The Higgs p_T Spectrum and Total Cross Section with Fiducial Cuts at N^{3}LL$'$+N^{3}LO

Johannes Michel
MIT CTP

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The Higgs p_T Spectrum and Total Cross Section with Fiducial Cuts at N^{3}LL′+N^{3}LO

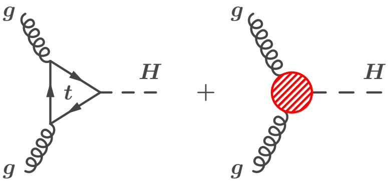
based on
[2102.08039]

in collaboration with
G. Billis, B. Dehnadi, M. Ebert, F. Tackmann

Motivation

- Measure fiducial & differential Higgs cross sections at the LHC
  - Most model-independent way we have to search for BSM in the Higgs sector



$$= \left(\frac{\alpha_s}{12\pi v} C_t + \frac{v}{\Lambda^2} C_{HG}\right) H\, G^a_{\mu\nu} G^{a,\mu\nu}$$

- Measure fiducial & differential Higgs cross sections at the LHC
  - Most model-independent way we have to search for BSM in the Higgs sector

	Individual			Marginalised		
SMEFT Coeff.	Best fit [$\Lambda = 1$ TeV]	95% CL range	Scale $\frac{\Lambda}{\sqrt{C}}$ [TeV]	Best fit [$\Lambda = 1$ TeV]	95% CL range	Scale $\frac{\Lambda}{\sqrt{C}}$ [TeV]
C_{Hq}	0.00	[-0.017, +0.012]	8.3	-0.05	[-0.11, +0.012]	4.1
$C_{Hq}^{(1)}$	0.02	[-0.1, +0.14]	2.9	-0.04	[-0.27, +0.18]	2.1
C_{Hd}	-0.03	[-0.13, +0.071]	3.1	-0.39	[-0.91, +0.13]	1.4
C_{Hu}	0.00	[-0.075, +0.073]	3.7	-0.19	[-0.63, +0.25]	1.5
$C_{H\Box}$	-0.27	[-1, +0.47]	1.2	-0.9	[-3, +1.2]	0.69
C_{HG}	0.00	[-0.0034, +0.0032]	17.0	0.00	[-0.014, +0.0086]	9.4
C_{HW}	0.00	[-0.012, +0.006]	11.0	0.12	[-0.38, +0.62]	1.4
C_{HB}	0.00	[-0.0034, +0.002]	19.0	0.07	[-0.09, +0.22]	2.5

[Ellis, Madigan, Mimasu, Sanz, You, 2012.02779; Tab. 6]

- Measure fiducial & differential Higgs cross sections at the LHC
  - Most model-independent way we have to search for BSM in the Higgs sector
- Uncertainty $\Delta\sigma$ on SM prediction translates into discovery reach:

$$\frac{\Delta\sigma}{\sigma} \sim \frac{v^2}{\Lambda_{\mathrm{BSM}}^2} \quad \Leftrightarrow \quad \Lambda_{\mathrm{BSM}} \sim v\sqrt{\frac{\sigma}{\Delta\sigma}}$$

Challenges for theory

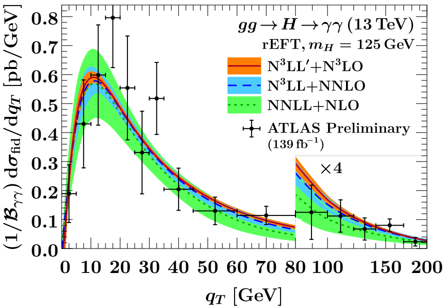
- QCD corrections to $gg \to H$ are large: $\sigma/\sigma_{\mathrm{LO}} \approx 3$
  - Calculation of inclusive cross section has been pushed to N^{3}LO [Anastasiou, Duhr, Dulat, Furlan, Gehrmann, Herzog, Lazopoulos, Mistlberger '15-'18]
- But LHC experiments apply kinematic selection cuts on Higgs decay products
  - Need complete interplay of QCD corrections and $\mathcal{O}(1)$ fiducial acceptance

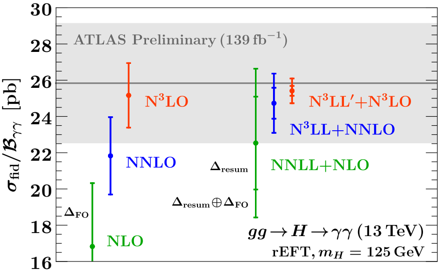
Consider $H \to \gamma\gamma$ with ATLAS fiducial cuts:

$$p_T^{\gamma 1} \geq 0.35\, m_H\,, \quad p_T^{\gamma 2} \geq 0.25\, m_H\,, \quad |\eta^\gamma| \leq 2.37\,, \quad |\eta^\gamma| \notin [1.37, 1.52]$$

