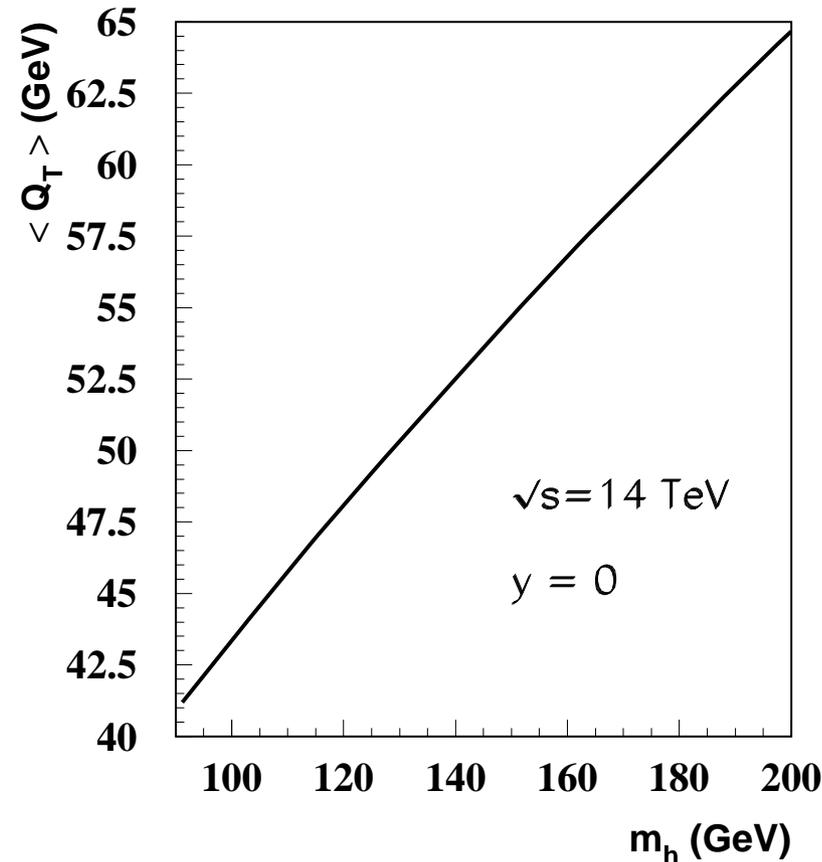
Berger and Qiu Phys Rev D67, 034026 (2003)



- Observe the divergence as $Q_T \rightarrow 0$ of the fixed-order result ('pert')
- The total prediction is dominated by the resummed result for $Q_T \leq Q$
- Resummation provides a well behaved $d\sigma/dQ_T$ at all Q_T .

It changes the predicted shape and normalization in the region of Q_T where the cross section is large

