Transverse momentum resummation for background and signal in Higgs $\to \gamma\gamma$

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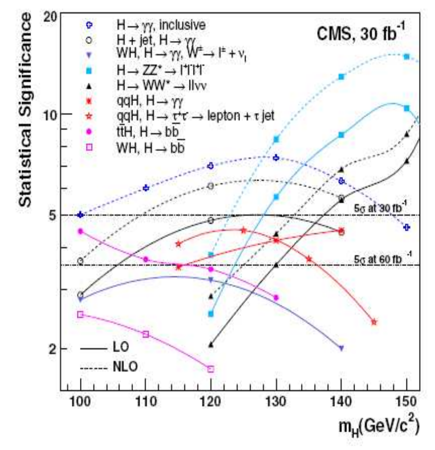
C. Balazs, E. Berger, **P. N.**, *C.-P. Yuan, arXiv:0704.0001; hep-ph/0702003; Phys. Lett., B637, 235 (2006)*

Light Higgs boson search at the LHC

- $gg \to h \to \gamma\gamma$ (via t-quark loop) is the leading search mode for $115 \lesssim M_H \lesssim 140$ GeV
- For $\mathcal{L} = 10\,\mathrm{fb}^{-1}$, a 5σ discovery of the SM Higgs boson and first measurements of M_H, $\sigma(H \to \gamma\gamma)$ may be feasible



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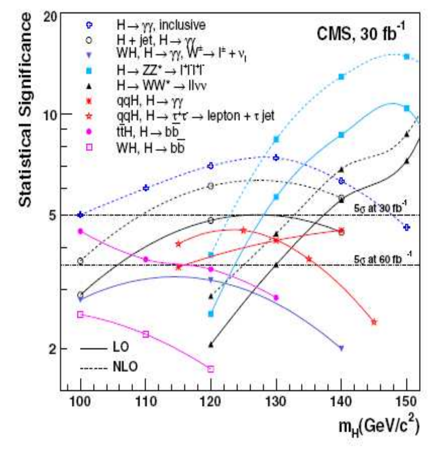
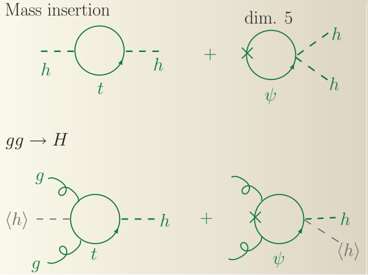
- The discovery potential strongly depends on the (new) physics model, QCD contributions, experimental resolution and systematics



Theoretical aspects affecting discovery potential

- Model dependence of the effective ggH and $\gamma\gamma H$ couplings g_{VVH} ($V = g,\gamma$)
  - It is expected that BSM models with "natural" ("unnatural") radiative corrections to M_H tend to have $g_{VVH} < g_{VVH}^{SM}$ ($g_{VVH} > g_{VVH}^{SM}$)
  - an upper limit on the excess of $\sigma(H \to \gamma\gamma)$ over the SM prediction helps to constrain "unnatural" BSM scenarios



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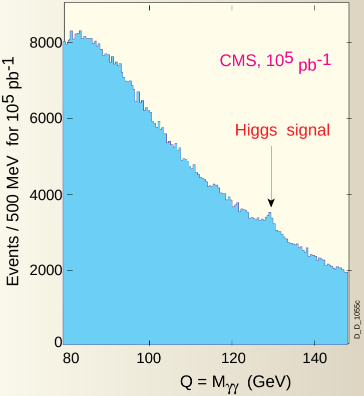
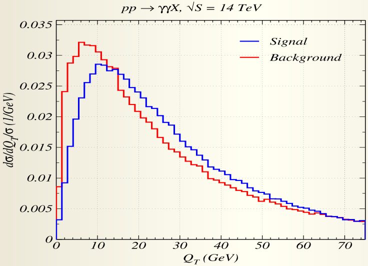
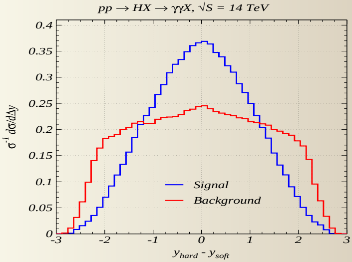


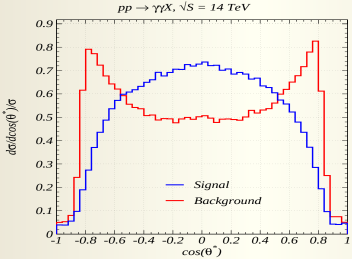
NNLL/NLO distributions for Higgs $\to \gamma\gamma$ signal and background (ResBos, normalized; $M_H = 130$ GeV, $128 < Q < 132$ GeV; ATLAS cuts)

