$h \to \gamma\gamma$ at the LHC:
resummed predictions for the signal and background

Pavel Nadolsky

Argonne National Laboratory

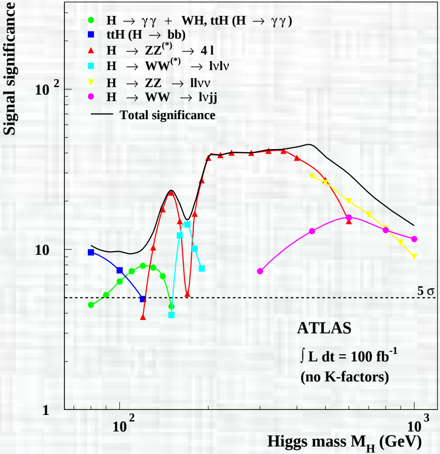
November 1, 2006

C. Balazs, E. Berger, **P. N.**, *C.-P. Yuan, Phys. Lett., B637, 235 (2006); hep-ph/0611xxx*

Yesterday: NNLL/NLO Q_T resummation for $\gamma\gamma$ event distributions
Today: application to Higgs searches

Light Higgs boson search at the LHC

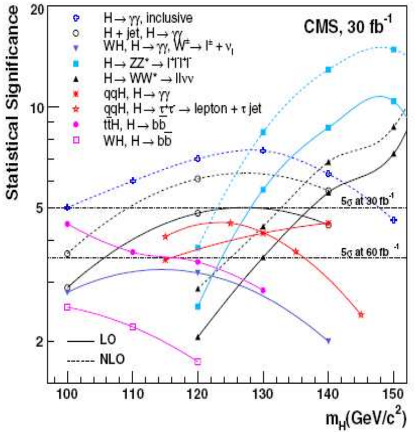
- The standard model and its extensions (MSSM) suggest existence of a Higgs scalar with a mass $115 \lesssim M_H \lesssim 140$ GeV
- $gg \to h \to \gamma\gamma$ (via t-quark loop) is the leading search mode in this mass region
- A 5σ discovery of SM Higgs boson is possible with $\mathcal{L} = 10 - 30$ fb^{-1}



- Prospects for Higgs discovery and cross section measurement in the $\gamma\gamma$ mode depend, among many factors, on the physics model (SM, MSSM, etc.) and form of signal and background event distributions

Light Higgs boson search at the LHC

- The standard model and its extensions (MSSM) suggest existence of a Higgs scalar with a mass $115 \lesssim M_H \lesssim 140$ GeV
- $gg \to h \to \gamma\gamma$ (via t-quark loop) is the leading search mode in this mass region
- A 5σ discovery of SM Higgs boson is possible with $\mathcal{L} = 10 - 30$ fb^{-1}



- Prospects for Higgs discovery and cross section measurement in the $\gamma\gamma$ mode depend, among many factors, on the physics model (SM, MSSM, etc.) and form of signal and background event distributions

Motivation to study $\gamma\gamma$ differential distributions

Higgs signal discrimination is improved by considering differential event rates

Effect on significance

- "Model-independent" resonance search
  - Sliding $M_{\gamma\gamma}$ window: unknown position of the resonance $\Downarrow$
  - unbinned likelihood analysis $\Uparrow$
- Search for a color-neutral spin-0 particle
  - differential likelihood analysis
  - discrimination based on p_T & decay angles $\Uparrow$

Motivation to study $\gamma\gamma$ differential distributions

- Acceptance & efficiency depend on $\gamma\gamma$ kinematical distributions; Q_T dependence propagates into the discovery significance and measured Higgs cross sections

$$N^{\gamma\gamma}_{observed} = \epsilon(Q_T, ...)N^{\gamma\gamma}_{produced};$$
$$S/\sqrt{B} \propto \epsilon_S/\sqrt{\epsilon_B};$$
$$...$$

- SM $\gamma\gamma$ production provides a "standard candle" benchmark required for the $\sigma(pp \to H \to \gamma\gamma)$ measurement
- Many distributions (including $d\sigma/dQ$) depend on $d\sigma/dQ_T$ because of p_T^γ cuts
  - unphysical discontinuities in fixed-order calculations destabilize predictions for $d\sigma/dQ$, etc. $\Rightarrow$ resummation

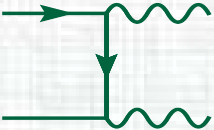
Motivation to study $\gamma\gamma$ differential distributions

- Predictions for $\gamma\gamma$ production are most reliable for $E_T^{iso} \lesssim Q_T \lesssim Q$ (E_T^{iso} is the photon isolation energy)
  - photon fragmentation and other large corrections are strongly enhanced outside of this region!