Goal

- Compute fiducial spectrum in $q_T \equiv p_T^H = p_T^{\gamma\gamma}$ at N^{3}LL′+N^{3}LO
- Compute total fiducial cross section at N^{3}LO, and improved by resummation





Goals of this talk

Consider $H \to \gamma\gamma$ with ATLAS fiducial cuts:

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- Previous state of the art was N^{3}LL(+NNLO$_1$) and NNLO, respectively
  [Chen et al. '18; Bizoń et al. '18; Gutierrez-Reyes et al. '19; Becher, Neumann '20]

Kicked off recent push for fiducial color singlet at complete three-loop accuracy:

- Complementary N^{3}LO results for fiducial $Y_{\gamma\gamma}, \eta_{\gamma 1}, \Delta\eta_{\gamma\gamma}$ (with different method)
  [Chen, Gehrmann, Glover, Huss, Mistlberger, 2102.07607]
- Fiducial N^{3}LL′ results for Drell-Yan (and Higgs) q_T spectrum
  [Camarda, Cieri, Ferrera, 2103.04974; Re, Rottoli, Torrielli, 2104.07509]

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$\Gamma_H \ll m_H \Rightarrow$ production and decay (acceptance) factorize *point by point* in q_T, Y:

$$\frac{d\sigma}{dq_T} = \int dY\, A(q_T, Y; \Theta)\, W(q_T, Y)\,, \quad A_{\text{incl}} = 1\,, \quad W(q_T, Y) = \frac{d\sigma_{\text{incl}}}{dq_T\, dY}$$

Takeaway

$\sigma_{\text{incl}} = \int dq_T\, W(q_T)$ resummation effects formally cancel under q_T integral

$\sigma_{\text{fid}} = \int dq_T\, A(q_T)\, W(q_T)$ *derived* quantity sensitive to resummation effects

$$\frac{\mathrm{d}\sigma}{\mathrm{d}q_T} = \frac{\mathrm{d}\sigma^{(0)}}{\mathrm{d}q_T} + \frac{\mathrm{d}\sigma^{(1)}}{\mathrm{d}q_T} + \frac{\mathrm{d}\sigma^{(2)}}{\mathrm{d}q_T} + \cdots$$
$$\sim \frac{1}{q_T}\left[\mathcal{O}(1) + \mathcal{O}\Big(\frac{q_T}{m_H}\Big) + \mathcal{O}\Big(\frac{q_T^2}{m_H^2}\Big) + \cdots\right]$$

(0) Implementing the $\mathrm{N^3LL'}$ cross section

(1) Treating fiducial power corrections right

(2) Extracting the nonsingular cross section

Implementing the N^{3}LL$'$ cross section

Leading-power hadronic dynamics factorize as:

$$W^{(0)}(q_T, Y) = H(m_H^2, \mu) \int \mathrm{d}^2\vec{k}_a\, \mathrm{d}^2\vec{k}_b\, \mathrm{d}^2\vec{k}_s\, \delta\big(q_T - |\vec{k}_a + \vec{k}_b + \vec{k}_s|\big)$$
$$\times\, B_g^{\mu\nu}(x_a, \vec{k}_a, \mu, \nu)\, B_{g\,\mu\nu}(x_b, \vec{k}_b, \mu, \nu)\, S(\vec{k}_s, \mu, \nu)$$

To reach N^{3}LL$'$ for $W^{(0)}$, implemented in `SCETlib`:

- Three-loop soft and hard function ...includes in particular the three-loop virtual form factor
  [Li, Zhu, '16] [Baikov et al. '09; Lee et al. '10; Gehrmann et al. '10]
- Three-loop unpolarized and two-loop polarized beam functions
  [Ebert, Mistlberger, Vita '20; Luo, Yang, Zhu, Zhu '20]
  [Luo, Yang, Zhu, Zhu '19; Gutierrez-Reyes, Leal-Gomez, Scimemi, Vladimirov '19]
- Four-loop cusp, three-loop noncusp anomalous dimensions
  [Brüser, Grozin, Henn, Stahlhofen '19; Henn, Korchemsky, Mistlberger '20; v. Manteuffel, Panzer, Schabinger '20] [Li, Zhu, '16; Moch, Vermaseren, Vogt '05; Idilbi, Ma, Yuan '06; Vladimirov '16]
- N^{3}LL solutions to virtuality/rapidity RGEs in b_T space
- Hybrid profile scales for fixed-order matching
  [Lustermans, JM, Tackmann, Waalewijn '19]

Leading-power hadronic dynamics factorize as:

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$$\times\, B_g^{\mu\nu}(x_a, \vec{k}_a, \mu, \nu)\, B_{g\,\mu\nu}(x_b, \vec{k}_b, \mu, \nu)\, S(\vec{k}_s, \mu, \nu)$$