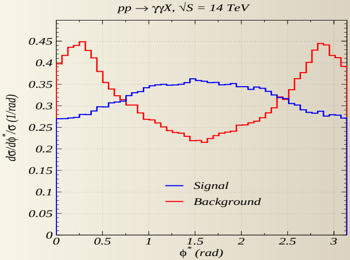
Q_T and $y_{\gamma_1} - y_{\gamma_2}$ in the lab frame





Decay angles θ_*, φ_* in the $\gamma\gamma$ rest frame





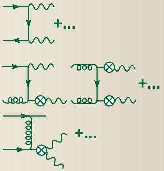
no singularities, in contrast to the fixed-order rate

QCD production of isolated prompt diphotons

Prompt photons = photons produced directly in perturbative QCD scattering or via parton fragmentation

as opposed to nonperturbative photon production in π, η decays, etc. (suppressed by isolation)

- Several classes of production processes
  - direct production
  - single-photon fragmentation
  - low-Q diphoton fragmentation



- Several sources of enhanced logarithmic corrections
  - Q_T logarithms from initial-state radiation $\Rightarrow$ resummation
  - final-state collinear singularities $\Rightarrow$ fragmentation functions
  - possibly small-x logs

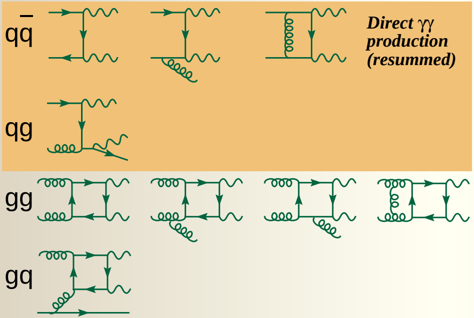
NNLL/NLO Q_T resummation for $p\overset{(-)}{p} \to \gamma\gamma X$

- Our study
  - computes fully differential $\gamma\gamma$ distributions in direct production
  - performs NNLL resummation of $\ln(Q_T/Q)$ logarithms at $Q_T \to 0$ (in the region with the largest rate)
  - includes essential information about photon fragmentation
  - numerical implementation: improved MC integrator program ResBos (publicly available at http://hep.pa.msu.edu/resum/)

Direct diphotons

The dominant production mode; evaluated up to NLO in α_s

Balazs, Berger, Nadolsky, Yuan, 2006



$q\bar{q} + qg$ channel

- NLO matrix elements:
  Aurenche et al.; Bailey, Owens, Ohnemus
- $q\bar{q}$ scattering dominates at the Tevatron
- qg scattering is strongly enhanced at the LHC by photon radiation off final-state quarks

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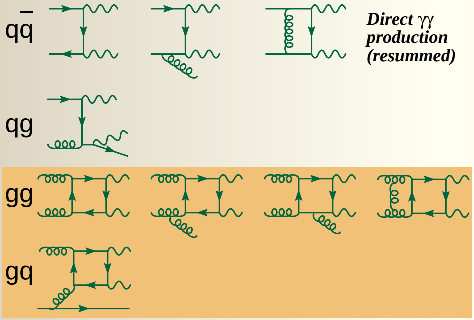


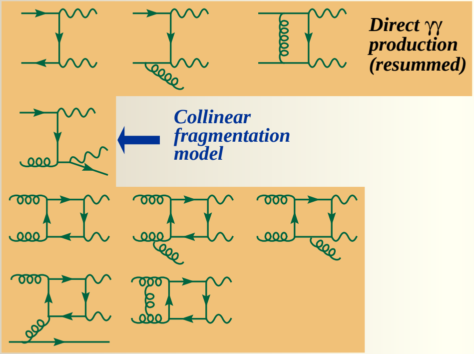
$gg + gq$ channel (via the quark box)

- contributes $\sim 20\%$ at both colliders
- NLO gg matrix elements: *Balazs, PN, Schmidt, Yuan; de Florian, Kunzst; Bern, De Freitas, Dixon; Bern, Dixon, Schmidt*
- gq matrix element: derived in this work from the $q\bar{q}ggg$ matrix element

Fragmentation model

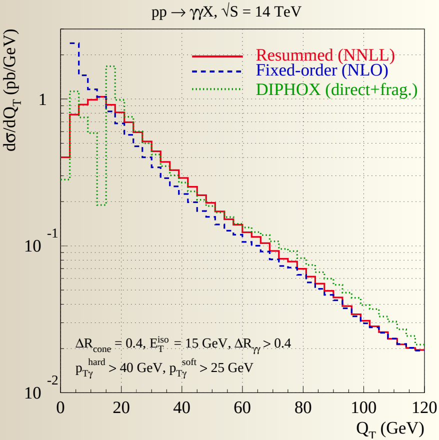
- The final-state singularity is removed by quasi-experimental isolation at $Q_T > E_T^{iso}$; by smooth-cone isolation *(cf. S. Frixione)* or tuned subtraction at $Q_T \leq E_T^{iso}$