Motivation to study $\gamma\gamma$ differential distributions

- Predictions for $\gamma\gamma$ production are most reliable for $E_T^{iso} \lesssim Q_T \lesssim Q$ (E_T^{iso} is the photon isolation energy)
  - photon fragmentation and other large corrections are strongly enhanced outside of this region!

Unknown or uncertain contributions

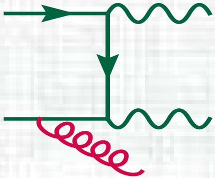


$t-$channel singularity $(Q_T = 0)$; excluded by $\min p_T^\gamma$ cuts

Motivation to study $\gamma\gamma$ differential distributions

- Predictions for $\gamma\gamma$ production are most reliable for $E_T^{iso} \lesssim Q_T \lesssim Q$ (E_T^{iso} is the photon isolation energy)
  - photon fragmentation and other large corrections are strongly enhanced outside of this region!

Unknown or uncertain contributions

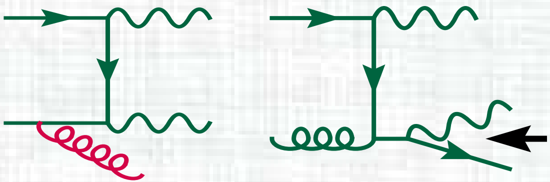


$t-$channel enhancement; not excluded at $Q_T > Q$

Motivation to study $\gamma\gamma$ differential distributions

- Predictions for $\gamma\gamma$ production are most reliable for $E_T^{iso} \lesssim Q_T \lesssim Q$ (E_T^{iso} is the photon isolation energy)
  - photon fragmentation and other large corrections are strongly enhanced outside of this region!

Unknown or uncertain contributions



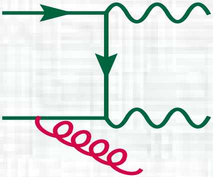
$t-$channel enhancement; not excluded at $Q_T > Q$

Single-γ fragmentation; enhanced at $Q_T < E_T^{iso}$ or $Q_T > Q$

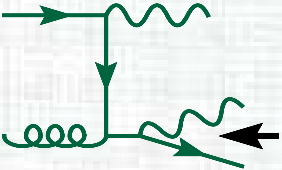
Motivation to study $\gamma\gamma$ differential distributions

- Predictions for $\gamma\gamma$ production are most reliable for $E_T^{iso} \lesssim Q_T \lesssim Q$ (E_T^{iso} is the photon isolation energy)
  - photon fragmentation and other large corrections are strongly enhanced outside of this region!

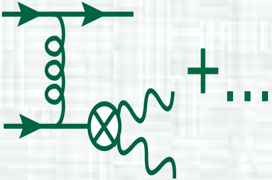
Unknown or uncertain contributions



$t-$channel enhancement; not excluded at $Q_T > Q$



Single-γ fragmentation; enhanced at $Q_T < E_T^{iso}$ or $Q_T > Q$

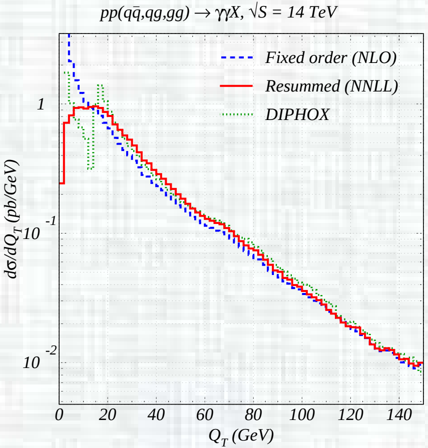


low-Q $\gamma\gamma$ fragmentation; $Q_T \gtrsim Q$

Resummation for $\gamma\gamma$ background

- Q_T resummation at NNLL/NLO accuracy in **direct** $q\bar{q} + qg$ and $gg + gq$ channels