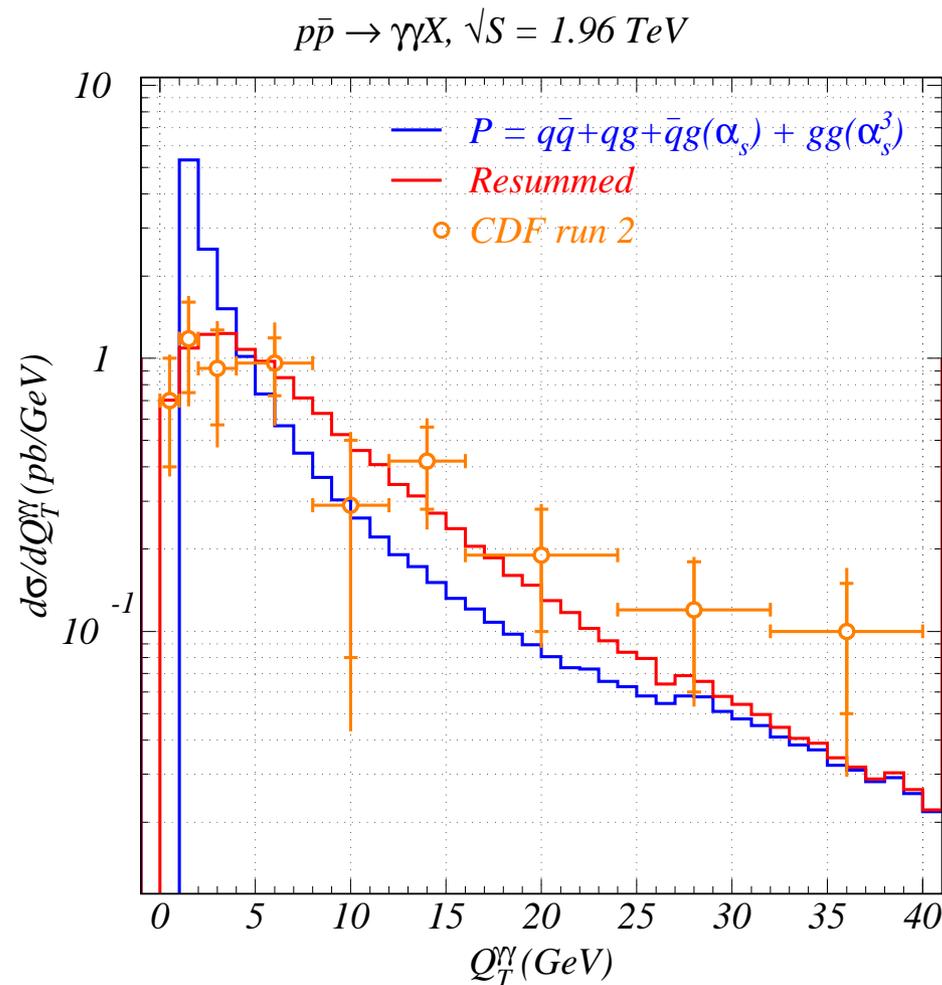
Average $\langle Q_T \rangle$ for Higgs boson production at LHC vs m_h Berger and Qiu Phys Rev D67, 034026 (2003)



- $\langle Q_T \rangle$ grows from about 41 GeV at $m_h = M_Z$ to about 65 GeV at $m_h = 200$ GeV
- Nearly a straight line over the range shown, with $\langle Q_T \rangle \simeq 0.21m_h + 22$ GeV

Comparison of our results with the CDF Run 2 data

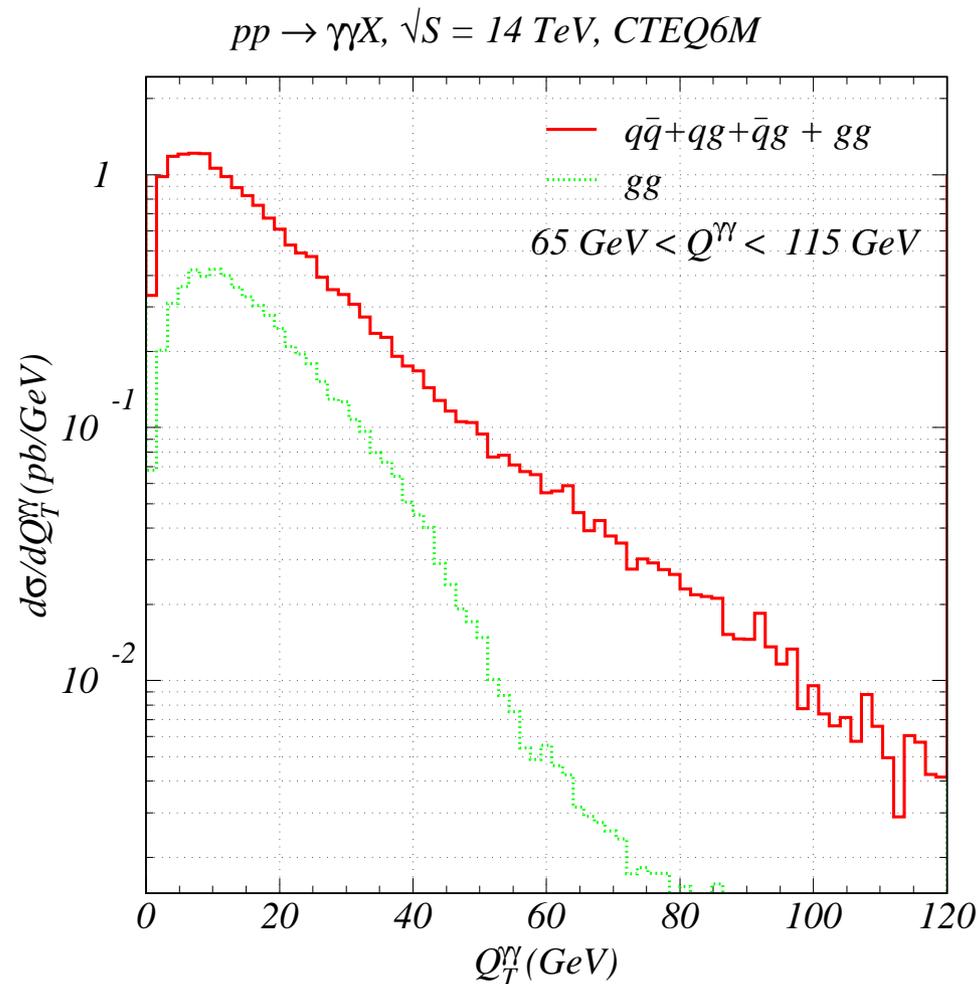
Balazs, Berger, Nadolsky, Yuan, hep-ph/0603037