- Use $\mu_{\mathrm{FO}} = \mu_R = \mu_F = m_H$ for central predictions
- Higgs cross section also contains large timelike logarithms $\ln \dfrac{-m_H^2 - \mathrm{i}0}{\mu^2}$
  [Ahrens, Becher, Neubert, Yang '08]
  - Resummed by hard evolution from $\mu_H = -\mathrm{i}m_H$:

$$W(q_T, Y) = H(m_H^2, \mu_H)\, U_H(Q, \mu_H, \mu_{\mathrm{FO}}) \left[\frac{W(q_T, Y)}{H(m_H^2, \mu_{\mathrm{FO}})}\right]_{\mathrm{FO}}$$

[Ebert, JM, Tackmann '17]

Efficient evaluation of beam function finite terms in SCETlib

- Beam function kernels are large expressions of HPLs and rational prefactors:

$$I_{ij}^{(n)}(z) = \sum_a \frac{P_a(z)}{Q_a(z)} H_{w_a}(z)\,, \qquad w_a = \left(\begin{smallmatrix}\pm 1\\ 0\end{smallmatrix}, \cdots, \begin{smallmatrix}\pm 1\\ 0\end{smallmatrix}\right) \text{ up to weight 5}$$

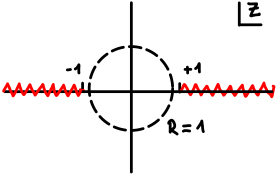
- Many tools for numerically evaluating *individual* HPLs on the market …
  [e.g. Gehrmann, Remiddi ’01; Buehler, Duhr ’11; Ablinger, Blümlein, Round, Schneider ’18]

! But big sum is slow and has uncontrolled floating-point cancellations, in particular in limits $z \to 0, 1$ relevant for convolution $I_{ij}^{(n)} \otimes f_j$ against PDFs

Key idea

Implement the kernels *directly* as smart series expansions,
using algebraic methods inspired by those developed for individual HPLs

1. Separate branch cuts by subtractions
   - Much more complex due to rational terms
   - ▶ Treat $Q_a(z)$ as additional primitives
2. Remap variables, push out remaining branch cut
   - Improves convergence radii of series



▶ Get $I_{ij}^{(3)}, P_{ij}^{(2)}, \ldots$ at machine precision in $\mathcal{O}(50\mathrm{k})$ cycles for any z,
≥ 100 times faster than naive implementation (and much more precise)

Treating fiducial power corrections right

Fiducial power corrections (in this case)

… are all the power corrections from the q_T-dependent acceptance:

$$\frac{\mathrm{d}\sigma^{\mathrm{fpc}}}{\mathrm{d}q_T} \equiv \int \mathrm{d}Y \Big[A(q_T, Y; \Theta) - A^{(0)}(Y; \Theta) \Big] W^{(0)}(q_T, Y)$$

- Contain all linear power corrections $\mathrm{d}\sigma^{(1)}$ because

$$W(q_T, Y) = W^{(0)}(q_T, Y) \Big[1 + \mathcal{O}\Big(\frac{q_T^2}{m_H^2}\Big) \Big]$$
$$A(q_T, Y; \Theta) = A^{(0)}(Y; \Theta) \Big[1 + \mathcal{O}\Big(\frac{q_T}{m_H}\Big) \Big]$$

- Also capture enhanced corrections $\sim q_T / p_L$ when approaching edges $p_L \to 0$ of Born phase space …example coming up
- Resummed to the same accuracy as leading-power terms by resumming $W^{(0)}$ and keeping exact $A(q_T, Y; \Theta)$

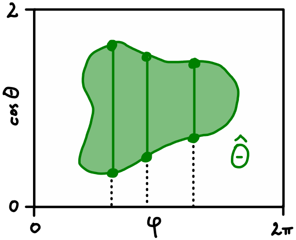
[Presence of linear terms pointed out in Ebert, Tackmann '20]

[Factorization demonstrated in Ebert, JM, Stewart, Tackmann '20; see talk by M. Ebert at SCET 2020]

… relies on fast & stable (for $q_T \to 0$) algorithm for evaluating the acceptance:

$$A(q_T, Y; \Theta) = \frac{1}{4\pi} \int \mathrm{d}\cos\theta \, \mathrm{d}\varphi \, \hat{\Theta}(q^\mu, \cos\theta, \varphi)$$

- $\hat{\Theta}(q_T = 0, Y, \cos\theta, \not{\varphi})$ is trivial
- For $q_T \neq 0$, analytically solve generic $\hat{\Theta}$ for bounds in θ at given q_T, Y, φ



Ruth doing $1 \to 2$ decay PS at rest.