- improved treatment of the **fragmentation** region
- improved model for nonperturbative resummed contributions
- resummed form factor in two resummation schemes
- continuous distributions $d\sigma/\left(d\vec{p}_{\gamma_3} d\vec{p}_{\gamma_4}\right)$; MC integration in revised ResBos



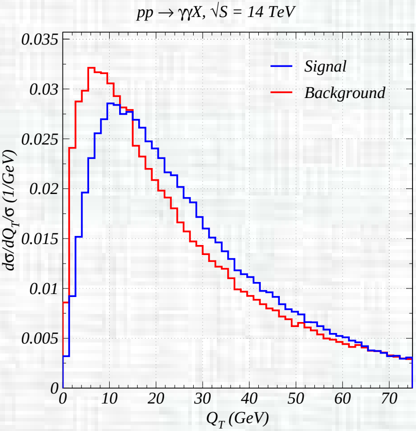
Resummed distributions for SM Higgs

I compare normalized distributions in Q_T, photon's polar angle θ_* and azimuthal angle φ_* in the Collins-Soper $\gamma\gamma$ rest frame; the figures are preliminary!

- Higgs signal for $M_H = 130$ GeV: the resummed cross section from *Balazs, Yuan, 2001*, upgraded to NNLL/NLO
- QCD background for $128 < M_{\gamma\gamma} < 132$ GeV
  - $p_T^\gamma > 40\,(25)$ GeV for the harder (softer) photon
  - rapidity $|y_\gamma| < 2.5$; $\Delta R_{\gamma\gamma} > 0.4$
  - Photon isolation: $E_T^{hadron} < 15$ GeV in $\Delta R_{cone} = 0.4$ around each photon
  - CTEQ6M PDF's

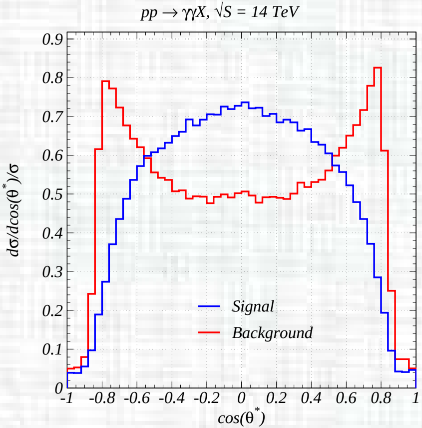
Transverse momentum (Q_T) distributions

- Resummation of ISR logs predicts the signal Q_T spectrum to be harder than the background Q_T spectrum
  - the leading Sudakov (cusp) functions in $q\bar{q} + qg \to \gamma\gamma$ and $gg + gq \to H$ satisfy $\mathcal{A}_{gg}(\mu) = (C_A/C_F)\mathcal{A}_{q\bar{q}}(\mu) = (9/4)\mathcal{A}_{q\bar{q}}(\mu)$



- However, FSR and isolation model affect the background Q_T spectrum at the level comparable to ISR resummation (increased uncertainties!)
- Better discrimination based on $d\sigma/dQ_T$ may be achieved in the future by tightening photon isolation and constraining FSR contributions in measurements at Q away from M_H

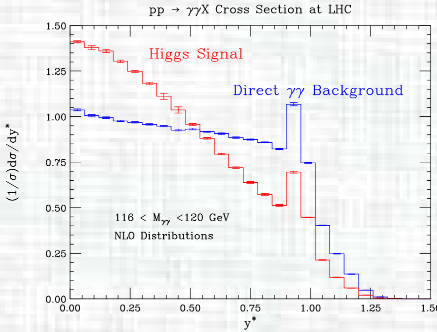
Polar angle (θ_*) distributions



Collins-Soper frame

- Higgs scalar decay is isotropic; suppressed at $\cos\theta_* = \pm 1$ by p_T^γ cuts
- The $t-$ and u-channel background contributions peak at $\cos\theta_* = \pm 1$