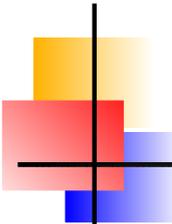
- Resummed calculation differs in shape and normalization from the finite-order perturbative result (P); it agrees well with data
- Discrepancy at the larger values of Q_T is understood – related to the region of small $m_{\gamma\gamma}$ ($< Q_T$) and small $\Delta\phi$ where other physical effects dominate – not of concern at the LHC

Prediction for the LHC *Balazs, Berger, Nadolsky, Yuan*

- Example for $\gamma\gamma$ invariant mass in the interval 65 to 115 GeV



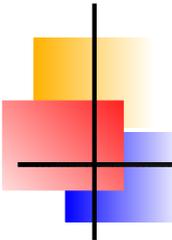
- The qg and $q\bar{q}$ subprocesses dominate. The glue glue subprocess is a small portion of the answer even at the LHC



Prediction for the LHC

Balazs, Berger, Nadolsky, Yuan

- The Q_T distribution broadens with increasing $m_{\gamma\gamma}$, just as it does for increasing m_h
- For $m_{\gamma\gamma} = (55-65, 65-95, 95-130, \text{ and } 130-250)$ GeV
 $\langle Q_T \rangle = (14, 17, 25, \text{ and } 33)$ GeV.
- For the SM Higgs boson mass range, 115 to 130 GeV, the $\gamma\gamma$ background peaks at a smaller value of Q_T than the Higgs boson signal. The background has $\langle Q_T \rangle \sim 27$ GeV, vs. ~ 40 GeV for the Higgs boson signal
- The $qg \rightarrow \gamma\gamma X$ and $q\bar{q} \rightarrow \gamma\gamma X$ subprocesses that dominate QCD background have a softer Q_T spectrum than that for Higgs boson production because there is less gluon radiation in fermionic subprocesses



Conclusions and Discussion

- $g + g \rightarrow hX$ dominates inclusive Higgs boson production at the LHC
- Irreducible backgrounds in the $h \rightarrow \gamma\gamma$ decay channel arise from fermionic subprocesses ($q\bar{q} \rightarrow \gamma\gamma X$; $qg \rightarrow \gamma\gamma X$) and gluonic subprocesses ($gg \rightarrow \gamma\gamma X$). The qg and $q\bar{q}$ subprocesses dominate. They have a softer Q_T spectrum than $gg \rightarrow hX$
- The two large scales, $m_{\gamma\gamma}$ and Q_T , and the fact that the fixed-order QCD contributions are singular as $Q_T \rightarrow 0$, necessitate all-orders resummation of large logarithmic contributions to obtain predictions for Q_T distributions
- Good agreement with CDF data on $p\bar{p} \rightarrow \gamma\gamma X$ at $\sqrt{S} = 1.96$ TeV
- Predictions presented for Q_T distributions of Higgs boson and $\gamma\gamma$ production at $\sqrt{S} = 14$ TeV for $m_{\gamma\gamma} = M_Z$ to 200 GeV
- **Suggestion:** a selection of events with large $Q_T^{\gamma\gamma}$ will help to improve S/B . The challenge remains formidable