- Do remaining 1D integral over φ adaptively
  - Takes $\mathcal{O}(1\,\mathrm{ms})$ on $2.50\,\mathrm{GHz}$ CPU for 10^{-7} target precision

Resummation effects in the total cross section

Key point

Fiducial power corrections induce resummation effects *in the total xsec.*

Compare fixed-order series:

$$\sigma_{\rm incl}^{\rm FO} = 13.80\,[1 + 1.291 + 0.783 + 0.299]\,\text{pb}$$

$$\sigma_{\rm fid}^{\rm FO} = 6.928\,[1 + 1.429 + 0.723 + 0.481]\,\text{pb}$$

$$= 6.928\,[1 + (1.300 + 0.129_{\rm fpc}) + (0.784 - 0.061_{\rm fpc}) + (0.331 + 0.150_{\rm fpc})]\,\text{pb}$$

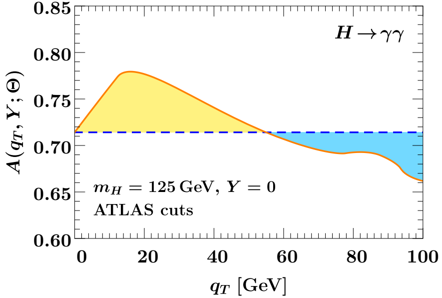
- Fiducial power corrections show no convergence, remainder is similar to inclusive

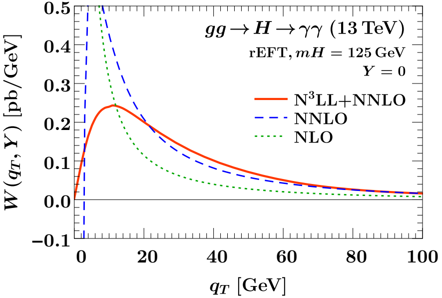
Key point

Fiducial power corrections induce resummation effects *in the total xsec.*

Two ways to understand this:

1. Acceptance acts as a weight in the q_T integral.





$$\sigma_{\mathrm{incl}} = \int \mathrm{d}q_T\, W(q_T) \qquad \sigma_{\mathrm{fid}} = \int \mathrm{d}q_T\, A(q_T)\, W(q_T)$$

Key point

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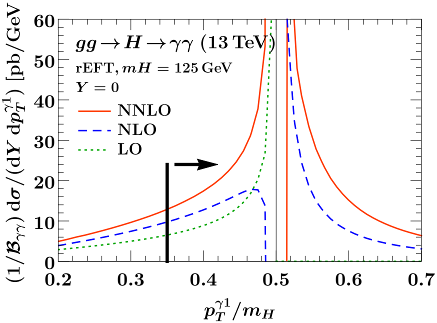
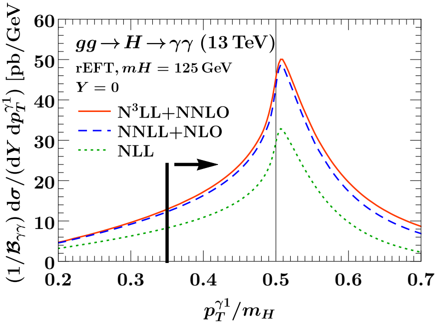
Two ways to understand this:

1. Acceptance acts as a weight in the q_T integral.
2. We're cutting on the resummation-sensitive photon p_T.





- Leaves behind logarithms of $\frac{p_L}{m_H} = \frac{p_T^{\text{cut}} - m_H/2}{m_H} = 0.15$

Resummation effects in the total cross section

Key point

Fiducial power corrections induce resummation effects *in the total xsec.*

Compare fixed-order series, isolating effect of $\int \mathrm{d}q_T \, \frac{\mathrm{d}\sigma^{\mathrm{fpc}}}{\mathrm{d}q_T}$:

$$\sigma_{\mathrm{incl}}^{\mathrm{FO}} = 13.80\,[1 + 1.291 + 0.783 + 0.299]\,\mathrm{pb}$$
$$\sigma_{\mathrm{fid}}^{\mathrm{FO}} = 6.928\,[1 + 1.429 + 0.723 + 0.481]\,\mathrm{pb}$$
$$= 6.928\,[1 + (1.300 + 0.129_{\mathrm{fpc}}) + (0.784 - 0.061_{\mathrm{fpc}}) + (0.331 + 0.150_{\mathrm{fpc}})]\,\mathrm{pb}$$

- Fiducial power corrections show no convergence, remainder is similar to inclusive

After resummation of $\sigma^{(0)} + \sigma^{\mathrm{fpc}}$, at successive matched orders:

$$\sigma_{\mathrm{incl}}^{\mathrm{res}} = 24.16\,[1 + 0.756 + 0.207 + 0.024]\,\mathrm{pb}$$
$$\sigma_{\mathrm{fid}}^{\mathrm{res}} = 12.89\,[1 + 0.749 + 0.171 + 0.053]\,\mathrm{pb}$$

Note Checked explicitly that for our profile scale setup, $\sigma_{\mathrm{incl}}^{\mathrm{res}}$ and $\sigma_{\mathrm{incl}}^{\mathrm{FO}}$ *agree* within Δ_{resum}

- *Differ* in the fiducial case $\Rightarrow$ resummation effect is resolved

Extracting the nonsingular cross section

Setup

So we dealt with this ...