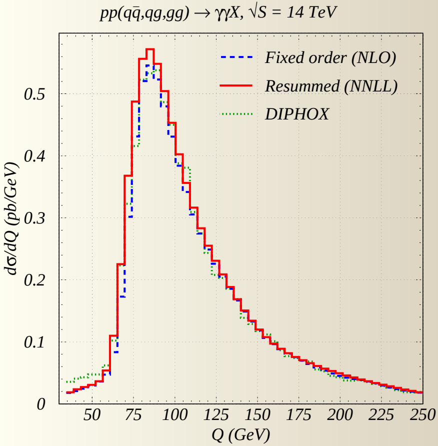
Balazs, Berger, Nadolsky, Yuan, 2006



- sufficient for description of fragmentation contributions at the Tevatron and LHC
- agrees with the inclusive NLO fragmentation rate *(Binoth et al.; DIPHOX program)* at both colliders
- good agreement with the Tevatron data

$\gamma\gamma$ production at the LHC (ATLAS cuts, $E_T^{iso} = 15$ GeV, $\Delta R = 0.4$)





- DIPHOX agrees with the resummation at large Q_T; exhibits integrable logarithmic singularities at $Q_T < E_T^{iso}$
- RESBOS shows a mild discontinuity at $Q_T = E_T^{iso}$

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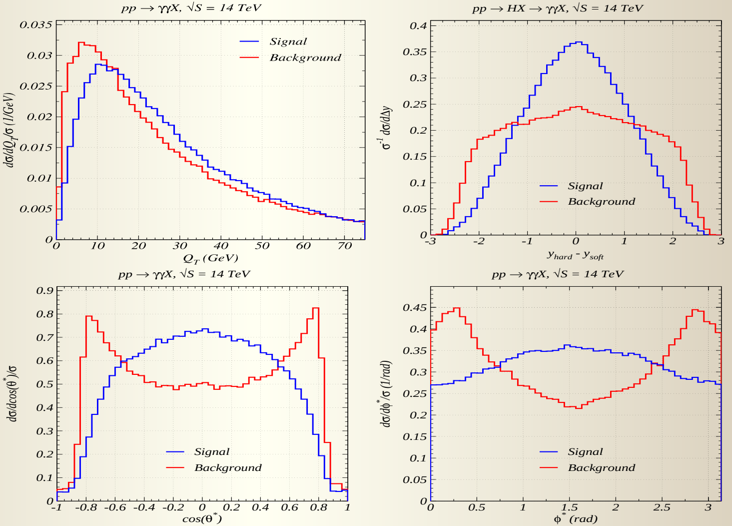


Our conclusions about the $H \to \gamma\gamma$ search

- 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

Measurements in the $\gamma\gamma$ mode with 10 fb^{-1}

Task	Feasible?	Comments
Measure, understand the QCD background in a wide range of $\gamma\gamma$ masses	yes	Essential for all other measurements
Rule out Higgs signal with $\sigma > \sigma^{SM}$	yes	Will constrain "unnatural" BSM models
Discover SM Higgs at 5σ c.l.; measure M_H and $\sigma(H \to \gamma\gamma)$	maybe	Depends on detector performance, QCD corrections; useful to define and study best- and worst-case scenarios
Measure Higgs boson spin	yes?	Decay angles θ_*, φ_* in the $\gamma\gamma$ rest frame
Rule out Higgs with $\sigma < \sigma^{SM}$	no?	Relevant for "less-tuned" BSM models

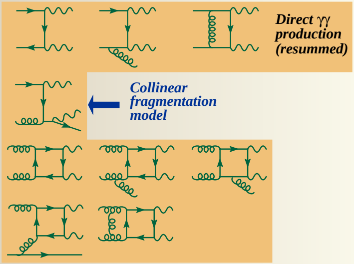
Measurements in the $\gamma\gamma$ mode with $10\ \mathrm{fb}^{-1}$

Quantitative details can be worked out at this workshop!

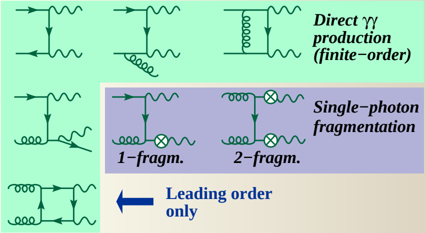
Backup slides

Our calculation vs. DIPHOX (Binoth et al.)

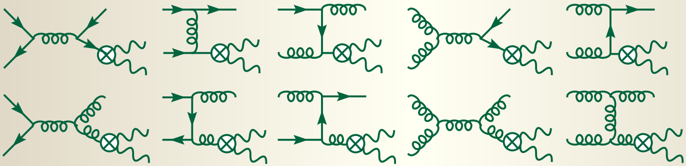
Balazs, Berger, Nadolsky, Yuan, 2006



Binoth, Guillet, Pilon, Werlen, 2001



Diphoton fragmentation (not implemented)



Low−Q diphoton fragmentation