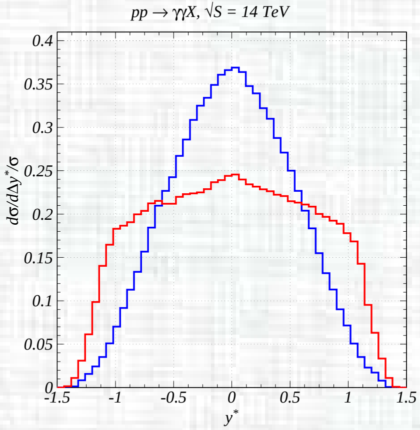
Polar angle (θ_*) distributions



Lab frame

- A related observable is $y_* \equiv (y_{hard} - y_{soft})/2$ (Bern, Dixon, Schmidt)
- An NLO distribution exhibits a kinematical singularity at $y^* \approx 0.94$, caused by incomplete cancellation of real and virtual corrections at $Q_T \approx 0$
- Our calculation predicts a continuous y^* distribution as a result of resummation of the small-Q_T singularity

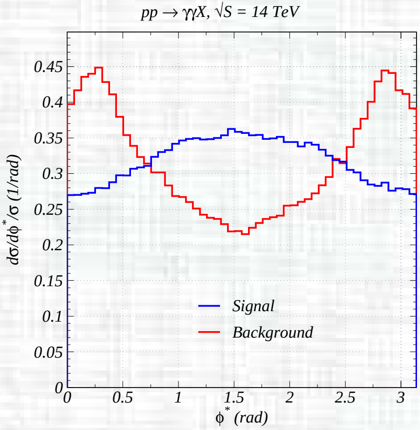
Polar angle (θ_*) distributions



Lab frame

- A related observable is $y_* \equiv (y_{hard} - y_{soft})/2$ (Bern, Dixon, Schmidt)
- An NLO distribution exhibits a kinematical singularity at $y^* \approx 0.94$, caused by incomplete cancellation of real and virtual corrections at $Q_T \approx 0$
- Our calculation predicts a continuous y^* distribution as a result of resummation of the small-Q_T singularity

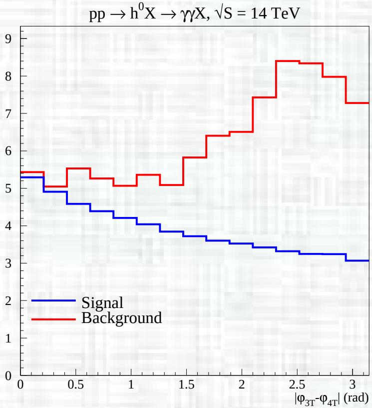
Azimuthal angle (φ_*) distributions



Collins-Soper frame

- φ_* is the angle between the plane of hadronic momenta $\vec{p}_1$ and $\vec{p}_2$ and the plane of photonic momenta $\vec{p}_3$ and $\vec{p}_4$
- Higgs scalar decay is isotropic; suppressed at $\varphi_* = 0$ or π by the isolation
- FSR background peaks at $\varphi_* = 0$ or π

Azimuthal angle (φ_*) distributions



Lab frame

- A related observable is $|\varphi_{3T} - \varphi_{4T}|$, with $\varphi_{iT} \equiv \pi - \arccos \frac{\vec{Q}_T \cdot \vec{p}_T^{\gamma_i}}{Q_T E_T^{\gamma_i}}$ for $i = 3, 4$; ($0 \leq \varphi_{iT} \leq \pi$)
- $|\varphi_{3T} - \varphi_{4T}|$ is a measure of closeness of unobserved QCD radiation to one of the photons
- FSR background prefers $|\varphi_{3T} - \varphi_{4T}| > \pi/2$, while the signal likes $\varphi_{3T} \sim \varphi_{4T}$

Conclusions

- Information about the shape of diphoton Q_T, θ_*, and φ_* distributions increases discrimination power of the likelihood analysis
- Radiative corrections have strong kinematic dependence. Selection of $\gamma\gamma$ events at $E_T^{iso} \lesssim Q_T \lesssim Q$, central θ_* and φ_* increases the signal significance, while reducing theory uncertainties
- Our NNLL/NLO resummation calculation improves understanding of Higgs signal and background. It will be nevertheless important to experimentally examine $\gamma\gamma$ distributions in a wide range of Q to facilitate further improvements in theory