$$\frac{\mathrm{d}\sigma^{\mathrm{sing}}}{\mathrm{d}q_T} = \int \mathrm{d}Y\, A(q_T, Y; \Theta)\, W^{(0)}(q_T, Y) = \frac{\mathrm{d}\sigma^{(0)}}{\mathrm{d}q_T} + \frac{\mathrm{d}\sigma^{\mathrm{fpc}}}{\mathrm{d}q_T}$$

To match to FO and be able to integrate to the total cross section, we still need:

$$\frac{\mathrm{d}\sigma_{\mathrm{FO}}^{\mathrm{nons}}}{\mathrm{d}q_T} = \int \mathrm{d}Y\, A(q_T, Y; \Theta) \left[W_{\mathrm{FO}}^{(2)}(q_T, Y) + \cdots\right] = \left[\frac{\mathrm{d}\sigma_{\mathrm{FO}_1}}{\mathrm{d}q_T} - \frac{\mathrm{d}\sigma_{\mathrm{FO}}^{\mathrm{sing}}}{\mathrm{d}q_T}\right]_{q_T > 0}$$

Challenges:

- Obtaining stable $H + 1j$ results for $q_T \to 0$ is *hard* ...in particular at NNLO_1
- Dropping the nonsingular below $q_T \leq q_T^{\mathrm{cut}}$ is not viable, either ...as we'll see shortly
  - In the context of q_T subtractions: crucial to use differential subtraction, not slicing

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$$\frac{d\sigma^{\text{nons}}_{\text{FO}}}{dq_T} = \int dY\, A(q_T, Y; \Theta) \left[W^{(2)}_{\text{FO}}(q_T, Y) + \cdots\right] = \left[\frac{d\sigma_{\text{FO}_1}}{dq_T} - \frac{d\sigma^{\text{sing}}_{\text{FO}}}{dq_T}\right]_{q_T>0}$$

Key idea

Fit nonsingular data to known form at subleading power and integrate *analytically*:

$$q_T \frac{d\sigma^{\text{nons}}_{\text{FO}}}{dq_T}\bigg|_{\alpha_s^n} = \frac{q_T^2}{m_H^2} \sum_{k=0}^{2n-1} \left(a_k + b_k \frac{q_T}{m_H} + c_k \frac{q_T^2}{m_H^2} + \cdots\right) \ln^k \frac{q_T^2}{m_H^2}$$

- Include higher-power b_k, c_k to get unbiased a_k
  - Allows us to use more precise data at higher q_T as lever arm in the fit

Setup

So we dealt with this ...

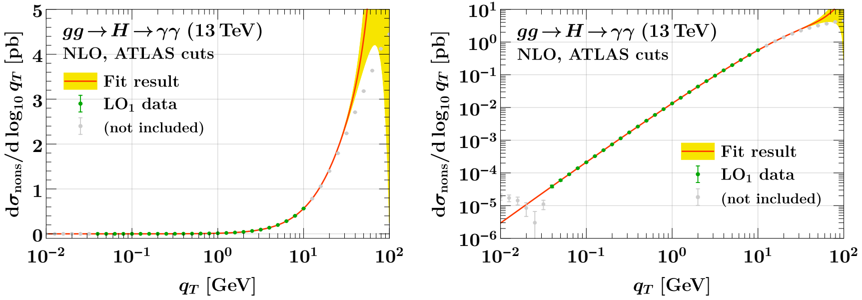
$$\frac{d\sigma^{\rm sing}}{dq_T} = \int dY\, A(q_T, Y; \Theta)\, W^{(0)}(q_T, Y) = \frac{d\sigma^{(0)}}{dq_T} + \frac{d\sigma^{\rm fpc}}{dq_T}$$

To match to FO and be able to integrate to the total cross section, we still need:

$$\frac{d\sigma^{\rm nons}_{\rm FO}}{dq_T} = \int dY\, A(q_T, Y; \Theta) \left[W^{(2)}_{\rm FO}(q_T, Y) + \cdots\right] = \left[\frac{d\sigma_{\rm FO_1}}{dq_T} - \frac{d\sigma^{\rm sing}_{\rm FO}}{dq_T}\right]_{q_T>0}$$

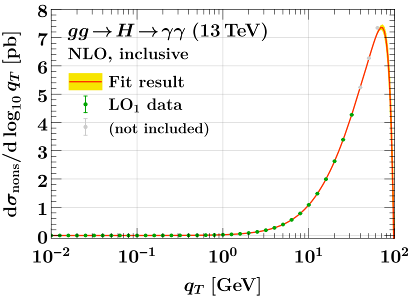
Fixed-order inputs:

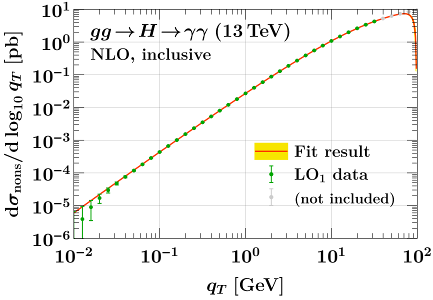
- NLO contribution to $W(q_T, Y)$ at $q_T > 0$ is easy
- At NNLO, renormalize & implement bare analytic results for $W(q_T, Y)$
  [Dulat, Lionetti, Mistlberger, Pelloni, Specchia '17]
- At N^3LO, use existing binned NNLO_1 results from `NNLOjet`
  [Chen, Cruz-Martinez, Gehrmann, Glover, Jaquier '15-16; as used in Chen et al. '18; Bizoń et al. '18]
- Use N^3LO total inclusive cross section as additional fit constraint on underflow
  [Mistlberger '18]



Fit procedure:

- Perform separate χ^2 fits of $\{a_k^{\mathrm{incl,fid}}\}$ to inclusive and fiducial nonsingular data
  [generated by our analytic implementation]
- Increase fit window to larger q_T until p value decreases
- Include subleading log coefficients at next higher power until p value decreases
- Also test intermediate combination to ensure fit is stable
  [procedure follows Moult, Rothen, Stewart, Tackmann, Zhu ’15-’16]





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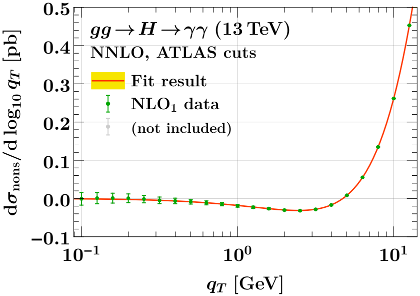
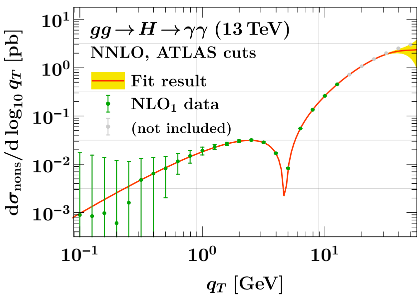
Fit results at (N)NLO





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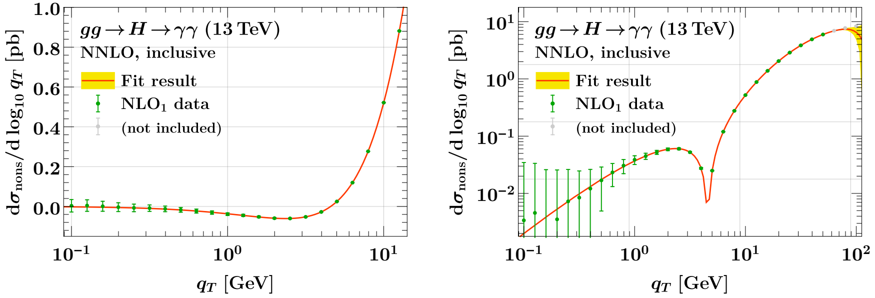

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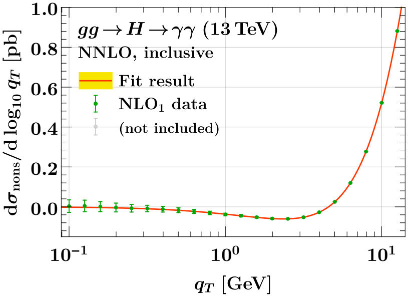
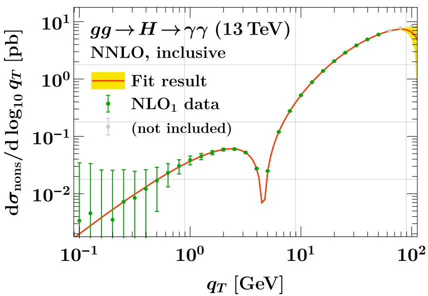
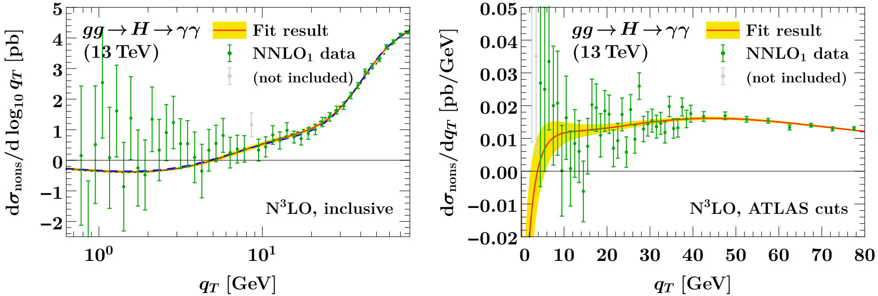




- Check the purely hadronic a_k^{fid} by directly fitting them to

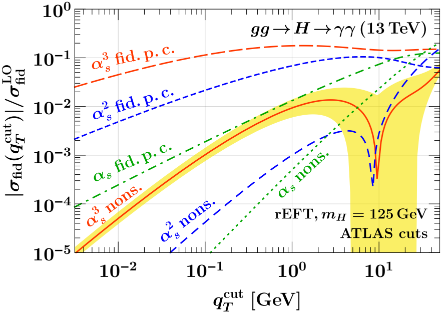
$$q_T \int \mathrm{d}Y \, A^{(0)}(Y;\Theta)\left[W - W^{(0)}\right] = \frac{q_T^2}{m_H^2} \sum_{k=0}^{2n-1} \left(a_k^{\mathrm{fid}} + c_k' \frac{q_T^2}{m_H^2} + \cdots \right) \ln^k \frac{q_T^2}{m_H^2} \quad ✓$$

- Recover analytic (N)NLO coefficient of σ_{incl} at 10^{-5} (10^{-4}) ✓
- Analytic implementation gives us awesome precision on *all* NLP coefficients
  (all logs at NLO *and* NNLO, also differential in Y, broken down by color structure, ...)
  - Can serve as benchmark for q_T factorization & resummation of $W^{(2)}$



Setup:

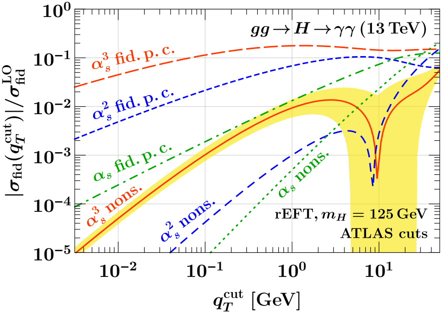
- Perform a combined fit to all inclusive and fiducial data
  [NNLO$_1$: Chen, Cruz-Martinez, Gehrmann, Glover, Jaquier ’15-16; as used in Chen et al. ’18; Bizoń et al. ’18]
  [Incl. N^{3}LO: Mistlberger ’18]
- Empirically find $0.4 \leq a_k^{\rm fid}/a_k^{\rm incl} \leq 0.55$ at (N)NLO $\Rightarrow$ use as weak 1σ constraint
  - Makes sense, $a_k^{\rm fid,incl}$ are same underlying $W^{(2)}$ in slightly different Y range
  - Note that we are *not* just rescaling any part of the cross section by an acceptance
- Add $\sigma_{\rm incl}(q_T \leq q_T^{\rm cut}) = \sigma_{\rm incl}^{\rm N^3LO} - \sigma_{\rm incl}(q_T > q_T^{\rm cut})$ as additional incl. data point



Most general form of q_T subtractions:

$$\sigma = \sigma^{\mathrm{sing}}(q_T^{\mathrm{off}}) + \sigma^{\mathrm{nons}}(q_T^{\mathrm{cut}}) + \int_{q_T^{\mathrm{cut}}}^{q_T^{\mathrm{off}}} \mathrm{d}q_T \left[\frac{\mathrm{d}\sigma}{\mathrm{d}q_T} - \frac{\mathrm{d}\sigma^{\mathrm{sing}}}{\mathrm{d}q_T}\right] + \int_{q_T^{\mathrm{off}}} \mathrm{d}q_T \, \frac{\mathrm{d}\sigma}{\mathrm{d}q_T}$$

- We literally take $q_T^{\mathrm{cut}} = 0$, second term *identically* vanishes
- Slicing calculation would use finite $q_T^{\mathrm{cut}} \sim 2\,\mathrm{GeV}$ and take $\sigma^{\mathrm{nons}}(q_T^{\mathrm{cut}}) \approx 0$
- That would be a bad (catastrophic) approximation with (without) $\sigma^{\mathrm{fpc}} \subset \sigma_{\mathrm{sing}}$

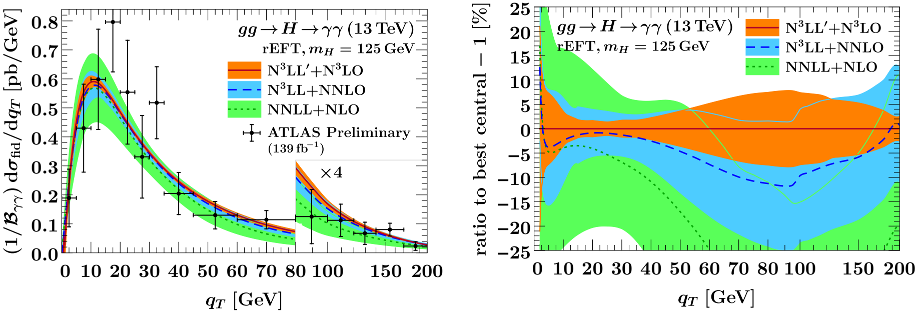


A word of numerical caution:

- Contributions from $\sigma^{\rm fpc}(q_T \lesssim 0.1\text{GeV})$ can be as high as $\mathcal{O}(10\%) \times \sigma_{\rm LO}$
- If evaluated by MC, as e.g. in projection-to-Born method, unbiased integration at these low q_T will be challenging (generation cuts, stability of amplitudes, ...)

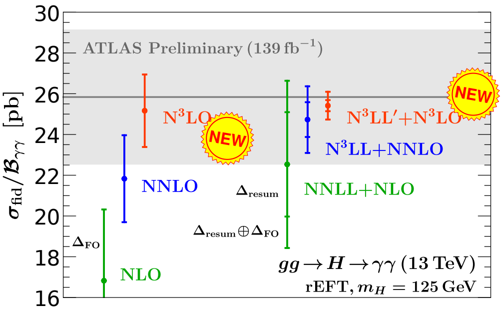
Results

The fiducial q_T spectrum at N^{3}LL$'$+N^{3}LO



- Total uncertainty is $\Delta_{\rm tot} = \Delta_{q_T} \oplus \Delta_\varphi \oplus \Delta_{\rm match} \oplus \Delta_{\rm FO} \oplus \Delta_{\rm nons}$
  [See also Ebert, JM, Stewart, Tackmann, 2006.11382 for details]
- Observe excellent perturbative convergence & uncertainty coverage
  - Crucial to consider *every* variation to probe all parts of the prediction
  - Three-loop beam function has noticeable efffect on central value and band
- Divide $H \to \gamma\gamma$ branching ratio $\mathcal{B}_{\gamma\gamma}$ out of data [LHC Higgs Cross Section WG, 1610.07922]
- Data are corrected for other production channels, photon isolation efficiency
  [ATLAS, 1802.04146]

The total fiducial cross section at N^{3}LO and N^{3}LL$'$+N^{3}LO



- Large N^{3}LO correction to fiducial cross section (worse than inclusive)
  - Caused by fiducial power corrections, *not* captured by rescaling
- Resummation restores convergence
  - Needs both q_T and timelike resummation (different effects, neither is sufficient)

Interesting: Infrared sensitivity observed e.g. in $\Delta\eta_{\gamma\gamma}$ spectrum at N^{3}LO [Chen, Gehrmann, Glover, Huss, Mistlberger, 2102.07607]

$\Leftrightarrow$ Precisely the fiducial p.c.'s we can deal with and resum

- Presented N^{3}LL′+N^{3}LO and N^{3}LO predictions for the fiducial q_T spectrum and the total fiducial cross section for $gg \to H$ at the LHC
  - First direct comparison to LHC data at this order and level of precision
- Observed, explained, and resummed large fiducial power corrections induced by the experimental acceptance
  - Even *total* fiducial cross sections are sensitive to q_T resummation effects
- Nonsingular extraction and matching to total cross section enabled by combining all information from $\sigma_{\mathrm{incl}}^{\mathrm{N^3LO}}$, FO $H + 1j$ data, fiducial power corrections, and the known structure of genuine NLP
- Sketched numerically efficient evaluation of three-loop beam functions and fiducial power corrections in `SCETlib`
  - Will be part of upcoming public release

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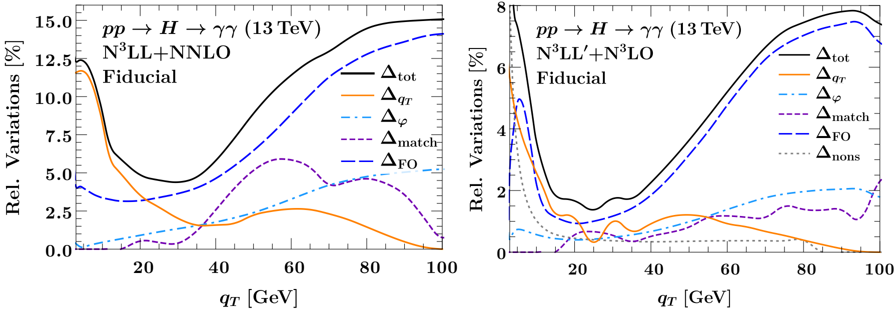
Thank you for your attention!

Backup

Uncertainty breakdown



N^{3}LO: $\sigma_{\rm fid}/\mathcal{B}_{\gamma\gamma} = (25.16 \pm 1.78_{\rm FO} \pm 0.12_{\rm nons})\,\text{pb}$

N^{3}LL′+N^{3}LO: $\sigma_{\rm fid}/\mathcal{B}_{\gamma\gamma} = (25.41 \pm 0.59_{\rm FO} \pm 0.21_{q_T} \pm 0.17_{\varphi} \pm 0.06_{\rm match} \pm 0.20_{\rm nons})\,\text{pb}$

- Δ_{q_T} 36 independent scale variations in $W^{(0)}$ factorization
- Δ_{φ} Vary phase of hard scale over $\arg \mu_H \in \{\pi/4, 3\pi/4\}$
- $\Delta_{\rm match}$ Vary transition points governing resummation turn-off
- $\Delta_{\rm FO}$ Vary $\mu_R/m_H \in \{1/2, 2\}$ (dominates over μ_F due to overall α_s^2)
- $\Delta_{\rm nons}$ Uncertainty on nonsingular extraction